CKM Angle ϕ_2 From $B \to \rho\rho$ Decays

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1) Motivation

2a) Measurements of $\mathcal{B}(B^0 \to \rho\rho)$

2b) Implication for ϕ_2

3)Outlook

BELLE

CP Violation

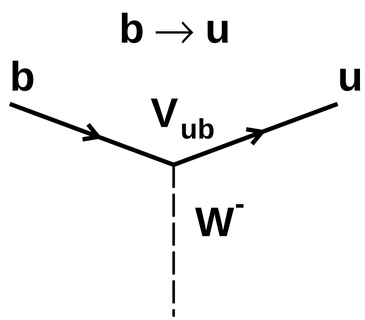
Where did the anti-matter go?

weak interaction violates the combined symmetry C(charge)P(parity),

complex, unitary quark-mixing matrix, V_{CKM} (Cabibbo-Kobayashi-Maskawa):

quark flavor transition probabilies V_{ij} ($W^{\pm}$ exchange).

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix}_{\mathrm{weak}} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{\mathrm{mass}}$$



succesfully testet BUT NOT able to produce observed asymmetry in our universe!!.

CPV Observables

4 free parameters(3 mixing angles, 1 complex phase) for 3 generations of quarks

Approx. represention of V_{CKM} in terms of the Cabibbo angle, $\lambda = \sin\theta_{\mathrm{C}} \approx 0.22$

$$V_{\mathrm{CKM}} \approx \mathcal{O}\begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4)$$

unitarity $\rightarrow$

$$V_{\mathrm{CKM}} V_{\mathrm{CKM}}^{\dagger} = \mathbf{1}$$

$$\sum_{i=1}^{3} V_{ij} V_{ik}^{*} = 0,\ j \neq k$$

relevant relation for B meson decays

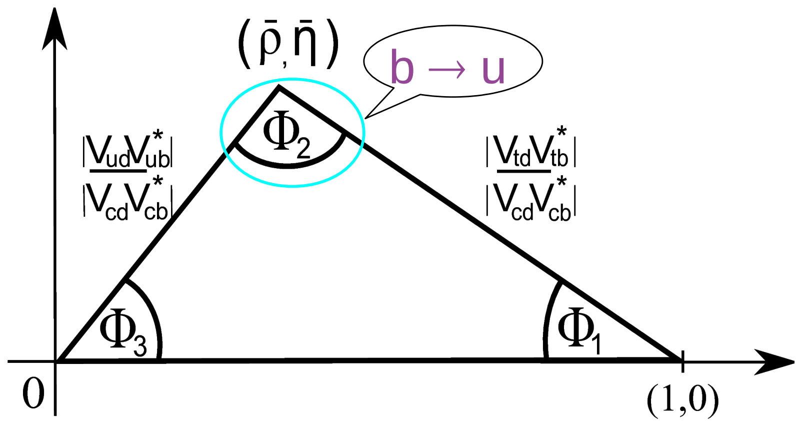
$$\begin{array}{ccccccc} V_{ud}V_{ub}^{*} & + & V_{cd}V_{cb}^{*} & + & V_{td}V_{tb}^{*} & = & 0 \\ \mathcal{O}(\lambda^3) & & \mathcal{O}(\lambda^3) & & \mathcal{O}(\lambda^3) & & \end{array}$$

can be represented as a triangle in the complex plane $\rightarrow$

sides with similar length $\Rightarrow$ large CP violation

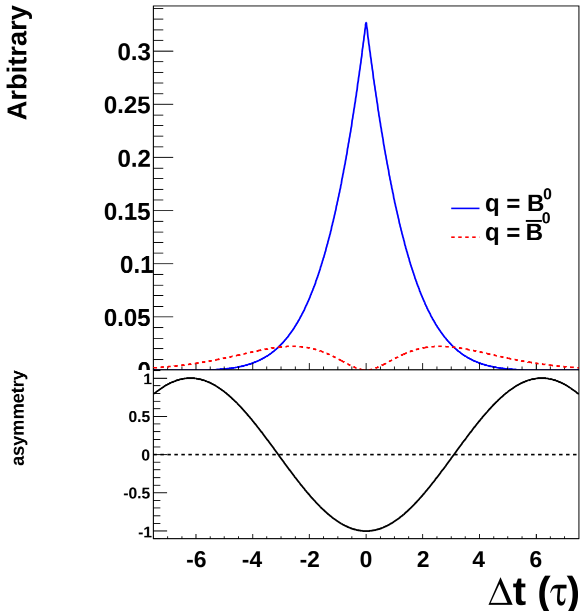
5 observables (3 angles, 2 sides) $\Rightarrow$ over-constraint

confirm SM **or** find new physics



CP Violation in the B System

$$\boxed{\frac{N_{\bar{B}^0}(\Delta t, f_{CP}) - N_{B^0}(\Delta t, f_{CP})}{N_{\bar{B}^0}(\Delta t, f_{CP}) + N_{B^0}(\Delta t, f_{CP})} = \mathcal{A}_{CP}\cos(\Delta m \Delta t) + \mathcal{S}_{CP}\sin(\Delta m \Delta t)}, \Delta t = t' - t$$



CP asymmetry parameters:

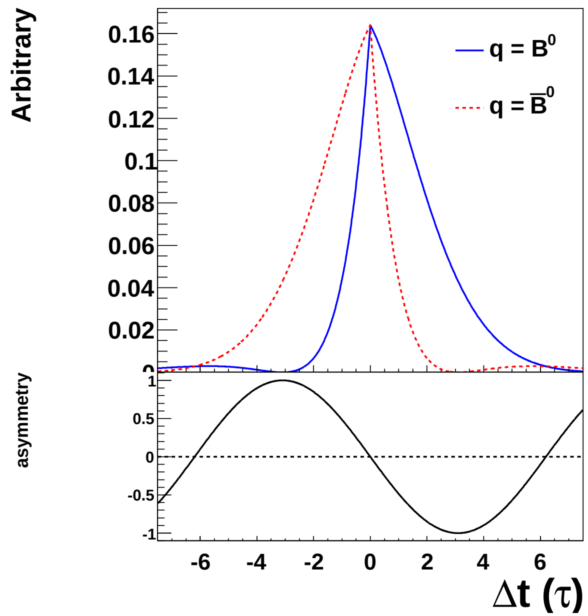
$\leftarrow \mathcal{A}_{CP}$(direct $\cancel{CP}$)

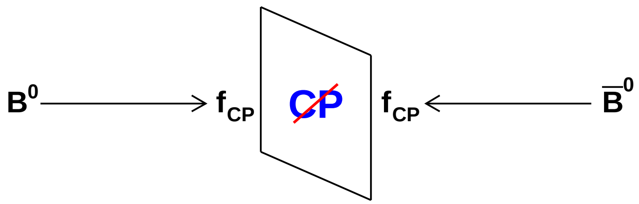
different decay rates

——— and ———-

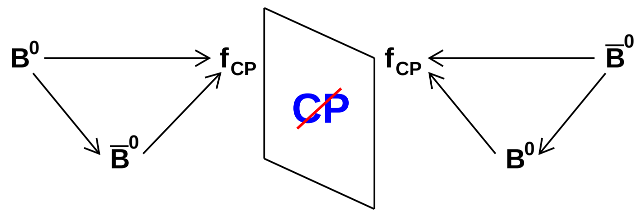
$\mathcal{S}_{CP}$(mix.ind. $\cancel{CP}$)$\rightarrow$

different time evolution





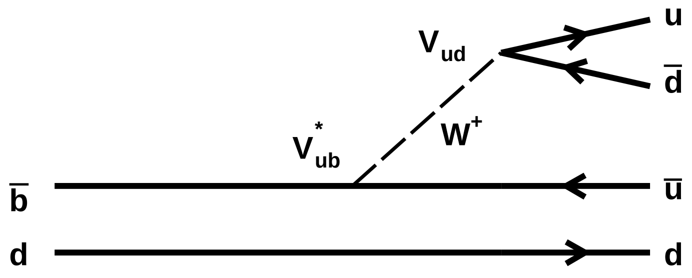
for B and $\bar{B}$ decaying into a CP eigenstate f_{CP}

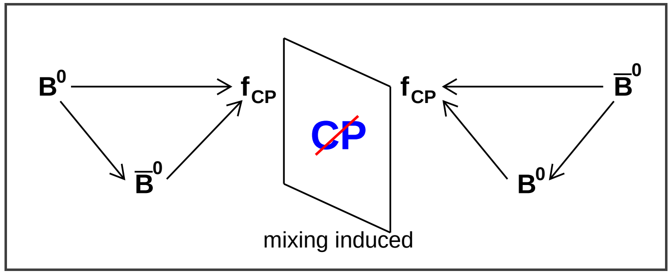


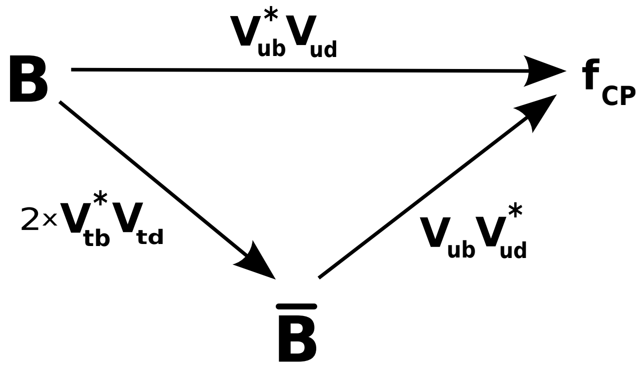
ϕ_2 and Mixing Induced $\cancel{CP}$

- $\boxed{\phi_2 = arg\left(\frac{V_{td}V_{tb}^*}{V_{ub}V_{ud}^*}\right)}$ accesible through mixing induced $\cancel{CP}$ in $b \to u$ transitions,

e.g. interference between $B \to \rho^+\rho^-$

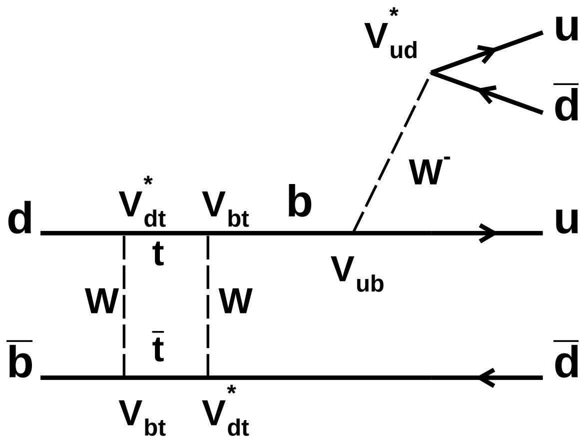






$f_{CP} = \pi\pi, \rho\rho$

and $B \to \bar{B} \to \rho^+\rho^-$



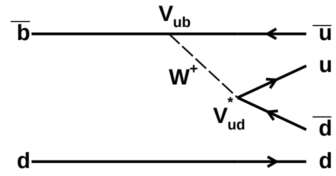
$\Rightarrow$ at tree level:

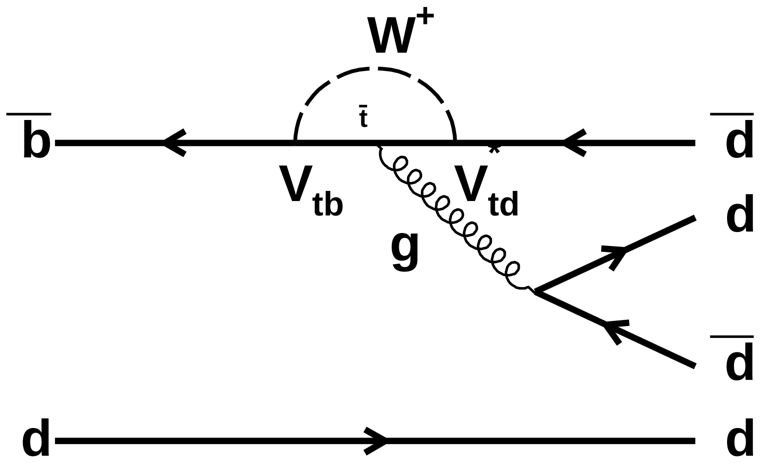
$$\boxed{\mathcal{S}_{CP} = \sin(2\phi_2), \quad \mathcal{A}_{CP} = 0}$$

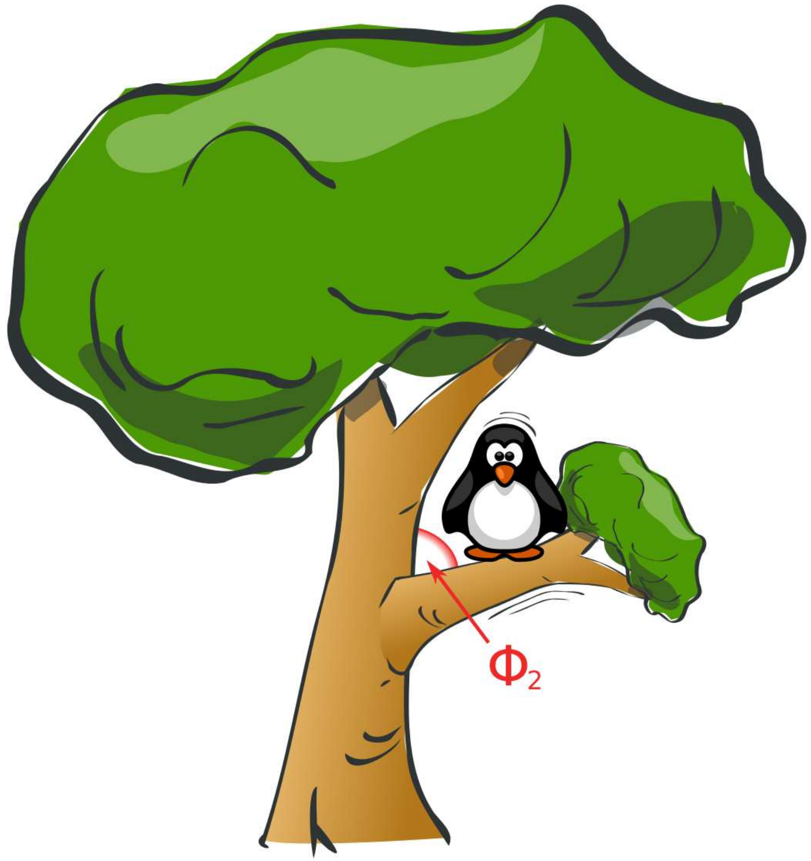
Penguin Pollution

At tree level: $\mathcal{S}_{CP} = \sin(2\phi_2)$ and $\mathcal{A}_{CP} = 0$.

BUT more amplitudes (penguins) can contribute







How the penguin distorts the tree level measurement

penguin pollution $\Rightarrow \Delta\phi_2, \mathcal{A}_{CP}$

$\Rightarrow$ measured observable $\phi_2^{eff} = \phi_2 + \Delta\phi_2$

and $\mathcal{A}_{CP} \neq 0$ possible

Recover ϕ_2

- **extraction of $\Delta\phi_2$ with isospin analysis** (remove penguin pollution) $\phi_2^{eff} = \phi_2 + \Delta\phi_2$

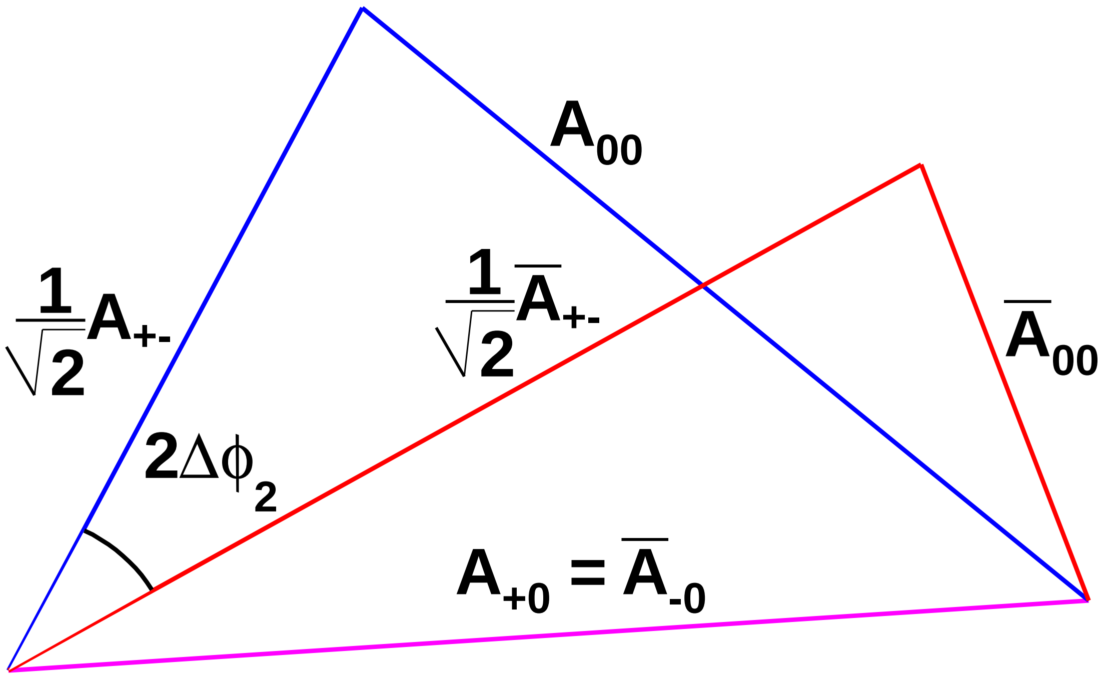
  for unflavored isospin triplets, e.g. ρ, π

  Bose statistics:$\Rightarrow$ I=0,2 (final states);

- tree I=0,2;
- penguin: I=0 only (gluon; I=0)

  allows to formulate relations of the decay amplitudes A

  e.g. $\bar{A}^{+-} = \mathcal{A}(\bar{B} \to \rho^+\rho^-)$

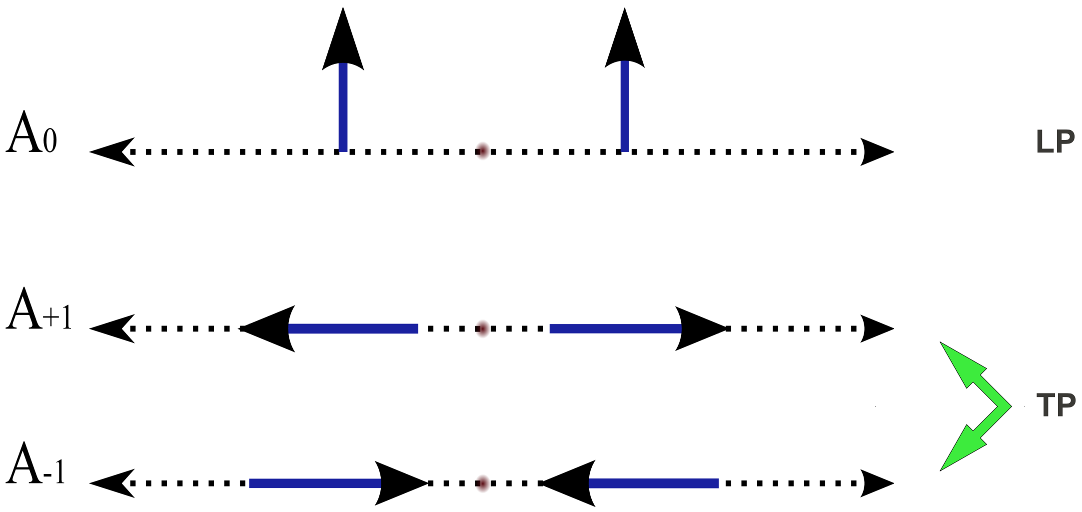


- $\frac{1}{\sqrt{2}}A^{+-} + A^{00} = A^{+0}$
- $\frac{1}{\sqrt{2}}\bar{A}^{+-} + \bar{A}^{00} = \bar{A}^{-0}$
- $A^{+0} = \bar{A}^{-0}$ (no penguin)

$\Rightarrow$ geometrical considerations reveal $\Delta\phi_2$

$B \to VV$

scalar $\to$ vector vector $(\rho : J^{PC} = 1^{--})$ $\Rightarrow$ three different polarization amplitudes



- $A_0 \to$ longitudinal(LP):
  pure CP eigenstates
  $\eta_{CP} = +1$
- $A_{\pm 1} \to$ transversal(TP):
  mixture of CP even and odd states
  $\eta_{CP} = +1, -1$

SM: LP dominant, $f_L \sim 1 - (m_V^2/m_B^2) \sim 1$

fraction of LP: $\boxed{f_L = \frac{|A_0|^2}{\sum |A_i|^2}}$

$$\boxed{\mathcal{S}_{CP} = \eta_{CP} \sin(2\phi_2^{\text{eff}})}$$

measure $f_L \Rightarrow$ separate longitudinal (CP-even) and tranvserse (CP-even&odd) polarization

Measuring ϕ_2

In $b \to u$ transitions (e.g. $B \to \pi\pi, \rho\rho, ...)$

- measurement of $\Delta t, q$ provides $\sin(2\phi_{2,eff}) = \sin(2(\phi_2 + \Delta\phi_2))$
- extraction of $\Delta\phi_2$ through isospin analysis possible

  but 2($\sin$)$\times$ 4($\Delta\phi_2$) = 8 fold ambiguity

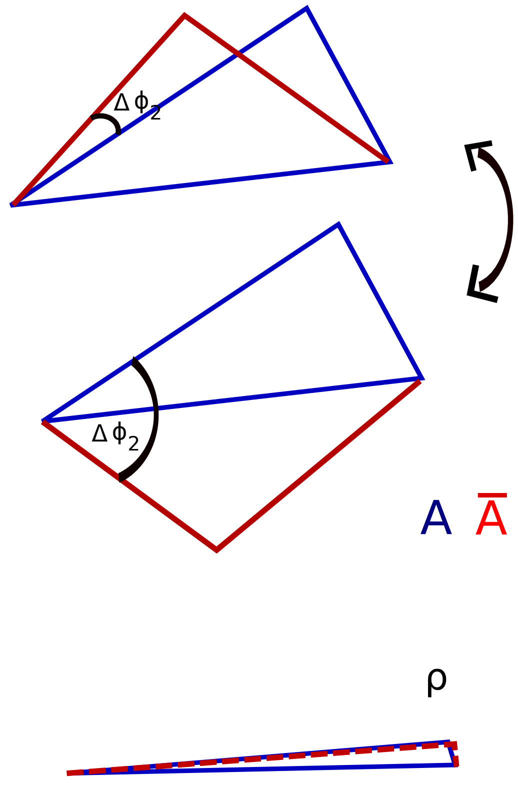
In the $B \to \rho\rho$ system the SM predicts small penguin pollution

- ϕ_2 from $B^0 \to \rho^+\rho^-$ (LP only)
- $\mathcal{BR}(B^0 \to \rho^0\rho^0)$ relatively very small

  multiple solutions due to $\Delta\phi_2$ overlap $\Rightarrow$ only 2 fold ambiguity
- current error on ϕ_2 dominated by the ρ system

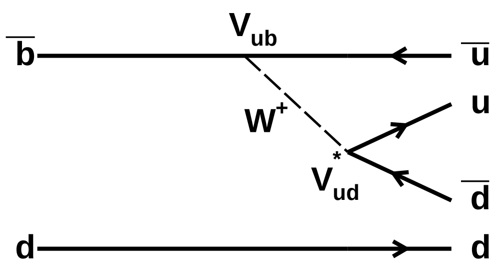
Need: **Branching Fractions, f_L and CPV parameters of:**

$B^0 \to \rho^+\rho^-, B^0 \to \rho^0\rho^0$ and $B^+ \to \rho^+\rho^0$



Previous Measurements

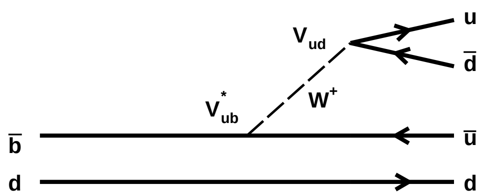
$B^0 \to \rho^0\rho^0$ (color-suppressed)



Experiment	BELLE	BaBar
$\mathcal{BR}(\times 10^{-6})$	0.4±0.4±0.25	0.92±0.32±0.14
f_L	1(assumed)	0.75 ±0.11 ± 0.04
$\mathcal{A}^L_{CP}$	-	-0.2 ± 0.8 ± 0.3
$\mathcal{S}^L_{CP}$	-	0.3±0.7±0.2
$B\bar{B}$ pairs $(\times 10^6)$	656.7	465

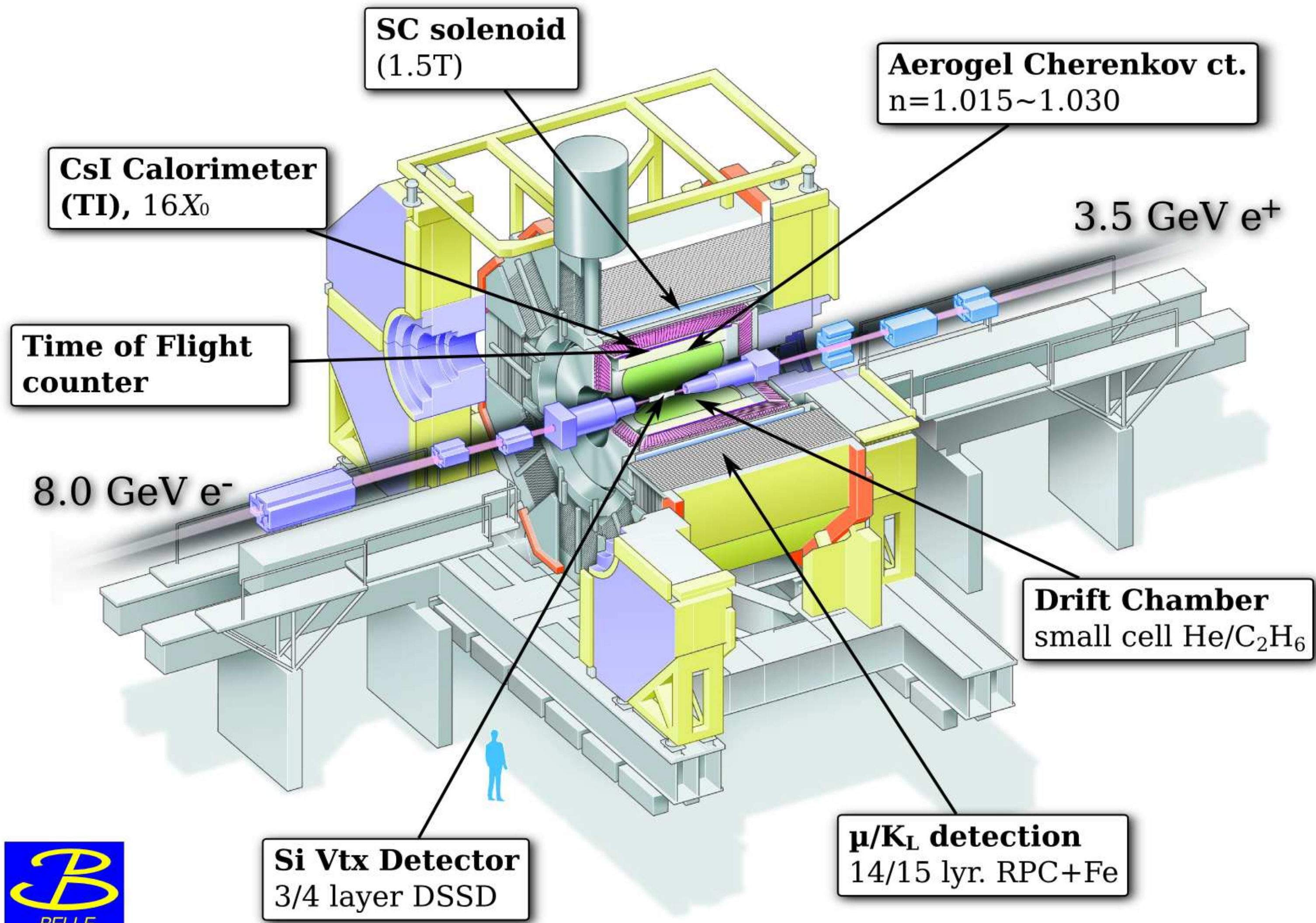
two independent measurements

$B^0 \to \rho^+\rho^-$



Experiment	BELLE	BaBar
$\mathcal{BR}(\times 10^{-6})$	$22.8\pm3.8^{+2.3}_{-2.6}$ $^{(*)}$	$25.5\pm2.1^{+3.6}_{-3.9}$
f_L	$0.941^{+0.034}_{-0.040} \pm 0.030$ $^{(*)}$	$0.992 \pm 0.024^{+0.026}_{-0.013}$
$\mathcal{A}^L_{CP}$	$0.16 \pm 0.21 \pm 0.08$	-0.01 ± 0.15 ± 0.06
$\mathcal{S}^L_{CP}$	$0.19 \pm 0.30 \pm 0.08$	$-0.17 \pm 0.20^{+0.05}_{-0.06}$
$B\bar{B}$ pairs $(\times 10^6)$	535($^{(*)}$200)	384

The Experimental Setup

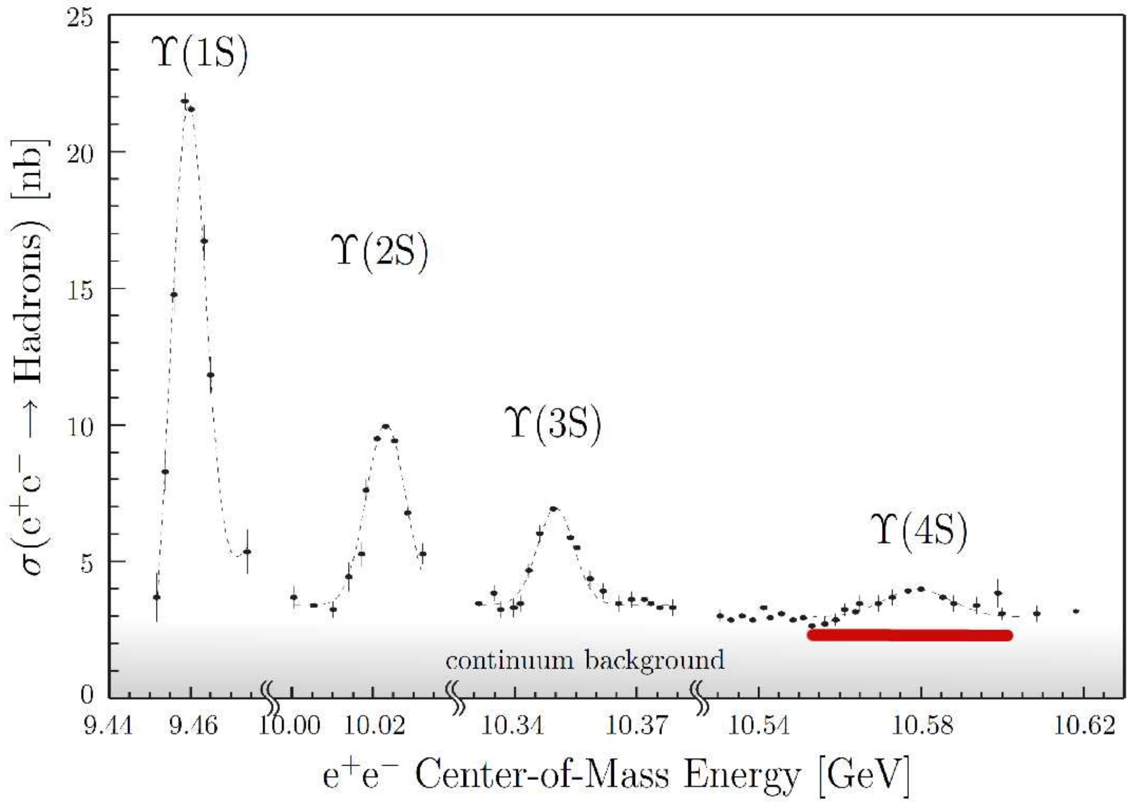


- located in Japan
- asymmetric e^+e^- collider (KEKB) (3.5 GeV on 8 GeV)
- luminosity world-record $\int Ldt = 1014 fb^{-1}$ $\sim$ $772 \times 10^6 B\bar{B}$ pairs

Belle Detector

- tracking
- PID

Where the Bs come from



$$m(\Upsilon(4S)) = 10.58 GeV/c^2 \sim 2 \times m(B)$$

$$m(B) = 5.28 GeV/c^2$$

- Υ states: $b\bar{b}$ bound states
- $\Upsilon(4S)$ exclusively into $B\bar{B}$ pairs
- $\Upsilon(4S)$: $J^{PC} = 1^{--}$
- $B : J^{PC} = 0^{--}$

  $\rightarrow B$ pair in p-wave
- asymmetric wave function

  $\rightarrow B$s have opposite flavor:

continuum: $e^+e^- \rightarrow q\bar{q}$

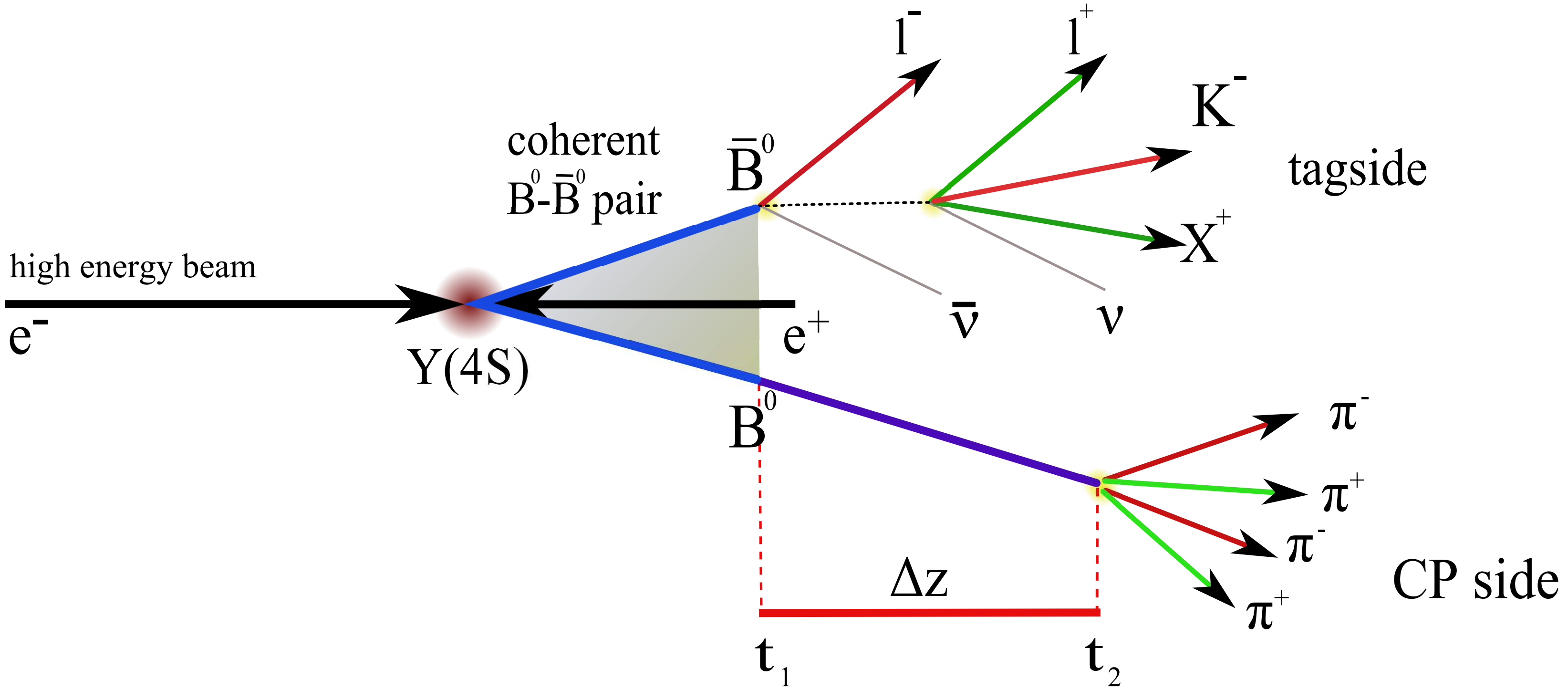
(u,d,s,c)

gives large contribution

CP Violation Measurement

different decay time-dependency for B and $\bar{B}$ decaying into a CP eigenstate

$$\frac{N_{\bar{B}^0}(\Delta t, f_{CP}) - N_{B^0}(\Delta t, f_{CP})}{N_{\bar{B}^0}(\Delta t, f_{CP}) + N_{B^0}(\Delta t, f_{CP})} = \mathcal{A}_{CP} \cos(\Delta m \Delta t) + \mathcal{S}_{CP} \sin(\Delta m \Delta t)$$



- $\Upsilon(4S) \rightarrow$ entangled $B\bar{B}$ pair ($\sim$ at rest in CMS) $\Rightarrow$ opposite side flavor tagging possible
- asymmetric beam energies $\Rightarrow$ boost of the CMS $\Rightarrow$ $\Delta t \rightarrow \Delta z$ $\quad$ ($\Delta t \sim 1.5ps$, $\Delta z \sim 100\mu$m)

Δt

$$\Gamma(\Delta t, q) = \frac{e^{-\Delta t/\tau_B}}{4\tau_B}\left(1 + (1 - 2w_l) q[\mathcal{S}_{CP}\sin(\Delta t \Delta m_d) + \mathcal{A}_{CP}\cos(\Delta t \Delta m_d)]\right)$$

- tagging eff: $\sim 30\%$

  (dominant dilution from misPID)

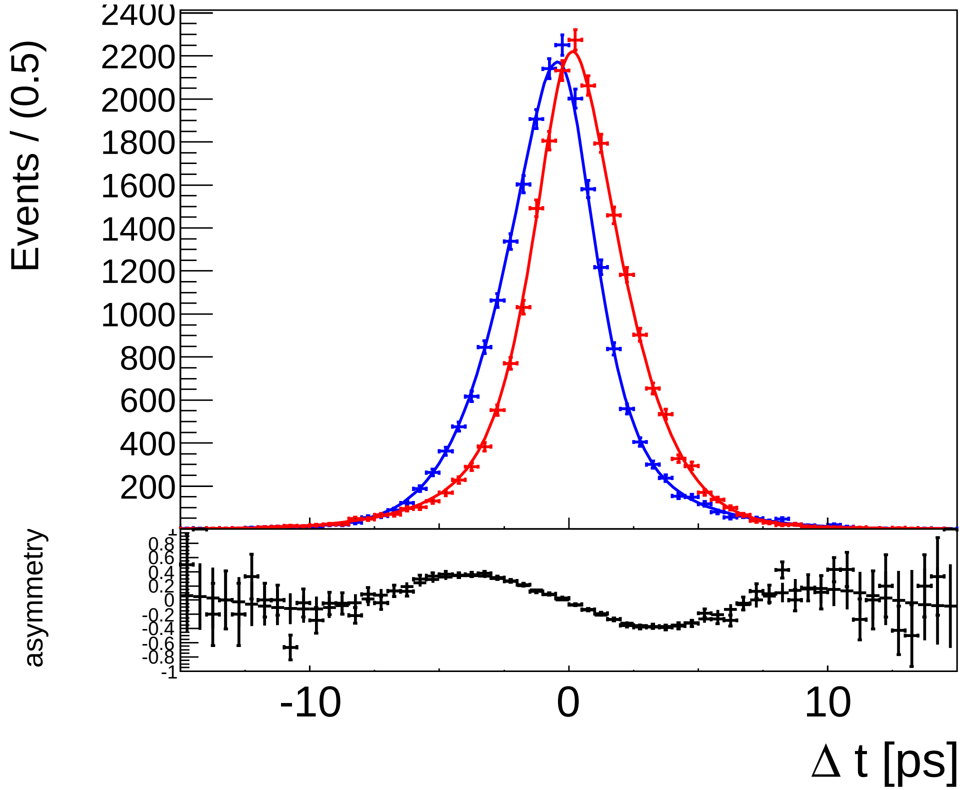
- wrong tag fraction included as a binned dilution factor $1 - 2w_l$

- convoluted with **resolution fct.**

  a) detector resolution

  b) smearing due to non primary tag-side tracks

  c) kinematic approx.,



signal MC: $\phi_2^{\text{generated}} = 45° \Rightarrow \mathcal{S}_{CP} = 1$

Helicity Measurement

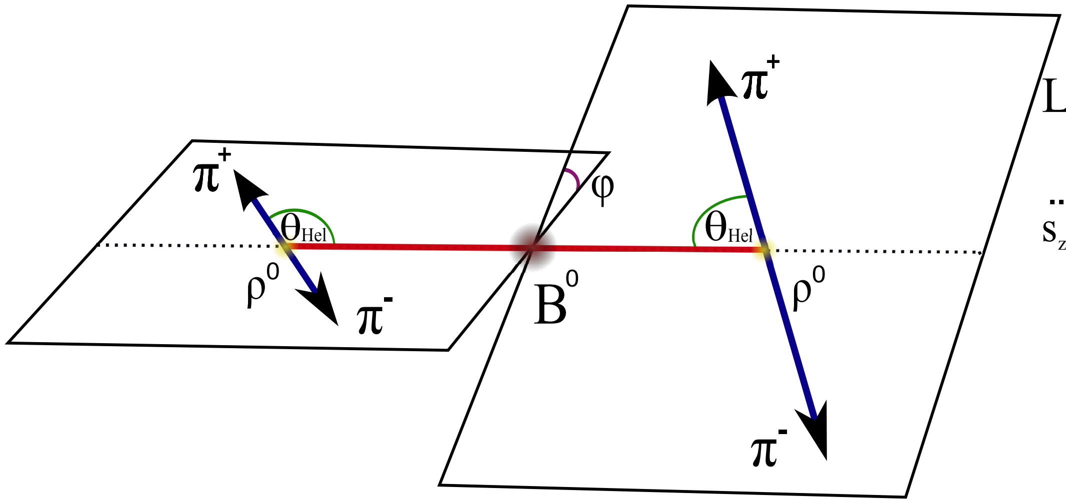
separate longitudinal(CP even) and transversal(CP even & odd) states

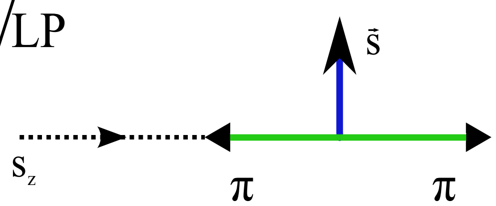
consider two signal components, fit $\cos(\theta_{Hel}) \to f_L$ (fraction of LP)

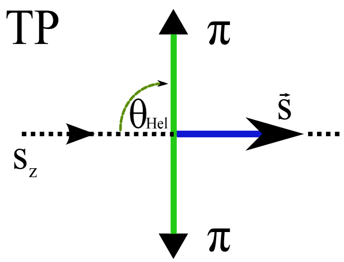
- e.g. for $B \to \rho^0\rho^0$ $\qquad J^{CP}$: $\rho^0 = 1^{--}$; $\pi^{\pm} = 0^{-}$

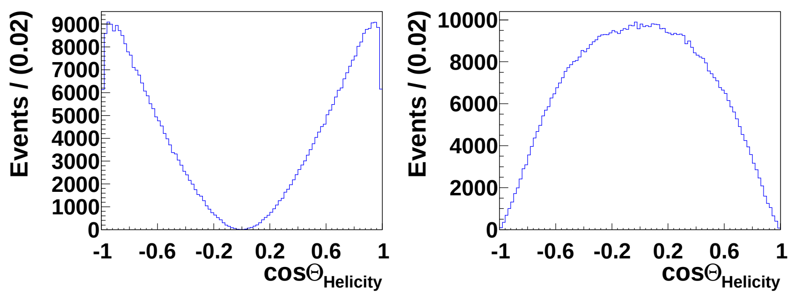
$$\rho^0 \to \pi^+\pi^-$$

θ_{Hel}: angle between the B^0 and the π^+ flight directions in the ρ frame







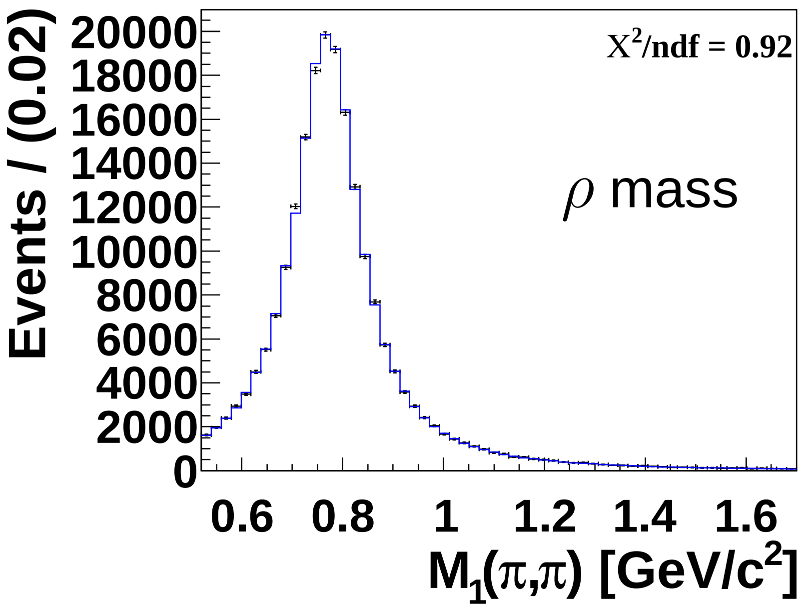


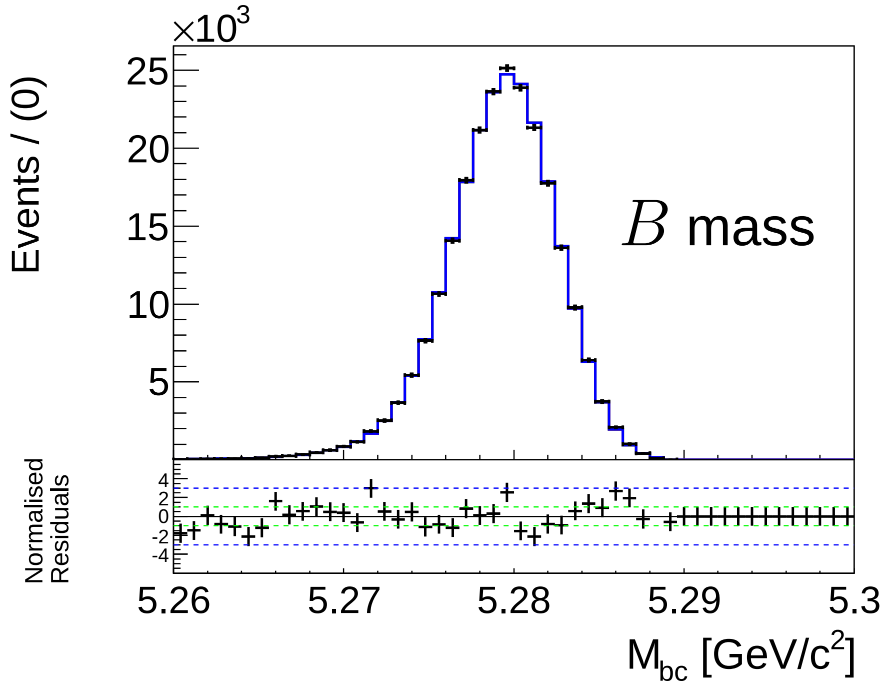
Reconstruction of $(B^0 \to \rho\rho)$

combine particles seen by detector

$$B^0 \to \rho^0 \rho^0$$
$$\rho^0 \to \pi^+ \pi^-$$

$$B^0 \to \rho^+ \rho^-$$
$$\rho^\pm \to \pi^\pm \pi^0$$
$$\pi^0 \to \gamma\gamma$$





$$M_{bc} \equiv \sqrt{E_{beam}^2 - \vec{p}_{B_{rec}}^{\,2}}$$

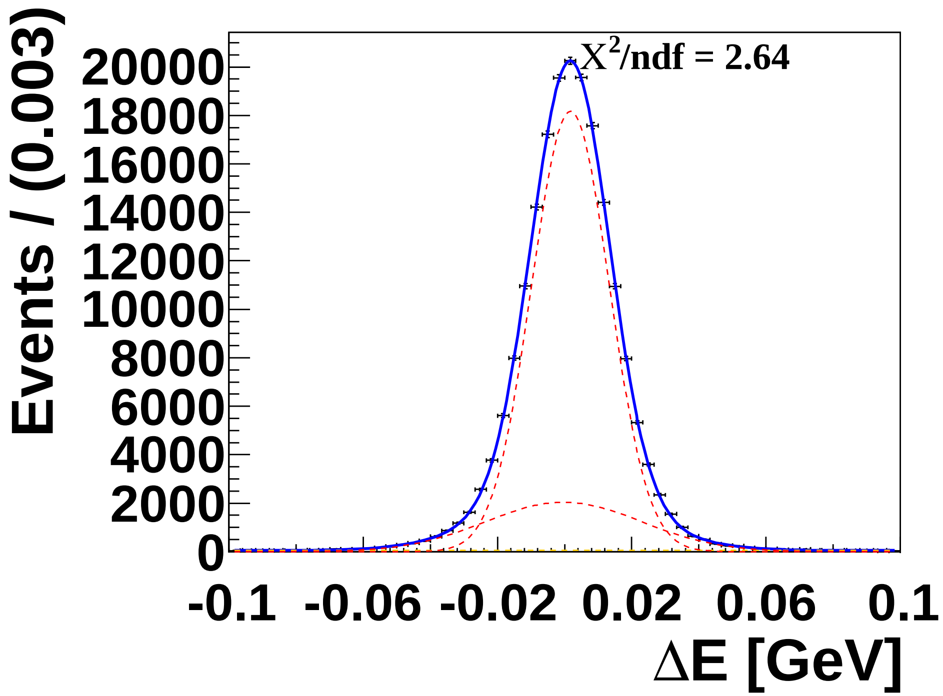
$$\rho : m_0 \sim 770\ \mathrm{MeV}, \Gamma \sim 150\ \mathrm{MeV}$$

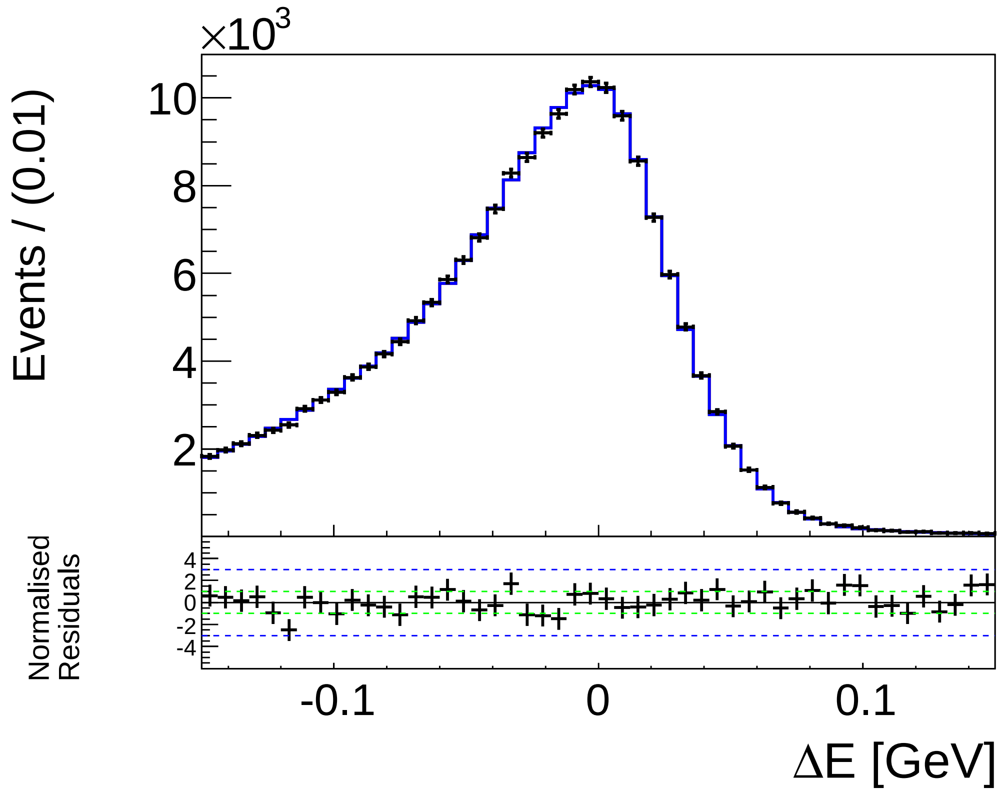
What a difference two π^0s make

$$\boxed{\Delta E \equiv E_{B_{rec}} - E_{beam}}$$

$(\pi^0 \to \gamma\gamma)$

- signal MC: $B^0 \to \rho^0\rho^0$ $B^0 \to \rho^+\rho^-$





$4\pi^\pm$ $2\pi^\pm, 2\pi^0$

Separate Signal from Background

multivariate (blind) analysis

- rare B decays are extremely BKG dominated: several sources

  -continuum: $e^+e^- \to q\bar{q}, q = u, d, s, c$ dominant

  -B decays with same final state: e.g. $B \to \pi\pi\pi\pi, \rho\pi\pi, \ldots$

  $\to$ inteference needs to be considered!! (here systematics)

  -combinatorial BKG from other B decays

- hard cuts destroys also signal yield (**rare decays**)

  $\Rightarrow$ multidimensional fit:

  (6D for $B \to \rho^0\rho^0$ and 8D for $B \to \rho^+\rho^-$)

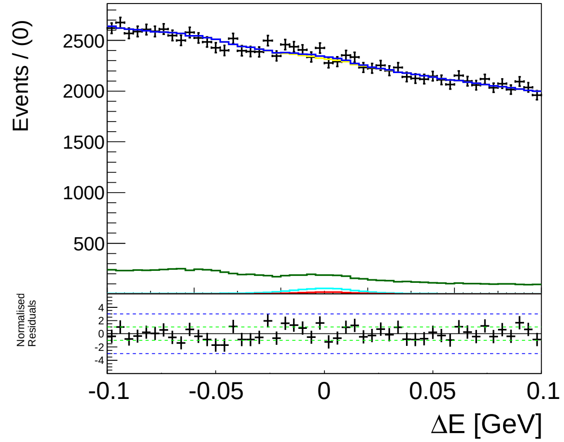
- consider each background separately

  (17 for $B \to \rho^0\rho^0$ and even more for $B \to \rho^+\rho^-$)

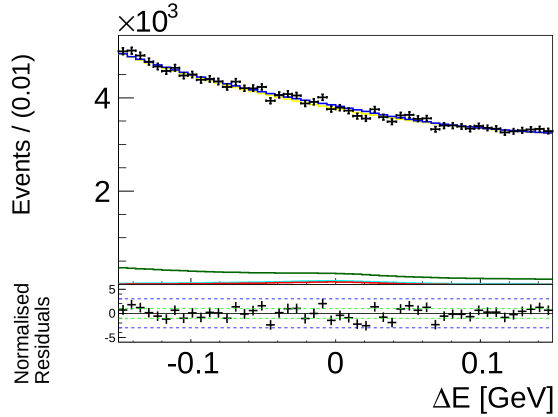
- $\Rightarrow$ simultanious fit of $\mathcal{B}$, f_L (and CPV parameters for $B \to \rho^+\rho^-$)

full projection:

$B \to \rho^0\rho^0$ (data)

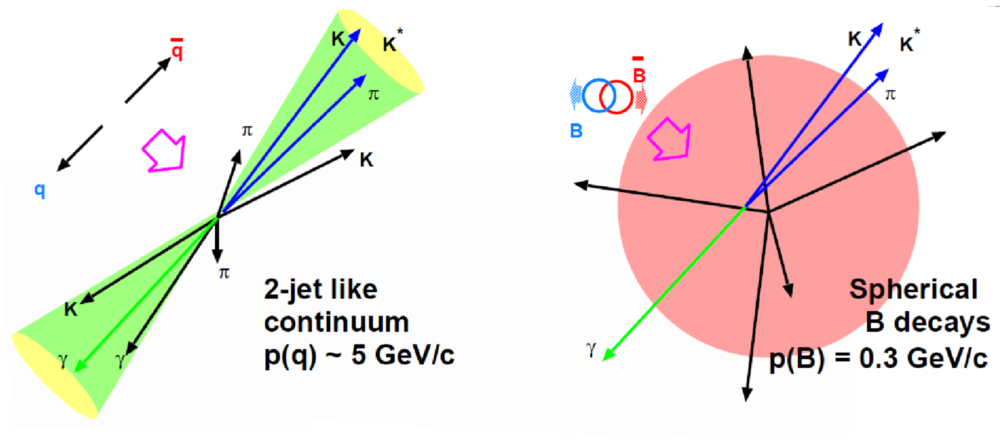


$B \to \rho^+\rho^-$ (MC)



Continuum Identification

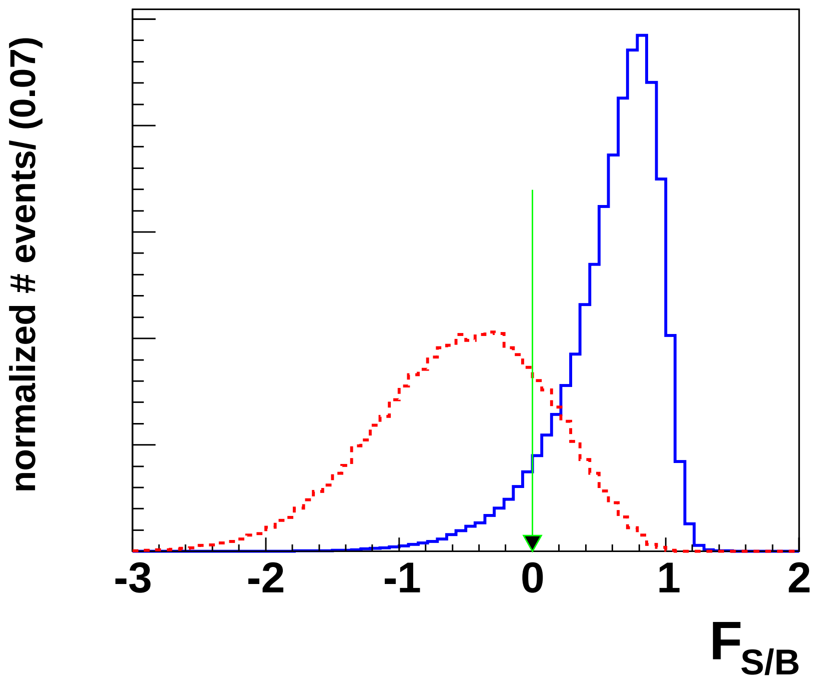
- $e^+e^- \rightarrow q\bar{q}, \quad (q = u, d, s, c)$ gives biggest contribution ($N_{q\bar{q}}/N_{sig} \sim 1000$)
- combine $\mathcal{O}(10)$ eventshape-dependent variables with Fisher discinimant $\rightarrow \mathcal{F}_{S/B}$



- include $\mathcal{F}_{S/B}$ in fit and apply loose cut

  $\rightarrow$ reject $\sim 80\%$ $q\bar{q}$ events

  BUT still huge contribution



$B\bar{B}$,$q\bar{q}$; same normalisation

Result: $B^0 \to \rho^0\rho^0$

6D fit to $\Delta E, \mathcal{F}_{S/B}, m_1(\pi^+\pi^-), m_2(\pi^+\pi^-), \cos\theta^1_{\rm Hel}, \cos\theta^2_{\rm Hel}$

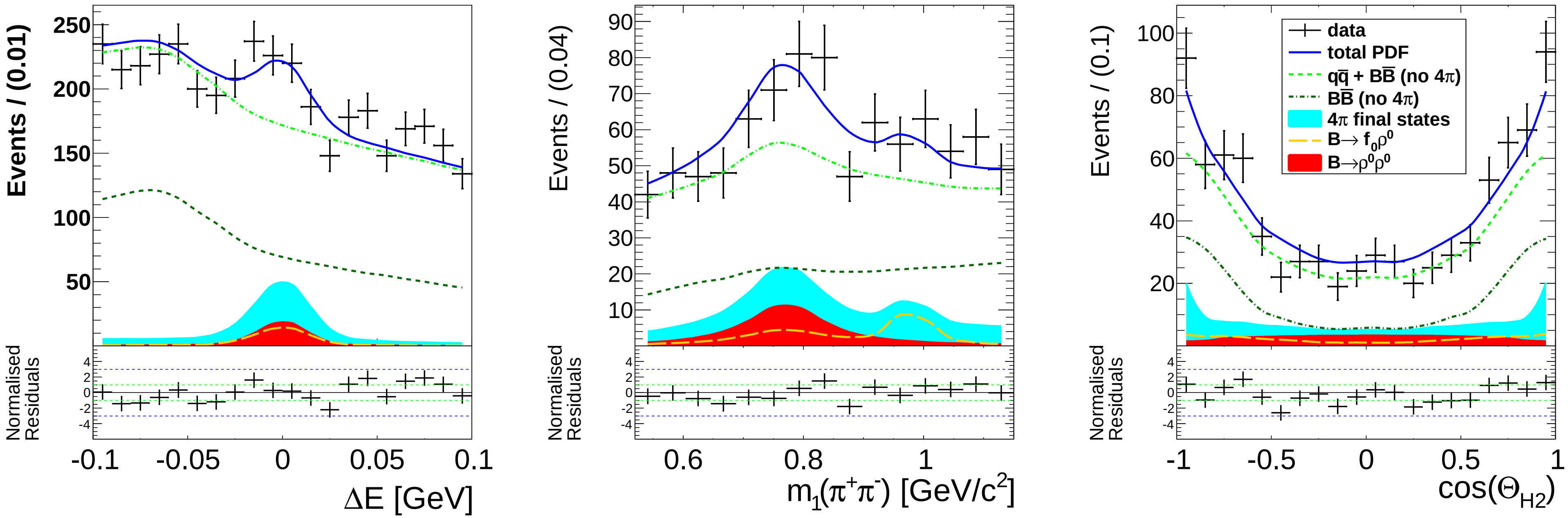
PRD **89 072008** **arXiv:1212.4015**

$$\boxed{\mathcal{B}(B^0 \to \rho^0\rho^0) = (1.02 \pm 0.30 \pm 0.15) \times 10^{-6}, 3.4\sigma}$$

$$\boxed{f_L = 0.21^{+0.18}_{-0.22} \pm 0.15}$$

also 1^{st} evidence of $B^0 \to f_0\rho^0$ (3.1σ)

Signal enhanced projections



ϕ_2 from $B \to \rho\rho$ Decays

isospin analysis

inputs: Belle results

- $\mathcal{B}, f_L$ of

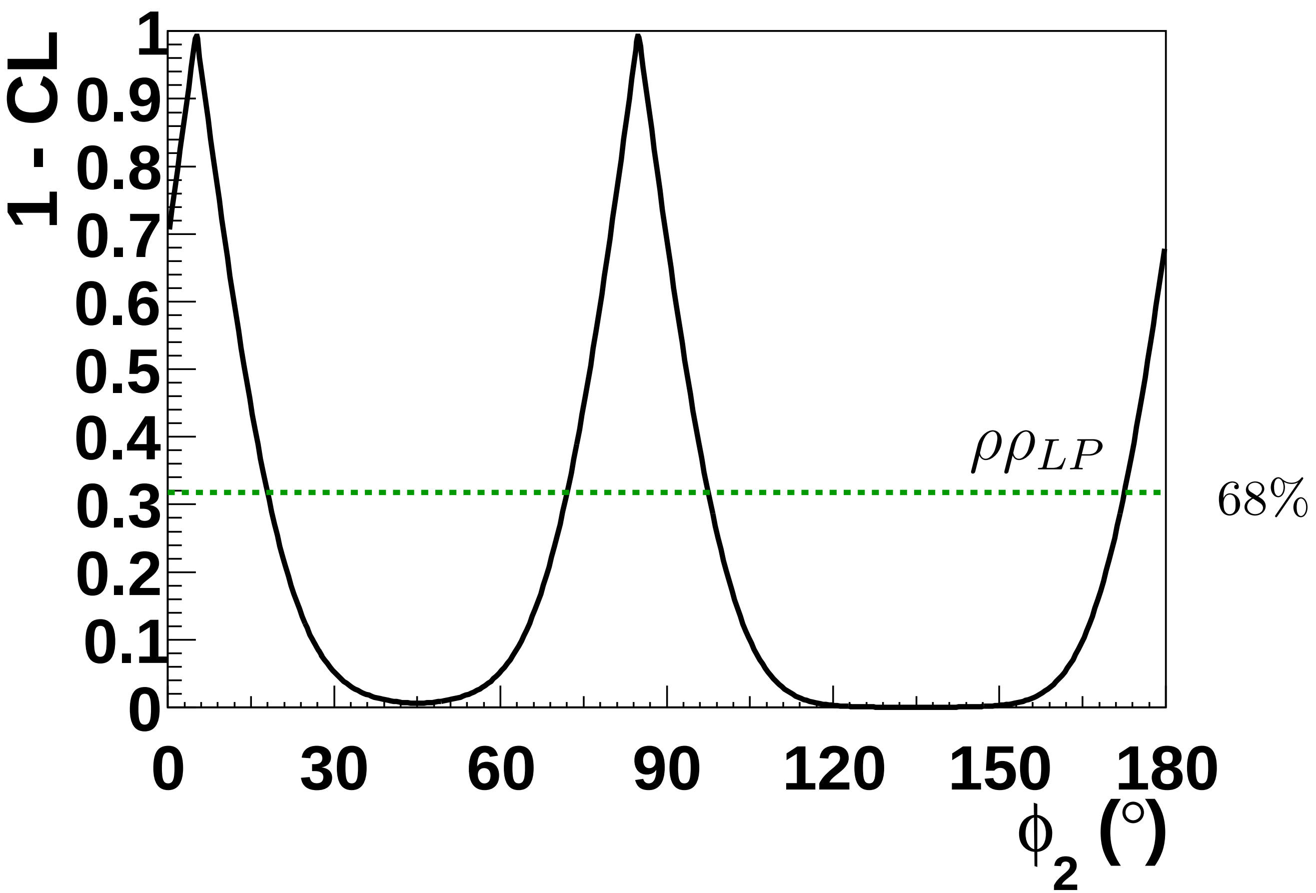
  $B^0 \to \rho^+\rho^-$

  $B^0 \to \rho^0\rho^0$

  $B^+ \to \rho^-\rho^0$

- $\mathcal{S}_{CP}, \mathcal{A}_{CP}$ of

  $B^0 \to \rho^+\rho^-$

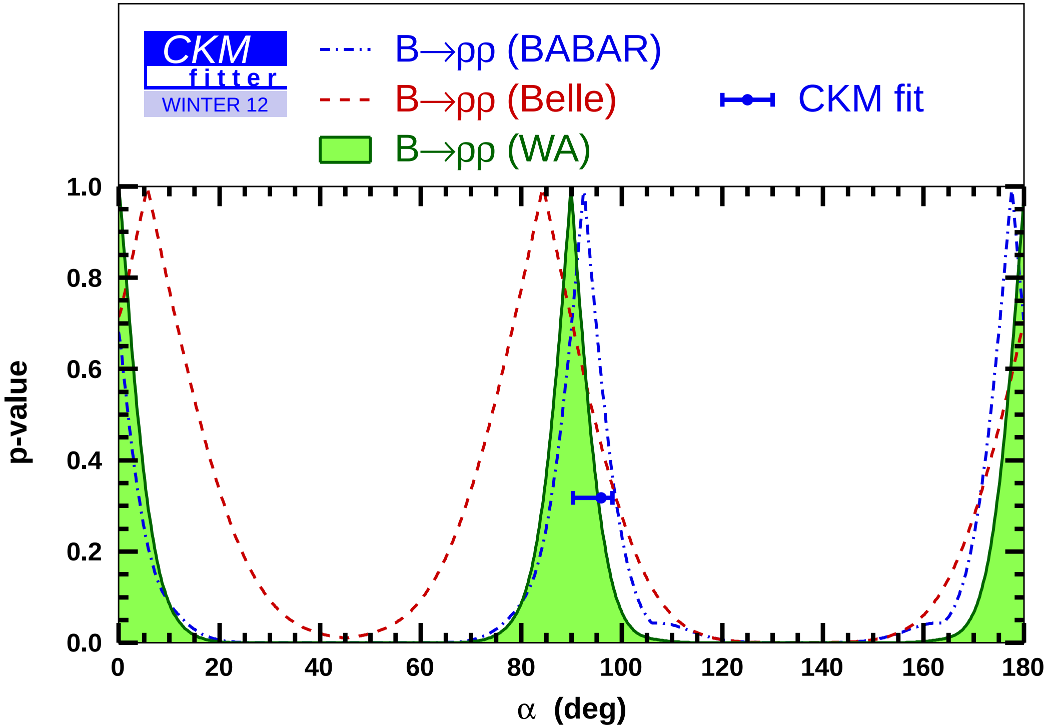


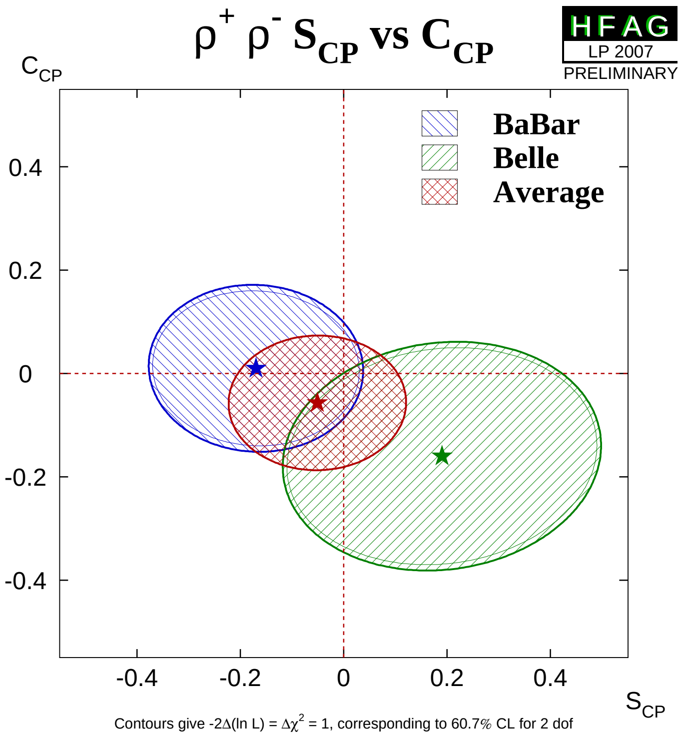
$\boxed{\phi_2 = (84.9 \pm 13.5)^\circ, \quad \Delta\phi_2 = (0 \pm 10.4)^\circ}$

arXiv:1212.4015

Comparison with BaBar

BaBars uncertainty on $\phi_2(\alpha)$ ($\rho\rho$ system) $\sim 7^\circ$





Belle NEEDS UPDATES on $B^0 \to \rho^+\rho^-$ and $B^+ \to \rho^+\rho^0$!!

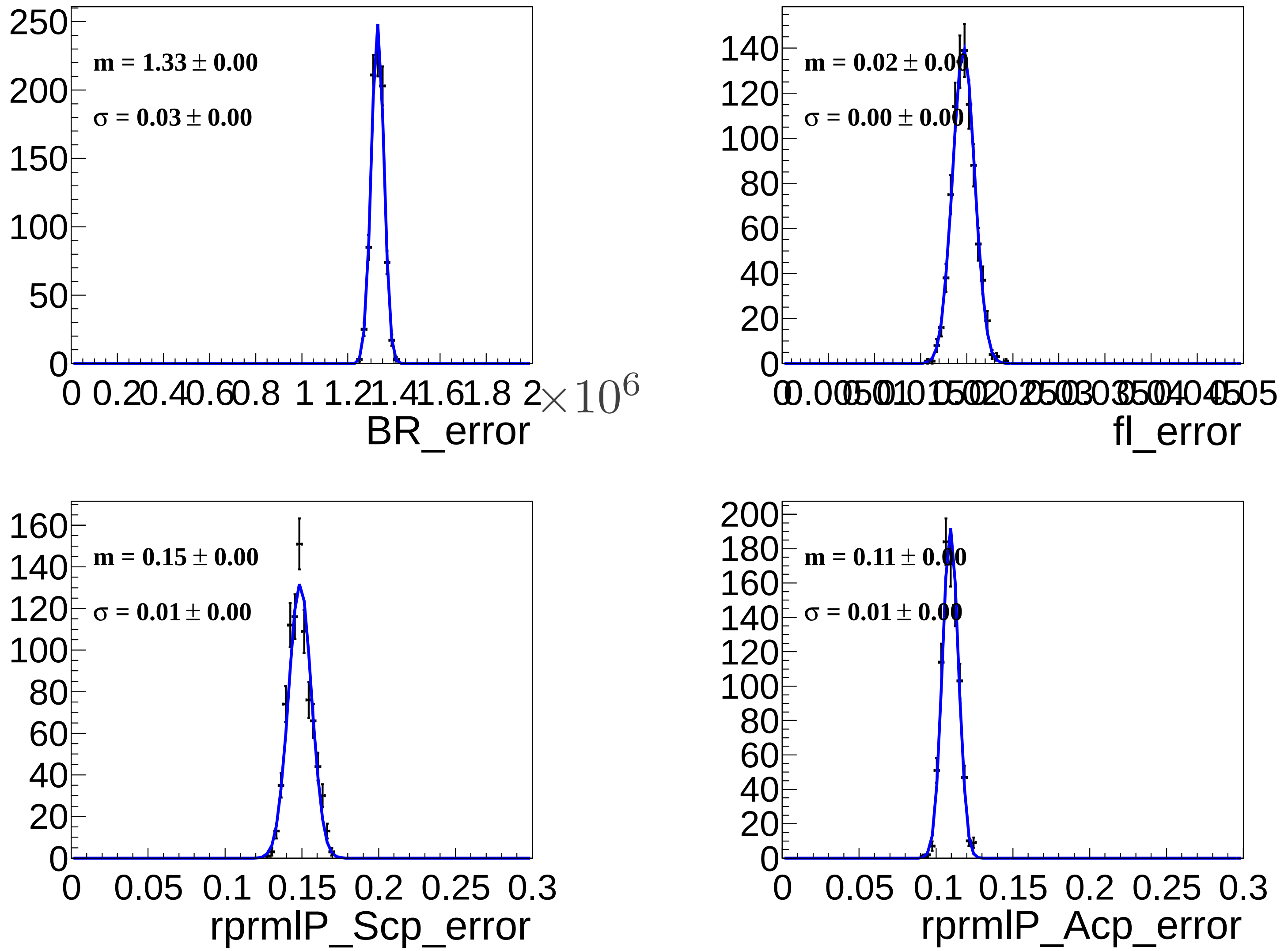
$B \to \rho^{\pm}\rho^{\mp,0}$

- **previous measurements**

Experiment	BELLE	BaBar
$\mathcal{BR}^{+-}(\times 10^{-6})$	$22.8 \pm 3.8^{+2.3}_{-2.6}$	$25.5 \pm 2.1^{+3.6}_{-3.9}$
f_L^{+-}	$0.941^{+0.034}_{-0.040} \pm 0.030$	$0.992 \pm 0.024^{+0.026}_{-0.013}$
$\mathcal{A}_{CP}^{+-}$	$0.16 \pm 0.21 \pm 0.07$	$-0.01 \pm 0.15 \pm 0.06$
$\mathcal{S}_{CP}^{+-}$	$0.19 \pm 0.30 \pm 0.07$	$-0.17 \pm 0.20^{+0.05}_{-0.06}$
$N_{B\bar{B}} \times 10^6$	535*	384
$\mathcal{BR}^{\pm 0}(\times 10^{-6})$	$31.7 \pm 7.1^{+3.8}_{-6.7}$	$23.7 \pm 1.4 \pm 1.4$
$f_L^{\pm 0}$	$0.948 \pm 0.106 \pm 0.021$	$0.950 \pm 0.015 \pm 0.006$
$\mathcal{A}_{CP}^{\pm 0}$	$0.00 \pm 0.22 \pm 0.03$	$0.054 \pm 0.055 \pm 0.010$
$N_{B\bar{B}} \times 10^6$	85	465

* : Belle only updated CP parameters; $\mathcal{BR}$, f_L from 275 $B\bar{B}$ pairs

Outlook



- 1^{st} toyMC studies for $B \to \rho^+\rho^-$
- MODEL NOT YET FINALIZED !!!

prev. BELLE
$\mathcal{BR}^{+-}(\times 10^{-6})$= $22.8 \pm 3.8^{+2.3}_{-2.6}$
f_L^{+-} = $0.941^{+0.034}_{-0.040} \pm 0.030$
$\mathcal{A}_{CP}^{+-}$ = $0.16 \pm 0.21 \pm 0.07$
$\mathcal{S}_{CP}^{+-}$ = $0.19 \pm 0.30 \pm 0.07$

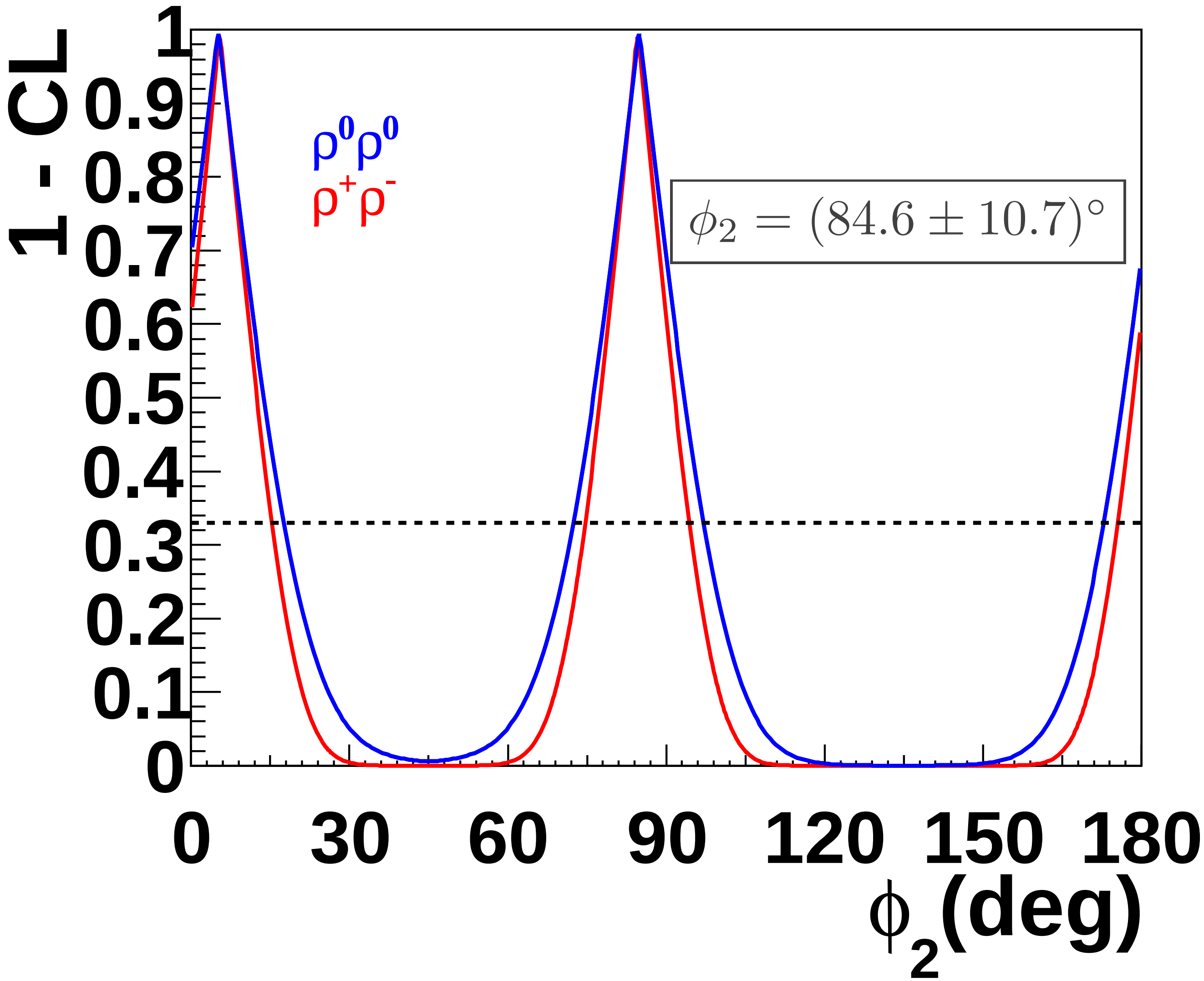
Outlook II

use expected errors for $B \to \rho^+\rho^-$ in isospin analysis

(see previous page)

$\mathcal{B}(B \to \rho^+\rho^-)$ dominated by syst.$\to$ $\delta = 2.5 \times 10^{-6}$

mean values remain unchanged

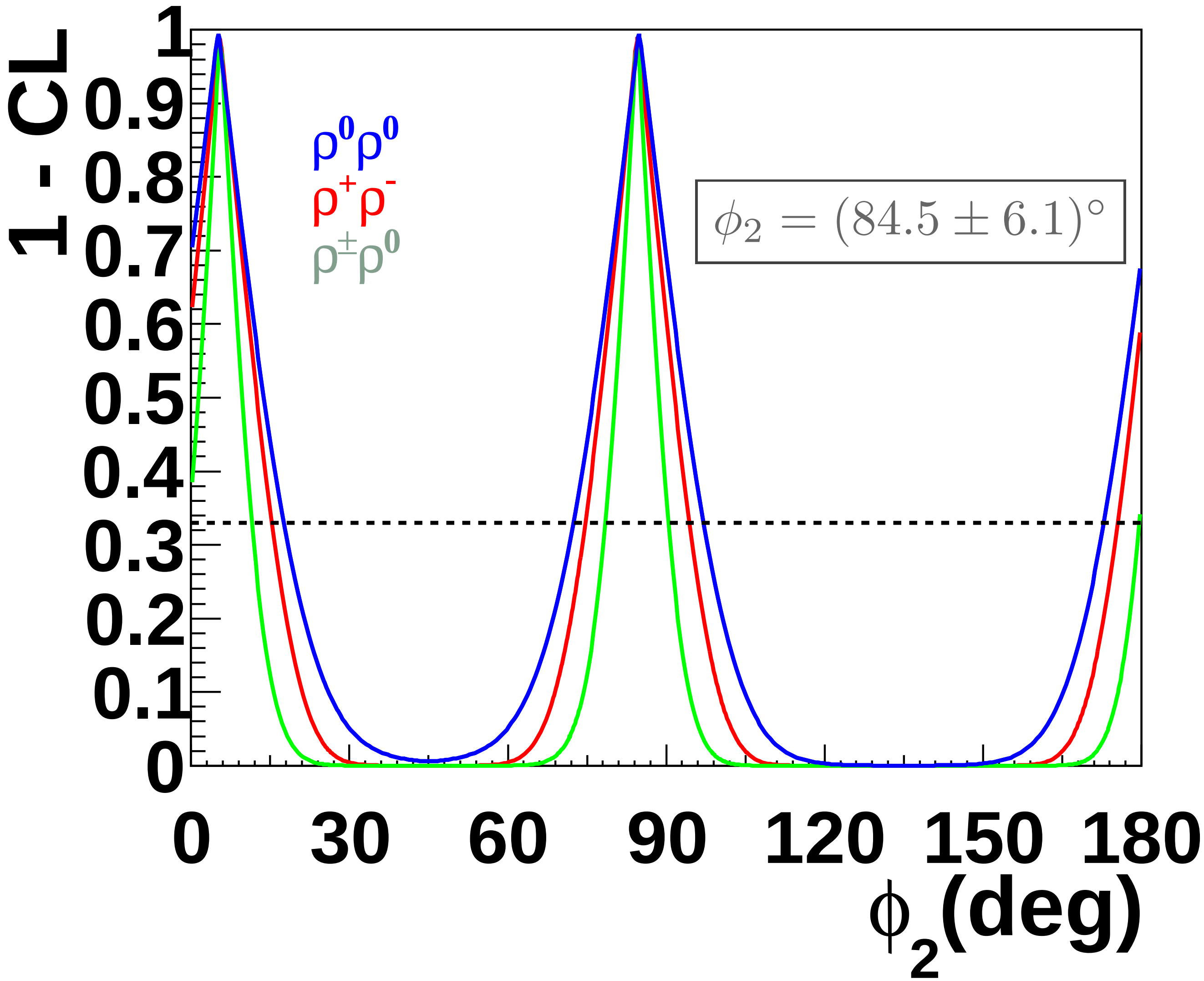


Outlook II

assume similar errors for $\mathcal{BR}(B^\pm \to \rho^\pm\rho^0)$ as for $\mathcal{BR}(B \to \rho^+\rho^-)$ in isospin analysis

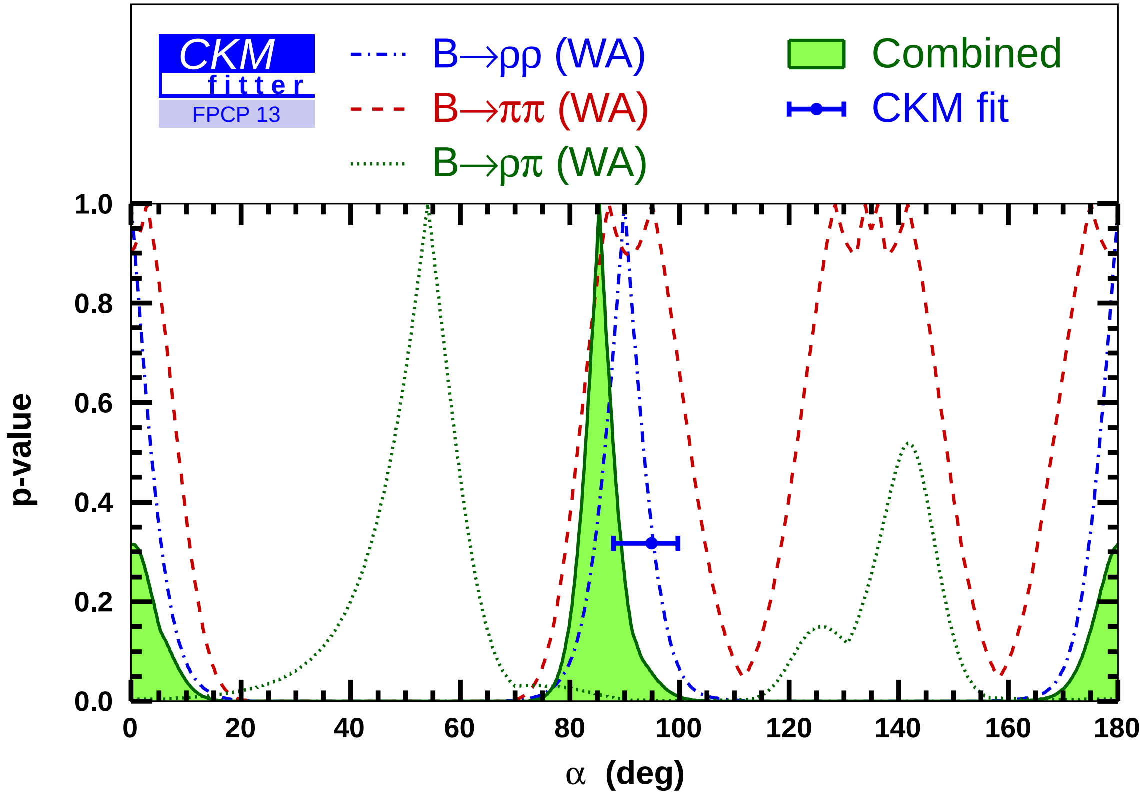
mean values remain unchanged

This is how Belle's final word on ϕ_2 from $B \to \rho\rho$ might look like



Current Status of ϕ_2

combine measurements from $B \to \pi\pi$, $B \to \rho\rho$ and $B \to \rho\pi$ $\boxed{\phi_2 = (88.7^{+4.6}_{-4.2})^\circ}$



Summary & Outlook

- presented measurement of $\mathcal{BR}(B^0 \to \rho^0\rho^0)$ (acc. by PRD)

$$\mathcal{BR}(B^0 \to \rho^0\rho^0) = (1.02 \pm 0.30 \pm 0.15) \times 10^{-6}. \quad 3.4\sigma$$

$$f_L = 0.21^{+0.18}_{-0.22}(stat.) \pm 0.15(syst.)$$

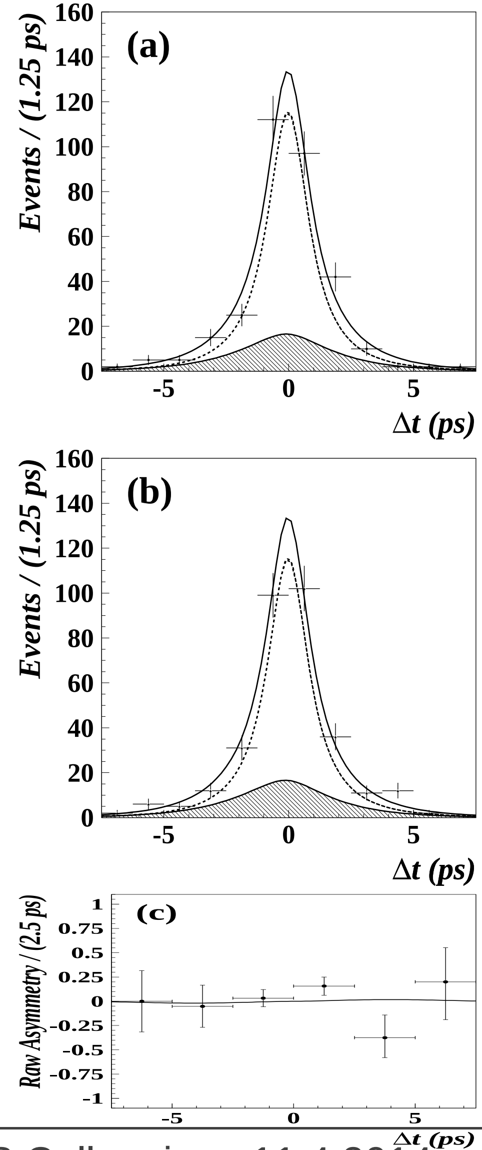
- and used it in isospin analysis

$$\phi_2 = (84.9 \pm 13.5)^\circ$$

- currently working on the final update of $B^0 \to \rho^+\rho^-$

$\to$ measurement of branching fraction, polarization and CP asymmetries.

$\rho^+\rho^-$ prev. Belle

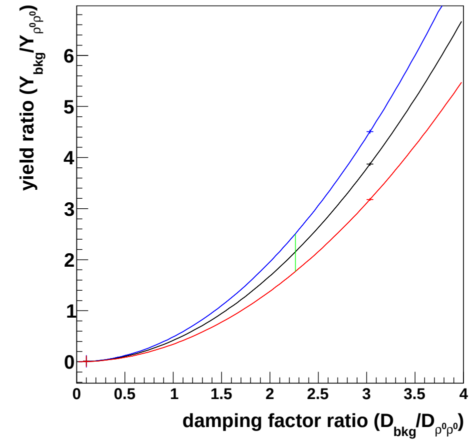


BACKUP

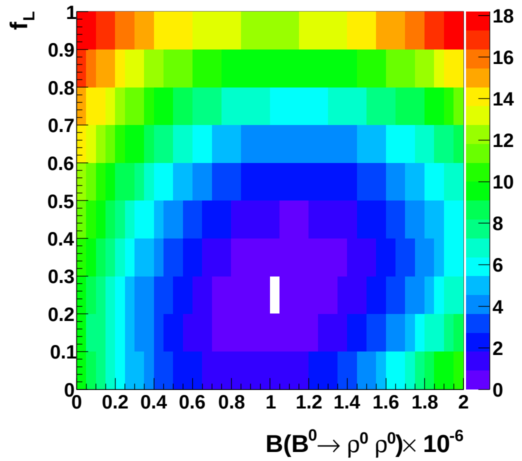
Systematic Uncertainties

Category	$\delta\mathcal{B}(B^0 \to \rho^0\rho^0)$ (%)	δf_L
$N(B\bar{B})$	1.4	—
Tracking	1.4	—
Particle identification	2.5	—
Mis-reconstruction fraction	1.3	< 0.001
ρ^0 shape	0.2	< 0.001
Model shape	5.1	0.08
Histogram shape	5.2	0.03
$\mathcal{B}(B^0 \to a_1\pi)$	0.4	0.03
$\mathcal{B}(B^0 \to b_1\pi)$	<0.1	< 0.001
$\mathcal{B}(B^0 \to a_2\pi)$	<0.1	< 0.001
Fit bias	1.9	0.03
Interference	19.2	0.03
$\rho^0\pi\pi$ helicity	6.3	0.05
Total	22.0	0.11

interference with $a_1\pi$



likelihood scan incl. syst.



$B \to VV$

naive SM predictions

amplitude ratios: $\boxed{\mathbf{A_0 : A_+ : A_- = 1 : \frac{m_V}{m_B} : \frac{m_V^2}{m_B^2}}}$

fraction of longitudinal polarized states f_L: $\boxed{\mathbf{f_L = \frac{|A_0|^2}{|A_0|^2+|A_+|^2+|A_-|^2} \sim 1 - \frac{m_V^2}{m_B^2}}}$

---

theoretical status:

LP (A_0)

calculable using QCD factorization in the heavy quark limit

Beneke, Buchalla, Neubert, Sachrajda: arXiv:hep-ph: 0104110, 9905312, 0006124

TP

suppressed by powers of (Λ_{QCD}/m_B)

amplitudes do NOT factorize $\Rightarrow$ hard to calculate (divergences)

M. Beneke, J. Rohrer and D. Yang : arXiv:hep-ph: 0612290

$B \to VV$

measurements

tree dominated: $(\rho, \omega, \ldots)$

$f_L \sim 1$ ✓

penguin dominated: $(K^*, \phi, \ldots)$

$f_L \sim 0.5$?

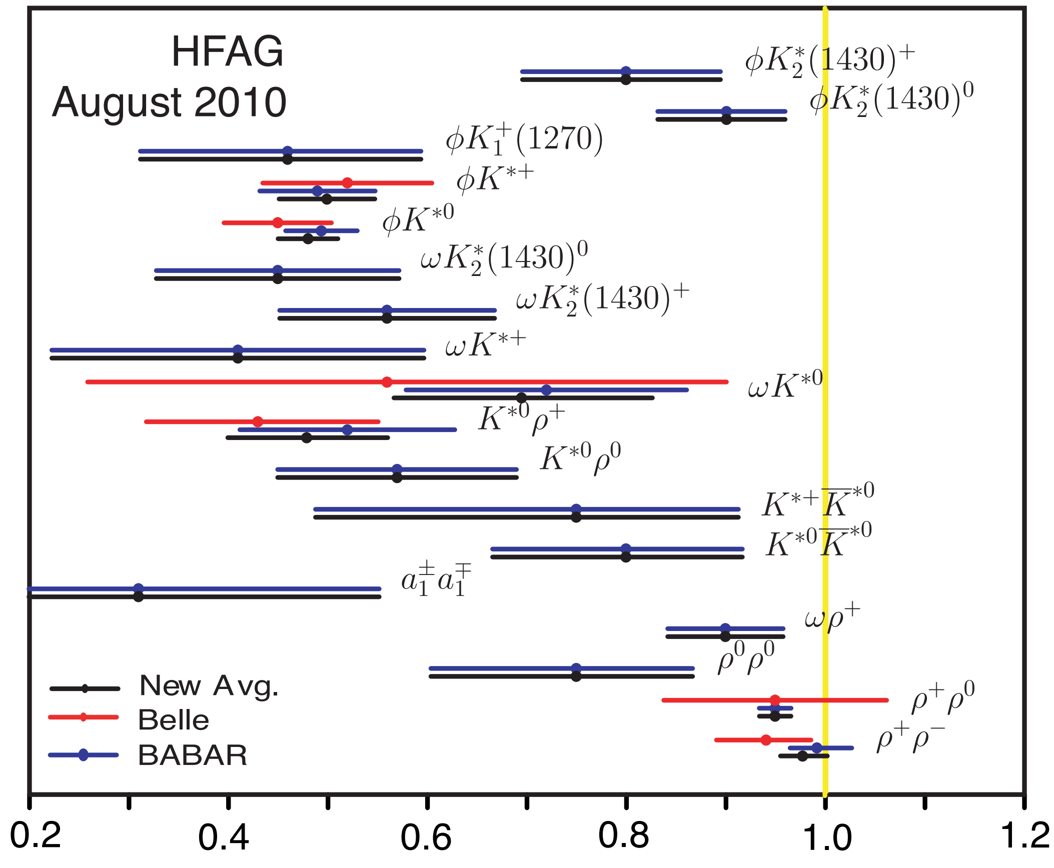
e.g.K^* *naive expectation:*

$f_L \sim 1 - (\frac{m_{K^*}}{m_B})^2 \sim 0.97$

$\rightarrow$ **"helicity puzzle"**

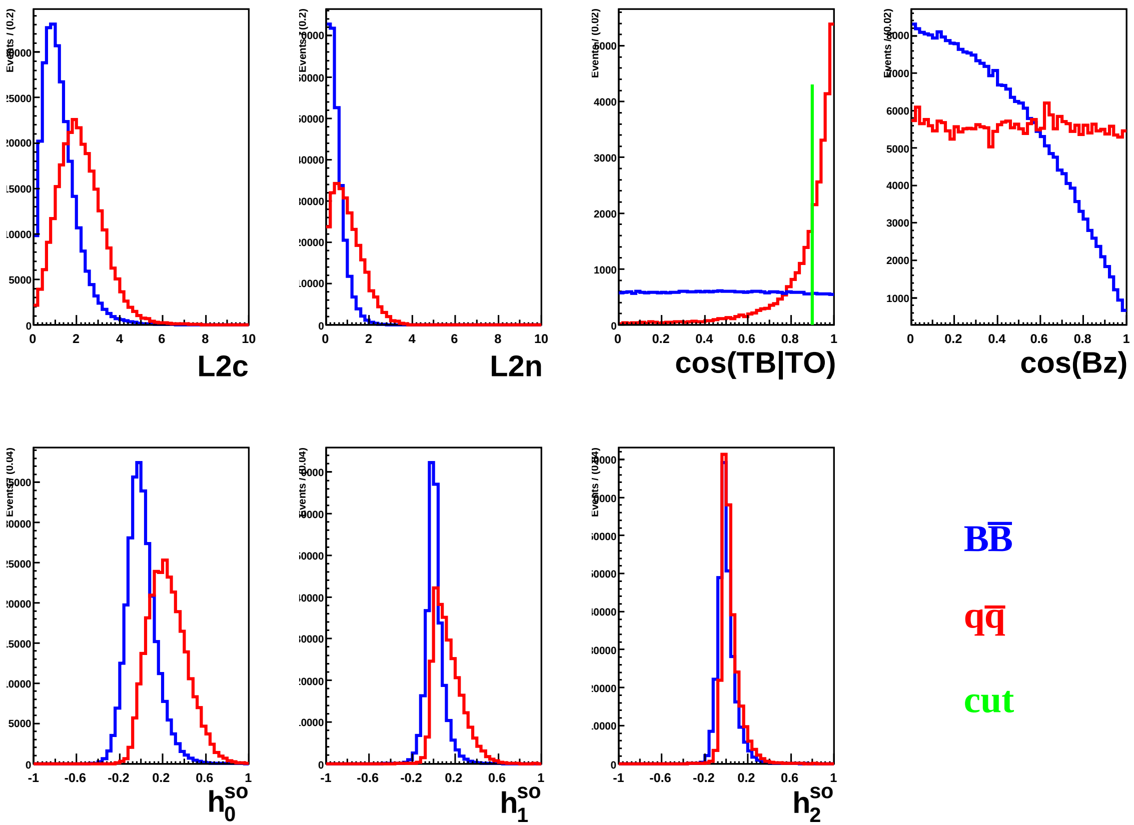
topic of ongoing research

Polarizations of Charmless Decays



Continuum Identification

What I use.



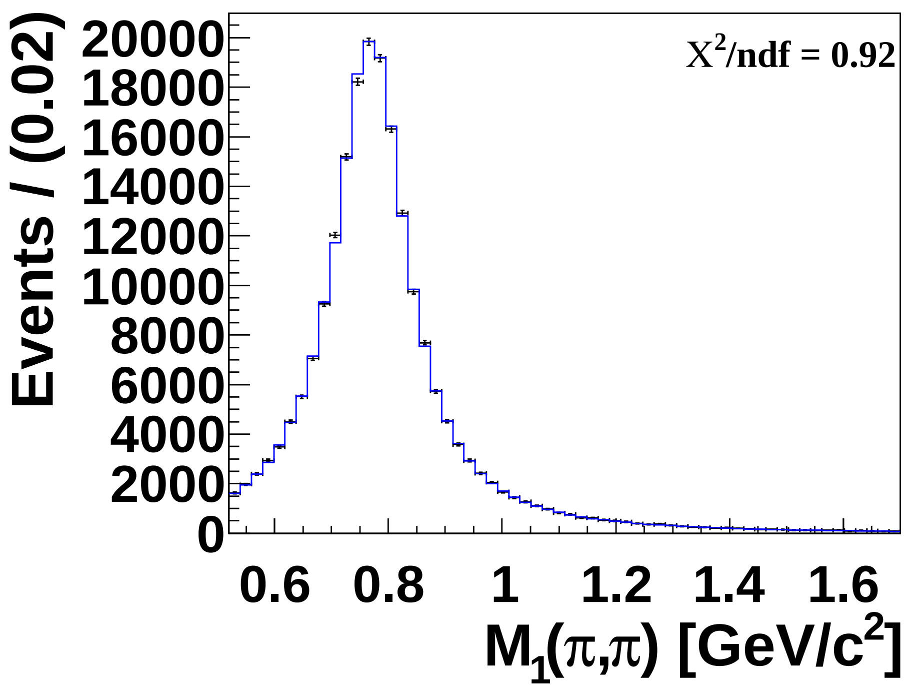
- momentum sum relative to thrust axis L_2
- angle between the 2 Bs thrust axis
- B flight direction
- fox wolfram moments

cut: $\cos(TB|TO) < 0.9$

removes $\sim 60\% q\bar{q}$

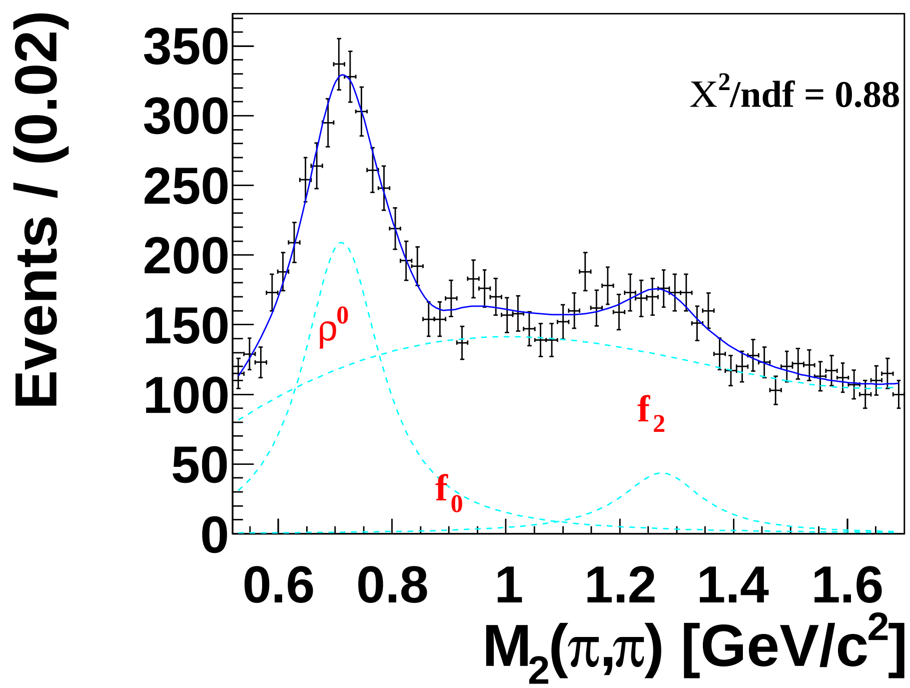
Model for $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

- signal MC(L pol)



$\mathcal{PDF}(m_{\pi^+\pi^-}) = \epsilon_{rec}(m_{\pi^+\pi^-})\times$Breit-Wigner

- neutral charmless decays

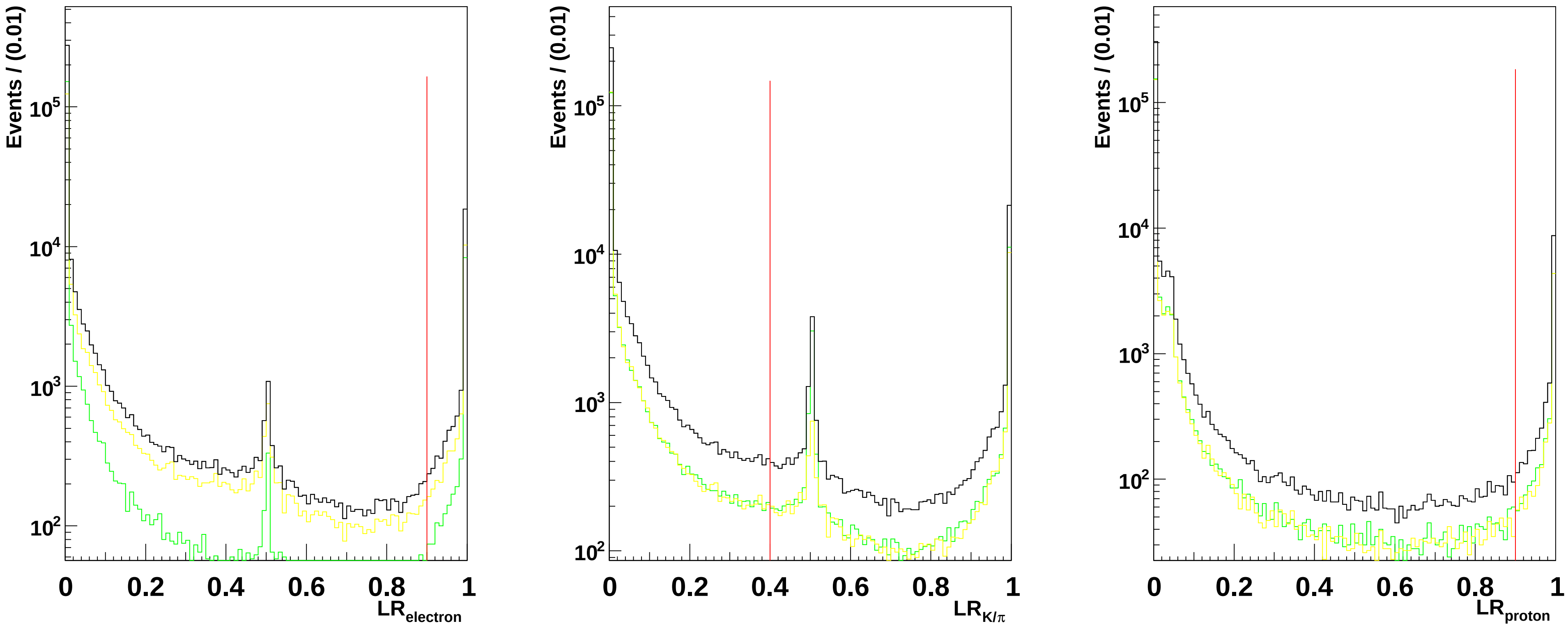


$\mathcal{PDF}(m_{\pi^+\pi^-}) = 2\times$Breit-Wigner + gaussian + $\sum_{i=1}^{4}$chebychev$_i$

Rec: PID Criterias

- information from different subdetectors $\rightarrow$ likelihood ratios $\mathcal{LR}_{i/j}$
- charged tracks from signal MC: standard set of cuts $\rightarrow$ syst. are known

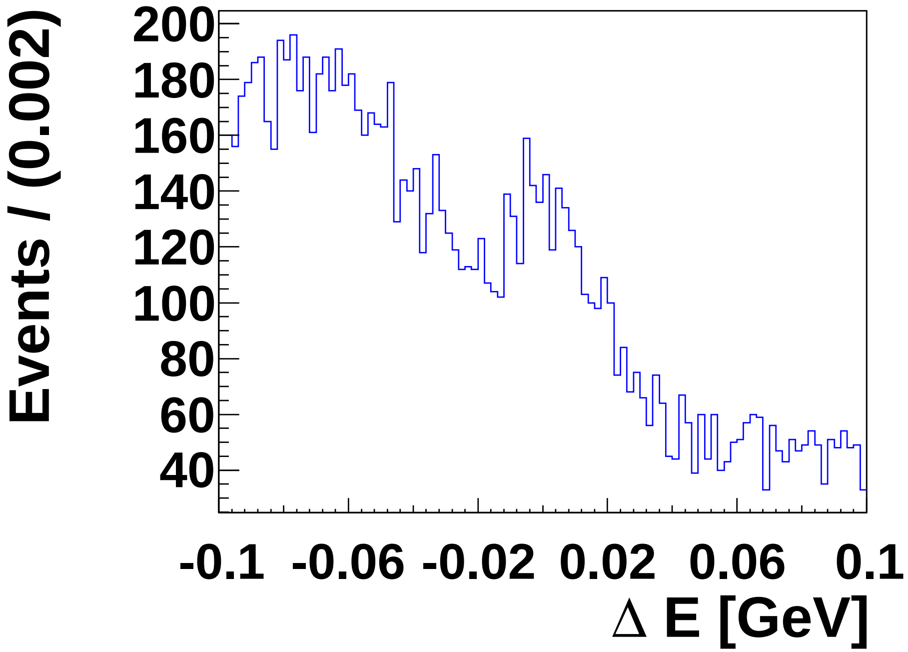
$\mathcal{LR}_e < 0.9$ $\mathcal{LR}_{K/\pi} < 0.4$ $\mathcal{LR}_{p/\pi} < 0.9$

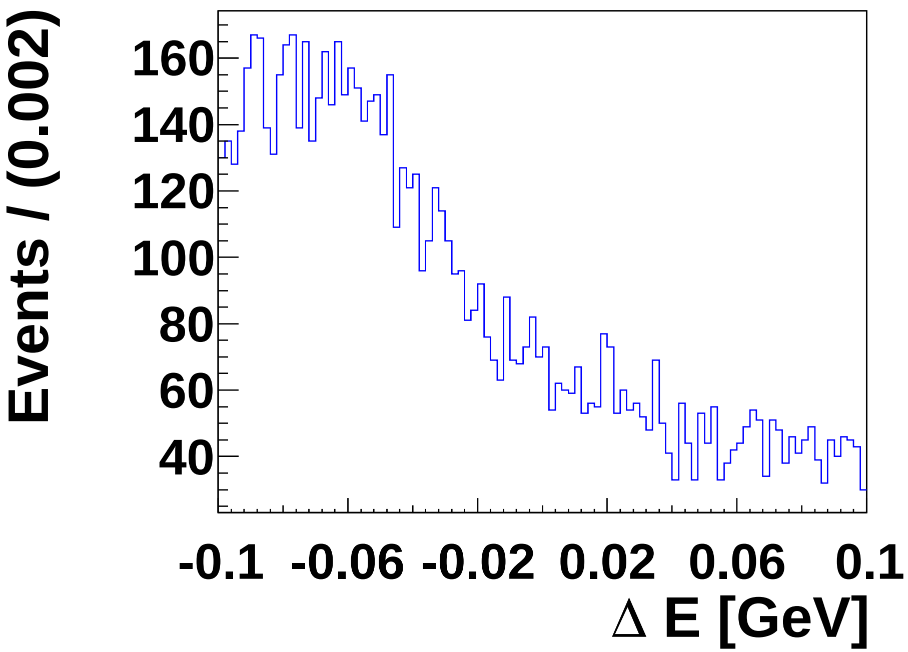


- require that tracks (*somehow*) origin at the IP: $|dr| < 0.5cm$ & $|dz| < 5cm$

Rec: Charm and Strange Vetos

- removes signal like features comming from background with similar final state topology, e.g. $B^0 \to D^-(\pi^-\pi^+\pi^-)\pi^+$ or wrong PID; $(\Delta E = E_{Brec} - E_{beam})$





before and after vetos

Rec: Charm and Strange Vetos

Cuts on $M(\pi\pi)$:

$D^0 : 1.86484 \pm 0.02[GeV/c^2]$

$K_s : 0.493677 \pm 0.018[GeV/c^2]$

Cuts on $M(\pi\pi\pi)$:

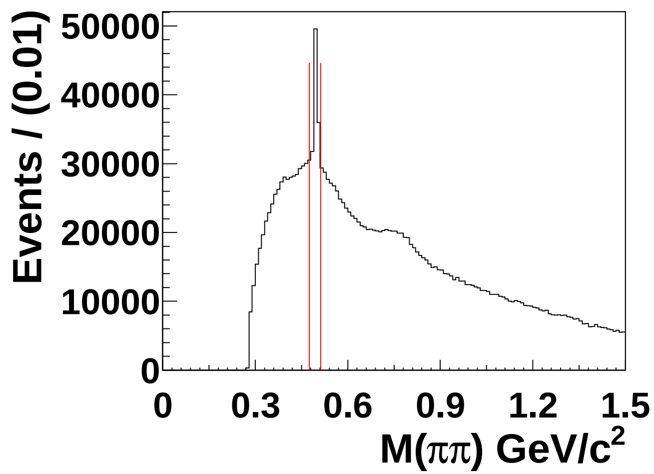
$D^{\pm} : 1.8696 \pm 0.02[GeV/c^2]$

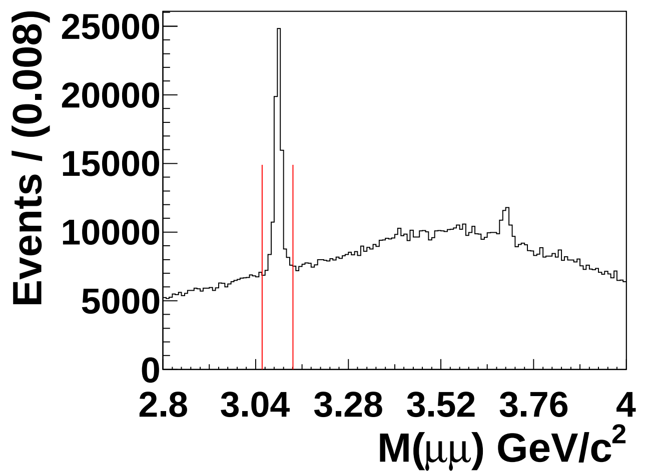
$D_s^{\pm} : 1.96849 \pm 0.02[GeV/c^2]$

Cuts on $M(\mu\mu)$:

$J\Psi : 3.0969 \pm 0.04[GeV/c^2]$

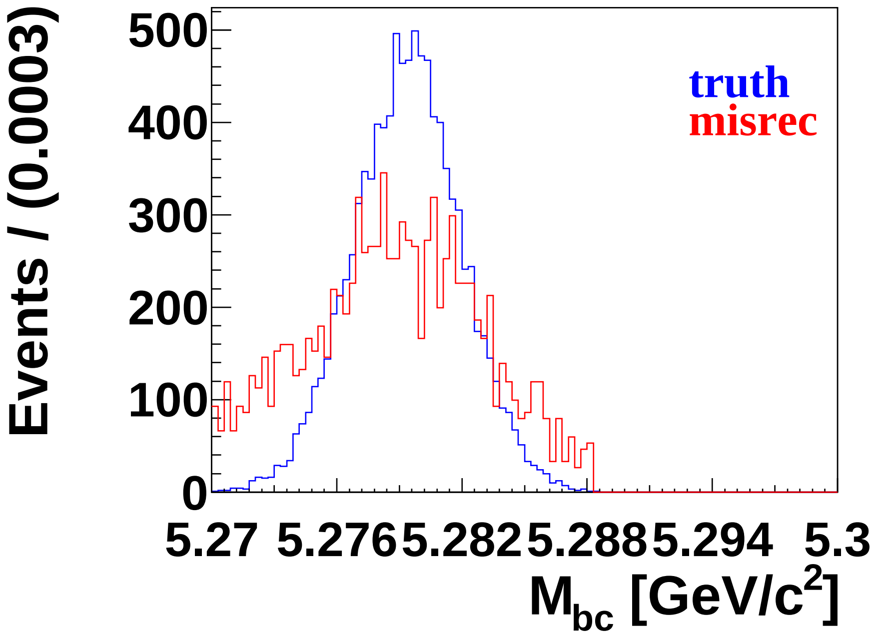
$\rightarrow$ loss in $\epsilon_{rec} < 4\%$

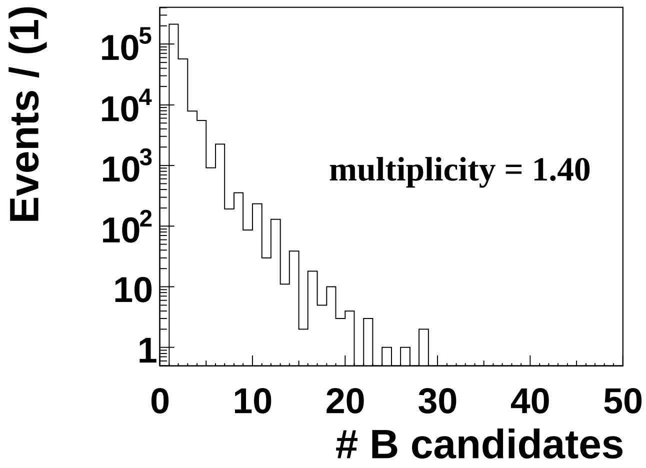




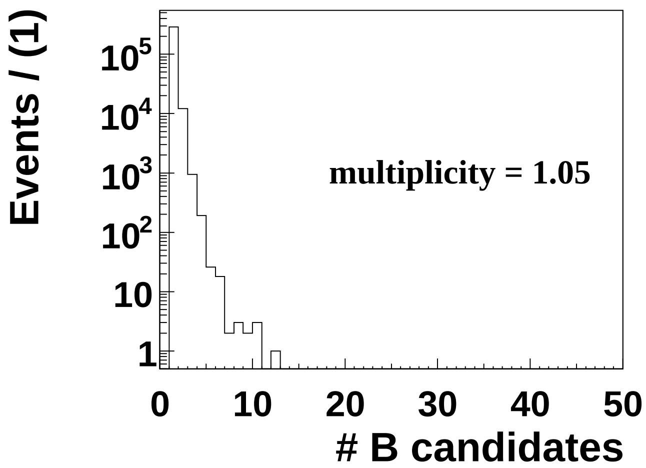
Rec: BCS

- **BCS:** best candidate selection





L(top) and T pol



if 2 candidates with same $M_{bc} = \sqrt{E_{beam}^2 - \vec{p}_B^2}$

$\Rightarrow$ choose combination with highest π^+ and lowest π^- momentum

$\rightarrow$ purity $= 76\%(L); 92\%(T)$

Measurement of $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

Extraction of $\mathcal{BR}(B^0 \to \rho^0\rho^0)$ **and** f_L

6D extended unbinned likelihood fit with the variables

$$\Delta E, \quad 2\times m_{\pi^+\pi^-}, \quad \mathcal{F}, \quad 2\times\cos\theta_{\mathrm{Hel}}$$

$$\boxed{\Delta E \equiv E_{B_{rec}} - E_{beam}}$$

The model consists of **17 components** which are: modeled using

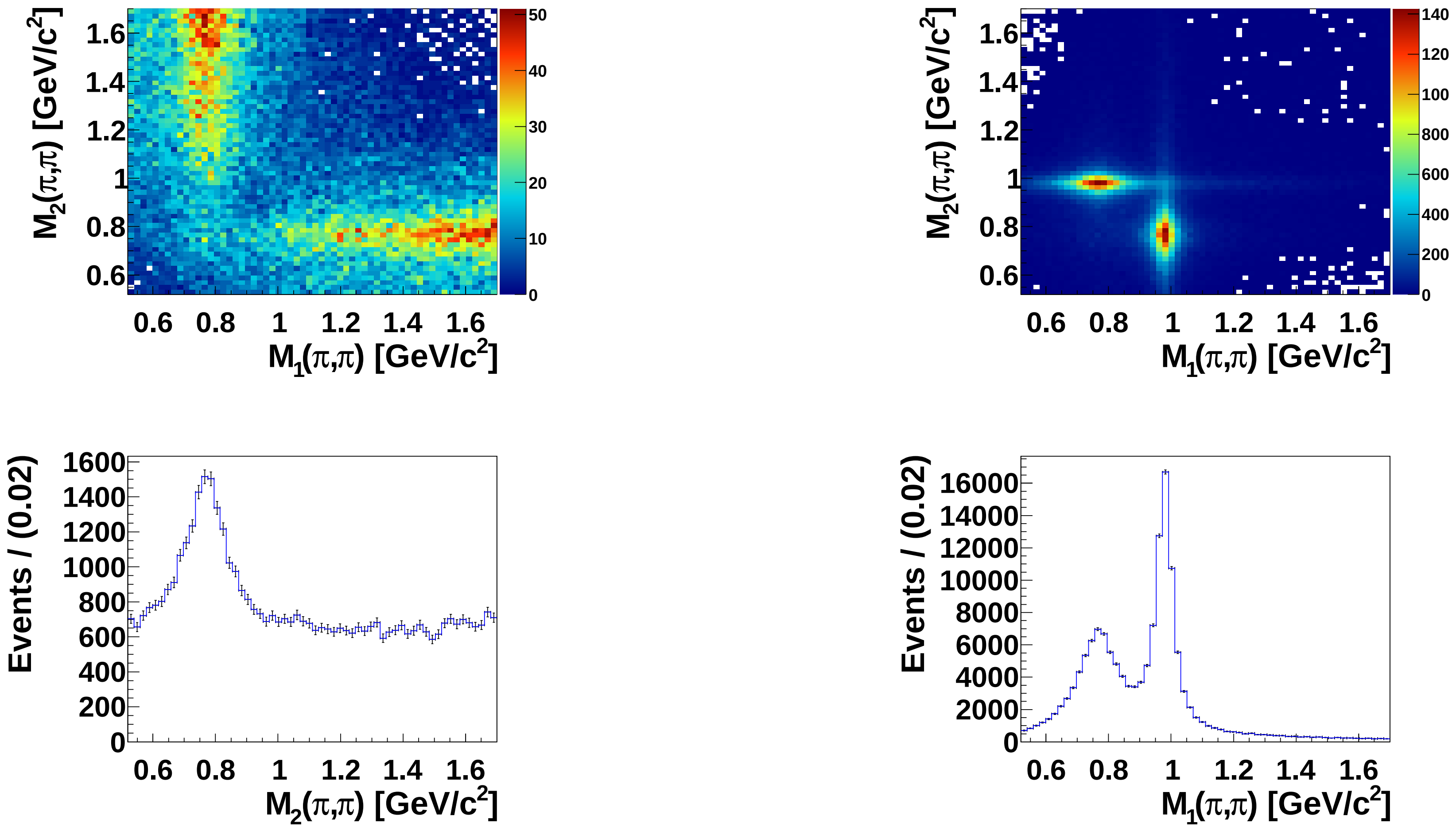
- $2\times$ signal (L pol, T pol); MC
- $2\times$ misreconstructed signal (L pol, T pol); MC
- continuum ($e^+e^- \to q\bar{q}$); data taken at $\sqrt{s} = 10.50GeV < m(\Upsilon(4S))$
- $4\times B\bar{B}$: charm and charmless $B^0(B^\pm)$ decays; MC
- $8\times$ peaking BKG (4πs finalstates); MC

  $\pi^+\pi^-\pi^+\pi^-$, $a_1^\pm\pi^\mp$, $a_2^\pm\pi^\mp$, $b_1^\pm\pi^\mp$, f_0f_0, $f_0\pi^+\pi^-$, $\rho^0\pi^+\pi^-$, $f_0\rho^0$. BR known

Correlations!

sometimes correlated multidimensional $\mathcal{PDF}$ needed

e.g. $a_1\pi$ or $f_0\rho^0$(peaking bkg: ΔE shape similar to signal)



Motivation

$B \to$ **light** VV $\qquad\qquad$ ($|B^0\rangle = |\bar{b}d\rangle$)

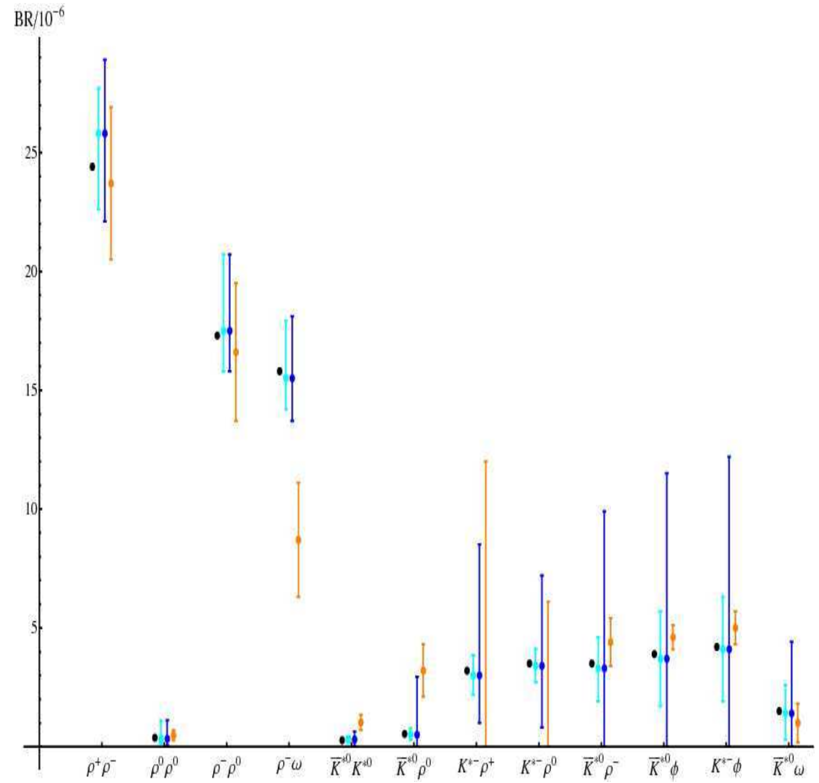
light hadronic vector states: $\rho, \omega, a_1, b_1, \phi, K^*$, ...

$\Rightarrow$ rich field of physics with different types of amplitudes

tree, QCD/EW penguin, weak annihilation

but: light $\leftrightarrow$ rare(CKM suppressed)

$\Rightarrow$ experimental difficulties



- extract flavor parameters, e.g. CP **asymmetries**
- find (hints of) new physics
- helps understanding

  a) QCD, b) helicity structure, c)...

Bartsch, Buchalla, Kraus: arxive: 0810.0249

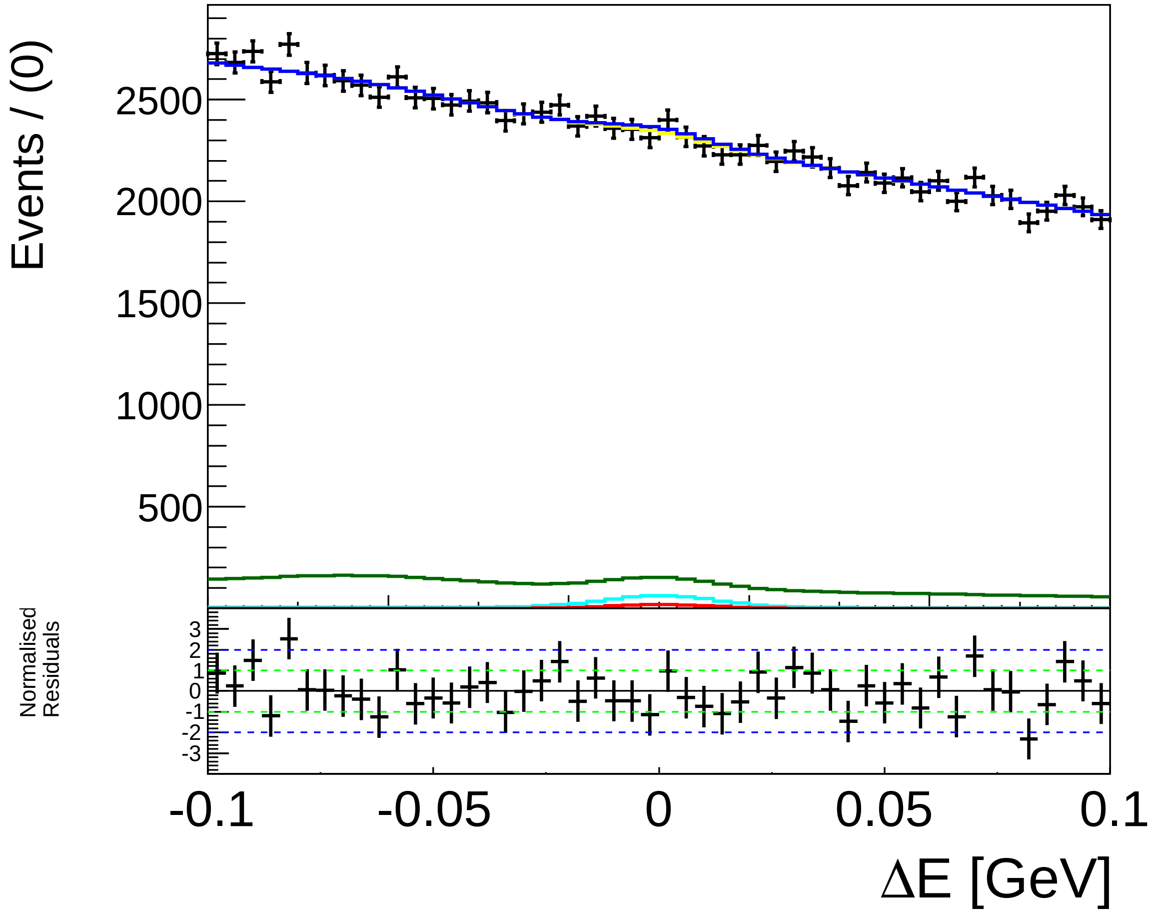
Toy MC Studies for $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

Estimate the fitter's ability to find signal with Toy MC, proj. into ΔE.

expected Nr of events:

- signal: $\sim$ 100
- 4 πs ff: $\sim$ 650

  (using world averages)
- $B\bar{B}$: $\sim$ 4500
- all: $\sim$ 110000



Fit Region:

$$5.27 < M_{\rm bc} < 5.29 \quad [GeV/c^2]$$

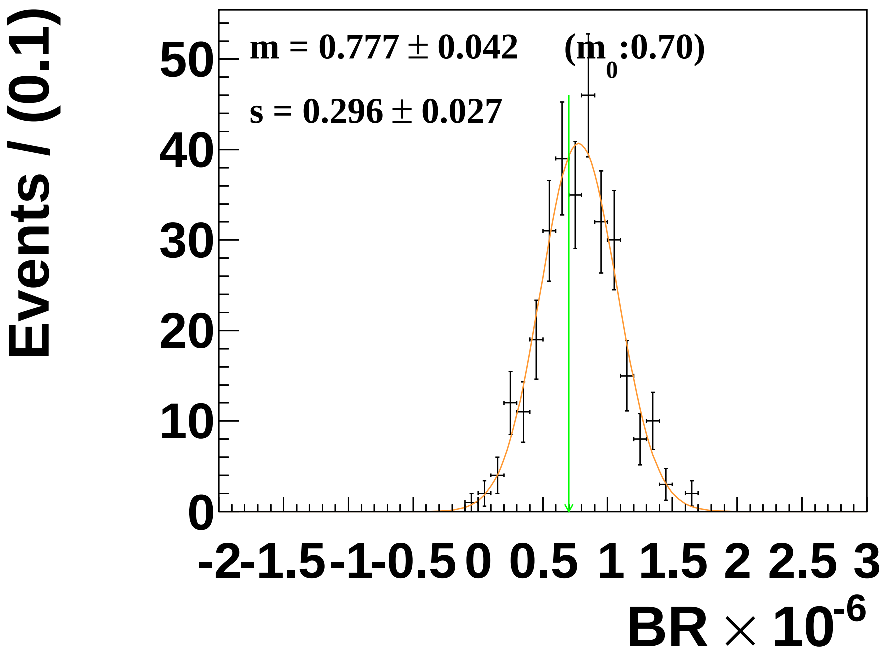
$$-0.1 < \Delta E < 0.1 \quad [GeV]$$

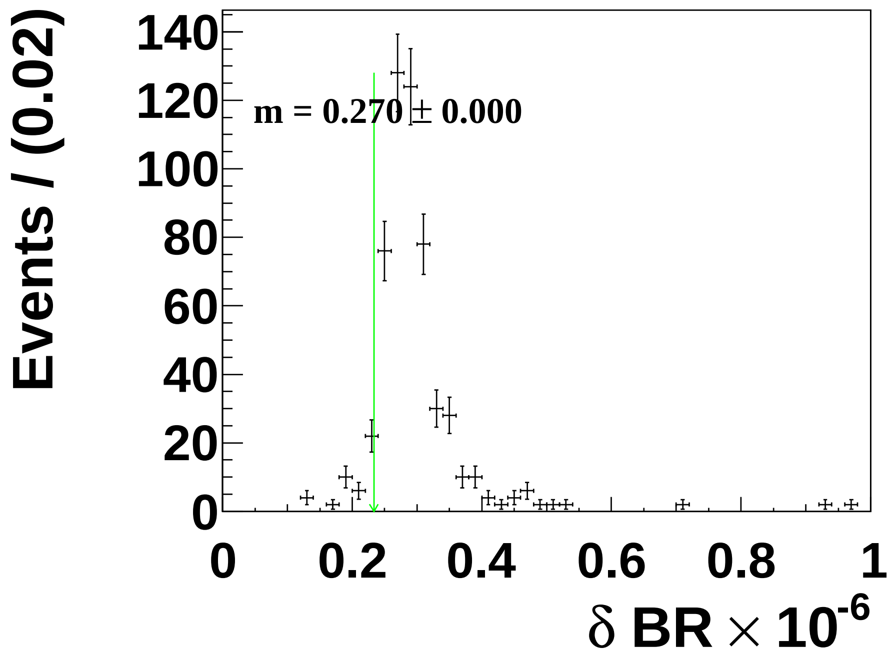
$$0.52 < m(\pi^+\pi^-) < 1.15[GeV/c^2]$$

$$-1 < cos(\theta_H) < 1$$

Toy MC Studies for $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

- performed fits on 300 toy MC samples





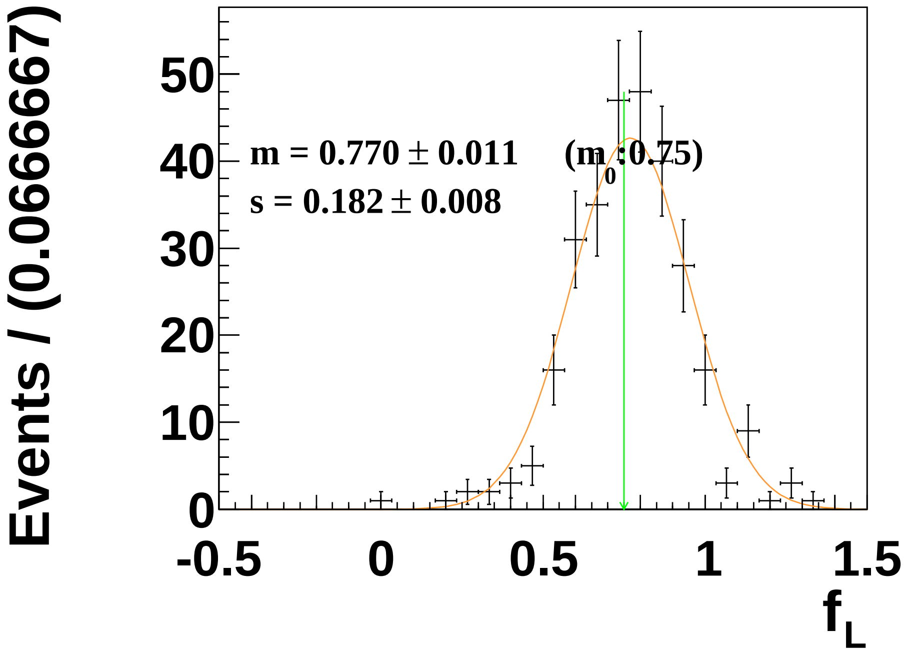
green line is input value

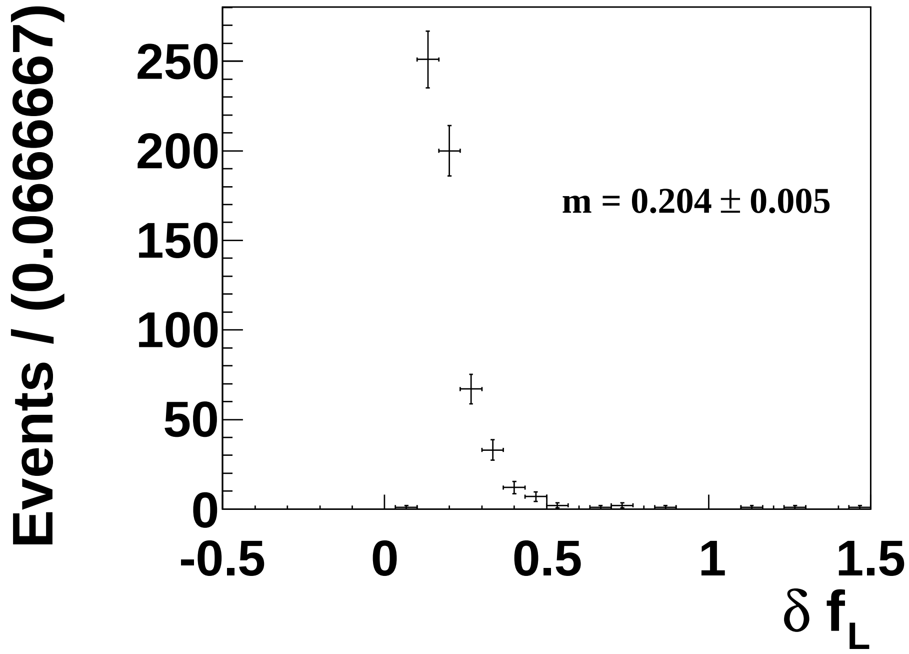
indicates 3 σ significance

$\Rightarrow$ on the edge of a observation with a 3 σ significance

Toy MC Studies for $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

- performed fits on 300 toy MC samples





green line is input value

$\Rightarrow$ measurement of f_L posibble

Flavor Tagging

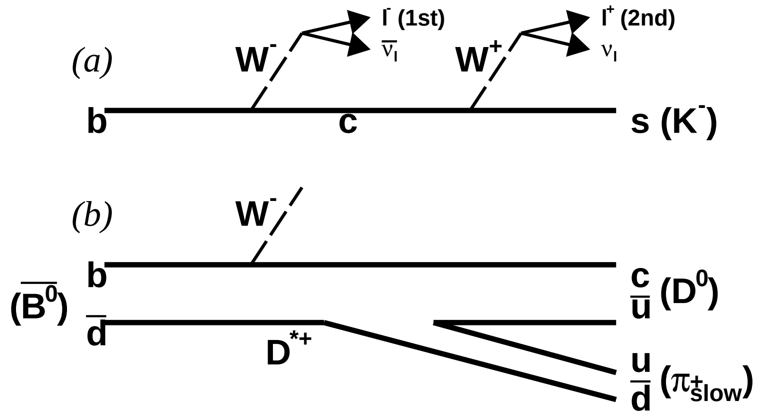
towards CPV measurement

$\Upsilon(4S) \rightarrow$ coherent $B\bar{B}$ pair

one $B \equiv B_{CP}$ decays into final state of interest.

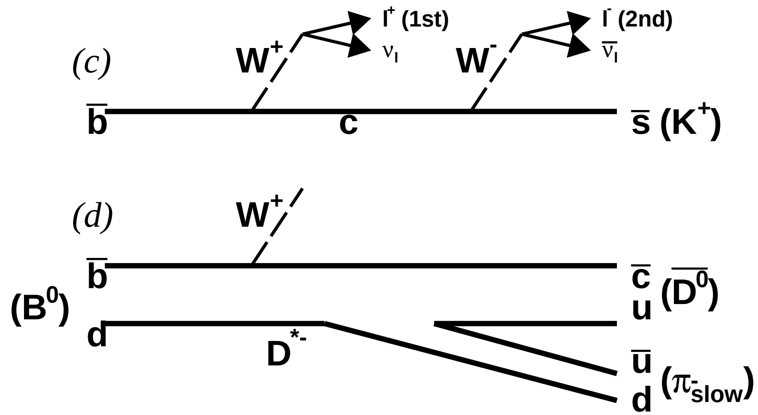
use flavor specific decays of the other $B \equiv B_{tag}$ to determine the flavor of B_{CP}; e.g.

$\bar{B}$ decays



vs

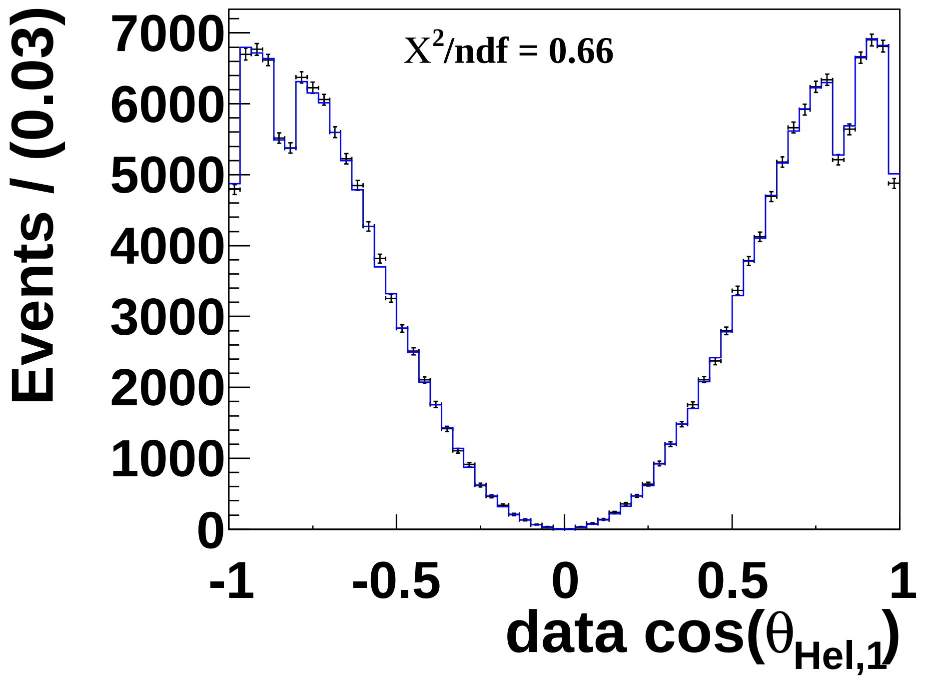
B decays

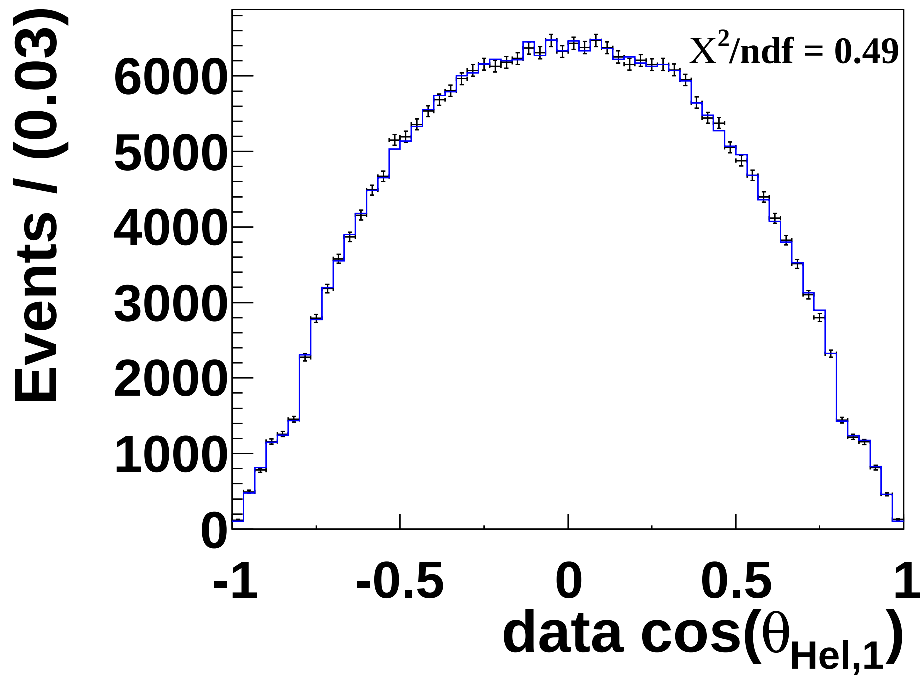


Model for $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

Helicity: weighted with reconstruction effiency histogram

- signal MC(L pol)
- signal MC(T pol)





$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta^1_{\rm Hel}\, d\cos\theta^2_{\rm Hel}} = \frac{9}{4}\left(f_L \cos^2\theta^1_{\rm Hel}\cos^2\theta^2_{\rm Hel} + \frac{1}{4}(1-f_L)\sin^2\theta^1_{\rm Hel}\sin^2\theta^2_{\rm Hel}\right)$$