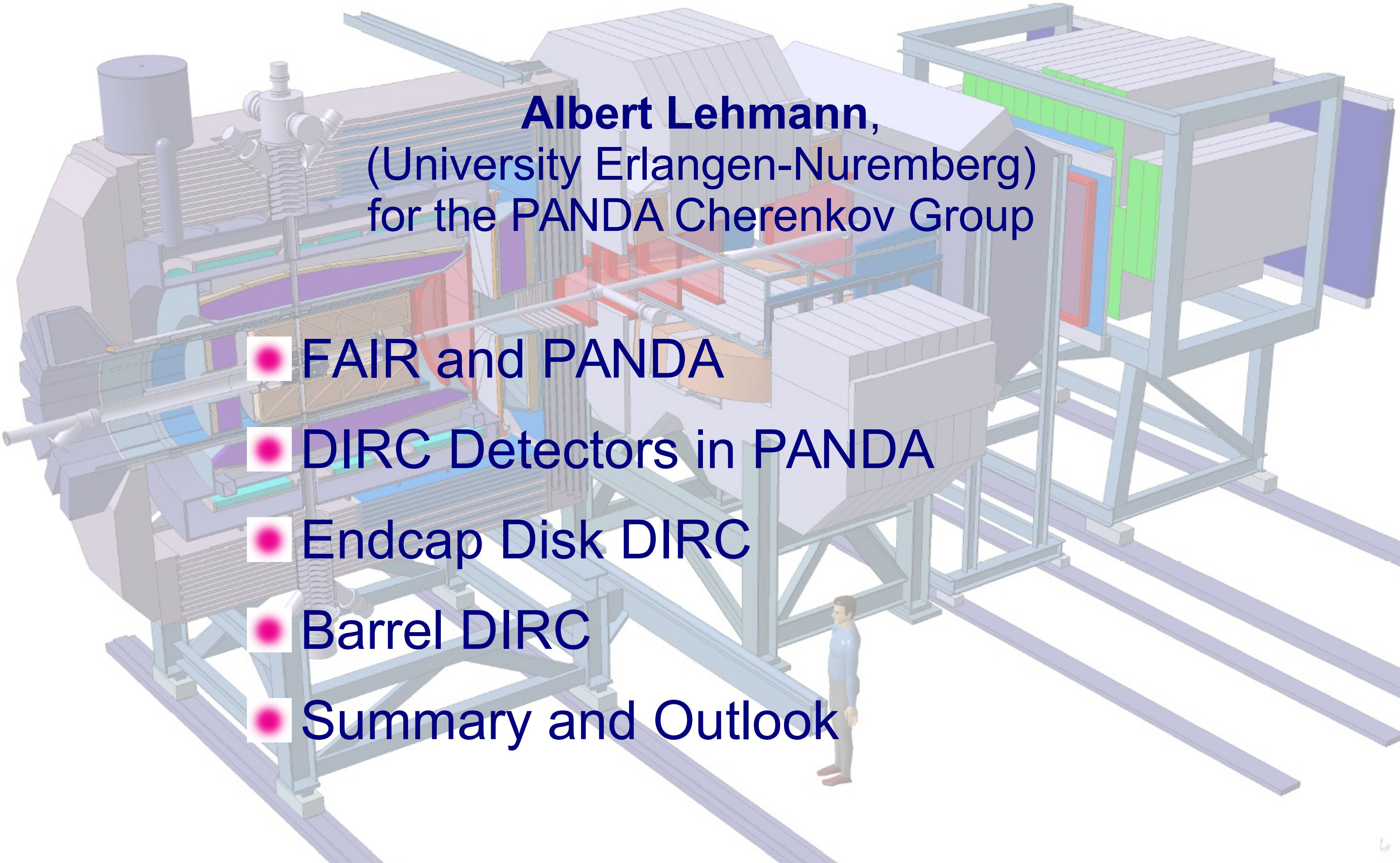
The DIRC Detectors at the PANDA Experiment



Albert Lehmann,
(University Erlangen-Nuremberg)
for the PANDA Cherenkov Group

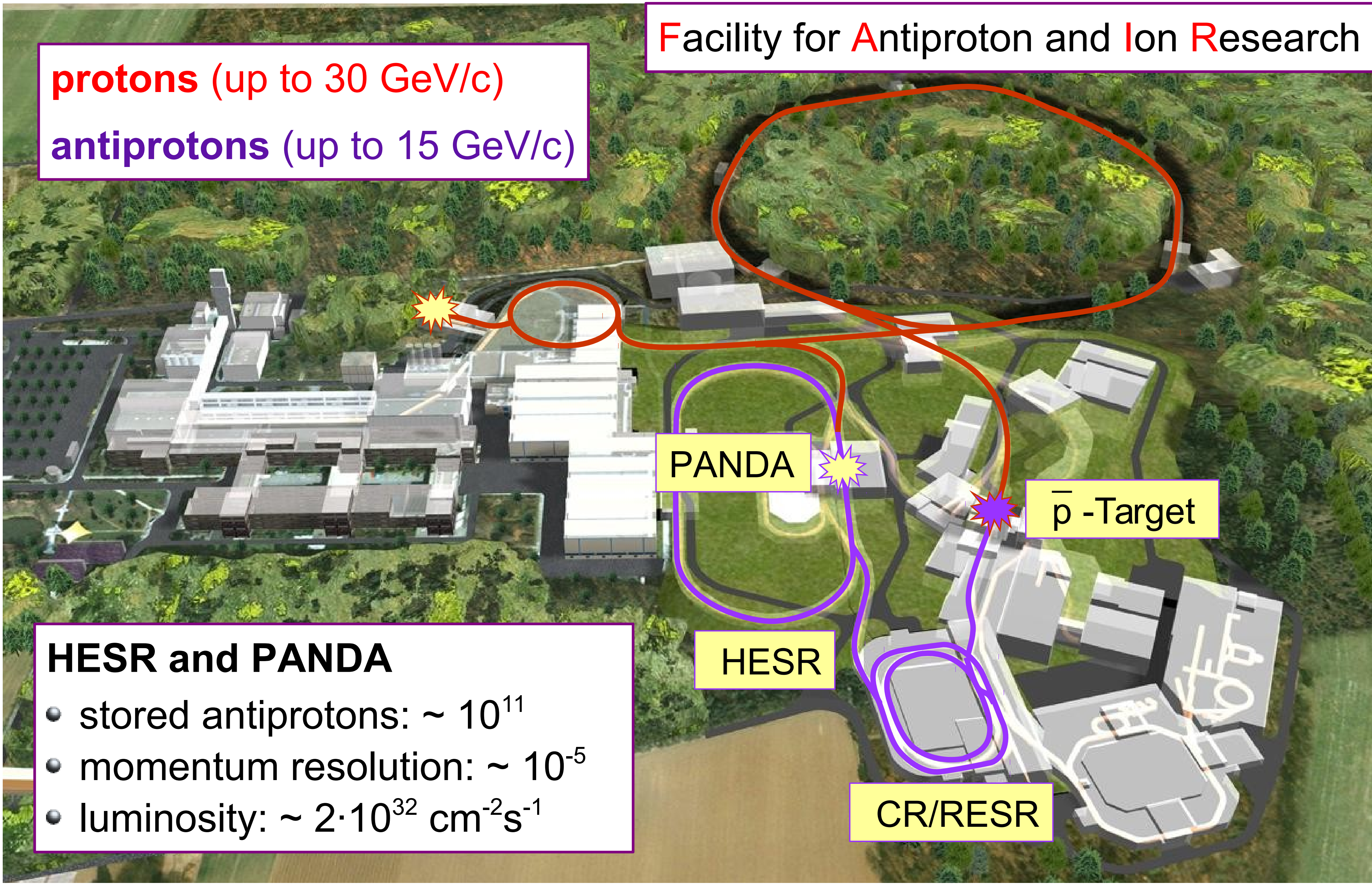
- FAIR and PANDA
- DIRC Detectors in PANDA
- Endcap Disk DIRC
- Barrel DIRC
- Summary and Outlook

FAIR and HESR/PANDA at GSI

Facility for Antiproton and Ion Research

protons (up to 30 GeV/c)

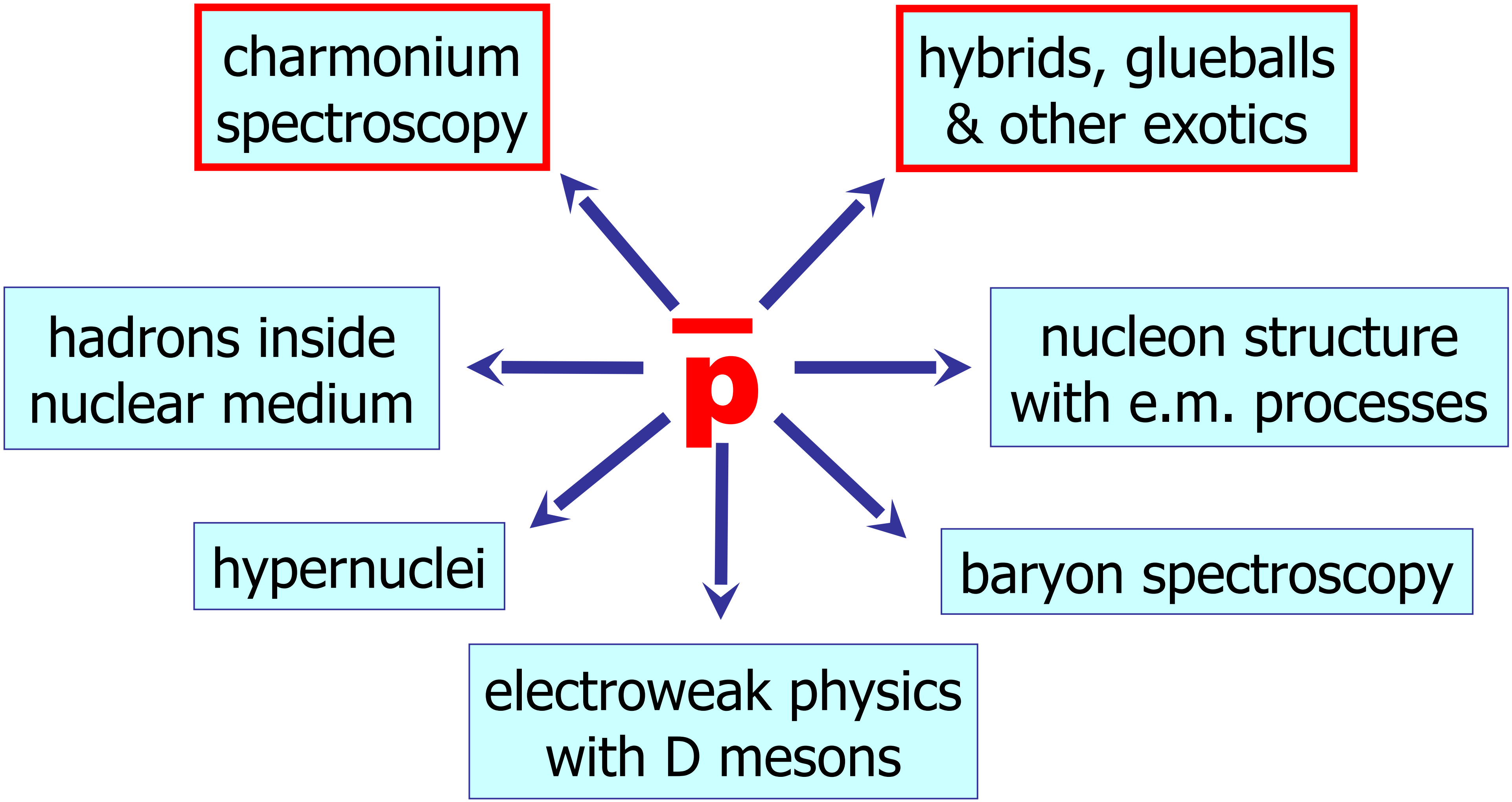
antiprotons (up to 15 GeV/c)



HESR and PANDA

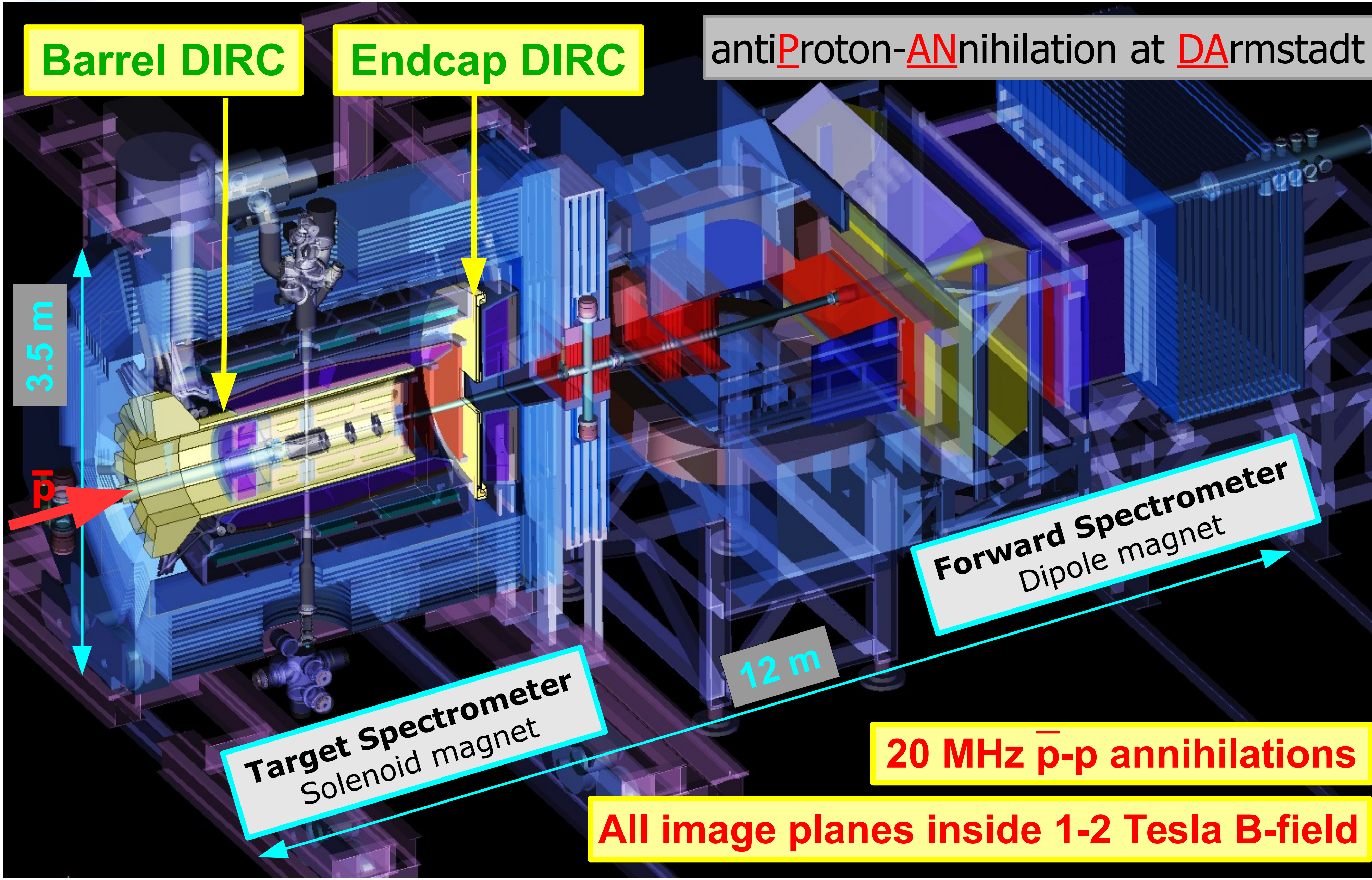
- stored antiprotons: ~ 10^{11}
- momentum resolution: ~ 10^{-5}
- luminosity: ~ $2 \cdot 10^{32}$ $cm^{-2}s^{-1}$

PANDA Physics Program

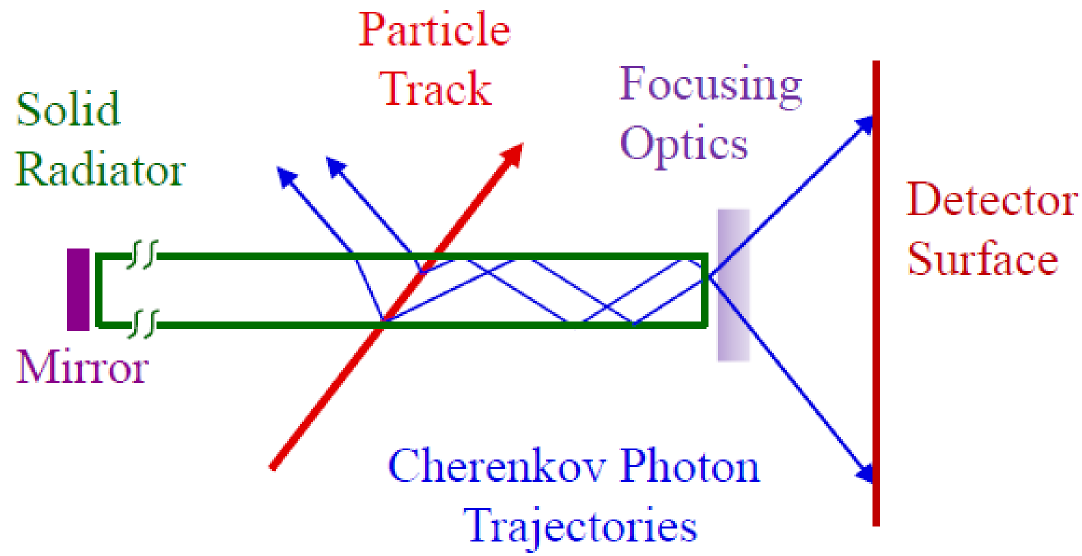


Excellent PID required, in particular π/K separation

PANDA Detector at FAIR



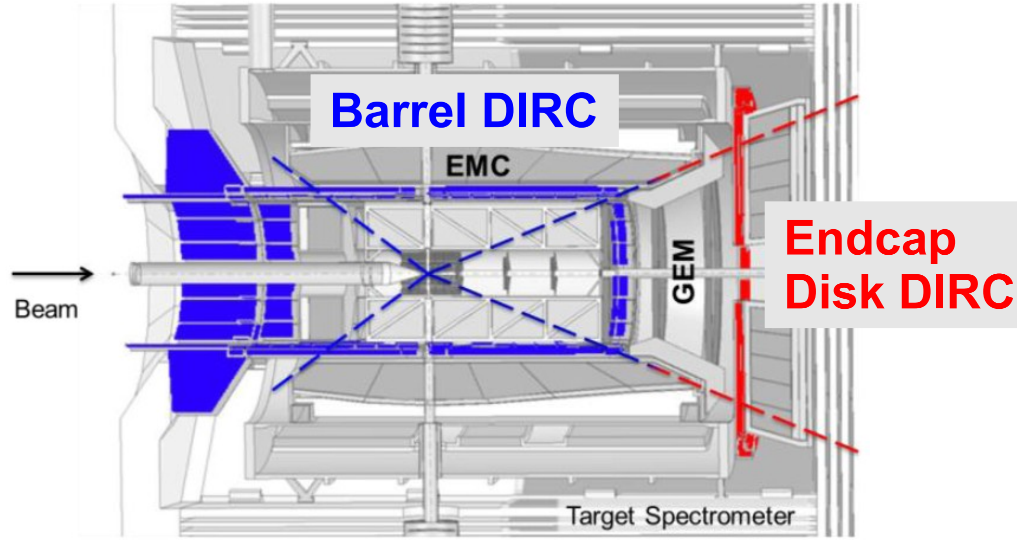
DIRC Principle



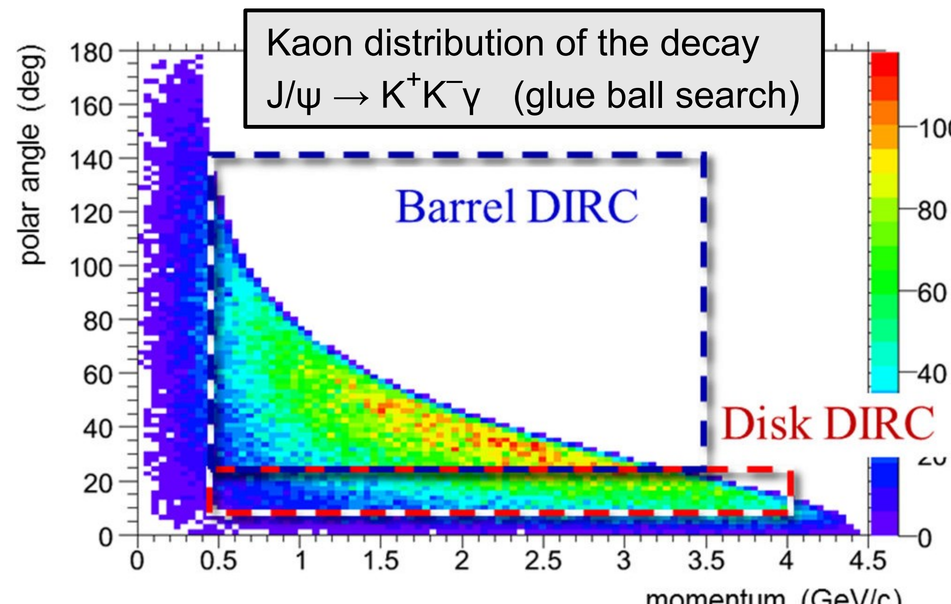
- radiator = light guide
  - refractive index n > √2
  - synthetic fused silica
  - bar, plate or disk
- Cherenkov photons
  - produced by charged particles with $\beta > 1/n$ on cone with $\cos\theta_C = 1/n\beta$
  - total internal reflection along radiator
  - reach image plane through (optional) focusing optics and expansion volume
- image plane = detector surface
  - multi-pixel array of photon detectors
  - measure x, y, and time of Cherenkov photons corresponding to θ_C, φ_C and t_{top}

PANDA DIRC Detectors

- Barrel DIRC
  - design similar to BaBar DIRC
  - polar angle coverage:
    $22° < \theta < 140°$
  - PID goal:
    3σ π/K separation up to 3.5 GeV/c
  - π/K Cherenkov angle difference at 3.5 GeV/c in fused silica (quartz):
    8.5 mrad

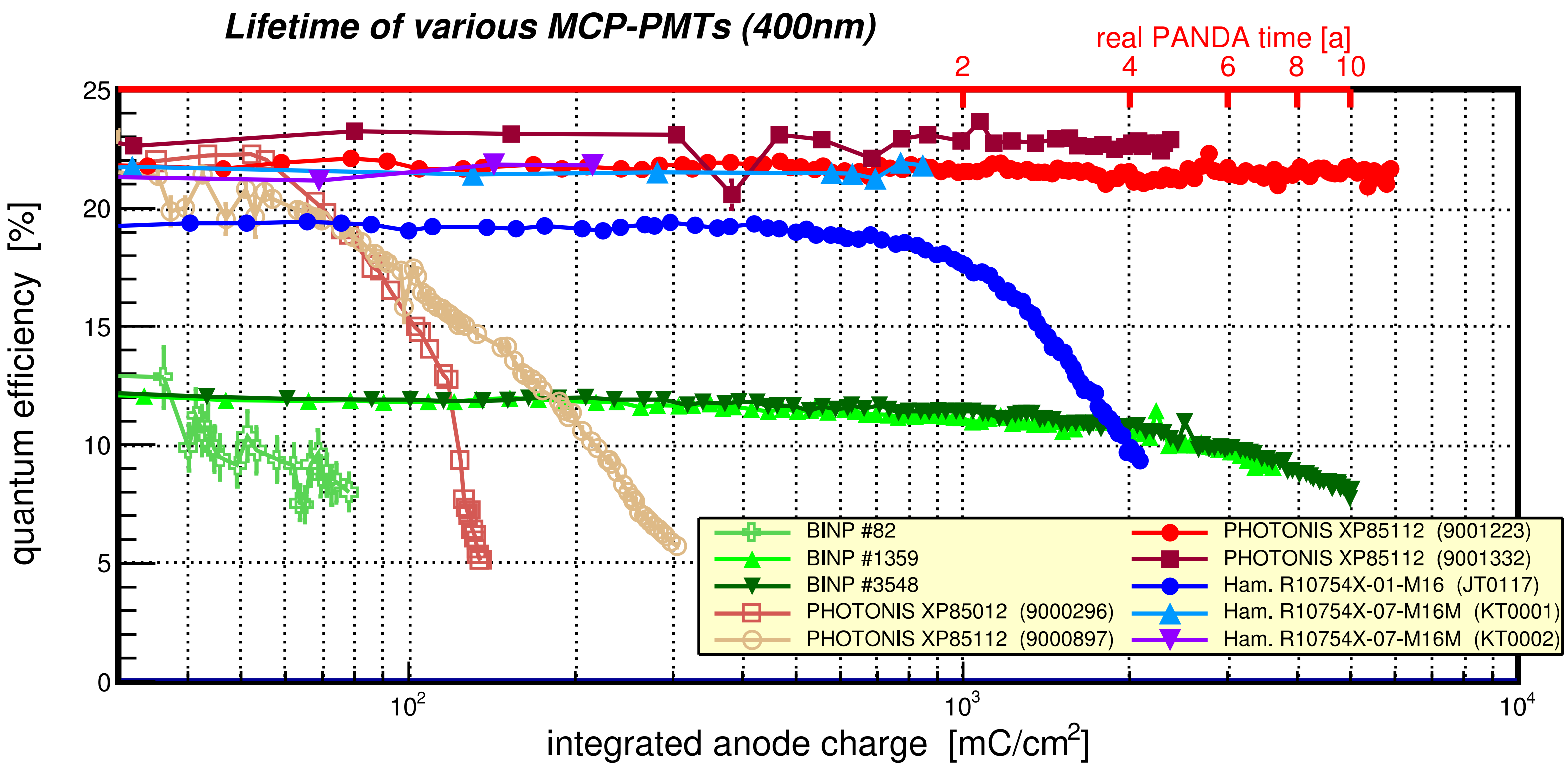


- Endcap Disk DIRC
  - novel design
  - polar angle coverage:
    $5° < \theta < 22°$
  - PID goal:
    3σ π/K separation up to 4 GeV/c



Special Challenge: Photo Sensors

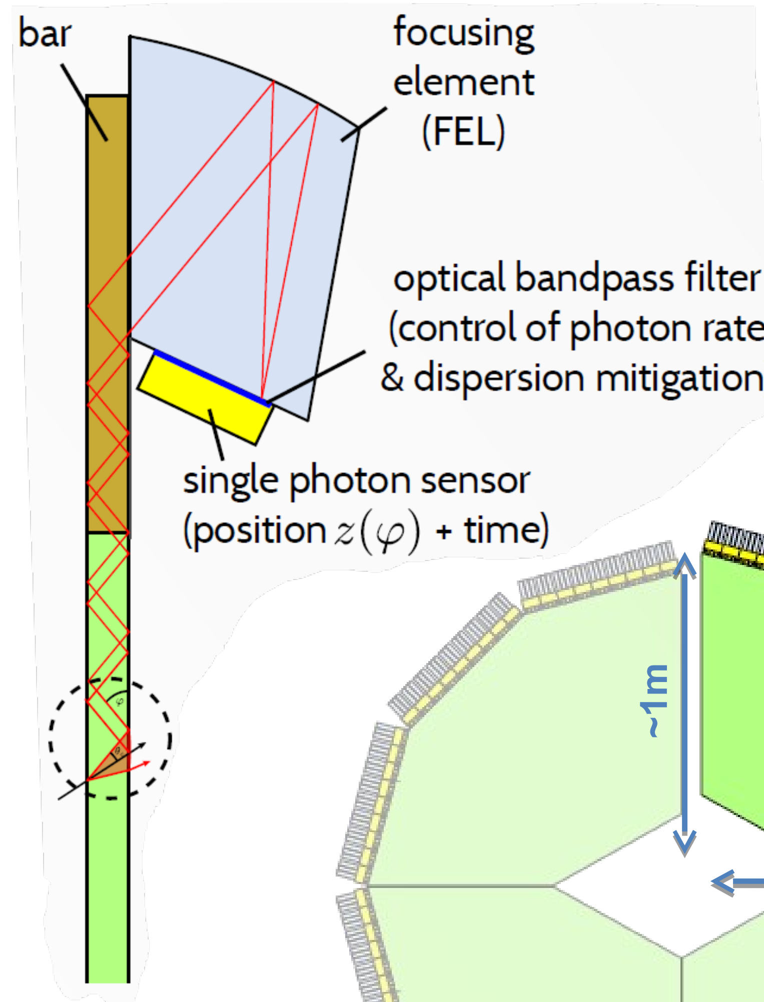
- immune to 1.5 T B-field & time resolution < 100 ps → **MCP-PMTs**
- aging issues: 3 years ago <200 mC/cm2 integrated anode charge

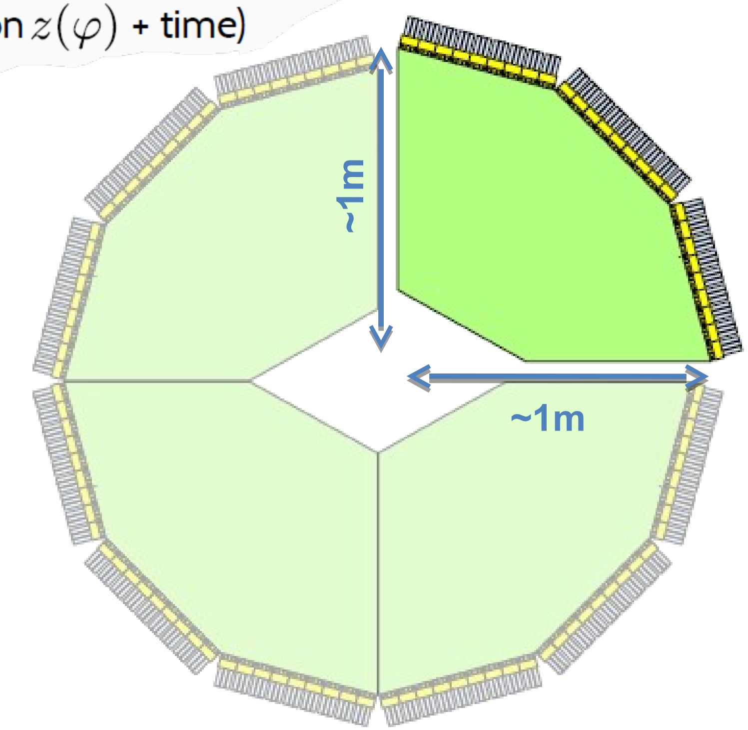


- recent developments: huge lifetime improvement of MCP-PMTs
- new PHOTONIS XP85112: **no Q.E. drop up to 6 C/cm^2**

Endcap Disk DIRC -- Design

- radiator disc (fused silica)
  - 4 independent sub-detectors
  - 210 cm diameter, 20 mm thickness
- bar and focusing element (FEL)
  - quartz bar + 16 mm wide FEL
  - polished cylindrical surface of FEL
  - option: angle correction with LiF prism bar to reduce chromatic errors
- optical bandpass filter
  - adjustment of photon wavelength (e.g. 385 – 460 nm → $\langle N_{ph} \rangle \approx 16$) to enhance sensor lifetime
  - fewer dispersion effects

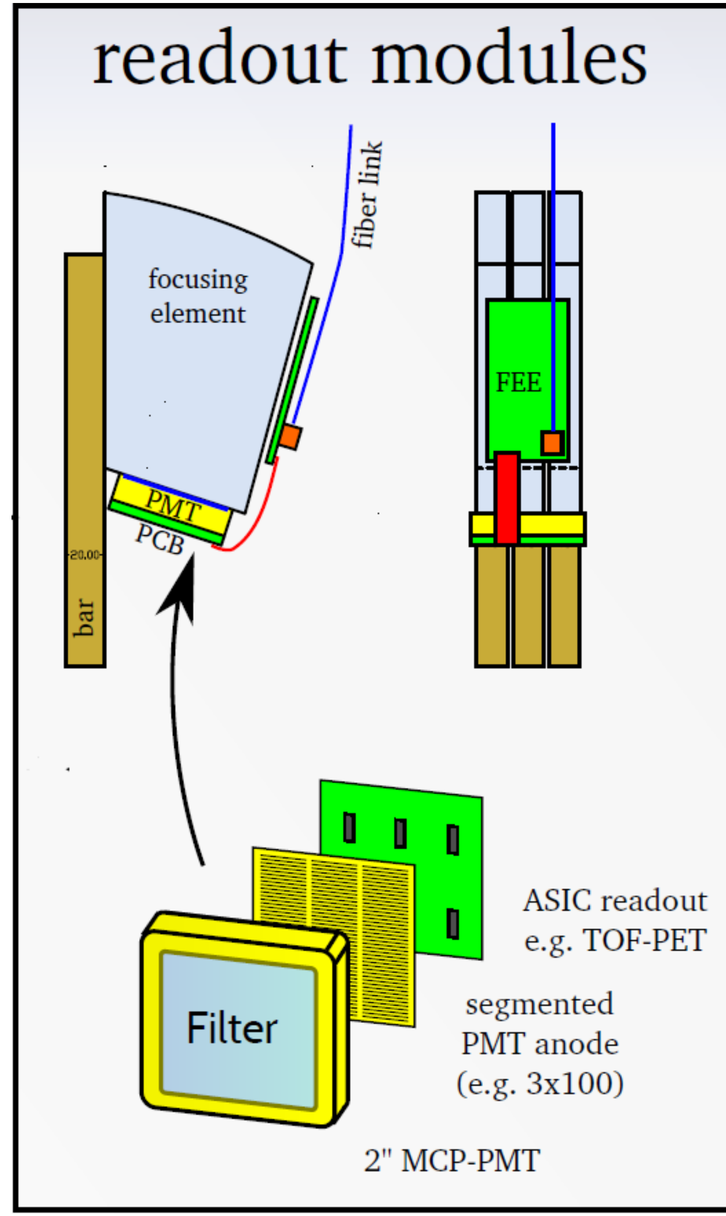




More details in poster of E. Etzelmüller and J. Rieke

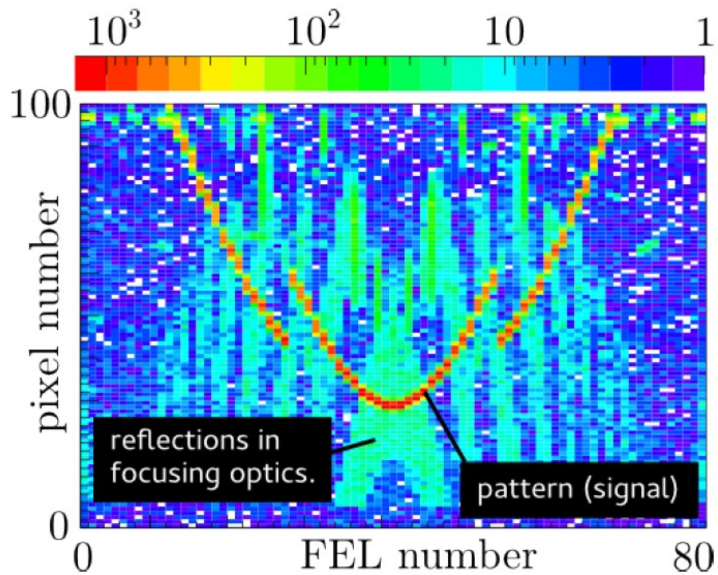
Endcap Disc DIRC -- Readout

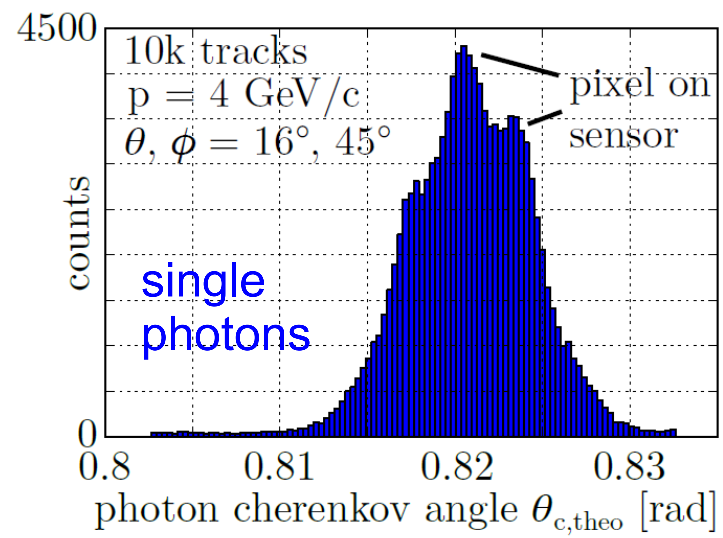
- optics
  - 27 readout modules per radiator plate
  - 3 bars and 3 FELs per readout module
  - 16 mm thickness of each prism and FEL
- readout module
  - 1 microchannel-plate PMT (2") with highly segmented anode (min. 3x100)
  - wavelength filter to reduce photon rate
  - average rate: 225 kHz/cm^2 (19 kHz/chan.)
  - integrated MCP anode charge: 5-6 C/cm^2
- ASIC
  - candidate: adjusted TOF-PET
  - close to PCB and read out by optical link

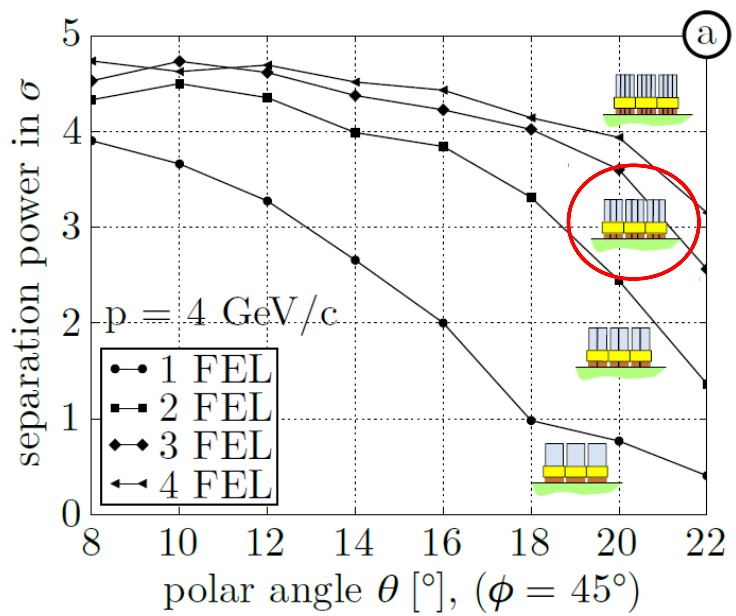


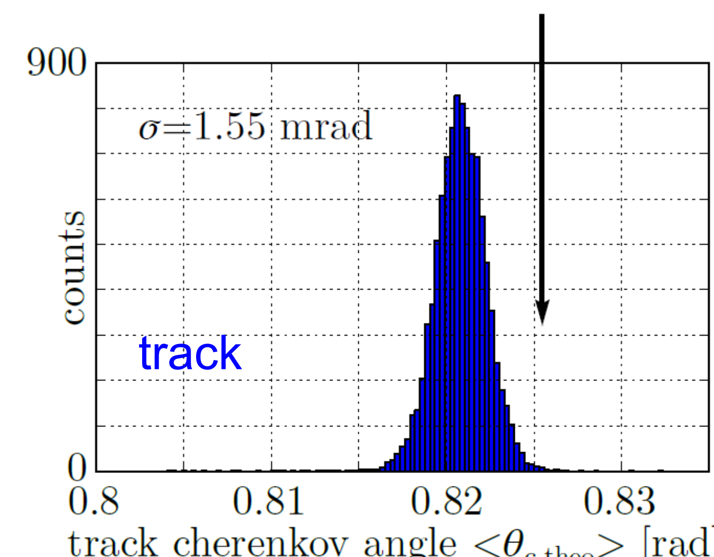
Endcap Disk DIRC -- Simulations

- hit pattern
  - simulated for signal/background
- angle resolution
  - single photon $\theta_{C,theo}$ resol.: ~7 mrad
  - $<\theta_{C,theo}>$ track resol.: 1.55 mrad
- separation power
  - best compromise: 3 FELs/PMT
  - ~0.5 mm pixel size needed to exploit full FEL resolution



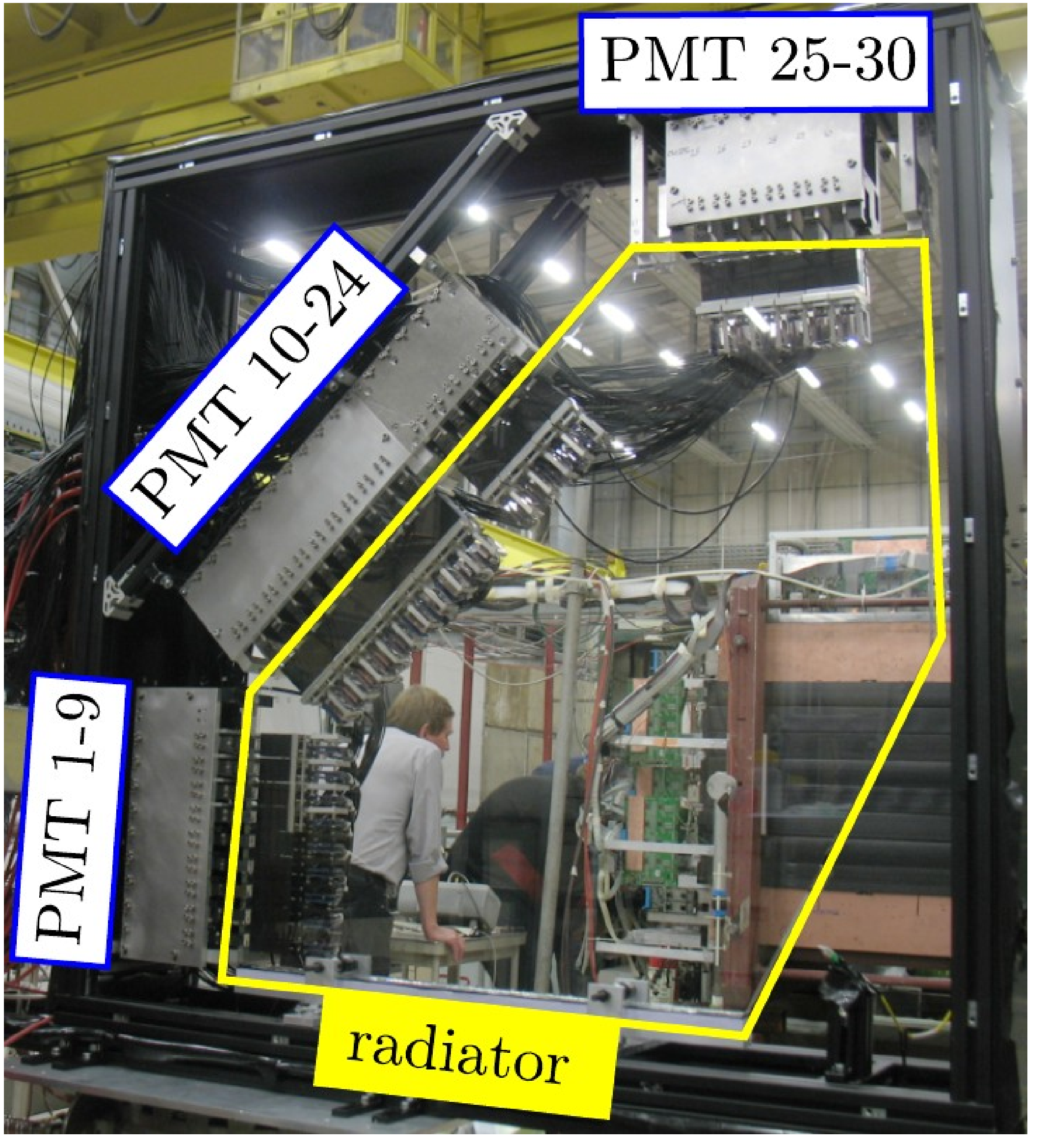






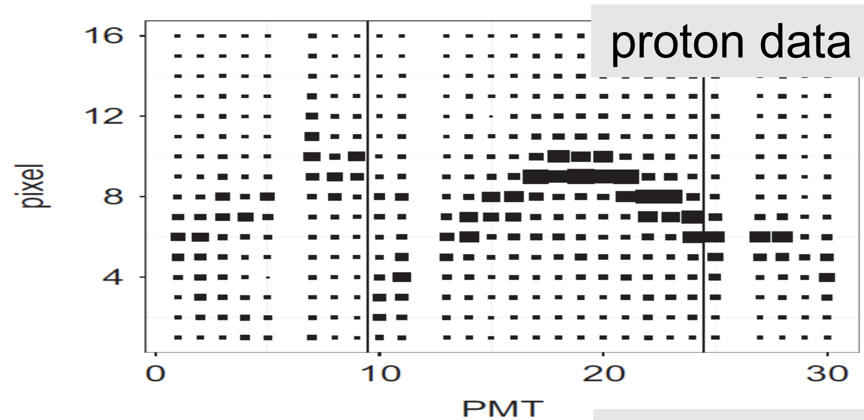
Endcap Disk DIRC -- Prototype

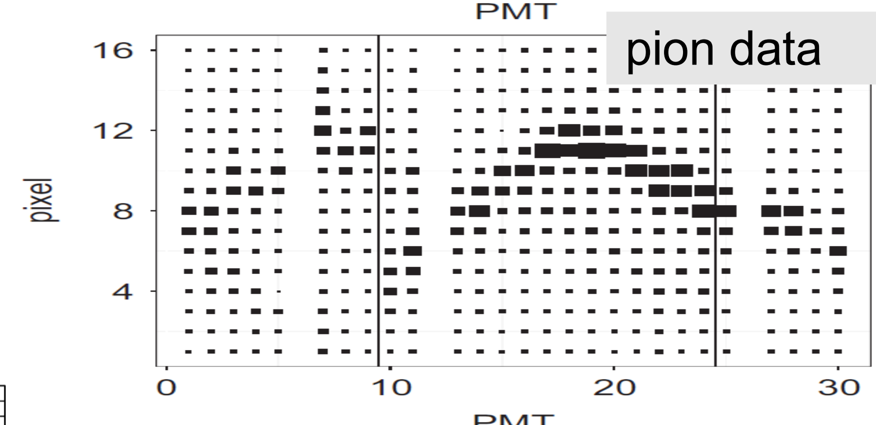
- setup
  - CERN T9 beam line with mixed lepton/hadron beam (3.5 GeV/c)
  - 1 quarter of borofloat radiator (80% final size)
- readout
  - 30 focusing elements (PMMA)
  - 30 MAPMTs (H10515B-100, 16 ch [16x1 mm^2] linear array)
  - GSI/HADES TRBv2 boards
- external particle identification
  - MCP-TOF with 120 ps resolution
  - threshold Cherenkov counters

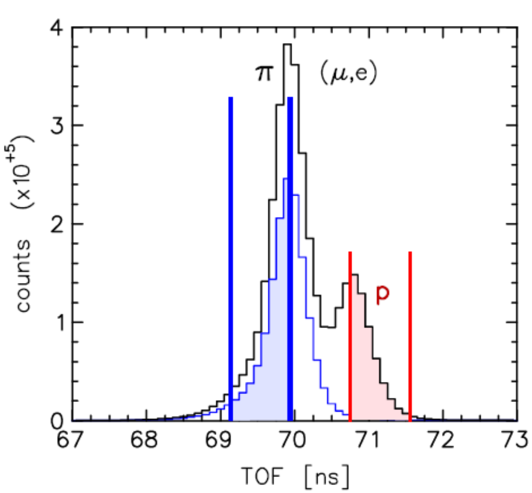


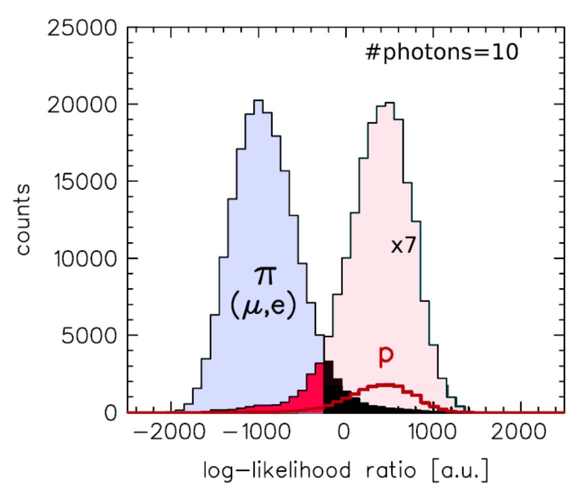
Disk DIRC – Prototype Results

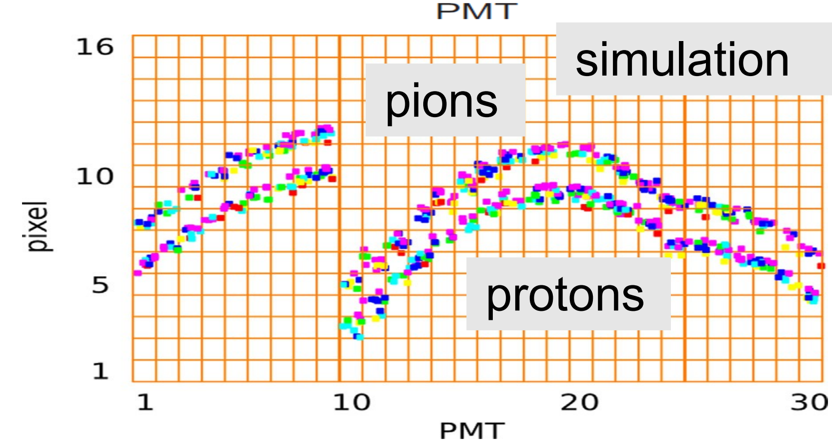
- cumulative hit patterns
  - patterns in data and simulations agree
  - pion/proton shift well reproduced
- single event patterns
  - shapes based on cumulative hit patterns
  - log-likelihood analysis
  - from overlap regions: <2% misidentified protons for >10 detected photons







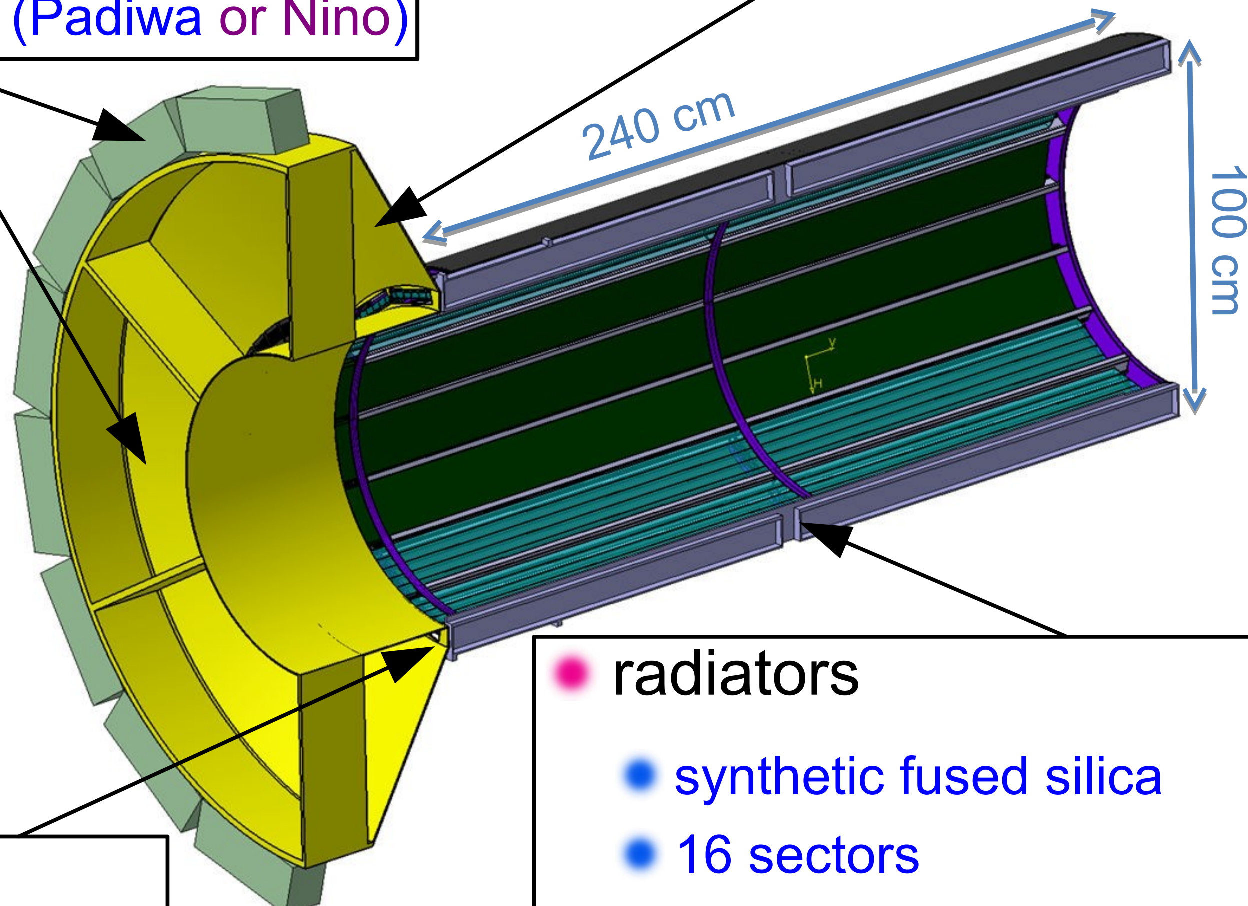




Barrel DIRC – Design Options

- photon detectors & electronics
  - MCP-PMTs (~15000 channels)
  - fast ADC &TDC FEE (Padiwa or Nino)

- expansion volume
  - 30 cm depth
  - mineral oil or prisms



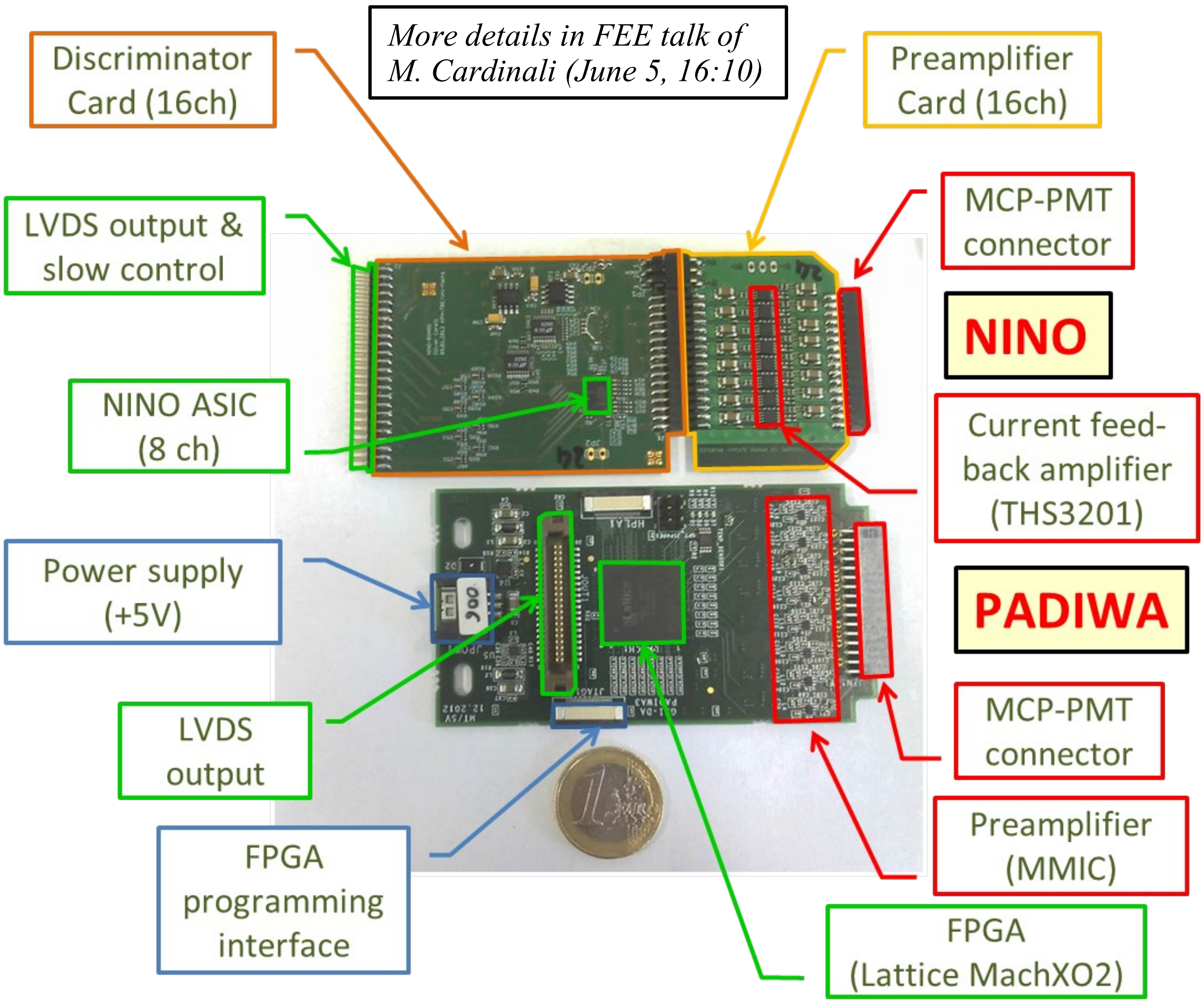
- performance goals
  - θ_C resol./photon: 8-10 mrad
  - det. photons/track: >20 at $\beta \approx 1$
  - timing resolution: 100 ps

- focusing optics
  - high refractive index lenses

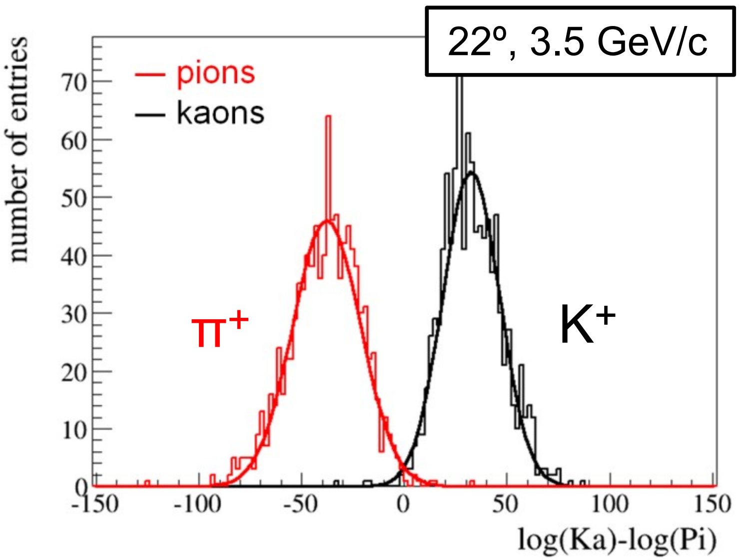
- radiators
  - synthetic fused silica
  - 16 sectors
  - 80 bars (17x32x2400 mm^3) or 16 plates (17x160x2400 mm^3)

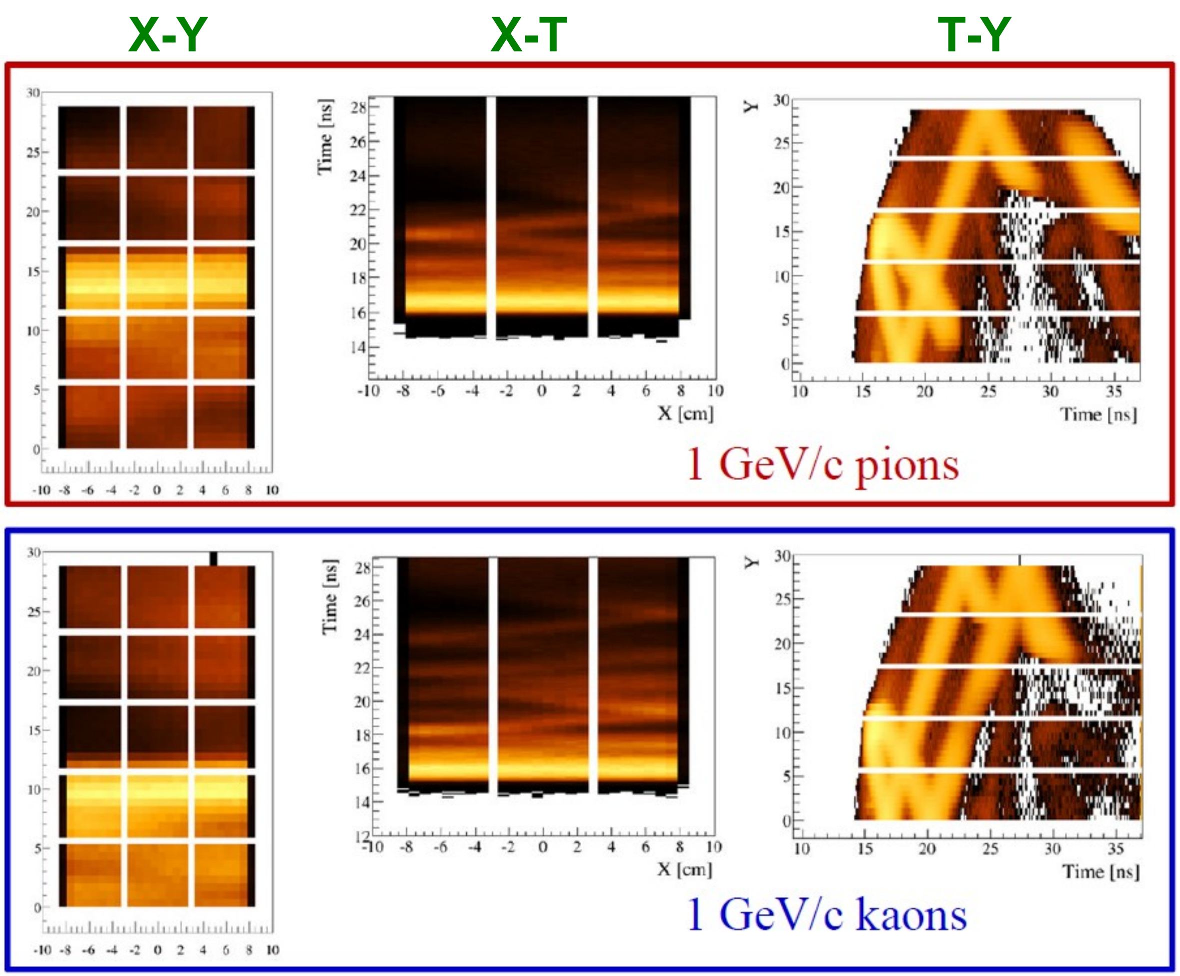
Barrel DIRC – Readout

- High resol. TDCs
  - <10 ps RMS timing
  - amplitude info from time-over-threshold (ToT) or ADCs
- Test different frontend boards
  - ASIC: NINO (CERN)
  - FPGA: PADIWA (GSI)
- DAQ based on GSI TRBv3 boards
  - hit rate: ~200 kHz/cm^2
  - data/PMT: 40 MB/s



Barrel DIRC – Reconstruction

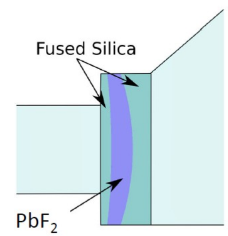




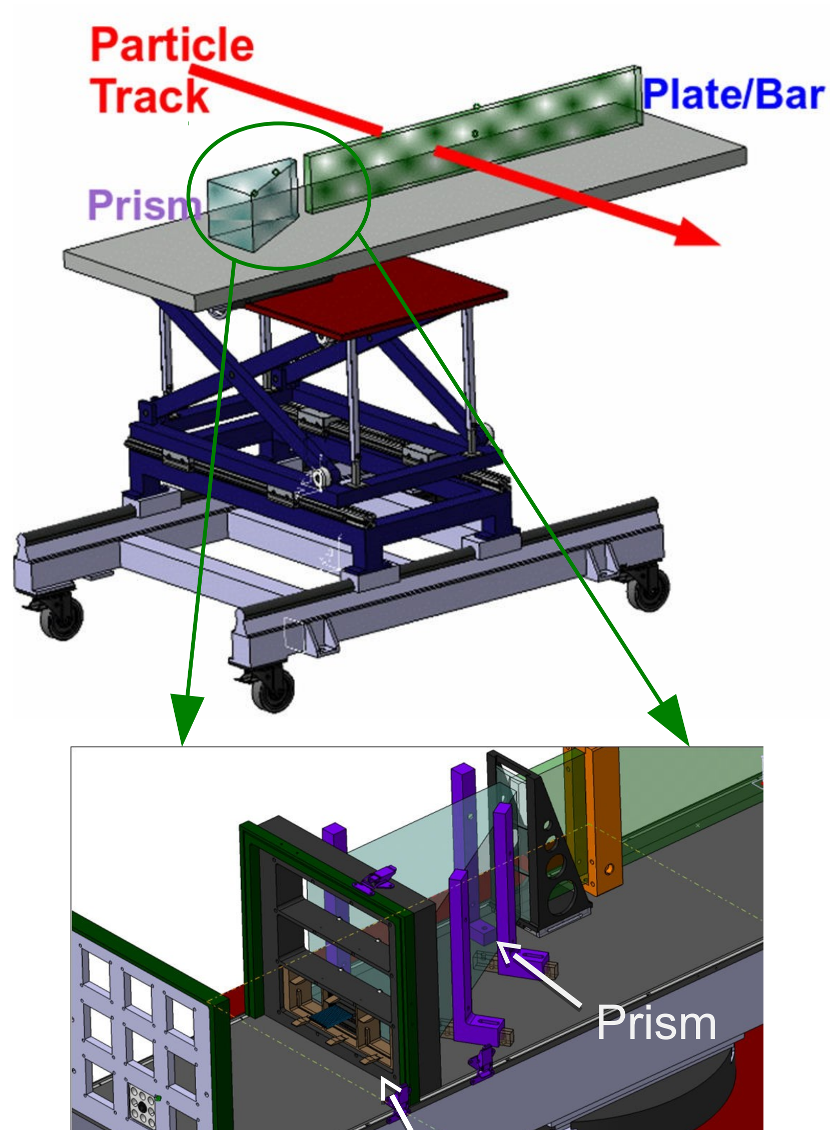
- narrow bars
  - look-up tables (BaBar-like)
- wide plates
  - log-likelihood analysis
  - Belle II-like time imaging approach
  - simulate probability density function of photon hit time per pixel
  - **clean π/K separation at 3.5 GeV/c even without focusing**

Barrel DIRC – Prototype Tests

- GSI & CERN T9 beamlines
- different configurations
  - bar with/without lenses and oil and/or prism
  - plate with prism



- radiators and lenses
  - several bars/plates of different vendors
  - high-n cyl./spherical lenses (e.g., SiO_2+PbF_2)
  - wide range of beam-bar angles and positions
- readout
  - different couplings of MCP-PMT and prism
  - different MCP-PMTs (final test with 3x3 array of 2" XP85012)
  - 640 channels with TRBv2 boards

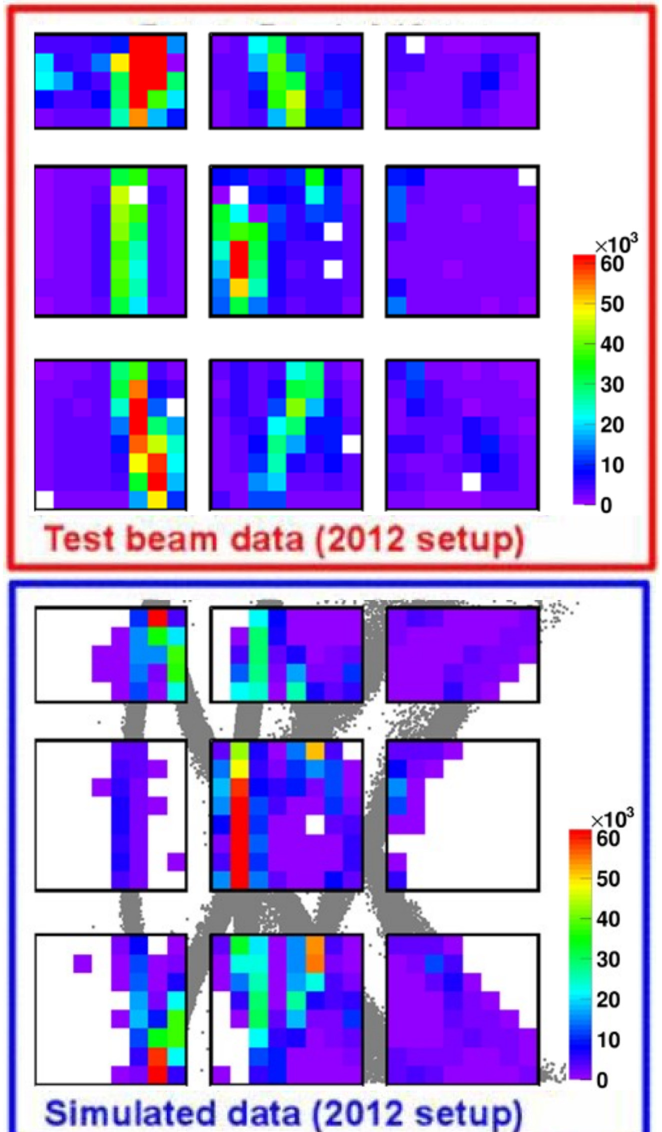


3×3 MCP-PMT matrix

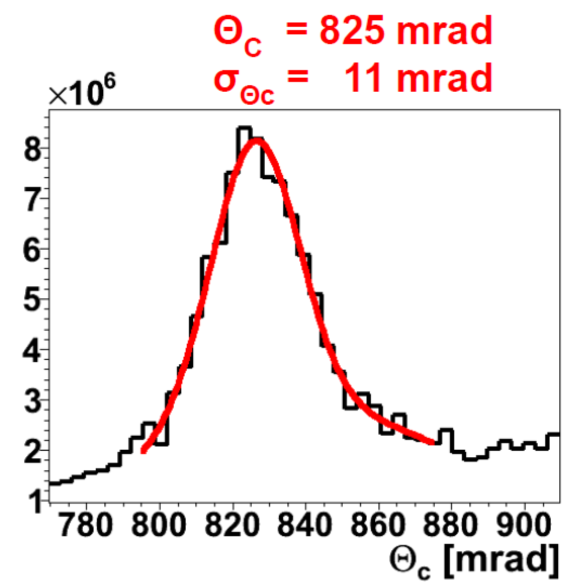
Barrel DIRC – Prototype Results

- bar + fused silica prism
  - complicated hit patterns (folding of ring image due to reflections in prism)
- angle reconstruction
  - pixel position and bar location define photon direction (look-up tables)
  - combination with particle track → calculate θ_C
  - path pixel-bar not unique → comb. background
- preliminary results
  - **>20 photons/track**
  - **$\sigma(\theta_C)$ = 11 mrad/photon** (close to design value)

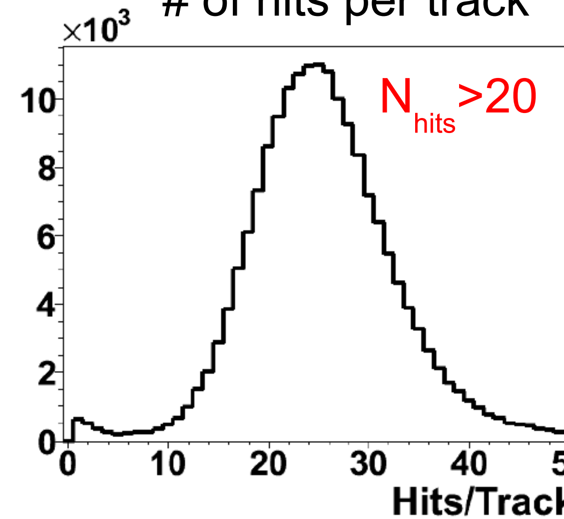
occupancy at 56º track angle



single photon θ_C resolution



# of hits per track



Summary and Outlook

- Both PANDA DIRCs are well on track
  - sensor problem appears solved (in particular aging issues)
  - prototype tests of novel disc DIRC design with promising results
  - usage of lens/prism combinations allows the building of a compact and fast focusing barrel DIRC
  - performance of the barrel DIRC bar design is close to PANDA requirements
- Outlook
  - Barrel DIRC: decision bar vs. plate after test run Aug. 2014
  - Endcap Disk DIRC: anode design and readout of MCP-PMTs still pending