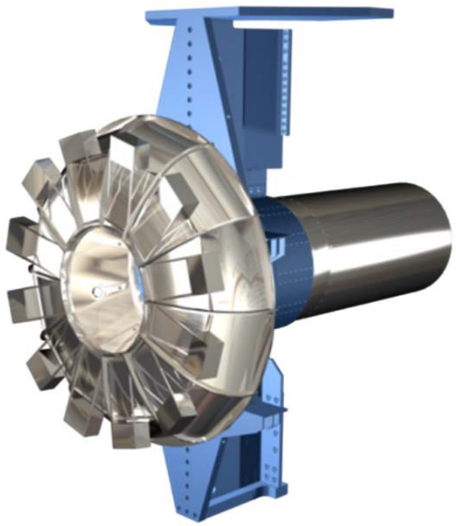
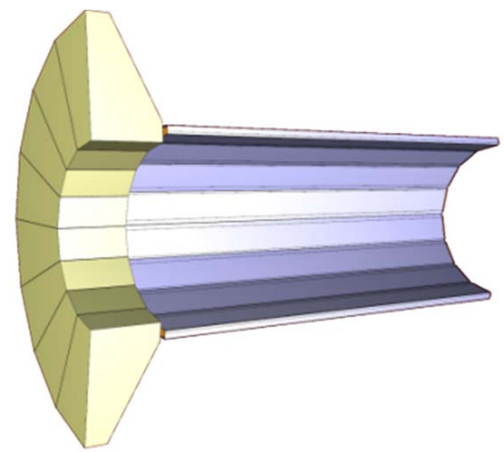
BARREL DIRC DETECTORS

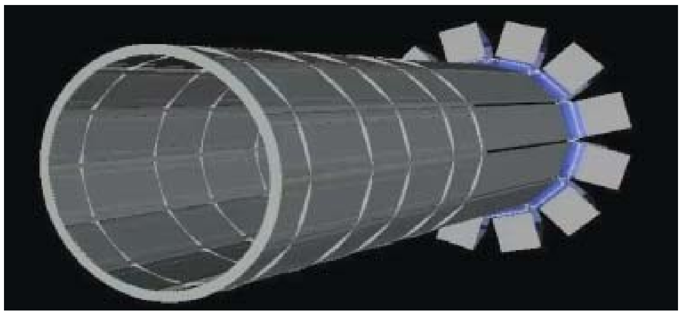
FROM BABAR TO PANDA AND SUPERB

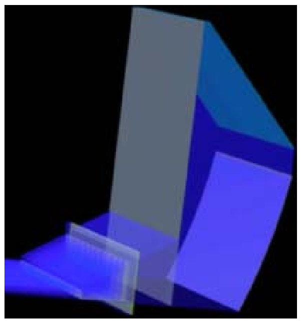


Jochen Schwiening

GSI







Brief Introduction

Experience with DIRC: BaBar

Design, Operations, Performance

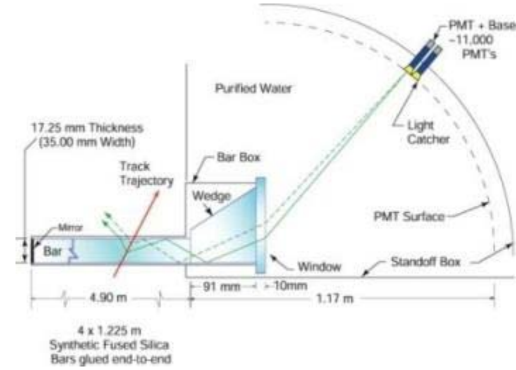
Disassembly

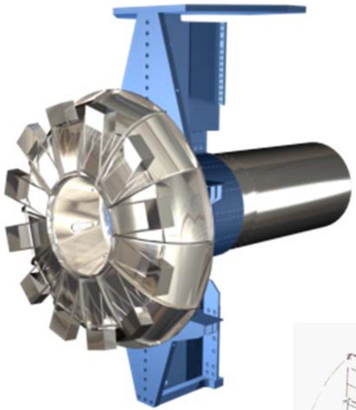
Upgrade R&D – Fast Focusing DIRC

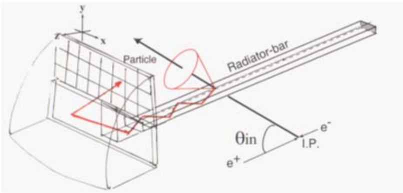
Future Barrel DIRCs

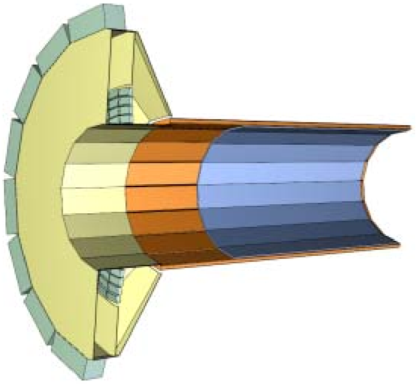
SuperB FDIRC

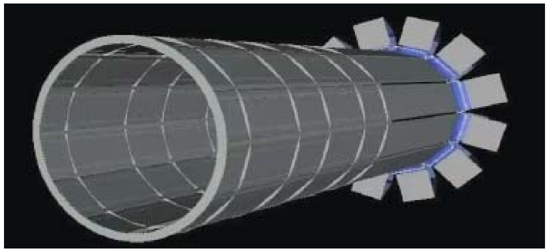
PANDA Barrel DIRC











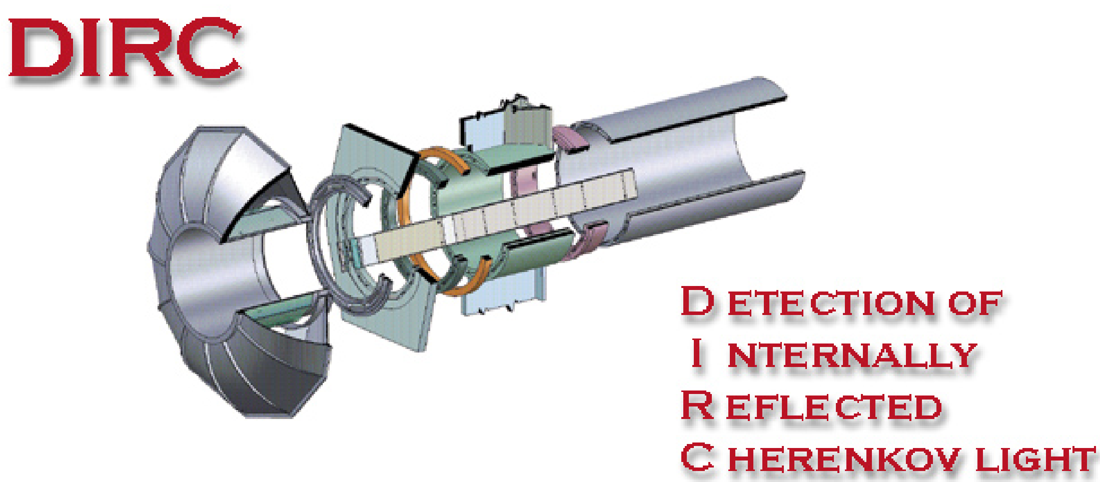
DIRC CONCEPT

Detection of Internally Reflected Cherenkov Light

Novel type of Ring Imaging CHerenkov detector [§]
based on total internal reflection of Cherenkov light.

Used for the first time in BABAR for hadronic particle ID (8+ years in factory mode).

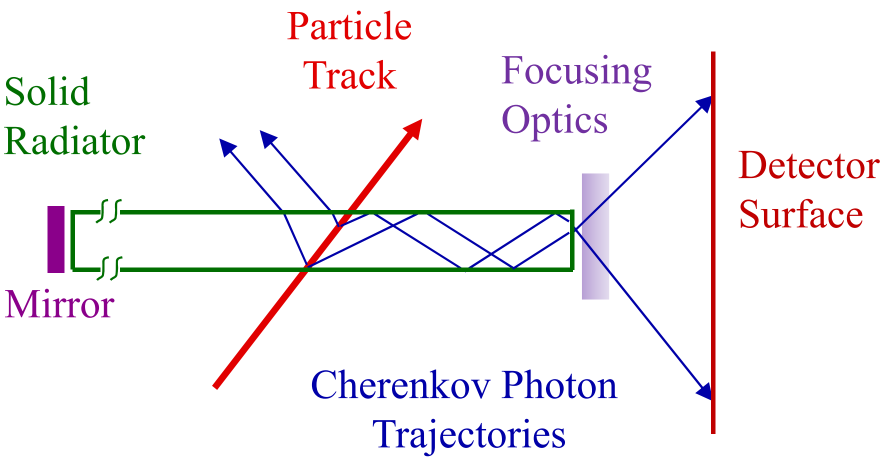
Recent improvements in photon detectors have motivated R&D efforts to improve the successful BABAR-DIRC and make DIRCs interesting for future experiments.



[§] *B.N. Ratcliff, SLAC-PUB-6047 (Jan. 1993)*

DIRC CONCEPT

- Charged particle traversing radiator with refractive index n with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos\theta_c = 1/\beta n(\lambda)$.

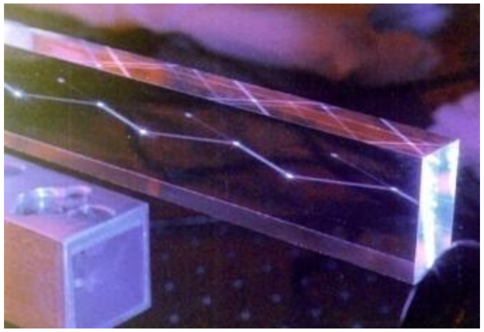


- For $n>\sqrt{2}$ some photons are always totally internally reflected for $\beta\approx1$ tracks.

- Radiator and light guide: bar, plate, or disk made from Synthetic Fused Silica ("Quartz") or fused quartz or acrylic glass or …

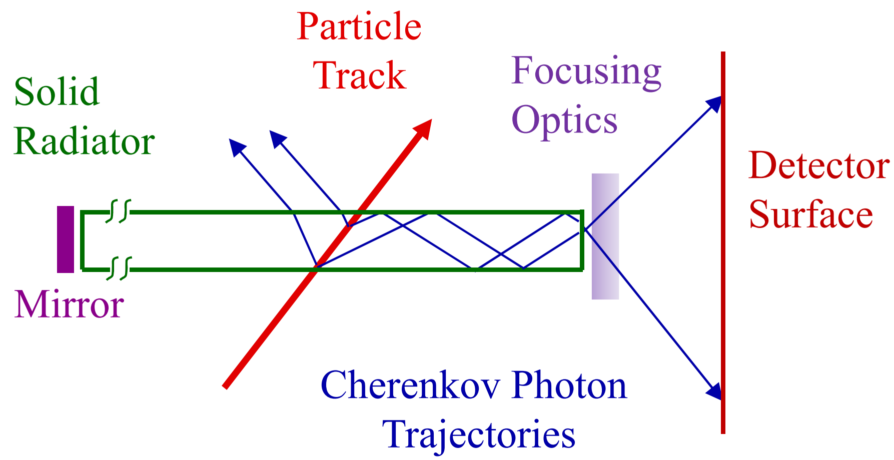
- Magnitude of Cherenkov angle conserved during internal reflections (provided optical surfaces are square, parallel, highly polished)

- Mirror attached to one bar end, reflects photon back to readout end.



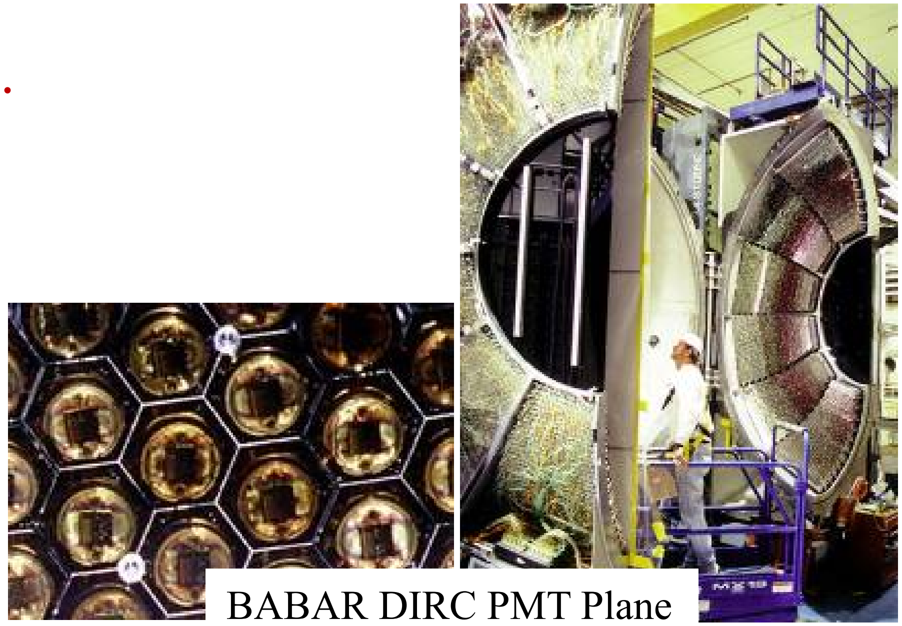
DIRC Concept

- Photons exit radiator via optional focusing optics into expansion region, detected on photon detector array.



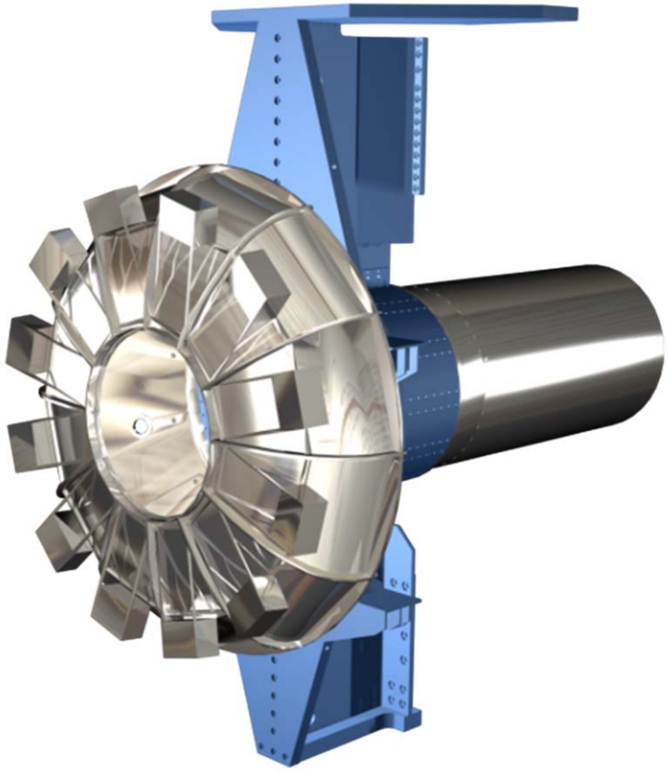
- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining θ_c, ϕ_c, $t_{propagation}$.

- Ultimate deliverable for DIRC: PID likelihoods.
  Calculate likelihood for observed hit pattern
  (in detector space or in Cherenkov space)
  to be produced by e/μ/π/K/p
  plus event/track background.

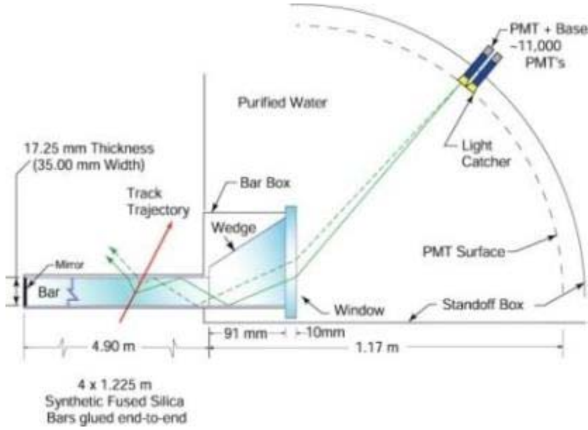


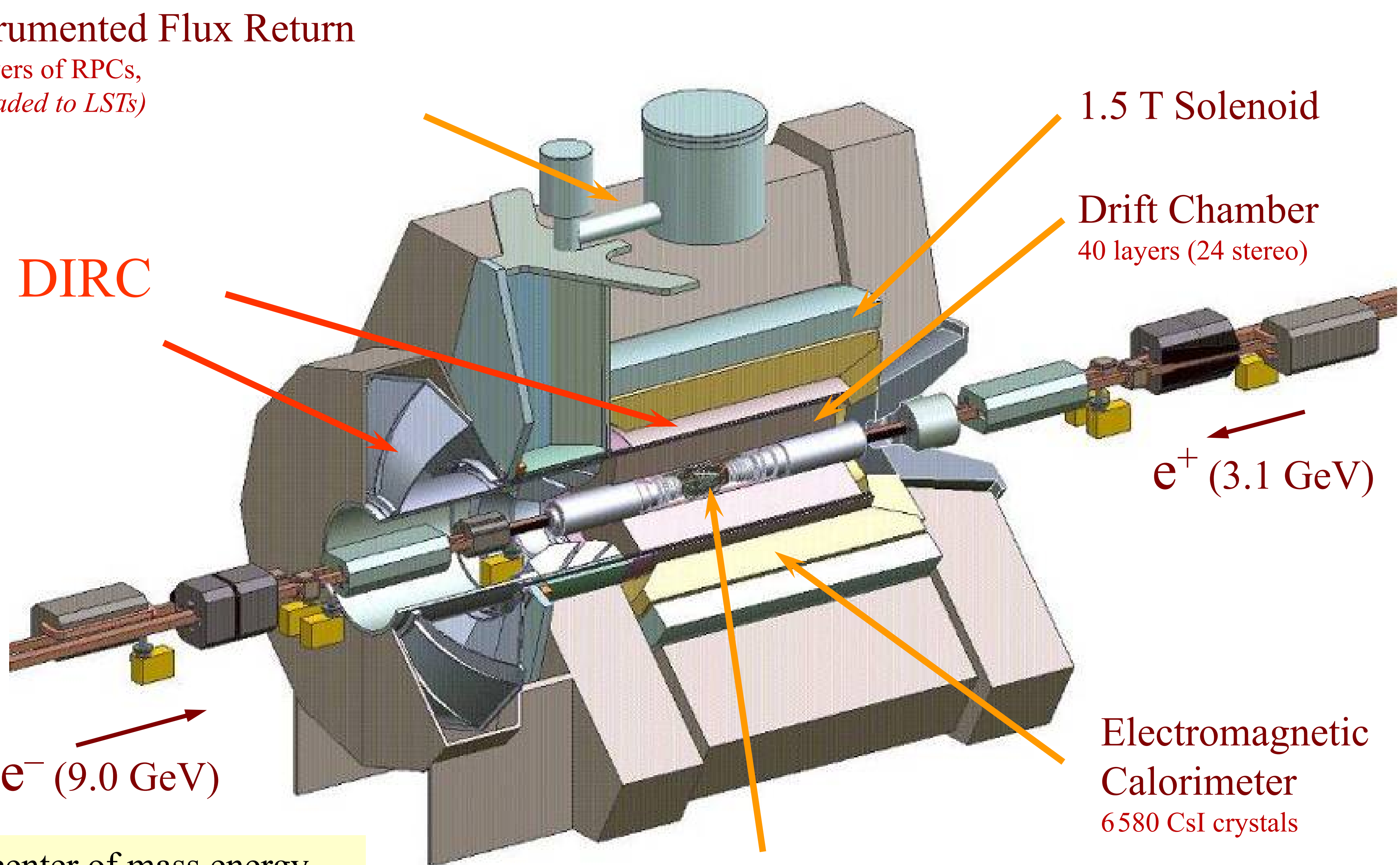
BABAR DIRC PMT Plane

THE BABAR DIRC



- DESIGN
- OPERATIONS
- PERFORMANCE
- DISASSEMBLY
- UPGRADE R&D





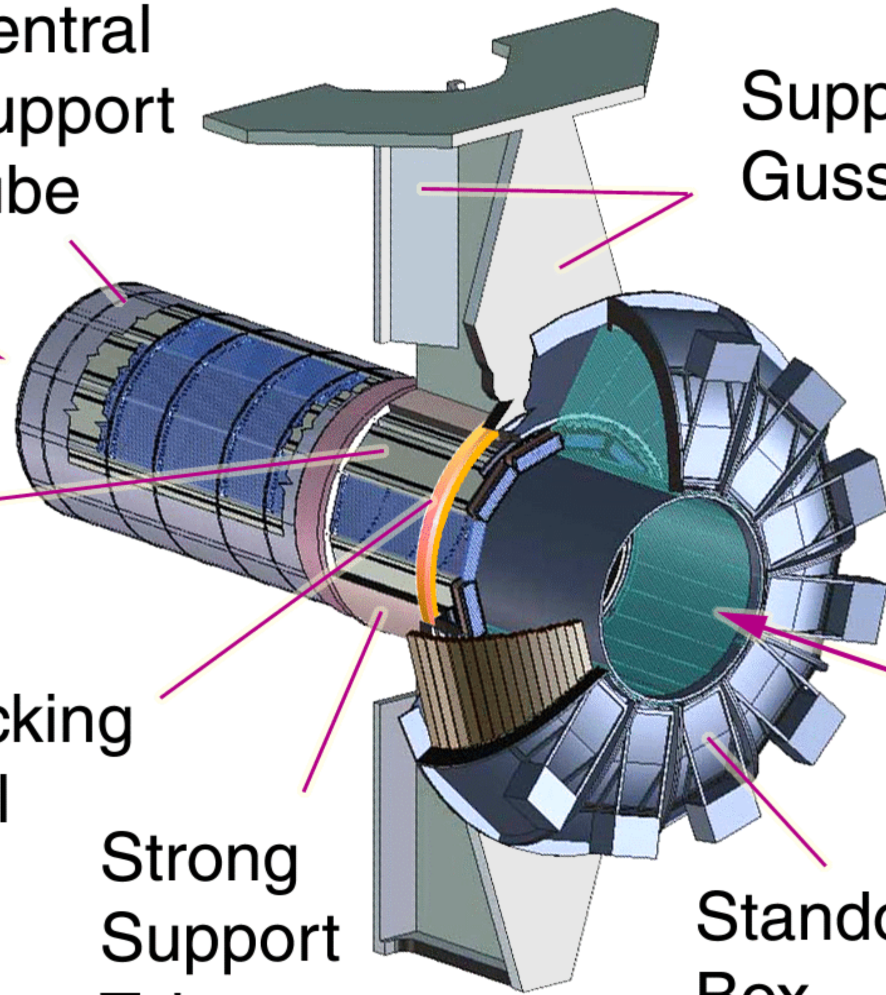
center of mass energy
$\approx M_{\Upsilon(4S)} = 10.58 \text{ GeV}/c^2$
$\beta\gamma = 0.56$

THE DIRC IN BABAR

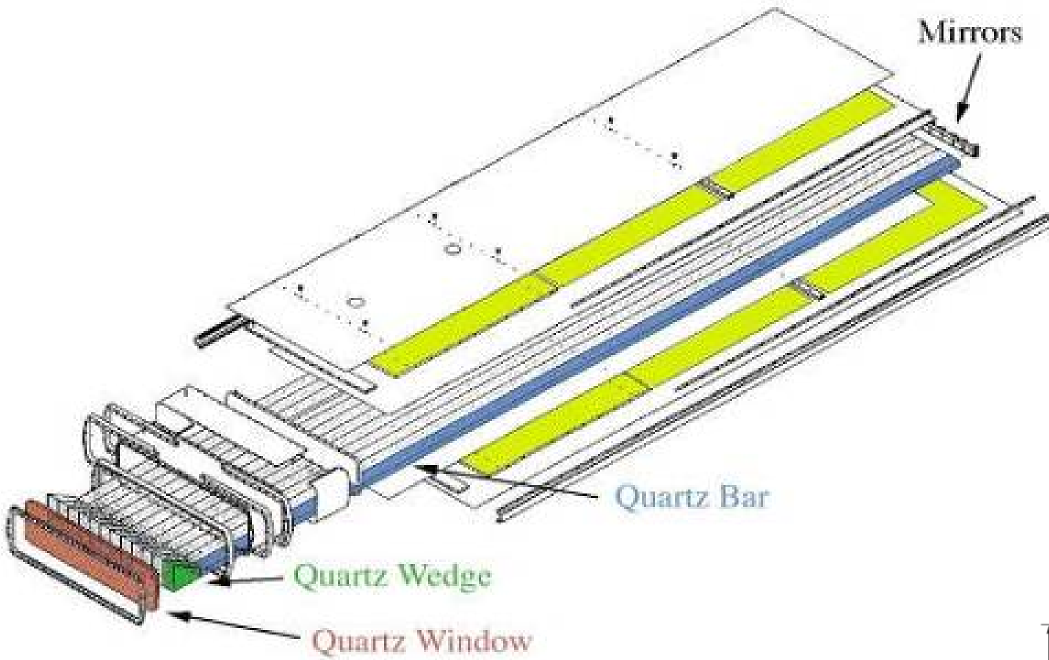
DIRC thickness:
- 8 cm radial incl. supports
- 19% radiation length at normal incidence

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

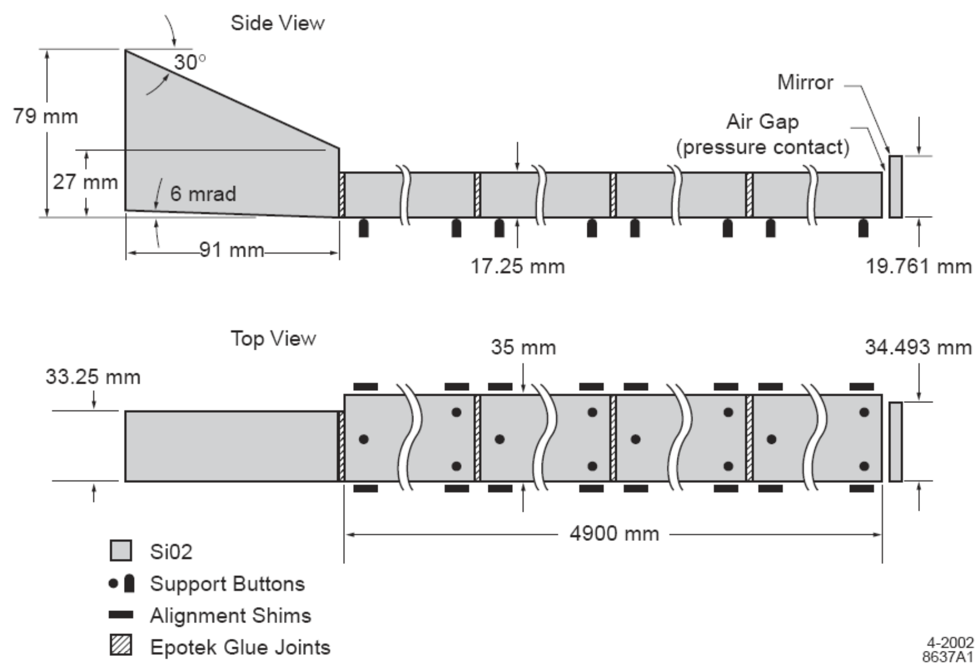
DIRC photon detection array:
- 10,752 PMTs ETL 9125



THE DIRC IN BABAR



Bar box: 12 bar boxes in BABAR
12 long (4.9m) bars per box
150µm air gap between bars
dry nitrogen flow



Long bar: 4 short (1.225m) bars
Mirror on forward end
Wedge on readout end

BABAR DIRC COLLABORATION

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Detailed review of BABAR DIRC:
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BABAR DIRC TIME LINE

- 1992: first publication of DIRC concept (Blair Ratcliff).
- 1993-1996: progression of prototypes and DIRC R&D.
- Nov 1994: decision in favor of DIRC for hadronic PID for BABAR.
- Nov 1998: installed part of DIRC; start of cosmic ray run, commissioning run.
- April 1999: BABAR moves into beam line, added 4 more bar boxes.
- Nov 1999: all 12 bar boxes installed, start of first physics run.
- April 2008: last event recorded with BABAR.

PEP-II peak luminosity: 12.07×10^{33} $cm^{-2}sec^{-1}$ (4 × design)

BABAR total recorded: ~ 467M $B\bar{B}$ pairs.

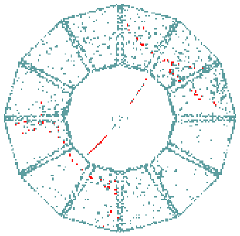
BABAR DIRC ran in factory mode for 8+ years.

DIRC Operations were Stable and Robust

- Calibration constants stable to typically *rms* < 0.1ns per year.
- No problems with water or gas systems.
- No evidence for deterioration of bar surfaces or glue boundaries.

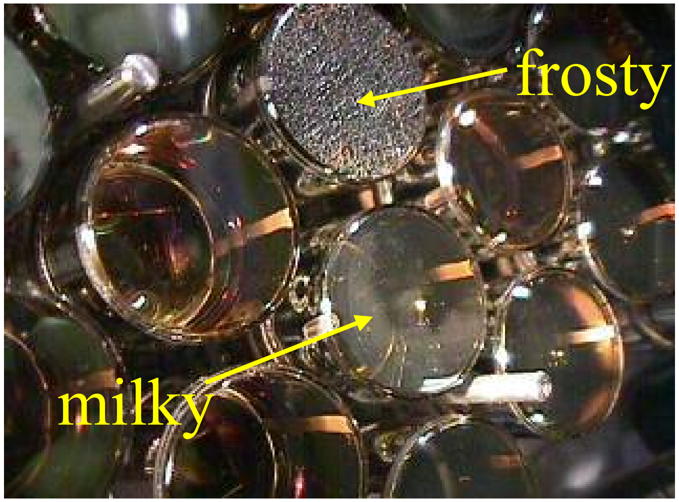
The three most significant operational issues:

- Concerns about PMT longevity due to PMT window degradation;
  → photon loss a few % level, no problem for PID performance.
- Some damage to electronics due to dust/dirt from civil engineering near experiment;
  → solved by cleaning and application of conformal coating.
- Sensitivity of the DIRC to machine background interacting in the water of the expansion region (primarily DAQ issue);
  → solved by adding lead shielding between beam line and DIRC inner radius and by upgrading TDCs.



PMT LONGEVITY

PMT front window corrosion



- Discovered after ~ 1 year immersion Oct. 99.
- Status Oct. 99: ~ 50 *frosty* tubes and ~ 2/3 visibly *milky*.
- Only front glass affected, side glass fine.

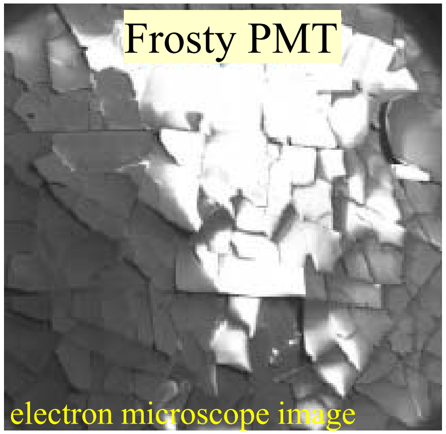
Studies →

- Strongly corroded (*frosty*) tubes are a bad batch of PMT glass (no zinc).
- *Milki*ness results from sodium depletion in near surface.

No obvious immediate effect (water provided good coupling) but ...

⇒ Worried that we might lose PMT efficiency with time.

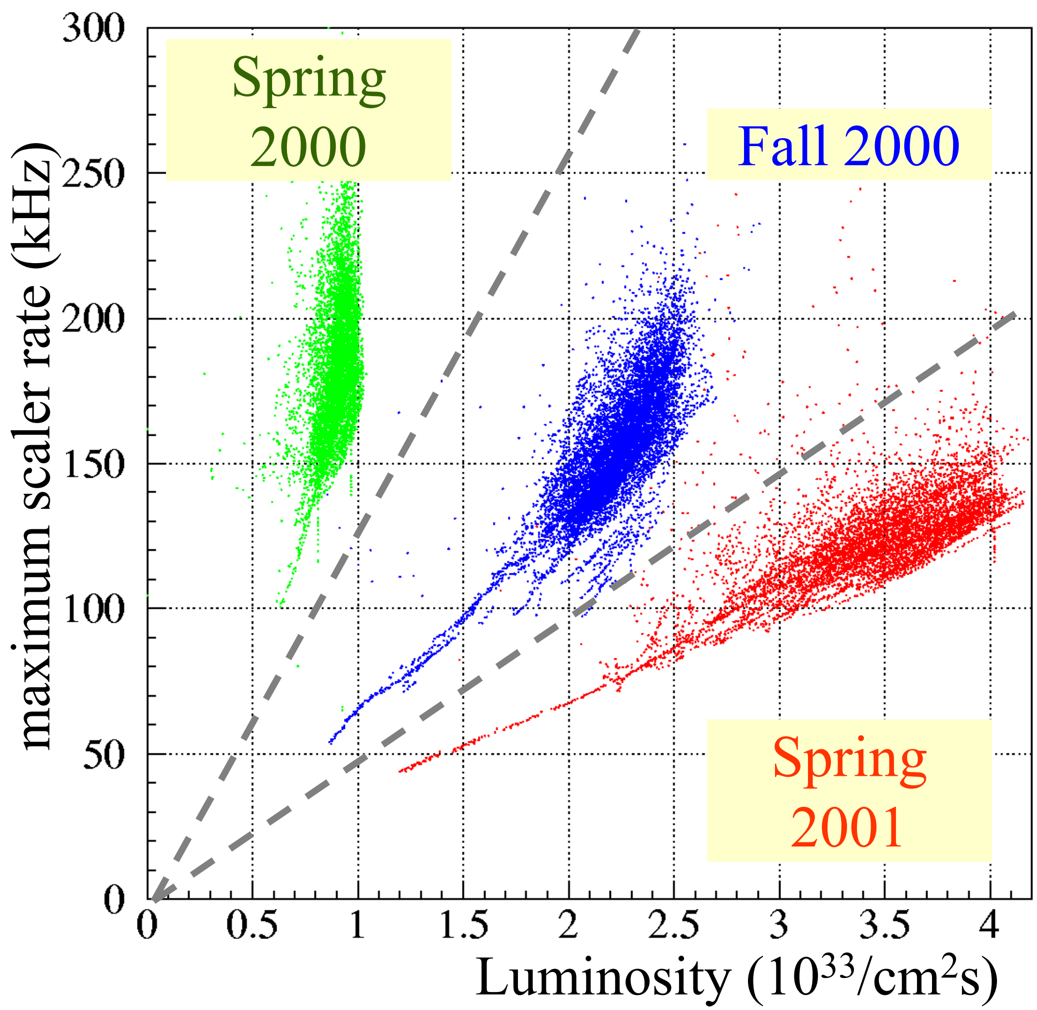
⇒ or might lose vacuum in some of the ~ 50 *frosty* tubes on 10 year time scale (front window thickness: 1mm).



Ultimately, until shutdown in Apr. 2008, no problems with milky or frosty PMTs observed. *(Stay tuned for update later.)*

Succession of lead shielding installed in 2000 and 2001.

Thanks to shielding, PMT rates acceptable even at 4 × design lumi.



DIRC TDC1: ~5% inefficiency at 250 kHz

PMT Rate vs. Luminosity shows that lead shielding essential in protecting DIRC from few MeV photon accelerator induced background (radiative Bhabhas etc).

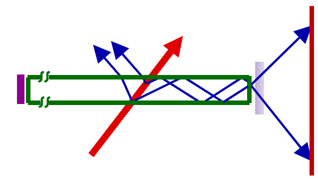
New TDC chips were installed during shutdown Fall 2002.

DIRC TDC2: <5% deadtime at 2.5MHz

Final TDC and shielding configuration were "background safe" at highest lumi.

RECONSTRUCTION

DIRC "Ring" images:



- limited acceptance for total internal reflection,
- reflection ambiguities (initial reflection up/down, left/right, reflection off mirror (and wedge)

  → up to 16 (θ_c, ϕ_c) ambiguities per PMT hit),
- toroidal detection surface,

→ Cherenkov ring images are distorted:

complex, disjoint images.

Low energy photons from accelerator hit Standoff Box.

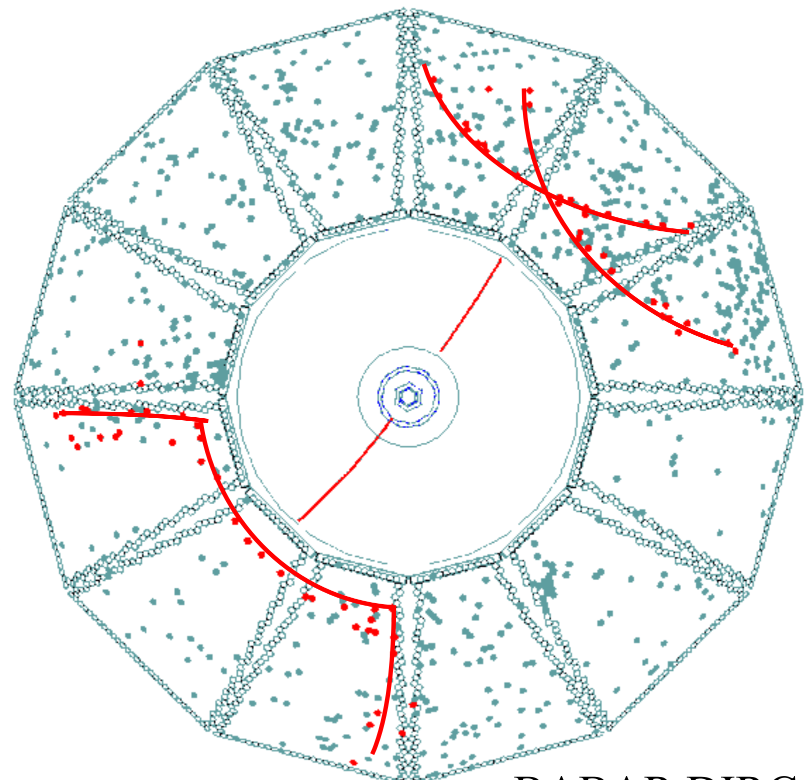
At typical luminosity that caused rates of 80-200 kHz/tube.
(100× the rate expected during experiment design phase.)

80-200 kHz ⊗ 10,752 PMTs ⊗ ± 300 nsec trigger window

→ 500-1300 background hits (~10% occupancy)

compared to

50-300 Cherenkov photons



BABAR DIRC

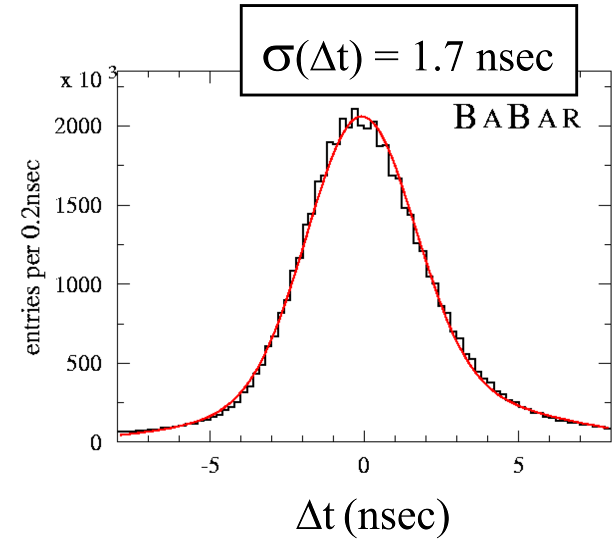
RECONSTRUCTION

For BABAR DIRC time information provided powerful tool to reject accelerator and event related background.

Calculate expected arrival time of Cherenkov photon based on

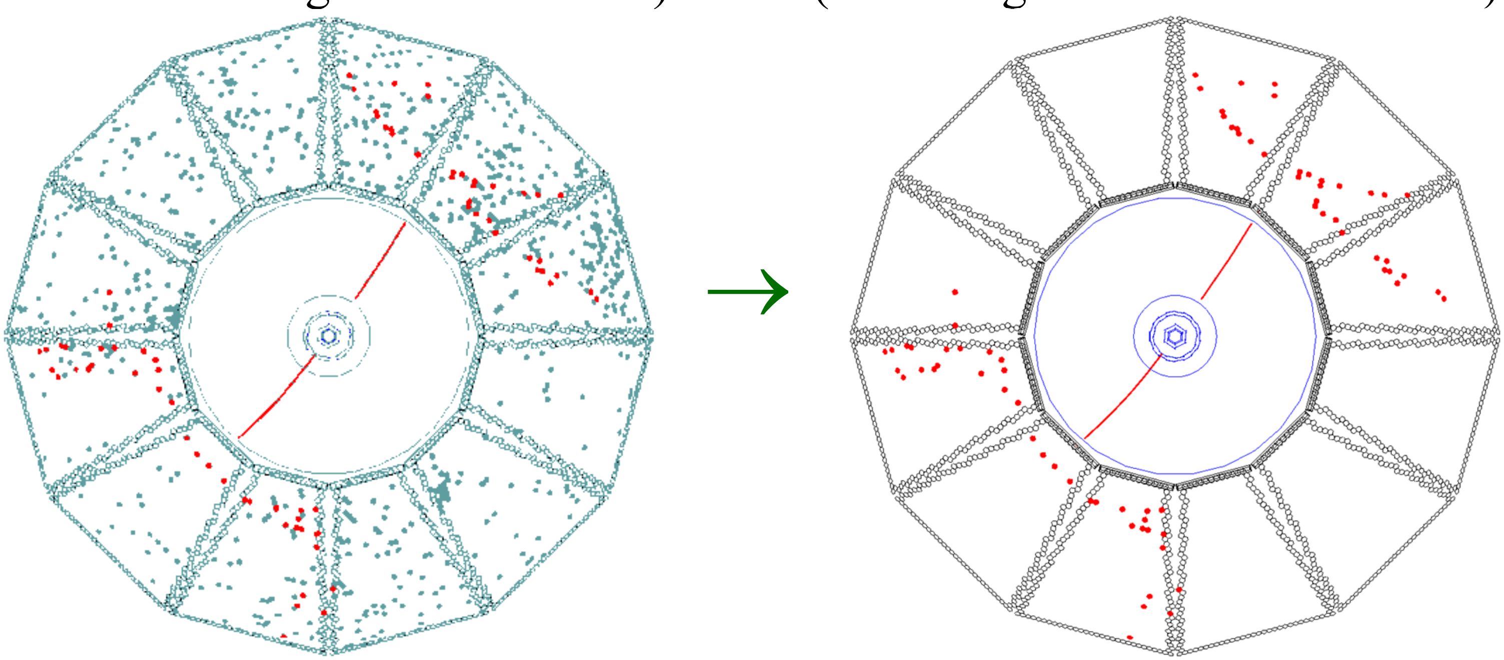
- track TOF
- photon propagation in radiator bar and in water

Δt: difference between measured and expected arrival time



± 300 nsec trigger window → ± 8 nsec Δt window

(~500-1300 background hits/event) (1-2 background hits/sector/event)



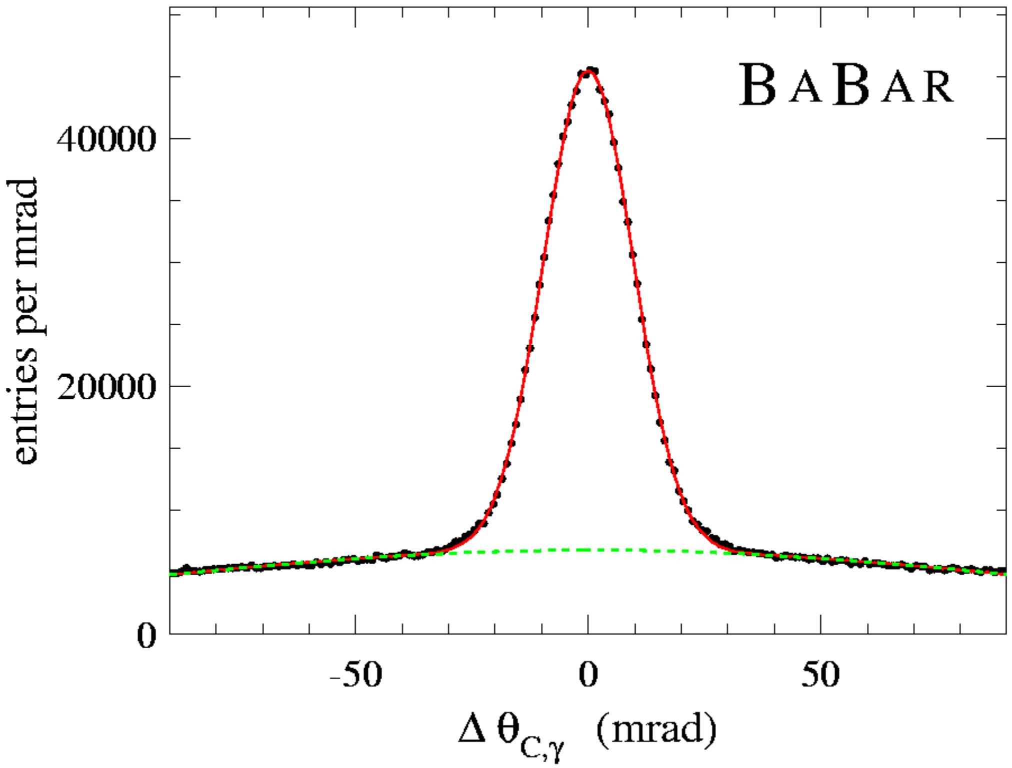
Δt also used to determine event time for "self-triggering" of DIRC.

PERFORMANCE EXAMPLE

BABAR DIRC single photon resolution agrees with design target.

Single Photon Cherenkov angle resolution:

$\Delta\theta_{c,\gamma}$: difference measured $\theta_{c,\gamma}$ per photon solution and expected track θ_c (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.

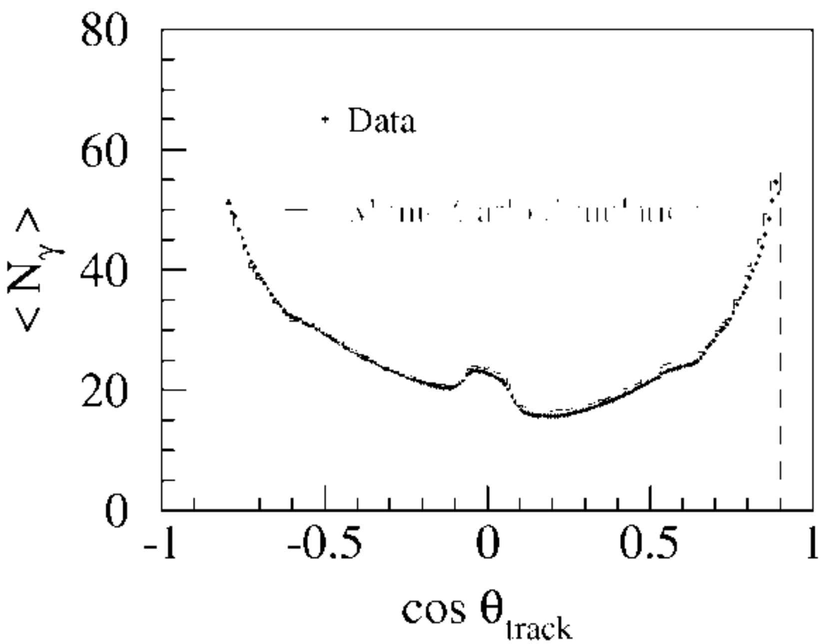
~10% Background under $\Delta\theta_{c,\gamma}$ peak:

combinatoric background, track overlap, accelerator background,

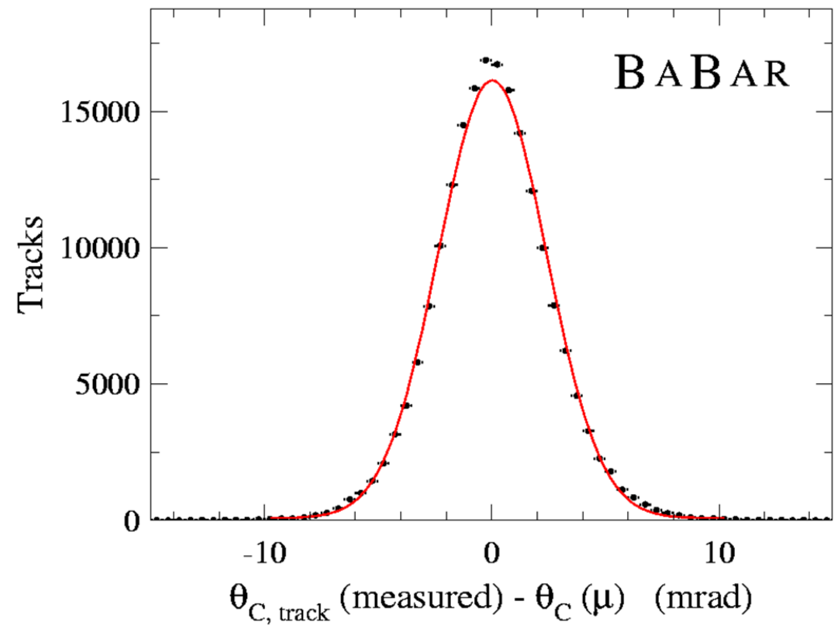
δ electrons in radiator bar, reflections at fused silica/glue interface, ...

PERFORMANCE EXAMPLE

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



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



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 (~ 1/√N)

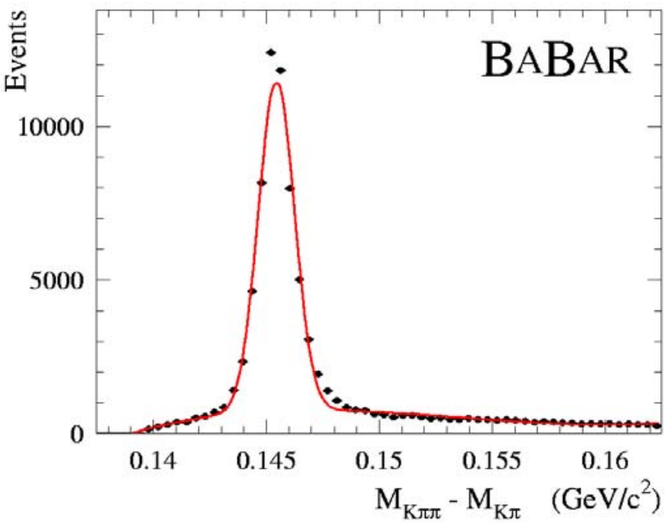
$\sigma(\Delta\theta_c) = 2.4$ mrad

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

Performance Example

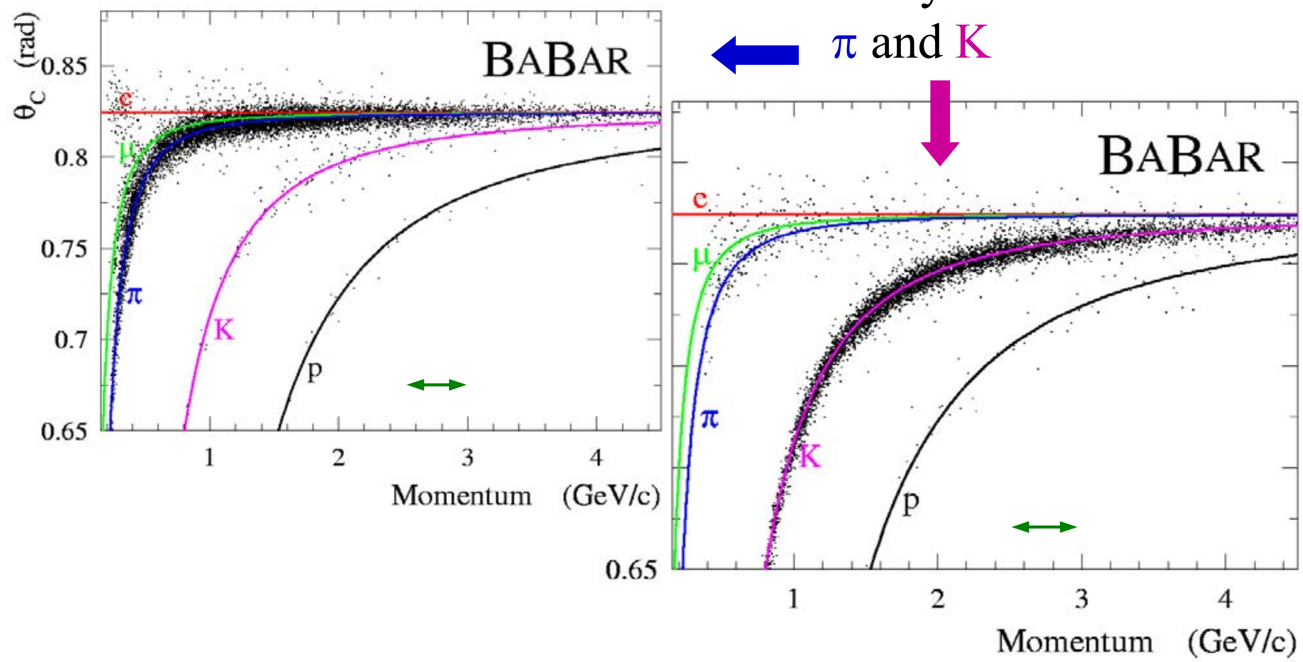
$D^{*-} \rightarrow D^0 \pi^-$

$\quad \hookrightarrow K^- \pi^+$

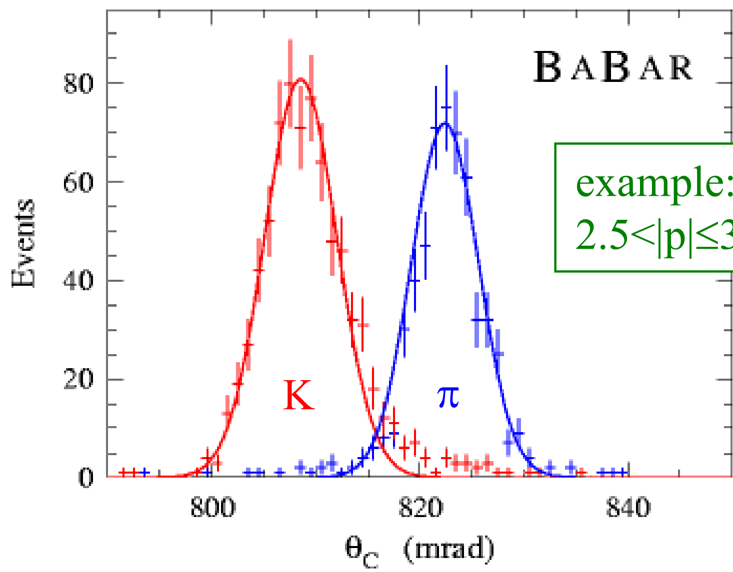


kinematically identified

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.



example:
2.5<|p|≤3GeV/c

DIRC likelihood

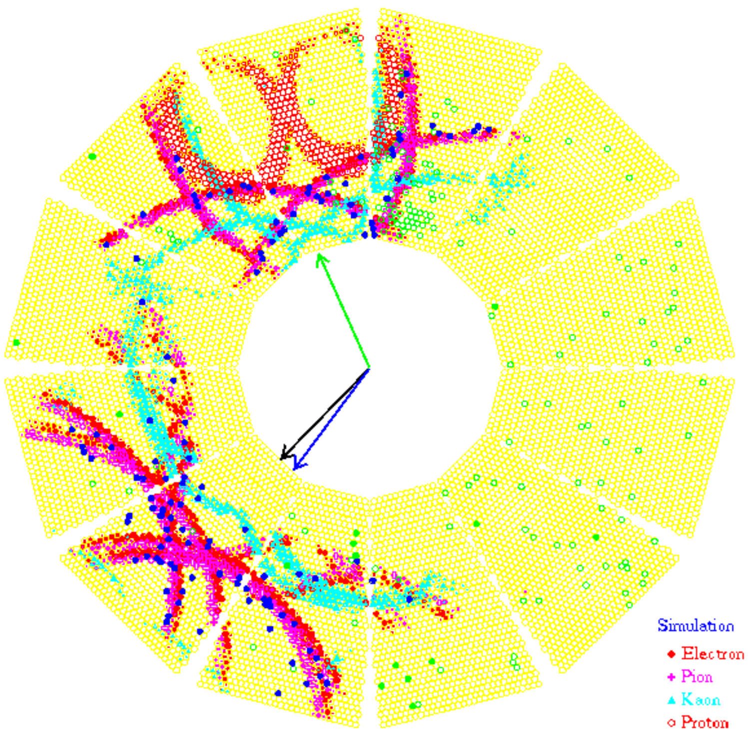
Calculate unbiased likelihood for observed PMT signals
to originate from e/μ/π/K/p track or from background.
(Likelihood: **Pdf(θ_c) ⊗ Pdf(Δt) ⊗ Pdf(N_γ)**)

Two complementary reconstruction algorithms:

- iterative process to maximize event likelihood, full correlation of all tracks;
- individual track fit provides θ_c, $\sigma(\theta_c)$, number of signal/background photons.

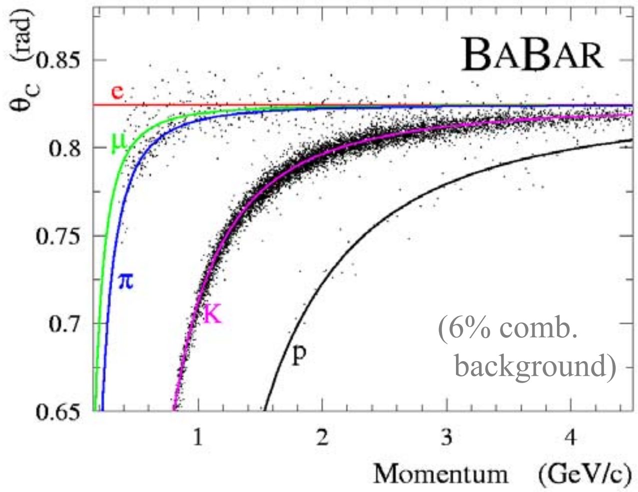
Reflection ambiguities: for BABAR Δt cut reduced these from up to 16 to typically 2-3

Particle ID is based on log likelihood differences of the five hypotheses.



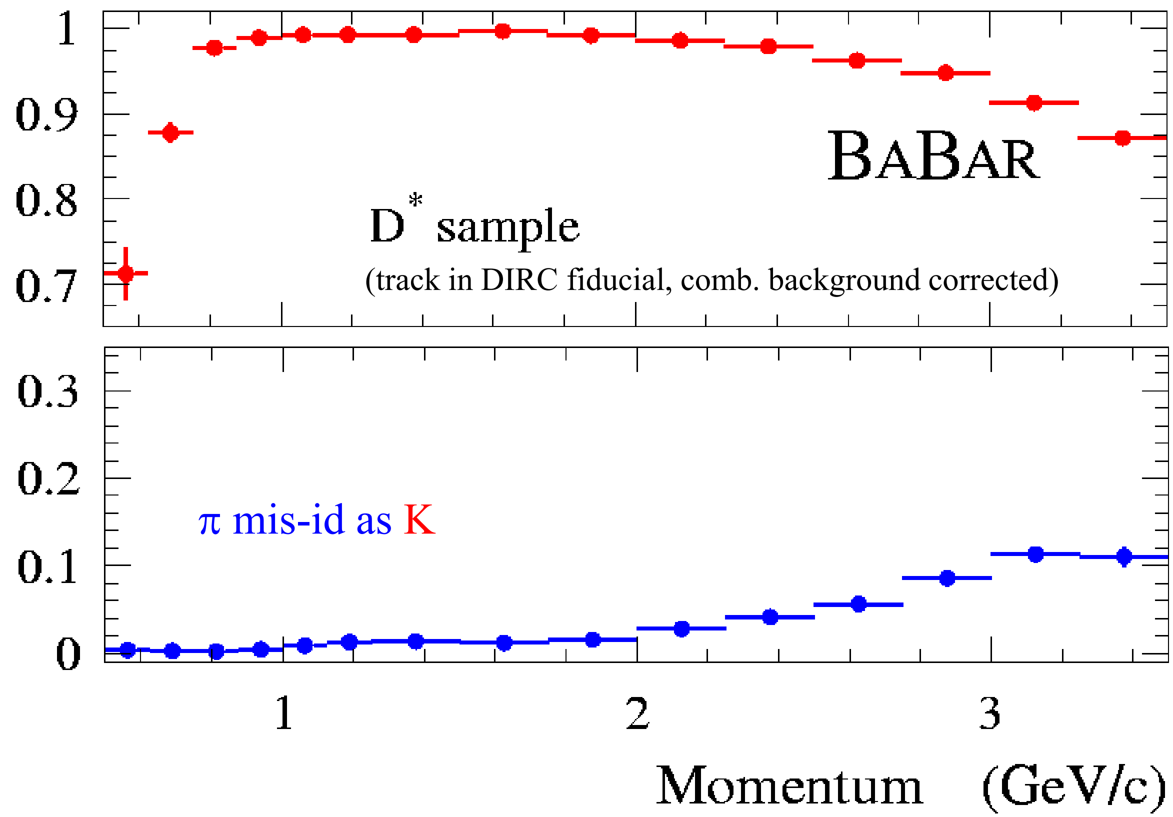
Example: Comparison of real event to simulated response of BABAR DIRC to e/π/K/p.

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



Kaon selection efficiency typically above 95% with mis-ID of 2-10% between 0.8-3GeV/c.

Kaon selection efficiency for $\mathcal{L}^K > \mathcal{L}^\pi$

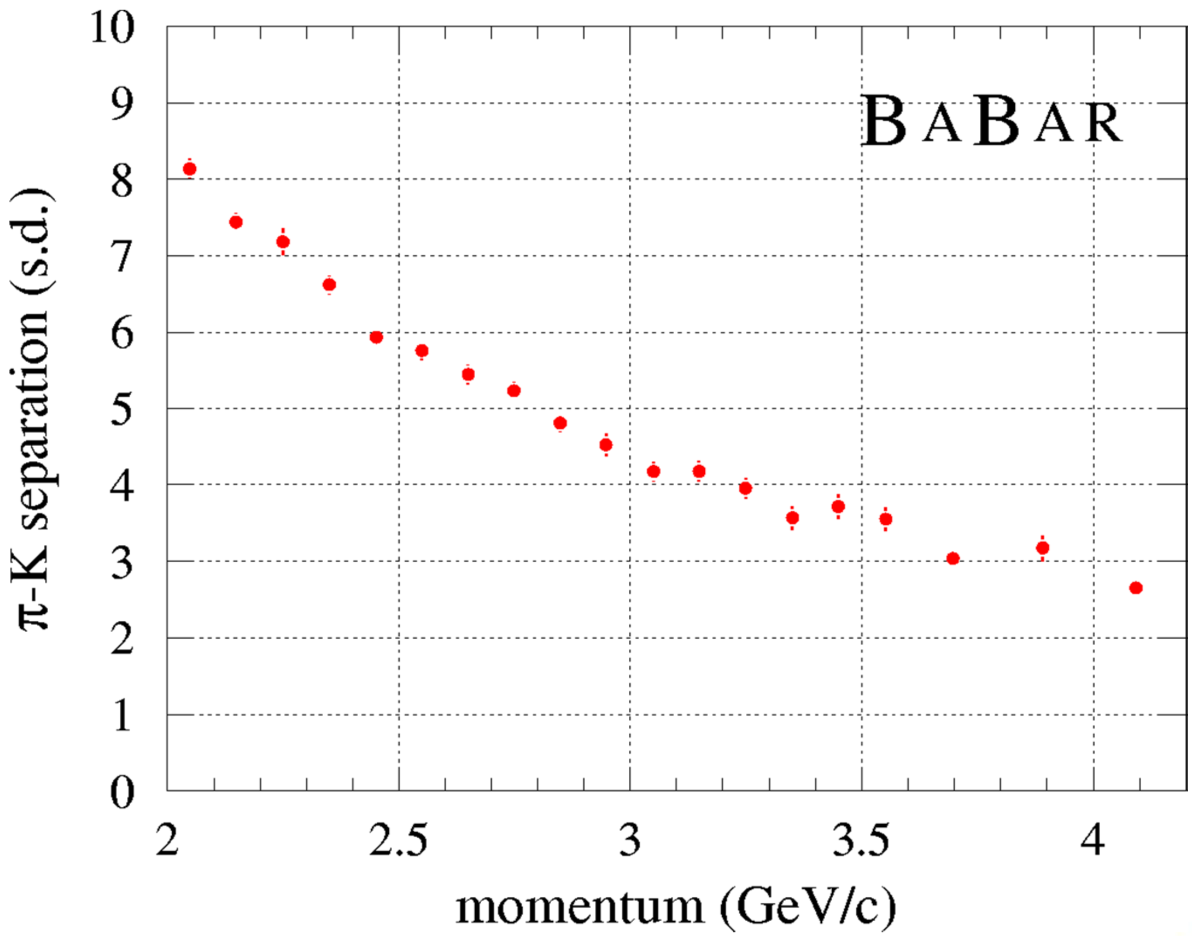


PERFORMANCE EXAMPLE

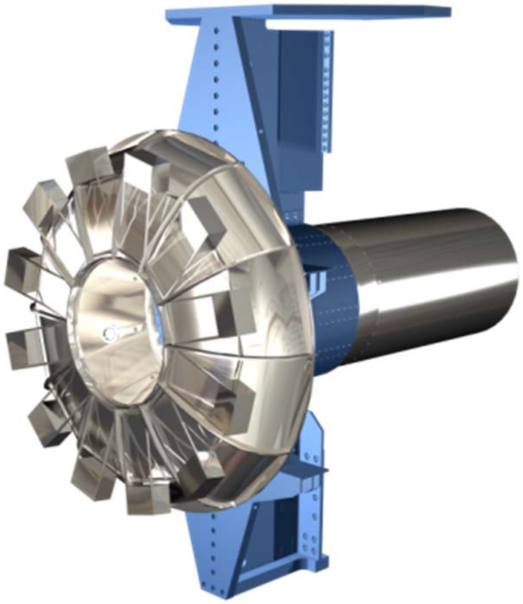
π/K separation power:

Measure Cherenkov angle resolution as function of track momentum for pions and kaons, kinematically identified in D* decays.

→ about 4.3σ separation at 3GeV/c, close to 3σ separation at 4GeV/c



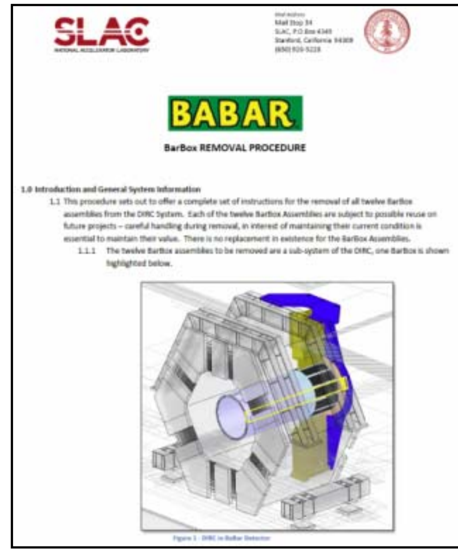
BABAR DIRC CONCLUSION



- The DIRC well matched to asymmetric B-factory environment,
  capable of π-K separation for momenta up to ~ 4 GeV/c.
- Eight+ years of experience in PEP-II/BABAR B-factory mode:
  DIRC very reliable, robust, easy to operate.
- After 8+ years no evidence of bar surface quality deterioration
  or radiation damage to bars or glue;
  98% of channels and pixels fully functional to the end.
- Machine backgrounds up to 300 kHz/PMT at $12 \cdot 10^{33}/cm^2 \cdot s$
  no problem for reconstruction due to good timing resolution.
- Lead shielding and new TDC chips, installed in 2002, kept DIRC working safely
  at four times design luminosity.
- Single photon time and Cherenkov angle resolution and photon yield close to nominal.
- Track Cherenkov angle resolution within 10% of design.
- DIRC plays significant role in almost all BABAR physics analyses published to date.

BABAR DIRC DISASSEMBLY

October 2010: DIRC disassembly – procedure planned out in detail.



SLAC
BABAR
BarBox REMOVAL PROCEDURE

1.0 Introduction and General System Information

1.1 This procedure sets out to offer a complete set of instructions for the removal of all twelve BarBox assemblies from the DIRC System. Each of the twelve BarBox Assemblies are subject to possible reuse on future projects – careful handling during removal, in interest of maintaining their current condition is essential to maintain their value. There is no replacement in existence for the BarBox Assemblies.

1.1.1 The twelve BarBox assemblies to be removed are a sub-system of the DIRC, one BarBox is shown highlighted below.

Open stand-off box, inspect and protect bar boxes and PMTs,
remove inner cylinder, remove doors,
remove bar boxes, mechanical support.

Start of work in IR-2

West door opened

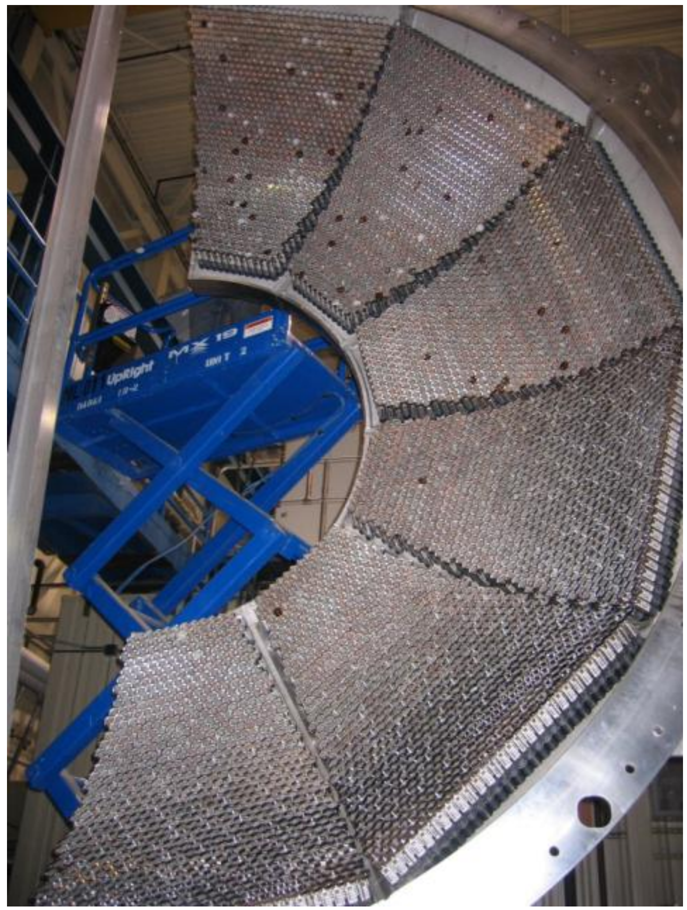
Camera flash reflected by windows/bars

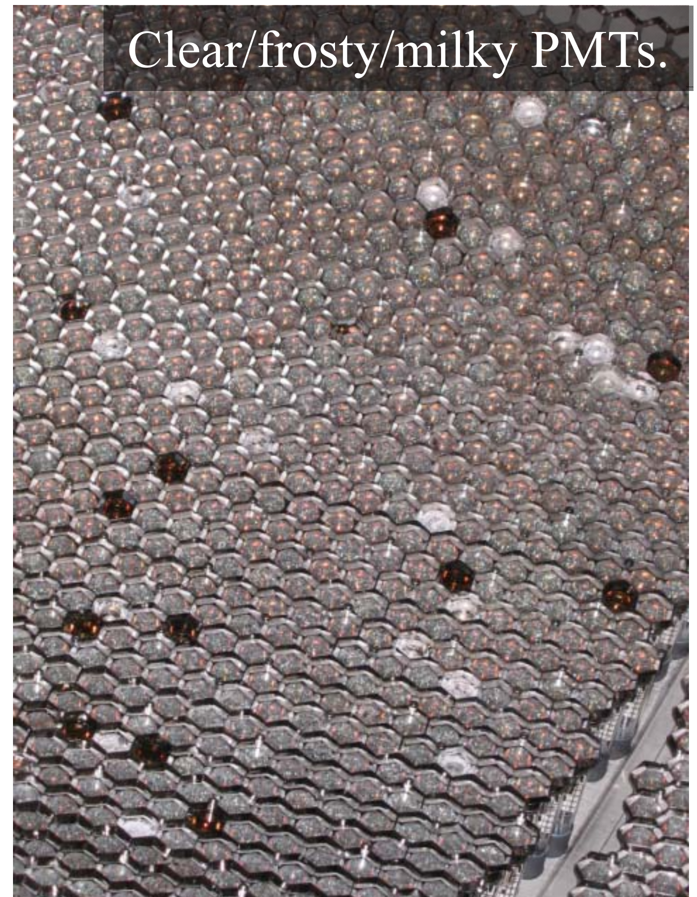
BABAR DIRC DISASSEMBLY

Inspection of PMTs shows that almost in air all PMT faces now appear “frosty.”

Some un-corroded PMT faces, clustered in some sectors (different glass).

Note that frosty PMTs performed just as well as non-frosty.





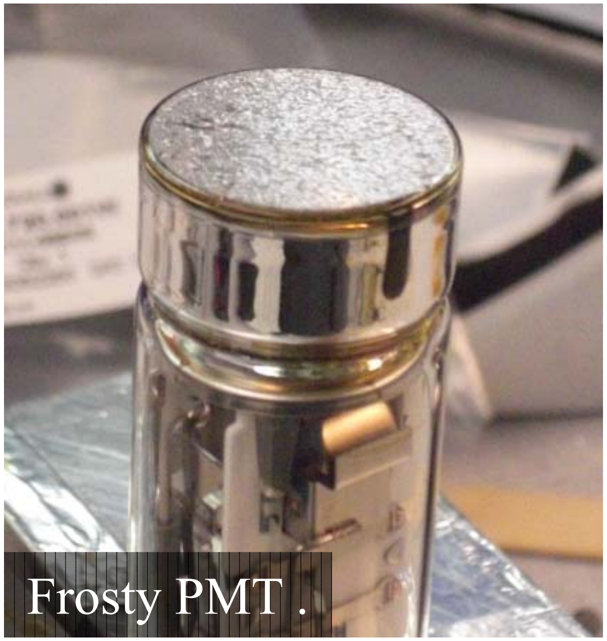
BABAR DIRC DISASSEMBLY

Frosty/milky appearance of front glass window for most DIRC PMTs.

Water provided good coupling, PMT glass looked transparent in water.

PMT performance (PDE) still good (J. Va'vra test with glued front glass)

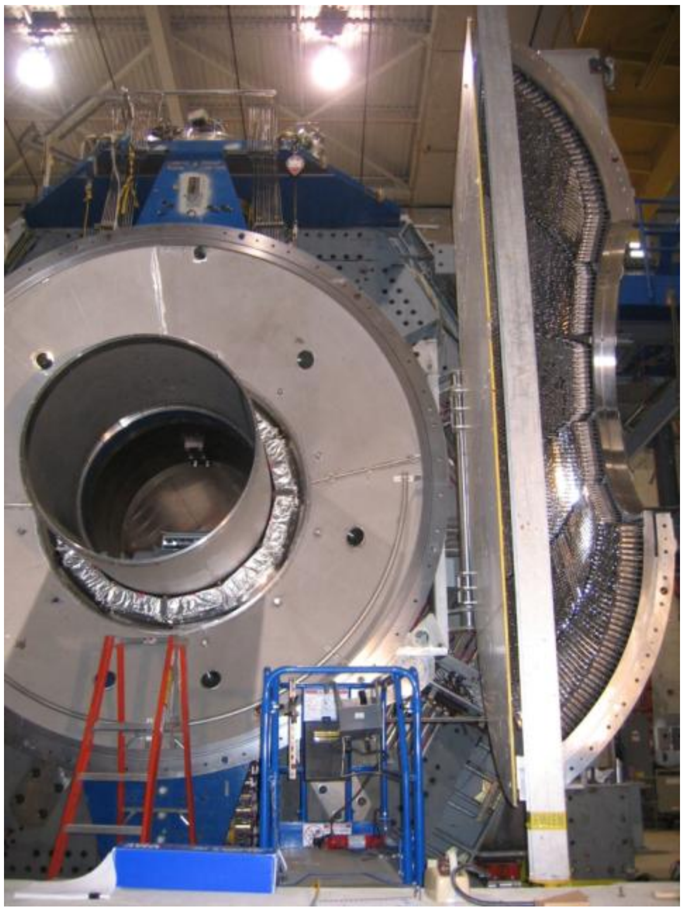

Three frosty/milky PMTs.

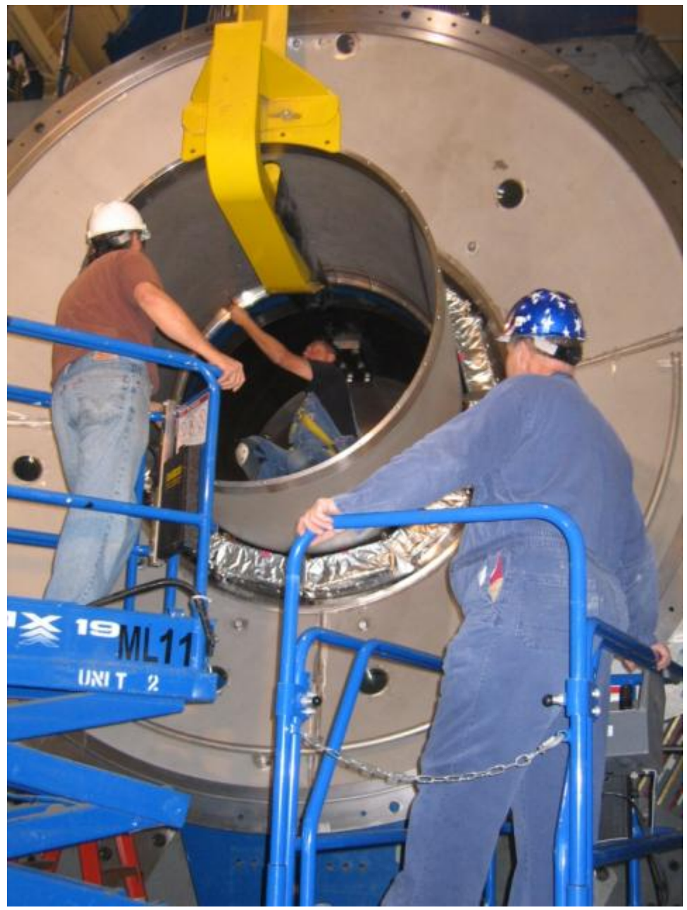

Frosty PMT .

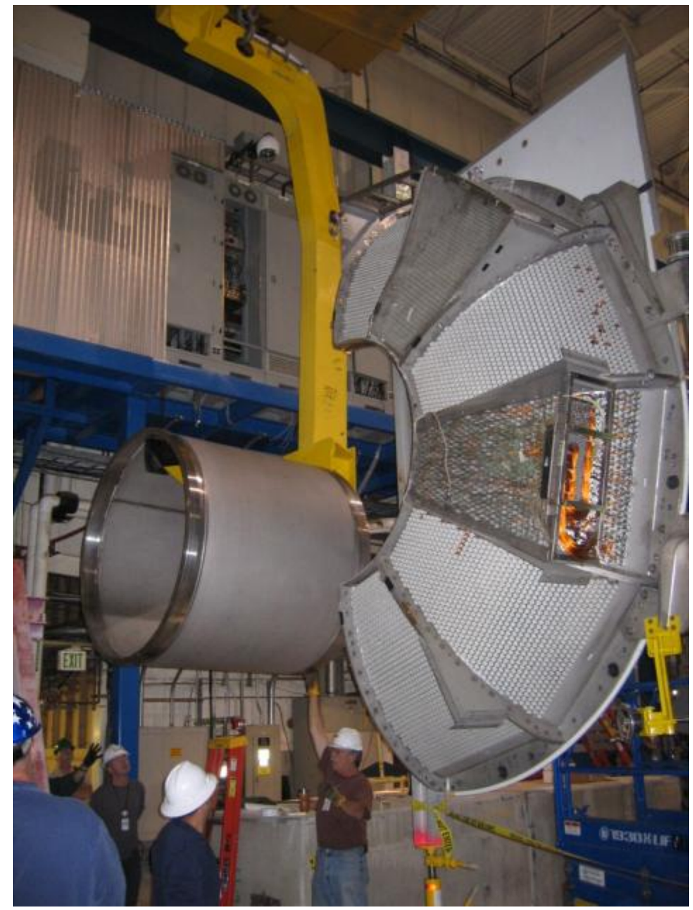

Drop of glue.


Glued glass window.

Removal of inner cylinder.





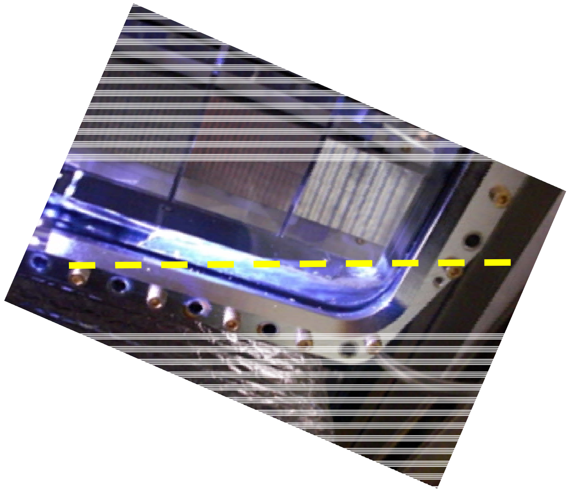


BABAR DIRC DISASSEMBLY

How do you remove bar boxes? Very carefully.

No indication of pollution or rust in tracks.

Water stain in corner of window of one bar box
(consistent with small water leak observed
via gas humidity following initial installation).



BABAR DIRC DISASSEMBLY

All 12 bar boxes in storage.

Visual inspection using bright light shows no damage to bars or glue bonds.

(Consistent with detailed detector analysis results.)

Sunny day in January 2011:
Strong support tube moved to storage.

All DIRC components now in storage, ready for trip to SuperB in Italy.

IMPROVING ON BABAR DIRC

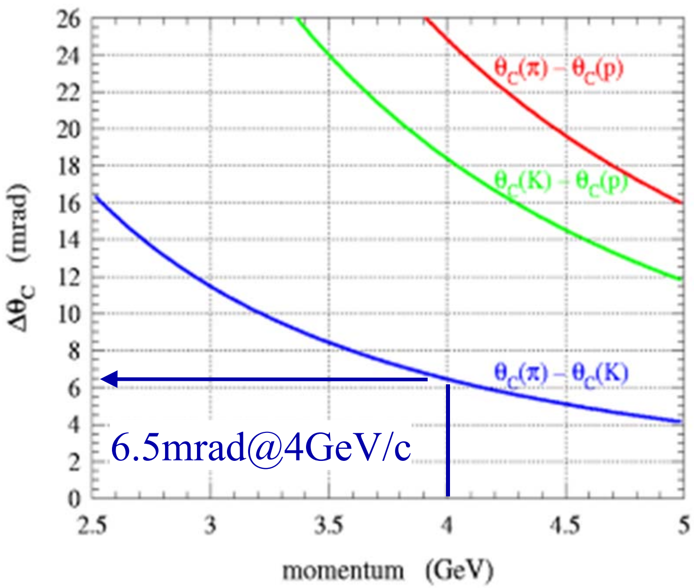
The DIRC approach was very successful in BABAR.

As early as 2000 R&D efforts underway to improve future DIRCs.

- Make DIRC less sensitive to background
  - decrease size of expansion volume;
  - use photon detectors with smaller pixels and faster timing;
  - place photon detector inside magnetic field.
- Investigate alternative radiator shapes (plates, disks)
- Push DIRC π/K separation by improving single-photon θ_C resolution
  - focusing optics to reduce bar size contribution;
  - smaller pixels to reduce pixel size contribution;
  - mitigate effect of dispersion using fast timing, filters, etc.

→ R&D for SuperB – Belle II – PANDA – and beyond

IMPROVING DIRC RESOLUTION



PID performance driven by Cherenkov angle (θ_C) resolution.
Required resolution defined by refractive index of radiator.

Example: π/K separation in synthetic fused silica <n>≈1.473
→ 6.5 mrad π/K difference in θ_C at 4 GeV/c;
→ need ~ 2.2 mrad resolution for 3 s.d. separation.

Cherenkov angle resolution determined by single photon resolution (scales with $1/\sqrt{N_\gamma}$) and correlated terms (mult. scattering, etc).

R&D ideas to push DIRC 3 s.d. π/K separation limit to higher momenta than BABAR.

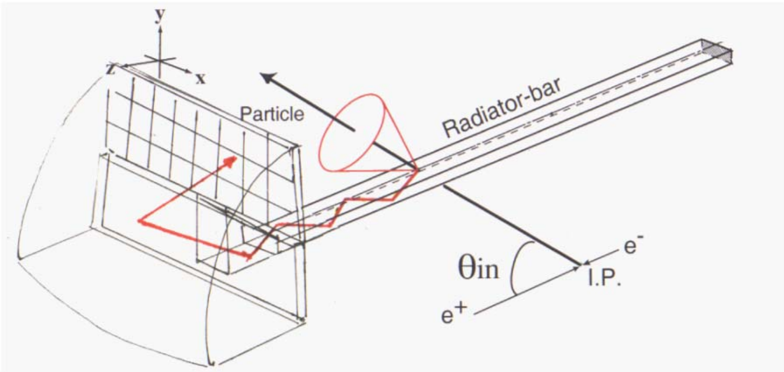
BABAR-DIRC Cherenkov angle resolution: 9.6 mrad per photon → 2.4 mrad per track

Limited in BABAR by:			Could be improved for future DIRCs via:
▪ size of bar image	~4.1 mrad	→	▪ focusing optics
▪ size of PMT pixel	~5.5 mrad	→	▪ smaller pixel size
▪ chromaticity ($n=n(\lambda)$)	~5.4 mrad	→	▪ better time resolution
	9.6 mrad	→	4-5 mrad per photon → < 1.5–2 mrad per track

SUPERB & PANDA DIRC Designs

BABAR DIRC UPGRADE

- In 2000 plans existed for a "Super B-Factory" at SLAC.
  - Super-PEP-II upgrade of accelerator and IR for 100x higher luminosity.
  - Super-BABAR upgrade to further improve physics performance and allow safe operation at high luminosity.
- BABAR DIRC group started R&D to push DIRC π/K separation power to higher momentum and reduce sensitivity to backgrounds.
- DIRC R&D effort at SLAC (led by J. Va'vra) concentrated on:
  - using focusing mirror to reduce contribution of bar size to θ_c resolution;
  - mitigating effect of chromatic dispersion using fast photon timing.
  - decreasing volume of stand-off box by factor 10;
- Started with R&D on compact multi-pixel photon detectors, progressed with multi-bar prototypes in cosmic ray telescope facility and test beams, including complex readout electronics R&D.



- Resulted in FDIRC design for SuperB in Italy.

Main criteria for selection

- Timing resolution

  timing resolution σ_t < 200ps required for chromatic correction (for BABAR-DIRC bar length)

- Pixel size

  small pixels allow reduction of size of expansion region without compromising angular resolution

- Single photon efficiency

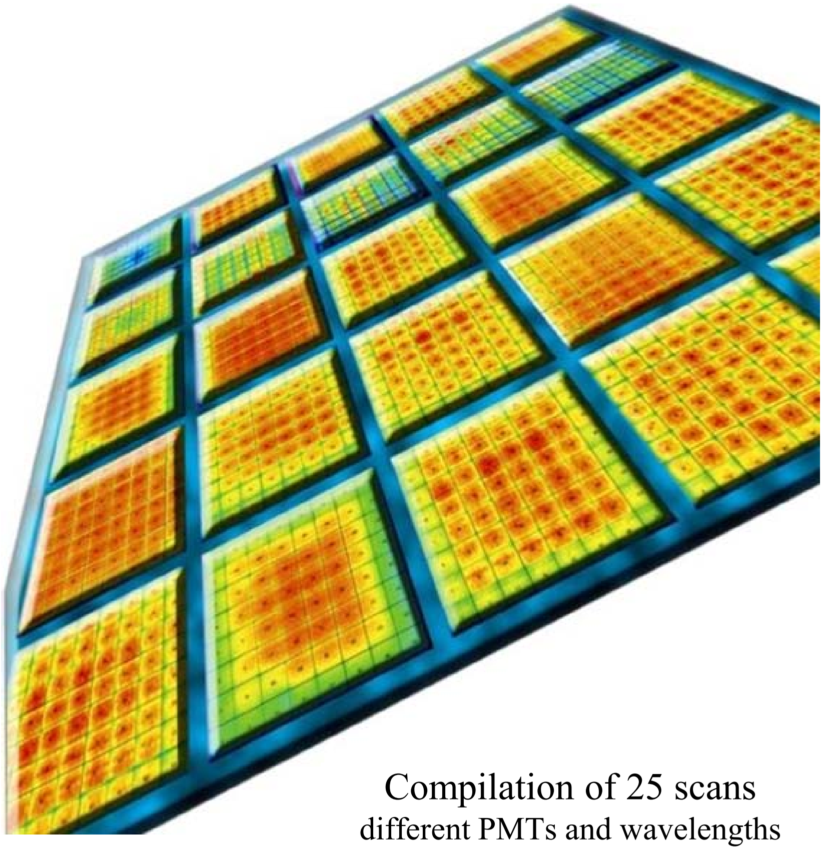
  need quantum efficiency ~20-30% and >70% packing efficiency to match BABAR-DIRC photon yield

Main candidates

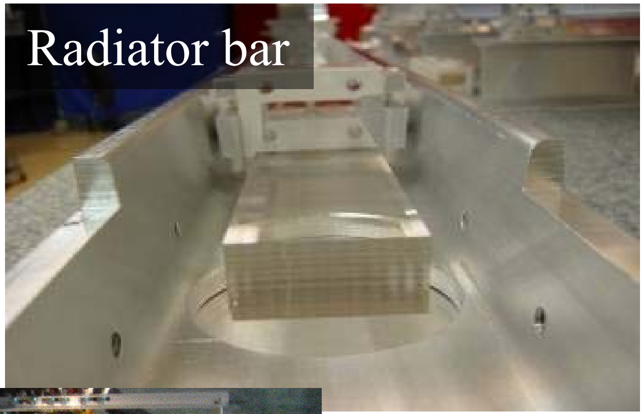
- Burle 85011-501 MCP-PMT
- Burle 85011-430 MCP-PMT
- Burle 85021-600 MCP-PMT
- Hamamatsu H-8500 Multianode PMT
- Hamamatsu H-9500 Multianode PMT

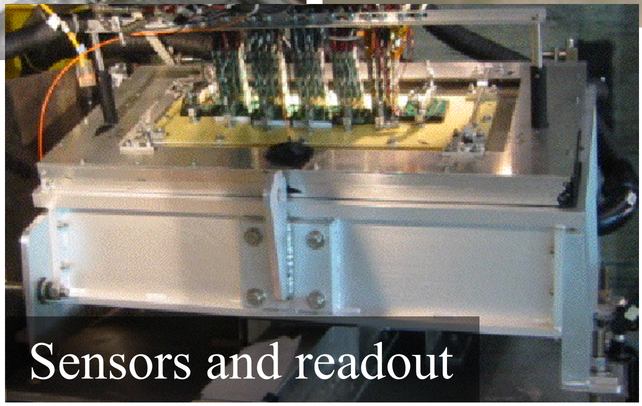
Measure timing resolution, uniformity, and cross talk

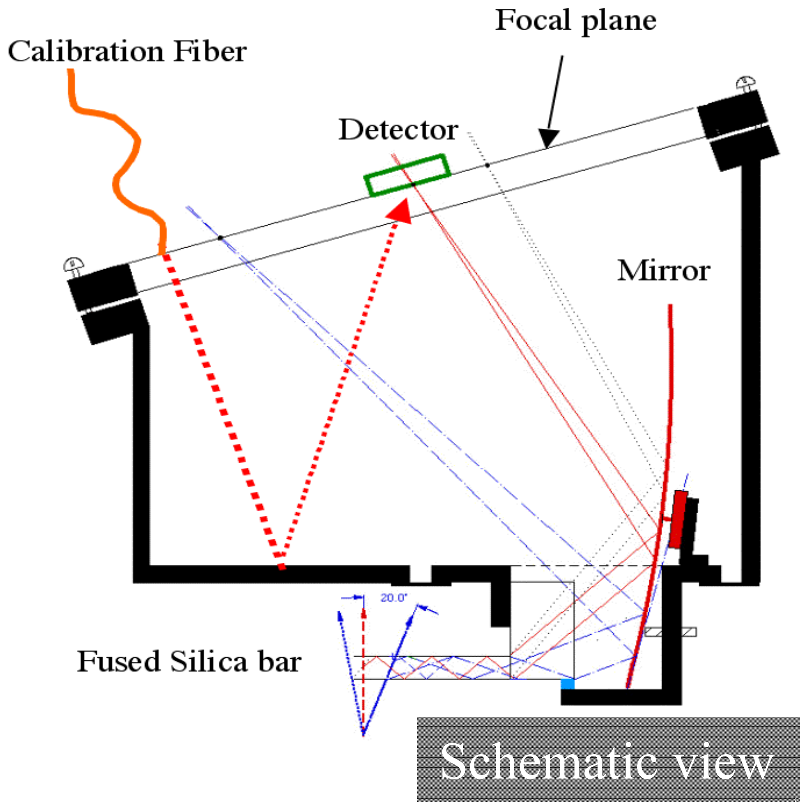
- PiLas laser diodes (35ps FWHM, λ = 407 / 635 nm)
- Scan PiLas across PMT face using motion-controlled x&y stage (typical step size 200-500μm)



Compilation of 25 scans
different PMTs and wavelengths



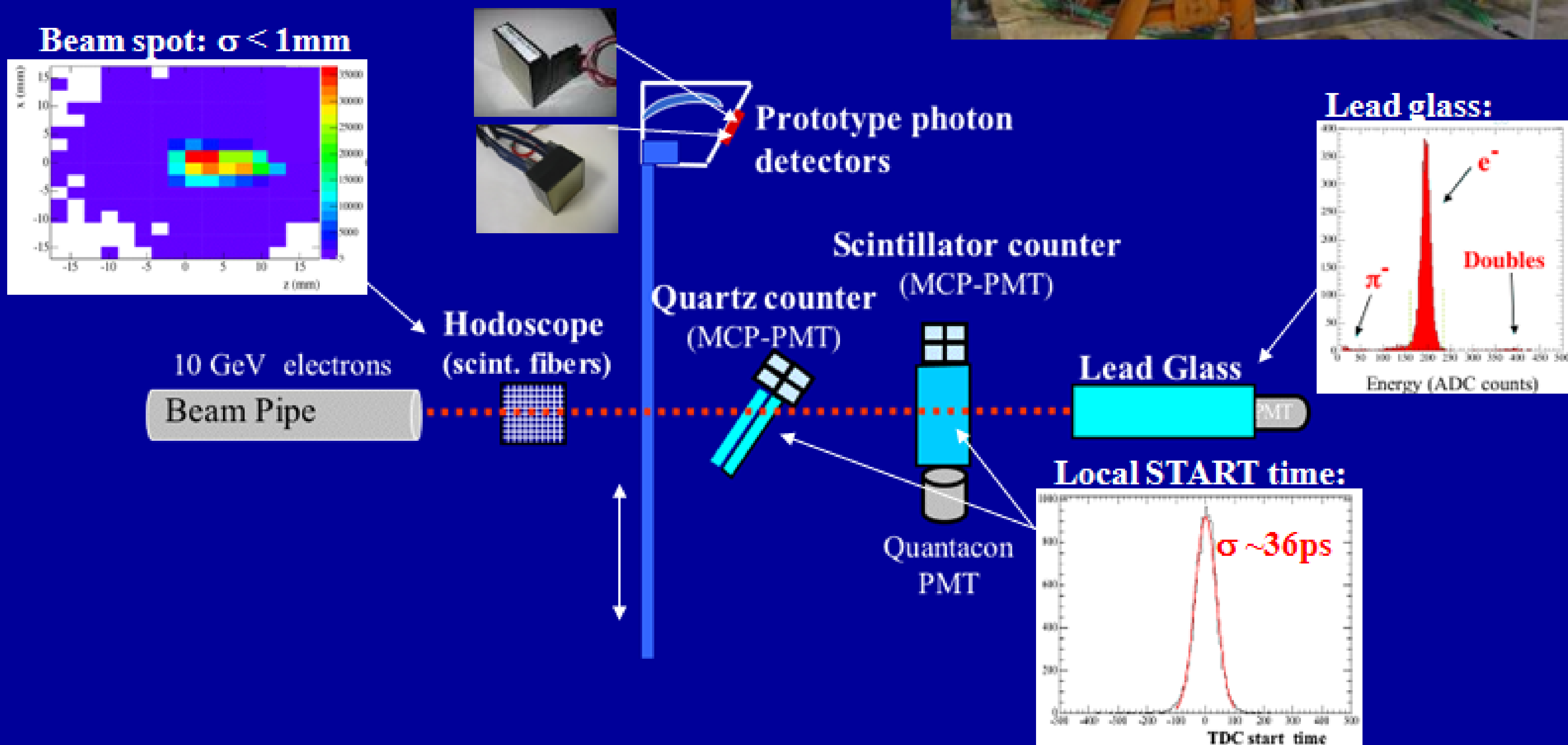




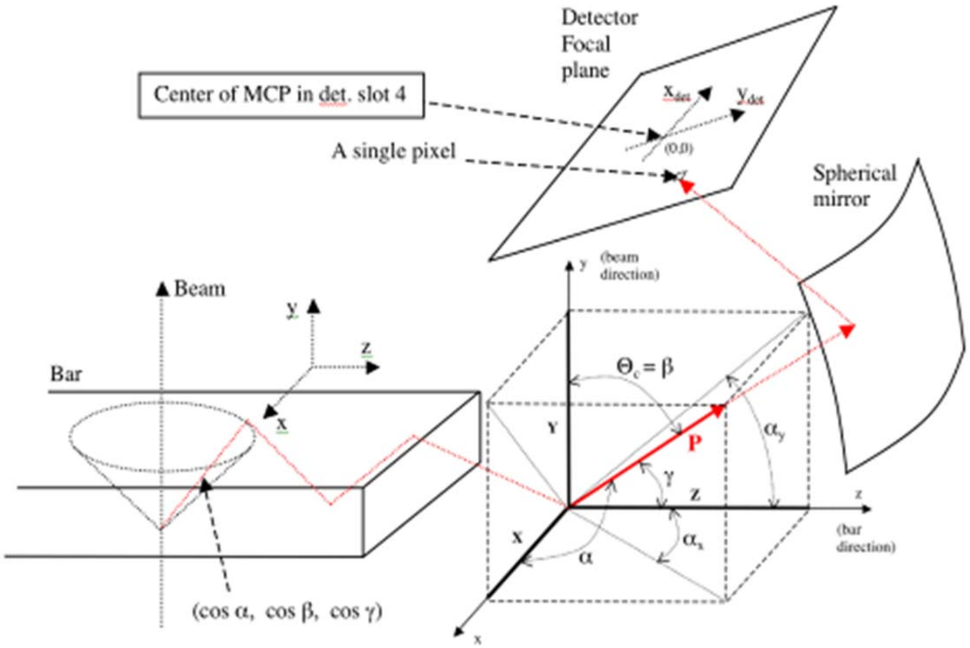
- Radiator:
  - 1.7 cm thick, 3.5 cm wide, 3.7 m long fused silica bar (spares from BABAR DIRC).
- Optical expansion region:
  - filled with a mineral oil to match the fused silica refraction index (KamLand oil).
  - include optical fiber for the electronics calibration (PiLas laser diode).
- Focusing optics:
  - a spherical mirror with 49cm focal length focuses photons onto a detector plane.

BEAM TEST SETUP

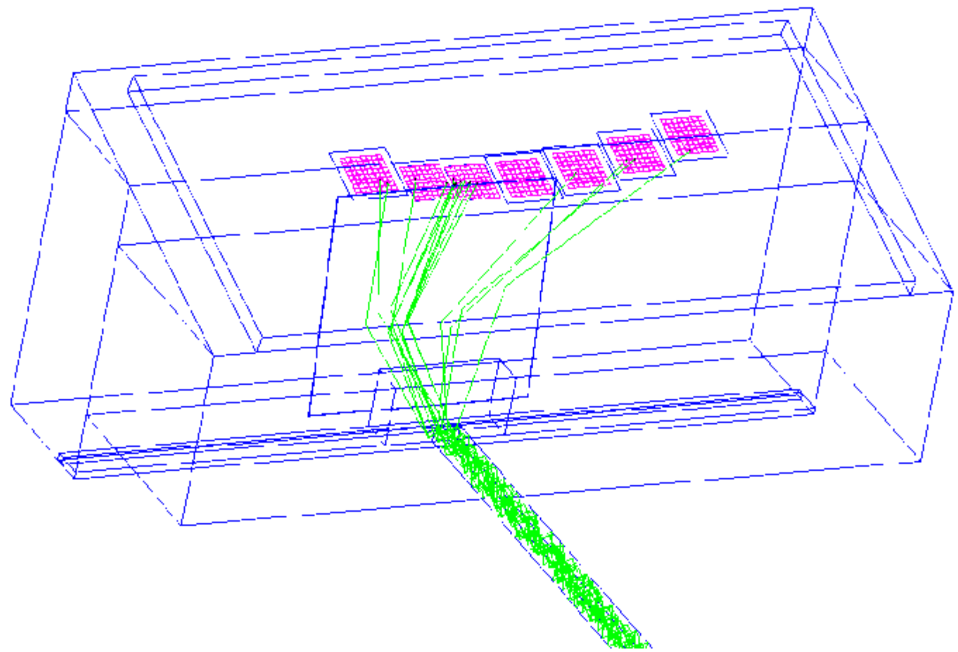
- SLAC 10 GeV/c electron beam in End Station A
- Beam enters bar at 90° angle
- Prototype is movable to 7 beam positions along bar
- Time start from the LINAC RF signal, but correctable with a local START counter
- SLAC-built amplifier and constant fraction discriminator
- TDC is Phillips 7186 (25ps/count), CAMAC readout



Prototype coordinate systems:



Geant 4 simulation of the prototype:



Approach similar to BABAR DIRC *(and current PANDA Barrel DIRC approach)*

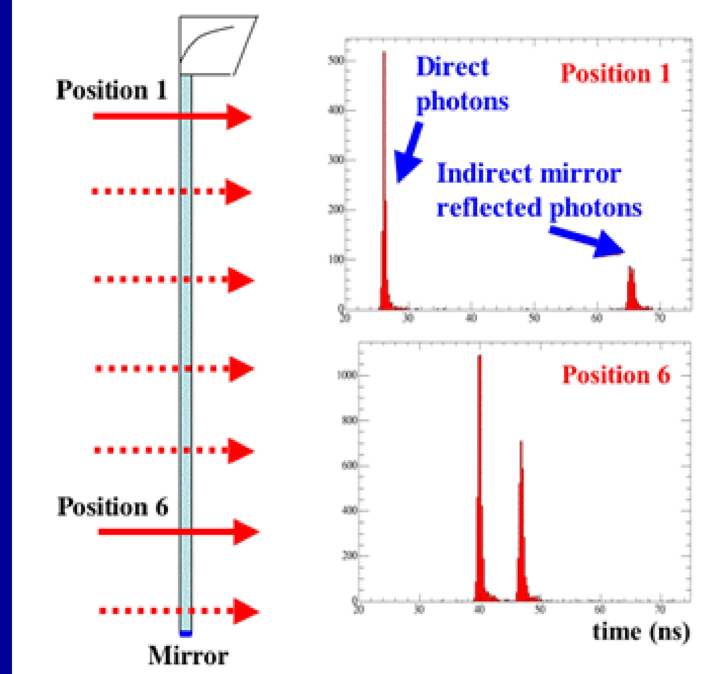
- Each detector pixel determines these photon parameters for average λ :
  θ_c, cos α, cos β, cos γ, Photon path length, time-of-propagation, number of photon bounces.

- Full GEANT4 simulation to obtain the photon track parameters for each pixel.
  (it is checked by a ray-tracing software)

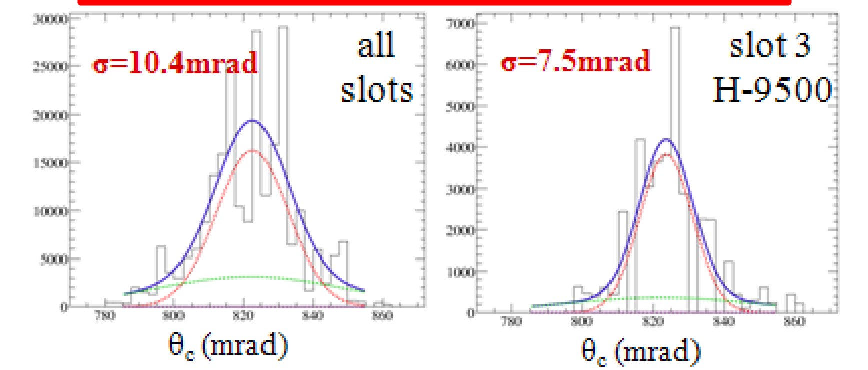
CHERENKOV PHOTON SIGNAL

- 10 GeV/c electron beam data
- approx. 7.7M triggers, 560k good single e^- events
- ~ 200 pixels instrumented
- Ring image is most narrow in the 3 x 12 mm pixel detector (H-9500 in slot 3)

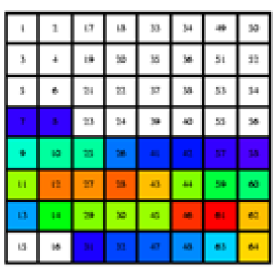
Cherenkov photons in time domain



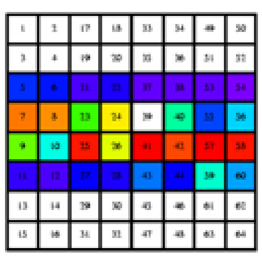
Cherenkov photons in θ_c domain



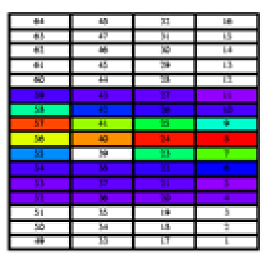
Cherenkov photons in pixel domain



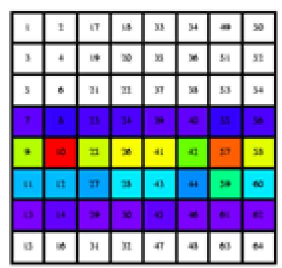
Burle 85011-501



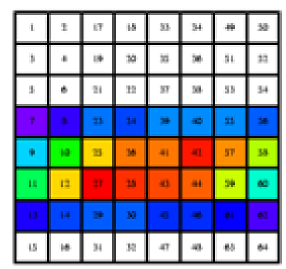
Hamamatsu H-8500



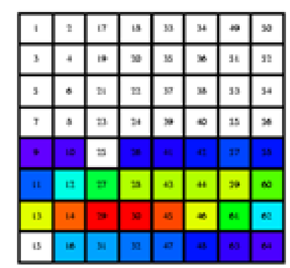
Hamamatsu H-9500



Burle 85011-501



Burle 85011-501



Burle 85011-501

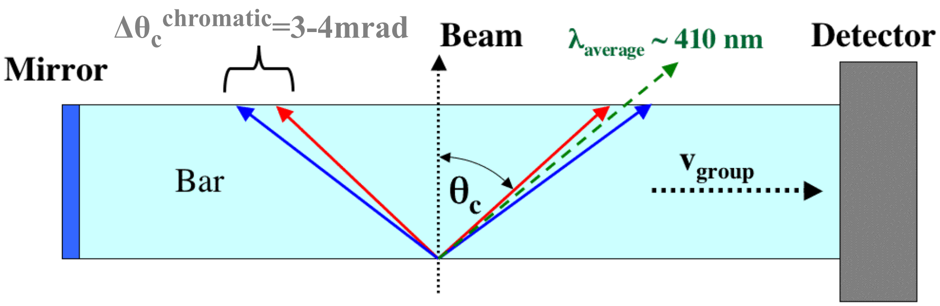
CORRECTING THE CHROMATIC ERROR ON θ_C

Cherenkov angle production controlled by n_{phase} ($\cos\theta_c = 1/(n_{phase}\beta)$):

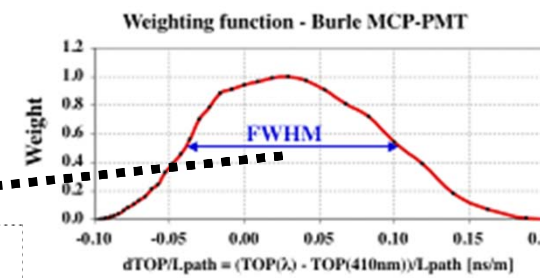
θ_c (red) < θ_c (blue)

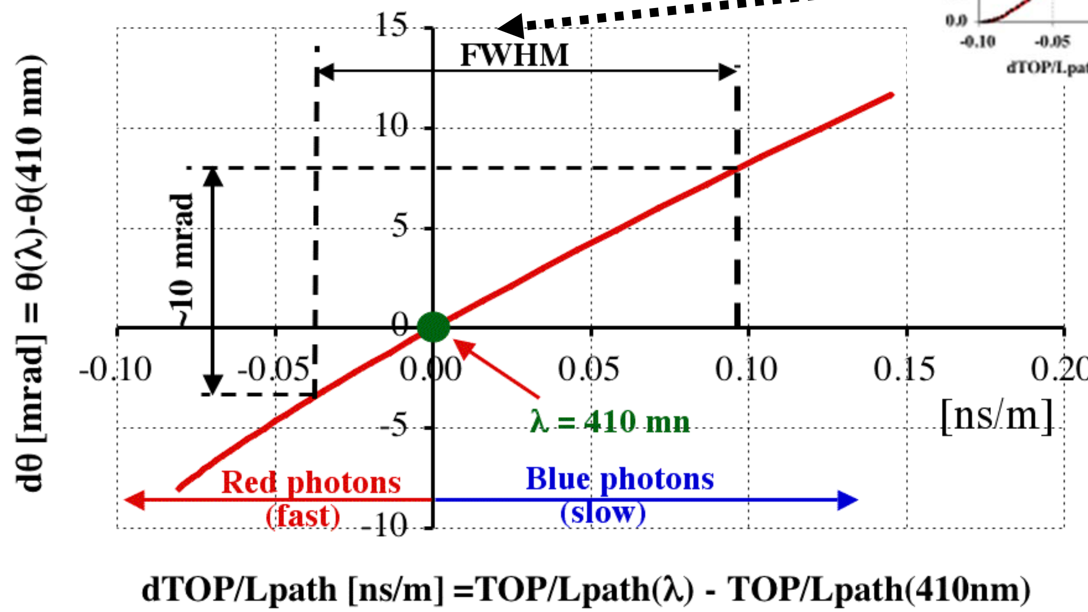
Propagation of photons is controlled by n_{group} ($v_{group} = c_0/n_{group} = c_0/[n_{phase} - \lambda \cdot dn_{phase}/d\lambda]$):

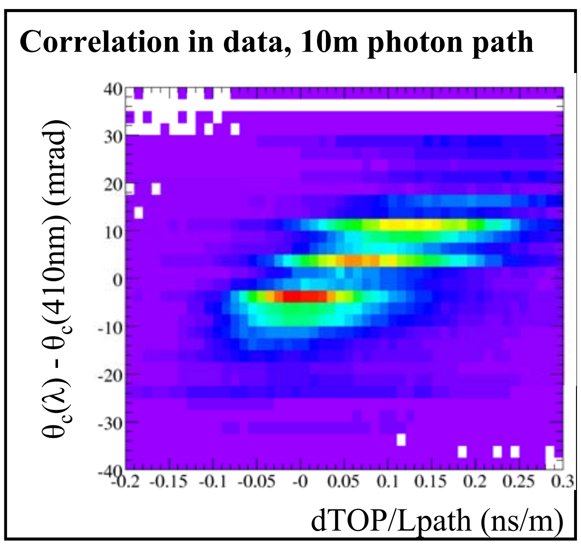
v_{group}(red) > v_{group} (blue)



Principle of chromatic correction by timing:



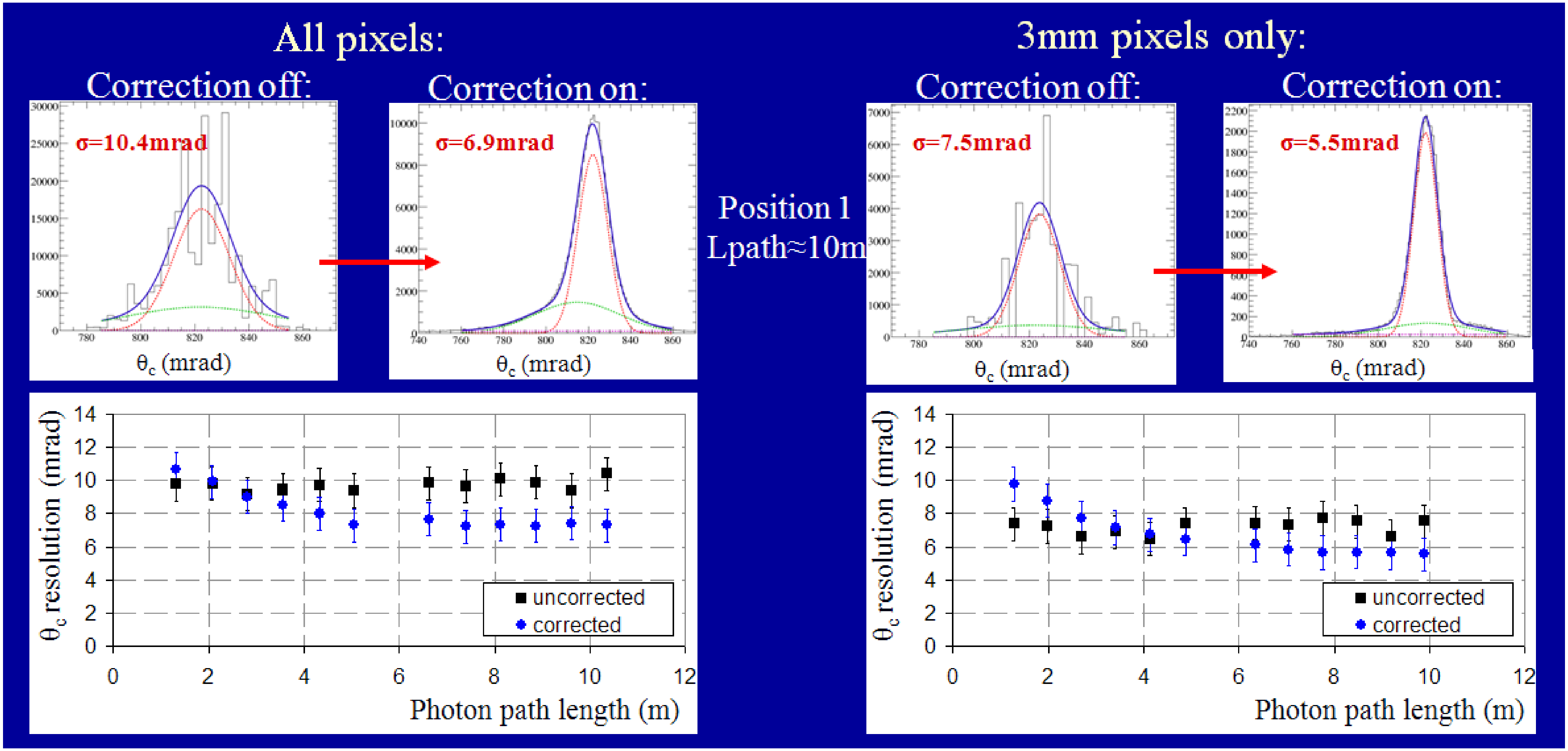




TOP = time of propagation of photon in the bar

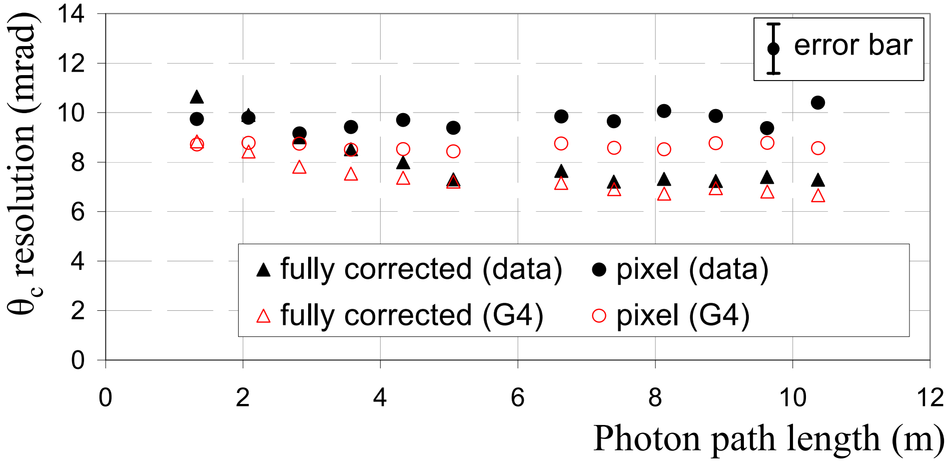
TOP/Lpath = $1/v_{group}(\lambda)$

CHROMATIC CORRECTION RESULTS

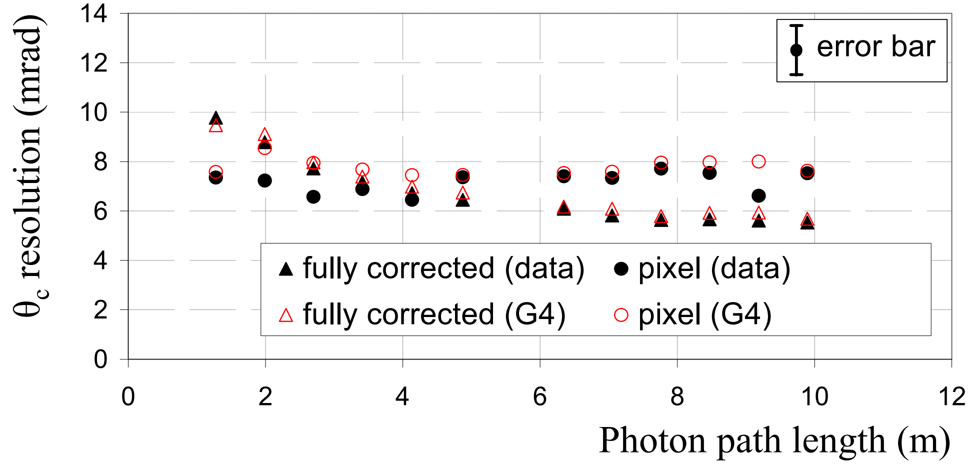


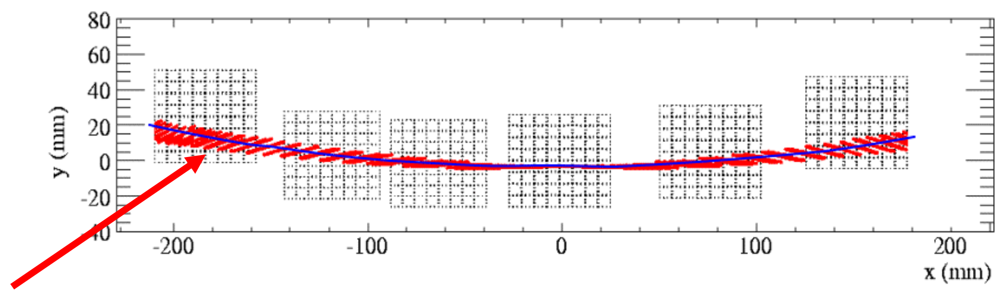
- The chromatic correction starts working for L_{path} > 2-3 meters due to a limited timing resolution of the present photon detectors.
- Holes in the <u>uncorrected</u> distributions are caused by the coarse <u>pixelization</u>, which also tends to worsen the resolution. In the corrected distributions this effect is removed because of the time correction.
- Smaller pixel size (3mm) helps to improve the Cherenkov angle resolution.

θ_c resolution - all pixels:



θ_c resolution - 3mm pixels only:





- Main contributions to the θ_c resolution:
  - chromatic smearing: ~ 3-4 mrad
  - 6mm pixel size: ~5.5 mrad
  - optical aberrations of this particular design:

    grows from 0 mrad at ring center to 9 mrad in outer wings of Cherenkov ring

    (this effect is caused by the spherical focusing mirror in the present design)

FDIRC R&D SUMMARY

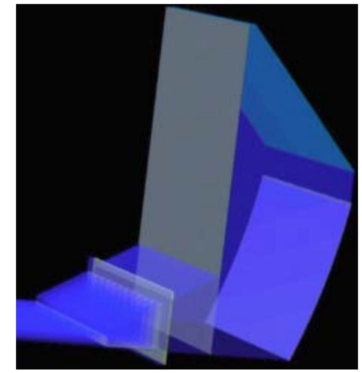
- R&D of photon detectors identified Hamamatsu H-8500 and H-9500 as well as Burle 85011 MCP-PMTs as good sensor candidates for SuperB.
- Small pixels allow compact expansion volume, reducing sensitivity to accelerator-induced background.
- Photon yield consistent with BABAR DIRC.
- Focusing mirror improved single-photon θ_C resolution.
- Demonstrated that the chromatic error of θ_C can be corrected using fast timing. (First RICH detector which has been able to do this.)
- Single-photon θ_C resolution 5.5 – 7 mrad after chromatic correction for long paths (consistent with G4 simulation).
- Successful proof of principle for SuperB.

J. Benitez, I. Bedajanek, D.W.G.S. Leith, G. Mazaheri, B. Ratcliff, K. Suzuki, J. Schwiening, J. Uher, L.L. Ruckman, G. Varner, and J. Va'vra,

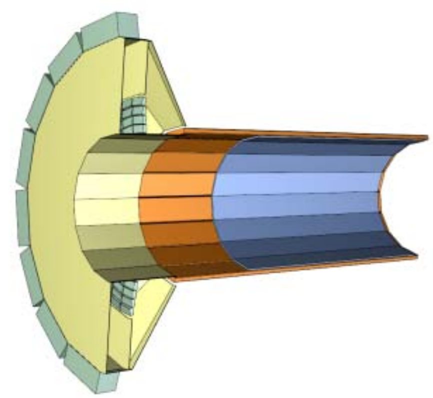
SLAC-PUB-12236 and NIMA 595 (2008) 104

FUTURE DIRC DETECTORS

- SUPERB DETECTOR IN ITALY
  - o FDIRC



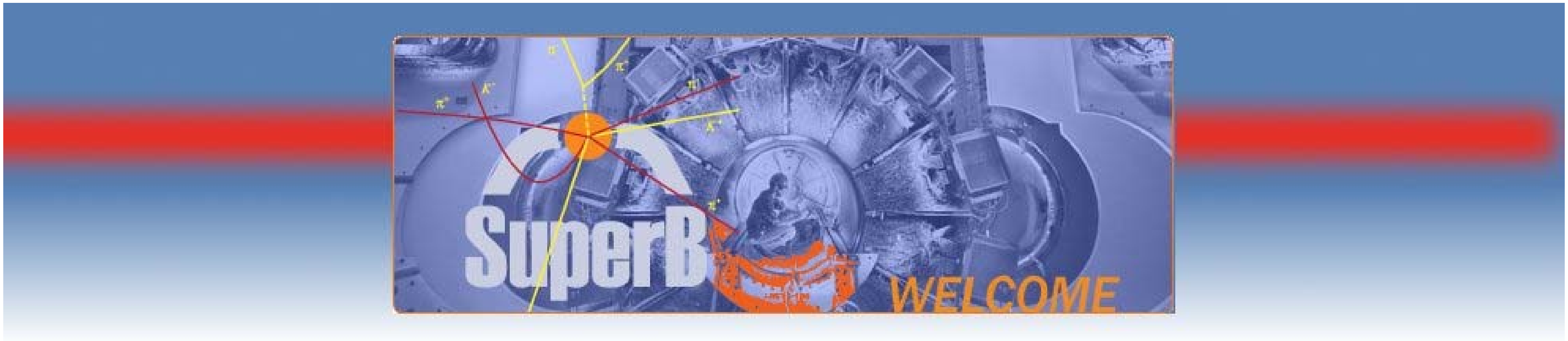
- PANDA
  - o BARREL DIRC → *more detail in Carsten's talk*
  - o ENDCAP DISK DIRC → *see Michael's talk*



- BELLE II DETECTOR AT SUPERKEKB IN JAPAN
  - o TOP COUNTER → *see Kazuhito's talk*
- WASA (COSY), LHCB UPGRADE, EIC & PHENIX UPGRADES, ETC

→ *see talks by Klaus, Thierry*

FDIRC FOR ITALIAN SUPERB



Italian priority flagship project, approved Dec. 2010, 250M€ recently released for machine.

Physics Goals

Exploration of CKM parameters at 1% precision.

New physics in search for CP violation in D decays,
in search LFV in tau decays,
in search CP violation in tau decays.

Sensitivity to New Physics phenomena
up to energies ~ 30 TeV
(beyond LHC energies)

Physics white paper
arXiv:1008.1541
Detector CDR
arXiv:0709.0451

Focusing DIRC (FDIRC):

barrel PID system for SuperB detector in Italy (Frascati/Tor Vergata).

Important constraint:

BABAR DIRC bar boxes will be reused, readout outside magnetic field.

Expect much higher backgrounds at $10^{36}/\text{cm}^2\cdot\text{s}$ (100 times BABAR luminosity)

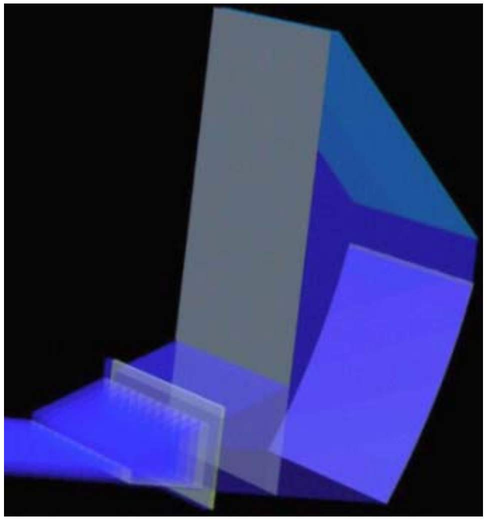
→ decrease size of expansion volume (main source of background in BABAR DIRC).

Design based on FDIRC R&D at SLAC (proof of principle); new optics and electronics

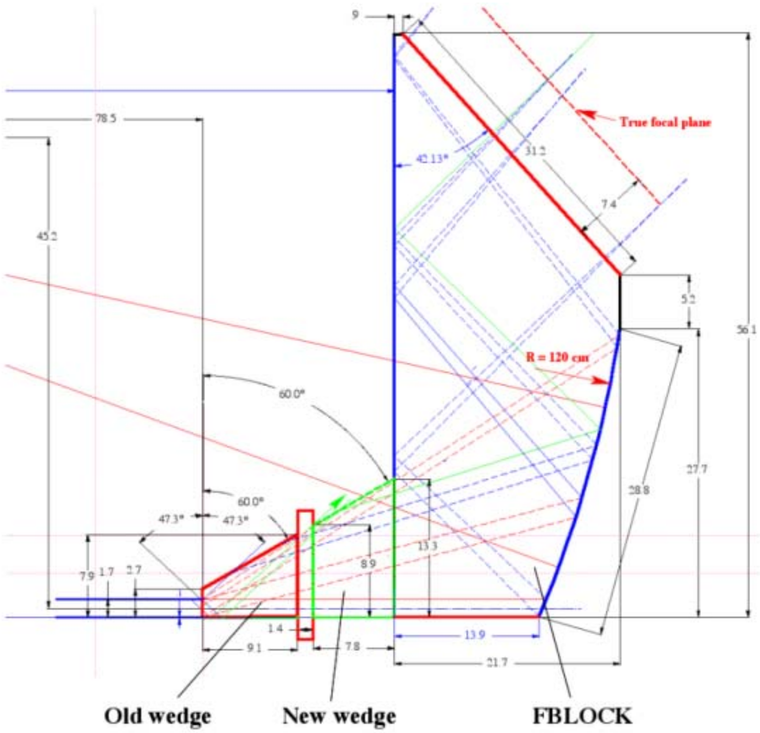
Complete redesign of the photon camera (SLAC-PUB-14282)

- True 3D imaging using:
  - 25× smaller volume of the photon camera
  - 10× better timing resolution to detect single photons
- Optical design is based entirely on Fused Silica glass

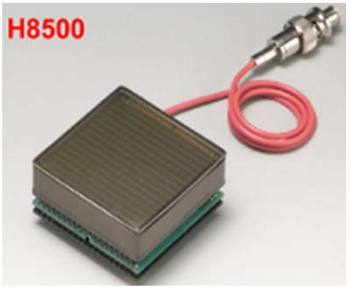
  avoid water or oil as optical medium

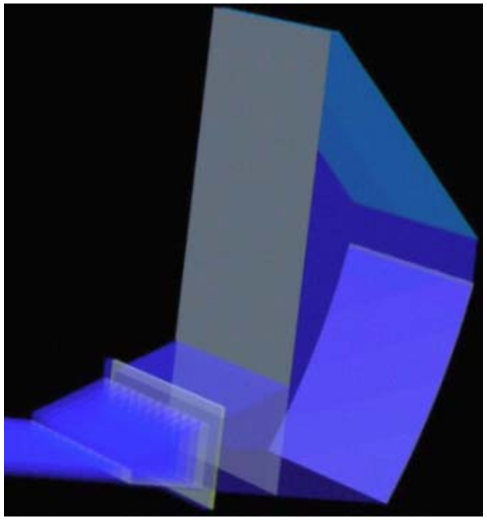


- Photon camera design (FBLOCK):
  - Initial design by ray-tracing (SLAC-PUB-13763)
  - Geant4 model now (SLAC-PUB-14282 – RICH 2010 talk)
  - Focusing block from Corning 7980 sythetic fused silica
- Main optical components
  - New wedge (old bar box wedge was not long enough)
  - Cylindrical mirror to remove bar thickness
  - Double-folded mirror optics to provide access to detectors



- Photon detectors: highly pixilated H-8500 MaPMTs
  - Total number of detectors per FBLOCK: 48
  - Total number of detectors: 576 [12 FBLOCKs]
  - Total number of pixels: 576 × 32 = 18,432

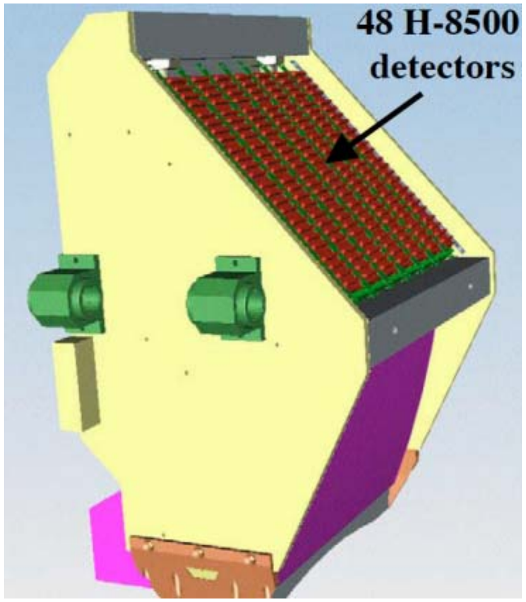


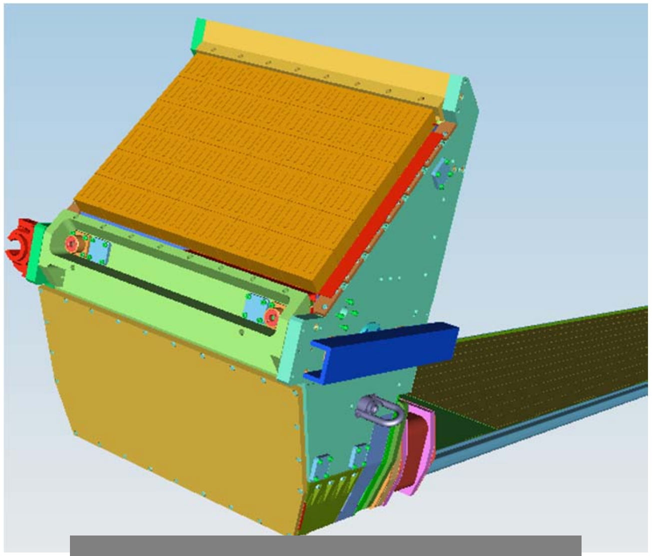


FDIRC FOR ITALIAN SUPERB

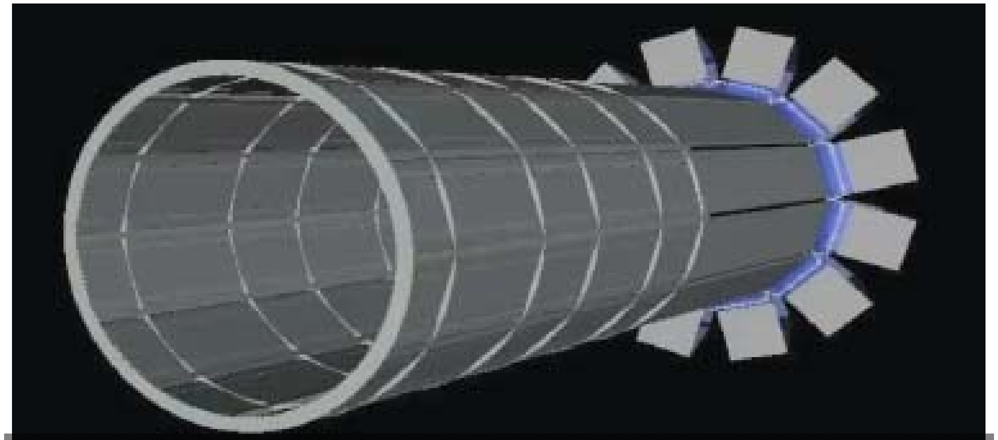
- FDIRC design parameters
  - Timing resolution per photon: ~200 ps
  - Cherenkov resolution per photon: 9-10 mrad
  - Cherenkov angle resolution per track: 2.5-3.0 mrad
  - Cherenkov angle determined from 2D spatial coordinates
  - Time primarily used to correct chromatic dispersion
- Members of the SuperB PID system
  - USA: SLAC, Maryland, Cincinnati
  - France: LAL, LPNHE
  - Italy: Bari, Padova
  - Russia: Novosibirsk

All SuperB FDIRC figures thanks to J. Va'vra, N. Arnaud



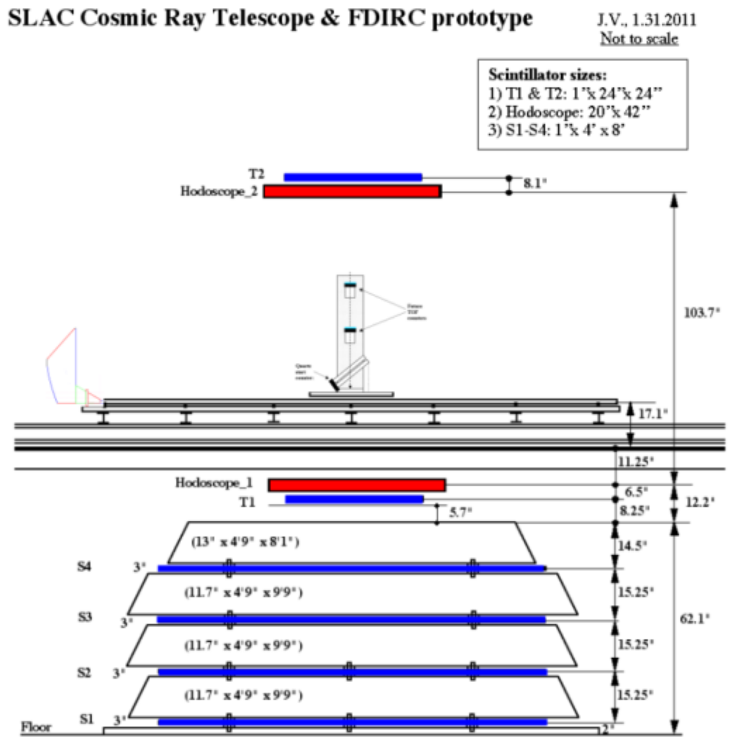


Mechanical design



Photon cameras at the end of bar boxes in Geant4

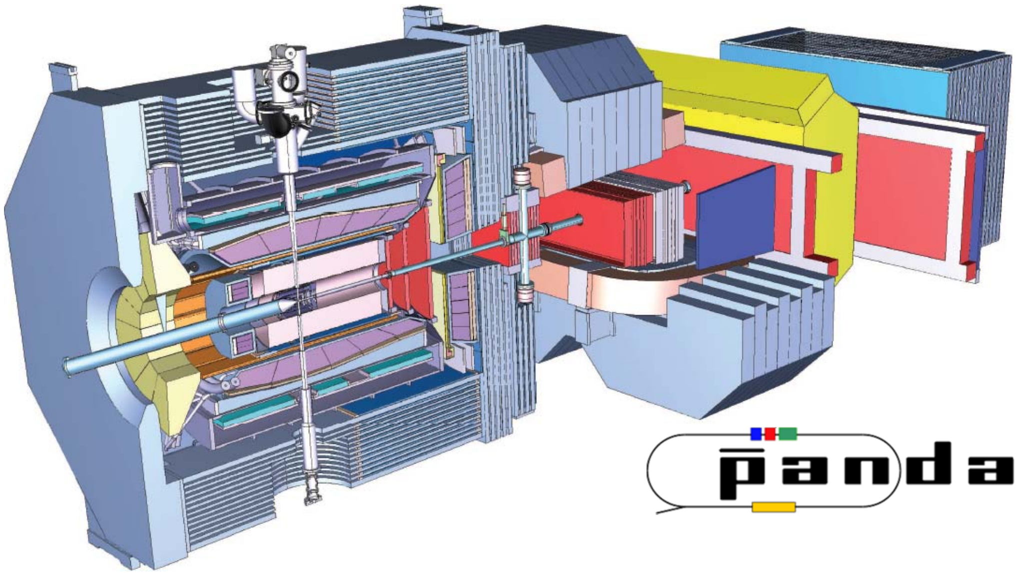
- FDIRC prototype to be tested this summer in the SLAC Cosmic Ray Telescope



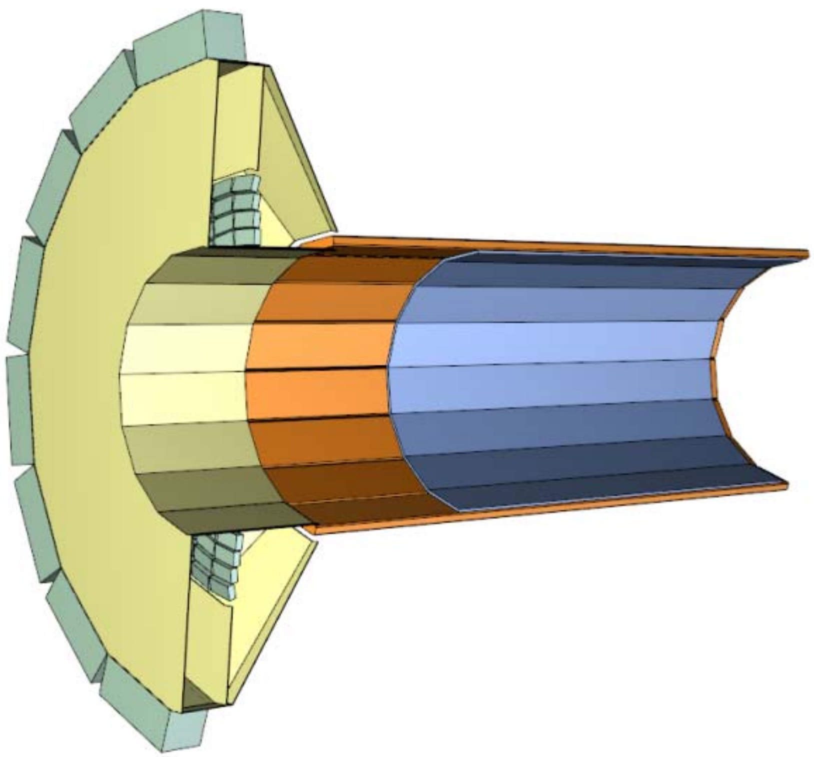
- Activities
  - Validation of the optics design
  - Mechanical design & integration
  - Front-end electronics

    TDC: 70 ps resolution; rate: a few MHz/pixel
  - Simulation: background, reconstruction...
- Design to be frozen for the TDR (early 2012)
- Main future challenge
  - Move from R&D to construction phase!

PANDA: Anti-Proton ANnihilation at DArmstadt (450 physicists, 17 countries)
future experiment at FAIR facility at GSI (*about an hour south from here*).

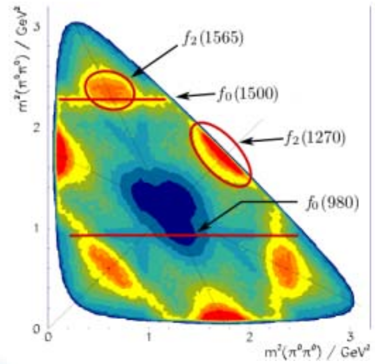


FAIR Facility for Antiproton and Ion Research

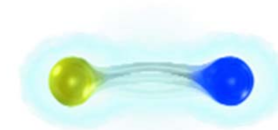


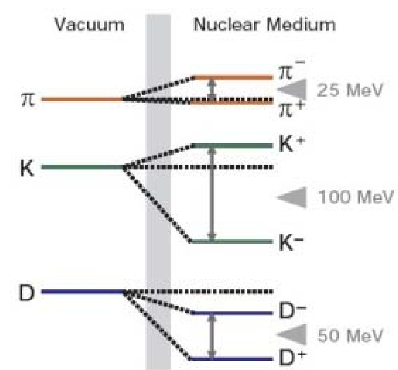
Study of QCD with Antiprotons

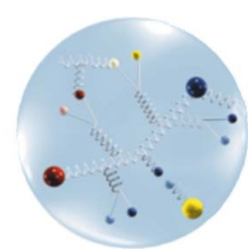
K. Götzen
TROIA'09

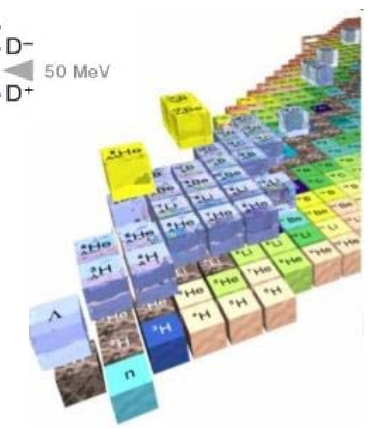


- Charmonium Spectroscopy
  - Precision Spectroscopy
  - Study of Confinement Potential
  - Access to all these puzzling X, Y and Z
- Search for Exotics
  - Look for Glueballs and Hybrids
  - Gluon rich environment → high discovery potential
  - Disentangle Mixing via PWA
- Hadrons in Medium
  - Study in-medium modification of Hadrons
- Nucleon Structure
  - Generalized Parton Distribution
  - Timelike Form Factor of the Proton
  - Drell-Yan Process
- Hypernuclear Physics *... and more*



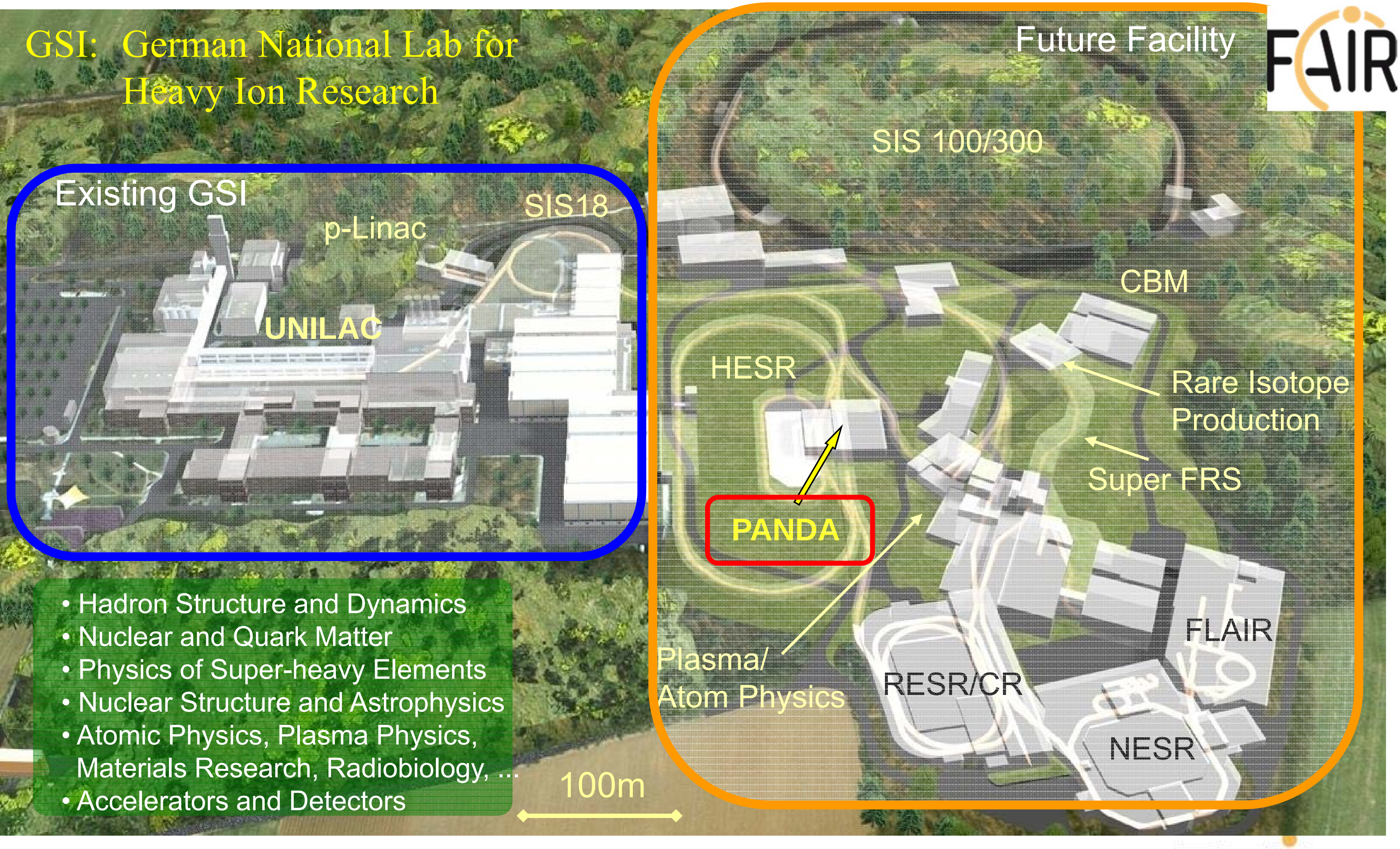






FAIR

Facility for **A**ntiproton and **I**on **R**esearch at GSI near Darmstadt, Germany



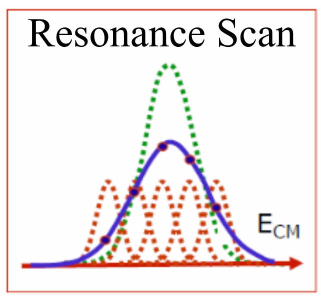
- Hadron Structure and Dynamics
- Nuclear and Quark Matter
- Physics of Super-heavy Elements
- Nuclear Structure and Astrophysics
- Atomic Physics, Plasma Physics, Materials Research, Radiobiology, ...
- Accelerators and Detectors

HESR: HIGH ENERGY STORAGE RING

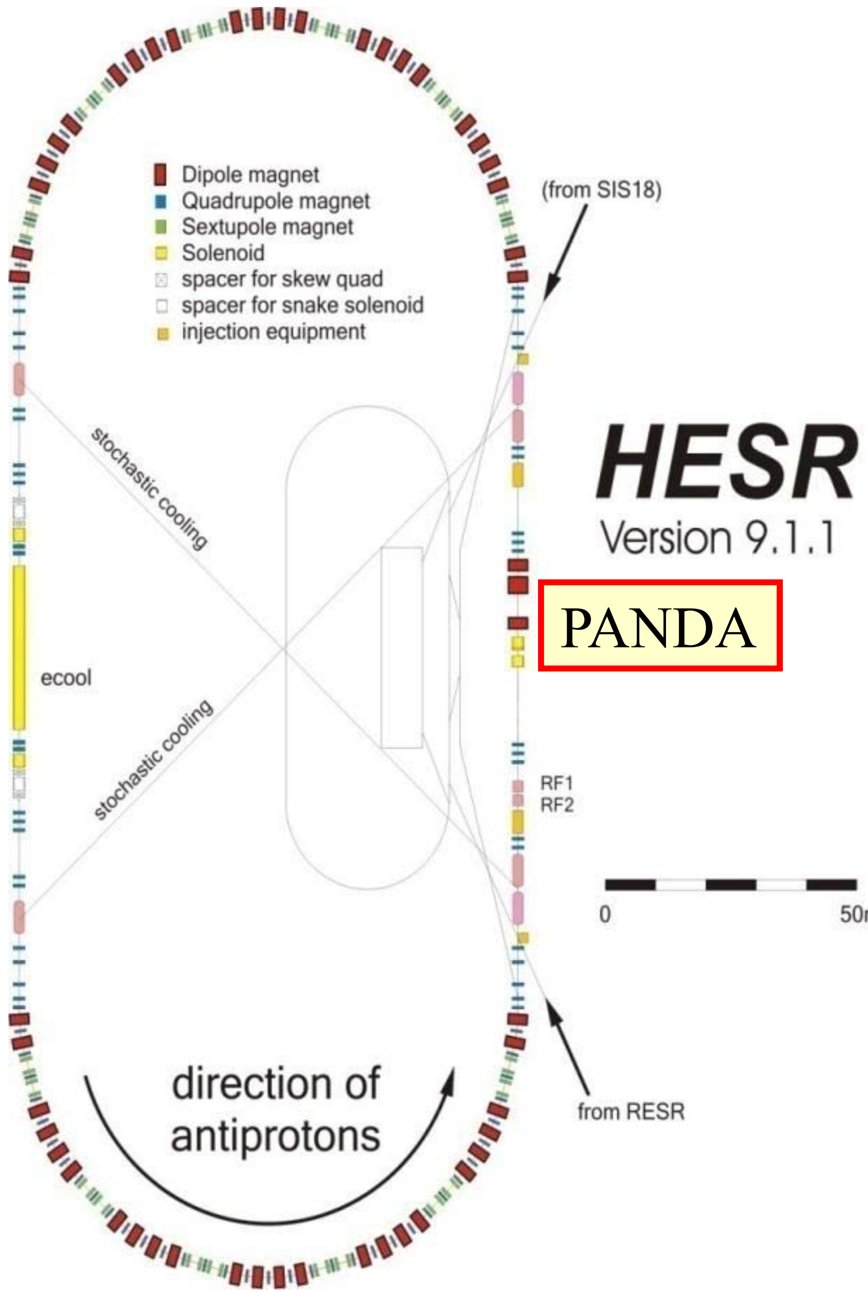
- Average production rate: 2×10^7/sec
- $p_{beam} = 1.5 \dots 15$ GeV/c
- N_{stored} = up to $1 \times 10^{11}\ \bar{p}$

- Internal Target
- Beam Cooling (Electron & Stochastic)

- High Resolution Mode
  (up to 8.9 GeV/c)
  - $\delta p/p \approx 10^{-5}$
  - $L = 10^{31}\ cm^{-2}s^{-1}$



- High Luminosity Mode
  - $\delta p/p \approx 10^{-4}$
  - $L = 2 \times 10^{32}\ cm^{-2}s^{-1}$

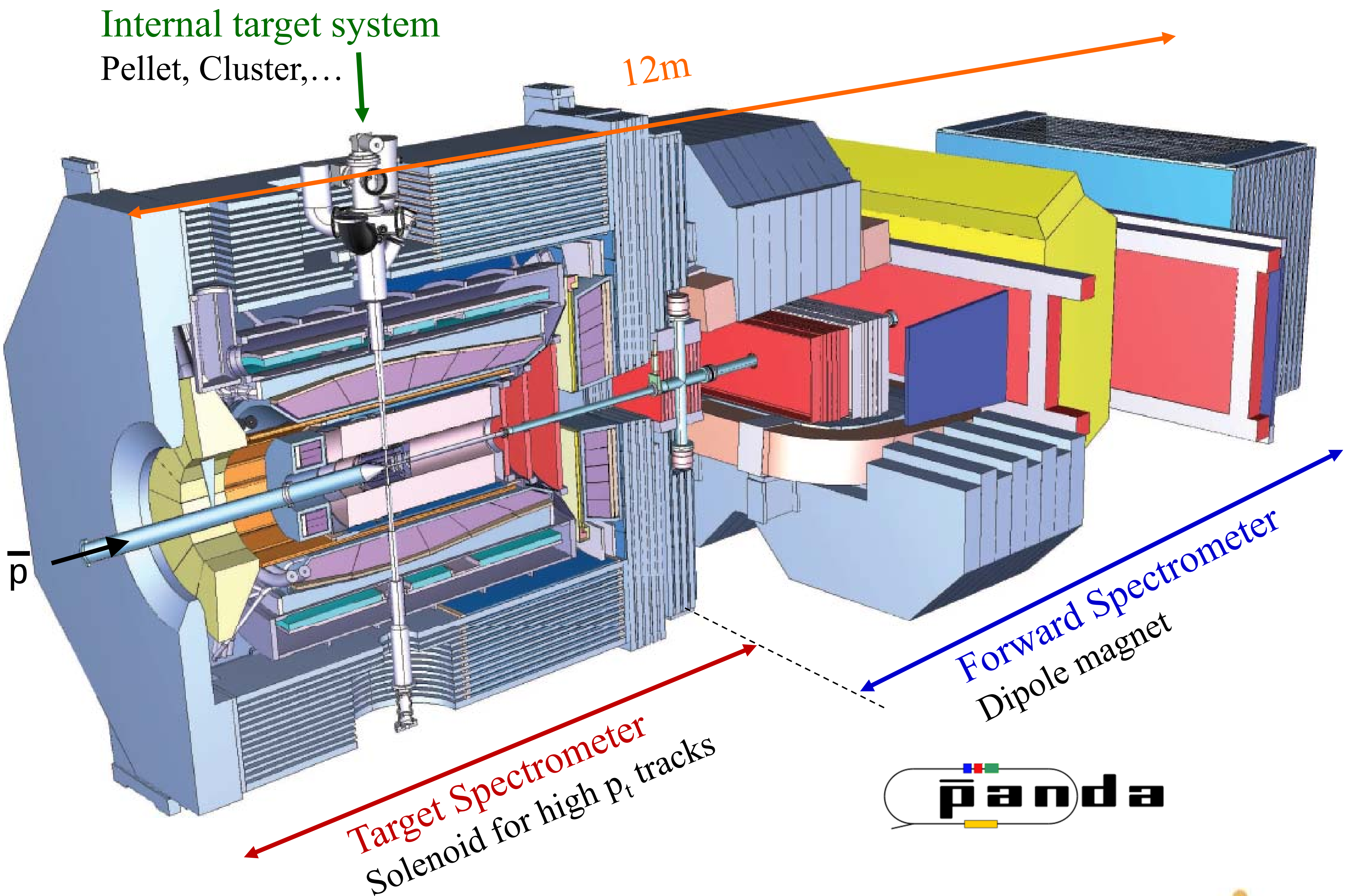


- At present a group of **460 physicists** from 54 institutions and 16 countries

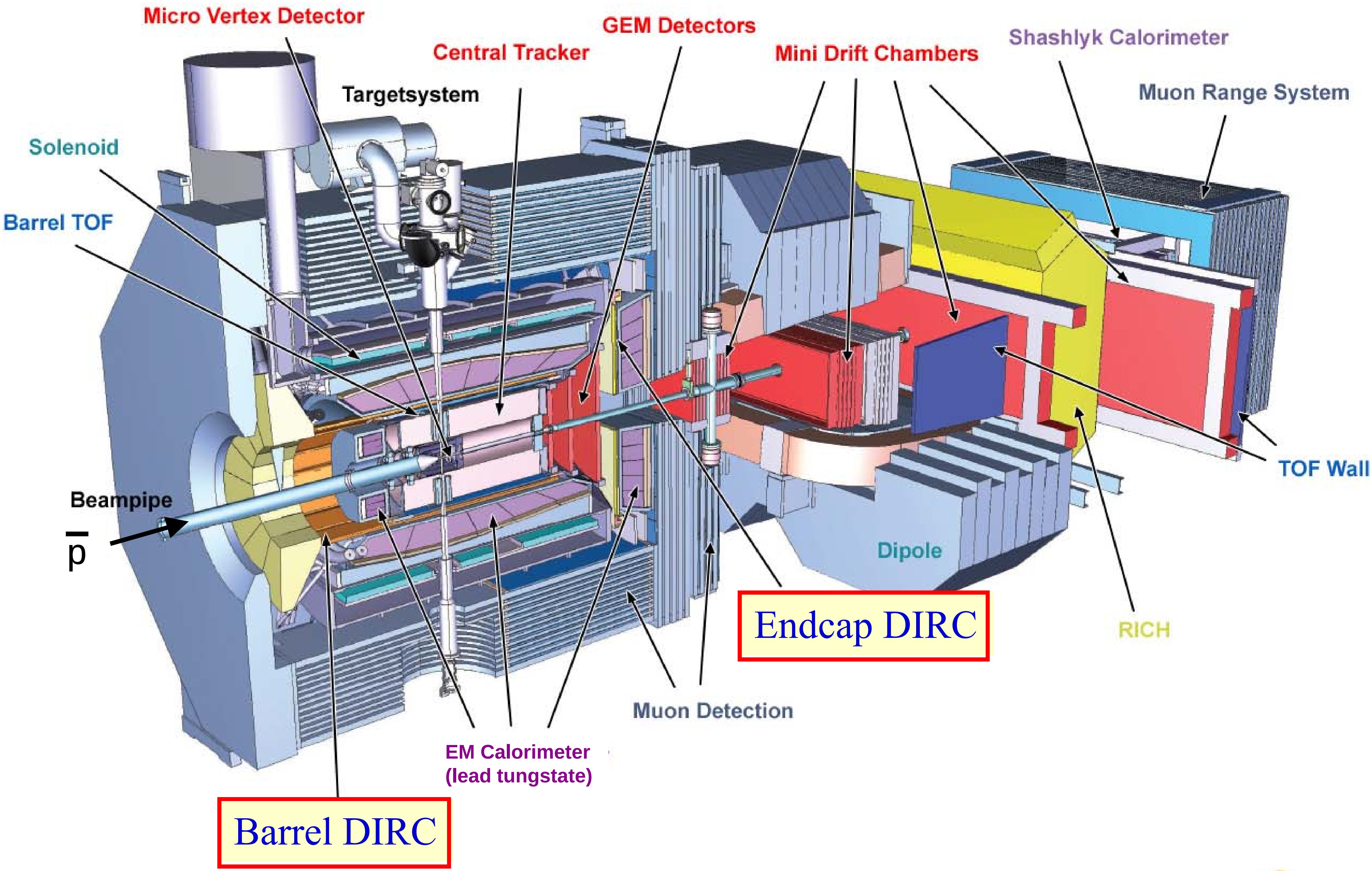
Austria – Belaruz – China – France – Germany – India – Italy – The Netherlands – Poland – Romania – Russia – Spain – Sweden – Switzerland – U.K. – U.S.A.

Basel, Beijing, Bochum, IIT Bombay, Bonn, Brescia, IFIN Bucharest, Catania, IIT Chicago, AGH-UST Cracow, JGU Cracow, IFJ PAN Cracow, Cracow UT, Edinburgh, Erlangen, Ferrara, Frankfurt, Genova, Giessen, Glasgow, GSI, FZ Jülich, JINR Dubna, Katowice, KVI Groningen, Lanzhou, LNF, Lund, Mainz, Minsk, ITEP Moscow, MPEI Moscow,TU München, Münster, Northwestern, BINP Novosibirsk, IPN Orsay, Pavia, IHEP Protvino, PNPI St.Petersburg, KTH Stockholm, Stockholm, Dep. A. Avogadro Torino, Dep. Fis. Sperimentale Torino, Torino Politecnico, Trieste, TSL Uppsala, Tübingen, Uppsala, Valencia, SINS Warsaw, TU Warsaw, AAS Wien

PANDA DETECTOR

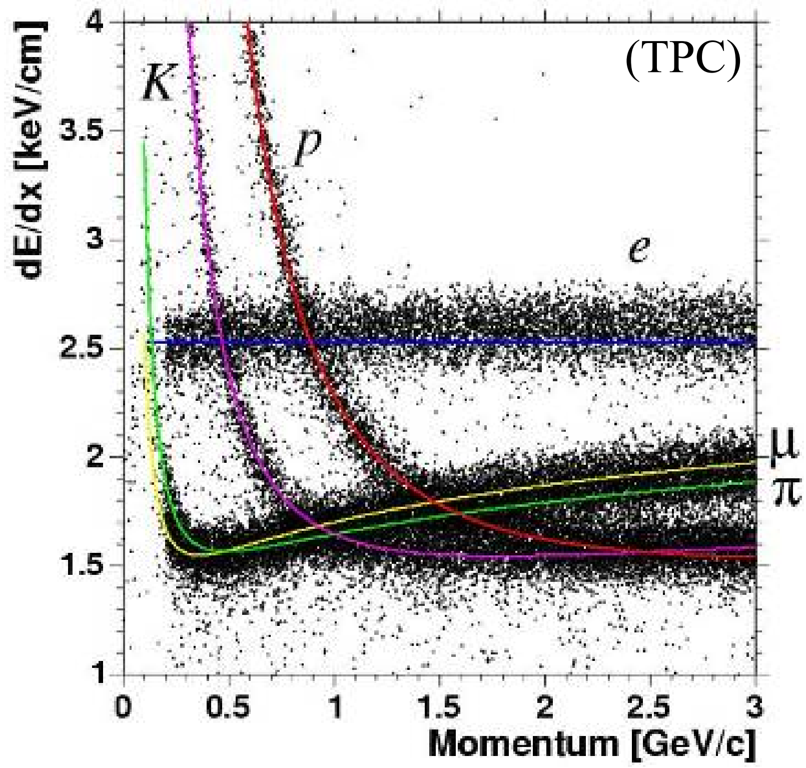


PANDA Detector



PANDA PID Requirements

- Particle identification essential tool.
- Momentum range 200 MeV/c – 10 GeV/c.
- Seversal PID methods needed
  to cover entire momentum range.



PID Processes

- Cherenkov radiation
  Radiators: synthetic fused silica
- Energy loss
  GEM TPC or Straw Tubes
- Time of flight:
  Scintillating Tiles
- Electromagnetic showers:
  EMC for e and γ

DIRC detector advantages

- Thin in radius and radiation length.
- Moderate and uniform amount of material in front of EM calorimeter.
- Fast and tolerant of background.
- Robust and stable detector operations.

G. Ahmed[1], A. Britting[2], P. Bühler[1], E. Cowie[3], V. Kh. Dodokhov[4], M. Düren[5], D. Dutta[6,a], W. Eyrich[2], K. Föhl[5], D. I. Glazier[7], A. Hayrapetyan[5], M. Hoek[3], R. Hohler[6], A. Lehmann[2], D. Lehmann[6], R. Kaiser[3], T. Keri[3], P. Koch[5], B. Kröck[5], J. Marton[1], O. Merle[5], R. Montgomery[3], K. Peters[6], S. Reinicke[2], G. Rosner[3], B. Roy[6,a], G. Schepers[6], L. Schmitt[6], C. Schwarz[6], J. Schwiening[6], B. Seitz[3], C. Sfienti[6,b], K. Suzuki[1], F. Uhlig[2], A. S. Vodopianov[4], D. P. Watts[7], W. Yu[5]

[1] Stefan Meyer Institut für subatomare Physik, Austrian Academy of Sciences, A-1090 Vienna, Austria.
[2] Physikalisches Institut Abteilung IV, University of Erlangen-Nuremberg, D-91058 Erlangen, Germany.
[3] Department of Physics & Astronomy, Kelvin Building, University of Glasgow, Glasgow G12 8QQ, United Kingdom.
[4] Laboratory of High Energies, Joint Institute for Nuclear Research, 141980 Dubna, Russia.
[5] II. Physikalisches Institut, University of Giessen, D-35392 Giessen, Germany.
[6] GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstrasse 1, 64291 Darmstadt, Germany.
[7] School of Physics, University of Edinburgh, Edinburgh EH9 3JZ, United Kingdom.
[a] *present address: Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai, India 400085.*
[b] *present address: Institut für Kernphysik, University of Mainz, D-55128 Mainz, Germany.*

PANDA: two DIRC detectors

- Barrel DIRC – similar to BABAR DIRC with several improvements.

  PID goal: 3σ π/K separation for p<3.5 GeV/c.

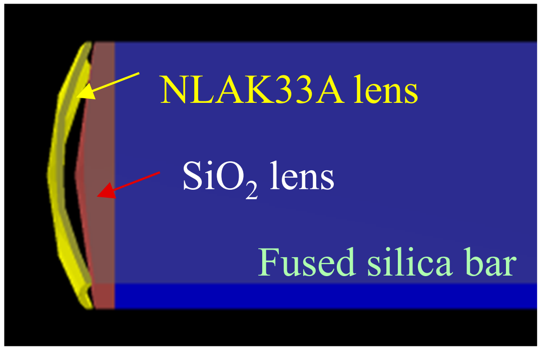
- Novel endcap Disc DIRC (3σ π/K separation up to 4 GeV/c).

Institutions currently involved in the two DIRCs

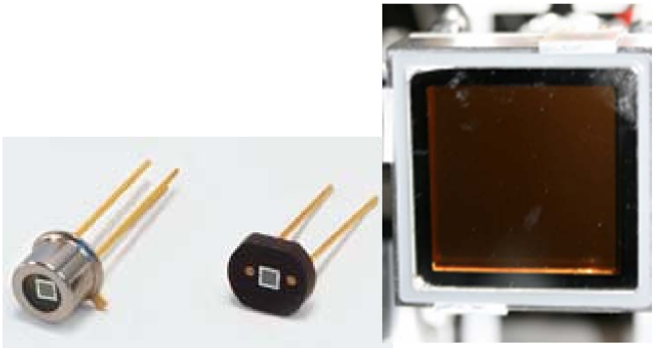
- Dubna, Edinburgh, Erlangen, Gießen, Glasgow, GSI, Mainz, Vienna.

How do we plan to improve on the successful BABAR-DIRC design for PANDA?

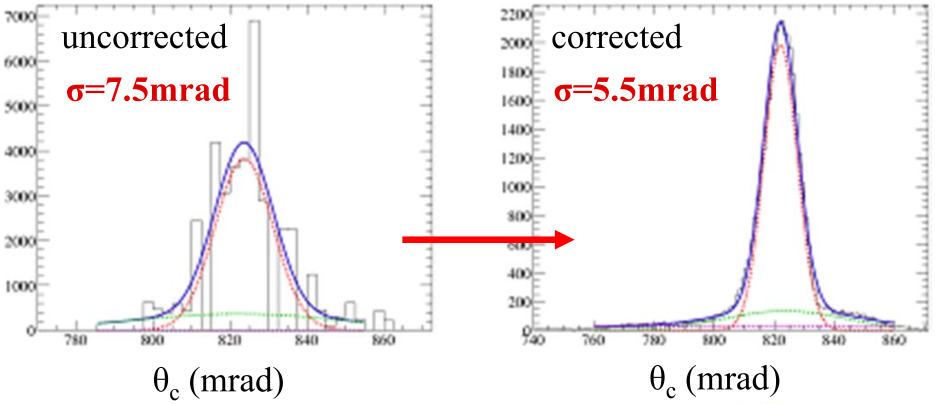
- Focusing optics remove bar size contribution
  from Cherenkov angle resolution term.
  Lens or mirror focusing on flat detector surface.



- Compact multi-pixel photon detectors
  allow smaller expansion region,
  make DIRC less sensitive to background.
  MCP-PMTs, MAPMTs, gAPDs potential candidates.



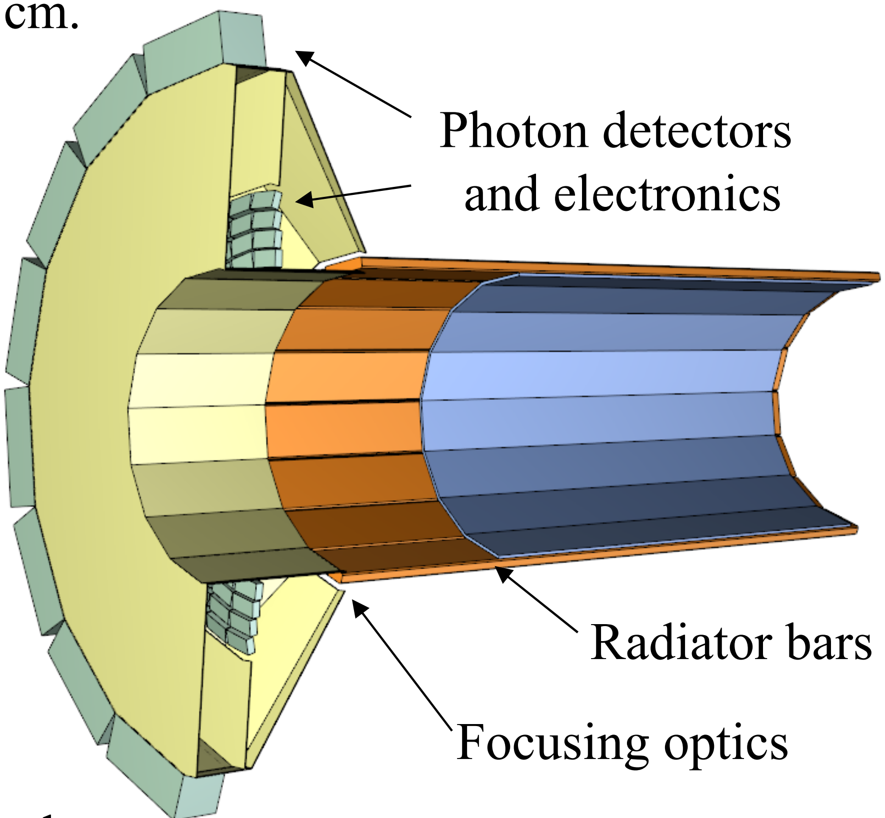
- Fast photon detection ($\sigma_{TTS} \approx 100-200$ps)
  allows correction of chromatic dispersion.
  Proof-of-principle shown in 2007
  by Focusing DIRC at SLAC.



PANDA Barrel DIRC Design

Current PANDA Barrel DIRC baseline design:

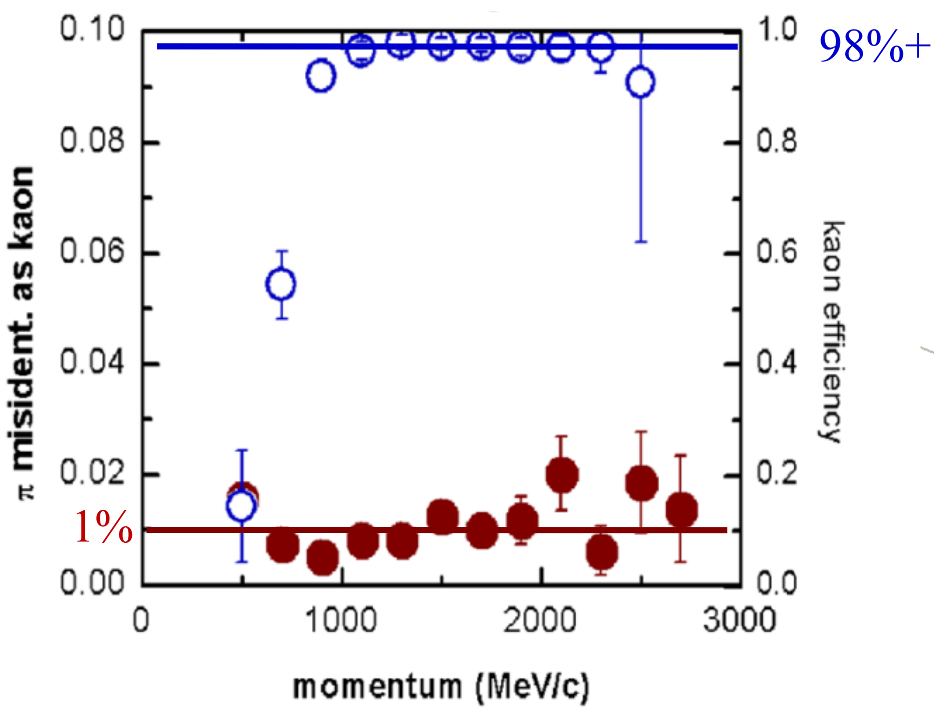
- Barrel radius ~50 cm; expansion volume depth: 30 cm.
- 80 radiator bars, synthetic fused silica
  17mm (T) × 33mm (W) × 2500mm (L).
- Focusing optics: doublet lens system.
- Compact photon detector:
  30 cm oil-filled expansion volume,
  10-15,000 channels of MCP-PMTs.
- Fast photon detection:
  fast TDC plus ADC (or ToT) electronics.
- Expected performance:
  Single photon Cherenkov angle resolution: 8-9 mrad.
  Number of photoelectrons per track: >20;
  PID: at least 3 standard deviations π/K separation from 0.5 GeV/c up to 4 GeV/c.



Still investigating several design options (*see Maria's talk on Wednesday*):
mirror focusing, radiator plates, photon detection outside magnetic field.

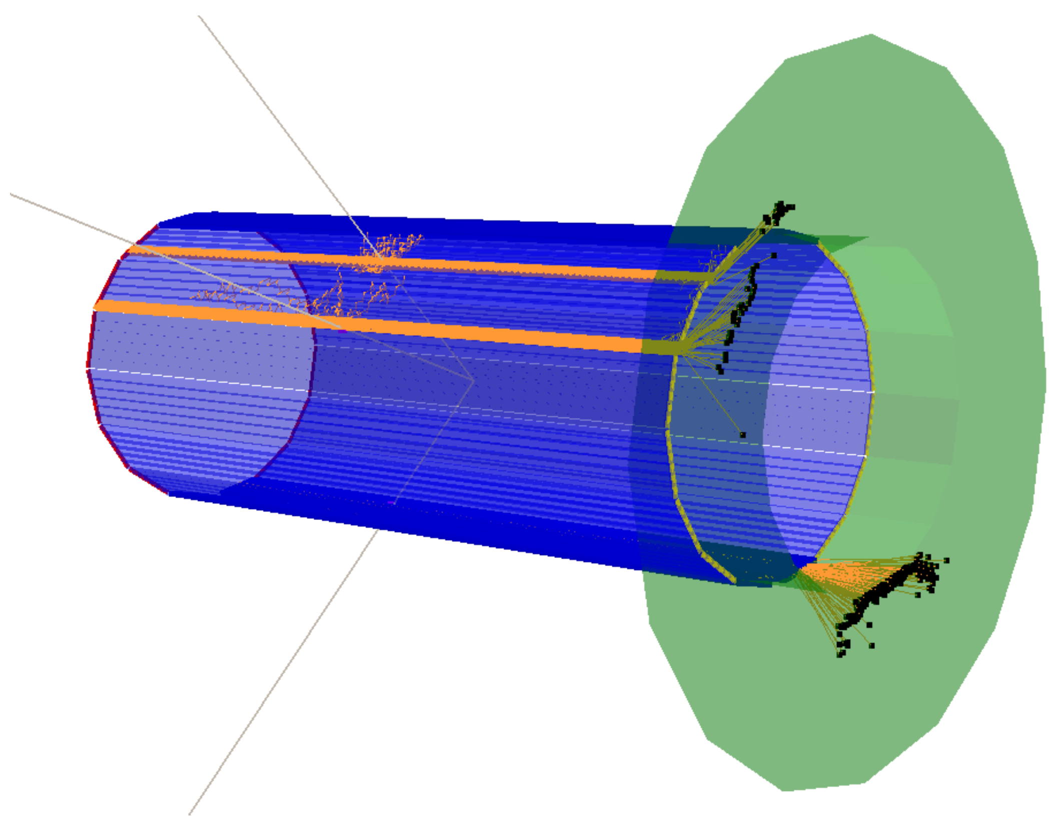
Expected PID performance example.

$p\bar{p} \rightarrow J/\Psi\ \Phi \quad \sqrt{s} = 4.4\ GeV/c^2$



(Based on early design version.
Updated study has started.)

Geant Cherenkov photon tracking in event display.



Examples of ongoing detector R&D projects for PANDA DIRC

- Photon detectors
  - Uniformity, gain, photo-detection efficiency
  - Rate tolerance, lifetime
- Radiators
  - Radiation hardness
  - Fabrication quality assurance
  - Gluing, assembly
- Readout
  - Amplification
  - Digitization (TDC, ADC, ToT, waveform sampling)
- Optics
  - Lightguides, lenses, mirrors, chromatic correction (software and hardware)
- Software
  - Simulation, reconstruction

Multiple presentations on R&D projects related to PANDA-DIRC this year at RICH 2010: E. Cowie, M. Hoek, A. Lehmann, J. Marton, C. Schwarz, J.S.

Barrel and disk detector prototypes in test beams at GSI, Jülich, CERN, and DESY since 2008.

Radiator Production

Production of large pieces (bars, plates, disk segments), mechanical tolerances on flatness, squareness and parallelism with optical finish and sharp corners.

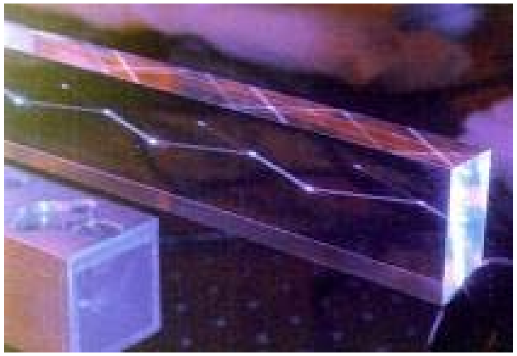
→ difficult, expensive, few qualified vendors worldwide.

BABAR-DIRC used bars polished to 5 Å *rms*, non-squareness < 0.25 mrad successfully done for BABAR, need to qualify/retrain vendors 10+ years later.

Can relax some of those specs for PANDA DIRCs due to shorter photon paths.

Technological advances may help PANDA DIRCs:
Extrusion of long bars, Magnetorheological Finishing (MRF), etc.

Have started discussions with potential vendors in Europe and USA, obtained several prototype bars, measuring surfaces and angles at GSI.

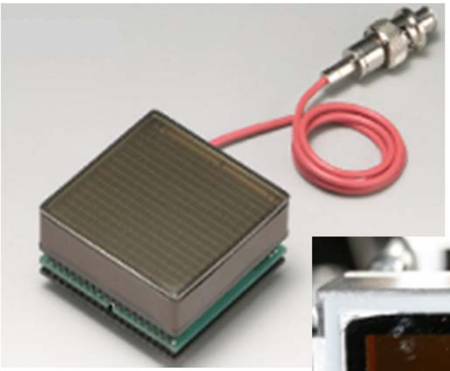


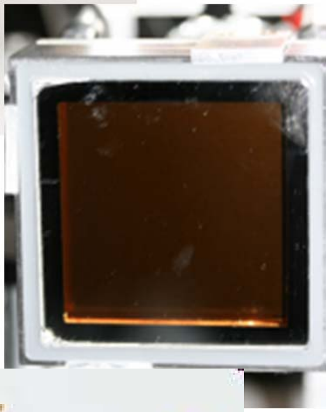
PHOTODETECTORS

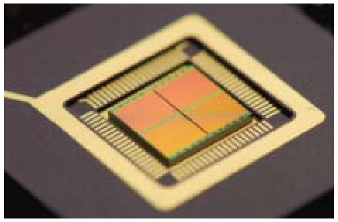
Yesterday you already heard a lot about the sensor challenge for PANDA.

Briefly: Barrel DIRC is asking a lot of fast compact multi-pixel photon detectors

- Single photon sensitivity, low dark count rate;
- Reasonably high photo detection efficiency;
- $\sigma_{TTS} \approx 100$ ps;
- Few mm position resolution;
- Operation in 0.9-1.1 T magnetic field;
- Tolerate rates of 0.2 MHz/cm^2;
- Long lifetime: ~0.5 C/cm^2/yr at 10^6 gain.







No currently available sensor matches all criteria;

promising candidates: MCP-PMTs, MAPMTs, SiPM/gAPDs, ...

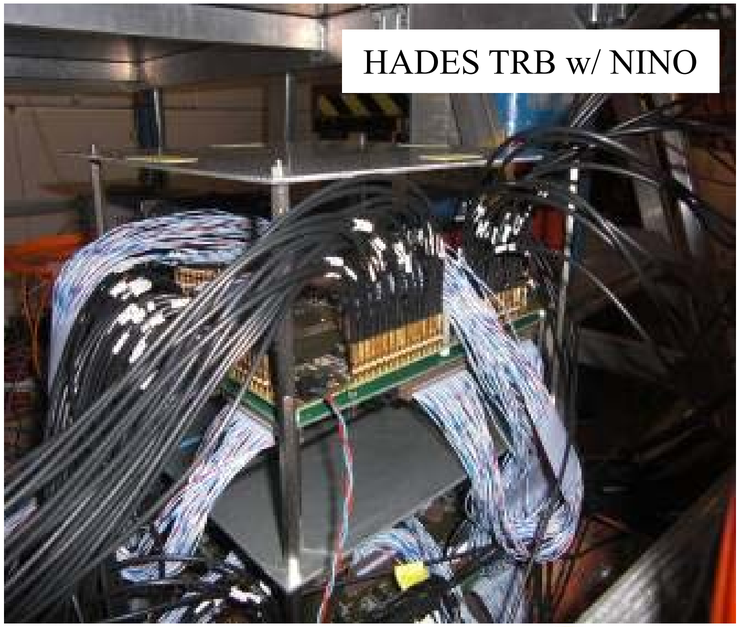
Testing detectors and readout electronics with DIRC prototypes in test beams

or with fast pico-second laser pulsers (PicoQuant, PiLas) on test bench.

Electronics design demanding

- Signal rise time typically few hundred picoseconds.
- 10-100x preamplifiers needed.
- High bandwidth 500MHz – few GHz (optimum bandwidth not obvious).
- Pulse height information required for < 100 ps timing (time walk correction),
  also desirable for 100-200 ps timing.
  ADC / time over threshold / waveform sampling / ...
- PANDA will run trigger-less.
- Example:
  HADES TRB board with NINO TOF add-on
  in GSI test beam in 2009, updated TOF add-on
  will be in 2011 test beams at GSI and CERN.

  → more detail in Michael's talk tomorrow
- Significant development effort ahead.



PANDA Barrel DIRC:

fast focusing DIRC inspired by BABAR-DIRC;

important improvements (compact readout, focusing, fast timing).

R&D activities (many common efforts with PANDA Disc DIRC):

radiator quality, focusing optics, photon detectors, readout electronics, fast timing, chromatic correction, simulation, reconstruction, and more.

Key challenges:

- Pico-second timing with single photons in environment with 1 C/cm^2/yr and 1 T.
  → Discussing solutions with industry, testing prototypes in lab.
- Cherenkov radiator (bars or plates) production and assembly.
  → Started discussion with potential vendors, purchased prototype pieces.
- Design of detector optics and reconstruction software.
  → Developing simulation framework (Geant and ray-tracing).

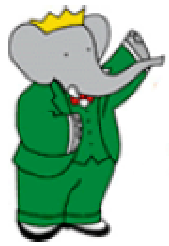
Test beams and pico-second laser pulsers:

essential tools for qualifying bars, sensors, and electronics.

DIRC Counter Summary

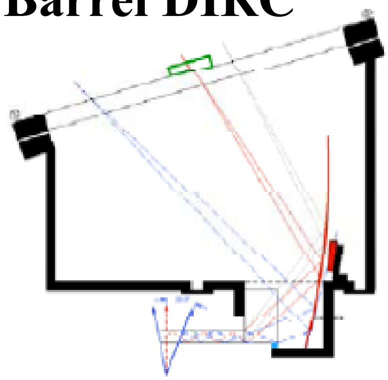
Performance

BaBar DIRC

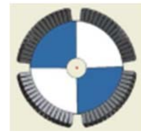


•Large (~1m) expansion
•Mainly x,y
•Very coarse t

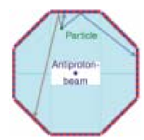
SuperB & PANDA Barrel DIRC



•Some expansion (~0.5 m)
•Focus to correct for finite bar thickness.
•Mainly x,y
•Order ~200 ps σ_t make chromatic corrections



PANDA Disc DIRC
WASA, TORCH



↕ More sensitive to tracking uncertainties

Imaging TOP

•Small expansion (~.1 m)
•Mainly x,t
•Focusing, coarse y to correct chromatic effects

↕ More sensitive to t_0 uncertainties

Focusing TOP

•No expansion
•Mainly x,t
•Focusing & coarse y to correct chromatic effects

TOP

•No expansion
•Only x,t
•No focusing → chromatic degradation

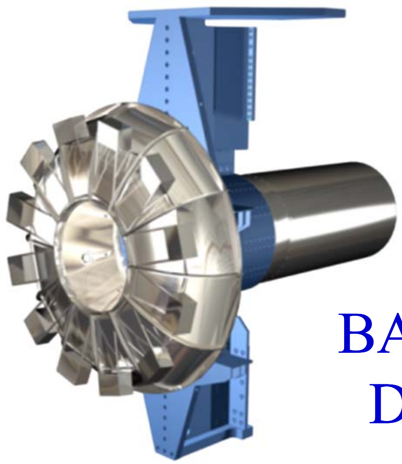
← **Mostly imaging**

Mostly timing →

Compactness

Slide inspired by Belle II/Gary Varner.

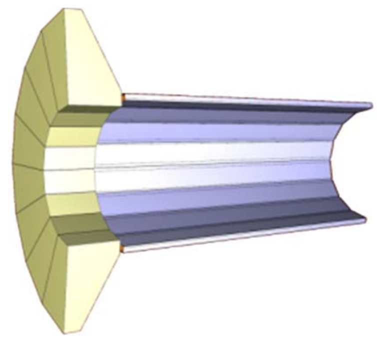
DIRC Counter Summary

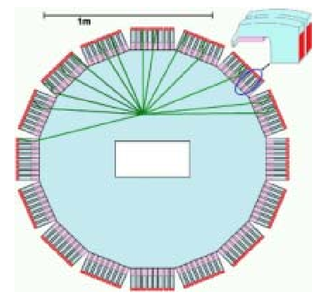


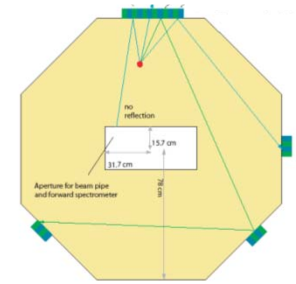
First of its kind – excellent performance, easy to operate, essential ingredient in most BABAR publications.

BABAR DIRC

PANDA DIRCs





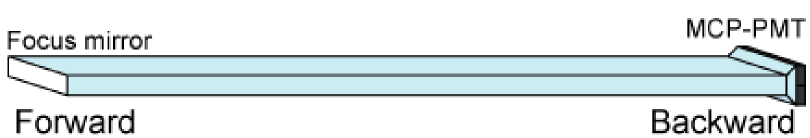


Barrel DIRC: focusing, compact version of BABAR DIRC.

Disk DIRC: first endcap DIRC, design decision soon.

… plus CEARA @ WASA TORCH @ LHCb, …

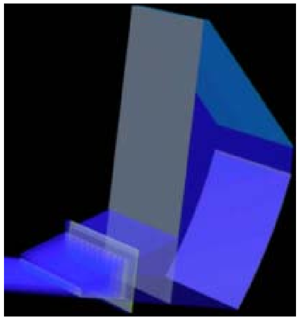
Belle II TOP



First DIRC with plate geometry.

Cherenkov angle from excellent timing plus 2 coarse space points.

SuperB FDIRC



Focusing optics and fast timing using existing BABAR DIRC bars.

Cherenkov angle from space points, timing for chromatic correction.

THANK YOU

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