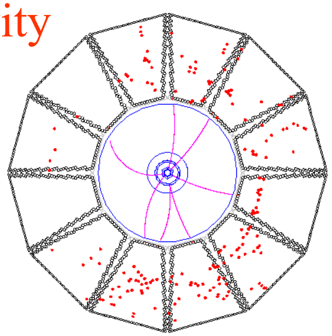
DIRC - THE PARTICLE IDENTIFICATION SYSTEM FOR BABAR

Outline:

- DIRC Concept and Design
- Operational Experience
  - Performance Highlights
  - Backgrounds and Longevity
- R&D Towards the Future



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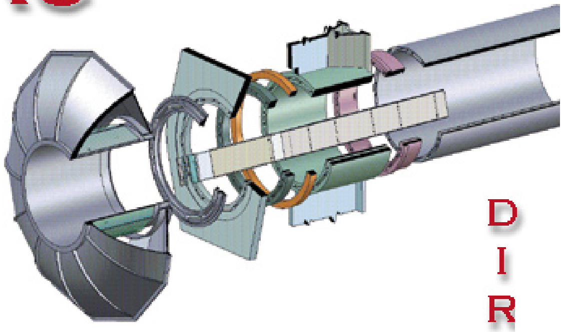
- DIRC grows out of our experience with the ring imaging Cherenkov detector in the SLD experiment, that was founded on a long partnership with Tom Ypsilantis—and called the CRID device.
- Blair Ratcliff had the **brilliant** idea of using the totally internally reflected light transported out to the end of the quartz bar radiators, to be his newly invented PID instrument.

DIRC = CRID Backwards

- The DIRC was the creation of a large international collaboration of US and French groups (see names).
- It has turned out to be a very **robust** detector
- And, is **working very** well in BaBar.

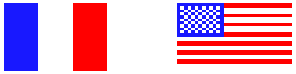
THE COLLABORATION

DIRC



DIRC combines with dE/dx from CDC and SVT (mostly in the $1/\beta^2$ region), to provide the hadronic particle identification system for BABAR.

DETECTION OF
INTERNALLY
REFLECTIVE
CHERENKOV LIGHT



The BaBar-DIRC Collaboration

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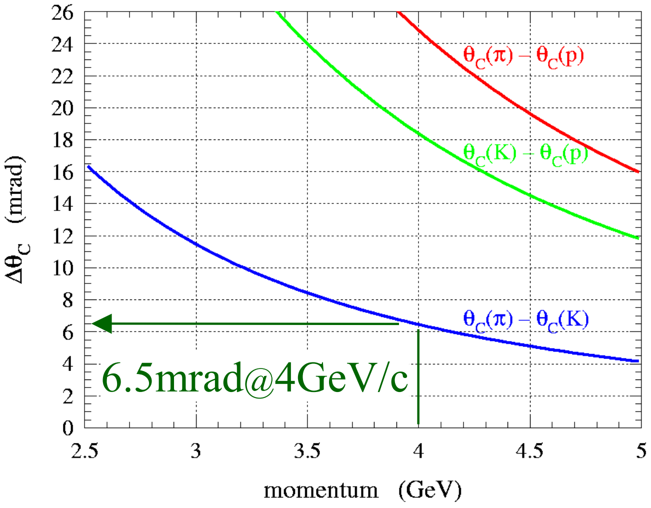
THE BABAR DIRC

BaBar requires Particle Identification (PID) up to 4.2 GeV/c momentum.

There are two distinct momentum regions and task to be done:

- $1.7 \leq p \leq 4.2$ GeV/c
- $p < 2$ GeV/c



The Particle Identification is achieved using dE/dx information from the Drift Chamber and the silicon vertex detector together with DIRC.

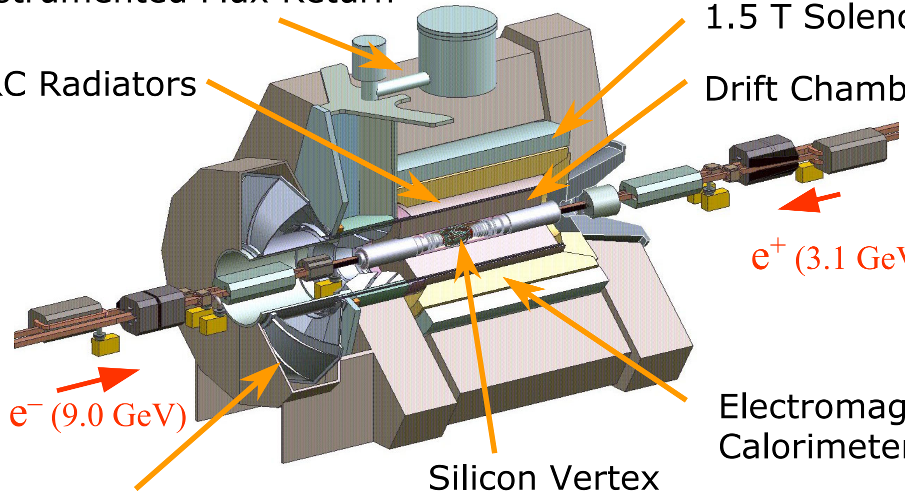
[dE/dx is effective for $p < 0.7$ GeV/c]

THE BABAR DIRC

Design Constraints:

- CsI Calorimeter needs to detect photons down to 20 MeV, thus small radiation length (< 20%) and small radial size required.
- Radiation robustness (expect 10 krad within 10 year lifetime).
- π/K separation at 4 GeV/c; this requires 2.2mrad angular resolution, to provide a 3σ separation.

THE DIRC IN BABAR



Instrumented Flux Return

DIRC Radiators

1.5 T Solenoid

Drift Chamber

e^+ (3.1 GeV)

e^- (9.0 GeV)

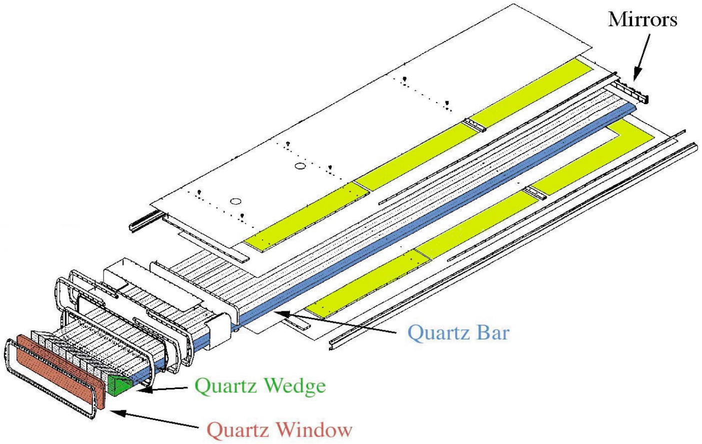
Electromagnetic Calorimeter

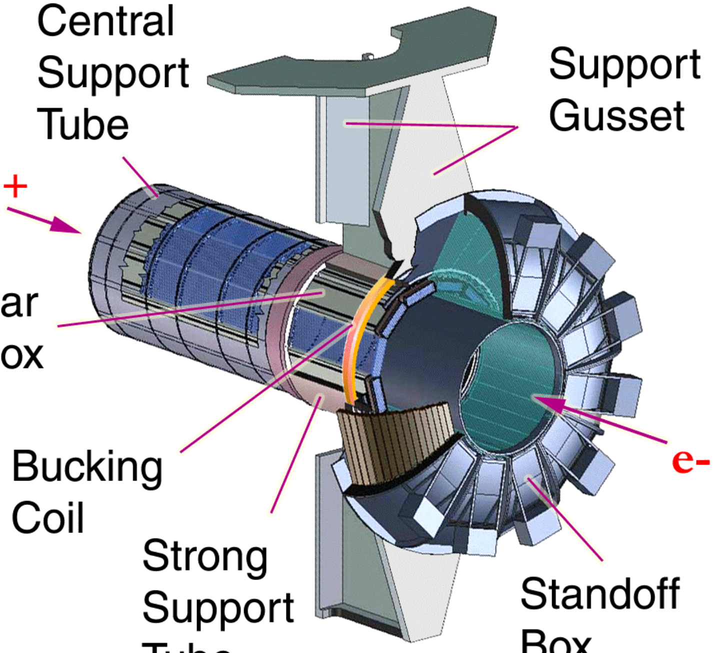
Silicon Vertex Detector

DIRC Standoff Box and Magnetic Shielding

DIRC thickness:
8 cm radial incl. supports
19% radiation length
at normal incidence

DIRC radiators cover:
94% azimuth,
83% c.m. polar angle





Central Support Tube

Support Gusset

e+

Bar Box

Bucking Coil

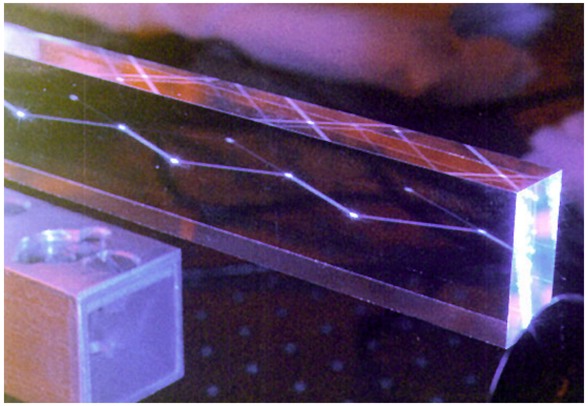
Strong Support Tube

Standoff Box

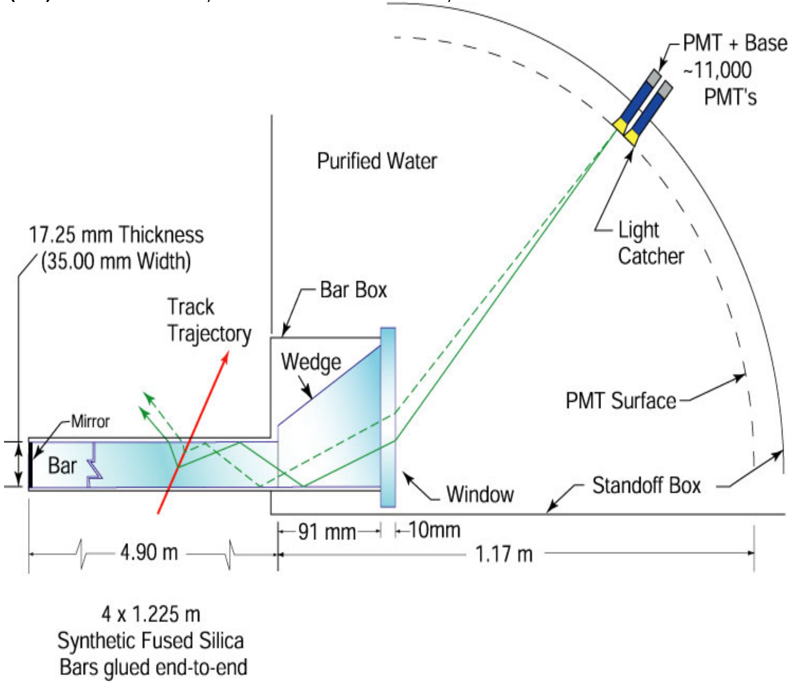
e-

DIRC PRINCIPLE, PART I

- A charged particle traversing a radiator with refractive index n with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos \theta_c = 1/n\beta$.
- If $n > \sqrt{2}$ some photons are always totally internally reflected for $\beta \approx 1$ tracks.



- Radiator and light guide: Long, rectangular Synthetic Fused Silica ("Quartz") bars (*Spectrosil:* average $<n(\lambda)> \approx 1.473$, radiation hard, homogenous, low chromatic dispersion;
  144 bars: $490 \times 1.7 \times 3.5$ cm^3,
  polished to surface roughness <5Å (*rms*);
  square to better than 0.3 mrad.)
- Square radiator bar → magnitude of θ_c preserved during internal reflections.



Typical DIRC photon:
  $\lambda \approx 400$ nm,
  ~ 200 bounces,
  ~ 10-60 ns propagation time
  ~ 5 m average path in bars.

DIRC PRINCIPLE, PART II

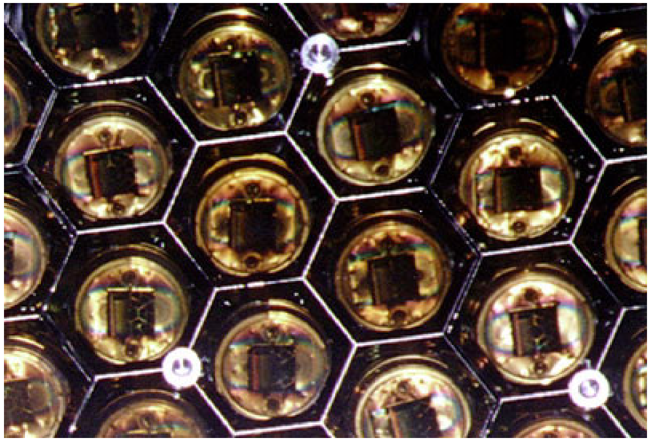
- Only one end of bar instrumented; mirror attached to other (forward) end.
- Spectrosil wedge glued to readout end reduces required number of PMTs by ~ factor 2 and improves exit angle efficiency for large angle photons .
- Photons exit from wedge into expansion region (filled with 6m^3 pure, de-ionized water).

  ($<n_{water}(\lambda)> \approx 1.346$, Standoff distance ≈ 120 cm, outside main magnetic field; shielding: B < ~ 1 Gauss)

- Pinhole imaging on PMT array (bar dimension small compared to standoff distance).

  (10,752 traditional PMTs ETL 9125, immersed in water, surrounded by hexagonal "light-catcher," transit time spread ~1.5 nsec)

- DIRC is a 3-D device, measuring: x, y and time of Cherenkov photons.
- PMT / radiator bar combination plus track direction and location from tracking define θ_c, ϕ_c, $t_{propagation}$ of photon.



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DIRC MEASUREMENTS

- ***DIRC measures photon arrival time at PMT position***

$$\left.\begin{matrix} x_{PMT} \\ y_{PMT} \\ t_{arrival} \end{matrix}\right\} \rightarrow \left\{\begin{matrix} \theta_{c}, \\ \varphi_{c} \\ \Delta t = t_{arrival} - t_{propagation} \end{matrix}\right.$$

consistency!

- ***expected uncertainties***

per photon:

$$\Delta\theta^2_C = \overset{\sim 1\text{-}2\ \text{mrad}}{\Delta\theta^2_{C,track}} + \overset{\sim 5.4\ \text{mrad}}{\Delta\theta^2_{C,dispersion}} + \overset{\sim 1\text{-}4\ \text{mrad}}{\Delta\theta^2_{C,transport}} +$$

$$\overbrace{\Delta\theta^2_{C,imaging} + \Delta\theta_{PMT}^2}^{\sim 7.0\ \text{mrad}}$$

$$\Delta t^2 \sim \Delta t^2_{PMT} \sim (1.7\ \text{ns})^2$$

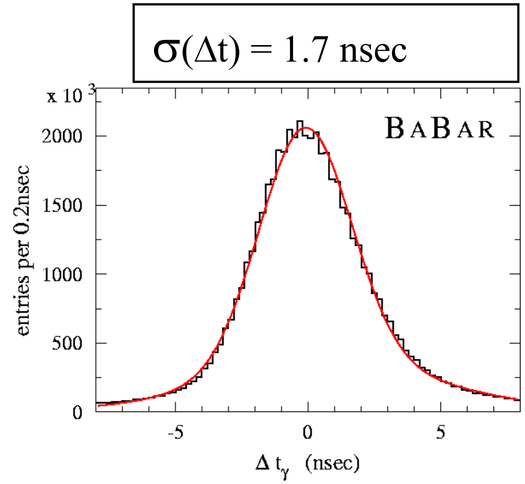
per track: $\Delta\theta^{track}_C \sim \Delta\theta^{photon}_C/\mathrm{sqrt}(N_{photons\text{-}per\text{-}track}) \oplus \Delta\theta^2_{C,track}$

DIRC RECONSTRUCTION

Time information provides powerful tool to reject accelerator and event related background.

Calculate expected arrival time of Cherenkov photon based on

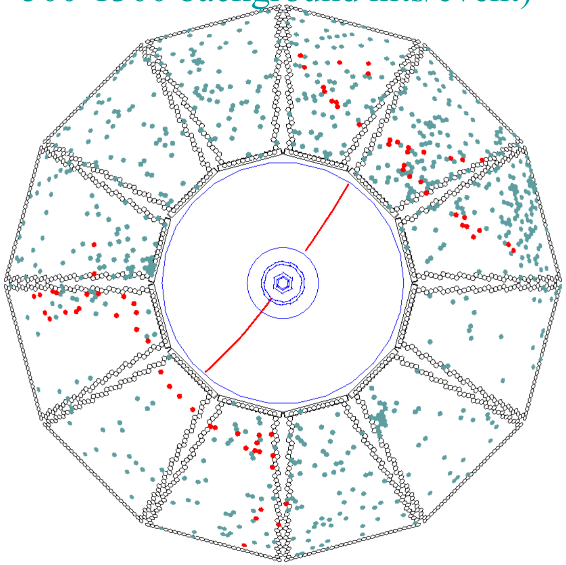
- track TOF
- photon propagation in radiator bar and in water


σ(Δt) = 1.7 nsec

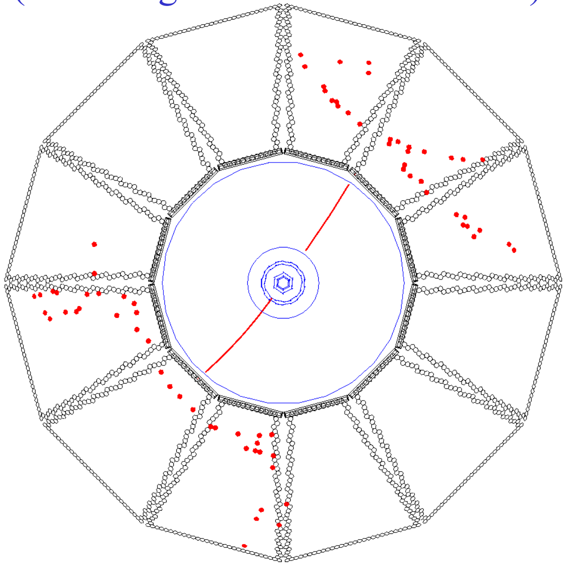
Δt: difference between measured and expected arrival time

± 300 nsec trigger window →
(~500-1300 background hits/event)

±8 nsec Δt window
±(1-2 background hits/sector/event)



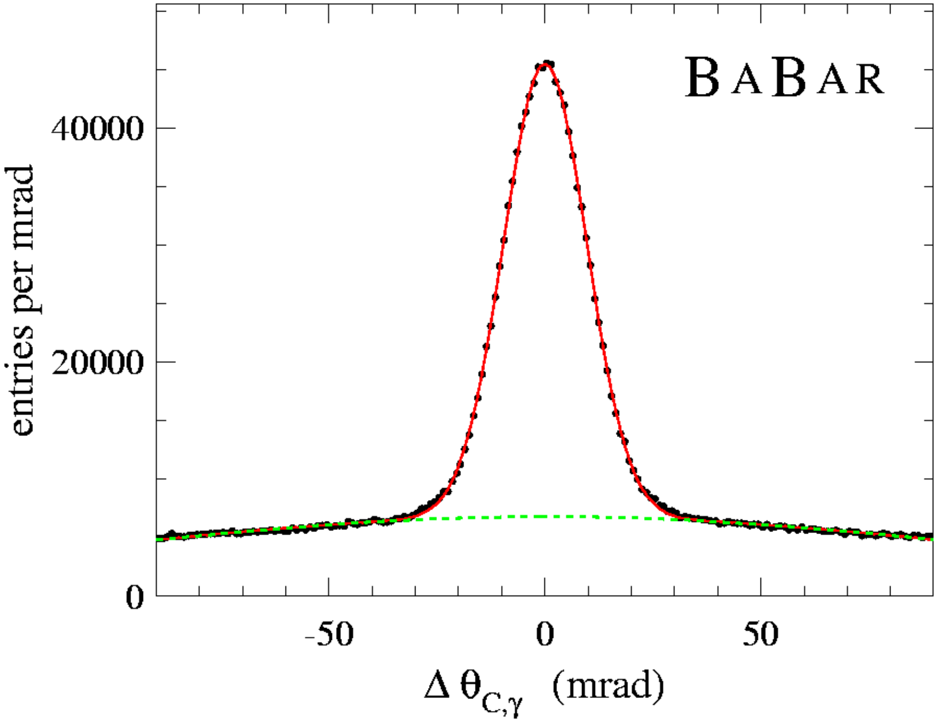
→



DIRC PERFORMANCE

Single Photon Cherenkov angle resolution:

$\Delta\theta_{c,\gamma}$: difference measured $\theta_{c,\gamma}$ per photon solution
and θ_c of track fit (di-muons)



$\sigma(\Delta\theta_{c,\gamma}) = 9.6$ mrad

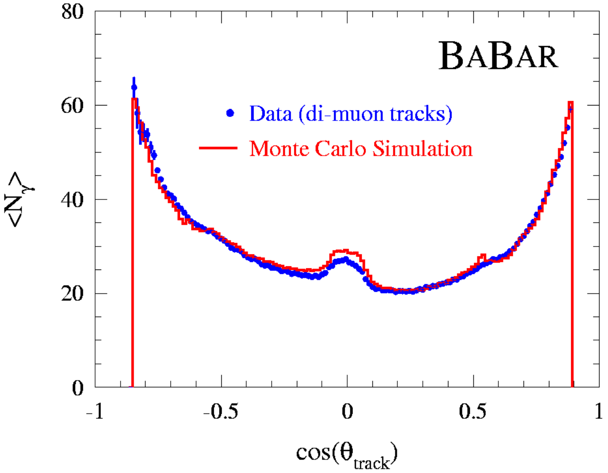
Expectation: ~9.5 mrad

dominated by:
7mrad from PMT/bar size,
5.4mrad from chromatic term,
2-3mrad from bar imperfections.

~10% Background under $\Delta\theta_{c,\gamma}$ peak:
combinatoric background, track overlap, accelerator background,
δ electrons in radiator bar, reflections at fused silica/glue interface, ...

DIRC PERFORMANCE

Number of Cherenkov photons per track (di-muons) *vs*. polar angle:



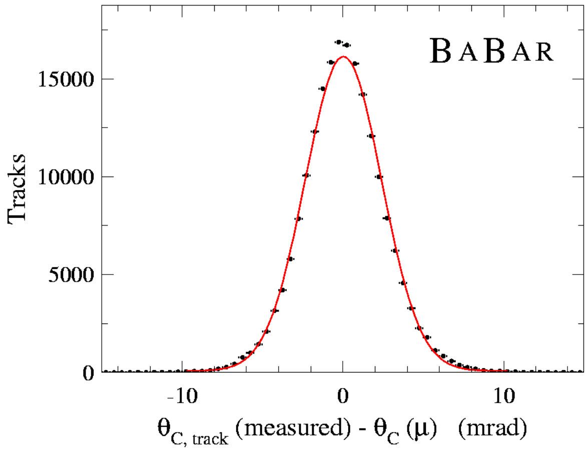
Between 20 and 60 signal photons per track.

Very useful feature in BABAR environment:

higher momentum correlated with larger polar angle values

→ more signal photons, better resolution ($\sim 1/\sqrt{N}$)

Resolution of Cherenkov angle fit per track (di-muons):



$\sigma(\Delta\theta_{c,}) = 2.4$ mrad

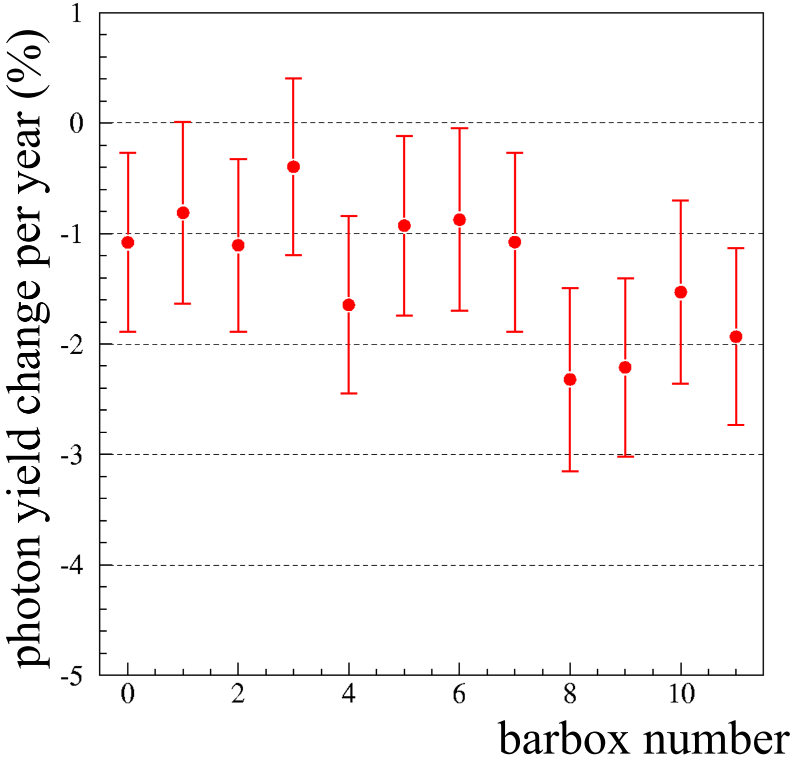
Track Cherenkov angle resolution is within ~10% of design.

Should improve with advances in track- and DIRC-internal alignment.

DIRC OPERATIONAL EXPERIENCE: PHOTON YIELD

Concern: stability of photon yield

- Observed PMT front glass corrosion;
- No direct experience with maintaining high (>0.999) radiator reflection coefficient for 10 years.



Detailed study of photon yield using:

- LED pulser calibration,
- PMT aging tests,
- comparison of photon yield in real Bhabha and di-muon events separately for every radiator bar (box).

Consistent result:

1-2% photon yield loss per year.

→ very minor impact on PID performance over 10 year lifetime of DIRC.

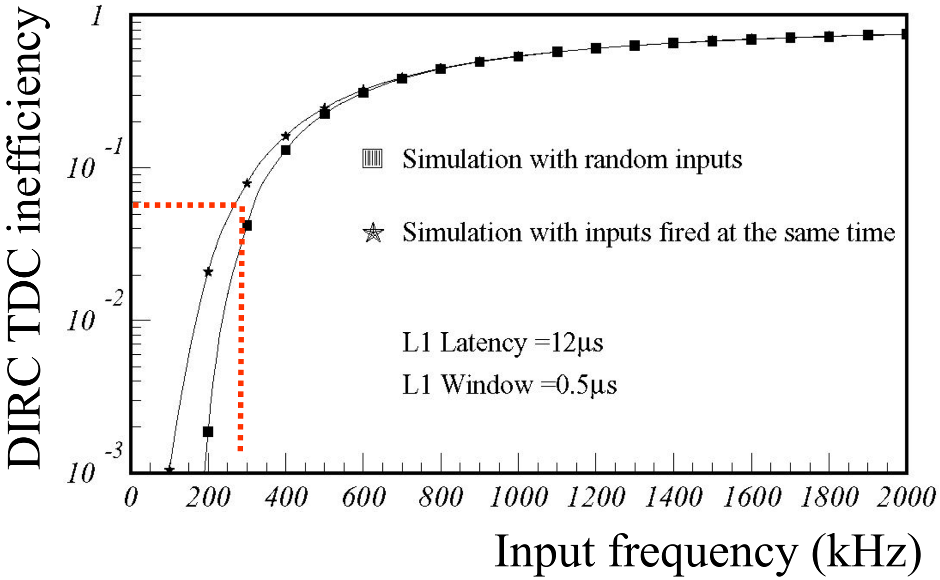
DIRC OPERATIONAL EXPERIENCE: BACKGROUNDS

PEP-II Luminosity and currents are rapidly increasing

- $4*10^{33}$ /cm^2·s now,
- expect >$5*10^{33}$ /cm^2·s at the end of the 2001/2002 run,
- 1-2 $*10^{34}$ /cm^2·s in 2004/5;
- 10^{35} - 10^{36} /cm^2·s discussed ("SuperBABAR").

Δt cut very effective in removing accelerator induced background from reconstruction.

But high counting rates cause inefficiency of present DIRC DAQ:

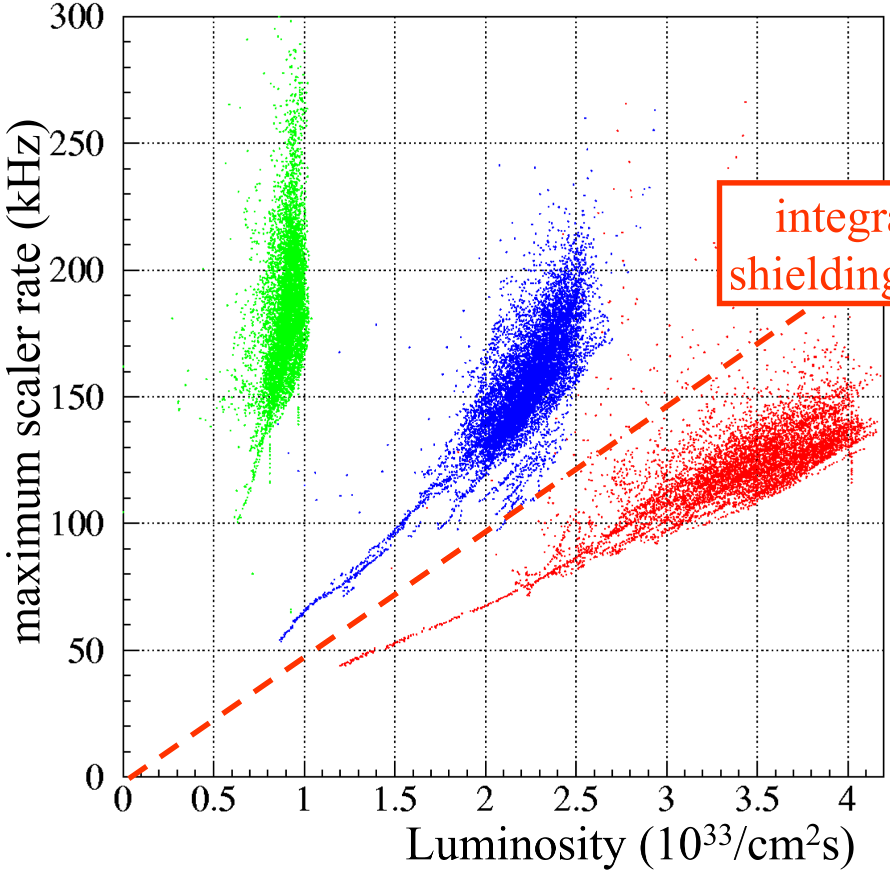


~5% inefficiency at 250 kHz

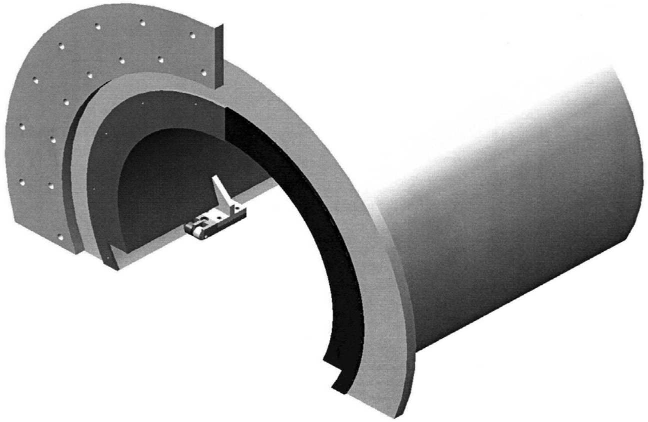
DIRC OPERATIONAL EXPERIENCE: BACKGROUNDS

In January 2001, installed new, more homogenous lead shielding (5-7cm of lead in upper 2/3, 2-3cm in lower 1/3 of shield).

Scaler rates acceptable even above design luminosity.

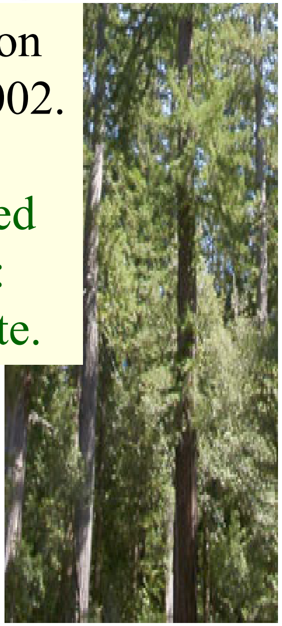


integrated shielding 2001



Current shielding configuration "background safe" through 2002.

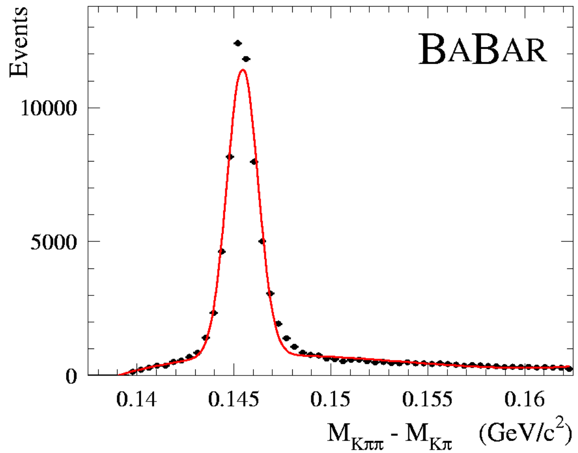
New TDC chips to be installed during shutdown Fall 2002: <5% deadtime at 2.5MHz rate.

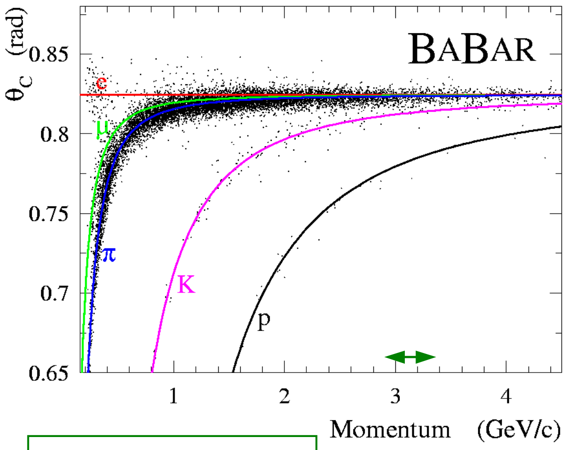


DIRC PARTICLE ID PERFORMANCE

$D^{*-} \to D^0 \pi^-$

$K^- \pi^+$

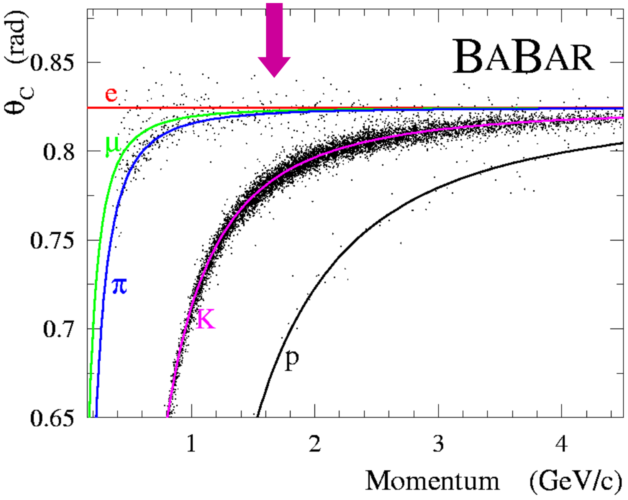




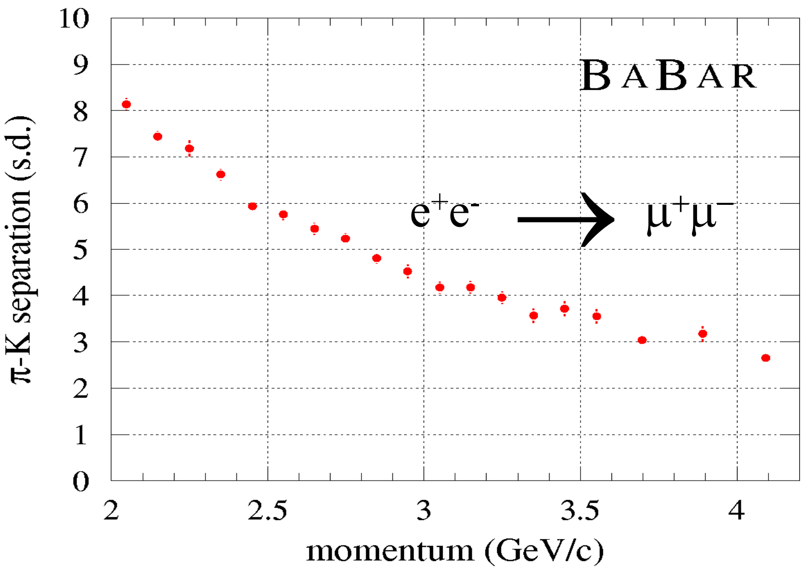
example:
2.5<|p|≤3GeV/c

kinematically identified

π and K

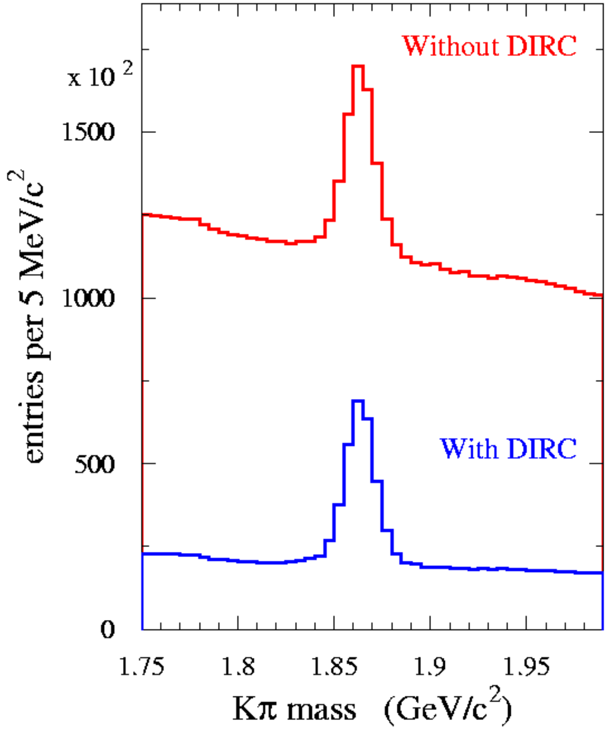


- Select D^0 candidate control sample with mass cut (±0.5 MeV/c^2)
- π and K are kinematically identified
- calculate selection efficiency and mis-id
- Correct for combinatorial background (avg. 6%) with sideband method.

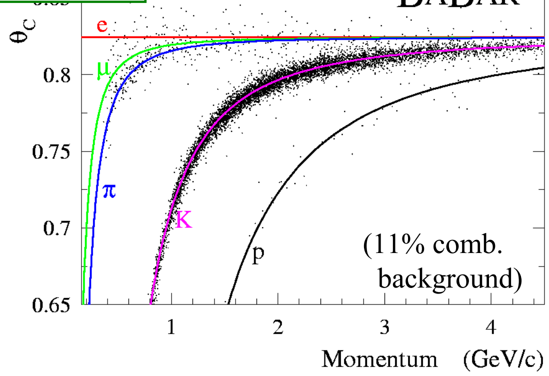


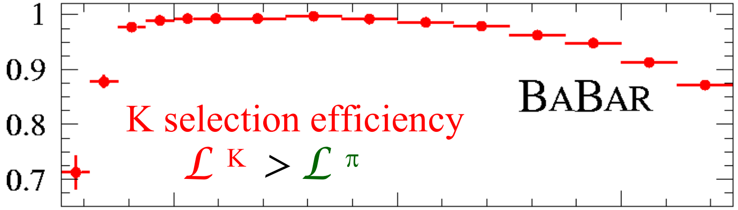
DIRC PARTICLE ID PERFORMANCE

$D^0 \rightarrow K^- \pi^+$

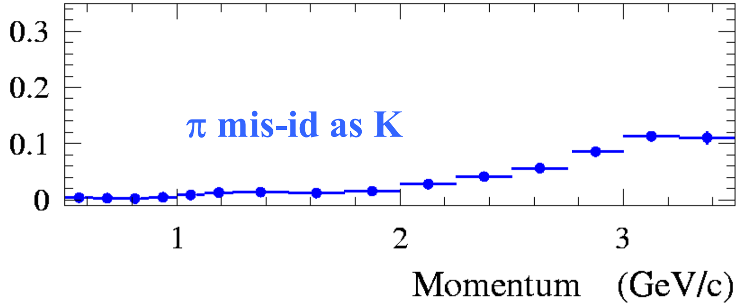


$D^{*-} \rightarrow D^0 \pi^-$
$\quad \hookrightarrow K^- \pi^+$





(track in DIRC fiducial, comb. background corrected)



~200,000 D^0 reconstructed from 9 fb^{-1} of data.

average K selection efficiency: 88%

average π mis-id: 2%

average rejection factor: 44

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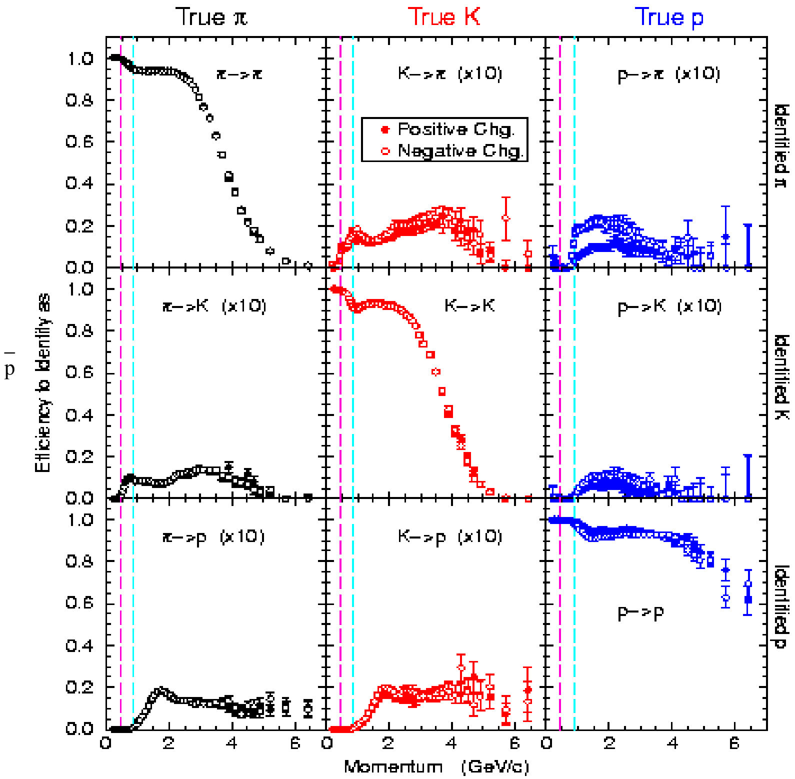
DIRC PERFORMANCE—ANOTHER VIEW

- MC from Charged Hadron Spectra analysis.
- Cuts different than the “standard”…designed to keep mis-ID <1-2% everywhere.
- In return, must accept somewhat lower ID efficiency especially a high momenta
- Note that mis-ID ≥ $\overline{p}$ mis-ID due to different interaction probability.



THE FUTURE

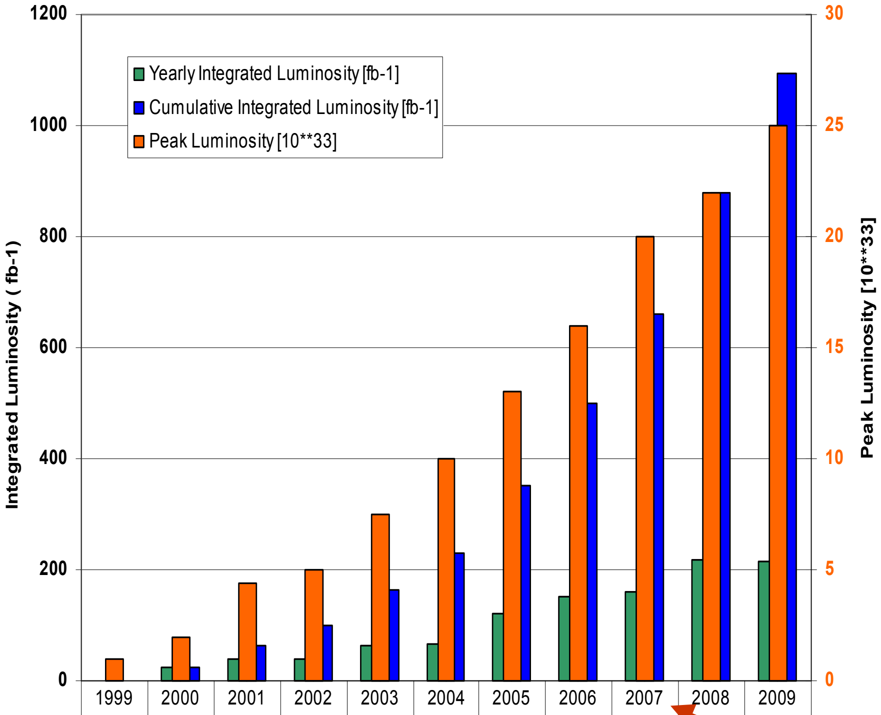
- The lab's goals for the luminosity for PEP-II/BaBar, in the midterm, is to integrate ~ ½ atobarn;

- Long-term, there is discussion of a possible 30^{36} $cm^{-2}sec^{-1}$ machine delivering 10 atobarn physics sample.

- Can we remove the 6 tons of water in DIRC and improve the particle ID performance for this era?

LONG-TERM LUMINOSITY

Luminosity Profile **“Adiabatic Scenario”**



	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
🟩 Yearly Integrated Luminosity [fb-1]	0.3	23	39	39	62.6	66.1	120.1	151	160.1	217	216
🟦 Cumulative Integrated Luminosity [fb-1]	0.3	23.3	62.3	101.3	163.9	230	350.1	501.1	661.2	878.2	1094.2
🟧 Peak Luminosity [10**33]	1	2	4.4	5	7.5	10	13	16	20	22	25

Year

LhcB,
Btev?

Realistic

From J. Seeman 10/26/2001

THE R&D PROGRAM

- Cosmic ray telescope test bed;
- Evaluate new multianode photodetectors;
- On the basis of measured performance, work on optimal focusing arrangement.

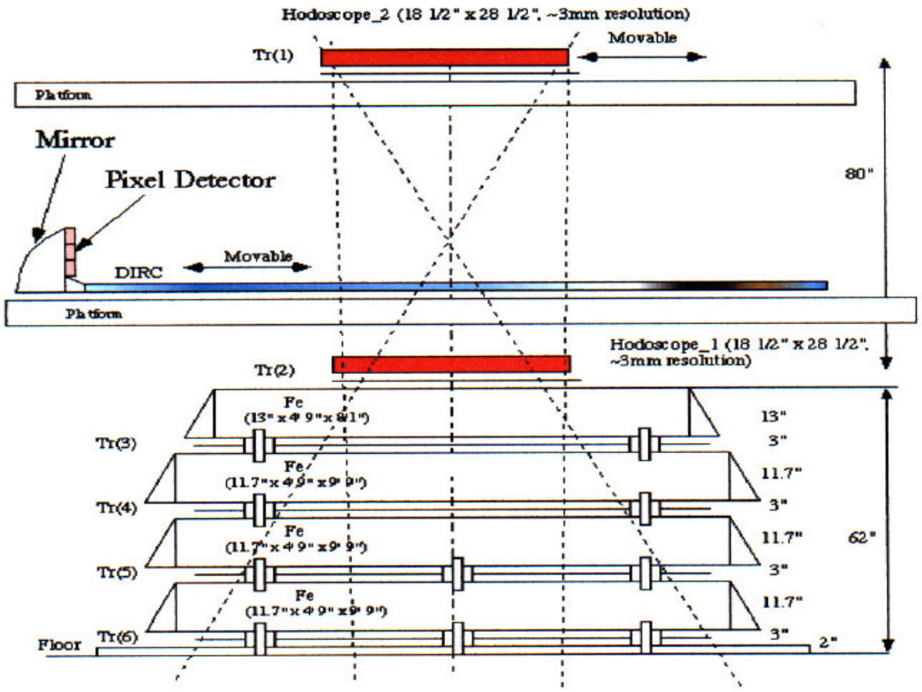
COSMIC RAY TELESCOPE

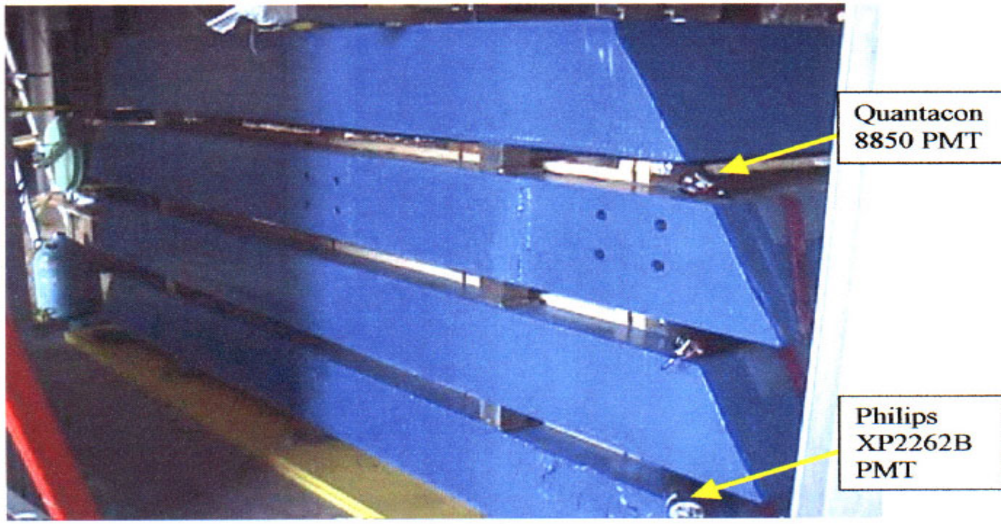
- **Four layers of 13″ thick steel absorber to harden muon spectrum (400 MeV to 2.5 GeV in 400 MeV steps).**
- **Trigger counters 1″ thick and 60″ x 90″**
- **Scintillation hodoscope for tracking**
  - **~1 mrad angular accuracy**
  - **~3 mm spatial accuracy**

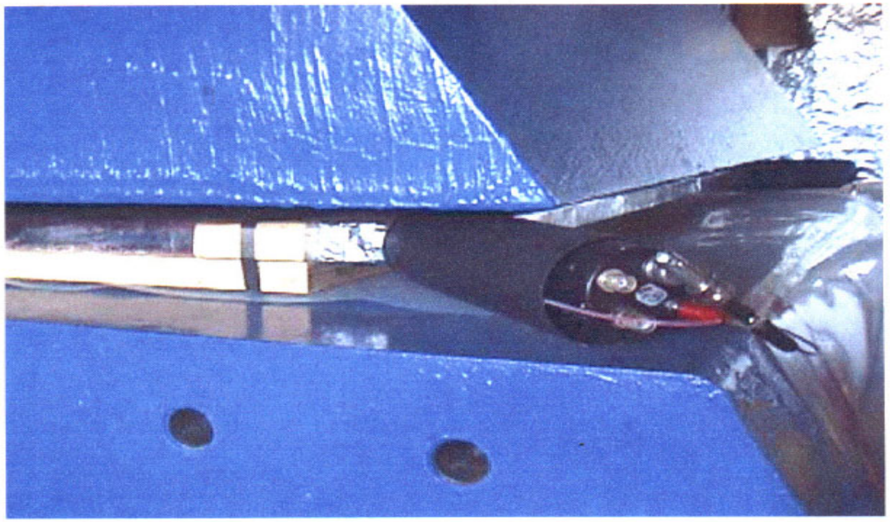
COSMIC RAY SETUP

Sizes:
a) Tr (1): 1" x 24" x 6'
Tr (2): 1" x 24" x 6'
Tr(3-6): 1" x 4' x 8.6'
b) Iron: 3x 11.7" x 4' 9" x 9' 9"
1x 13" x 4' 9" x 8' 1"
c) Hodoscopes:
1) x, y, u
2a, b) x, y

Side view




Quantacon
8850 PMT
Philips
XP2262B
PMT



NEW PHOTODETECTORS

Requirement:

- compact devices;
- good quantum efficiency (20-30%) ;
- good spatial resolution (~ mm) ;
- good time capability (~ 150 psec) ;

→ embarking on a program to evaluate performance of the new devices.

NEW PHOTODETECTORS

1) Hamamatsu flat panel 64-channel PMT [H8500].

Specifications:

- 8x8 array of 6 mm x 6 mm pads.
- gain ~ a few 10^6
- rise time < 1 nsec., with ± 150 psec spread
- cross talk ~ few %
- gain variation across 64 anodes ~ x 2
- active area 49.7 mm x 49.7 mm
- total package size 50.5 mm x 50.5 mm
- bi-alkali cathode
- 800-1100 volts HV

NEW PHOTODETECTORS

2. DEP HPD (hybrid photodiodes)

a) **Electrostatically focusing device**
[HPD PP0380 AU]
with 61 channels of 2x2 mm pads.

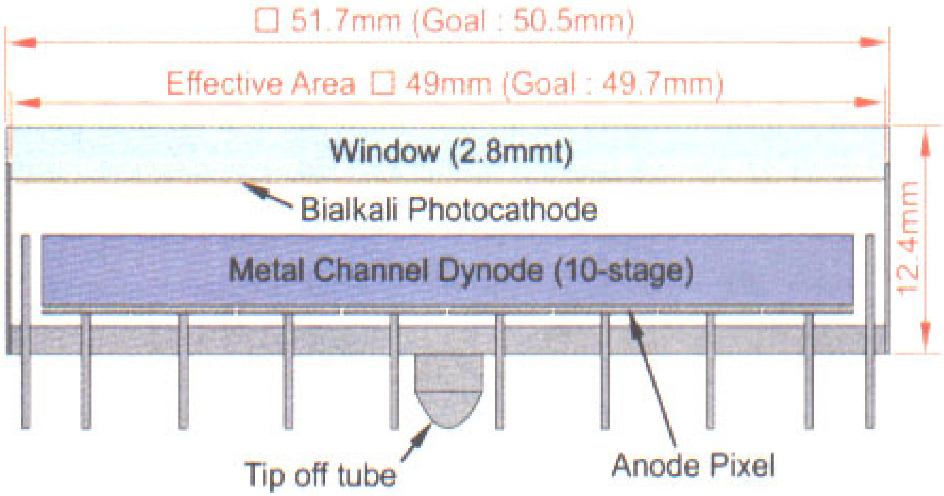
b) **Proximity focusing device**
[HPD 0380 AJ]
with 73 channels with 2x2 mm pads.

Both HDP's come with direct connection from the pad to the outside world.

J. Va'vra, 1.8.2002

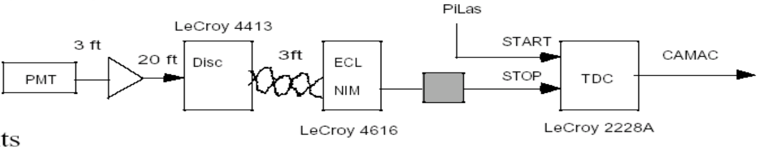
Hamamatsu 64-Channel Multi-Anode PMT

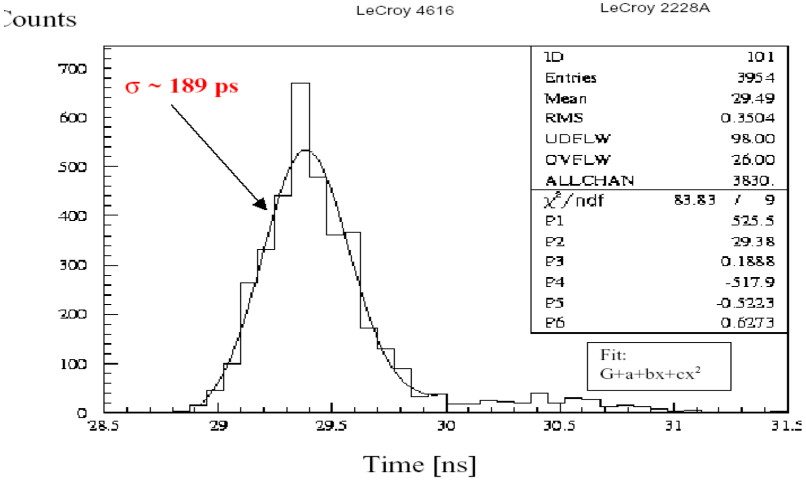
J. Va'vra



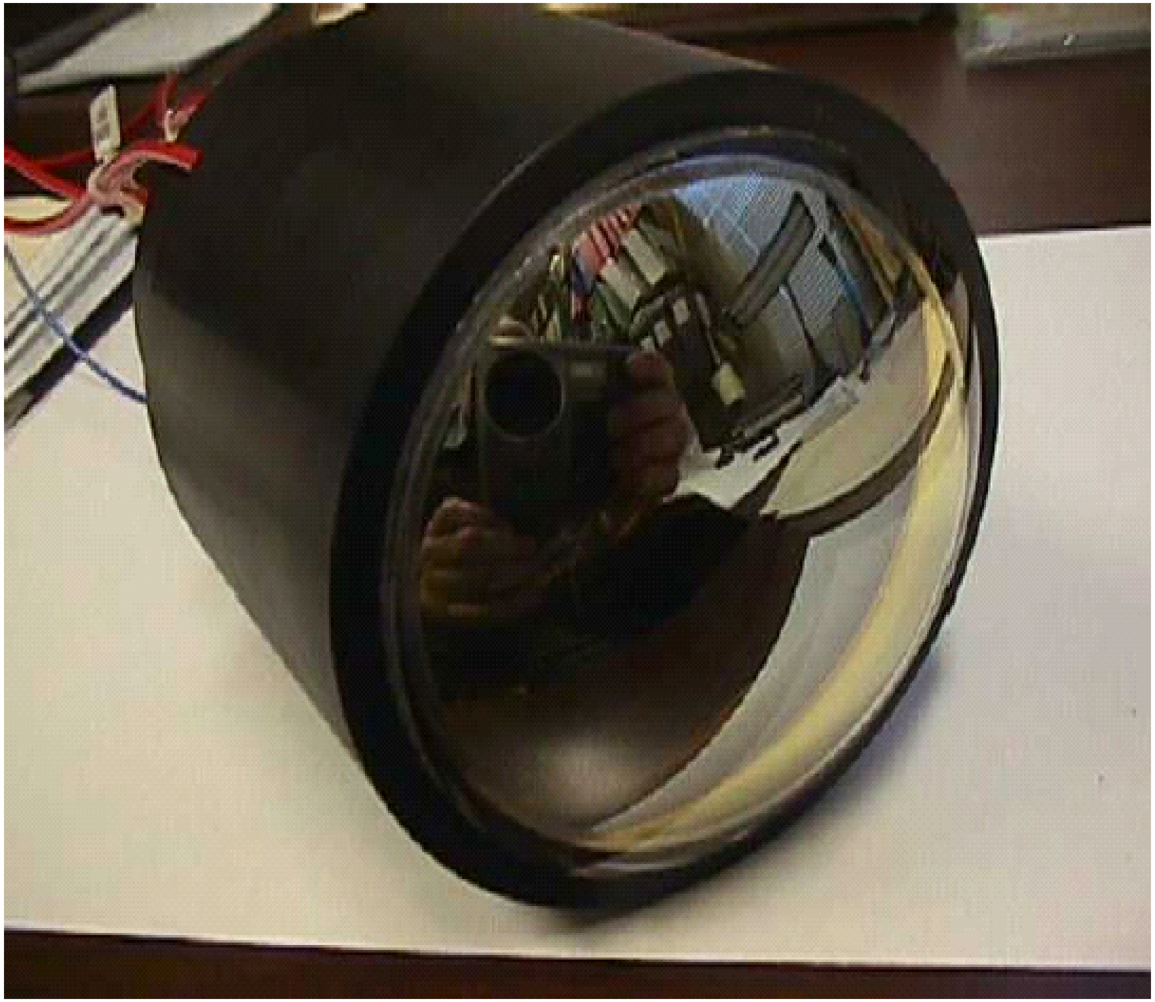
Timing study with a single threshold, with an amplifier:

(preliminary)

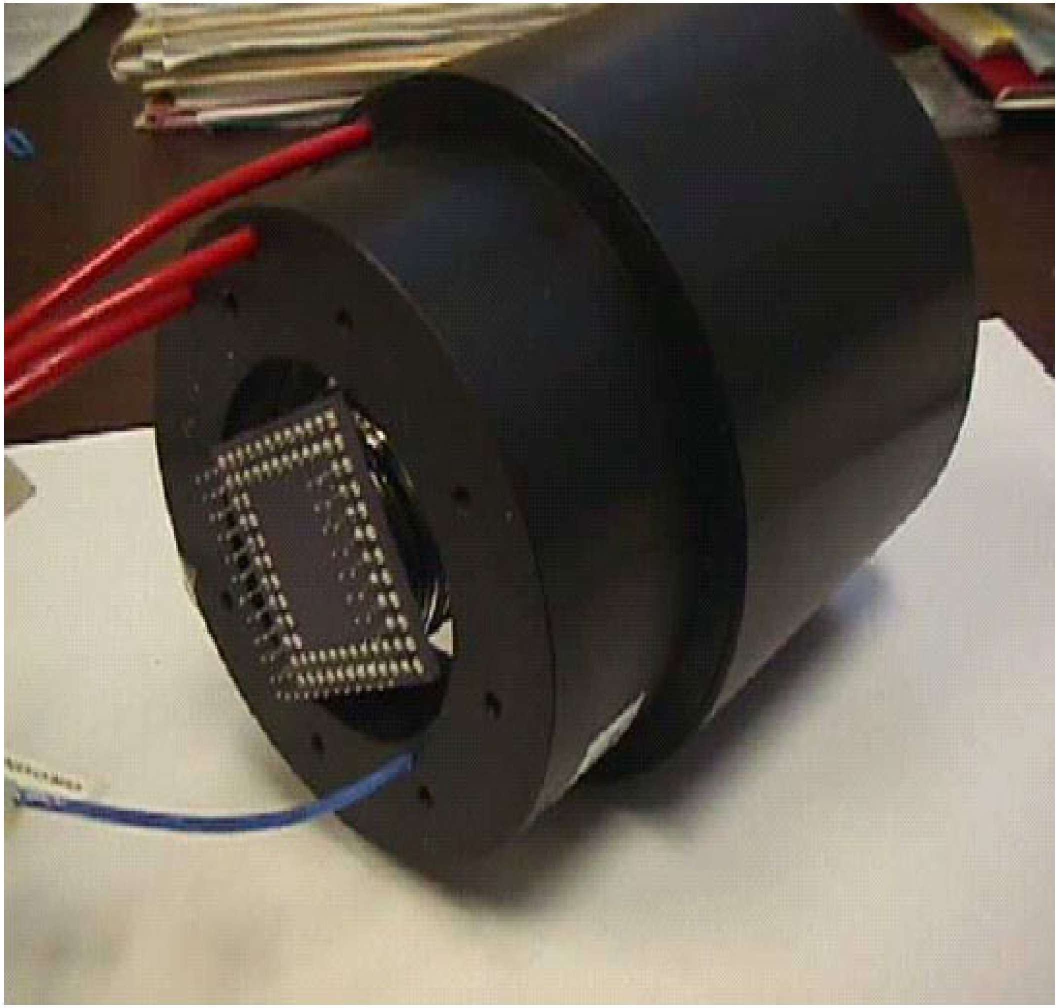




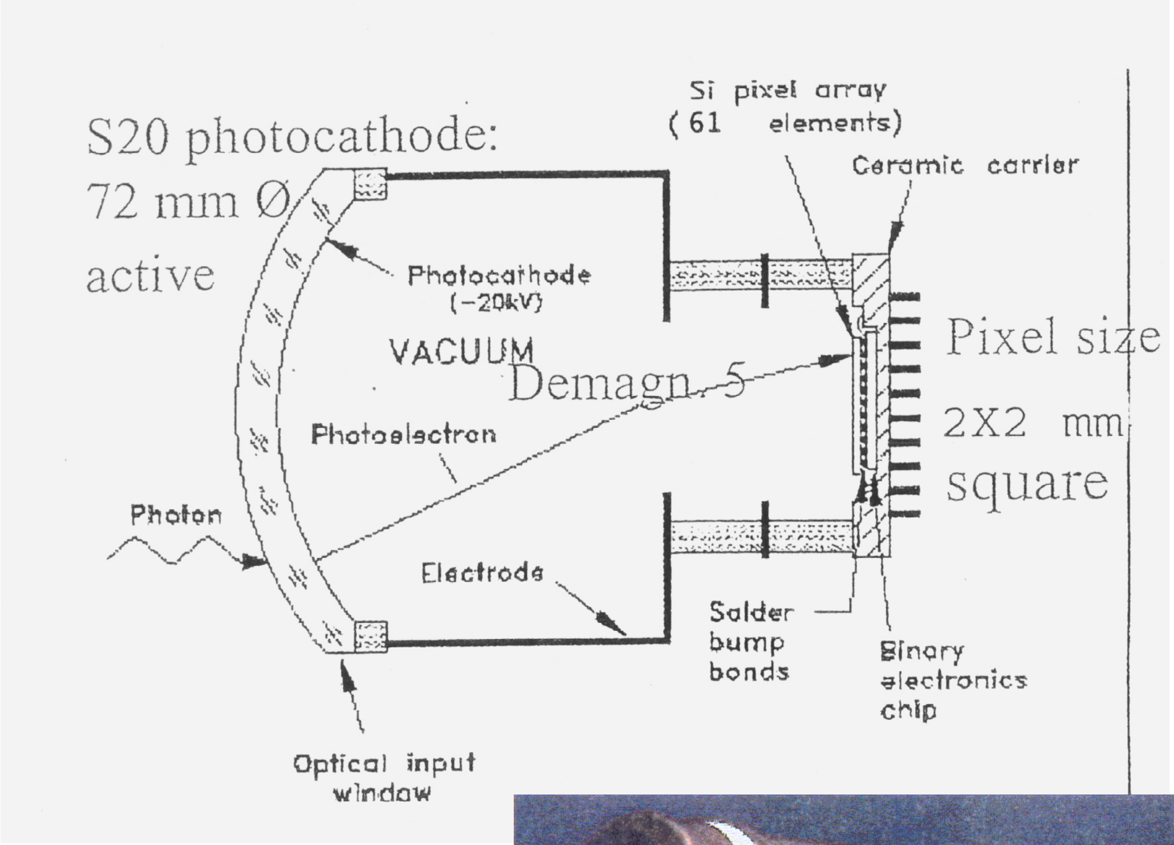
DEP 61-Channel Electrostatically Focusing HPD



DEP HPD [61 pixel of (2x2) mm]



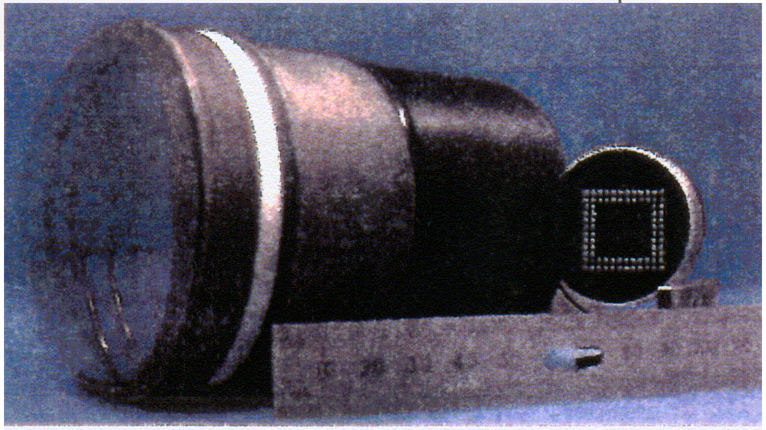
DEP HPD [PPO380AU]



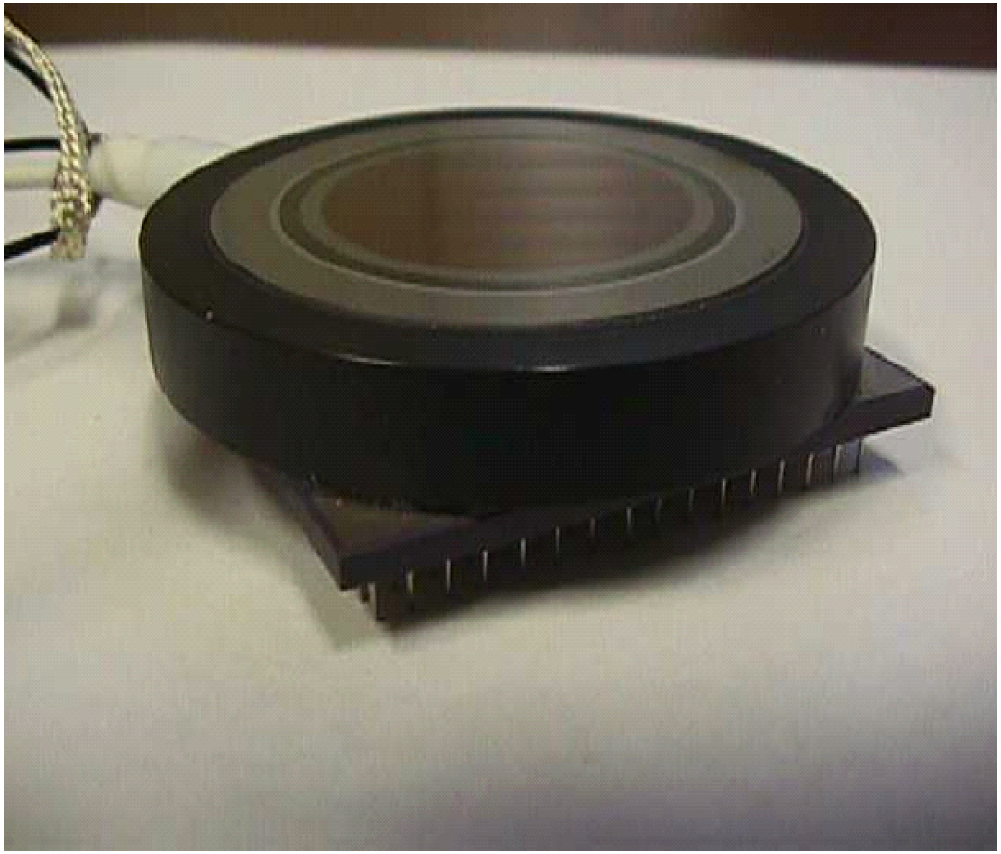
S20 photocathode:
72 mm Ø
active

Demagn. 5

Pixel size
2X2 mm
square



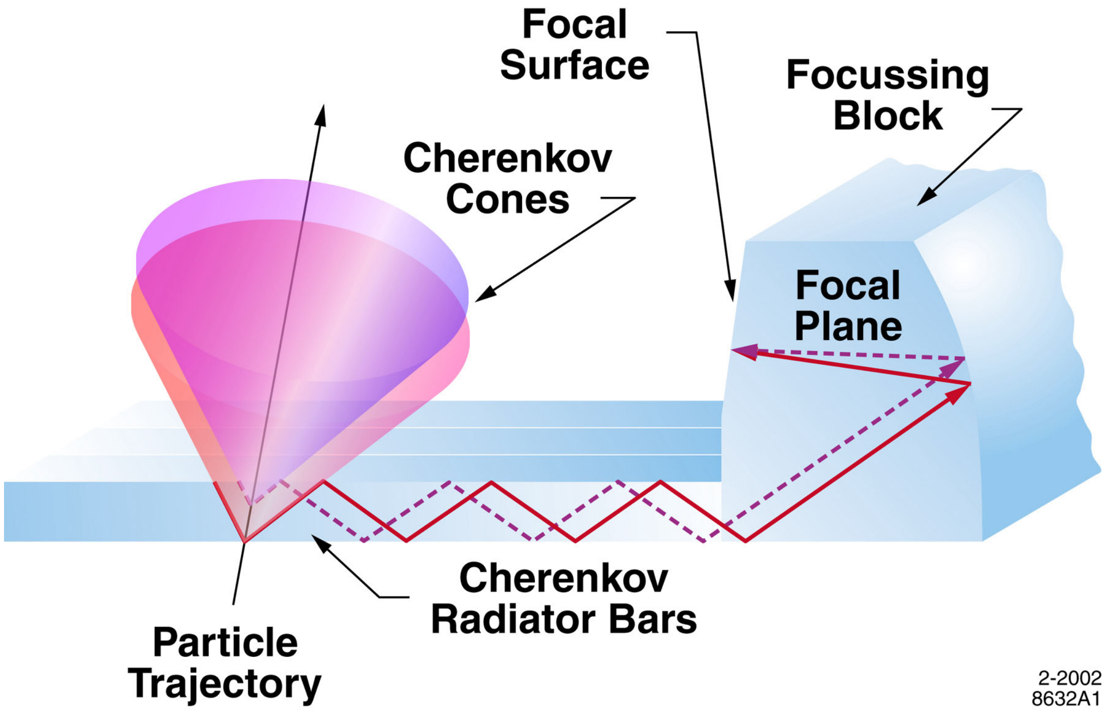
DEP 73-Channel Proximity Focusing HPD (0380AJ)



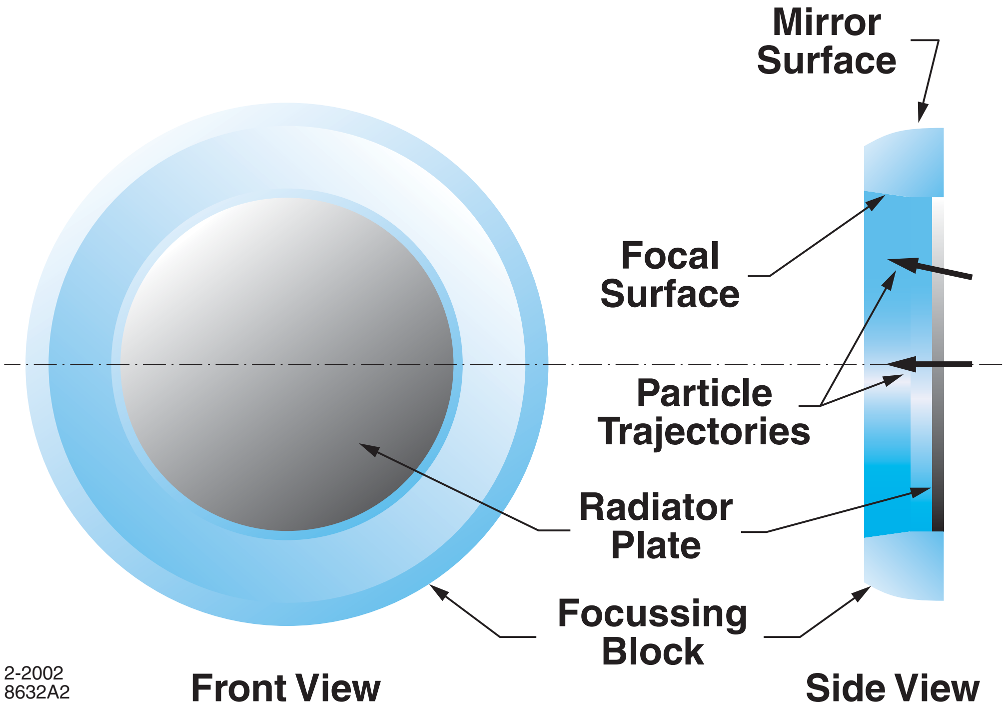
GEOMETRY/OPTICS

- **Barrel**
  - **Use magnetic shielding volume of existing SOB, conceptional geometry**
- **End Cap**
  - **With improved performance, π/K separation in the forward region could be increased.**

BARREL GEOMETRY



END-CAP GEOMETRY

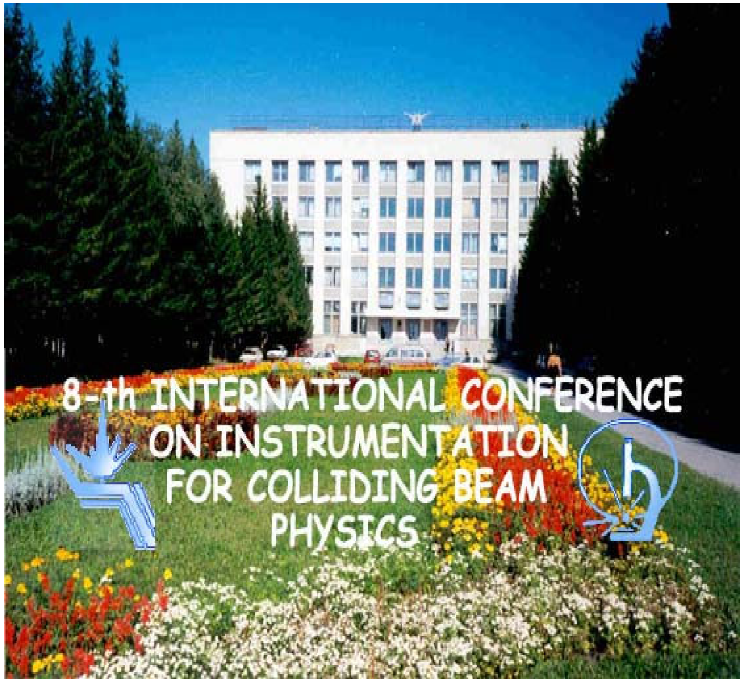


R&D PROGRAM SUMMARY

- Cosmic ray telescope now beginning operation,
- New multianode, single-photon detectors are now in hand,
- First results look promising,
- Expect interesting results by RICH2002 and IEEE2002.

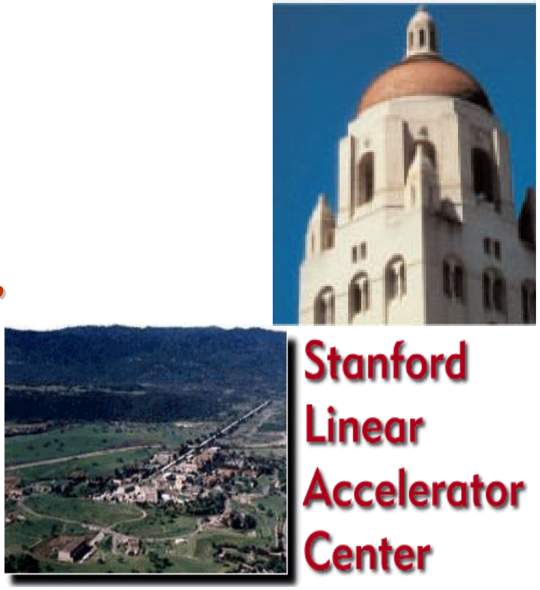
CONCLUSIONS

- **Brilliant idea for a π/K detector in B factory energy regime!**
- **Robust device delivering close to promised performance.**
- **Particle Identification is important in almost all BaBar physics analyses.**
- **With the current upgrade of DAQ electronics should be OK up to luminosities x10 design (10^{34} cm^{-2} sec^{-1}).**
- **R&D for improved PID performance, and to survive in a high-luminosity environment, is under way-- expect results in Fall of 2002.**



Please join me in thanking our hosts for their hospitality and this stimulating conference—continuing a long line of such meetings, since 1977.

I have the privilege in welcoming you all to the next meeting of the Instrumentation for Colliding Beams in 2005, to Stanford—hosted by SLAC and Stanford University.



Stanford
Linear
Accelerator
Center

I wish you all safe travels home!