Particle Identification Algorithms for the PANDA Barrel DIRC

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Motivation:
- Excellent particle identification is required to achieve the PANDA physics goals
- Hadronic PID in the PANDA target spectrometer will be delivered by two DIRC counters
- Developed reconstruction methods for PANDA Barrel DIRC, applied to simulation and CERN test beam data

The PANDA Experiment

Key Components

- **Radiators:**
  48 synthetic fused silica bars
- **Focusing optics:**
  Spherical lens system
- **Expansion volume:**
  Quartz prism, 30 cm depth
- **Sensors:**
  Microchannel Plate Photomultiplier Tubes (MCP-MTs)

The PANDA Barrel DIRC
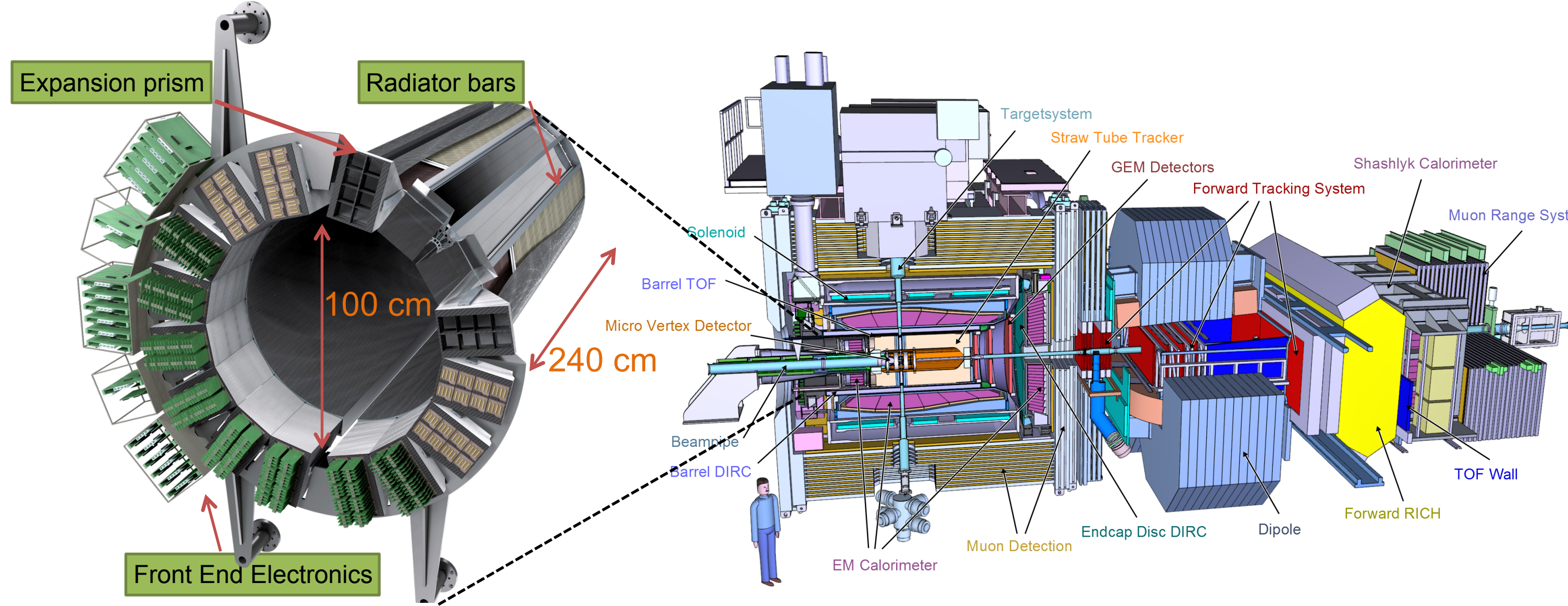
- Physics cases: Hadron physics, Exotic quark systems, Nucleon structure and Charmonium spectroscopy
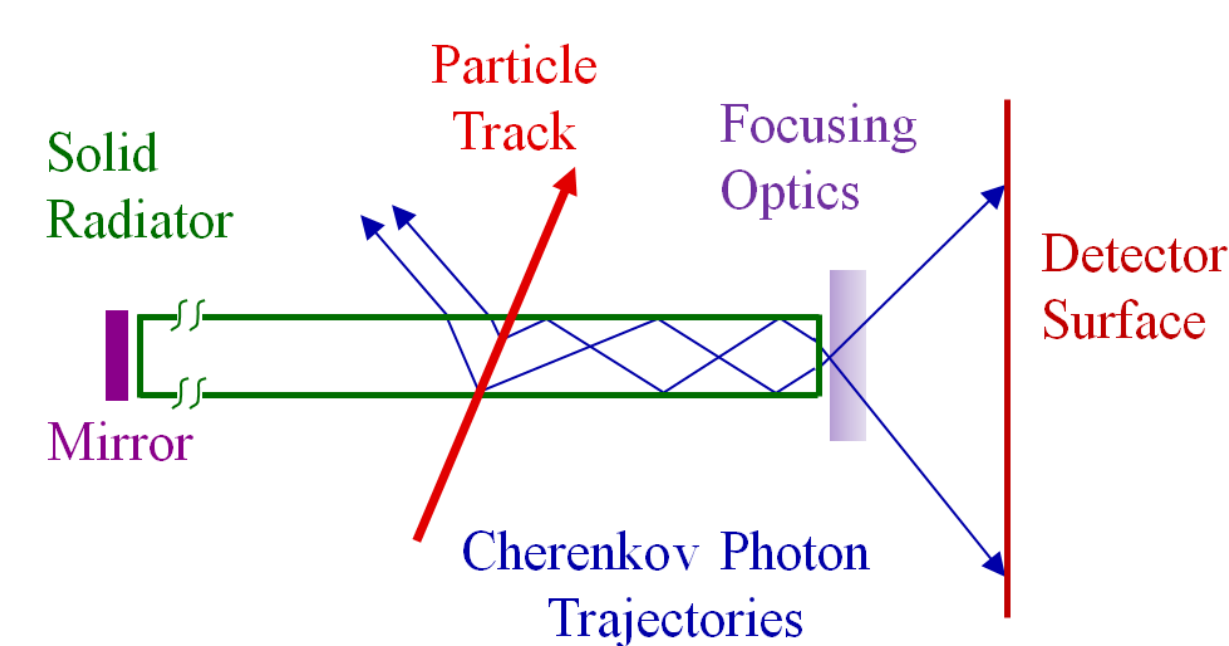- Use Antiproton beam 1.5 GeV/c – 15 GeV/c

Kaons produced in $\bar{p}$ – p collisions, $\bar{p}$ momentum range 6 - 15 GeV/c. Barrel DIRC range
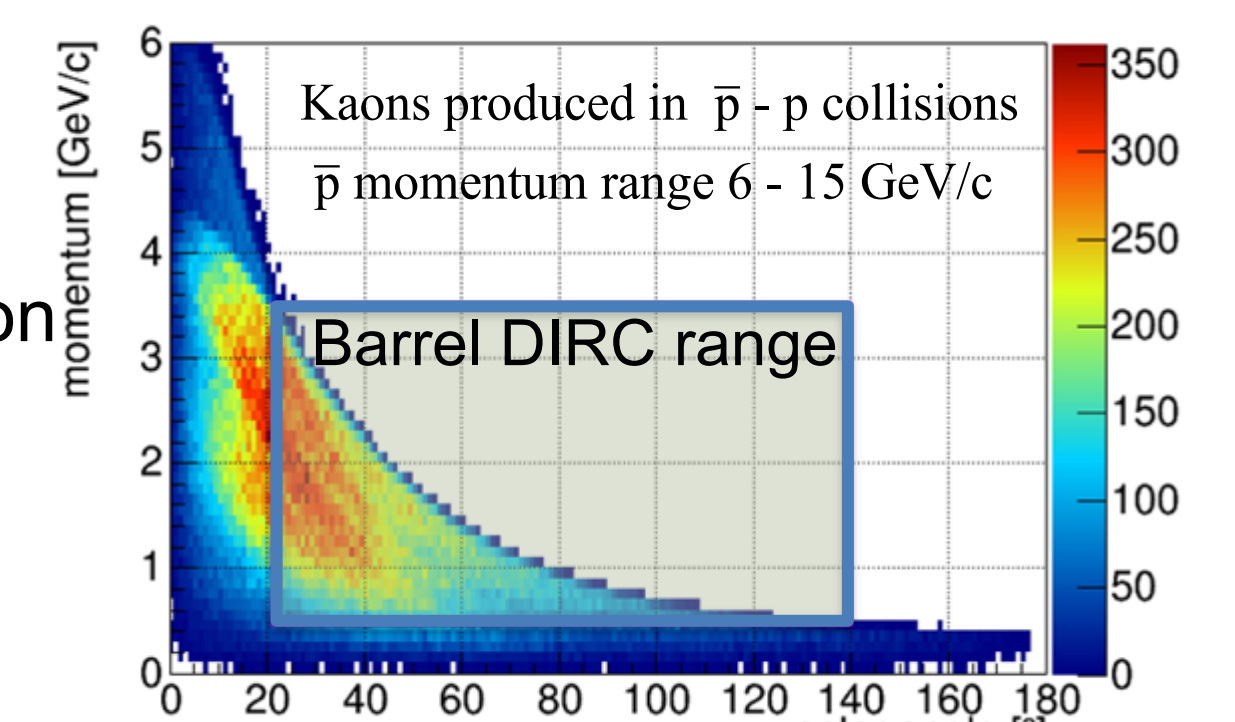
Hadronic Particle Identification goal: 3σ π/K separation power up to 3.5 GeV/c

PANDA Barrel DIRC TDR
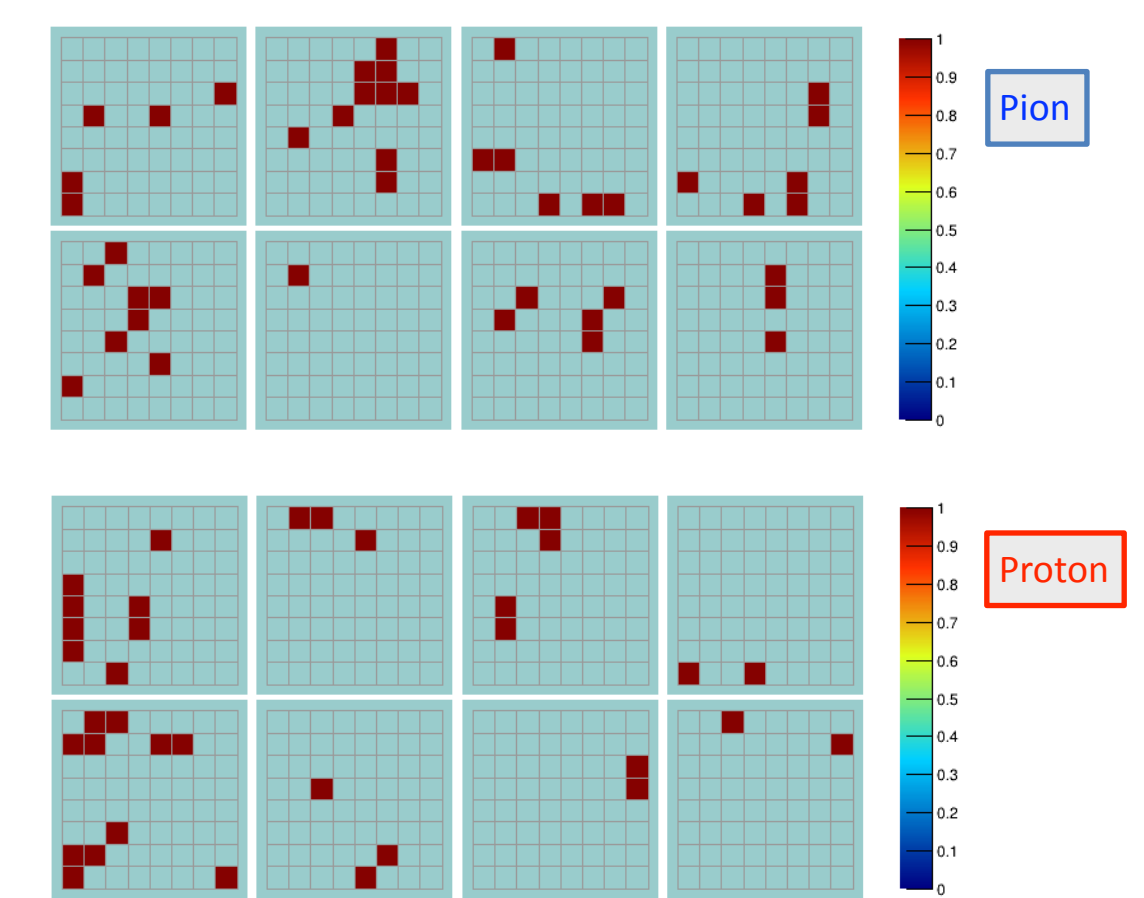J. Phys. G: Nucl. Part. Phys. 46 045001
arXiv:1710.00684

DIRC Principle

- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining: θ_c, φ_c and $t_{propagation}$
- Ultimate deliverable for DIRC: PID likelihoods

Time-based Imaging

- Based on Belle II time-of-propagation (TOP) counter
- Create PDFs (Probability Density Function) for the expected photon time for every pixel and for every particle hypothesis
- Measure Cherenkov photons arrival time in each event
- Compare photon arrival time to the corresponding PDFs
- PDFs can be generated using real data, simulations or analytically

PDF example

Accumulated hit pattern for pion events at 7 GeV/c at 20° polar angle

Accumulated hit pattern for protons events at 7 GeV/c at 20° polar angle

Preliminary 4.8 s.d. — pions, protons
Simulated log-likelihood difference distributions, at 7 GeV/c and 20° polar angle

Simplified Time-based Imaging

- Generate a large number of photons from a point-like source inside the bar along the charged particle track.
- Database contains: photon generation vectors, photon hit position on the photo-sensors, photon propagation time.
- PDFs created for every pixel and for every particle hypothesis by applying cut on the expected Cherenkov angle based on particle momentum and direction

Visualization of photon vertices at the generation

Simplified Cherenkov cone for pions blue and protons red

Event display shows pion trajectory in magenta and the Cherenkov photon trajectory in yellow

PDF example — Pion, Proton

Simulation of one direct photon track from generation to detection on a certain MCP-PMT pixel

Preliminary 4.2 s.d. — protons, pions
Simulated log likelihood difference distribution at 7 GeV/c and 20° polar angle
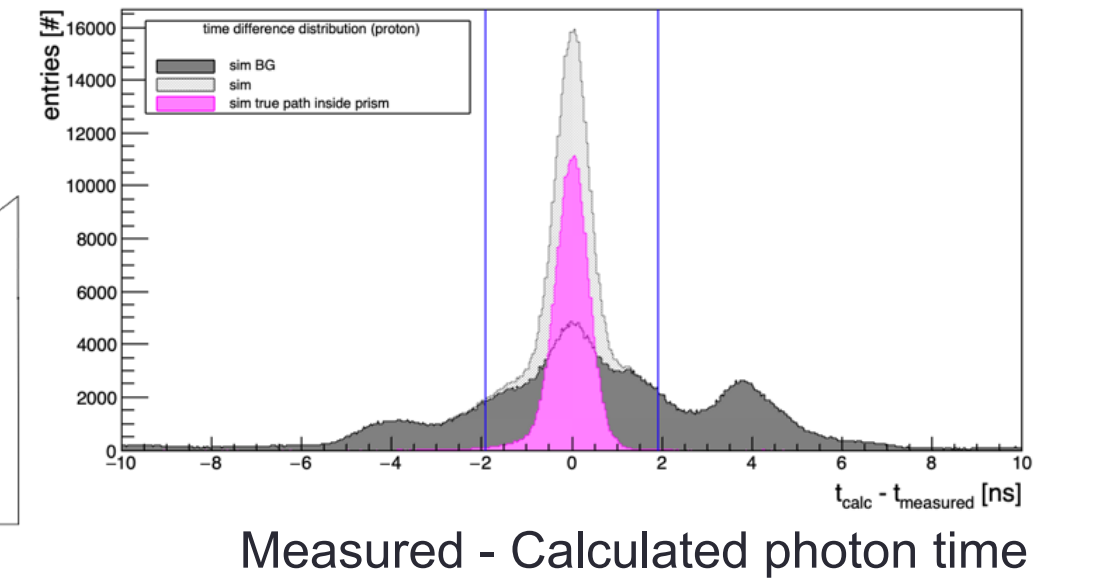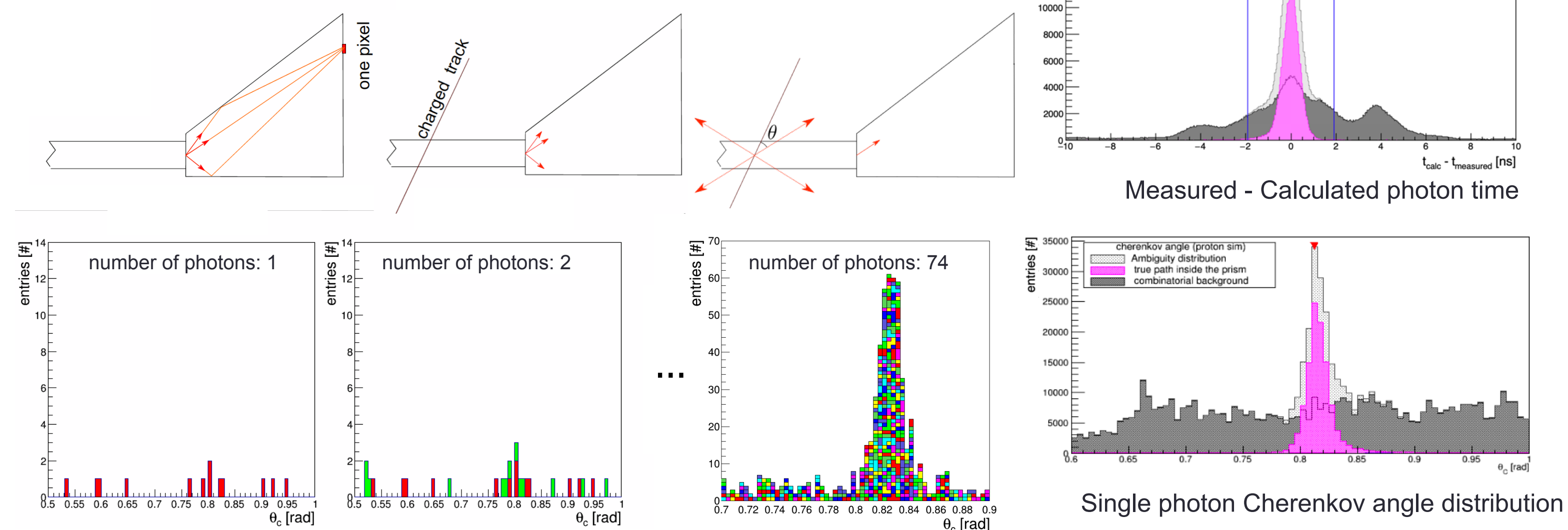
Geometrical Reconstruction

- Adapted from BaBar DIRC reconstruction
- Look-Up Table (LUT) creation: Photon gun in Geant4 simulation, store direction vectors from the end of the bar to each pixel
- Reconstruction: direction from LUT for hit pixels are combined with charged track direction
- Provides (ambiguous) Cherenkov angle for each detected photon, timing and angular resolution, Cherenkov angle per particle, photon yield
- PID performed by likelihood fit using different mass hypothesis

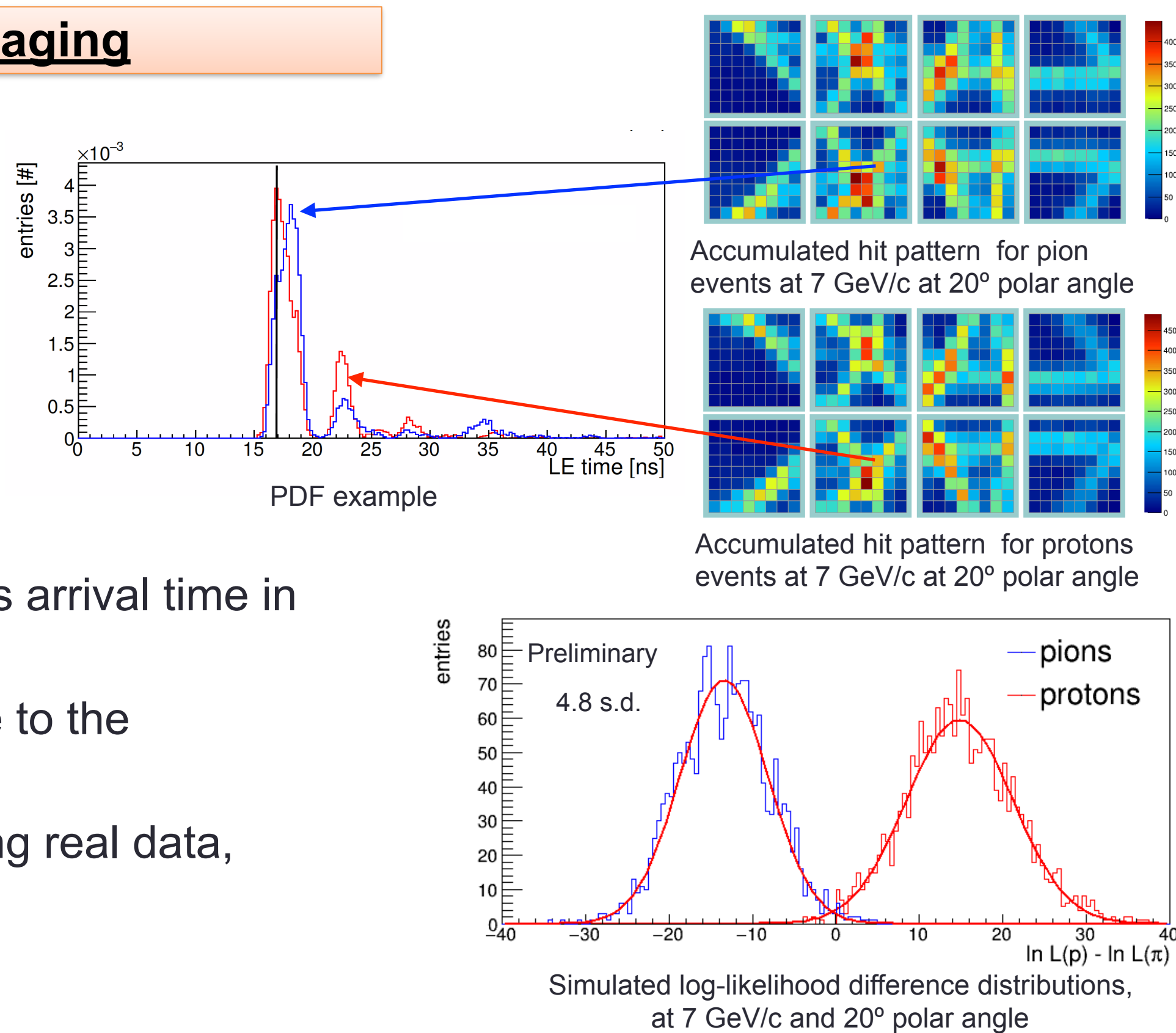Pion · Proton

Single event hit pattern at 7 GeV/c and 20° polar angle
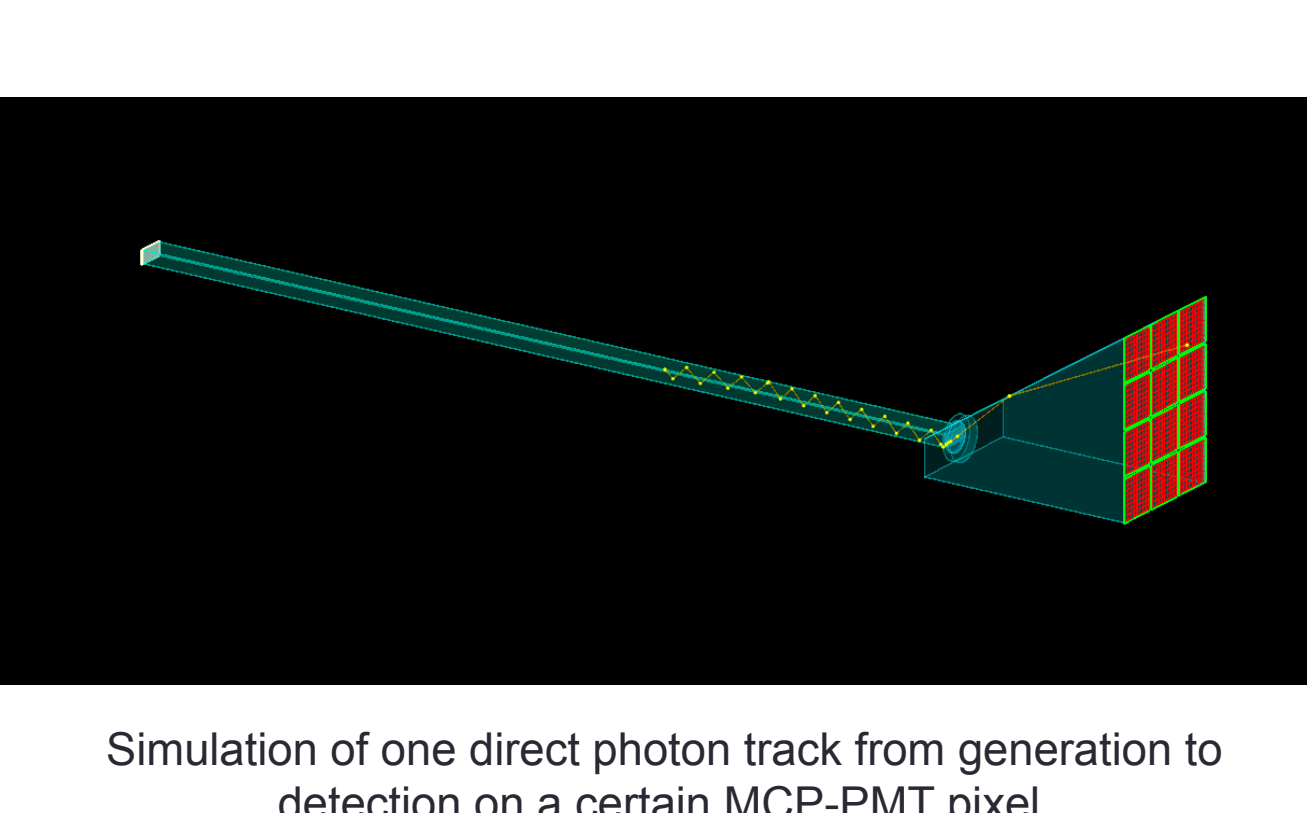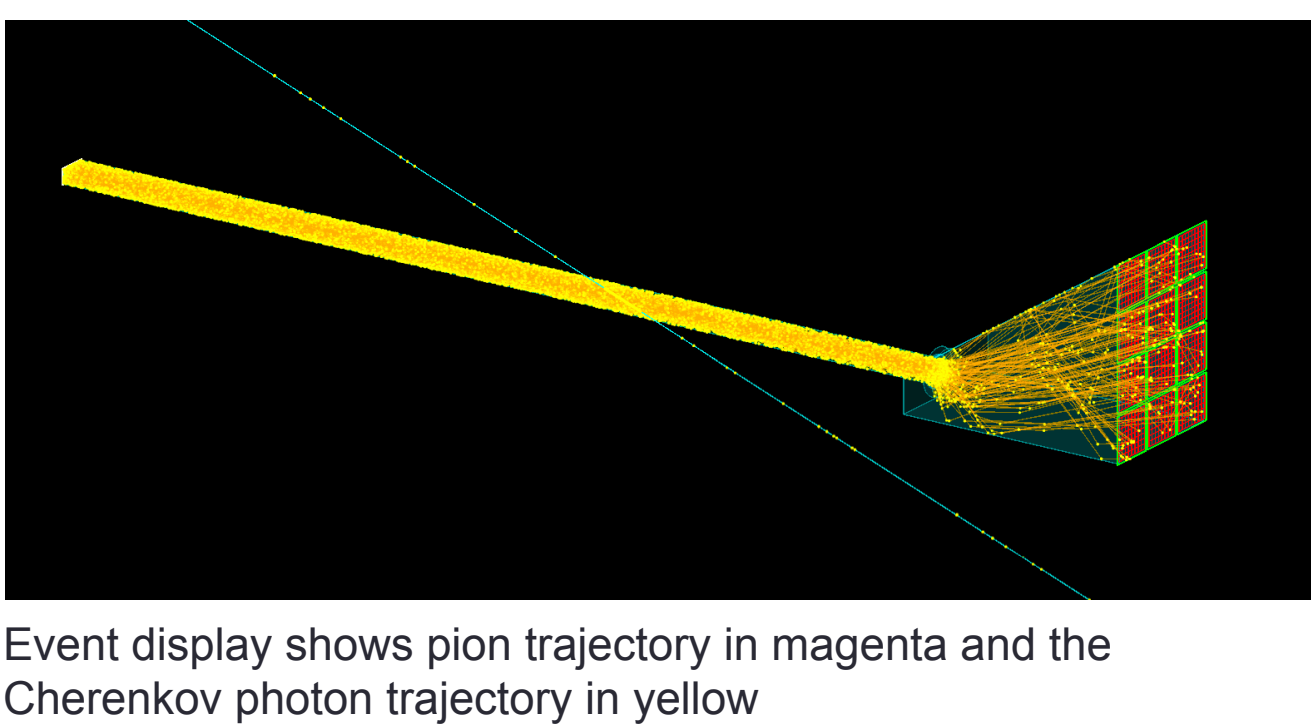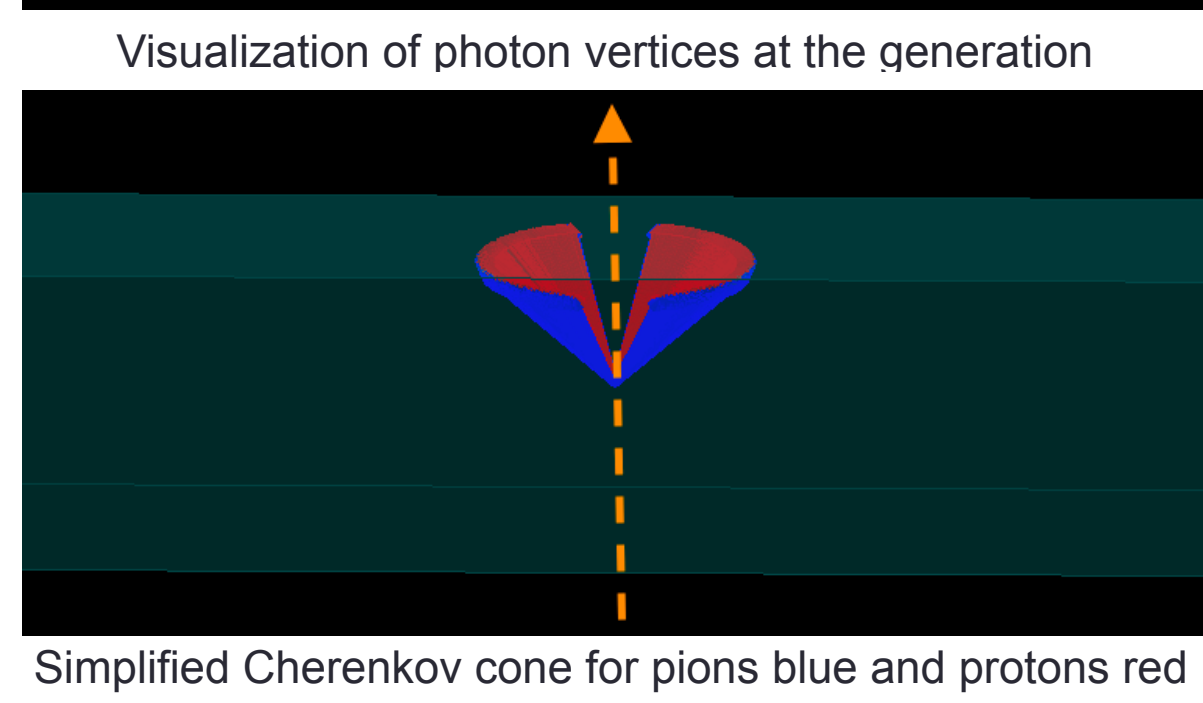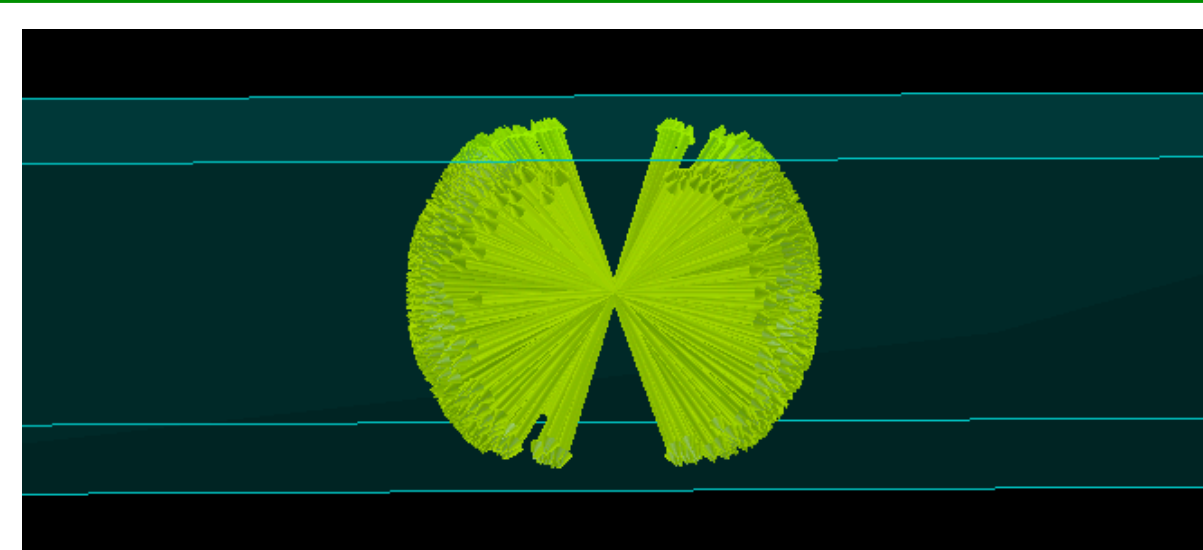
Measured - Calculated photon time

number of photons: 1 · number of photons: 2 · number of photons: 74

Single photon Cherenkov angle distribution

pion candidate · proton candidate

Likelihood hypotheses test

pions, protons Preliminary 3.9 s.d.
Simulated log-likelihood difference distributions, at 7 GeV/c and 20° polar angle

Test Beam at CERN PS

- PANDA barrel DIRC prototype setup 2018 at CERN PS
- Mixed hadron beam with momenta up to 10 GeV/c
- pi/K @ 3.5 GeV/c approximately pi/p @ 7 GeV/c
- Radiator: Fused silica bar
- Expansion volume: Fused silica prism
- Focusing optics: 3-layer spherical lens
- Array of MCP-PMTs for photon detection
- Readout with timing 150 - 300 ps

Separation power for pion/proton at 7 GeV/c — beam data, simulation
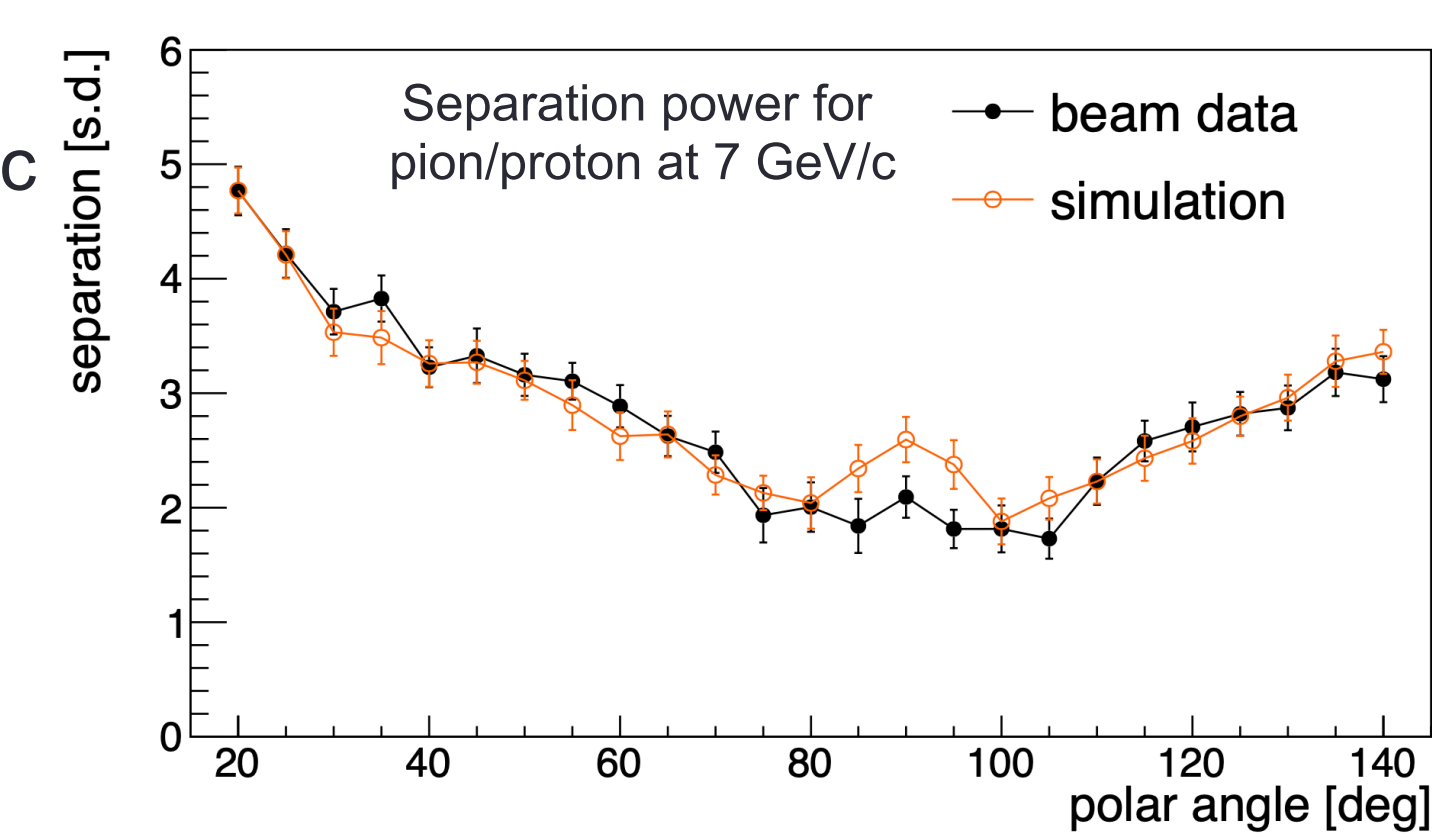
- Geant4 simulation of Cherenkov photons transportation includes the wavelength-dependent properties of all optical materials and detection
- Implemented for PANDA Barrel DIRC and prototype

Sensors and electronics · Dark box for optics

Narrow bar, spherical lens, prism
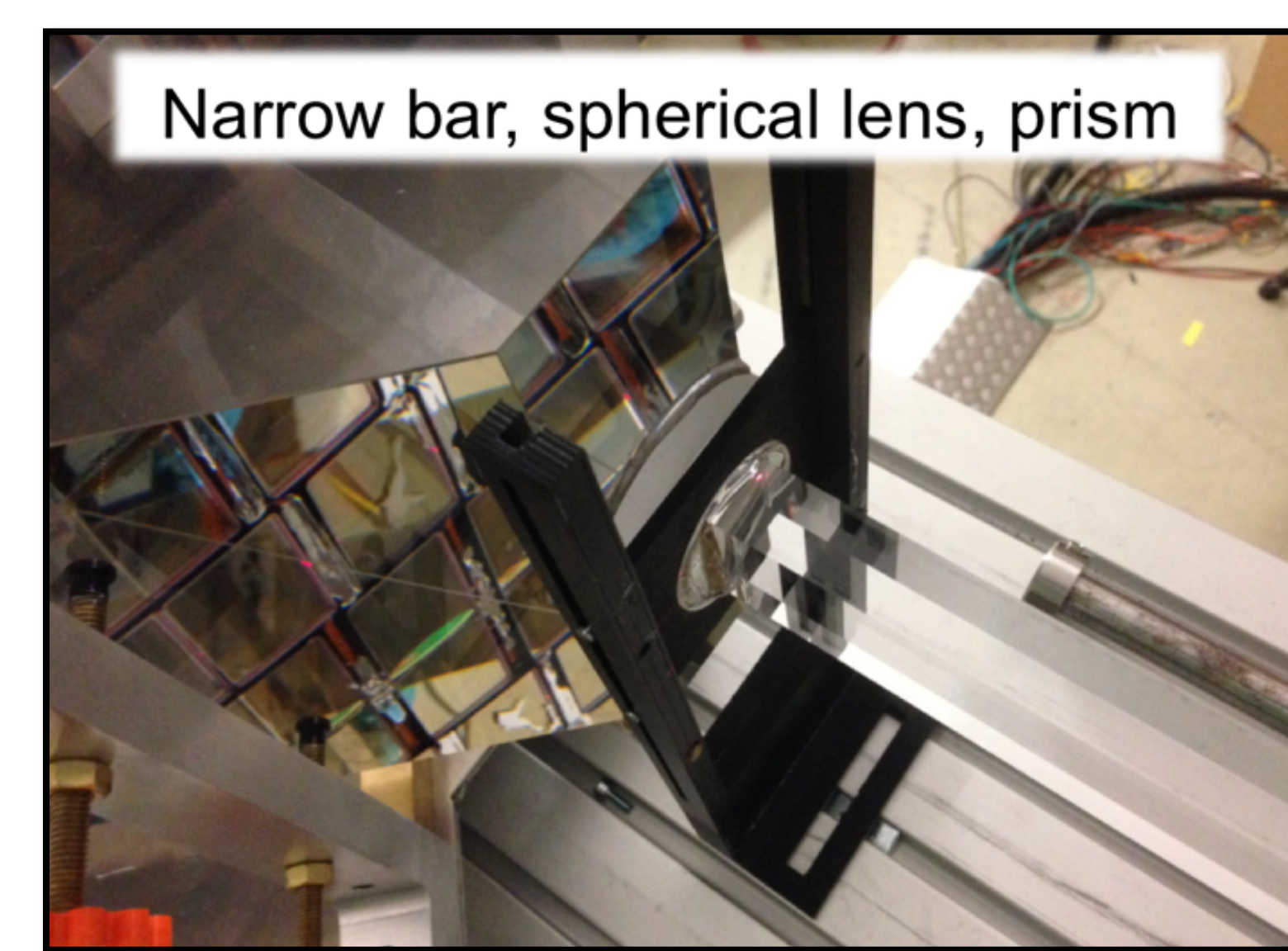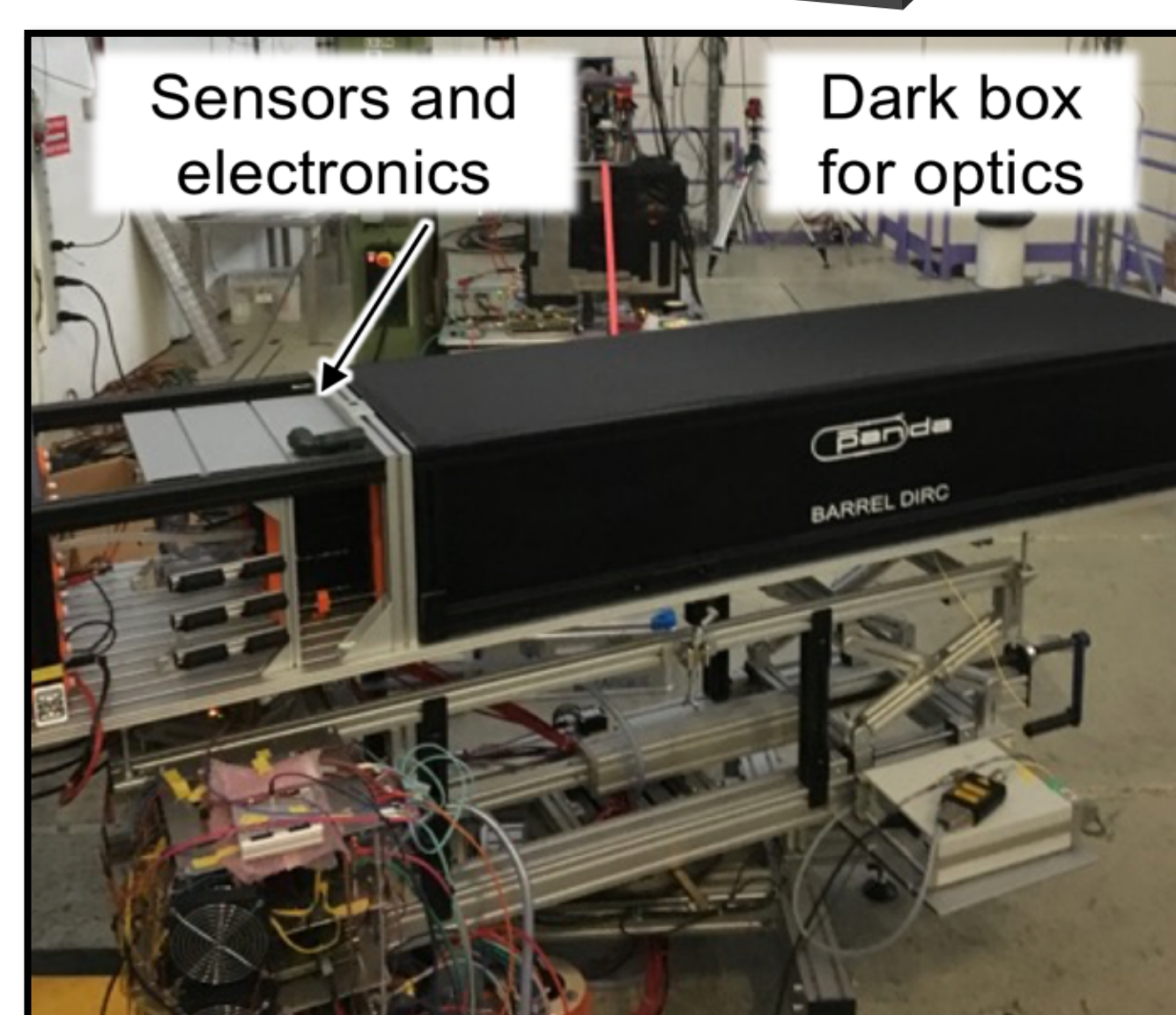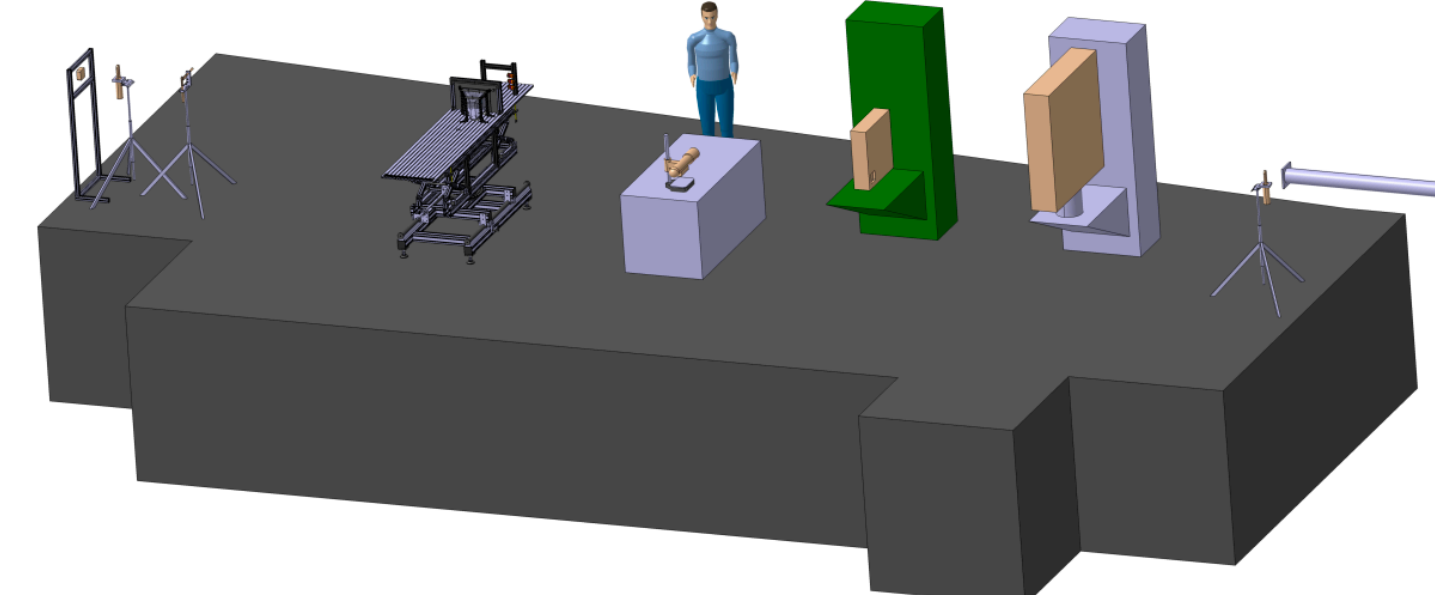
Conclusions

Geometrical Reconstruction
- Delivers a measurement of important variables for the detector performance studies
- Fast algorithm since the LUTs depend only on the detector geometry and not on the particle properties Less sensitive to time resolution
- LUT can be created prior to event reconstruction

Time-based Imaging
- Performance superior to geometrical reconstruction results
- Require large storage capacities
- Significant reduction of memory requirements can be achieved by using analytical PDFs

Simplified Time-based Imaging
- Faster creation of PDFs
- Performance close to time-based imaging