Initial Performance of the BaBar Experiment

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Measuring CP violation in the B system

Interference between mixing and direct decay of B0 to a CP eigenstate leads to the time-dependent asymmetry

$$A(\delta t) \equiv \frac{N(\delta t) - \overline{N}(\delta t)}{N(\delta t) + \overline{N}(\delta t)} \propto A_{CP} \sin(\Delta m_d \, \delta t)$$

Where:

$N(\delta t)$ is the number of $B^0(\delta t = 0)$ that decay to f_{CP} at time δt.

$\overline{N}(\delta t)$ is the number of $\overline{B}^0(\delta t = 0)$ that decay to f_{CP} at time δt.

Typical branching fraction for f_{CP} is $\approx 10^{-4}$ or less.

Experimental Requirements:

- Produce and observe millions of B hadrons / year.
- Measure ("tag") initial flavor of B hadron that decays to f_{CP}

- For $\Upsilon(4s)$ resonance:

  $B^0\overline{B}^0$ produced coherently.

  δt ranges from $-\infty$ to ∞.

  $\int_{-\infty}^{+\infty} d\delta t \; A(\delta t) = 0.$

  Measurement of δt essential!

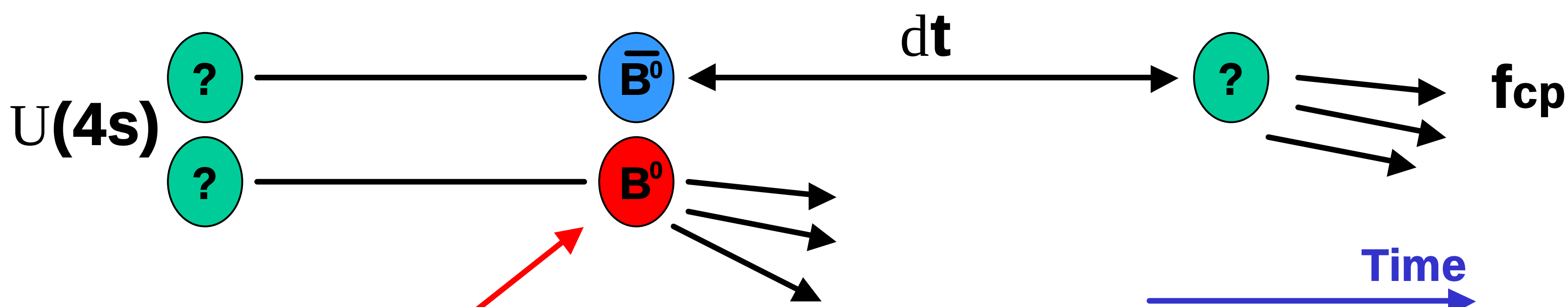
- For Z^0 or $p\overline{p} \to b\overline{b}\,X$

  b and $\overline{b}$ hadronize independently.

  δt ranges from 0 to ∞.

  $\int_{0}^{+\infty} d\delta t \; A(\delta t) \neq 0$ if $A_{CP} \neq 0.$

Flavor Tagging



Can't hope to fully reconstruct. Use flavor of daughters to tag B flavor.

Kaons

$\bar{B}^0$ $b \rightarrow c \rightarrow s$ K^-

B^0 $\bar{b} \rightarrow \bar{c} \rightarrow \bar{s}$ K^+

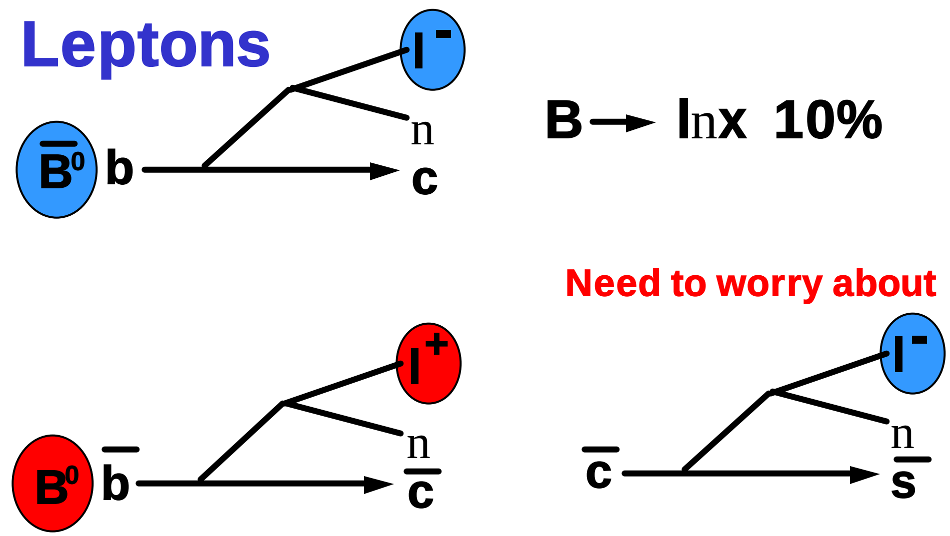
$\frac{c}{\bar{u}}D^0 \rightarrow K^- x$ 53 %

$K^+ x$ 3 %

$\frac{c}{\bar{d}}D^0 \rightarrow K^- x$ 24 %

$K^+ x$ 6 %

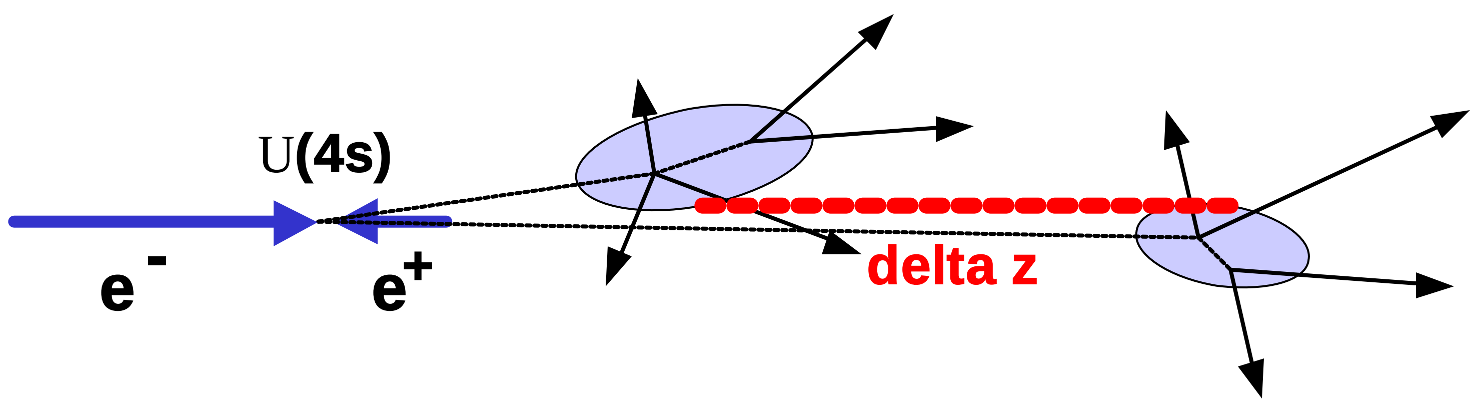
Leptons



PEP-II asymmetric B factory design parameters

- Luminosity = 3×10^{33} cm^{-1} s^{-1}
  - Achieved through high currents and strong focusing.
    - HER(e^-) = 990 mA, LER(e^+) = 2160 mA, 1658 bunches.
  - L x 1.05 nb x 10^7 s / year = **30 million BB / year**.
  - **Satisfies high statistics requirement for CP measurement.**

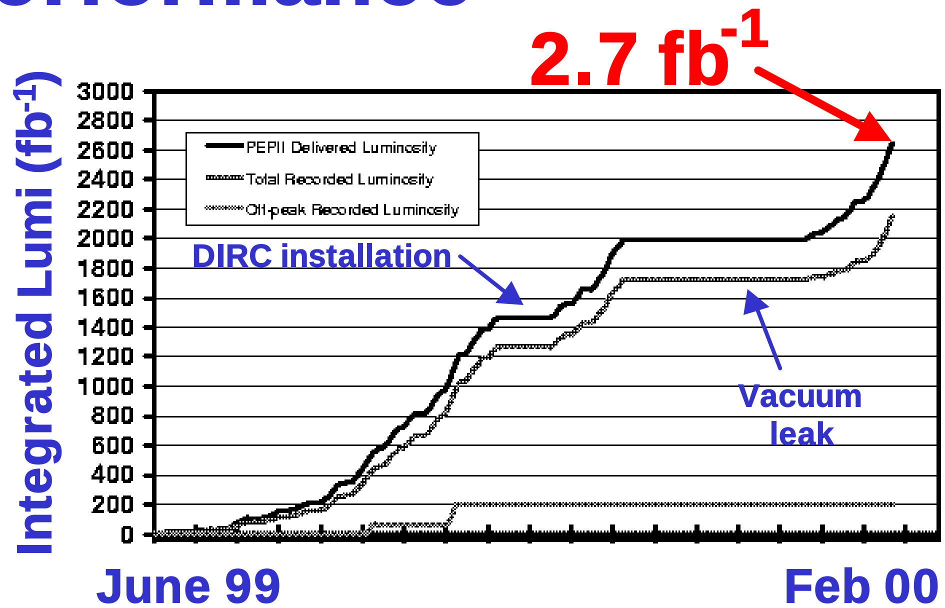
- Beam energies: HER(e) = 9.0 GeV, LER(e) = 3.1 GeV.
  - B hadrons in lab have **$\beta\gamma$ = 0.56**, $c\tau\beta\gamma$ = 250 μm.
  - **Boost of CM frame means can measure delta z which gives delta t.**



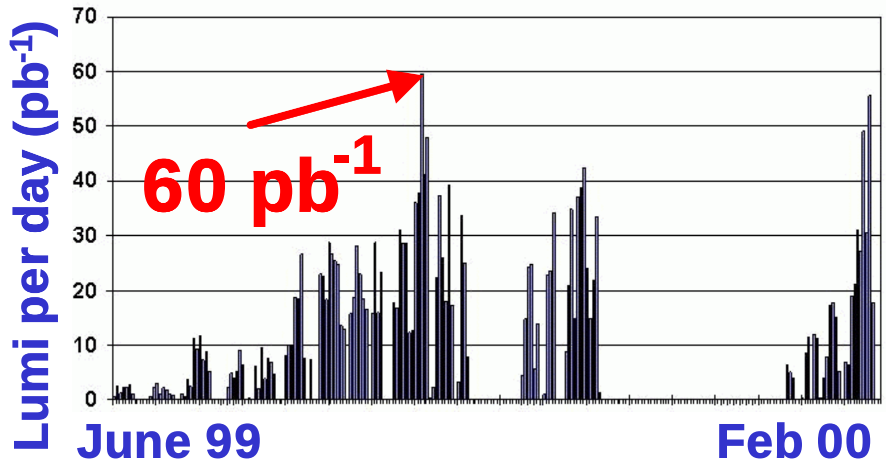
PEP-II performance

Timeline:

- **May 97 - HER commissioning begins**
- **July 98 - LER installation complete.**
  HER: 759 mA, 1222 bunches.
- **Feb 99 - LER: 1171 mA (world record).**
- **March 99 - Install BaBar.**
  $L = 5.2 \times 10^{32}$, 786 bunches.
  HER: 350 mA, LER: 680 mA.
- **May 99 - First collisions with BaBar.**
- **Nov 99 - $L = 1.4 \times 10^{33}$ (world record).**

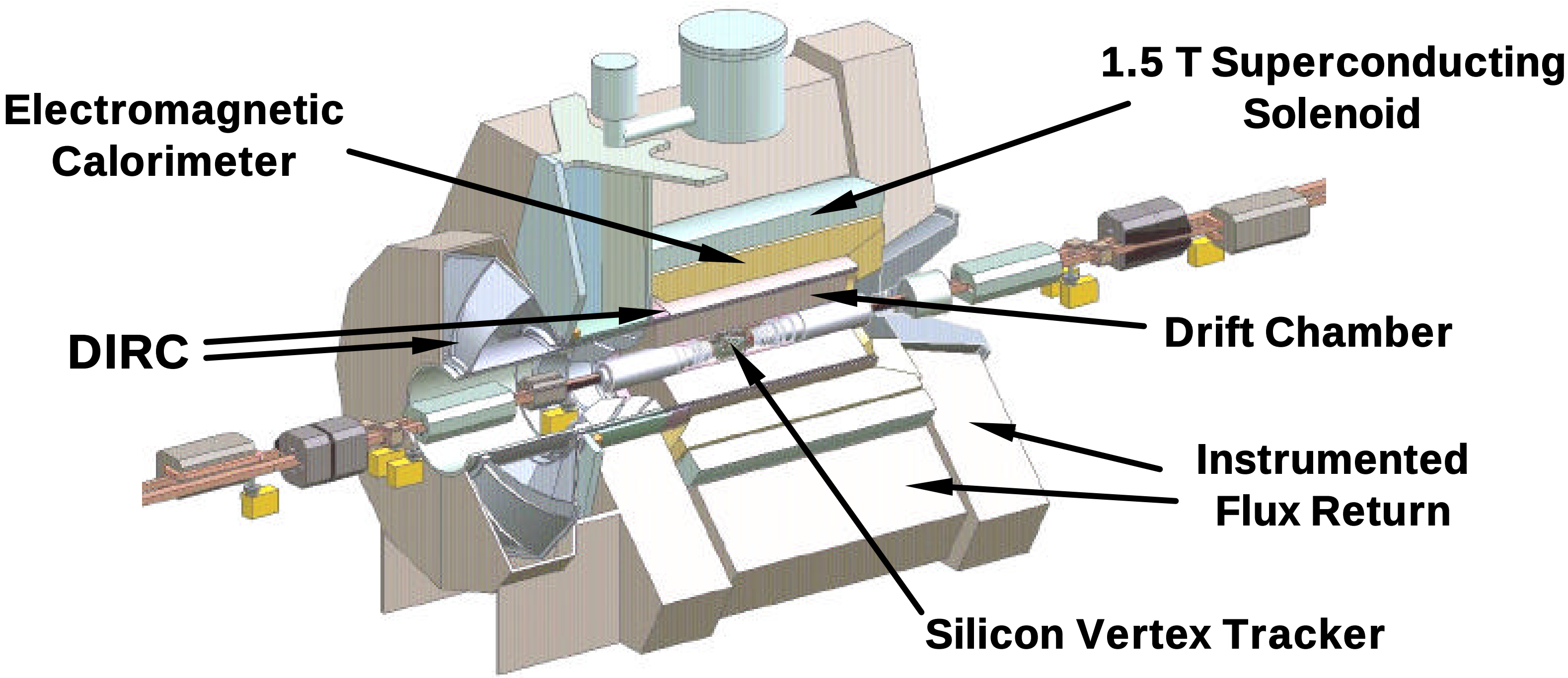


- **Luminosity already 1/2 design.**
- **Always on or ahead of schedule.**
- **Backgrounds a bit high but within operational limits.**



The BaBar Experiment

- **Silicon Vertex Tracker (SVT): 5 layers of double-sided Si. Delta z resolution < 120 μm.**
- **Drift chamber (DCH): P measurement and particle ID through dE/dX (low P).**
- **Detector of Internally Reflected Cherenkov Light (DIRC): particle ID (high P).**
- **Electromagnetic calorimeter (EMC): π^0 and K^0-long reconstruction, e ID.**
- **Instrumented Flux Return (IFR): μ ID and K^0-long reconstruction.**
- **Trigger: Two levels: L1 up to 2 KHz, L3 up to 100 Hz.**
- **Offline software and event store: C++ and Object Oriented databases.**



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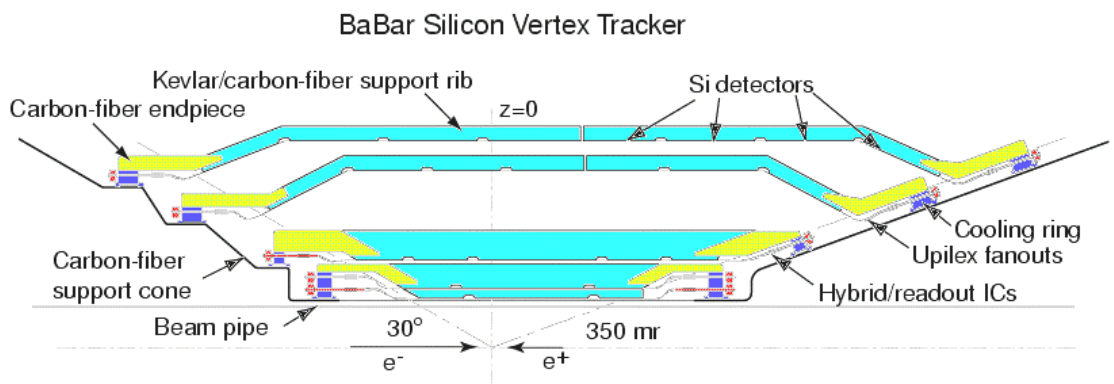
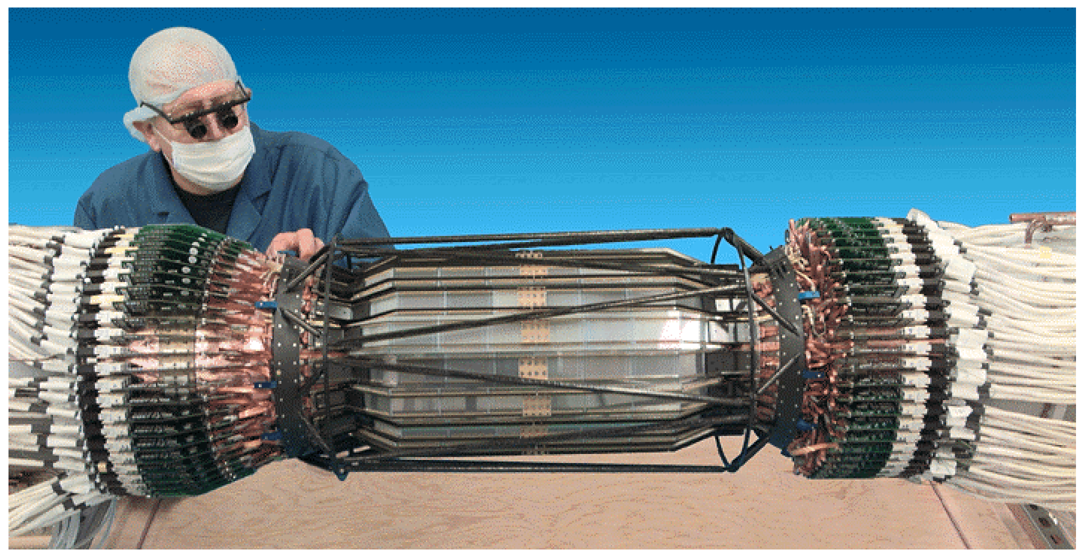
The Silicon Vertex Tracker

Design features:
- **5 layers, double-sided Si.**
- **Custom rad-hard readout IC.**
- **Low mass design.**
- **Inner 3-layers: angle and d0**
- **Outer 2-layers: pattern rec.**
- **Low Pt tracking (50-200 MeV).**

Operating history:
- **9 / 208 sections bad (4.3%).**
  - **8 bad at time of installation.**
  - **1developed short after solenoid quench.**
- **Noise levels consistent with test bench measurements:**
  - **Noise 800 - 1600 ele**
  - **MIP signal 22000 ele**
- **No unexpected radiation damage.**
  - **5 p-stop shorts out of 152,000 channels!**

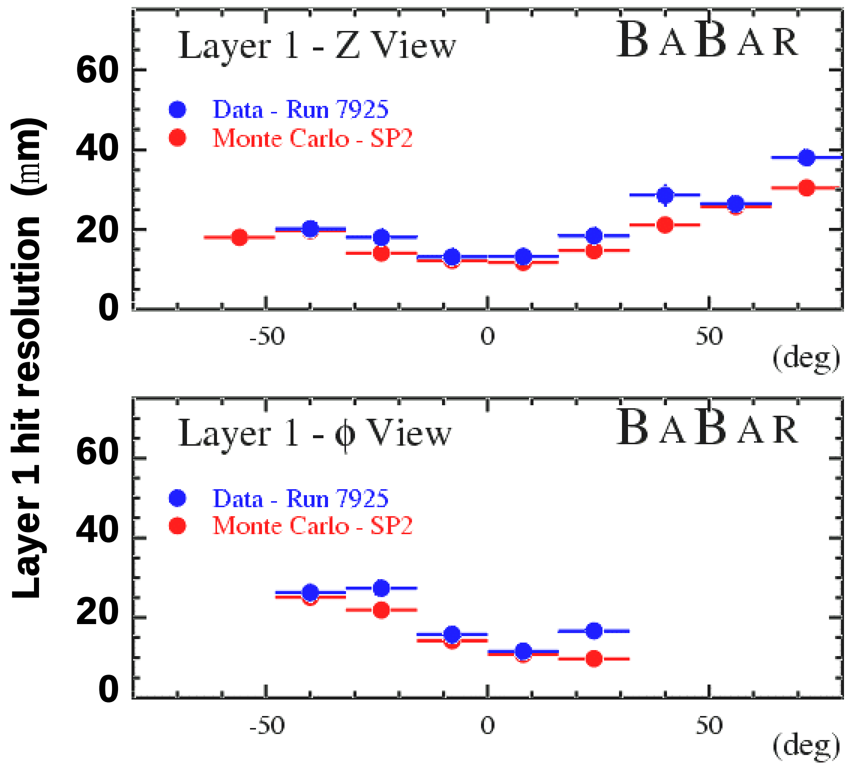




Silicon Vertex Tracker Performance

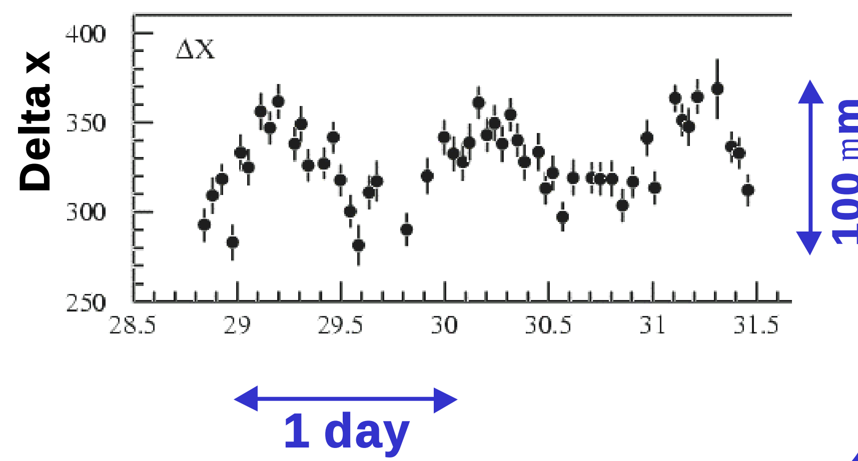
Single hit resolution in Layer 1:

- **Most important layer for delta z.**
- **Data performance is consistent with Monte Carlo and design spec.**



SVT-DCH relative alignment:

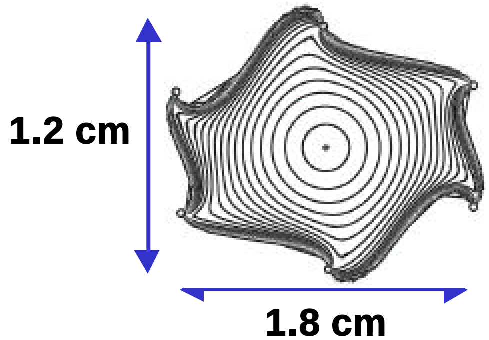
- **SVT moves by as much as 100 mm in a diurnal pattern.**
- **SVT-DCH alignment is produced for *every run* !**
- **Alignment is done automatically as a "rolling" calibration in prompt reconstruction.**
- **Good SVT-DCH alignment is crucial for obtaining good mass resolution.**

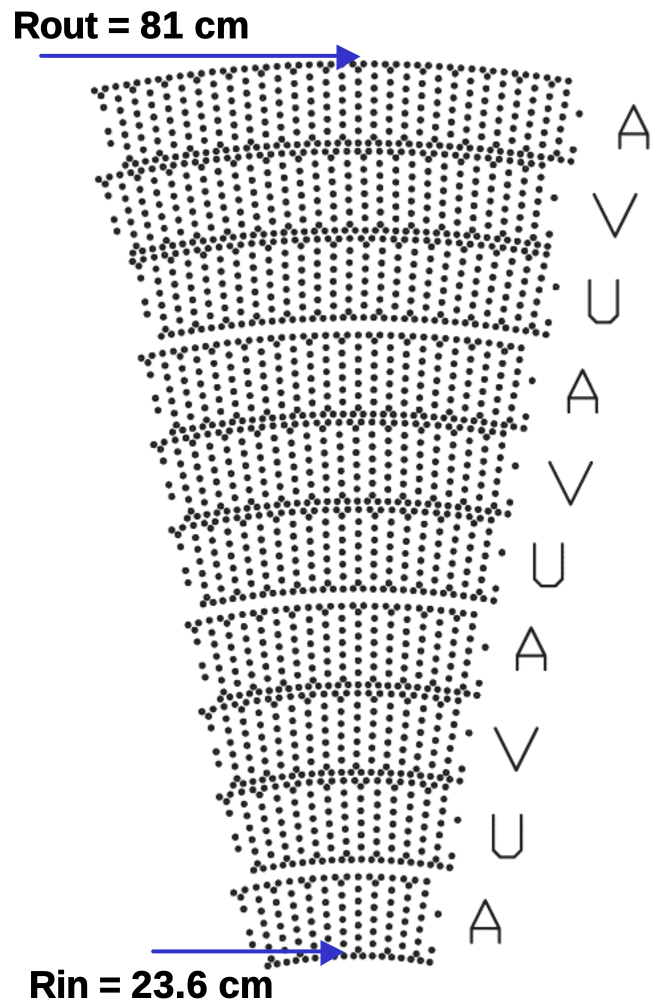


The Drift Chamber

Design specifications:
- **10 super-layers, 4 cells / super-layer.**
- **Operates in 1.5 T solenoid.**
- **Average spatial resolution per cell < 140 μm.**
- **dE/dX resolution 7% with 40 measurements.**
- **Low-mass design:**
  - **Gas: 80% Helium**
  - **Inner cylinder: 1mm Beryllium (0.28 % X_0).**
  - **Outer cylinder: Carbon fiber, foam (1.5% X_0).**

Cell geometry with 50 ns isochrones.

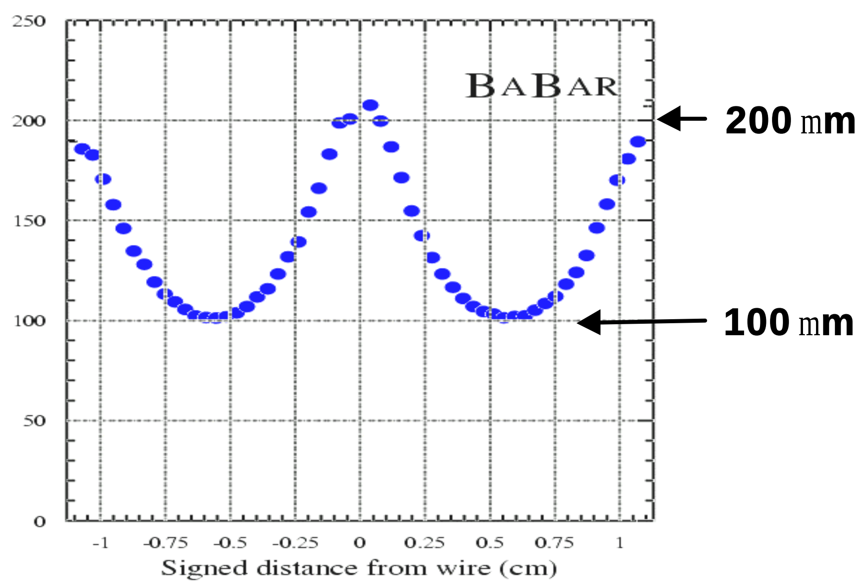


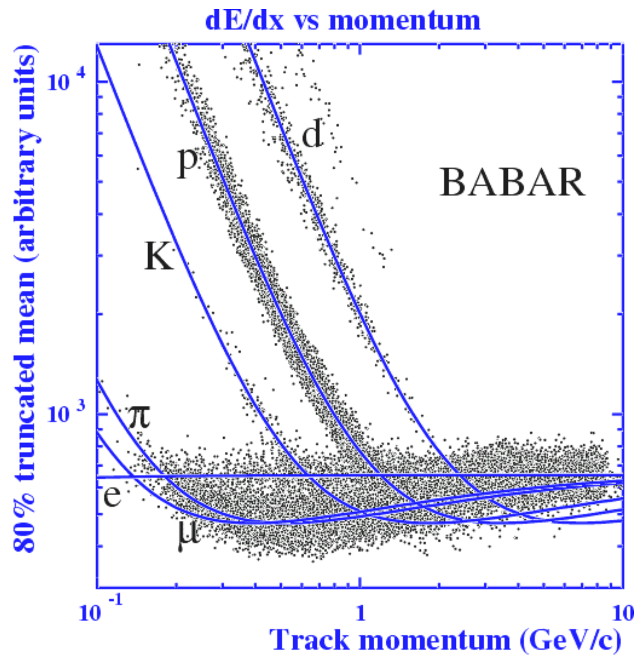


Drift Chamber Performance

- **Momentum resolution:**
  - **Measured with di-muon events. dPt / Pt = 2.9 % x Pt. Consistent with spec.**
- **Hit resolution:**
  - **Measured to be 100 - 200 μm, average value 125 μm. Exceeds spec of 140 μm.**
- **dE/dX resolution:**
  - **Measured 7.5% with bhabha events.**
  - **Hope to achieve 7% with further corrections.**

DCH Hit Resolution





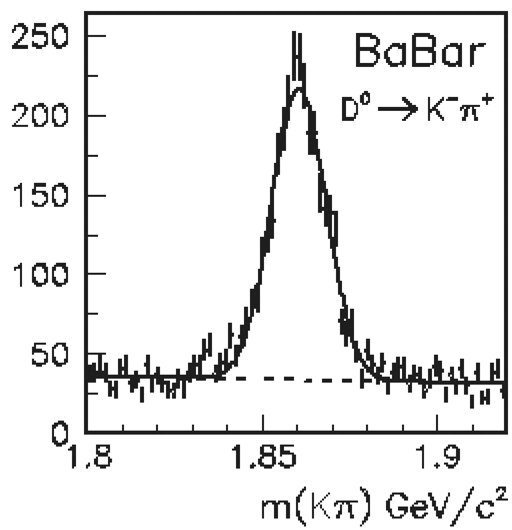
Integrated tracking performance

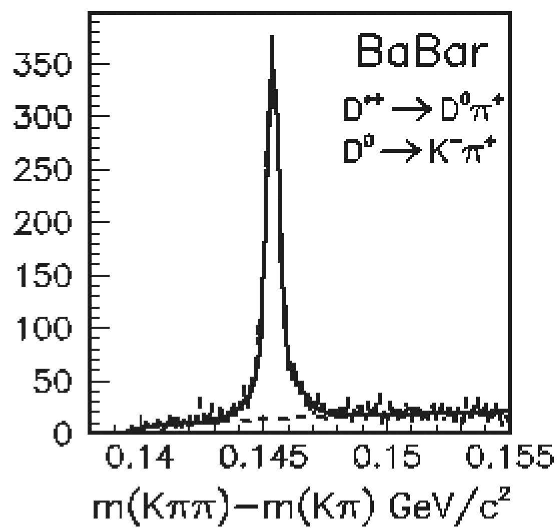
Mass resolution:

- $D^0 \rightarrow K^- p^+$ S m = 7.9 +/- 0.2 MeV/c
- $D^{*+} \rightarrow D^0 p^+$; $D^0 \rightarrow K^- p^+$ S (m(Kpp) - m(Kp)) = 252 +/- 12 KeV (55%)

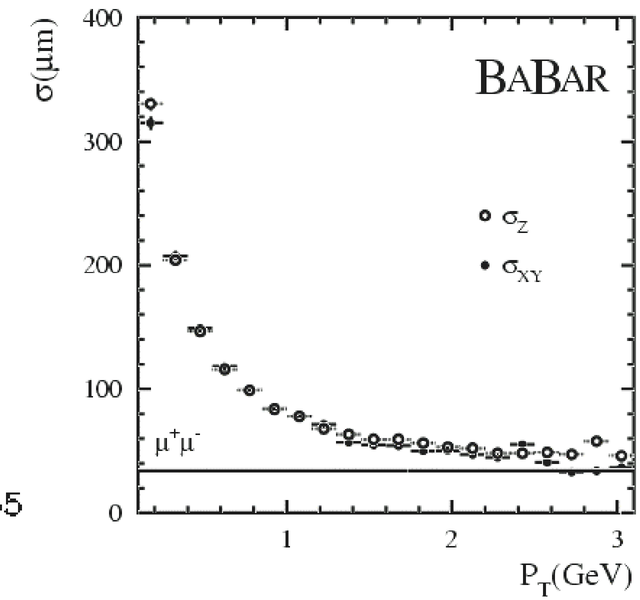
Impact parameter resolution:

- Measured with hadronic and di-muon events.
- The errors on dxy and dz are comparable.
- Asymptotic resolution < 40 mm.

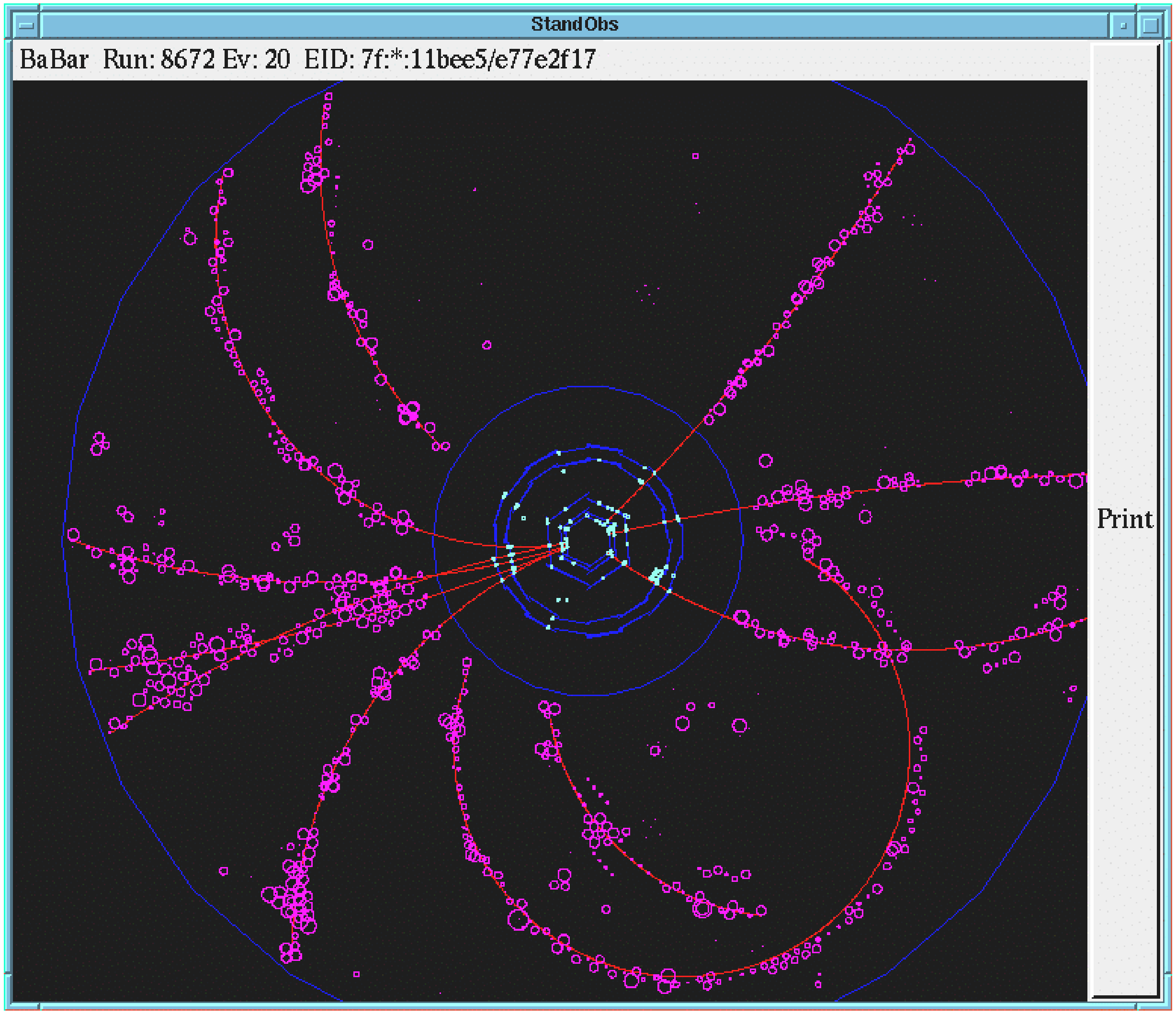




Impact parameter resolution



A Typical Event



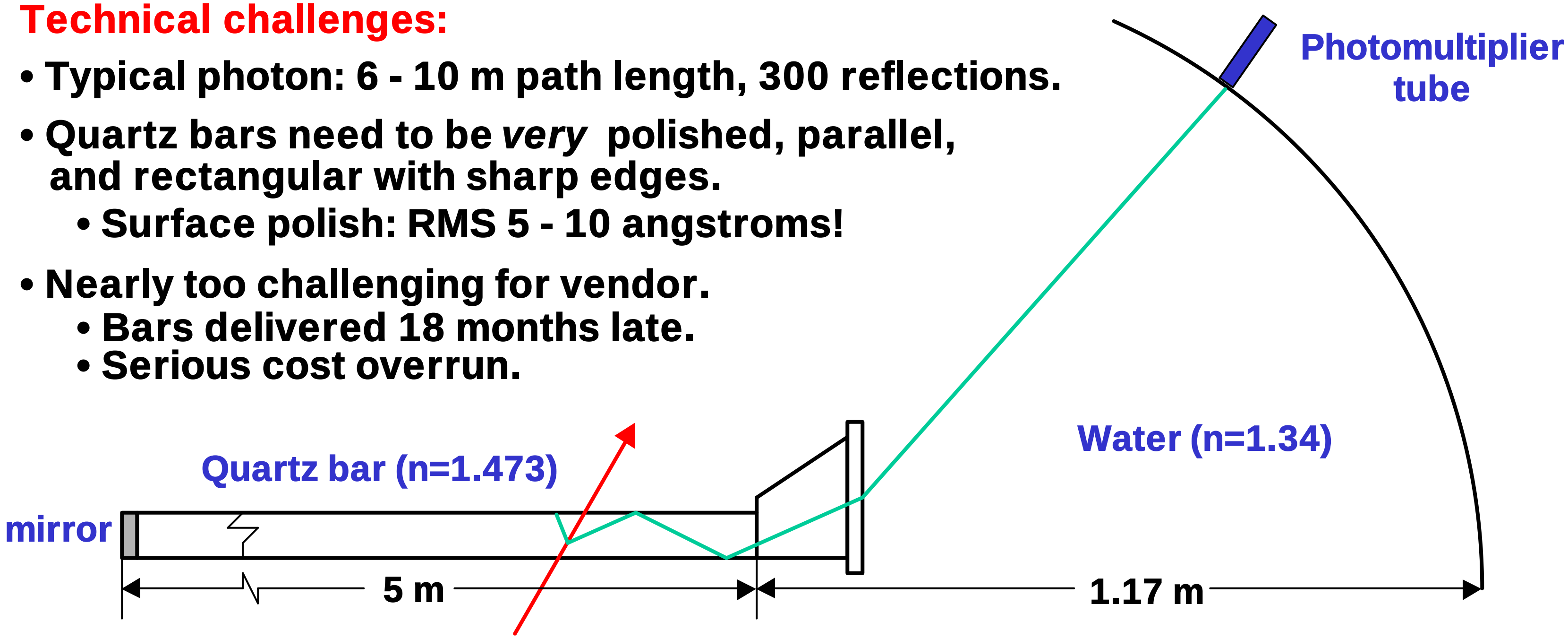
The Detector of Internally Reflected Cherenkov Radiation (DIRC)

How it works:

- **Cherenkov light generated in quartz with: $\cos\theta = 1/(n\beta)$.**
- **Angle θ preserved as light internally reflects in quartz.**
- **Cherenkov ring of photons expands in water tank and is detected with array of photomultipliers.**

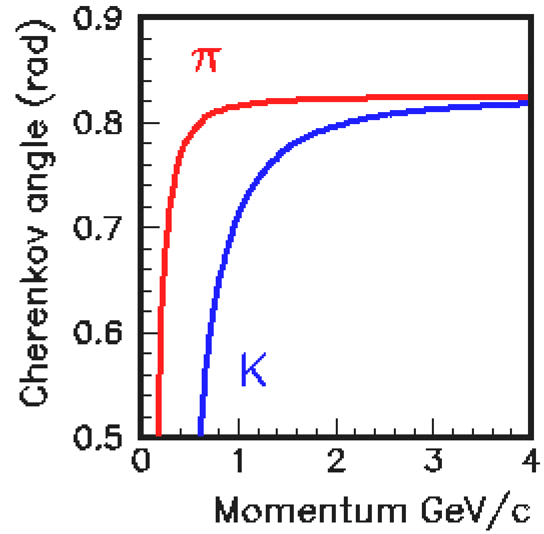
Technical challenges:

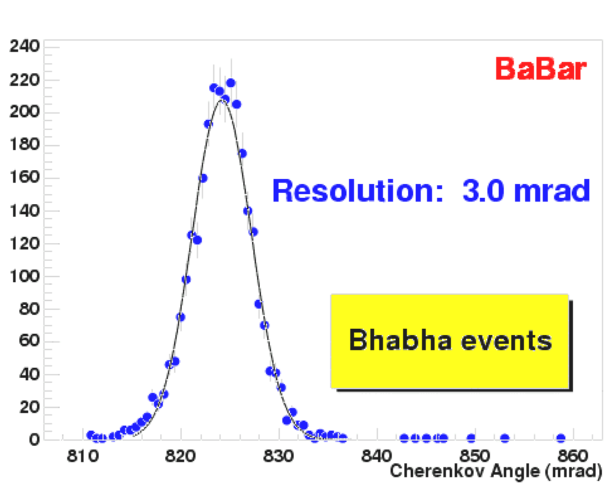
- **Typical photon: 6 - 10 m path length, 300 reflections.**
- **Quartz bars need to be *very* polished, parallel, and rectangular with sharp edges.**
  - **Surface polish: RMS 5 - 10 angstroms!**
- **Nearly too challenging for vendor.**
  - **Bars delivered 18 months late.**
  - **Serious cost overrun.**

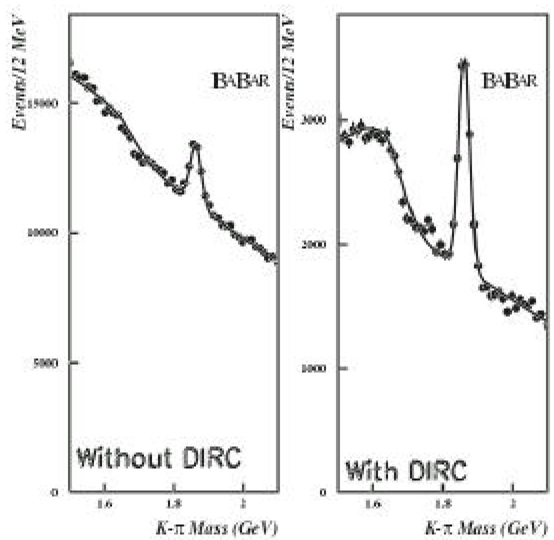


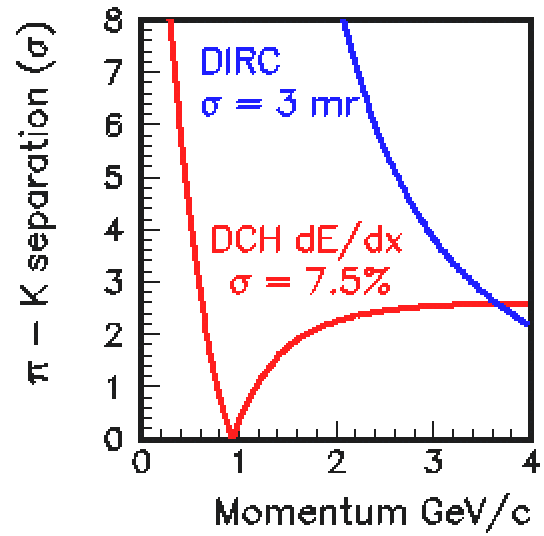
DIRC performance and comparison with dE/dx

- Cherenkov angle resolution measured to be **3.0 mrad**.
- Angle difference for Kπ at 4.0 GeV/c is 6.4 mrad.
- Improvements that will lead to design goal of 2 mrad:
  - Better event t measurement gives better BG rejection.
  - Improved reconstruction algorithm.
- DIRC and DCH dE/dx both give > 2σ Kπ separation at high momenta with current reconstruction.
- Particle identification will only get better!

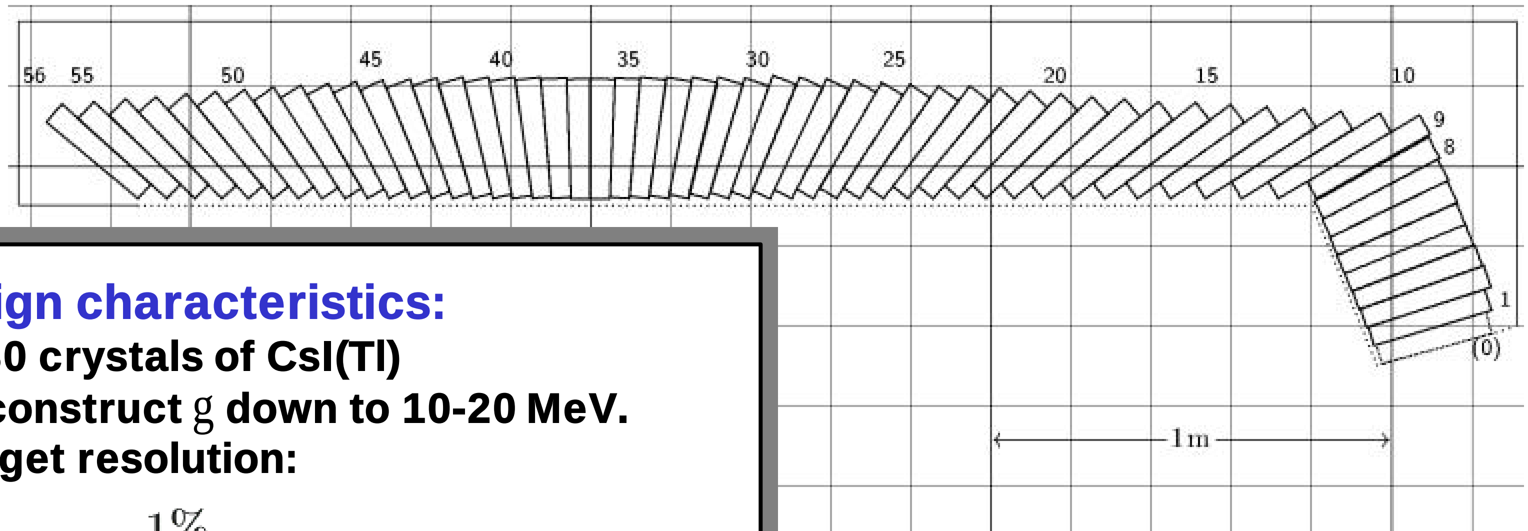








The Electromagnetic Calorimeter



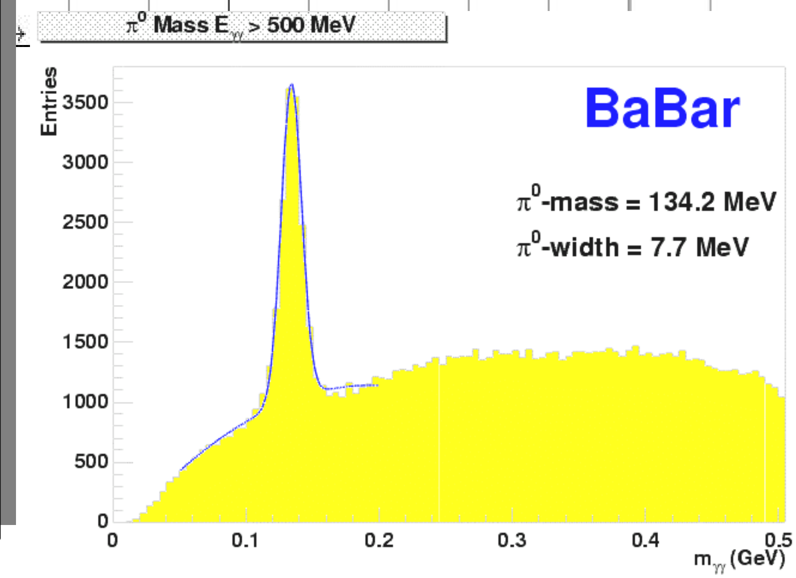
Design characteristics:

- 6580 crystals of CsI(Tl)
- Reconstruct g down to 10-20 MeV.
- Target resolution:

$$\frac{\sigma_E}{E} = \frac{1\%}{\sqrt[4]{E(\mathrm{GeV})}} \oplus 1.2\% \quad \text{at } \theta = 90^0$$

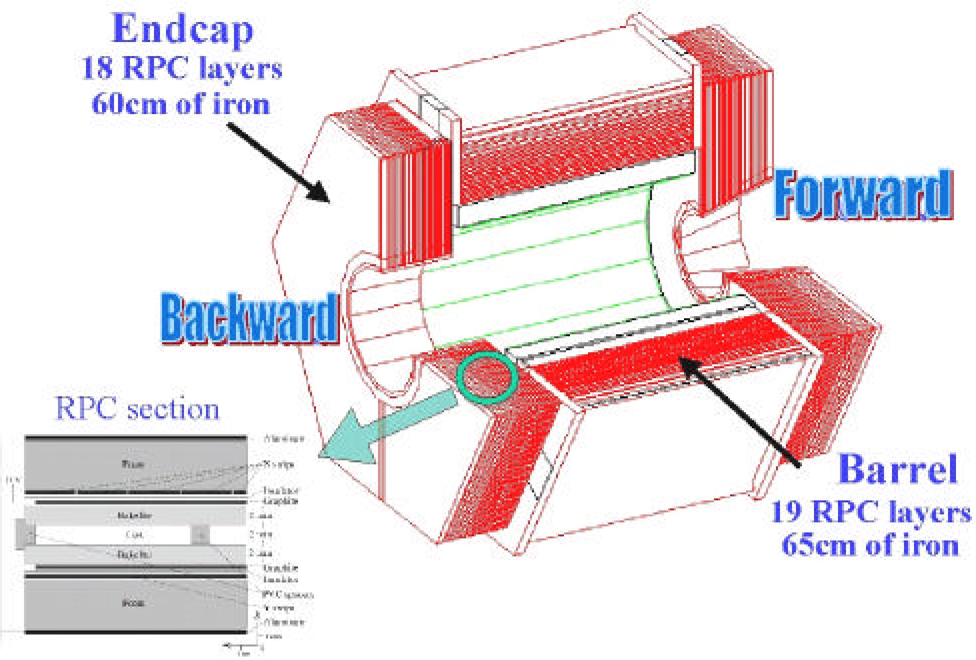
Performance:

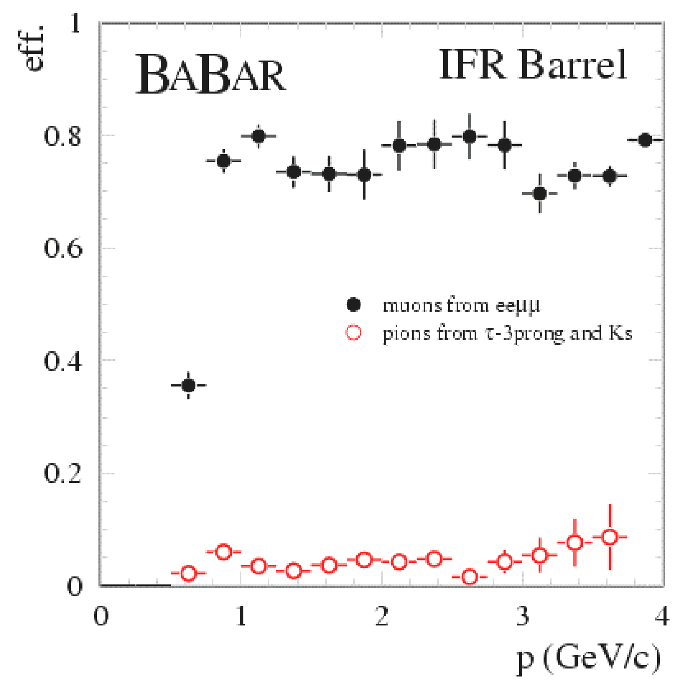
- E/P width from bhabhas 2.4 %
  - consistent with MC expectations.
- Correct p^0 mass. A bit wider than the MC.
- Significant improvements in noise.
  - Energy cut per crystal now 0.8 MeV.



The Instrumented Flux Return

- Graded segmentation of iron layers optimized for m ID and K-long reconstruction.
- Early operation had problems with iron heating up leading to high currents in the RPCs.
- Fixed by adding water cooling.





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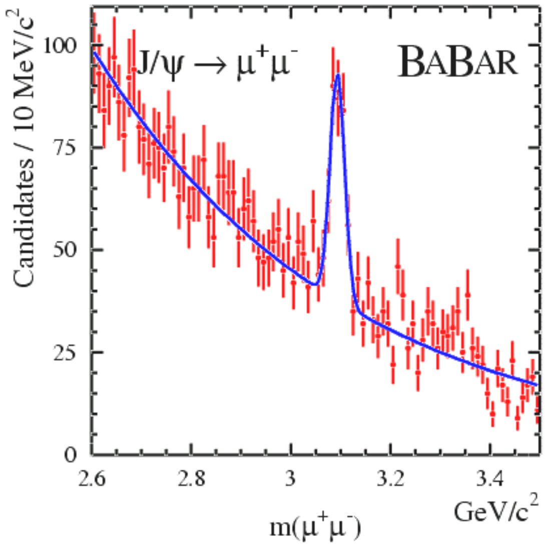
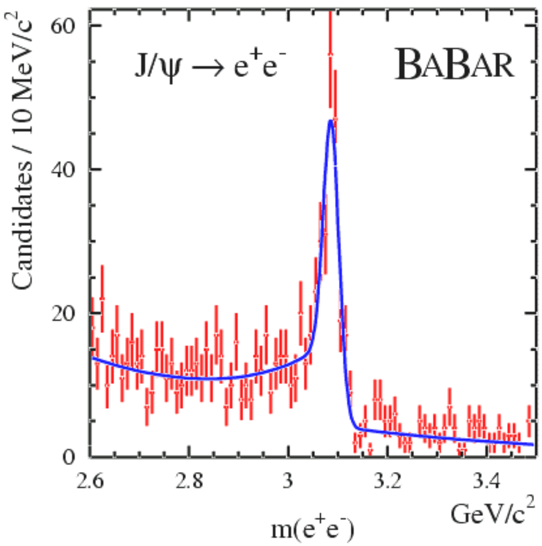
Some preliminary analysis plots

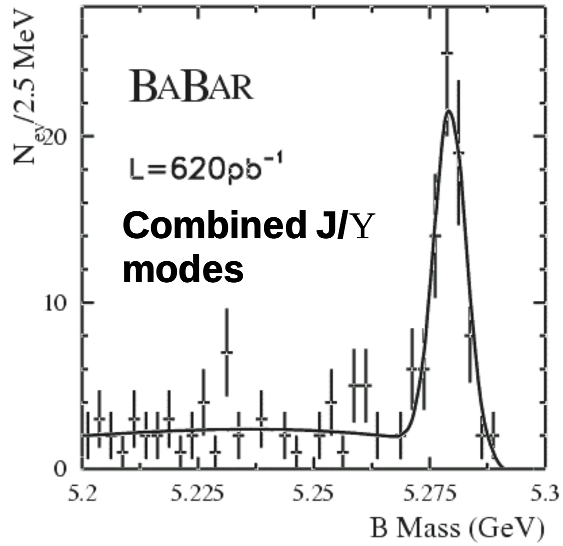


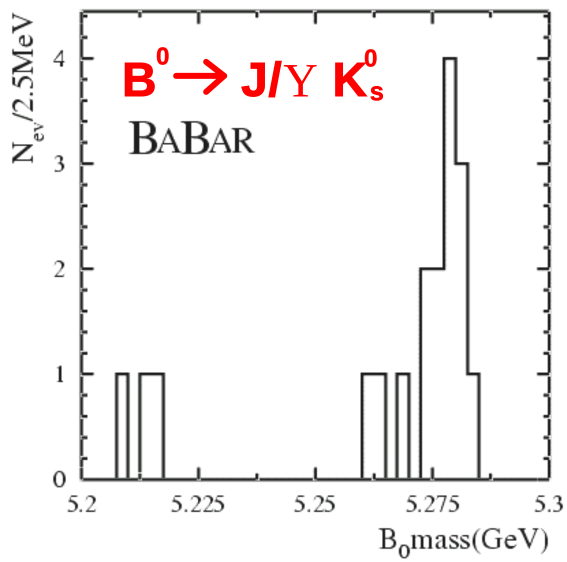


$J/\Upsilon \rightarrow e^{+} e^{-}$ and $J/\Upsilon \rightarrow m^{+} m^{-}$.

- **Plots are from**
  - **$J/\Upsilon \rightarrow e^{+} e^{-}$ 540 pb^{-1}.**
  - **$J/\Upsilon \rightarrow m^{+} m^{-}$ 380 pb^{-1}.**
- **Yield is in rough agreement with expectations.**
- **Mass resolution a bit wide.**
  - **Data 15 MeV/c^2.**
  - **MC 11 MeV/c^2.**
- **Muon selection is very loose due to hardware problems in the IFR.**
- **Working on recovering the Bremsstrahlung tail in $J/\Upsilon \rightarrow e^{+} e^{-}$.**

Some preliminary analysis plots





- **Analysis uses 620 pb^{-1}.**
- **Exclusive J/ψ modes:**
  - $B^+ \rightarrow J/\psi\ K^+$
  - $B^+ \rightarrow J/\psi\ K^{*+}$, $K^{*+} \rightarrow K^0_s\, \pi^+$, $K^0_s \rightarrow \pi^+\pi^-$.
  - $B^0 \rightarrow J/\psi\ K^{*0}$, $K^{*0} \rightarrow K^+\pi^-$.
  - $B^0 \rightarrow J/\psi\ K^0_s$, $K^0_s \rightarrow \pi^+\pi^-$.
- **Yield consistent with expectations.**
- **Improvements in calibration and reconstruction will increase efficiency, improve mass resolution, and signal to noise.**

What to expect from BaBar and PEP-II in the future

Goals for BaBar and PEP-II:

- **Record 10 fb^{-1} on peak luminosity by the end of the summer.**
  - **Already have 2 fb^{-1} in the can.**
- **First BaBar measurement of sin(2b).**

Requirements for meeting goals:

- **Steady increase of PEP-II luminosity from 1.5×10^{33} to 3.0×10^{33}.**
- **Combined BaBar & PEP-II overall efficiency >= 50%.**

Stay Tuned!