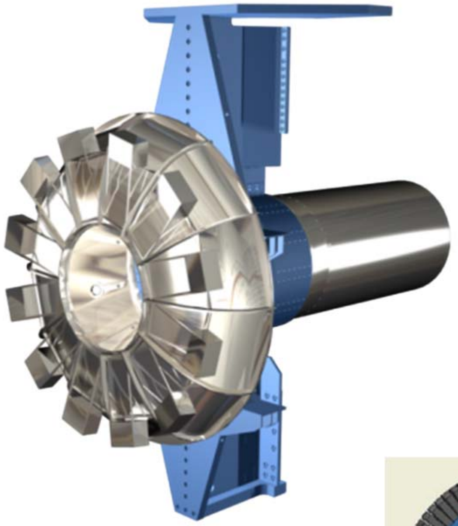
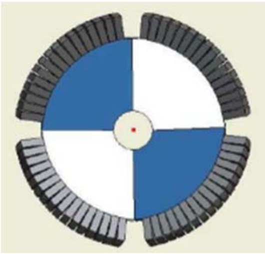
DIRC DETECTORS:

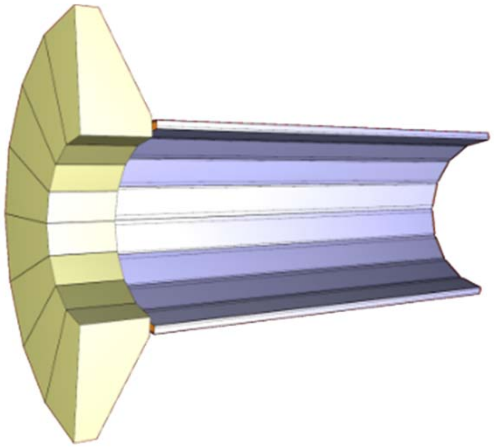
FROM BABAR TO PANDA AND BEYOND

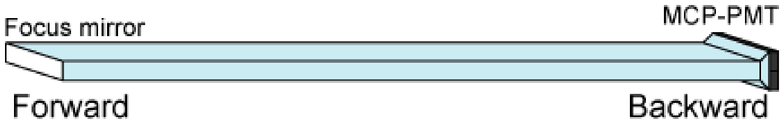
Jochen Schwiening

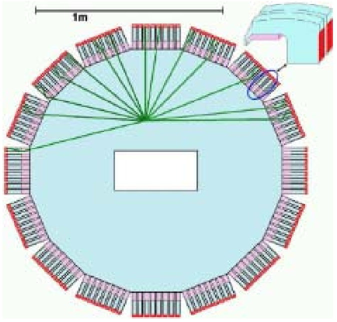
GSI

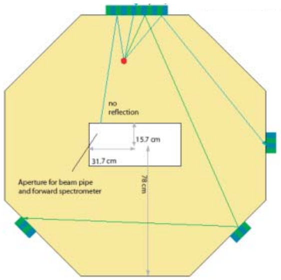


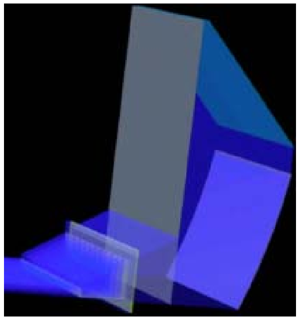






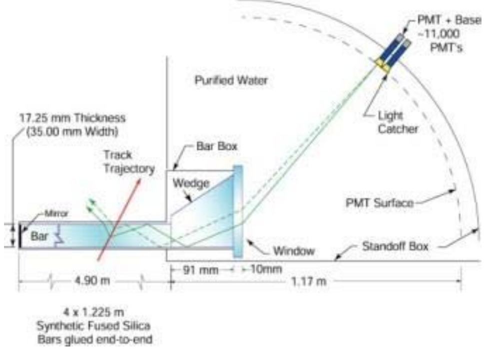






OUTLINE

The DIRC Concept

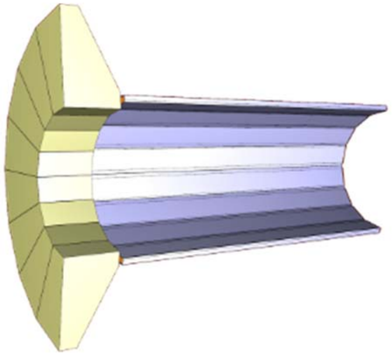


Experience with DIRC Detectors: BABAR DIRC

- R&D and Operations
- Detector Performance

Future DIRC Detectors: PANDA DIRCs

- The PANDA Experiment at FAIR
- Barrel DIRC – improved version of BABAR DIRC
- Disk (or Disc) DIRC – first endcap DIRC



Other future DIRC Detectors (*…time permitting*)

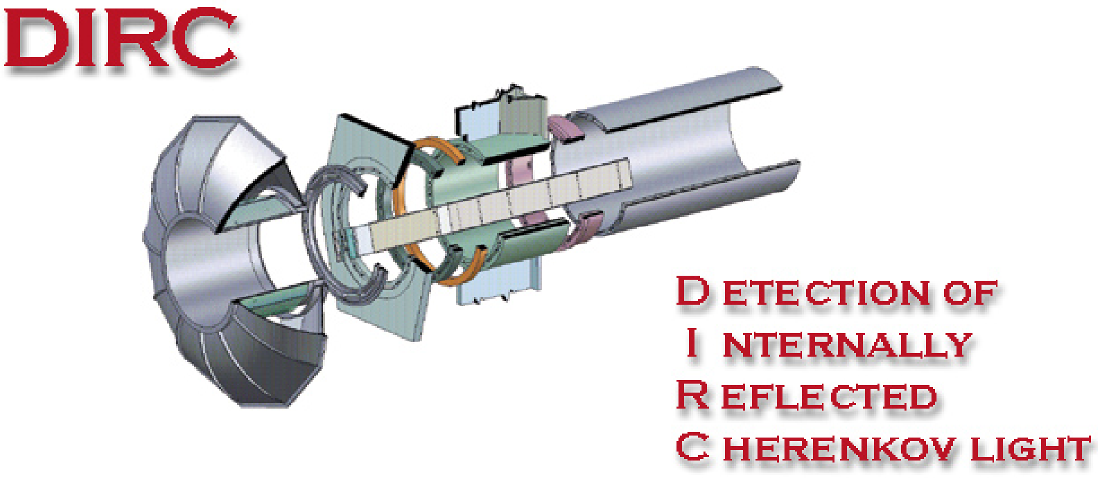
DIRC CONCEPT

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).

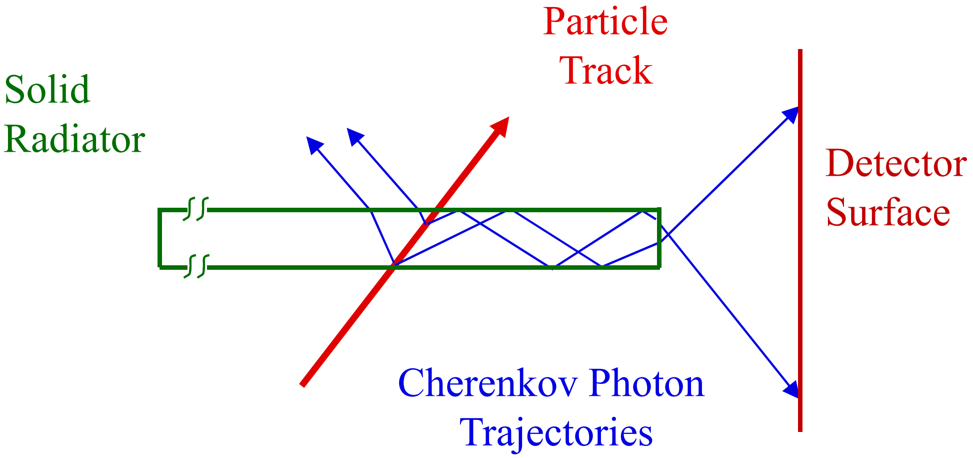
Recent improvements in photon detectors have motivated R&D efforts to improve the successful BABAR-DIRC and make DIRCs interesting for future experiments.



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

DIRC CONCEPT

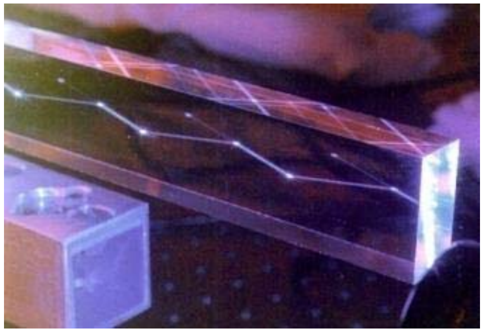
- Charged particle traversing radiator with refractive index n with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos\theta_c = 1/\beta n(\lambda)$.



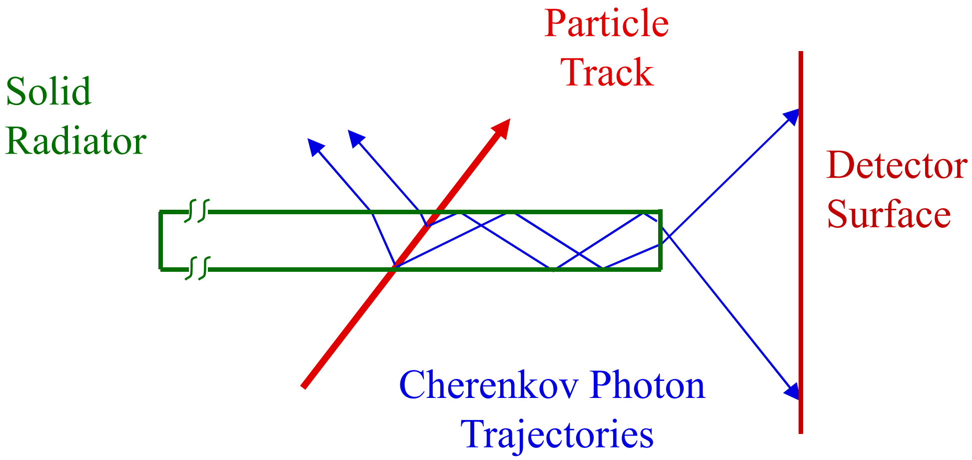
- For $n>\sqrt{2}$ some photons are always totally internally reflected for $\beta\approx1$ tracks.

- 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)



DIRC CONCEPT

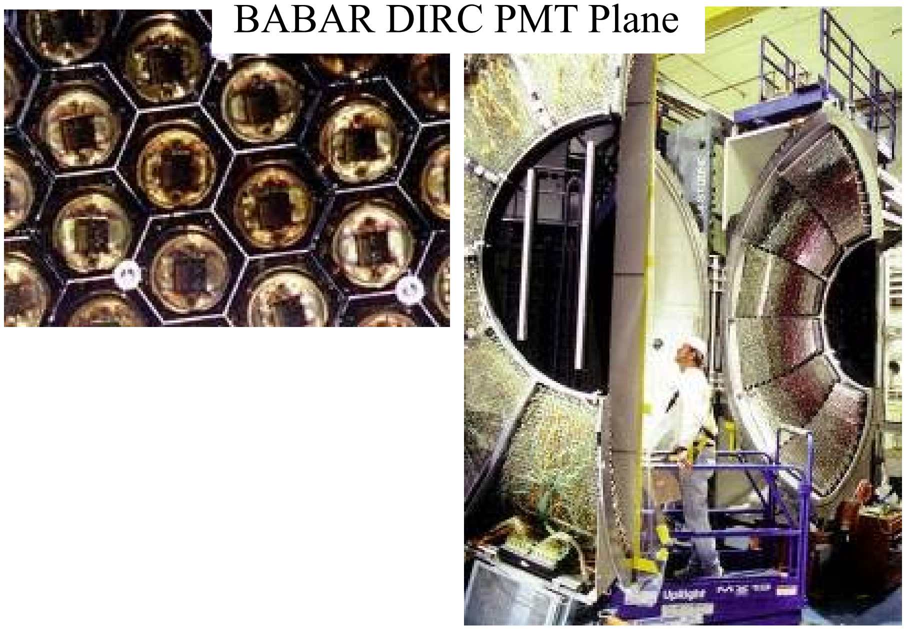


Particle Track

Solid Radiator

Detector Surface

Cherenkov Photon Trajectories



BABAR DIRC PMT Plane

- Photons exit radiator into expansion region,

  detected on photon detector array.

  (pinhole imaging/camera obscura or focusing optics)

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

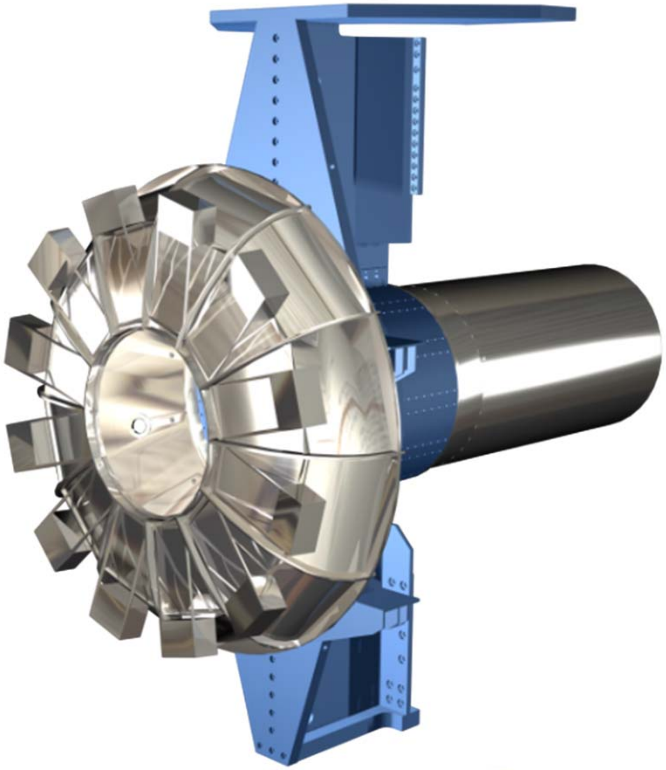
- Ultimate deliverable for DIRC: PID likelihoods

  Calculate likelihood for observed hit pattern (in x, y, time or in θ_c, ϕ_c, $t_{propagation}$)

  to be produced by e/μ/π/K/p plus event/track background

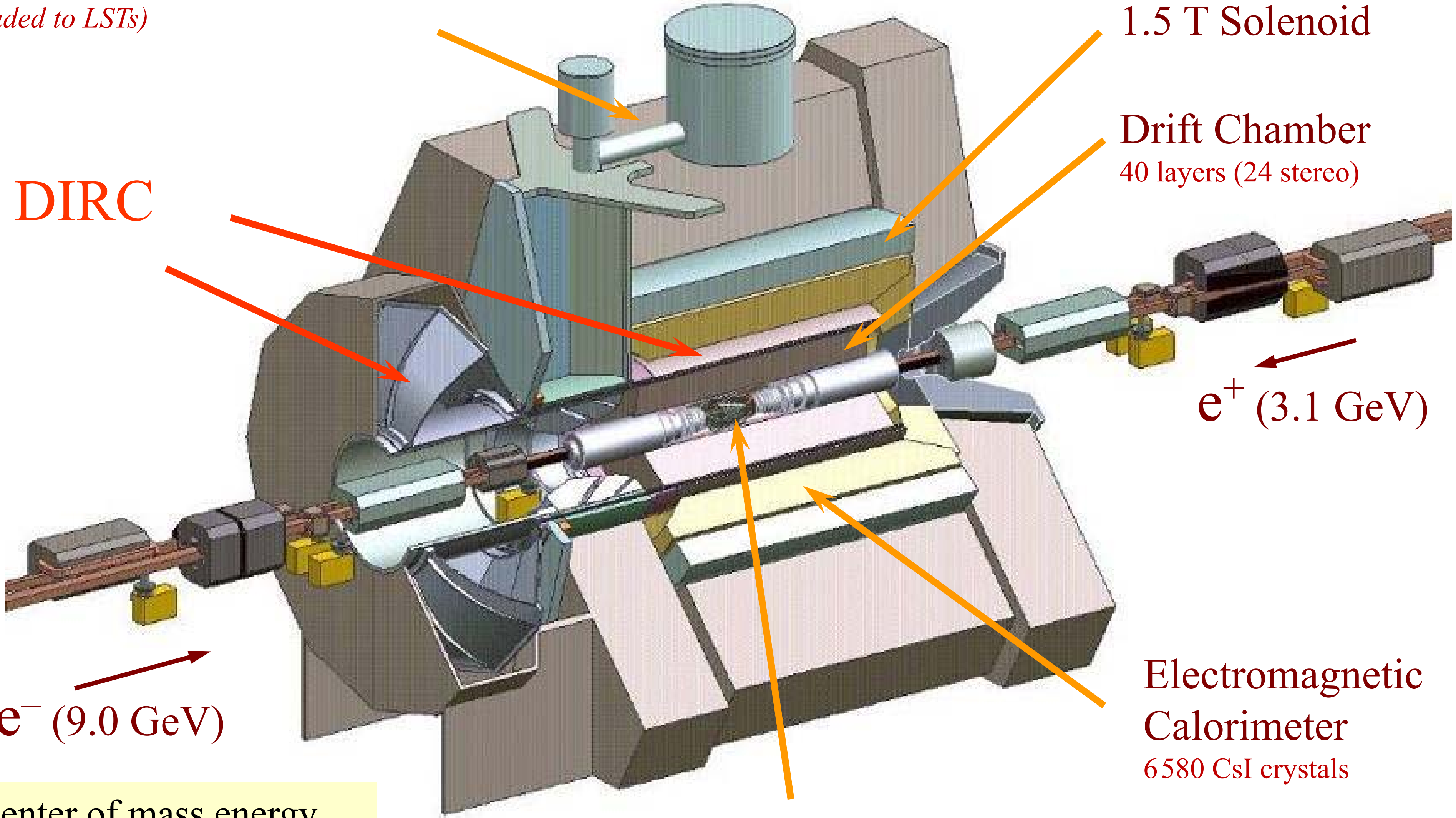
THE BABAR DIRC

- DESIGN
- OPERATIONS
- PERFORMANCE



THE BABAR DETECTOR

All BABAR DIRC slides today:
J.S., RICH 2002/4, Giessen 2009



Instrumented Flux Return

19 layers of RPCs,
(upgraded to LSTs)

1.5 T Solenoid

Drift Chamber

40 layers (24 stereo)

DIRC

e^+ (3.1 GeV)

e^- (9.0 GeV)

Electromagnetic Calorimeter

6580 CsI crystals

Silicon Vertex Detector

5 layers of double sided silicon strips

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

THE DIRC IN BABAR

DIRC thickness:

8 cm radial incl. supports

19% radiation length

at normal incidence

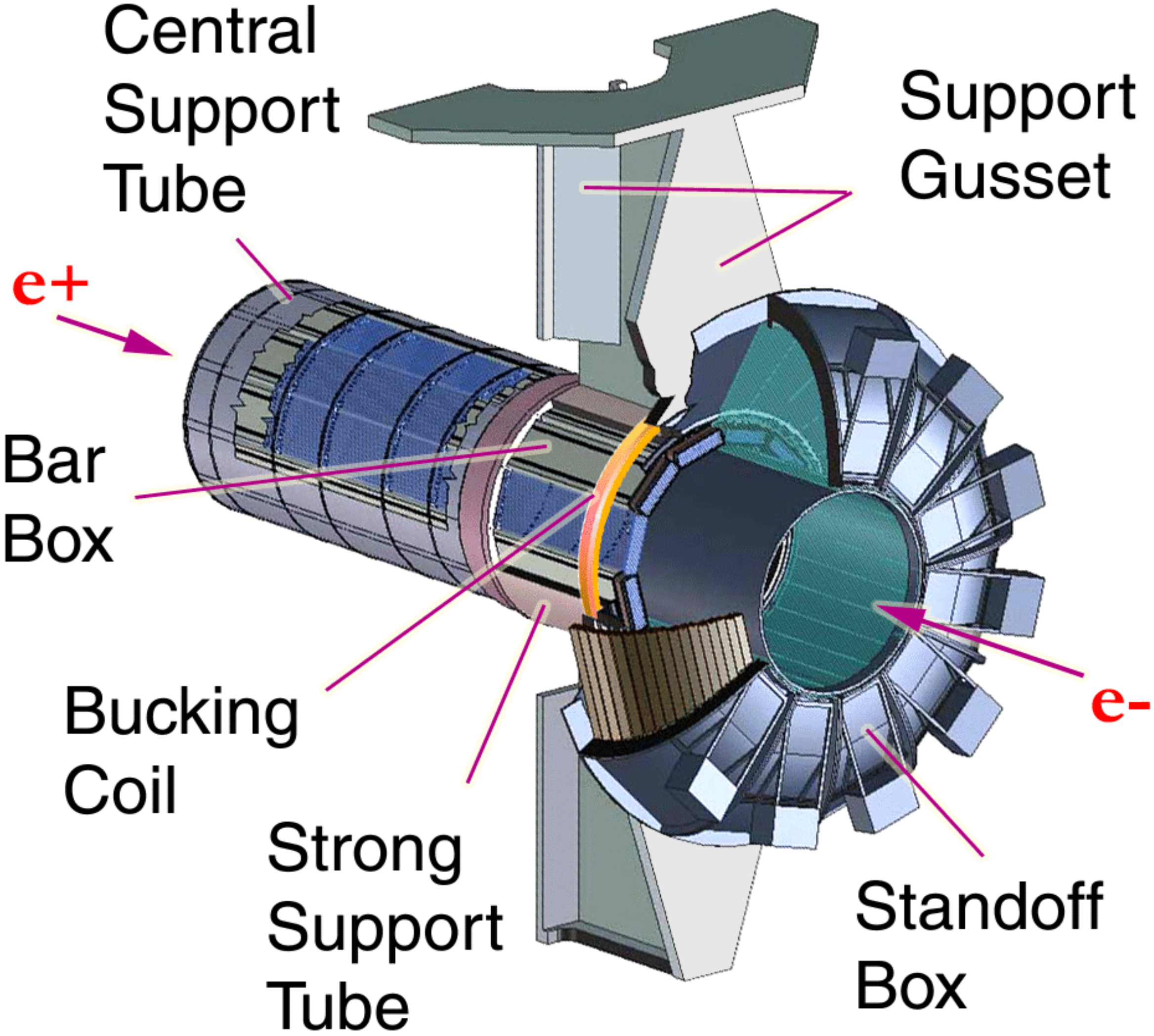
DIRC radiators cover:

94% azimuth,

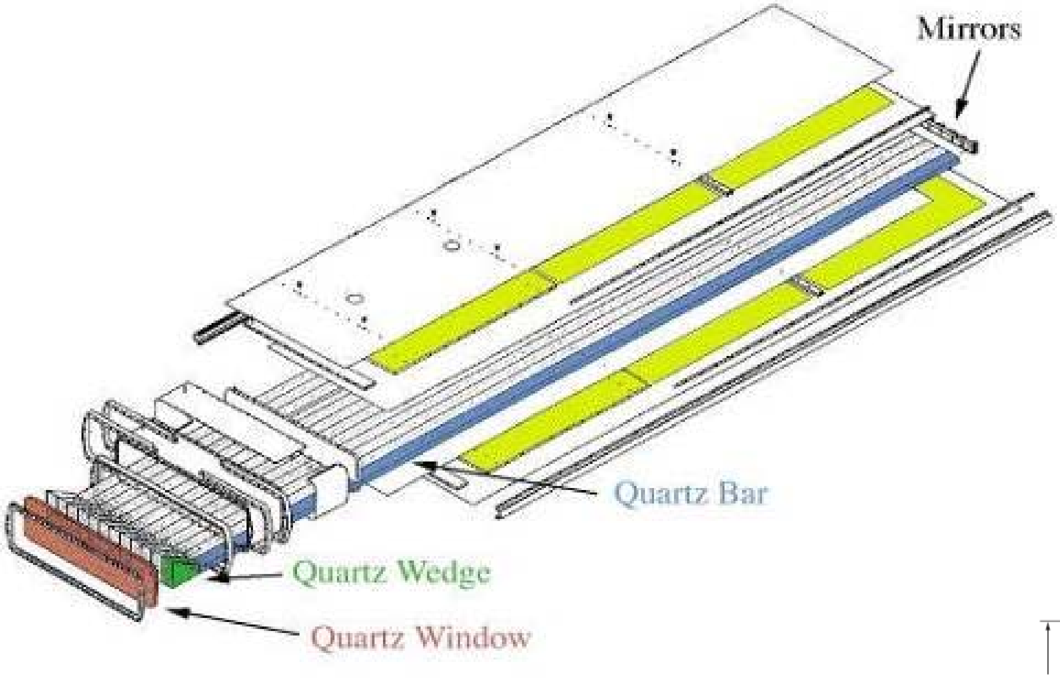
83% c.m. polar angle

DIRC photon detection array:

10,752 PMTs ETL 9125

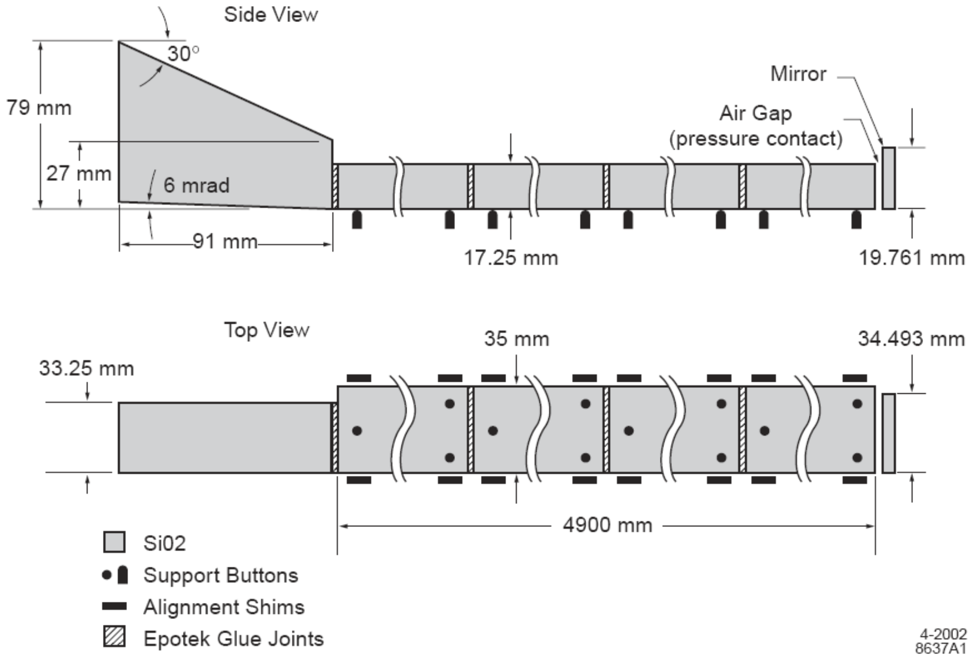


THE DIRC IN BABAR



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



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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: $12.07 \times 10^{33}\ \mathrm{cm}^{-2}\mathrm{sec}^{-1}$ (4 × design)

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

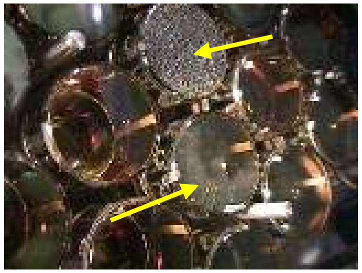
BABAR DIRC ran in factory mode for 8+ years.

OPERATIONAL EXPERIENCE

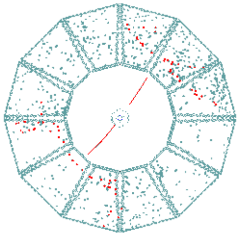
DIRC Operations were Stable and Robust

- 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:



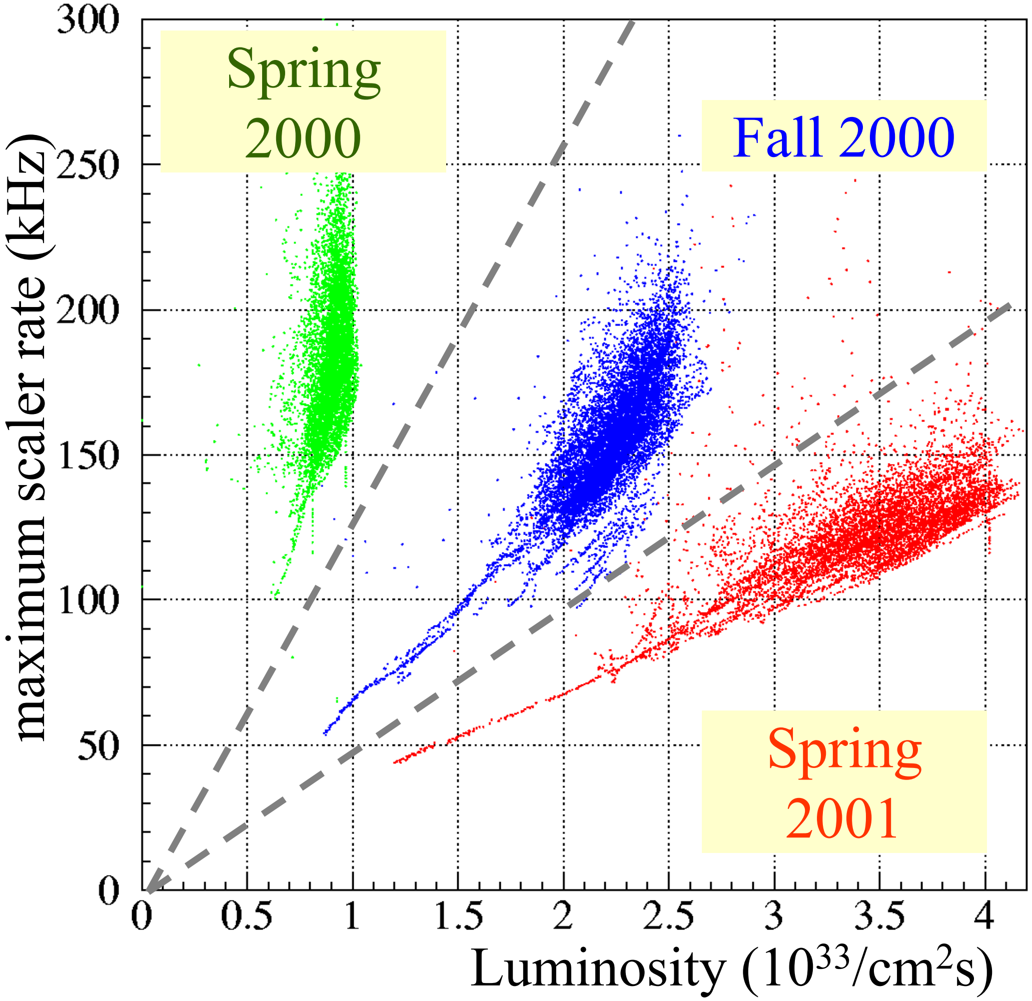
- Concerns about PMT longevity due to PMT window degradation;
  → photon loss a few % level, no problem for PID performance.
- Some damage to electronics due to dust/dirt from civil engineering near experiment;
  → solved by cleaning and application of conformal coating.
- Sensitivity of the DIRC to 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.



OPERATIONAL EXPERIENCE: BACKGROUNDS

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.

DIRC 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.

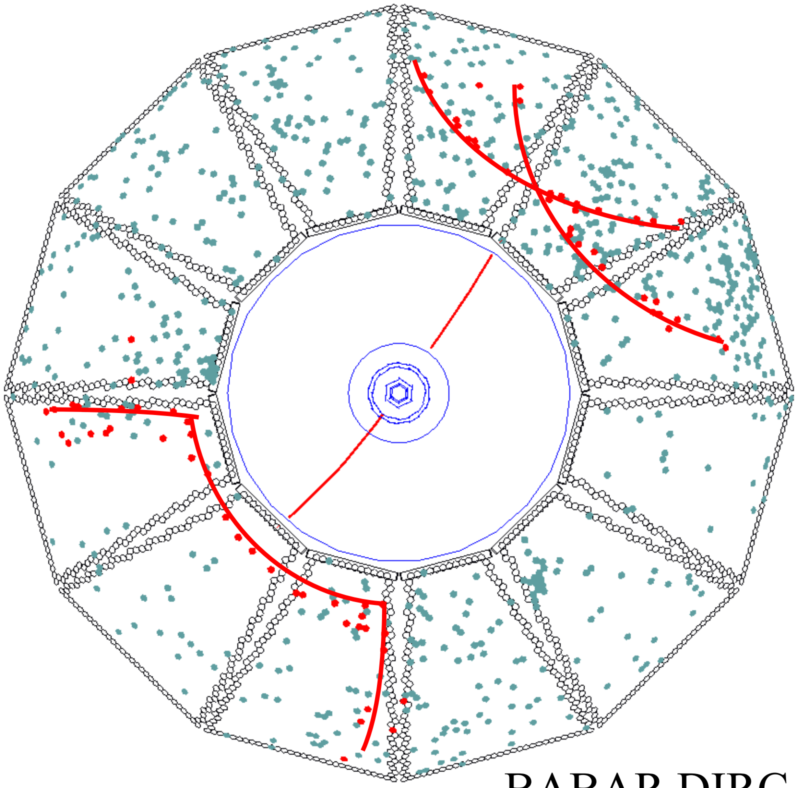
At typical luminosity that caused rates of 80-200 kHz/tube.
(100 × the rate expected during experiment design phase.)

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

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

compared to

50-300 Cherenkov photons



BABAR DIRC

Note that accelerator induced background currently expected to be no issue at PANDA.

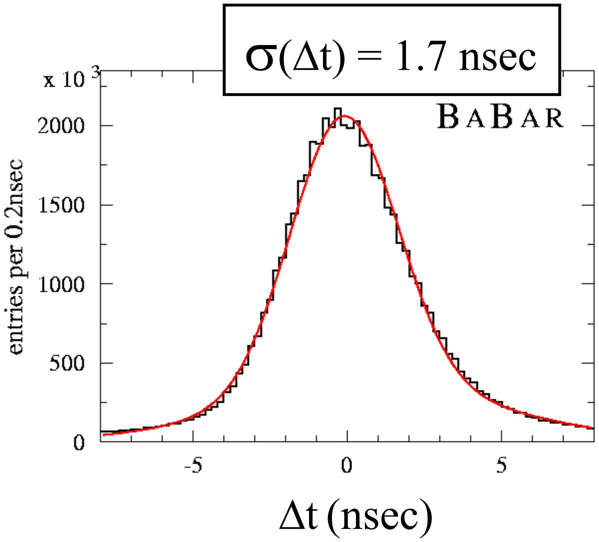
DIRC RECONSTRUCTION

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

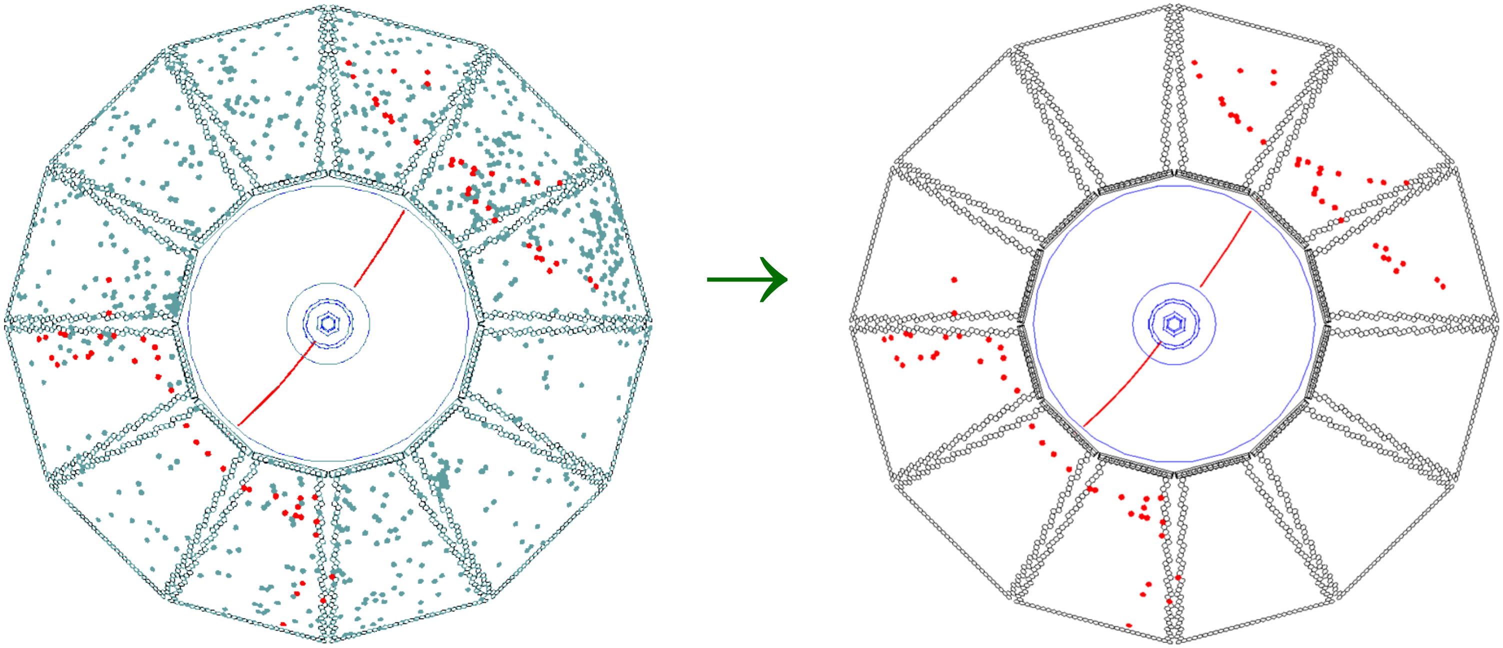
Δt: difference between measured and expected arrival time



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

± 300 nsec trigger window → ± 8 nsec Δt window

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



DIRC RECONSTRUCTION

DIRC likelihood

Calculate unbiased likelihood for observed PMT signals to originate from $e/\mu/\pi/K/p$ track or from background.

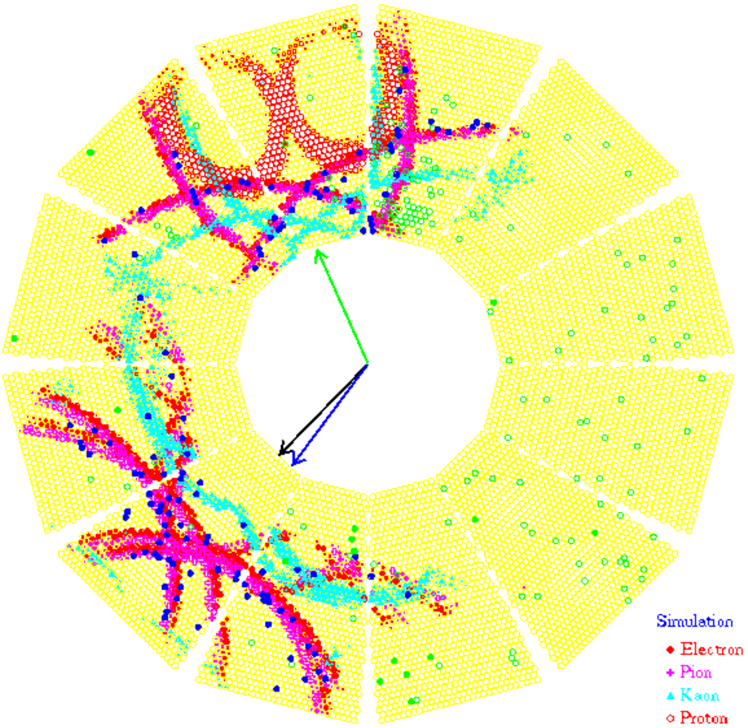
(Likelihood: **Pdf(θ_c) $\otimes$ Pdf(Δt) $\otimes$ Pdf(N_γ)**)

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.



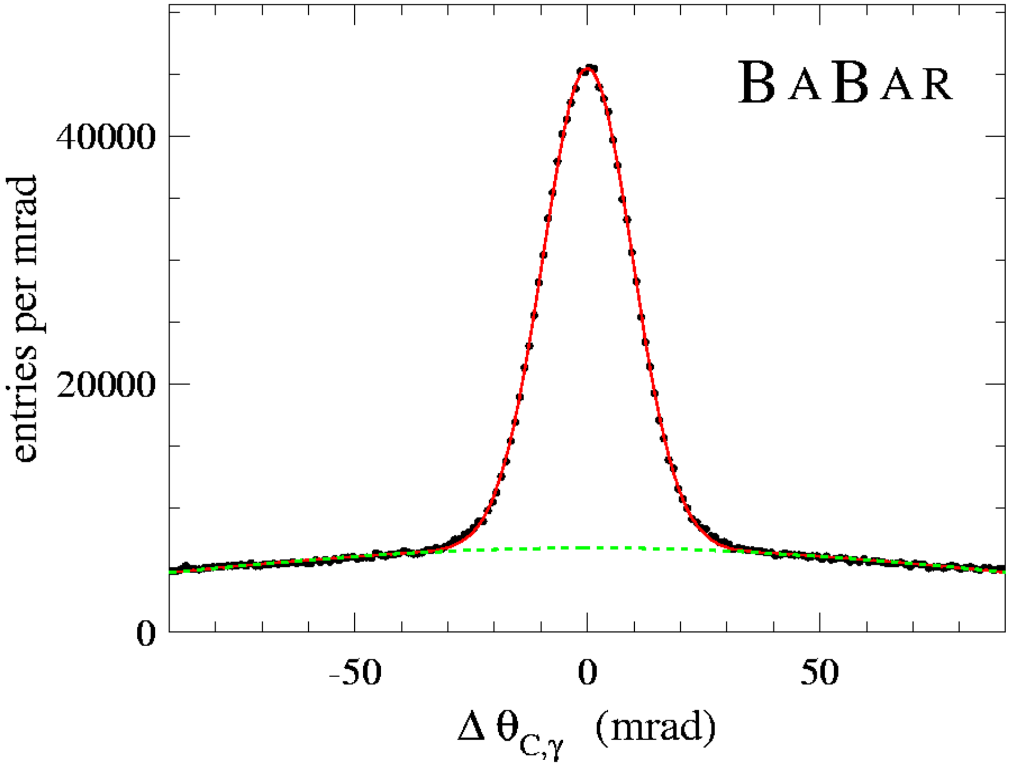
Example: Comparison of real event to simulated response of BABAR DIRC to $e/\pi/K/p$.

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.*

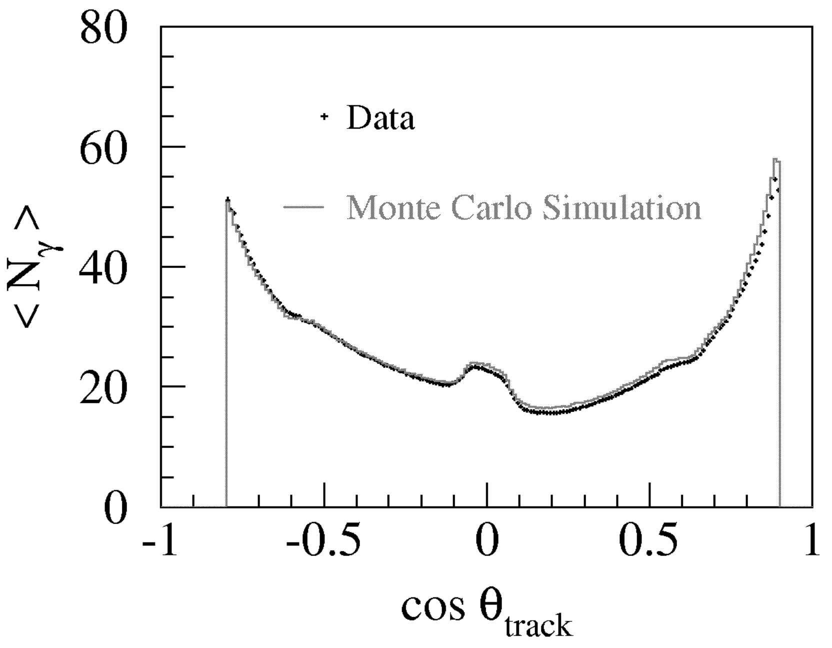
~10% Background under $\Delta\theta_{c,\gamma}$ peak:

combinatoric background, track overlap, accelerator background,

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

DIRC PERFORMANCE EXAMPLE

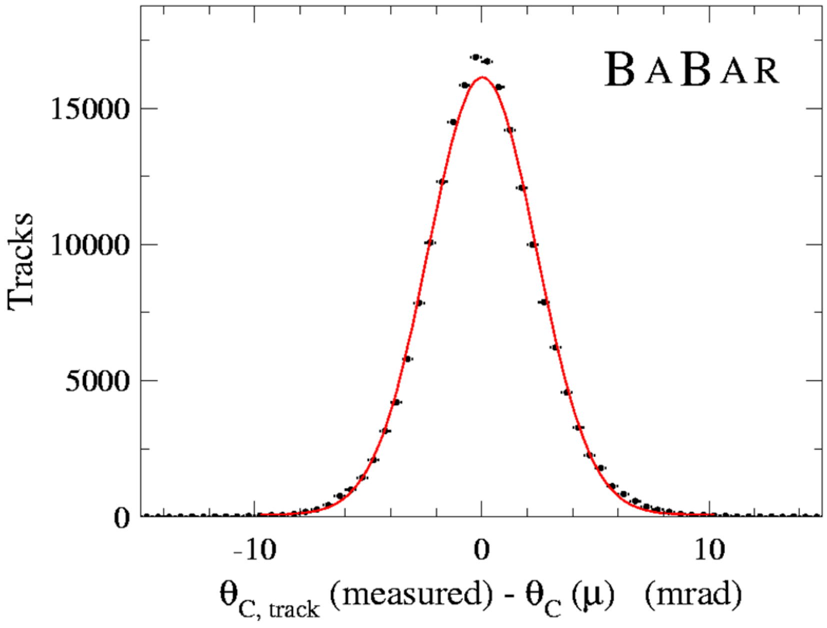
Number of Cherenkov photons per track (di-muons) *vs.* polar angle:



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 (~ 1/√N)

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



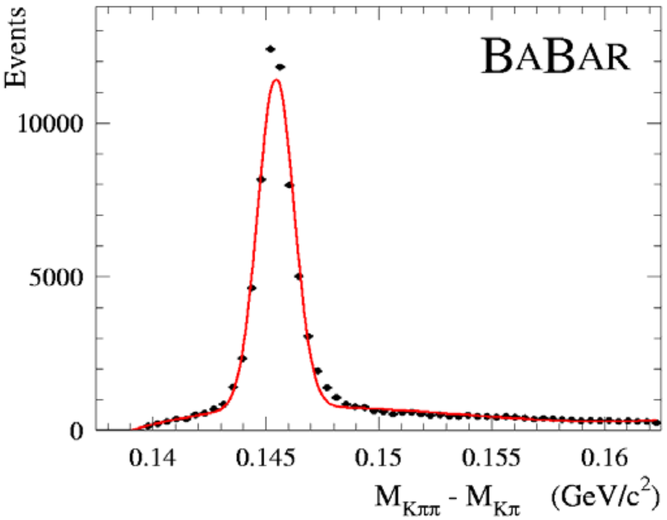
$\sigma(\Delta\theta_c) = 2.4$ mrad

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

BABAR DIRC PERFORMANCE EXAMPLE

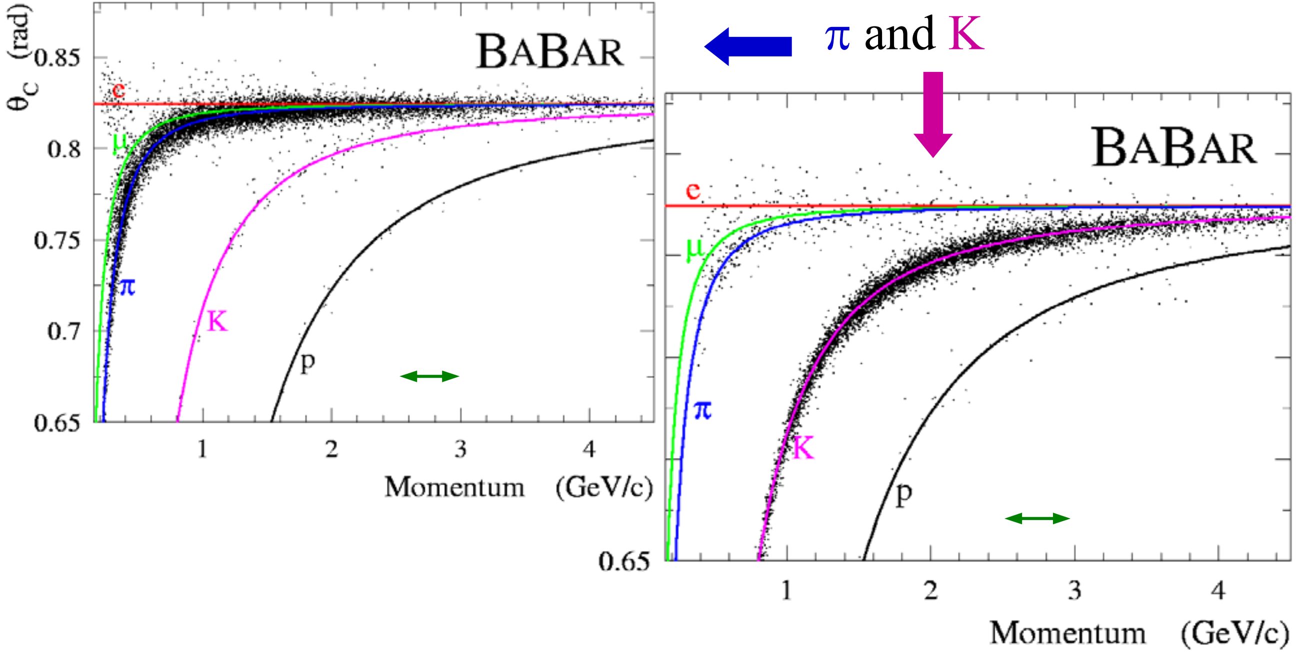
$D^{*-} \to D^0 \pi^-$

↳ $K^- \pi^+$

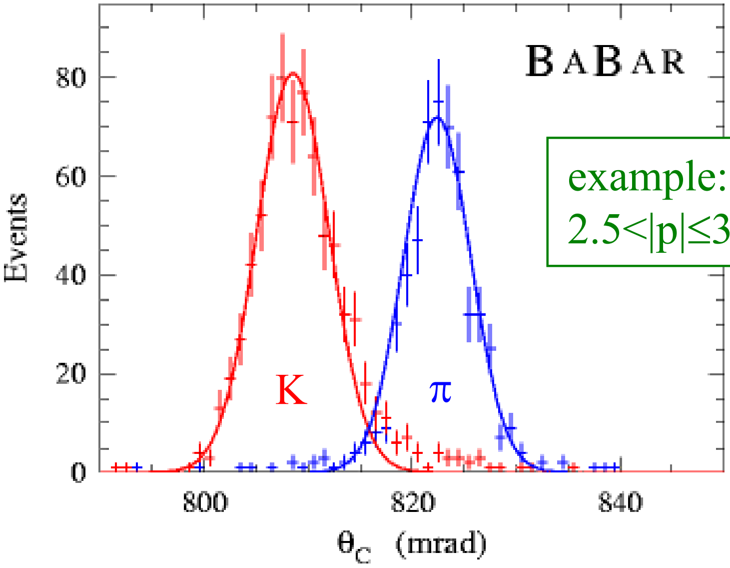


kinematically identified

π and K



- Select D^0 candidate control sample with mass cut (±0.5 MeV/c²)
- π and K are kinematically identified
- calculate selection efficiency and mis-id
- Correct for combinatorial background (avg. 6%) with sideband method.

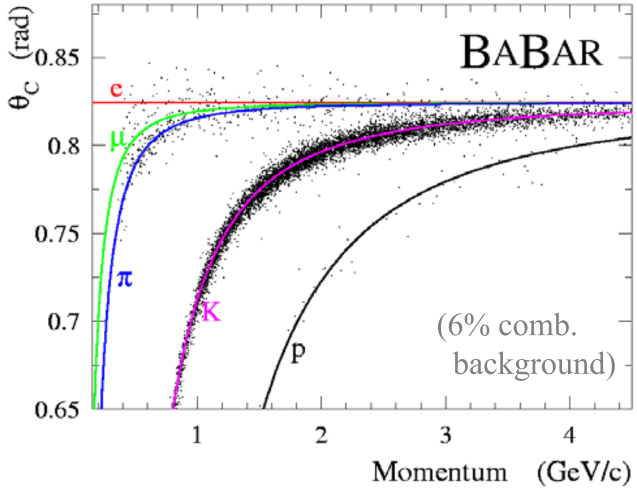


example:
$2.5<|p|\leq3$GeV/c

BABAR DIRC PERFORMANCE EXAMPLE

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

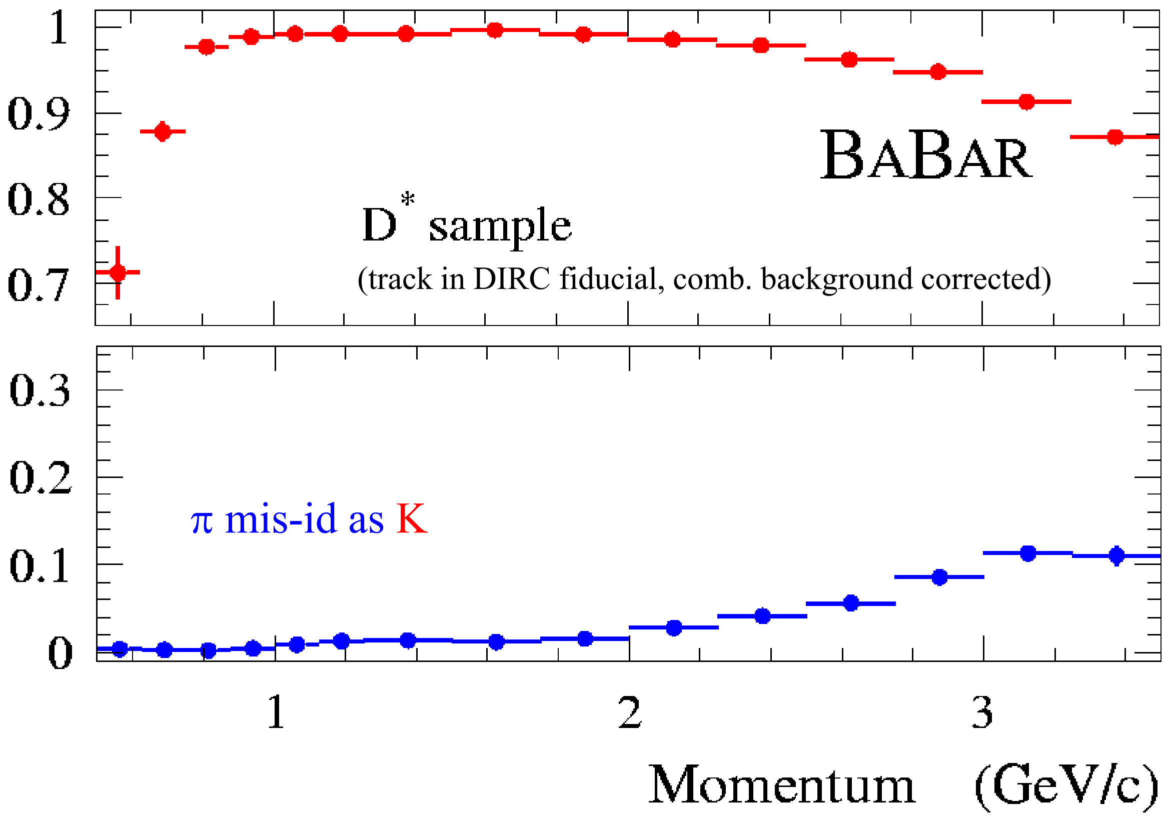
$\hookrightarrow K^- \pi^+$



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

Kaon selection efficiency for

$\mathcal{L}_K > \mathcal{L}_\pi$

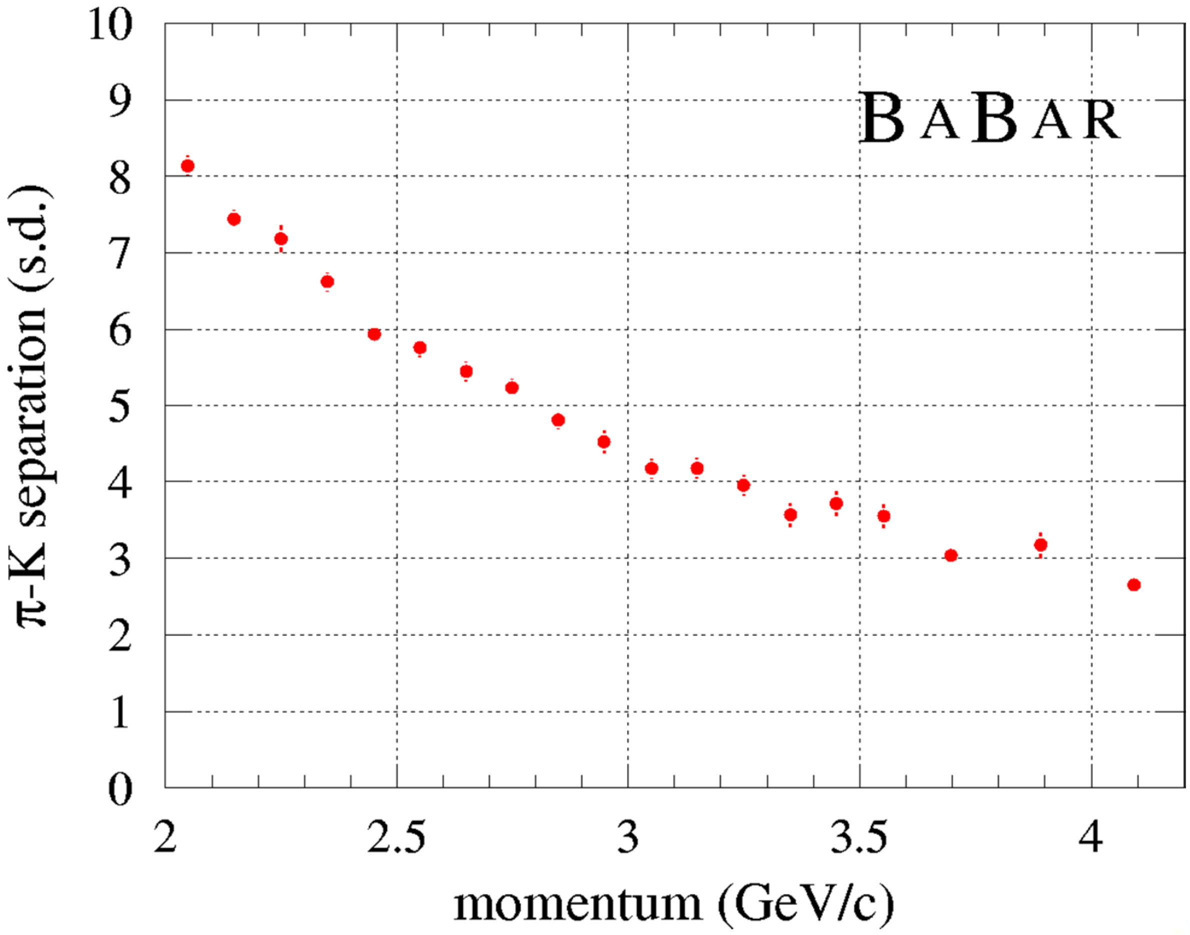


DIRC PERFORMANCE EXAMPLE

π/K separation power:

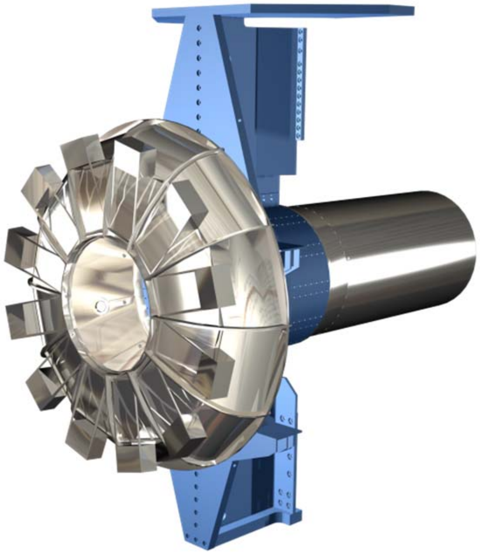
Measure Cherenkov angle resolution as function of track momentum
for pions and kaons, kinematically identified in D* decays.

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



BABAR DIRC CONCLUSION

- The DIRC is a novel type of particle identification system, 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; 98% of channels fully functional to the end.
- Machine backgrounds up to 300 kHz/PMT at $12 \cdot 10^{33}/\mathrm{cm}^2 \cdot \mathrm{s}$ 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.

FUTURE DIRC DETECTORS

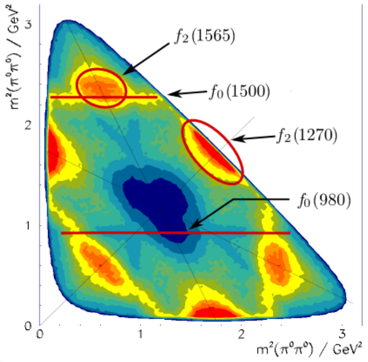
- PANDA
  - FOCUSING BARREL DIRC
  - ENDCAP DISK DIRC
    - FOCUSING LIGHTGUIDE DIRC
    - TIME OF PROPAGATION DIRC
    - HYBRID DIRC
- SUPERB DETECTOR IN ITALY
  - FDIRC
- BELLE II DETECTOR AT SUPERKEKB IN JAPAN
  - TOP COUNTER
- WASA (COSY), TORCH (LHCB UPGRADE), ETC

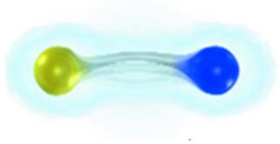
PANDA PHYSICS PROGRAM

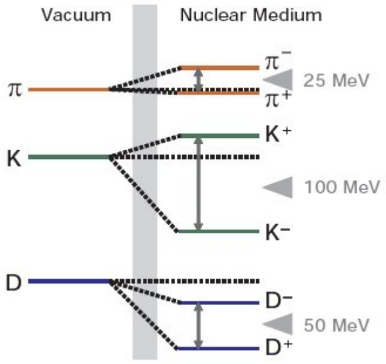
Study of QCD with Antiprotons

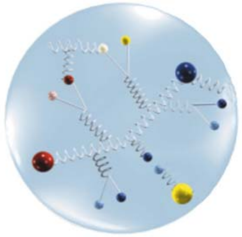
K. Götzen
TROIA'09

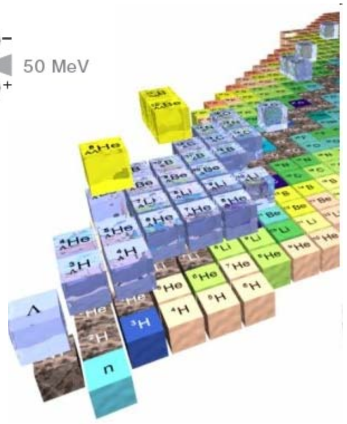
- Charmonium Spectroscopy
  - Precision Spectroscopy
  - Study of Confinement Potential
  - Access to all these puzzling X, Y and Z
- Search for Exotics
  - Look for Glueballs and Hybrids
  - Gluon rich environment → high discovery potential
  - Disentangle Mixing via PWA
- Hadrons in Medium
  - Study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





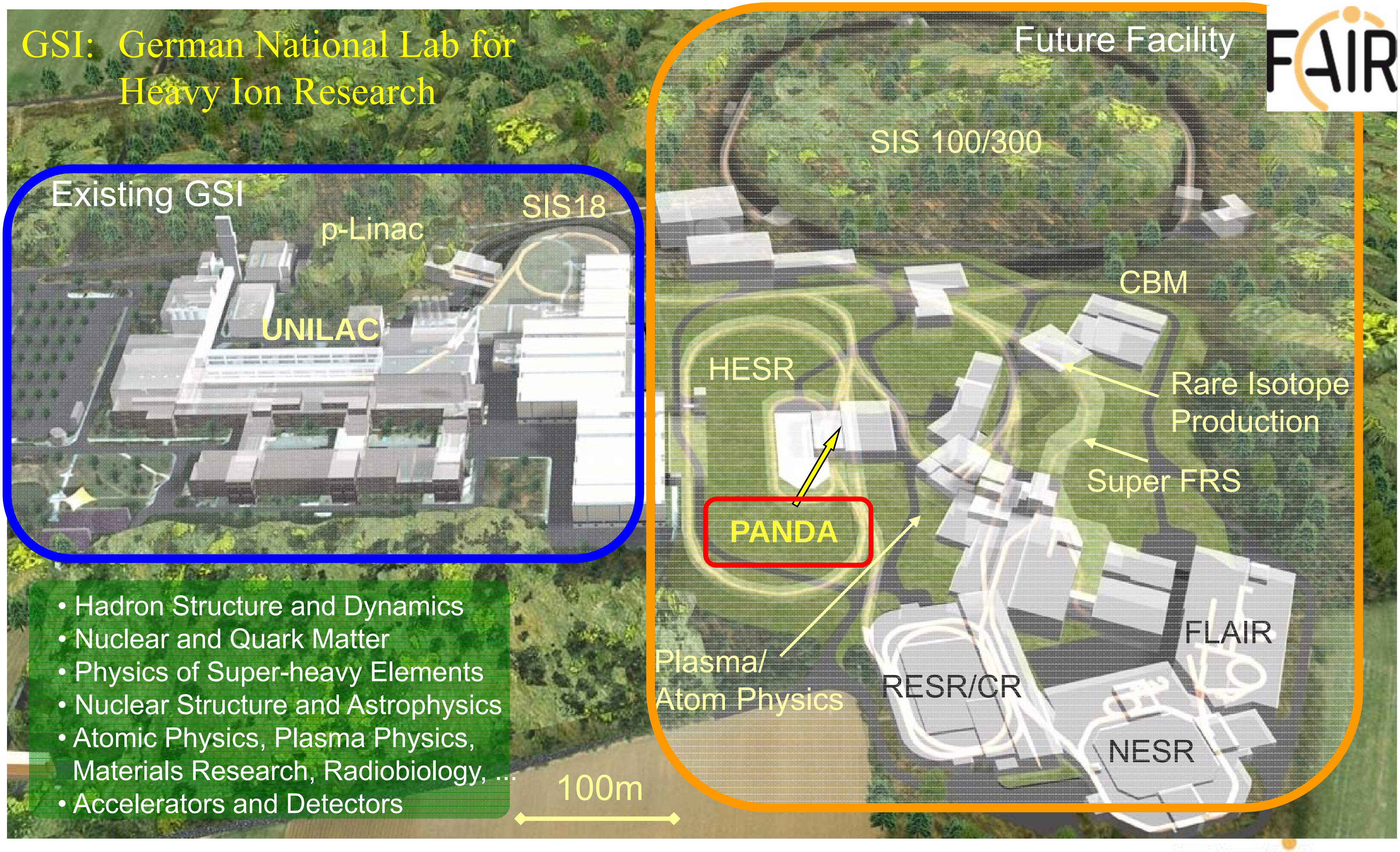






FAIR

Facility for Antiproton and Ion Research at GSI near Darmstadt, Germany



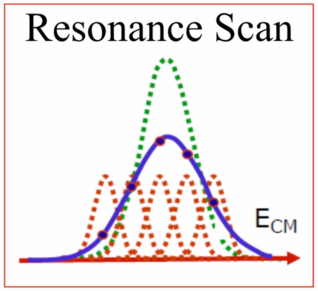
- Hadron Structure and Dynamics
- Nuclear and Quark Matter
- Physics of Super-heavy Elements
- Nuclear Structure and Astrophysics
- Atomic Physics, Plasma Physics, Materials Research, Radiobiology, ...
- Accelerators and Detectors

HESR: HIGH ENERGY STORAGE RING

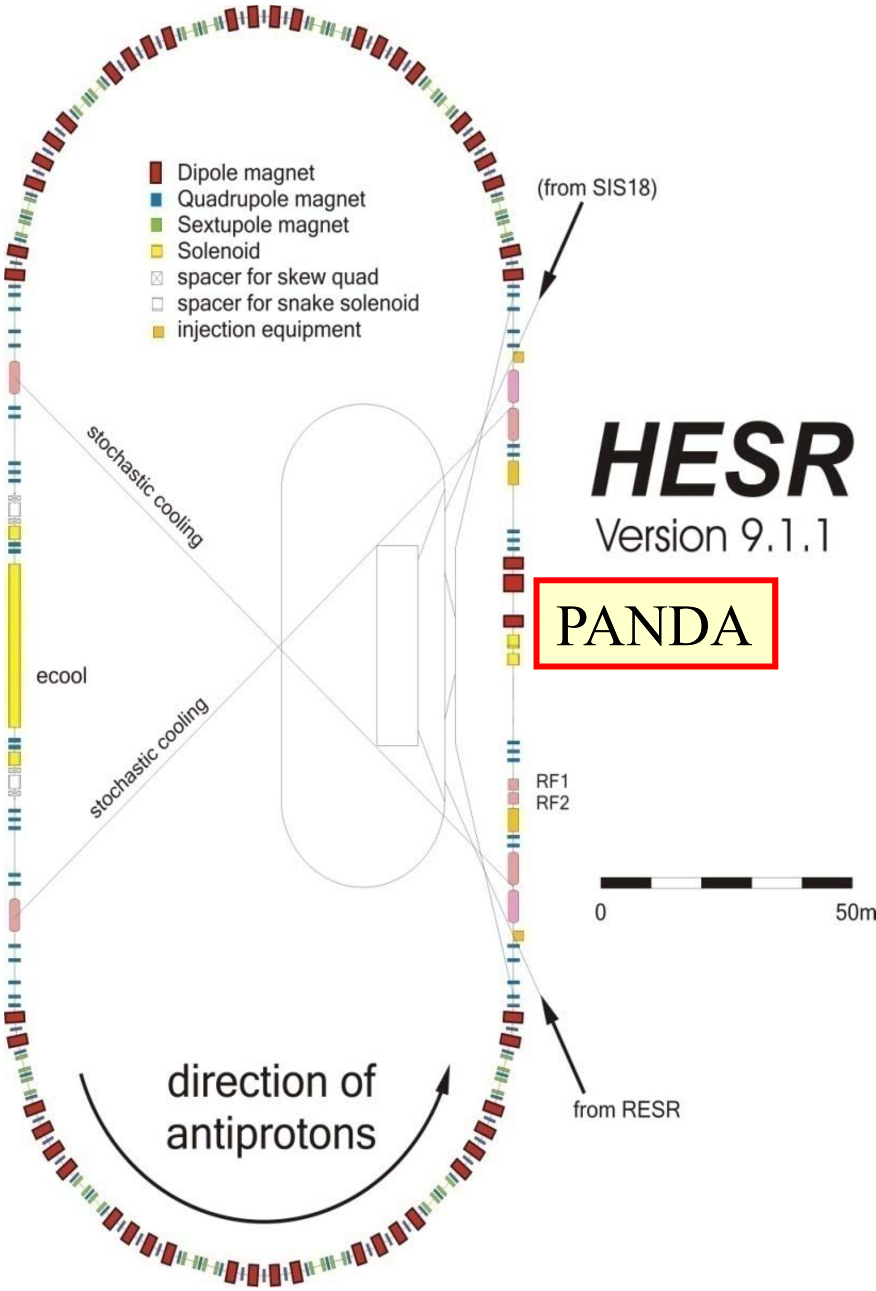
- Average production rate: 2×10^{7}/sec
- $p_{beam} = 1.5 \ldots 15$ GeV/c
- N_{stored} = up to $1 \times 10^{11}\ \bar{p}$

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



PANDA COLLABORATION

FAIR Convention expected to be signed by partner nations this fall.

PANDA installation approx. 2016/17.

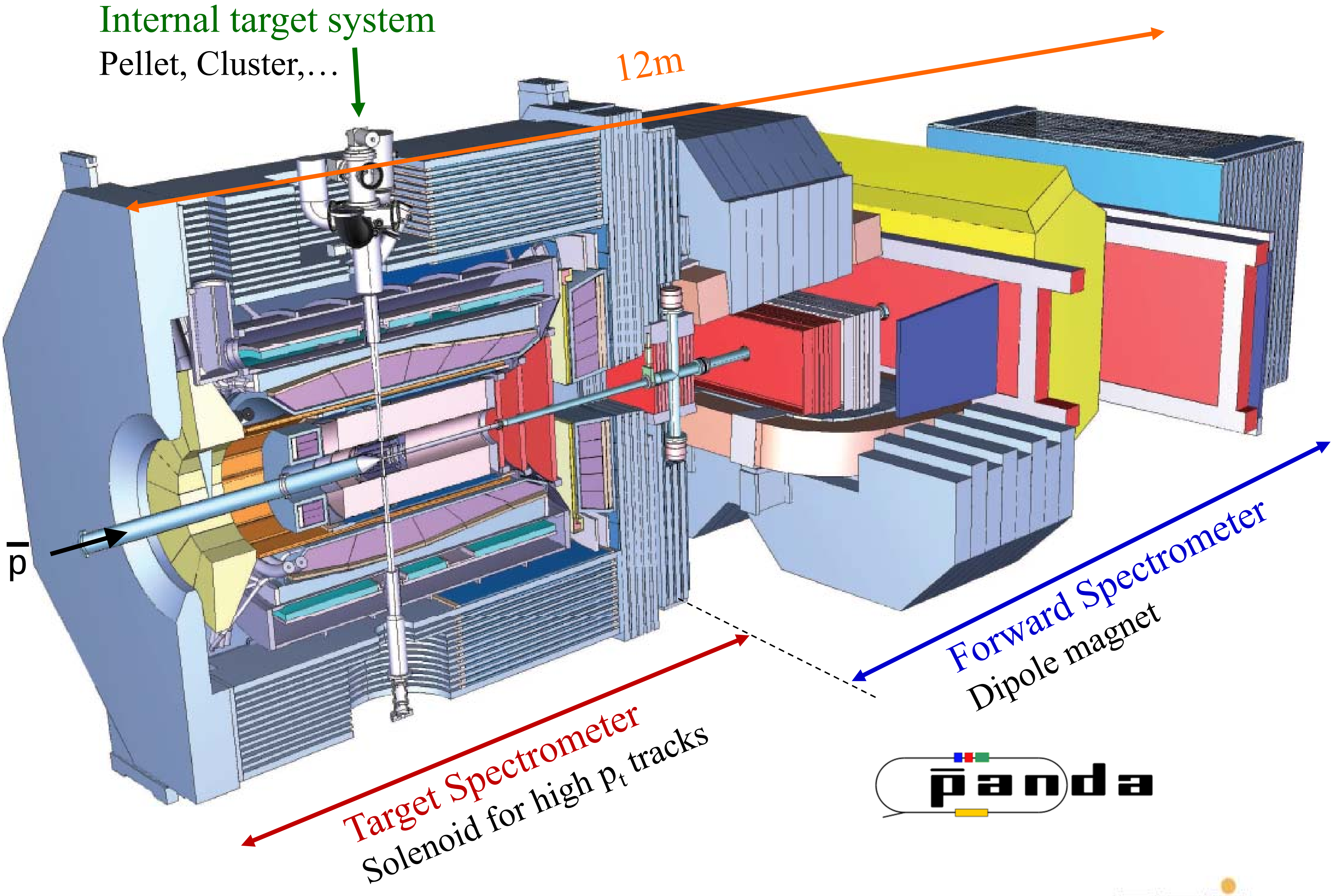
About 420 physicists from 53 institutions in 16 countries

U Basel
IHEP Beijing
U Bochum
IIT Bombay
U Bonn
IFIN-HH Bucharest
U & INFN Brescia
U & INFN Catania
JU Cracow
TU Cracow
IFJ PAN Cracow
GSI Darmstadt
TU Dresden
JINR Dubna
(LIT,LPP,VBLHE)
U Edinburgh
U Erlangen
NWU Evanston

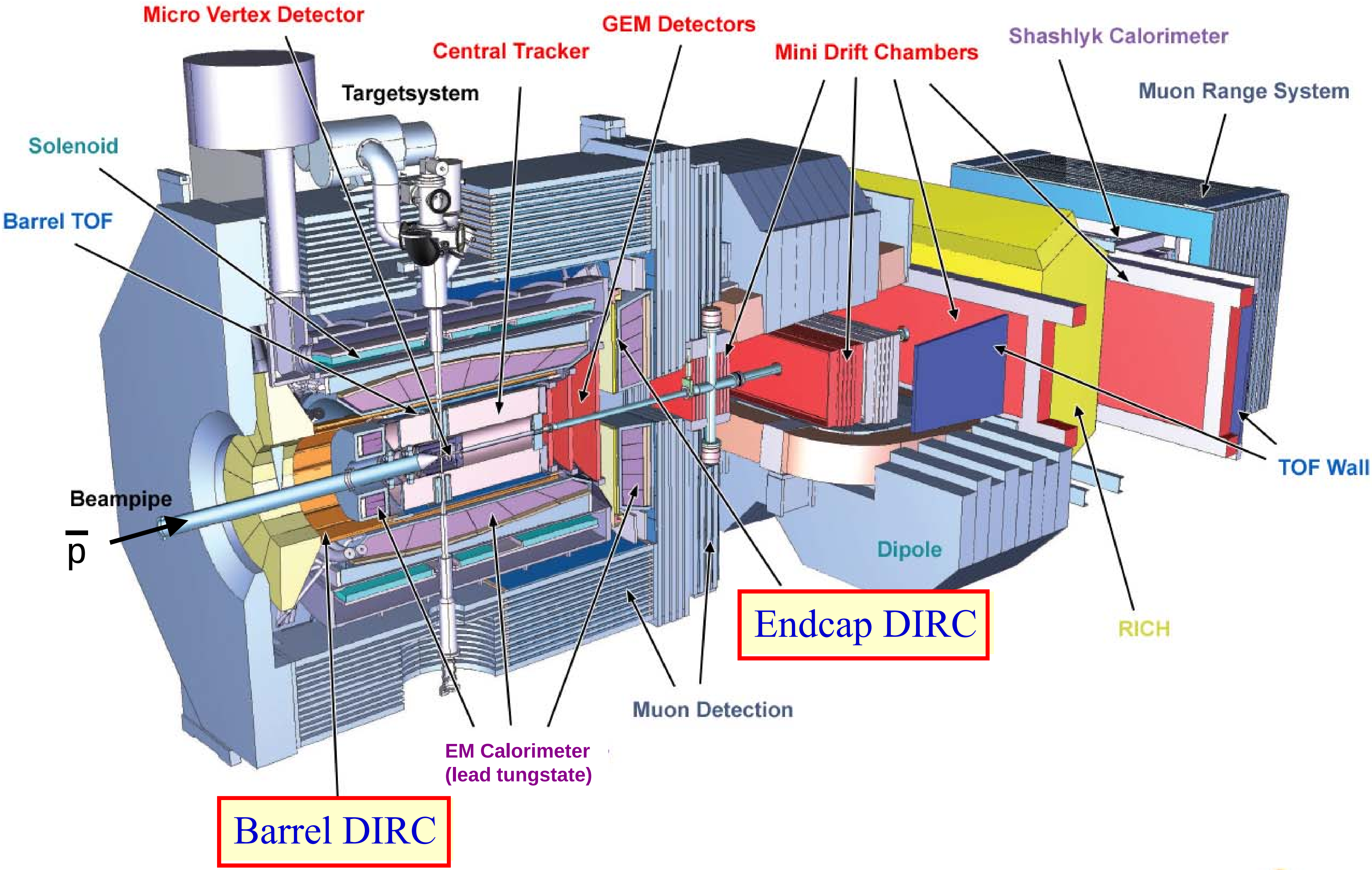
U & INFN Ferrara
U Frankfurt
LNF-INFN Frascati
U & INFN Genova
U Glasgow
U Gießen
KVI Groningen
IKP Jülich I + II
U Katowice
IMP Lanzhou
U Lund
U Mainz
U Minsk
ITEP Moscow
MPEI Moscow
TU München
U Münster
BINP Novosibirsk

IPN Orsay
U & INFN Pavia
IHEP Protvino
PNPI Gatchina
U of Silesia
U Stockholm
KTH Stockholm
U & INFN Torino
Politechnico di Torino
U Piemonte Orientale, Torino
U & INFN Trieste
U Tübingen
TSL Uppsala
U Uppsala
U Valencia
SMI Vienna
SINS Warsaw
TU Warsaw

PANDA DETECTOR



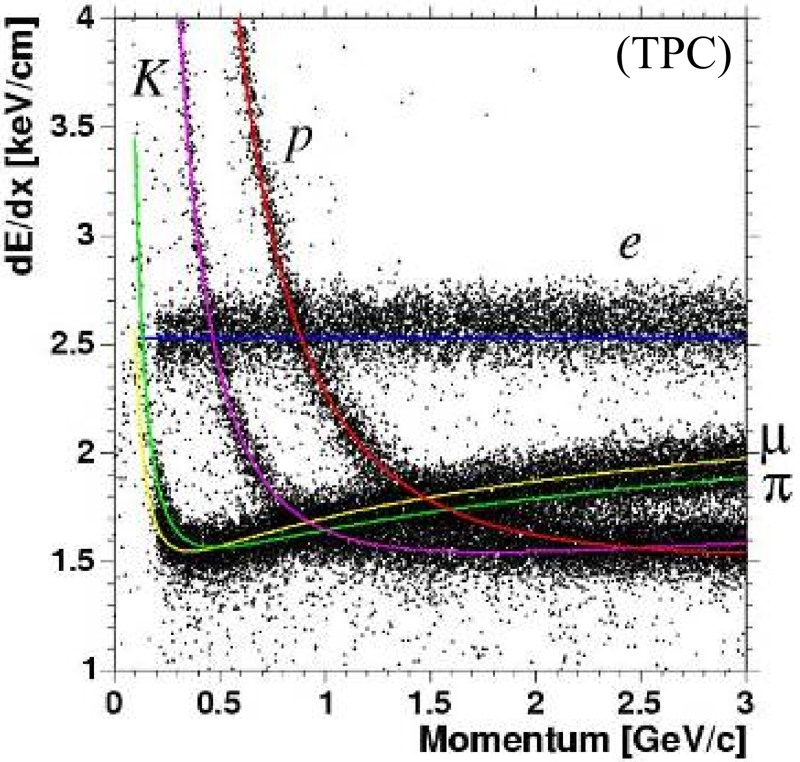
PANDA DETECTOR



PARTICLE IDENTIFICATION

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:
  Challenge: no start detector, relative timing
- Electromagnetic showers:
  EMC for e and γ

DIRC IN PANDA

Most recent review
of PANDA DIRCs:
C. Schwarz
RICH2010

DIRC detector advantages

- Thin in radius and radiation length.
- Moderate and uniform amount of material in front of calorimeter.
- Number of signal photons increases in forward direction *(good match to asymmetric detector at fixed target experiment)*.
- Fast and tolerant of background.
- Robust and stable detector operations.

PANDA design includes two DIRC detectors

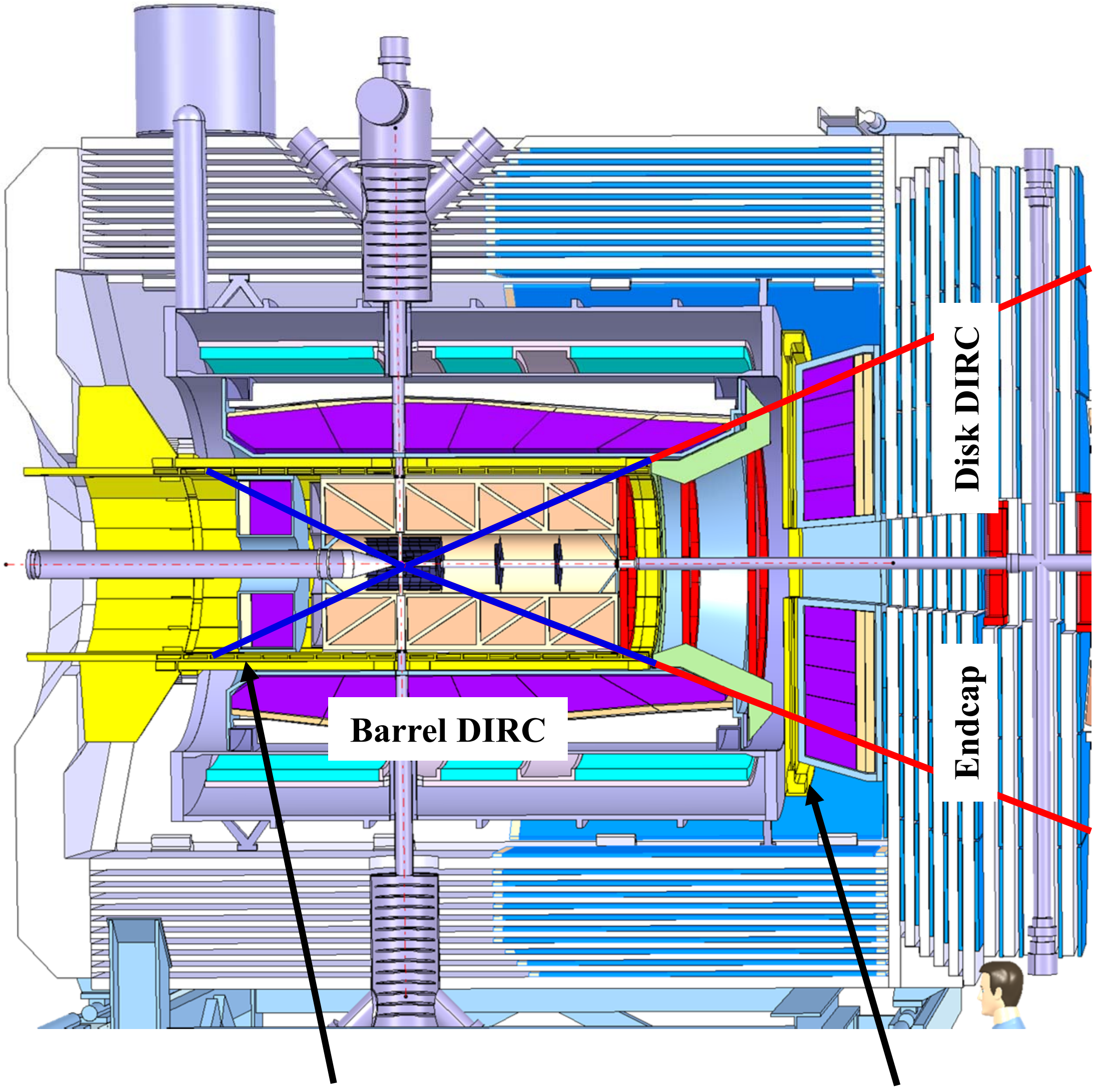
- Barrel DIRC similar to BABAR DIRC.
- Novel endcap Disk DIRC.

Institutions currently involved

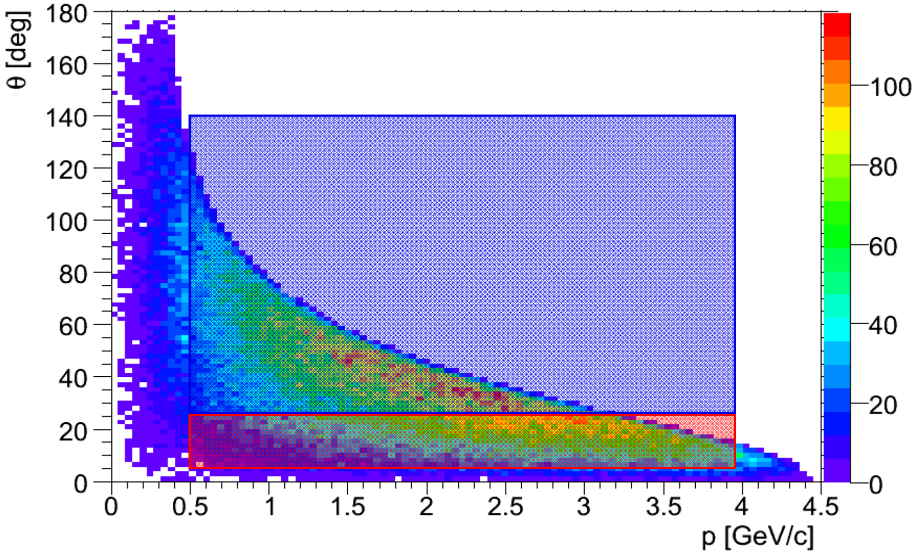
- Edinburgh, Erlangen, Dubna, Ferrara, Gießen, Glasgow, GSI, Vienna.

DIRC IN PANDA

Particle Identification coverage of the two DIRC detectors



Barrel DIRC **Endcap Disk DIRC**

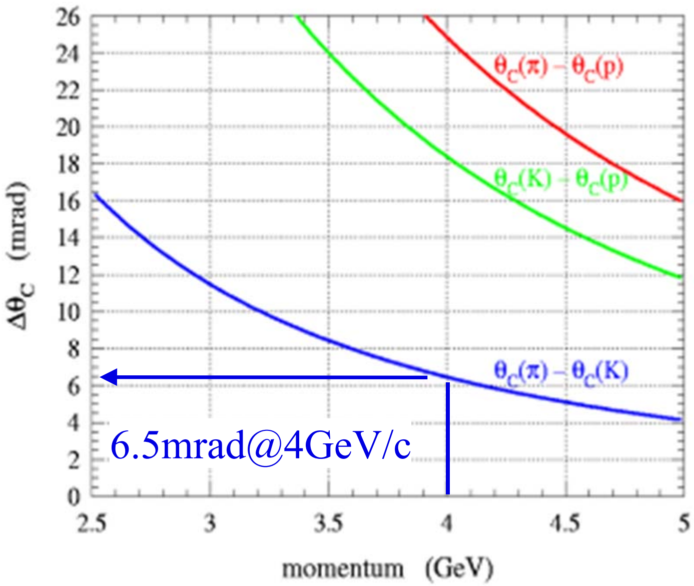


Kaon distribution of the radiative decay

$J/\psi \rightarrow K^+K^-\gamma$

(search of glue balls)

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

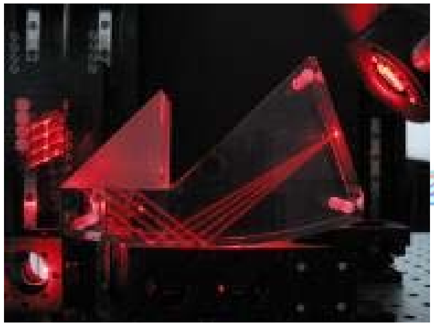
Limited in BABAR by:			Could be improved for PANDA via:
▪ size of bar image	~4.1 mrad	→	▪ focusing optics
▪ size of PMT pixel	~5.5 mrad	→	▪ smaller pixel size
▪ chromaticity (n=n(λ))	~5.4 mrad	→	▪ better time resolution
	9.6 mrad	→	4-5 mrad per photon → < 1.5–2 mrad per track

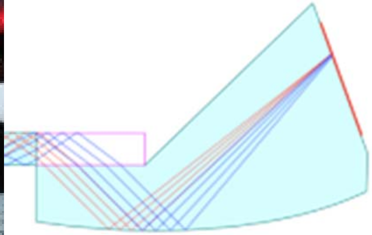
PANDA DIRC Design

PANDA DIRC

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

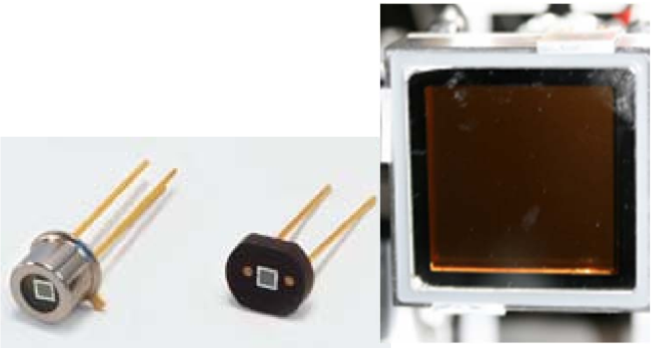
- Focusing optics remove bar size contribution
  from Cherenkov angle resolution term.
  Lens or mirror focusing on flat detector surface.



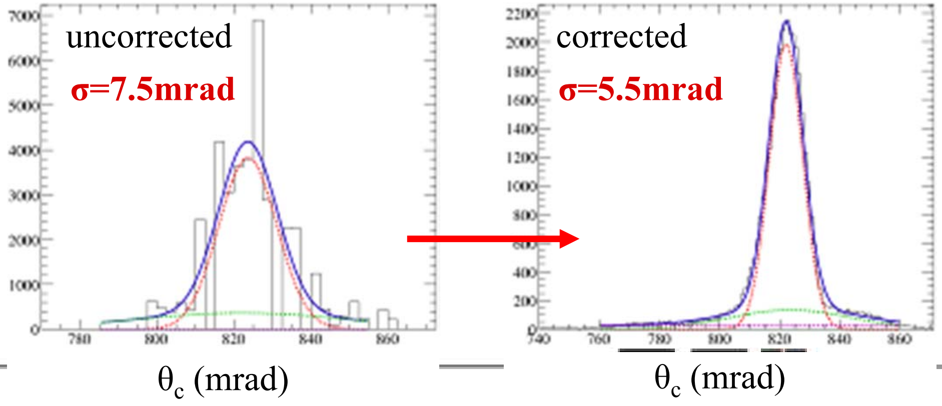


Light guide for disk

- 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.
  Alternative: hardware correction of
  chromatic effects using LiF block.

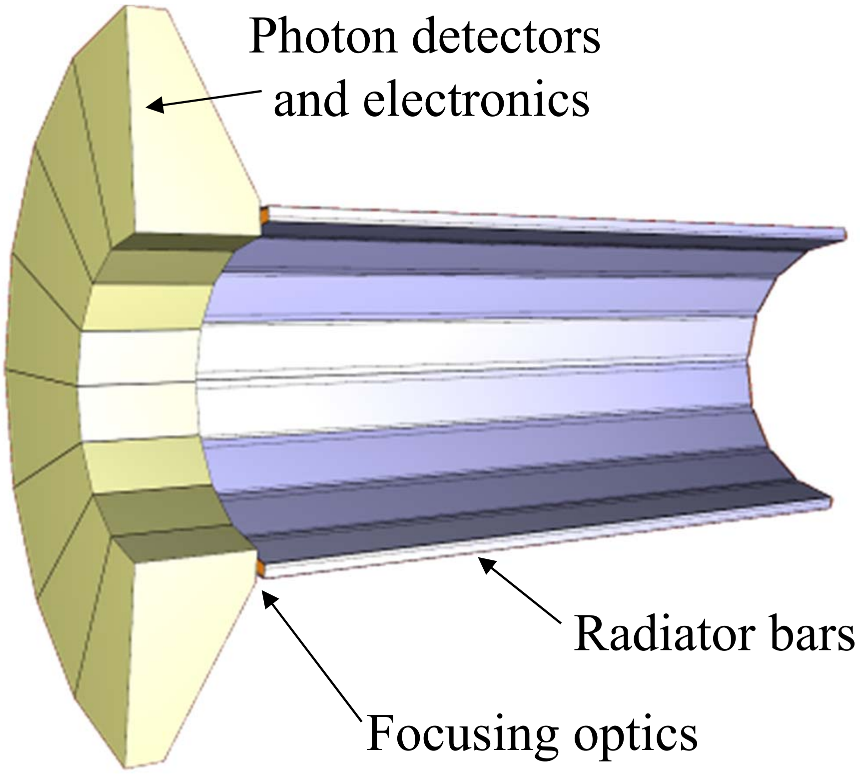


PANDA BARREL DIRC

Improved version of proven BABAR-DIRC design

More compact, faster, focusing optics

- 96 radiator bars, synthetic fused silica
  17mm (T) × 33mm (W) × 2500mm (L)
- Focusing optics: lens system
- Compact photon detector: array of
  Burle Planacon MCP-PMT
  or Geiger-mode APD,
  total 7000-10000 channels.
- Fast photon detection: MCP-PMT/gAPD plus
  fast TDC/ADC (ToT) electronics
  → 100-200 ps timing.



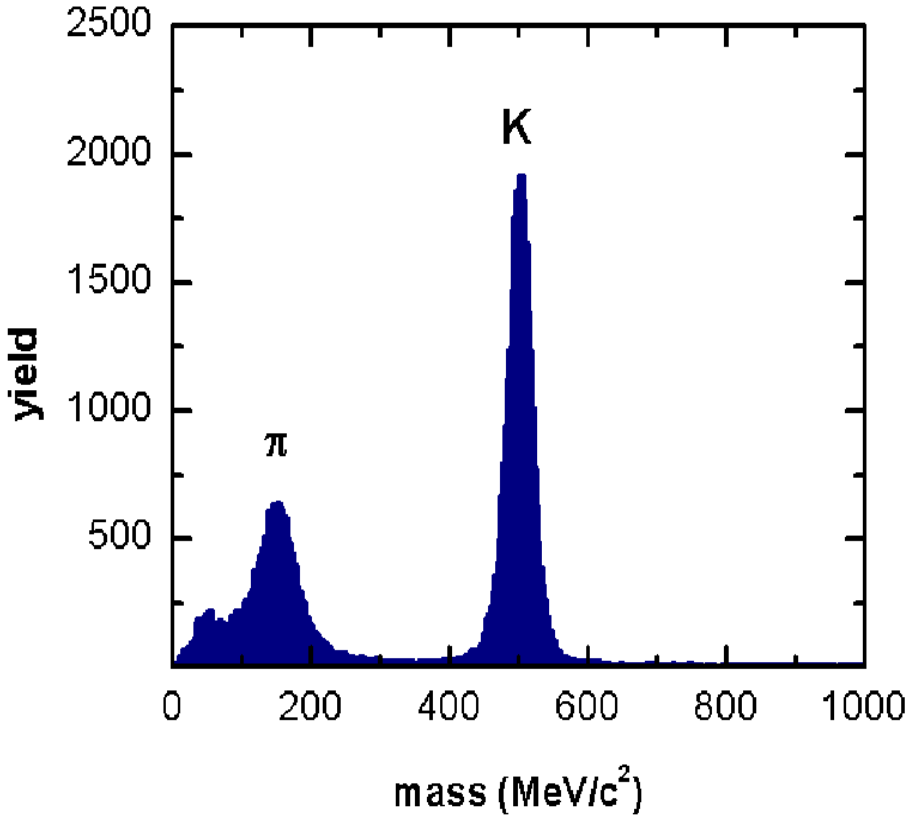
Still investigating several design options:

mirror focusing, radiator plates, photon detection outside magnetic field

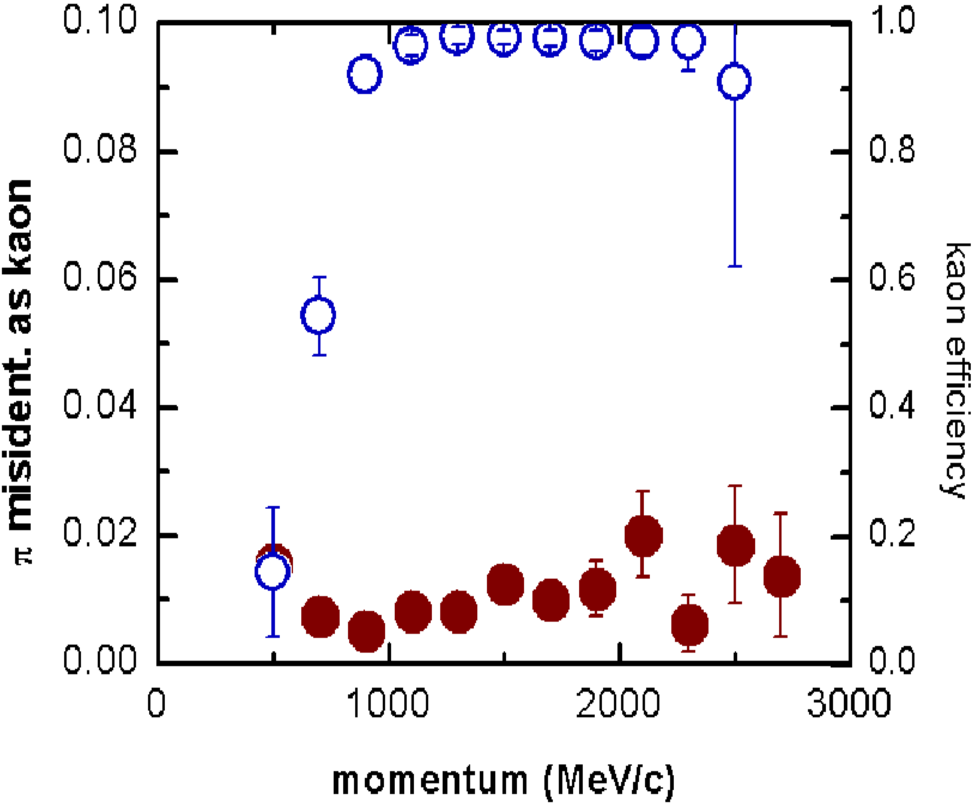
PANDA BARREL DIRC PERFORMANCE

Expected PID performance example from simulation.

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



kaon efficiency 98% @ 2% π mis-ID



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

PANDA BARREL DIRC DESIGN

Barrel DIRC design, readout inside magnet yoke.

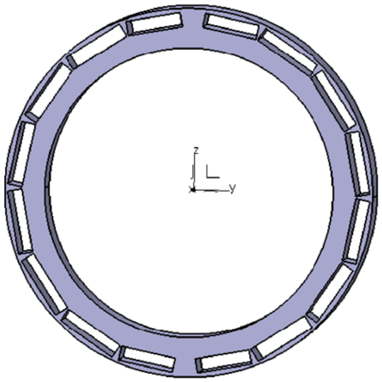
(*prelim. dimensions)*

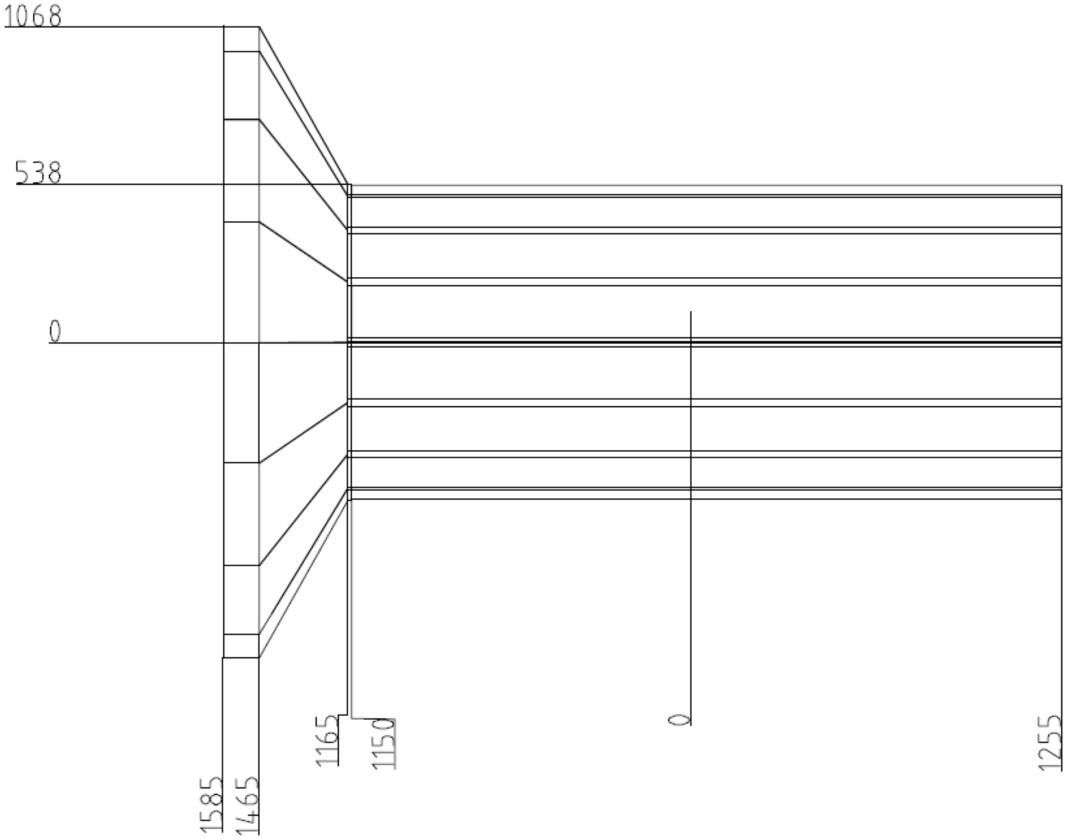
Barrel radius ~50 cm, length ~250 cm,

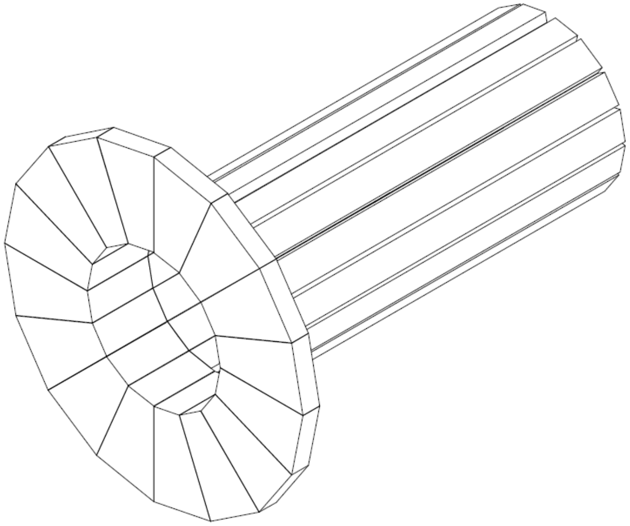
gap (2*one bar) for target pipe at 12 o'clock and 6 o'clock,

Expansion volume depth ~30 cm, height ~50cm

(plus space for PMTs and cables).

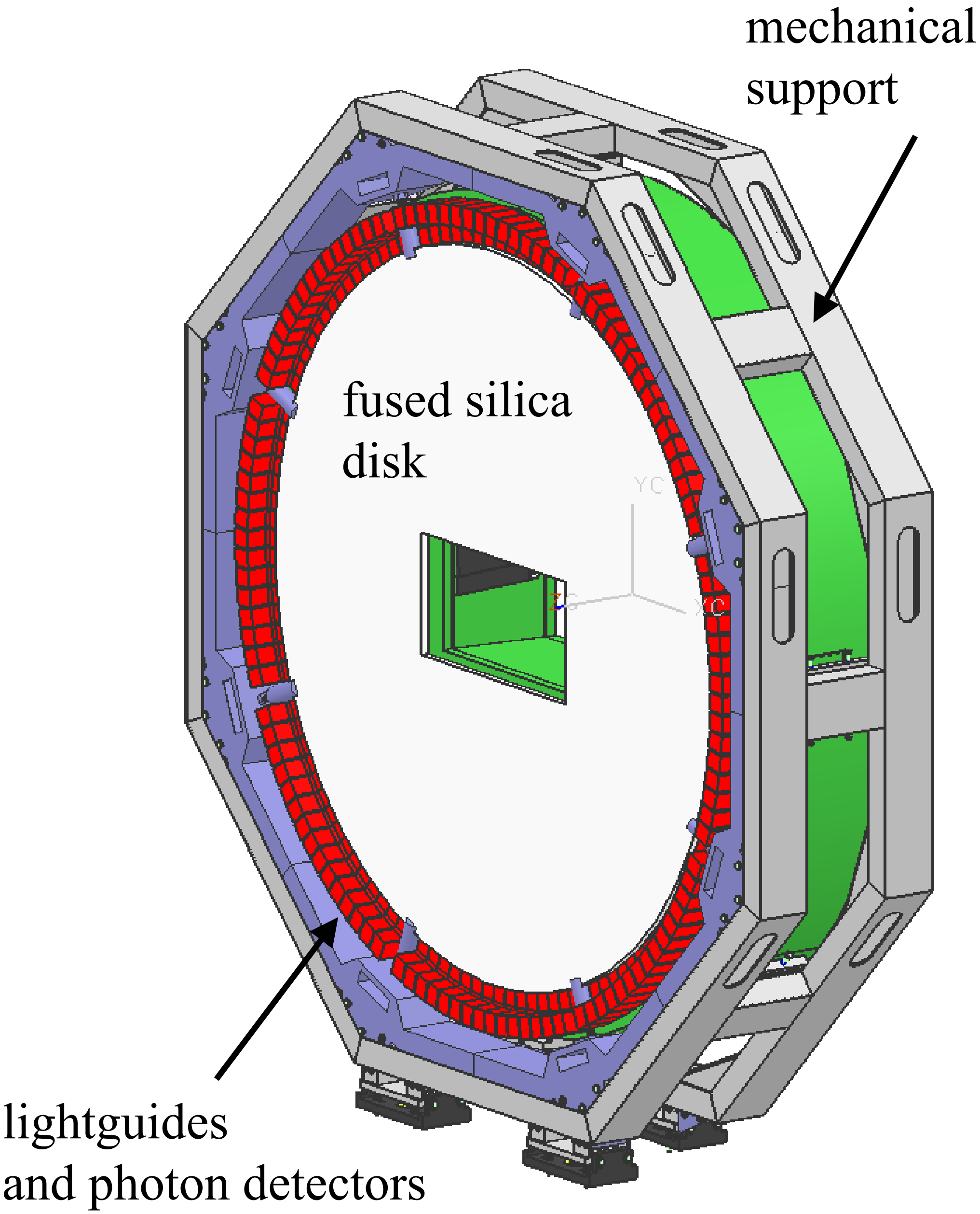






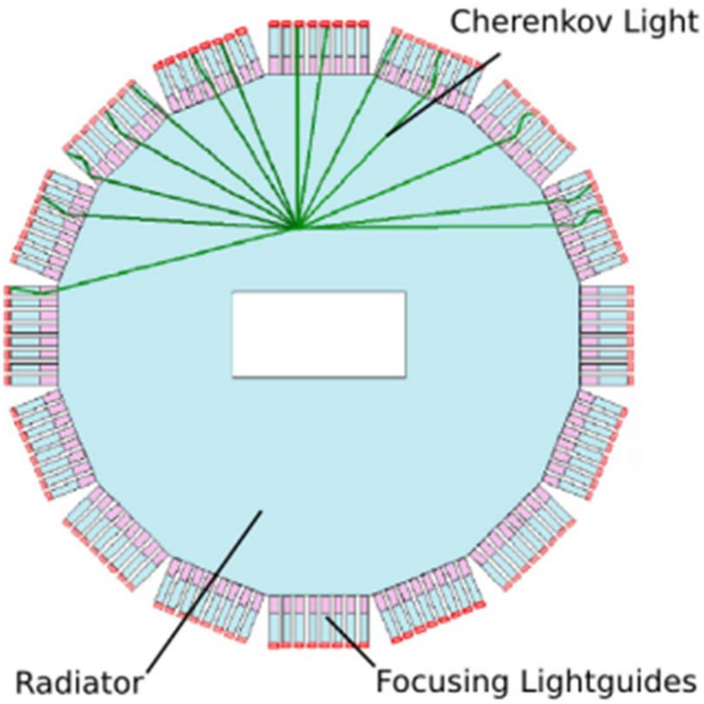
PANDA FOCUSING DISK DIRC

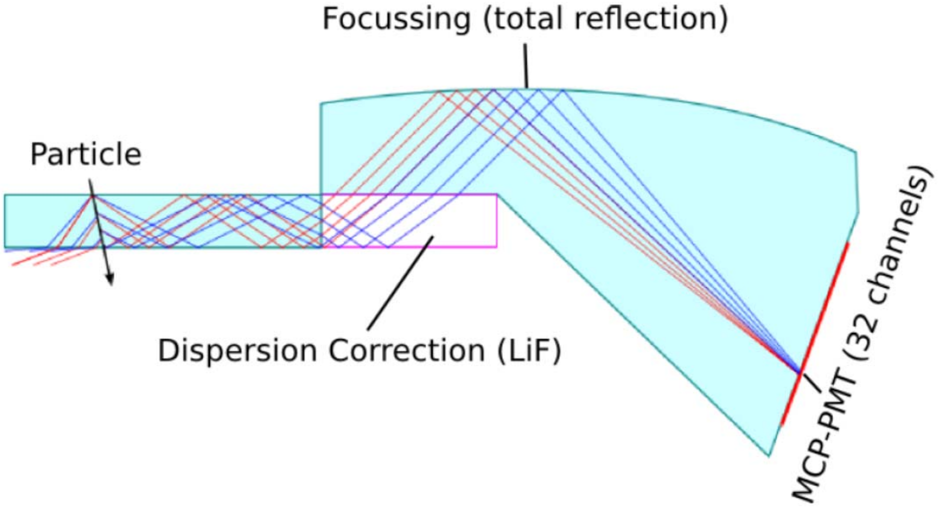
- Image reconstruction in 2D (X, Y)
- Timing used for event correlation and background subtraction
- Radiator: synthetic fused silica, 20 mm thick, 1100 mm radius
- Focusing optics for imaging with dispersion correcting element (LiF)
- Compact detection plane on each light guide (50x50 mm^2)
- 128 light guides, 4096 R/O channels



PANDA FOCUSING DISK DIRC

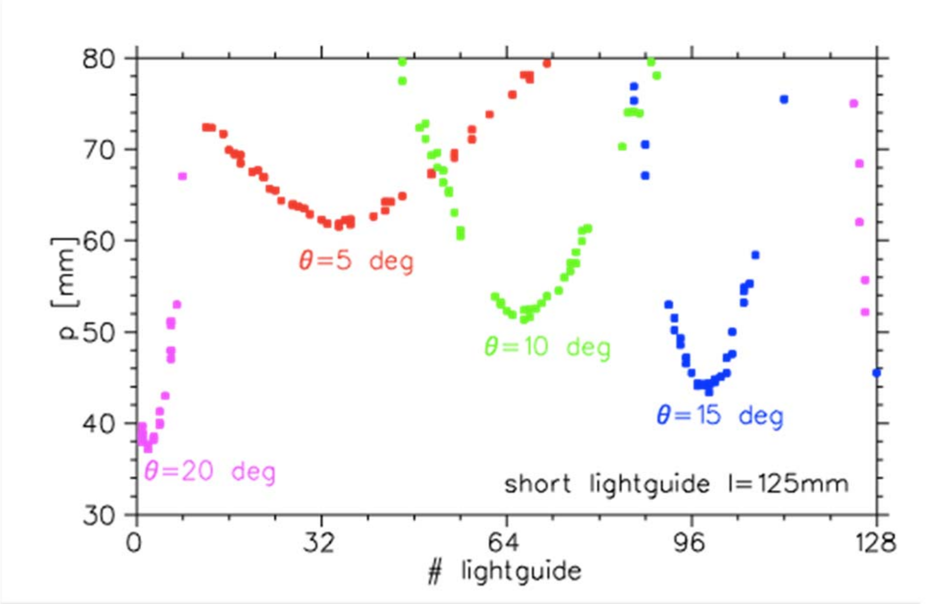
- Direct measurement of Cherenkov angle
  → need expansion region
- Design of expansion region = light guide
  compromise between compact size and
  performance with given MCP-PMT size
- Transition from fused silica
  to LiF and back has two-fold
  prism effect and mitigates dispersion

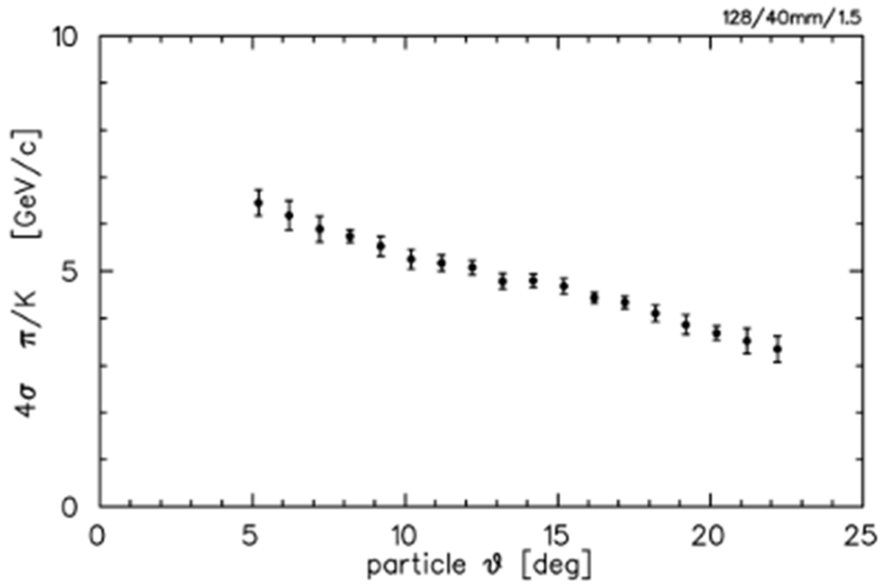




PANDA FOCUSING DISK DIRC

- Cherenkov images: pattern in θ/φ space.
- θ will be measured by PMT.
- φ is given by the light guide number.
- Excellent π/K separation.





FOCUSING DISK DIRC

Focusing Disk DIRC for WASAatCOSY:

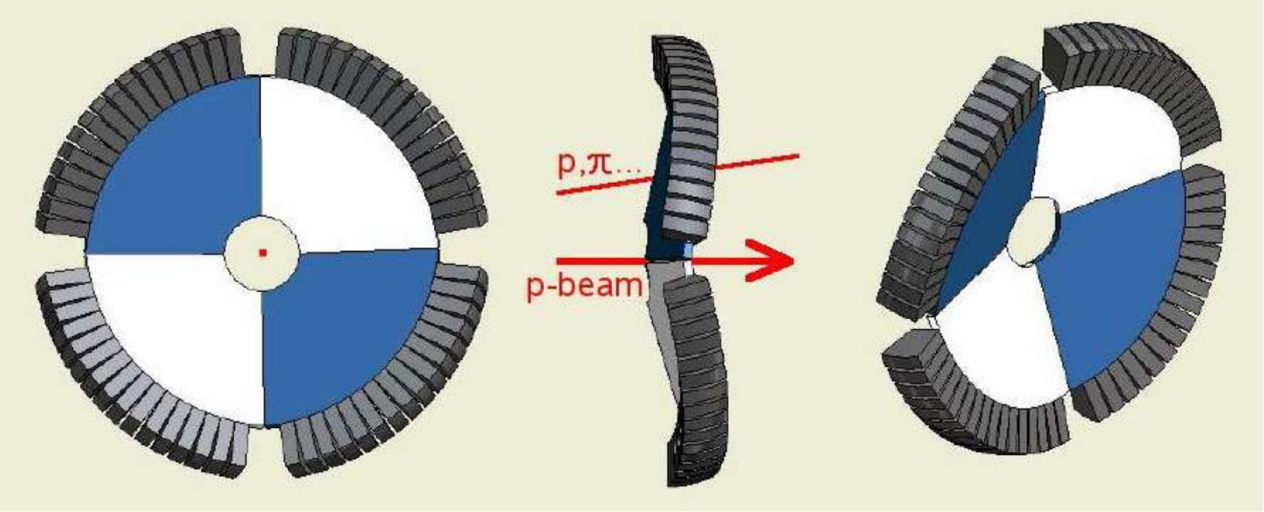
K. Föhl
2009 JINST 4 P11026

WASA experiment currently running at COSY in FZ Jülich, Germany.

Upgrade to detector to measure β of high-momentum tracks in forward direction.

Proposed FDD with inclined quarter segments *(to improve Cherenkov photon yield)*

→ CEARA design



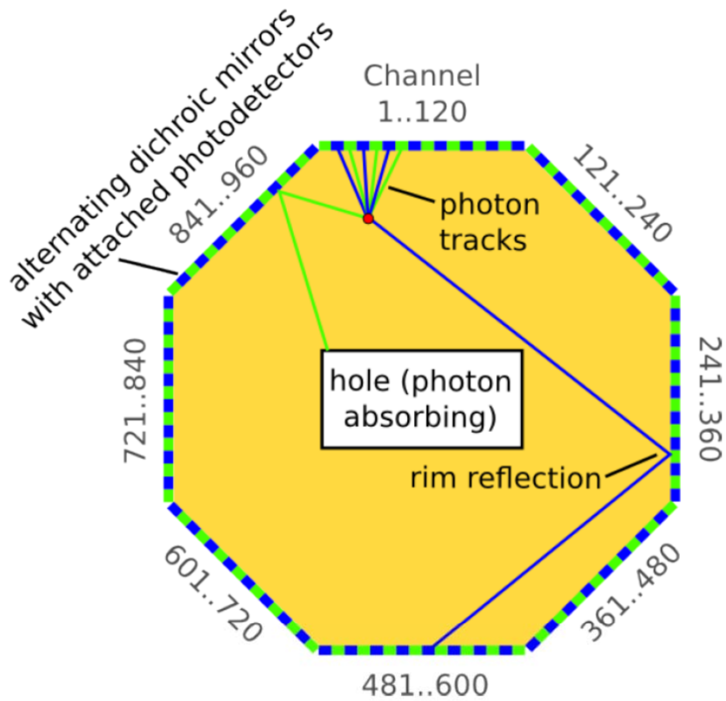
Lower radiation load at WASA than at PANDA, plan to use acrylic glass radiator.

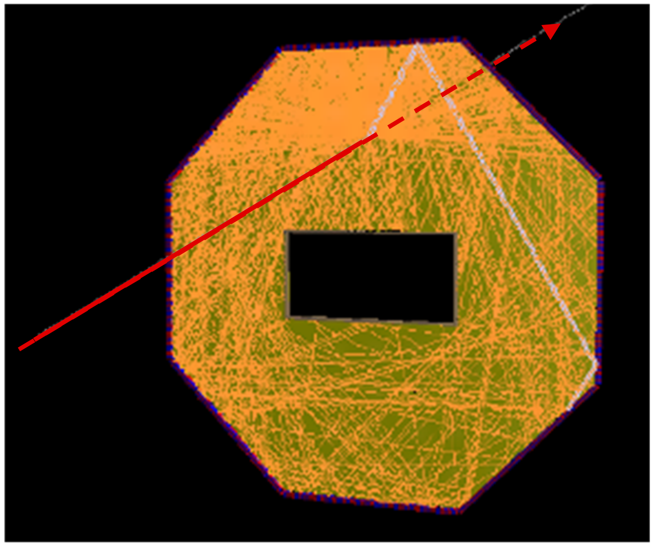
Synergy with PANDA

→ Real-experiment prototype validating essential design parts of Disk DIRC.

PANDA TIME-OF-PROPAGATION DISK DIRC

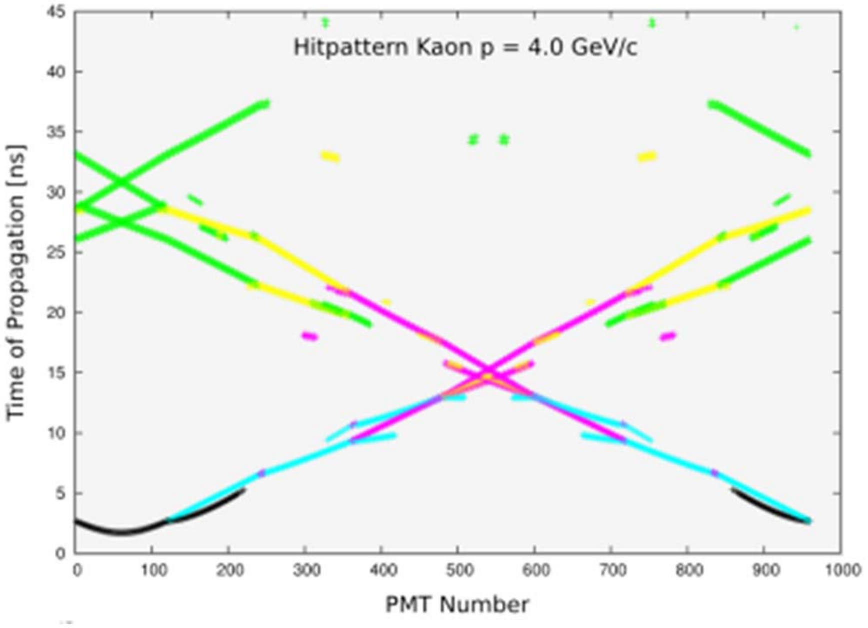
- Reconstruction in 1D+t.
- Indirect measurement of Cherenkov angle using time-of-propagation (TOP) and photon propagation angle in disk.
- Requires photon path reconstruction and fast single-photon timing $\sigma_t < 50\text{ps}$
- Dichroic mirrors to select wavelength band and to increase light path
(relative error drops with increasing path length)
- Approx. 1000 R/O channels.

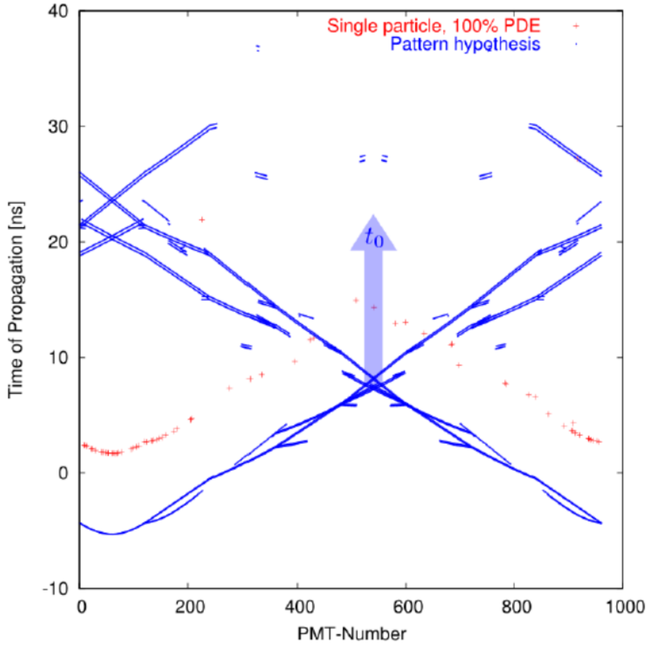


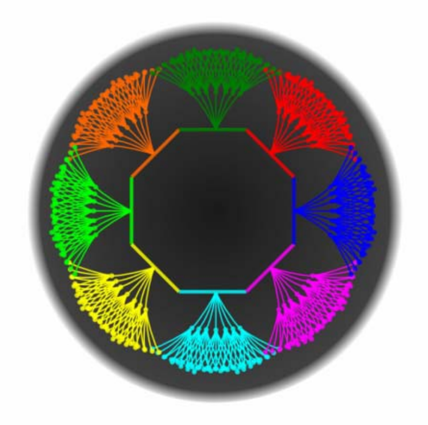


PANDA TIME-OF-PROPAGATION DISK DIRC

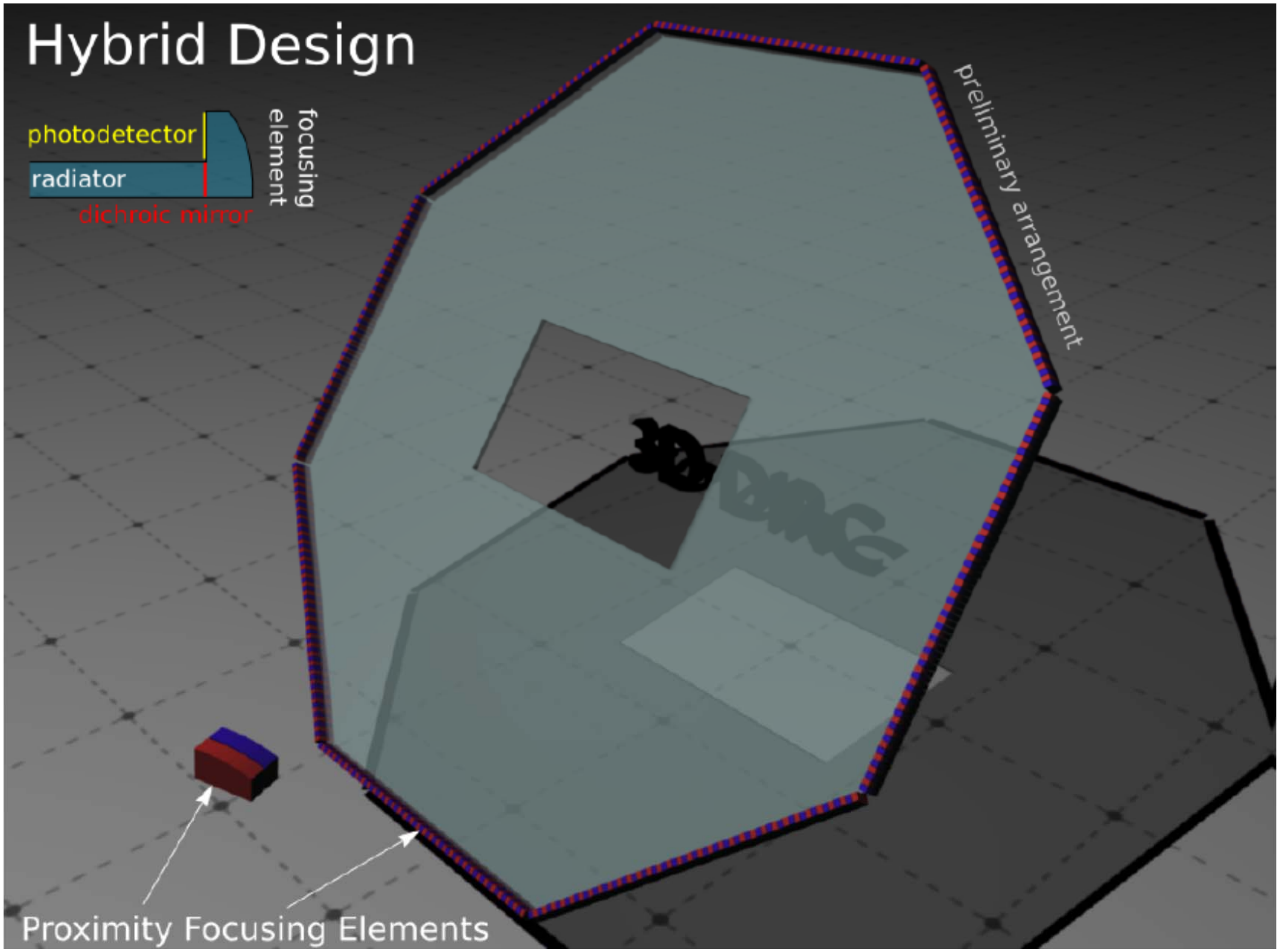
- Cherenkov images: pattern in TOP/φ space (φ given by PMT pixel number).
- Use first arriving photons to determine event (start) time t_0.
- Consider all photon paths up to 4 rim reflections for particle hypothesis test.
- Robust reconstruction method required to deal with multiple tracks and backgrounds.







PANDA HYBRID DISK DIRC



Possible hybrid design combining best elements of both Disk DIRC designs.

PANDA R&D AND PROTOTYPES

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
last month 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, and DESY since 2008.

RADIATOR PRODUCTION

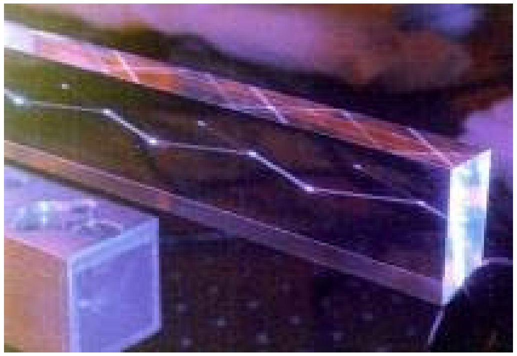
Production of large pieces (bars, plates, disk segments), mechanical tolerances on flatness,
squareness and parallelism with optical finish and sharp corners.
→ difficult, expensive, few qualified vendors worldwide.

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.

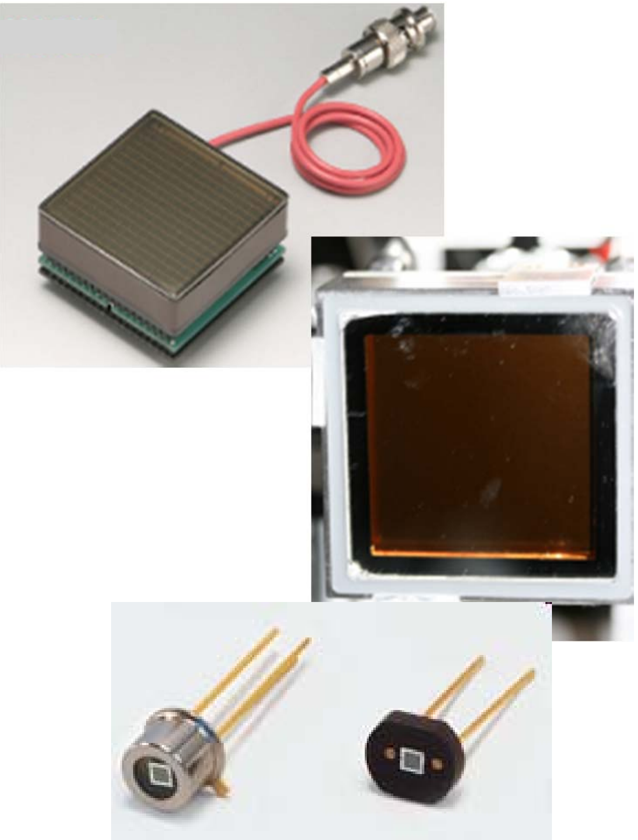
Have started discussions with potential vendors in Europe and USA,
obtained first prototype bar samples, measuring surfaces and angles at GSI.



PHOTODETECTORS

Asking a lot of fast compact multi-pixel photon detectors

- Single photon sensitivity, low dark count rate;
- Reasonably high photo detection efficiency;
- $\sigma_{TTS} = 50$ ps ... 100−200 ps;
- Few mm position resolution;
- Operation in 1-2 T magnetic field;
- Tolerate rates around 1 MHz/cm^{2};
- Long lifetime: > 1-10 C/cm^{2}/yr at 10^{6} gain.



No currently available sensor matches all criteria;

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

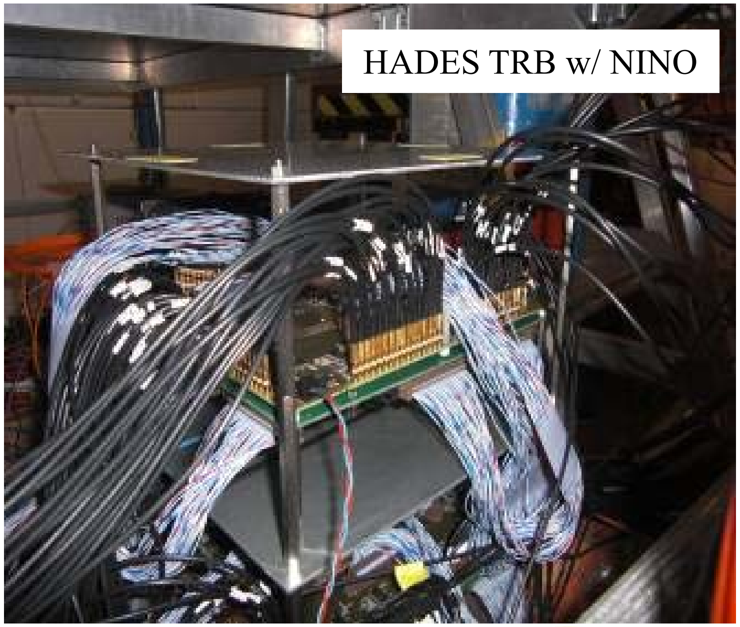
Testing detectors and readout electronics with DIRC prototypes in test beams

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

READOUT ELECTRONICS

Electronics design demanding

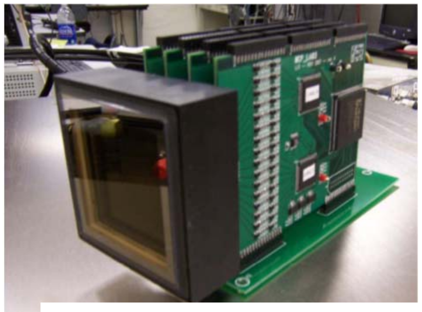
- Signal rise time typically few hundred picoseconds.
- 10-100x preamplifiers needed.
- High bandwidth 500MHz – few GHz (optimum bandwidth not obvious).
- Pulse height information required for 50 ps timing (time walk correction),
  also desirable for 100-200 ps timing.
  ADC / time over threshold / waveform sampling / ...
- PANDA will run trigger-less.
- Tested HADES TRB board with NINO TOF add-on
  in GSI test beam in 2009,
  plan to test other candidates in the future
  in beam test and picosecond laser setup.
  (GET4 (GSI), DRS4 (PSI), BLAB (Hawaii),
  USB-WaveCatcher (Saclay), ...)
- Significant development effort ahead.


HADES TRB w/ NINO

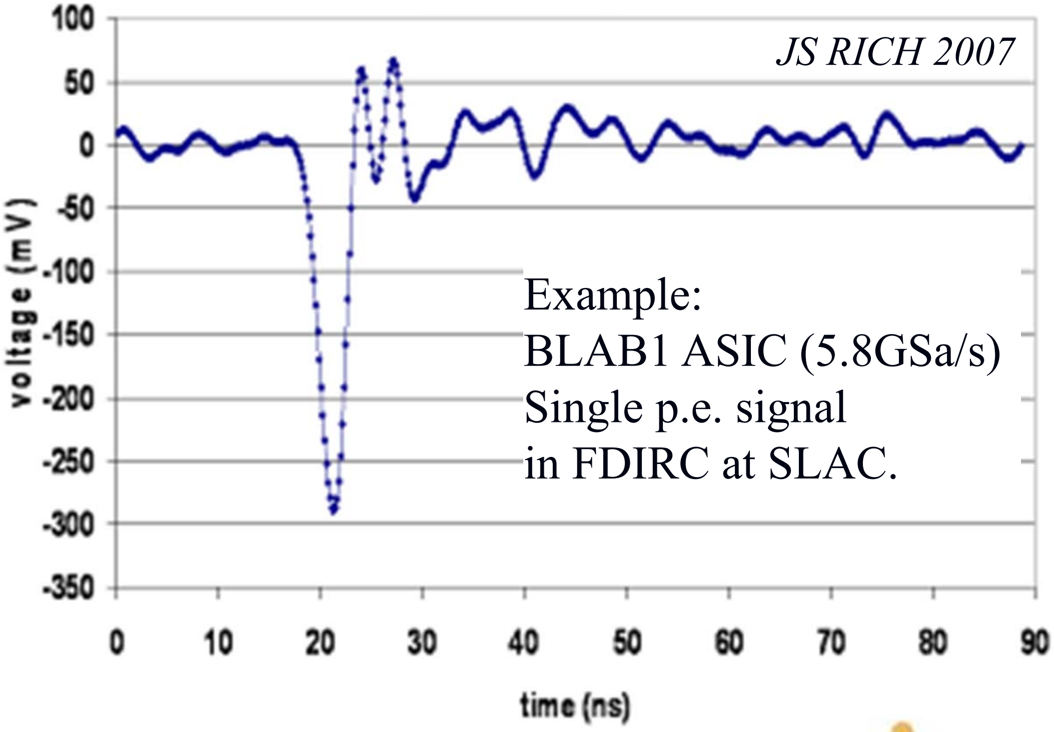
READOUT ELECTRONICS

Electronics design demanding

- Waveform sampling very attractive for picosecond timing, access to detailed signal information, ability to apply digital filters to clean up signal.
- Not clear if waveform sampling works in trigger-less PANDA environment will need excellent zero suppression.
- Available chips: DRS4 (PSI), BLAB3 (Hawaii)


BLAB2 assembly w/ MCP-PMT


DRS4 evaluation board



JS RICH 2007

Example:
BLAB1 ASIC (5.8GSa/s)
Single p.e. signal
in FDIRC at SLAC.

PANDA DIRC SUMMARY

PANDA target spectrometer design includes two DIRC detectors for hadronic PID:

Barrel DIRC: fast focusing DIRC inspired by BABAR-DIRC;

Endcap Disk DIRC: fast plate DIRC, first if its kind, several viable designs.

R&D activities: 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 1-10 C/cm^2/yr and 1-2 T.
  → Discussing solutions with industry, testing prototypes in lab.
- Cherenkov radiator (bars, disk) 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.

FDIRC FOR ITALIAN SUPERB

Focusing DIRC (FDIRC):

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

Important constraint:

BABAR DIRC bar boxes will be reused.

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

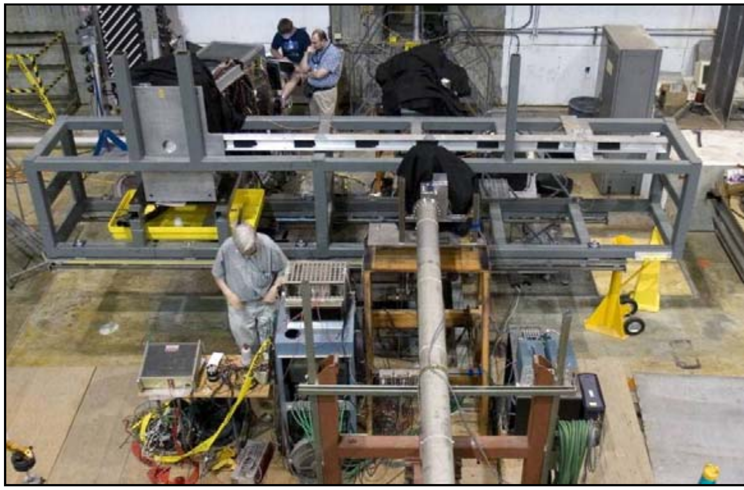
→ decrease size of expansion volume (main source of background in BABAR DIRC).

Smaller expansion volume requires smaller pixels and focusing optics.

R&D at SLAC started in 2001,

FDIRC prototype in SLAC test beams:

- proof of principle;
- good performance from MCP-PMTs and MaPMTs;
- mirror focusing successful;
- fast timing allowed first correction of chromatic dispersion in a RICH detector.



FDIRC FOR ITALIAN SUPERB

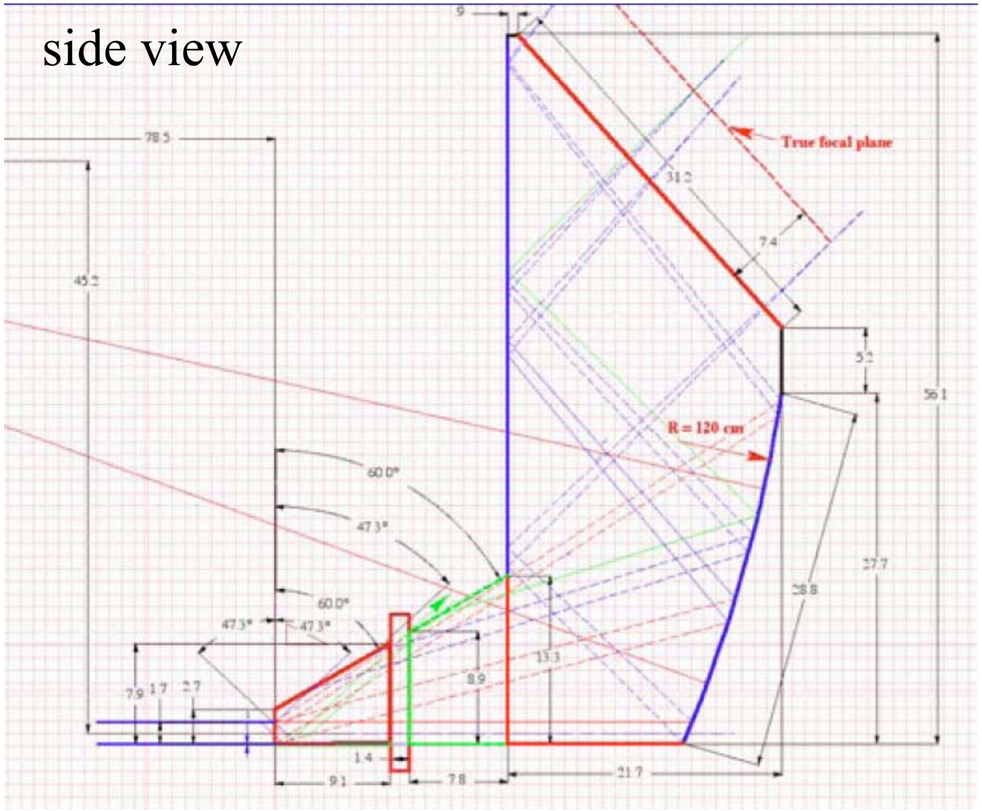
Focusing DIRC (FDIRC) Design:

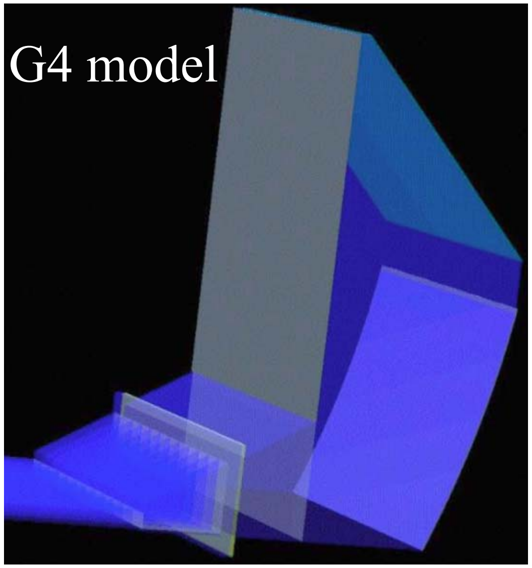
large synthetic fused silica block (Corning) for expansion region and focusing.

“Camera” approach:

each of the 12 bar boxes read out with one optically isolated block/readout module.

Additional wedge required to image all photons on cylindrical mirror of focusing block.



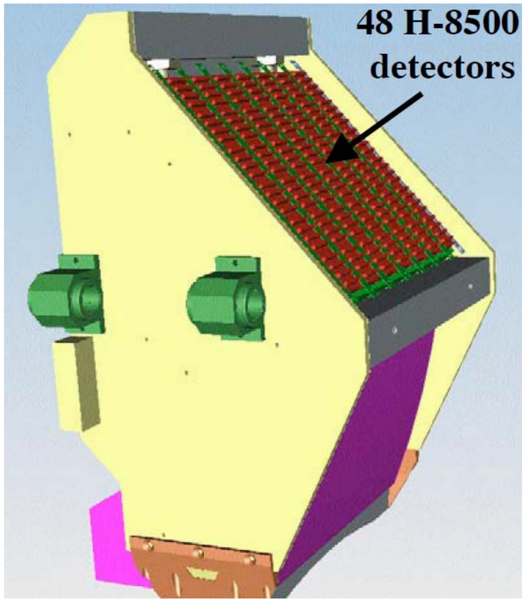


Figures from J. Va’vra RICH2010

FDIRC FOR ITALIAN SUPERB

Photodetector:

12 arrays of 6*8 MaPMTs (HPK H8500) → 18,432 pixels.



camera design model

Readout Electronics:

TDC/ADC information for every photon.

Bottom line:

Conservative, robust design;

10x better timing resolution than BABAR DIRC;

25x smaller expansion volume than BABAR DIRC;

Cherenkov angle determined from 2D spatial coordinates;

Time primarily used to correct chromatic dispersion.

Eagerly awaiting project approval to proceed with large prototype.

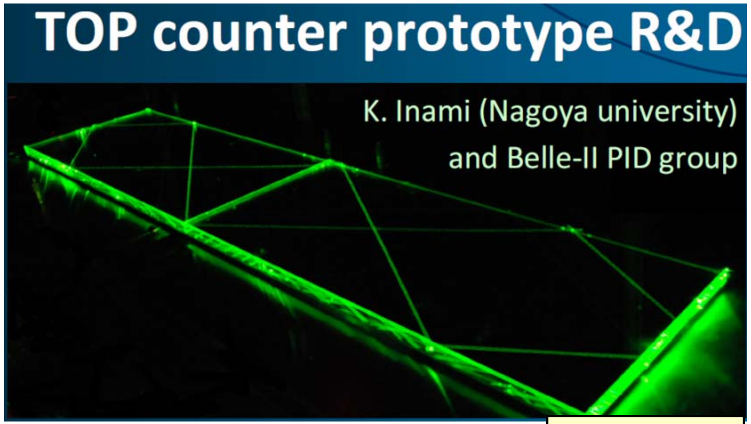
BELLE II TOP COUNTER

For upgrade of Belle detector for Japanese Super B project;

replace Aerogel Cherenkov Counter in barrel with time-of-propagation (TOP) DIRC;

design goal 4σ π/K separation up to 4 GeV/c;

use plates (~40 cm x 250 cm), synthetic fused silica.



K. Inami
RICH2010

Initial design was pure 2D TOP detector

high precision timing + one space coordinate

(linear array or PMT pixels – HPK SL10).

Recent addition of alternative 3D designs:

segmentation of barrel into a "TOF zone" and "TOP zone"

with focusing optics and second space coordinate (X, Y of hit, 4x4 version of SL10);

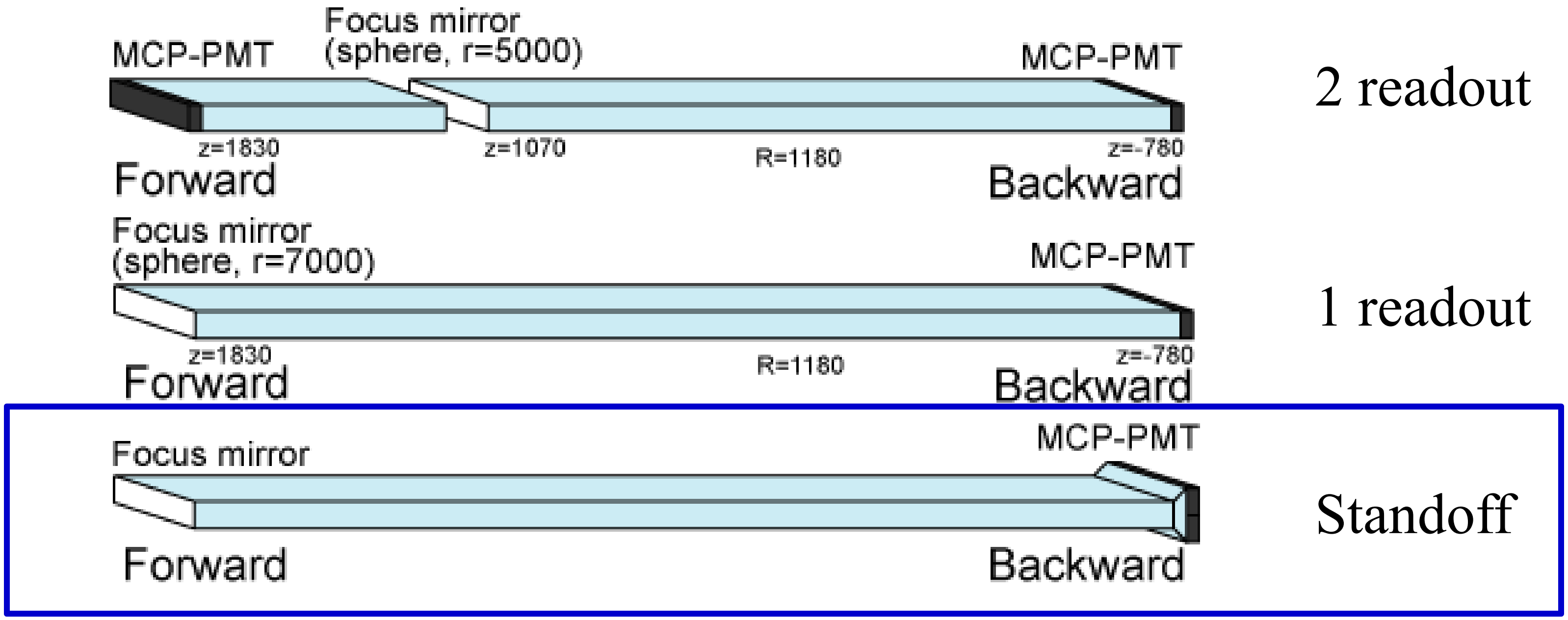
small fused silica expansion volume with 4x4 version of SL10.

3D has many advantages, redundancy and robustness among them.

BELLE II TOP COUNTER

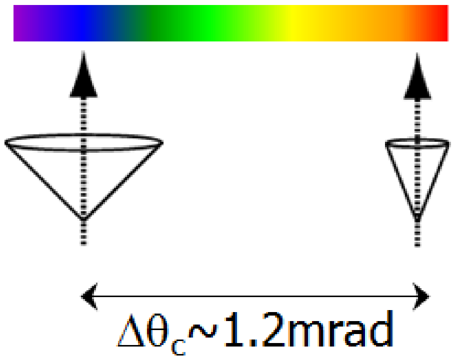
K. Inami
Giessen 2009
RICH2010

- Better performance and robustness for additional fluctuation
  - Start timing T_0, tracking resolution, beam BG etc.
- Simple structure
  - Less systematic error for analysis
  - (Cost reduction)
- TOP with small (10 cm) standoff block *(new baseline design since mid-May 2010)*
  - Larger readout plane
  - Relax the complicated ring image
  - Reduce the occupancy of PMT hit channels

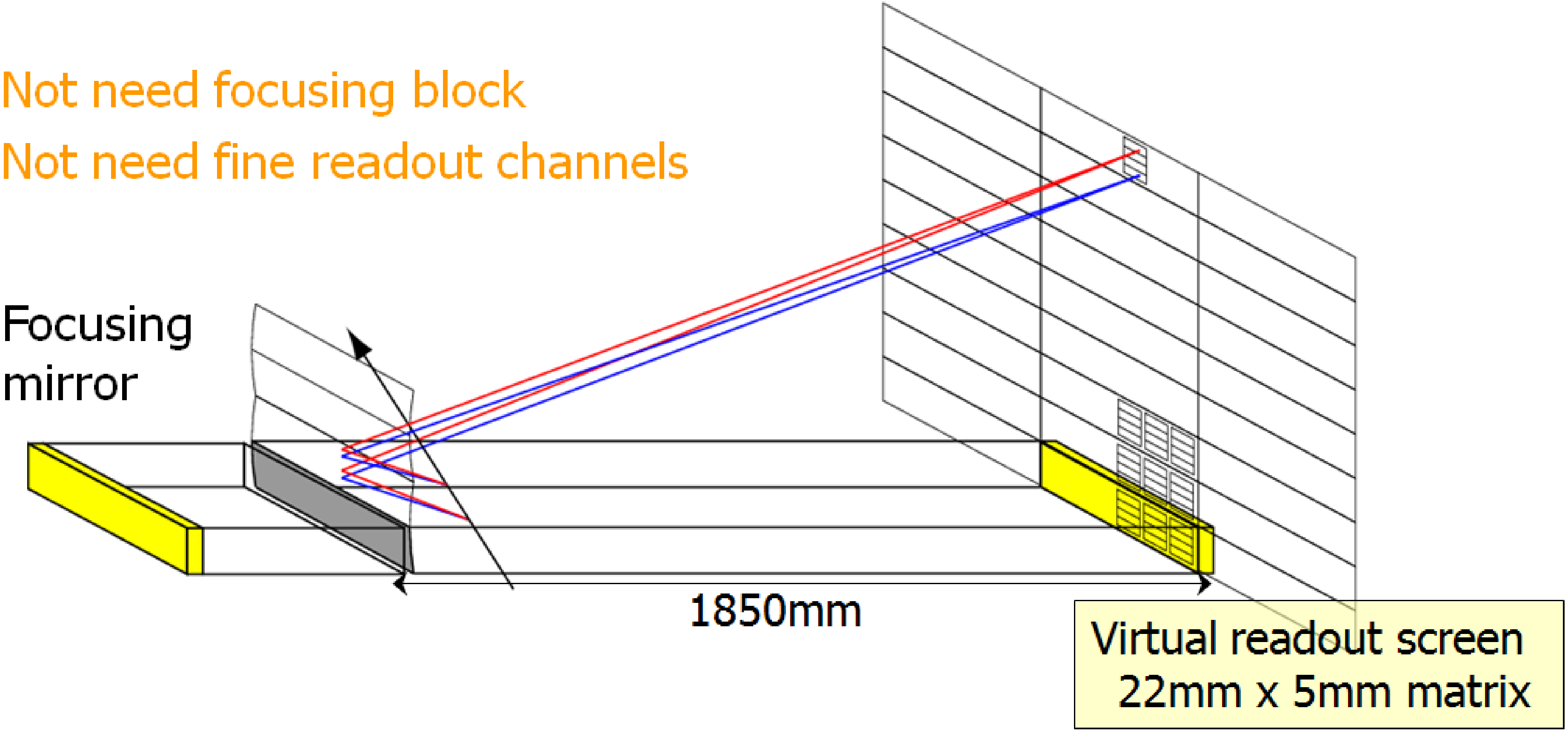


BELLE II TOP COUNTER

- $\Delta\theta_c$~1.2mrad over sensitive λ range
- → Δy~20mm (~quartz thickness)
  - We can measure λ dependence and obtain good separation even with narrow mirror and readout plane, because of long propagation length.



  - Not need focusing block
  - Not need fine readout channels



K. Inami
Giessen 2009
RICH2010

Summary

- R&Ds of TOP counter are in progress!
- Prototype developments
  - Quartz radiator
    - Enough quartz quality for single photon propagation
  - Multi-anode MCP-PMT
    - Developing with Hamamatsu photonics
    - Very good TTS (<40ps) and sufficient efficiency and gain
- Performance test with electron beam
  - Proper ring image, number of detected photons (16 photons)
  - Time resolution as expected by simulation

    → Confirmed level of chromatic dispersion effect
- MCP-PMT lifetime for Belle-II
  - Obtained sufficient lifetime (>3 Belle-II years) with improved version

K. Inami

RICH2010

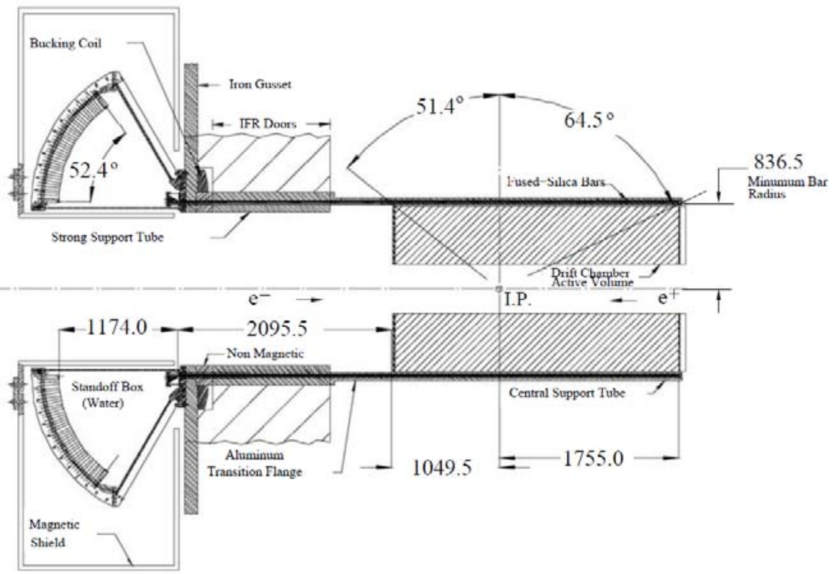
DIRC Components – a “shopping list”

- Radiators
  - Synthetic fused silica is radiation hard, readily available.
    Fused quartz or acrylic glass may be alternative for low-radiation environment.
  - BABAR DIRC demonstrated: bars can be fabricated by industry (at a price)
    using standard pitch polishing process (InSync Inc. and Zygo Corp. still interested).
    Belle II are testing the water for plate production (Zygo Corp.).
  - Cherenkov image quality remains good after 10m+ photon path and 200+ reflections.
  - After ~10 years in bar box no evidence for deterioration of bar surfaces (SuperB).
    Keep bar surfaces clean during construction, constant flow of dry nitrogen in bar box.
- Expansion volume (EV)
  - Main source of background for BABAR DIRC. Water tank (6000 l) outside magnet yoke.
  - SuperB FDIRC will use 25x smaller EV made of solid fused silica outside yoke.
  - PANDA Barrel DIRC plans to use small EV box filled with mineral oil inside yoke.
    (Fallback option to place EV outside yoke.)
  - Belle II TOP plans to use very small EV made of fused silica inside yoke.

DIRC Components – a “shopping list” (continued)

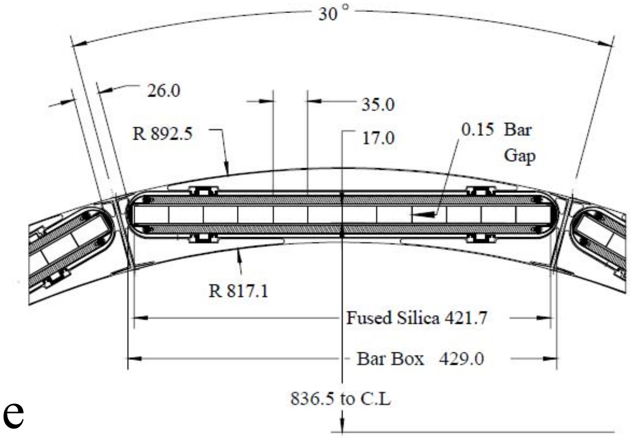
- Focusing optics
  - – BABAR DIRC had large EV compared to small bar thickness, pinhole focusing worked.
  - – Smaller EV will require focusing.
    FDIRC will use mirror focusing, PANDA DIRC plans either mirror or lens focusing, Belle II has mirror option.
- Photon detector
  - – Traditional PMTs worked well outside B field, submersed for 10+ years in water.
  - – New fast, multi-pixel detectors open new design options.
  - – Can keep sensors inside magnetic field, simplify overall detector design.
  - – Fast timing allows (partial) correction of chromatic dispersion or reconstruction of the Cherenkov angle from timing plus single space coordinate.
  - – Remaining issues: MHz+ rate capability at modern accelerators, ageing due to photocathode damage from ion backflow (MCP-PMTs), dark noise (GAPDs), operation in high magnetic fields (MaPMTs).
  - – Industry making progress: HPK H8500/H9500, Burle XP85012/85112, HPK SL10, …

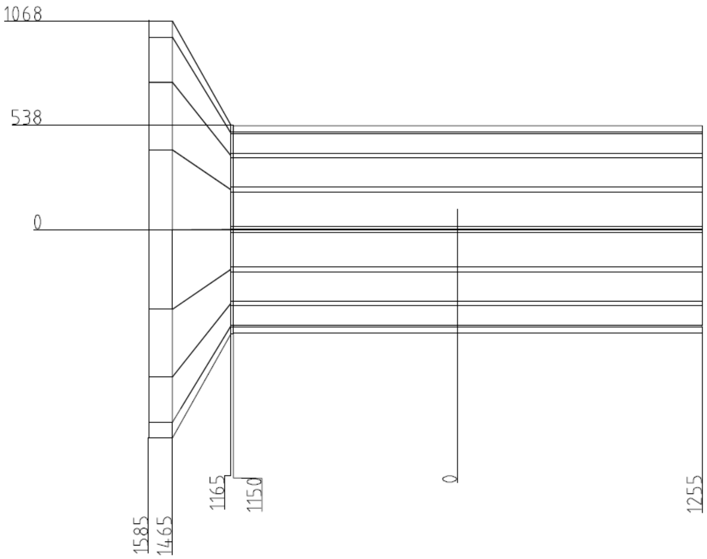
DIRC DIMENSIONS



BABAR DIRC:

84 cm radius
8 cm radial incl. supports
19% radiation length
at normal incidence
5 cm bar box thickness
~120 cm expansion distance





Some dimensions scale with DIRC radius

PANDA Barrel DIRC:

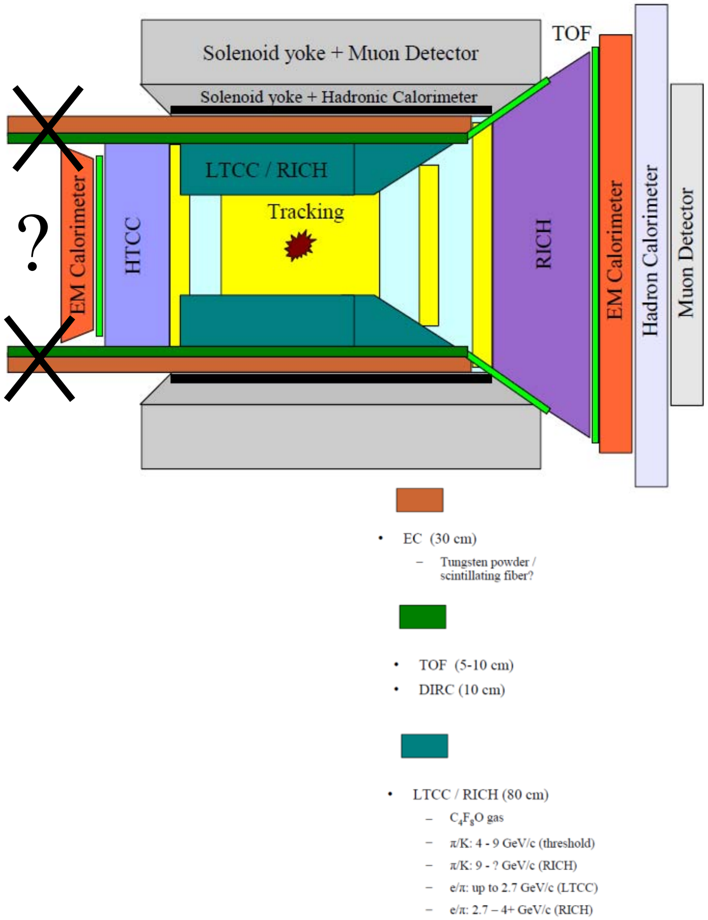
~50 cm radius
~5 cm radial thickness
~4 cm bar box thickness
~30 cm expansion distance

DIRC GEOMETRY FOR EIC DETECTOR

New focusing approaches and magnetic field tolerant photon detectors may make it possible to incorporate a DIRC into a much smaller available space.

Belle II TOP DIRC needs no (or very small) expansion volume (EV), compact readout.

PANDA Barrel DIRC design: EV 30 cm deep + room for readout, ~50 cm high.

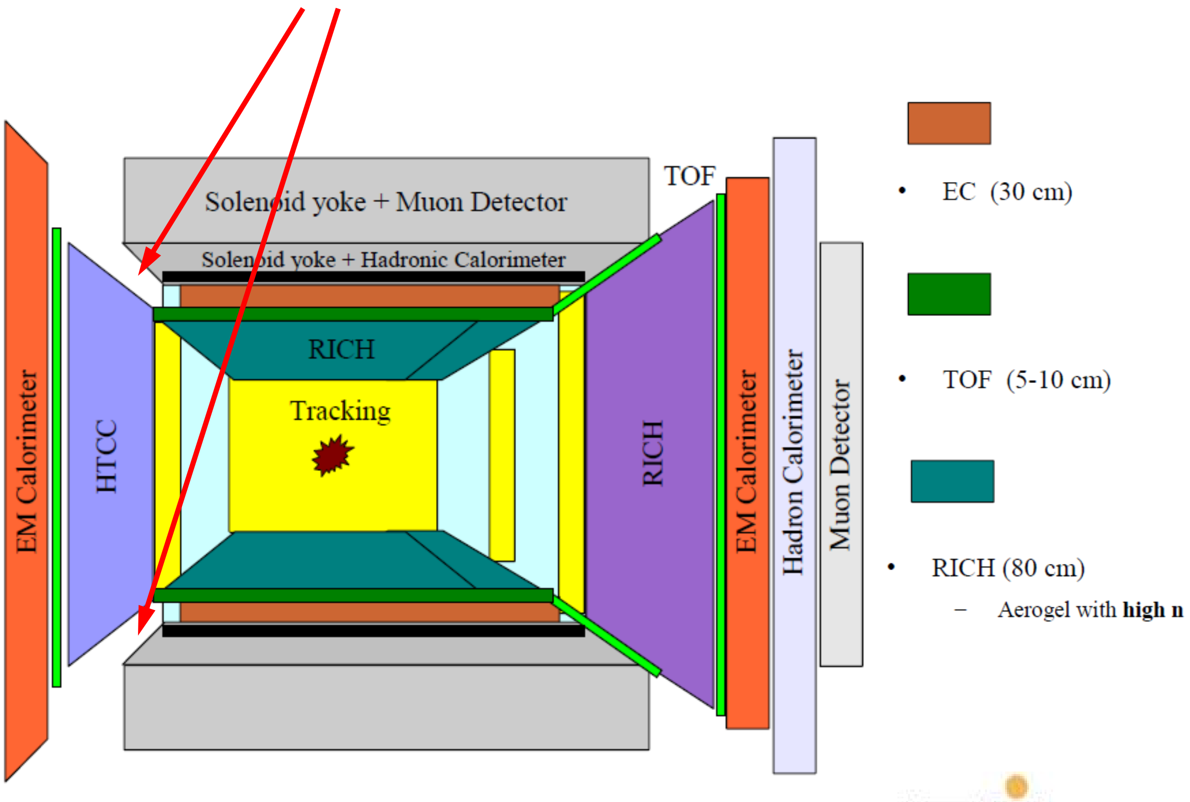


🟧
- EC (30 cm)
  - Tungsten powder / scintillating fiber?

🟩
- TOF (5-10 cm)
- DIRC (10 cm)

🟦
- LTCC / RICH (80 cm)
  - C_4F_8O gas
  - π/K: 4 - 9 GeV/c (threshold)
  - π/K: 9 - ? GeV/c (RICH)
  - e/π: up to 2.7 GeV/c (LTCC)
  - e/π: 2.7 – 4+ GeV/c (RICH)

Fit readout and small expansion volume in here?

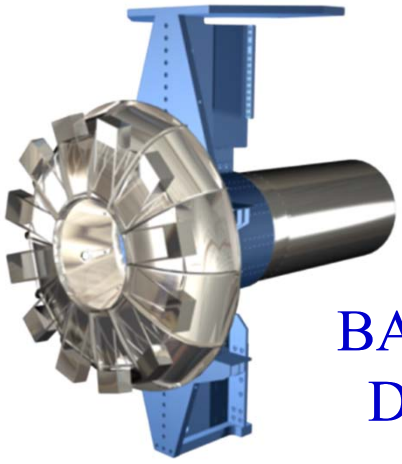


🟧
- EC (30 cm)

🟩
- TOF (5-10 cm)

🟦
- RICH (80 cm)
  - Aerogel with **high n**

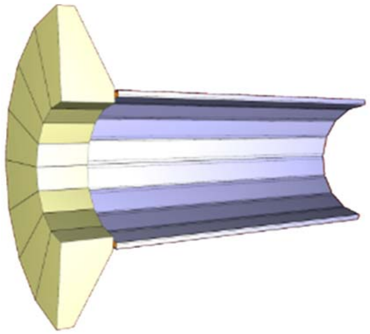
DIRC COUNTER SUMMARY

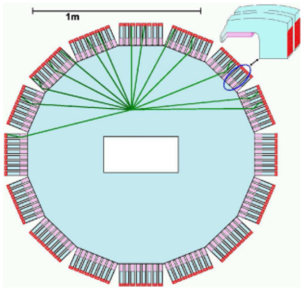


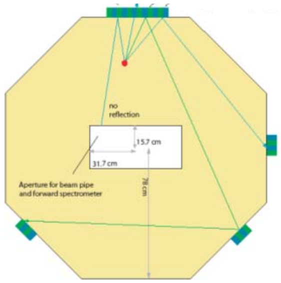
First of its kind – excellent performance, easy to operate, essential ingredient in most BABAR publications.

BABAR DIRC

PANDA DIRCs





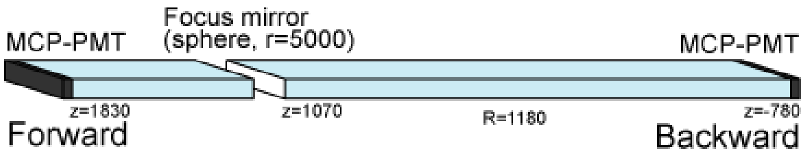


Barrel DIRC: focusing, compact version of BABAR DIRC.

Disk DIRC: first endcap DIRC, several viable designs.

… plus CEARA @ WASA
TORCH @ LHCb, …

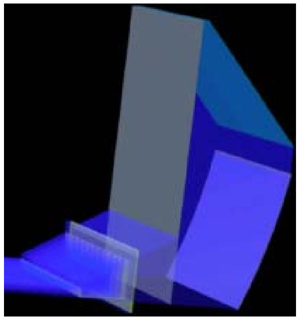
Belle II TOP



First DIRC with plate geometry.

Cherenkov angle from excellent timing plus 1 or 2 space points.

SuperB FDIRC



Focusing optics and fast timing using existing BABAR DIRC bars.

Cherenkov angle from space points, timing for chromatic correction.