Direct CP and Rare Decays

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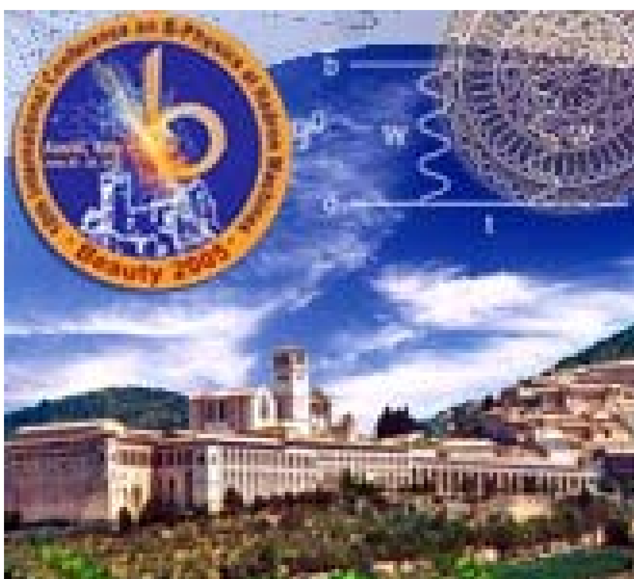
National Taiwan University

June 21, 2005
B Physics at Hadronic Machines, Assisi



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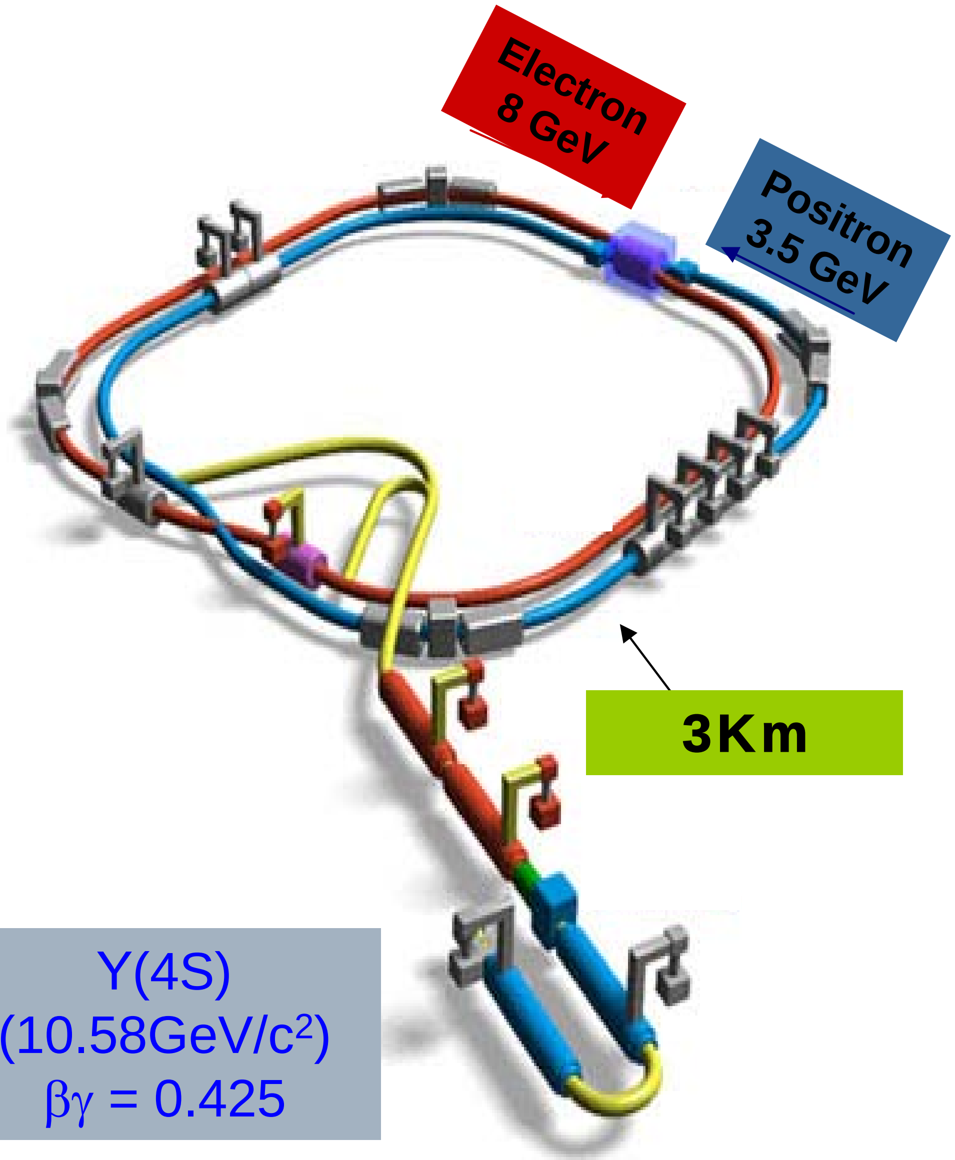
Outline

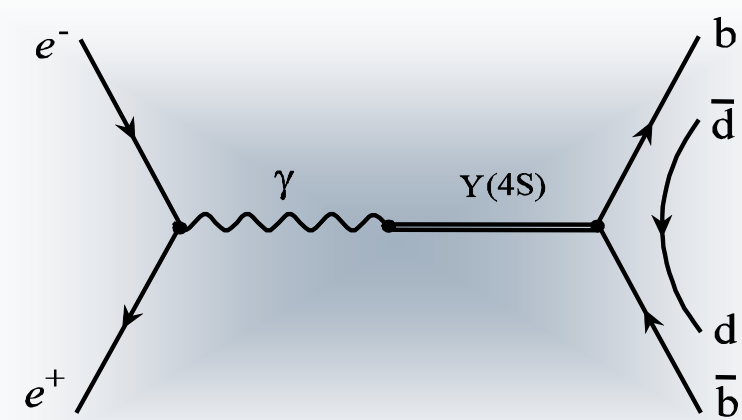
- **Machine, Detector, Basic Method**
- **Direct CPV in $K\pi$**
- **Observation of $\pi^0\pi^0$**
- **Polarization in ϕK^*, $\rho^+ K^{*0}$**
- **Khh Dalitz Analysis**
- **Baryonic Modes**

New Results only at LP05 and I

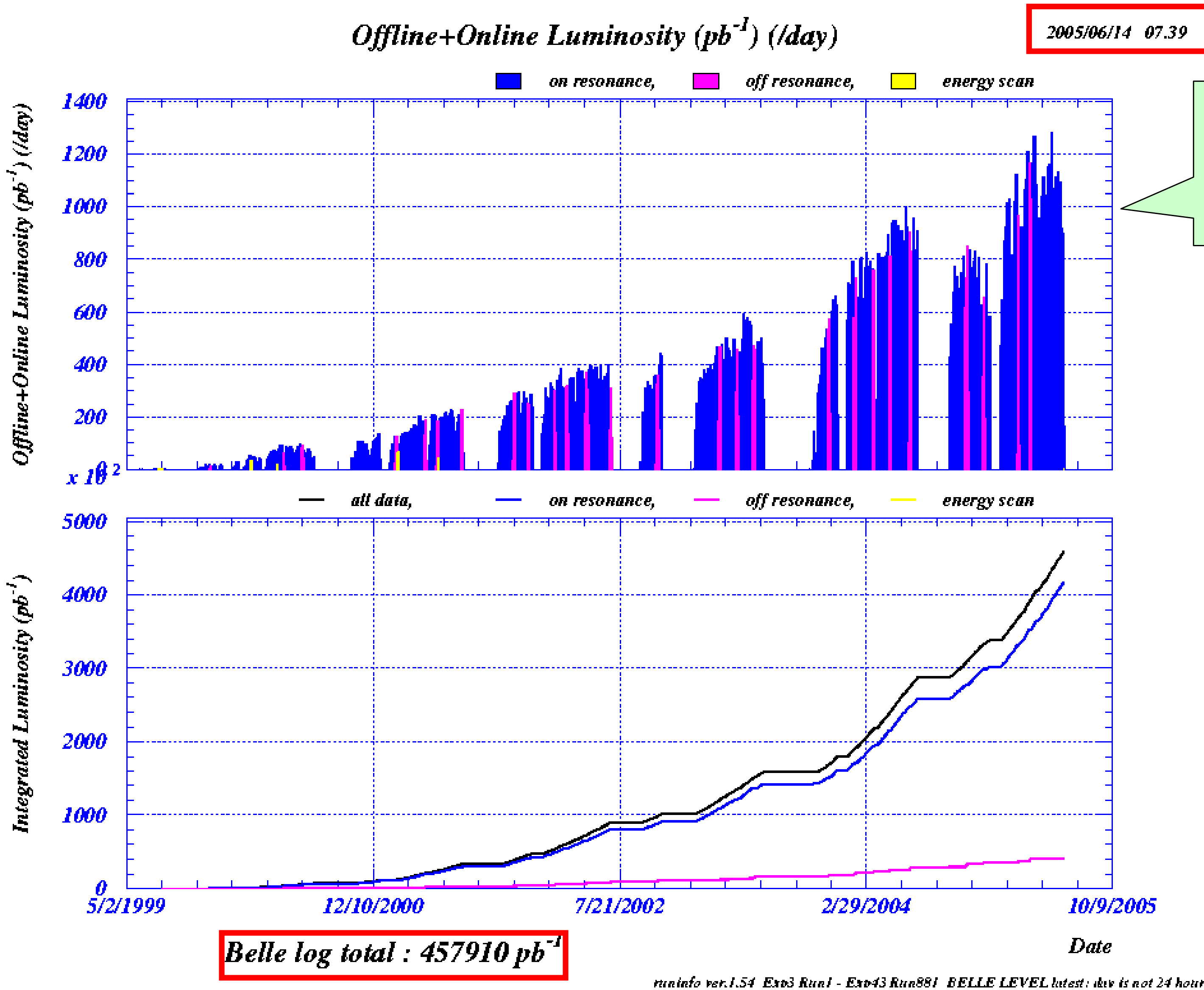
KEKB B-Factory



Y(4S)
(10.58GeV/c^2)
$\beta\gamma = 0.425$



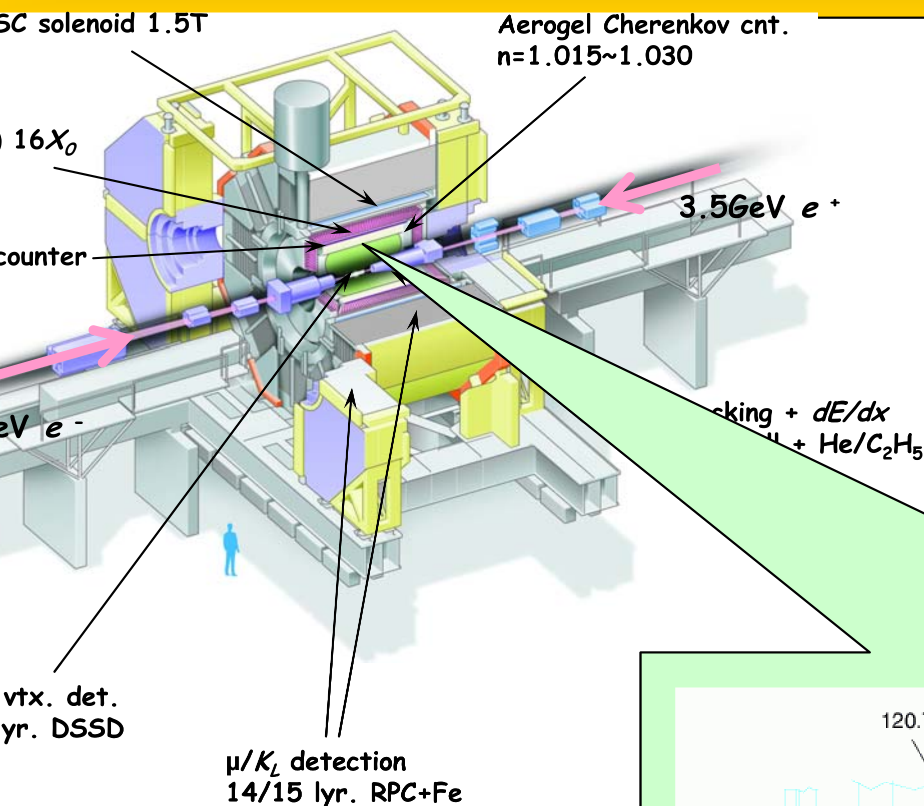
Luminosity

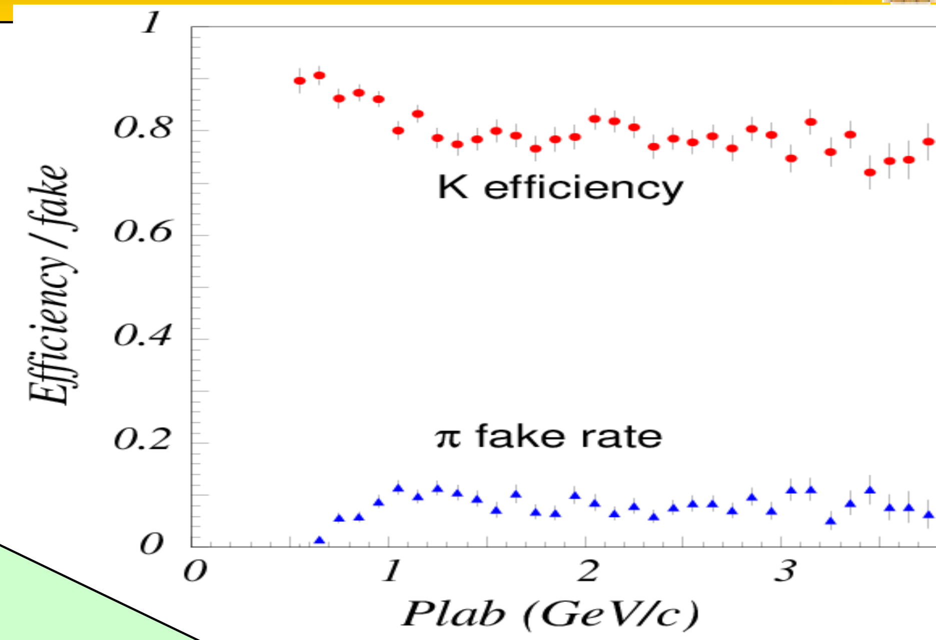


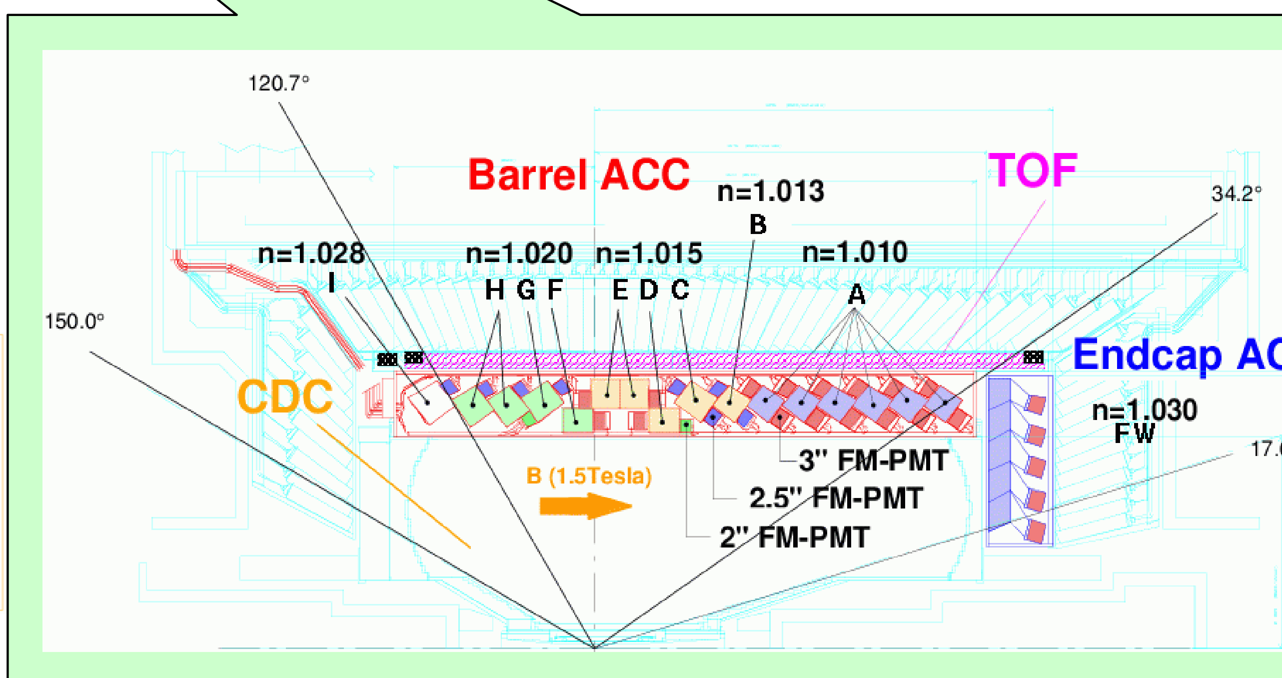
1 fb^{-1} per day

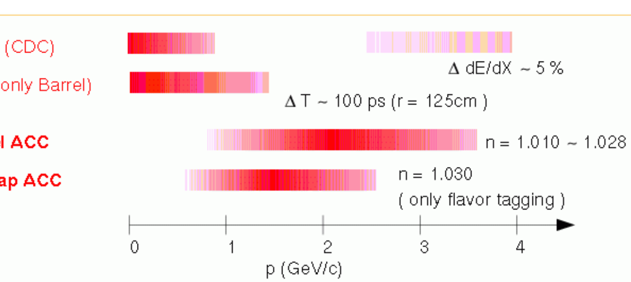
peak luminosity = 15.81 /nb/sec (May 18, 2005)

Belle Detector

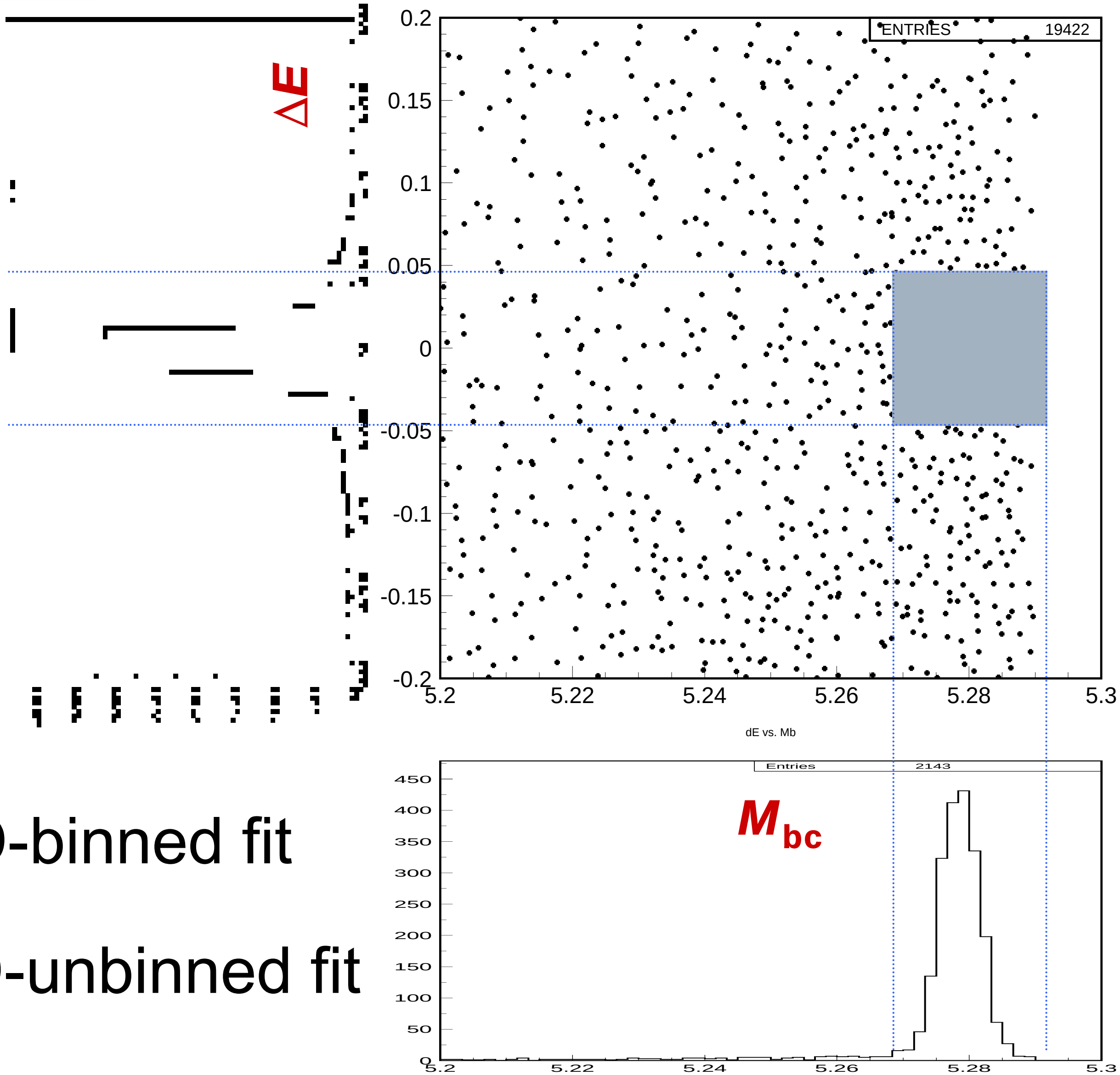








B Signal Reconstruction



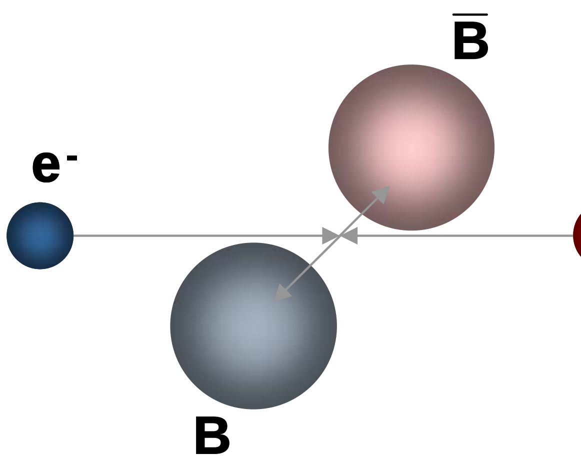
1D-binned fit

2D-unbinned fit

In $\Upsilon(4S)$ rest fram

$$M_{bc} = \sqrt{E^2_{beam} - p^2_{B}}$$

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



Background Suppression

Main background for hadronic rare B is continuum $q\bar{q}$ events.
(q=u,d,s,c).

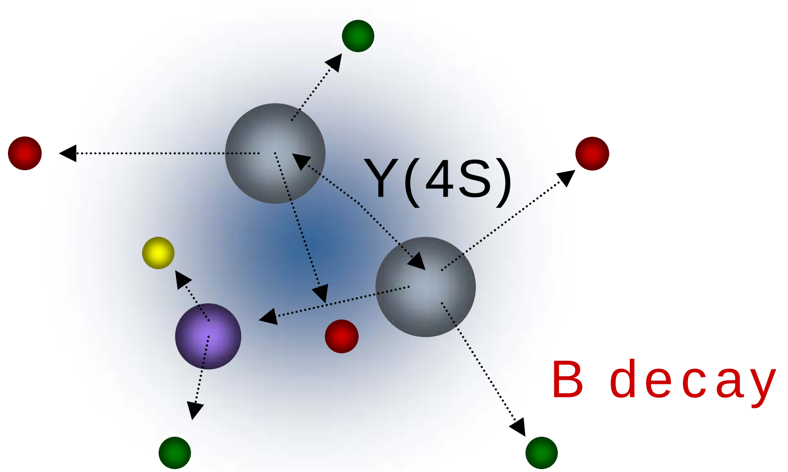
Topology of continuum events and B decays are different.
Choose $|\cos\theta_{Thrust}|$ $S_\perp$ R_2^{so} R_4^{so} R_2^{oo} R_3^{oo} R_4^{oo} as input to Fisher,
and combine it with $\mathbf{\cos\theta_B}$ to calculate the $\mathcal{L}$ikelihood $\mathcal{R}$atio.

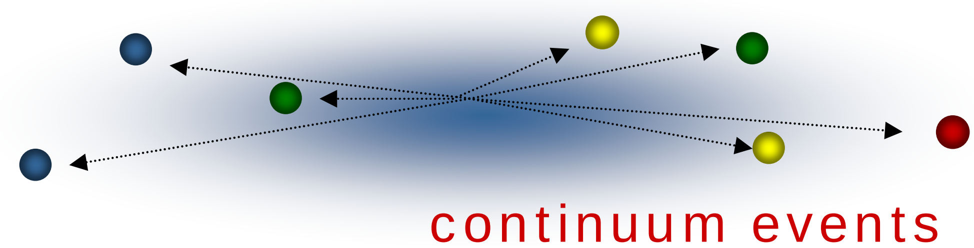
Define modified Fox-Wolfram moment:

$$F = \sum_{i=2,3,4} \alpha_i R_i^{oo} + \sum_{i=2,4} \beta_i R_i^{so} + \gamma\,|\cos\theta_{Thrust}| + \delta S_\perp$$

Use Fisher discriminant to optimize the coefficients.

$$\boxed{\mathcal{LR} = \frac{\mathcal{L}_s}{\mathcal{L}_s + \mathcal{L}_b}}$$

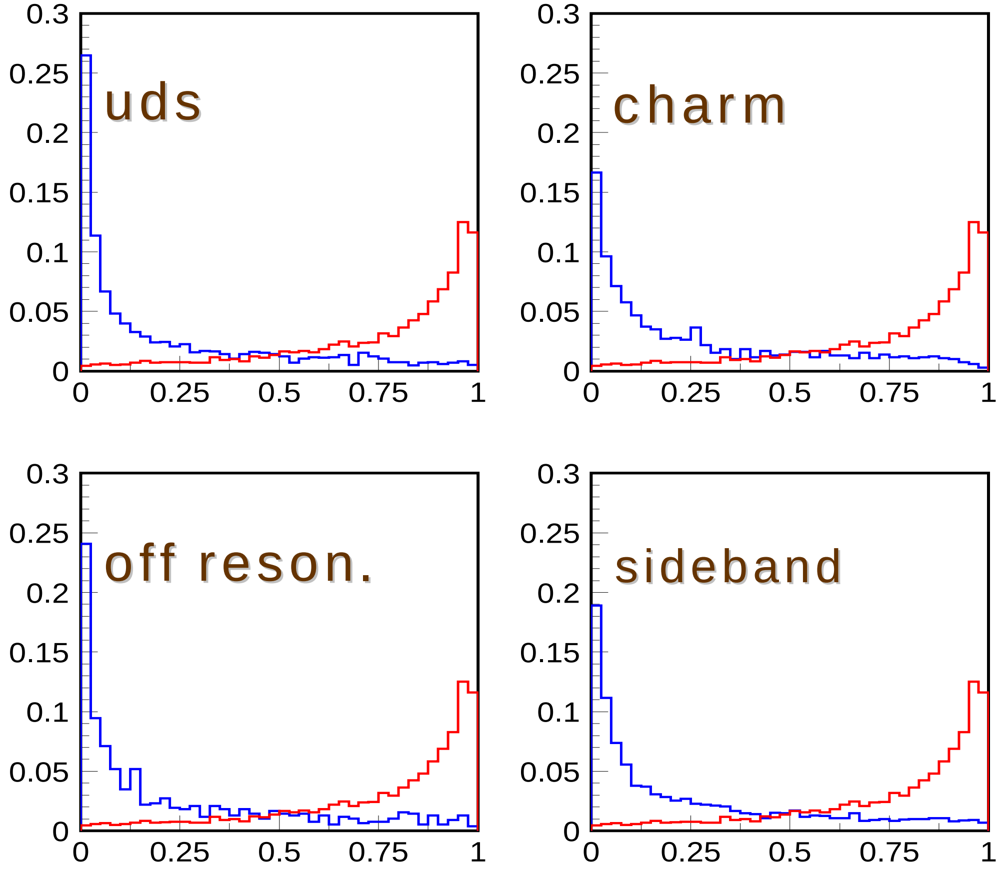




$\mathcal{L}$ikelihood $\mathcal{R}$atio ($\mathcal{LR}$)

$$\mathcal{LR} = \frac{\mathcal{L}_s}{\mathcal{L}_s + \mathcal{L}_b}$$

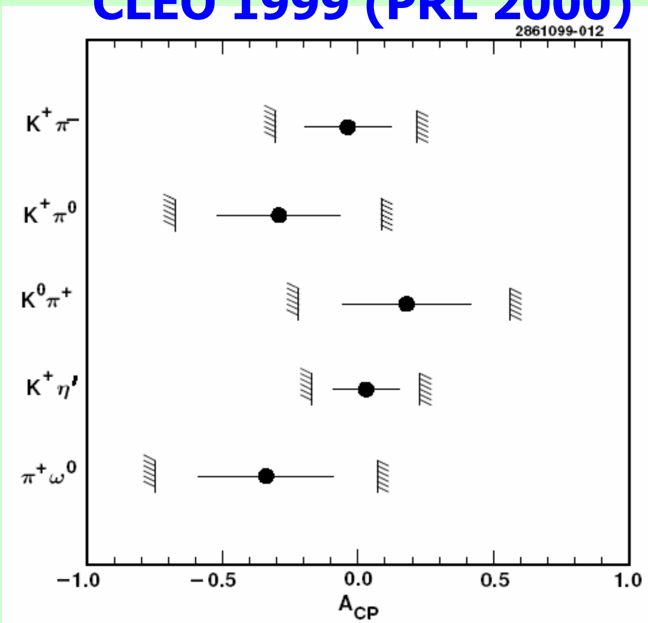
Optimize



Evidence for DCPV in $B \to K\pi$

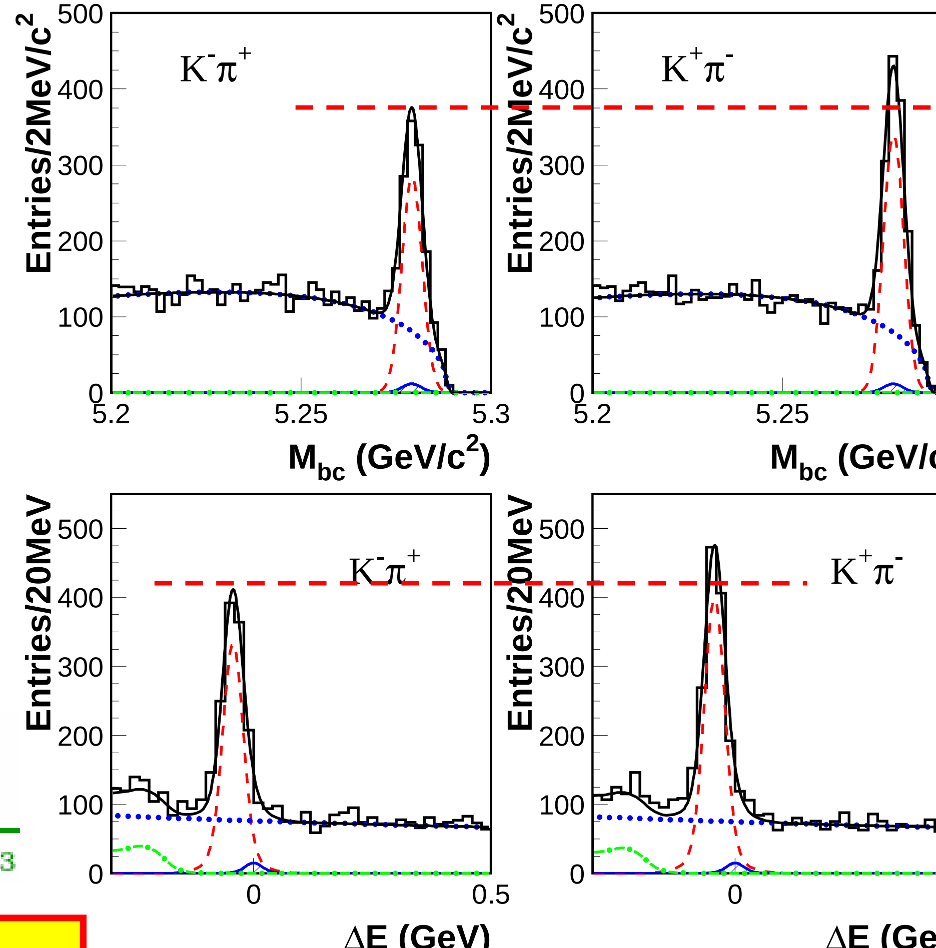
Y. Chao, P. Chang et al. PRL 2004

CLEO 1999 (PRL 2000)



2140 ± 53 evts

253 fb



$\mathcal{A}_{CP}$ defined as: $\mathcal{A}_{CP} = \frac{N(\bar{B}\to\bar{f})-N(B\to f)}{N(\bar{B}\to\bar{f})+N(B\to f)}$

ϕ_3 through $b \to u$ transition

$$\mathcal{A}_{CP}(K^+\pi^-) = \frac{2|T||P|\sin\Delta\delta\sin\phi_3}{|T|^2+|P|^2+2|T||P|\cos\Delta\delta\cos\phi_3}$$

$\mathcal{A}_{CP}(K^+\pi^-)$ =

–10. 1 ± 2.5 (stat) ± 0.5 (syst) %

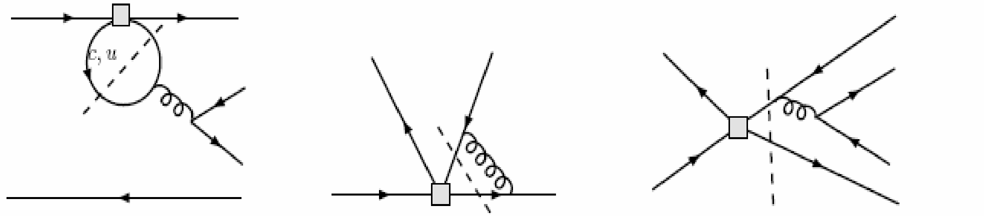
3.9σ

w/ BaBar → > 5σ

$\mathcal{A}_{K\pi}, \mathcal{A}_{\pi\pi}$ Sizable

ynamical enhancement mechanism → Large Branching ratios of PP, VP and VV
odes [Keum, Li, Sanda]

ew source of strong phases → Large direct CP violations [Keum, Li]

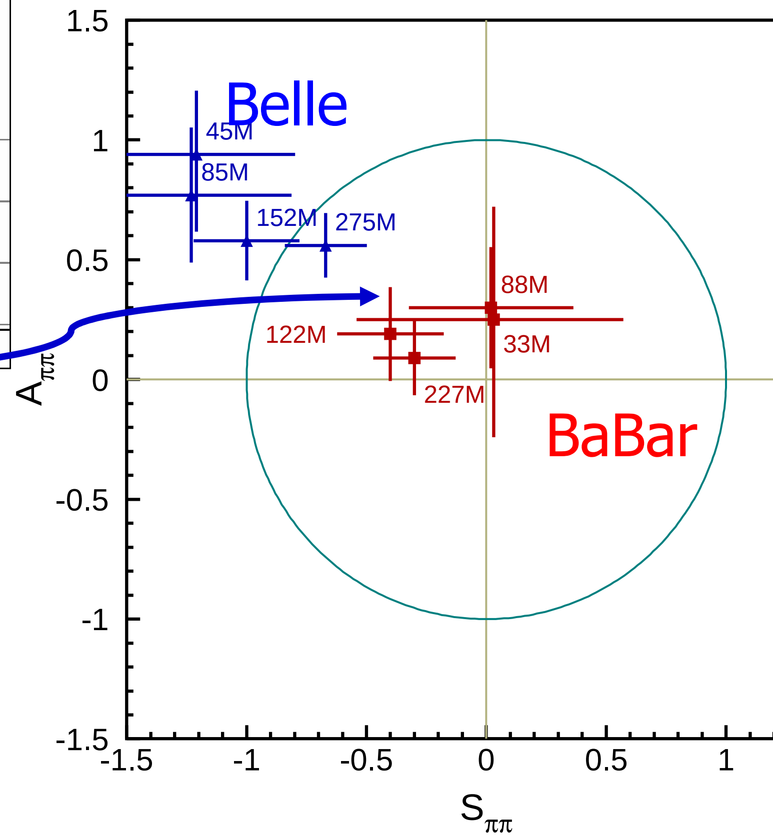


BSS – mechanism *Vertex diagram in QCDF* *Annihilation diagram in PQCD*

Direct CP Asymmetry in $\pi\pi$ and $K\pi$ decays (%)

de	BELLE	BABAR	PQCD	QCDF(BBNS)
K^-	$-10.1 \pm 2.5 \pm 0.5$	$-13.3 \pm 3.0 \pm 0.9$	$-12.9 \sim -21.9$	$-5.4 \sim +13.6$
π^-	$58 \pm 15 \pm 7$	$9 \pm 15 \pm 4$	$16.0 \sim 30.0$	$-19.8 \sim 7.2$

Ali @ ICHEP2004



SU(3) relates $\mathcal{A}_{\pi\pi} = -3\mathcal{A}_{K\pi}$
(Gronau & Rosner)

Sizable T-P Strong Phase

$\mathcal{A}_{K\pi^0} \neq \mathcal{A}_{K\pi}$?

Y. Chao, P. Chang et al. PRL 2004

728 ± 34 evts 253 fb

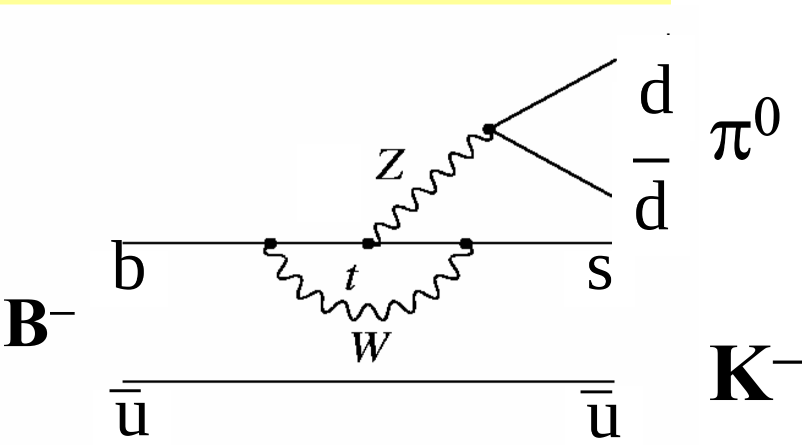
$\mathcal{A}_{CP}(K^+\pi^0) = 4 \pm 5 \pm 2\ \%$

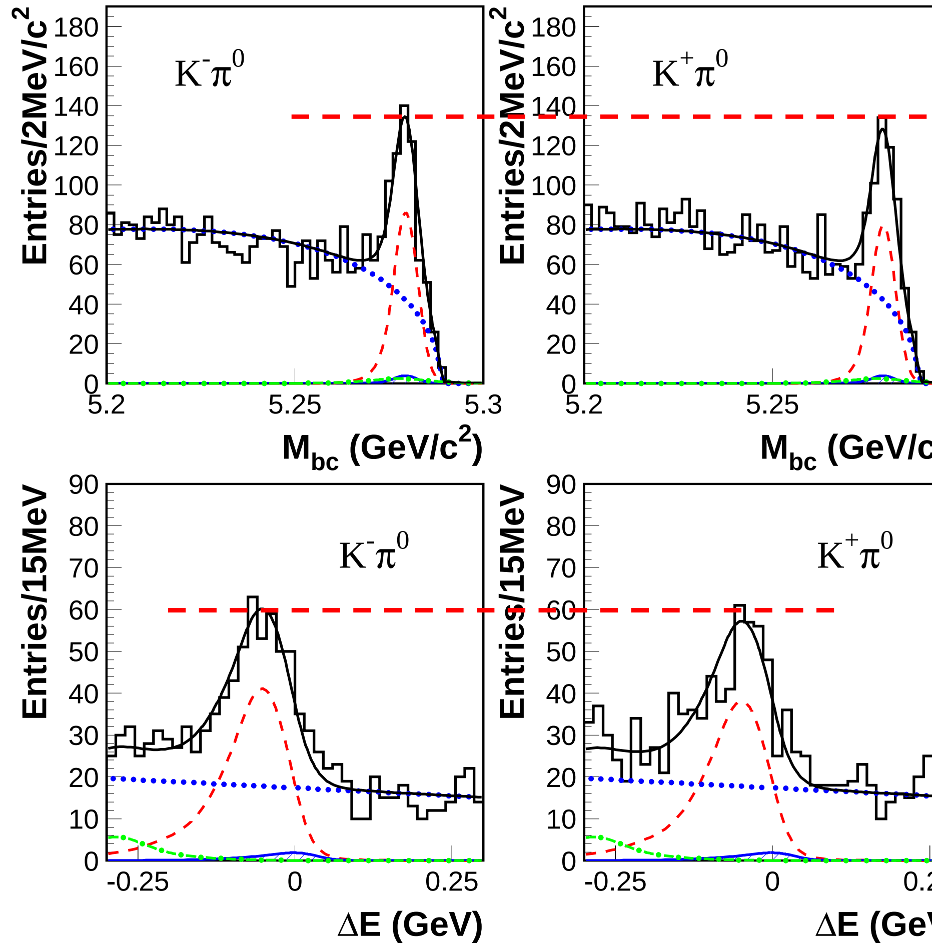
2.4σ from $K^+\pi^-$

(**3.6σ** w/ BaBar)

Large EWPenguin ?

Large C ?





Observation of $B^0 \to \pi^0\pi^0$

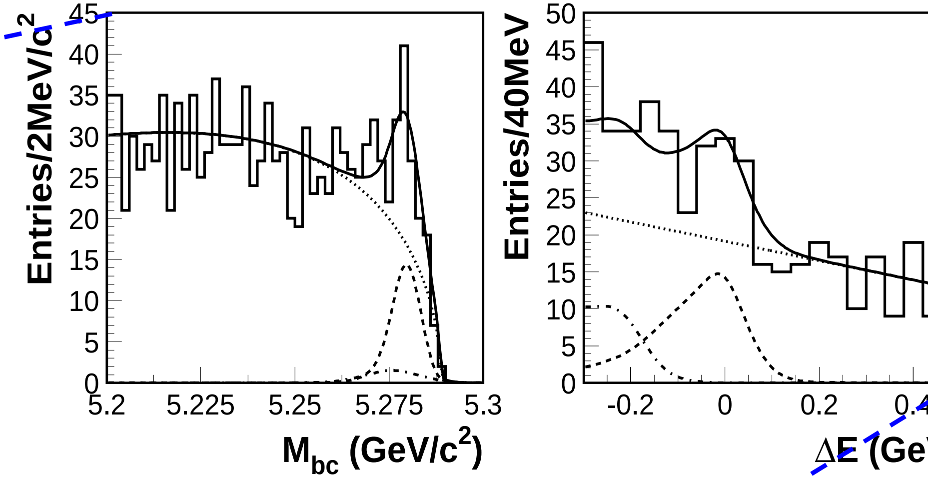
Y. Chao, P. Chang et al. PRL 2005

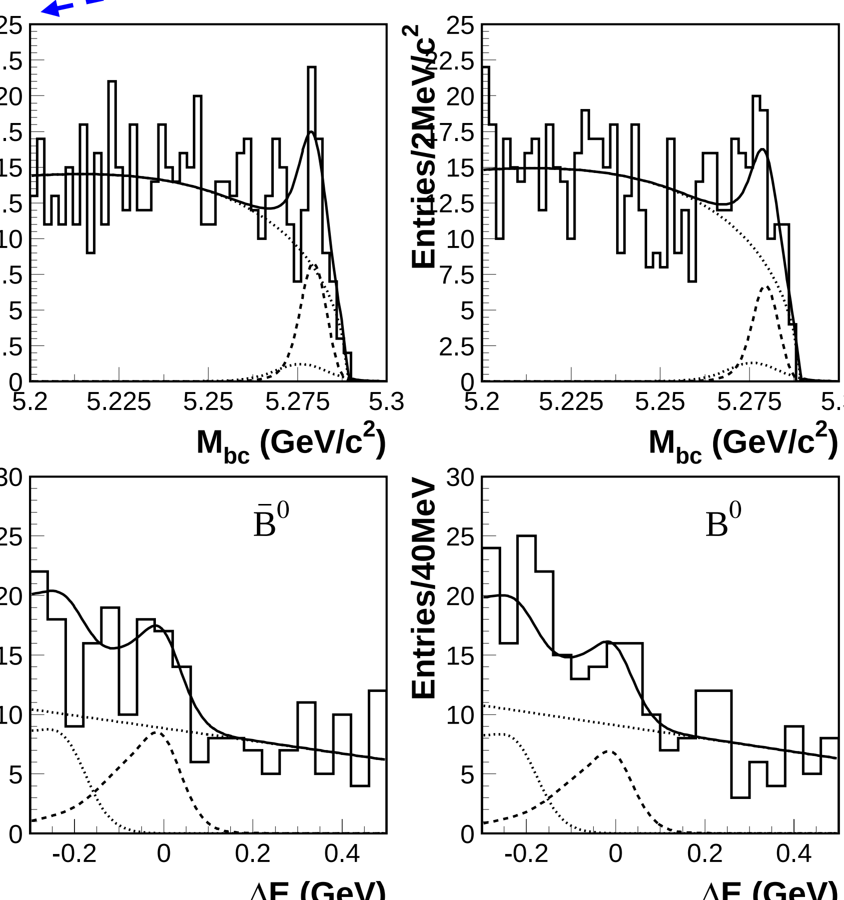
82 ± 16 evts

253 fb

$\mathcal{B} = (2.32 \pm^{0.44}_{0.48} \pm^{0.22}_{0.18}) \times 10^{-6}$

5.8 σ





Use same flavor-tagging as TCPV analysis

$\mathcal{A}_{CP} = 44 \pm^{53}_{52} \pm 17\ \%$

Main limiting factor for ϕ_2 program from $\pi\pi$

ϕK^* polarization anomaly?

Longitudinal polarization is expected to be dominant.
This is true for most of the tree dominated decays:

BaBar(89M)	$f_L(\rho^+\rho^-) =$	$\boxed{0.99} \pm 0.03^{+0.04}_{-0.03}$
BaBar(89M)	$f_L(\rho^+\rho^0) =$	$\boxed{0.97}^{+0.03}_{-0.07} \pm 0.04$
Belle(85M)	$f_L(\rho^+\rho^0) =$	$\boxed{0.95} \pm 0.11 \pm 0.02$
BaBar(89M)	$f_L(\rho^+\omega) =$	$\boxed{0.88}^{+0.12}_{-0.15} \pm 0.03$

But Low longitudinal polarization fractions were already found in $B \to \phi K^*$ decays:

BaBar(227M)	$f_L(\phi K^{*0}) =$	$\boxed{0.52} \pm 0.05 \pm 0.0$
Belle(152M)	$f_L(\phi K^{*0}) =$	$\boxed{0.52} \pm 0.07 \pm 0.0$
BaBar(89M)	$f_L(\phi K^{*+}) =$	$\boxed{0.46} \pm 0.12 \pm 0.0$
Belle(152M)	$f_L(\phi K^{*+}) =$	$\boxed{0.49} \pm 0.13 \pm 0.0$

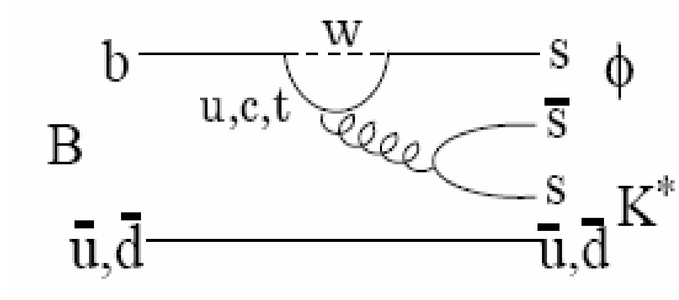
ew physics Grossman, IJMP A19, 907 (2004)
nihilation Kagan, PLB 601, 151 (2004)
scattering Colangelo, PLB 597, 291 (2004)
ansverse gluon (Hou et al., hep-ph/0408007)

…?

Polarization in $B \to \phi K^*$

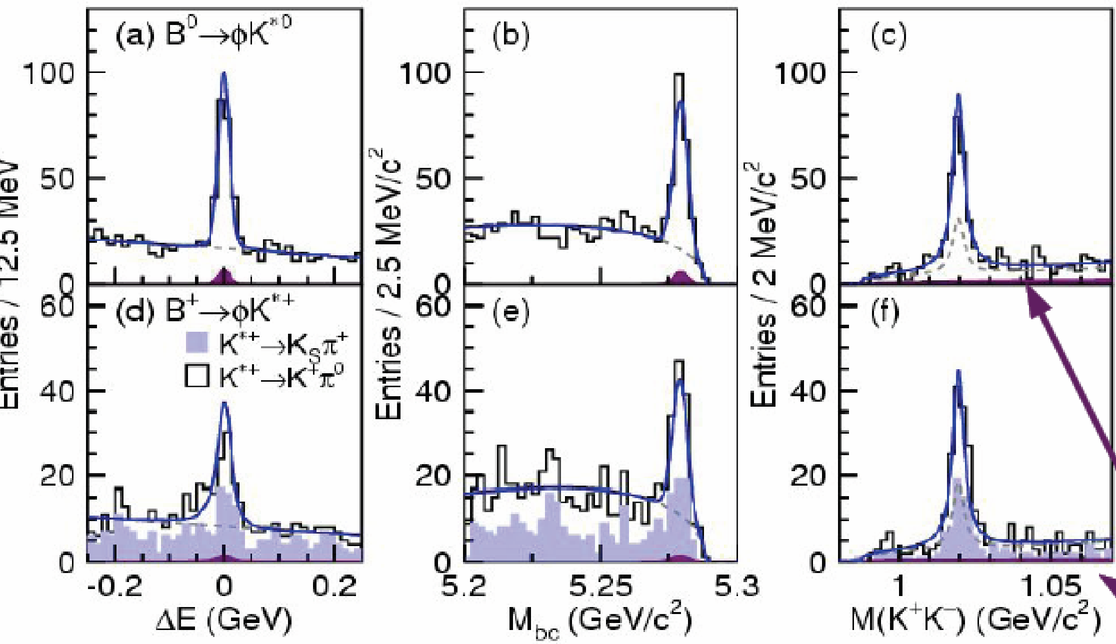
K.F. Chen et al., hep-ex/0503013, to appear PRL

ure penguin $b \to s$ decay



- Signal yields are extracted by fits to ΔE, M_{bc}, and M_{KK} :

253 fb



- $N_{sig}(B\to\phi K^{*0})$: 173 ±16
- $N_{sig}(B\to\phi K^{*+})$: $85\ ^{+12}_{-11}$

$A_{CP}(B\to\phi K^{*0})$ = 0.02 ±0.09 ±0.02

$A_{CP}(B\to\phi K^{*+})$ = −0.02 ±0.14 ±0.03

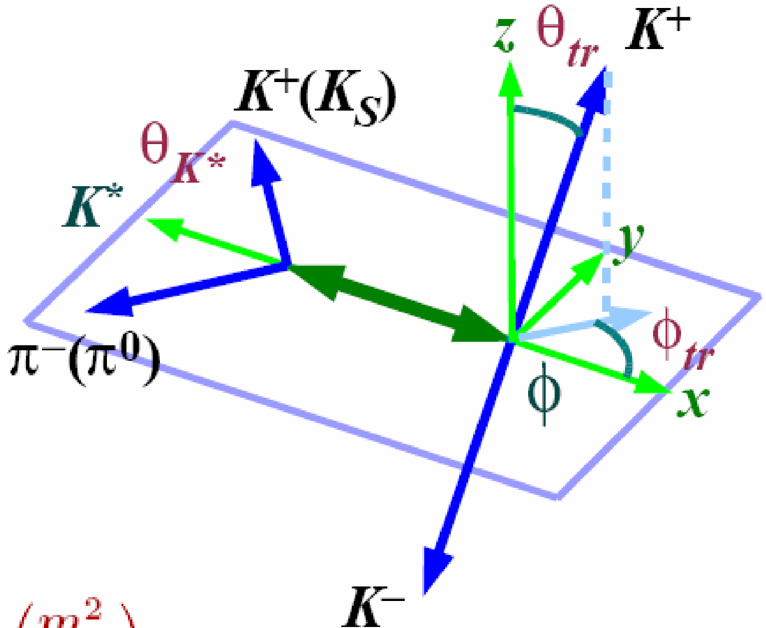
$B\to f_0K^*$ & (non-ϕ) KKK^* component

φK* Polarization

$$\frac{d^3\Gamma(\phi_{\rm tr},\cos\theta_{\rm tr},\cos\theta_{K^*})}{d\phi_{\rm tr}d\cos\theta_{\rm tr}d\ \cos\theta_{K^*}} = \frac{9}{32\pi}[|A_\perp|^2 2\cos^2\theta_{\rm tr}\sin^2\theta_{K^*}$$
$$+|A_\parallel|^2 2\sin^2\theta_{\rm tr}\sin^2\phi_{\rm tr}\sin^2\theta_{K^*}$$
$$+|A_0|^2 4\sin^2\theta_{\rm tr}\cos^2\phi_{\rm tr}\cos^2\theta_{K^*}$$
$$+\sqrt{2}{\rm Re}(A_\parallel^* A_0)\sin^2\theta_{\rm tr}\sin 2\phi_{\rm tr}\sin 2\theta_{K^*}$$
$$-\eta\sqrt{2}{\rm Im}(A_0{}^* A_\perp)\sin 2\theta_{\rm tr}\cos\phi_{\rm tr}\sin 2\theta_{K^*}$$
$$-2\eta{\rm Im}(A_\parallel^* A_\perp)\sin 2\theta_{\rm tr}\sin\phi_{\rm tr}\sin^2\theta_{K^*}]\ ,$$

($\eta = 1$ for $\bar{b}$ or -1 for b)

transversity basis



$$\boxed{f_L = \frac{|A_0|^2}{|A_0|^2+|A_\parallel|^2+|A_\perp|^2}}$$

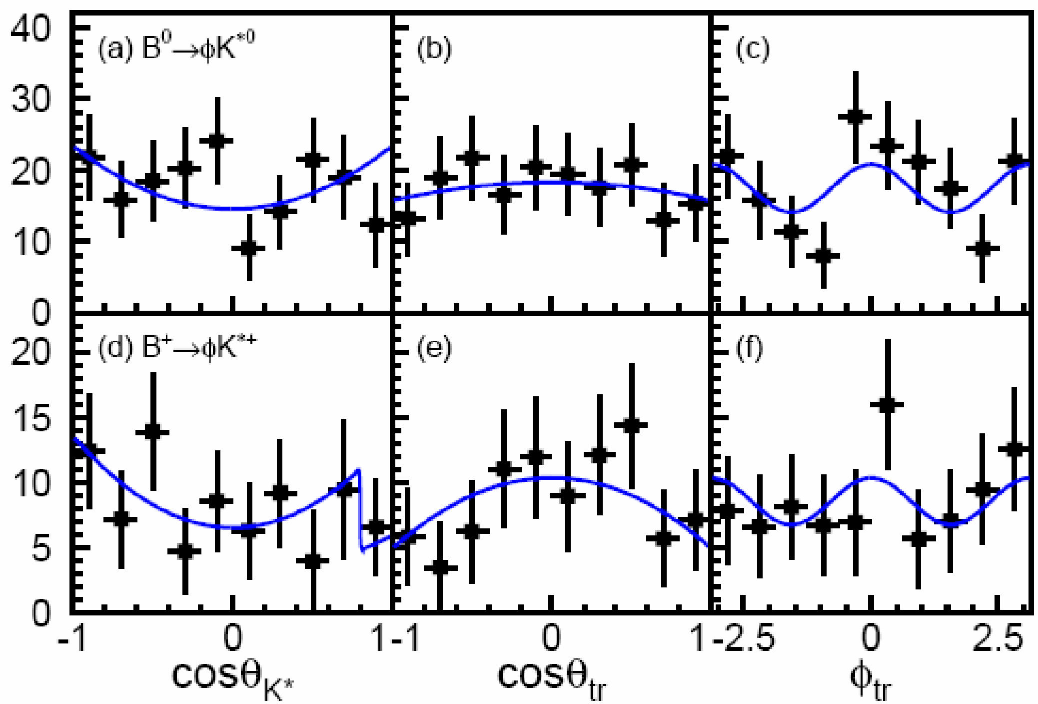
Naively

$$\approx 1 - O\left(\frac{m_V^2}{m_B^2}\right) \approx 1$$

normalization: $|A_0|^2 + |A_\parallel|^2 + |A_\perp|^2 = 1$

phase convention: take A_0 real

Angular Analysis for ϕK^* Polarization



Confirm f_L ~ 0.

	ϕK^{*0}	ϕK^{*+}
$\|A_0\|^2$	$0.45 \pm 0.05 \pm 0.02$	$0.52 \pm 0.08 \pm 0.03$
$\|A_\perp\|^2$	$0.30 \pm 0.06 \pm 0.02$	$0.19 \pm 0.08 \pm 0.02$
$\arg(A_\parallel)$	$2.39 \pm 0.24 \pm 0.04$	$2.10 \pm 0.28 \pm 0.04$
$\arg(A_\perp)$	$2.51 \pm 0.23 \pm 0.04$	$2.31 \pm 0.30 \pm 0.07$

4.3σ evidence for FSI (strong phas

New Physics Test with ϕK^* Polarization

	$\bar{b}$ decays $B(\phi K^{*0};\ \phi K^{*+})$	b decays $\overline{B}\ (\phi\overline{K}^{*0};\ \phi K^{*-})$
$\lvert A_0\rvert^2$	$0.39 \pm 0.08 \pm 0.03$	$0.51 \pm 0.07 \pm 0.02$
$\lvert A_\perp\rvert^2$	$0.37 \pm 0.09 \pm 0.02$	$0.25 \pm 0.07 \pm 0.01$
$\arg(A_\parallel)$	$2.72^{+0.46}_{-0.38} \pm 0.14$	$2.08 \pm 0.31 \pm 0.04$
$\arg(A_\perp)$	$2.81 \pm 0.36 \pm 0.11$	$2.22 \pm 0.35 \pm 0.05$
$\boldsymbol{A_T^0}$	$\mathbf{0.13^{+0.11}_{-0.14} \pm 0.04}$	$\mathbf{0.28 \pm 0.08 \pm 0.01}$
$\boldsymbol{A_T^\parallel}$	$\mathbf{0.03 \pm 0.08 \pm 0.01}$	$\mathbf{0.03 \pm 0.06 \pm 0.01}$

$$\mathbf{A_T^0} \equiv \frac{\mathrm{Im}(\mathbf{A}_\perp \mathbf{A}_0^*)}{\mathbf{A}_0^2 + \mathbf{A}_\perp^2 + \mathbf{A}_\parallel^2}; \qquad \mathbf{A_T^\parallel} \equiv \frac{\mathrm{Im}(\mathbf{A}_\perp \mathbf{A}_\parallel^*)}{\mathbf{A}_0^2 + \mathbf{A}_\perp^2 + \mathbf{A}_\parallel^2}$$

T-odd CPV

Datta & London 2004

No significant difference between B and $\overline{B}$

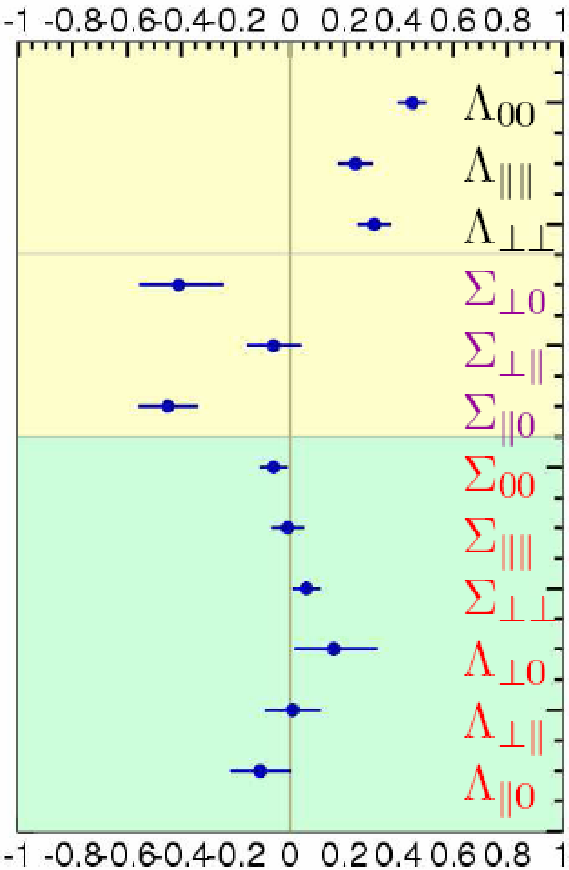
More Observables with ϕK^* Polarization

$$\Lambda_{\lambda\lambda} = \frac{1}{2}(|A_\lambda|^2 + |\overline{A}_\lambda|^2) \qquad \Sigma_{\lambda\lambda} = \frac{1}{2}(|A_\lambda|^2 - |\overline{A}_\lambda|^2)$$

$$\Sigma_{\perp i} = -\mathrm{Im}(A_\perp A_i^* + \overline{A}_\perp \overline{A}_i^*) \qquad \Lambda_{\perp i} = -\mathrm{Im}(A_\perp A_i^* - \overline{A}_\perp \overline{A}_i^*)$$

$$\Lambda_{\|0} = \mathrm{Re}(A_\| A_0^* + \overline{A}_\| \overline{A}_0^*) \qquad \Sigma_{\|0} = \mathrm{Re}(A_\| A_0^* - \overline{A}_\| \overline{A}_0^*)$$

$$(\lambda \in \{0, \|, \perp\}, \quad i \in \{0, \|\})$$



$0.45 \pm 0.05 \pm 0.02$

$0.24 \pm 0.06 \pm 0.02$

$0.31 \pm 0.06 \pm 0.01$

$-0.41 \; {}^{+0.16}_{-0.14} \pm 0.04$

$-0.06 \pm 0.10 \pm 0.01$

$-0.45 \pm 0.11 \pm 0.01$

$-0.06 \pm 0.05 \pm 0.01$

$-0.01 \pm 0.06 \pm 0.01$

$0.06 \pm 0.05 \pm 0.01$

$0.16 \; {}^{+0.16}_{-0.14} \pm 0.03$

$0.01 \pm 0.10 \pm 0.02$

$-0.11 \pm 0.11 \pm 0.02$

Non-0 can be caused by FSI

If no new physics, should be 0.

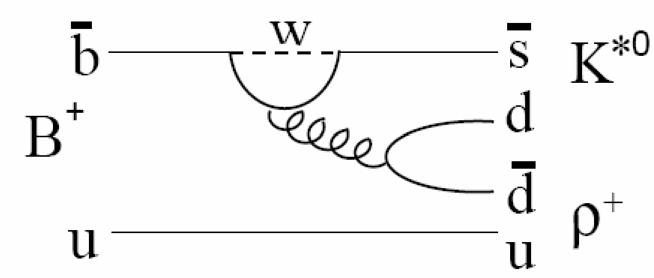
No evidence for new physics

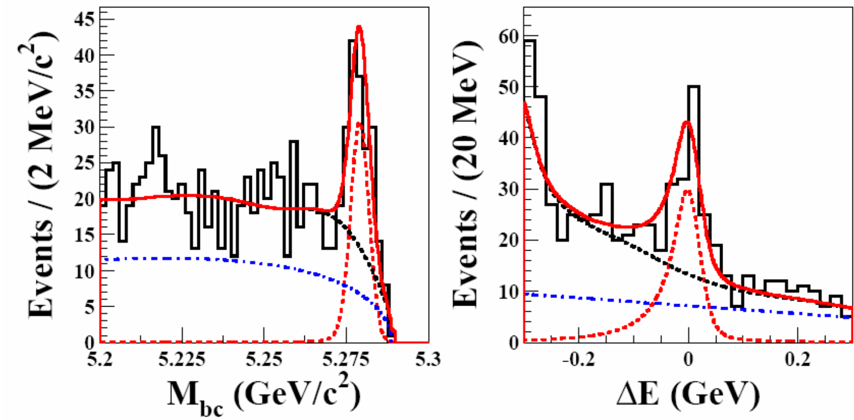
Polarization in $B \to \rho^+ K^{*0}$

J. Zhang et al., hep-ex/0503013, submitted PRL

nother pure penguin $b \to s$ decay

253 fb



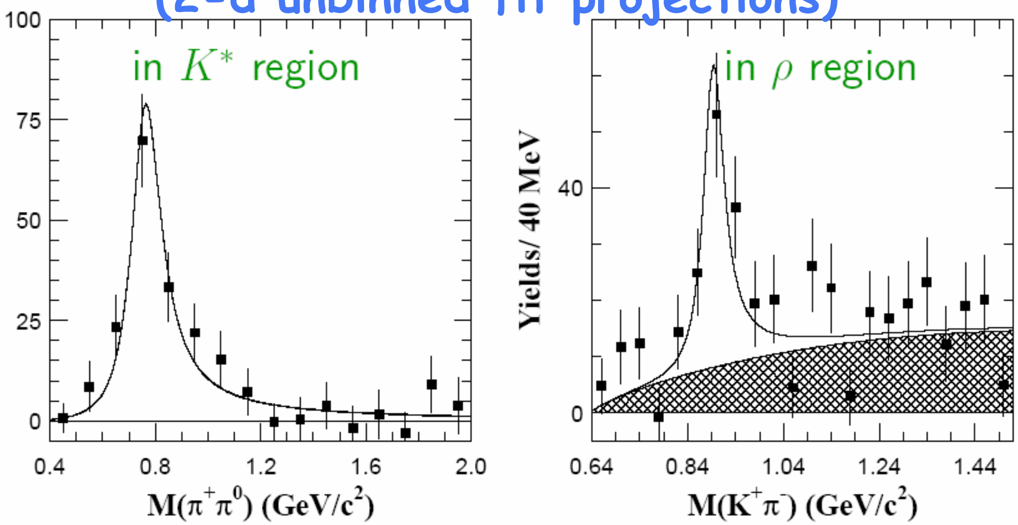


$N_{B^+ \to K^+\pi^+\pi^-\pi^0}$: 134.8 ± 16.9

(including bkg from non-resonant process)

1D Binned χ^2 Mass Fit

(2-d unbinned fit projections)



in ρ region:

ρ : 125.4 ± 15.8;

NR $K^*\pi\pi$: -0.3 ± 3.0

in K^* region:

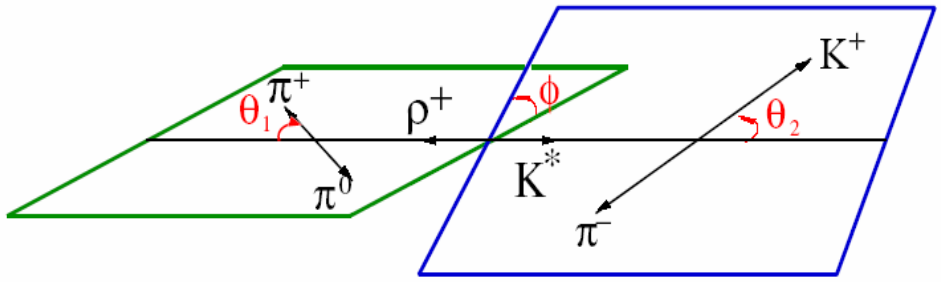
K^* : 85.4 ± 16.1 $(5.2\,\sigma)$

NR $\rho K\pi$: 28.8 ± 4.1

Non-resonant $\rho^+ K^+ \pi^-$ Significant

Take into account in Angular Analy

Angular (f_L) Analysis for ρ^+K^{*0}

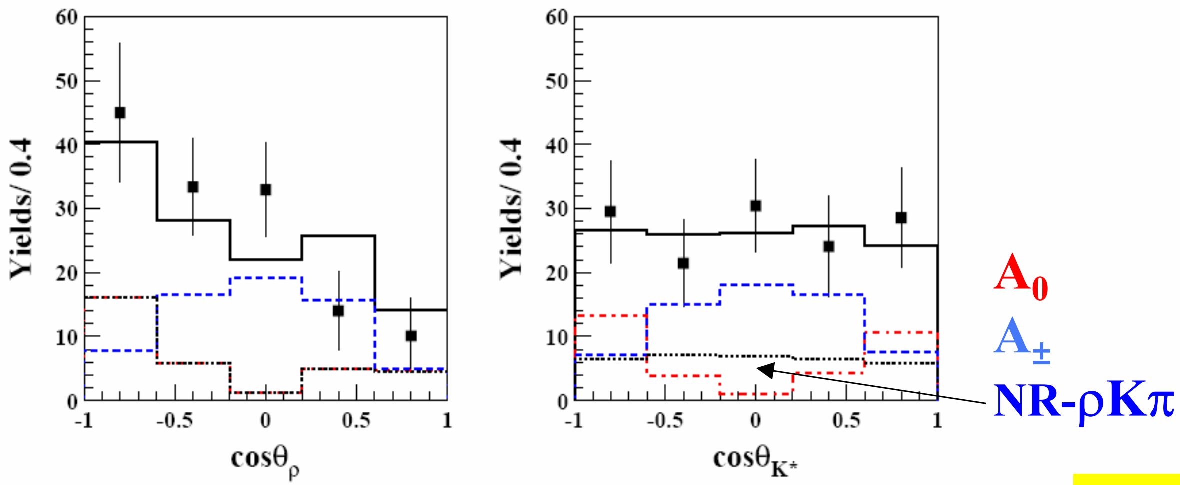


helicity basis

integrated over ϕ

θ_1 (θ_2): ρ (K^*) helicity angle

$$\frac{1}{\Gamma}\frac{d^3\Gamma}{d\cos\theta_1 d\cos\theta_2} = \frac{9}{4} f_L \cos^2\theta_1 \cos^2\theta_2 + \frac{9}{16}(1-f_L)\sin^2\theta_1 \sin^2\theta_2$$



$$f_L = 0.43 \pm 0.11(\text{stat})^{+0.05}_{-0.02}(\text{sys})$$

$$\mathcal{B} = (8.9 \pm 1.7(\text{stat}) \pm 1.2(\text{sys})) \times 10^{-6}$$

Another pure-P f_L ~ 0.5

Khh Dalitz Analysis Summary

A. Garmash et al., hep-ex/0412066, submitted PRD

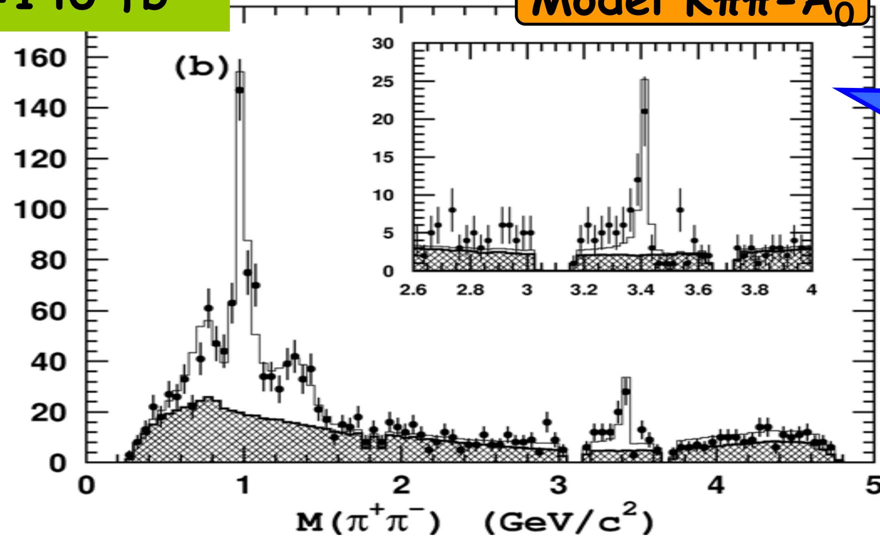
140 fb

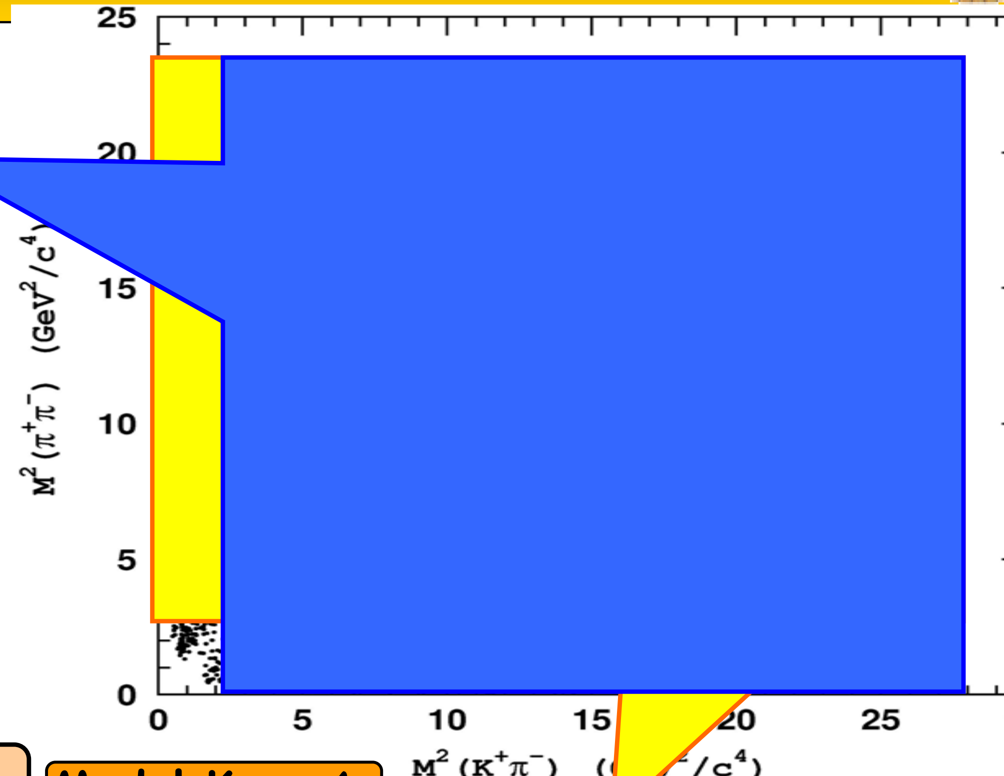
Mode	$\mathcal{B}(B^+ \to Rh^+) \times \mathcal{B}(R \to h^+h^-) \times 10^6$	$\mathcal{B}(B^+ \to Rh^+) \times 10^6$
$\boxed{K^+\pi^+\pi^-}$ charmless total	–	$46.6 \pm 2.1 \pm 4.3$
$K^*(892)^0\pi^+$, $K^*(892)^0 \to K^+\pi^-$	$6.55 \pm 0.60 \pm 0.60^{+0.38}_{-0.57}$	$9.83 \pm 0.90 \pm 0.90^{+0.57}_{-0.86}$
$K_0^*(1430)^0\pi^+$, $K_0^*(1430)^0 \to K^+\pi^-$	$27.9 \pm 1.8 \pm 2.6^{+8.5}_{-5.4}$	$45.0 \pm 2.9 \pm 6.2^{+13.7}_{-8.7}$
	$(5.12 \pm 1.36 \pm 0.49^{+1.91}_{-0.51})$	$(8.26 \pm 2.20 \pm 1.19^{+3.08}_{-0.82})$
$K^*(1410)^0\pi^+$, $K^*(1410)^0 \to K^+\pi^-$	< 2.0	–
$K^*(1680)^0\pi^+$, $K^*(1680)^0 \to K^+\pi^-$	< 3.1	–
$K_2^*(1430)^0\pi^+$, $K_2^*(1430)^0 \to K^+\pi^-$	< 2.3	–
$\rho(770)^0K^+$, $\rho(770)^0 \to \pi^+\pi^-$	$4.78 \pm 0.75 \pm 0.44^{+0.91}_{-0.87}$	$4.78 \pm 0.75 \pm 0.44^{+0.91}_{-0.87}$
$f_0(980)K^+$, $f_0(980) \to \pi^+\pi^-$	$7.55 \pm 1.24 \pm 0.69^{+1.48}_{-0.96}$	–
$f_2(1270)K^+$, $f_2(1270) \to \pi^+\pi^-$	< 1.3	–
Non-resonant	–	$17.3 \pm 1.7 \pm 1.6^{+17.1}_{-7.8}$
$\boxed{K^+K^+K^-}$ charmless total	–	$30.6 \pm 1.2 \pm 2.3$
ϕK^+, $\phi \to K^+K^-$	$4.72 \pm 0.45 \pm 0.35^{+0.39}_{-0.22}$	$9.60 \pm 0.92 \pm 0.71^{+0.78}_{-0.46}$
$\phi(1680)K^+$, $\phi(1680) \to K^+K^-$	< 0.8	
$f_0(980)K^+$, $f_0(980) \to K^+K^-$	< 2.9	
$f_2'(1525)K^+$, $f_2'(1525) \to K^+K^-$	< 4.9	
$a_2(1320)K^+$, $a_2(1320) \to K^+K^-$	< 1.1	
Non-resonant	–	$24.0 \pm 1.5 \pm 1.8^{+1.9}_{-5.7}$
$\chi_{c0}K^+$, $\chi_{c0} \to \pi^+\pi^-$	$1.37 \pm 0.28 \pm 0.12^{+0.34}_{-0.35}$	–
$\chi_{c0}K^+$, $\chi_{c0} \to K^+K^-$	$0.86 \pm 0.26 \pm 0.06^{+0.20}_{-0.05}$	–
	$(2.58 \pm 0.43 \pm 0.19^{+0.20}_{-0.05})$	–
$\chi_{c0}K^+$ combined	–	$196 \pm 35 \pm 33^{+197}_{-26}$

$B^+ \to K^+\pi^+\pi^-$: Model Fitting to Signal

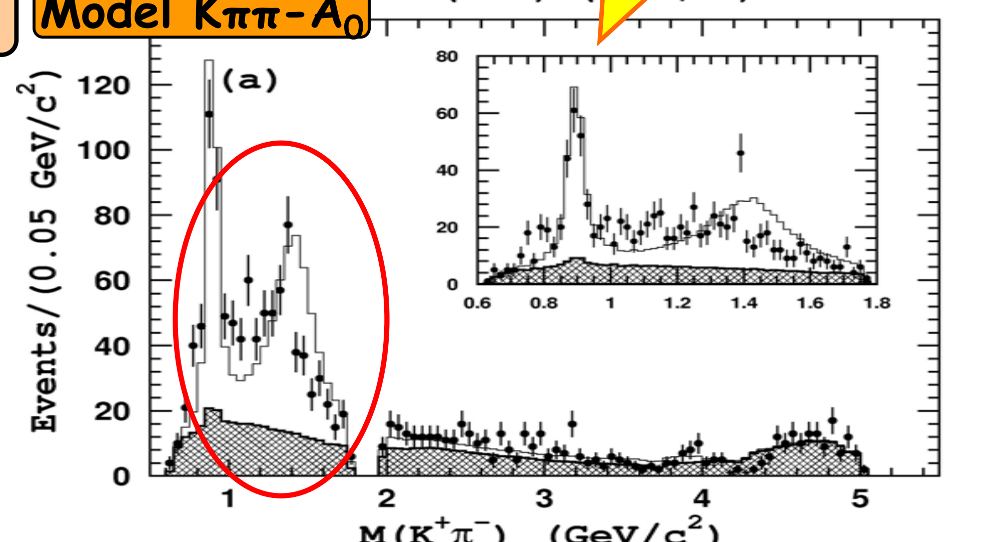
:140 fb^{-1}

Model $K\pi\pi$-A_0





Model $K\pi\pi$-A_0



odel $K\pi\pi$-A_J:

$S_{AJ}(K\pi\pi) = A_1(K^*(892)) + A_0(K^*_0(1430))$

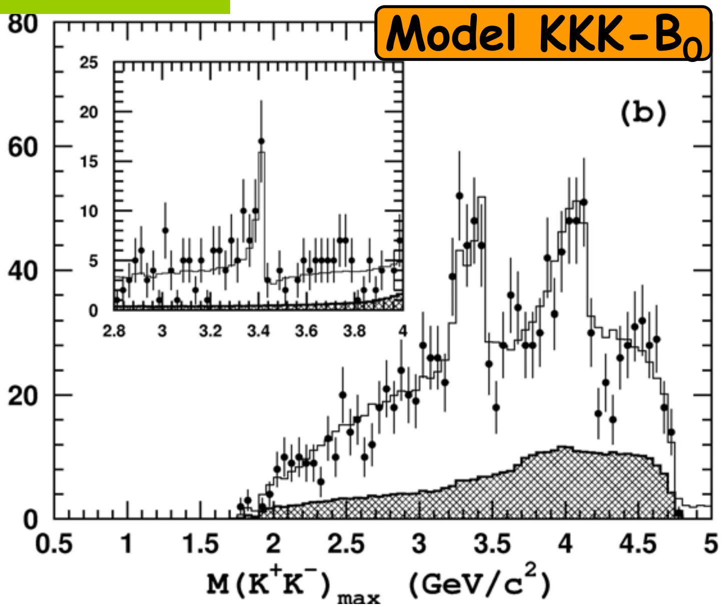
$+ A_1(\rho(770)) + A_0(f_0(980))$

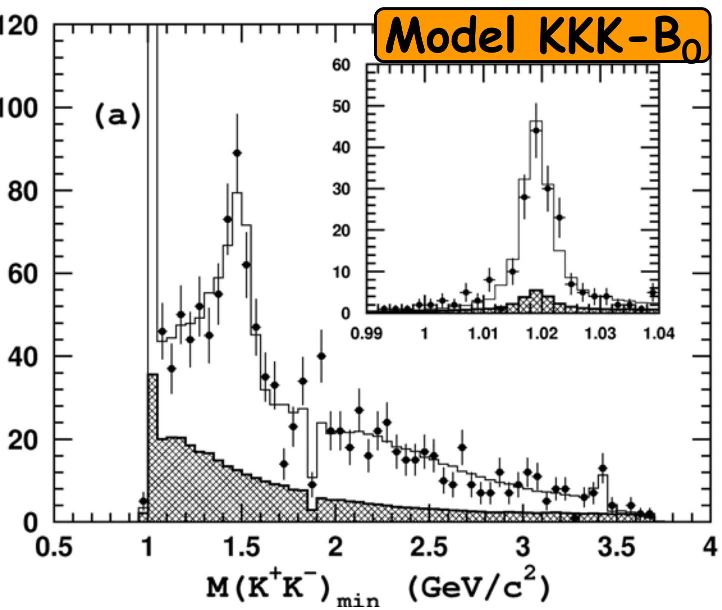
$+ A_J(f_X(1300)) + A_0(\chi_{c0})$

it the data with different spin assumptions

$B^+ \to K^+K^+K^-$: Model Fitting to Signal

=140 fb^{-1}





Model KKK-B_J:

$$S_{BJ}(KKK) = A_1(\varphi(1020)) + A_J(f_X(1500)) + A_0(\chi_{c0}) + A_{NR}$$

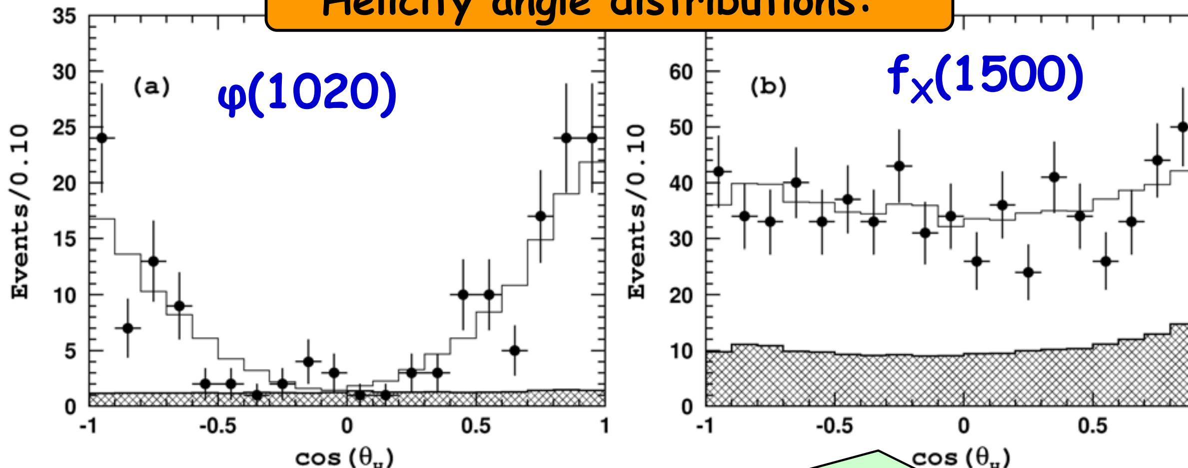
A_{NR} Parameterizations used:

$$A_{NR}(s_{13},s_{23}) = a_1 e^{i\delta}$$

$$A_{NR}(s_{13},s_{23}) = a_1[(1/s_{13})^\beta + (1/s_{23})^\beta]e^{i\delta}$$

$$A_{NR}(s_{13},s_{23}) = a_1(e^{-\beta s_{13}} + e^{-\beta s_{23}})e^{i\delta}$$

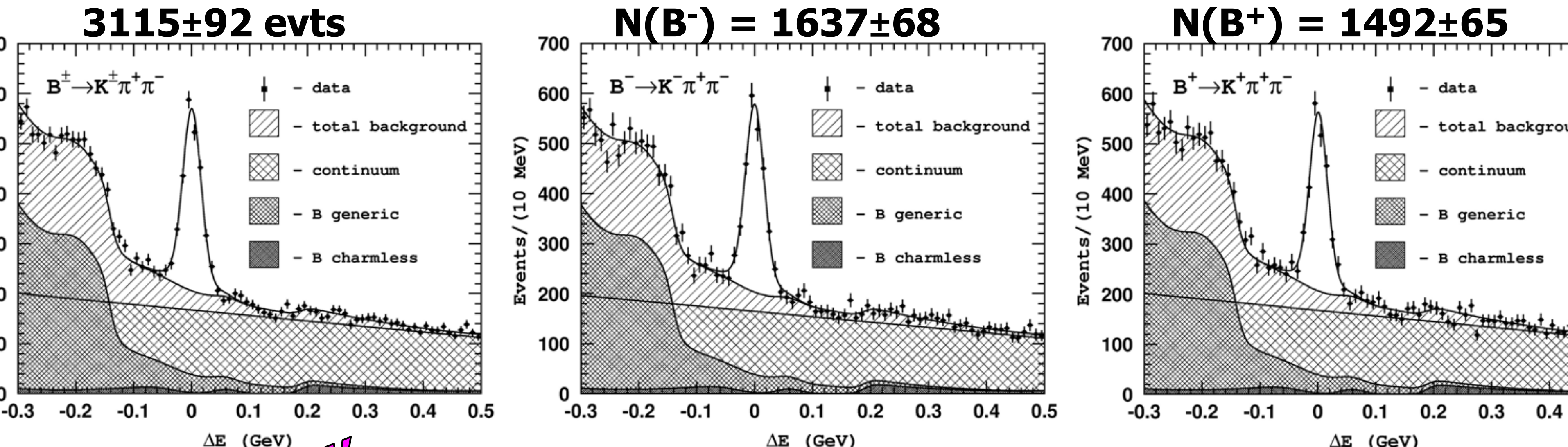
Helicity angle distributions:



$f_X(1500)$ is best fit with the scalar hypothesis

Search for DCPV in $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}$

253 fb



preliminary

$$\mathcal{A}_{CP}(K^{\pm}\pi^{+}\pi^{-}) = \frac{N(K^{-}\pi^{-}\pi^{+}) - N(K^{+}\pi^{+}\pi^{-})}{N(K^{-}\pi^{-}\pi^{+}) + N(K^{+}\pi^{+}\pi^{-})} = (+4.6 \pm 3.0^{+1.7}_{-1.2})\ \%$$

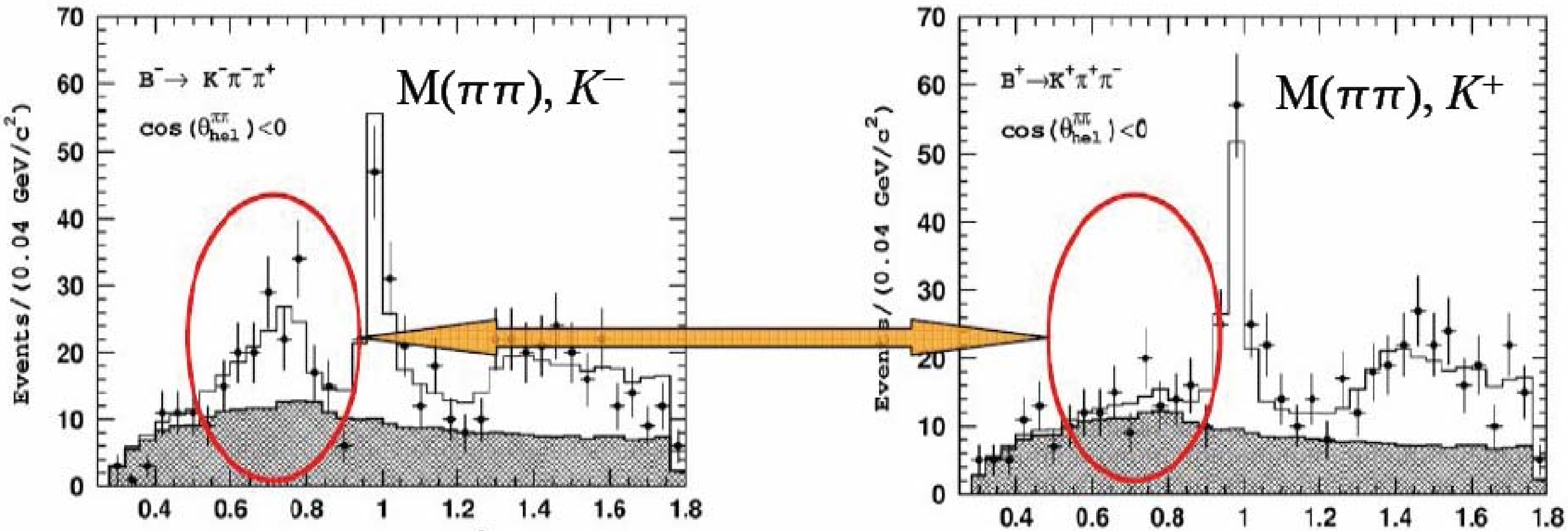
Null asymmetry tests:

- qq related background: $A_{CP}(qq)=(-0.83\pm1.30)\%$
- BB related background: $A_{CP}(BB)=(-1.15\pm2.18)\%$
- B->Dπ->Kππ signal: $A_{CP}(D\pi)=(-1.16\pm0.86)\%$

Considered as a systematic error due to detector asymmetry

DCPV Hint in $B^+ \to \rho^0 K^+$

253 fb



A **2.4σ** hint for Direct CP violation in $B^\pm \to \rho(770)^0 K^\pm$

preliminary

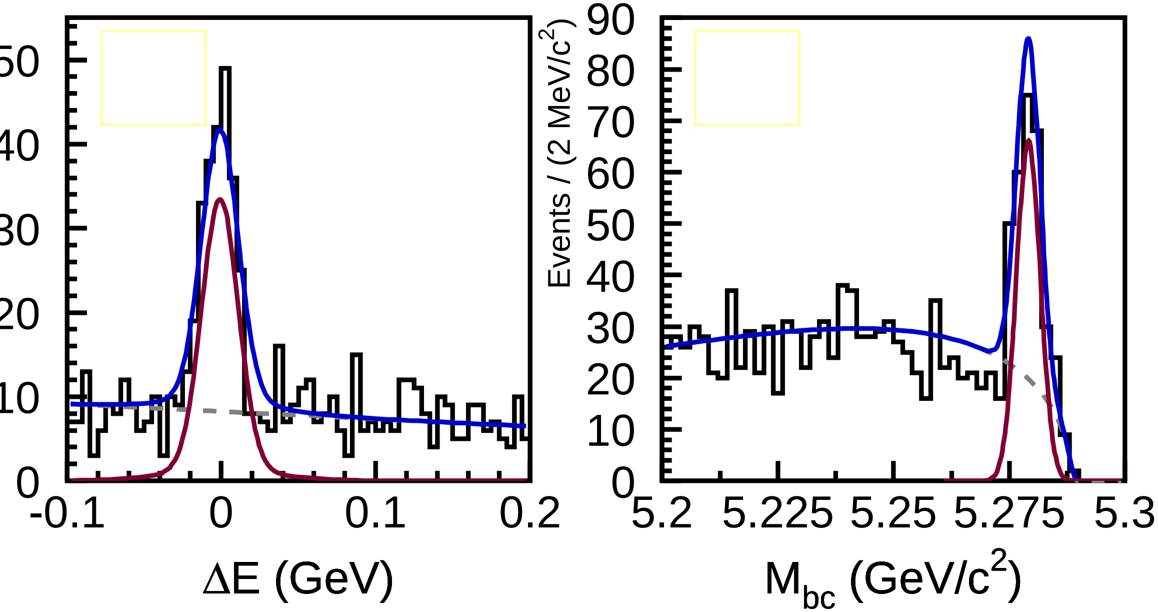
$\mathcal{A}_{CP}(\rho^0 K^\pm) = 27 \pm 12 \pm 2^{+59}_{-3}$ %

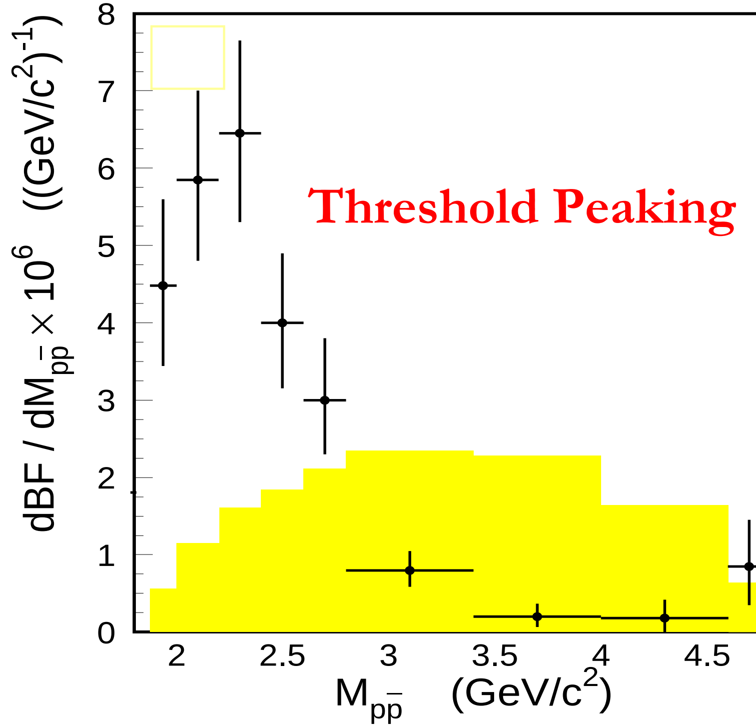
Improved $B^+ \to p\bar{p}K^+$ Measurement

M.Z. Wang et al., PLB 2005

140 fb

217 ± 17 evts





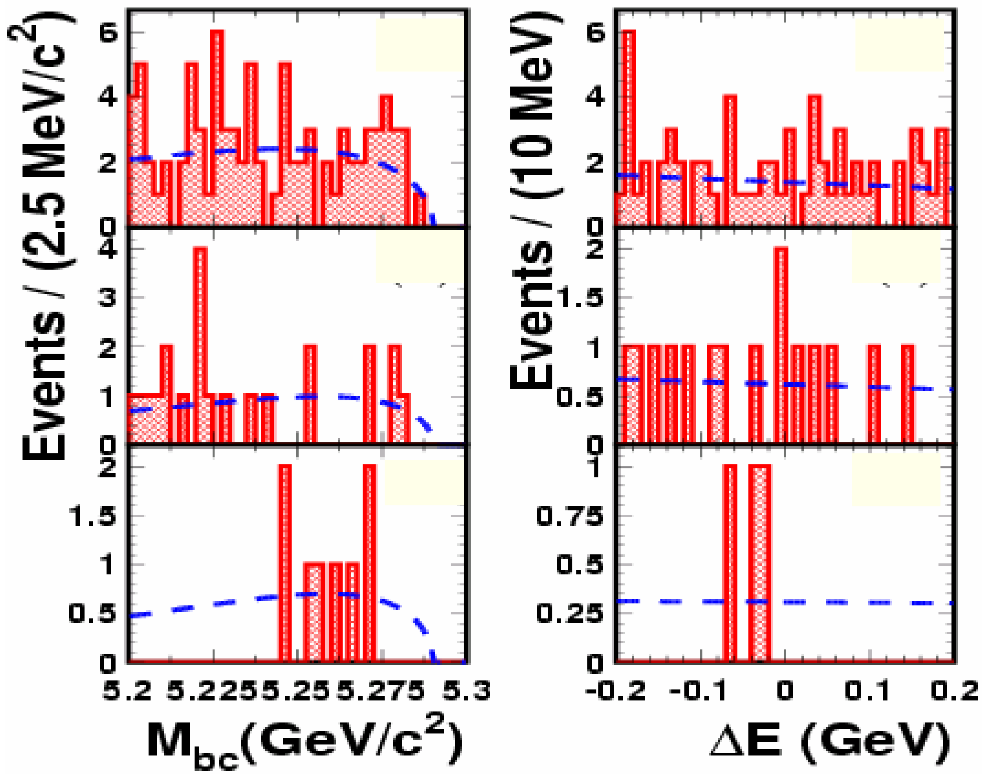
BF: $4.59^{+0.38}_{-0.34} \pm 0.50 \times 10^{-6}$

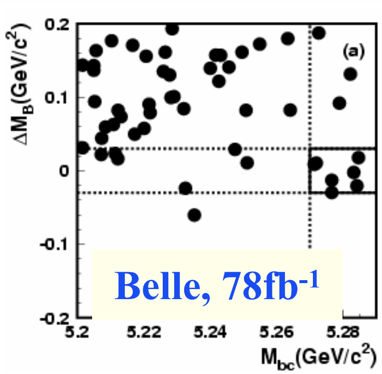
(4.89 x 10^{-6}, PRL92, 131801, 2004)

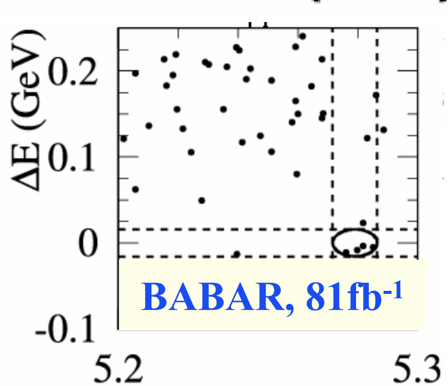
Two-body not yet seen.

$B^0 \to \Lambda\bar{\Lambda}$, $\bar{\Lambda}p$, $p\bar{p}$ and other

M.C. Chang et al. PRD 2005 140 fb







90% confidence level UL:

$B^0 \to p\bar{p}$ $< 4.1 \times 10^{-7}$

$B^0 \to \bar{\Lambda}p$ $< 4.9 \times 10^{-7}$

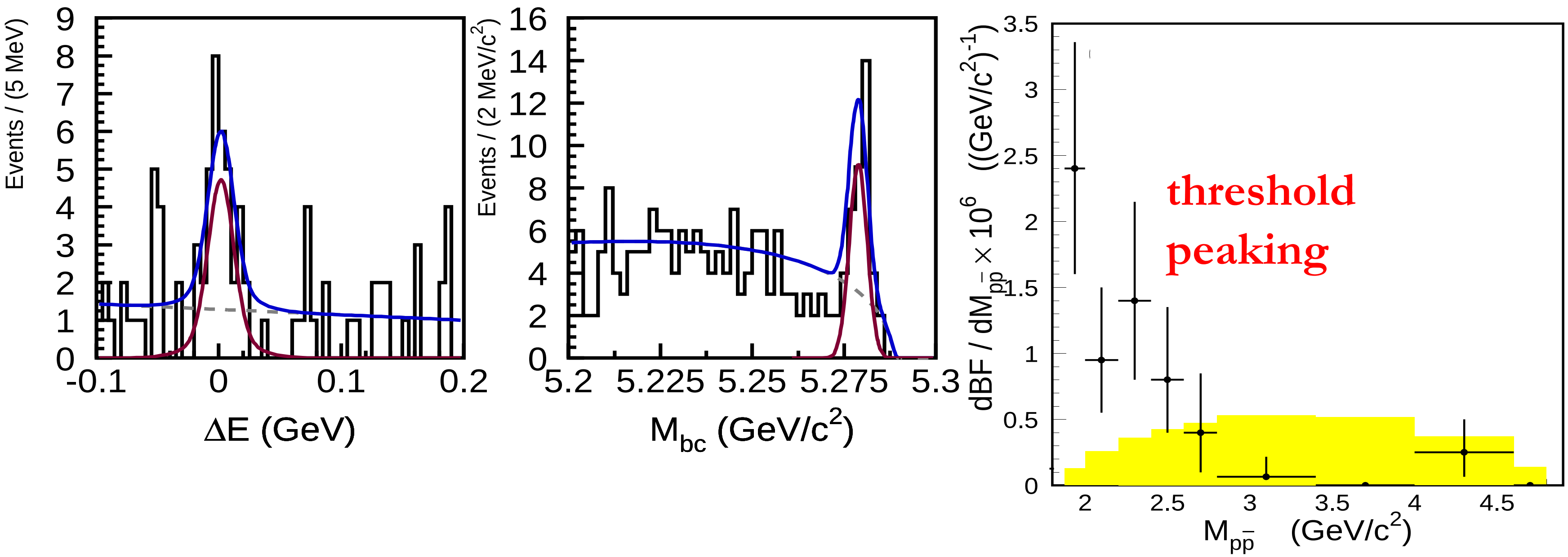
$B^0 \to \Lambda\bar{\Lambda}$ $< 6.9 \times 10^{-7}$

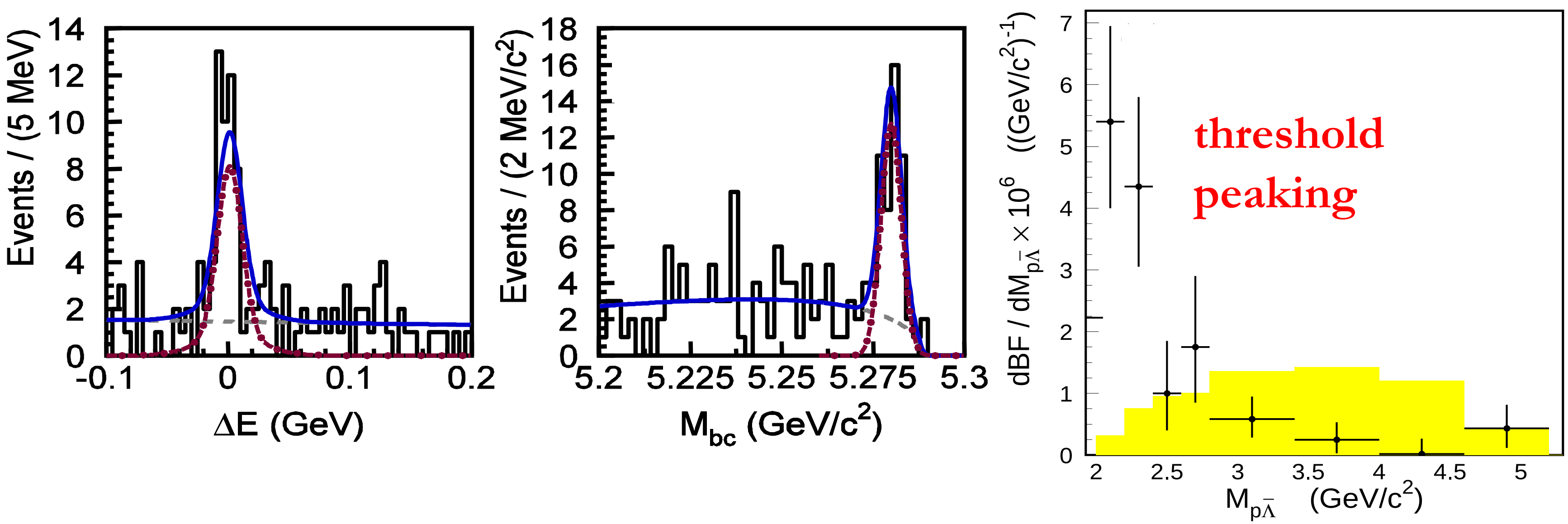
Belle: $B^+ \to J/\psi p\bar{\Lambda}$ $< 4.1 \times 10^{-5}$

BABAR: $B^+ \to J/\psi p\bar{\Lambda}$ $< 2.6 \times 10^{-5}$

$B^+ \to J/\psi p\bar{p}$ $< 1.9 \times 10^{-5}$

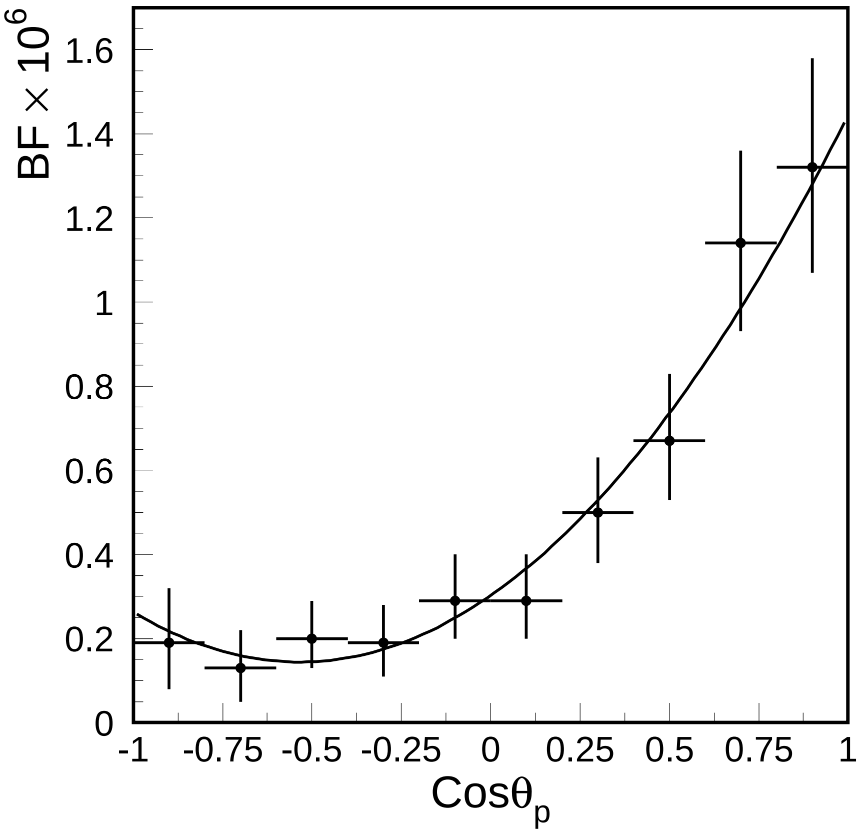
Threshold Peaking: ppKs & pΛπ

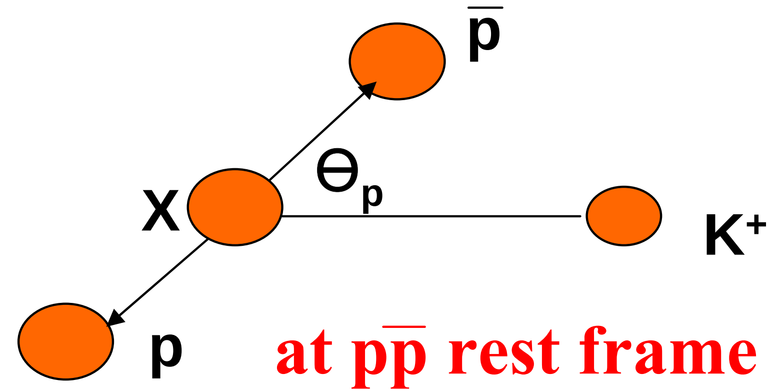




Angular Distribution: ppK$^+$

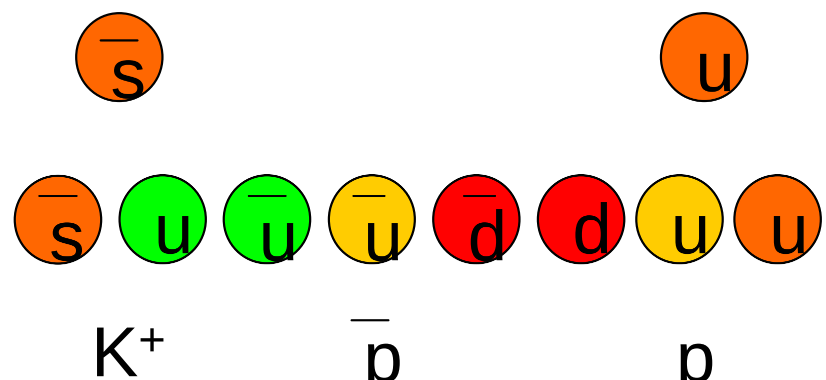
$p\bar{p}K$ signal





b→s dominant process

Fragmentation picture



Proton against K^- ($\bar{p}$ against K^+) : flavor dependence!

(Expect symmetric distribution if effective 2-body)

Outline

- **Machine, Detector, Basic Method**
- **Direct CPV in $K\pi$**
- **Observation of $\pi^0\pi^0$**
- **Polarization in ϕK^*, $\rho^+ K^{*0}$**
- **Khh Dalitz Analysis**
- **Baryonic Modes**

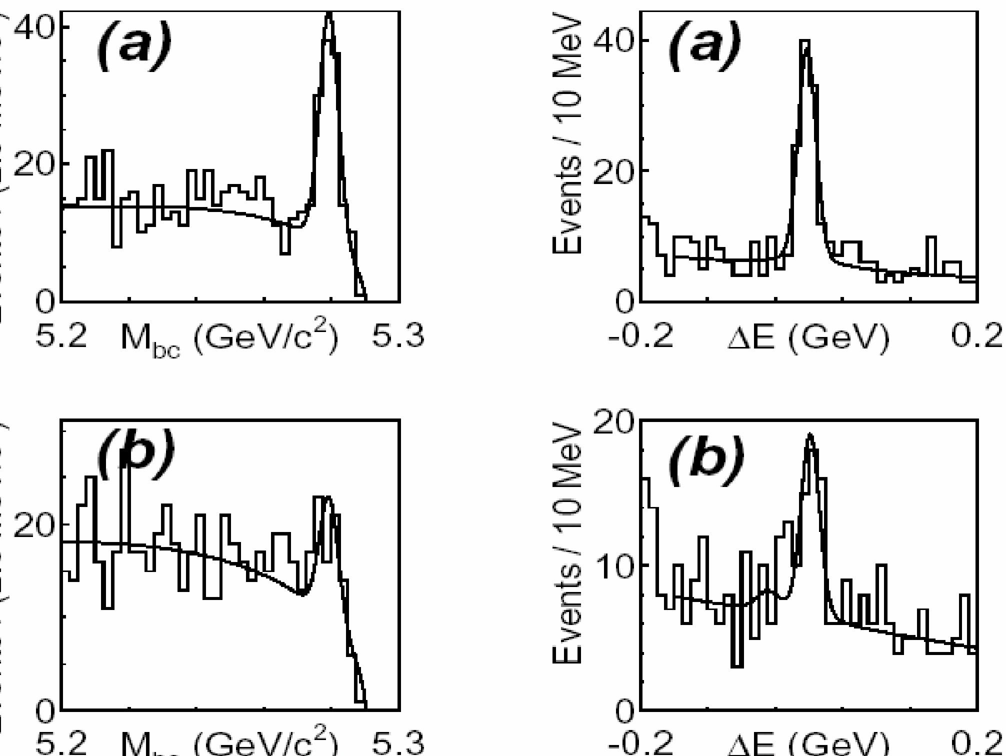
New Results only at LP05 and I

Backup

Previous $B^+ \to ppK^+$, $pp\pi^+$ Measurement

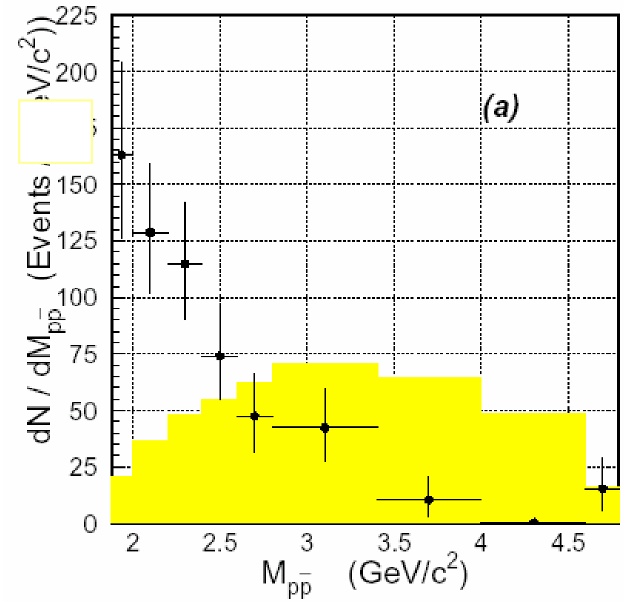
M.Z. Wang et al., PRL 2004

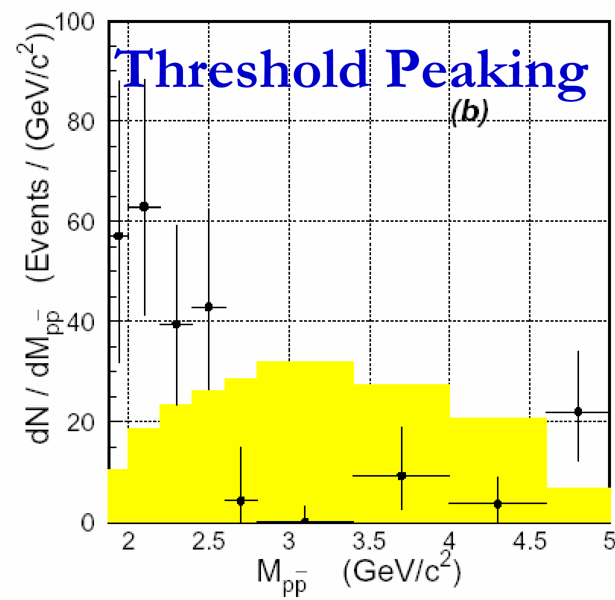
$78\ \mathrm{fb}^{-1}$



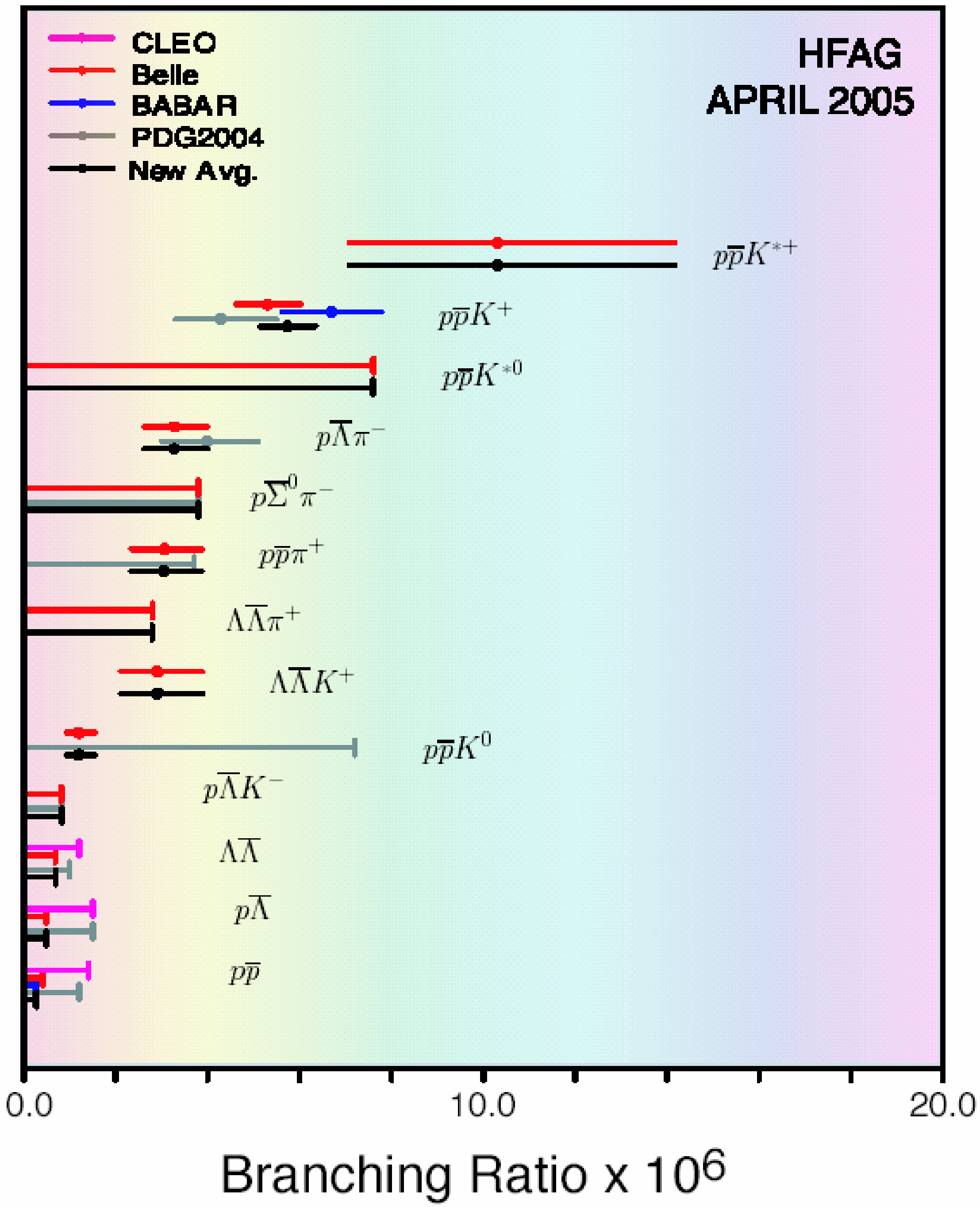
$p\bar{p}K^+$

$p\bar{p}\pi^+$





Charmless Baryonic Modes



$pp\pi^+$ < ppK^+