THE BARREL DIRC FOR THE PANDA EXPERIMENT AT FAIR

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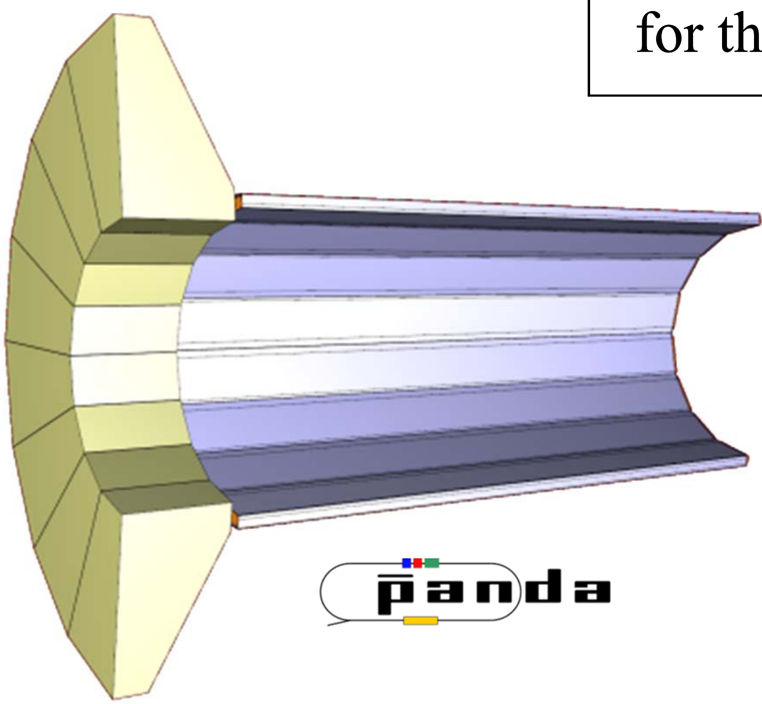
for the PANDA Cherenkov Group



- The DIRC Concept
- The PANDA Experiment
- Barrel DIRC Design
- Prototype and R&D

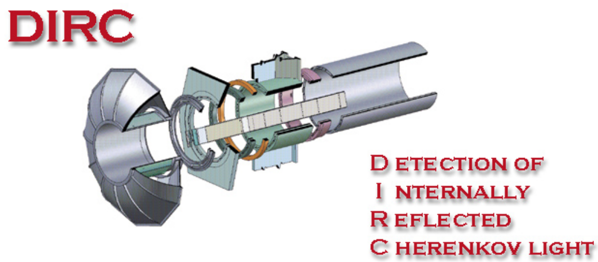
Detection of Internally Reflected Cherenkov Light

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

Used for the first time in BABAR experiment at SLAC for hadronic particle ID ¶:

- Eight+ years of experience in PEP-II/BABAR B-factory mode:
  DIRC very reliable, robust, easy to operate.
- Quickly achieved particle identification performance close to design values.
- DIRC played significant role in almost all BABAR physics analyses published to date.

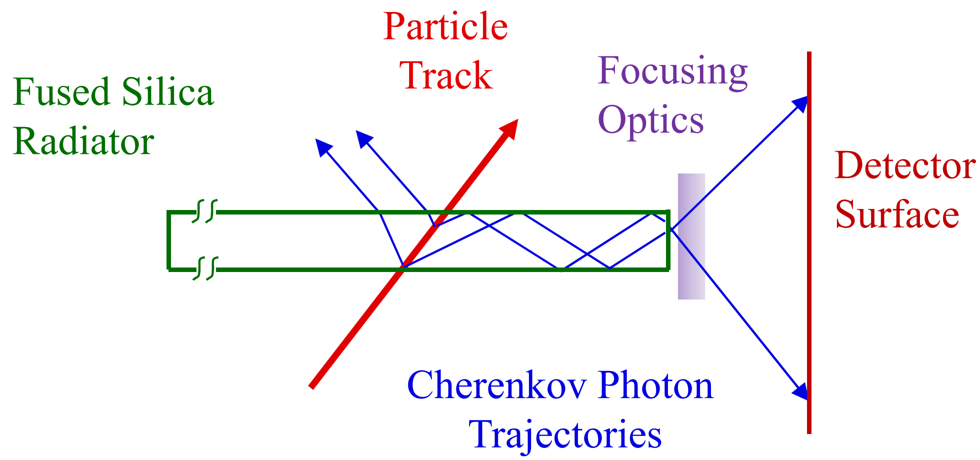
Recent improvements in photon detectors have motivated R&D efforts to improve the successful BABAR-DIRC and make DIRCs interesting for future experiments.



§ *B.N. Ratcliff, SLAC-PUB-6047 (Jan. 1993)*
¶ *Nucl. Instr. Methods A 538 (2005) 281-357*

PANDA DIRC CONCEPT

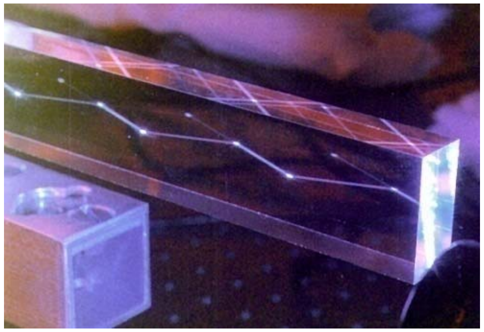
- Charged particle traversing radiator with refractive index ($n \approx 1.47$) with $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle $\cos \theta_c = 1/\beta n(\lambda)$.

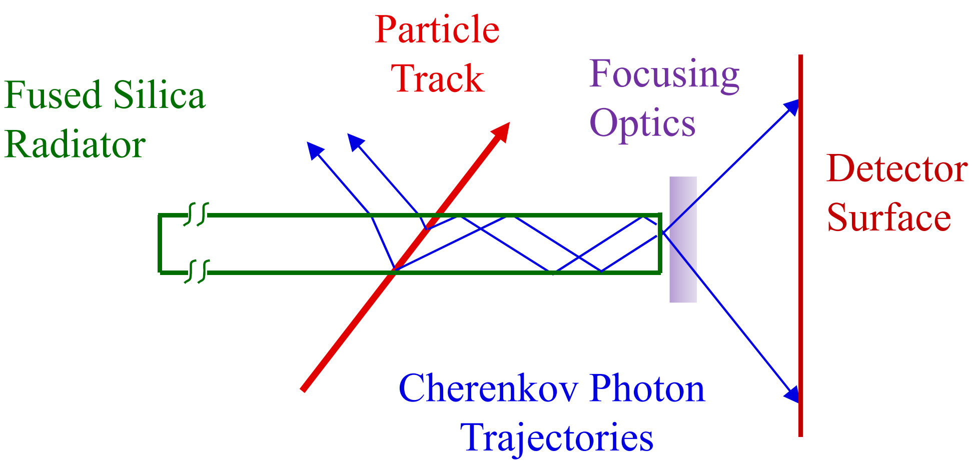


- Some photons are always totally internally reflected for $\beta \approx 1$ tracks.

- Radiator and light guide: long rectangular bar made from Synthetic Fused Silica ("Quartz")

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





BABAR DIRC PMT Plane

- Photons exit radiator via focusing optics (lenses or mirror) 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, $t_{propagation}$ 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

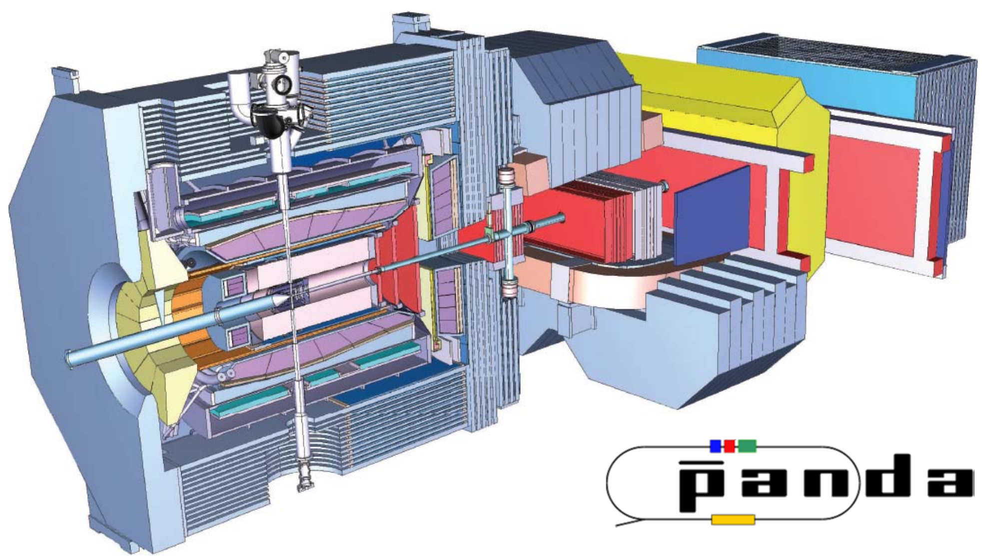
PANDA EXPERIMENT

PANDA: Anti-Proton ANnihilation at DArmstadt (450 physicists, 17 countries)
future experiment at FAIR facility at GSI
(German National Lab for Heavy Ion Research near Darmstadt)

FAIR Facility for Antiproton and Ion Research

High-intensity anti-proton beam on internal pellet/cluster target.

- Average production rate: 2×10^7/sec;
- Beam momentum: 1.5 ... 15 GeV/c;
- Luminosity up to 2×10^{32} cm^{-2}s^{-1}.



Study of QCD with Antiprotons

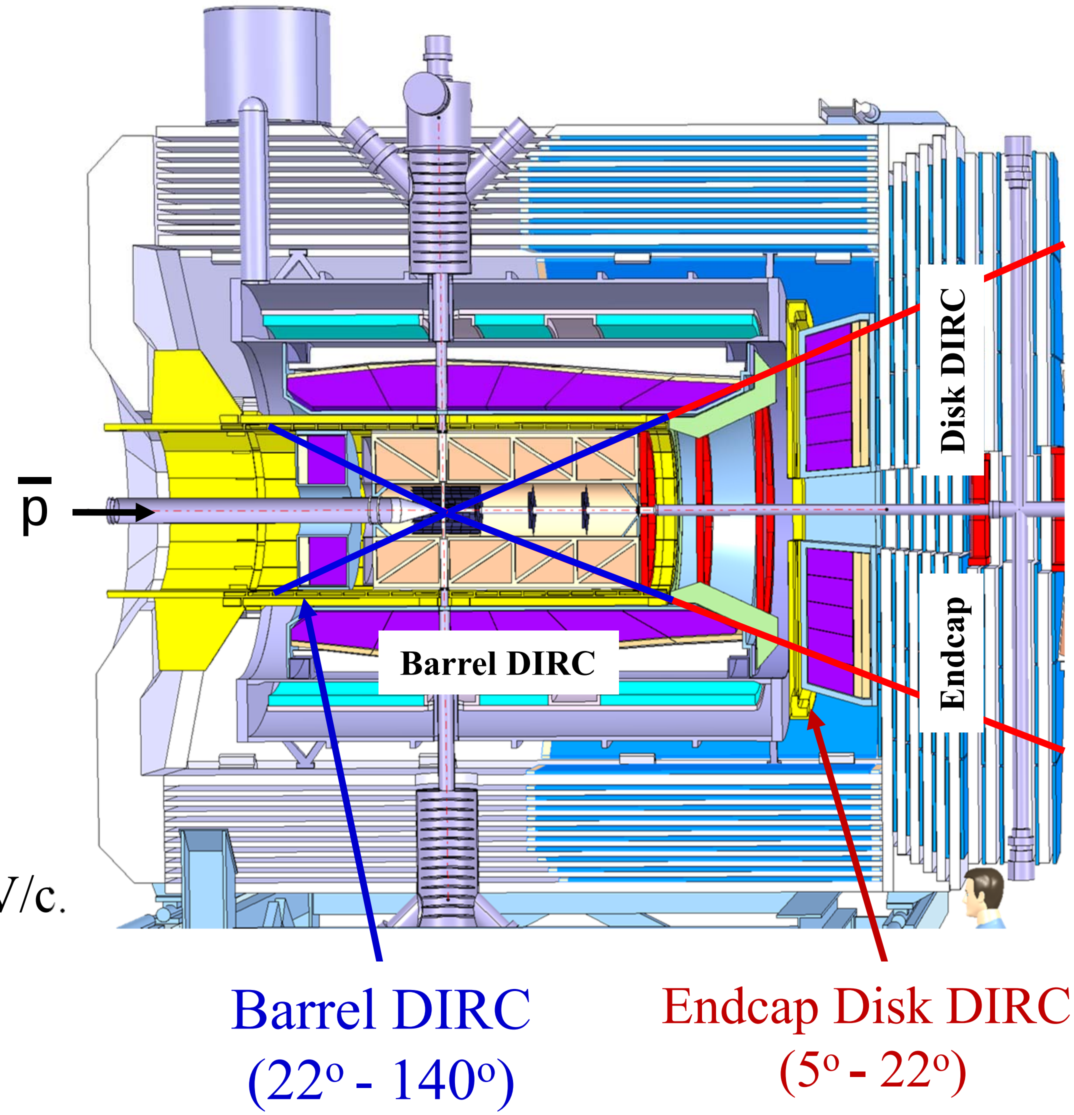
Charmonium Spectroscopy;
Search for Exotics; Hadrons in Medium;
Nucleon Structure; Hypernuclear Physics.

Particle identification essential

- Momentum range 200 MeV/c – 10 GeV/c.
- Several PID methods needed to cover entire momentum range.
- dE/dx, EM showers, Cherenkov radiation in forward & target spectrometer configuration.

DIRC detector advantages

- Thin in radius and radiation length.
- Moderate and uniform amount of material in front of EM calorimeter.
- Number of signal photons increases in forward direction.
- Fast and tolerant of background.
- Robust and stable detector operations.



PANDA includes two DIRC detectors

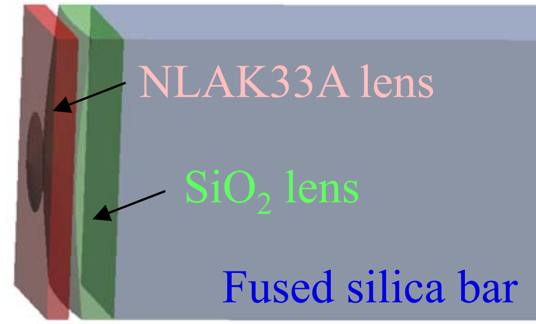
- Barrel DIRC – similar to BABAR DIRC with several improvements.
  PID goal: 3σ π/K separation for p<3.5 GeV/c.
- Novel endcap Disk DIRC.

Institutions currently involved

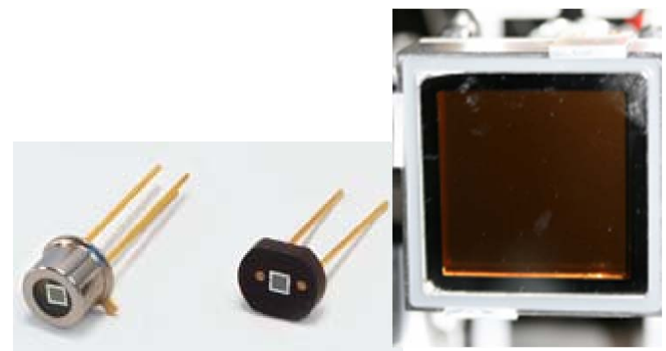
- Edinburgh, Erlangen, Dubna, Gießen, Glasgow, GSI, Vienna.

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

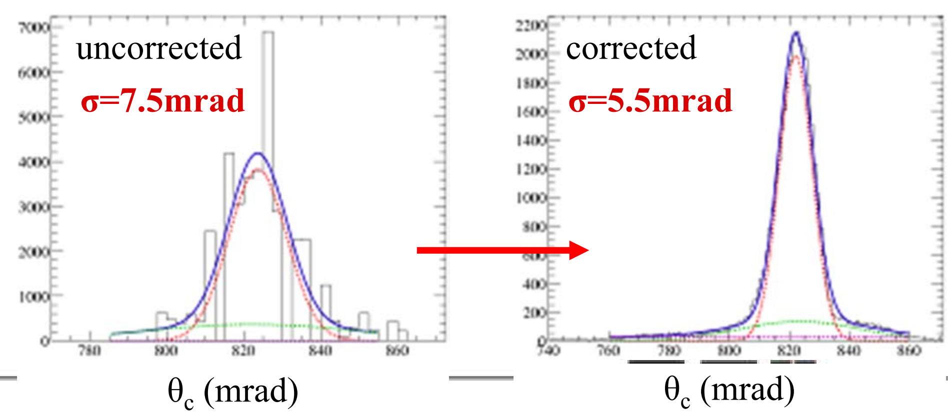
- Focusing optics: removes bar size contribution
  from Cherenkov angle resolution term.
  Lens doublet and/or mirror focusing on flat detector surface.



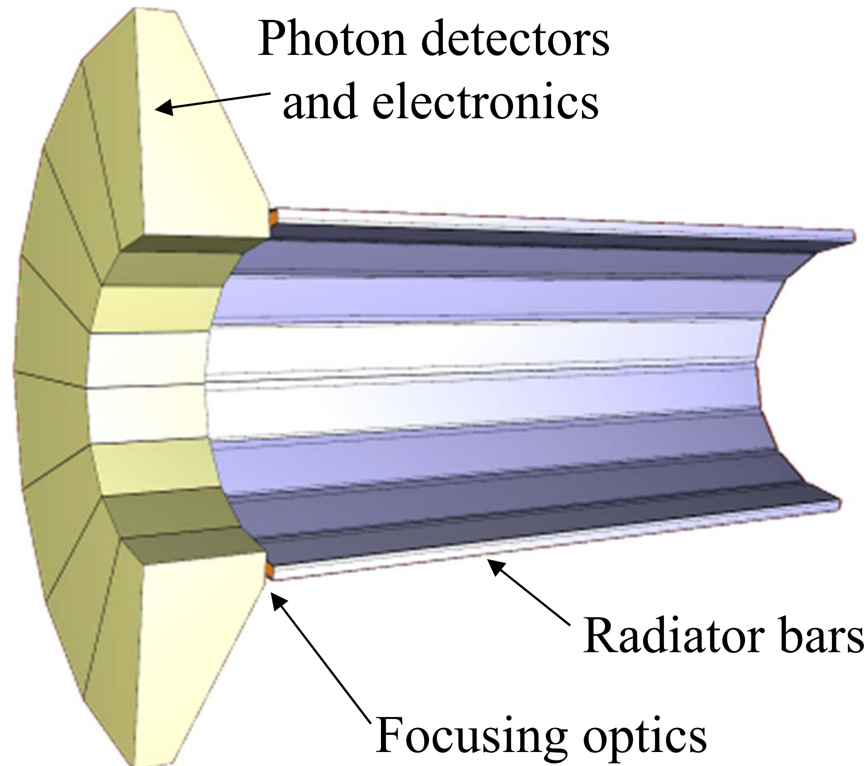
- Compact multi-pixel photon detectors:
  allows smaller expansion region, readout inside solenoid,
  makes DIRC less sensitive to background,
  simplifies detector design.
  MCP-PMTs, MAPMTs, gAPDs potential candidates.



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



Current PANDA Barrel DIRC baseline design:



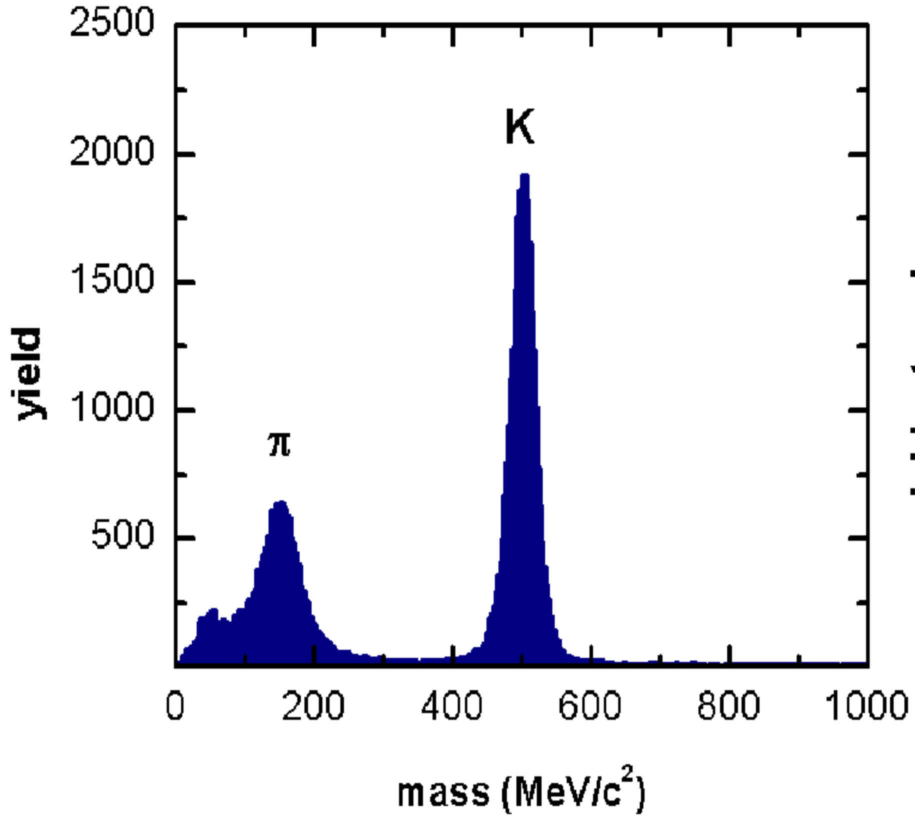
- 96 radiator bars, synthetic fused silica
  17mm (T) × 33mm (W) × 2500mm (L).
- Focusing optics: doublet lens system.
- Compact photon detector:
  array of MCP-PMT or Geiger-mode APD,
  total approx. 10,000 channels.
- Fast photon detection: MCP-PMT/gAPD plus
  fast TDC/ADC (ToT) electronics
  → 100-200 ps timing.
- 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:

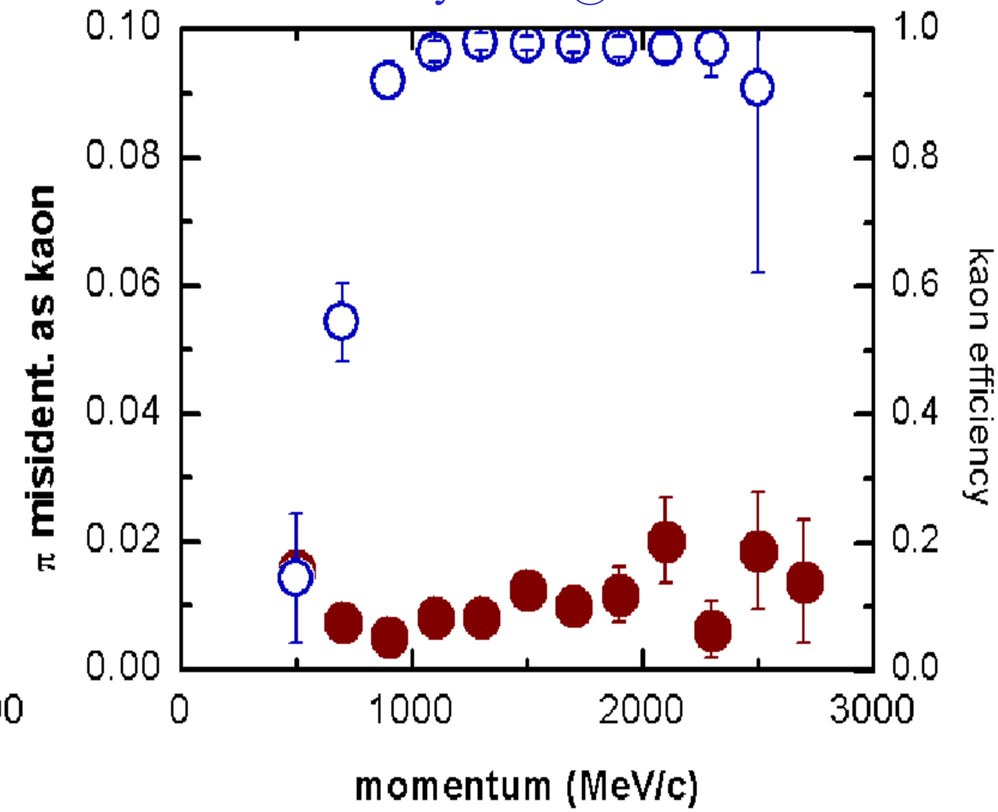
mirror focusing, radiator plates, photon detection outside magnetic field.

Expected PID performance example from simulation.

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



kaon efficiency 98% @ 2% π mis-ID



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

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.

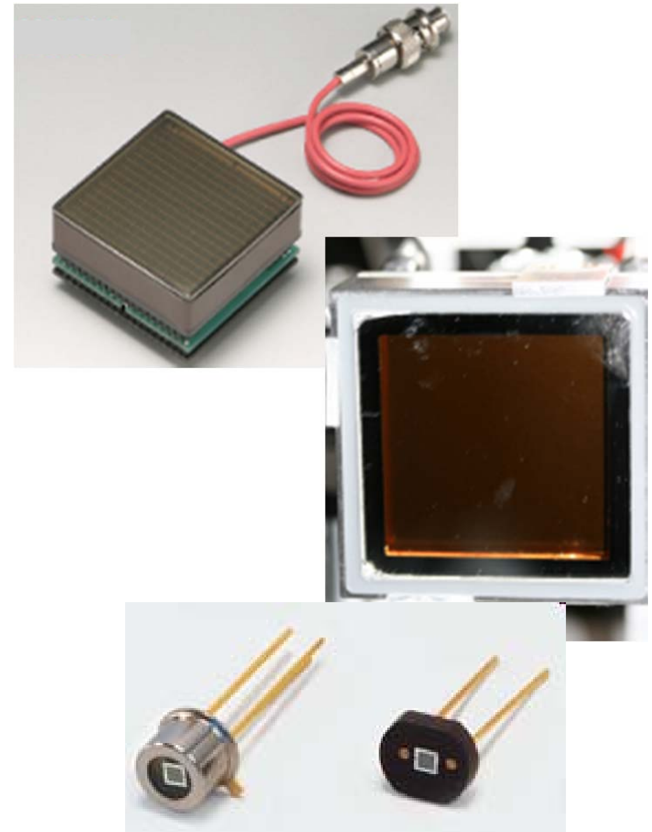
Multiple presentations on PANDA DIRC R&D projects at RICH 2010 (see proceedings): E. Cowie, D. Dutta, M. Hoek, A. Lehmann, C. Schwarz, J.S.

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

PHOTODETECTORS

Asking a lot of fast compact multi-pixel photon detectors

- Single photon sensitivity, low dark count rate;
- Reasonably high photo detection efficiency;
- σ_{TTS} = 100–200 ps;
- Few mm position resolution;
- Operation in 1 T magnetic field;
- Tolerate rates around 1 MHz/cm^2;
- Long lifetime: > 1 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.

PHOTODETECTORS

A. Lehmann, RICH 2010

	Barrel DIRC	Endcap DIRC	XP85012	R10754
Gain [*10^6]	> 0.5 @ 1 T	> 0.5 @ 2 T	barrel ok	endcap ok
Time resolution [ps]	< 100	< 50	37	32
Rate stability [MHz/cm^2]	0.2	2	> 1	> 5
Lifetime [C/cm^2/year]	~ 1	4 – 10	barrel in reach	w. prot. layer: maybe endcap in reach

- Latest models of MCP-PMTs fulfil most specifications for PANDA DIRC except lifetime.
- Recent developments have increased lifetime of MCPs significantly, but further improvements will be needed.

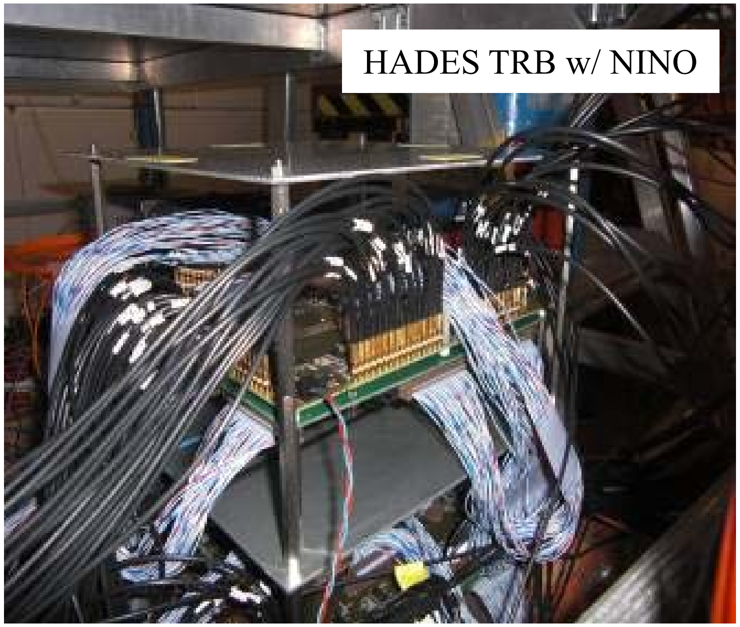
We have a fallback solution: extend barrel DIRC through magnet yoke and place MaPMT photon detector outside magnetic field (like BABAR).

Expensive solution that would have significant negative impact on rest of PANDA.

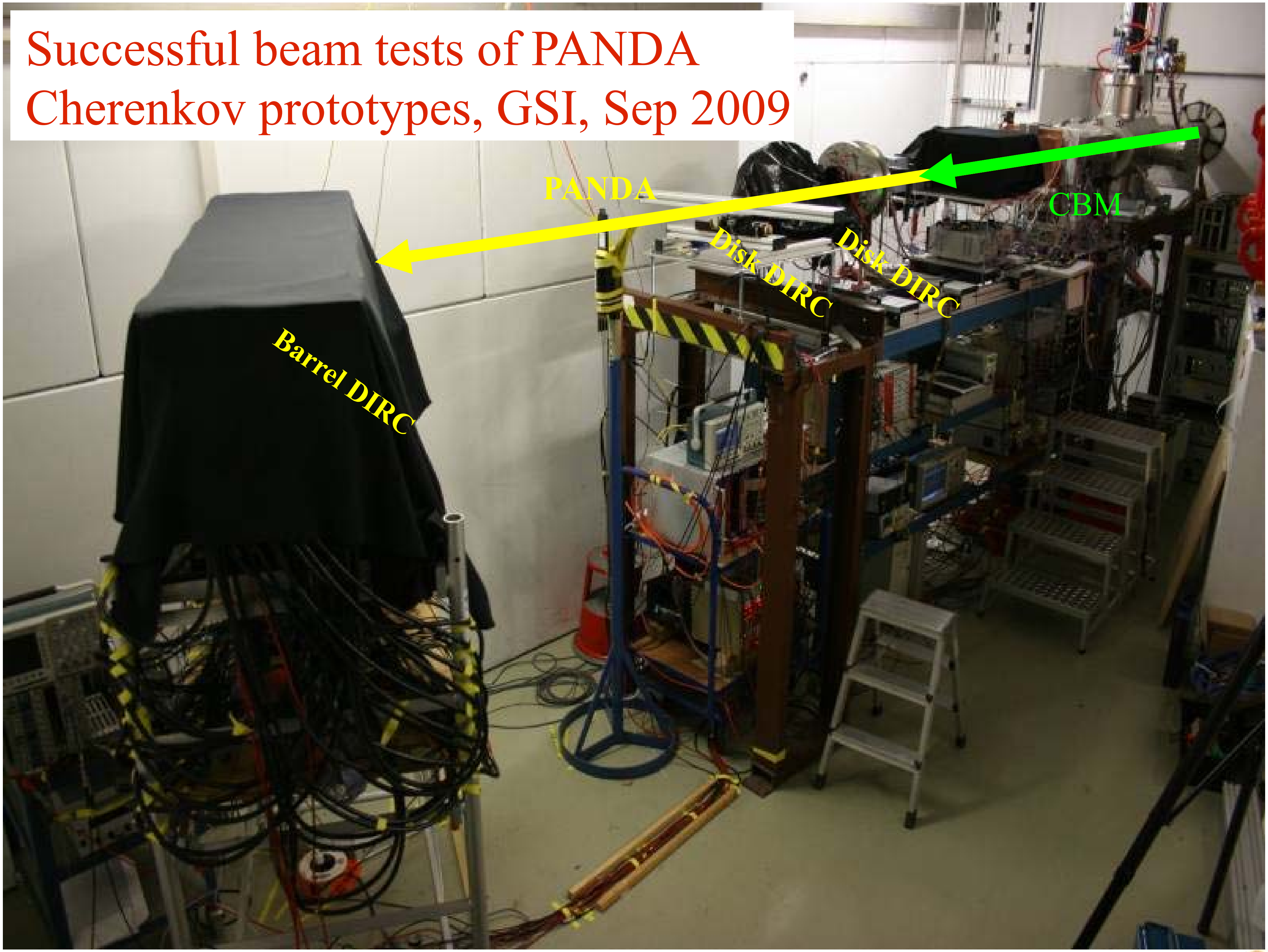
READOUT ELECTRONICS

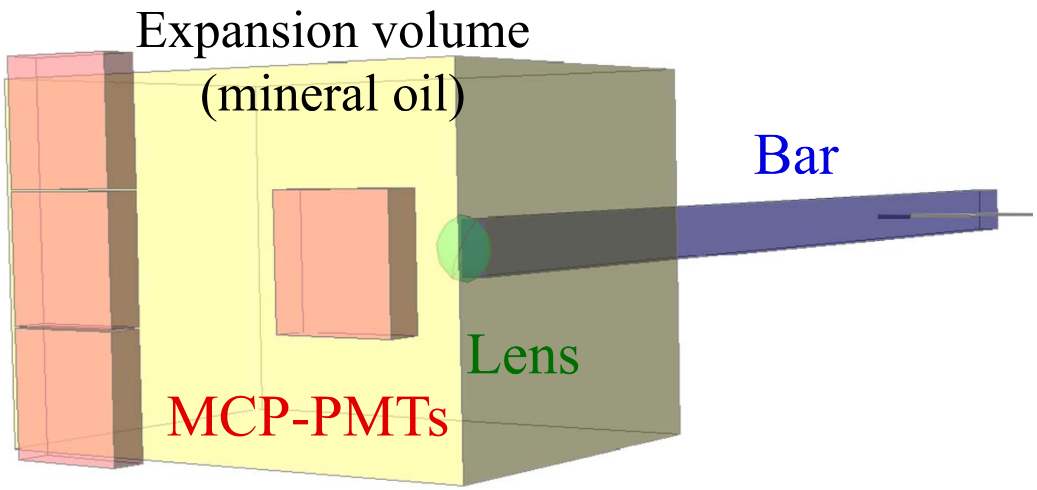
Electronics design demanding

- 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.



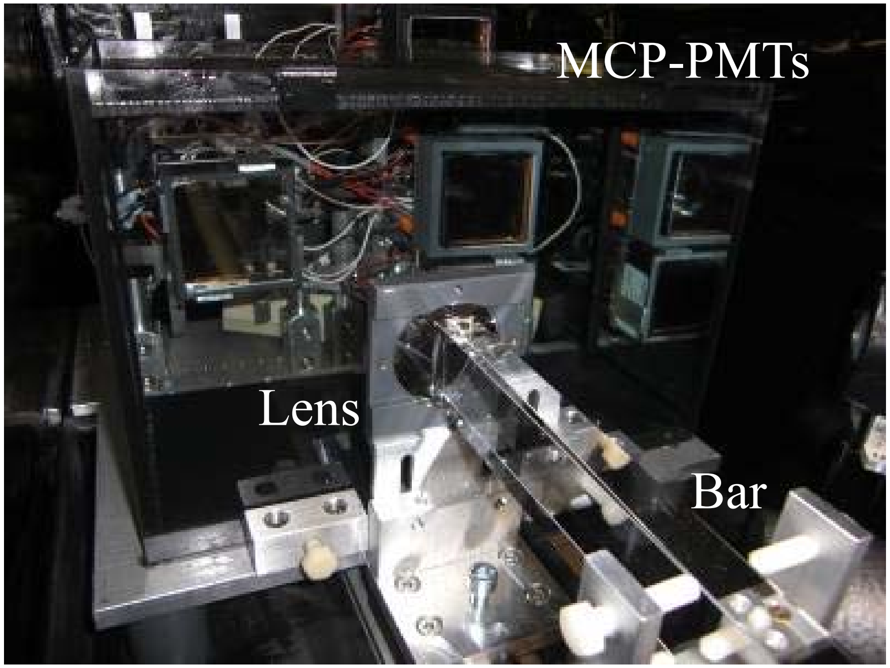
Successful beam tests of PANDA Cherenkov prototypes, GSI, Sep 2009

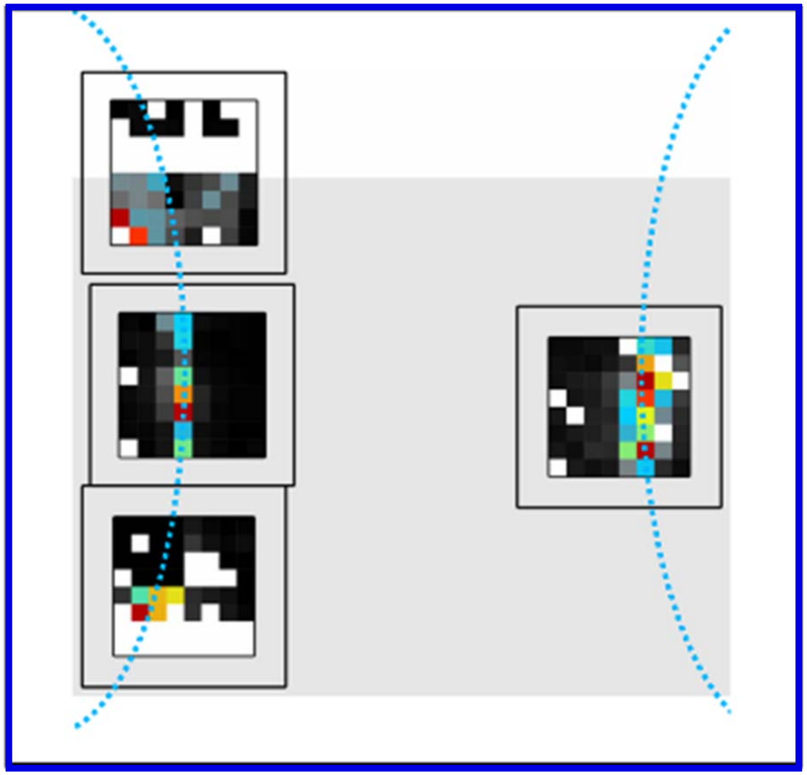




Barrel DIRC Prototype

in proton test beam at GSI





Cherenkov Ring segments
observed in Aug/Sep 2009

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 few C/cm^2/yr and 1 T.
  → Discussing solutions with industry, testing prototypes in lab.
- Cherenkov radiator (long bars) 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).

Particle test beams and pico-second laser pulsers:

essential tools for qualifying bars, sensors, and electronics.