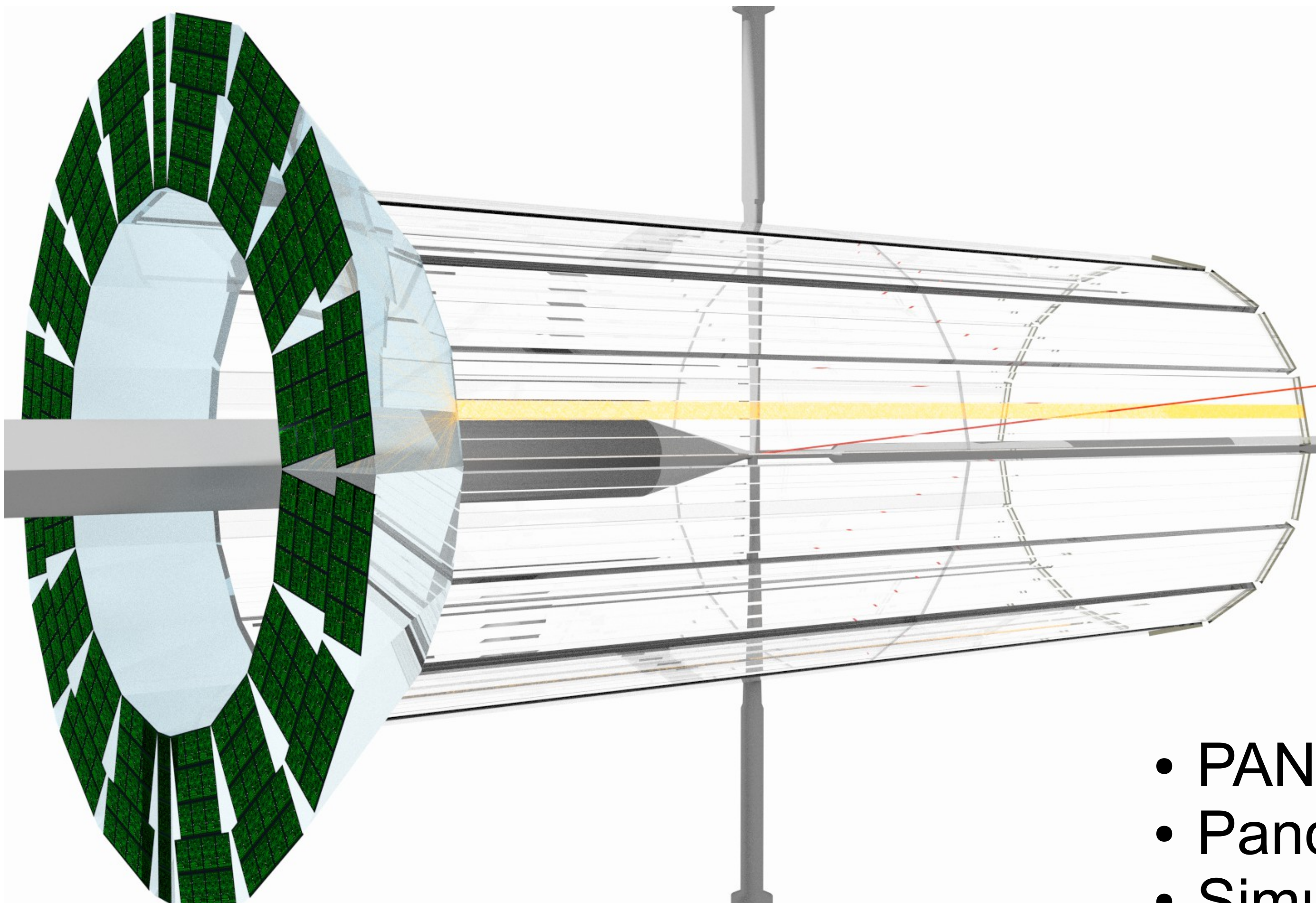
Status of the PANDA Barrel DIRC



- PANDA Requirements
- Panda Barrel DIRC
- Simulation
- Prototype Setup
- Summary & Outlook

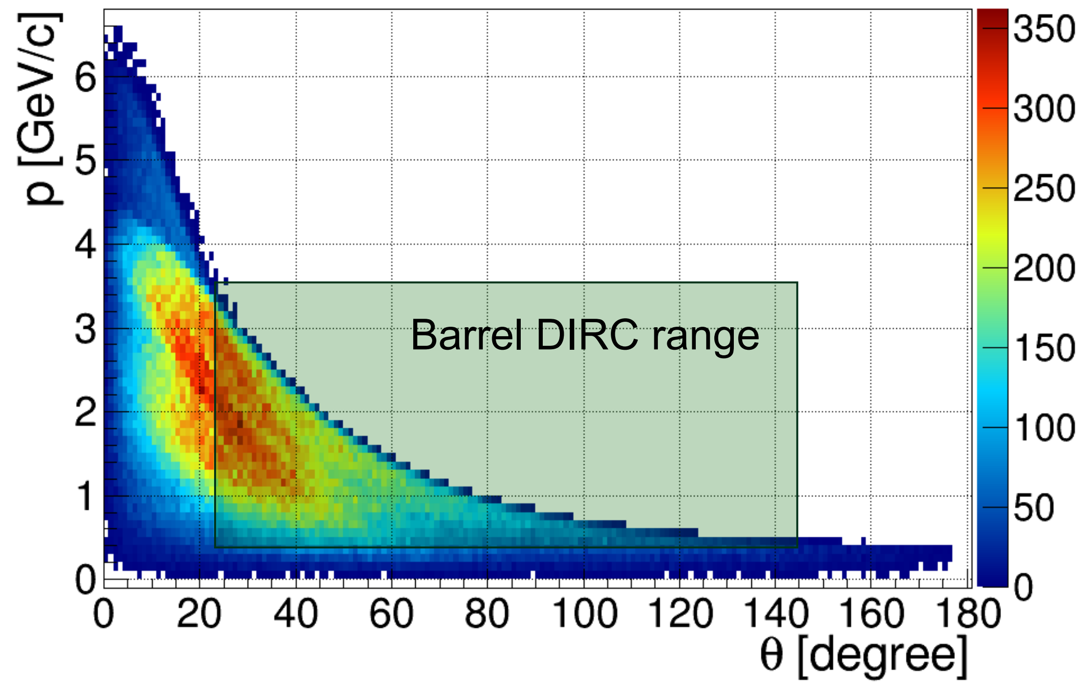
Roman Dzhygadlo
for the PANDA Cherenkov Group

PANDA Requirements

- Hadronic particle identification: 200 MeV/c - 10 GeV/c.
- Cannot be performed by single PID component. =>
  - Barrel DIRC
  - Endcap Disc DIRC
  - Time-of-Flight system
  - dE/dx of tracking system

Barrel DIRC

- Acceptance: 22-140 degree
- Momentum range: 0.5 - 3.5 GeV/c
- PID goal: 3σ π/K separation



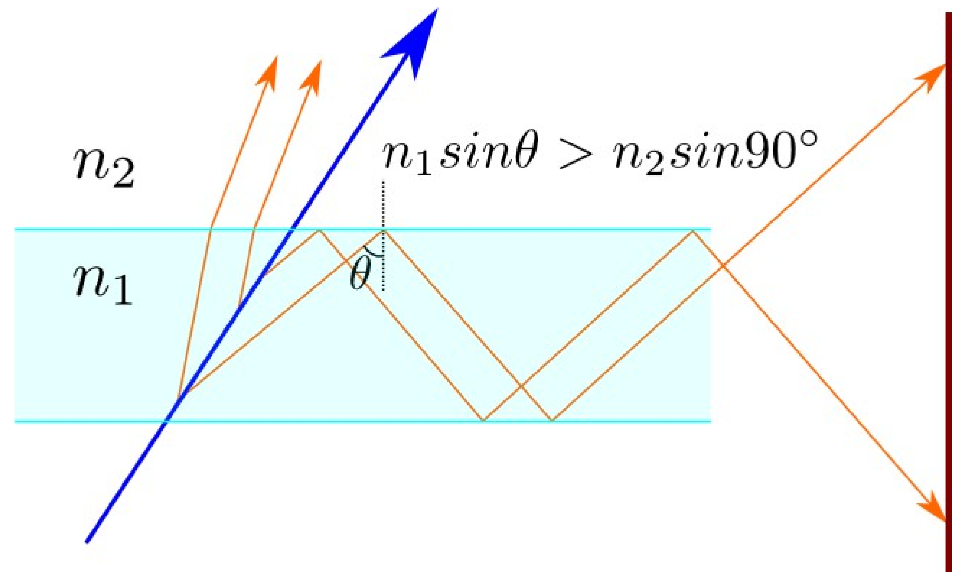
Kaon momentum distribution of the major channels @ 6-15 GeV/c.

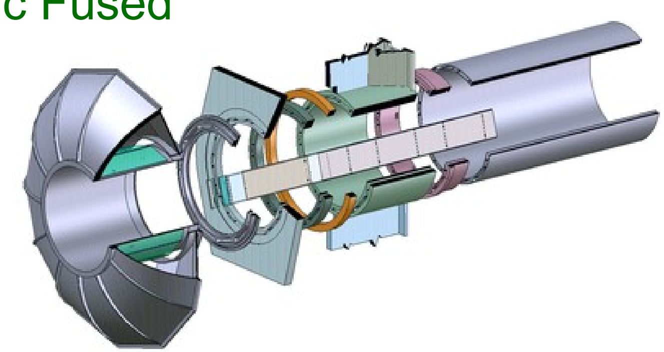
DIRC Principle

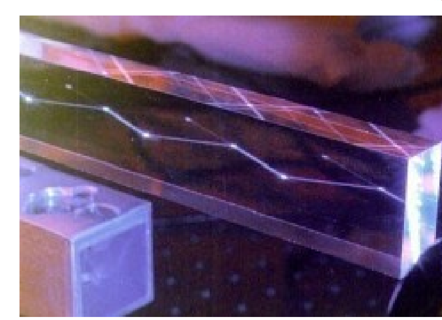
Detection of Internally Reflected Cherenkov Light

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

- Charged particle traversing radiator with refractive index ($n_1 \approx 1.47$) and $\beta = v/c > 1/n$ 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: polished, long rectangular bar made from Synthetic Fused Silica ("Quartz").
- Proven to work (BABAR-DIRC).

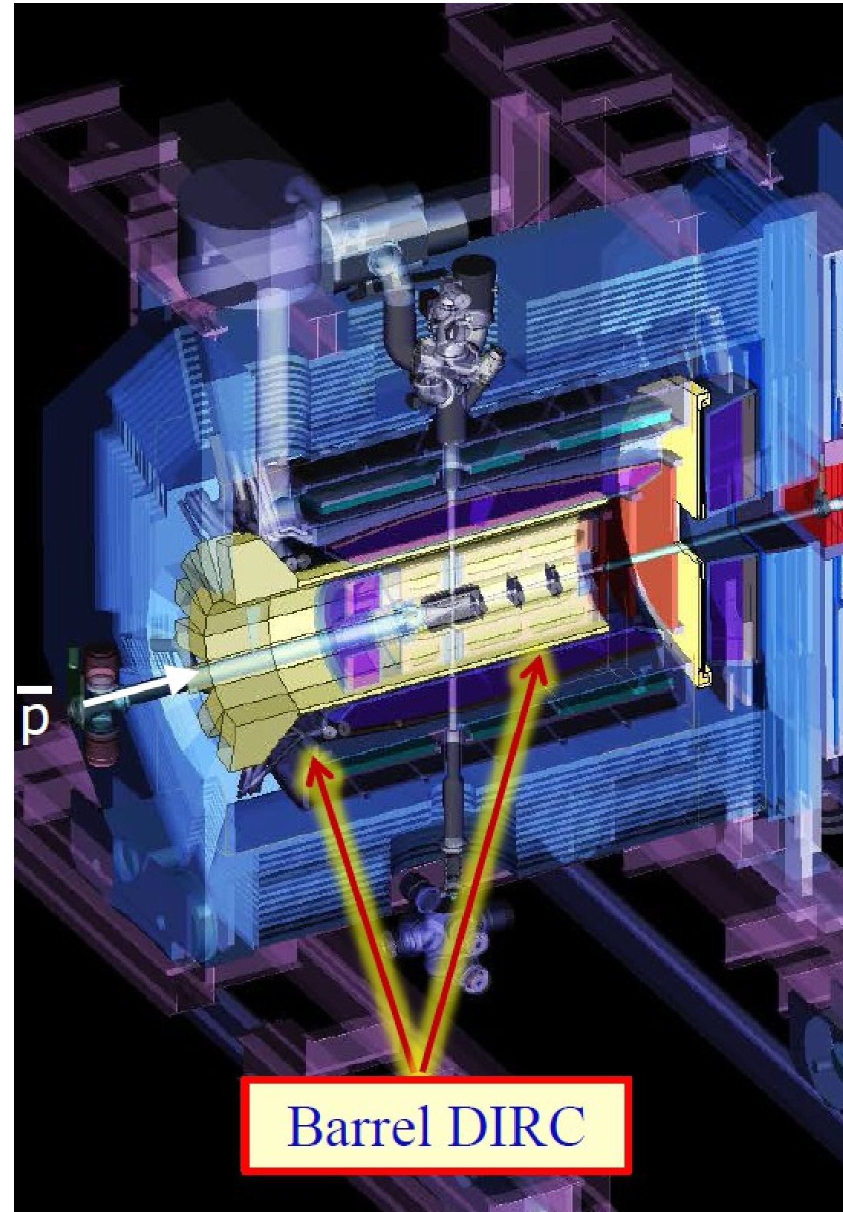






PANDA Barrel DIRC: Overview

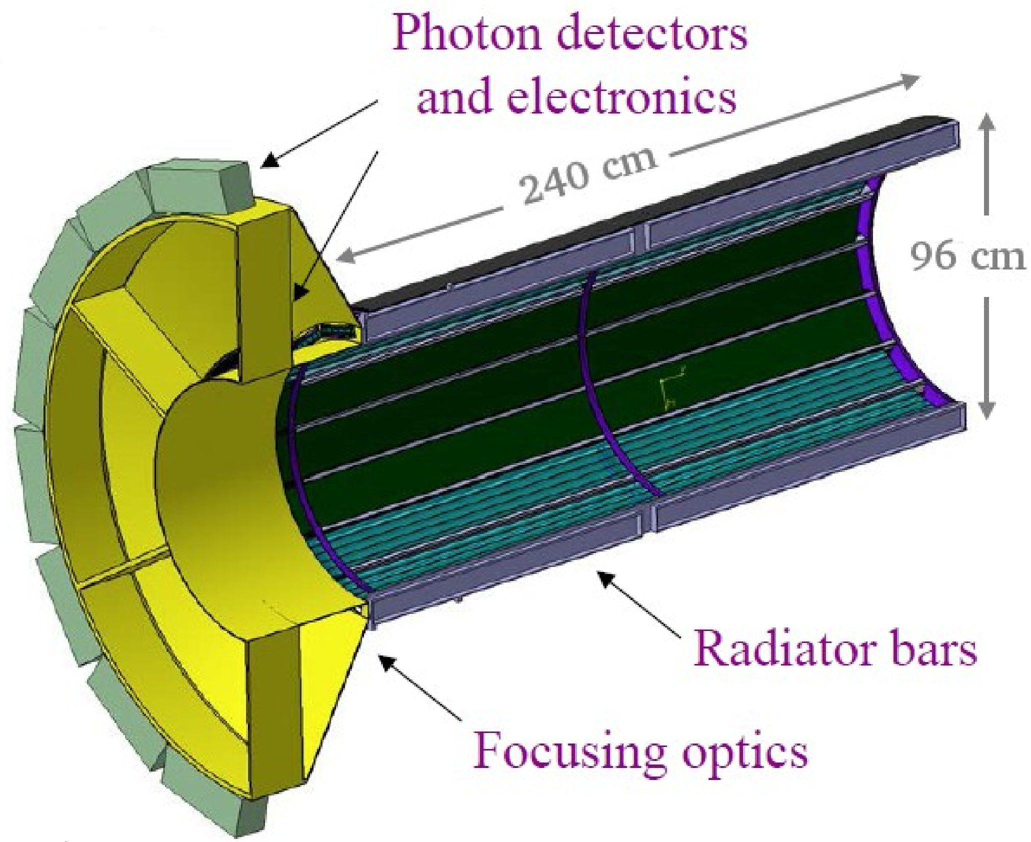
- Based on BABAR-DIRC with key improvements.
- Good particle identification.
- Uniquely thin and compact design.
- Nearly full solid angle coverage.
- High efficiency and purity of identification.
- High rate capability.

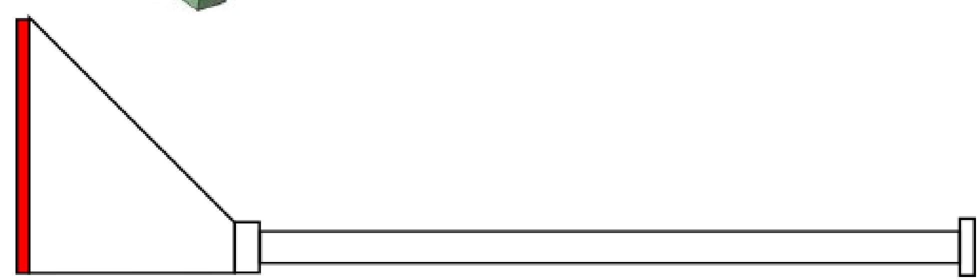


Current R&D and construction: in cooperation with many institutions (HIM Mainz, JGU Mainz, FAU Erlangen-Nurnberg, JLU Giesen, JINR Dubna, U. Glasgow, SMI OeAW Vienna)

Panda Barrel DIRC: Components

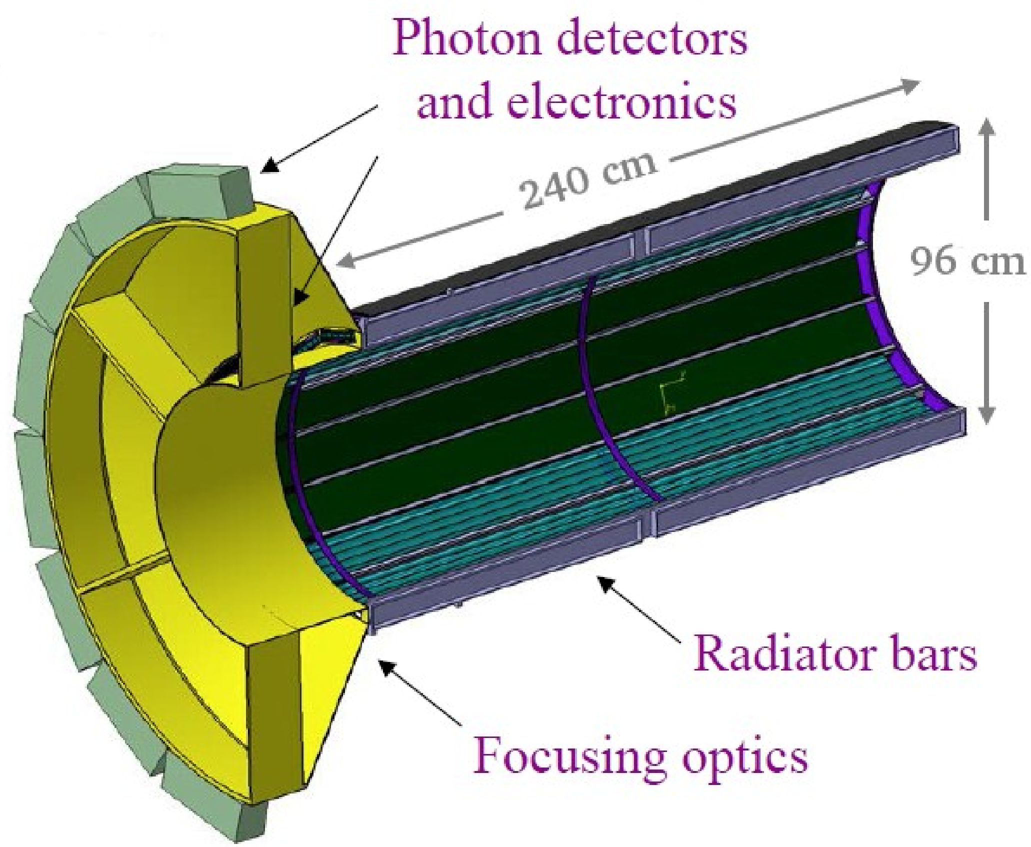
- Highly polished rectangular bars made from synthetic fused silica ("quartz") to produce Cherenkov light and guide photons to detectors.
- Mirror – to reflect forward going photons.
- Focusing optics images Cherenkov photons ("Cherenkov ring") on sensor array.
- Compact expansion volume.
- Compact multi-anode photon detectors for efficient, fast detection of single photons.
- Fast readout electronics to measure photon signal charge and arrival time with ~100 ps resolution at average reaction rate of 20 MHz in trigger-less environment.



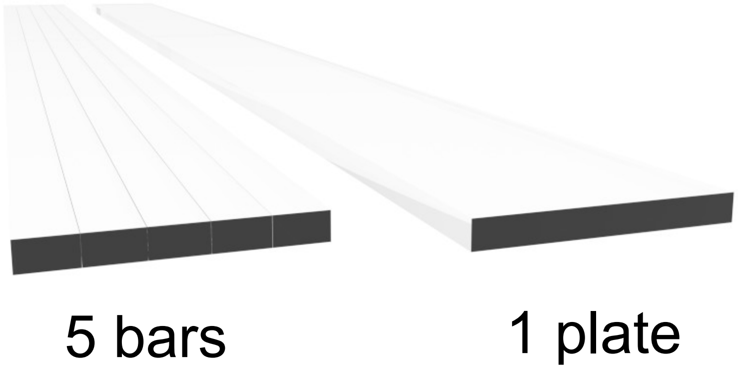


Baseline design

- Baseline design: based on BABAR DIRC with key improvements
- Barrel radius ~48 cm;
- 80 radiator bars, synthetic fused silica
  17mm (T) × 32mm (W) × 2400mm (L)
  packed into 16 sectors.
- Focusing optics: lens system.
- Compact EV: 30 cm in depth, oil-filled.
- Photon detector: ~15,000 channels of MCP-PMTs.
- Fast photon detection:
  fast TDC plus ADC (or ToT) electronics.
- Expected performance:
  - Single photon Cherenkov angle resolution: 8-10 mrad.
  - Number of detected photons for $\beta \approx 1$ track: 15-50.
- Other options under active investigation.



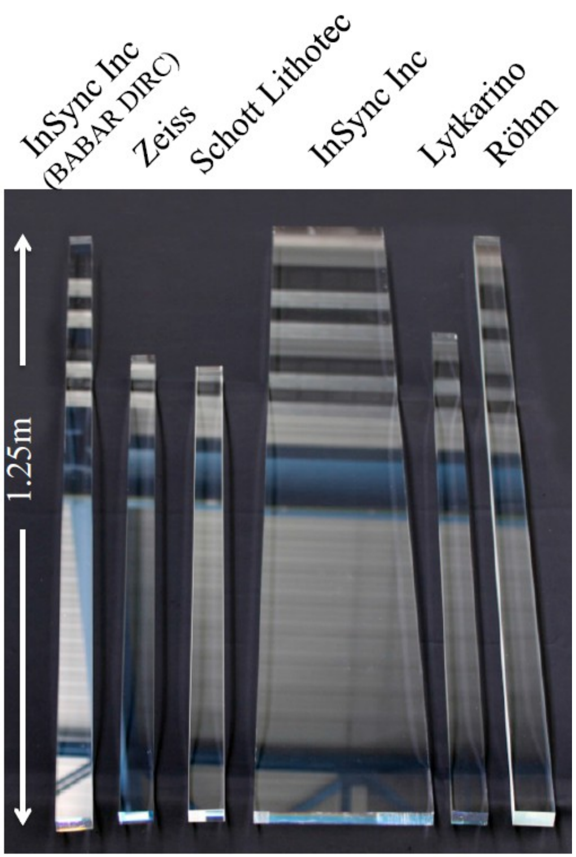
Radiator

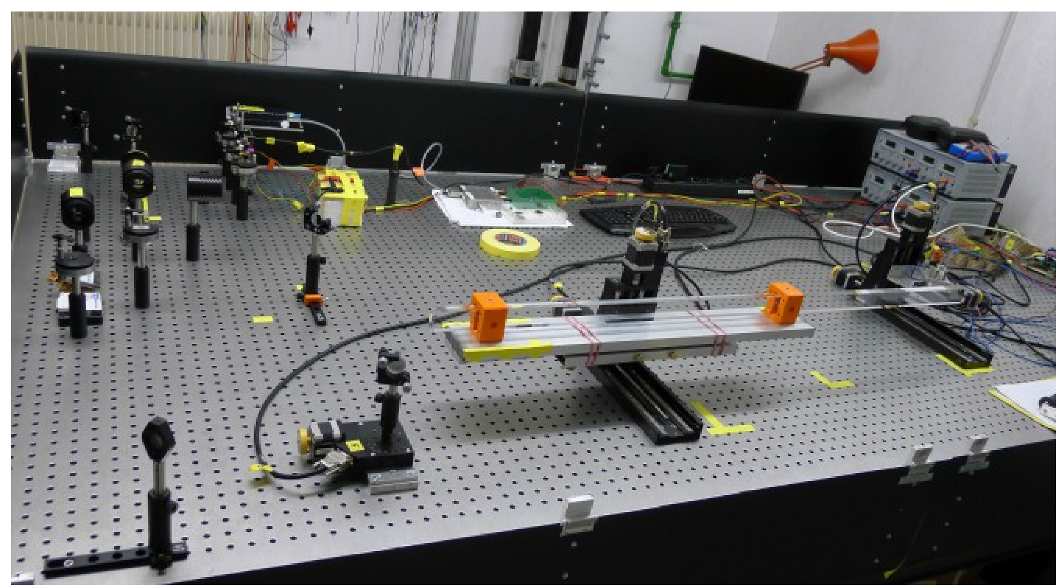


- Expensive
- Production challenge
  - Highly polished
  - Surface roughness (10-15Å rms), squareness (<0.5 mrad), parallelism with optical finish and long sharp edges

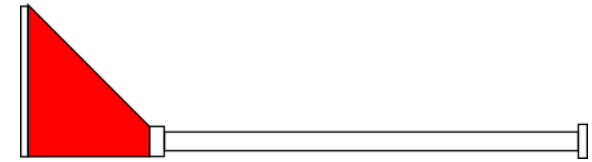
Working with potential vendors in Europe and USA, obtained ~30 prototype bars and plates from several companies.

Verification of the surfaces and angles with the test setup shows: several vendors are able to produce required radiators (InSync, Zeiss, Zygo).

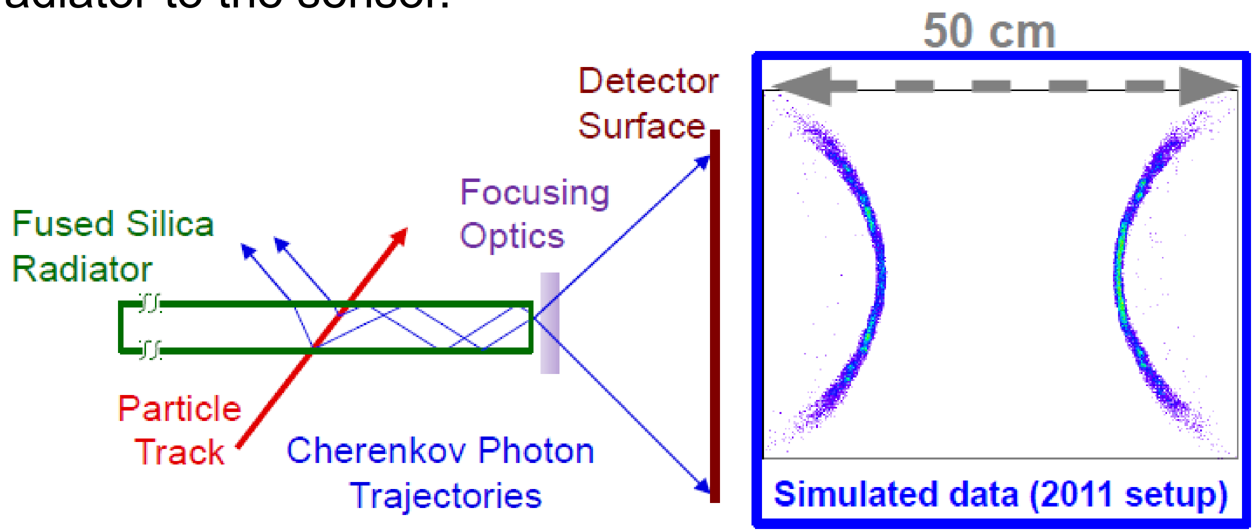


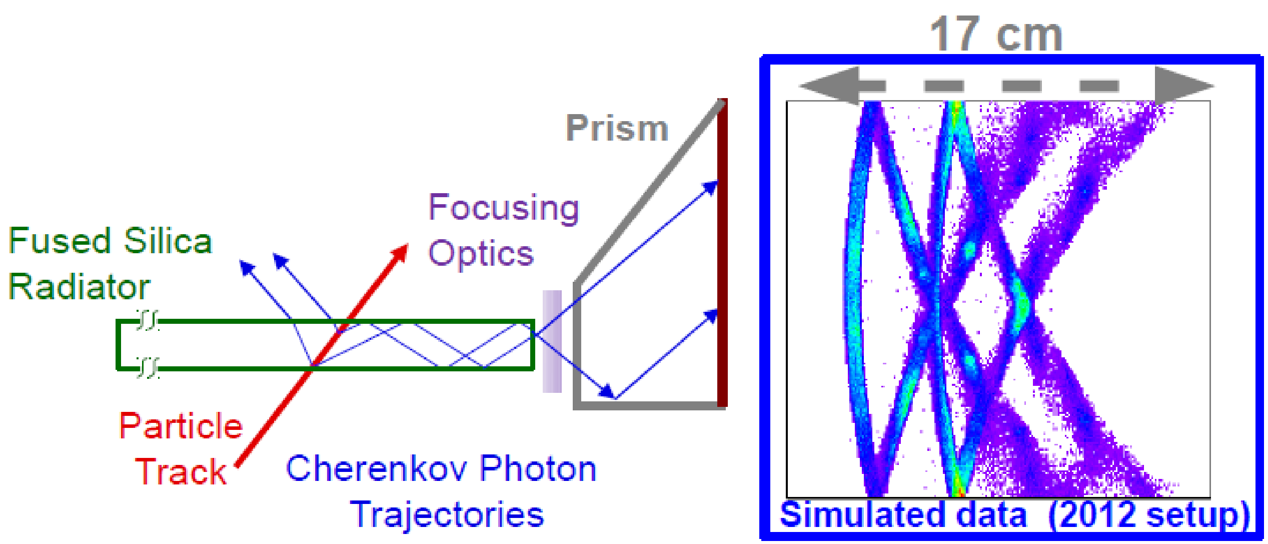


Expansion Volume

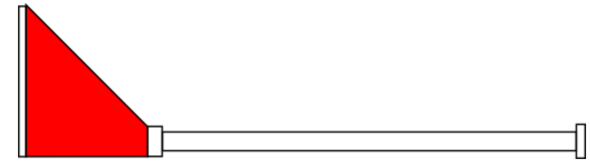


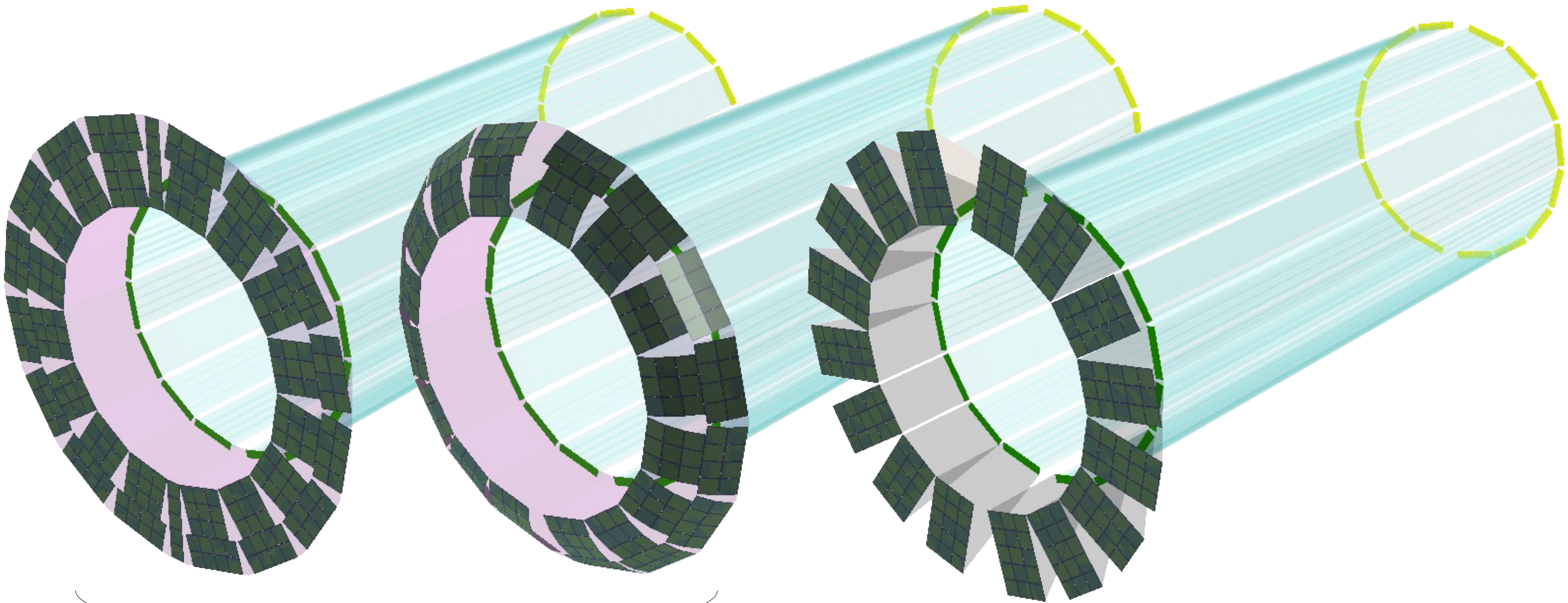
Expansion volume projects Cherenkov light from the radiator to the sensor.





Expansion Volume

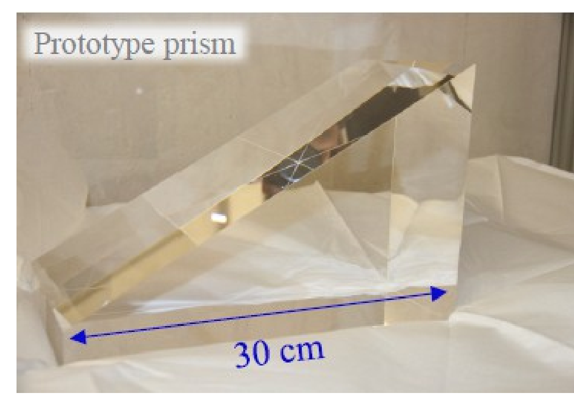




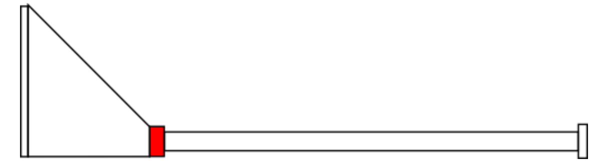
Oil tank (mineral oil)

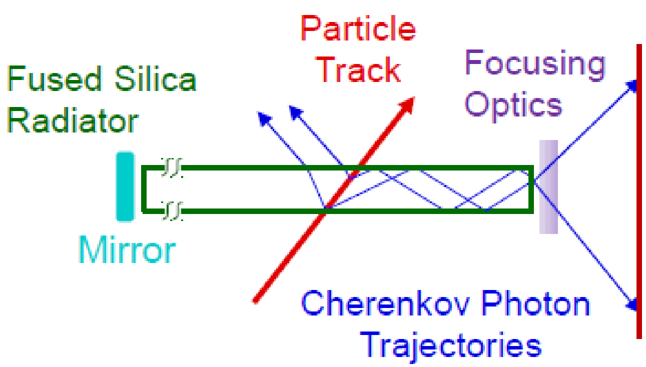
Separated Prisms (fused silica)

- Oil tank:
  - fewer reflections – simpler hit pattern
  - low photon yield due to absorption
- Prism:
  - minor photon losses
  - more reflections – complicated hit pattern

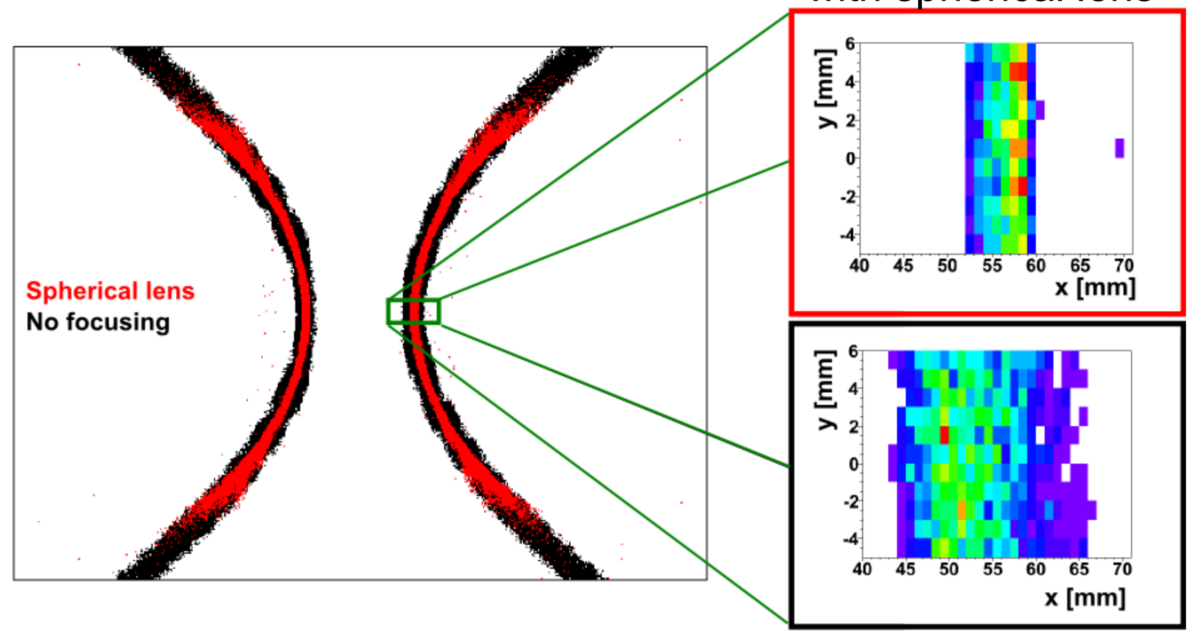


Focusing



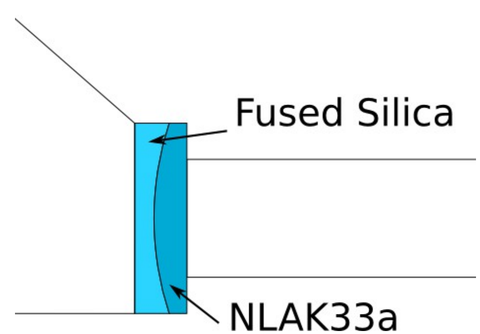


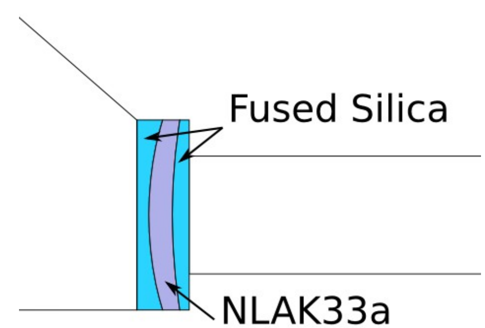
with spherical lens



with no focusing

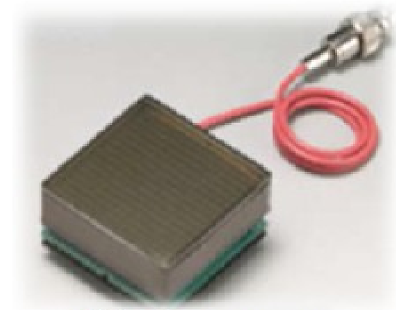
- Materials with high-refractive index (NLAK33, PbF_{2},).
- Single or doublet lens attached to the backward end of the bar box
  - cylindrical
  - spherical
- Lenses with and without air gap are tested.
- Design is optimized by ZEMAX
  and Geant simulations.



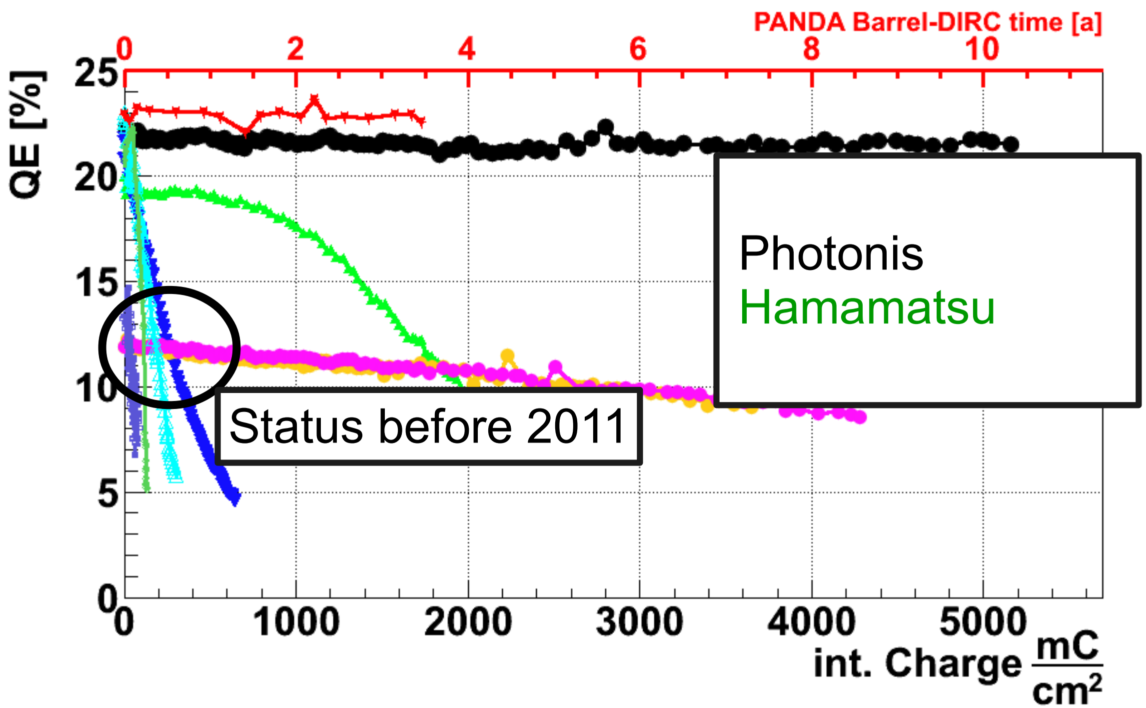


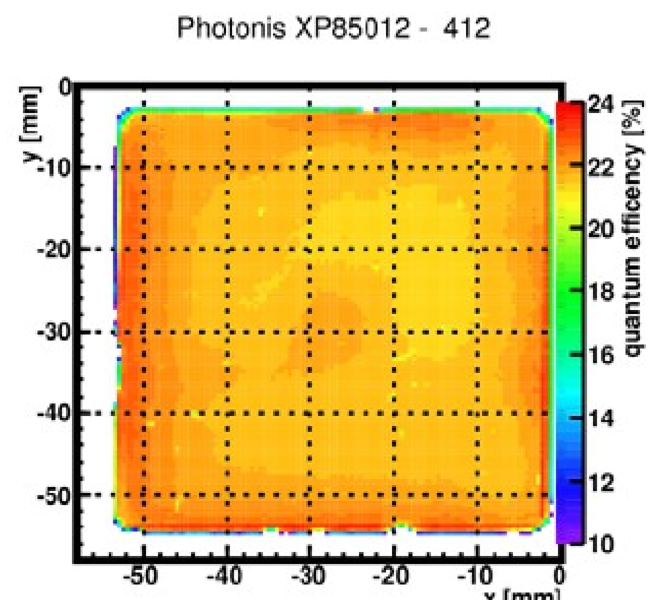
Sensors

- Array of micro-channel plate photomultiplier tubes (MCP-PMTs) with ~30 ps time resolution operating in 1T magnetic field with a high rates up to 0.2 MHz/cm^2 .
- Obtained prototype sensors from Hamamatsu and Photonis. Setup to scan sensors for quantum efficiency and gain, measure rate tolerance and lifetime.
- R&D cooperation with industry resulted in breakthrough lifetime improvement: from 0.2-0.3 C/cm^2 to > 5 C/cm^2.
- Sensor candidate for PANDA Barrel DIRC identified (Photonis). (8x8 pixels with a pixel size of about 6.5 mm x 6.5 mm)



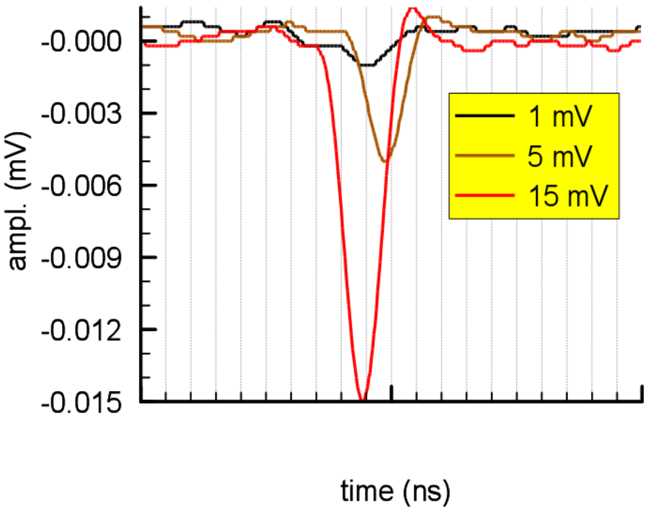
Photon sensor





Electronics

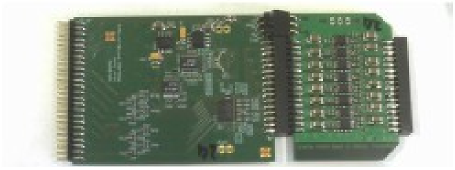
- Signal rise time typically few hundred picoseconds.
- 10-100x preamplifier usually needed.



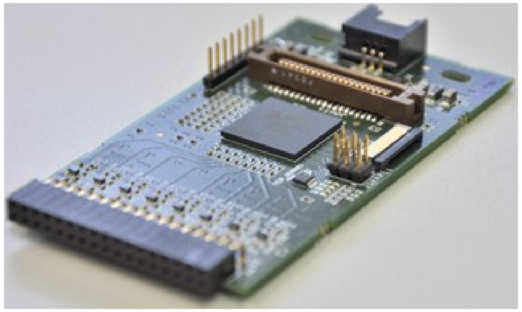
TRBv3

- High bandwidth 500MHz – few GHz.
- Radiation hardness may be an issue (FPGA). .
- Current approach:
  - HADES TRBv3 board with amplifier/discriminator front-end card mounted on MCP-PMT.
  - Front end electronics cards developed at Mainz and at GSI.
- Verify electronics performance with fast laser pulsers and several dedicated beam times at MAMI B, X1.

Mainz FEE card (NINO)



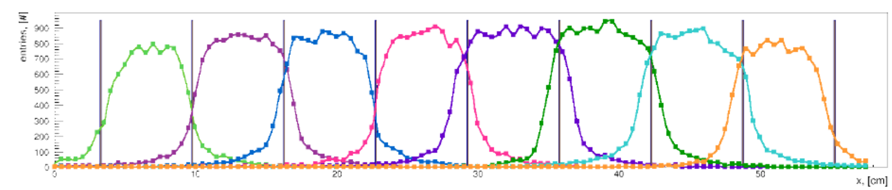
PADIWA (FPGAs)



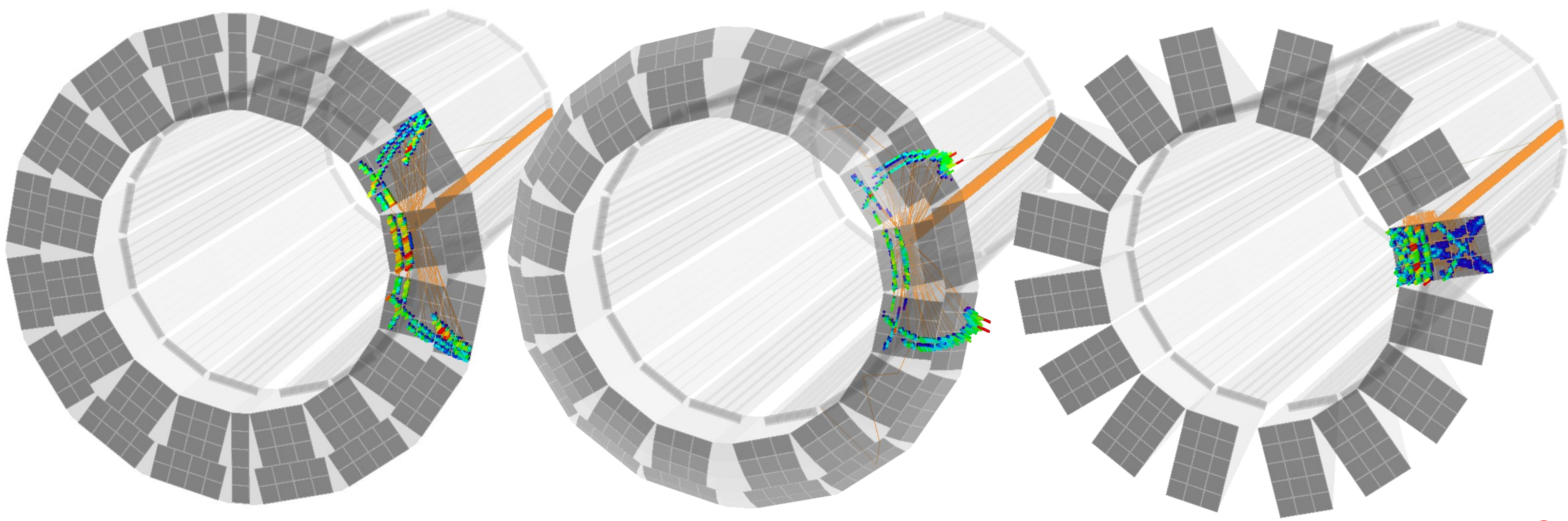
Simulation and Reconstruction

Event generation
↓
Particle transport
↓
Digitization
↓
Hit Finder
↓
Reconstruction

- Geant3, Geant4.
- All geometry options are implemented.
- Effects included in simulation:
  - Charge sharing
  - Dark counts
  - Transport efficiency
  - Detector efficiency
  - Single photon time resolution

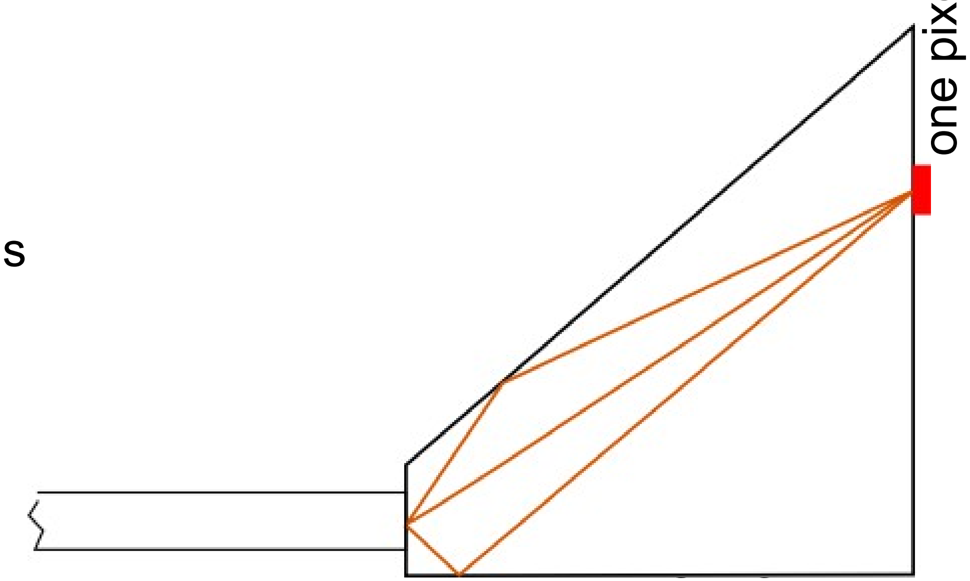


- Two favorite reconstruction methods (geometric reconstruction, time likelihood)

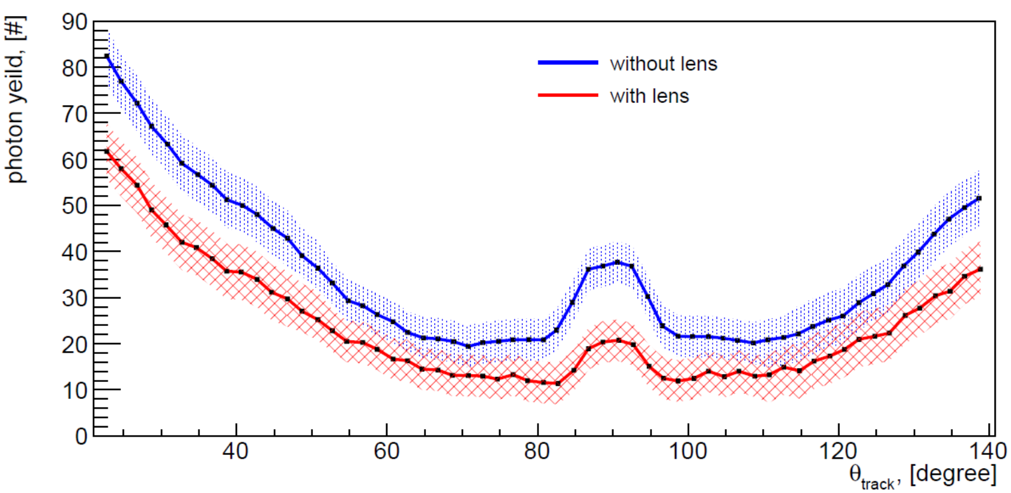


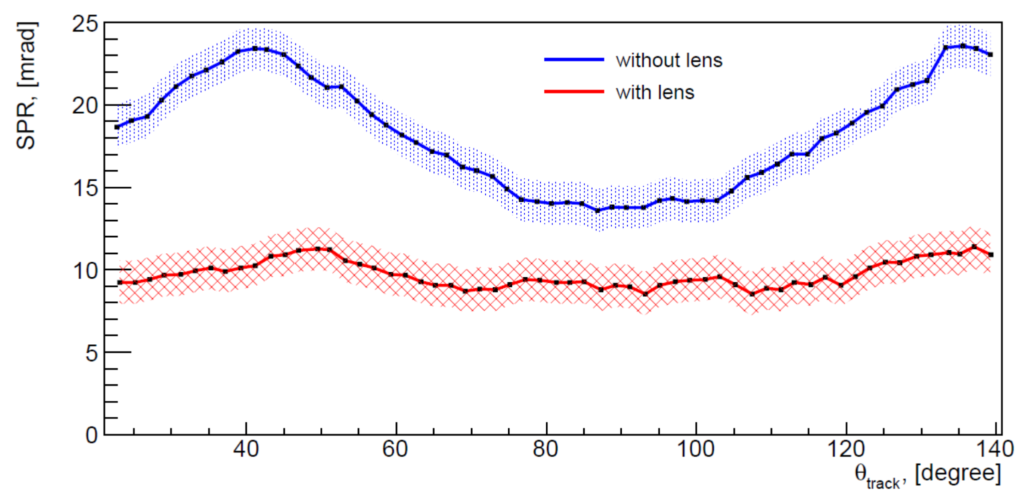
Reconstruction Methods: Geometric reco.

- BABAR-like reconstruction
- Simulation: store direction at the end of the radiators for each fired pixel by full simulation using photon gun.
- Reconstruction: stored direction for fired pixels are combined with charge track direction.
- Performance is evaluated using photon yield and single photon resolution (SPR)



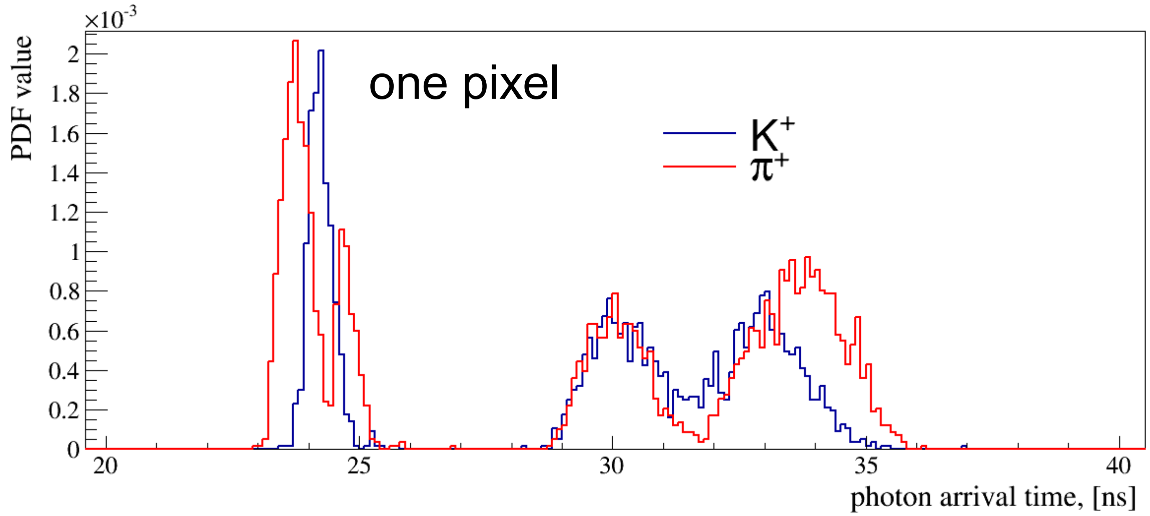
Example:



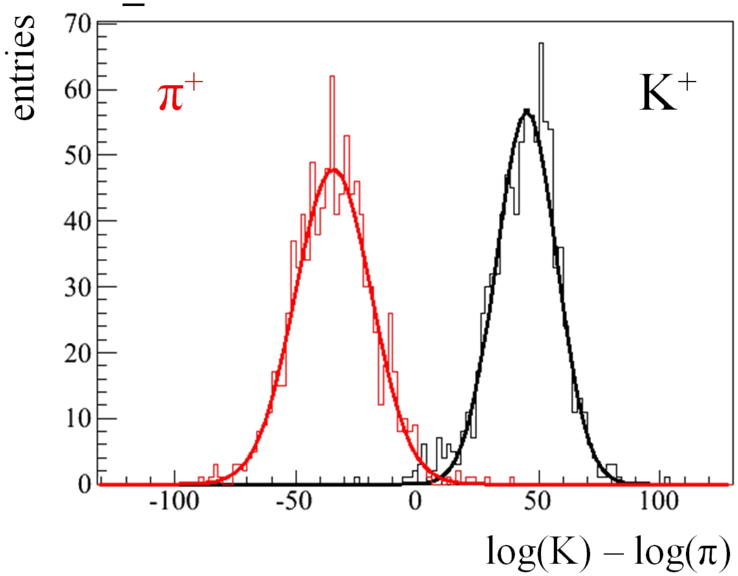


Reconstruction Methods: Time Likelihood

- Belle II-like reconstruction.
- Simulation: for each pixel store arrival time of photons from different charge particles as a Probability Density Functions.



p_track = 3.5 GeV/c
θ_track = 22°



- Reconstruction: arrival time of each photon from given track is compared with PDF to calculate time-based likelihood for the photon to originate from a given particle species.
- Combination of obtained likelihood with the Poissonian PDF of the number of observed photons creates the full likelihood.

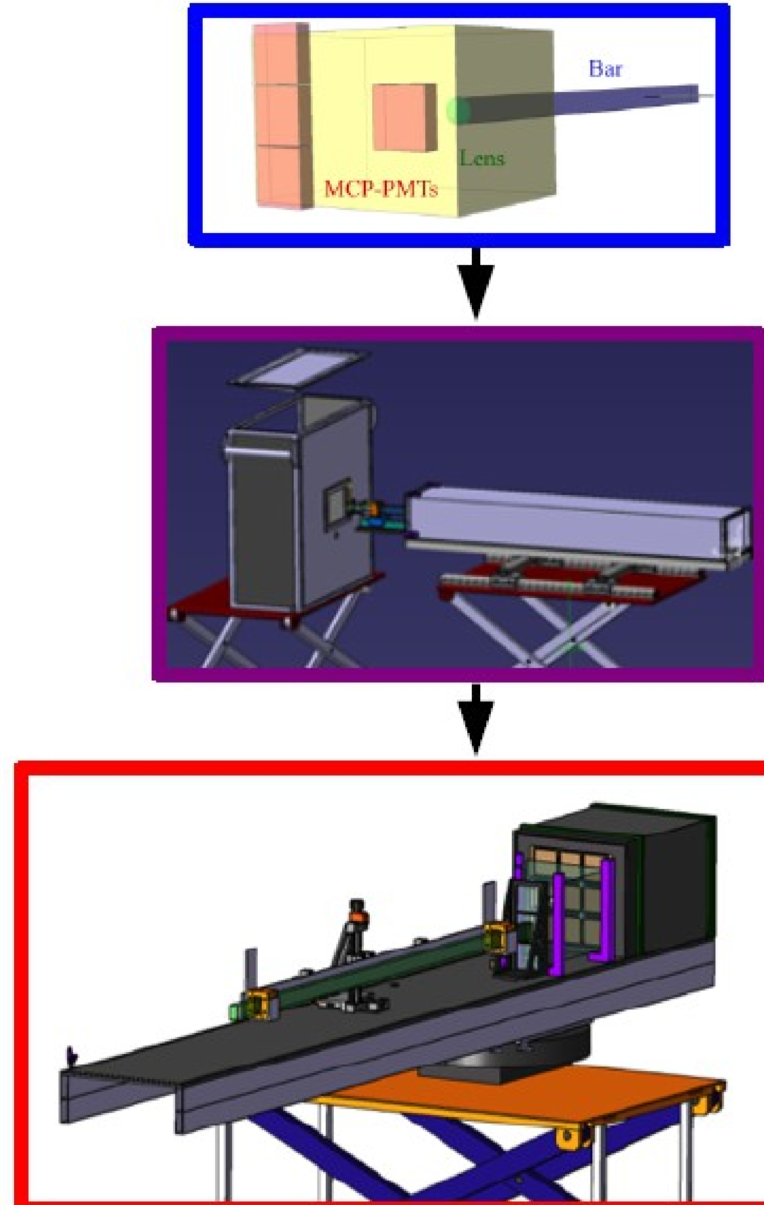
➔ Clean π/K separation at 3.5 GeV/c even without optics.

Barrel DIRC prototypes

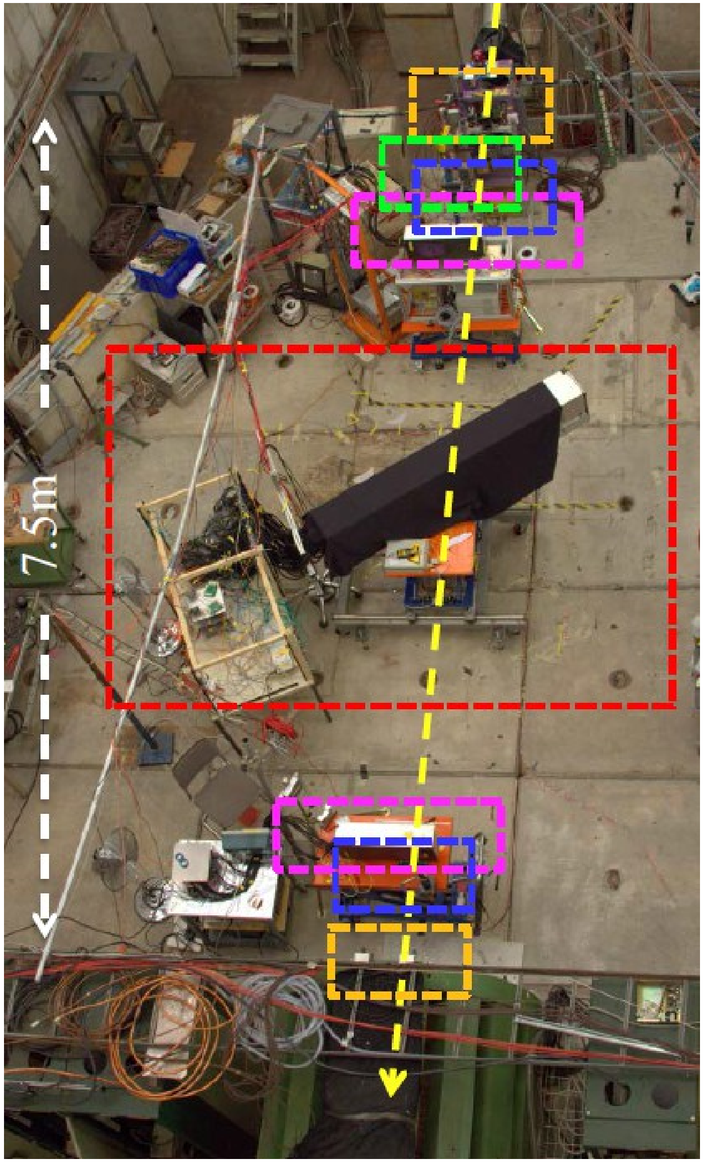
- **2008, 2009 – GSI:**
  - Schott Lithotec bar, spherical lens.
  - Expansion volume: small oil tank.
  - MCP-PMTs with pre-amplifiers.
  - ➔ First clear Cherenkov ring observed.

- **2011 – GSI, CERN:**
  - Larger, deeper expansion volume filled with mineral oil.
  - Movable and rotatable prototype support.
  - Sensors (MCP-PMTs, SiPM, Multi Anode PMT). 640 electronics channels (HADES TRB/NINO)
  - Focusing lenses with different coatings.
  - ➔ First determination of angle resolution (**σΘc= 9 mrad**) and number of photons per track (**Nph = 3**)

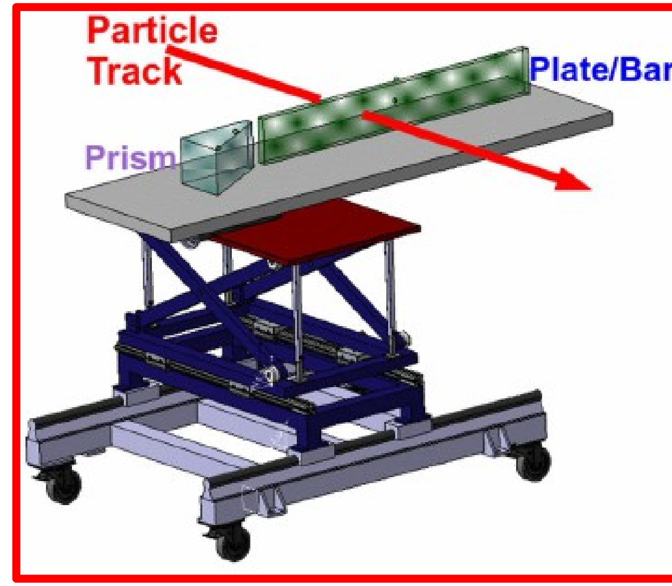
- **2012 – CERN**



Prototype 2012



MCP-TOF station
SciTil
Fiber Tracker station
DIRC prototype



- 15-10 GeV/c beam
- 4 weeks beam time.
- 220M trigers recorded.

- Compact solid fused silica expansion
- volume (prism) instead of oil tank.

- Wide range of beam-bar angles and beam z position – similar to PANDA phase space.

- Wide fused silica plate in addition to narrow bars.

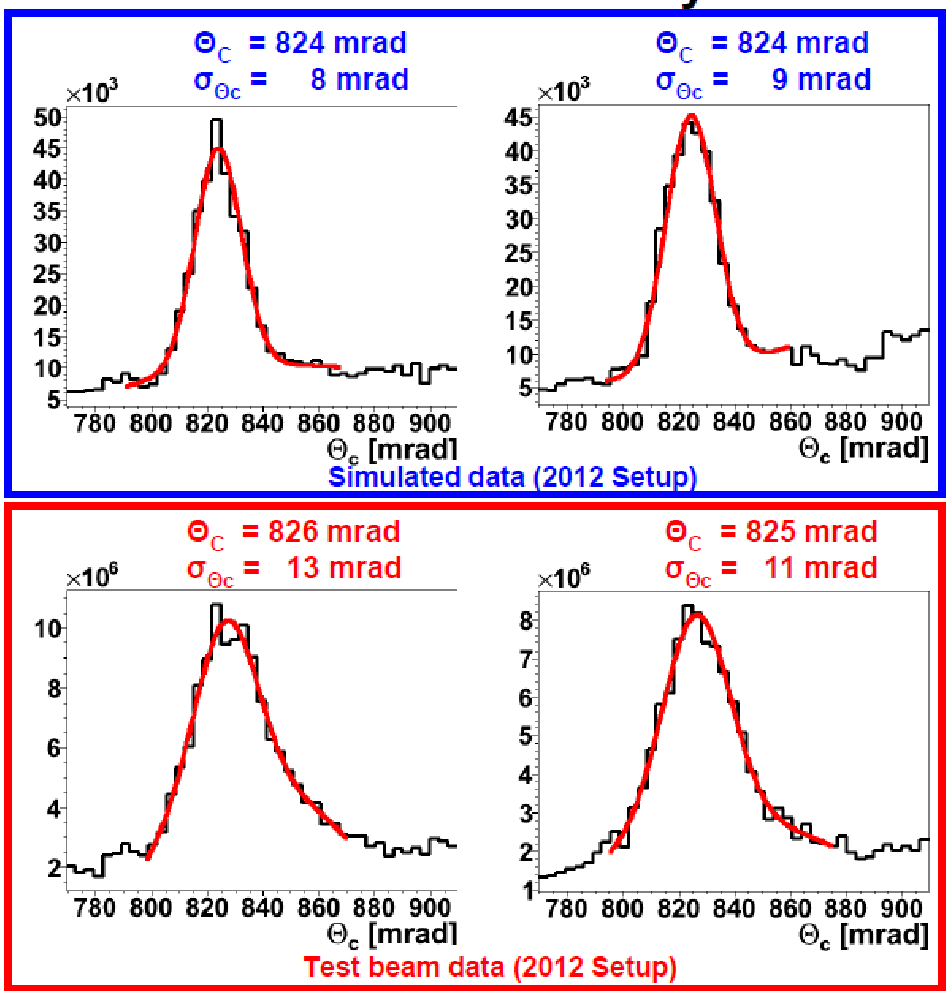
- Focal plane almost fully covered by array of 3x3 Photonis Planacon MCP-PMTs, 896 channel DAQ.

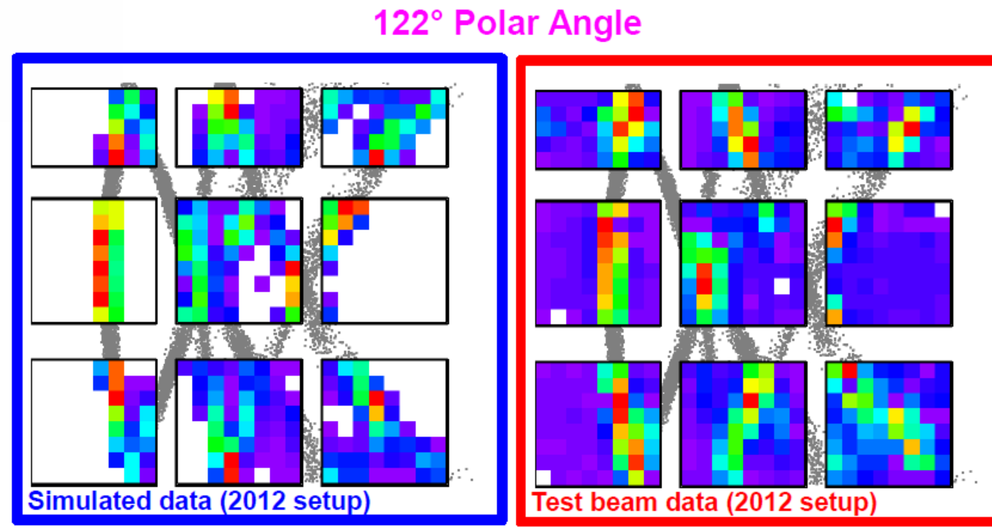
- Different lenses for the focusing system.

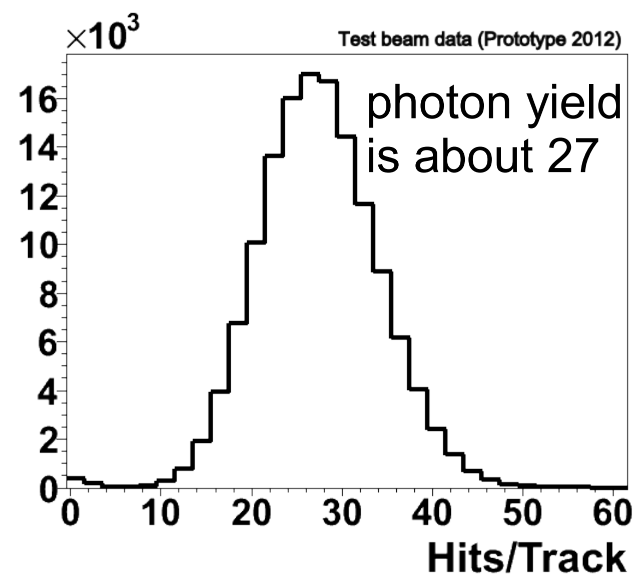
Prototype 2012: Results

- Clear Cherenkov signal.
- Good agreement with simulations.

Zeiss bar: **InSync bar:**







Summary

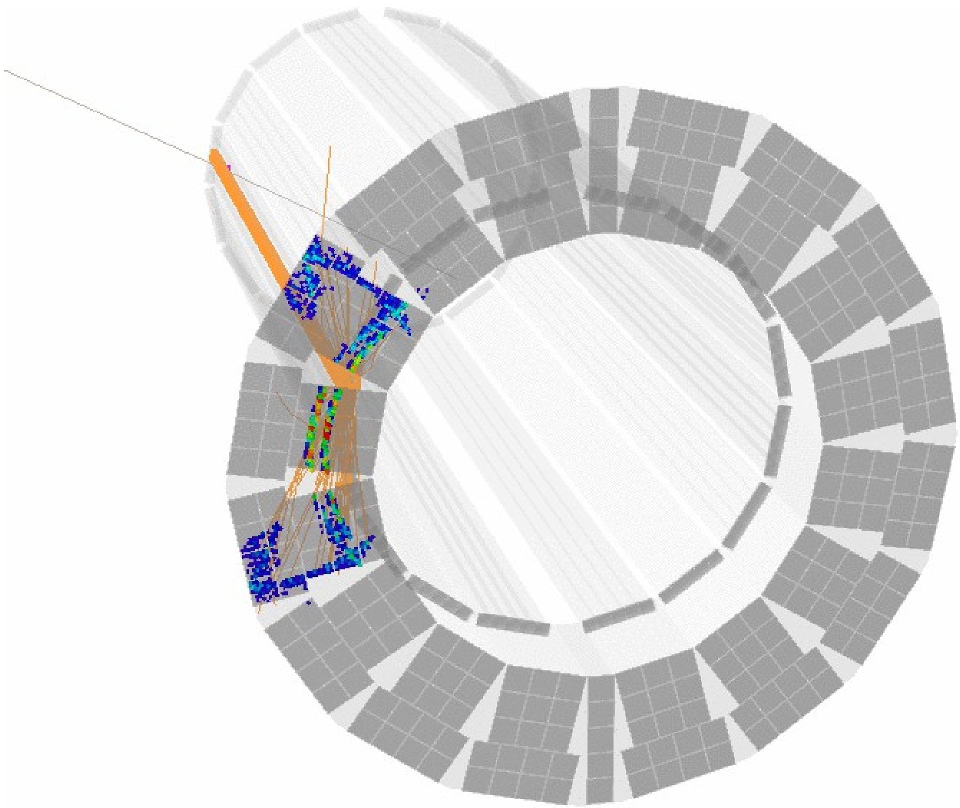
- The Barrel DIRC is a key component of the PANDA particle identification system.
- Baseline design with narrow bars and high-refractive lens system meet PANDA PID goals.
- Recent lifetime advances make MCP-PMTs an excellent sensor choice.
- Ongoing prototype program has identified several potential vendors for radiator fabrication.
- Analysis of the prototype data shows promising results.
- Ongoing R&D activities: radiator quality, focusing optics, photon detectors, readout electronics, fast timing, chromatic correction, simulation, reconstruction, and more.

Outlook

- 2014: Continue R&D, test designs in particle beams, write TDR.
  - Summer 2014: beam tests at GSI, basis for design decisions and TDR (bars vs. plates, tank expansion volume vs. prisms)
- 2015-2017: Component Fabrication, Assembly, Installation.
- Ready for commissioning in 2018.

Thank you for the attention

Baseline Barrel DIRC design



Barrel DIRC prototype 2012