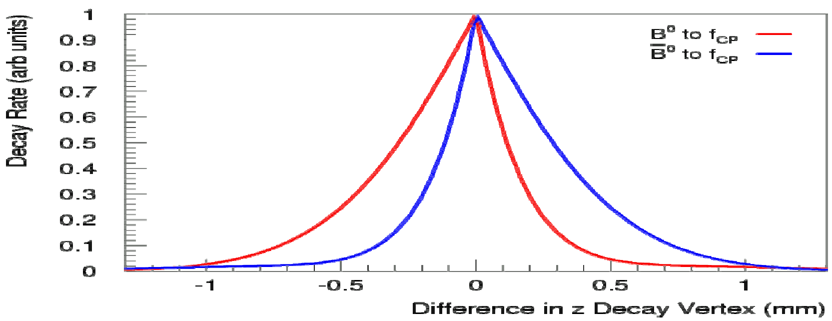
CP violation and B factories



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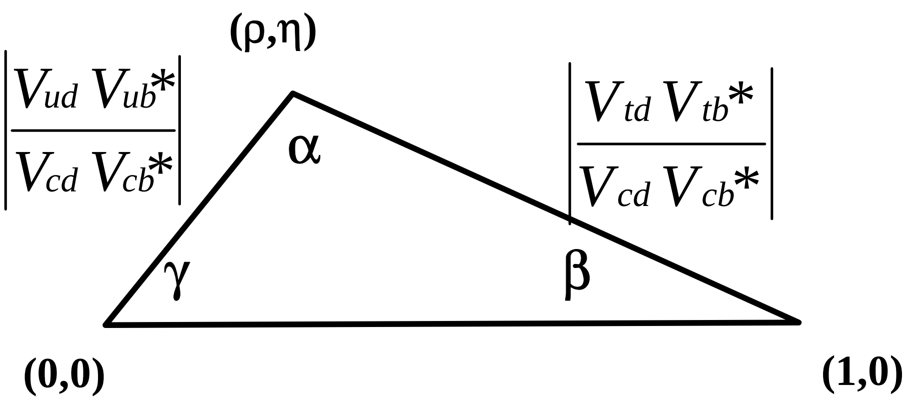
May 17th/19th 2004

LNF spring school 2004



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BaBar@PEP-II taken as example. Belle@KEK-B is comparable in all respects

I. CP violation and the Standard Model

II. Time-Dependent CP-Violating Asymmetries and Asymmetric B-Factories

III. Reconstructing B Mesons

IV. Other ingredients: tagging and vertexing

V. Fit for sin2β

VI. Measurement of the other angles

Chapter I

CP violation and the Standard Model

What is CP violation and why are we trying to study it?

Start with the “mirror” transformations C, P, and T:

C = charge conjugation $C^2 = 1$

P = parity inversion $P^2 = 1$

T = time reversal $T^2 = 1$

Any symmetry has an associated non-observable quantity:

C$\Rightarrow$ no absolute sign of electric charge
P $\Rightarrow$ no absolute right-handed coordinate system
T $\Rightarrow$ no absolute direction of time

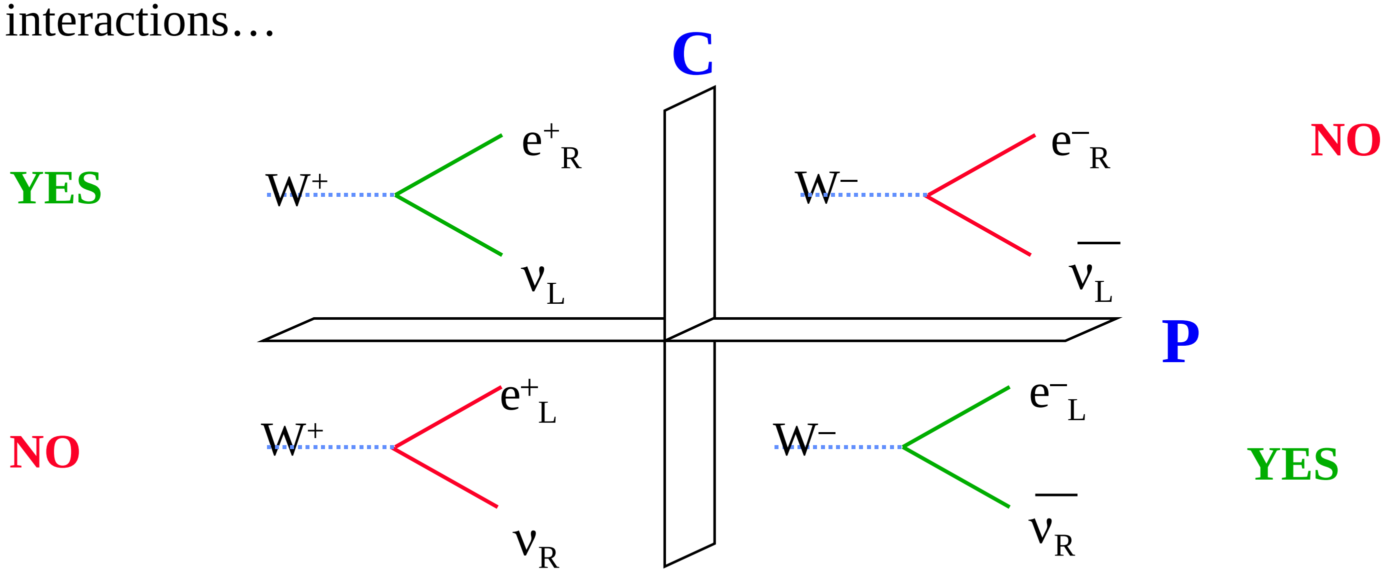
How can you tell if an extraterrestrial being is made of matter or antimatter?

(solution in a few slides)

Parity Violation

In 1956, Lee and Yang proposed, and in 1957, Wu and others showed experimentally, that **nature is not invariant under the PARITY transformation.**

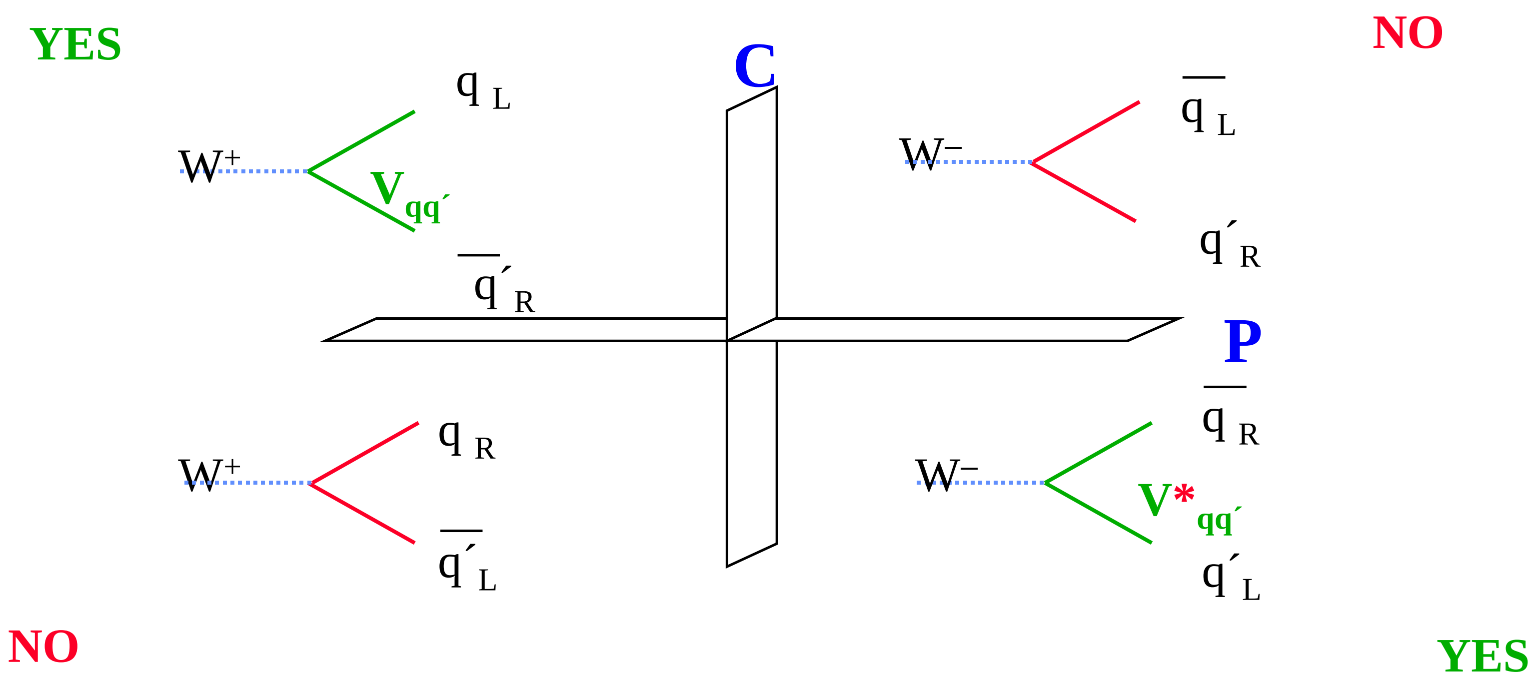
In the Standard Model, C and P are maximally violated in charged weak interactions…



CP Violation

In 1964, Cronin, Fitch and others found that even CP symmetry is violated in the weak decays of neutral Kaons.

In the Standard Model, CP violation can be accommodated in (again) the charged weak interaction, in the quark sector.



Significance of CP Violation

If C, P and CP are violated, does nature respect any mirror symmetries?

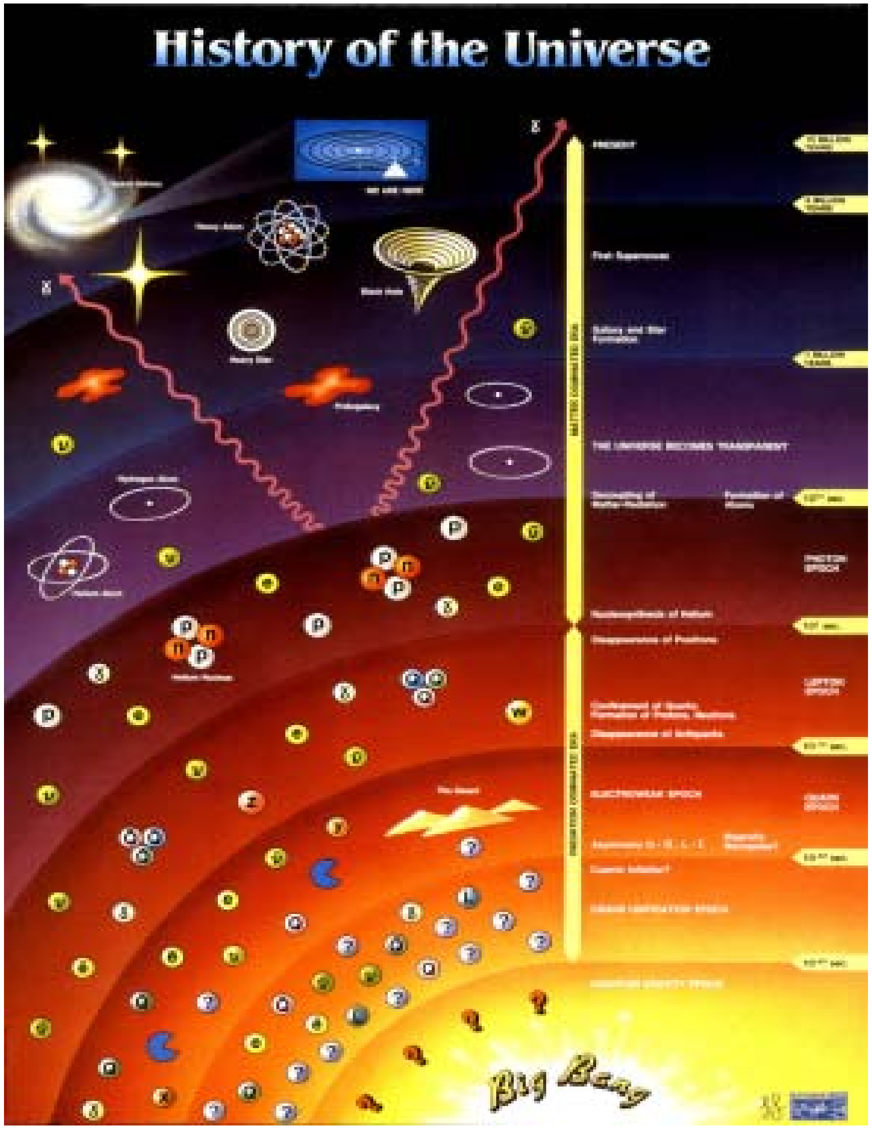
CPT: combined action of C, P, and T is a symmetry of any local relativistic field theory.

If CPT is a good symmetry, **CP violation ⇒ T violation**.

Sakharov's three conditions for a net excess of matter over antimatter in the universe include CP violation.

Answer to "extraterrestrial" puzzle: 'ask it if the KL decays most of the time into a lepton of the same charge as the nuclei'

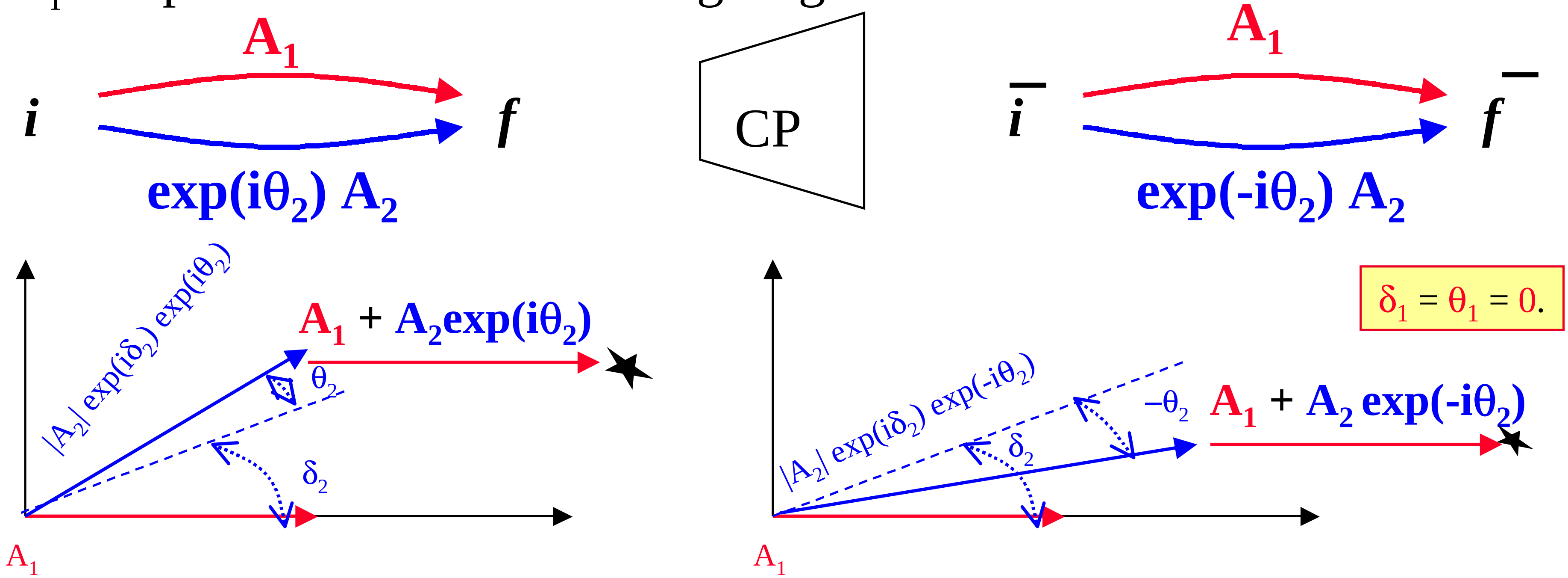
$$\delta = \frac{Br(K_L \to \pi^- l^+ \nu) - Br(K_L \to \pi^+ l^- \nu)}{Br(K_L \to \pi^- l^+ \nu) - Br(K_L \to \pi^+ l^- \nu)} = 0.33\%$$



How can physically observable CP-violating effects arise?

θ_i is a phase that does change sign under CP;

δ_i is a phase that does not change sign under CP.



$P(i \to f) - P(\bar{i} \to \bar{f})\ \alpha\ \ 2\,|A_1\ A_2|\,[\cos(\delta_2 - \theta_2) - \cos(\delta_2 + \theta_2)] = 2\,|A_1\ A_2|\,\sin(\delta_2)\,\sin(\theta_2)$

$\Rightarrow$ CP-violating asymmetries between the decay of a particle and its antiparticle can arise from the interference between two decay amplitudes with relative CP-violating **and** non-CP-violating phases.

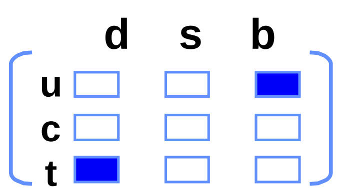
CP Violation in the Standard Model

Any physical phase in a coefficient (mass, coupling strength) of the Lagrangian can violate CP symmetry.

We can generally make coefficients real with suitable choice of phase convention for fields.

In the Standard Model, a nontrivial phase does appear in the unitary mixing matrix between quark weak interaction and mass eigenstates, in the case of at least three generations of quarks. The elements of this matrix, V_{qp}, describe the coupling of the W boson to quarks p and q. The matrix is called the Cabibbo-Kobayashi-Maskawa (or CKM) matrix.

It is possible to parametrize the quark mixing matrix such that the only elements that have a significant complex part are the two that are furthest from the diagonal: V_{ub} and V_{td}.



CKM matrix
(■ = complex)

"The" Unitarity triangle

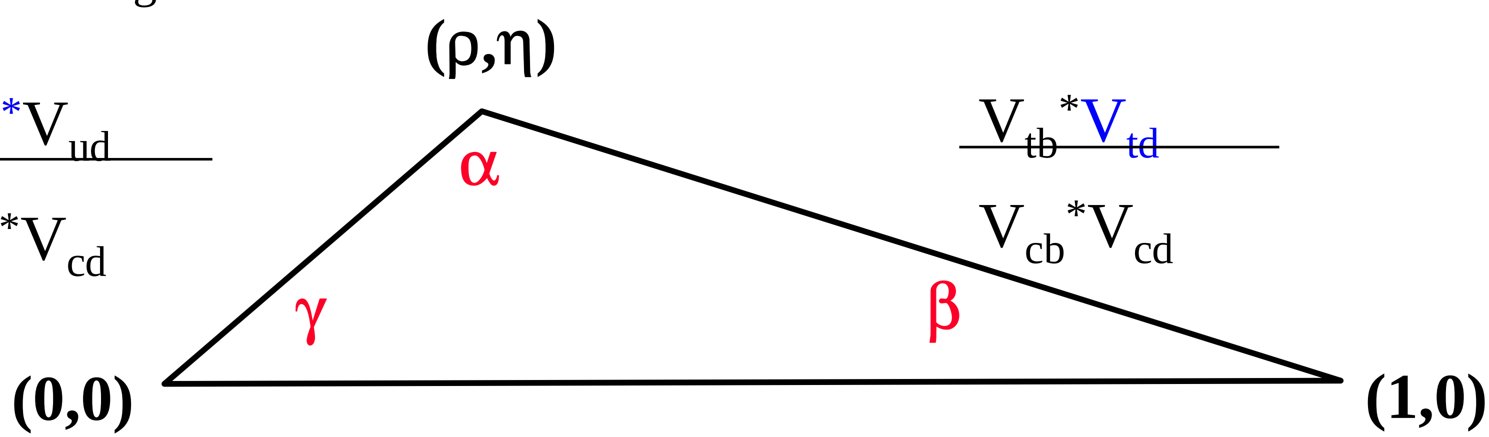
The unitarity condition that gives the most open triangle is

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

The first and last terms contain the most-off-diagonal elements V_{ub} and V_{td} , those with the most significant complex part.

It is convenient to divide each term by the middle term so that the base of the triangle has unit length.

$$\frac{V_{ub}^{*}V_{ud}}{V_{cb}^{*}V_{cd}} \qquad \frac{V_{tb}^{*}V_{td}}{V_{cb}^{*}V_{cd}}$$

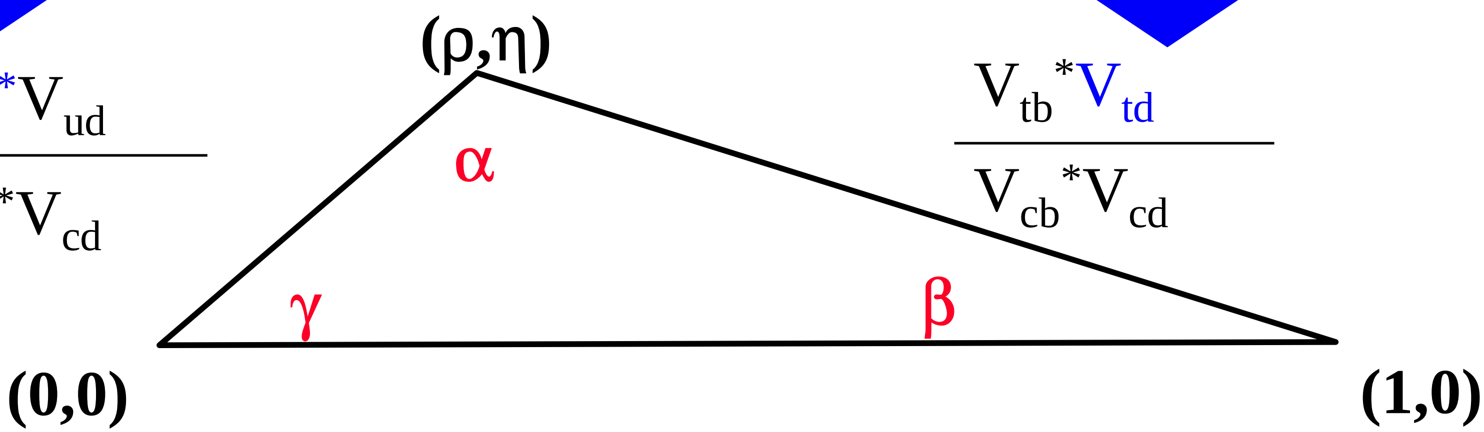


What were the constraints on the triangle before the asymmetric BFs?

$|V_{ub}/V_{cb}|$ is determined from the momentum spectrum of charged leptons in **semileptonic B decays.**

$|V_{td}|$ is determined from **mixing in the B_d system, and the ratio of B_d to B_s mixing.**

$$\frac{V_{ub}^{*} V_{ud}}{V_{cb}^{*} V_{cd}}$$

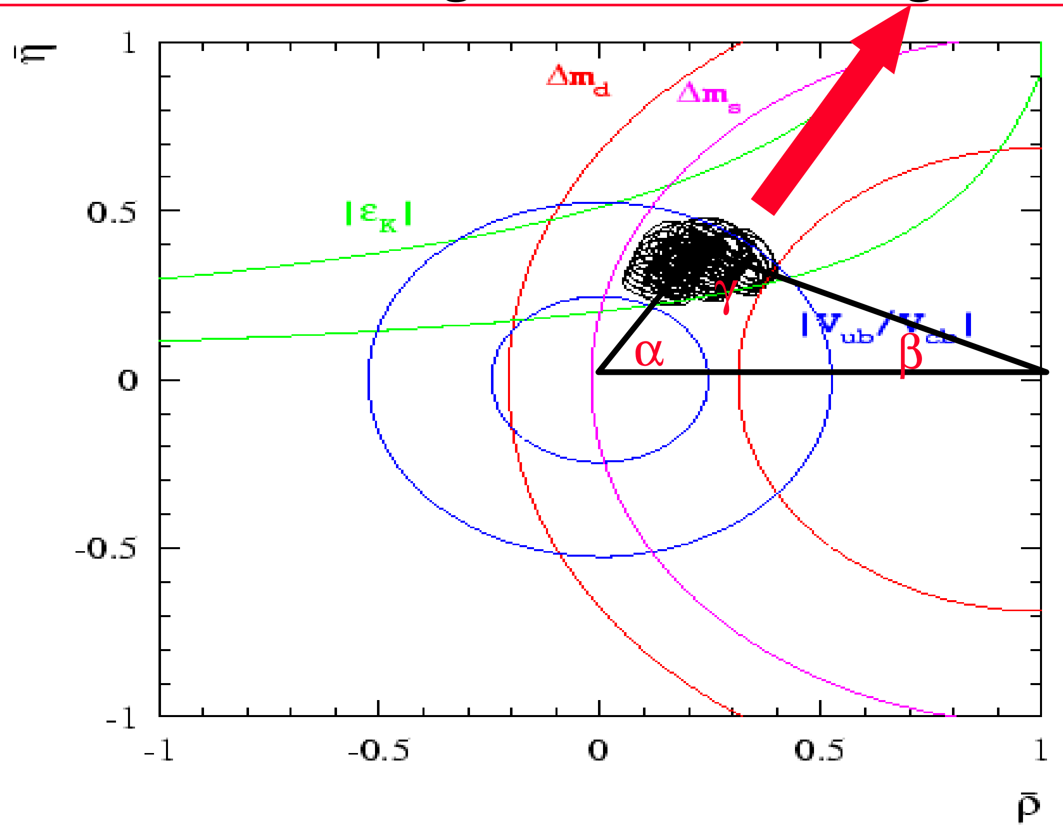


$$\frac{V_{tb}^{*} V_{td}}{V_{cb}^{*} V_{cd}}$$

Measured rate of **CP violation in the K system** ($|\varepsilon_K|$) restricts the upper apex of the triangle to lie along a hyperbola in the complex plane.

Experimental Constraints on the Unitarity Triangle prior to BFs

Existing measurements restricted the upper apex of the triangle to lie in this region.

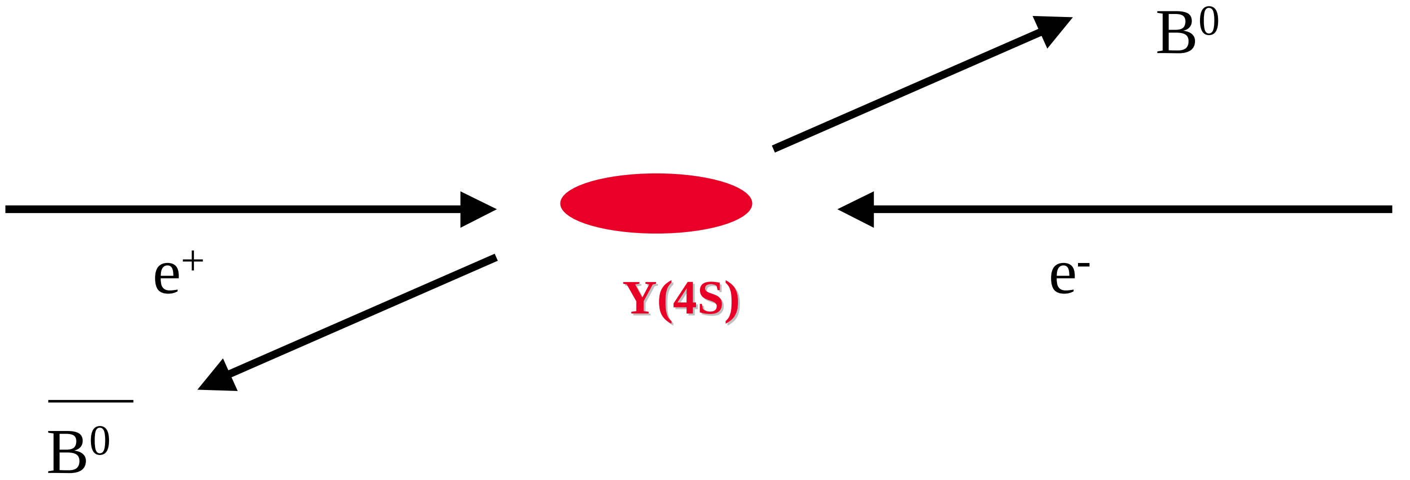


In asymmetric B-Factories, we measure the angles directly.

Chapter II

Time-Dependent CP-Violating Asymmetry and Asymmetric B Factories

In a B Factory

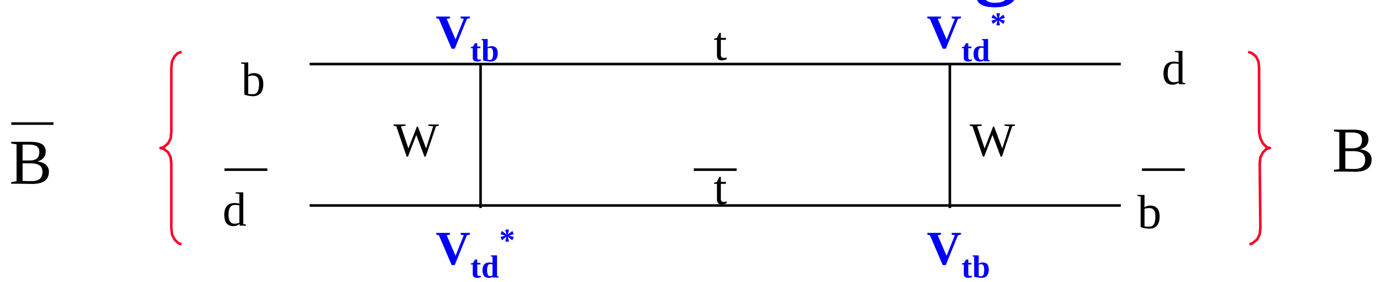


Since J(Y)=1 and J(B)=0 and the B0 mesons have to obey the bose-einstein statistics

$$|\Upsilon(4S)> = \frac{|B^0\overline{B}^0> - |\overline{B}^0 B^0>}{\sqrt{2}}$$

Two B mesons with opposite flavour are produced in a coherent state

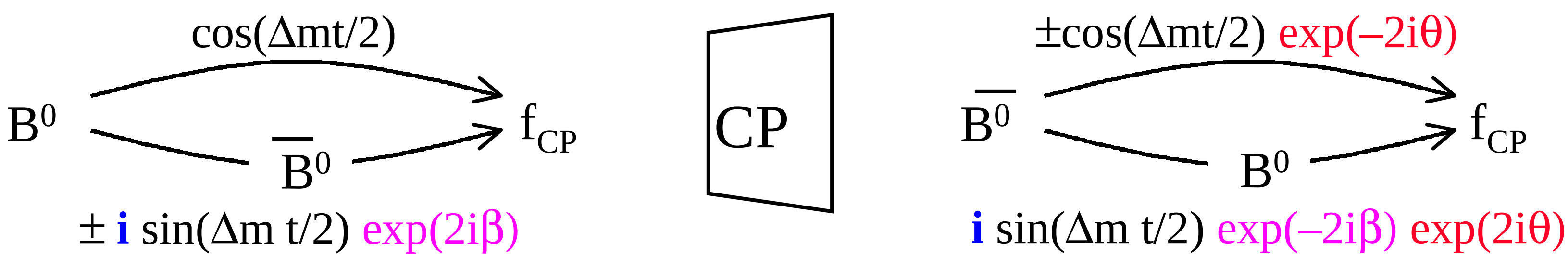
$B^0 \leftrightarrow \overline{B}^0$ Mixing



Meson mixing provides a source of error-free non-CKM phase shift by $\delta_1 - \delta_2 = 90^o$ (**i**):

$$|B^0(t)\rangle \propto \cos(\Delta m\, t/2)\, |B^0\rangle - \mathbf{i}\, \sin(\Delta m\, t/2)\, |\overline{B}^0\rangle\, \exp(2i\beta)$$

The interference between $B^0 \leftrightarrow \overline{B}^0$ mixing and decays into a CP eigenstate (accessible to both B^0 and $\overline{B}^0$) provides the cleanest theoretical predictions:



with a CP-violating asymmetry $\approx \sin 2(\beta - \theta)$.

The CKM angle ϕ is associated with the mixing box diagram.
The CKM angle θ depends on the final state f_{CP}

$$2\theta = Arg\left(\frac{A(B^0 \to f)}{A(\overline{B}^0 \to f)}\right)_{DK}$$

~~CP~~ in Oscillations+ Decay

Study the oscillation frequency in decay channels common to B^0 and $\overline{B^0}$

$$A_{CP} = \frac{\Gamma(\overline{B^0}(t) \to f) - \Gamma(B^0(t) \to f)}{\Gamma(\overline{B^0}(t) \to f) + \Gamma(B^0(t) \to f)} = \frac{(1-|\lambda|^2)\cos(\Delta M t) + 2\,\mathrm{Im}\,\lambda \sin(\Delta M t)}{1-|\lambda|^2}$$

$$\lambda = \frac{A(\overline{B} \to f) V_{td}^* V_{tb}}{A(B \to f) V_{td} V_{tb}^*} \cong \frac{\overline{A}}{A} e^{-i2\beta}$$

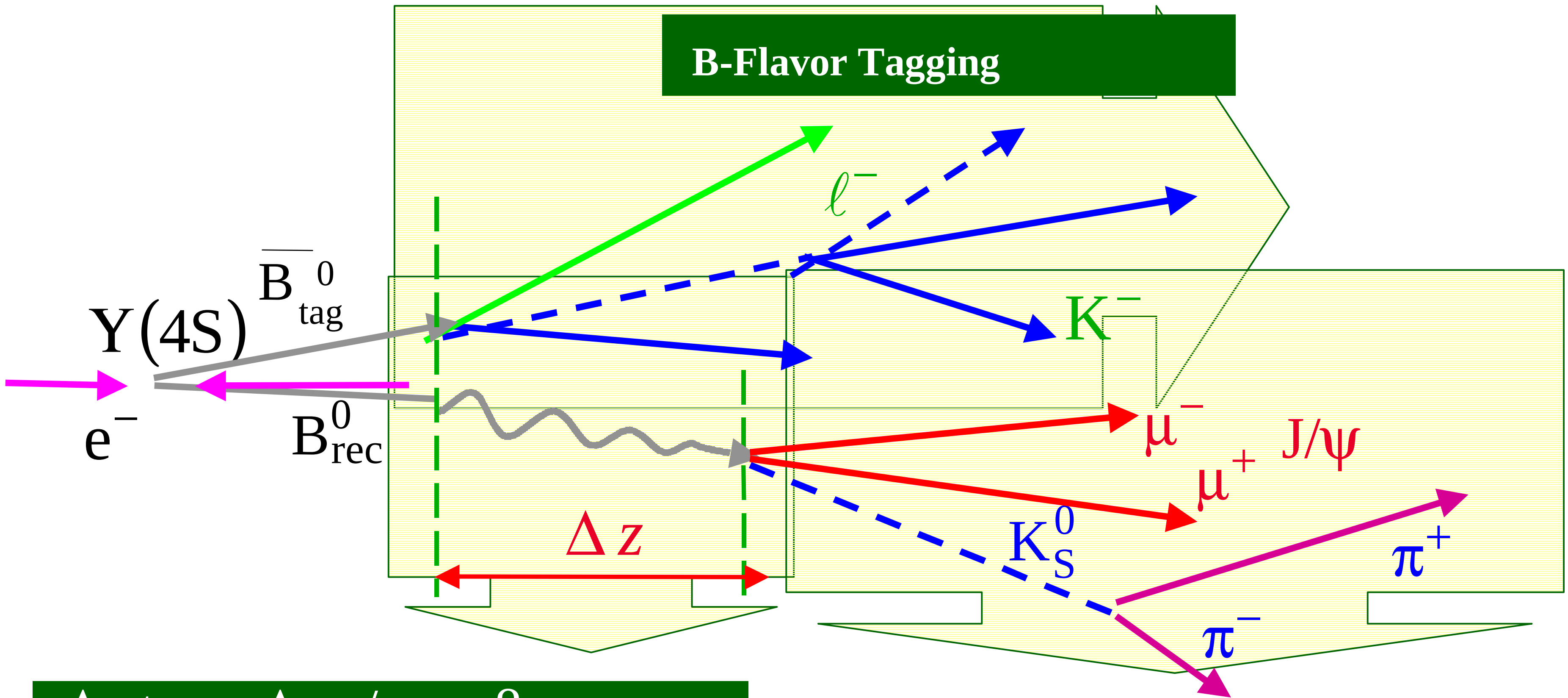
Notes:

- the measured λ depends on the final state
- if only one amplitude contributed $|\lambda|=1$

Examples for these lectures:

	f	$Arg(\frac{\overline{A}}{A})$	$\lvert\lambda\rvert$	output
mixing	$B_0 \to l\nu X, D^{(*)}\pi, \rho, a_1$	0	~0	ΔM_{B0}
"sin2β"	$B_0 \to J/\Psi K^0, \phi K^0$	0	1	sin2β
"sin2α"	$B_0 \to \pi\pi, \rho\rho$	~(-2γ)	~1	sin2α
sin(2β+γ)	$B_0 \to D^{(*)+}\pi^-$	~(-γ)	~0.02	sin(2β+γ)

Experimental Technique



$\Delta t \approx \Delta z / \langle \beta\gamma \rangle c$

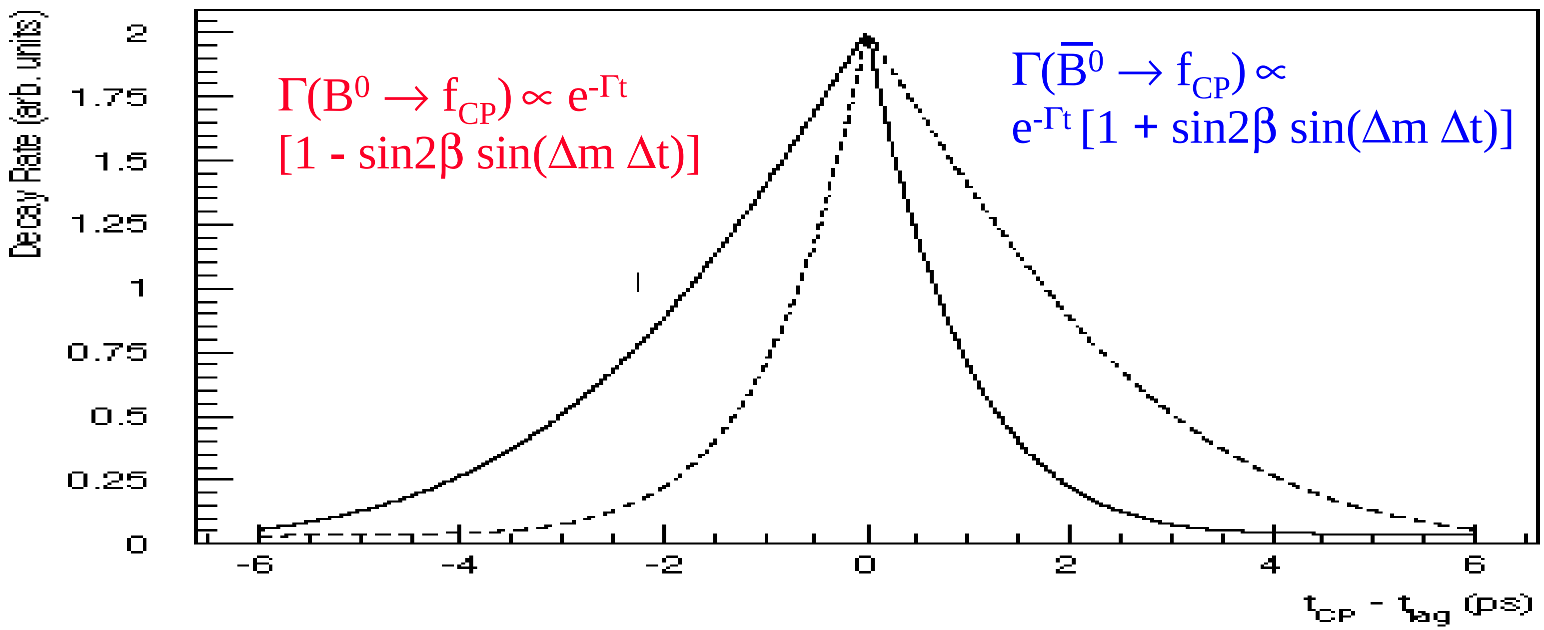
Accurate and unbiased measurement of the vertices

Exclusive B Meson Reconstruction

Low BR (10^{-5}) means high luminosity

Time-dependent asymmetry

Because of correlation of B^0 and $\overline{B}^0$ state, need to measure difference in decay times to see asymmetry due to interference between mixing and direct decay:



$\Delta t = t_{CP} - t_{tag}$ (picoseconds)

asymmetry $\propto$ $\sin 2\beta \sin(\Delta m\, \Delta t)$

Integrated asymmetry $\equiv 0$

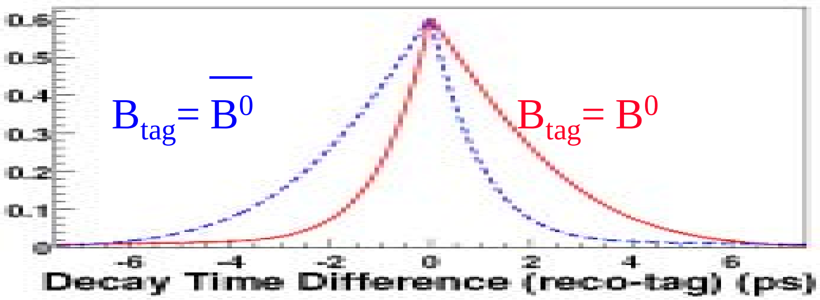
From the ideal world to “reality”…

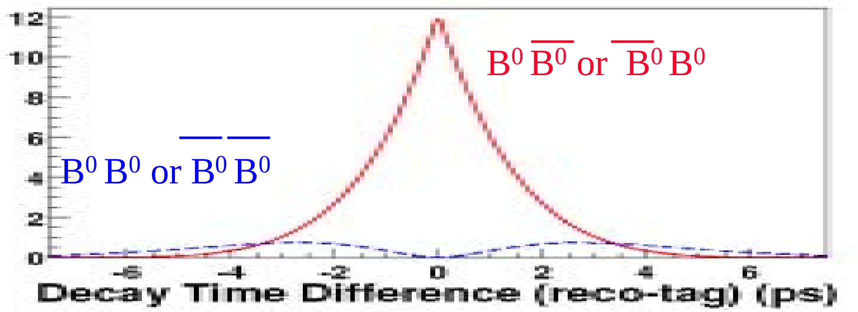
CP analysis:

reconstruct f_{CP} and tag other side as B^0 or $\bar{B}^0$.

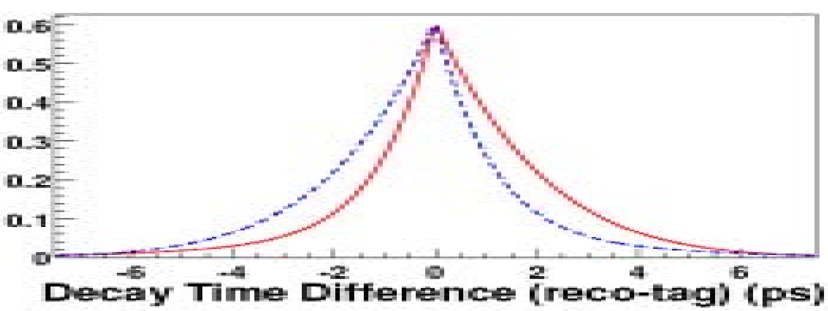
Mixing analysis:

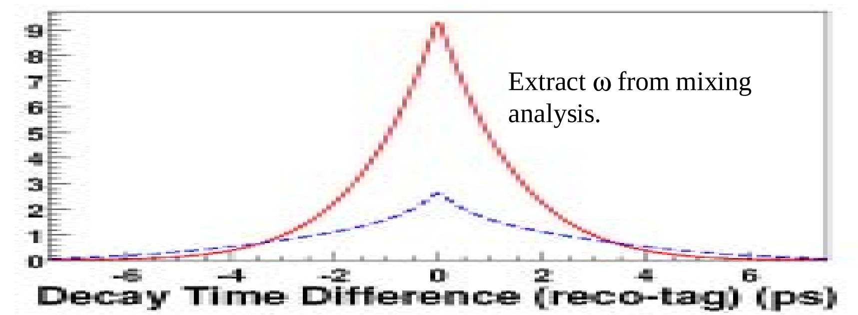
tag both sides as B^0 or $\bar{B}^0$; e.g., fully reconstruct one B decay to a non-CP state; tag other side.





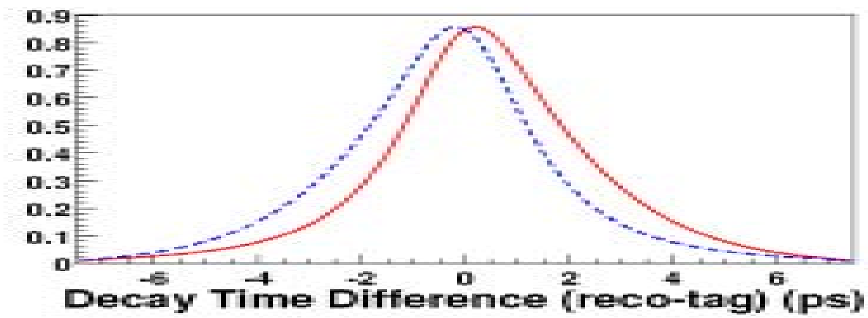
First add dilution due to **imperfect tagging**. Assume the mistag rate is ω = 22%. Time-dependent CP asymmetry is diluted by (1-2ω) = 0.56

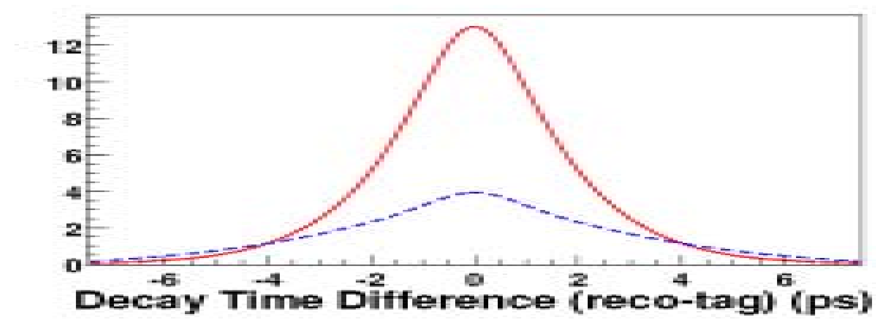




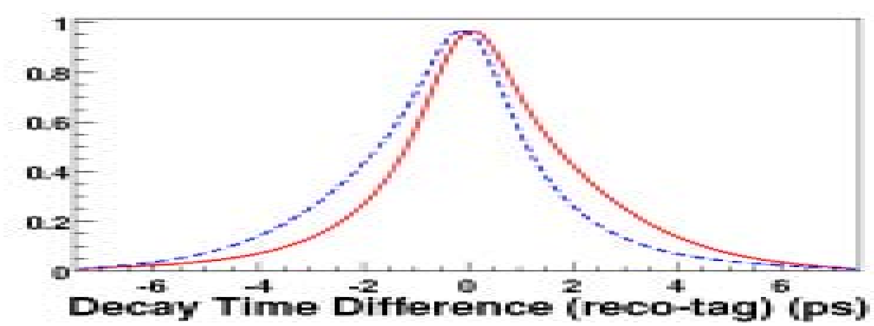
From the ideal world to reality...

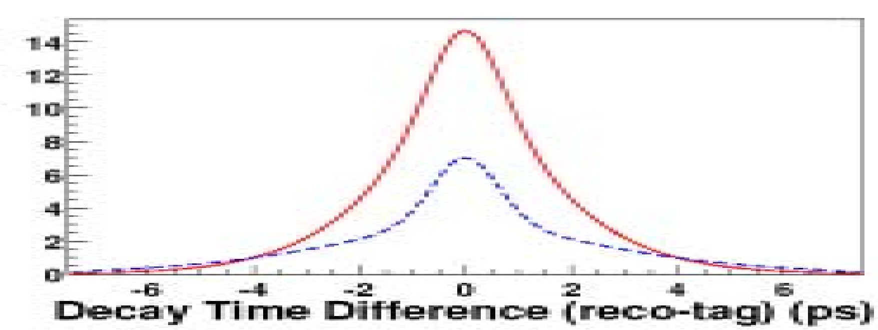
Now add effect of **imperfect measurement of Δt.** Assume double Gaussian Δz resolution of 100 microns (80%) and 300 microns (20%). [βγc ~ 170 microns/ps]





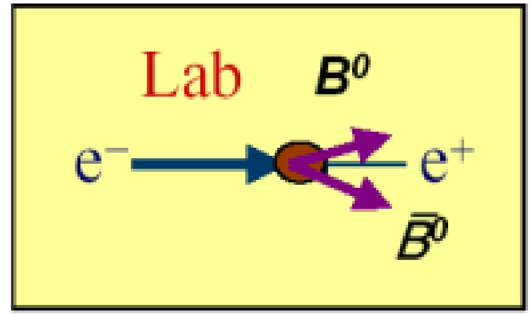
Finally add **background** contribution. Assume N_S/N_B ~ 10:1 for mixing analysis, 50:1 for CP analysis.





PEP-II &KEK-B

- Decay time determined from decay distance between B decays $\Delta z = \Delta t\ (c\ \beta\gamma)$
- In $\Upsilon(4S)$ CMS daughter B's travel only $\Delta z \sim 20\ \mu m$
- Boost at PEP-II / KEKB decay gives much larger separation $<|\Delta z|> \sim 250/200\ \mu m$ (BaBar/Belle)
  - measurable with high resolution Silicon Vertex Detectors (typical resolution 200 μm)

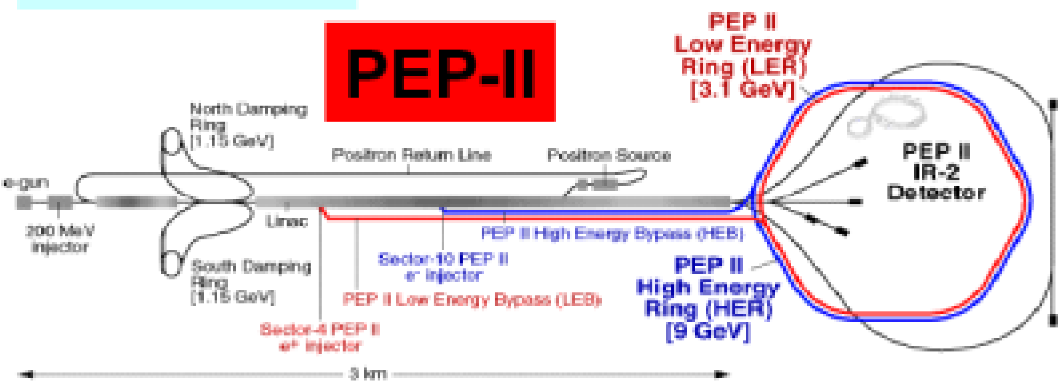


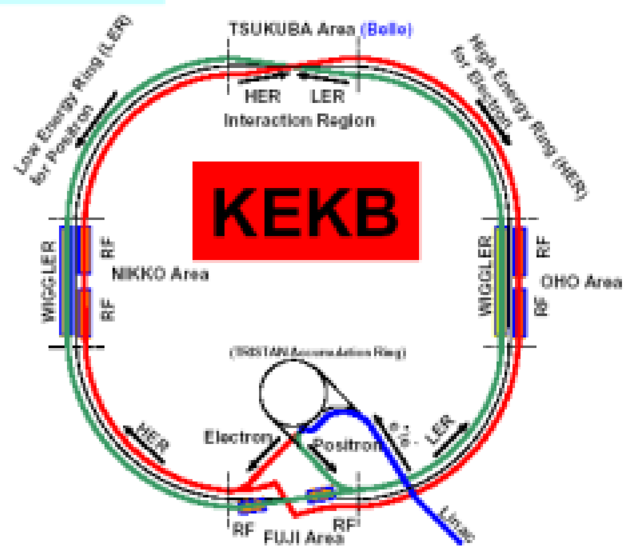
$E_+ = 3.5$ GeV
$E_- = 8$ GeV

$\beta\gamma = 0.43$

$E_+ = 3$ GeV
$E_- = 9.1$ GeV

$\beta\gamma = 0.56$



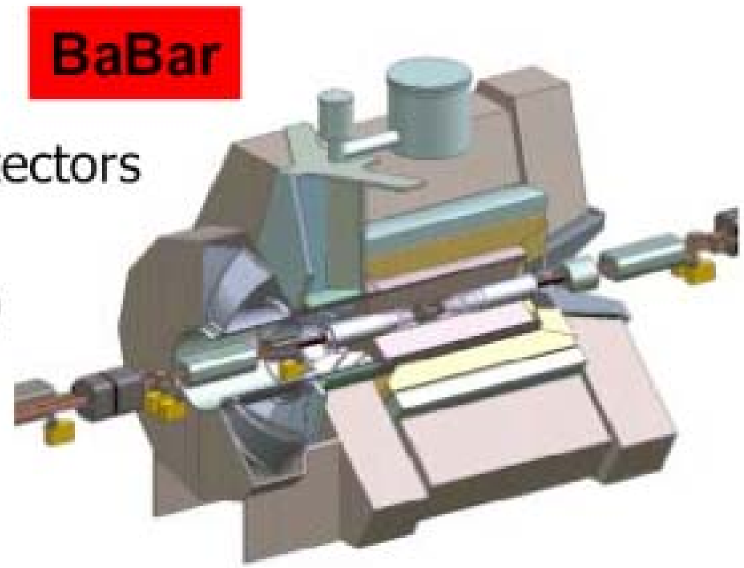


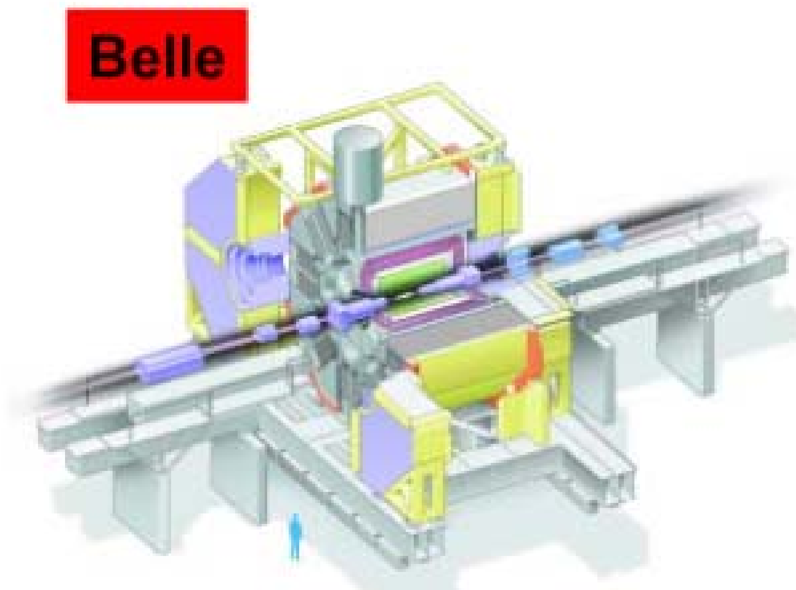
PEPII @ SLAC

The Detectors

Multi-purpose 4π detectors

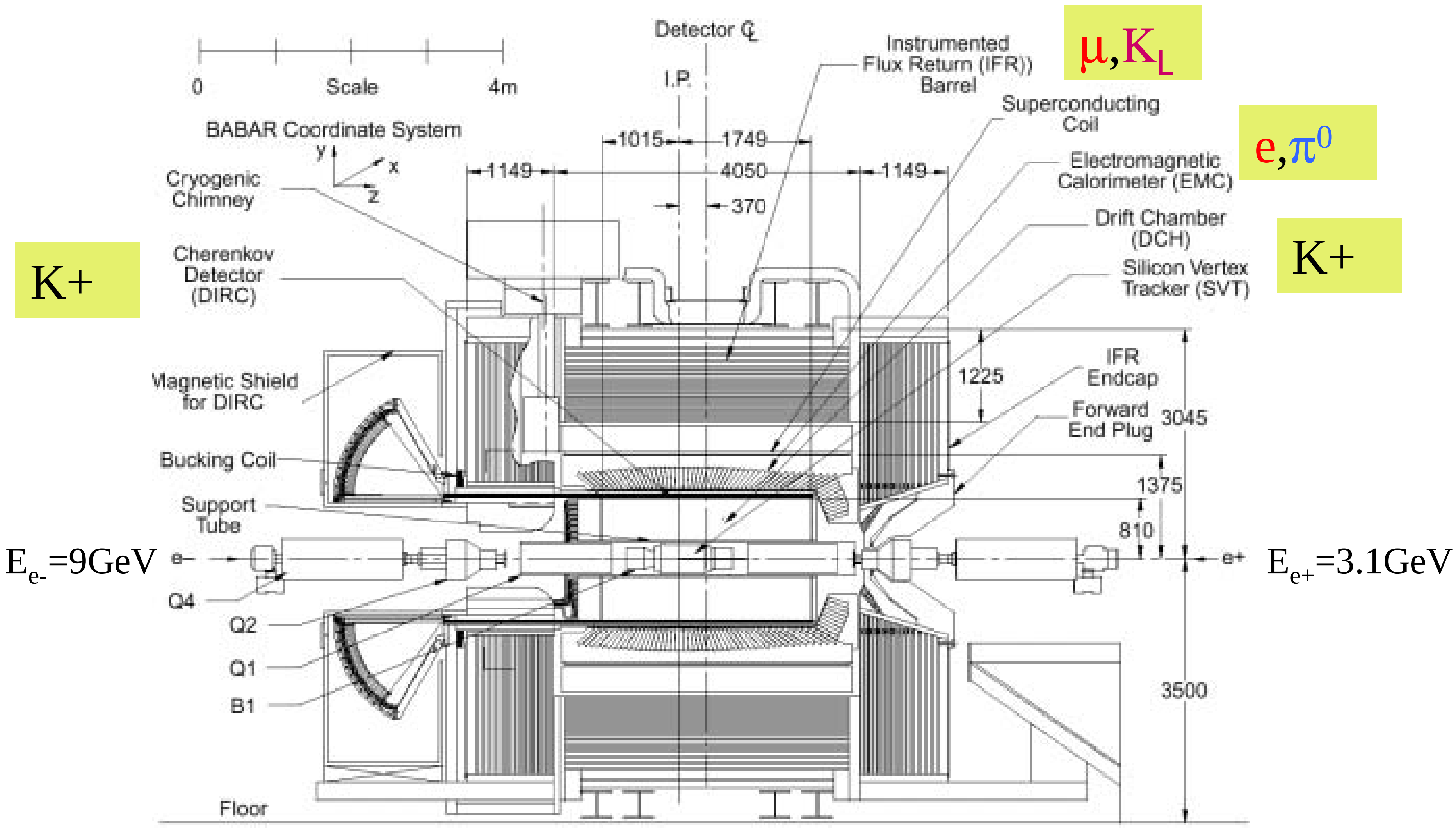
- Precision vertexing with silicon strip detectors
- Tracking with central drift chamber
- PID (BaBar: DIRC, Belle: Aerogel+TOF)
- Super-conducting coil
- EM CsI calorimeter
- Muon detection with RPCs



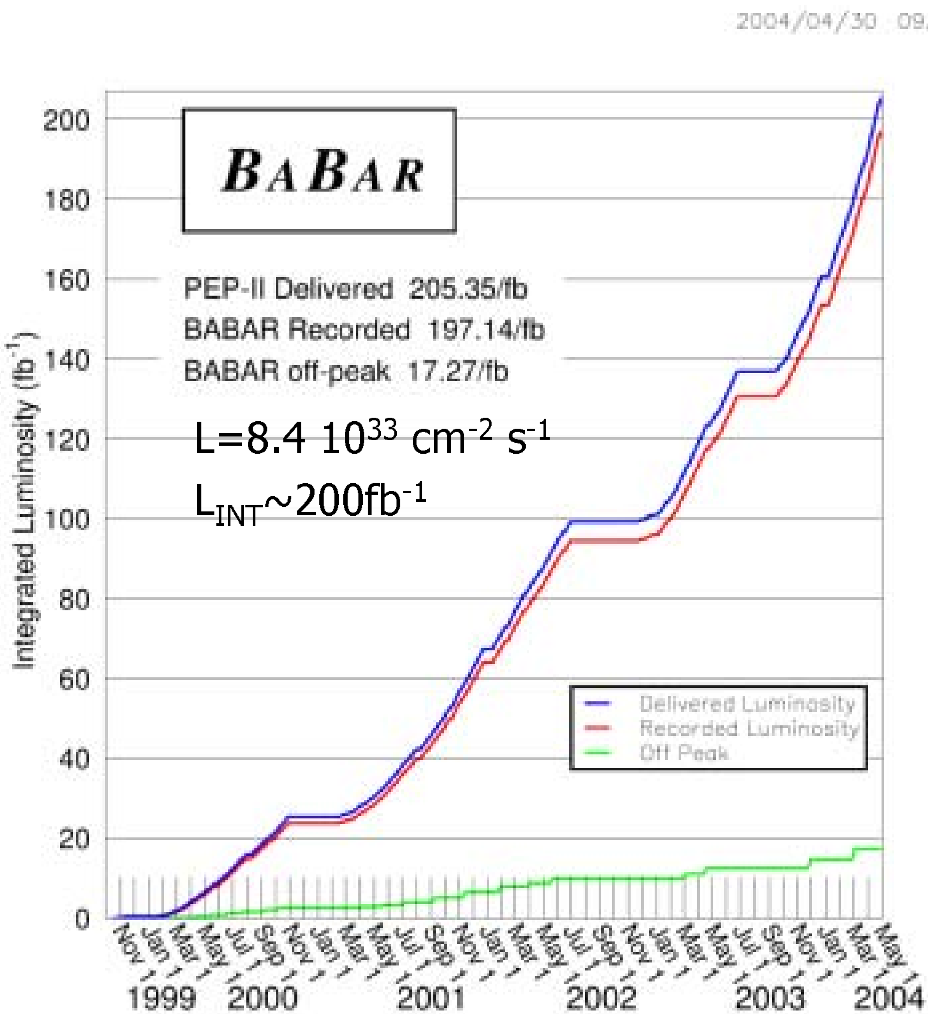


WARNING : All future detector descriptions refer to BaBar

The BaBar experiment

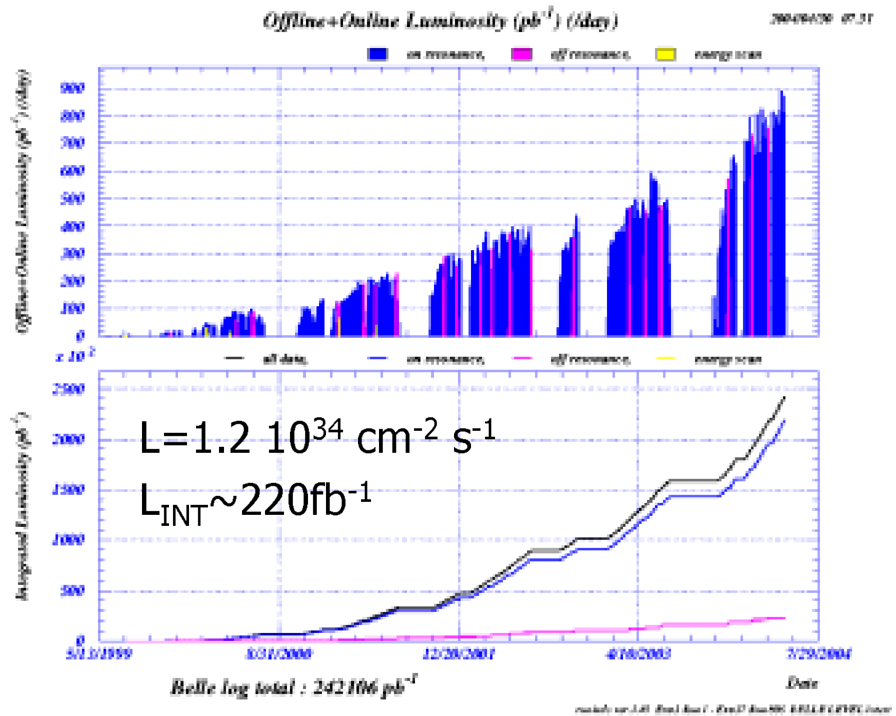


Current Luminosities



$L=8.4\ 10^{33}\ cm^{-2}\ s^{-1}$

L_{INT}~200fb^{-1}



$L=1.2\ 10^{34}\ cm^{-2}\ s^{-1}$

L_{INT}~220fb^{-1}

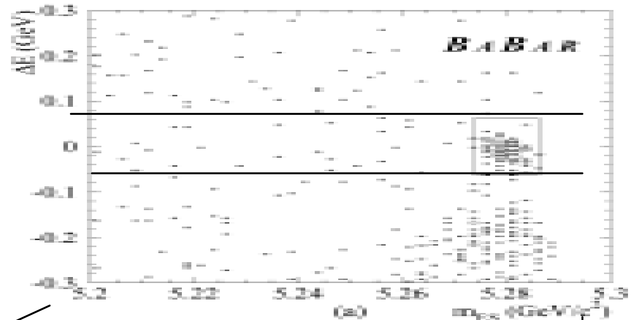
Belle

The BABAR Author List

Chapter III
Reconstructing B Mesons

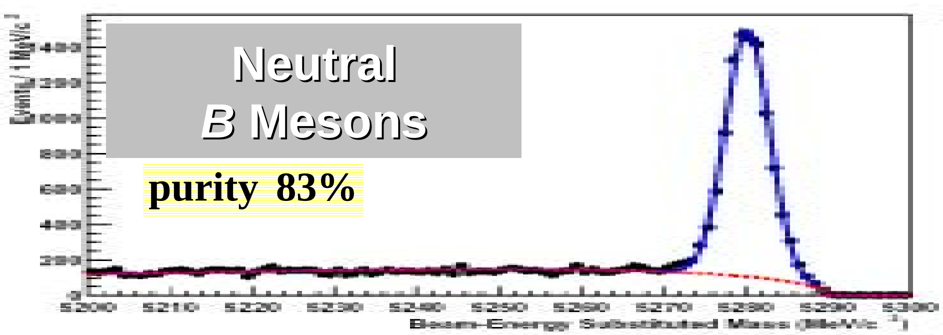
B FACTORY:
flavour eigenstates

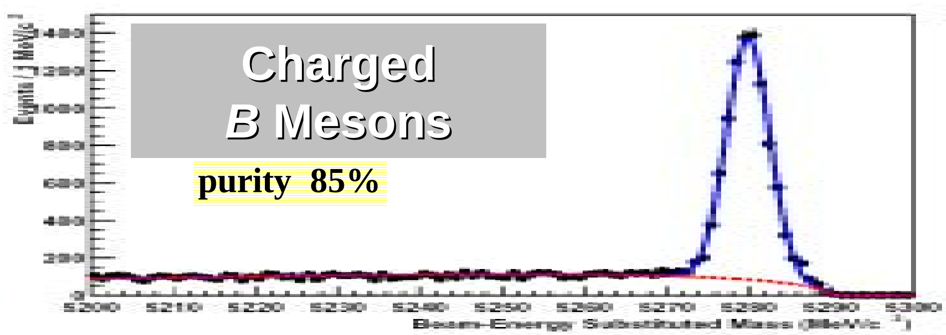
- **$B^0 \to D^{(*)-}\pi^+$, $D^{(*)-}\rho^+$, $D^{(*)-}a_1^+$, $J/\Psi K^{*0}$**
- **$B^- \to D^{(*)0}\pi^-$, $J/\Psi K^-$, $\Psi(2S)K^-$**
- Kinematic variables for signal and background estimates



$\Delta E = E^*_B - \sqrt{s}/2$ $\sigma \sim 15$ MeV

$m_{ES} = \sqrt{(s/4 - p^{*2}_B)}$ $\sigma \sim 3$MeV

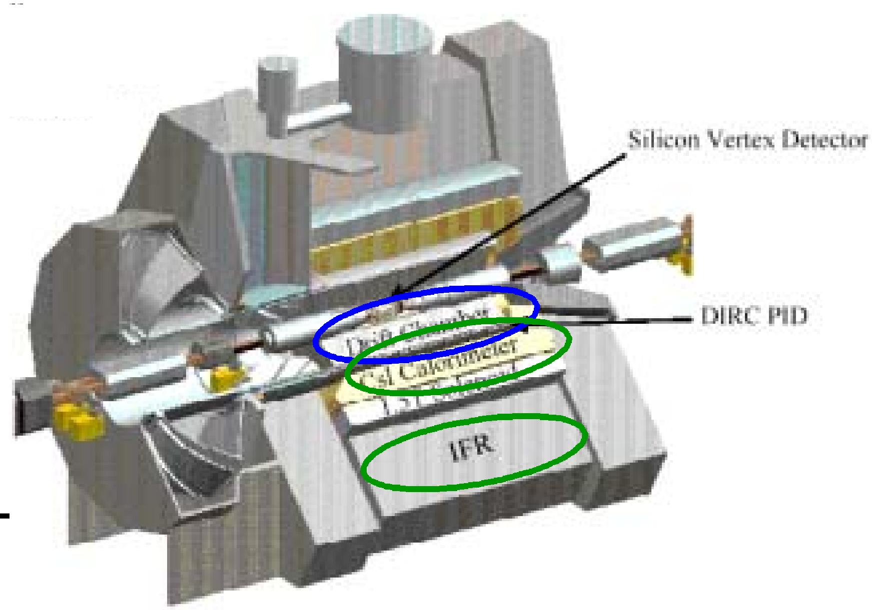




J/Ψ Ks reconstruction

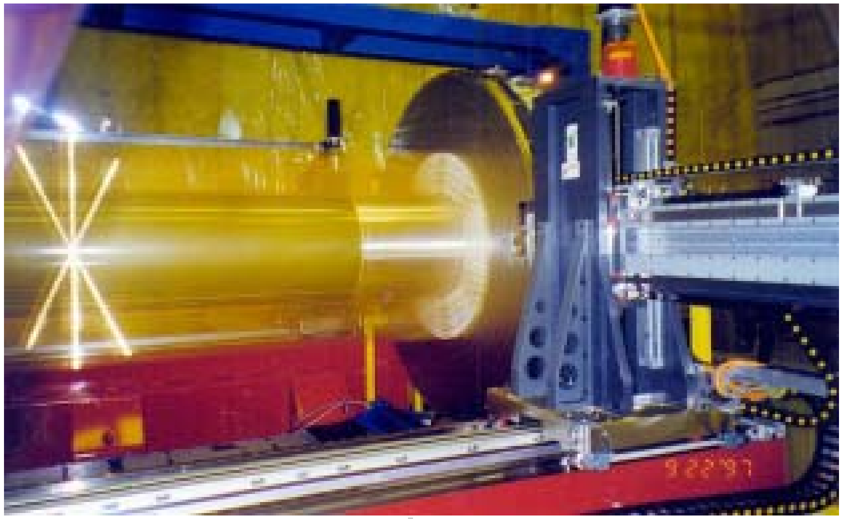
Reconstruction of $B \to J/\Psi K_s$, $J/\Psi \to ee,\mu\mu$ and $K_s \to \pi\pi$ requires :

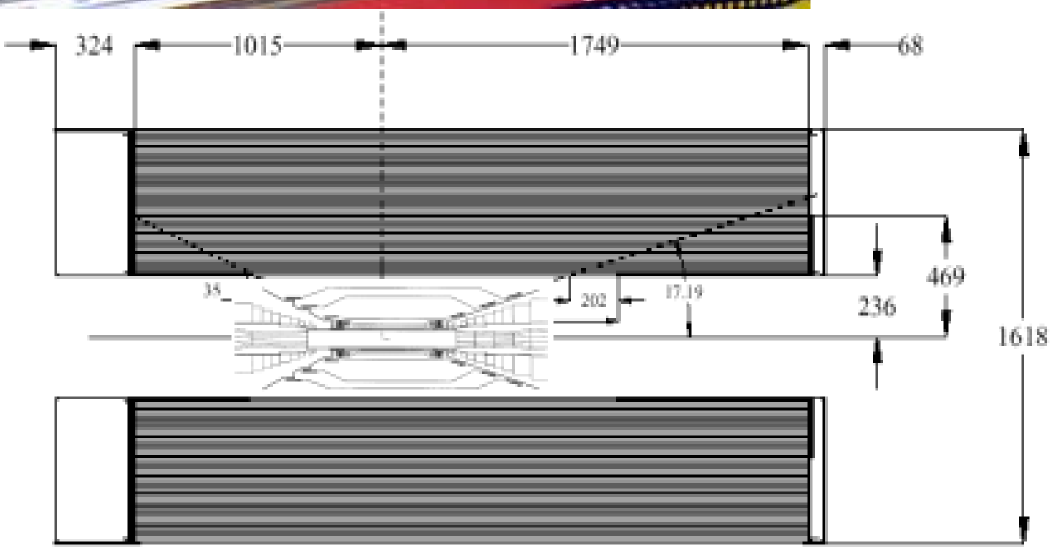
- reconstruction of charged tracks, in particular daughters of long living particles
  ⇒ Drift Chamber (DCH)
- identification of electrons and muons
  ⇒Electromagnetic Calorimeter (EMC)
  ⇒Instrumented Flux Return (IFR)

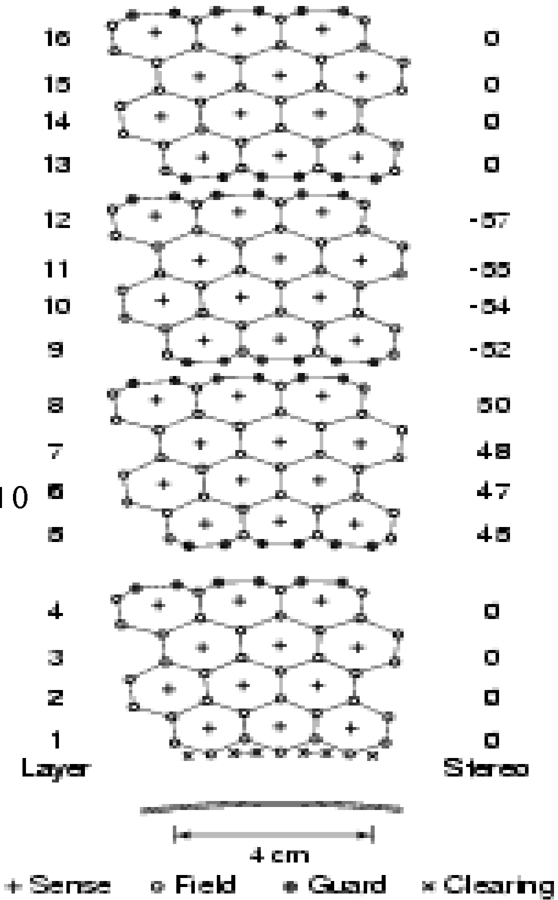


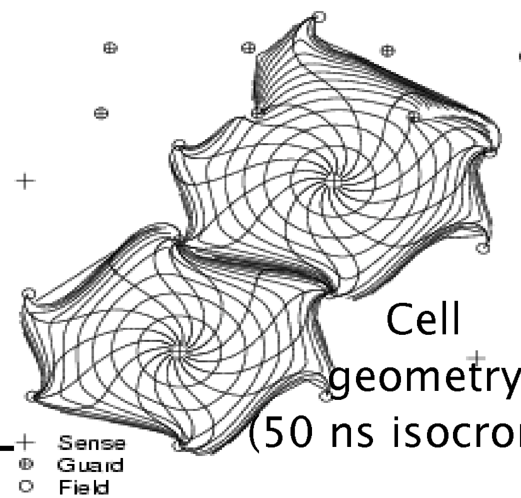
Drift Chamber

- 40 Layers
  (10 super-layers)
- Low-mass
  gas 80%He-20%C_4H_{10}
  Inner(outer)cylinder:
  0.28 (1.5) % X_0





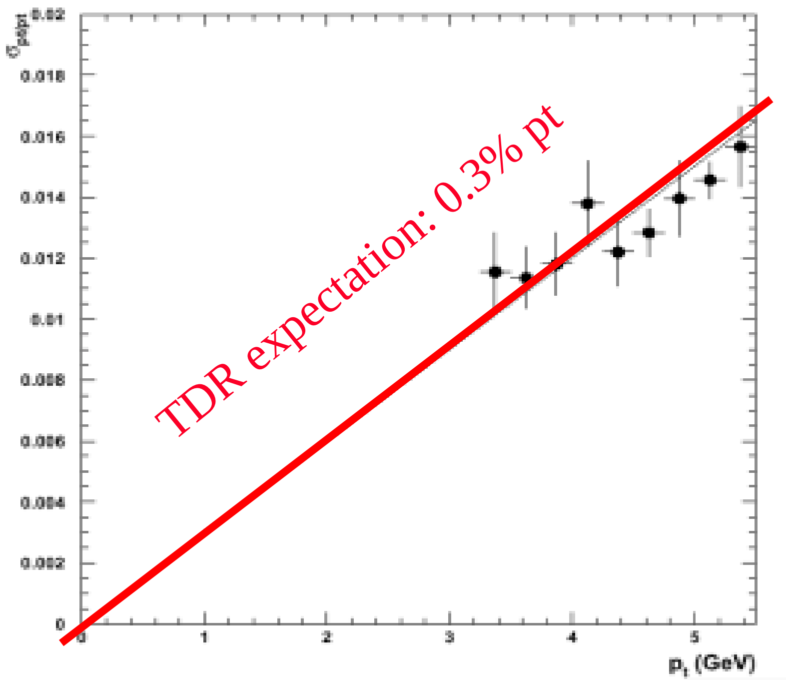




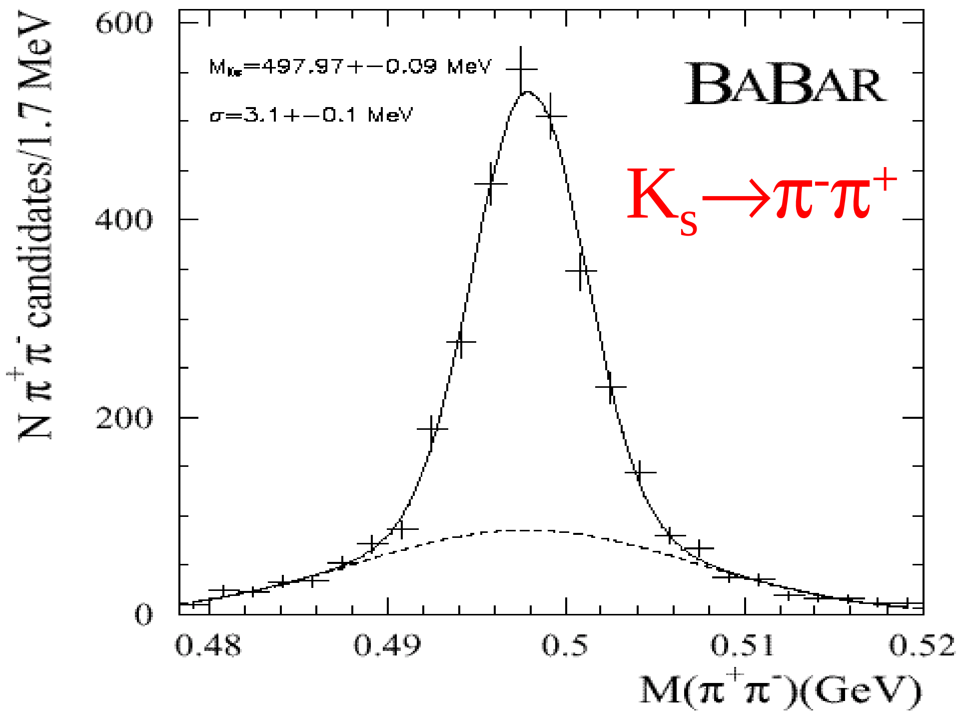
Cell geometry
(50 ns isocrones)

DCH Performances

σ_{P_t}/P_t



P_t

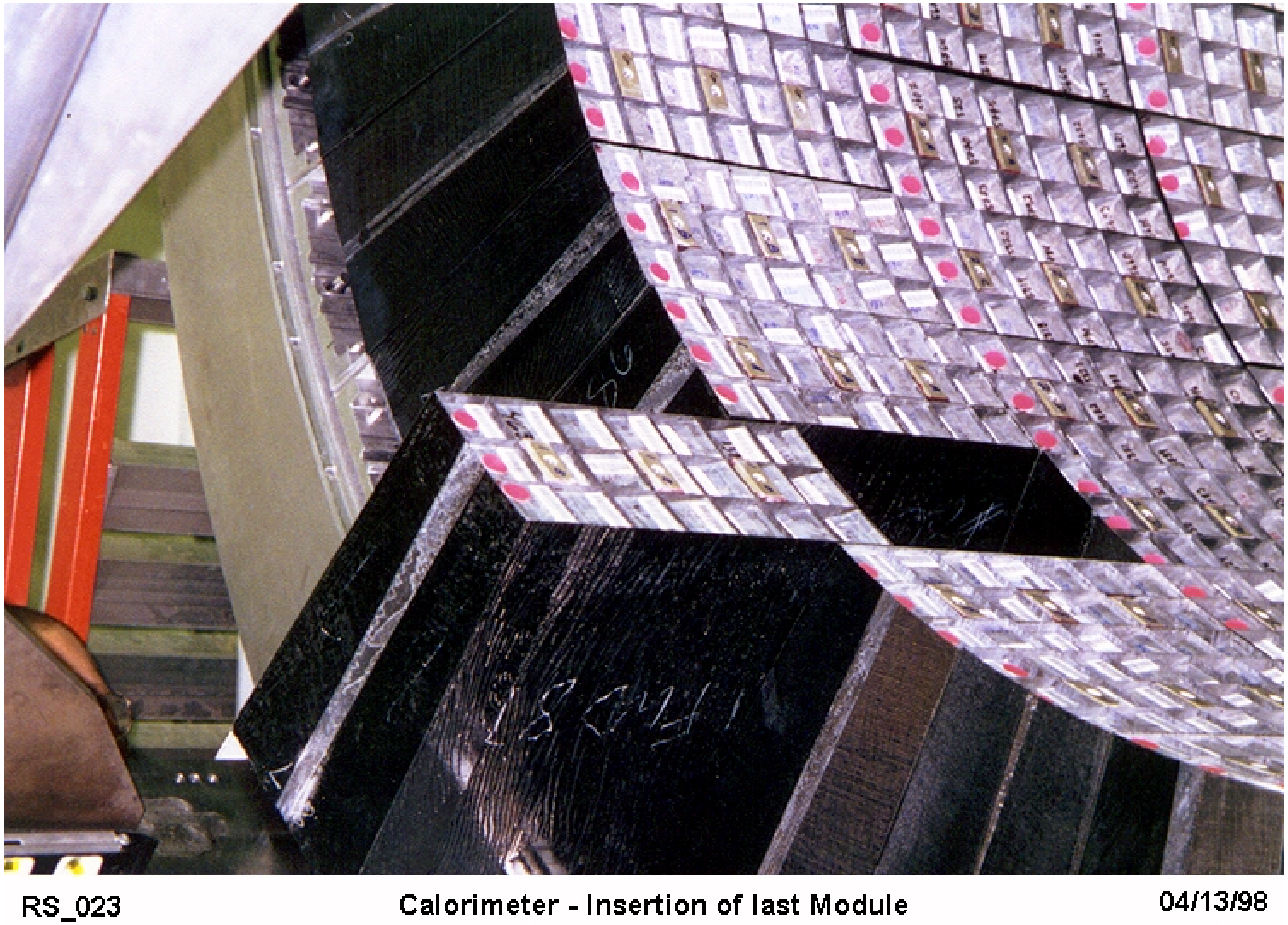


Momentum resolution

$\sigma_{P_t}/P_t = a \oplus bP_t$

K_s mass reconstruction

Electromagnetic Calorimeter

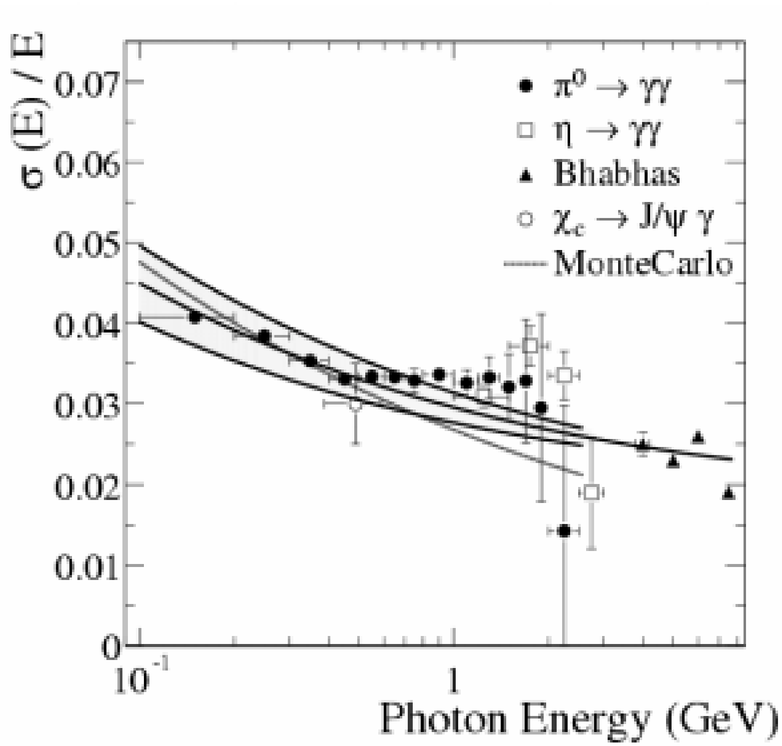


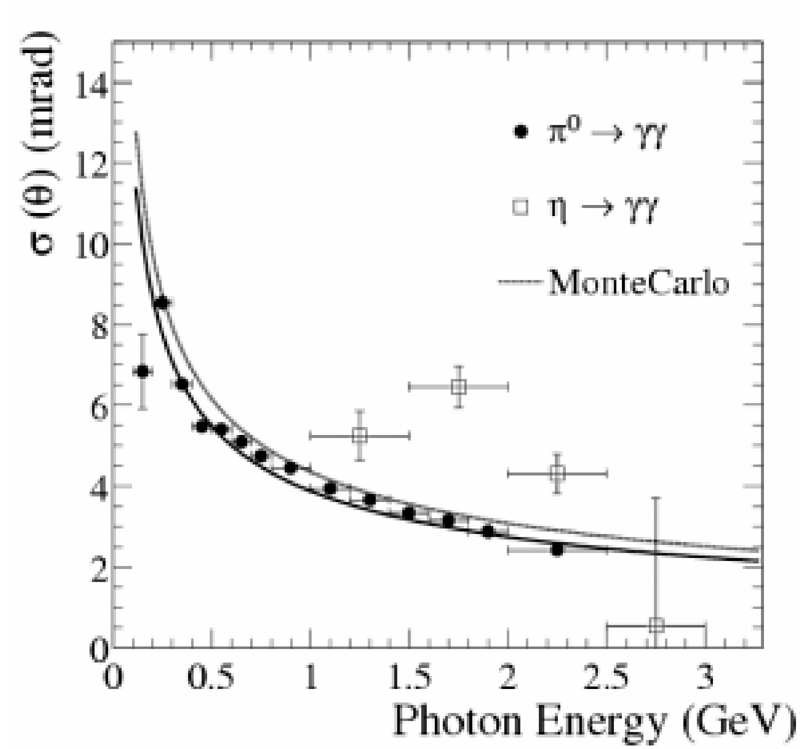
~6500 crystals of CsI ~18 X_0

EMC performances

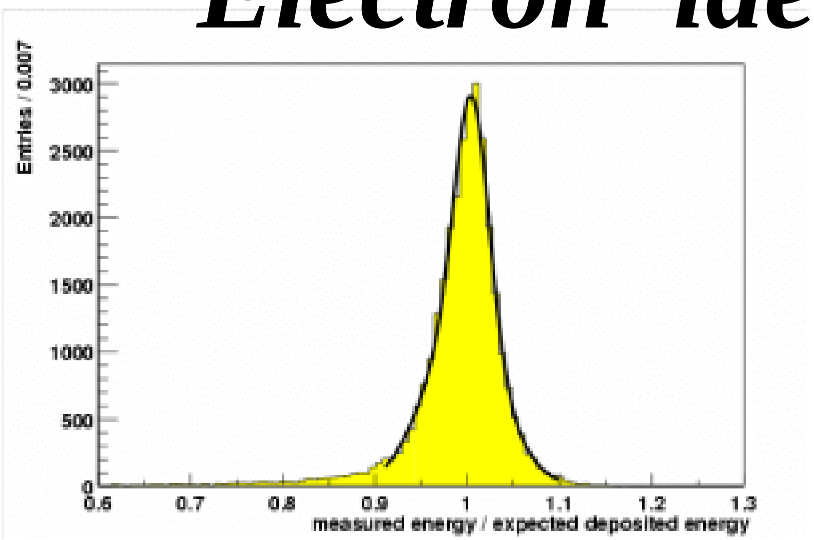
$$\frac{\sigma_E}{E} = \frac{2.3\%}{\sqrt[4]{E(GeV)}} \oplus 1.8\%$$

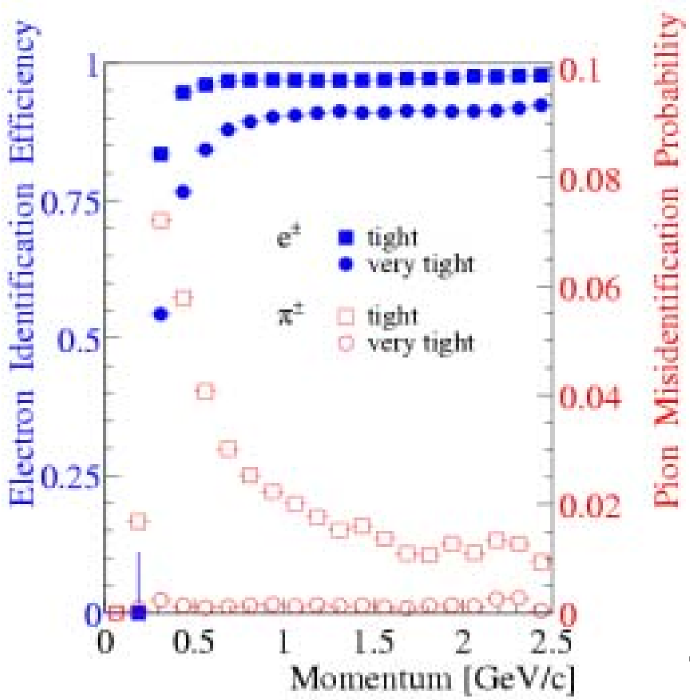
$$\sigma_\theta = (\frac{3.9}{\sqrt{E(GeV)}} \pm 0.04) mrad$$





Electron identification





Electron/charged hadron separation based on:

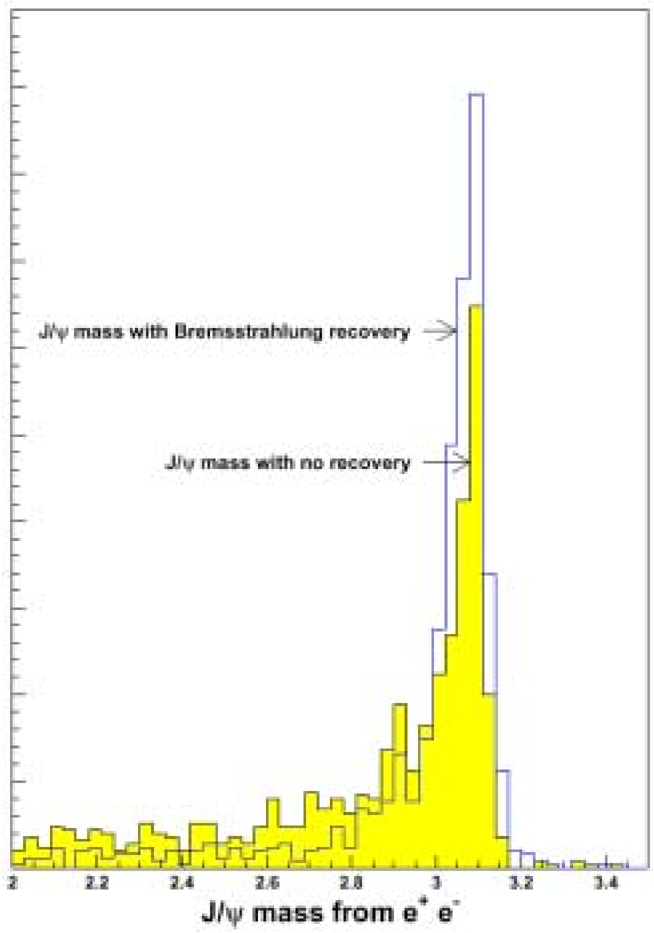
- shower energy (E/p)
- lateral shower size
- dE/dx and Θ_c consistency

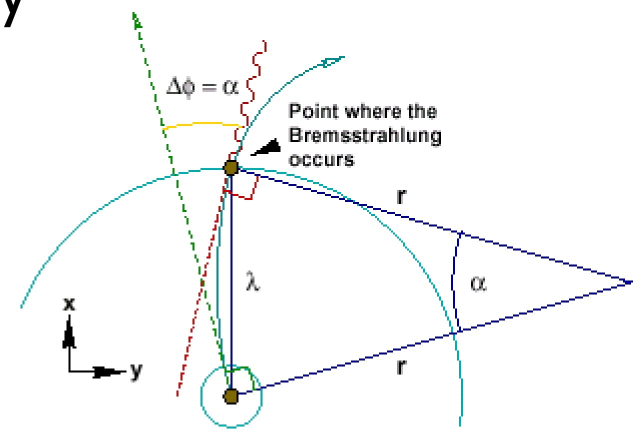
Control samples:

- efficiency: $e^+e^- \rightarrow e^+e^- e^+e^-$
- pion mis. ID:
  - K^0_s and 3-prong τ decays

BremsStrahlung recovery

Need to improve reconstruction when e→eγ :able to make prediction on where the photon will impact. Requires good granularity





Effect on J/Ψ mass reconstruction

μ and K_L identification

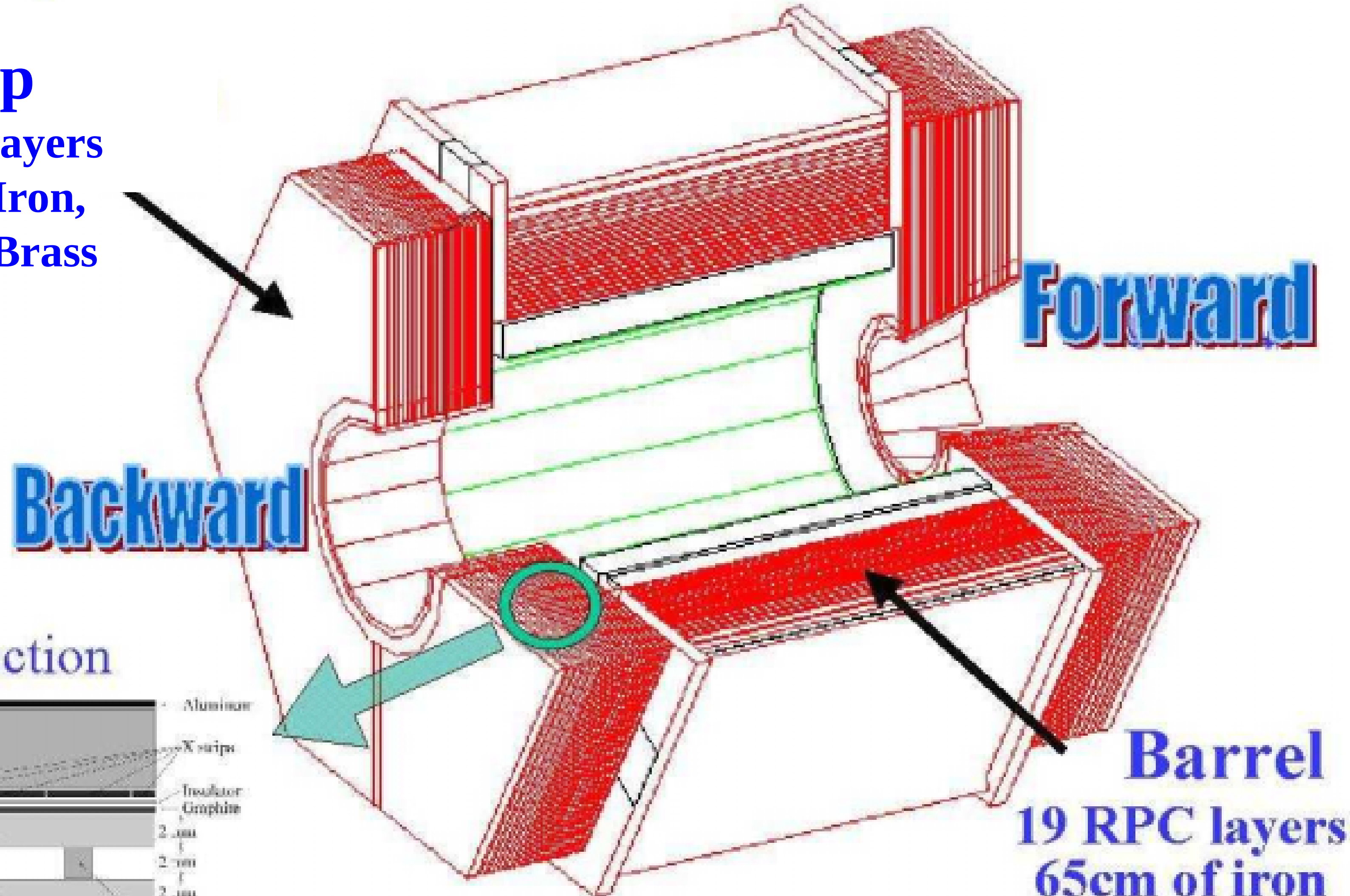
- K_L identification needs:
  - hadronic shower shape information (transverse granularity)
  - impact position determination (only measurement of K_L direction)
- μ identification needs:
  - large amount of traversed material (μ identified as a MIP)
  - large solid angle coverage

iron layers interspaced of Resistive Plate Counters:

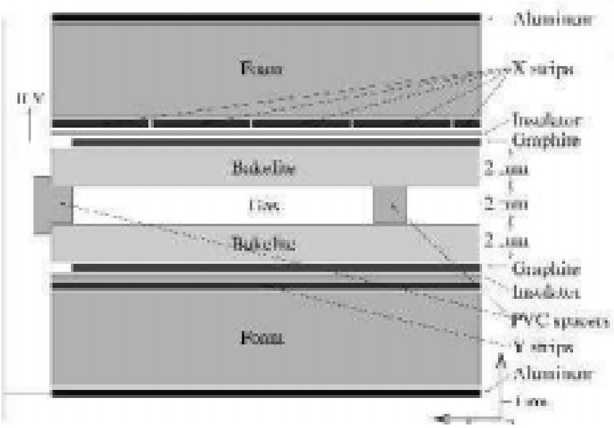
- easy to shape, I.e. high coverage
- finer layers at the beginning of the shower

Instrumented Flux Return

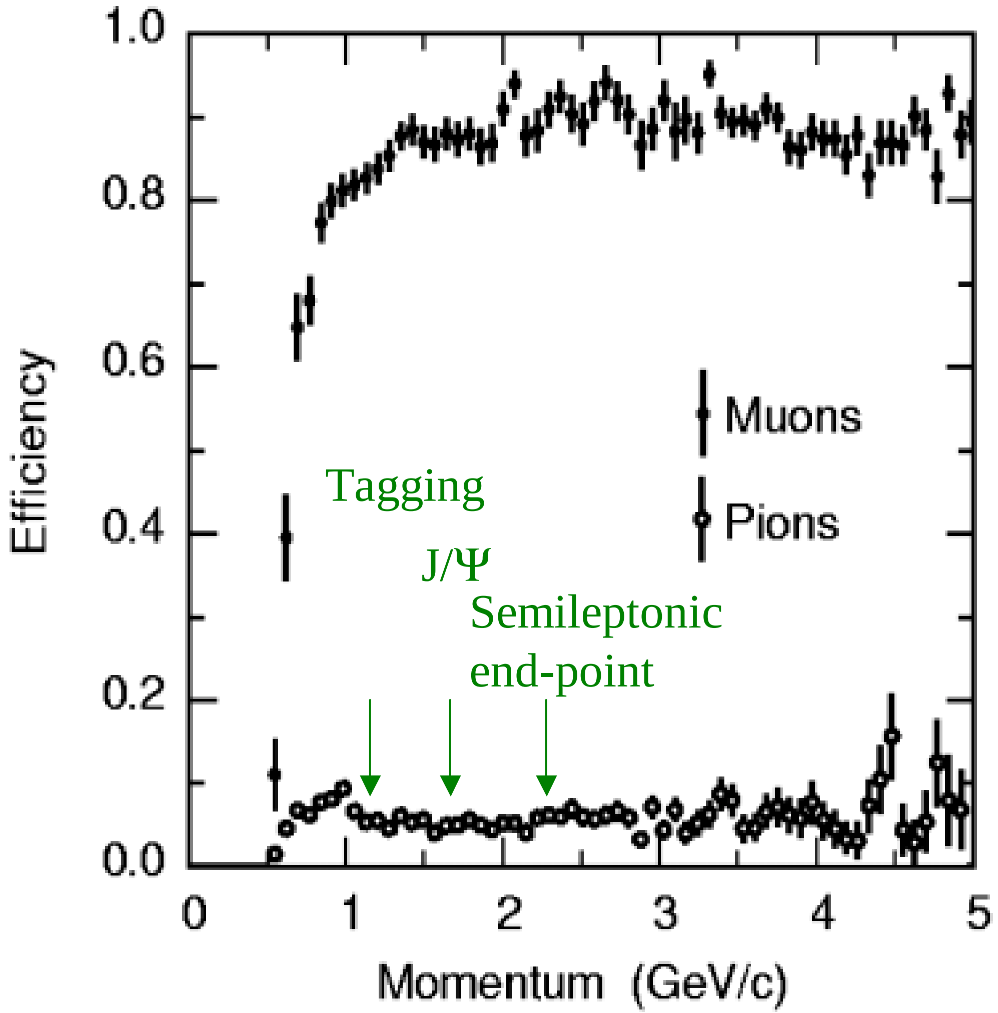
Endcap
19 RPC layers
60cm of Iron,
13cm of Brass



RPC section



Muon efficiency and purity



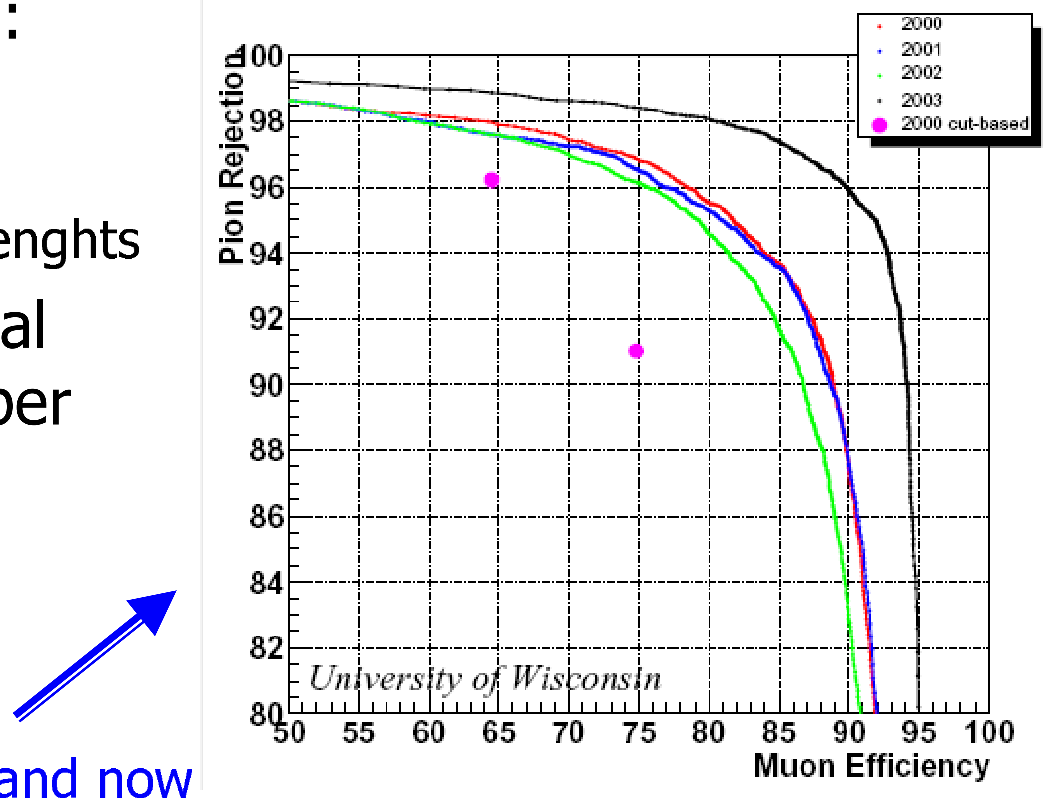
Cut on

- # interaction lengths
- IFR hit pattern rejects hadron showers
- consistency with a MIP in the EMC

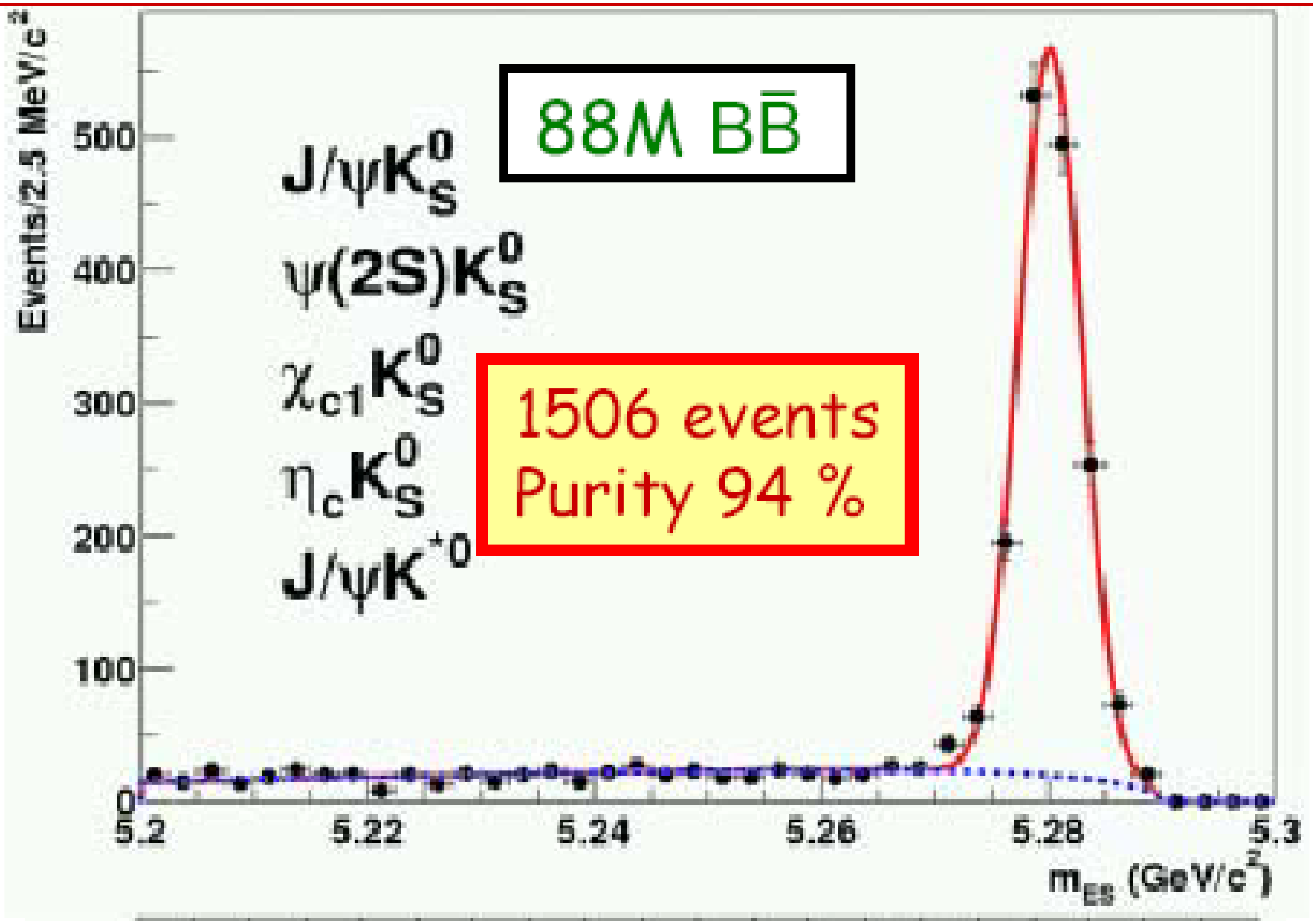
Muon selection:
90% efficiency for
1<p < 3 GeV/c
with ~4 % pion fake rate

Some History

- 'Only' 5 interaction lengths:
  - few % of π survive with no interaction
  - upgraded to 7 interaction lenghts
- Low RPC efficiency (original chambers going down 1% per month)
  - · operational problems with temperature
  - · defect at construction time
  - · Forward Upgraded in 2002 and now fully performant



CP sample: cleanest modes



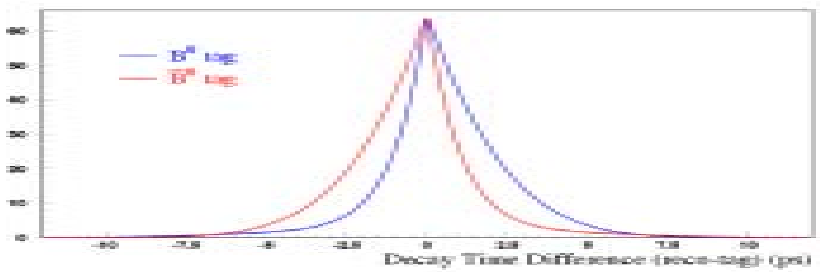
K_L reconstruction

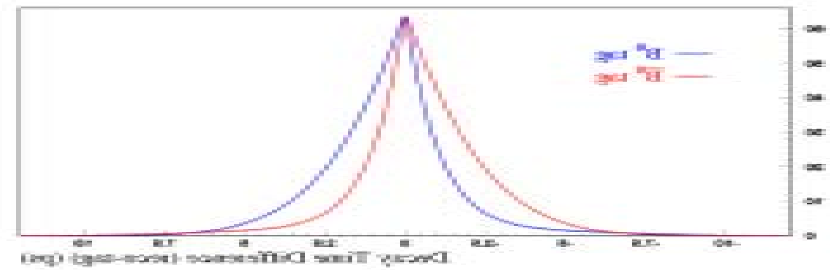
- Ask for a "large and short" IFR cluster not matching with any track or …
- … an EMC cluster not consistent with photon
- use the direction (K_L angular resolution: ~60 mrad) to close kinematics and determine K_L momentum (B mass is imposed to B candidate)

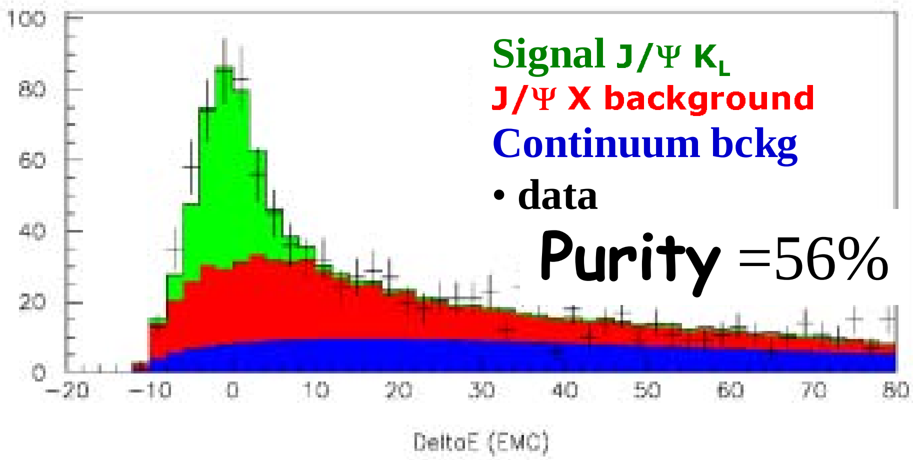
The IFR K_L efficiency ~ 30 %

CP modes: J/ΨK$_L$

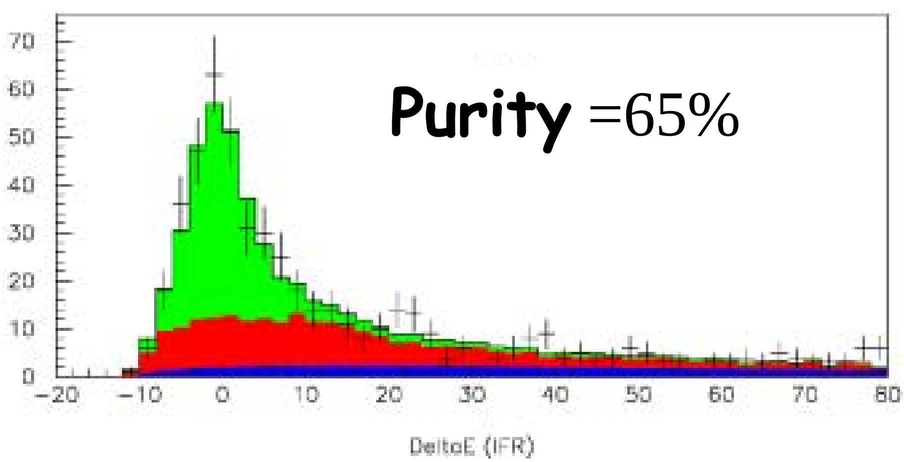
CP eigenvalue is opposite to J/ΨK$_S$ because K$_L$ has opposite CP







Reconstructed with calorimeter

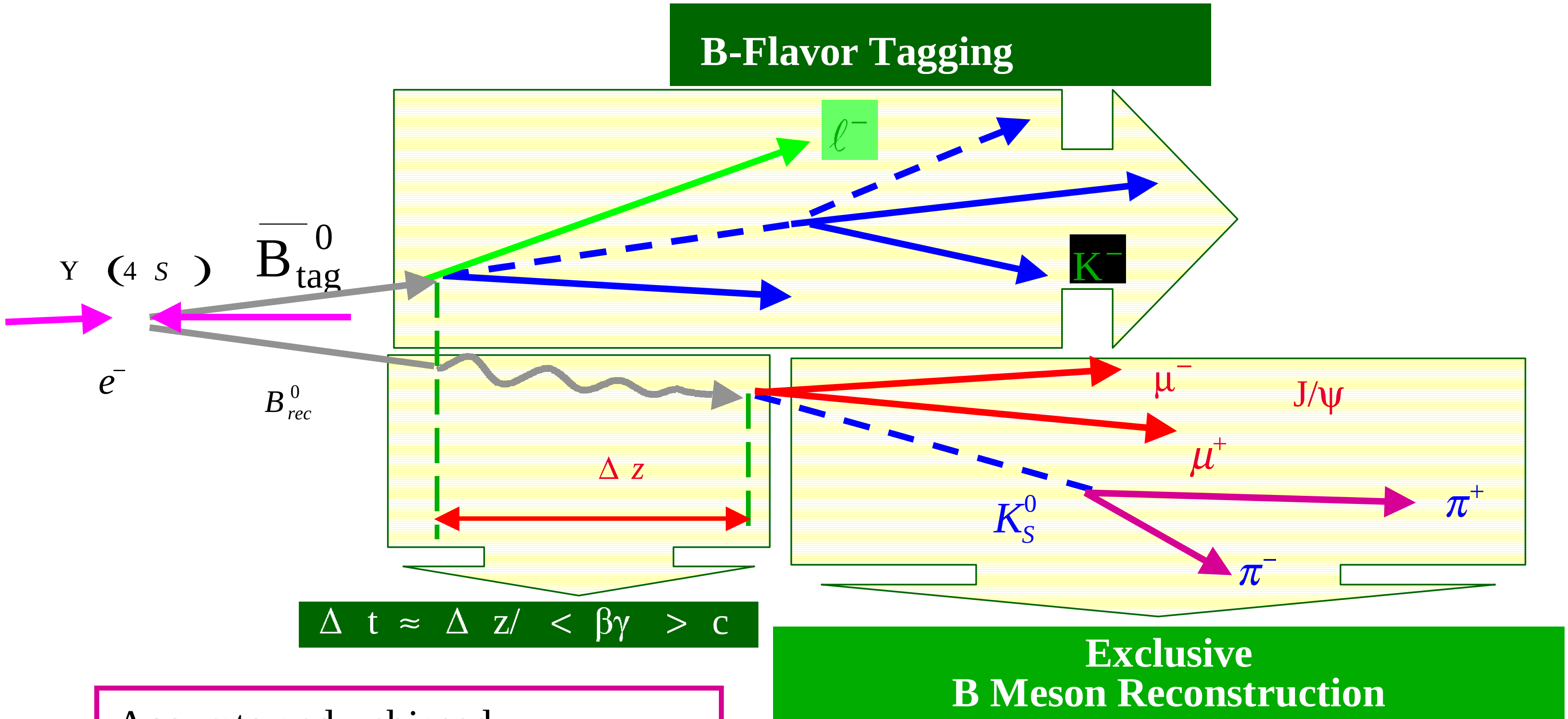


Reconstructed with IFR

Chapter IV

Other Ingredients: tagging and vertexing

Experimental Technique

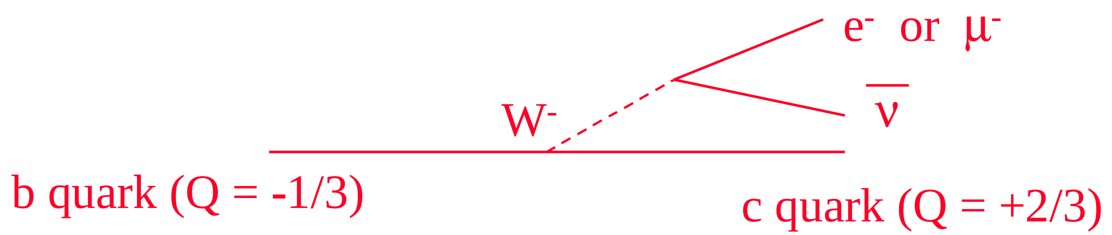


Accurate and unbiased measurement of the vertices

Low BR (10^{-5}) means high luminosity

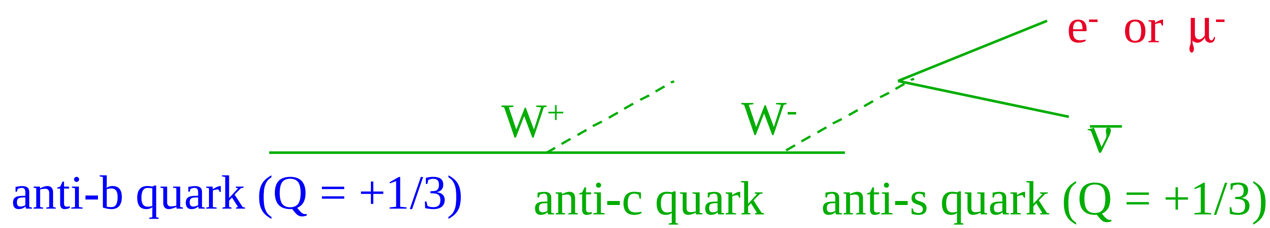
Tagging with leptons

b quarks are tagged by negatively charged leptons.



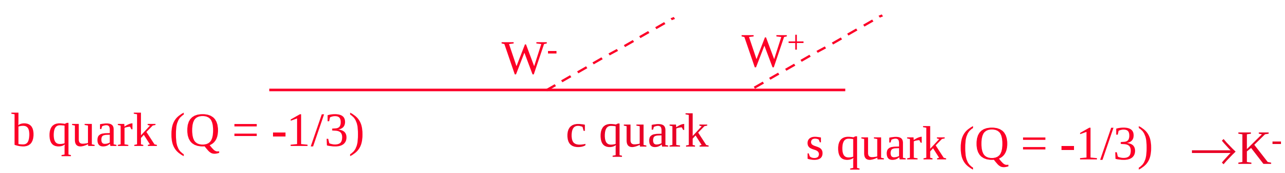
Anti- b quarks are tagged by positively charged leptons.

BUT : cascade events can mimic opposite tag



Tagging with Kaons

b quarks are tagged by negatively charged kaons.



Anti- b quarks are tagged by positively charged kaons.

<u>BUT:</u>

- W decays can also contain Kaons of any charge
- also neutral kaons could be produced
- s-quarks can also produce $\phi \rightarrow K^+K^-, K_s K_L$ mesons

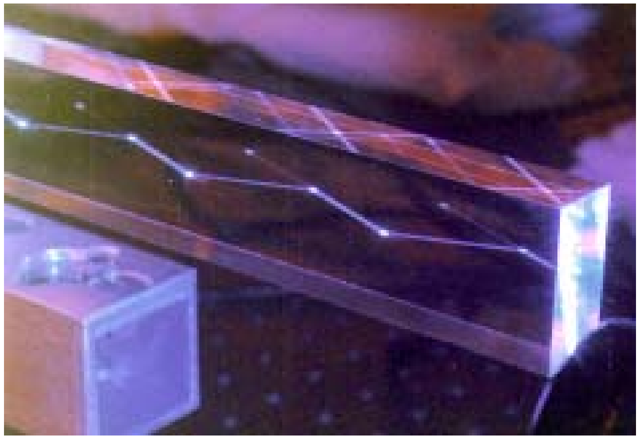
Detector of Internally Reflected Cherenkov Light

Basic Design idea:

Have the radiator and the light pipes in the same physical space

Fused synthetic silica:

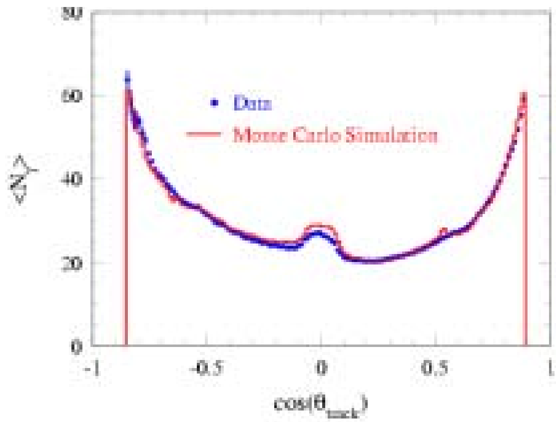
- Resistent to ionizing radiation
- Long attenuation length
- Low chromatic dispersion
- Appropriate refraction index



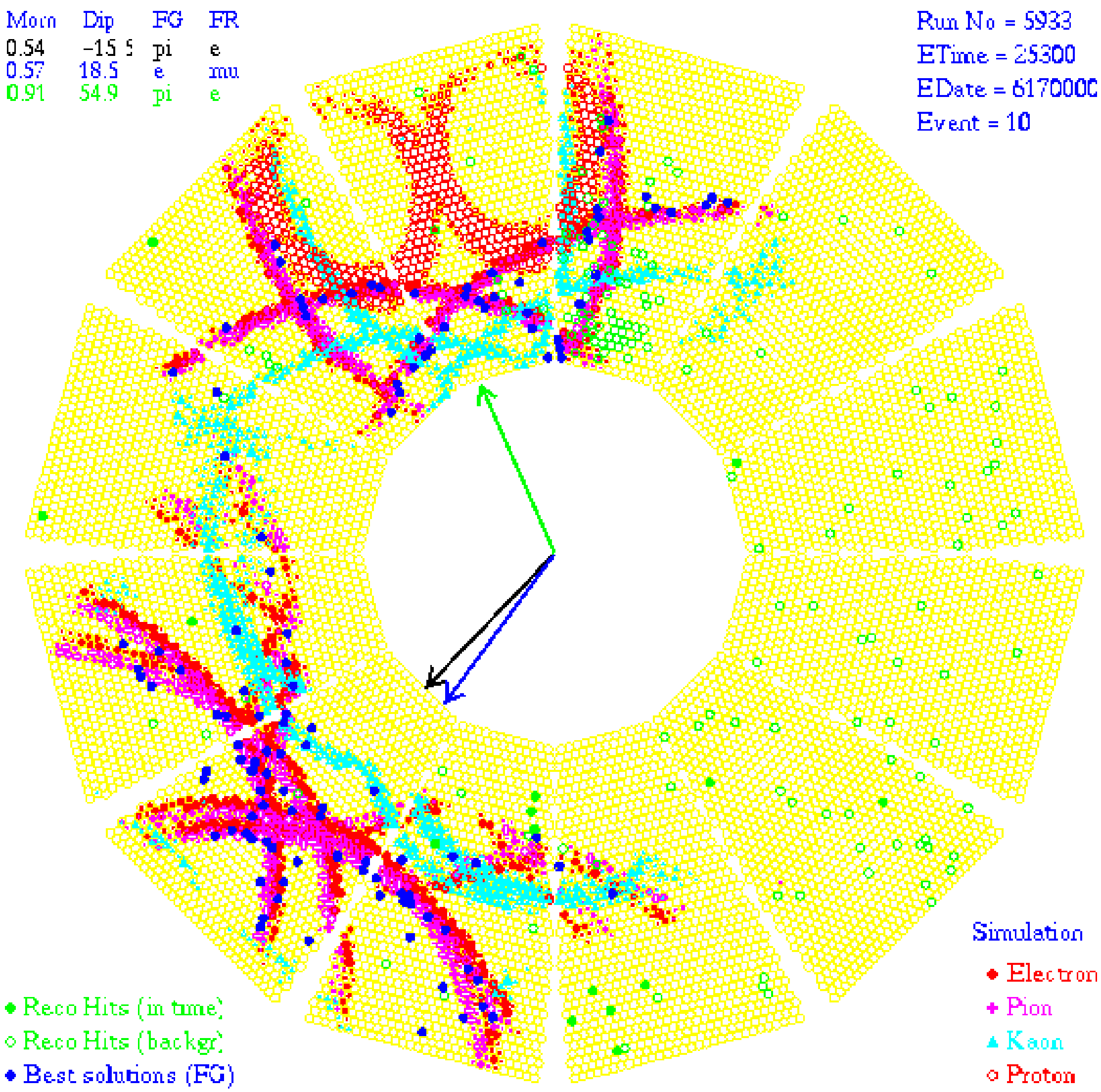
Find a material that has the correct refraction index to emit cherenkov and have internal reflection.

DRC

Light Cone is amplified in a water filled tank and photons are detected by FMT

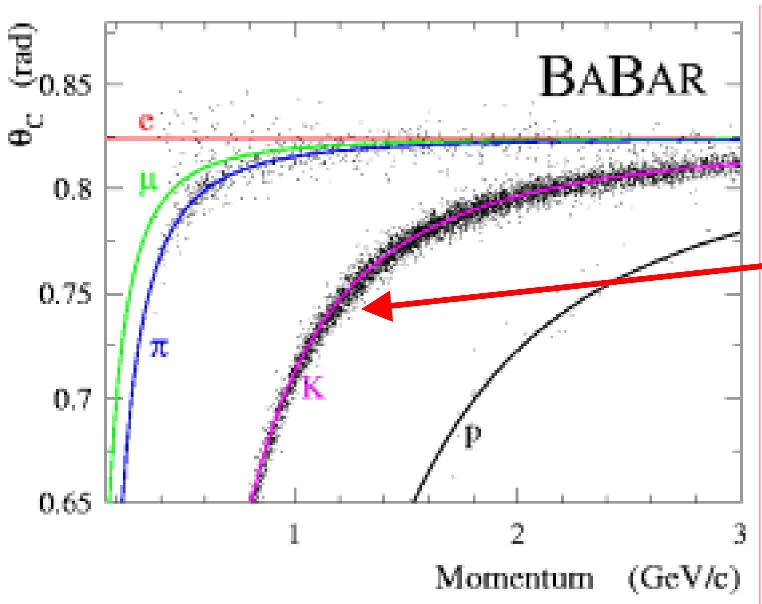


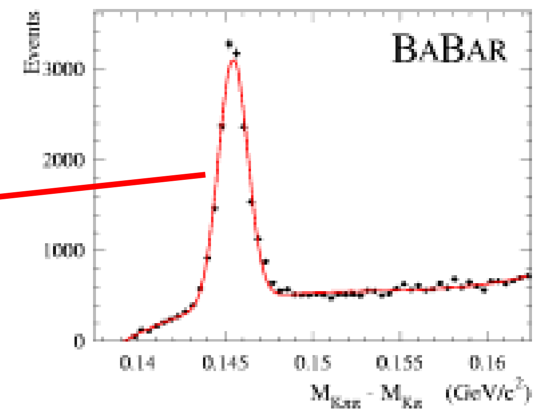
DRC:
from the photons to the angles



Several PID hypotheses are tested

Cherenkov angle measurement



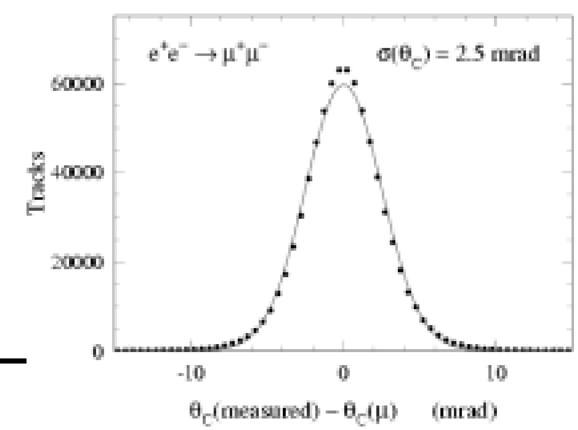


π and K candidates from D^0 decays tagged by soft π from D^{*+}; about 11% contamination from backgrounds

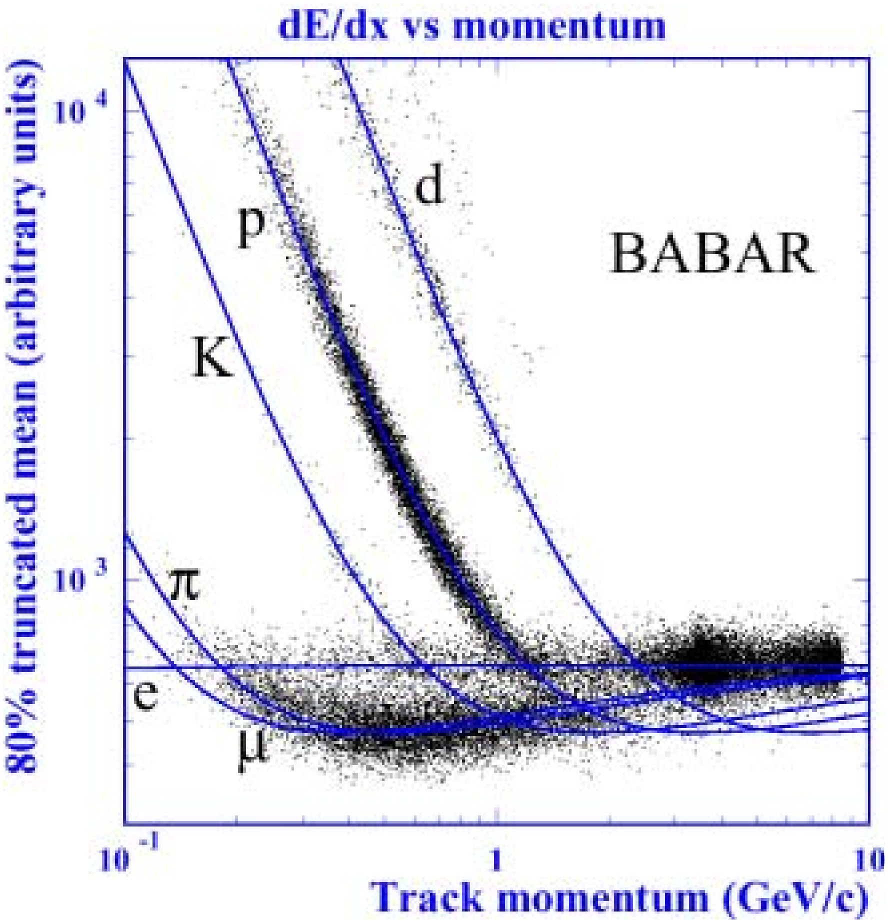
$$\cos\Theta_c = 1/n\beta$$

$$\sigma_{c,\mathrm{track}} = \sigma_{c,1\gamma} / \sqrt{N_\gamma}$$

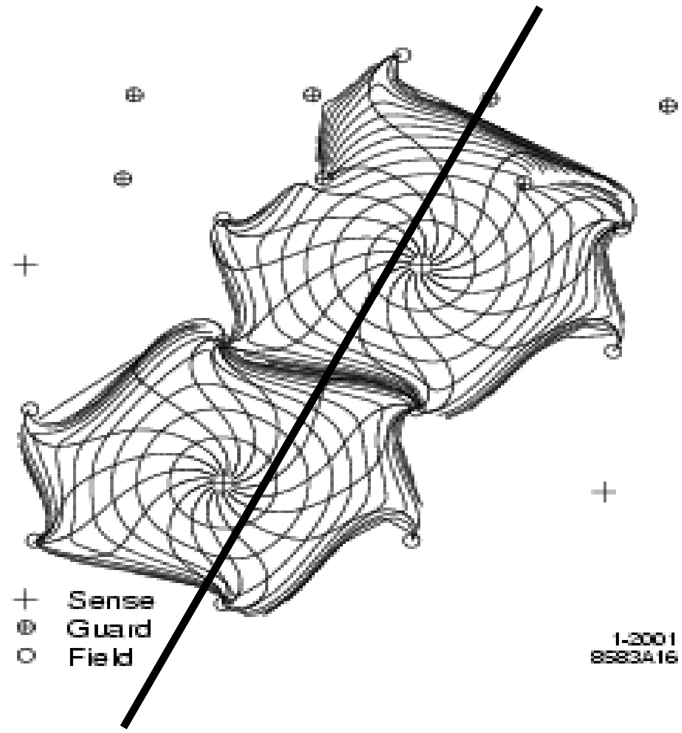
Θ_c resolution:



PID in DCH



Measurement of energy loss by ionization in traversing the cells



PID in DCH: performances

Gas mixture design:

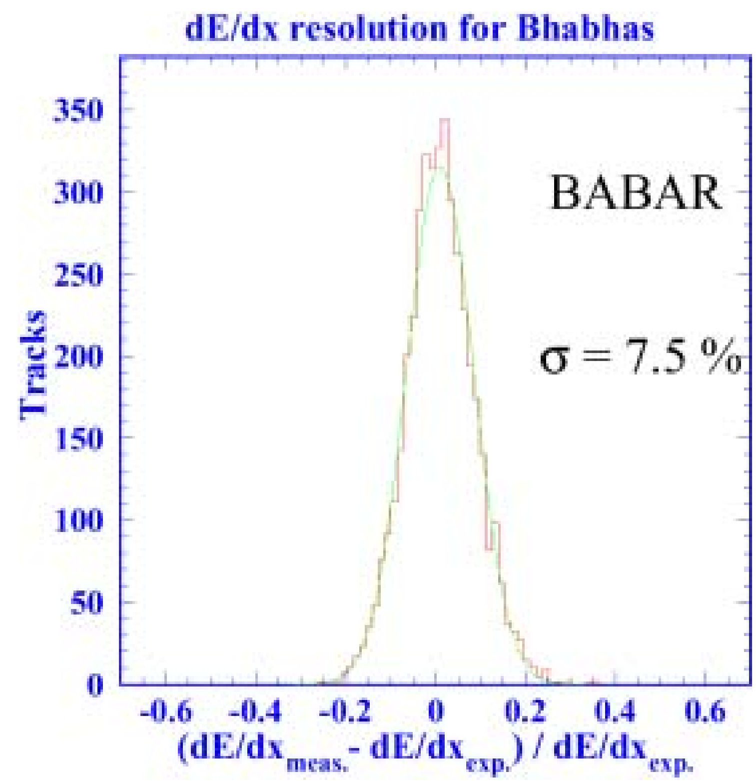
- Light gas (Helium) to reduce multiple scattering
- Heavy and complex gas (Isobutane) to avoid recombination and increase gain

Feature extraction: from TDC and ADC reading to charge.

- Elephant CHIP returns total integrated charge in time intervals (ADC) & time at which threshold is overcome

Truncated mean algorithm

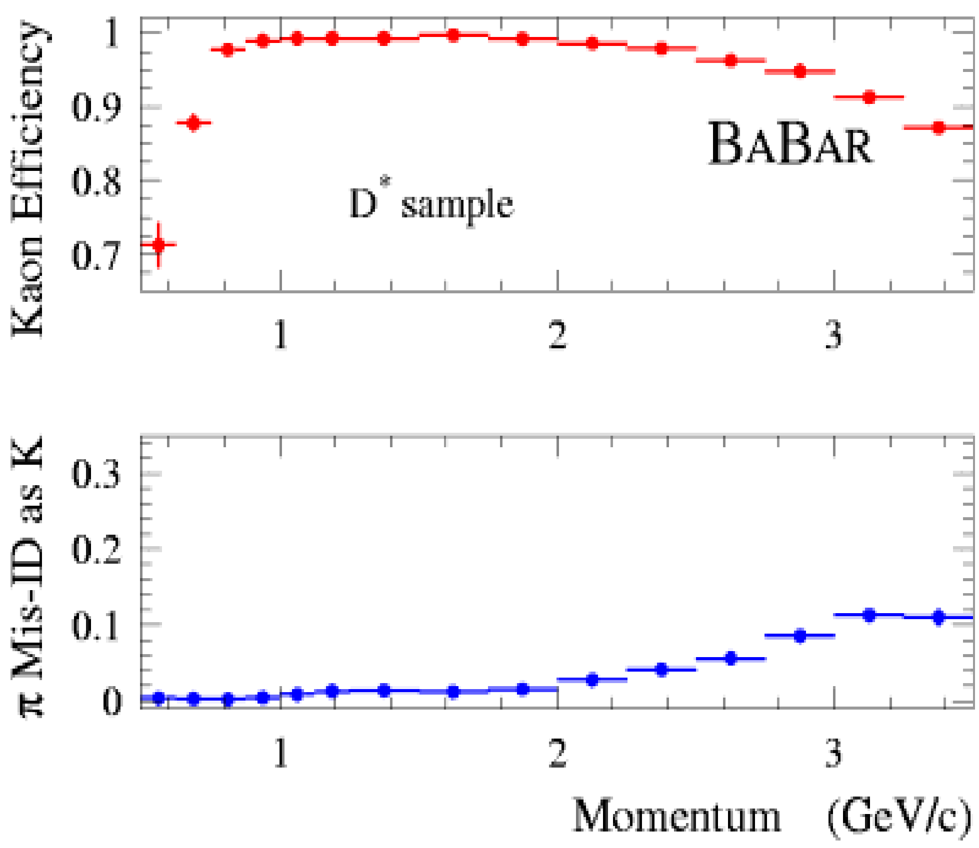
- 7% dE/dX resolution
- K/π separation better than 2σ up to 700 MeV



KAON ID PERFORMANCES

Uses:
- SVT and DCH *dE/dx*
- DIRC Cherenkov angle

Performances evaluated on control samples



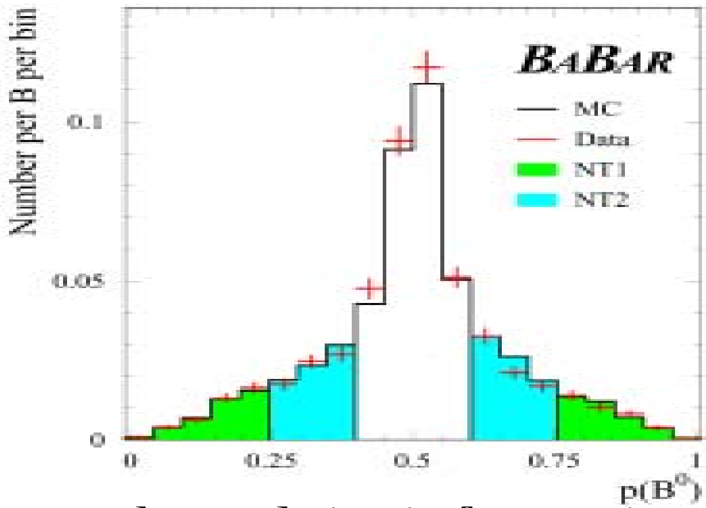
Tagging Algorithm

Category	ε (%)	w (%)	Q (%)
Lepton	9.1 ± 0.2	3.3 ± 0.6	7.9 ± 0.3
Kaon I	16.7 ± 0.2	10.0 ± 0.7	10.7 ± 0.4
Kaon II	19.8 ± 0.3	20.9 ± 0.8	6.7 ± 0.4
Inclusive	20.0 ± 0.3	31.5 ± 0.9	2.7 ± 0.3
All	65.6 ± 0.5		28.1 ± 0.7

Effective efficiency:

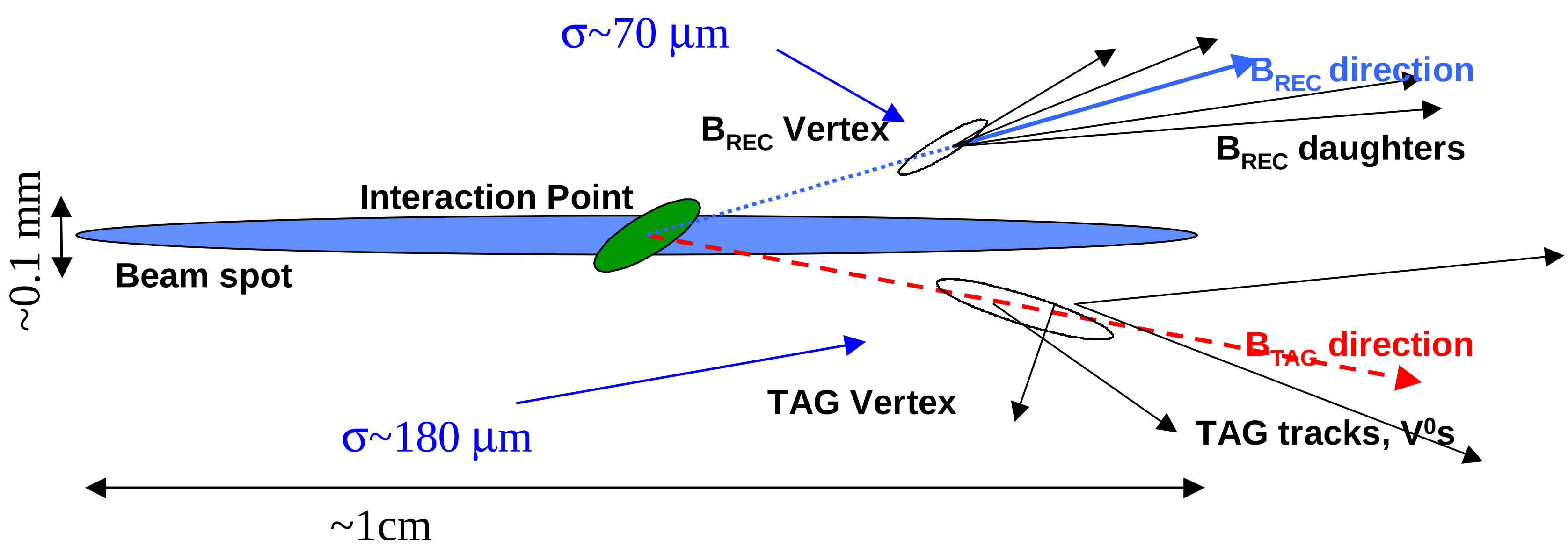
$$Q = \varepsilon(1-2\omega)^2$$

$$\propto \frac{1}{\sigma^2(\sin 2\beta)}$$



Inclusive: Neural network exploits information carried by non-identified leptons and kaons, soft pions from D^* decays

Vertexing Algorithm



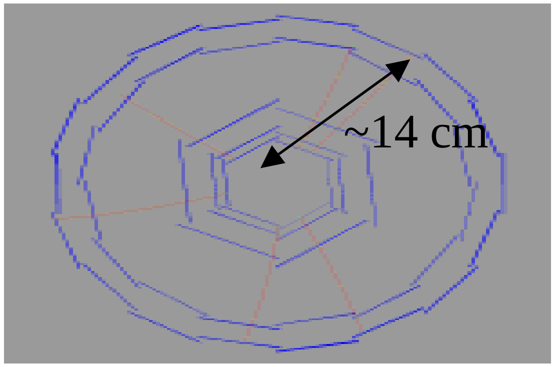
One of the two B mesons is fully reconstructed ("CP"), while the other is only partially reconstructed (dropping tracks with bad χ^2)

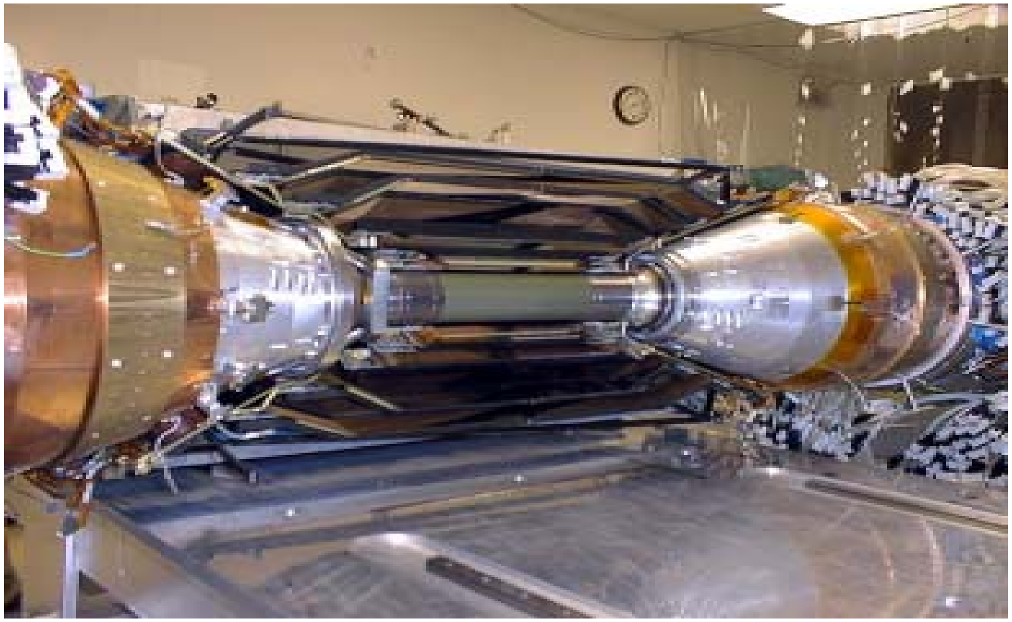
Full power of the SVT and of the kinematic and vertexing constraints exploited

Silicon Vertex Tracker (SVT)

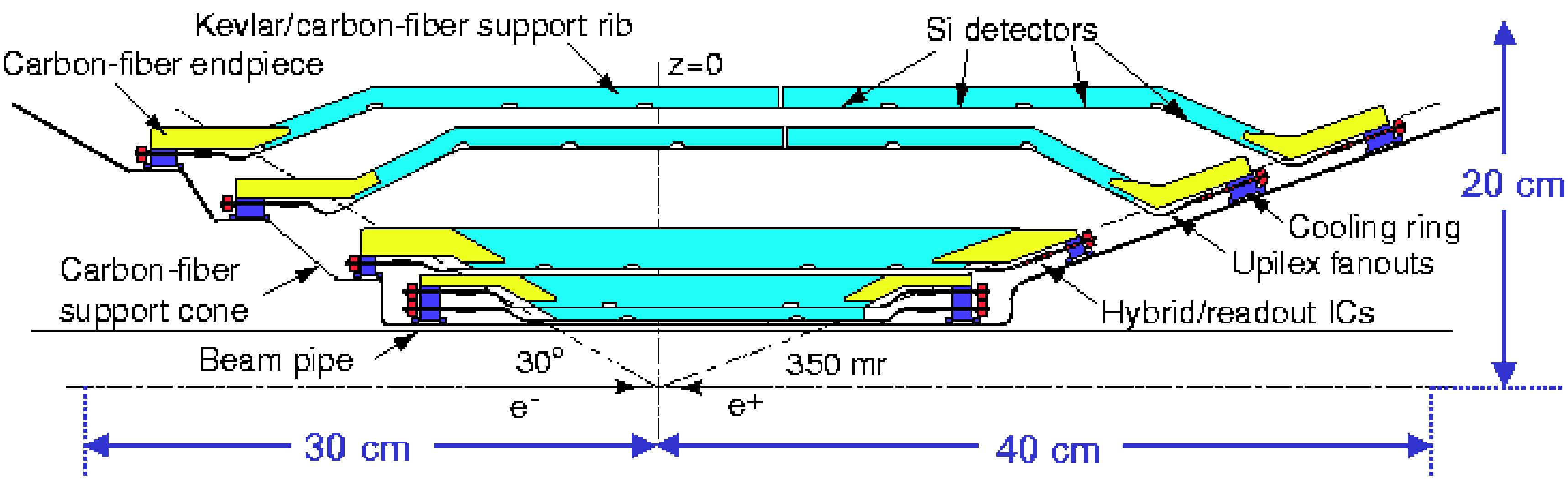
BABAR

•5 double-sided layers
•Radiation hard (2 MRad)
•radius = (32 - 140) mm
•angular acceptance in lab: 20.1^o to 150.2^o
•143k channels ($0.94\ m^2$)





Silicon Vertex Tracker



- 5 Layers of double-sided Silicon detectors
  - 300 µm thick /AC coupled
  - Poly-Si bias resistors
  - ~150 000 r.o. channels / active surface ~1 m^2
- Inner 3 layers: track impact parameters
- Outer 2 layers: pattern recognition and low P_t tracking

(arch-shaped to minimize the Si to cover the solid angle and avoid large incident angle)

- Point resolution: 15 (40) µm inner (outer) layers

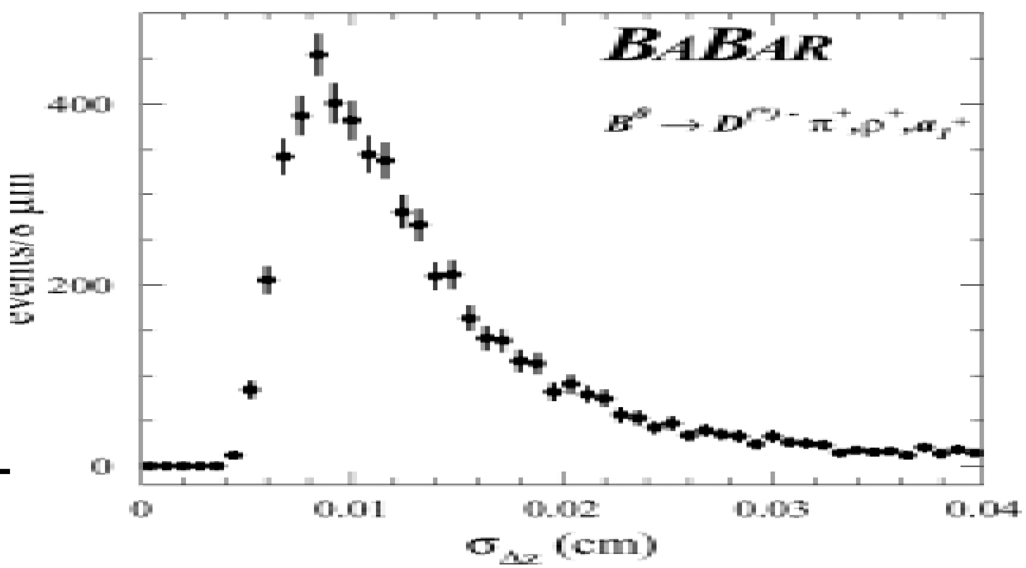
Multiple scattering is the limiting factor

Vertexing Algorithm: performances

One of the two B mesons is fully reconstructed ("CP"), while the other is only partially reconstructed (dropping tracks with bad χ^2)

$\sigma(\mu m)$	Z_{CP}	ΔZ
Core	45	110
(fraction %)	(80)	(65)
RMS	70	190

In order to use all the detector knowledge we use the **event per event error** and parametrize the resolution function with **scaling factors**

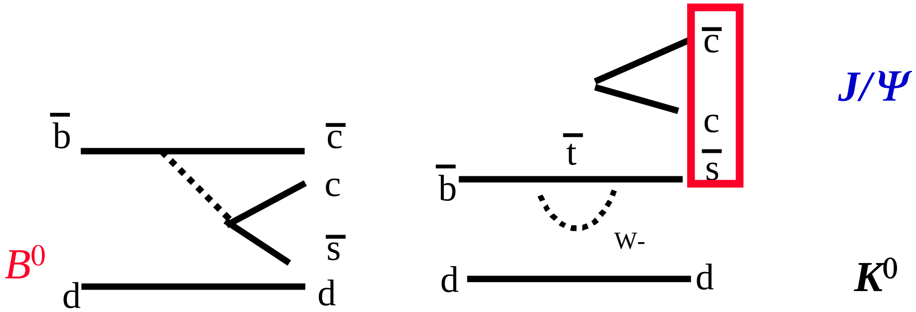


$\Delta t = \Delta z / < \beta\gamma c >$

Chapter V

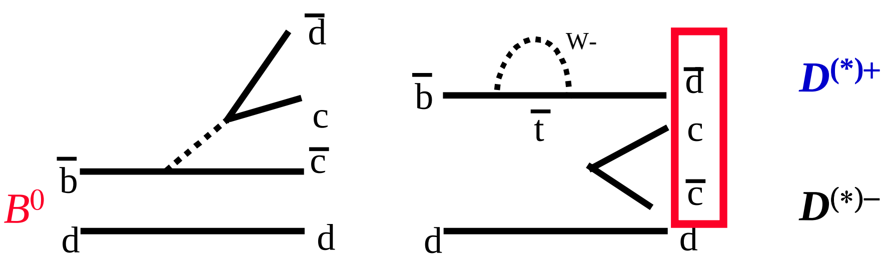
Fit for sin2β

Measurements of β



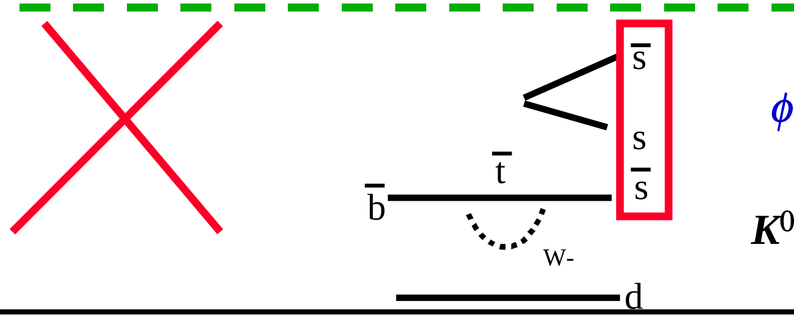
Charmonium K^0

Penguin and tree have the same weak phase



$D^{(*)}D^{(*)}$ and $J/\Psi\pi^0$

Penguin and tree have different weak phases: asymmetry not necessarily = sin2β



ϕK^0 and $\eta^{(\prime)}K^0$

Mostly penguin. In principle measures sin2β, but sensitive to new physics

Fitting Strategy

Mixing and sin2β measurements are done with the same strategy: do a global fit to all the events that can carry information:

Mixing : tagged flavour eigenstates

sin2β : tagged flavour and CP eigenstates

Extract as many parameters as possible from data

parameter	# params	Sensitive evts
sin2β	1	CP ← Only in CP fit
Δm_d	1	flavour ← Only in mixing
w & Δw	8	flavour
Δt resolution	8 x 2	flavour and CP
Background τ	6	sidebands
Background w	8	sidebands
Background Δt	6	sidebands

Biggest correlation with sin2β: 12%

Blind Analysis

The sin2β analysis was done blind to eliminate possible experimenter bias

- The amplitude in the asymmetry $A_{CP}(\Delta t)$ was hidden by arbitrarily flipping its sign and by adding an arbitrary offset
- The *CP* asymmetry in the Δt distribution was hidden by multiplying Δt by the sign of the tag and by adding an arbitrary offset
- The blinded approach allows systematic studies of tagging, vertex resolution and their correlations to be done while keeping the value of sin2β hidden
- The result was unblinded two weeks before publication for final checks

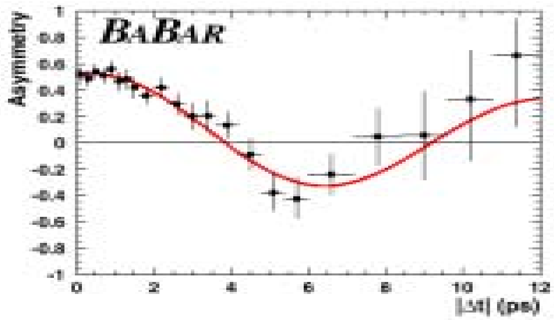
Mixing Measurement

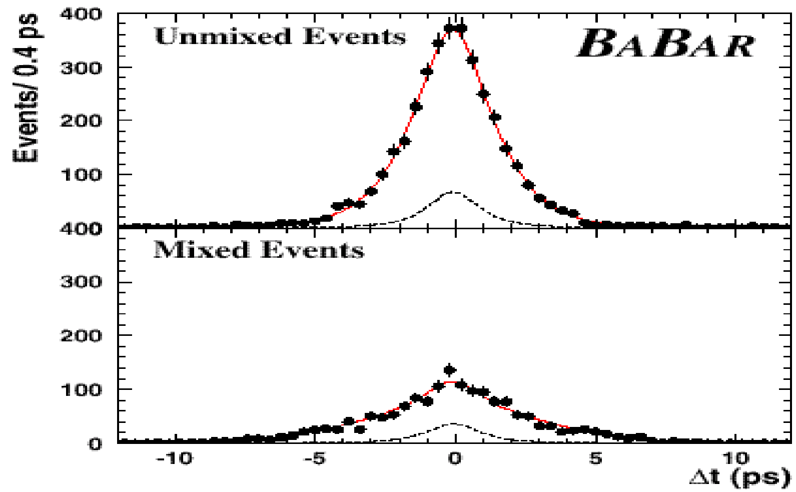
Simultaneous likelihood fit to each tagging category; mixed and unmixed events with common resolution function

$$1/4\ \Gamma\ e^{-\Gamma|\Delta t|}\ [1 \pm (1-2w)\cos(\Delta m_d\ \Delta t)] \otimes R(\Delta t;a)$$

Allows extraction of mistag rates and resolution function parameters

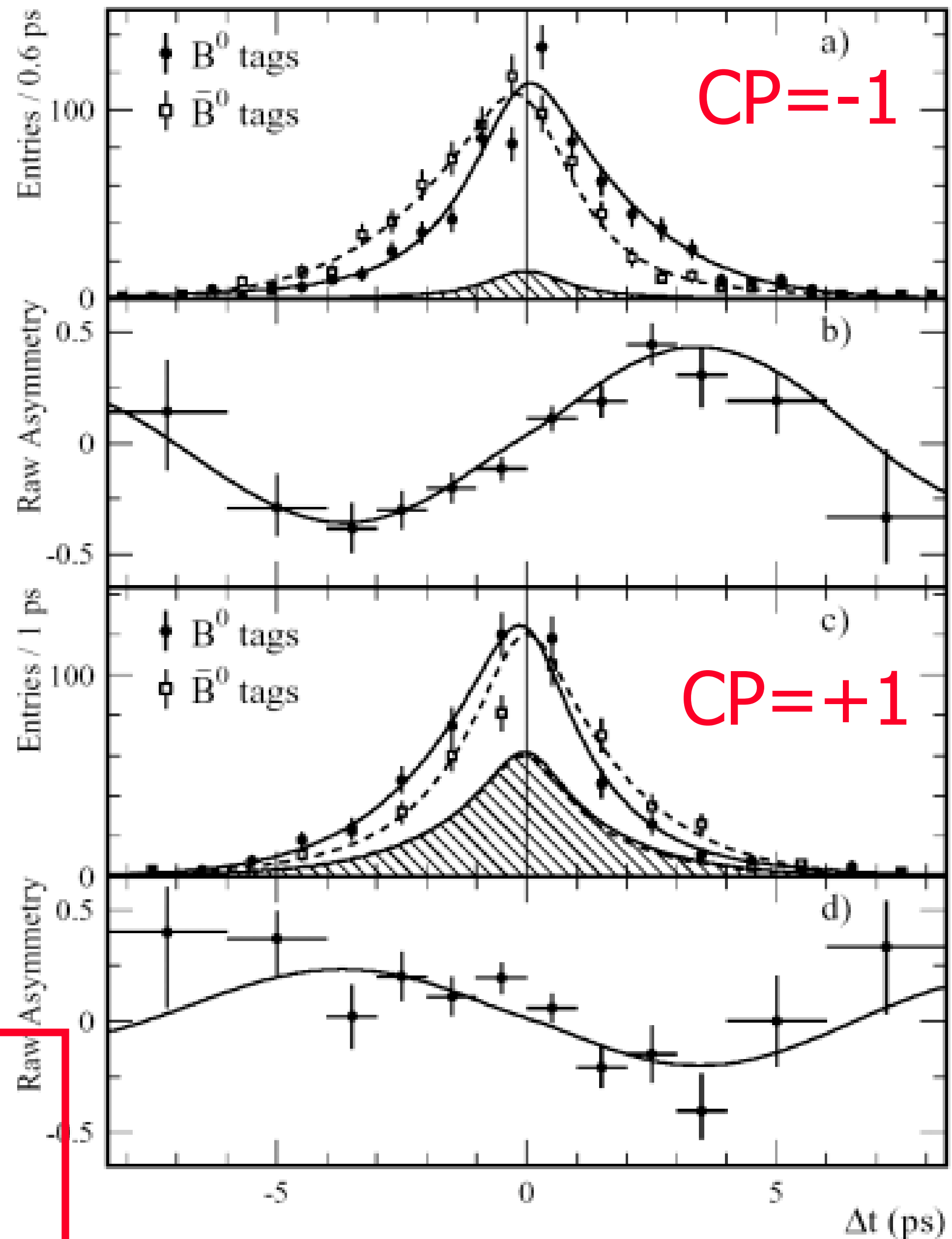
Fully reco'd B's





$\Delta m_d = 0.519 \pm 0.020\ (\text{stat}) \pm 0.016\ (\text{syst})\ ps^{-1}$ **(BaBar hadronic)**

Charmonium K^0



$\sin 2\beta = 0.739 \pm 0.048$ (Belle+BaBar)

systematics

0.013 from vertexing

0.007 from tagging

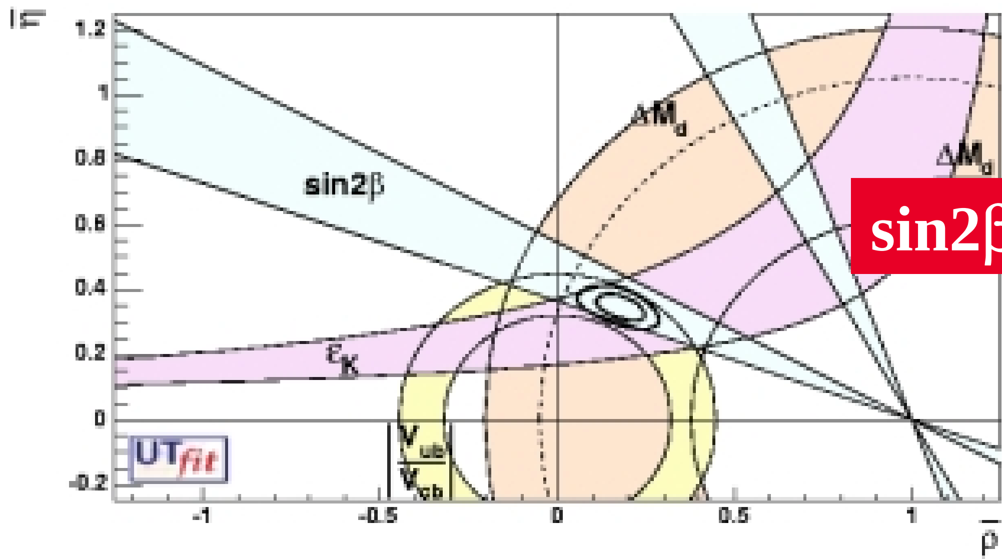
0.020 from background

0.020 from fit technique

Total 0.035

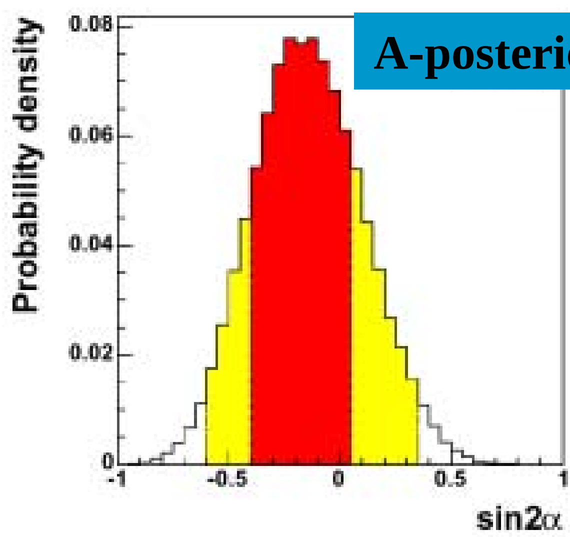
Source	CP Sample			
	$J/\psi K_S^0$	$J/\psi K_L^0$	$J/\psi K^{*0}$	Full
Signal parameters				
Δt signal resolution	±0.008			
Δt signal resolution outliers	±0.003			
Δt Art Effect	±0.002			
signal dilutions	±0.007			
Δt signal resolution model	±0.003	±0.006		±0.004
Tail scale factor	±0.003	±0.016	±0.024	±0.003
Background parameters				
Signal probability: CP sample	±0.007	—	—	±0.005
Signal probability: B_{flav} sample	±0.002			
M_{ES} endpoint	±0.001	±0.001	±0.001	0
CP background peaking component	±0.007	—	—	±0.006
CP background CP content (Argus)	±0.017	—	—	±0.013
CP background CP content (Peak)	±0.015	—	—	±0.011
CP background τ	±0.003	—	—	±0.003
CP background resolution	±0.002	—	—	±0.001
B_{flav} background mixing contrib.	±0.002	±0.002	±0.002	±0.003
B_{flav} background peaking component	±0.007	0	±0.002	±0.001
external parameters				
B^0 lifetime	±0.014	±0.010	±0.031	±0.010
Δm_d	±0.009	±0.009	±0.021	±0.010
$J/\psi K_L^0$ Total (w/o Δm_d and B^0 lifetime)	—	±0.057	—	±0.013
detector effects				
z scale + boost	±0.003			
Beam spot	±0.005			
SVT alignment	±0.010			
Monte Carlo correction	±0.014			
Total systematic error	±0.038	±0.065	±0.10	±0.035
Statistical error	±0.100	±0.193	±0.559	±0.088

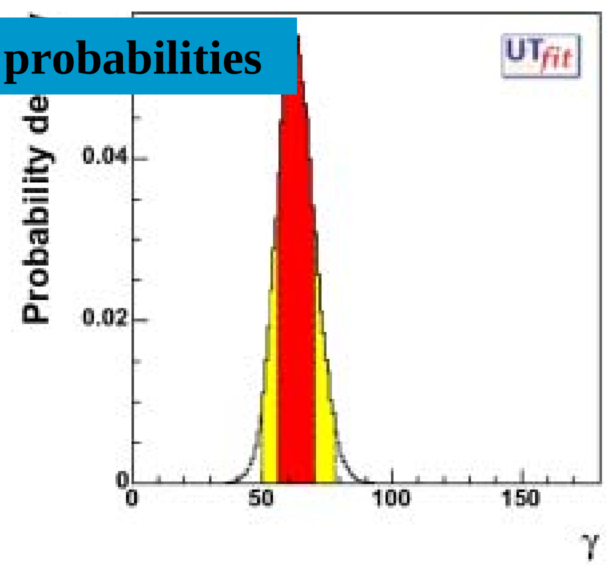
Unitarity triangle Fit with golden modes

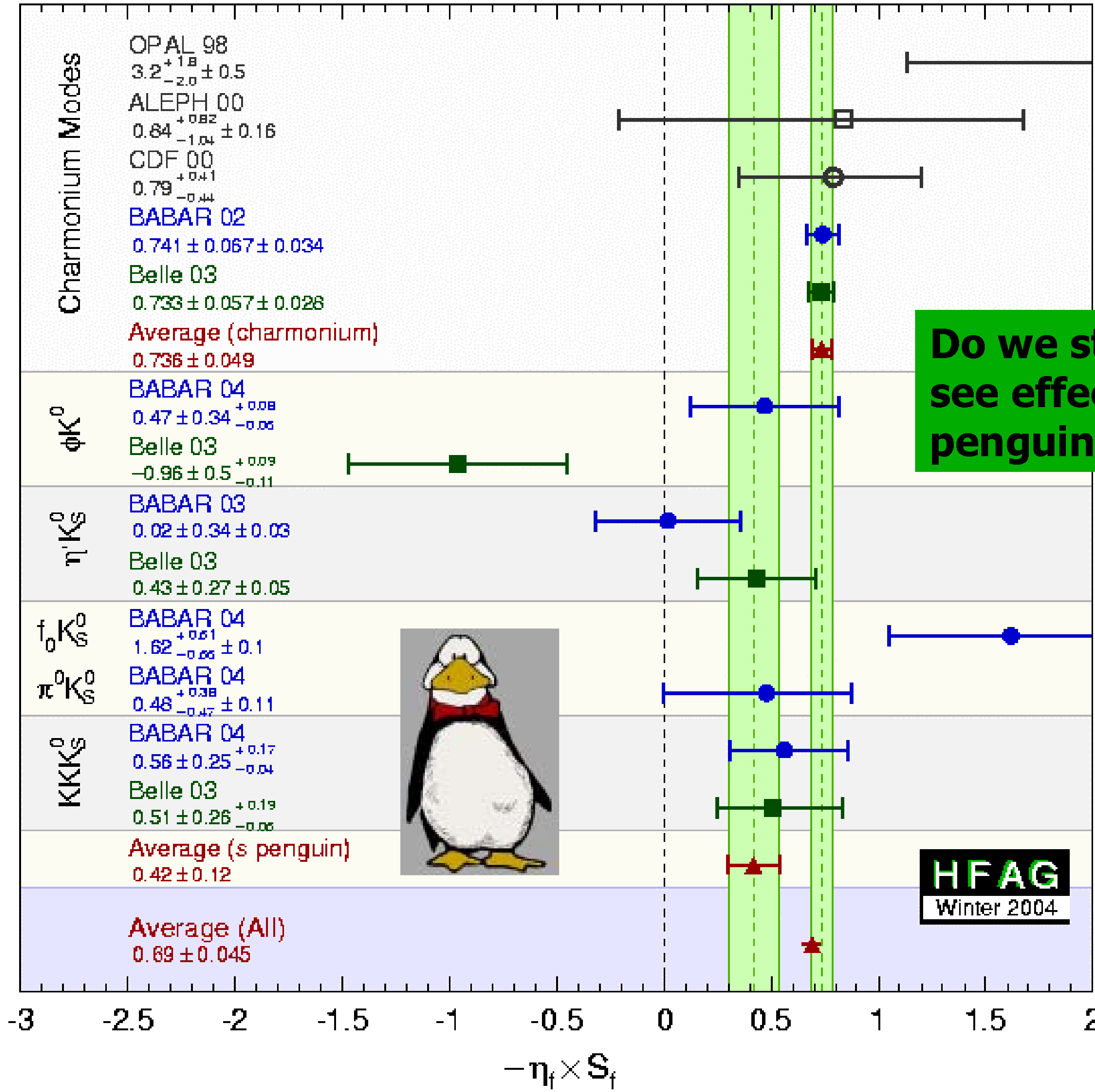


$\sin 2\beta_{dir}$=0.739±0.048

A-posteriori probabilities

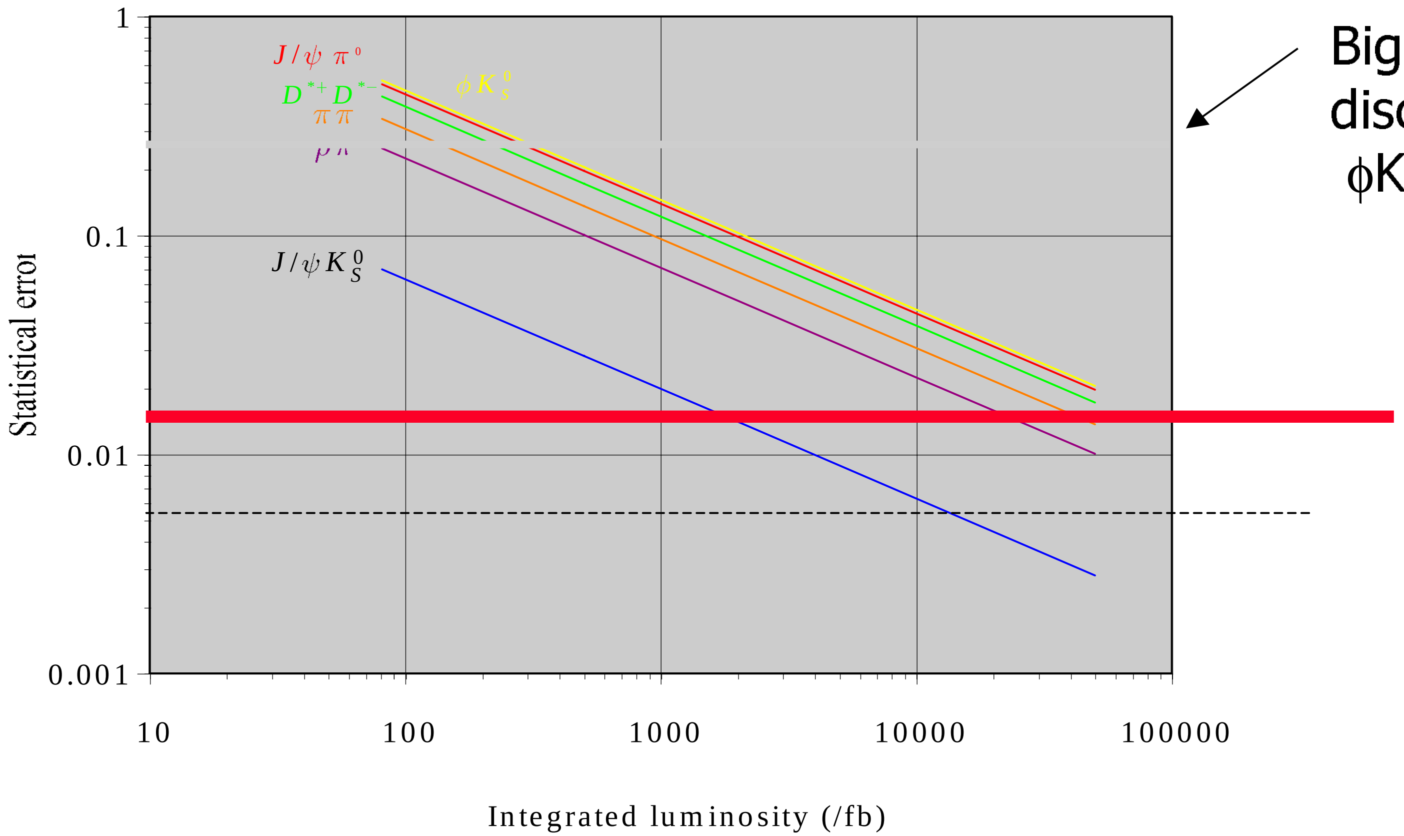






Do we start to see effects in the penguin modes?

Precision Measurement of angles



Biggest allowed discrepancy on φKs in SM

Sys err

Sys err lepton tags

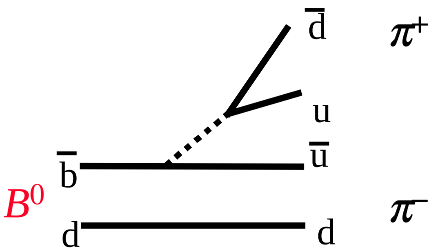
(stat err. ~70% larger)

Only J/ΨK$_s$ will be syst. Limited, but one can use only the cleaner tags to reduce the error. All comparisons still stat. Limited.

Chapter VI

Measurement of the other angles

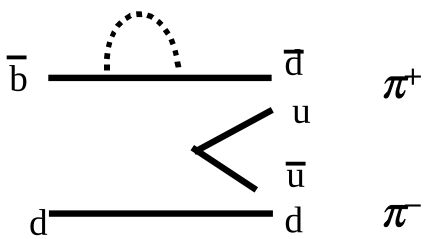
Measuring α: B→π⁺π⁻



Tree is promising because

$$\frac{T}{\bar{\bar{T}}} = \frac{V_{ub}^*}{V_{ub}} = e^{-2i\gamma}$$

… but penguin has a different phase

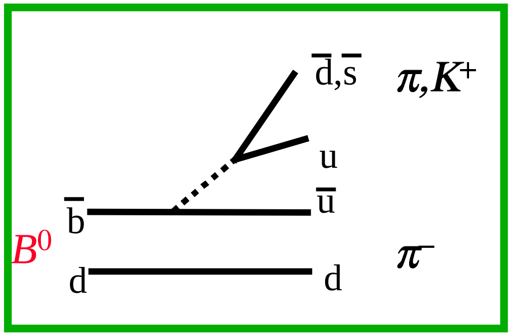


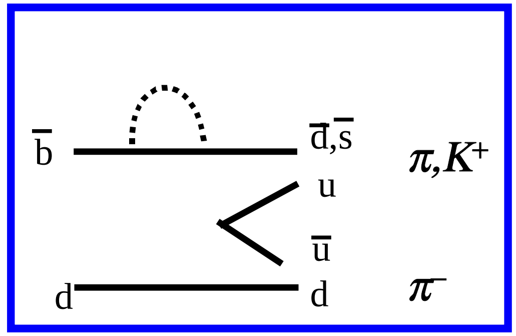
$$\lambda = e^{-2i\beta}\frac{\bar{T}+\bar{P}}{T+P} = e^{-2i\alpha}\frac{1+\frac{P}{T}}{1+\frac{\bar{\bar{P}}}{\bar{\bar{T}}}} = e^{-i(2\alpha+K_{\pi\pi})}$$

Is P large?

YES (see next slide)

Large penguins: $B \to K^+ \pi^-$





$A_{\pi\pi} = T_{\pi\pi} + P_{\pi\pi}$

$A_{K\pi} = T_{K\pi} + P_{K\pi}$

$\sim T_{\pi\pi} |V_{us}/V_{ud}| + P_{\pi\pi} |V_{ts}/V_{td}|$

$\sim 0.2\ T_{\pi\pi} + 5\ P_{\pi\pi}$

The measured $A_{K\pi} \sim 2A_{\pi\pi}$ implies P/T~0.6 !!!

(Naïve but conceptually right)

Isospin analysis

Need to measure

$$K_{\pi\pi} = Arg\left(\frac{A(\overline{B}^0 \to \pi^+\pi^-)}{A(B^0 \to \pi^+\pi^-)}\right) - Arg\left(\frac{\overline{T}}{T}\right)$$

Ingredients:

- T has contributions from ΔI=3/2 and ½
- P has contributions from ΔI= ½ only because of I=0 for gluons
- no I=1 ππ state can be produced in B decays because of bose-einstain statistics

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

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

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

$$A(B^- \to \pi^-\pi^0) = \frac{\sqrt{3}}{2} A_{3/2} e^{-2i\gamma}$$

$$A(B^0 \to \pi^+\pi^-) = \frac{1}{\sqrt{6}} A_{3/2} e^{-2i\gamma} - \frac{1}{\sqrt{3}} A_{1/2} e^{-2i\varphi}$$

$$A(B^0 \to \pi^0\pi^0) = \frac{1}{\sqrt{3}} A_{3/2} e^{-2i\gamma} + \frac{1}{\sqrt{6}} A_{1/2} e^{-2i\varphi}$$

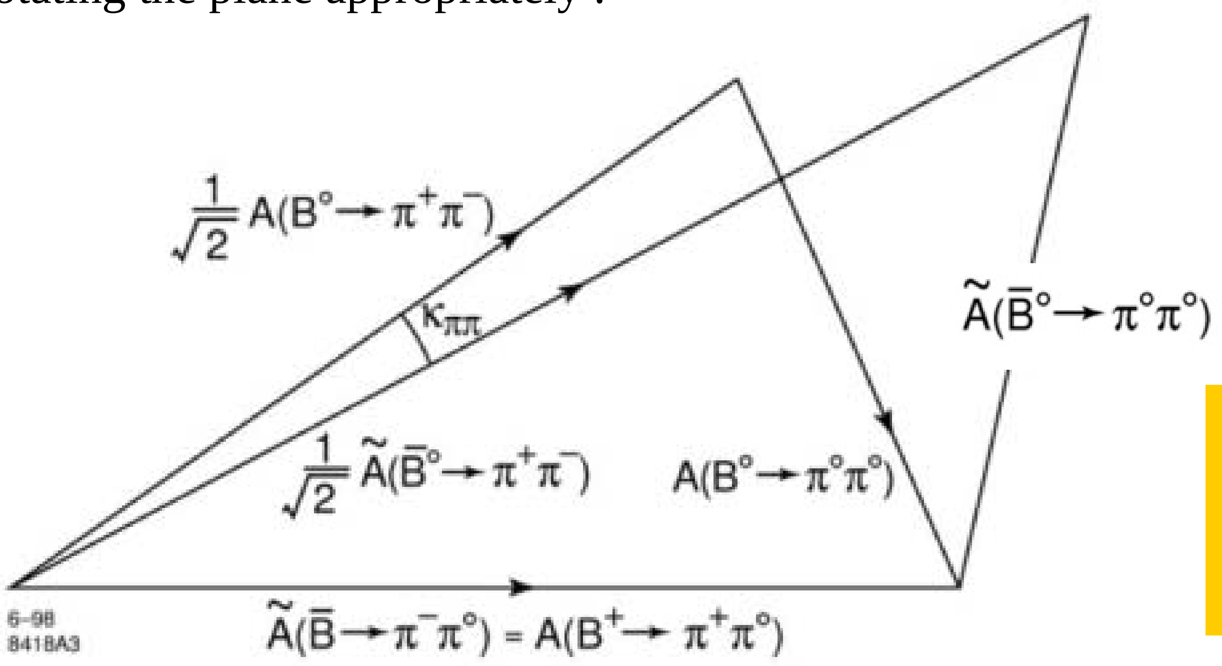
Isospin analysis (II)

⇒Two relationships in the complex plane :

$$\frac{1}{\sqrt{2}}A(B^0 \to \pi^+\pi^-) + A(B^0 \to \pi^0\pi^0) = A(B^+ \to \pi^+\pi^0)$$

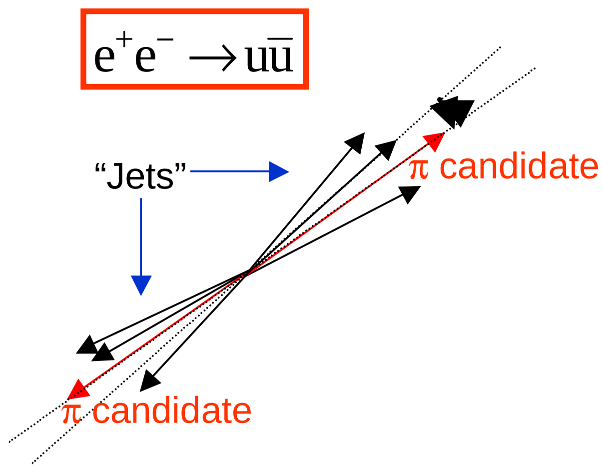
$$\frac{1}{\sqrt{2}}A(\overline{B}^0 \to \pi^+\pi^-) + A(\overline{B}^0 \to \pi^0\pi^0) = A(B^- \to \pi^-\pi^0)$$

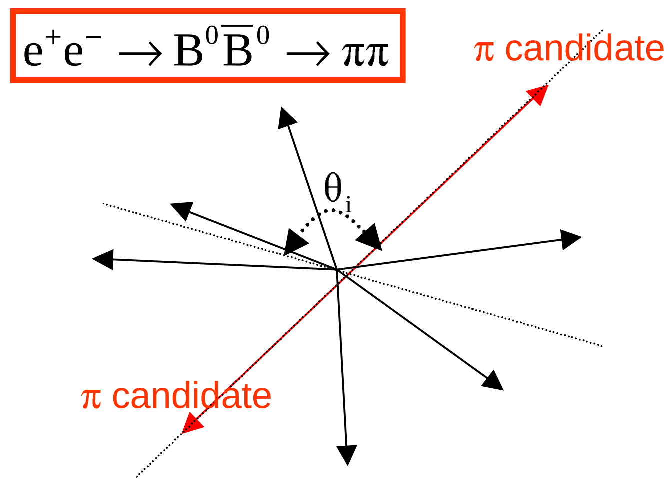
Rotating the plane appropriately :



Measure $\overline{B}^0 \to \pi^0\pi^0$ and $B^0 \to \pi^0\pi^0$ separately or prove them small

Experimentally: LARGE BACKGROUNDS



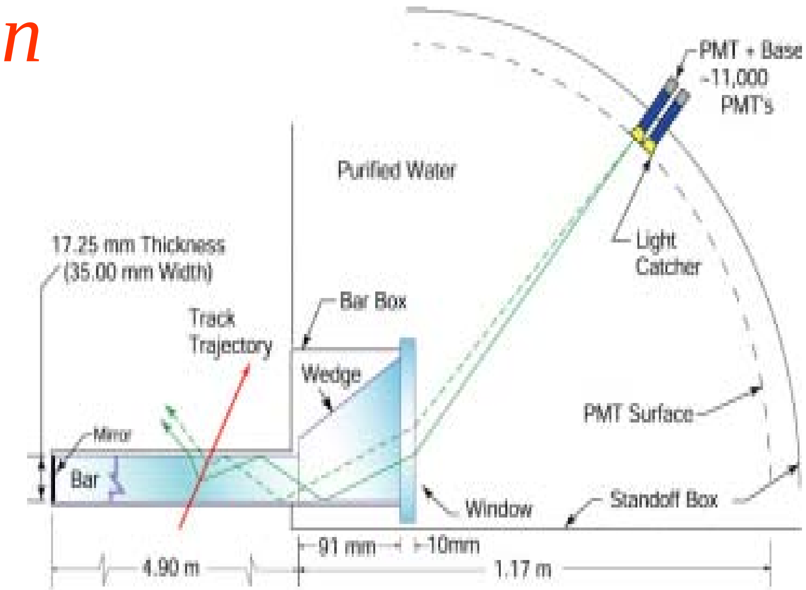


- **Spherical B events vs jet-like continuum:**
  - Techniques exploiting event topology and angular distributions
- **Fisher variable:**
  - Combine two “monomials”

$$L_0 = \sum_i p_i^* \quad \text{and} \quad L_2 = \sum_i p_i^* \left|\cos(\theta_i^*)\right|^2$$

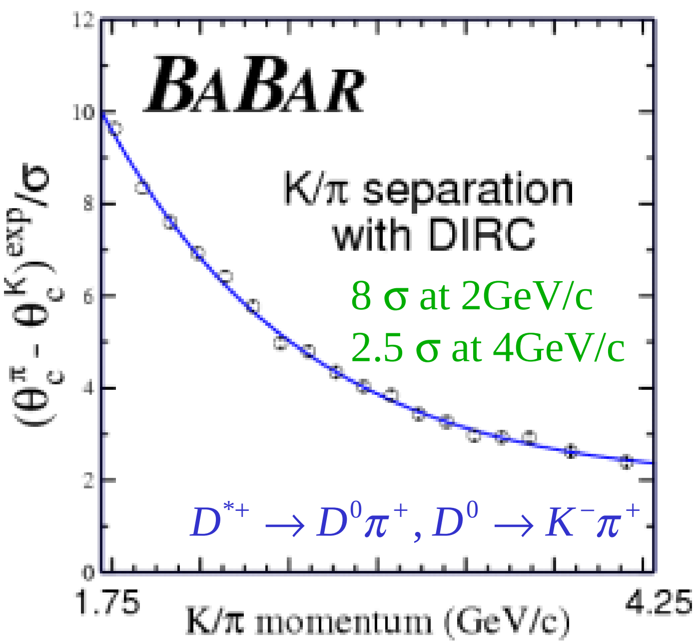
  - Use as a discriminating variable in the Likelihood

High energy K/π Separation

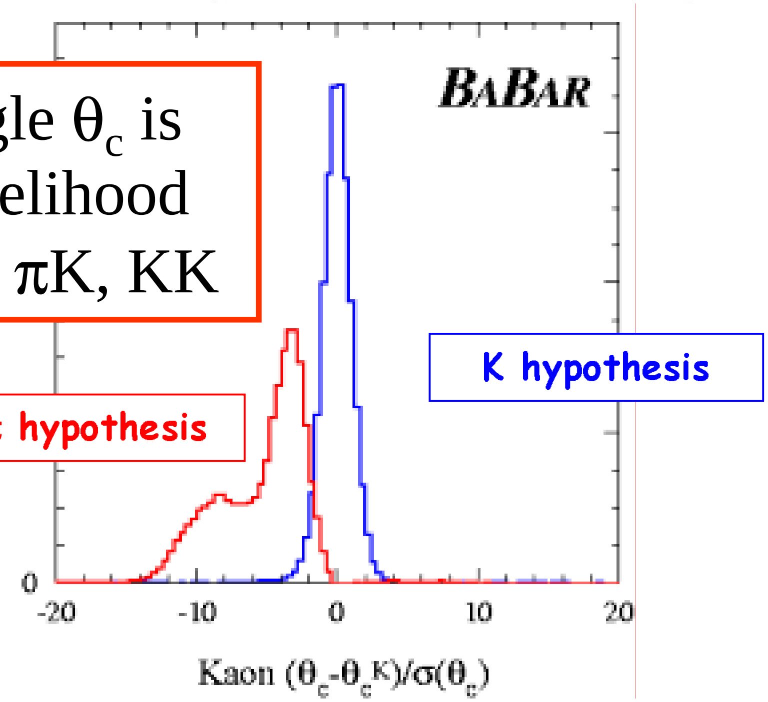


DIRC:

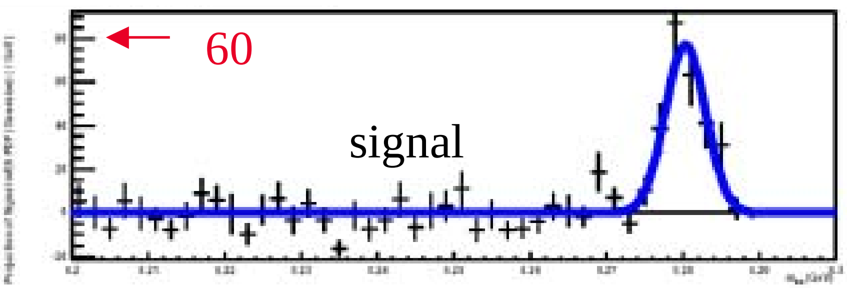
- Cherenkov light emitted by the track around a cone with $\cos\theta_c = 1/n\beta$
- **Photons are** captured by internal reflection in the bar and transmitted to a PMT matrix.
- Resolution $\sigma(\theta_c)$ = 2.5 mrad ($e^+e^- \to \mu^+\mu^-$)

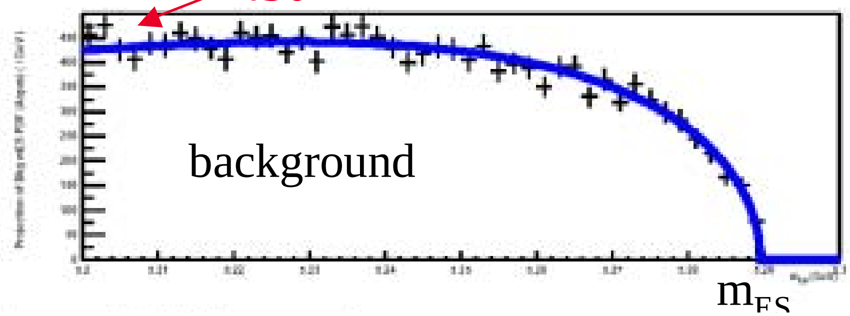


Cherenkov angle θ_c is used in the likelihood to separate ππ, πK, KK



Likelihood fit





⇒ Extended ***global maximum likelihood fit*** → signal yields (n^{sig})

m_{ES}, ΔE, Fisher, θ_C, Δt

⇒ Uncorrelated variables

$$\mathcal{P}^k = \mathcal{P}^k_{m_{\rm ES}} \mathcal{P}^k_{\Delta E} \mathcal{P}^k_{\mathcal{F}} \mathcal{P}^k_{\theta_+} \mathcal{P}^k_{\theta_-}$$

each event i :

$$L = \frac{e^{-\left(\sum n_j\right)}}{N!} \prod_{i=1}^{N} L_i$$

$$L_i = \Sigma_j n_j^{sig} P_j^{sig}(\vec{x}_i) + \Sigma_j n_j^{bkg} P_j^{bkg}(\vec{x}_i)$$

Independent **control samples** to study

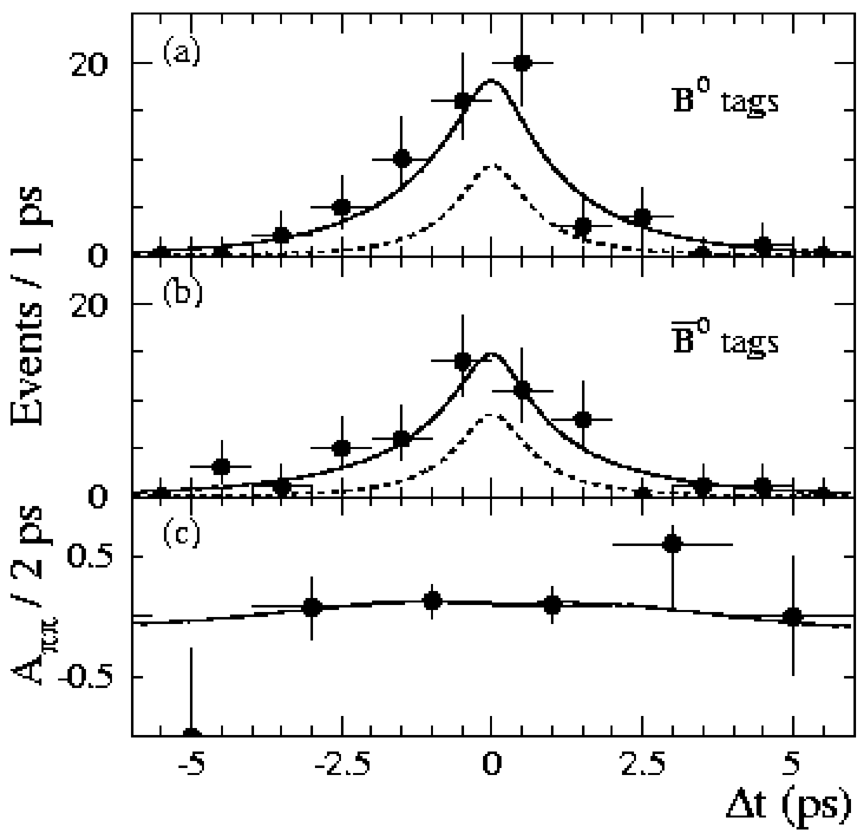
Probability Density Function for both **BKG** and **SIG**

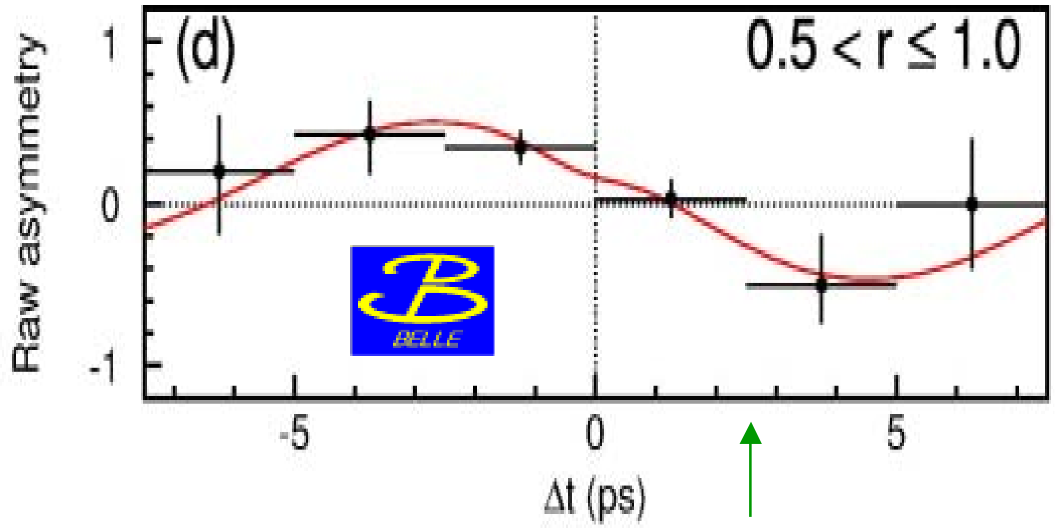
$\pi^+\pi^-$ CP Asymmetries

S →

$$A_{CP}(\Delta t) = \frac{2\ \mathrm{Im}\lambda}{1+|\lambda|^2}\sin\Delta m\Delta t \quad - \quad \frac{1-|\lambda|^2}{1+|\lambda|^2}\cos\Delta m\Delta t$$

← C

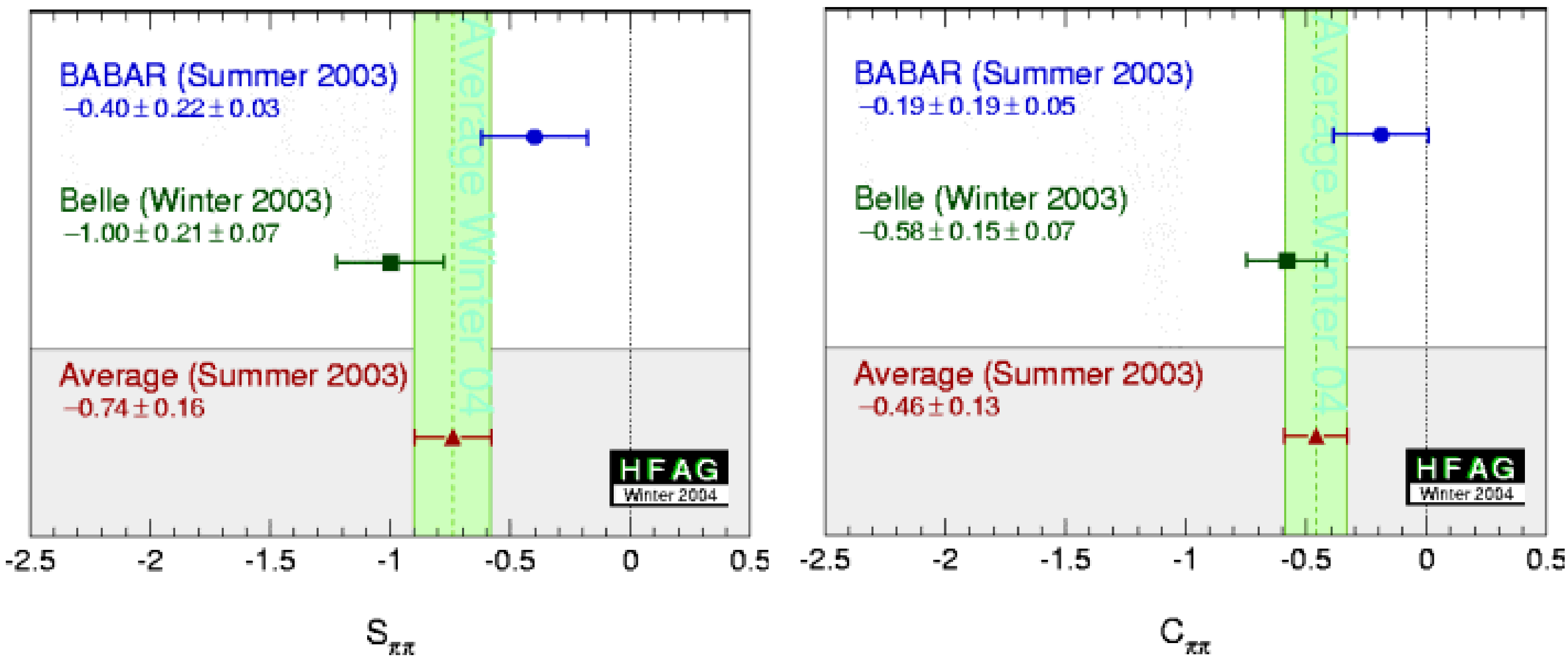




Belle: 140 fb^{-1}
5.2σ CPV (!)

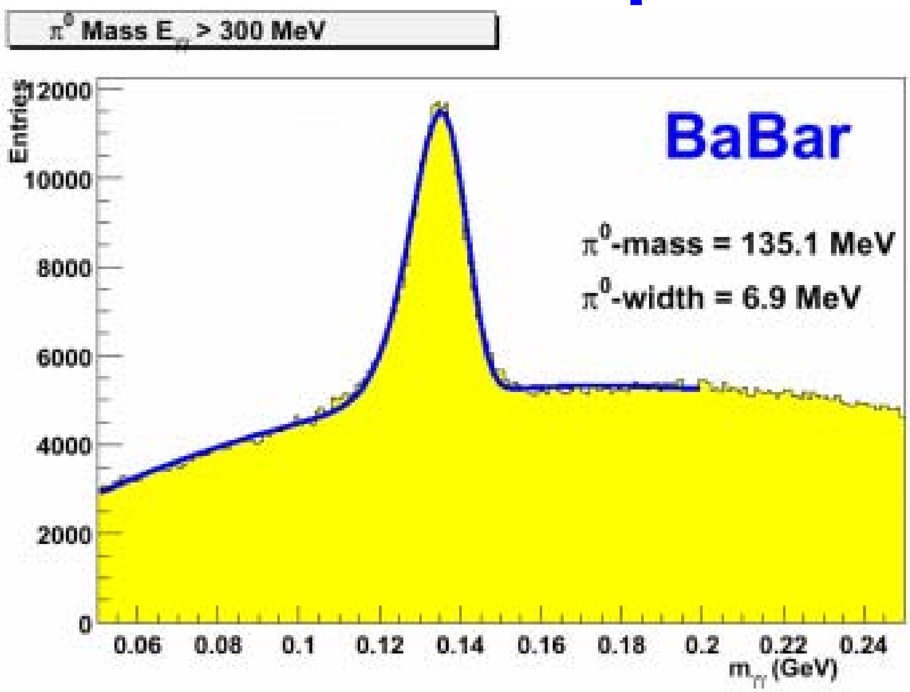
BaBar: 113 fb^{-1}
~ 2σ CPV

$\pi^+\pi^-$ CP Asymmetries

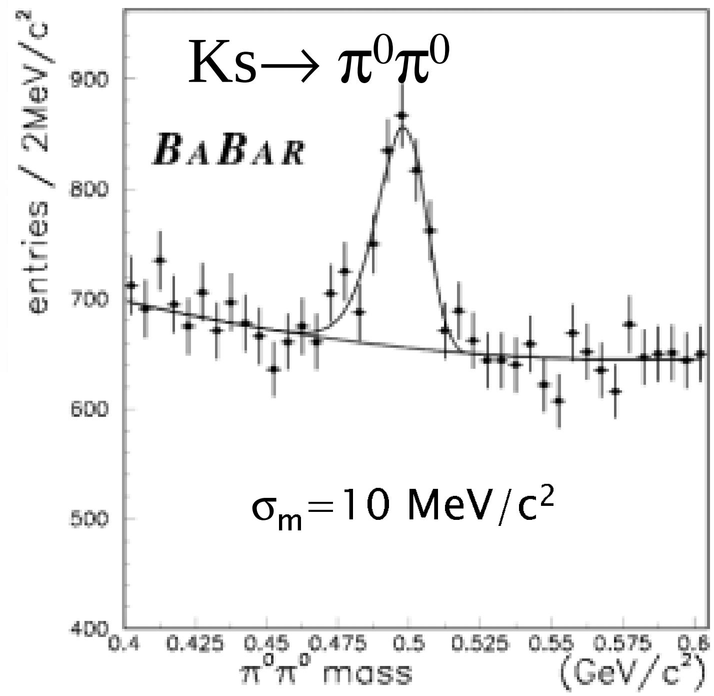


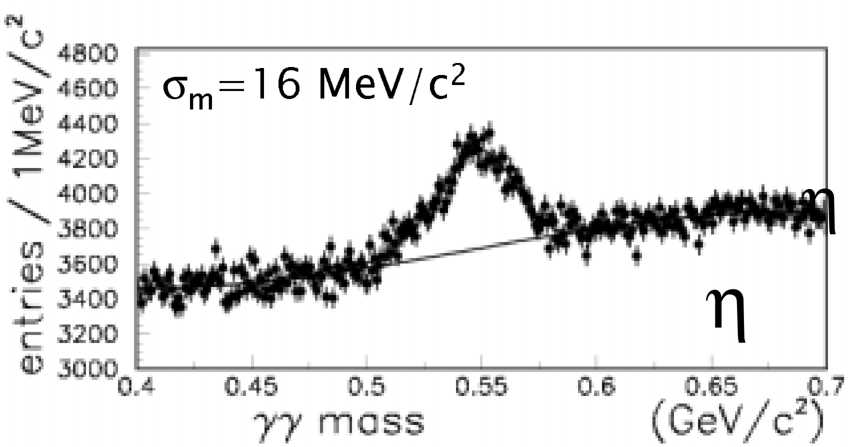
Disagreement at the ~ 2.2σ level between Belle and BaBar

π^0 and η identification

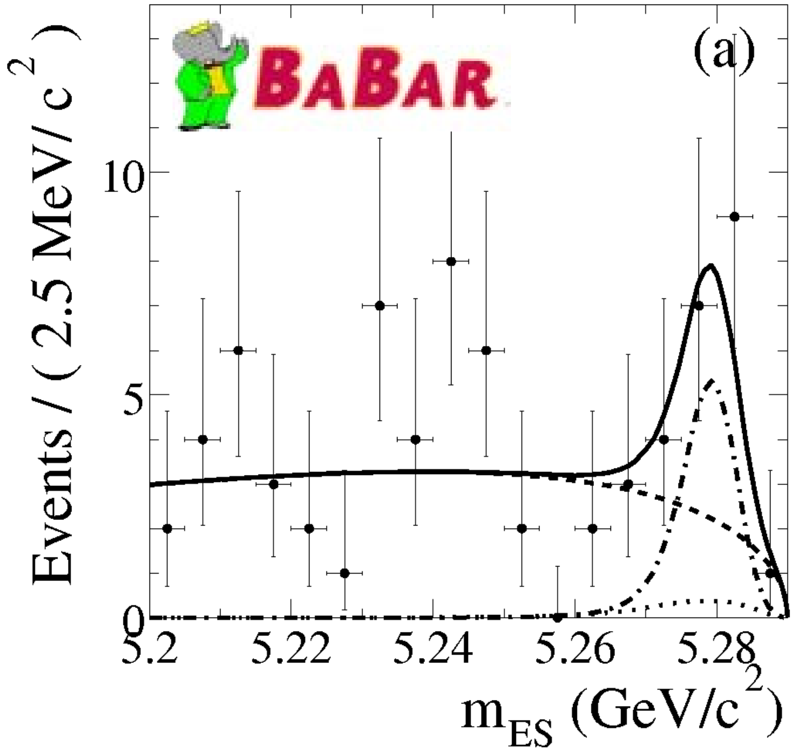


Belle: $\sigma(m_{\pi 0}) \sim 5\text{MeV}$





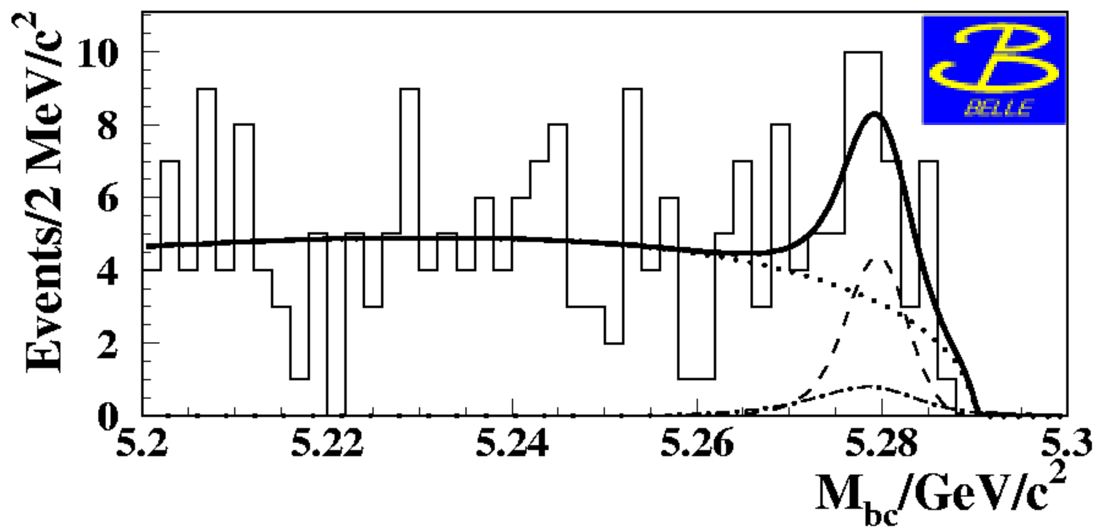
$\pi^0\pi^0$ has now been seen…….



46 ± 13 events

BR = (2.1 ± 0.6 ± 0.3) 10^{-6}

4.2σ significance



26 ± 9 events

BR = (1.7 ± 0.6 ± 0.2) 10^{-6}

3.4σ significance

……but we don't like it !

Too small for isospin analysis

Too large for useful bound

- e.g., Grossmann-Quinn bound (PRD58, 017504, 1998)

$$\sin^2(\alpha_{eff} - \alpha) < \frac{\mathrm{BR}(B^0/\bar{B}^0 \to \pi^0\pi^0)}{\mathrm{BR}(B^\pm \to \pi^+\pi^-)}$$

Gives $|\alpha_{eff} - \alpha| < 47^o$

B→$\rho^+\rho^-$: it gets better….

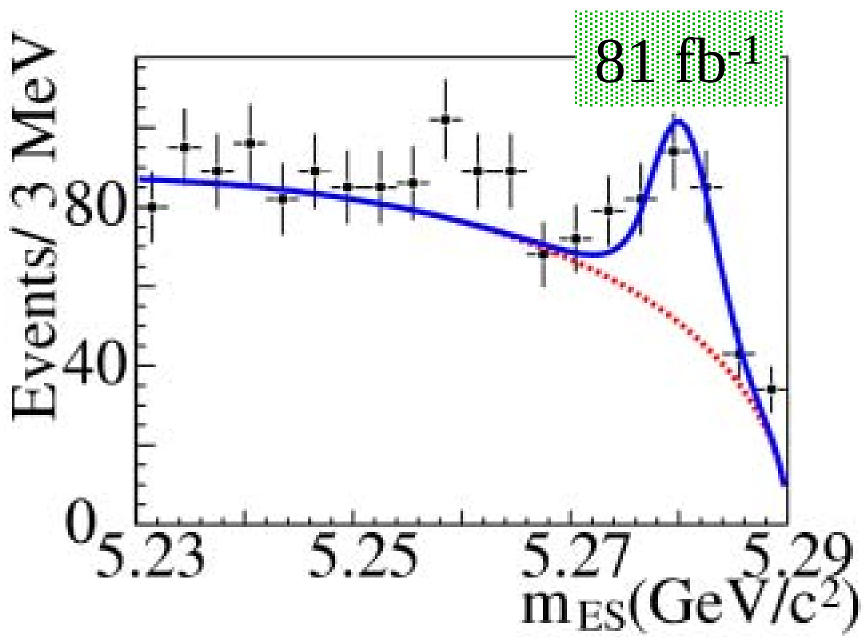
Mode	BR
$B^0/B^0 \to \rho^+\rho^-$	$(30 \pm 4 \pm 5) \times 10^{-6}$
$B^\pm \to \rho^\pm\rho^0$	$(26.4 \pm 6.4) \times 10^{-6}$
$B^0/\bar{B}^0 \to \rho^0\rho^0$	$(0.62^{+0.72}_{-0.60} \pm 0.12) \times 10^{-6}$

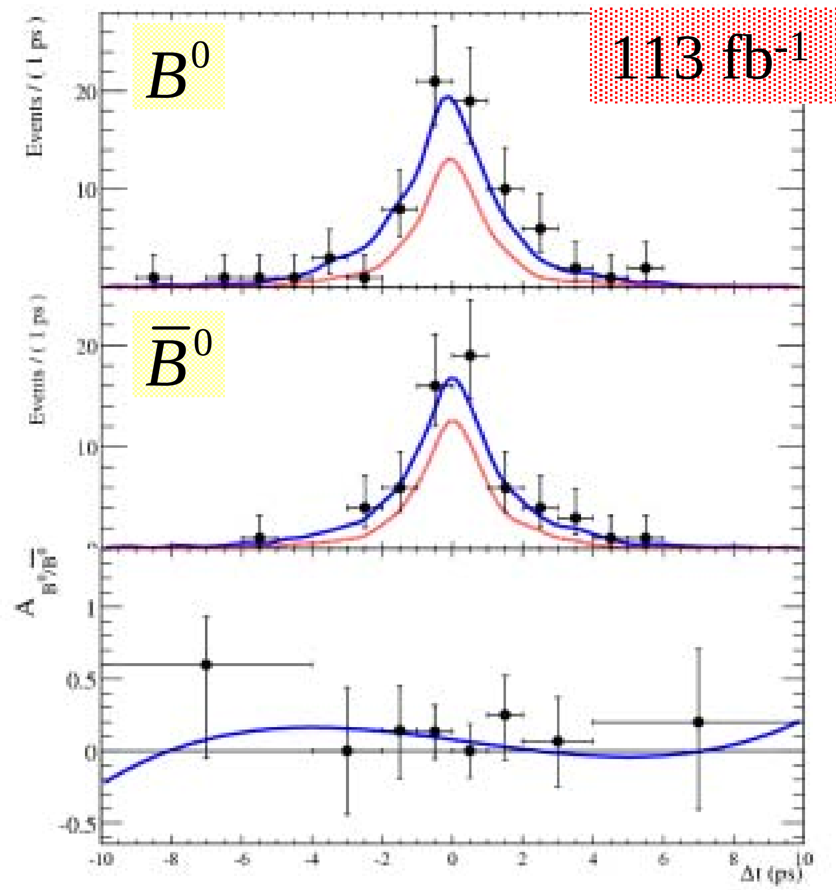
B → $\rho^0\rho^0$ is <u>very</u> small!

Grossman-Quinn bound is useful

$|\alpha_{eff} - \alpha| < 16^{o}$ (13^{o}) @ 90% (68.3%) C.L.

$B \rightarrow \rho^+\rho^-$ asymmetry

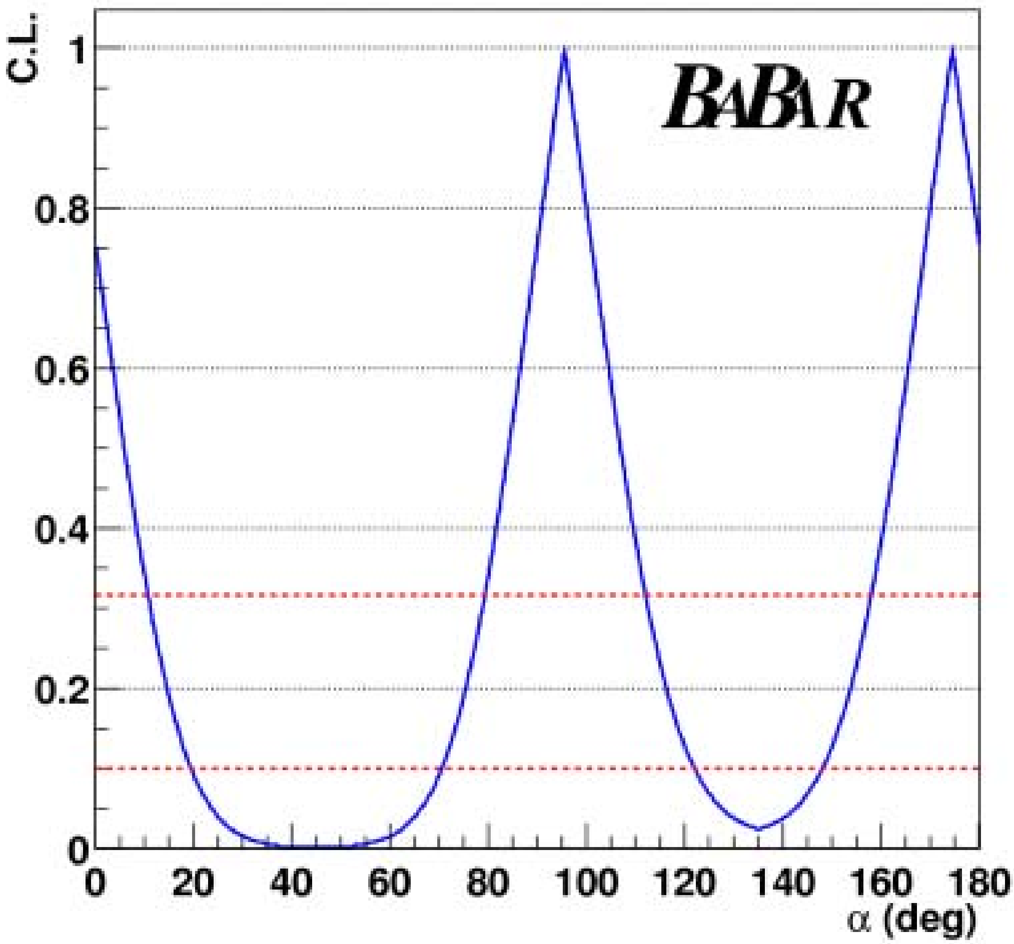




$S_{long} = -0.19 \pm 0.33 \pm 0.11$

$C_{long} = -0.23 \pm 0.24 \pm 0.14$

B→ρρ isospin analysis



$\alpha = 96^o \pm 10^o$ (stat.) $\pm\ 4^o$ (syst.) $\pm\ 13^o$ (penguin)

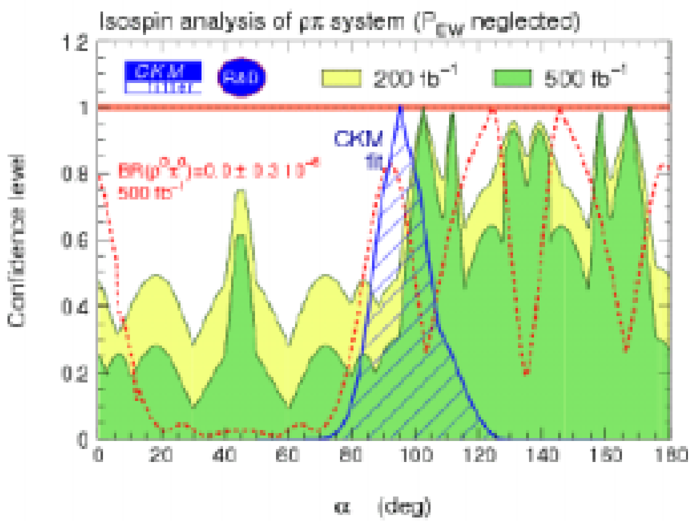
Preliminary, neglecting interference, NR contribution, I=1 amp.

$B \rightarrow \pi\pi\pi^0$

Trying two approaches:

- Measure $\sin 2\alpha_{eff}$ and individual BF and the apply the isospin relationships:
  - $\Rightarrow$Quite hopeless, also because of multiple solutions

- Do the full time-dependent and Dalitz analysis $\rightarrow$



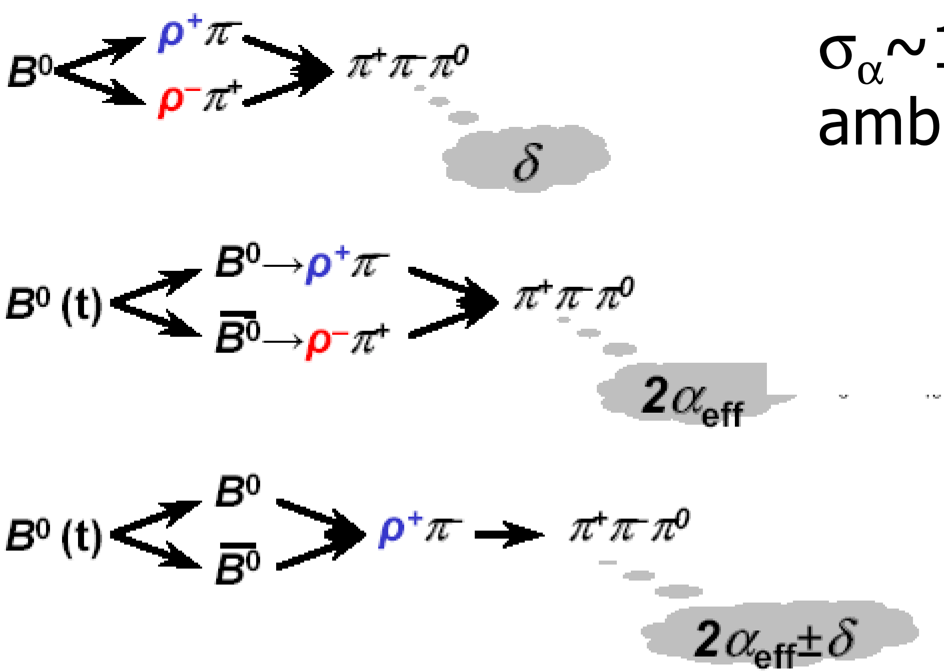
Full Dalitz analysis

- Time-dependent fit of complex *T*'s and *P*'s and α :

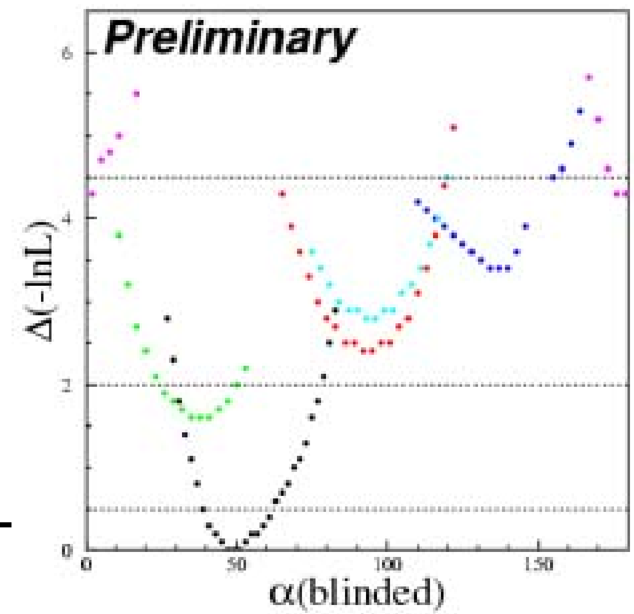
total of 9 free parameters + one global normalization + one global phase

$$f_{3\pi}^{B^0\text{-tag}} = \frac{1}{Norm}\left(|A_{3\pi}|^2 + |\bar{A}_{3\pi}|^2 + 2\,\mathrm{Im}\left[\bar{A}_{3\pi}A_{3\pi}^*\right]\sin(\Delta m_d \Delta t) - \left(|A_{3\pi}|^2 - |\bar{A}_{3\pi}|^2\right)\cos(\Delta m_d \Delta t)\right)$$

$$f_{3\pi}^{\bar{B}^0\text{-tag}} = \frac{1}{Norm}\left(|A_{3\pi}|^2 + |\bar{A}_{3\pi}|^2 - 2\,\mathrm{Im}\left[\bar{A}_{3\pi}A_{3\pi}^*\right]\sin(\Delta m_d \Delta t) + \left(|A_{3\pi}|^2 - |\bar{A}_{3\pi}|^2\right)\cos(\Delta m_d \Delta t)\right)$$



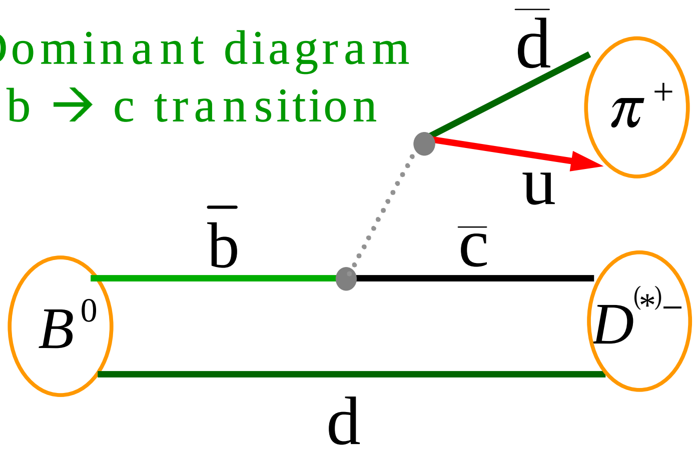
σ_α~10° in 113 fb^{-1} with no ambiguity



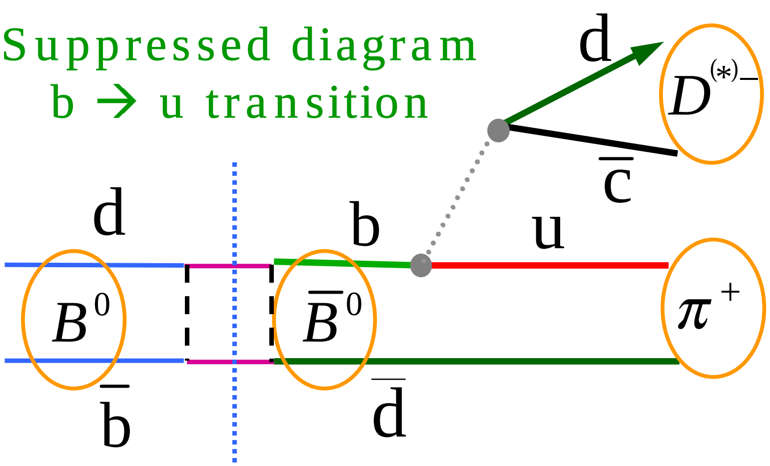
Sensitivity to γ in $B^0 \rightarrow D^{(*)}\pi$

CP violation appearing in interference between 2 amplitudes

Dominant diagram
b → c transition



Suppressed diagram
b → u transition



- **Final states are not CP eigenstates**
- **No penguin pollution**

- **b → u transition → relative weak phase γ between the 2 amplitudes**
- **Mixing → 2β**
- **Relative strong phase δ between the 2 amplitudes**

→ Measure sin(2β+γ±δ)

$$\begin{cases} BF_{favored}\left(B^0 \rightarrow D^{(*)-}\pi^+\right) \approx 3.10^{-3} \\ BF_{suppressed}\left(B^0 \rightarrow D^{(*)+}\pi^-\right) \approx 10^{-6} \end{cases}$$

CP violation proportional to:

$$r \approx \left|V_{ub}^* V_{cd} / V_{cb} V_{ud}^*\right| \approx 0.020$$

Determination of sin(2β+γ) from Time Dependent Evolution

- **Time evolution for $D^-\pi^+$ final states:**

$$B^0 \text{ decays: } R(D^-\pi^+,\Delta t) = N e^{-\Gamma|\Delta t|}\{1 + C\cos(\Delta m_d \Delta t) + S\sin(\Delta m_d \Delta t)\}$$

$$\overline{B^0} \text{ decays: } R(D^-\pi^+,\Delta t) = N e^{-\Gamma|\Delta t|}\{1 - C\cos(\Delta m_d \Delta t) - S\sin(\Delta m_d \Delta t)\}$$

- **Time evolution for $D^+\pi^-$ final states:**

$$B^0 \text{ decays: } R(D^+\pi^-,\Delta t) = N e^{-\Gamma|\Delta t|}\{1 + C\cos(\Delta m_d \Delta t) - \bar{S}\sin(\Delta m_d \Delta t)\}$$

$$\overline{B^0} \text{ decays: } R(D^+\pi^-,\Delta t) = N e^{-\Gamma|\Delta t|}\{1 - C\cos(\Delta m_d \Delta t) + \bar{S}\sin(\Delta m_d \Delta t)\}$$

- **Similar equation for $D^*\pi$**

$$C = \frac{1-r^2}{1+r^2} \approx 1$$

$$\left.\begin{aligned} S &= \frac{2r}{1+r^2}\sin(2\beta+\gamma-\delta) \\ \bar{S} &= \frac{2r}{1+r^2}\sin(2\beta+\gamma+\delta) \end{aligned}\right\} \approx [-0.04,+0.04]$$

Need to know both S and $\bar{S}$ to determine (2β+γ) and δ

☞ *There are four ambiguities in (2β+γ) determination*

Determination of Amplitude Ratio: r

$$r(D^{(*)}\pi) \equiv r_{(*)} = \left| \frac{A(\overline{B}^0 \to D^{(*)-}\pi^+)}{A(B^0 \to D^{(*)-}\pi^+)} \right| \approx 0.02$$

$$r_{(*)} \approx \sqrt{\frac{Br(B^0 \to D_s^{(*)+}\pi^-)}{Br(B^0 \to D^{(*)-}\pi^+)}} \left| \frac{V_{cd}}{V_{cs}} \right| \frac{f_{D^{(*)}}}{f_{D_S^{(*)}}}$$

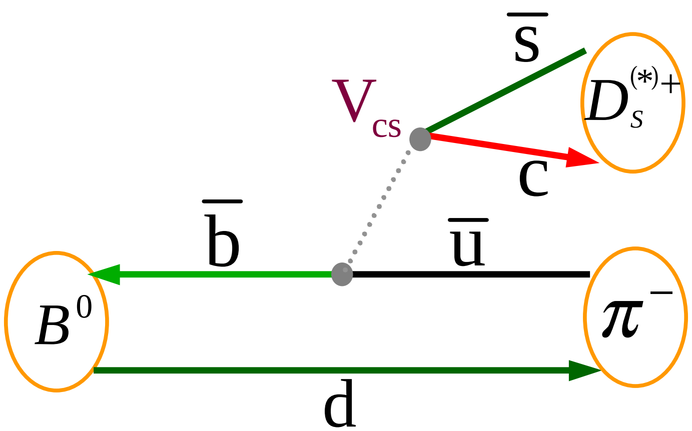
BaBar – hep-ex/0207053 (2002)

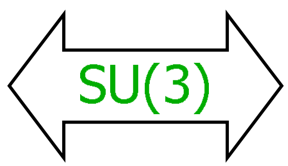
Simultaneous determination of sin(2β+γ) and $r_{(*)}$ is not possible with the current statistics

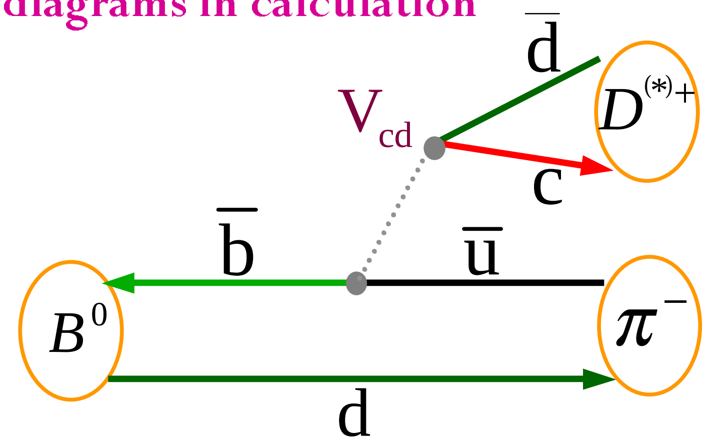
- Use $B^0 \to D_s^{(*)+}\pi^-$ ***(I. Dunietz, Phys. Lett. B 427, 179 (1998))***
- and SU(3) symmetry

$$r(D\pi) = 0.021^{+0.004}_{-0.005} \qquad r(D^*\pi) = 0.017^{+0.005}_{-0.007}$$

Add another 30% systematic error for SU(3) breaking uncertainty and for missing W-exchange diagrams in calculation



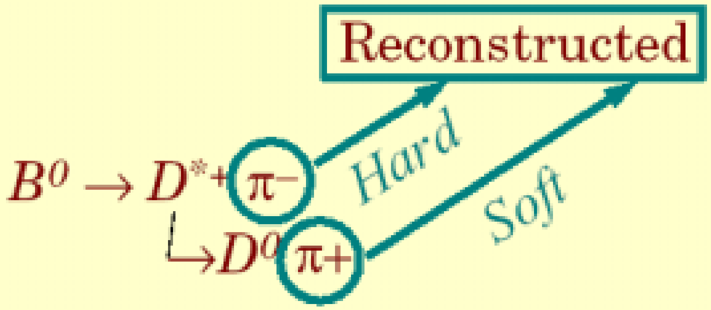




Partial Reconstruction

76 fb^{-1}

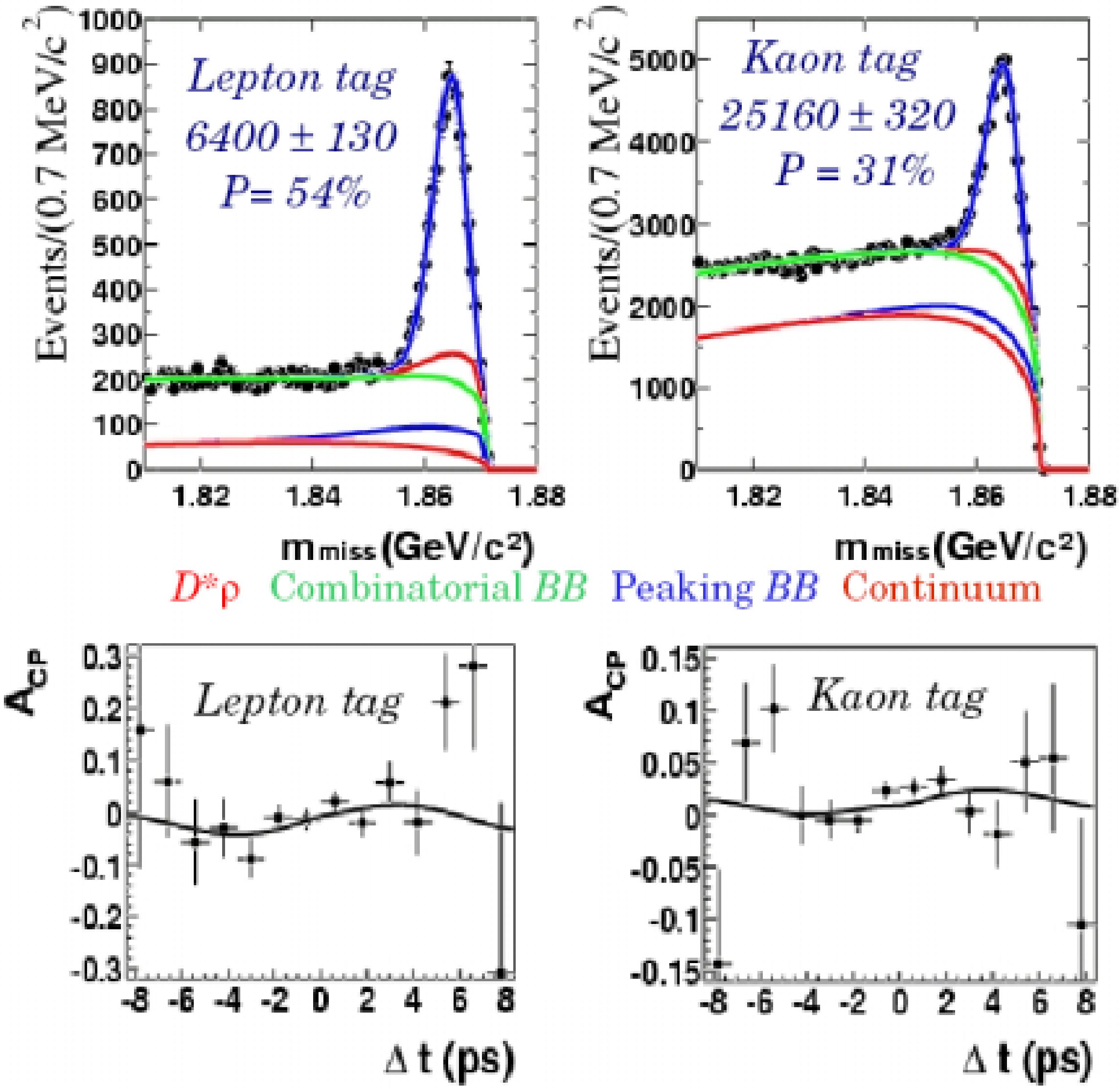
(hep-ex/0310037)



No efficiency loss for D^0 reconstruction

m_{miss} = D invariant mass

$$A_{CP} = \frac{N_{B^0_{tag}} - N_{\overline{B}^0_{tag}}}{N_{B^0_{tag}} + N_{\overline{B}^0_{tag}}}$$



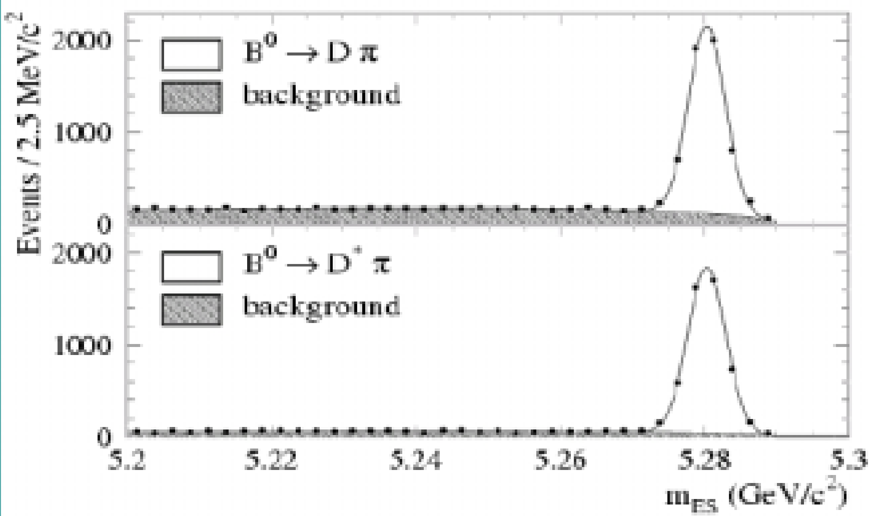
Full reconstruction

81 fb^{-1}

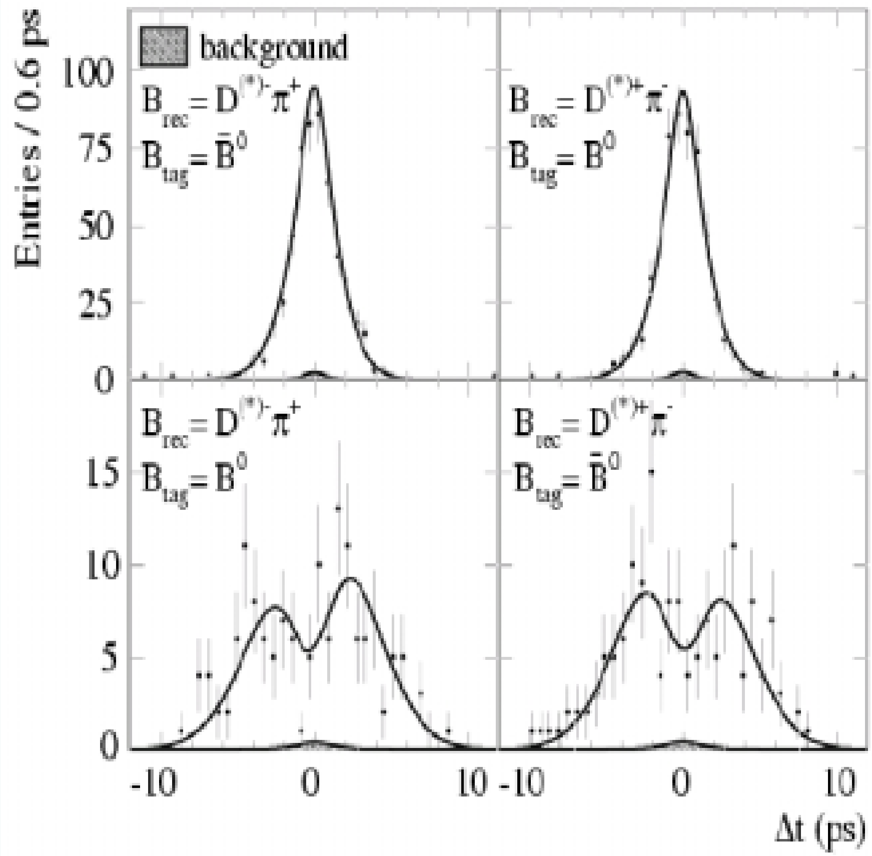
(hep-ex/0309017)

	signal events	*purity*
$B^0 \to D\pi$	5207 ± 87	84.9%
$B^0 \to D^*\pi$	4746 ± 78	94.4%

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

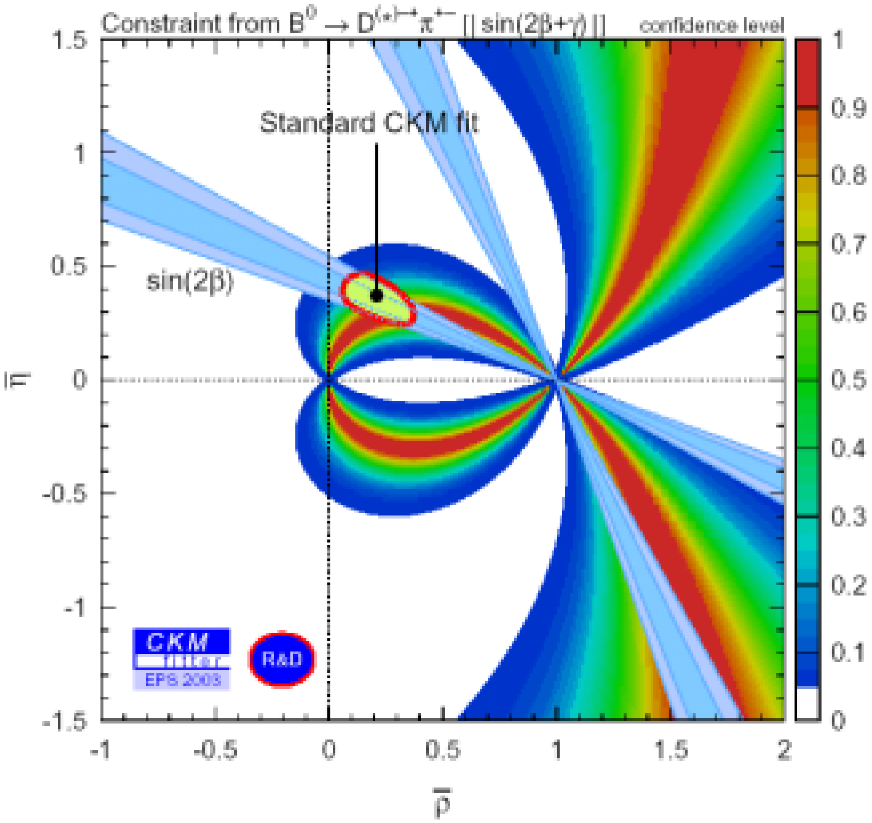


Time evolution for lepton category



Constraints in the ρ, η Plane from BaBar Measurements

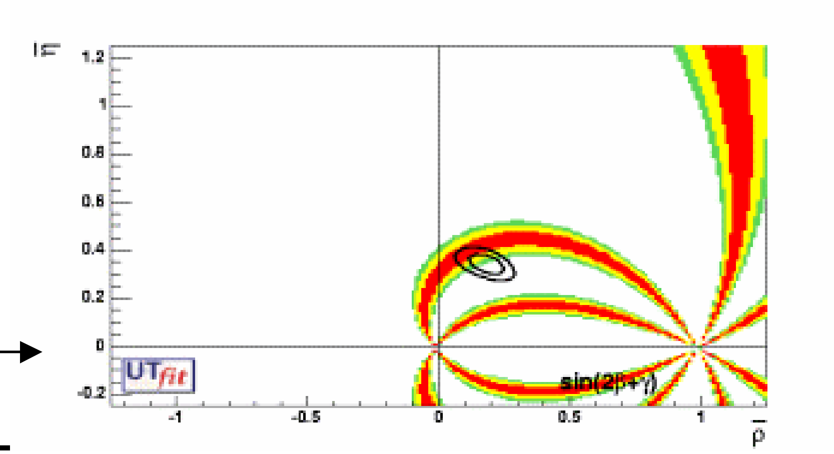
Constraint from **sin**$(2\beta+\gamma)$ <u>assuming a given value of r</u> with 30% theoretical error



$a = 2r\,\sin(2\beta+\gamma)\,\cos\delta$
$b = 2r'\,\sin(2\beta+\gamma)\,\cos\delta'$
$c = 2\,\cos(2\beta+\gamma)\,(r\,\sin\delta - r'\sin\delta')$

		a	c_{lep}
Full reco	$D\pi$	$-0.022 \pm 0.038 \pm 0.020$	$0.025 \pm 0.068 \pm 0.033$
	$D^*\pi$	$-0.068 \pm 0.038 \pm 0.020$	$0.031 \pm 0.070 \pm 0.033$
Partial reco	$D^*\pi$	$-0.022 \pm 0.038 \pm 0.020$	$-0.022 \pm 0.038 \pm 0.020$

Infinite statistics →



What Shall Thou Remember

- There are lots of phenomena associated to **CP violation** weak interactions among quarks, and the Standard Model has only 1 parameter to explain all of them
  - redundant measurements test SM and are sensitive to New Physics
  - info summarized in the Unitarity Triangle
- There are two **Asymmetric B-Factories**, KEK-B (Japan) and PEP-II (US)
  - there is one experiment on each of them : Belle and BaBar
  - their luminosity are about 12 and 8 10^{33} cm^{-2} s^{-1} respectively
  - they have collected ~200fb-1 respectively so far
- CP violation manifests itself in **distribution of the time** elapsed before the decays of B mesons
  - B-Factories need to be asymmetric in order to stretch time intervals
- Given a final state 'f' we are sensitive to **Im(λ)** where

$$\lambda = \frac{A(\bar{B} \to f)}{A(B \to f)} e^{-i2\beta}$$

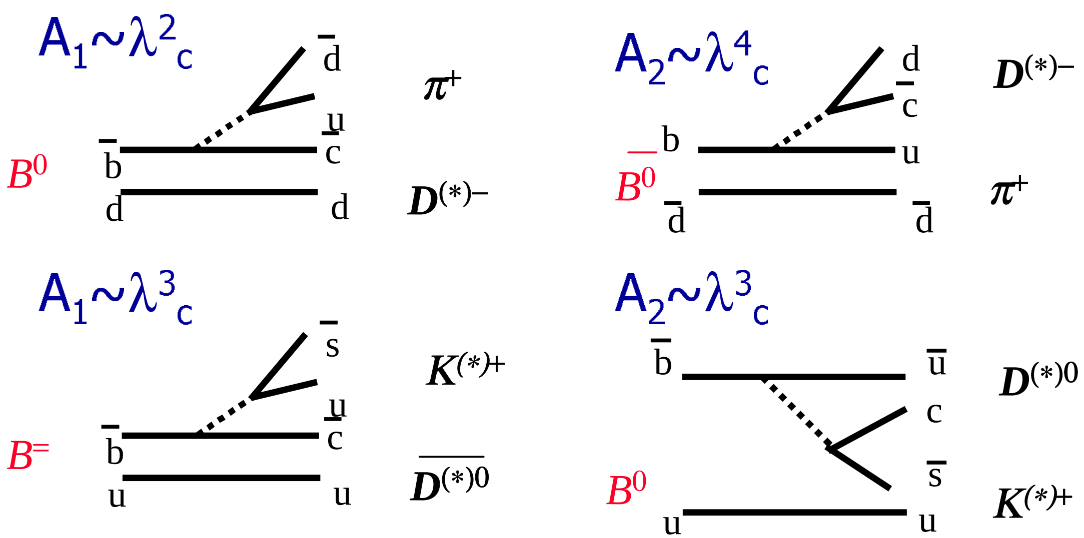
  - examples where shown on how to measure all angles

PHYSICS PROGRAM AT B-FACTORIES IS MUCH BROADER, BUT I ONLY HAD 3 HOURS …

APPENDICES

Measurements of γ

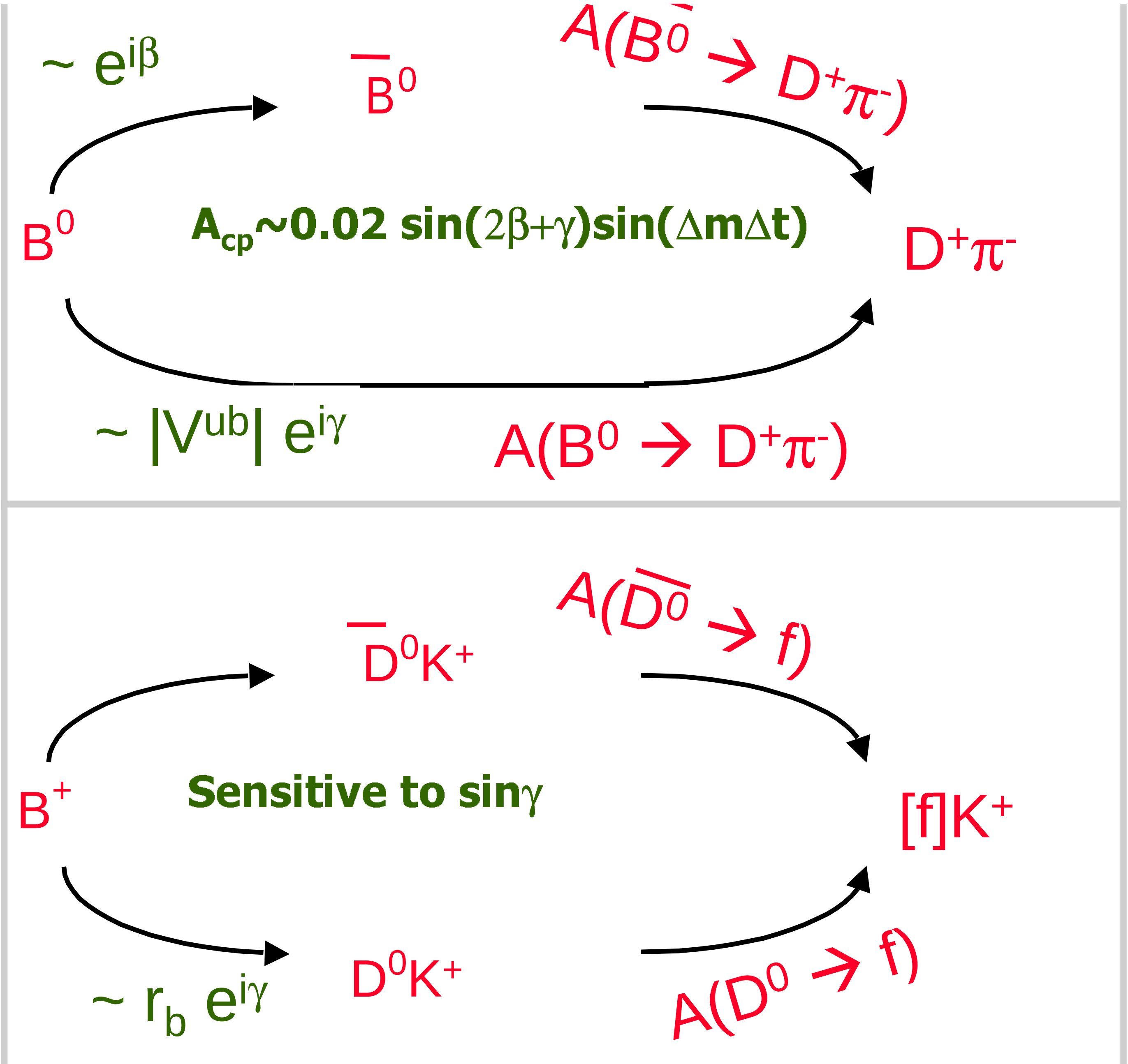
- Contributions from b→u transitions bring a dependence of CPV from γ
  - Measure γ directly in direct CP asymmetries & B+ decay rates
  - Measure 2β+γ with CPV in mixing
- Two cases



sin2β+γ: A_2 doubly cabibbo suppressed

sinγ: A_2 colour suppressed

Grafically:



~ $e^{i\beta}$
$\overline{B}^0$
$A(\overline{B}^0 \to D^+\pi^-)$
B^0
A_{cp}~0.02 sin(2β+γ)sin(ΔmΔt)
$D^+\pi^-$
~ $|V^{ub}|\, e^{i\gamma}$
$A(B^0 \to D^+\pi^-)$
$\overline{D}^0K^+$
$A(\overline{D^0} \to f)$
B^+
Sensitive to sinγ
$[f]K^+$
~ $r_b\, e^{i\gamma}$
D^0K^+
$A(D^0 \to f)$

γ from B→DK, the classic Gronau-London-Wyler (GLW) method

D$_\pm$ is CP-odd or CP-even neutral D combination

$$R_\pm \equiv 2\frac{\Gamma(B^-\to D_\pm K^-)+\Gamma(B^+\to D_\pm K^+)}{\Gamma(B^-\to D^0 K^-)+\Gamma(B^+\to \bar{D}^0 K^+)}$$

$$A_\pm \equiv \frac{\Gamma(B^-\to D_\pm K^-)-\Gamma(B^+\to D_\pm K^+)}{\Gamma(B^-\to D_\pm K^-)+\Gamma(B^+\to D_\pm K^+)}$$

with

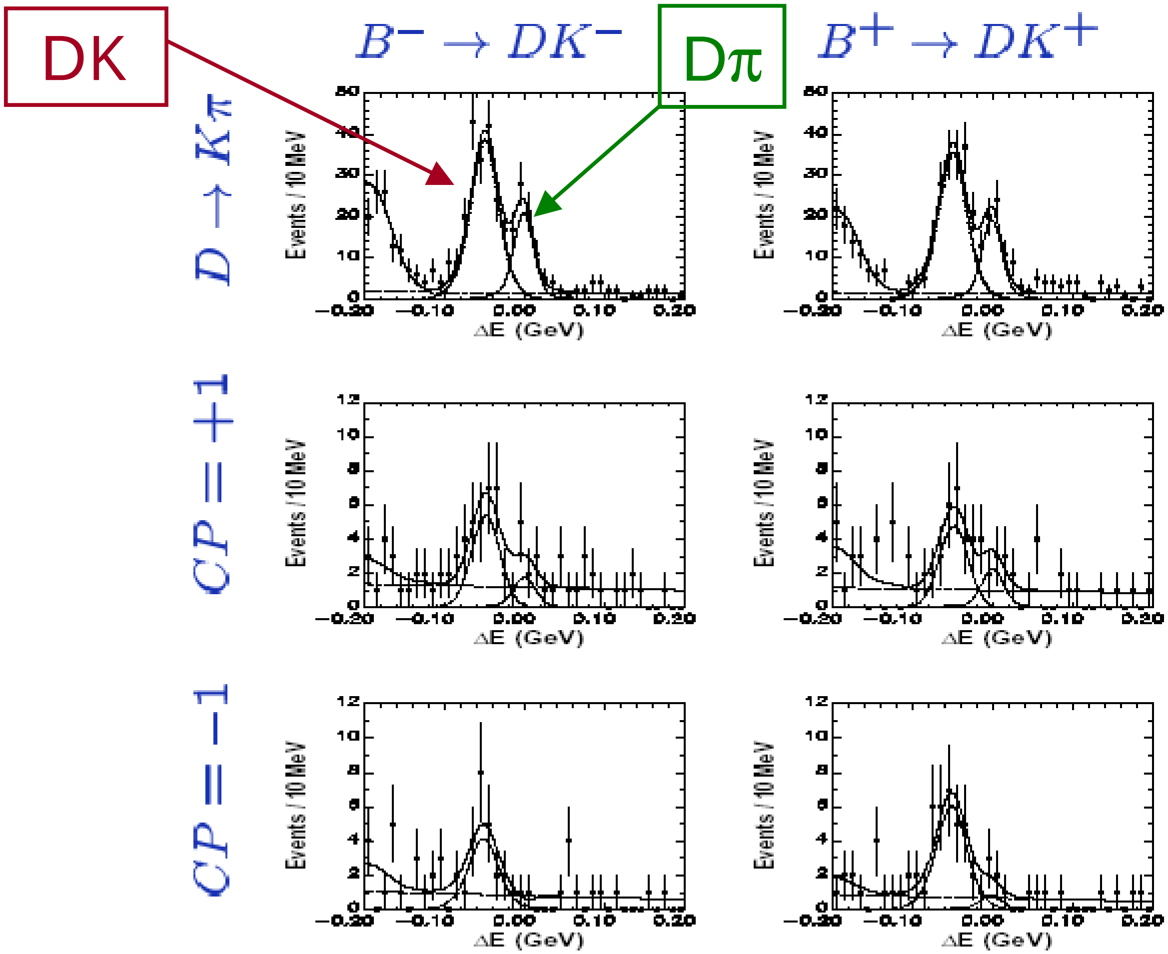
strong phase

$$R_\pm = 1 + r_B^2 \pm 2 r_B \cos\delta_B \cos\gamma$$

$$A_\pm = \frac{\pm 2 r_B \sin\delta_B \sin\gamma}{R_\pm}$$

Measure $A_\pm, R_\pm$: solve for δ_B, r_B, and γ

ol



D → K^+K^-, $\pi^+\pi^-$

D → $K_S\pi^0$, $K_S\phi$, $K_S\omega$, $K_S\eta$, $K_S\eta'$

	Belle	Babar
$\frac{\Gamma(B^- \to D^0 K^-)}{\Gamma(B^- \to D^0 \pi^-)}$	$7.7 \pm 0.5 \pm 0.6\%$	$8.31 \pm 0.35 \pm 0.2\%$
A_+	$0.06 \pm 0.19 \pm 0.04$	$0.07 \pm 0.17 \pm 0.06$
A_-	$-0.19 \pm 0.17 \pm 0.05$	
R_+	$1.21 \pm 0.25 \pm 0.14$	$\frac{8.8 \pm 1.6 \pm 0.5\%}{8.31 \pm 0.35 \pm 0.20\%}$
R_-	$1.41 \pm 0.27 \pm 0.15$	

O(90M)
BB pairs

GLW

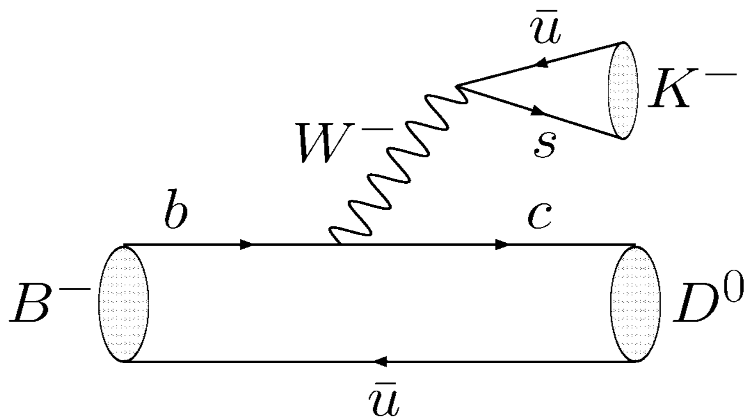
No useful constraints yet.

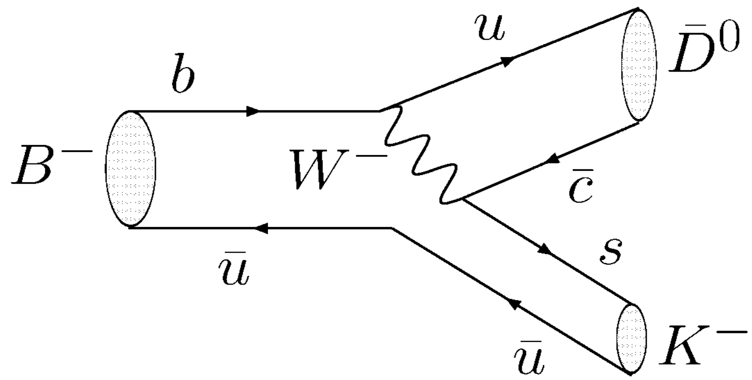
- Asym = $2r_B \sin\delta_B \sin\gamma \sim (0.0\text{-}0.4)\sin\gamma$
- Stat uncertainties ~ 20% / experiment

Important point:

- This and (likely) all other methods will not work by themselves at the B-factories.
- But: when combined together they might.
- Combinations are straightforward
  - $\Rightarrow$Root-N statistics

Atwood-Dunietz-Soni (ADS)





Like GLW, but common D^0/D^0 final state not CP eigenstate.

- ADS: Cabibbo favored and doubly-Cabibbo suppressed
  - e.g. $D^0 \to K^+\pi^-$ and $D^0 \to K^+\pi^-$
- Both singly Cabibbo suppressed
  - e.g. $K^{*+}K^-$

- Treatment like to GLW, but strong phase in D decay comes in

ADS

e.g., for final state $K^+\pi^-$ ratio of ADS rate to Cabibbo favored modes, $D^0 \rightarrow K^-\pi^+$ and c.c. is simply:

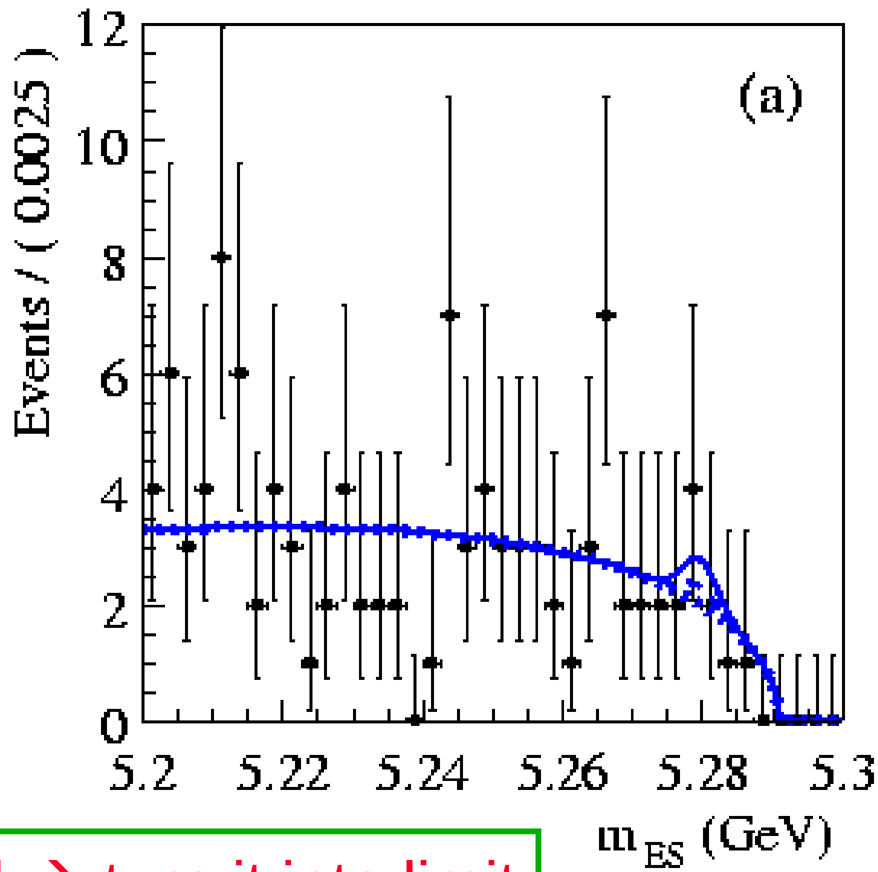
$$\frac{BR([K^+\pi^-]K^-)}{BR([K^-\pi^+]K^+)} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D + \gamma)$$
$$\frac{BR([K^-\pi^-]K^+)}{BR([K^+\pi-]K^-)} = r_B^2 + r_D^2 + 2r_B r_D \cos(\delta_B + \delta_D - \gamma)$$

Where

$$r_D^2 = \frac{BR(D^0 \rightarrow K^+\pi^-)}{BR(D^0 \rightarrow K^-\pi^+)} = (3.9 \pm 0.6) \times 10^{-3}$$

Bonus: large CP violation because $r_B \sim r_D$

ADS (Kπ mode)



No signal → turn it into limit

$r_B < 0.22$ (any γ)

$r_B < 0.20$ ($48^{\pm} < \gamma < 73^{\pm}$)

A promising method

Interference in the Dalitz plot of $B^- \to DK^-$ with $D/\bar{D} \to K_S \pi^+ \pi^-$.

$B^- \to D^0 K^-$ $\qquad$ $B^- \to \bar{D}^0 K^-$

$$A(B^-) = f(M_-^2, M_+^2) + r_B e^{i(\delta-\gamma)} f(M_+^2, M_-^2)$$

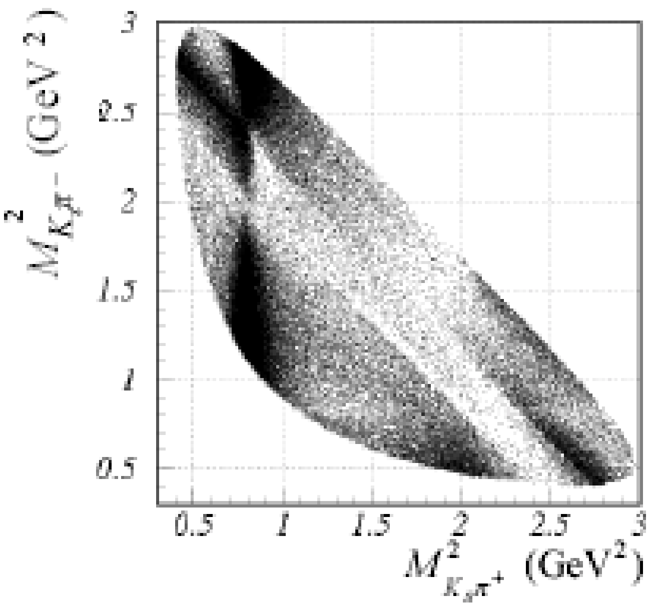
$$A(B^+) = f(M_+^2, M_-^2) + r_B e^{i(\delta+\gamma)} f(M_-^2, M_+^2)$$

$B^+ \to \bar{D}^0 K^+$ $\qquad$ $B^+ \to D^0 K^+$

$M^\pm$=mass($K_s\pi^\pm$)
f =Dalitz D decay amplitude

Belle Analysis

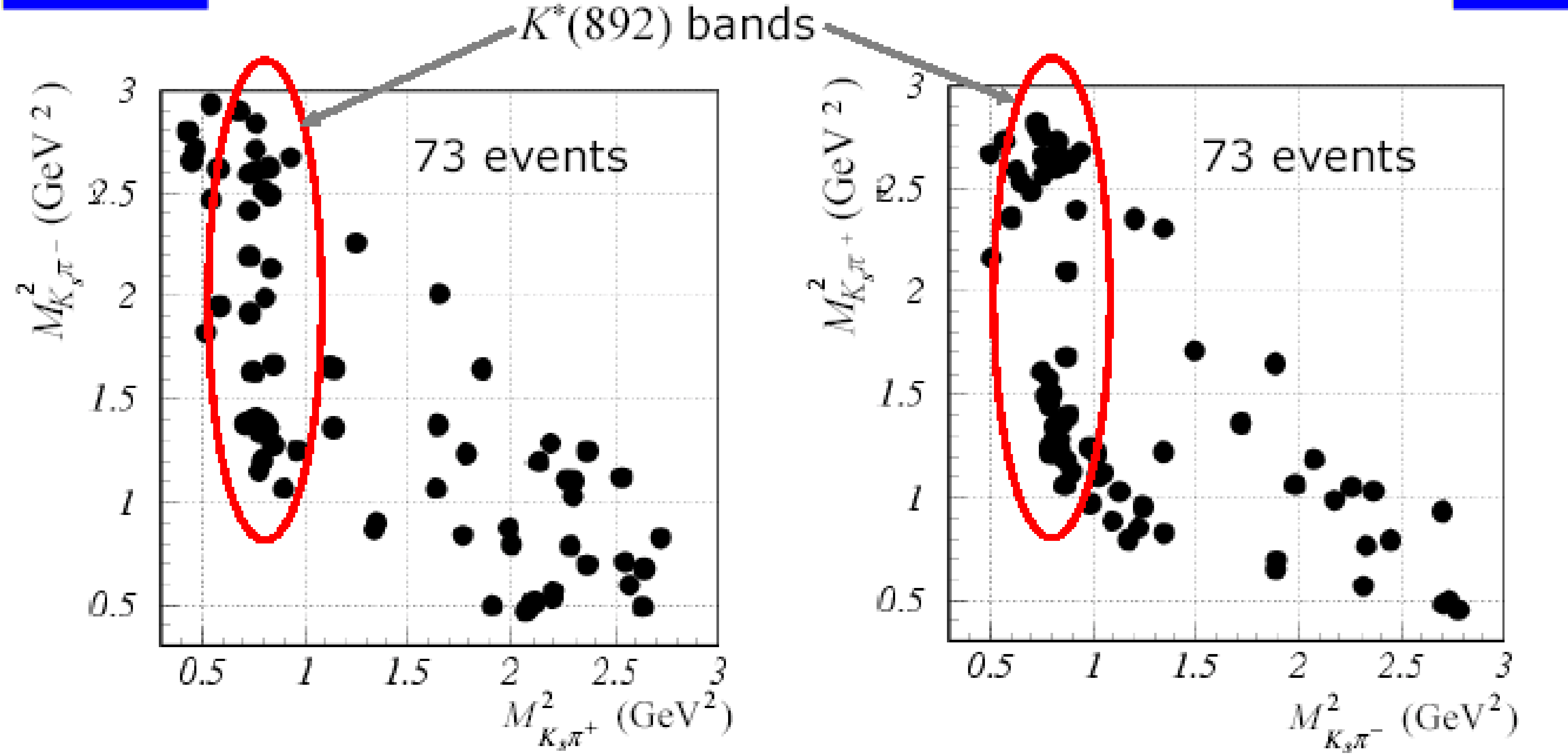
f = sum of resonances determined from large sample of $D^{*-} \rightarrow D^0\pi^-$



Resonance	Our fit		
	Amplitude	Phase, °	Fit fraction
$\sigma_1\ K_s$	1.66±0.11	218.0±3.8	11%
$\rho(770)\ K_S$	1	0	21%
$\omega\ K_s$	$(3.30\pm1.13)\cdot10^{-2}$	114.3±2.3	0.4%
$f_0(980)\ K_s$	0.405±0.008	212.9±2.3	4.8%
$\sigma_2\ K_s$	0.31±0.05	236±11	0.9%
$f_2(1270)\ K_s$	1.36±0.06	352±3	1.5%
$f_0(1370)\ K_s$	0.82±0.10	308±8	0.9%
$K^*(892)^-\pi^+$	1.656±0.012	137.6±0.6	60%
$K^*(892)^+\pi^-$	0.149±0.007	325.2±2.2	0.5%
$K^*_0(1430)^-\pi^+$	1.96±0.04	357.3±1.5	5.8%
$K^*_0(1430)^+\pi^-$	0.30±0.05	128±8	0.1%
$K^*_2(1430)^-\pi^+$	1.32±0.03	313.5±1.8	2.8%
$K^*_2(1430)^+\pi^-$	0.21±0.03	281.5±9	0.07%
$K^*(1680)^+\pi^-$	2.56±0.22	70±6	0.4%
$K^*(1680)^-\pi^+$	1.02±0.22	102±11	0.07%
Non resonant	6.1±0.3	146±3	24%

some model dependency

$B \rightarrow D/D\ K \quad D/D \rightarrow K_S\pi^+\pi^-$



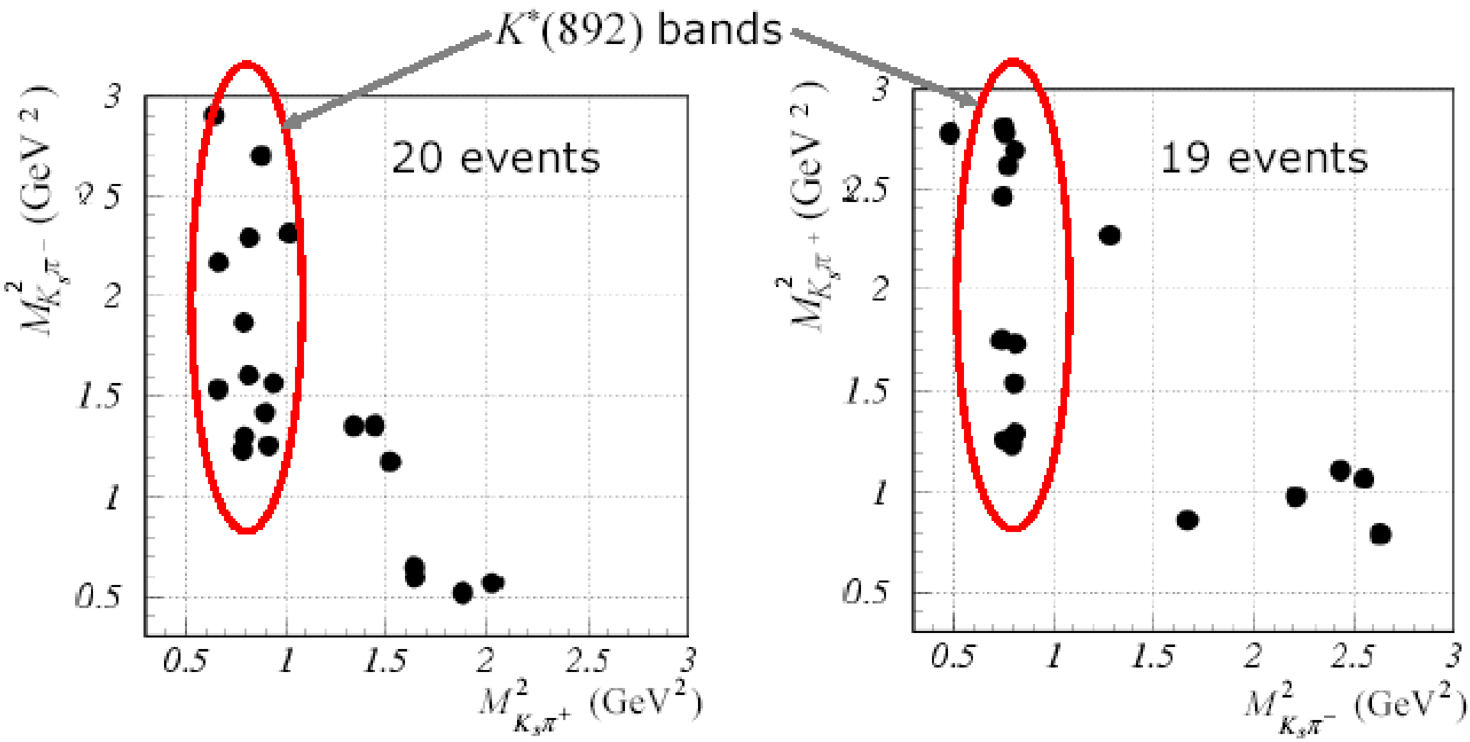
D^0 from $B^+ \rightarrow D^0K^+$

D^0 from $B^- \rightarrow D^0K^-$
(π^+ and π^- interchanged)

$$r_B = 0.28^{+0.09}_{-0.11}$$

$$\gamma = 86° \pm 20°$$

$B \rightarrow D^*/D^* \quad D^*/D^* \rightarrow D/D\pi^0 \quad D/D \rightarrow K_S \pi^+\pi^-$



D^0 from $B^+ \rightarrow D^{*0}K^+$

D^0 from $B^- \rightarrow D^{*0}K^-$
(π^+ and π^- interchanged)