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

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Seminar LAPP Annecy – Friday Feb. 12th 2010

Currently

- **Post-Doc at LAL working with the SuperB and BaBar groups**

- **SuperB:** Detector Geometry Working Group (DGWP). Test of the physics cases $B \rightarrow K^{(*)}\nu\nu$ and $B^{+} \rightarrow \tau^{+}\nu$ using the Semi-Leptonic recoil technique

- **BaBar:** fully inclusive BF and energy spectrum measurement of $B \rightarrow X_s \gamma$ using the Hadronic recoil technique

Outline

- Introduction

- **Analysis:** time-dependent amplitude analysis of $B^0 \to K^0_S \pi^+ \pi^-$ decays with BaBar

- **Phenomenological interpretation:** SU(2) isospin analysis of the $B \to K^* \pi$ and $B \to \rho K$ modes.

Introduction

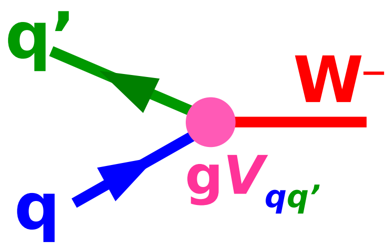
CP Violation and the CKM Matrix

In the Standard Model (SM):
Mass states ≠ Weak states

quarks

Weak states		CKM matrix	Mass states

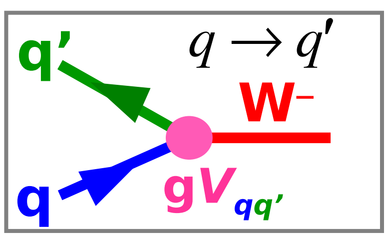
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



quark flavor changes with the quark mixing couplings

CP conservation only if:

$$A(q \rightarrow q') = \bar{A}(\bar{q} \rightarrow \bar{q}')$$



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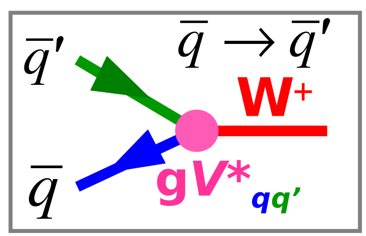


➔ $V_{CKM} = V^*_{CKM}$

V_{CKM} complex → CPV in SM!

CKM Matrix and the unitarity Triangle

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

quark mixing only described by
- 3 real rotation angles and,
- 1 irreductible 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 $\eta \neq 0$

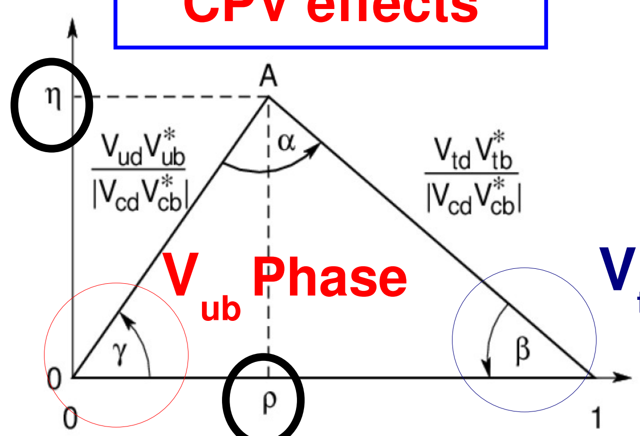
Unitarity Relations:

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: $\boxed{V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0}$

Expected large CPV effects



V_{td} Phase

B mesons and CP violation

Types of CP violation

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

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

B mesons and CP violation

Types of CP violation

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

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

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

B mesons and CP violation

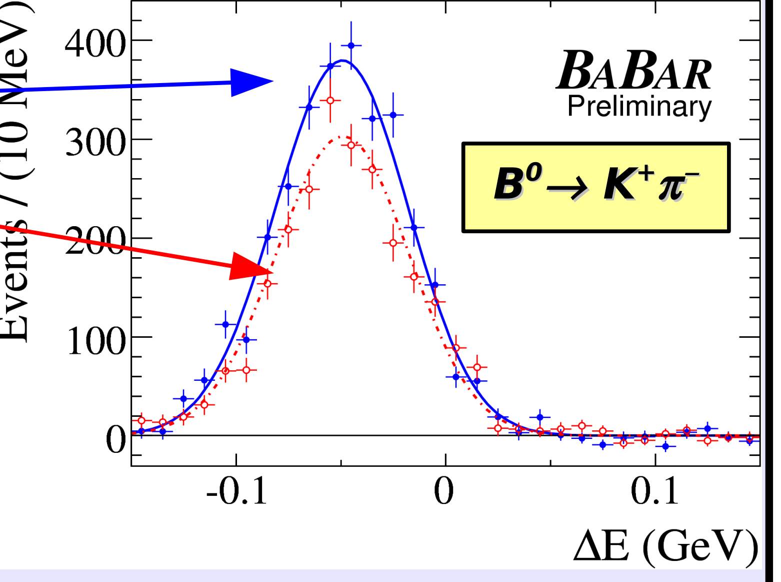
Types of CP violation

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

  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:** $|B^0 \to \overline{B}^0|^2 \neq |\overline{B}^0 \to B^0|^2 \quad |q/p| \neq 1$

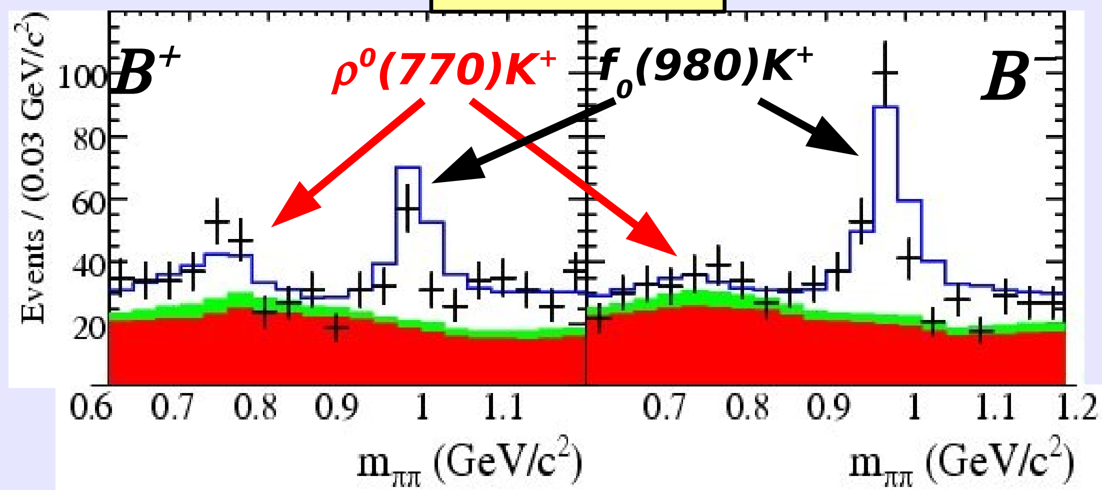
  For B mesons $|q/p| \sim 1$ (B Mixing parameter)

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

$$|B \to f_1 + B \to f_2|^2 \to \delta_{12}$$
$$\neq$$
$$|\overline{B} \to \overline{f}_1 + \overline{B} \to \overline{f}_2|^2 \to \overline{\delta}_{12}$$

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

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



B mesons and CP violation

Types of CP violation

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

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

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

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

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

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

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

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

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

B mesons and CP violation

Types of CP violation

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

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

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

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

$|\bar{B}^0 \to f_{CP} +$

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

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

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

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

SM Prediction:

$S = \sin(2\beta)$

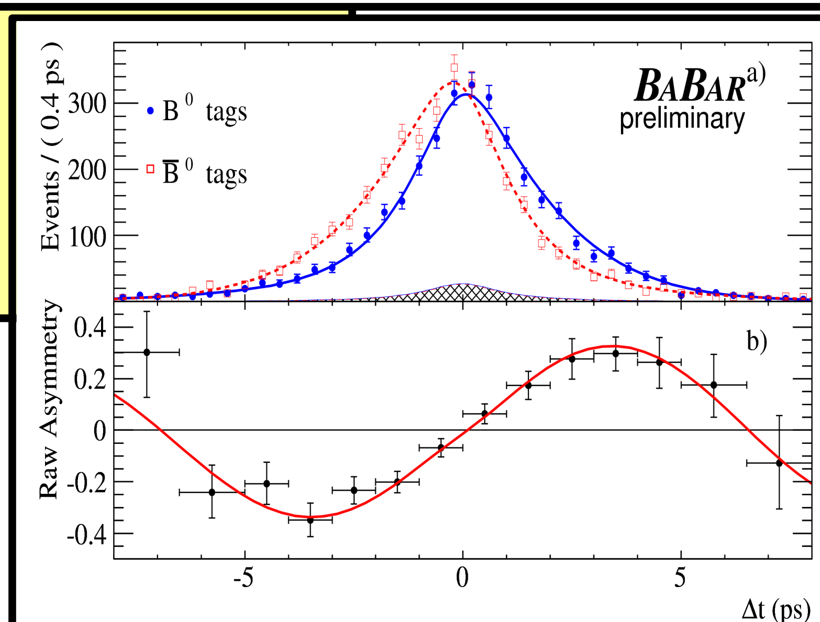
$C = 0$

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



Unitarity Triangle Parameters

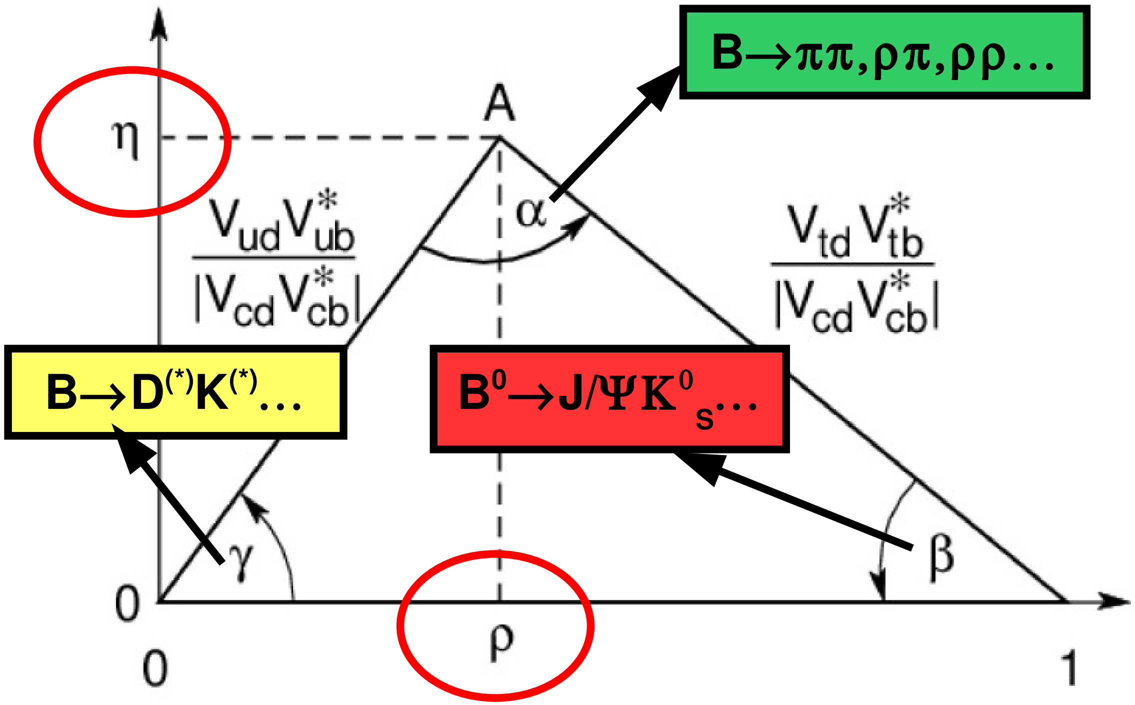
Unitarity Triangle (UT)

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

Rescaled UT by $V_{cd}V^*_{cb}$

For each observable, its theoretical expression is a function of (ρ,η)

Measurement: constraint on (ρ,η)

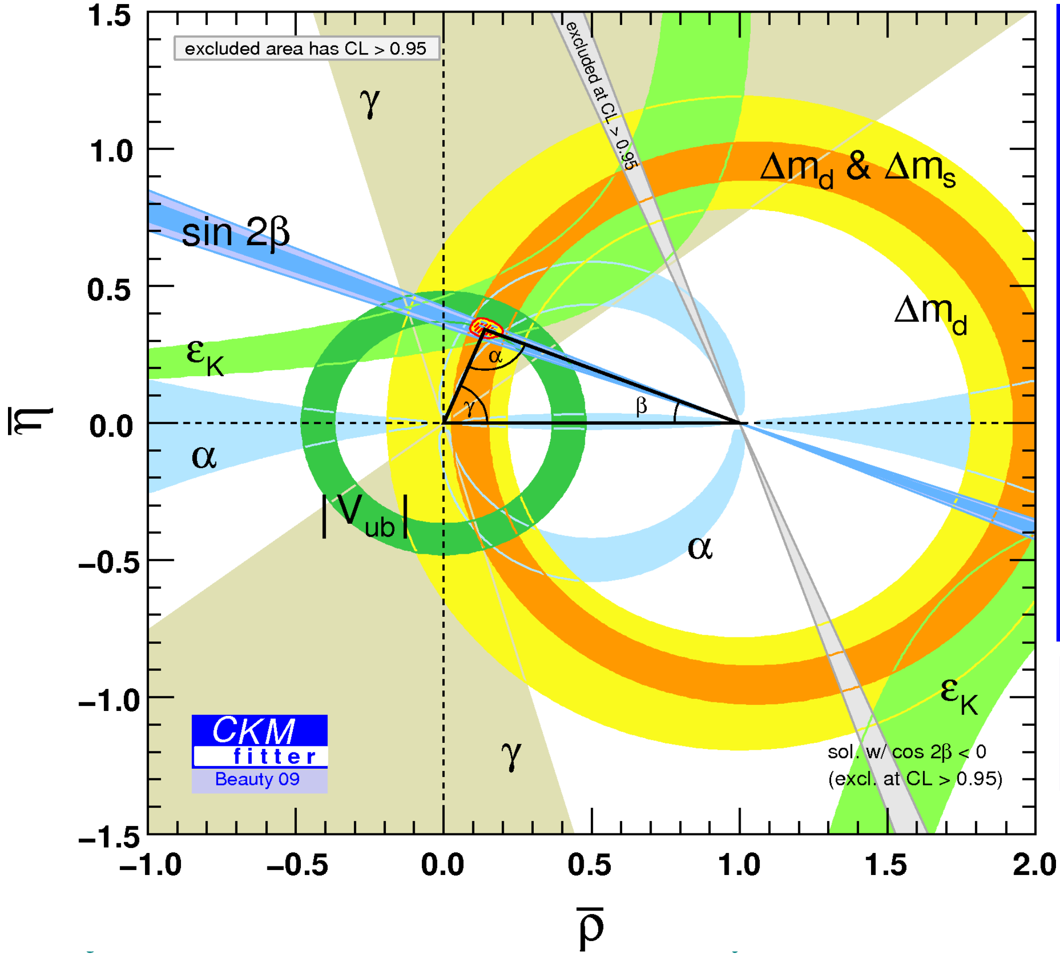


The CKM Unitarity predicts that all constraints intersect at a point!

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

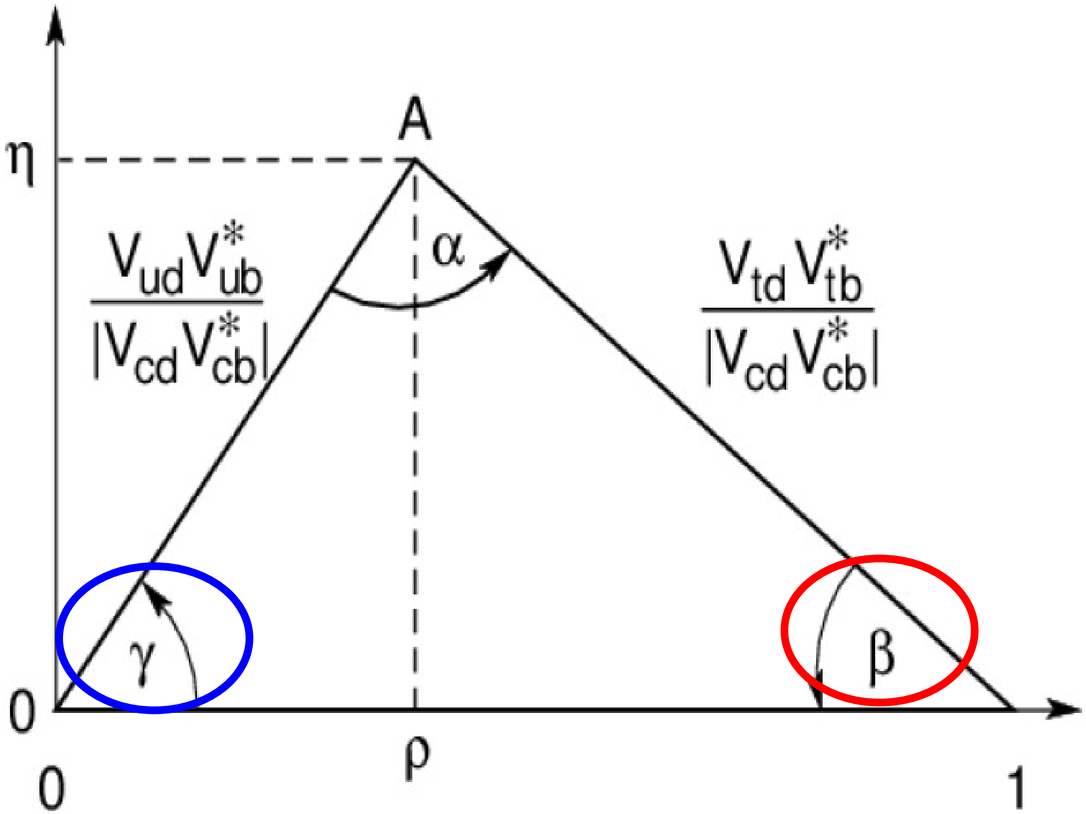
CKMfitter Group (J. Charles et al.), Eur. Phys. J. C41, 1-131 (2005) [hep-ph/0406184], updated results and plots available at: http://ckmfitter.in2p3.fr

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

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

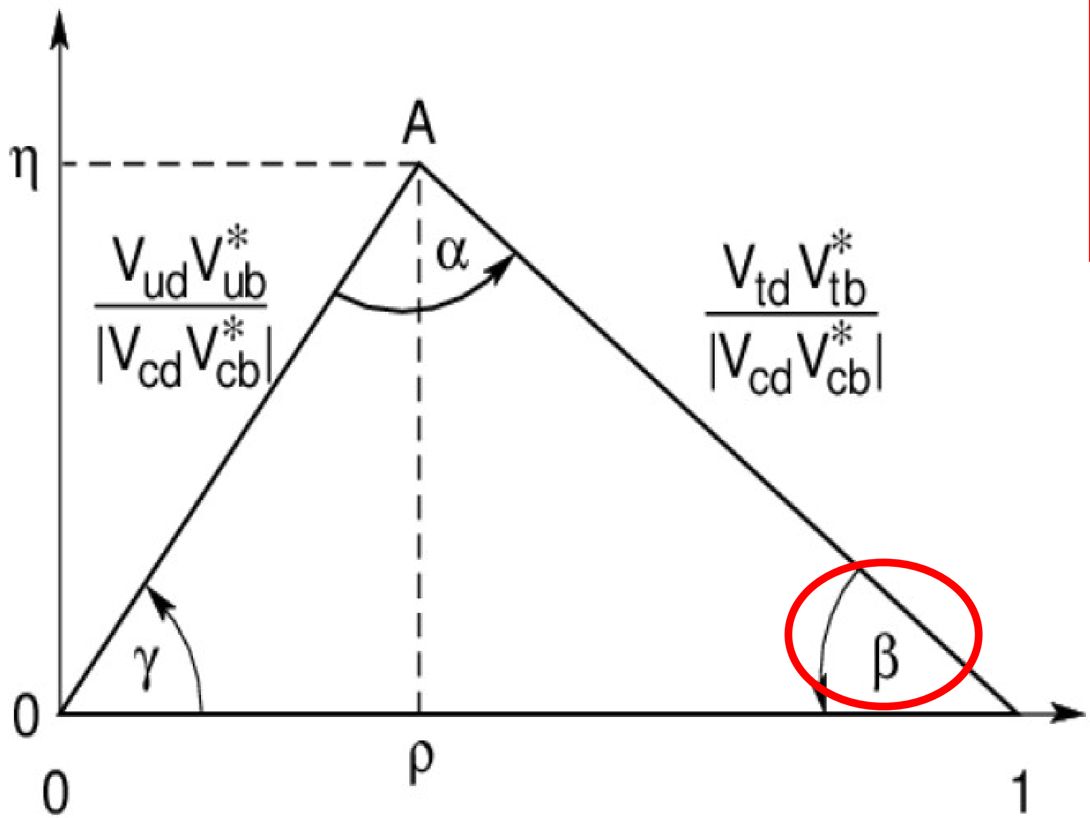
Motivations



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)



Standard Model (SM)

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

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

New Physics (NP)

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

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

Penguin dominated modes

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

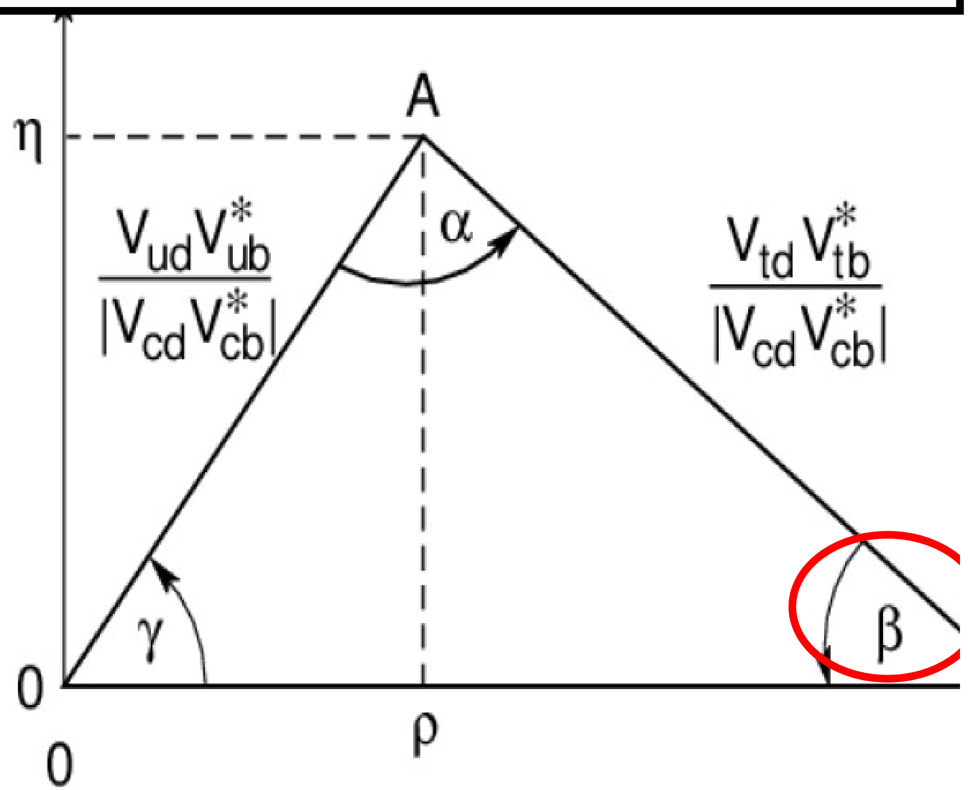
contribute $B^0 \rightarrow K^0_s \pi^+ \pi^-$

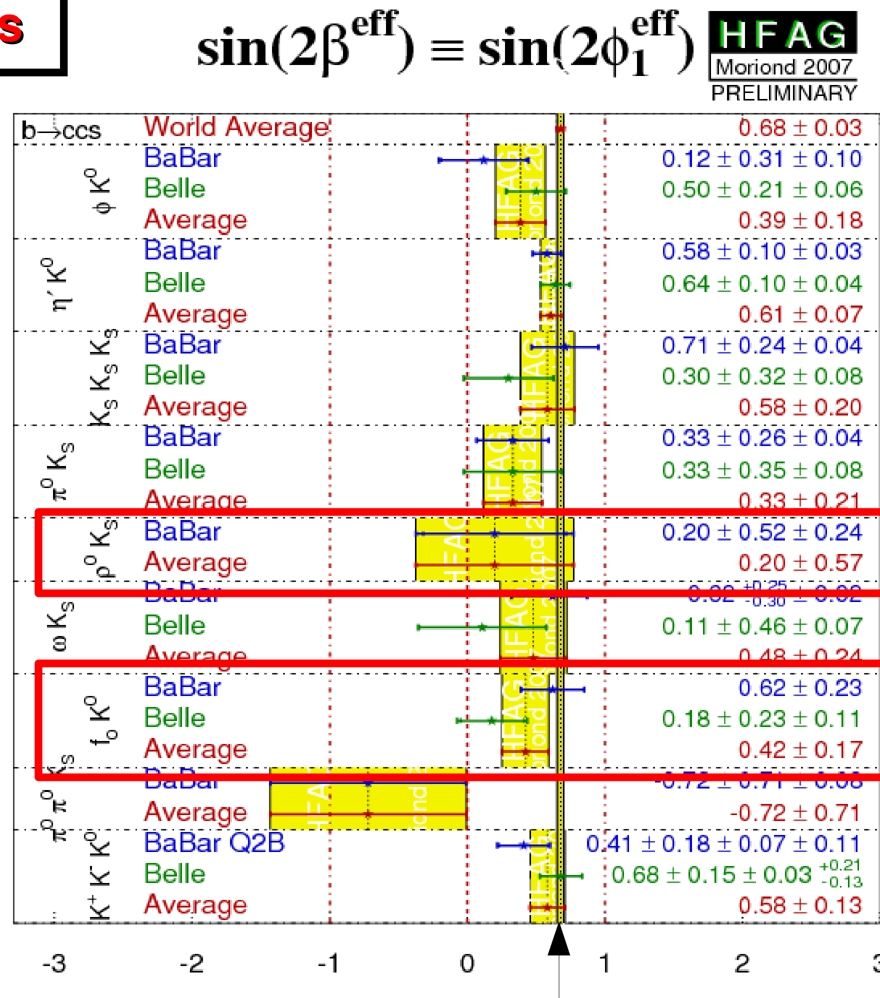
Motivations

New physics in penguin dominated modes

- **Theo: predicts higher values than b→ccs**
- **Expe: systematically shifter to low values**

Hint: a place to look for NP?





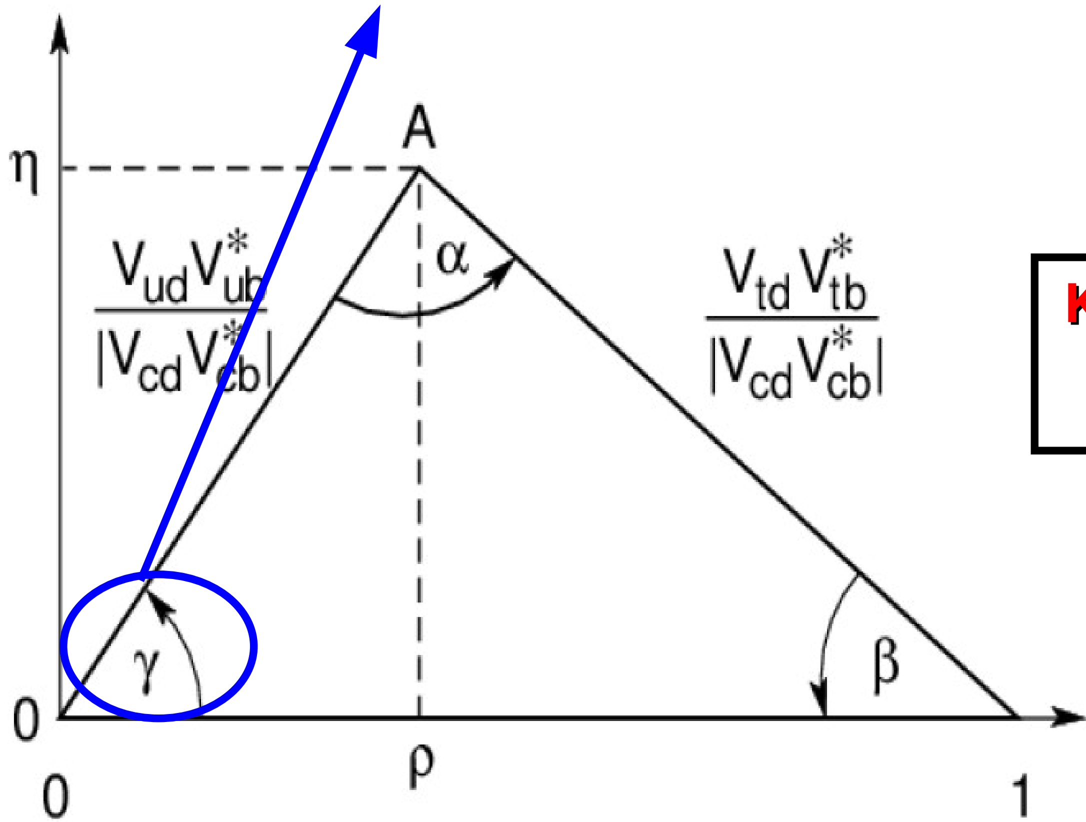
b →ccs value

Motivations

CPS/GPSZ method:

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

CPS PRD74:051301
GPSZ PRD75:014002



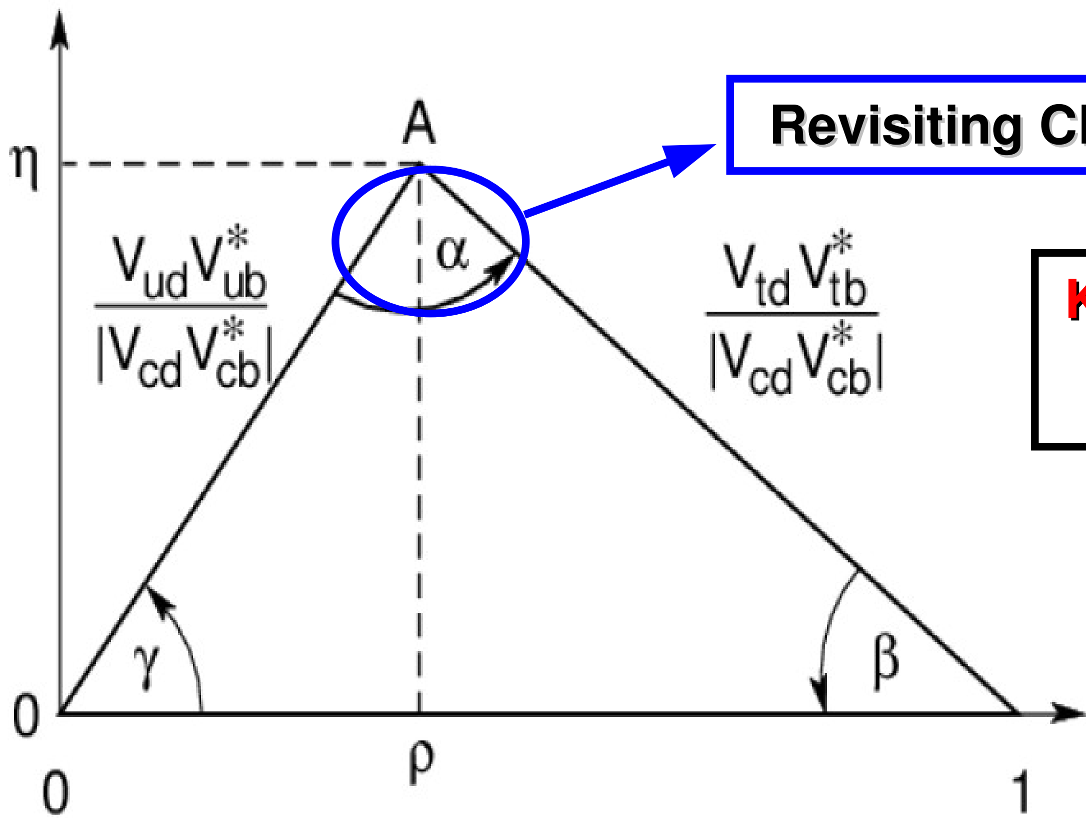
$K^{*+}(892)\pi^{-}$ contribution to $B^{0} \rightarrow K^{0}_{S}\pi^{+}\pi^{-}$

Motivations

CPS/GPSZ method:

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

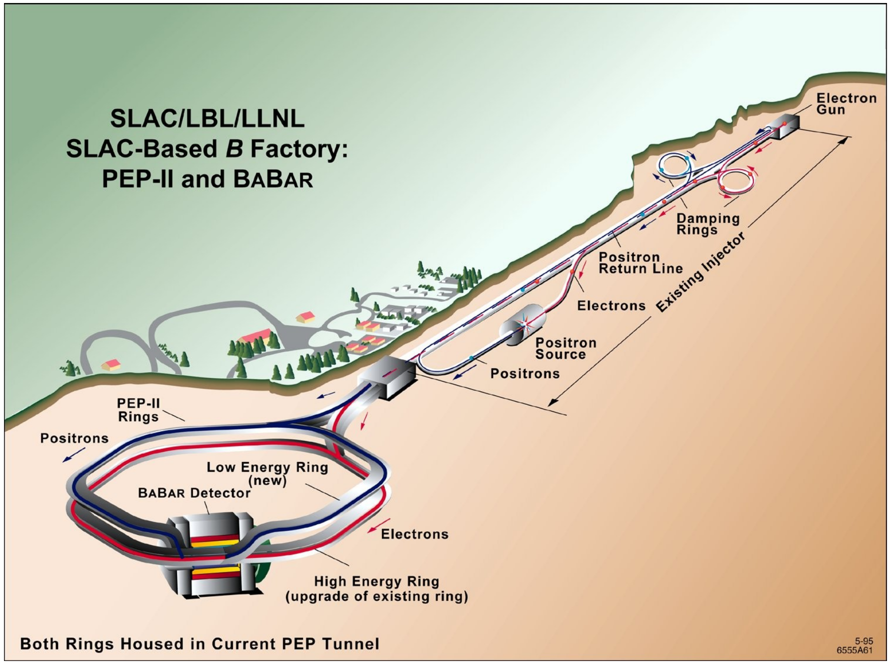
CPS PRD74:051301
GPSZ PRD75:014002



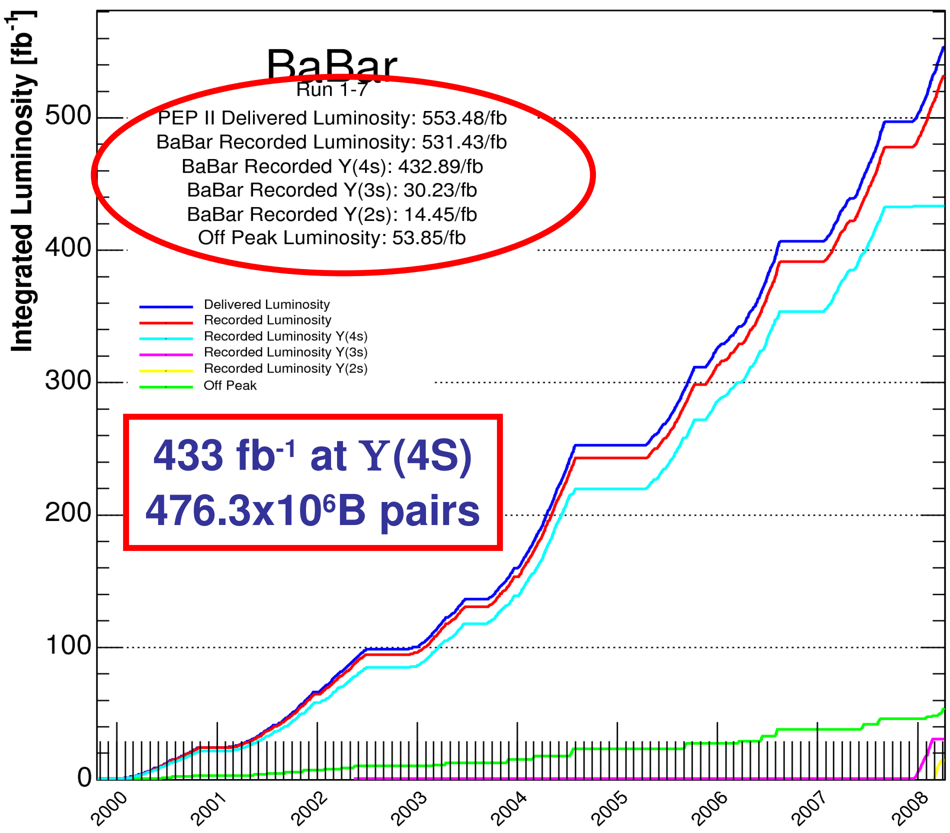
Revisiting CPS/GPSZ: access to α

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

PEP-II: a B factory at SLAC



As of 2008/04/11 00:00



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

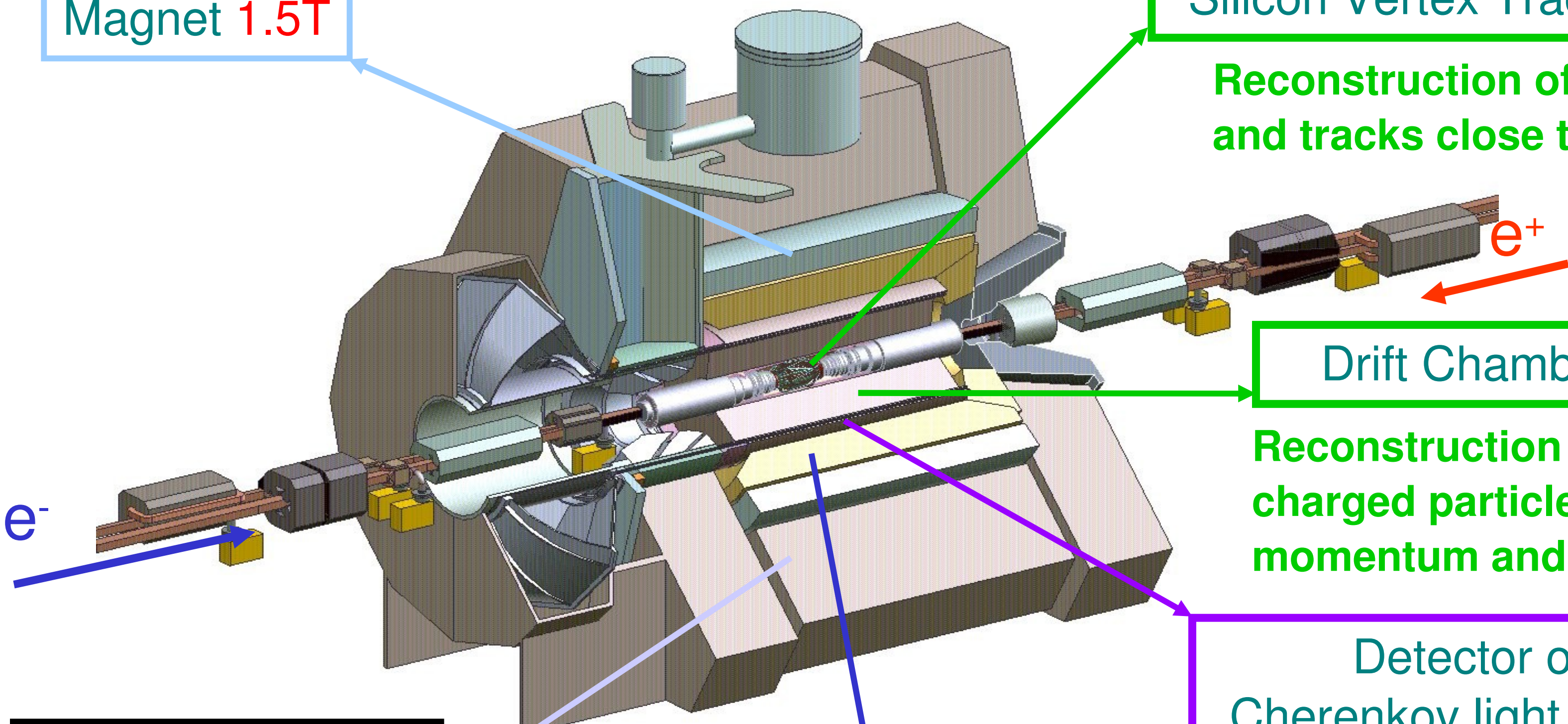
- **On-Peak: $\sqrt{s}$ at the $\Upsilon(4S)$ peak**
- **Off-Peak: $\sqrt{s}$ 40 MeV below**

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 >2.5σ 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

Time-dependent amplitude analyses

- Counting rate analyses → signal identification

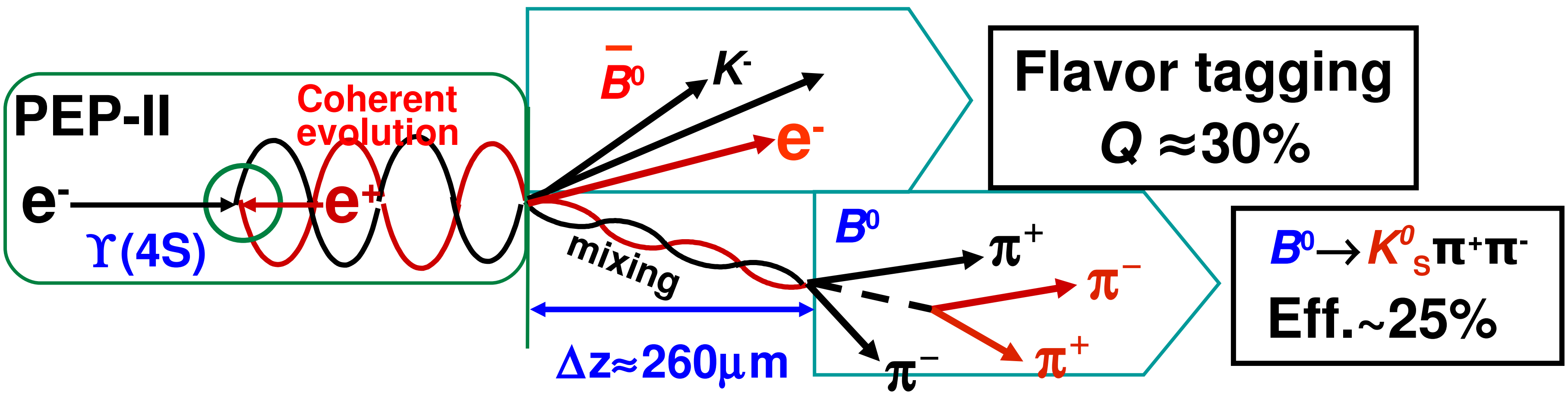
- Time-dependent analyses → time-evolution of signal

- Amplitude analyses → Interference of signal

- **Time-dependent amplitude analyses →**
  time-evolution of signal interference

Δt measurement and flavor tagging

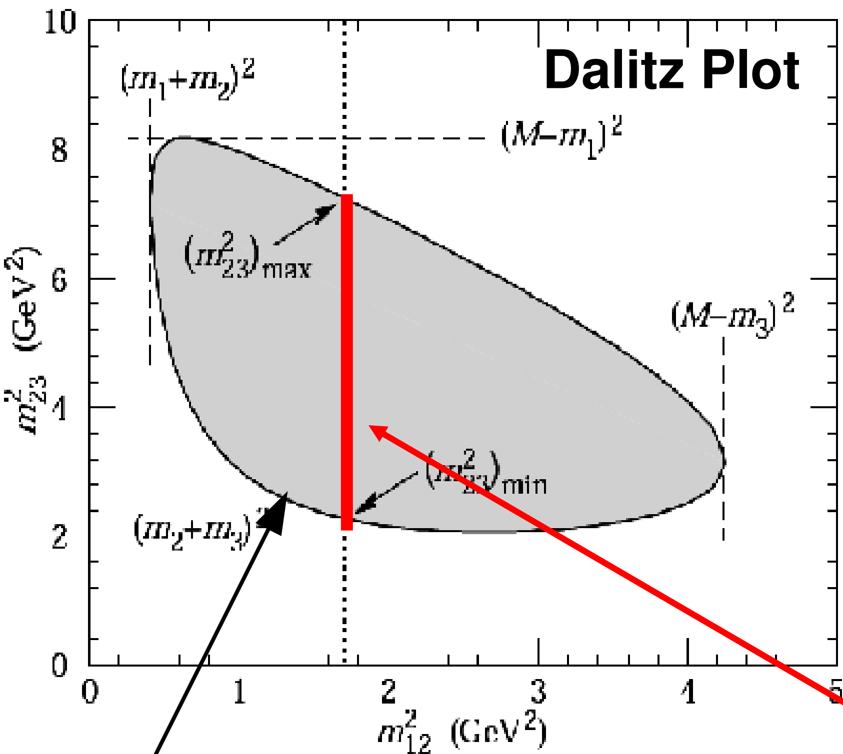
- Neutral B mesons produced in a coherent B^0-$\bar{B}^0$ state
- Flavor tagging with B partner
- Δt extracted from Δz measurement ($\Delta t \approx \Delta z \gamma\beta$)

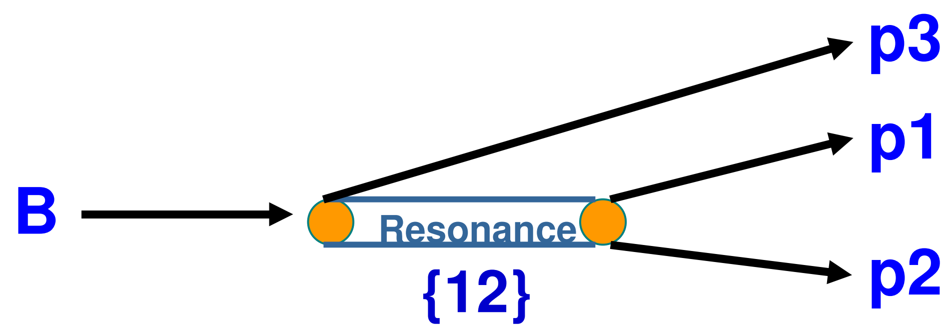


Dalitz Plot (DP)

Tree-body decays described by two parameters:

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





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

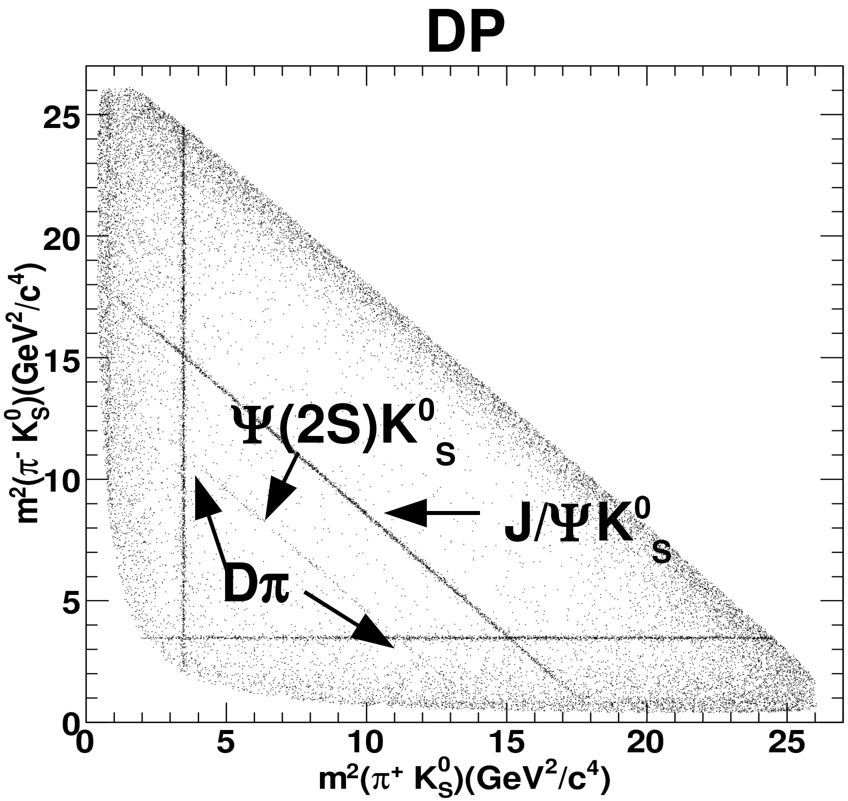
$$P_{res} \rightarrow p_1 + p_2$$

Kinematic boundary

(Distribution around resonance mass)

Data Set

- Run 1-5: 347.3 fb^{-1} → 382.9×10^6 $B\bar{B}$ pairs.
- Reconstruction and Selection → 22525 events
- Overall signal efficiency → 25%



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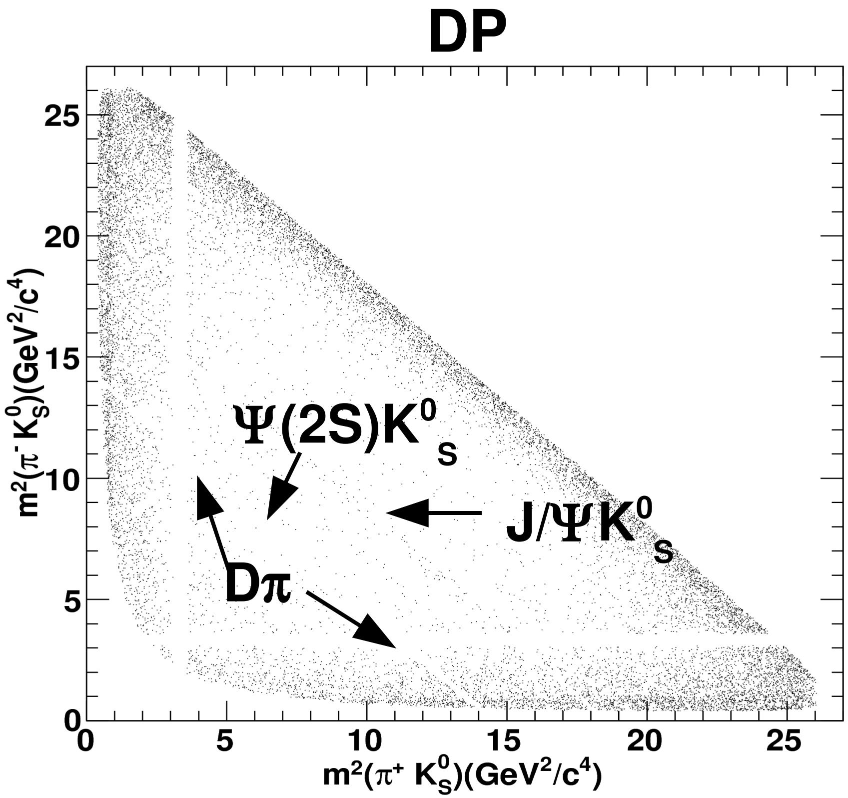

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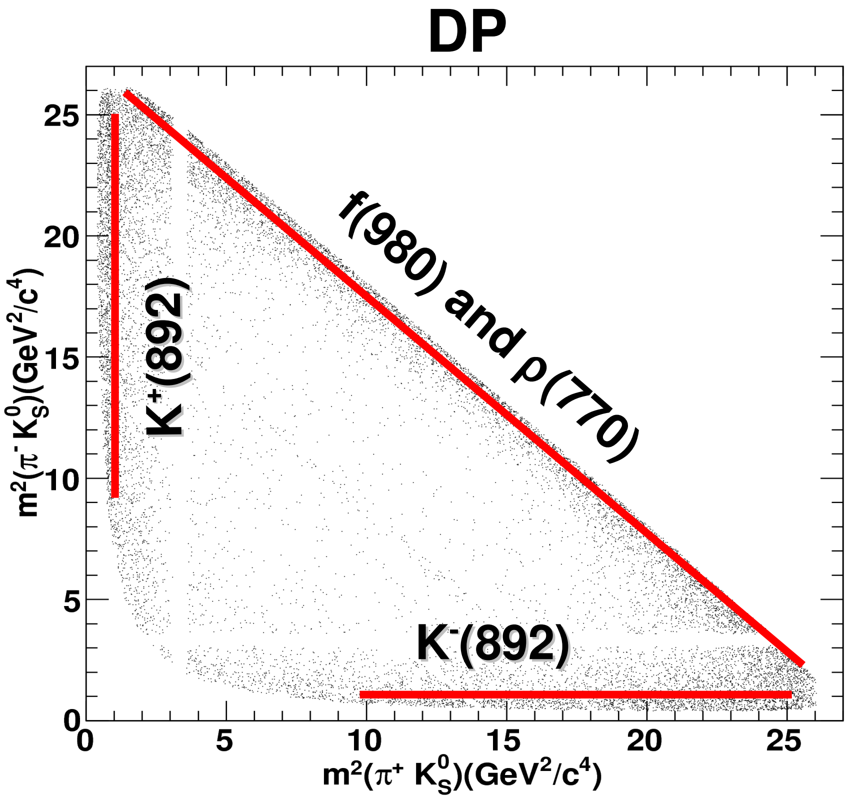

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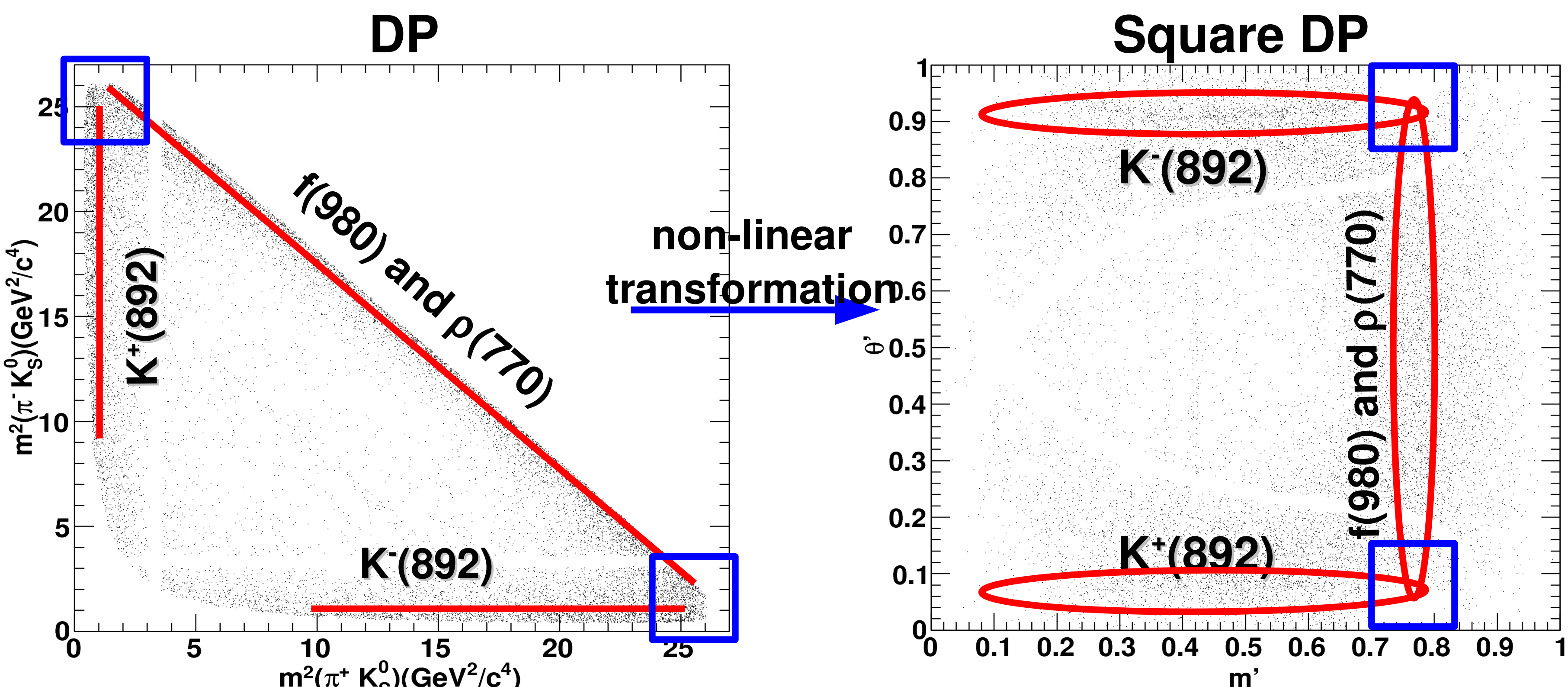

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- Run 1-5: 347.3 fb^{-1} → 382.9x10^6 $B\bar{B}$ pairs.
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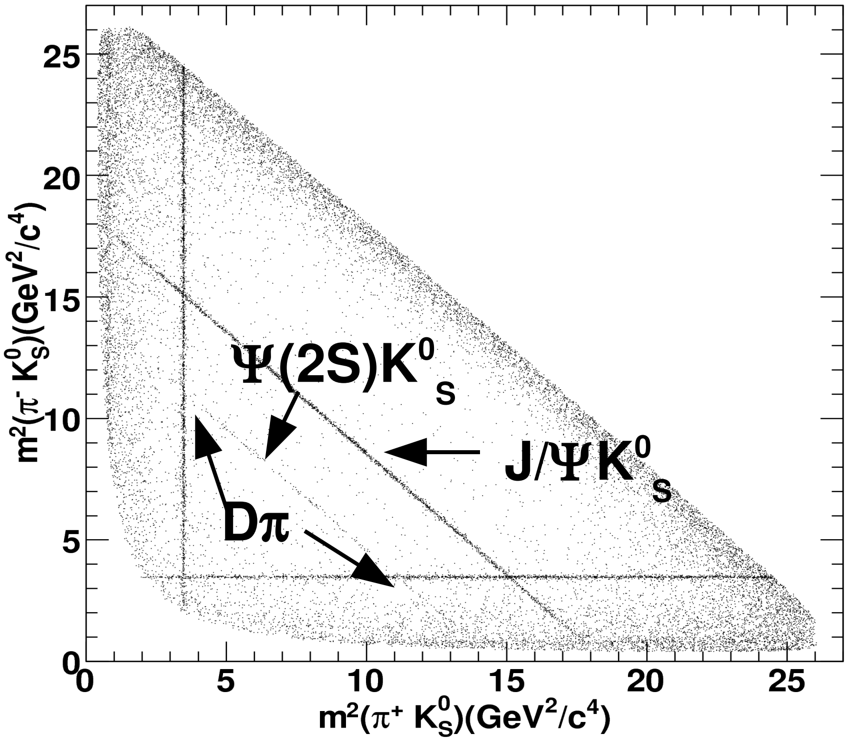
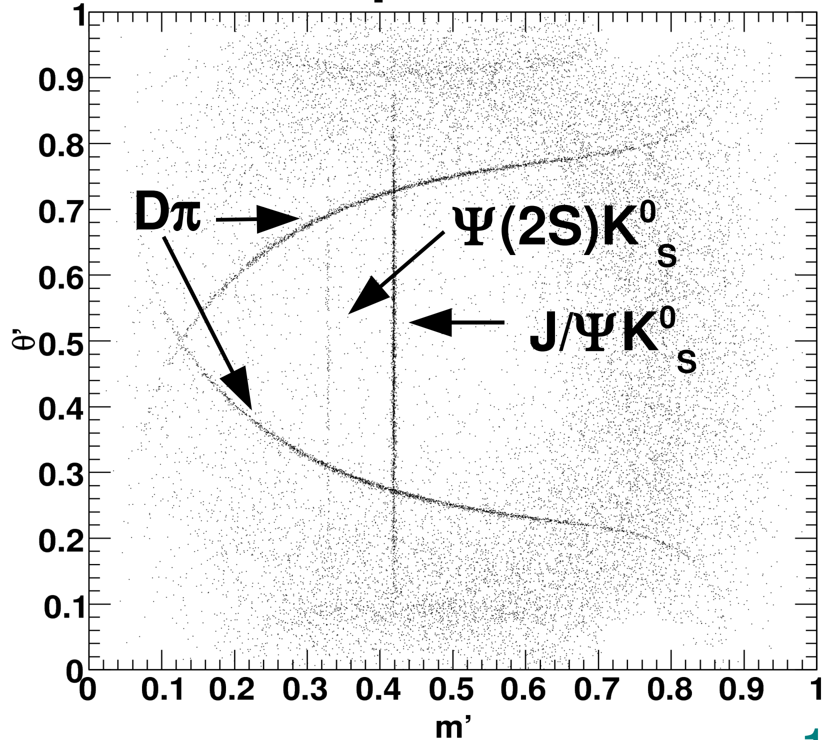
DP



Square DP



Likelihood Function

The Likelihood Function

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

Likelihood Function

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Continuum Component

Likelihood Function

The Likelihood Function

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B-background Components

Likelihood Function

The Likelihood Function

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

Signal Component

Truth-Match (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**

Decay amplitude parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot
Isobar Model

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

Decay amplitude parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot
Isobar Model

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

Isobar amplitudes:

Weak phases information

Decay amplitude 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

Decay amplitude 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

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

Lineshape

Kinematic function

Decay amplitude 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: **$K^*(892)\pi$**

Flatte: **$f_0(980)K$**

Gounaris-Sakurai (GS): **$\rho(770)K$**

S-wave $K\pi$: **LASS lineshape.**

Decay amplitude 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

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

Rela

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

Gou

S-wave Kπ: **LASS lineshape.**

Nucl. Phys., B296:493, 1988

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)**

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

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

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)

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

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

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

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

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

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)

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

mixing and decay CPV

DCPV

Complex amplitudes a_i and $\bar{a}_j$ determine DP interference pattern.
Module and phase con 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:

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

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

Phase differences:

$$2\beta^j_{\mathrm{eff}} = \arg[\,a_j\,\bar{a}_j^*\,(q/p)^*\,] \quad \Rightarrow f_0(980) \text{ and } \rho^0(770)$$

$$\Delta\varphi_{j\bar{j}} = \arg[\,a_j\,\bar{a}_{\bar{j}}^*\,(q/p)^*\,] \quad \Rightarrow K^*(892)\pi \text{ ("CPS phase")}$$

The phases accessed through interference over the DP

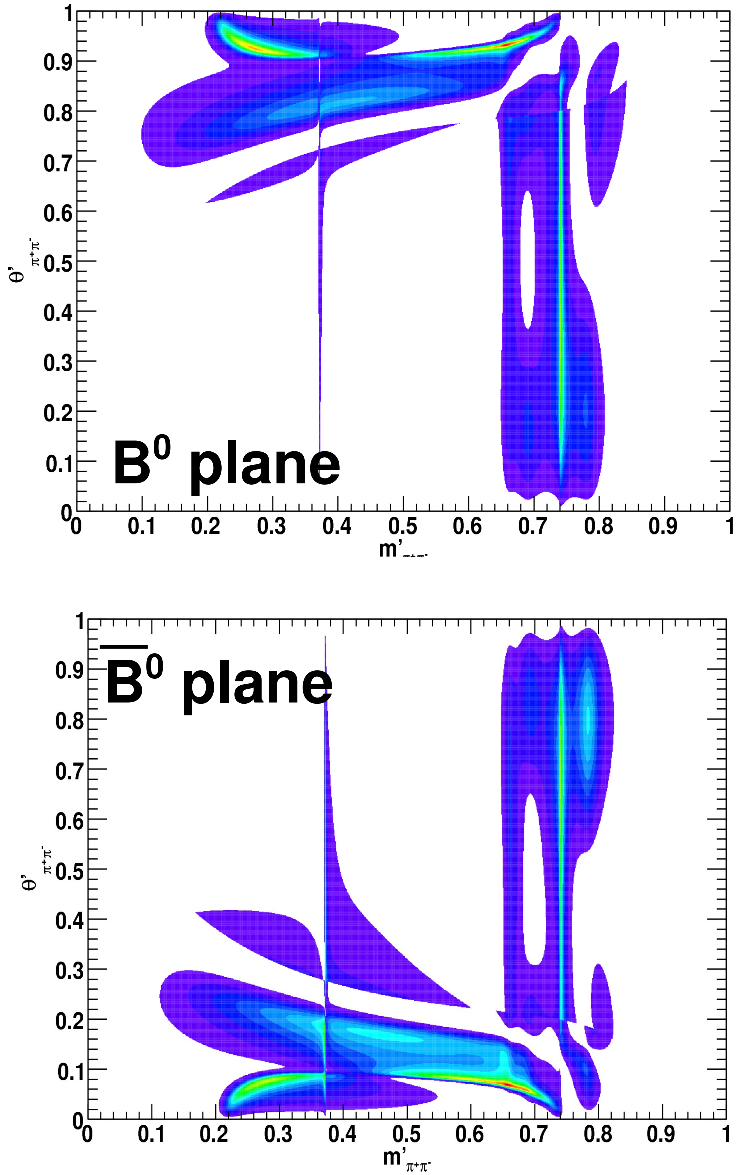
Nominal Signal Model

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)
- $B^0 \to f_2(1270) K^0_S$ (RBW)
- $B^0 \to \chi_{c0} K^0_S$ (RBW)

Common Signal Model for all BaBar $B \to K\pi\pi$ analyses

Square DP



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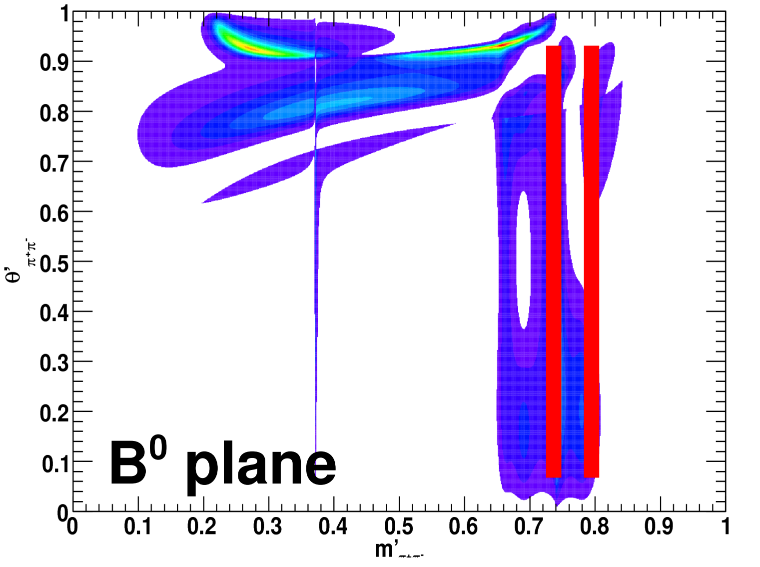

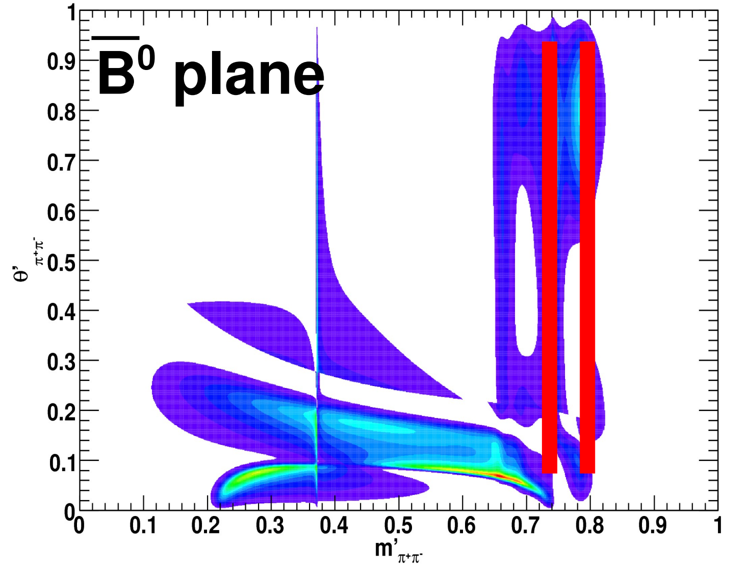

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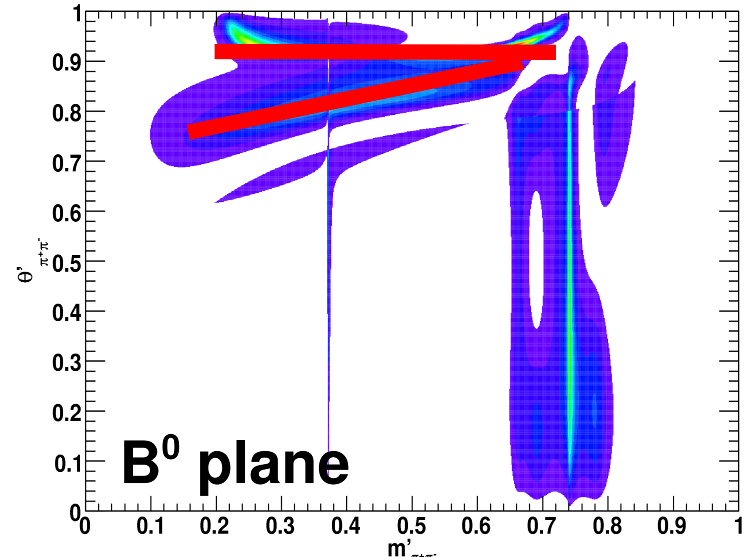
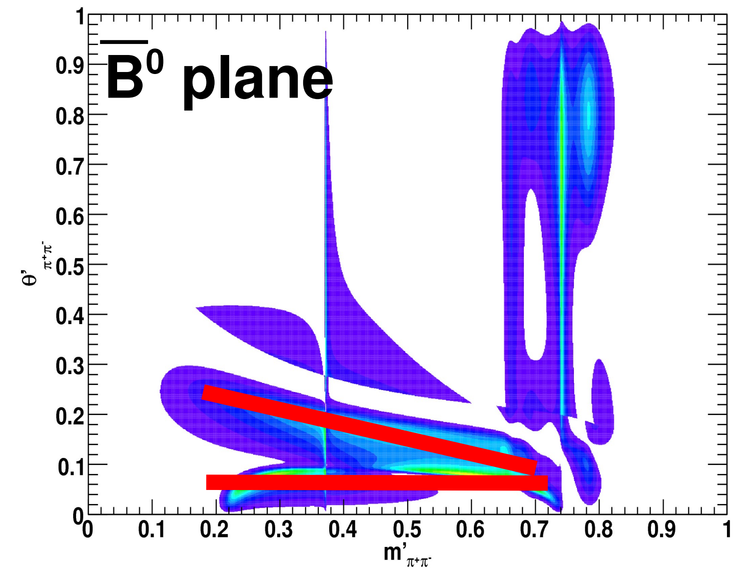
Common Signal Model for all BaBar $B\to K\pi\pi$ analyses

Square DP





Nominal Signal Model

Signal Model:

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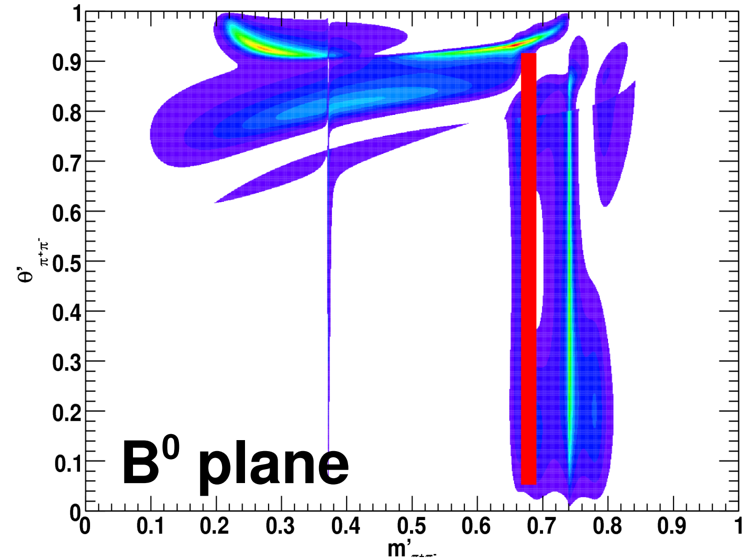
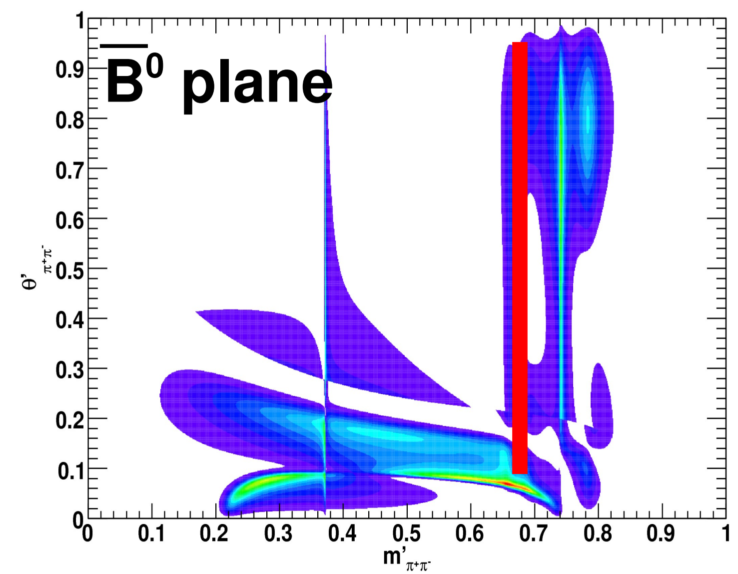
Common Signal Model for all BaBar $B \to K\pi\pi$ analyses

Square 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: 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$(B^0 \to J/\Psi K^0_s)$	1804 ± 44	1803 ± 43
N$(B^0 \to \eta' K^0_s)$	46 ± 16	44 ± 16
N$(B^0 \to \Psi(2S) K^0_s)$	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 ± 0.007 ps	0.018 ± 0.007 ps
$\sigma_{core}(\Delta t)$ Continuum	1.14 ± 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 ± 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 ± 0.9 ps	10.7 ± 0.8 ps

Find two solutions almost degenerated, differing by 0.16 in -2Log(L) units

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
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$\mu_{core}(\Delta E)$ Signal	[illegible]	[illegible]
$\sigma_{core}(\Delta E)$ Signal	[illegible]	[illegible]
$\mu_{tail}(\Delta E)$ Signal	[illegible]	[illegible]
$\sigma_{tail}(\Delta E)$ Signal	[illegible]	[illegible]
Slope(ΔE) Continuum	[illegible]	[illegible]
$\mu(m_{ES})$ Signal	[illegible]	[illegible]
$\sigma_L(m_{ES})$ 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
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Find two solutions almost degenerated, differing by 0.16 in -2Log(L) units

Non-Isobar parameters identical in both solutions

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
$A(K^{*+}(892)\pi^-)$	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
$A(f_X(1300)K_S^0)$	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

Fit Results: Isobar

Isobar Amplitude	$\|A\|$ Sol-I	$\phi[deg]$ Sol-I	$\|A\|$ Sol-II	$\phi[deg]$ Sol-II
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Moduli of isobar amplitudes similar in both solutions

(Mean differences in NR and minor components)

Fit Results: Isobar

Isobar Amplitude	$\lvert A\rvert$ Sol-I	$\phi[deg]$ Sol-I	$\lvert A\rvert$ Sol-II	$\phi[deg]$ Sol-II
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But some phases vary significantly!

Fit Results: Isobar

Isobar Amplitude	$\|A\|$ Sol-I	$\phi[deg]$ Sol-I	$\|A\|$ Sol-II	$\phi[deg]$ Sol-II
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$A(\rho(770)K^0_S)$	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
$A(K^{*+}(892)\pi^-)$	[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]
$A(f_X(1300)K^0_S)$	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

Ambiguity in resolving the interference pattern over the DP

But some phases vary significantly!

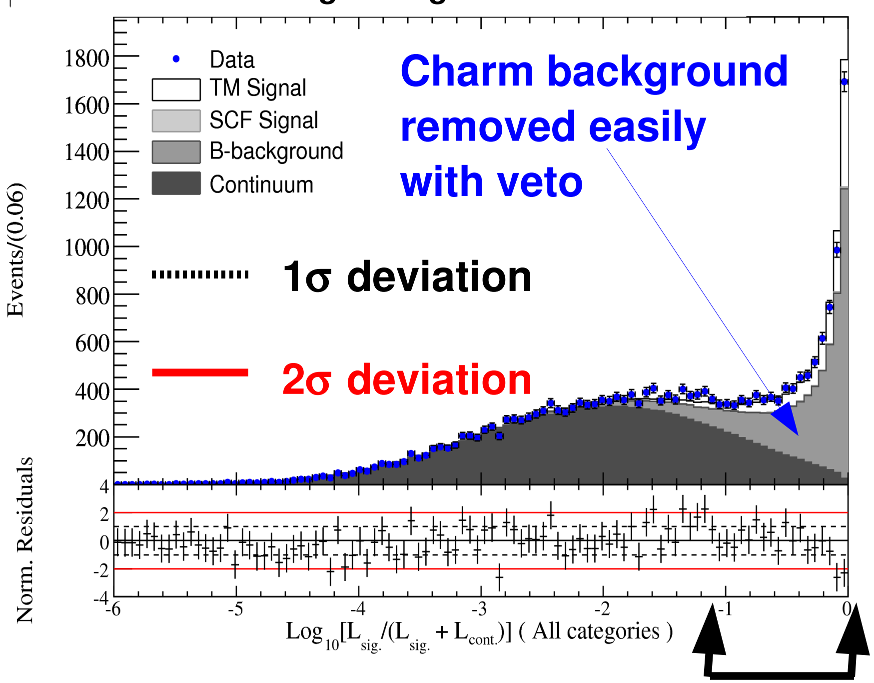
Goodness of Fit
(Projection Plots)

Fit Results: Proj. Plots (I)

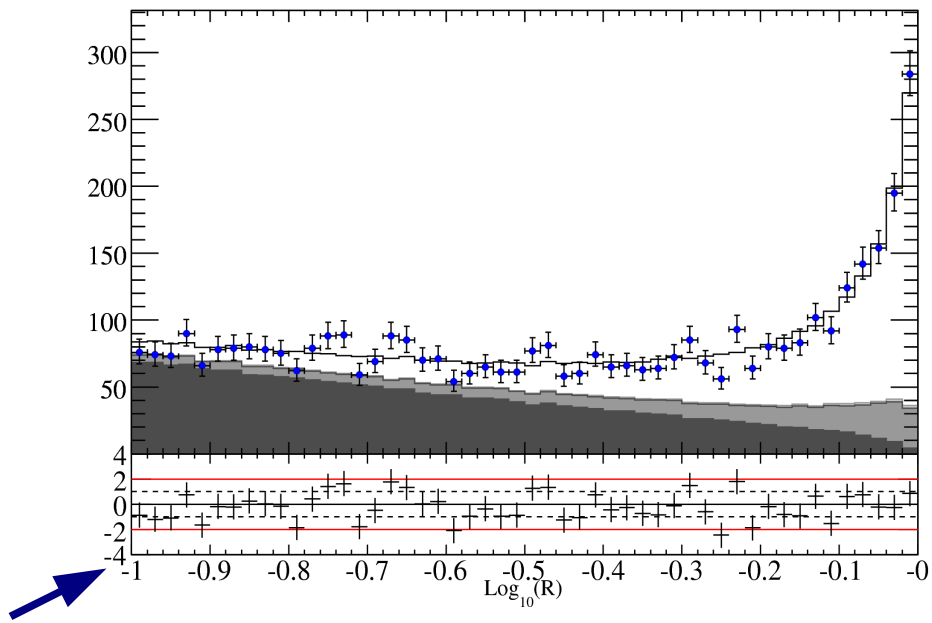
Likelihood Ratio

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

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



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



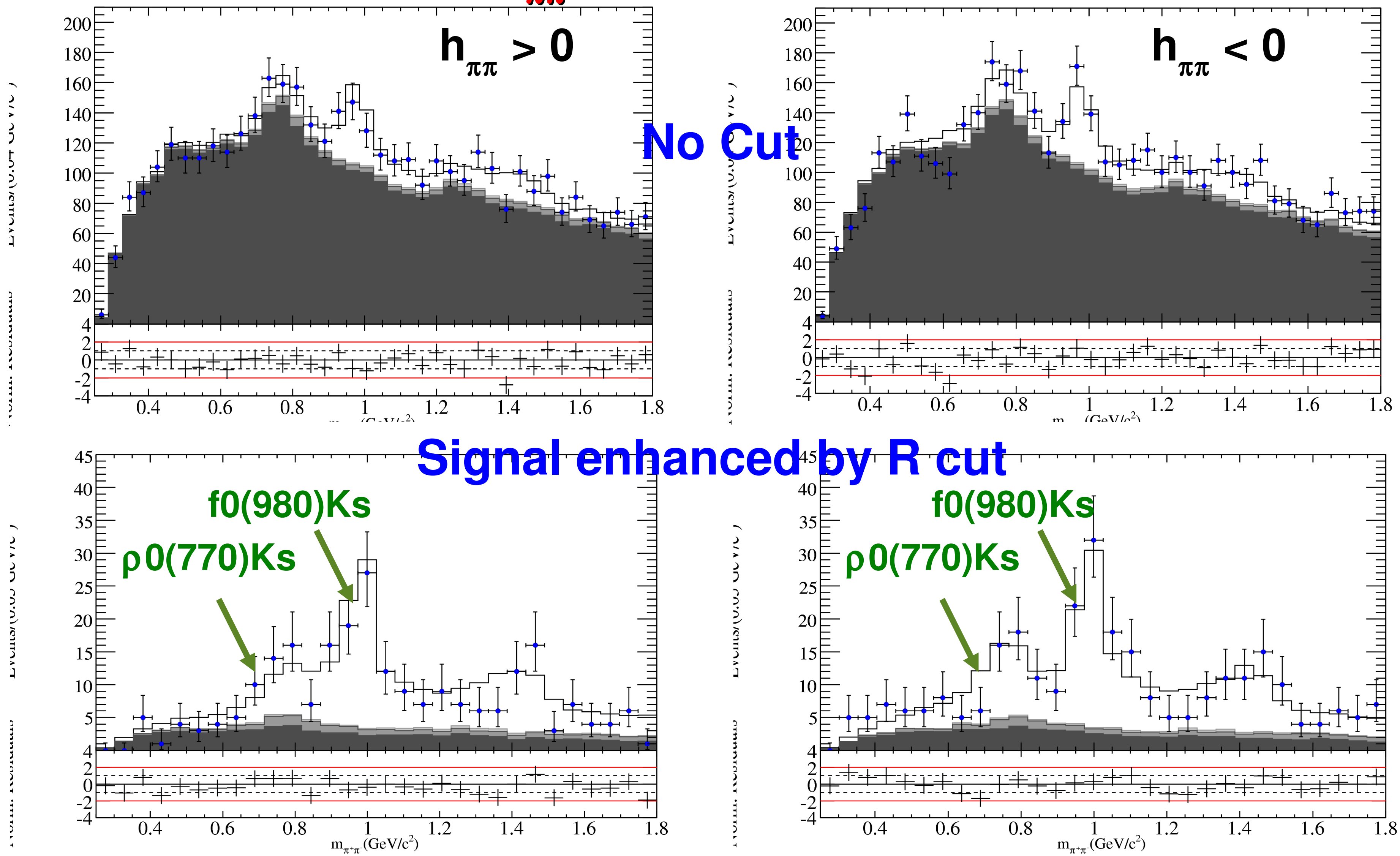
Zoom on the signal region

Veto on Charm Background

Fit Results: Proj. Plots (II)

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

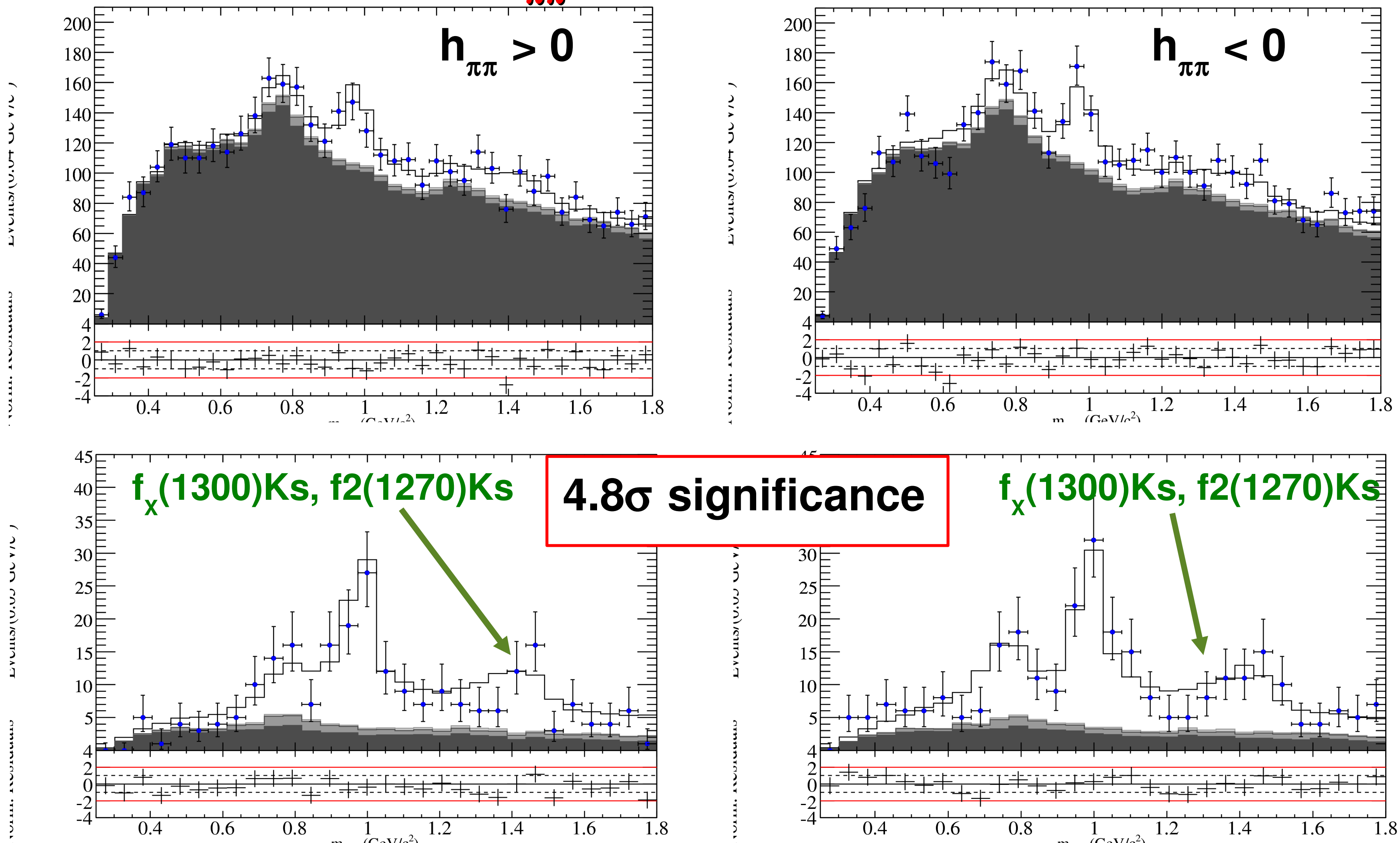
Dπ veto



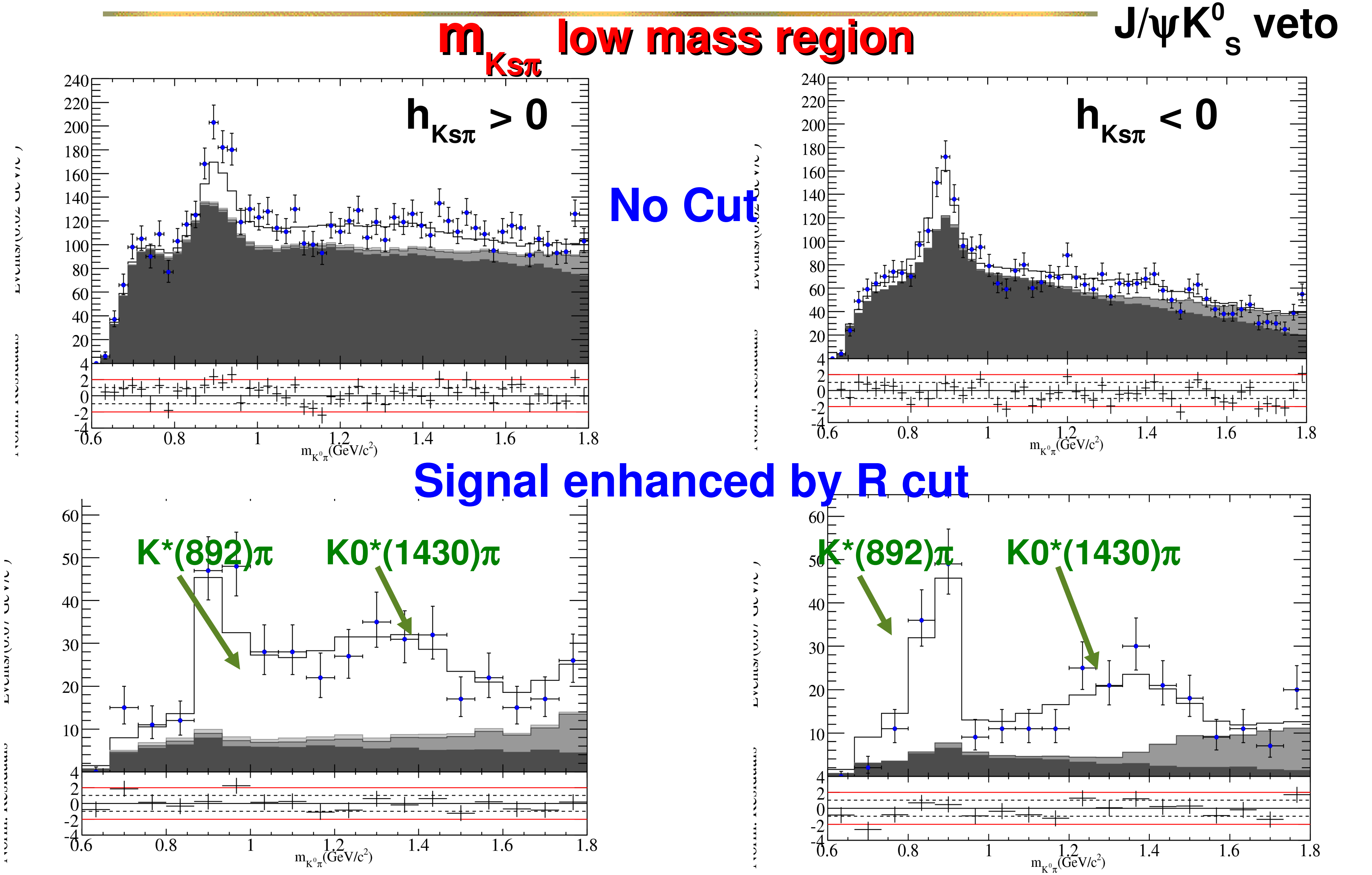
Fit Results: Proj. Plots (II)

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

$D\pi$ veto



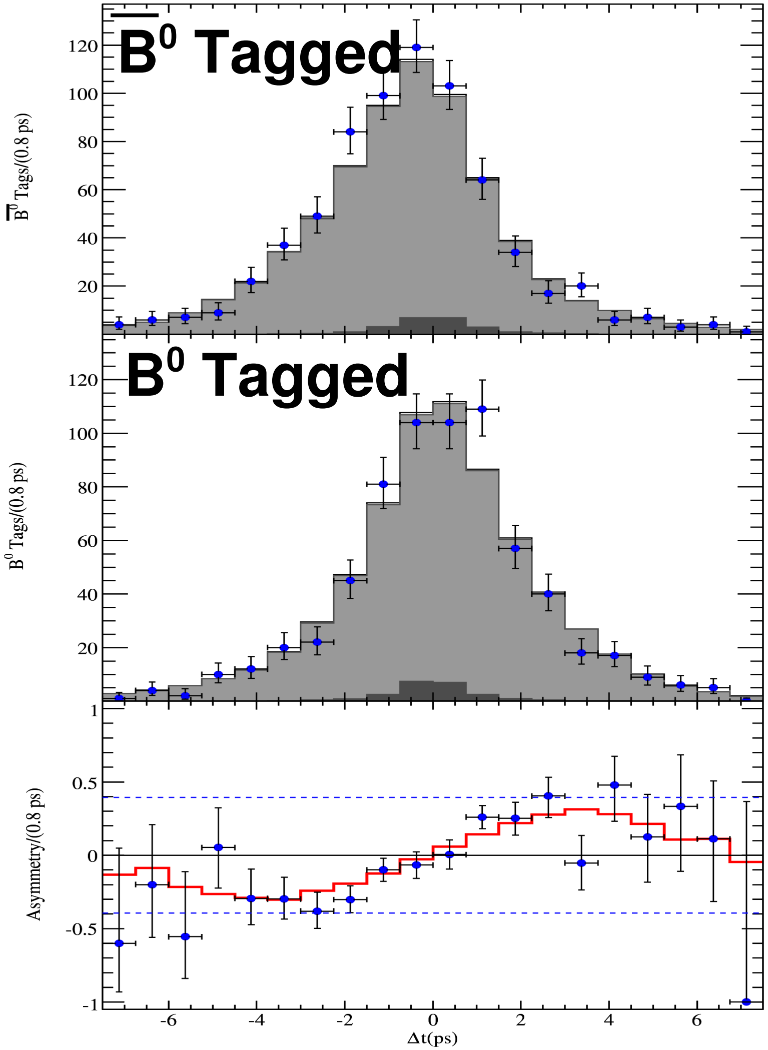
Fit Results: Proj. Plots (III)

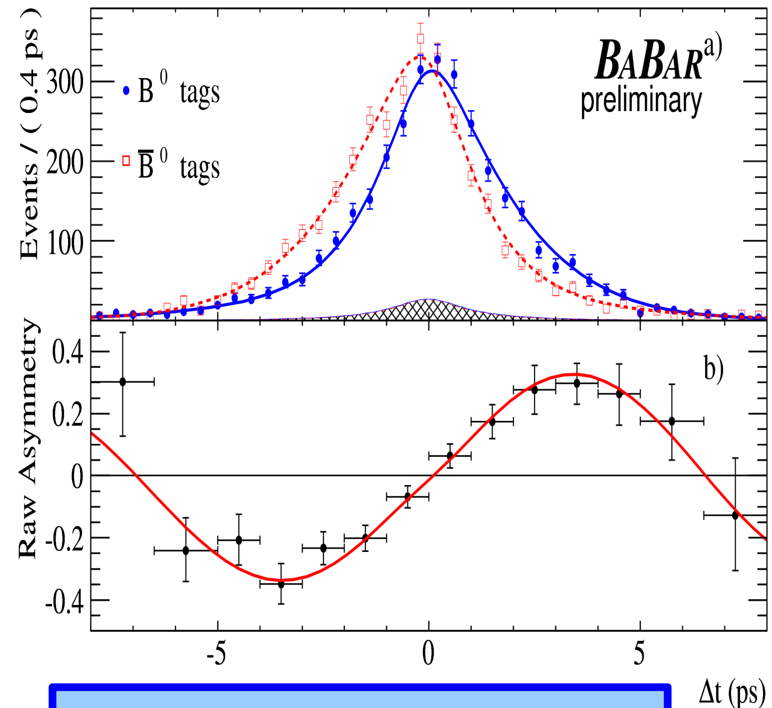


Fit Results: Proj. Plots (IV)

Δt dependent asymmetry:

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





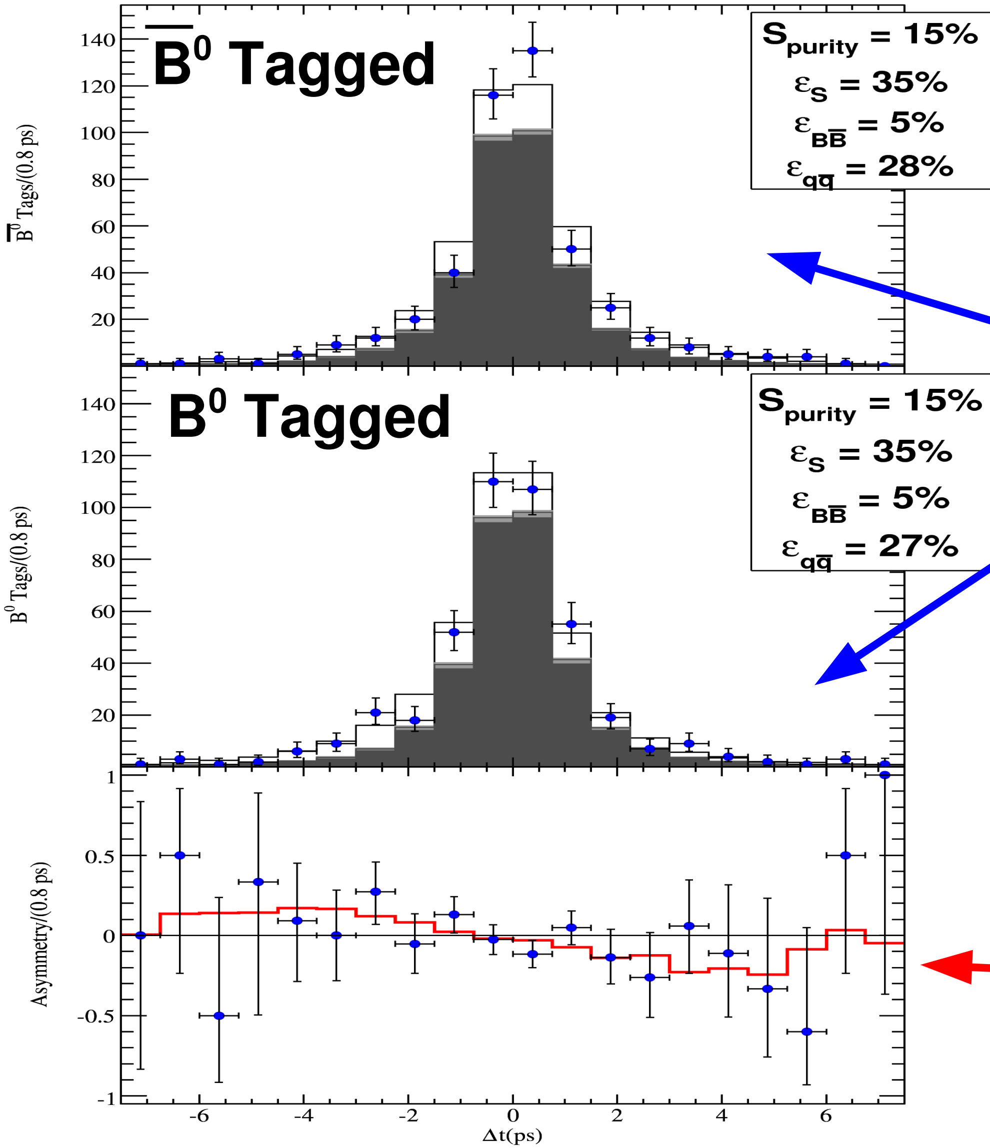
S = 0.660 ± 0.036 ± 0.012

Fit to our data gives:

S = 0.690 ± 0.077

Fit Results: Proj. Plots (V)

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



All Events in

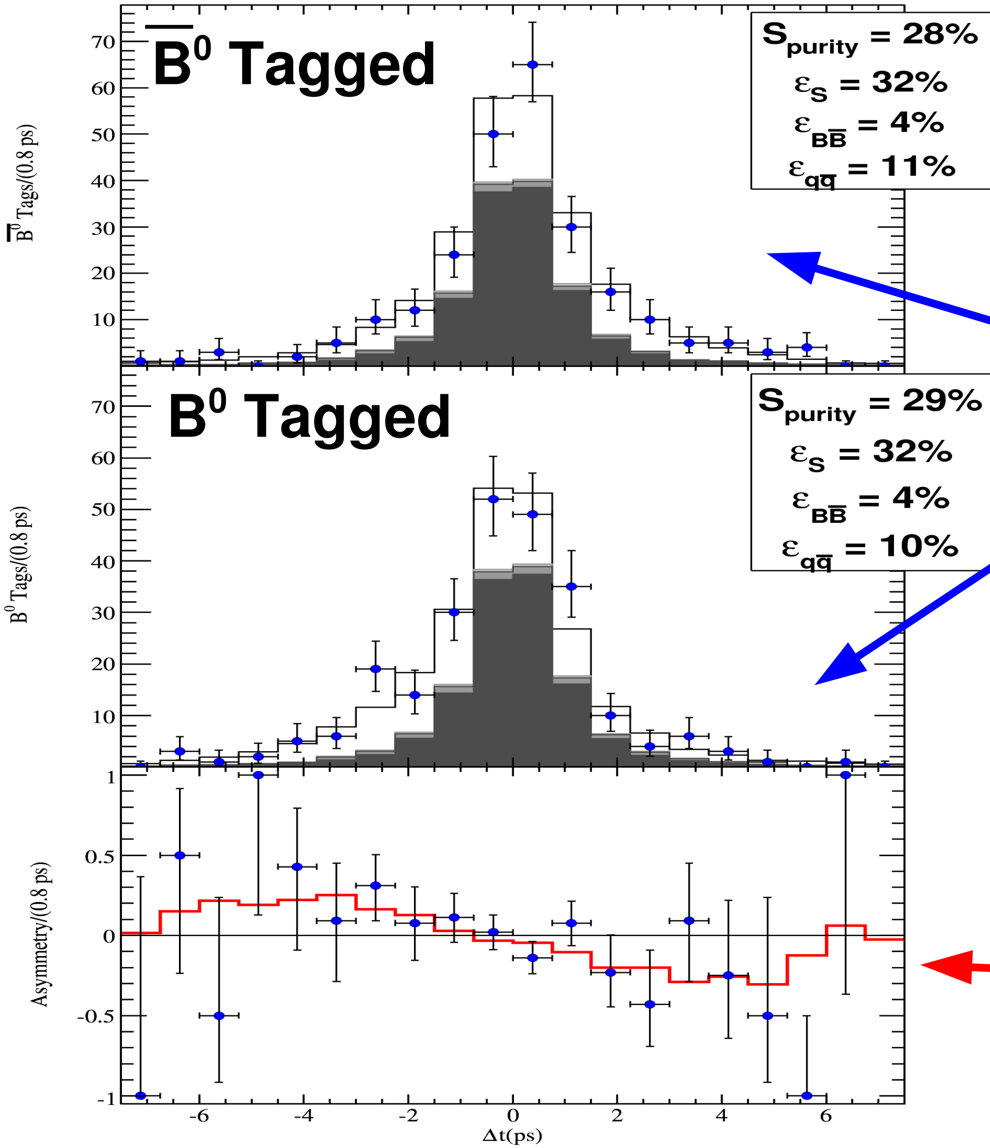
$0.86 < m_{\pi\pi} < 1.06$GeV

Time-dependent rate asymmetry

(diluted by large background)

Fit Results: Proj. Plots (V)

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



Signal enhanced

by R cut

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

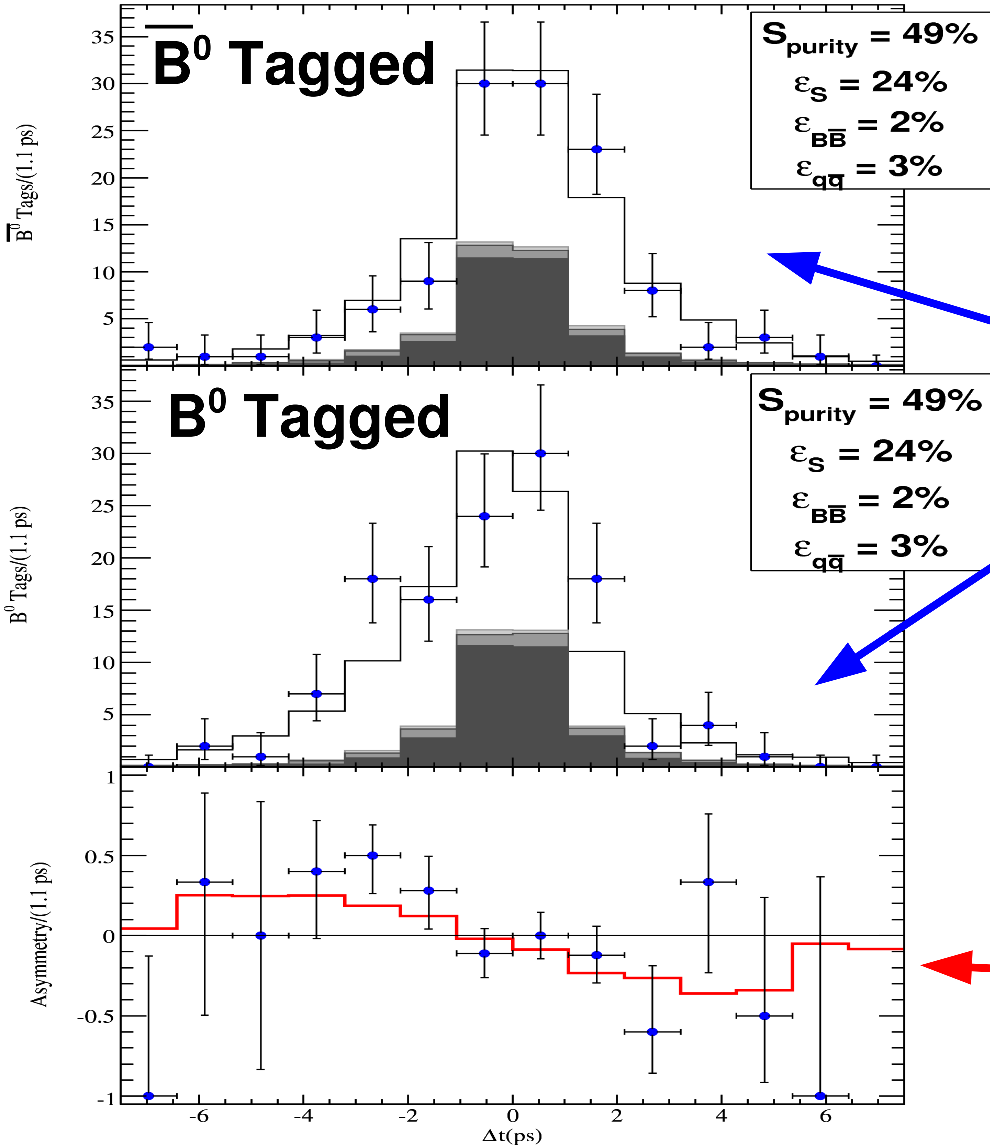
(Removed ~70% of qqbar)

Time-dependent rate asymmetry

(starts to be visible)

Fit Results: Proj. Plots (V)

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



Signal enhanced

by R cut

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

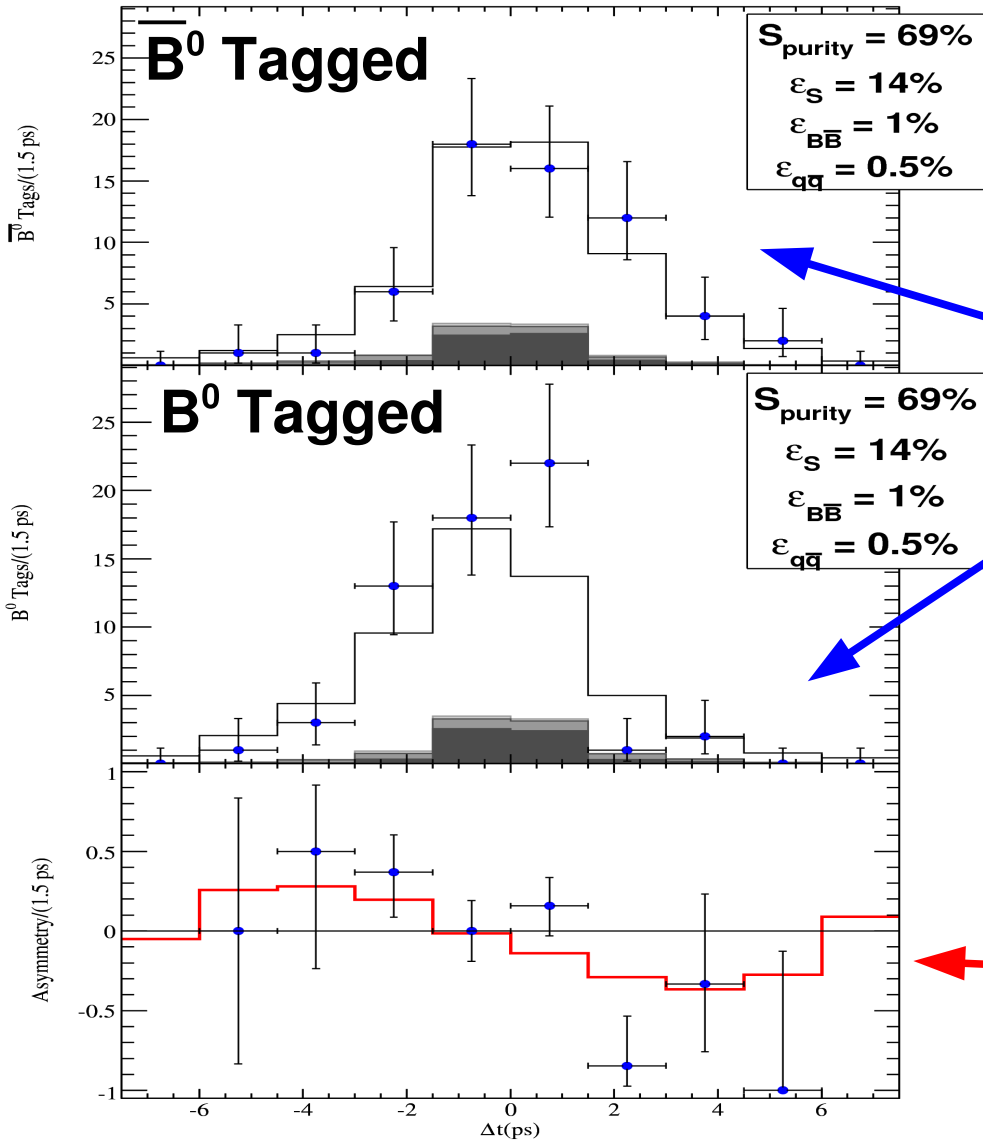
(Removed ~90% of qqbar)

Time-dependent rate asymmetry

(even more visible)

Fit Results: Proj. Plots (V)

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



Signal enhanced

by R cut

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

(Removed ~99% of qqbar, but also ~60% of signal)

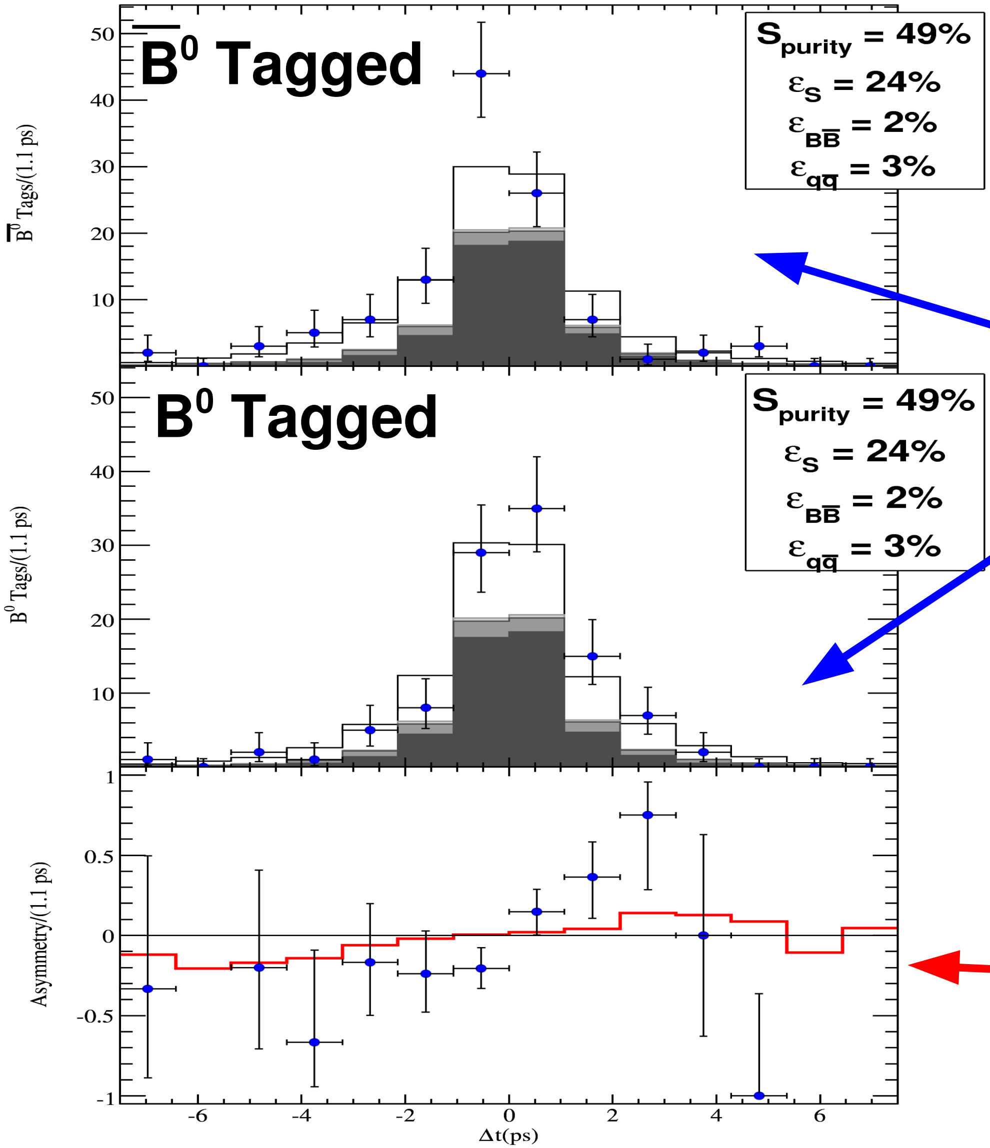
Time-dependent rate asymmetry

(even more visible,

too tight on signal now)

Fit Results: Proj. Plots (VI)

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



Signal enhanced

by R cut

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

(Removed ~97% of qqbar)

Time-dependent rate asymmetry

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

Results on physical observables

Fit Results: Measured observables

- "Counting rate like":

  - 9 BFs $\rightarrow$ 8 exclusive and 1 inclusive

  - 9 A_{CP} $\rightarrow$ 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")

  - $\Delta\phi \rightarrow K^*(892)\pi$

Fit Results: Measured observables

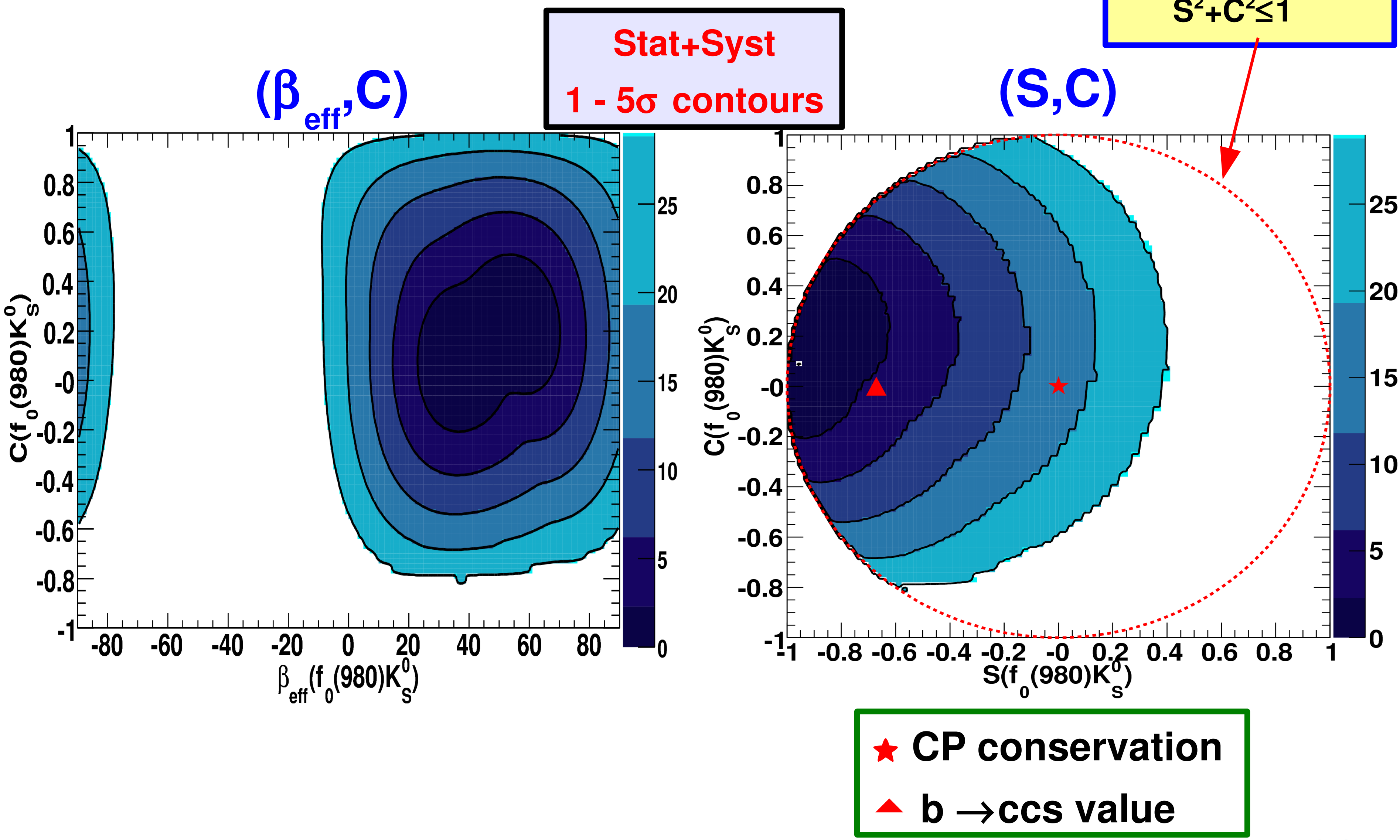
- "Counting rate like":
  - 9 BFs $\rightarrow$ 8 exclusive and 1 inclusive
  - 9 A_{CP} $\rightarrow$ 8 exclusive and 1 inclusive

- 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")
  - $\Delta\phi$ $\rightarrow$ $K^*(892)\pi$

Fit Results: (β_{eff},C) f_0(980)Ks



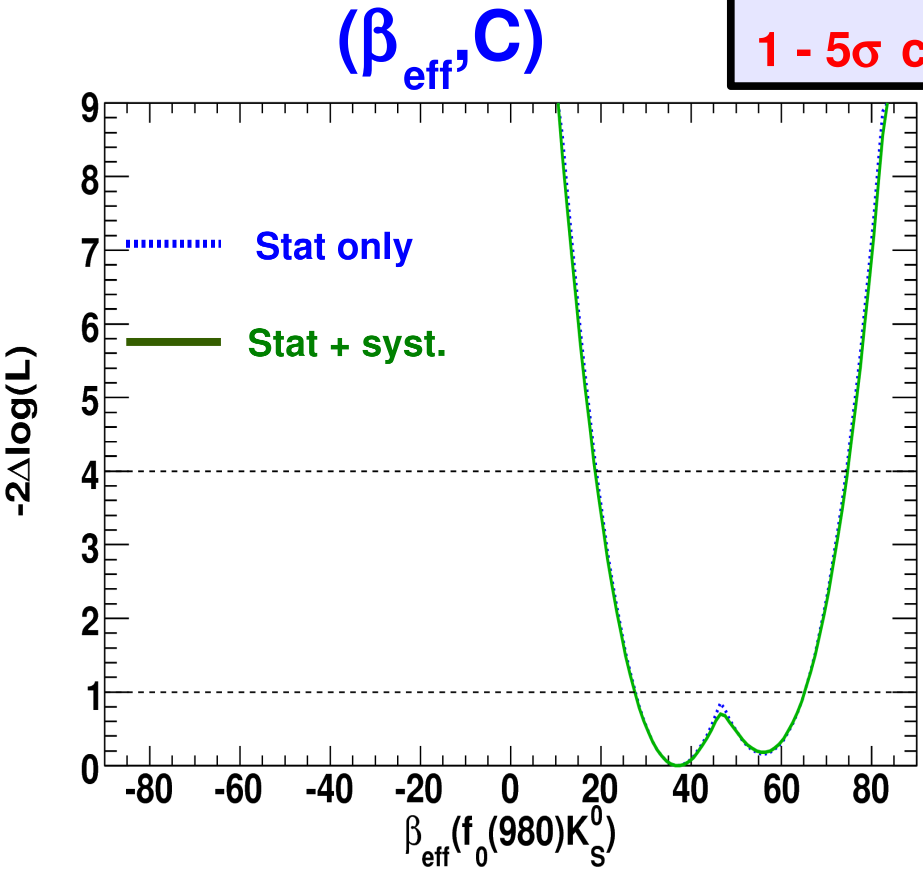
Fit Results: (β_{eff},C) f_0(980)Ks

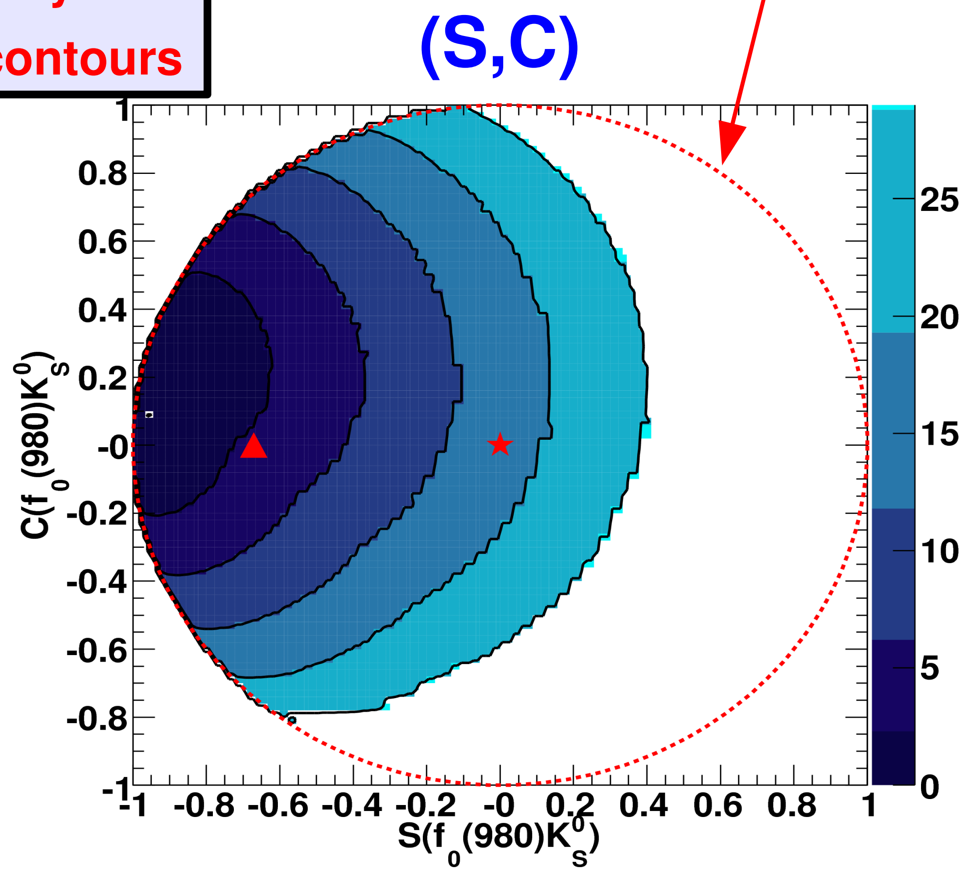
Stat+Syst

1 - 5σ contours

Physical region:

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





Does not resolve trigonometrical ambiguity above and below 45°

★ CP conservation

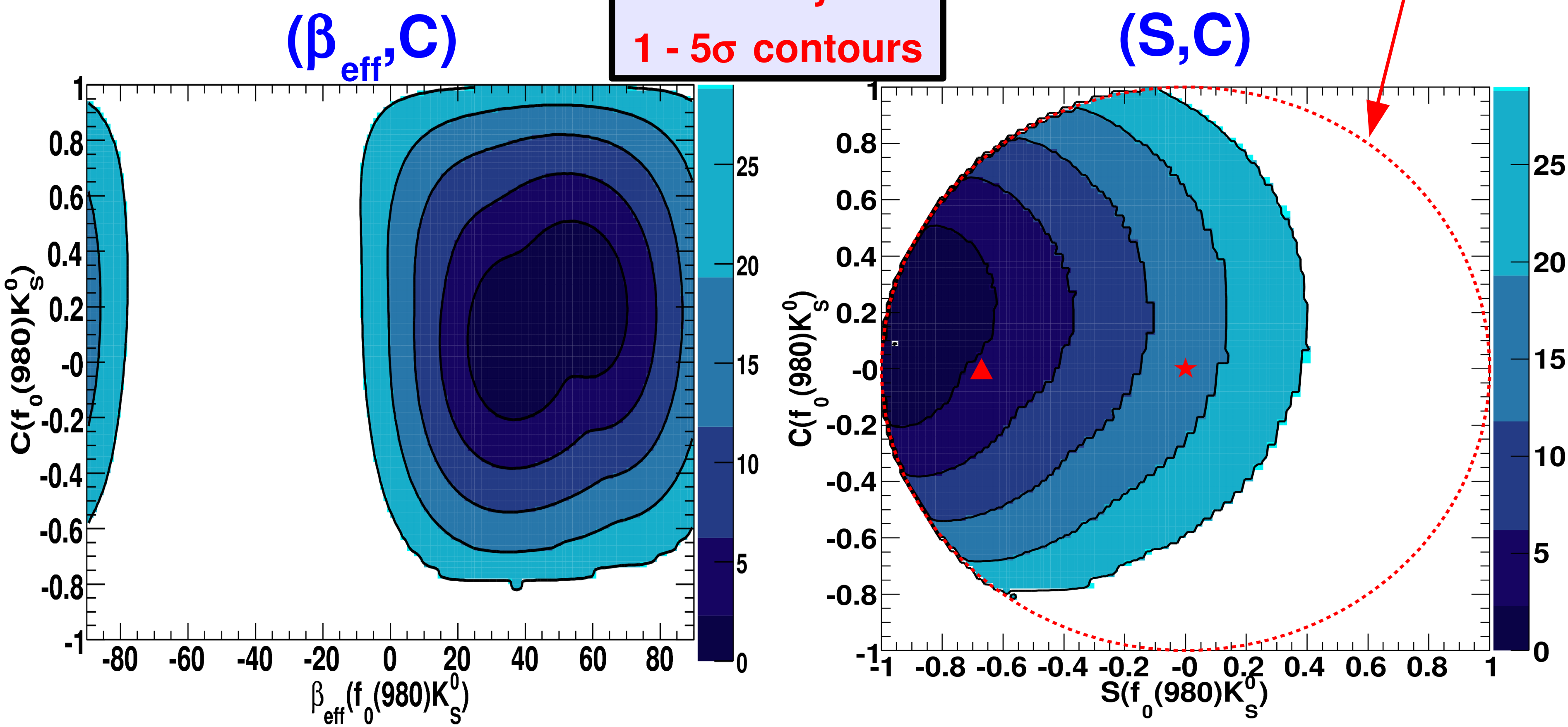
▲ b →ccs value

Fit Results: (β_{eff},C) f_0(980)Ks

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

Stat+Syst

1 - 5σ contours



CP conservation excluded at 3.5σ
Agreement with b → ccs at 1.1σ

★ CP conservation
▲ b →ccs value

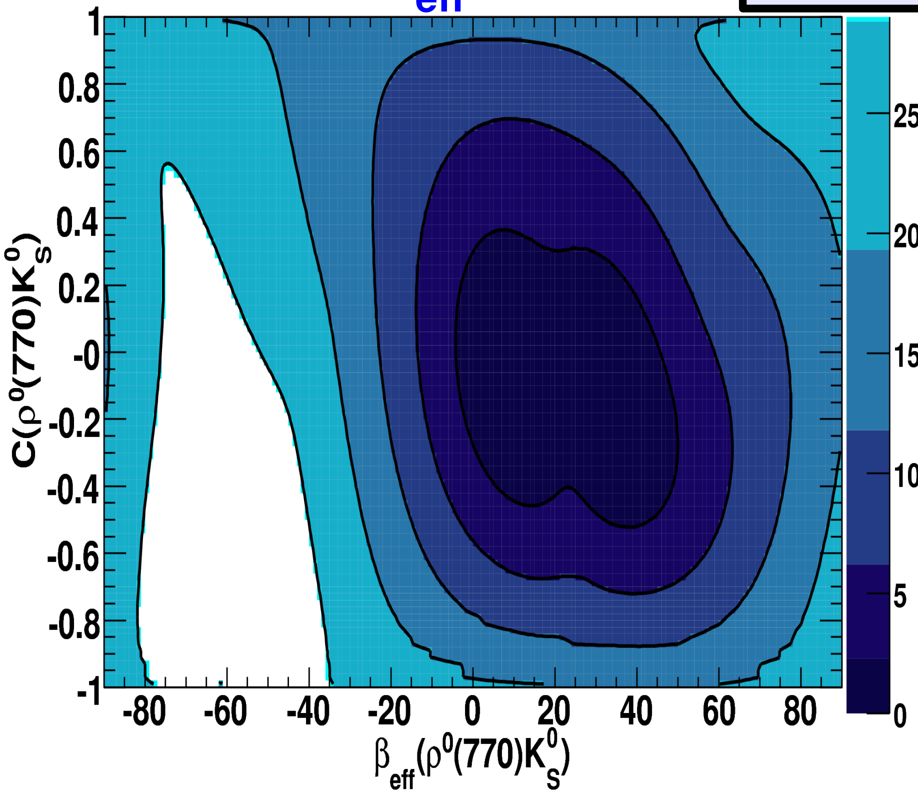
Fit Results: (β_{eff}, C) $\rho^0(770)Ks$

Stat+Syst

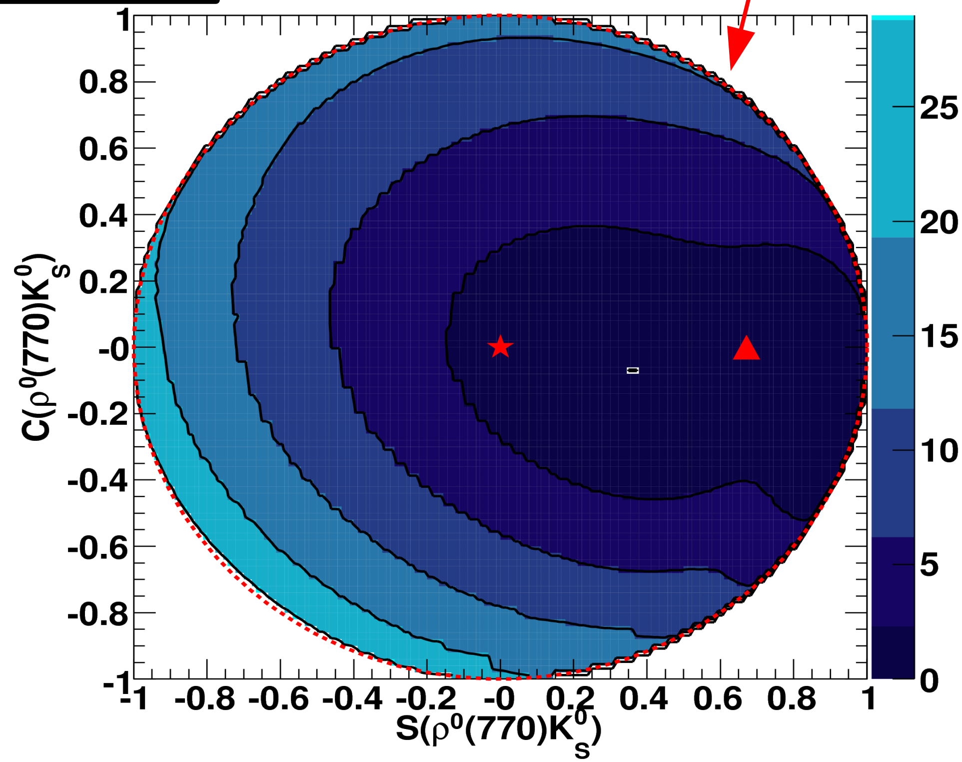
1 - 5σ contours

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

(β_{eff}, C)



(S, C)



★ CP conservation

▲ $b \rightarrow ccs$ value

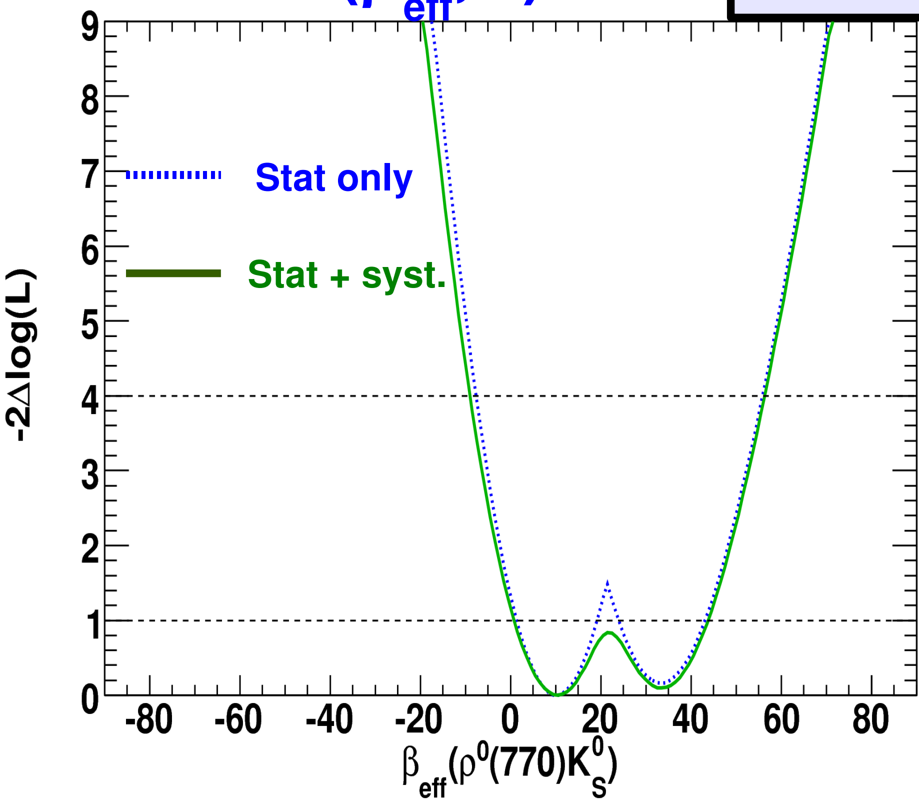
Fit Results: (β_{eff},C) $\rho^0(770)K_s$

Stat+Syst

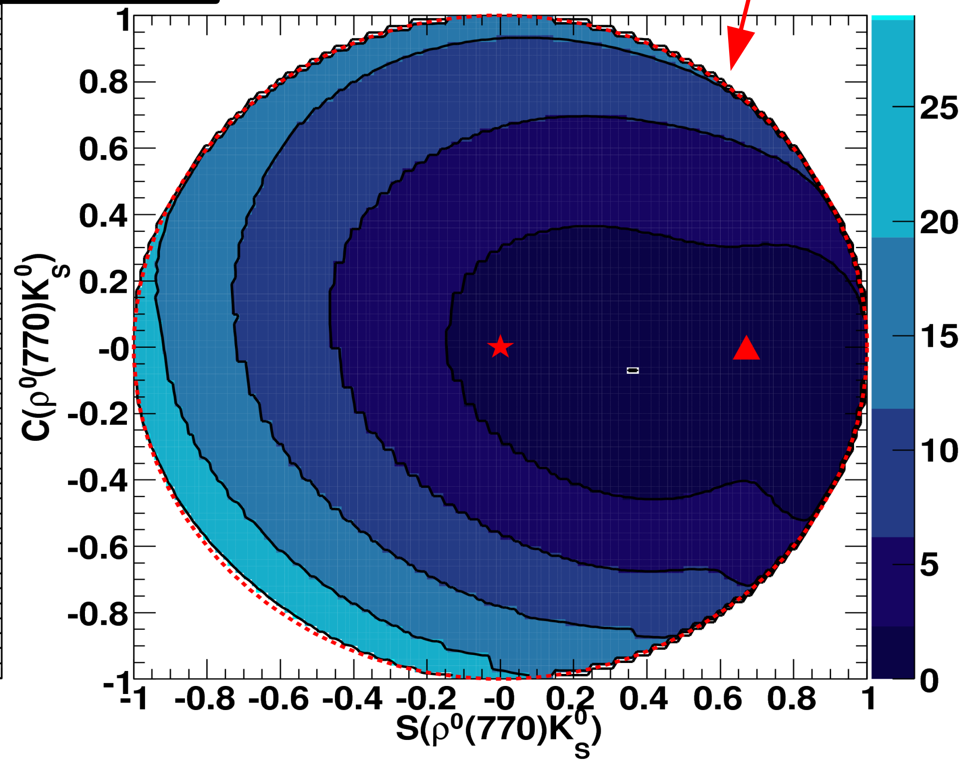
1 - 5σ contours

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

(β_{eff},C)



(S,C)



trigonometrical ambiguity disfavoured at 1.9σ

★ CP conservation

▲ b →ccs value

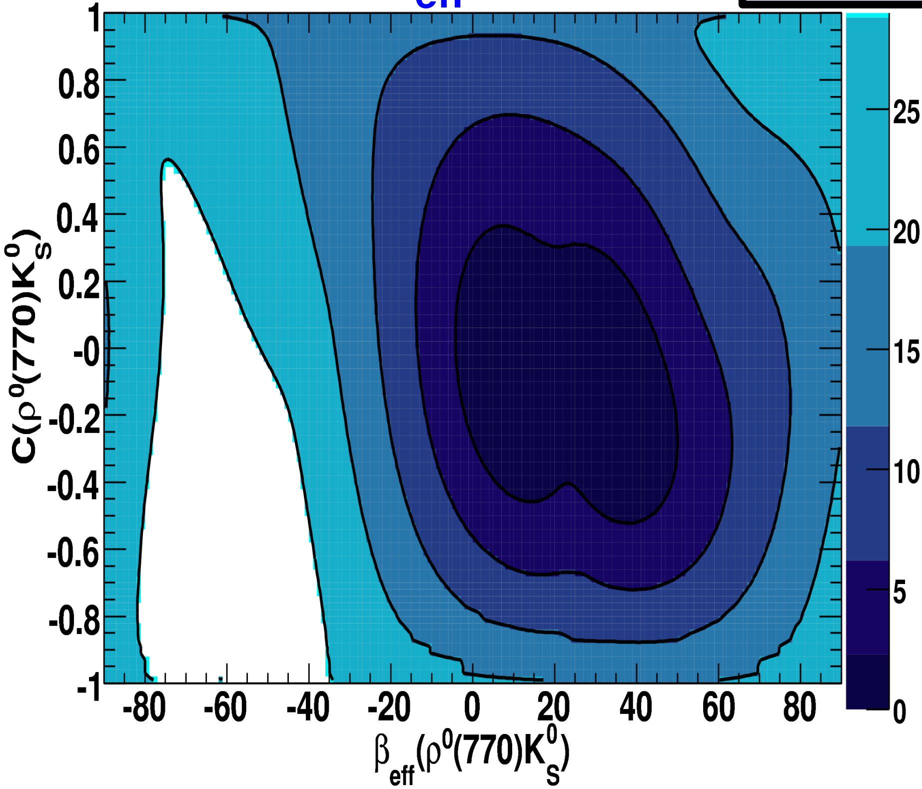
Fit Results: (β_{eff}, C) $\rho^0(770)Ks$

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

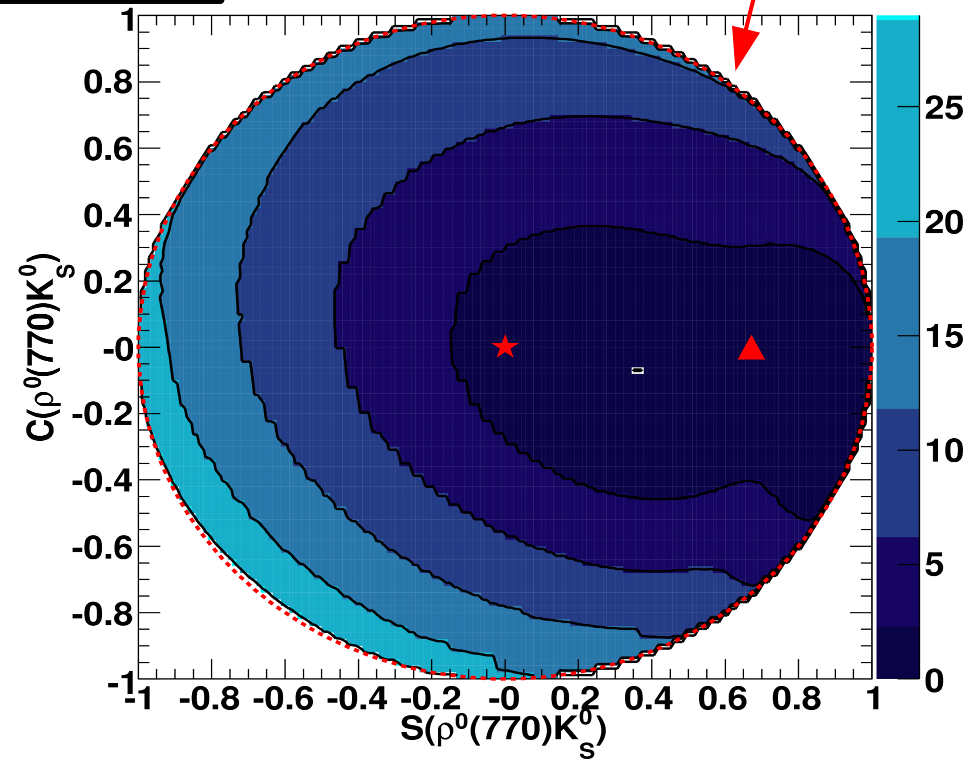
Stat+Syst

1 - 5σ contours

(β_{eff}, C)



(S,C)



Compatible both with CPV conservation and $b \to ccs$ value

★ CP conservation

▲ $b \to ccs$ value

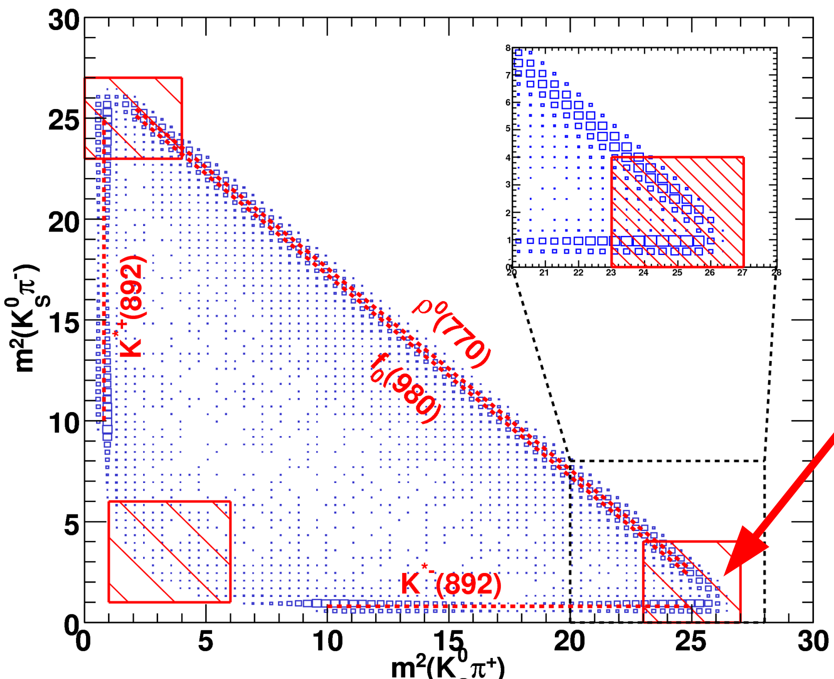
Fit Results: CPS Phase $K^*(892)\pi$

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

- Sensitivity not by direct interference

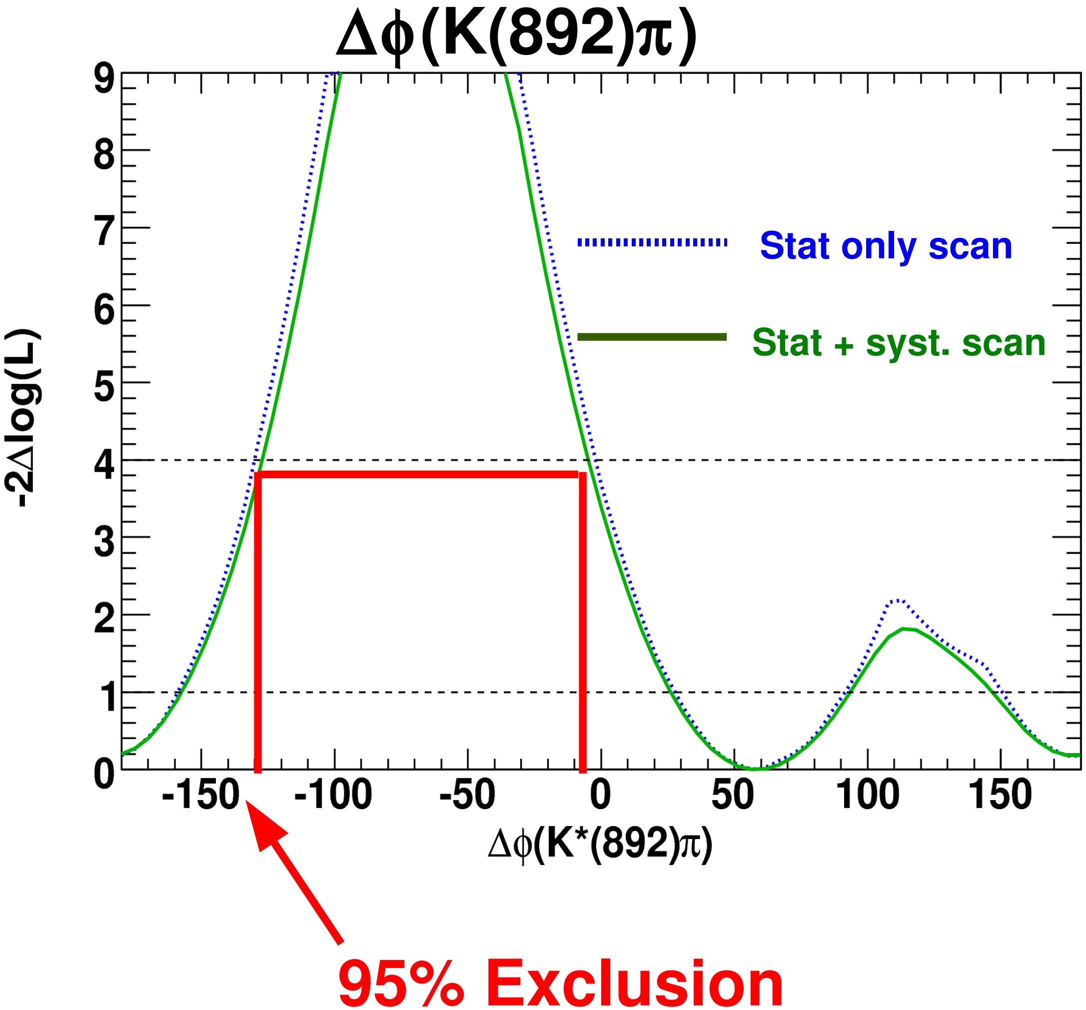
- Only by interference with other components in the DP:

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



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

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



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

Part II:
The Phenomenological Analysis

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

- **Isospin analysis of the modes $B \to K^{*}\pi$**
- **Isospin analysis of the modes $B \to \rho K$**
- **Isospin analysis combining the modes $B \to K^{*}\pi$ and $B \to \rho K$**

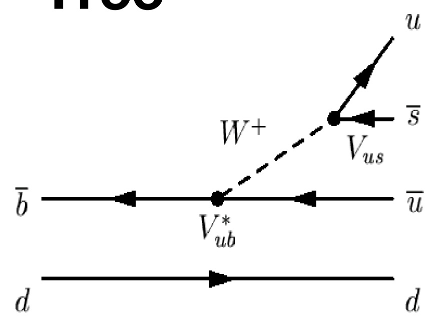
With the world averages of
BaBar, Belle and CLEO

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

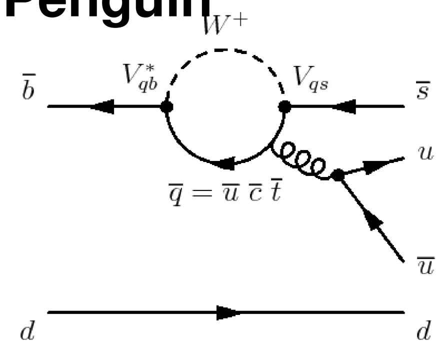
$B \to K^{*}\pi$ System: Isospin relations

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

Tree



Penguin



SU(2) Isospin relations:

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

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

(S)

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

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

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

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

- N^{0+} : annihilation contributions
- T^{00}_{C} : color suppressed tree
- P_{EW} and P^{C}_{EW} : color allowed and color suppressed electroweak penguins
- Hadronic amplitudes receive contributions of different topologies

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

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

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

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

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

(S)

Neglecting P_{EW}, the amplitude combinations:

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

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

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

CPS PRD74:051301
GPSZ PRD75:014002

Direct access to γ CKM angle

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

Neglecting P_{EW}, the amplitude combinations:

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

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

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

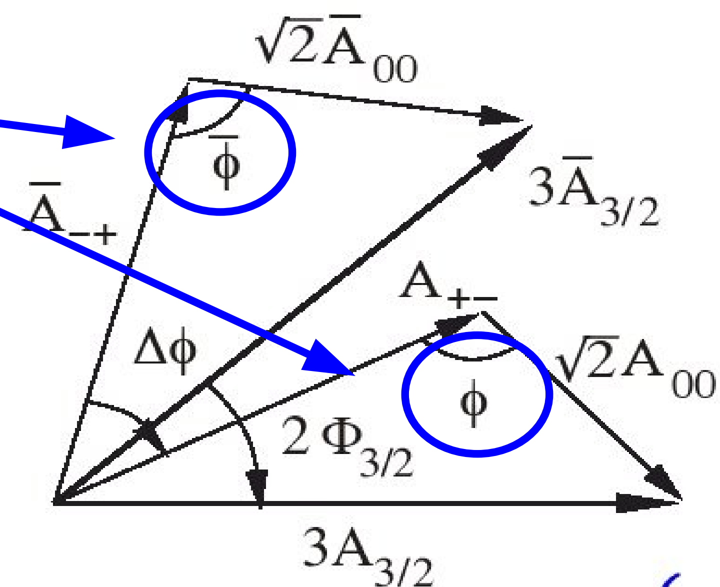
CPS PRD74:051301
GPSZ PRD75:014002

From experiment:

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

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

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



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

Neglecting P_{EW}, the amplitude combinations:

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

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

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

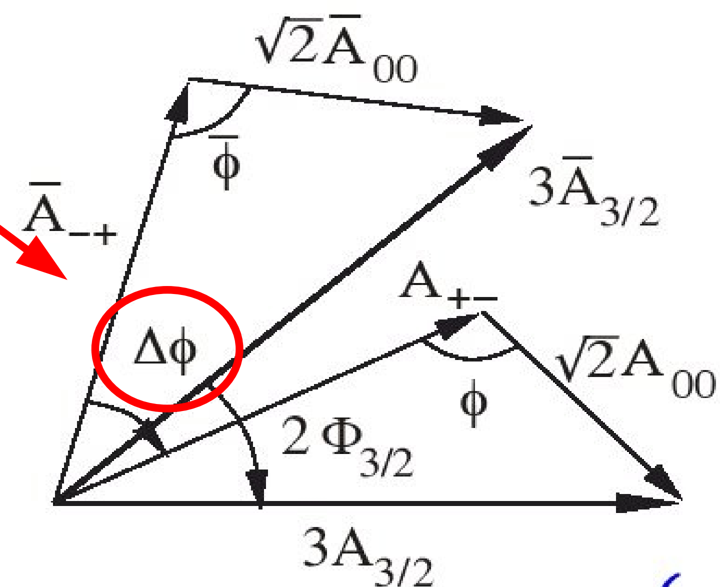
CPS PRD74:051301
GPSZ PRD75:014002

From experiment:

Measurable from

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

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

- We claim $R_{3/2}$ is not a physical observable
- Define $R'_{3/2} = (q/p)R_{3/2}$ which a physical observable
- With $P_{EW} = 0$, $R'_{3/2} = (q/p)R_{3/2} = e^{-2i\beta}e^{-2i\gamma} = e^{-2i\alpha}$

  $\rightarrow$ **Direct 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"

$B\to K^*\pi$ System: Physical Observables

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

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

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

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

11 QCD and 2 CKM = 13 unknowns

(S)

Observables:

- 4 BFs and 4 A_{CP} from DP and Q2B analyses.
- 5 phase differences:
  - * $\Delta\phi = \arg((q/p)A(\bar{B}^0\to K^{*-}\pi^+)A^*(B^0\to K^{*+}\pi^-))$ from $B^0\to K^0_S\pi^+\pi^-$
  - * $\bar{\phi} = \arg(\bar{A}(\bar{B}^0\to \bar{K}^{*0}\pi^0)\bar{A}^*(\bar{B}^0\to K^{*+}\pi^-))$ and
    $\phi = \arg(A(B^0\to K^{*0}\pi^0)A^*(B^0\to K^{*-}\pi^+))$ from $B^0\to K^+\pi^-\pi^0$
  - * $\bar{\phi} = \arg(\bar{A}(B^+\to \bar{K}^{*0}\pi^+)\bar{A}^*(B^+\to K^{*+}\pi^0))$ and
    $\phi = \arg(A(B^-\to K^{*0}\pi^-)A^*(B^-\to K^{*-}\pi^0))$ from $B^+\to K^0\pi^+\pi^0$

A total of 13 observables

Constrained system... but...

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

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

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

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

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

(S)

Reparameterization Invariance (RpI): Impossible to fit for hadronic and CKM parameters simultaneously

O

* 3 phase differences:

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

ϕ = arg(A(B → K π)A (B → K π)) from B → K π π

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

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

A total of 13 observables

$B \to K^{*}\pi$ 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 exprimental measurements
- output:
  - * Prediction of unavailable observables
  - * Explore hadronic amplitudes, test of theoretical calculations

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

- If Had $\to$ Had + δHad gives CKM $\to$ CKM + δCKM ☺

  Ex.: α from $B \to \pi\pi$

- If Had $\to$ Had + δHad gives CKM $\to$ CKM + ΔCKM ☹

Goal: test CPS/GPSZ method

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

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

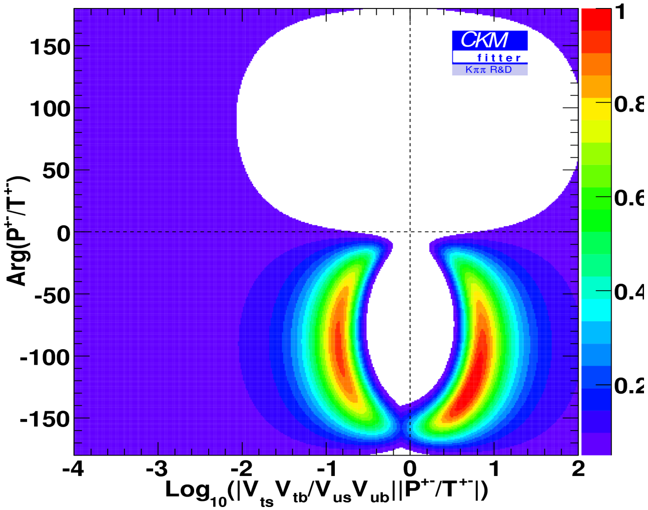
- $B \to \pi\pi$: $P_{EW} = R T_{3/2}$, $R = 1.35\%$ and real. (SU(2) and Wilson coeff. $|c_{8,9}|$ small).
  P and T CKM of same order $\to$ P_{EW} negligible

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

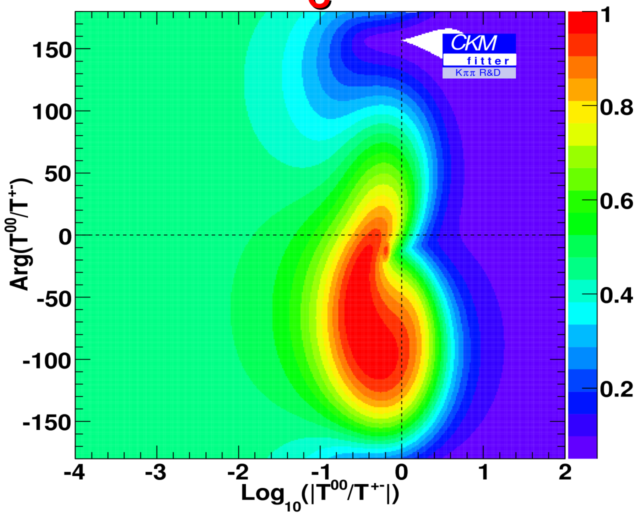
- $B \to K^{*}\pi$: $P_{EW} = R_{eff} T_{3/2}$
  - $R_{eff} = R(1-r_{VP})/(1+r_{VP})$,
  - r_{VP} complex $\to$ vector-pseudoscalar phase space,
  - GPSZ estimation $|r_{VP}| < 5\%$

Scenario 1: exploring hadronic parameters

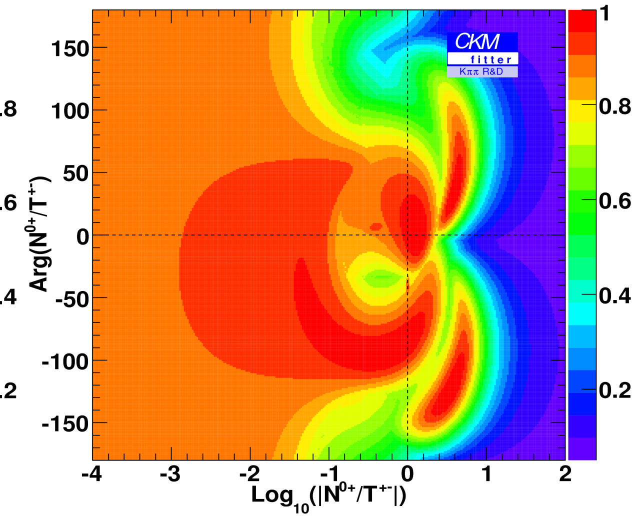
P^{+-}/T^{+-}



T^{00}_{C}/T^{+-}



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

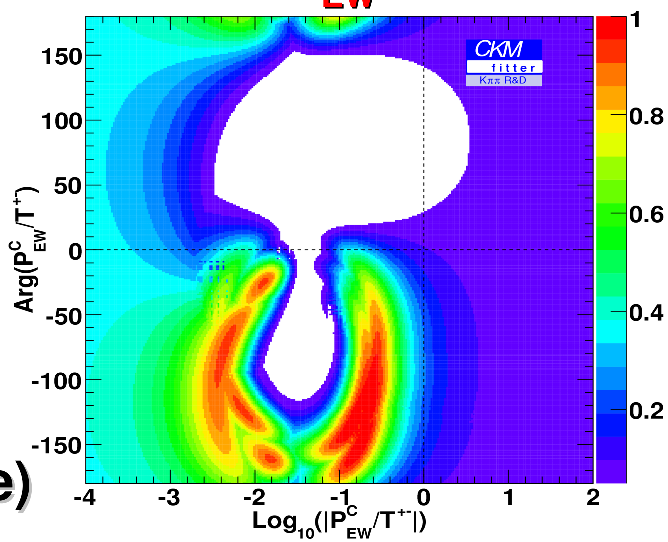


Input here:

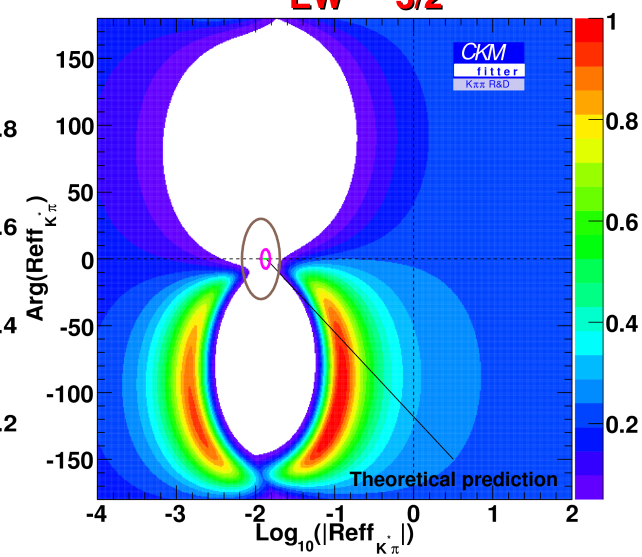
- **Experimental measurements**
- **CKM from global fit**

(No assumption on any hadronic amplitude)

P^{C}_{EW}/T^{+-}



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



Scenario 1: exploring hadronic parameters

Input here:

- Experimental measurements
- CKM from global fit

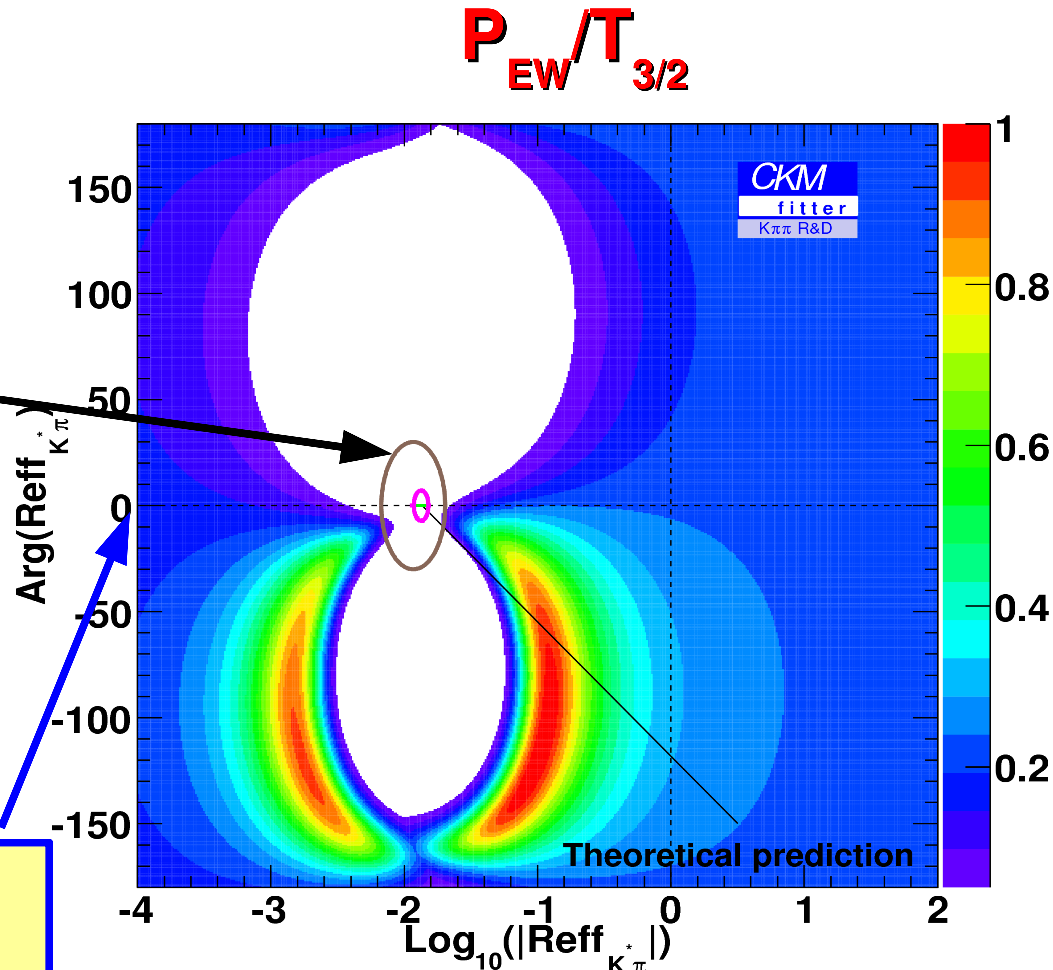
(No assumption on any hadronic amplitude)

— GPSZ error

— 5xGPSZ error

Constraint marginally compatible with GPSZ prediction (~2σ)

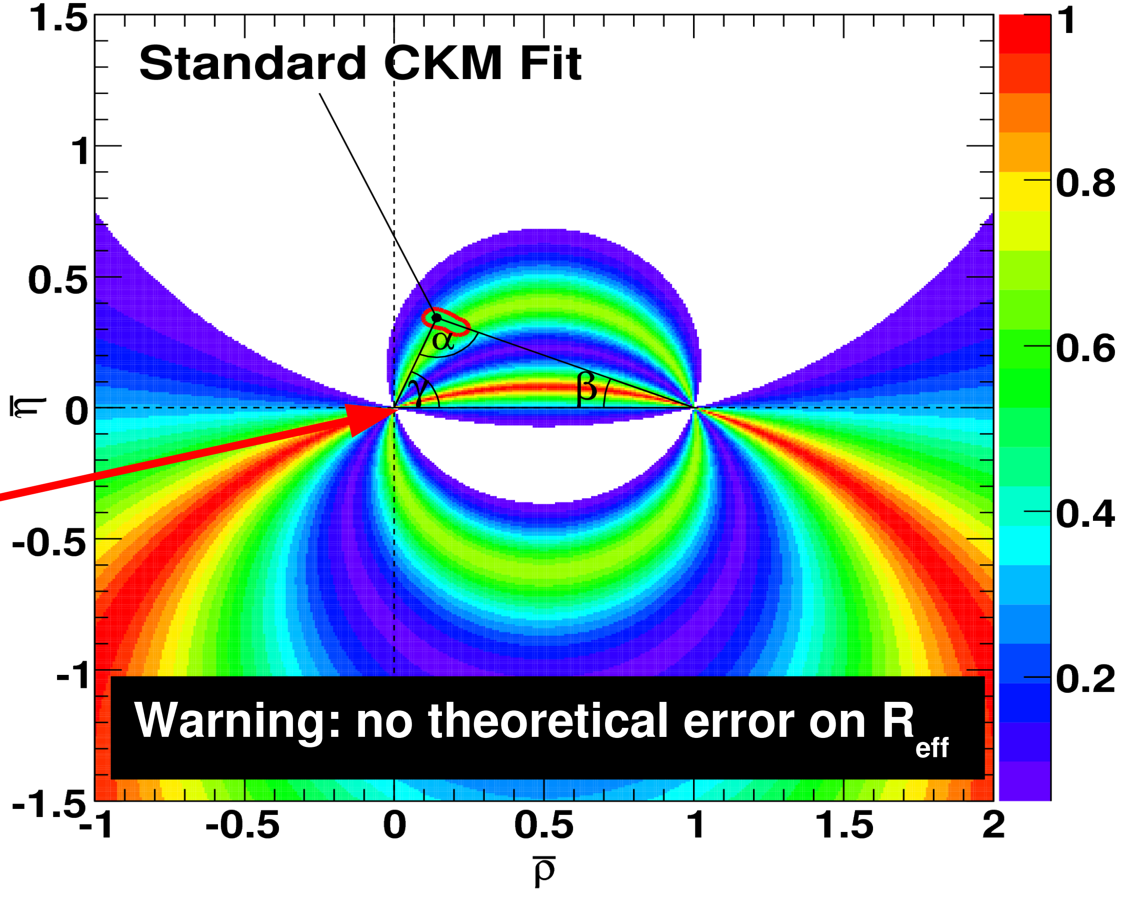
P_{ew} = 0 better compatibility with data



Scenario 2: exploring CKM

Vanishing P_{EW}

$R_{eff} = 0$



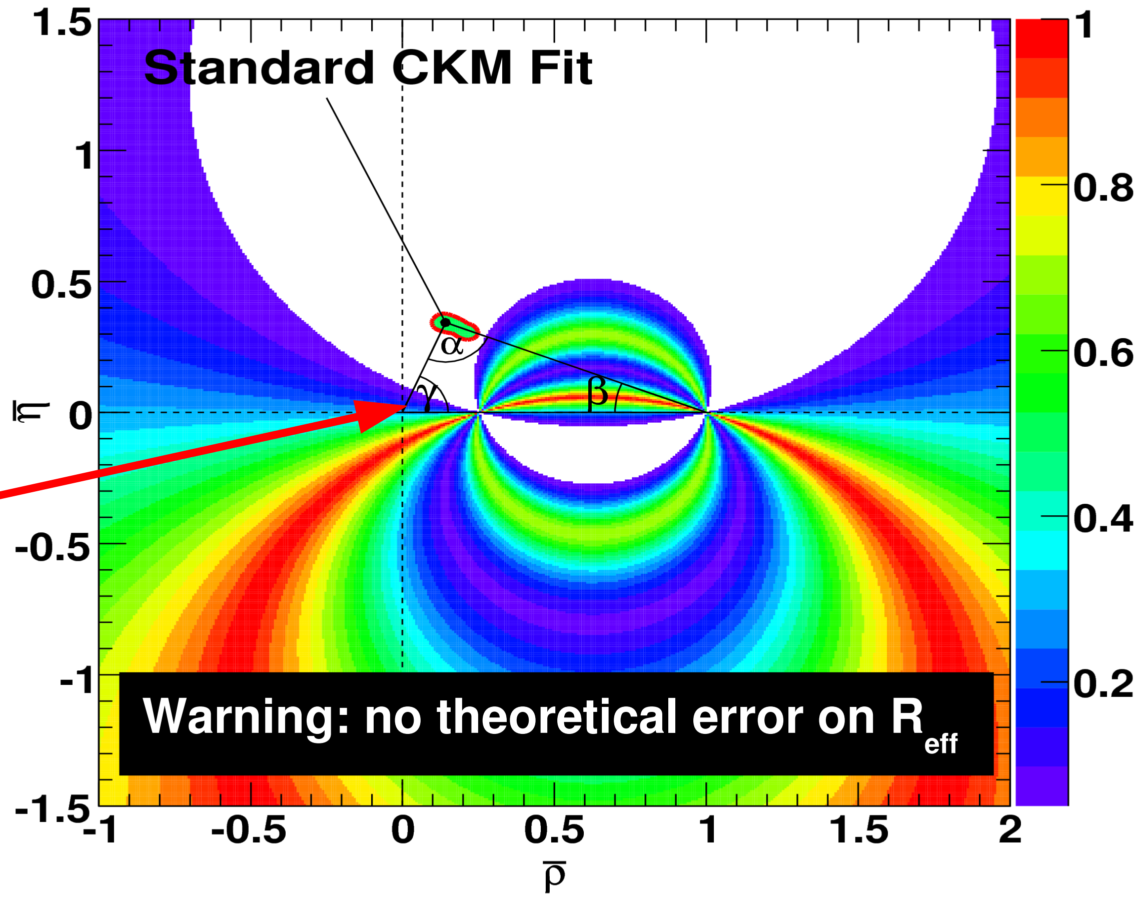
Constraint set on α not γ!

Scenario 2: exploring CKM

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

$R_{eff} = 1.35\%$ (GPSZ)

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

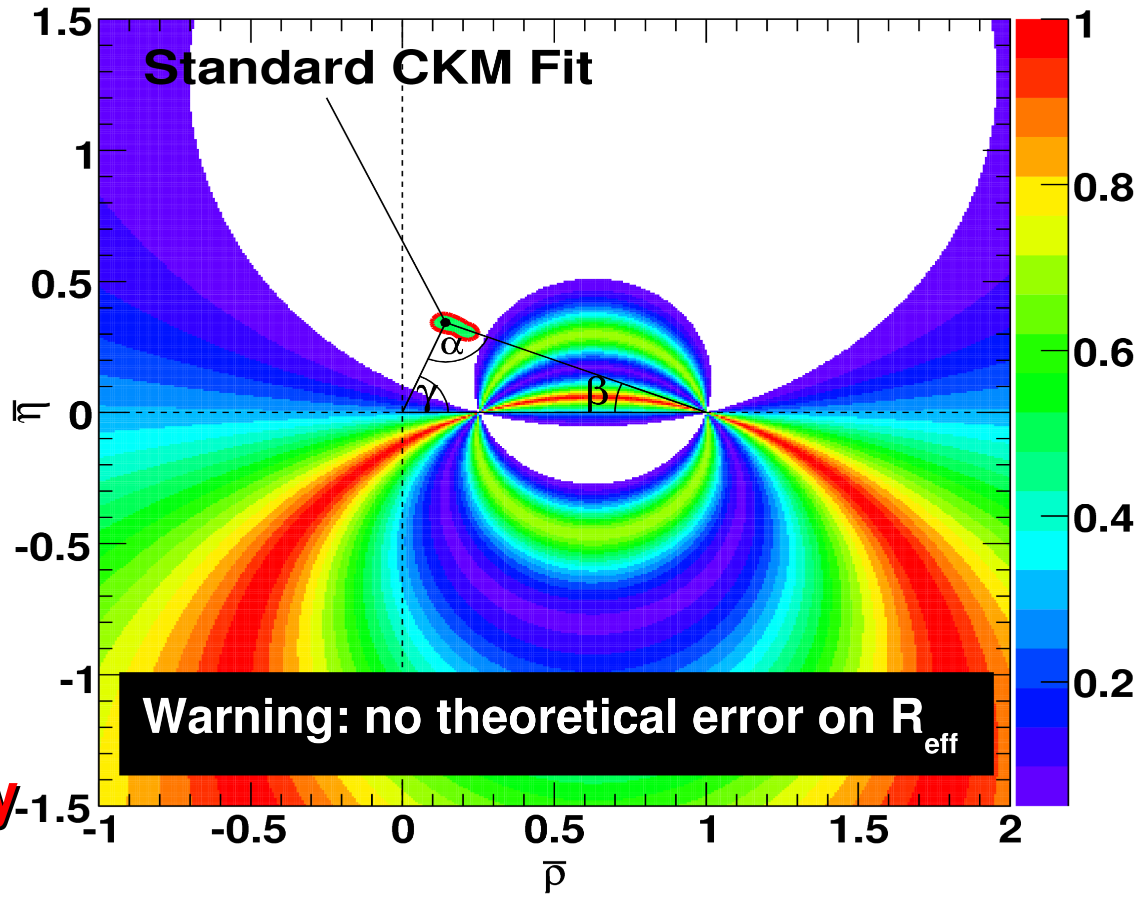


Scenario 2: exploring CKM

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

$R_{eff} = 1.35\%$ (GPSZ)

Small change in Reff changes significantly the constraint: dominated by theoretical uncertainty



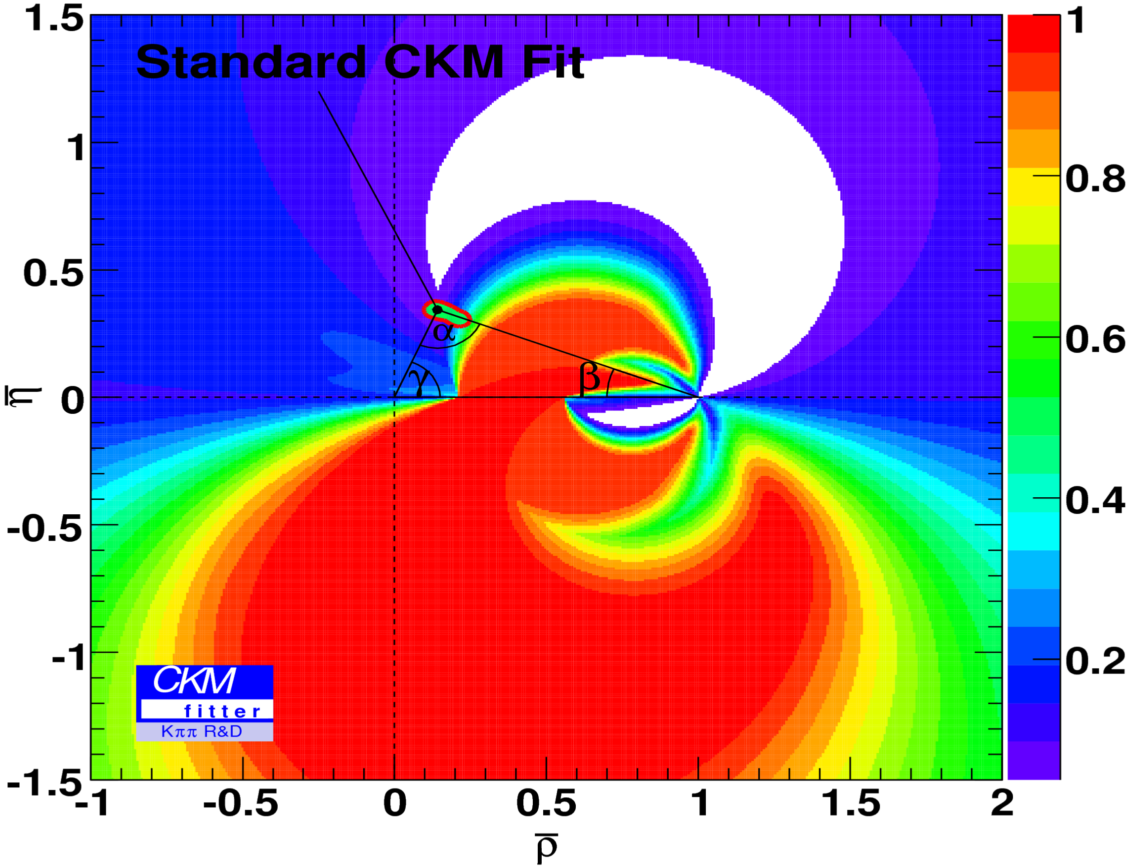
Scenario 2: exploring CKM

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

R_{eff} = 1.35% (GPSZ)

Conservative theoretical error dilutes strongly the constraint

CPS/GPSZ method totally dominated by theoretical errors



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

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

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

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

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

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

A total of 9 observables

Under constraint system

B→ρK System: Physical Observables

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

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

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

$\sqrt{2}A(B^0$

Observab

- 4 BFs

- 1 pha

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

A total of 9 observables

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

Same Isospin relations as $K^*\pi$

Under constraint system

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

ρK+K*π system: Extrapolation

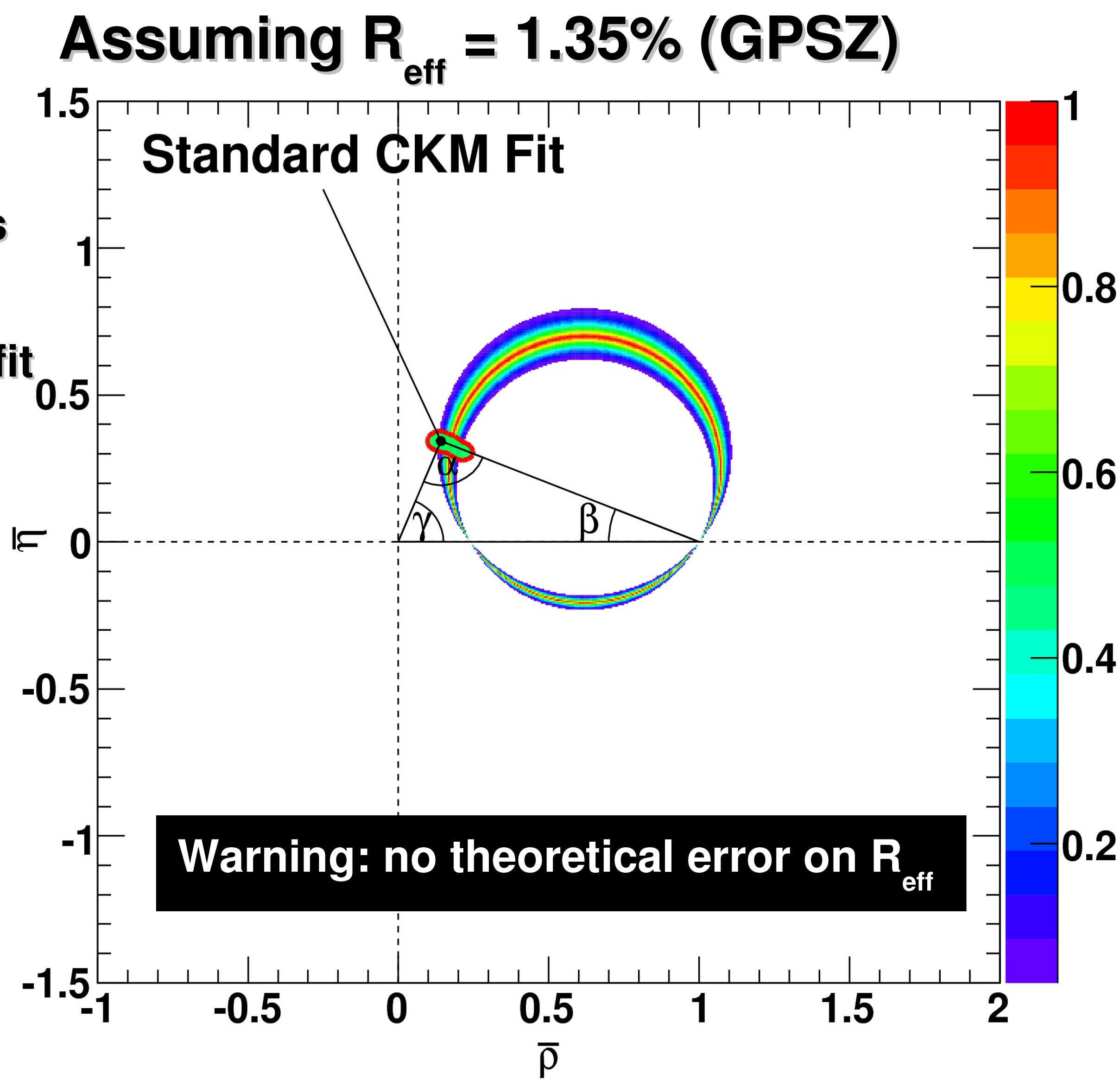
Inputs:

- 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



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 $b \to ccs$ at 1.1σ

  - Trigonometric ambiguity not resolved

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

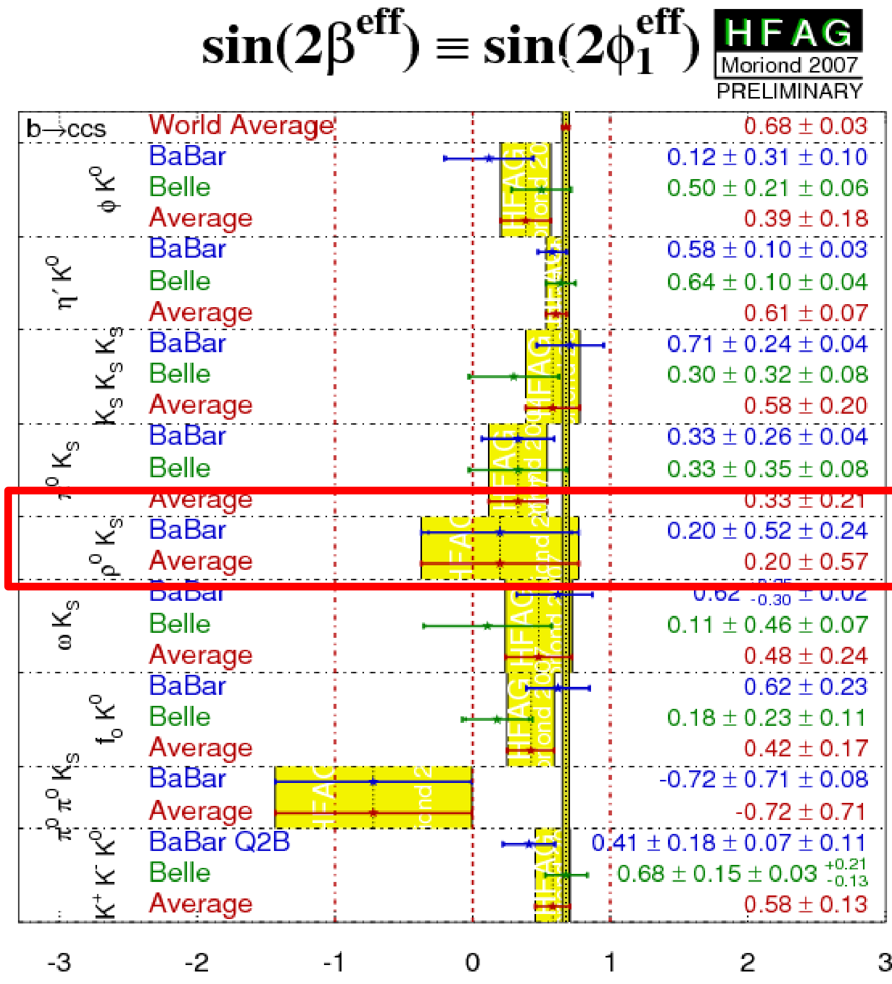
  - Trigonometric ambiguity disfavored at 1.9σ

  - Preferred solution in agreement with $b \to ccs$

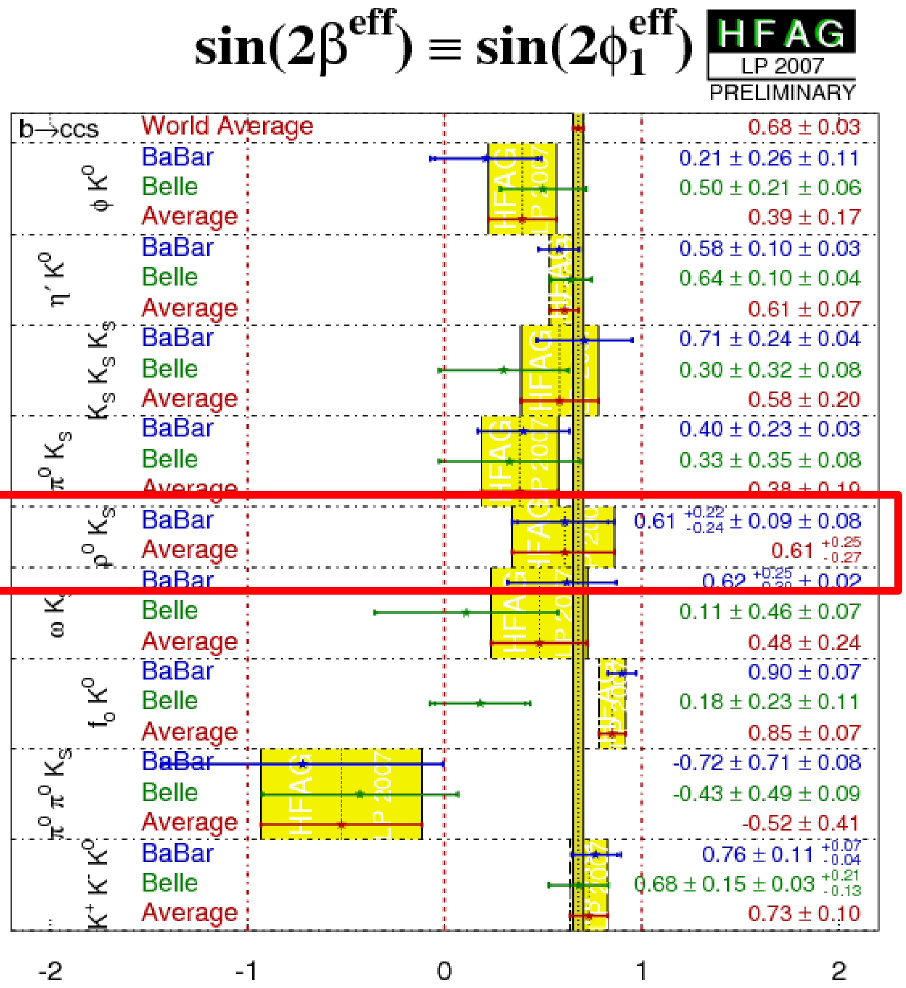
- $\Delta\phi(K^*(892)\pi)$ measured for the first time

Conclusions (I)

Before these measurements

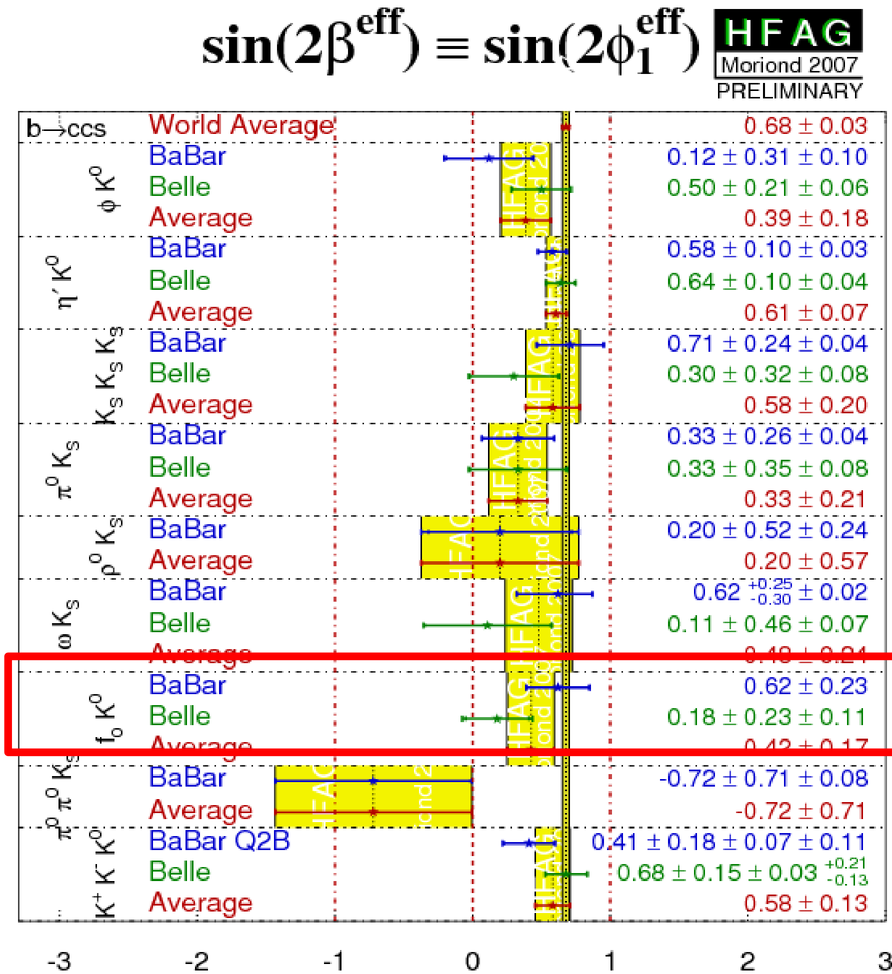


After these measurements

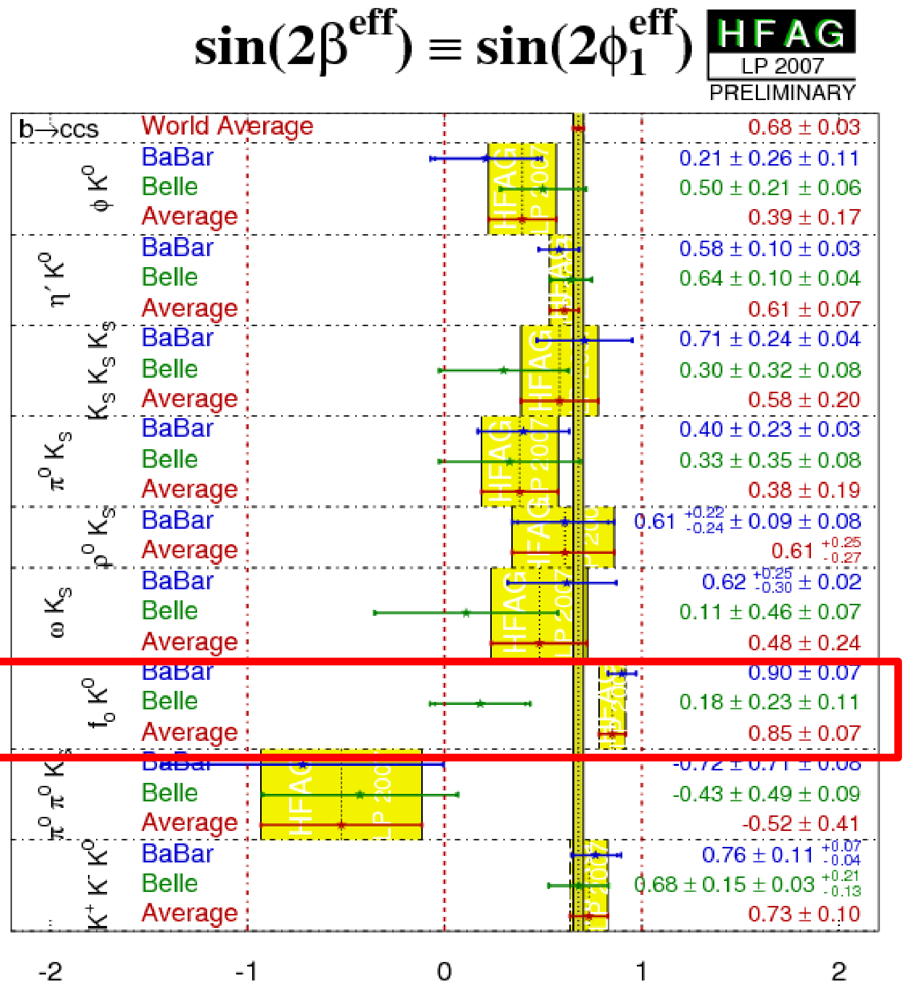


Conclusions (I)

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

- $K^*\pi$: marginal constrain on CKM parameters (assuming CPS/GPSZ)
- ρK: many parameters and not so many observables

  $\Rightarrow$ under constraint system
- $K^*\pi+\rho K$: many redundant observables

  $\Rightarrow$ seems promising

- Potential for CKM physics will depend on the evolution of the theoretical errors

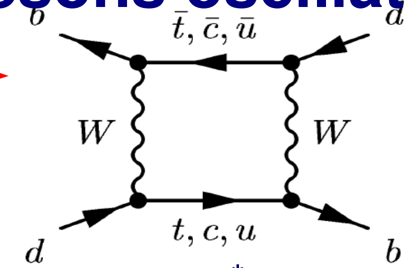
Back up Slides

B mesons Oscillation

Weak states
$\neq$
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,

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

Oscillation frequency

Mixing parameter

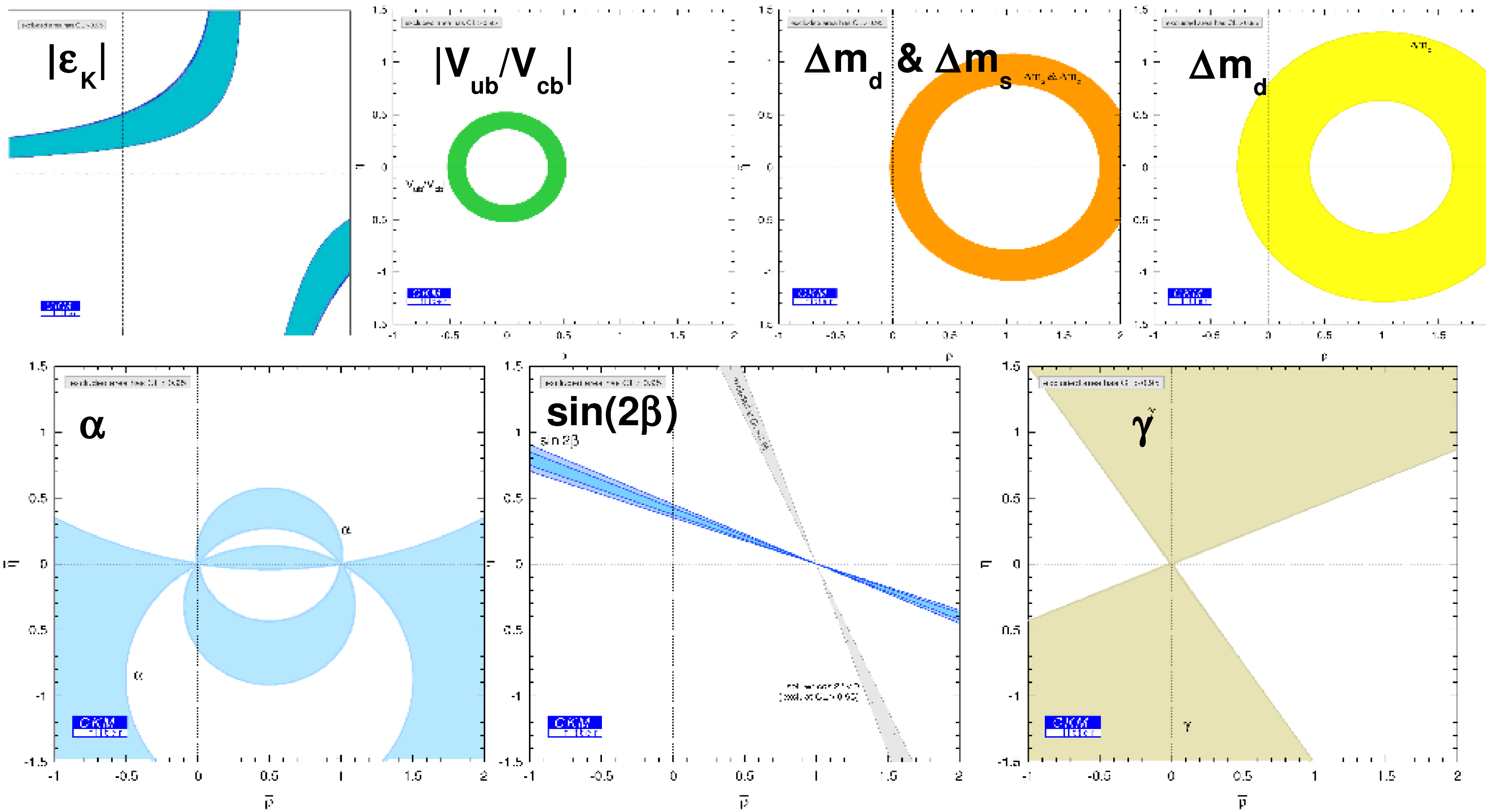
In the SM $q/p \approx e^{-2i\beta}$

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

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, $|V_{ud}|$, $|V_{us}|$



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: $2\beta_{eff}$

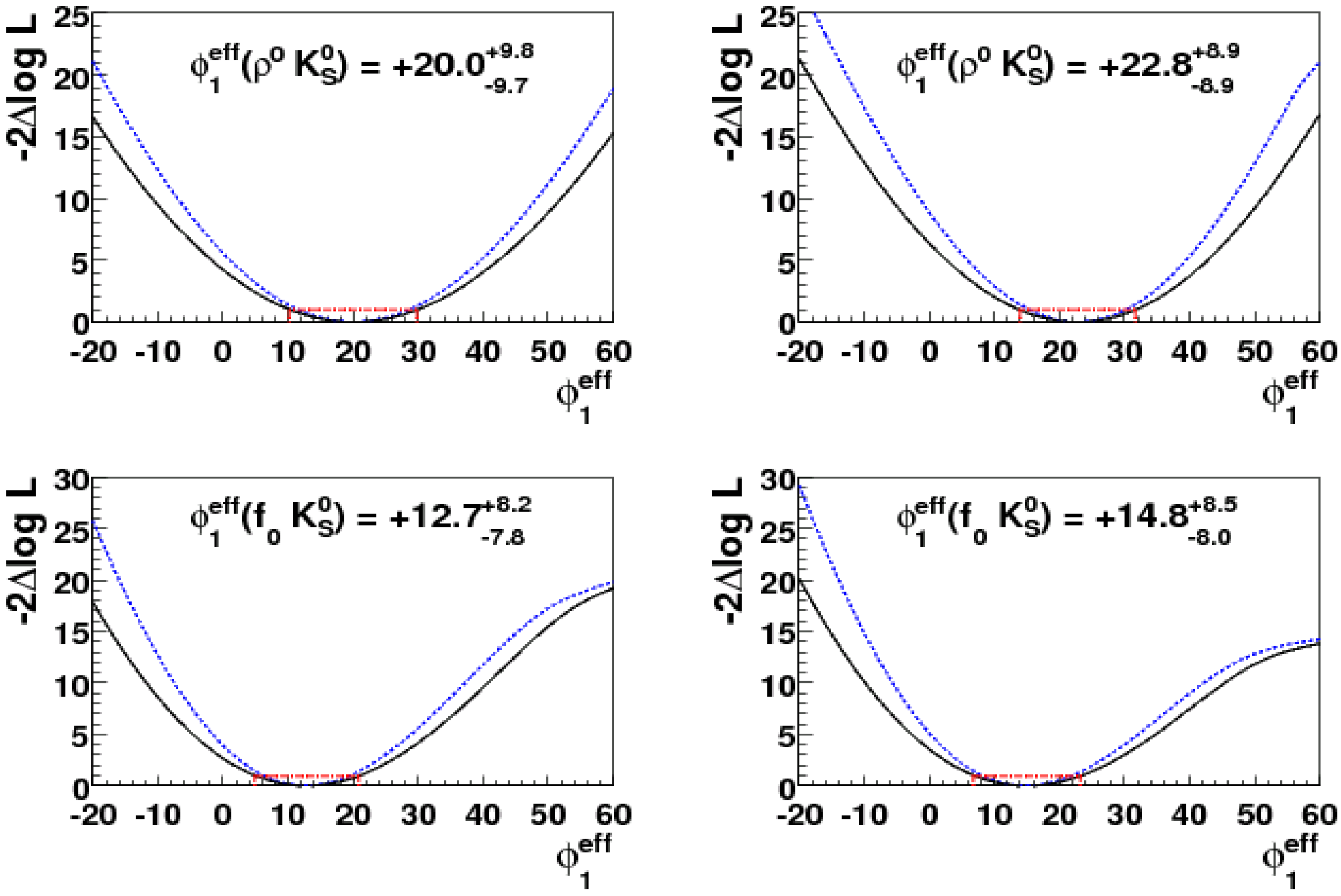


FIG. 5: Likelihood scans of $\phi_1^{\rm eff}$ for $B^0 \to \rho^0(770)K_S^0$ (top) and $B^0 \to f_0(980)K_S^0$ (bottom) for Solution 1 (left) and Solution 2 (right). The solid (dashed) curve contains the total (statistical) error and the dotted box indicates the parameter range corresponding to $\pm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

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

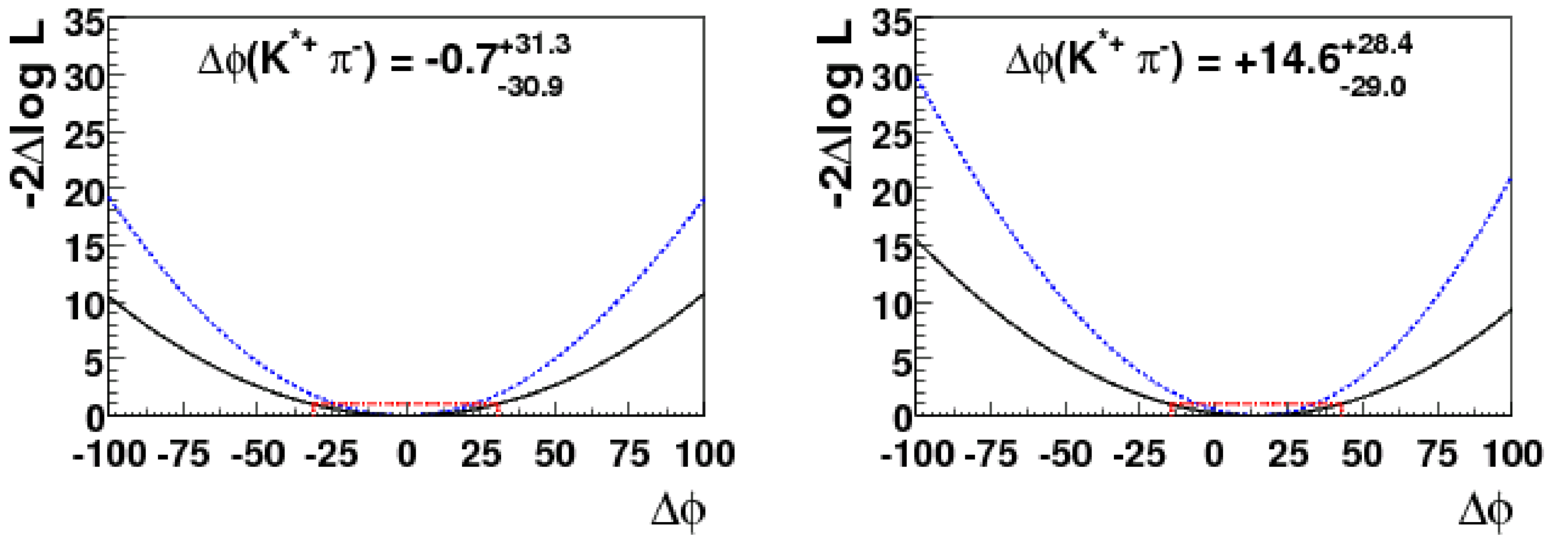


FIG. 7: Likelihood scan of $\Delta\phi$ for Solution 1 (left) and Solution 2 (right). The solid (dashed) curve contains the total (statistical) error and the dotted box indicates the parameter range corresponding to $\pm 1\sigma$.

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
- $|M(K^0_S) - M(K^0_S)PDF| < 15$ 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%

<u>Multiple candidates:</u>
candidate selected arbitrarily, in order to not to bias the ΔE distribution

Mod(time-stamp,nCands)

Background discrimination

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

Discrimination

Beam-energy substituted mass

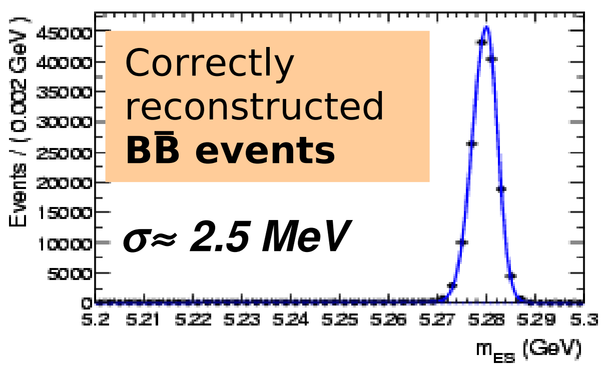
$$m_{ES} = \sqrt{E_{beam}^{*\,2} - p_B^{*\,2}}$$

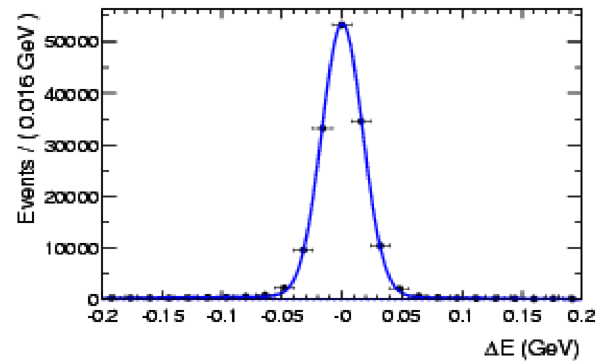
Energy difference

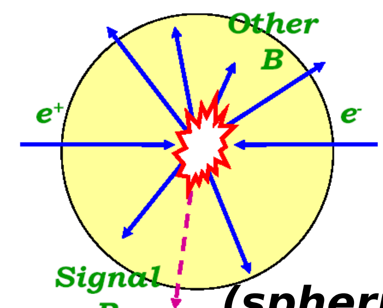
$$\Delta E = E_B^{*} - E_{beam}^{*}$$

Event topology

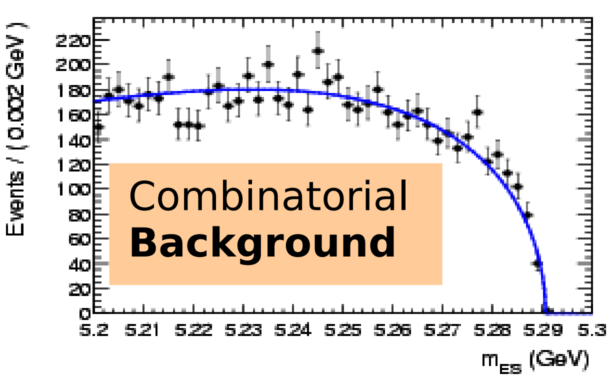
(multivariate methods)

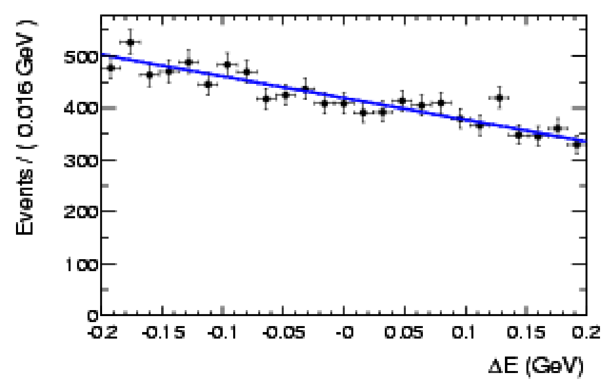


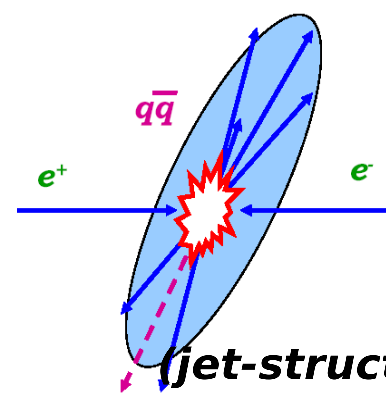




(spherical)







(jet-structure)

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)
  - $B^0 \to \psi(2S)K^0_s$
  - $B^0 \to \eta'(\to \rho\gamma)K^0_s$
  - $B^0 \to a_1^+\pi^-$

Modes treated exclusively

1123	$B^0 \to X, \overline{B^0} \to D^{*+}\pi^-, D^{*+} \to D^0\pi^+, D^0 \to X + CC$	Cat. 1
1126	$B^0 \to X, \overline{B^0} \to D^{*+}\pi^-, D^{*+} \to D^+\pi^0, D^+ \to X + CC$	Cat. 1
1160	$B^0 \to X, \overline{B^0} \to D^+\pi^-, D^+ \to X + CC$ (excluding modes 1591 2437 and 3749)	Cat. 2
3299	$B^0 \to D^-K^+(D^- \to K^0_s\pi^-)$	Cat. 2
3749	$\overline{B^0} \to D^+\pi^-, D^+ \to K^0_s K + c.c.$	Cat. 2
2437	$B^0 \to D^-\pi^+(D^- \to K^+\pi^-\pi^-)$	Cat. 2
3733	$B^0 \to D^-\mu^+\nu(D^- \to K^0_s\pi^-), \overline{B^0} \to X + c.c.$	Cat. 2
1159	$B^0 \to X, \overline{B^0} \to D^+\rho^-, D^+ \to X + CC$ (excluding modes 7330 and 5635)	Cat. 3
7330	$B^0 \to X, \overline{B^0} \to D^+\rho^-, D^+ \to K^0_s\pi^+ + CC$	Cat. 3
5635	$B^0 \to X, \overline{B^0} \to D^+\rho^-, D^+ \to K^0_s K^+ + CC$	Cat. 3
1157	$B^0 \to X, \overline{B^0} \to D^{*+}\rho^-, D* \to D\pi^0, D \to X + CC$	Cat. 3
1158	$B^0 \to X, \overline{B^0} \to D^{*+}\rho^-, D* \to D^0\pi, D^0 \to X$	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)
- **$D\pi$ and $J/\psi K^0_s$ 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: $\vec{x}_i = \left(m_{ES}, \Delta E, NN, Qtag, \Delta t, DP\right)$

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:** 2[nd] degree polynomial (parameters floated)

Parameterization (III)

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

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:

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

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

$\Delta_{\rm Dalitz}$: Distance to DP center

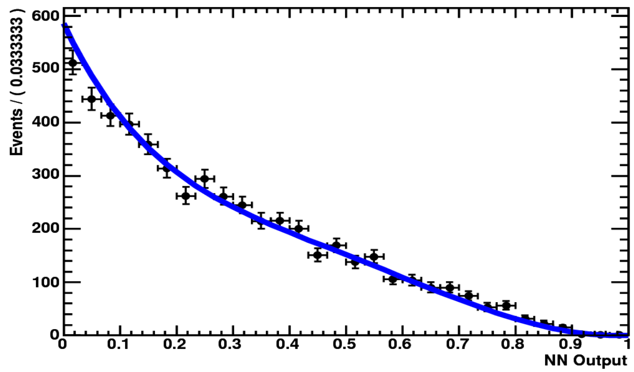
Parameterization (III)

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

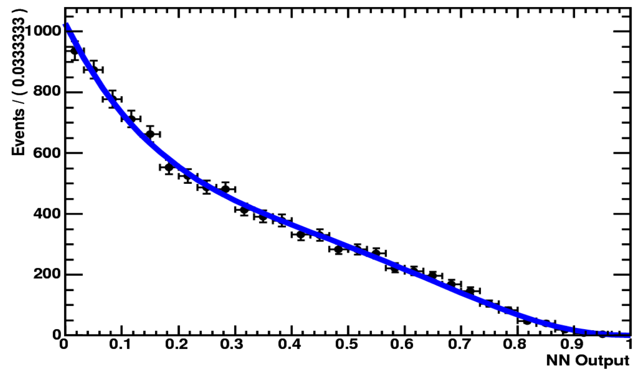
Continuum: Non-negligible correlation with DP Variables

Fit on off-peak data for different DP regions

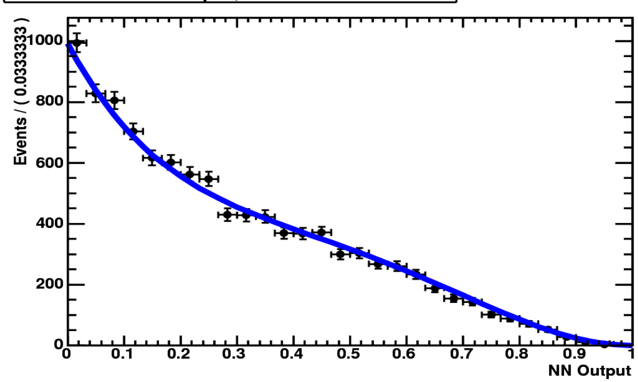
Continuum NNouput, m<0.7 GeV/c^2 (DP edges)



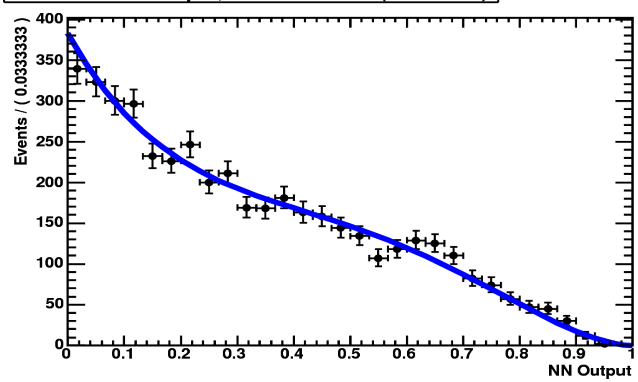
Continuum NNoutput, 0.7<m<1.0 GeV/c^2



Continuum NNoutput, 1.0<m<1.5 GeV/c^2



Continuum NNoutput, 1.5<m GeV/c^2 (DP center)



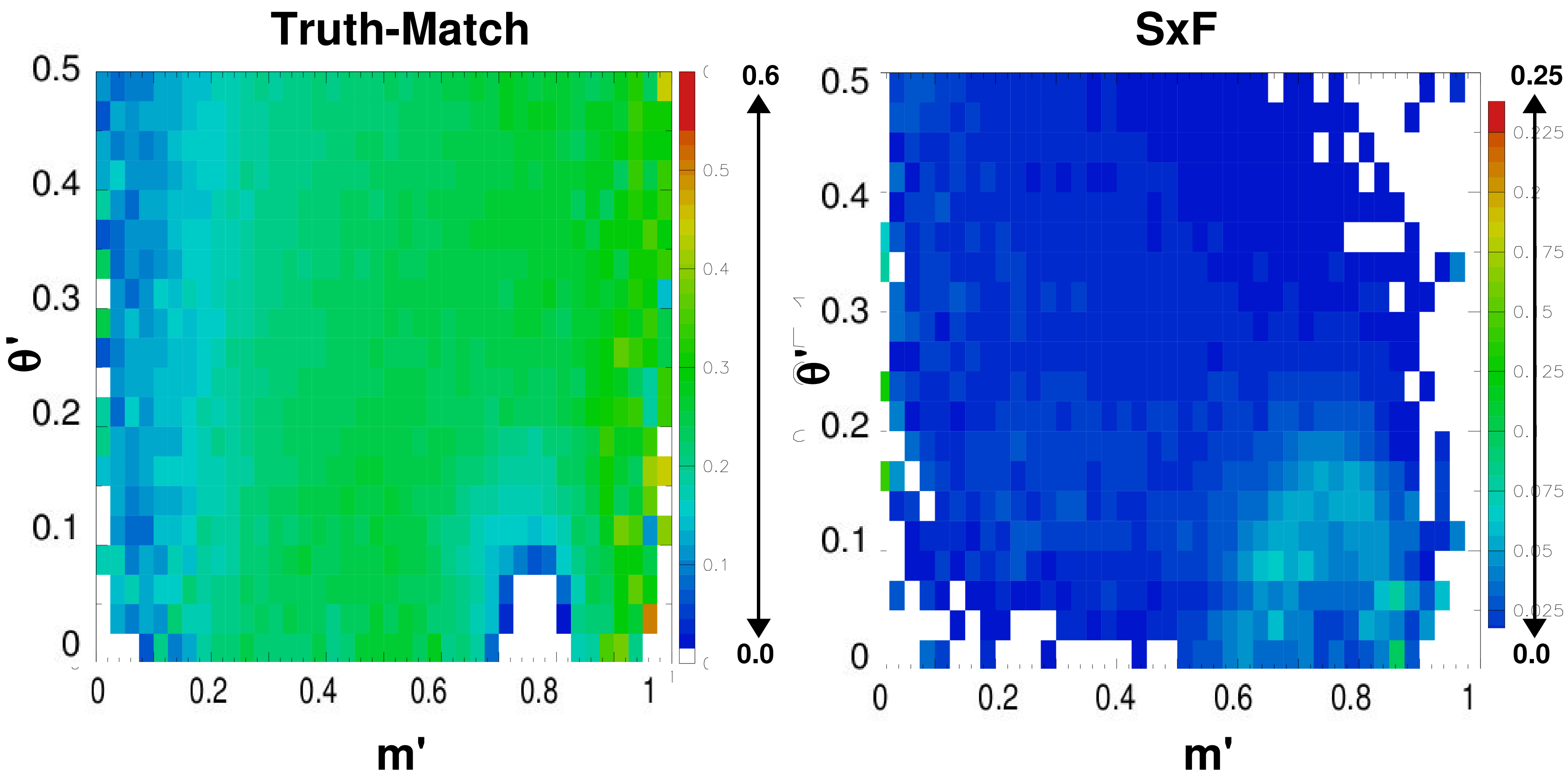
Parameterization (V)

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

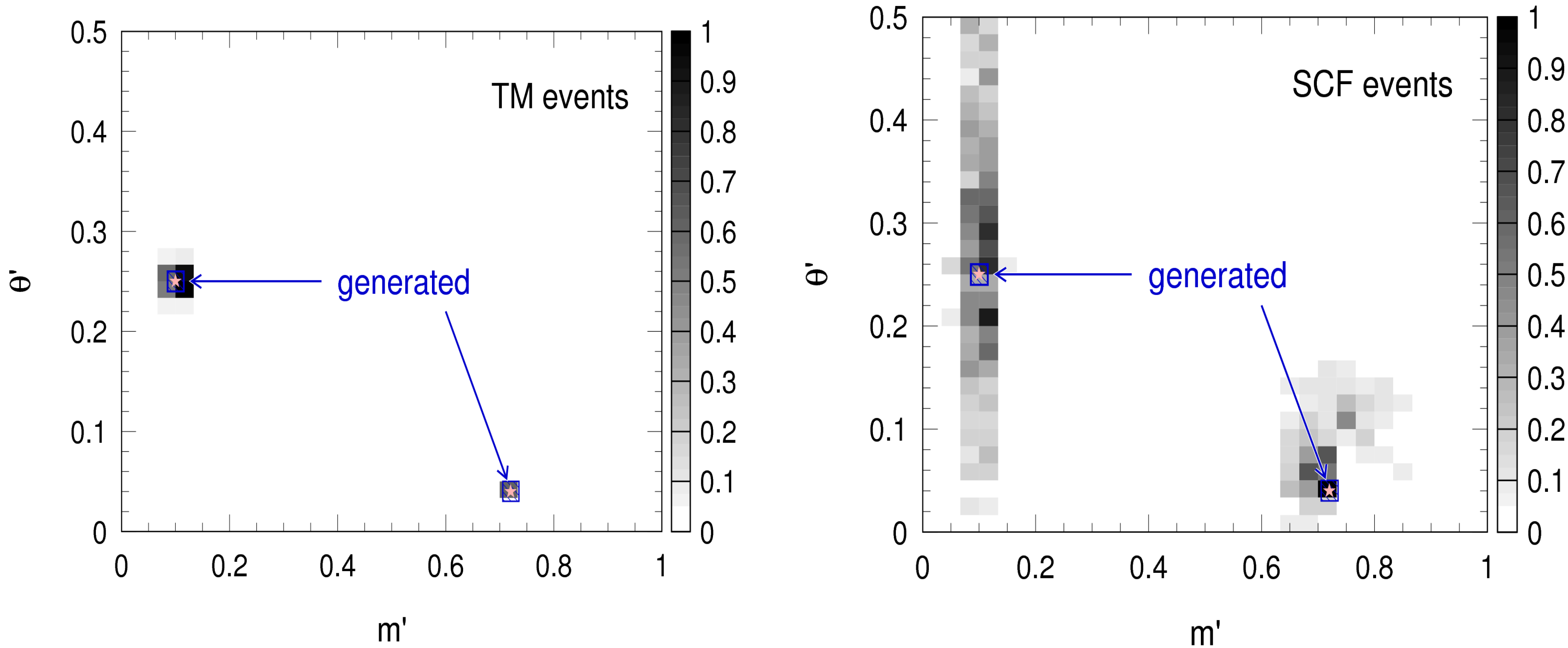
Signal efficiency over DP



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

DP resolution function

Truth-Match **SxF**



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

  (smaller than widths of resonant structures)

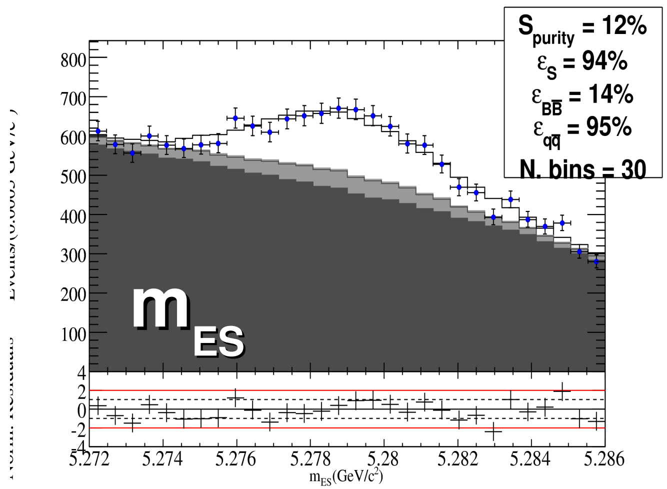
- **Significant dispersion of SCF events**

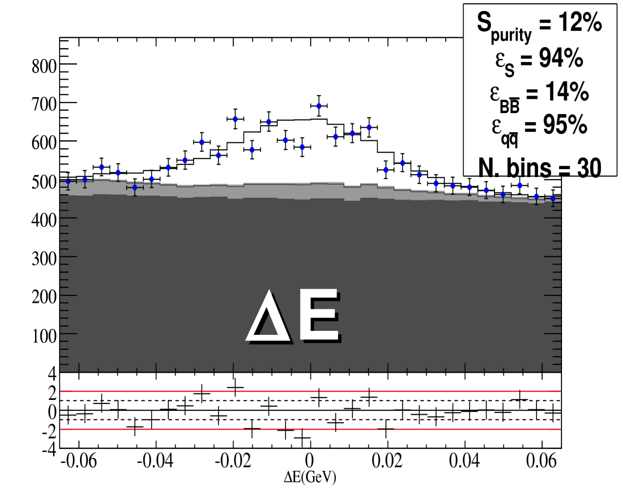
  ⇒ **2D Convolution with resolution function $R_{SCF}(m'_{rec},\theta'_{rec},m'_{true},\theta'_{true})$**

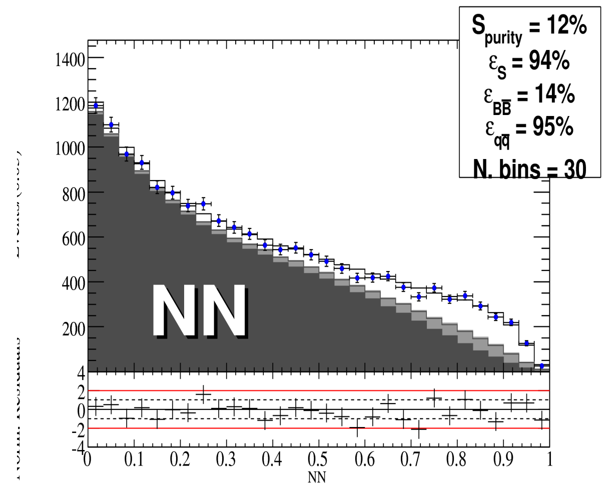
Fit Results: Proj. Plots

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

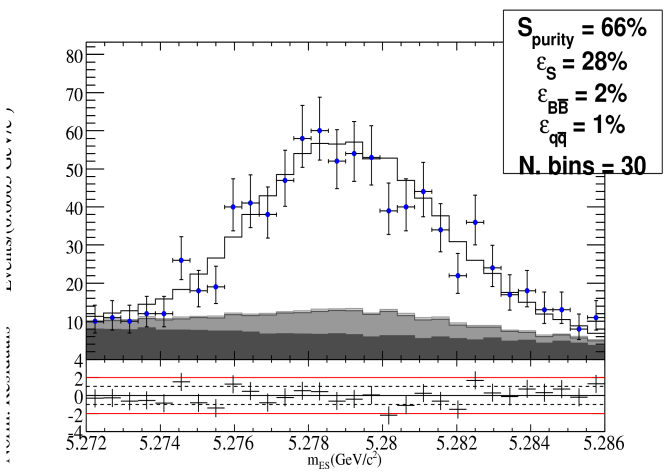
No R cut

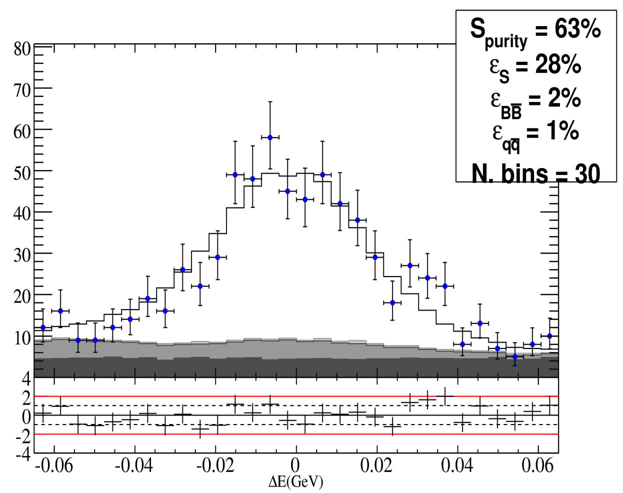


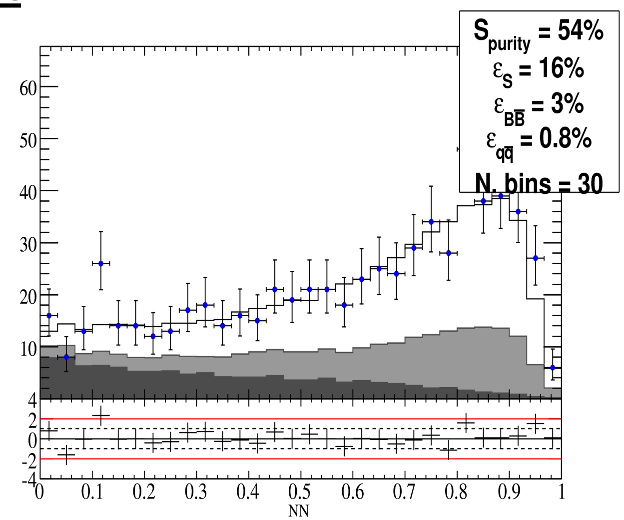




Signal enhanced by R cut

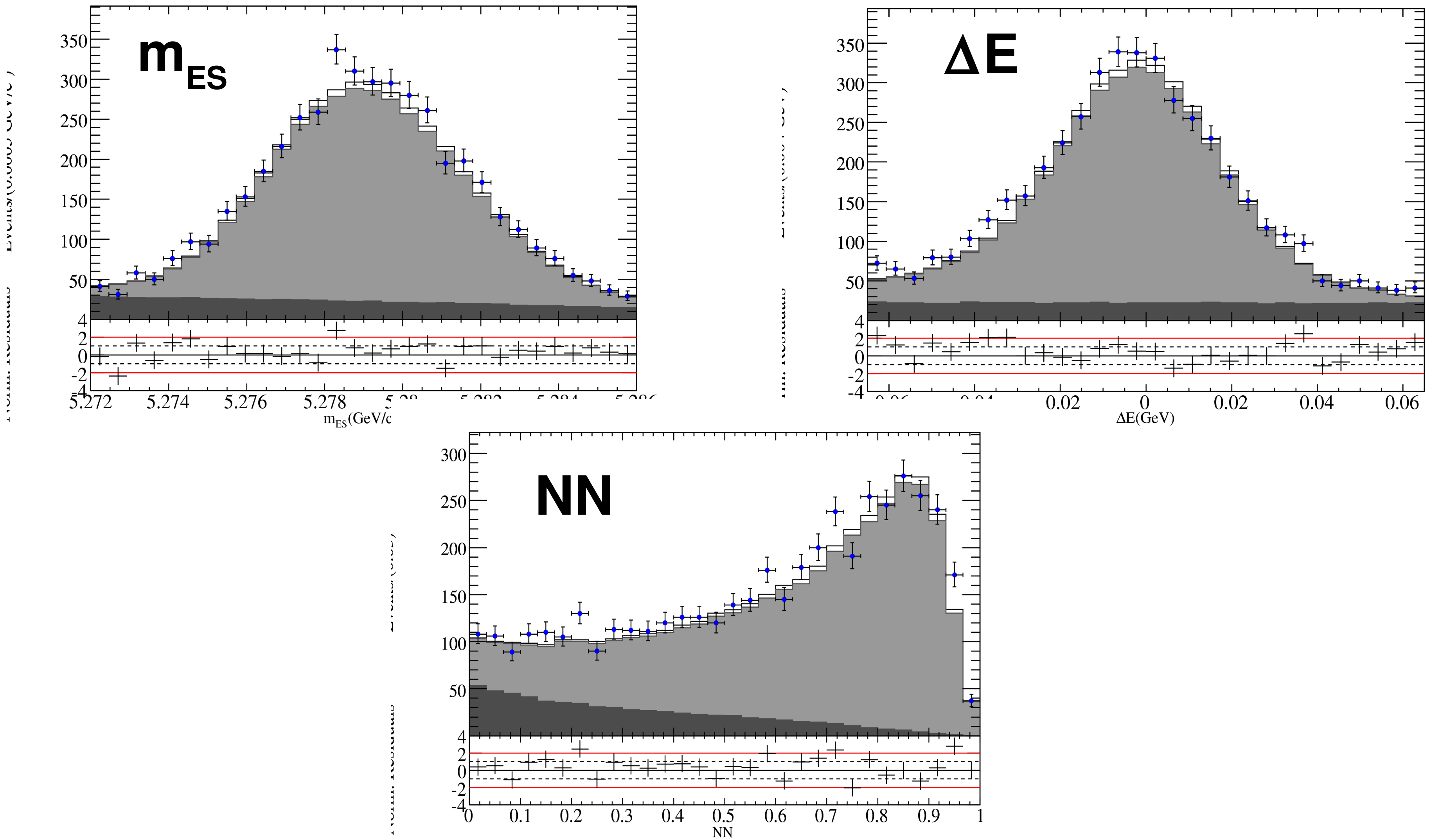






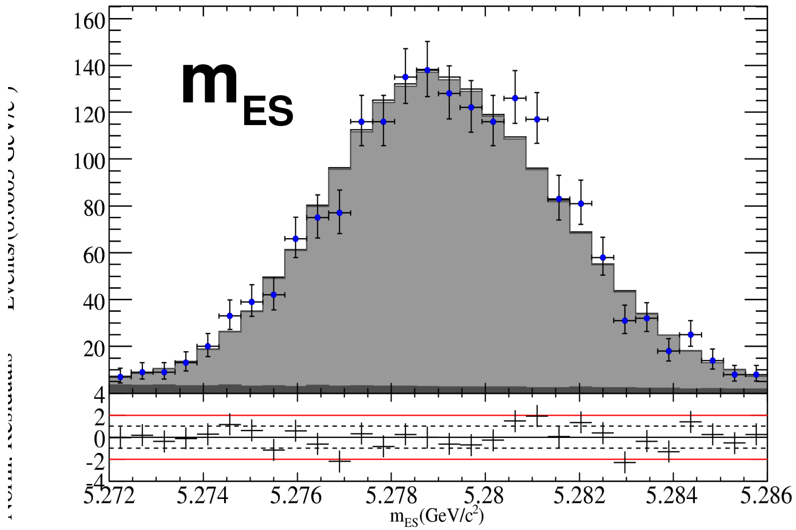
Fit Results: Proj. Plots

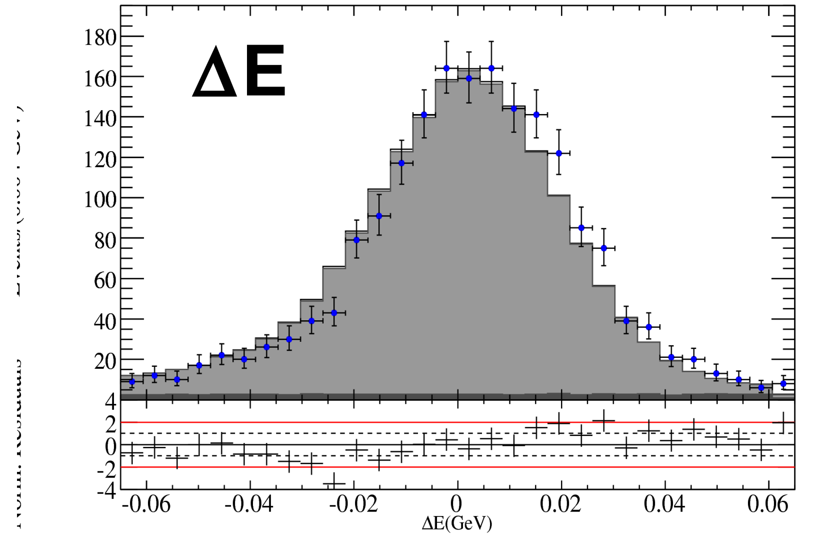
Dπ Band

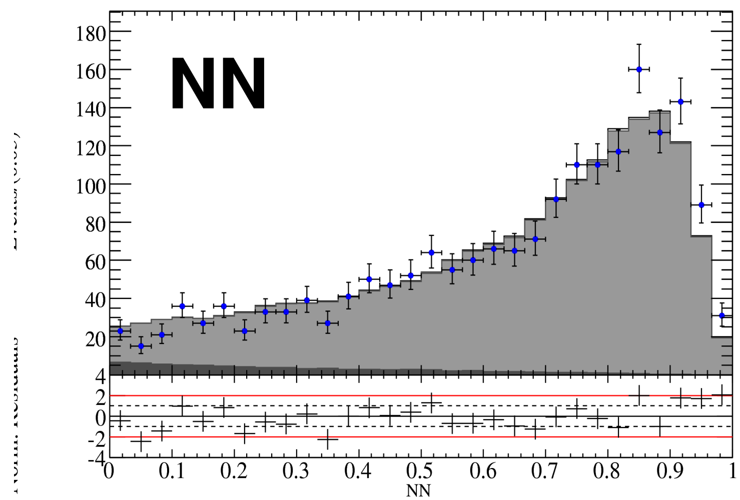


Fit Results: Proj. Plots

J/ψ Band

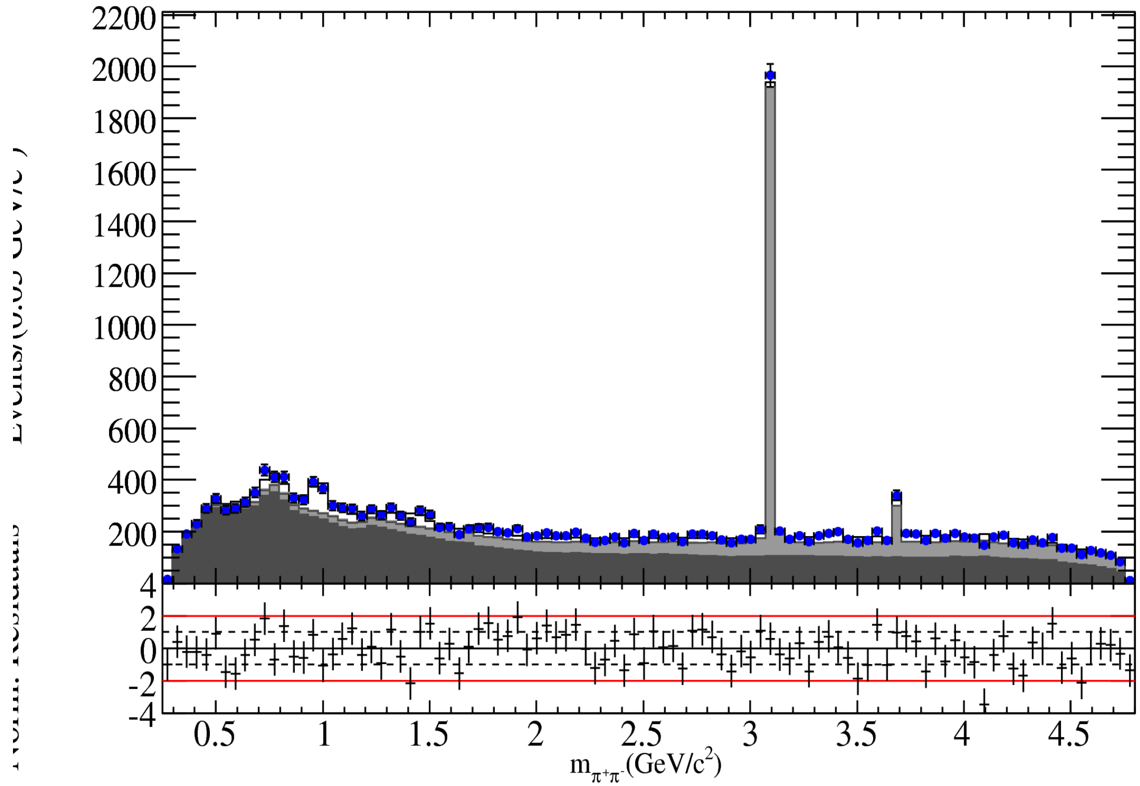






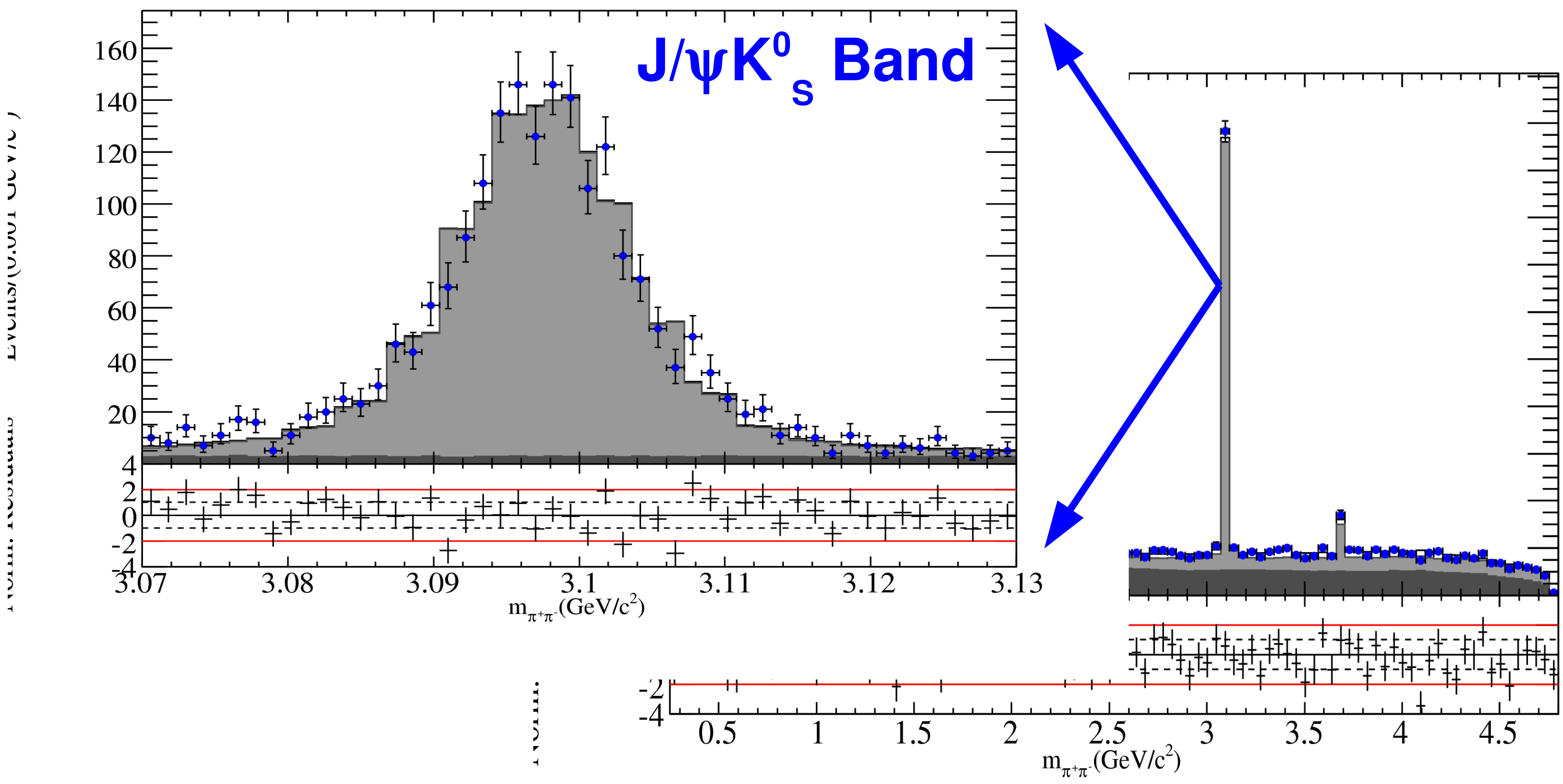
Fit Results: Proj. Plots

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



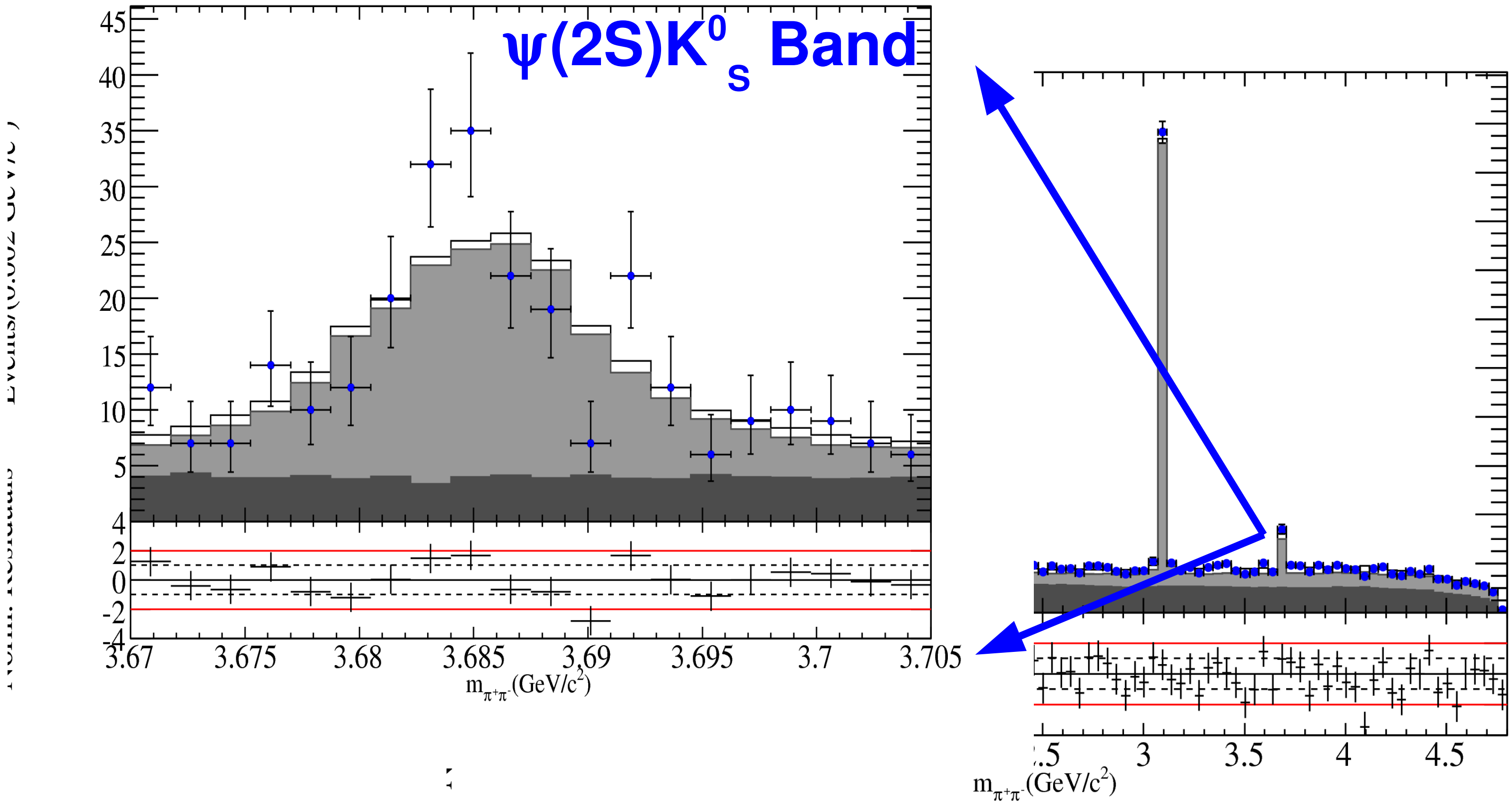
Fit Results: Proj. Plots

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



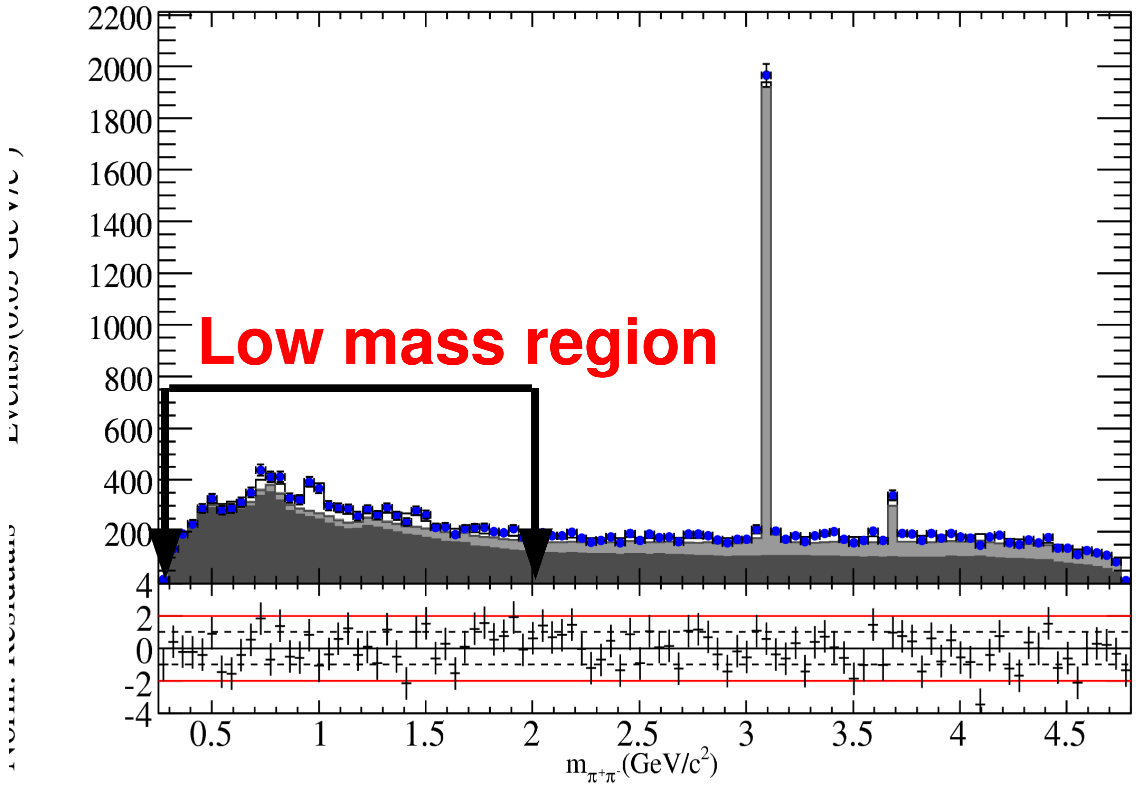
Fit Results: Proj. Plots

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



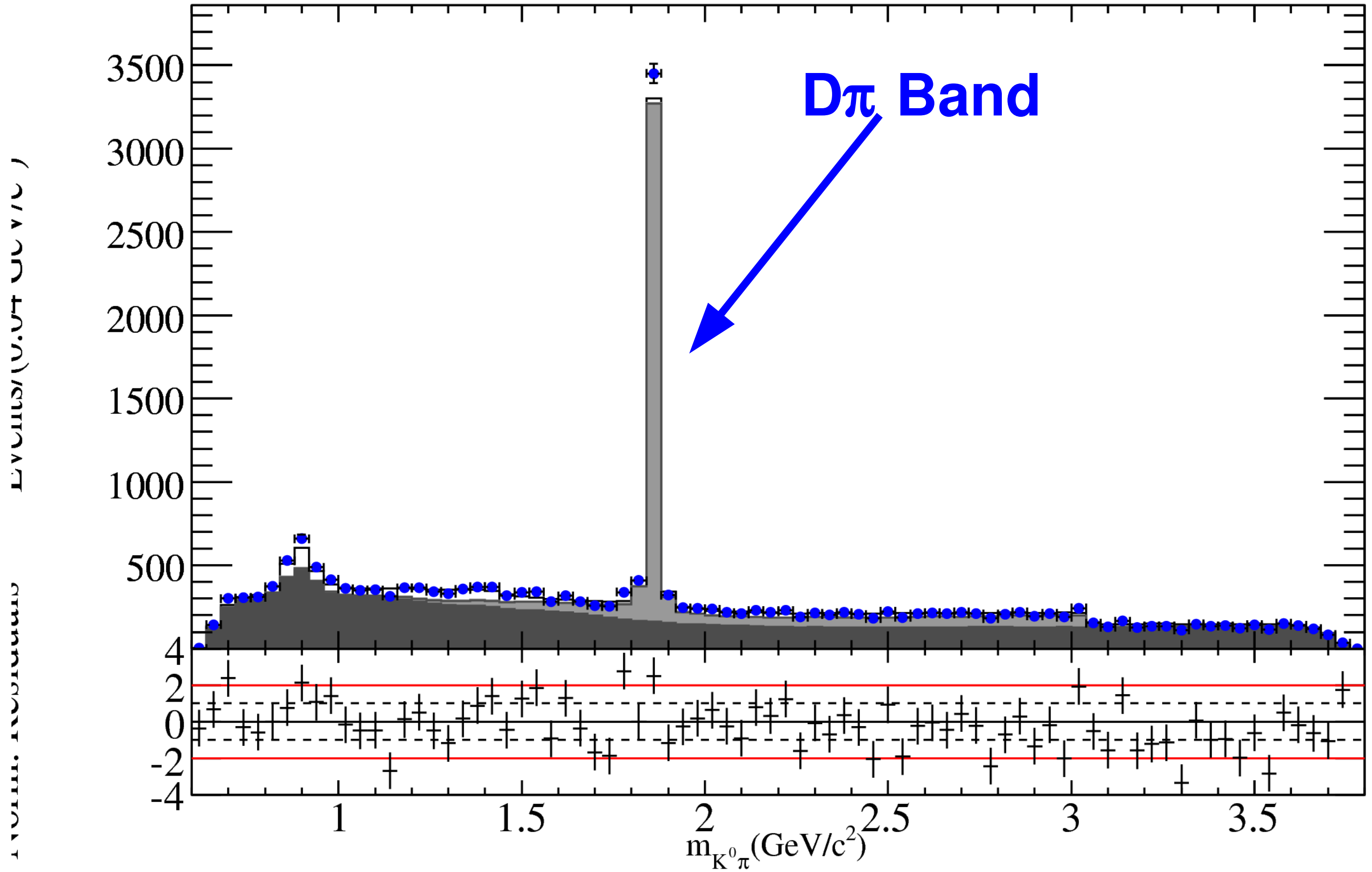
Fit Results: Proj. Plots

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

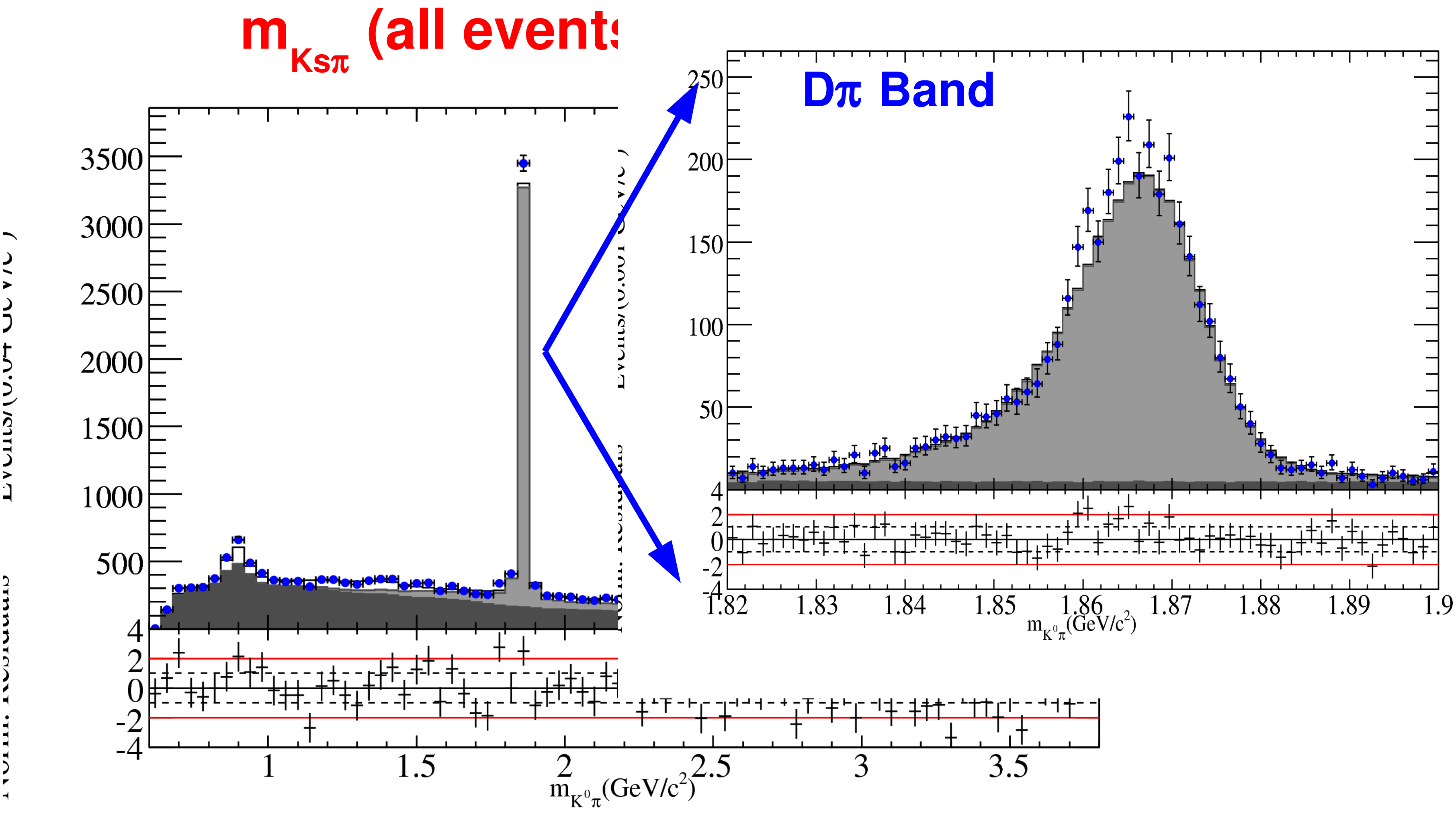


Fit Results: Proj. Plots

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

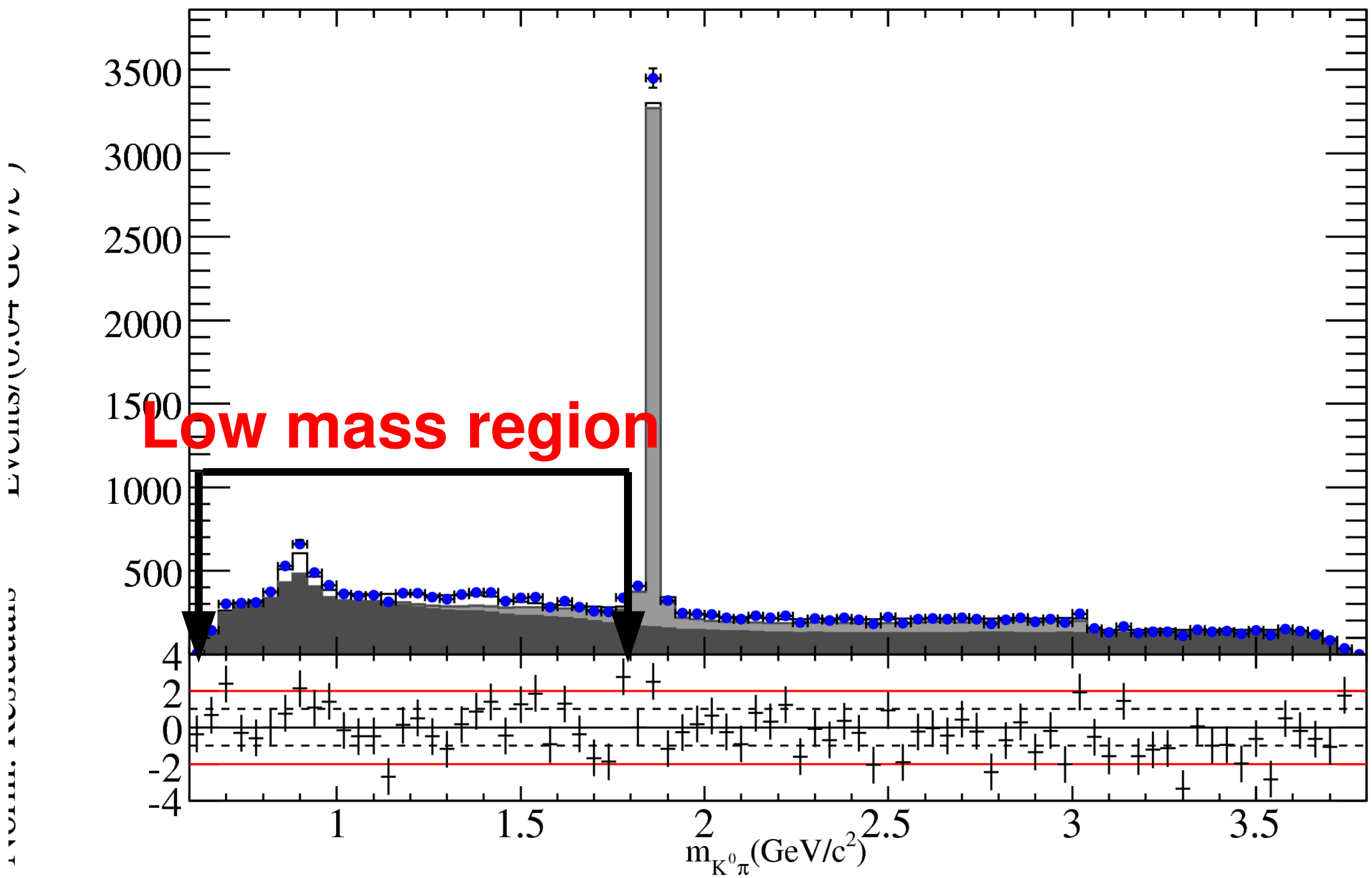


Fit Results: Proj. Plots



Fit Results: Proj. Plots

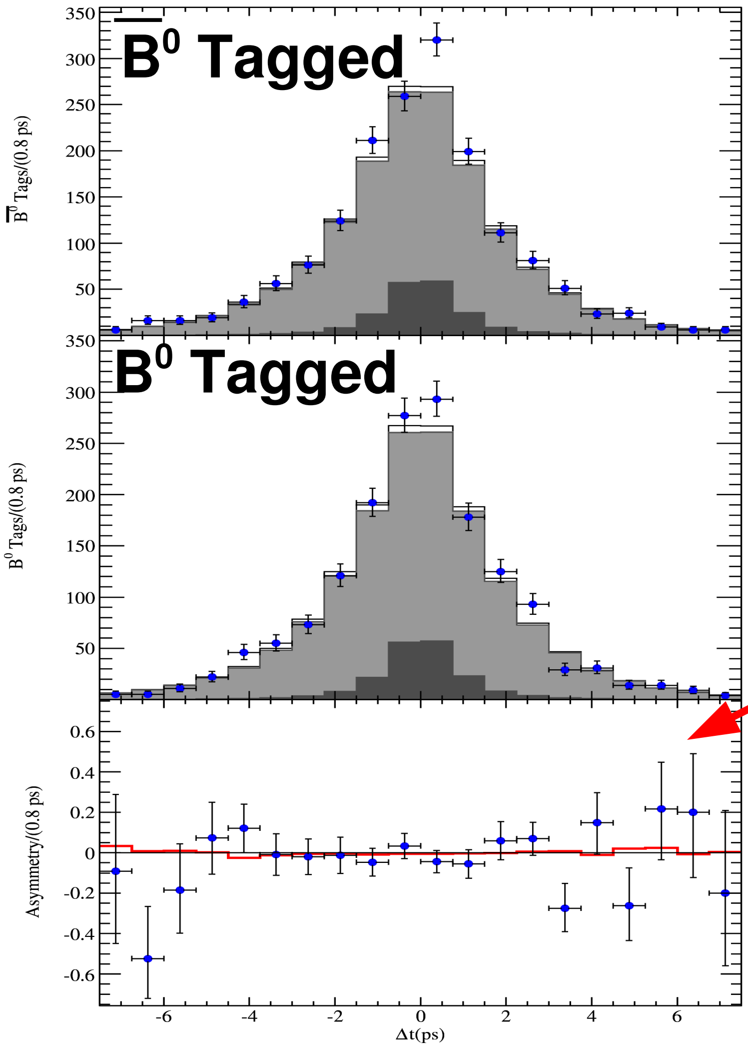
$m_{K_S\pi}$ (all events)



Fit Results: Proj. Plots

Δt dependent asymmetries

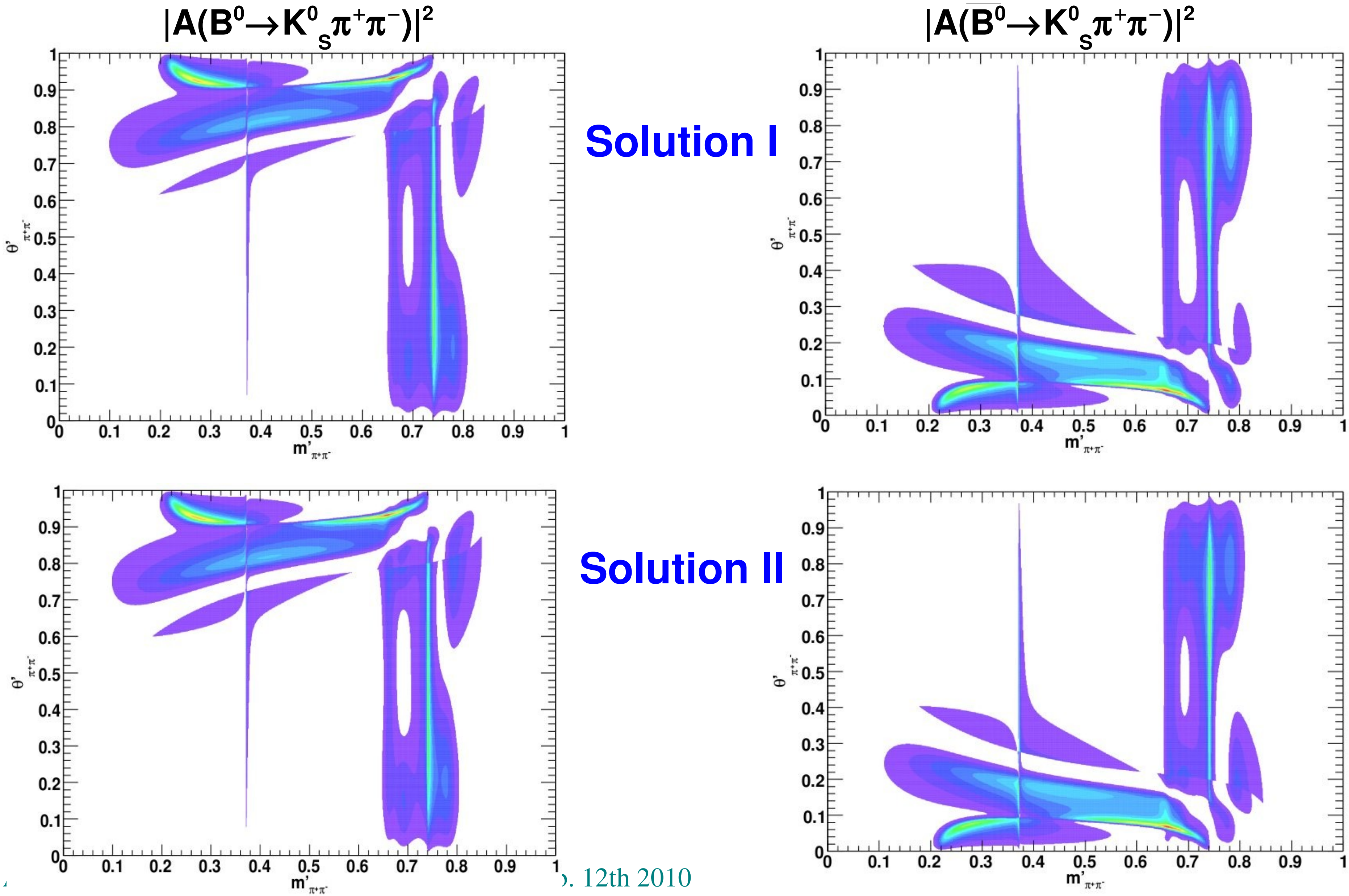
Dπ Band



Zero time-dependent CP asymmetry.

As expected!

Ambiguity to resolve DP interference pattern



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 $\rightarrow$ 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*(14
    - BF(K*(16

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 Frations

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 mesurements

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 compatible with no CPV

Fit Results: DCPV

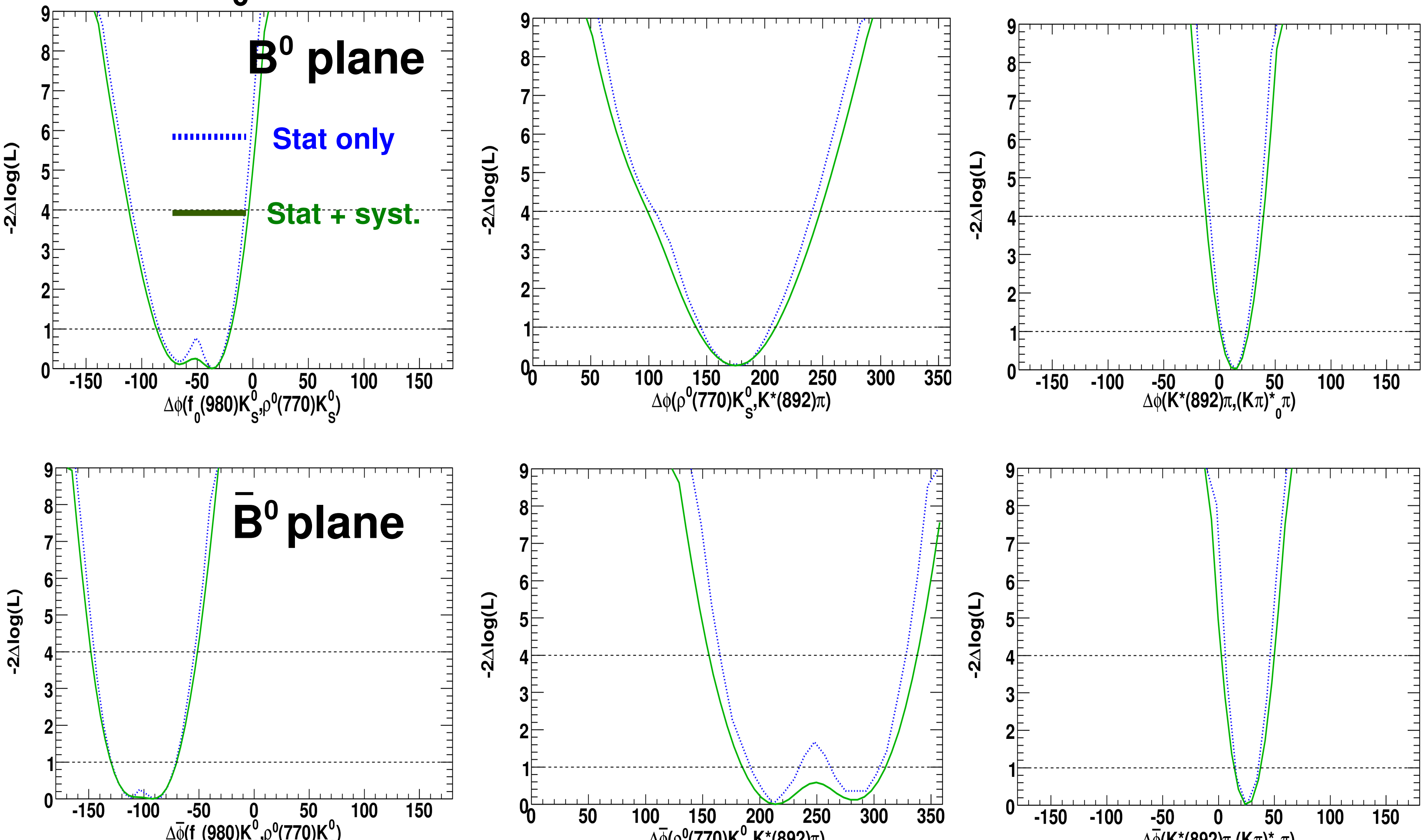
Component	DCPV
$C(B^0 \to f_0(980)K^0)$	$0.08^{+0.32}_{-0.18} \pm 0.03 \pm 0.04$
$C(B^0 \to \rho^0(770)K^0)$	$-0.05^{+0.28}_{-0.29} \pm 0.10 \pm 0.03$
$\boxed{A_{CP}(B^0 \to K^{*+}(892)\pi^-)}$	$\boxed{-0.21 \pm 0.10 \pm 0.01 \pm 0.02}$
$A_{CP}(B^0 \to (K\pi)^{*+}_0\pi^-)$	$0.09 \pm 0.12 \pm 0.02 \pm 0.02$
$C(B^0 \to f_2(1270)K^0)$	$0.28^{+0.35}_{-0.60} \pm 0.08 \pm 0.07$
$C(B^0 \to f_X(1300)K^0)$	$0.13^{+0.51}_{-0.36} \pm 0.04 \pm 0.09$
$C(NR)$	(-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 compatible with no CPV

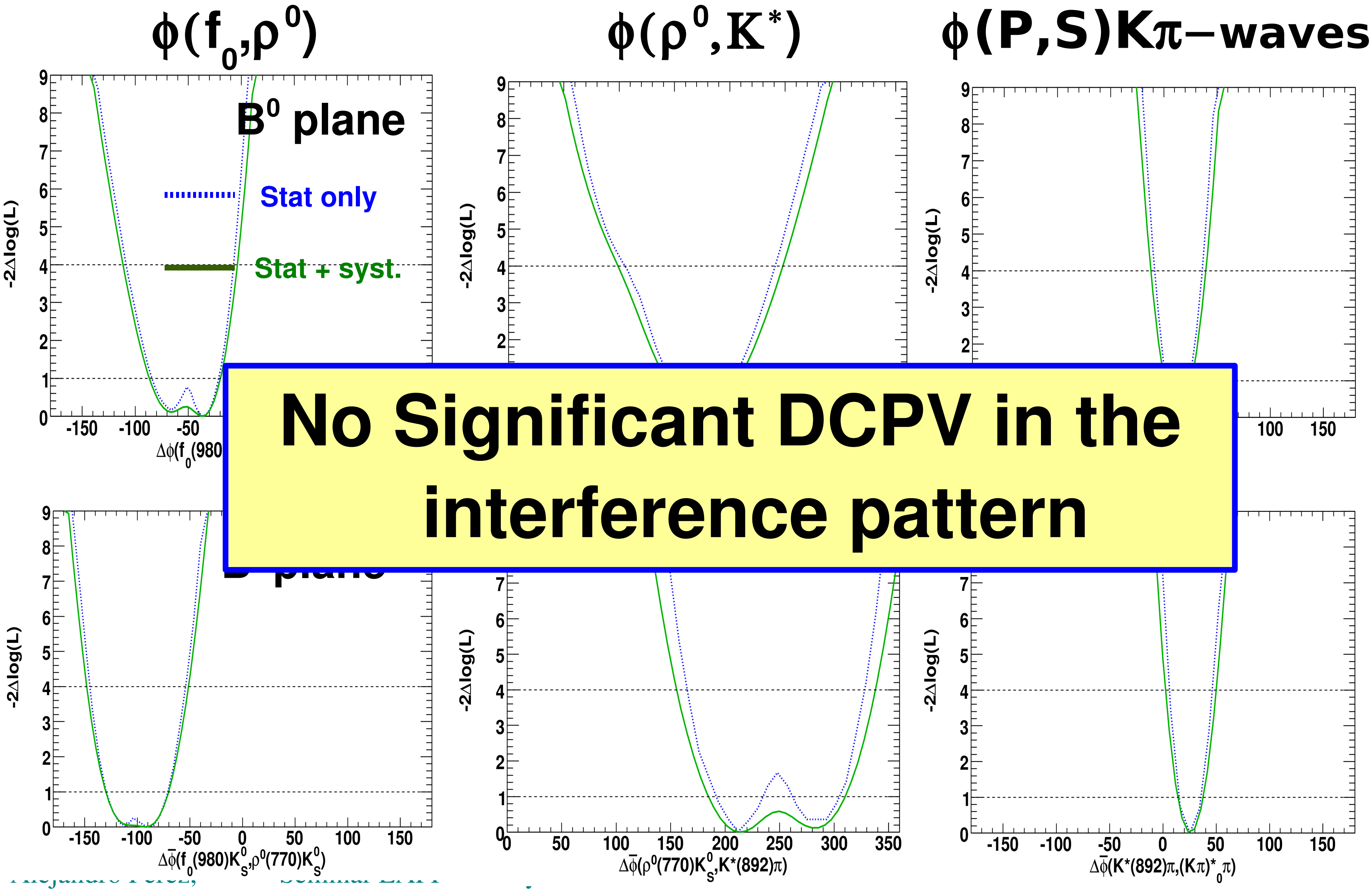
$B^0 \to K^*(892)\pi$ 2σ away from zero

Fit Results: interference pattern

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

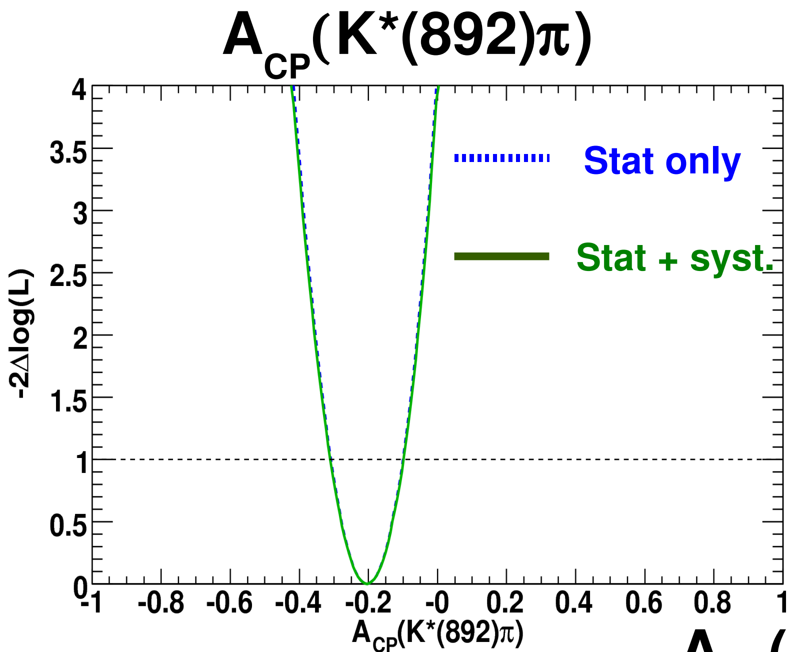


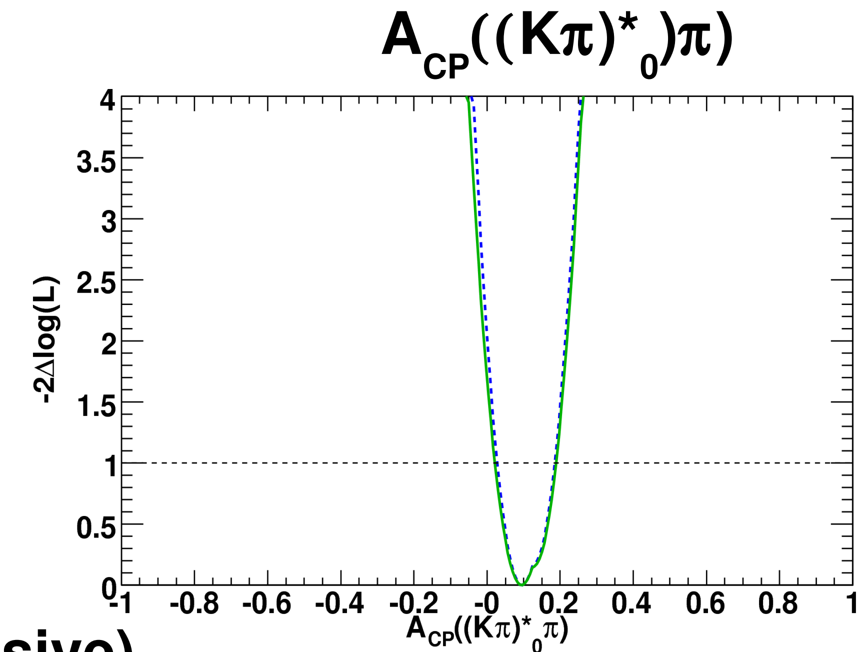
Fit Results: interference pattern

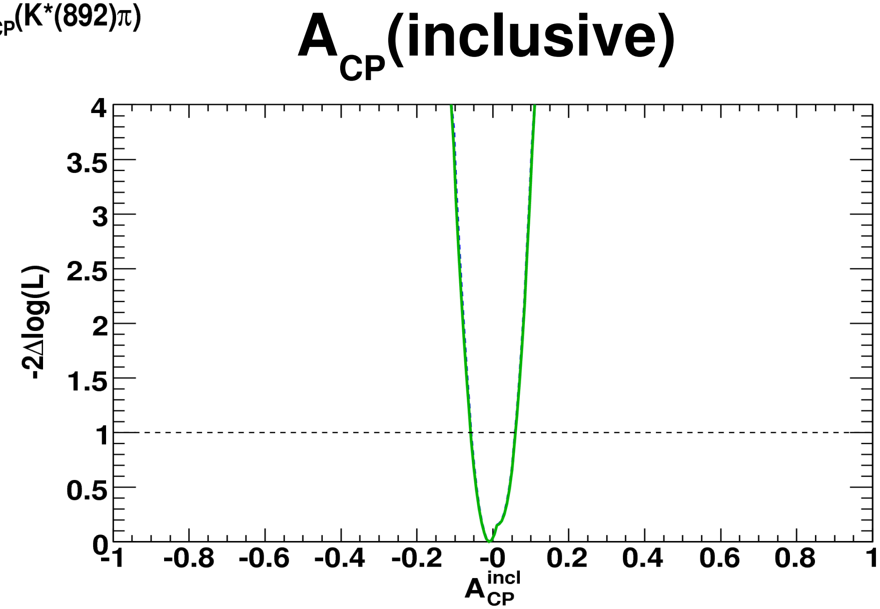


No Significant DCPV in the interference pattern

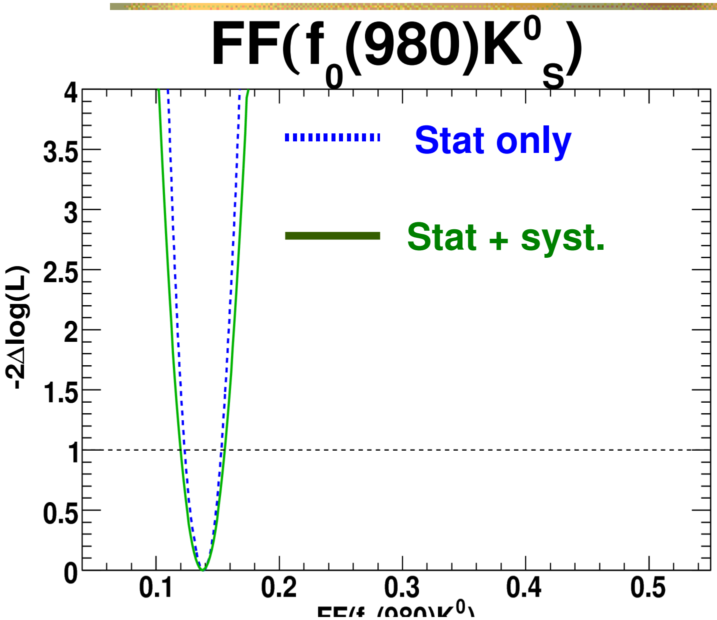
Fit Results: Direct CPV

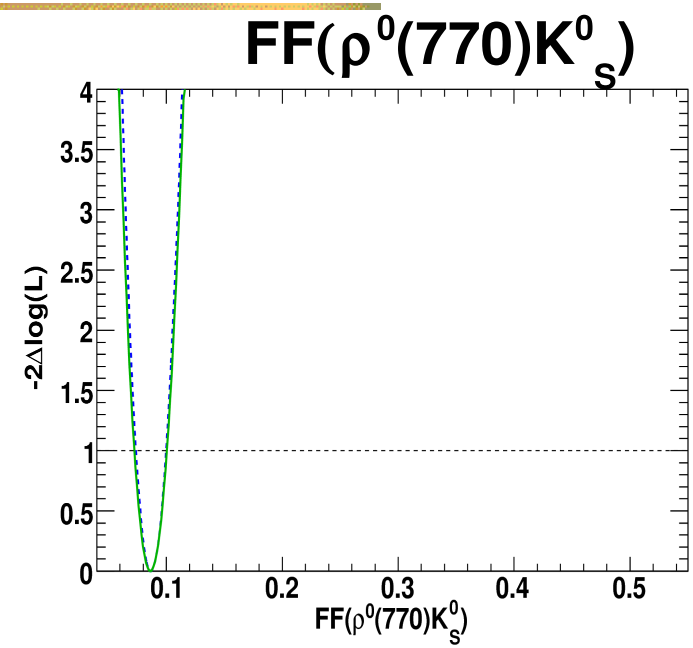


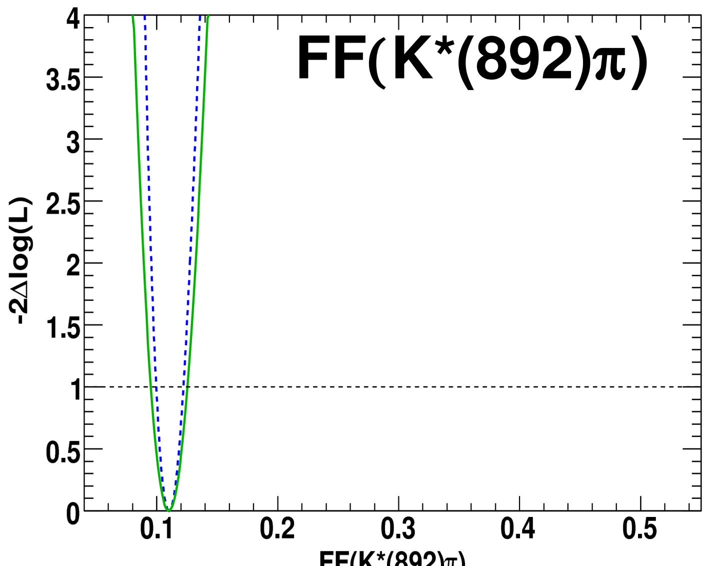


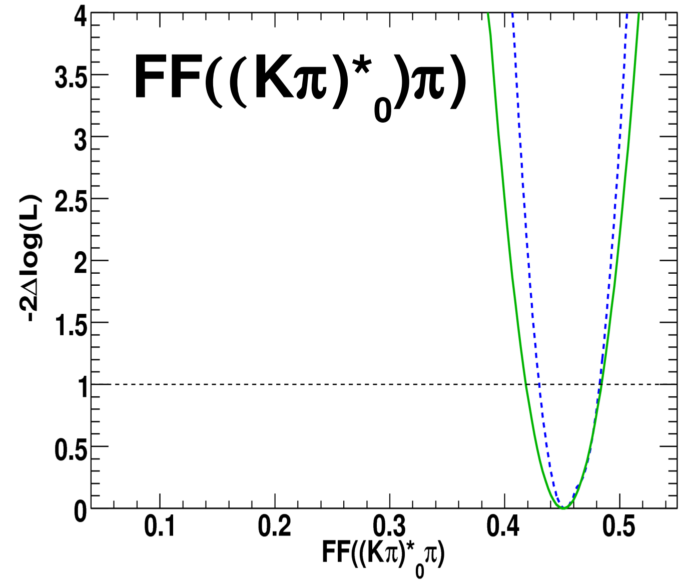


Fit Results: Fit Fractions (I)



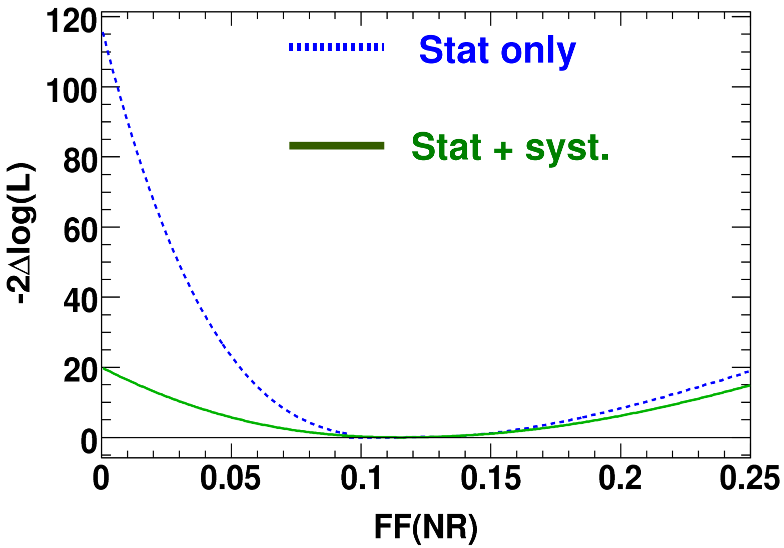




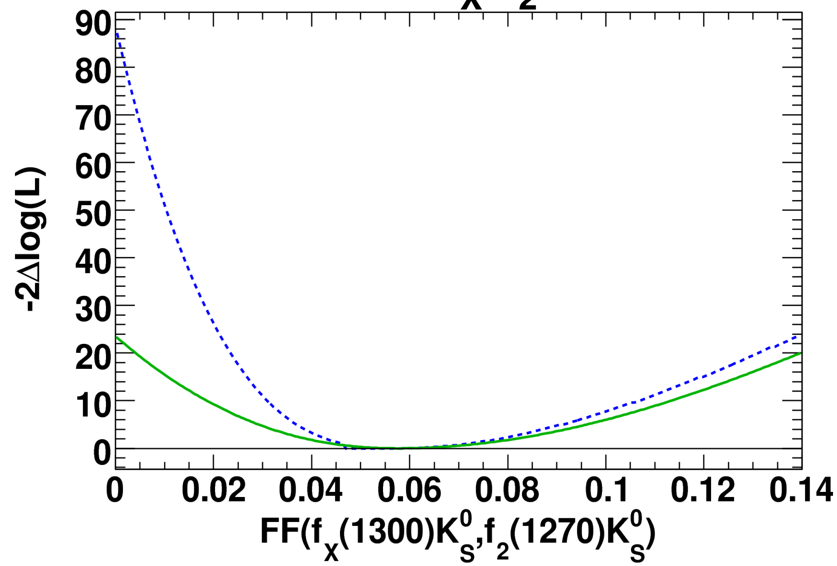


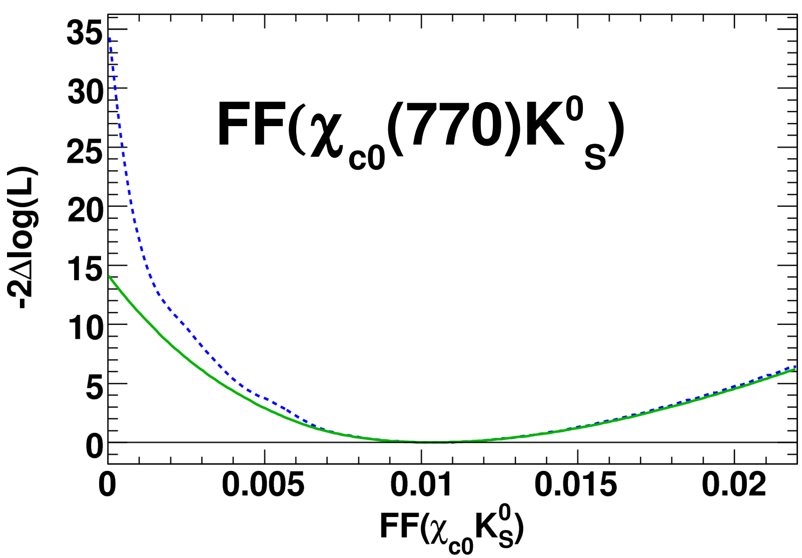
Fit Results: Fit Fractions (II)

FF(NR)

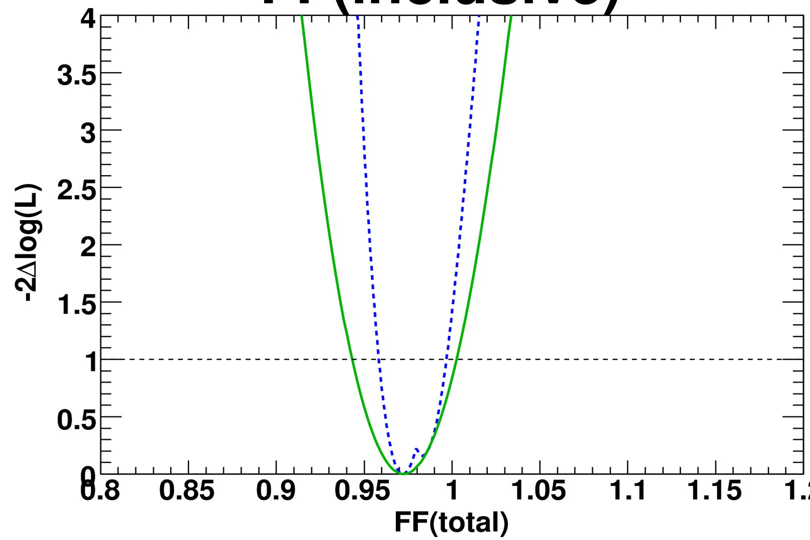


$FF(f_X, f_2)$





FF(inclusive)



No Free Lunch Theorem: Rpl

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

$$A = M_1\, e^{+i\phi_1}\, e^{i\delta_1} + M_2\, e^{+i\phi_2}\, e^{i\delta_2} \;,$$
$$\bar{A} = M_1\, e^{-i\phi_1}\, e^{i\delta_1} + M_2\, e^{-i\phi_2}\, e^{i\delta_2} \;,$$

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→K*π 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

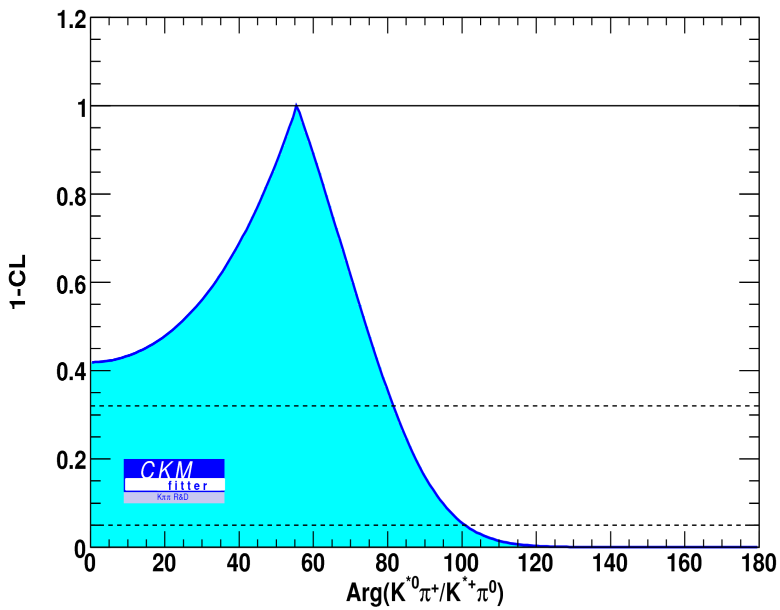
Scenario 1: prediction of unavailable phases

Input here:

- Experimental measurements
- CKM from global fit

(No assumption on any hadronic amplitude)

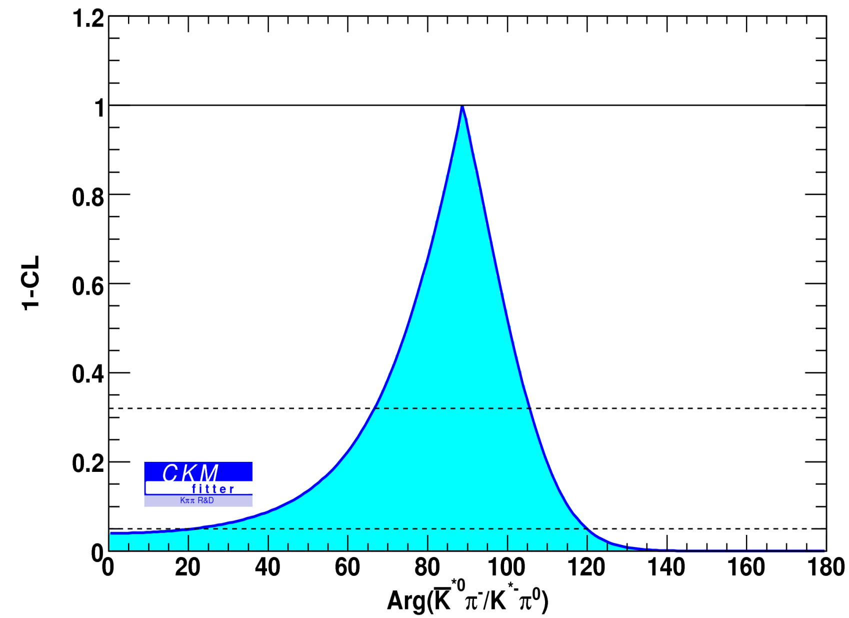
$|\phi| = |\arg(A(B^+\to K^{*0}\pi^+)A^*(B^+\to K^{*+}\pi^0))|$



Central value = 58°

(0,85)° at 1σ

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



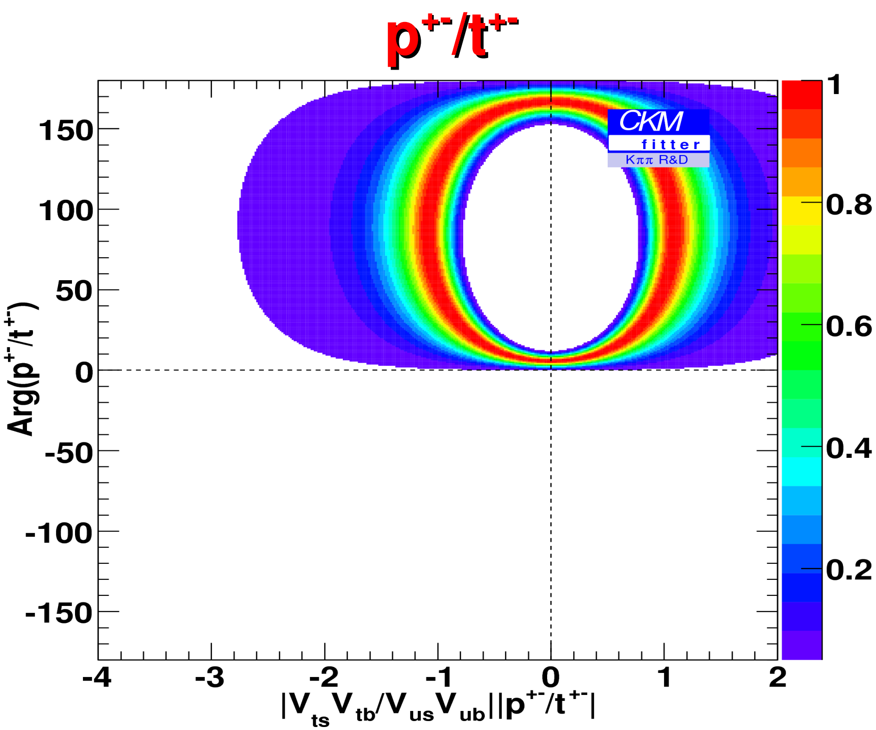
Central value = 95°

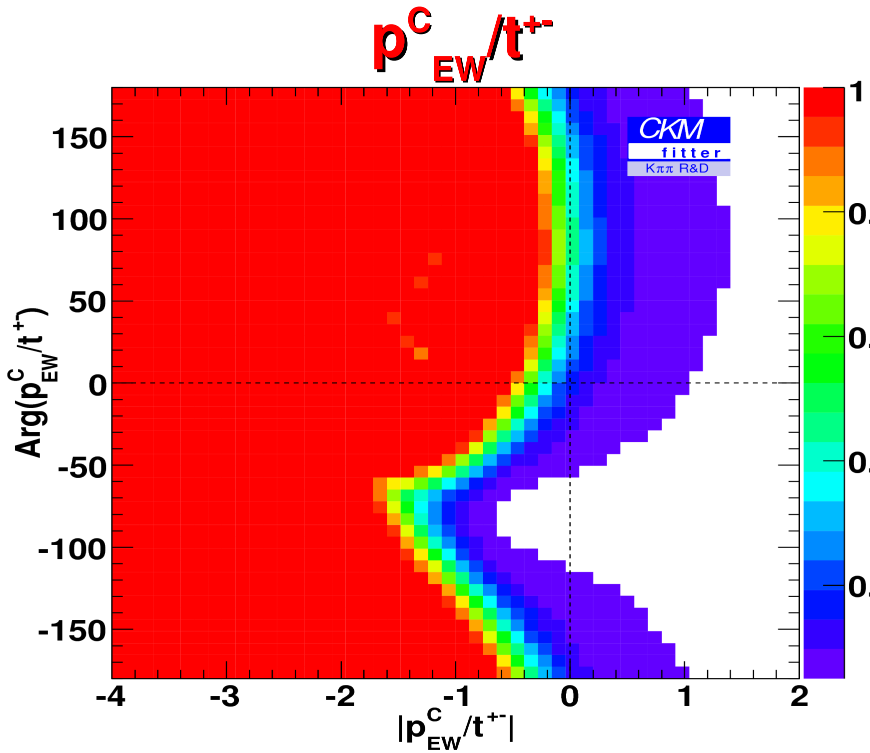
(68,107)° at 1σ

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
$\mathcal{A}_{CP}(K^+\rho^0)$	$0.44 \pm 0.10^{+0.06}_{-0.14}$	$0.405 \pm 0.101^{+0.036}_{-0.077}$	–	$0.419^{+0.081}_{-0.104}$
$2\beta_{\rm eff}(K^0\rho^0)$	$20.4 \pm 19.6 \pm 7.1$ (global min.)	–	–	20.4 ± 20.8
	$33.4 \pm 20.8 \pm 7.1$ ($\Delta\chi^2 = 0.16$)	–	–	33.4 ± 22.0

B→ρK system: exploring hadronic parameters





Exclude negative values of phase

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

Weak constraints on most paramters

ρK+K*π 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 $\phi_{3/2}$:

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

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

- both are independent functions of observables

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

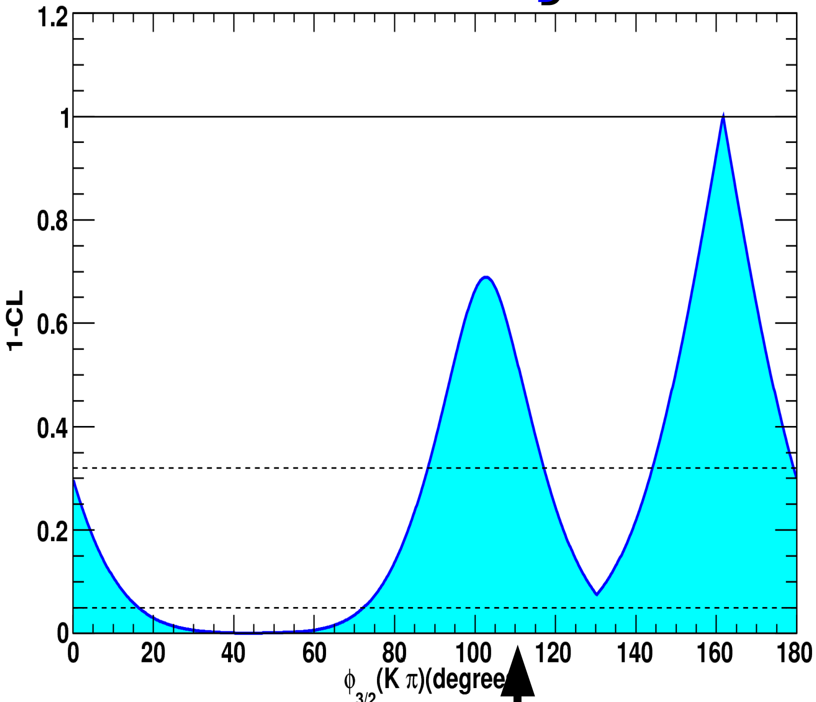
  Ex.: $P_{EW} = 0 \to \phi_{3/2} = \alpha$

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

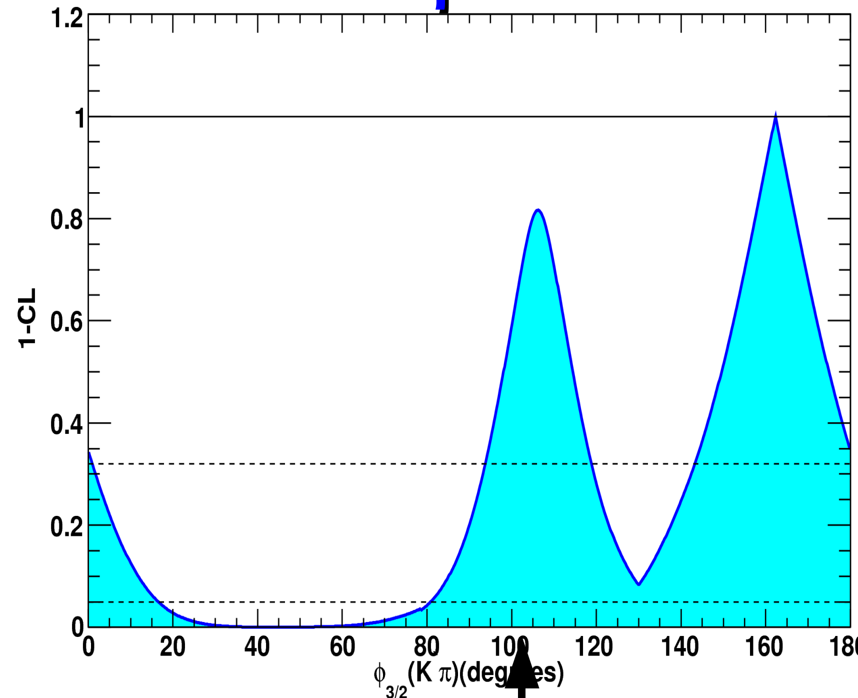
$\rho K + K^*\pi$ system: exploring $\phi_{3/2}(K^*\pi)$

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

$K^*\pi$ only



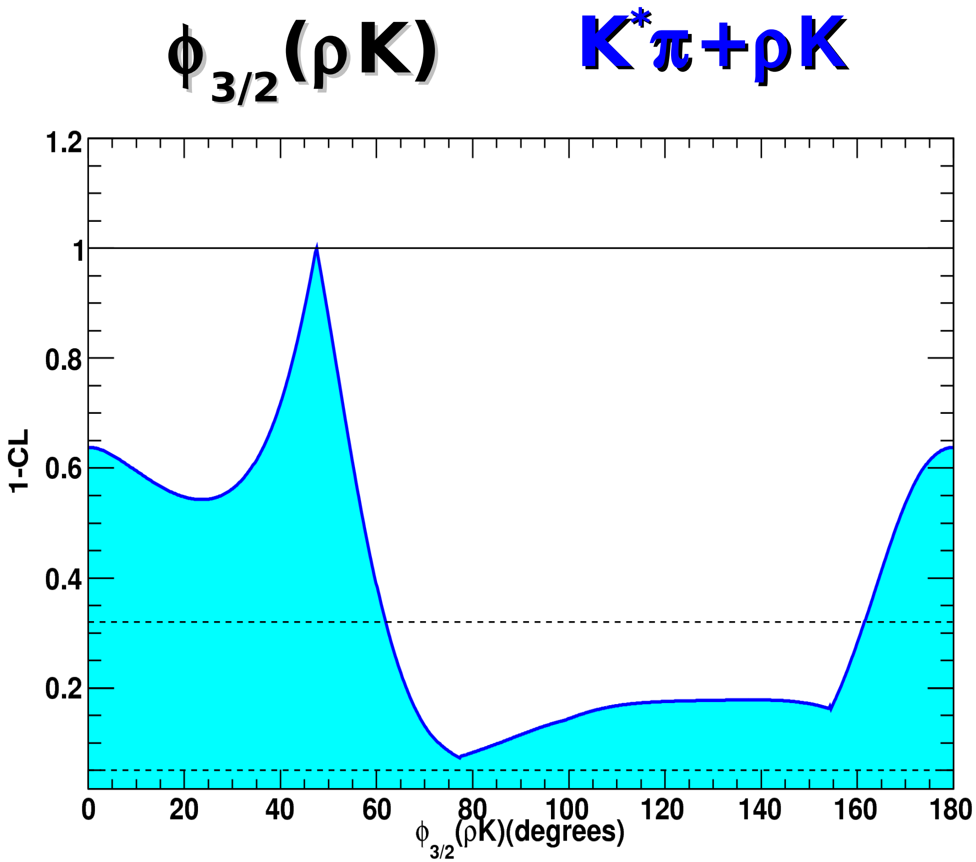
$K^*\pi+\rho K$



(~18° $\rightarrow$ ~15°)

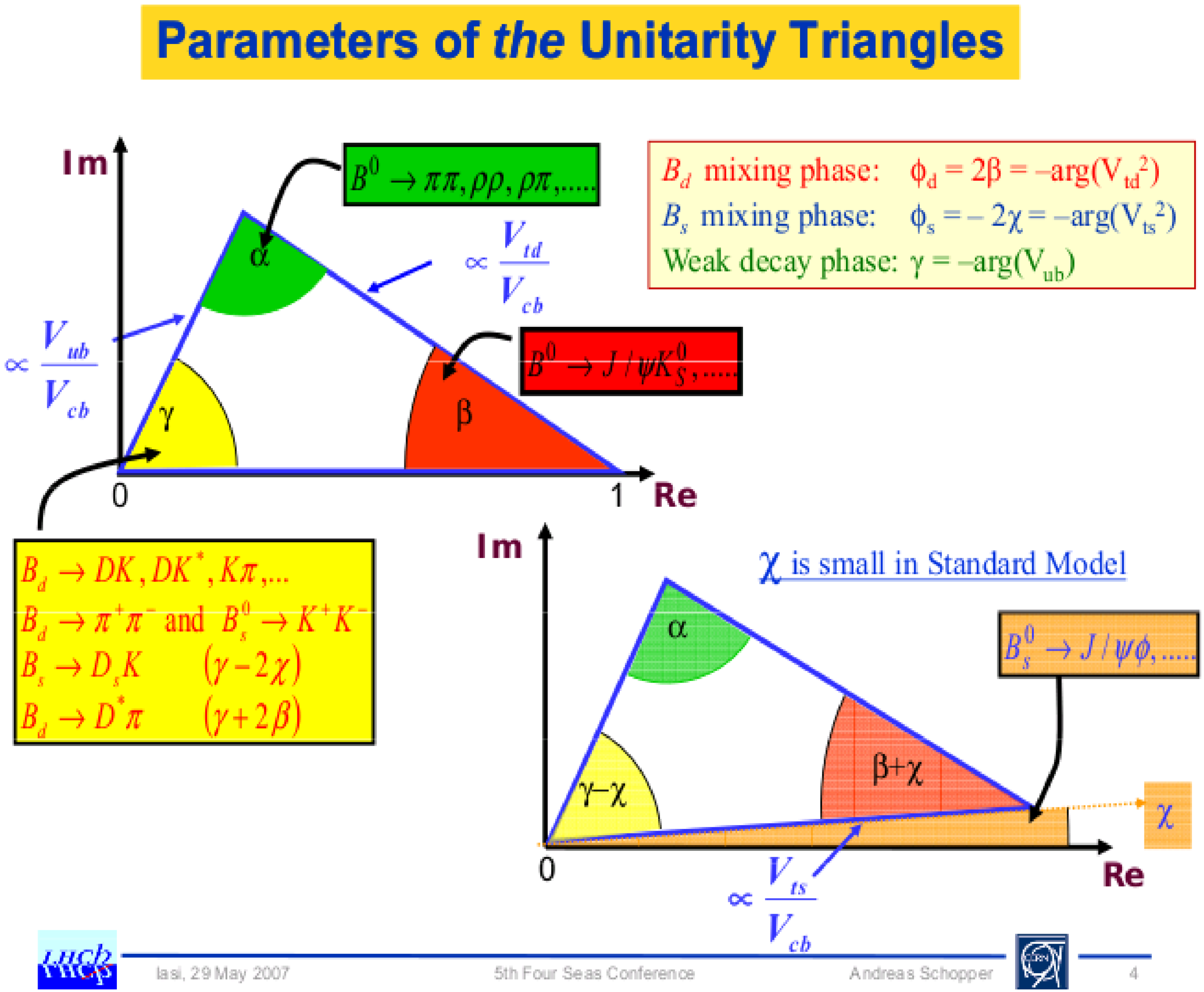
- **Error for each solution improves by only adding ρK system**
- **Adding the additional phases will further improve**

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



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

Limited constraint with current experimental inputs and errors

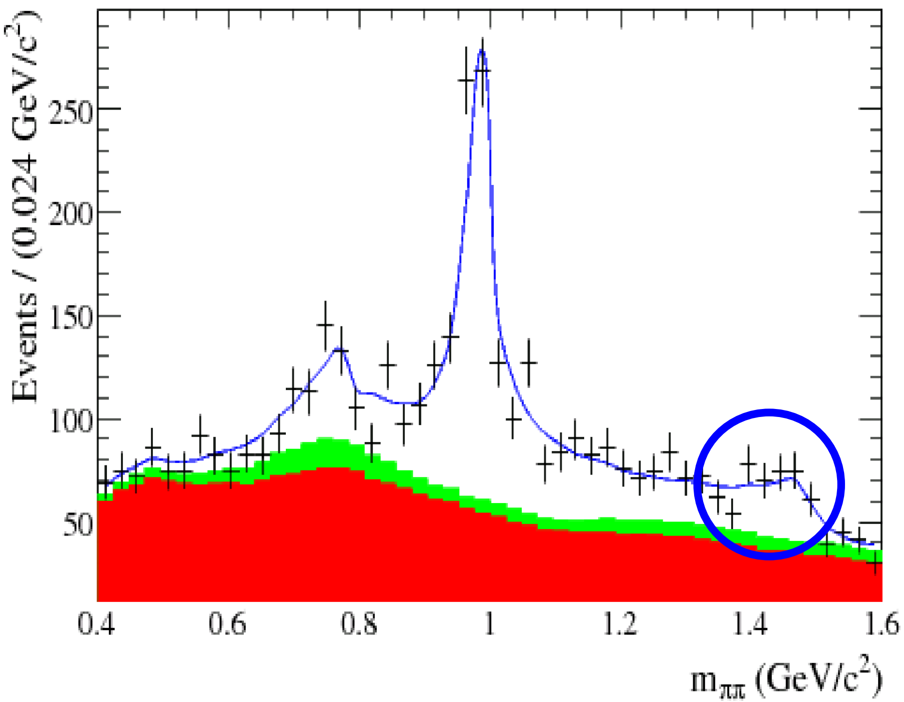

Parameters of the Unitarity Triangles
Im
$B^0 \to \pi\pi, \rho\rho, \rho\pi, \ldots$
α
$\propto \frac{V_{td}}{V_{cb}}$
$\propto \frac{V_{ub}}{V_{cb}}$
$B^0 \to J/\psi K^0_S, \ldots$
γ
β
0
1
Re
B_d mixing phase: $\phi_d = 2\beta = -\arg(V_{td}^2)$
B_s mixing phase: $\phi_s = -2\chi = -\arg(V_{ts}^2)$
Weak decay phase: $\gamma = -\arg(V_{ub})$
$B_d \to DK, DK^*, K\pi, \ldots$
$B_d \to \pi^+\pi^-$ and $B^0_s \to K^+K^-$
$B_s \to D_s K \quad (\gamma - 2\chi)$
$B_d \to D^*\pi \quad (\gamma + 2\beta)$
Im
χ is small in Standard Model
α
$B^0_s \to J/\psi\phi, \ldots$
$\beta+\chi$
$\gamma-\chi$
χ
0
Re
$\propto \frac{V_{ts}}{V_{cb}}$
Iasi, 29 May 2007
5th Four Seas Conference
Andreas Schopper
4

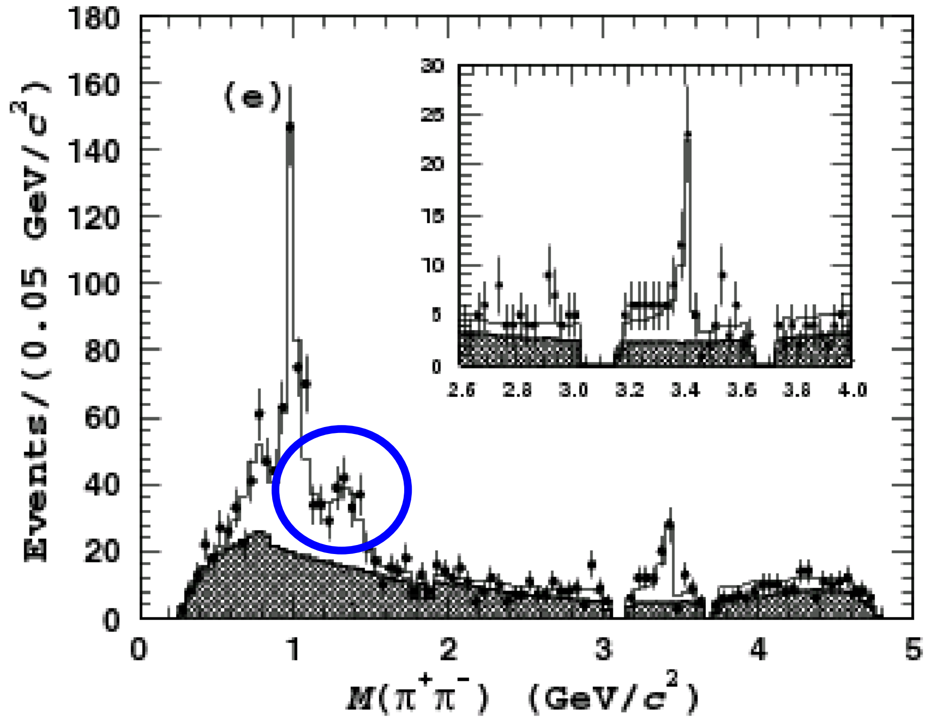
The $f_x(1300)$

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

BaBar PRD78:012004 (2008)

Belle PRL96:251803 (2006)





$M = 1479 \pm 8$ MeV
$\Gamma = 80 \pm 19$ MeV

$M = 1449 \pm 13$ MeV
$\Gamma = 126 \pm 25$ MeV

Data prefers scalar over vector and tensor