CP studies & other B-physics with Belle

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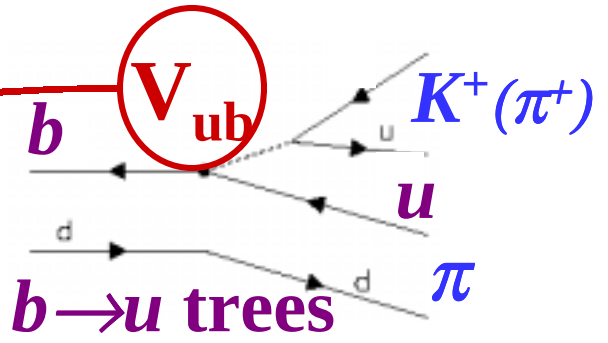
- **Introduction**
- **Tools**
  - **KEKB**
  - **Belle**
- **CP measurements**
  - ϕ_1 (β)
  - ϕ_2 (α)
  - ϕ_3 (γ)
  - ϕ_{NP} **non-SM**
- **EW penguins**
  - **B→K$^{(*)}$ l^+l^-**

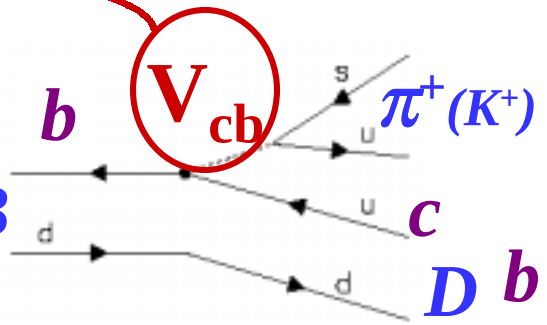
Goal 1: map out CKM matrix with B mesons

CPV phases are here

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

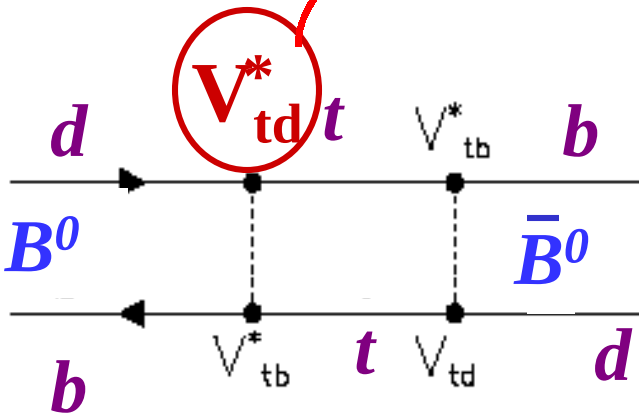


$b \to u$ trees

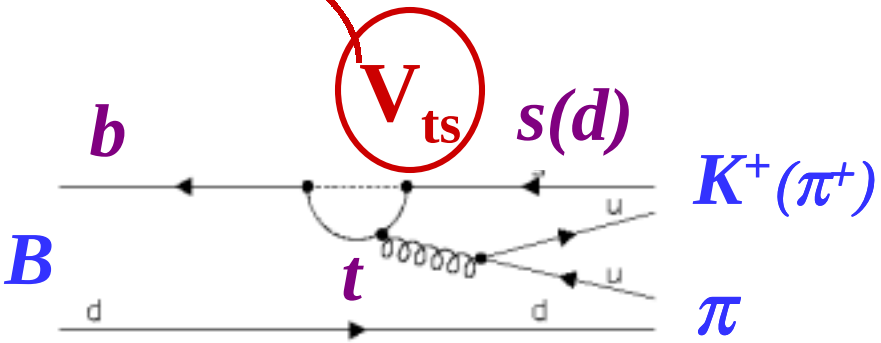


$b \to c$ trees

>99% of decays



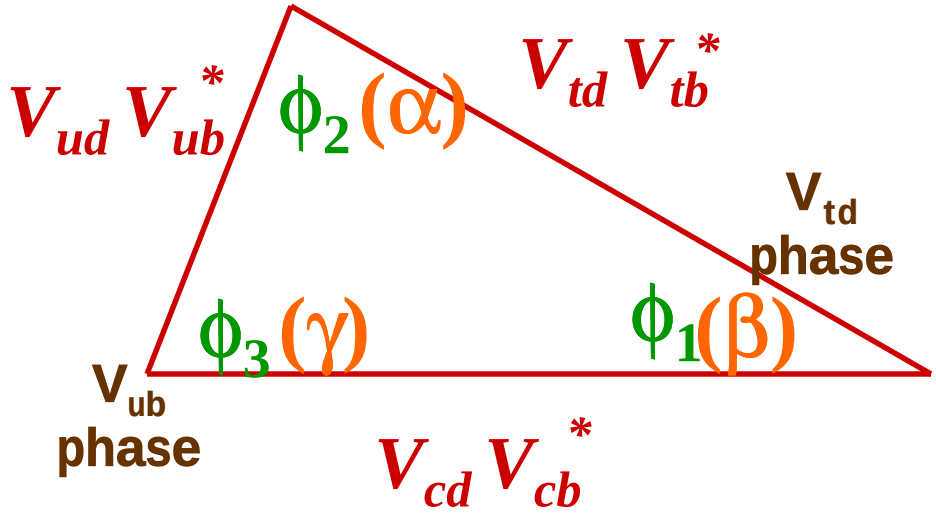
B-$\bar{B}$ mixing



$b \to s\ (d)$ penguins

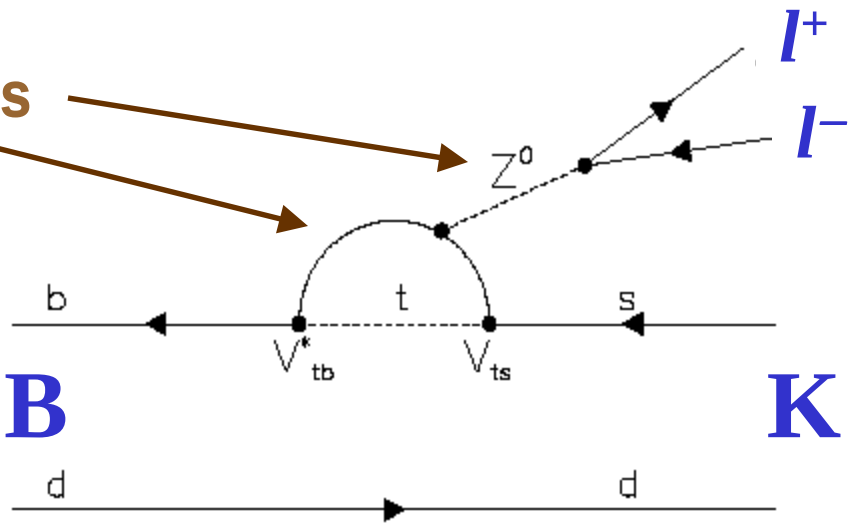
Goal 2: probe for non-SM physics

- **CKM: is that all there is?**
  - is the unitarity triangle a triangle?
  - are there non-SM phases



- **"virtual" new physics**

sensitive to possible massive "new" particles



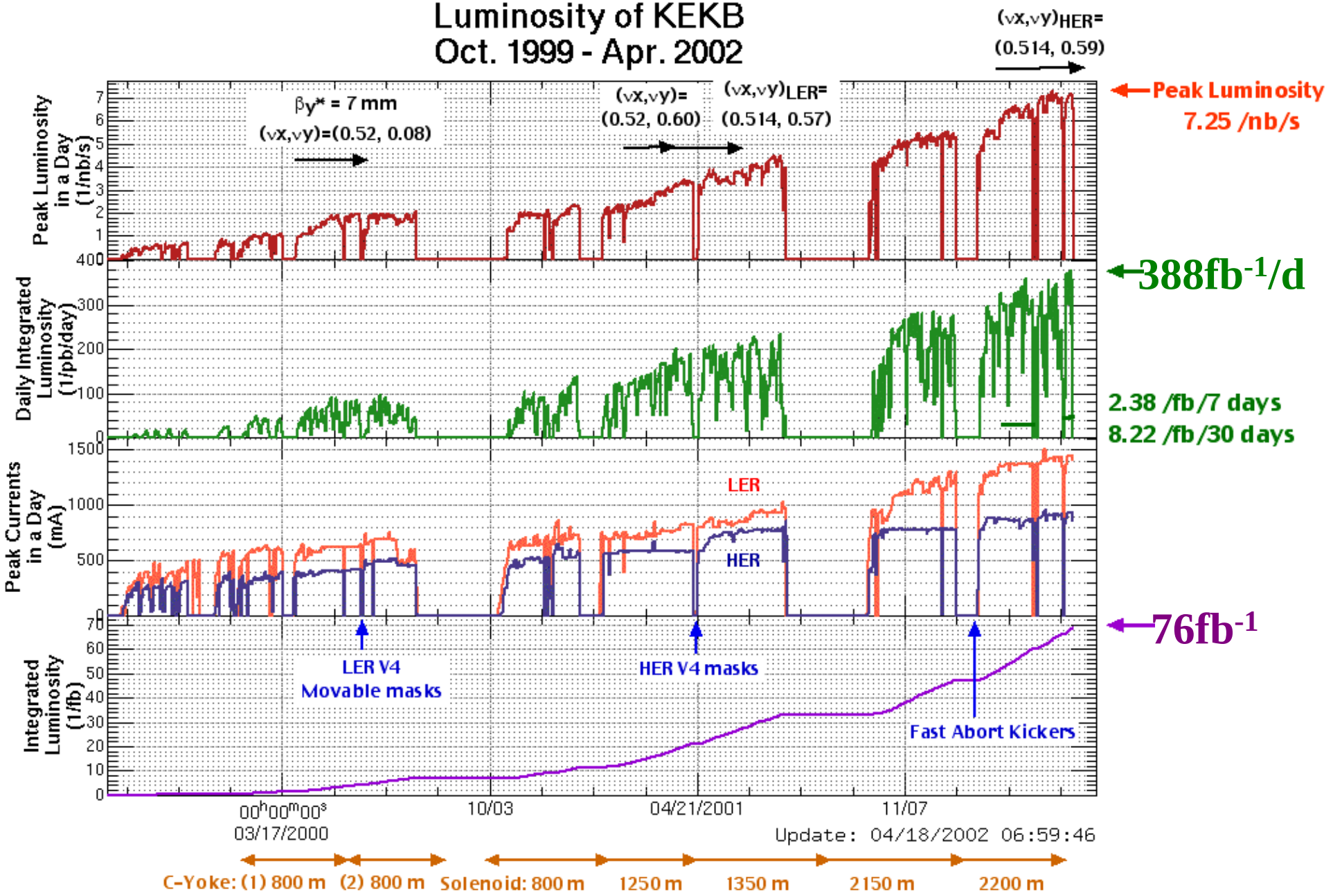
EW Penguin ($b \to s\, l^+ l^-$)

Tools

KEKB

asymmetric e^+e^- collider

- Two separate rings
  - e^+ (LER) : 3.5 GeV
  - e^- (HER) : 8.0 GeV
- E_{CM} : 10.58 GeV at $\Upsilon(4S)$
- Luminosity
  - target: 10^{34} /cm^2/s
  - achieved: 7.2×10^{33}/cm^2/s
- Small beam sizes:
  - $\sigma_y \approx 3$ μm; $\sigma_x \approx 100$ μm
- ±11 mrad crossing angle

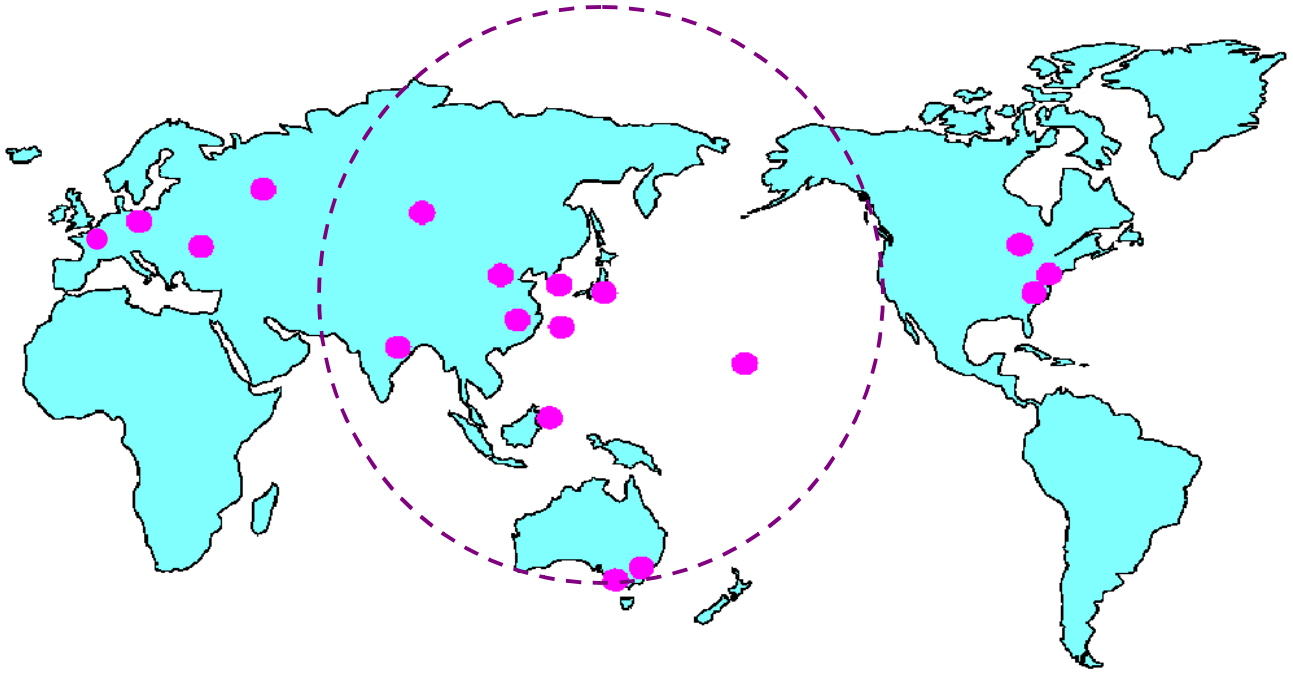

Luminosity of KEKB
Oct. 1999 - Apr. 2002
(νx,νy)HER=
(0.514, 0.59)
Peak Luminosity
7.25 /nb/s
βy* = 7 mm
(νx,νy)=(0.52, 0.08)
(νx,νy)=
(0.52, 0.60)
(νx,νy)LER=
(0.514, 0.57)
Peak Luminosity in a Day (1/nb/s)
388fb-1/d
Daily Integrated Luminosity (1/pb/day)
2.38 /fb/7 days
8.22 /fb/30 days
Peak Currents in a Day (mA)
LER
HER
76fb-1
LER V4
Movable masks
HER V4 masks
Fast Abort Kickers
Integrated Luminosity (1/fb)
00h00m00s
03/17/2000
10/03
04/21/2001
11/07
Update: 04/18/2002 06:59:46
C-Yoke: (1) 800 m
(2) 800 m
Solenoid: 800 m
1250 m
1350 m
2150 m
2200 m

Machine Parameters of the KEKB (March 28/2002)

	LER	HER	
Horizontal Emittance	18	24	nm
Beam current	1393	869	mA
Number of bunches	1223		
Bunch current	1.138	0.710	mA
Bunch spacing	2.4		m
Bunch trains	1		
Total RF volatage Vc	6.6	12.0	MV
Synchrotron tune ν_s	-0.0225	-0.0199	
Betatron tune ν_x / ν_y	45.513/43.566	44.514/41.580	
beta's at IP β_x^* / β_y^*	59/0.62	63/0.7	cm
beam-beam parameters ξ_x / ξ_y	0.078/0.049	0.074/0.043	
Beam lifetime	98@1393	276@ 869	min.@mA
Luminosity (Belle CsI)	7.25		$10^{33}/cm^2/sec$
Luminosity records per day/ 7 days / month	359/2207/7248		/pb

high lum. with low currents

The Collaboration



A World-Wide Activity Involving ~50 Institutions

The Belle Collaboration

Observation of $B \to J/\psi K_1(1270)$

The Belle Collaboration

K. Abe[10], K. Abe[36], I. Adachi[10], Byoung Sup Ahn[16], H. Aihara[40], M. Asai[11], Y. Asano[45], T. Aso[44], V. Aulchenko[2], T. Aushev[14], A. M. Bakich[38], E. Banas[26], W. Bartel[8,10], S. Behari[10], P. K. Behera[46], D. Beliine[9], A. Bondar[2], A. Bozek[26], T. E. Browder[9], B. C. K. Casey[9], P. Chang[25], Y. Chao[25], B. G. Cheon[35], S.-K. Choi[6], Y. Choi[35], J. Dragic[19], A. Drutskoy[14], S. Eidelman[2], Y. Enari[21], F. Fang[9], H. Fujii[10], C. Fukunaga[42], M. Fukushima[12], A. Garmash[2,10], A. Gordon[19], K. Gotow[47], R. Guo[23], J. Haba[10], H. Hamasaki[10], K. Hanagaki[32], K. Hara[30], T. Hara[30], N. C. Hastings[19], H. Hayashii[22], M. Hazumi[10], E. M. Heenan[19], Y. Higasino[21], I. Higuchi[39], T. Higuchi[40], H. Hirano[43], T. Hojo[30], Y. Hoshi[36], S.-R. Hou[25], W.-S. Hou[25], S.-C. Hsu[25], H.-C. Huang[25], Y. Igarashi[10], T. Ijima[10], H. Ikeda[10], K. Inami[21], A. Ishikawa[21], H. Ishino[41], R. Itoh[10], G. Iwai[28], H. Iwasaki[10], Y. Iwasaki[10], D. J. Jackson[30], P. Jalocha[26], H. K. Jang[34], M. Jones[9], R. Kagan[14], H. Kakuno[41], J. Kaneko[41], J. H. Kang[48], J. S. Kang[16], P. Kapusta[26], N. Katayama[10], H. Kawai[3], H. Kawai[40], N. Kawamura[1], T. Kawasaki[28], H. Kichimi[10], D. W. Kim[35], Heejong Kim[48], H. J. Kim[48], Hyunwoo Kim[16], S. K. Kim[34], T. H. Kim[48], K. Kinoshita[5], S. Kobayashi[33], S. Koishi[41], P. Krokovny[2], R. Kulasiri[5], S. Kumar[31], A. Kuzmin[2], Y.-J. Kwon[48], J. S. Lange[7], S. H. Lee[34], D. Liventsev[14], R.-S. Lu[25], D. Marlow[33], T. Matsubara[40], S. Matsui[21], S. Matsumoto[4], T. Matsumoto[21], Y. Mikami[39], K. Miyabayashi[22], H. Miyake[30], H. Miyata[28], G. R. Moloney[19], G. F. Moorhead[19], S. Mori[45], T. Mori[4], A. Murakami[33], T. Nagamine[39], Y. Nagasaka[11], Y. Nagashima[30], T. Nakadaira[40], E. Nakano[29], M. Nakao[10], J. W. Nam[35], S. Narita[39], Z. Natkaniec[26], K. Neichi[38], S. Nishida[17], O. Nitoh[43], S. Noguchi[22], T. Nozaki[10], S. Ogawa[37], T. Ohshima[21], T. Okabe[21], S. Okuno[15], S. L. Olsen[9], H. Ozaki[10], P. Pakhlov[14], H. Palka[26], C. S. Park[34], C. W. Park[16], H. Park[16], L. S. Peak[38], M. Petric[9], L. E. Piilonen[47], E. Prebys[33], J. L. Rodrigues[9], N. Root[2], M. Rozanska[26], K. Rybicki[26], H. Sagawa[10], Y. Sakai[10], H. Sakamoto[17], M. Satapathy[46], A. Satpathy[10,5], S. Schrenk[5], S. Semenov[14], K. Senyo[21], M. E. Sevior[19], H. Shibuya[37], B. Shwartz[2], S. Stanič[45], A. Sugi[21], A. Sugiyama[21], K. Sumisawa[10], T. Sumiyoshi[10], J.-I. Suzuki[10], K. Suzuki[3], S. Suzuki[21,*], S. Y. Suzuki[10], S. K. Swain[9], T. Takahashi[29], F. Takasaki[10], M. Takita[30], K. Tamai[10], N. Tamura[28], J. Tanaka[40], M. Tanaka[10], Y. Tanaka[20], G. N. Taylor[19], Y. Teramoto[29], M. Tomoto[10], T. Tomura[40], S. N. Tovey[19], K. Trabelsi[9], T. Tsuboyama[10], T. Tsukamoto[10], S. Uehara[10], K. Ueno[26], Y. Unno[3], S. Uno[10], Y. Ushiroda[10], S. E. Vahsen[32], K. E. Varvell[38], C. H. Wang[24], J. G. Wang[47], M.-Z. Wang[25], Y. Watanabe[41], E. Won[34], B. D. Yabsley[10], Y. Yamada[10], M. Yamaga[39], A. Yamaguchi[39], H. Yamamoto[9], Y. Yamashita[27], M. Yamauchi[10], S. Yanaka[41], K. Yoshida[21], Y. Yusa[39], H. Yuta[1], C. C. Zhang[13], J. Zhang[45], H. W. Zhao[10], Y. Zheng[9], V. Zhilich[2], and D. Žontar[45]

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[2] *Budker Institute of Nuclear Physics, Novosibirsk*
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~250 Authors

[21] *Nagoya University, Nagoya*
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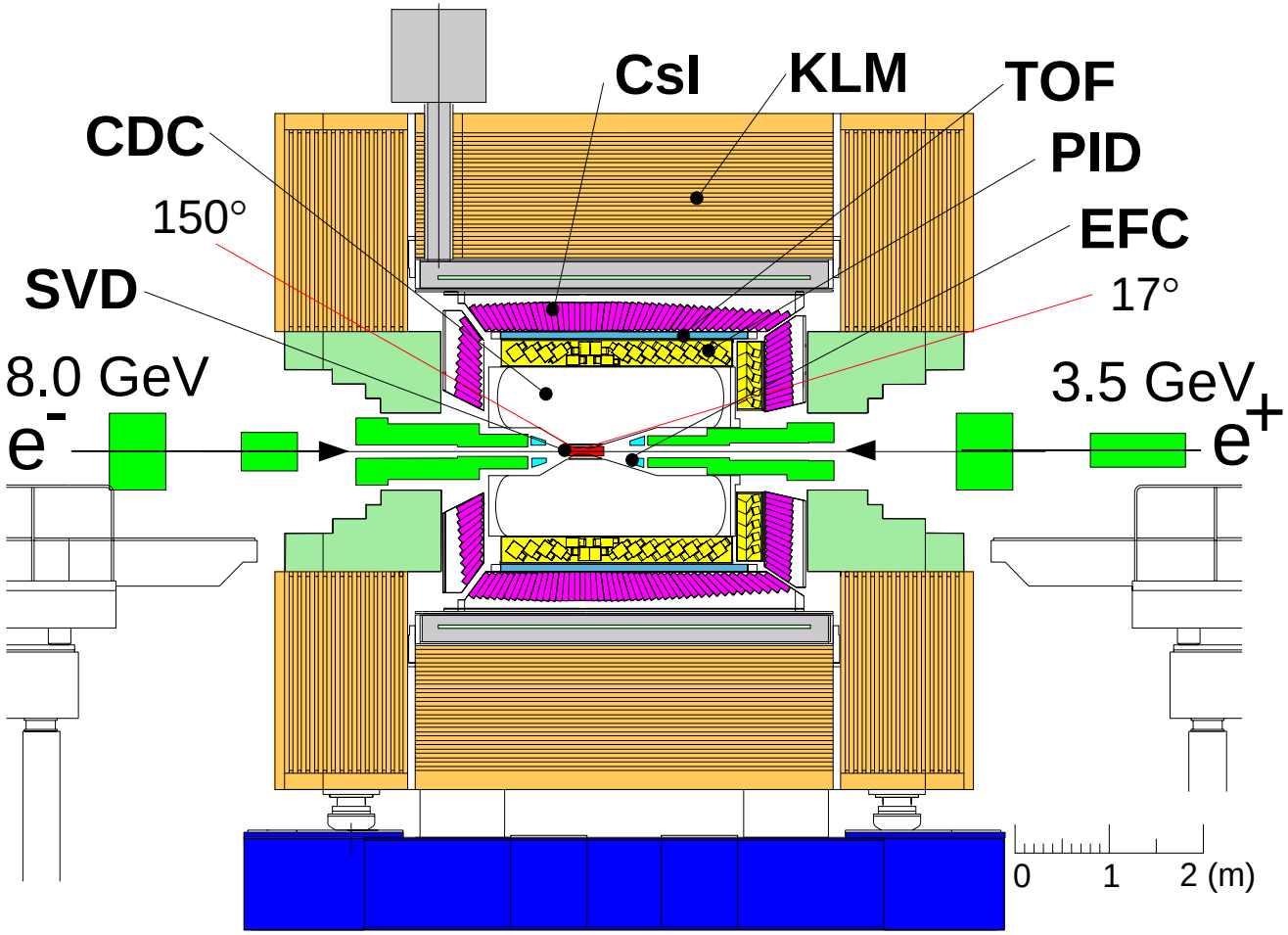
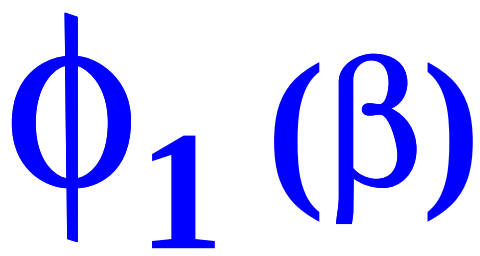
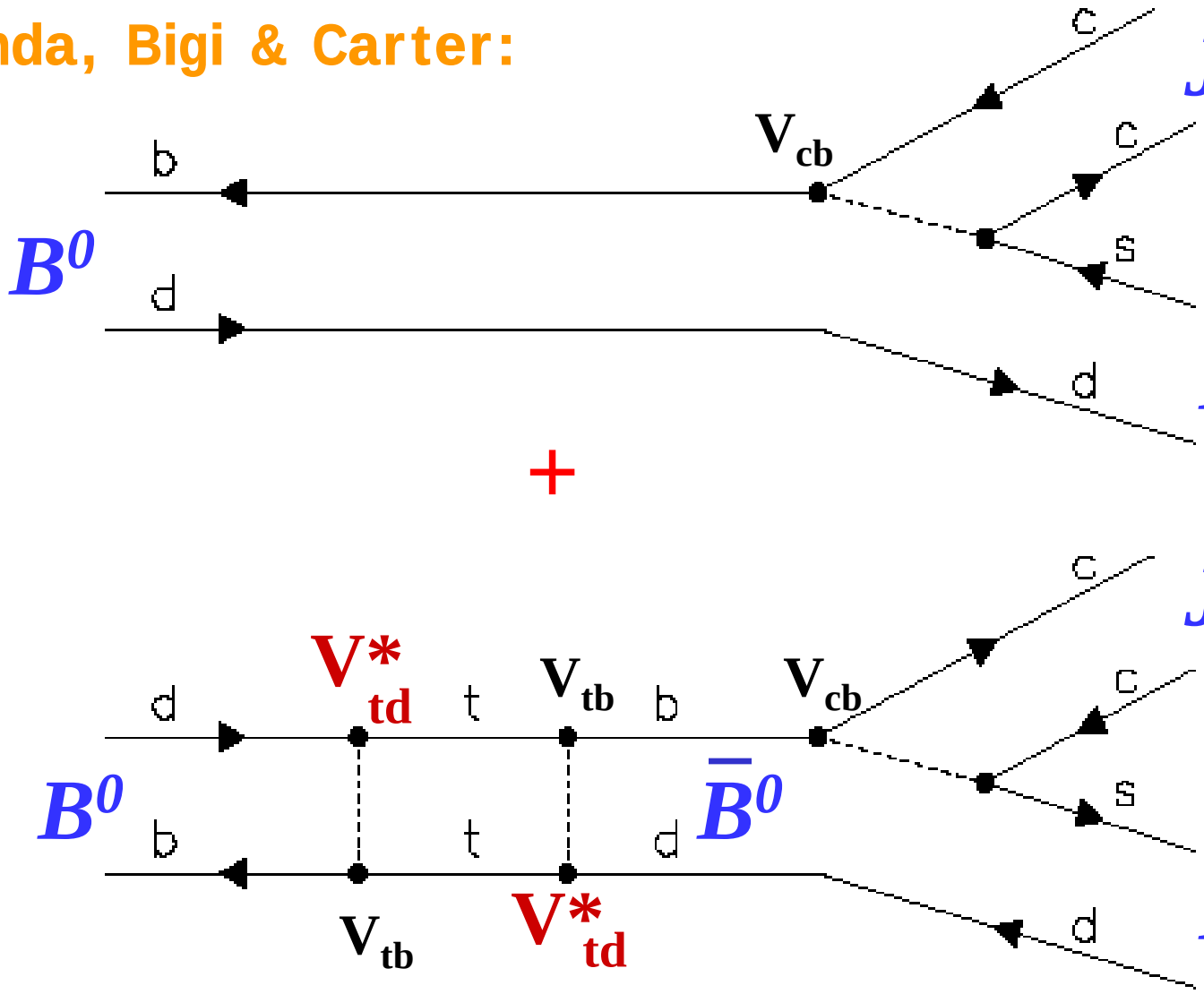
- SVD $\sigma \sim 55\mu m$ for 1GeV/c @ 90°
- CDC $\sigma_p/p \sim 0.35\%$ @ 1GeV/c; σ_π(dE/dx) ~ 7%
- $K^\pm$ id: TOF (σ ~100 ps); Aerogel (n = 1.01 ~ 1.03)
- CsI $\sigma_E/E_\gamma \sim 1.5\%$ @ 1GeV
- KLM (RPCs) $\mu^\pm$: effic. > 90% ; ~2% fakes




$\phi_1(\beta)$

ϕ_1: interfere $B \to f_{CP}$ with $B \leftrightarrow \bar{B} \to f_{CP}$

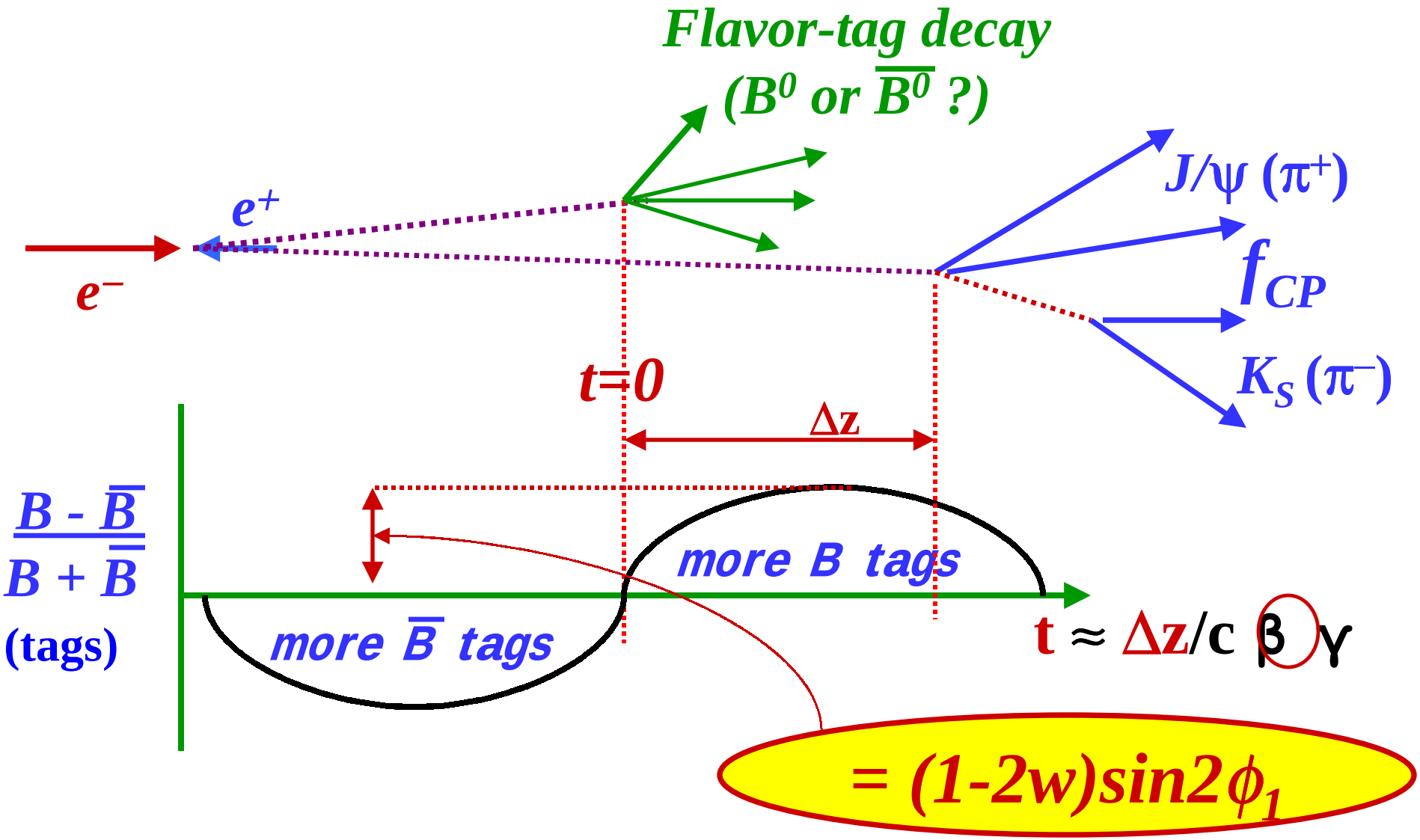
Sanda, Bigi & Carter:



$\propto V_{td}^{*2}$

$(\sin 2\phi_1)$

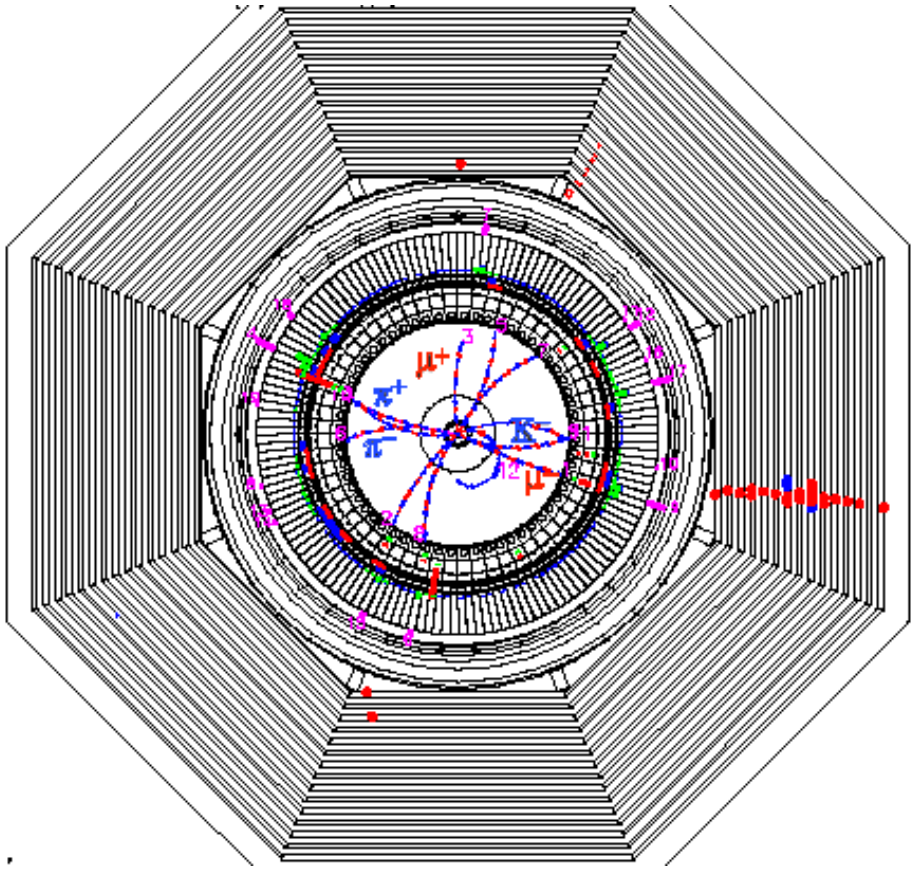
What do we measure?

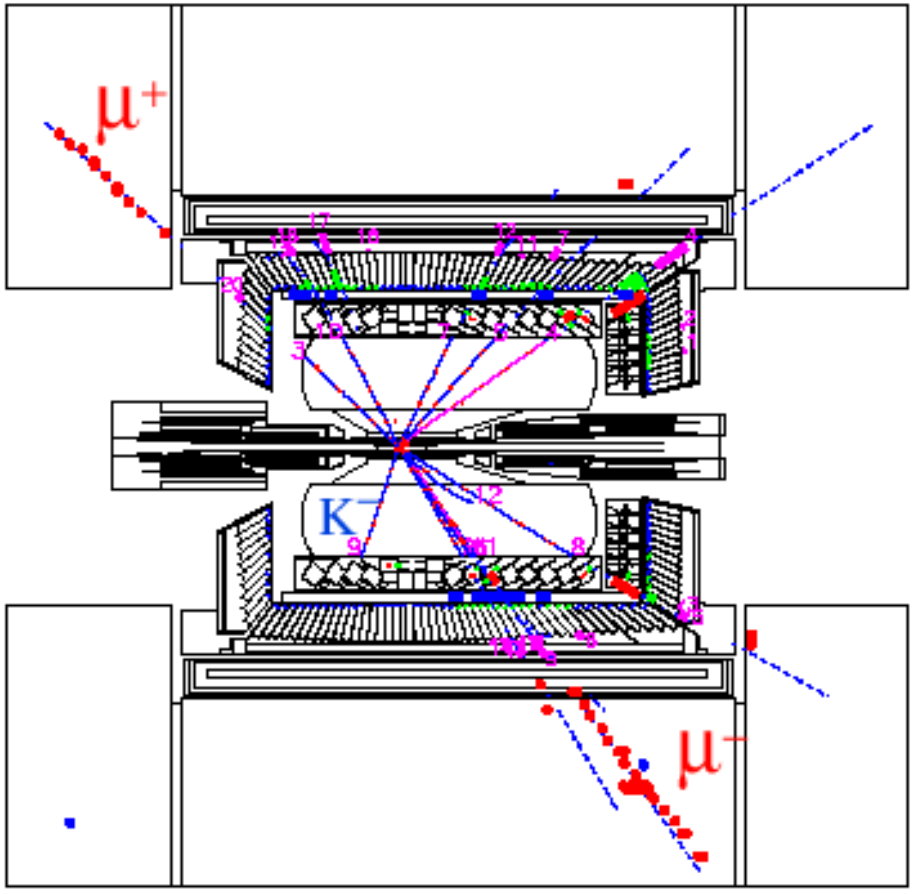


What's needed?

- **Lots of B mesons** ($Br\,(B \to f_{CP}) \sim 10^{-3}$)
  - **very high Luminosity $\Rightarrow$ KEKB**
- **Find CP eigenstate decays**
  - **high quality ~4π detector $\Rightarrow$ Belle**
- **Tag other B's flavor**
  - **good particle id $\Rightarrow$ *dE/dx*, Aerogel, TOF**
- **Measure decay-time difference**
  - **Asymmetric energies $\Rightarrow$ (@KEKB: $\gamma\beta c\tau \approx 200\mu m$)**
  - **good vertexing $\Rightarrow$ silicon strip vertex detector**

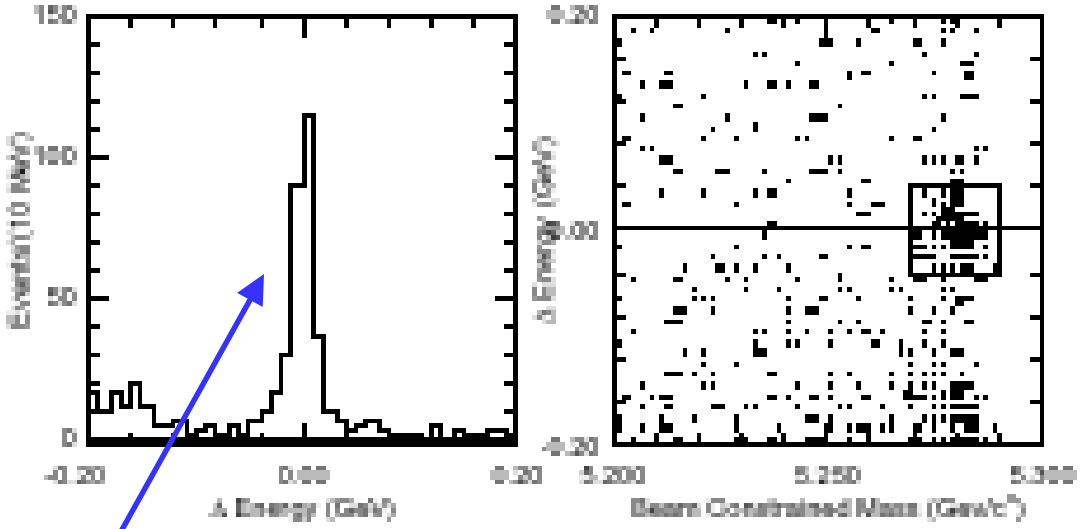
$$B \rightarrow J/\psi K_S \quad J/\psi \rightarrow \mu^+\mu^- \quad K_S \rightarrow \pi^+\pi^-$$





$B^0 \to J/\psi\, K_S(\to \pi^+\pi^-)$, etc

913 CP=–1 evts
~10% bkgd

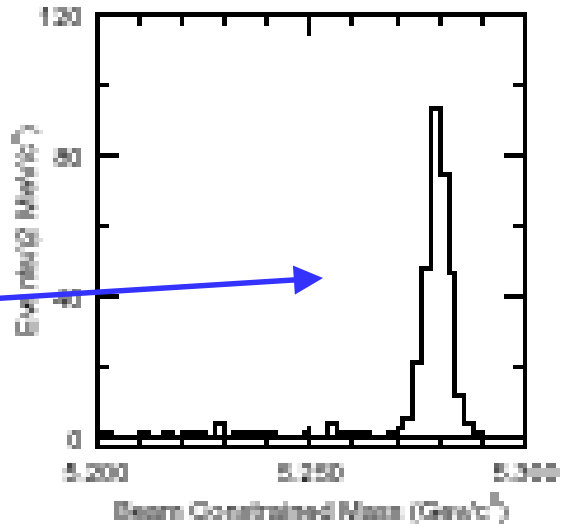


Energy difference:

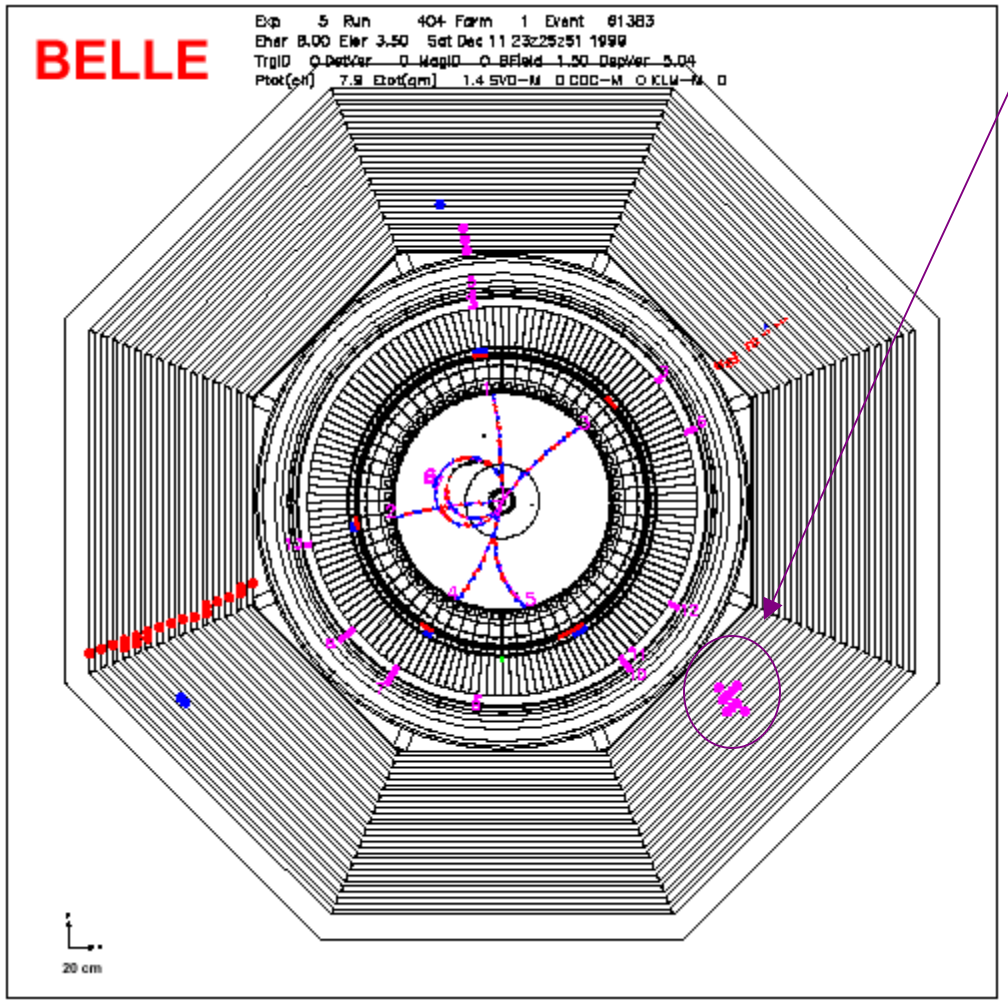
$$\Delta E \equiv E_{J/\psi} + E_{K_S} - E_{CM}/2$$

Beam-constrained mass:

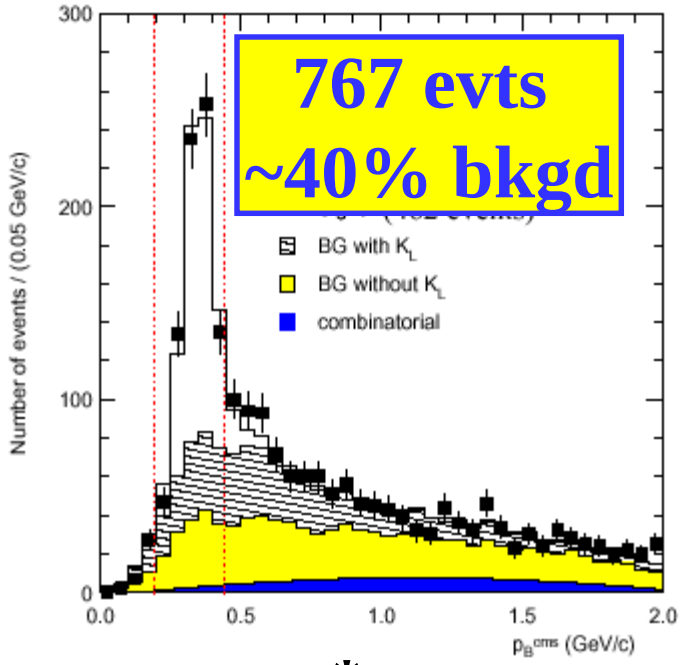
$$m_{bc} = \sqrt{(E_{CM}/2)^2 - (\vec{p}_{J/\psi} + \vec{p}_{K_S})^2}$$



$B \rightarrow J/\psi K_L$



Measure K_L angles in KLM, use B-mass to get |p|



P_B^*

Flavor-tag the other B meson

Use *inclusive* flavor-specific properties:

- ***Inclusive Leptons:***
  - ***high-p*** l^-
  - ***intermed-p*** l^+

$b \rightarrow c\, l^- \nu$

$\hookrightarrow s\, l^+ \nu$

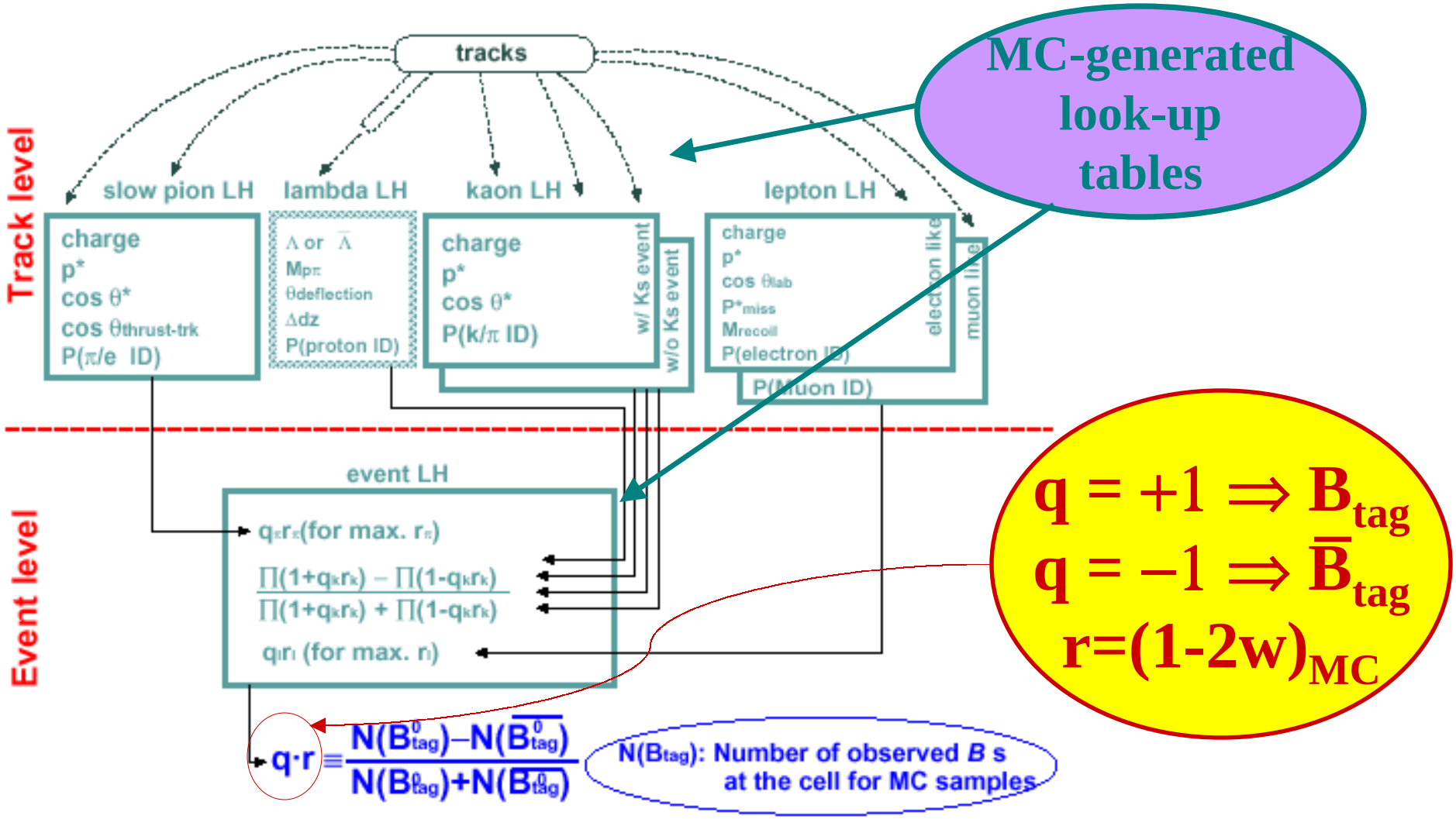
- ***Inclusive Hadrons:***
  - ***high-p*** π^-
  - ***intermed-p*** K^-
  - ***low-p*** π^+

$\bar{B}^0 \rightarrow D^{(*)+} \pi^-$, $D^{(*)+} \rightarrow K^- X$, $D^0 \pi^+$

ρ^-, *etc.* $\hookrightarrow \pi^- \pi^0$

Also need to consider *correlations*

2-level multi-dimensional flavor tagging



Determination of wrong tag fraction w_l

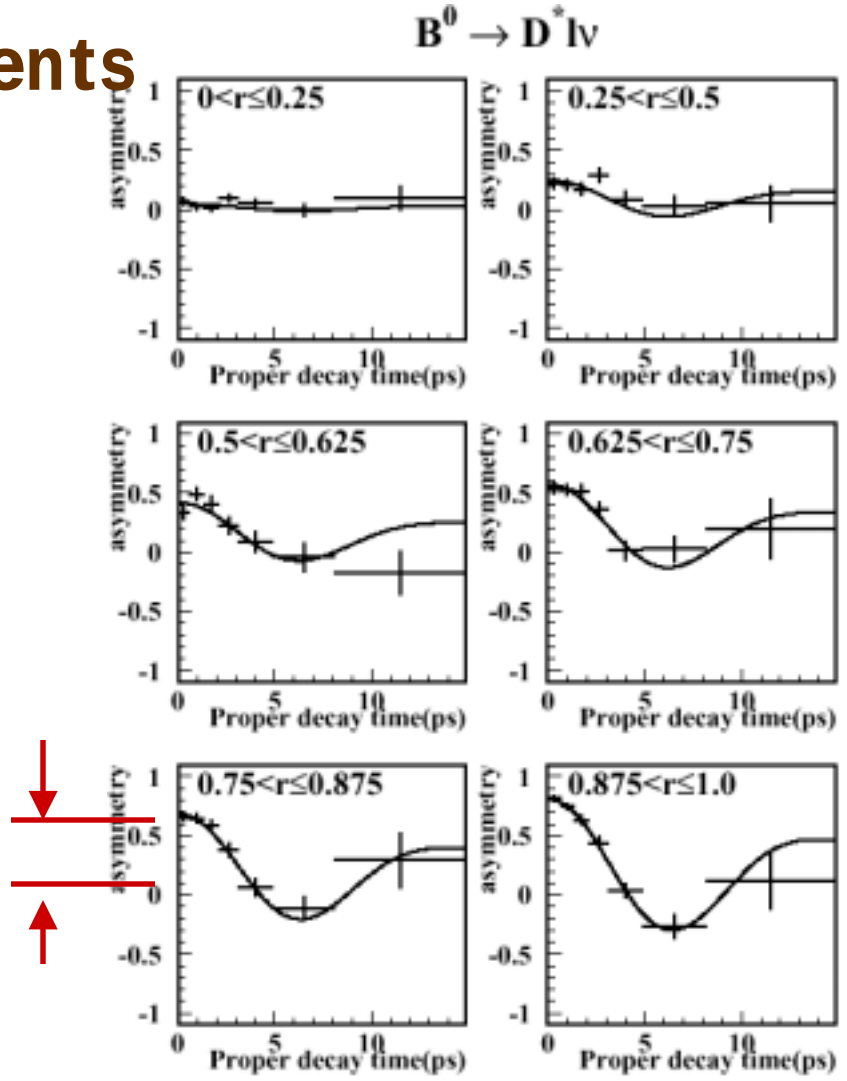
only use r to classify events

-reconstruct a B→D*$l\nu$

-tag the other B

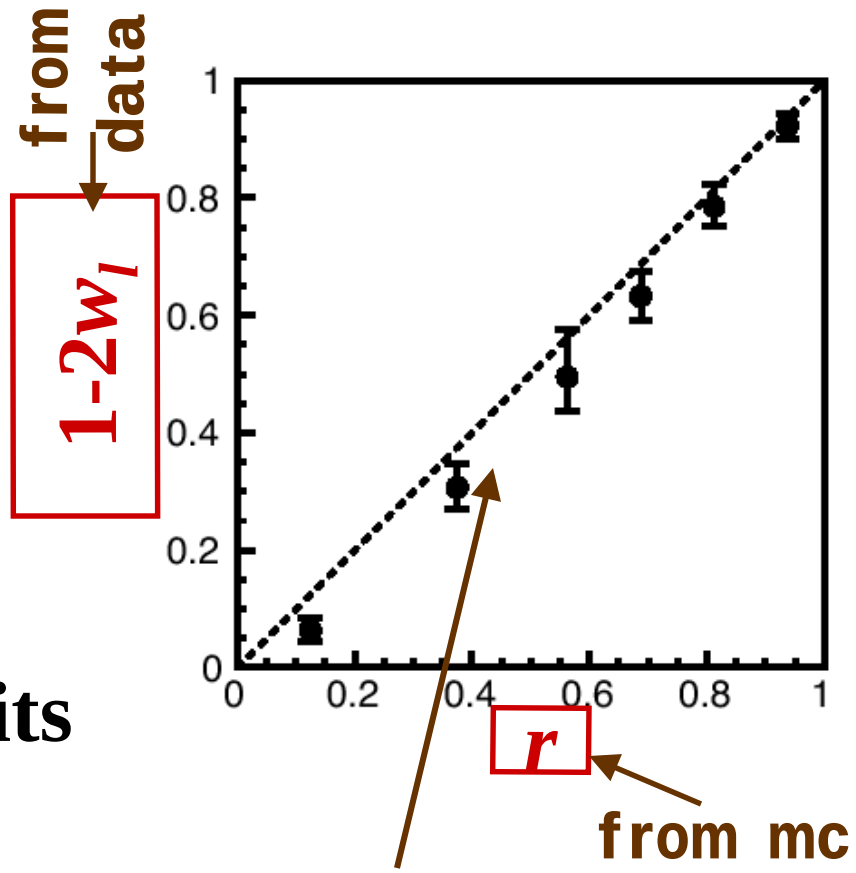
-get w from the B⇔$\overline{\text{B}}$ mixing amplitude:

$(1-2w_l)\cos(\Delta m_d\,\Delta t)$



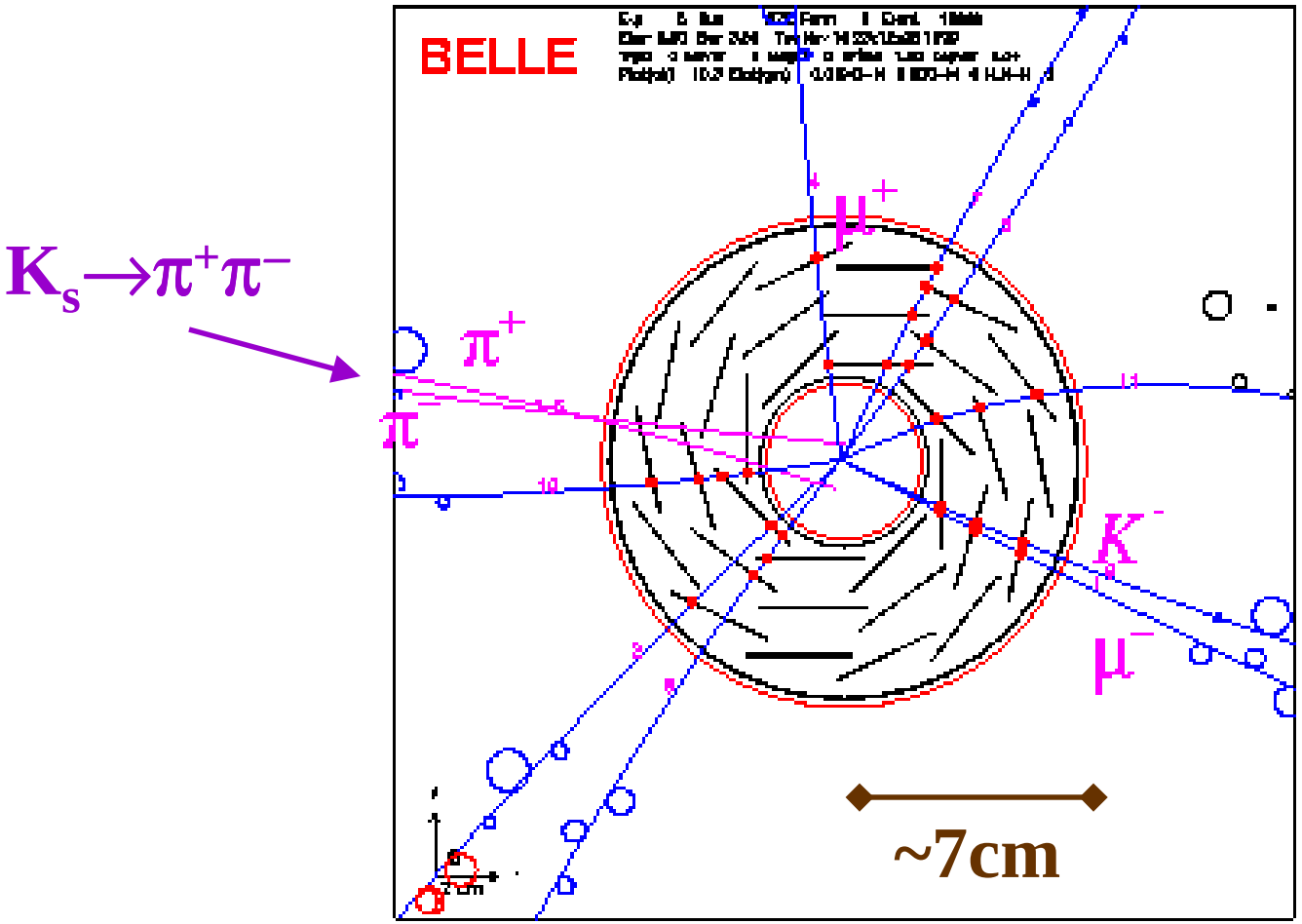
Multi-dimensional Flavor Tagging

- **Uses all events**
  - **Efficiency > 99%**
  - $\varepsilon_{\text{effective}} = 28 \pm 1.4\%$
- **Includes correlations**
- **Use *r* (from mc) to classify**
- **Use *w* (from data) for CP fits**

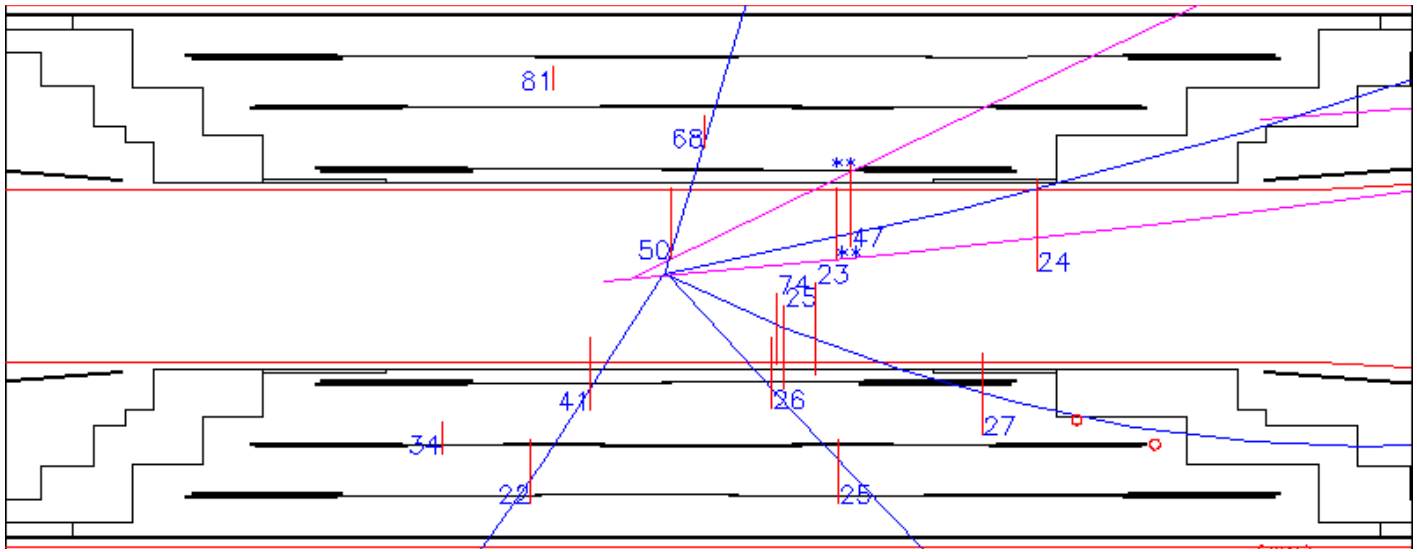


Data & MC track pretty well

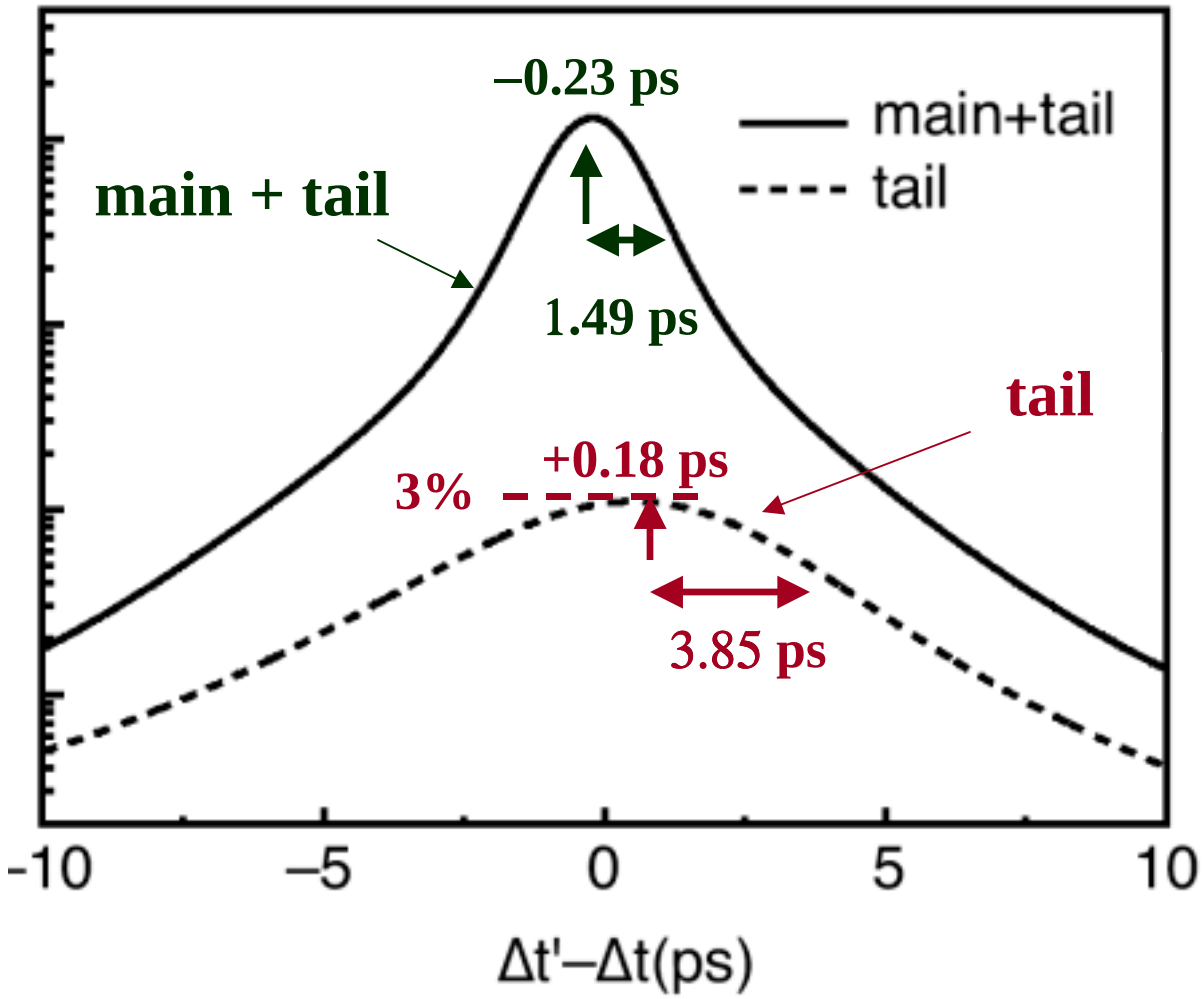
Magnified vertex



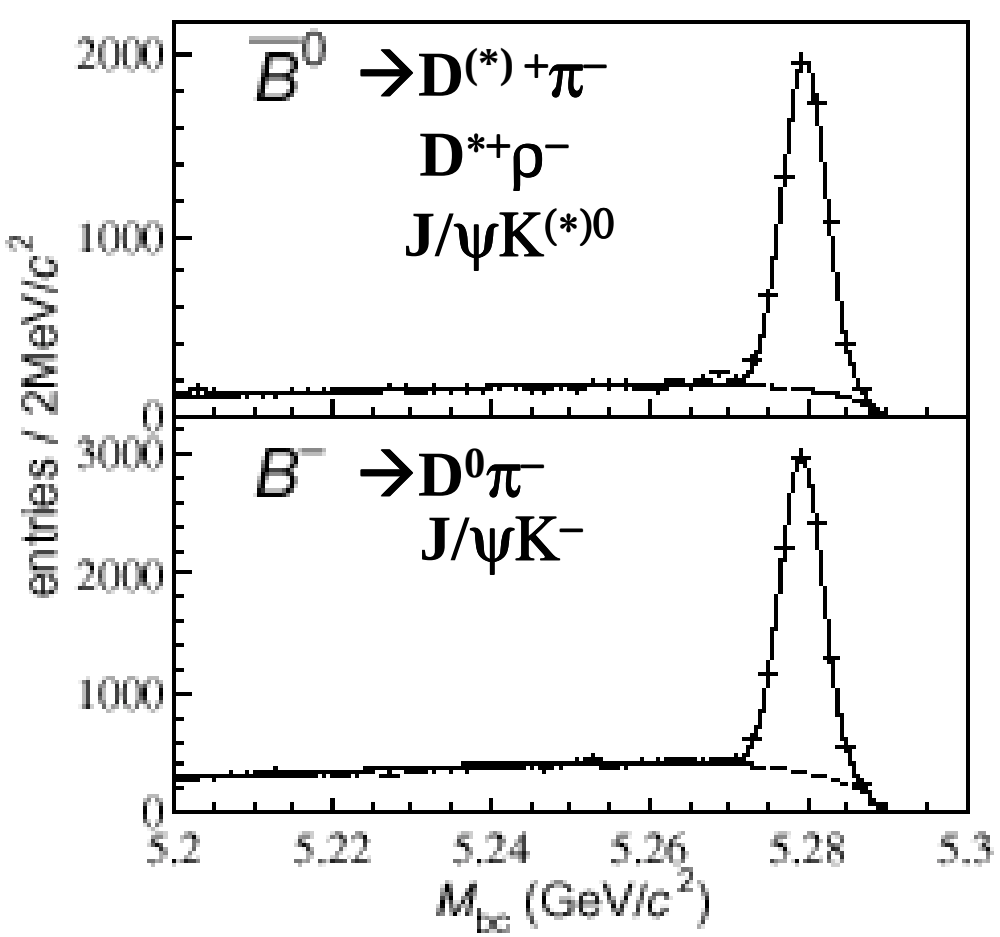
y-z vertices

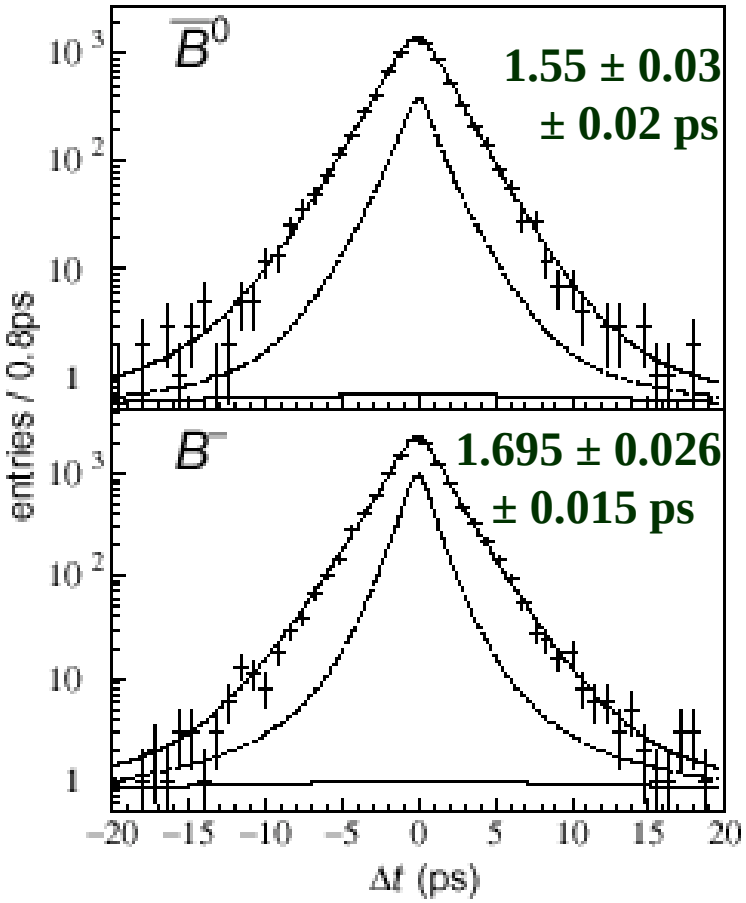


Vertex Resolution Function



verify with B^0 & B^+ lifetimes





$\tau^+/\tau^0 = 1.091 \pm 0.023 \pm 0.014$

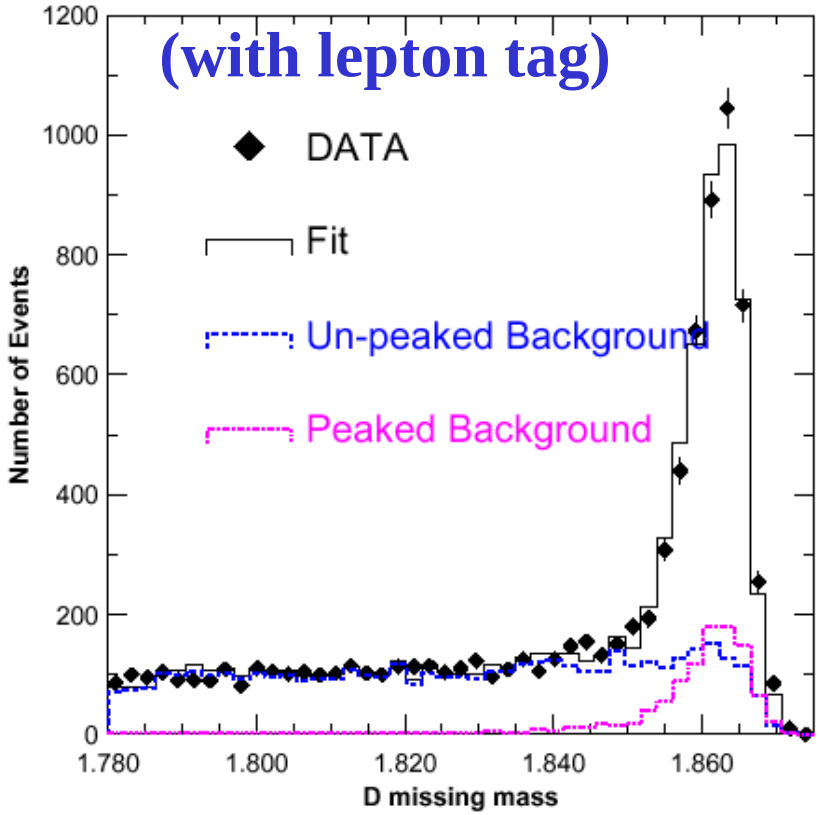
PRL 88, 171801 (2002)

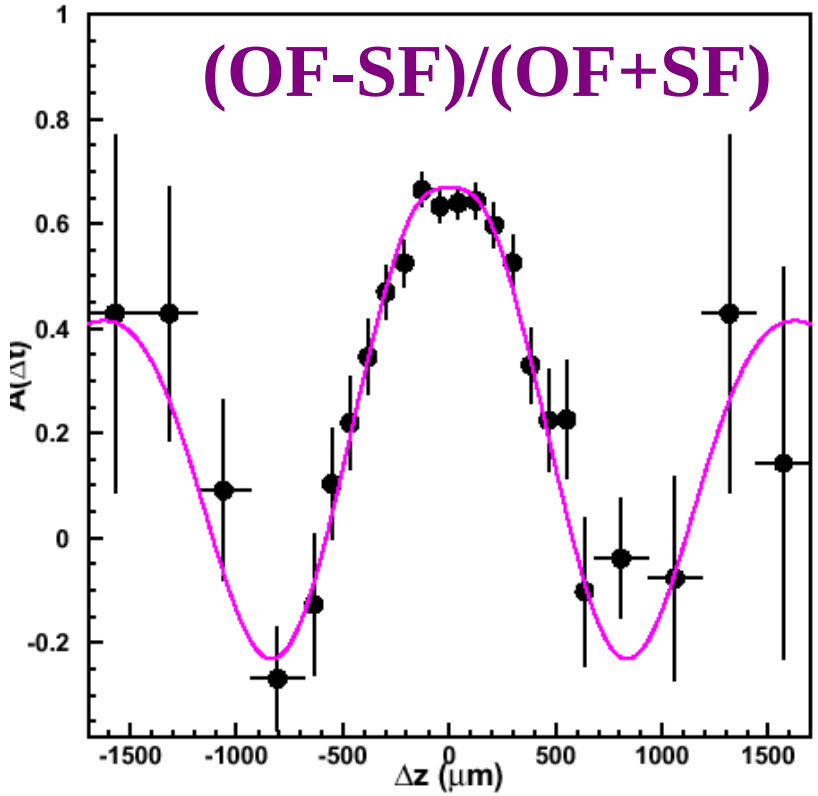
B^0-$\overline{B}^0$ mixing ($B^0 \to D^{*-}\pi^+$, partial)

$D^{*-} \to D^0\pi^-$

only use these

D^0 missing mass





$\Delta m_d = 0.505 \pm 0.017 \pm 0.020\ ps^{-1}$

Event-by-event Likelihood

$$\mathcal{L}_i = \int ((1-f_{bk})\mathcal{P}_{sig} + f_{bk}\mathcal{P}_{bk}) \times \mathcal{R}(\Delta t - \Delta t')\, d\Delta t'$$

background frac

Sidebands & MC

resolution function B-lifetime studies

b-flavor tag

PDG

$$\mathcal{P}_{sig} = \frac{e^{-|\Delta t|/\tau_B}}{2\tau_B}(1 - \xi_f q(1-2w)\sin 2\phi_1 \sin \Delta m \Delta t)$$

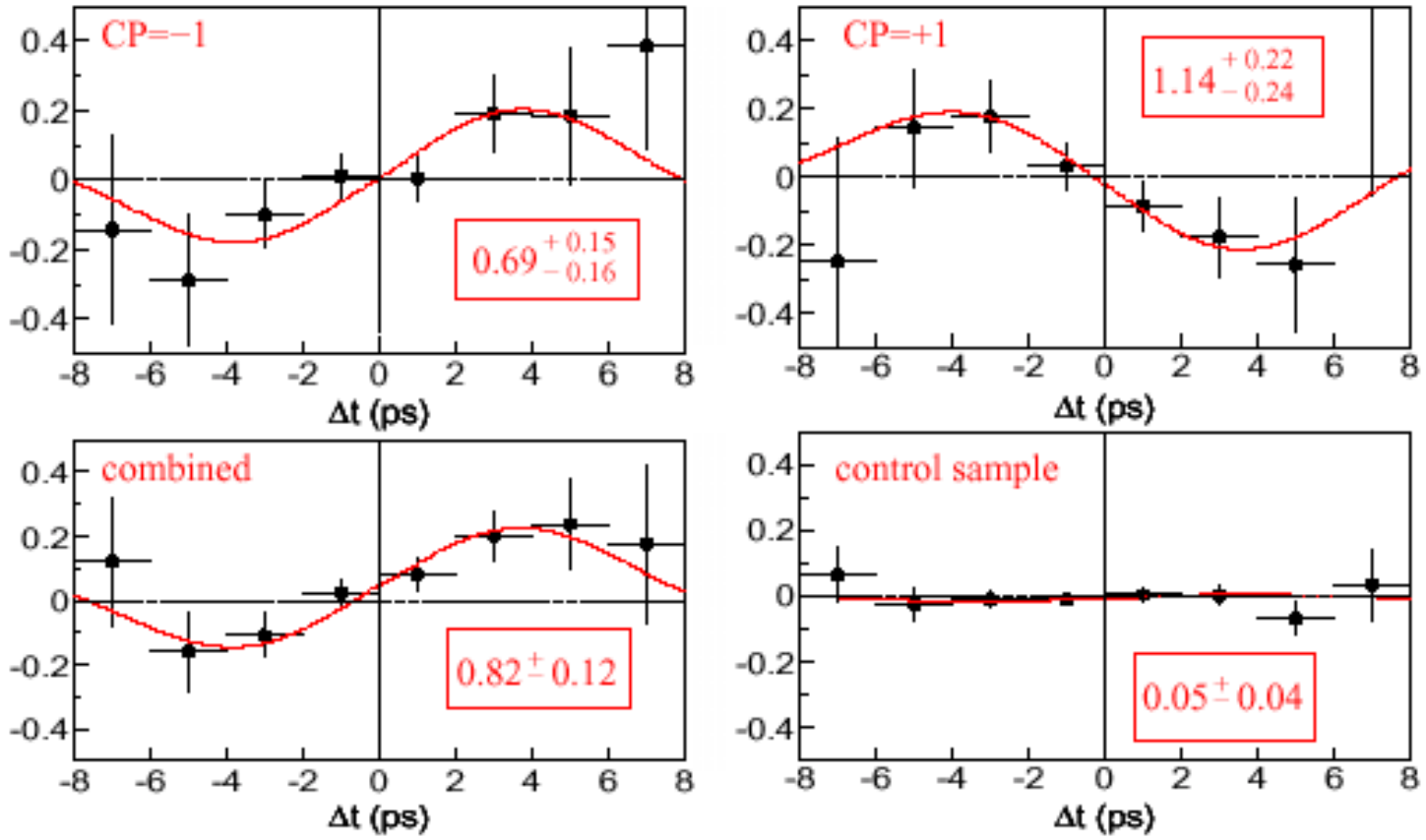
$\xi_f = \pm 1$ *for CP* $= \pm 1$

lone free parameter

wrong-tag frac.

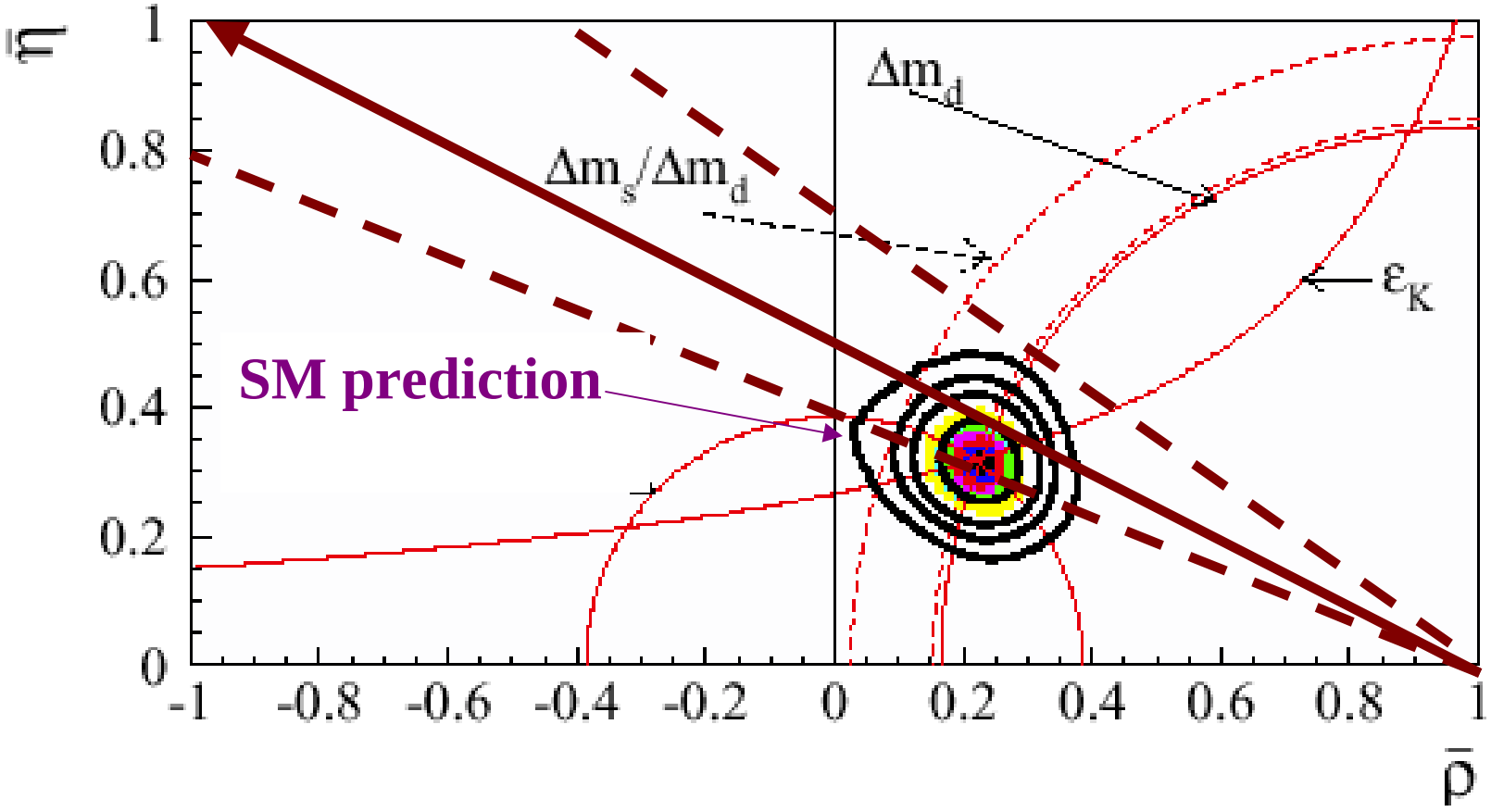
Latest $\sin 2\phi_1$ results (Spr 2002)

"Raw" asymmetries:



$\sin 2\phi_1(\beta) = 0.82 \pm 0.12$ (stat) $\pm$ 0.05 (sys)

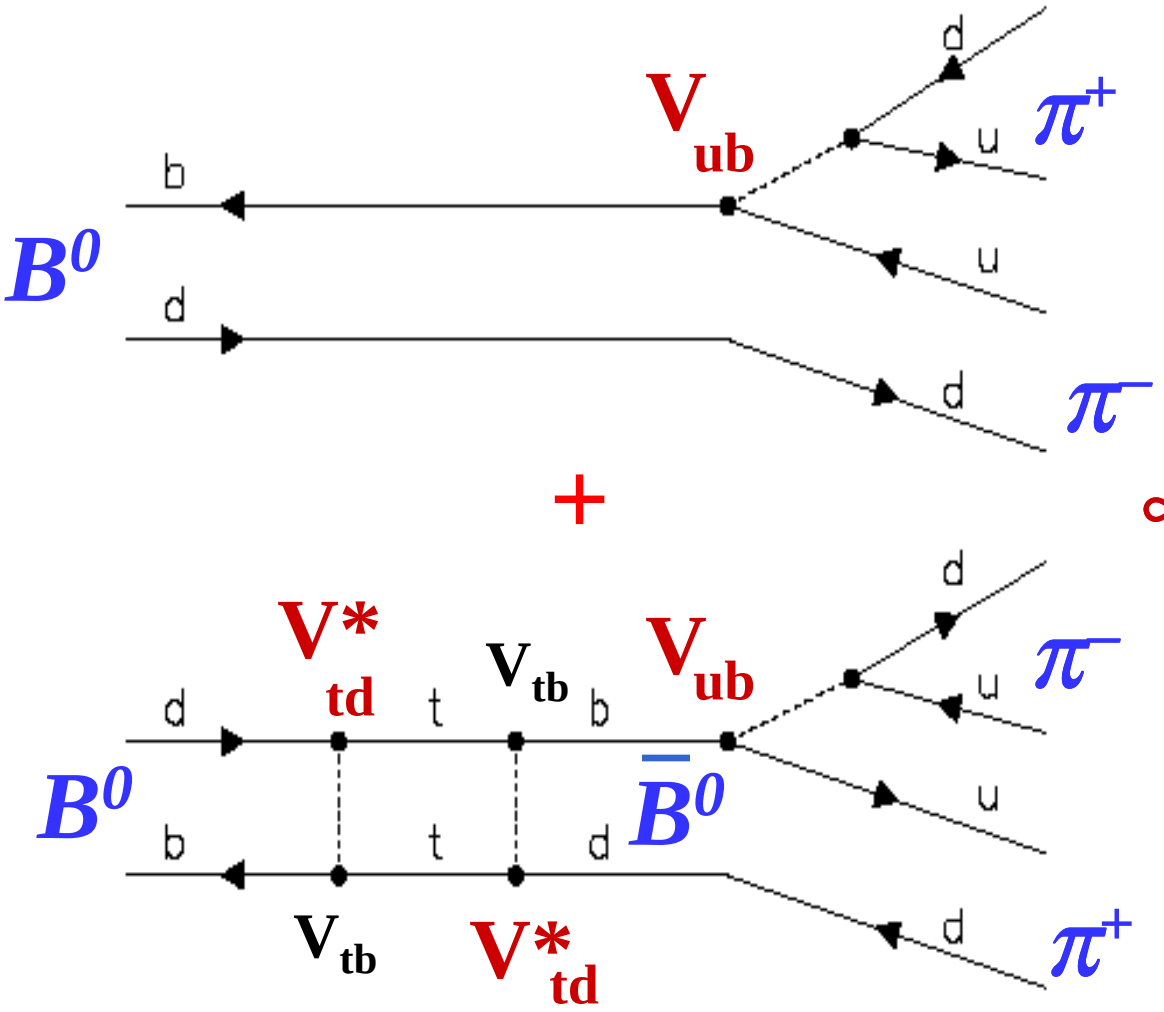
Compare with SM prediction



Conclude: KM model works

$$\phi_2(\alpha)$$

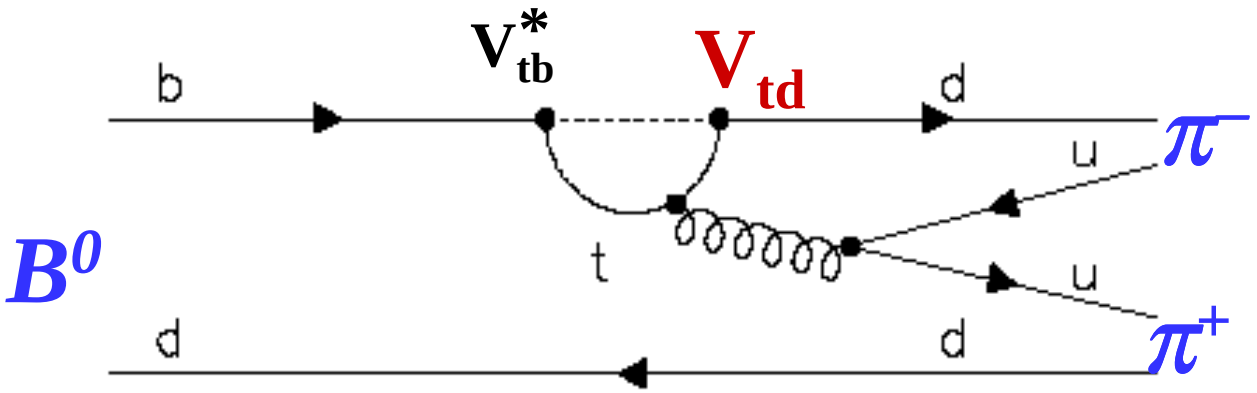
ϕ_2 (α) from $B \to \pi^+\pi^-$



$\propto V^{*2}_{td} V^2_{ub} \propto \sin 2\phi_2$

Must deal with "Penguin Pollution"

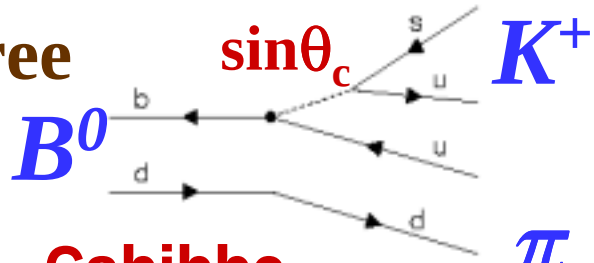
i.e. additional, non-tree amplitudes



Penguins can be ~comparable in strength to b→u transitions

B→Kπ

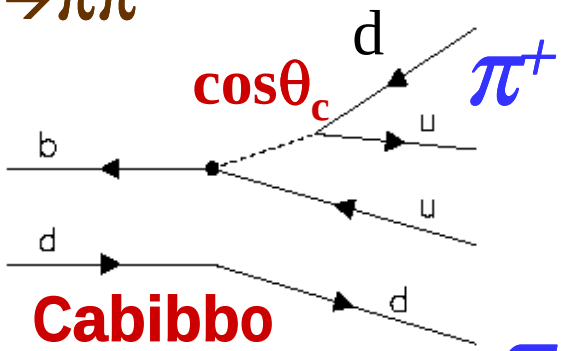
tree



Cabibbo suppressed

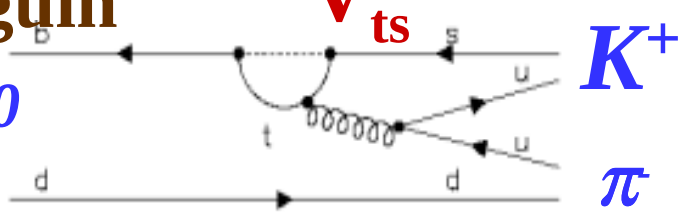
B→ππ

tree



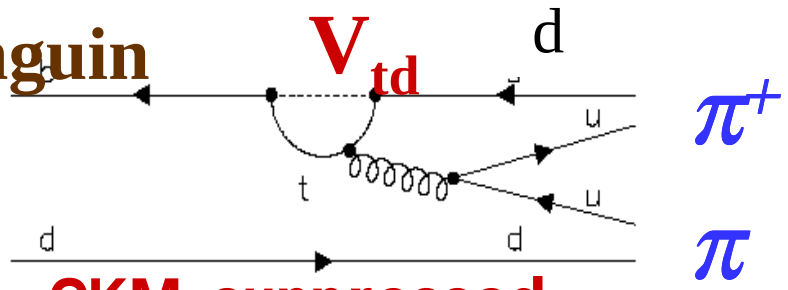
Cabibbo allowed

penguin



CKM enhanced

penguin



CKM suppressed

Γ(Kπ)~3xΓ(ππ)

penguins ~ V_{ub} trees

Δt dependence for $B \to \pi^+\pi^-$

direct CPV

mixing-induced CPV

$$R_q(\Delta t) \propto 1 + q\,(A_{\pi\pi}\cos(\Delta m \Delta t) + S_{\pi\pi}\sin(\Delta m \Delta t))$$

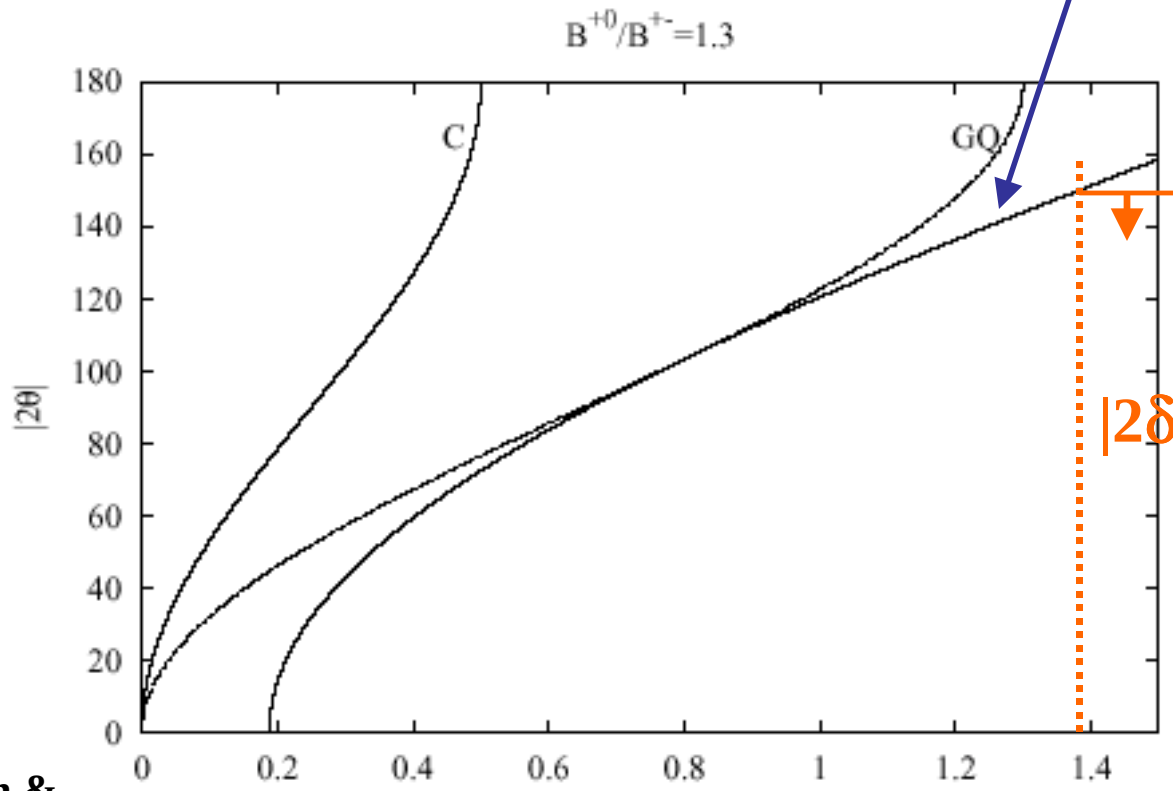
$q = +1 \Rightarrow B^0$ tag

$-1 \Rightarrow \overline{B}^0$ tag

What are SM expectations?

$S_{\pi\pi} = \sin 2\phi_{eff} = \sin 2(\phi_W + \delta)$

penguin pollution phase



|2δ| limits

$|2\delta| < 150^0$

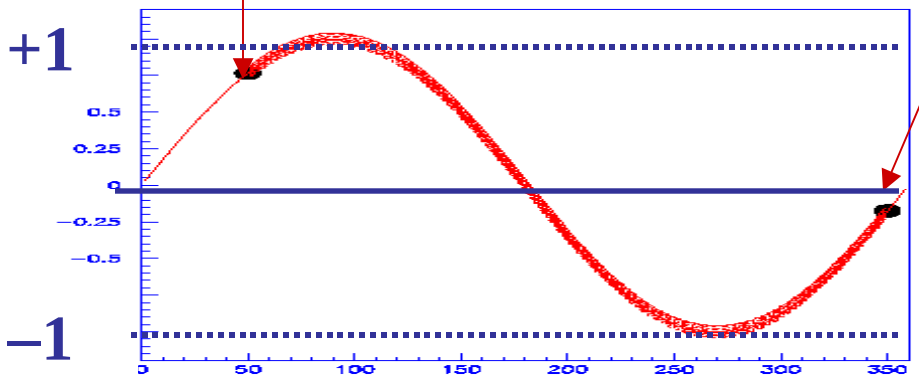
Gronau, London & Sinha[2] (PLB514, 315)

$\Gamma(\pi^0\pi^0)/\Gamma(\pi^+\pi^-)$

ϕ_2 (α) $\approx 100^o$ **(from SLAC's poster)**

SM expectation: $\phi_2 + \delta \approx 100^o \pm 75^o$

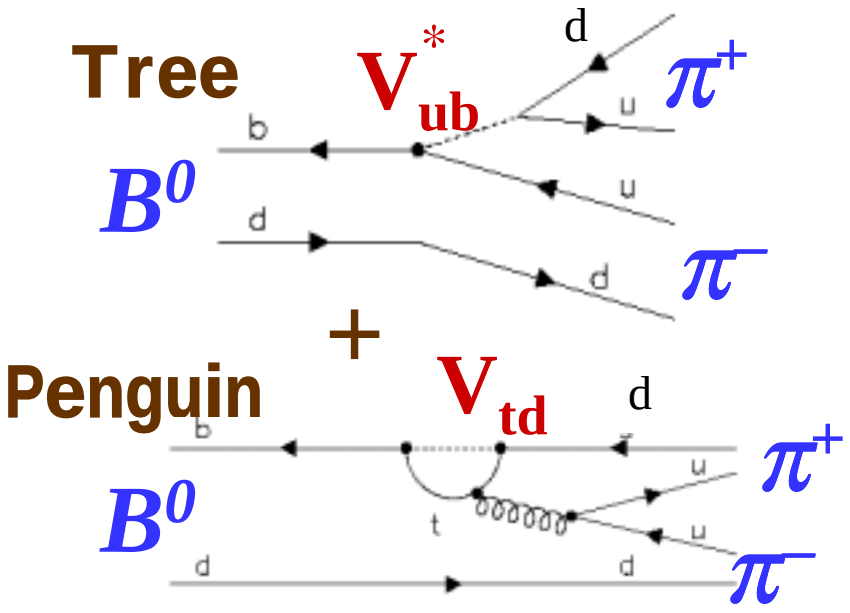
$50^o < 2(\phi_2 + \delta) < 350^o$



$\therefore -1.0 \leq \sin 2(\phi_W + \delta) \leq +1.0$

Expectations for direct CPV

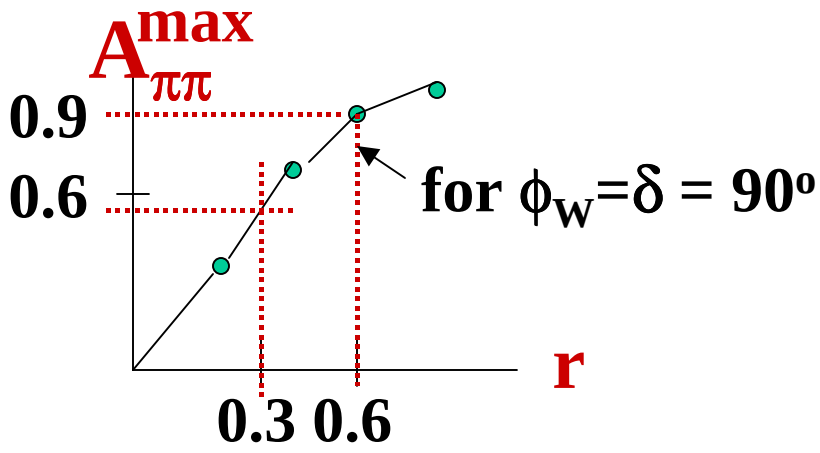
tree-penguin interference



$$A_{\pi\pi} = \frac{\bar{B}\to\pi^+\pi^- - B\to\pi^+\pi^-}{\bar{B}\to\pi^+\pi^- + B\to\pi^+\pi^-}$$

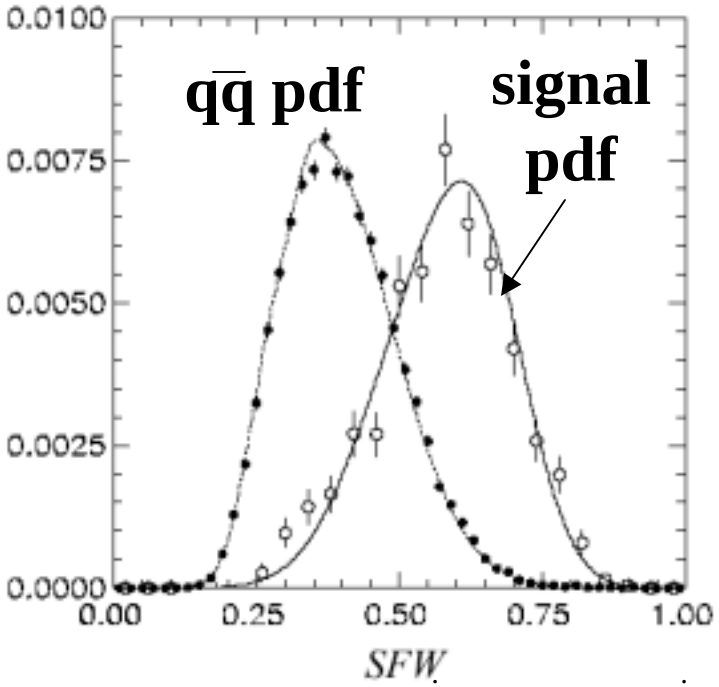
$$= \frac{2r\sin\phi_W\sin\delta}{1+r^2+2r\cos\phi_W\cos\delta}$$

ϕ_W = weak phase
δ = strong phase
r = |penguin/tree|



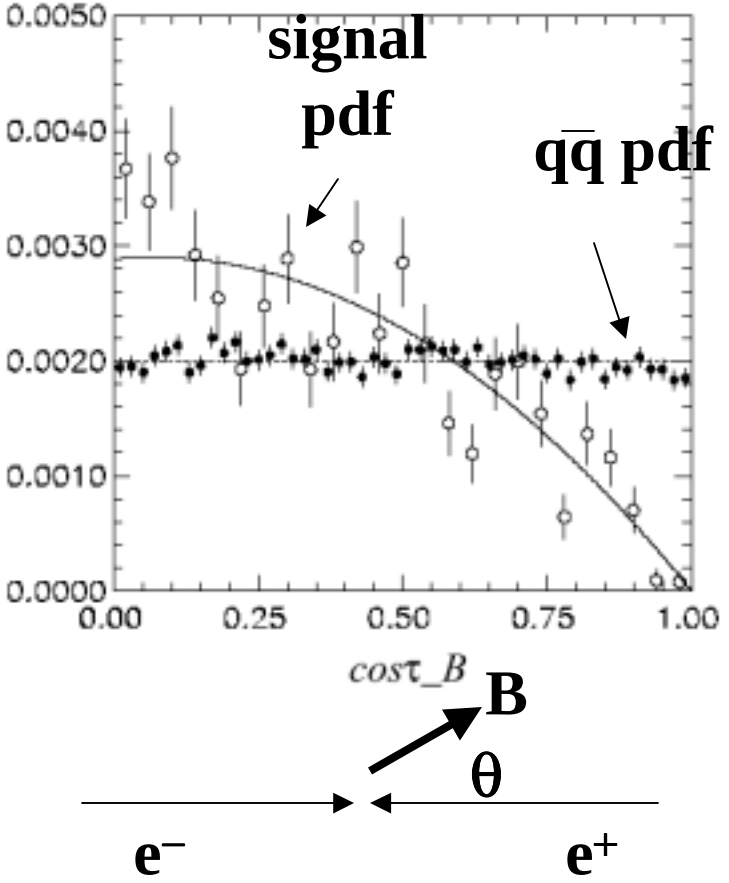
continuum bkgd suppression:

Event-shape variable



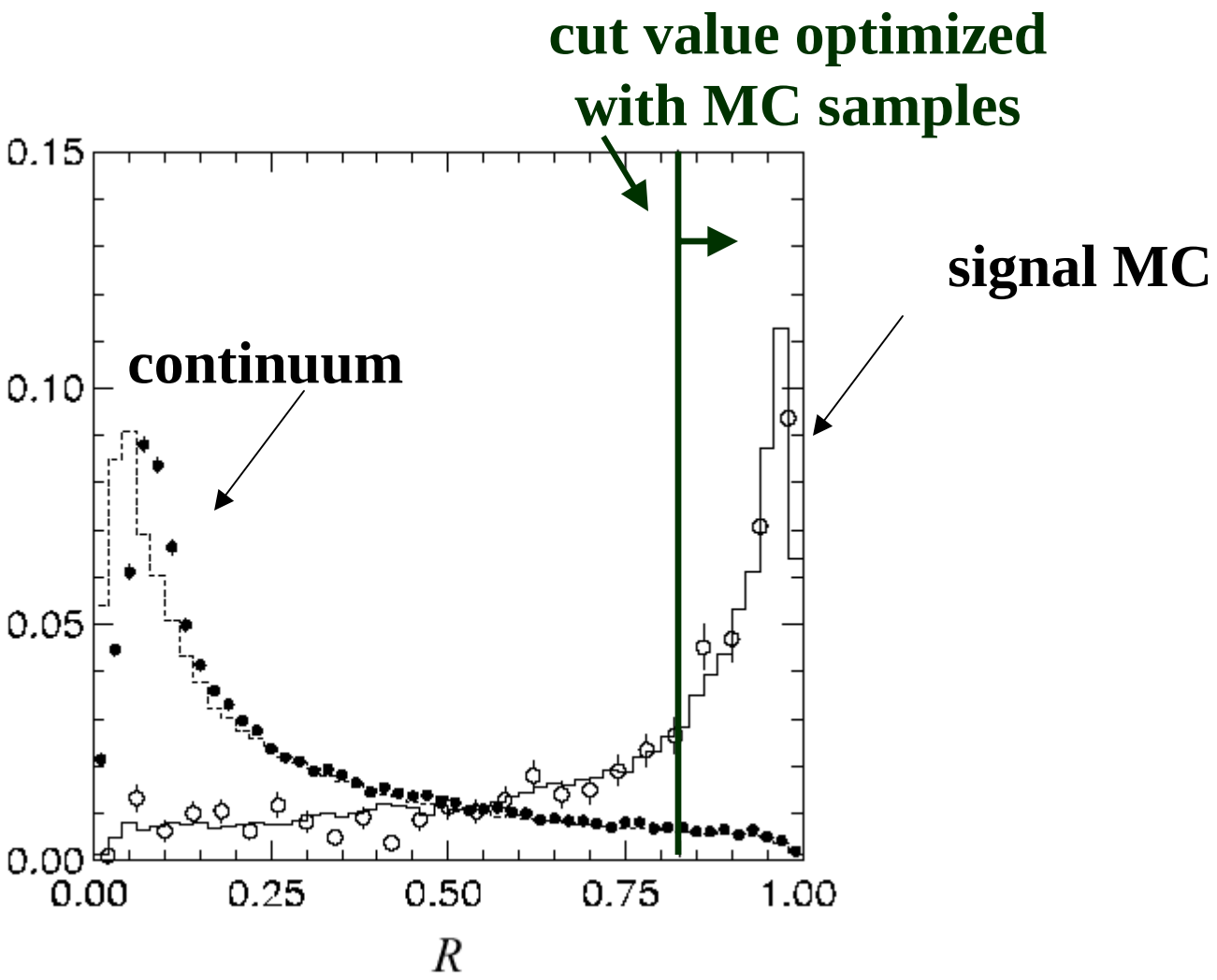
$$SFW = \sum_{2,4} \alpha_i \frac{h^i_{os}}{h^0_{os}} + \sum_{1-4} \beta_i \frac{h^i_{oo}}{h^0_{oo}}$$

B-candidate production angle

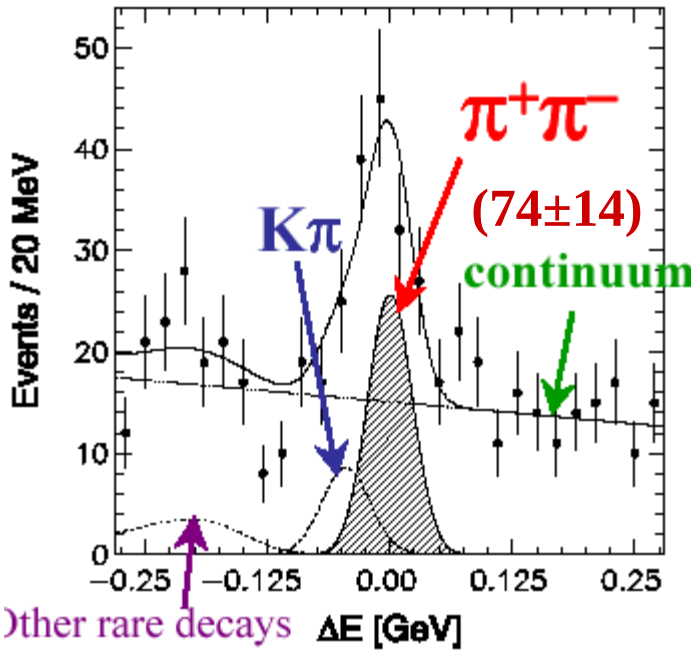


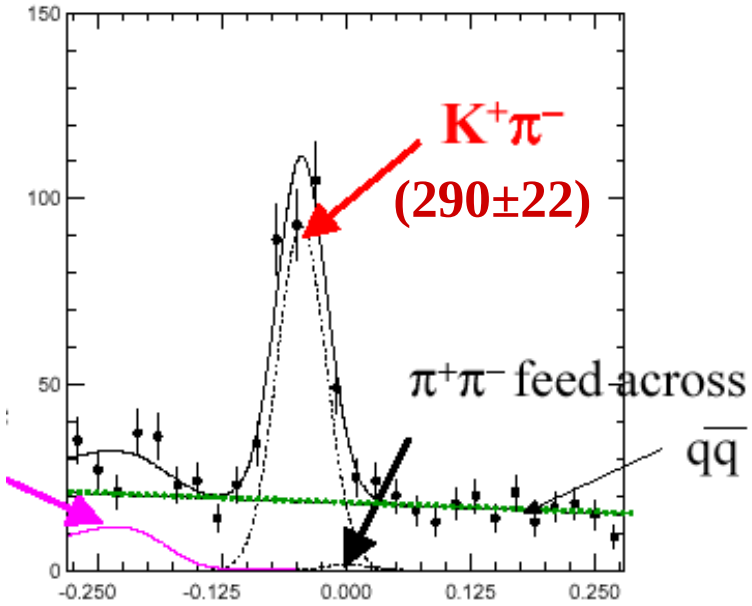
Combine into Likelihood ratios

$$\frac{L_{sig}}{L_{sig} + L_{q\bar{q}}}$$



ΔE for $B \to \pi^+\pi^-/K^+\pi^-$



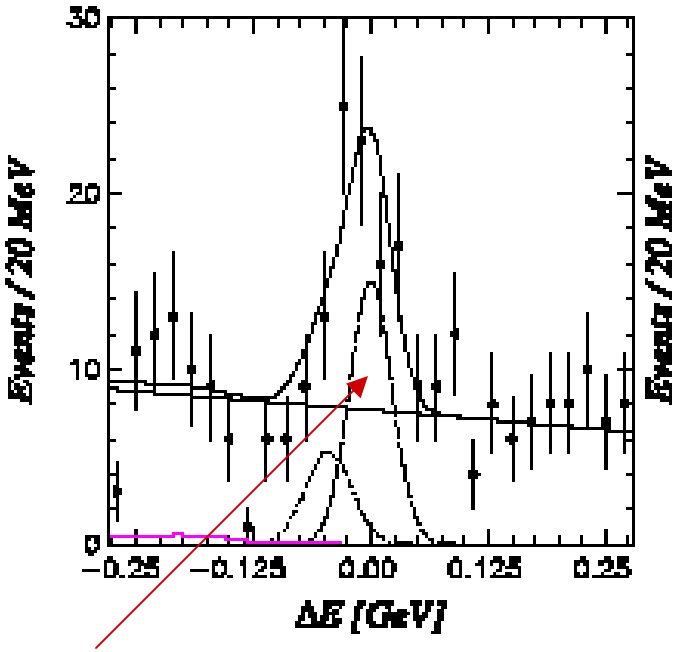


Kπ: 28±13

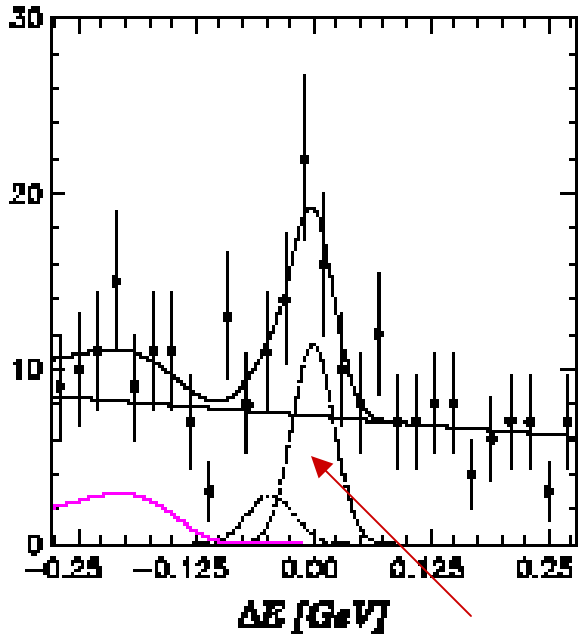
qq: 99± 7

B^0– and $\overline{B}^0$–tagged $\pi^+\pi^-$ yields

B^0 tags



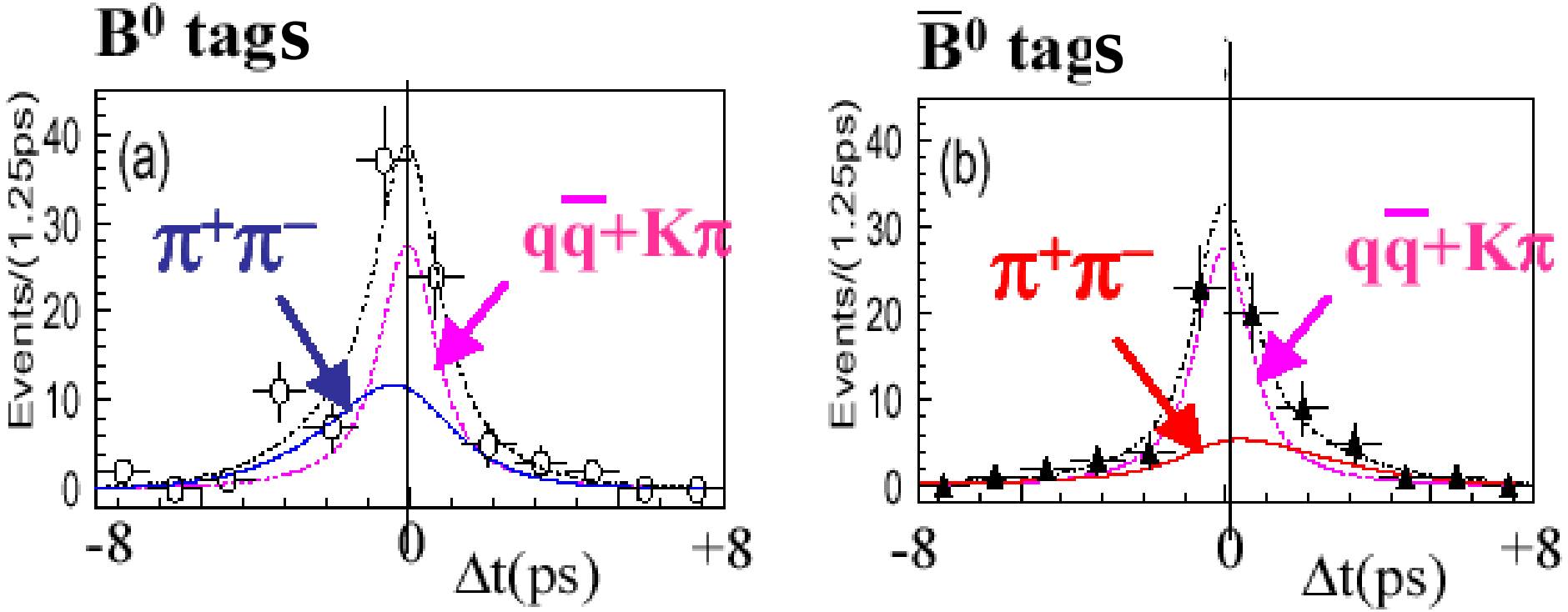
$\overline{B}^0$ tags



$N_{\pi\pi} = 44.5 \pm 9.8$

$\overline{N}_{\pi\pi} = 28.8 \pm 8.5$

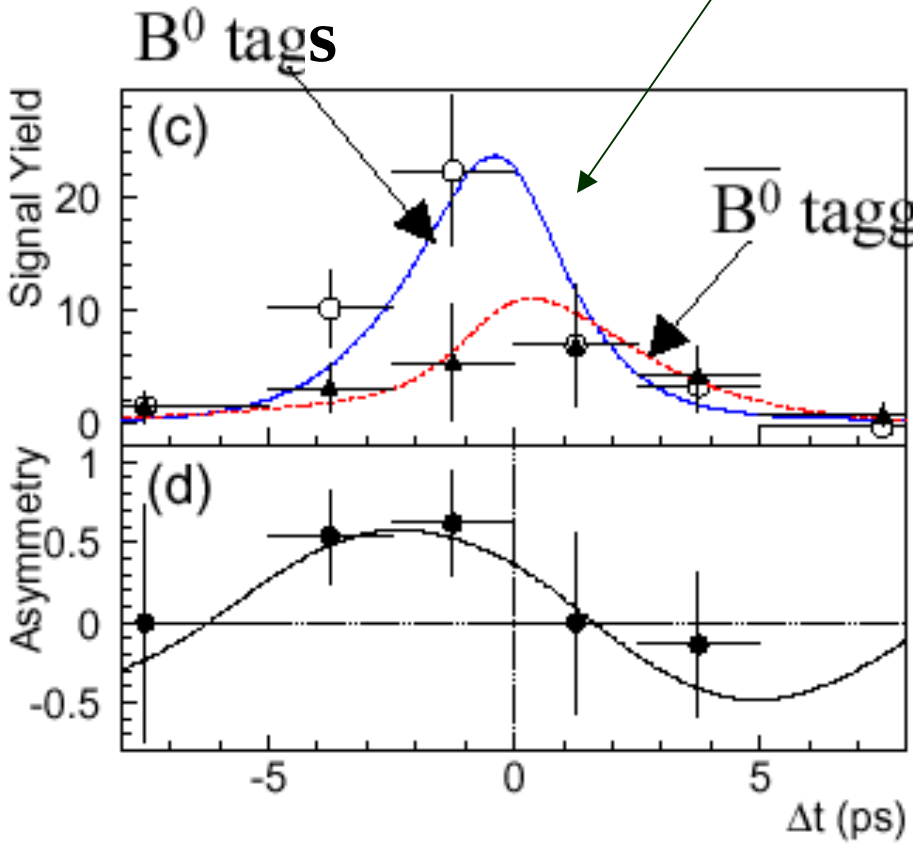
“raw” asymmetries for $\pi^+\pi^-$



- more B^0 tags than $\bar{B}^0$ tags
- more B^0 tags with $\Delta t<0$ than $\Delta t>0$

Fit for ($A_{\pi\pi}$, $S_{\pi\pi}$)

(qq and Kπ subtracted)



hep-ex/0204002 →PRL

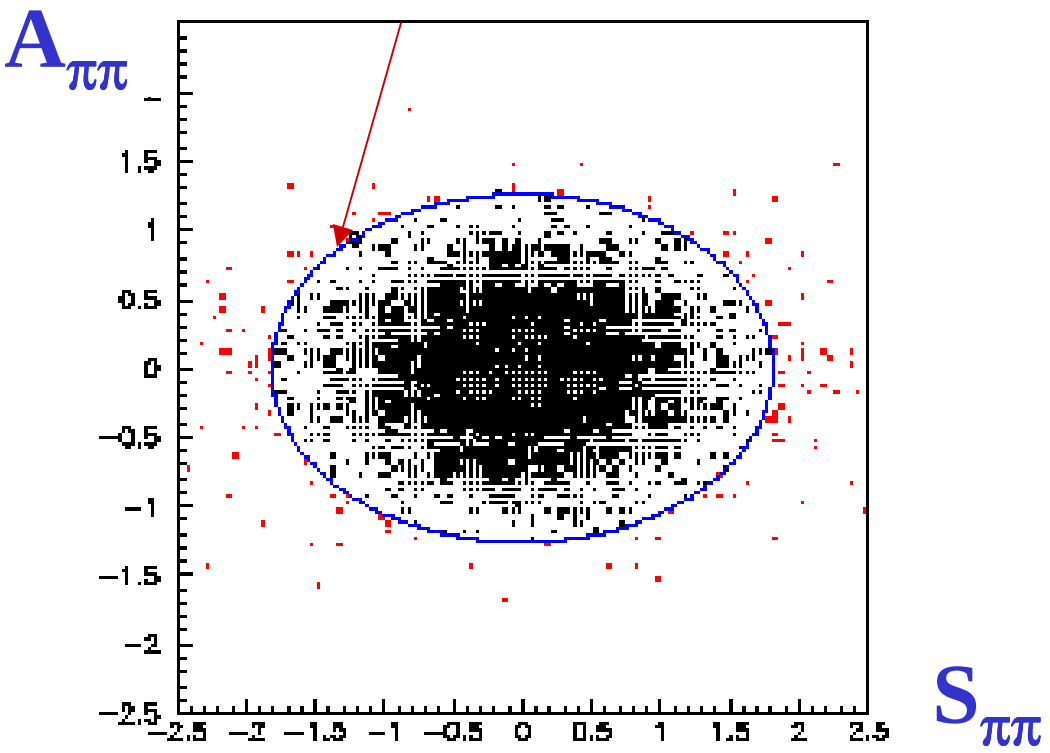
$$A_{\pi\pi} = +0.94\,^{+0.25}_{-0.31} \pm 0.09$$

$$S_{\pi\pi} = -1.21\,^{+0.38\ +0.16}_{-0.27\ -0.13}$$

~3σ from (0,0) !!!

Significance?

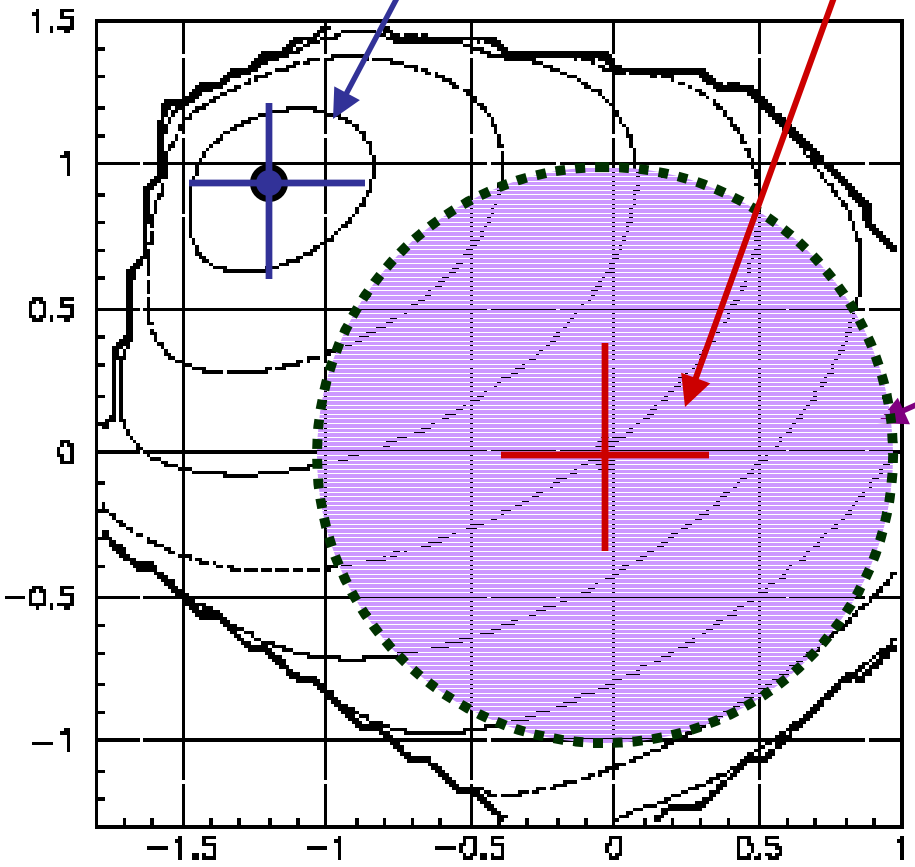
$(A_{\pi\pi}, S_{\pi\pi}) = (0.94, -1.21)$



1.6% of the events generated with $(A_{\pi\pi}, S_{\pi\pi}) = (0,0)$ are outside the ellipse

Compare: Belle & BaBar

(hep-ex/0203007)



$A_{\pi\pi}$

physical region

$S_{\pi\pi}$

- **Belle's ($A_{\pi\pi}$,$S_{\pi\pi}$) is ~1.2σ from the $A^2_{\pi\pi} + S^2_{\pi\pi} = 1$ boundary**
- **Belle & BaBar disagree by >2σ**
- **Belle's $S_{\pi\pi}$ errors are < BaBar's**

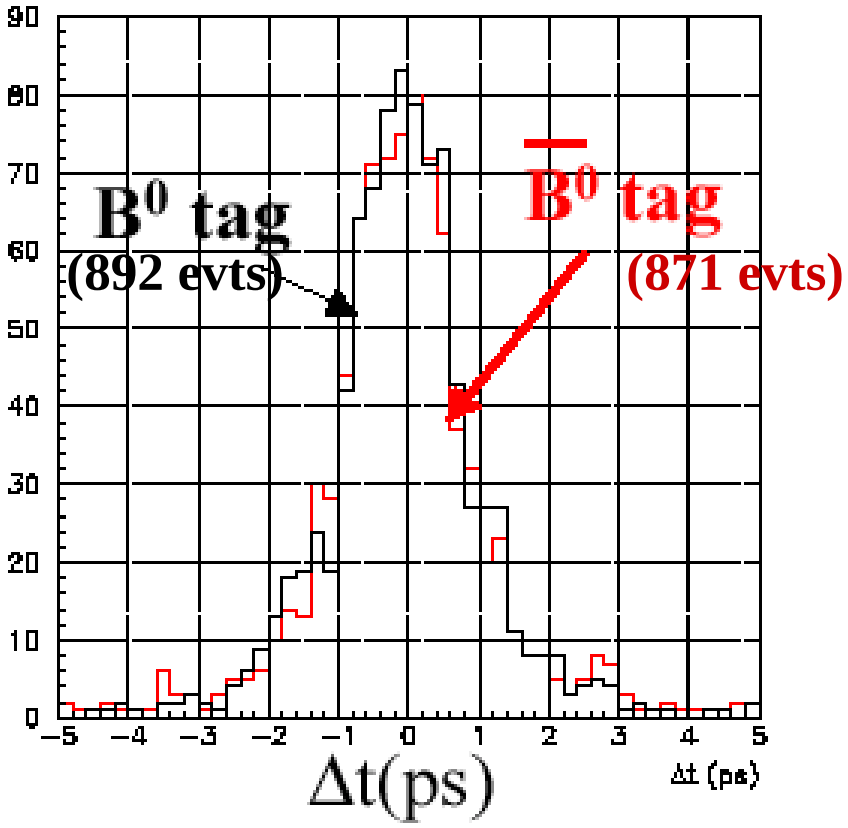
What (if anything) can be wrong?

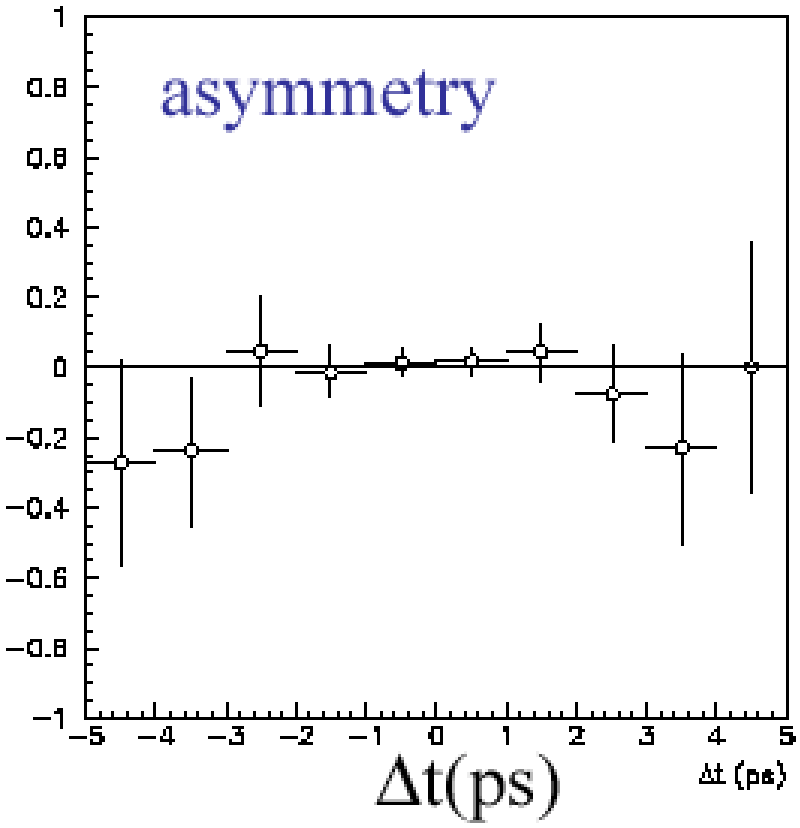
(The component parts of the analysis are the same as those used to measure $\sin 2\phi_1$, τ_B, Δm_d, $B \to h^+h^-$, etc, all in *reasonable* agreement with BaBar & PDG averages.)

Possibilities

- **are the backgrounds asymmetric?**
  - **check with $K\pi$ and qq-sideband samples**
  - **check with high statistics $B^- \to D^{(*)}\pi^-$, $D^*\rho^-$ samples**
- **is vertexing wrong for $B \to h^+h^-$ decays?**
  - **measure τ_B & Δm_d for $B \to \pi^+\pi^-$ & $K^+\pi^-$ decays**
- **flavor tagging different than $J/\psi K$?**
  - **MC studies of effects of continuum suppression cuts**
- **do the likelihood values & errors make sense?**
  - **do toy MC experiments**
- **…?**
- **statistical fluctuations?**

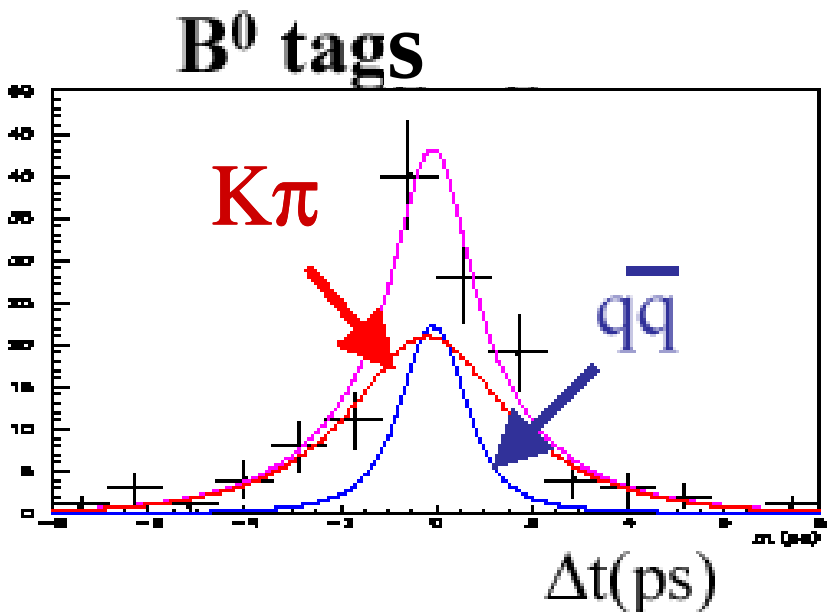
apply fit to ($q\bar{q}$) sideband data

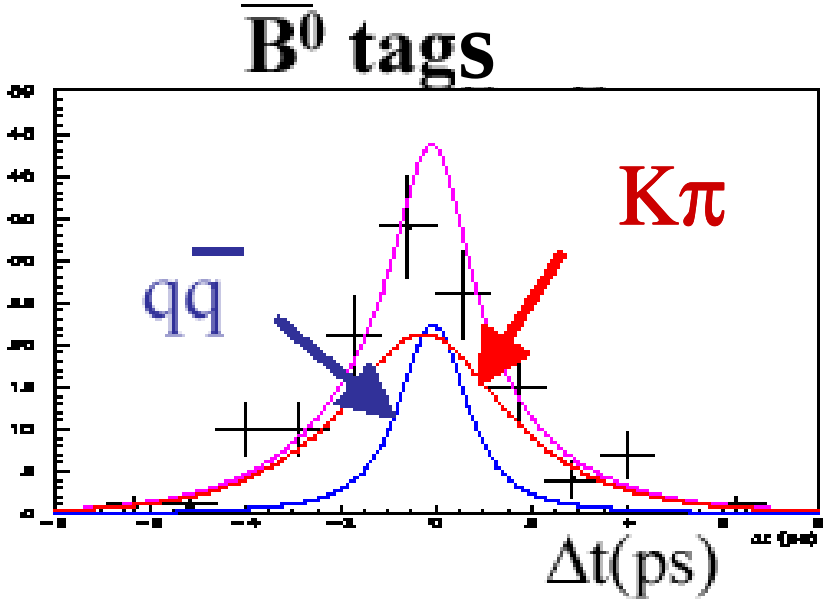




no asymmetry

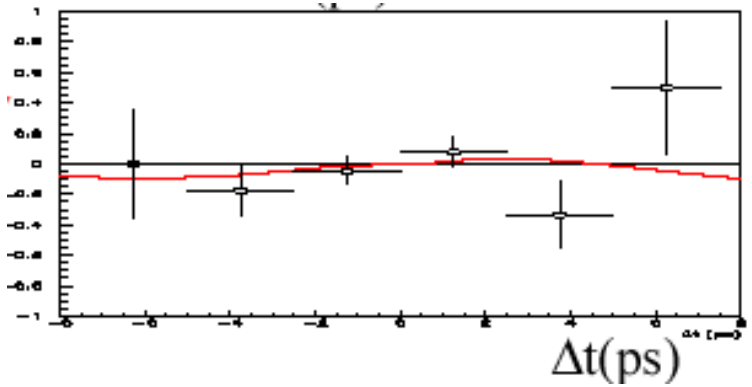
fit to the ~300 event Kπ sample





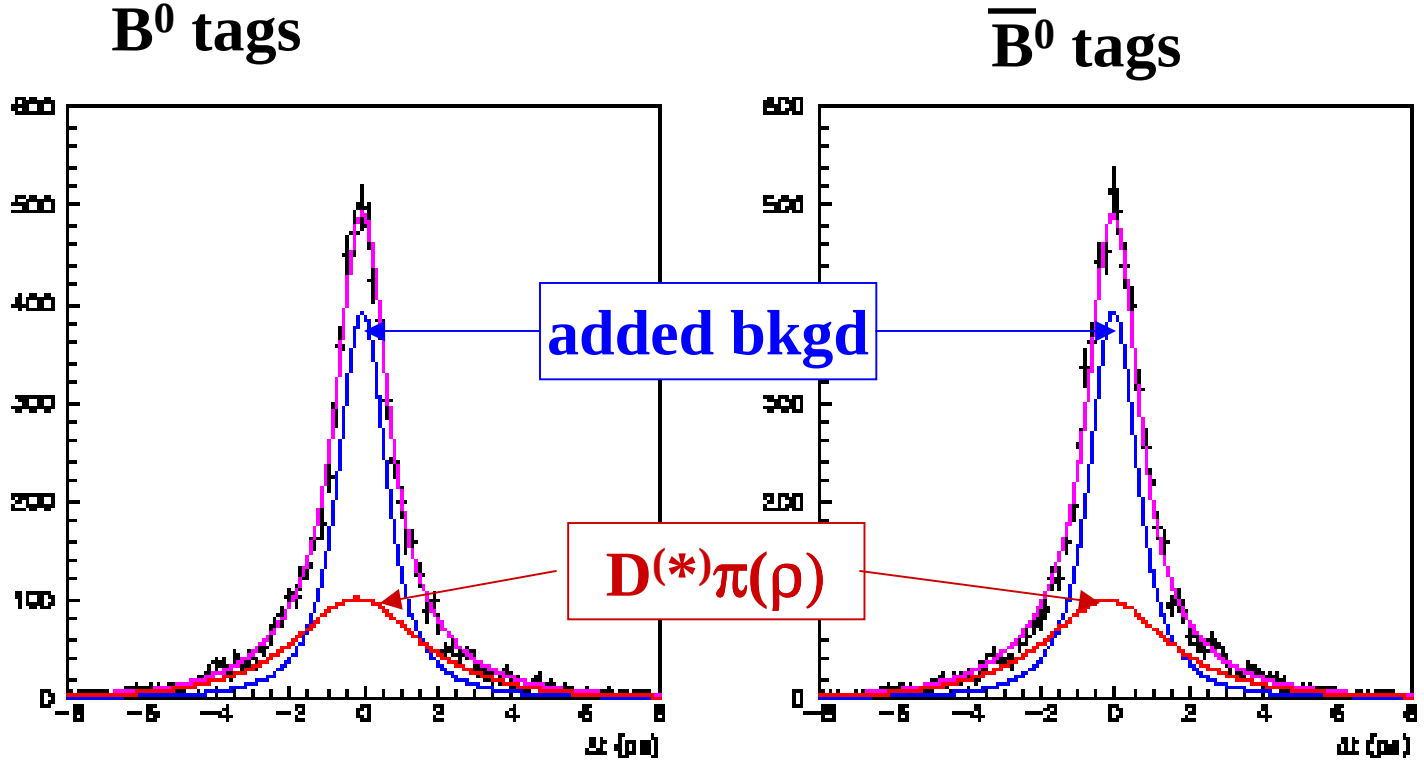
$A_{K\pi}$= +0.07 ±0.17

$S_{K\pi}$= 0.15 ±0.25



no asymmetry

Bkgnd “enriched” $D^{(*)}\pi(\rho)$ sample



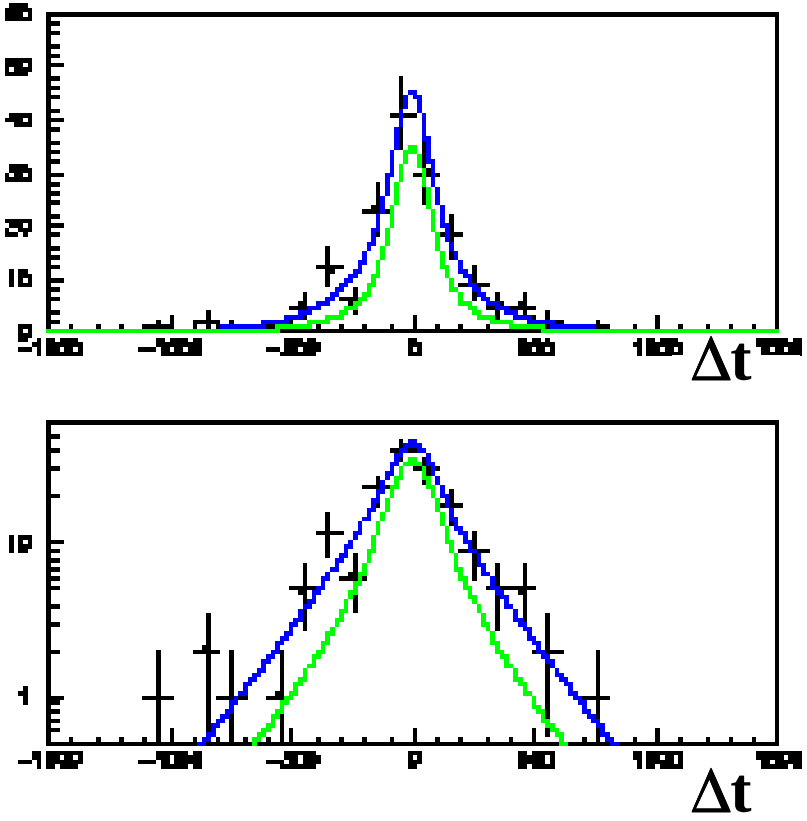
“$A_{\pi\pi}$”= +0.03 ±0.04

“$S_{\pi\pi}$”= 0.08 ±0.06

no asymmetry

Measure τ_B for B→ $\pi^+\pi^-$ and $K^+\pi^-$

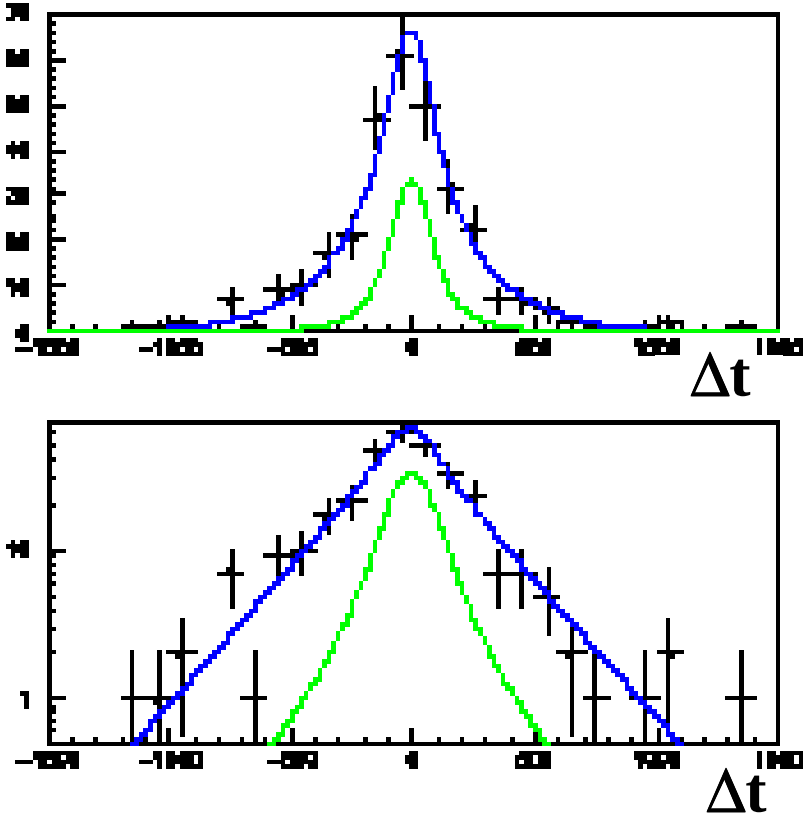
$\pi^+\pi^-$



τ_B=1.49±0.21 ps

additional evidence that the qq background is understood

$K^+\pi^-$



τ_B=1.73±0.15 ps

(Δm_d=0.57±0.08 ps^{-1})

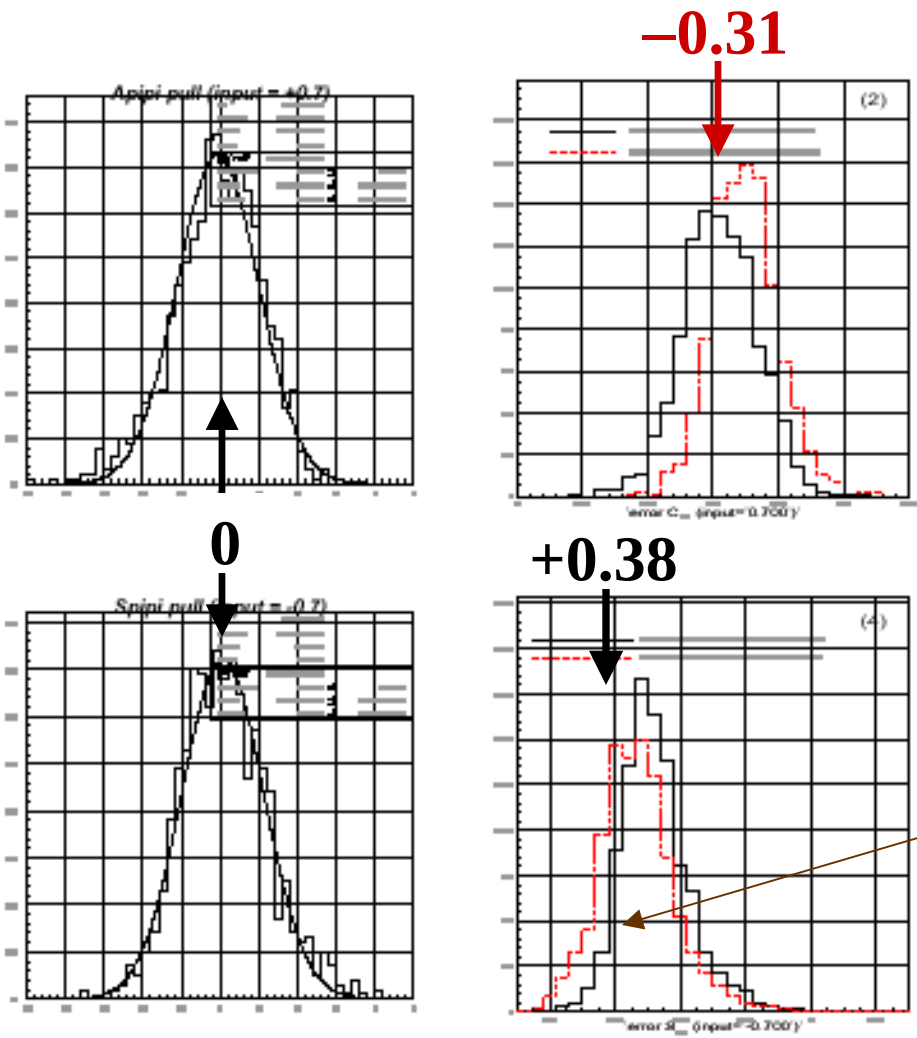
(PDG: τ_B=1.55±0.03 ps)

Pulls & errors

toy MC results with input $(A_{\pi\pi},S_{\pi\pi})=(0.7,-0.7)$

$A_{\pi\pi}$

$S_{\pi\pi}$



5.4% of the toy MC expts have smaller +errors

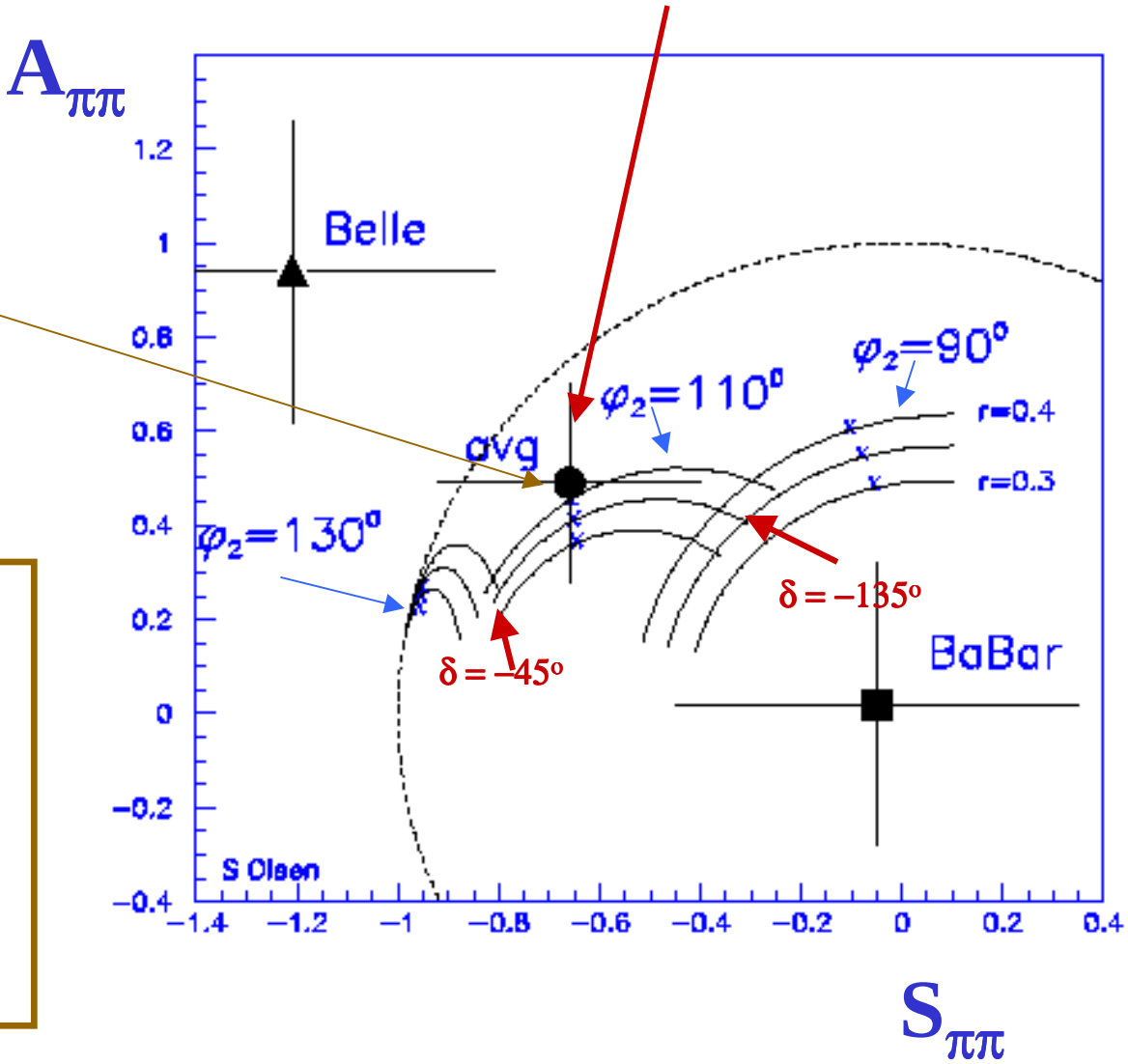
Possibilities revisited

- **are the backgrounds asymmetric?**
  - **$K\pi$, qq-sideband & $D\pi/\rho$ samples have null asymmetries**
- **is vertexing wrong for $B \rightarrow h^+h^-$ decays?**
  - **lifetimes for $B \rightarrow \pi^+\pi^-$ & $K^+\pi^-$ samples are OK**
- **flavor tagging different than $J/\psi K$?**
  - **differences are in the noise**
- **do the likelihood values & errors make sense?**
  - **$S_{\pi\pi}$ errors are small but allowable**
- **statistical fluctuations?** ← **most likely**

(↑for Belle & ↓for BaBar?)

Belle/BaBar avg: $(A_{\pi\pi}, S_{\pi\pi}) = (0.49 \pm 0.21, -0.66 \pm 0.26)$

- $r \approx 0.4$
- $\phi_2 \approx 110^o$
- $\delta \approx -90^o$

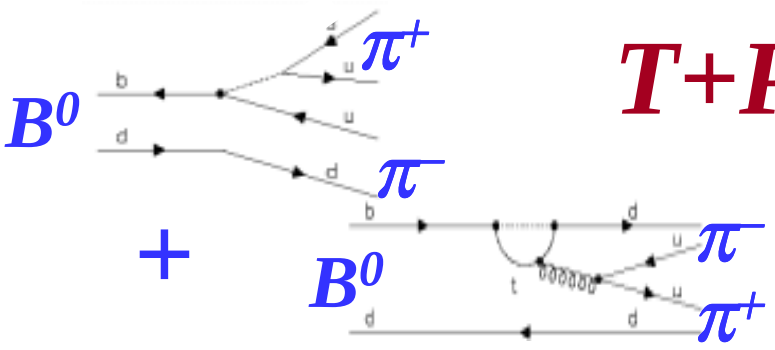


Comment:

for $\delta \approx -45^o \sim -135^o$, ϕ_2 is fairly unambiguous

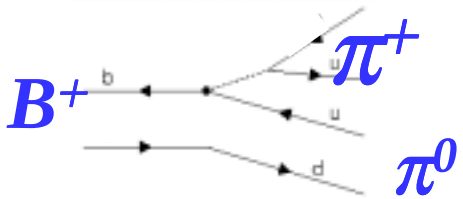
Gronau & Rosner
hep-ph/0202170

sort out with $B \rightarrow \pi\pi$



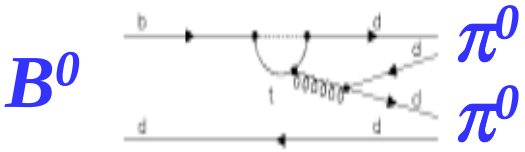
$T+P$

Br:=5.1 ± 1.0 x 10^{-6}



$(T+c)/\sqrt{2}$

Br:=7.0 ± 2.0 x 10^{-6}



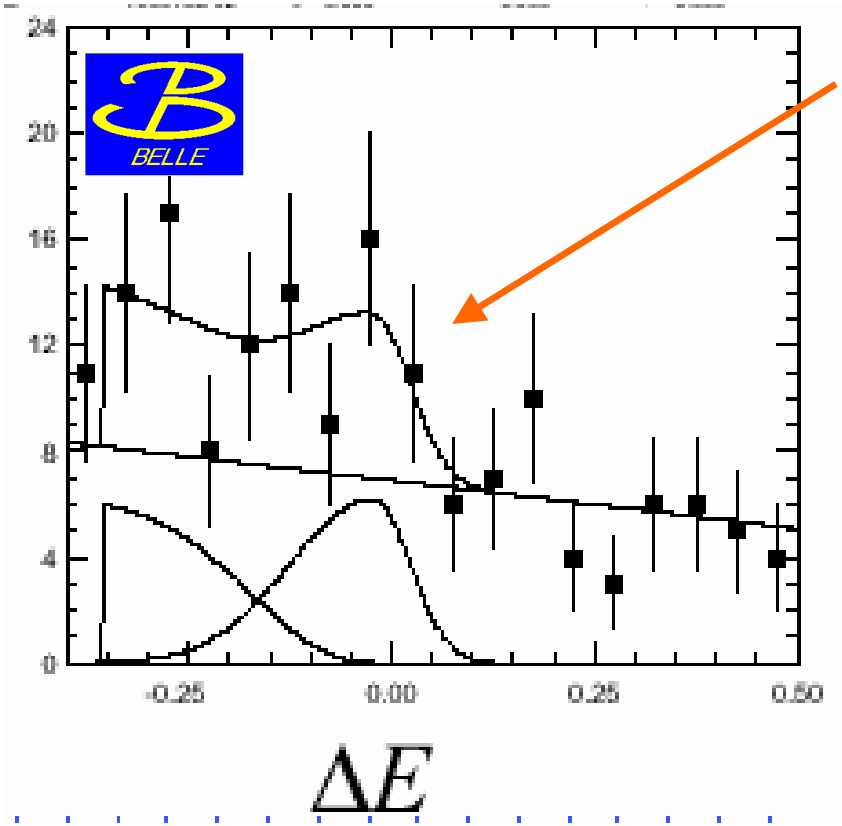
$(c-P)/\sqrt{2}$

Br: <5.6 x 10^{-6}
90%CL

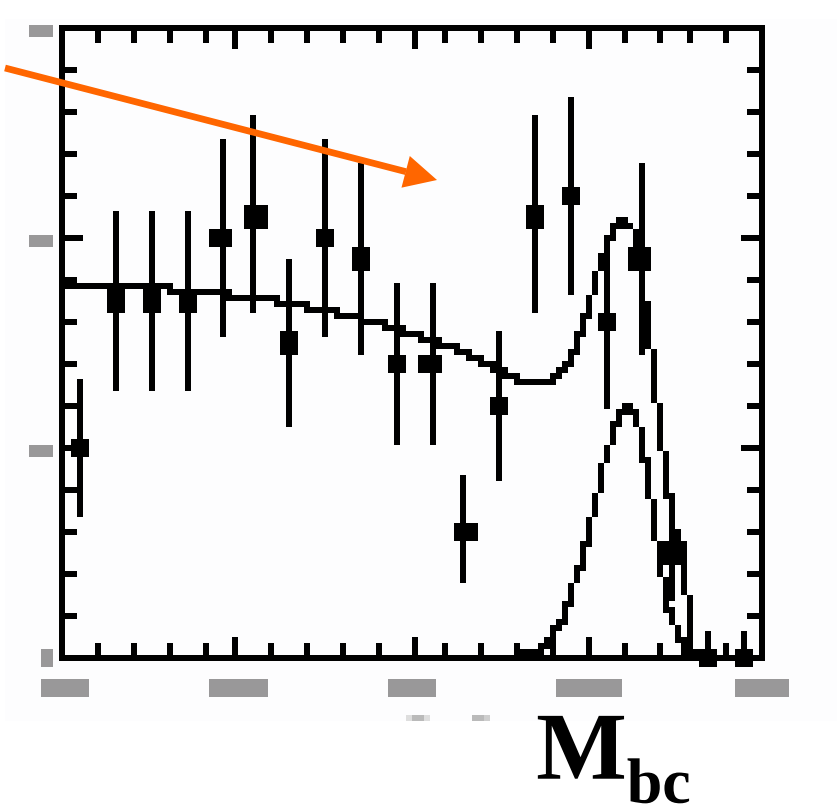
Chiang & Rosner hep-ph/012285

Large r & |δ| ➔large $B^0 \rightarrow \pi^0\pi^0$ ie Br ~ few x 10^{-6}

big question: what's $B \to \pi^0\pi^0$?



~2.5σ



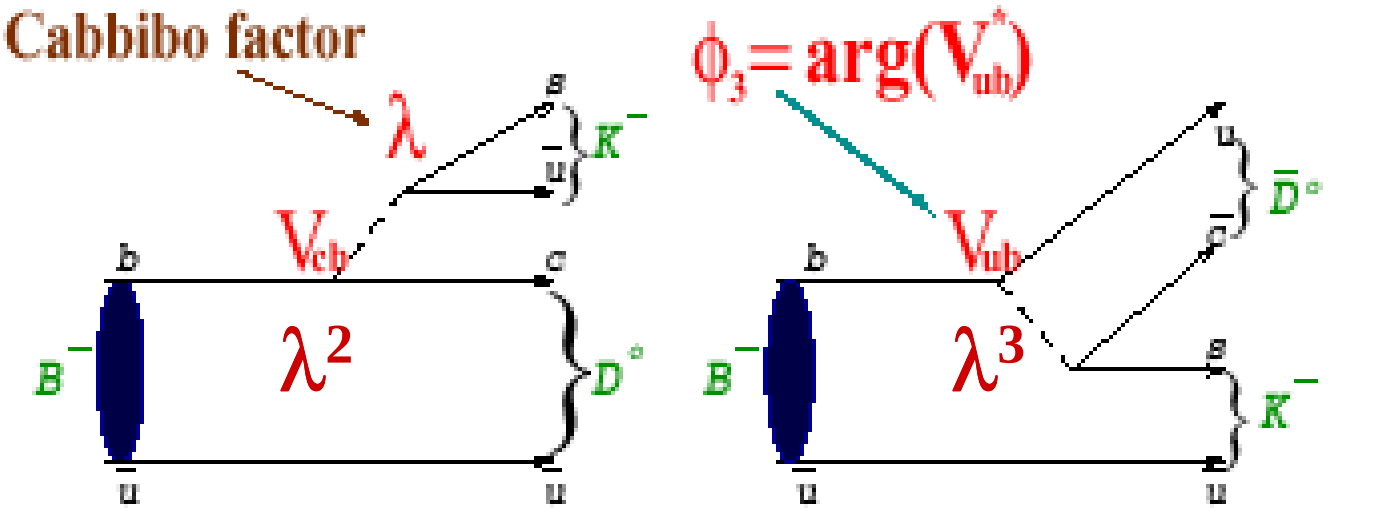
$Br(B \to \pi^0\pi^0) < 5.6 \times 10^{-6}$ ($29 fb^{-1}$)

($Br \approx 3 \times 10^{-6}$)

$\phi_3\ (\gamma)$

interference in $B^- \to K^- D^0(\bar{D}^0)$

$B^\pm \to K^\pm D_{CP}$; D_{CP} → CP eigenstate



Color-favoured :A_1 Color-suppressed :A_2

$r = |A_1/A_2| \sim 0.1$

$D^0 \rightarrow$ non-CP

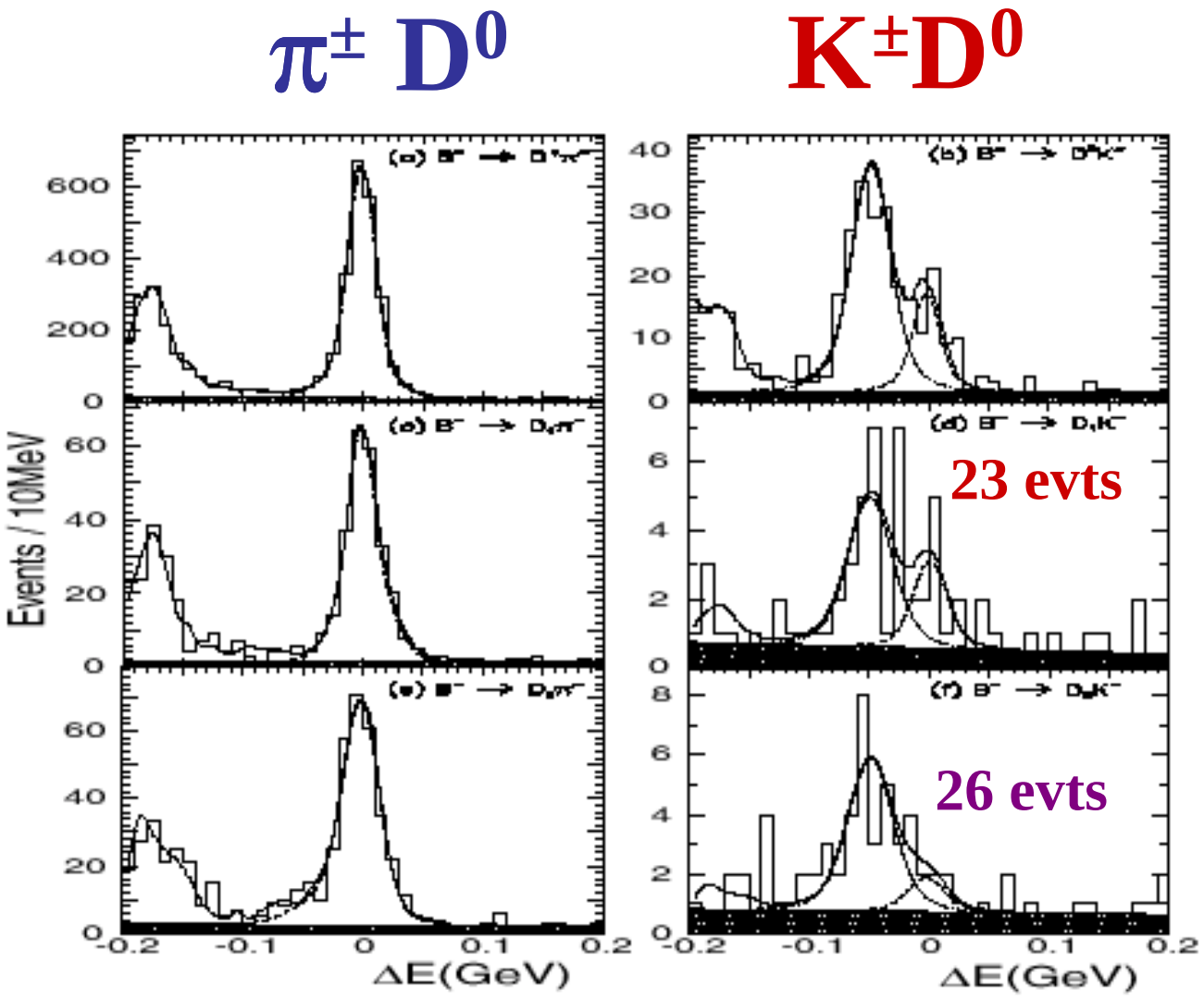
(Kπ, K$\pi\pi\pi$, etc)

$D^0 \rightarrow CP=+1$

($\pi^+\pi^-$ & K^+K^-)

$D^0 \rightarrow CP=-1$

($K_s\pi^0$,ω,η,η',ϕ)



Results (with 29 fb^{-1})

$$A_{1,2} = \frac{Br(D_{1,2}\,K^-) - Br(D_{1,2}\,K^+)}{Br(D_{1,2}\,K^-) + Br(D_{1,2}\,K^+)} = \frac{\pm 2r \sin\phi_3 \sin\delta}{1 + r^2 \pm 2r \cos\phi_3 \cos\delta}$$

$$A_1 = 0.29 \pm 0.26 \pm 0.05$$

$$A_2 = -0.22 \pm 0.24 \pm 0.04$$

$$A_{\text{non CP}} = 0.00 \pm 0.09 \pm 0.04$$

constraints on r & δ

$$R_{1,2} = \frac{Br(D_{1,2}\, K^{\pm}) / Br(D_{1,2}\, \pi^{\pm})}{Br(D^0\, K^{\pm}) / Br(D^0 \pi^{\pm})} = 1 + r^2 \pm 2r \cos\phi_3 \cos\delta$$

$+ \rightarrow D_1$

$- \rightarrow D_2$

$$R_1 = 1.33 \pm 0.37 \pm 0.12$$

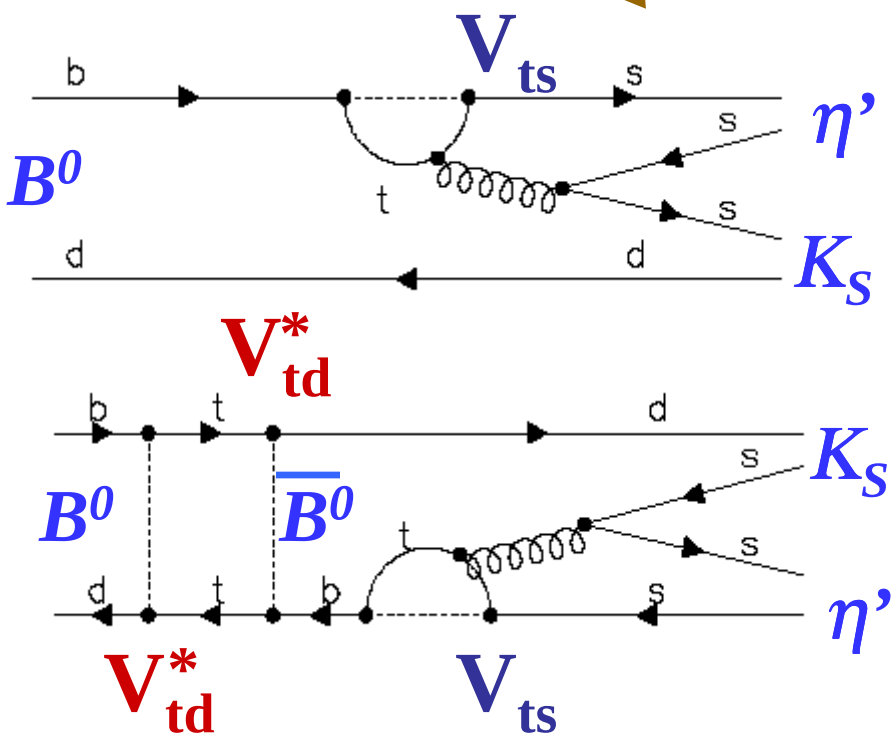
$$R_2 = 1.27 \pm 0.29 \pm 0.09$$

needs ~ 10x more data (ie 300~400 fb^{-1})


NP

non-SM phases in $B \to K_S \eta'$?

no SM CPV phase

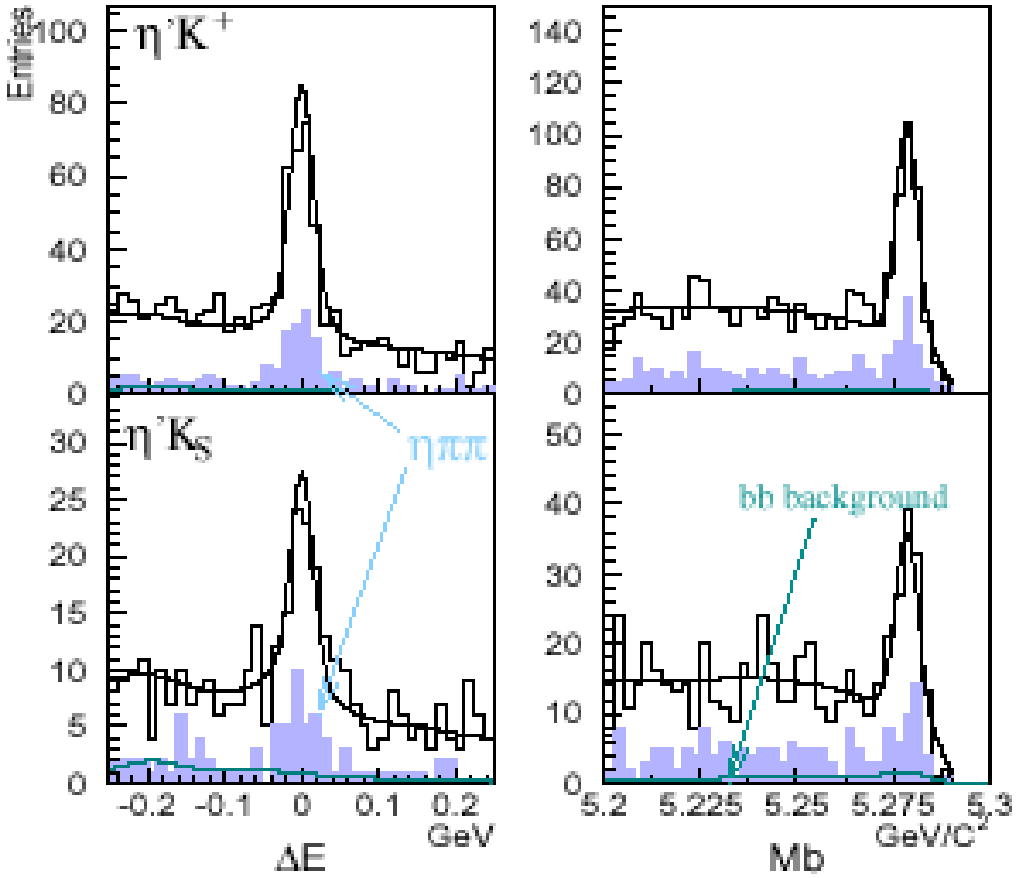


$S_{K\eta'} = \sin 2\phi_1$ (in SM)

SM prediction is same as for $J/\psi K_S$

A non-SM particle in the loop with a complex coupling would cause deviations from $\sin 2\phi_1$

Use $\eta' \rightarrow \pi^+\pi^-\eta$ and $\rho\gamma$



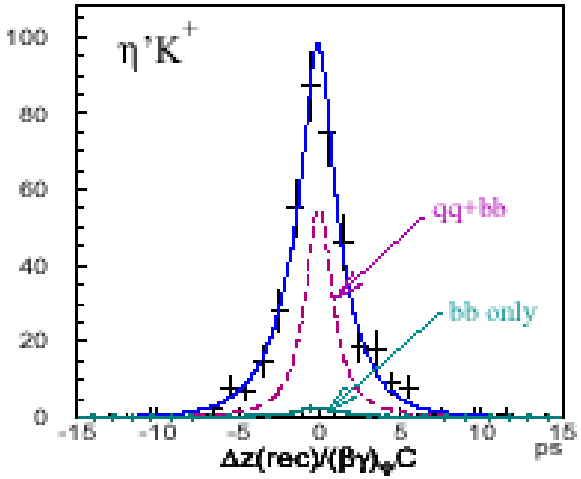
$N(K^+ \pi\pi\eta) = 78 \pm 10$

$N(K^+ \rho\gamma) = 152 \pm 14$

$N(K_S \pi\pi\eta) = 28 \pm 6$

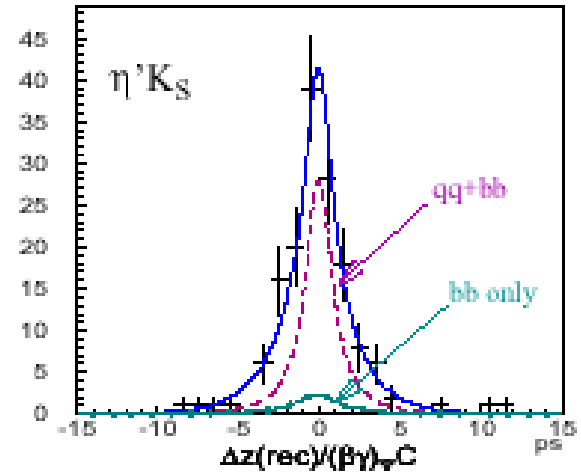
$N(K_S \rho\gamma) = 46 \pm 8$

B lifetimes with η'K samples



$\tau(B^+) = 1.54 \pm 0.14$ ps

PDG: 1.65 ± 0.03 ps

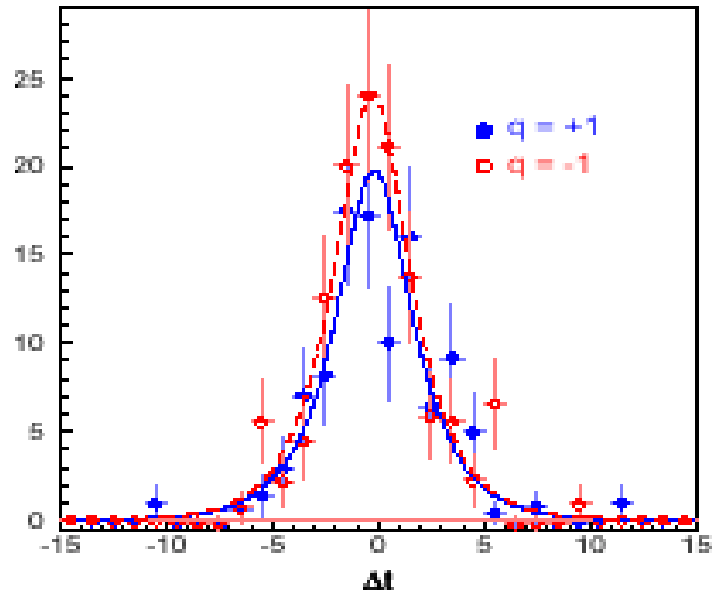


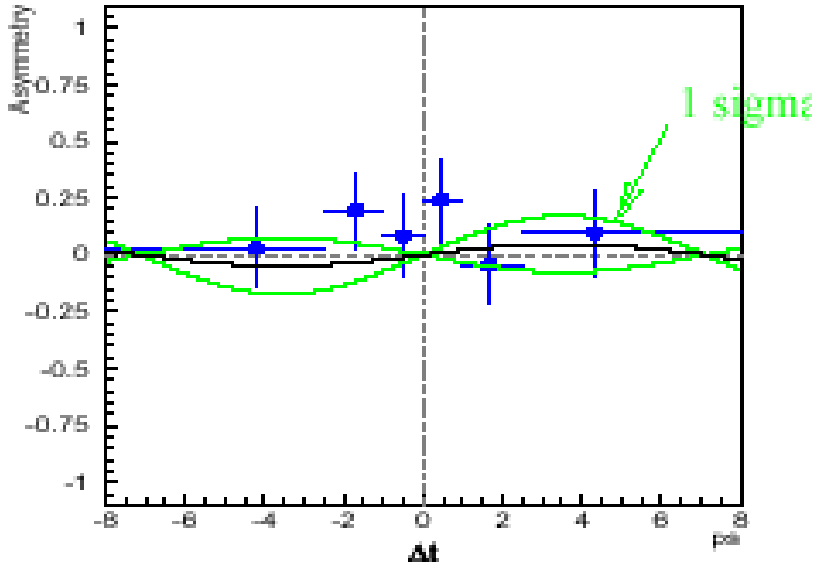
$\tau(B^0) = 1.58 \pm 0.30$ ps

PDG: 1.55 ± 0.03 ps

Use $B \rightarrow K^{+}\eta'$ as control sample

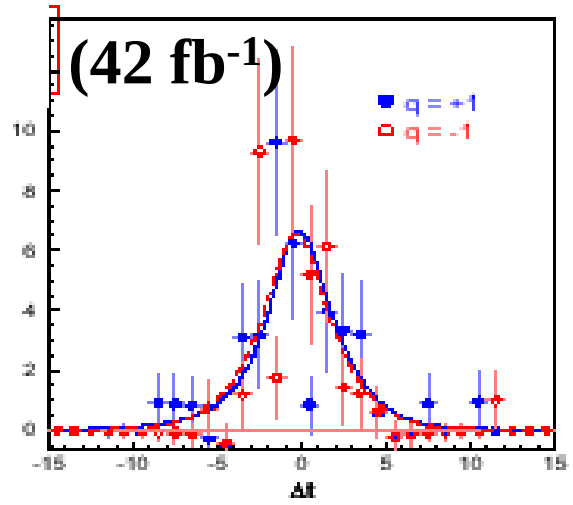
"$\sin 2(\phi_1+\theta_{NP})$"= 0.12 ± 0.40



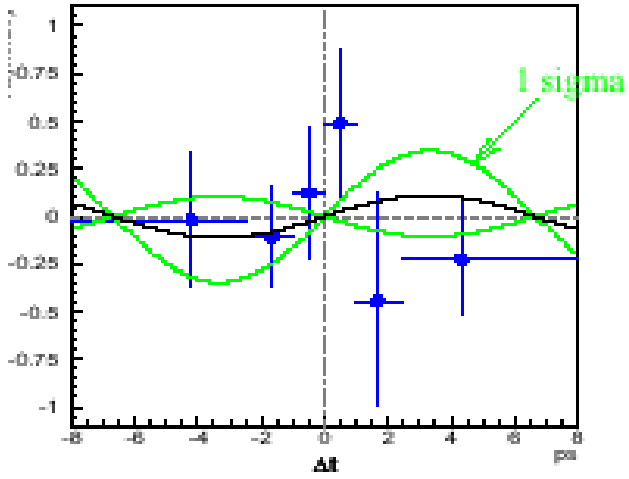


Fit the 73 $B \rightarrow K_S \eta'$ events

$$\sin 2(\phi_1 + \theta_{NP}) = 0.29 \pm 0.54 \pm 0.07$$



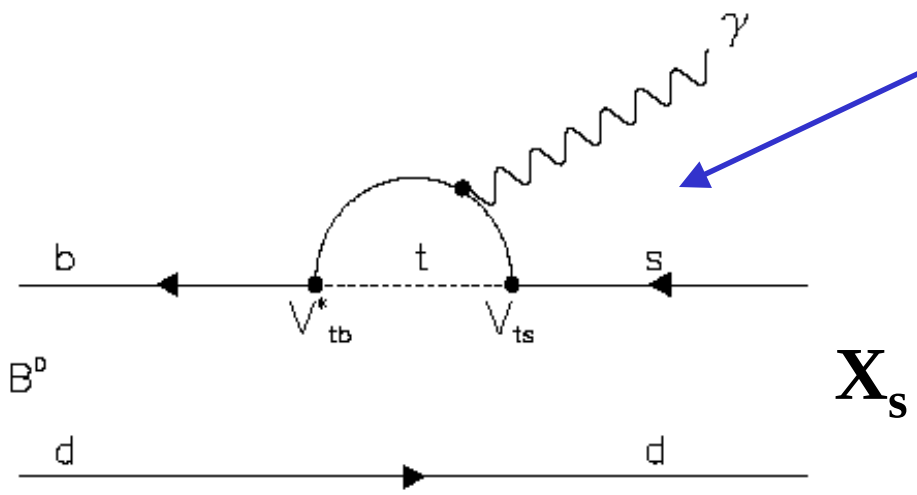
A clean and potentially powerful method for searching for non-SM CPV



needs more data

b-changing neutral currents

EM & EW Penguins

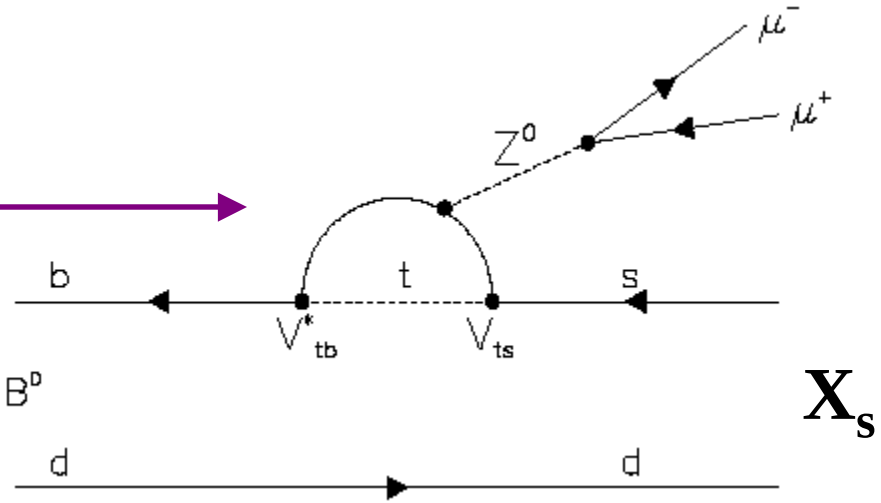


EM Penguin (b→sγ)

- **1st found by CLEO**
- **rate agrees with SM**
- **limits on new particles in loop (eg H^+)**

EW Penguin (b→s l^+l^-)

- **≈100x smaller in SM**
- **M $_{l+l-}$ dist & F-B asymm sensitive to new physics**

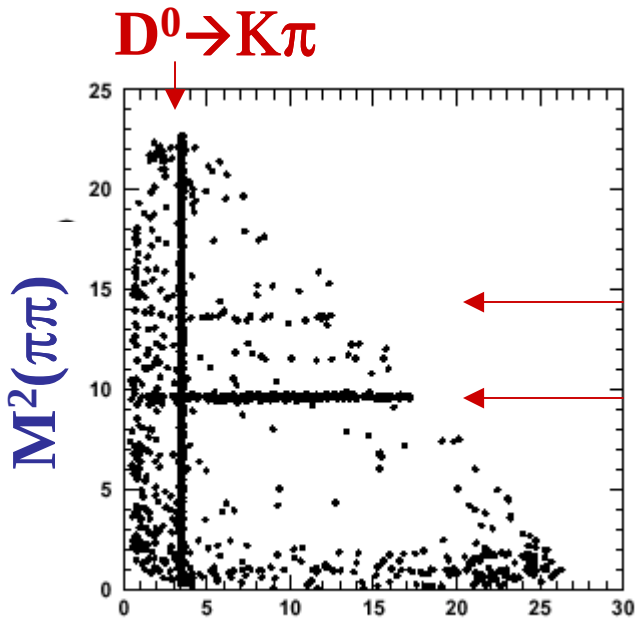


Search for $B \to K^{(*)} l^+ l^-$

Backgrounds:

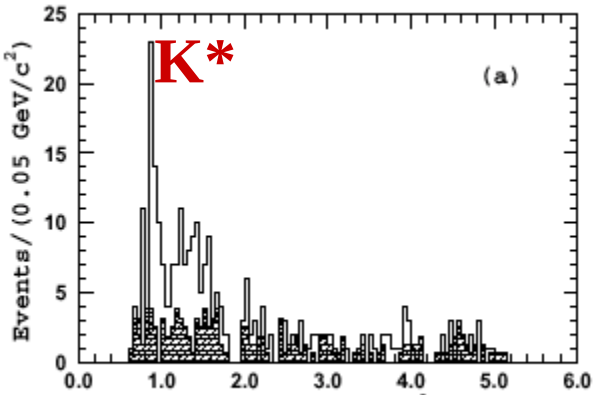
- $B \to J/\psi\ (\psi')\ K^{(*)}$ ← use J/ψ (ψ') veto
- $B \to X l^+ \nu$ & $B \to Y l^- \nu$ ← no ΔE & M_{bc} peaks
  - E_{vis} & $\cos\theta_B$
- $B \to K^{(*)} h^+ h^-$; → 2 fake l's ← ΔE & M_{bc} peaks
- Continuum ← no ΔE & M_{bc} peaks
  - Event shape, $\cos\theta_B$

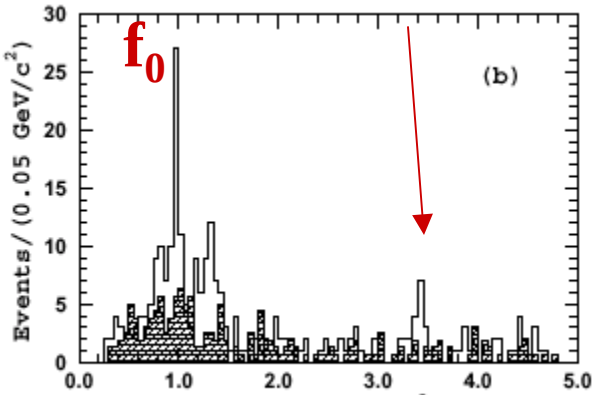
$B^+ \to K^+\pi^+\pi^-$ in Belle



hep-ex/0201007 →PRD

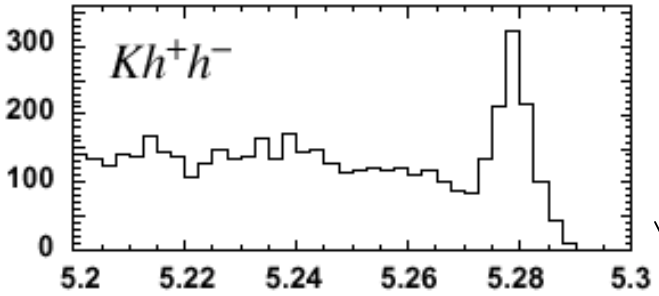
χ_{c0} (PRL 88, 032182, 2002)



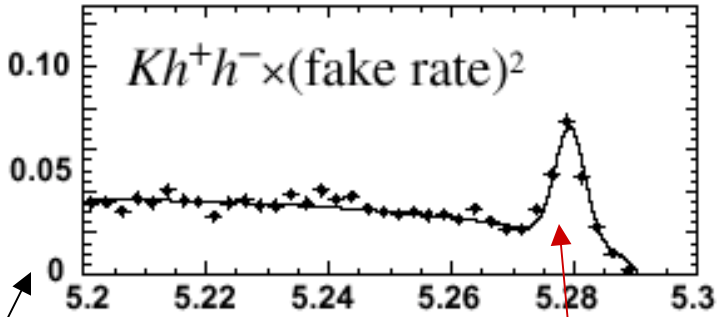


$K^{(*)}\ h^+h^-$ with fake μs

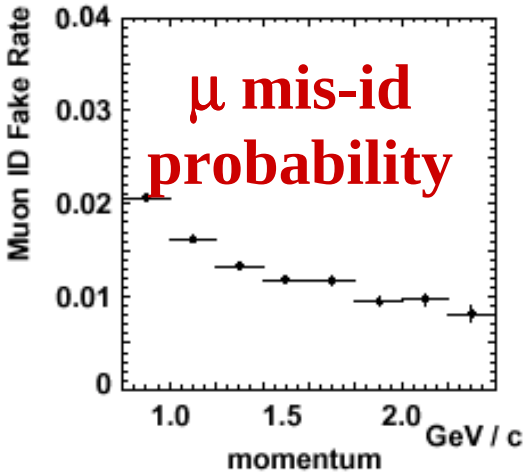
Data



apply trk-by-trk fake rate



0.27±0.03 fake events

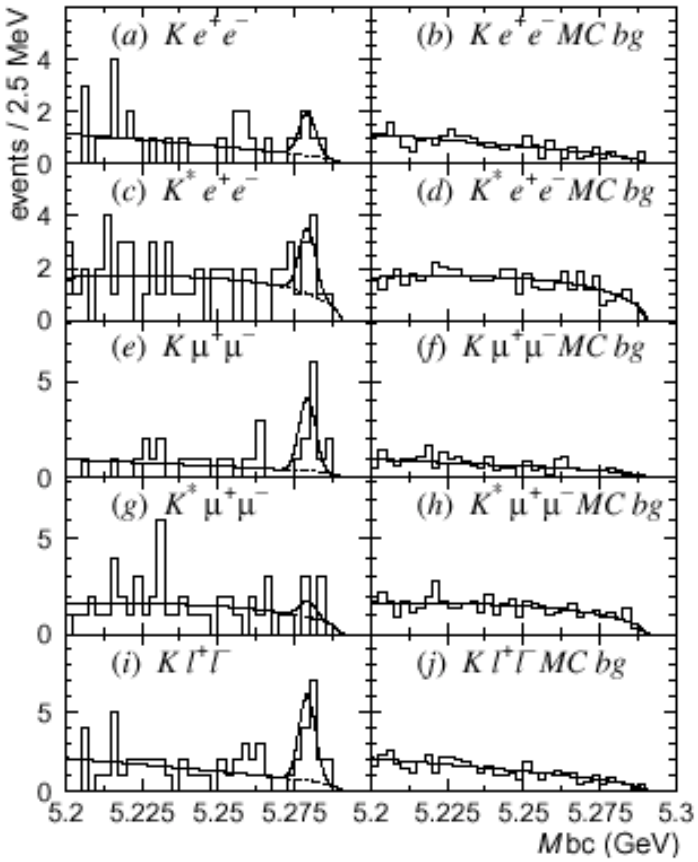


μ mis-id probability

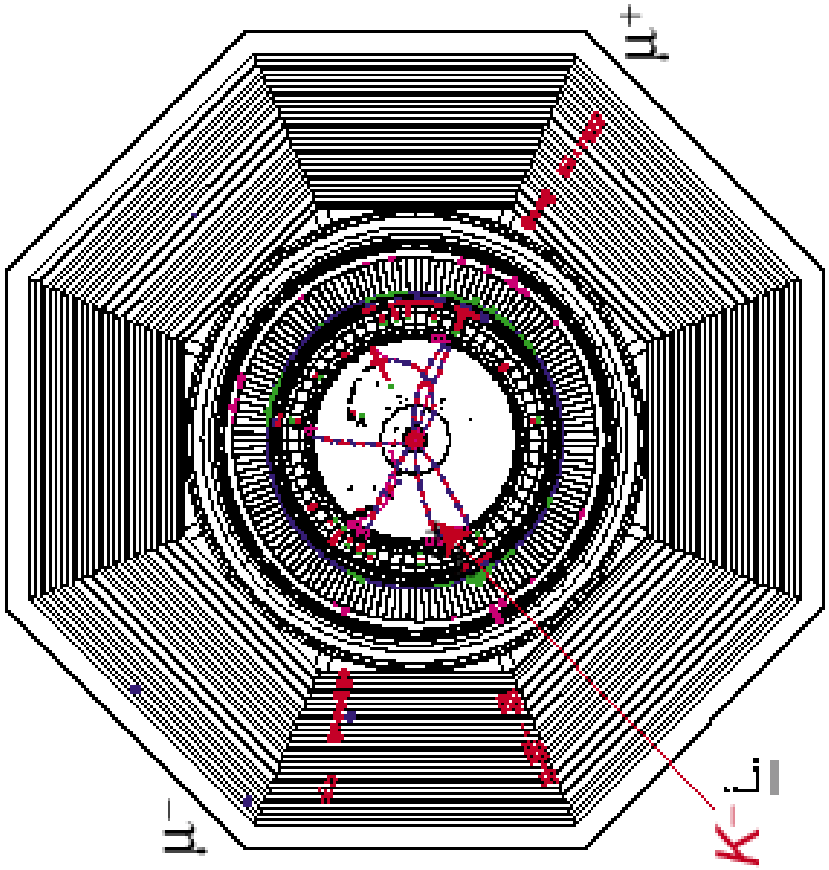
B→K$^{(*)}l^+l^-$ results

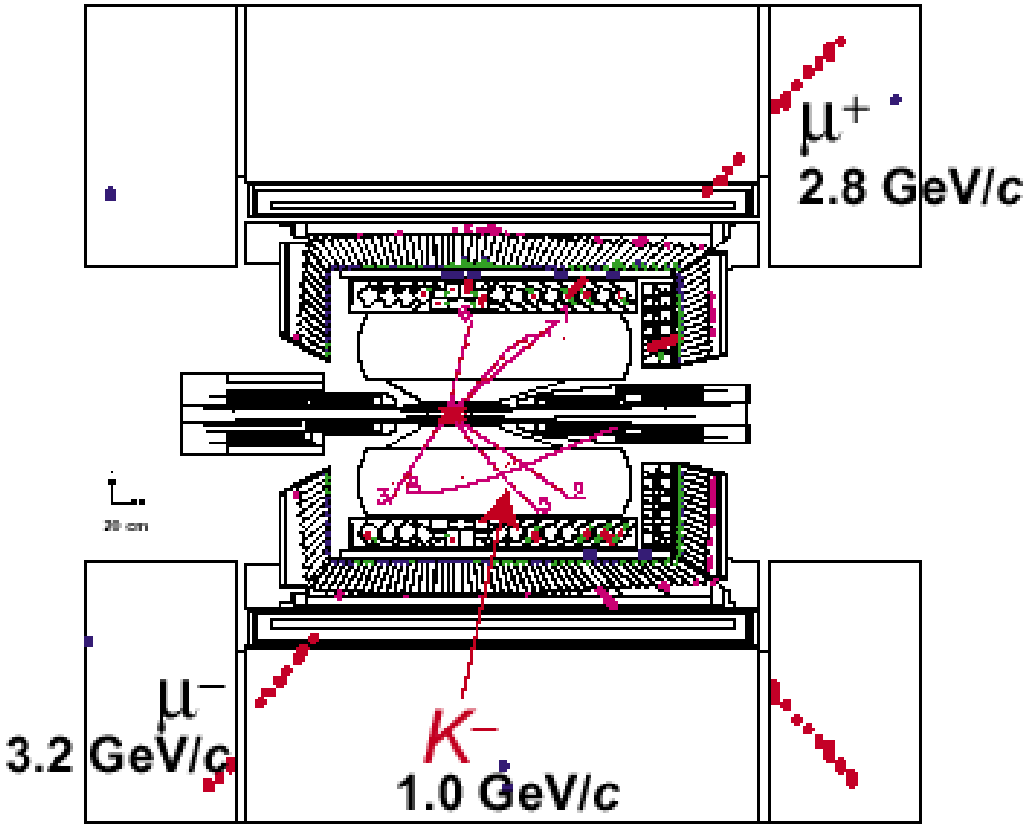
mode	signal	BF($\times 10^{-6}$)	signif.
Ke^+e^-	$4.1^{+2.7+0.6}_{-2.1-0.8}$	< 1.3	2.5
$K^*e^+e^-$	$6.3^{+3.7+1.0}_{-3.0-1.1}$	< 5.6	2.5
$K\mu^+\mu^-$	$9.5^{+3.8+0.8}_{-3.1-1.0}$	$0.99^{+0.40+0.13}_{-0.32-0.14}$	4.7
$K^*\mu^+\mu^-$	$2.1^{+2.9+0.9}_{-2.1-1.0}$	< 3.1	–
Kl^+l^-	$13.6^{+2.9+0.9}_{-2.1-1.0}$	$0.75^{+0.25}_{-0.21}\pm 0.09$	5.3

Phys. Rev. Lett. 88. 021801 (2002)

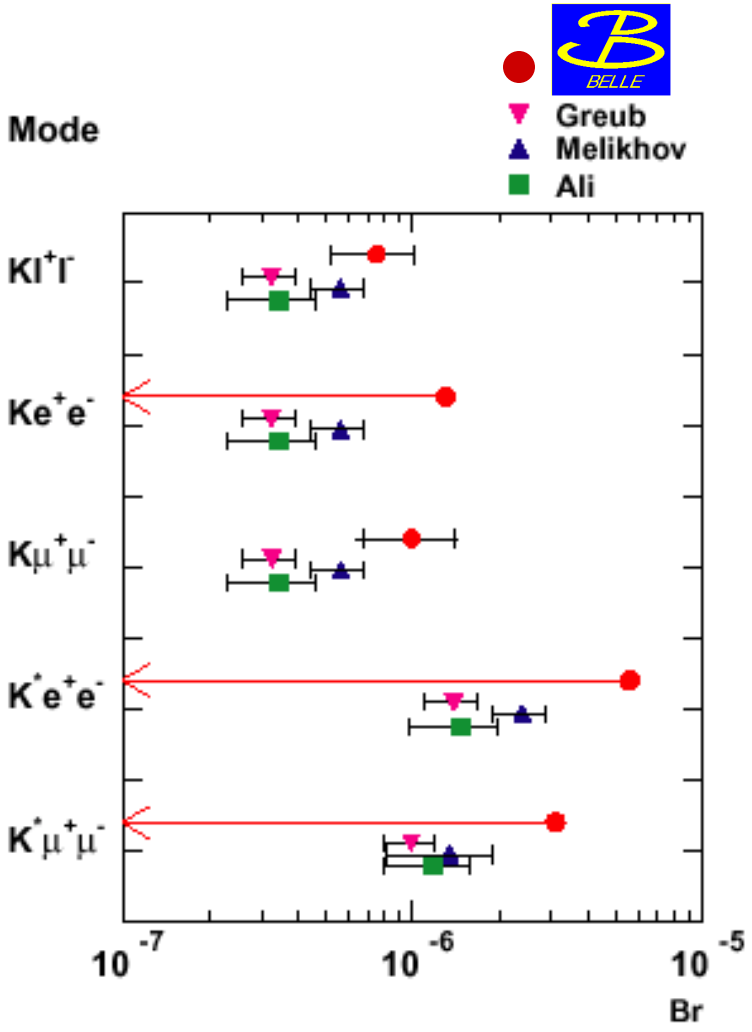


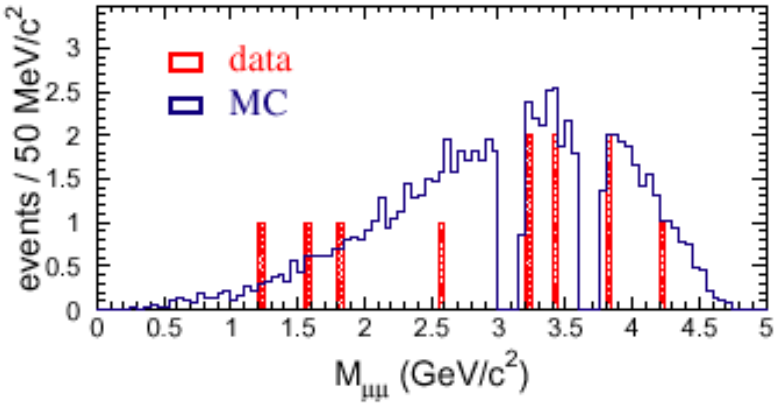
$B^- \to K^- \mu^+ \mu^-$ event in Belle





B→K$^{(*)}l^+l^-$ results (cont'd)



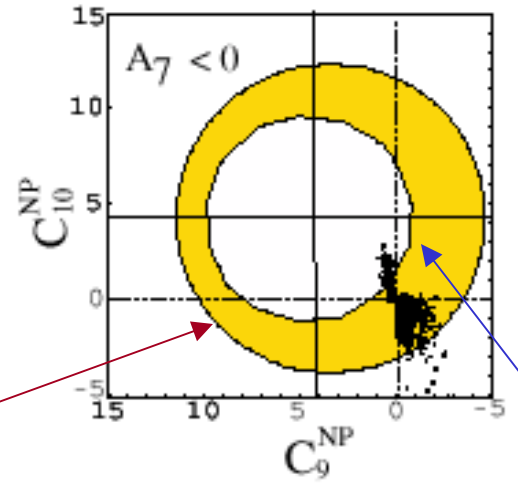


PRL 88 021801 (2002)

Wilson coefficient constraints

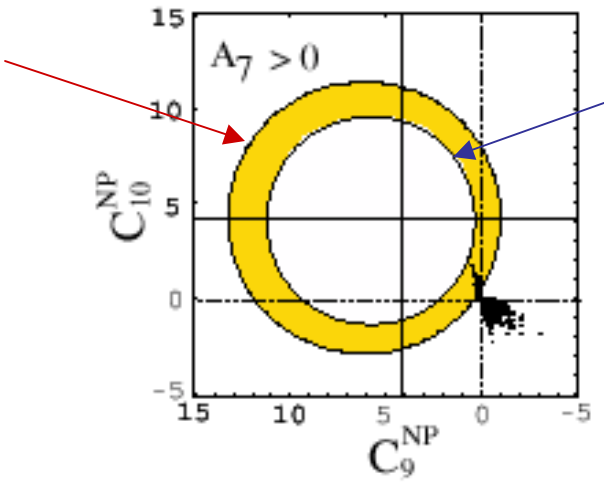
$$C_9^{NP} = C_9 - C_9^{SM}$$

$$C_{10}^{NP} = C_{10} - C_{10}^{SM}$$



Br(B→ $X_s e^+ e^-$)<10.2x10^{-6}
(Belle 90%CL limit)

Kl^+l^- width



Ali et al, hep-ph/0112300

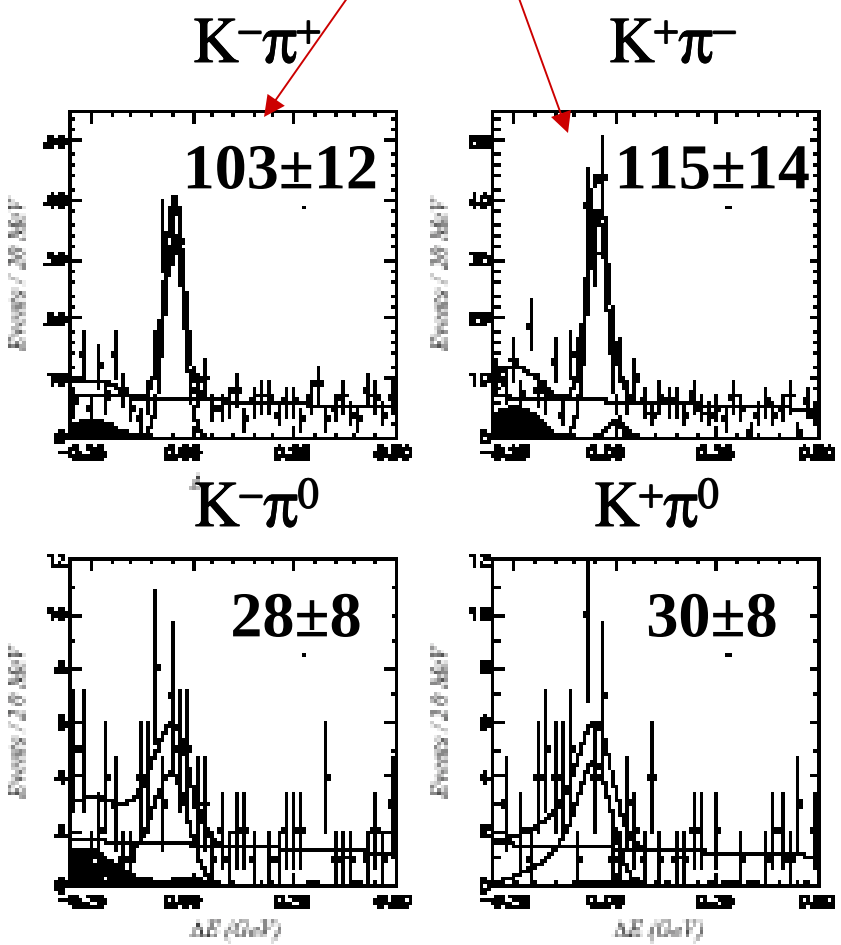
Summary

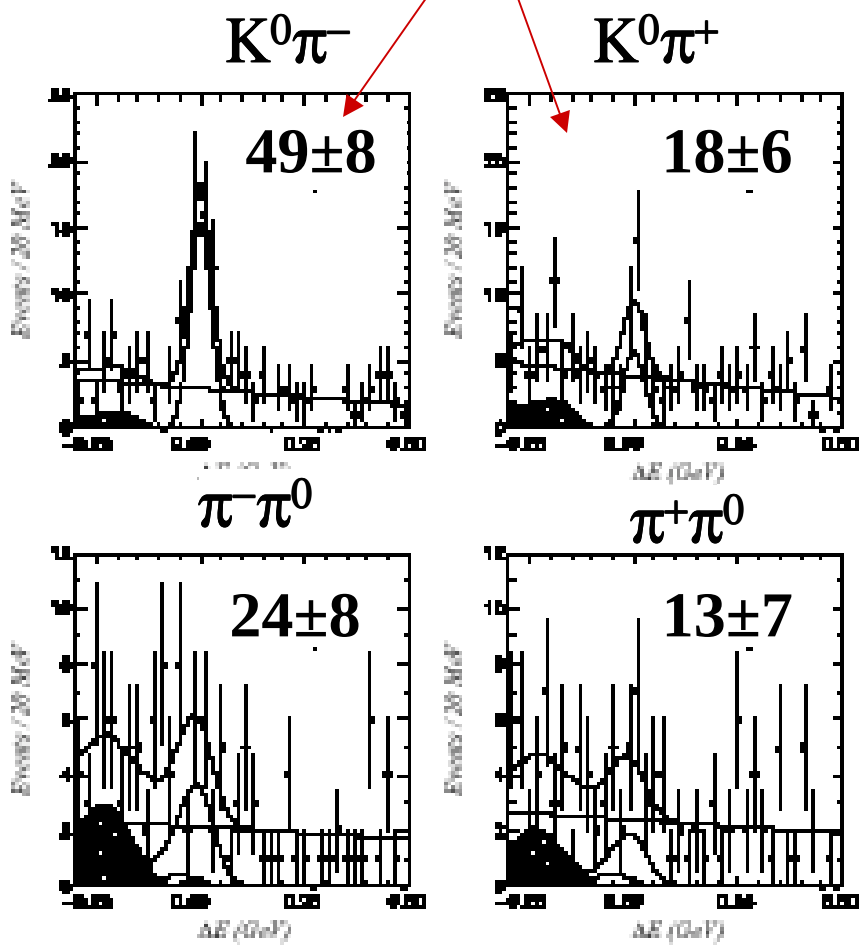
- **Progress on CPV front**
  - **ϕ_1 (β) measured; agrees with SM**
  - **ϕ_2 (α) in progress; definitive results may be soon.**
    - **need Br(B→$\pi^o\pi^o$); this summer?**
  - **ϕ_3 (γ) under way; a few years to go??**
  - **ϕ_{NP} just starting;**
- **Neutral currents/EW penguins**
  - **B→Kl^+l^- seen; at ~expected level**
  - **B→ K*l^+l^- & $X_s l^+l^-$ next**
- **Many, many other results:**
  - **b→c (Cabibbo- & color-suppressed), b→u,…**
  - **EM penguins**
  - **charm & charmonium**
  - **taus, two-photons, …**

A_{CP} from self-tagged $K\pi/\pi\pi$

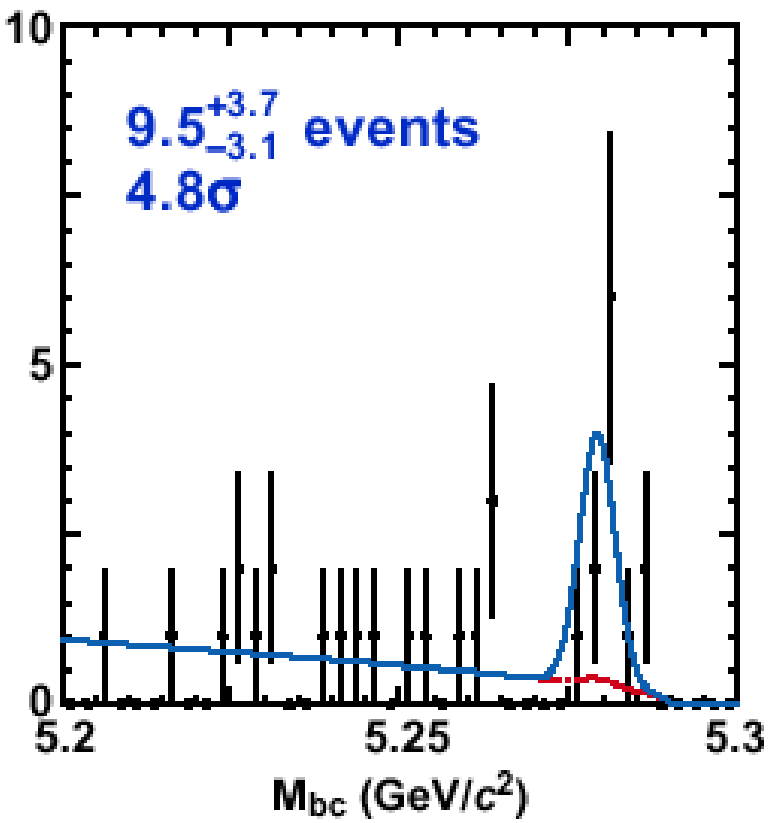
$A(K^-\pi^+) = -0.06 \pm 0.08 \pm 0.01$

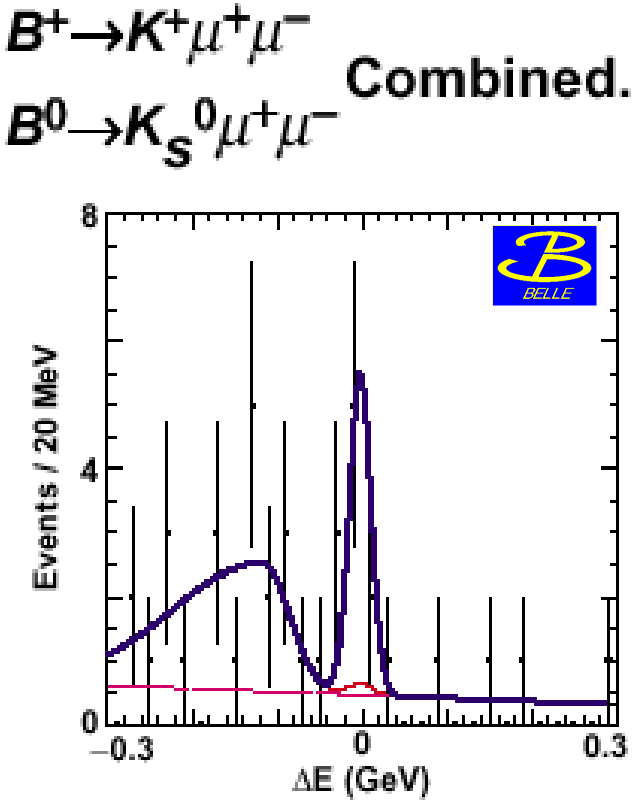
$A(K^0\pi^\pm) = 0.45 \pm 0.15 \pm 0.02$





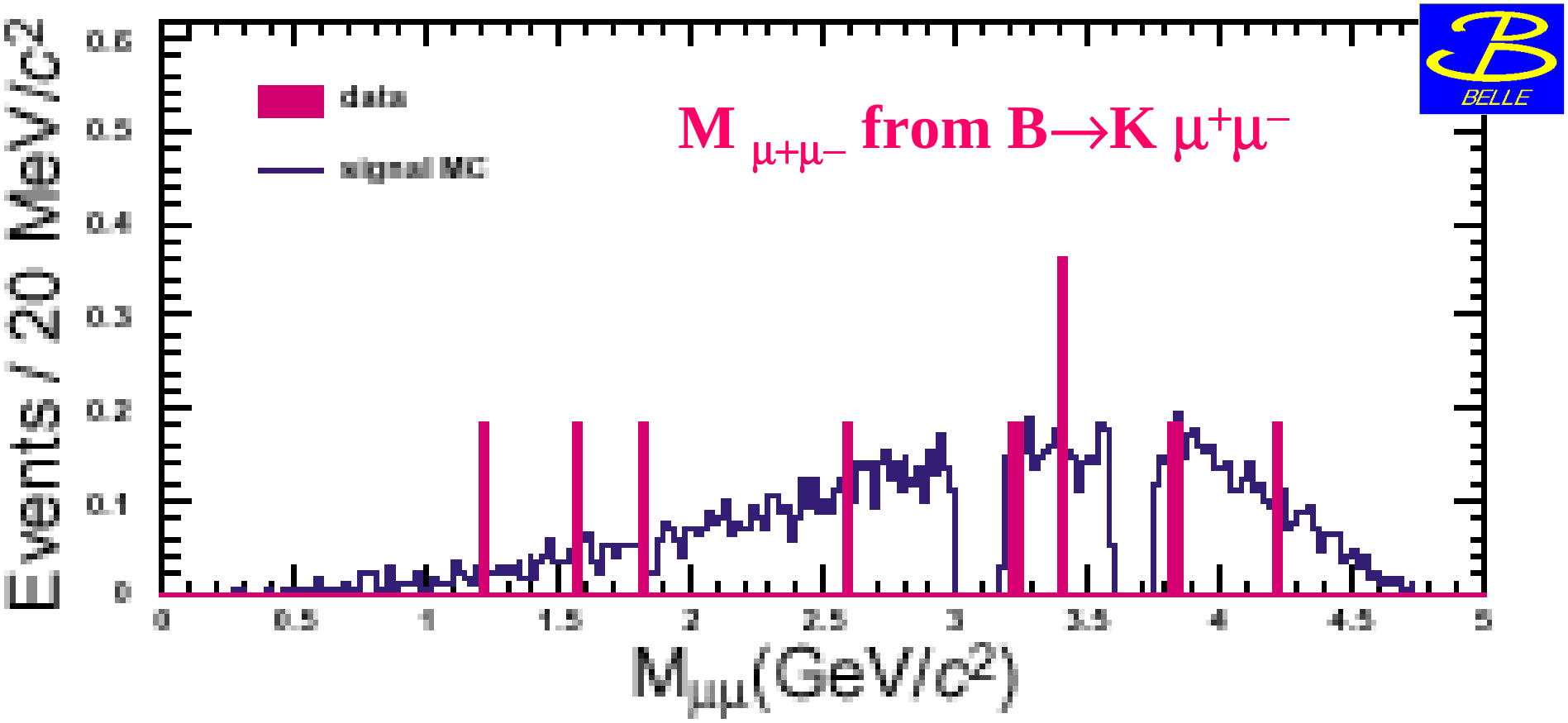
hep-ex/0109026 → PRL





$Br(B \to K \mu^+\mu^-) = 1.0\ ^{+0.4}_{-0.3}\ ^{+0.1}_{-0.1} \times 10^{-6}$ **(SM: 0.3~0.6×10^{-6})**

$\mu^+\mu^-$ mass distribution



(also see ≈2.5σ level signals in Ke^+e^-, $K^*e^+e^-$ & $X_s\,\mu^+\mu^-$)