Charmless 2-body B decays: a way to α and γ

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CP Violation in the SM

CP violation expected in the S.M. due to the existence of three quark families

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

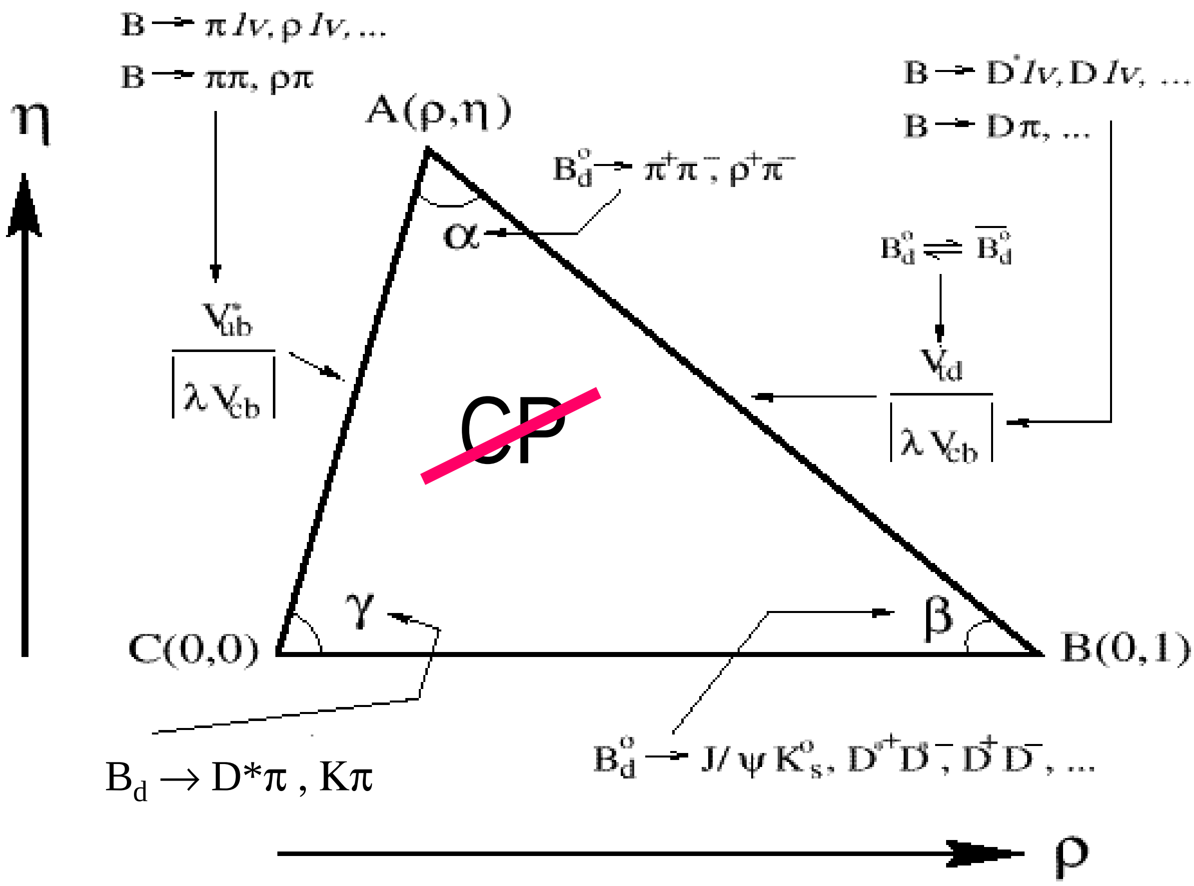
The scale of the elements has suggested

the "Wolfenstein Parameterization"

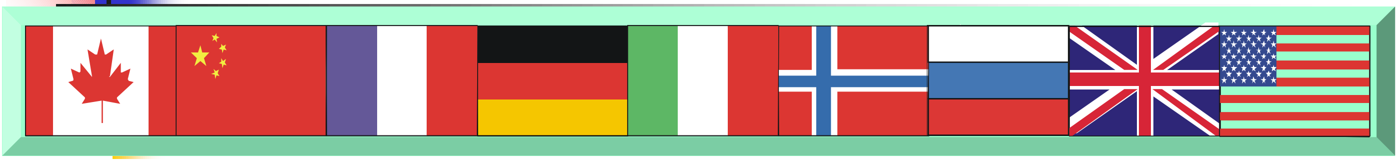
$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \mathcal{O}(\lambda^4).$$

The Triangle

$$V_{ud}V_{ub}^{*} + V_{cd}V_{cb}^{*} + V_{td}V_{tb}^{*} = 0.$$



BABAR Collaboration



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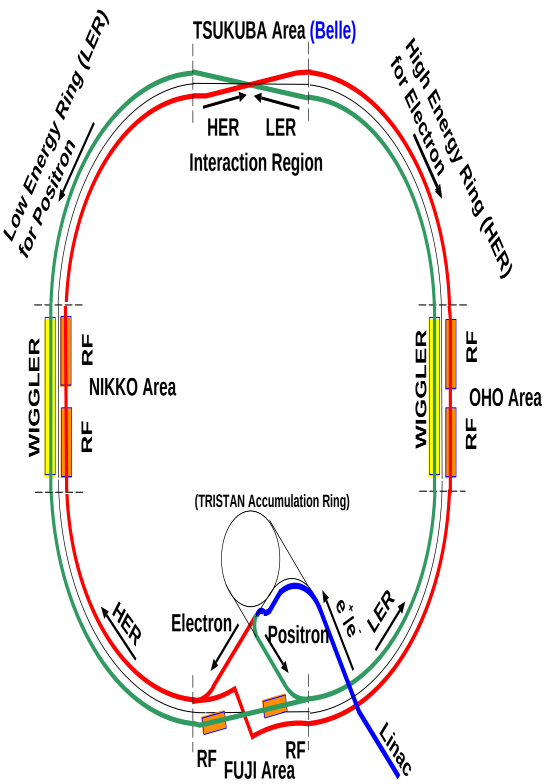
Belle Collaboration

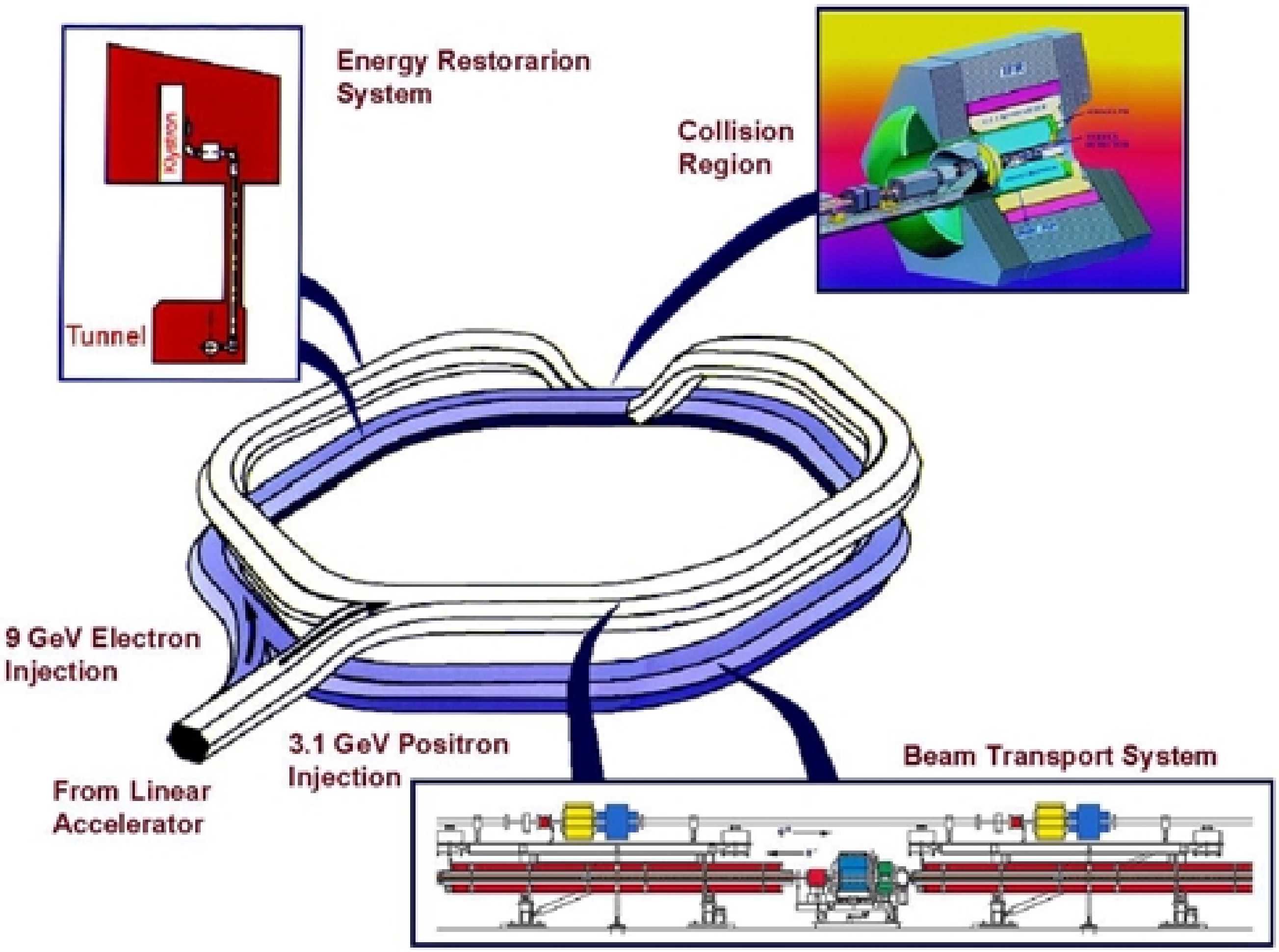
The Belle Collaboration
274 Authors from 45 Institutions

The KEKB Accelerator



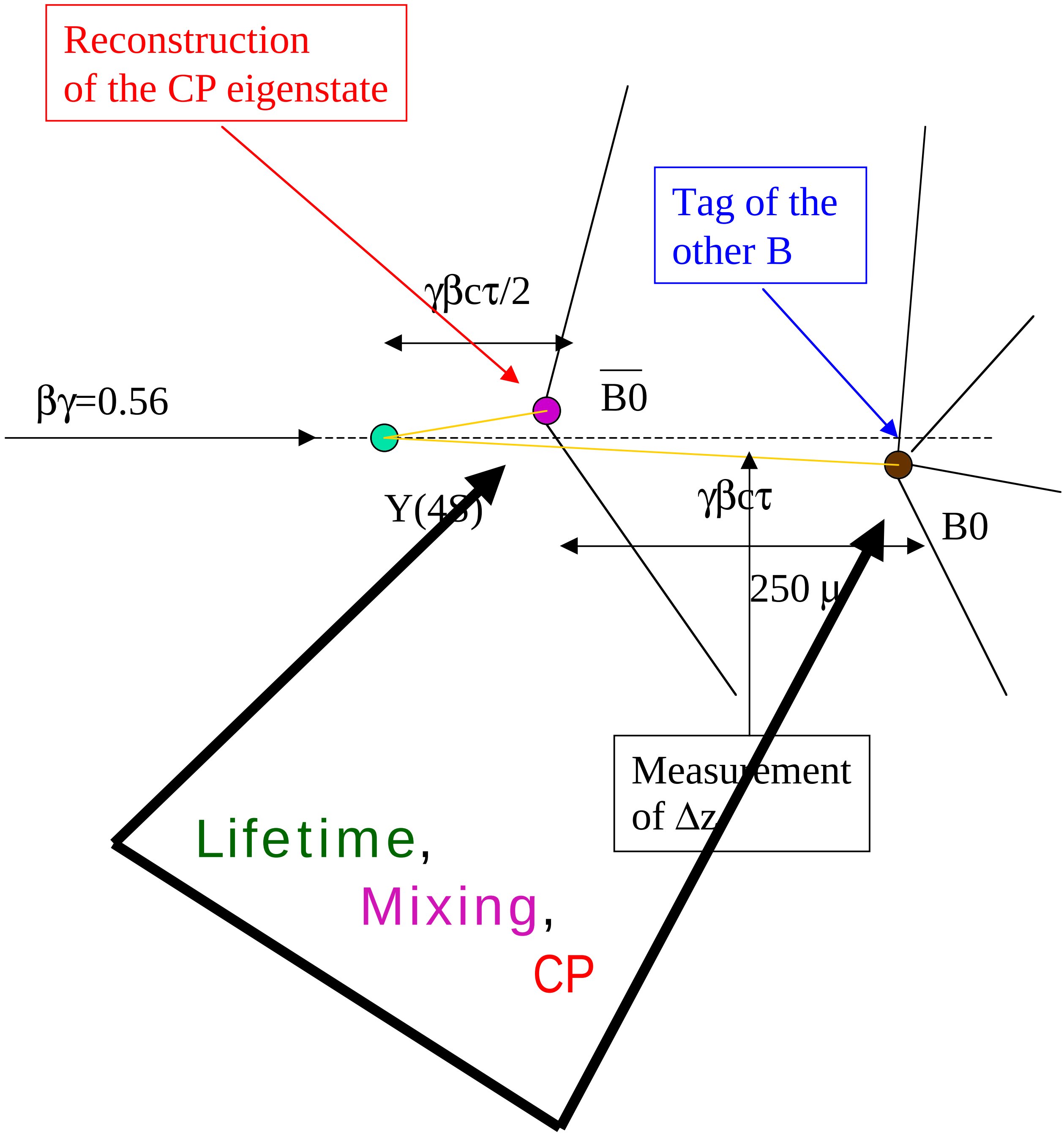
- Asymmetric Rings
  - 8.0GeV(HER)
  - 3.5GeV(LER)
- E_{cm}=10.58GeV= M(ϒ(4S))
- Target Luminosity: $10^{34}s^{-1}cm^{-2}$
- Circumference: 3016m
- Crossing angle: ±11mr
- RF Buckets: 5120
- ⇒ 2ns crossing time

PEPII

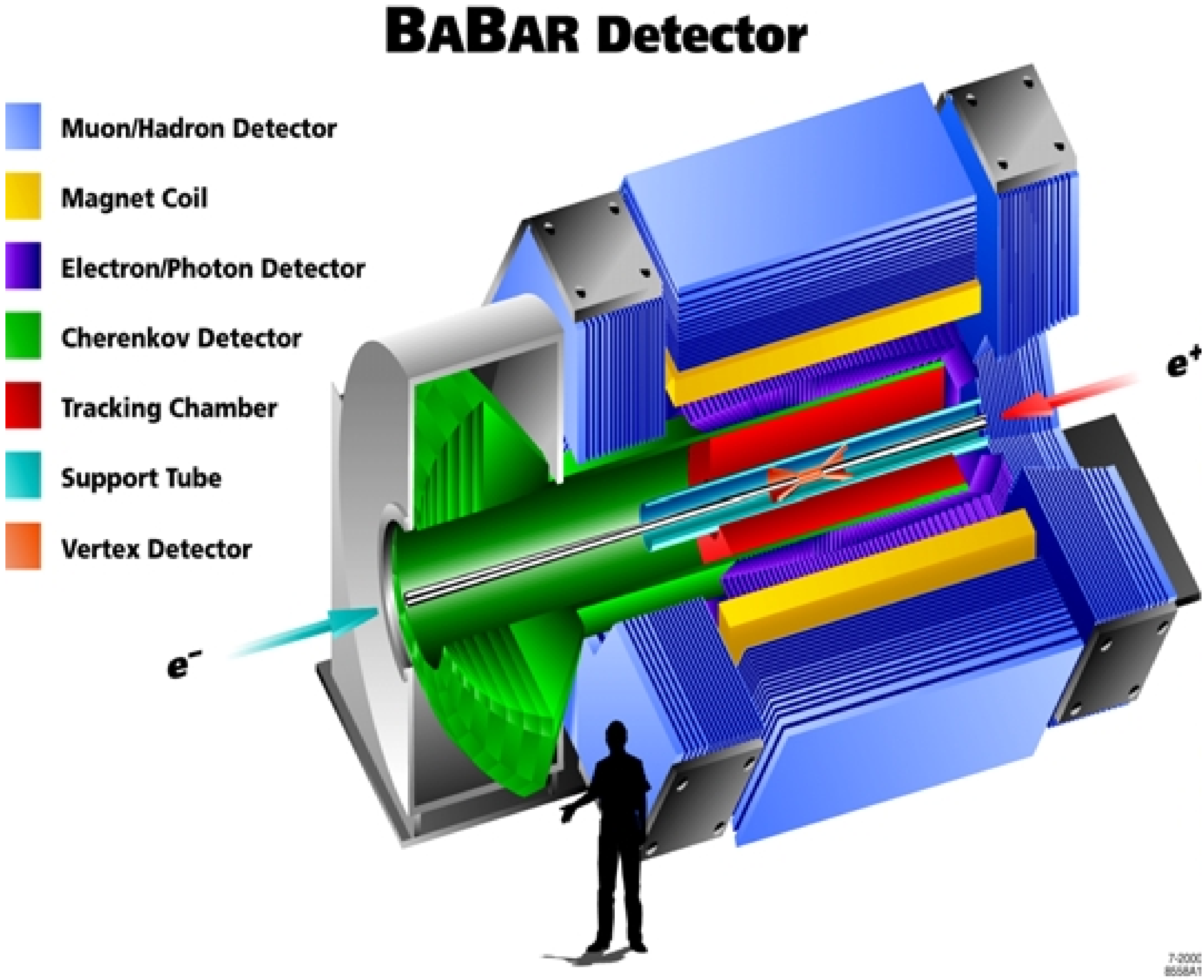


Energy Restorarion System
Klystron
Tunnel
Collision Region
9 GeV Electron Injection
From Linear Accelerator
3.1 GeV Positron Injection
Beam Transport System

B decay topology



BaBar



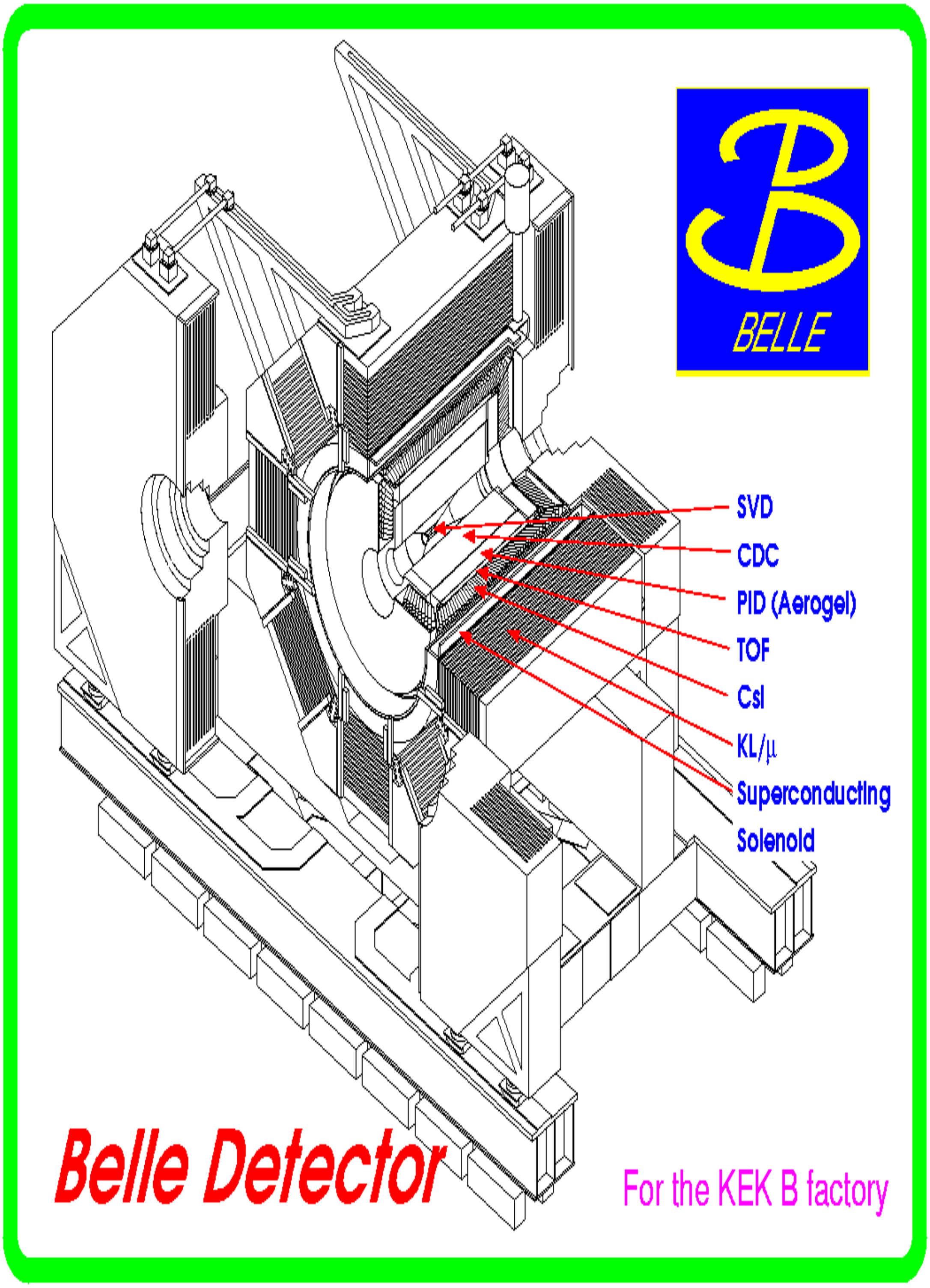
SVT: z resolution ~70 microns

Tracking: $\sigma(p_T)/p_T = 0.13\% \times p_T \oplus 0.45\%$

DIRC: K-π separation > 3.4σ for P<3.5GeV

EMC: $\sigma_E/E = 1.33\% \cdot E^{-1/4} \oplus 2.1\%$

The Belle Detector



PEPII-BaBar Operations

Design: **3.0** nb^{-1}/s **135** pb^{-1}/d ~**0.80** fb^{-1}/w ~ **3.3** fb^{-1}/m

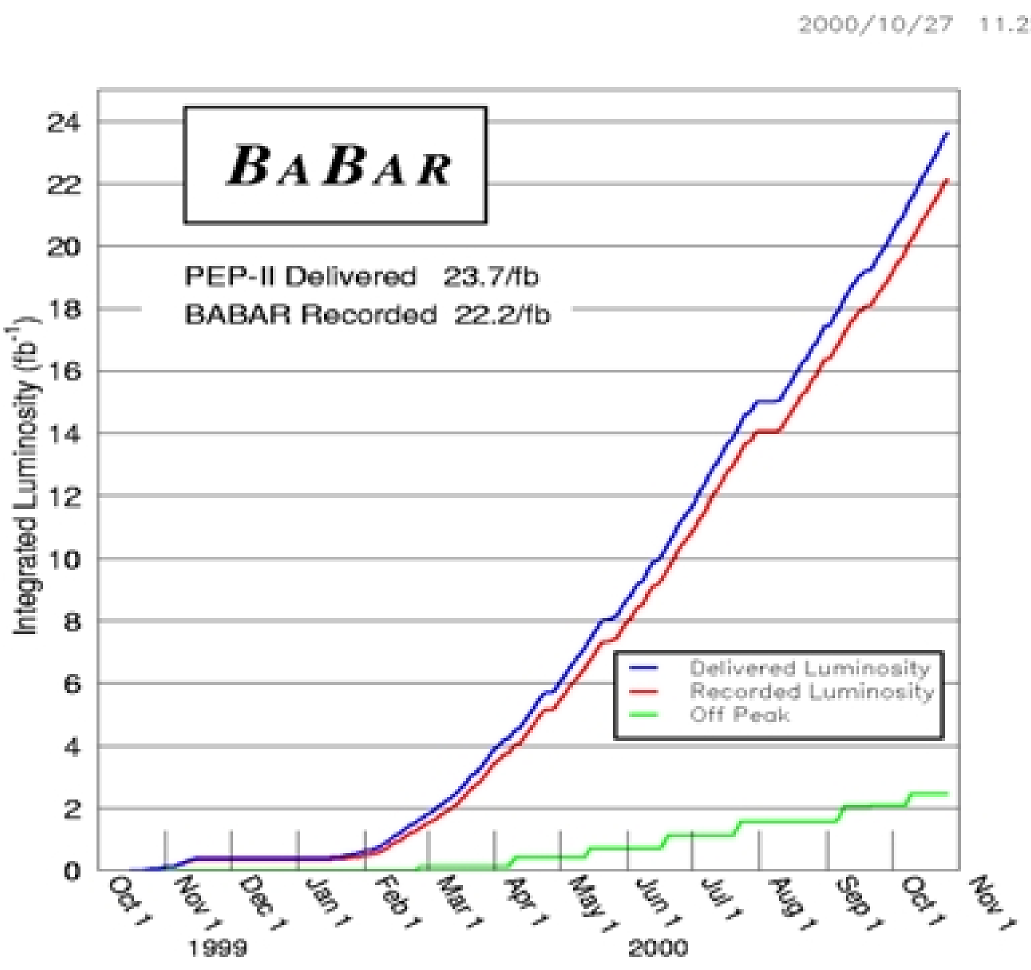
Achieved : **3.28** **184** **1.03** **3.8**

Data from 1999-2000 run

• ***20.7 fb^{-1} on-resonance***

N(Υ(4S)) = 22.74 ±0.36 million

• ***2.6 fb^{-1} off-resonance***



KEKB-Belle Operations

All luminosity records belong now to Belle.
2001 Run extremely succesfull.

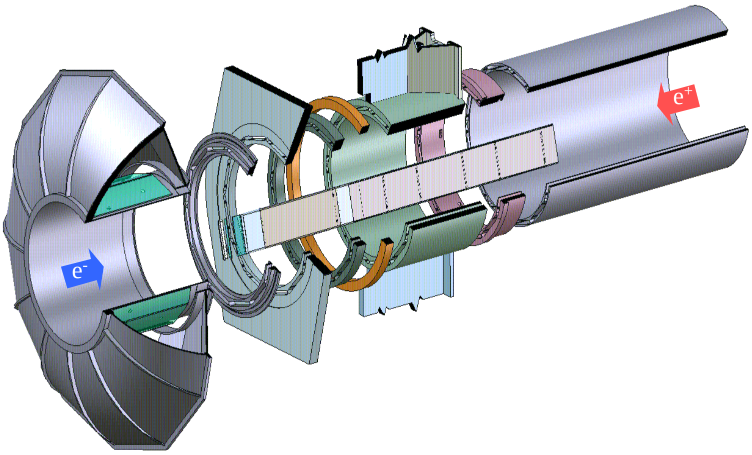
Peak luminosity in excess of **4.0** nb^{-1}/s and performances over a day in excess of **200** pb^{-1}/d have been achieved.

Looking forward for a great competition.

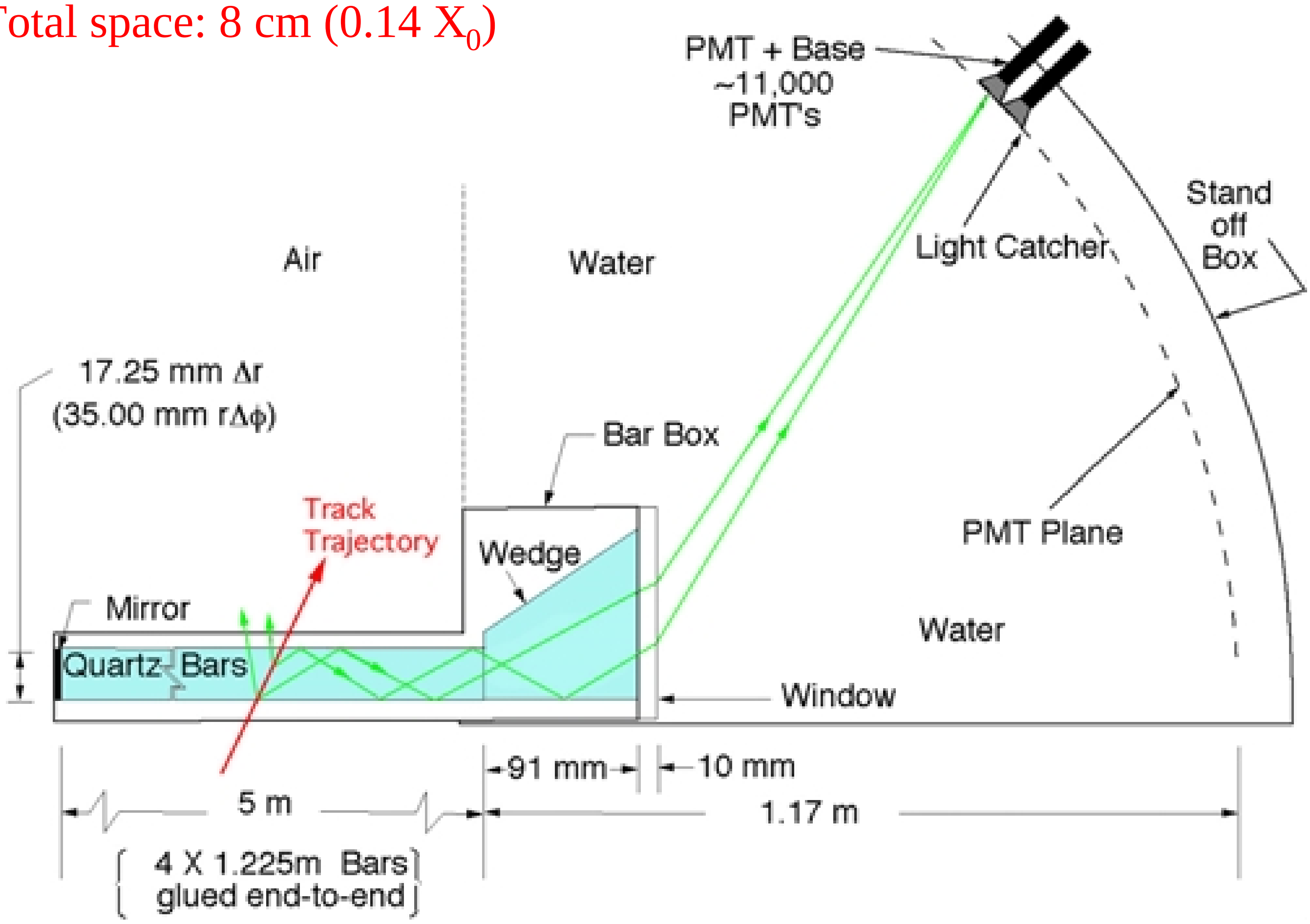
DIRC: *Detection of Internally Reflected Cherenkov light*

New design for a Cherenkov detector

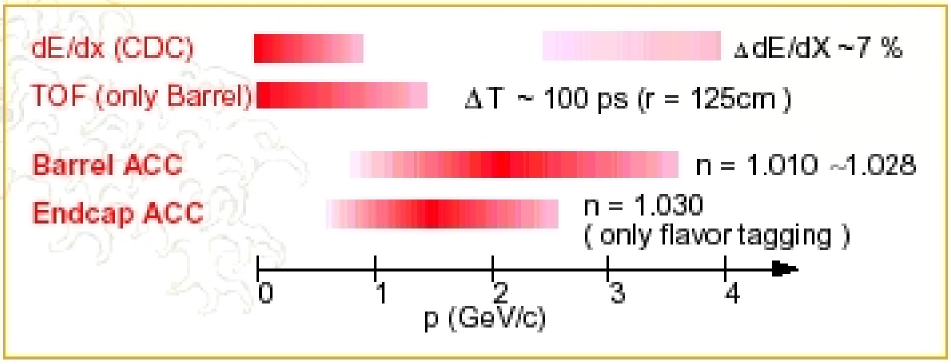
144 quartz bars (1.7 cm thick)
10752 PMT in 6 m^3 of purified water

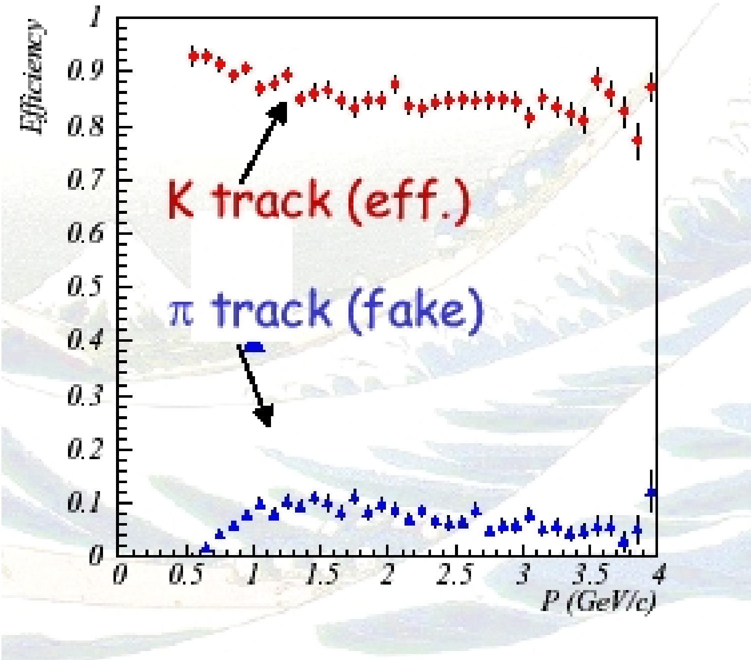


Total space: 8 cm (0.14 X_0)



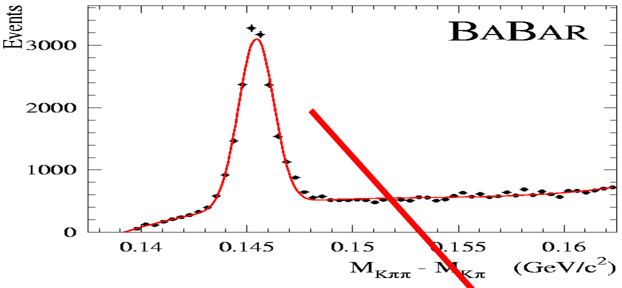
Belle PID Systems

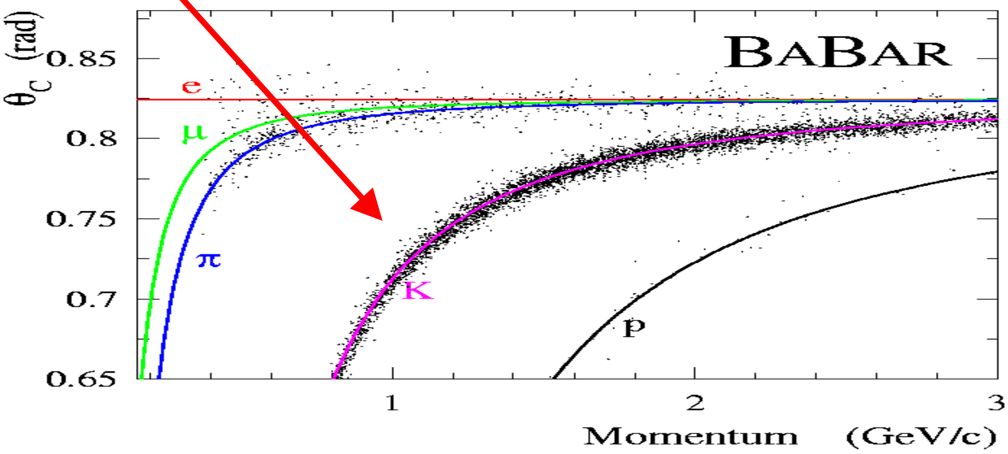


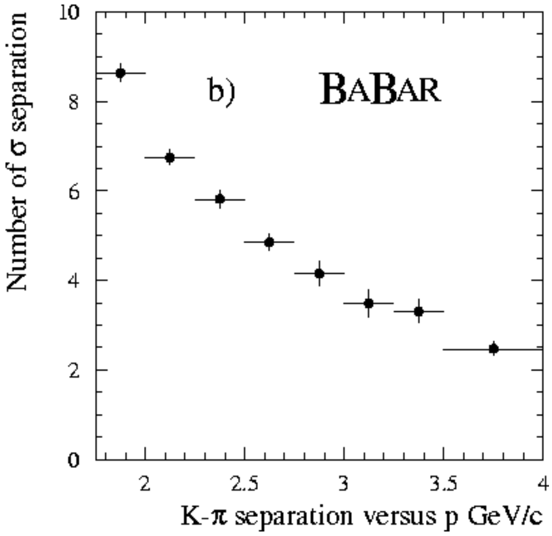


Calibration with $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$

K/π separation







Pion-Kaon separation
at high momenta

B reconstruction

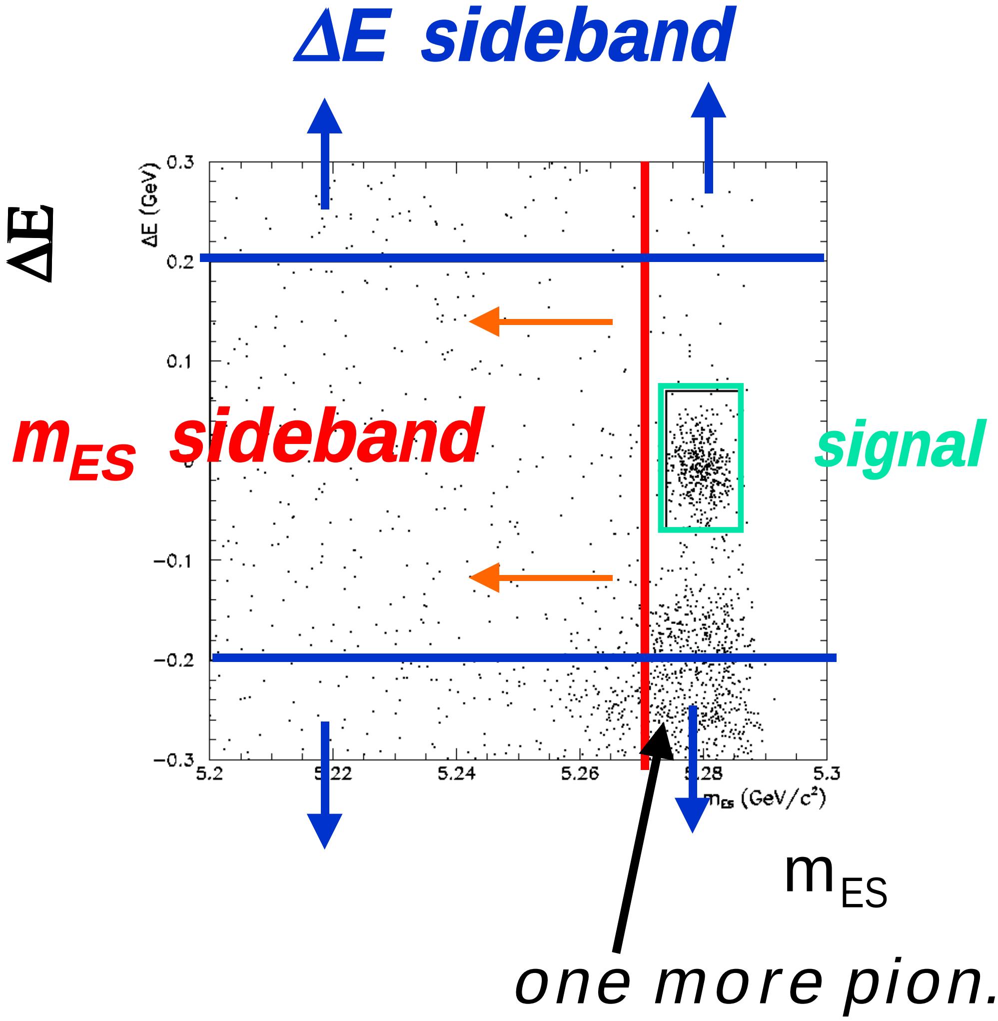
- $\Upsilon(4S) \to B\bar{B}$

energy substituted* (constrained) *mass

$$m_{ES} = \sqrt{E_{beam}^{*2} - p_B^{*2}}$$

energy difference

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



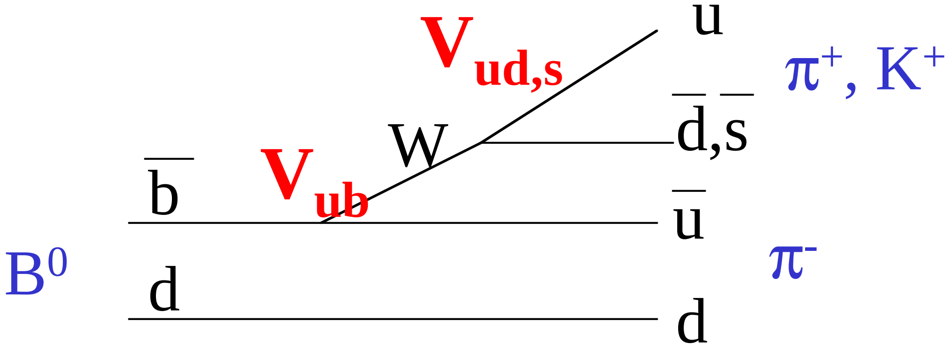
Charmless two-body B decays

Direct CP search

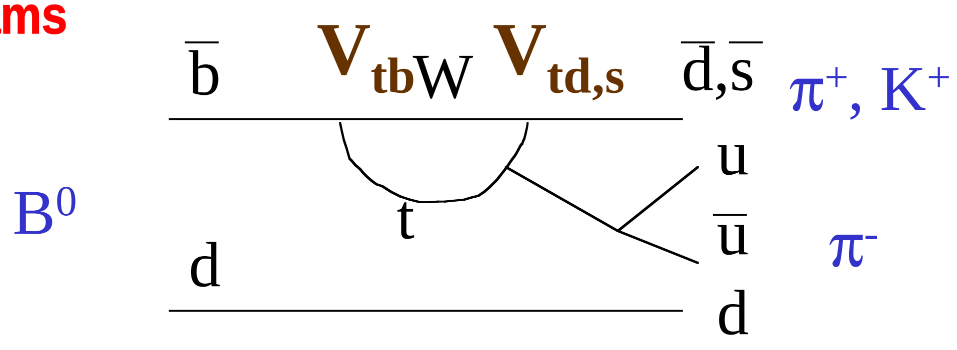
Time-dependent CP asymmetry

$\pi^+\pi^- \rightarrow \sin(2\alpha)$, $\phi K^0 \rightarrow \sin(2\beta)$

Theoretical model validation



Cabibbo-suppressed tree diagrams



penguin diagrams

Charmless decays

$\pi^+\pi^-$, $K^+\pi^-$, K^+K^- (h^+h^-)
$\pi^0\pi^+$, $\pi^0 K^+$ ($\pi^0 h^+$)
$K^0\pi^+$, $K^0 K^+$ ($K^0 h^+$)
$K^0\pi^0$

K^0 as K_S to $\pi^+\pi^-$

Fully reconstructed decays

Efficiency **(with daughter BF)**

$K^0\pi^0$,$h^+\pi^0$,h^+K^0,h^+h: 10-45%

Likelihood analysis

Use an extended *global likelihood fit* to extract different signal yields (N_S) in each topology

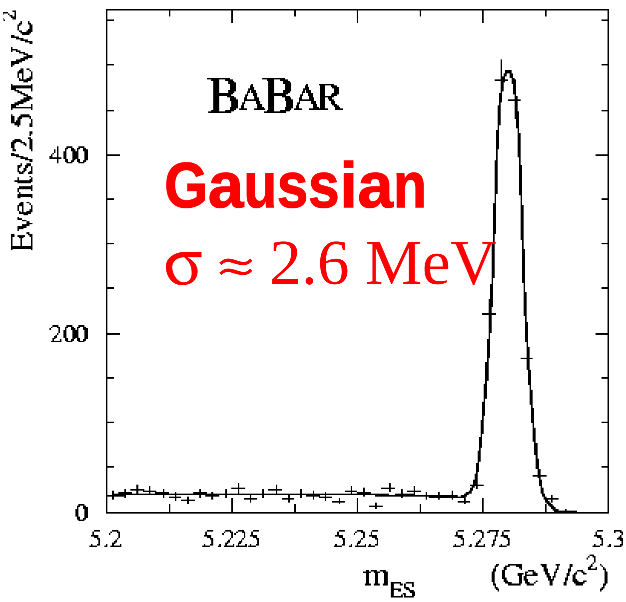
m_{ES}, ΔE, Fisher($\cos\theta_{Th}$), (ϕ mass), θ_C

Independent control sample to study Probability Density Function for both BKG and SIG

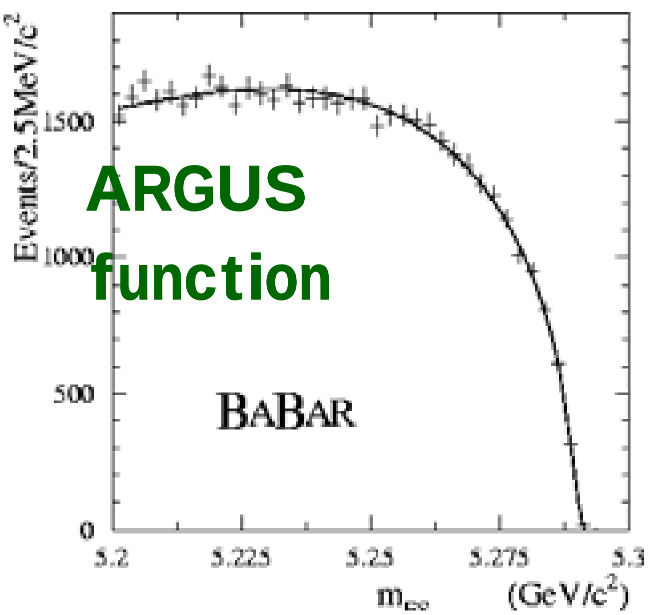
$$f(m_{ES}) \propto m_{ES}\sqrt{1-x^2}\,\exp\left[-\xi(1-x^2)\right]$$

$x = m_{ES}/E^*_{beam}$

$B^- \rightarrow D^0\pi^-$



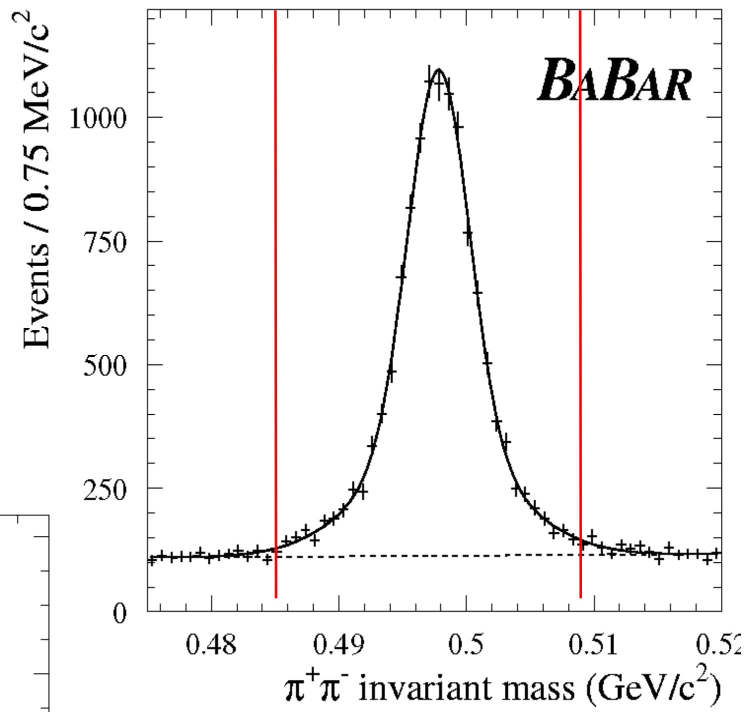
h+h- ΔE sideband



Composite particles

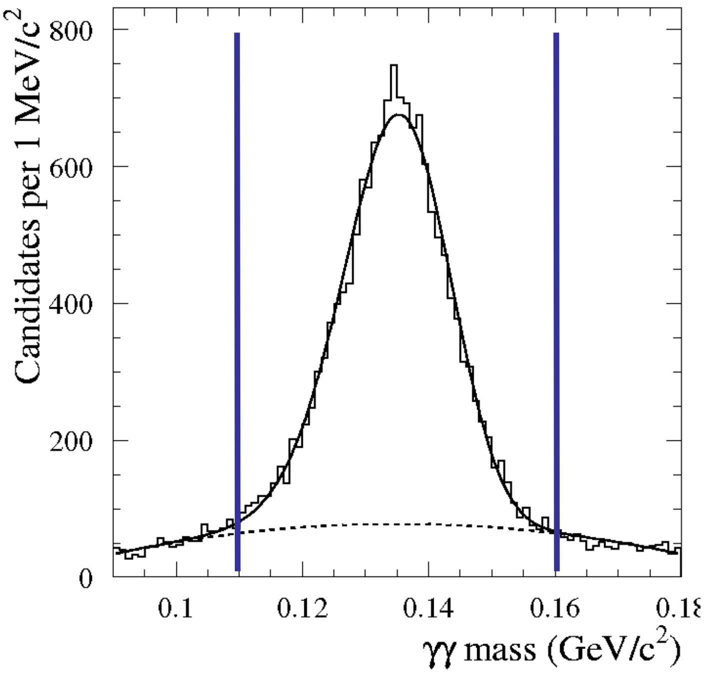
< E > ~ 3 GeV

σ= 4.3 MeV



K_S mass

σ= 8.5 MeV



π^0 mass

The search of a tiny signal

23 fb^{-1} (i.e. BaBar) are ~ 120 ML events

Using topological cuts (background is mostly qqbar):

Two particles with an invariant mass between 5.2 and 5.3 GeV and whose energy sum is consistent with machine energy at 420 MeV level

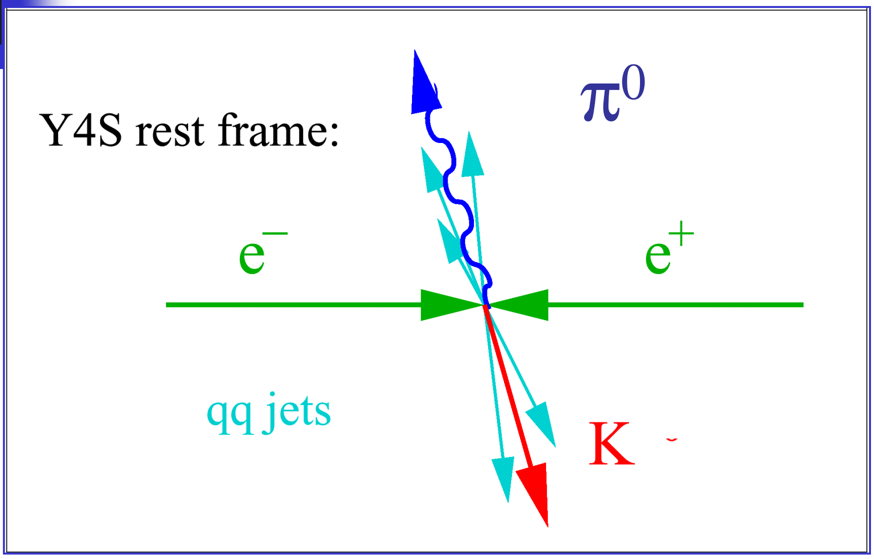
$|\cos\Theta_s| < 0.9$: angle between sphericity axis of B candidate and the rest of the event

We are left with 26000 events, and after requiring a PID measurement on both tracks only 16000

Signal (expect 200) has been reduced by a factor 2, Background by 7000.

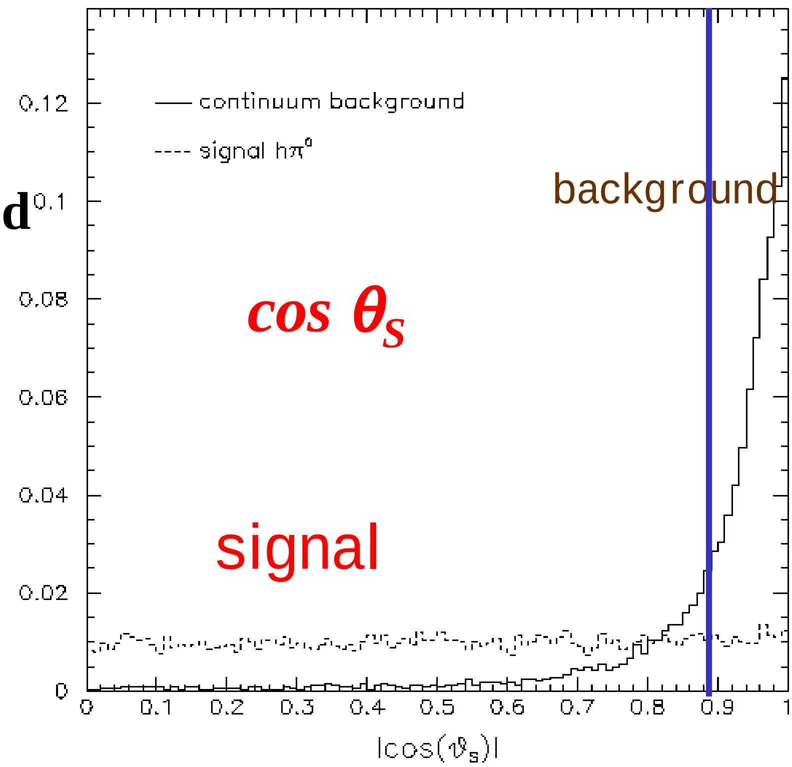
Now we need another factor 100.

Background suppression



Jet-like topology

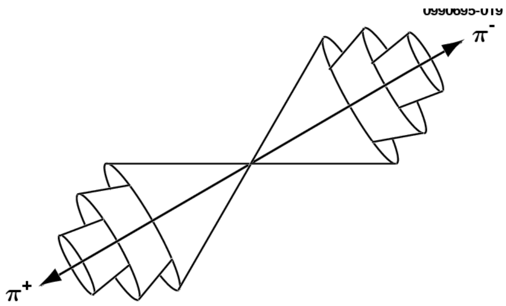
Background dominated by continuum qqbar production (u,d,s,c)



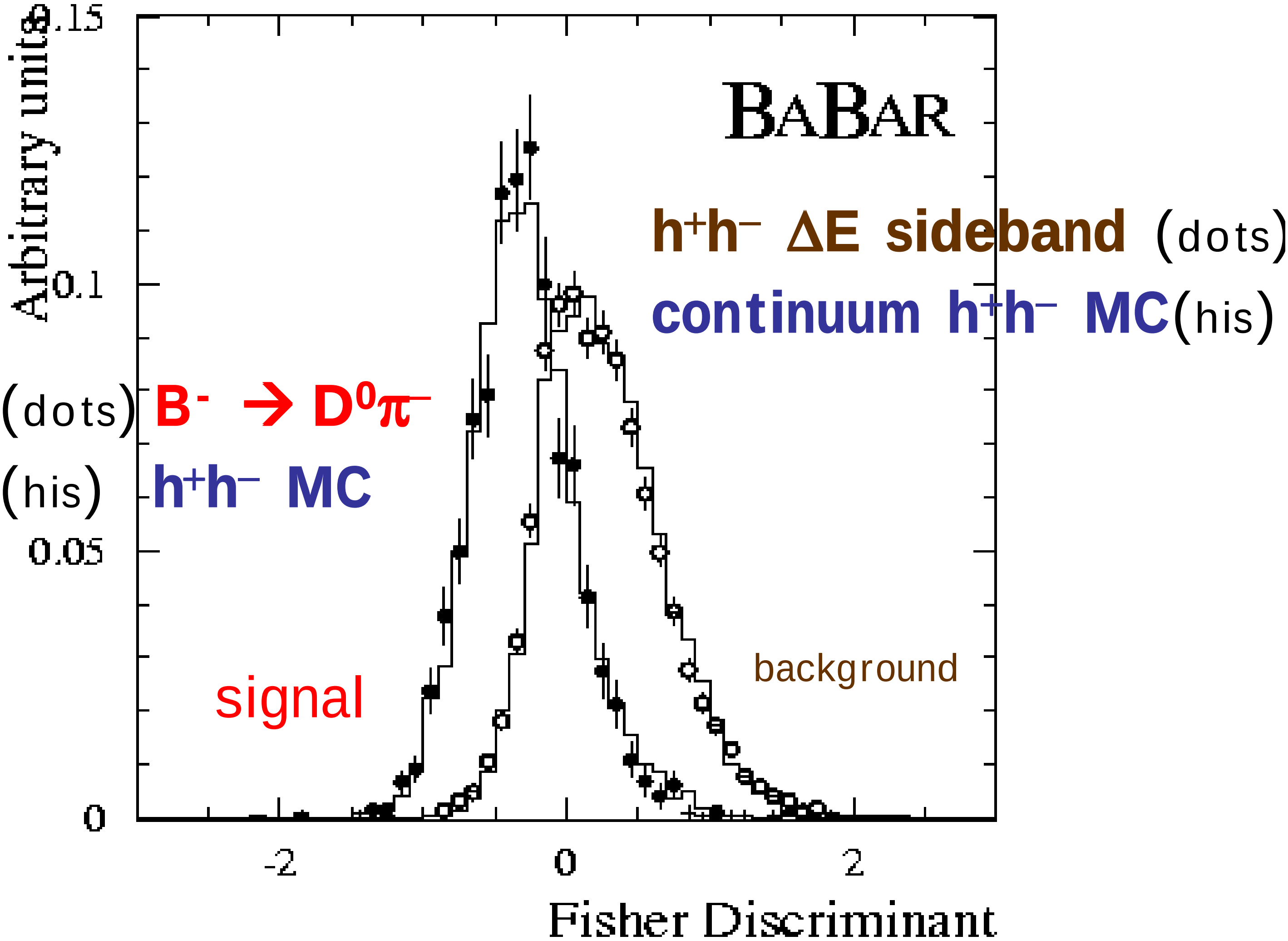
$\cos(\theta_S)$ cosine of angle between sphericity axes of B and rest of the event

Background suppression

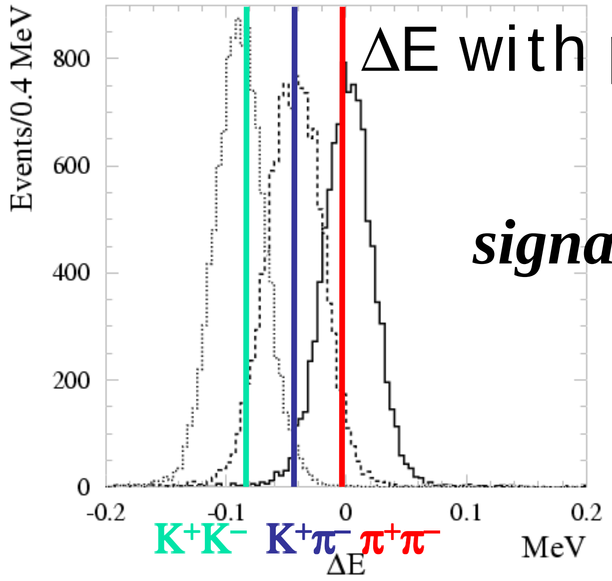
Fisher discriminant



Linear combination of event-shape variables (cones)



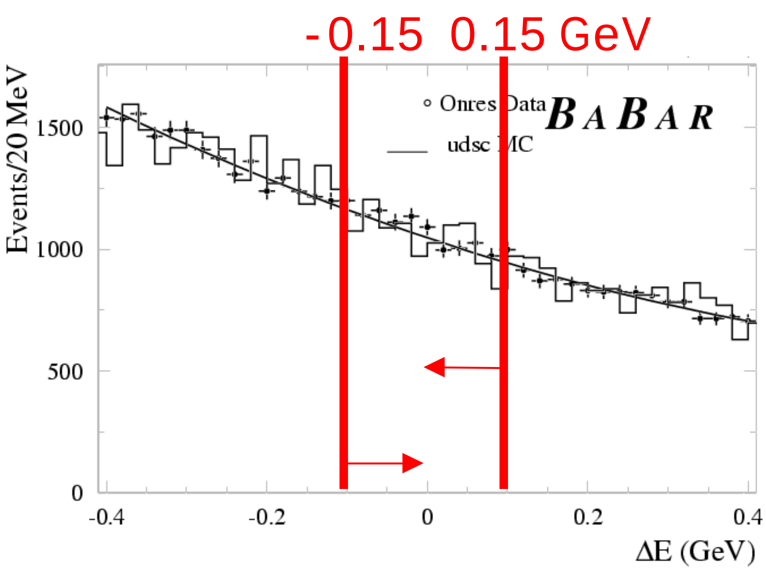
More PDFs



ΔE with pion hypothesis

signal MC

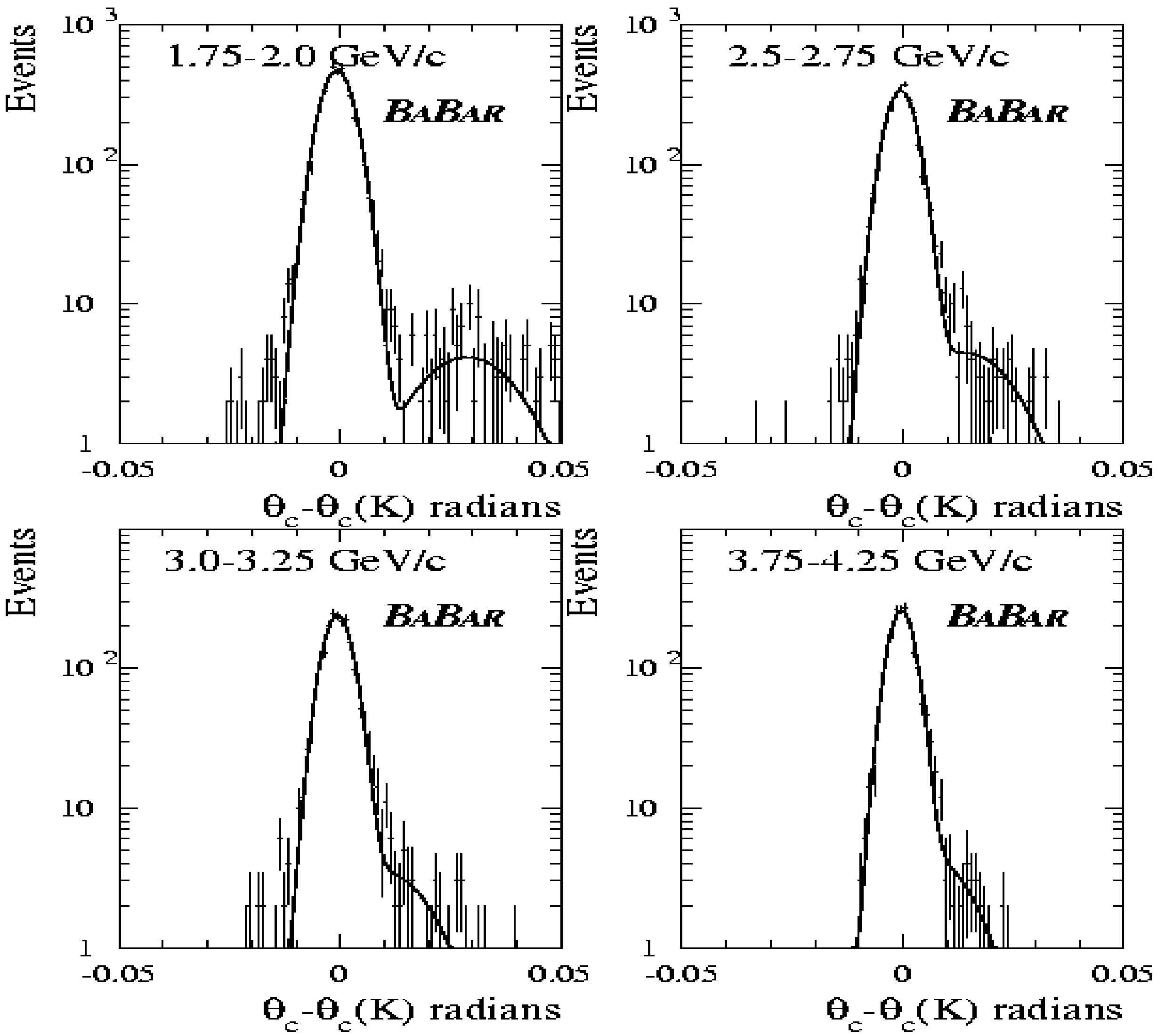
Background udsc



More PDFs (Cherenkov)

Control sample: $D^{*+} \rightarrow D^0\pi^+ \rightarrow K^-\pi^+$

$$\theta_C - \theta_C(K)$$



BaBar results

Mode	ε (%)	N_S	S (σ)	$\mathcal{B}(10^{-6})$	$\mathcal{A}$
$\pi^+\pi^-$	45	$41 \pm 10 \pm 7$	4.7	$4.1 \pm 1.0 \pm 0.7$	
$K^+\pi^-$	45	$169 \pm 17 \pm 13$	15.8	$16.7 \pm 1.6 \pm 1.3$	$-0.19 \pm 0.10 \pm 0.03$
K^+K^-	43	$8.2^{+7.8}_{-6.4} \pm 3.5$	1.3	< 2.5 (90% C.L.)	
$\pi^+\pi^0$	32	$37 \pm 14 \pm 6$	3.4	< 9.6 (90% C.L.)	
$K^+\pi^0$	31	$75 \pm 14 \pm 7$	8.0	$10.8^{+2.1}_{-1.9} \pm 1.0$	$0.00 \pm 0.18 \pm 0.04$
$K^0\pi^+$	14	$59^{+11}_{-10} \pm 6$	9.8	$18.2^{+3.3}_{-3.0} \pm 2.0$	$-0.21 \pm 0.18 \pm 0.03$
$\overline{K}^0K^+$	14	$-4.1^{+4.5}_{-3.8} \pm 2.3$	–	< 2.4 (90% C.L.)	
$K^0\pi^0$	10	$17.9^{+6.8}_{-5.8} \pm 1.9$	4.5	$8.2^{+3.1}_{-2.7} \pm 1.2$	

Systematics

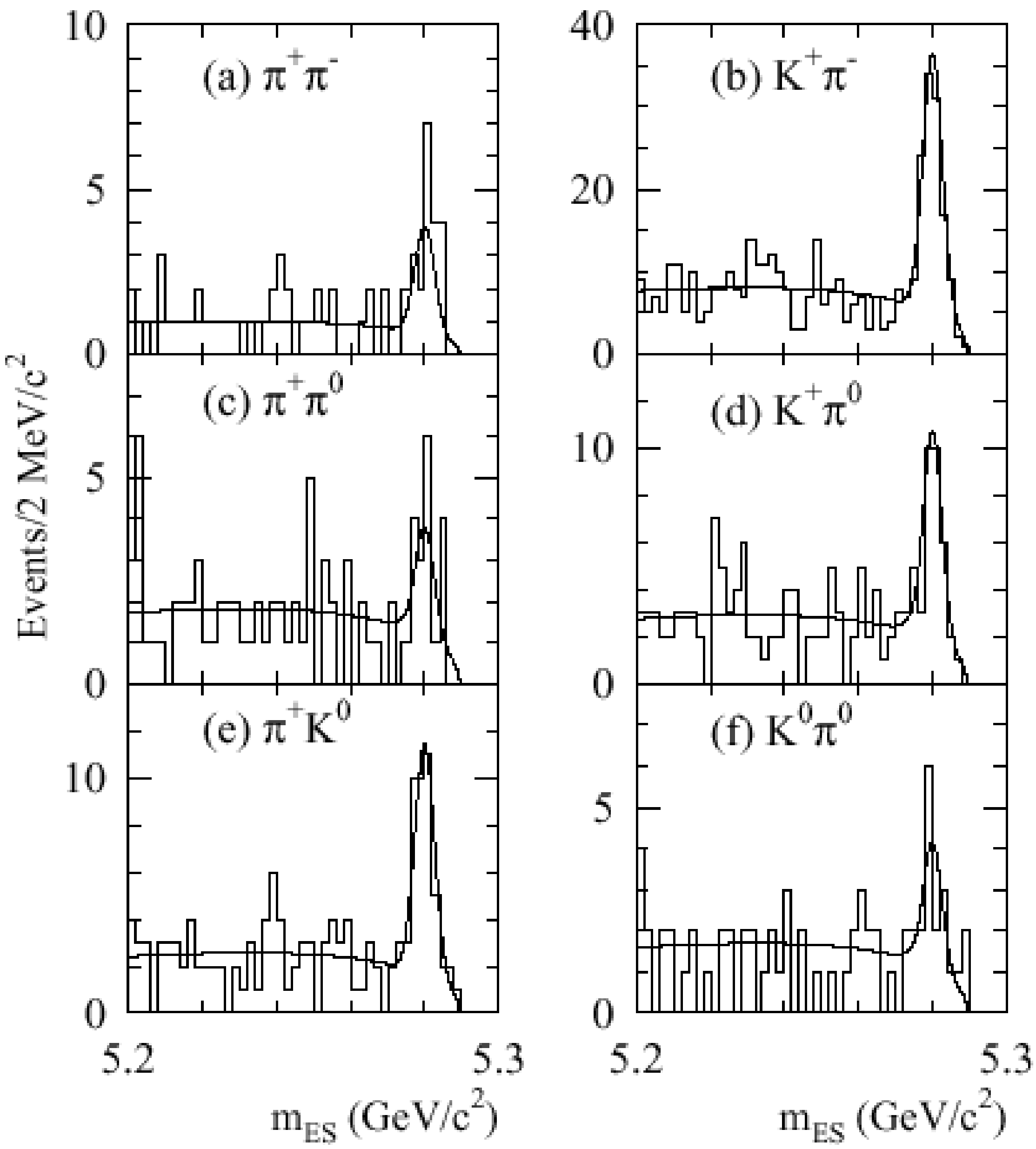
- **Vary PDF parameters**
- **alternative PDF**

Variation in %

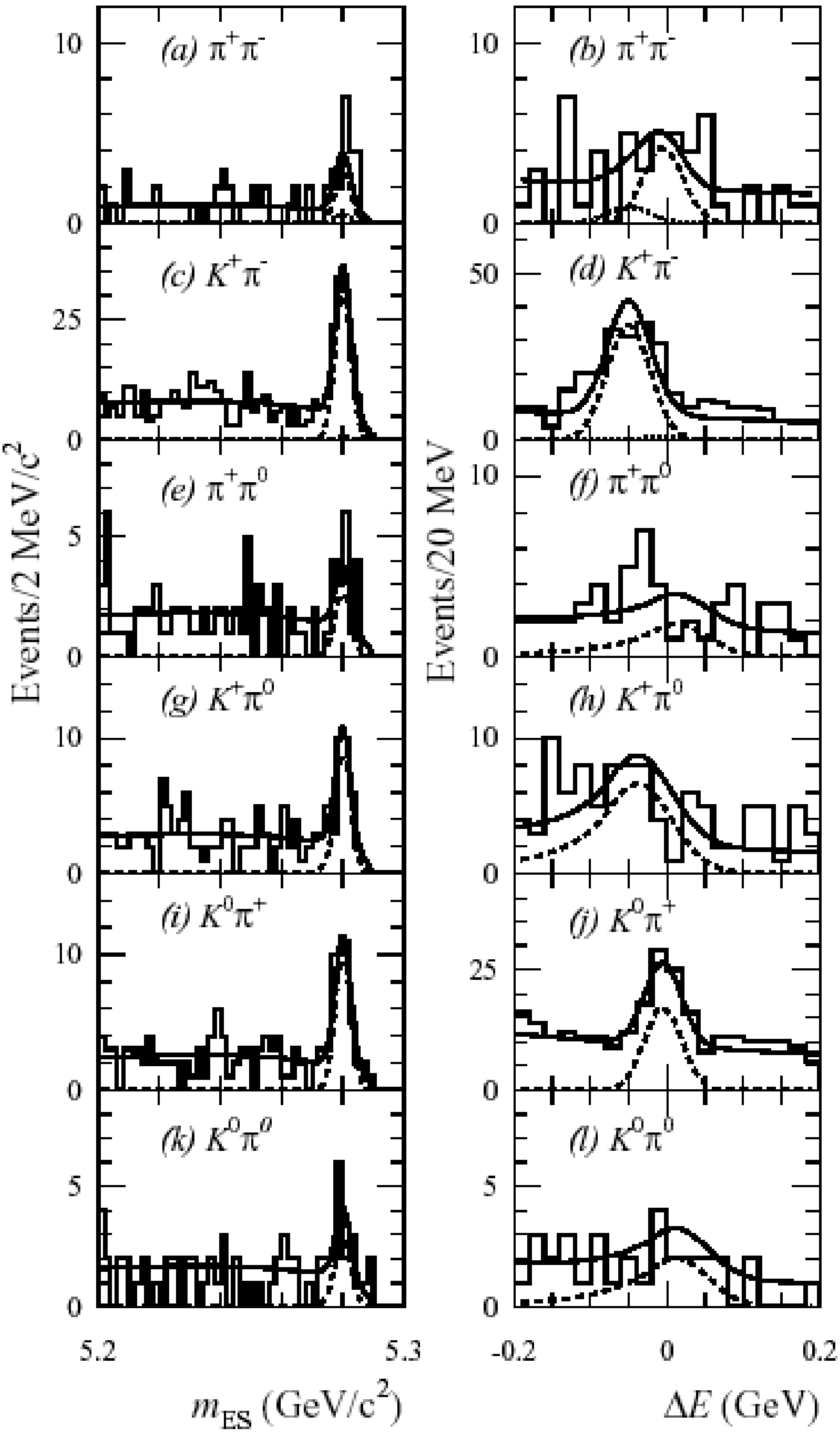
Parameter	$N_{\pi\pi}$	$N_{K\pi}$	N_{KK}
bkg M_{ES}	±5.3	±1.6	±11
bkg ΔE	±0.2	±0.2	±1.3
bkg Fisher	±13	±3.0	±34
$\langle m_{ES} \rangle$	$^{+0.0}_{-2.2}$	$^{+0.3}_{-1.4}$	$^{+10}_{-8.9}$
$\sigma(m_{ES})$	$^{+0.7}_{-1.2}$	±0.5	$^{+5.1}_{-3.8}$
$\langle \Delta E \rangle$	±4.2	$^{+0.5}_{-1.4}$	$^{+7.6}_{-8.9}$
$\sigma(\Delta E)$	$^{+5.9}_{-6.4}$	$^{+6.3}_{-9.2}$	$^{+10}_{-8.9}$
$\mathcal{F}\ (D^0\pi)$	±3.7	0	±3.8
θ_c	$^{+5.0}_{-5.5}$	±1.3	±17
Total	±17	$^{+7.3}_{-10}$	±43

Results

Likelihood visualization onto m_{ES}



Results ($\Delta E/m_{ES}$)-BaBar



Belle Cut-based analysis

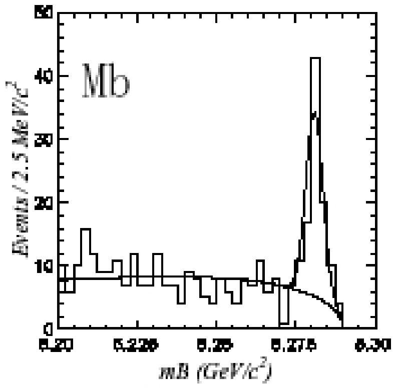
$B^0 \rightarrow K^+\pi^-$ Signals

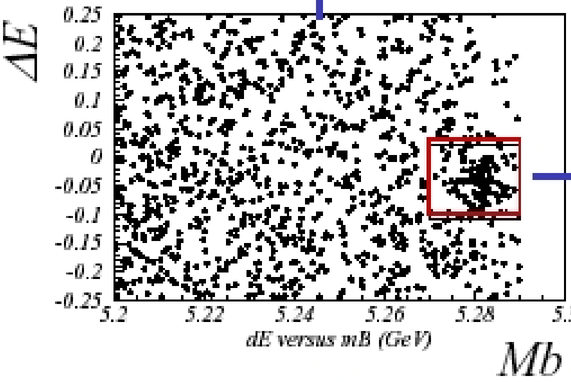
$Ns = 60.3^{+10.6}_{-9.9}\ K^+\pi^-\ signal\ events$

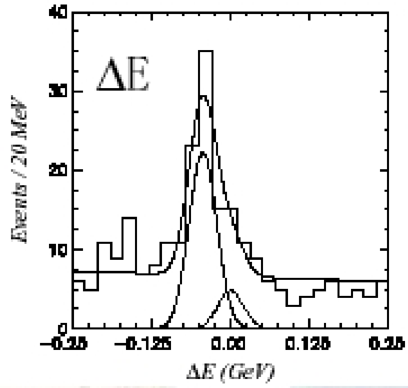
$12 \pm 7\ \pi^+\pi^-\ background$

$$Br(B^0 \rightarrow K^+\pi^-) = (1.87^{+0.33}_{-0.31}) \times 10^{-5}$$

$Signif. = 7.8\sigma$



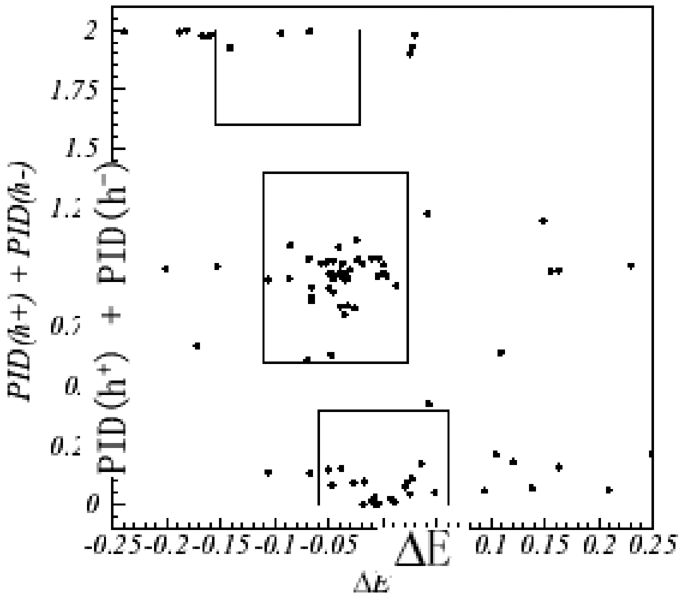


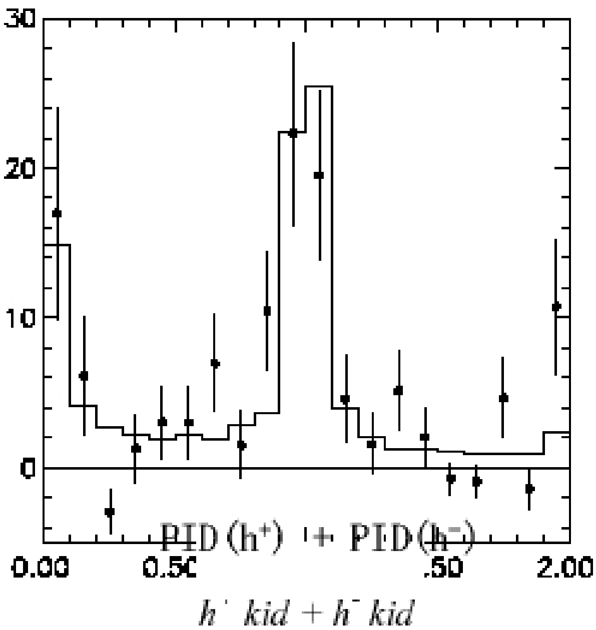


Belle PID

Kπ/ππ/KK Separation with PID

- PID(h^+) + PID(h^-)
  - ~0 for $\pi^+\pi^-$, ~1 for $K^+\pi^-$, ~2 for K^+K^-



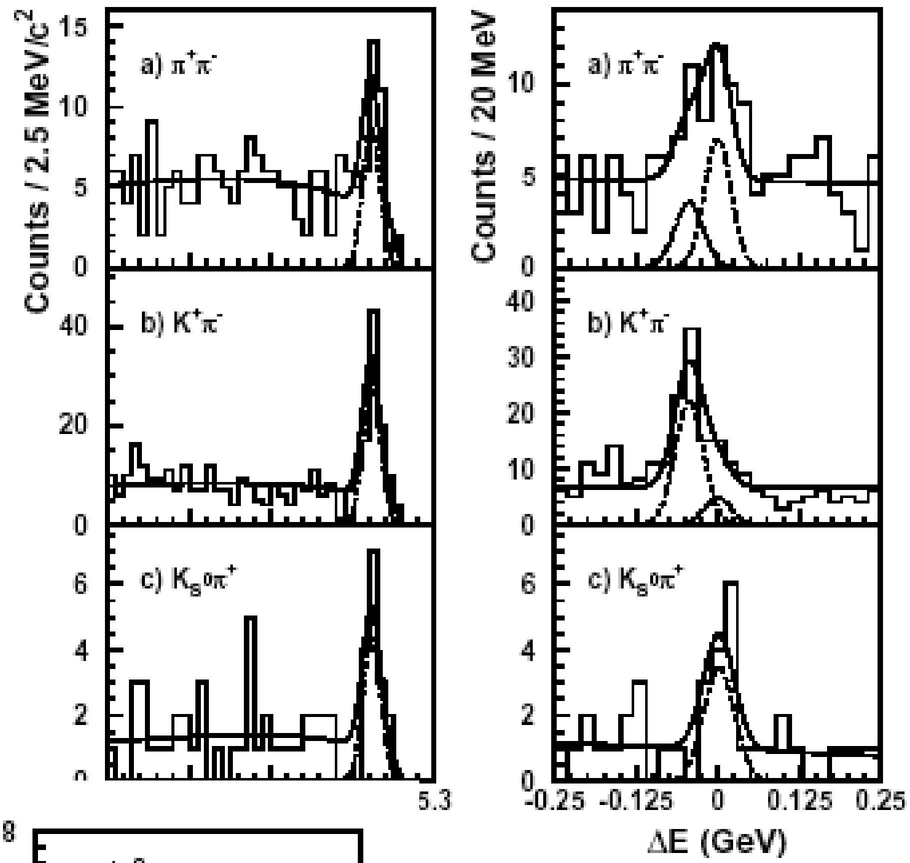


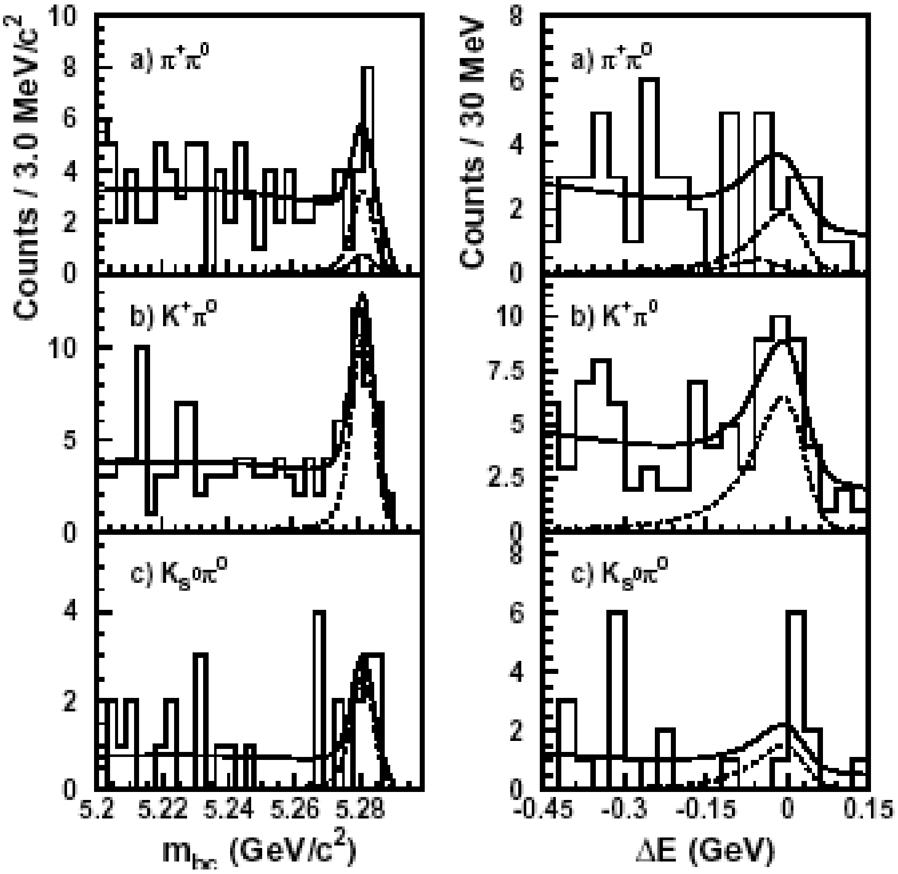
Belle results

Mode	N_s	Σ	ϵ [%]	$\mathcal{B}$ [$\times 10^{-5}$]	U.L. [$\times 10^{-5}$]
$B^0 \to \pi^+\pi^-$	$17.7\ ^{+7.1}_{-6.4}\ ^{+0.3}_{-1.1}$	3.1	28.1	$0.56\ ^{+0.23}_{-0.20} \pm 0.04$	–
$B^+ \to \pi^+\pi^0$	$10.4\ ^{+5.1}_{-4.3}\ ^{+1.2}_{-1.6}$	2.7	12.0	$0.78\ ^{+0.38}_{-0.32}\ ^{+0.08}_{-0.12}$	1.34
$B^0 \to K^+\pi^-$	$60.3\ ^{+10.6}_{-9.9}\ ^{+2.7}_{-1.1}$	7.8	28.0	$1.93\ ^{+0.34}_{-0.32}\ ^{+0.15}_{-0.06}$	–
$B^+ \to K^+\pi^0$	$34.9\ ^{+7.6}_{-7.0}\ ^{+0.6}_{-2.0}$	7.2	19.2	$1.63\ ^{+0.35}_{-0.33}\ ^{+0.16}_{-0.18}$	–
$B^+ \to K^0\pi^+$	$10.3\ ^{+4.3}_{-3.6}\ ^{+0.4}_{-0.1}$	3.5	13.5	$1.37\ ^{+0.57}_{-0.48}\ ^{+0.19}_{-0.18}$	–
$B^0 \to K^0\pi^0$	$8.4\ ^{+3.8}_{-3.1}\ ^{+0.4}_{-0.6}$	3.9	9.4	$1.60\ ^{+0.72}_{-0.59}\ ^{+0.25}_{-0.27}$	–
$B^0 \to K^+K^-$	$0.2\ ^{+3.8}_{-0.2}$	–	24.0	–	0.27
$B^+ \to K^+\overline{K}^0$	$0.0\ ^{+0.9}_{-0.0}$	–	12.1	–	0.50

Modes	Ratio
$\mathcal{B}(B^+ \to \pi^+\pi^0)/\mathcal{B}(B^0 \to \pi^+\pi^-)$	< 2.67
$2\,\mathcal{B}(B^+ \to K^+\pi^0)/\mathcal{B}(B^0 \to K^+\pi^-)$	$1.69\ ^{+0.46}_{-0.45}\ ^{+0.17}_{-0.19}$
$\mathcal{B}(B^0 \to \pi^+\pi^-)/\mathcal{B}(B^0 \to K^+\pi^-)$	$0.29\ ^{+0.13}_{-0.12}\ ^{+0.01}_{-0.02}$
$\mathcal{B}(B^0 \to K^+\pi^-)/2\,\mathcal{B}(B^0 \to K^0\pi^0)$	$0.60\ ^{+0.25}_{-0.29}\ ^{+0.11}_{-0.16}$
$2\,\mathcal{B}(B^+ \to K^+\pi^0)/\mathcal{B}(B^+ \to K^0\pi^+)$	$2.38\ ^{+0.98}_{-1.10}\ ^{+0.39}_{-0.26}$
$\mathcal{B}(B^0 \to K^+\pi^-)/\mathcal{B}(B^+ \to K^0\pi^+)$	$1.41\ ^{+0.55}_{-0.63}\ ^{+0.22}_{-0.20}$

Belle results





A_{CP} asymmetries

Our detectors are made of matter...

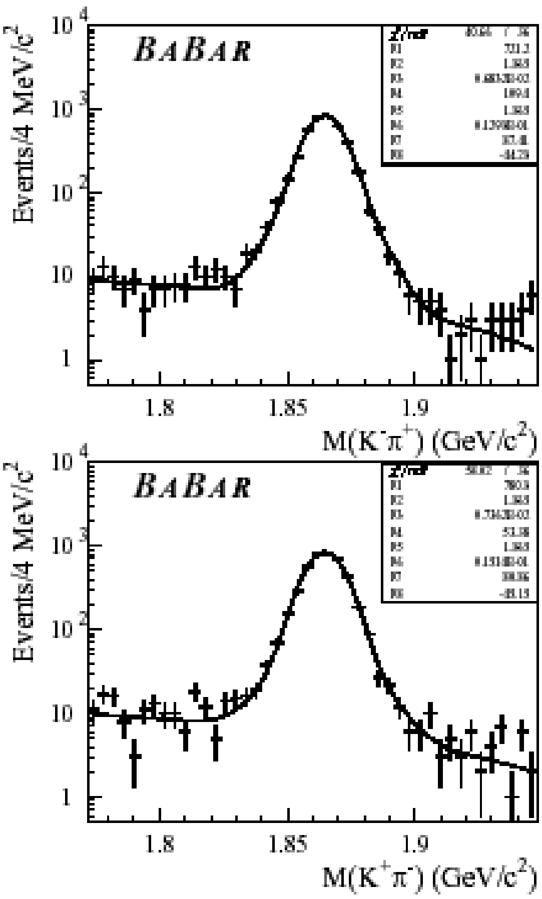
Tracking effects studied in

$e^+e^- \to \tau\tau$ events ('3+1 prong')

Negligible effects (<1%)

PID effects studied in $D^0 \to K\pi$

Negligible effects (<1%)



Averages (strictly my responsibility)

	CLEO	Belle	BaBar	<> BR
$\pi^+\pi^-$	4.3+/-1.7	5.6+/-2.3	4.1+/-1.2	**4.4+/-0.9**
$K^+\pi^-$	17.2+/-2.8	19.3+/-3.7	16.7+/-2.1	**7.3+/-1.5**
$K^0\pi^+$	18.2+/-4.9	13.7+/-6.0	18.2+/-3.9	**7.3+/-2.7**
$K^+\pi^0$	11.6+/-3.3	16.3+/-3.8	10.8+/-2.3	**2.1+/-1.7**
$\pi^+\pi^0$	5.6+/-3.1	7.8+/-3.9	5.1+/-2.2	**5.7+/-1.6**
$K^0\pi^0$	14.6+/-6.4	16.0+/-7.6	8.2+/-3.3	**0.4+/-2.7**

	CLEO	Belle	BaBar	<> ACP
$K^+\pi^-$	-0.04+/-0.16	0.04+/-0.18	-0.19+/-0.10	-0.11+/-0.08
$K^0\pi^+$	0.18+/-0.24		-0.21+/0.18	-0.07+/-0.14
$K^+\pi^0$	-0.29+/-0.23	0.02+/-0.22	0.00+/0.18	-0.07+/-0.12

A_{CP} sign convention

$$\frac{\Gamma(b \rightarrow f) - \Gamma(\bar{b} \rightarrow \bar{f})}{\Gamma(b \rightarrow f) + \Gamma(\bar{b} \rightarrow \bar{f})}$$

What do we do with this ?

Hope to eventually measure:

α and γ

Supply by now theorists with data that shall allow to refine the model phase space

The clean way would be:

TECHNION-PH-91-13
April 1991

Elimination of Penguin Contributions to CP Asymmetries in B Decays through Isospin Analysis

Michael Gronau
Technion – Israel Institute of Technology
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ABSTRACT

Isospin symmetry in $B_d^0 \to \pi^+\pi^-, B_d^0 \to \pi^0\pi^0, B^+ \to \pi^+\pi^0$ has been shown to remove the theoretical uncertainty due to penguin diagrams in the predictions for CP asymmetries in these decays.

that means:

Gluon is I=0, so b $\longrightarrow$ d penguin is pure ΔI =1/2 while the tree amplitude has both ΔI =1/2 and 3/2 components.

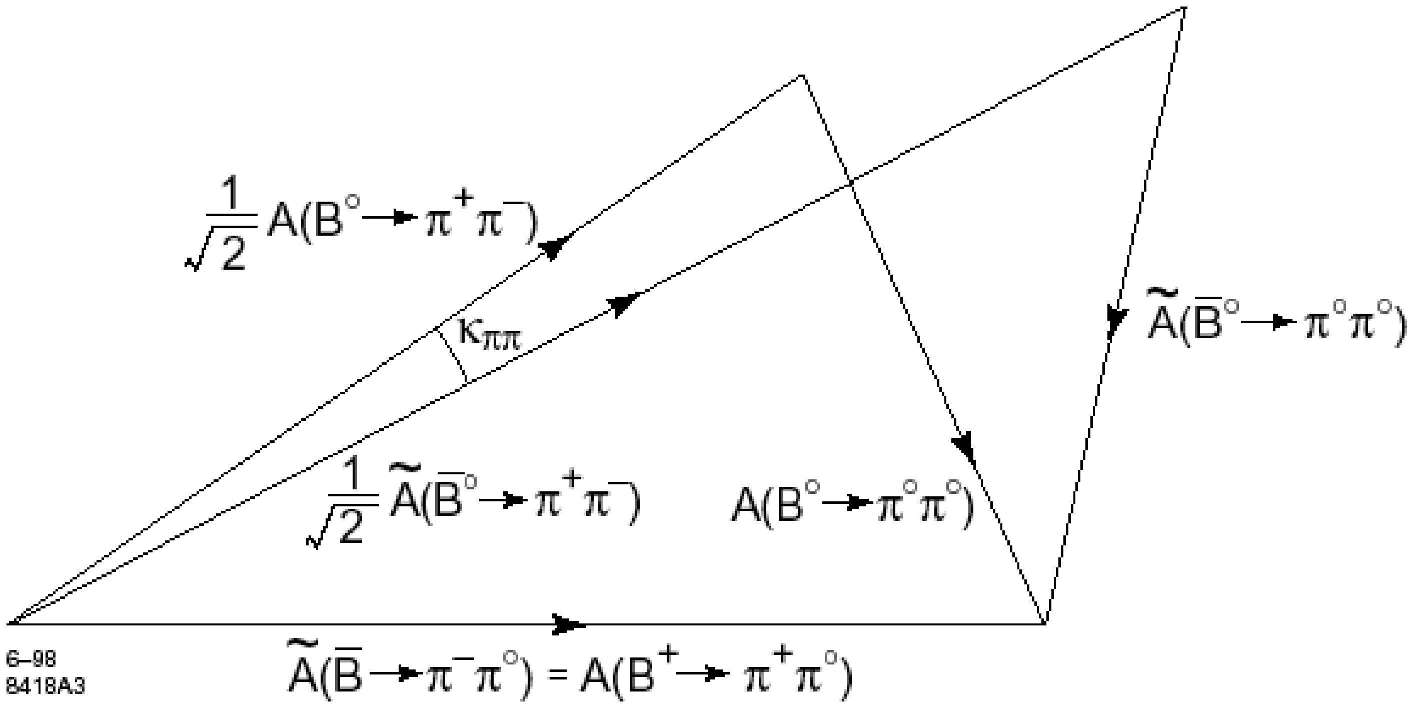
The key point is in isolating ΔI =3/2

$\pi\pi$	$A(B^+ \to \pi^+\pi^0) = \frac{\sqrt{3}}{2} A_{3/2,2}$ $\frac{1}{\sqrt{2}} A(B^0 \to \pi^+\pi^-) = \frac{1}{\sqrt{12}} A_{3/2,2} - \sqrt{\frac{1}{6}} A_{1/2,0}$ $A(B^0 \to \pi^0\pi^0) = \frac{1}{\sqrt{3}} A_{3/2,2} + \sqrt{\frac{1}{6}} A_{1/2,0}$

$$\frac{1}{\sqrt{2}} A^{+-} + A^{00} = A^{+0}$$

$$\frac{1}{\sqrt{2}} \overline{A}^{+-} + \overline{A}^{00} = A^{-0}$$

Bello e Impossibile (G. Nannini)



Require the measurement of :_

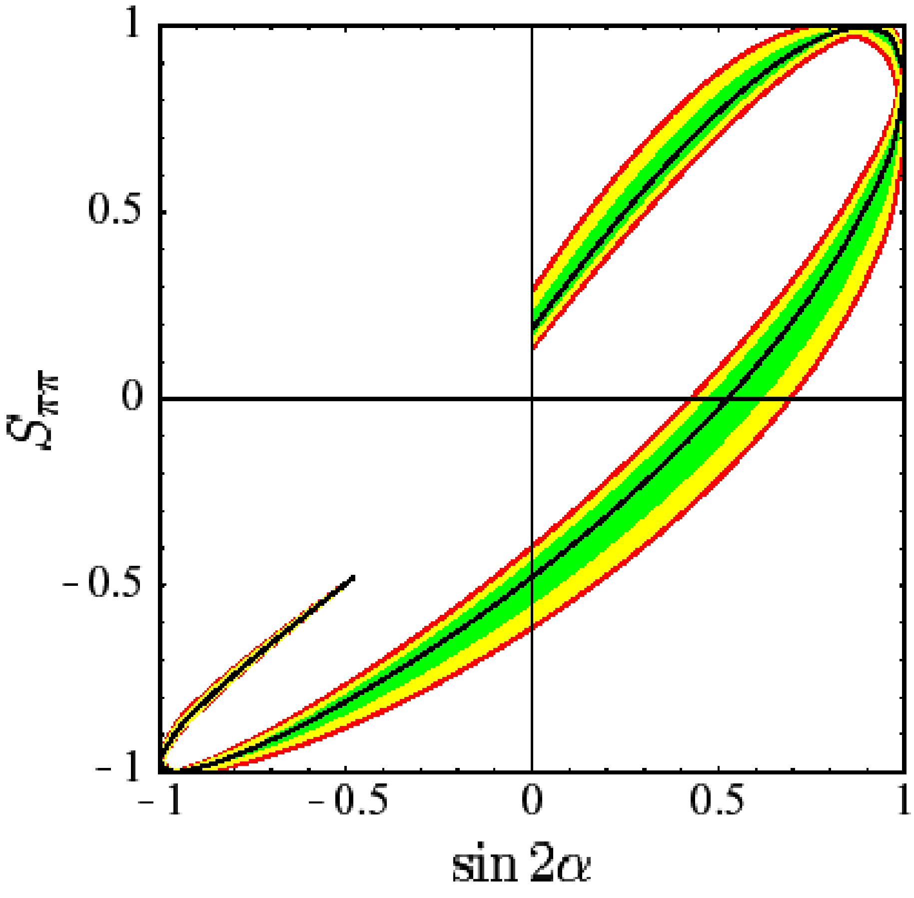
BR $(B^+ \to \pi^+\pi^0)$, BR$(B^0 \to \pi^0\underset{(-)}{\pi^0})$, BR$(B^0 \to \pi^0\pi^0)$

and the time evolution $B^0(t) \to \pi^+\pi^-$

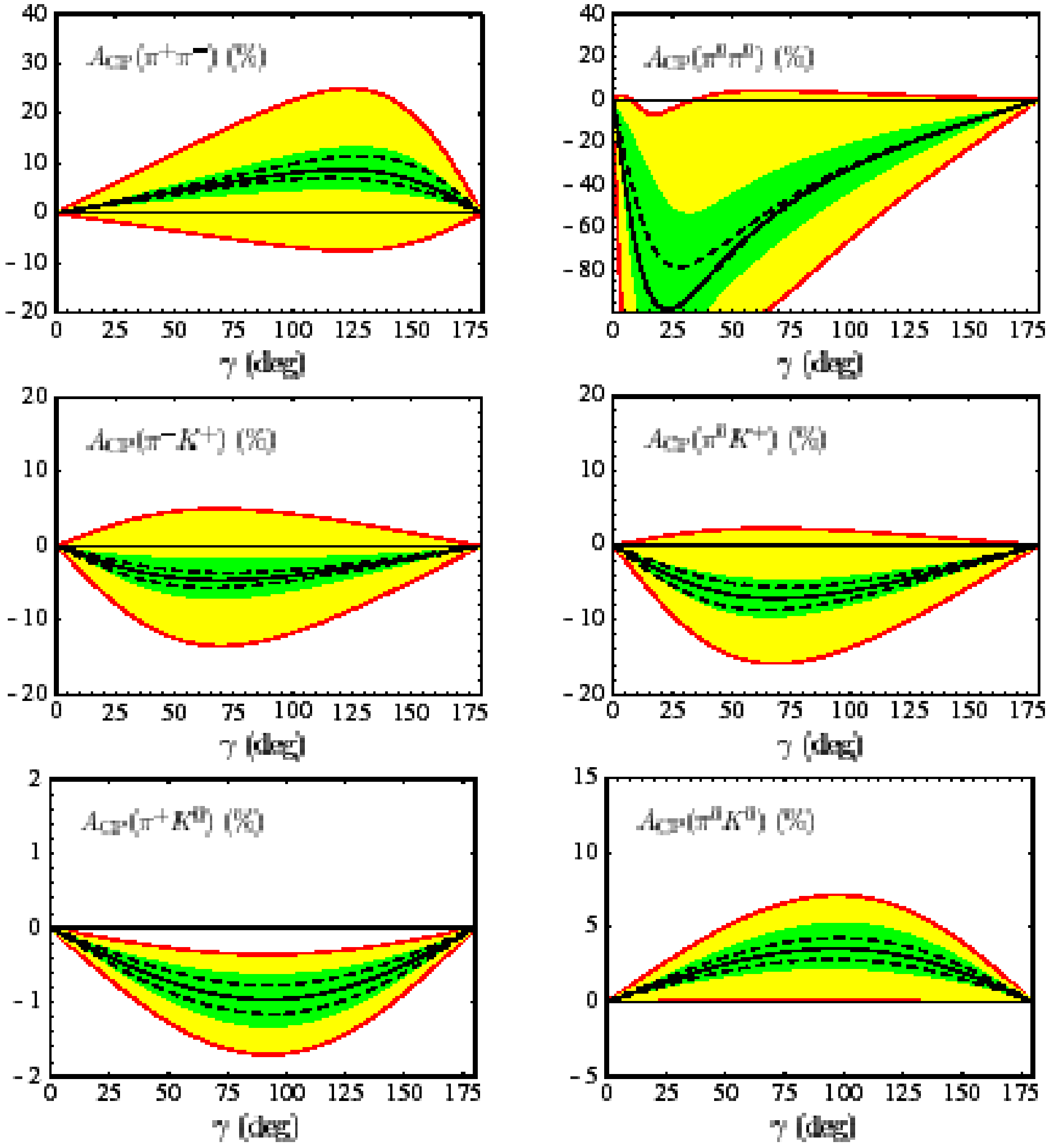
Determination of α (Neubert's way)

$$A_{\rm CP}^{\pi\pi}(t) = \frac{{\rm Br}(B^0(t)\to\pi^+\pi^-) - {\rm Br}(\bar{B}^0(t)\to\pi^+\pi^-)}{{\rm Br}(B^0(t)\to\pi^+\pi^-) + {\rm Br}(\bar{B}^0(t)\to\pi^+\pi^-)}$$
$$= -S_{\pi\pi}\sin(\Delta m_B\, t) + C_{\pi\pi}\cos(\Delta m_B\, t)\,,$$

$$S_{\pi\pi} = \frac{2\,{\rm Im}\,\lambda_{\pi\pi}}{1+|\lambda_{\pi\pi}|^2}\,, \quad C_{\pi\pi} = \frac{1-|\lambda_{\pi\pi}|^2}{1+|\lambda_{\pi\pi}|^2}\,, \quad \lambda_{\pi\pi} = e^{-2i\beta}\,\frac{e^{-i\gamma}+P_{\pi\pi}/T_{\pi\pi}}{e^{i\gamma}+P_{\pi\pi}/T_{\pi\pi}}$$



Prediction on Asymmetries



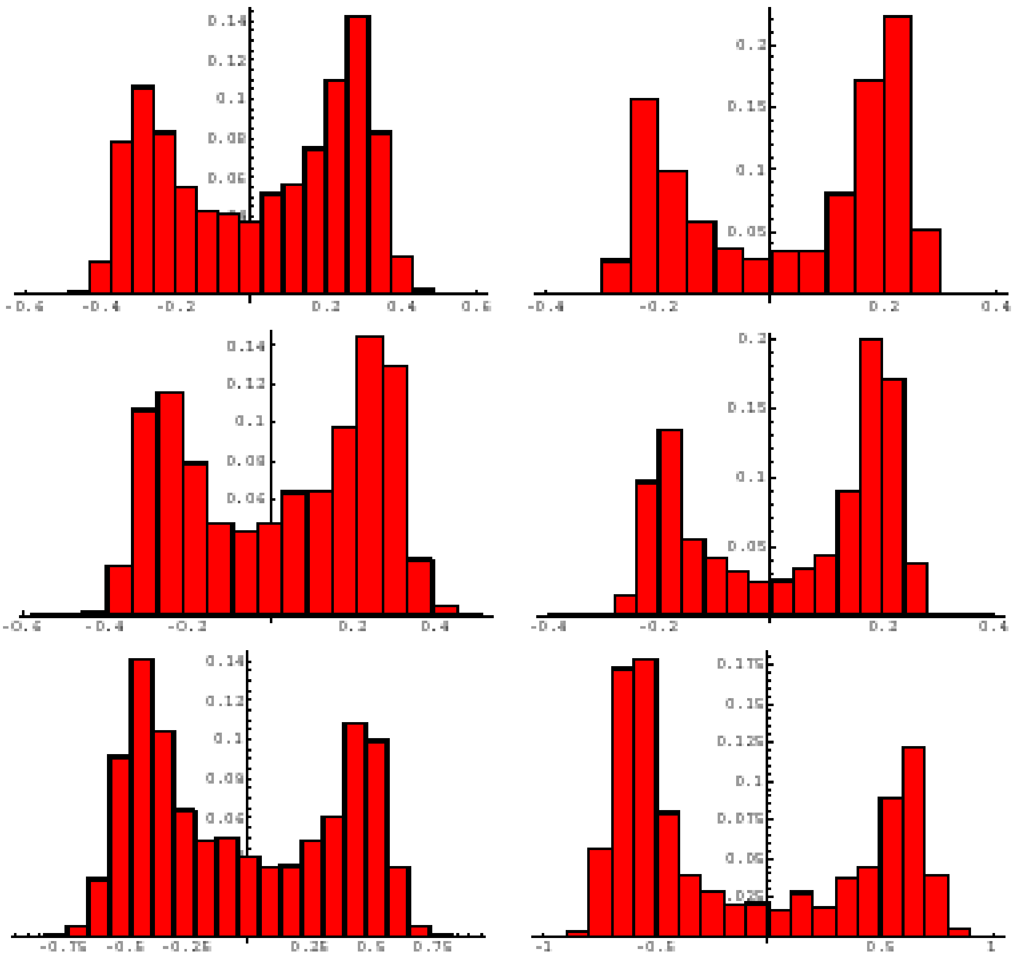
A couple of %

Prediction on Asymmetries

$K^+\pi^0$

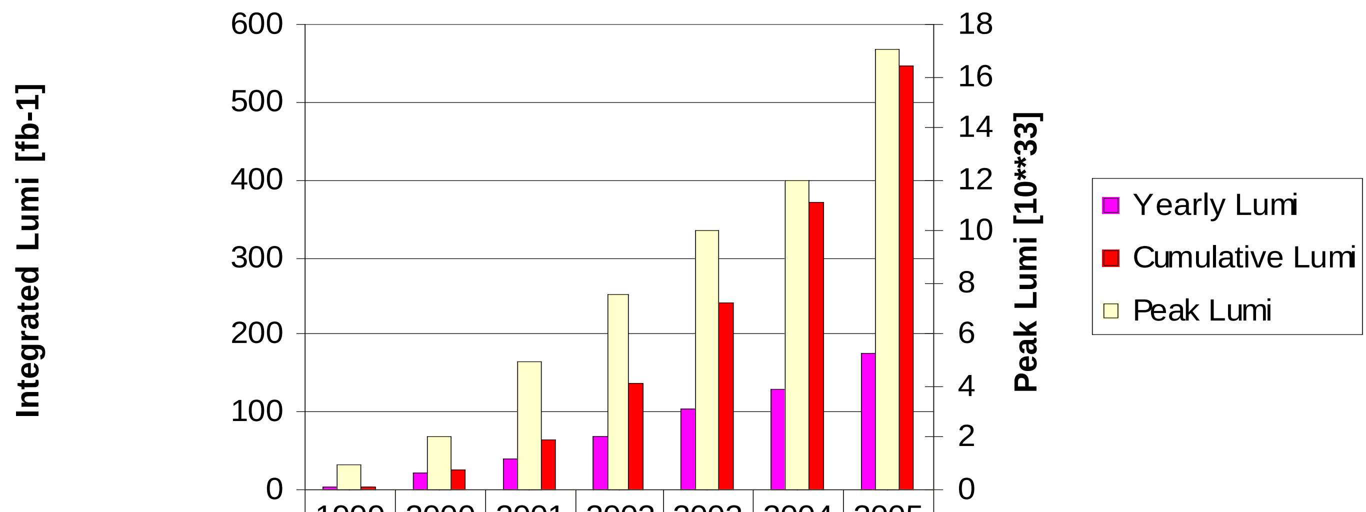
$K^+\pi^-$

$\pi^+\pi^-$



Possibly big

The near future



	1999	2000	2001	2002	2003	2004	2005
Yearly Lumi	2	23	40	70	105	130	175
Cumulative Lumi	2	25	65	135	240	370	545
Peak Lumi	1	2	5	7.5	10	12	17

Year

Expect to have $40fb^{-1}$ more by the end of the run II\

Similar perspectives for Belle.

Extrapolation

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Rule of thumb: normalize to BaBar error (20fb^{-1})
The combined Belle+BaBar harvest will give:
2001: divide by 2
2002: divide by 3+/- 0.5
2005: divide by 6+/-1

Conclusions

All the 2-body charmless B decays are potentially accessible to B-factories.

Soon (two years) $\pi^+\pi^-$ will be known at 10%.

Direct CP Asymmetries will be determined at 1-2% in the next four years.

$\pi^0\pi^0$ and KK are indeed difficult. BR less than 10^{-6} are almost impossible.

A combined effort of experiment and theory might allow the determination of α and γ.