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Time-Dependent Amplitude Analysis of $B^0 \rightarrow K^0_S \pi^+\pi^-$ Decays

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Outline

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- Existing Measurements

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- Parameterization
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- Likelihood scans and Branching Fractions
- Systematic Uncertainties

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Motivations

- $K^0_S\pi^+\pi^-$ is dominated by $b \to s$ penguin diagrams. Most interesting observables are related to the phases.
- Two good ways to study the phases:
  - - Time dependent analysis
  - - Dalitz plot analysis

The present analysis makes advantage of both techniques

- Many intermediate states contribute and interfere: $f_0(980)$, $\rho^0(770)$, K*(892)...
- $2\beta_{eff}$ from $f_0(980)$ and $\rho^0(770)$ can be measured directly, resolving the Q2B analyses ambiguities ($\sin(2\beta_{eff}) = \sin(\pi - 2\beta_{eff})$)
- Phases from $\rho^0(770)$ and K*(892) are interesting for phenomenological analyses (see Reina's talk)
- Measurement of inclusive and exclusive direct CP violation
- Measurement of total and partial branching fractions

Existing Measurements (I)

- Time dependent Q2B analysis:

  - BaBar 2004 (PRL94:041802)

$S[f_0(980)K^0_S] = -0.95^{+0.32}_{-0.23} \pm 0.1$

$C[f_0(980)K^0_S] = -0.24 \pm 0.31 \pm 0.15$

  - Belle 2005 (arXiv:hep-ex/0507037)

$S[f_0(980)K^0_S] = -0.47 \pm 0.36 \pm 0.08$

$C[f_0(980)K^0_S] = -0.23 \pm 0.23 \pm 0.13$

  - BaBar 2006 (PRL98:051803)

$S[\rho^0(770)K^0_S] = 0.20 \pm 0.52 \pm 0.24$

$C[\rho^0(770)K^0_S] = 0.64 \pm 0.41 \pm 0.20$

Existing Measurements (II)

- **BaBar time integrated, Q2B analysis:**
  - **BAD 1065 (K.Ford et al.) Runs 1-4 (210 *fb*$^{-1}$)**
  - **Results:**

    Branching Fractions:

$$\begin{aligned}
\mathcal{B}(B^0 \to K^0\pi^+\pi^- \text{ Inclusive}) &= (43.0 \pm 2.3 \pm 2.3) \times 10^{-6} \\
\mathcal{B}(B^0 \to K^0_S\pi^+\pi^- \text{ nonresonant}) &< 2.1 \times 10^{-6} \\
\mathcal{B}(B^0 \to K^{**\pm}\pi^\mp, K^{**\pm} \to K^0\pi^\pm) &= (24.4 \pm 2.6 \pm 0.9) \times 10^{-6} \\
\mathcal{B}(B^0 \to \rho^0 K^0_S) &= (4.0 \pm 1.0 \pm 0.5 \pm 0.2) \times 10^{-6} \\
\mathcal{B}(B^0 \to f_0 K^0_S) &= (5.5 \pm 0.7 \pm 0.5 \pm 0.3) \times 10^{-6} \\
\mathcal{B}(B^0 \to K^{*+}\pi^-) &= (11.0 \pm 1.5 \pm 0.5 \pm 0.5) \times 10^{-6}
\end{aligned}$$

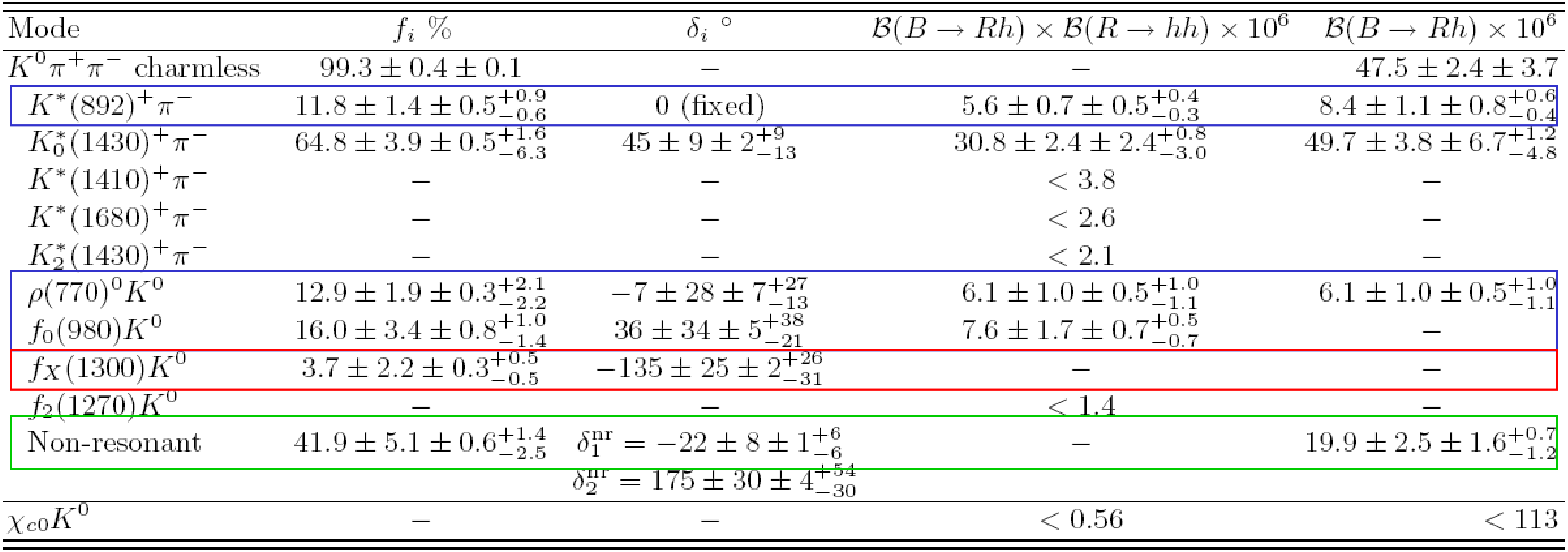
  - **Asymmetry for $B^0 \to K^{*+}\pi^-$**

Acp ($B^0 \to K^{*+}\pi^-$) = -0.11 ± 0.14 ± 0.05

Existing Measurements (III)

- **Belle (PR D73:031101) time and tagging integrated Dalitz plot analysis (357 *fb*$^{-1}$)**

  - **Results:**



Mode	f_i %	δ_i °	$\mathcal{B}(B \to Rh) \times \mathcal{B}(R \to hh) \times 10^6$	$\mathcal{B}(B \to Rh) \times 10^6$
$K^0\pi^+\pi^-$ charmless	$99.3 \pm 0.4 \pm 0.1$	–	–	$47.5 \pm 2.4 \pm 3.7$
$K^*(892)^+\pi^-$	$11.8 \pm 1.4 \pm 0.5^{+0.9}_{-0.6}$	0 (fixed)	$5.6 \pm 0.7 \pm 0.5^{+0.4}_{-0.3}$	$8.4 \pm 1.1 \pm 0.8^{+0.6}_{-0.4}$
$K_0^*(1430)^+\pi^-$	$64.8 \pm 3.9 \pm 0.5^{+1.6}_{-6.3}$	$45 \pm 9 \pm 2^{+9}_{-13}$	$30.8 \pm 2.4 \pm 2.4^{+0.8}_{-3.0}$	$49.7 \pm 3.8 \pm 6.7^{+1.2}_{-4.8}$
$K^*(1410)^+\pi^-$	–	–	< 3.8	–
$K^*(1680)^+\pi^-$	–	–	< 2.6	–
$K_2^*(1430)^+\pi^-$	–	–	< 2.1	–
$\rho(770)^0K^0$	$12.9 \pm 1.9 \pm 0.3^{+2.1}_{-2.2}$	$-7 \pm 28 \pm 7^{+27}_{-13}$	$6.1 \pm 1.0 \pm 0.5^{+1.0}_{-1.1}$	$6.1 \pm 1.0 \pm 0.5^{+1.0}_{-1.1}$
$f_0(980)K^0$	$16.0 \pm 3.4 \pm 0.8^{+1.0}_{-1.4}$	$36 \pm 34 \pm 5^{+38}_{-21}$	$7.6 \pm 1.7 \pm 0.7^{+0.5}_{-0.7}$	–
$f_X(1300)K^0$	$3.7 \pm 2.2 \pm 0.3^{+0.5}_{-0.5}$	$-135 \pm 25 \pm 2^{+26}_{-31}$	–	–
$f_2(1270)K^0$	–	–	< 1.4	–
Non-resonant	$41.9 \pm 5.1 \pm 0.6^{+1.4}_{-2.5}$	$\delta_1^{\rm nr} = -22 \pm 8 \pm 1^{+6}_{-6}$ $\delta_2^{\rm nr} = 175 \pm 30 \pm 4^{+54}_{-30}$	–	$19.9 \pm 2.5 \pm 1.6^{+0.7}_{-1.2}$
$\chi_{c0}K^0$	–	–	< 0.56	< 113

- **In general, compatible with Q2B result from BaBar**
- **Observed signal excess in $m_{\pi\pi}$ ~ 1.5 GeV/c^2 region**
- **Exception: non-resonant**

Existing Measurements (IV)

- **Belle time-dependent DP analysis (657 fb-1)**

They plan to finish the analysis soon. They already presented a limited set of preliminary results at ICHEP08 and CKM08, with errors comparable to ours

Analysis Strategy

- Similar to $B^0 \to (\rho\pi)^0$ (BAD #637) and $B^0 \to K^+\pi^-\pi^0$ (BAD #826)

- Simultaneous fit including:
  - - m_{ES}, ΔE, Neural Net (NN), Δt and tagged Dalitz Plot

- The complex isobar amplitudes are directly fitted, allowing for CP violation parameters measurement (see later)

- RhoPiTools and PiPiKsTools are used to do the fit

Data Set

- **Signal MC (SP8):**
  - **- non-resonant (5401K events)**
  - **- $B^0 \rightarrow f_0(980)$ (134K events)**
  - **- $B^0 \rightarrow \rho^0(980)$ (143K events)**
  - **- $B^0 \rightarrow K^*(892)$ (134K events)**
  - **- B-background MC. See**

(http://www.slacstanford.edu/BFROOT/www/Organization/CollabMtgs/2007/detFeb07/Thur1b/aperez.pdf)

  - **- Charged and Neutral Generic**
  - **- Exclusive modes**
- **Data**

  - On/off resonance

Run 1-5,
Vivace data set

R18b BtoCPP skim with BtoCPP_K_S0pi+pi- tagbit

Processed with QnBUser package in analysis-32

Event Selection

- π candidates from GoodTrackLoose List
- K^0_S candidates from KsDefault List
- B^0 candidates vertexed using TreeFitter
- $5.272 < m_{ES} < 5.286\ \mathrm{GeV}/c^2$
- $|\Delta E| < 65$ MeV
- $|\Delta t| < 20$ ps
- $\sigma(\Delta t) < 2.5$ps
- $|M(Ks) - M(Ks)PDF| < 15\ \mathrm{MeV}/c^2$
- Lifetime significance > 5
- cos(Ks,Ks daughters) < 0.999
- NN > -0.4
- PID requirements to separate from kaons and reject leptons

Total efficiency ~ 25%

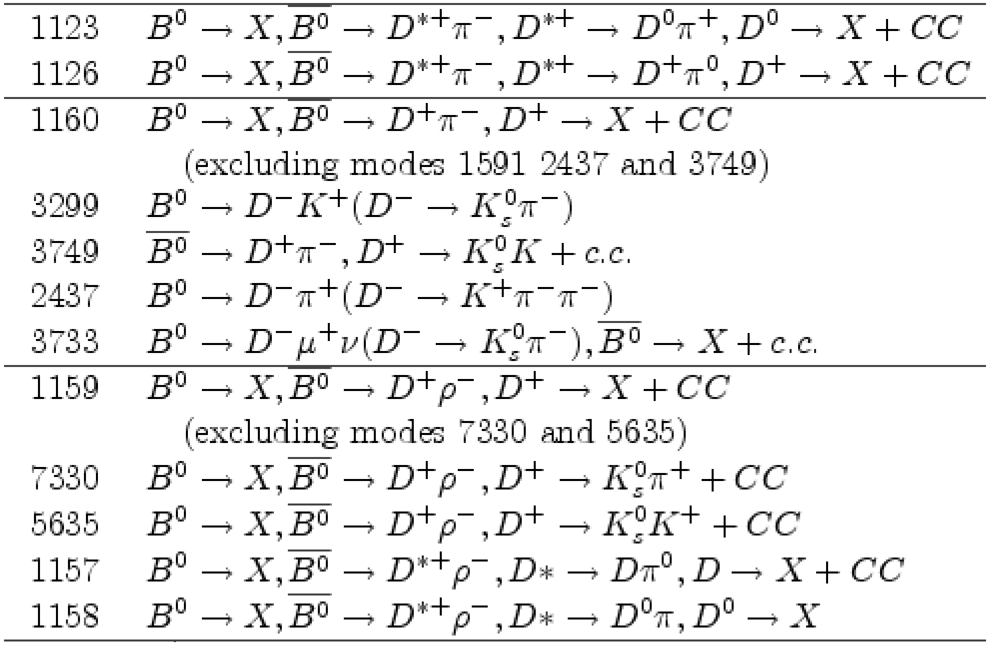
Multiple candidates:
cadidate selected arbitrarily, in order to not to bias the ΔE distribution

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

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

Cat. 2

Cat. 3

Modes treated semi-exclusively grouped into categories

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

Modes treated Inclusively

Likelihood Function

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

The Likelihood Function

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

Likelihood Function

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

The Likelihood Function

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

Signal Component

TM **SCF**

Likelihood Function

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

The Likelihood Function

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

Continuum Component

Likelihood Function

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

The Likelihood Function

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

B-background Components

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

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**

Parameterization (III)

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

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

PDF dependent on the DP:

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

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

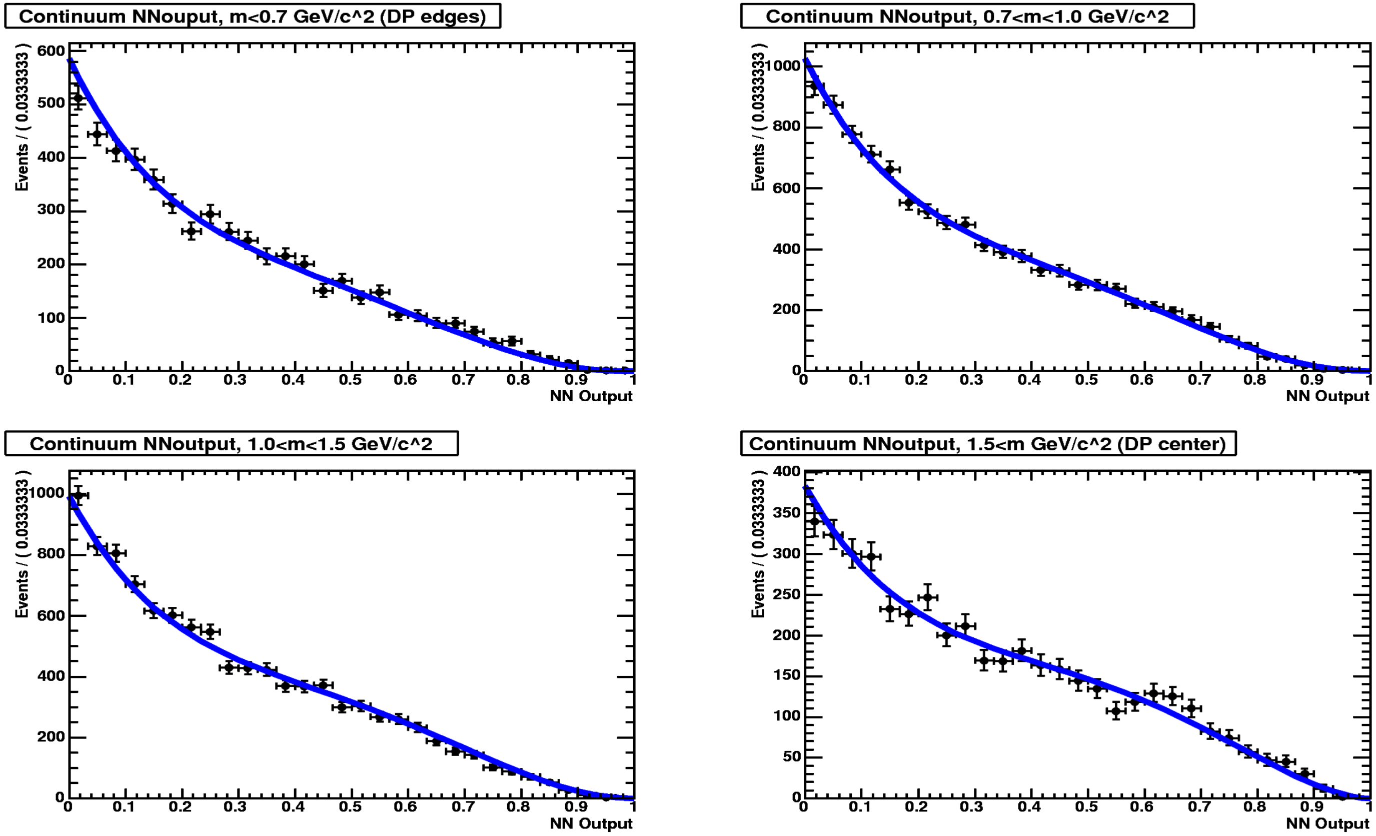
Δ_{Dalitz} : **Distance to DP center**

Parameterization (III)

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

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

Fit on off-peak data for different DP regions


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 (IV)

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

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 intermediates states over DP

Parameterization (IV)

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 intermediates states over DP

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

Parameterization (IV)

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 intermediates 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 (IV)

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 intermediates states over DP

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

Relativistic Breit-Wigner:	**K*(892)π, and for other less significant components (f_2(1270)K, K*(1410)π, K*(1680)π, …).**
Flatte:	**f_0(980)K**
Gounaris-Sakurai:	**ρ(770)K**
S-wave Kπ:	**LASS lineshape.**

Parameterization (IV)

Parameterizing Decay amplitude using Isobar Model:

Dalitz Plot Isobar Model

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

Shapes of intermediates states over DP

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

Rela

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

Gou

S-wave Kπ: **LASS lineshape.**

Nucl. Phys., B296:493, 1988

Parameterization (IV)

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 intermediates states over DP

Time-dependent DP PDF

$$f(\Delta t, DP, q_{tag}) \propto \left(|A|^2 + |\overline{A}|^2\right) \frac{e^{-|\Delta t|/\tau}}{4\tau} \left(1 + q_{tag} \frac{2\,\mathrm{Im}[\overline{A} A^*]}{|A|^2 + |\overline{A}|^2} \sin(\Delta m_d \Delta t) - q_{tag} \frac{|A|^2 - |\overline{A}|^2}{|A|^2 + |\overline{A}|^2} \cos(\Delta m_d \Delta t)\right)$$

Misstag and time-resolution effects are taken into account

Parameterization (IV)

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 intermediates states over DP

Time-dependent DP PDF

mixing and decay CPV

DCPV

$$f(\Delta t, DP, q_{tag}) \propto \left(|A|^2 + |\overline{A}|^2\right) \frac{e^{-|\Delta t|/\tau}}{4\tau} \left(1 + q_{tag} \frac{2\,\mathrm{Im}[\overline{A} A^*]}{|A|^2 + |\overline{A}|^2} \sin(\Delta m_d \Delta t) - q_{tag} \frac{|A|^2 - |\overline{A}|^2}{|A|^2 + |\overline{A}|^2} \cos(\Delta m_d \Delta t)\right)$$

CP violation varies over DP

Complex amplitudes a_j and $\overline{a}_j$ determine DP interference pattern.
Module and phase con be directly fitted on data.

Parameterization (IV)

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 intermediates states over DP

Time-dependent DP PDF

mixing and decay CPV

DCPV

$$f(\Delta t, DP, q_{tag}) \propto \left(|A|^2 + |\overline{A}|^2\right) \frac{e^{-|\Delta t|/\tau}}{4\tau} \left(1 + q_{tag} \frac{2\,\mathrm{Im}[\overline{A}A^*]}{|A|^2 + |\overline{A}|^2} \sin(\Delta m_d \Delta t) - q_{tag} \frac{|A|^2 - |\overline{A}|^2}{|A|^2 + |\overline{A}|^2} \cos(\Delta m_d \Delta t)\right)$$

CP violation varies over DP

Complex amplitudes a_j and $\overline{a}_j$ determine DP interference pattern.
Module and phase con be directly fitted on data.

Time-dependent CPV parameters:

$$C_j = \frac{|a_j|^2 - |\overline{a}_j|^2}{|a_j|^2 + |\overline{a}_j|^2} \qquad S_j = \frac{2\,\mathrm{Im}[a_j \overline{a}_j^{\,*}]}{|a_j|^2 + |\overline{a}_j|^2}$$

Interference helps disentangling strong and weak phases and thus raises the degeneracy on the phases.

Parameterization (V)

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

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**

Physical Parameters (I)

Direct CP asymmetries:

$$C_j = \frac{|a_j|^2 - |\bar{a}_j|^2}{|a_j|^2 + |\bar{a}_j|^2}$$

Only for neutral intermediate states

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

Only for charged intermediate states

The mixing and decay CPV S parameter

$$S_j = \frac{2\,\mathrm{Im}[a_j \bar{a}_j{}^*]}{|a_j|^2 + |\bar{a}_j|^2}$$

Only for neutral intermediate states

Phase differences and Isobar Fractions

$$\phi^{j\,mix} = \arg[\,a_j \bar{a}_{j^{\text{¿}}}\,]$$

$$\Delta\phi_{j\bar{j}} = \arg[a_j \bar{a}^*_{\bar{j}}]$$

$$\boldsymbol{FF_j} = \frac{\left(|a_j|^2 + |\bar{a}_j|^2\right)\left\langle |F_j|^2 \right\rangle}{\sum_{kl} (a_k a_l^* + \bar{a}_k \bar{a}_l^*)\left\langle F_k F_l^* \right\rangle}$$

The phases can be accessed through DP interference

Physical Parameters (II)

Inclusive Direct CP asymmetry

$$A_{CP}^{incl} = \frac{\int_{DP} [|\mathcal{A}(DP)|^2 - |\overline{\mathcal{A}}(DP)|^2] d(DP)}{\int_{DP} [|\mathcal{A}(DP)|^2 + |\overline{\mathcal{A}}(DP)|^2] d(DP)},$$

Inclusive Branching Fraction

$$\mathcal{B}^{incl} = \mathcal{B}(B^0 \to K^0\pi^+\pi^-) = \frac{N_{sig}}{\mathcal{B}(K^0 \to K_S^0)\langle\varepsilon\rangle N_{B\overline{B}}},$$

Exclusive Branching Fractions

$$\mathcal{B}(\sigma) = FF_\sigma \mathcal{B}^{incl}$$

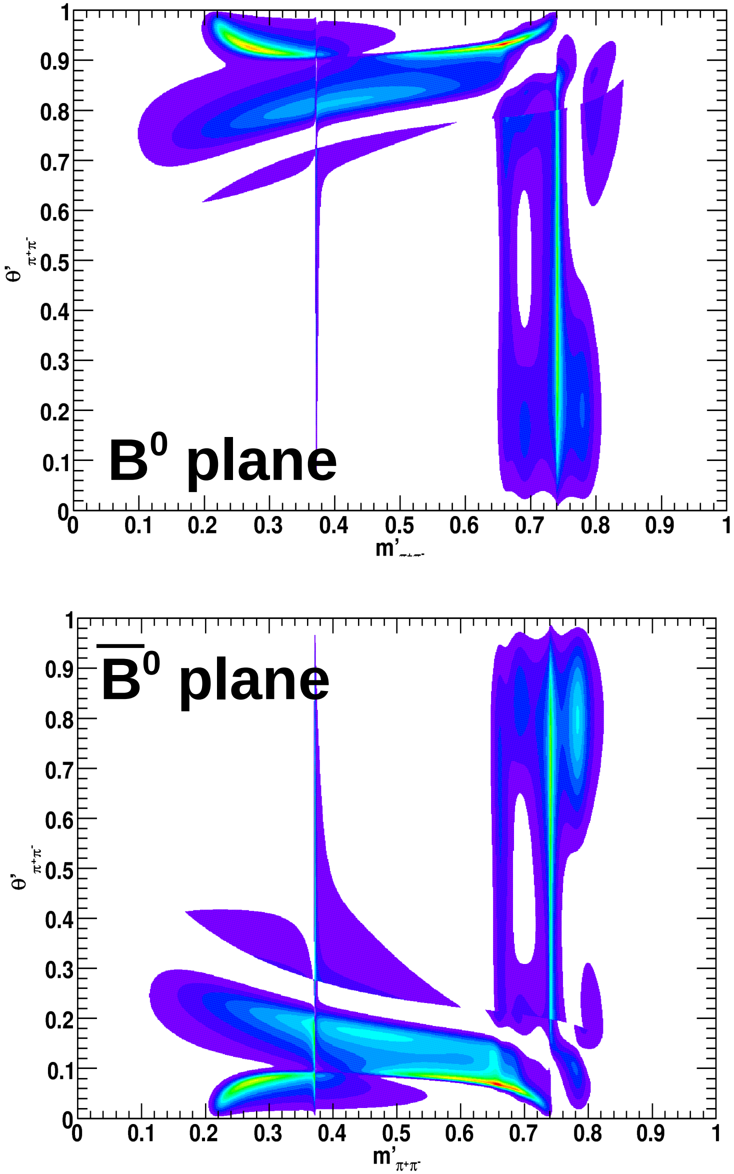
Nominal Signal Model

List of components included in nominal fit:

- $B^0 \rightarrow \rho^0(770) K^0_S$ (GS)
- $B^0 \rightarrow f_0(980) K^0_S$ (Flatté)
- $B^0 \rightarrow K^*(892)\pi$ (RBW)
- $K\pi$ S-wave (LASS)
- Non-resonant (flat phase space)
- $B^0 \rightarrow f_X(1300) K^0_S$ (RBW)
- $B^0 \rightarrow f_2(1270) K^0_S$ (RBW)
- $B^0 \rightarrow \chi_{c0} K^0_S$ (RBW)

Same Signal Model as in $B^+ \rightarrow K^+\pi^-\pi^+$ analysis BAD #1512

Square DP



New Fitter Configuration (I)

- **Reminder:** **preliminary results were present at LP07**

hep-ex/0708.2097

- **Changes in fit configuration since then:**

- No changes on Data sample and Selection.

- No changes on DP signal model.

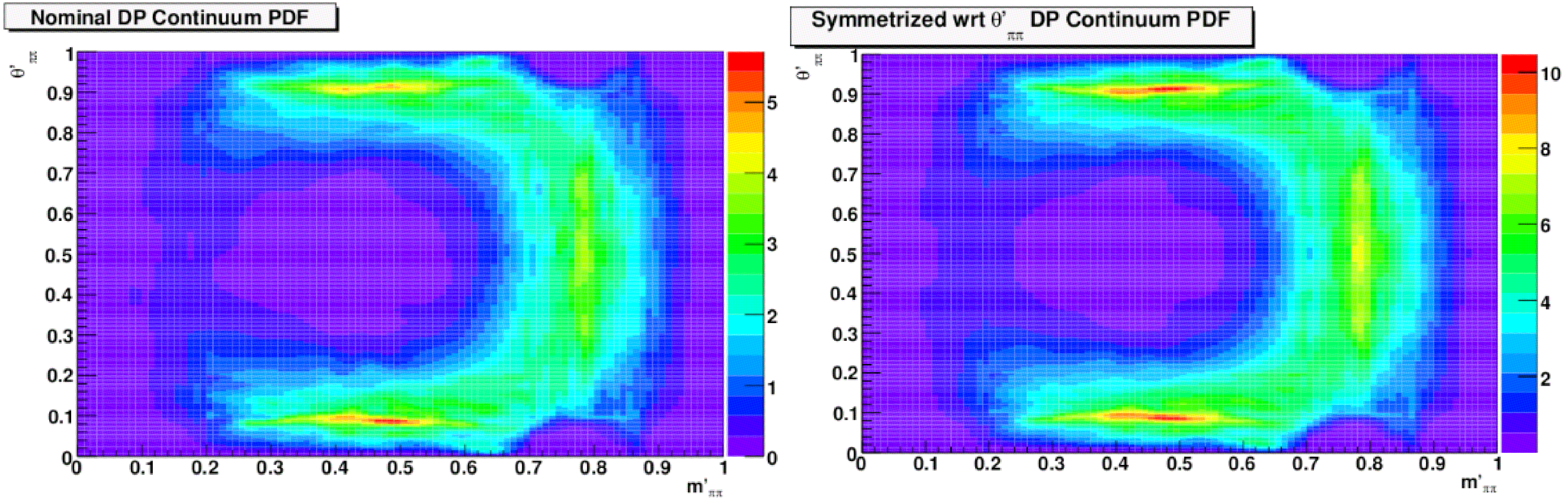
- Corrected a mistake in the GS lineshape for the $\rho^0(770)K^0_S$

New Fitter Configuration (II)

- **Reminder:** **preliminary results were present at LP07** **hep-ex/0708.2097**

- **Changes in fit configuration since then:**

  - Now we use a charge symmetric DP continuum PDF for all tagging categories (except for Non-tagged events).



Before

Now

Square DP

New Fitter Configuration (III)

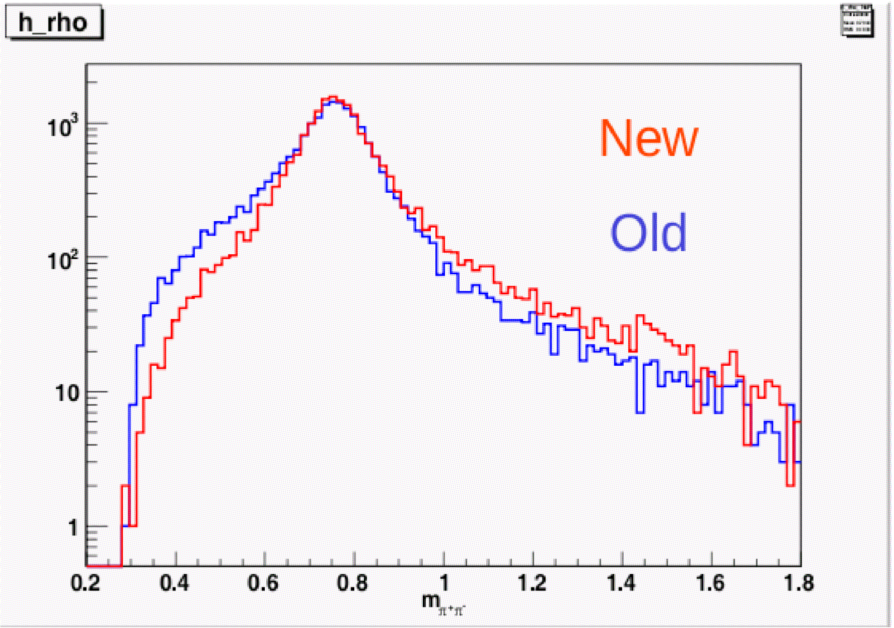
- **Reminder:** preliminary results were present at LP07 **hep-ex/0708.2097**

- **Changes in fit configuration since then:**

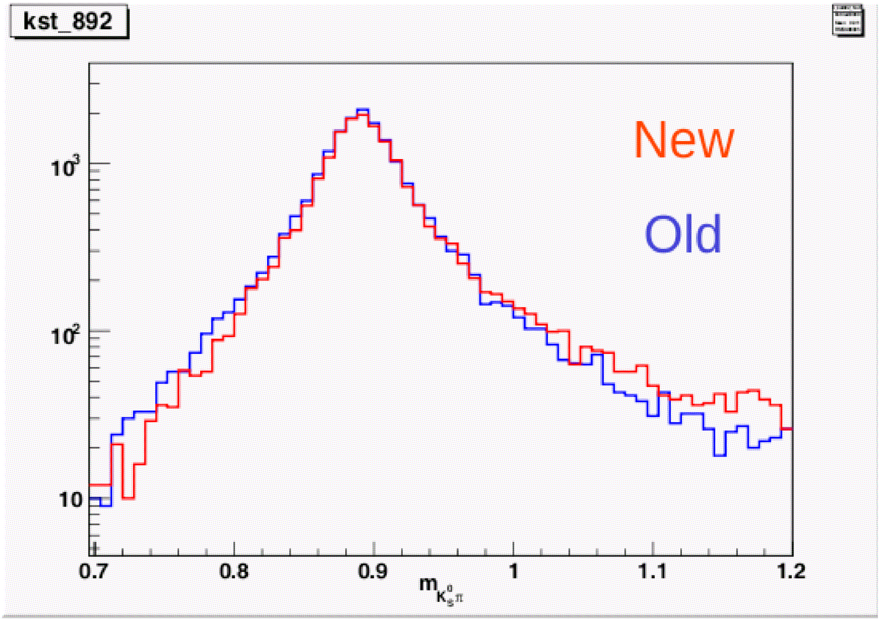
- Now taking into account resonances barrier factors. Before we used r = 0, now PDG values.

Only affects vector resonances.

ρ(770)Ks



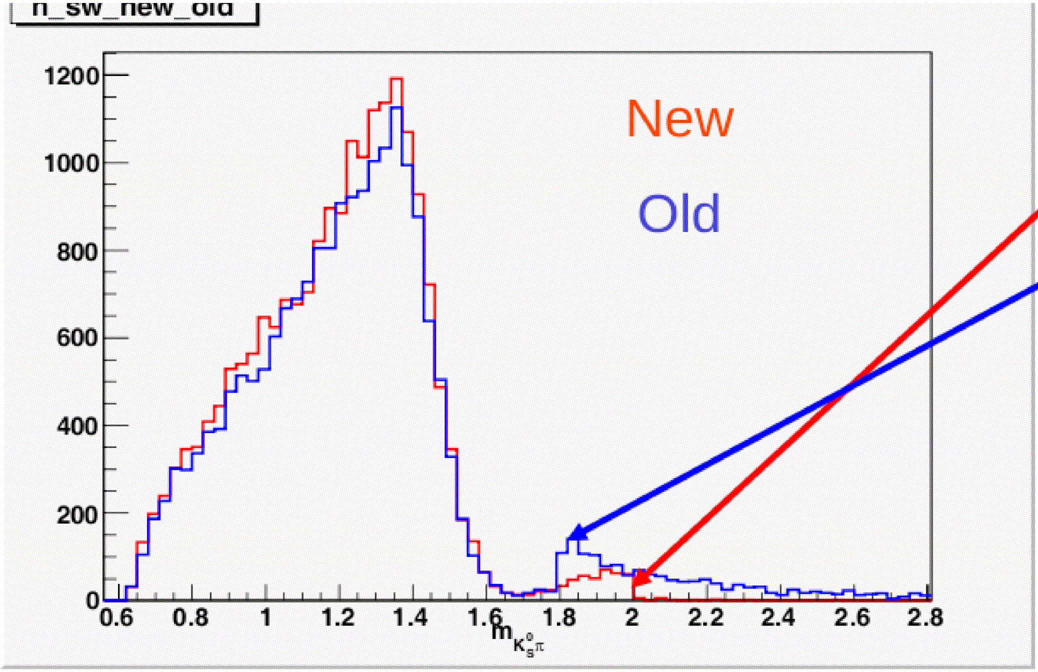
K*(892)π



New Fitter Configuration (IV)

- **Reminder:** **preliminary results were present at LP07** **hep-ex/0708.2097**

- **Changes in fit configuration since then:**
  - Before: **cutting the whole LASS amplitude above 2.0GeV/c^2**
  - Now : cutting only effective range part above 1.8GeV/c^2,
  same configuration as in $B^+ \rightarrow K^+\pi^-\pi^+$ analysis **BAD #1512**



Old cut of whole amplitude at 2.0GeV/c^2

New cutting of effective range at 1.8GeV/c^2

New Fitter Configuration (IV)

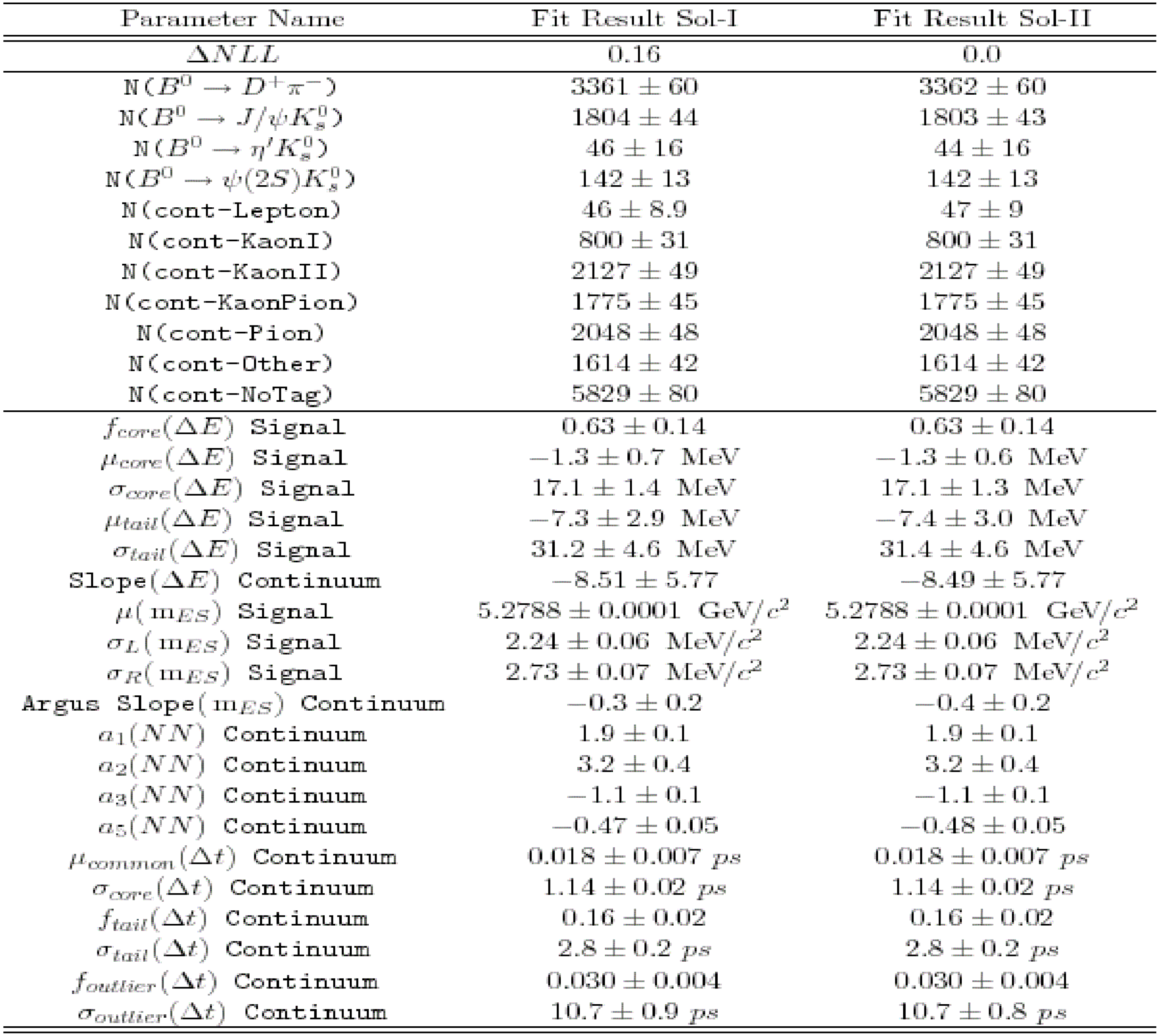
- **Reminder:** preliminary results were present at LP07

hep-ex/0708.2097

- Changes in fit configuration since then:

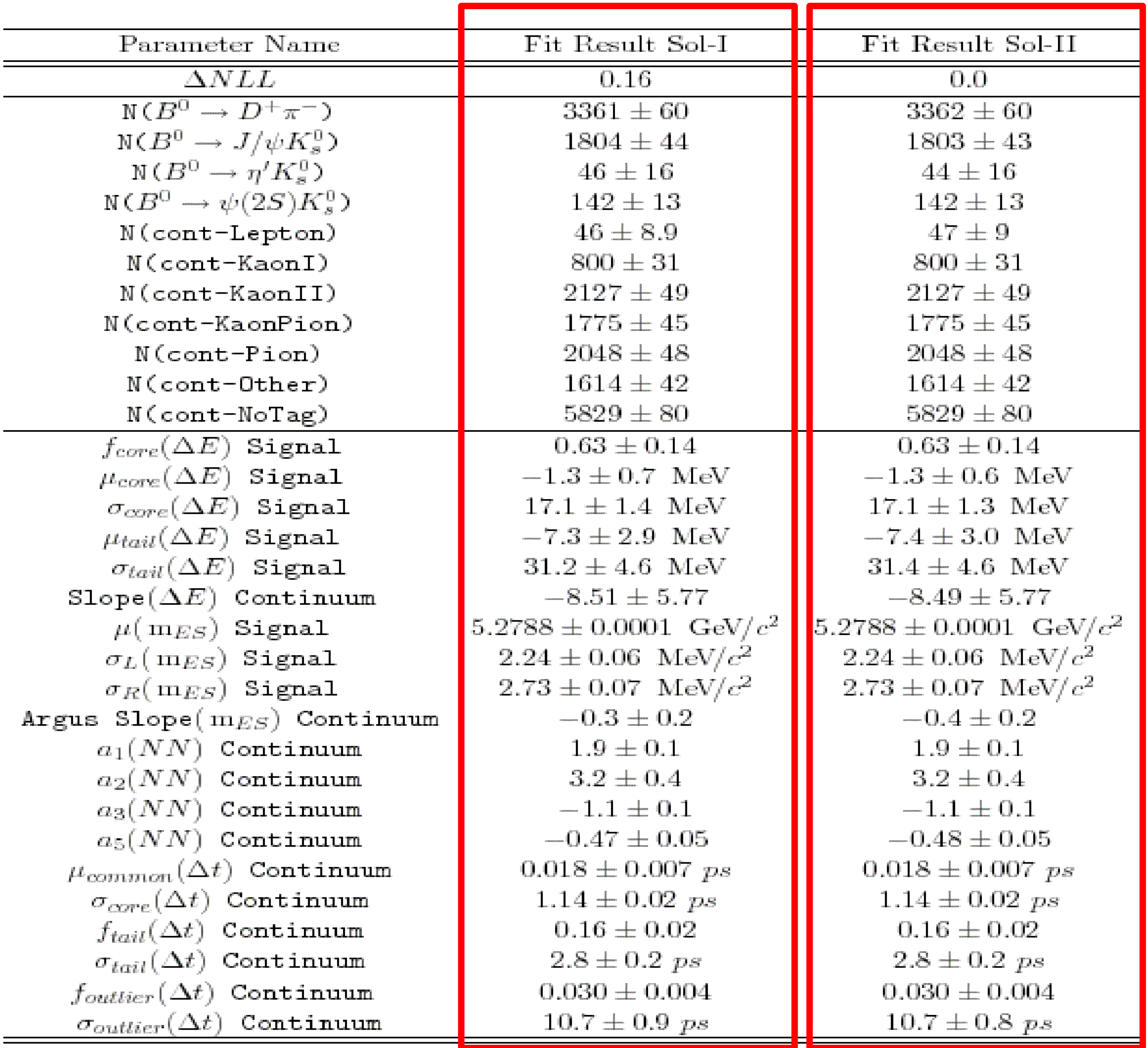
  - BFs are now measured
  - All systematics have been recalculated
  - Improved evaluation of DP signal model systematics, based on toys
  - Efficiency systematics are calculated

Fit Results: central values (I)



Parameter Name	Fit Result Sol-I	Fit Result Sol-II
ΔNLL	0.16	0.0
N($B^0 \longrightarrow D^+\pi^-$)	3361 ± 60	3362 ± 60
N($B^0 \longrightarrow J/\psi K^0_s$)	1804 ± 44	1803 ± 43
N($B^0 \longrightarrow \eta' K^0_s$)	46 ± 16	44 ± 16
N($B^0 \longrightarrow \psi(2S) K^0_s$)	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
μ(m_{ES}) Signal	5.2788 ± 0.0001 GeV/c^2	5.2788 ± 0.0001 GeV/c^2
σ_L(m_{ES}) Signal	2.24 ± 0.06 MeV/c^2	2.24 ± 0.06 MeV/c^2
σ_R(m_{ES}) Signal	2.73 ± 0.07 MeV/c^2	2.73 ± 0.07 MeV/c^2
Argus Slope(m_{ES}) Continuum	-0.3 ± 0.2	-0.4 ± 0.2
$a_1(NN)$ Continuum	1.9 ± 0.1	1.9 ± 0.1
$a_2(NN)$ Continuum	3.2 ± 0.4	3.2 ± 0.4
$a_3(NN)$ Continuum	-1.1 ± 0.1	-1.1 ± 0.1
$a_5(NN)$ Continuum	-0.47 ± 0.05	-0.48 ± 0.05
$\mu_{common}(\Delta t)$ Continuum	$0.018 \pm 0.007\ ps$	$0.018 \pm 0.007\ ps$
$\sigma_{core}(\Delta t)$ Continuum	$1.14 \pm 0.02\ ps$	$1.14 \pm 0.02\ ps$
$f_{tail}(\Delta t)$ Continuum	0.16 ± 0.02	0.16 ± 0.02
$\sigma_{tail}(\Delta t)$ Continuum	$2.8 \pm 0.2\ ps$	$2.8 \pm 0.2\ ps$
$f_{outlier}(\Delta t)$ Continuum	0.030 ± 0.004	0.030 ± 0.004
$\sigma_{outlier}(\Delta t)$ Continuum	$10.7 \pm 0.9\ ps$	$10.7 \pm 0.8\ ps$

Fit Results: central values (I)



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$f_{tail}(\Delta t)$ 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
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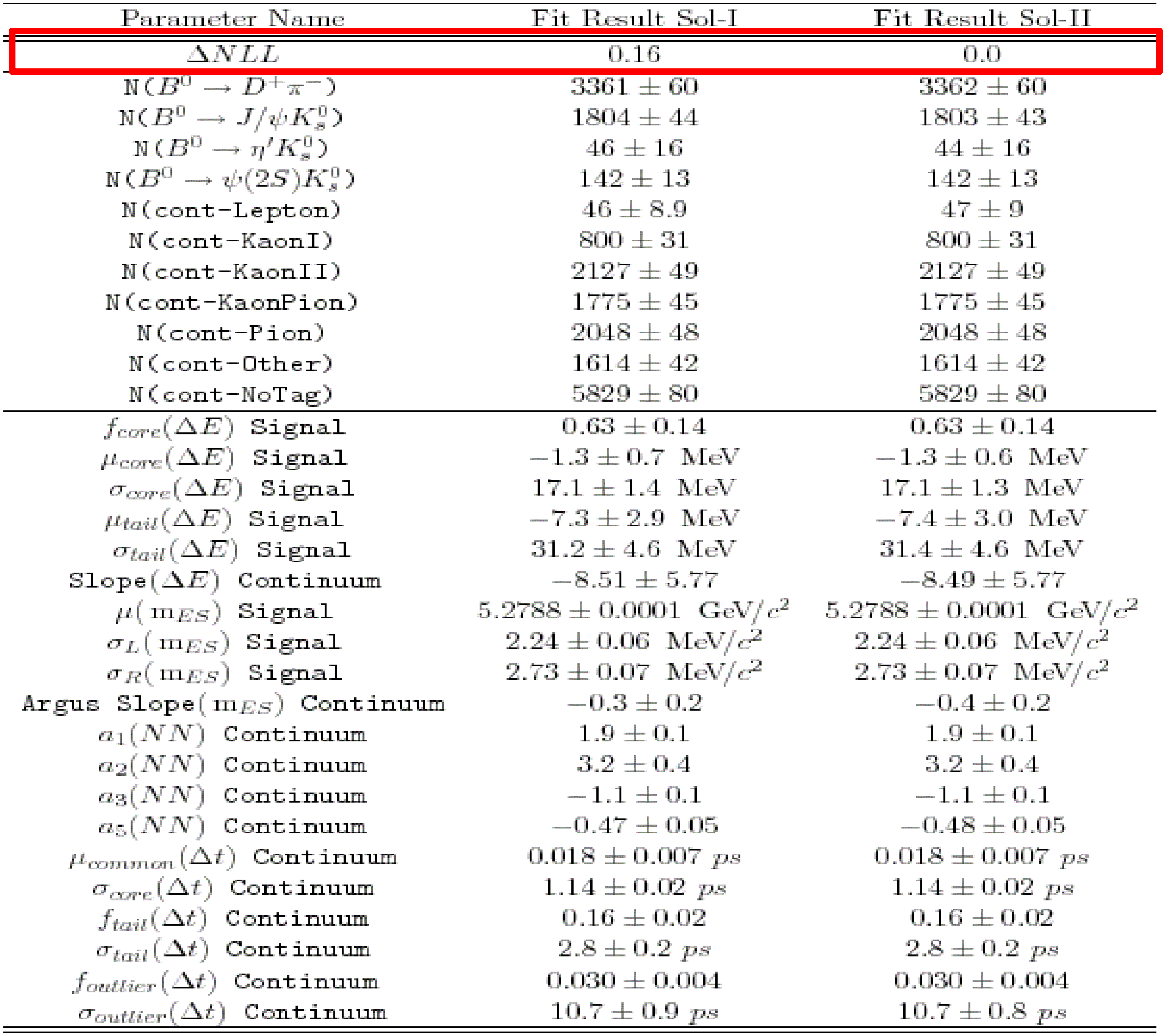
There are two solutions almost degenerated.

Fit Results: central values (I)



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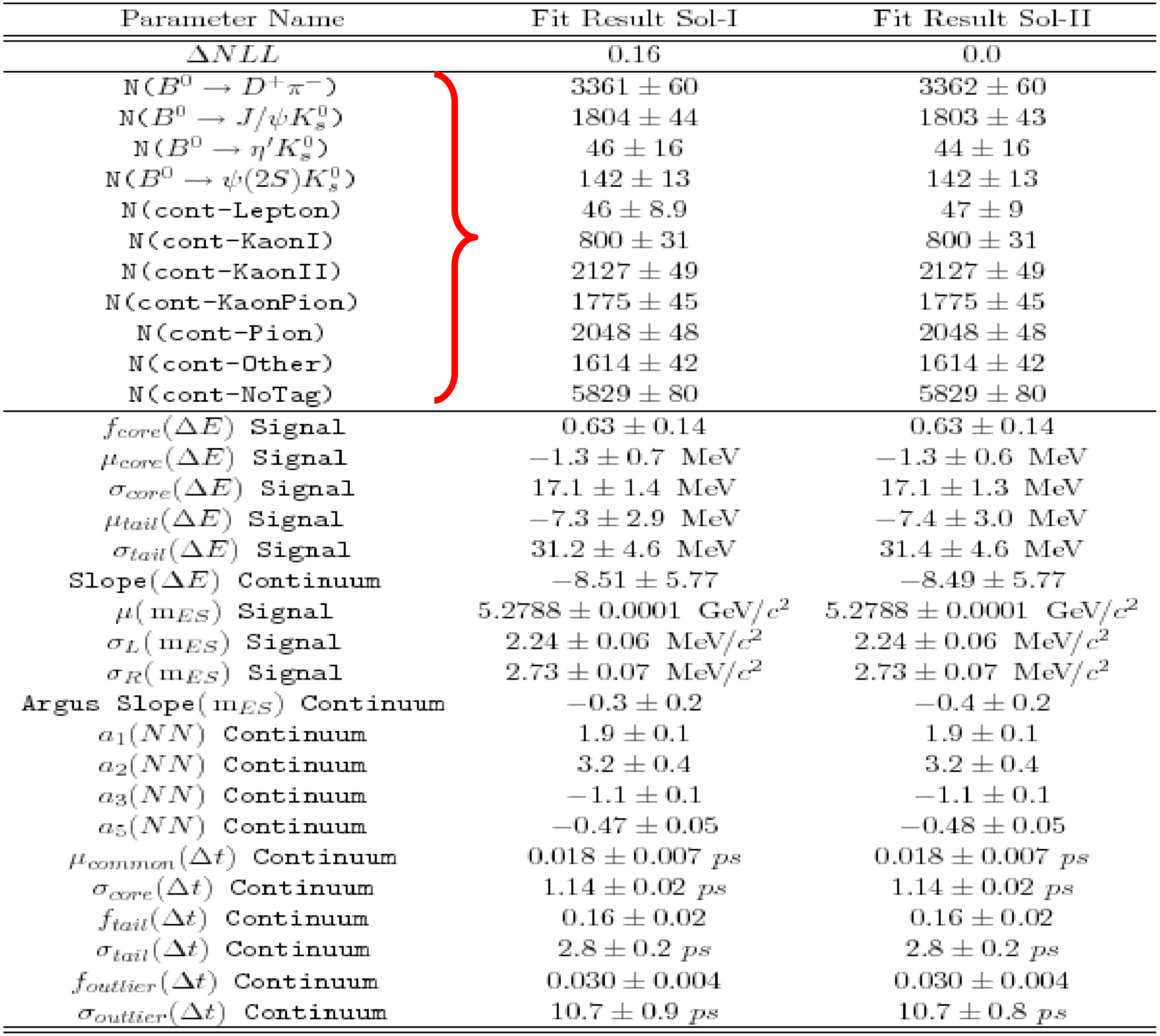
There are two solutions almost degenerated.

They differ by 0.16 in NLL units

Fit Results: central values (I)



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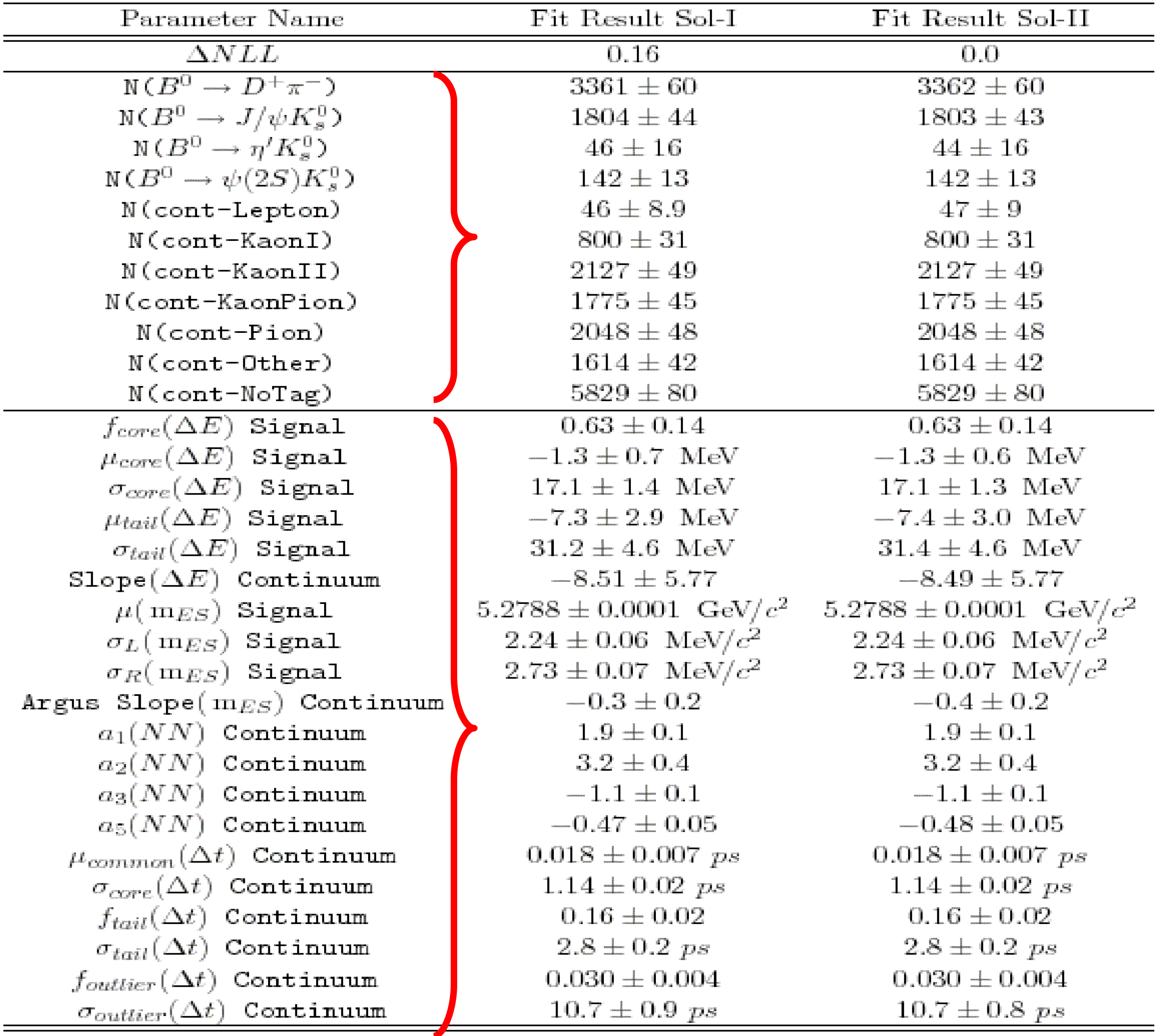
Fit Parameters:

- 11 Yields,

Fit Results: central values (I)



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$a_3(NN)$ Continuum	-1.1 ± 0.1	-1.1 ± 0.1
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$f_{outlier}(\Delta t)$ Continuum	0.030 ± 0.004	0.030 ± 0.004
$\sigma_{outlier}(\Delta t)$ Continuum	10.7 ± 0.9 ps	10.7 ± 0.8 ps

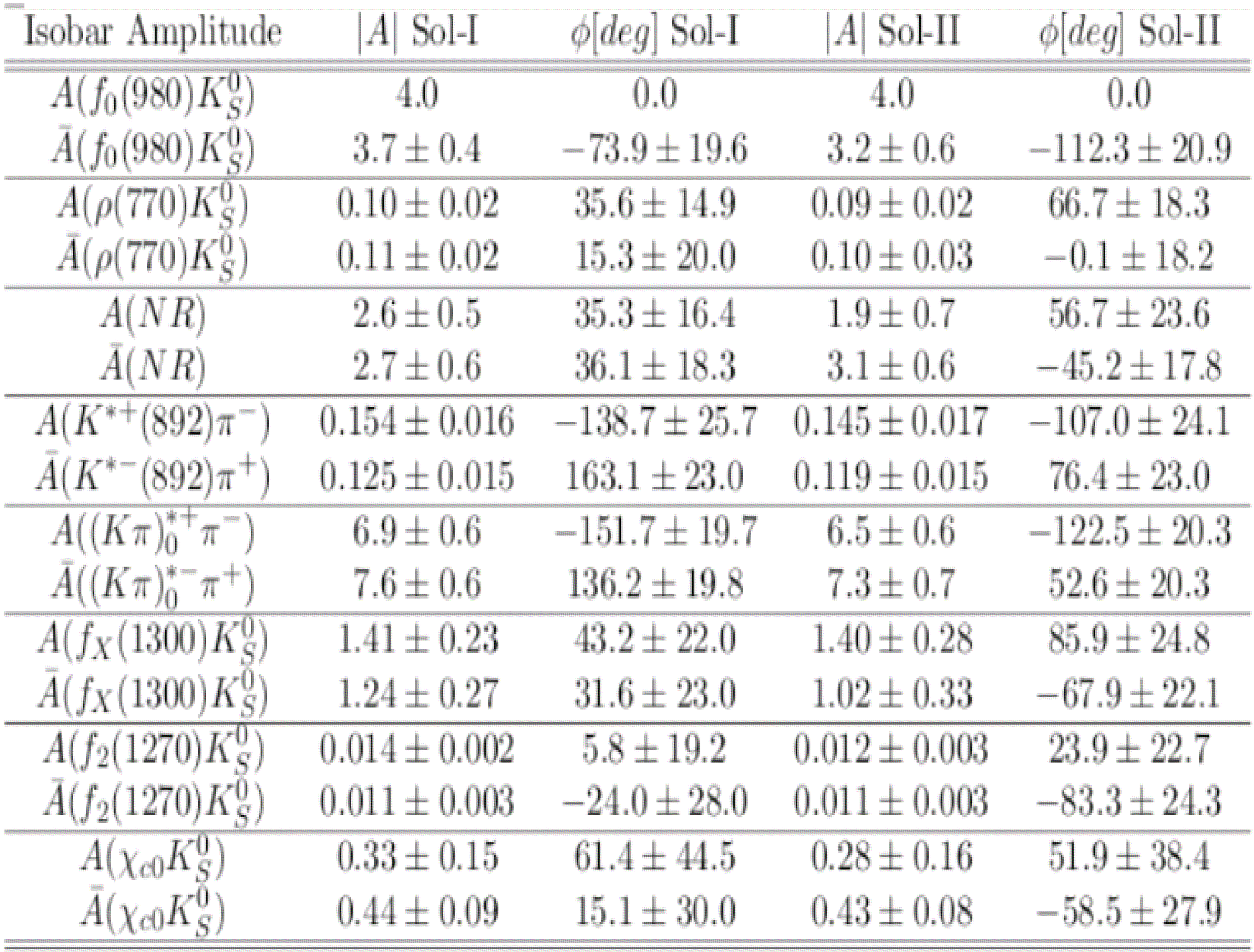
Fit Parameters:

- **11 Yields,**
- **20 Shape parameters,**
- **14 other parameters,**

Very similar in both solutions!

Fit Results: central values (II)

Amplitudes and Phases of Isonbar amplitudes



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 Parameters:

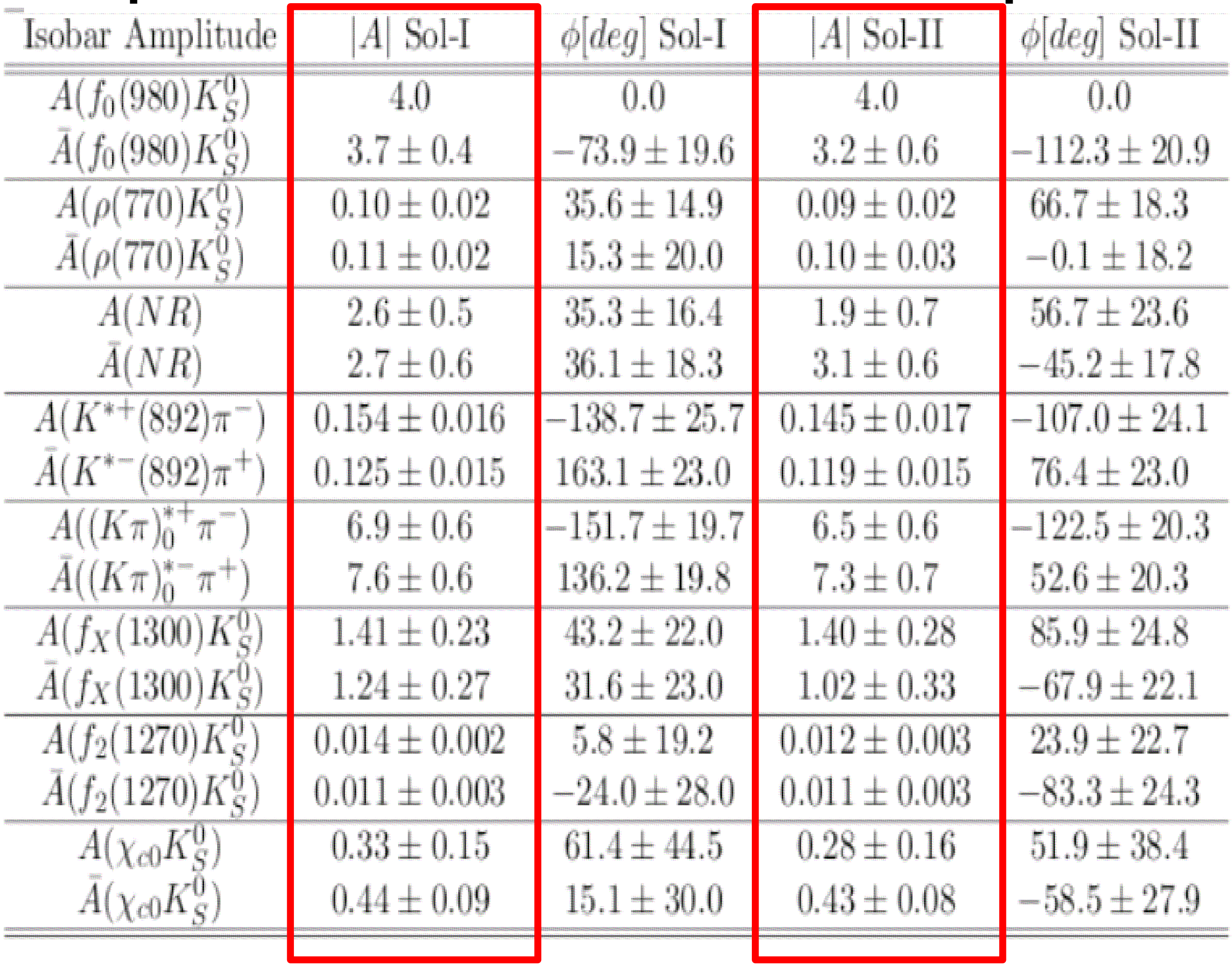
- **11 Yields,**
- **20 Shape parameters,**
- **14 other parameters,**
- **30 Ampli. and Phases,**

Total:

75 parameters floated!

Fit Results: central values (II)

Amplitudes and Phases of Isonbar amplitudes



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$A(K^{*+}(892)\pi^-)$	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 Parameters:

- 11 Yields,
- 20 Shape parameters,
- 14 other parameters,
- 30 Ampli. and Phases,

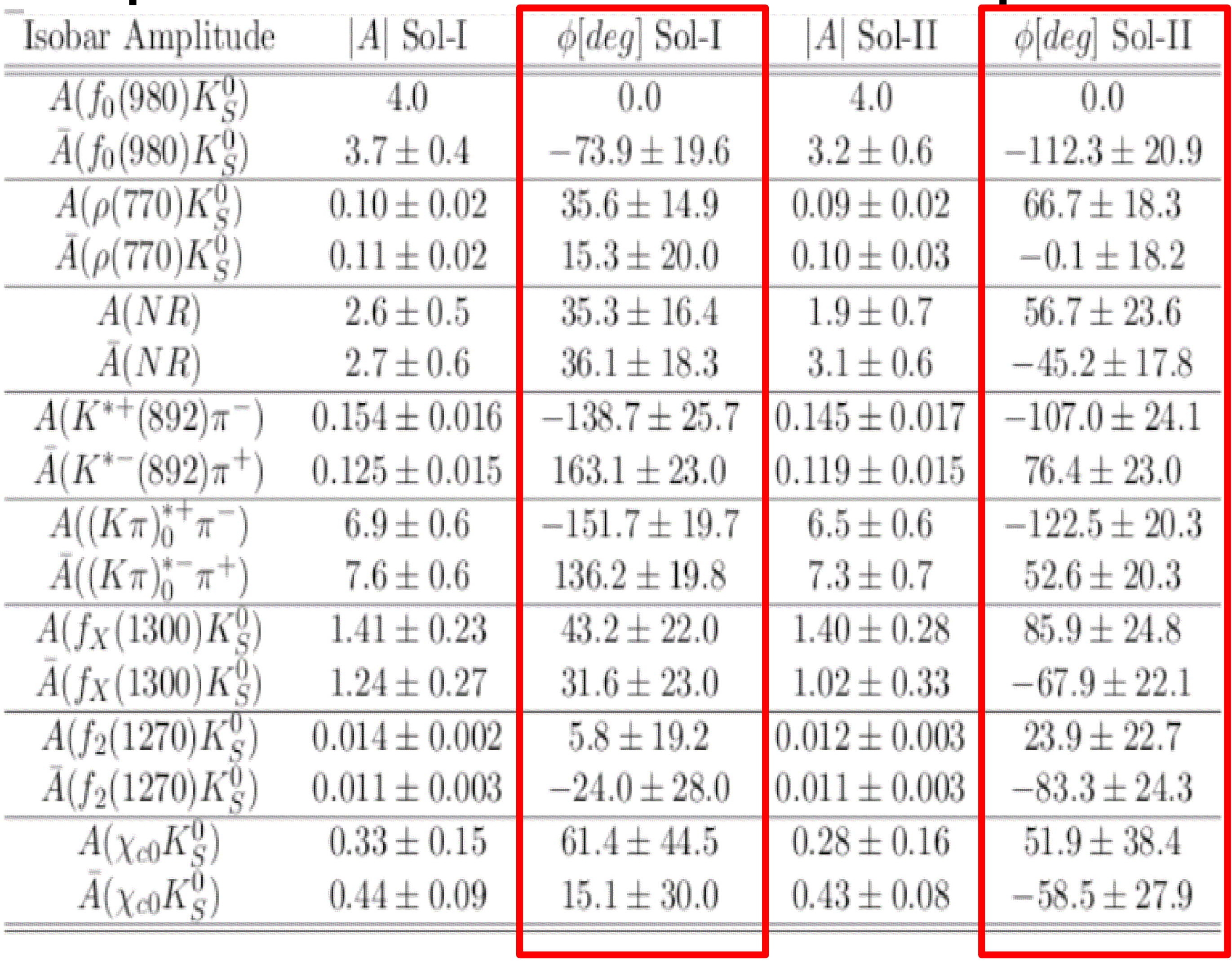
Total:

75 parameters floated!

Moduli of isobar amplitudes very similar in both solutions

Fit Results: central values (II)

Amplitudes and Phases of Isonbar amplitudes



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

Fit Parameters:

- **11 Yields,**
- **20 Shape parameters,**
- **14 other parameters,**
- **30 Ampli. and Phases,**

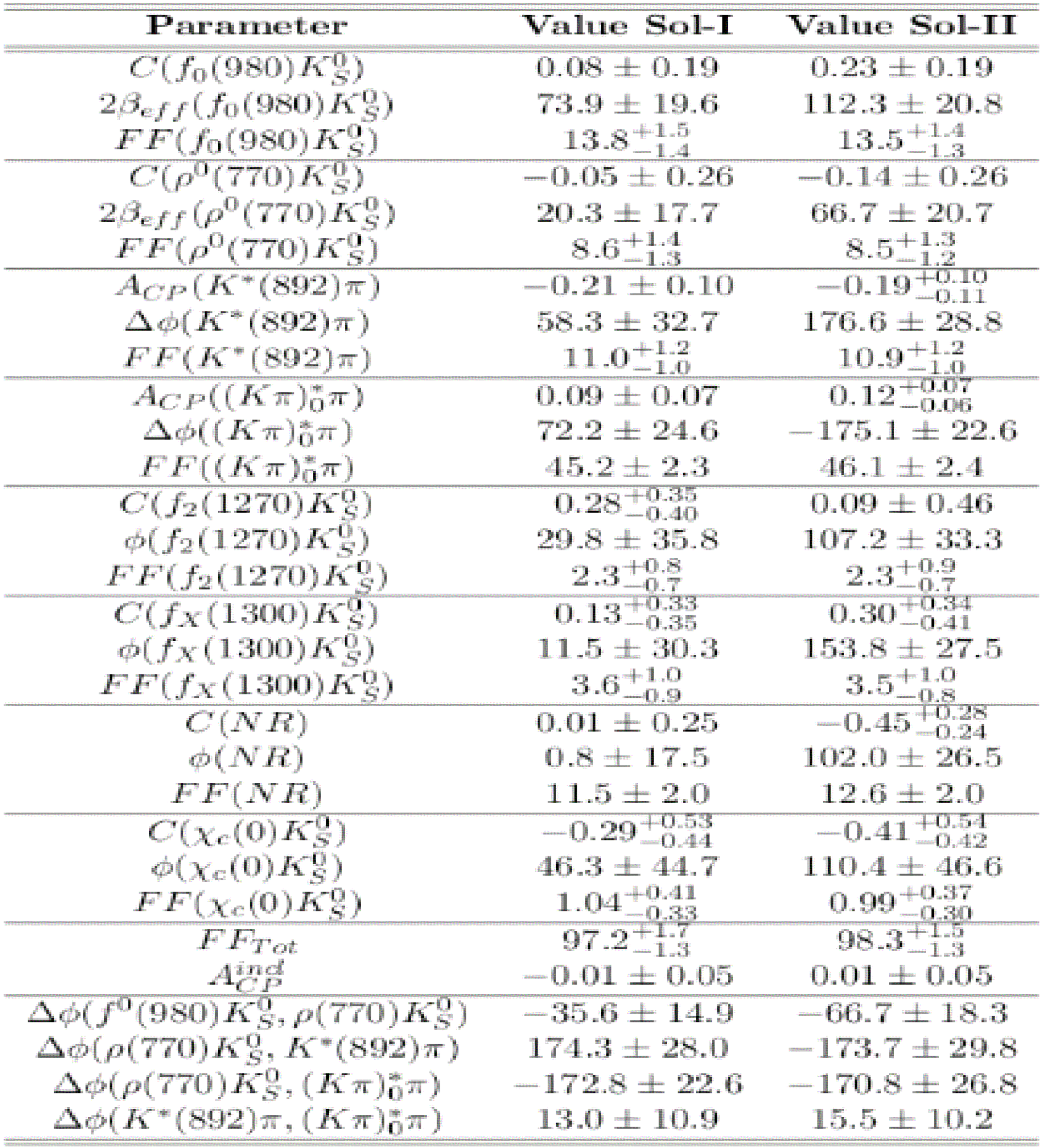
Total:

75 parameters floated!

But their phases do vary significantly!

Fit Results: central values (III)

Results on Q2B parameters



Parameter	Value Sol-I	Value Sol-II
$C(f_0(980)K_S^0)$	0.08 ± 0.19	0.23 ± 0.19
$2\beta_{eff}(f_0(980)K_S^0)$	73.9 ± 19.6	112.3 ± 20.8
$FF(f_0(980)K_S^0)$	$13.8^{+1.5}_{-1.4}$	$13.5^{+1.4}_{-1.3}$
$C(\rho^0(770)K_S^0)$	-0.05 ± 0.26	-0.14 ± 0.26
$2\beta_{eff}(\rho^0(770)K_S^0)$	20.3 ± 17.7	66.7 ± 20.7
$FF(\rho^0(770)K_S^0)$	$8.6^{+1.4}_{-1.3}$	$8.5^{+1.3}_{-1.2}$
$A_{CP}(K^*(892)\pi)$	-0.21 ± 0.10	$-0.19^{+0.10}_{-0.11}$
$\Delta\phi(K^*(892)\pi)$	58.3 ± 32.7	176.6 ± 28.8
$FF(K^*(892)\pi)$	$11.0^{+1.2}_{-1.0}$	$10.9^{+1.2}_{-1.0}$
$A_{CP}((K\pi)_0^*\pi)$	0.09 ± 0.07	$0.12^{+0.07}_{-0.06}$
$\Delta\phi((K\pi)_0^*\pi)$	72.2 ± 24.6	-175.1 ± 22.6
$FF((K\pi)_0^*\pi)$	45.2 ± 2.3	46.1 ± 2.4
$C(f_2(1270)K_S^0)$	$0.28^{+0.35}_{-0.40}$	0.09 ± 0.46
$\phi(f_2(1270)K_S^0)$	29.8 ± 35.8	107.2 ± 33.3
$FF(f_2(1270)K_S^0)$	$2.3^{+0.8}_{-0.7}$	$2.3^{+0.9}_{-0.7}$
$C(f_X(1300)K_S^0)$	$0.13^{+0.33}_{-0.35}$	$0.30^{+0.34}_{-0.41}$
$\phi(f_X(1300)K_S^0)$	11.5 ± 30.3	153.8 ± 27.5
$FF(f_X(1300)K_S^0)$	$3.6^{+1.0}_{-0.9}$	$3.5^{+1.0}_{-0.8}$
$C(NR)$	0.01 ± 0.25	$-0.45^{+0.28}_{-0.24}$
$\phi(NR)$	0.8 ± 17.5	102.0 ± 26.5
$FF(NR)$	11.5 ± 2.0	12.6 ± 2.0
$C(\chi_c(0)K_S^0)$	$-0.29^{+0.53}_{-0.44}$	$-0.41^{+0.54}_{-0.42}$
$\phi(\chi_c(0)K_S^0)$	46.3 ± 44.7	110.4 ± 46.6
$FF(\chi_c(0)K_S^0)$	$1.04^{+0.41}_{-0.33}$	$0.99^{+0.37}_{-0.30}$
FF_{Tot}	$97.2^{+1.7}_{-1.3}$	$98.3^{+1.5}_{-1.3}$
A_{CP}^{ind}	-0.01 ± 0.05	0.01 ± 0.05
$\Delta\phi(f^0(980)K_S^0, \rho(770)K_S^0)$	-35.6 ± 14.9	-66.7 ± 18.3
$\Delta\phi(\rho(770)K_S^0, K^*(892)\pi)$	174.3 ± 28.0	-173.7 ± 29.8
$\Delta\phi(\rho(770)K_S^0, (K\pi)_0^*\pi)$	-172.8 ± 22.6	-170.8 ± 26.8
$\Delta\phi(K^*(892)\pi, (K\pi)_0^*\pi)$	13.0 ± 10.9	15.5 ± 10.2

Fit Parameters:

- **11 Yields,**
- **20 Shape parameters,**
- **14 other parameters,**
- **30 Ampli. and Phases,**

Total:

75 parameters floated!

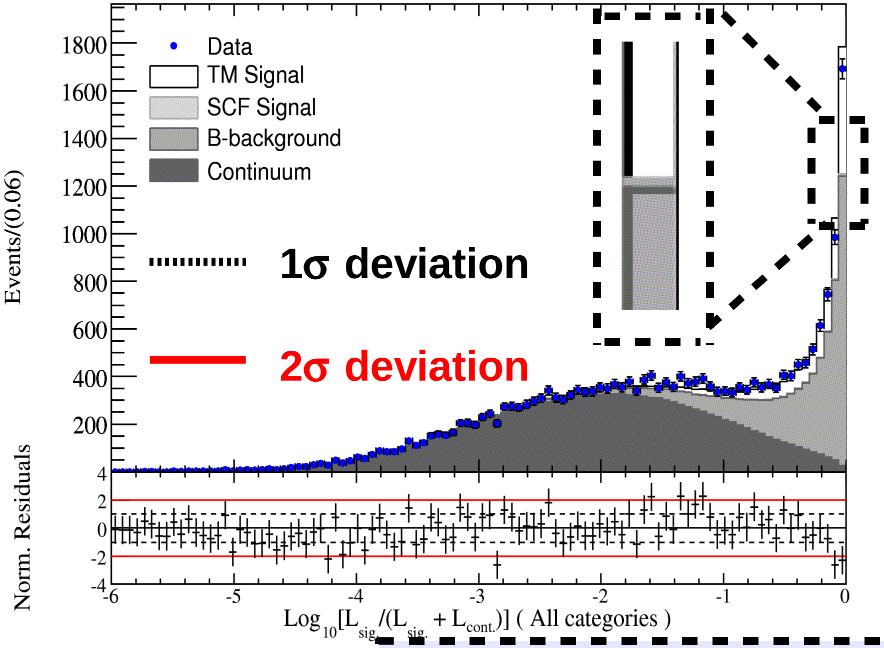
From the fitted isobar amplitudes the Q2B parameters are calculated

Fit Results: Proj. Plots (I)

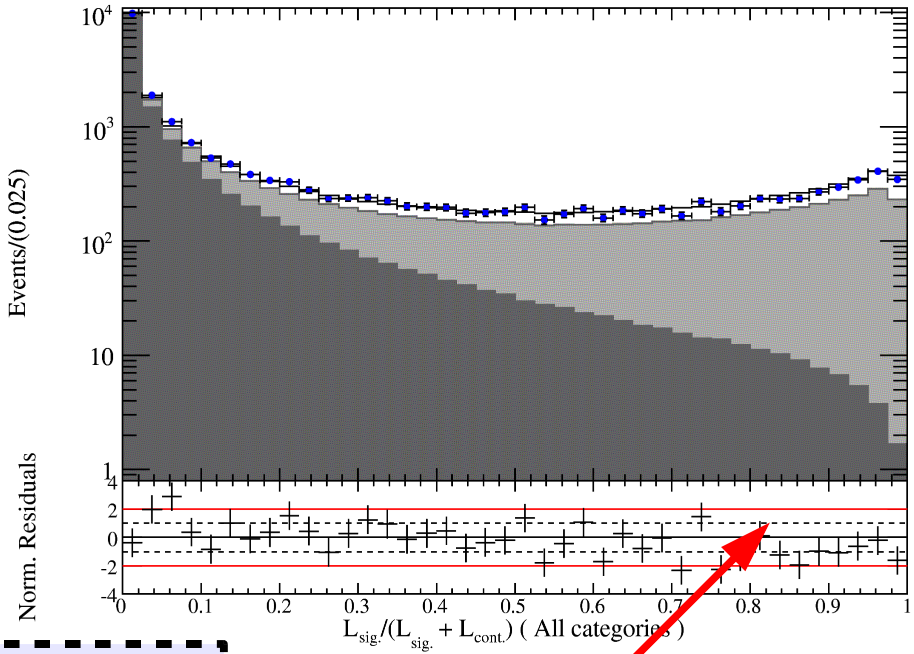
Likelihood Ratio

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

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



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



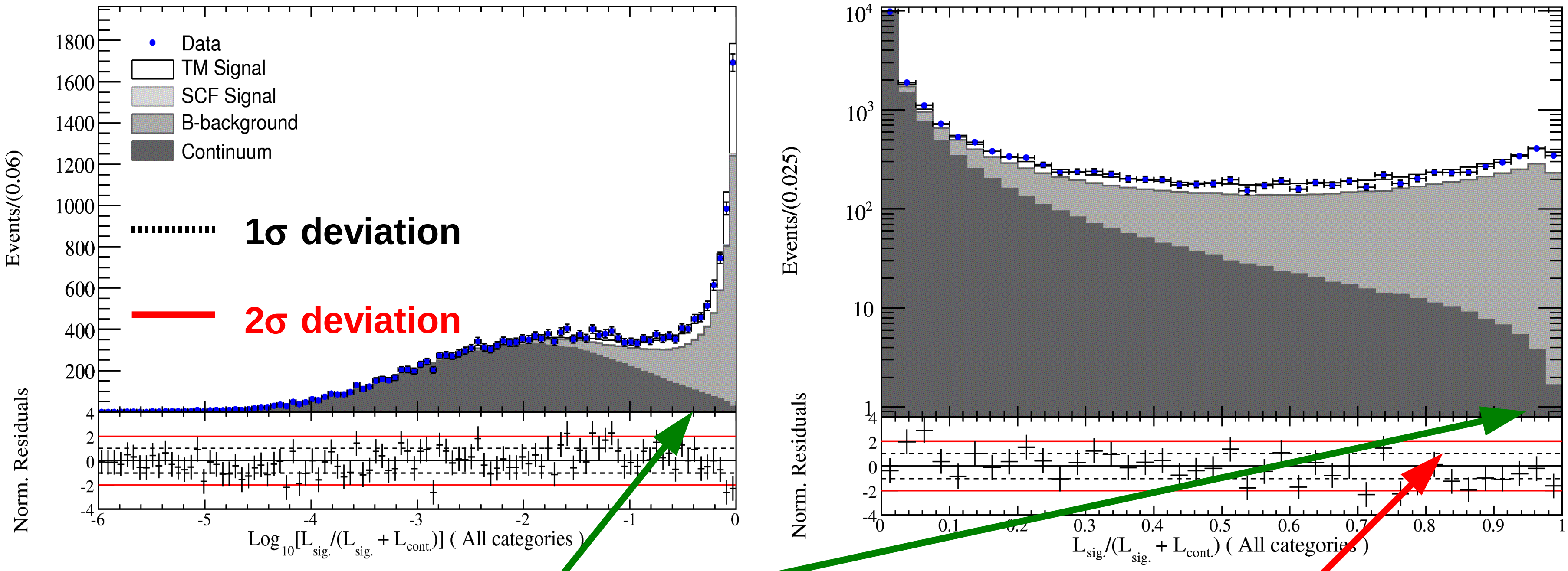
SCF barely seen, only 2% of signal

Residuals normalized in error units

Fit Results: Proj. Plots (I)

Likelihood Ratio

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



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

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

Signal Region

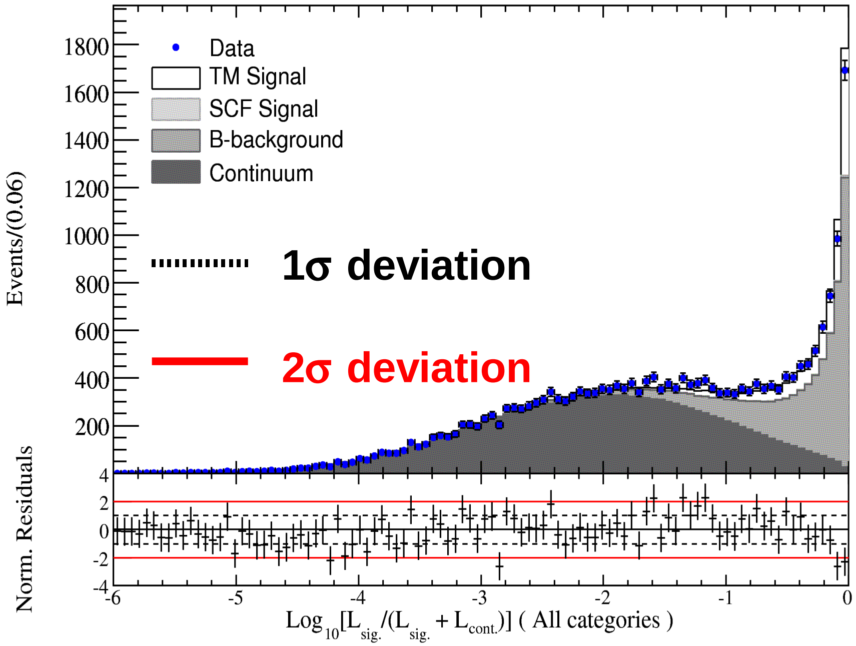
Residuals normalized in error units

Fit Results: Proj. Plots (I)

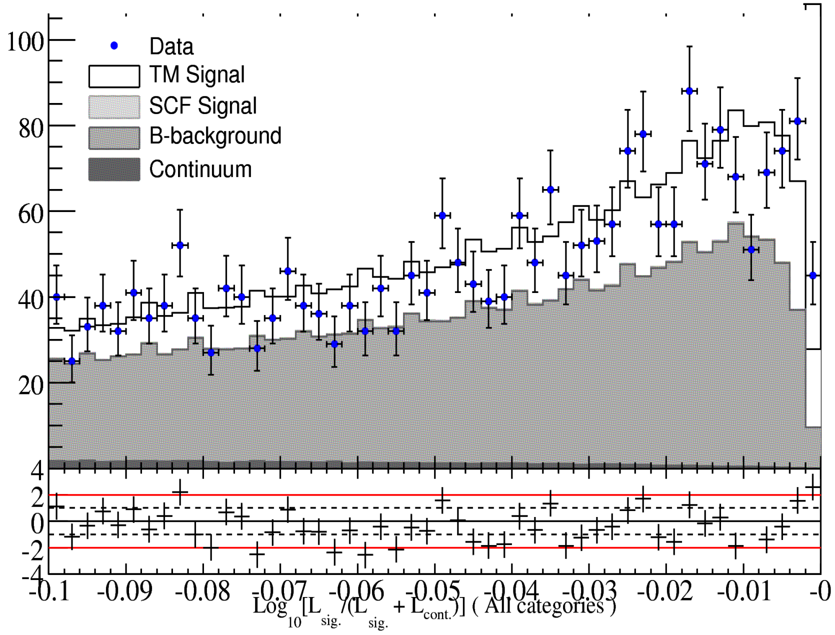
Likelihood Ratio

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

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



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

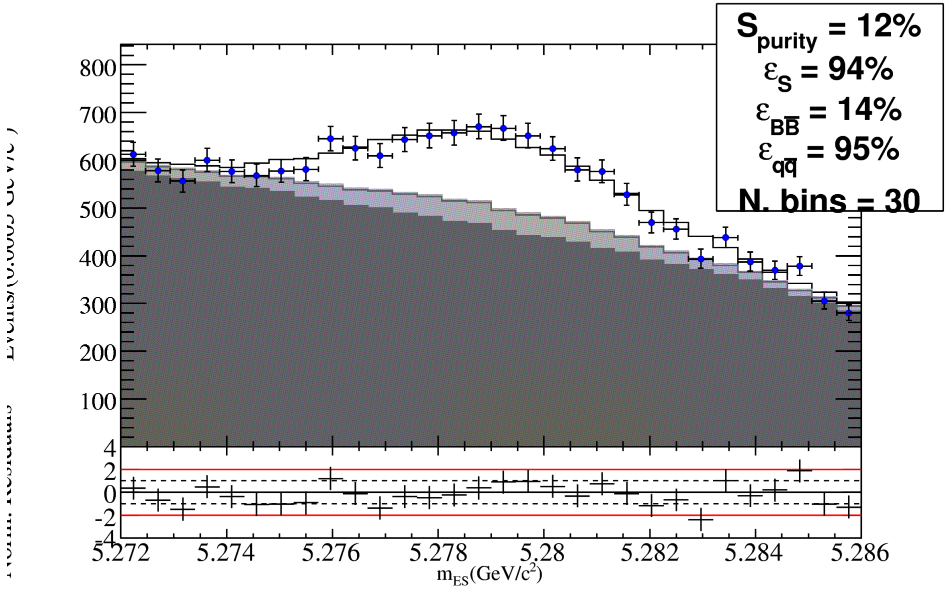


Zoom on the signal region

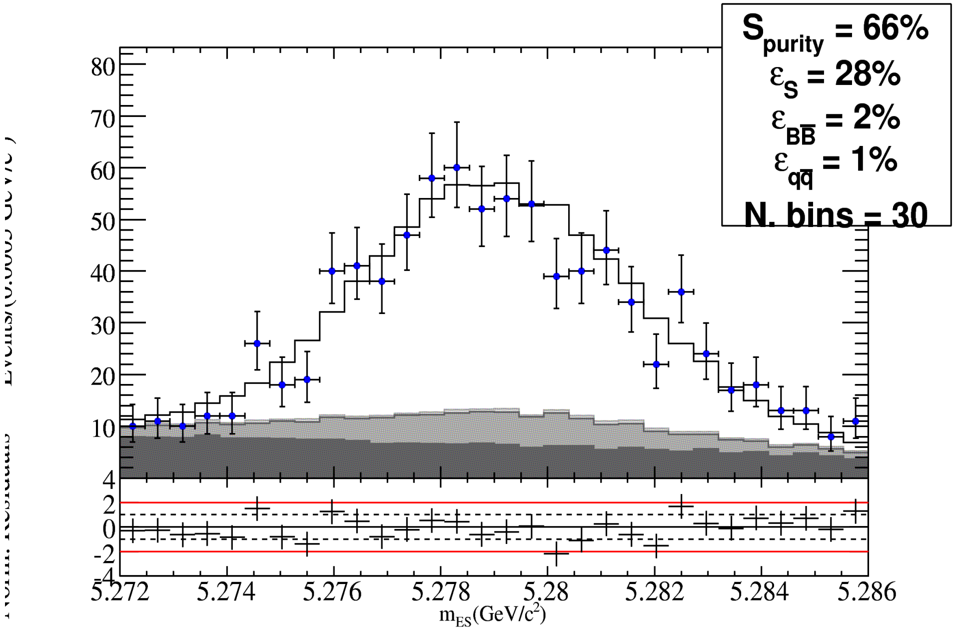
Fit Results: Proj. Plots (II)

m_{ES}

No R cut, Dπ and J/ψ vetoed



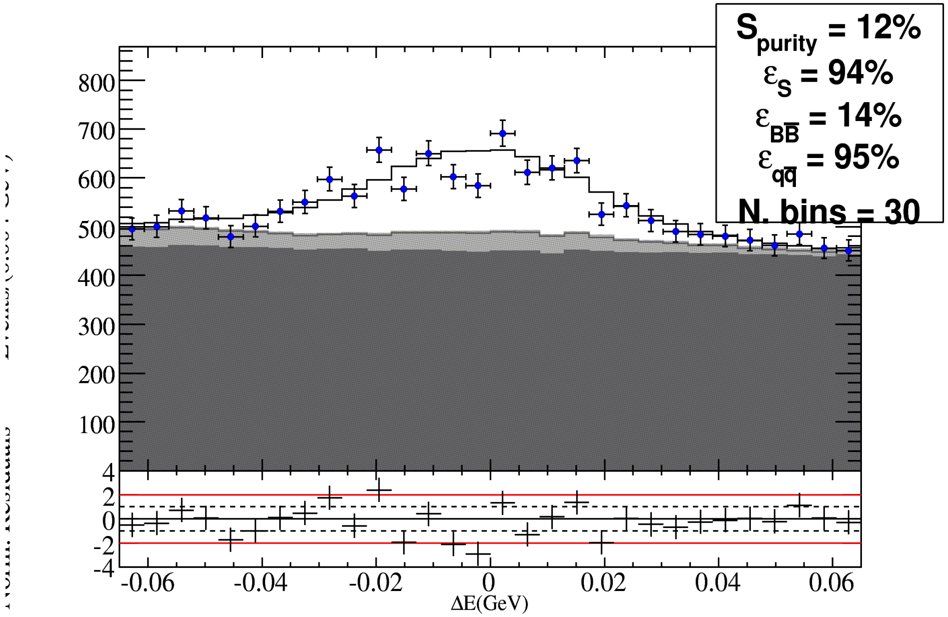
Signal enhanced by R cut, Dπ and J/ψ vetoed



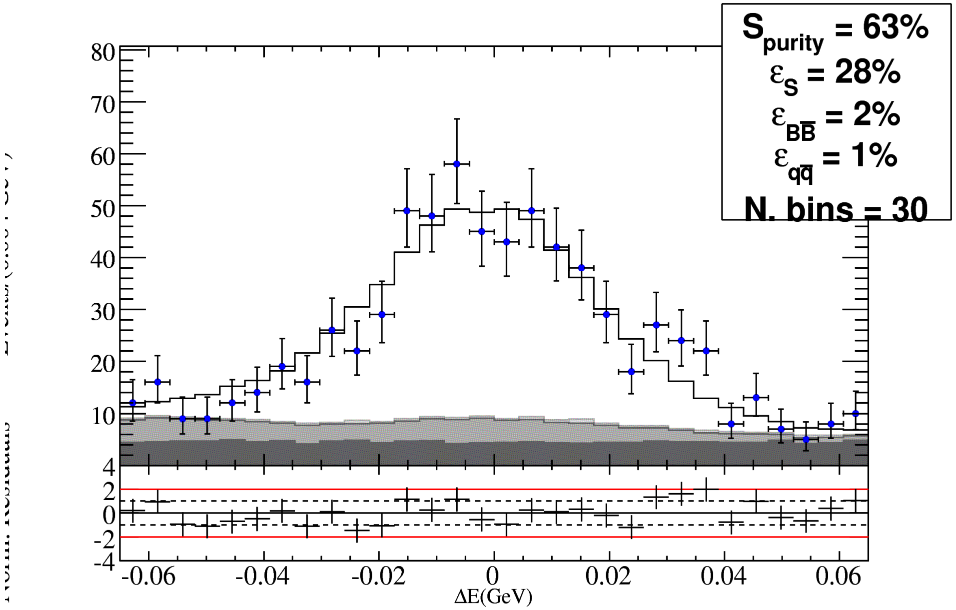
Fit Results: Proj. Plots (III)

ΔE

No R cut, Dπ and J/ψ vetoed



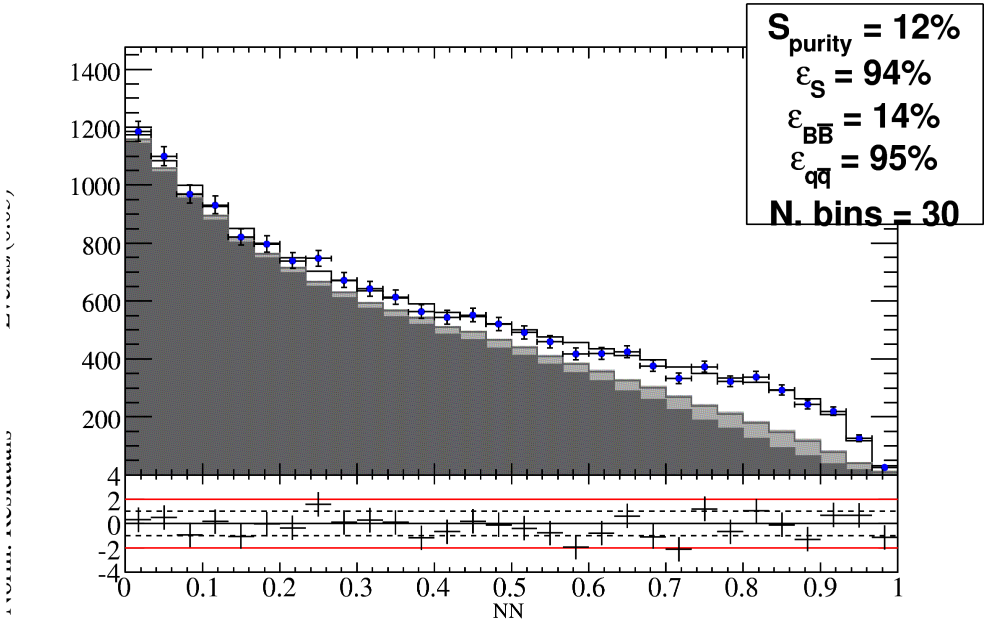
Signal enhanced by R cut, Dπ and J/ψ vetoed



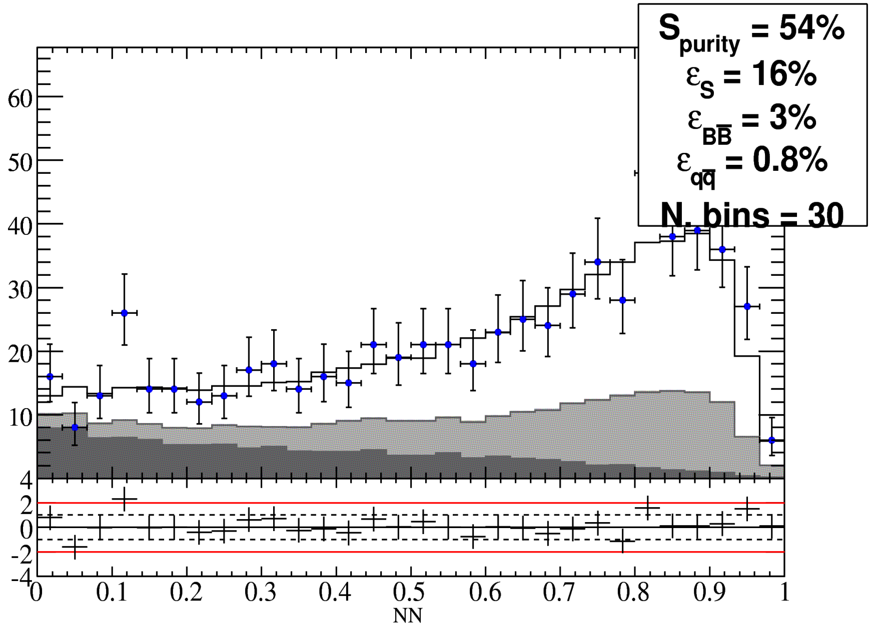
Fit Results: Proj. Plots (IV)

NN

No R cut, Dπ and J/ψ vetoed

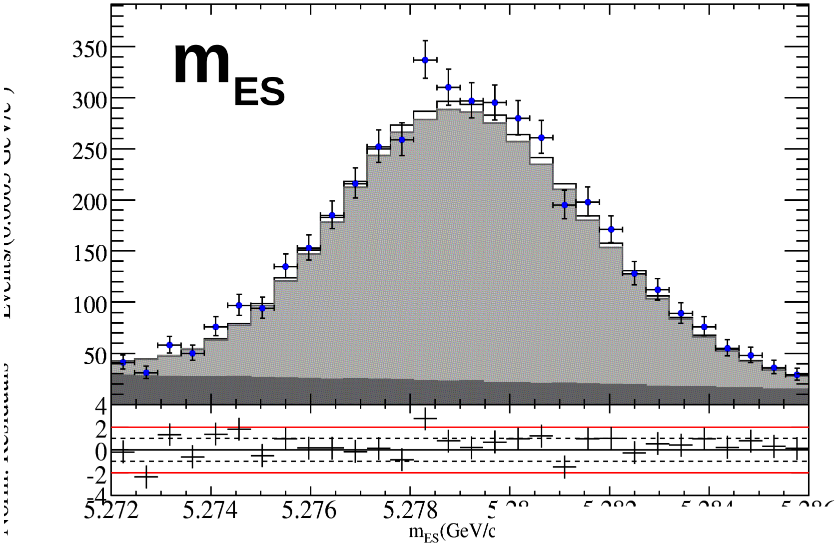


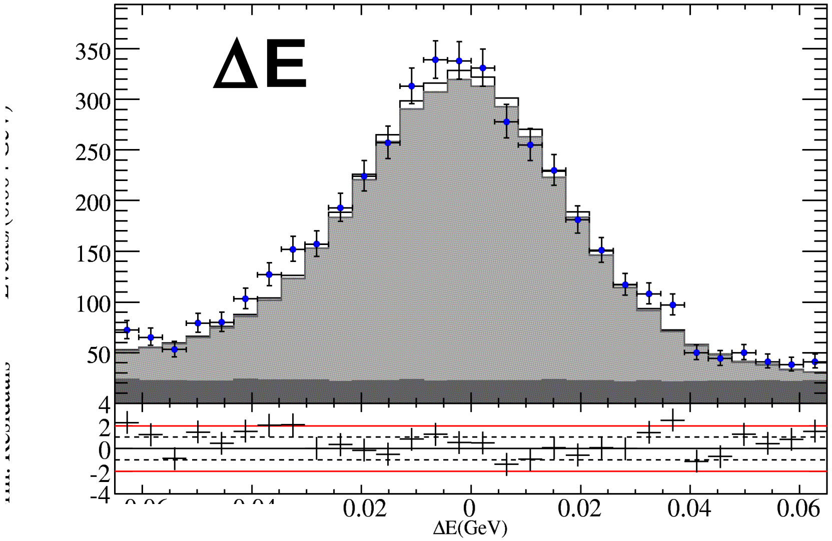
Signal enhanced by R cut, Dπ and J/ψ vetoed

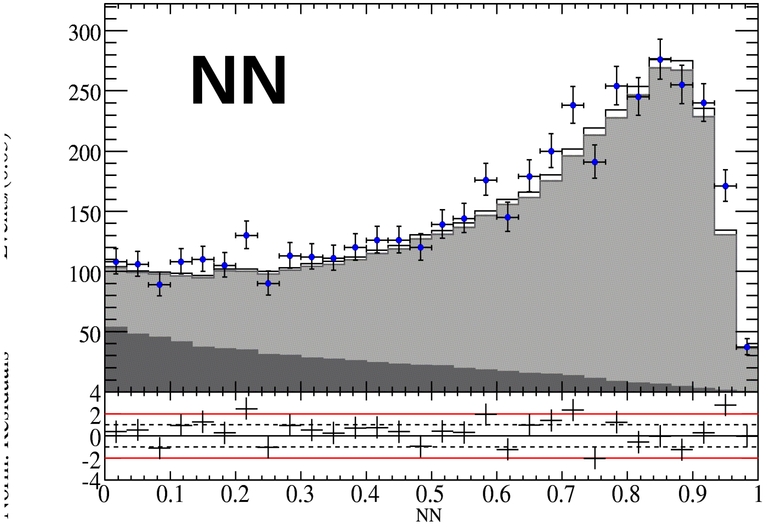


Fit Results: Proj. Plots (V)

Dπ Band

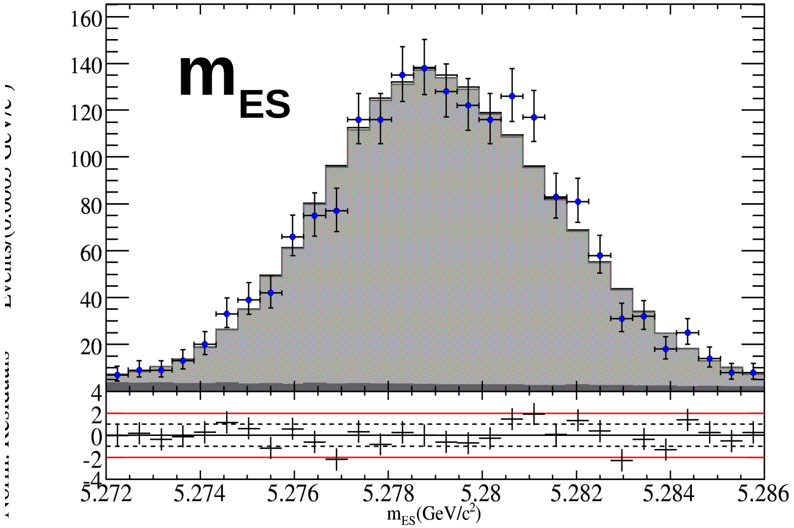


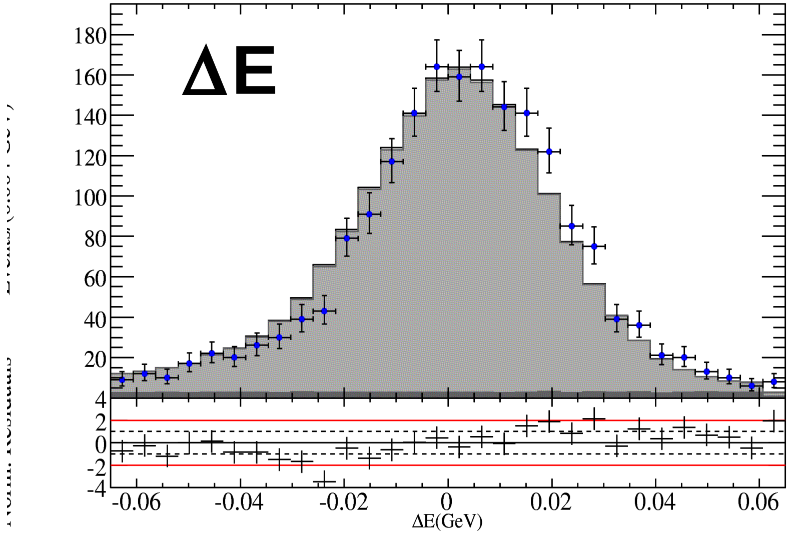


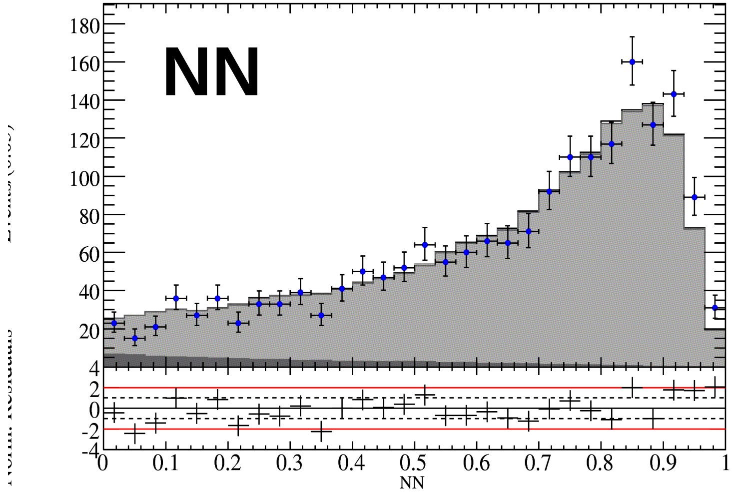


Fit Results: Proj. Plots (VI)

J/ψ Band



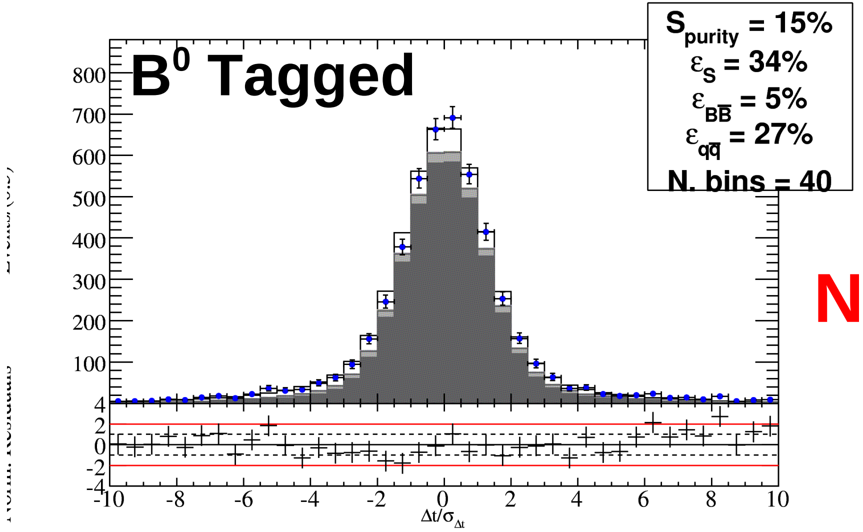


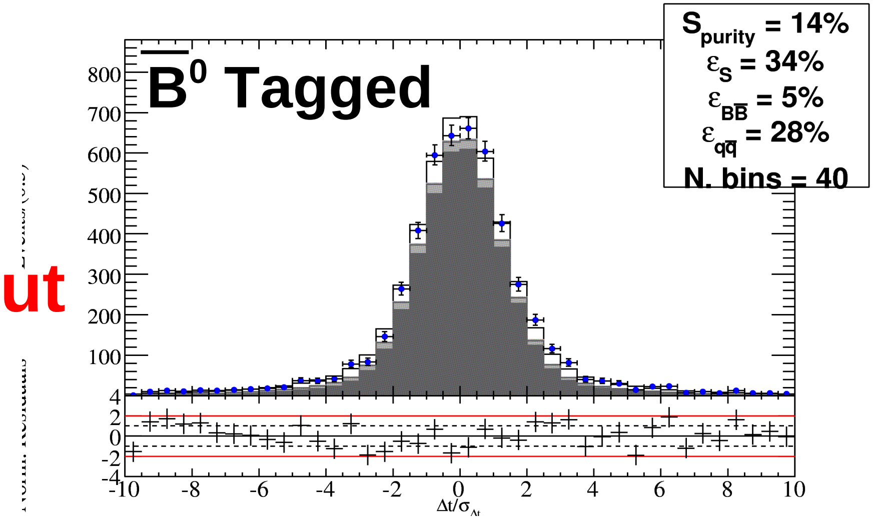


Fit Results: Proj. Plots (VII)

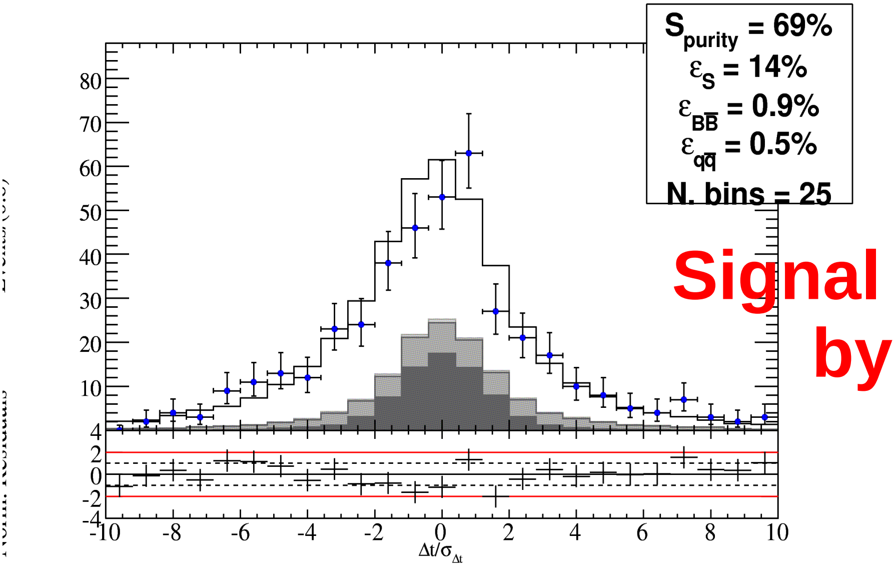
$\Delta t/\sigma(\Delta t)$ (NoTag events excl.)

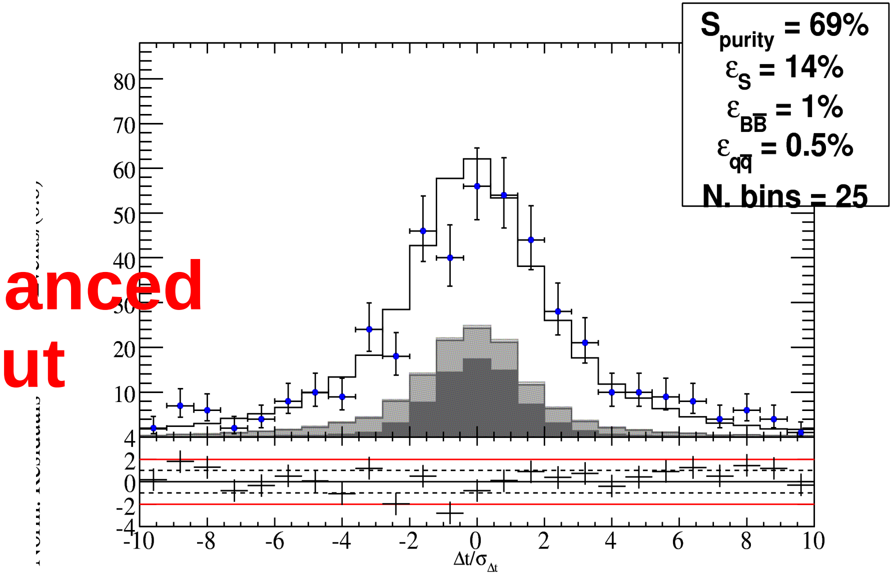
Dπ and J/ψ vetoed





No R cut





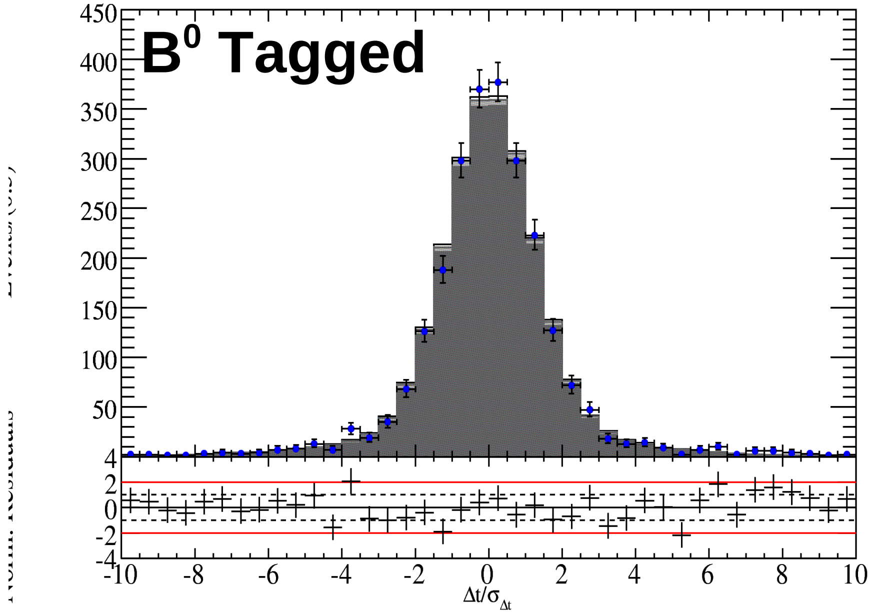
Signal enhanced by R cut

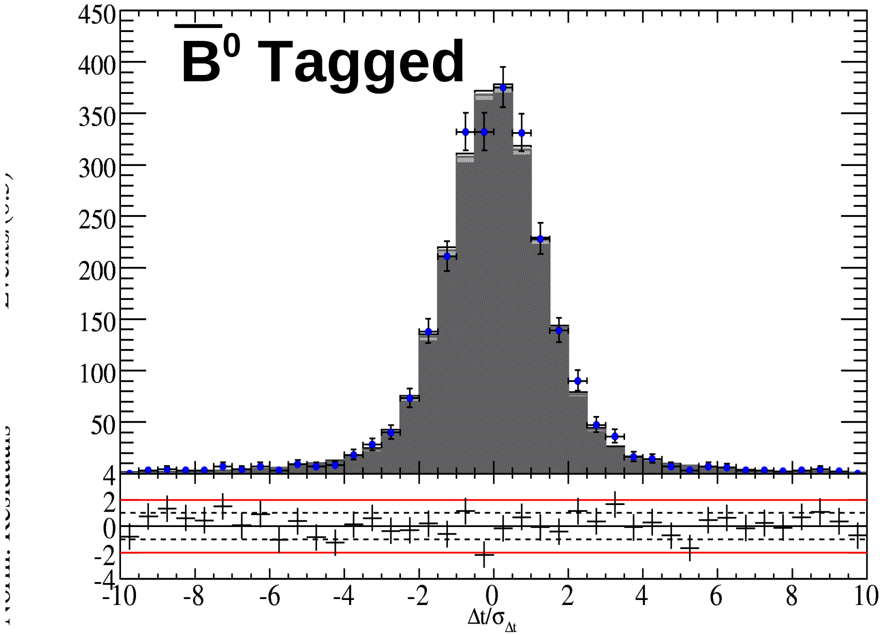
Fit Results: Proj. Plots (VIII)

$\Delta t/\sigma(\Delta t)$ (NoTag events excl.)

Dπ and J/ψ vetoed

Continuum enhanced by R cut



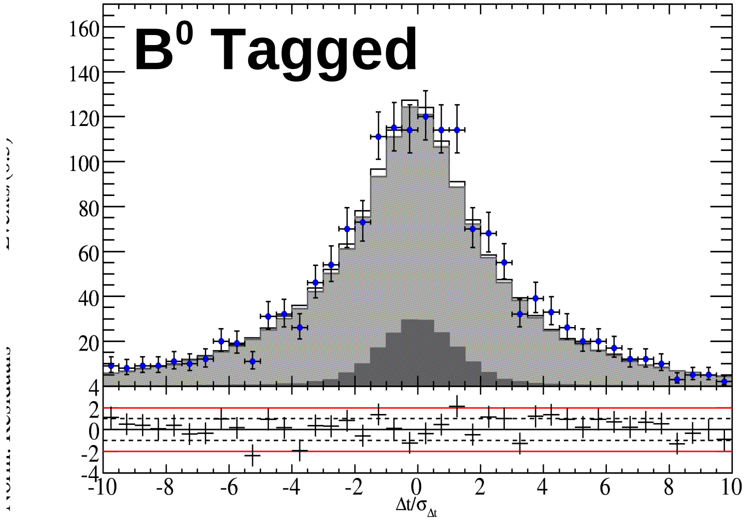


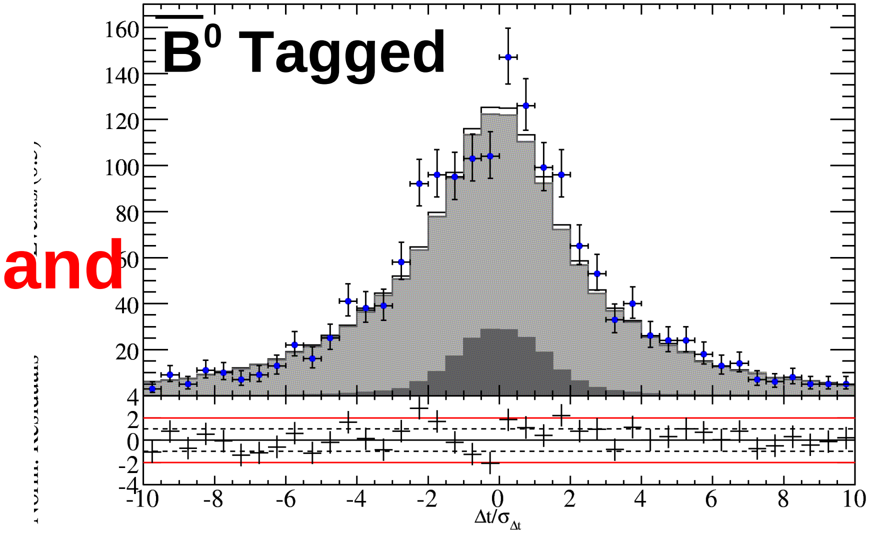
Fit Results: Proj. Plots (IX)

$\Delta t/\sigma(\Delta t)$ (NoTag events excl.)

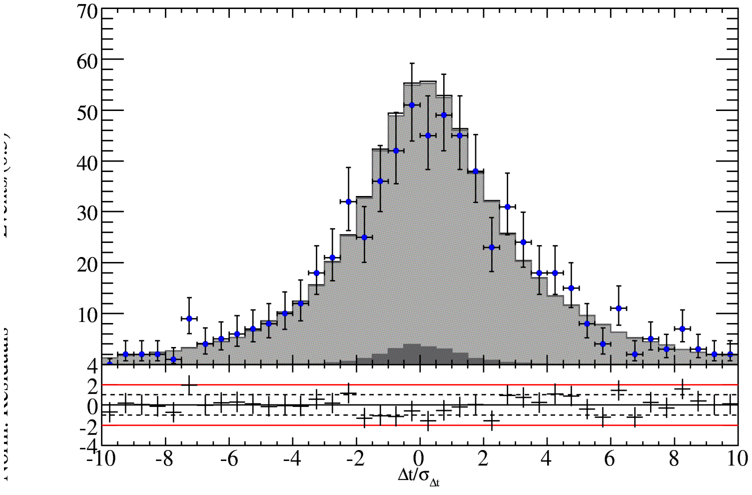
Dπ and J/ψ vetoed

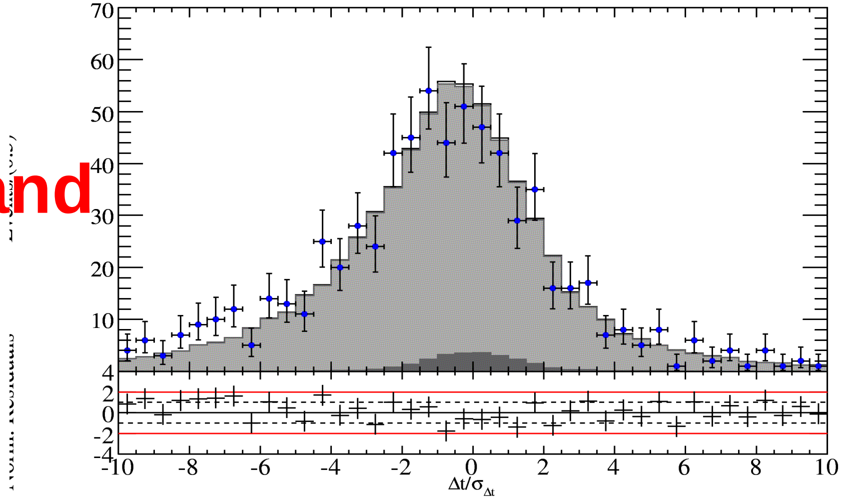
Dπ Band





J/ψ Band

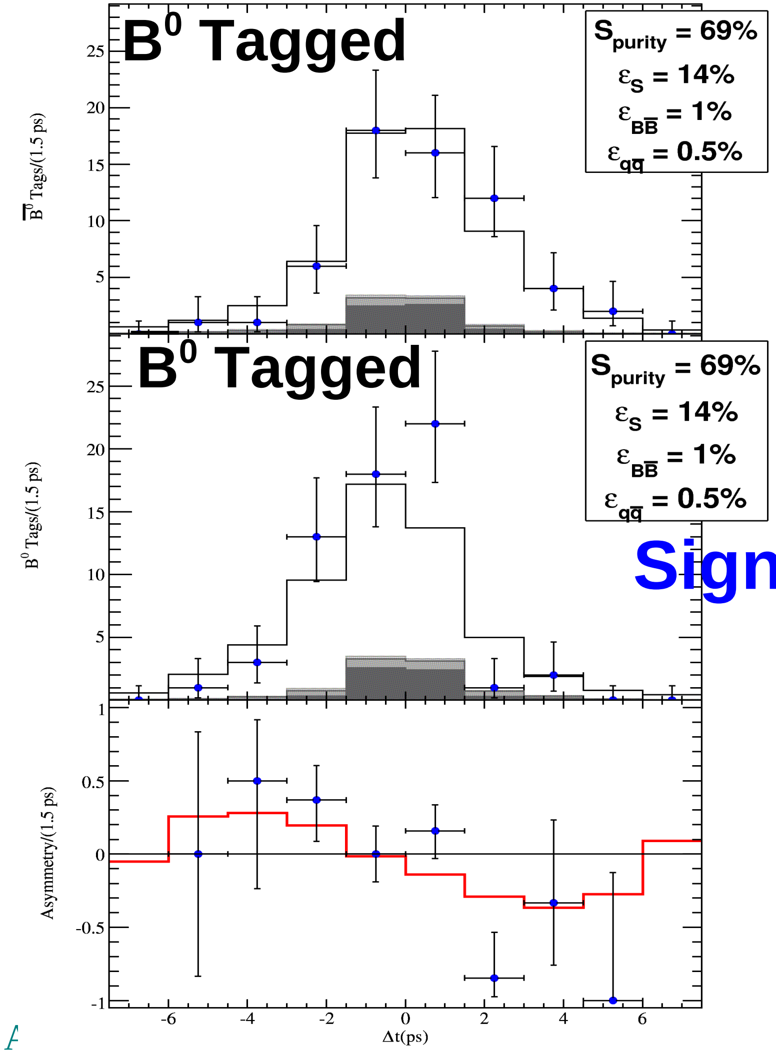




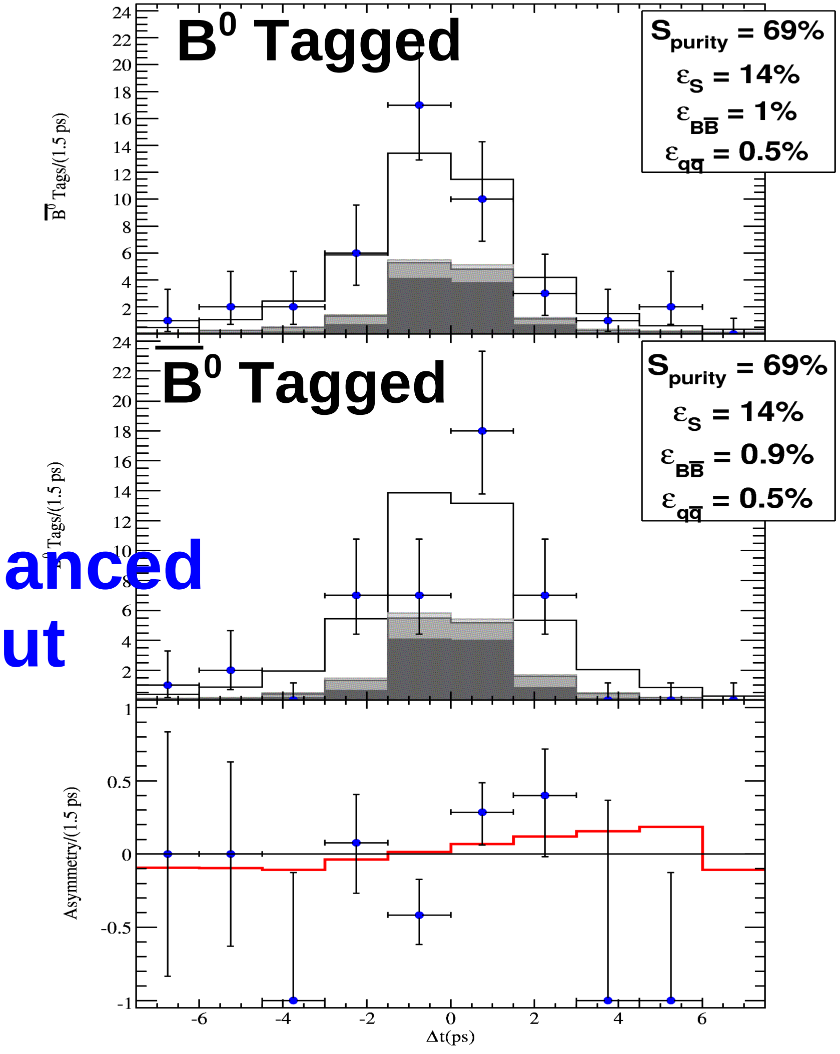
Fit Results: Proj. Plots (X)

Δt dependent asymmetries

$f_0(980)K^0_S$ Band



$\rho^0(770)K^0_S$ Band

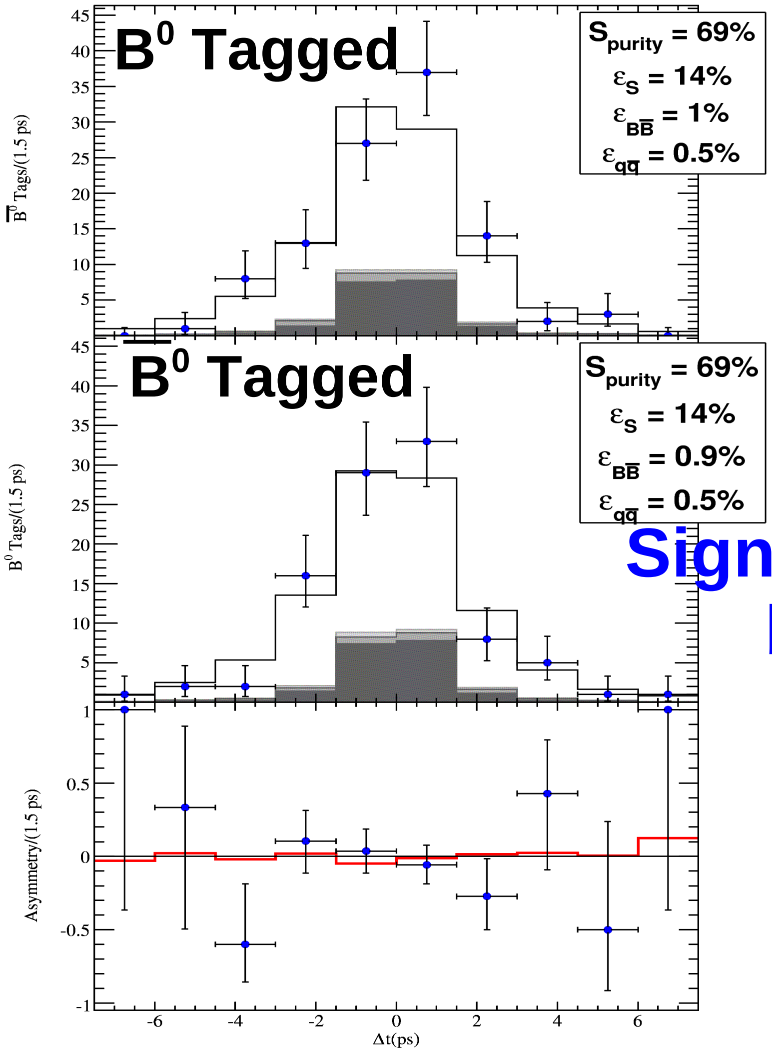


Signal enhanced by R cut

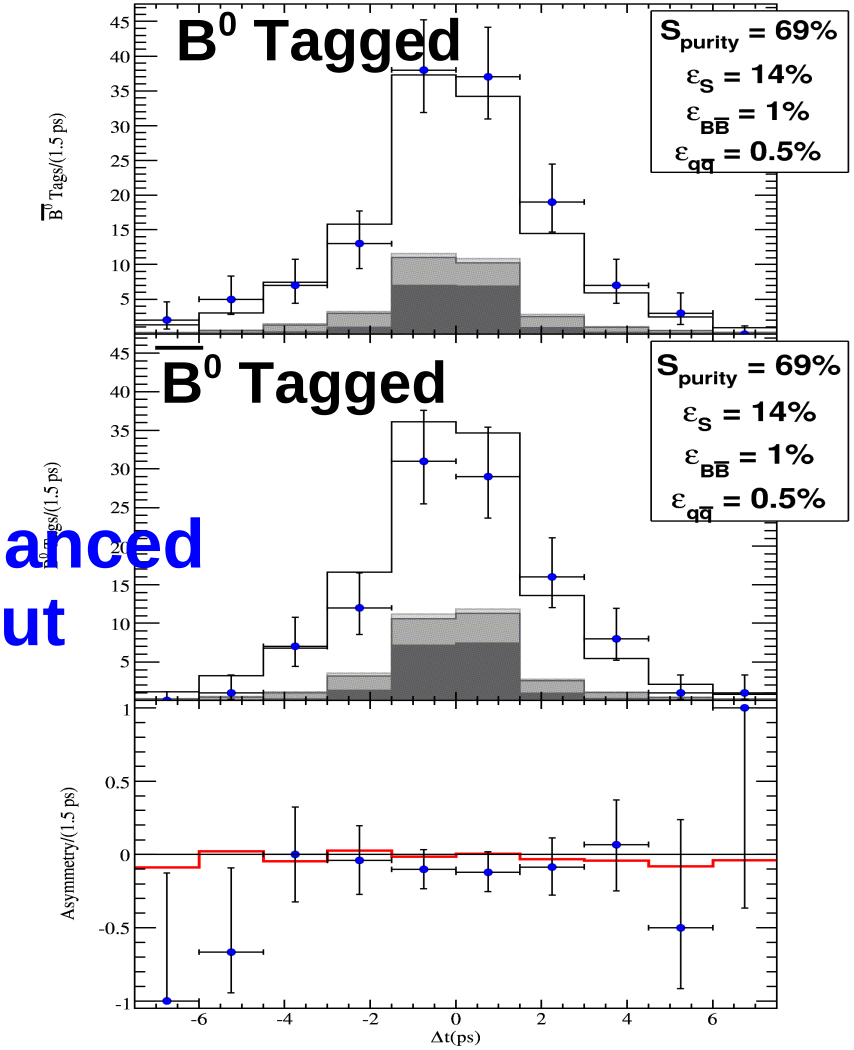
Fit Results: Proj. Plots (XI)

Δt dependent asymmetries

K*(892)π Band



S-wave Kπ Band



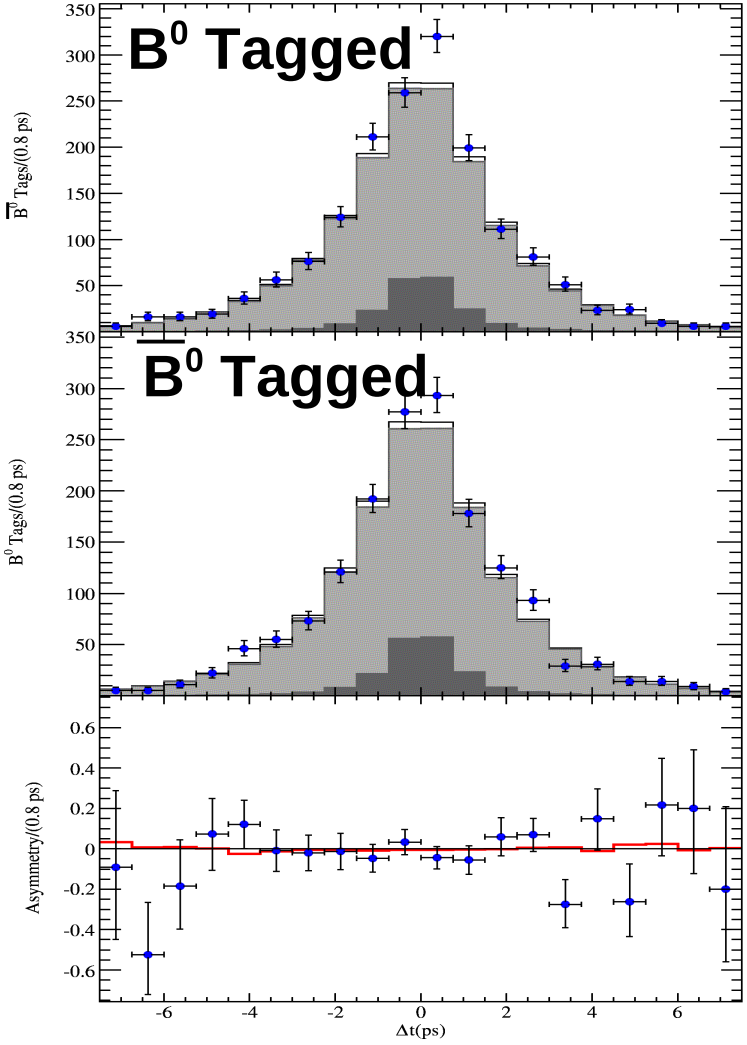
Signal enhanced by R cut

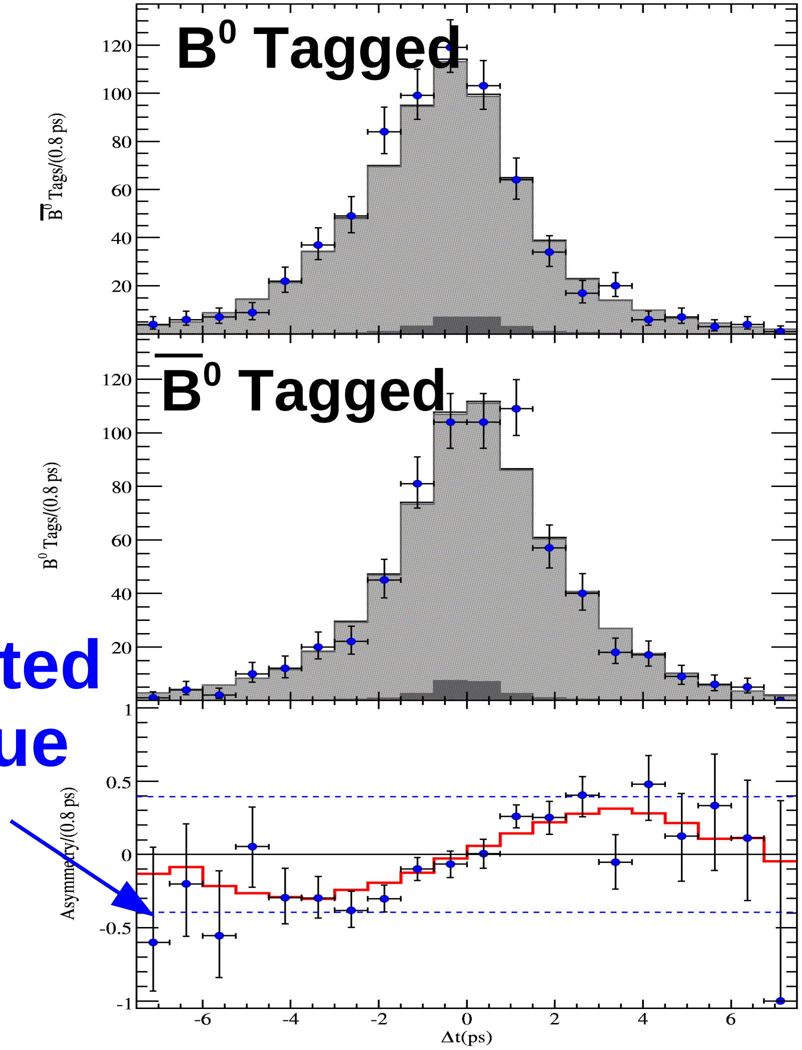
Fit Results: Proj. Plots (XII)

Δt dependent asymmetries

Dπ Band

J/ψ Band

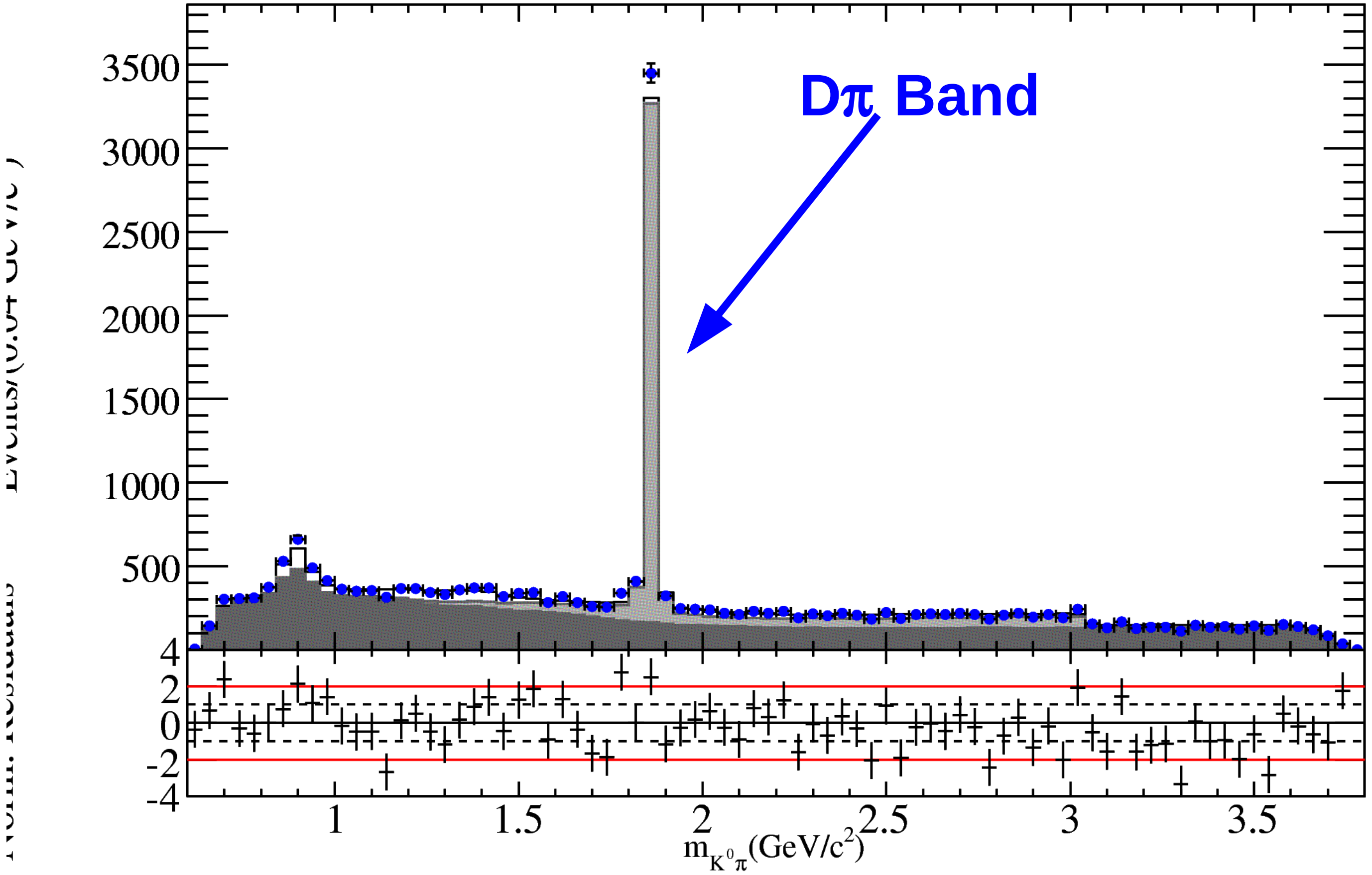




Expected S value

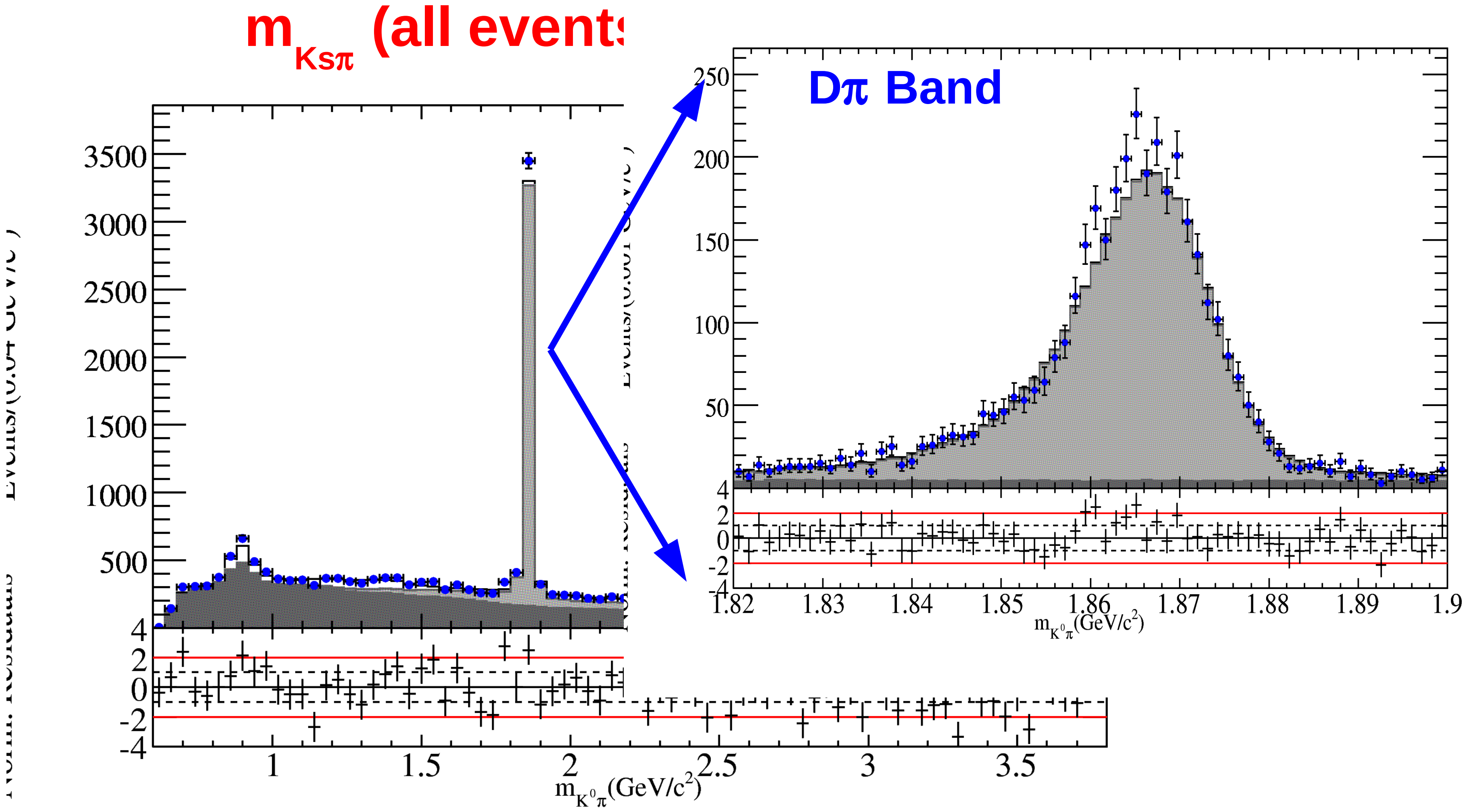
Fit Results: Proj. Plots (XIII)

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



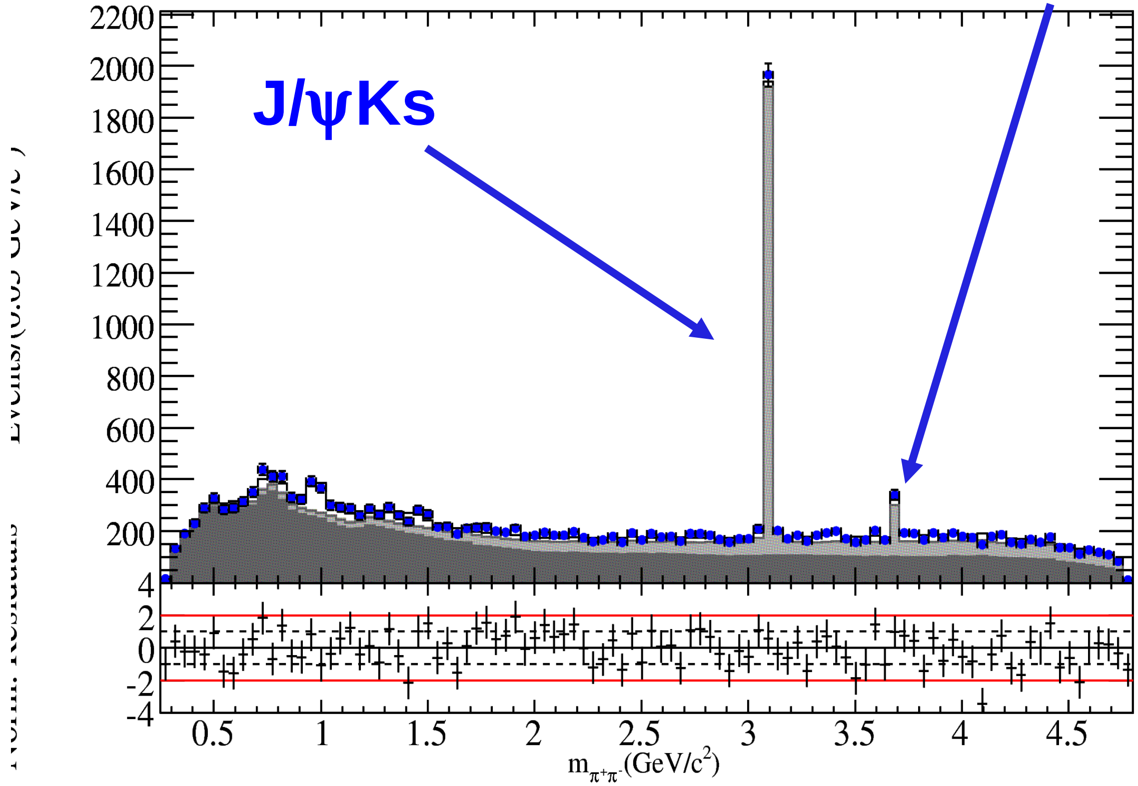
Dπ Band

Fit Results: Proj. Plots (XIII)



Fit Results: Proj. Plots (XIV)

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

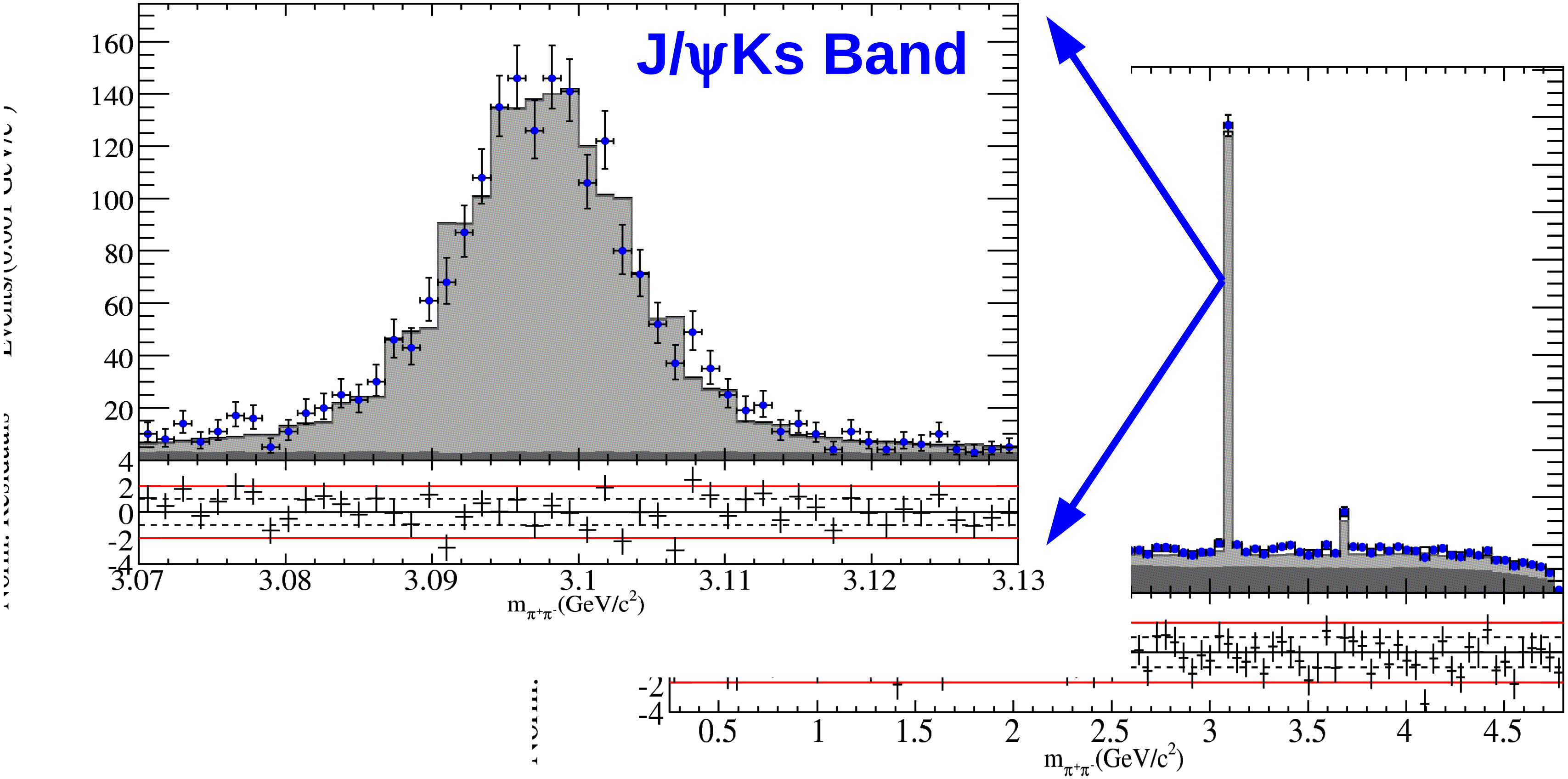


ψ(2S)Ks

J/ψKs

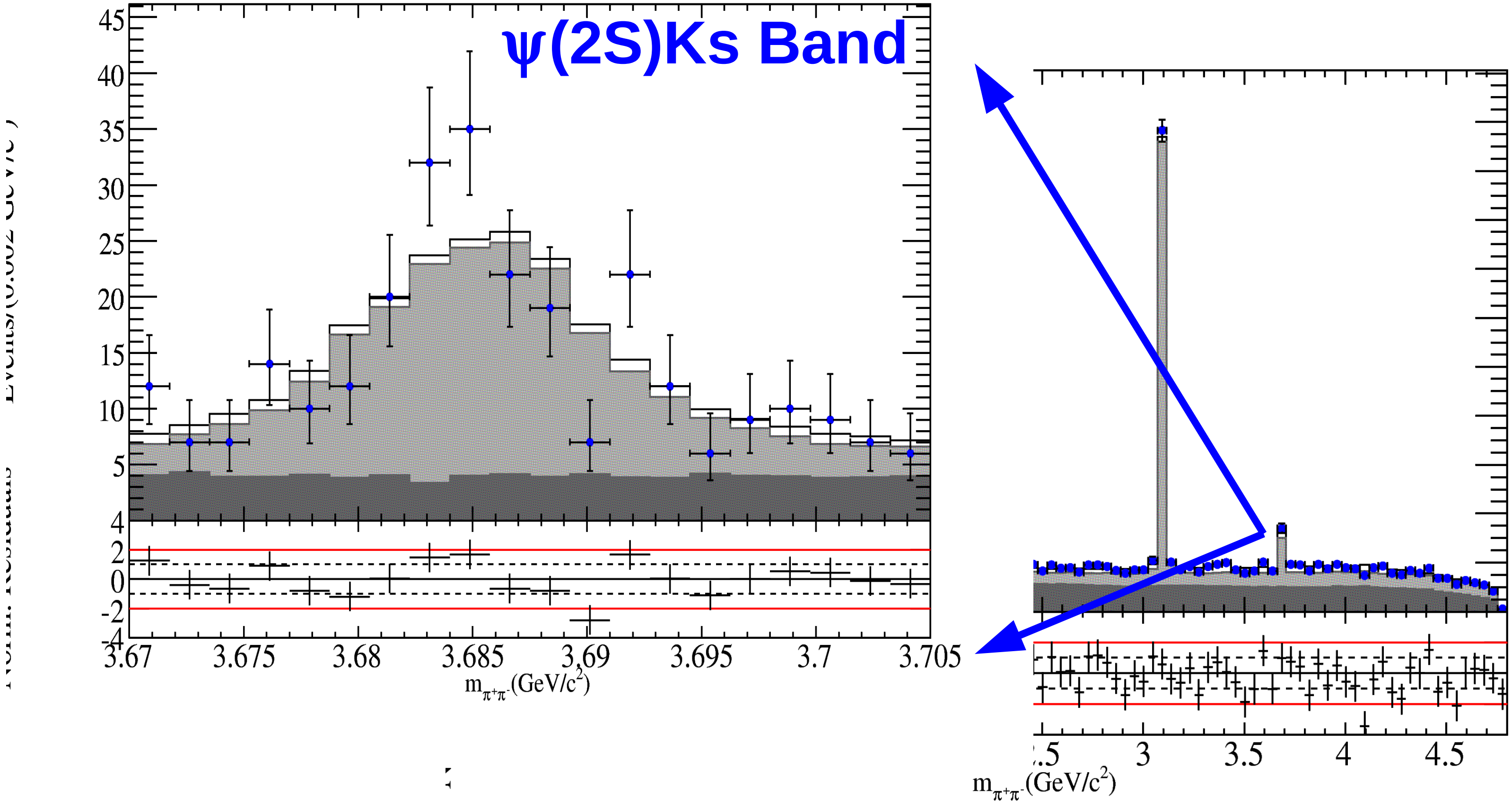
Fit Results: Proj. Plots (XIV)

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



Fit Results: Proj. Plots (XIV)

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

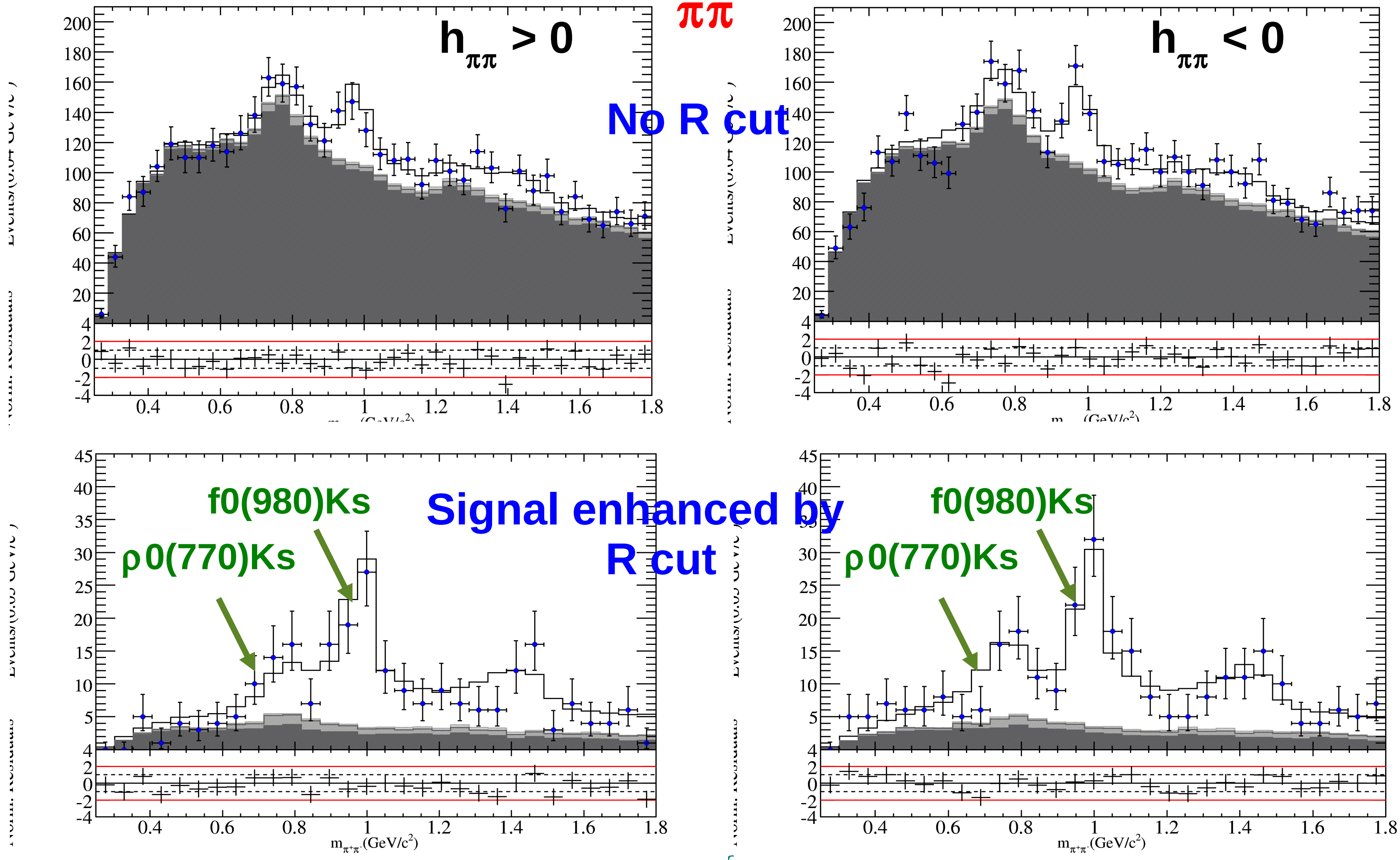


ψ(2S)Ks Band

Fit Results: Proj. Plots (XV)

$m_{\pi\pi}$

Dπ veto



No R cut

Signal enhanced by R cut

f0(980)Ks

ρ0(770)Ks

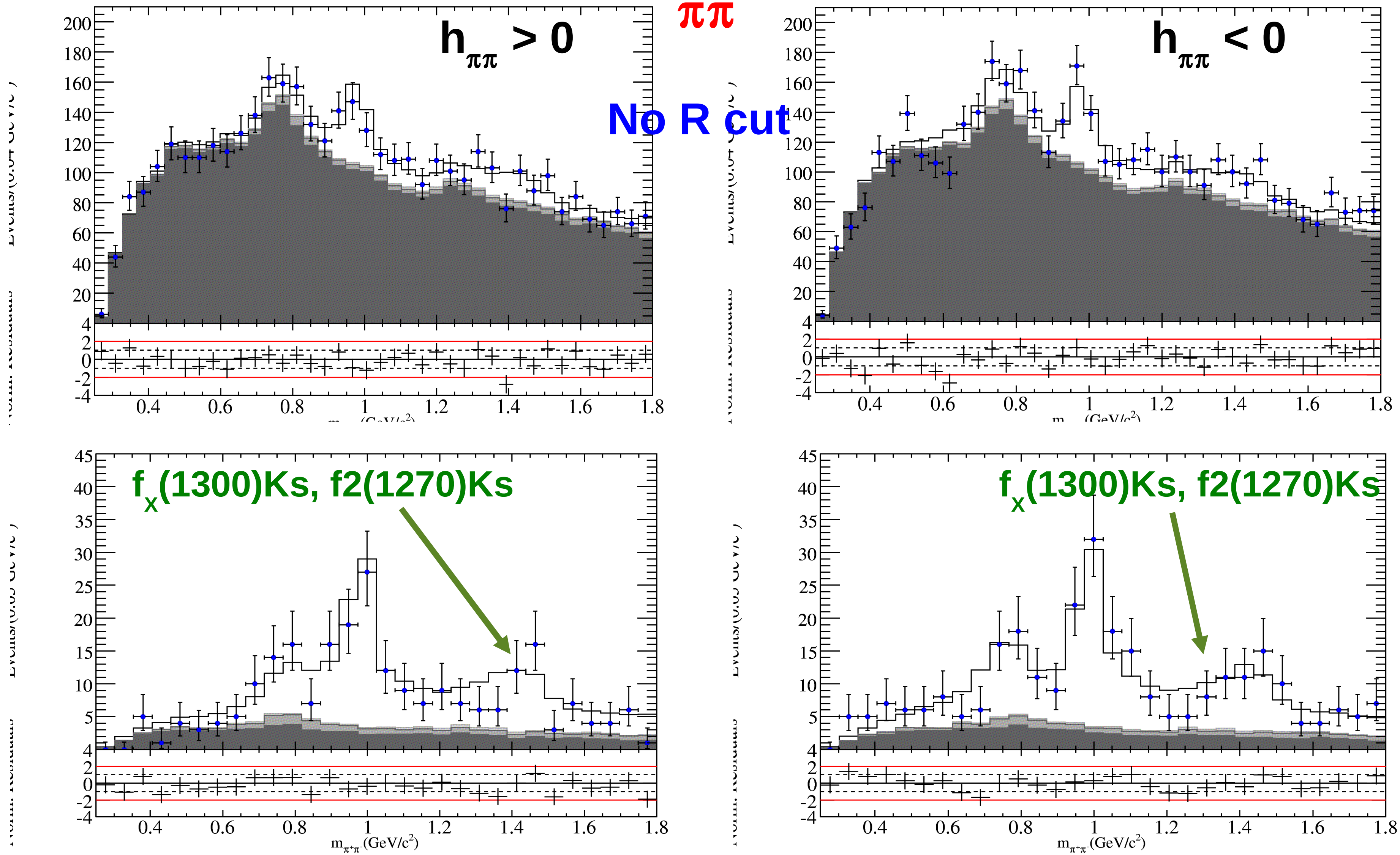
f0(980)Ks

ρ0(770)Ks

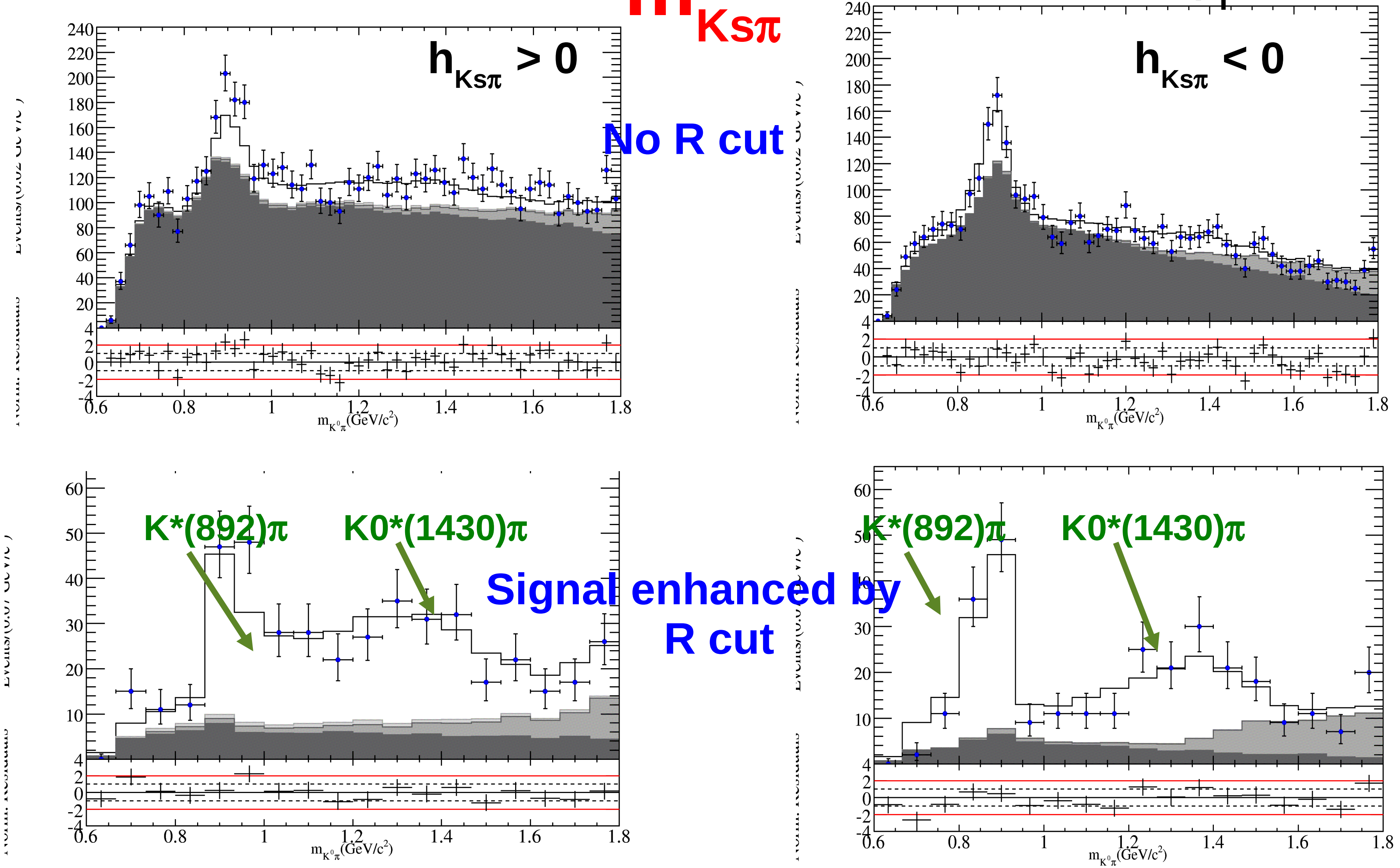
Fit Results: Proj. Plots (XV)

$m_{\pi\pi}$

Dπ veto



Fit Results: Proj. Plots (XVI)



$m_{Ks\pi}$

J/ψKs veto

$h_{Ks\pi} > 0$

$h_{Ks\pi} < 0$

No R cut

K*(892)π K0*(1430)π

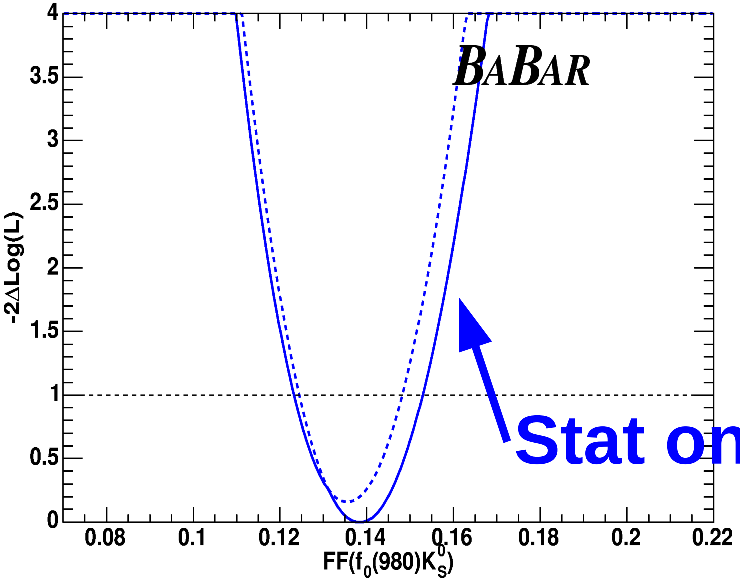
K*(892)π K0*(1430)π

Signal enhanced by R cut

Fit Results: 1D Like. Scans (I)

Fit fractions

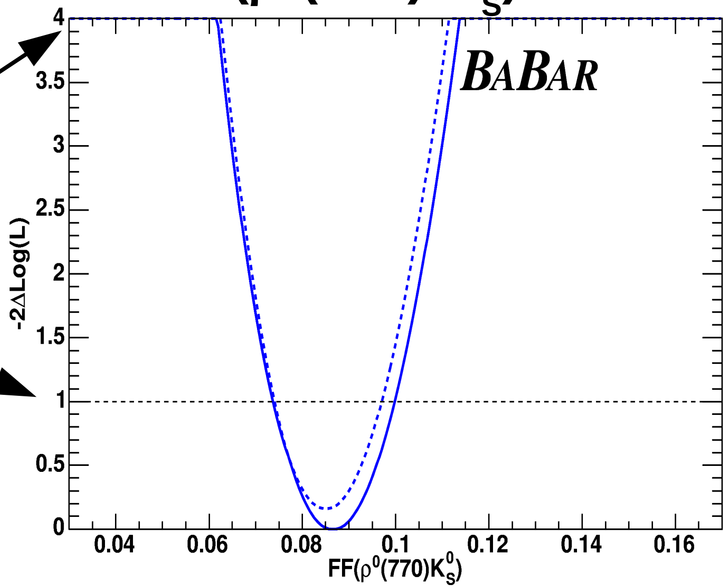
FF(f_0(980)K^0_S)



FF(ρ^0(770)K^0_S)

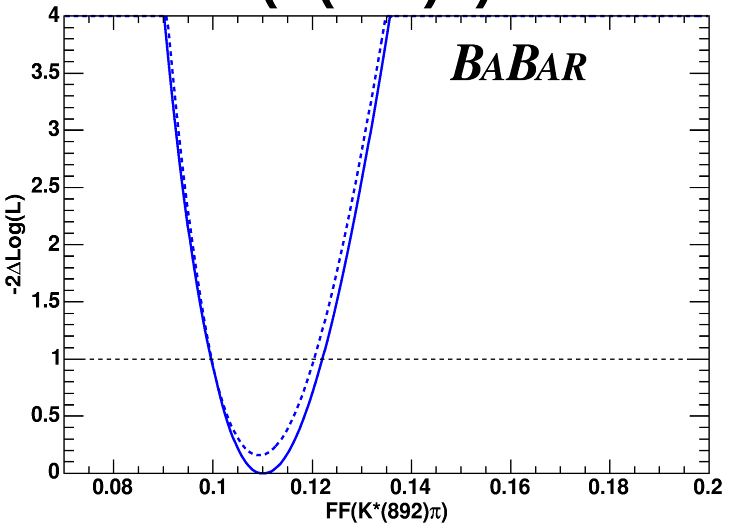
-2Log(L) = 4

-2Log(L) = 1

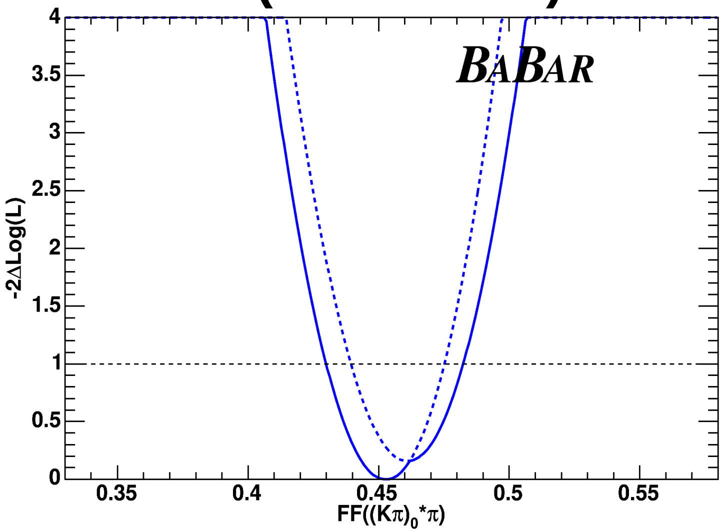


Stat only scans

FF(K(892)π)

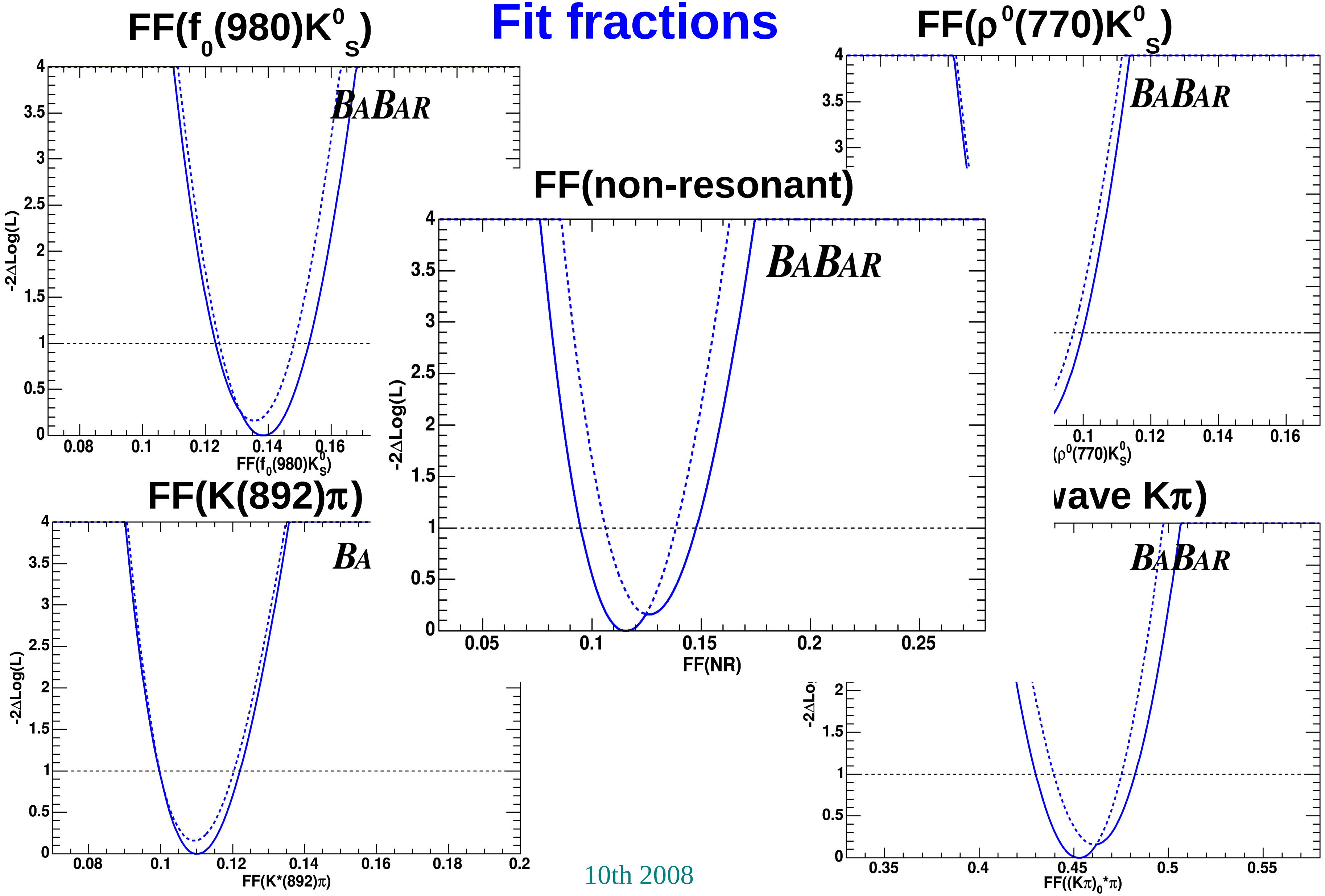


FF(S-wave Kπ)



Fit Results: 1D Like. Scans (I)

Fit fractions



FF(f_0(980)K^0_S)

FF(ρ^0(770)K^0_S)

FF(non-resonant)

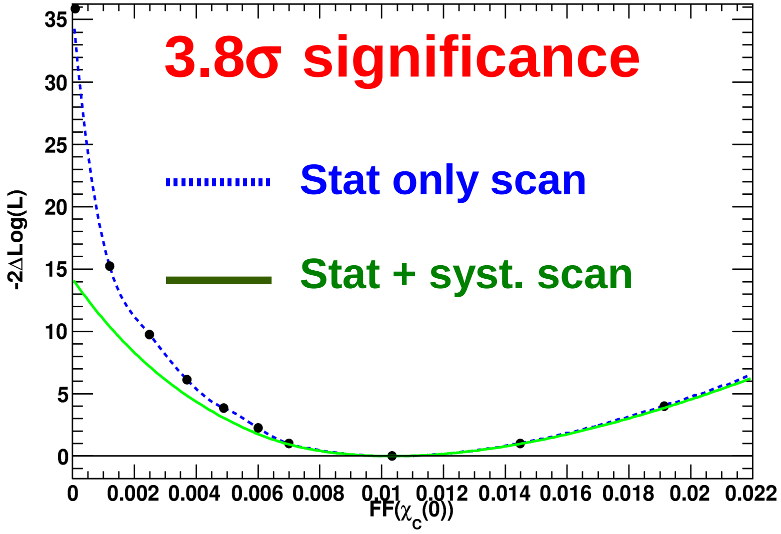
FF(K(892)π)

vave Kπ)

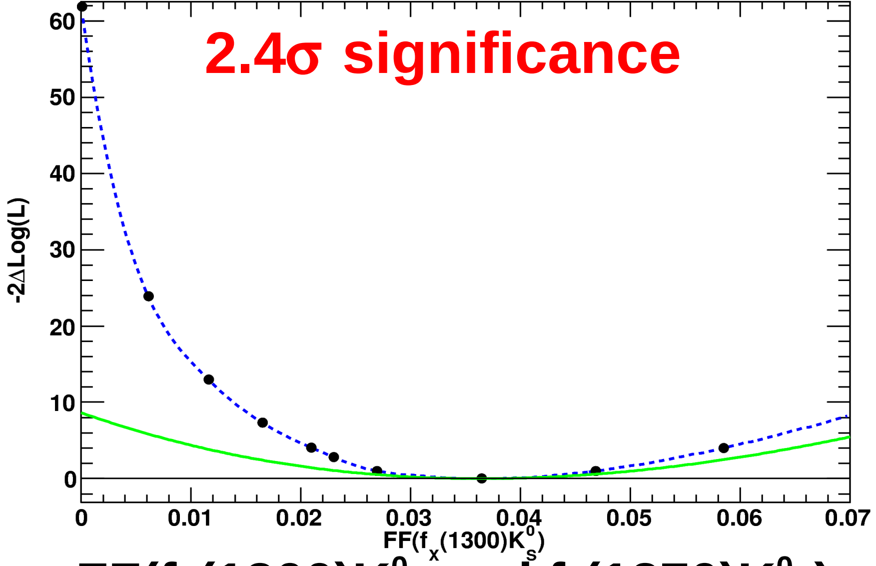
Fit Results: 1D Like. Scans (II)

Fit fractions

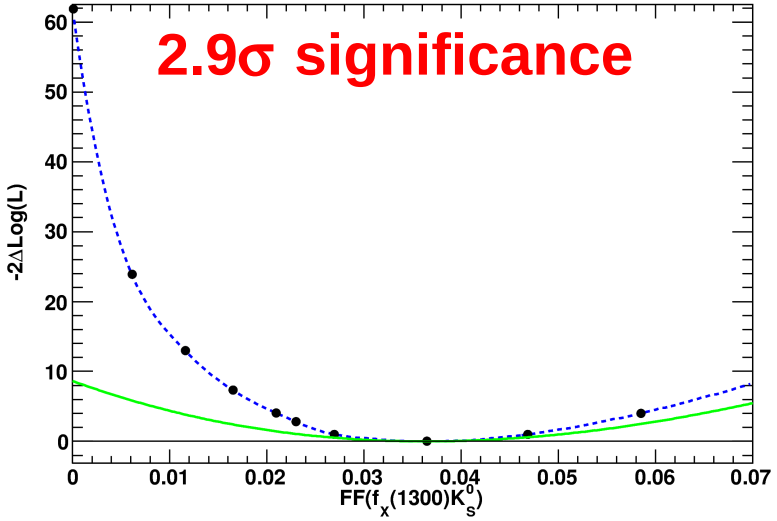
$\mathrm{FF}(\chi(c0)K^0_S)$



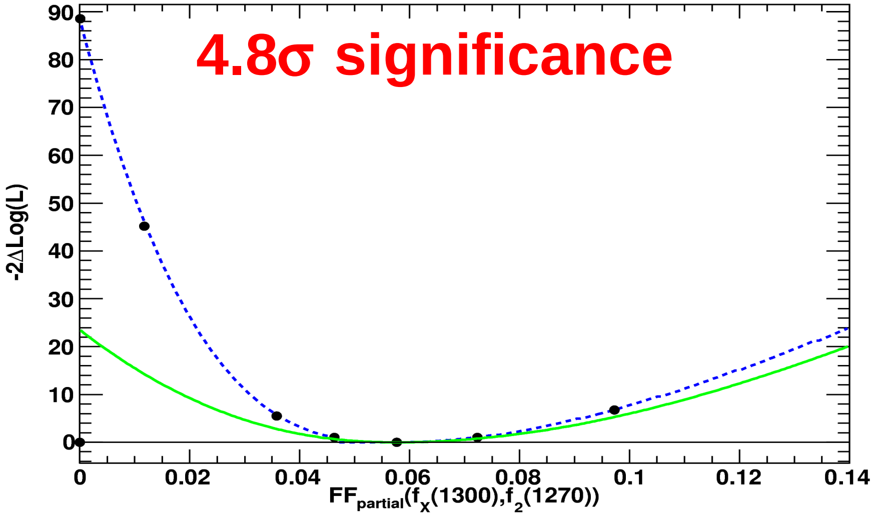
$\mathrm{FF}(f_2(1270)K^0_S)$



$\mathrm{FF}(f_X(1300)K^0_S)$

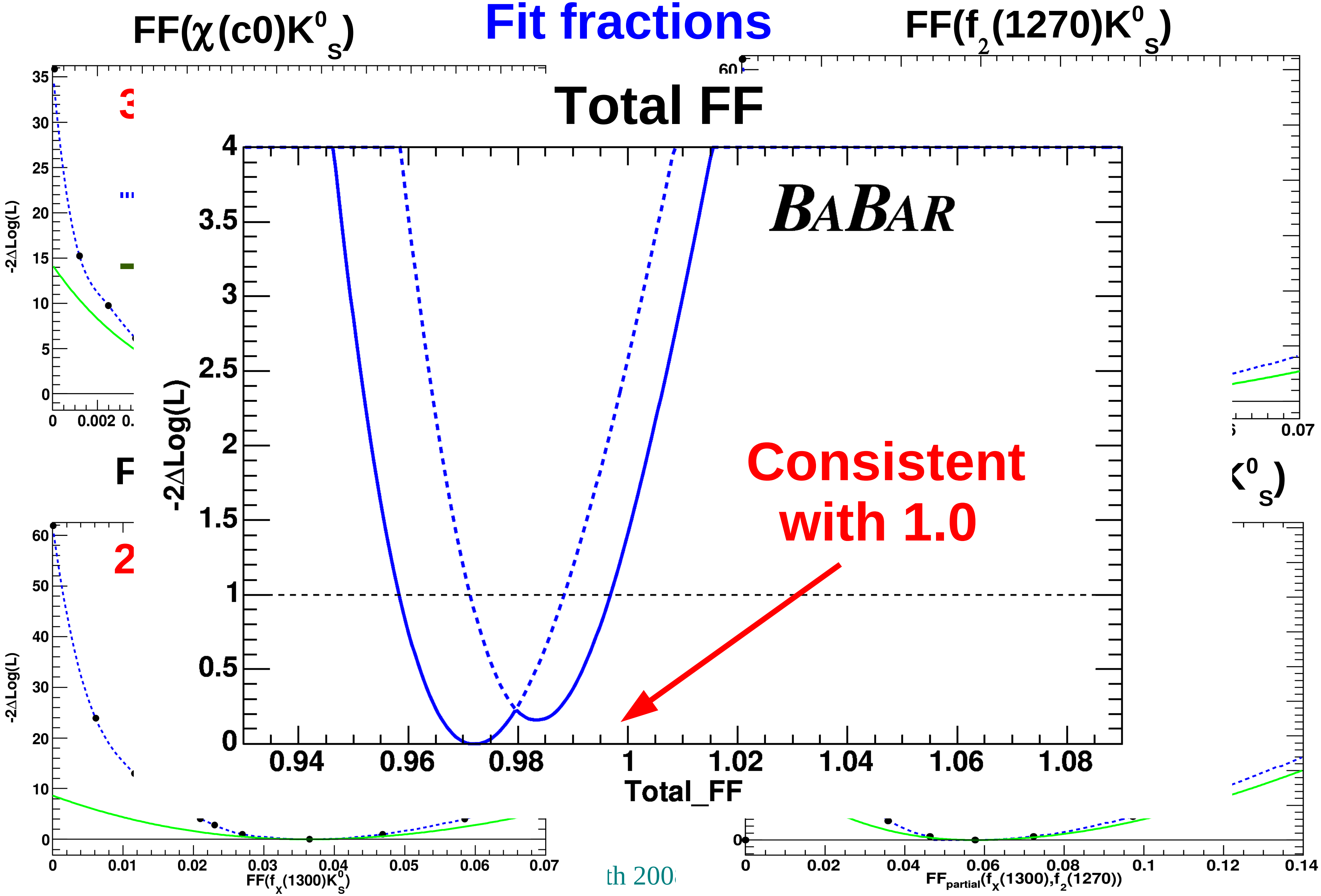


$\mathrm{FF}(f_X(1300)K^0_S \text{ and } f_2(1270)K^0_S)$



Fit Results: 1D Like. Scans (II)

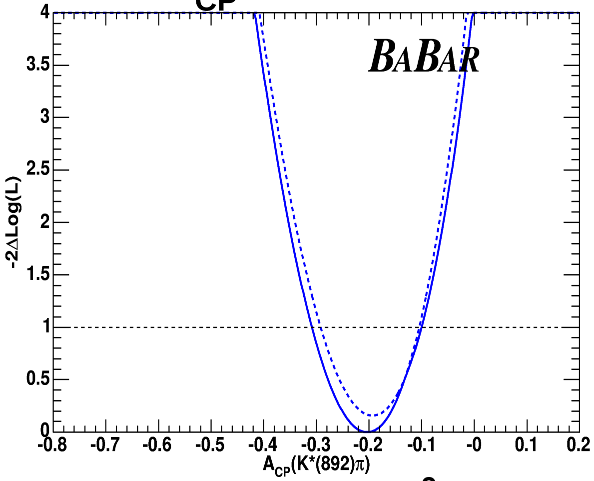
Fit fractions

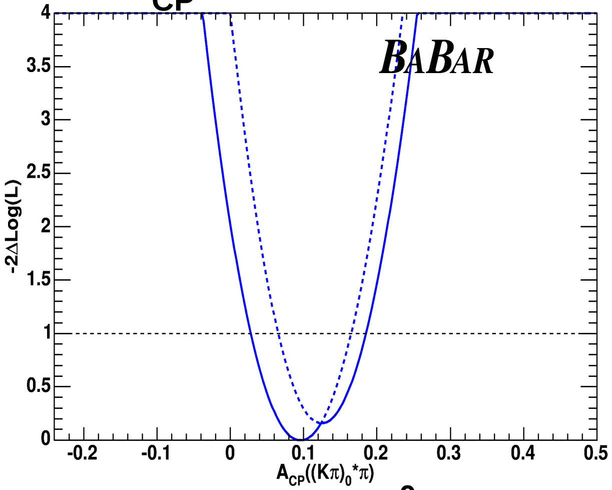


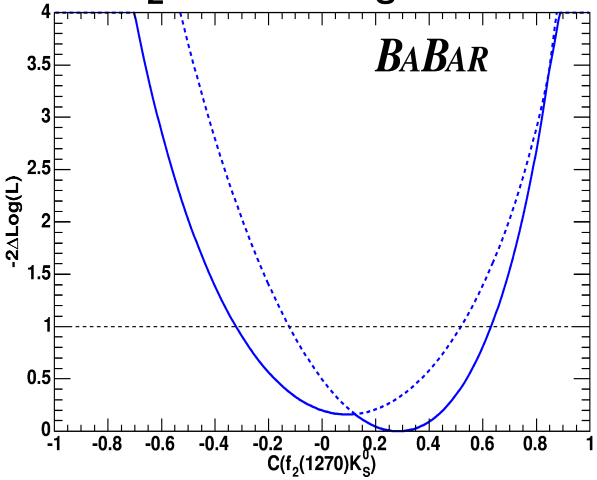
Consistent with 1.0

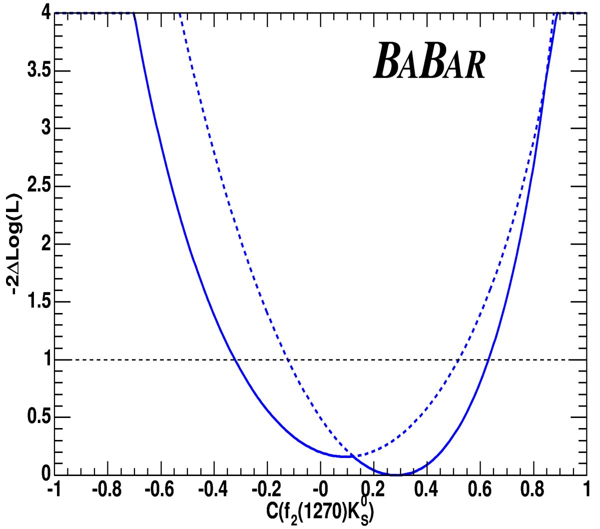
Fit Results: 1D Like. Scans (III)

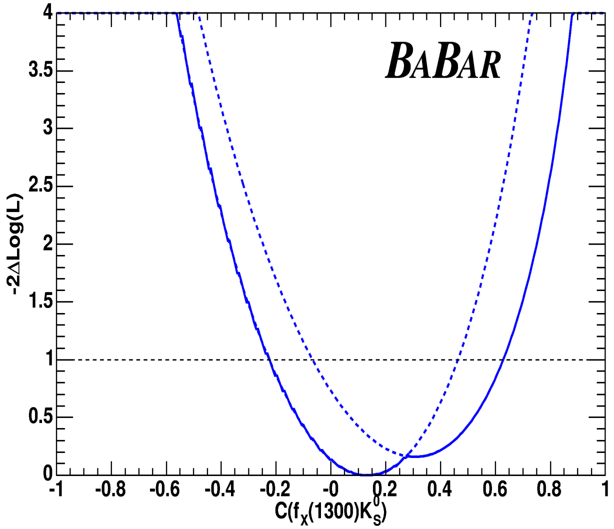
Direct CP asymmetries

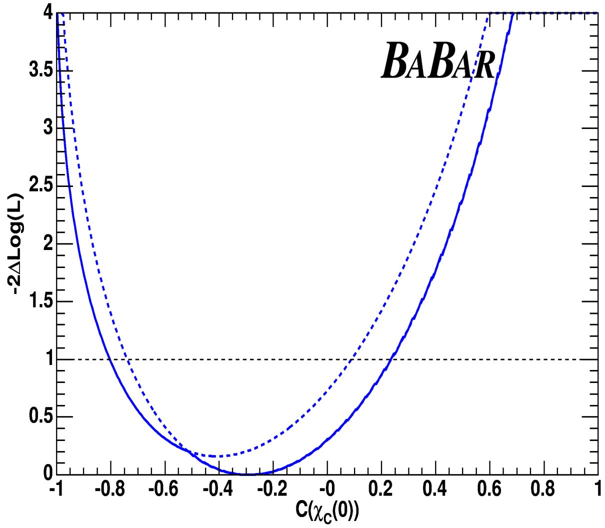

$A_{CP}(K(892)\pi)$


$A_{CP}(S\text{-wave } K\pi)$


$C(f_2(1270)K^0_S)$


$C(f_2(1270)K^0_S)$

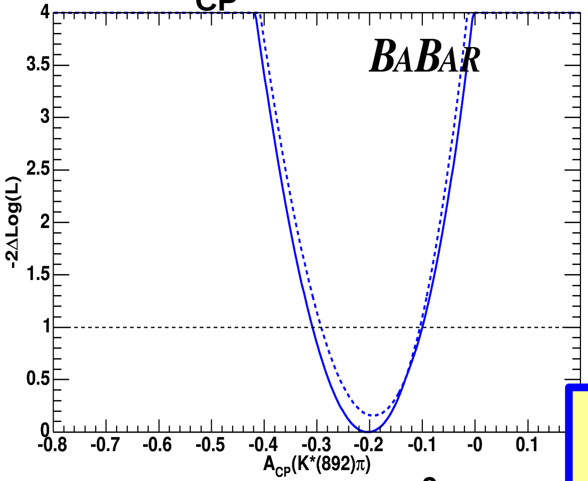

$C(f_X(1300)K^0_S)$


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

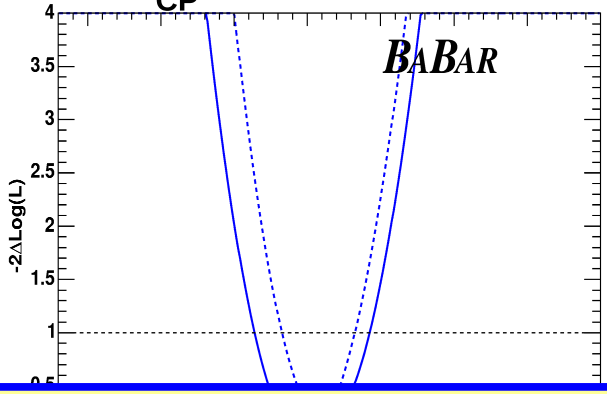
Fit Results: 1D Like. Scans (III)

Direct CP asymmetries

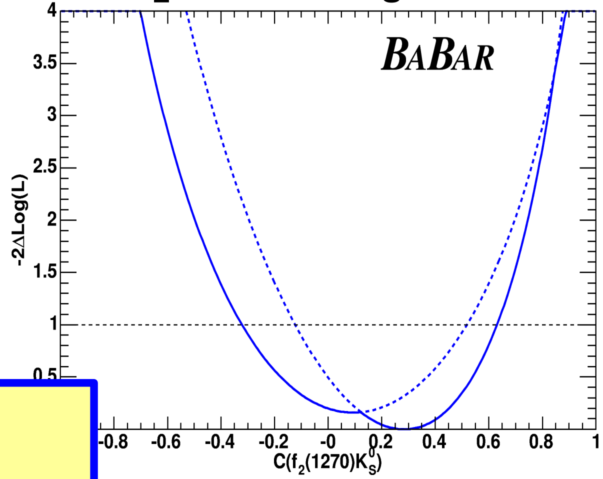
$A_{CP}(K(892)\pi)$



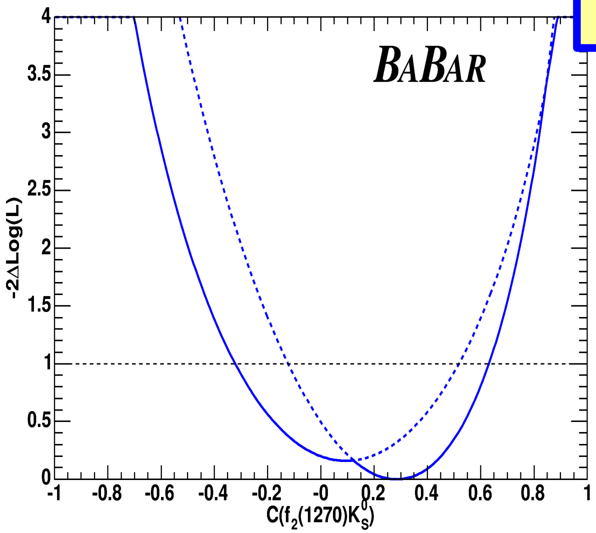
$A_{CP}(\text{S-wave } K\pi)$

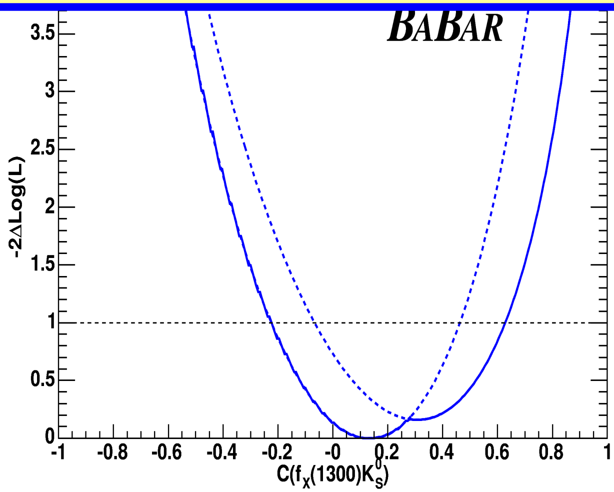


$C(f_2(1270)K^0_S)$

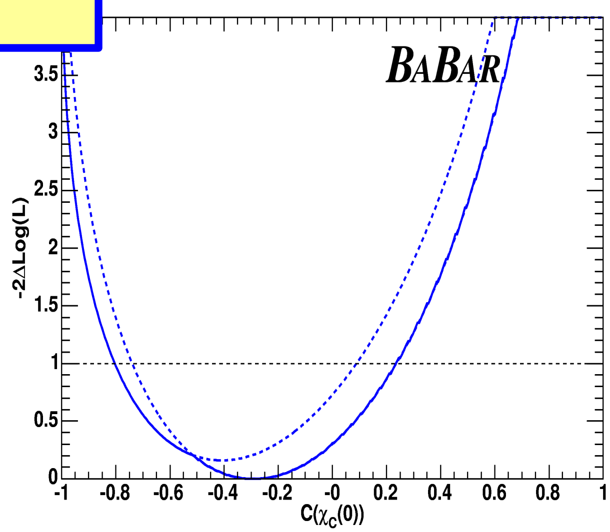


$C(f_2(1270)K^0_S)$





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

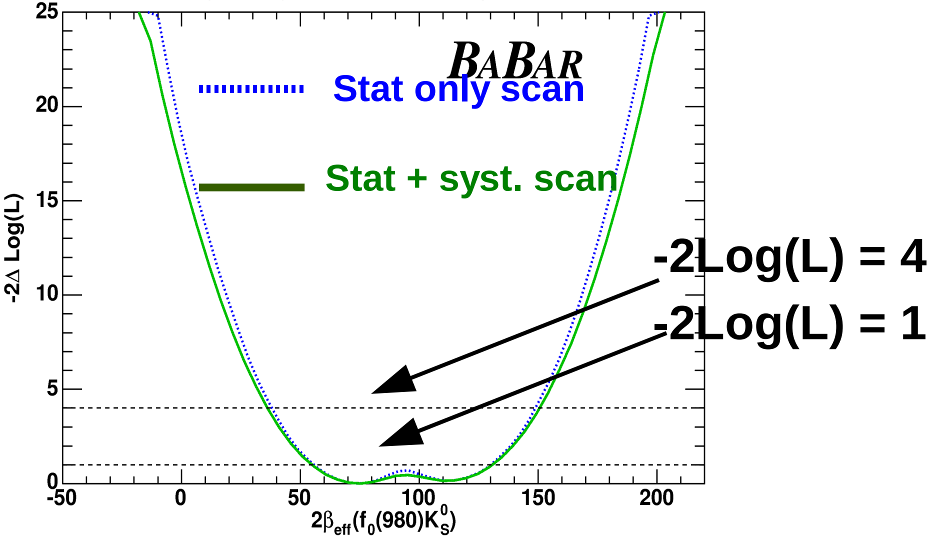


No significant Direct CPV

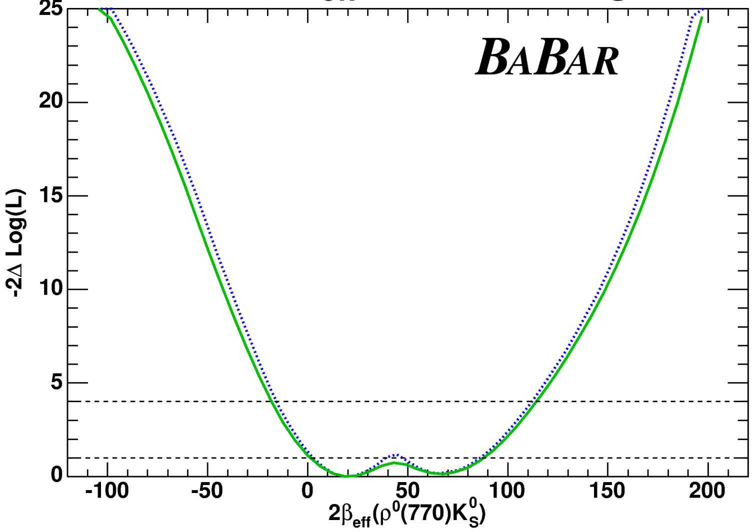
Fit Results: 1D Like. Scans (IV)

Phase Differences

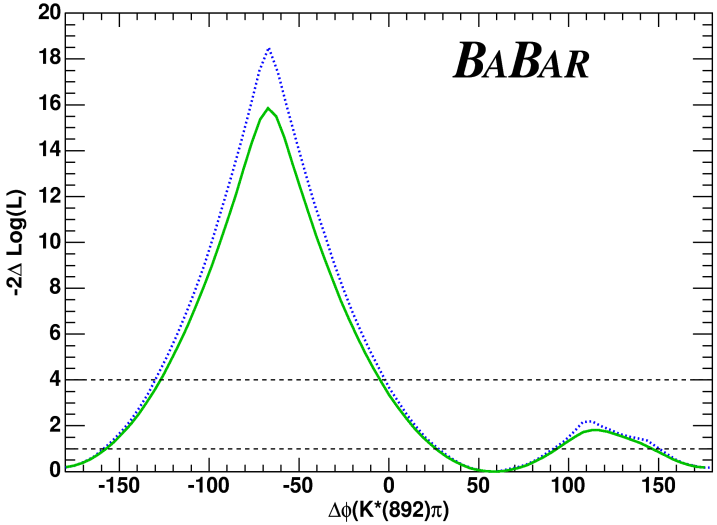
$2\beta_{\mathrm{eff}}(f_0(980)K^0_S)$



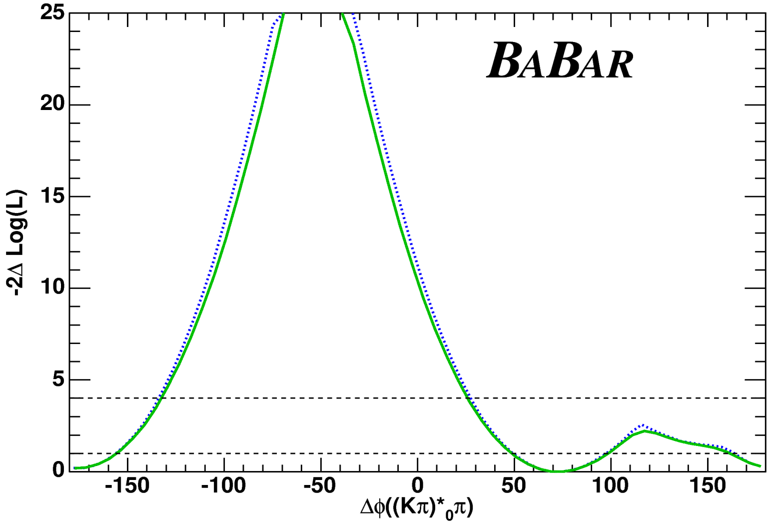
$2\beta_{\mathrm{eff}}(\rho^0(770)K^0_S)$



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



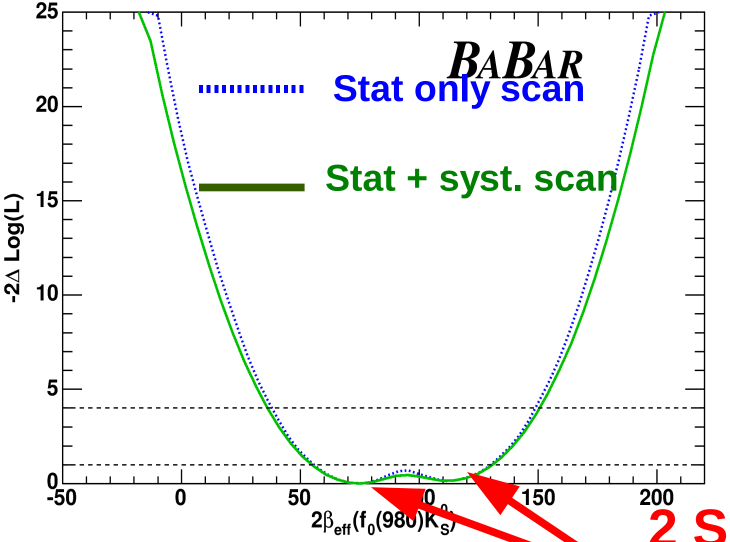
$\Delta\phi(\text{S-wave } K\pi)$



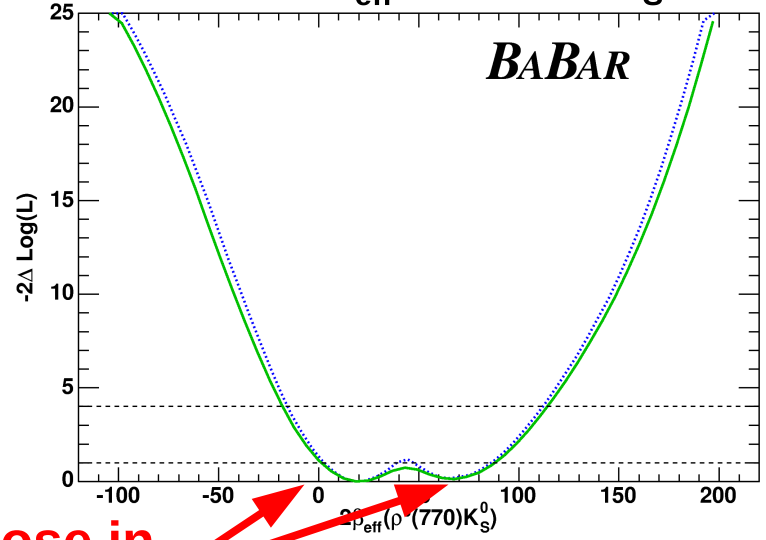
Fit Results: 1D Like. Scans (IV)

Phase Differences

$2\beta_{eff}(f_0(980)K^0_S)$

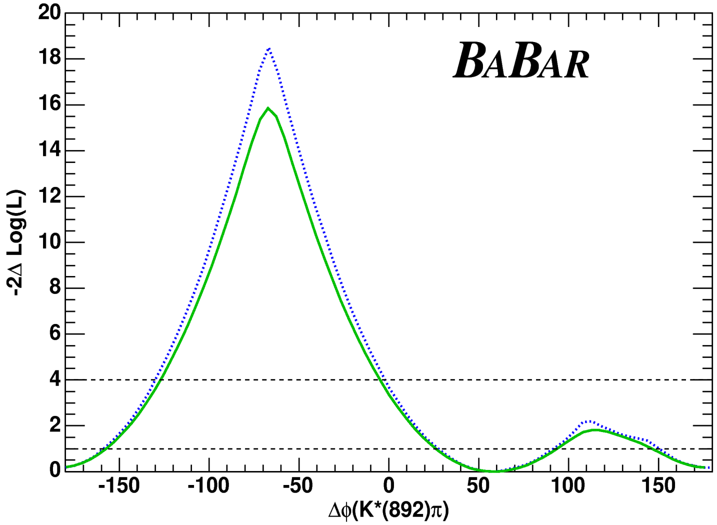


$2\beta_{eff}(\rho^0(770)K^0_S)$

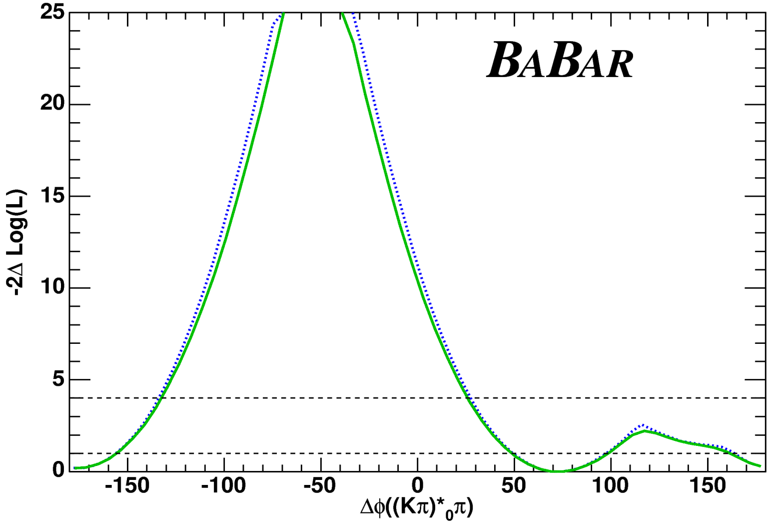


2 Sol. Very close in -2ΔLog(L) units

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



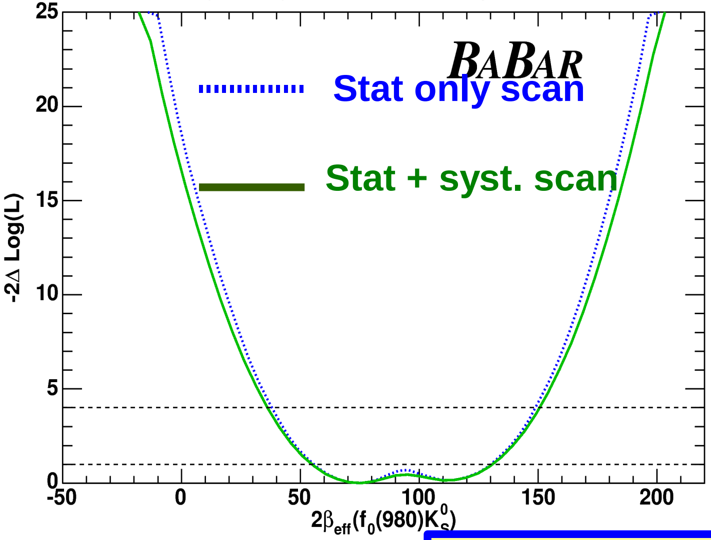
$\Delta\phi$(S-wave Kπ)



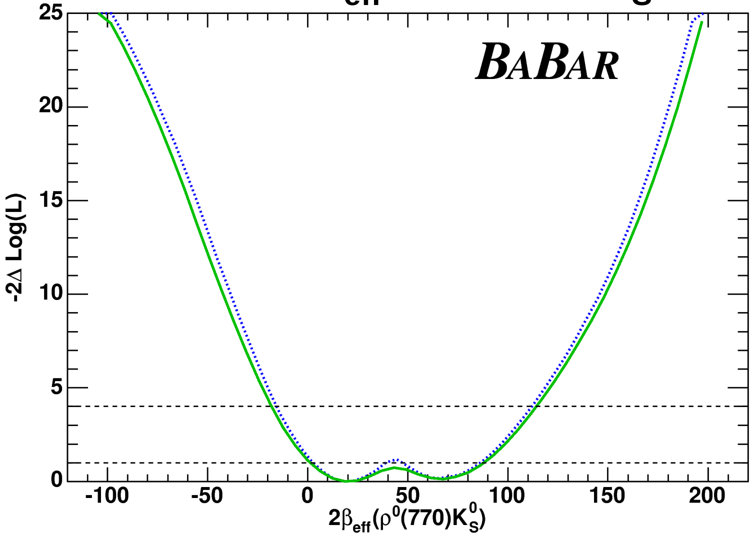
Fit Results: 1D Like. Scans (IV)

Phase Differences

$2\beta_{eff}(f_0(980)K^0_S)$



$2\beta_{eff}(\rho^0(770)K^0_S)$

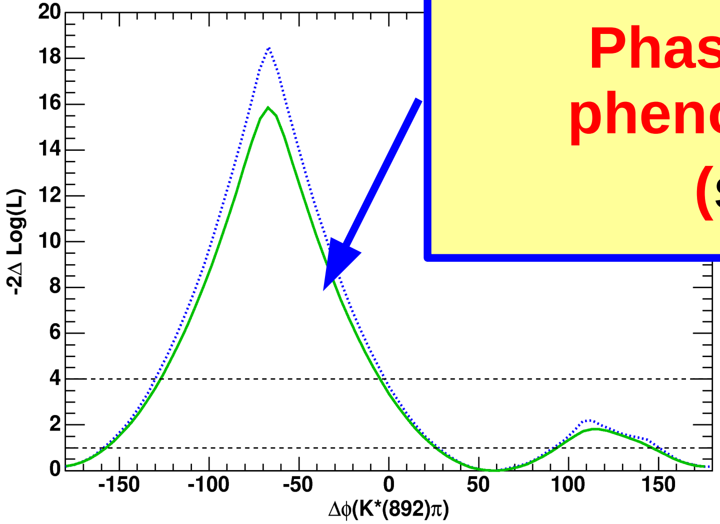


Statistically limitated constraint.

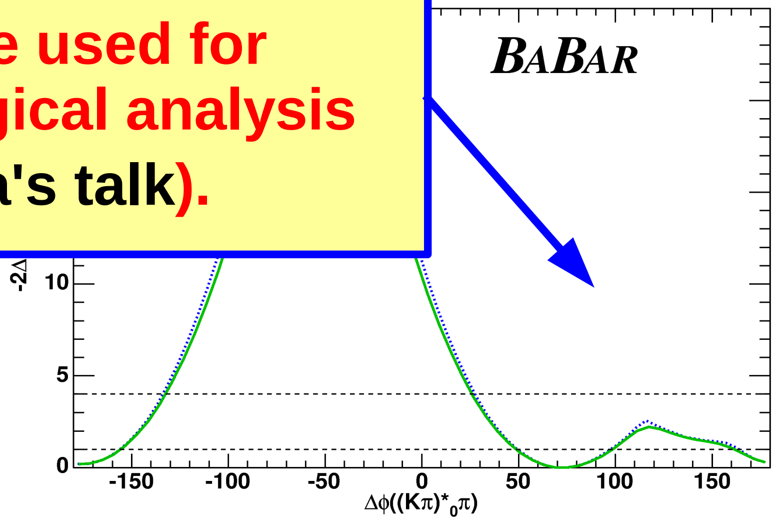
Phases can be used for phenomenological analysis

(see Reina's talk).

$\Delta\phi$(K(892



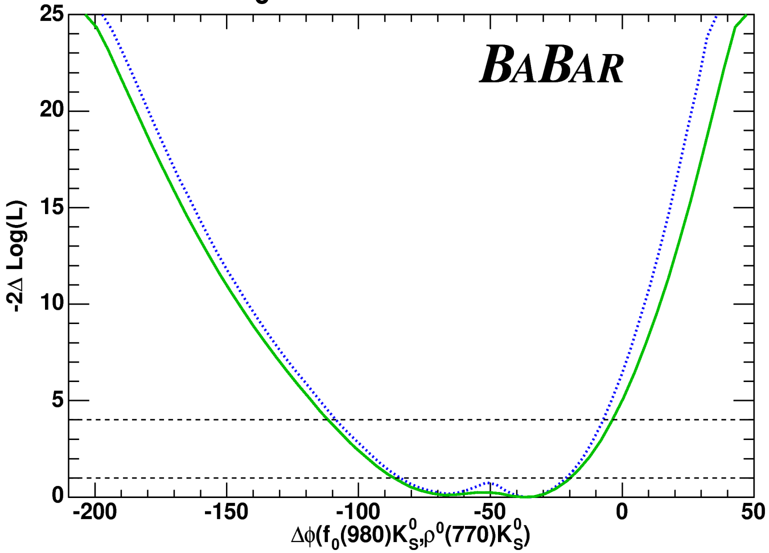
ave Kπ)



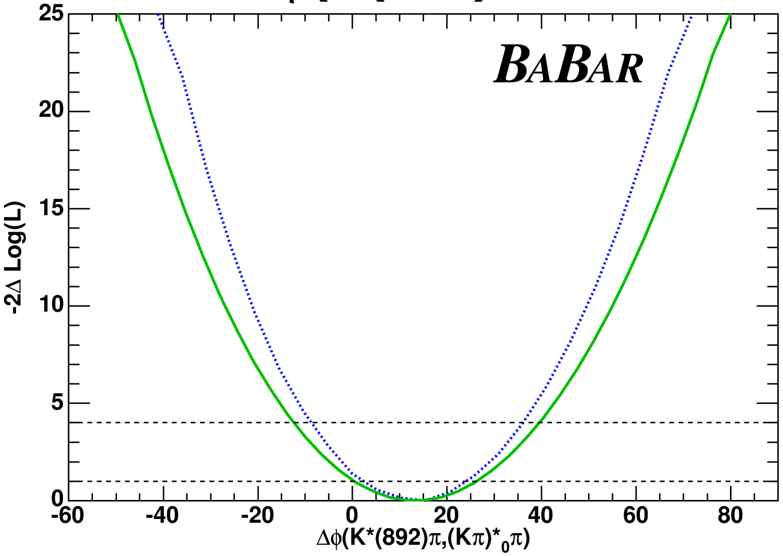
Fit Results: 1D Like. Scans (V)

Phase Differences

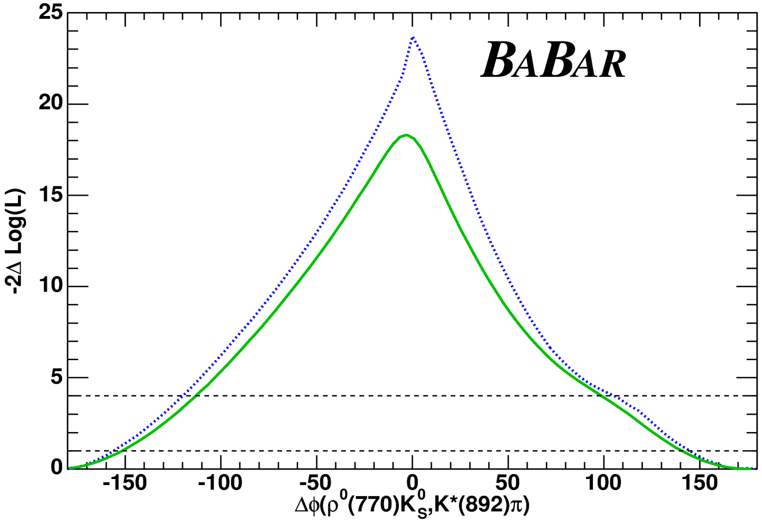
$\Delta\phi(f_0(980),\rho^0(770))$



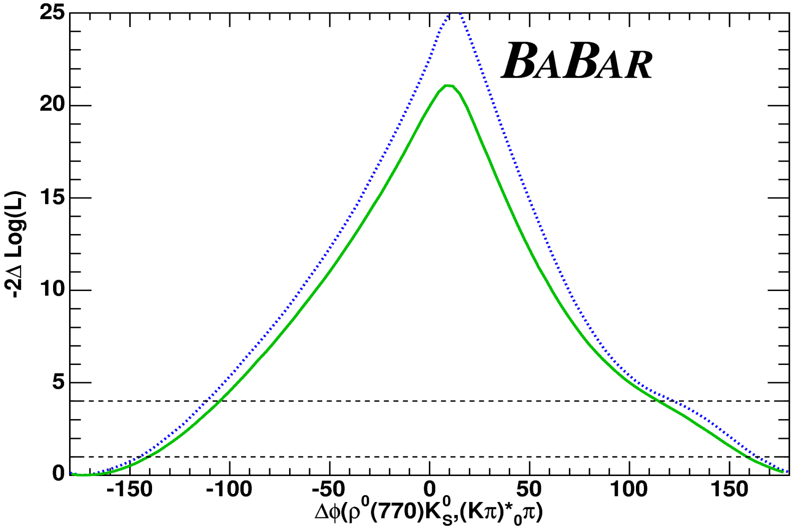
$\Delta\phi(K(892)\pi,\text{S-wave }K\pi)$



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

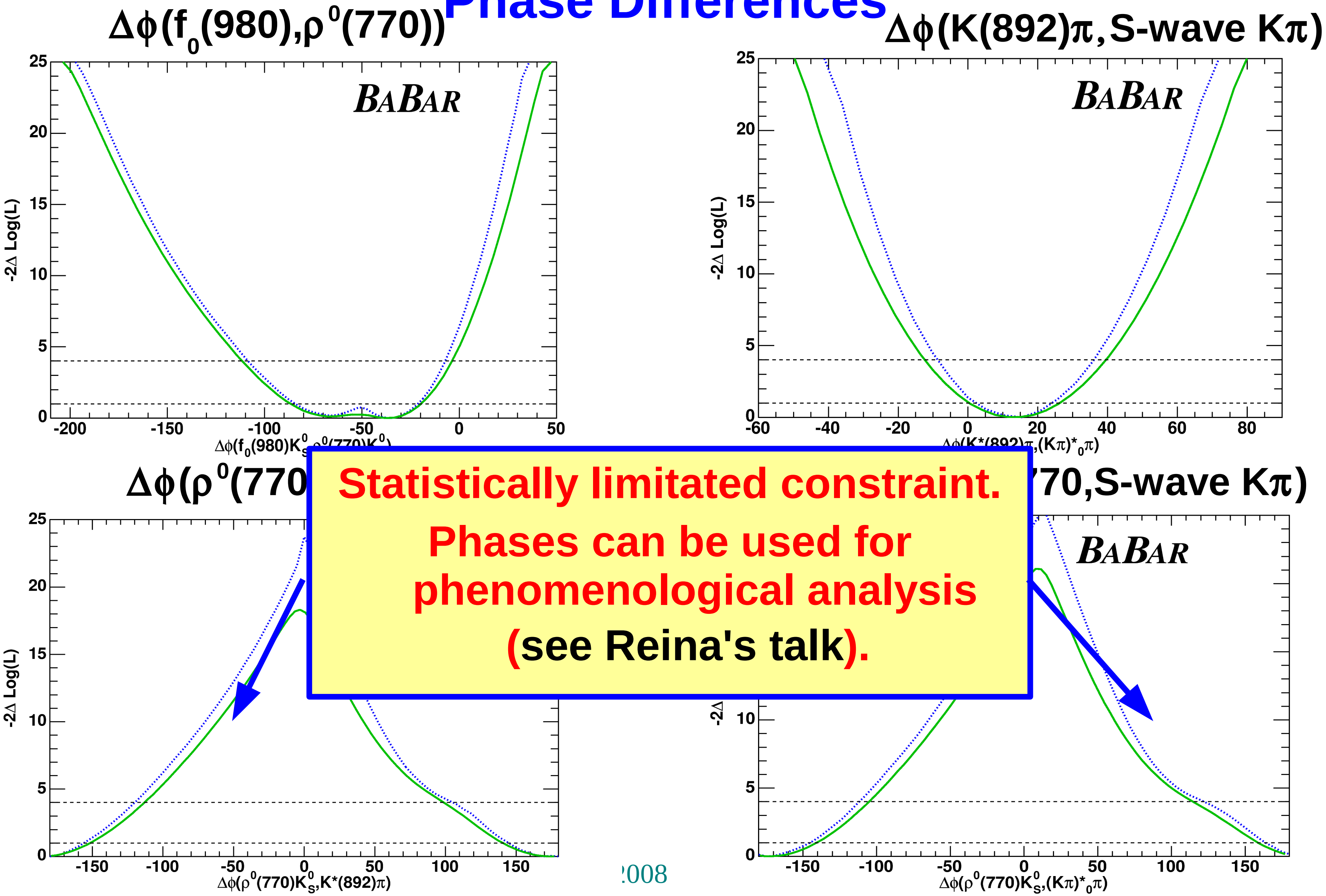


$\Delta\phi(\rho^0(770,\text{S-wave }K\pi)$



Fit Results: 1D Like. Scans (V)

Phase Differences



Statistically limitated constraint.

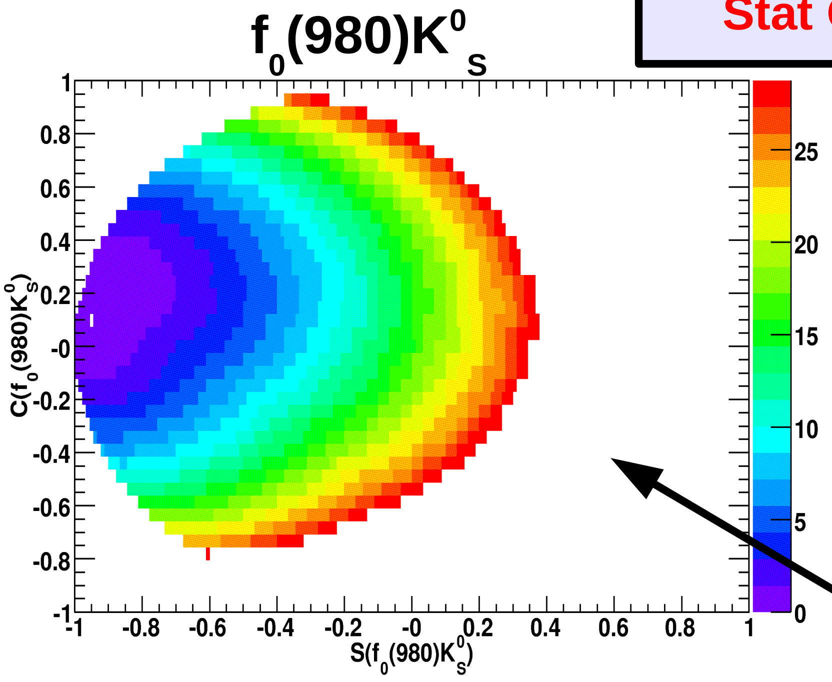
Phases can be used for phenomenological analysis

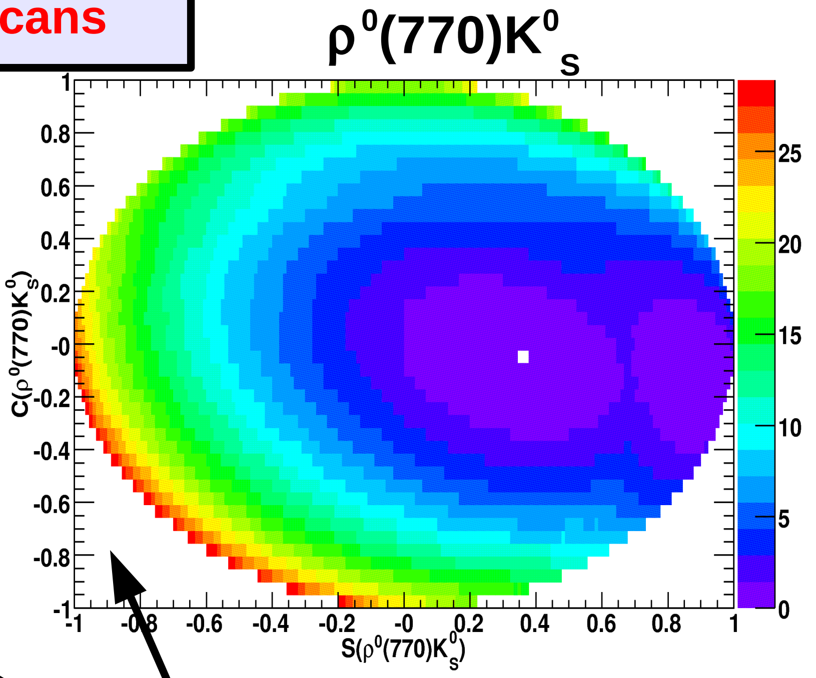
(see Reina's talk).

Fit Results: 2D Like. Scans

(C,S) 2D scans

Stat Only Scans


$f_0(980)K^0_S$


$\rho^0(770)K^0_S$

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

In white:

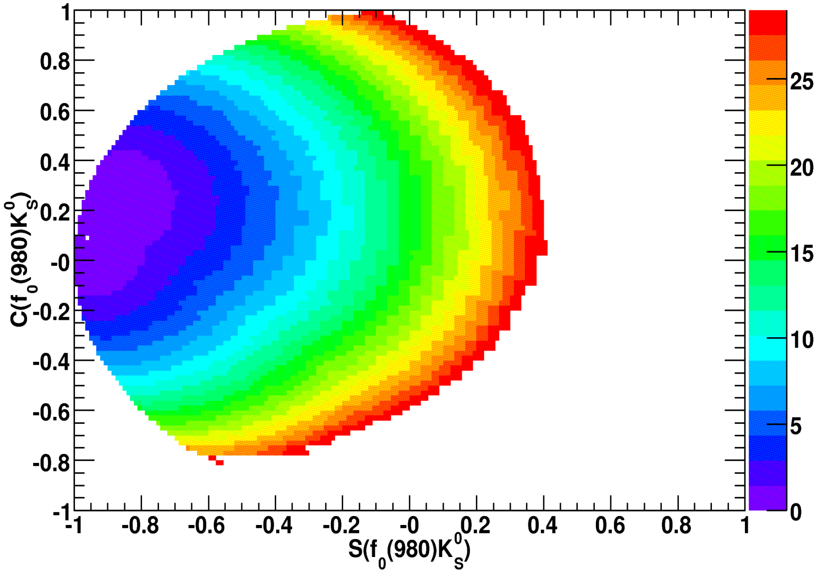
(unphysical regions) U (5σ excl.)

Fit Results: 2D Like. Scans

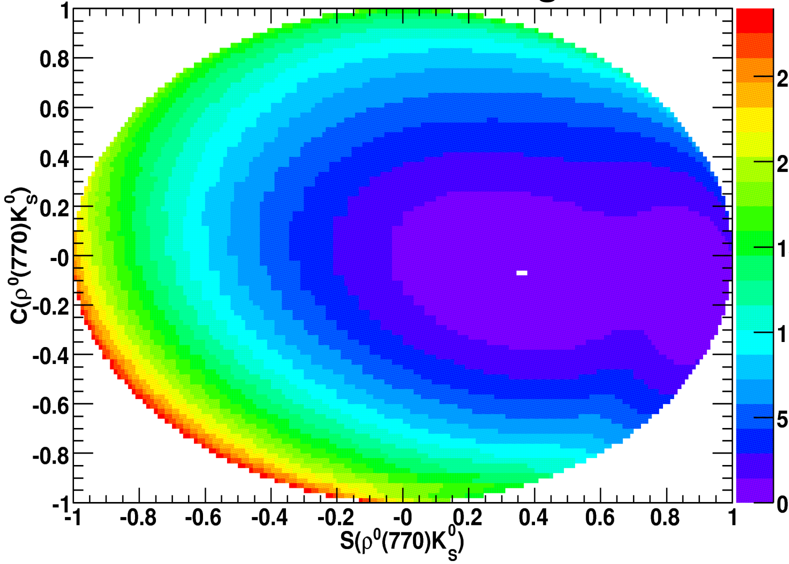
(C,S) 2D scans

Conv. with systematics

$f_0(980)K^0_S$



$\rho^0(770)K^0_S$

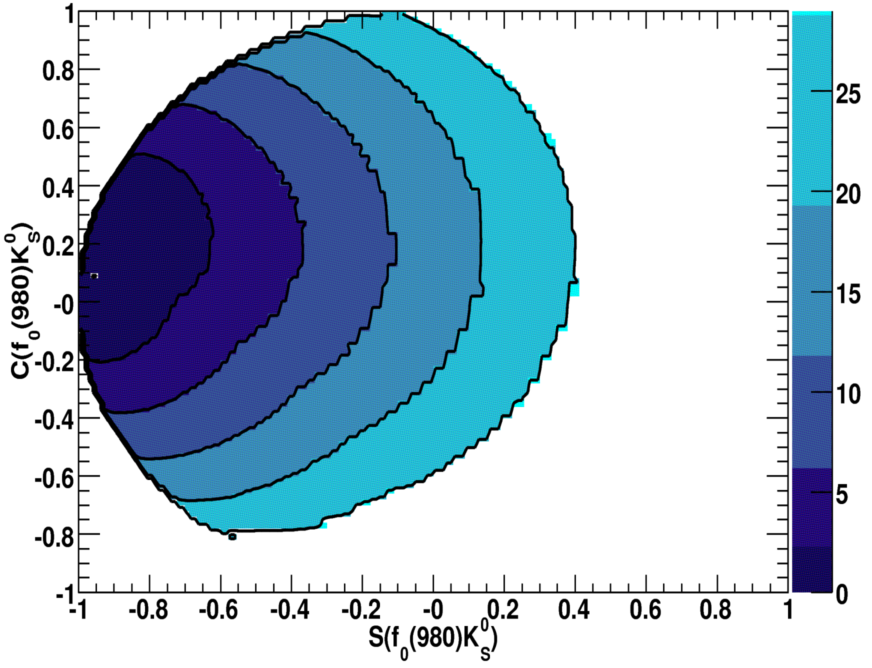


Fit Results: 2D Like. Scans

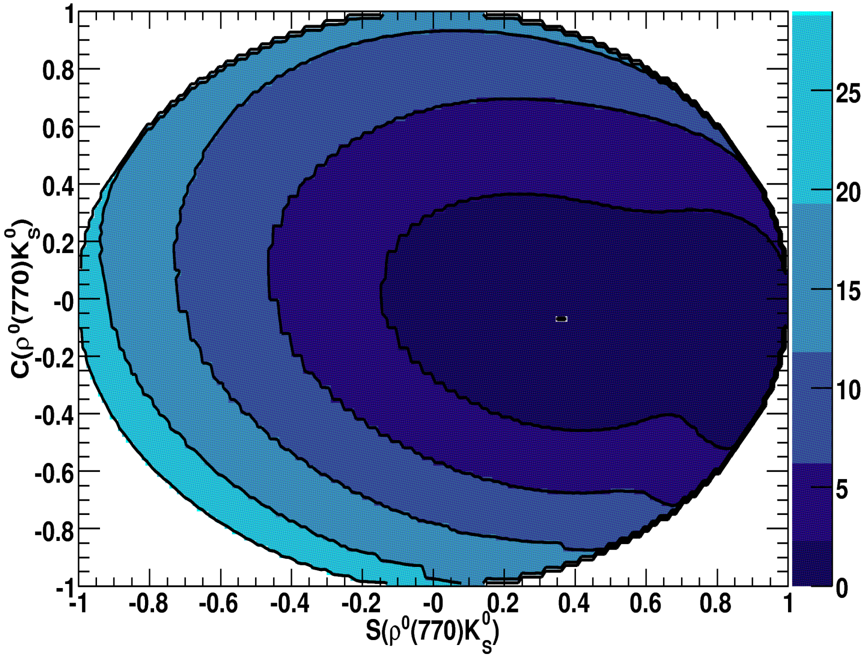
(C,S) 2D scans

1, 2, 3, 4 and 5σ contours

$f_0(980)K^0_S$



$\rho^0(770)K^0_S$

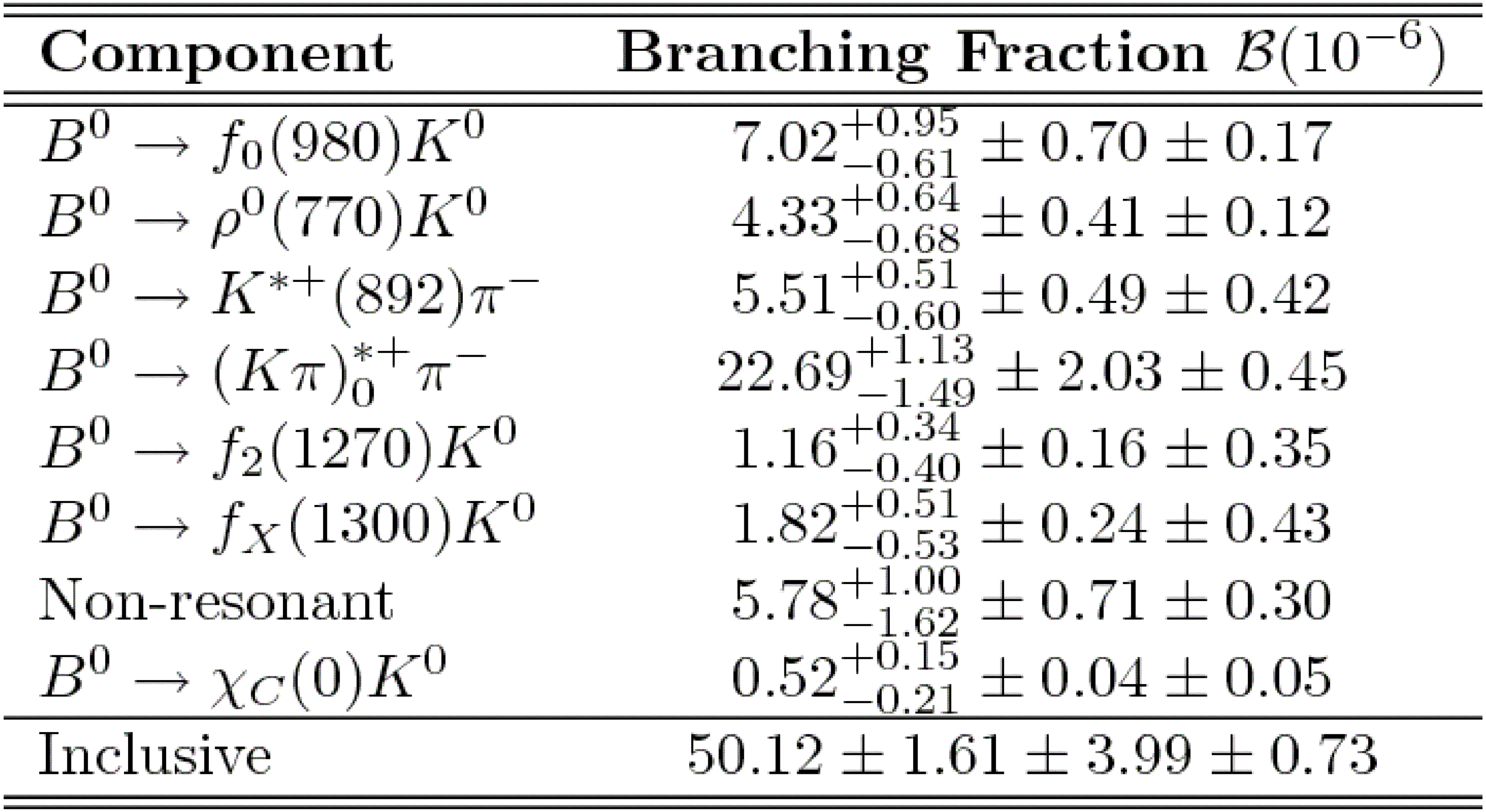


No CPV (0,0) excluded at 3.5σ

SM prediction (sin(2β),0) is not excluded

No CPV (0,0) and SM predictions are not excluded

Fit Results: Branching Frations



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

All BFs are consistent with previous mesurements

Systematic Uncertainties

All Systematics have been reevaluated:

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

- Signal DP Model:

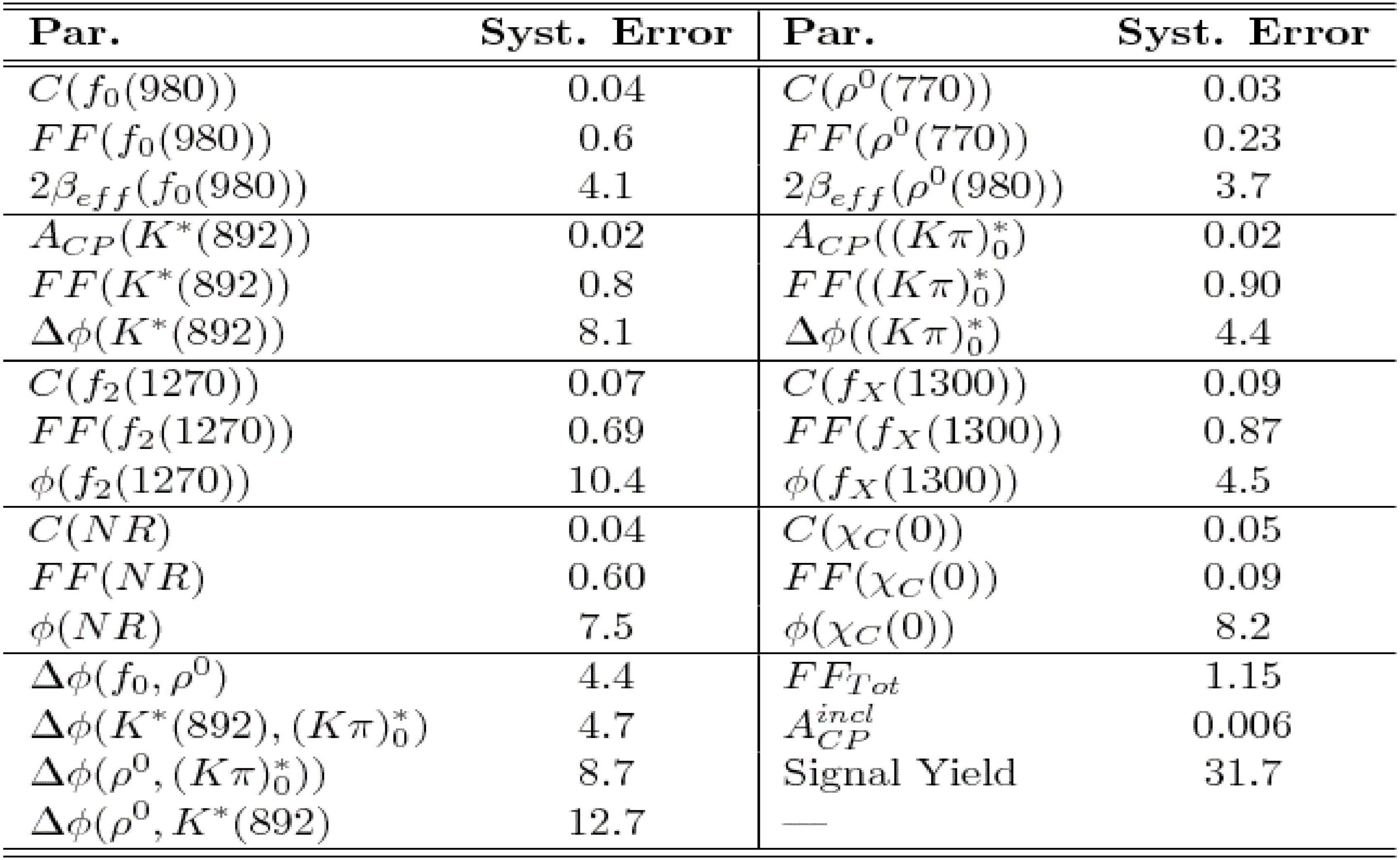
  - Lineshapes fix parameters
  - Component contributing to the signal model:
    * Previously it was evaluated adding resonant components one-by-one and refitting data. Some systematic effects were then double counted.
    * Now are evaluated on toys.

Systematics: Signal DP Model (I)

- Nominal signal model (NSM): f0(980), ρ(770), K*(892), K0*(1430), NR, fX(1300), f2(1270), χc0.
- Supplementary components tested: ρ(1450), ρ(1700), f0(1710), χc2, K*2(1430), K*(1410), K*(1680).
- First steep: fit on Data fixing NSM and adding supp. components. Q2B parameters obtained are used to generate toys with NSM + supp. Compos.
- For components: ρ(1450), K*(1410) and K*(1680) big isobar fraction where found. So took these number from other analyses with better sensitivity.
- The isobar fractions used for toys:
  - 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)
- Using these results toys where made: generate 100 signal only high statistics (10K events). Fitting with/without supp. Compos. **Systematics evaluated as mean bias between both configurations.**

Systematics: Signal DP Model (II)

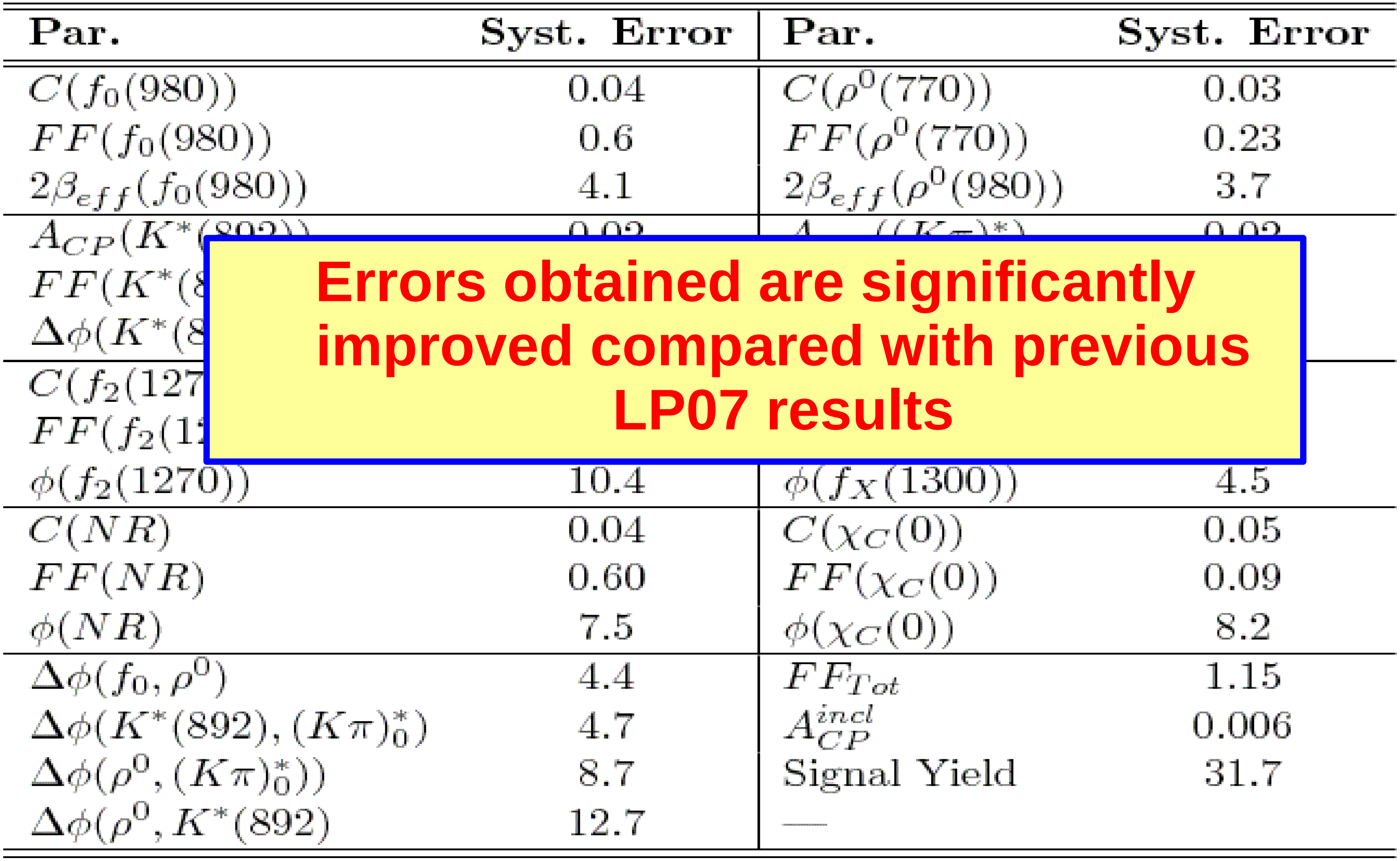
Results:



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	—	

Systematics: Signal DP Model (II)

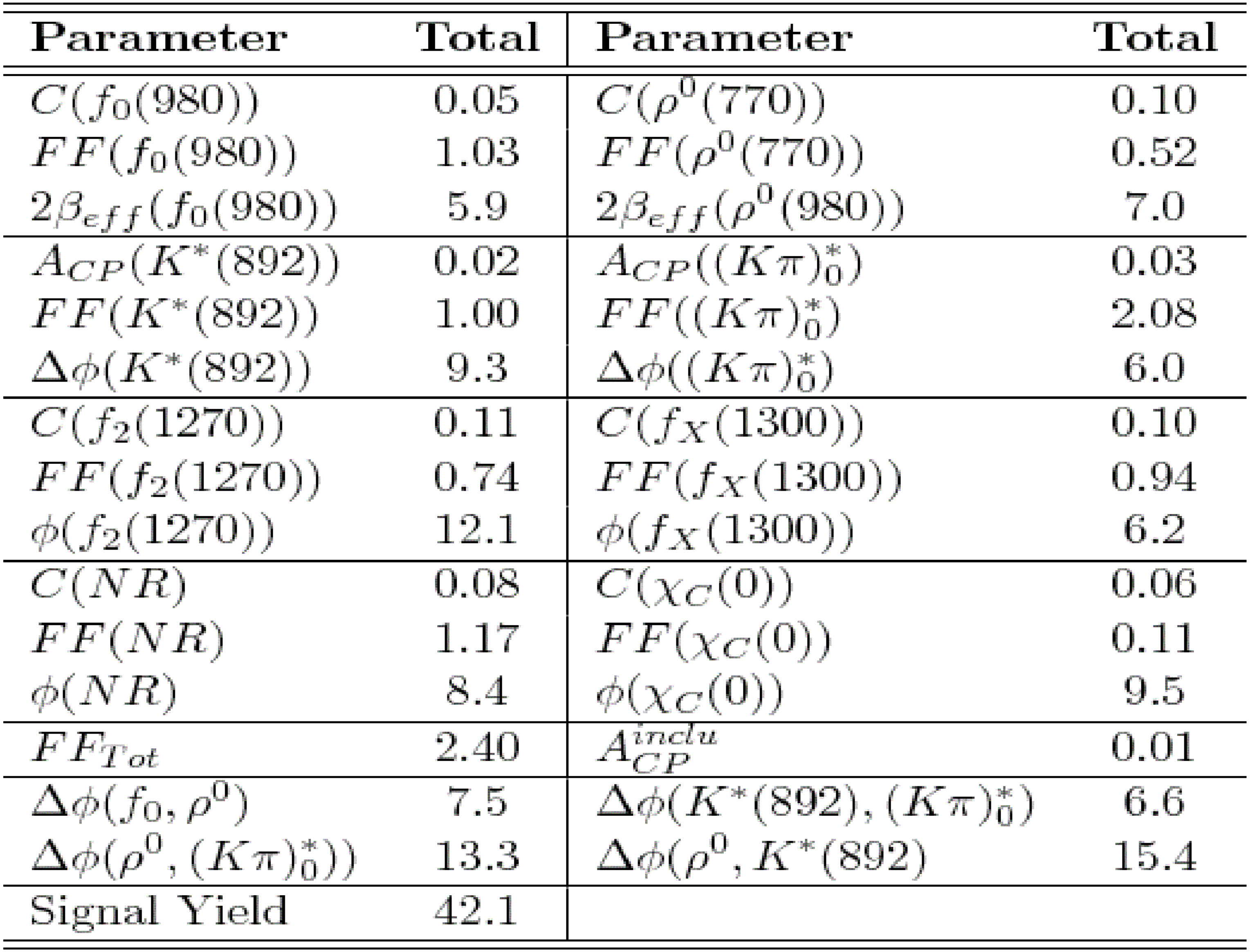
Results:



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
$FF(K^*(8$			
$\Delta\phi(K^*(8$			
$C(f_2(127$			
$FF(f_2(1$			
$\phi(f_2(1270))$	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	—	

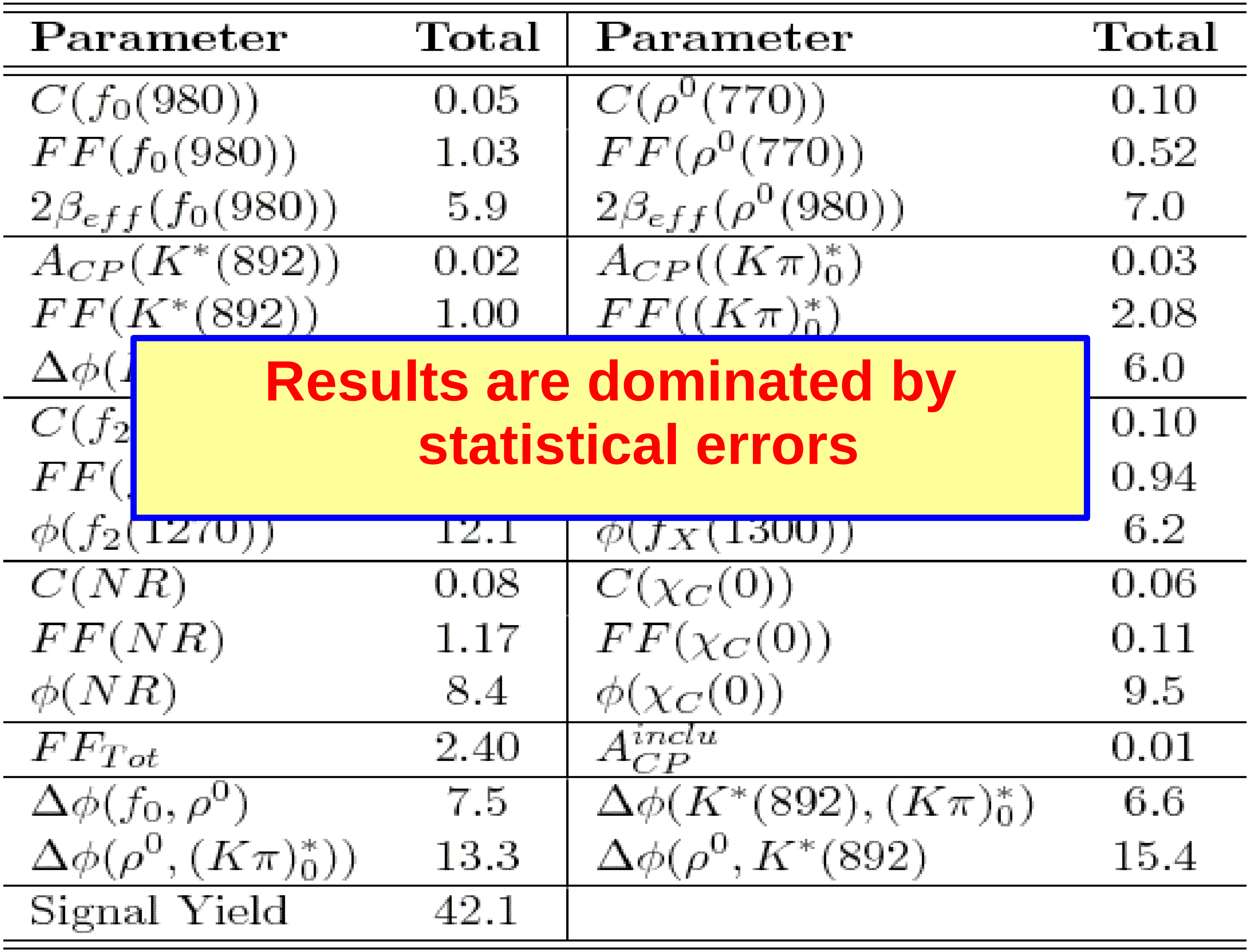
Errors obtained are significantly improved compared with previous LP07 results

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		

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
$\Delta\phi($			6.0
$C(f_2$			0.10
$FF($			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		

Results are dominated by statistical errors

Conclusions and Perspectives (I)

- All the Q2B parameters are extracted, including BF
- All BF are consistent with previous analyses
- All direct CP asymmetries are consistent with zero at 2σ
- $2\beta_{eff}$ for $f_0(980)$ has been measured, CP conservation (0 and 180°) is excluded at the 4.1σ and 3.6σ, respectively. Agreement with ccs value at 1.7σ
- $2\beta_{eff}$ for $\rho^0(770)$ has been measured for the first time. Its is consistent with zero within 1σ level, the value 180° being excluded at the 4.2σ. Agreement with ccs value at 1.0σ

Conclusions and Perspectives (II)

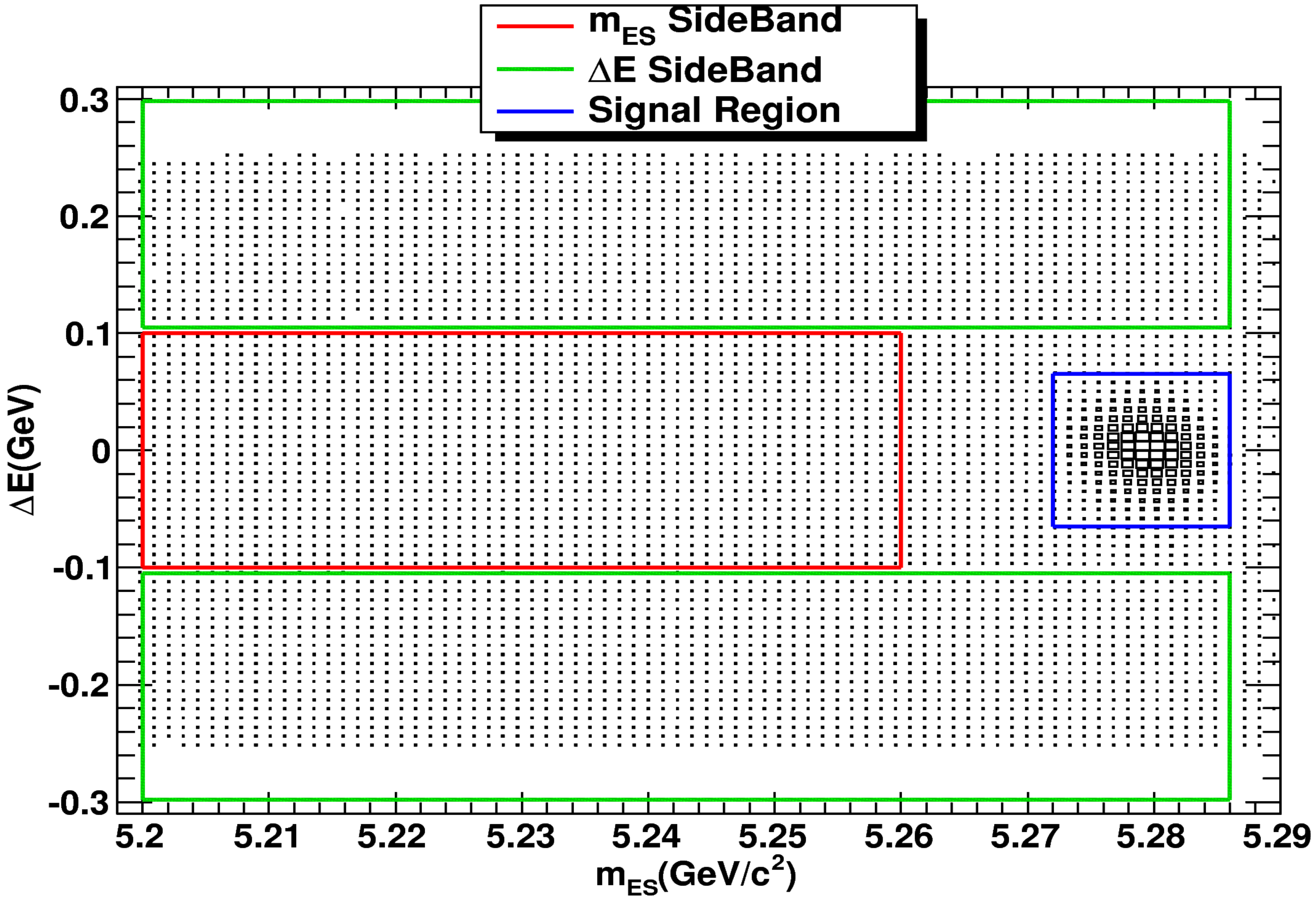
- Phase differences $\Delta\phi(K^*(892)\pi)$, $\Delta\phi(\text{S-wave } K\pi)$, $\Delta\phi(\rho^0(770),K^*(892)\pi)$ and $\Delta\phi(\rho^0(770),\text{S-wave } K\pi)$ have been measured, some of them for the first time. They can be used in phenomenological analyses (see Reina's Talk). Constraint are statistically limited
- (S,C) 2D scans have been performed for the $f_0(980)$ and $\rho^0(770)$ components. The zero CPV and SM values are excluded at the 3.5σ and 1.1σ level, respectively, for the $f_0(980)$ component. The same values are not excluded for the $\rho^0(770)$ at 1σ

Perspectives:

- **BAD #2112** uploaded
- Review is ongoing: B. Meadows, F. Porter and N. Arnaud
- The goal is to publish in PRD
- PHD thesis defence in December

Back up Slides

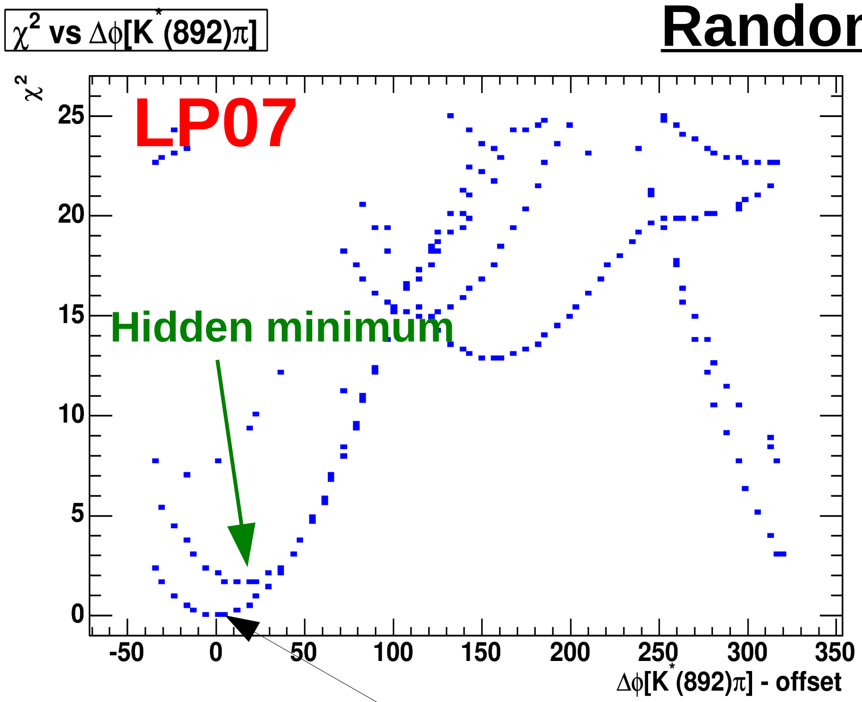
(m_{ES},ΔE) Sideband



Local Minima configuration

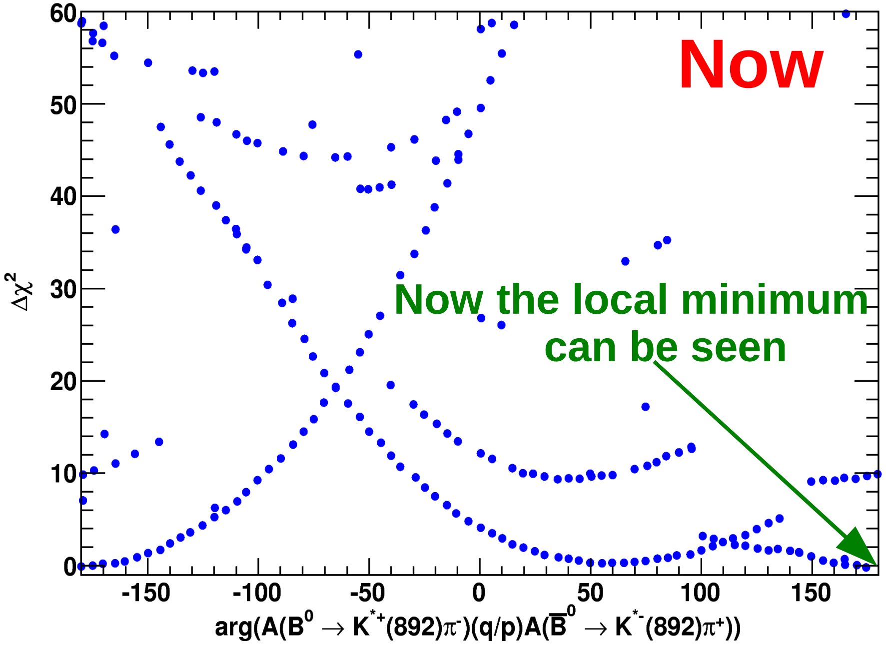
- Local Minima structure is qualitaively the same.
- Previously there were two solutions close in NLL units, but one of them was hidden by the other
- With the new fit configuration the minima shifted a bit

Randomized Scans



LP07

Hidden minimum



Now

Now the local minimum can be seen

Global minimum shifted to zero