BEAUTY'99
Conference Summary

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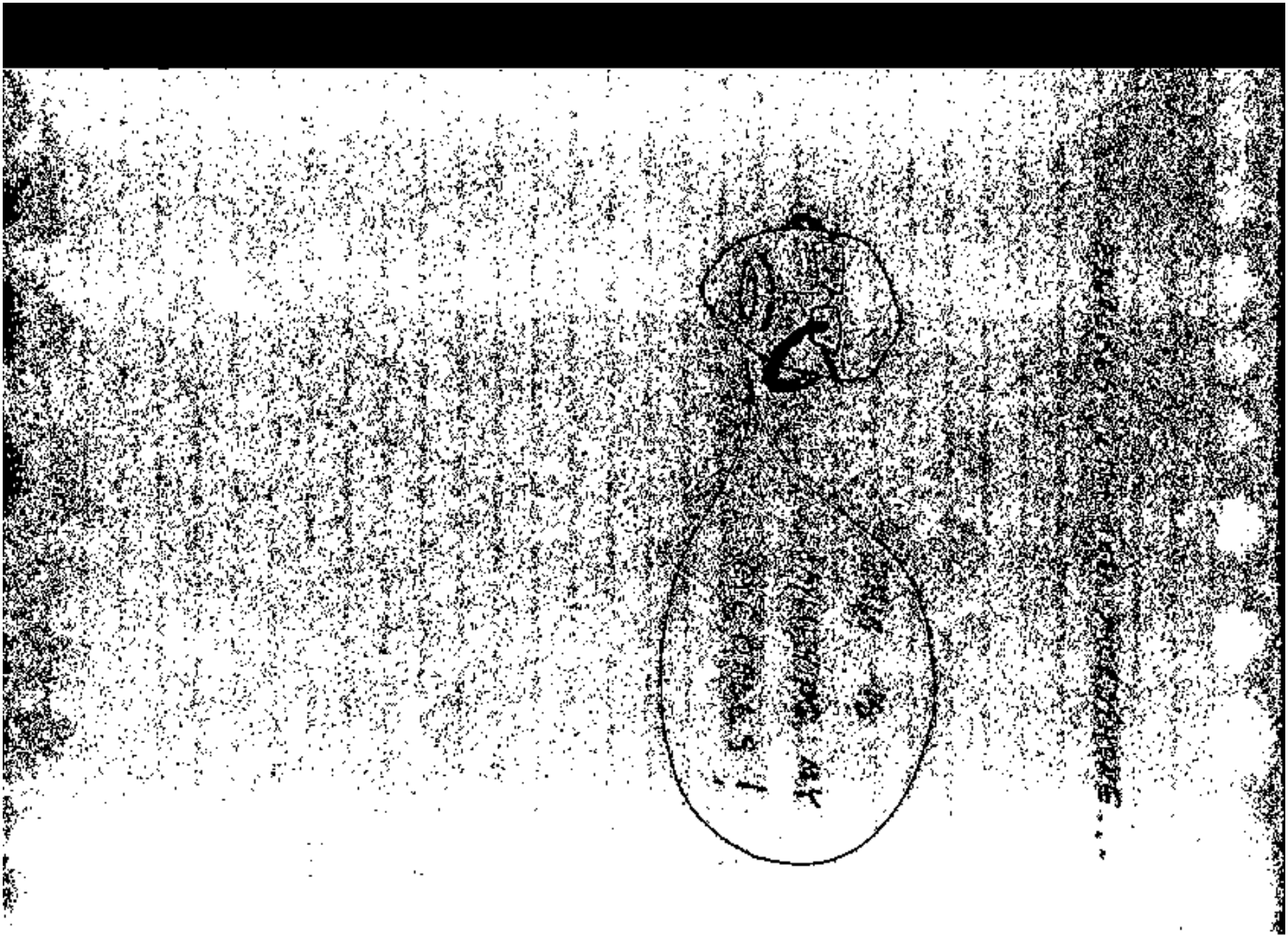
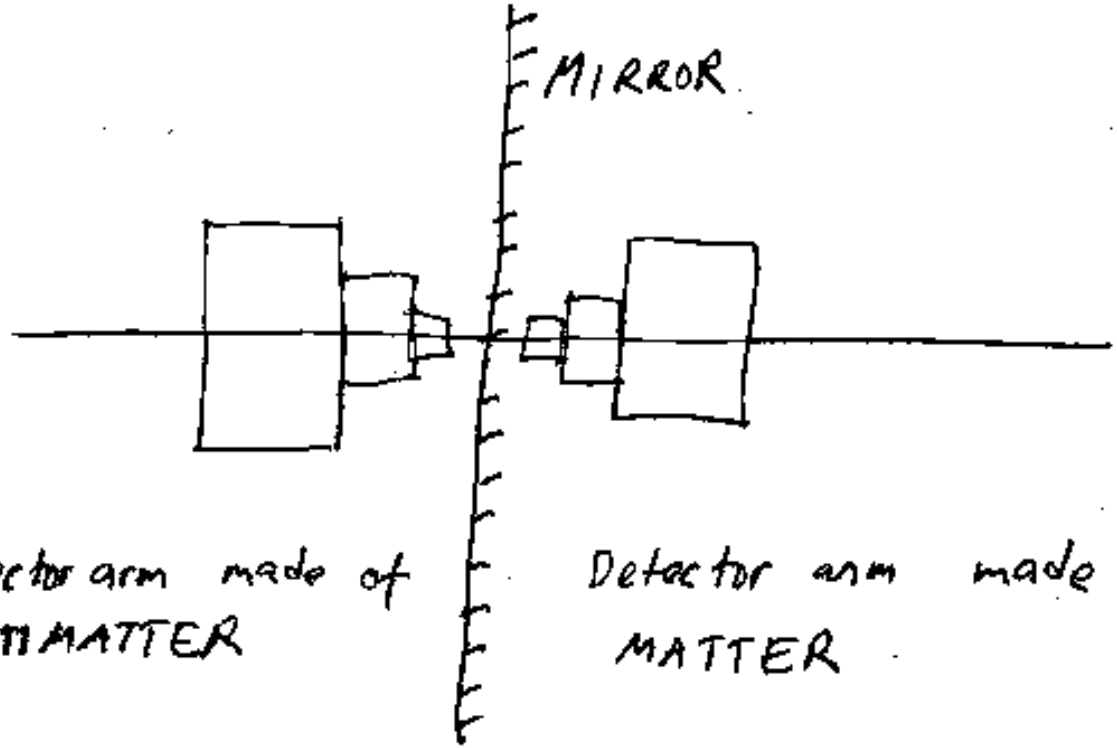


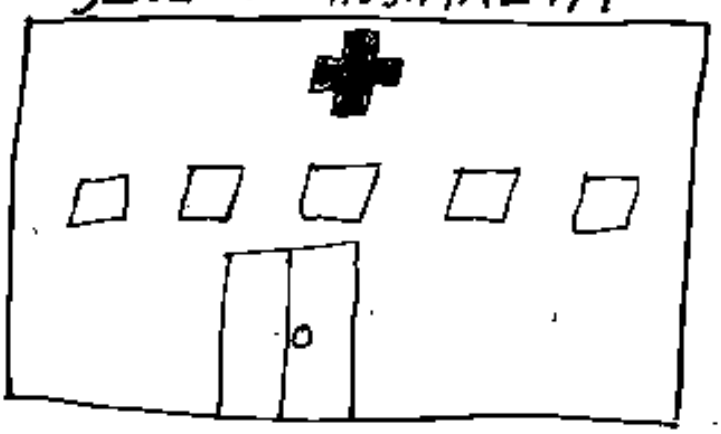
EXERCISES WITH ASYMMETRIES ...

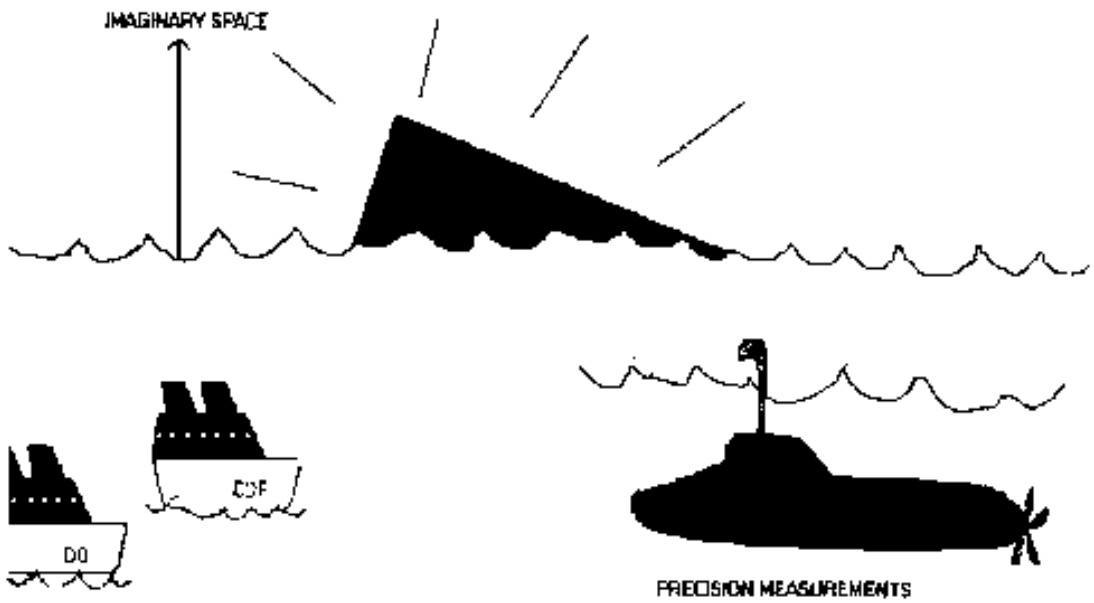
EXERCISES WITH ~~CP~~ ...



BTeV

SLOVENIAN HOSPITALITY




IMAGINARY SPACE
CDF
D0
PRECISION MEASUREMENTS
HERA-B
BABAR
BELLE
ATLAS
CMS
BTeV

Measurements of the CKM matrix parameters are essential in understanding the origin of the CP violation:

- measurements of the phase and 3 angles , equivalently Wolfenstein parameters λ (Cabibbo angle), A, ρ and η
- measurements of the 9 matrix elements

Measurements are performed by:

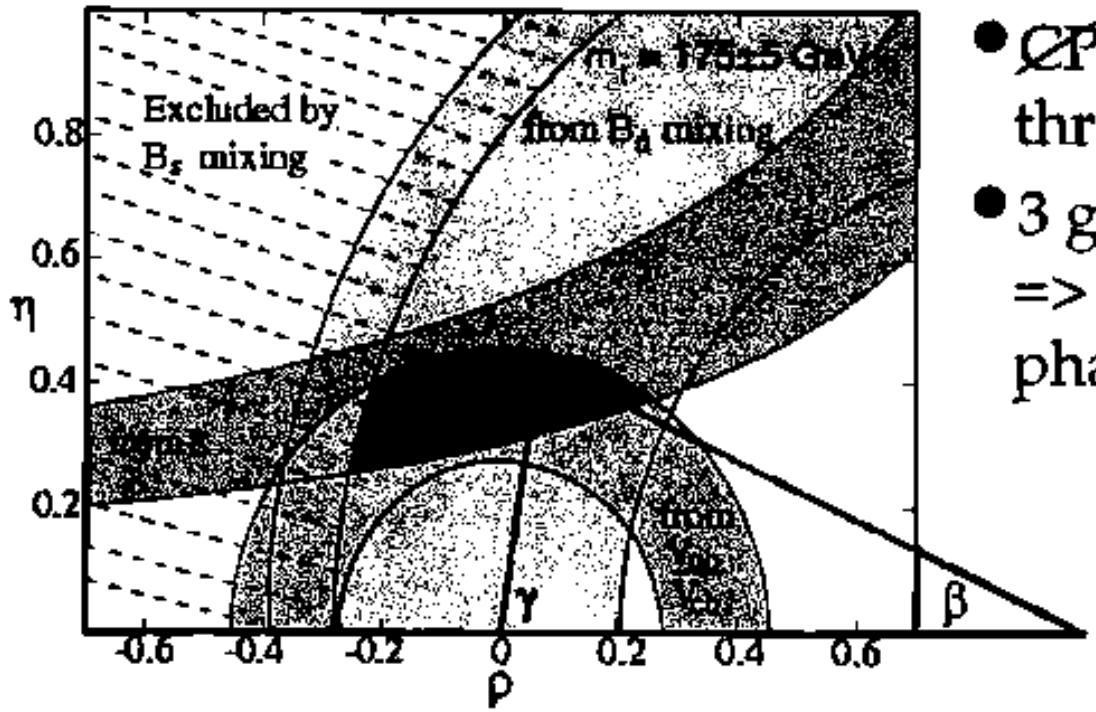
- measuring the angles α, β and γ of the Unitarity Triangle, defined as

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

$$\frac{V^*_{ub}}{\lambda V_{cb}} + \frac{V_{td}}{\lambda V_{cb}} = 1$$

- measuring the sides of the Unitarity Triangle: the base $|V_{cb}|$, $|V_{ub}|/|V_{cb}|$, and $|V_{td}|$ via B_d and B_s mixing. In addition, V_{tq} via loop decays.

CKM Model of CP Violation



- $\mathcal{CP}$ in SM through V_{CKM}
- 3 generations => complex phase $\rho + i\,\eta$

Measurement techniques

In the past few years, much theoretical progress has been made in understanding the interplay between the different sources of CP violation, and analyses methods have been developed accordingly.

Experimentally, analysis methods have improved considerably:

- efficient use of different tagging methods: lepton, kaon, pion, jet-charge
- use of angular analyses
- use of amplitude fits, more sophisticated signal+background fitting methods

Angle β: Rate asymmetry of B^0_d->$J/\psi K^0_S$ measures cleanly sin(2β), since decay is dominated by one weak phase <-> CP violation originates from interference of mixed/non-mixed decays.

$$a_{f_{CP}} = \frac{\Gamma(B^0 \to J/\psi K_S^0) - \Gamma(\bar{B}^0 \to J/\psi K_S^0)}{\Gamma(B^0 \to J/\psi K_S^0) + \Gamma(\bar{B}^0 \to J/\psi K_S^0)}$$

$$= -\sin(2\beta)\sin(\Delta m_d t)$$

Angle α: at tree-level, decay asymmetry of $B^0_d \to \pi^+\pi^-$ is related to $\sin 2(\gamma+\beta) = -\sin(2\alpha)$.
There are, however, penguin contributions with a different weak phase <-> **CP violation has contributions from both interference (tree) and direct CP violation (penguins):**

$$a_{f_{CP}} = a_{dir}\cos(\Delta m_d t) + b_{mix}\sin(\Delta m_d t)$$

$$a_{dir} = 2\frac{A_P}{A_T}\sin\delta\sin\alpha$$

$$b_{mix} = -\sin(2\alpha) - 2\frac{A_P}{A_T}\cos\delta\cos(2\alpha)\sin\alpha$$

There are hopes to obtain a precise theoretical determination of A_P/A_T (penguin-to-tree-amplitude ratio) from measurements of $B^+ \to \pi^+K^0$ and $B^+ \to \pi^+\pi^0$ BR's => get α and δ (strong phase) from a_{dir} and b_{mix}.

Alternatively, one can separate penguin and tree contributions using isospin analysis. Requires measuring rates of

$B^+ \to \pi^+\pi^0$, $B^0 \to \pi^+\pi^-$, $B^0 \to \pi^0\pi^0$ +c.c.

Small BR for **$B^0 \to \pi^0\pi^0$**, EW penguins.

In addition to 2π decays, also 3π and 4π decays can be used for extracting angle α. $B^0 \to \rho\pi$ decays theoretically clean (Snyder-Quinn).

Angle γ: the most problematic one, since decays to CP eigenstates ($B_s \to \rho K^0_S$) difficult theoretically and experimentally.

Other methods:

1. $B_s \to D_s^{+-} K^{-+}$ **+ c.c.,** CP violation due to interference of direct and mixed decays. Measures $\sin(\gamma' +- \delta)$, where $\gamma' = \gamma - 2\delta\gamma$, $\delta\gamma$=phase of V_{ts}, δ=strong phase.

2. $B^0 \to D^0_{CP} K^*$, $B^0 \to \overline{D}^0 K^*$, $B^0 \to D^0 K^*$ **+c.c.** Amplitudes related by two triangles => measurement of γ. Similarly for charged B: $B^+ \to D^0_{CP} K^+$, $B^+ \to \overline{D}^0 K^+$, $B^+ \to D^0 K^+$ **+c.c.**

3. $B^0_d \to D^{(*)+-} \pi^{-+}$

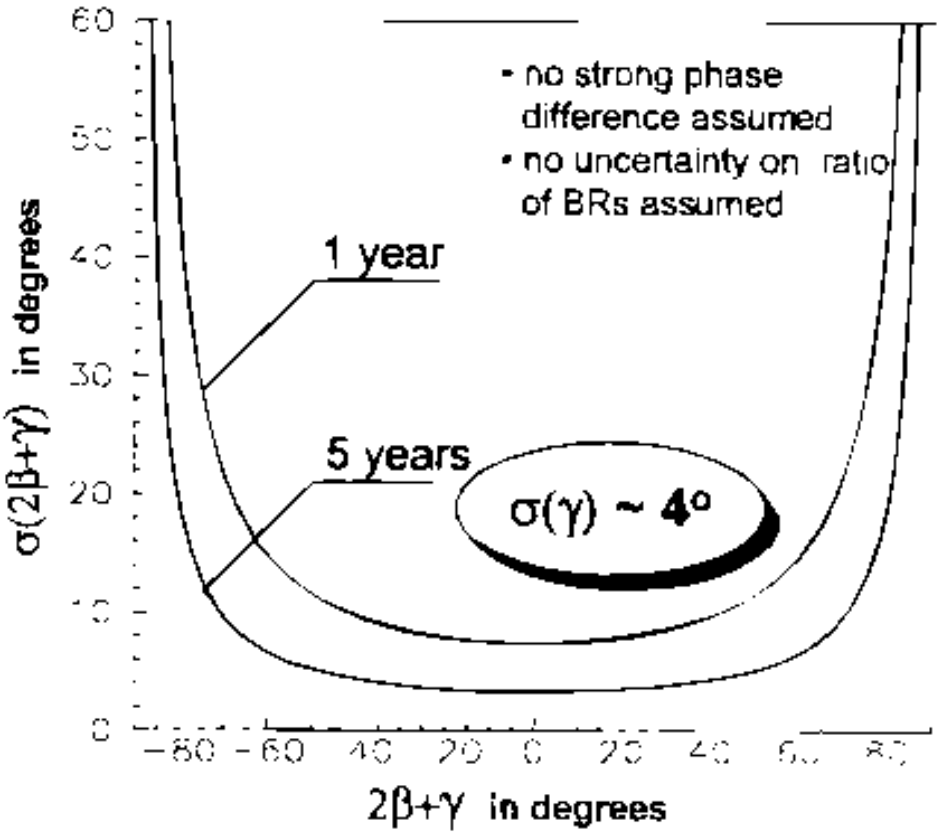
Asymmetry measures $\sin(2\beta+\gamma)$. Studied by (BaBar/Belle) Partial reconstruction.
LHCb / BTeV

$B_d \to \overline{D}^{*-}\pi^+,\ D^{*+}\pi^-$

Extraction of $2\beta+\gamma$ from 4 time-dependent decay rates, use β from $J/\psi K_S$ to get γ

- need large stat. (CP asymmetry very small)
- efficient hadron trigger essential

– reconstruct D* inclusively (using slow pion)
~ 270 k events / year with S/B ~ 7
– add D^*a_1 channels
~ 320 k events / year



4. Extraction of γ using B->Kπ, B->$\pi\pi$, B->KK. Under intensive theoretical development.

(A) Fleisher-Mannel

$$R = \frac{\tau(B^+)}{\tau(B^0)} \cdot \frac{BR(B^0 \to \pi^- K^+) + BR(\overline{B}^0 \to \pi^+ K^-)}{BR(B^+ \to \pi^- K^0) + BR(B^- \to \pi^- \overline{K}^0)} \geq (\sin\gamma)^2$$

(B) Neubert-Rosner, Gronau-Rosner

$$R_* = \frac{BR(B^+ \to \pi^+ K^0) + BR(B^- \to \pi^- \overline{K}^0)}{2(BR(B^+ \to \pi^0 K^+) + BR(B^- \to \pi^0 K^-))} \propto \cos\gamma^2$$

(C) Fleisher

Measure a_{dir} and b_{mix} for $B_d^0 \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$ => when sin2β measured, get γ.

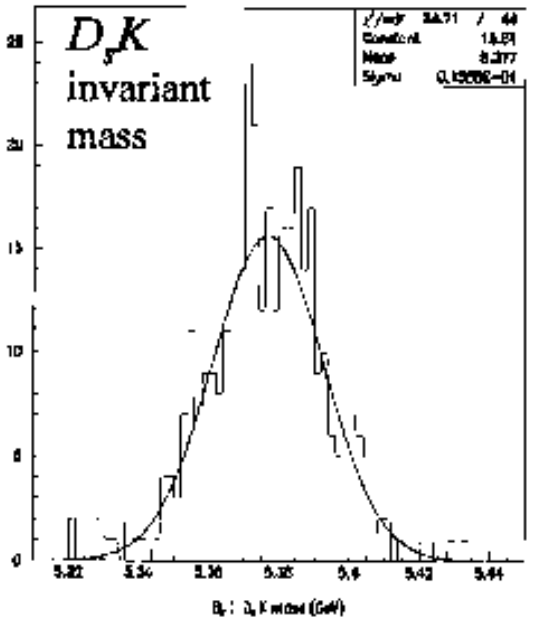
Measurements of the CKM angle γ

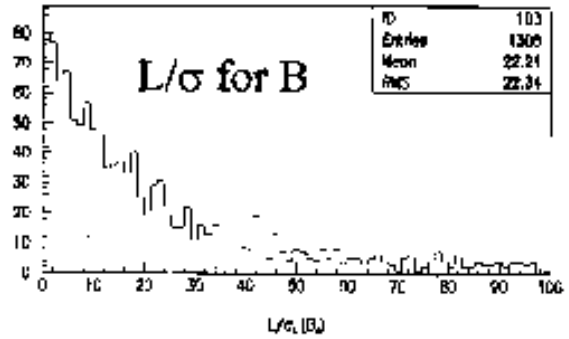
BTEV CD

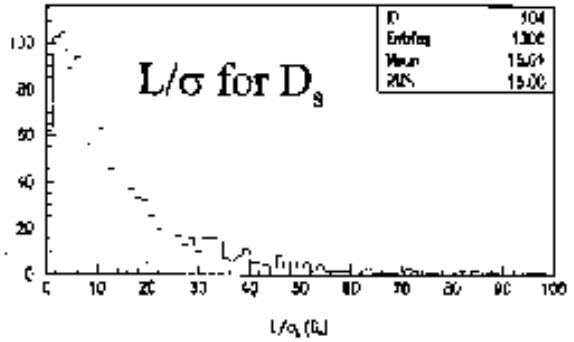
- All methods are challenging either experimentally, theoretically, or both.

- Consider three final states:

FinalState	N	$\sigma(\gamma)$
$B_s \to D_s K$	2.7k	11°
$B^- \to K^- D^0$	2k	13°
$B^- \to K\pi$	11k	<5°







Measurements of B_s-mesons

Measurement of B_s mixing parameter Δm_s <->
use amplitude methods with $B_s \to D_s\pi$, $D_s a_1$

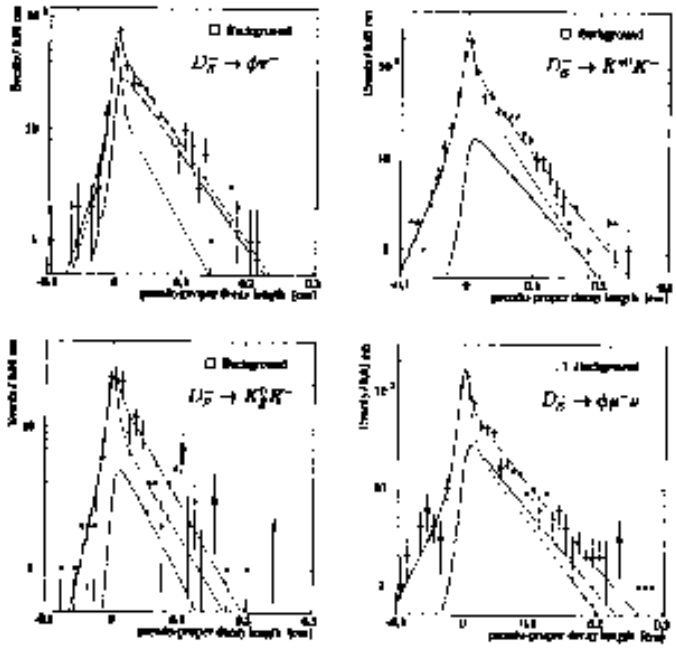
Angular analysis of $B_s \to J/\psi\phi$ gives
$\Delta\Gamma_s = \Gamma_H - \Gamma_L$, Γ_s, CP amplitudes $A_{\parallel}$ and $A_{\perp}$.
weak phase $\delta\gamma$.

Limit on $\Delta\Gamma_s/\Gamma_s$ in $B_s \to \ell D_s$

- two mass eigenstates of B_S^0: B_S^H and B_S^L
- $\Delta m_s = m_H - m_L$, $\quad \Delta\Gamma_s = \Gamma_L - \Gamma_H$
  $\Gamma_s = (\Gamma_H + \Gamma_L)/2$
- two-component lifetime fit in $B_s \to \ell D_s X$ to $e^{-\Gamma_H t} + e^{-\Gamma_L t}$ measures $\Delta\Gamma_s$

- $B_s \to \ell D_s X$
  ≈ 600 events
- $\frac{\Delta\Gamma_s}{\Gamma_s} = 0.34^{+0.31}_{-0.34}$

  $\frac{\Delta\Gamma_s}{\Gamma_s} < 0.83$
  at 95% C.L.

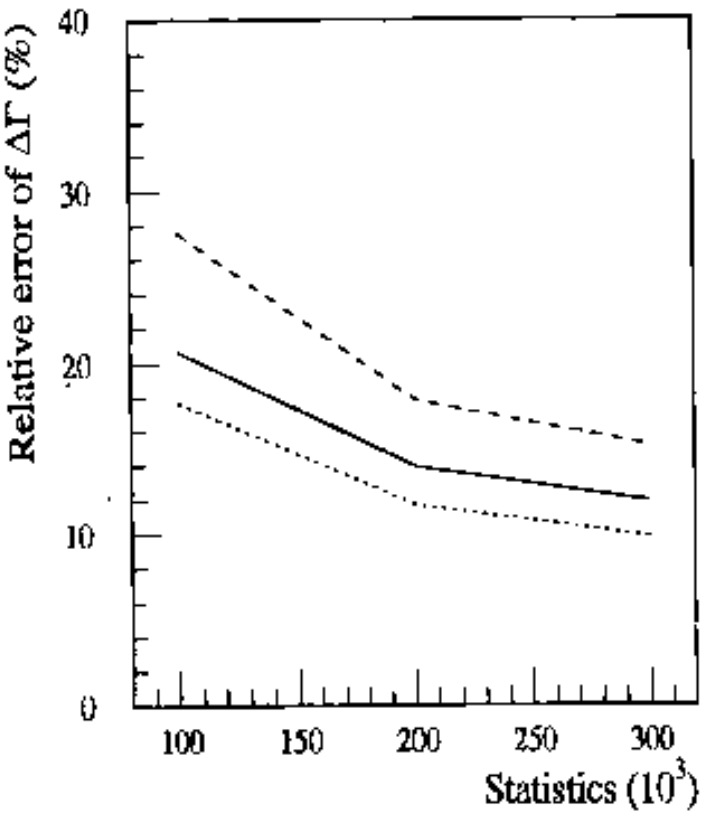


- In Std. Model, $\Delta\Gamma_s$ related to Δm_s by a scale factor *independent* of CKM:

$$\frac{\Delta\Gamma_s}{\Delta m_s} = -\frac{3\pi}{2}\frac{m_b^2}{m_t^2}\frac{\eta_{QCD}^{\Delta\Gamma_s}}{\eta_{QCD}^{\Delta m_s}} \Rightarrow \Delta m_s < 96\ \mathrm{ps}^{-1} \text{ at 95\% C.L.}$$

Bottom Line: In Run II, either measure Δm_s directly, or $\Delta\Gamma_s$!

LHC



The relative error of $\Delta\Gamma_s$ as a function of signal $B_s^0 \to J/\psi\phi$ statistics for three levels of background: 15% full line, 30% dashed line and no background dotted line. Other parameters of the fit were $\Gamma, |A_{\parallel}(t=0)|, |A_{\perp}(t=0)|, \xi$.

Present results

CDF Run I (110 pb^{-1}): $\sin(2\beta)=0.79^{+0.41}_{-0.44}$

(+exploratory measurement from OPAL)

Precision data fits using $|V_{cb}|$, $|V_{ub}|/|V_{cb}|$, Δm_d, Δm_s **limit,** ε_K**, masses, and hadronic factors (lattice estimates):**

$\sin(2\beta) = 0.725^{+0.050}_{-0.060}$.

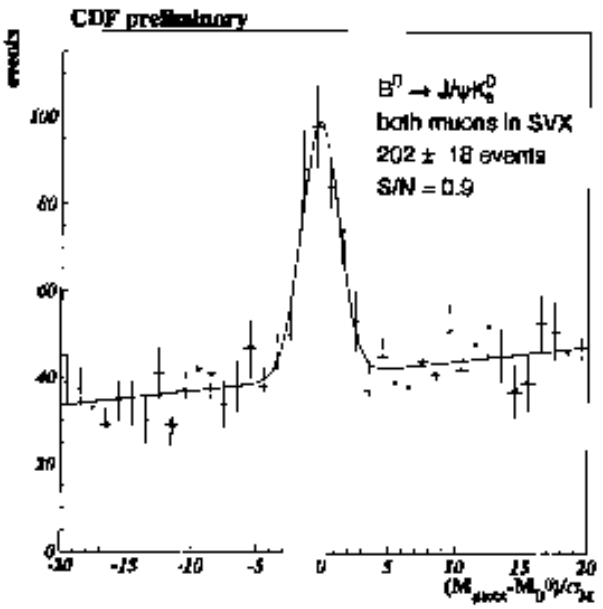
$\sin(2\alpha) = -0.26^{+0.29}_{-0.28}$

$\gamma = (59.5^{+8.5}_{-7.5})^{\circ}$

$\sin 2\beta$: $B^0 \to J/\psi K^0_S$ sample

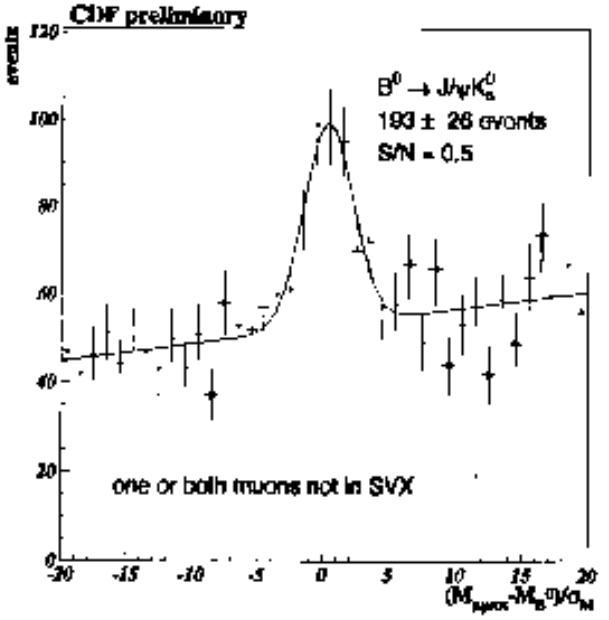
Both muons in the SVX

about 200 events have precise lifetime information $\Rightarrow$ time-dependent analysis



One or no muons in the SVX

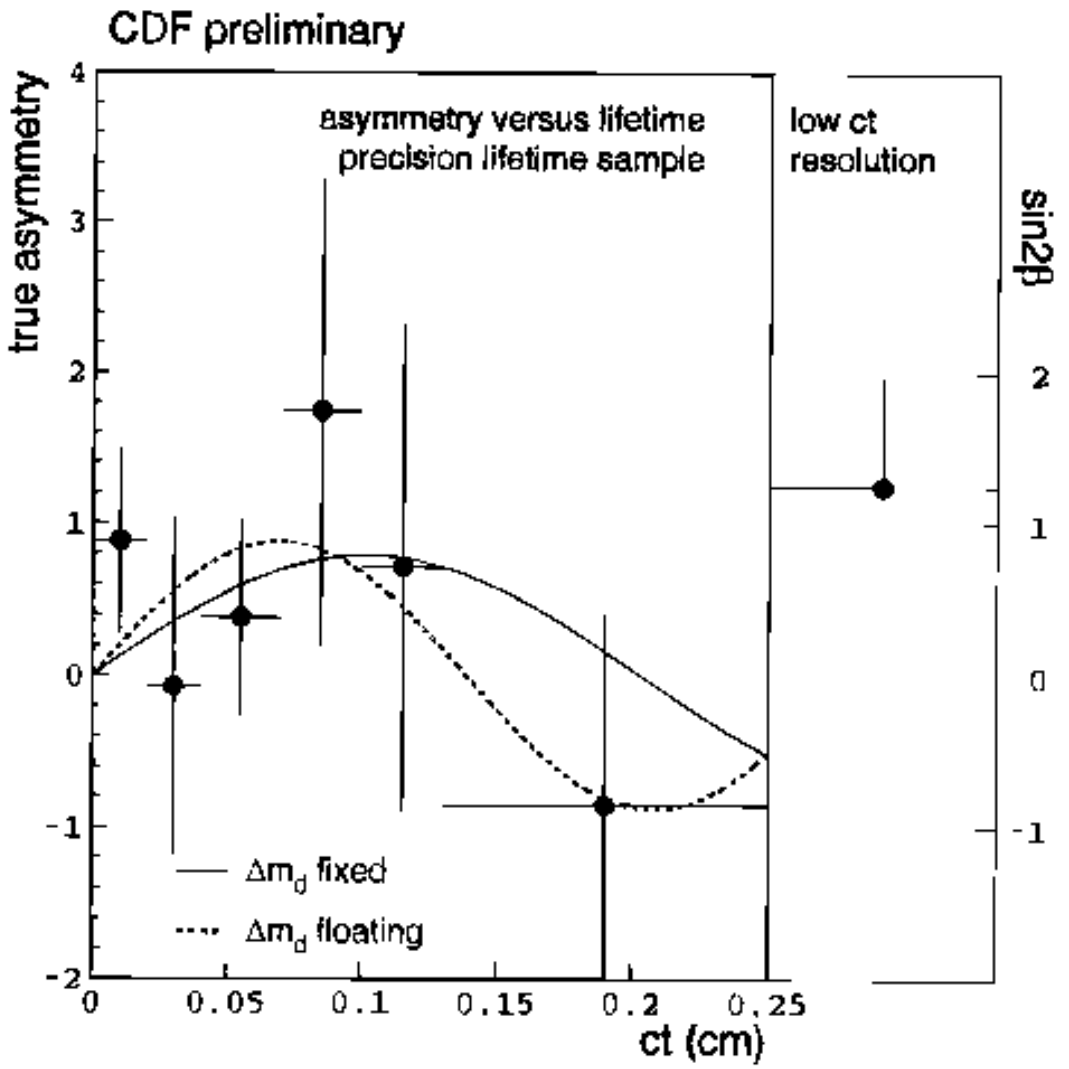
about 200 events have *imprecise* lifetime information $\Rightarrow$ time-averaged analysis



$\sin 2\beta$: Results – asymmetry

Measure CP asymmetry vs proper time:

$$\mathcal{A}_{CP}(t) = \frac{N_{\bar{B}^0} - N_B}{N_{\bar{B}^0} + N_B} = \mathcal{D} \sin 2\beta \sin \Delta m_d t$$



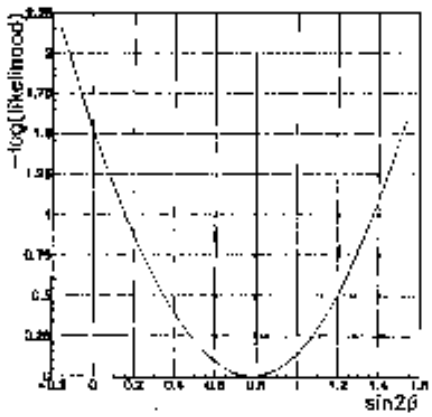
Result of the full unbinned likelihood fit

$$\sin 2\beta = 0.79 \, ^{+0.41}_{-0.44} \, (\text{stat.} + \text{syst.})$$

$\sin 2\beta$: Limits

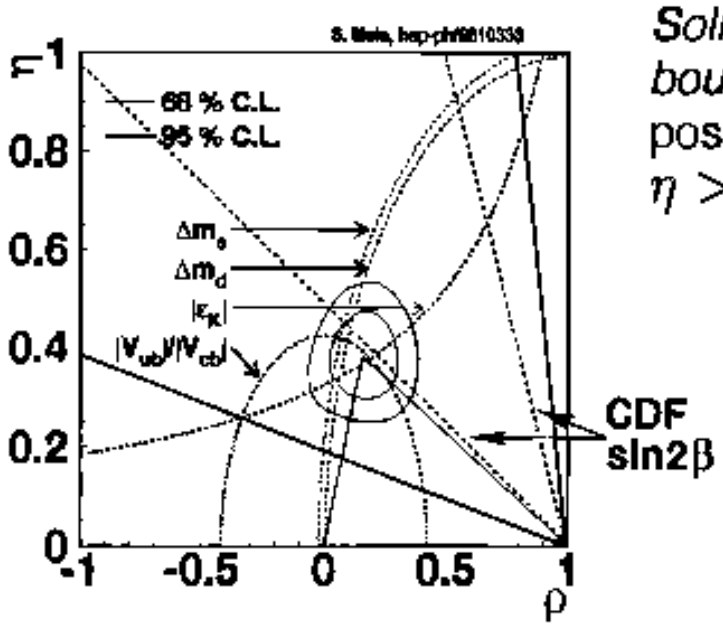
Feldman-Cousins frequentist:
$0 < \sin 2\beta < 1$ **at** 93% CL

Bayesian
(assuming flat prior in $\sin 2\beta$**)**
$0 < \sin 2\beta < 1$
at 95% CL



A scan of the likelihood function:

$\sin 2\beta$: Impact on ρ-η plane



Solid red lines are 1σ *bounds: account for* two possible values *for* β *in* $\eta > 0$.

CLEO II

CONCLUSIONS

1. **The Standard Model is still OK.**

   - FCNC – penguin consistency
     $b \to s\gamma$ and $b \to s$ *gluon*
     stringent constraints on new physics
   - Negative searches ($< 10^{-5}$)
     $B \to \ell^+\ell^-$, $B \to \gamma\gamma$, ...
   - Unitarity triangle consistency
     $b \to c\ell\nu$, $b \to u\ell\nu$, $B^0 \leftrightarrow \bar{B}^0$,
     $B_s^0 \leftrightarrow \bar{B}_s^0$, ϵ_K,
     bounds on γ from $B \to K\pi$

2. **CKM accuracy is improving.**

$|V_{cb}| = 0.0385 \pm 0.0021 \pm 0.0022 \pm 0.0012$ $\quad A = 0.79 \pm 0.06$

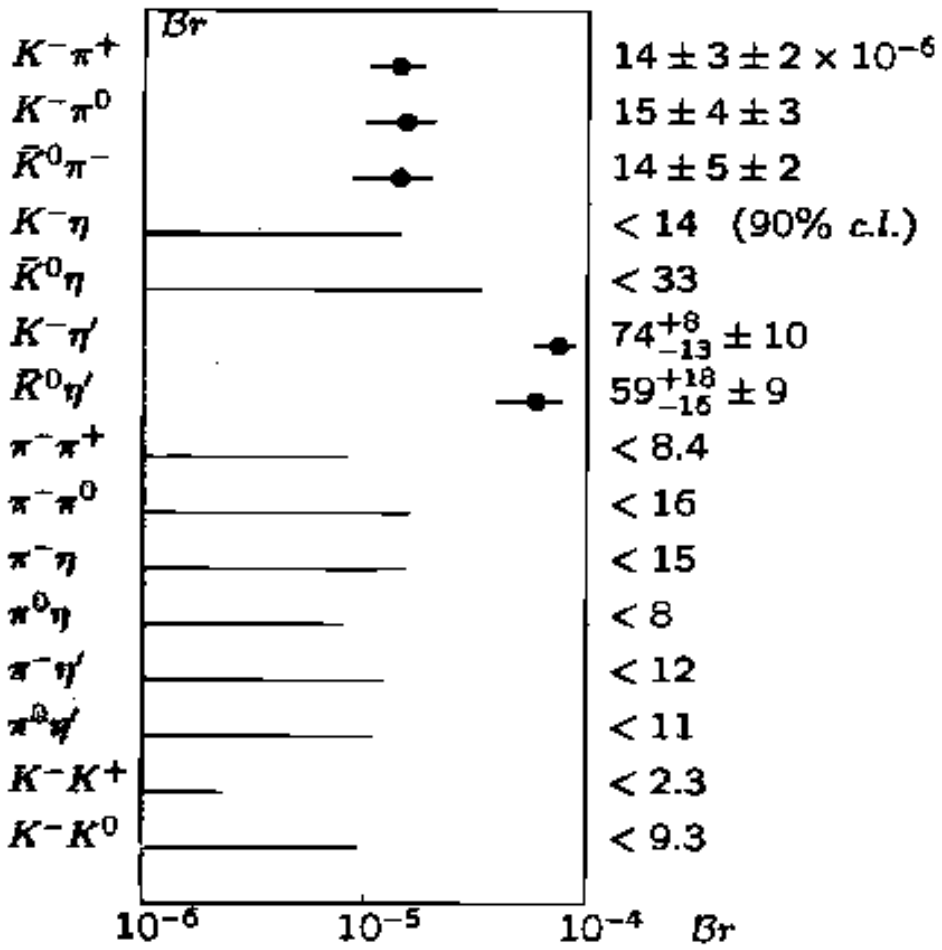
$|V_{ub}| = (3.25 \pm 0.14^{+0.21}_{-0.29} \pm 0.55) \times 10^{-3}$ $\quad \sqrt{\rho^2+\eta^2} = 0.43 \pm 0.08$

$|V_{td}| = (9.0 \pm 0.5 \pm 0.17) \times 10^{-3}$

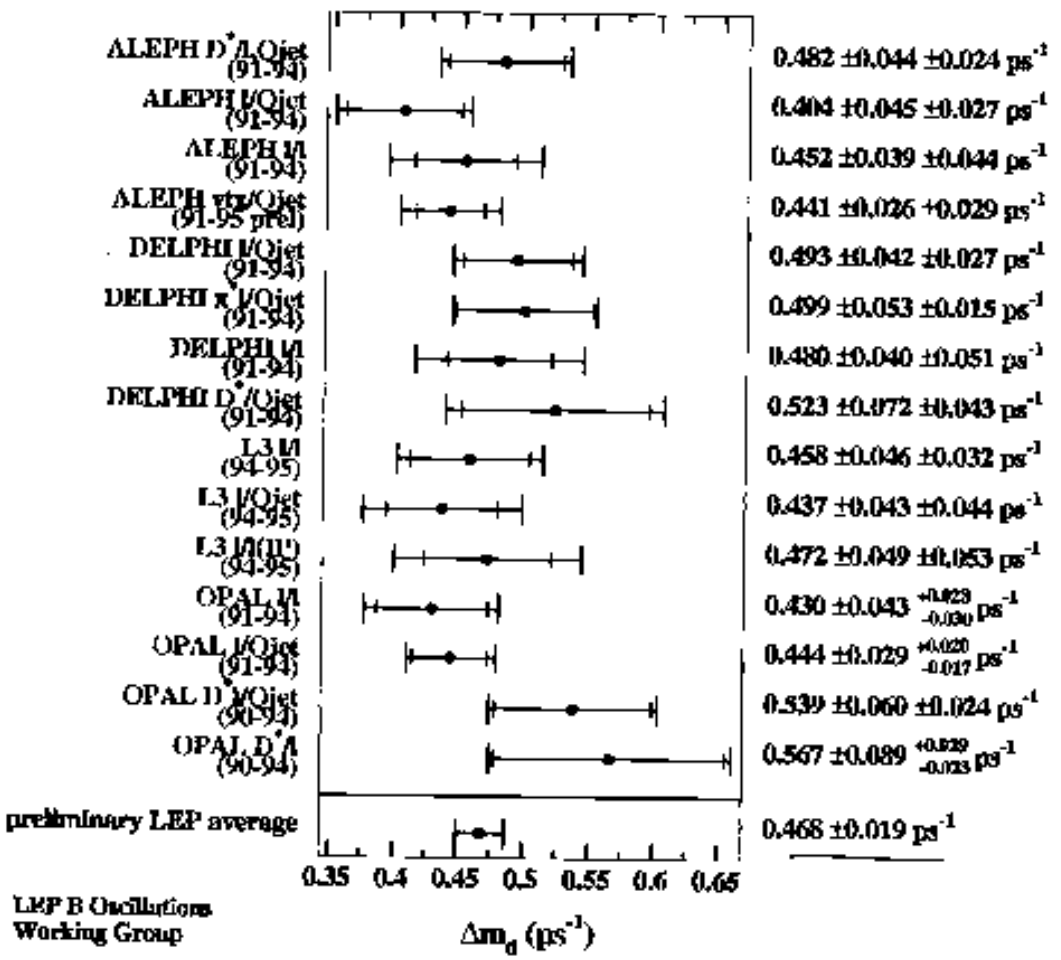
$(8.6 \pm 0.3 \pm 0.17) \times 10^{-3}$ $\quad \sqrt{(1-\rho)^2+\eta^2} = 1.04 \pm 0.1$

Uncertainties are mainly theoretical:
$f_B\sqrt{B_B}$, $b \to \rho\ell\nu$ models

Results: $B \to$ **2 Pseudoscalars**

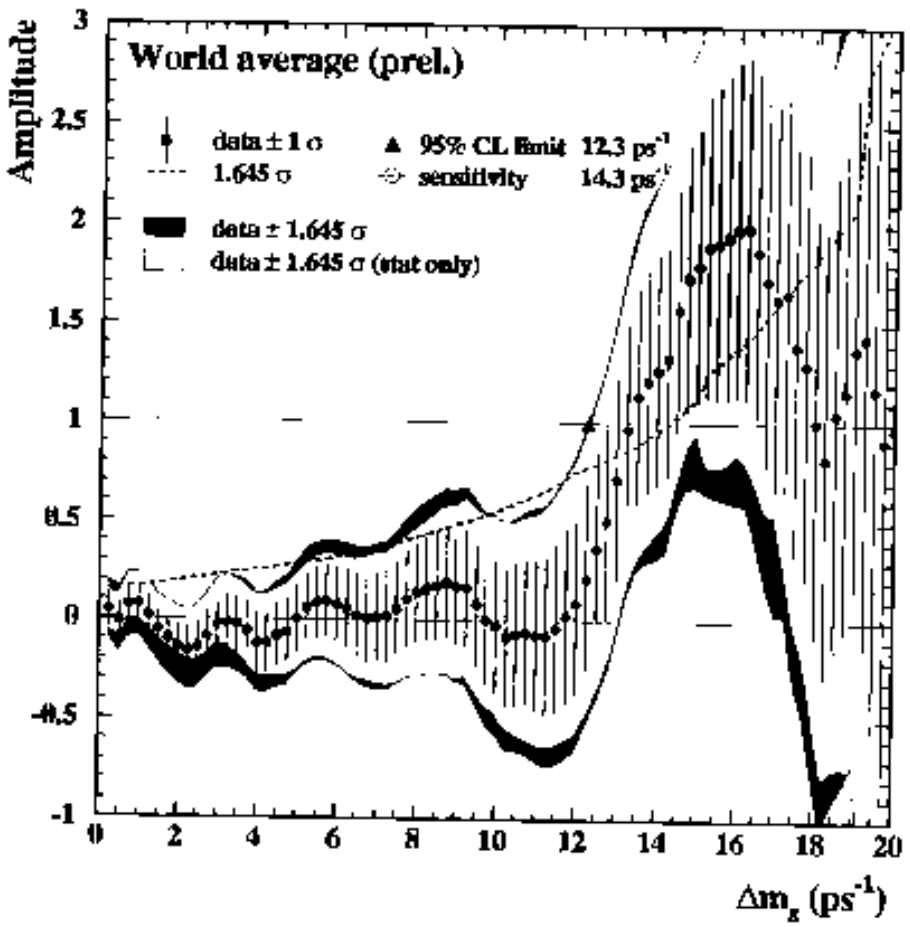


Δm_d measurements



LEP + SLD + COF + $\Upsilon(4S)$ $\Delta m_d = (0.471 \pm 0.016)\,ps^{-1}$

LEP + SLD + CDF combined Δm_s limit



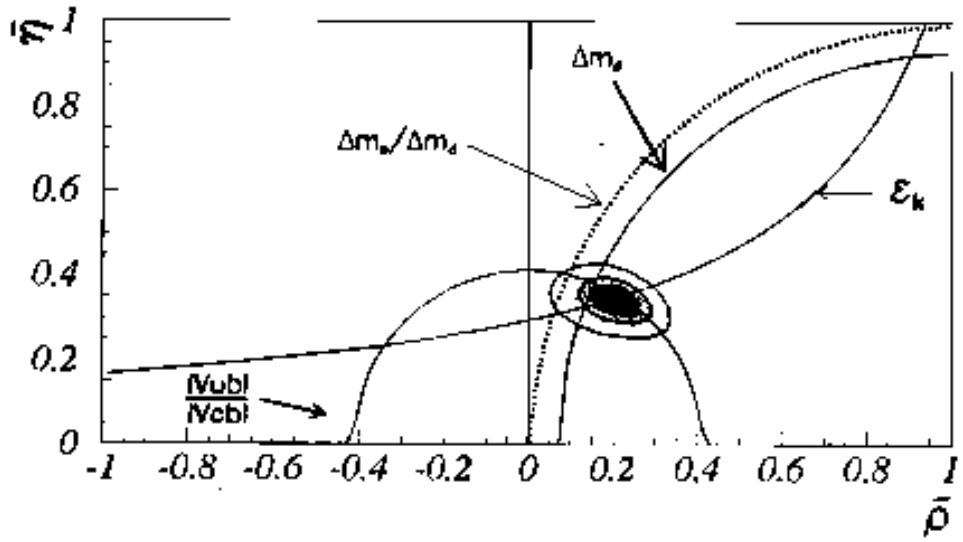


Figure 2: *The allowed region for $\bar{\rho}$ and $\bar{\eta}$ using the parameters listed in Table 6. The contours at 68 % and 95 % are shown. The full lines correspond to the central values of the constraints given by the measurements of $\frac{|V_{ub}|}{|V_{cb}|}$, $|\epsilon_K|$ and Δm_d. The dotted curve corresponds to the 95 % C.L. upper limit obtained from the experimental limit on Δm_s.*

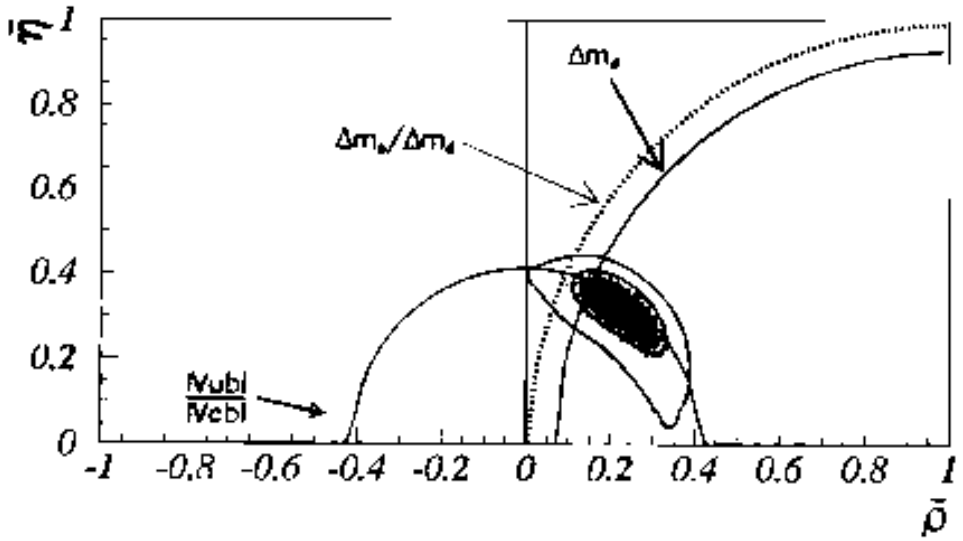
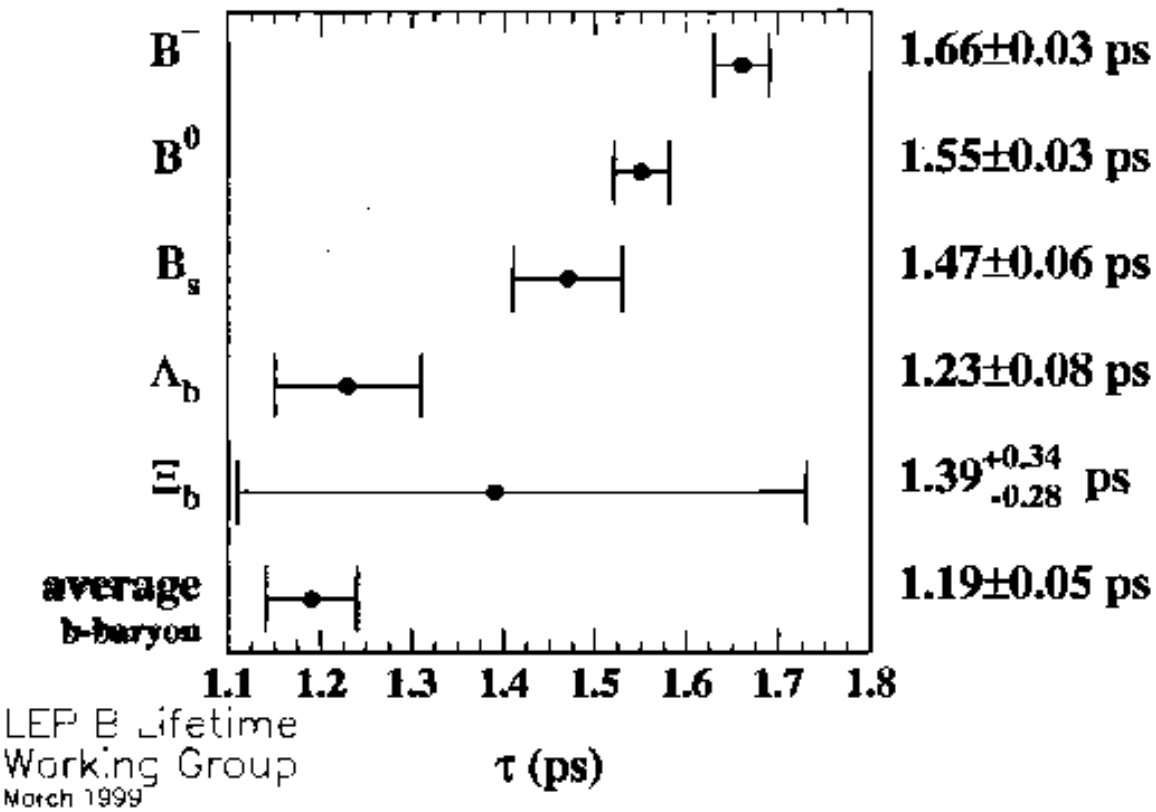
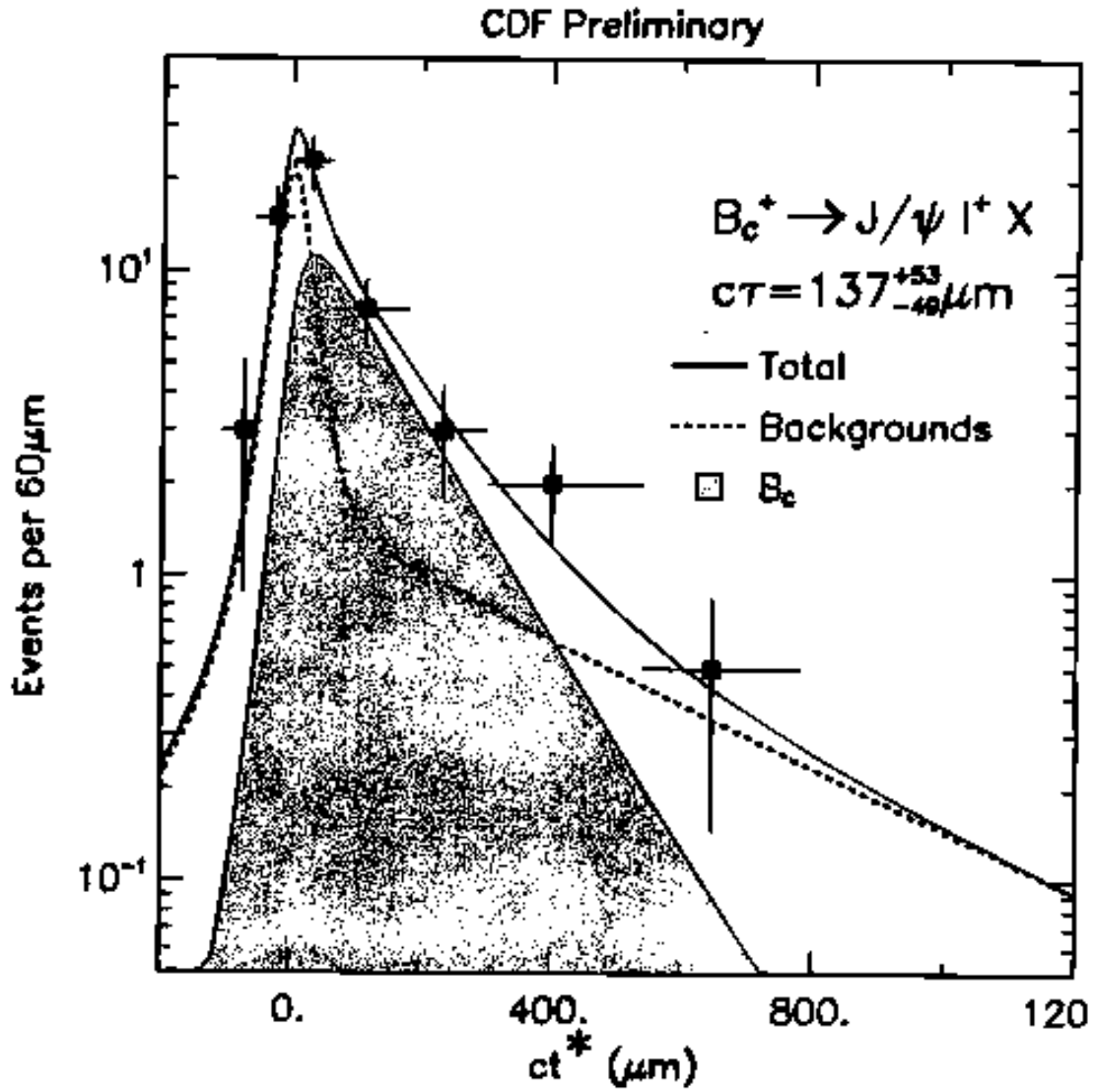


Figure 3: *The allowed region for $\bar{\rho}$ and $\bar{\eta}$ using the parameters listed in Table 6 without using the $|\epsilon_K|$ constraint. The contours at 68 % and 95 % are shown. The dotted curve corresponds to the 95 % C.L. upper limit obtained from the experimental limit on Δm_s.*


B^-
B^0
B_s
Λ_b
Ξ_b
average
b-baryon
1.66±0.03 ps
1.55±0.03 ps
1.47±0.06 ps
1.23±0.08 ps
$1.39^{+0.34}_{-0.28}$ ps
1.19±0.05 ps
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
LEP B Lifetime
Working Group
March 1999
τ (ps)



$\tau_{B_c} = 0.46 \pm 0.18 \pm 0.05$ ps

$M_{B_c} = 6.40 \pm 0.39 \pm 0.13$ GeV

$N_{ev.} = 20.4 \pm 6.2 \pm 3.5$

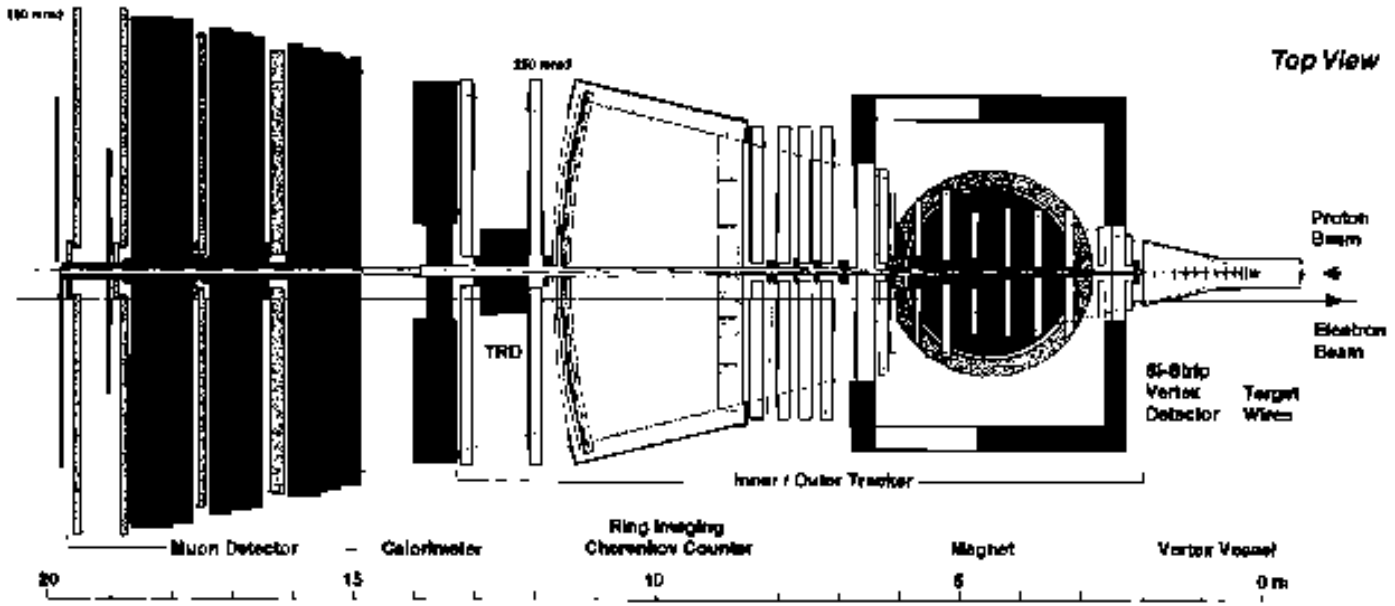
Experiments embarking on data taking

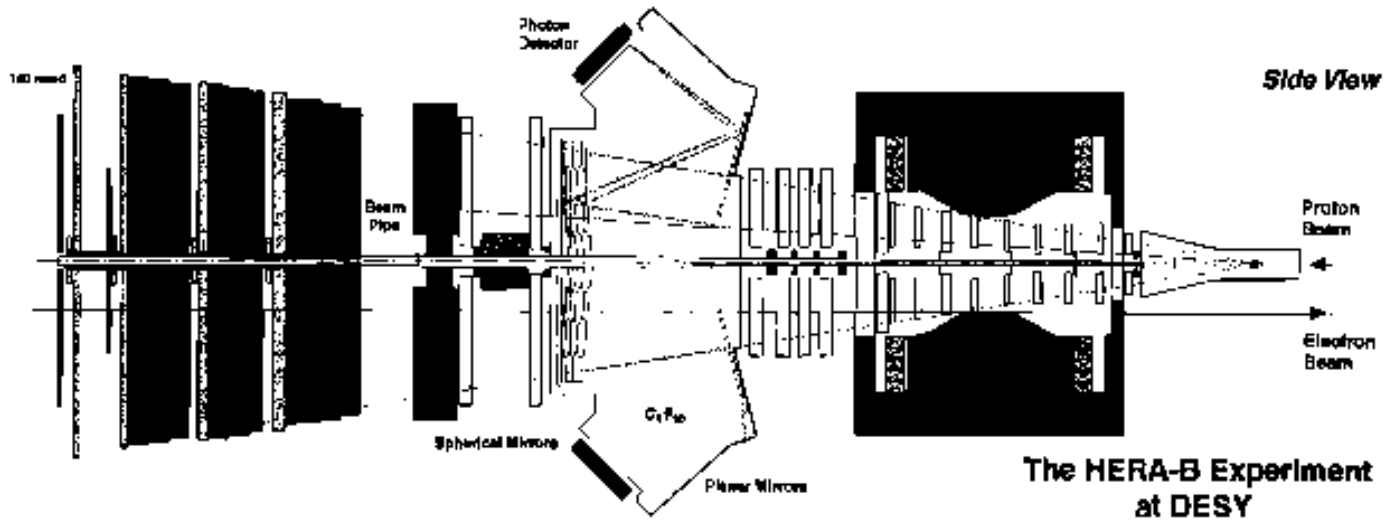
HERA-B at DESY (1999->): Fixed-target B-experiment, challenging due to the small ratio of b-to-total cross-section => difficult trigger conditions. Cross-section 12 nb, nominal one year data 30 fb-1.

BaBar (SLAC), Belle (KEK) (1999->): Asymmetric e^+e^- factory experiments, $B\overline{B}$ from Y(4S). Cross-section 1 nb, nominal one year data 30 fb-1. Possibility of using isospin analysis for $B^0_d \to \pi^+\pi^-$, $B^0_d \to \pi^0\pi^0$, $B^+ \to \pi^+\pi^0$.

CLEOIII, upgrade at CESR, symmetric e^+e^-.

CDF and D0 at Tevatron Run II (2000->): Upgraded general-purpose experiments. Expect total 2 fb^{-1}, $\sigma(b\bar{b})$=100 μb.





The HERA-B Experiment at DESY

Actual status

VDS: Completed.

RICH: Completed.

ECAL: Completed.

MUON: Almost completed.

OTR: Half trigger chambers installed.

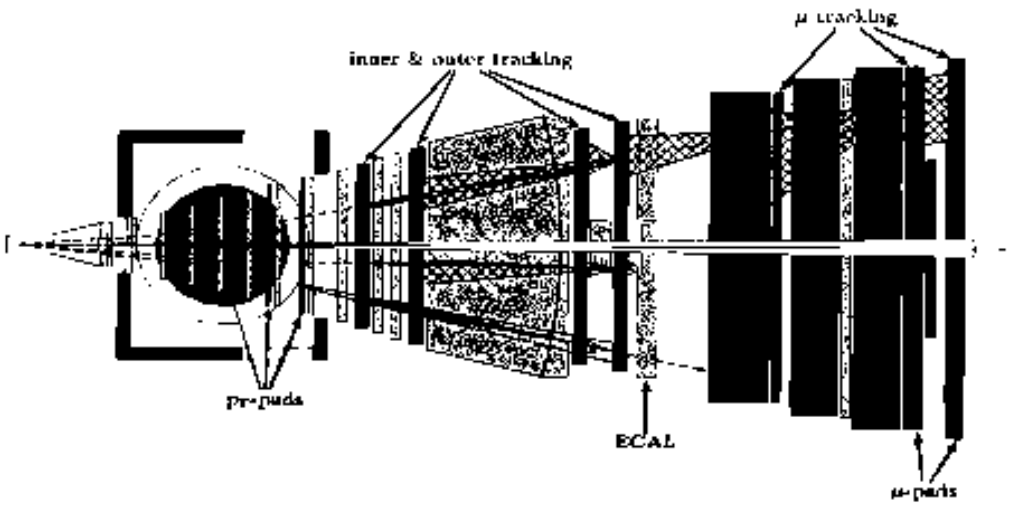
ITR: One station installed.

DAQ: Routinely running.

Triggers: Commission starting

Detector will be completed during 1999

Pretrigger & First Level Trigger



Pretrigger: Initiate track search with defined particle ID: electrons, muons (and particles with high p_T).

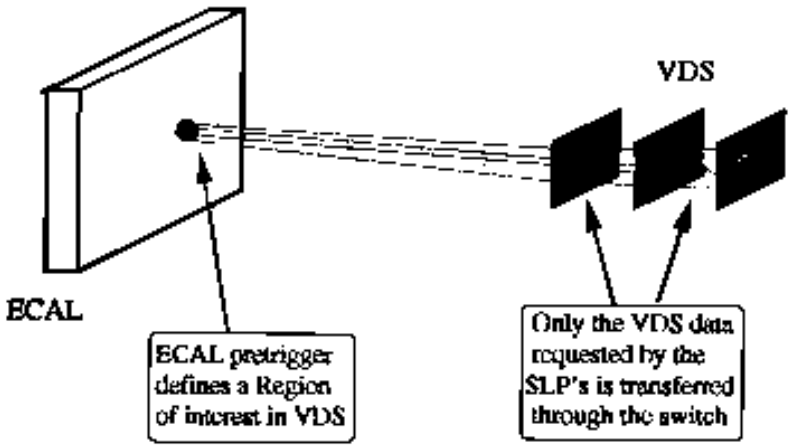
<trigger seeds> ~ 10/BX

FLT: Reconstruct tracks opposite to beam direction in field free region.
→ Apply two particle mass cut
→ Initiate Trigger

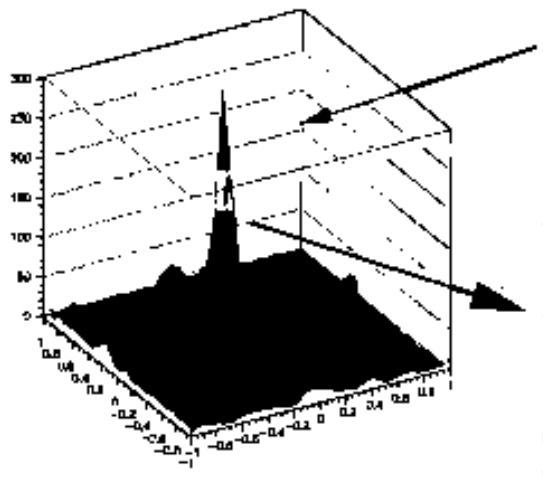
Input rate = 10 MHz
Output rate = 50 kHz
} **suppression = 200**

Latency (Pretrigger + FLT) = **10 μs**

SLT: data path



→ First test of the SLT system in a dialog mode. (transaction rate limit to be tested)



Extrapolate track candidates to the target z-position

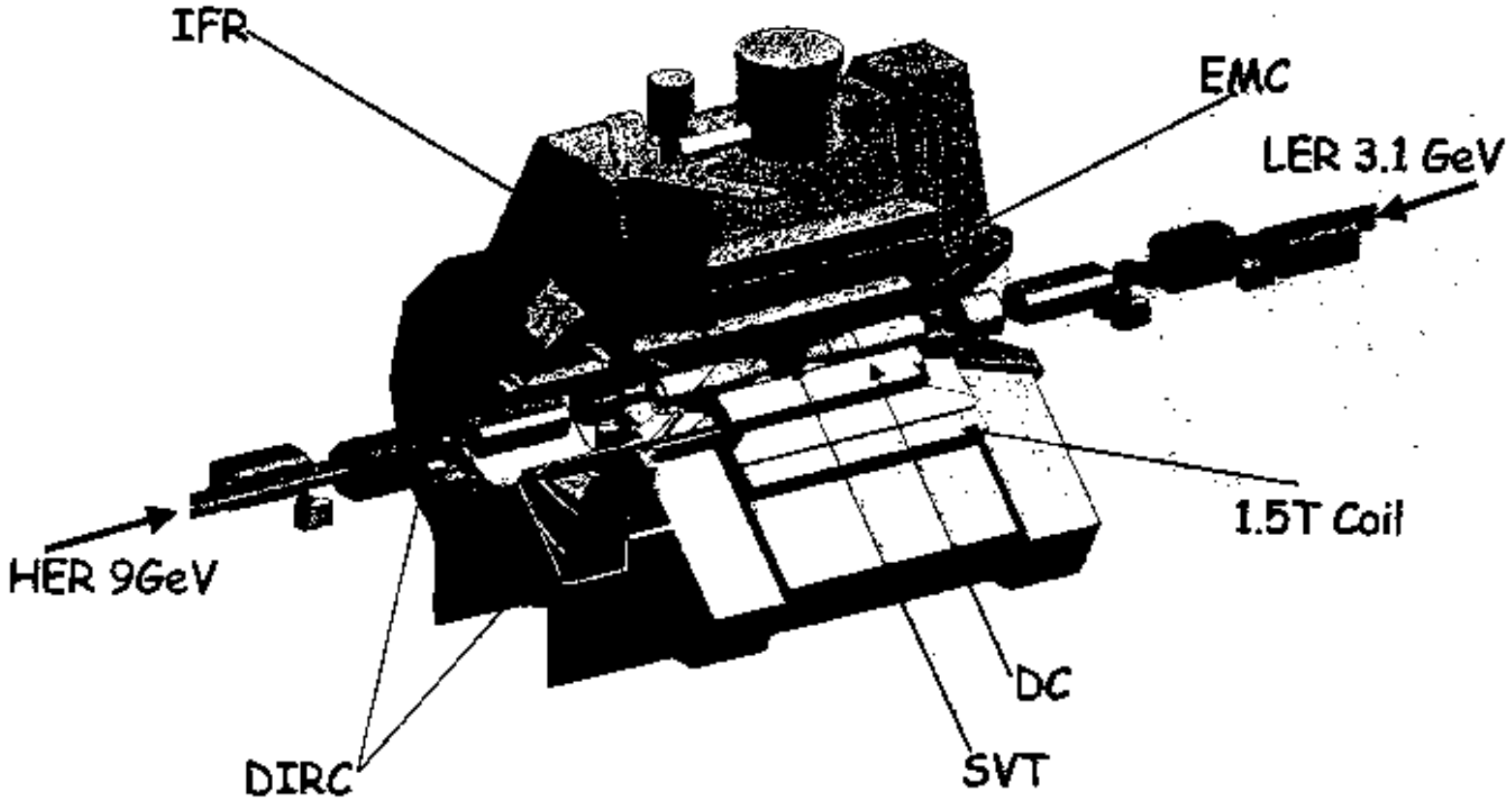
TARGET spot reproduced online

Data path and SLT code are working properly

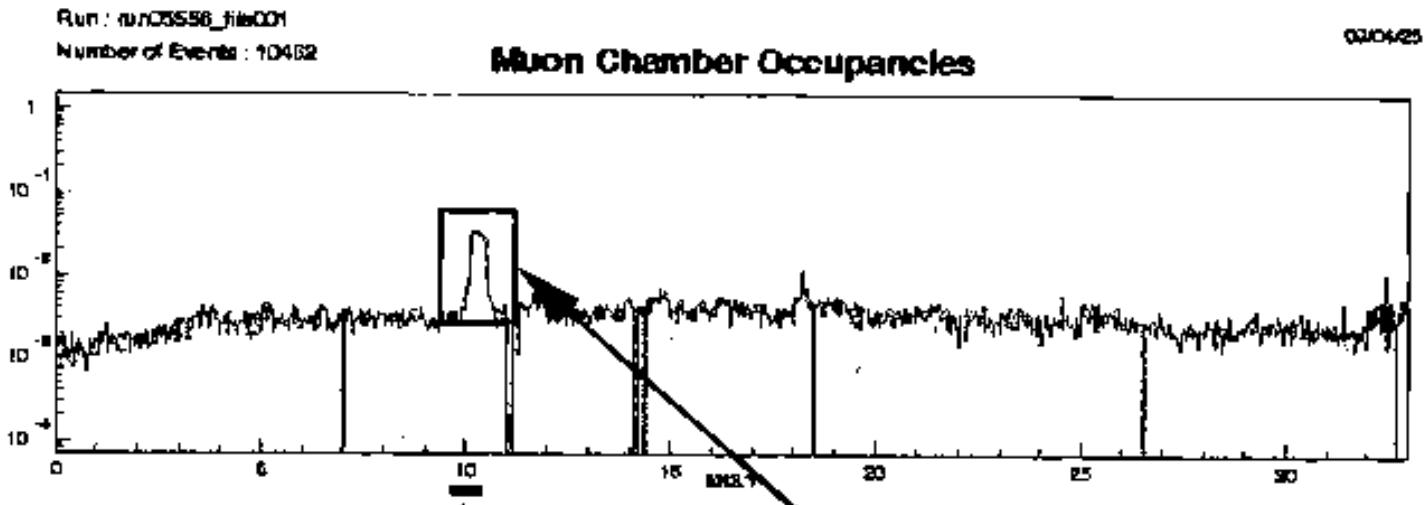
Vertex was also reconstructed online at the third level trigger Farm

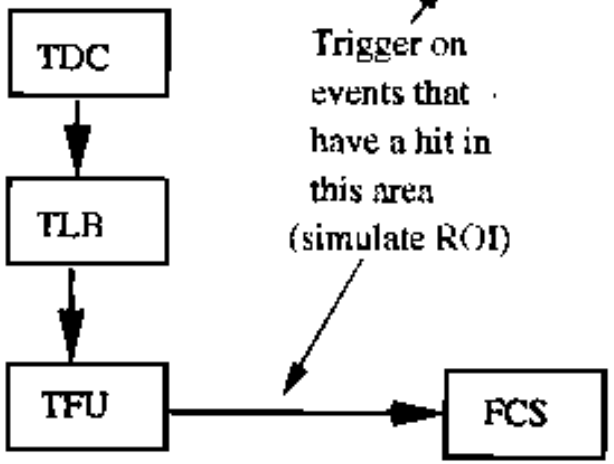
↳ Important to select physics that are not triggered at lower levels (combine leptons and pions from B's)

BaBar Detector



FLT: Working chain....





Trigger on events that have a hit in this area (simulate ROI)

Occupancy plot shows the enhancement in the right area

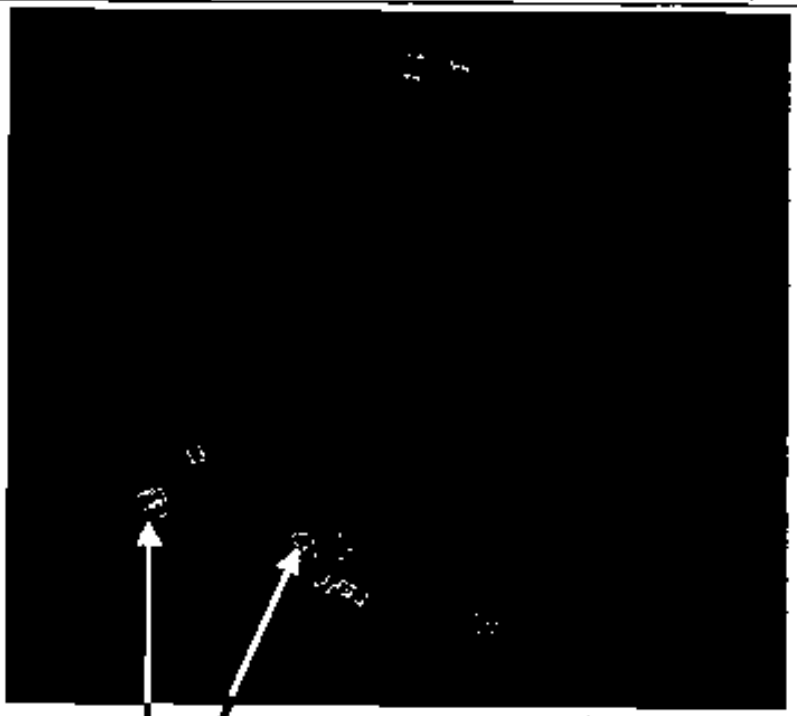
→ Hardware works

Also done with the OTR, looking at coincidences in 3 stereo-angles

Conclusions : 17th June

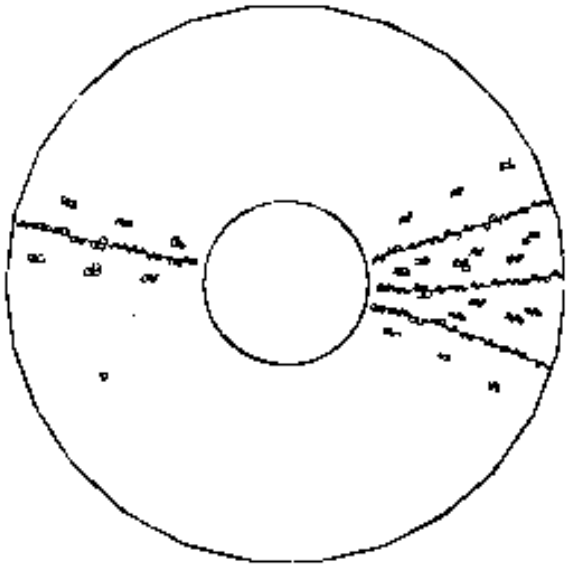
- Babar started taking colliding beam data on May 26th 1999.
  - Prior to that we have collected 60×10^6 cosmic rays
  - We have approximately [illegible] on Tape.
- All subsystems are operational and are performing well and some are at or close to design specifications.
- Expect 60% of design luminosity by the end of the summer.
- We are looking forward to 10 years of B physics with first results on CP violation soon.

Event Gallery : First data run 5354



combined mass 0.138 GeV

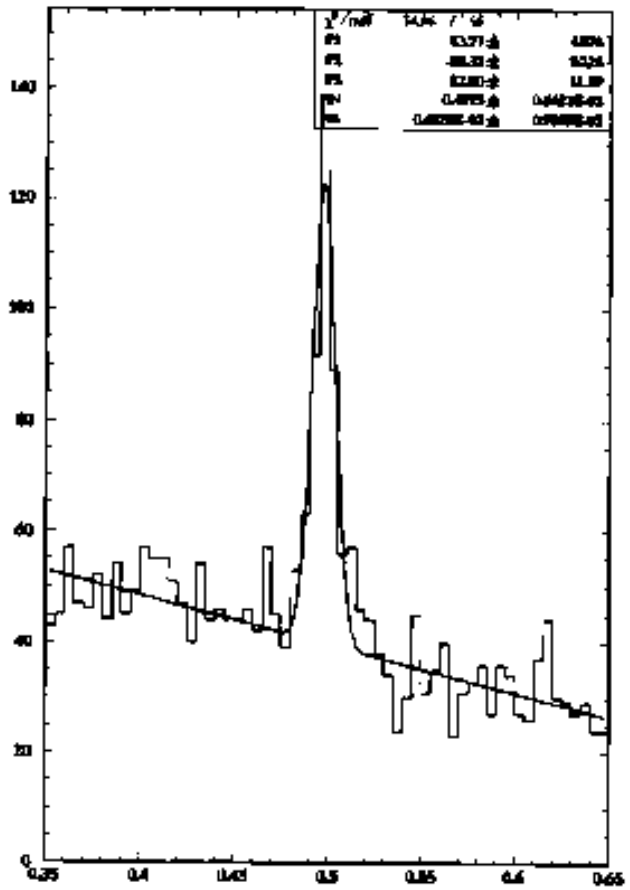
3+1 tau candidate

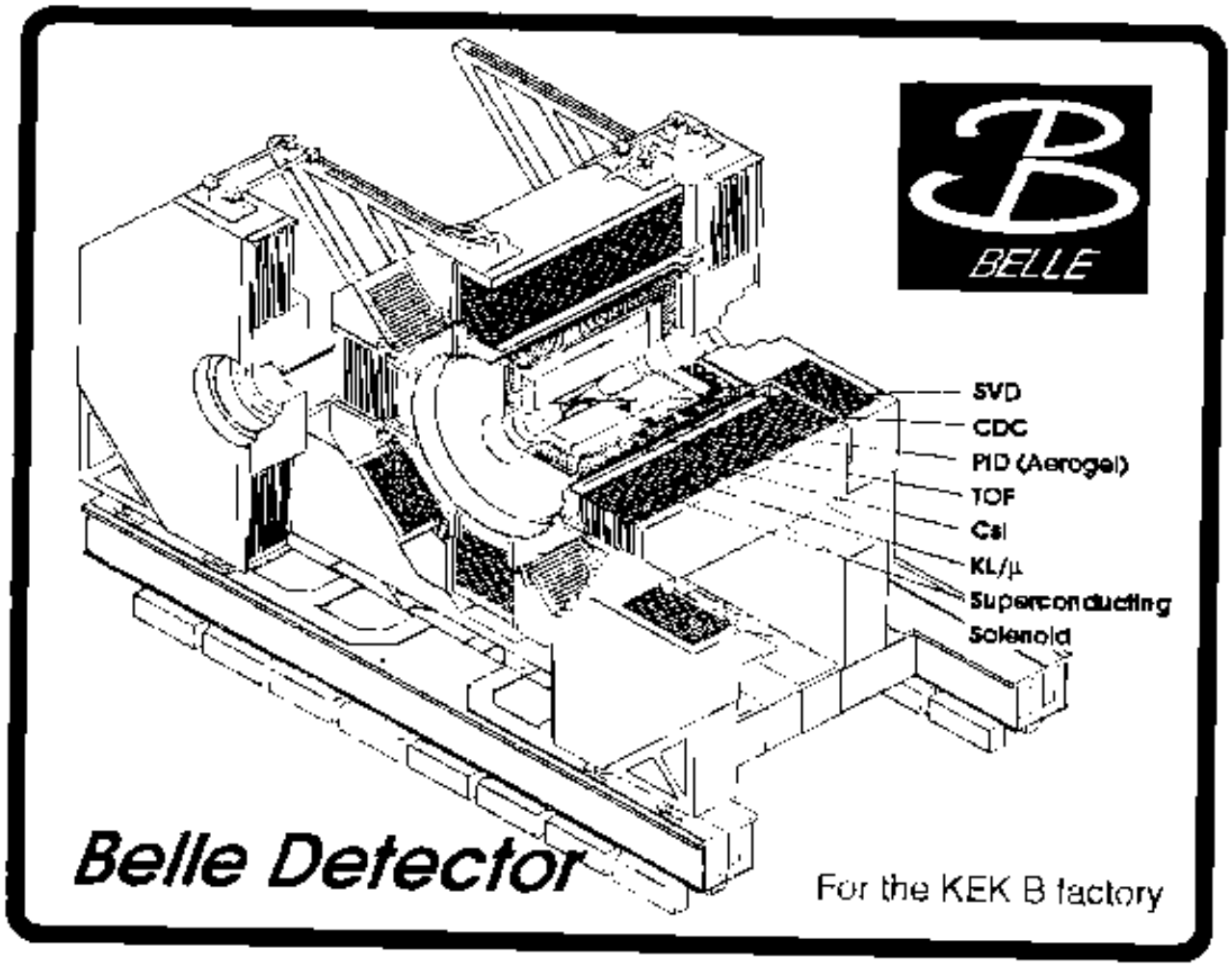


2 unassociated clusters.
Their combined mass consistent with π^0

Event Gallery : First Data

- K short peak.
  - Invariant mass of oppositely signed charged tracks.
  - Loose vertex pointing requirements.
  - Mass of combined tracks 0.497GeV.
  - Width 6MeV
  - No particle ID used.




BELLE
SVD
CDC
PID (Aerogel)
TOF
CsI
KL/μ
Superconducting
Solenoid
Belle Detector
For the KEK B factory

KEKB/BELLE physics run

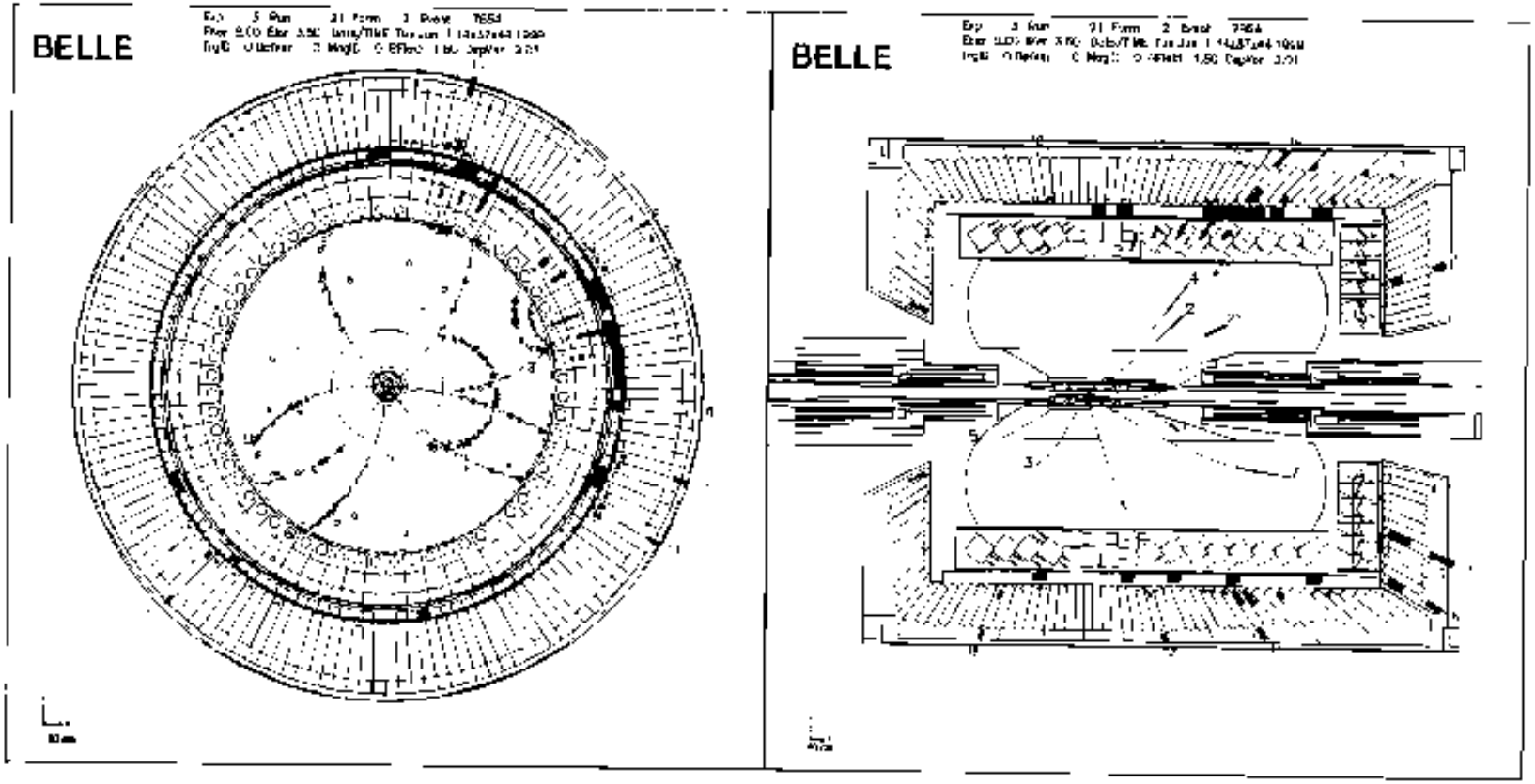
- May 1 BELLE roll in
- May 24 KEKB operation resumed
- June 1~2 1st run for 18.5 hours
  1st collision events
- June 9~10 2nd run for 24 hours
  "1000 hadronic events" run

Run Statistics

Run statistics			
	1st run	2nd run	Total
Barrel Bhabha	149	3457	3606
Hadronic Events	61	1269	1330
μ-pair events	11	234	245
γ-pair events	61	881	942
Integrated L (nb^-1)	21.8	505.4	527.2

- **Note: Results shown here are preliminary.**
  - Numbers must be corrected by trigger and tracking efficiencies
  - Calibration for some sub-detectors are still in progress.

June 1, 1999: Our First Hadronic Event!!



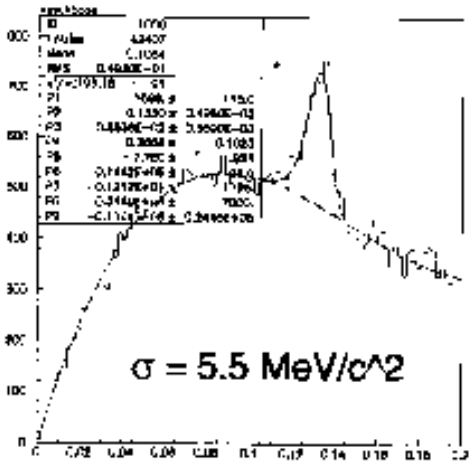
pi0 reconstruction

Two-gamma invariant mass distribution

Eγ > 20MeV

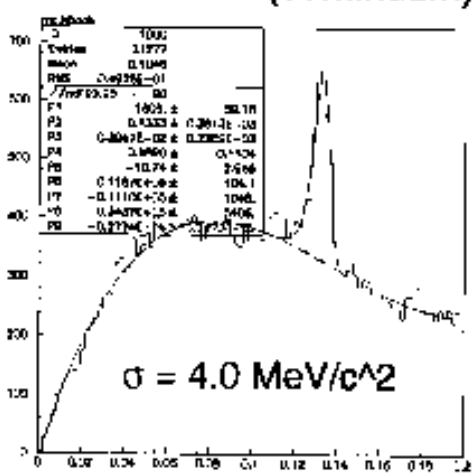
All two-gamma combinations are plotted.

Data



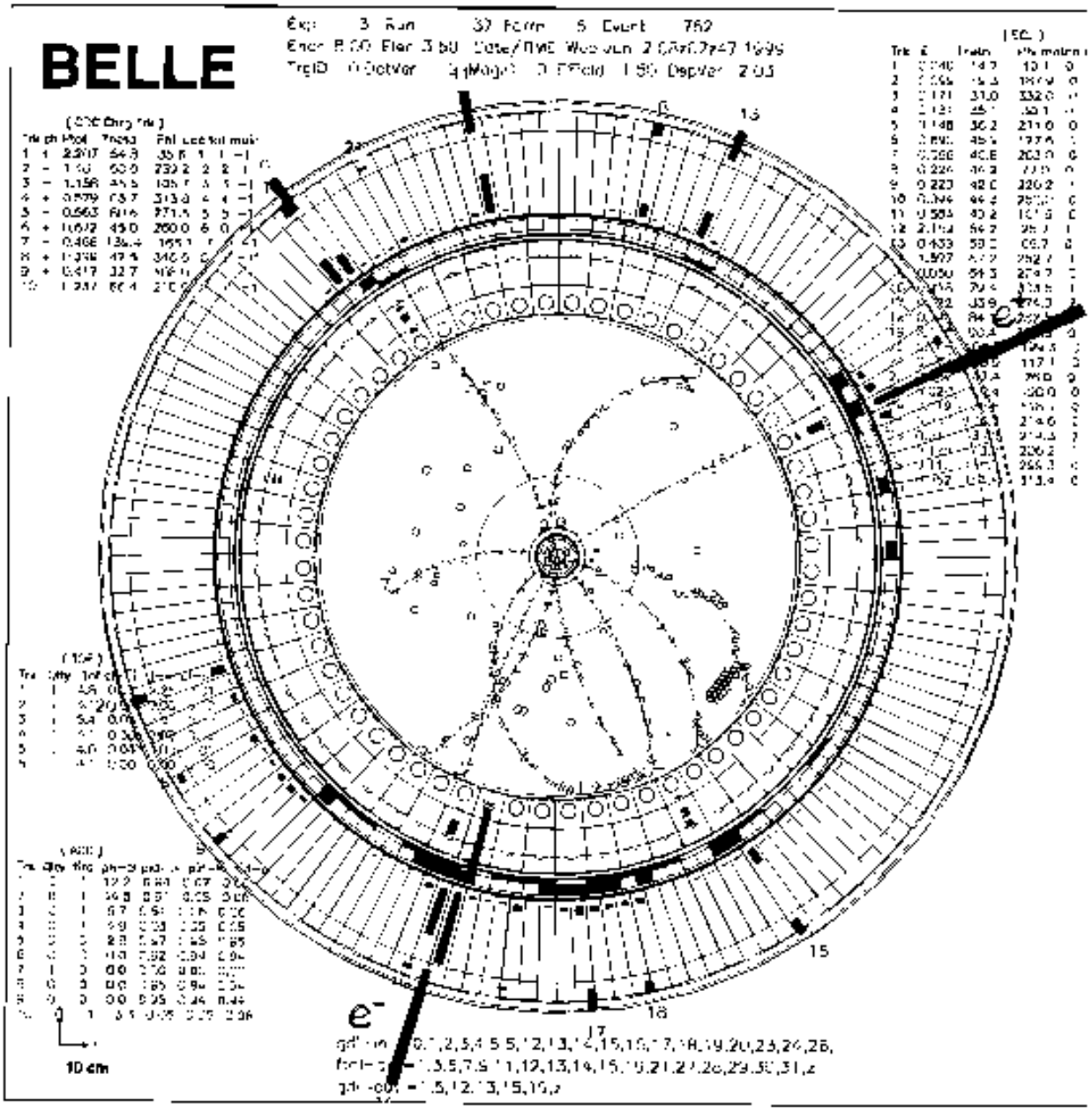
Mγγ

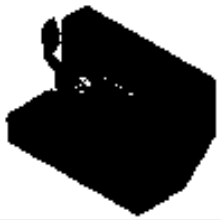
Monte Carlo (continuum)



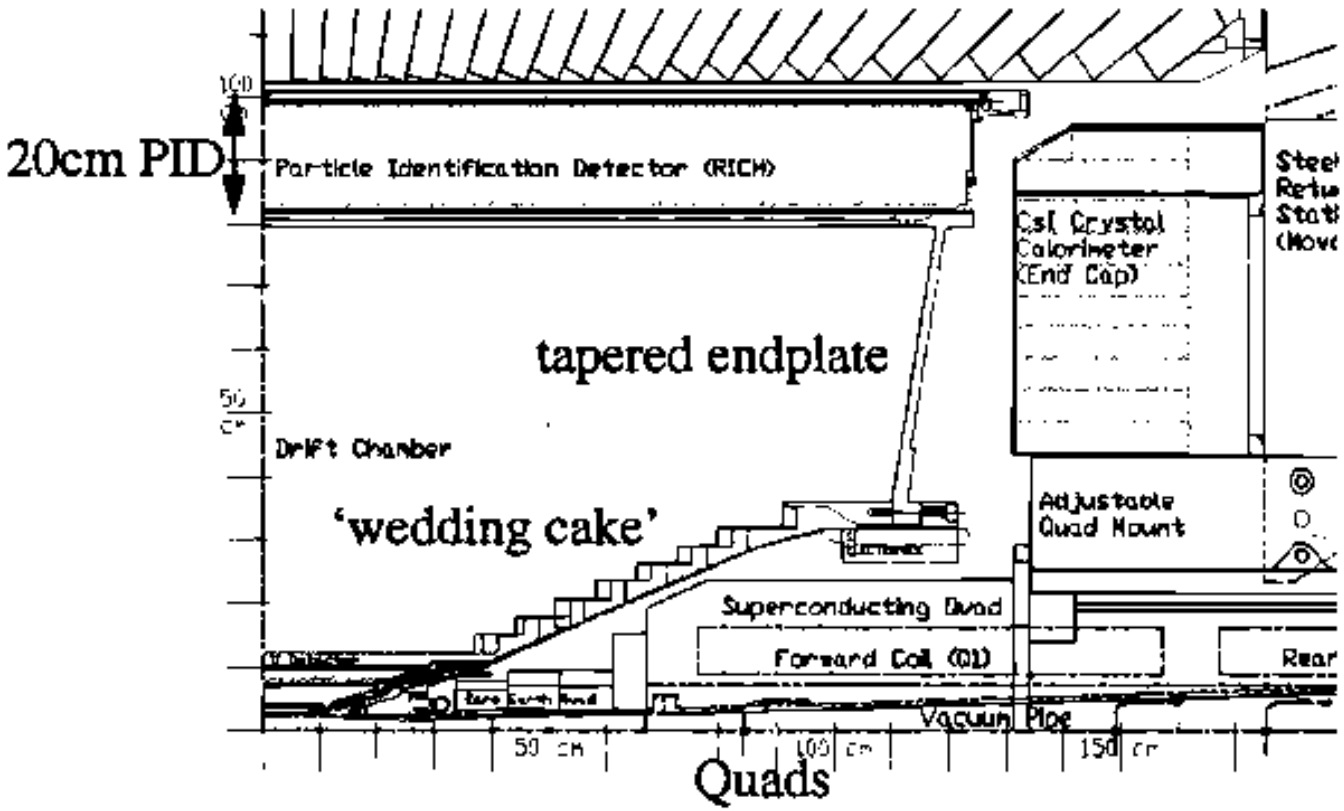
Mγγ

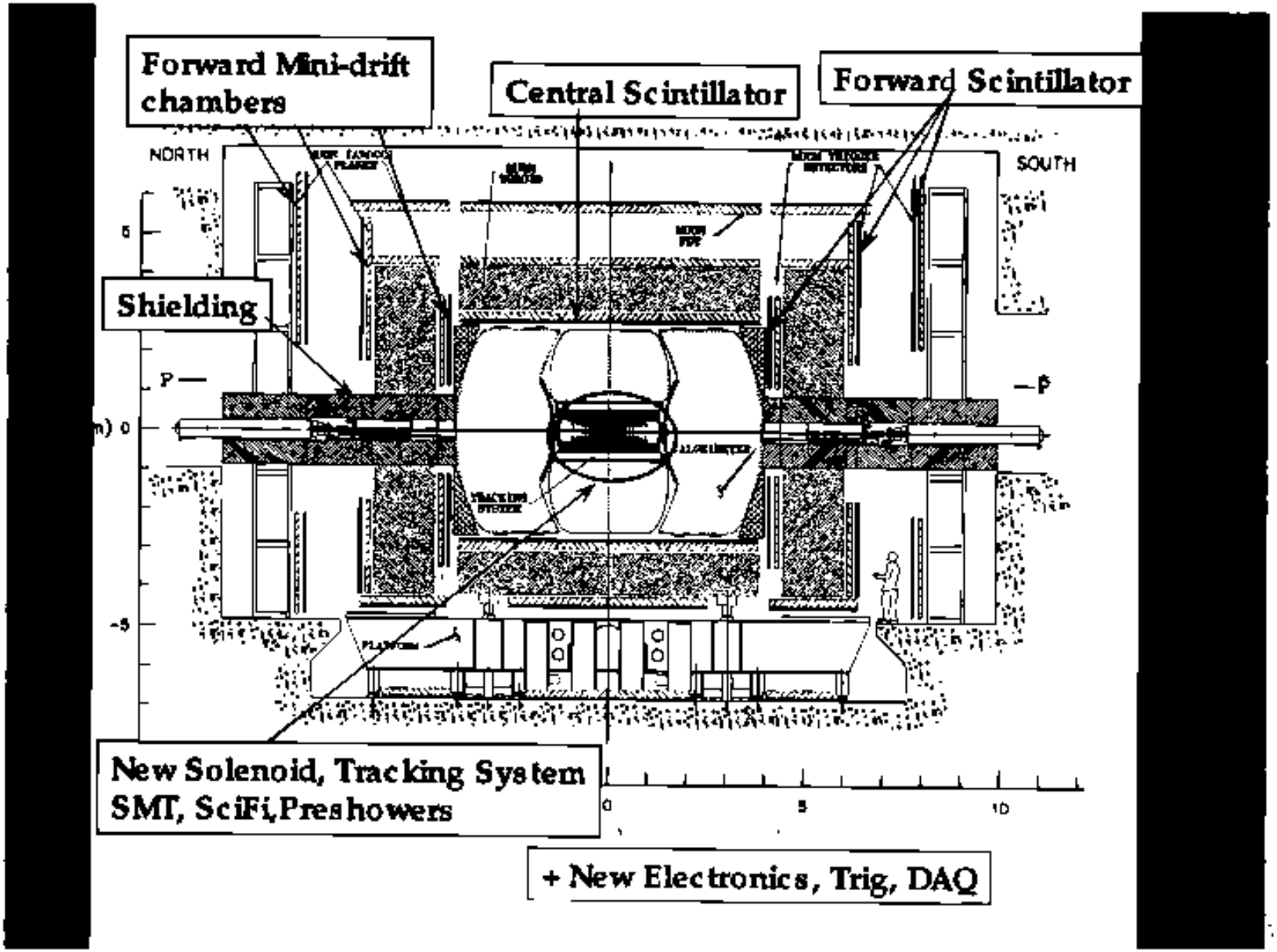
$J/\psi \to e^+e^-$





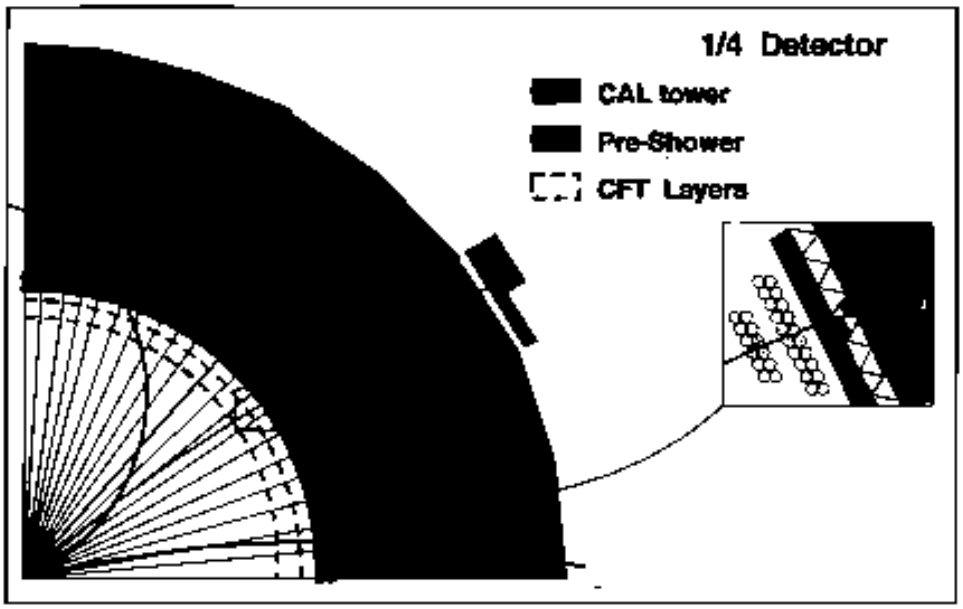
CLEO III


20cm PID
Particle Identification Detector (RICH)
CsI Crystal Calorimeter (End Cap)
tapered endplate
Drift Chamber
'wedding cake'
Adjustable Quad Mount
Superconducting Quad
Forward Coil (Q1)
Vacuum Pipe
50 cm
100 cm
150 cm
Quads


Forward Mini-drift chambers
Central Scintillator
Forward Scintillator
NORTH
SOUTH
Shielding
New Solenoid, Tracking System
SMT, SciFi,Preshowers
+ New Electronics, Trig, DAQ

Trigger on two electrons:

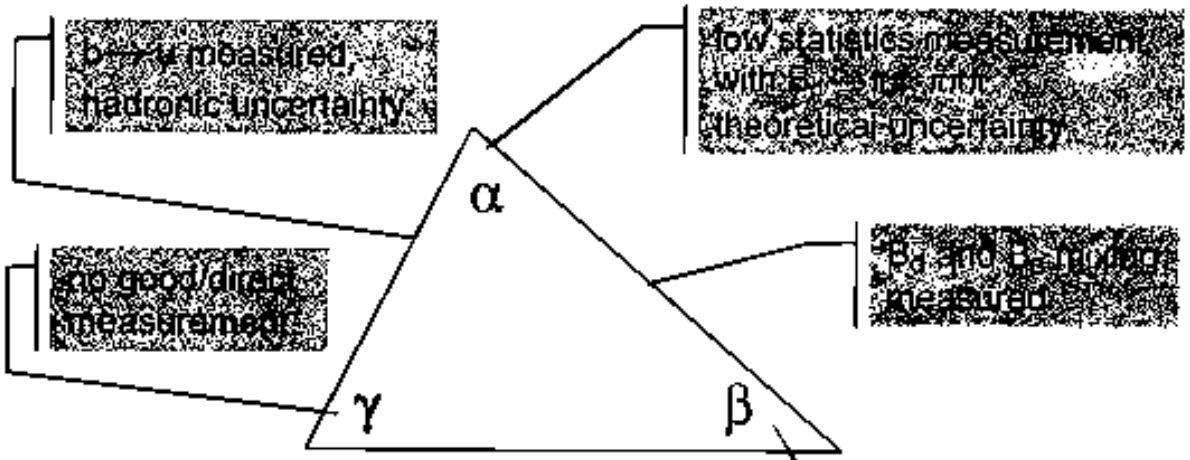
- **Requirements:**
  - **Low E_T cut for in EM CAL** **(2.0 GeV)**
  - **Low threshold PS clusters** **(2.0-.5.0 MIPs)**
  - **Low p_T track / charge sign** **(1.5 GeV/c)**



- **Level 1 trigger:**
  - **Matching: Track / PS Cluster** **(+- 3 strips)**
    CAL / PS Cluster **(quadrant)**
- **Level-2 trigger:**
  - **Matching: Calorim / PS clusters in (η, Φ)**
  - **EM fraction, ΔR(e-,e+), M (e-,e+), $\Delta\Phi$(e-,e+)**

Introduction

Before 2005, various experiments will explore unitarity triangle:



Constraints on triangle will indicate:
- consistency with SM within errors,
- or inconsistency with SM (which will not be fully understood)

In any case:

Next generation experiments at LHC / Tevatron needed for full investigation of CP violation:

- precision (high stat.) measurements on many B_d and B_s decay channels
- aim for theoretically clean channels (not necessarily easiest experimentally)
- overconstrain CKM matrix, including terms beyond $O(\lambda^3)$

Physics Motivation and Requirements

BTEV/C0

Physics Quantity	Decay Mode	Vertex Trigger	K/π sep	γ det	Decay time σ
$\sin(2\alpha)$	$B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$	✓	✓	✓	
$\cos(2\alpha)$	$B^0 \to \rho\pi \to \pi^+\pi^-\pi^0$	✓	✓	✓	
$\text{sign}(\sin(2\alpha))$	$B^0 \to \rho\pi$ & $B^0 \to \pi^+\pi^-$	✓	✓	✓	
$\sin(\gamma)$	$B_s \to D_s K^-$	✓	✓		✓
$\sin(\gamma)$	$B^+ \to D^0 K^+$	✓	✓		
$\sin(\gamma)$	$B \to K\pi$	✓	✓	✓	
$\sin(\gamma)$	$B^0 \to \pi^+\pi^-$ & $B_s \to K^+K^-$	✓	✓		✓
$\sin(2\chi)$	$B_s \to J/\psi\eta'$, $J/\psi\eta$		✓	✓	✓
$\sin(2\beta)$	$B^0 \to J/\psi K_s$				
$\sin(2\beta)$	$B^0 \to \phi K_s, \eta' K_s, \psi\pi^0$	✓	✓	✓	
$\cos(2\beta)$	$B^0 \to J/\psi K^*$ & $B_s \to J/\psi\phi$				
x_s	$B_s \to D_s\pi^-$	✓	✓		✓
$\Delta\Gamma$ for B_s	$B_s \to J/\psi\eta'$, K^+K^-, $D_s\pi^-$	✓	✓	✓	

Experiments being constructed/designed

Dedicated B-physics experiments

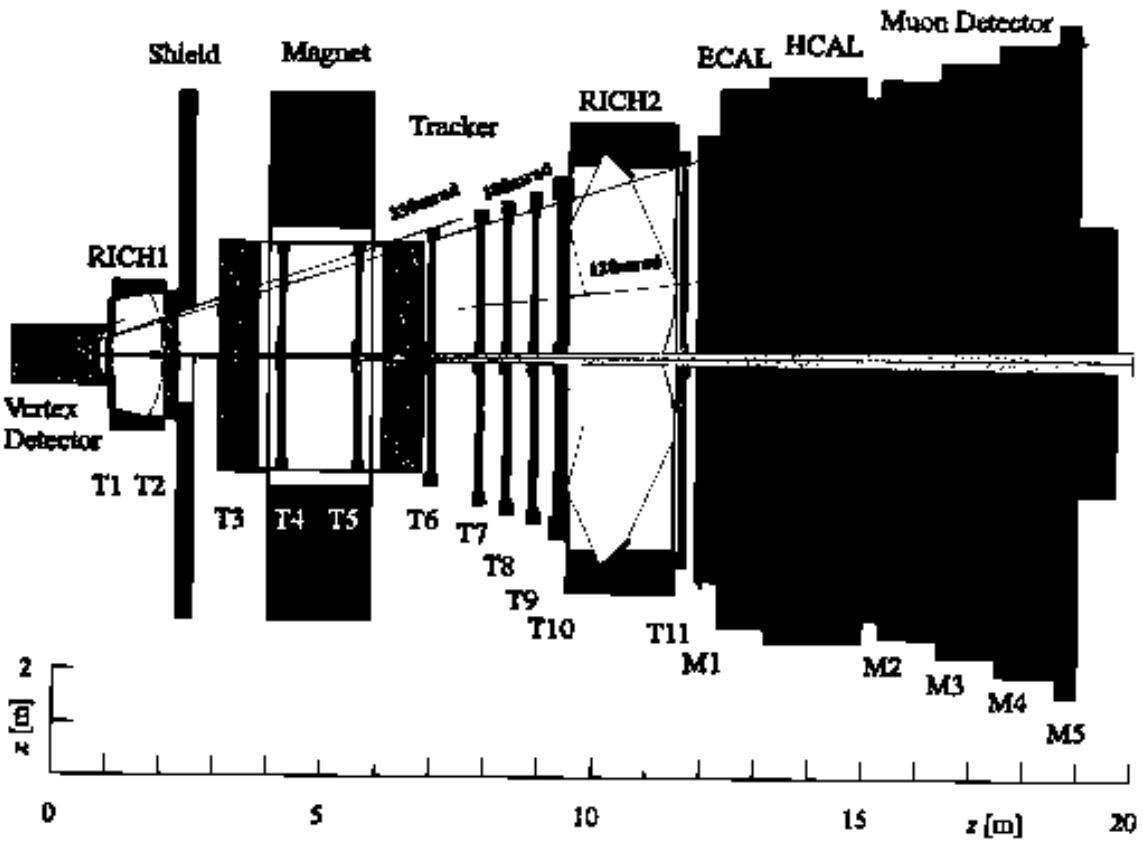
- LHC-B, forward single-arm spectrometer at LHC with good particle identification (RICH). $\sigma(b\bar{b})$=500 μb, $\sigma(b\bar{b})/\sigma(tot)$=0.007. Nominal 1 year data 1.5 fb-1. Usable $b\bar{b}$-events: 5.6 10^{11} per year. × acceptance
- BTeV, forward two-arm spectrometer at Tevatron with good particle identification (RICH). $\sigma(b\bar{b})$=100 μb. → $2 \cdot 10^{11}$ × acceptance

ATLAS, CMS at LHC

- General purpose high-p_T experiments for heavy particle searches and precision physics, with central rapidity coverage (5-6 units). $\sigma(b\bar{b})$=500 μb, nominal 1 year data 10 fb^{-1}. Usable $b\bar{b}$-events 2.5 10^{10} per year. (including trigger acceptance at LVL1)

Detector layout

View in bending plane (horizontal)
as proposed in 1998:

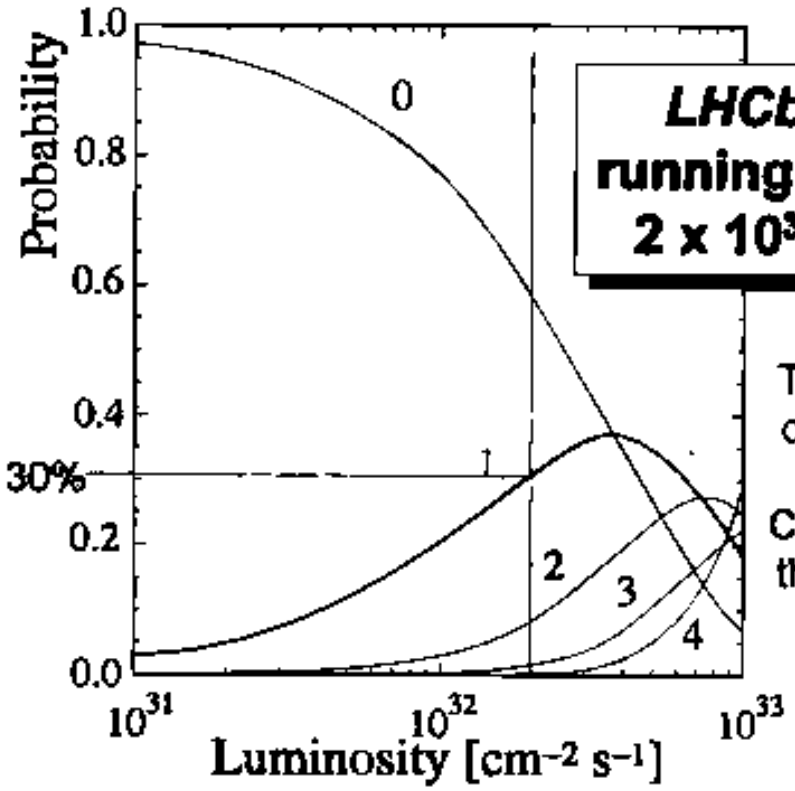


open geometry → easy access to all components

Running luminosity

Aiming for single pp interactions per bunch crossing

- radiation damage
- detector occupancy
- pattern recognition



LHCb chosen running luminosity
2×10^{32} cm^{-2} s^{-1}

Tune luminosity by defocusing beams

Constant luminosity throughout LHCb's lifetime

5.6×10^{11} $b\bar{b}$ pairs per year in single pp interactions

assuming $\sigma_{inel} = 80$ mb and $\sigma_{b\bar{b}} = 500$ µb

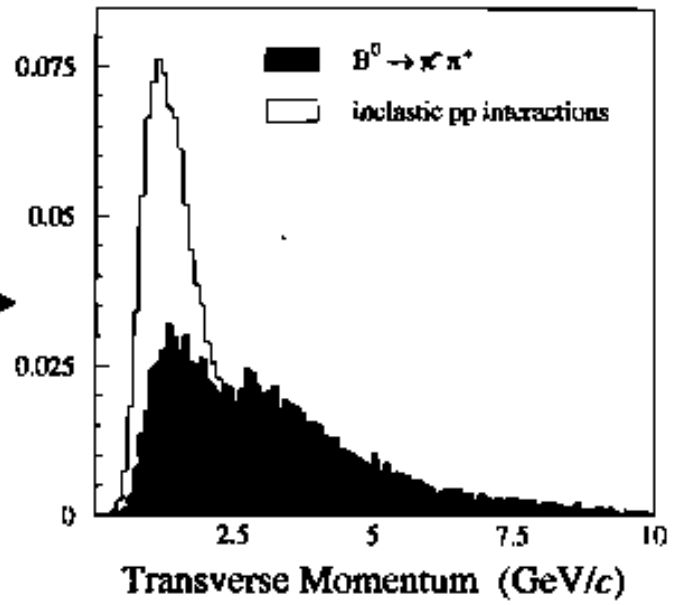
Level-0 trigger

Pile-up veto

- 2 dedicated Si disks to reject multiple pp interactions (i.e. primary vertexes)
- size of luminous region: $\sigma_z \sim 5$ cm

p_T or E_T single track triggers

– **muon**	muon chambers	~ 20 %
– **electron**	ECAL	~ 10%
– **hadron**	ECAL+HCAL	~ 60%
– photon	ECAL	
– ...		



40 MHz —4.0 μs→ 1 MHz

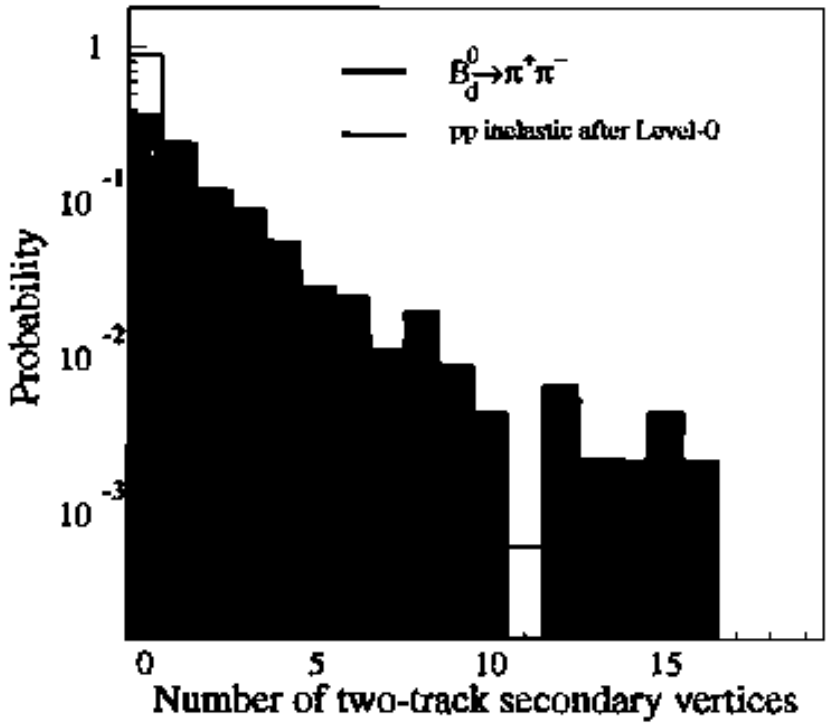
Input rate — Latency — Output rate

Level-1 trigger

(details from C. Parkes tomorrow)

Topological identification of secondary vertexes

- find tracks in silicon (only)
- reconstruct primary vertex
- form secondary vertexes with large impact parameter tracks



512–2048 μs

1 MHz → 40 kHz

Input rate — Latency — Output rate

The Tevatron as a b and c source

BTEV/CO

Luminosity	$2 \times 10^{32}\ cm^{-2} s^{-1}$
b cross-section	$\sim 100\ \mu b$
B events per 10^7 sec	2×10^{11}
B fraction	10^{-3}
c cross-section	$> 500\ \mu b$
c events per 10^7 sec	$> 10^{12}$
Bunch spacing	> 132 ns
Luminous region length	$\sigma_z = 30$ cm
Luminous region width	$\sigma_x \sim \sigma_y \sim 50\ \mu m$
<Interactions/crossing>	2

⊕ Lower $\sqrt{s}$ ⇒ larger angles, shorter detector, easier RICH, less radiation

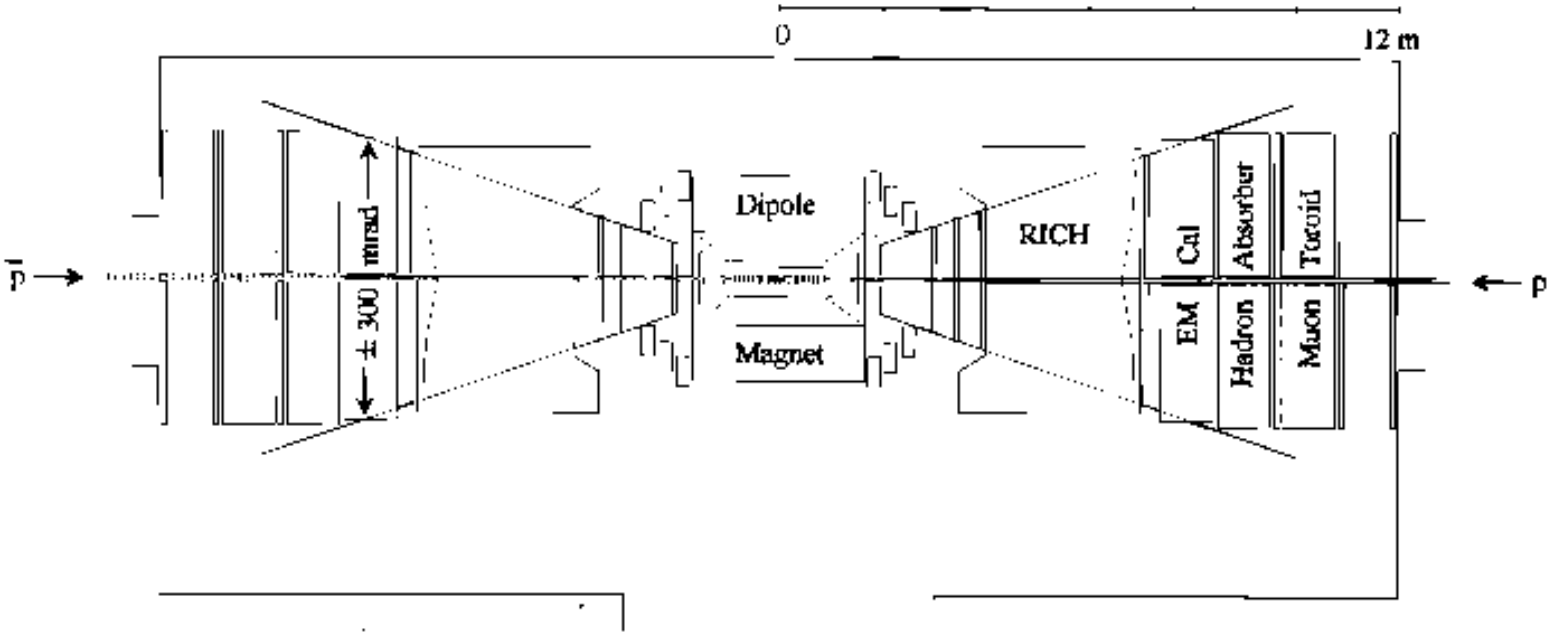
⊕ Bunch spacing: long i.a. region ⇒ vertexing easier

Key Design Features of BTeV

BTeV/Co

1. A dipole located ON the IR, gives BTeV TWO spectrometers -- one covering the forward proton rapidity region and the other covering the forward antiproton rapidity region.
2. A precision vertex detector based on planar pixel arrays
3. A vertex trigger at Level I which makes BTeV especially efficient for states that have only hadrons. The tracking system design has to be tied closely to the trigger design to achieve this.
4. Strong particle identification based on a Ring Imaging Cerenkov counter. Many states that will be of interest in this phase of B physics will only be separable from other states if this capability exists. It also allows one to use charged kaons for tagging.
5. A lead tungstate electromagnetic calorimeter for photon and π^0 reconstruction

Plan View of the BTeV Detector



Magnet properties:

- Dipole BxL= 5.2 Tm
- Central Field = 1.6 T

Detector Subsystems:

- Pixel/Vertex Detector
- Forward Tracker
- Ring Imaging Cerenkov Counter
- Electromagnetic Calorimeter
- Muon Detector

Pixel Vertex Detector

BTEV/CO

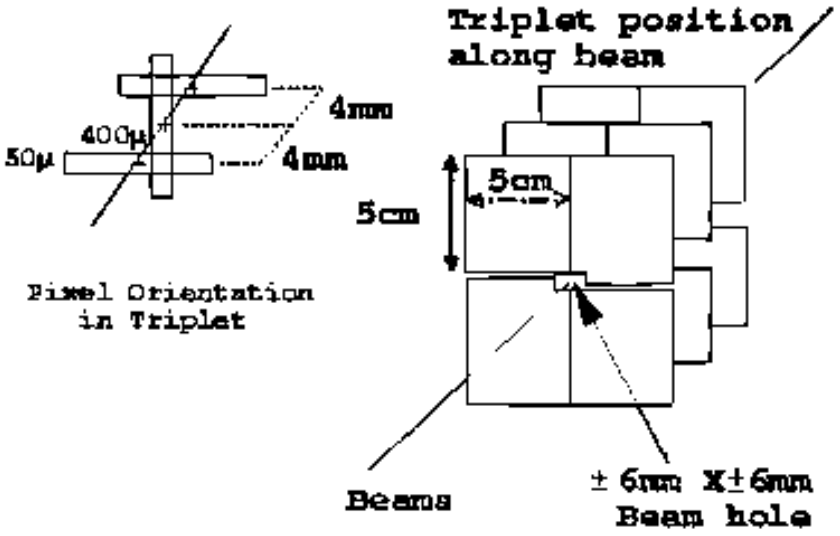
Why Pixels?

- Superior signal to noise
- Excellent spatial resolution: 5-10 μm depending on angle
- Very low occupancy
- Very fast
- Radiation hard

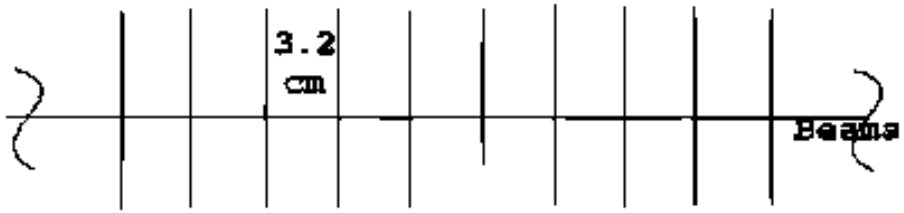
Special features:

- Used directly in the L1 trigger
- Pulse height is measured on every channel with a 2,3 bit FADC
- Located in dipole field thus gives a crude standalone momentum measurement

The BTeV Baseline Pixel Detector



Elevation View
10 of 31 Triplet Stations



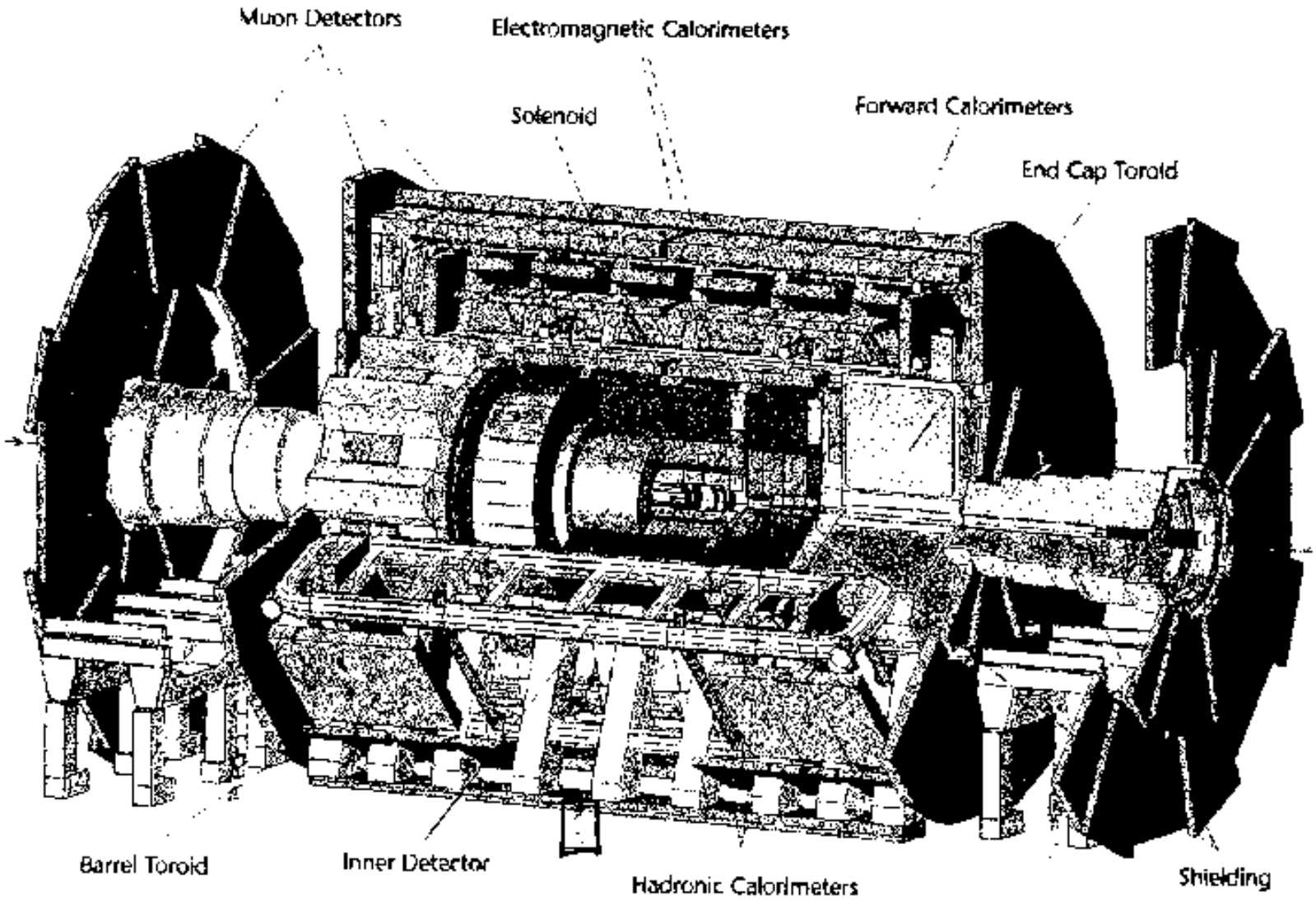
Trigger and DAQ

BTEV/C0

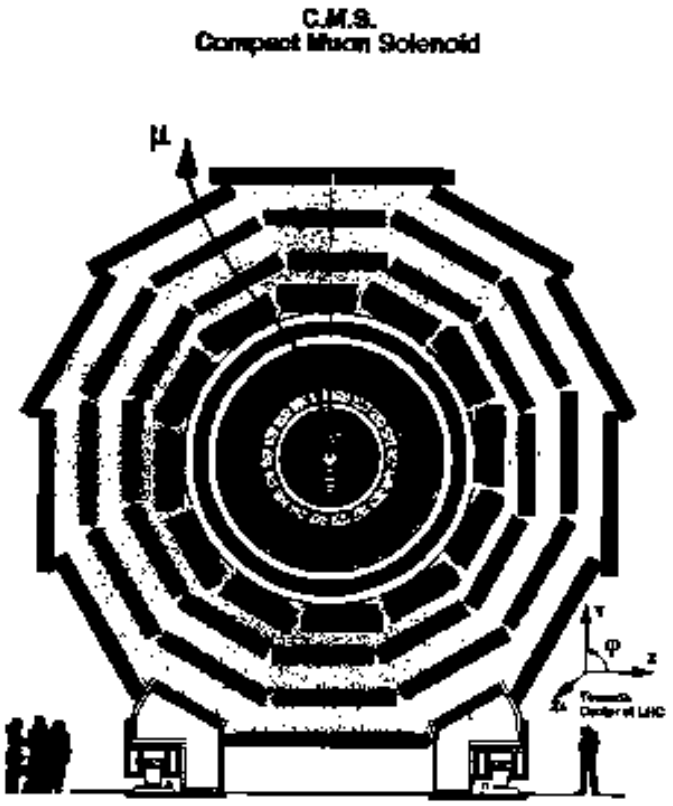
Level I trigger uses information from the Pixel Detector to find the primary vertex and then look for tracks that are detached from it

- Detailed studies of efficiency and rejection for up to an average of three interactions/crossing
- For a requirement of at least 2 tracks detached by more than 4σ, we trigger on only 1% of the beam crossings and achieve the following efficiencies for these states:

State	efficiency(%)	state	efficiency(%)
$B \to \pi^+\pi^-$	55	$B^0 \to K^+\pi^-$	54
$B_s \to D_s K$	70	$B^0 \to J/\psi\, K_s$	50
$B^- \to D^0 K^-$	60	$B_s \to J/\psi K^*$	69
$B^- \to K_s \pi^-$	40	$B^0 \to K^*\gamma$	40


Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

The CMS Detector



History

- Concept: 1990
- LoI: 1992
- TP: 1994
- TDRs: 1996÷98

Parameters

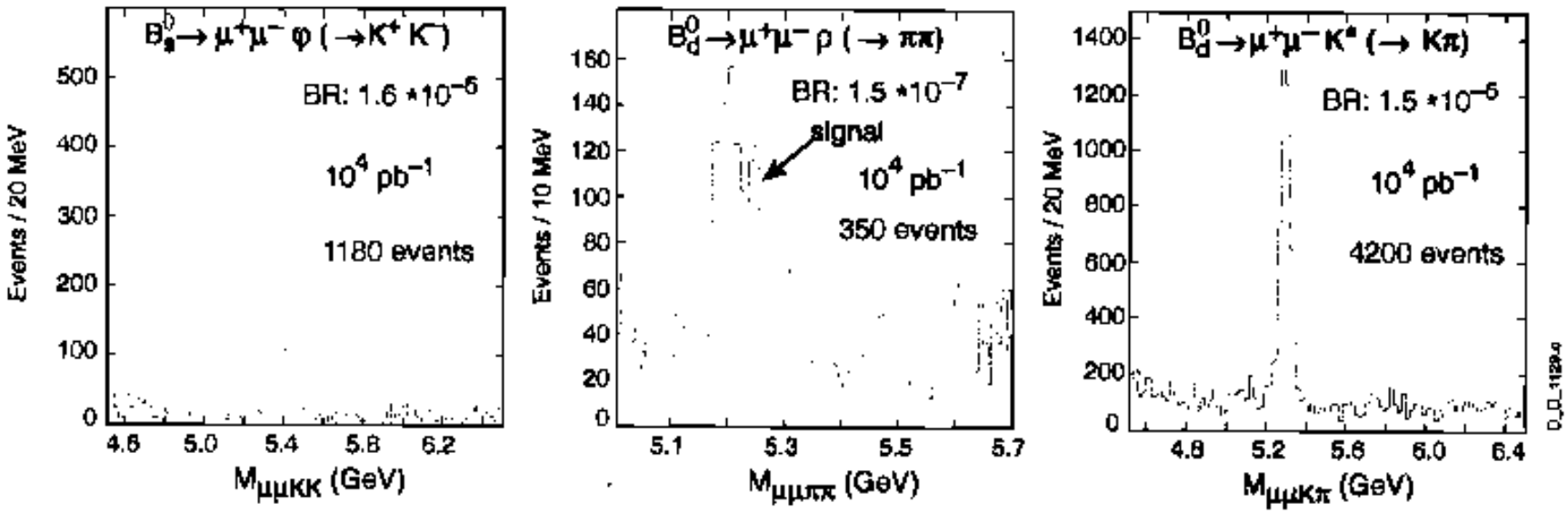
- L=21.6m
- D=14.6m
- M=14500t
- B=4T

Conclusions

While facing inevitable competition from LHC-B, ATLAS will be able to make an important contribution to b-physics

Observable	Expected precision	1999 data	
$\sin 2\alpha$	$\delta(\alpha) \approx 2^\circ$	$\sin 2\alpha = -0.26^{+0.29}_{-0.28}$	Fit
$\sin 2\beta$	$\delta(\sin 2\beta) \approx 0.010$	$\sin 2\beta = 0.79^{+0.41}_{-0.44}$	CDF
γ	-	Est. $\gamma = \left(59.5^{+8.5}_{-7.5}\right)^\circ$	Fit
phase $\xi = \delta\gamma$	$\delta(\xi) = 0.03$	$\xi = 0.024 \cdot\!\!-\!\!- 0.054$	PDG
Δm_s	up to $38.5\,\mathrm{ps}^{-1}$	$\Delta m_s > 12.4\,\mathrm{ps}^{-1}$	Fit
$\tau(B_s)$	$\delta\Gamma_s/\Gamma_s = 0.7\%$	$\tau(B_s) = 1.54 \pm 0.07\,\mathrm{ps}$	PDG
$\Delta\Gamma_s$	$\delta(\Delta\Gamma_s)/\Delta\Gamma_s = 12\%$	$\Delta\Gamma_s/\Gamma_s < 0.83$	CDF
$\lvert V_{td}\rvert/\lvert V_{ts}\rvert$	$\delta(\lvert V_{td}\rvert/\lvert V_{ts}\rvert) = 14\%$	$\lvert V_{td}\rvert/\lvert V_{ts}\rvert < 0.27$	PDG
$\tau(\Lambda_b)$	$\delta(\Lambda_b) = 0.3\%$	$\tau(\Lambda_b) = 1.24 \pm 0.08\,\mathrm{ps}$	PDG
$B\tau(B_s \to \mu\mu)$	4.3σ signal (SM)	Not seen	
$B\tau(B_d \to \mu\mu)$	Limit $< 3 \times 10^{-10}$ (SM)	Not seen	
A_{FB} muons	$\delta(A_{FB}) < 5\%$	Not observed	

Rare semileptonic FCNC $B^0_{d,s}$ decays

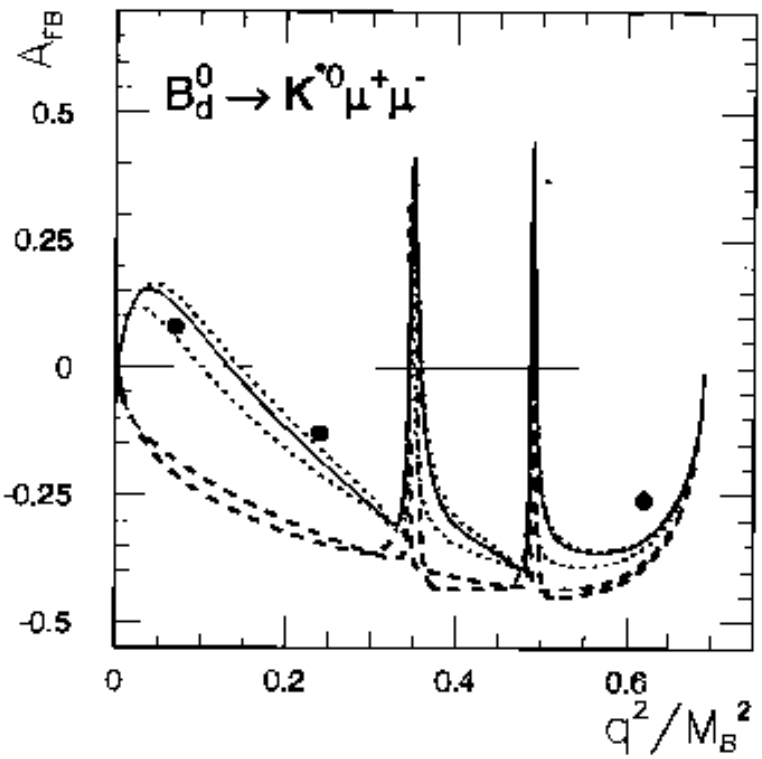


- Signal should be seen for all 3 channels.
- Good statistics, S/B ~ 1 for ρ, S/B = 14 and 9 for φ and K*
- Expected statistical error on $\dfrac{BR(B^0_d \to K^* \mu^+\mu^-)}{BR(B^0_d \to \rho\, \mu^+\mu^-)}\ \alpha \left(\dfrac{|V_{ts}|^2}{|V_{td}|^2}\right)$ of 7%
- Clean measurements of dimuon invariant mass spectra and of forward backward asymmetry should give information on angle γ

Forward-backward asymmetry of lepton wrt B-direction
in lepton pair rest frame sensitive to $C_{7\gamma}$
$\Longrightarrow$ could distinguish between SM and MSSM
Three regions of $s = q^2/M_B^2$ of interest

Quantity	$s < 0.14$	$0.14 < s < 0.33$	$s > 0.55$
δA_{FB}(stat)	5%	4.5%	6.5%
SM A_{FB}	10%	-14%	-29%
MSSM A_{FB}	$-17 \pm 0.5\%$	$-35 \pm 13\%$	$-33 \pm 29\%$

Low point could easily exclude SM



Detector R&D, prototypes and running experience

Targets and beams

- PEPII, KEK-B commissioning of asymmetric e^+e^- operation
- HERA-B wire target operation

Multilevel triggering

- Level-1: high-pT leptons/hadrons. In addition, tracking/event topology. Data sits in pipelines.
- Level-2 -> Level-N: online event prosessing, data storage at 100 Hz rate.

Tracking and vertexing

- Microvertex detectors for precise secondary vertex measurements
- Trackers: progress with new techniques

MSGC: advanced passivation
GEM

EXP	HADRON ID	STATUS
CDF	dE/dx TOF	working design
DØ	-	
CLEO III	RICH LiF + chambers (TEA)	being mounted
Babar	DIRC, dE/dx	working
Belle	Aerogel, TOF, dE/dx	working
HERA-B	RICH C_4F_{10} + PMT's	working
LHCb	RICH × 2 aerogel + C_4F_{10} ; CF_4 HPD's OR PMT's	design
BTeV	RICH × 2 (both arms) aerogel + C_4F_{10}	design
ATLAS	dE/dx in TRT	to be verified in beam
CMS	? dE/dx in Si ?	

HERA-B

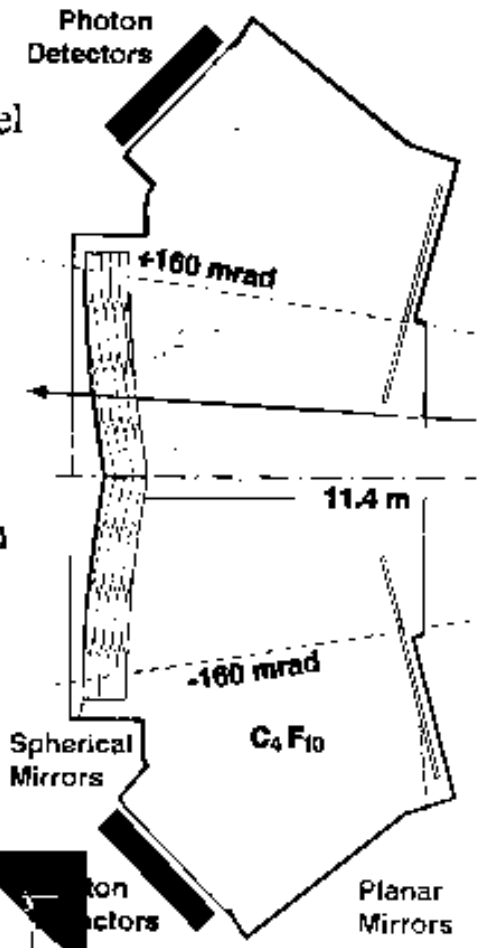
RICH at Large

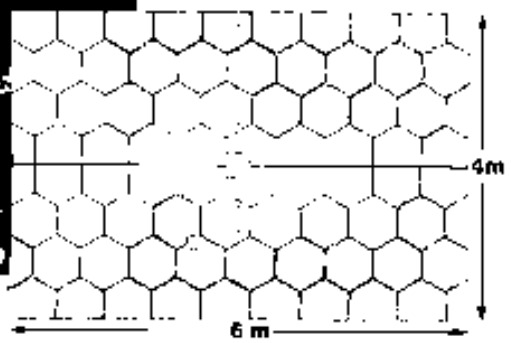
❑ Radiator

- 100 m^3 stainless steel vessel
- C_4F_{10} $n = 1.00135$
- $\Theta_{\check{C}erenkov} = 52$ mrad

❑ Mirrors

- Spherical ($r = 11.4$ m), tilted up/down, 80 hexagon based elements
- Planar mirrors move focal plane *above* and *below* flux of particles





Photon Detector

❑ Focal Plane

- Best approximated by two cylinders
- Light exits through 2 mm thick UV grade *Plexiglas* windows
- Incidence angle $\approx 2\ \theta_C$ due to unknown z of photon emission and effect of magnetic field

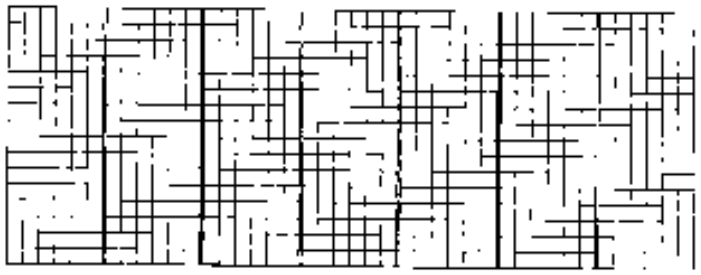
❑ Multi-Anode Photomultipliers

- *Hamamatsu R5900* with 18×18 mm^2 photocathode
- *1500* with 16 anodes **M16**
  750 with 4 anodes

❑ Mounting

- Soft iron box (supermodule) with 32×12 mounting positions
- PMTs placed according to occupancy

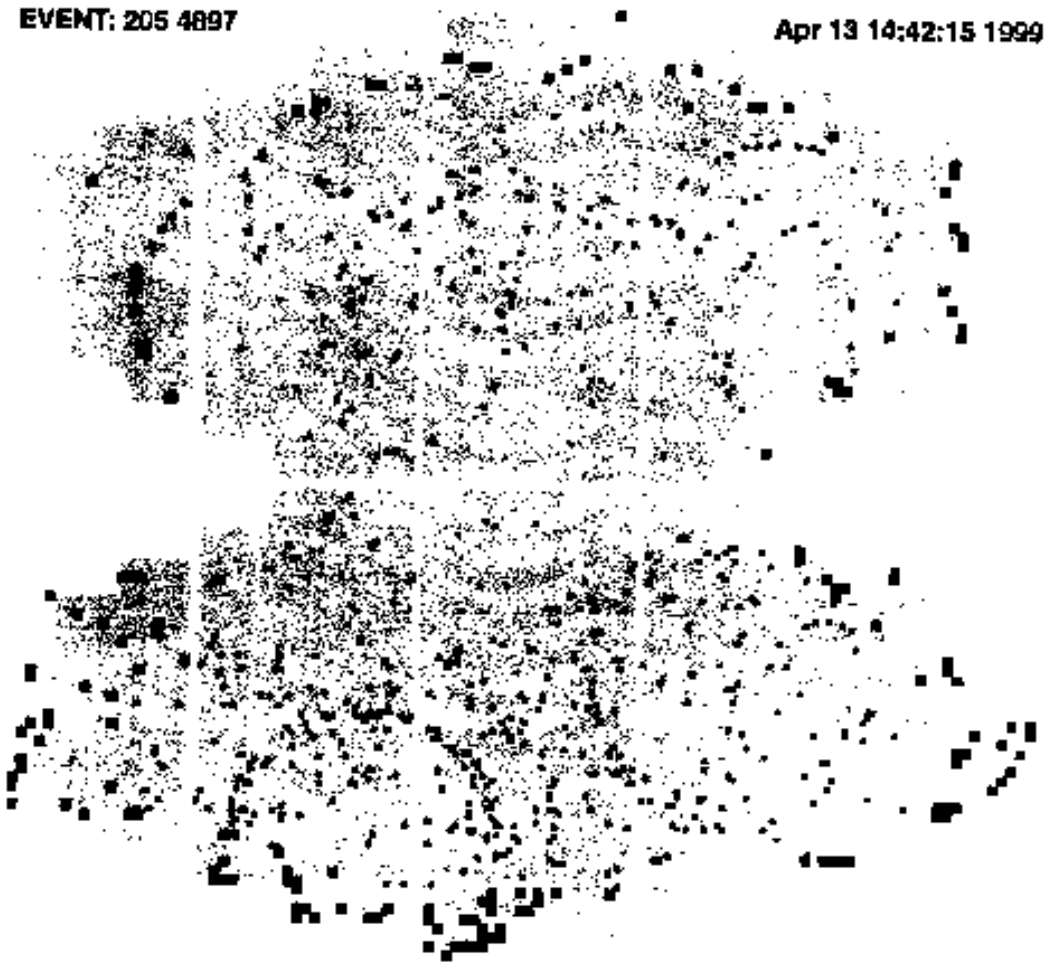
empty



Supermodules in upper focal plane

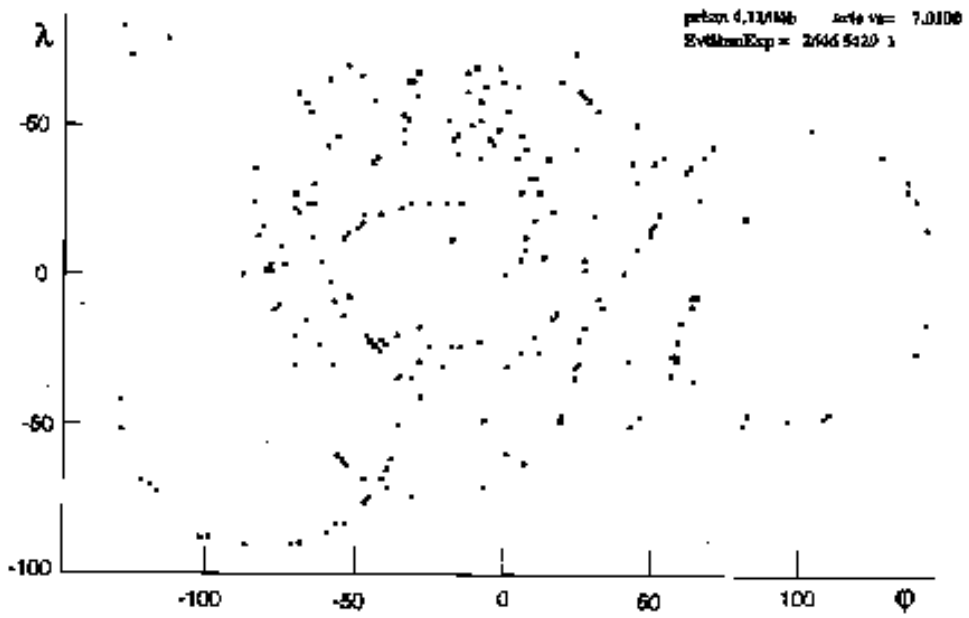
Events

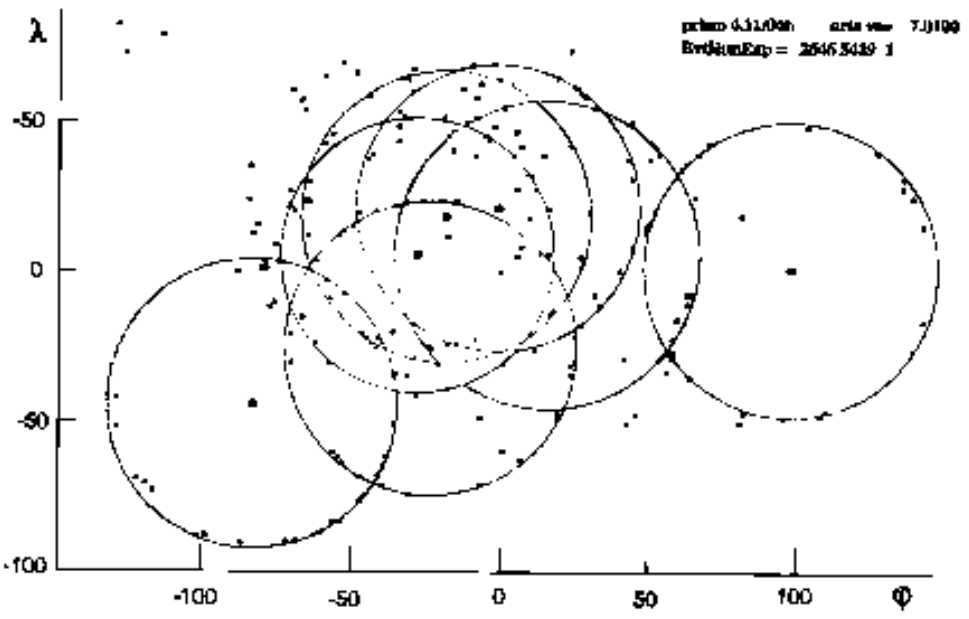
- ❑ All Magnet On
- ❑ "Typical" (754 hits)



Reconstructed Rings

- Software finds rings





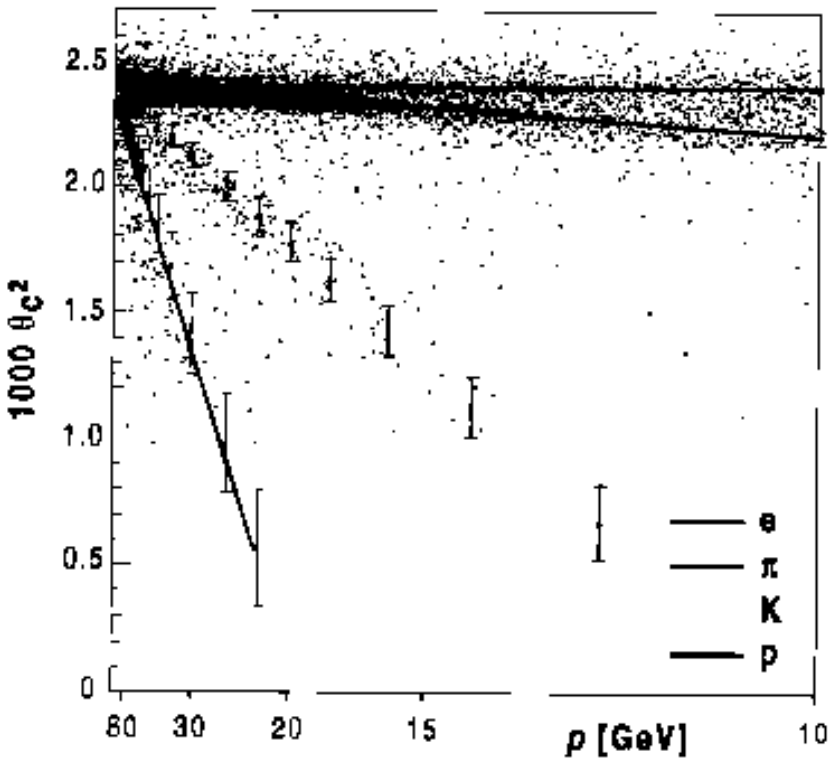
Particle ID

❑ RICH-ECAL measured quantities

- Čerenkov relation, $\cos\theta_C = 1/n\beta$, relates the angle to momentum:

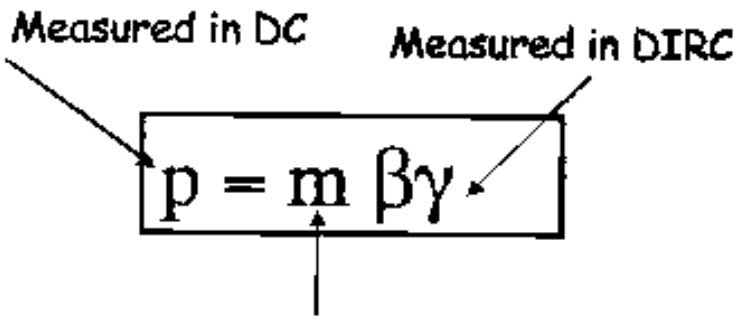
$$\theta_C^2 = \theta_0^2 - \frac{m^2}{p^2} \qquad \theta_0 \equiv \text{“}\beta = 1\text{”}$$

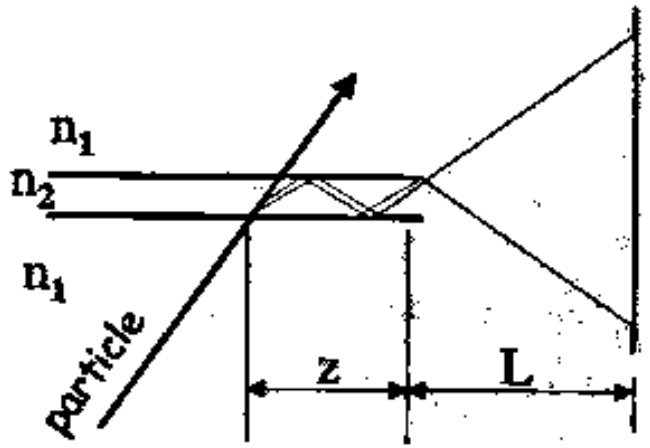
- $\theta_C{}^2$ vs. $1/p^2$: particles of same mass on straight lines



DIRC

See talk by Andreas Hoecker

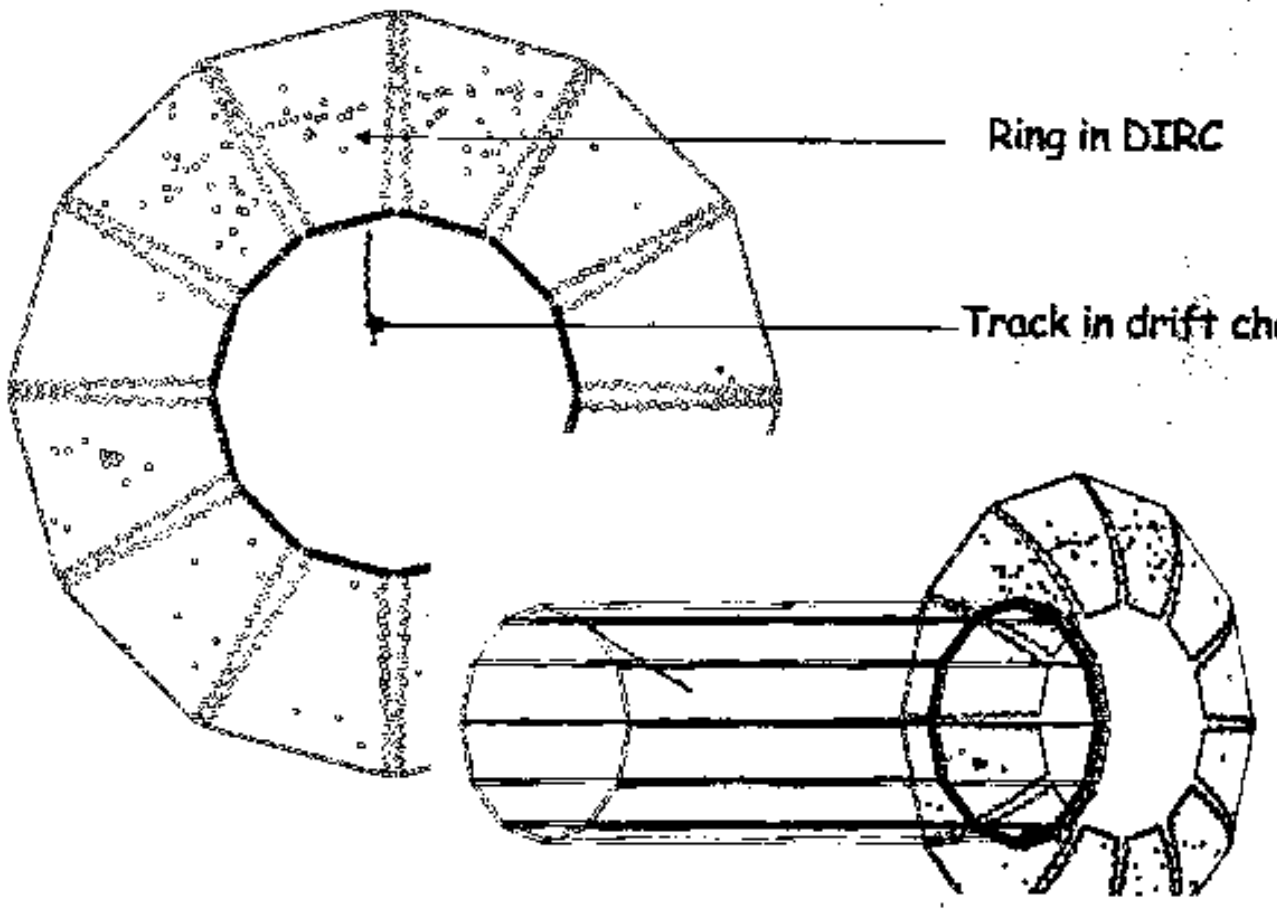




- Principal
  - particle traverses quartz bar.
  - Cherenkov photons trapped due to internal reflection
  - angle preserved along length of bars
  - ring allowed to expand and be measured.

- Status
  - all PM tubes infrastructure and electronics in place
  - 5 of 12 bar boxes are in place
  - balance in shutdown

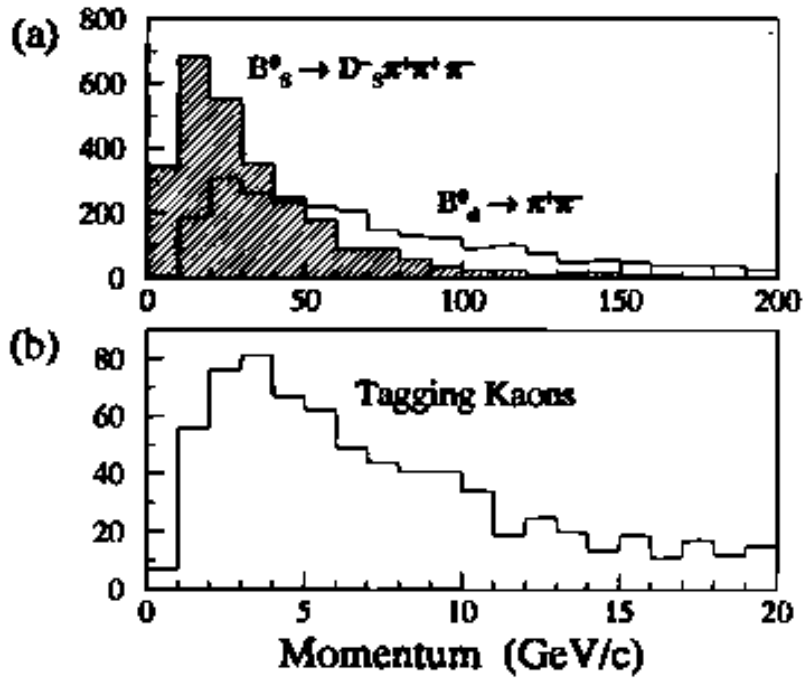
DIRC : Event Picture : Single arm Bhabha



Why RICH?

Momentum coverage:

- (a) Up to 150 GeV/c for $B^0_d \rightarrow \pi^+\pi^-$ and
  $B^0_s \rightarrow D^-_s\pi^+\pi^+\pi^-$
- (b) Down to 1 GeV/c for B flavor tagging Kaons

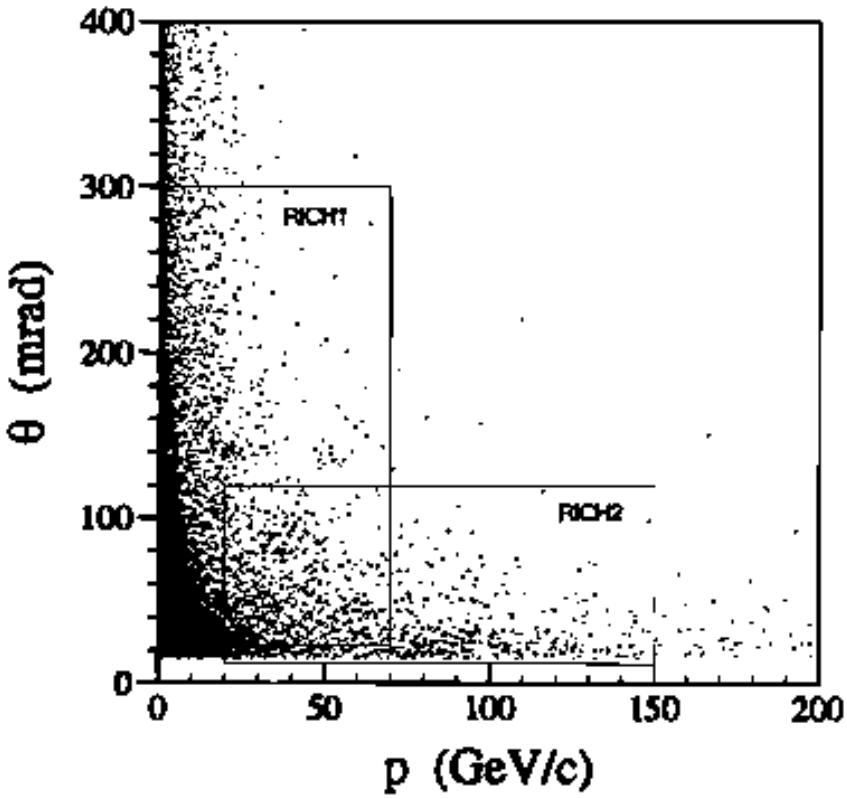


⇒ Use RICH technique

Goal: K/π separation in 1-150 GeV/c range

Why Two RICHes?

Momentum and polar angle correlation

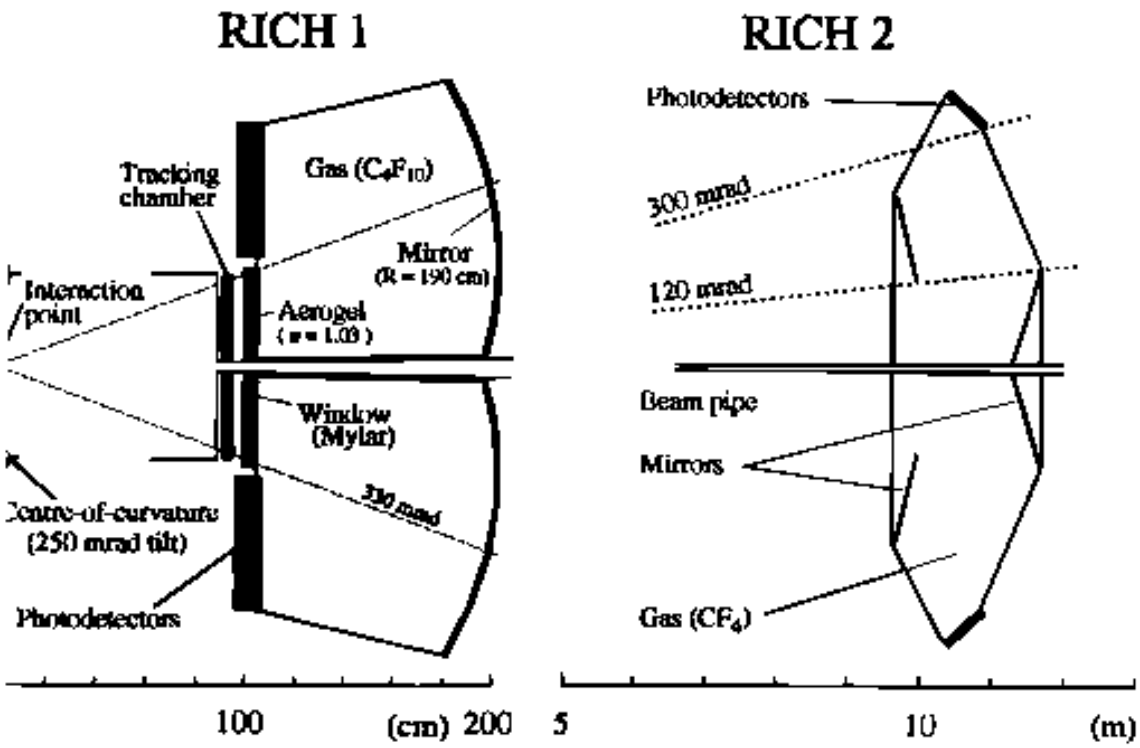


⇒ Two separate RICHes:

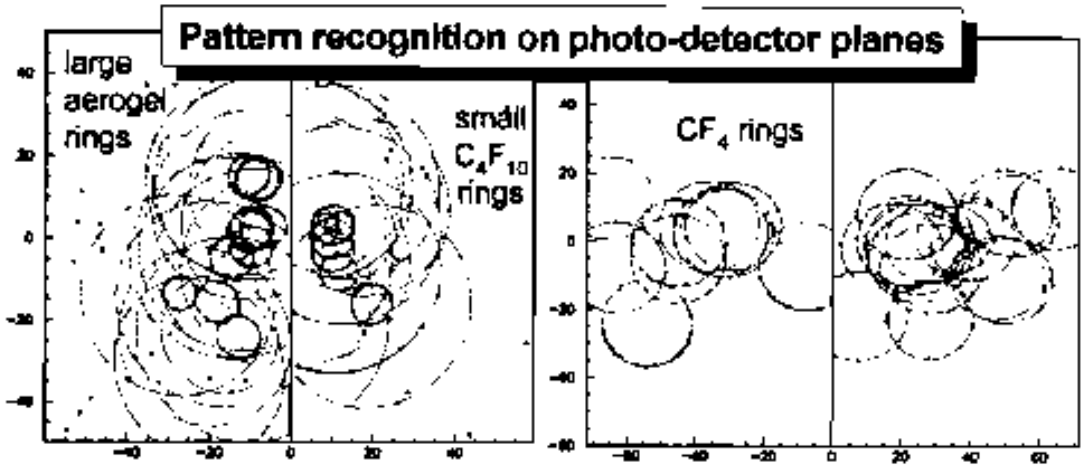
- RICH 1: wider angular coverage for lower momentum tracks, located before the magnet
- RICH 2: very forward angle coverage but higher momentum tracks, located after the magnet

RICH detectors

(details from A. Go on Thursday)



	Aerogel	C4F10	CF4
π threshold	0.6 GeV/c	2.6 GeV/c	4.4 GeV/c
K threshold	2.0 GeV/c	9.3 GeV/c	15.6 GeV/c



Photodetectors

Requirements:

- Total of ≈3m^2 coverage, ≥73% active area coverage
- 2.5 x 2.5 mm^2 granularity, 340.000 channels
- Single photon sensitivity, high quantum efficiency in both UV and visible region
- LHC compatible readout, ~25ns

3 options under study:

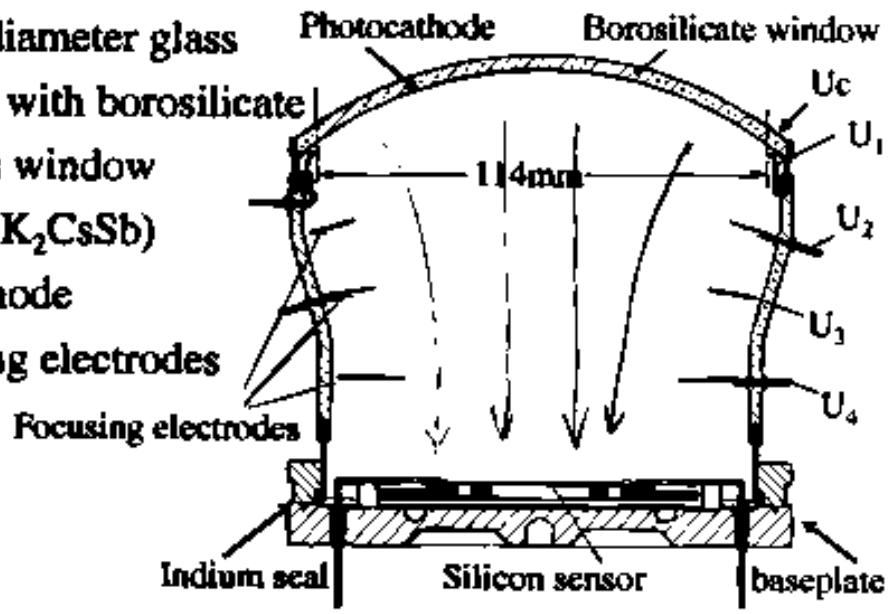
- Pad HPD*:
  - 127mm tube, 2048 channels
  - Encapsulated analog readout
- Pixel HPD:
  - 80mm tube, 1024 channels
  - Encapsulated binary readout
- Multi-anode PMT:
  - 64 channels (8x8)
  - External analog readout

*HPD: Hybrid Photo Diode

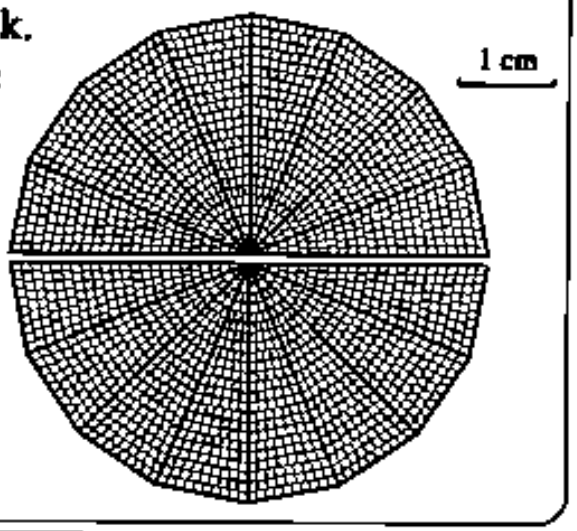
Pad HPD

HPD = Photocathode + HV + Silicon sensor.

- 127mm diameter glass envelope with borosilicate UV-glass window
- Bialkali (K_2CsSb) photocathode
- 4 Focusing electrodes

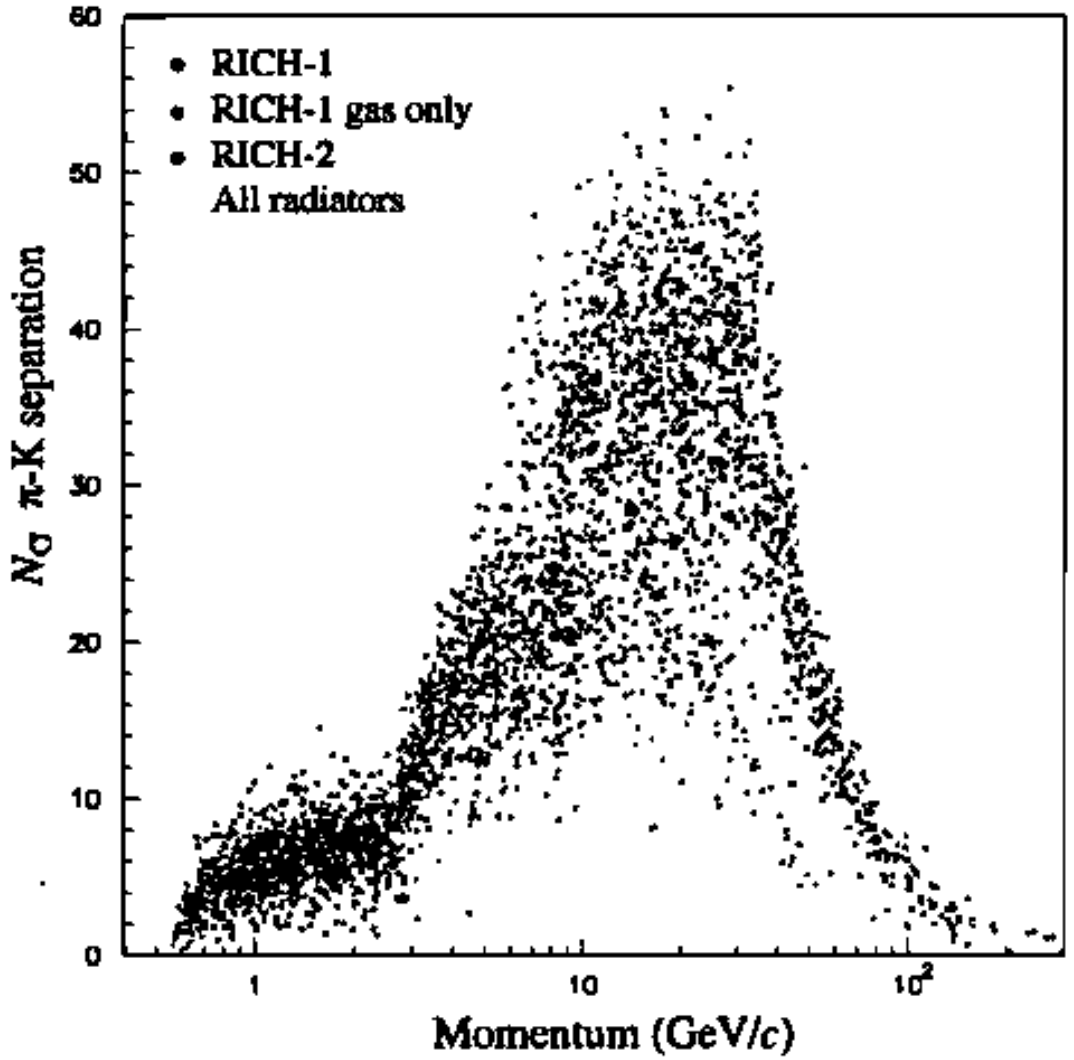


- 50mm diameter, 300μm thick.
- 16 sectors with 128 1x1mm² pad sensor.
- The sensor is wire bonded to the printed ceramic board with analog readout electronics.
- Baseplate with 40 Feedthroughs



K/π Separation Performance

Expected overall K/π separation



Particle Identification

BTEV/CP

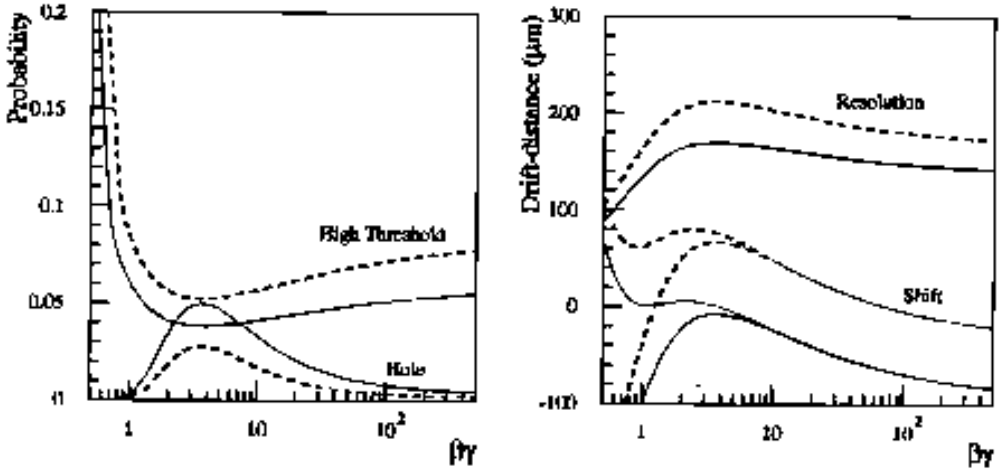
Momentum range: 3 GeV/c to 70 GeV/c (2 body decays)

Solution: A Ring Imaging Cherenkov Counter using C_4F_{10} read out with MultiAnode Photomultiplers (MAPMTs) and probably assisted by an aerogel counter using the same readout plane

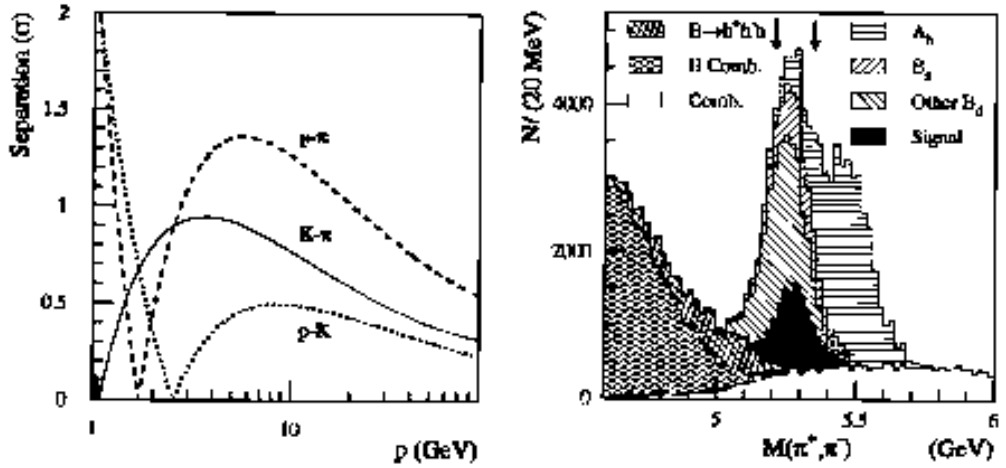
Parameter	C_4F_{10}	Aerogel
Aerogel		
n	1.00138	1.03
$\theta_c(\beta=1)$	52.5 mr	243 mr
π threshold	2.5	0.6
K threshold	9.0	2.0
p threshold	17.1	3.8
length	283cm	5cm

Error source	C_4F_{10}	Aerogel
emission pt	0.4 mr	0.1 mr
Chromatic	0.4 mr	1.9 mr
segmentation	0.2mr	0.5 mr
error/photon	0.6 mr	2.0 mr
# of photons	50	9
error/track	**0.094mr**	**0.7 mr**

TRT π/K separation



Left: no-hit and high-threshold hit probability vs βγ.
Right: drift-distance shift and resolution vs βγ.
Solid (dashed): track at 1.5 (0.5) mm from wire.



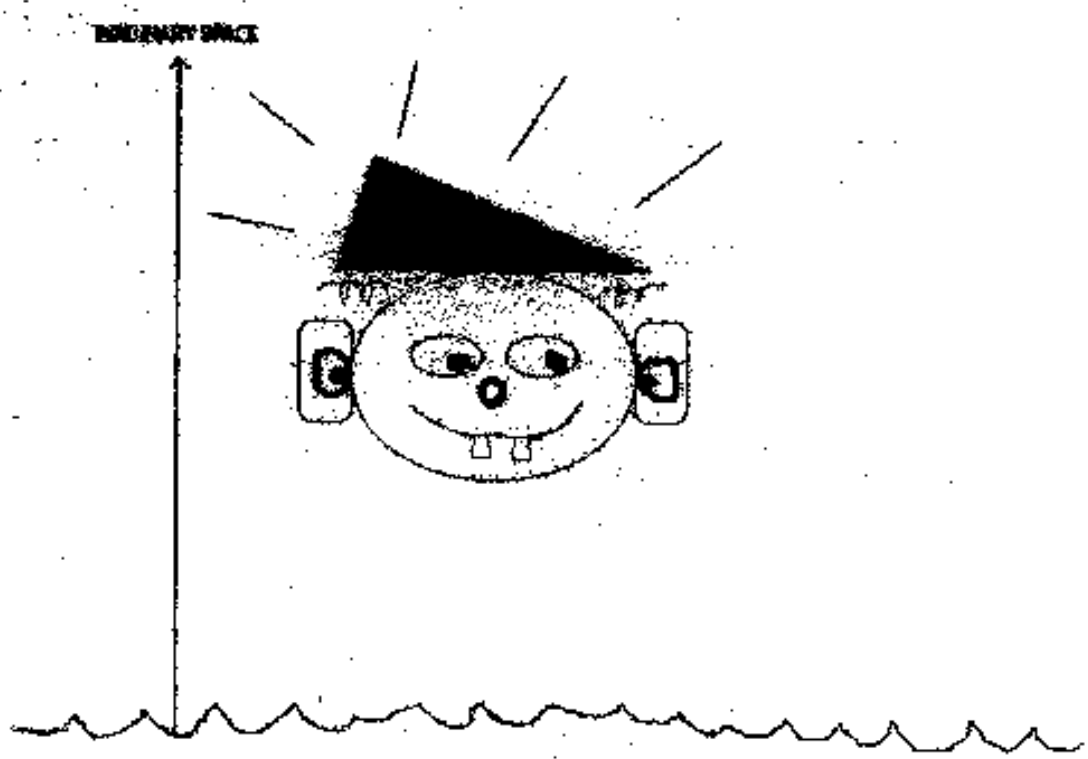
Left: separation as function of momentum.
Right: ππ mass spectrum.
TRT particle identification improves by 35% the sensitivity to $B_d^0 \to \pi\pi$ decay asymmetry (global fit).

Performance comparison

****** 1% measurement**
***** few % measurement**
**** 10% measurement**
*** a mensurement**

	BaBar Belle	HeraB	CDF D0	LHCb	Atlas CMS	BTeV
sin2β	**	**	**	****	****	****
sin2α	**	**	**	***	**	***
	nπ modes, isos-pin?			hh ?		hh ?
angle γ	(* ?)			***		***
	D*π, Kπ?			D_sK D^0K^* $D^*\pi$		D_sK D^0K^* $D^*\pi$
B_s mixing		*	*	***	**	***
B_s analy-ses		*	**	***	**	***
B->μμ B->Kγ	** (Kγ)			***	**(κ)	***

Conclusions

These are exciting times for us class-B-physicists...

Something is becoming visible above the horizon, and we are eagerly hoping that the "something" is not a triangle...