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

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Seminar LPC Clermont – Friday 3 April 2009

Outline

- Introduction
- **Analysis:** time-dependent amplitude analysis of $B^0 \rightarrow K^0_S \pi^+ \pi^-$ decays with BaBar
- **Phenomenological interpretation:** SU(2) isospin analysis of the $B \rightarrow K^* \pi$ and $B \rightarrow \rho K$ modes.

Introduction

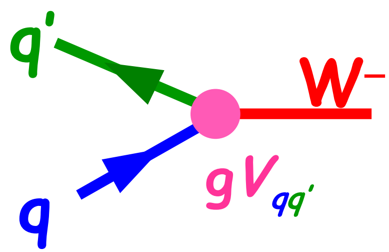
CP Violation and the CKM Matrix

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

quarks

Weak states — CKM matrix — Mass states

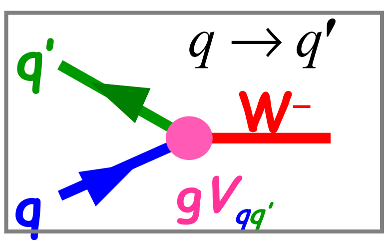
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



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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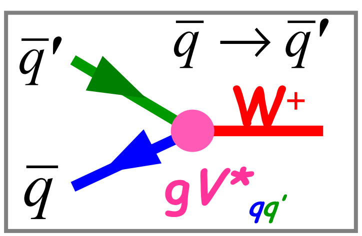

→ $V_{CKM} = V^*_{CKM}$

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

quark flavor sector highly predictive!

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 $O(\lambda^4)$, with $\lambda=\sin(\theta_c) \approx 0.22$

CKM matrix — Wolfenstein parameterization:

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

Experimental hierarchy among CKM elements

~O(1)

CKM Matrix and the Unitarity Triangle

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Experimental hierarchy among CKM elements

$\sim O(\lambda)$

CKM Matrix and the Unitarity Triangle

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Experimental hierarchy among CKM elements

$\sim O(\lambda^2)$

CKM Matrix and the Unitarity Triangle

$V_{CKM} V^{\dagger}_{CKM} = 1$ →

quark mixing only described by
- 3 real rotation angles and,
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Expansion in power of λ until $O(\lambda^4)$, with $\lambda = \sin(\theta_c) \approx 0.22$

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Experimental hierarchy among CKM elements

$\sim O(\lambda^3)$

CKM Matrix and the unitarity Triangle

$V_{CKM} V^{\dagger}_{CKM} = 1$ → quark mixing only described by
- 3 real rotation angles and,
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Expansion in power of λ until $O(\lambda^4)$, with $\lambda = \sin(\theta_c) \approx 0.22$

CKM matrix — Wolfenstein parameterization:

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

Experimental hierarchy among CKM elements

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

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:

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

Unitarity Relations:

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-degenerate**

CKM Matrix and the unitarity Triangle

$V_{CKM} V^{\dagger}_{CKM} = 1$ →

quark mixing only described by
- 3 real rotation angles and,
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Expansion in power of λ until O(λ⁴), with λ=sin(θ$_c$) ≈ 0.22

CKM matrix — Wolfenstein parameterization:

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

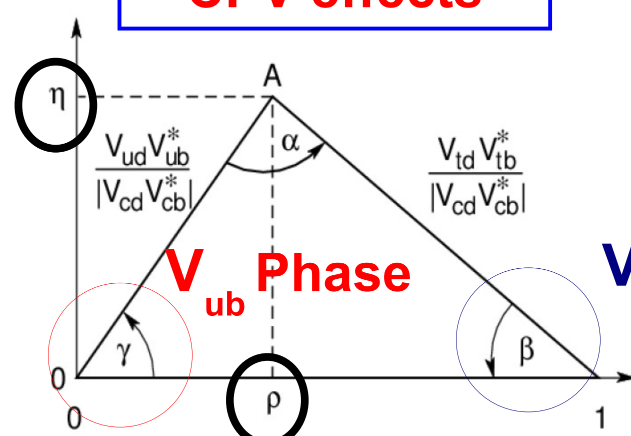
Unitarity Relations:

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

Expected large CPV effects



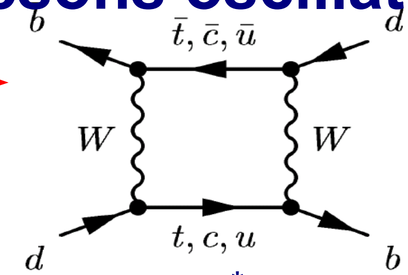
V_{td} Phase

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,

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

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}**

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 mesons and CP violation

Types of CP violation

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

B mesons and CP violation

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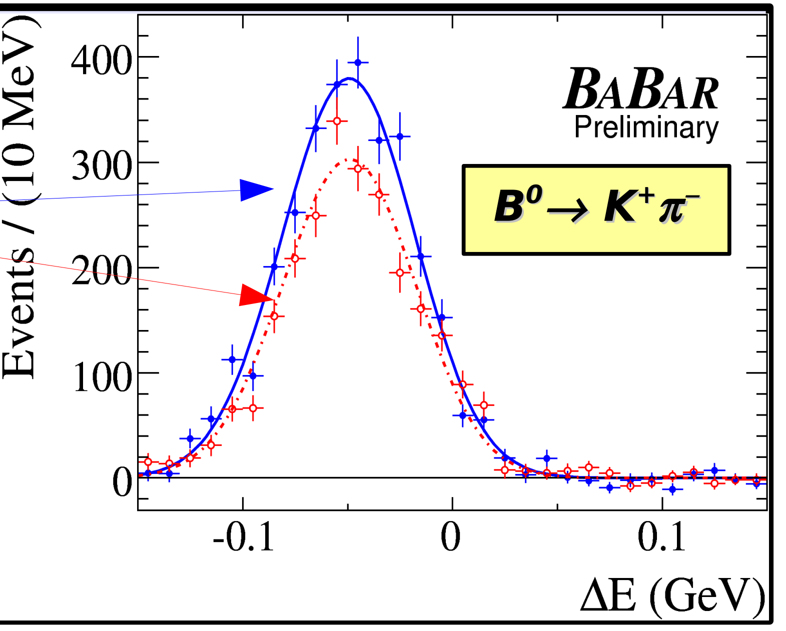
For B mesons $|q/p| \sim 1$

- 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 $|q/p| \sim 1$

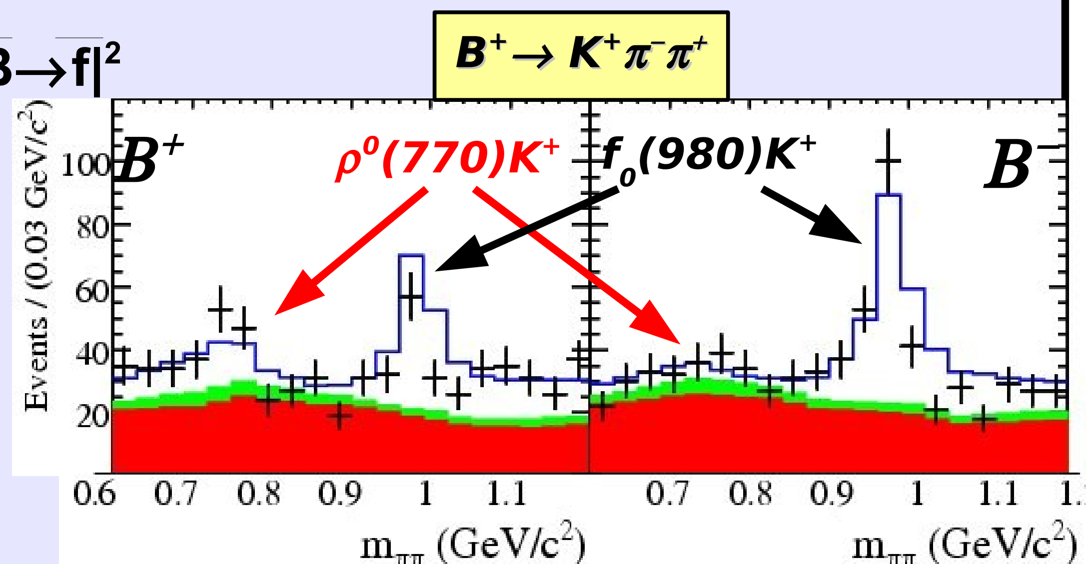
- Direct CPV: $|B \to f|^2 \neq |\overline{B} \to \overline{f}|^2$

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

$$\neq$$

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

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



B mesons and CP violation

Types of CP violation

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

  For B mesons $|q/p| \sim 1$

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

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

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

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

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

$$C = (1-|\lambda_{CP}|^2)/(1+|\lambda_{CP}|^2) \qquad \lambda_{CP} = (q/p)[\overline{A}(\overline{B}^0 \to f_{CP})/A(B^0 \to f_{CP})]$$

B mesons and CP violation

Types of CP violation

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

- Di...

- Mi... $\overline{B}^0 \to B$ ... $\overline{B}^0 \to B$ ... $\Delta m_d \Delta t)$

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

$C = (1-|\lambda_{CP}|^2)/(1+|\lambda_{CP}|^2)$ $\lambda_{CP} = (q/p)[\overline{A}(\overline{B}^0 \to f_{CP})/A(B^0 \to f_{CP})]$

SM Prediction:

$S = \sin(2\beta)$

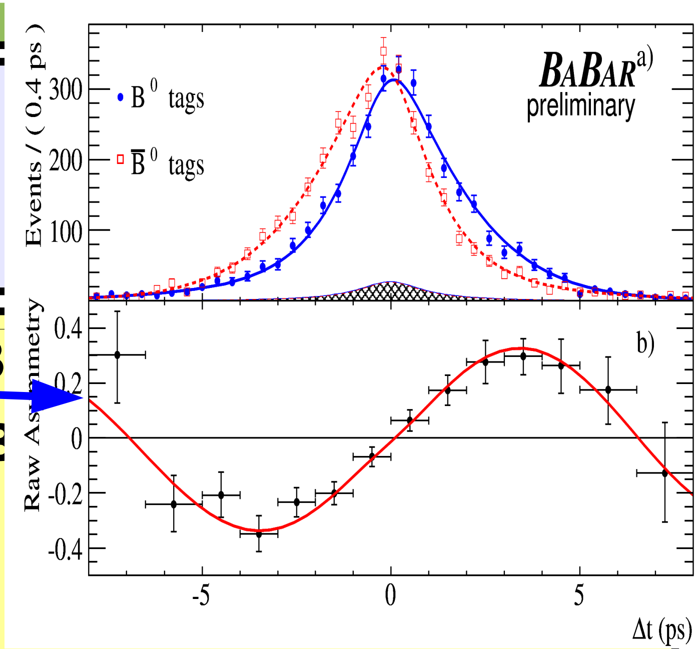
$C = 0$

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

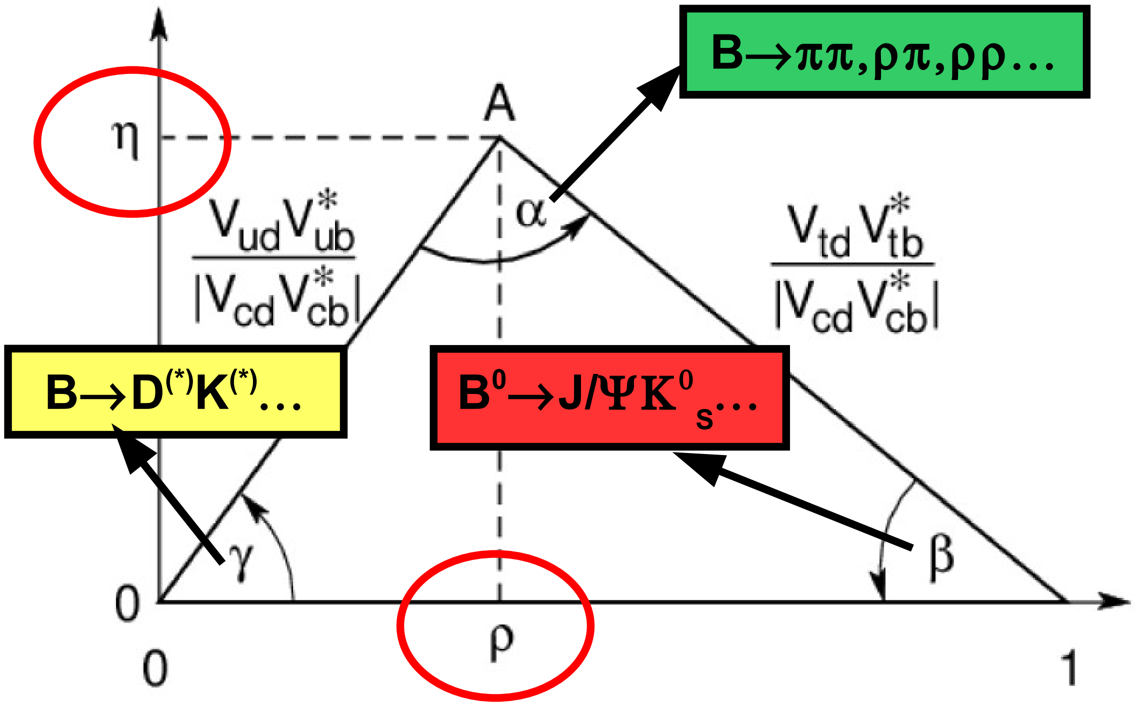
Unitarity Triangle (UT)

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)

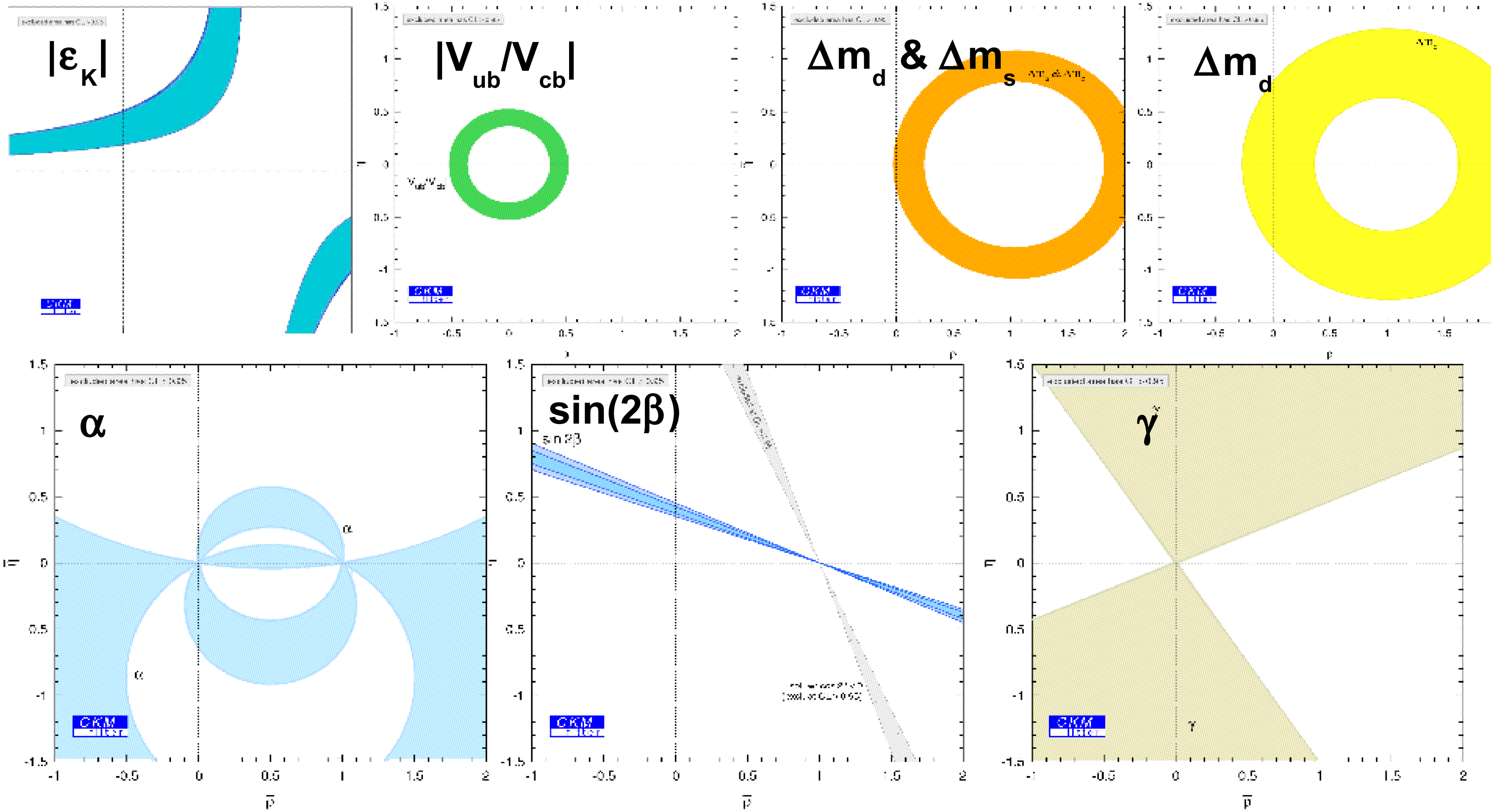


The CKM Unitarity predicts that all constraints intersect at a point!

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



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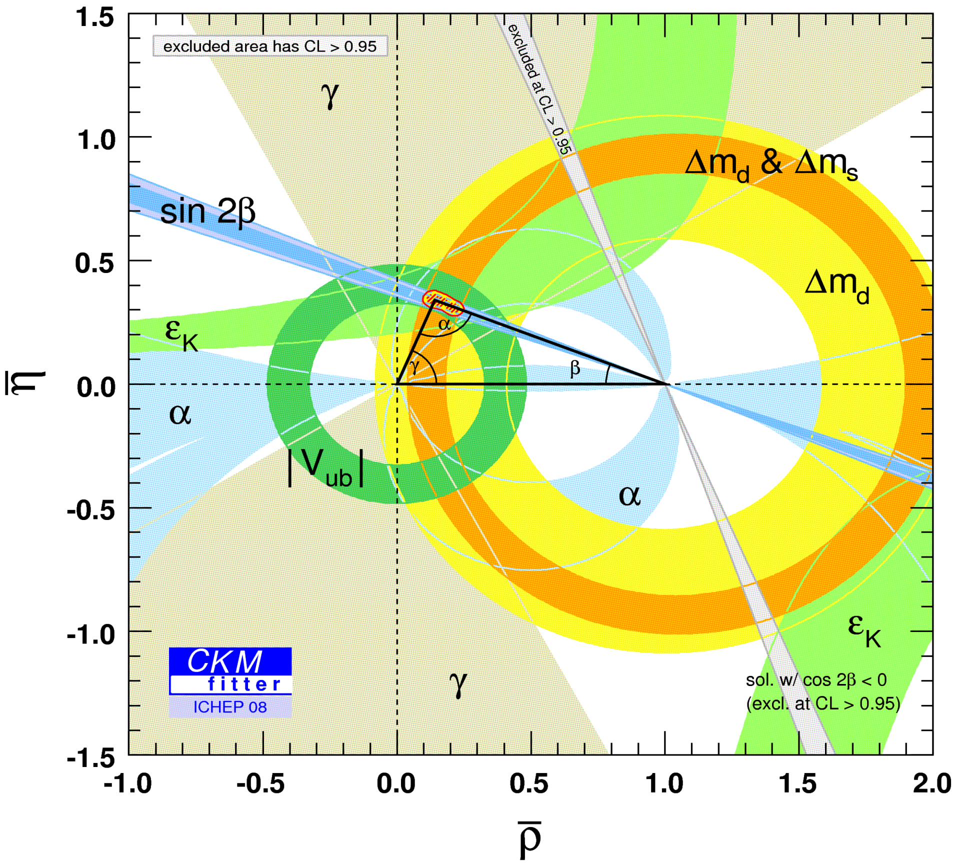


- **Combined constraint limited in a small region of parameter space.**
- **Striking confirmation of CKM mechanism.**

Two simultaneous strategies:

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

This thesis:

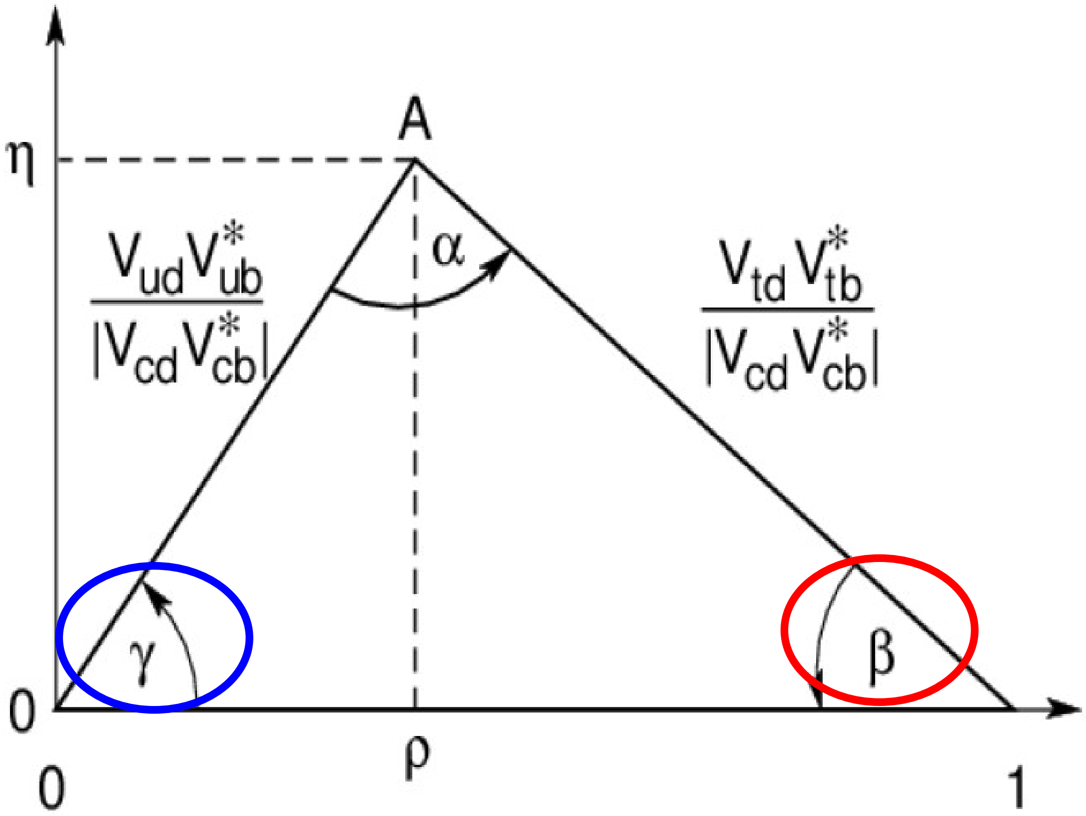
amplitude analyses of loop dominated modes

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

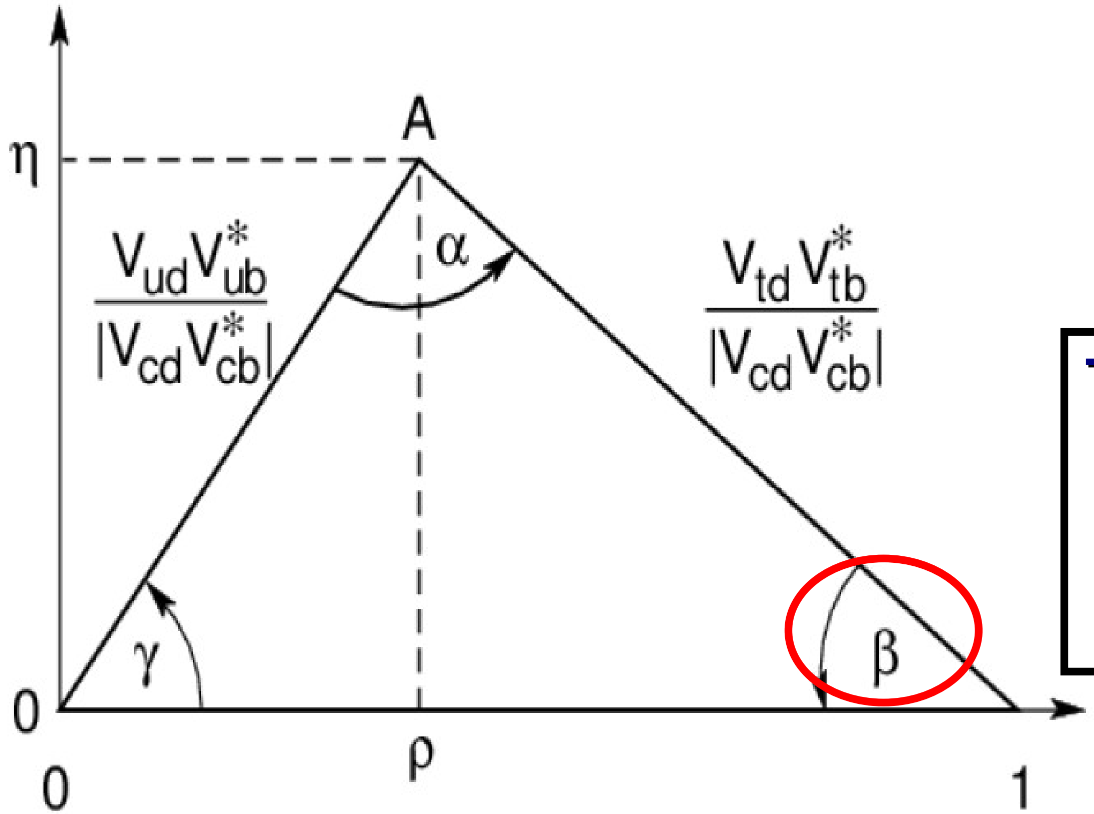
Motivations



Motivations

New physics in penguin dominated modes

- $b \to c\bar{c}s$ (i.e. $J/\Psi K^0_s$) golden modes
- $b \to q\bar{q}s$ ($q = u,d,s$) loop dominated



Standard Model

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

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

New Physics

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

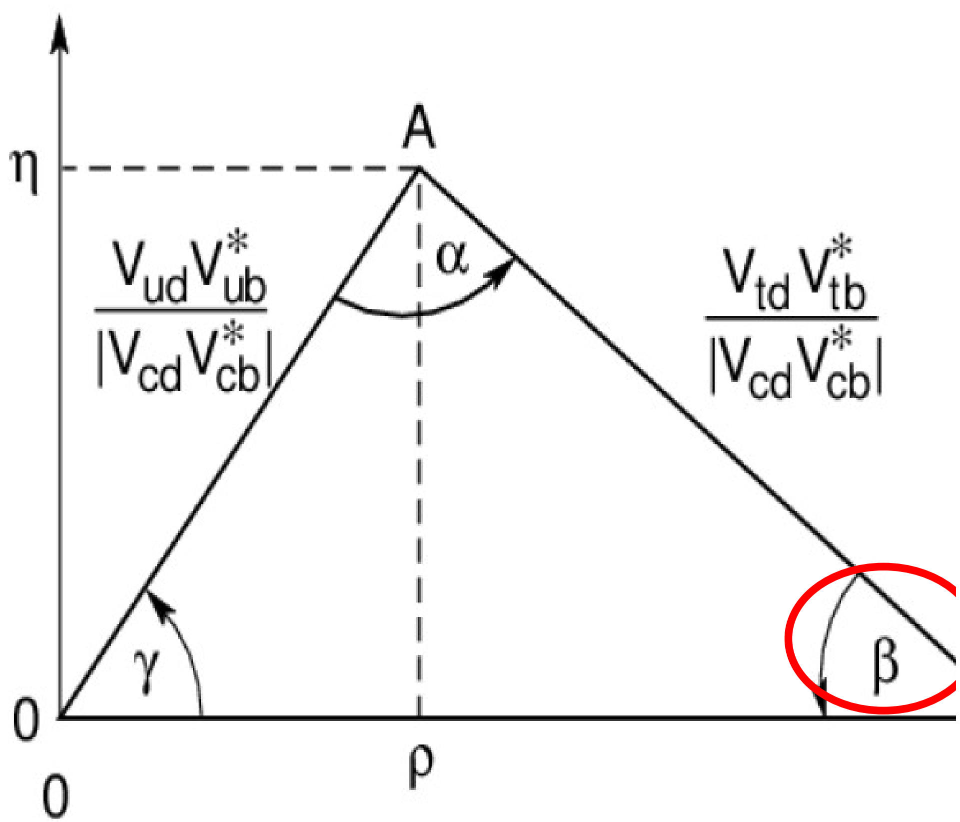
$$C_{ccs} \neq C_{qqs}$$

To the $B^0 \to K^0_s \pi^+\pi^-$ Dalitz Plot contribute two penguin dominated modes:

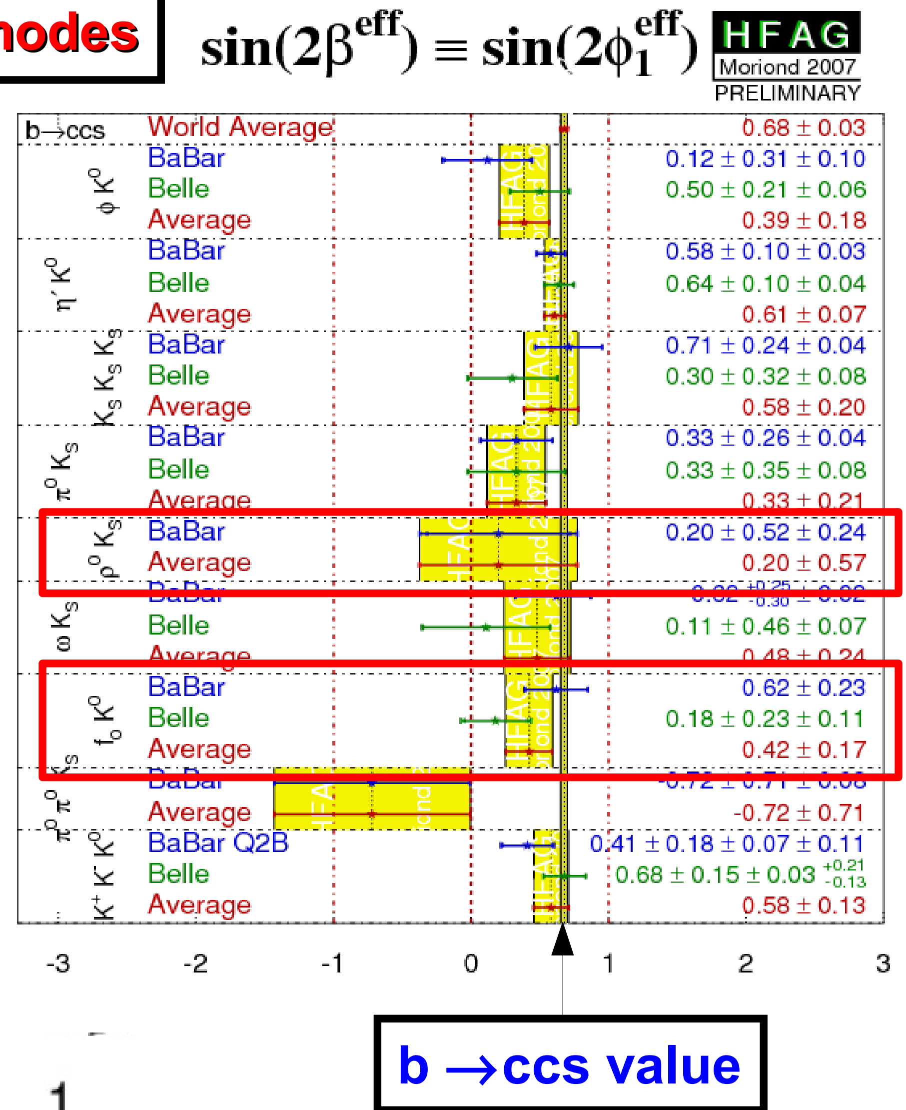
$f_0(980)K^0_s$ and $\rho^0(770)K^0_s$

Motivations

New physics in penguin dominated modes



$\sin(2\beta^{eff}) \equiv \sin(2\phi_1^{eff})$

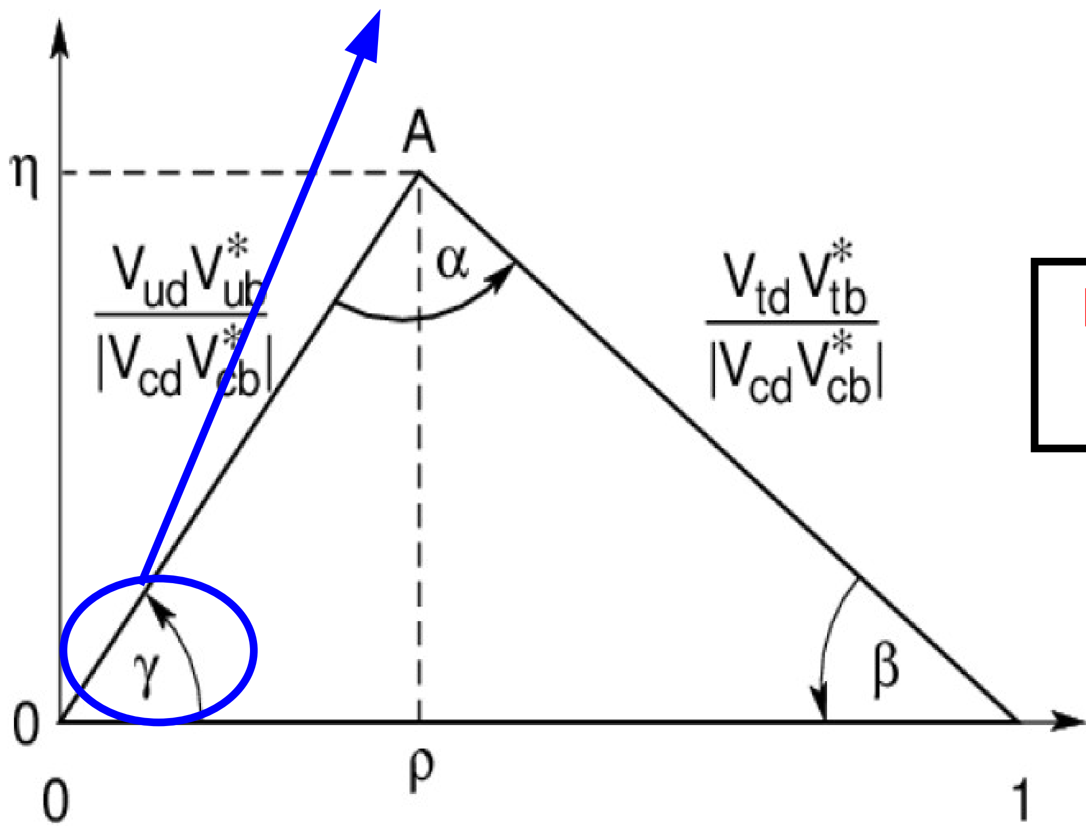


Motivations

CPS/GPSZ method:

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

CPS PRD74:051301
GPSZ PRD75:014002



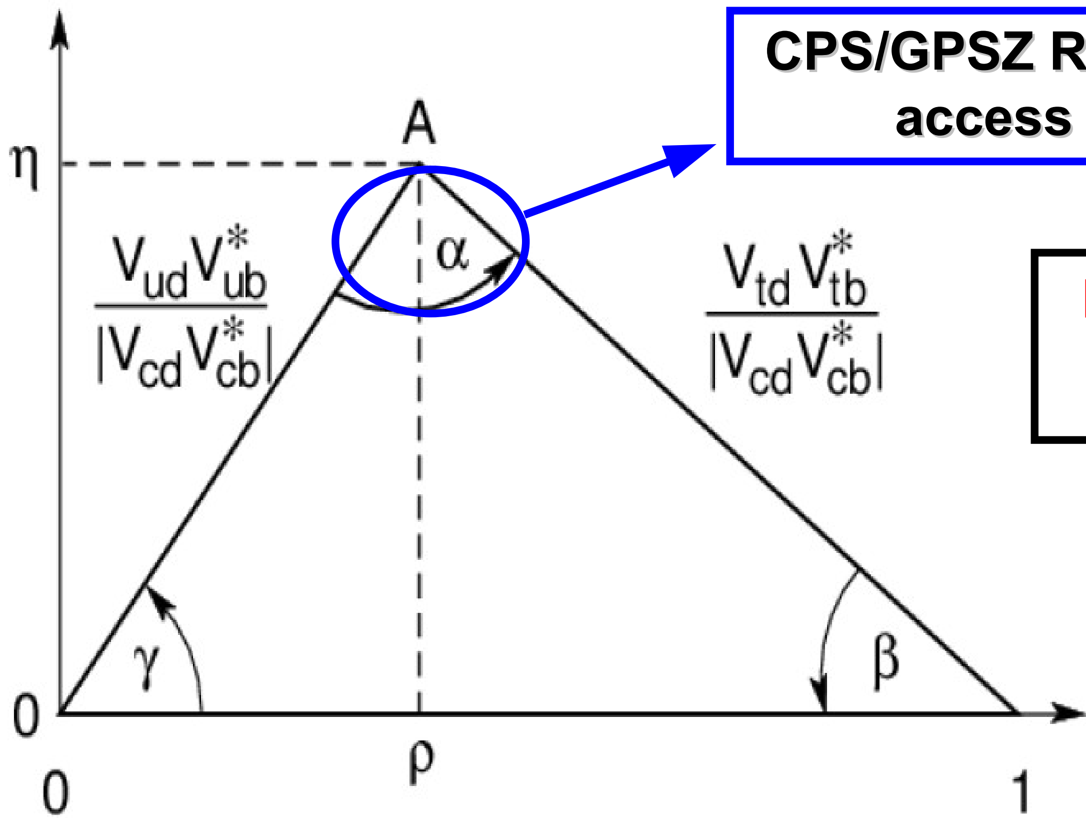
$K^{*+}(892)\pi^{-}$ contribute to the $B^0 \to K^0_s\pi^+\pi^-$ Dalitz Plot

Motivations

CPS/GPSZ method:

use $B \to K^* \pi$ modes access to γ

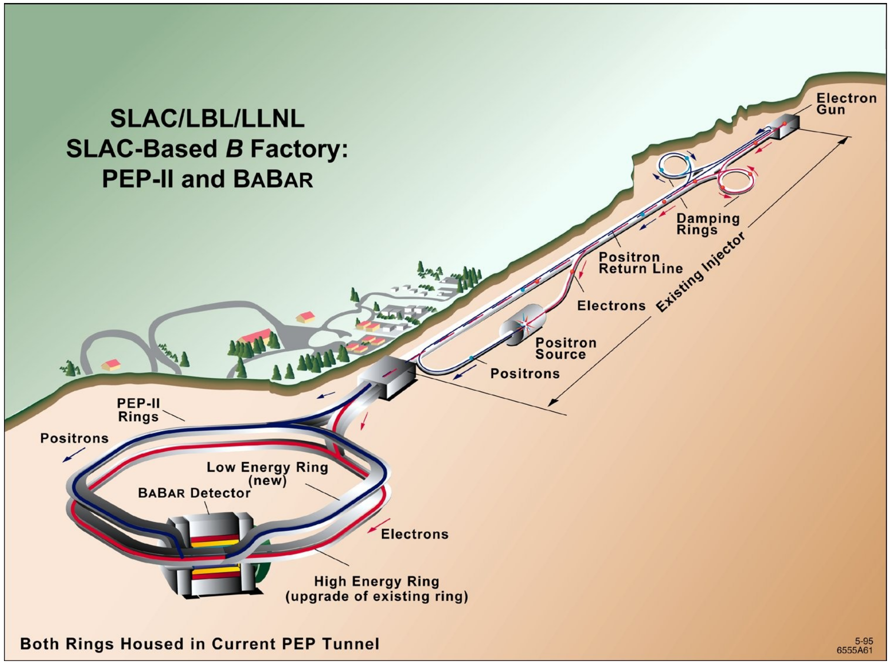
CPS PRD74:051301
GPSZ PRD75:014002

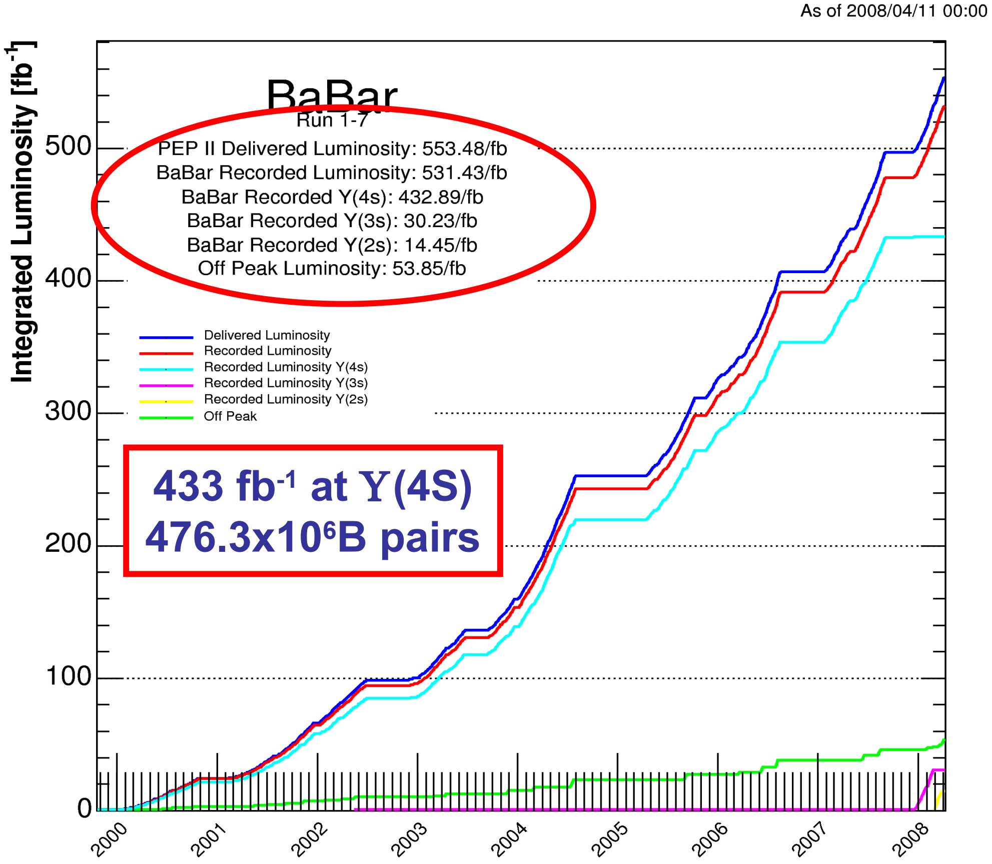


CPS/GPSZ Revisiting: access to α

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

PEP-II: a B factory at SLAC





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

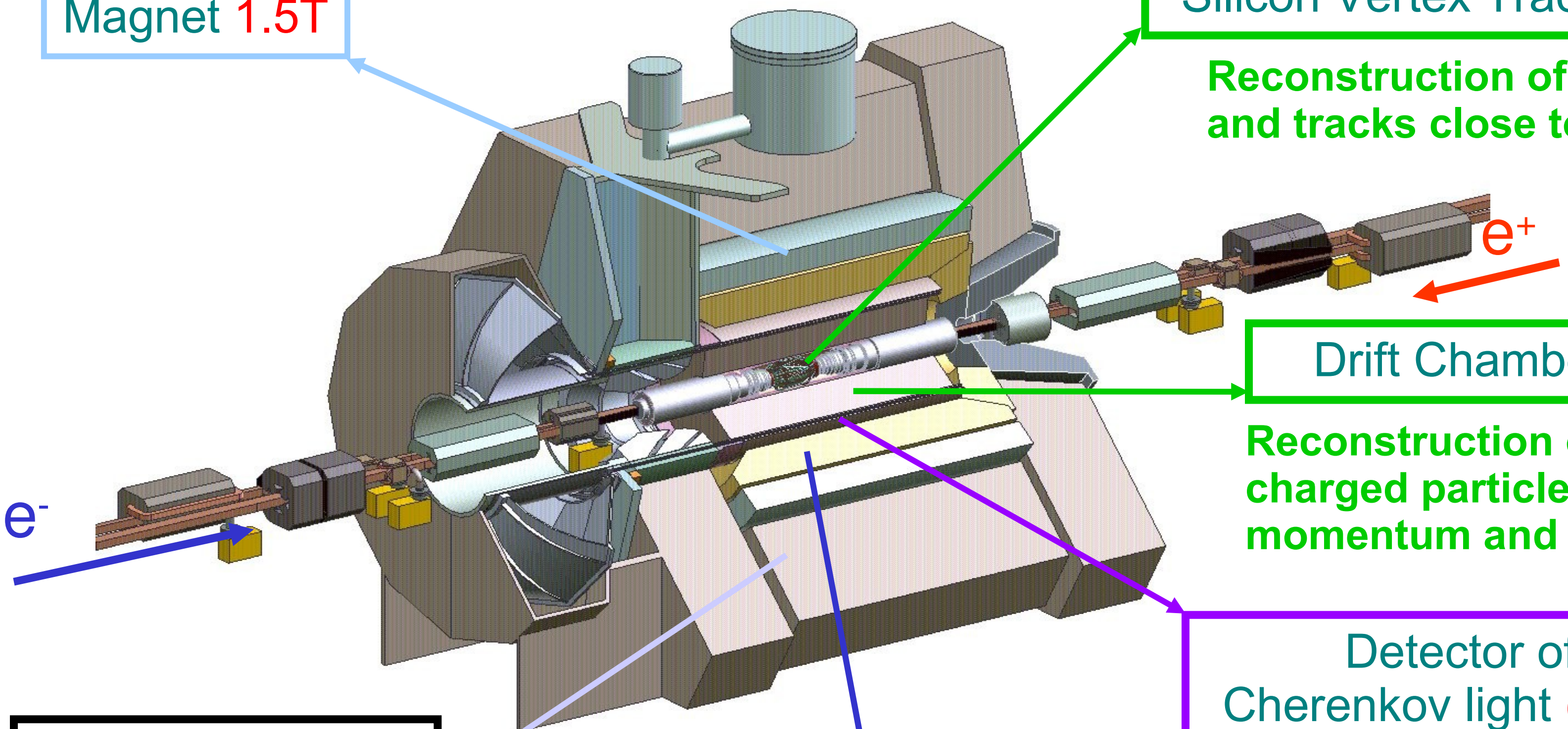
- **On-Peak: $\sqrt{s}$ at the $\Upsilon(4S)$ peak**
- **Off-Peak: $\sqrt{s}$ 40 MeV below**

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)

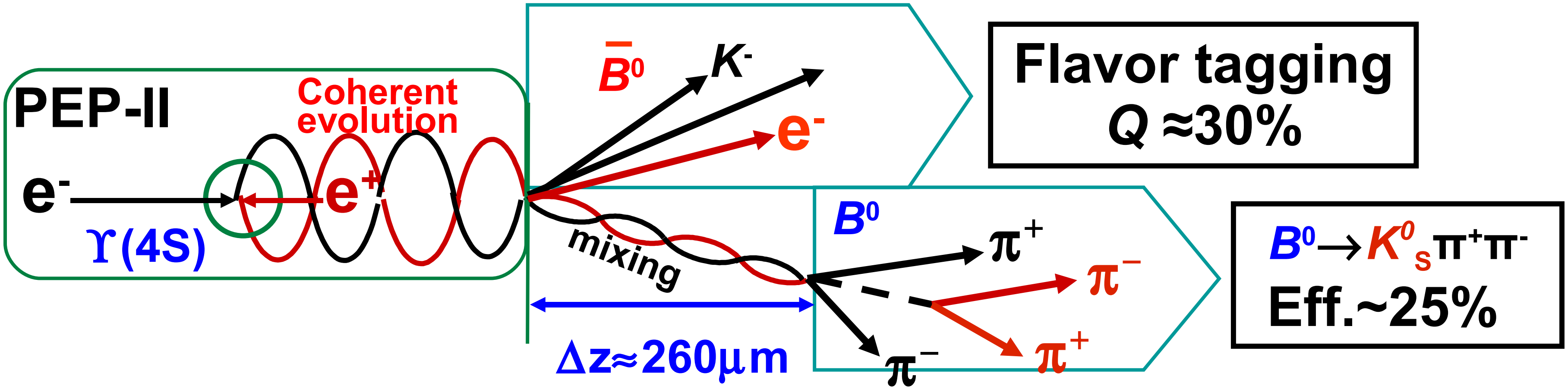
Detection of γ, e^- identification
Reconstruction of $\pi^0 \to \gamma\gamma$, Energy measurement

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

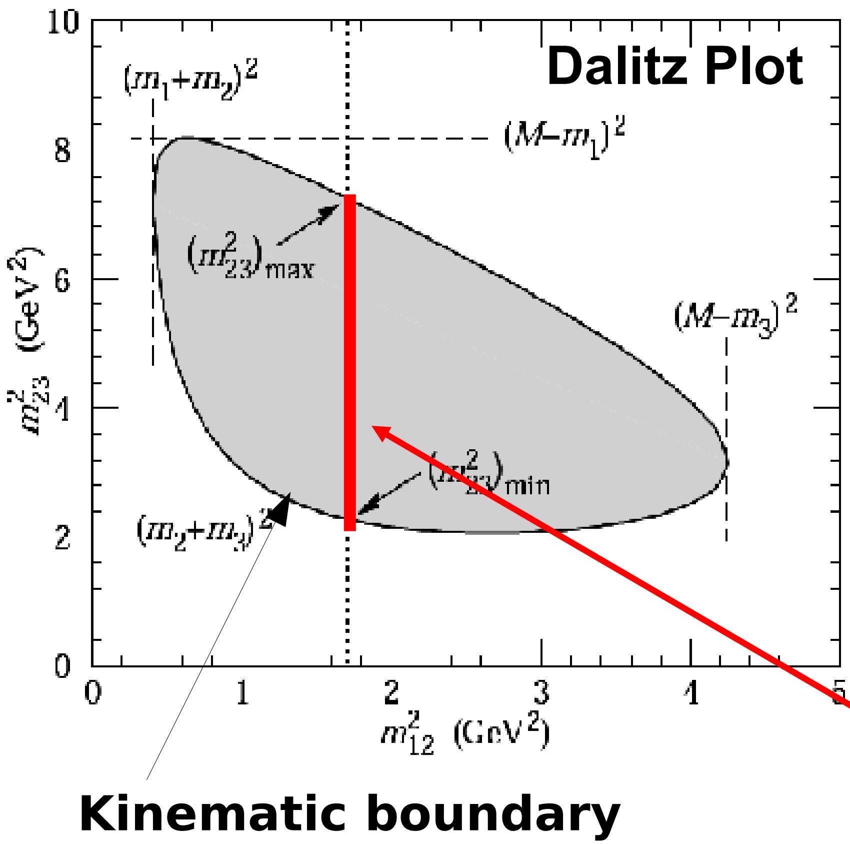
- Neutral B mesons produced in a coherent B^0-$\bar{B}^0$ state
- Flavor tagging with B partner
- Δt extracted from Δz measurement ($\Delta t \approx \Delta z \gamma\beta$)

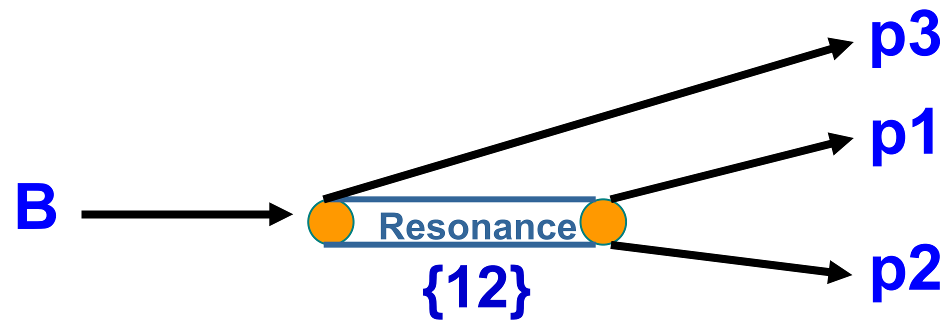


Dalitz Plot (DP)

Tree-body decays described by two parameters:

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





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

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

(Distribution around resonance mass)

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)

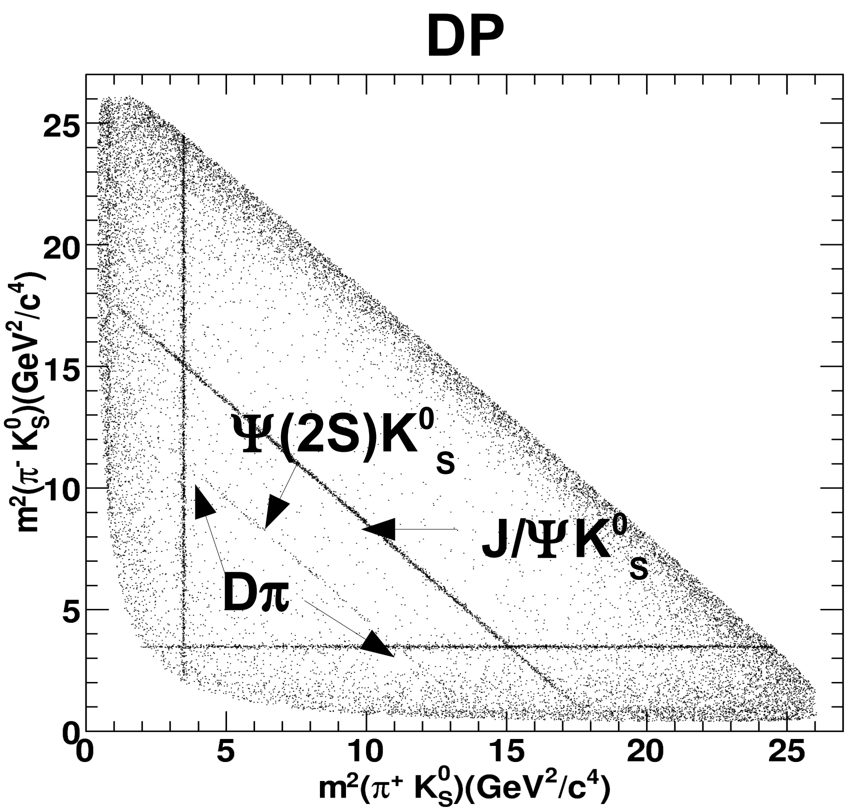
- **Our Preliminary Results TD DP analysis presented at LP07.**
  383×10^6 BB, BaBar 2007 (arXiv:hep-ex/0708.2097)

- 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

Data Set

- Run 1-5: 347.3 fb^{-1} → 382.9x10^6 $B\bar{B}$ pairs.
- Reconstruction and Selection → 22525 events



Data Set

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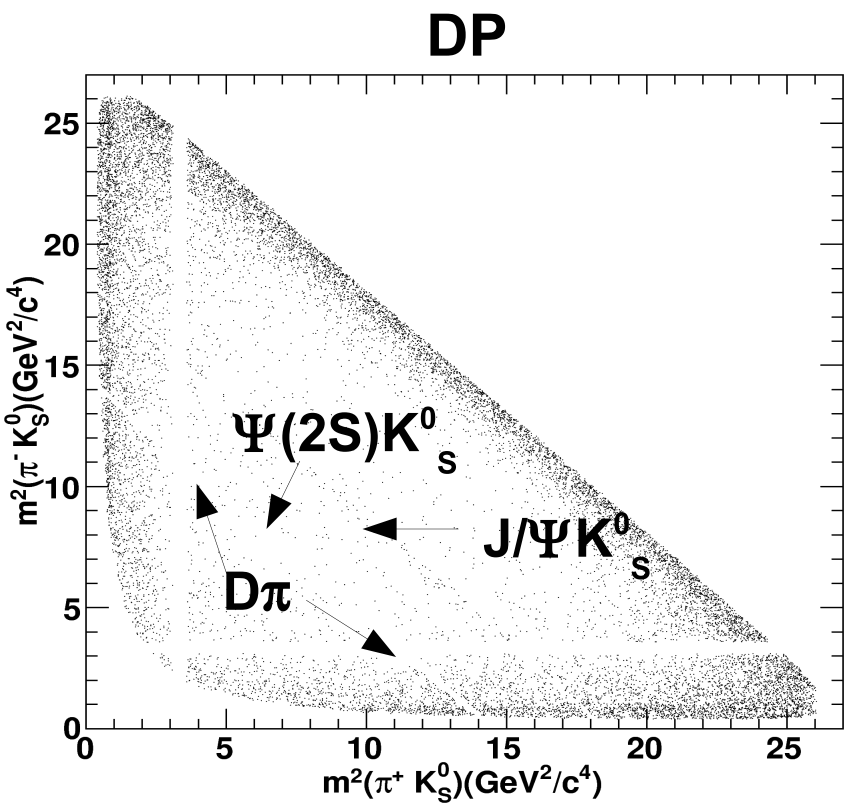

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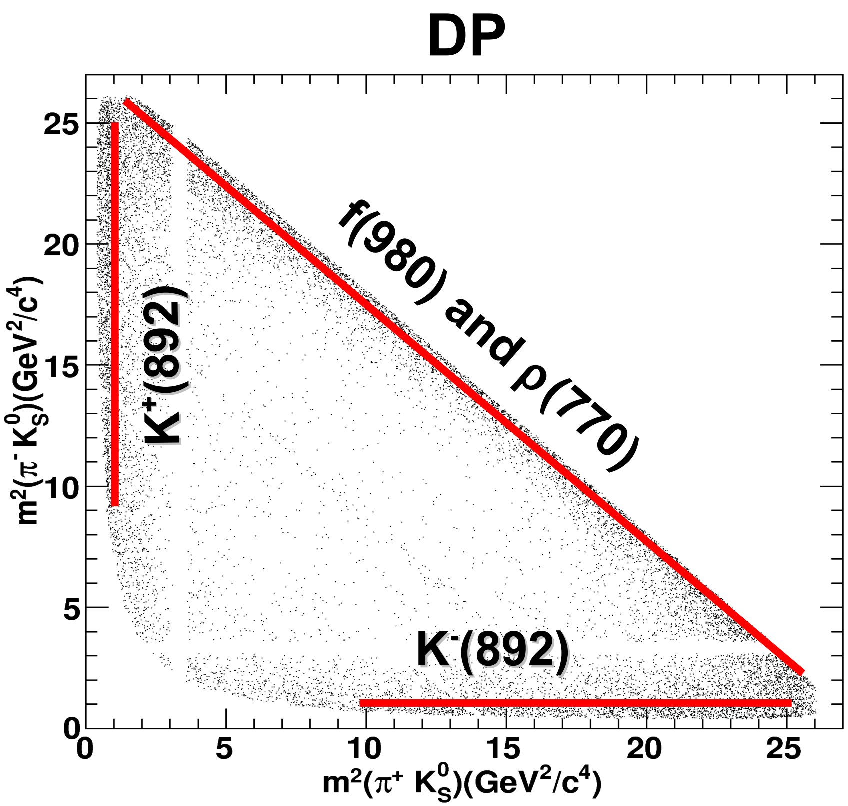

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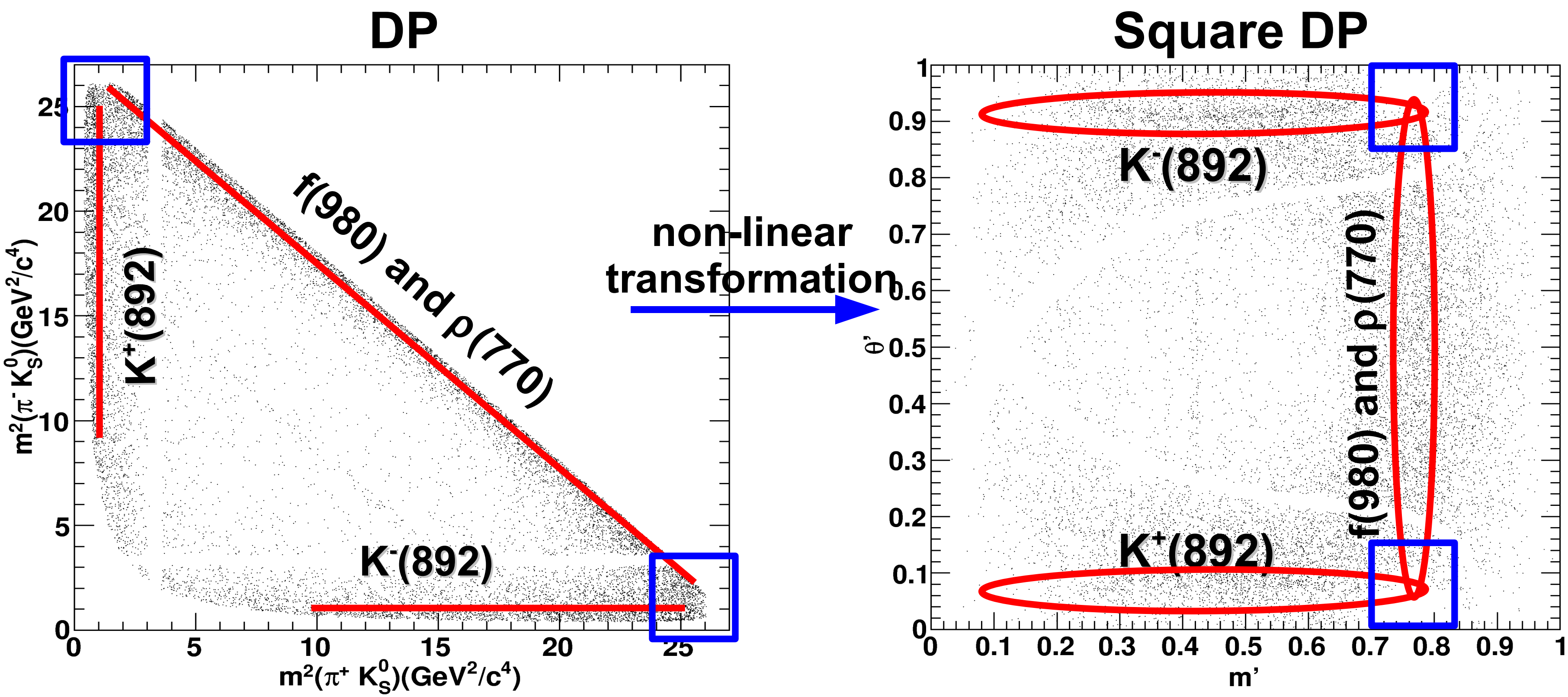

Data Set

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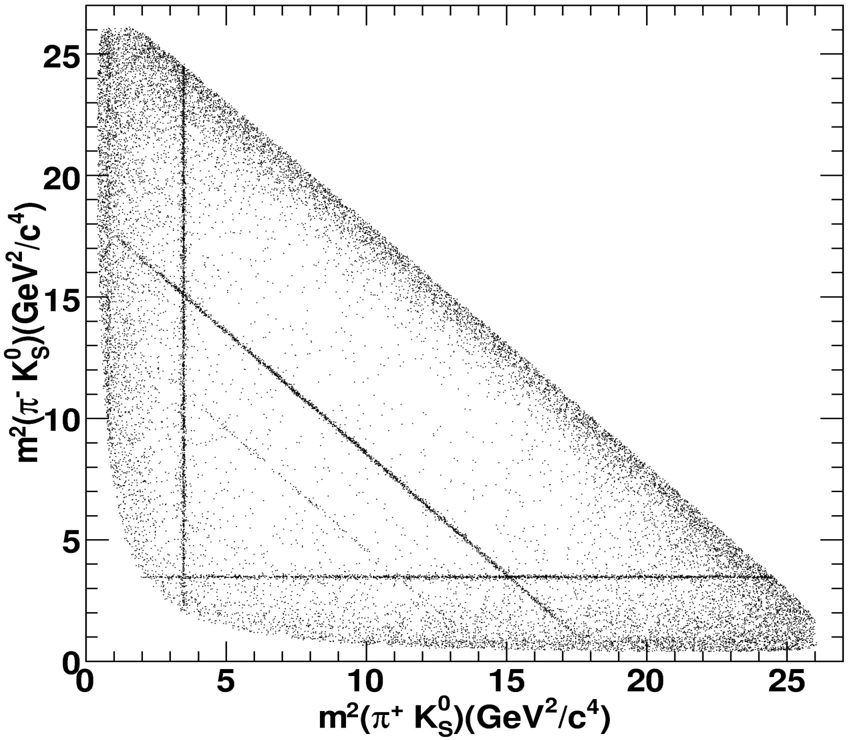
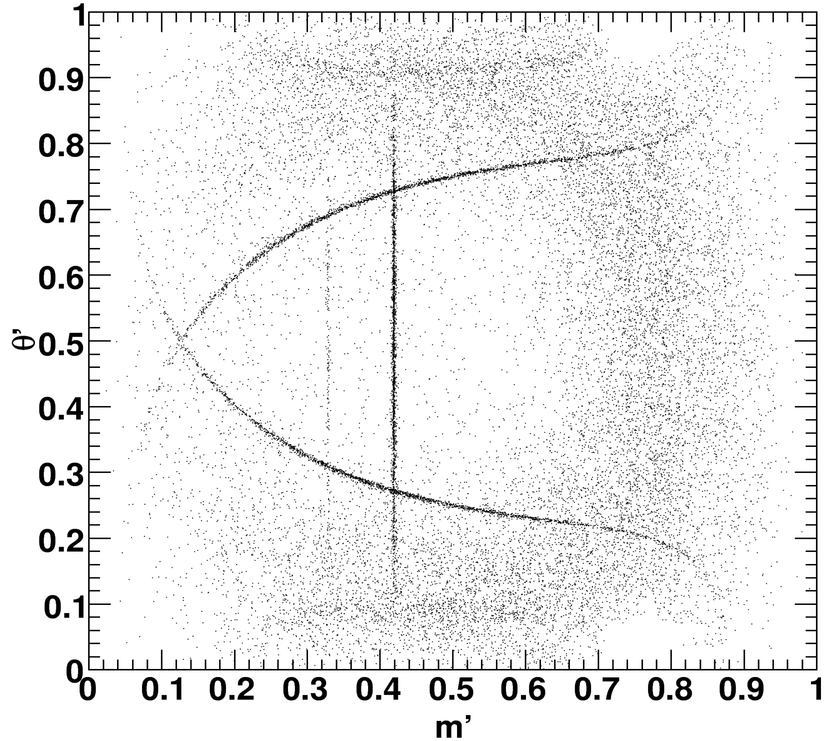
DP



Square DP



Likelihood Function

The Likelihood Function

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

Likelihood Function

The Likelihood Function

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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

TM **SCF**

Likelihood Function

The Likelihood Function

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

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

Discrimination **Dynamics**

Parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

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

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

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

Parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

$$A(DP) = \sum a_j F_j(DP)$$

$$\overline{A}(DP) = \sum \overline{a}_j \overline{F}_j(DP)$$

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

Parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

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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:

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Rela

Gou

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

S-wave Kπ: **LASS lineshape.**

Nucl. Phys., B296:493, 1988

Parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

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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

Parameterization

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

Parameterization

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

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

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

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

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

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

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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:

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

The mixing and decay CPV S parameter:

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

Phase differences:

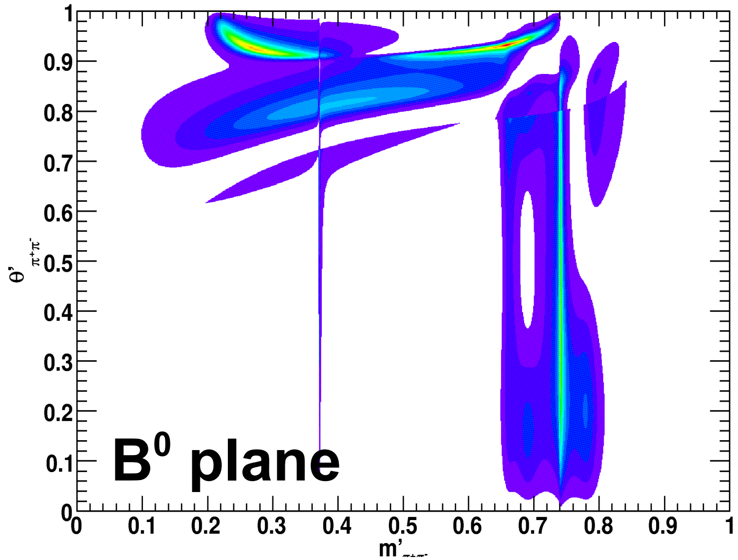
$$2\beta^j_{eff} = \arg[\, a_j \bar{a}^*_j \,(q/p)^* \,]$$ → **for $f_0(980)$ and $\rho^0(770)$**

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

The phases can be accessed through interference over the DP

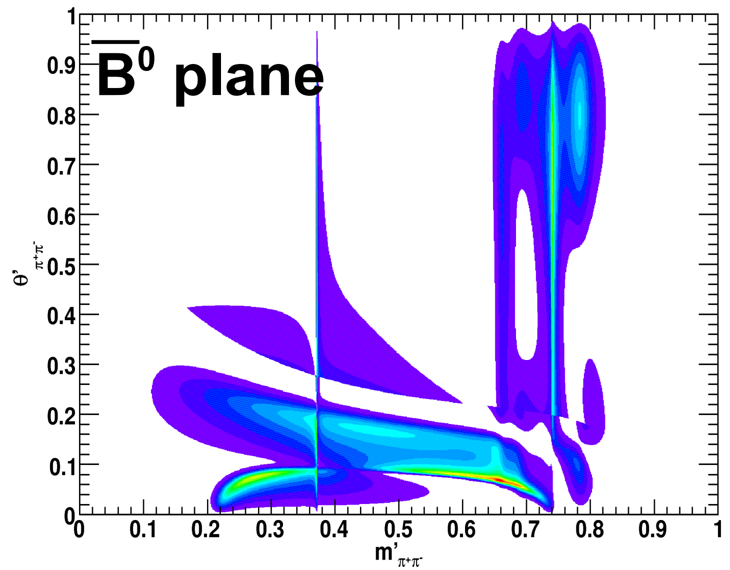
Nominal Signal Model

Square DP



<u>List of components included :</u>

- $B^0 \to \rho^0(770)\, K^0_S$ (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

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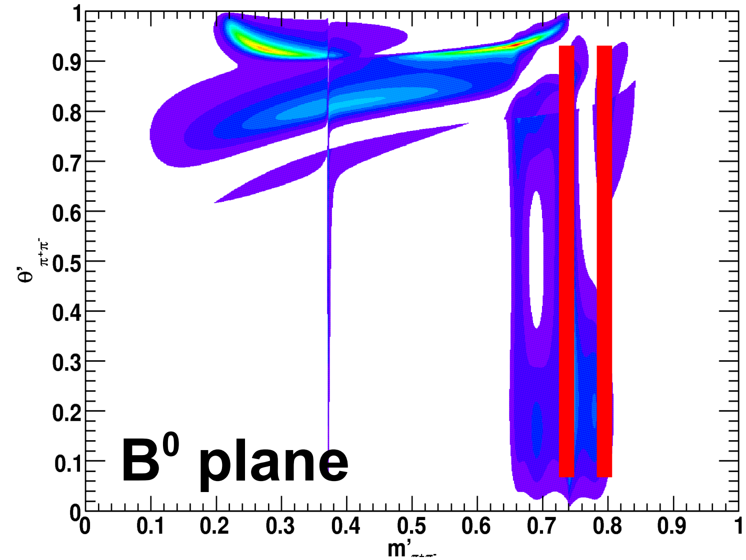

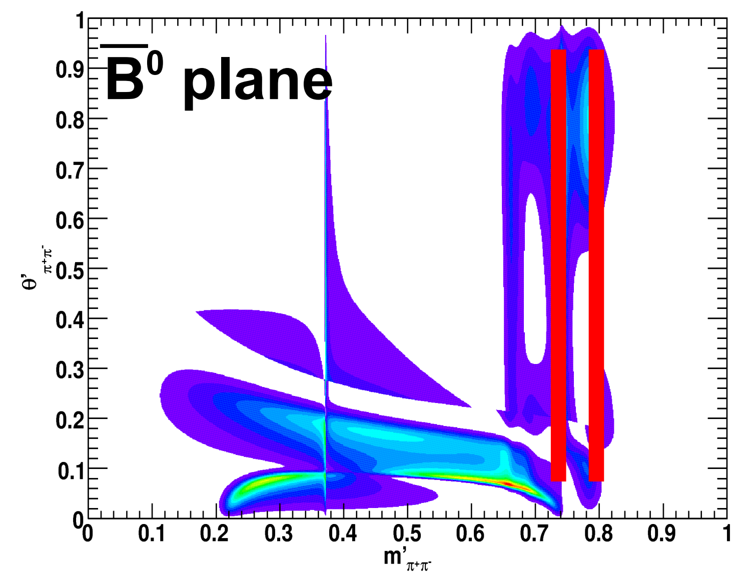

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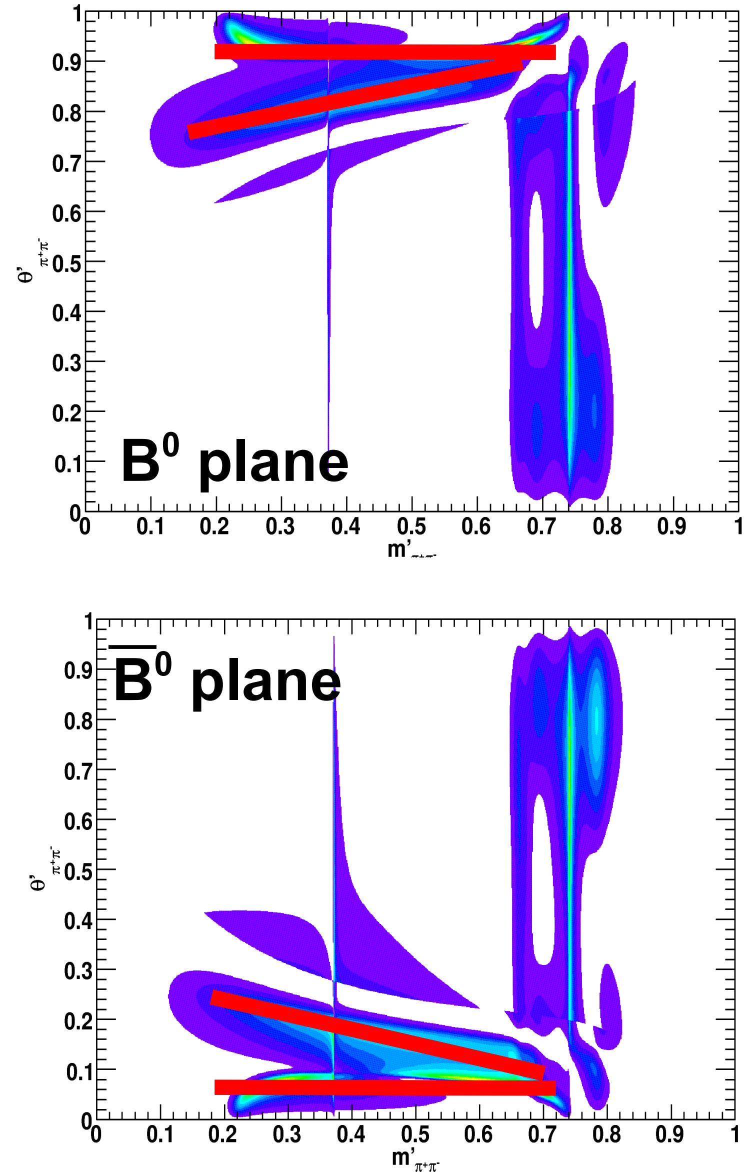

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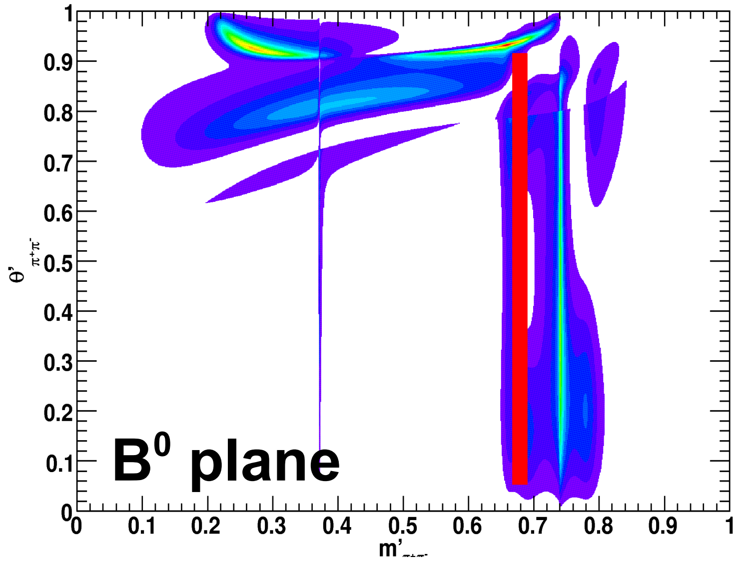

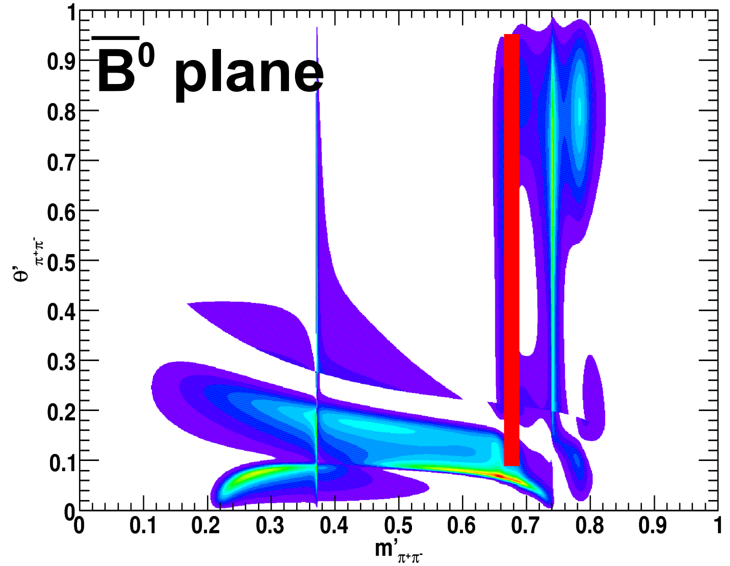

Maximum Likelihood Fit Results

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

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
ΔNLL	0.0	0.16
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Non-Isobar parameters identical in both solutions

There are two solutions almost degenerated.

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

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

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
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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
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But some phases vary significantly!

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Ambiguity in resolving the interference pattern in the DP

But some phases vary significantly!

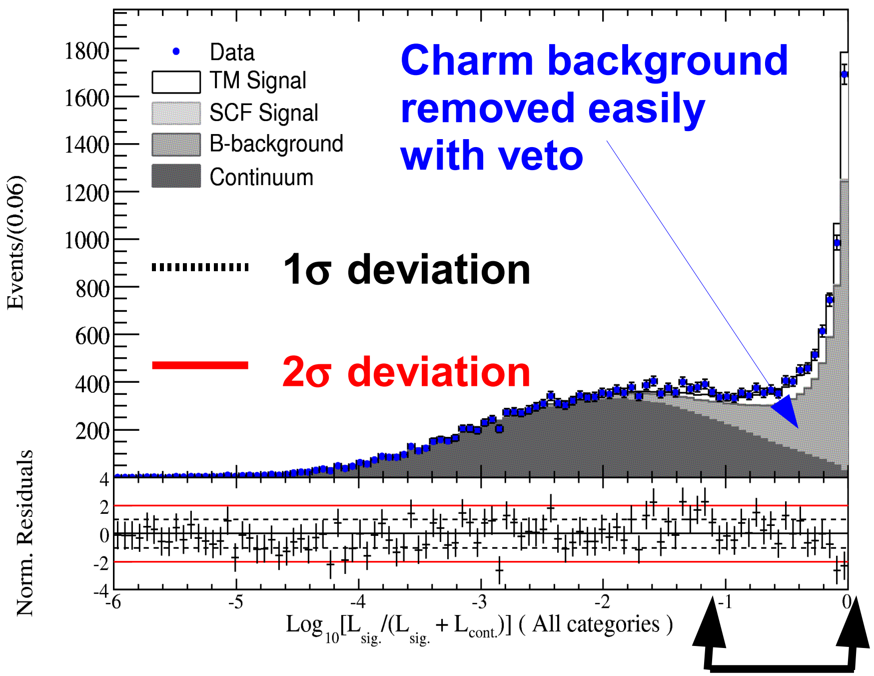
Goodness of Fit
(Projection Plots)

Fit Results: Proj. Plots (I)

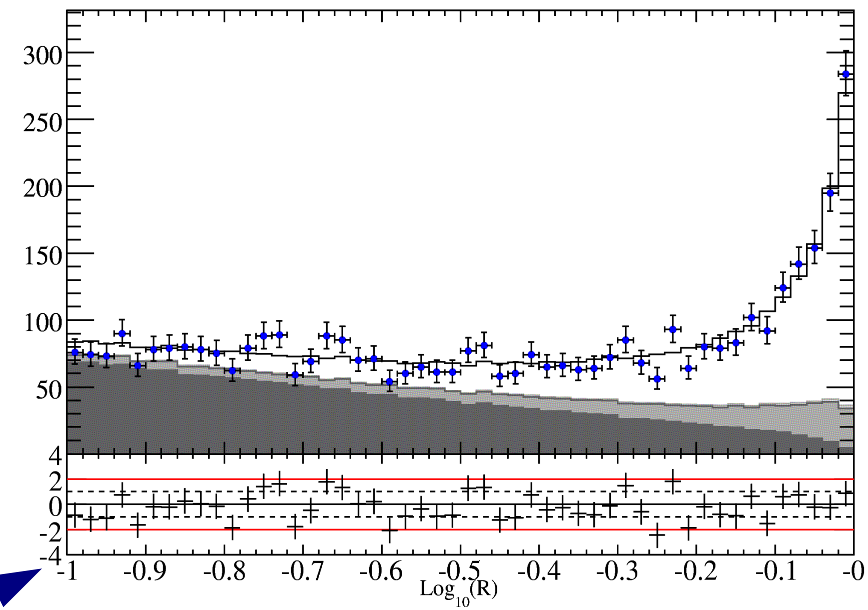
Likelihood Ratio

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

$Log_{10}(L_{sig}/(L_{sig} + L_{back}))$



$Log_{10}(L_{sig}/(L_{sig} + L_{back}))$



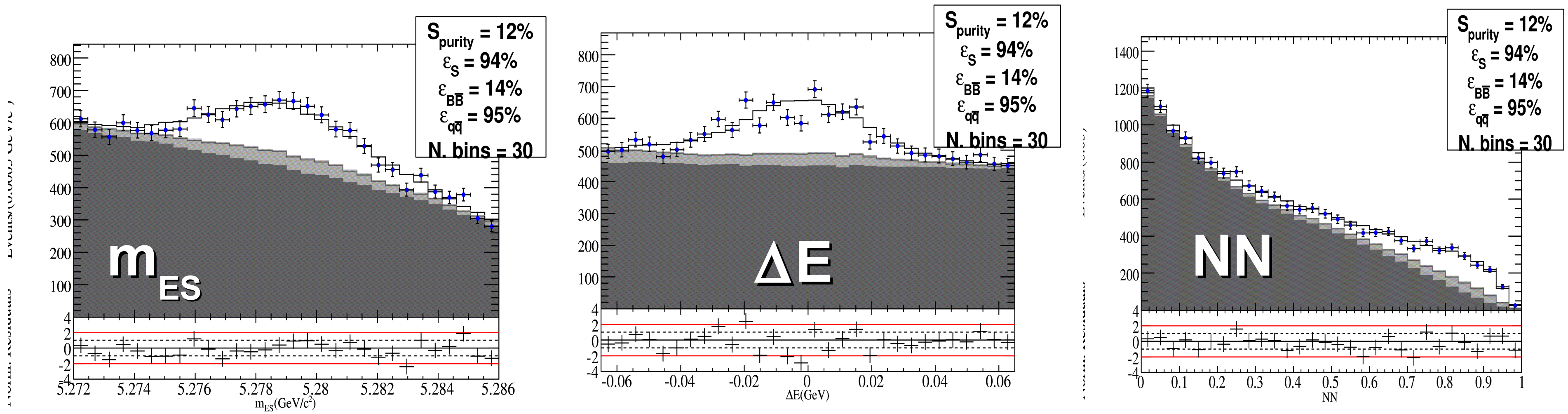
Zoom on the signal region

Veto on Charm Background

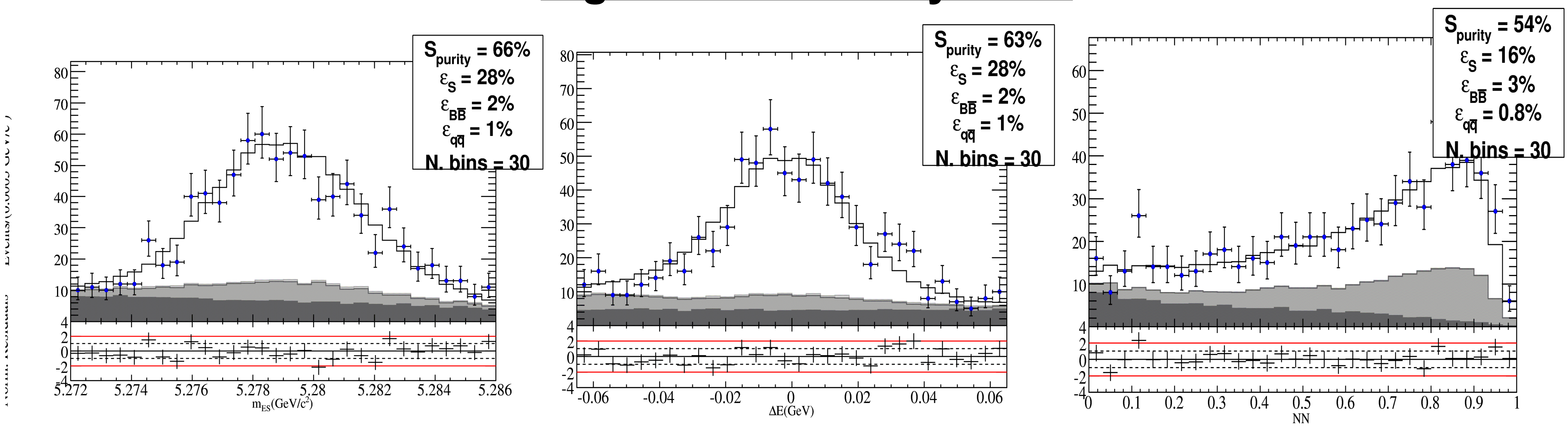
Fit Results: Proj. Plots (II)

Dπ, J/ψK^0_S vetoed

No R cut

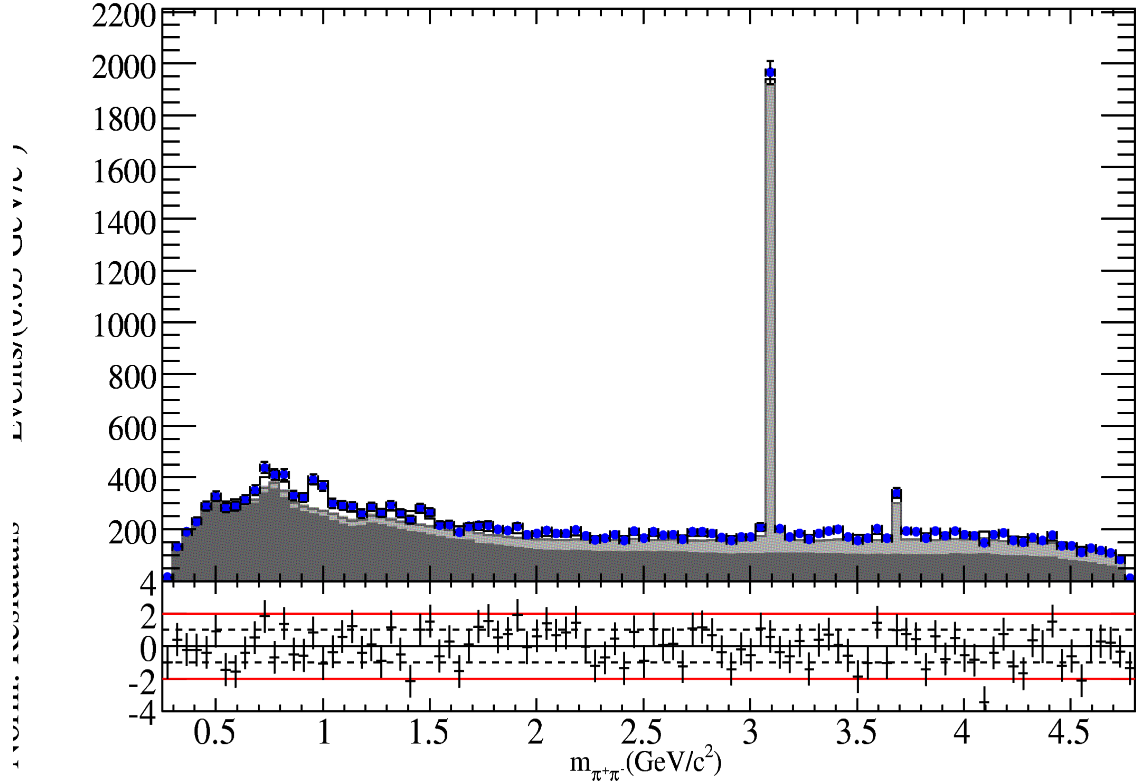


Signal enhanced by R cut



Fit Results: Proj. Plots (III)

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



Fit Results: Proj. Plots (III)

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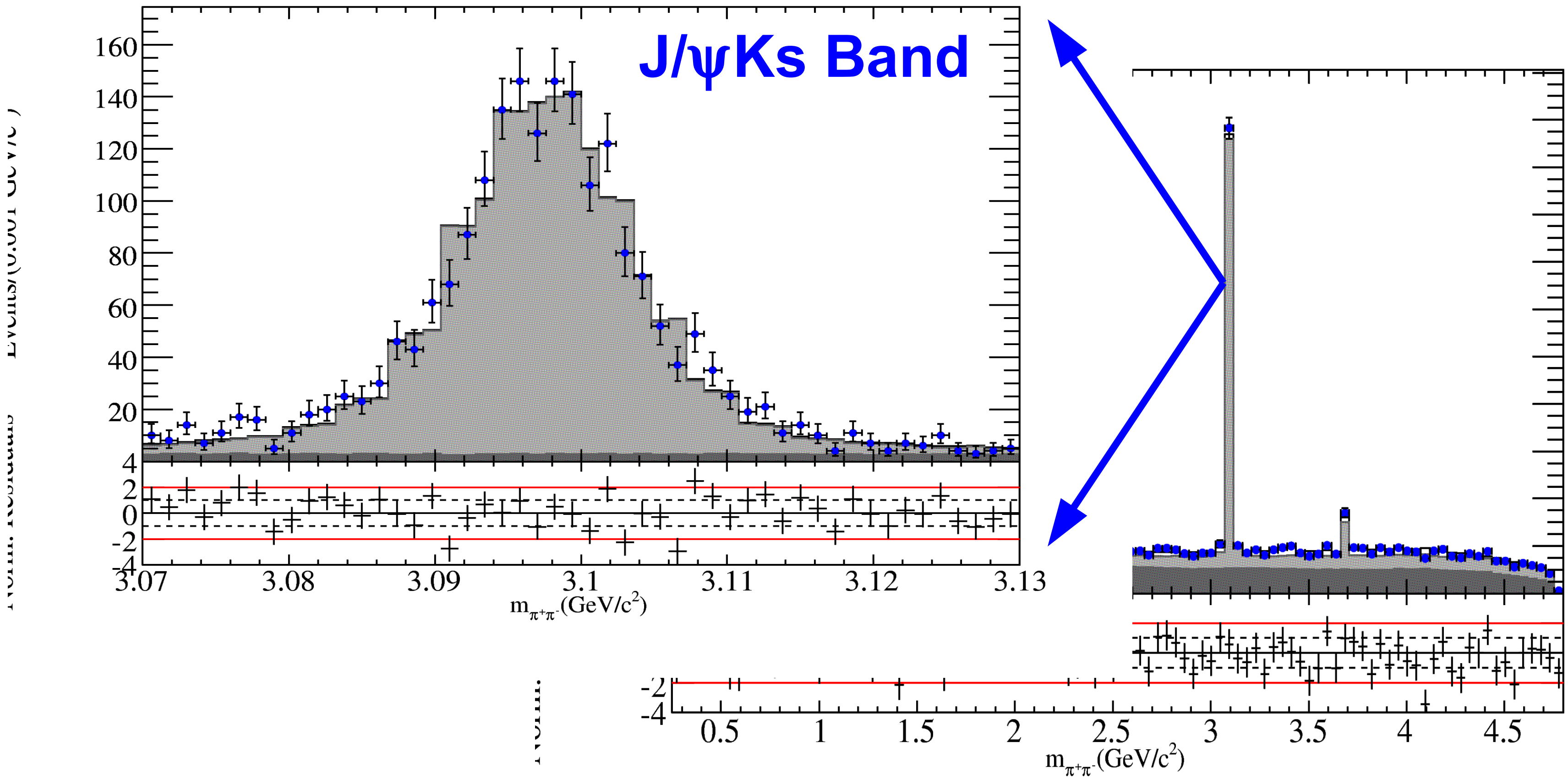

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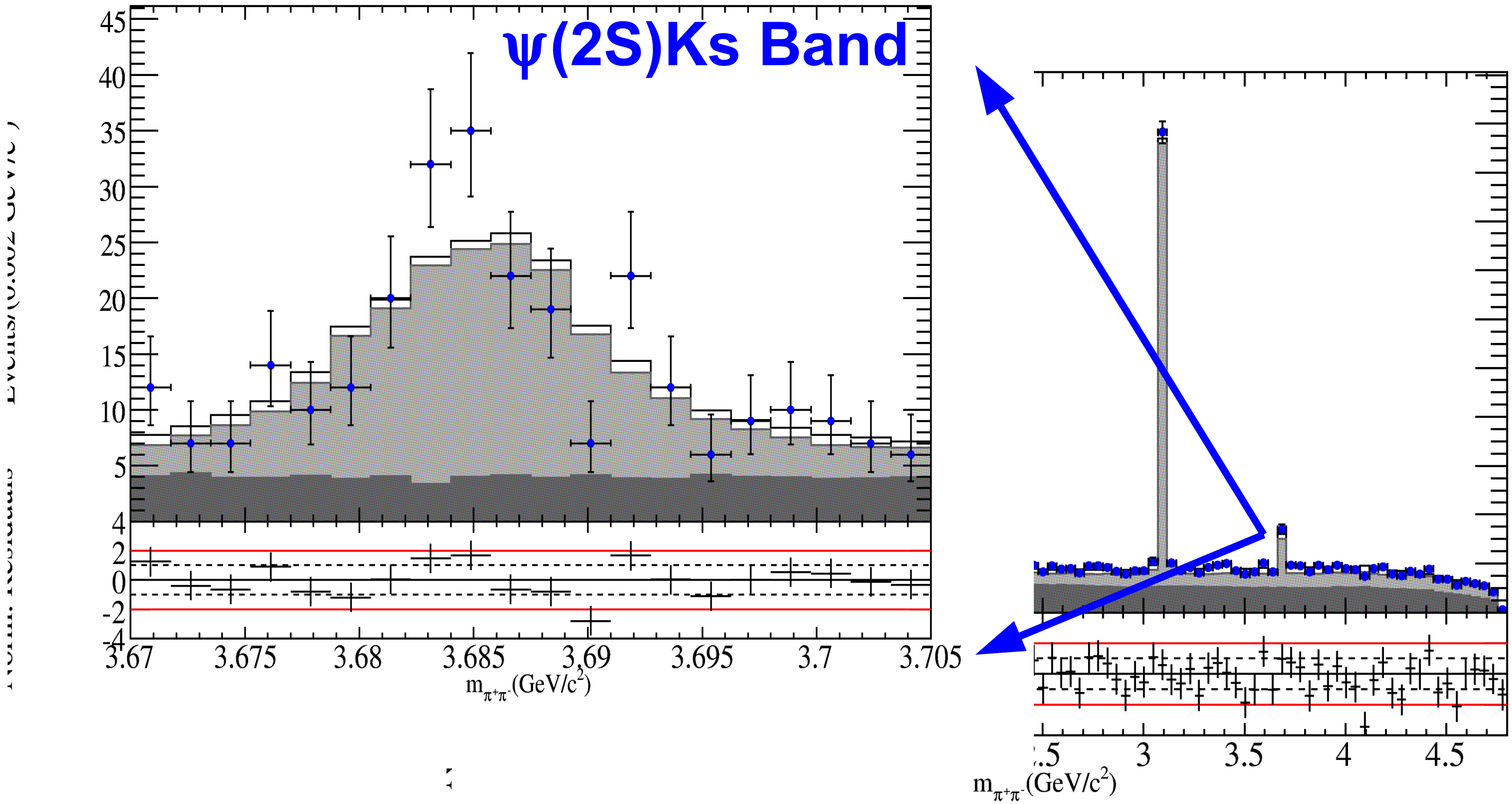

Fit Results: Proj. Plots (III)

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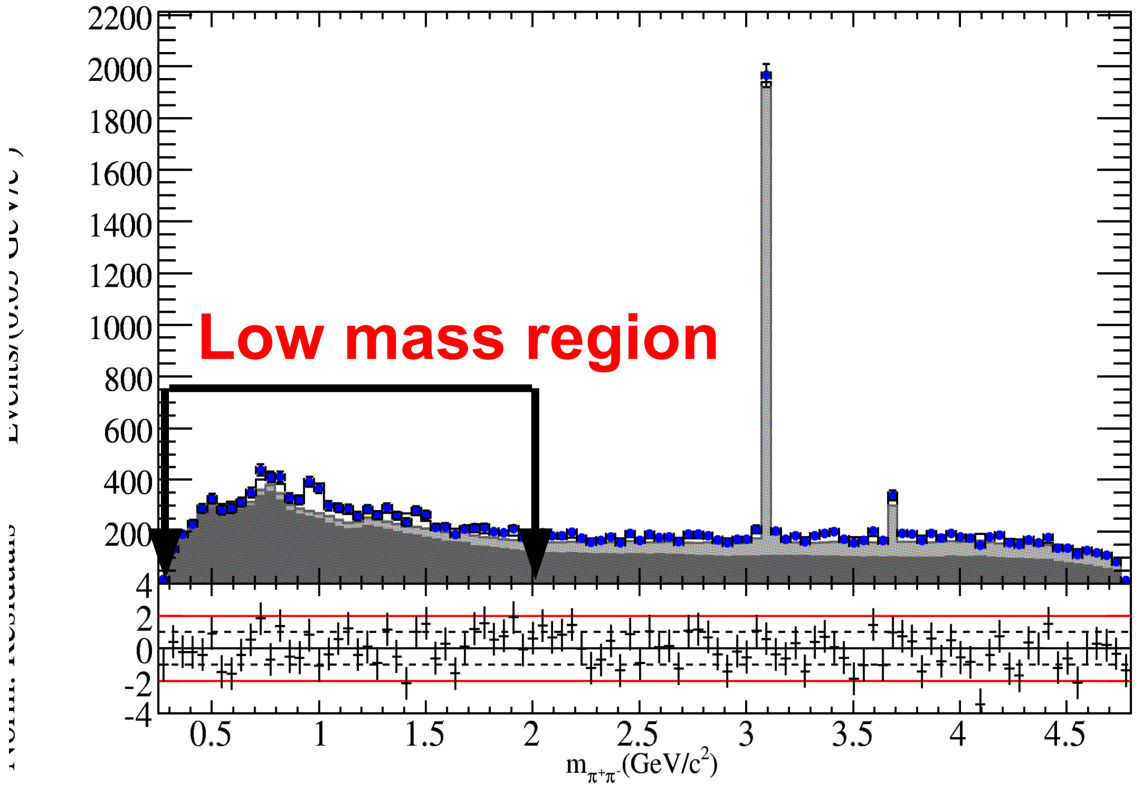
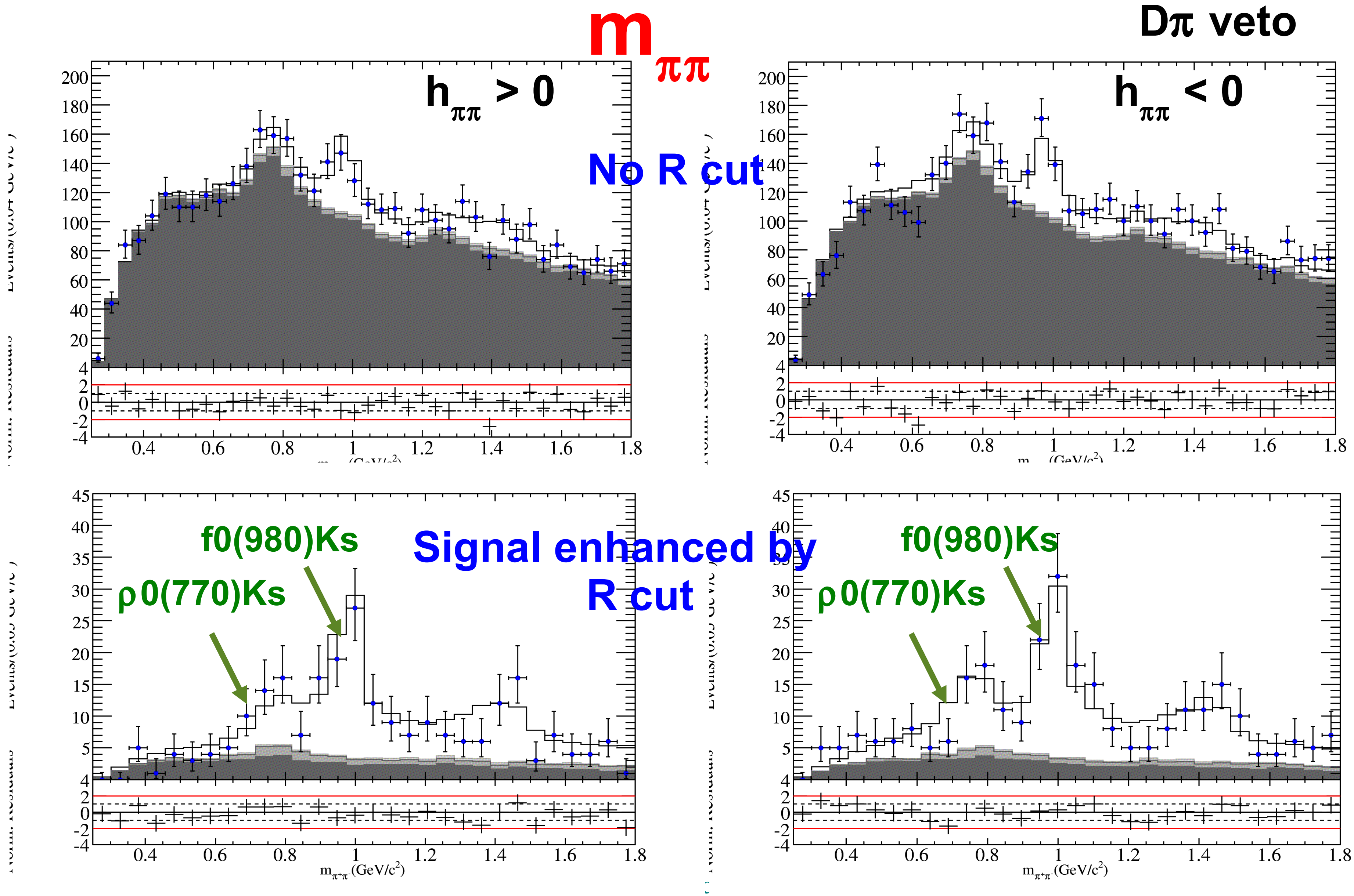
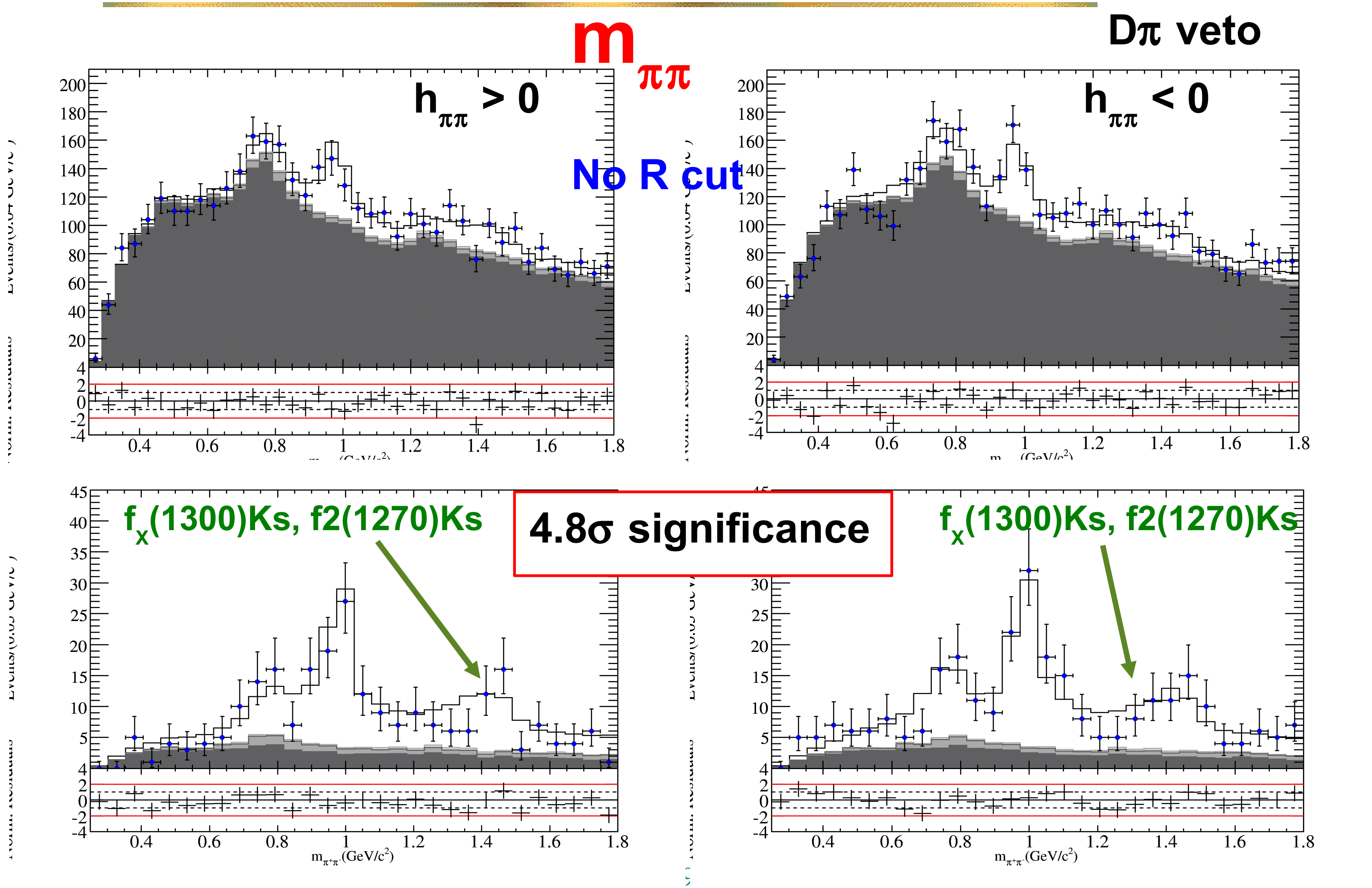


Fit Results: Proj. Plots (IV)

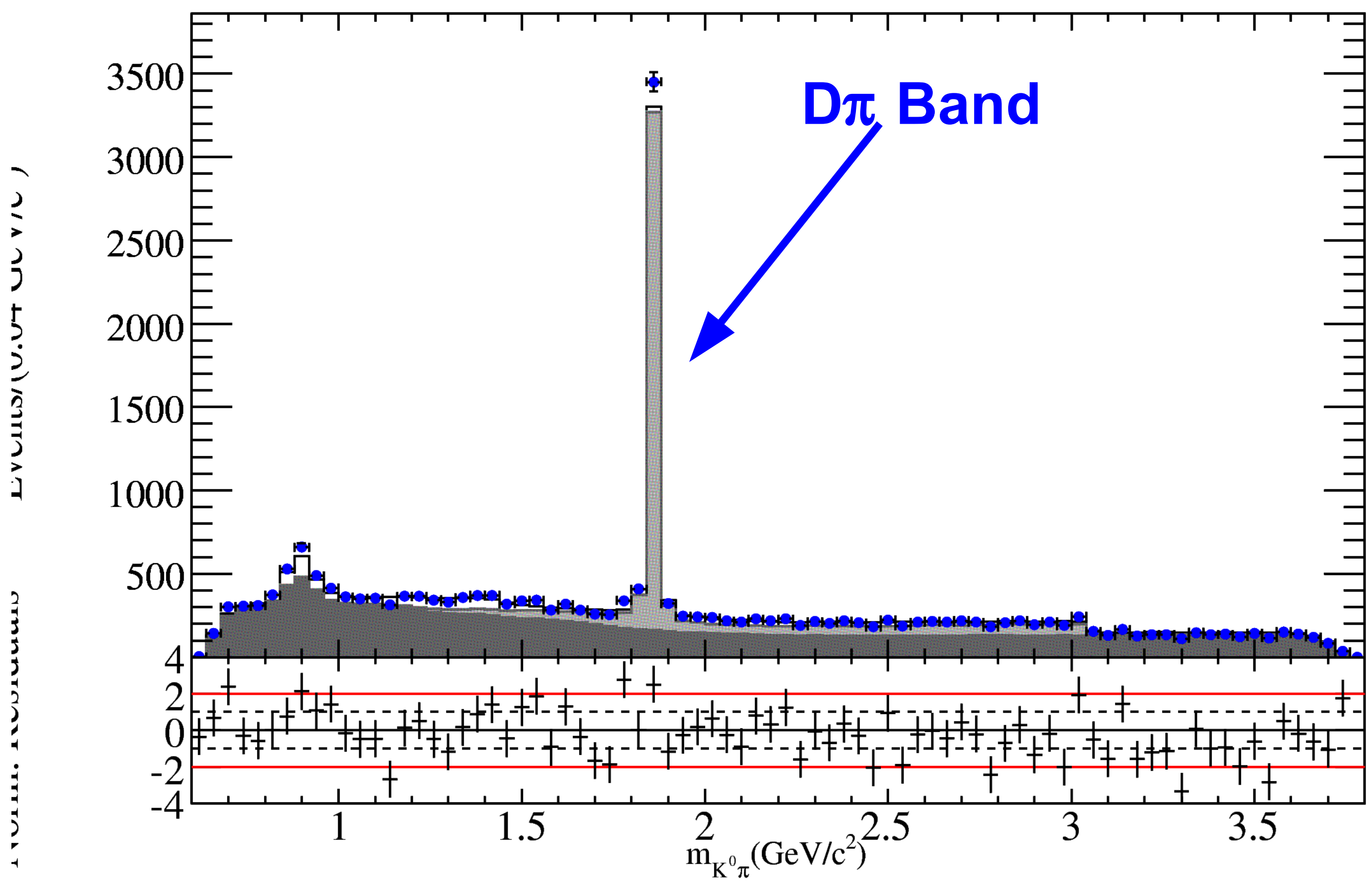


Fit Results: Proj. Plots (IV)

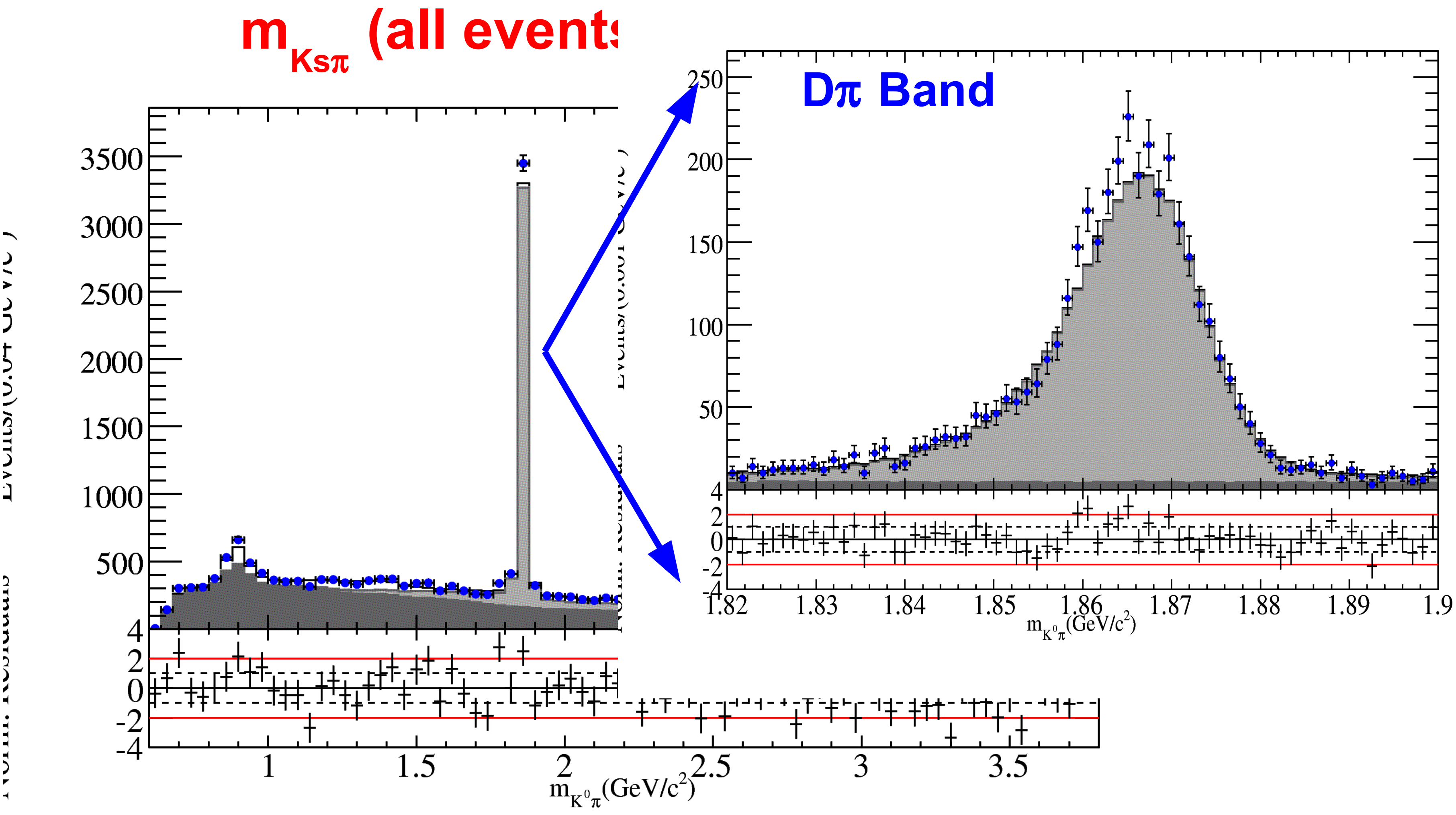


Fit Results: Proj. Plots (V)

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

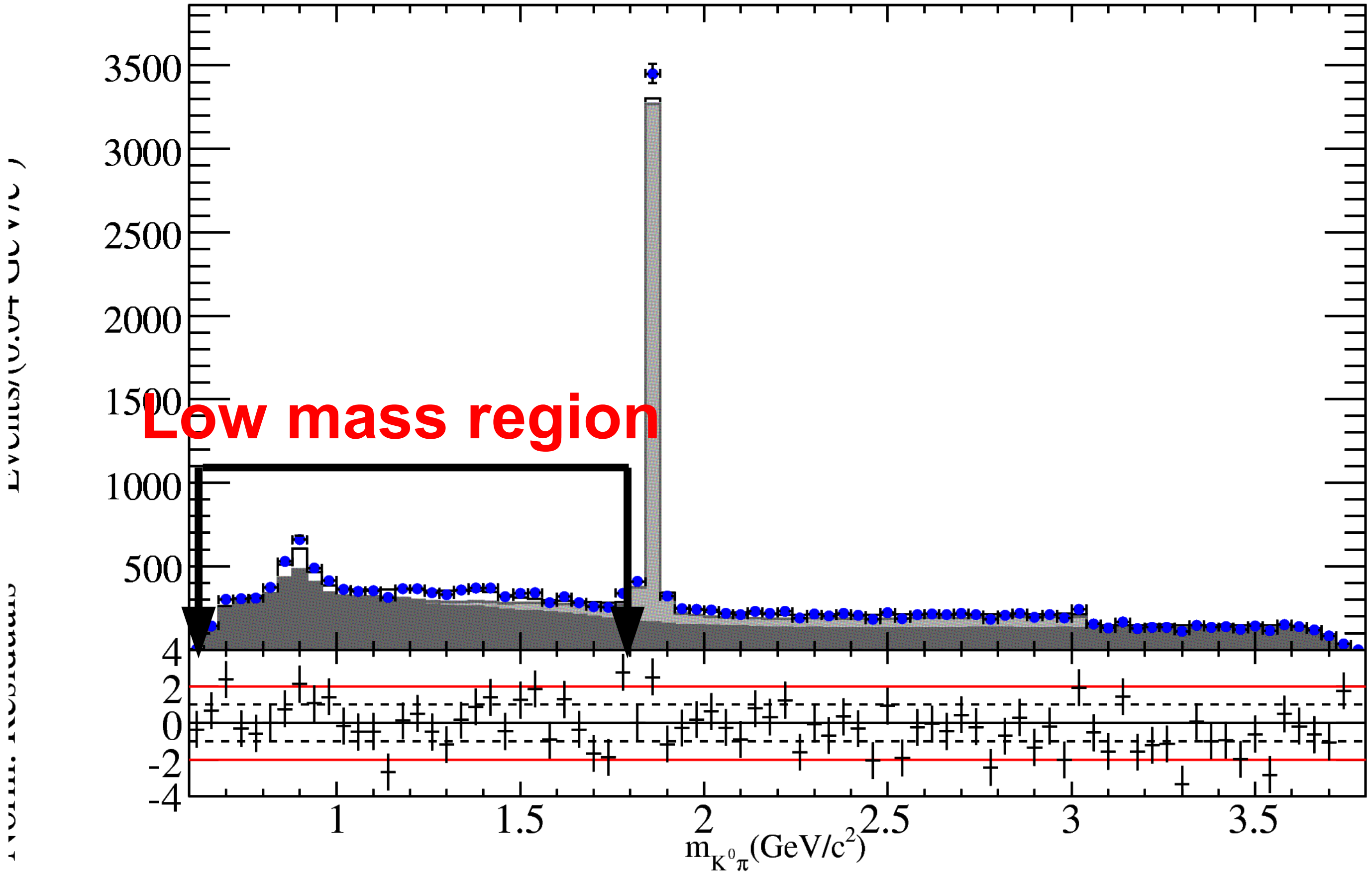


Fit Results: Proj. Plots (V)

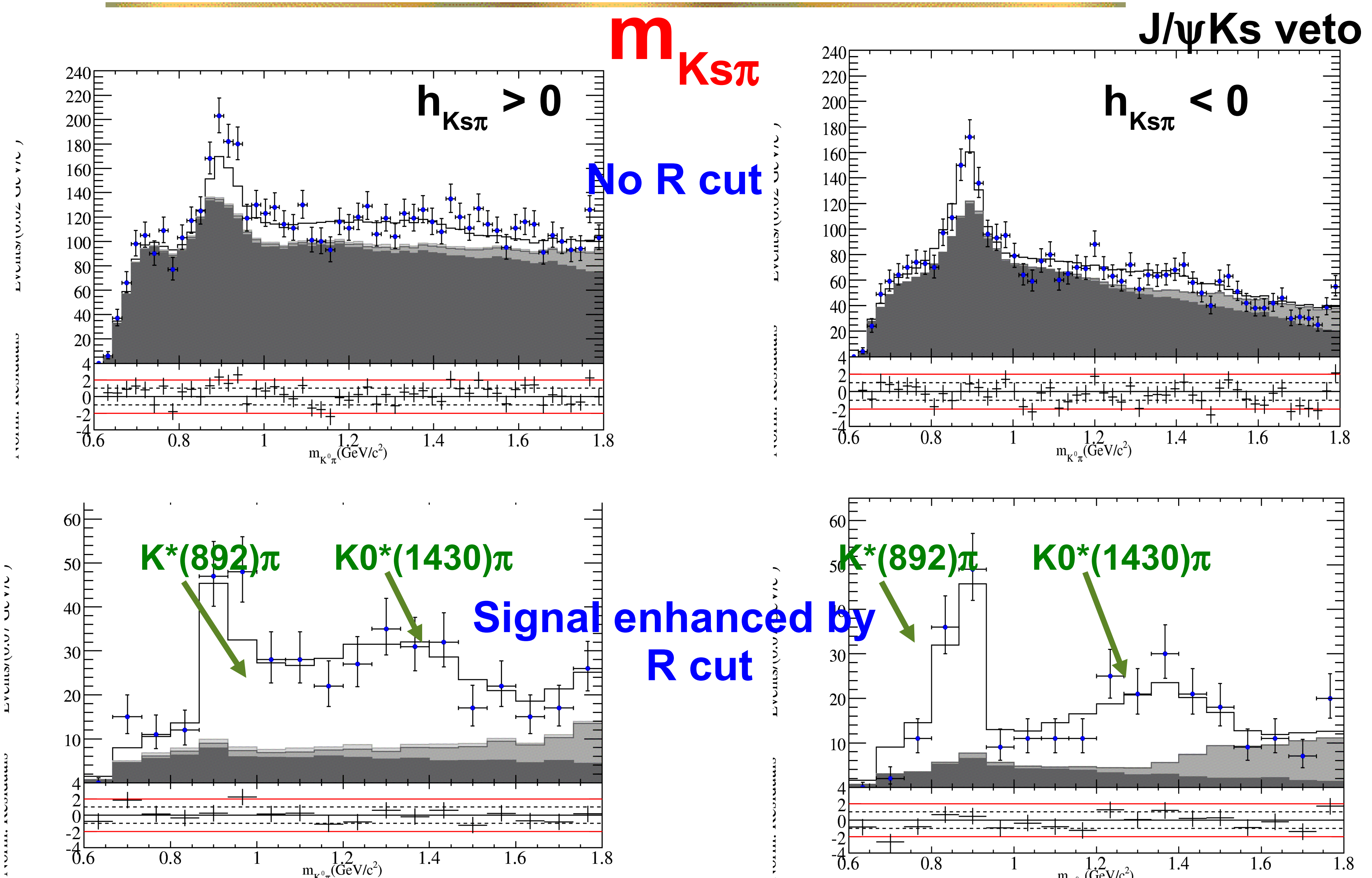


Fit Results: Proj. Plots (V)

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



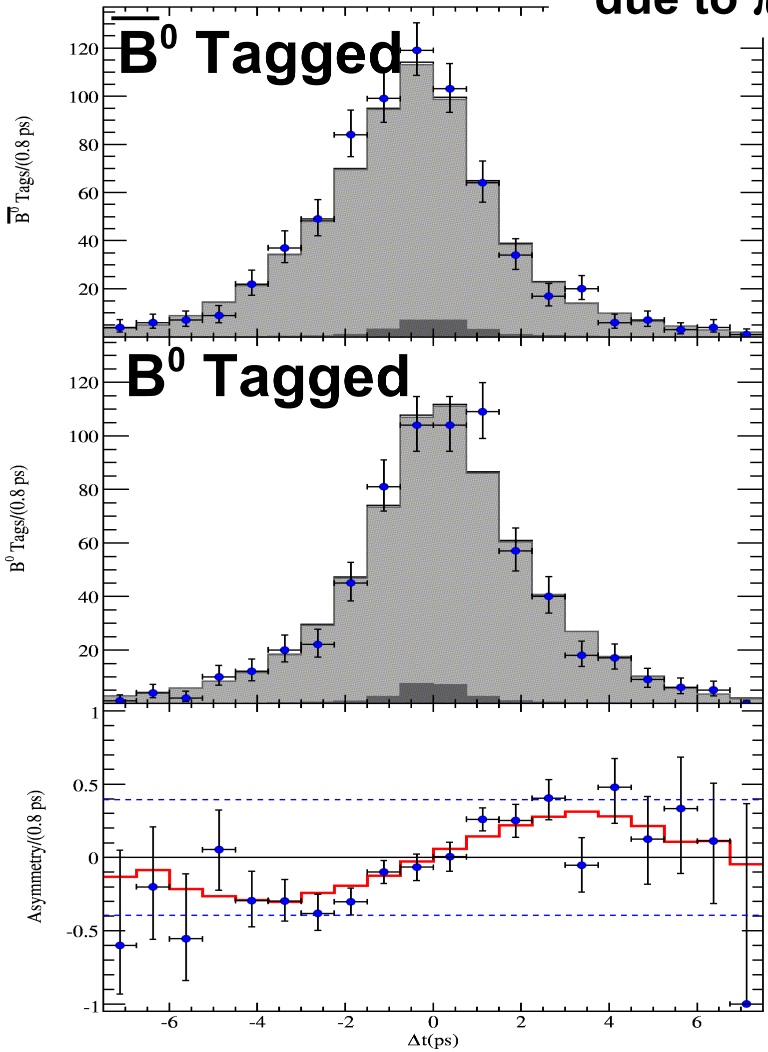
Fit Results: Proj. Plots (VI)

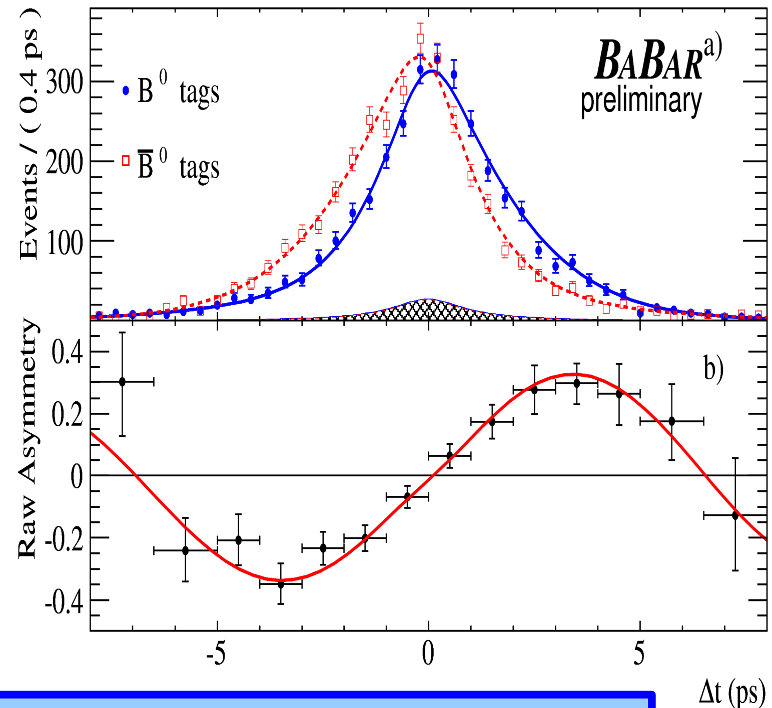


Fit Results: Proj. Plots (VII)

Δt dependent asymmetry:

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





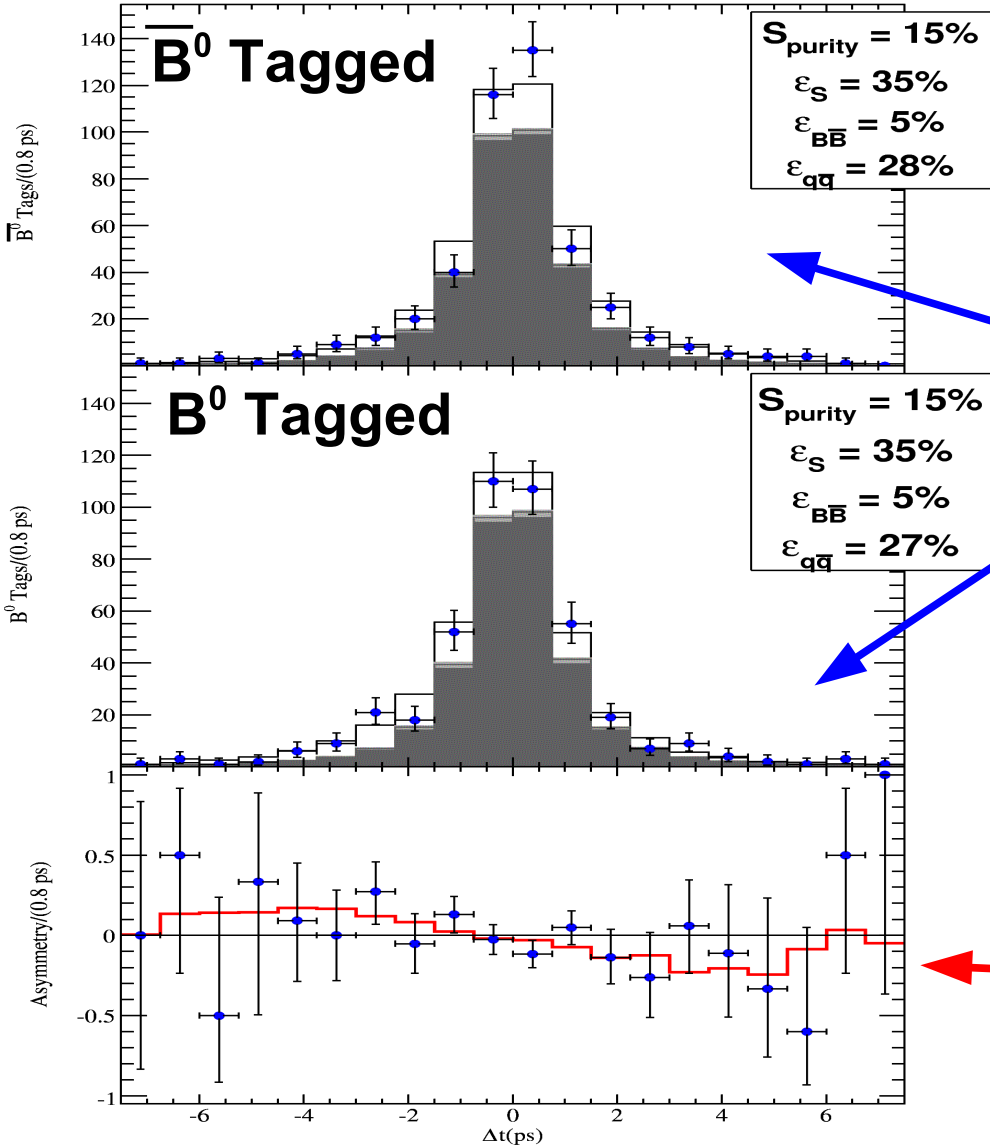
S = 0.660 ± 0.036 ± 0.012

Fit to our data gives:

S = 0.690 ± 0.077

Fit Results: Proj. Plots (VIII)

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



All Events in

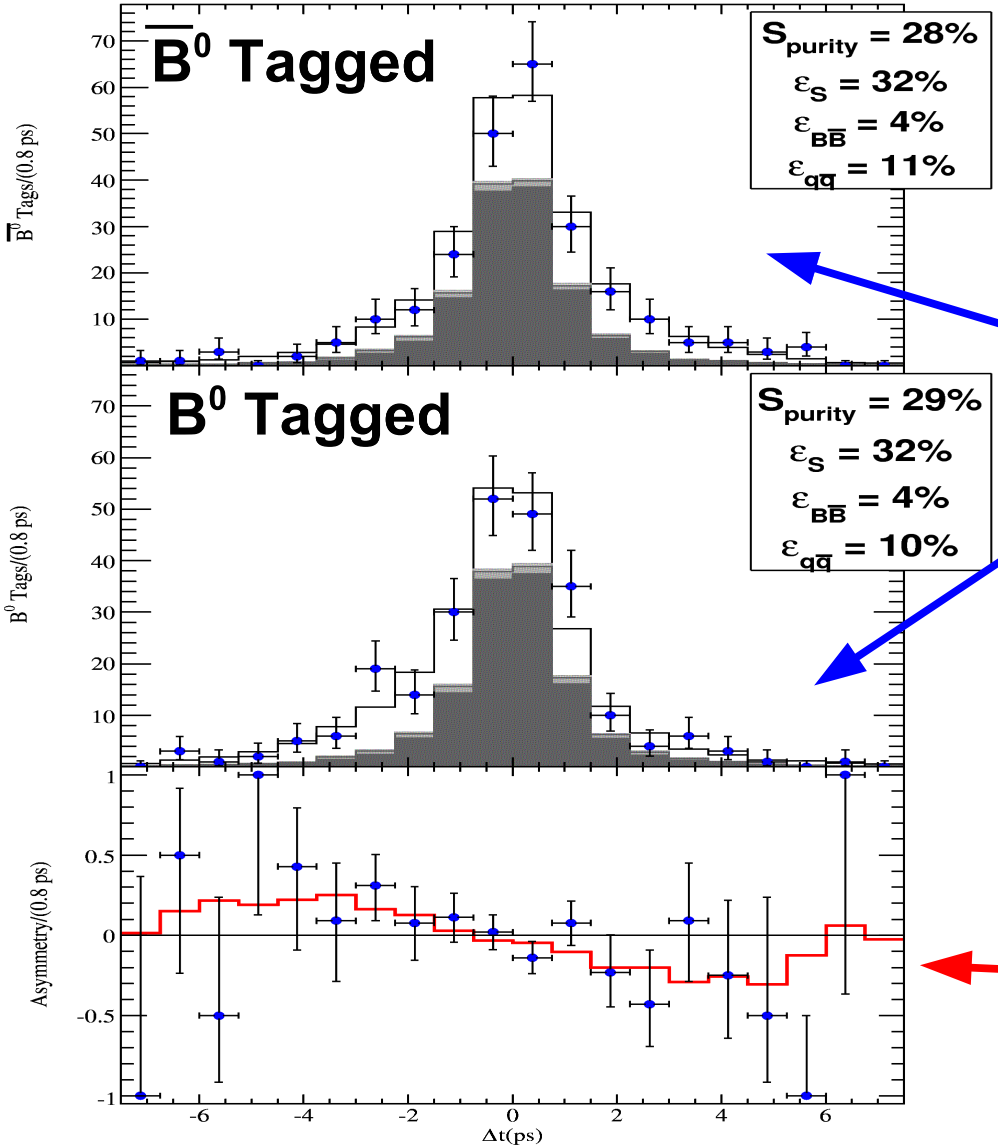
$0.86 < m_{\pi\pi} < 1.06$GeV

Time-dependent rate asymmetry

(diluted by large background)

Fit Results: Proj. Plots (VIII)

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



Signal Enhanced by R cut

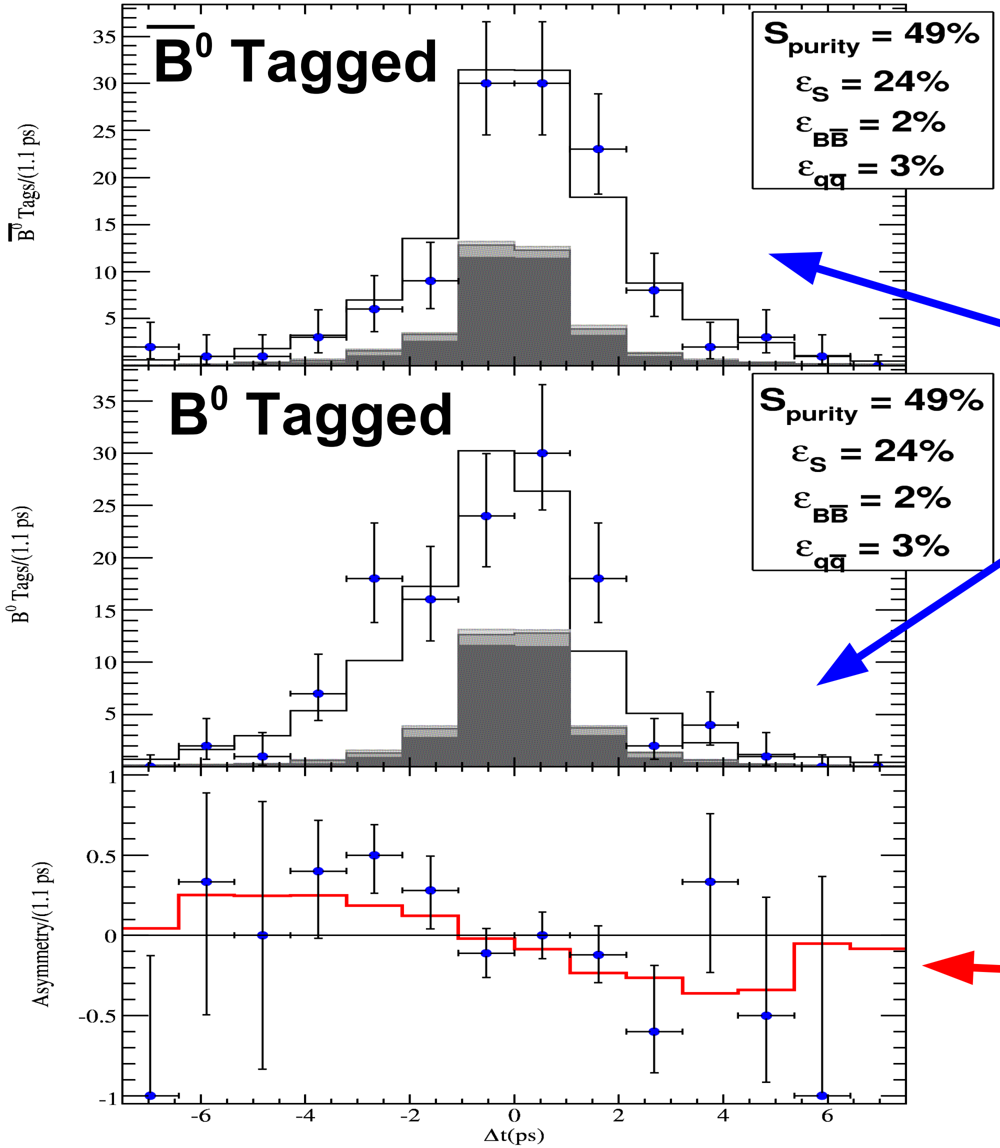
Removed ~70% of qqbar

Time-dependent rate asymmetry

(starts to be visible)

Fit Results: Proj. Plots (VIII)

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



Signal Enhanced by R cut

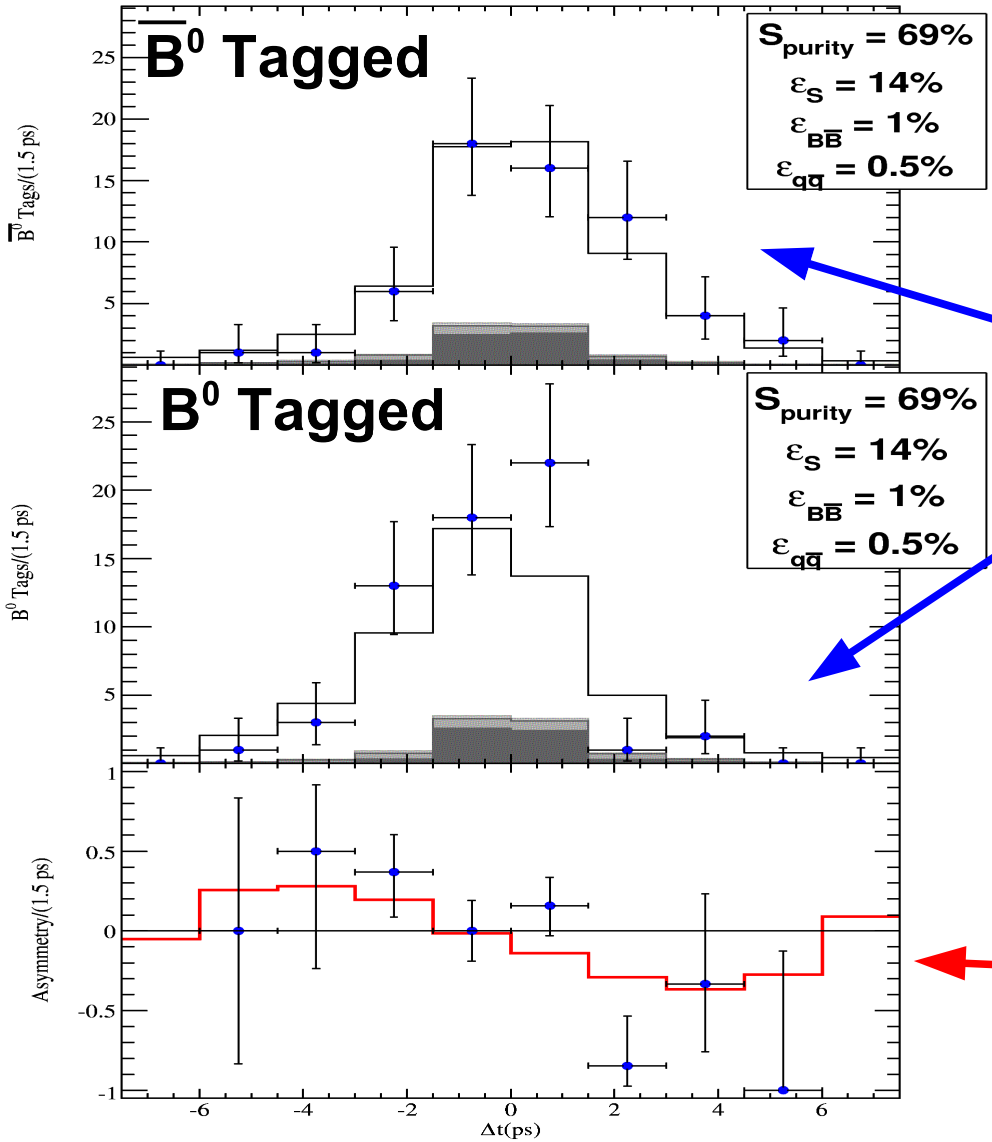
Removed ~90% of qqbar

Time-dependent rate asymmetry

(even more visible)

Fit Results: Proj. Plots (VIII)

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



Signal Enhanced by R cut

Removed ~99% of qqbar...

but also ~ 60% of signal

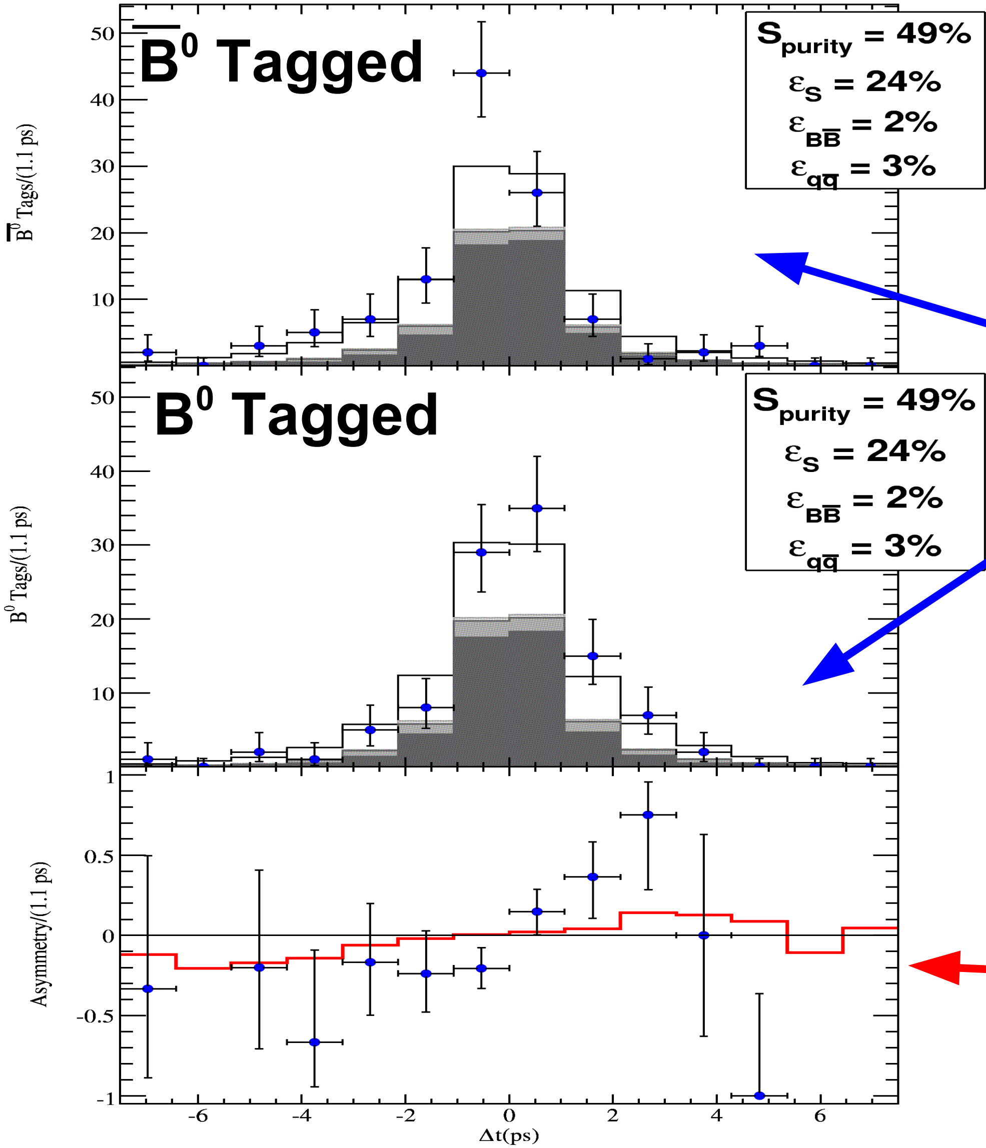
Time-dependent rate asymmetry

(even more visible,

too tight on signal now)

Fit Results: Proj. Plots (IX)

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



Signal Enhanced by R cut

Time-dependent rate asymmetry not as significant as $f_0(980)K^0_s$

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 ρπ analysis)
  - BF(ρ(1700)) = 7.0 % * BF(ρ(770)) (From ρπ 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 Kππ)
  - BF(K*(1680)) = 15.6 % * BF(K*(892)) (From charged Kππ)

- 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
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  - Isobar pa

  - BF(ρ(145
  - BF(ρ(170
  - BF(f0(17
  - BF(χc2)
  - BF(K*2(1
  - BF(K*(14
  - 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

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

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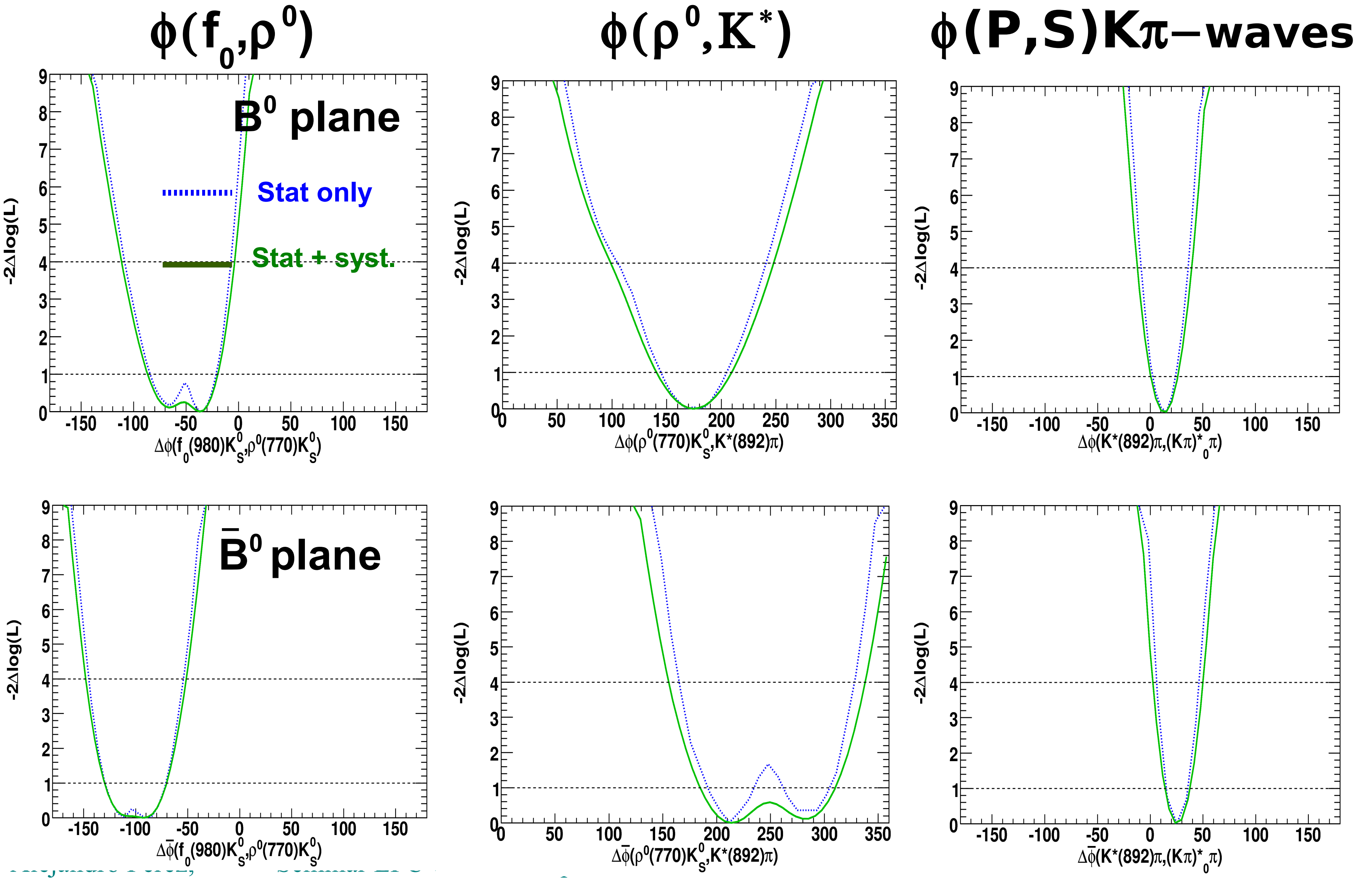
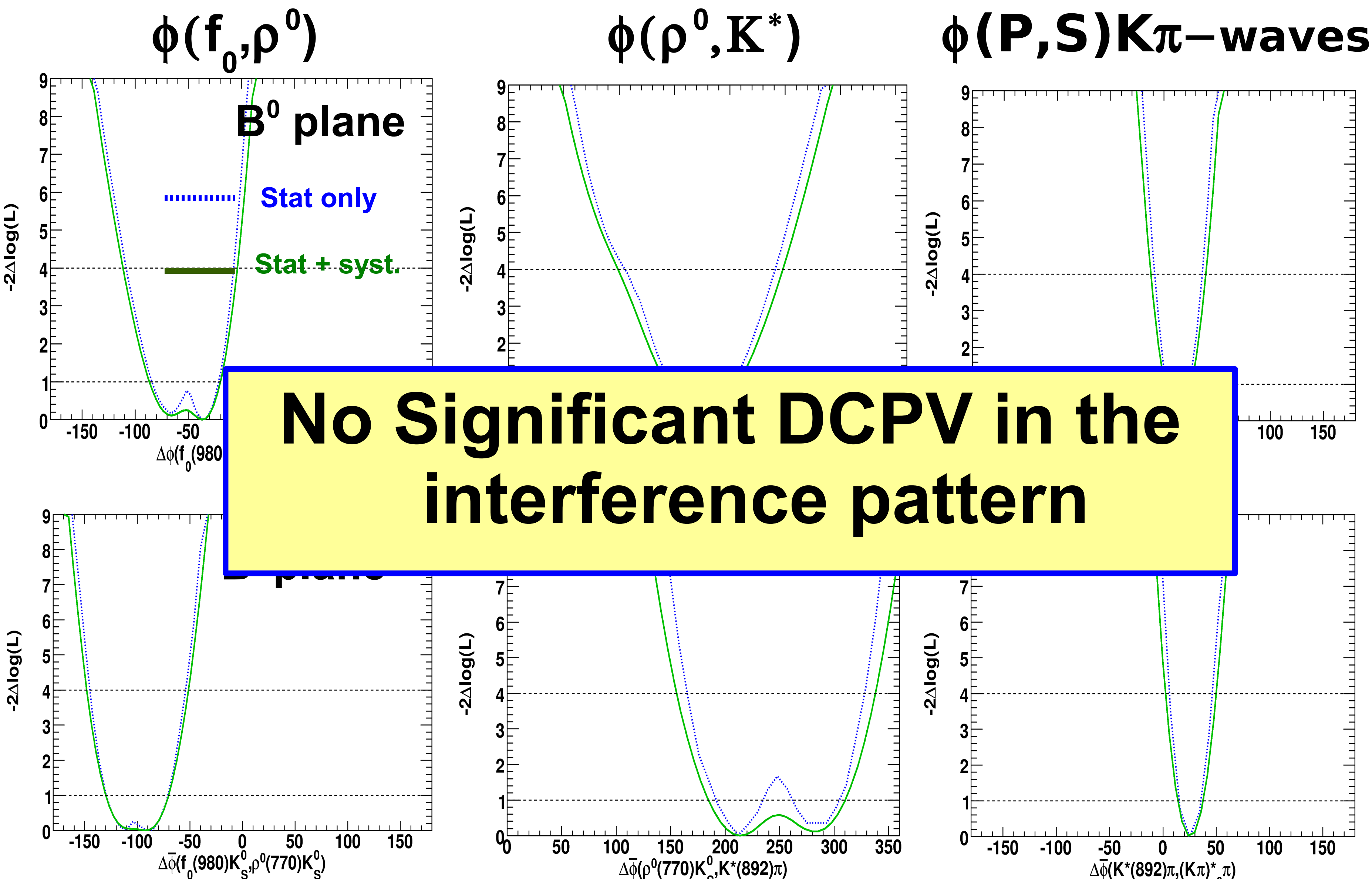
Fit Results: interference pattern

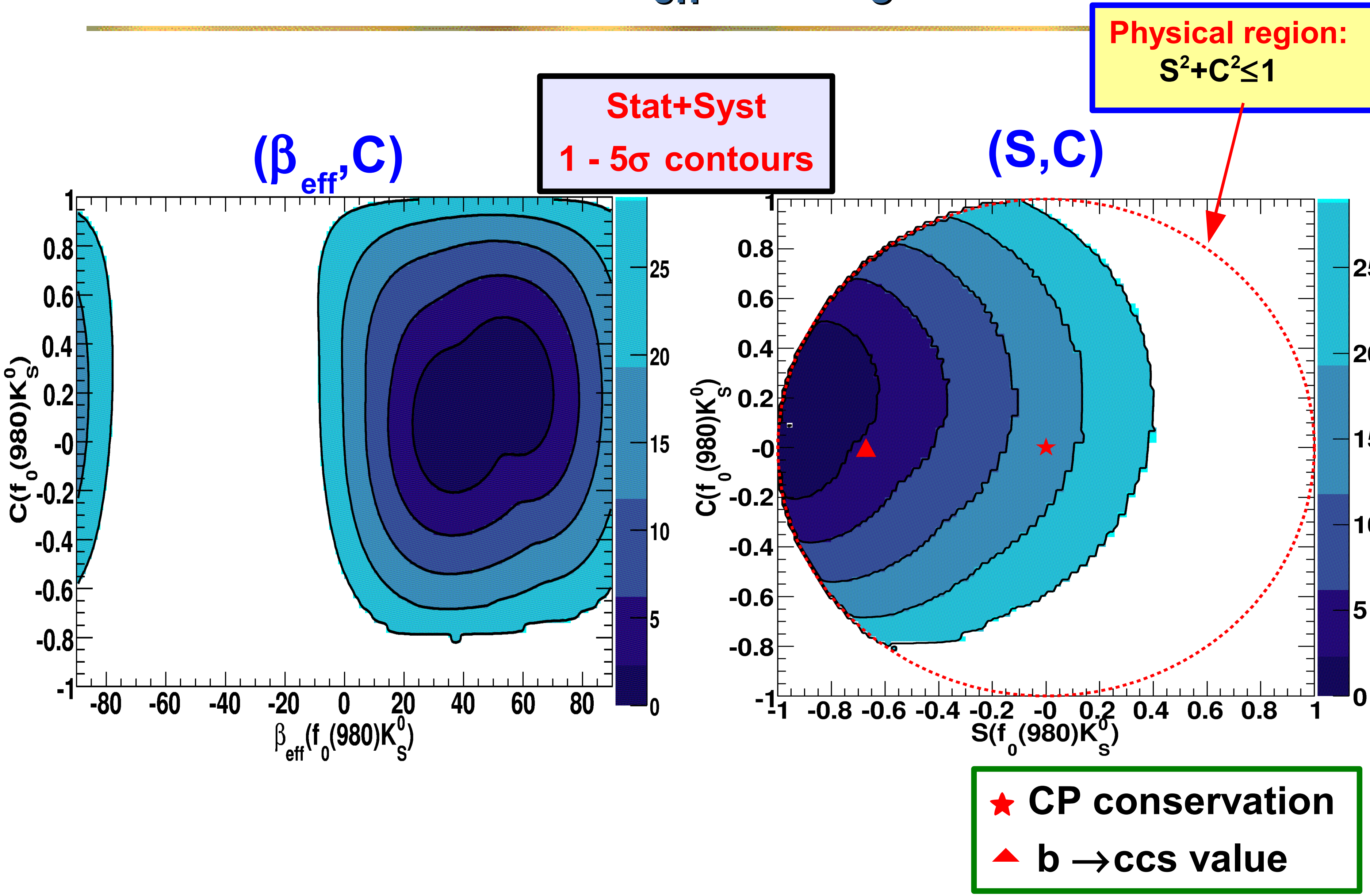


Fit Results: interference pattern



No Significant DCPV in the interference pattern

Fit Results: (β_{eff},C) f_0(980)Ks

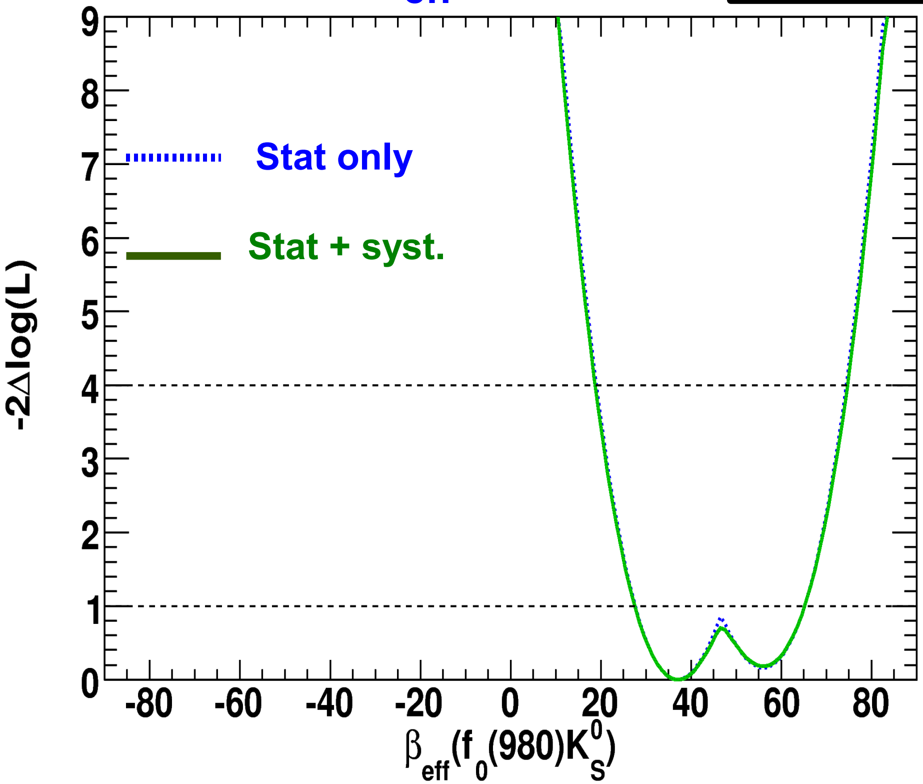


Fit Results: (β_{eff},C) f_0(980)Ks

Stat+Syst

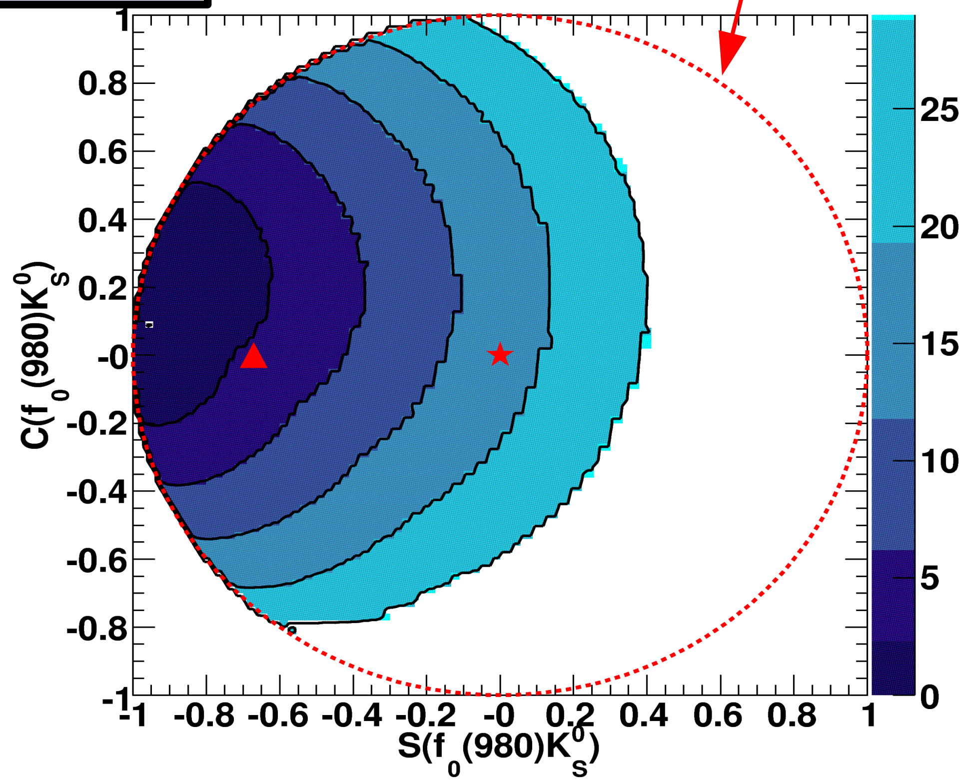
1 - 5σ contours

(β_{eff},C)



(S,C)

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

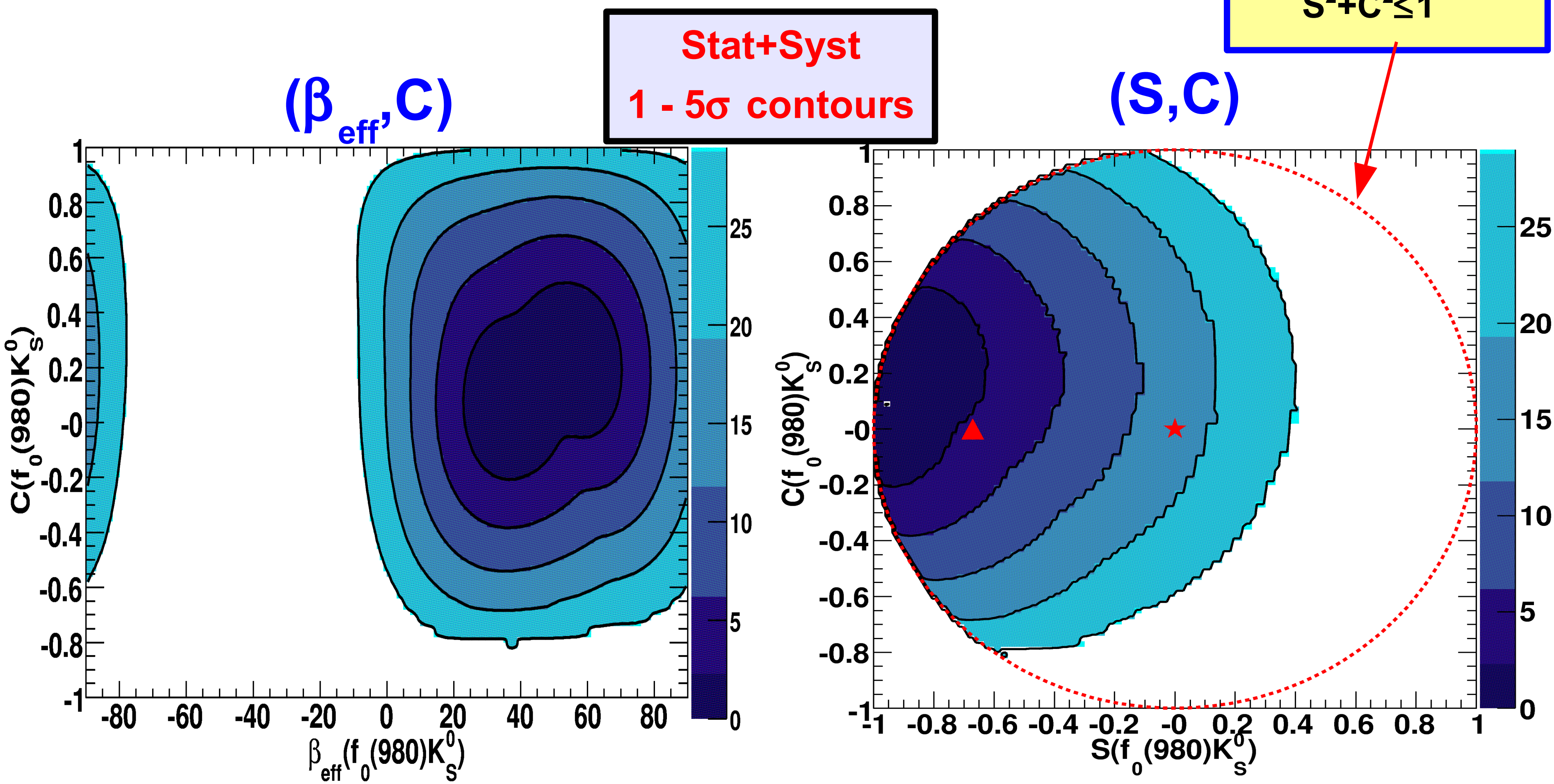


Does not resolve trigonometrical ambiguity above and below 45°

★ CP conservation

▲ b →ccs value

Fit Results: (β_{eff},C) f_0(980)Ks



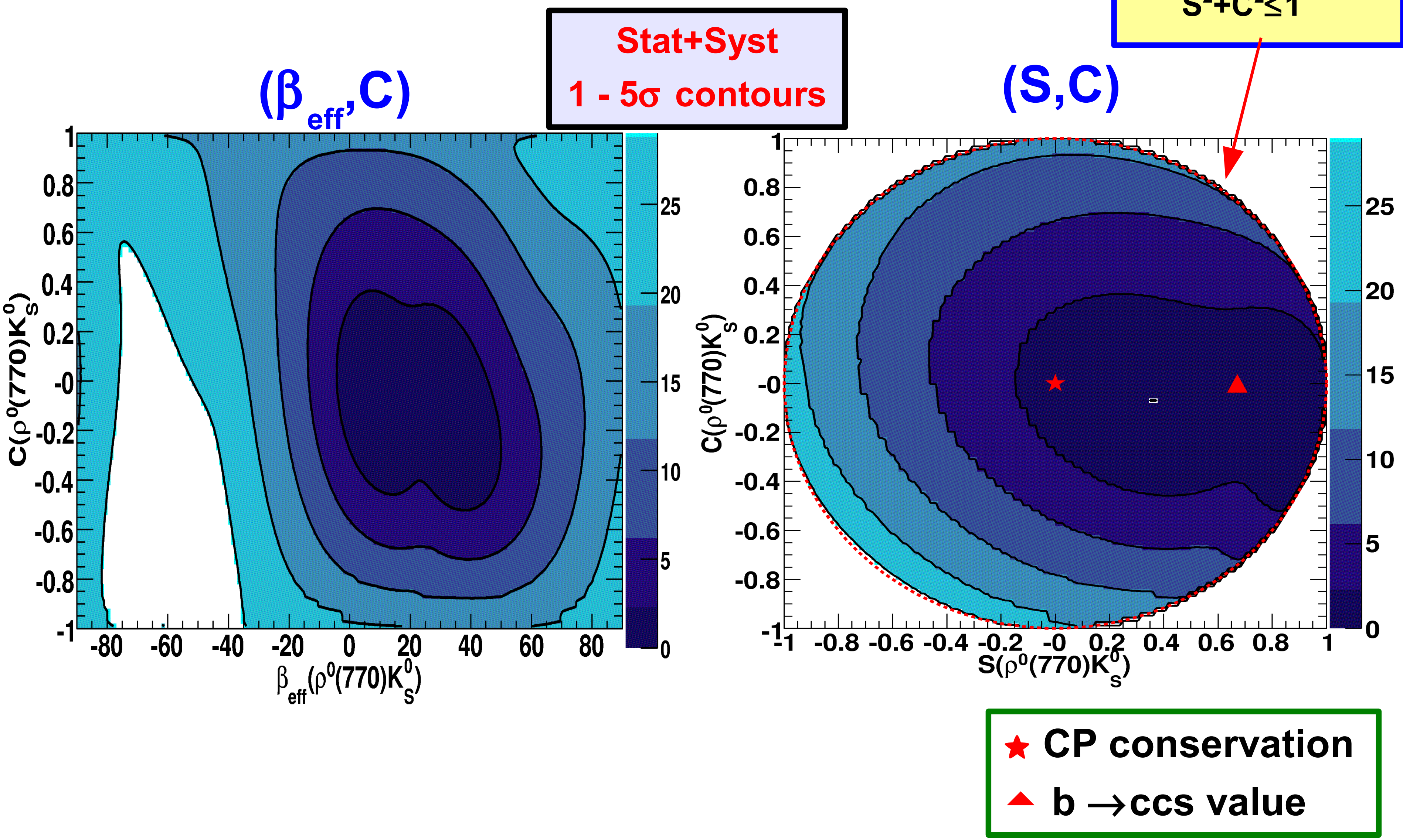
CP conservation excluded at 3.5σ

Agreement with b → ccs at 1.1σ

★ CP conservation

▲ b → ccs value

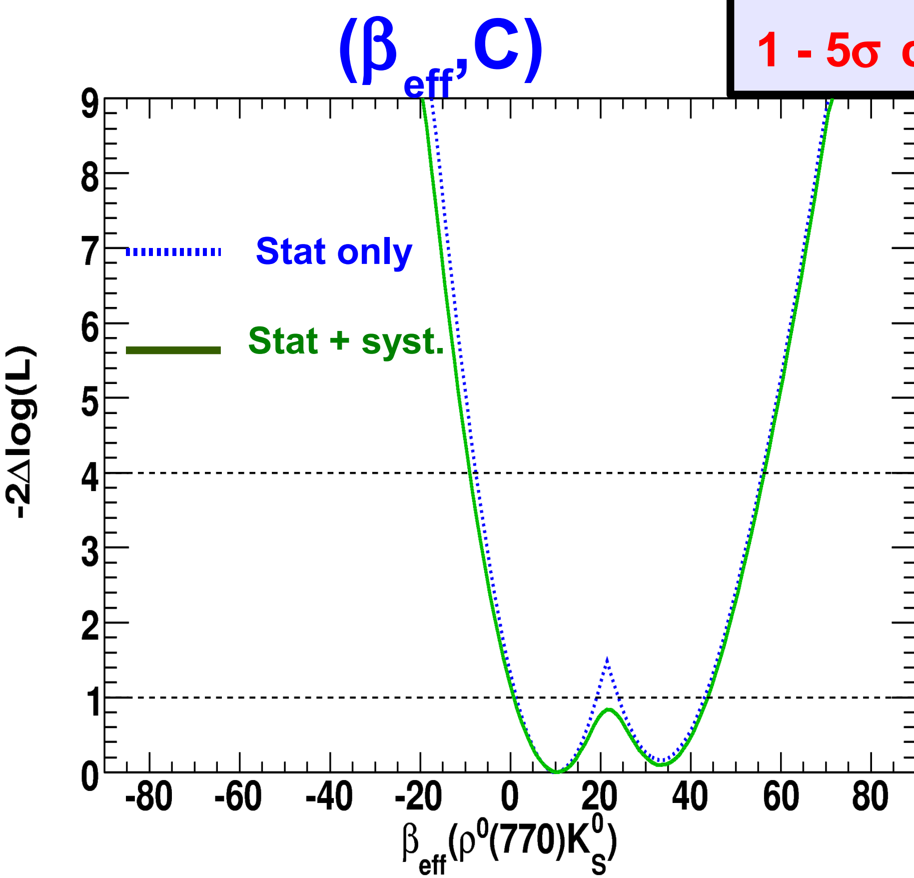
Fit Results: (β_{eff},C) ρ^0(770)Ks

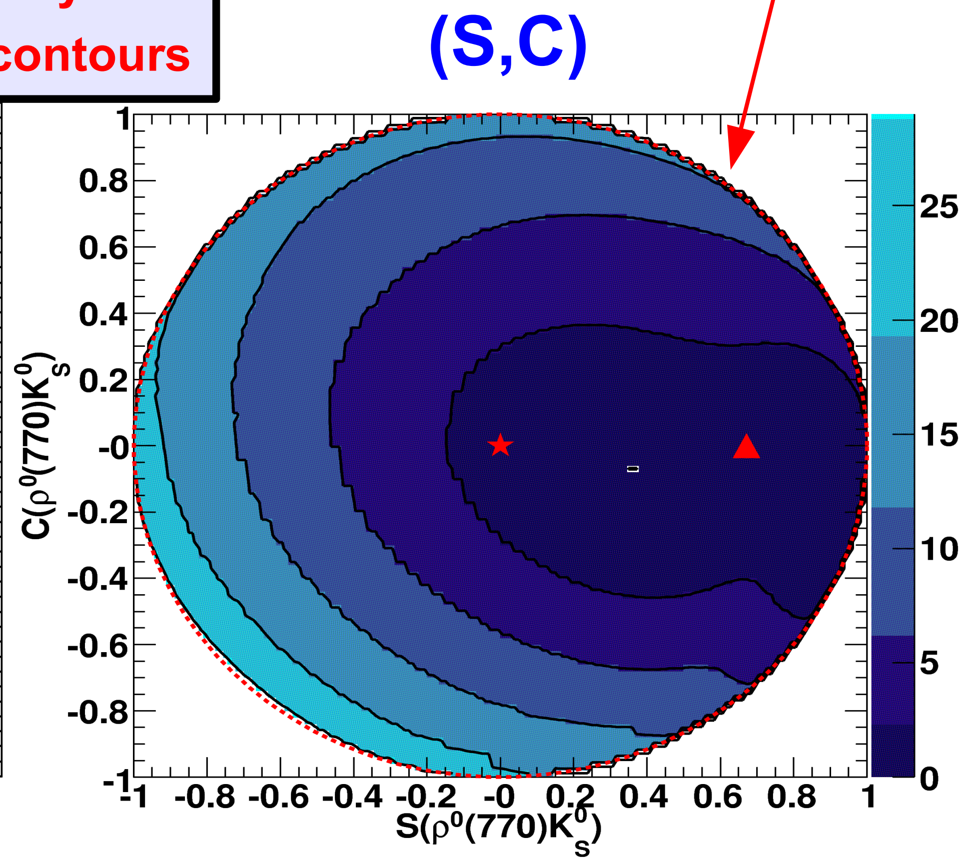


Fit Results: (β_{eff},C) ρ^0(770)Ks

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

Stat+Syst
1 - 5σ contours





trigonometrical ambiguity disfavoured at 1.9σ

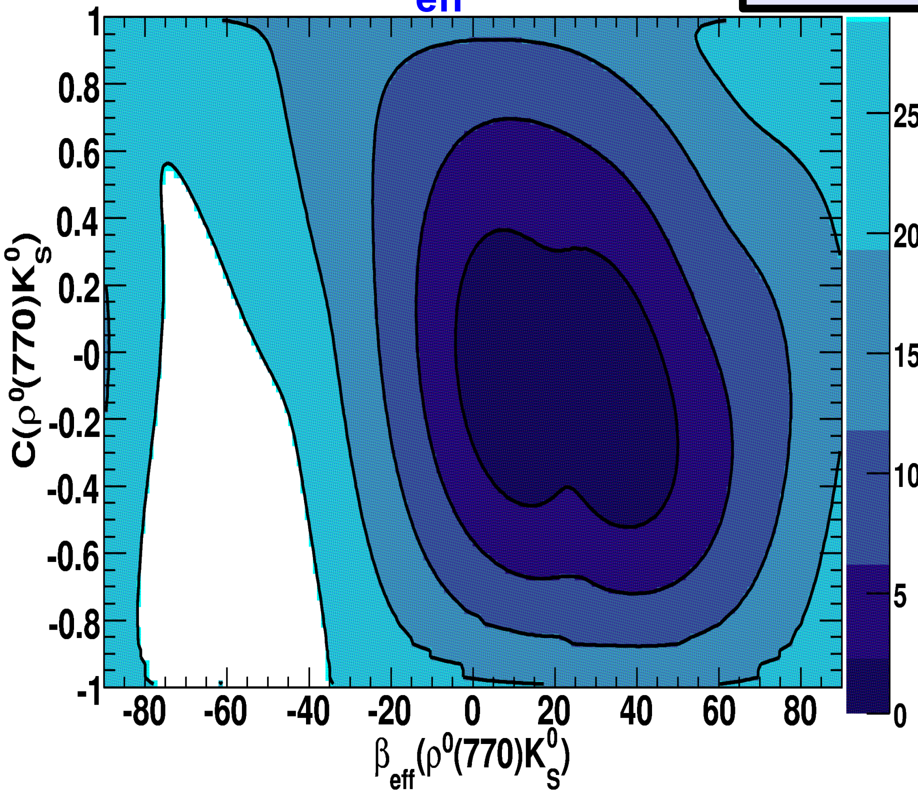
★ CP conservation
▲ b →ccs value

Fit Results: (β_{eff},C) ρ^0(770)Ks

Stat+Syst

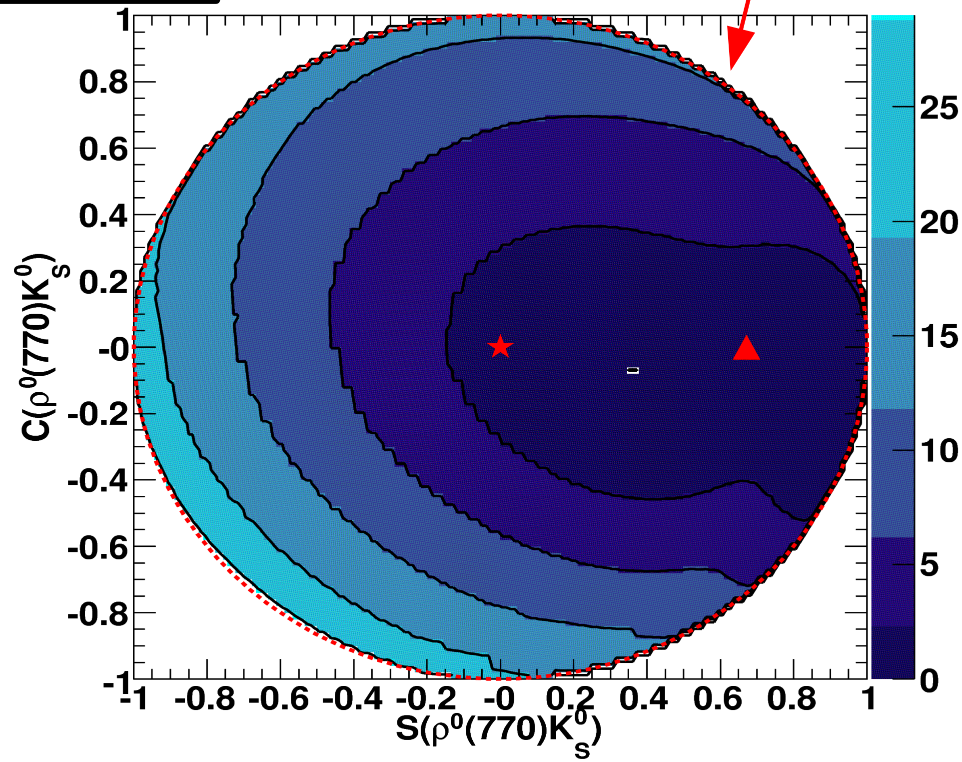
1 - 5σ contours

(β_{eff},C)



(S,C)

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



Compatible both with CPV conservation and b → ccs value

★ CP conservation

▲ b → ccs value

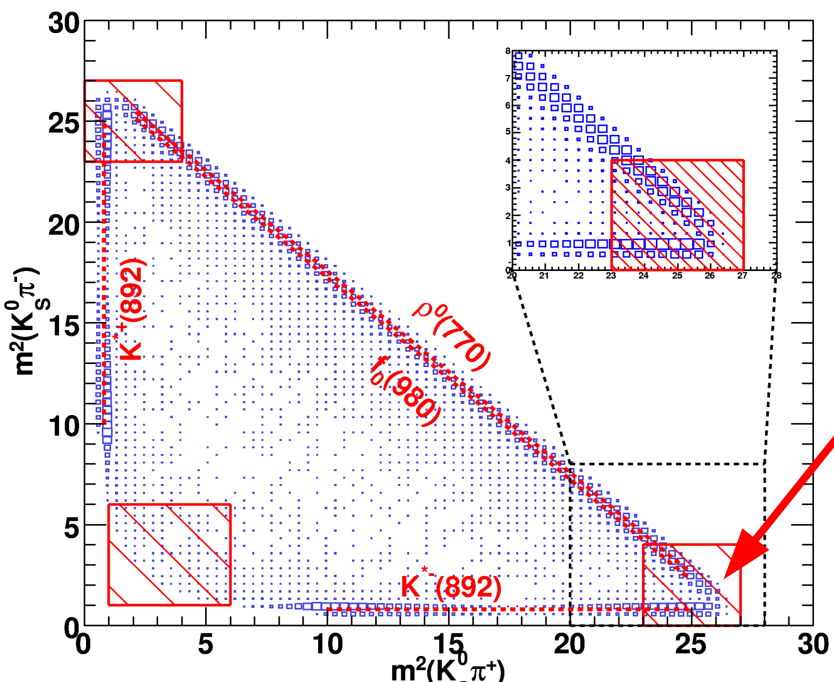
Fit Results: CPS Phase $K^*(892)\pi$

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

- Sensitivity not by direct interference

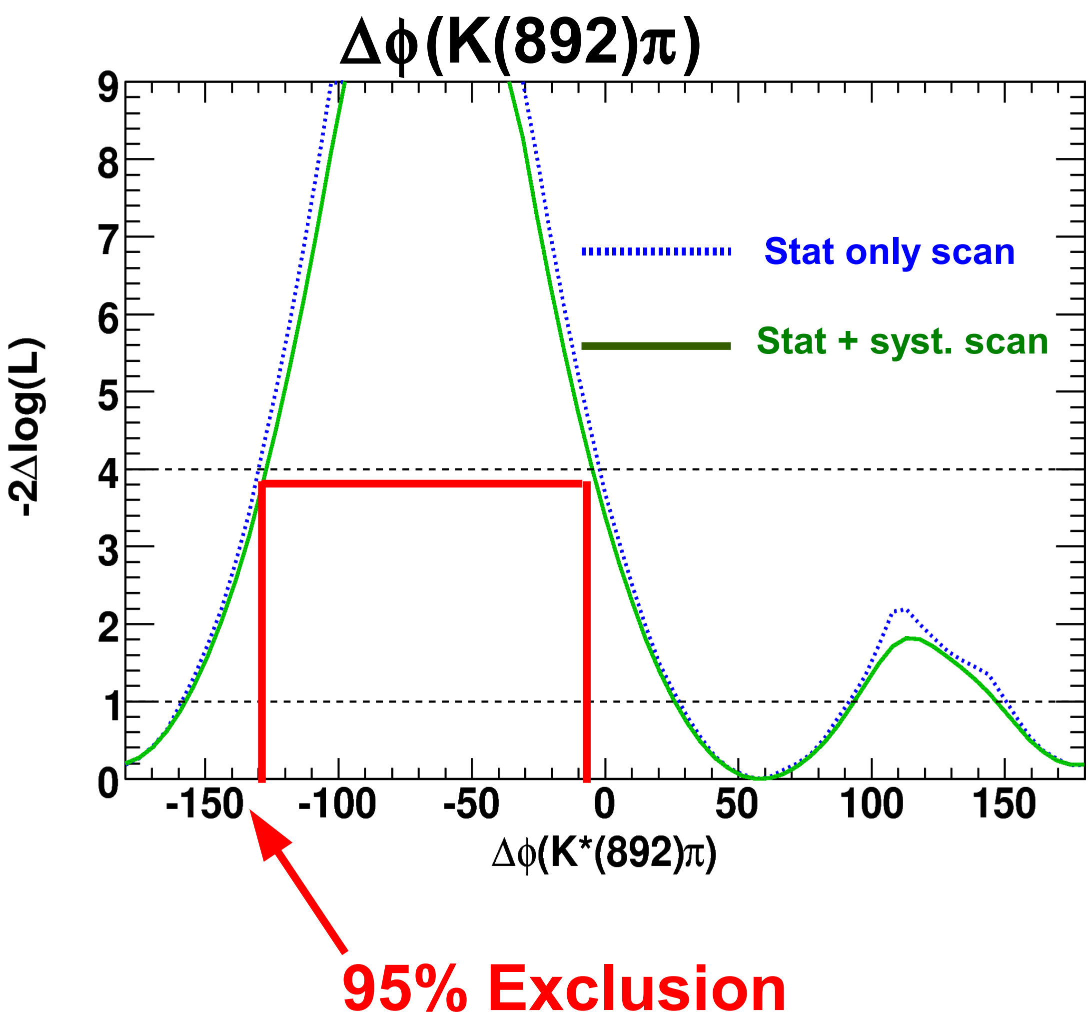
- Only by interference with other components in the DP:

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



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

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



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

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

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$A_{CP}^{\mathrm{incl.}}$	$-0.010 \pm 0.050 \pm 0.008 \pm 0.006$

All compatible with no CPV

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

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/

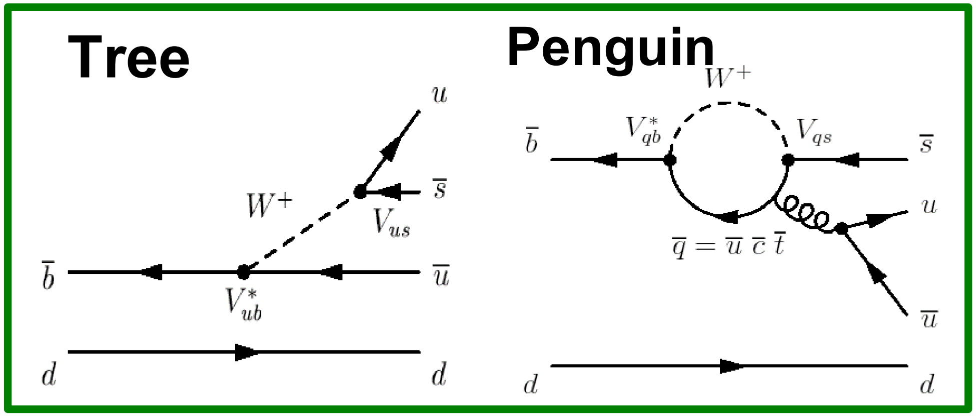
$B\to K^{*}\pi$ System: Isospin relations

SU(2) Isospin relations:

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

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

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



(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:

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

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

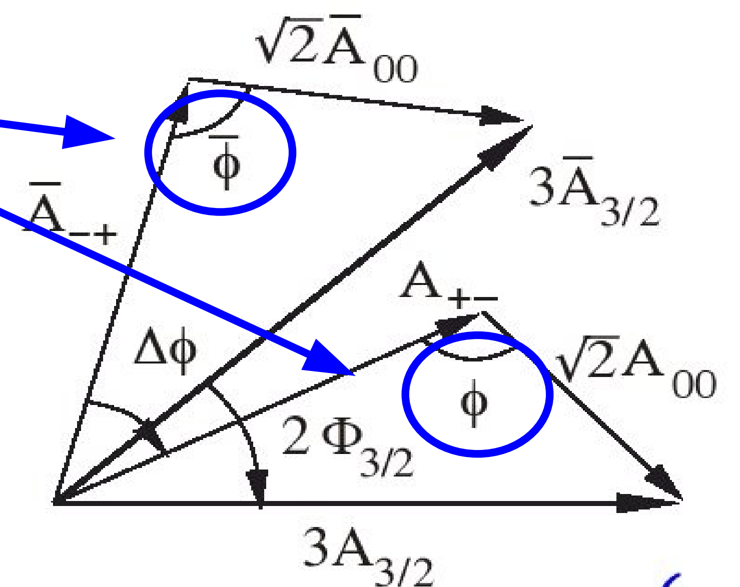
CPS PRD74:051301
GPSZ PRD75:014002

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:

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

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

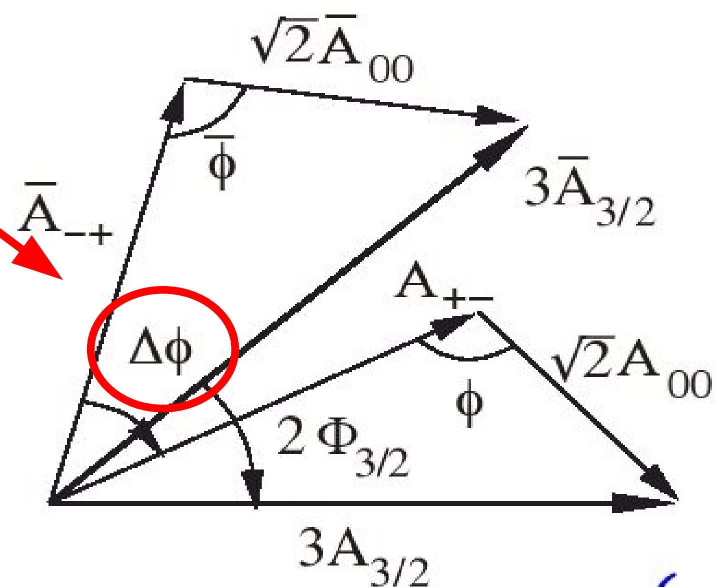
which gives: $R_{3/2} = (3A_{3/2})/(3\overline{A}_{3/2}) = e^{-2i\gamma}$

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

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

A total of 13 observables

Constrained system… but…

B→K*π 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

- 5 phase differences:

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

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

$\bar{\phi} = \arg(\bar{A}(B^-\to \bar{K}^{*0}\pi^-)\bar{A}^*(B^-\to K^{*-}\pi^0))$ 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 $T_{3/2} = T^{+-} + T^{00}_{C}$

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

- $B \to K\pi$: $P_{EW} = RT_{3/2}$ (same as $\pi\pi$ and SU(3))
  P amplified CKM wrt. T ($|V_{ts}V^{*}_{tb}/V_{us}V^{*}_{ub}| \sim 50$) $\to$ 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 $|r_{VP}| < 5\%$

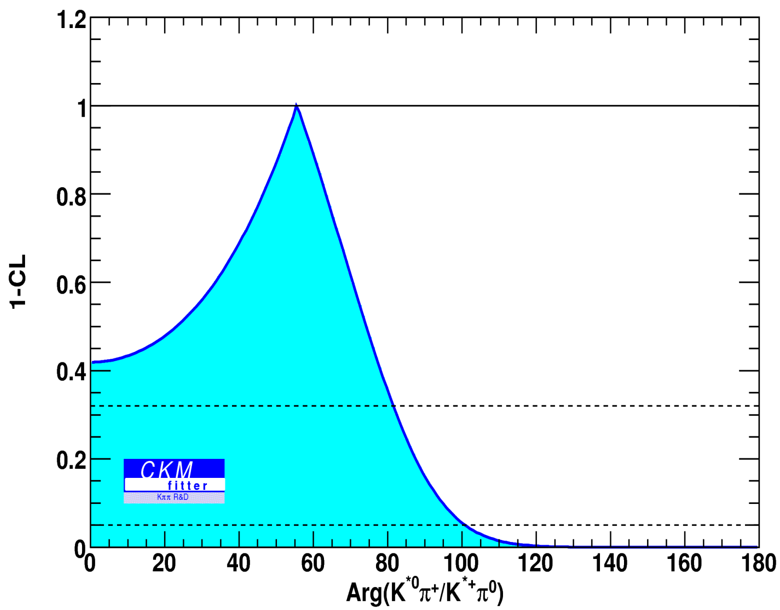
Scenario 1: prediction of unavailable phases

Input here:

- Experimental measurements
- CKM from global fit

(No assumption on any hadronic amplitude)

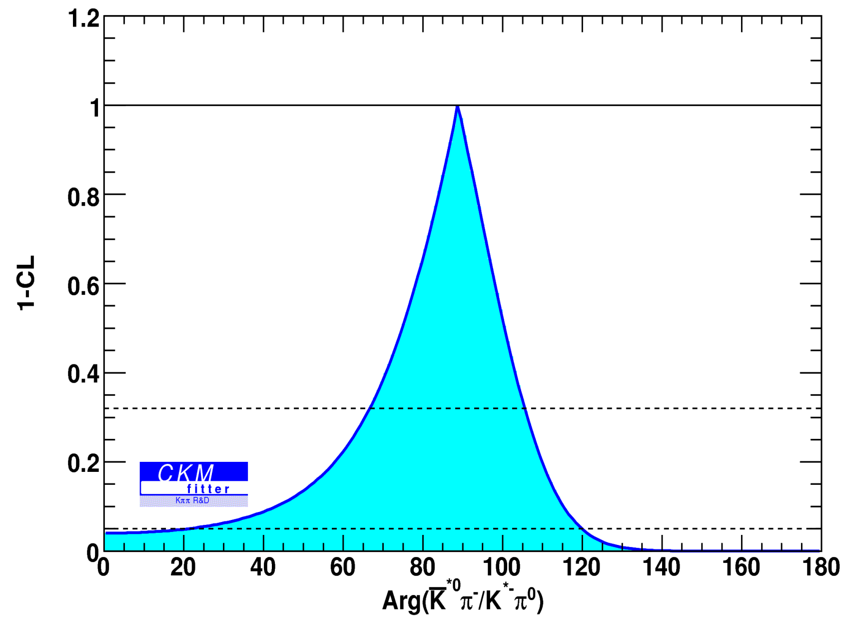
$|\phi| = |\arg(A(B^+ \to K^{*0}\pi^+)A^*(B^+ \to K^{*+}\pi^0))|$



Central value = 58°

(0,85)° at 1σ

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

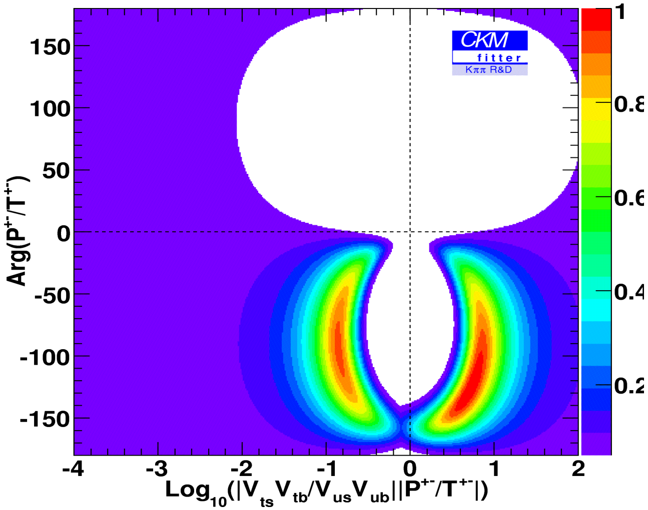


Central value = 95°

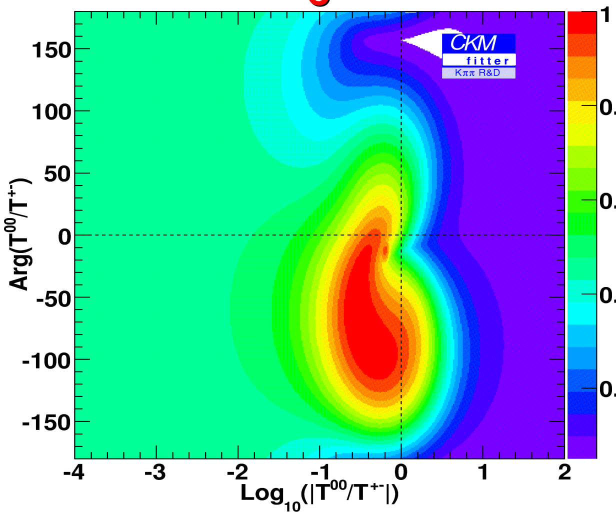
(68,107)° at 1σ

Scenario 1: exploring hadronic parameters

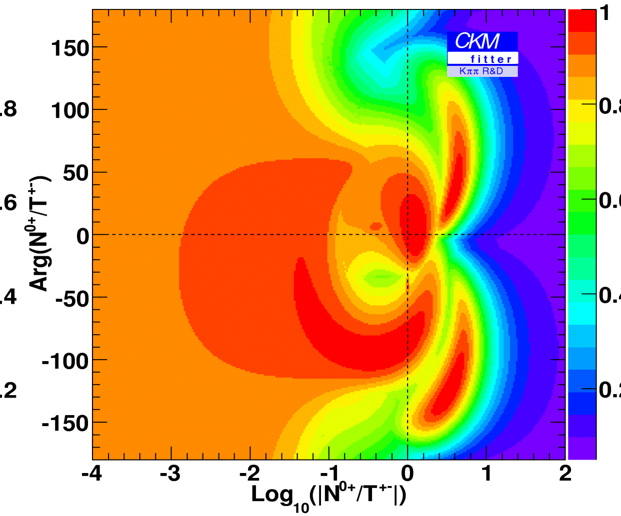
P^{+-}/T^{+-}



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



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

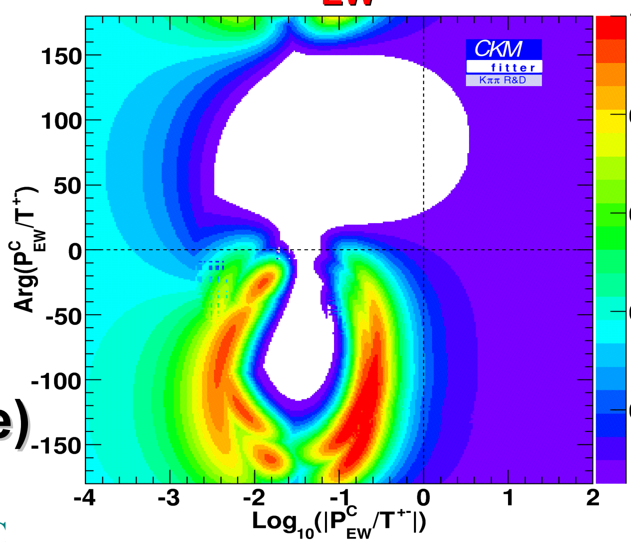


Input here:

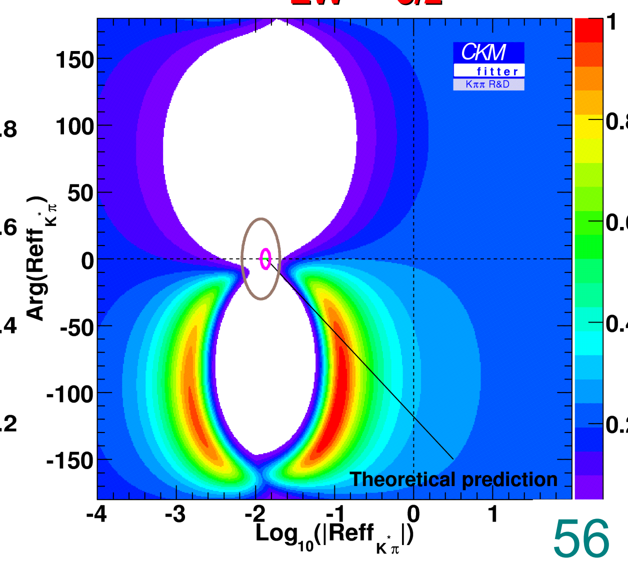
- Experimental measurements
- CKM from global fit

(No assumption on any hadronic amplitude)

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



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



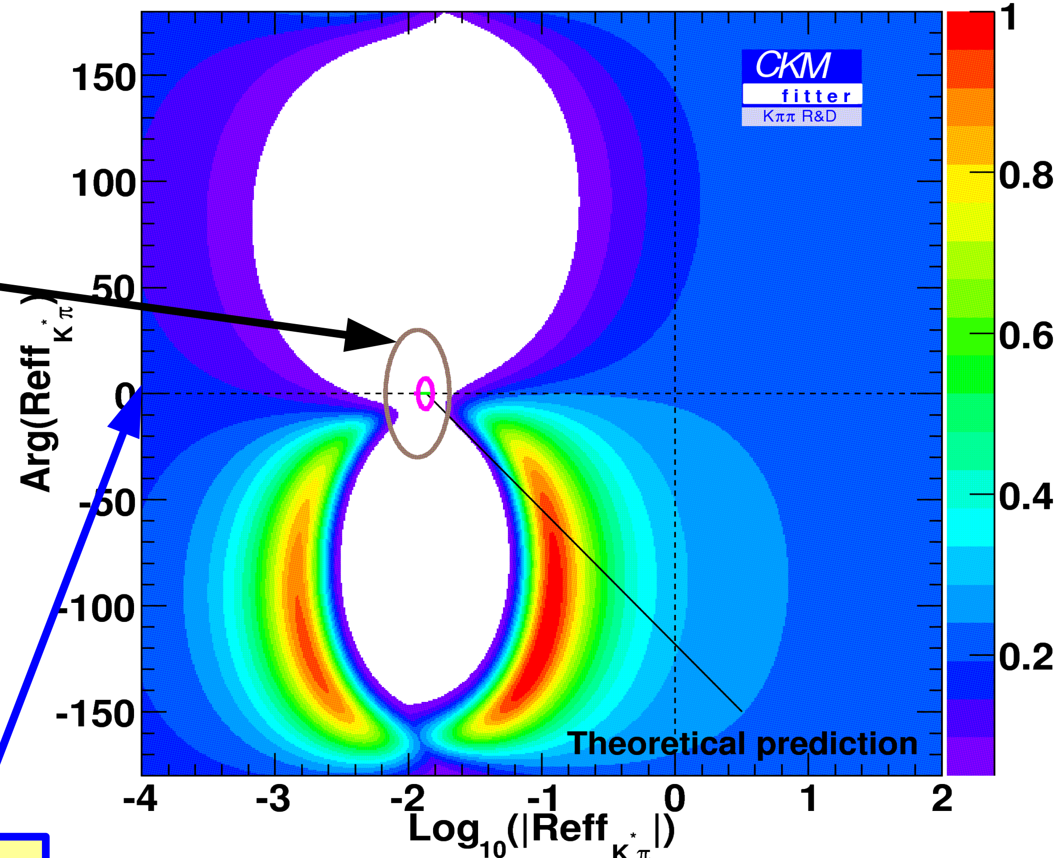
Scenario 1: exploring hadronic parameters

Input here:

- Experimental measurements
- CKM from global fit

(No assumption on any hadronic amplitude)

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



— GPSZ error

— 5*GPSZ error

Constraint marginally compatible with GPSZ prediction (~2σ)

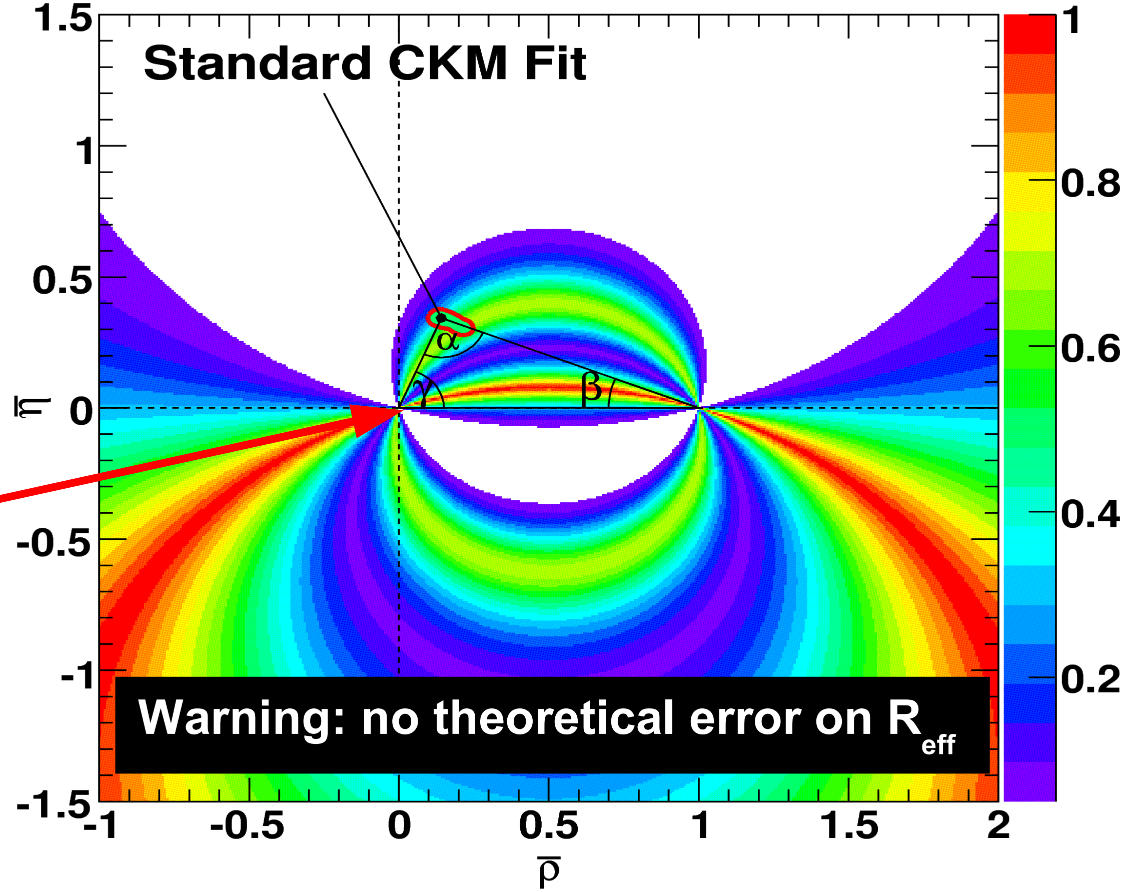
P_{ew} = 0 better compatibility with data

Scenario 2: exploring CKM

Vanishing P_{EW}

$R_{eff} = 0$

Constraint set on α not γ!

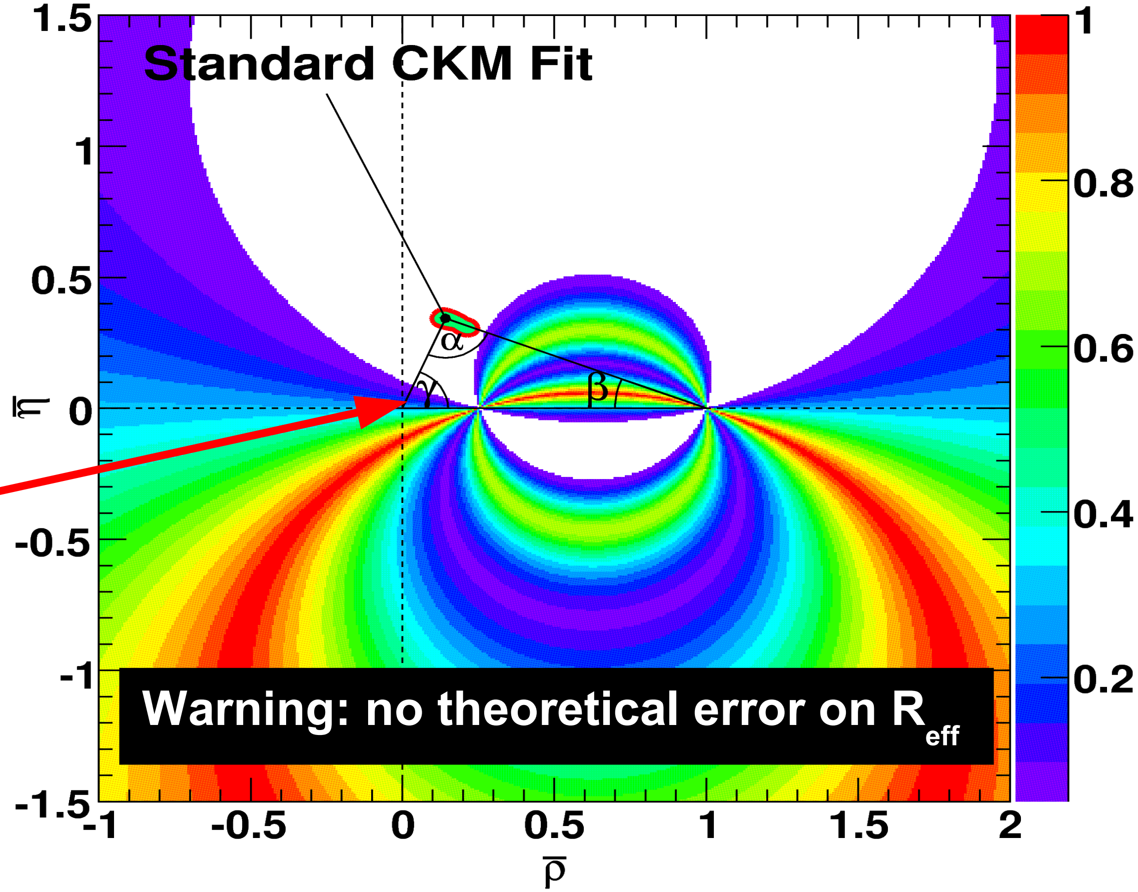


Scenario 2: exploring CKM

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

R_{eff} = 1.35% (GPSZ)

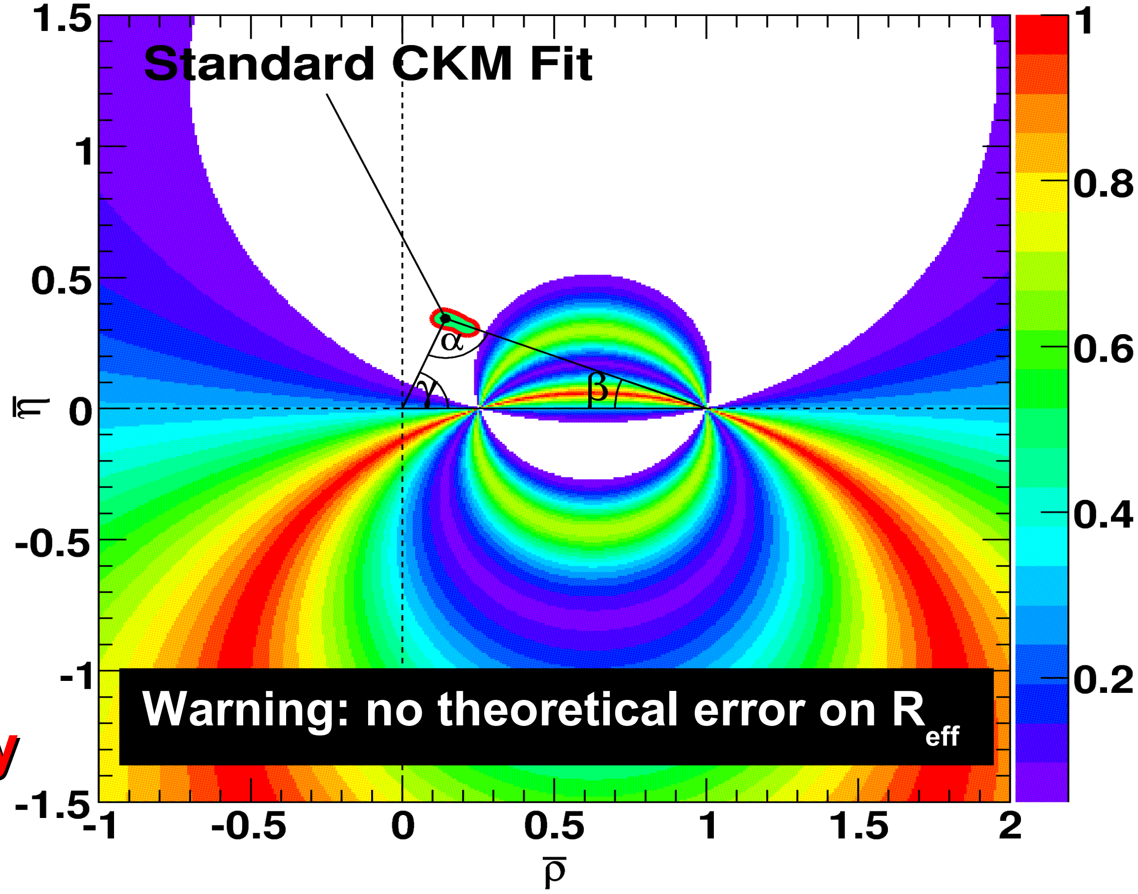
Constraint set on "α shifted" ($\phi_{3/2}$)



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

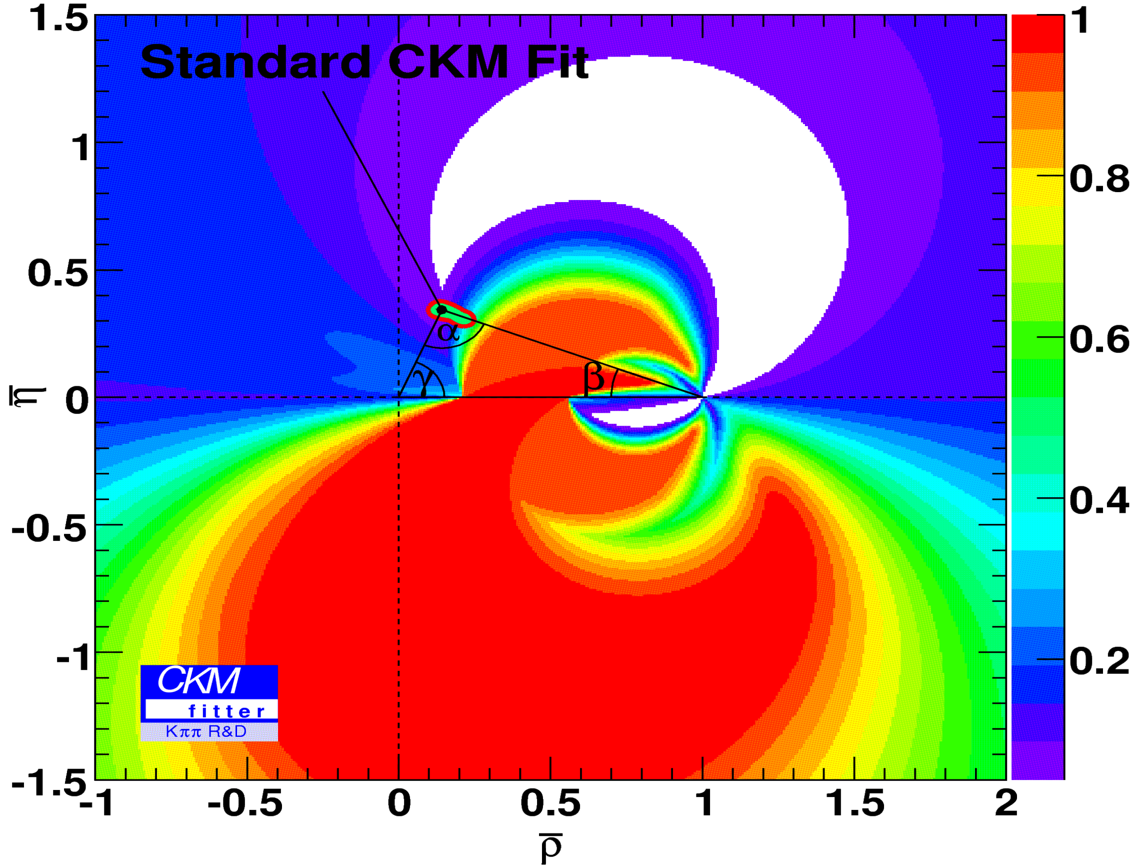
Scenario 2: exploring CKM

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

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

Conservative theoretical error dilutes strongly the constraint

CPS/GPSZ method totally dominated by theoretical errors



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

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

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

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

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

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

A total of 9 observables

Under constraint system

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

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

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

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

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

Same Isospin relations as $K^*\pi$

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

Observab

- 4 BFs
- 1 pha

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

A total of 9 observables

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

Many redundant observables

Observables:

- $K^{*}\pi$ only: 1
- ρK only: 9 observables
- 7 phase differences from: interference between $K^{*}\pi$ and ρK resonances contributing to the same DP
  - $\phi = \arg(A(B^0 \rightarrow \rho^0 K^0) A^{*}(B^0 \rightarrow K^{*+}\pi^-))$ from $B^0 \rightarrow K^0_S \pi^+\pi^-$
  - $\phi = \arg(A(B^0 \rightarrow \rho^- K^+) A^{*}(B^0 \rightarrow K^{*+}\pi^-))$ and CP conjugated from $B^0 \rightarrow K^+\pi^-\pi^0$
  - $\phi = \arg(A(B^0 \rightarrow \rho^0 K^+) A^{*}(B^0 \rightarrow K^{*0}\pi^+))$ and CP conjugated from $B^+ \rightarrow K^+\pi^-\pi^+$
  - $\phi = \arg(A(B^0 \rightarrow \rho^+ K^0) A^{*}(B^0 \rightarrow K^{*+}\pi^0))$ and CP conjugated from $B^+ \rightarrow K^0\pi^+\pi^0$

A total of 29 experimentally independent observables

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

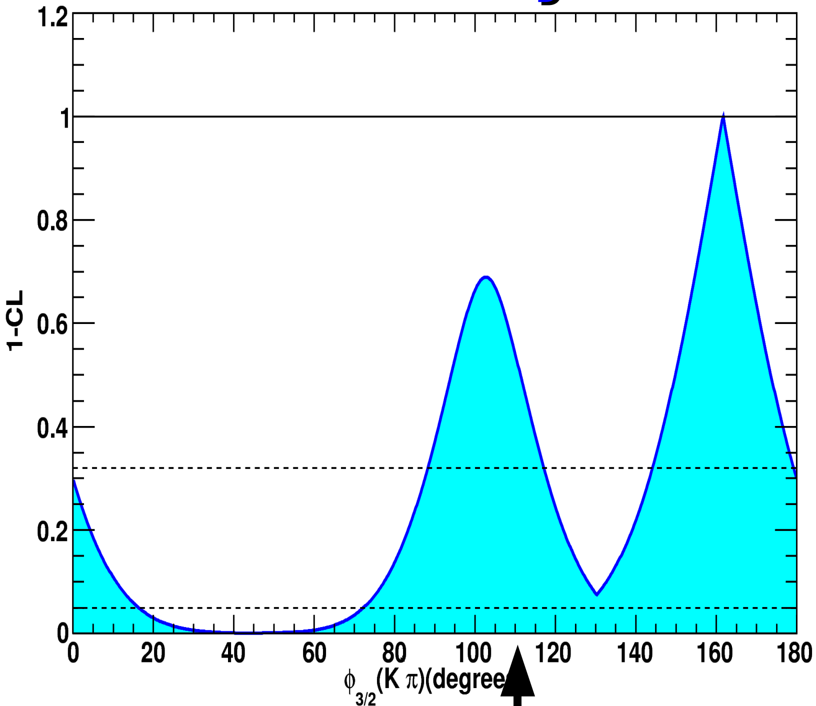
- both can provide constraints on (ρ,η)
  with additional theoretical input.

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

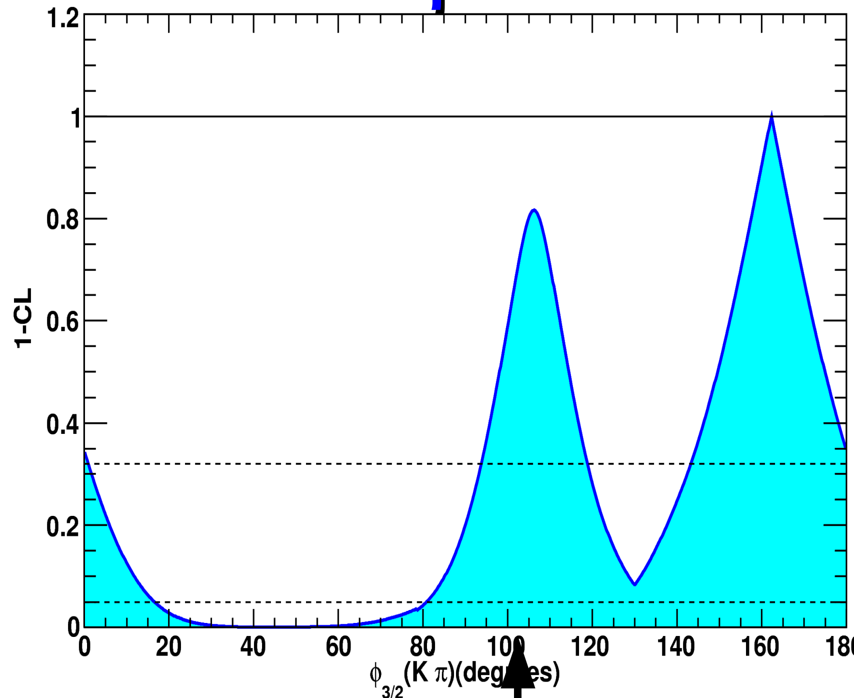
$\rho K + K^*\pi$ system: exploring $\phi_{3/2}(K^*\pi)$

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

$K^*\pi$ only



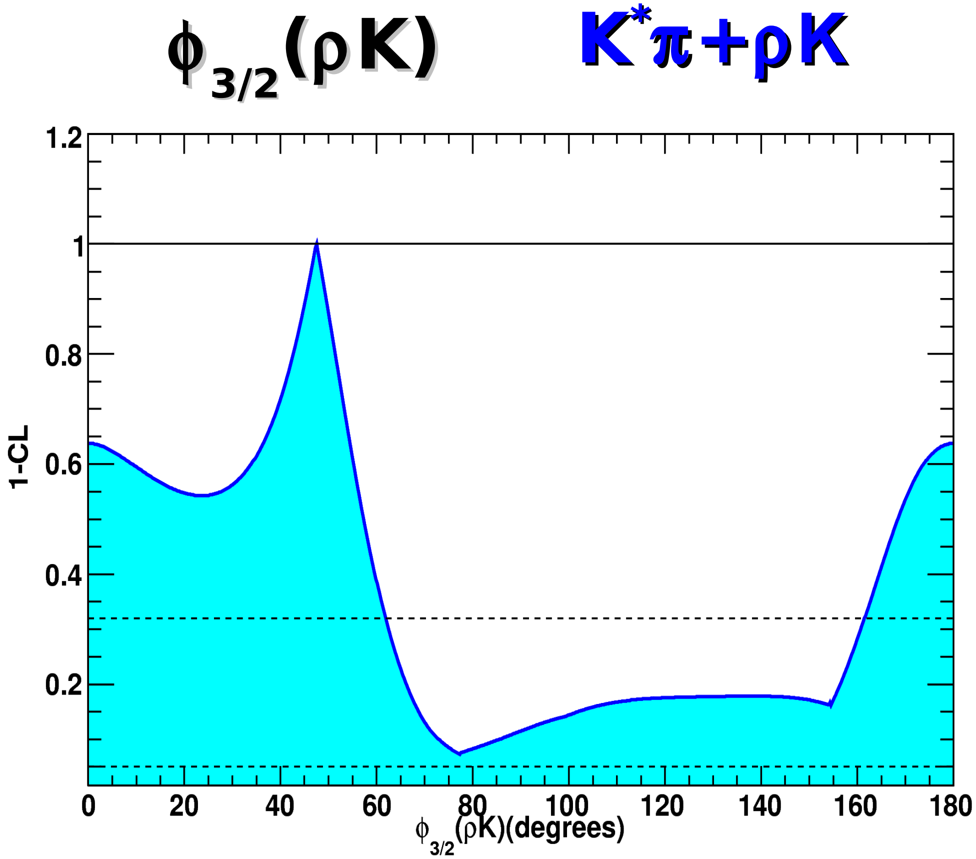
$K^*\pi + \rho K$



(~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 $\phi_{3/2}(\rho K)$



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

Limited constraint with current experimental inputs and errors

ρK+K*π system: Extrapolation

Inputs:

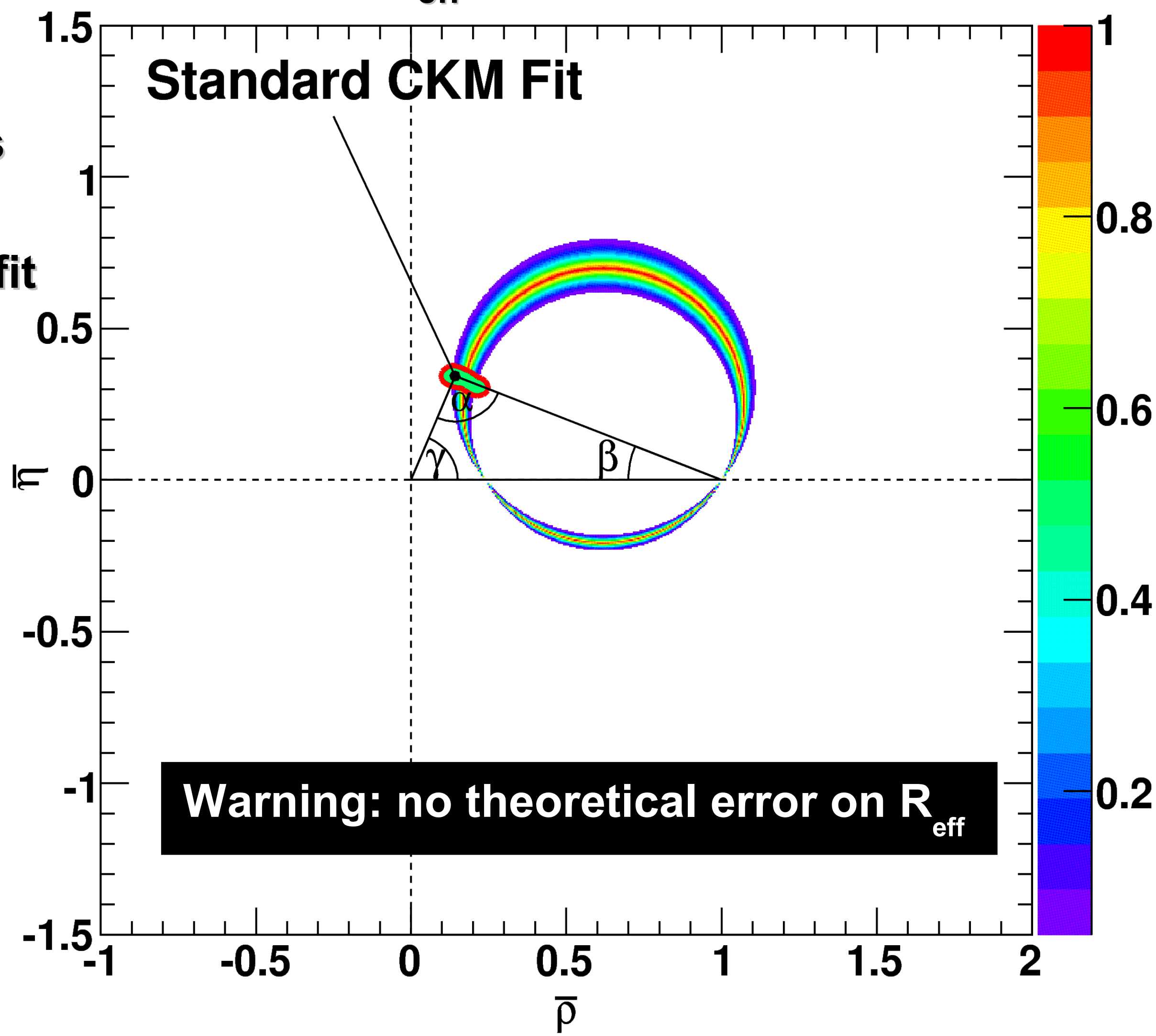
- All 27 K*π + ρK observables
- Assume central values in agreement with global CKM fit

Extrapolated errors:

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

roughly equivalent to current systematics

Assuming R_{eff} = 1.35% (GPSZ)



Conclusions

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 $b \rightarrow ccs$ at 1.1σ

  - Trigonometric ambiguity not resolved

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

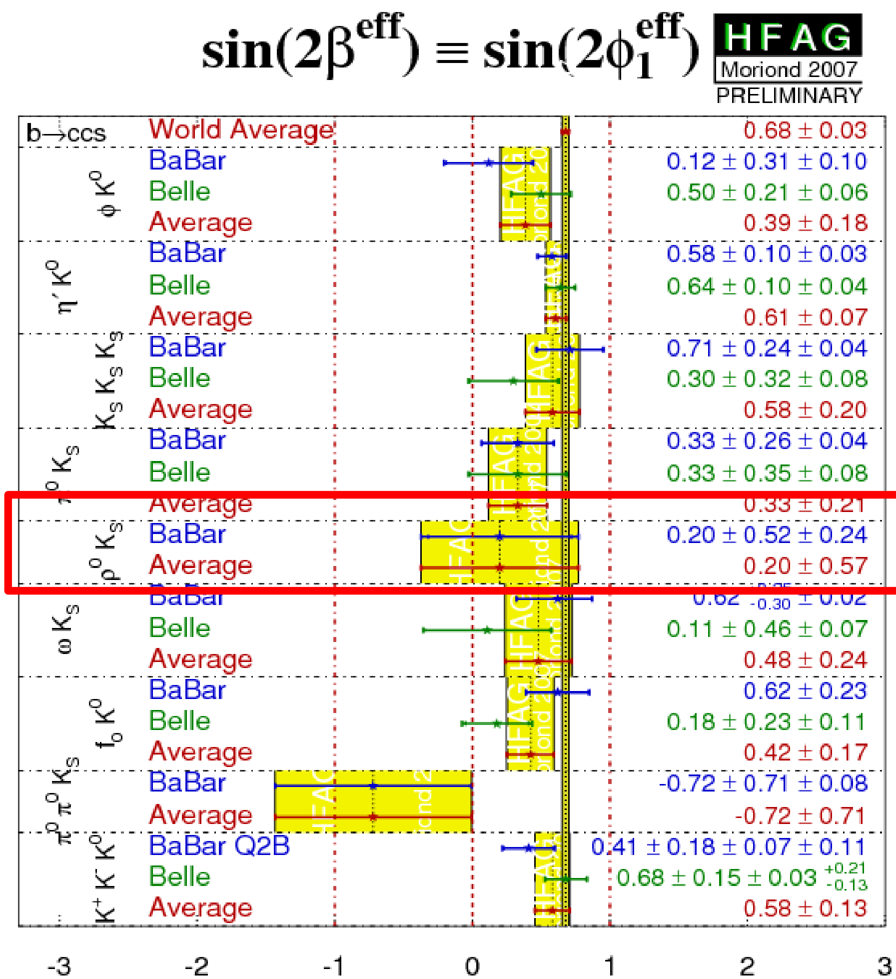
  - Trigonometric ambiguity disfavored at 1.9σ

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

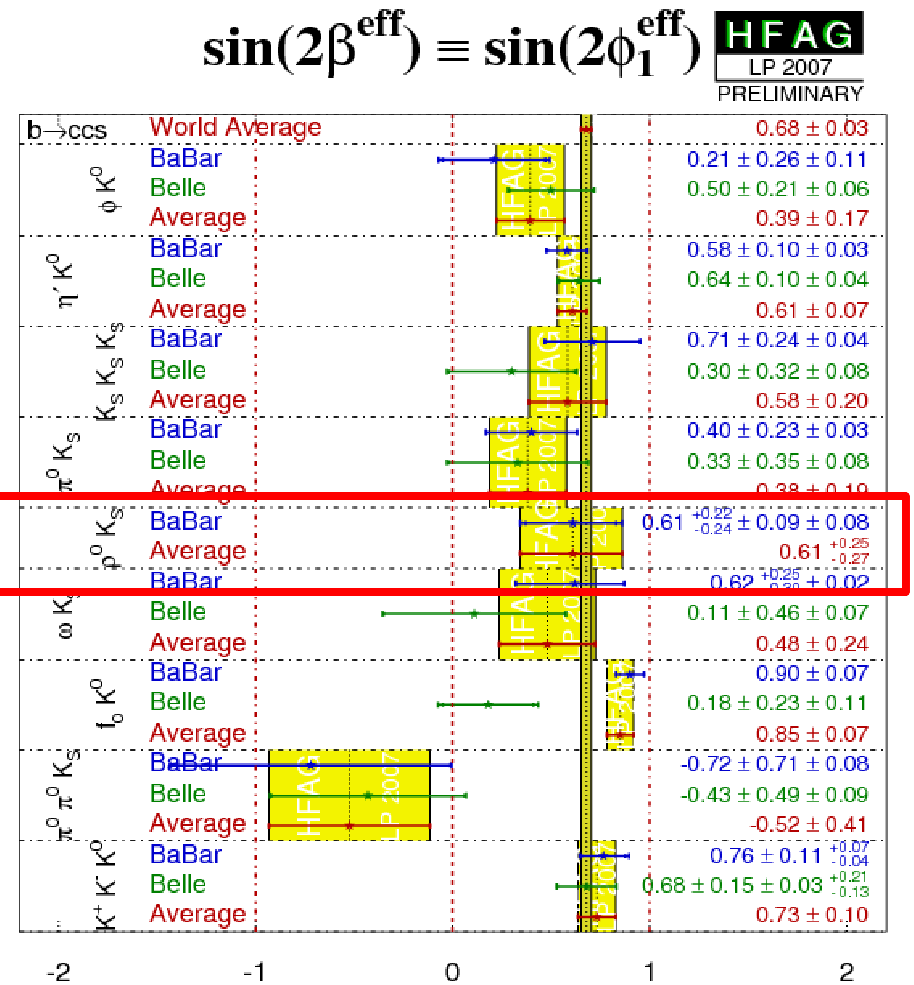
- $\Delta\phi(K^*(892)\pi)$ measured for the first time

Conclusions

Before these measurements

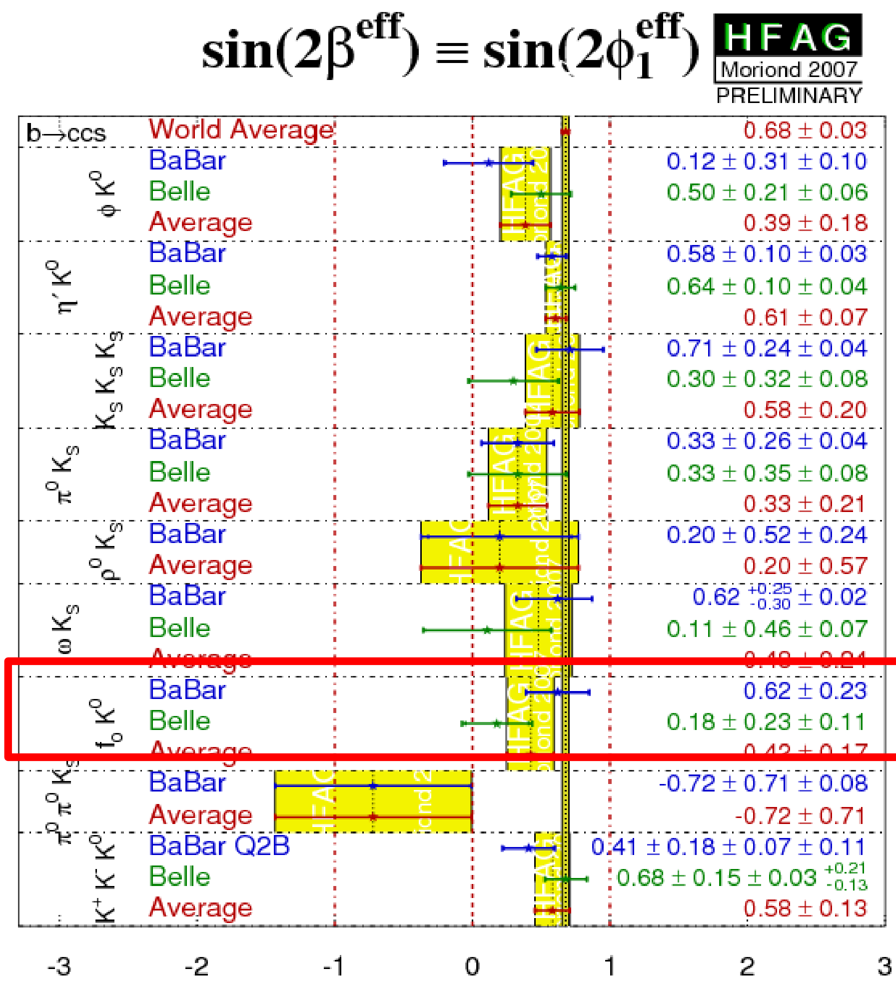


After these measurements

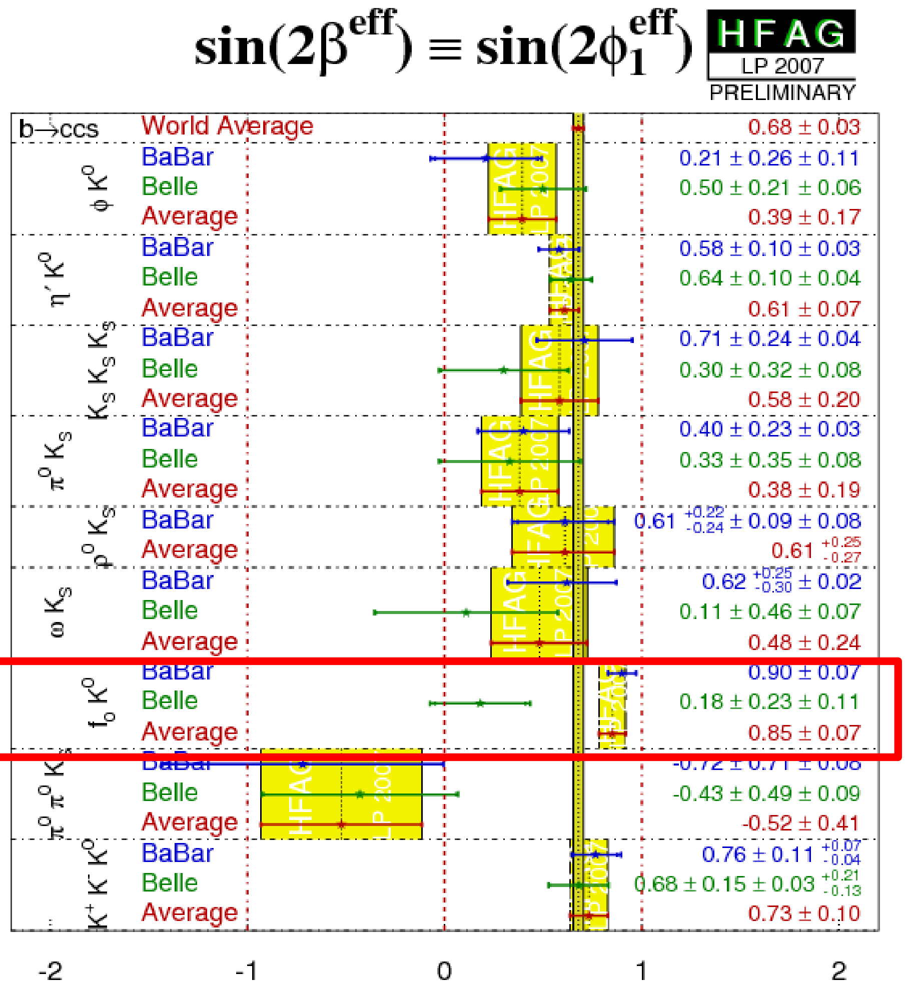


Conclusions

Before these measurements



After these measurements



Conclusions

Phenomenological analysis

- Theoretical expectation on P_{ew} marginally compatible with data
- CPS/GPSZ method dominated by theoretical uncertainty

- $\phi_{3/2}$ current precision ~20°
- Decreases using all observables
- Its potential for CKM physics will depend on evolution of theoretical errors

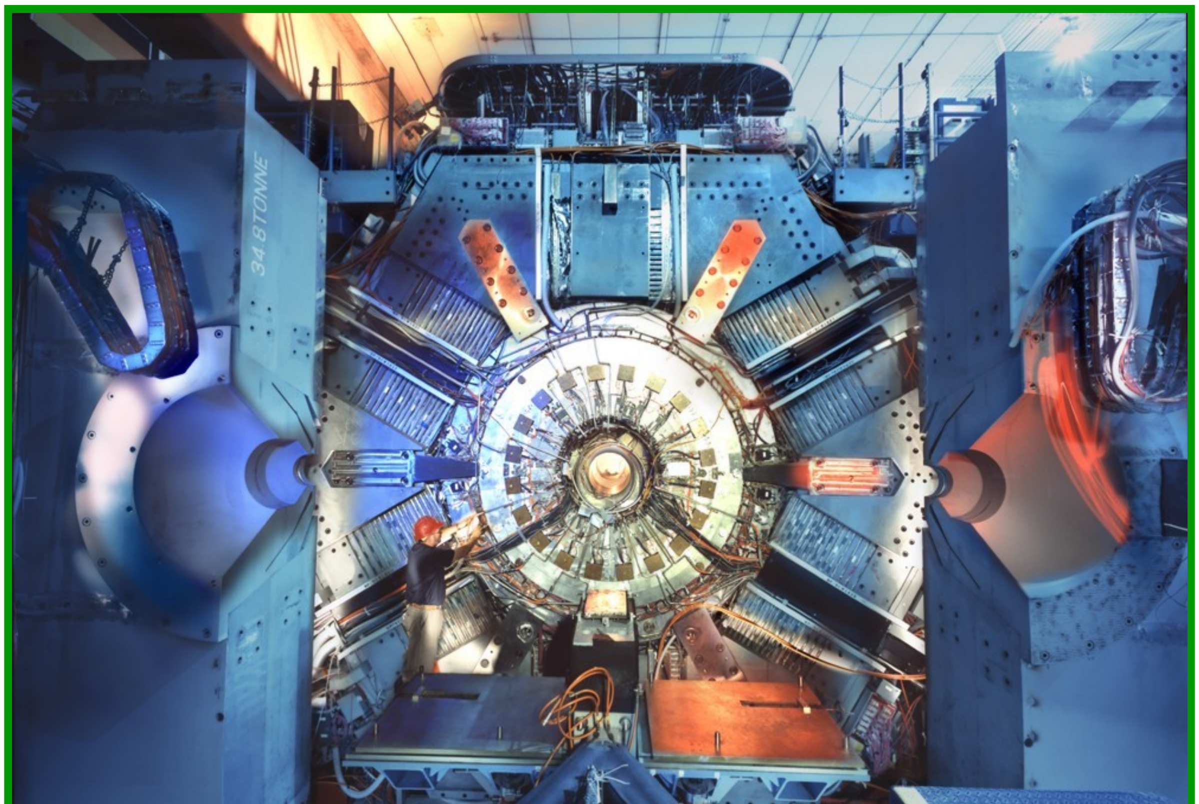
Back up Slides

The BaBar Detector

BaBar Collaboration:

11 pays, 80 institutions

623 physiciens



Perspectives

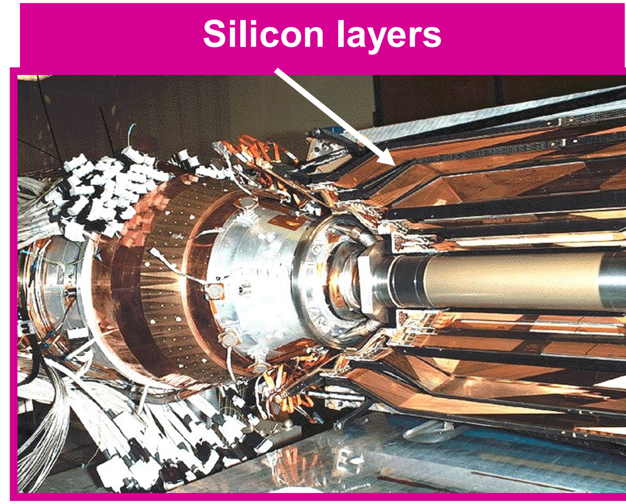
Experimental analysis

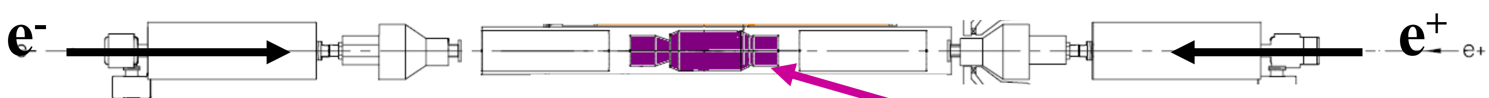
- Physics approved
- The plan is to submit for publication in PRD
- Other $K\pi\pi$ analyses are ongoing in BaBar (LPNHE)

Phenomenological analysis

- Work in progress
- The plan is to publish soon

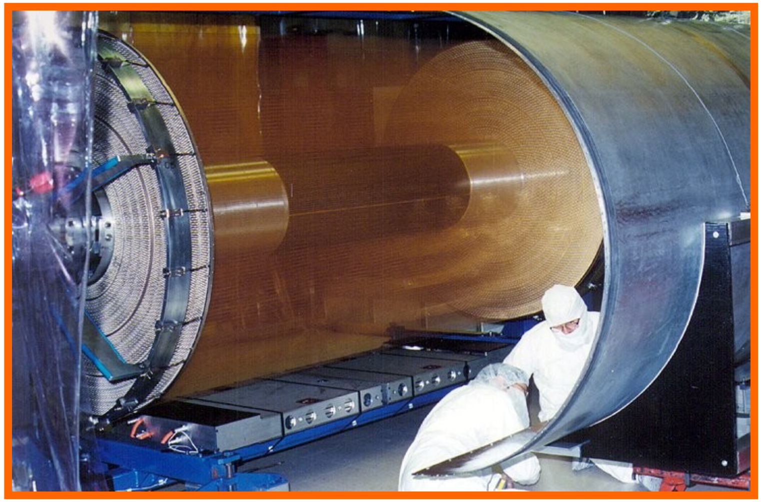
The BaBar Detector



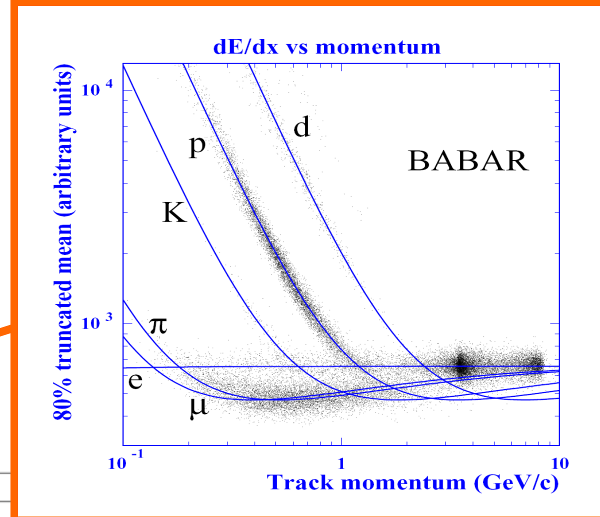


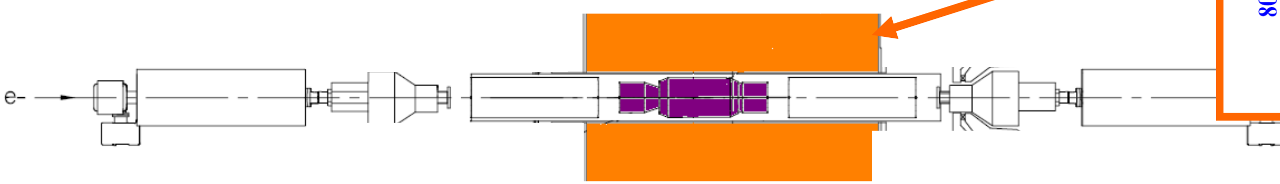
Silicon Vertex Detector (SVT), momentum (π slow), vertex, identification, flight time measurement

The BaBar Detector

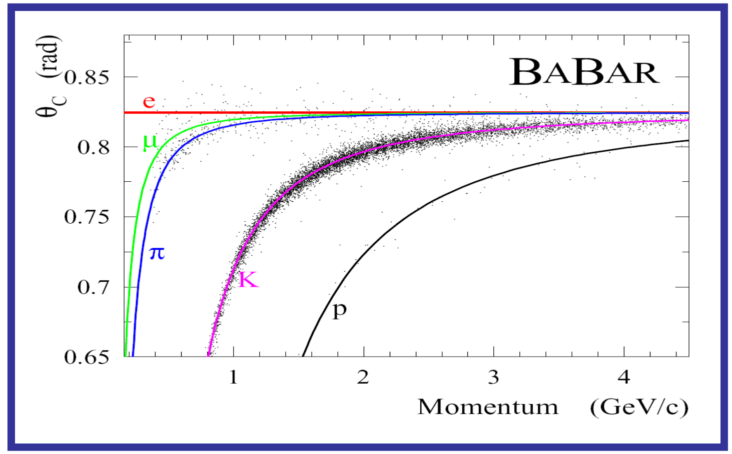


Drift Chamber (DCH): momenta, charged tracks ID dE/dx

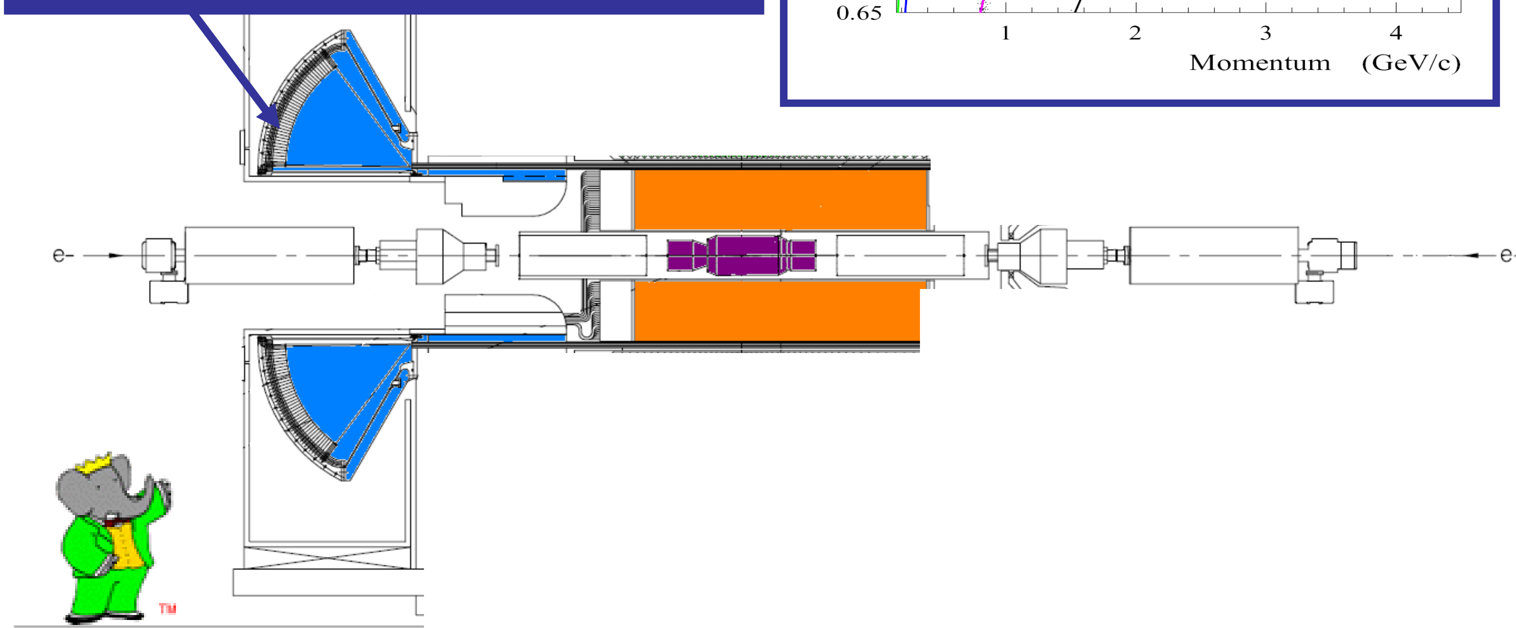




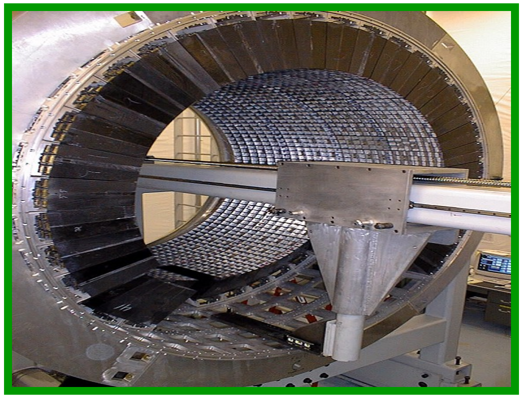
The BaBar Detector

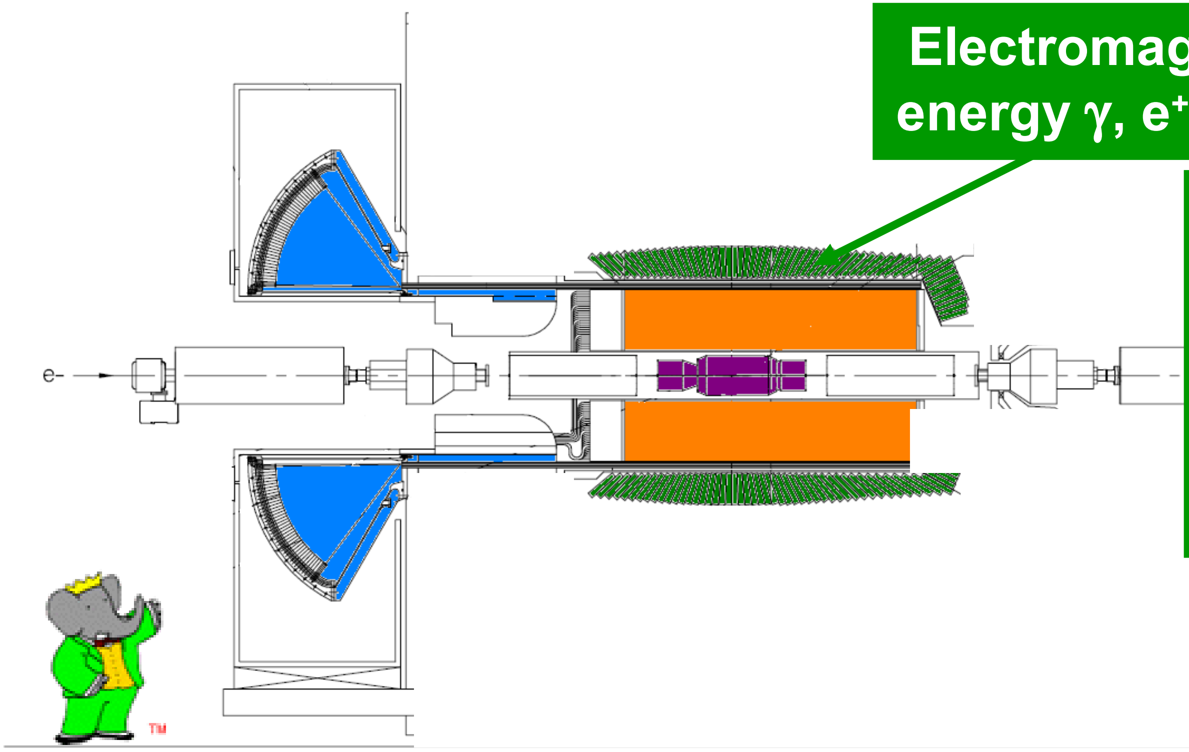


Cherenkov Detector (DIRC): PID (K/π separation)

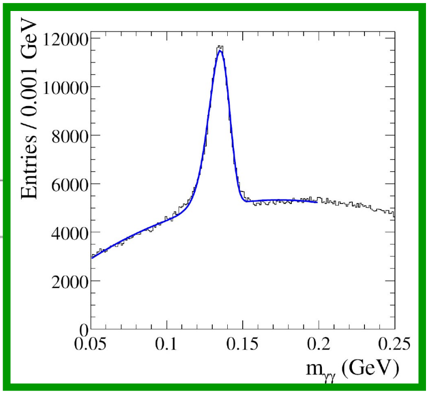


The BaBar Detector

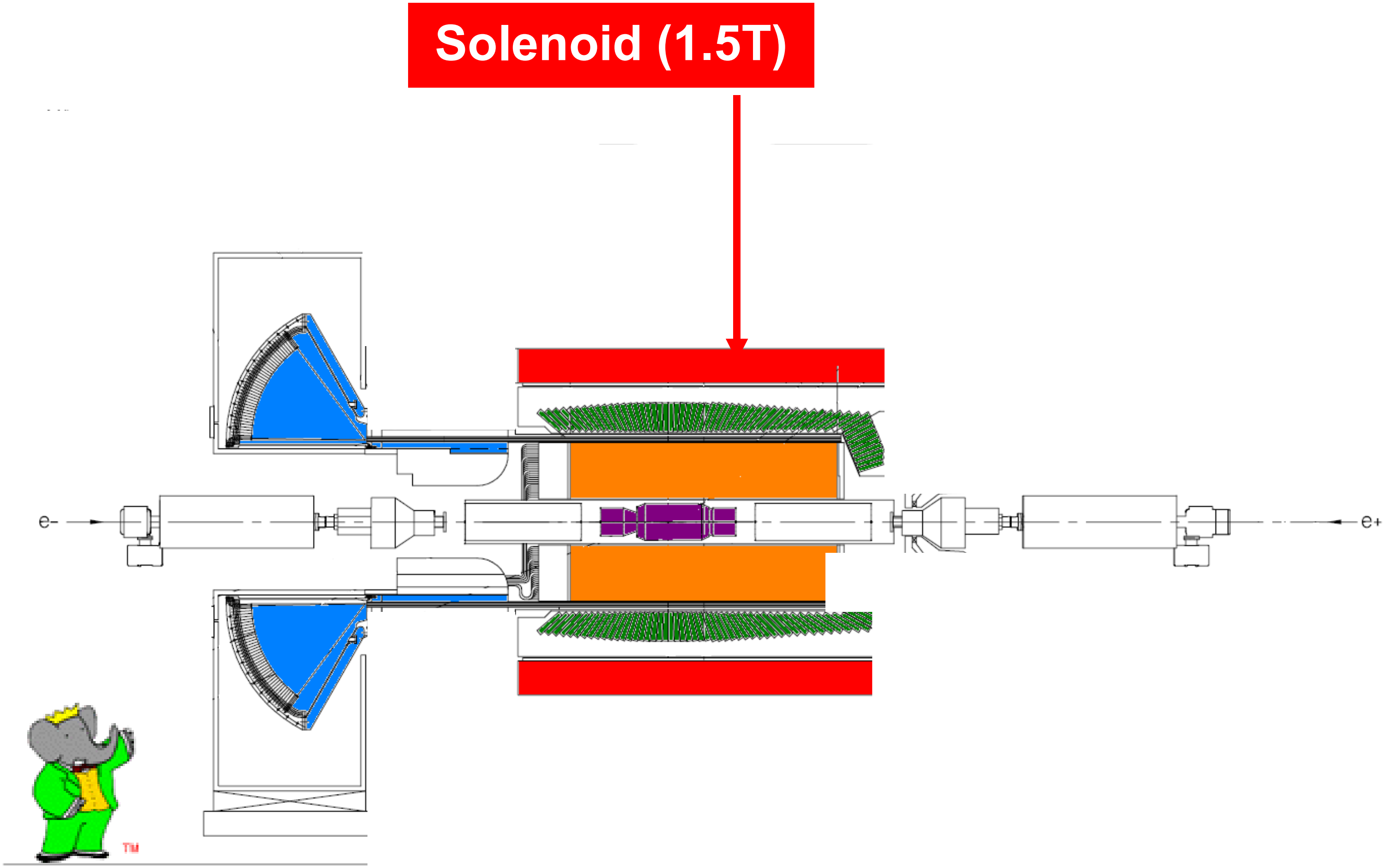




Electromagnetic Calorimeter (EMC):
energy γ, $e^{+/-}/\gamma$ PID, π^0 reconstruction

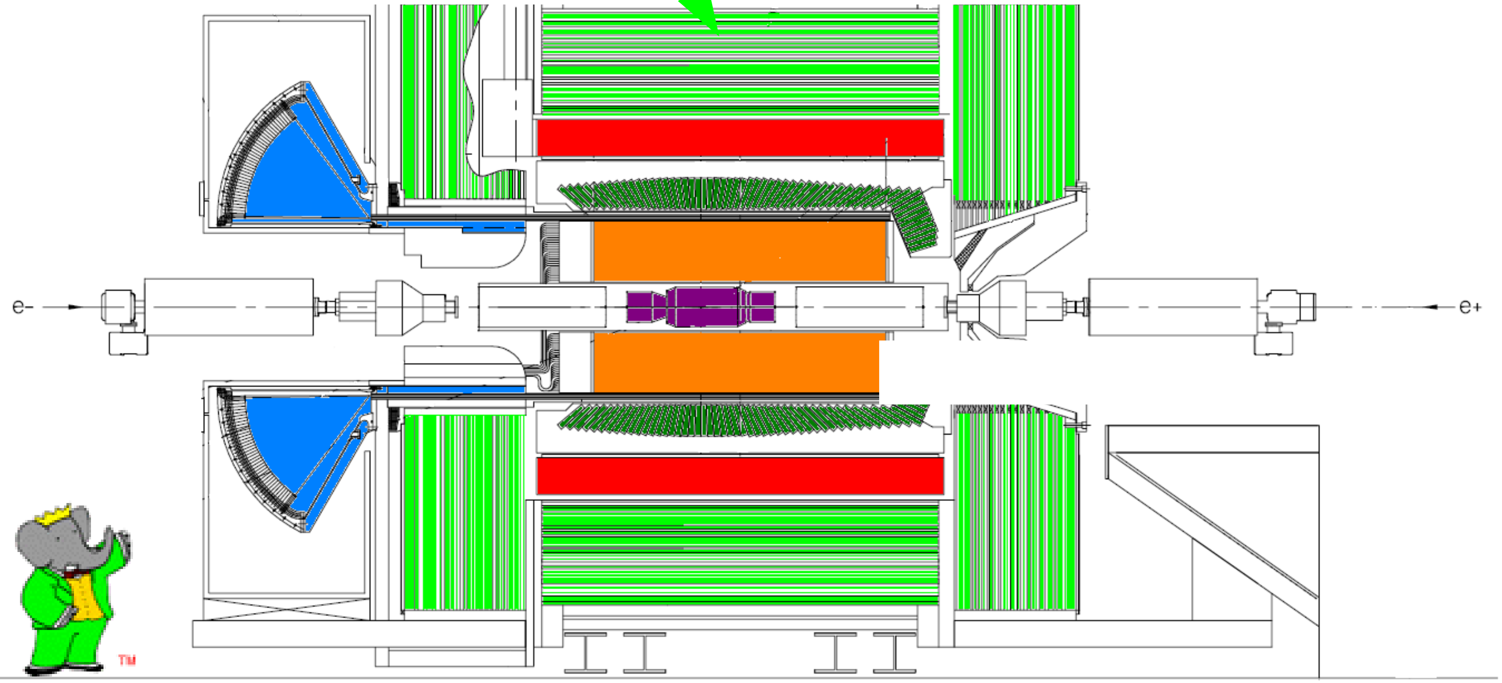


The BaBar Detector



The BaBar Detector

Instrumented Flux Return (IFR): muon detection



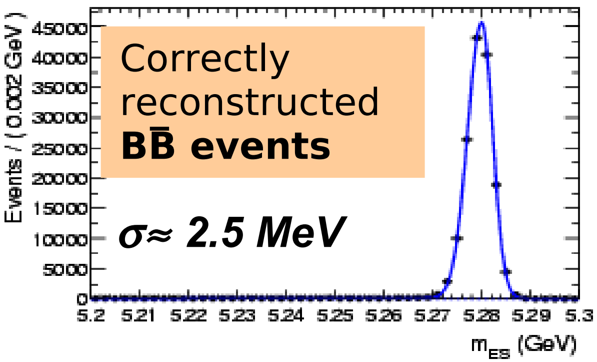
Background discrimination

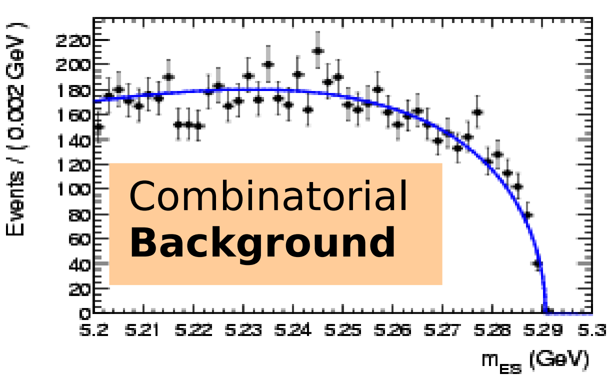
Fit Variables: $\vec{x}_i = (m_{ES}, \Delta E, NN, Qtag, \Delta t, DP)$

Discrimination

Beam-energy substituted mass

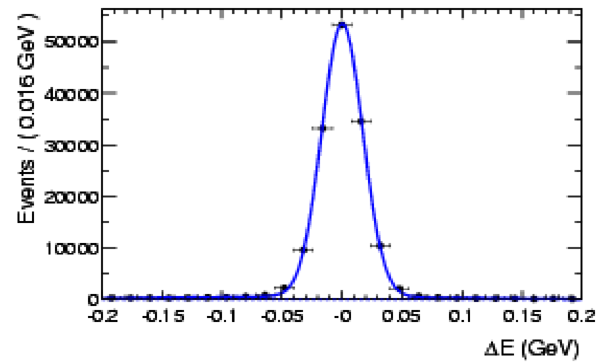
$$m_{ES} = \sqrt{E_{beam}^{*\,2} - p_B^{*\,2}}$$

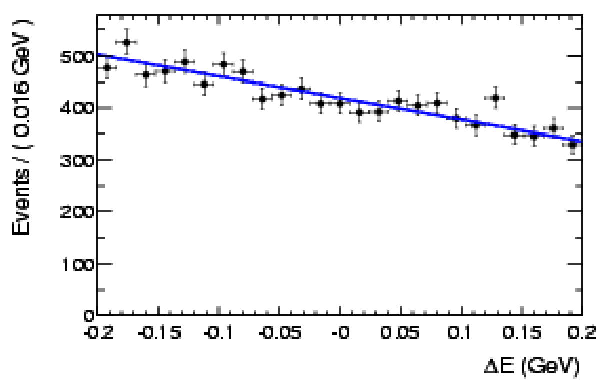




Energy difference

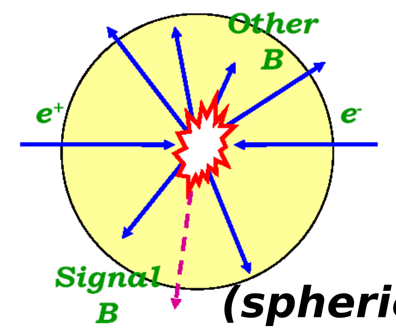
$$\Delta E = E_B^* - E_{beam}^*$$



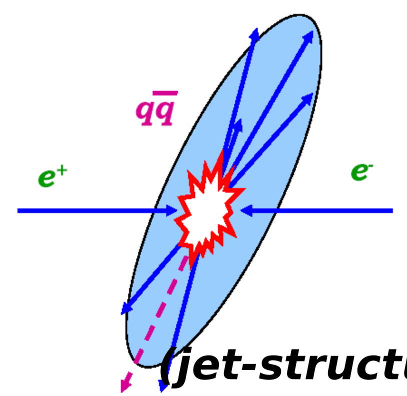


Event topology

(multivariate methods)



(spherical)



(jet-structure)

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
- $|M(Ks) – M(Ks)PDF| < 15$ MeV/c^2
- Lifetime significance > 5
- cos(Ks,Ks daughters) < 0.999
- NN > -0.4
- PID requirements to separate from kaons and reject leptons

Total efficiency ~ 25%

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

Mod(timeStamp,nCands)

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	$B^0 \to X, \overline{B^0} \to D^{*+}\pi^-, D^{*+} \to D^0\pi^+, D^0 \to X + CC$
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 (1123, 1126)

Cat. 2 (1160, 3299, 3749, 2437, 3733)

Cat. 3 (1159, 7330, 5635, 1157, 1158)

Modes treated semi-exclusively grouped into categories

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

Modes treated Inclusively

Parameterization (I)

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

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

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:

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

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

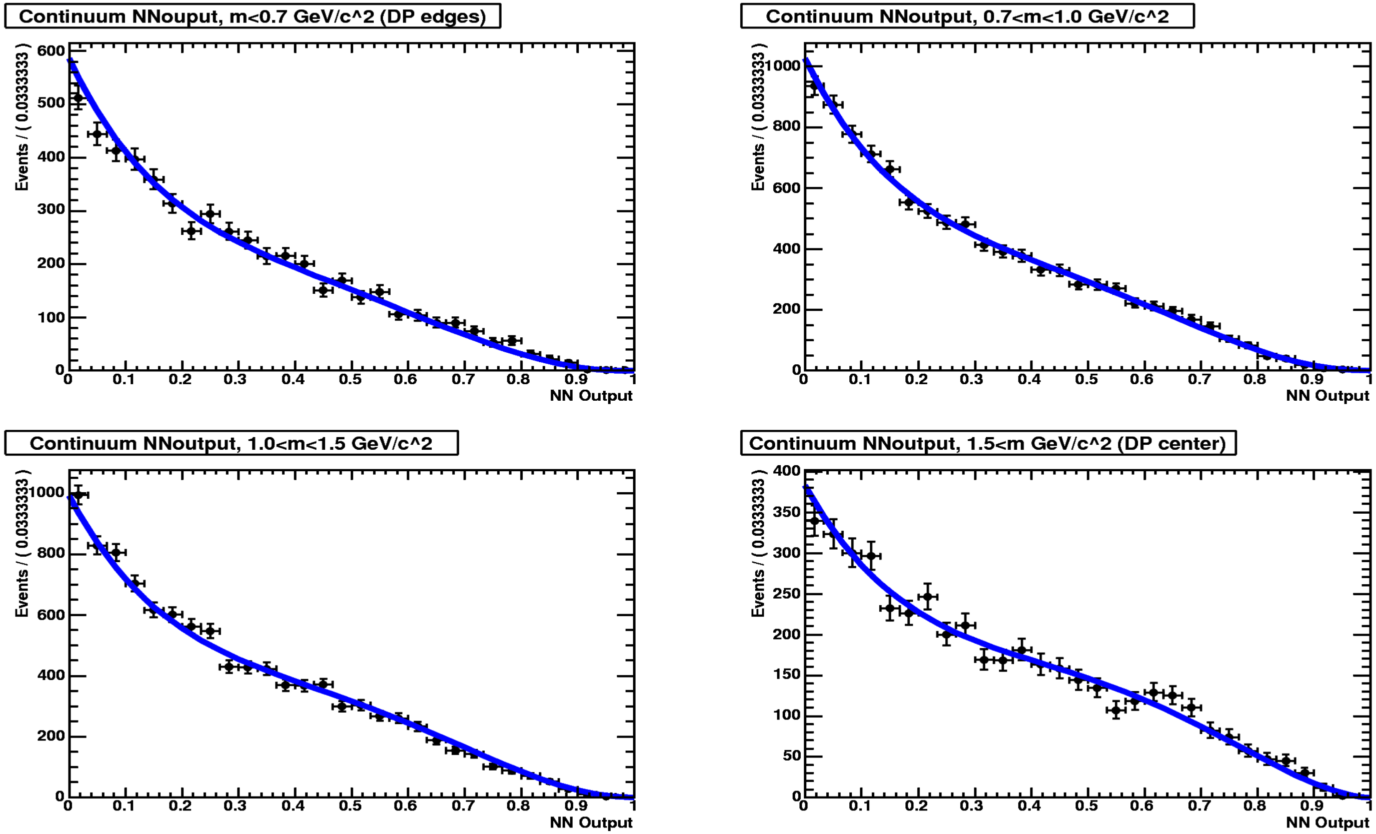
$\Delta_{\rm Dalitz}$: **Distance to DP center**

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



Parameterization (V)

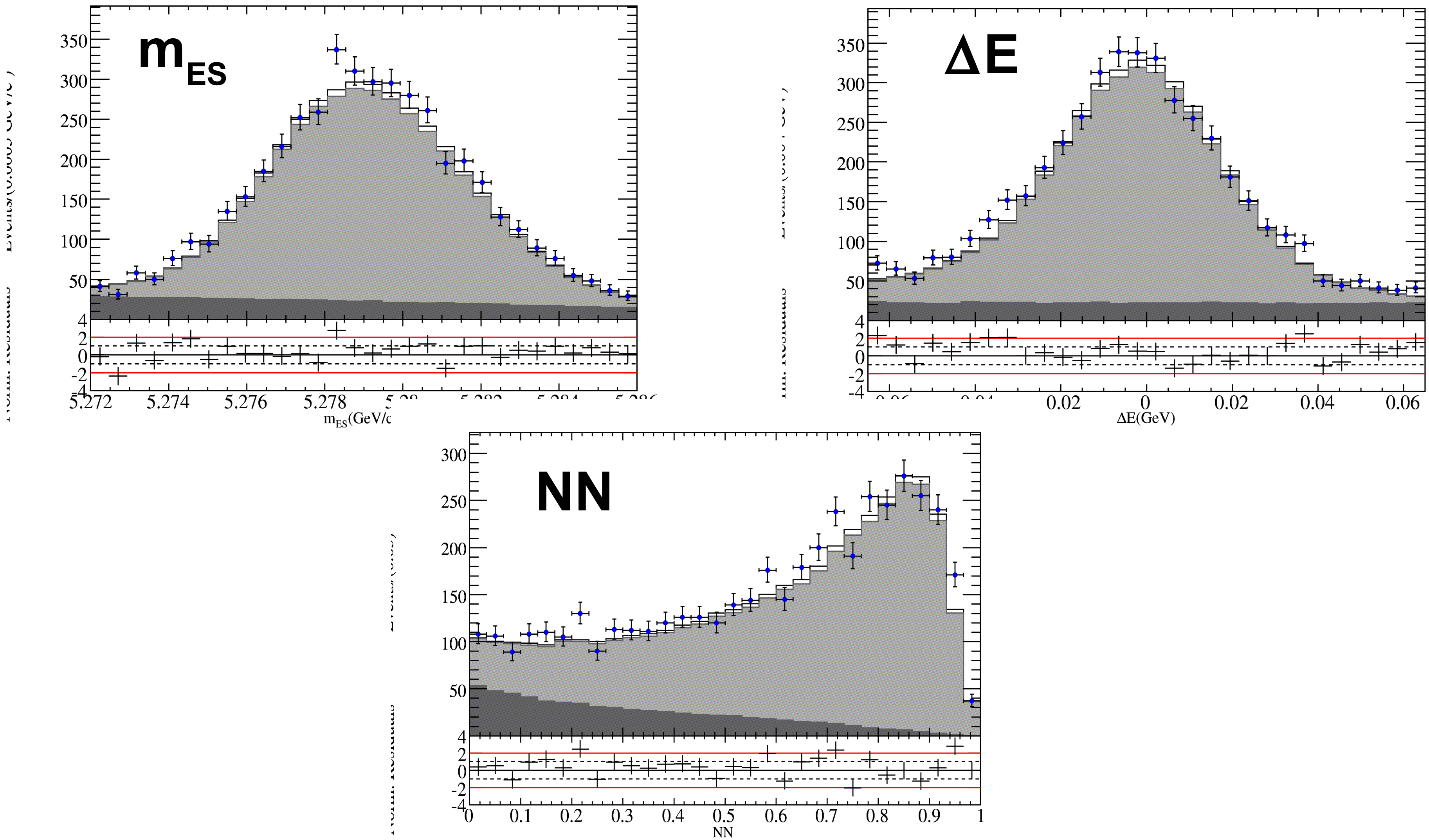
Fit Variables: $\vec{x}_i = (m_{ES}, \Delta E, NN, Qtag, \Delta t, DP)$

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

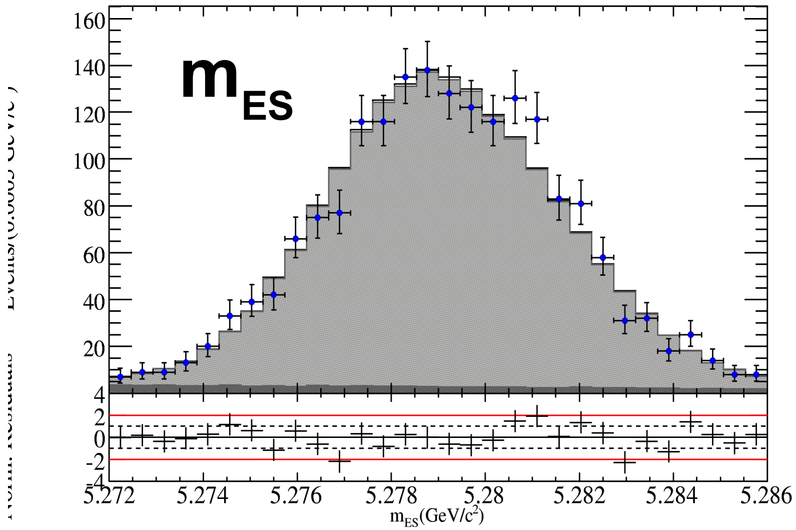
Fit Results: Proj. Plots (V)

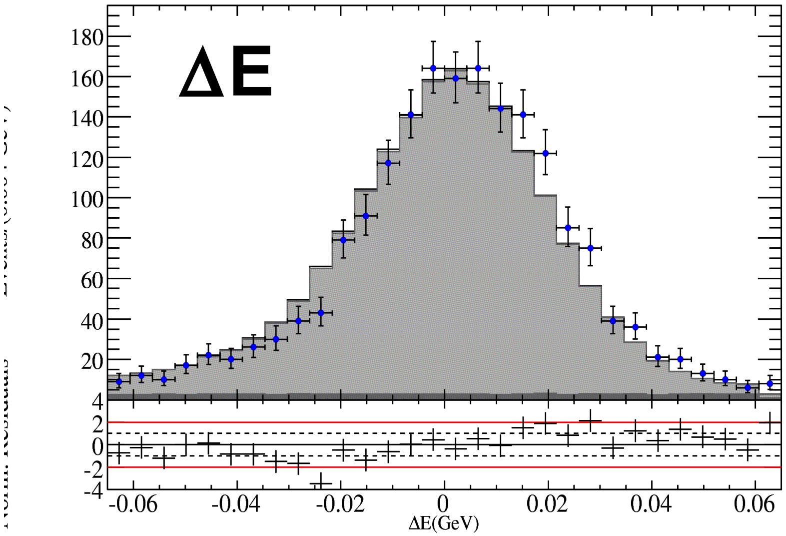
Dπ Band

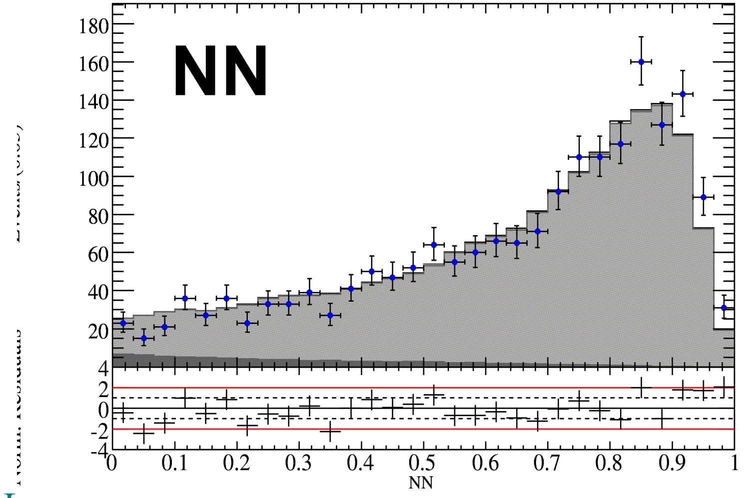


Fit Results: Proj. Plots (VI)

J/ψ Band



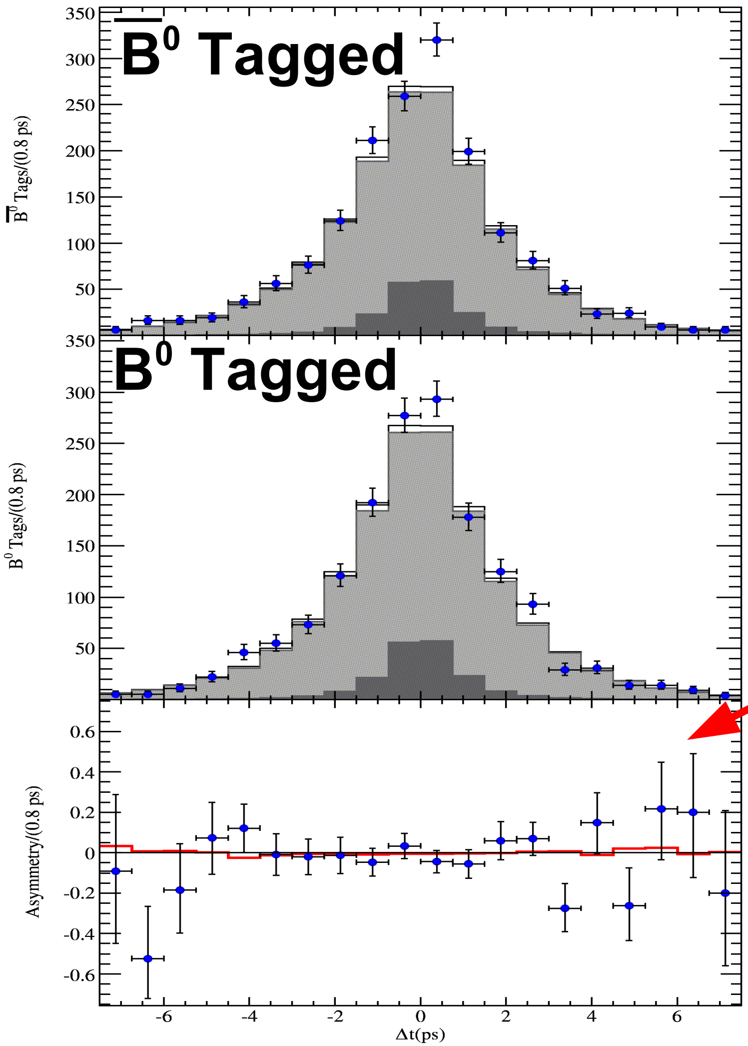




Fit Results: Proj. Plots (IX)

Δt dependent asymmetries

Dπ Band



Zero time-dependent CP asymmetry.

As expected!

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		

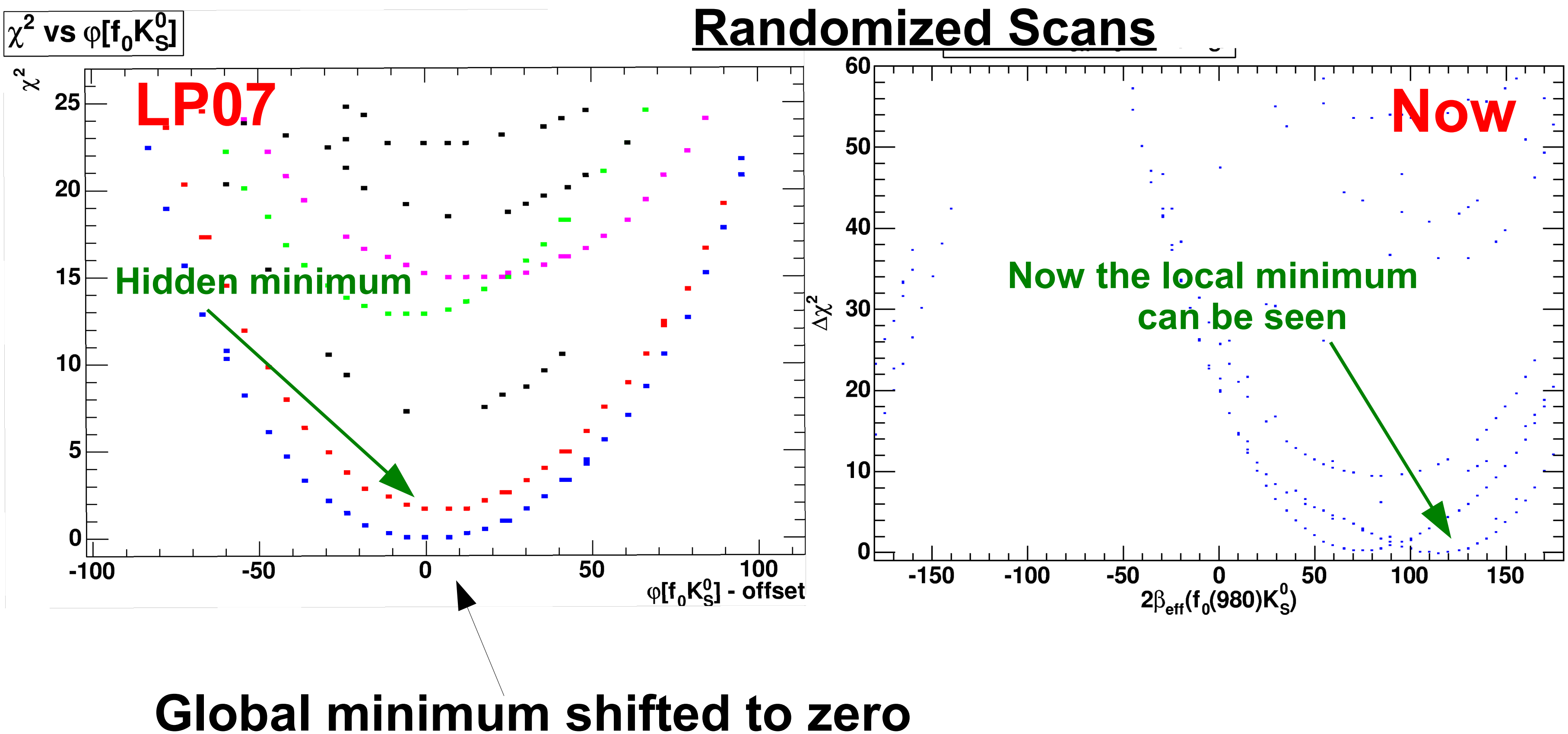
Fit Results: Branching Frations

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

Local Minima configuration

- Local Minima structure is qualitaively the same.
- Previously there were two solutions close in NLL units, but one of them was hidden by the other
- With the new fit configuration the minima shifted a bit



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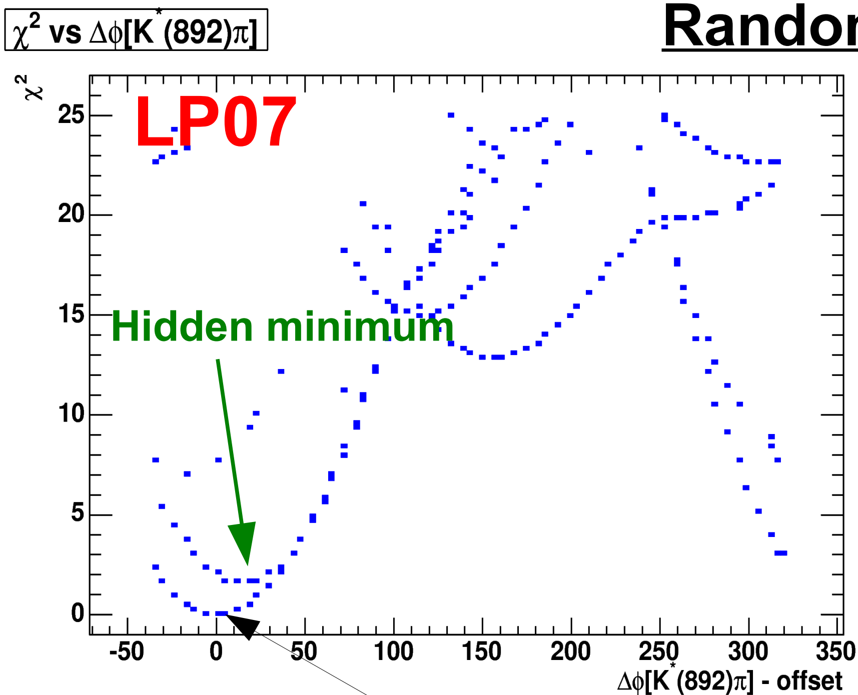
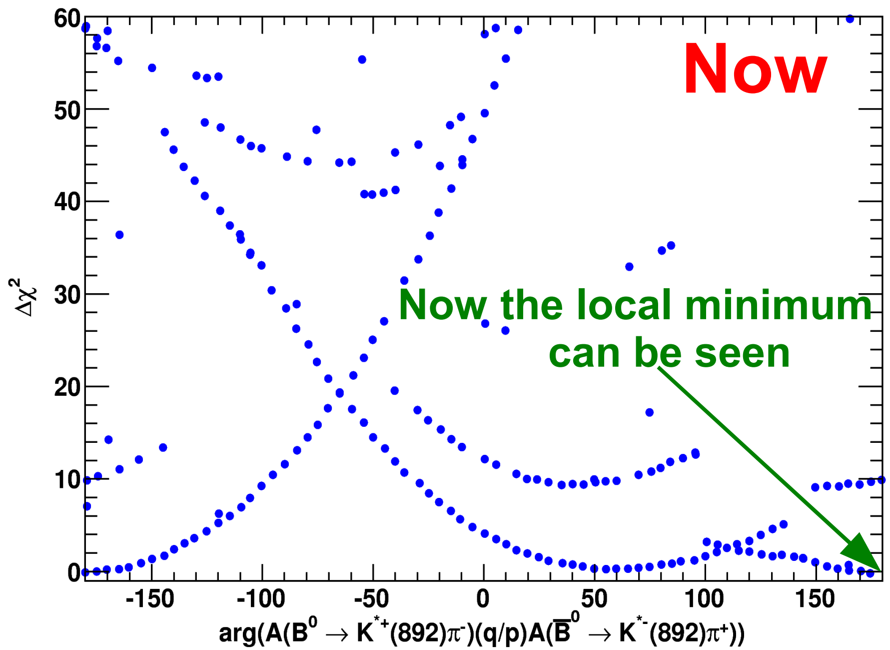
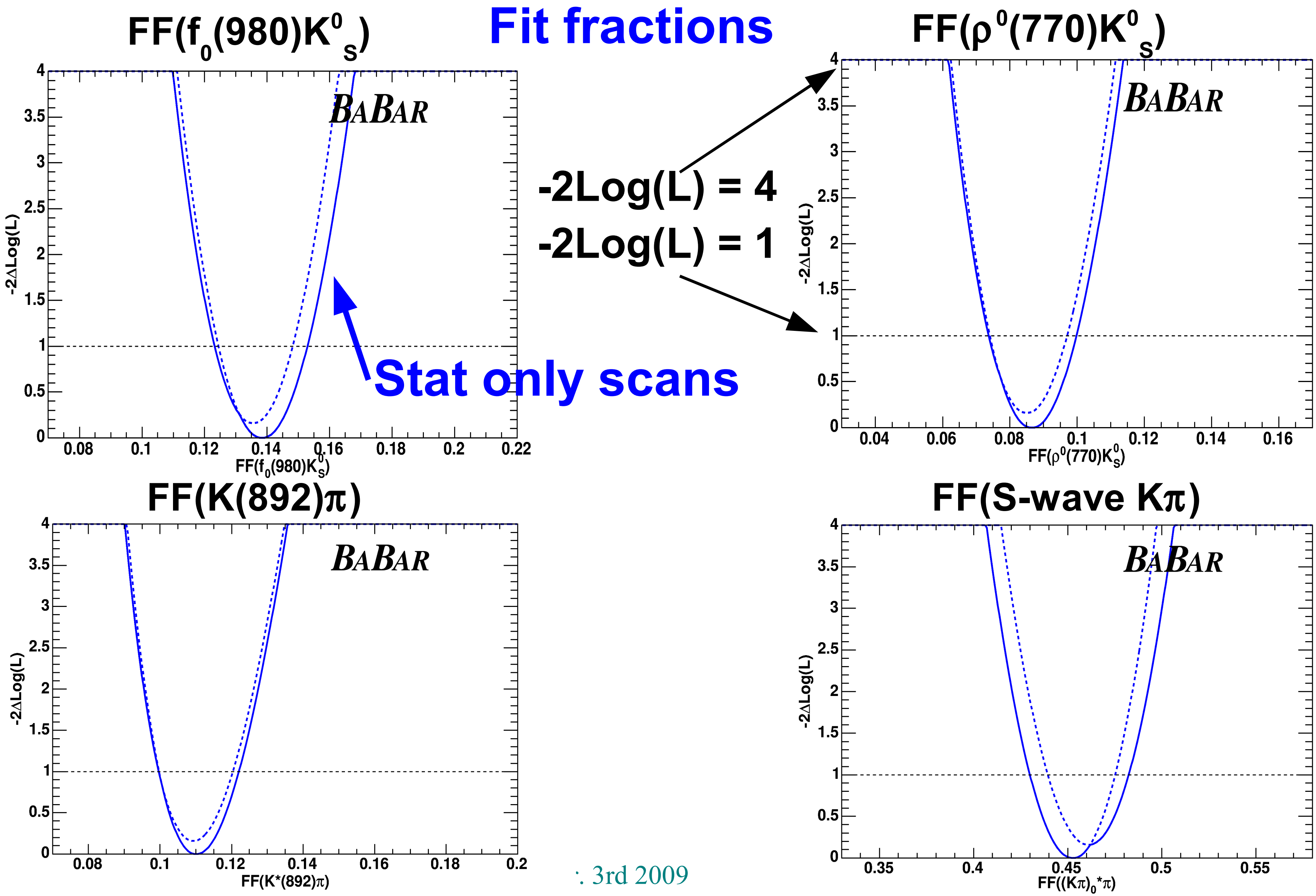
Randomized Scans





Global minimum shifted to zero

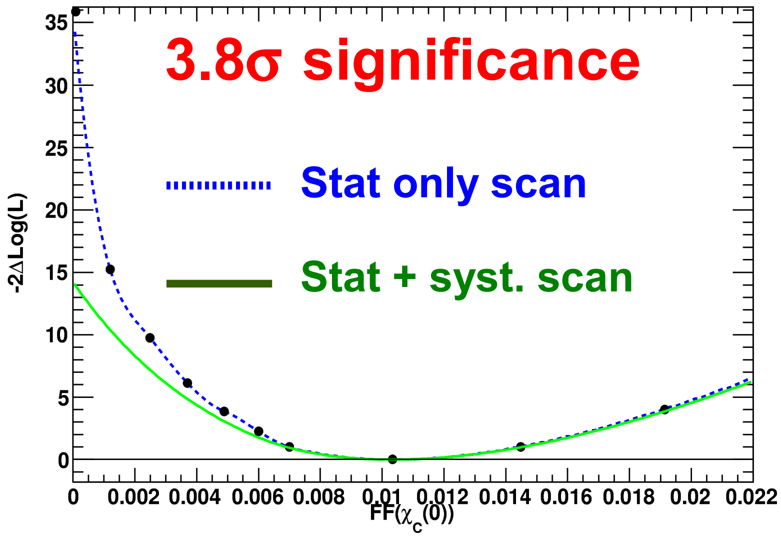
Fit Results: 1D Like. Scans (I)



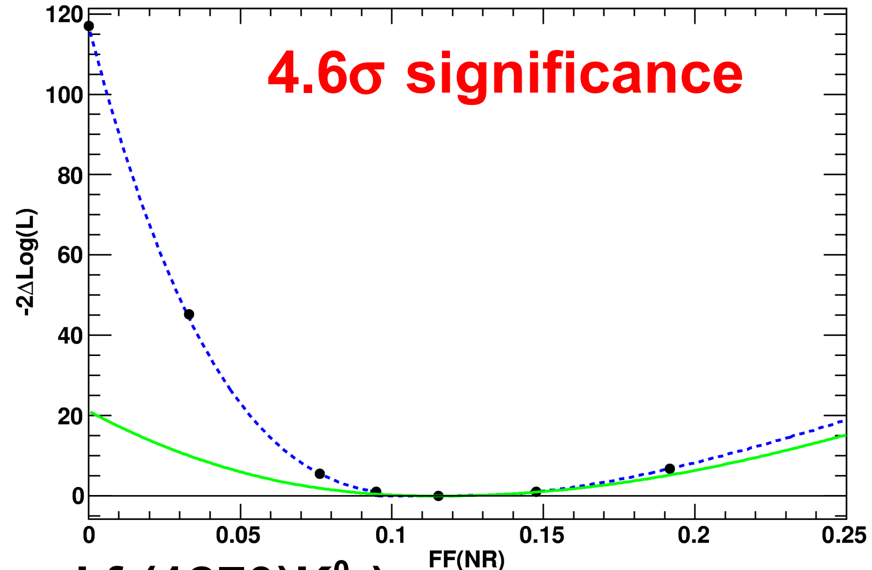
Fit Results: Like. Scans (VI)

Fit fractions

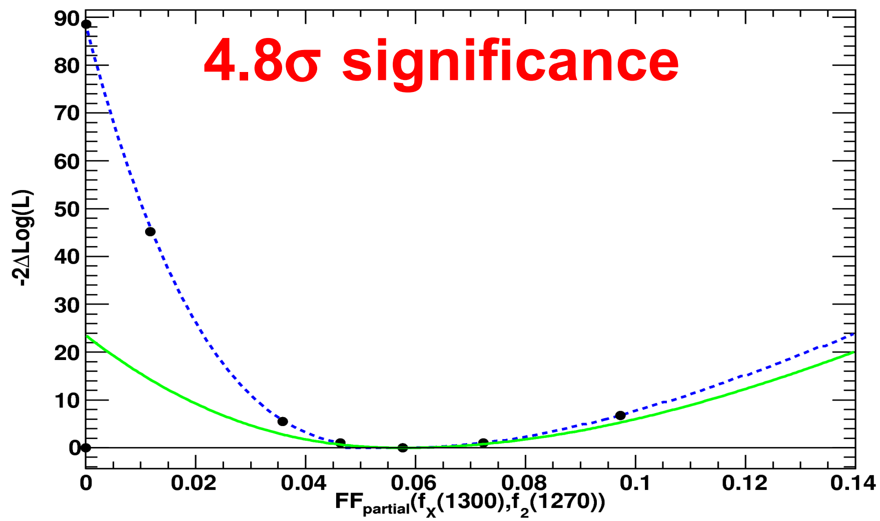
FF($\chi(c0)K^0_S$)



FF(NR)

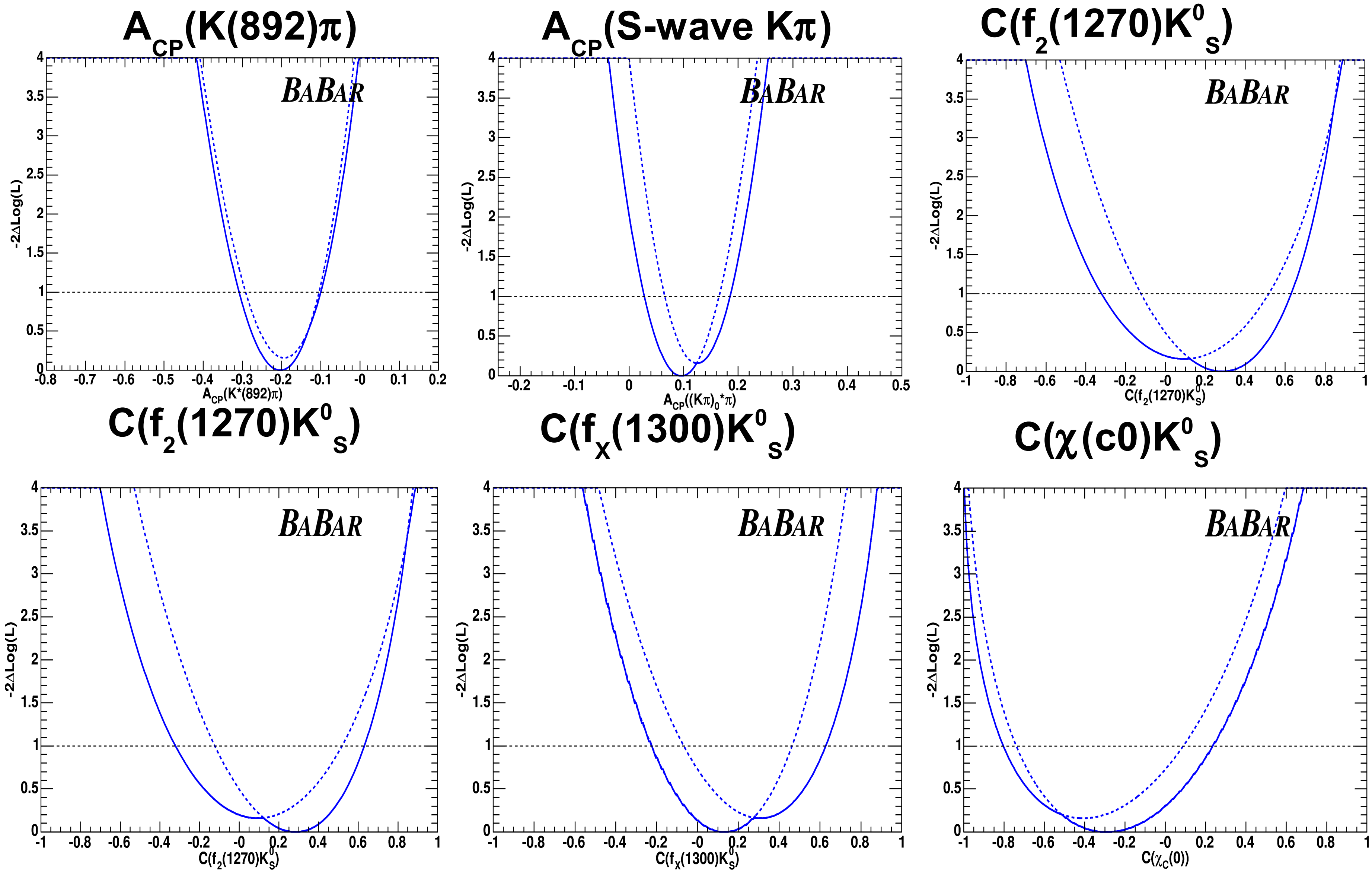


FF($f_X(1300)K^0_S$ and $f_2(1270)K^0_S$)



Fit Results: 1D Like. Scans (III)

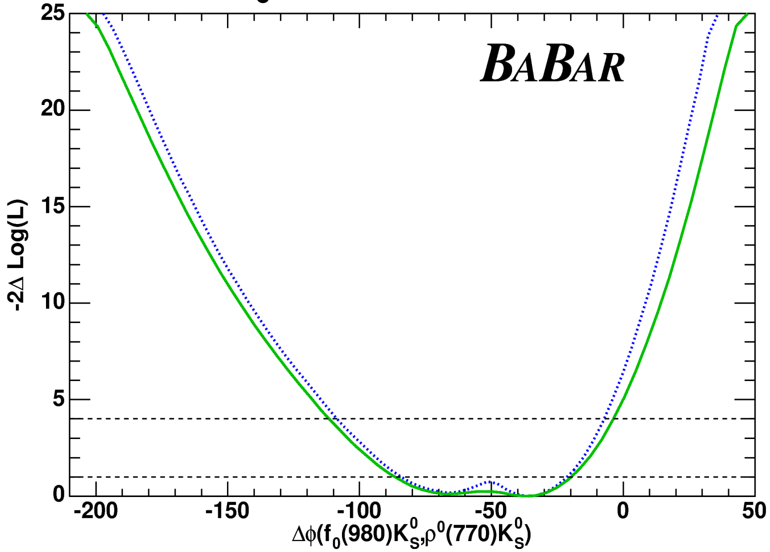
Direct CP asymmetries



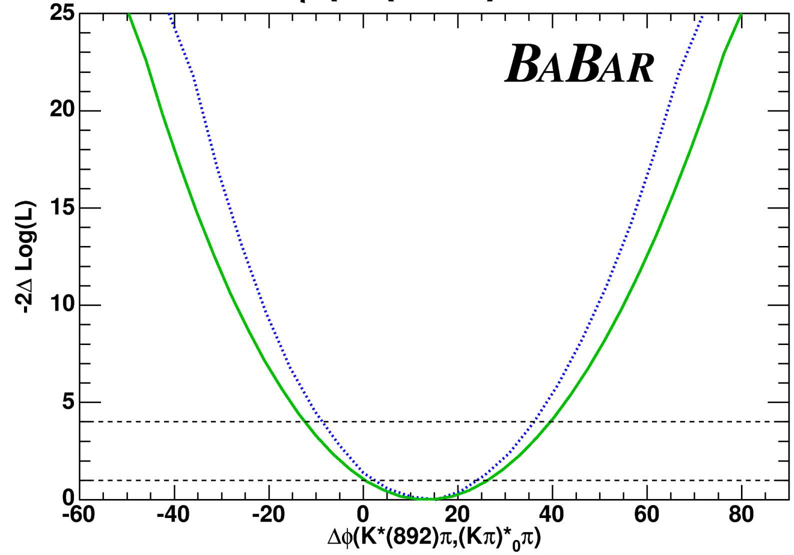
Fit Results: 1D Like. Scans (V)

Phase Differences

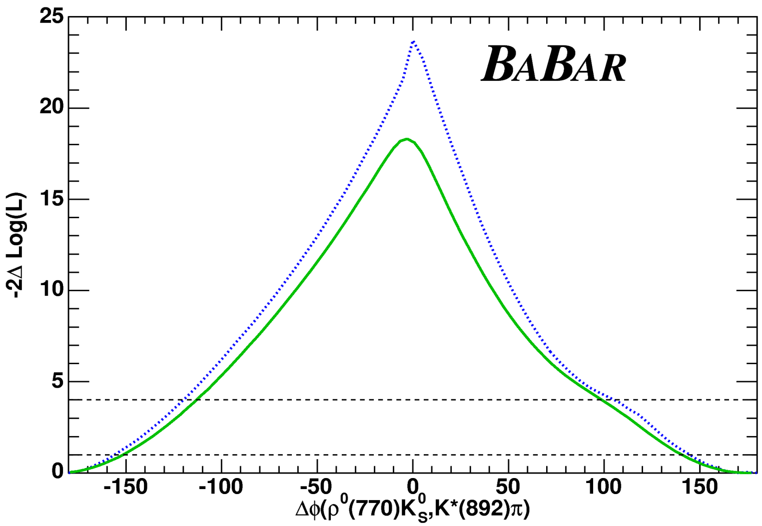
$\Delta\phi(f_0(980),\rho^0(770))$



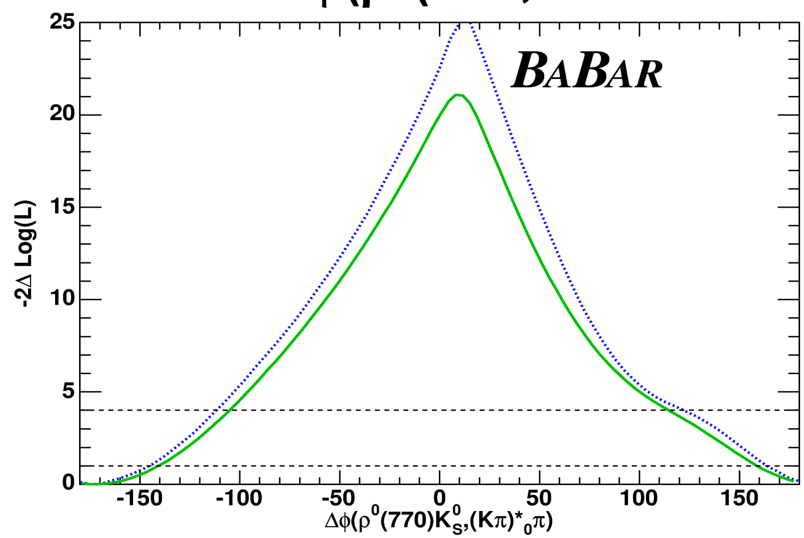
$\Delta\phi(K(892)\pi, \text{S-wave } K\pi)$



$\Delta\phi(\rho^0(770),K(892)\pi)$



$\Delta\phi(\rho^0(770, \text{S-wave } K\pi)$



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

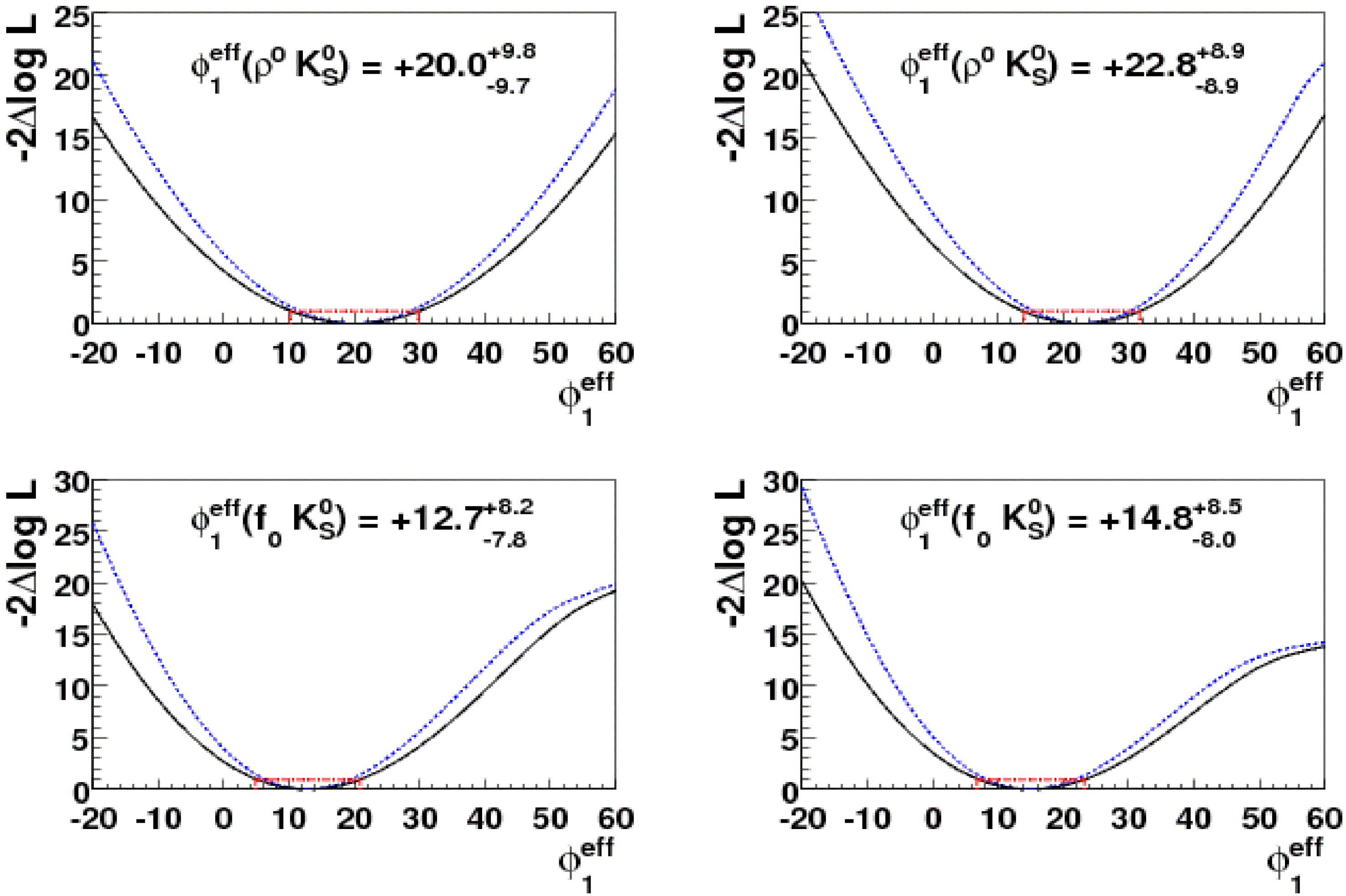


FIG. 5: Likelihood scans of $\phi_1^{\rm eff}$ for $B^0 \to \rho^0(770)K_S^0$ (top) and $B^0 \to f_0(980)K_S^0$ (bottom) for Solution 1 (left) and Solution 2 (right). The solid (dashed) curve contains the total (statistical) error and the dotted box indicates the parameter range corresponding to $\pm1\sigma$.

Belle results 2008: Δϕ(K*(892)π)

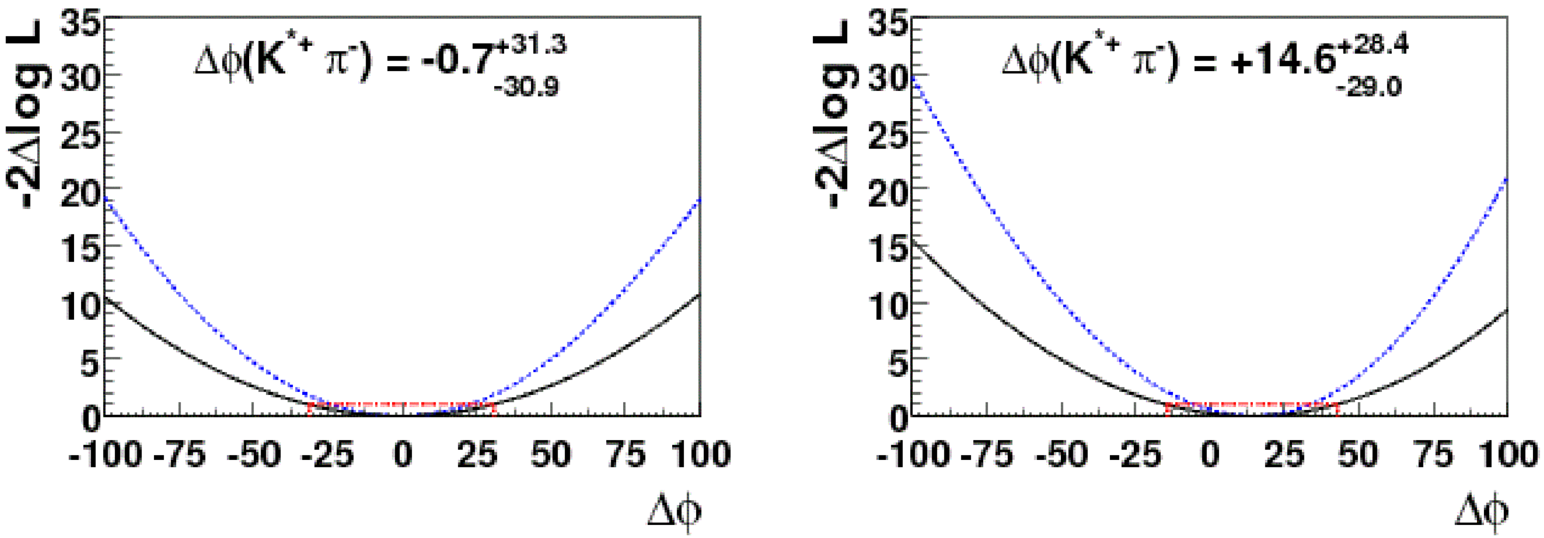


FIG. 7: Likelihood scan of $\Delta\phi$ for Solution 1 (left) and Solution 2 (right). The solid (dashed) curve contains the total (statistical) error and the dotted box indicates the parameter range corresponding to $\pm 1\sigma$.

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

$B\to K^{*}\pi$ system can be parameterized by:

- 8 hadronic amplitudes
- CKM couplings

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

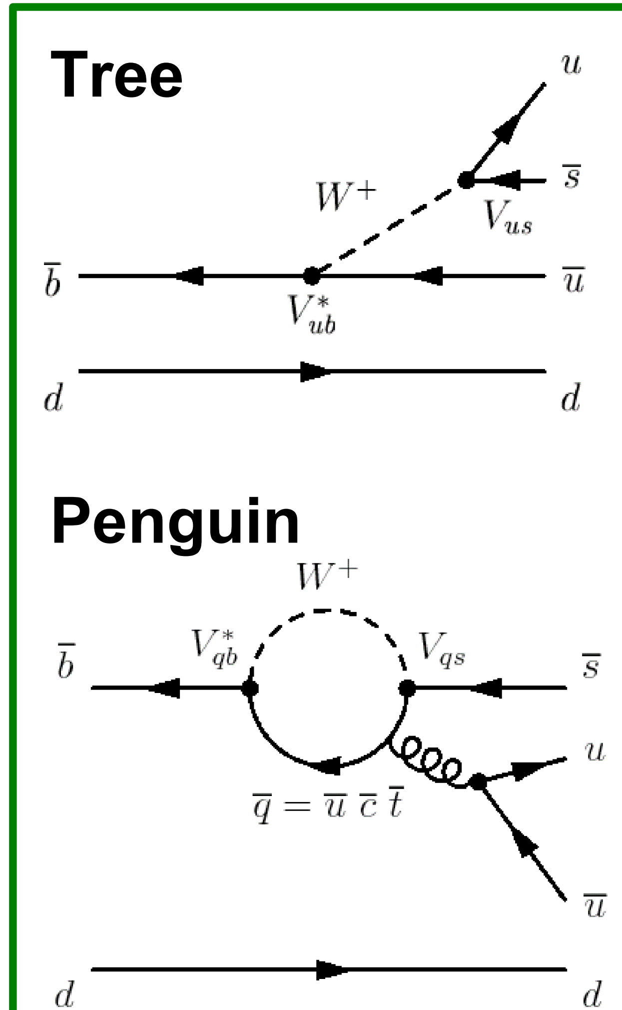
$A(B^+\to K^{*0}\pi^+) = V_{us}V^{*}_{ub}T^{0+} + V_{ts}V^{*}_{tb}P^{0+}$

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

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

Hadronic amplitudes receive contributions of different topologies

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



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)

$B \to K^* \pi$ 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

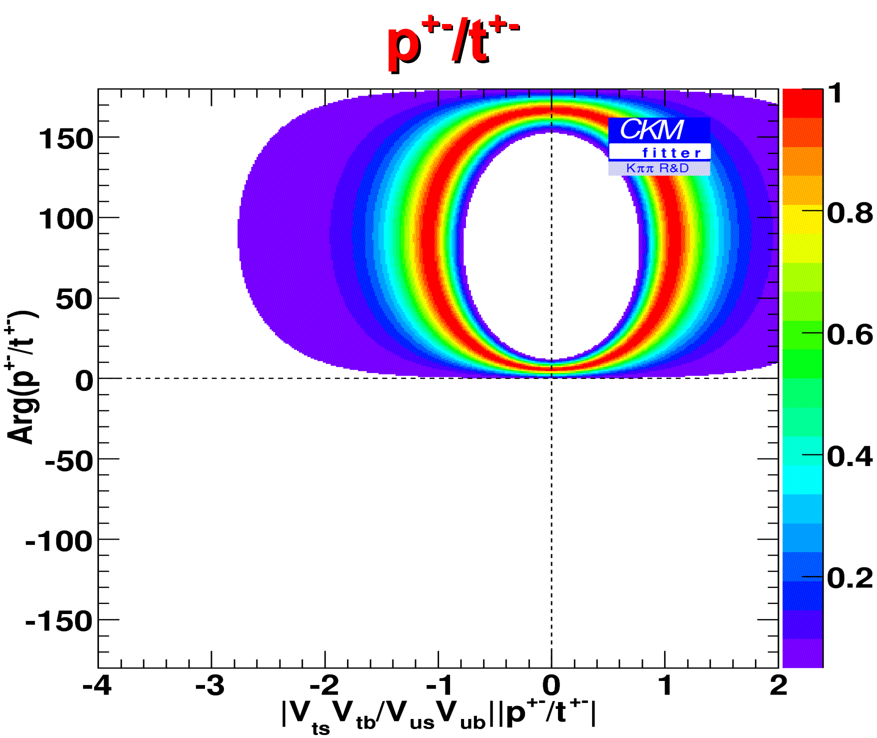
B→ρK system: experimental inputs

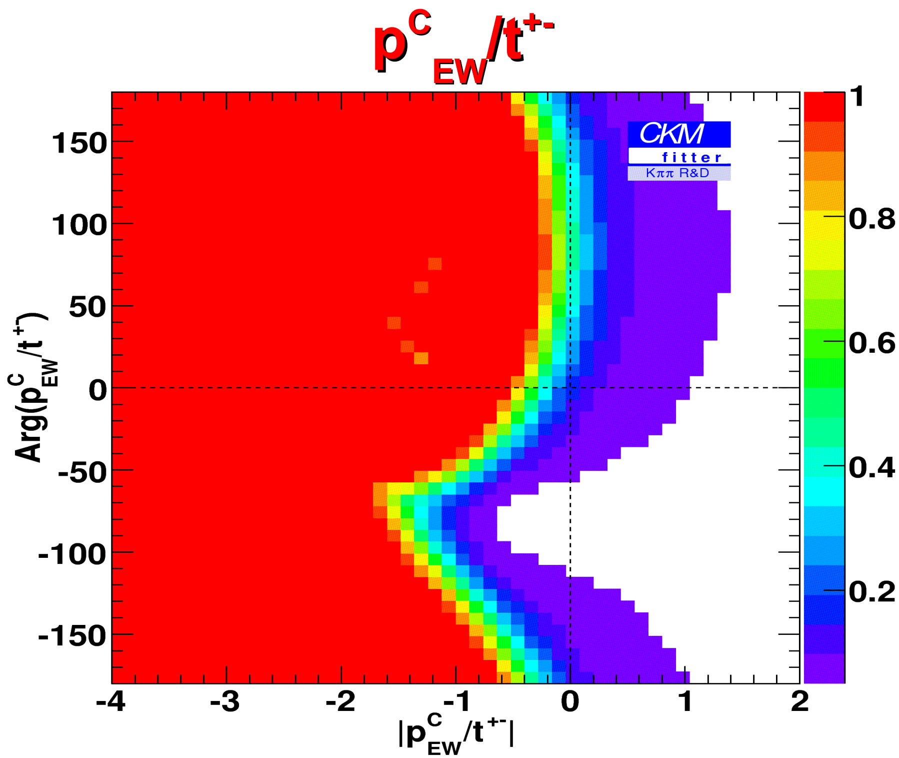
Parameter	BABAR	Belle	CLEO	WA
$\mathcal{B}(K^+\rho^-)$	$8.0^{+0.8}_{-1.3} \pm 0.6$	$15.1^{+3.4+2.4}_{-3.3-2.6}$	$16^{+8}_{-6} \pm 3$	$8.6^{+0.9}_{-1.1}$
$\mathcal{B}(K^0\rho^0)$	$4.9 \pm 0.8 \pm 0.9$	$6.1 \pm 1.0^{+1.1}_{-1.2}$	< 39	$5.4^{+0.9}_{-1.0}$
$\mathcal{B}(K^0\rho^+)$	$8.0^{+1.4}_{-1.3} \pm 0.6$	–	< 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

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

B→ρK system: exploring hadronic parameters

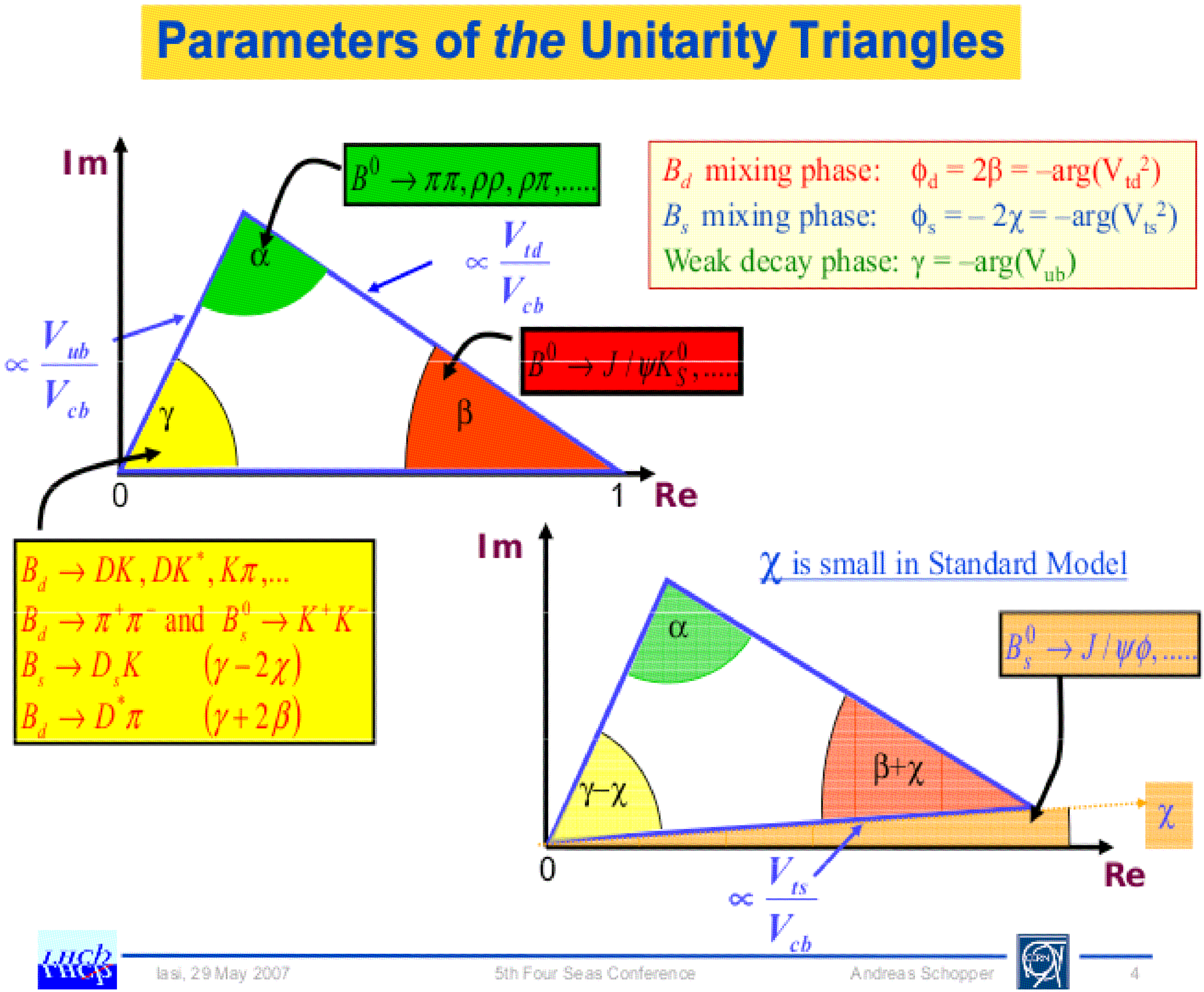




Exclude negative values of phase

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

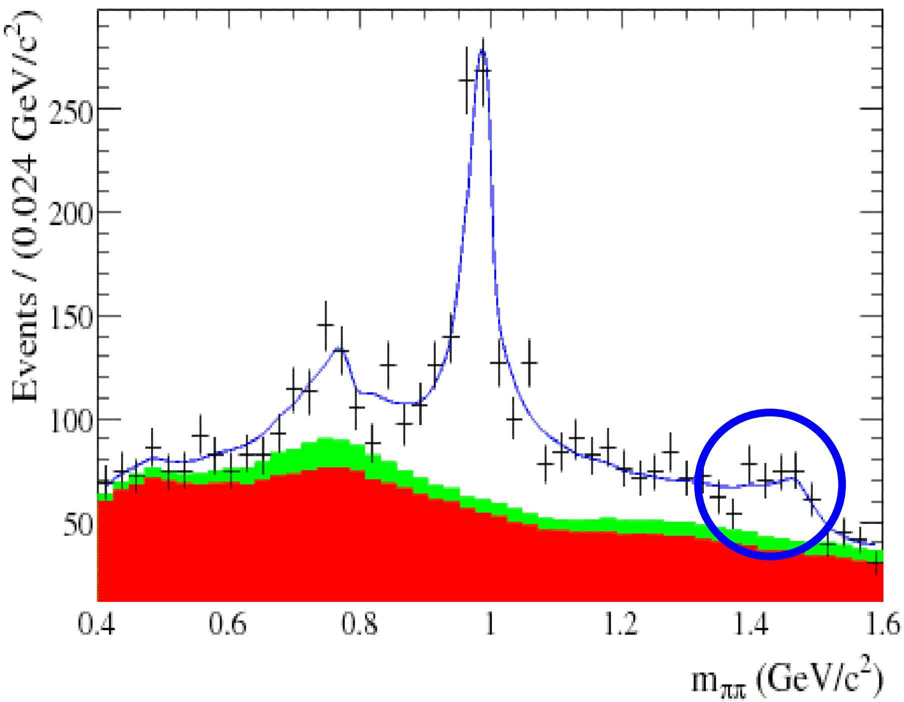
Weak constraints on most paramters


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

The $f_x(1300)$

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

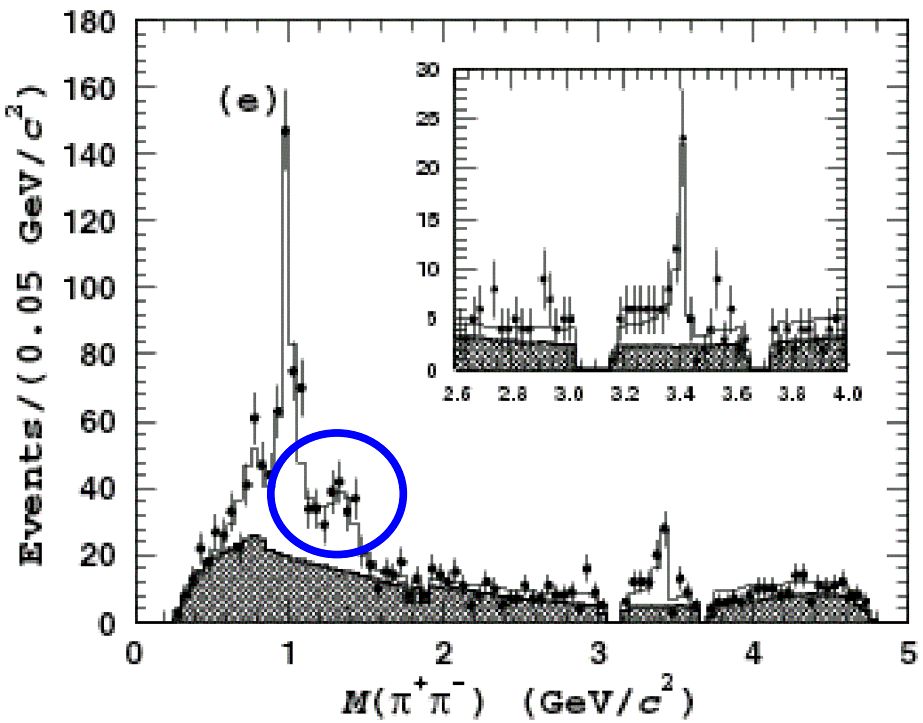
BaBar PRD78:012004 (2008)



$M = 1479 \pm 8$ MeV

$\Gamma = 80 \pm 19$ MeV

Belle PRL96:251803 (2006)



$M = 1449 \pm 13$ MeV

$\Gamma = 126 \pm 25$ MeV

Data prefers scalar over vector and tensor