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

Pit Vanhoefer

Max-Planck-Institut für Physik

pvanhoef at mpp.mpg.de

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

1) Motivation

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

2b) Implication for ϕ_2

3)Outlook

BELLE

CP Violation

matter anti-matter asymmetry

weak interaction can violate C(charge), P(parity) as well as CP symmetry

$\Rightarrow$ particel and antiparticle can behave differently

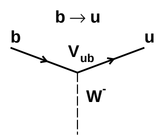
SM has a build-in mechanism that generates CP violation: CKM mechanism.

weak and mass Eigenstates are related through a complex, unitary matrix:

Cabibbo-Kobayashi-Maskawa CKM Matrix

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

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



BUT NOT able to produce observed asymmetry in our universe.

CP Violation

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 $\rightarrow$

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

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

relevant relation for B meson decays

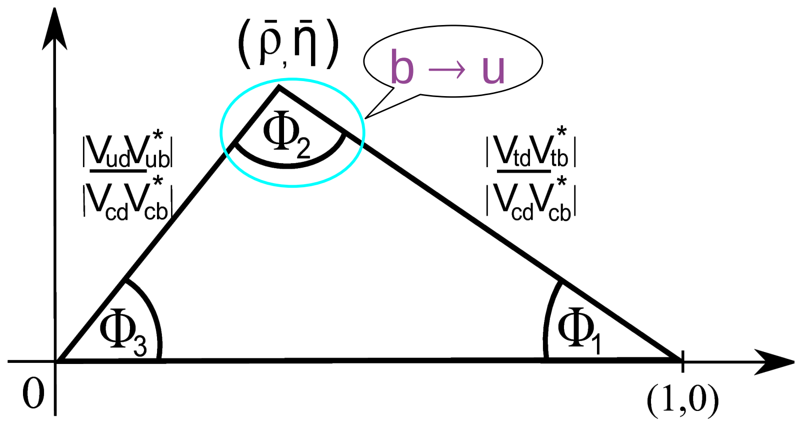
$$\underset{\mathcal{O}(\lambda^3)}{V_{ud}V_{ub}^{*}} + \underset{\mathcal{O}(\lambda^3)}{V_{cd}V_{cb}^{*}} + \underset{\mathcal{O}(\lambda^3)}{V_{td}V_{tb}^{*}} = 0$$

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

difference of particle (B) and anti-particle ($\bar{B}$):

- complex quantity: $\lambda_{CP} \equiv \frac{qA_f}{p\bar{A}_f} = e^{-i\phi_W} \frac{|q|}{|p|} \frac{|A_f|}{|\bar{A}_f|} e^{-i\phi_S}$

$A_f(\bar{A}_f)$: amplitude for $B(\bar{B}) \to$ final state f, p, q mixing parameters and $\phi_{W,S}$: weak/strong phase differences

$\Rightarrow$ 3 different types of $\not{C}\not{P}$

A) $|A_f| \neq |\bar{A}_f| \to$ different rates for B and $\bar{B}$:$\Rightarrow$ **direct** $\not{C}\not{P} \to \mathcal{A}_{CP}$

B) $|\frac{q}{p}| \neq 1$: $\not{C}\not{P}$ in the mixing (e.g. $K \leftrightarrow \bar{K}$), but in the B syst. $p \approx q$

C) $|A_f| = |\bar{A}_f|$ and $|p| = |q|$ but $\mathcal{I}(\lambda_{CP}) \neq 0$:$\Rightarrow$ **indirect** $\not{C}\not{P} \to \mathcal{S}_{CP}$

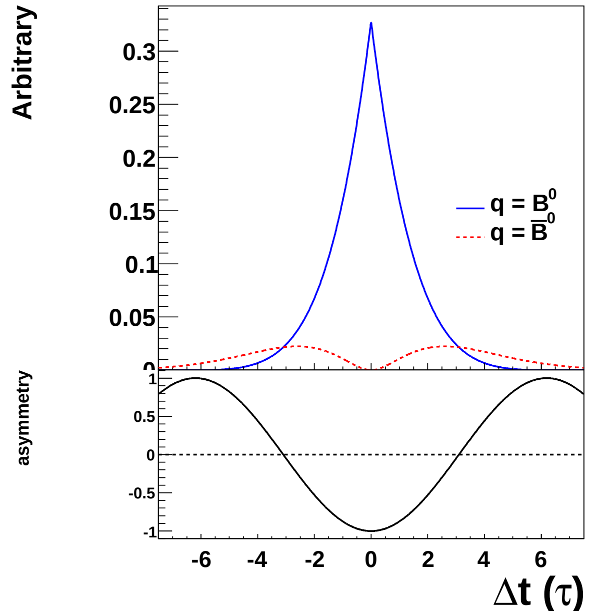
and is interefence between A) and B)

- time (Δt) and flavor ($q = \pm 1$) dependent decay rate

$$\boxed{\mathcal{P}(\Delta t, q) = \frac{e^{-|\Delta t|/\tau_{B^0}}}{4\tau_{B^0}} \left\{ 1 + q \left[\mathcal{S}_{CP} \sin(\Delta m_d \Delta t) + \mathcal{A}_{CP} \cos(\Delta m_d \Delta t) \right] \right\}}$$

CP Violation in the B System

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



CP asymmetry parameters:

← (direct $\not{CP}$)

$$\mathcal{A}_{CP} = \frac{|\lambda_c^2| - 1}{|\lambda_c^2| + 1}$$

different decay rates

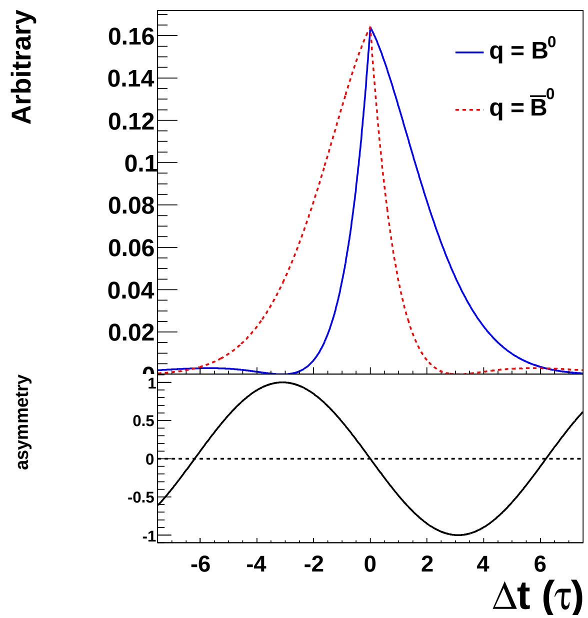
——— and ———-

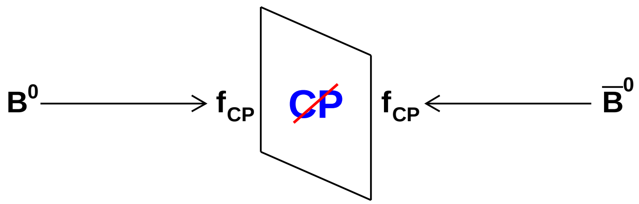
(indirect $\not{CP}$)→

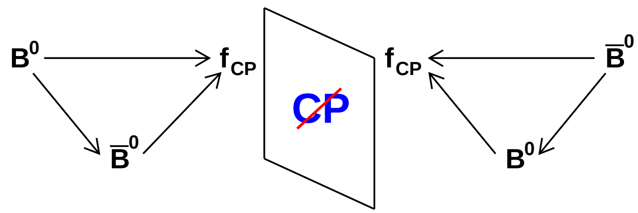
$$\mathcal{S}_{CP} = \frac{2\mathcal{I}(\lambda_{CP})}{|\lambda_c^2| + 1}$$

different time evolution

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

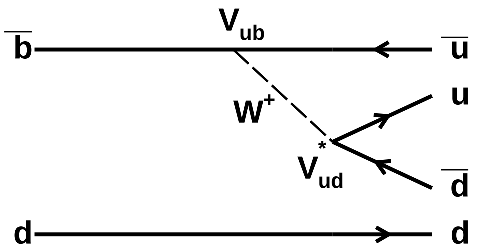




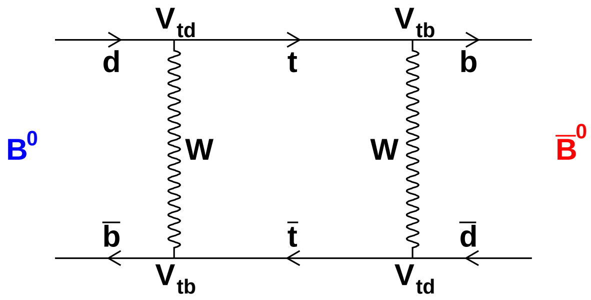


ϕ_2 and mixing induced $\not{CP}$

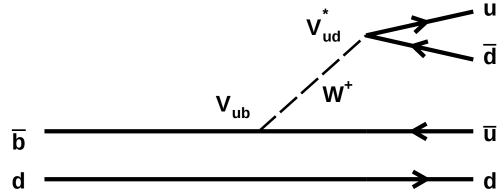
$B \to \rho^0\rho^0$



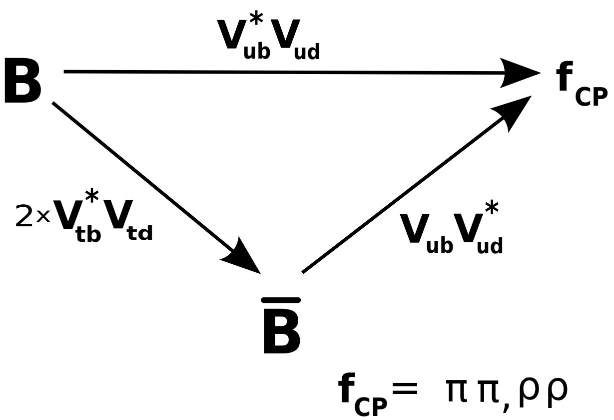
$B\bar{B}$ mixing



same for e.g. $B \to \rho^+\rho^-$, $B \to \pi^+\pi^-$, $B \to \pi^0\pi^0$ ...

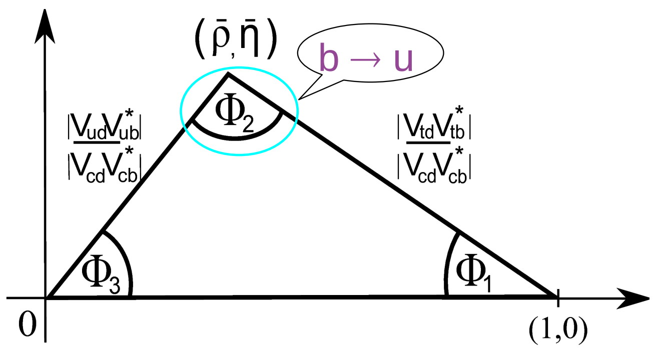


- ϕ_2 is phase between $V_{td}V_{tb}^*$ and $V_{ub}V_{ud}^*$
- ϕ_2 only through indirect $\not{CP}$ in $b \to u$e.g. interference between $B \to \rho\rho$ and $B \to \bar{B} \to \rho\rho$



$$\phi_2 = arg\left(\frac{V_{td}V_{tb}^*}{V_{ub}V_{ud}^*}\right)$$

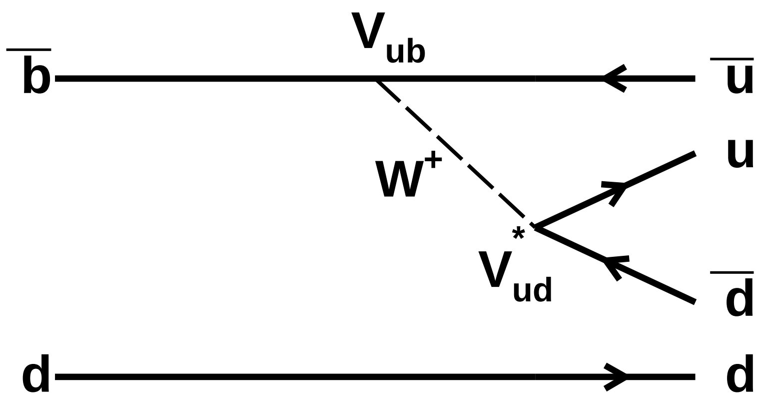
$\Rightarrow S_{CP} \sim \sin(2\phi_2)$

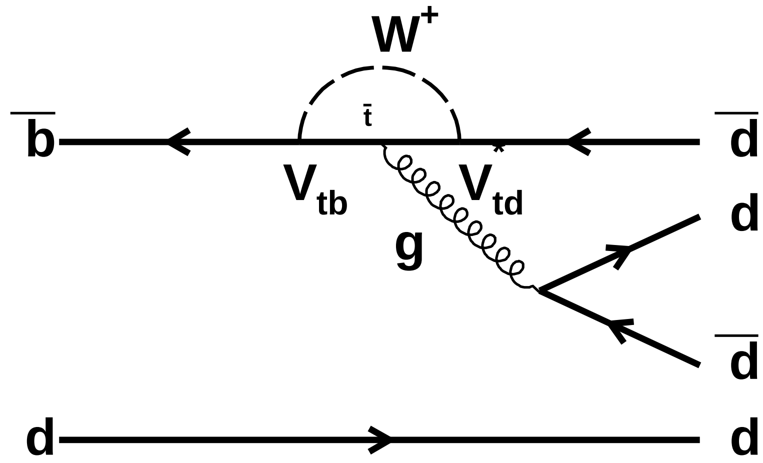


Living With Pollution

$b \to u$ (ρ, π, ...) at Tree level: sensitive to ϕ_2 ($\mathcal{S}_{CP}$) and no direct $\not{C}\not{P}$ ($\mathcal{A}_{CP} = 0$)

BUT more amplitudes (penguins) can contribute





$\Rightarrow \phi_2$

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

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

$\to$ extraction of $\Delta\phi_2$ with isospin analysis is possible

$\mathcal{A}_{CP} \neq 0 \Rightarrow$ direct $\not{C}\not{P}$

$\mathcal{S}_{CP} \neq 0 \Rightarrow$ indirect $\not{C}\not{P}$

Recover ϕ_2

- **extraction of $\Delta\phi_2$ with isospin analysis** (remove penguin pollution)

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

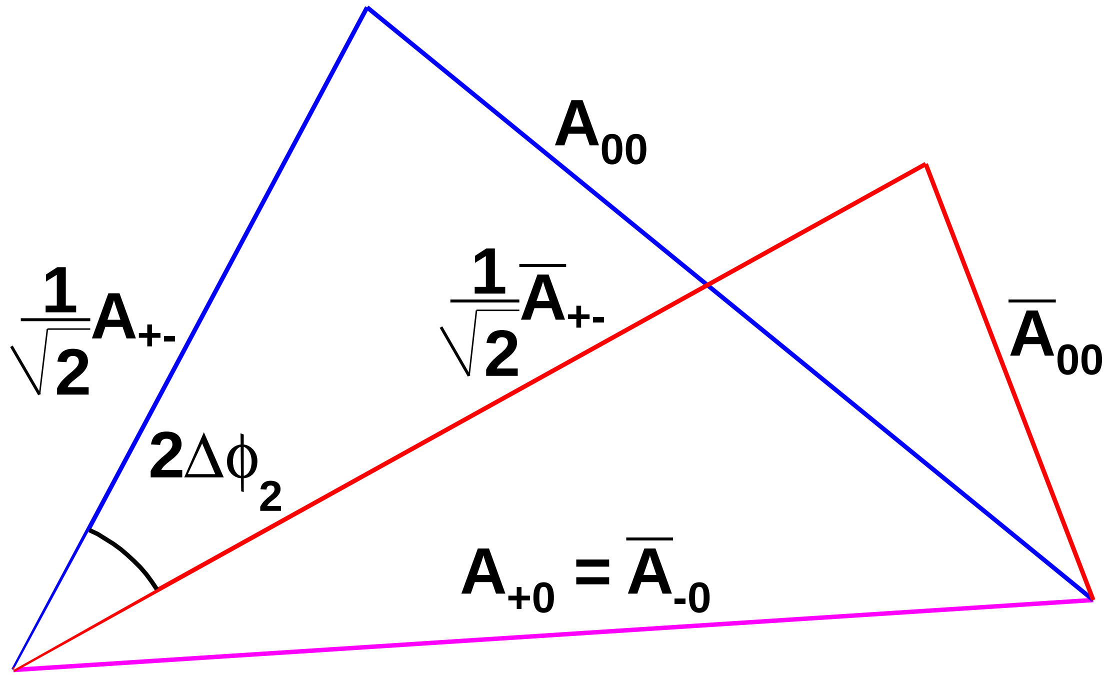
  Bose statistics:$\Rightarrow$ I=0,2 (final states);

  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 $\Delta\phi_2$

Recover ϕ_2

In $b \to u$ transitions

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

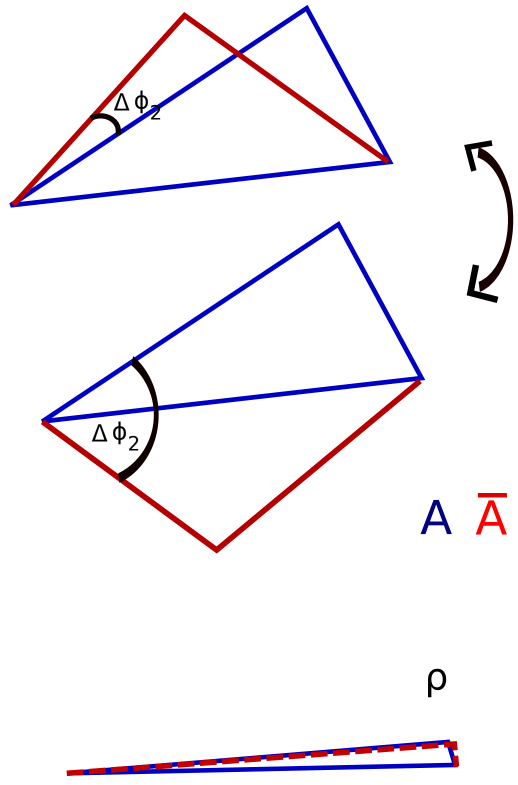
    but 2($\sin$)$\times$ 4($\Delta\phi_2$) = 8 fold ambiguity

In the ρ system the SM predicts small penguin pollution

- ϕ_2 from $B^0 \to \rho^+\rho^-$
- $\mathcal{BR}(B^0 \to \rho^0\rho^0)$ 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

  $\Rightarrow$ this talk: measurement of $\mathcal{B}(B^0 \to \rho^0\rho^0)$



Impact on CKM Angle ϕ_2

- **variation of**

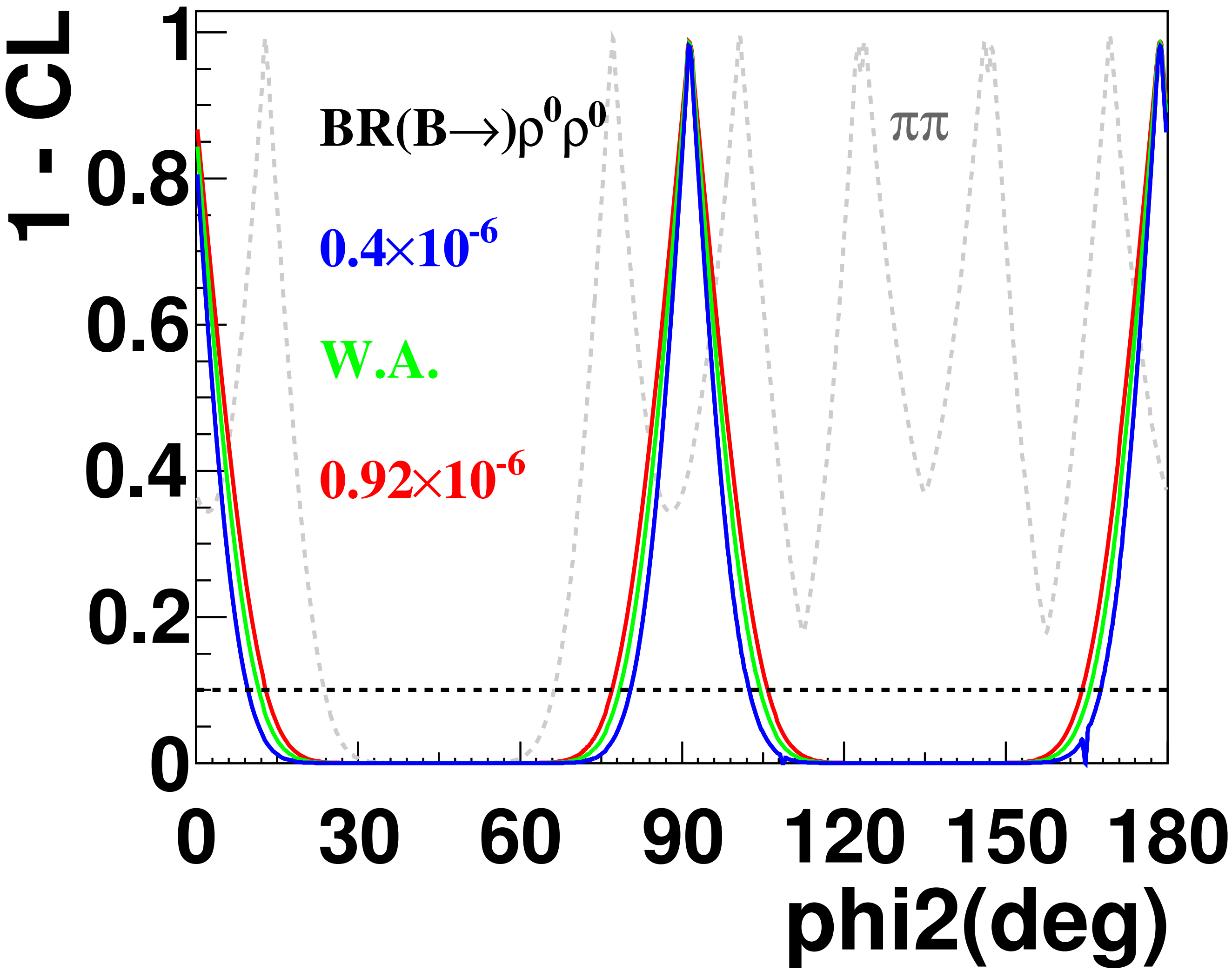
  $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

  in isospin analysis

  W.A. = $(0.73 \pm 0.28) \times 10^{-6}$

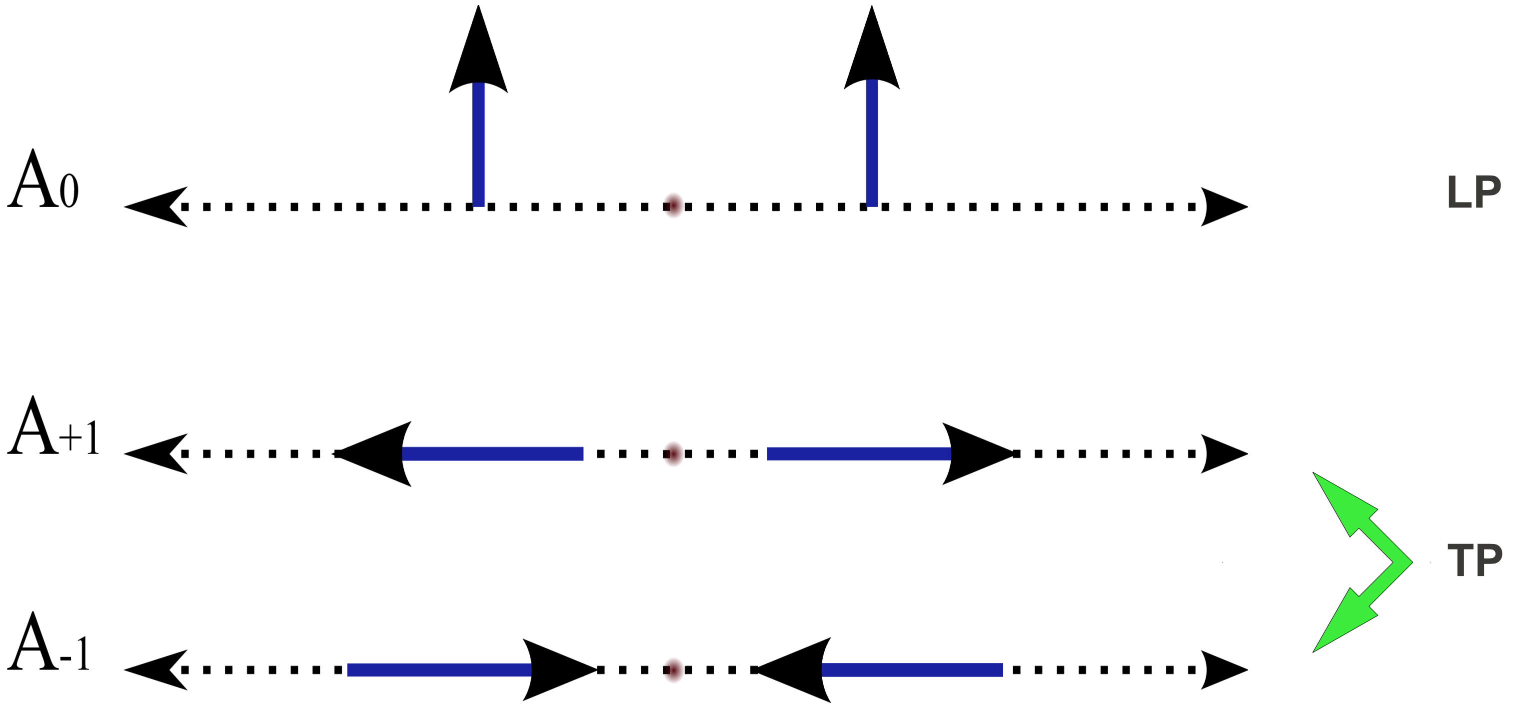
  prev. Belle

  Babar



$B \to VV$

3 different polarization amplitudes contribute $\to$ important for CP measurements



- only longitudinal(LP; A_0) is a pure CP eigenstate (even)
- transversal(TP) states are a mixture of CP even and odd states

SM: LP dominant, $f_L \sim 1 - (m_V^2/m_B^2) \sim 1$ (fraction of LP: $f_L = \frac{|A_0|^2}{\sum |A_i|^2}$)

Break

Aiming at a better understanding of the CKM angle ϕ_2

1^{st}: extraction of signal from all events = signal + backgrounds $\leftrightarrow$ **branching fraction**

- rare B decays are extremely background dominated (esp. at a e^+e^- collider)

  $\rightarrow$ multivariate analysis

2^{nd}: measurement of **time and flavor dependent decay rate** $\rightarrow$ $\mathcal{A}_{CP}, \mathcal{S}_{CP}$

- $b \rightarrow u$: observable $\mathcal{S}_{CP} \sim \sin(2\phi_2^{eff})$ **polluted by penguins**

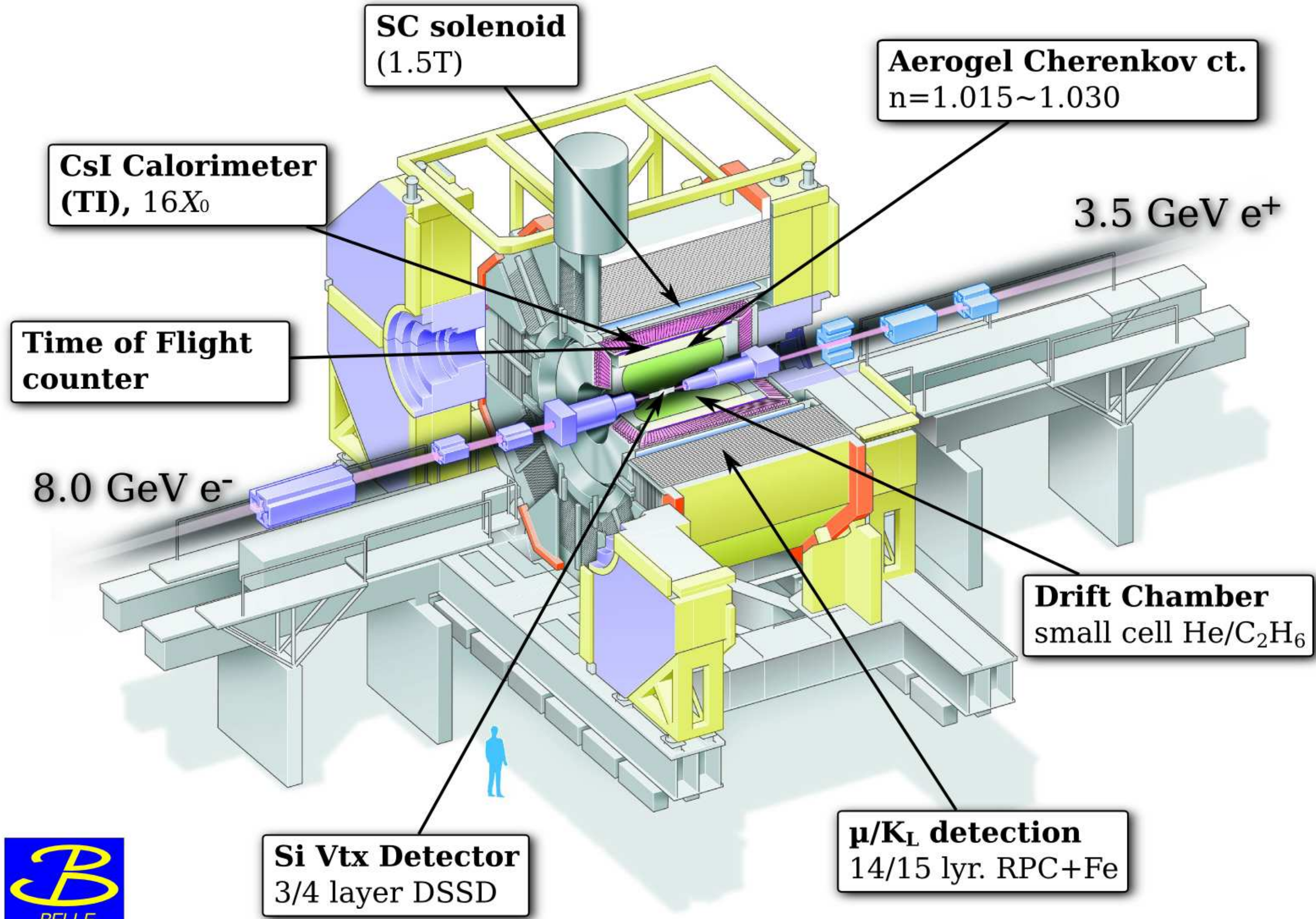
3^{rd} remove pollution with **isospin analysis**

- e.g. with $B \rightarrow \rho^+\rho^-, \rho^0\rho^0, \rho^+\rho^0$

$\Rightarrow$ several measurements of branching fractions and CP parameters needed to pin down ϕ_2

1^{st} and 2^{nd} can be performed in one step

The Experimental Setup

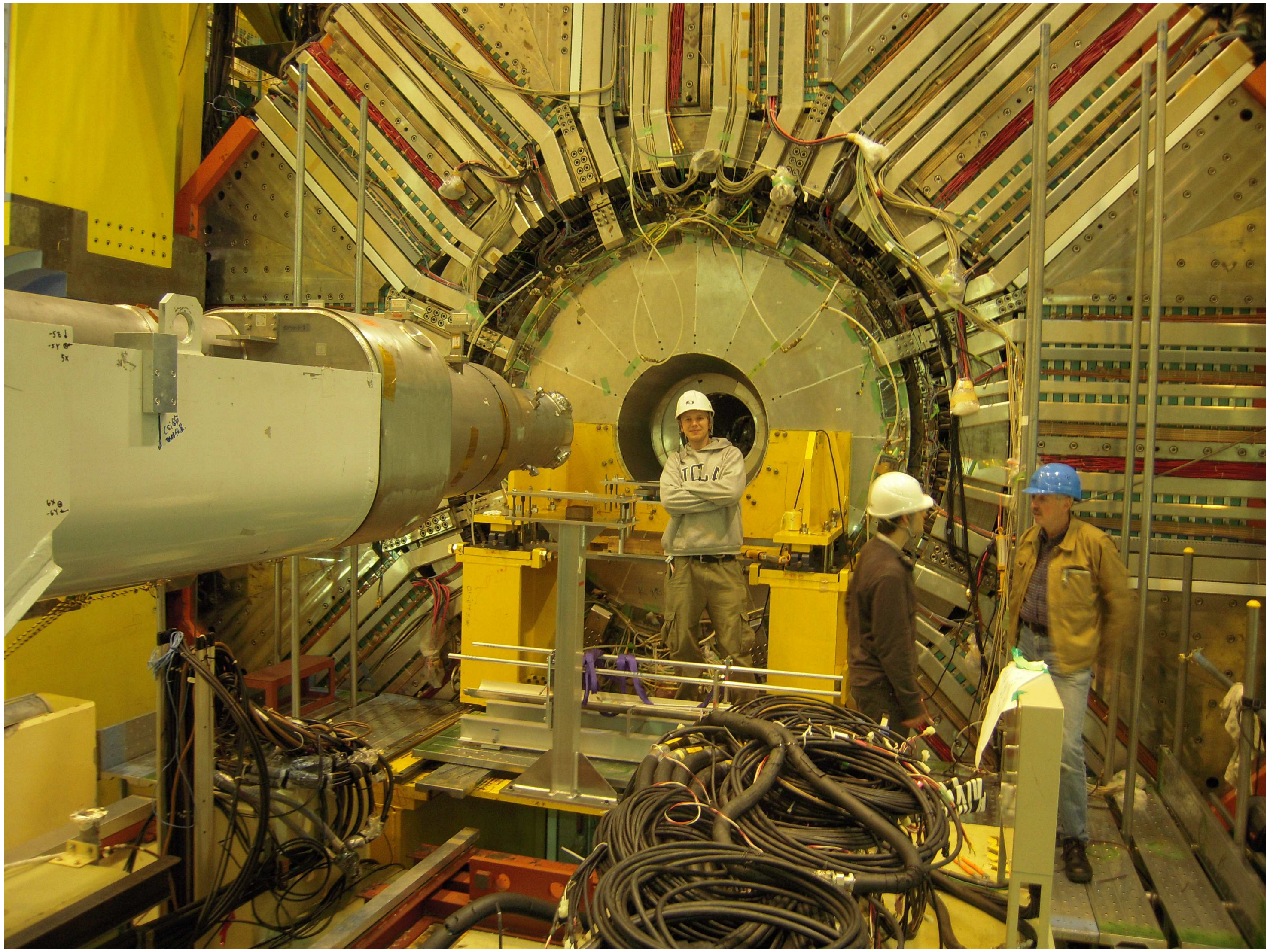


- located in Japan
- asymmetric e^+e^- collider (KEKB) (3.5 GeV on 8 GeV)
- luminosity world-record $\int Ldt = 1014 fb^{-1}$ $\sim 772 \times 10^6 B\bar{B}$ pairs

Belle Detector

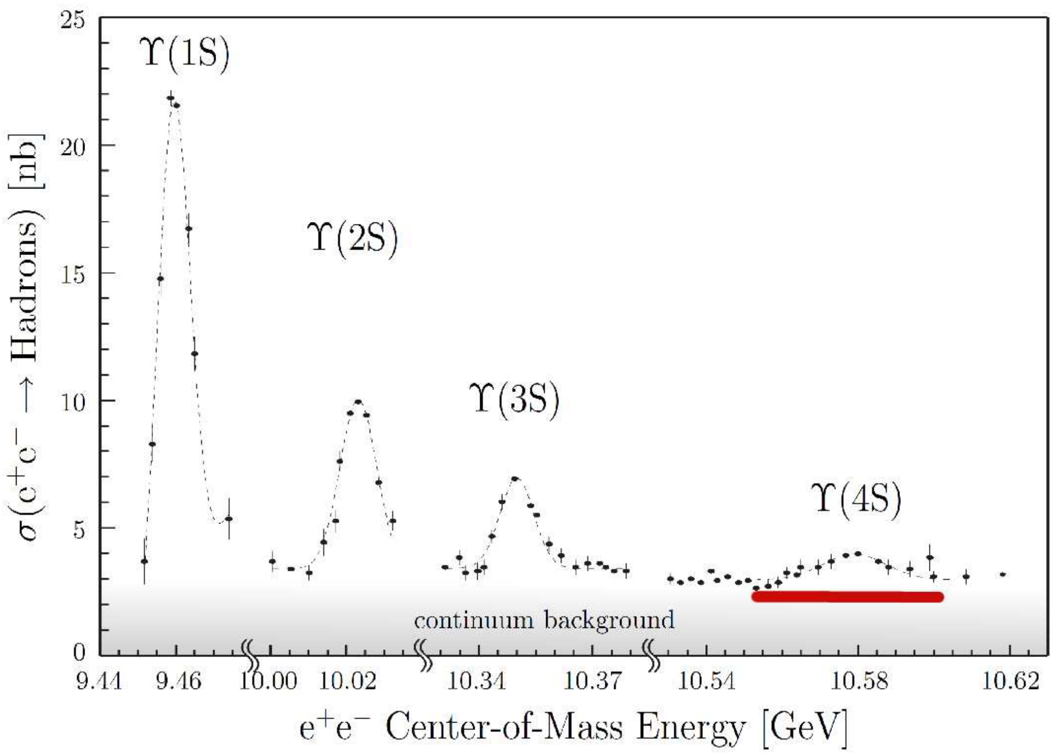
- tracking
- PID

The Belle Detector



CP Violation measurement

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

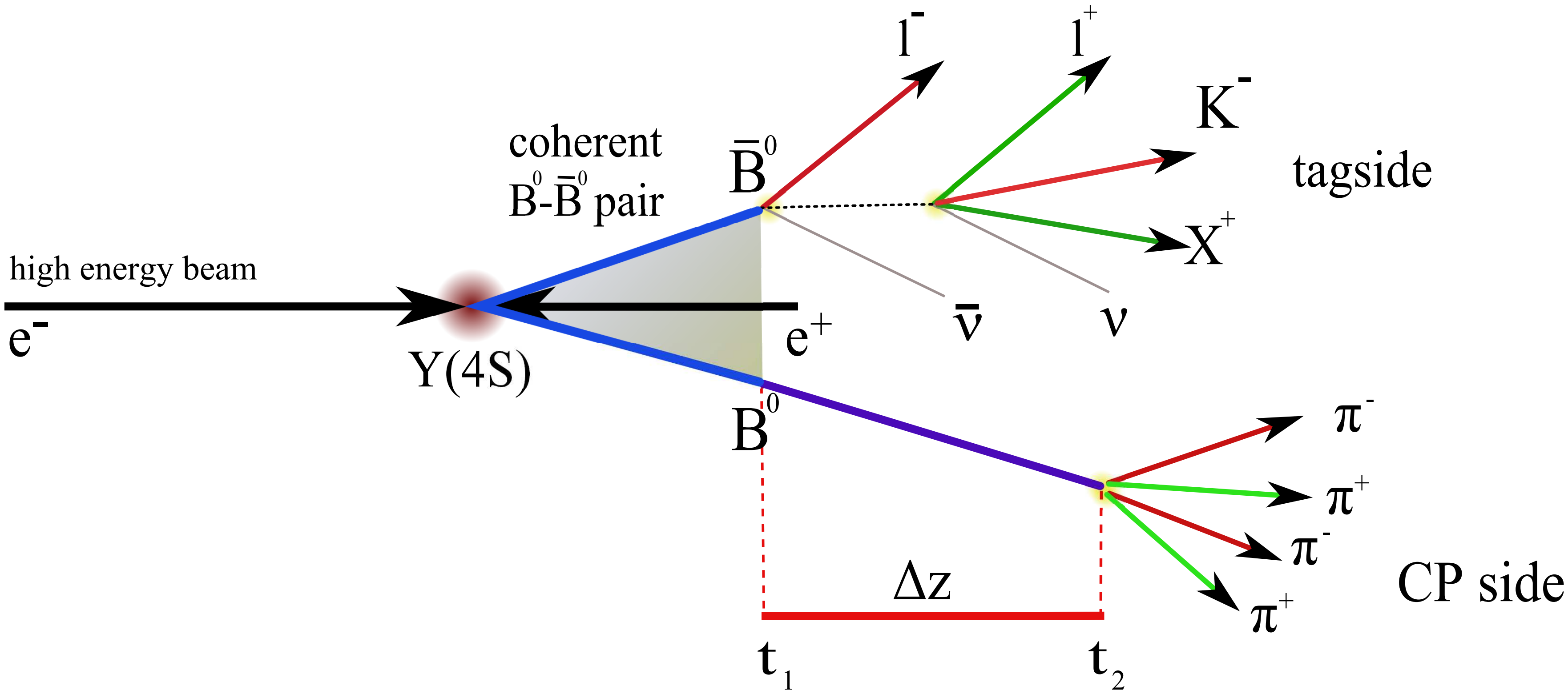
  $\rightarrow B$s have opposite flavor:

  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, indirect ~~CP~~



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

Flavor Tagging

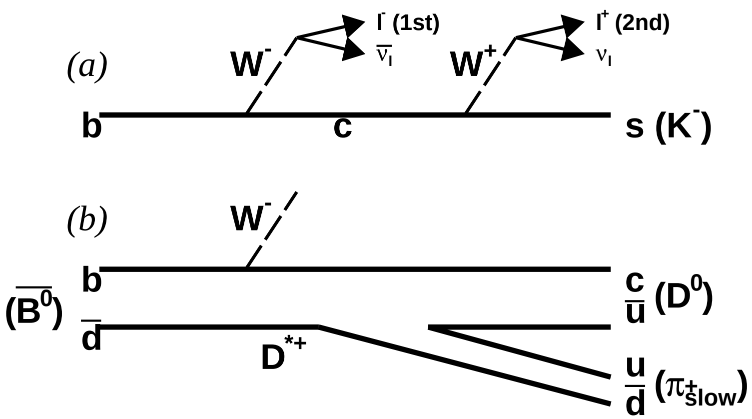
towards CPV measurement

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

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

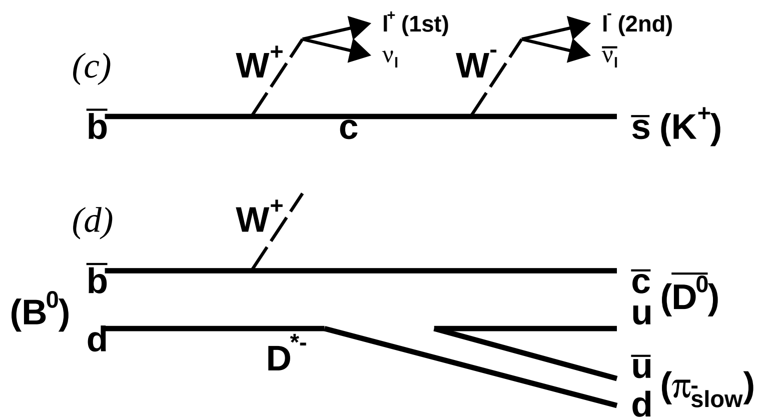
use flavor specific decays of the other $B \equiv B_{tag}$ to determine the flavor of B_{CP}; e.g.

$\bar{B}$ decays



vs

B decays



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

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

$\Rightarrow$ 4 charged πs in the detector

- **select $\pi^\pm$ candidates**: PID criterias
- **reconstruct ρ^0 candidates from $\pi^+\pi^-$ pairs**

  ρ^0(770): broad resonance($\Gamma \sim 149 MeV$)

  $\to m_{\pi^+\pi^-} \in$ [0.52, 1.15] GeV/c^2

  excludes K_S^0(0.49GeV)
- **reconstruct B^0 candidates from $\rho^0\rho^0$ pairs**
- charm and strange vetos (due to combinatorics) $\to$ removes peaking BKG

- vertexing (Δz)
- flavor tagging (B or $\bar{B}$)
- select best B^0 candidate

  (M_{bc} closest to Bmass)

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

- continuum identification
- randomize events to remove asymmetry due to ordering in the reconstruction

$\Rightarrow$ **end up with a B candidate beeing a potential mother of two ρ^0s**

also from background!!

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

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

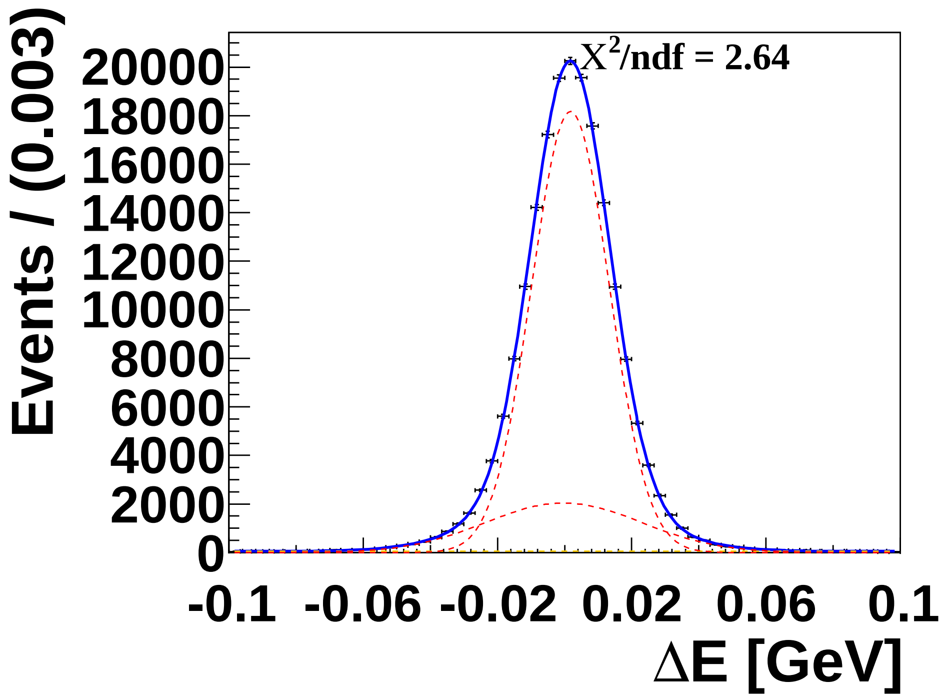
$$\Delta E, \quad 2 \times m_{\pi^+\pi^-}, \quad \mathcal{F}, \quad 2 \times \cos\theta_{\mathrm{Hel}}$$

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 $\sqrt{s} = 10.50 GeV < m(\Upsilon(4S))$
– $4 \times B\bar{B}$: charm and charmless $B^0(B^\pm)$ decays;	MC
– $8\times$ peaking BKG (4πs finalstates);	MC
$\pi^+\pi^-\pi^+\pi^-, a_1^\pm\pi^\mp, a_2^\pm\pi^\mp, b_1^\pm\pi^\mp, f_0 f_0, f_0\pi^+\pi^-, \rho^0\pi^+\pi^-, f_0\rho^0.$	BR known

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

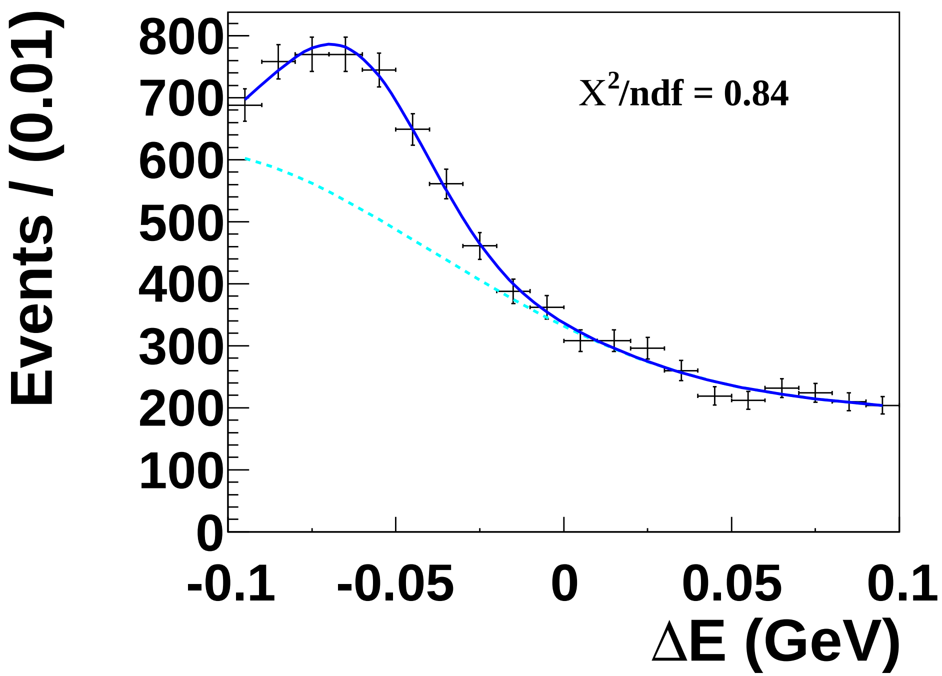
$$\Delta E \equiv E_{B_{rec}} - E_{beam}$$

- signal MC(L pol)



$\mathcal{PDF}(\Delta E)$=2× bifurcated gaussian

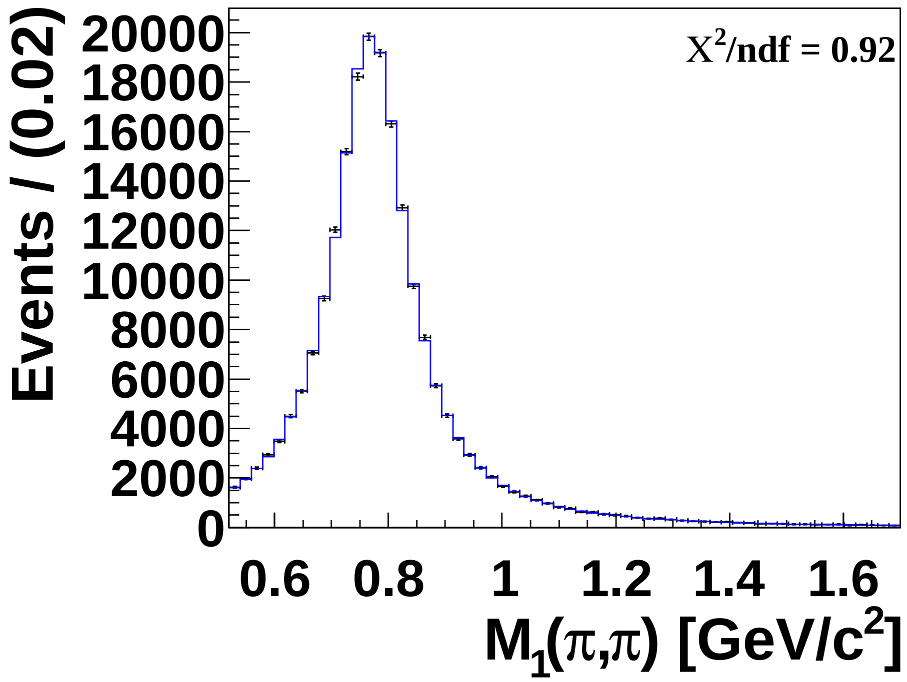
- neutral charm decays



$\mathcal{PDF}(\Delta E)$=gaussian + $\sum_{i=1}^{8}$ chebychev$_i$

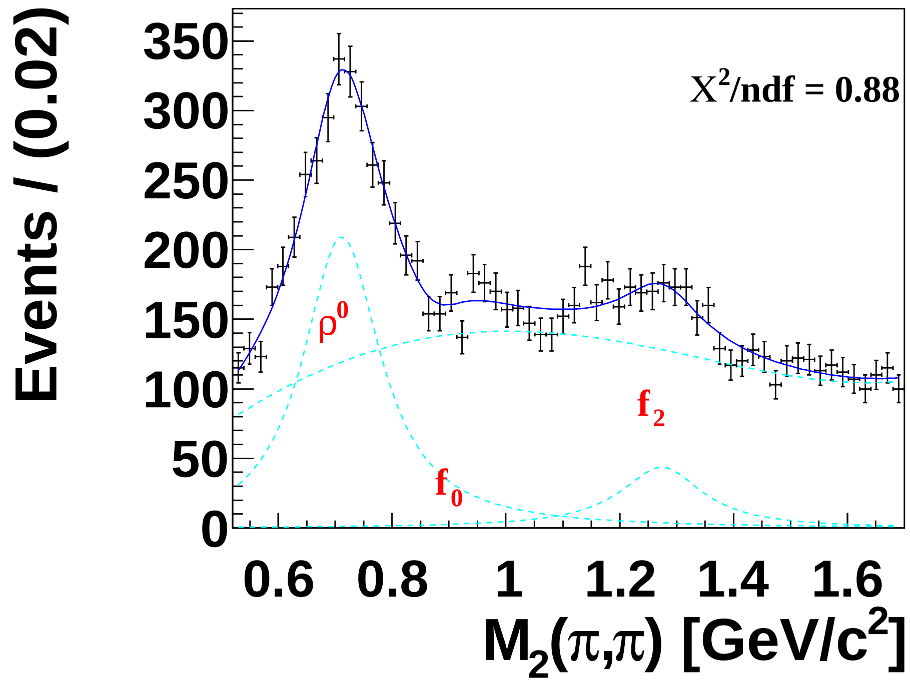
Model for $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

- 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$_i$

Helicity

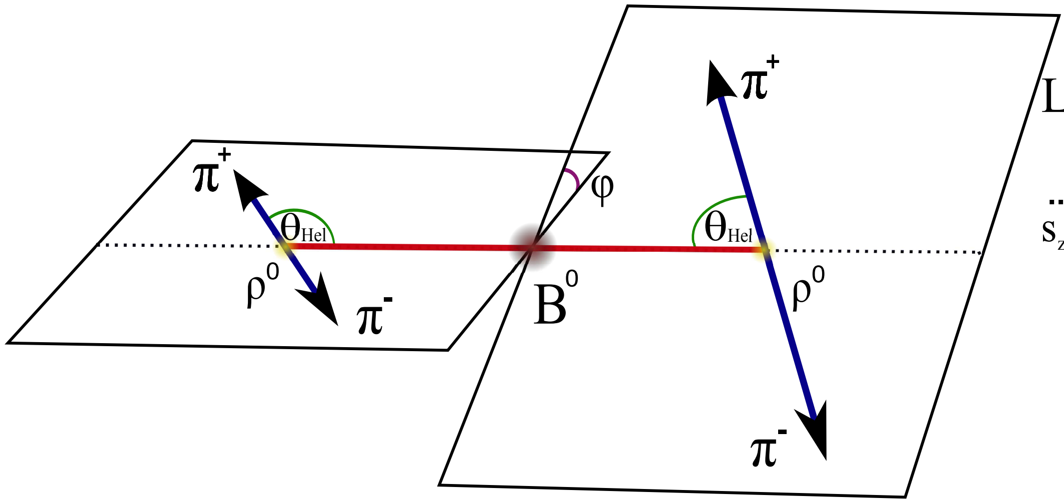
- **e.g. for** $B \to \rho^0\rho^0$ $\qquad J^{CP}$: $\rho^0 = 1^{--}$; $\pi^{\pm} = 0^{-}$

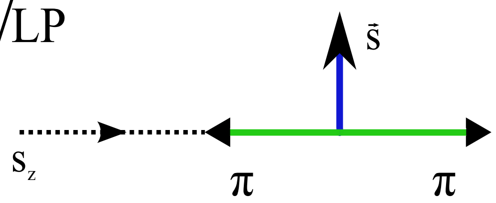
$$\rho^0 \to \pi^+\pi^-$$

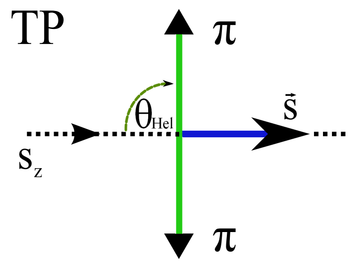
2 different polarizations, longitudinal(L pol, CP even) and transversal(T pol, CP even & odd)

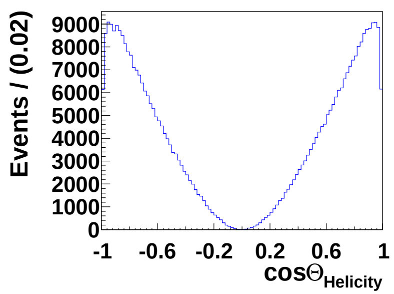
f_L: fraction of L pol,through helicity analysis (SM: L pol dominant)

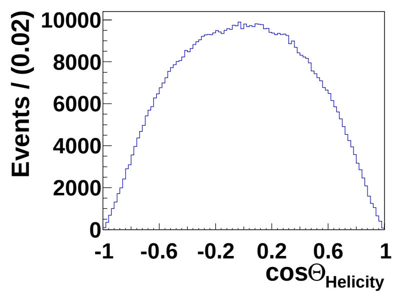
θ_{Hel}: angle between the B^0 and the π^+ flight directions in the ρ frame







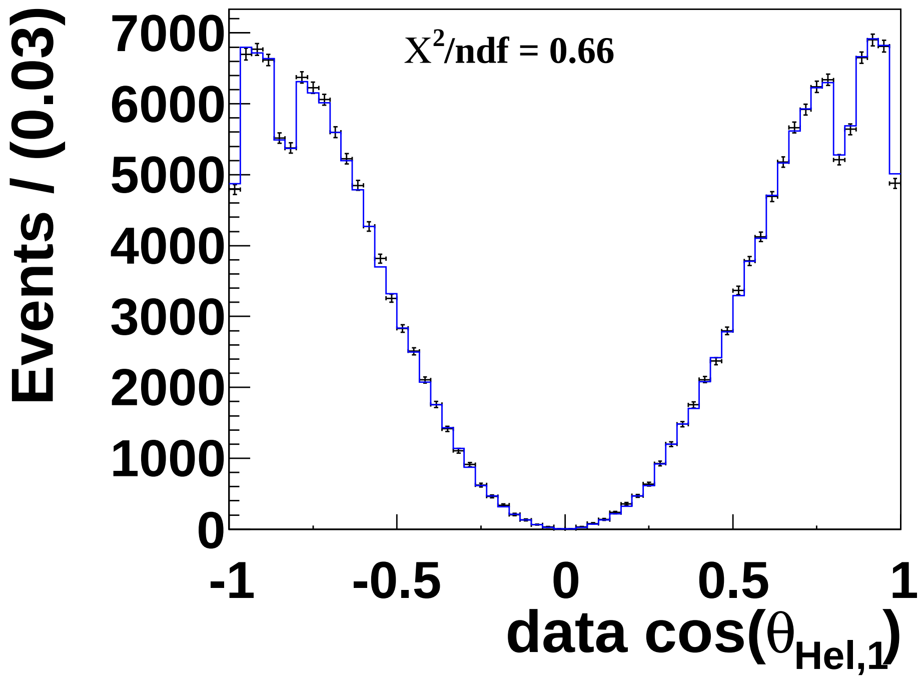


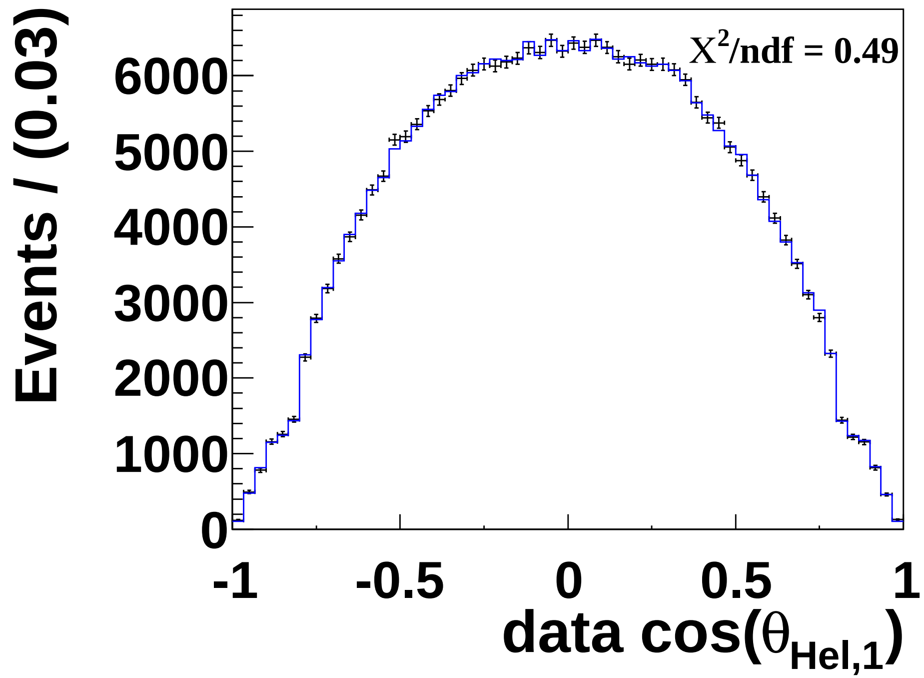


Model for $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

Helicity: weighted with reconstruction effiency histogram

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



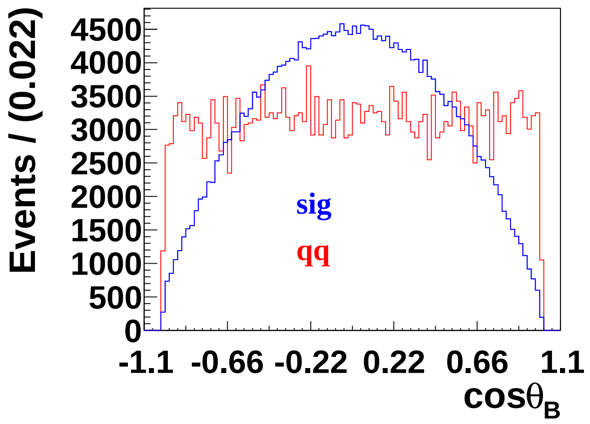


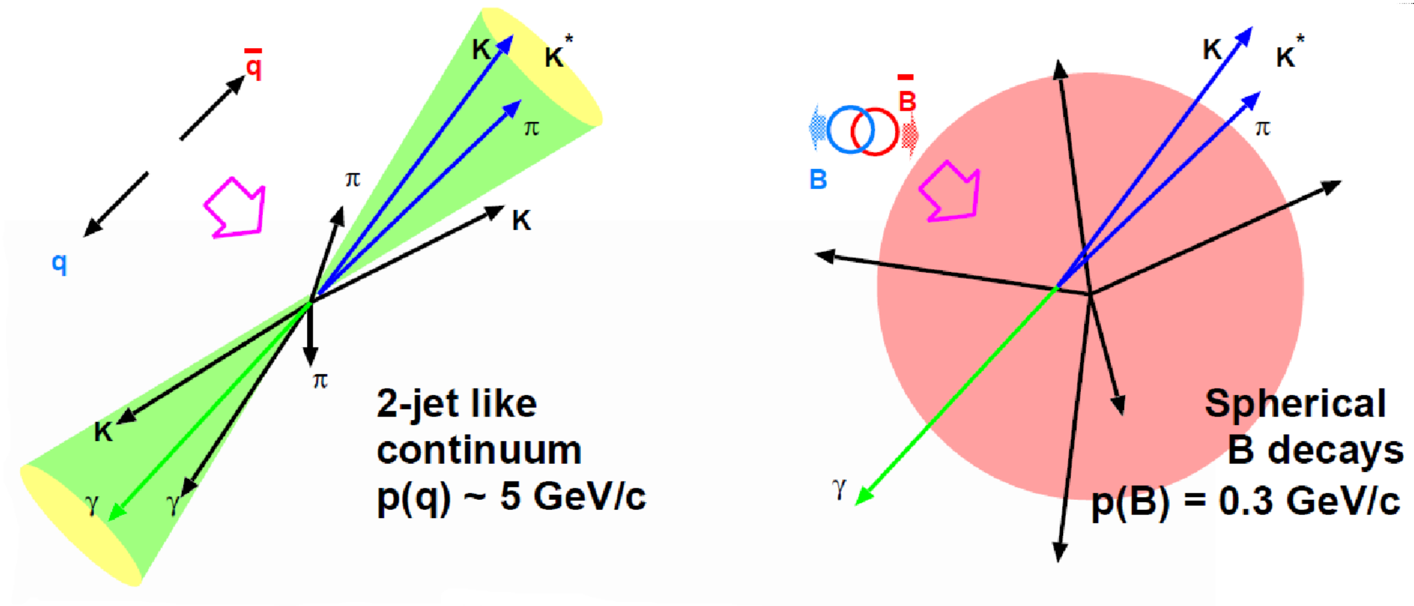
$$\frac{1}{\Gamma}\frac{d^2\Gamma}{d\cos\theta^1_{\mathrm{Hel}}\,d\cos\theta^2_{\mathrm{Hel}}} = \frac{9}{4}\left(f_L\cos^2\theta^1_{\mathrm{Hel}}\cos^2\theta^2_{\mathrm{Hel}} + \frac{1}{4}(1-f_L)\sin^2\theta^1_{\mathrm{Hel}}\sin^2\theta^2_{\mathrm{Hel}}\right)$$

Continuum Identification

$e^+e^- \to q\bar{q}, \quad (q = u, d, s, c)$ gives biggest contribution ($N_{q\bar{q}}/N_{sig} \sim 1000$)

- combined eventshape variables using fisher disciminant $\to \mathcal{F}$
- $\cos(\theta_B)$ (B flight direction)



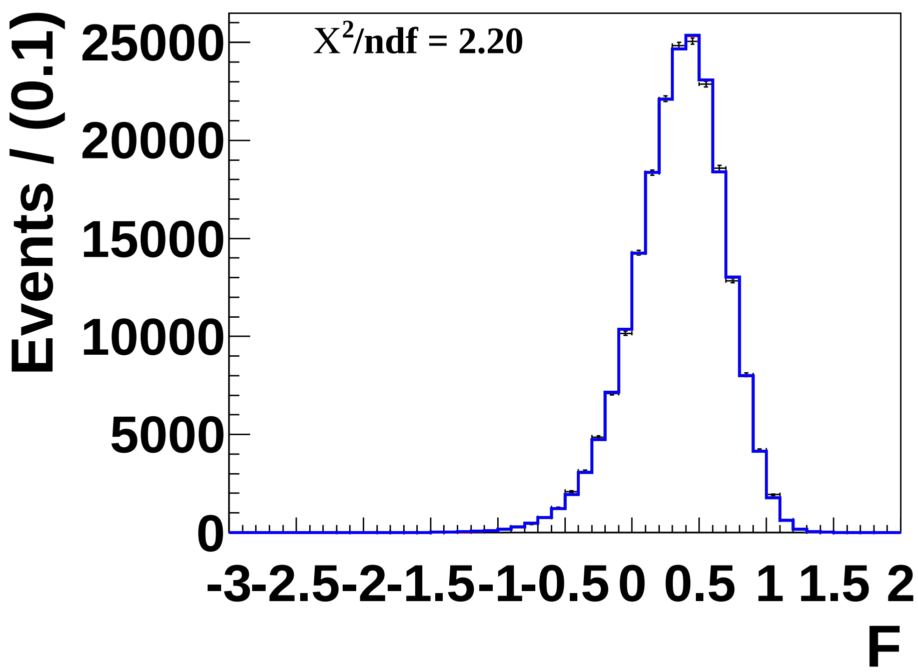


- fox-wolfram moments: $H_l = \sum_{i,j} \frac{|\vec{p}_i||\vec{p}_j|}{s} P_l(cos\phi_{ij})$ with legendre poly. P_l
- thrust, sphericity, ...

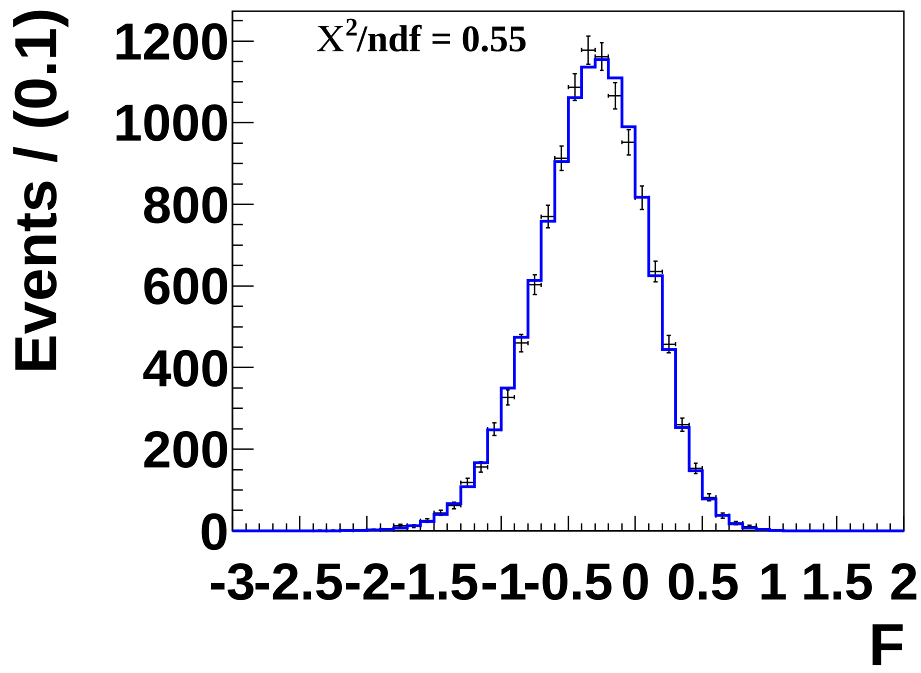
Model for $\mathcal{BR}(B^0 \to \rho^0\rho^0)$

F consists of eventshape variables: $B\bar{B} \to$ spherical, $q\bar{q} \to$ 2 jet like

- signal MC(L pol)

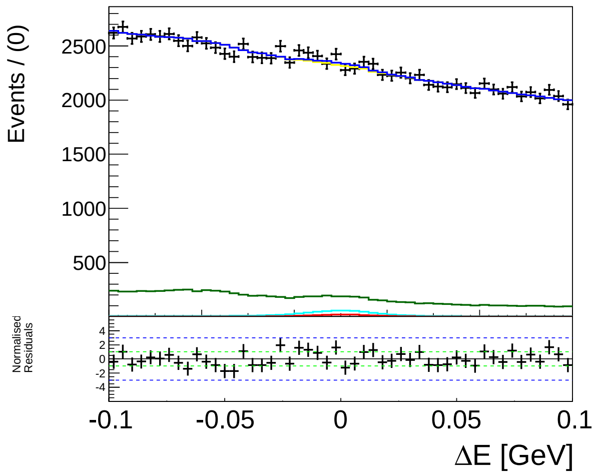


- continuum



$\mathcal{PDF} =$ double bifurcated gaussian

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

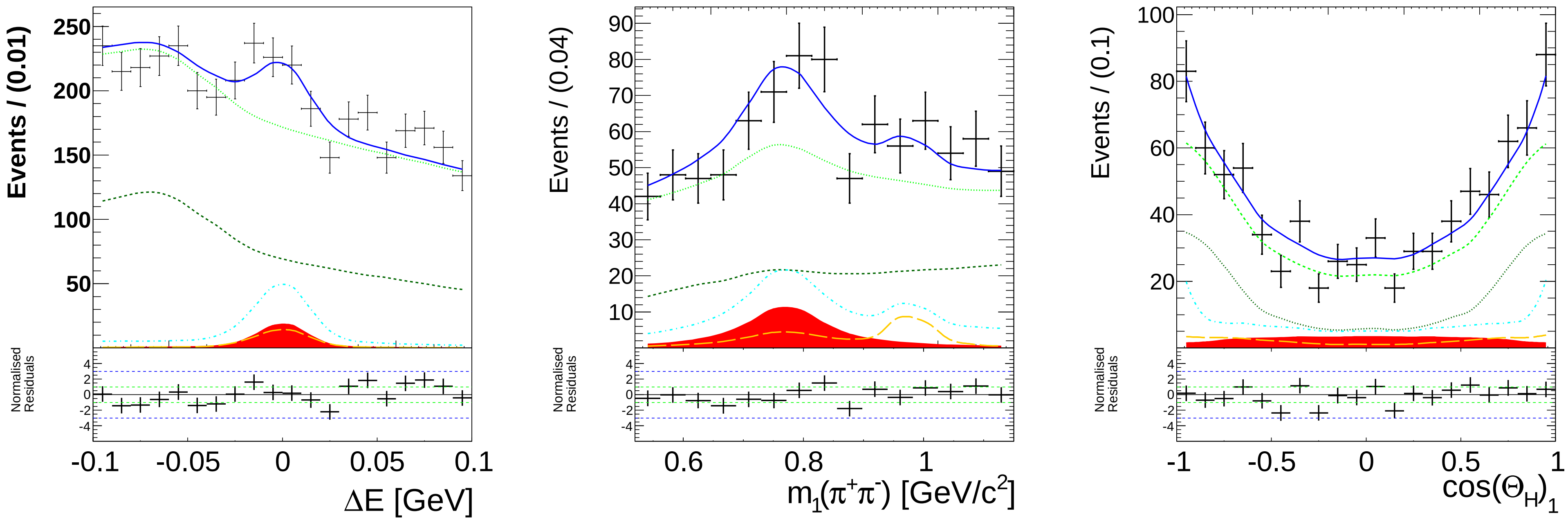


PRELIMINARY

New results, **arXiv:1212.4015**

Signal enhanced projections

$B^0 \to \rho^0\rho^0$, $B^0 \to f_0\rho^0$, 4π final states,
$B\bar{B}$ bkg, total non-peaking bkg, total



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

- 6D fitter: **PRELIMINARY** *New results*, **arXiv:1212.4015**

$\Delta E, m_{\pi^+\pi^-}, m_{\pi^+\pi^-}, \cos\theta_{\mathrm{Hel}}, \cos\theta_{\mathrm{Hel}}, \mathcal{F}_{s/b}$ ($m_{\pi^+\pi^-}$ is invariant ρ^0 mass)

mode	branching fraction$\times 10^{-6}$	events	significance
$\mathcal{B}(B^0 \to \rho^0\rho^0)$	< 1.5		U.L.
$f_L = 0.21^{+0.18}_{-0.22} \pm 0.11$	$(1.02 \pm 0.30 \pm 0.22)$	166 ± 49	$\sim 3\sigma$
$\mathcal{B}(B^0 \to f_0\rho^0) \times (f_0 \to \pi^+\pi^-)$	$(0.86 \pm 0.27 \pm 0.15)$	149 ± 47	3.0σ 1st evidence
$\mathcal{B}(B^0 \to f_0 f_0) \times (f_0 \to \pi^+\pi^-)^2$	< 0.2	-5 ± 17	U.L.
$\mathcal{B}(B^0 \to \rho^0\pi^+\pi^-)$	< 12.2	33 ± 82	U.L.
$\mathcal{B}(B^0 \to f_0\pi^+\pi^-) \times (f_0 \to \pi^+\pi^-)$	< 3.1	-27 ± 43	U.L.
$\mathcal{B}(B^0 \to \pi^+\pi^-\pi^+\pi^-)$	< 11.7	-25 ± 54	U.L.

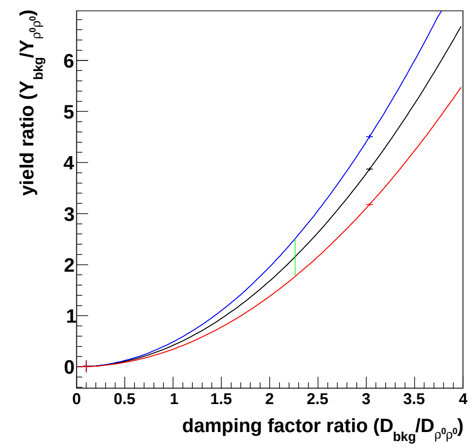
- $B^0 \to \rho^0\rho^0$ suffers from large systematic uncertainty through interference with $B \to a_1^{\pm}\pi^{\mp}$
- previous Belle result: -$\mathcal{B}(B^0 \to \rho^0\rho^0)_{prev.} < 1.0 \times 10^{-6}$, assuming $f_L = 1$

  -$\mathcal{B}(B^0 \to f_0\rho^0)_{prev.} < 0.3 \times 10^{-6}$ ($657 \times 10^6 B\bar{B}$ pairs)

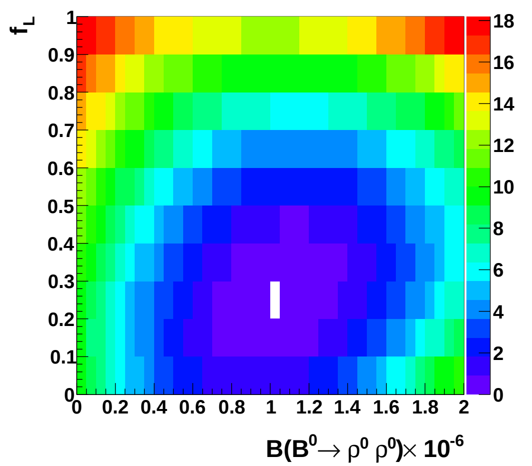
Systematic Uncertainties

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.



ϕ_2 from $B \to \rho\rho$ Decays

isospin analysis

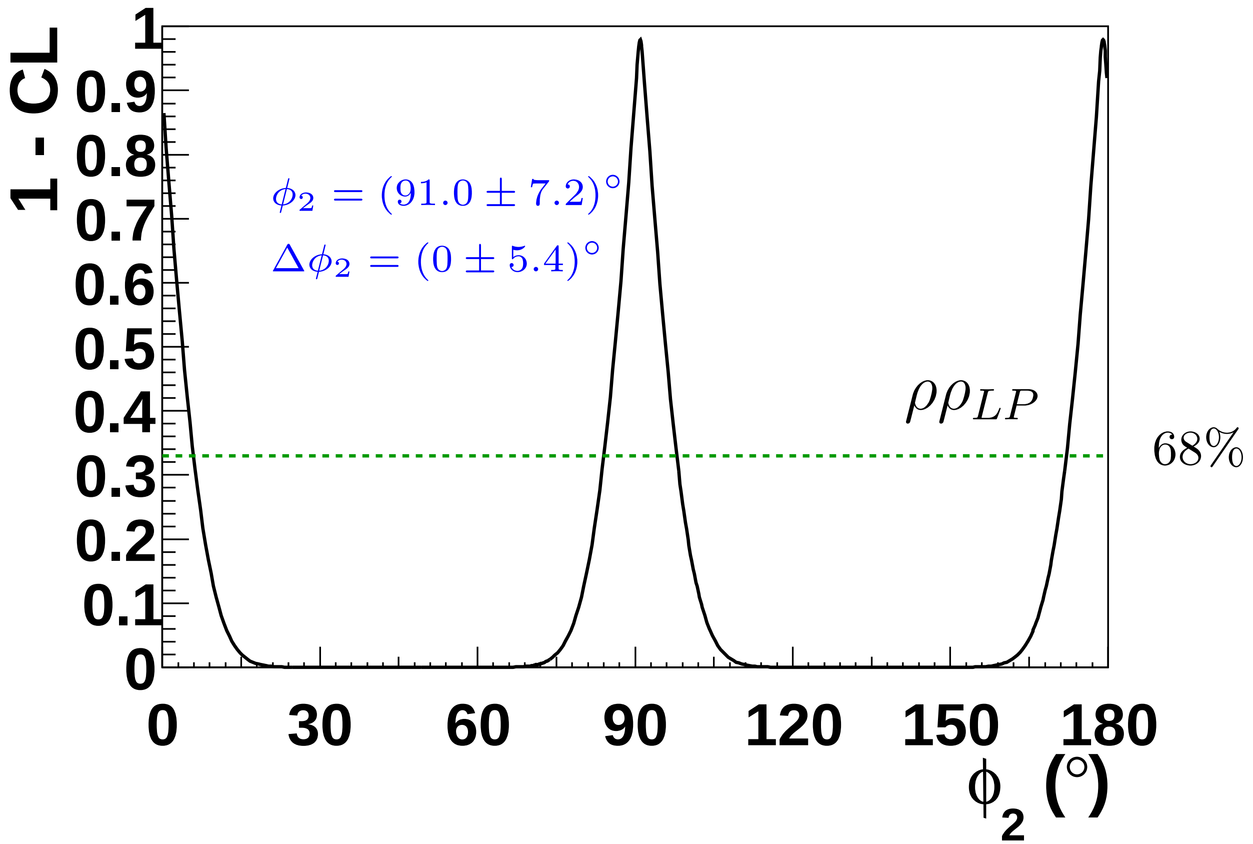
inputs:

- my result on

  $B^0 \to \rho^0\rho^0|_{LP}$

  $\mathcal{B}(B^0 \to \rho^0\rho^0)|_{LP} = (0.21 \pm 0.36) \times 10^{-6}$

- and world averages else



---

same scan with the world average

$\mathcal{B}(B^0 \to \rho^0\rho^0) = (0.74 \pm 0.28) \times 10^{-6} \to \phi_2 = (90.9 \pm 8.4)^\circ$

Summary & Outlook

- presented measurement of $\mathcal{BR}(B^0 \to \rho^0\rho^0)$ **(arXiv:1212.4015)**

  preliminary results (presented at CKM 2012)

  $\mathcal{BR}(B^0 \to \rho^0\rho^0) = (1.02 \pm 0.30(stat.) \pm 0.22(syst.)) \times 10^{-6}$

  $f_L = 0.21^{+0.18}_{-0.22}(stat.) \pm 0.11(syst.)$

- and used it in isospin analysis

  $\phi_2 = (91.0 \pm 7.2)^\circ$

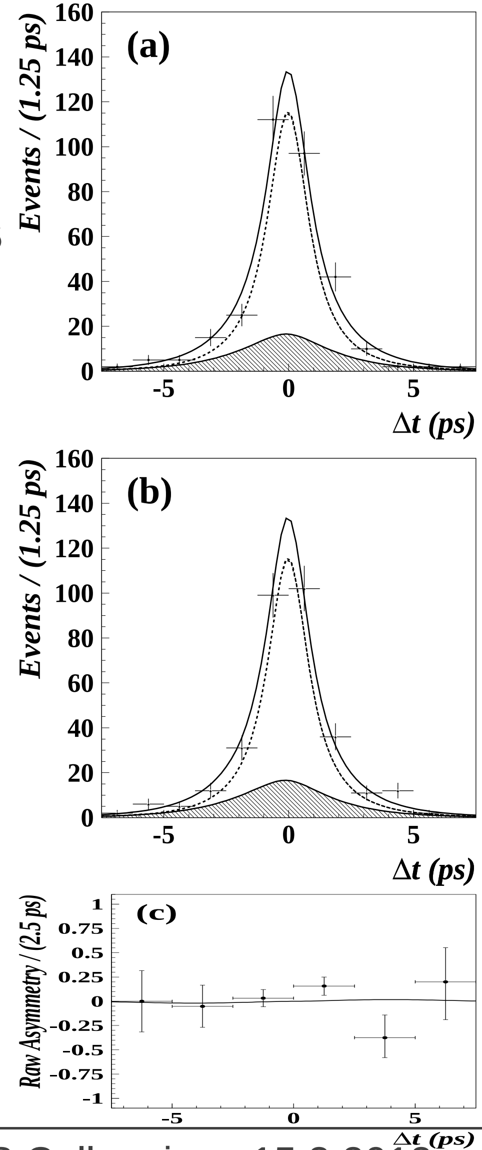
- currently working on the final update of $B^0 \to \rho^+\rho^-$

  $\to$ measurement of branching fraction, polarization

  and CP asymmetries.

- most precise measurement of ϕ_2 in the $B \to \rho\rho$ system ?

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



BACKUP

$B \to VV$

naive SM predictions

amplitude ratios:

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

fraction of longitudinal polarized states f_L:

$$\mathbf{f_L = \frac{|A_0|^2}{|A_0|^2+|A_+|^2+|A_-|^2} \sim 1 - \frac{m_V^2}{m_B^2}}$$

---

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

$f_L \sim 0.5$?

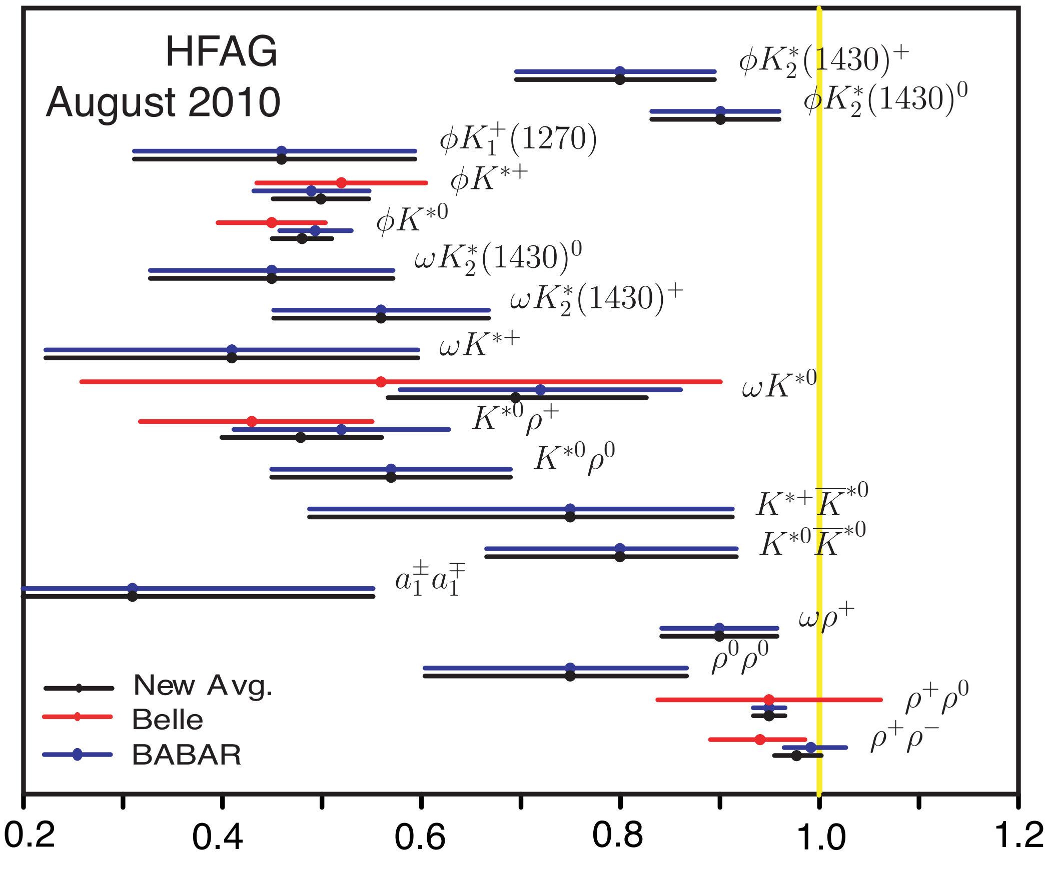
e.g. K^* *naive expectation:*

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

$\to$ **"helicity puzzle"**

topic of ongoing research

Polarizations of Charmless Decays



Helicity

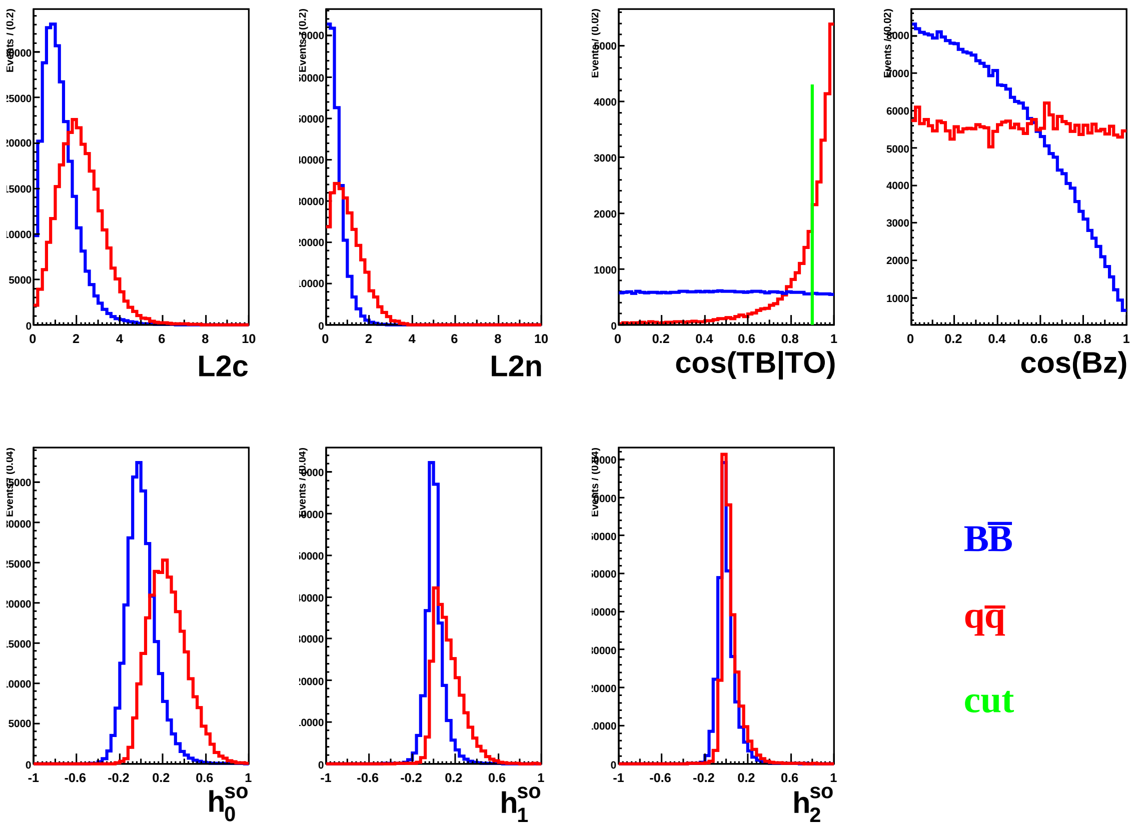
f_L not only over fit to $\cos(\Theta_H)$.

- in fact i build models for two signal components, LP and TP.
- they only share the same shape for the ρ mass.
- slightly different ΔE and $\mathcal{F}$ due to different momentum distributions.
- $\cos(\Theta_H)$ gives best discrimination

$\Rightarrow$ fit a common branching ratio and obtain the yields for each polarization by fitting also f_L.

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

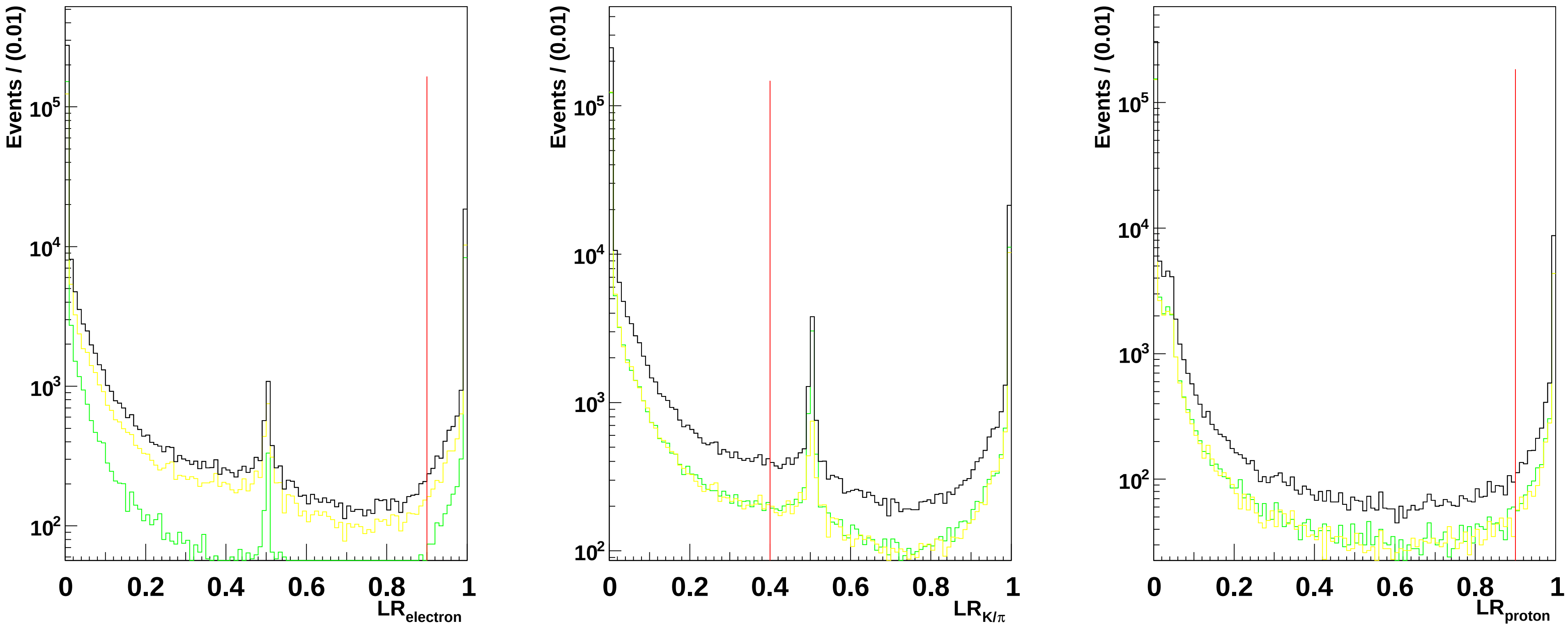
cut: $\cos(TB|TO) < 0.9$

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

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

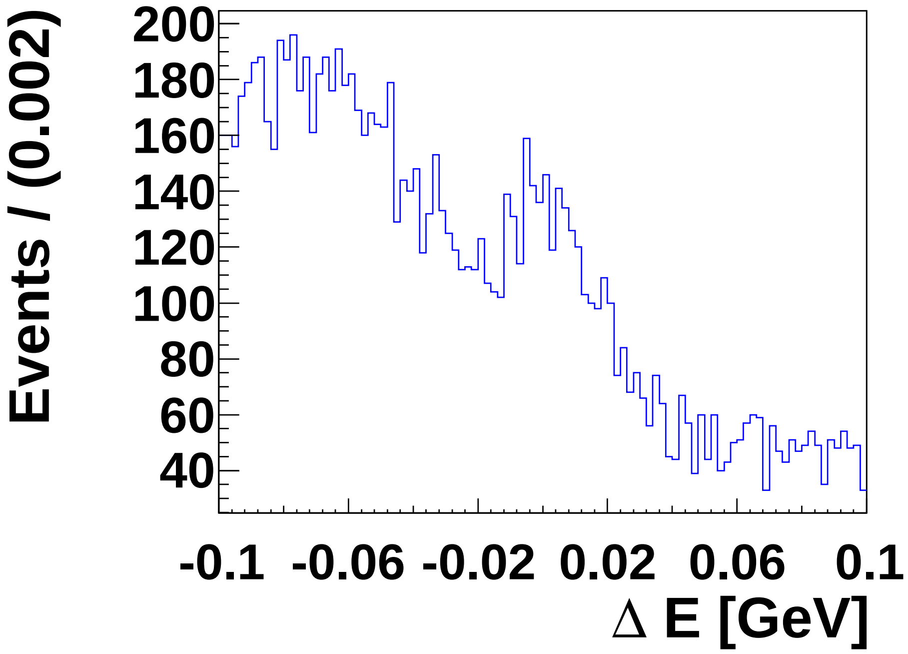
$\mathcal{LR}_e < 0.9$ $\mathcal{LR}_{K/\pi} < 0.4$ $\mathcal{LR}_{p/\pi} < 0.9$

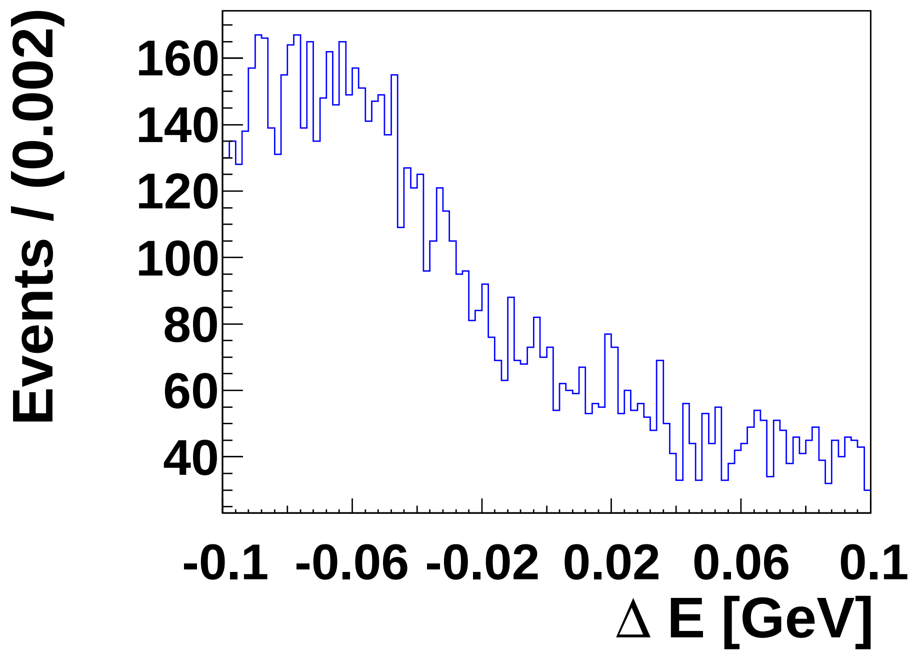


- require that tracks (*somehow*) origin at the IP: $|dr| < 0.5cm$ & $|dz| < 5cm$

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 $M(\pi\pi\pi)$:

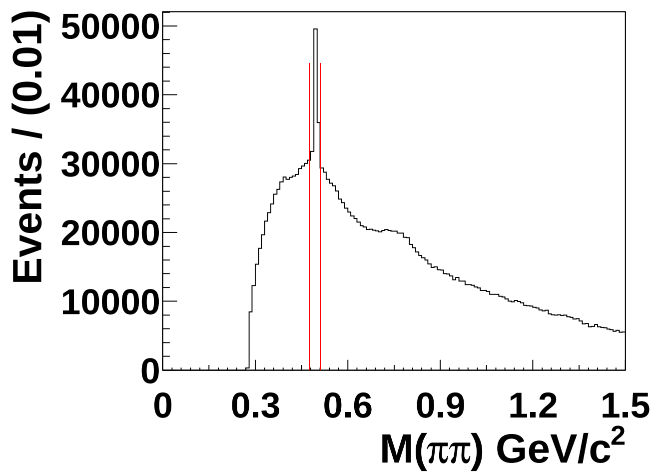
$D^{\pm} : 1.8696 \pm 0.02[GeV/c^2]$

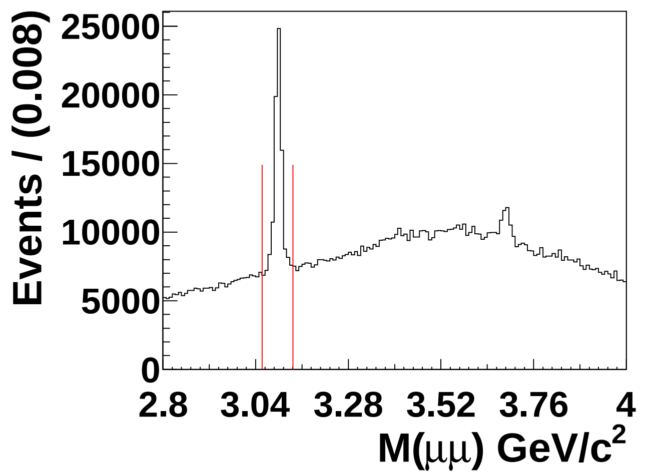
$D_s^{\pm} : 1.96849 \pm 0.02[GeV/c^2]$

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

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

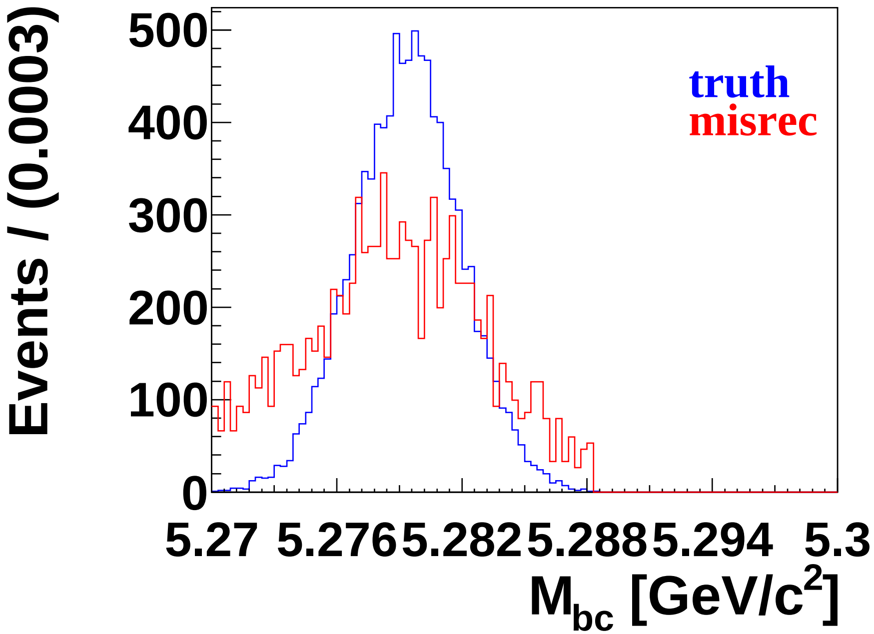
$\rightarrow$ loss in $\epsilon_{rec} < 4\%$

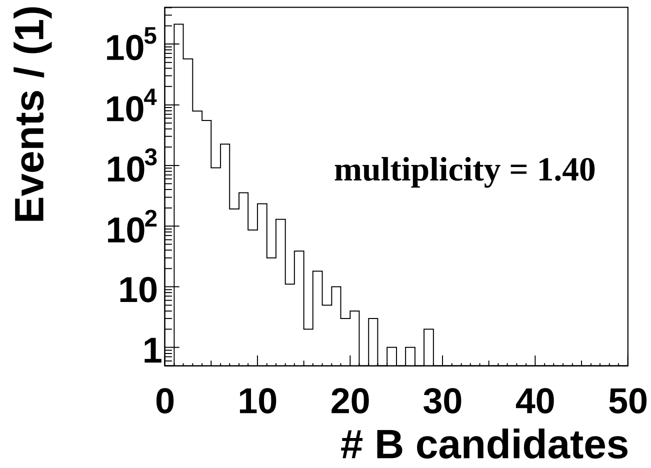




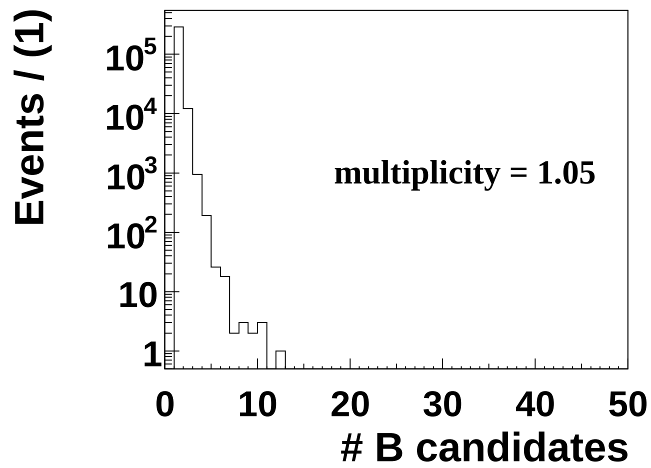
Rec: BCS

- **BCS:** best candidate selection





L(top) and T pol



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

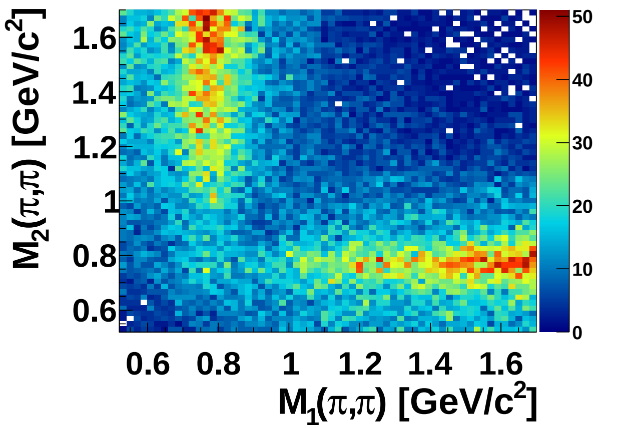
$\Rightarrow$ choose combination with highest π^+ and lowest π^- momentum

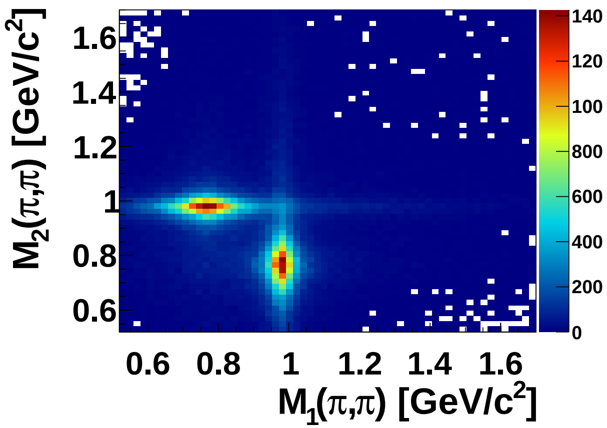
$\rightarrow$ purity $= 76\%(L); 92\%(T)$

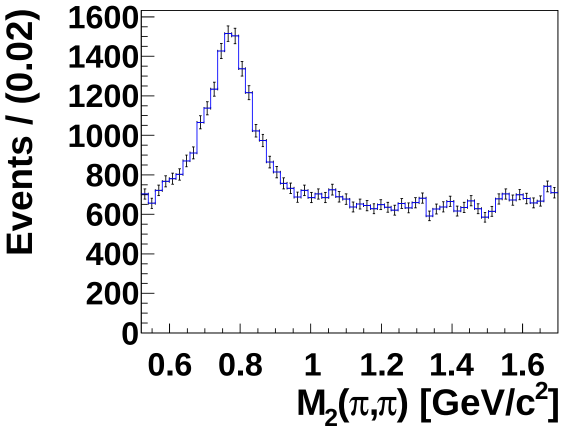
Correlations!

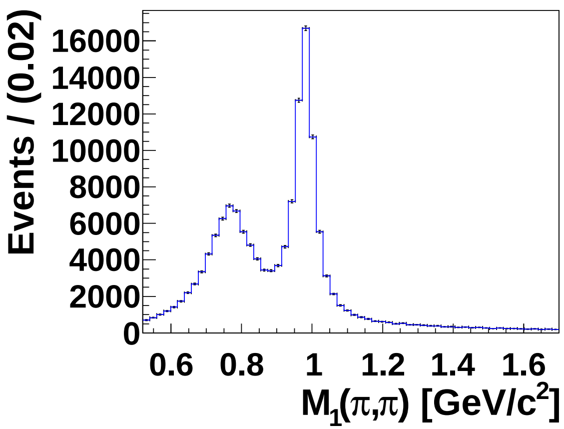
sometimes correlated multidimensional $\mathcal{PDF}$ needed

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









Motivation

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

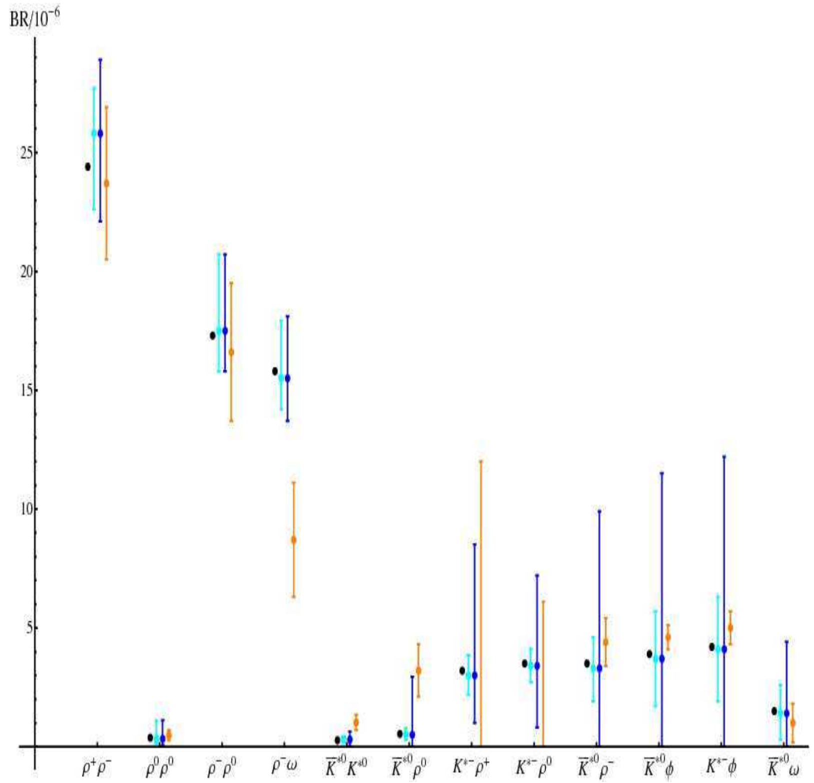
light hadronic vector states: $\rho, \omega, a_1, b_1, \phi, K^*$, ...

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

tree, QCD/EW penguin, weak annihilation

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

$\Rightarrow$ experimental difficulties



Bartsch, Buchalla, Kraus: arxive: 0810.0249

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

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

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

- **previous measurements**

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

$\Rightarrow$ no observation made at Belle (yet) although more data available ($\sim 2\times$)

challenging analysis

- rare decay: $\mathcal{BR} \leq 10^{-6}$
- large backgrounds
- helicity structure

$\Longrightarrow$

new method on full data set

- no cut-based but multivariat analysis, including eventshape and f_L

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

Estimate the fitter's ability to find signal with Toy MC,

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:

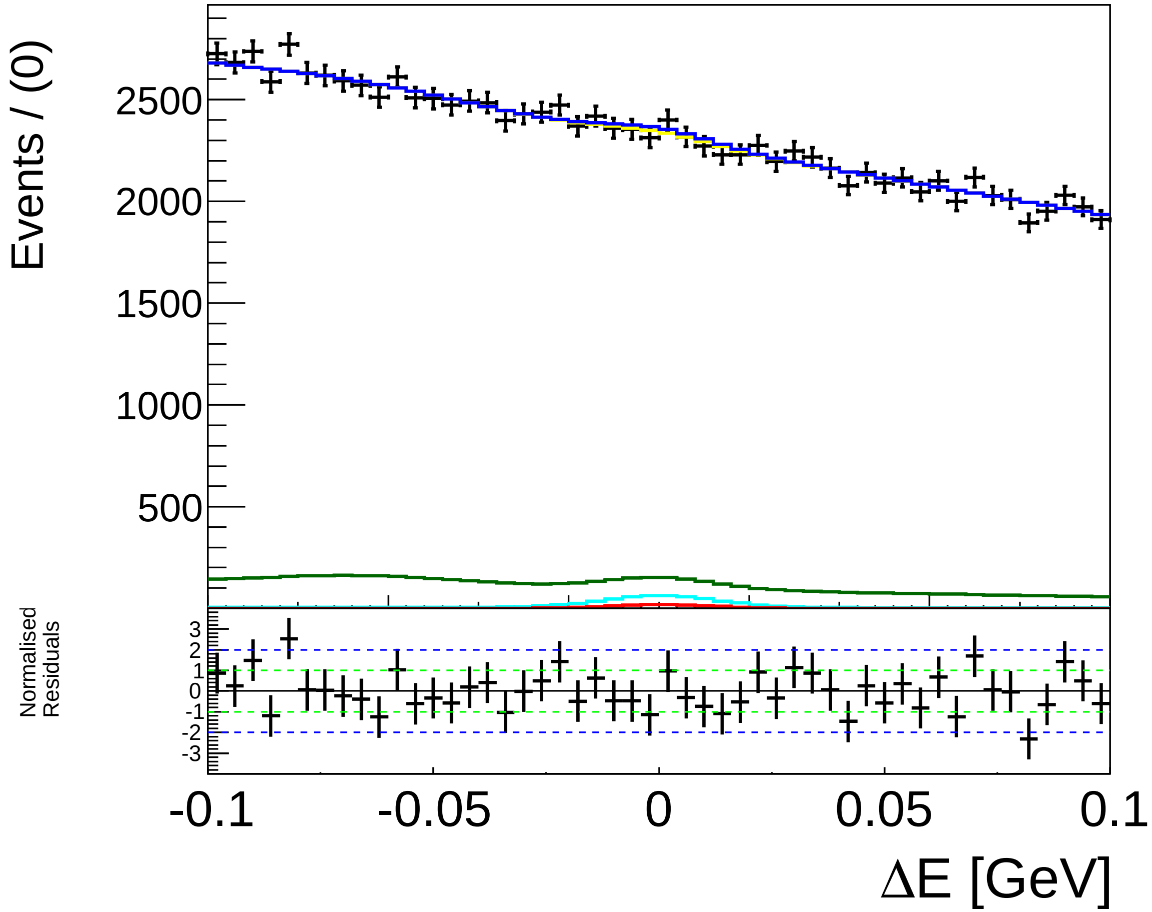
$$5.27 < M_{\rm bc} < 5.29 \quad [GeV/c^2]$$

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

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

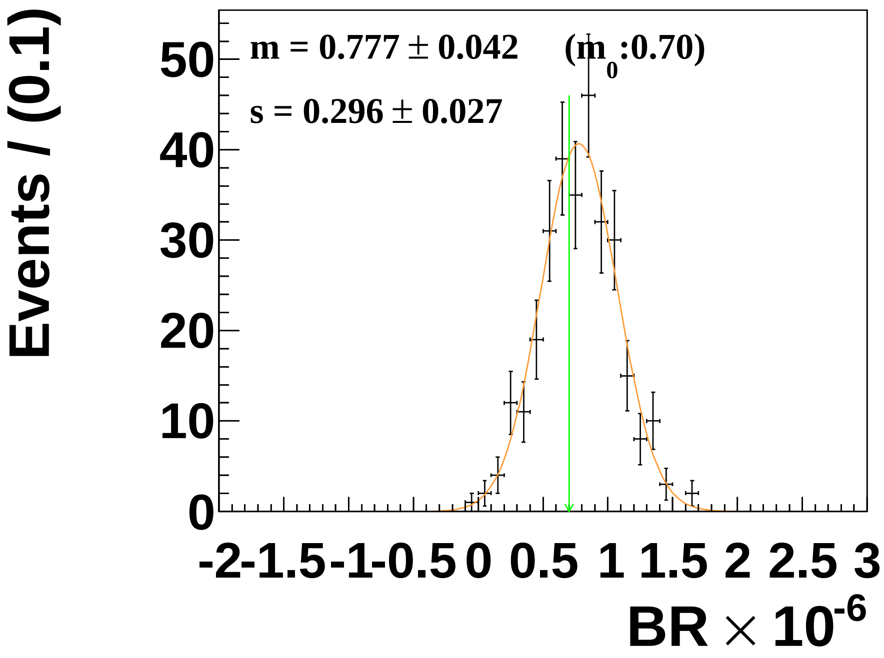
$$-1 < cos(\theta_H) < 1$$

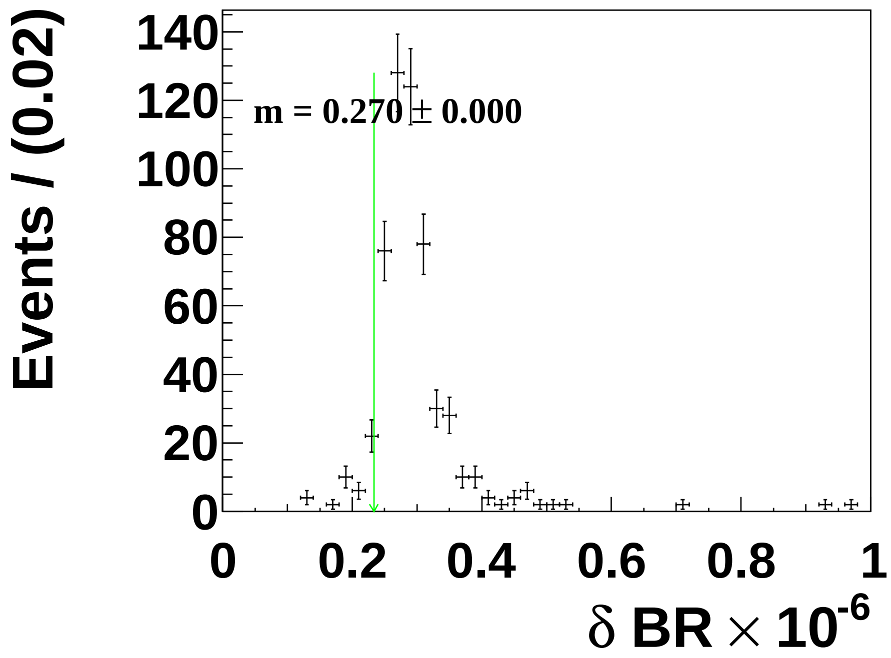
proj. into ΔE.



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

- performed fits on 300 toy MC samples





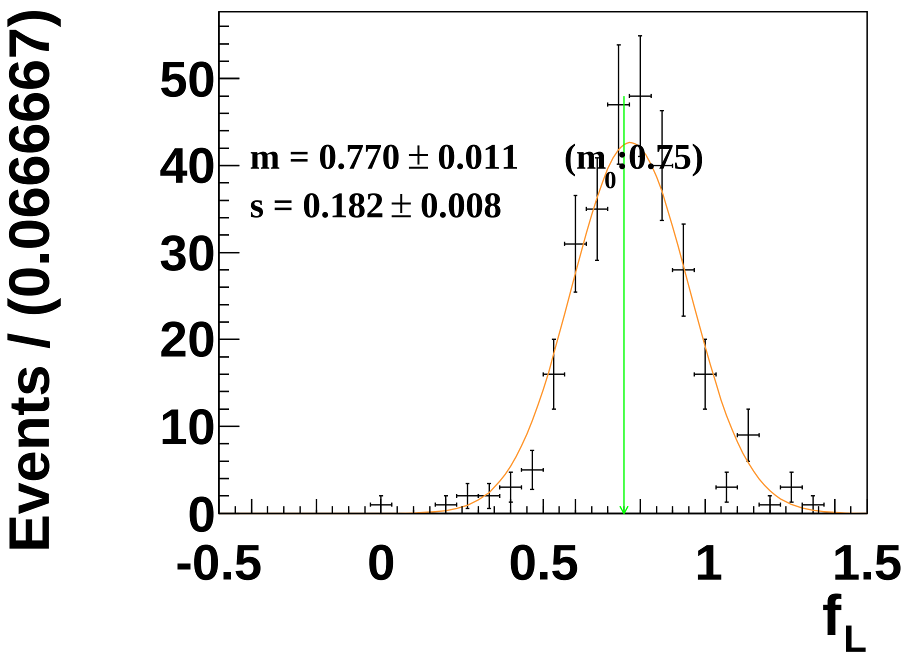
green line is input value

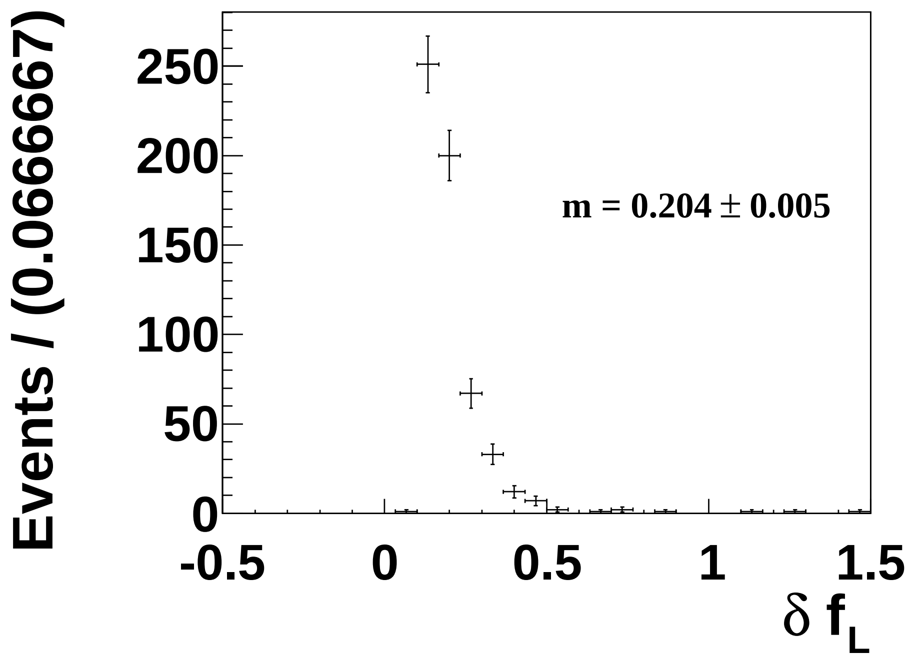
indicates 3 σ significance

$\Rightarrow$ 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