Time-dependent Amplitude Analysis of $B^0 \rightarrow K^0_S\pi^+\pi^-$ decays with BaBar
and
constrains on the CKM matrix with the $B \rightarrow K^*\pi$ modes

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LABORATOIRE
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Seminar CPPM Marseille – Monday Feb. 22nd 2010

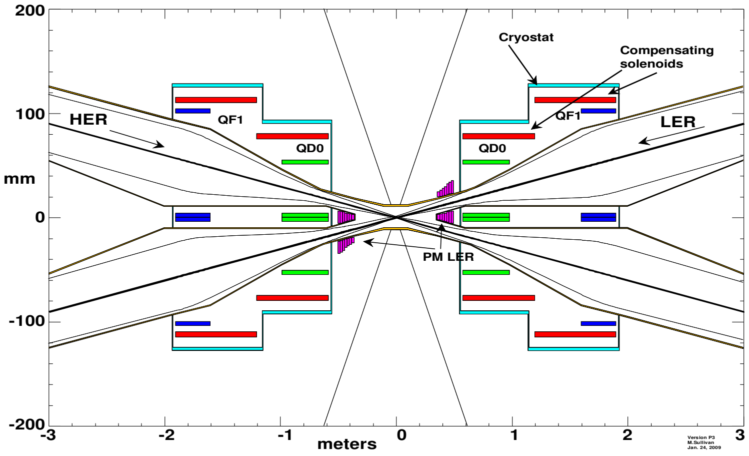
My research activities

- **Ph.D. Thesis at LPNHE 2006-2008:**
  - Experimental data analysis with BaBar data ($B^0 \rightarrow K^0_S \pi^+\pi^-$)
  - Phenomenological analysis

- **Since Feb. 2009 post-doc at LAL working with the SuperB and BaBar groups**
  - **SuperB:** Detector Geometry Working Group (DGWP). Use the physics cases $B \rightarrow K^{(*)}\nu\nu$ and $B^+ \rightarrow \tau^+\nu$, to test the different detector geometries
  - **BaBar:** Fully inclusive BF and energy spectrum measurement of $B \rightarrow X_s\gamma$

The “SuperB Era”

- **SuperB aims at the construction of a very high luminosity asymmetric e^+e^- flavor factory**



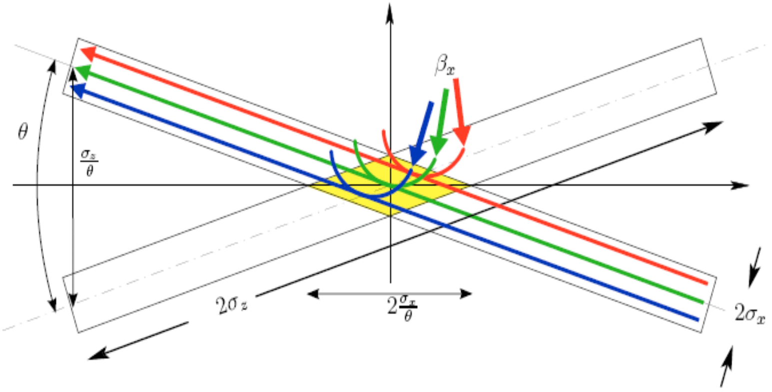


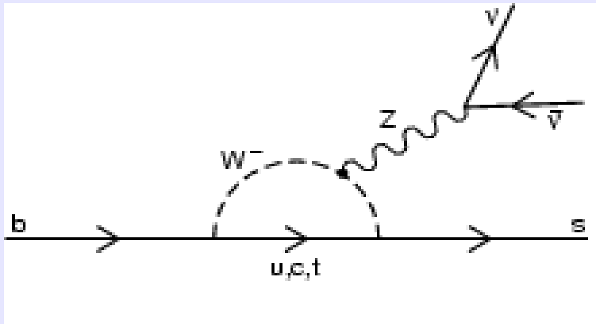
Figure 3-1. *Large Piwinski angle and crabbed waist scheme. The collision area is shown in yellow.*

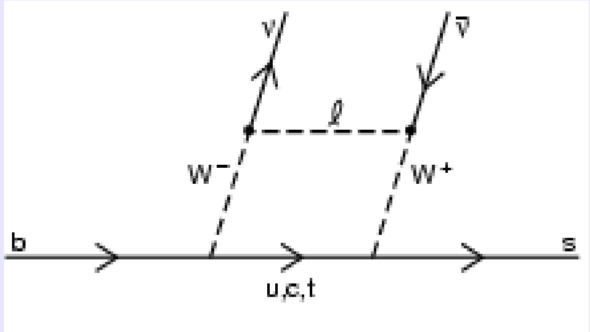
- **Aims:**
  - Operate at a reduced boost of $\beta\gamma = 0.28$ (BaBar is at 0.56)
  - Very high luminosity of $1\text{x}10^{36}$ $\text{cm}^{-2}\text{s}^{-1}$ or more (100 more than BaBar)
  - Polarized e^- at interaction point ⇒ τ physics
  - Ability to collide at the Υ(4S) and the J/ψ ⇒ B and D physics

- **The plan is to built the accelerator facility at Frascati**
- **Expect funding approval from Italian government by mid March 2010**

$B \to K^{(*)}\nu\nu$: theoretical status

Standard Model





$BF_{SM}(B \to K^{+}\nu\nu) = (4.5 \pm 0.7) \times 10^{-6}$

$BF_{SM}(B \to K^{*}\nu\nu) = (6.8\ {}^{+1.0}_{-1.1}) \times 10^{-6}$

$\langle F_{L}(B \to K^{*}\nu\nu) \rangle = (0.54 \pm 0.01)$

(W. Altmannshofer et al. TUM-HEP-709-09)

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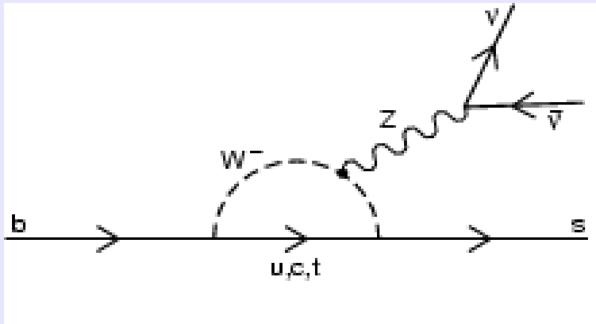

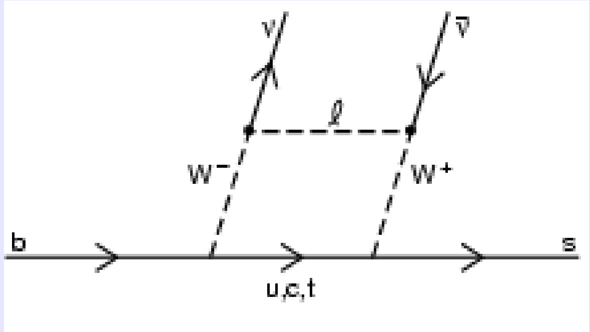

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Angular Distribution

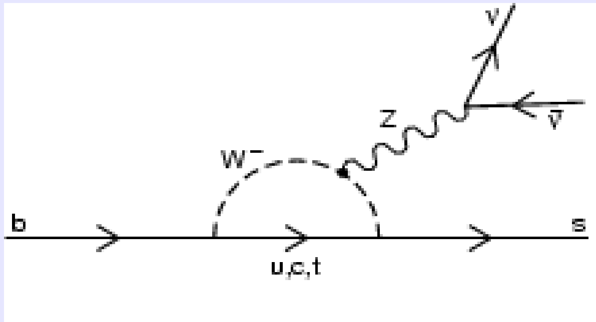
$$\frac{d\Gamma}{d\cos\theta} \propto \frac{3}{4}(1- < F_L >)\sin^2\theta + \frac{3}{2} < F_L > \cos^2\theta$$

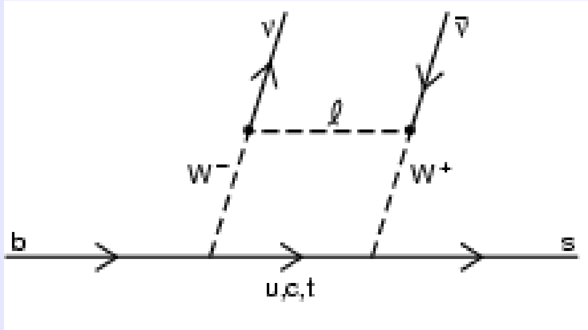
θ = angle between:

- **K* direction in B rest frame**
- **K direction in K* rest frame**

$B\to K^{(*)}\nu\nu$: theoretical status

Standard Model





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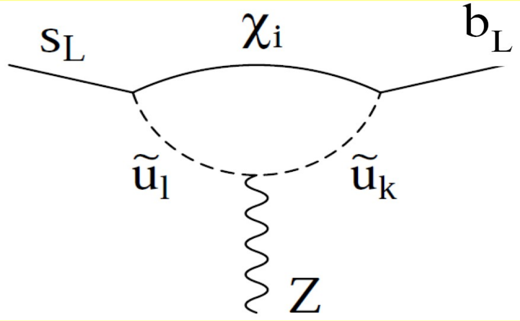
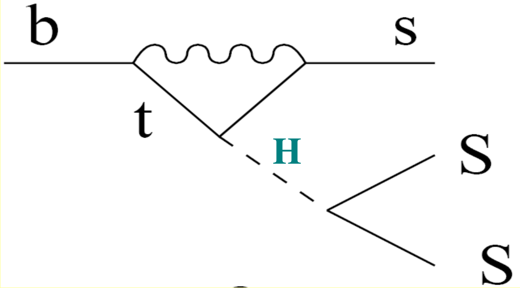
New Physics Effects

Some Examples



Non-Standard Z-couplings



New missing energy sources

BFs can be enhanced up to a factor 50

Buchalla et al. Hep-ph/0006136

Bird et al. Hep-ph/0401195

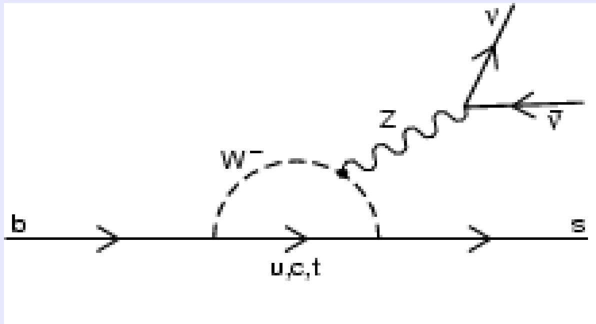
Aliev et al. arXiv:0705.4542

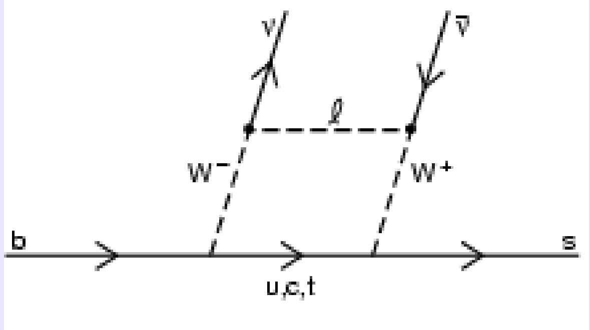
Neubert at LLWI '09

Kim et al. arXiv:0904.0318

$B \to K^{(*)}\nu\nu$: theoretical status

Standard Model





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New Physics Effects

Can study observable correlations (ε,η)

$$\mathrm{BR}(B \to K^* \nu\bar{\nu}) = 6.8 \times 10^{-6}\,(1 + 1.31\,\eta)\epsilon^2\ ,$$

$$\mathrm{BR}(B \to K \nu\bar{\nu}) = 4.5 \times 10^{-6}\,(1 - 2\,\eta)\epsilon^2\ ,$$

$$\mathrm{BR}(B \to X_s \nu\bar{\nu}) = 2.7 \times 10^{-5}\,(1 + 0.09\,\eta)\epsilon^2\ ,$$

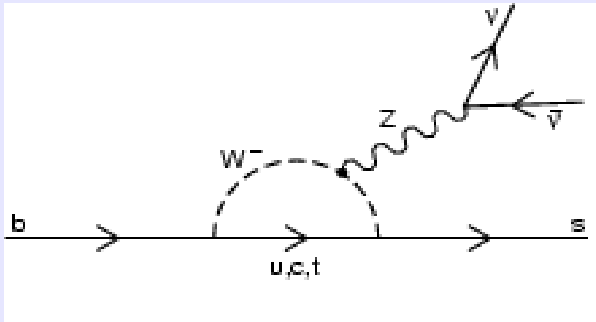
$$\langle F_L \rangle = 0.54\,\frac{(1 + 2\,\eta)}{(1 + 1.31\,\eta)}\ .$$

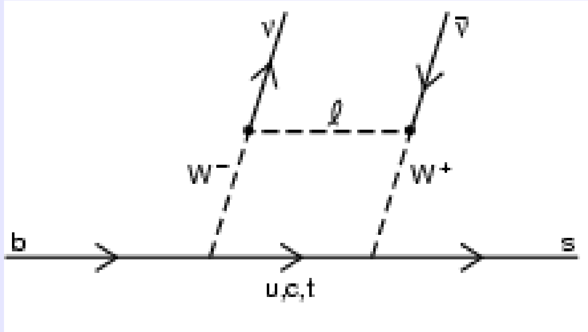
$(\epsilon,\eta)_{SM} = (1,0)$

$$\epsilon = \frac{\sqrt{|C_L^\nu|^2 + |C_R^\nu|^2}}{|(C_L^\nu)^{\mathrm{SM}}|}\ , \qquad \eta = \frac{-\mathrm{Re}\,(C_L^\nu C_R^{\nu *})}{|C_L^\nu|^2 + |C_R^\nu|^2}\ ,$$

$B\to K^{(*)}\nu\nu$: theoretical status

Standard Model





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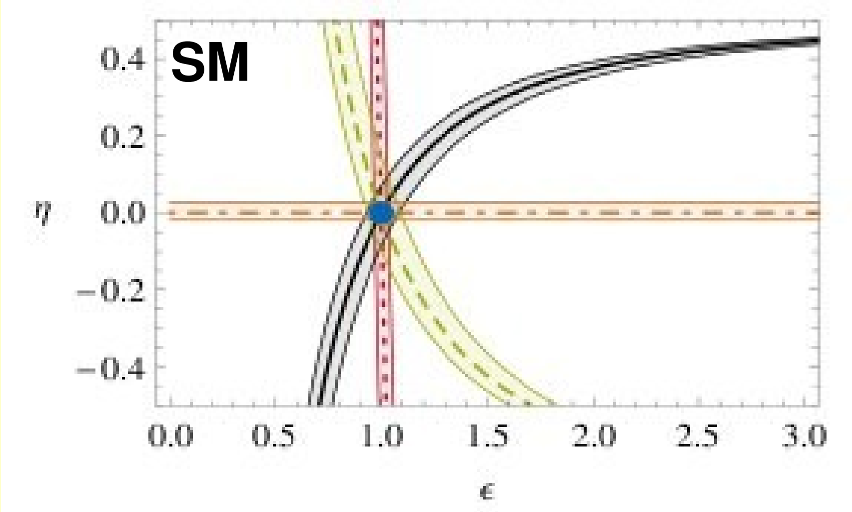
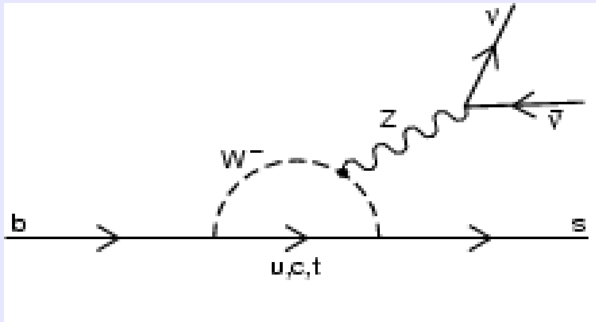
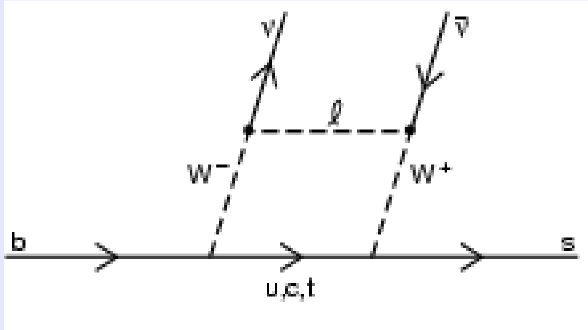


B→K$^{(*)}$νν: theoretical status

Standard Model





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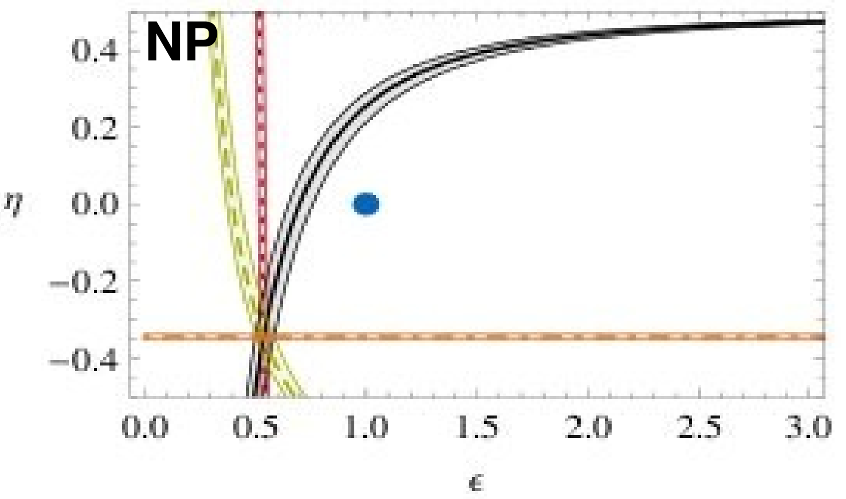
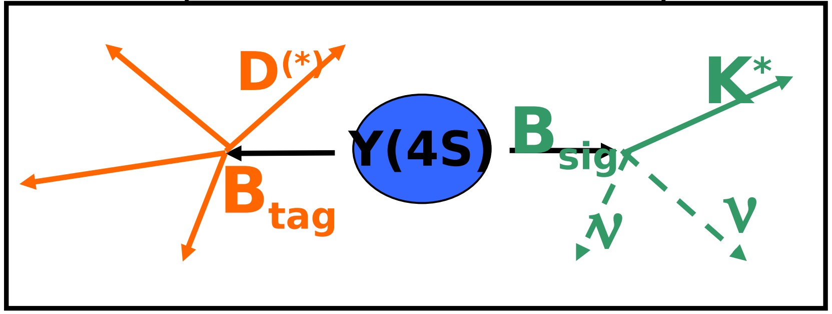


$B \to K^{(*)}\nu\nu$: experimental status

- **Most of the searches for rare B decays performed by exploiting the Recoil Technique:**

$e^+e^- \to \Upsilon(4S) \to BB$



B_{tag}: full (partial) reconstruction in one hadronic (semi-leptonic) decay

B_{sig}: look for the signal signature, e.g. $K^{(*)}$ not accompanied by additional (charged+neutral) particles + missing energy

Recoil technique at B-Factories:

- Search for rare decays (10^{-5}) with missing energy (Not possible at hadronic machines)
- Several benchmark channels at SuperB: $B\to\tau\nu$, $B\to K^{(*)}\nu\nu$, ...
- Complementary to LHCb ($B\to K^{(*)}ll$)

Babar Characters TM & © Laurent de Brunhoff

SL Recoil (90 million BB)[2]: $BF(B^+\to K^+\nu\nu) < 5.2\times10^{-5}$

Had Recoil (351 million BB)[3]: $BF(B^+\to K^+\nu\nu) < 4.2\times10^{-5}$

Had+SL Recoil (454 million BB)[4]:

$BF(B^+\to K^{*+}\nu\nu) < 8.0\times10^{-5}$

$BF(B^0\to K^{*0}\nu\nu) < 12.0\times10^{-5}$

BELLE

Had Recoil (535 million BB pairs)[1]:

$BF(B^+\to K^+\nu\nu) < 1.4\times10^{-5}$

$BF(B^0\to K^0_s\nu\nu) < 1.6\times10^{-4}$

$BF(B^+\to K^{*+}\nu\nu) < 1.4\times10^{-4}$

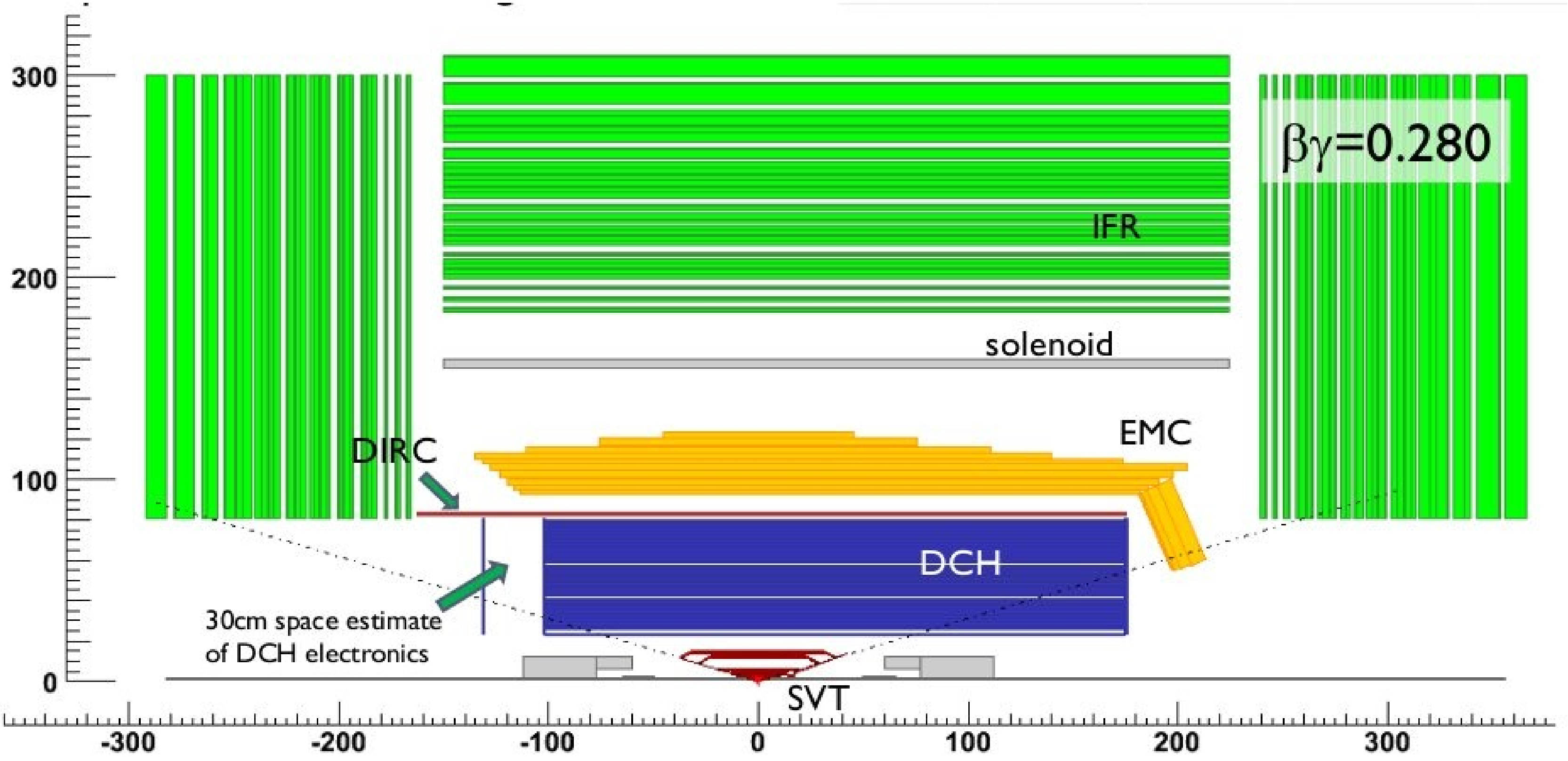
$BF(B^0\to K^{*0}\nu\nu) < 3.4\times10^{-4}$

All measurements still consistent with SM expectation

[1] K. F. Chen et al. [BELLE Collaboration], Phys. Rev. Lett. 99, 221802 (2007). [2] B. Aubert et al. [BaBar collaboration], Phys.Rev. Lett. 101801 (2005)
[3] H.Kim on behalf of the BaBar collaboration, arXiv:hep-ex/08052365 (2008). [4] B. Aubert et al. [BaBar collaboration], Phys.Rev.D78:072007,2008

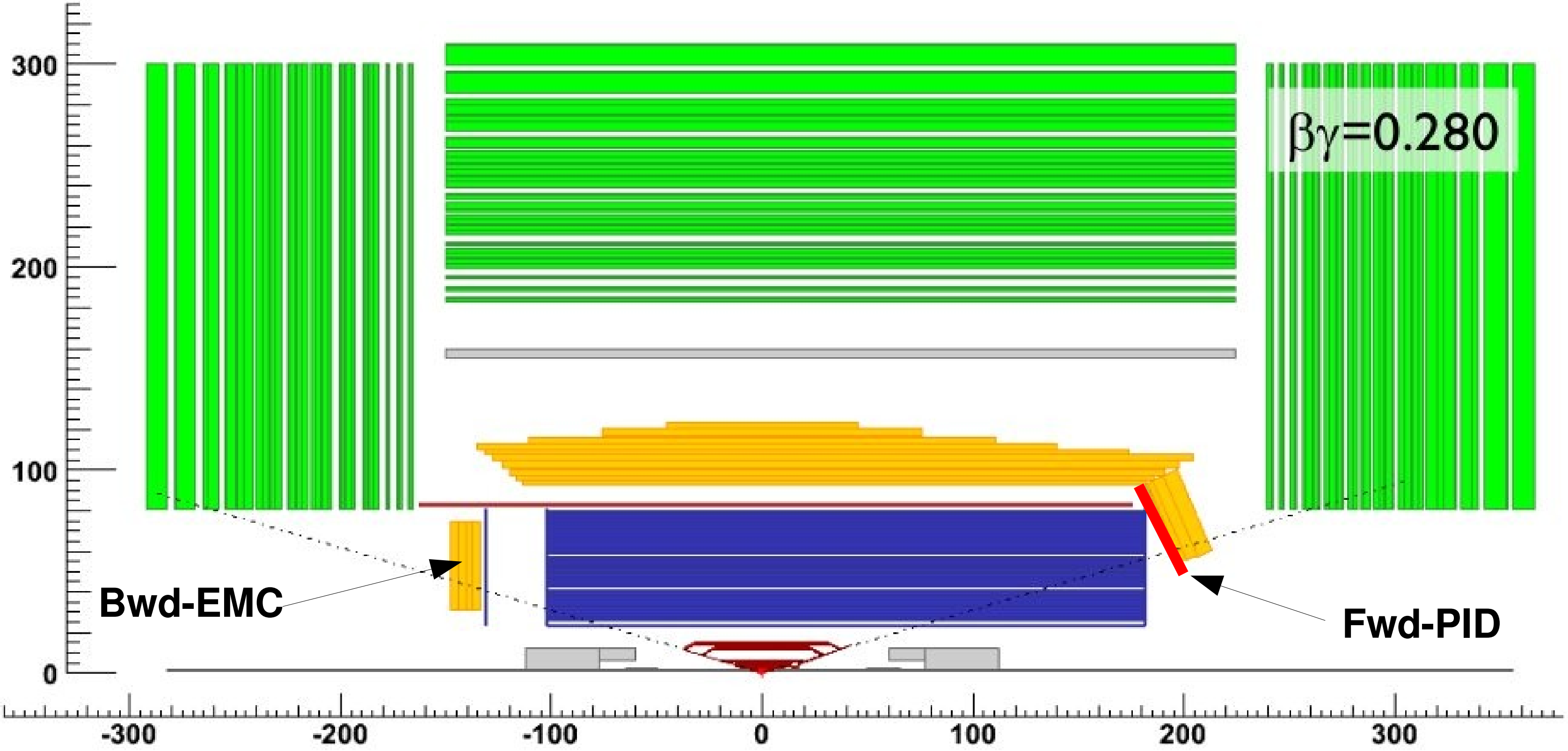
SuperB detector (I)

- **Use BaBar detector as baseline design**
- **Reduce boost from $\gamma\beta$ = 0.56 → 0.28 ⇒ better geometrical acceptance**
- **Expect significant improvement for rare decays with missing energy**



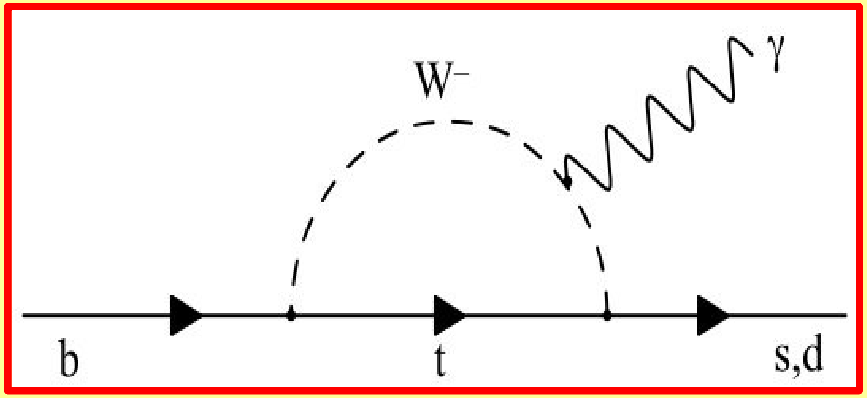
SuperB detector (II)

- **Improve current sub-detectors performances using new technologies**
- **Study the addition of other sub-detectors to improve coverage:**
  - Bwd EMC and Fwd PiD
- **Expect significant improvement for rare decays with missing energy**
- **My job is to try quantify those improvements**



$b \to s\gamma$: Motivations

- **Flavor changing neutral current:**
  - **not present at tree level in SM**
- **Loop diagram**
  - **measurement sensitive to new heavy particles (H^+,SUSY?)**



- **Photon spectrum are sensitive to Heavy Quark parameters m_b and μ_π^2**
- **Extraction of these with small errors leads to improvement of $|V_{ub}|$ from $B \to X_u l\nu$ decays**

- **Current status on $B(B \to X_s\gamma, E_\gamma > 1.6 GeV)$:**
  - **Experiment (HFAG): $(3.52 \pm 0.23_{stat+syst} \pm 0.09_{shpFcn}) \times 10^{-4}$**
  - **Theory: - $(3.15 \pm 0.23) \times 10^{-4}$ (Misiak, *et al.*)**
    - $(2.98 \pm 0.26) \times 10^{-4}$ (Becher/Neubert)

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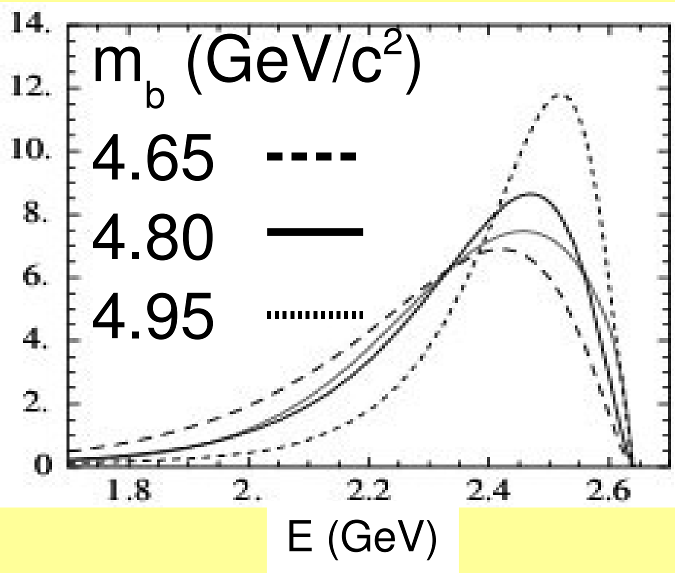

Eur. Phys. J. C7: 5-27,1999

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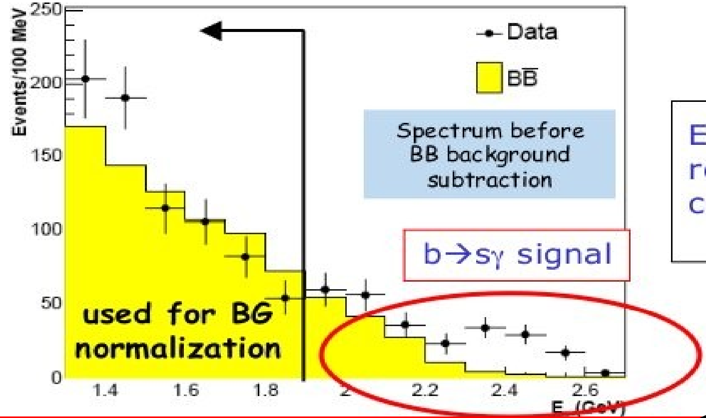
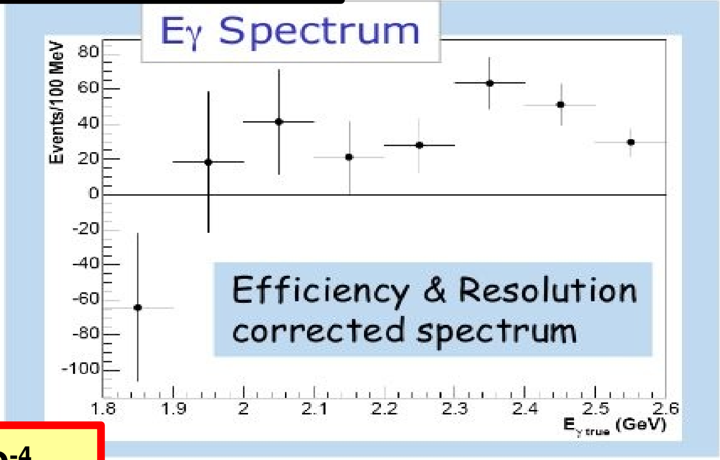
$b\to s\gamma$: Previous BaBar Analysis

Run 1-4 dataset = 210.5fb^{-1}

PRD77:051103, 2008



Efficiency, resolution corrections



$B(B\to X_s\gamma, E_\gamma>1.9\mathrm{GeV}) = (3.66\pm0.85_{stat}\pm0.59_{syst})\times10^{-4}$

Unexpected large systematic:

- **12% due to yields extraction from m_{ES} fits**
- **out of which 10% is due to BB background modeling**

- **Need understand these systematics** ⇒ measurement will be systematics dominated for SuperB expected statistic (100 times BaBar+Belle)
- **The plan is to produce a publication with the whole BaBar dataset**

Outline

- Introduction

- Analysis: time-dependent amplitude analysis of $B^0 \rightarrow K^0_S \pi^+ \pi^-$ decays with BaBar
  - Physical motivation
  - Dataset
  - Time-dependent Dalitz fit
  - Results

- Phenomenological interpretation: SU(2) isospin-based analysis of the $B \rightarrow K^* \pi$ modes

- Conclusions and perspectives

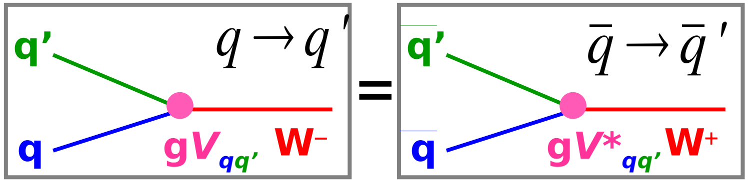
Introduction

CP Violation and the CKM Matrix

Standard Model (SM):

quark flavor changes with the quark mixing couplings

$$\begin{array}{cccc} & \text{Weak states} & \text{CKM matrix} & \text{Mass states} \\ \text{quarks} & \begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = & \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} & \begin{pmatrix} d \\ s \\ b \end{pmatrix} \end{array}$$



V_{CKM} complex → CPV
only CPV source in SM!

CP Violation and the CKM Matrix

Standard Model (SM):

Weak states CKM matrix Mass states

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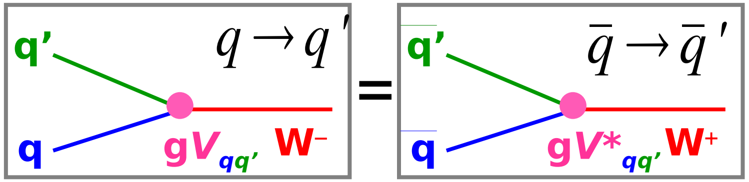

V_{CKM} complex → CPV only CPV source in SM!

$V_{CKM} V^{\dagger}_{CKM} = 1$ →

quark mixing only described by
- **3 real rotation angles and,**
- **1 irreducible phase with all the CPV information**

Expansion in power of λ until O(λ^4), with $\lambda = \sin(\theta_c) \approx 0.22$

CKM matrix Wolfenstein parameterization:

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

CPV only possible in the SM if $\eta \neq 0$

Experimental hierarchy between CKM elements

Unitarity Relations:

K^0 $$V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* = 0$$

B_s^0 $$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

B_d^0 $$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

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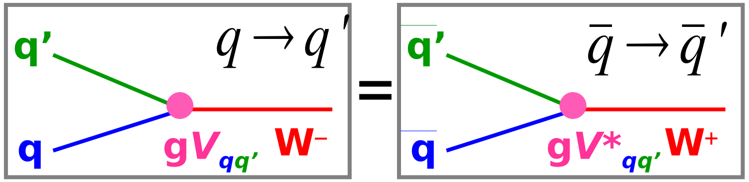

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K^0	$V_{ud}V^*_{us} + V_{cd}V^*_{cs} + V_{td}V^*_{ts} = 0$	$\sim\lambda, \sim\lambda, \sim\lambda^5$ →	**Flat triangle**
B_s^0	$V_{us}V^*_{ub} + V_{cs}V^*_{cb} + V_{ts}V^*_{tb} = 0$	$\sim\lambda^4, \sim\lambda^2, \sim\lambda^2$ →	**Flat triangle**
B_d^0	$V_{ud}V^*_{ub} + V_{cd}V^*_{cb} + V_{td}V^*_{tb} = 0$	$\sim\lambda^3, \sim\lambda^3, \sim\lambda^3$ →	**non-degenerated**

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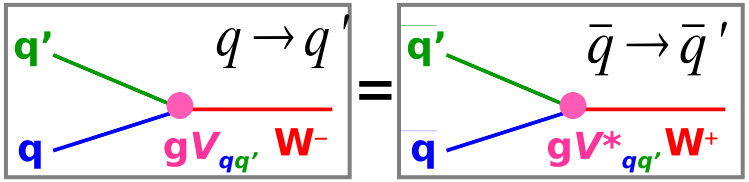
quarks
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



V_{CKM} complex → CPV
only CPV source in SM!

$V_{CKM}V^{\dagger}_{CKM} = 1$

quark mixing only described by
- 3 real rotation angles and,
- 1 irreducible phase with all the CPV information

Expansion in power of λ until O(λ⁴), with λ=sin(θ$_c$) ≈ 0.22

CKM matrix Wolfenstein parameterization:

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

CPV only possible in the SM if η≠0

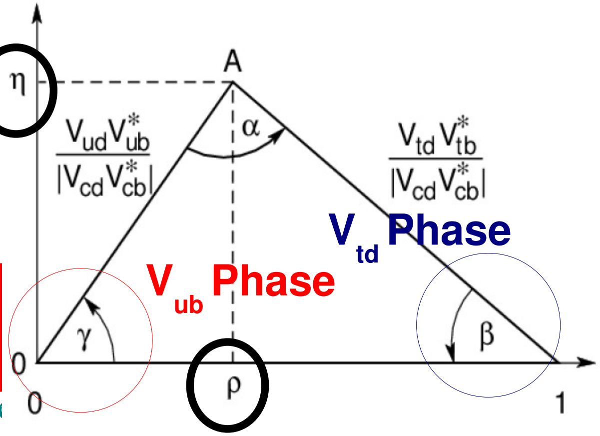
Experimental hierarchy between CKM elements

Unitarity Relations:

K^0 $$V_{ud}V_{us}^* + V_{cd}V_{cs}^* + V_{td}V_{ts}^* = 0$$

B_s^0 $$V_{us}V_{ub}^* + V_{cs}V_{cb}^* + V_{ts}V_{tb}^* = 0$$

B_d^0 $$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



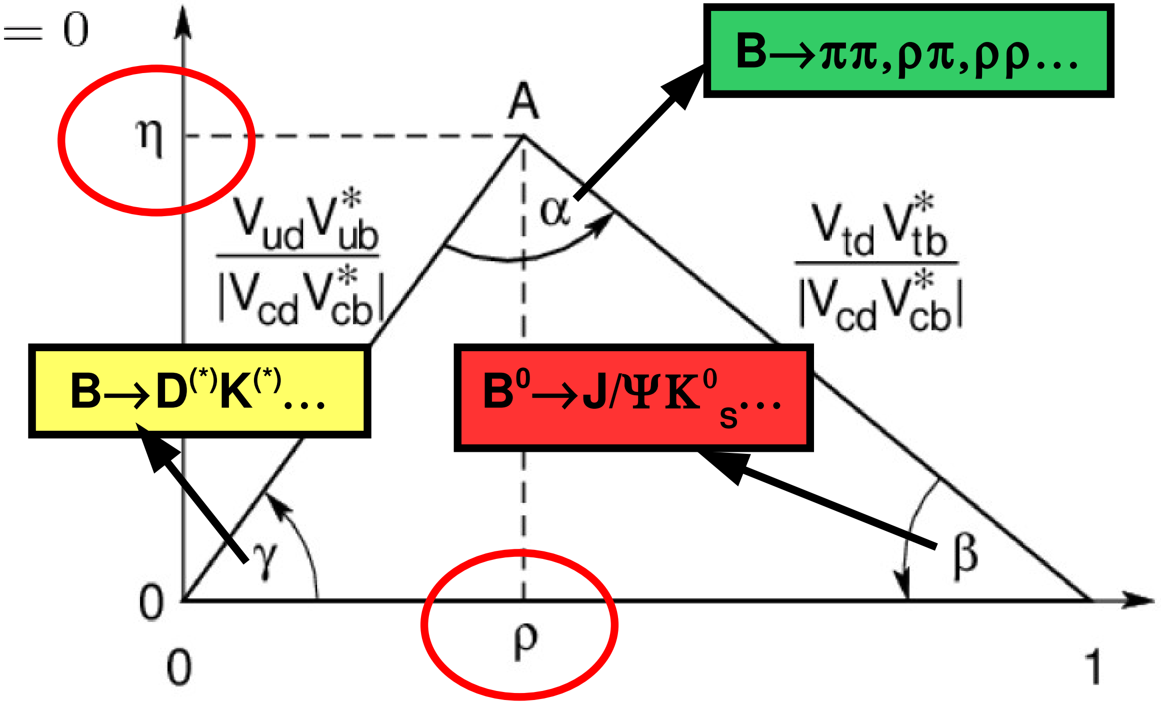
B^0_d system:

- **Direct couplings to complex CKM**
- **Couplings of same size**
- **Expects a rich phenomenology**

Unitarity Triangle Parameters

Unitarity Triangle (UT)

B_d^0 $V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$



B→ππ,ρπ,ρρ…

B→D$^{(*)}$K$^{(*)}$…

B^0→J/ΨK^0_s…

Theoretical expression of each observable is a function of (ρ,η)

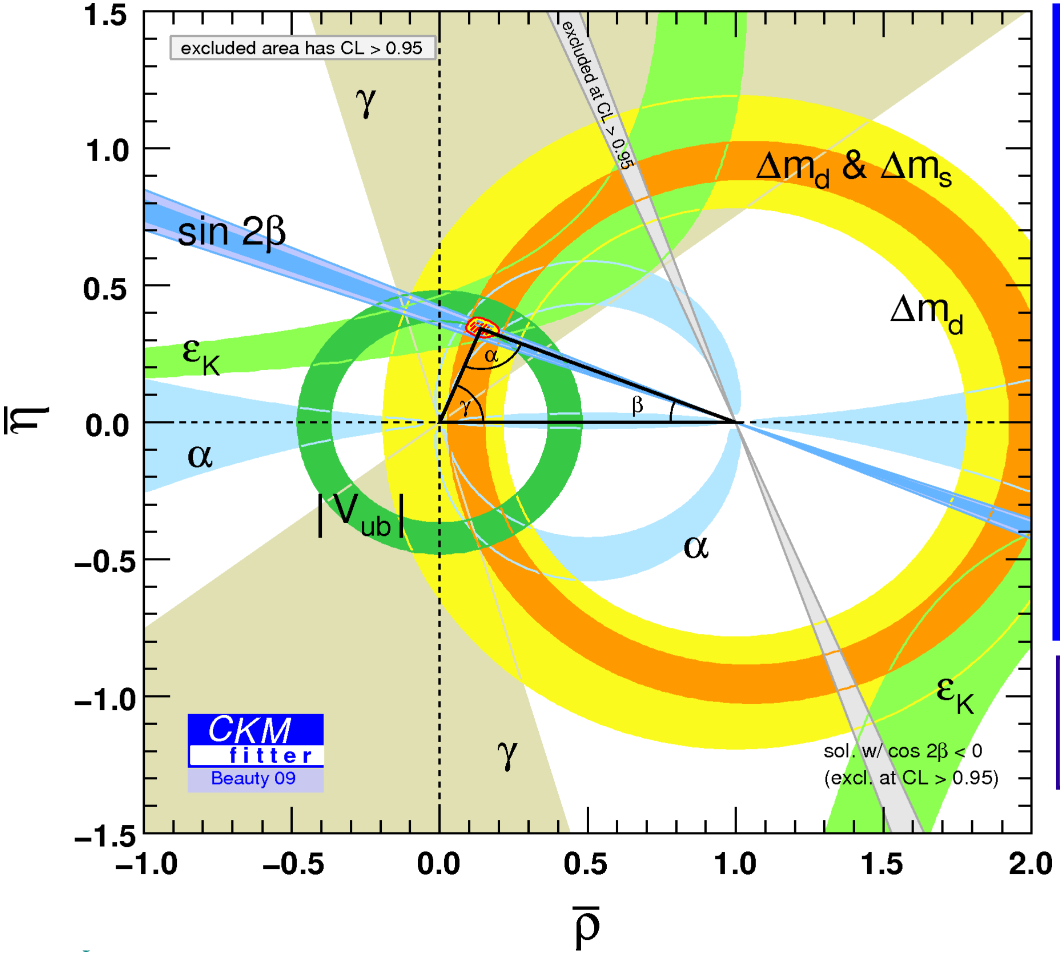
Measurement is a constraint on (ρ,η)

The CKM Unitarity predicts that all constraints intersect at one point!

Current Status of CKM parameters

Standard CKM fit uses diverse measurements theoretically under control:

- **From B factories:** Δm_d, $\sin 2\beta$, $|V_{cb}|$, $|V_{ub}|$, α, γ
- **Other sources:** $|\varepsilon_K|$, Δm_s, $|V_{ud}|$, $|V_{us}|$



- **Combined constraint limited in a small region of parameter space.**
- **Striking confirmation of CKM mechanism.**

Two simultaneous strategies:

- **Improve precision of measurements**
- **Look for processes sensitive to NP**

This presentation:

amplitude analyses of loop dominated modes

CKMfitter Group (J. Charles et al.),
Eur. Phys. J. C41, 1-131 (2005) [hep-ph/0406184],
updated results and plots available at: http://ckmfitter.in2p3.fr

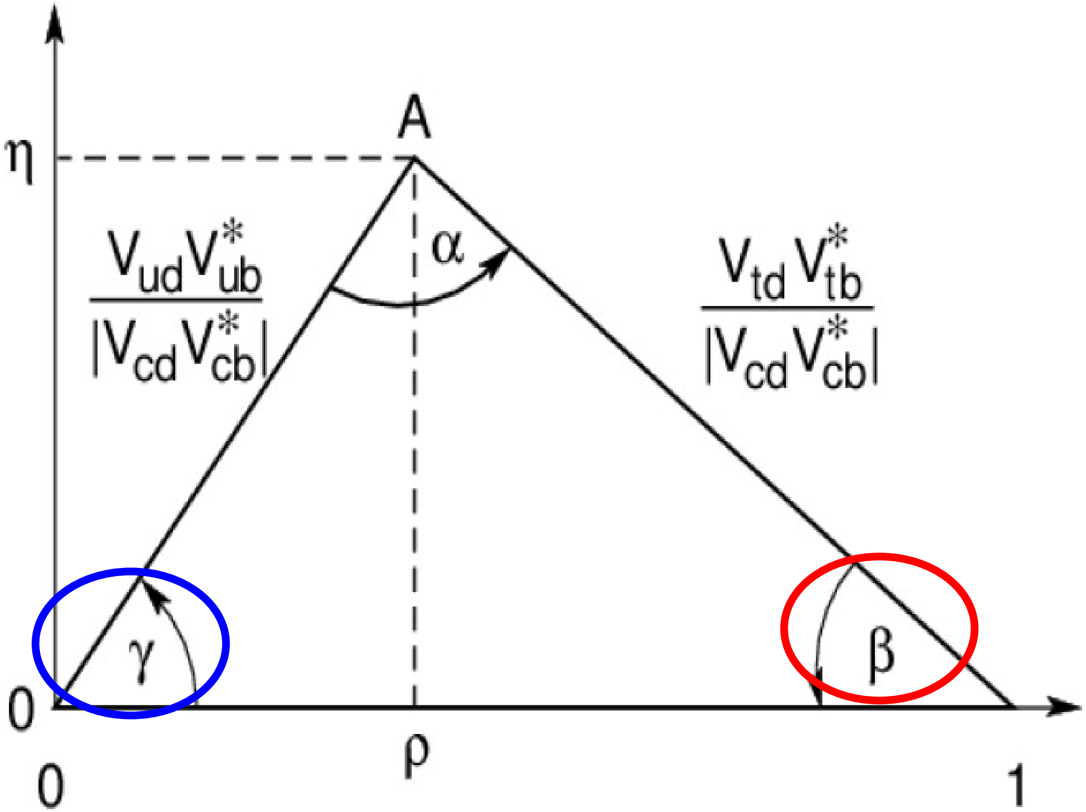
$B^0 \rightarrow K^0_S \pi^+ \pi^-$ Analysis

B. Aubert *et al.* [BaBar Collaboration], *Time-dependent amplitude analysis of $B^0 \rightarrow K^0_S \pi^+ \pi^-$, Phys. Rev.* D**80**:112001 (2009).

HPWS Group:
E. Ben Haim, M. Graham,
J. Ocariz, A. Pérez, M. Pierini, J. Wu

UK Group:
P. Del Amo Sanchez, T. Gershon, P. Harrison,
C. Hawkes, J. Ilic, T. Latham, M. Gagan,
N. Soni, F. Wilson

Motivations



Motivations

New physics in penguin dominated modes

- b →ccs (i.e. $J/\Psi K^0_s$) golden modes (Theo. clean)
- b →qqs (q = u,d,s) loop dominated (NP sensitive)

Time-dependent CPV parameters

- C: Direct CP asymetry
- S: mixing induced CP asymmetry

Standard Model (SM)

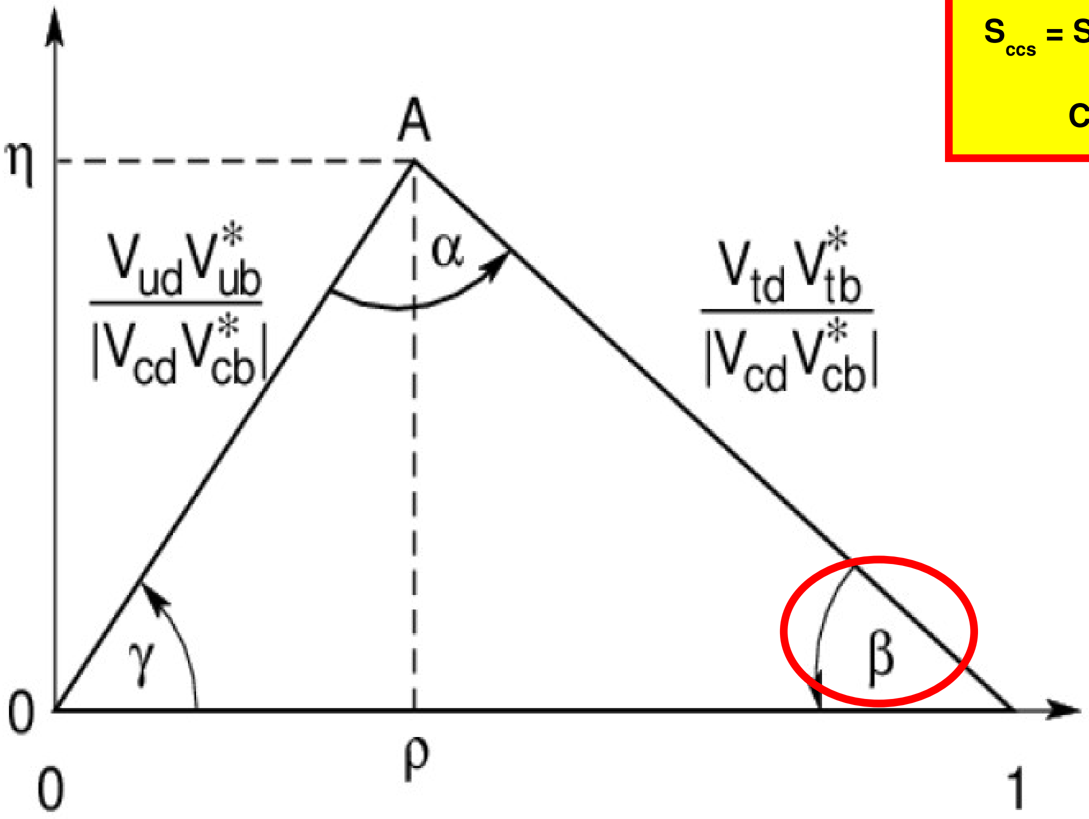
$S_{ccs} = S_{qqs} + \Delta S_{SM} = \sin 2\beta$

$C_{ccs} \approx C_{qqs} \approx 0$

New Physics (NP)

$S_{ccs} \neq S_{qqs} + \Delta S_{SM}$

$C_{ccs} \neq C_{qqs}$

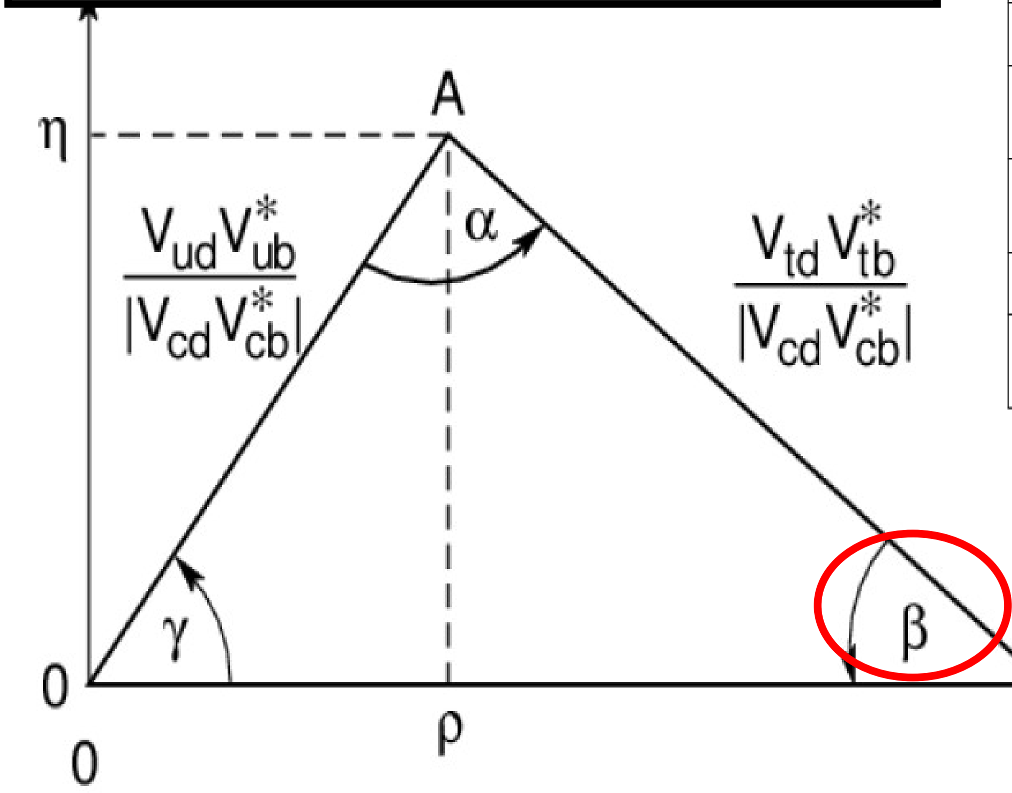


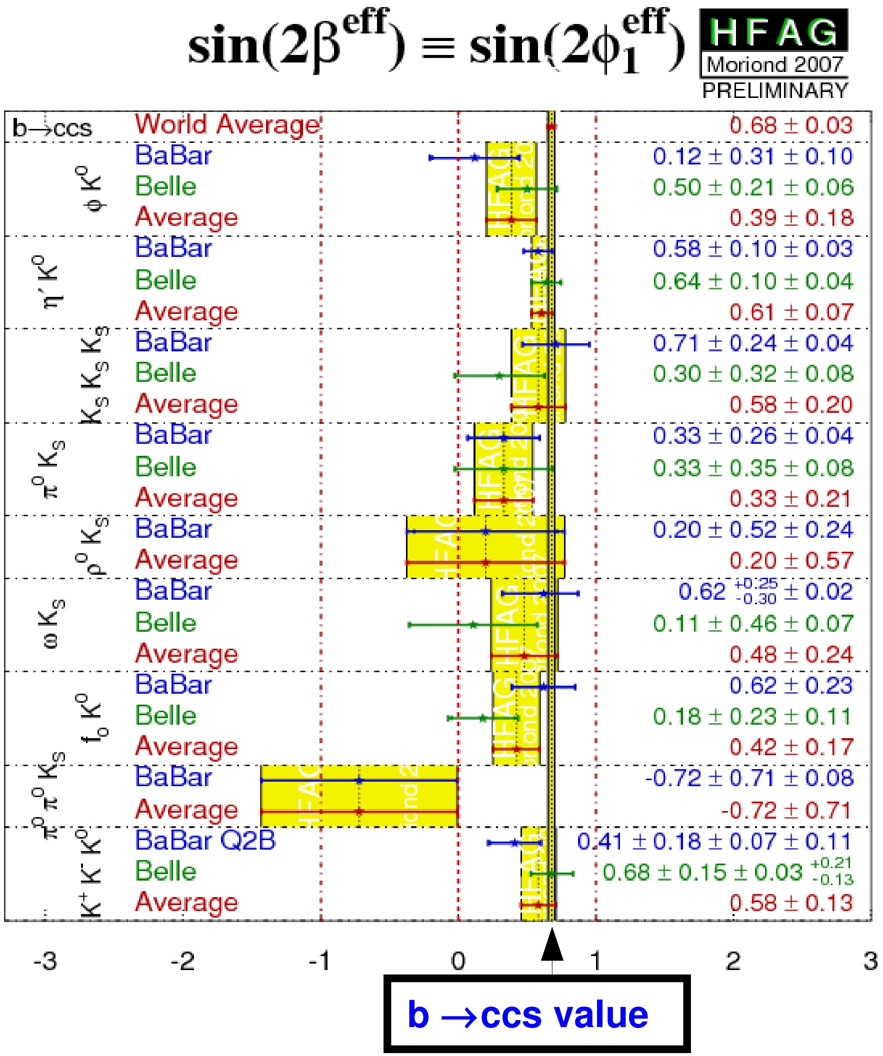
Motivations

New physics in penguin dominated modes

ΔS_{SM} tension, a hint to NP?

- **Theo: predicts positive values**
- **Expe: systematically obtain negative values. Errors still large.**





b →ccs value

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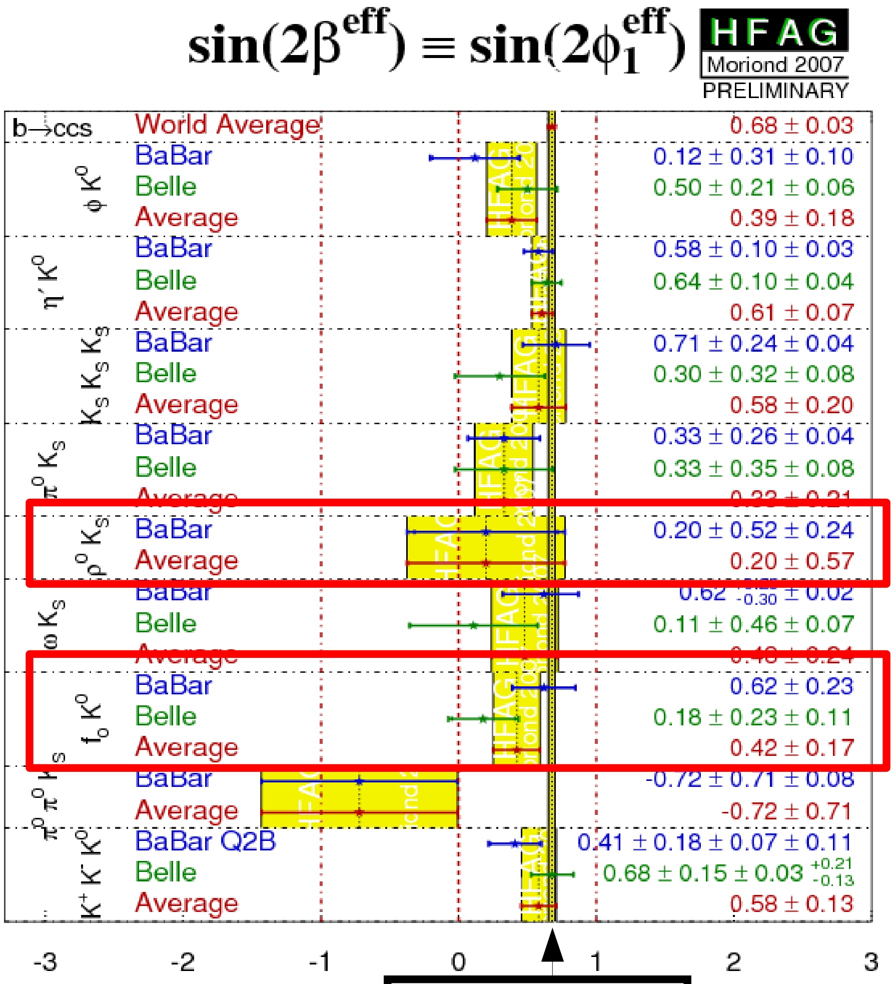

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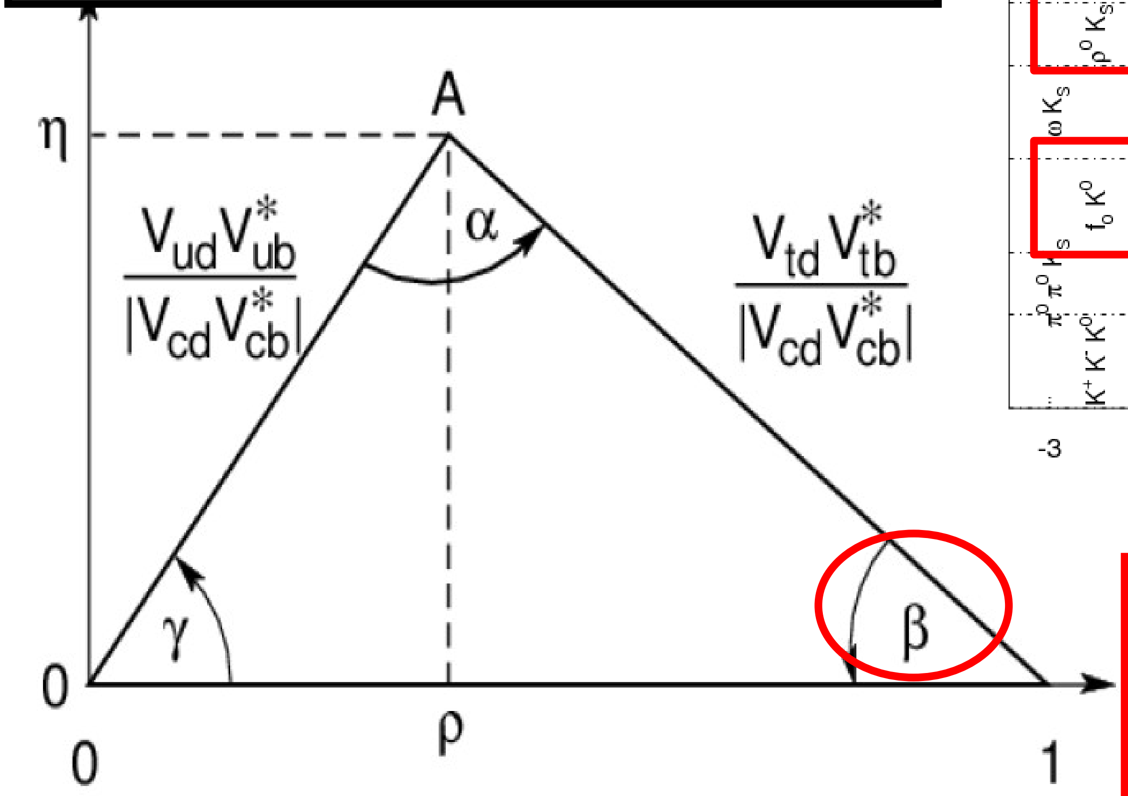


Penguin dominated modes

$f_0(980)K^0_S$ and $\rho^0(770)K^0_S$

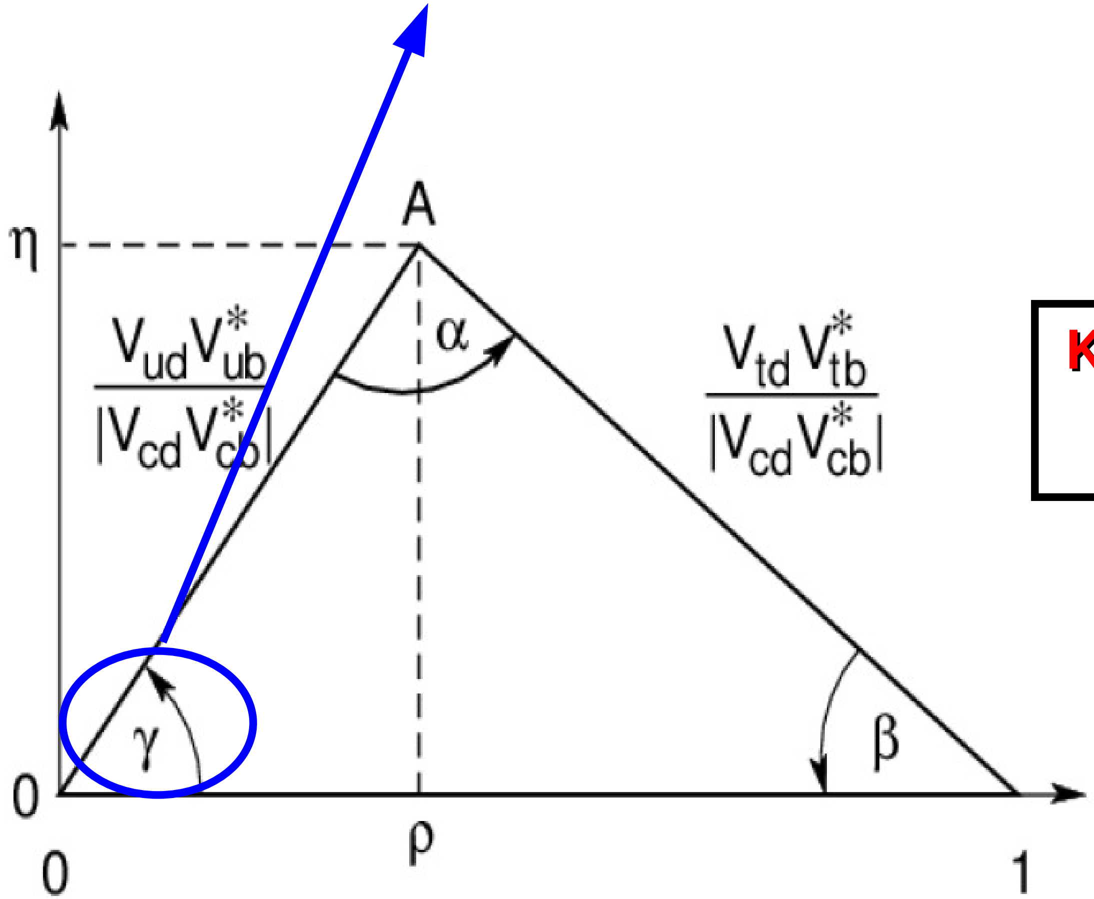
contribute to $B^0 \to K^0_S\pi^+\pi^-$

Motivations

CPS/GPSZ method:

access to γ with $B \to K^{*}\pi$ modes

CPS PRD74:051301
GPSZ PRD75:014002



$K^{*+}(892)\pi^{-}$ contribute to $B^0 \to K^0_S\pi^+\pi^-$

Motivations

CPS/GPSZ method:

access to γ with $B \rightarrow K^{*}\pi$ modes

CPS PRD74:051301
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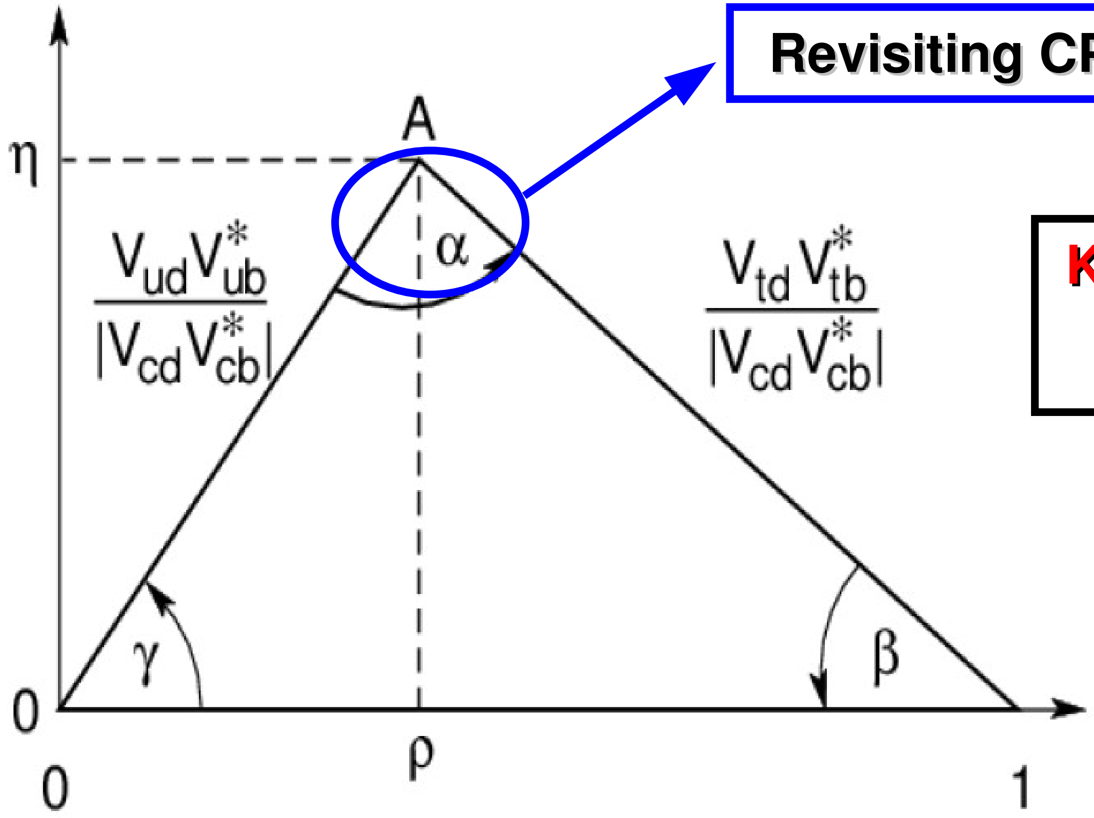


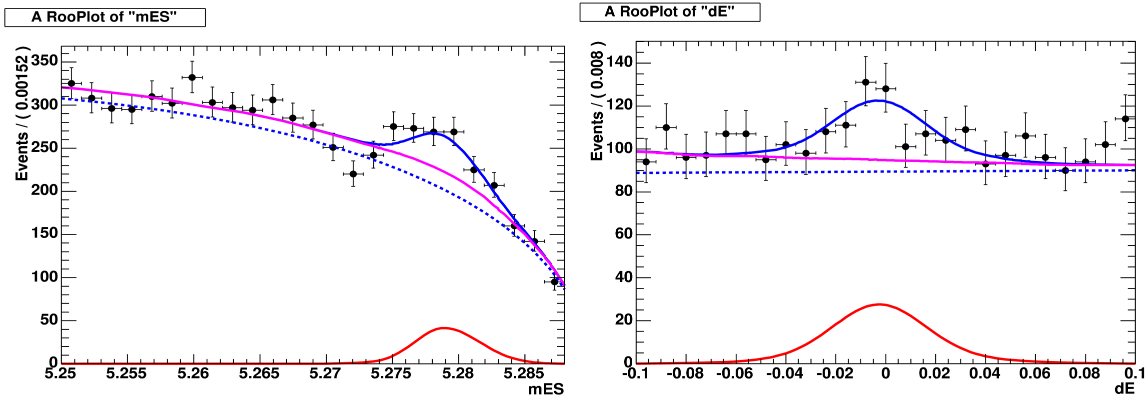
Revisiting CPS/GPSZ: access to α

$K^{*+}(892)\pi^{-}$ contribute to $B^{0} \rightarrow K^{0}_{S}\pi^{+}\pi^{-}$

Time-dependent amplitude analyses

Time-dependent amplitude analyses

- **Counting rate analyses ⇒ signal-background discrimination**



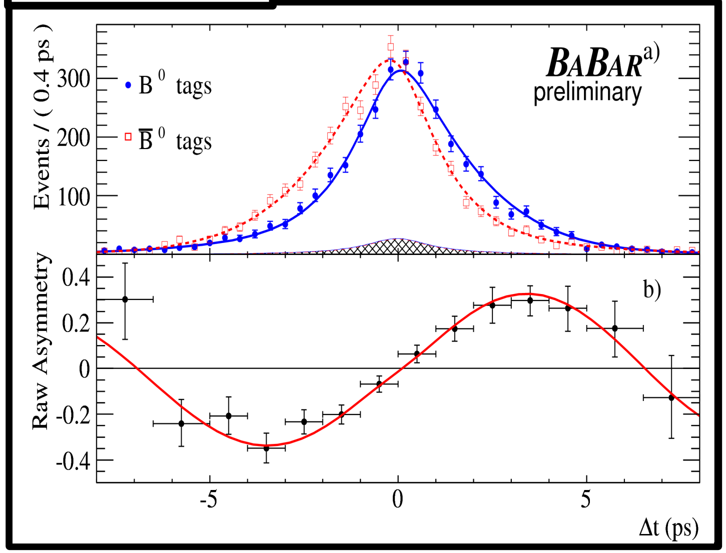
Measure

Decay Rates

Time-dependent amplitude analyses

- **Counting rate analyses ⇒ signal-background discrimination**
- **Time-dependent analyses ⇒ time-evolution of signal**

$J/\Psi K^0_s$ decays

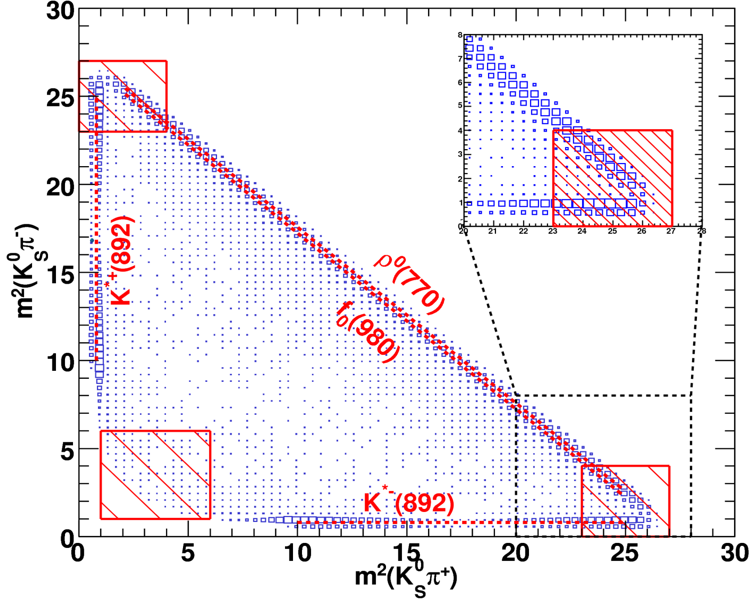


Measure
Time-dependent
CP asymmetries

Time-dependent amplitude analyses

- Counting rate analyses ⇒ signal-background discrimination
- Time-dependent analyses ⇒ time-evolution of signal
- Amplitude analyses ⇒ Interference of signal in phase-space

Dalitz Plot (DP)



Can study decay dynamics

Measure phases differences from interference

Time-dependent amplitude analyses

- Counting rate analyses ⇒ signal-background discrimination

- Time-dependent analyses ⇒ time-evolution of signal

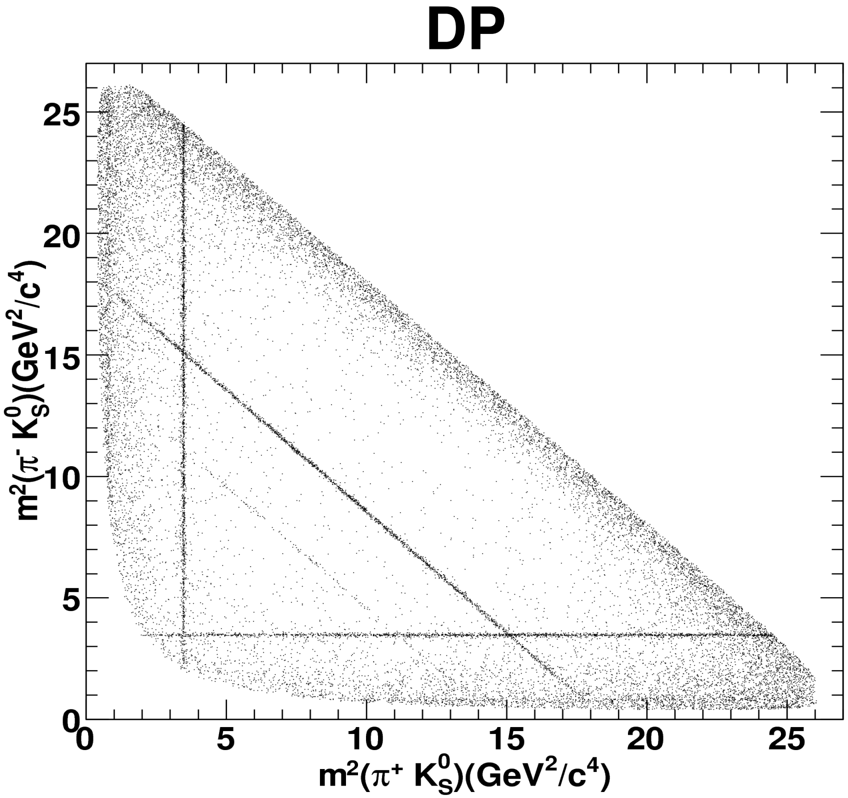
- Amplitude analyses ⇒ Interference of signal in phase-space

- **Time-dependent amplitude analyses ⇒ time-evolution of signal interference**
  - Use all available information
  - Can measure all previous observables
  - Additionally can measure phase differences related with time-dependent CPV

- Will only concentrate in describing modeling of time-evolution of decay-dynamics

Data Set

- **Run 1-5: $347.3\ fb^{-1}$ → $382.9x10^6$ $B\bar{B}$ pairs**
- **Reconstruction and Selection → 22525 events**
- **Overall signal efficiency → 25%**



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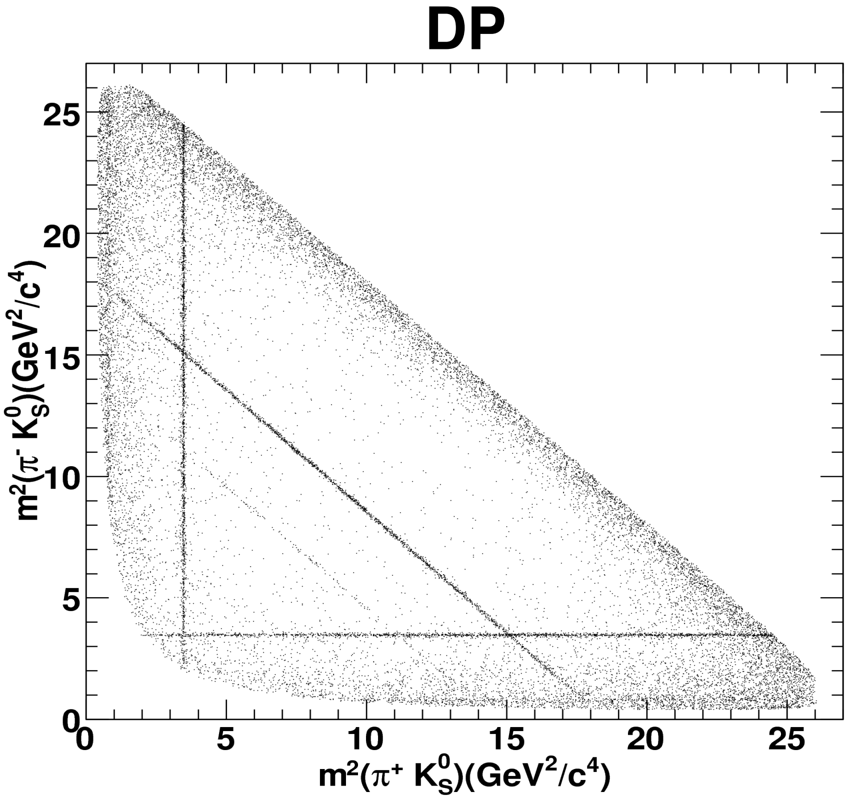

Main contributions:

- **Continuum ($e^+e^- \rightarrow qq$, q=u,d,s,c) background (~14k events)**

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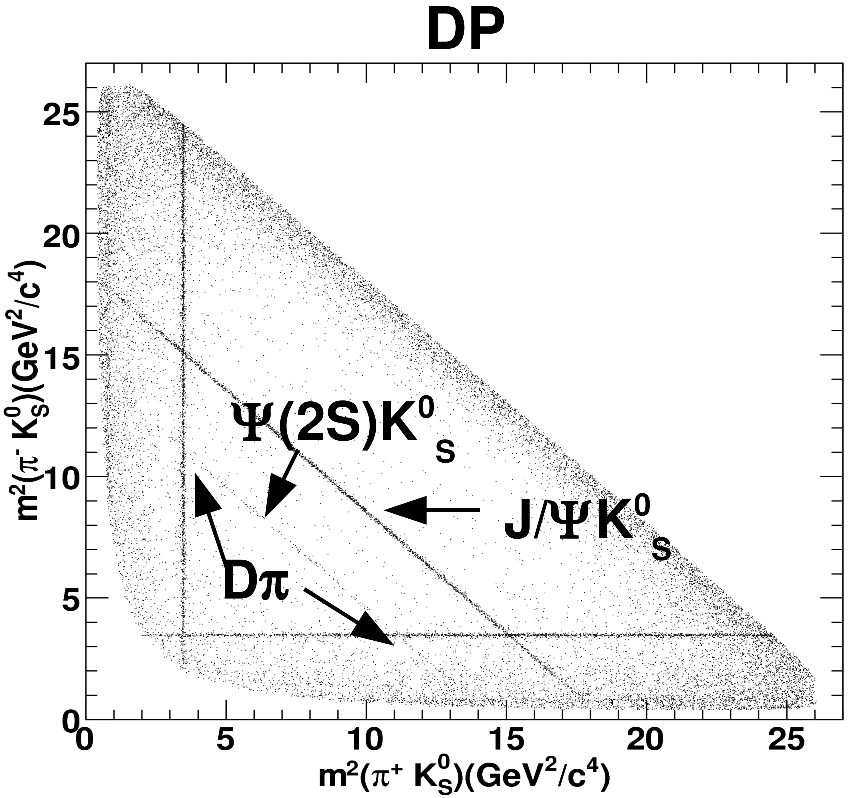

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- **B-background: peaking in DP (~5k vents)**

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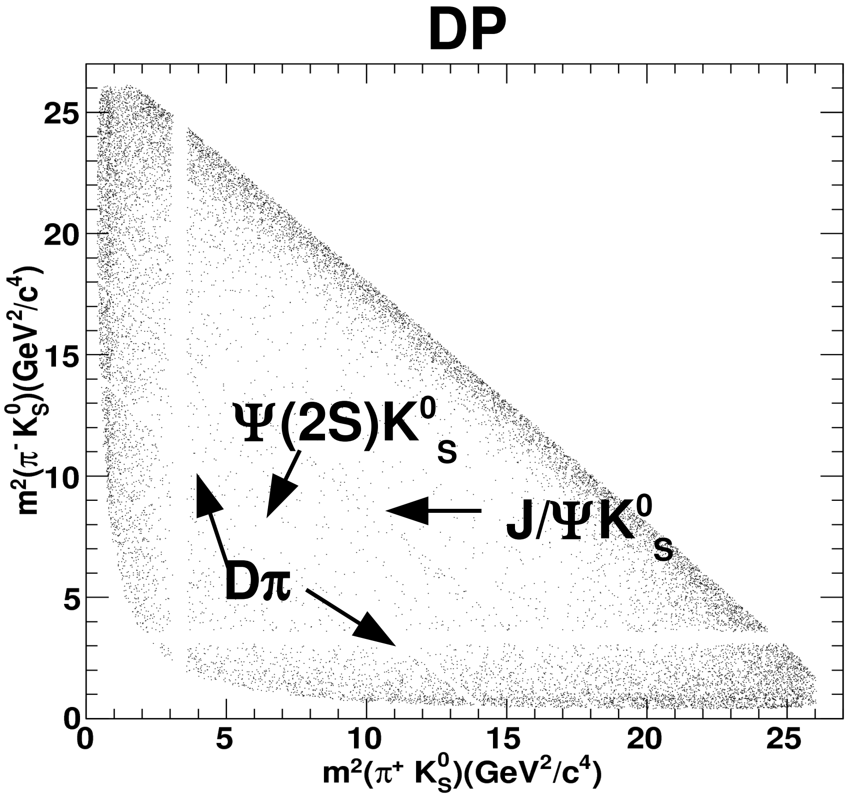

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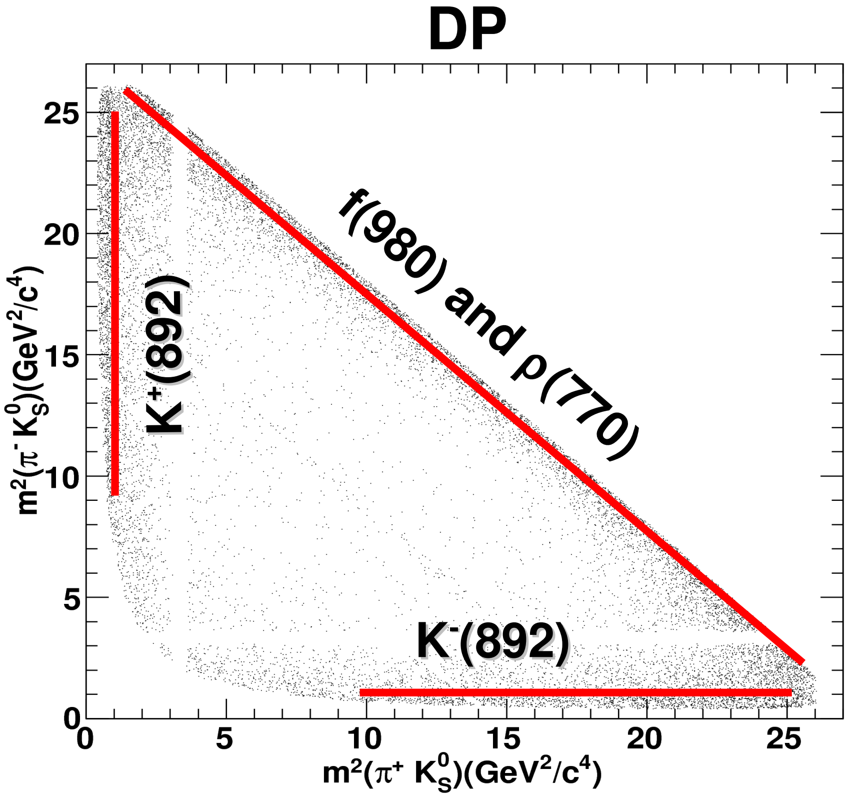

Main contributions:

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- B-background: peaking in DP (~5k vents)
- Signal

Data Set

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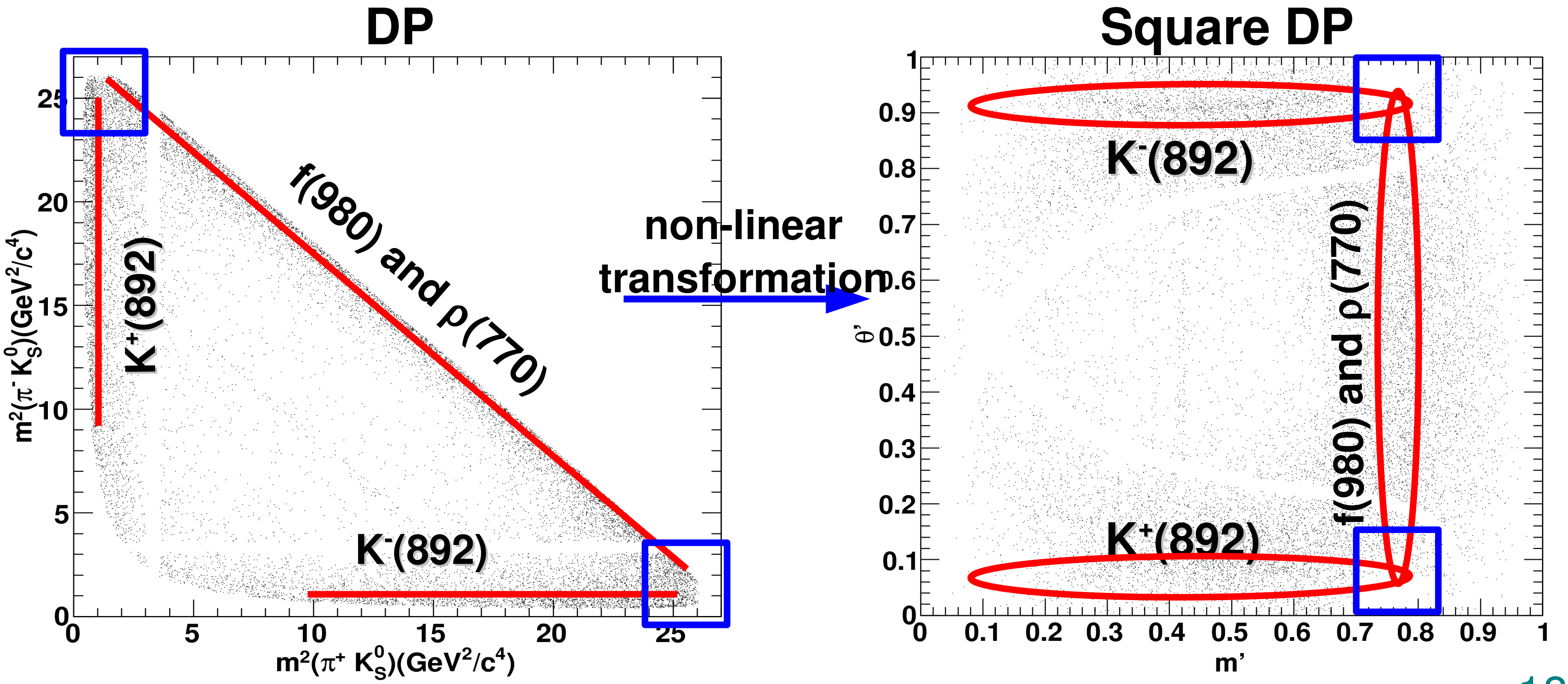

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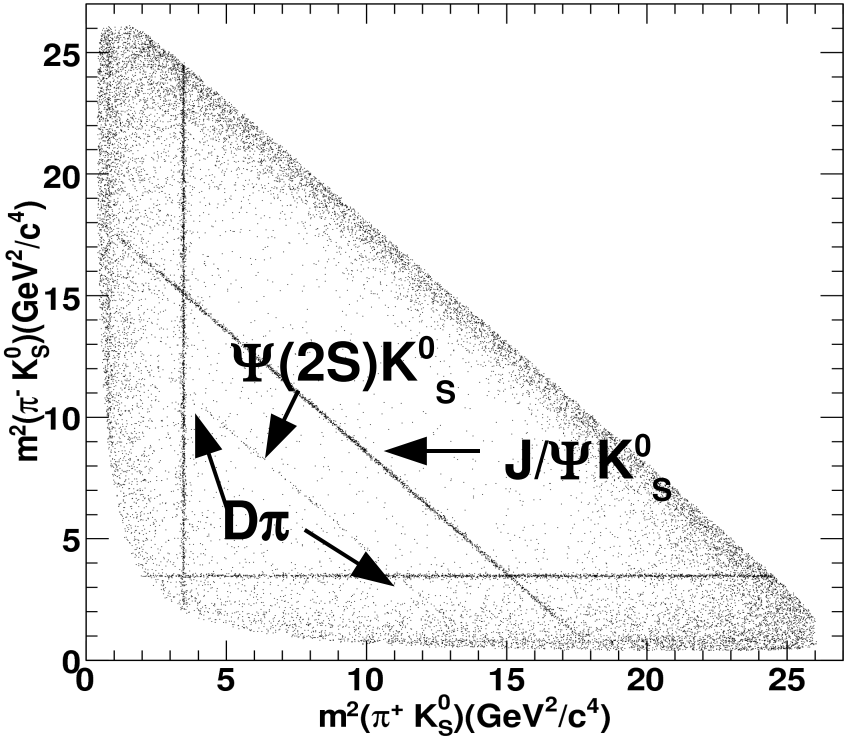
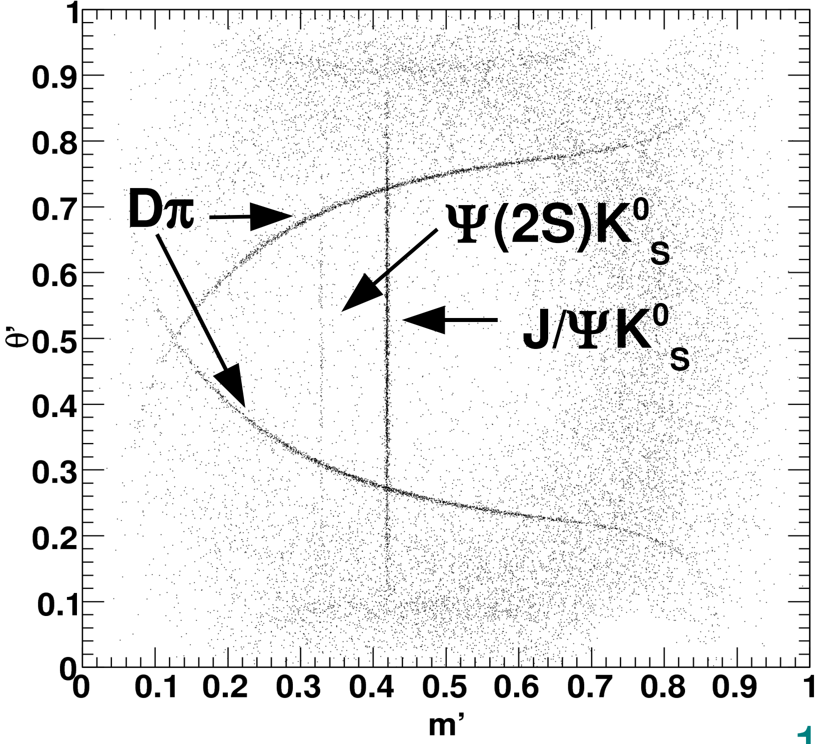


DP



Square DP

DP and time-dependent PDF

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot

Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP) \end{cases}$$

DP and time-dependent PDF

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Isobar amplitudes:

Weak phases information

DP and time-dependent PDF

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Shapes of intermediate states over DP

DP and time-dependent PDF

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Shapes of intermediate states over DP

Signal Model:

- $B^0 \to \rho^0(770) K^0_S$ (GS)
- $B^0 \to f_0(980) K^0_S$ (Flatté)
- $B^0 \to K^*(892)\pi$ (RBW)
- $K\pi$ S-wave (LASS)
- Non-resonant (flat phase space)
- $B^0 \to f_X(1300) K^0_S$ (RBW)
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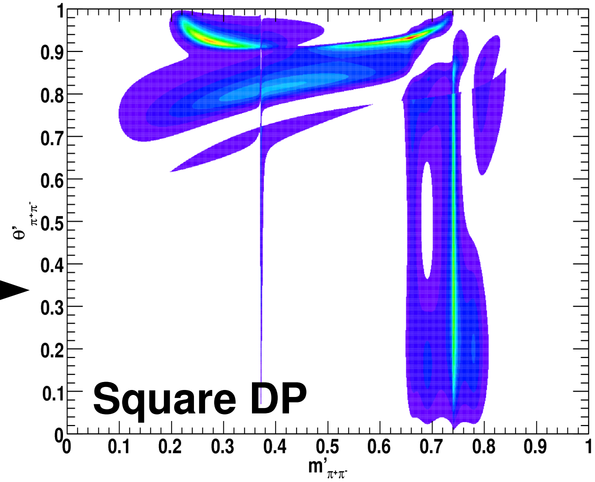
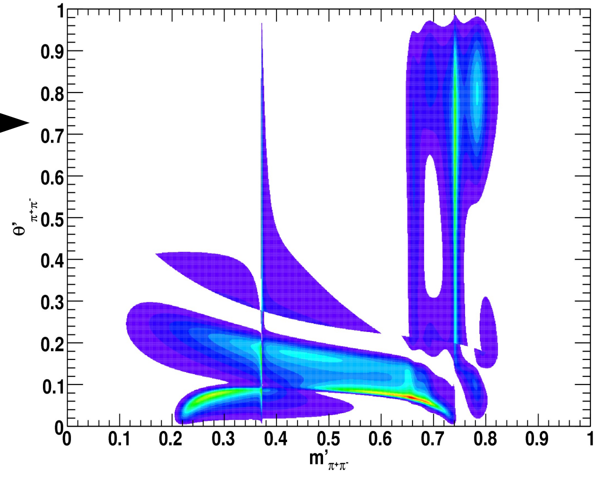
$|A(SDP)|^2 \longrightarrow$



$|\overline{A}(SDP)|^2 \longrightarrow$



Common Signal Model for all BaBar B→Kππ analyses

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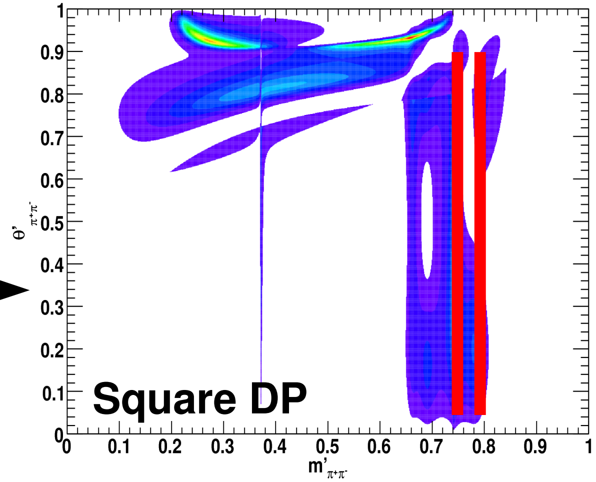

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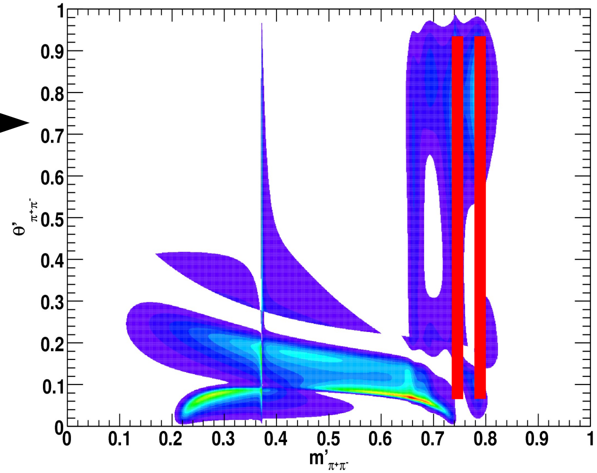

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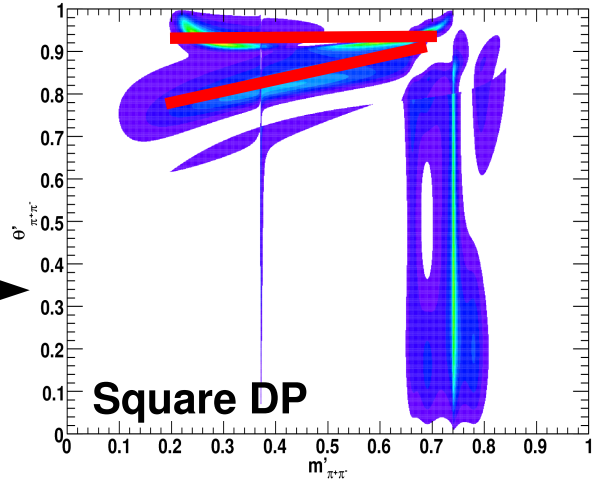

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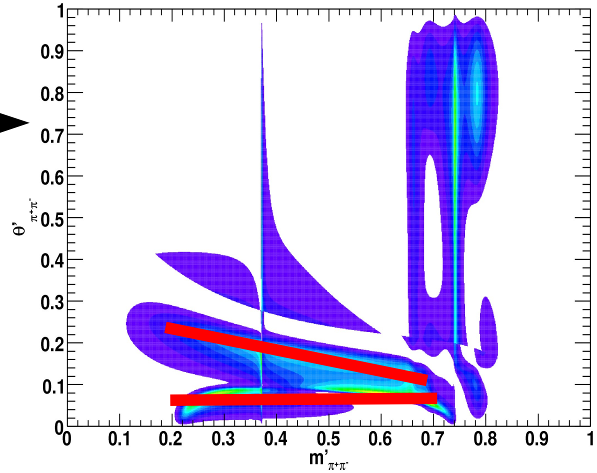

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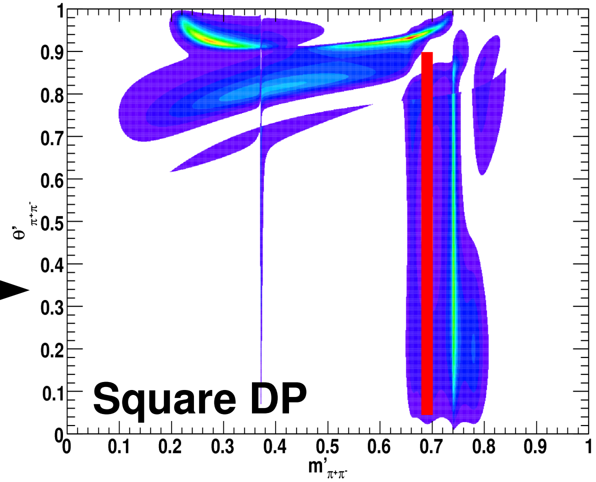
$|A(SDP)|^2$ →



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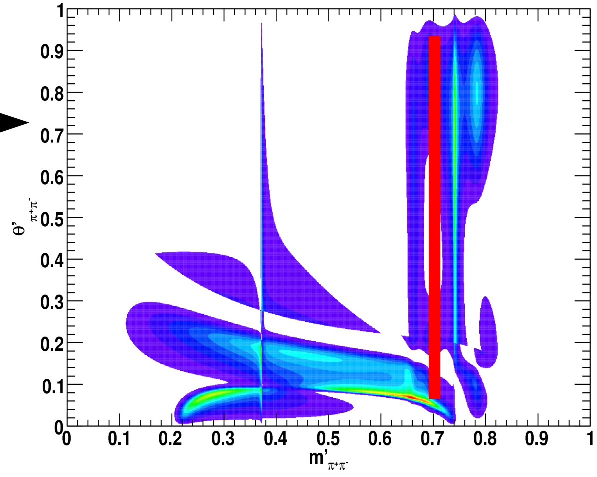

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Time-dependent DP PDF **(|q/p| ~ 1)**

Δt = time difference between B^0-$\overline{B}^0$ decays

$$f(\Delta t, DP, q_{\rm tag}) \;\; \propto \;\; (|A|^2 + |\bar{A}|^2)\,\frac{e^{-|\Delta t|/\tau}}{4\tau}$$

$$\left(1 + q_{\rm tag}\frac{2\mathcal{I}m[(q/p)\bar{A}A^*]}{|A|^2+|\bar{A}|^2}\sin(\Delta m_d \Delta t) - q_{\rm tag}\frac{|A|^2-|\bar{A}|^2}{|A|^2+|\bar{A}|^2}\cos(\Delta m_d \Delta t)\right)$$

mixing and decay CPV

DCPV

DP and time-dependent PDF

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot
Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \bar{A}(DP) = \sum \bar{a}_j \bar{F}_j(DP) \end{cases}$$

Sensitivity to phase differences between a_i and $\bar{a}_j$ amplitudes.
Includes q/p mixing phase.

Time-dependent DP PDF **(|q/p| ~ 1)**

$$f(\Delta t, DP, q_{\rm tag}) \propto (|A|^2 + |\bar{A}|^2)\frac{e^{-|\Delta t|/\tau}}{4\tau}$$
$$\left(1 + q_{\rm tag}\frac{2\mathcal{I}m[(q/p)\bar{A}A^*]}{|A|^2+|\bar{A}|^2}\sin(\Delta m_d \Delta t) - q_{\rm tag}\frac{|A|^2-|\bar{A}|^2}{|A|^2+|\bar{A}|^2}\cos(\Delta m_d \Delta t)\right)$$

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Time-dependent DP PDF **(|q/p| ~ 1)**

Sensitivity to phase difference between amplitudes in the same DP plane (B^0 or $\bar{B}^0$).

$$f(\Delta t, DP, q_{\rm tag}) \propto (|A|^2 + |\bar{A}|^2)\frac{e^{-|\Delta t|/\tau}}{4\tau} \left(1 + q_{\rm tag}\frac{2\mathcal{I}m[(q/p)\bar{A}A^*]}{|A|^2+|\bar{A}|^2}\sin(\Delta m_d \Delta t) - q_{\rm tag}\frac{|A|^2 - |\bar{A}|^2}{|A|^2+|\bar{A}|^2}\cos(\Delta m_d \Delta t)\right)$$

mixing and decay CPV

DCPV

DP and time-dependent PDF

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot

Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP) \end{cases}$$

Time-dependent DP PDF (|q/p| ~ 1)

$$f(\Delta t, DP, q_{\rm tag}) \quad \propto \quad (|A|^2 + |\bar{A}|^2)\,\frac{e^{-|\Delta t|/\tau}}{4\tau}$$

$$\left(1 + q_{\rm tag}\,\underbrace{\frac{2\mathcal{I}m[(q/p)\bar{A}A^*]}{|A|^2+|\bar{A}|^2}}_{\text{mixing and decay CPV}}\sin(\Delta m_d \Delta t) - q_{\rm tag}\underbrace{\frac{|A|^2-|\bar{A}|^2}{|A|^2+|\bar{A}|^2}}_{\text{DCPV}}\cos(\Delta m_d \Delta t)\right)$$

Complex amplitudes a_i and $\bar{a}_j$ determine DP interference pattern.
Module and phase can be directly fitted on data.

Physical Parameters

Direct CP asymmetries:

$$C_j = \frac{|a_j|^2 - |\bar{a}_j|^2}{|a_j|^2 + |\bar{a}_j|^2} \qquad A_{CP}^{j} = \frac{|\bar{a}_{\bar{j}}|^2 - |a_j|^2}{|\bar{a}_{\bar{j}}|^2 + |a_j|^2}$$

The mixing and decay CPV S parameter:

$$S_j = \frac{2\,\mathrm{Im}[a_j^{*}\bar{a}_j\,(\mathrm{q/p})]}{|a_j|^2 + |\bar{a}_j|^2} = \sqrt{(1-C^2)}\,\sin(2\beta^{j}_{\mathrm{eff}})$$

Counting rate measurements:
sinus ambiguity $2\beta_{\mathrm{eff}} \leftrightarrow \pi - 2\beta_{\mathrm{eff}}$

Phase differences:

$$2\beta^{j}_{\mathrm{eff}} = \arg[\,a_j\,\bar{a}_j^{\,*}\,(\mathrm{q/p})^{*}\,]$$

⇒ $f_0(980)$ and $\rho^0(770)$

$$\Delta\varphi_{j\bar{j}} = \arg[\,a_j\,\bar{a}^{¿}_{\bar{j}}\,(\mathrm{q/p})^{*}\,]$$

⇒ K*(892)π (“CPS phase”)

The phases accessed through interference over the DP

Maximum Likelihood Fit Results

Fit Results

Fit Parameters:

- 11 yields (Signal and background),

- 34 shape parameters (i.e. signal and background PDFs for discriminant variables),

- 30 moduli and phases of isobar amplitudes

Total: 75 parameters floated!

Fit Results: qualitative

- **The fit founds two solutions almost degenerated differing by 0.16 in -2Log(L) units**

- **Non-isobar parameters:**
  - Values found are identical in both solutions

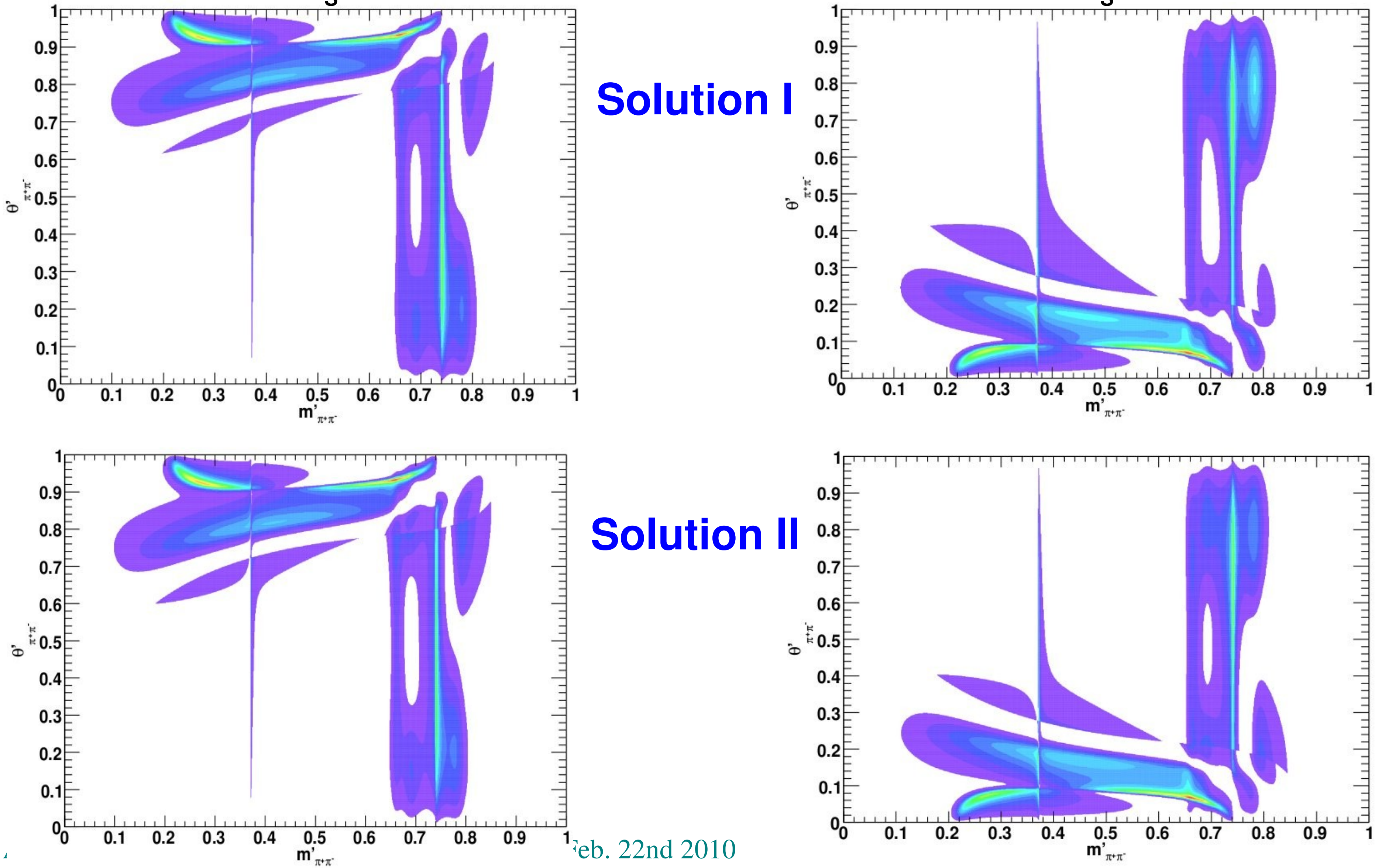
- **Isobar parameters:**
  - Moduli of isobar amplitudes are similar in both solutions. Mean differences in non-resonant (NR) and minor components
  - Phases vary significantly for one solution to the other

- **There is an intrinsic ambiguity in resolving the interference pattern in the DP**

Fit Results: qualitative

$|A(B^0 \to K^0_S \pi^+ \pi^-)|^2$

$|A(\overline{B^0} \to K^0_S \pi^+ \pi^-)|^2$



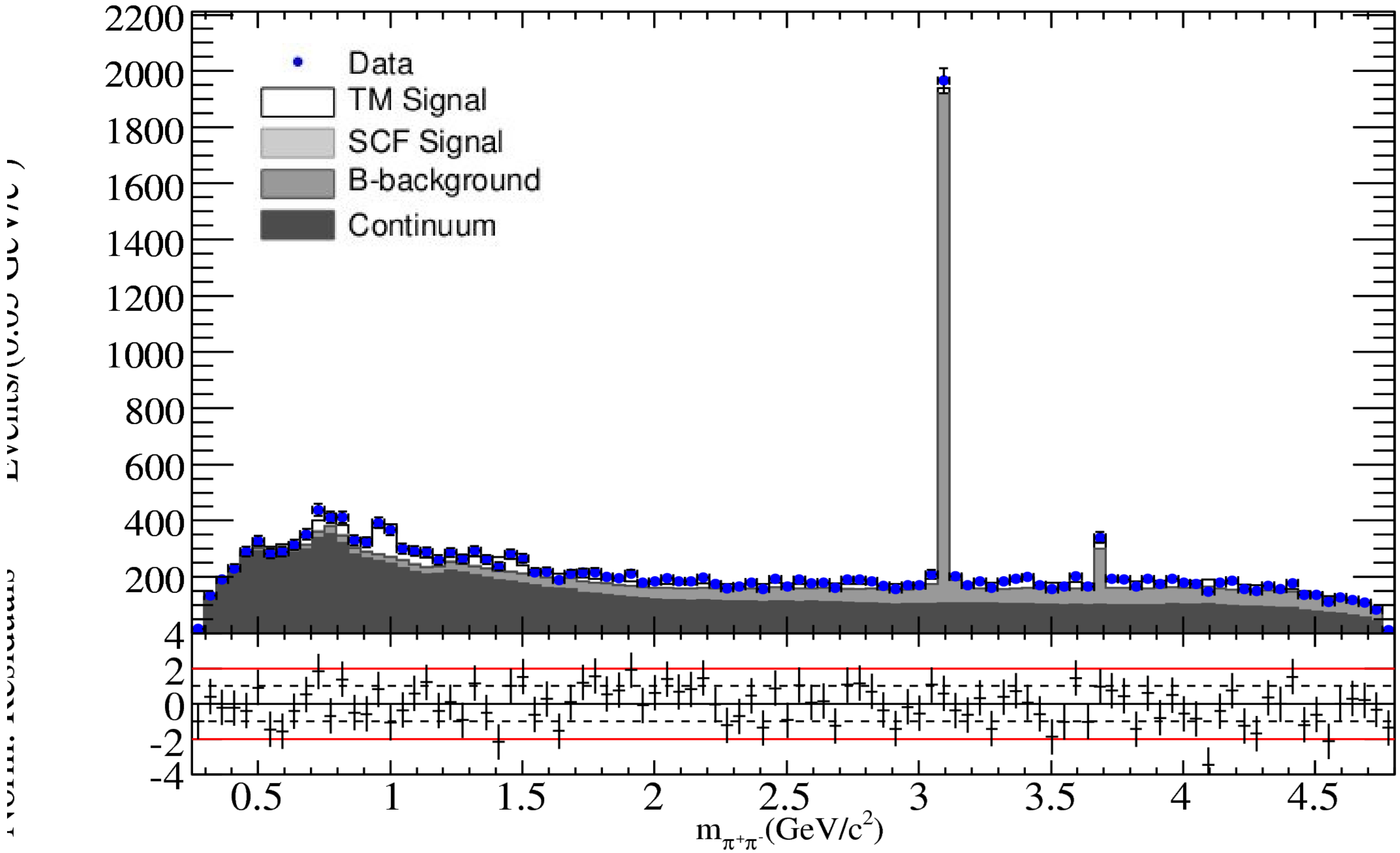
Solution I

Solution II

Goodness of Fit (Projection Plots)

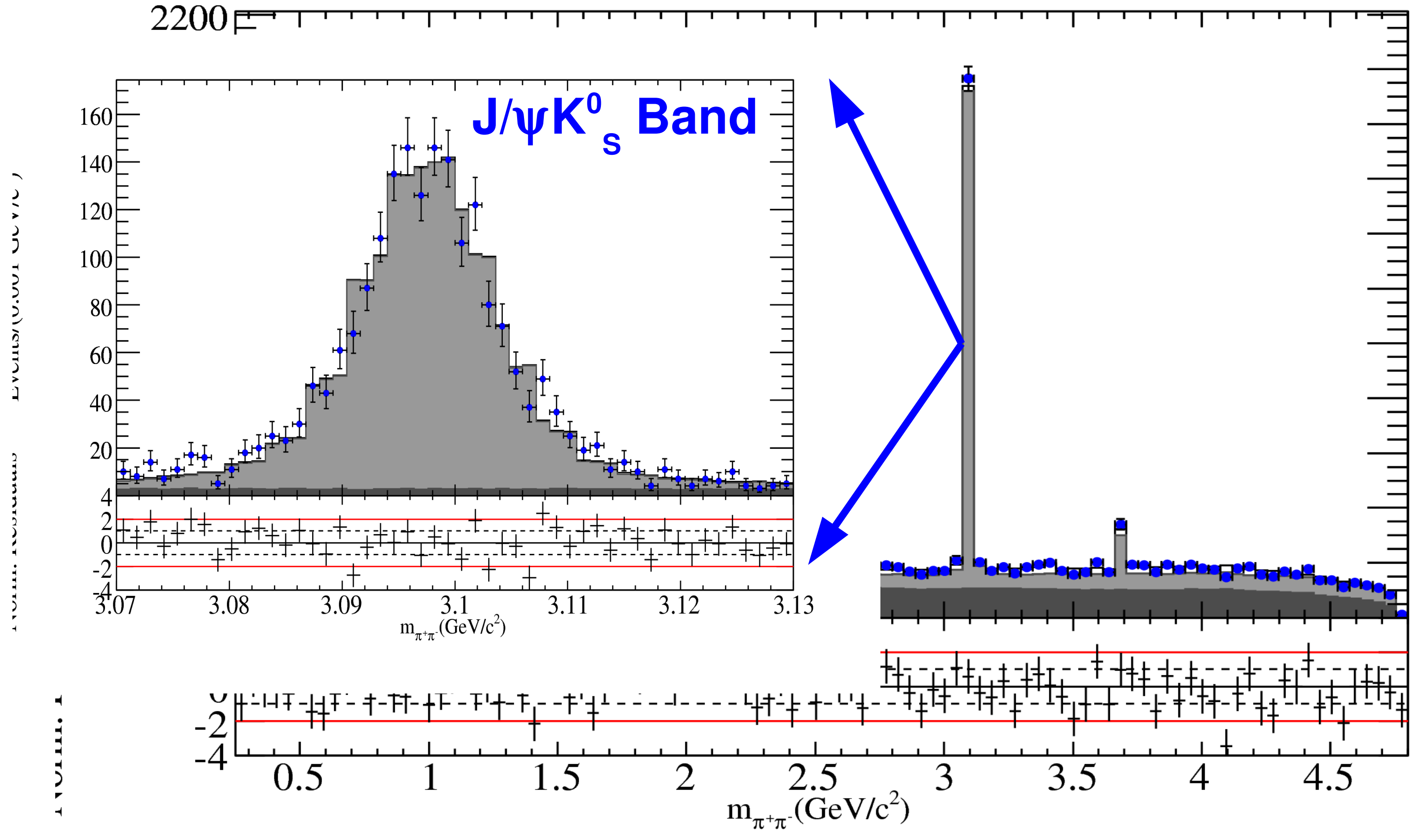
Fit Results: Proj. Plots (I)

$m_{\pi\pi}$ (all events)



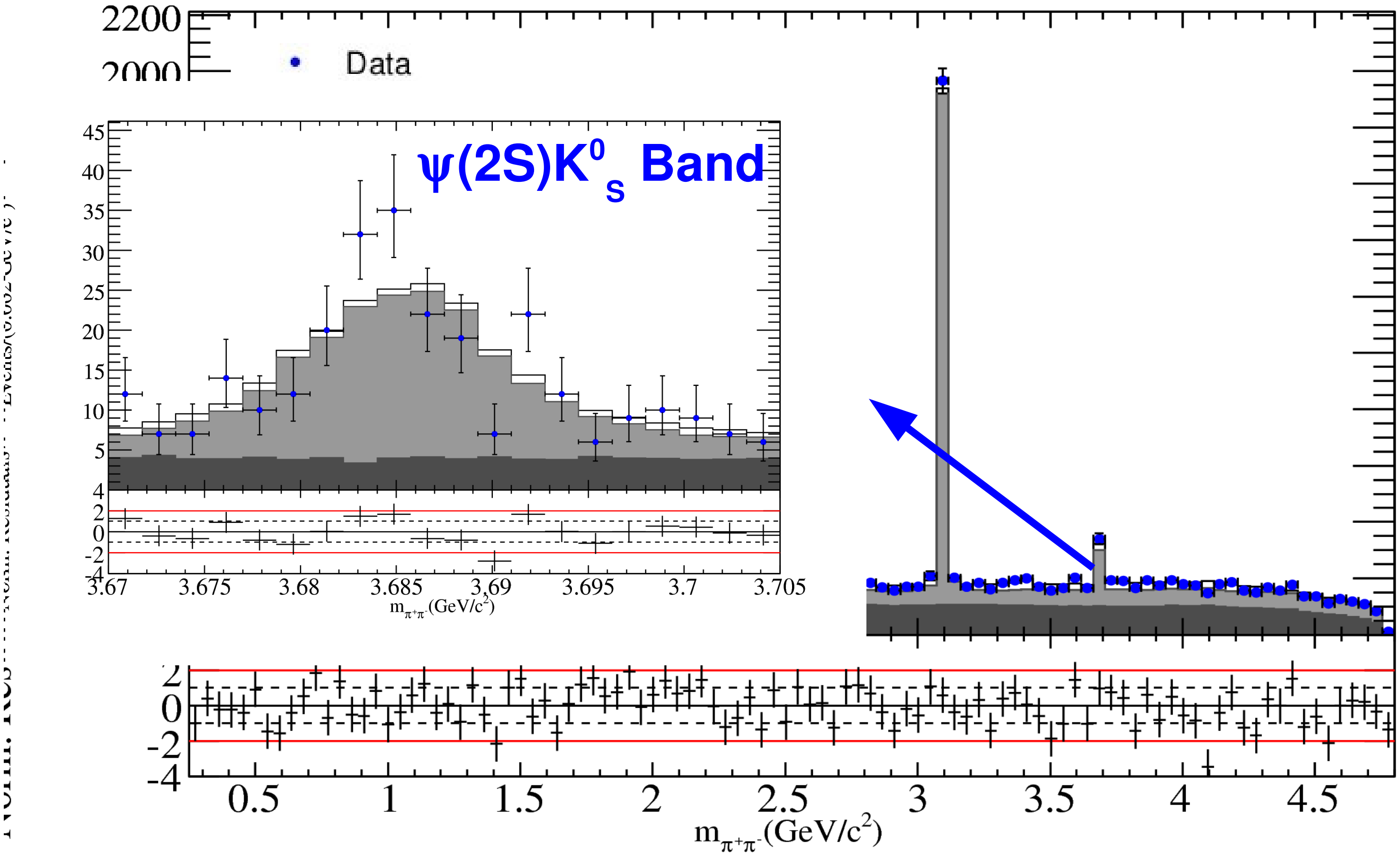
Fit Results: Proj. Plots (I)

$m_{\pi\pi}$ (all events)



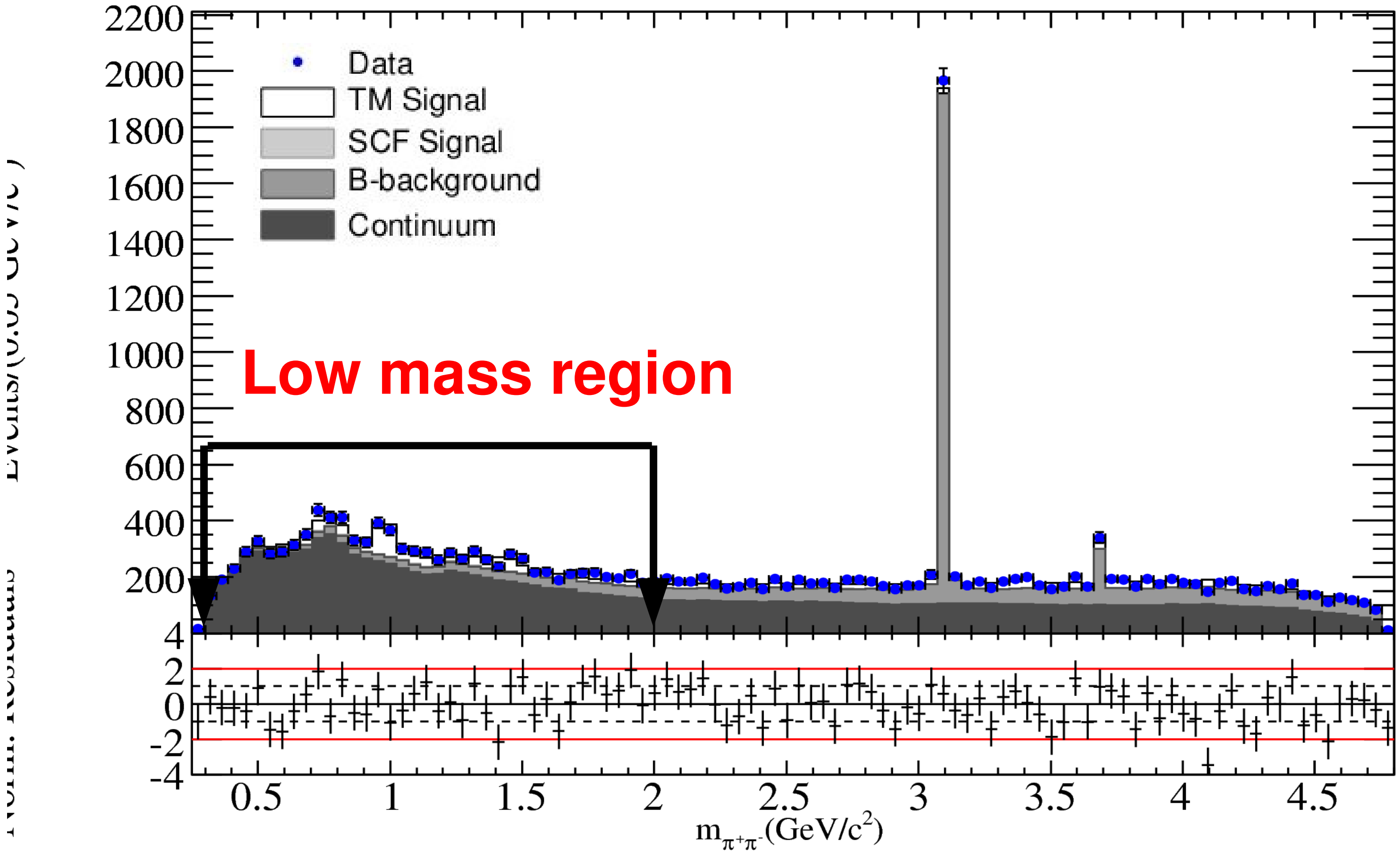
Fit Results: Proj. Plots (I)

$m_{\pi\pi}$ (all events)



Fit Results: Proj. Plots (I)

$m_{\pi\pi}$ (all events)

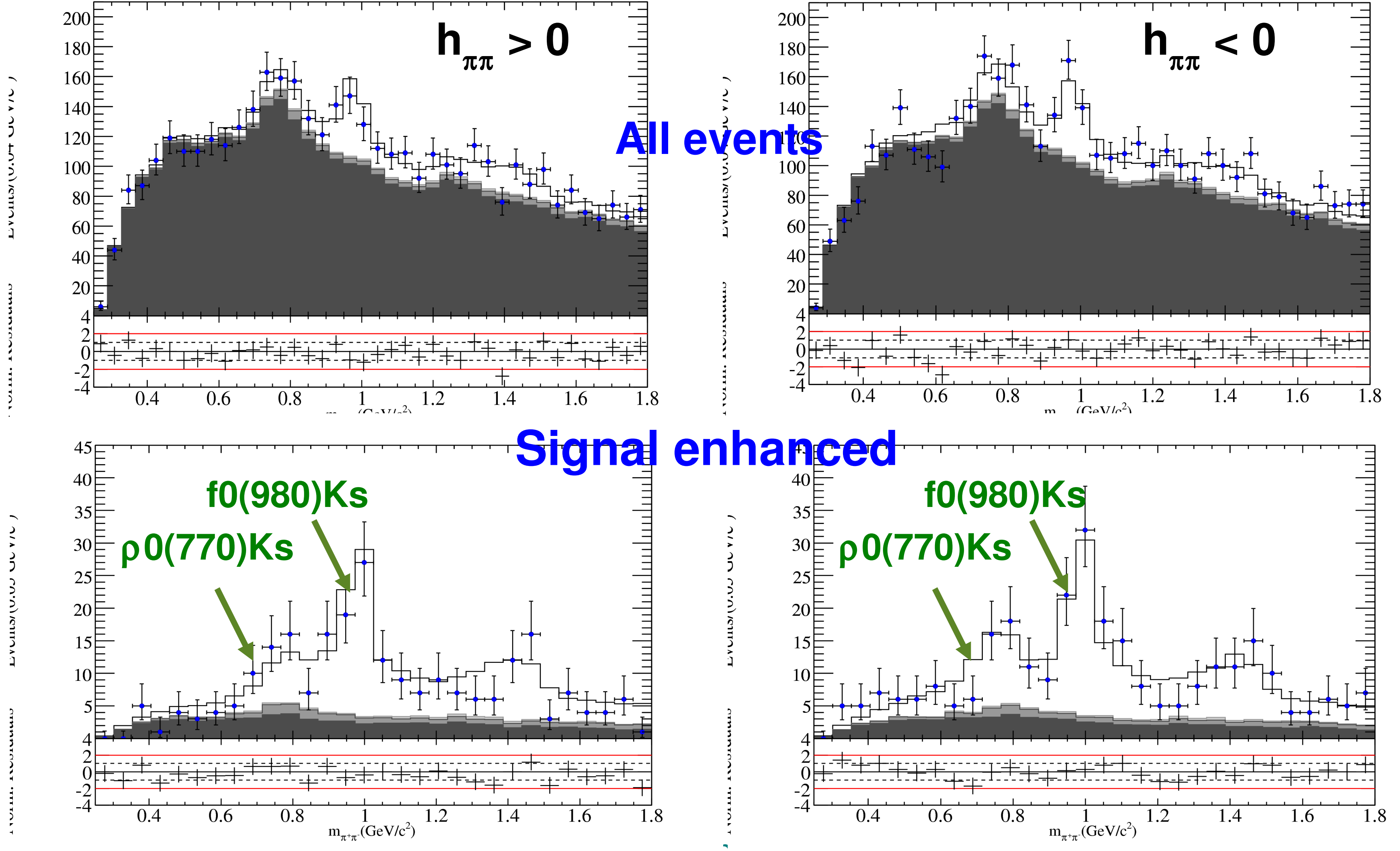


Low mass region

Fit Results: Proj. Plots (II)

$m_{\pi\pi}$ low mass region

Dπ veto



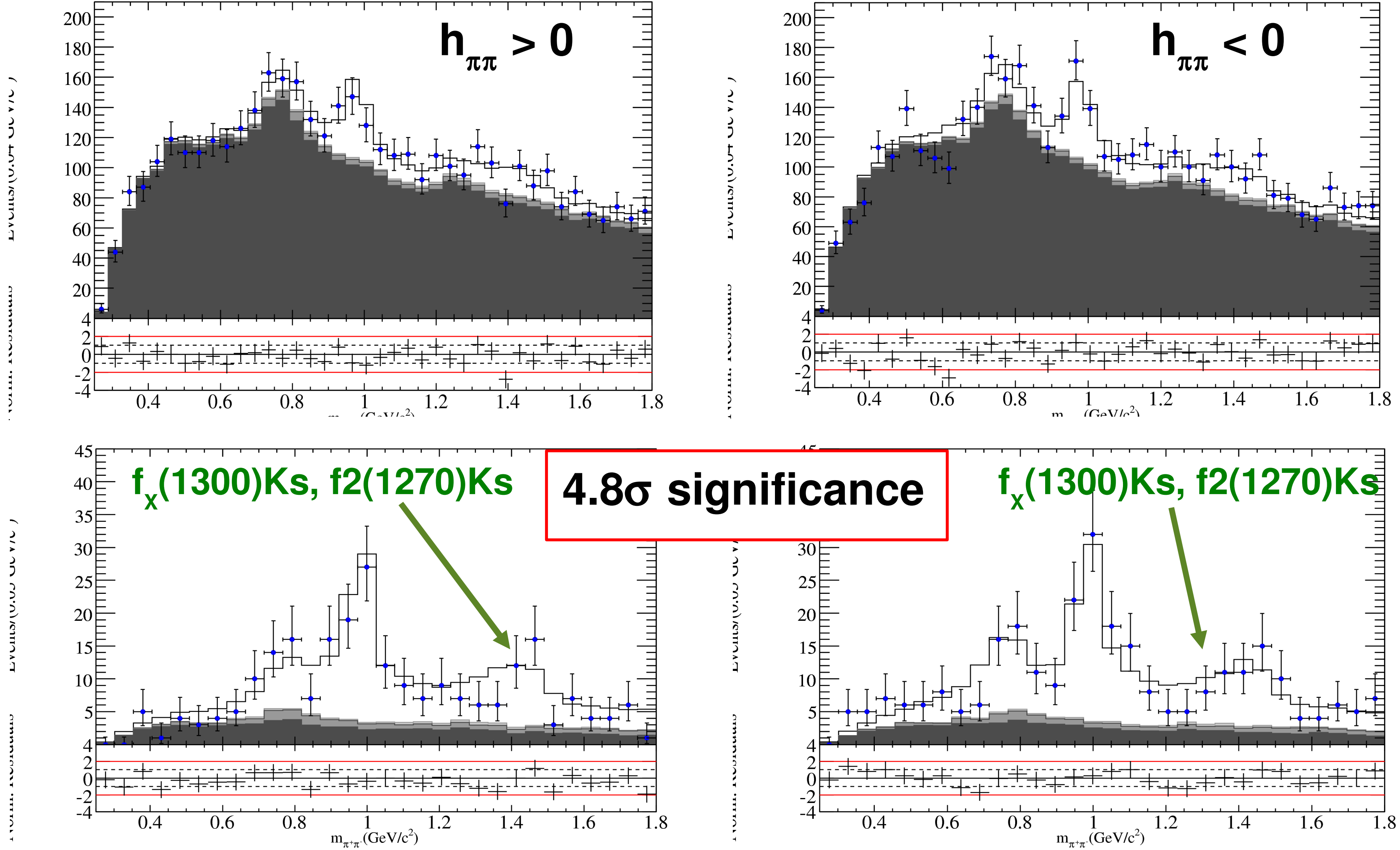
All events

Signal enhanced

Fit Results: Proj. Plots (II)

$m_{\pi\pi}$ low mass region

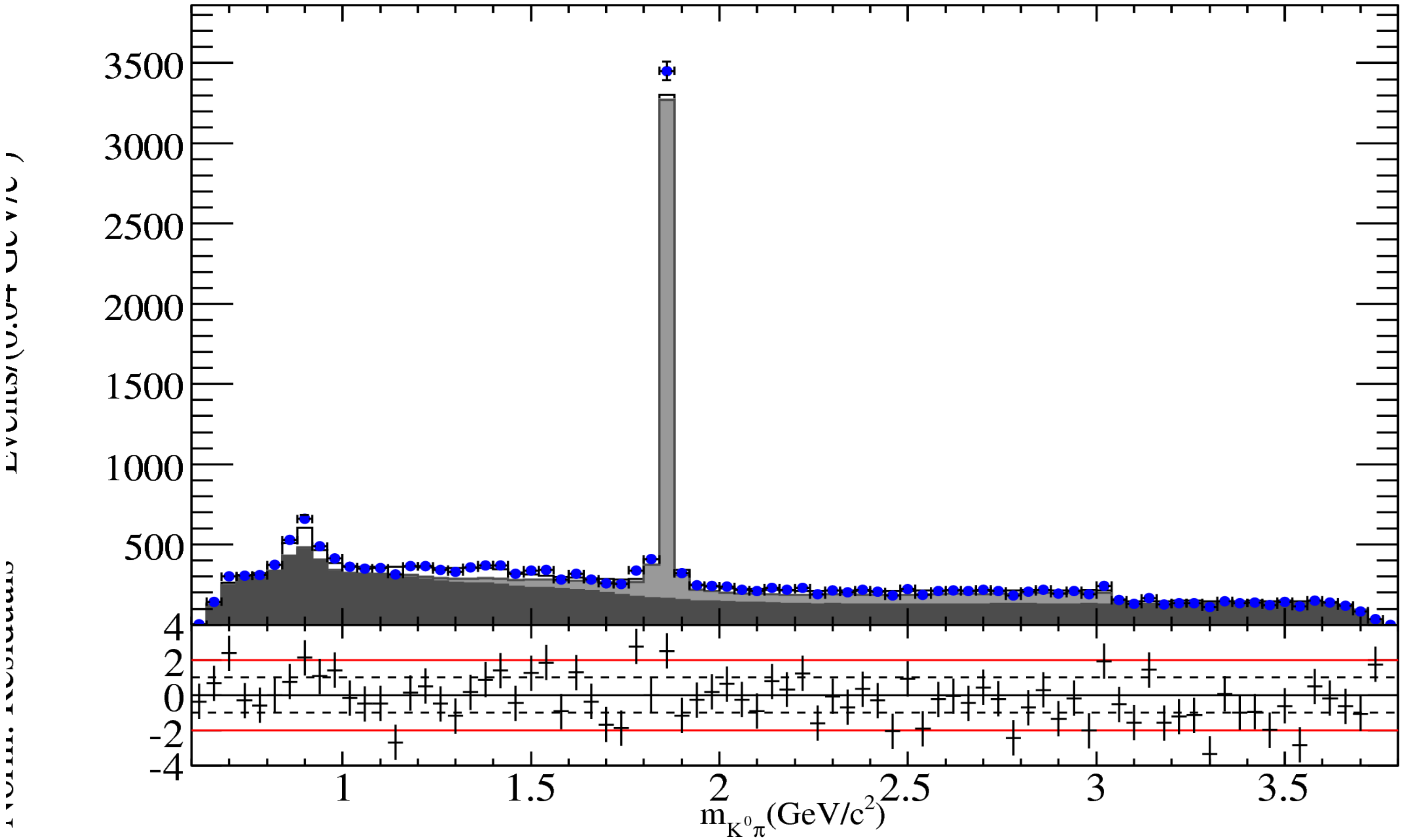
Dπ veto



4.8σ significance

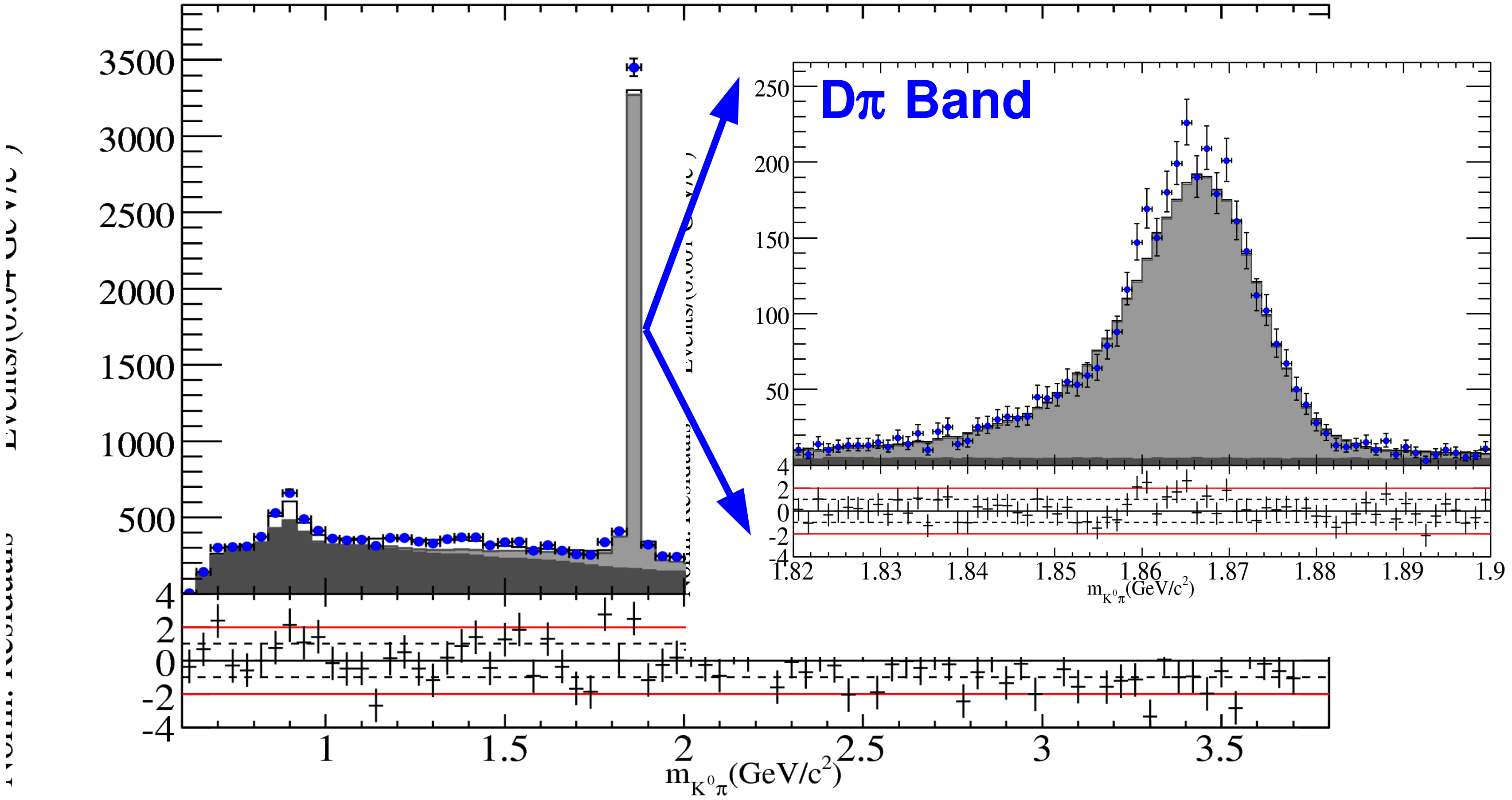
Fit Results: Proj. Plots (III)

$m_{Ks\pi}$ (all events)



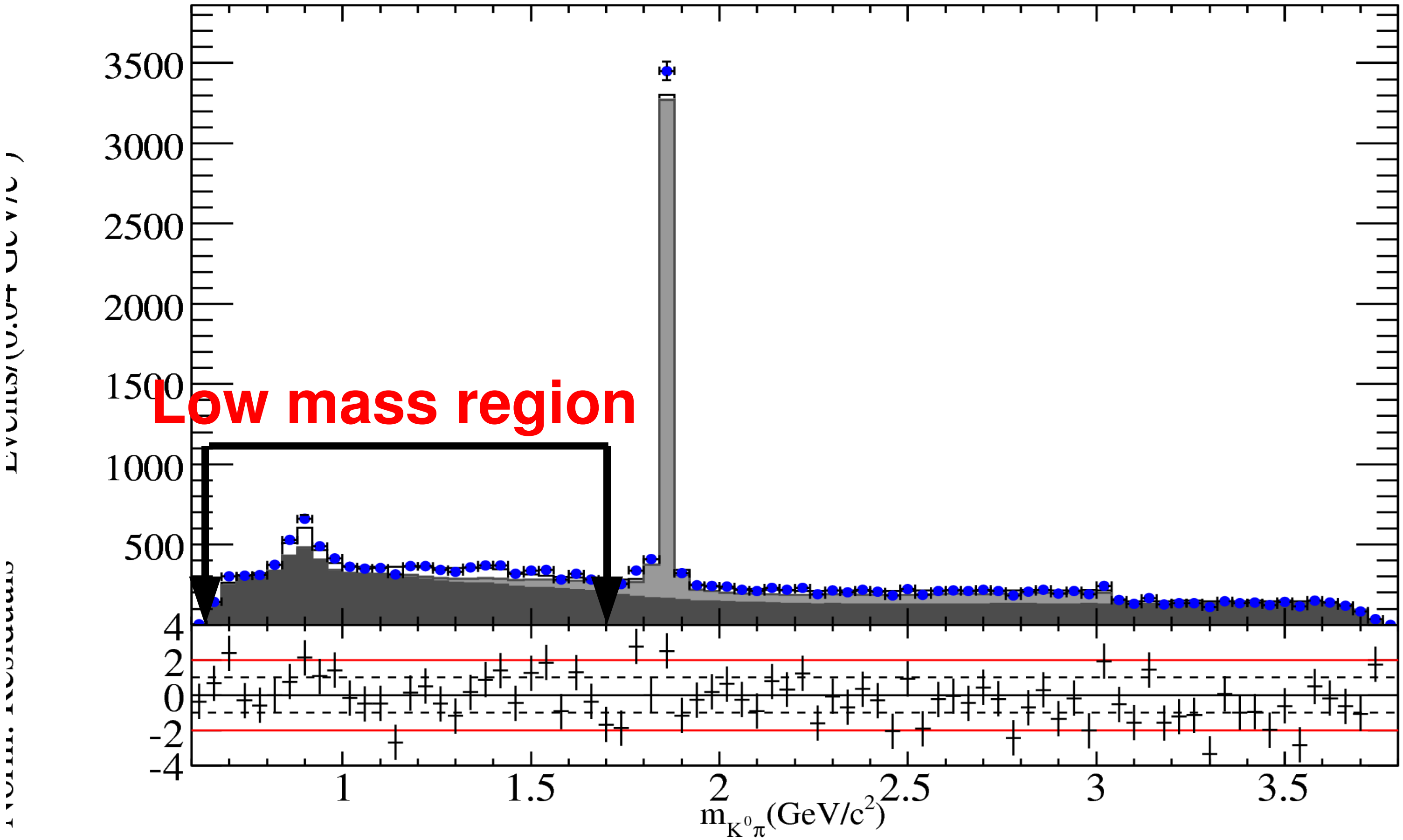
Fit Results: Proj. Plots (III)

$m_{Ks\pi}$ (all events)



Fit Results: Proj. Plots (III)

$m_{K_S\pi}$ (all events)



Low mass region

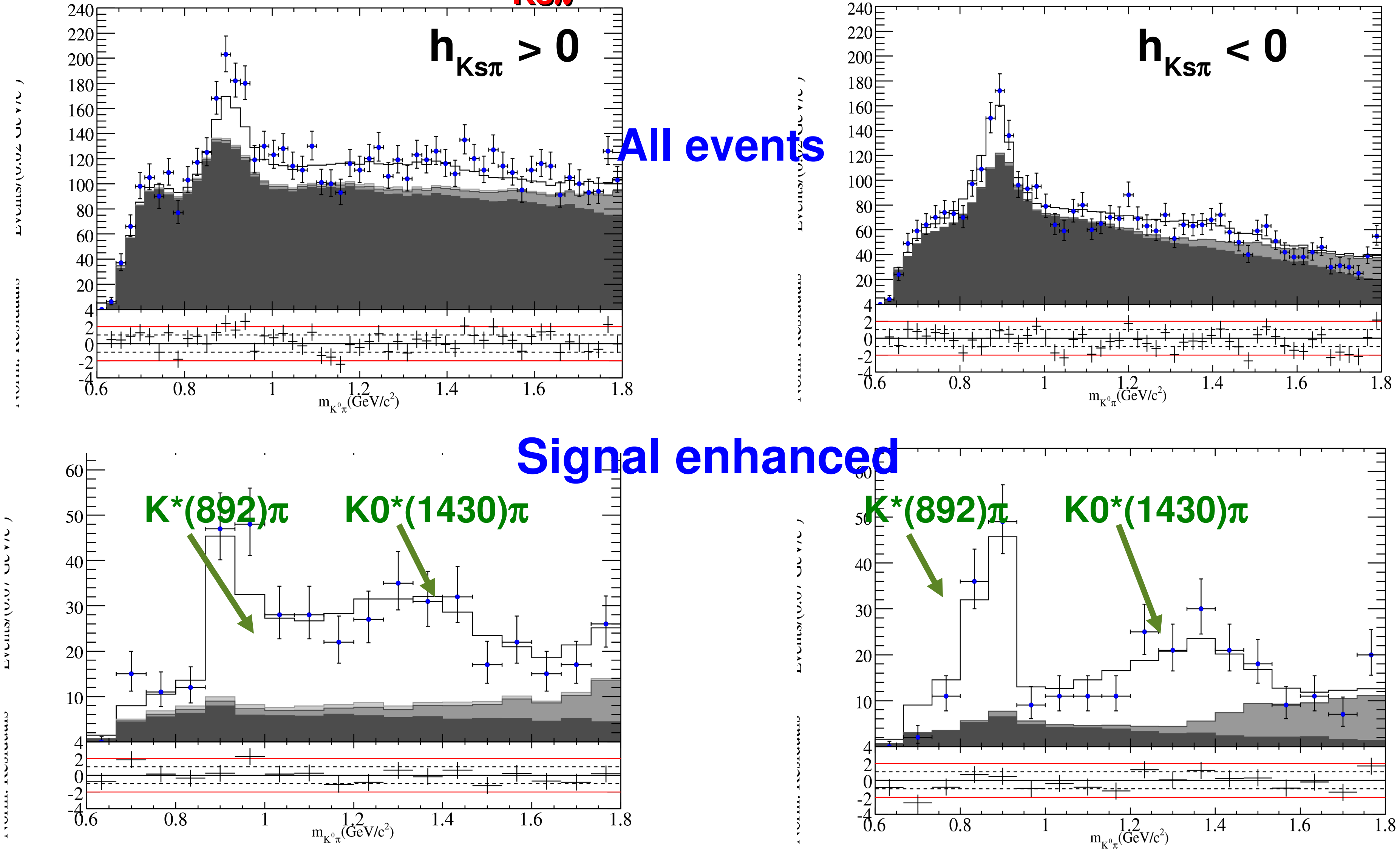
Fit Results: Proj. Plots (IV)

$m_{K_S\pi}$ low mass region

$J/\psi K^0_S$ veto

All events

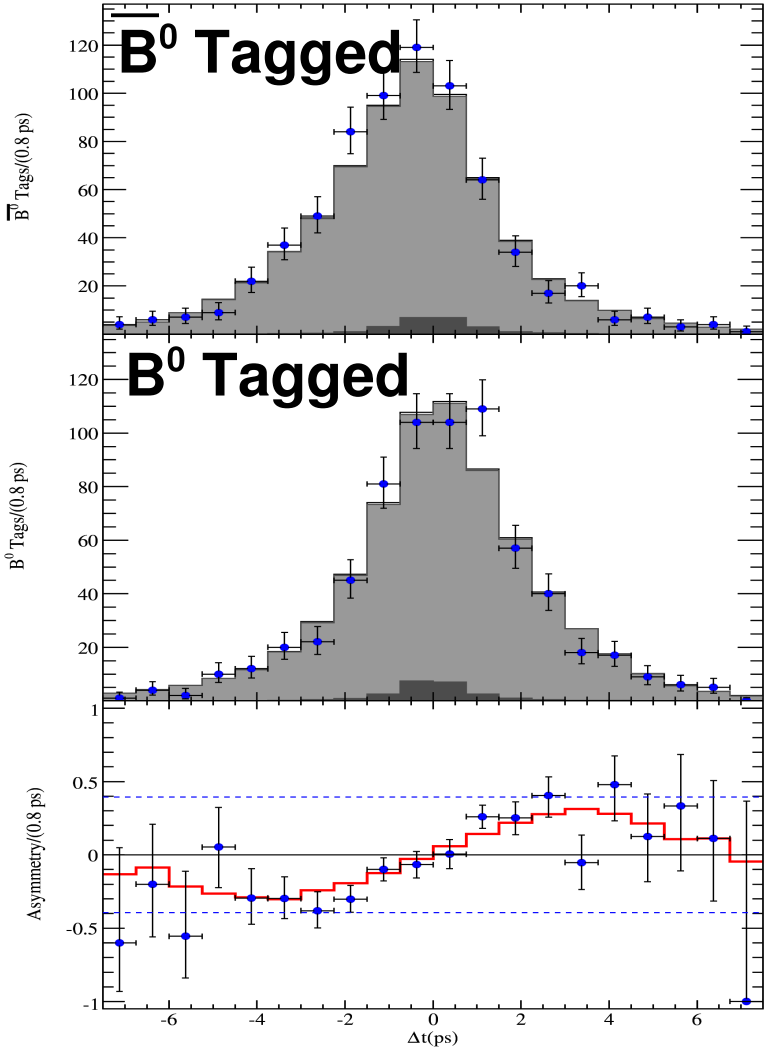
Signal enhanced

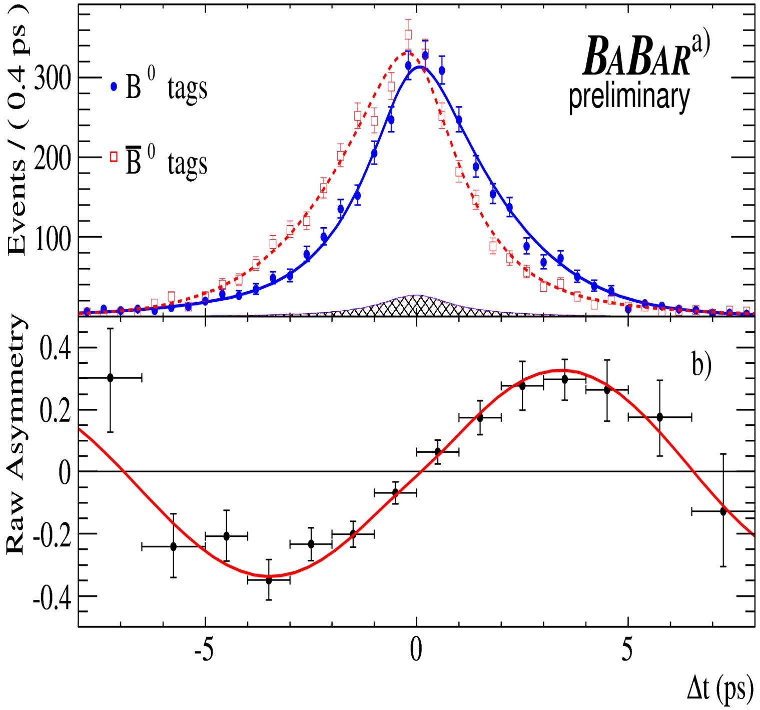


Fit Results: Proj. Plots (V)

Δt dependent asymmetry:

J/ψ Band (Background events due to π/μ mis-ID)





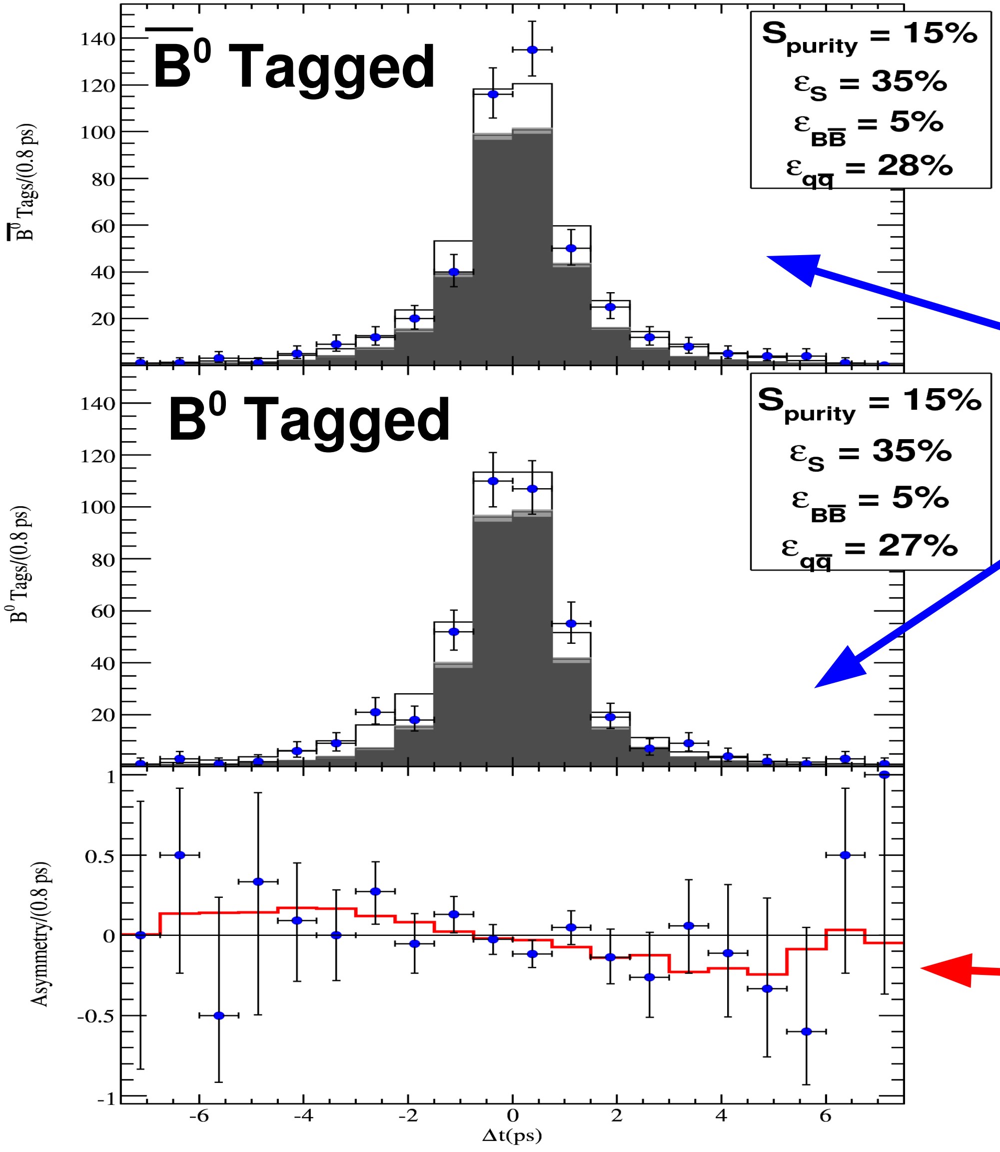
Latest BaBar: S = 0.660 ± 0.036 ± 0.012

Fit to our data gives:

S = 0.690 ± 0.077

Fit Results: Proj. Plots (VI)

Δt dependent asymmetry: $f_0(980)K^0_S$ Band



All Events

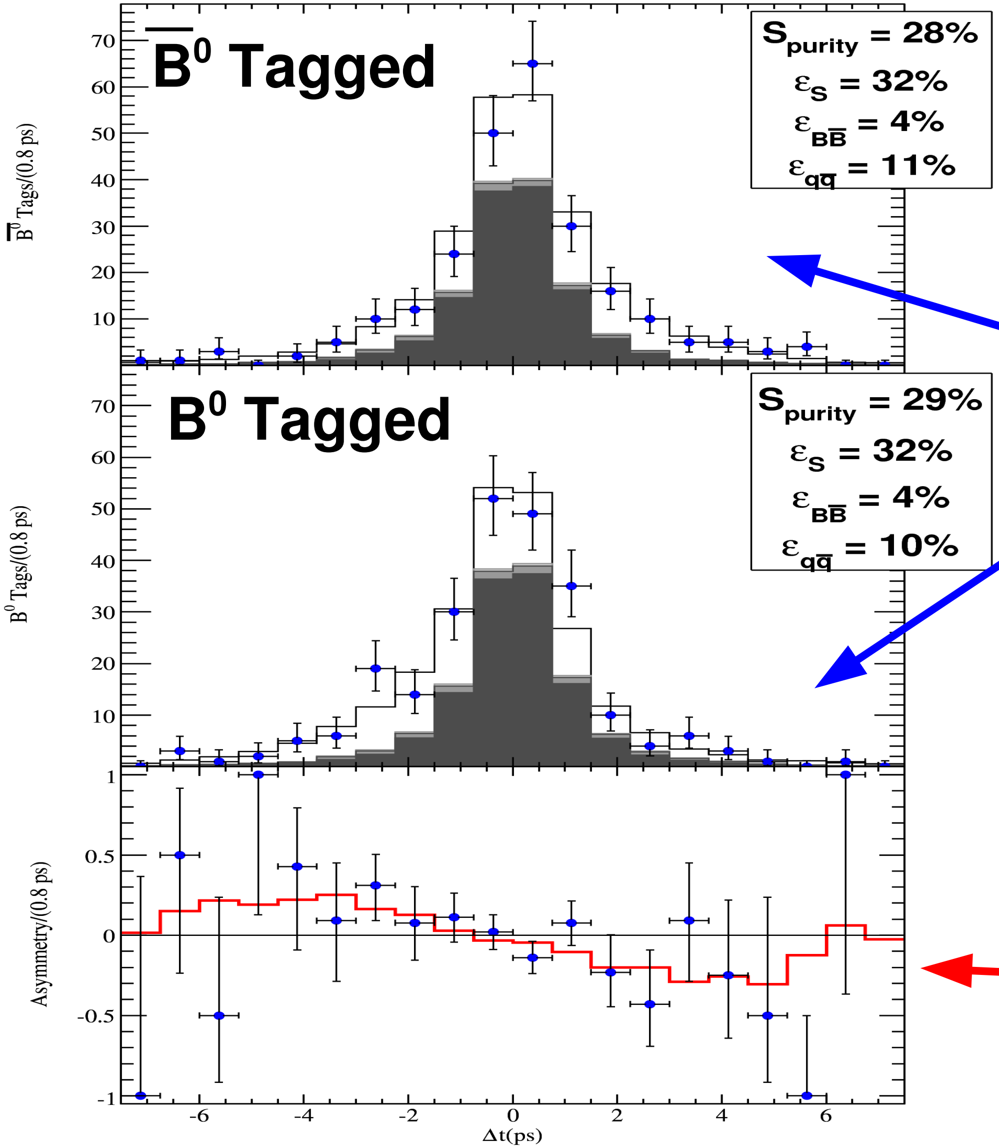
$0.86 < m_{\pi\pi} < 1.06$GeV

Time-dependent rate asymmetry

(diluted by large background)

Fit Results: Proj. Plots (VI)

Δt dependent asymmetry: $f_0(980)K^0_S$ Band



Signal enhanced

$0.86 < m_{\pi\pi} < 1.06$GeV

(Removed ~70% of qqbar)

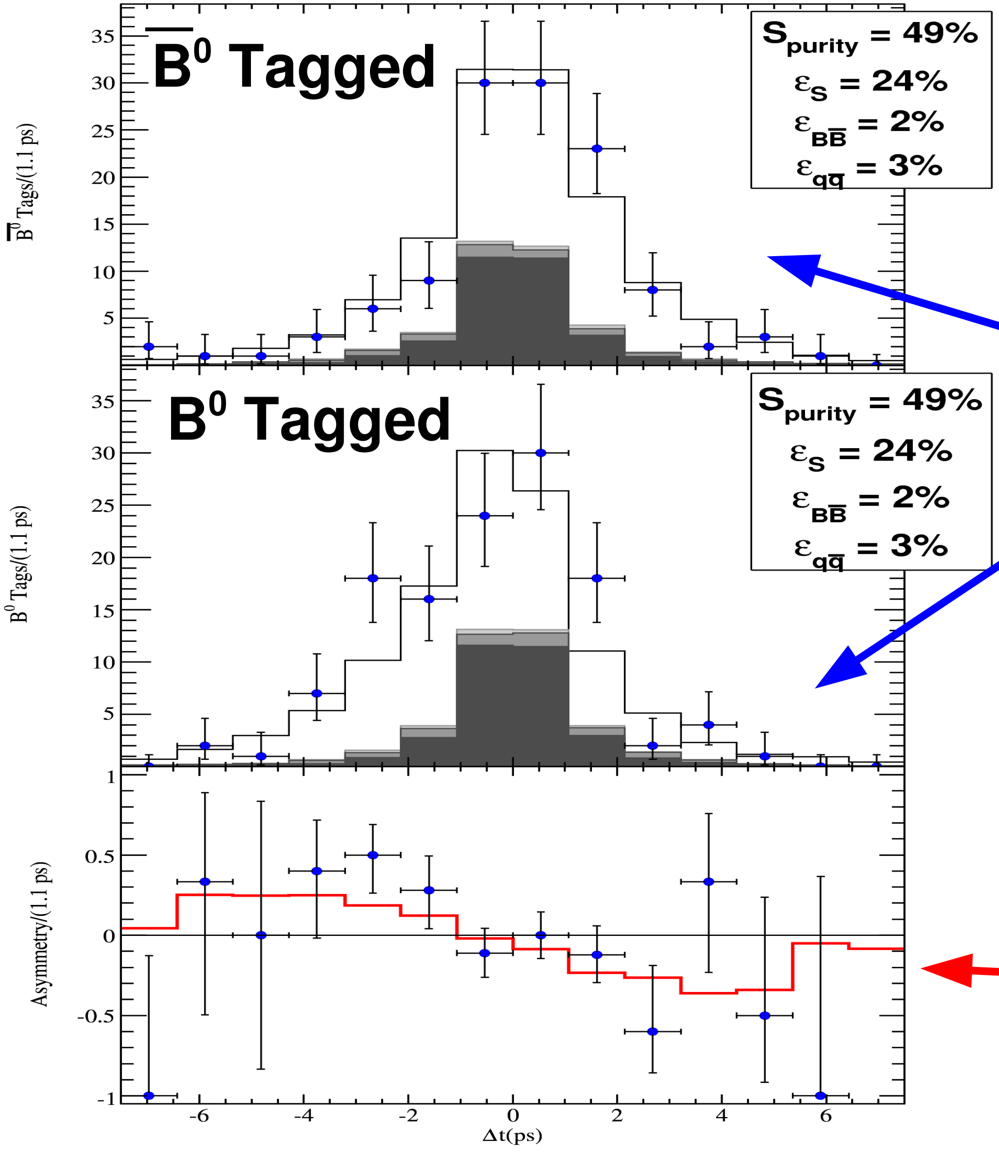
Time-dependent rate asymmetry

(starts to be visible)

0

Fit Results: Proj. Plots (VI)

Δt dependent asymmetry: $f_0(980)K^0_S$ Band



Signal enhanced

$0.86 < m_{\pi\pi} < 1.06$GeV

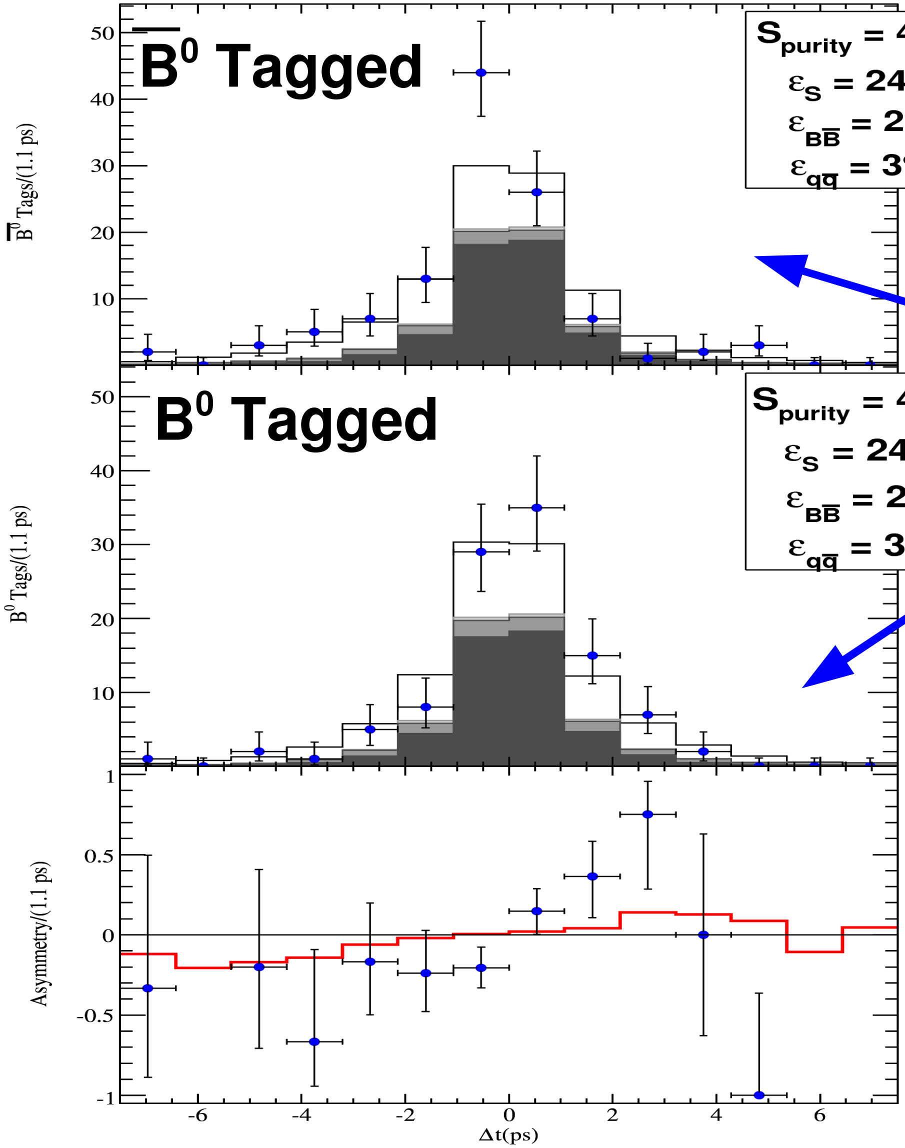
(Removed ~90% of qqbar)

Time-dependent rate asymmetry

(even more visible)

Fit Results: Proj. Plots (VII)

Δt dependent asymmetry: $\rho^0(770)K^0_S$ Band



Signal enhanced

$0.50 < m_{\pi\pi} < 0.86$GeV

(Removed ~97% of qqbar)

Time-dependent rate asymmetry

not as significant as $f_0(980)K^0_S$

0

Results on physical observables

Fit Results: Measured observables

- "Counting rate like":

  - 9 BFs → 8 exclusive and 1 inclusive

  - 9 A_{CP} → 8 exclusive and 1 inclusive

- Interference pattern:

  - $\phi(f_0,\rho^0)$, ϕ(P-wave $K\pi$,S-wave $K\pi$), $\phi(\rho^0,K^*)$ for B^0 or $\overline{B^0}$

- TD CPV (counting rate only access to $S = \sin(2\beta_{eff})$):

  - C and $\beta_{eff} \rightarrow f_0(980)K^0_S$

  - C and $\beta_{eff} \rightarrow \rho^0(770)K^0_S$

- Phase difference between B^0 and $\overline{B^0}$ ("CPS")

  - $\Delta\phi$ → $K^*(892)\pi$

Fit Results: Measured observables

- "Counting rate like":

  - 9 BFs → 8 exclusive and 1 inclusive

  - 9 A_{CP} → 8 exclusive and 1 inclusive

- Interference pattern:

  - $\phi(f_0,\rho^0)$, ϕ(P-wave $K\pi$,S-wave $K\pi$), $\phi(\rho^0,K^*)$ for B^0 or $\overline{B}^0$

- TD CPV (counting rate only access to $S = \sin(2\beta_{eff})$):

  - C and β_{eff} → $f_0(980)K^0_S$

  - C and β_{eff} → $\rho^0(770)K^0_S$

- Phase difference between B^0 and $\overline{B}^0$ ("CPS")

  - $\Delta\phi$ → $K^*(892)\pi$

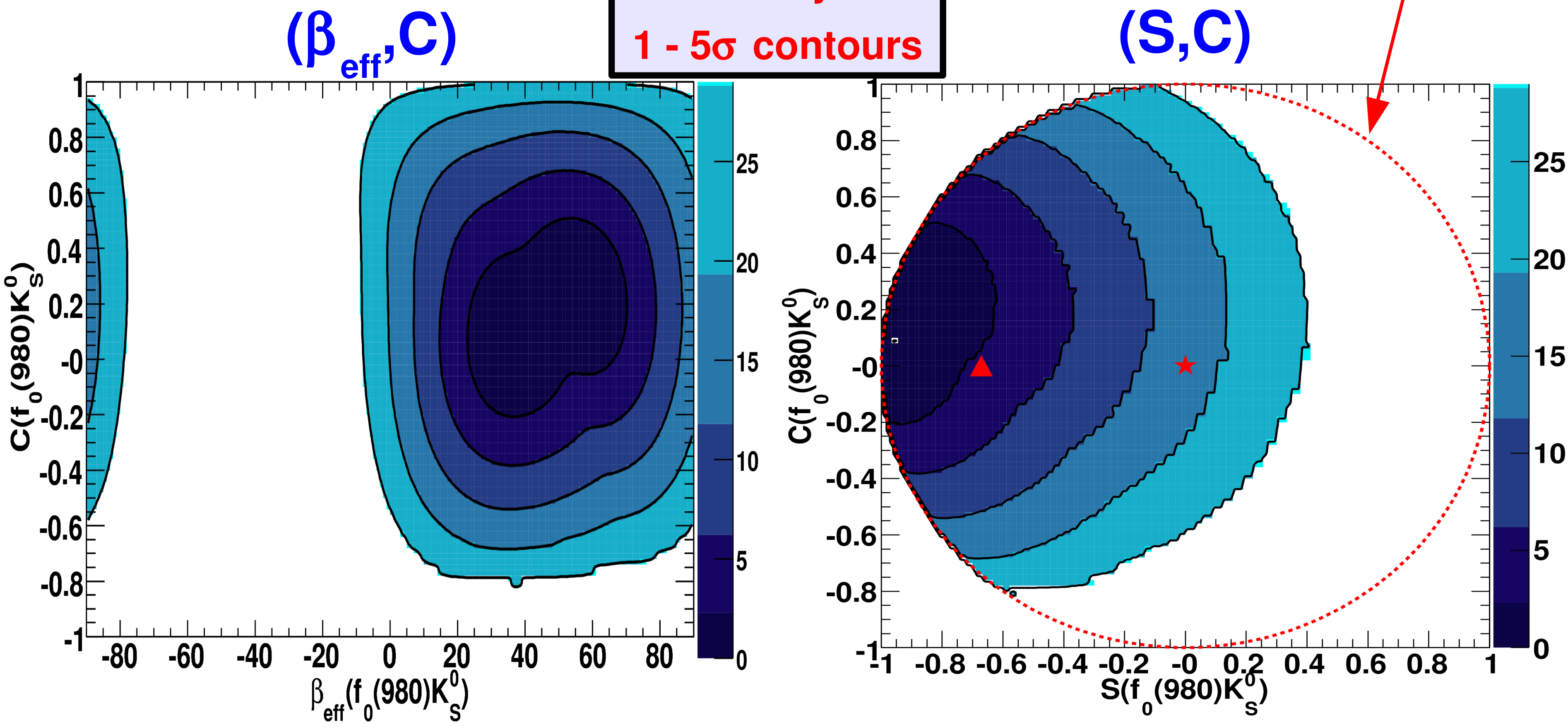
Fit Results: (β_{eff},C) f_0(980)Ks

Stat+Syst

1 - 5σ contours

Physical region:

$S^2+C^2 \leq 1$



★ **CP conservation**

▲ **b →ccs value**

Fit Results: (β_{eff},C) f_0(980)Ks

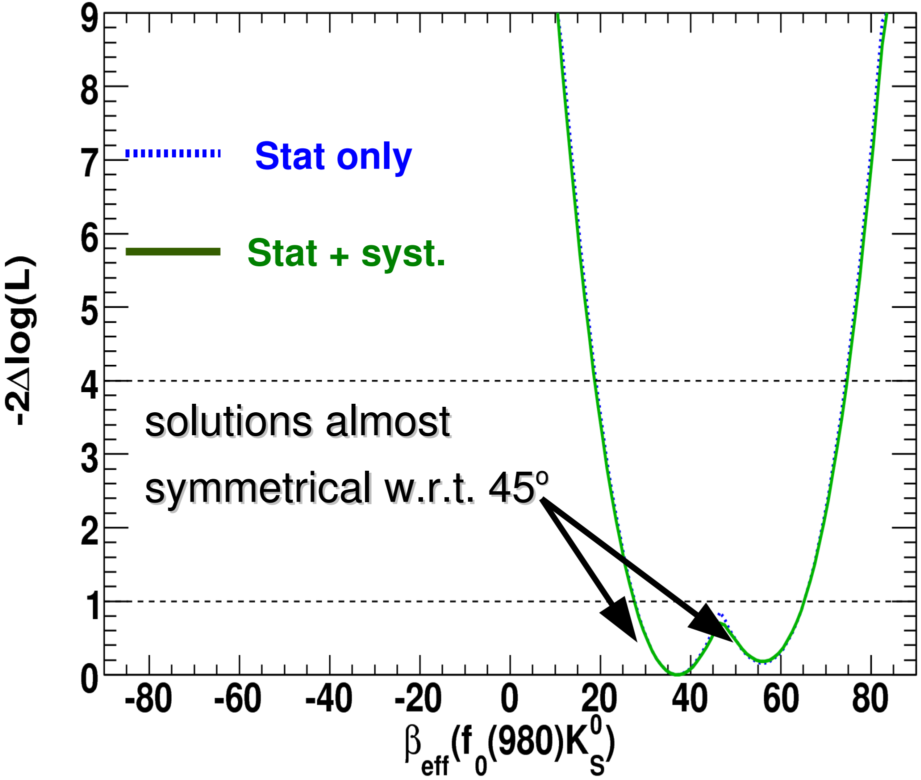
Stat+Syst

1 - 5σ contours

Physical region:

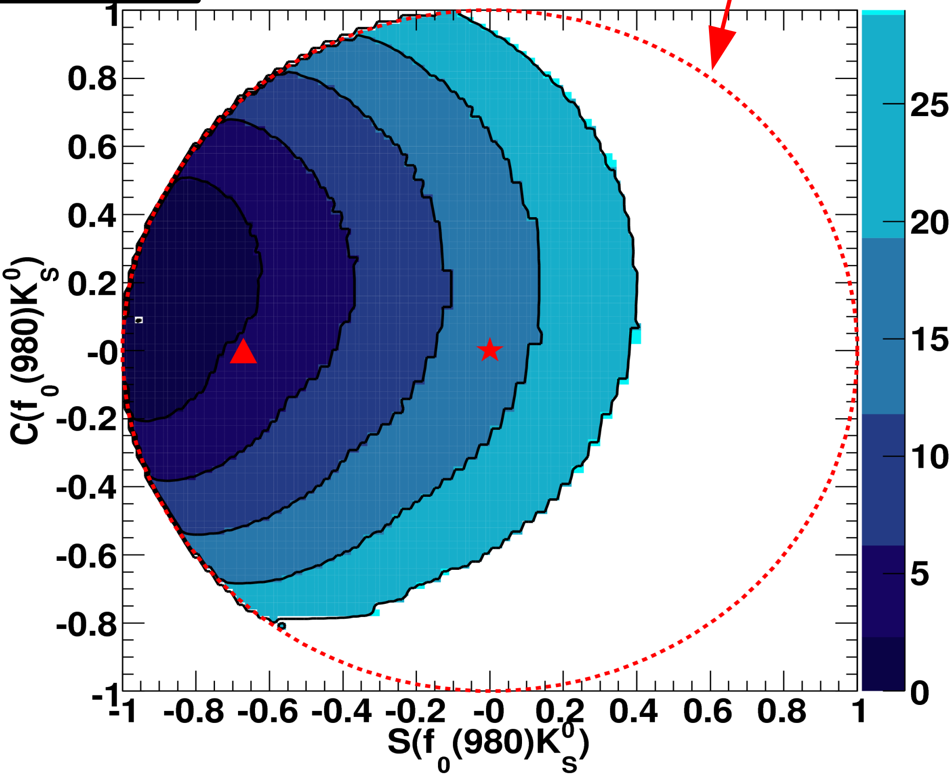
$S^2+C^2\leq 1$

(β_{eff},C)



solutions almost symmetrical w.r.t. 45°

(S,C)



Does not resolve trigonometrical ambiguity above and below 45°

★ CP conservation

▲ b →ccs value

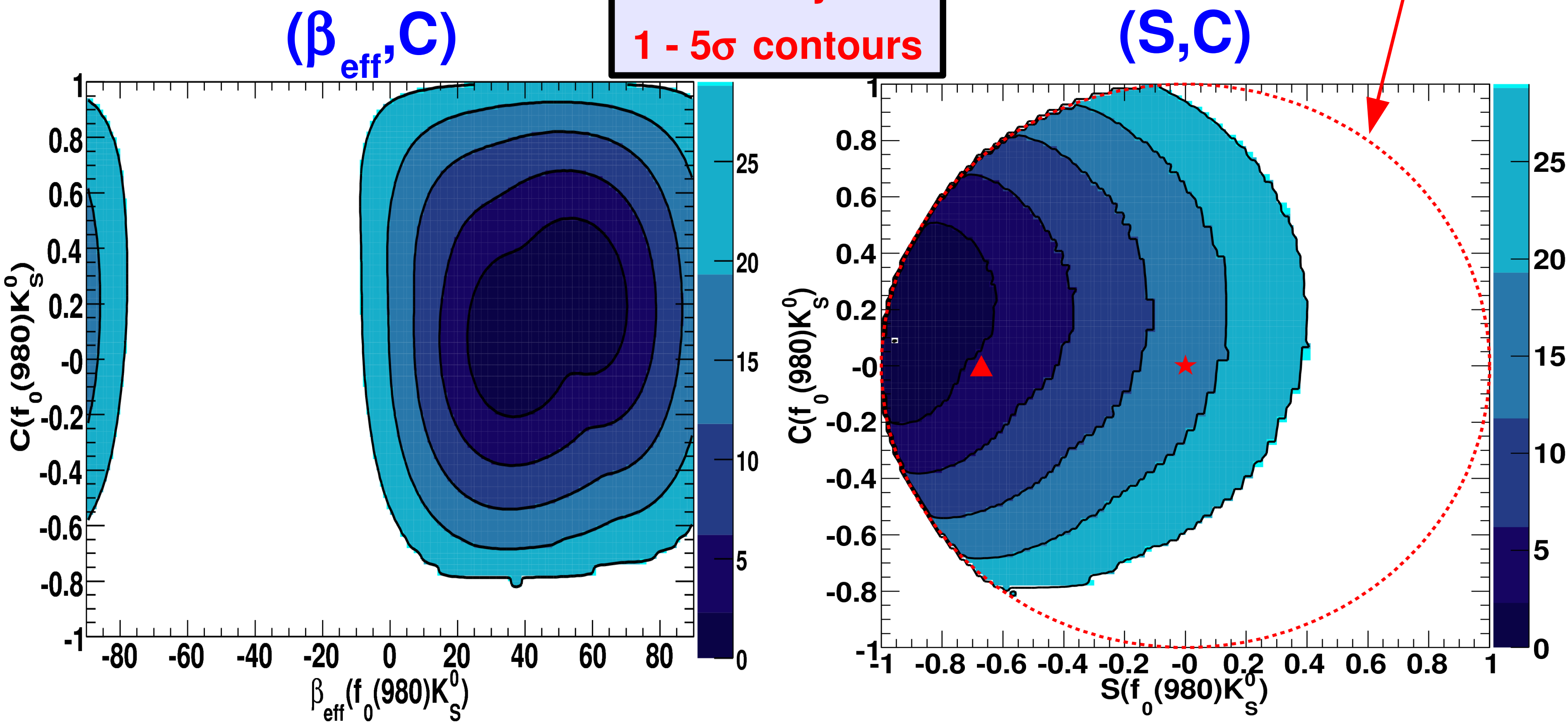
Fit Results: (β_{eff},C) f_0(980)Ks

Stat+Syst

1 - 5σ contours

Physical region:

$S^2+C^2 \leq 1$



CP conservation excluded at 3.5σ

Agreement with b → ccs at 1.1σ

★ **CP conservation**

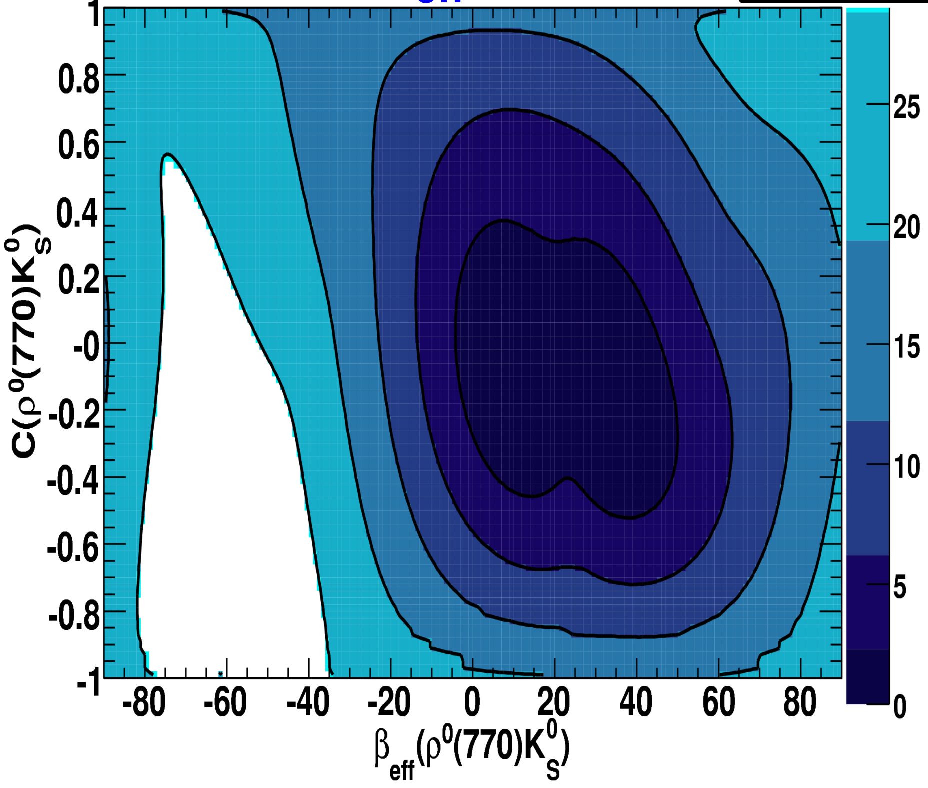
▲ **b →ccs value**

Fit Results: (β_{eff},C) ρ^0(770)Ks

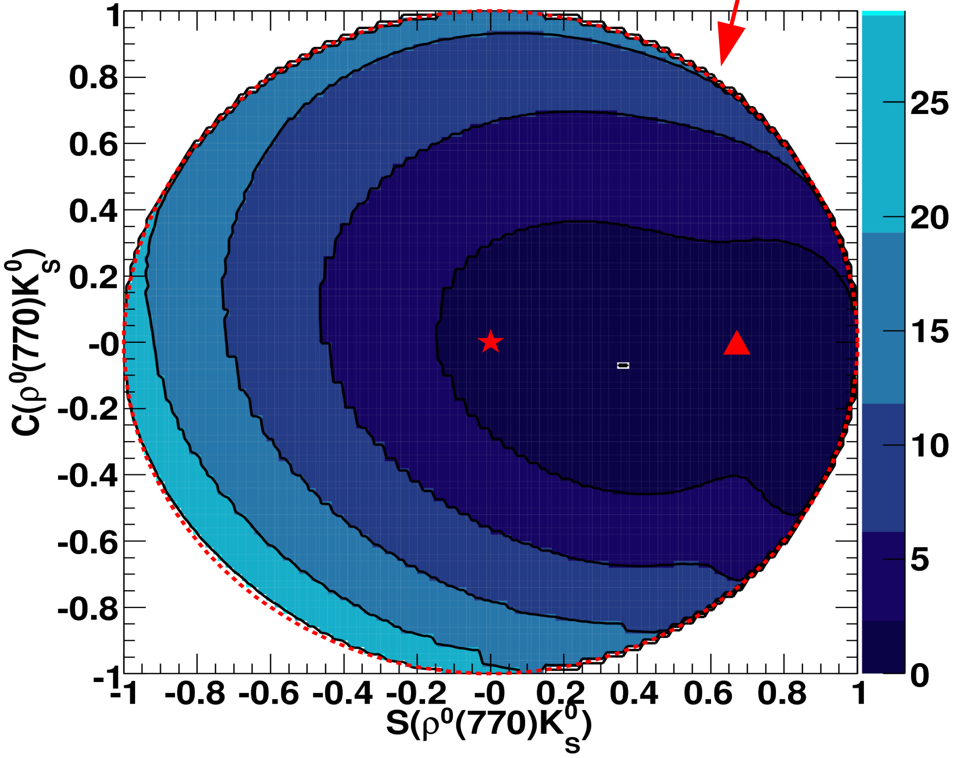
Physical region:
$S^2+C^2\leq1$

Stat+Syst
1 - 5σ contours

(β_{eff},C)



(S,C)



★ CP conservation
▲ b →ccs value

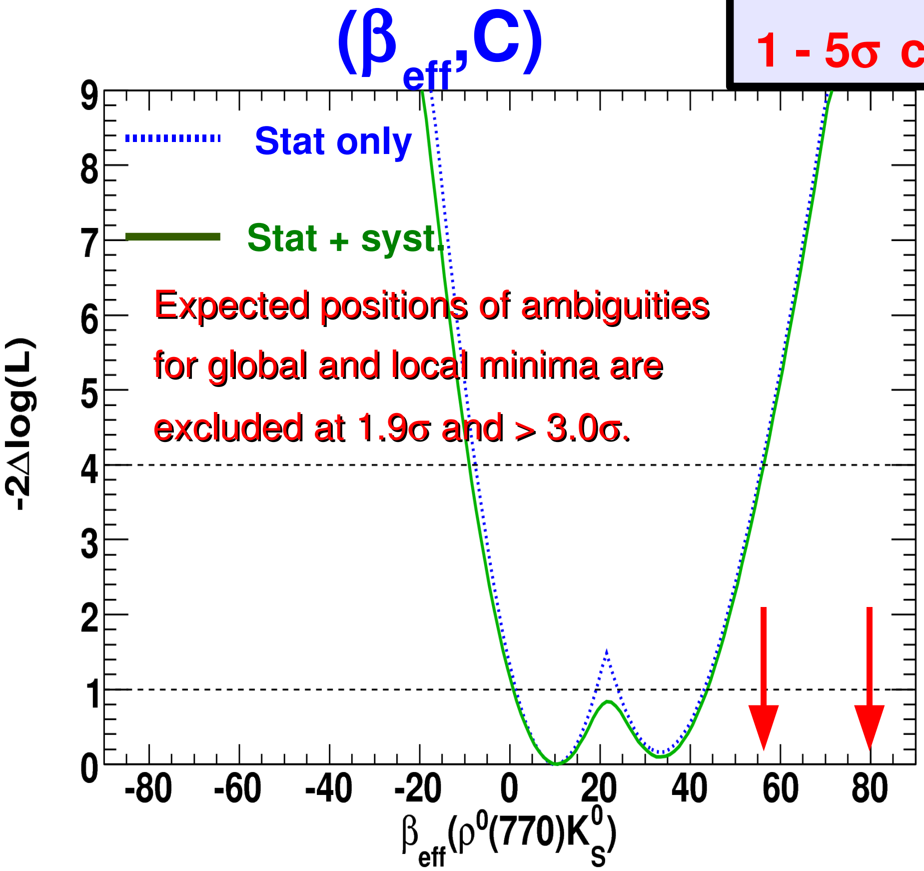
Fit Results: (β_{eff},C) ρ^0(770)Ks

Stat+Syst

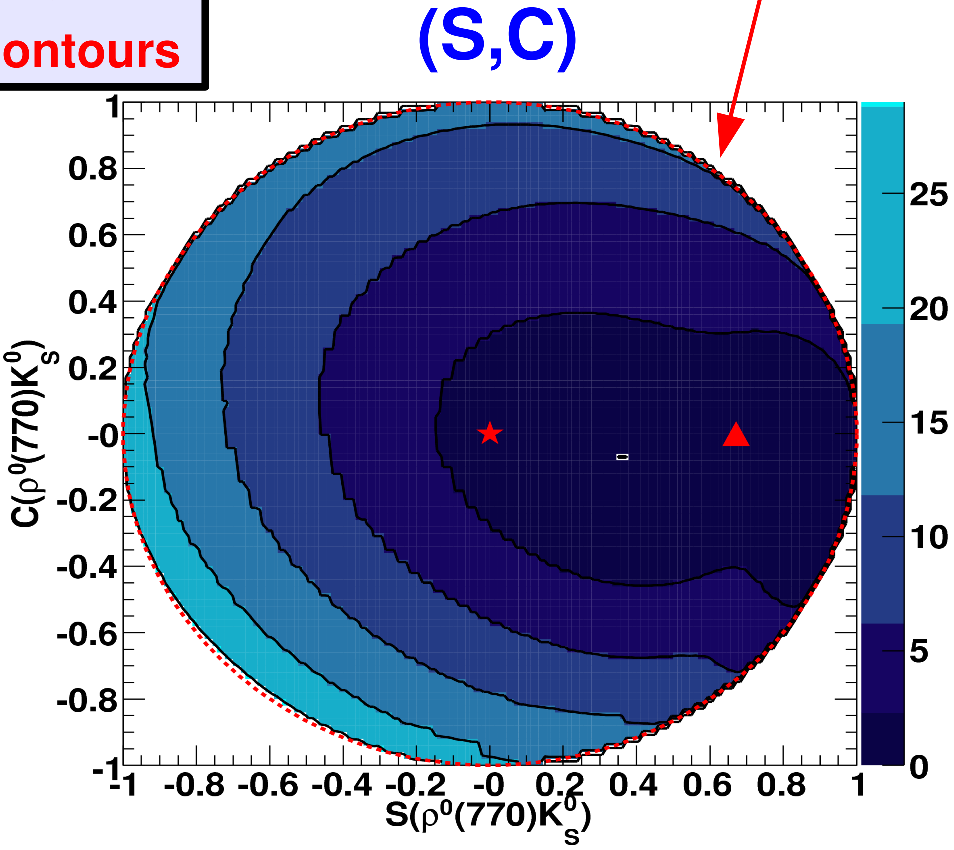
1 - 5σ contours

Physical region:

$S^2+C^2 \leq 1$



Expected positions of ambiguities for global and local minima are excluded at 1.9σ and > 3.0σ.



trigonometrical ambiguity disfavoured at 1.9σ

★ **CP conservation**

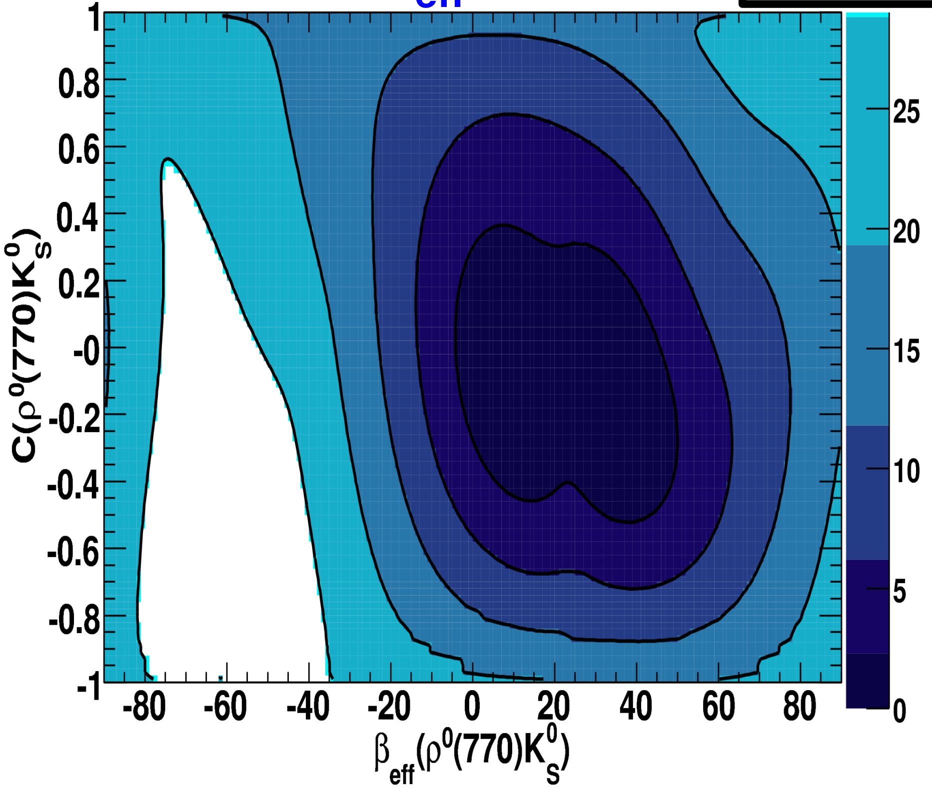
▲ **b →ccs value**

Fit Results: (β_{eff},C) ρ^0(770)Ks

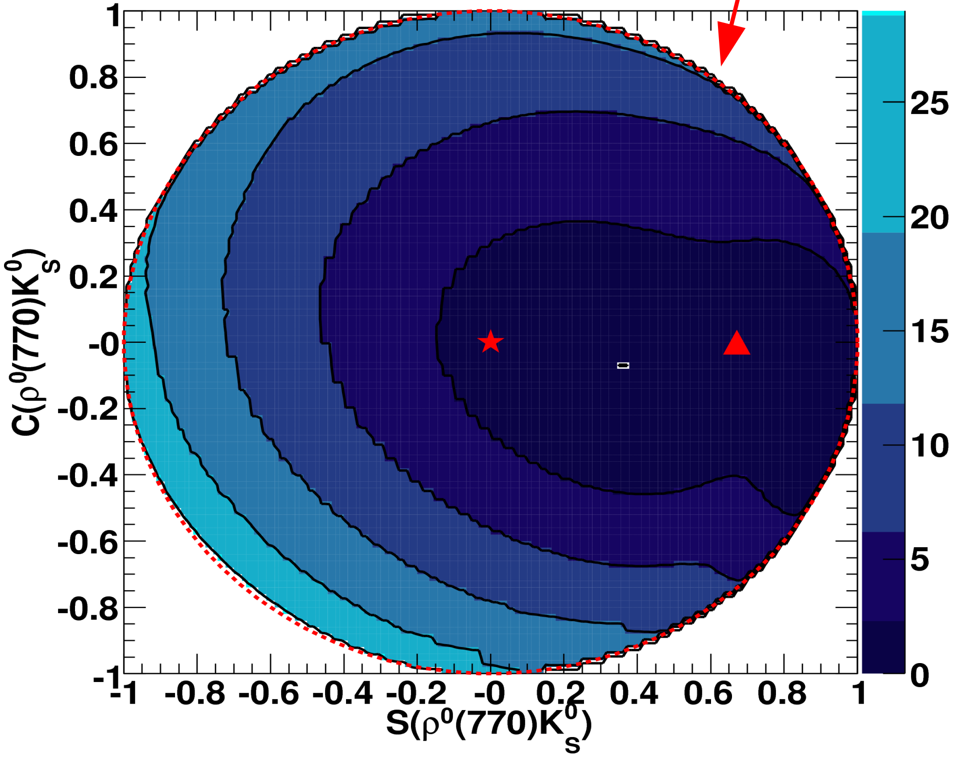
Physical region:
$S^2+C^2 \leq 1$

Stat+Syst
1 - 5σ contours

(β_{eff},C)



(S,C)



Compatible both with CPV conservation and b → ccs value

★ CP conservation

▲ b →ccs value

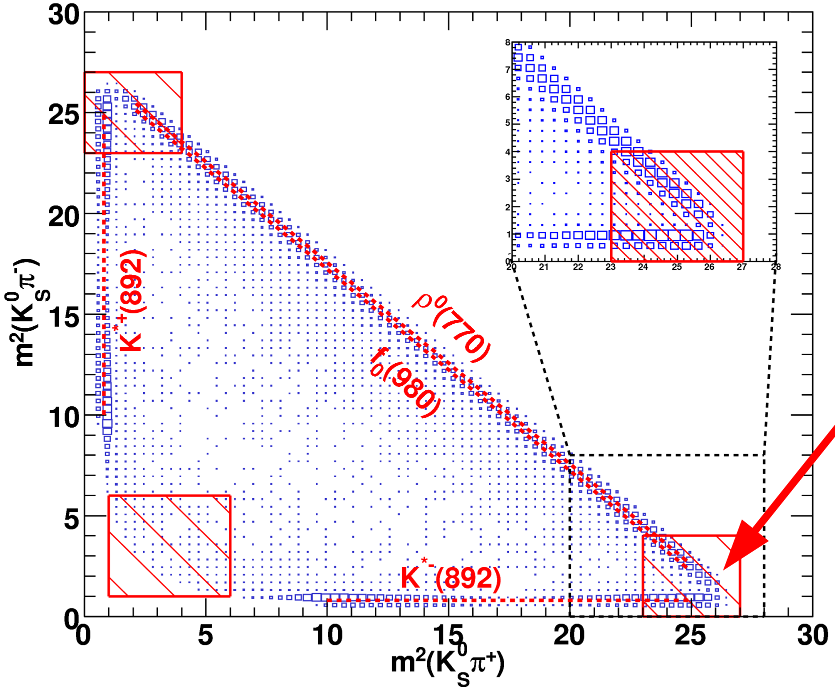
Fit Results: CPS Phase $K^{*}(892)\pi$

$\Delta\phi(K(892)\pi)$:

- Sensitivity not by direct interference

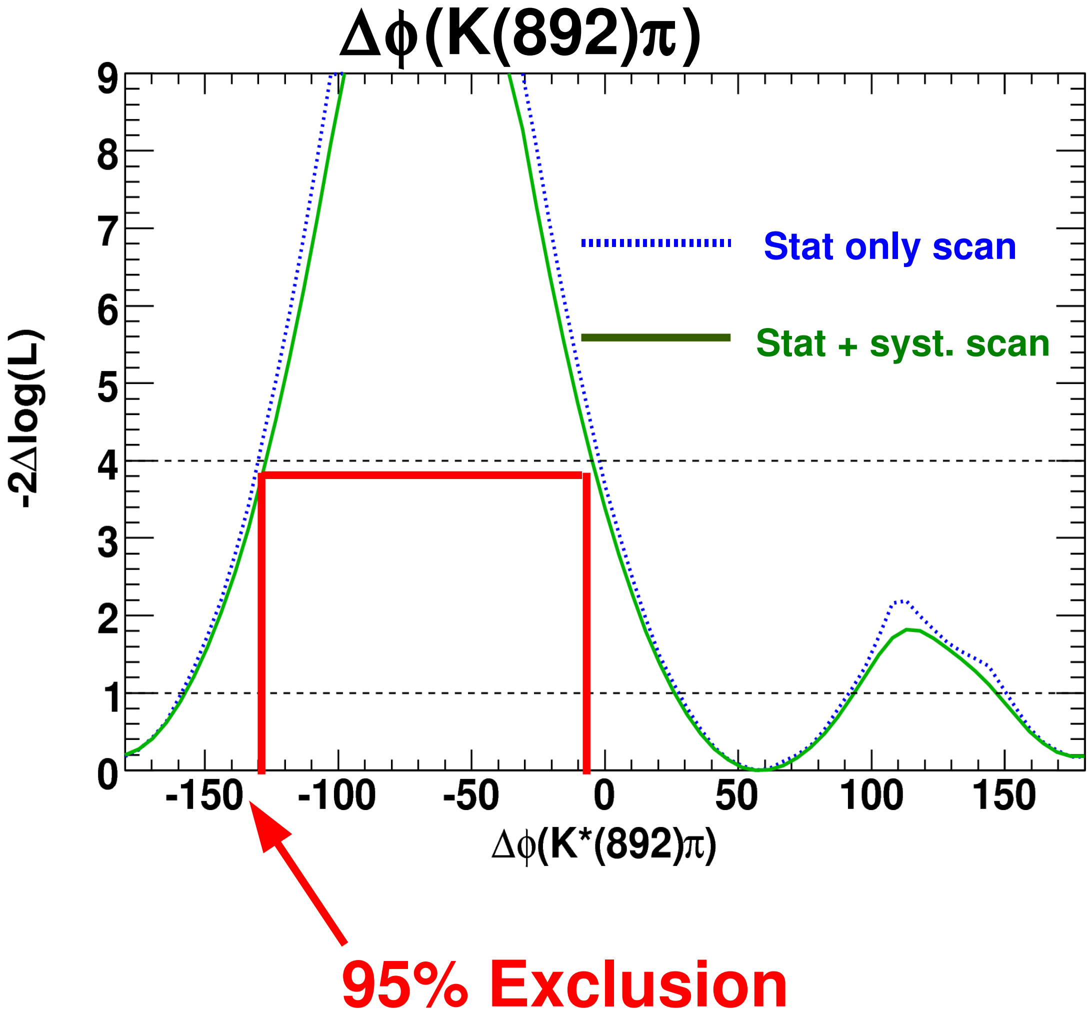
- Only by interference with other components in the DP:

$f_0(980)$ and $\rho^0(770)$



$\Delta\phi(K(892)\pi)$: measured by interference in the corners of the DP

Fit Results: CPS Phase K*(892)π



- Stat+Syst error for each solution ~30°
- Solutions differ by a significant amount, dilutes constraint
- Only excludes negative values of the phase

The Phenomenological Analysis

J. Charles, R. Camacho,
J. Ocariz, A. Pérez

- **Isospin-based analysis of the modes B →$K^*\pi$**
- **More developments can be found in my Ph.D. Thesis:**

http://tel.archives-ouvertes.fr/docs/00/37/91/88/PDF/thesis.pdf

With the world averages of
BaBar, Belle and CLEO

Work with CKMfitter software
http://ckmfitter.in2p3.fr/

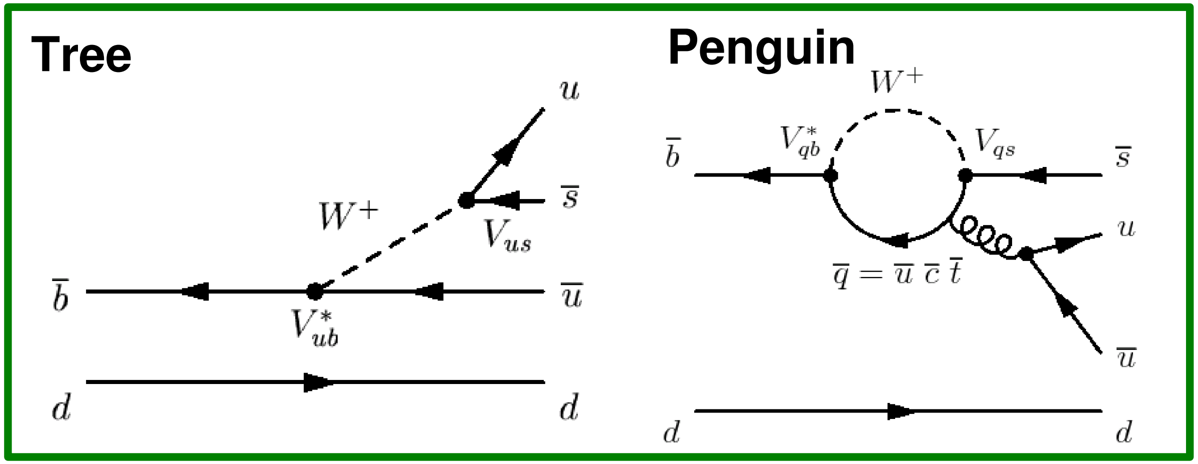
B→K*π System: Isospin relations

SU(2) Isospin relations:

$$A^{0+} + \sqrt{2}A^{+0} = \sqrt{2}A^{00} + A^{+-}$$

$$\overline{A}^{0+} + \sqrt{2}\overline{A}^{+0} = \sqrt{2}\overline{A}^{00} + \overline{A}^{+-}$$

$B^0 \to K^{*+}\pi^-$


Tree

Penguin

$$A(B^0 \to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$\sqrt{2}A(B^0 \to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00}_{C} + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

(S)

CKM factors appear as complex conjugated in CP conjugated amplitudes

- T^{+-} : tree
- P^{+-} : penguin
- T^{00}_{C} : color suppressed tree
- P_{EW} : electroweak penguins
- Hadronic amplitudes receive contributions from different topologies

$B\to K^*\pi$ System: measure γ (CPS/GPSZ)

$$A(B^0\to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$\sqrt{2}A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00}_C + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

(S)

Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0\to K^{*+}\pi^-) + \sqrt{2}\,A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0}\to K^{*-}\pi^+) + \sqrt{2}\,\overline{A}(\overline{B^0}\to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = \boxed{e^{-2i\gamma}}$

CPS PRD74:051301
GPSZ PRD75:014002

γ CKM angle

$B\to K^{*}\pi$ System: measure γ (CPS/GPSZ)

$$A(B^0\to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

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(S)

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$$3A_{3/2} = A(B^0\to K^{*+}\pi^-) + \sqrt{2}\,A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0}\to K^{*-}\pi^+) + \sqrt{2}\,\overline{A}(\overline{B^0}\to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = \boxed{e^{-2i\gamma}}$

CPS PRD74:051301
GPSZ PRD75:014002

From experiment:

- Measurable from $K^+\pi^-\pi^0$ DP analysis

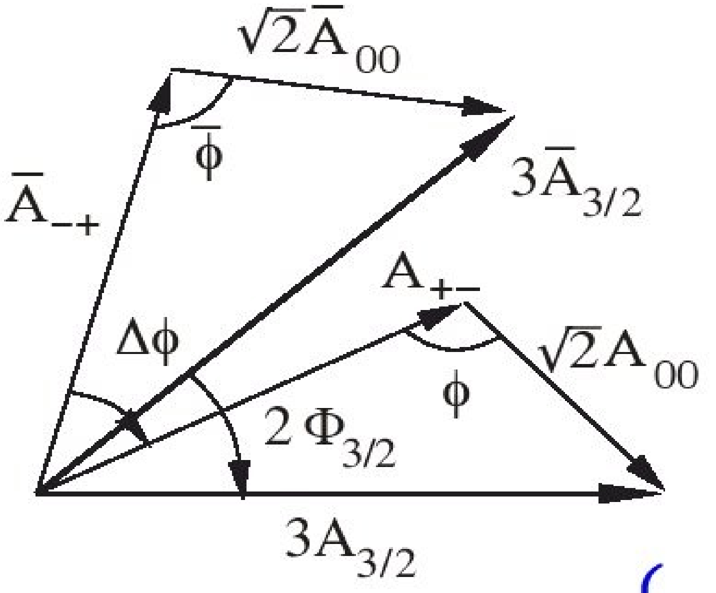
  $\overline{\phi} = \arg(\overline{A}(\overline{B^0}\to K^{*+}\pi^-)\overline{A}^*(\overline{B^0}\to K^{*0}\pi^0))$

  $\phi = \arg(A(B^0\to K^{*+}\pi^-)A^*(B^0\to K^{*0}\pi^0))$

- Measurable from $K^0_S\pi^+\pi^-$ from a

  TI DP analysis

  $\Delta\phi = \arg(\overline{A}(\overline{B^0}\to K^{*-}\pi^+)A^*(B^0\to K^{*+}\pi^-))$



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$$A(B^0\to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$\sqrt{2}A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00}_{C} + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

(S)

Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0\to K^{*+}\pi^-) + \sqrt{2}\,A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0}\to K^{*-}\pi^+) + \sqrt{2}\,\overline{A}(\overline{B^0}\to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = e^{-2i\gamma}$

CPS PRD74:051301
GPSZ PRD75:014002

From experiment:

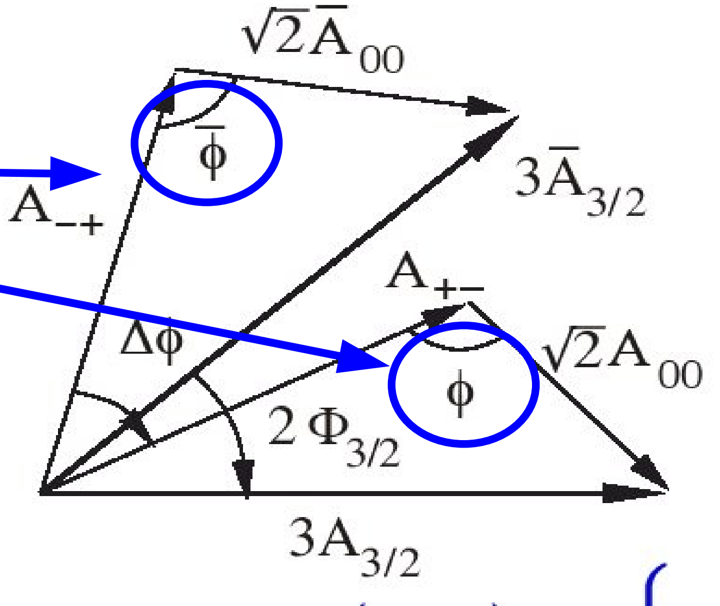
- Measurable from $K^+\pi^-\pi^0$ DP analysis

$$\overline{\phi} = \arg(\overline{A}(\overline{B^0}\to K^{*+}\pi^-)\overline{A}^*(\overline{B^0}\to K^{*0}\pi^0))$$

$$\phi = \arg(A(B^0\to K^{*+}\pi^-)A^*(B^0\to K^{*0}\pi^0))$$

- Measurable from $K^0_S\pi^+\pi^-$ from a TI DP analysis

$$\Delta\phi = \arg(\overline{A}(\overline{B^0}\to K^{*-}\pi^+)A^*(B^0\to K^{*+}\pi^-))$$



$B\to K^*\pi$ System: measure γ (CPS/GPSZ)

$$A(B^0\to K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$\sqrt{2}A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00}_{C} + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

(S)

Neglecting P_{EW}, the amplitude combinations:

$$3A_{3/2} = A(B^0\to K^{*+}\pi^-) + \sqrt{2}\,A(B^0\to K^{*0}\pi^0) = V_{us}V^*_{ub}(T^{+-}+T^{00})$$

$$3\overline{A}_{3/2} = \overline{A}(\overline{B^0}\to K^{*-}\pi^+) + \sqrt{2}\,\overline{A}(\overline{B^0}\to \overline{K}^{*0}\pi^0) = V^*_{us}V_{ub}(T^{+-}+T^{00})$$

gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = \boxed{e^{-2i\gamma}}$

CPS PRD74:051301
GPSZ PRD75:014002

From experiment:

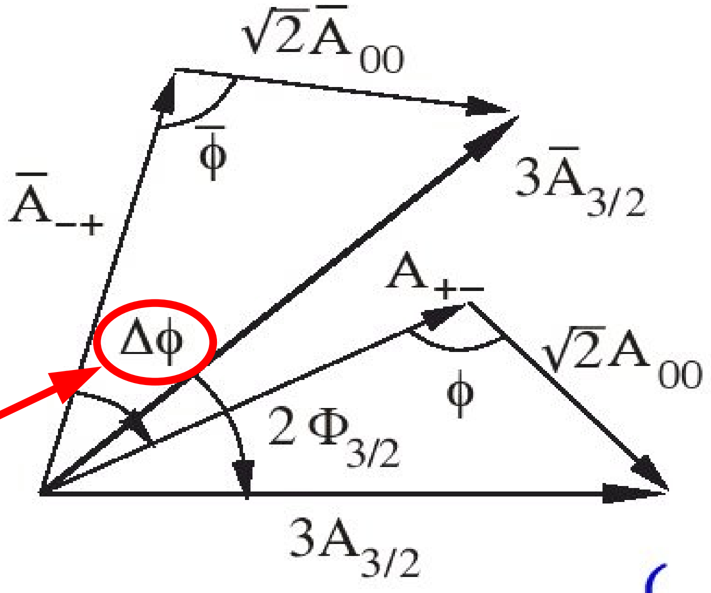
- Measurable from $K^+\pi^-\pi^0$ DP analysis

$$\overline{\phi} = \arg(\overline{A}(\overline{B^0}\to K^{*+}\pi^-)\overline{A}^*(\overline{B^0}\to K^{*0}\pi^0))$$

$$\phi = \arg(A(B^0\to K^{*+}\pi^-)A^*(B^0\to K^{*0}\pi^0))$$

- Measurable from $K^0_S\pi^+\pi^-$ from a TI DP analysis

$$\Delta\phi = \arg(\overline{A}(\overline{B^0}\to K^{*-}\pi^+)A^*(B^0\to K^{*+}\pi^-))$$



Revisiting CPS/GPSZ

- **Original plan:** extend CPS/GPSZ method by including all available observables of $K^*\pi$ system

Phase difference between B^0 and $\overline{B}^0$ amplitudes only accessible from TD DP analyses (include q/p factor)

From $K^0_s\pi^+\pi^-$:

$\Delta\phi = \arg((q/p)\overline{A}(\overline{B}^0\to K^{*-}\pi^+)A^*(B^0\to K^{*+}\pi^-))$ and not

$\Delta\phi = \arg(\overline{A}(\overline{B}^0\to K^{*-}\pi^+)A^*(B^0\to K^{*+}\pi^-))$

- Physical observable is $R'_{3/2} = (q/p)R_{3/2}$.
- With $P_{EW} = 0$, $R'_{3/2} = (q/p)R_{3/2} = e^{-2i\beta}e^{-2i\gamma} = e^{-2i\alpha}$

$\rightarrow$ **Access to α and not γ!**

- In case of $P_{EW} \neq 0$, $R'_{3/2} = \exp(-2i\phi_{3/2})$, $\phi_{3/2}$: “α shifted”

$B\rightarrow K^{*}\pi$ System: Physical Observables

$$A(B^0\rightarrow K^{*+}\pi^-) = V_{us}V^*_{ub}T^{+-} + V_{ts}V^*_{tb}P^{+-}$$

$$\sqrt{2}A(B^0\rightarrow K^{*0}\pi^0) = V_{us}V^*_{ub}T^{00}_{C} + V_{ts}V^*_{tb}(-P^{+-}+P_{EW})$$

7 QCD and 2 CKM = 9 unknowns

(S)

Observables:

- 2 BFs and 2 A_{CP} from DP and Q2B analyses.
- 3 phase differences:

$$* \ \Delta\phi = \arg((q/p)\overline{A}(\overline{B}^0\rightarrow K^{*-}\pi^+)A^*(B^0\rightarrow K^{*+}\pi^-)) \text{ from } B^0\rightarrow K^0_S\pi^+\pi^-$$

$$\left.\begin{array}{l} * \ \phi = \arg(A(B^0\rightarrow K^{*0}\pi^0)A^*(B^0\rightarrow K^{*+}\pi^-)) \\ \overline{\phi} = \arg(\overline{A}(\overline{B}^0\rightarrow \overline{K}^{*0}\pi^0)\overline{A}^*(\overline{B}^0\rightarrow K^{*-}\pi^+)) \end{array}\right\} \text{ from } B^0\rightarrow K^+\pi^-\pi^0$$

A total of 7 observables

Need an additional hypothesis

$B \to K^{*}\pi$ system: two strategies

Scenario 1: use CKM from external input (global fit) and fit hadronic parameters:

- Uncontroversial: only assumes CKM unitarity
- inputs: CKM from global fit and experimental measurements
- output:
  - Explore hadronic amplitudes, test of theoretical calculations

Scenario 2: use external hadronic input and fit for CKM:

- If Had → Had + δHad gives CKM → CKM + δCKM ☺

  Ex.: α from $B \to \pi\pi$

- If Had → Had + δHad gives CKM → CKM + ΔCKM ☹

Goal: test CPS/GPSZ method

$B \to K^{*}\pi$ system: Theoretical prediction

CPS/GPSZ: relation between the P_{EW} and $T_{3/2} = T^{+-} + T^{00}_{C}$

- $B \to \pi\pi$: $P_{EW} = RT_{3/2}$, R=1.35% and real. (SU(2) and Wilson coeff. $|c_{8,9}|$ small).
  P and T CKM of same order → P_{EW} negligible

- $B \to K\pi$: $P_{EW} = RT_{3/2}$ (same as $\pi\pi$ and SU(3))
  P amplified CKM wrt. T ($|V_{ts}V^{*}_{tb}/V_{us}V^{*}_{ub}|\sim 50$) → P_{EW} non-negligible

- $B \to K^{*}\pi$: $P_{EW} = R_{eff}T_{3/2}$
  - $R_{eff} = R(1-r_{VP})/(1+r_{VP})$,
  - r_{VP} complex → vector-pseudoscalar phase space,
  - GPSZ estimation $|r_{VP}| < 5\%$

Scenario 1: exploring hadronic parameters

Input here:

- Experimental measurements
- CKM from global fit

(No assumption on any hadronic amplitude)

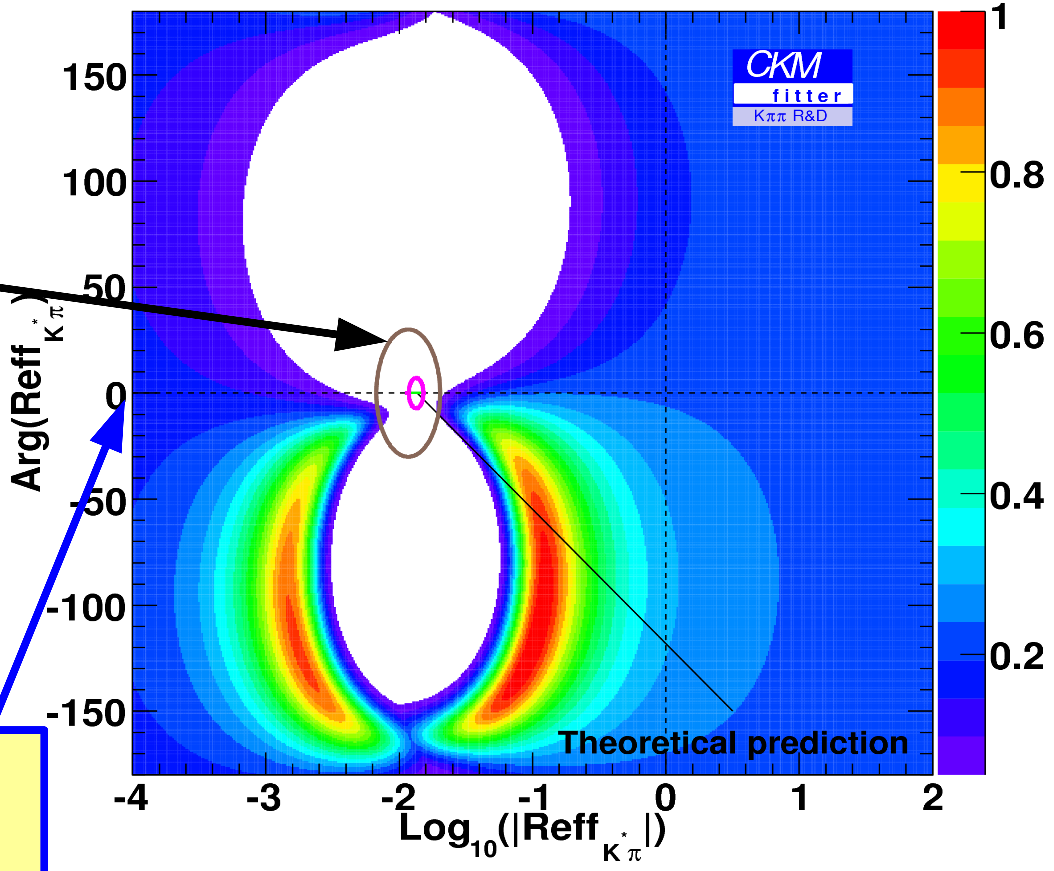
— GPSZ error

— 5xGPSZ error

Constraint marginally compatible with GPSZ prediction (~2σ)

$P_{ew} = 0$ better compatibility with data

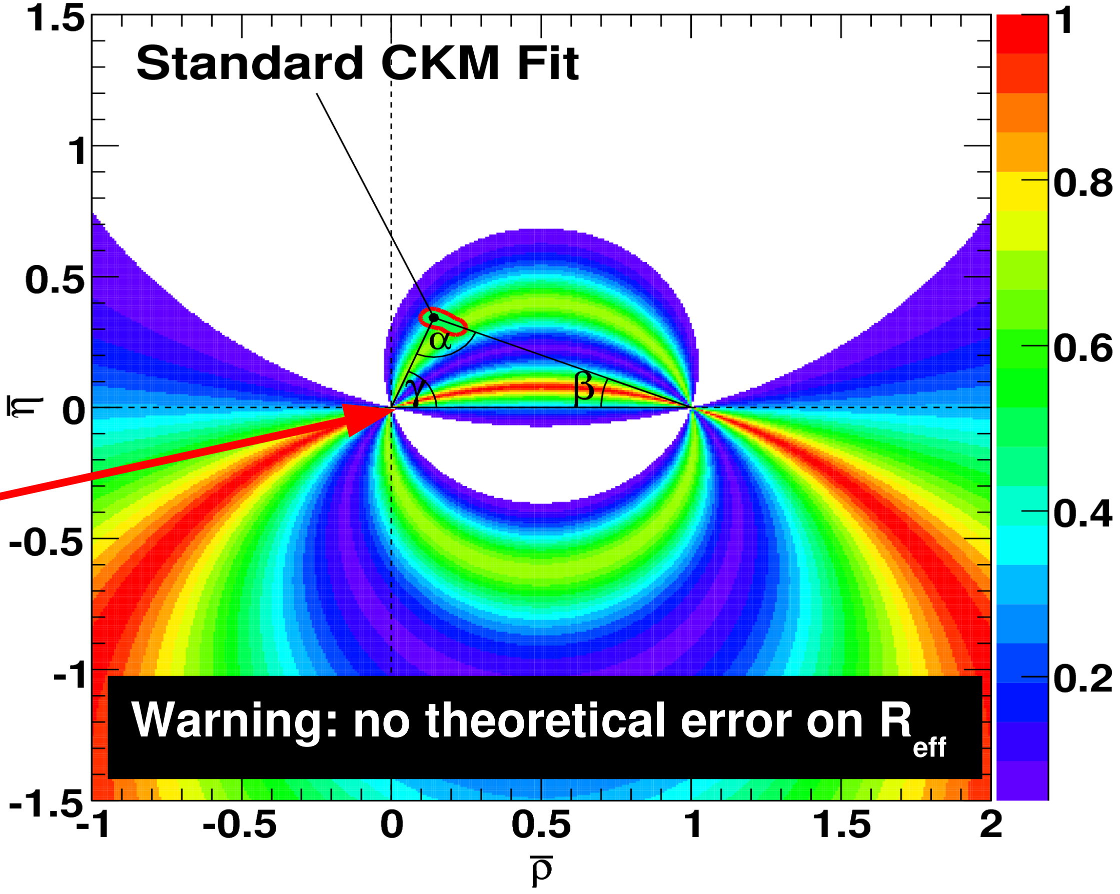
$P_{EW}/T_{3/2}$



Scenario 2: exploring CKM

Vanishing P_{EW}

$R_{eff} = 0$



Warning: no theoretical error on R_{eff}

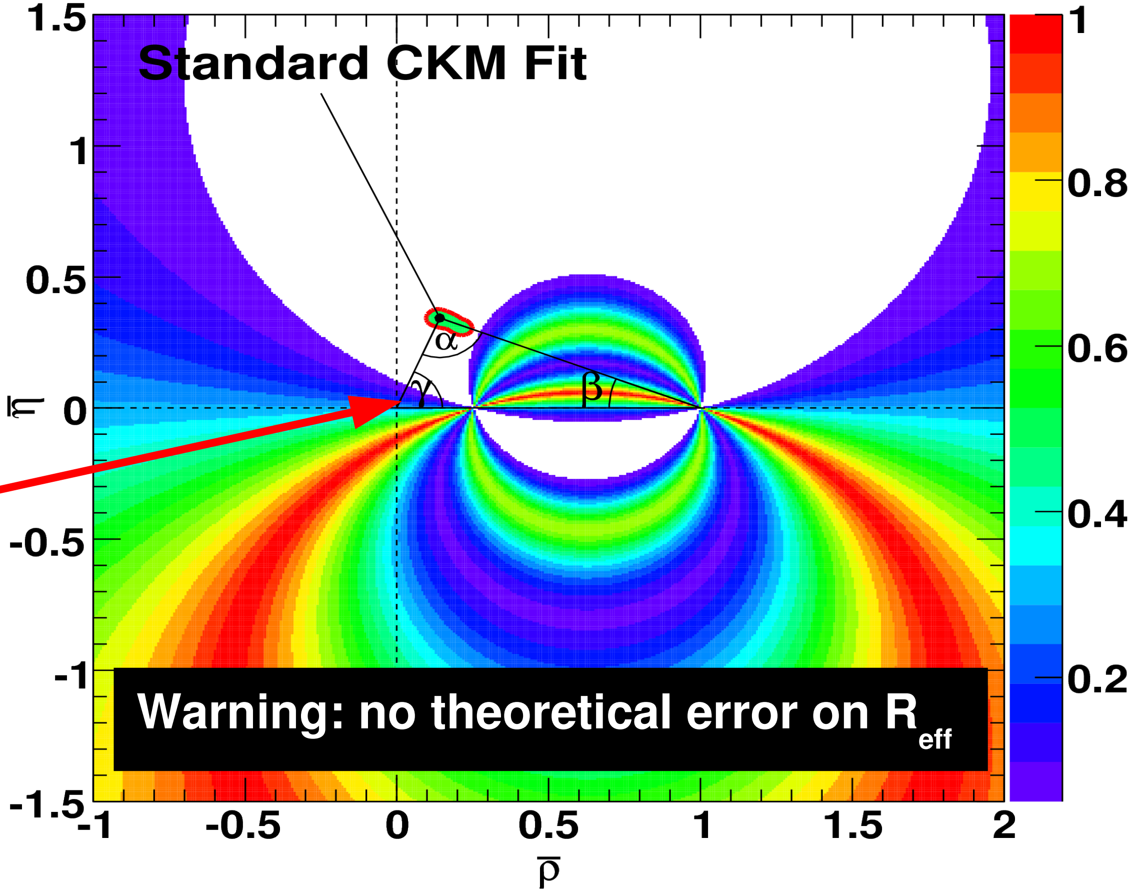
Constraint set on α not γ!

Scenario 2: exploring CKM

$P_{EW} = R_{eff} T_{3/2}$

R_{eff} = 1.35% (GPSZ)

Constraint set on "α shifted" ($\phi_{3/2}$)

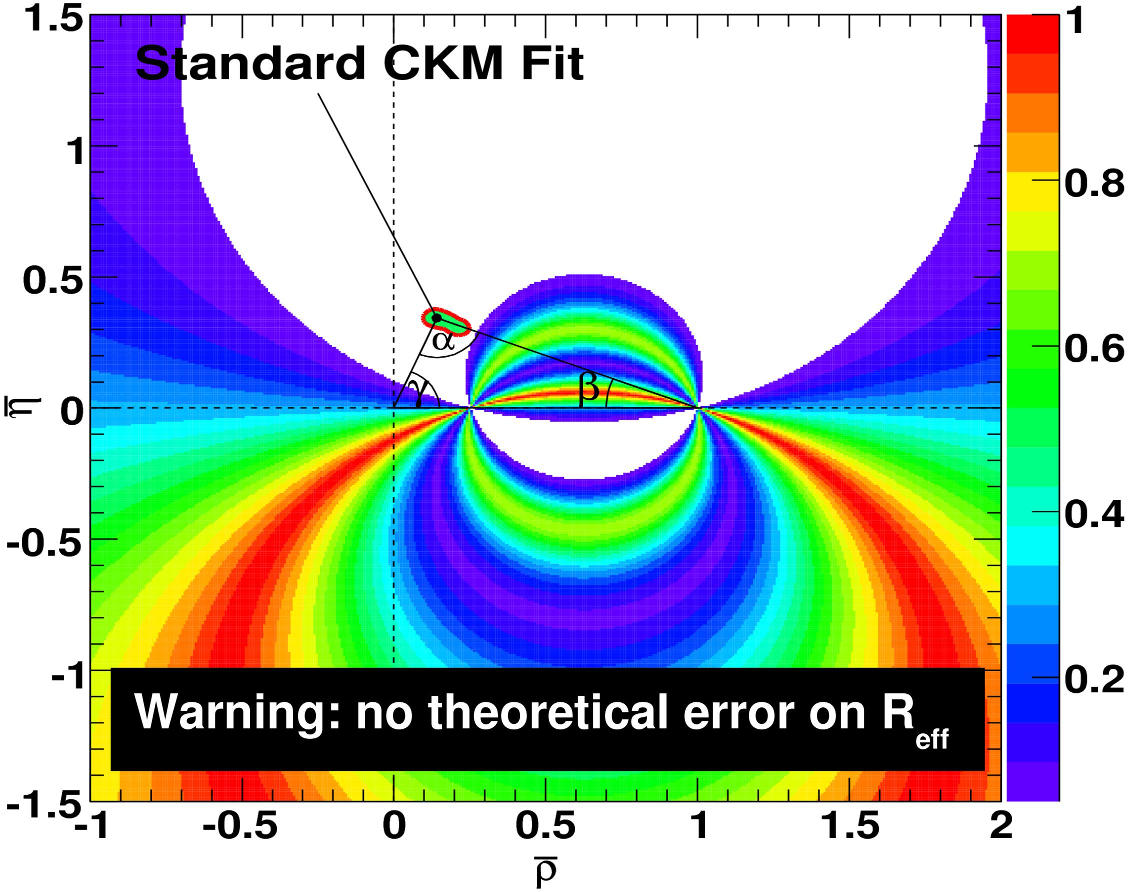


Scenario 2: exploring CKM

$P_{EW} = R_{eff} T_{3/2}$

R_{eff} = 1.35% (GPSZ)

Small change in Reff changes significantly the constraint!



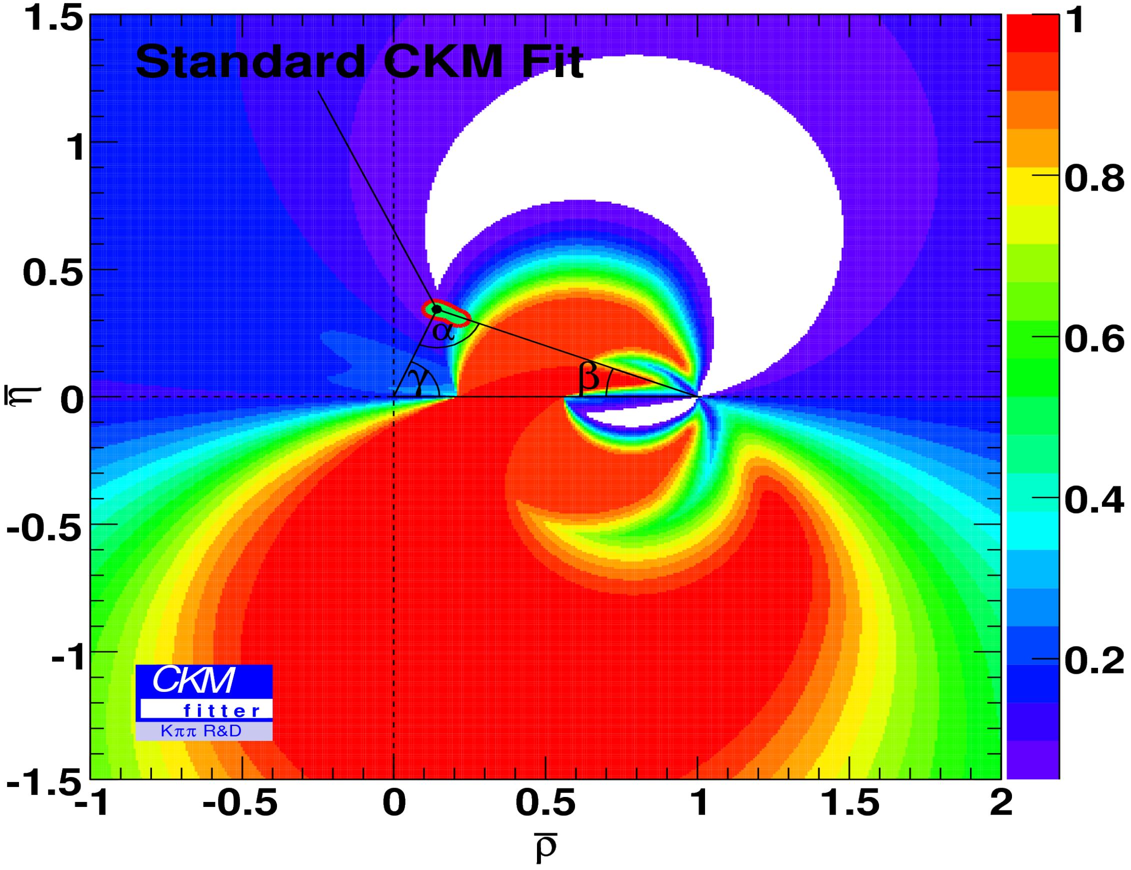
Scenario 2: exploring CKM

$P_{EW} = R_{eff} T_{3/2}$

R_{eff} = 1.35% (GPSZ)

Conservative theoretical error dilutes strongly the constraint

CPS/GPSZ method totally dominated by theoretical errors



Conclusions (I)

Experimental analysis

- Measure (β_{eff},C) for f_0(980)Ks and ρ^0(770)Ks

  f_0(980)Ks: - CPV conservation excluded at 3.5σ

  - Agreement with b→ccs at 1.1σ
  - Trigonometric ambiguity not resolved

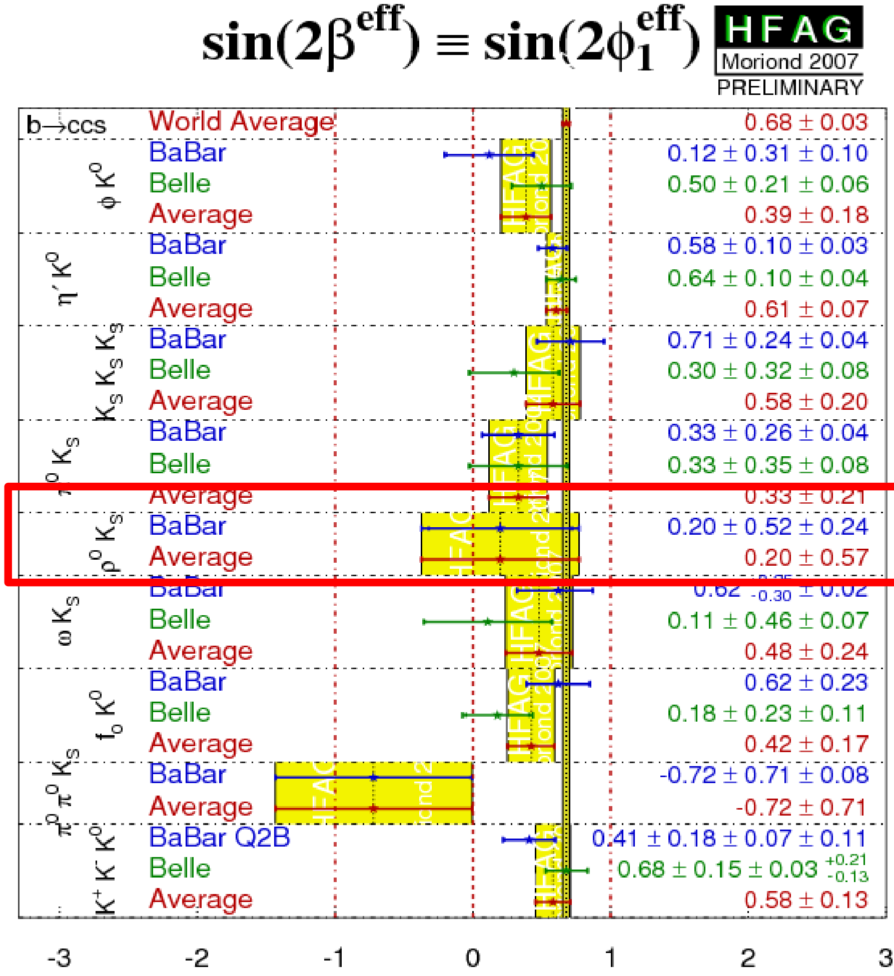
  ρ^0(770)Ks: - β_{eff} measured for the first time

  - Trigonometric ambiguity disfavoured at 1.9σ
  - Preferred solution in agreement with b→ccs
- Δϕ(K*(892)π) measured for the first time
- Analysis published in PRD

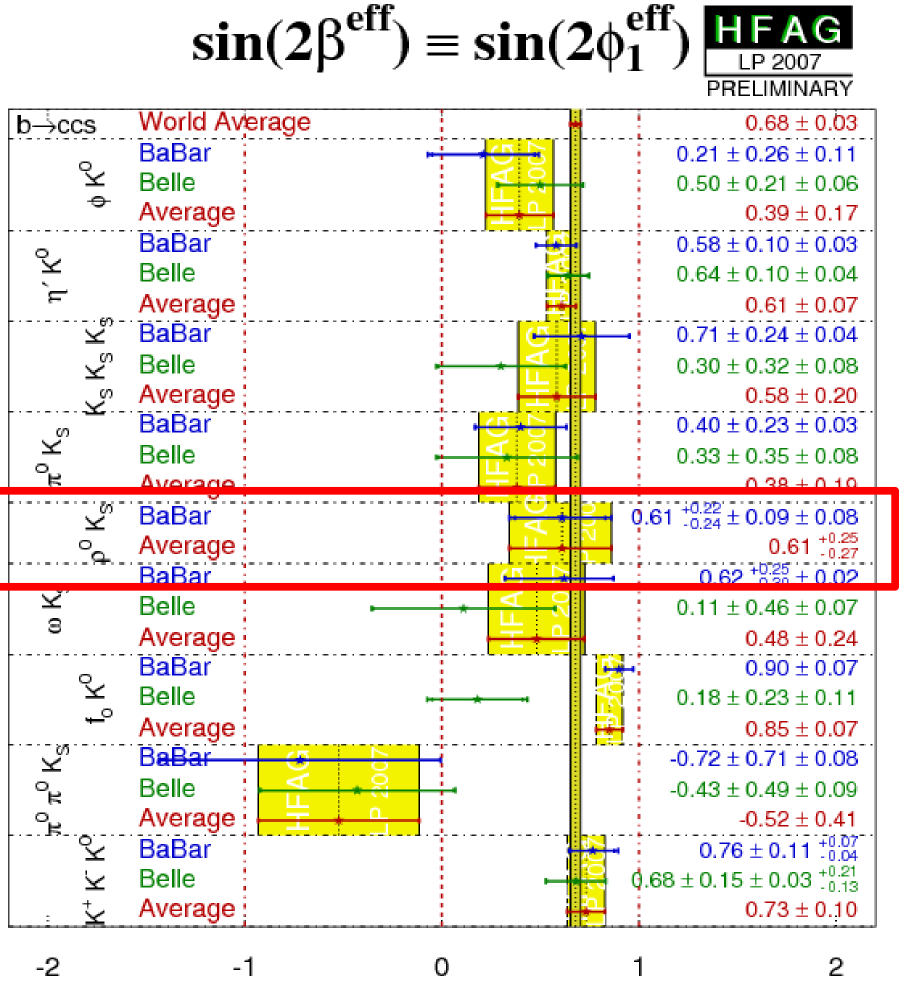
- BaBar and Belle are steeping down ⇒ it is now the turn of LHCb and maybe the future SuperB project to improve the measurements on $B^+ \rightarrow K^+\pi^-\pi^+$, $B^0 \rightarrow K^+\pi^-\pi^0$ and $B^0 \rightarrow K^0_S\pi^+\pi^-$

Conclusions (I)

Before these measurements

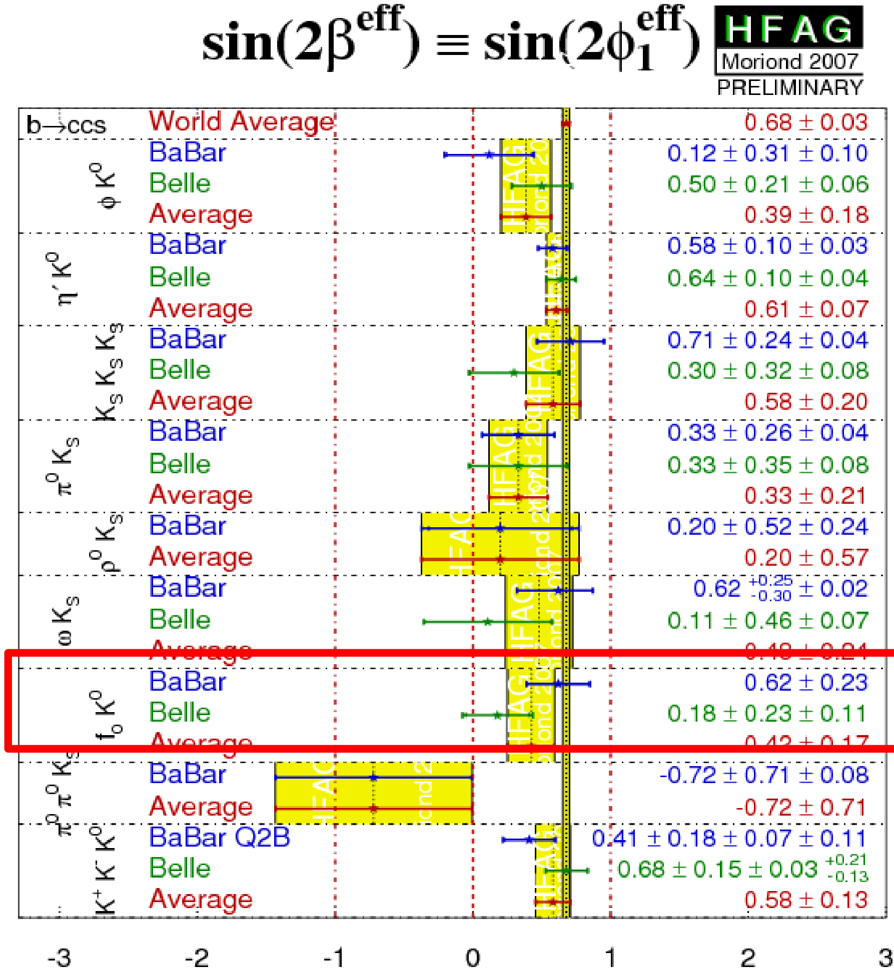


After these measurements

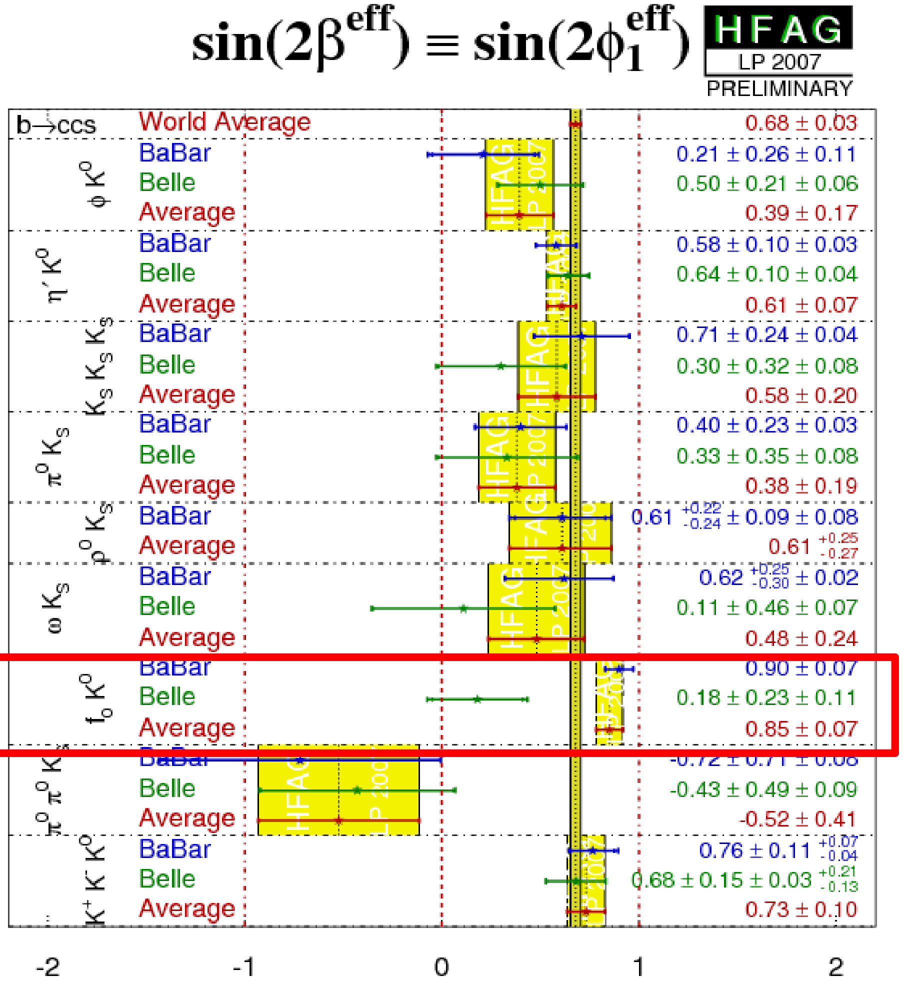


Conclusions (I)

Before these measurements



After these measurements



Conclusions (II)

Phenomenological analysis

- Theoretical expectation on P_{ew} marginally compatible with data
- CPS/GPSZ method dominated by theoretical uncertainty
- K*π: marginal constrain on CKM parameters with current measurements (assuming CPS/GPSZ)
- Potential for CKM physics will depend on the evolution of the theoretical errors

Back up Slides

B mesons Oscillation

Weak states

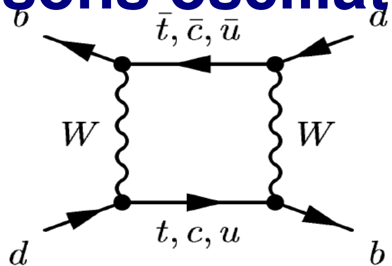
≠

flavor states

$$|B_L\rangle = p|B^0\rangle + q|\overline{B}^0\rangle$$

$$|B_H\rangle = p|B^0\rangle - q|\overline{B}^0\rangle$$

B mesons oscillation



$\arg(V_{td}V^*_{tb}) = -\beta$

Time evolution of a B^0 state at t=0,

$$|B^0(t)\rangle = e^{-im_Bt}e^{-\Gamma_dt/2}\left[\cos\left(\frac{\Delta m_dt}{2}\right)|B^0\rangle + i\frac{q}{p}\sin\left(\frac{\Delta m_dt}{2}\right)|\overline{B}^0\rangle\right]$$

Oscillation frequency

Mixing parameter

In the SM $q/p \approx e^{-2i\beta}$

- **High Mass** **(large phase space)**
- **Direct couplings with complex elements of the V_{CKM}**

B mesons and CP violation

Types of CP violation

- CPV in mixing: $|B^0 \to \overline{B}^0|^2 \neq |\overline{B}^0 \to B^0|^2$ $|q/p| \neq 1$

For B mesons $|q/p| \sim 1$ (B Mixing parameter)

B mesons and CP violation

Types of CP violation

- CPV in mixing: $|B^0 \rightarrow \overline{B}^0|^2 \neq |\overline{B}^0 \rightarrow B^0|^2 \quad |q/p| \neq 1$

For B mesons |q/p| ~ 1 (B Mixing parameter)

- Direct CPV: $|B \rightarrow f|^2 \neq |\overline{B} \rightarrow \overline{f}|^2$

B mesons and CP violation

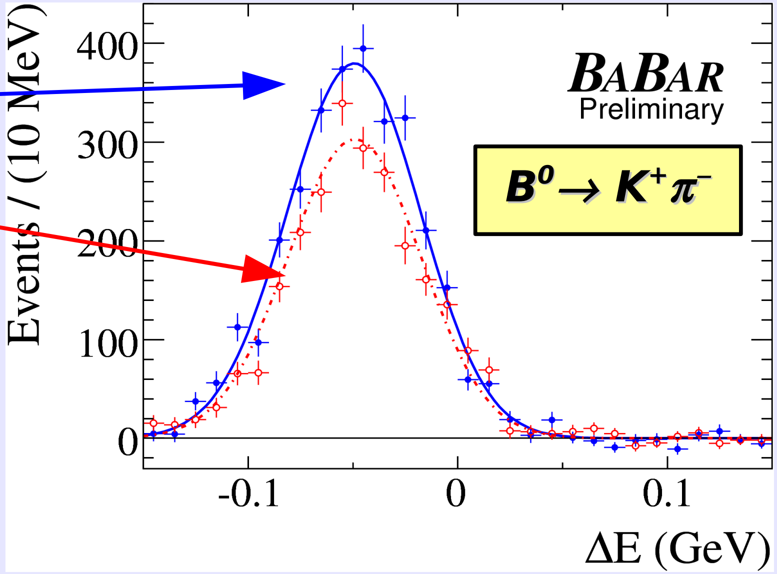
Types of CP violation

- CPV in mixing: $|B^0 \to \overline{B}^0|^2 \neq |\overline{B}^0 \to B^0|^2$ $|q/p| \neq 1$

For B mesons $|q/p| \sim 1$ (B Mixing parameter)

- Direct CPV: $|B \to f|^2 \neq |\overline{B} \to \overline{f}|^2$

$$A_{CP} = \frac{\Gamma(\overline{B} \to \overline{f}) - \Gamma(B \to f)}{\Gamma(\overline{B} \to \overline{f}) + \Gamma(B \to f)}$$



B mesons and CP violation

Types of CP violation

- **CPV in mixing:** $|B^0 \to \overline{B}^0|^2 \neq |\overline{B}^0 \to B^0|^2$ $|q/p| \neq 1$

  For B mesons |q/p| ~ 1 (B Mixing parameter)

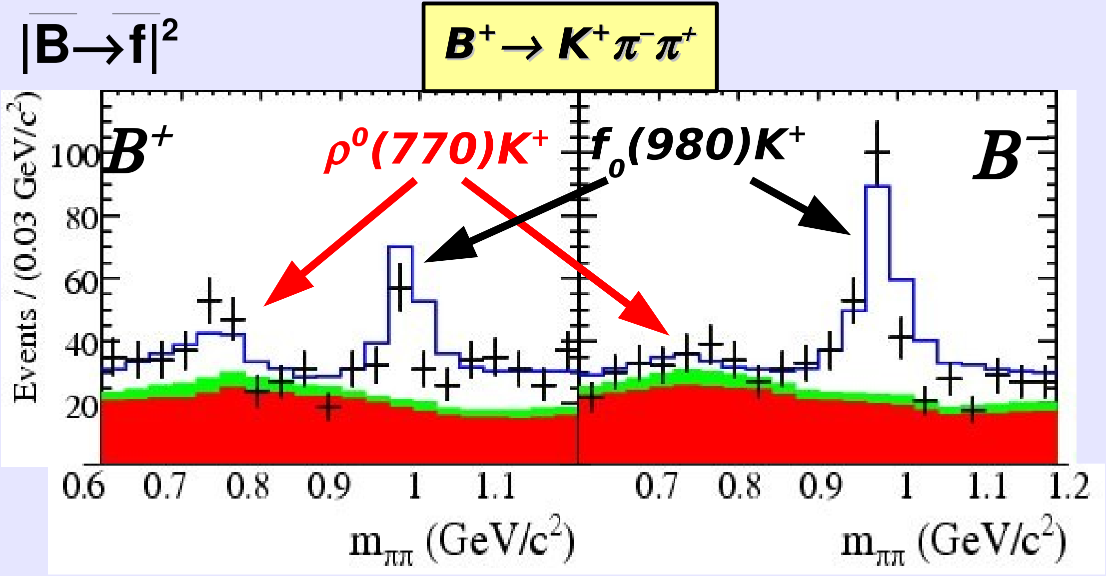
- **Direct CPV:** $|B \to f|^2 \neq |\overline{B} \to \overline{f}|^2$

$$|B \to f_1 + B \to f_2|^2 \to \delta_{12}$$

$$\neq$$

$$|\overline{B} \to \overline{f}_1 + \overline{B} \to \overline{f}_2|^2 \to \overline{\delta}_{12}$$

$$\Delta\phi_{12} = \delta_{12} - \overline{\delta}_{12}$$



B mesons and CP violation

Types of CP violation

- CPV in mixing: $|B^0 \rightarrow \overline{B}{}^0|^2 \neq |\overline{B}{}^0 \rightarrow B^0|^2$ $|q/p| \neq 1$

For B mesons $|q/p| \sim 1$ (B Mixing parameter)

- Direct CPV: $|B \rightarrow f|^2 \neq |\overline{B} \rightarrow \overline{f}|^2$

- Mixing and decay CPV: $|B^0 \rightarrow f_{CP} + B^0 \rightarrow \overline{B}{}^0 \rightarrow f_{CP}|^2 \neq$

$|\overline{B}{}^0 \rightarrow f_{CP} + \overline{B}{}^0 \rightarrow B^0 \rightarrow f_{CP}|^2$

$A_{CP}(t) = S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)$

$S = 2\mathrm{Im}(\lambda_{CP})/(1+|\lambda_{CP}|^2)$

$C = (1-|\lambda_{CP}|^2)/(1+|\lambda_{CP}|^2)$

$\lambda_{CP} = (q/p)[A(\overline{B}{}^0 \rightarrow f_{CP})/A(B^0 \rightarrow \overline{f}_{CP})]$

B mesons and CP violation

Types of CP violation

- CPV in mixing: $|B^0 \rightarrow \overline{B}^0|^2 \neq |\overline{B}^0 \rightarrow B^0|^2$ $|q/p| \neq 1$

For B mesons $|q/p| \sim 1$ (B Mixing parameter)

- Direct CPV: $|B \rightarrow f|^2 \neq |\overline{B} \rightarrow \overline{f}|^2$

- Mixing and decay CPV: $|B^0 \rightarrow f_{CP} + B^0 \rightarrow \overline{B}^0 \rightarrow f_{CP}|^2 \neq$

$|\overline{B}^0 \rightarrow f_{CP} +$

$$A_{CP}(t) = S\sin(\Delta m_d \Delta t) - C\cos(\Delta m_d \Delta t)$$

$$S = 2\mathrm{Im}(\lambda_{CP})/(1+|\lambda_{CP}|^2)$$

$$C = (1-|\lambda_{CP}|^2)/(1+|\lambda_{CP}|^2)$$

$$\lambda_{CP} = (q/p)[A(B^0 \rightarrow f_{CP})/A(\overline{B}^0 \rightarrow \overline{f}_{CP})]$$

SM Prediction:

$S = \sin(2\beta)$

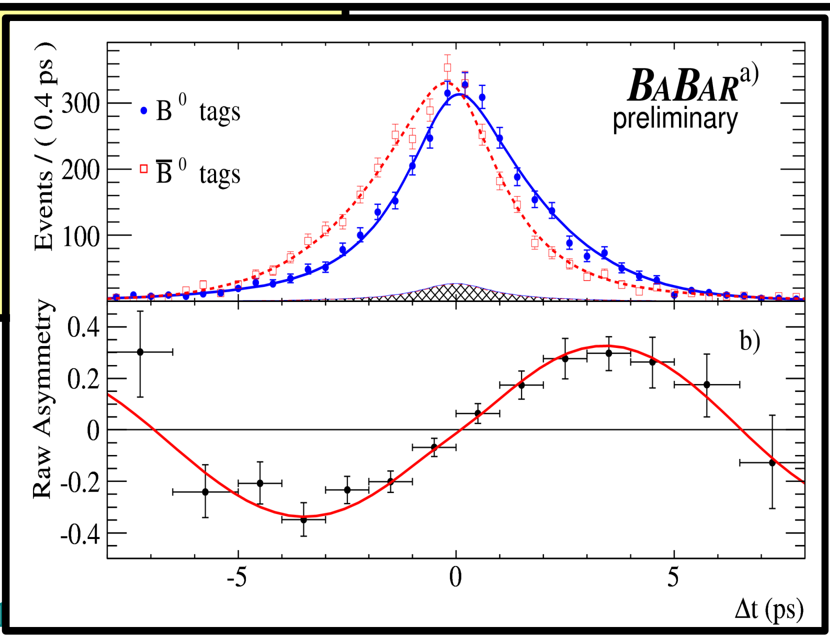
$C = 0$

Latest BaBar result:

$S = 0.660 \pm 0.036 \pm 0.012$

$C = 0.029 \pm 0.026 \pm 0.017$

Time-dependent CP asymmetry in $J/\Psi K^0_s$ decays



Existing Measurements

- TD Q2B analysis $f_0(980)K^0_S$. 123×10^6 BB, BaBar 2004 (PRL94:041802)
- TD Q2B analysis $f_0(980)K^0_S$. 386×10^6 BB, Belle 2005 (arXiv:hep-ex/0507037)
- TD Q2B analysis $\rho^0(770)K^0_S$. 227×10^6 BB, BaBar 2006 (PRL98:051803)

- TI Q2B analysis $K_S\pi^+\pi^-$. 232×10^6 BB, BaBar 2006 (PRD73:031101)

- TI tag-integrated DP analysis.
  388×10^6 BB, Belle 2006 (PRD75:012006)

- **Our Preliminary Results TD DP analysis presented at LP07.**
  383×10^6 BB, BaBar 2007 (arXiv:hep-ex/0708.2097)

- Two weeks before my thesis: TD DP analysis
  657×10^6 BB, Belle 2008 (arXiv:hep-ex/0811.3665)

TD = Time dependent
TI = Time integrated
DP = Dalitz Plot
Q2B = Quasi-Two Body

Belle results 2008: $2\beta_{eff}$

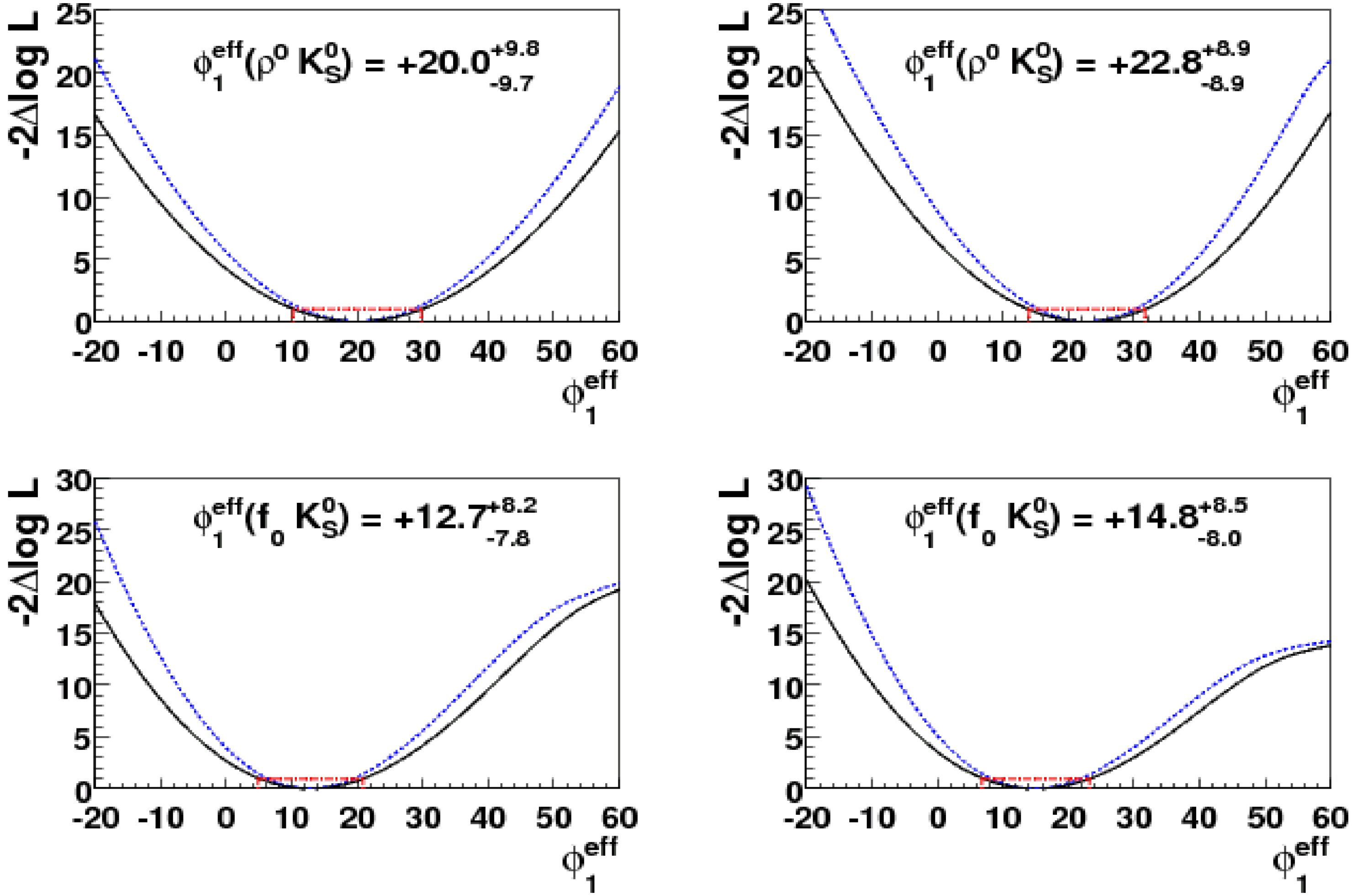


FIG. 5: Likelihood scans of $\phi_1^{\rm eff}$ for $B^0 \to \rho^0(770)K_S^0$ (top) and $B^0 \to f_0(980)K_S^0$ (bottom) for Solution 1 (left) and Solution 2 (right). The solid (dashed) curve contains the total (statistical) error and the dotted box indicates the parameter range corresponding to $\pm1\sigma$.

Belle results 2008: $\Delta\phi(K^*(892)\pi)$

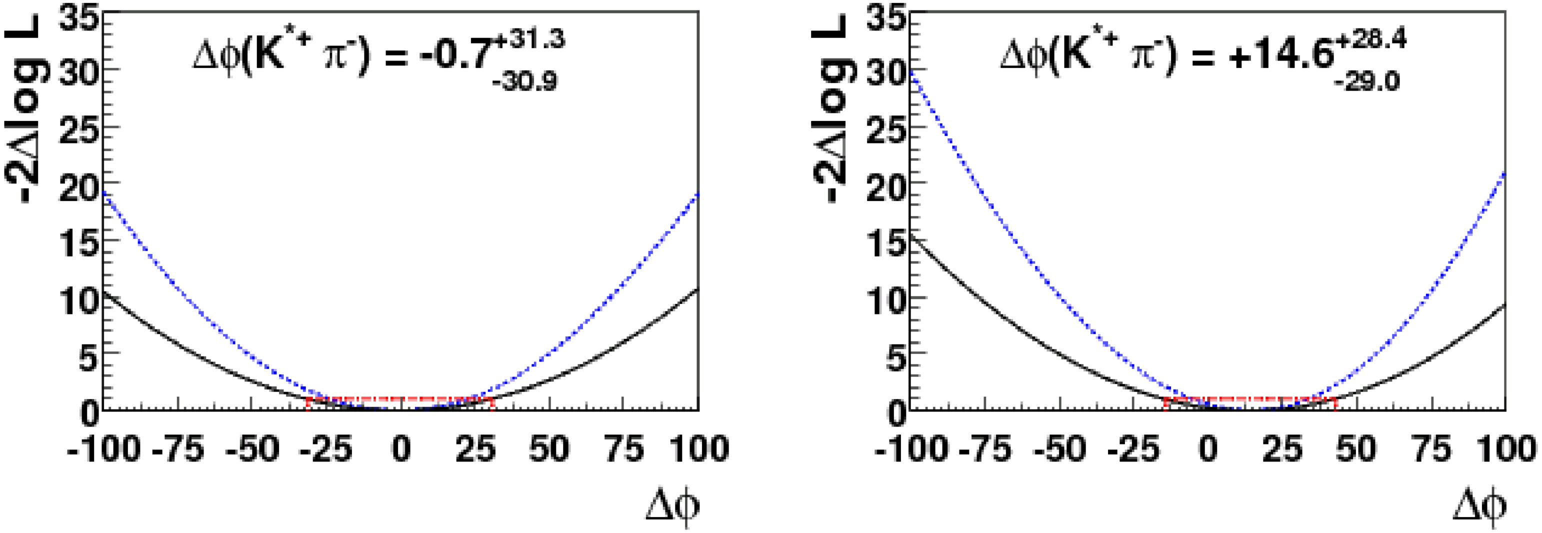
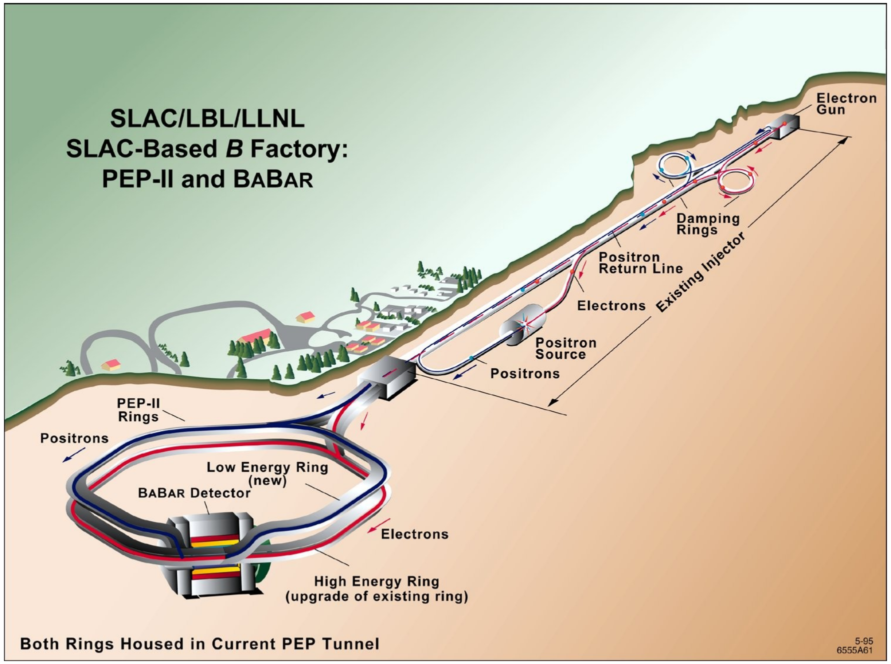
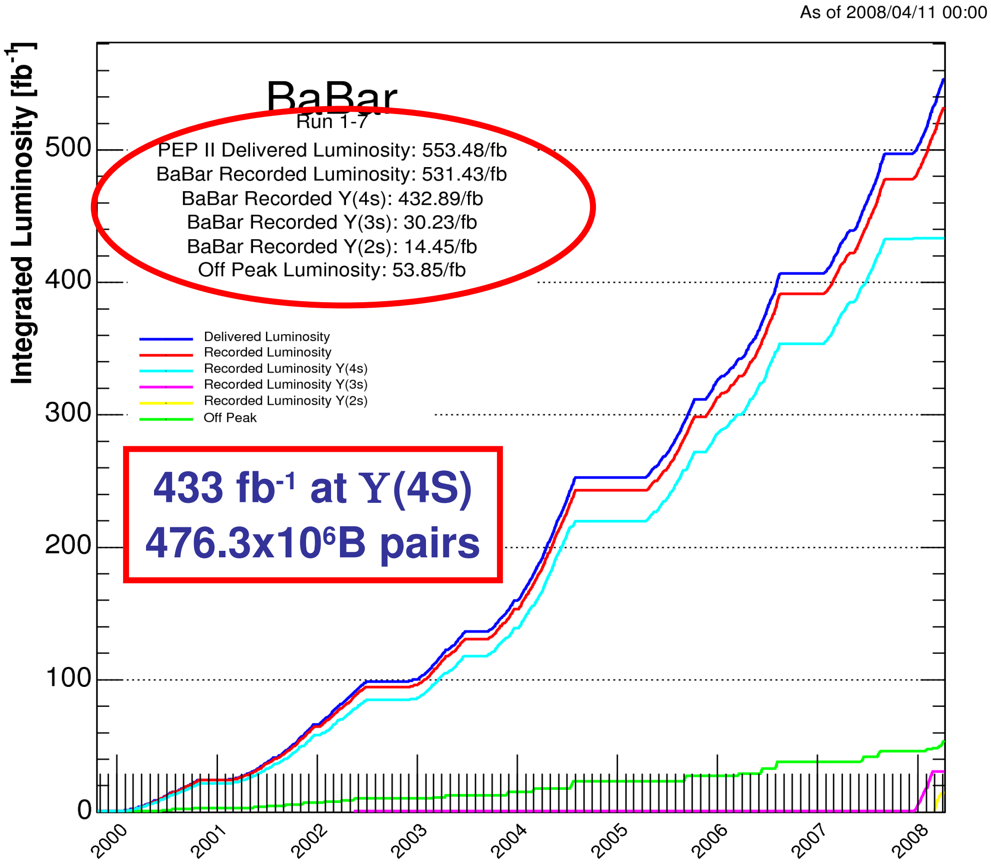


FIG. 7: Likelihood scan of $\Delta\phi$ for Solution 1 (left) and Solution 2 (right). The solid (dashed) curve contains the total (statistical) error and the dotted box indicates the parameter range corresponding to $\pm 1\sigma$.

PEP-II: a B factory at SLAC



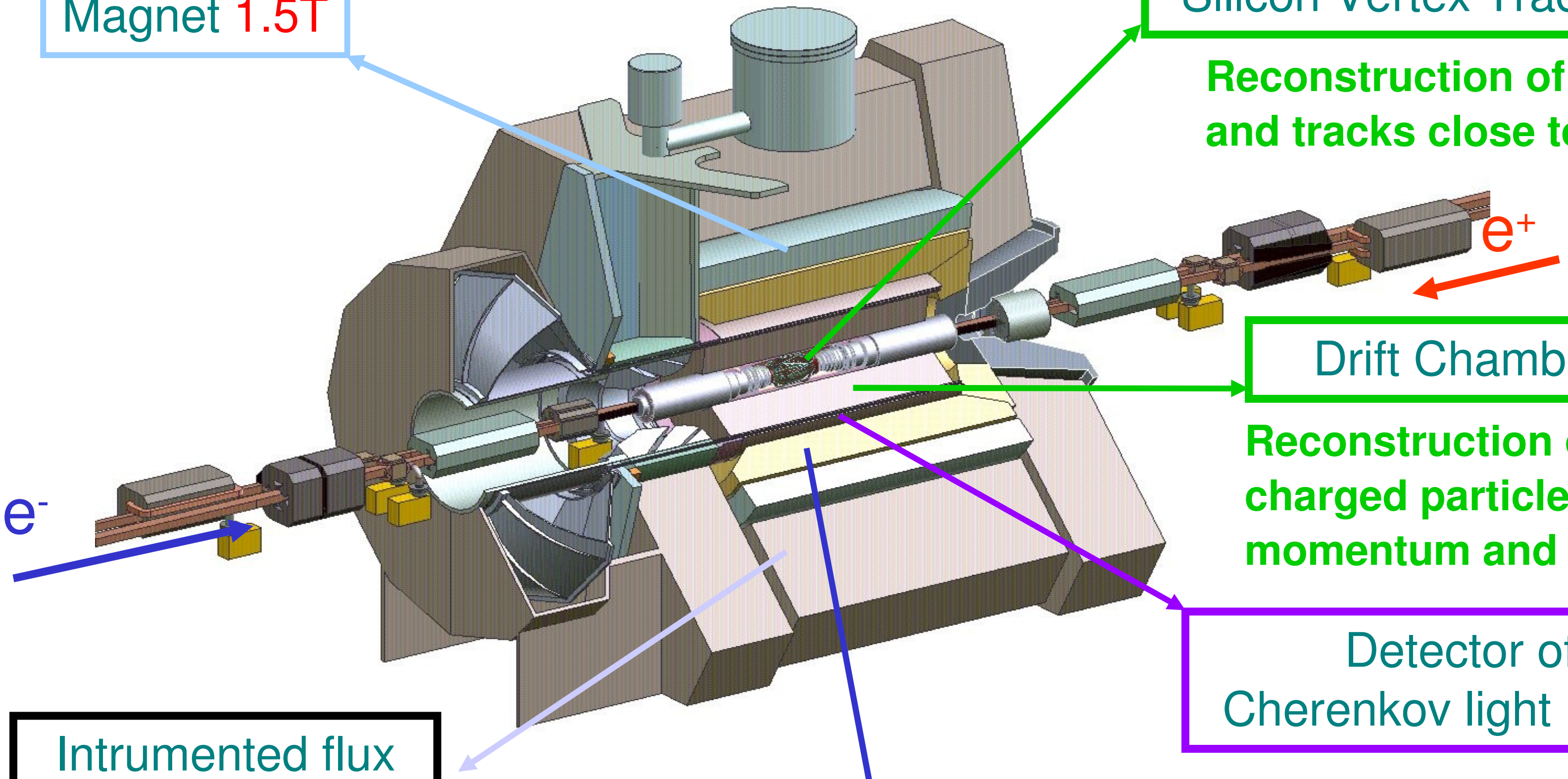
- e^-/e^+ Collision (9GeV/3.1GeV)
- E_{CM} = m(Υ(4S)) = 10.58GeV
- B-production: $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$
- B mesons almost at rest in the CM
- Υ(4S) boost of $\beta\gamma = 0.56$
- Background: $e+e- \rightarrow q\overline{q}$ (q = u,d,s,c)



433 fb^{-1} at Υ(4S)
476.3x10^6B pairs

- On-Peak: √s at the Υ(4S) peak
- Off-Peak: √s 40 MeV below

The BaBar Detector



Magnet 1.5T

Silicon Vertex Tracker (SVT)

Reconstruction of decay vertex and tracks close to the IP

Drift Chamber (DCH)

Reconstruction of deviated charged particles tracks: momentum and angles

Detector of Cherenkov light (DIRC)

Identification of charged particles

Separation K/π $>2.5\sigma$ up to 4 GeV/c

Intrumented flux return (IFR)

Identification of $\mu^{+/-}$

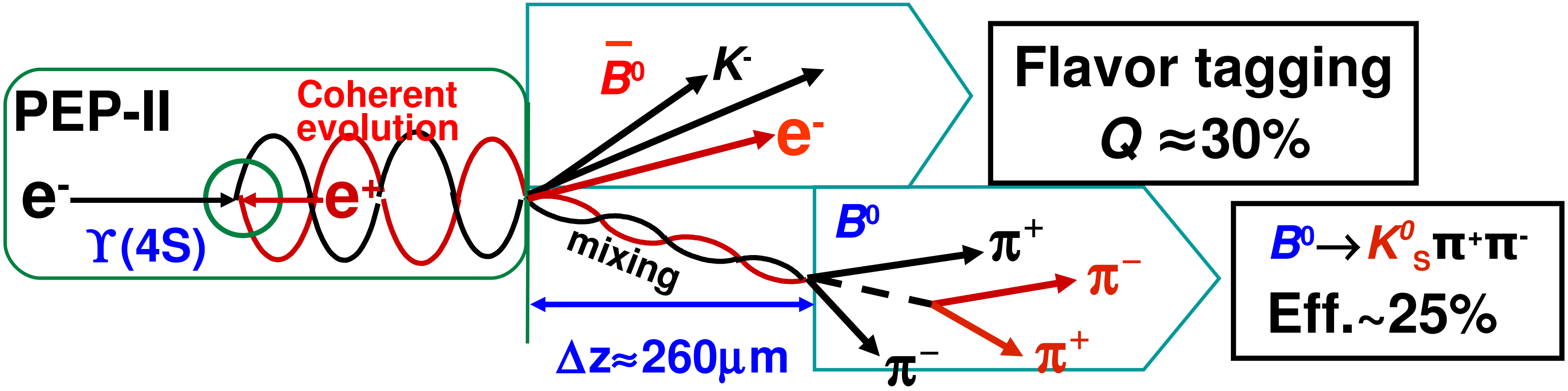
Electromagnetic calorimeter (EMC)

Detection of γ, e^- identification

Reconstruction of $\pi^0 \to \gamma\gamma$, Energy measurement

Δt measurement and flavor tagging

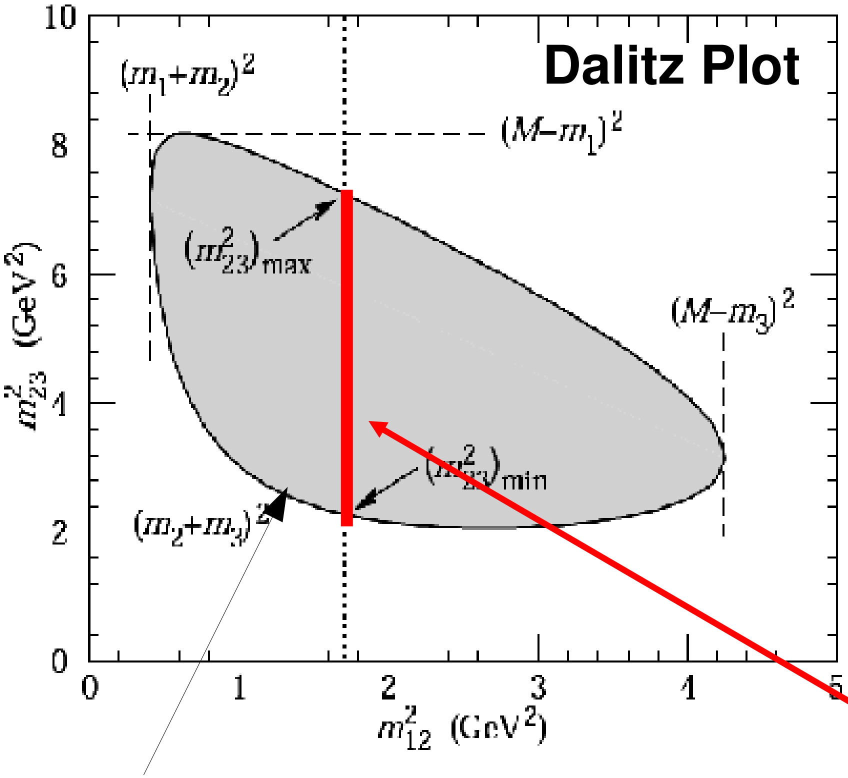
- Neutral B mesons produced in a coherent B^0-$\bar{B}^0$ state
- Flavor tagging with B partner
- Δt extracted from Δz measurement ($\Delta t \approx \Delta z \gamma\beta$)



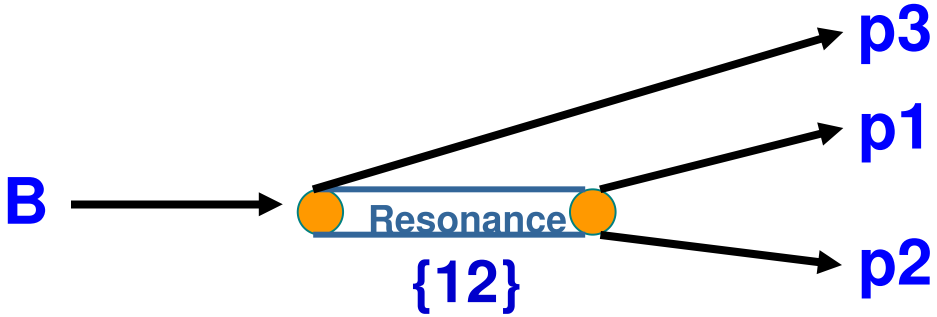
Dalitz Plot (DP)

Tree-body decays described by two parameters:

Mandelstam variables $m_{ij}^2 = (p_i + p_j)^2$



Kinematic boundary



$$P \rightarrow P_{res} + p_3$$

$$P_{res} \rightarrow p_1 + p_2$$

(Distribution around resonance mass)

Likelihood Function

The Likelihood Function

$$L = \prod_{c=1}^{5} e^{-N'_c} \prod_{i=1}^{N_c} \left(N_s \varepsilon_c (1 - f_{SCF,c}) P_{S,c}^{TM} + N_s \varepsilon_c f_{SCF,c} P_{S,c}^{SCF} + N_{q\bar{q}} P_{q\bar{q},c} + \sum_{i=1}^{N_{class}^{B}} N_{B,j} \varepsilon_{B,c} P_{B,c} \right) (\vec{x}_i)$$

Likelihood Function

The Likelihood Function

$$L = \prod_{c=1}^{5} e^{-N'_c} \prod_{i=1}^{N_c} \left(N_s \varepsilon_c \left(1 - f_{SCF,c}\right) P^{TM}_{S,c} + N_s \varepsilon_c f_{SCF,c} P^{SCF}_{S,c} + N_{q\bar{q}} P_{q\bar{q},c} + \sum_{i=1}^{N^B_{class}} N_{B,j} \varepsilon_{B,c} P_{B,c} \right) (\vec{x}_i)$$

Continuum Component

Likelihood Function

The Likelihood Function

$$L = \prod_{c=1}^{5} e^{-N'_c} \prod_{i=1}^{N_c} \left(N_s \varepsilon_c \left(1 - f_{SCF,c}\right) P_{S,c}^{TM} + N_s \varepsilon_c f_{SCF,c} P_{S,c}^{SCF} + N_{q\bar{q}} P_{q\bar{q},c} + \sum_{i=1}^{N_{class}^{B}} N_{B,j} \varepsilon_{B,c} P_{B,c} \right) (\vec{x}_i)$$

B-background Components

Likelihood Function

The Likelihood Function

$$L = \prod_{c=1}^{5} e^{-N'_c} \prod_{i=1}^{N_c} \left(N_s \varepsilon_c \left(1 - f_{SCF,c}\right) P_{S,c}^{TM} + N_s \varepsilon_c f_{SCF,c} P_{S,c}^{SCF} + N_{q\bar{q}} P_{q\bar{q},c} + \sum_{i=1}^{N^B_{class}} N_{B,j} \varepsilon_{B,c} P_{B,c} \right) (\vec{x}_i)$$

Signal Component

TM

SCF

Likelihood Function

The Likelihood Function

$$L = \prod_{c=1}^{5} e^{-N'_c} \prod_{i=1}^{N_c} \left(N_s \varepsilon_c \left(1 - f_{SCF,c}\right) P_{S,c}^{TM} + N_s \varepsilon_c f_{SCF,c} P_{S,c}^{SCF} + N_{q\bar{q}} P_{q\bar{q},c} + \sum_{i=1}^{N_{class}^{B}} N_{B,j} \varepsilon_{B,c} P_{B,c} \right) (\vec{x}_i)$$

$$\boxed{P = P(m_{ES}, \Delta E, NN) \times P(Q_{tag}, \Delta t, DP)}$$

Discrimination **Dynamics**

Parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot

Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP) \end{cases}$$

Shapes of intermediate states over DP

$$F_j^L(DP) = \underbrace{R_j(m)}_{\text{Lineshape}} \times \underbrace{X_L(|\vec{p}^\star|\, r) \times X_L(|\vec{q}|\, r) \times T_j(L, \vec{p}, \vec{q})}_{\text{Kinematic function}}$$

Parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot
Isobar Model

$$\begin{cases} A(DP) = \sum a_j F_j(DP) \\ \overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP) \end{cases}$$

Shapes of intermediate states over DP

$$F_j^L(DP) = R_j(m) \times X_L(|\vec{p}^\star|\,r) \times X_L(|\vec{q}|\,r) \times T_j(L, \vec{p}, \vec{q})$$

Relativistic Breit-Wigner: K*(892)π

Flatte: f_0(980)K

Gounaris-Sakurai: ρ(770)K

S-wave Kπ: LASS lineshape.

Parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot
Isobar Model

$$\left\{\begin{array}{l} A(DP)=\sum a_j F_j(DP) \\ \overline{A}(DP)=\sum \overline{a}_j \overline{F}_j(DP) \end{array}\right.$$

Shapes of intermediate states over DP

$$F_j^L(DP)=R_j(m)\times X_L(|\vec{p}^\star|\,r)\times X_L(|\vec{q}\,|\,r)\times T_j(L,\vec{p},\vec{q})$$

Rela

$$R_j(m_{K\pi})=\frac{m_{K\pi}}{\underbrace{q\cot\delta_B-iq}_{\text{Effective Range Term}}}+e^{2i\delta_B}\frac{m_0\Gamma_0\frac{m_0}{q_0}}{(m_0^2-m_{K\pi}^2)-im_0\Gamma_0\frac{q}{m_{K\pi}}\frac{m_0}{q_0}}$$

Gou

S-wave Kπ: **LASS lineshape.**

Nucl. Phys., B296:493, 1988

Event Selection

- π candidates from standard list
- K^0_S candidates from two $\pi^+\pi^-$ (standard list)
- B^0 candidates using mass constrained vertexing
- $5.272 < m_{ES} < 5.286$ GeV/c^2
- $|\Delta E| < 65$ MeV
- $|\Delta t| < 20$ ps
- $\sigma(\Delta t) < 2.5$ps
- $|M(K^0_S) - M(K^0_S)\text{PDF}| < 15$ MeV/c^2
- Lifetime significance > 5
- $\cos(K^0_S, K^0_S$ daughters$) < 0.999$
- NN > -0.4
- PID requirements to separate from kaons and reject leptons

Total efficiency ~ 25%

Multiple candidates:
candidate selected arbitrarily, in order to not to bias the ΔE distribution

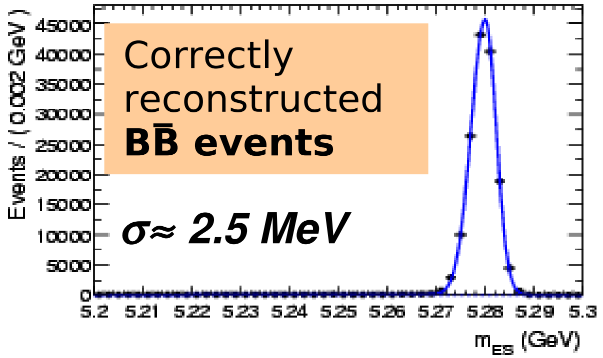
Mod(time-stamp,nCands)

Background discrimination

Fit Variables: $$\vec{x}_i = \big(\underbrace{m_{ES}, \Delta E, NN}_{\text{Discrimination}}, Qtag, \Delta t, DP\big)$$

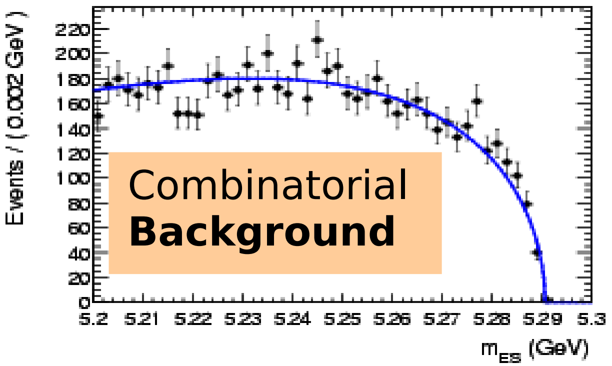
Beam-energy substituted mass

$$m_{ES} = \sqrt{E^{*\,2}_{beam} - p^{*\,2}_{B}}$$



Correctly reconstructed **$B\bar{B}$ events**

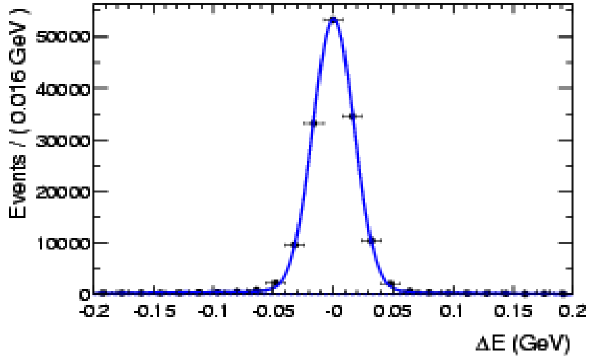
σ≈ 2.5 MeV

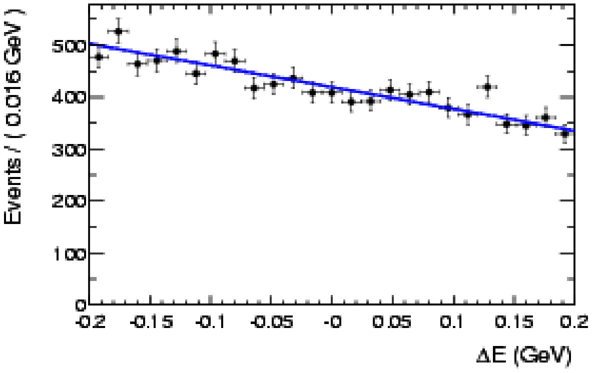


Combinatorial **Background**

Energy difference

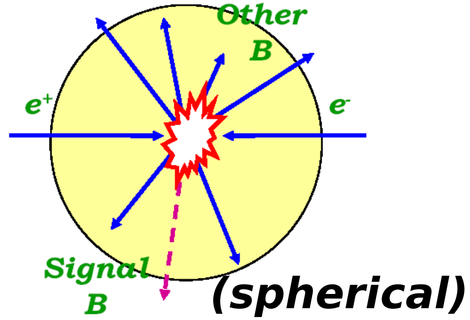
$$\Delta E = E^*_B - E^*_{beam}$$

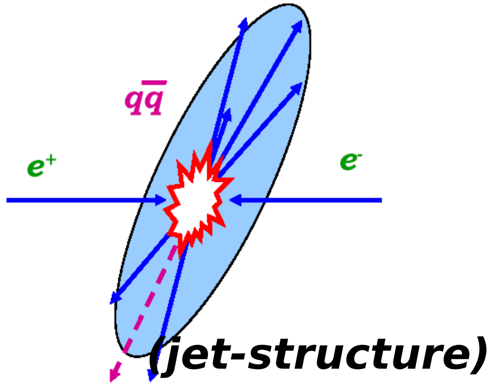




Event topology

(multivariate methods)

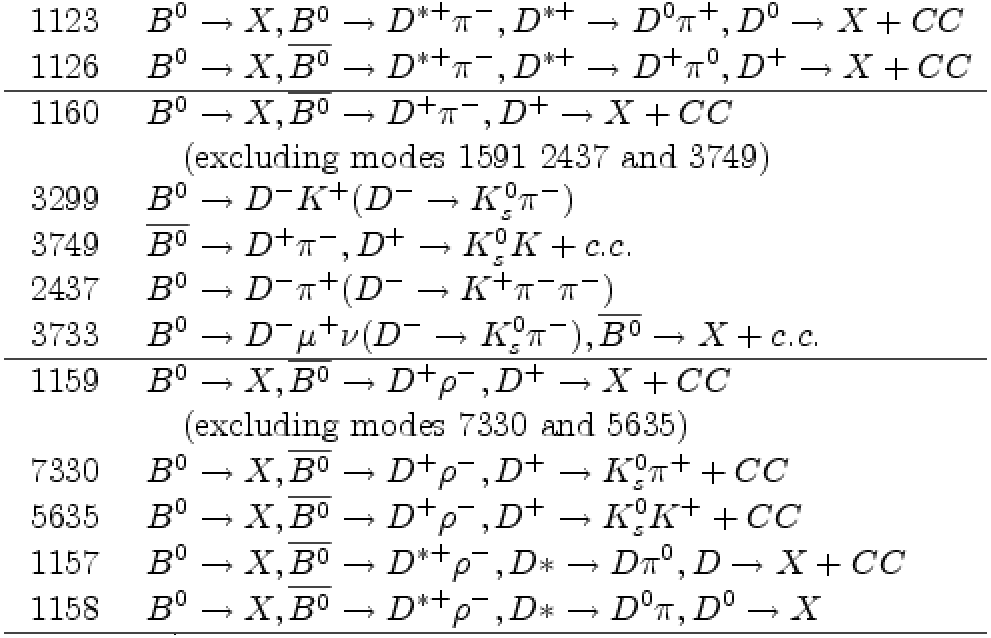




B-background Model

- **List of B-background components:**
  - $B^0 \to D^-(\to \pi^- K^0{}_s)\pi^+$ (Same final state as signal)
  - $B^0 \to J/\psi(\to l^+l^-)K^0{}_s$ (π/μ mis-ID)
  - $B^0 \to \psi(2S)K^0{}_s$
  - $B^0 \to \eta'(\to \rho\gamma)K^0{}_s$
  - $B^0 \to a\,^+\pi^-$

Modes treated exclusively



1123	$B^0 \to X, \overline{B^0} \to D^{*+}\pi^-, D^{*+} \to D^0\pi^+, D^0 \to X + CC$
1126	$B^0 \to X, \overline{B^0} \to D^{*+}\pi^-, D^{*+} \to D^+\pi^0, D^+ \to X + CC$
1160	$B^0 \to X, \overline{B^0} \to D^+\pi^-, D^+ \to X + CC$ (excluding modes 1591 2437 and 3749)
3299	$B^0 \to D^-K^+(D^- \to K^0_s\pi^-)$
3749	$\overline{B^0} \to D^+\pi^-, D^+ \to K^0_s K + c.c.$
2437	$B^0 \to D^-\pi^+(D^- \to K^+\pi^-\pi^-)$
3733	$B^0 \to D^-\mu^+\nu(D^- \to K^0_s\pi^-), \overline{B^0} \to X + c.c.$
1159	$B^0 \to X, \overline{B^0} \to D^+\rho^-, D^+ \to X + CC$ (excluding modes 7330 and 5635)
7330	$B^0 \to X, \overline{B^0} \to D^+\rho^-, D^+ \to K^0_s\pi^+ + CC$
5635	$B^0 \to X, \overline{B^0} \to D^+\rho^-, D^+ \to K^0_s K^+ + CC$
1157	$B^0 \to X, \overline{B^0} \to D^{*+}\rho^-, D* \to D\pi^0, D \to X + CC$
1158	$B^0 \to X, \overline{B^0} \to D^{*+}\rho^-, D* \to D^0\pi, D^0 \to X$

Cat. 1

Cat. 2

Cat. 3

Modes treated semi-exclusively grouped into categories

- Neutral Generic (Exclusive and semi-exclusive modes vetoed)
- Charge Generic

Modes treated Inclusively

Parameterization (I)

Fit Variables: $\vec{x}_i = \left(m_{ES}, \Delta E, NN, Qtag, \Delta t, DP\right)$

Standard Parameterizations:

- **Signal TM:** **Bifurcated Crystal Ball (parameters floated)**
- **Signal SCF:** **Non-parametric (Keys)**
- **Dπ and J/ψK^0_s Bbkg:** **Share same PDF as signal. Allows to fit parameters directly on data.**
- **All other B-backgrounds:** **Non-parametric (Keys)**
- **Continuum:** **Argus (parameters floated)**

Parameterization (II)

Fit Variables: $\vec{x}_i = (m_{ES}, \boxed{\Delta E}, NN, Qtag, \Delta t, DP)$

Standard Parameterizations:

- **Signal TM:** Double Gaussian (parameters floated)
- **Signal SCF:** Gaussian (fix parameters)
- **Dπ:** Share same PDF as signal. Allows to fit parameters directly on data.
- **All other B-backgrounds:** Non-parametric (Keys)
- **Continuum:** 2nd degree polynomial (parameters floated)

Parameterization (III)

Fit Variables: $\vec{x}_i = (m_{ES}, \Delta E, NN, Qtag, \Delta t, DP)$

Standard Parameterizations:

- **Signal TM and SCF:** Non-parametric (Keys). Separated in tagging categories
- **All other B-backgrounds:** Non-parametric (Keys). Same for all tagging categories
- **Continuum:** conditional PDF. Non-negligible correlation with DP Variables

Parameterization (III)

Fit Variables: $\vec{x}_i = \left(m_{ES}, \Delta E, NN, Qtag, \Delta t, DP\right)$

Continuum: **Non-negligible correlation with DP Variables**

PDF dependent on the DP:

$$P_{q\bar{q}}(NN; \Delta_{\mathrm{Dalitz}}, A, B_0, B_1, B_2) = (1 - NN)^A \left(B_2 NN^2 + B_1 NN + B_0\right).$$

$$\begin{aligned} A &= a_1 + a_4 \Delta_{\mathrm{Dalitz}}, \\ B_0 &= c_0 + c_1 \Delta_{\mathrm{Dalitz}}, \\ B_1 &= a_3 + c_2 \Delta_{\mathrm{Dalitz}}, \\ B_2 &= a_2 + c_3 \Delta_{\mathrm{Dalitz}}, \end{aligned}$$

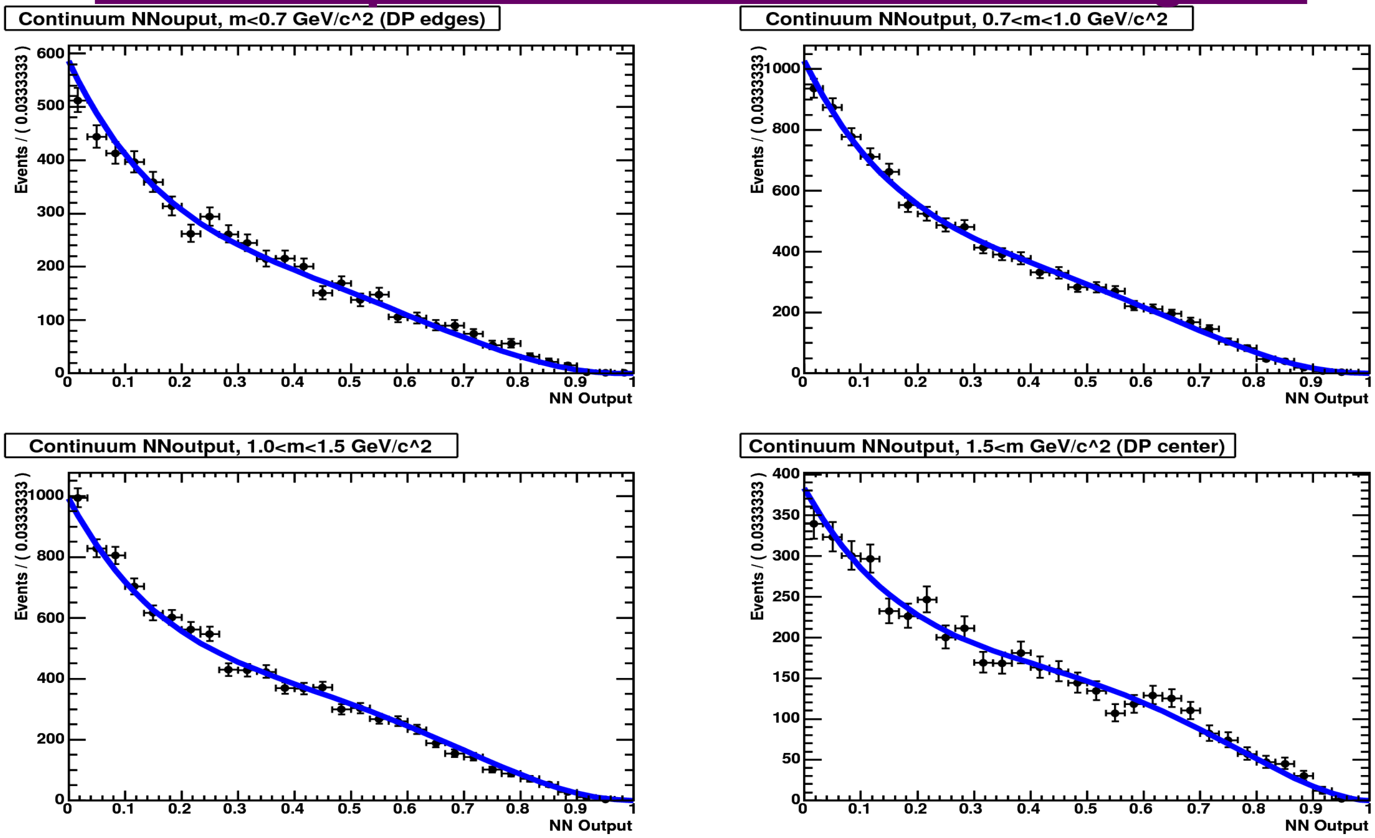
Δ_{Dalitz} : **Distance to DP center**

Parameterization (III)

Fit Variables: $\vec{x}_i = \left(m_{ES}, \Delta E, NN, Qtag, \Delta t, DP\right)$

Continuum: **Non-negligible correlation with DP Variables**

Fit on off-peak data for different DP regions



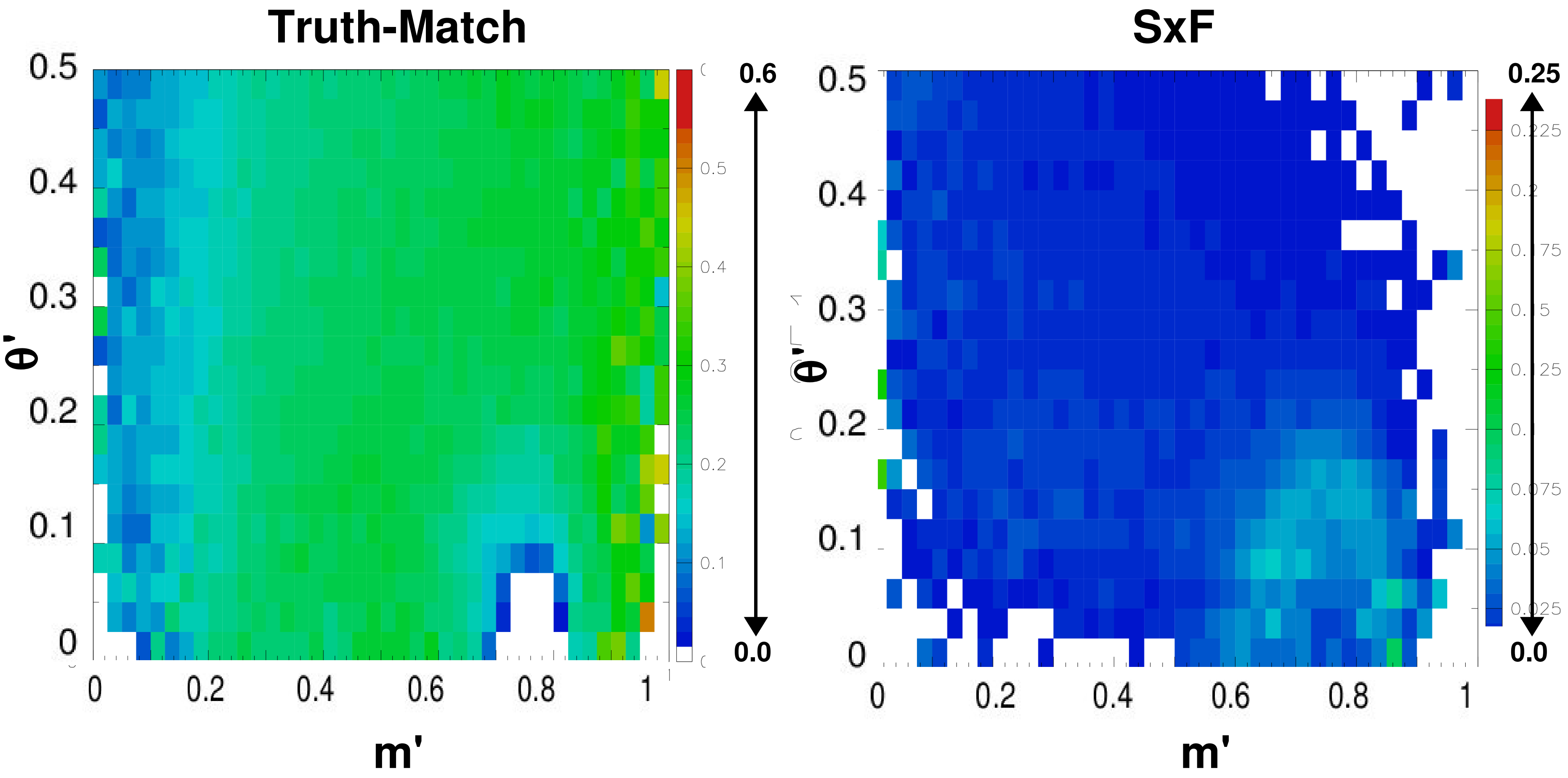
Parameterization (V)

Fit Variables: $\vec{x}_i = (m_{ES}, \Delta E, NN, Qtag, \Delta t, DP)$

Background Parameterizations:

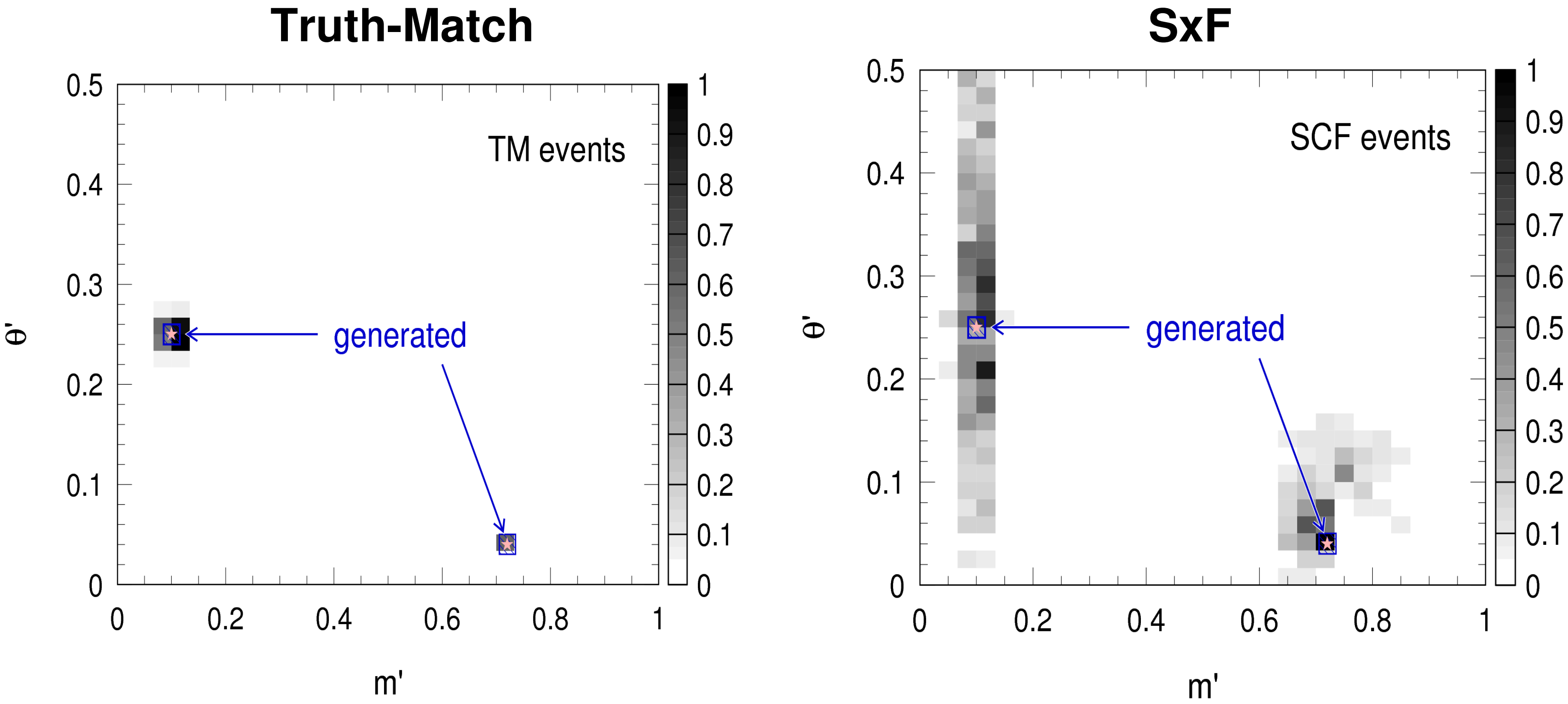
- **DP PDF:** Non-parametric PDF.
  - **Continuum:** constructed using off-peak and on-peak (m_{ES},ΔE) side band data.
  - **B-background:** constructed using MC
- **Δt PDF:**
  - **Continuum:** empirical parameterization (triple-gaussian)
  - **B-background:** same as signal for most neutral modes. Customized PDFs for charged generic and Dπ components

Signal efficiency over DP



- **TM and SCF efficiencies vary significantly over the DP**
- **Take these effect into account in the time-DP PDF**

DP resolution function



- **Negligible DP resolutions effects for TM events**

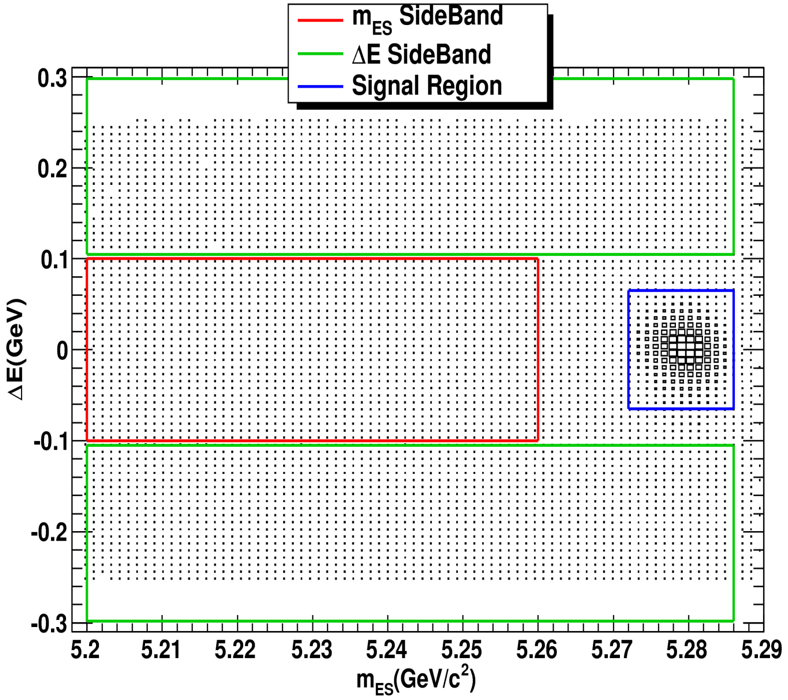
  (smaller than widths of resonant structures)

- **Significant dispersion of SCF events**

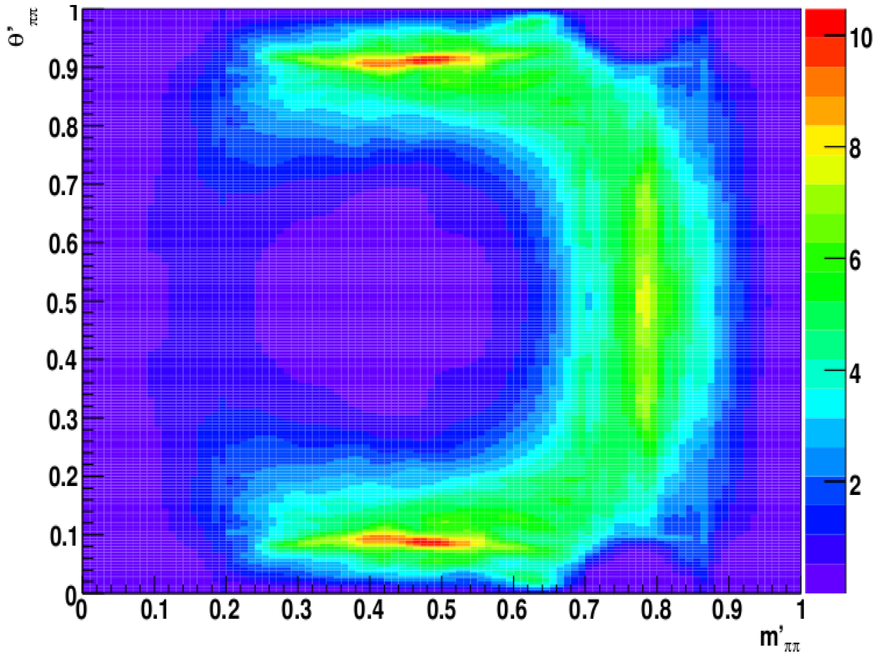
⇒ 2D Convolution with resolution function $R_{SCF}(m'_{rec},\theta'_{rec},m'_{true},\theta'_{true})$

Continuum DP PDF

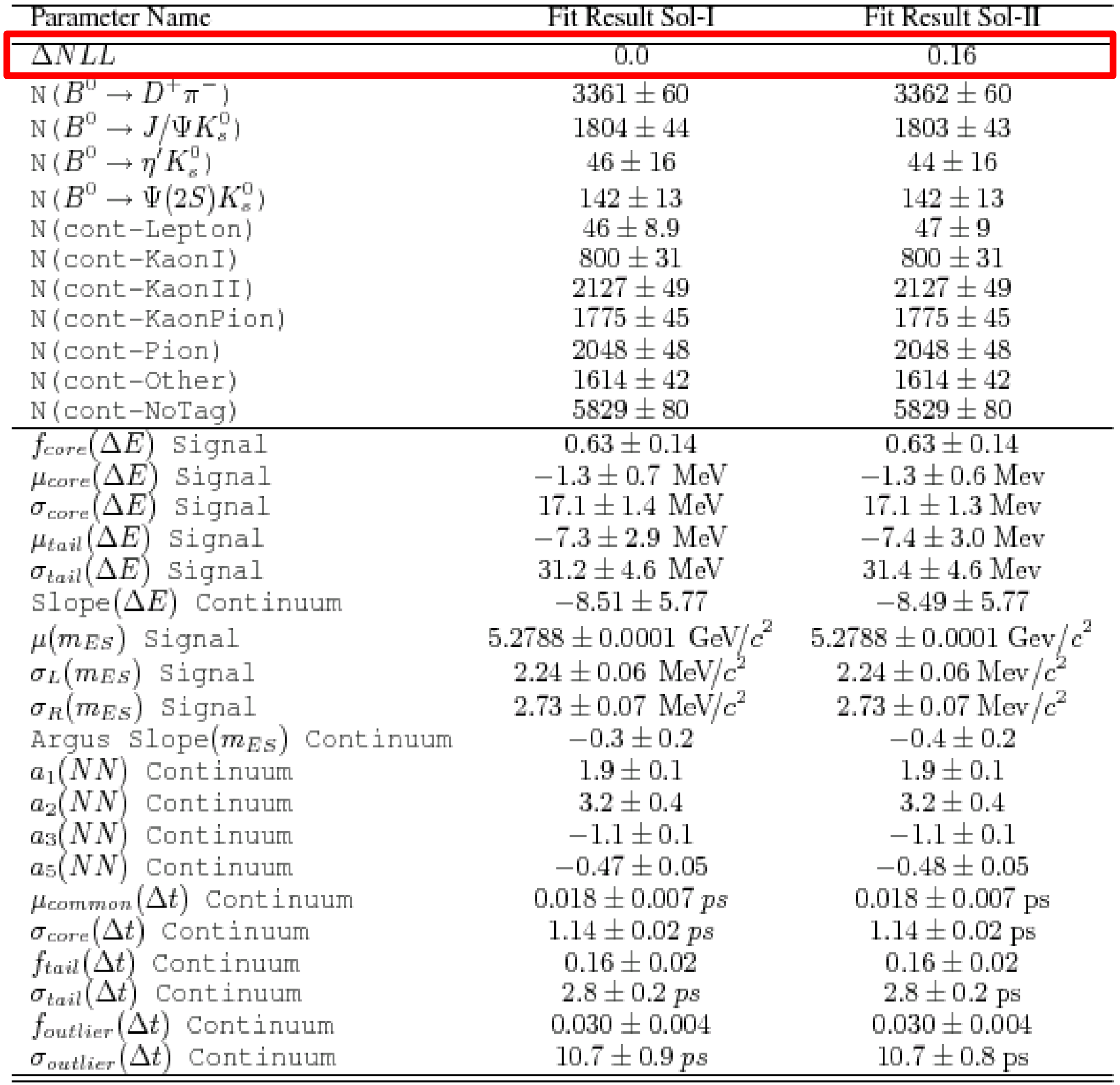
Use m_{ES} and ΔE side-bands on data to build DP PDF for continuum events



Square DP



Fit Results: Non isobar



Parameter Name	Fit Result Sol-I	Fit Result Sol-II
ΔNLL	0.0	0.16
N($B^0 \to D^+\pi^-$)	3361 ± 60	3362 ± 60
N($B^0 \to J/\Psi K_s^0$)	1804 ± 44	1803 ± 43
N($B^0 \to \eta' K_s^0$)	46 ± 16	44 ± 16
N($B^0 \to \Psi(2S) K_s^0$)	142 ± 13	142 ± 13
N(cont-Lepton)	46 ± 8.9	47 ± 9
N(cont-KaonI)	800 ± 31	800 ± 31
N(cont-KaonII)	2127 ± 49	2127 ± 49
N(cont-KaonPion)	1775 ± 45	1775 ± 45
N(cont-Pion)	2048 ± 48	2048 ± 48
N(cont-Other)	1614 ± 42	1614 ± 42
N(cont-NoTag)	5829 ± 80	5829 ± 80
$f_{core}(\Delta E)$ Signal	0.63 ± 0.14	0.63 ± 0.14
$\mu_{core}(\Delta E)$ Signal	-1.3 ± 0.7 MeV	-1.3 ± 0.6 Mev
$\sigma_{core}(\Delta E)$ Signal	17.1 ± 1.4 MeV	17.1 ± 1.3 Mev
$\mu_{tail}(\Delta E)$ Signal	-7.3 ± 2.9 MeV	-7.4 ± 3.0 Mev
$\sigma_{tail}(\Delta E)$ Signal	31.2 ± 4.6 MeV	31.4 ± 4.6 Mev
Slope(ΔE) Continuum	-8.51 ± 5.77	-8.49 ± 5.77
$\mu(m_{ES})$ Signal	5.2788 ± 0.0001 GeV/c^2	5.2788 ± 0.0001 Gev/c^2
$\sigma_L(m_{ES})$ Signal	2.24 ± 0.06 MeV/c^2	2.24 ± 0.06 Mev/c^2
$\sigma_R(m_{ES})$ Signal	2.73 ± 0.07 MeV/c^2	2.73 ± 0.07 Mev/c^2
Argus Slope(m_{ES}) Continuum	-0.3 ± 0.2	-0.4 ± 0.2
$a_1(NN)$ Continuum	1.9 ± 0.1	1.9 ± 0.1
$a_2(NN)$ Continuum	3.2 ± 0.4	3.2 ± 0.4
$a_3(NN)$ Continuum	-1.1 ± 0.1	-1.1 ± 0.1
$a_5(NN)$ Continuum	-0.47 ± 0.05	-0.48 ± 0.05
$\mu_{common}(\Delta t)$ Continuum	$0.018 \pm 0.007\ ps$	0.018 ± 0.007 ps
$\sigma_{core}(\Delta t)$ Continuum	$1.14 \pm 0.02\ ps$	1.14 ± 0.02 ps
$f_{tail}(\Delta t)$ Continuum	0.16 ± 0.02	0.16 ± 0.02
$\sigma_{tail}(\Delta t)$ Continuum	$2.8 \pm 0.2\ ps$	2.8 ± 0.2 ps
$f_{outlier}(\Delta t)$ Continuum	0.030 ± 0.004	0.030 ± 0.004
$\sigma_{outlier}(\Delta t)$ Continuum	$10.7 \pm 0.9\ ps$	10.7 ± 0.8 ps

There are two solutions almost degenerated.

They differ by 0.16 in -2Log(L) units

Fit Results: Non isobar

Parameter Name	Fit Result Sol-I	Fit Result Sol-II
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$\sigma_{core}(\Delta E)$ Signal		
$\mu_{tail}(\Delta E)$ Signal		
$\sigma_{tail}(\Delta E)$ Signal		
Slope(ΔE) Continuu		
$\mu(m_{ES})$ Signal		
$\sigma_L(m_{ES})$ Signal	2.24 ± 0.06 MeV/c	2.24 ± 0.06 MeV/c
$\sigma_R(m_{ES})$ Signal	2.73 ± 0.07 MeV/c^2	2.73 ± 0.07 Mev/c^2
Argus Slope(m_{ES}) Continuum	-0.3 ± 0.2	-0.4 ± 0.2
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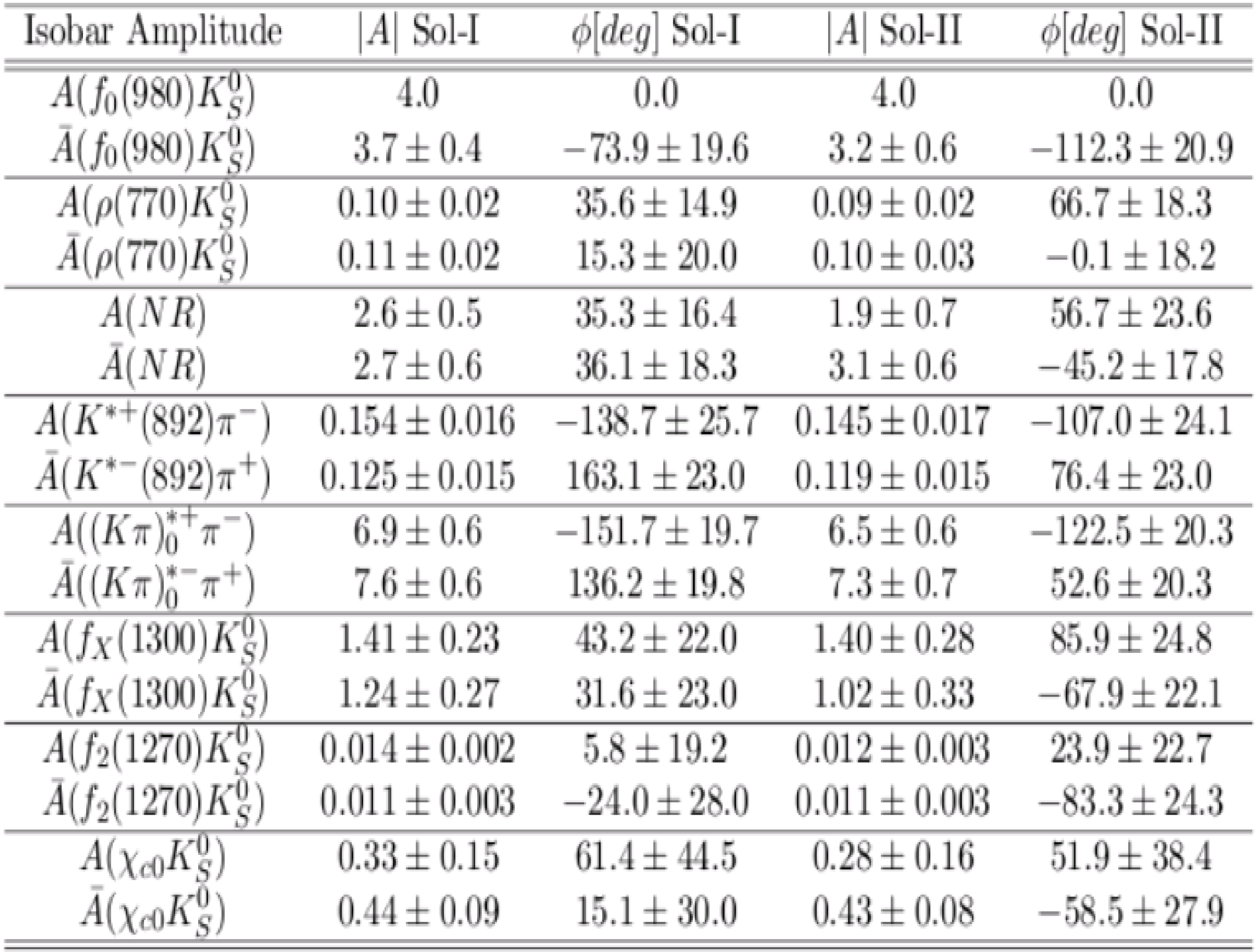
There are two solutions almost degenerated.

They differ by 0.16 in -2Log(L) units

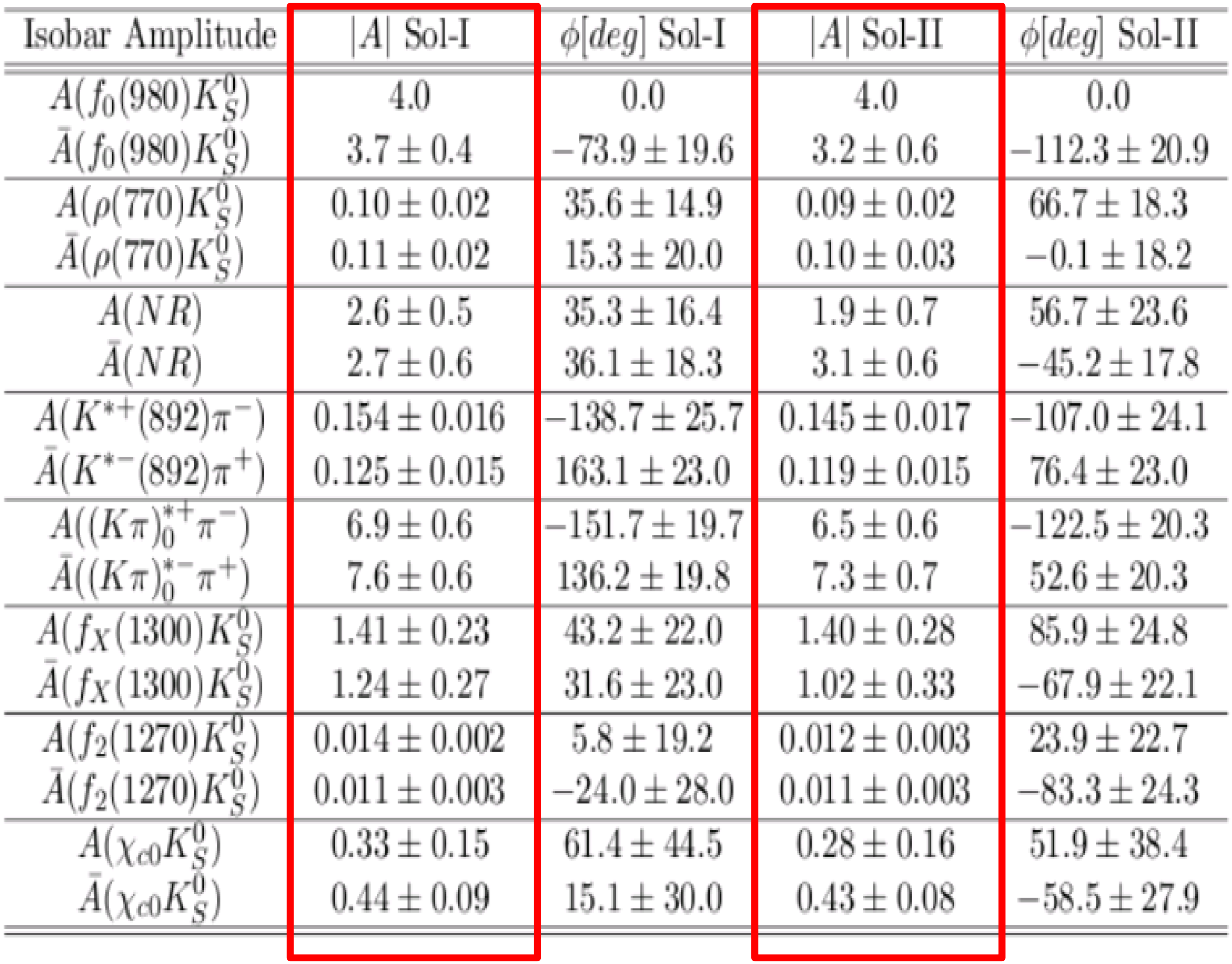
Non-Isobar parameters identical in both solutions

Fit Results: Isobar



Isobar Amplitude	$\lvert A\rvert$ Sol-I	$\phi[deg]$ Sol-I	$\lvert A\rvert$ Sol-II	$\phi[deg]$ Sol-II
$A(f_0(980)K^0_S)$	4.0	0.0	4.0	0.0
$\bar{A}(f_0(980)K^0_S)$	3.7 ± 0.4	-73.9 ± 19.6	3.2 ± 0.6	-112.3 ± 20.9
$A(\rho(770)K^0_S)$	0.10 ± 0.02	35.6 ± 14.9	0.09 ± 0.02	66.7 ± 18.3
$\bar{A}(\rho(770)K^0_S)$	0.11 ± 0.02	15.3 ± 20.0	0.10 ± 0.03	-0.1 ± 18.2
$A(NR)$	2.6 ± 0.5	35.3 ± 16.4	1.9 ± 0.7	56.7 ± 23.6
$\bar{A}(NR)$	2.7 ± 0.6	36.1 ± 18.3	3.1 ± 0.6	-45.2 ± 17.8
$A(K^{*+}(892)\pi^-)$	0.154 ± 0.016	-138.7 ± 25.7	0.145 ± 0.017	-107.0 ± 24.1
$\bar{A}(K^{*-}(892)\pi^+)$	0.125 ± 0.015	163.1 ± 23.0	0.119 ± 0.015	76.4 ± 23.0
$A((K\pi)^{*+}_0\pi^-)$	6.9 ± 0.6	-151.7 ± 19.7	6.5 ± 0.6	-122.5 ± 20.3
$\bar{A}((K\pi)^{*-}_0\pi^+)$	7.6 ± 0.6	136.2 ± 19.8	7.3 ± 0.7	52.6 ± 20.3
$A(f_X(1300)K^0_S)$	1.41 ± 0.23	43.2 ± 22.0	1.40 ± 0.28	85.9 ± 24.8
$\bar{A}(f_X(1300)K^0_S)$	1.24 ± 0.27	31.6 ± 23.0	1.02 ± 0.33	-67.9 ± 22.1
$A(f_2(1270)K^0_S)$	0.014 ± 0.002	5.8 ± 19.2	0.012 ± 0.003	23.9 ± 22.7
$\bar{A}(f_2(1270)K^0_S)$	0.011 ± 0.003	-24.0 ± 28.0	0.011 ± 0.003	-83.3 ± 24.3
$A(\chi_{c0}K^0_S)$	0.33 ± 0.15	61.4 ± 44.5	0.28 ± 0.16	51.9 ± 38.4
$\bar{A}(\chi_{c0}K^0_S)$	0.44 ± 0.09	15.1 ± 30.0	0.43 ± 0.08	-58.5 ± 27.9

Fit Results: Isobar



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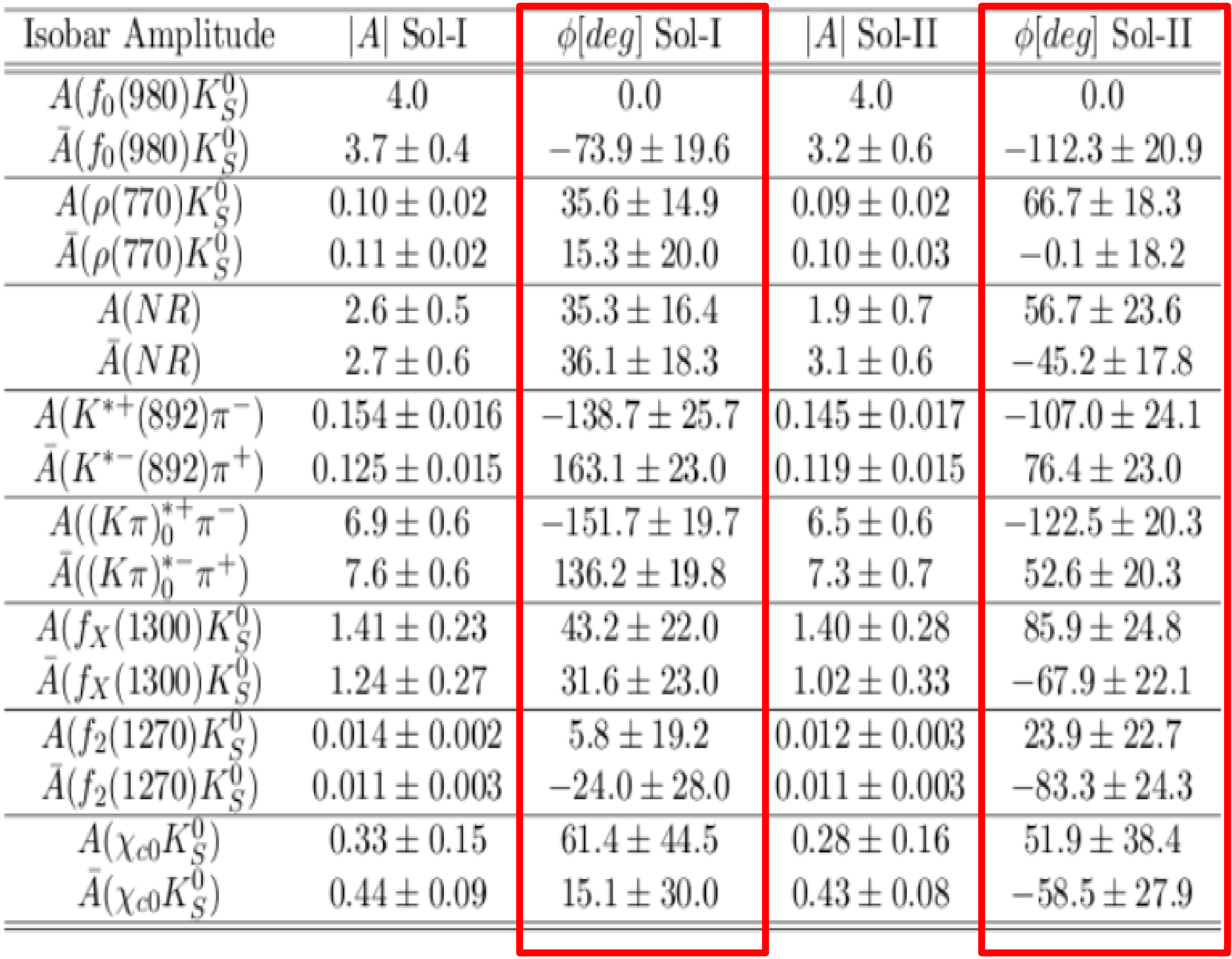
$\bar{A}(f_2(1270)K_S^0)$	0.011 ± 0.003	-24.0 ± 28.0	0.011 ± 0.003	-83.3 ± 24.3
$A(\chi_{c0}K_S^0)$	0.33 ± 0.15	61.4 ± 44.5	0.28 ± 0.16	51.9 ± 38.4
$\bar{A}(\chi_{c0}K_S^0)$	0.44 ± 0.09	15.1 ± 30.0	0.43 ± 0.08	-58.5 ± 27.9

Moduli of isobar amplitudes similar in both solutions

(Mean differences in NR and minor components)

Fit Results: Isobar



Isobar Amplitude	$\|A\|$ Sol-I	$\phi[deg]$ Sol-I	$\|A\|$ Sol-II	$\phi[deg]$ Sol-II
$A(f_0(980)K^0_S)$	4.0	0.0	4.0	0.0
$\bar{A}(f_0(980)K^0_S)$	3.7 ± 0.4	-73.9 ± 19.6	3.2 ± 0.6	-112.3 ± 20.9
$A(\rho(770)K^0_S)$	0.10 ± 0.02	35.6 ± 14.9	0.09 ± 0.02	66.7 ± 18.3
$\bar{A}(\rho(770)K^0_S)$	0.11 ± 0.02	15.3 ± 20.0	0.10 ± 0.03	-0.1 ± 18.2
$A(NR)$	2.6 ± 0.5	35.3 ± 16.4	1.9 ± 0.7	56.7 ± 23.6
$\bar{A}(NR)$	2.7 ± 0.6	36.1 ± 18.3	3.1 ± 0.6	-45.2 ± 17.8
$A(K^{*+}(892)\pi^-)$	0.154 ± 0.016	-138.7 ± 25.7	0.145 ± 0.017	-107.0 ± 24.1
$\bar{A}(K^{*-}(892)\pi^+)$	0.125 ± 0.015	163.1 ± 23.0	0.119 ± 0.015	76.4 ± 23.0
$A((K\pi)^{*+}_0\pi^-)$	6.9 ± 0.6	-151.7 ± 19.7	6.5 ± 0.6	-122.5 ± 20.3
$\bar{A}((K\pi)^{*-}_0\pi^+)$	7.6 ± 0.6	136.2 ± 19.8	7.3 ± 0.7	52.6 ± 20.3
$A(f_X(1300)K^0_S)$	1.41 ± 0.23	43.2 ± 22.0	1.40 ± 0.28	85.9 ± 24.8
$\bar{A}(f_X(1300)K^0_S)$	1.24 ± 0.27	31.6 ± 23.0	1.02 ± 0.33	-67.9 ± 22.1
$A(f_2(1270)K^0_S)$	0.014 ± 0.002	5.8 ± 19.2	0.012 ± 0.003	23.9 ± 22.7
$\bar{A}(f_2(1270)K^0_S)$	0.011 ± 0.003	-24.0 ± 28.0	0.011 ± 0.003	-83.3 ± 24.3
$A(\chi_{c0}K^0_S)$	0.33 ± 0.15	61.4 ± 44.5	0.28 ± 0.16	51.9 ± 38.4
$\bar{A}(\chi_{c0}K^0_S)$	0.44 ± 0.09	15.1 ± 30.0	0.43 ± 0.08	-58.5 ± 27.9

But some phases vary significantly!

Fit Results: Isobar

Isobar Amplitude	$\|A\|$ Sol-I	$\phi[deg]$ Sol-I	$\|A\|$ Sol-II	$\phi[deg]$ Sol-II
$A(f_0(980)K_S^0)$	4.0	0.0	4.0	0.0
$\bar{A}(f_0(980)K_S^0)$	3.7 ± 0.4	-73.9 ± 19.6	3.2 ± 0.6	-112.3 ± 20.9
$A(\rho(770)K_S^0)$	0.10 ± 0.02	35.6 ± 14.9	0.09 ± 0.02	66.7 ± 18.3
$\bar{A}(\rho(770)K_S^0)$	0.11 ± 0.02	15.3 ± 20.0	0.10 ± 0.03	-0.1 ± 18.2
$A(NR)$	2.6 ± 0.5	35.3 ± 16.4	1.9 ± 0.7	56.7 ± 23.6
$\bar{A}(NR)$	2.7 ± 0.6	36.1 ± 18.3	3.1 ± 0.6	-45.2 ± 17.8
$A(K^{*+}(892)\pi^-)$	[illegible]	[illegible]	[illegible]	[illegible]
$\bar{A}(K^{*-}(892)\pi^+)$	[illegible]	[illegible]	[illegible]	[illegible]
$A((K\pi)_0^{*+}\pi^-)$	[illegible]	[illegible]	[illegible]	[illegible]
$\bar{A}((K\pi)_0^{*-}\pi^+)$	[illegible]	[illegible]	[illegible]	[illegible]
$A(f_X(1300)K_S^0)$	1.41 ± 0.23	43.2 ± 22.0	1.40 ± 0.28	85.9 ± 24.8
$\bar{A}(f_X(1300)K_S^0)$	1.24 ± 0.27	31.6 ± 23.0	1.02 ± 0.33	-67.9 ± 22.1
$A(f_2(1270)K_S^0)$	0.014 ± 0.002	5.8 ± 19.2	0.012 ± 0.003	23.9 ± 22.7
$\bar{A}(f_2(1270)K_S^0)$	0.011 ± 0.003	-24.0 ± 28.0	0.011 ± 0.003	-83.3 ± 24.3
$A(\chi_{c0}K_S^0)$	0.33 ± 0.15	61.4 ± 44.5	0.28 ± 0.16	51.9 ± 38.4
$\bar{A}(\chi_{c0}K_S^0)$	0.44 ± 0.09	15.1 ± 30.0	0.43 ± 0.08	-58.5 ± 27.9

Ambiguity in resolving the interference pattern in the DP

But some phases vary significantly!

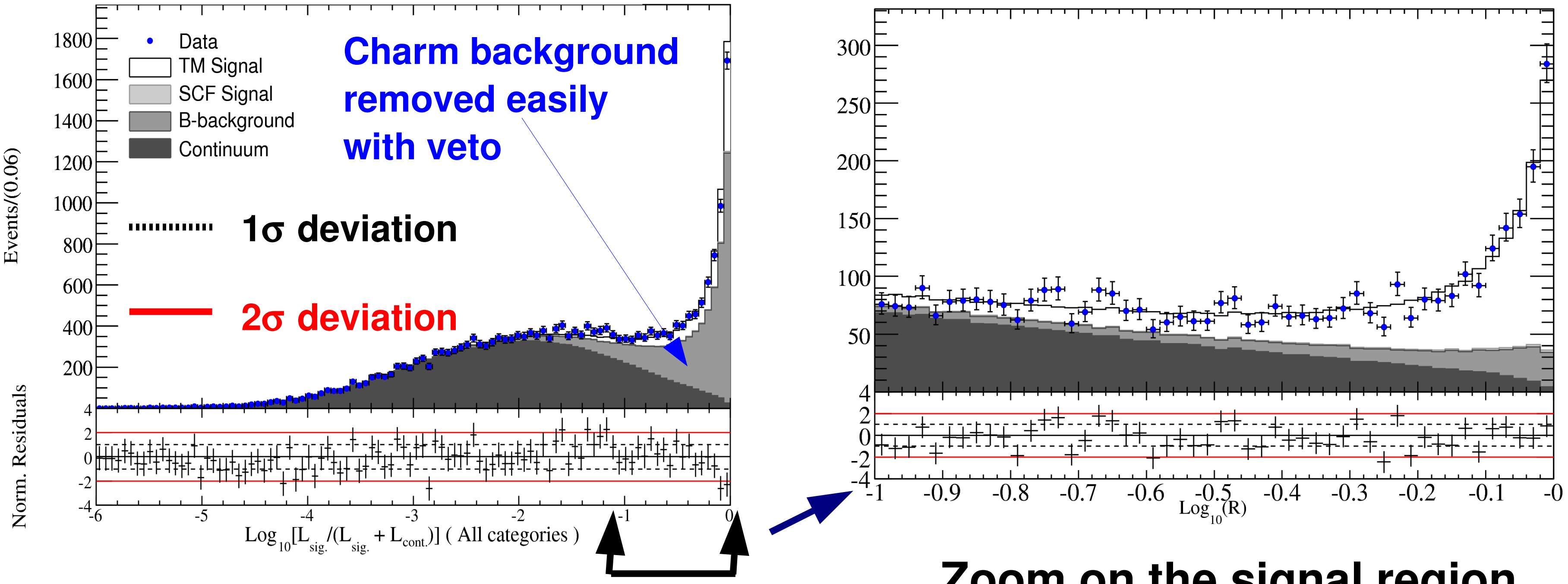
Fit Results: Proj. Plots (I)

Likelihood Ratio

$$R \equiv \frac{\mathcal{L}_{TM}}{\mathcal{L}_{TM} + \mathcal{L}_{SCF} + \mathcal{L}_{continuum} + \mathcal{L}_{BBack}}$$

$\mathrm{Log}_{10}(L_{sig}/(L_{sig} + L_{back}))$

$\mathrm{Log}_{10}(L_{sig}/(L_{sig} + L_{back}))$



Charm background removed easily with veto

1σ deviation

2σ deviation

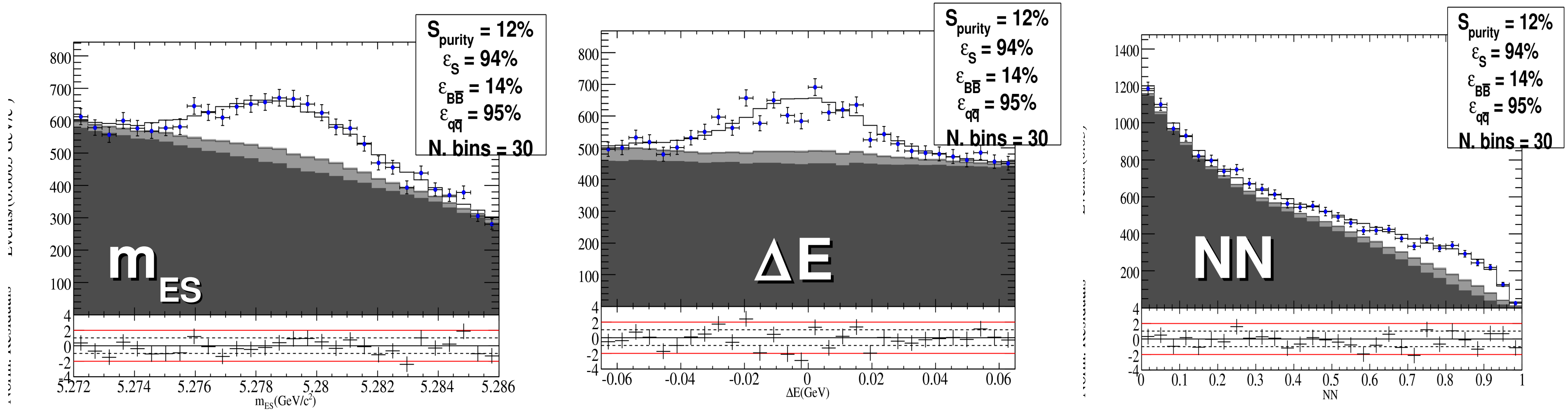
Zoom on the signal region

Veto on Charm Background

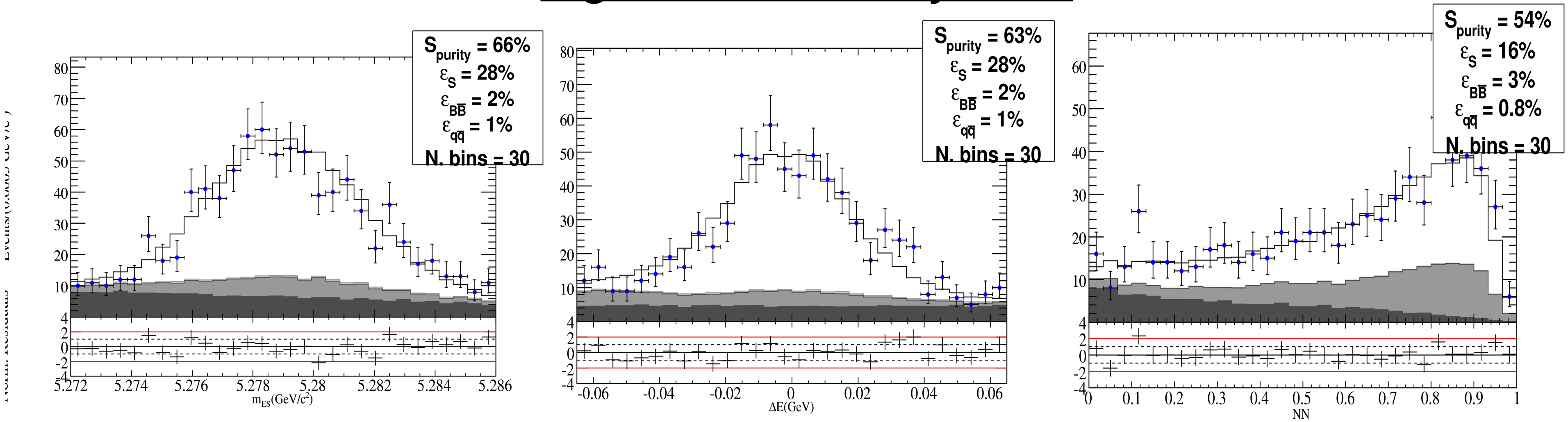
Fit Results: Proj. Plots

$D\pi$, $J/\psi K^0_S$ vetoed

No R cut

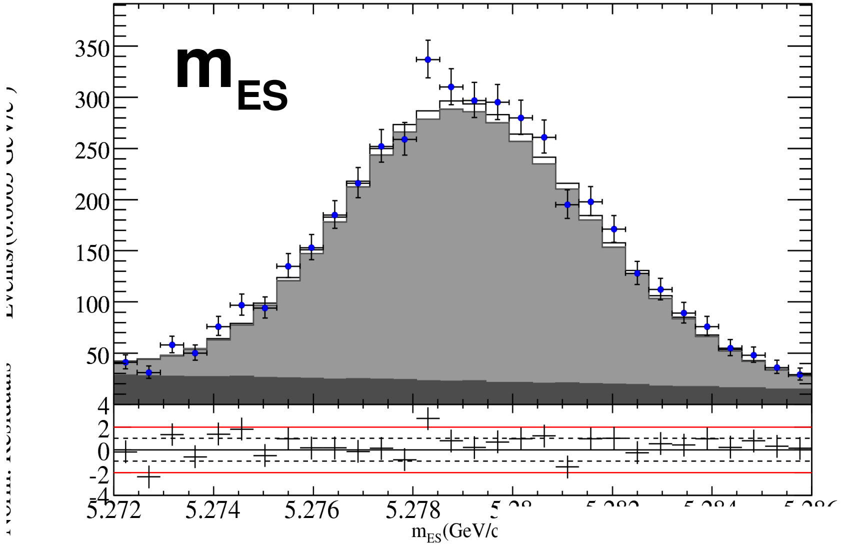


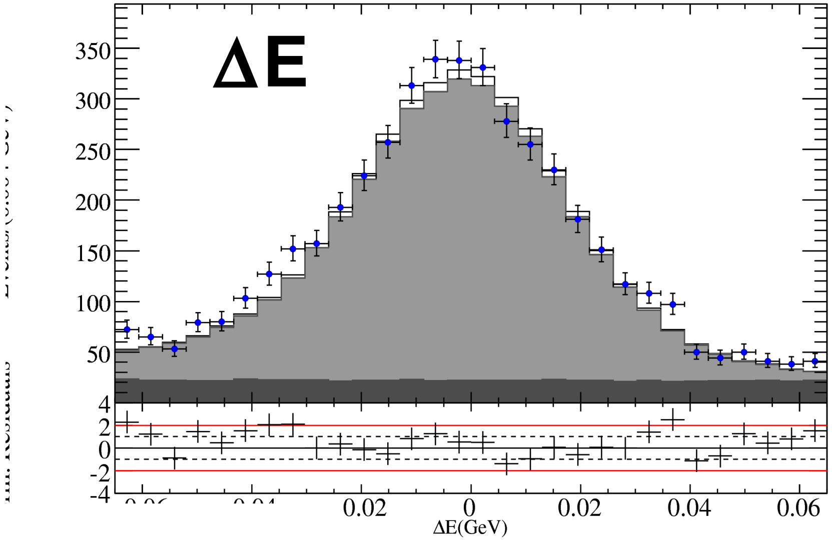
Signal enhanced by R cut

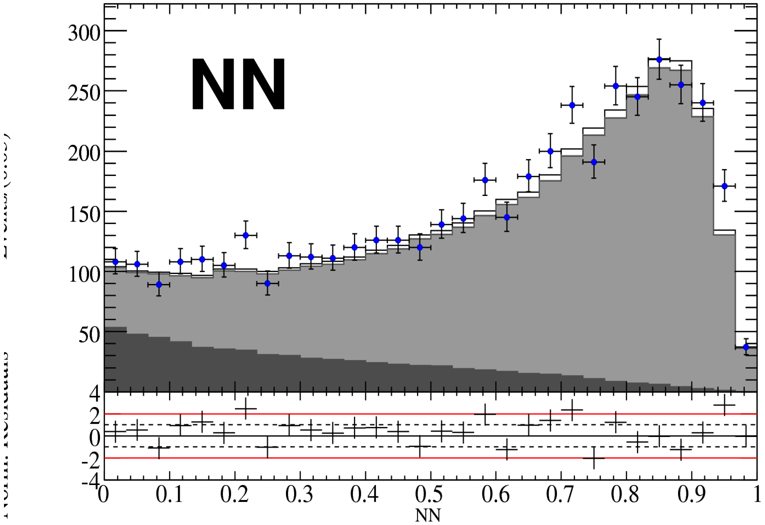


Fit Results: Proj. Plots

Dπ Band

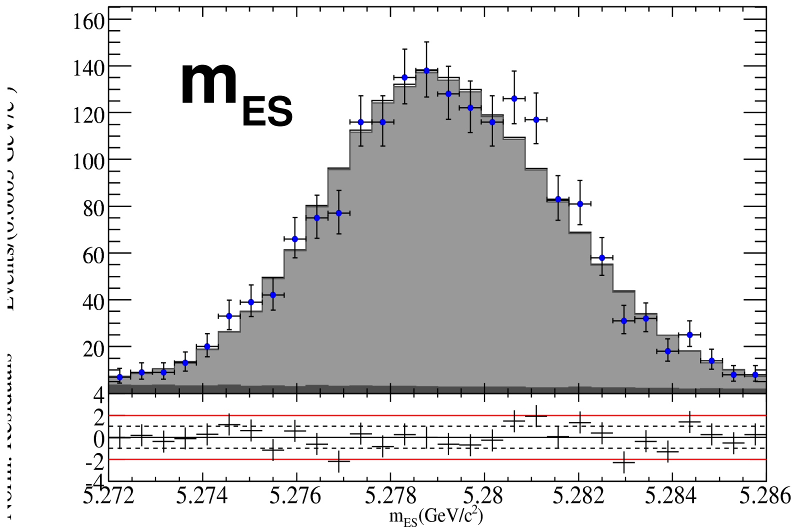


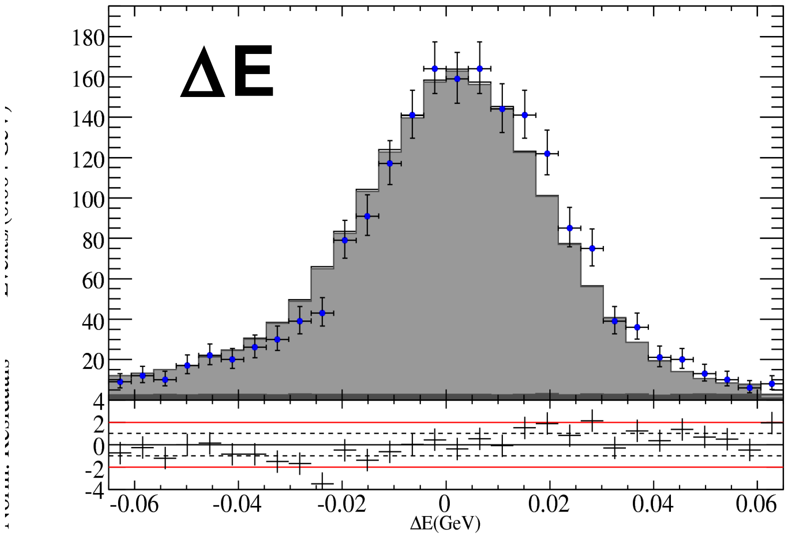


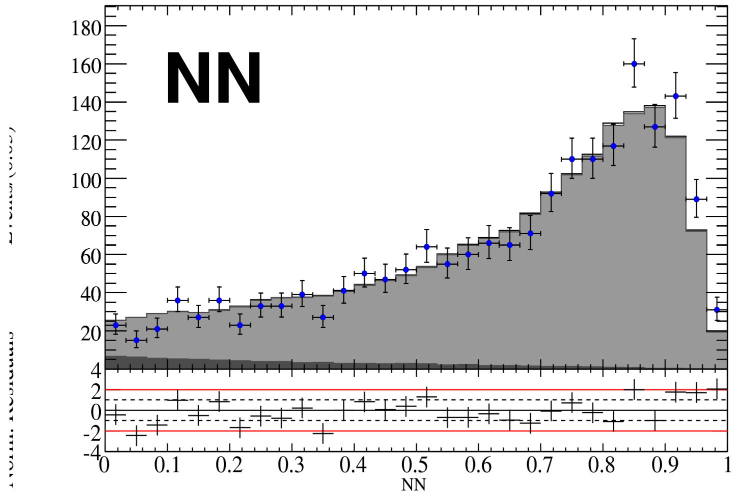


Fit Results: Proj. Plots

J/ψ Band



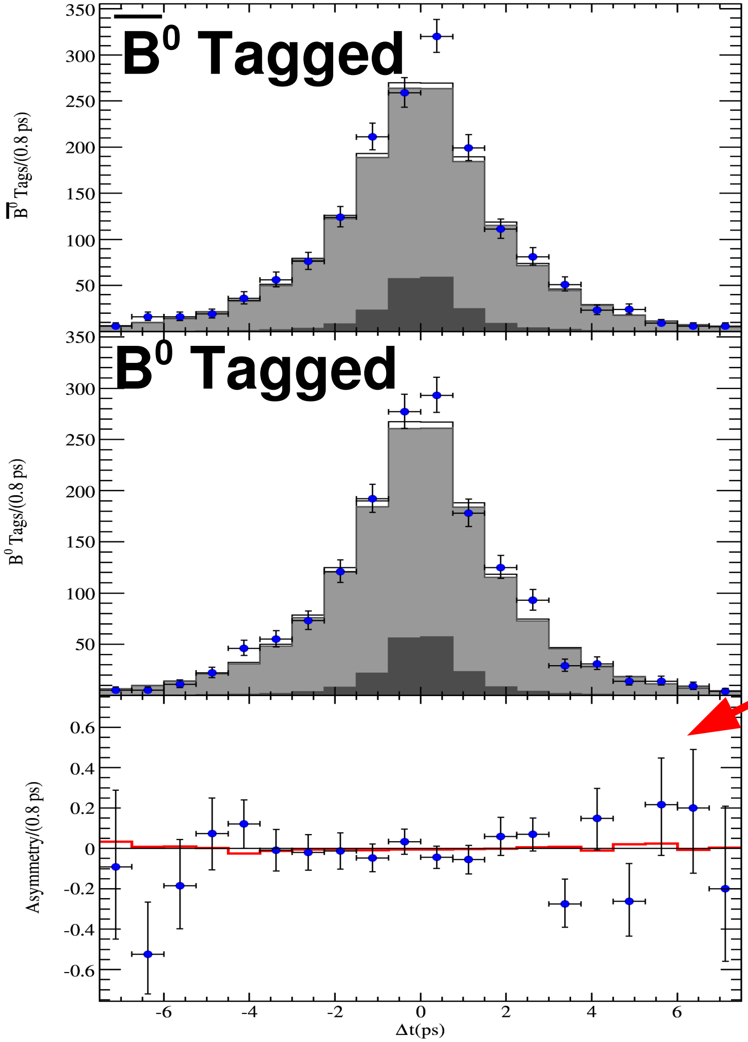




Fit Results: Proj. Plots

Δt dependent asymmetries

$D\pi$ Band



Zero time-dependent CP asymmetry.

As expected!

Systematic Uncertainties

Systematic Uncertainties

- Reconstruction and SCF model
- Ks efficiency, tracking effic., PID and luminosity
- Fixed params. in fit
- Tag-side interference
- Continuum and B-background PDFs

Experimental.
Relatively small

- Signal DP Model:

- Lineshapes fix parameters: mass, width, radius.

- Uncertainty on the signal model components

Dominant

Systematics: Signal DP Model (I)

- **Isobar Model:** predefined list of resonant components
- **Signal model construction:** add resonances that improves fit significantly, exclude the rest → Systematic uncertainty

- **Systematic evaluation:**
  - Use MC high statistics samples with rich resonant structure
  - Isobar parameters estimated in the best way available

  - BF(ρ(1450)) = 13.0 % * BF(ρ(770)) (From $\rho\pi$ analysis)
  - BF(ρ(1700)) = 7.0 % * BF(ρ(770)) (From $\rho\pi$ analysis)
  - BF(f0(1710)) = (3.0 ± 11.2)(%) * BF(f0(892)) (From fit on Data)
  - BF(χc2) = (1.5 ± 0.7)(%) * BF(χc0) (From fit on Data)
  - BF(K*2(1430)) = (4.1 ± 1.5)(%) * BF(K*0(1430)) (From fit on Data)
  - BF(K*(1410)) = 2.7 % * BF(K*(892)) (From charged $K\pi\pi$)
  - BF(K*(1680)) = 15.6 % * BF(K*(892)) (From charged $K\pi\pi$)

- **Fit high statistics samples with nominal signal model**

Systematics evaluated as bias on isobar parameters

Systematics: Signal DP Model (I)

- **Isobar Model:** predefined list of resonant components
- **Signal model construction:** add resonances that improves fit significantly, exclude the rest → Systematic uncertainty

- **Systematic evaluation:**

  - Use MC high statistics samples with rich resonant structure

  - Isobar pa

    - BF(ρ(145
    - BF(ρ(170
    - BF(f0(17
    - BF(χc2)
    - BF(K*2(1
    - BF(K*(1410)) = 2.7 % * BF(K*(892)) (From charged Kππ)
    - BF(K*(1680)) = 15.6 % * BF(K*(892)) (From charged Kππ)

Biases:

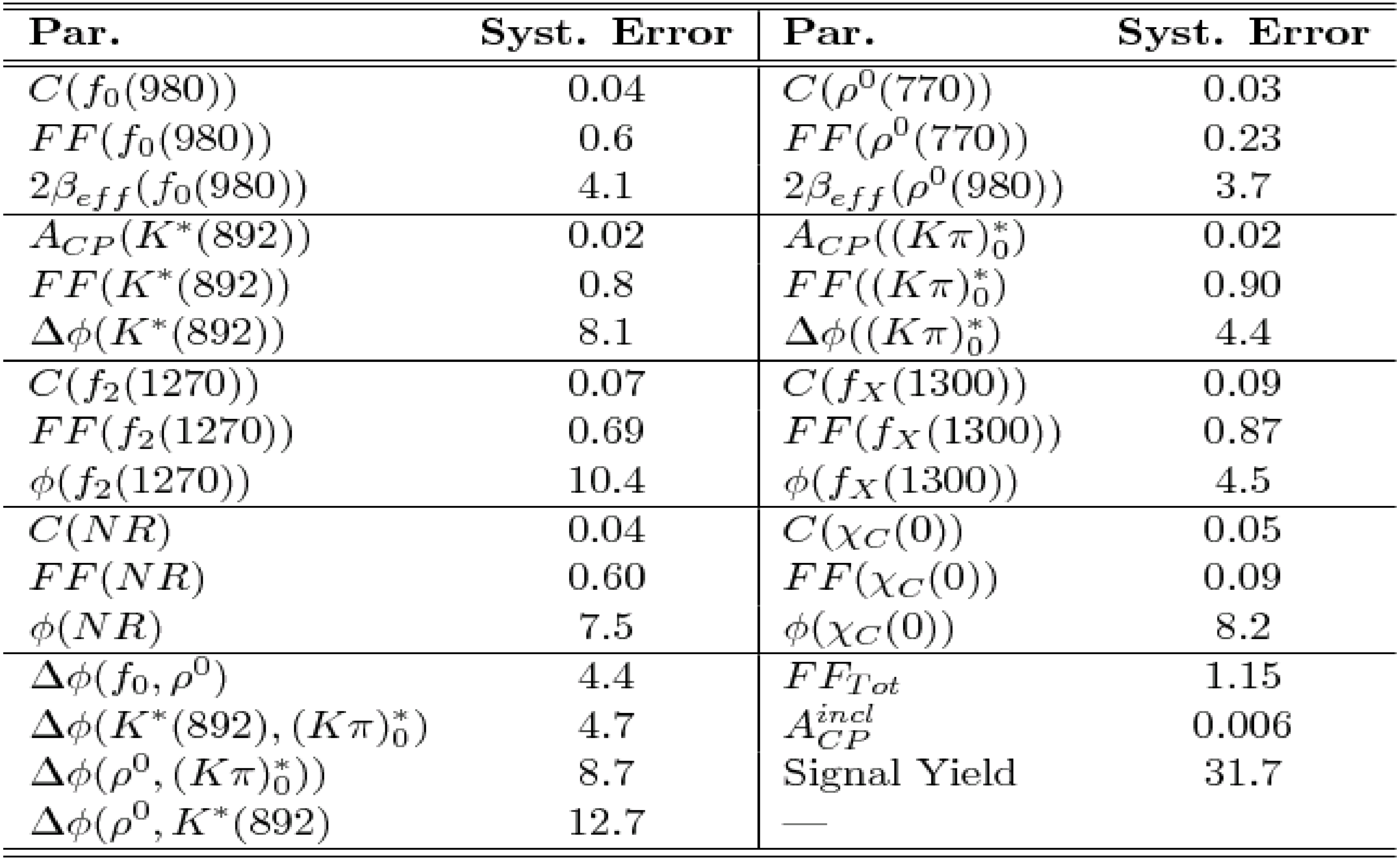
- BFs small
- A_{CP} small
- dominant in phases

- **Fit high statistics samples with nominal signal model**

Systematics evaluated as bias on isobar parameters

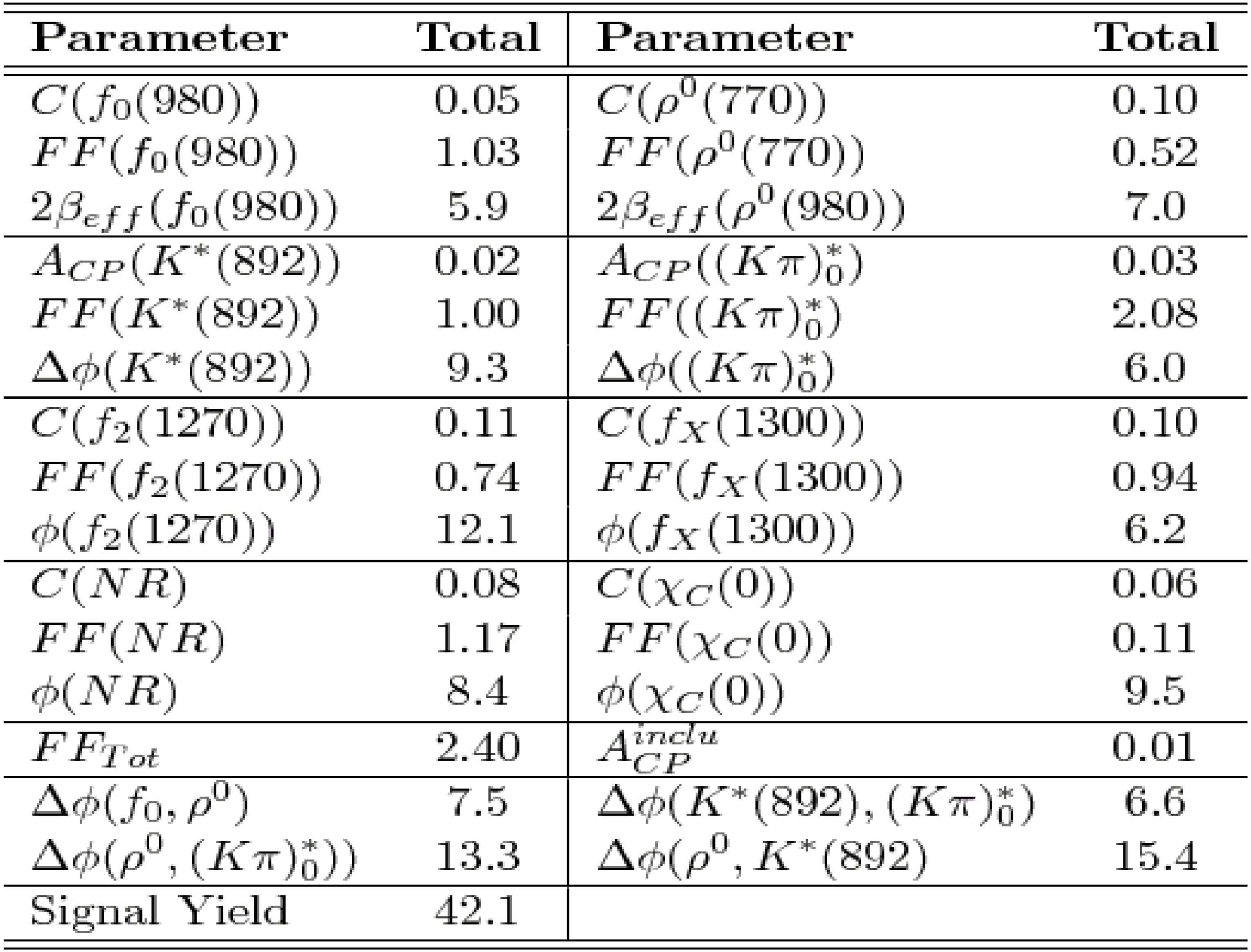
Systematics: Signal DP Model (II)

Results:



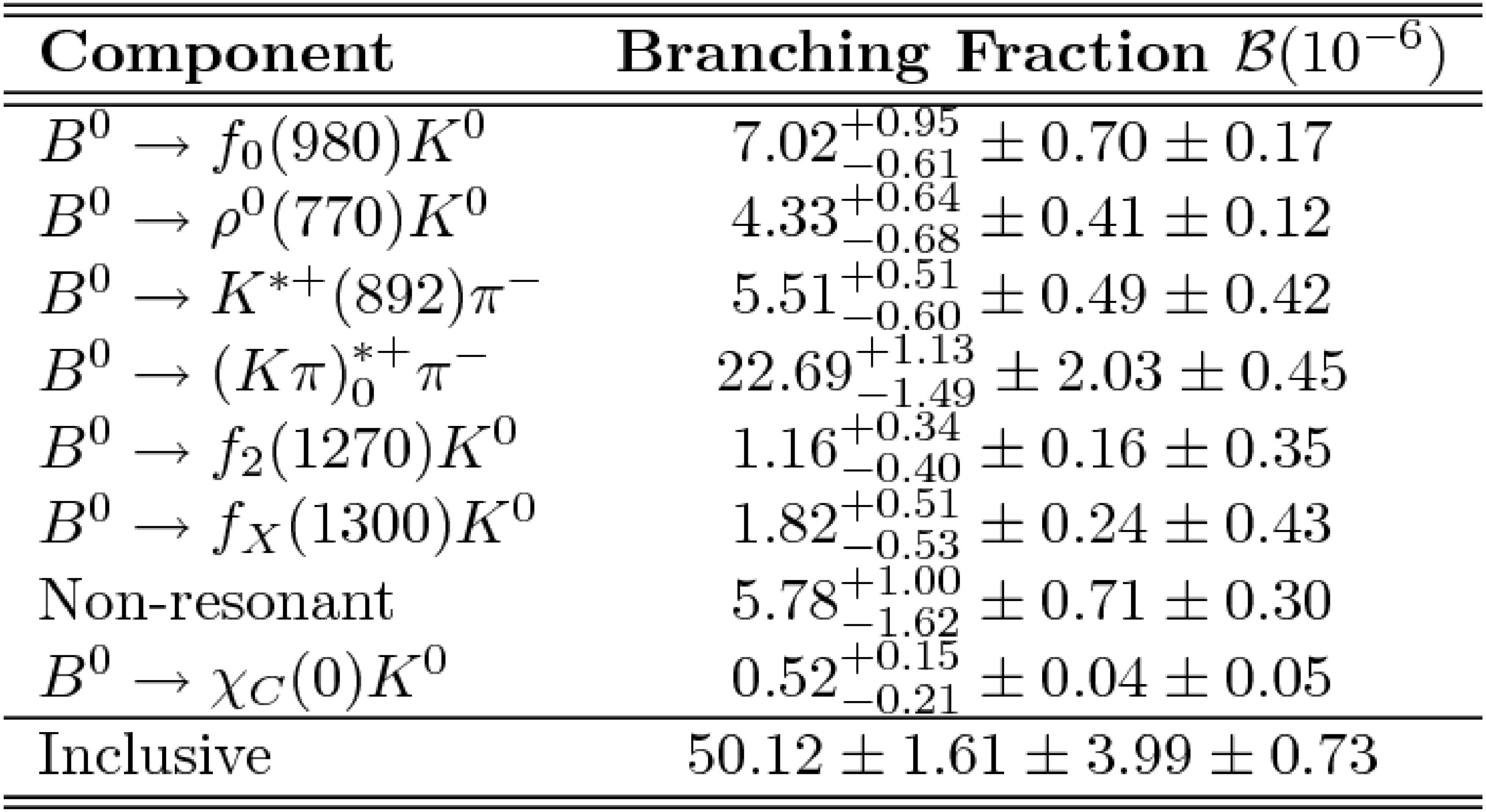
Par.	Syst. Error	Par.	Syst. Error
$C(f_0(980))$	0.04	$C(\rho^0(770))$	0.03
$FF(f_0(980))$	0.6	$FF(\rho^0(770))$	0.23
$2\beta_{eff}(f_0(980))$	4.1	$2\beta_{eff}(\rho^0(980))$	3.7
$A_{CP}(K^*(892))$	0.02	$A_{CP}((K\pi)^*_0)$	0.02
$FF(K^*(892))$	0.8	$FF((K\pi)^*_0)$	0.90
$\Delta\phi(K^*(892))$	8.1	$\Delta\phi((K\pi)^*_0)$	4.4
$C(f_2(1270))$	0.07	$C(f_X(1300))$	0.09
$FF(f_2(1270))$	0.69	$FF(f_X(1300))$	0.87
$\phi(f_2(1270))$	10.4	$\phi(f_X(1300))$	4.5
$C(NR)$	0.04	$C(\chi_C(0))$	0.05
$FF(NR)$	0.60	$FF(\chi_C(0))$	0.09
$\phi(NR)$	7.5	$\phi(\chi_C(0))$	8.2
$\Delta\phi(f_0, \rho^0)$	4.4	FF_{Tot}	1.15
$\Delta\phi(K^*(892), (K\pi)^*_0)$	4.7	A_{CP}^{incl}	0.006
$\Delta\phi(\rho^0, (K\pi)^*_0))$	8.7	Signal Yield	31.7
$\Delta\phi(\rho^0, K^*(892)$	12.7	—	

Total Systematic



Parameter	Total	Parameter	Total
$C(f_0(980))$	0.05	$C(\rho^0(770))$	0.10
$FF(f_0(980))$	1.03	$FF(\rho^0(770))$	0.52
$2\beta_{eff}(f_0(980))$	5.9	$2\beta_{eff}(\rho^0(980))$	7.0
$A_{CP}(K^*(892))$	0.02	$A_{CP}((K\pi)_0^*)$	0.03
$FF(K^*(892))$	1.00	$FF((K\pi)_0^*)$	2.08
$\Delta\phi(K^*(892))$	9.3	$\Delta\phi((K\pi)_0^*)$	6.0
$C(f_2(1270))$	0.11	$C(f_X(1300))$	0.10
$FF(f_2(1270))$	0.74	$FF(f_X(1300))$	0.94
$\phi(f_2(1270))$	12.1	$\phi(f_X(1300))$	6.2
$C(NR)$	0.08	$C(\chi_C(0))$	0.06
$FF(NR)$	1.17	$FF(\chi_C(0))$	0.11
$\phi(NR)$	8.4	$\phi(\chi_C(0))$	9.5
FF_{Tot}	2.40	A_{CP}^{inclu}	0.01
$\Delta\phi(f_0, \rho^0)$	7.5	$\Delta\phi(K^*(892), (K\pi)_0^*)$	6.6
$\Delta\phi(\rho^0, (K\pi)_0^*))$	13.3	$\Delta\phi(\rho^0, K^*(892))$	15.4
Signal Yield	42.1		

Fit Results: Branching Fractions



Component	Branching Fraction $\mathcal{B}(10^{-6})$
$B^0 \to f_0(980)K^0$	$7.02^{+0.95}_{-0.61} \pm 0.70 \pm 0.17$
$B^0 \to \rho^0(770)K^0$	$4.33^{+0.64}_{-0.68} \pm 0.41 \pm 0.12$
$B^0 \to K^{*+}(892)\pi^-$	$5.51^{+0.51}_{-0.60} \pm 0.49 \pm 0.42$
$B^0 \to (K\pi)^{*+}_0\pi^-$	$22.69^{+1.13}_{-1.49} \pm 2.03 \pm 0.45$
$B^0 \to f_2(1270)K^0$	$1.16^{+0.34}_{-0.40} \pm 0.16 \pm 0.35$
$B^0 \to f_X(1300)K^0$	$1.82^{+0.51}_{-0.53} \pm 0.24 \pm 0.43$
Non-resonant	$5.78^{+1.00}_{-1.62} \pm 0.71 \pm 0.30$
$B^0 \to \chi_C(0)K^0$	$0.52^{+0.15}_{-0.21} \pm 0.04 \pm 0.05$
Inclusive	$50.12 \pm 1.61 \pm 3.99 \pm 0.73$

All BFs are consistent with previous measurements

Fit Results: DCPV

Component	DCPV
$C(B^0 \to f_0(980)K^0)$	$0.08^{+0.32}_{-0.18} \pm 0.03 \pm 0.04$
$C(B^0 \to \rho^0(770)K^0)$	$-0.05^{+0.28}_{-0.29} \pm 0.10 \pm 0.03$
$A_{CP}(B^0 \to K^{*+}(892)\pi^-)$	$-0.21 \pm 0.10 \pm 0.01 \pm 0.02$
$A_{CP}(B^0 \to (K\pi)^{*+}_0\pi^-)$	$0.09 \pm 0.12 \pm 0.02 \pm 0.02$
$C(B^0 \to f_2(1270)K^0)$	$0.28^{+0.35}_{-0.60} \pm 0.08 \pm 0.07$
$C(B^0 \to f_X(1300)K^0)$	$0.13^{+0.51}_{-0.36} \pm 0.04 \pm 0.09$
$C(NR)$	(-0.87,0.53) at 95% CL
$C(B^0 \to \chi_C(0)K^0)$	$-0.29 \pm 0.53 \pm 0.04 \pm 0.05$
$A_{CP}^{\mathrm{incl.}}$	$-0.010 \pm 0.050 \pm 0.008 \pm 0.006$

All consistent with no CPV

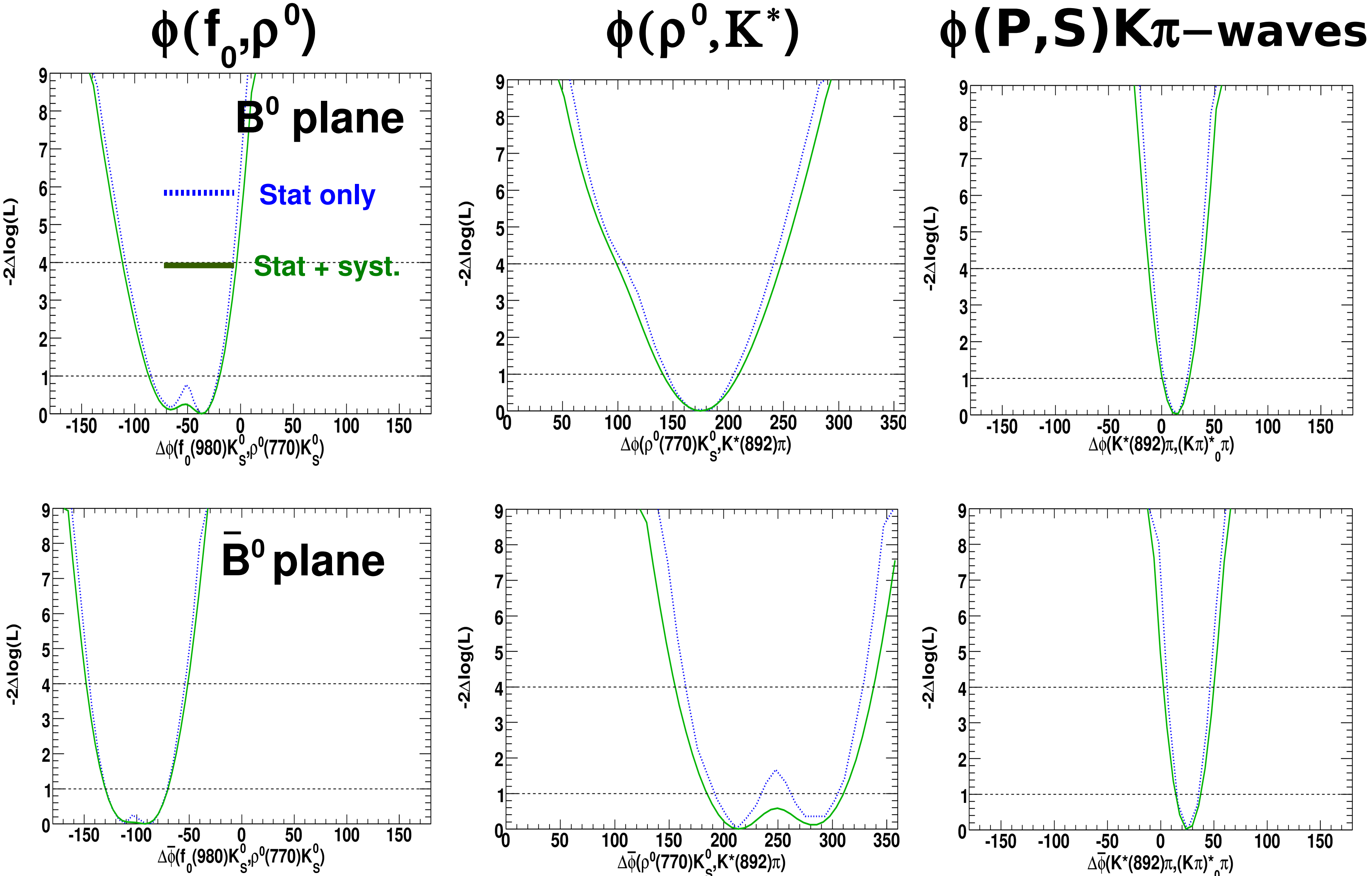
Fit Results: DCPV

Component	DCPV
$C(B^0 \to f_0(980)K^0)$	$0.08^{+0.32}_{-0.18} \pm 0.03 \pm 0.04$
$C(B^0 \to \rho^0(770)K^0)$	$-0.05^{+0.28}_{-0.29} \pm 0.10 \pm 0.03$
$A_{CP}(B^0 \to K^{*+}(892)\pi^-)$	$-0.21 \pm 0.10 \pm 0.01 \pm 0.02$
$A_{CP}(B^0 \to (K\pi)^{*+}_0\pi^-)$	$0.09 \pm 0.12 \pm 0.02 \pm 0.02$
$C(B^0 \to f_2(1270)K^0)$	$0.28^{+0.35}_{-0.60} \pm 0.08 \pm 0.07$
$C(B^0 \to f_X(1300)K^0)$	$0.13^{+0.51}_{-0.36} \pm 0.04 \pm 0.09$
$C(NR)$	(-0.87,0.53) at 95% CL
$C(B^0 \to \chi_C(0)K^0)$	$-0.29 \pm 0.53 \pm 0.04 \pm 0.05$
$A_{CP}^{\text{incl.}}$	$-0.010 \pm 0.050 \pm 0.008 \pm 0.006$

All consistent with no CPV

$B^0 \to K^*(892)\pi$ 2σ away from zero

Fit Results: interference pattern

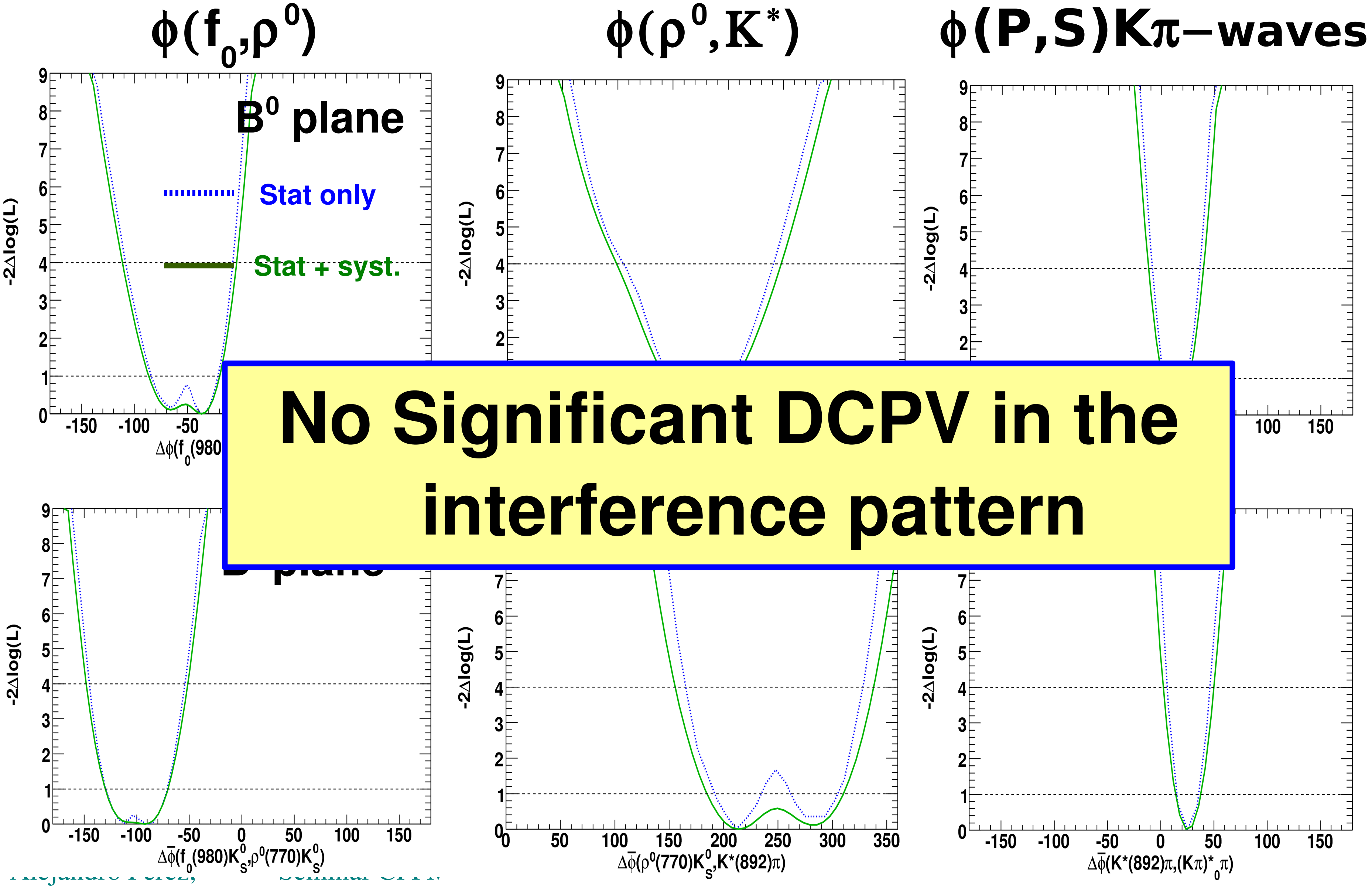


$\phi(f_0,\rho^0)$

$\phi(\rho^0,K^*)$

$\phi(P,S)K\pi$–waves

Fit Results: interference pattern

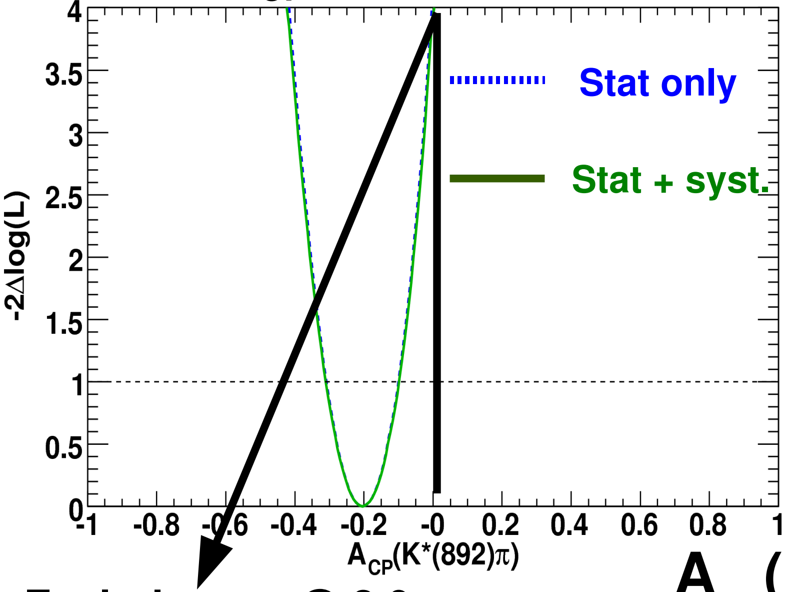


$\phi(f_0,\rho^0)$ | $\phi(\rho^0,K^*)$ | $\phi(P,S)K\pi$−waves

No Significant DCPV in the interference pattern

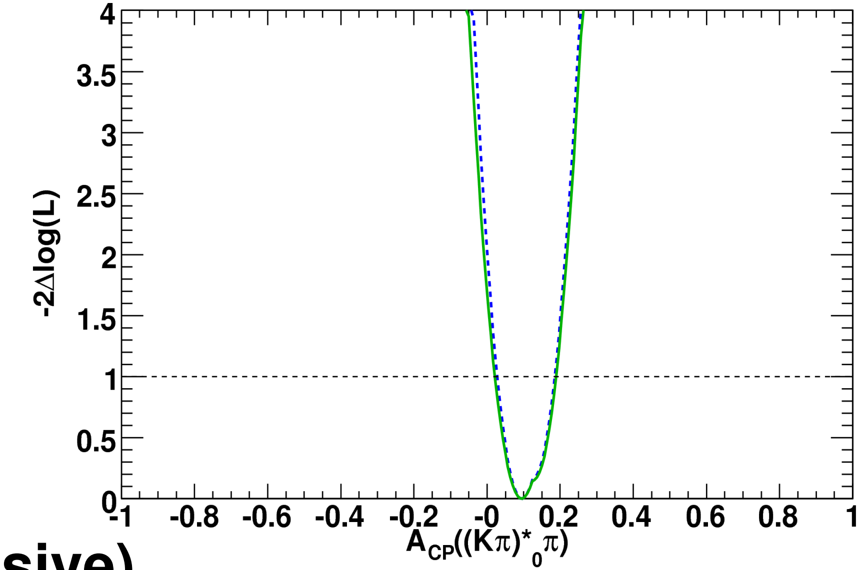
Fit Results: Direct CPV

$A_{CP}(K^*(892)\pi)$

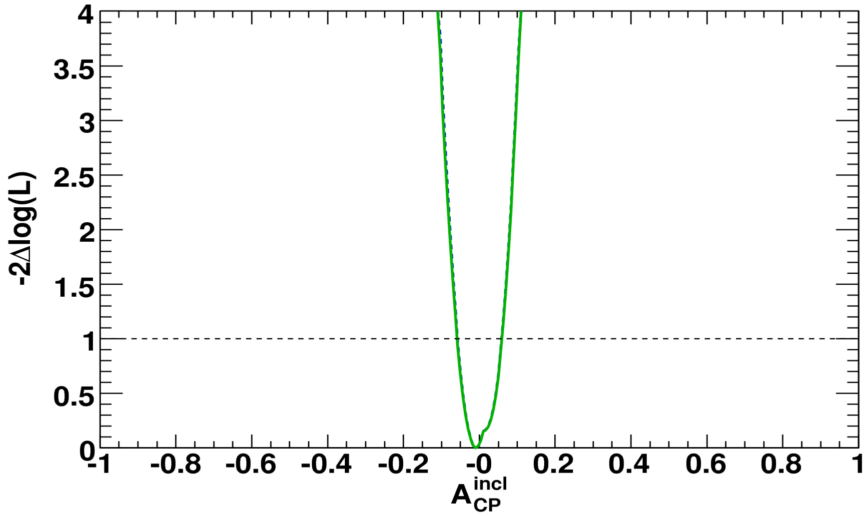


Exclude zero @ 2.0σ

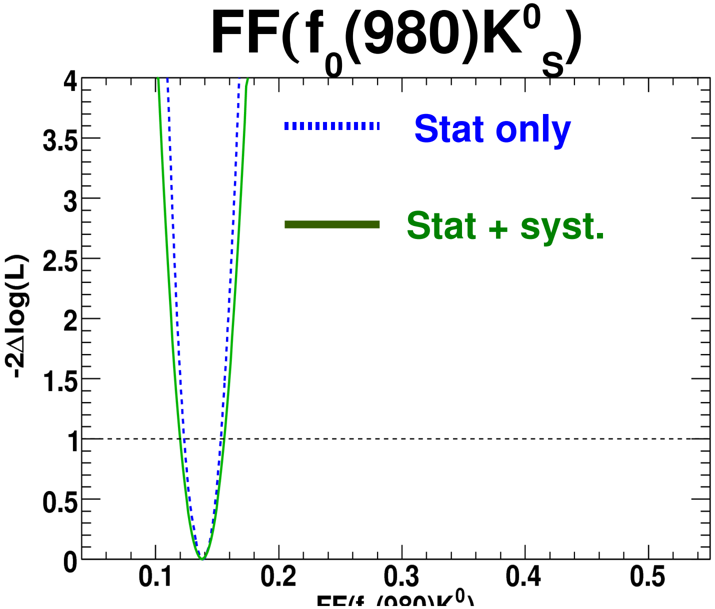
$A_{CP}((K\pi)^*_0)\pi)$

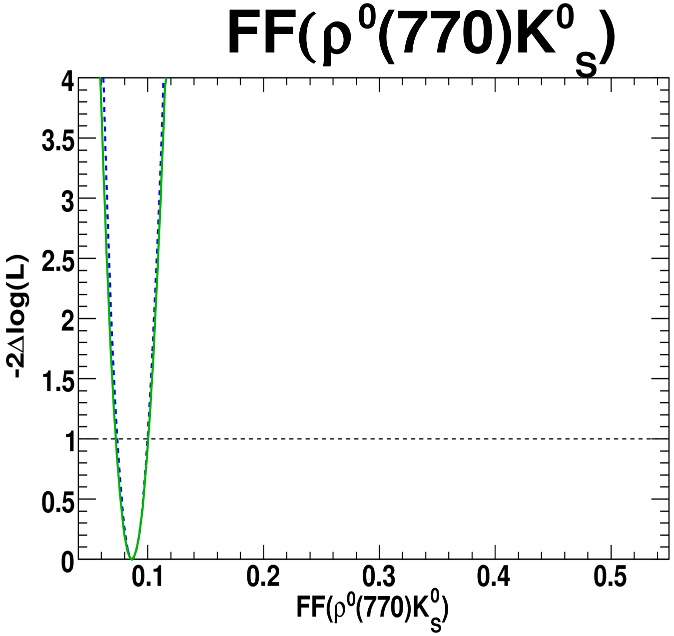


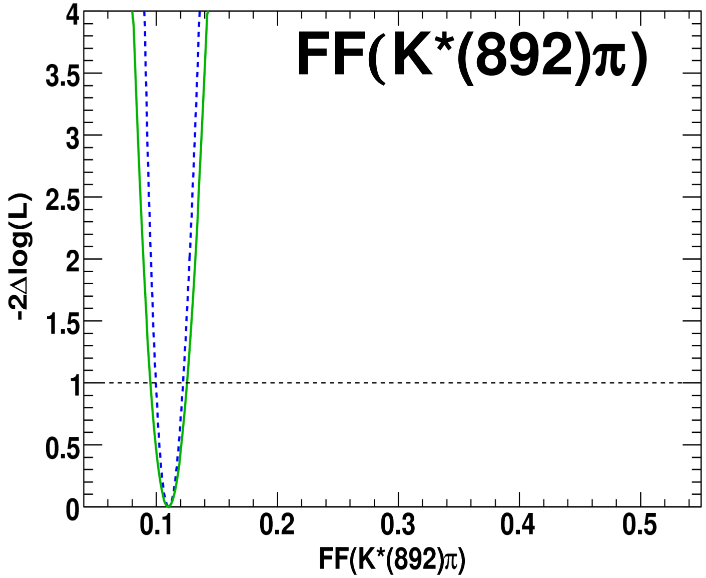
A_{CP}(inclusive)

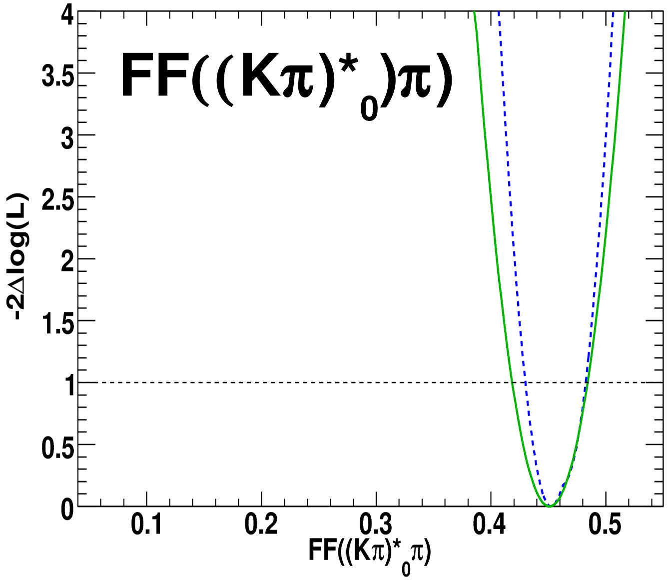


Fit Results: Fit Fractions (I)



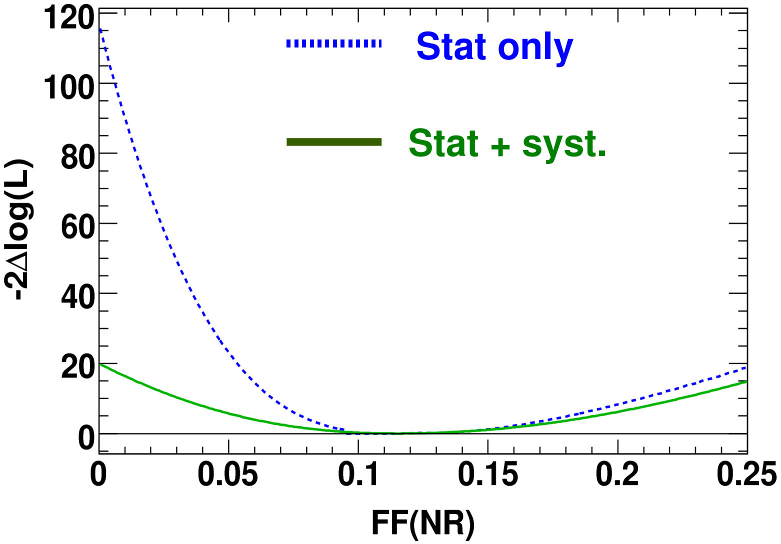




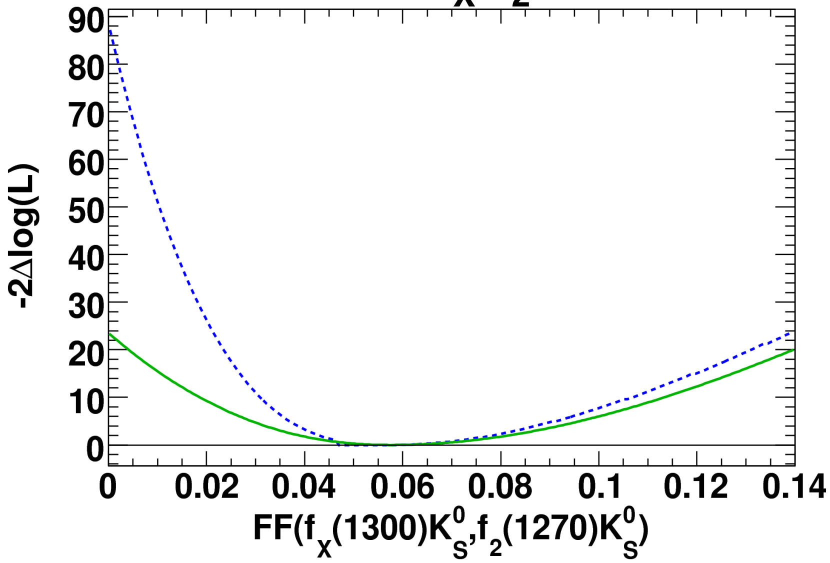


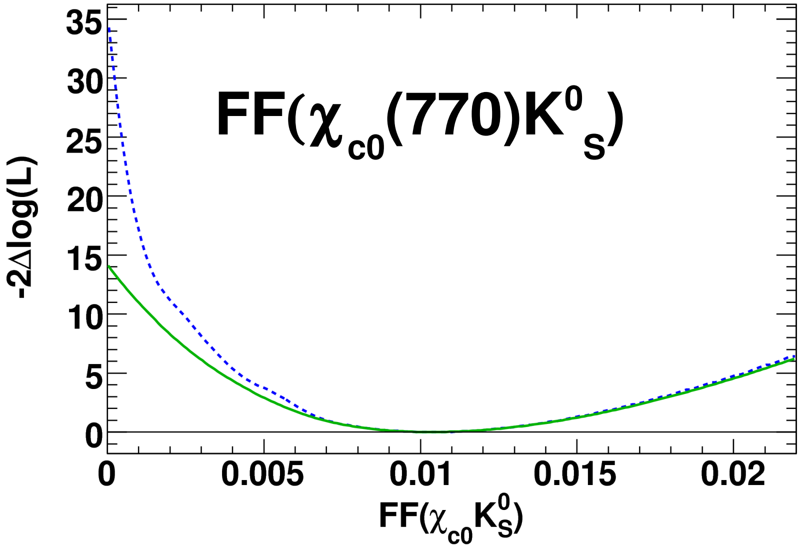
Fit Results: Fit Fractions (II)

FF(NR)

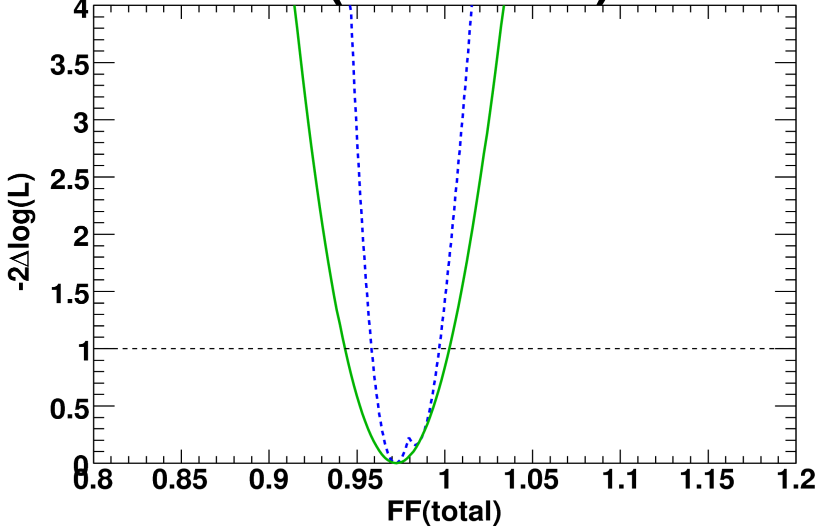


$FF(f_X,f_2)$



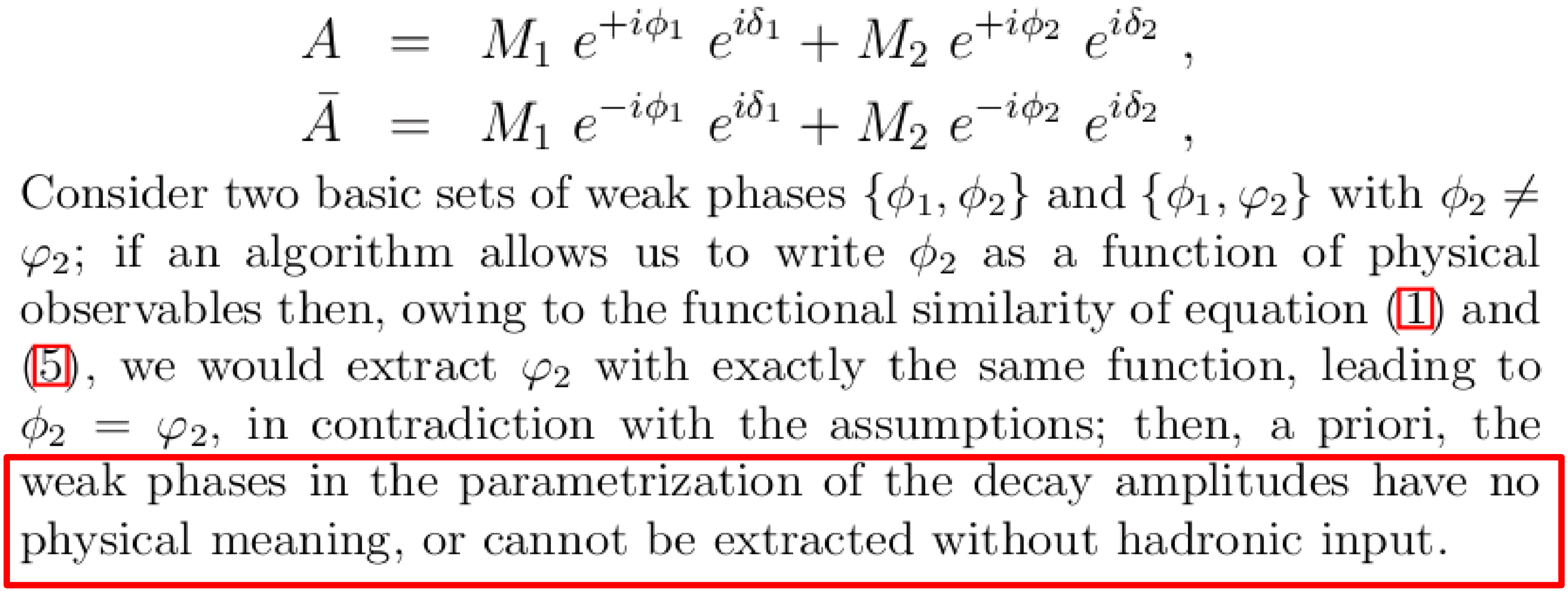


FF(inclusive)



No Free Lunch Theorem: Rpl

Freedom in writing decay amplitudes in terms of weak and strong phases.



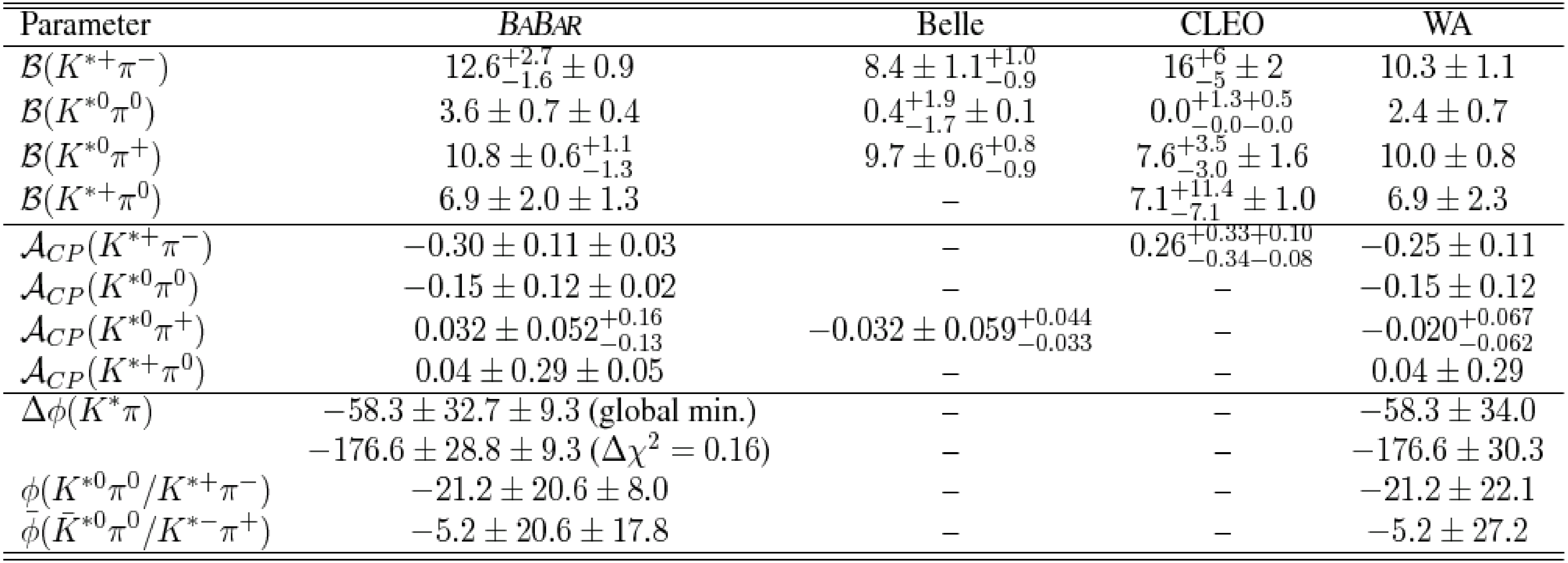
$$\begin{aligned} A &= M_1\, e^{+i\phi_1}\, e^{i\delta_1} + M_2\, e^{+i\phi_2}\, e^{i\delta_2}\ , \\ \bar{A} &= M_1\, e^{-i\phi_1}\, e^{i\delta_1} + M_2\, e^{-i\phi_2}\, e^{i\delta_2}\ , \end{aligned}$$

Consider two basic sets of weak phases $\{\phi_1, \phi_2\}$ and $\{\phi_1, \varphi_2\}$ with $\phi_2 \neq \varphi_2$; if an algorithm allows us to write ϕ_2 as a function of physical observables then, owing to the functional similarity of equation (1) and (5), we would extract φ_2 with exactly the same function, leading to $\phi_2 = \varphi_2$, in contradiction with the assumptions; then, a priori, the weak phases in the parametrization of the decay amplitudes have no physical meaning, or cannot be extracted without hadronic input.

It is not possible to extract at the same time hadronic and CKM parameters without additional input

Botella and Silva PRD71:094008 (2005)

$B \to K^{*}\pi$ system: experimental inputs



Parameter	BABAR	Belle	CLEO	WA
$\mathcal{B}(K^{*+}\pi^-)$	$12.6^{+2.7}_{-1.6} \pm 0.9$	$8.4 \pm 1.1^{+1.0}_{-0.9}$	$16^{+6}_{-5} \pm 2$	10.3 ± 1.1
$\mathcal{B}(K^{*0}\pi^0)$	$3.6 \pm 0.7 \pm 0.4$	$0.4^{+1.9}_{-1.7} \pm 0.1$	$0.0^{+1.3+0.5}_{-0.0-0.0}$	2.4 ± 0.7
$\mathcal{B}(K^{*0}\pi^+)$	$10.8 \pm 0.6^{+1.1}_{-1.3}$	$9.7 \pm 0.6^{+0.8}_{-0.9}$	$7.6^{+3.5}_{-3.0} \pm 1.6$	10.0 ± 0.8
$\mathcal{B}(K^{*+}\pi^0)$	$6.9 \pm 2.0 \pm 1.3$	–	$7.1^{+11.4}_{-7.1} \pm 1.0$	6.9 ± 2.3
$\mathcal{A}_{CP}(K^{*+}\pi^-)$	$-0.30 \pm 0.11 \pm 0.03$	–	$0.26^{+0.33+0.10}_{-0.34-0.08}$	-0.25 ± 0.11
$\mathcal{A}_{CP}(K^{*0}\pi^0)$	$-0.15 \pm 0.12 \pm 0.02$	–	–	-0.15 ± 0.12
$\mathcal{A}_{CP}(K^{*0}\pi^+)$	$0.032 \pm 0.052^{+0.16}_{-0.13}$	$-0.032 \pm 0.059^{+0.044}_{-0.033}$	–	$-0.020^{+0.067}_{-0.062}$
$\mathcal{A}_{CP}(K^{*+}\pi^0)$	$0.04 \pm 0.29 \pm 0.05$	–	–	0.04 ± 0.29
$\Delta\phi(K^{*}\pi)$	$-58.3 \pm 32.7 \pm 9.3$ (global min.)	–	–	-58.3 ± 34.0
	$-176.6 \pm 28.8 \pm 9.3$ ($\Delta\chi^2 = 0.16$)	–	–	-176.6 ± 30.3
$\phi(K^{*0}\pi^0/K^{*+}\pi^-)$	$-21.2 \pm 20.6 \pm 8.0$	–	–	-21.2 ± 22.1
$\bar{\phi}(\bar{K}^{*0}\pi^0/K^{*-}\pi^+)$	$-5.2 \pm 20.6 \pm 17.8$	–	–	-5.2 ± 27.2

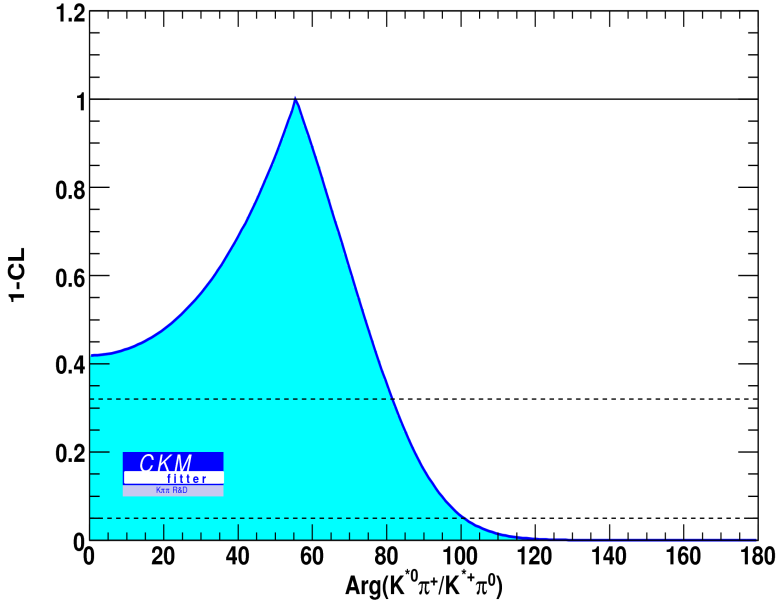
Scenario 1: prediction of unavailable phases

Input here:

- Experimental measurements
- CKM from global fit

(No assumption on any hadronic amplitude)

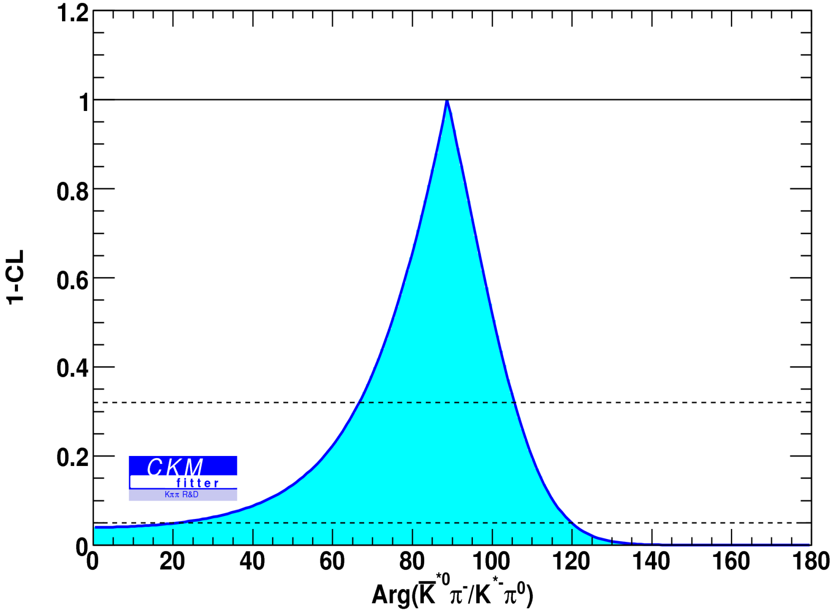
$|\phi| = |\arg(A(B^+ \to K^{*0}\pi^+)A^*(B^+ \to K^{*+}\pi^0))|$



Central value = 58°

(0,85)° at 1σ

$|\phi| = |\arg(A(\overline{B}^- \to \overline{K}^{*0}\pi^-)A^*(B^- \to K^{*-}\pi^0))|$

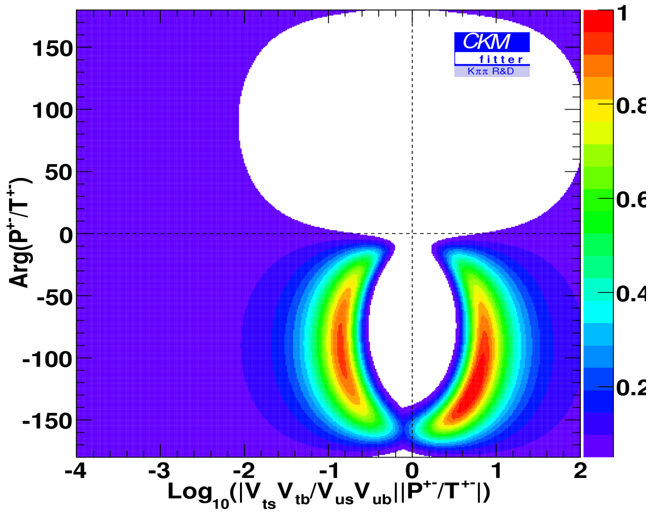


Central value = 95°

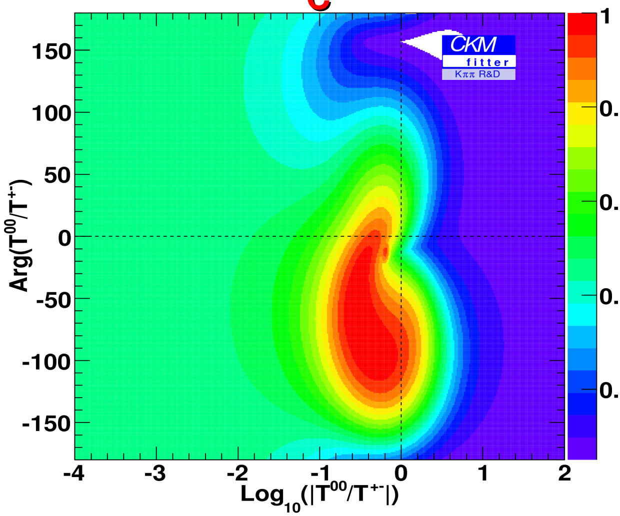
(68,107)° at 1σ

Scenario 1: exploring hadronic parameters Vuelatela

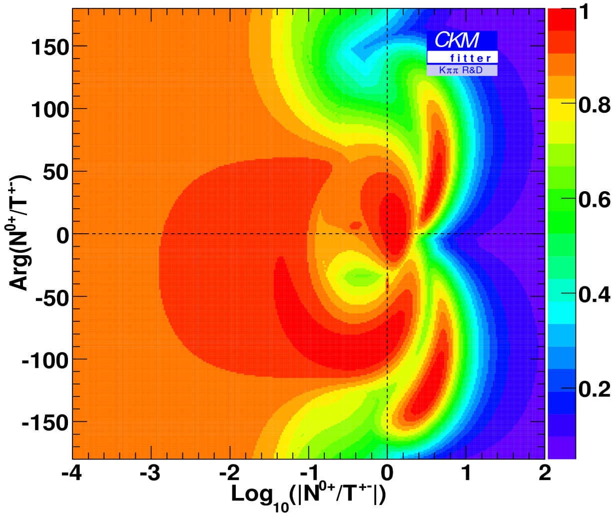
P^{+-}/T^{+-}



T^{00}_C/T^{+-}



N^{0+}/T^{+-}

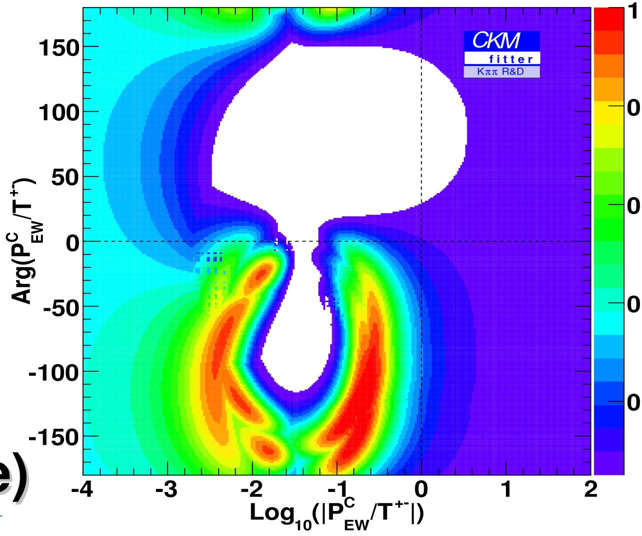


Input here:

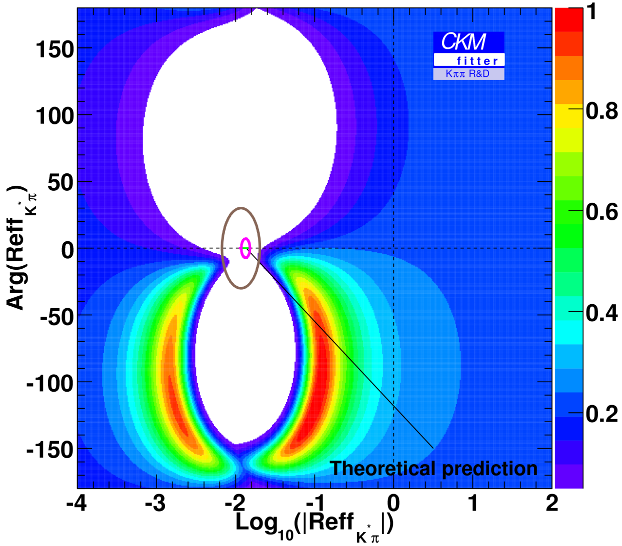
- Experimental measurements
- CKM from global fit

(No assumption on any hadronic amplitude)

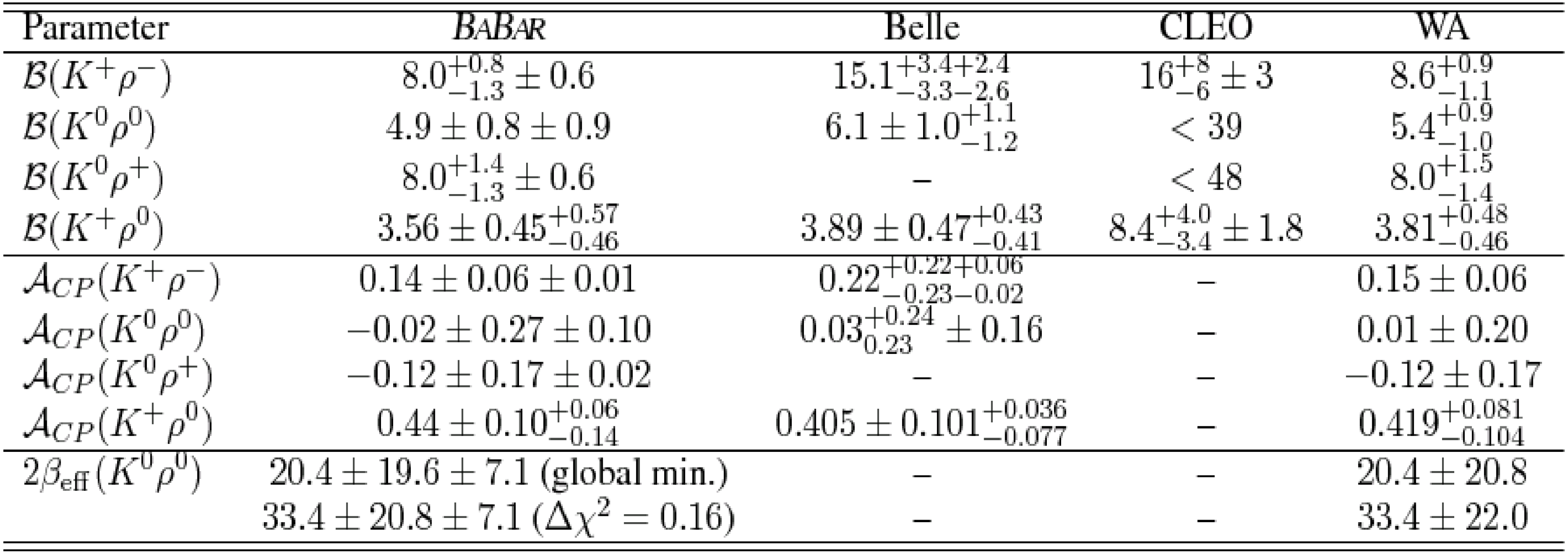
P^C_{EW}/T^{+-}



$P_{EW}/T_{3/2}$



B→ρK system: experimental inputs



Parameter	BABAR	Belle	CLEO	WA
$\mathcal{B}(K^+\rho^-)$	$8.0^{+0.8}_{-1.3} \pm 0.6$	$15.1^{+3.4+2.4}_{-3.3-2.6}$	$16^{+8}_{-6} \pm 3$	$8.6^{+0.9}_{-1.1}$
$\mathcal{B}(K^0\rho^0)$	$4.9 \pm 0.8 \pm 0.9$	$6.1 \pm 1.0^{+1.1}_{-1.2}$	< 39	$5.4^{+0.9}_{-1.0}$
$\mathcal{B}(K^0\rho^+)$	$8.0^{+1.4}_{-1.3} \pm 0.6$	–	< 48	$8.0^{+1.5}_{-1.4}$
$\mathcal{B}(K^+\rho^0)$	$3.56 \pm 0.45^{+0.57}_{-0.46}$	$3.89 \pm 0.47^{+0.43}_{-0.41}$	$8.4^{+4.0}_{-3.4} \pm 1.8$	$3.81^{+0.48}_{-0.46}$
$\mathcal{A}_{CP}(K^+\rho^-)$	$0.14 \pm 0.06 \pm 0.01$	$0.22^{+0.22+0.06}_{-0.23-0.02}$	–	0.15 ± 0.06
$\mathcal{A}_{CP}(K^0\rho^0)$	$-0.02 \pm 0.27 \pm 0.10$	$0.03^{+0.24}_{0.23} \pm 0.16$	–	0.01 ± 0.20
$\mathcal{A}_{CP}(K^0\rho^+)$	$-0.12 \pm 0.17 \pm 0.02$	–	–	-0.12 ± 0.17
$\mathcal{A}_{CP}(K^+\rho^0)$	$0.44 \pm 0.10^{+0.06}_{-0.14}$	$0.405 \pm 0.101^{+0.036}_{-0.077}$	–	$0.419^{+0.081}_{-0.104}$
$2\beta_{\text{eff}}(K^0\rho^0)$	$20.4 \pm 19.6 \pm 7.1$ (global min.)	–	–	20.4 ± 20.8
	$33.4 \pm 20.8 \pm 7.1$ ($\Delta\chi^2 = 0.16$)	–	–	33.4 ± 22.0

$B\to\rho K$ System: Physical Observables

$$A(B^0\to\rho^+K^-) = V_{us}V^*_{ub}t^{+-} + V_{ts}V^*_{tb}p^{+-}$$

$$A(B^+\to\rho^0K^+) = V_{us}V^*_{ub}n^{0+} + V_{ts}V^*_{tb}(-p^{+-}+p^C_{EW})$$

$$\sqrt{}2A(B^+\to\rho^+K^0) = V_{us}V^*_{ub}(t^{+-}+t^{00}_C-n^{0+}) + V_{ts}V^*_{tb}(p^{+-}-p^C_{EW}+p_{EW})$$

$$\sqrt{}2A(B^0\to\rho^0K^0) = V_{us}V^*_{ub}t^{00}_C + V_{ts}V^*_{tb}(-p^{+-}+p_{EW})$$

11 QCD and 2 CKM = 13 unknowns

Same Isospin relations as $K^*\pi$

Observables:

- 4 BFs and 4 A_{CP} from DP and Q2B analyses.
- 1 phase differences:
  - * $2\beta_{eff}$ = arg($(q/p)\overline{A}(\overline{B}^0\to\rho^0\overline{K}^0)A^*(B^0\to\rho^0K^0)$) from $B^0\to K^0_S\pi^+\pi^-$

A total of 9 observables

Under constraint system

B→ρK System: Physical Observables

$A(B^0\to\rho^+K^-) = V_{us}V^*_{ub}t^{+-} + V_{ts}V^*_{tb}p^{+-}$

$A(B^+\to\rho^0K^+) = V_{us}V^*_{ub}n^{0+} + V_{ts}V^*_{tb}(-p^{+-}+p^C_{EW})$

$\surd 2A(B^+\to\rho^+K^0) = V_{us}V^*_{ub}(t^{+-}+t^{00}_C-n^{0+}) + V_{ts}V^*_{tb}(p^{+-}-p^C_{EW}+p_{EW})$

$\surd 2A(B^0$

No possible constraint on CKM parameters
Some weak bounds on hadronic parameters

Observab

- 4 BFs

- 1 pha

* $2\beta_{eff}$ = arg($(q/p)\overline{A}(\overline{B^0}\to\rho^0\overline{K^0})A^*(B^0\to\rho^0K^0)$) from $B^0\to K^0_S\pi^+\pi^-$

A total of 9 observables

Same Isospin relations as $K^*\pi$

Under constraint system

ρK+K$^*\pi$ system: Physical Observables

Global phase between K$^*\pi$ and ρK now accessible:

- K$^*\pi$: 13 parameters
- ρK: 13 parameters
- global phase: 1 parameter

A total of = 27 unknowns

Observables:

- K$^*\pi$ only: 13 observables
- ρK only: 9 observables
- 7 phase differences from: interference between K$^*\pi$ and ρK resonances contributing to the same DP
  - ϕ = arg(A($B^0 \rightarrow \rho^0 K^0$)A*($B^0 \rightarrow K^{*+}\pi^-$)) from $B^0 \rightarrow K^0_S \pi^+\pi^-$
  - ϕ = arg(A($B^0 \rightarrow \rho^- K^+$)A*($B^0 \rightarrow K^{*+}\pi^-$)) and CP conjugated from $B^0 \rightarrow K^+\pi^-\pi^0$
  - ϕ = arg(A($B^0 \rightarrow \rho^0 K^+$)A*($B^0 \rightarrow K^{*0}\pi^+$)) and CP conjugated from $B^+ \rightarrow K^+\pi^-\pi^+$
  - ϕ = arg(A($B^0 \rightarrow \rho^+ K^0$)A*($B^0 \rightarrow K^{*+}\pi^0$)) and CP conjugated from $B^+ \rightarrow K^0\pi^+\pi^0$

A total of 29 experimentally independent observables

$\rho K+K^*\pi$ system: Physical Observables

Global phase between $K^*\pi$ and ρK now accessible:

- $K^*\pi$: 13 parameters
- ρK: 13 parameters
- global phase: 1 parameter

A total of = 27 unknowns

Observables:

- $K^*\pi$ only: 13
- ρK only: 9

Many redundant observables

- 7 phase differences from: interference between $K^*\pi$ and ρK resonances contributing to the same DP
  - $\phi = \arg(A(B^0\to\rho^0K^0)A^*(B^0\to K^{*+}\pi^-))$ from $B^0\to K^0_S\pi^+\pi^-$
  - $\phi = \arg(A(B^0\to\rho^-K^+)A^*(B^0\to K^{*+}\pi^-))$ and CP conjugated from $B^0\to K^+\pi^-\pi^0$
  - $\phi = \arg(A(B^0\to\rho^0K^+)A^*(B^0\to K^{*0}\pi^+))$ and CP conjugated from $B^+\to K^+\pi^-\pi^+$
  - $\phi = \arg(A(B^0\to\rho^+K^0)A^*(B^0\to K^{*+}\pi^0))$ and CP conjugated from $B^+\to K^0\pi^+\pi^0$

A total of 29 experimentally independent observables

$\rho K + K^*\pi$ system: Extrapolation exercise

Inputs:

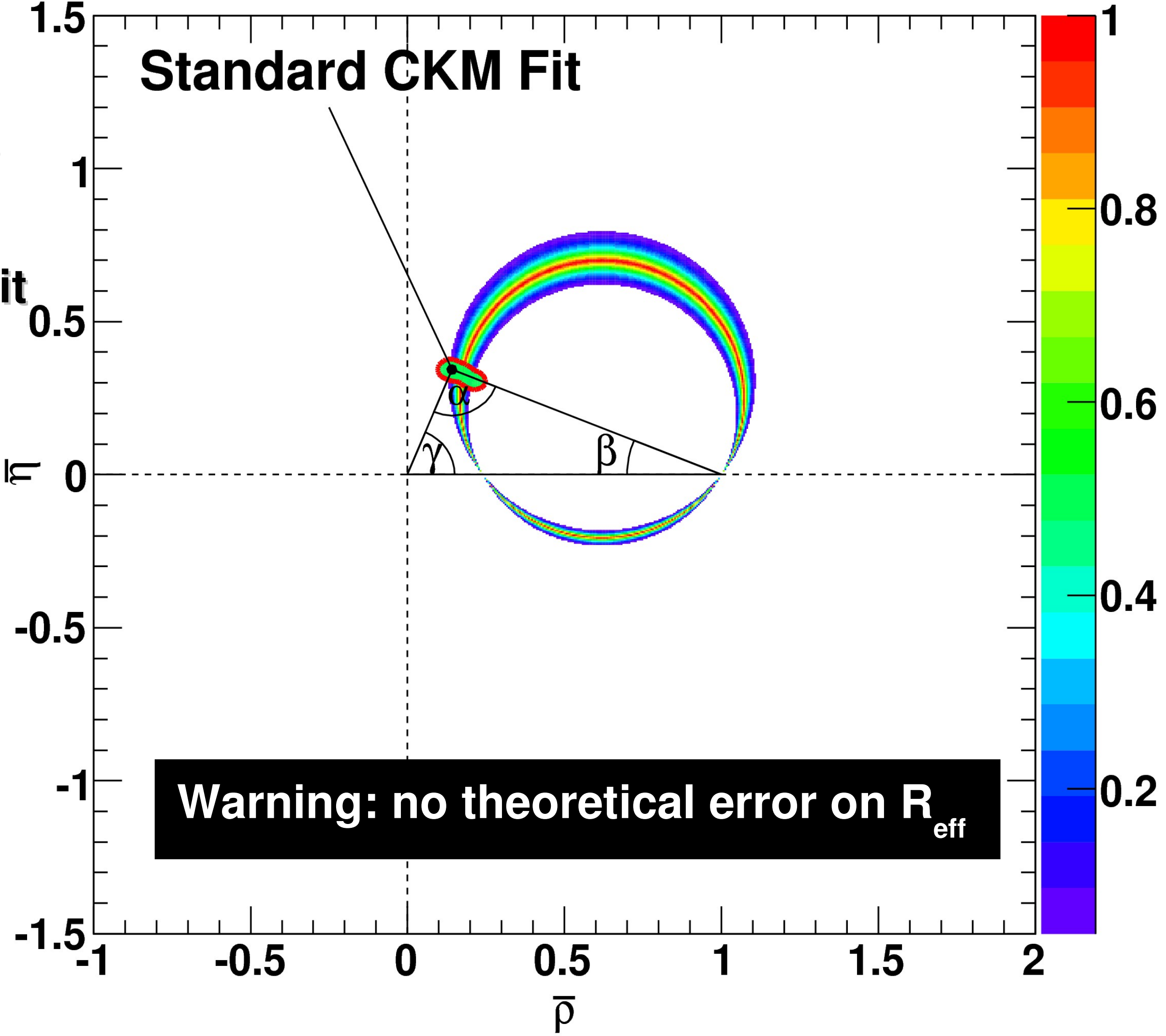
- All 27 $K^*\pi$ + ρK observables
- Assume central values in agreement with global CKM fit

Extrapolated errors:

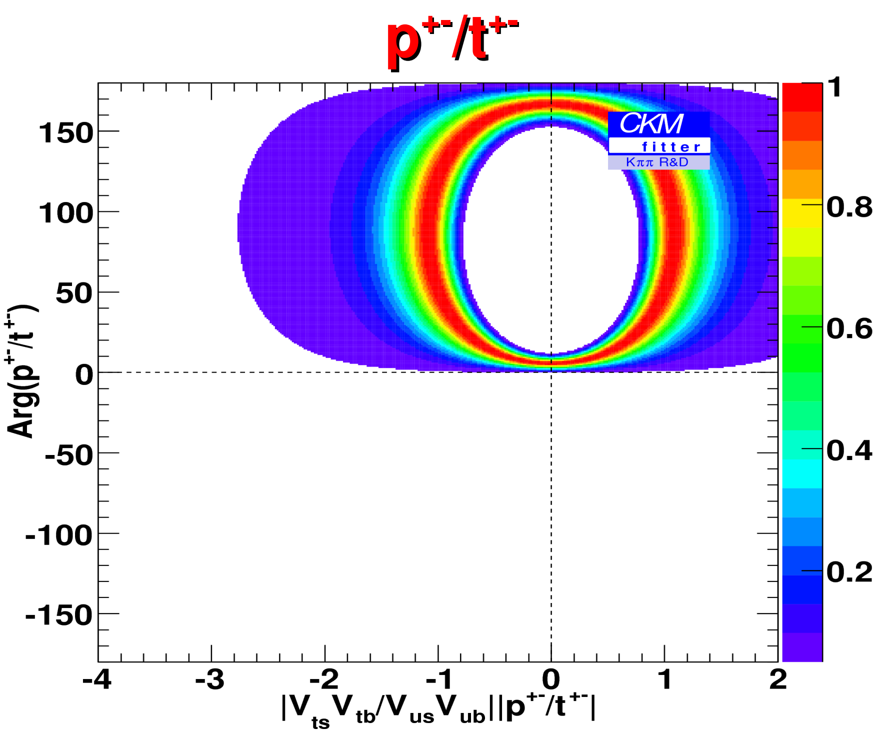
- ~5° on phases
- ~3% on BF
- ~3% on A_{CP}

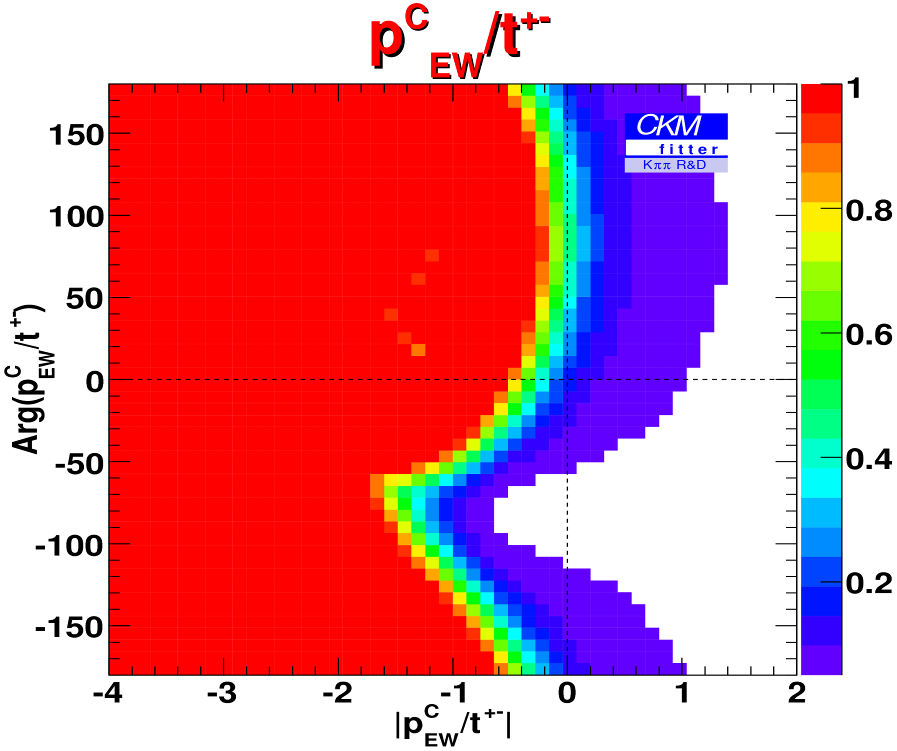
roughly equivalent to current systematics

Assuming R_{eff} = 1.35% (GPSZ)



$B\rightarrow\rho K$ system: exploring hadronic parameters



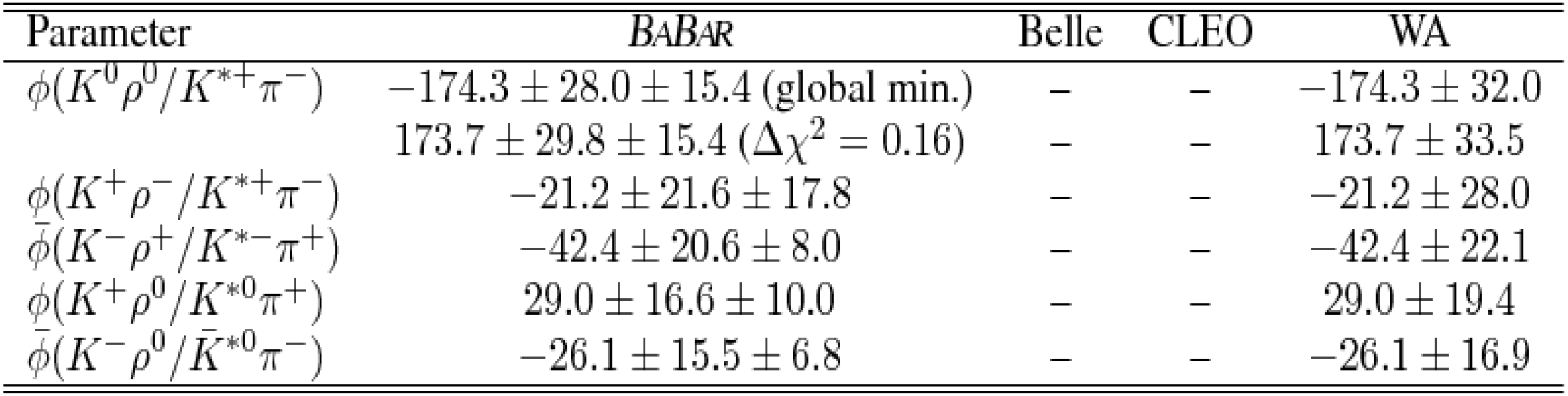


Exclude negative values of phase

Due to Significance in $K^+\rho^-$ Direct CPV

Weak constraints on most paramters

$\rho K + K^{*}\pi$ system: experimental inputs



Parameter	BABAR	Belle	CLEO	WA
$\phi(K^0\rho^0/K^{*+}\pi^-)$	$-174.3 \pm 28.0 \pm 15.4$ (global min.)	–	–	-174.3 ± 32.0
	$173.7 \pm 29.8 \pm 15.4$ ($\Delta\chi^2 = 0.16$)	–	–	173.7 ± 33.5
$\phi(K^+\rho^-/K^{*+}\pi^-)$	$-21.2 \pm 21.6 \pm 17.8$	–	–	-21.2 ± 28.0
$\bar{\phi}(K^-\rho^+/K^{*-}\pi^+)$	$-42.4 \pm 20.6 \pm 8.0$	–	–	-42.4 ± 22.1
$\phi(K^+\rho^0/K^{*0}\pi^+)$	$29.0 \pm 16.6 \pm 10.0$	–	–	29.0 ± 19.4
$\bar{\phi}(K^-\rho^0/\bar{K}^{*0}\pi^-)$	$-26.1 \pm 15.5 \pm 6.8$	–	–	-26.1 ± 16.9

$\rho K + K^{*}\pi$ system: exploring $\phi_{3/2}$

- We use two independent $\phi_{3/2}$:

$$R'_{3/2}(K^{*}\pi) = (q/p)\,\frac{A(\overline{B}^{0}\rightarrow K^{*-}\pi^{+}) + \sqrt{2}.A(\overline{B}^{0}\rightarrow \overline{K}^{*0}\pi^{0})}{A(B^{0}\rightarrow K^{*+}\pi^{-}) + \sqrt{2}.A(B^{0}\rightarrow K^{*0}\pi^{0})} = \exp(-2i\phi_{3/2}(K^{*}\pi))$$

$$R'_{3/2}(\rho K) = (q/p)\,\frac{A(\overline{B}^{0}\rightarrow K^{-}\rho^{+}) + \sqrt{2}.A(\overline{B}^{0}\rightarrow \overline{K}^{0}\rho^{0})}{A(B^{0}\rightarrow K^{+}\rho^{-}) + \sqrt{2}.A(B^{0}\rightarrow K^{0}\rho^{0})} = \exp(-2i\phi_{3/2}(\rho K))$$

- both are independent functions of observables

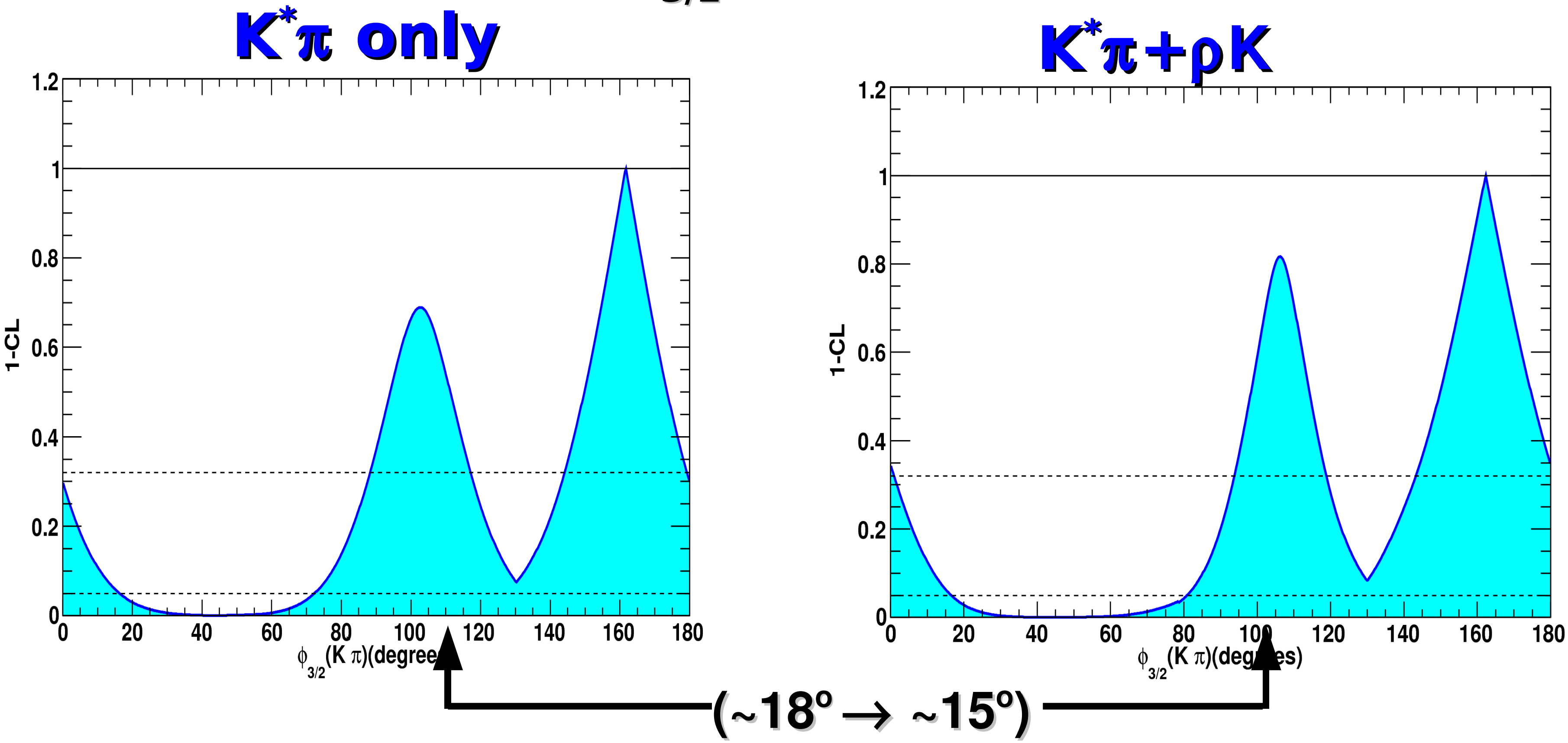
- both can provide constraints on (ρ,η) with additional theoretical input.

  Ex.: $P_{EW} = 0 \rightarrow \phi_{3/2} = \alpha$

- With current inputs only can set a marginal constraint on $\phi_{3/2}$

$\rho K+K^*\pi$ system: exploring $\phi_{3/2}(K^*\pi)$

$\phi_{3/2}(K^*\pi)$



$K^*\pi$ only

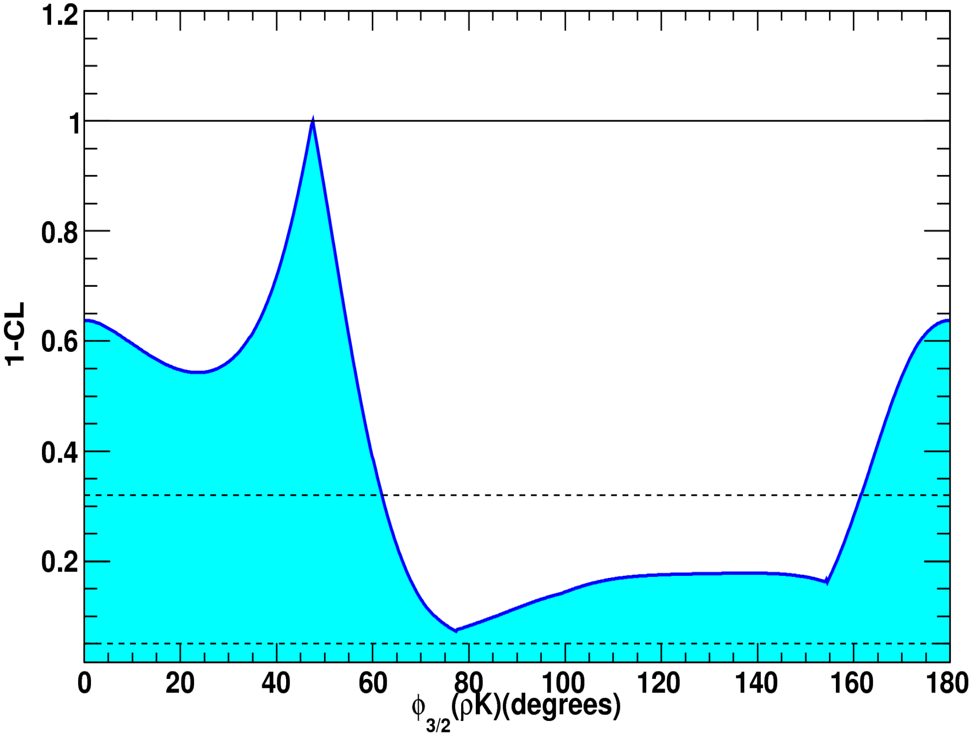
$K^*\pi+\rho K$

(~18° → ~15°)

- Error for each solution improves by only adding **ρK** system
- Adding the additional phases will further improve

$\rho K + K^{*}\pi$ system: exploring $\phi_{3/2}(\rho K)$

$\phi_{3/2}(\rho K)$ $K^{*}\pi+\rho K$



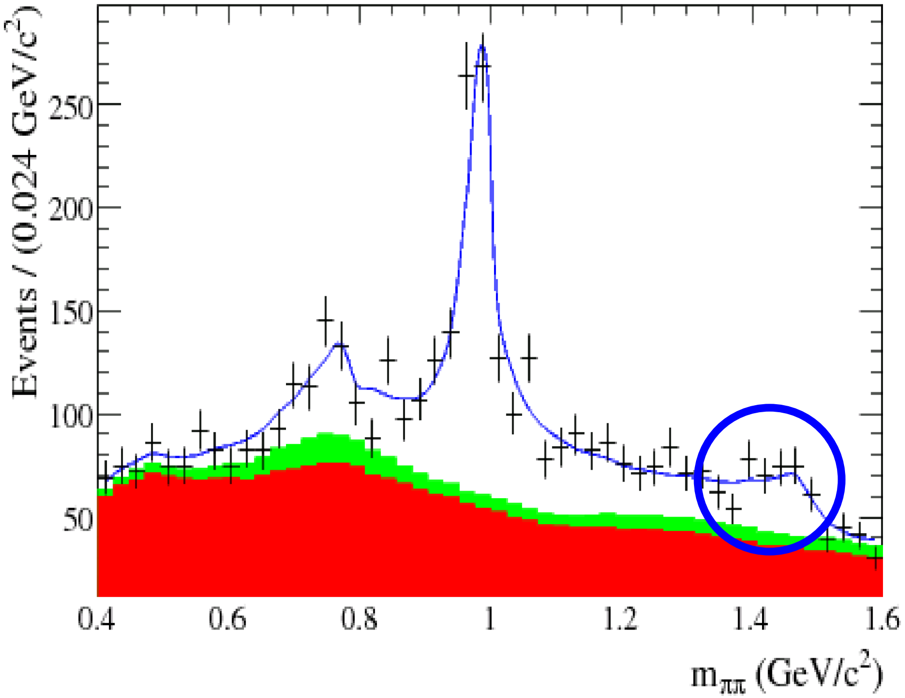
$\phi_{3/2}(\rho K)$ fixed with information from interference of different $K^{*}\pi$ and ρK resonances.

Limited constraint with current experimental inputs and errors

The $f_X(1300)$

$B^+ \rightarrow K^+\pi^-\pi^+$

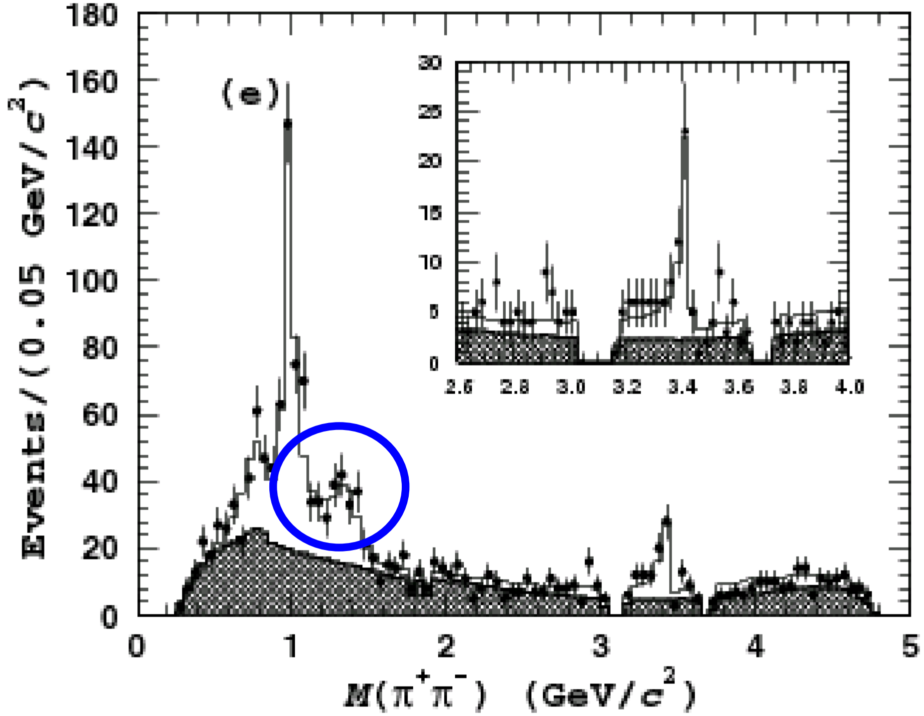
BaBar PRD78:012004 (2008)



M = 1479 ± 8 MeV

Γ = 80 ± 19 MeV

Belle PRL96:251803 (2006)



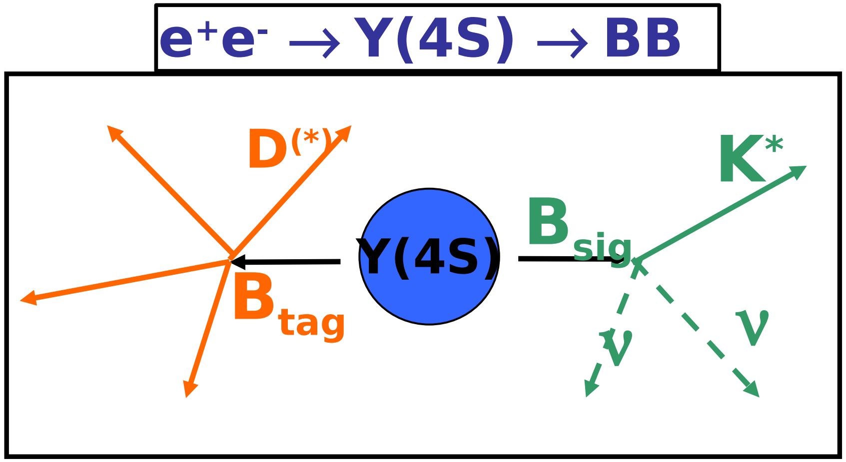
M = 1449 ± 13 MeV

Γ = 126 ± 25 MeV

Data prefers scalar over vector and tensor

Recoil Analysis Technique (I)

- **Most of the searches for rare B decays performed by exploiting the Recoil Technique:**



B_{tag} : full (partial) reconstruction in one hadronic (semi-leptonic) decay

B_{sig} : look for the signal signature, e.g. $K^{(*)}$ not accompanied by additional (charged+neutral) particles + missing energy

Recoil technique at B-Factories:

- **search for rare decays (10^{-5}) with missing energy (Not possible at hadronic machines)**
- **Several benchmark channels at SuperB: $B \to \tau\nu$, $B \to K^{(*)}\nu\nu$, ...**

Recoil Analysis Technique (II)

- Aim: collect as many as possible fully/partially reconstructed B mesons in order to study the properties of the recoil
- 1st step: reconstruction D→hadrons

$D^{*+} \to D^0\pi^+$

$D^{*0} \to D^0\pi^0$

$D^{*0} \to D^0\gamma$

$D^0 \to K^-\pi^+$

$D^0 \to K^-\pi^+\pi^0(\gamma\gamma)$

$D^0 \to K^-\pi^+\pi^+\pi^-$

$D^0 \to K^0_S\pi^+\pi^-$

$D^+ \to K^-\pi^+\pi^-$

$D^+ \to K^-\pi^+\pi^-\pi^0$

$D^+ \to K^0_S\pi^+$

$D^+ \to K^0_S\pi^+\pi^-\pi^+$

$D^+ \to K^0_S\pi^+\pi^0$

2nd step:

Hadronic Breco:

- Use D as a seed and add X to have system compatible with B hypothesis

  (X = $n\pi^{\pm}$ $mK^{\pm}$ rK^0_S $q\pi^0$ and n+m+r+q<6)
- Sample of 1100 B decay modes with different purities
- Kinematics constrained completely ☺
- Low reconstruction efficiencies ☹

  (~0.4%)

Semi-Leptonic Breco:

- Use D as a seed and a lepton to form a Dl pair (l = $e^{\pm}$,$\mu^{\pm}$)
- Sample of 14 B decay modes
- Kinematics is unconstrained due to neutrino ☹
- Higher reconstruction efficiencies (~2.0%) ☺