THE DIRC DETECTORS FOR THE PANDA EXPERIMENT AT FAIR

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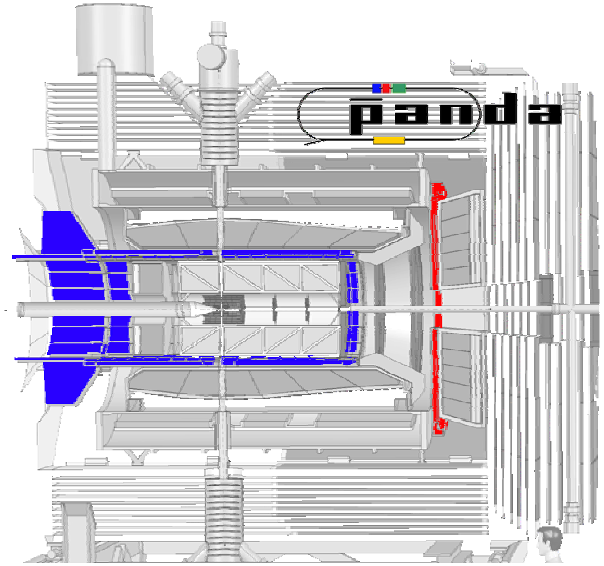
GSI

for the PANDA Cherenkov Group



- PANDA Experiment
- DIRC Concept
- Barrel & Disk DIRC Design
- Prototypes and R&D

PANDA: Anti-Proton ANnihilation at DArmstadt (450 physicists, 17 countries)
future experiment at new international FAIR facility at GSI
(German national lab for heavy ion research near Darmstadt)

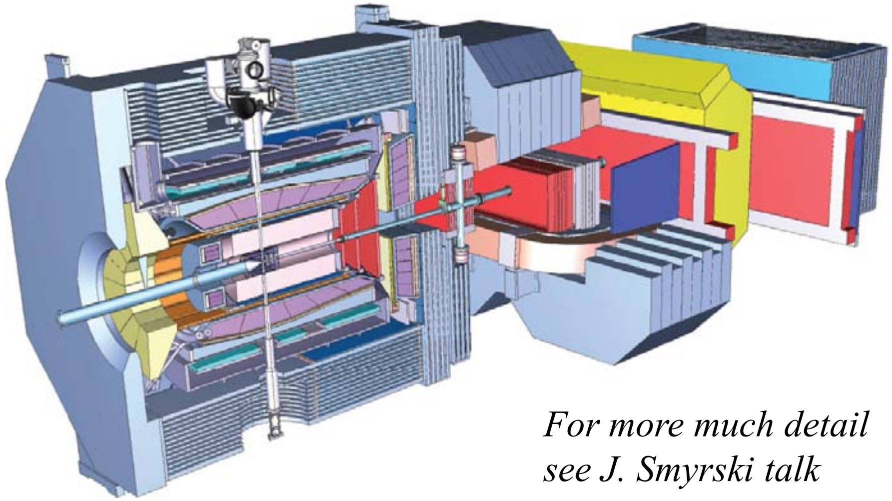
FAIR Facility for Antiproton and Ion Research

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

- Average production rate: 2×10^7/sec;
- Beam momentum 1.5 ... 15 GeV/c; $\Delta p/p$ as good as 10^{-5};
- 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.



For more much detail see J. Smyrski talk

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 CONCEPT

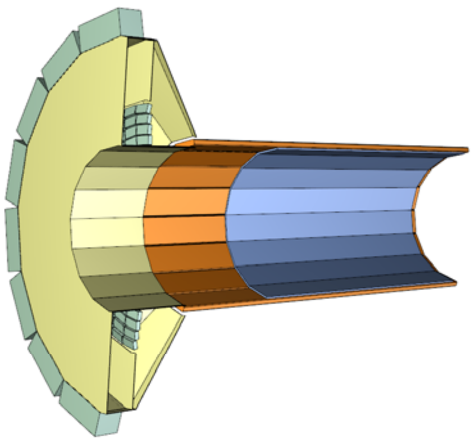
Cherenkov detectors in PANDA target spectrometers: Barrel DIRC & Disk DIRC

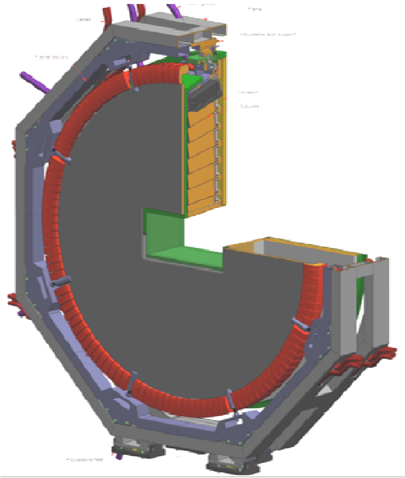
Detection of Internally Reflected Cherenkov Light

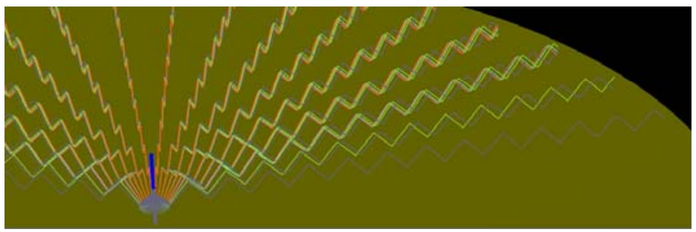
Novel type of Ring Imaging CHerenkov detector §
based on total internal reflection of Cherenkov light.

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.



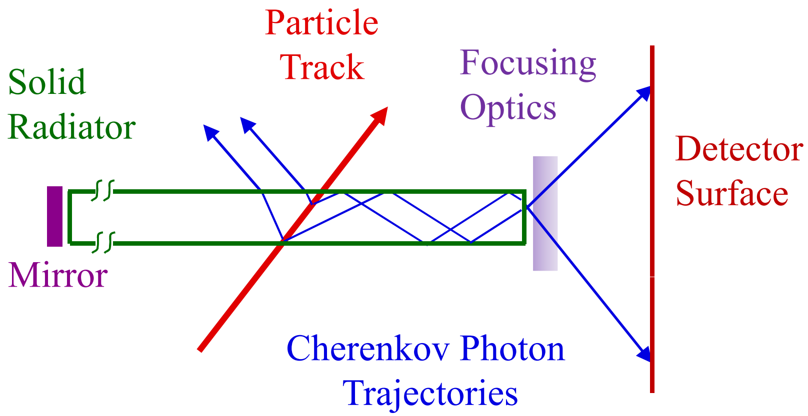




§B.N. Ratcliff, SLAC-PUB-6047 (Jan. 1993)

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 $\cos\theta_c = 1/\beta n(\lambda)$.

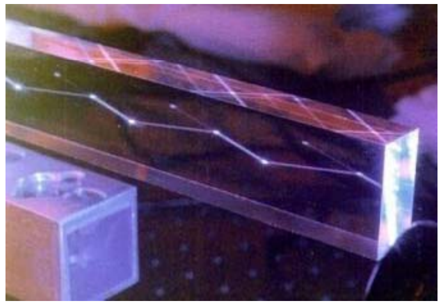


- For $n>\sqrt{2}$ some photons are always totally internally reflected for $\beta \approx 1$ tracks.

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

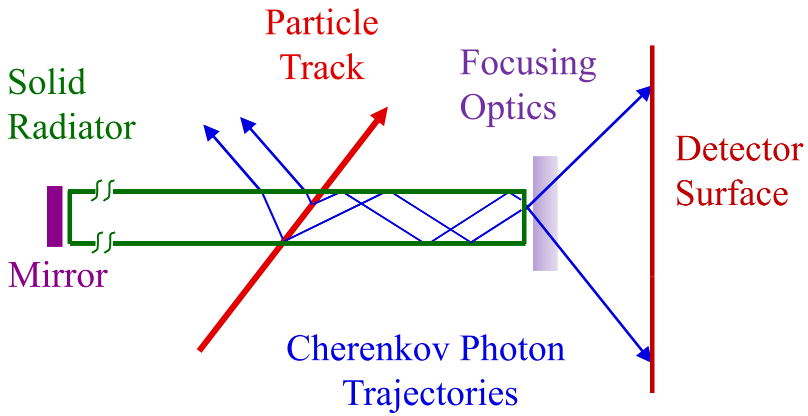
- Magnitude of Cherenkov angle conserved during internal reflections (provided optical surfaces are square, parallel, highly polished)

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



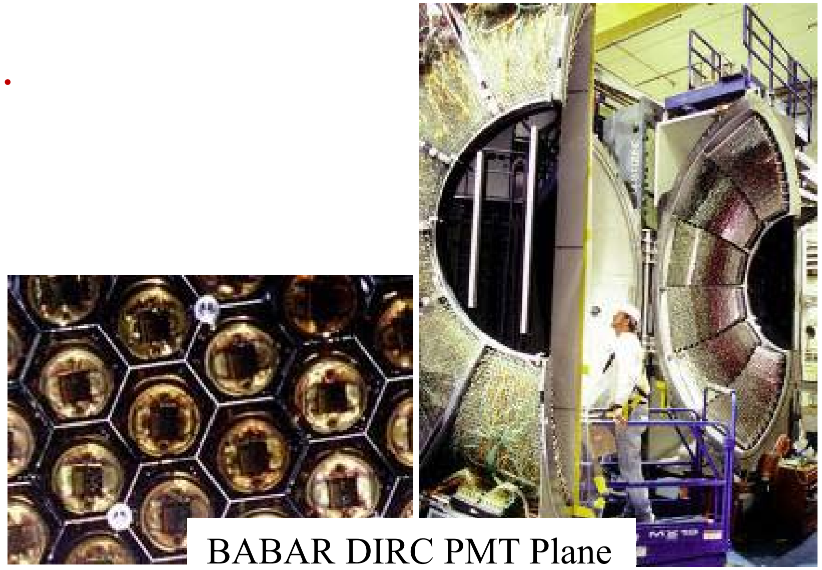
DIRC CONCEPT

- 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 (/no particle)
  plus event/track background.



BABAR DIRC PMT Plane

DIRC detector advantages

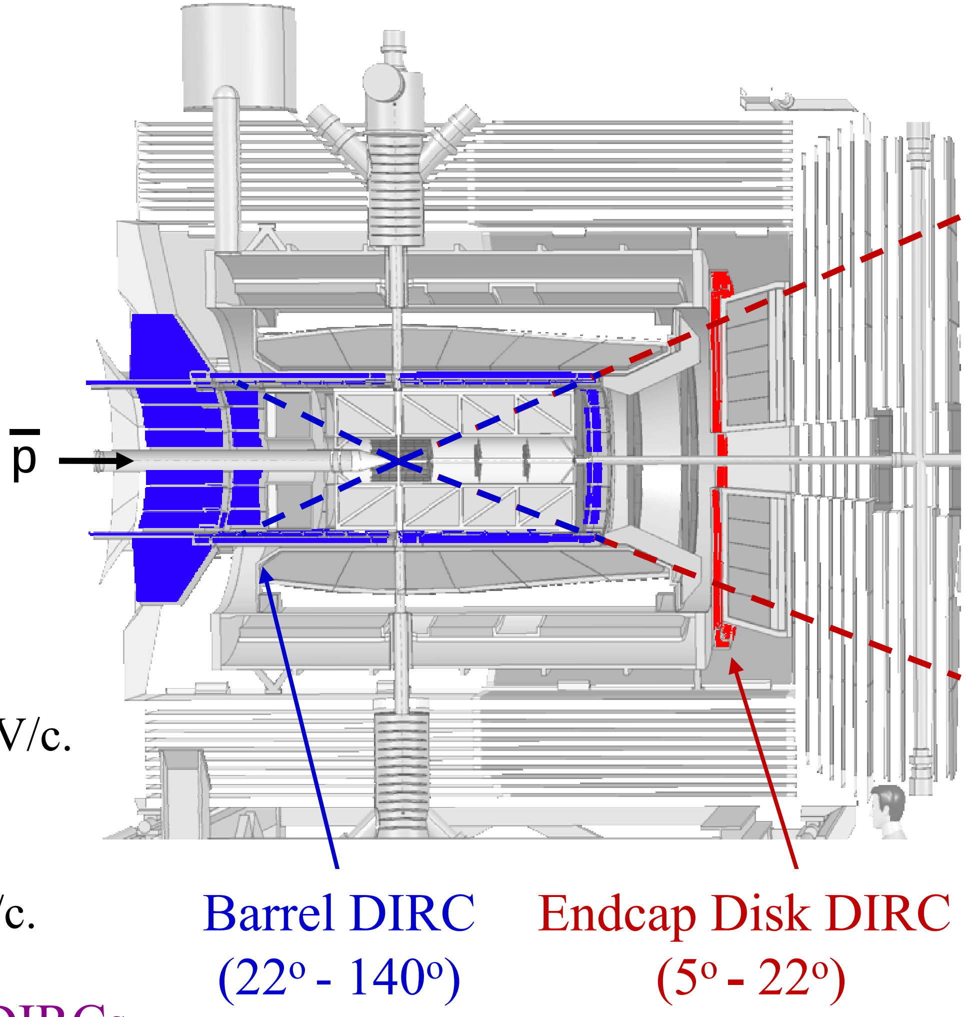
- Thin in radius and radiation length.
- Moderate and uniform amount of material in front of EM calorimeter.
- Fast and tolerant of background.
- Robust and stable detector operations.

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 Disk (or Disc) DIRC.

  PID goal: 3σ π/K separation for p<4 GeV/c.



Institutions currently involved in the two DIRCs

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

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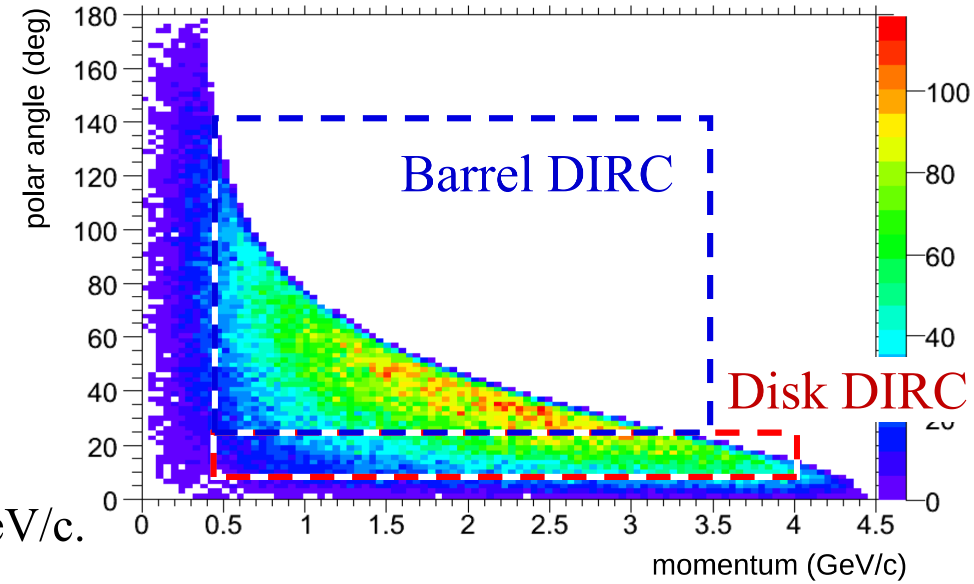

Kaon distribution of the radiative decay

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

(search of glue balls)

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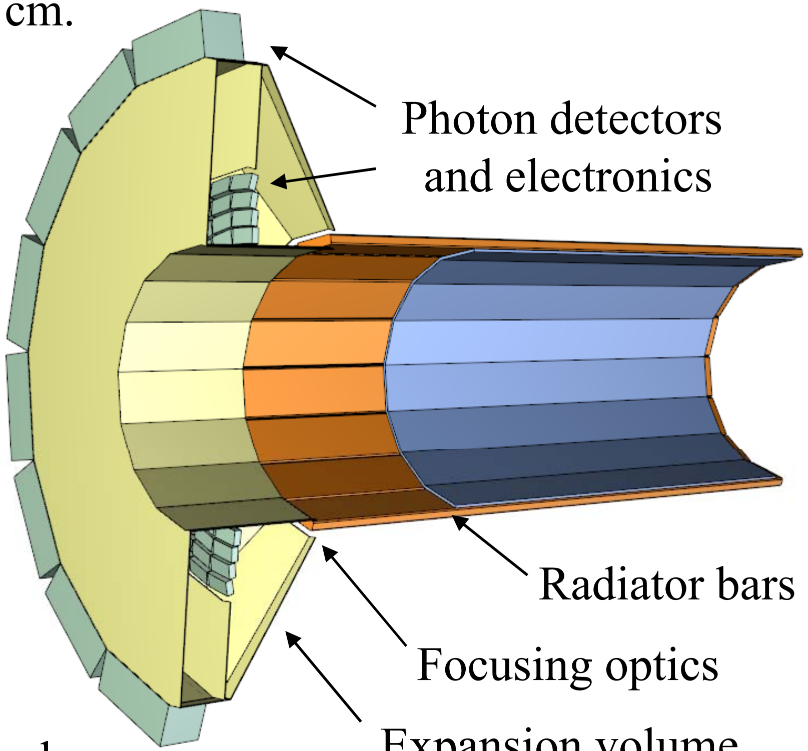
PANDA BARREL DIRC DESIGN

Current PANDA Barrel DIRC baseline design:

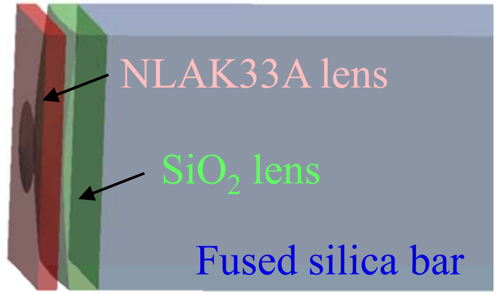
- Barrel radius ~50 cm; expansion volume depth: 30 cm.
- 80 radiator bars, synthetic fused silica
  17mm (T) × 33mm (W) × 2500mm (L).
- Focusing optics: doublet lens system.
- Compact photon detector:
  30 cm oil-filled expansion volume,
  10-15,000 channels of MCP-PMTs.
- Fast photon detection:
  fast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



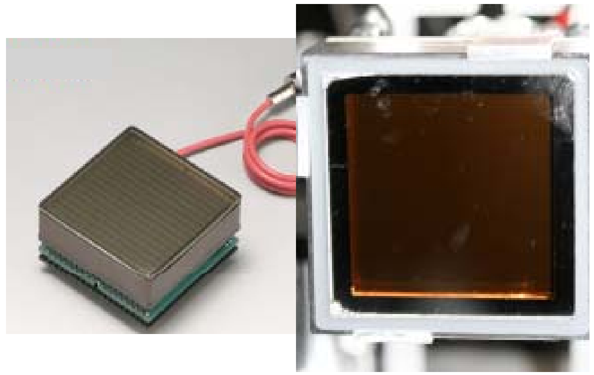
Still investigating several design options:
mirror focusing, radiator plates, photon detection outside magnetic field.

PANDA BARREL DIRC

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

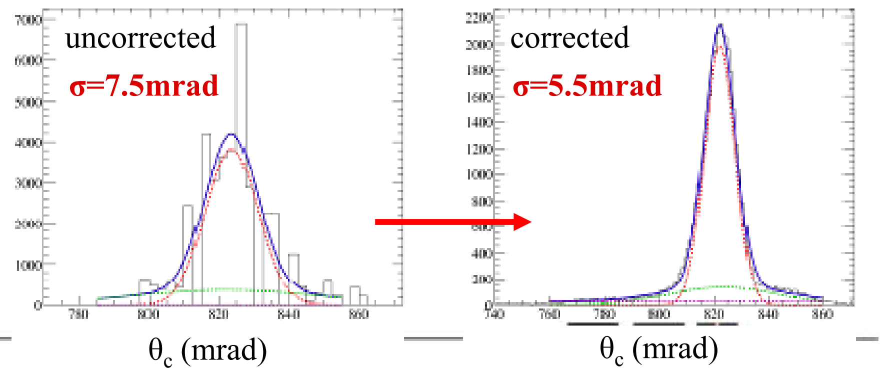


- Focusing optics: remove bar size contribution
  from Cherenkov angle resolution term.
  Lens doublet and/or mirror focusing on flat detector surface.



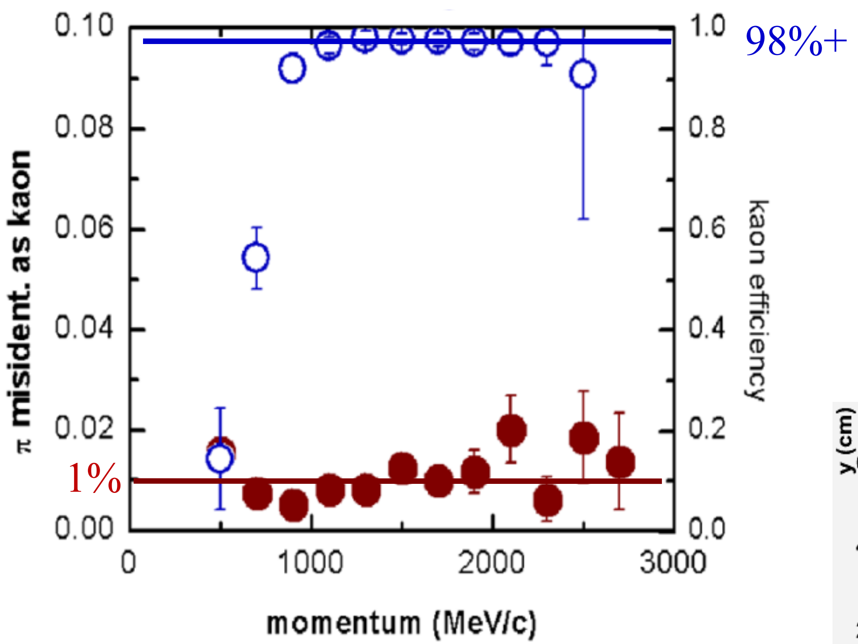
- Compact multi-pixel photon detectors:
  allow smaller expansion region,
  make DIRC less sensitive to background.
  MCP-PMTs, MAPMTs, SiPM/G-APD potential candidates.

- Fast photon detection ($\sigma_{TTS} \approx 100-200$ps):
  software correction of chromatic dispersion.
  Proof-of-principle shown in 2007
  by Focusing DIRC at SLAC.
  (Nucl. Instr. and Meth. Phys. Res. Sect. A 595 (2008) 104-107)



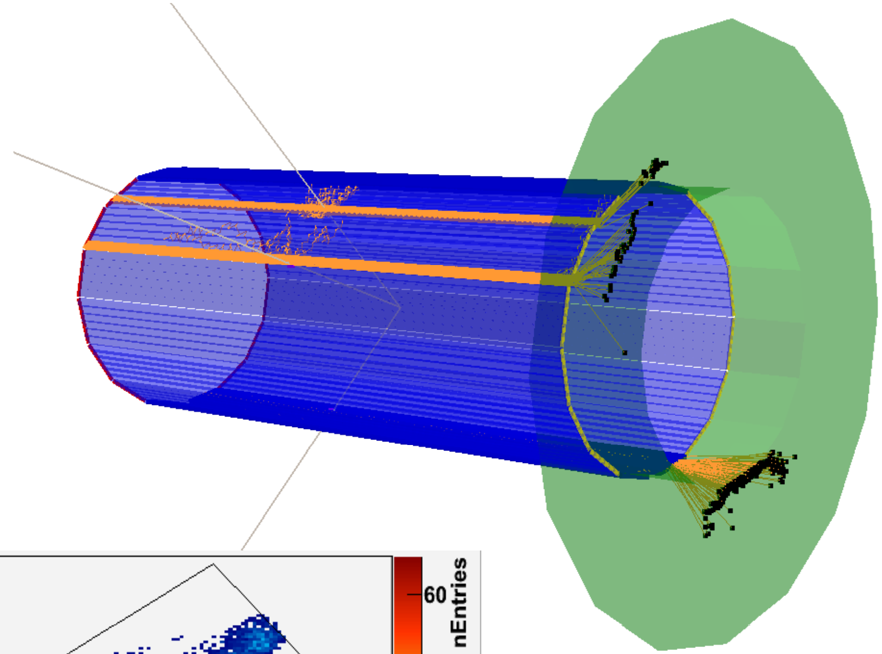
Expected PID performance example.

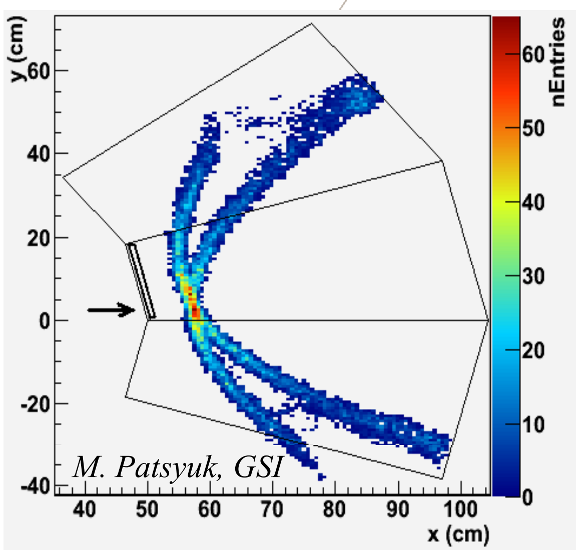
$p\bar{p} \rightarrow J/\Psi\ \Phi \quad \sqrt{s} = 4.4\ GeV/c^2$



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

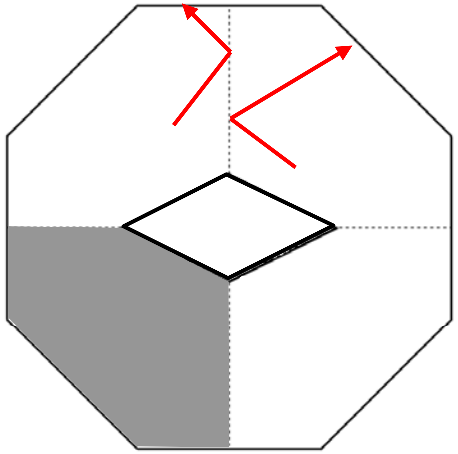
Geant Cherenkov photon tracking in event display.



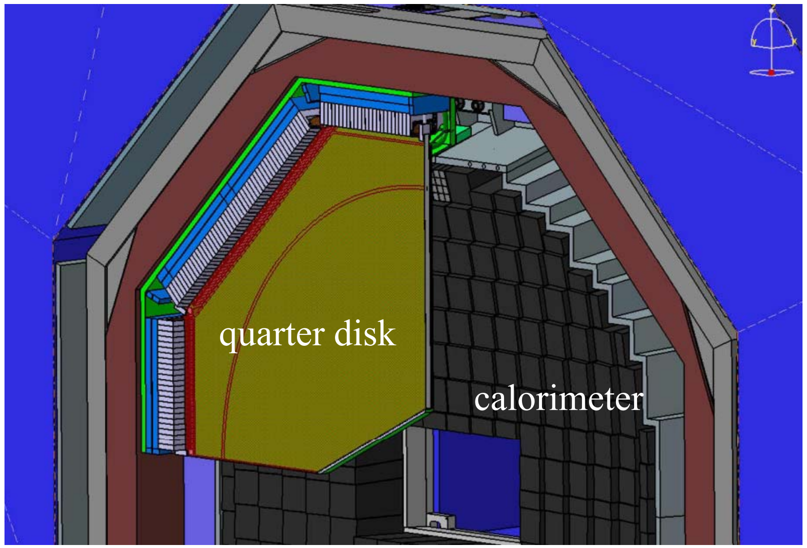


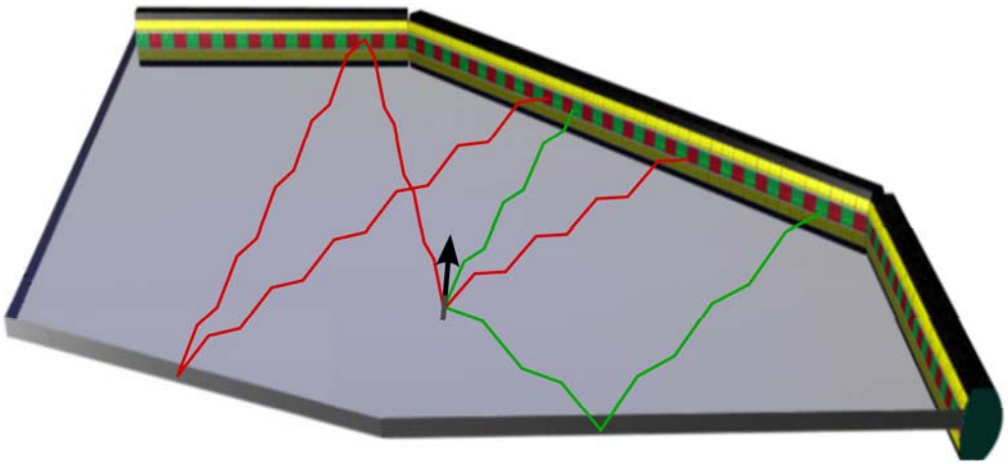
Example: Accumulated hit pattern in Geant.

Current PANDA Disk DIRC baseline design: "3D Disk DIRC"



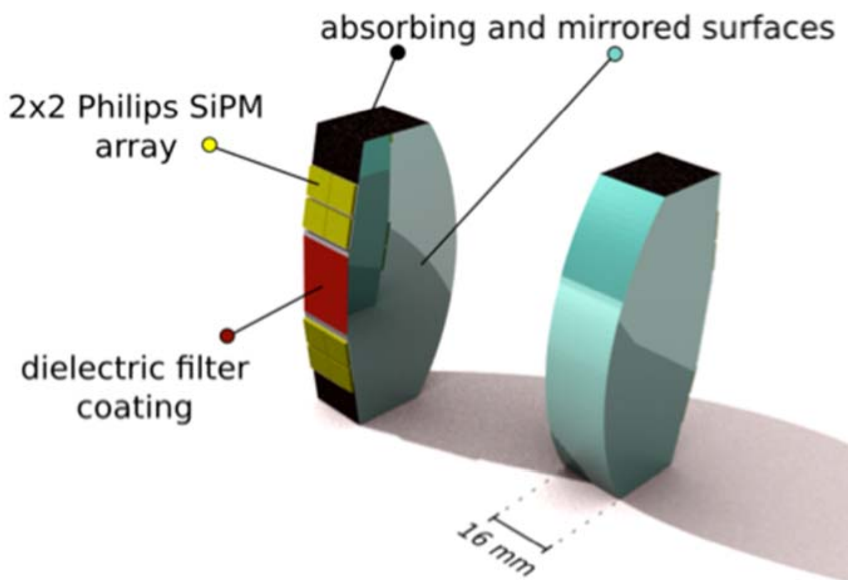
- Octagonal disk, ~2m diameter, 2cm thick, synthetic fused silica, placed in front of forward calorimeter.
- Disk made from four identical, optically isolated pieces with polished, reflecting sides.
- Dichroic mirrors on rim serve as optical band-pass filters (dispersion mitigation).
- 432 small focusing light guides image photons on digital SiPM or MCP-PMT.

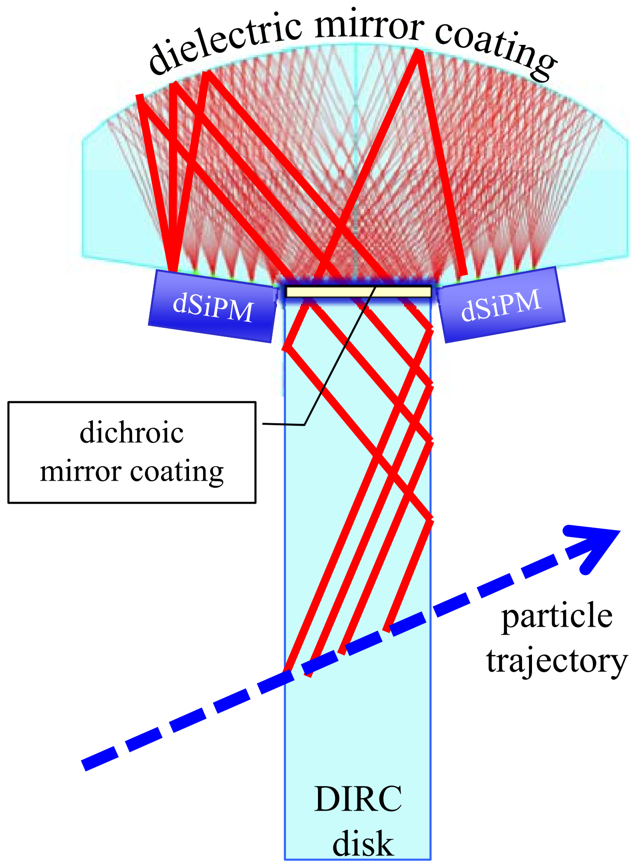




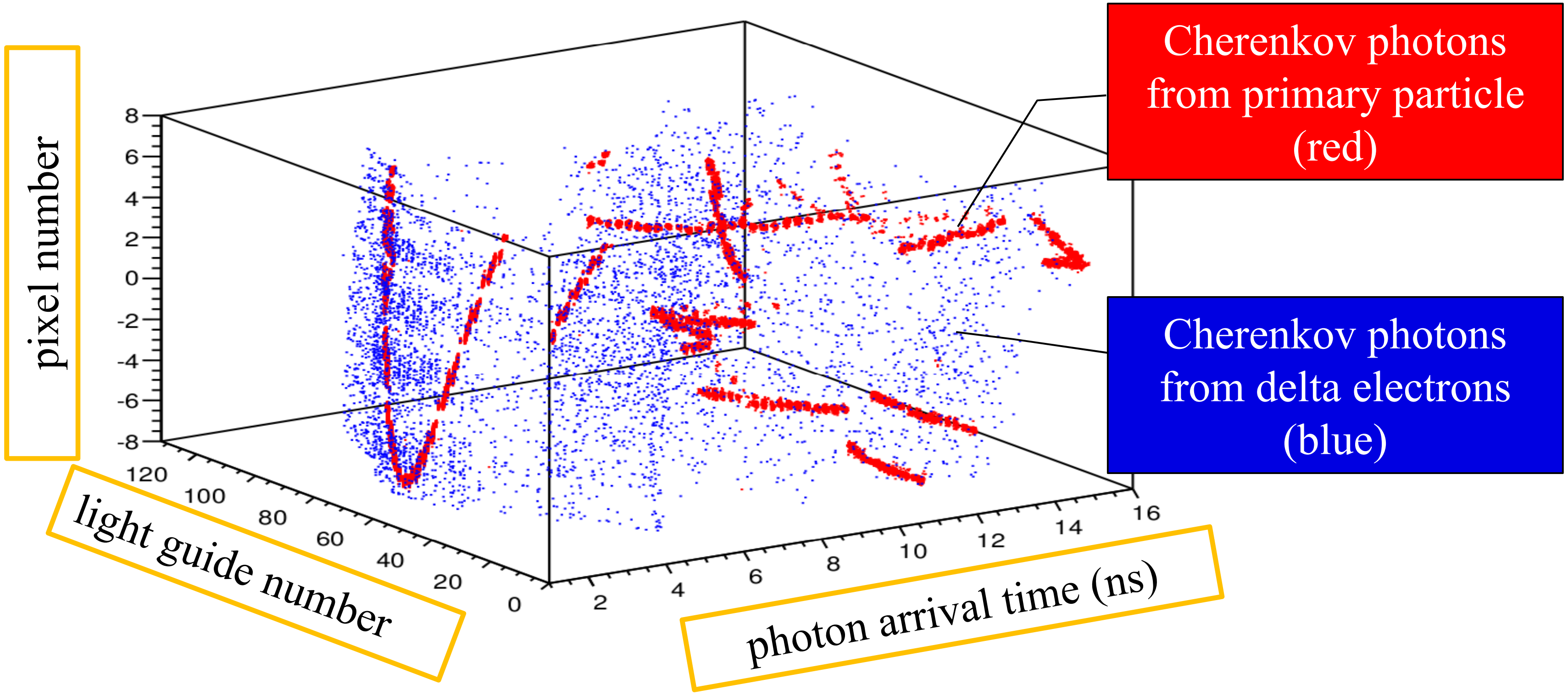
PANDA DISK DIRC DESIGN

- Fast and small pixel detectors: dSiPMs or MCP-PMTs
- Two 2 × 2 dSiPM arrays (or 2 MCP) per light guide.
- Two types of dichroic mirrors:
  400-500nm, 500-700nm, alternating along rim.
- Angle measurement using small focussing light guides and multi-pixel detectors.
- Time-of-Propagation measurement using the light guides and fast photo detectors.





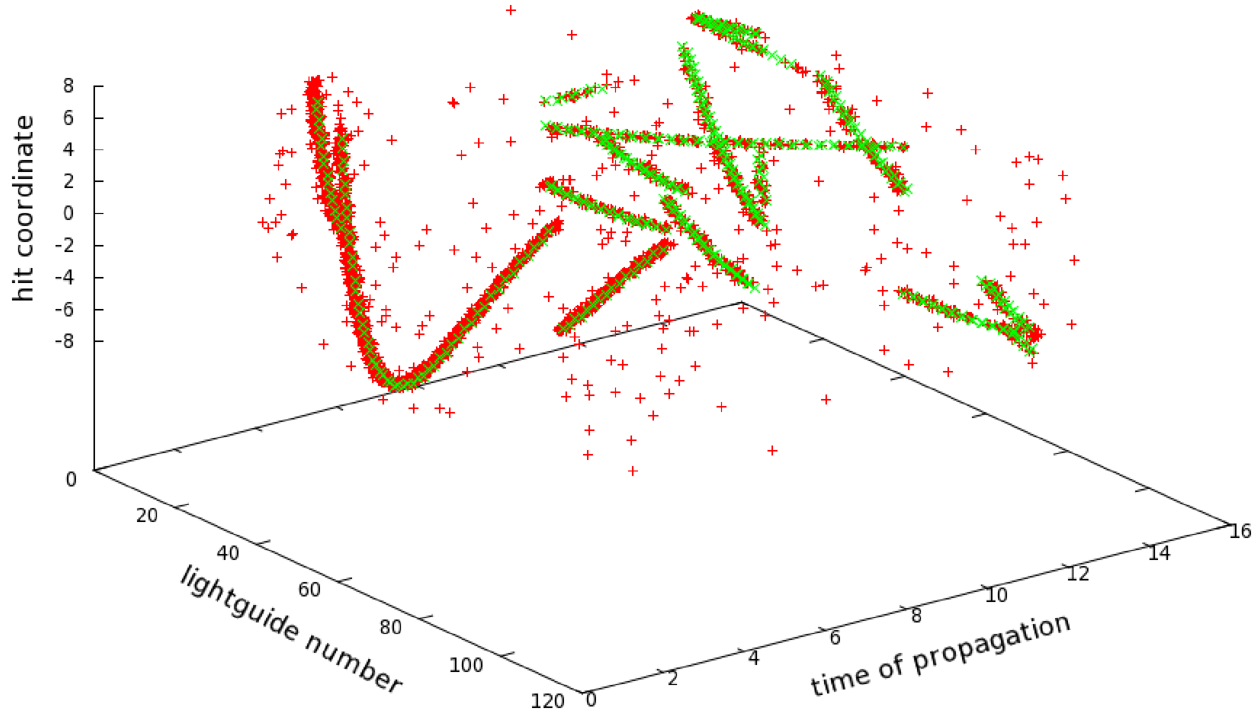
3D hit pattern looks complicated but...



... signal/background separation much easier and robust in 3 dimensions than in a 2-dimensional projection.

Full 3D Geant simulation of geometry, photon generation, and photon propagation.

Red: photons emitted by primary particle (100 identical tracks).
Green: Pattern prediction generated by the reconstruction method.

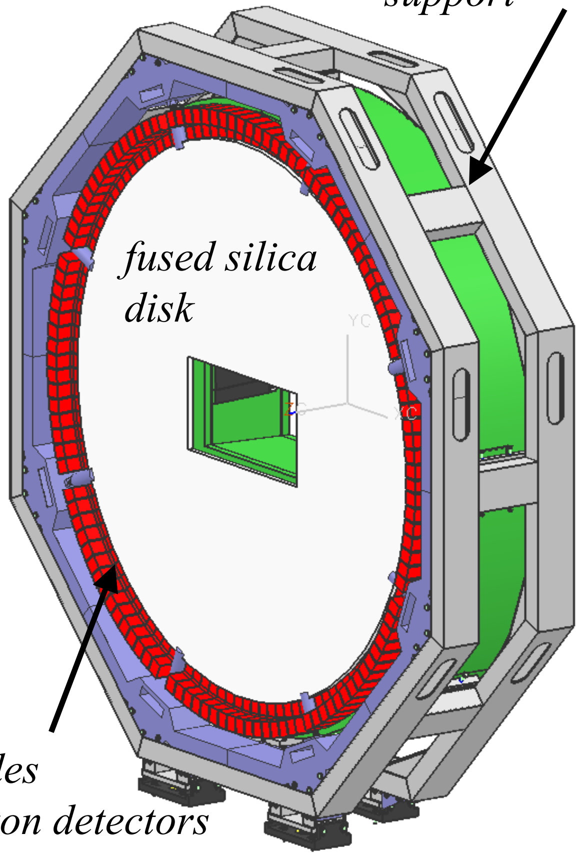


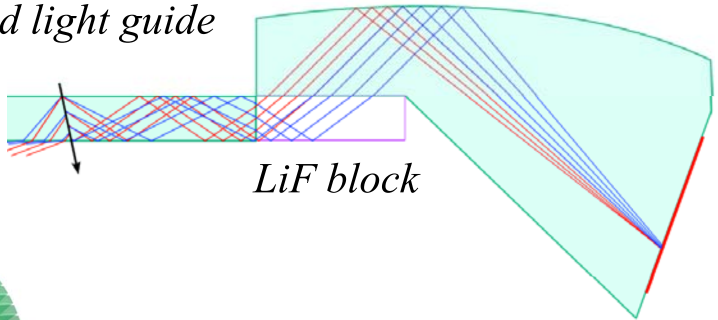
Reconstruction algorithm robust, background-tolerant.

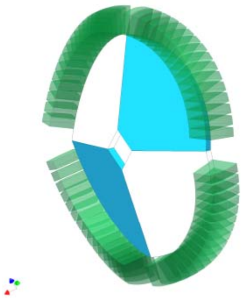
Preliminary performance study shows pion/kaon mis-ID rate at 4GeV/c at 1-2% level.

Investigating design alternatives: "Focusing Light Guide DIRC"

- 128-sided polygonial disk, glued from six pieces
  (→ disk shape, gluing).
- LiF block glued to rim of synthetic fused silica disk
  (→ dispersion mitigation).
- Focusing light guides image photons on MCP-PMTs
  (→ light guide shape, sensor and readout technology).



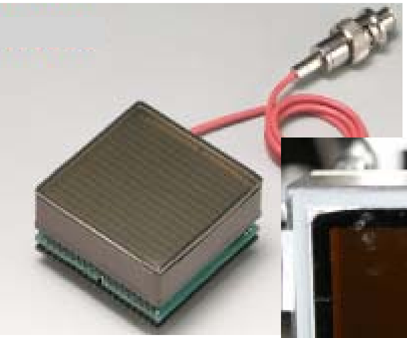
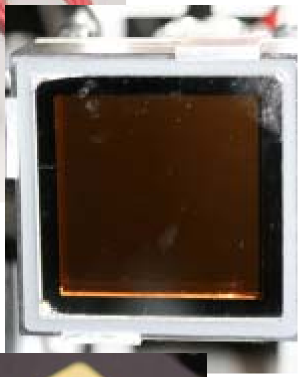
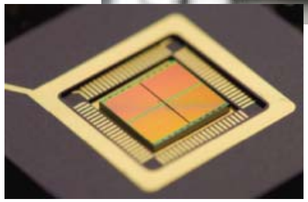




Will be able to test a simplified design in an experiment very soon:
Focusing Light Guide DIRC (CEARA) for WASA at COSY (FZ Jülich).

PANDA DIRCs are asking a lot of fast compact multi-pixel photon detectors

- Single photon sensitivity, low dark count rate;
- Reasonably high photo detection efficiency;
- Fast timing: $\sigma_{TTS} \approx$ 50-100 ps (Barrel: 100-200 ps);
- Few mm position resolution;
- Operation in up to 1.5 T (Barrel: ~1 T) magnetic field;
- Tolerate high rates up to 2 MHz/cm^2 (Barrel: 0.2 MHz/cm^2);
- Long lifetime: 4-10 C/cm^2 per year at 10^6 gain (Barrel: 0.5 C/cm^2/yr).

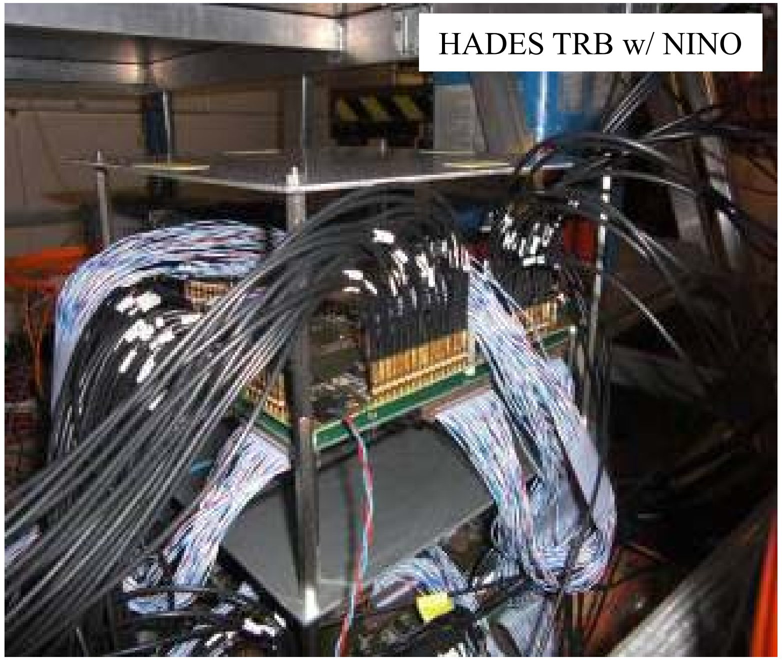
No currently available sensor matches all criteria;
promising candidates: MCP-PMTs, MAPMTs, SiPM.

Starting ageing test of two very new enhanced lifetime MCP-PMTs side-by-side:
Hamamatsu SL-10 and Burle 85112 – both may be (almost) acceptable for barrel DIRC.

Digital SiPM (Philips) promising sensor for Disk: excellent timing and lifetime, integrated readout electronics, masking of hot pixels.
But: needs cooling, needs redesign for single photons, new technology, prototypes only.

Electronics design demanding

- Signal rise time typically few hundred picoseconds.
- 10-100x preamplifier usually needed.
- High bandwidth 500MHz – few GHz (optimum bandwidth not obvious).
- Pulse height information required for < 100 ps timing (time walk correction),
  and desirable for 100-200 ps timing (ADC / time over threshold / waveform sampling / ...)
- PANDA will run trigger-less.
- Large data volume (Disk: up to 200 Gb/s).
- Example:
  HADES TRB board with NINO TOF add-on in GSI test beam in 2009, updated TOF add-on in test beams at GSI (next week) and at CERN in July.
- Significant development effort ahead.
- dSiPM with digitization on chip – no TDC, preamp, ADC, etc development required.


HADES TRB w/ NINO

DIRC RADIATOR PRODUCTION

Production of large fused silica pieces (bars, plates, disk segments) is challenging.

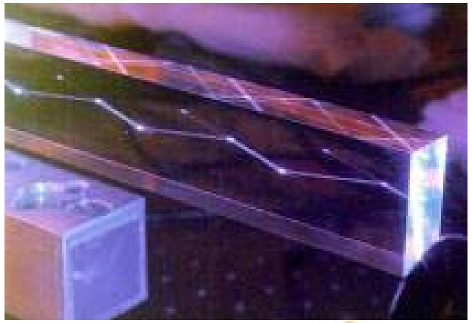
DIRCs require mechanical tolerances on flatness, squareness, and parallelism
with optical finish and long sharp edges.
→ difficult, potentially expensive, few qualified vendors worldwide.

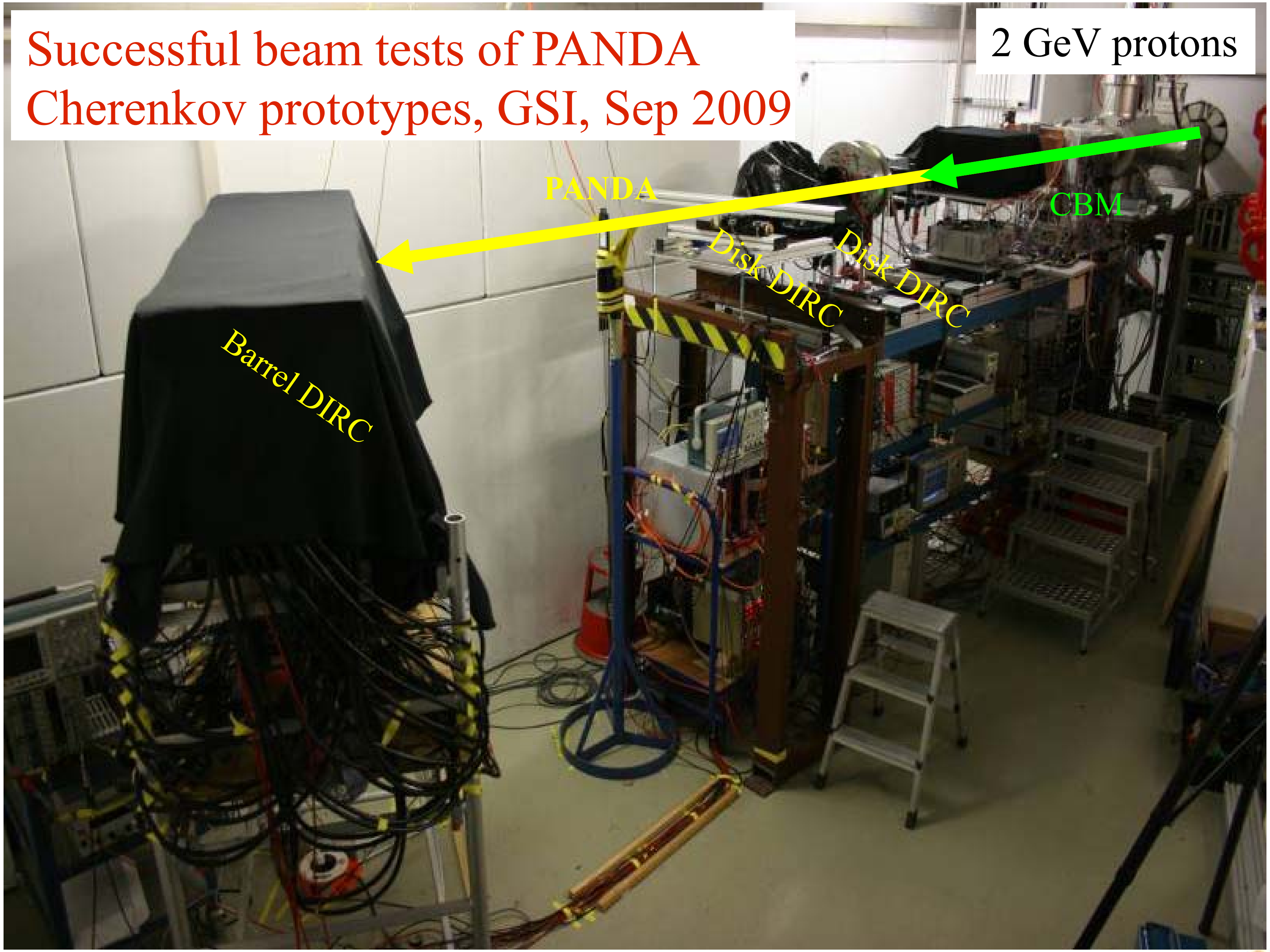
BABAR-DIRC used bars polished to 5 Å *rms*, non-squareness < 0.25 mrad;
successfully done for BABAR, need to qualify/retrain vendors 10+ years later.

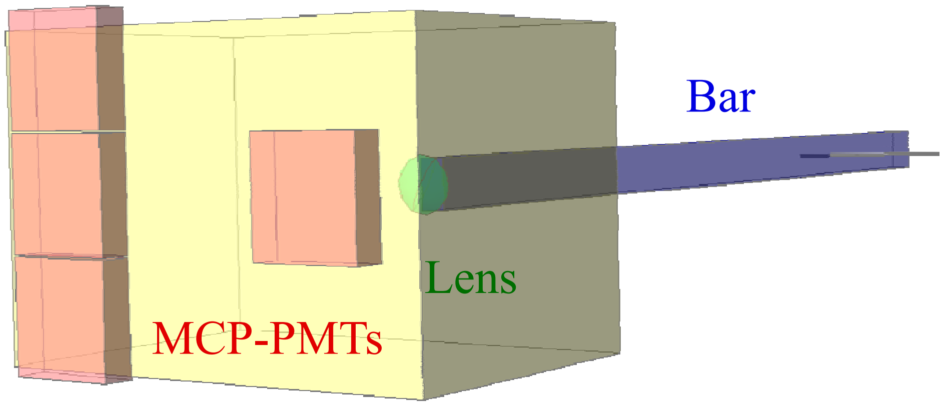
Can afford to relax some of those specs for PANDA DIRCs due to shorter photon paths
(surface roughness 10-20 Å *rms*, non-squareness 0.5-1 mrad, etc).

Identified several good candidates for synthetic fused silica material (Heraeus, Corning).

Have been working with potential vendors in Europe and USA, obtained/ordered prototype bars, plates, disk segments from several companies, verifying surfaces and angles.

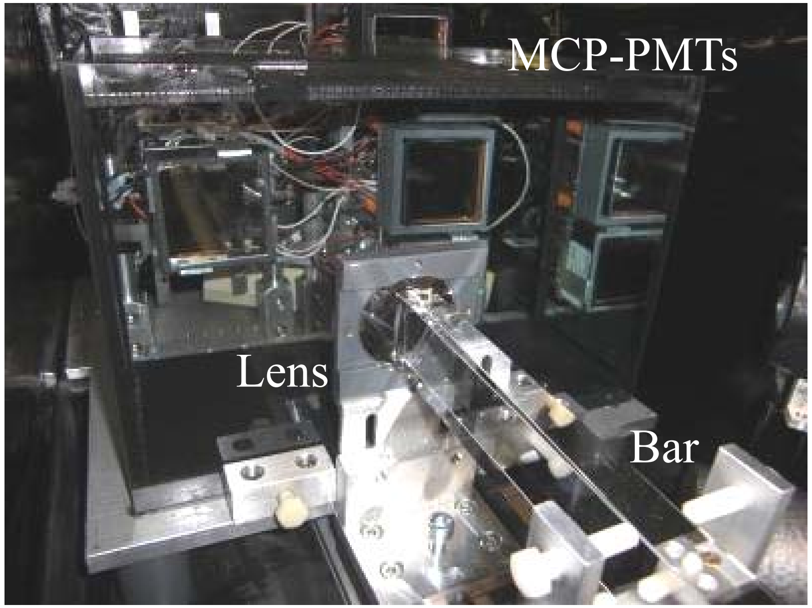


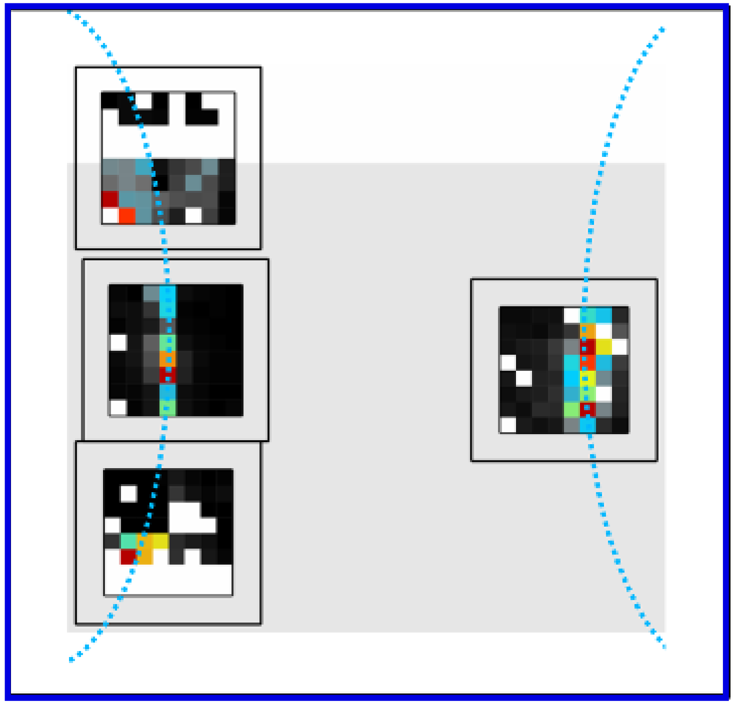

Successful beam tests of PANDA
Cherenkov prototypes, GSI, Sep 2009
2 GeV protons
PANDA
CBM
Disk DIRC
Disk DIRC
Barrel DIRC



Barrel DIRC Prototype

in proton test beam at GSI

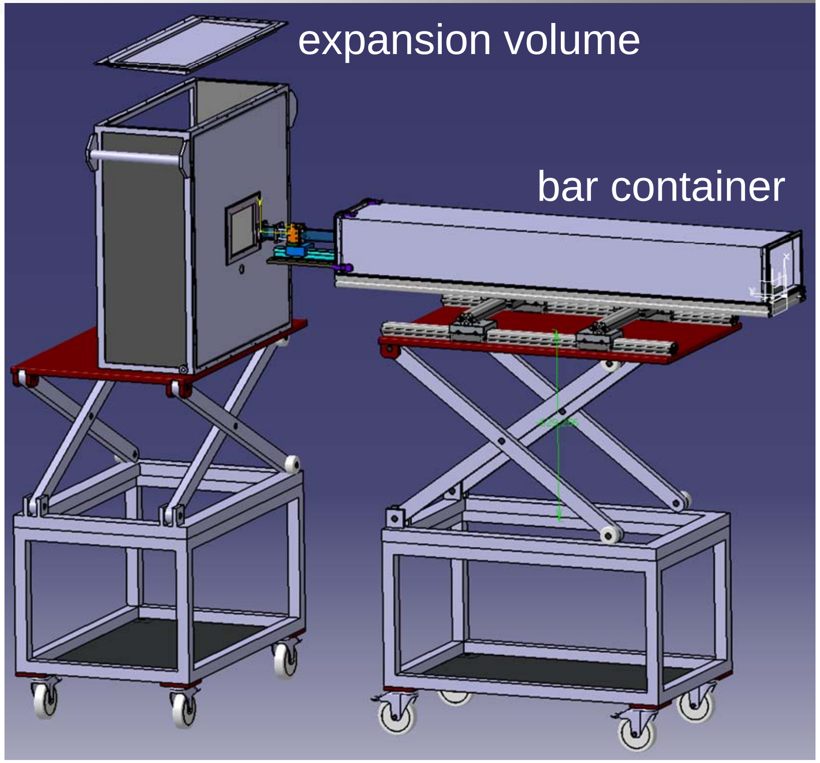


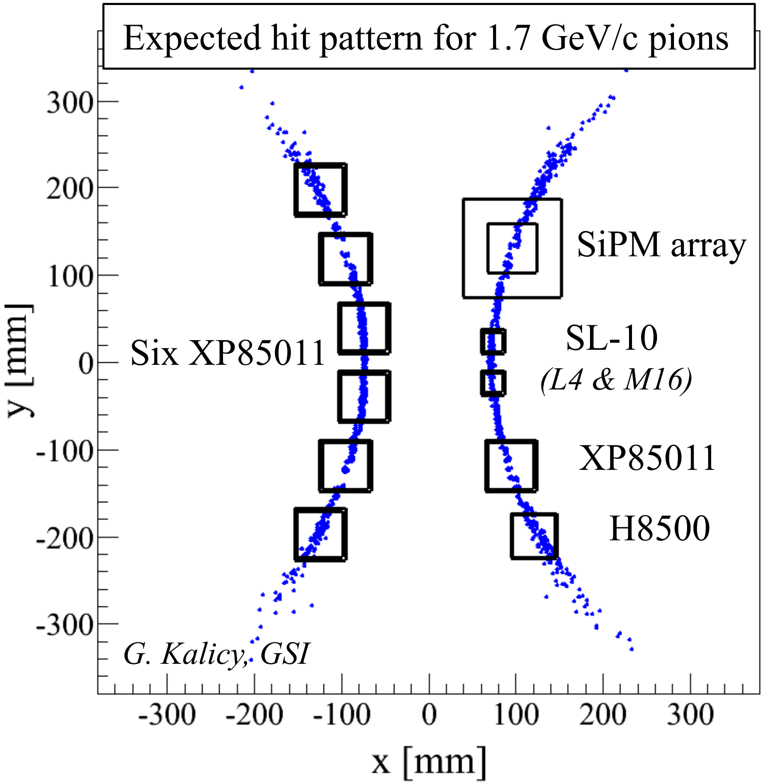


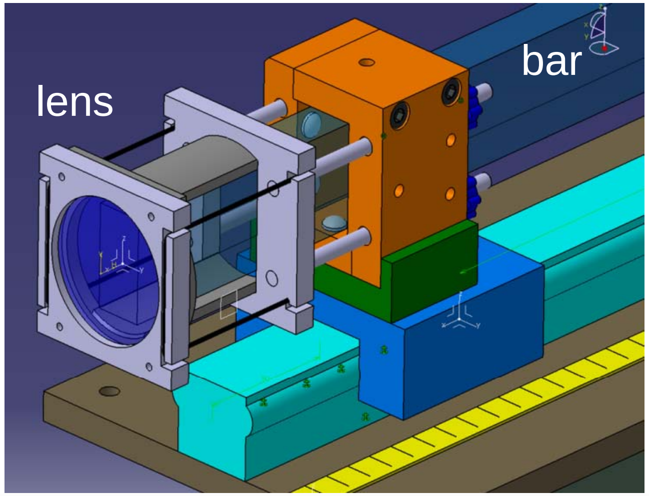
Cherenkov Ring segments observed in Aug/Sep 2009

New Barrel DIRC Prototype

- Larger, deeper expansion volume.
- Larger detector plane, space for more sensors.
- 640 electronics channels (HADES TRB/NINO)
- Focusing lenses with different AR coatings.



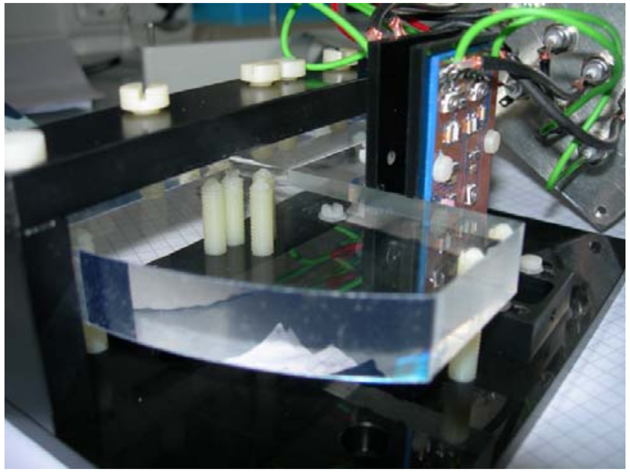


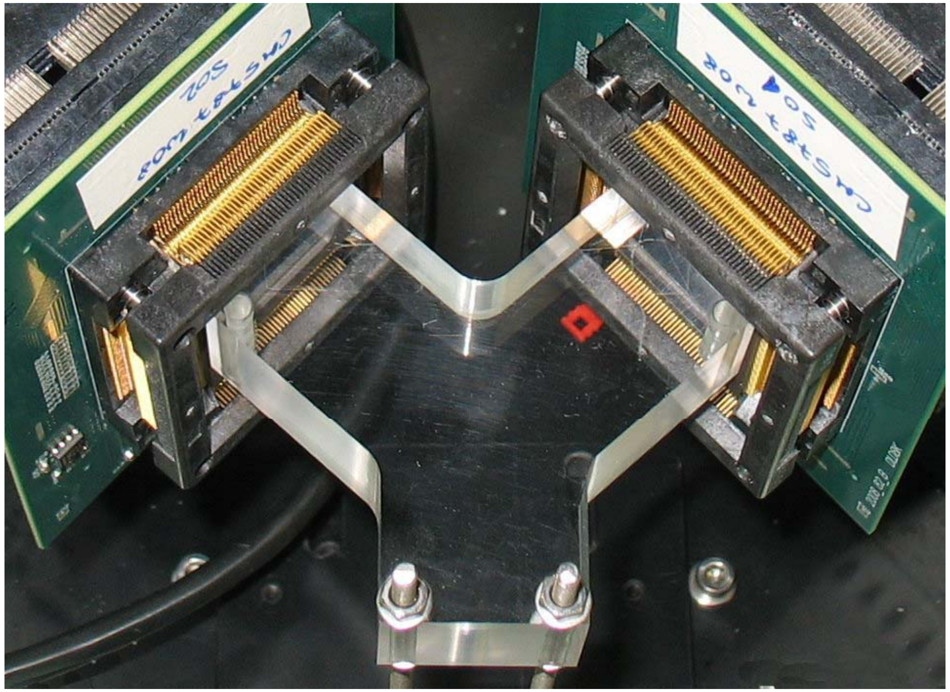


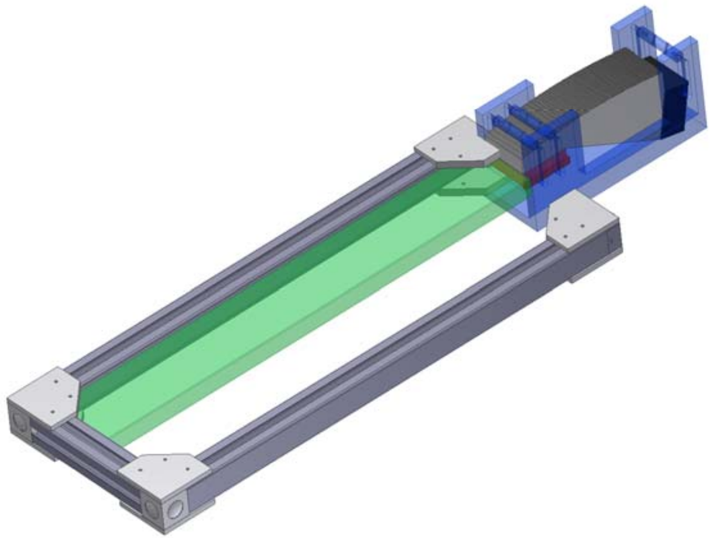
Ready for test beam on Tuesday.

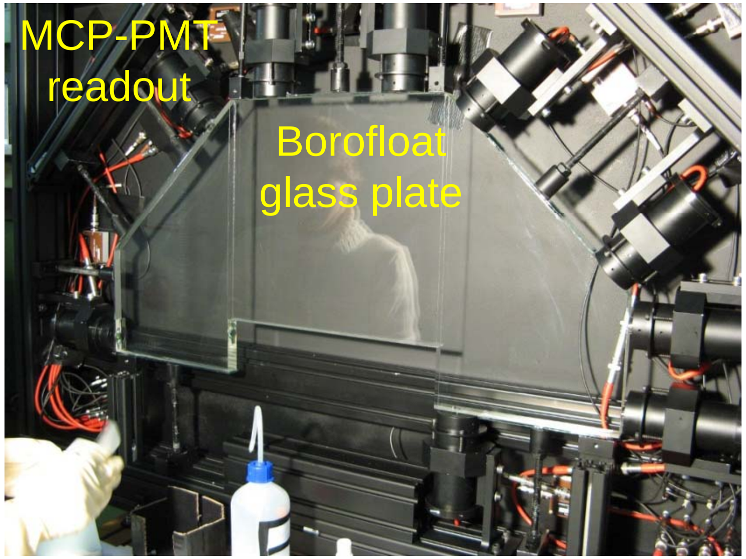
Several test beam campaigns since 2008 to test

- focusing light guides,
- photon yield and light transmission in bulk material,
- performance of SiPM/dSiPM sensors.









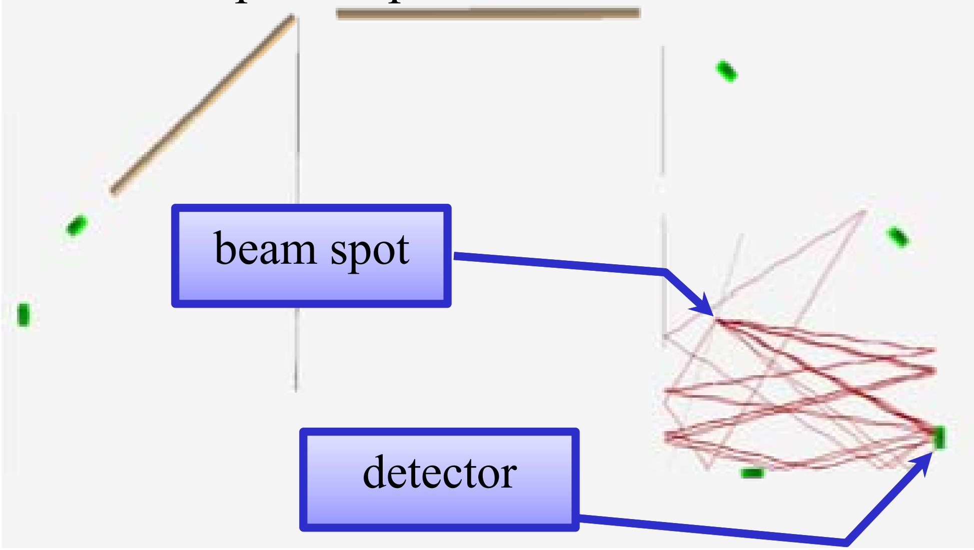
Protoype at DESY

glued glass plate
(~40% scale)

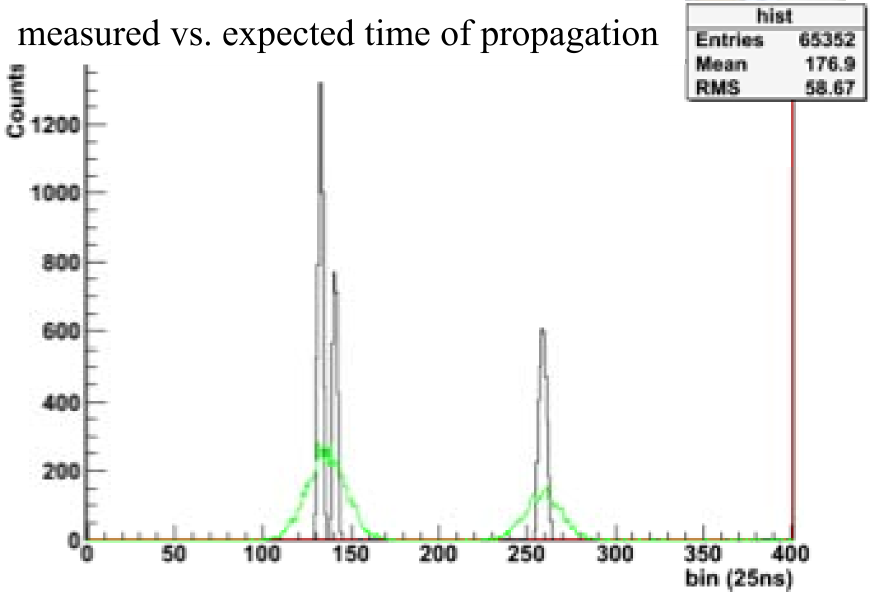
Sensors: 9 MCP-PMTs

studied timing, paths

Simulated photon paths



measured vs. expected time of propagation



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

Key challenges:

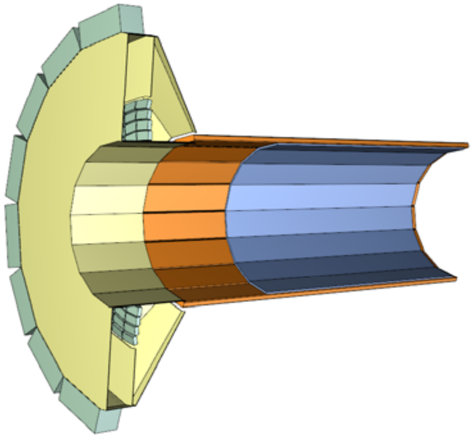
- Pico-second timing with single photons in environment with 1-10 C/cm^2/yr and 1-1.5 T.
  → Discussing solutions with industry, testing prototypes in lab.
- Cherenkov radiator (bars, plates, disk) production and assembly.
  → In contact with vendors in Germany, Russia, USA, testing prototype pieces.
- Design of detector optics and reconstruction software.
  → Developing simulation framework (Geant and ray-tracing).

Validating technology and design choices in test beams.

FAIR construction to start within the year, DIRC installation planned 2016/2017.

THANK YOU

Thanks to the organizers for the opportunity to give this talk.



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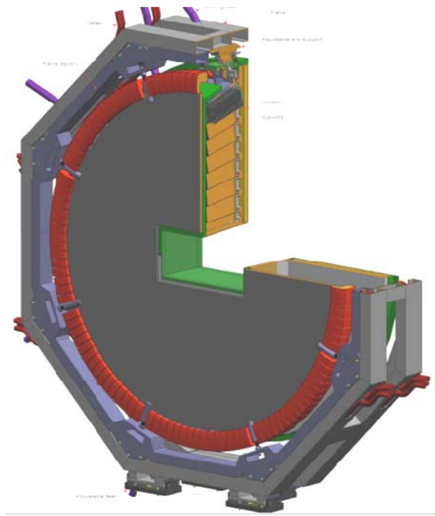

And thank you all for your attention.