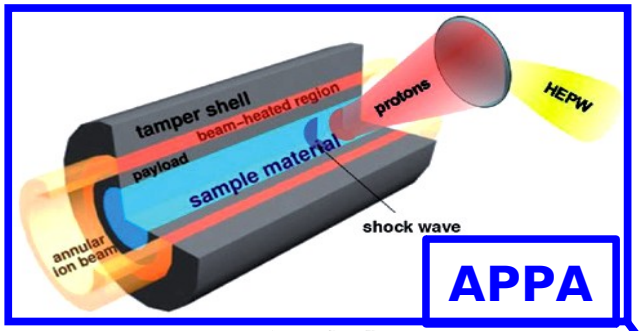
PID of the PANDA Experiment with the Barrel DIRC

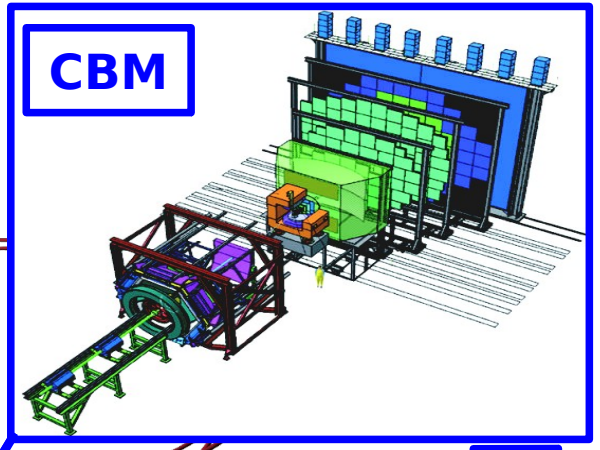
Carsten Schwarz, GSI

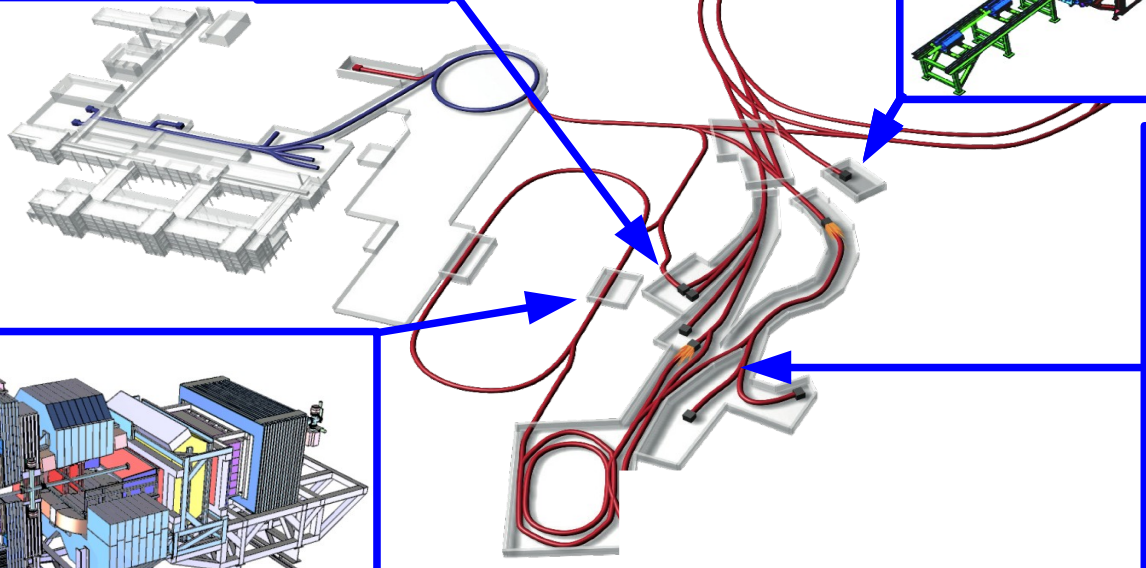
for the
PANDA Cherenkov group

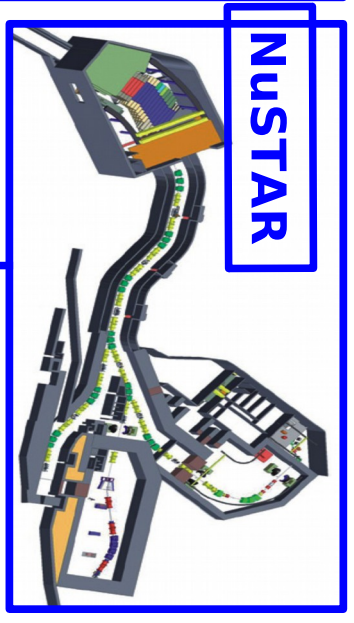
GSI Darmstadt
University of Erlangen
University of Giessen
University of Mainz
Helmholtz-Institut Mainz

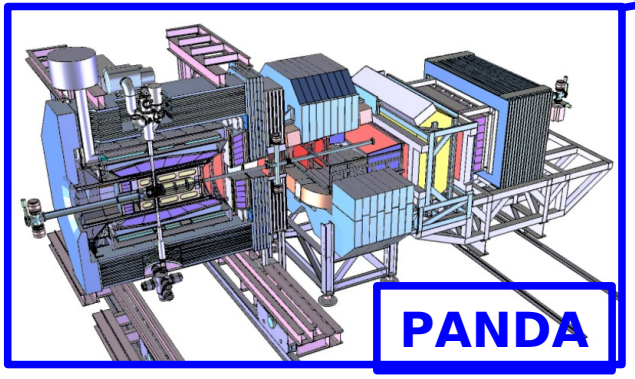
The PANDA detector
Barrel DIRC
Beam test
Series production
Current activities







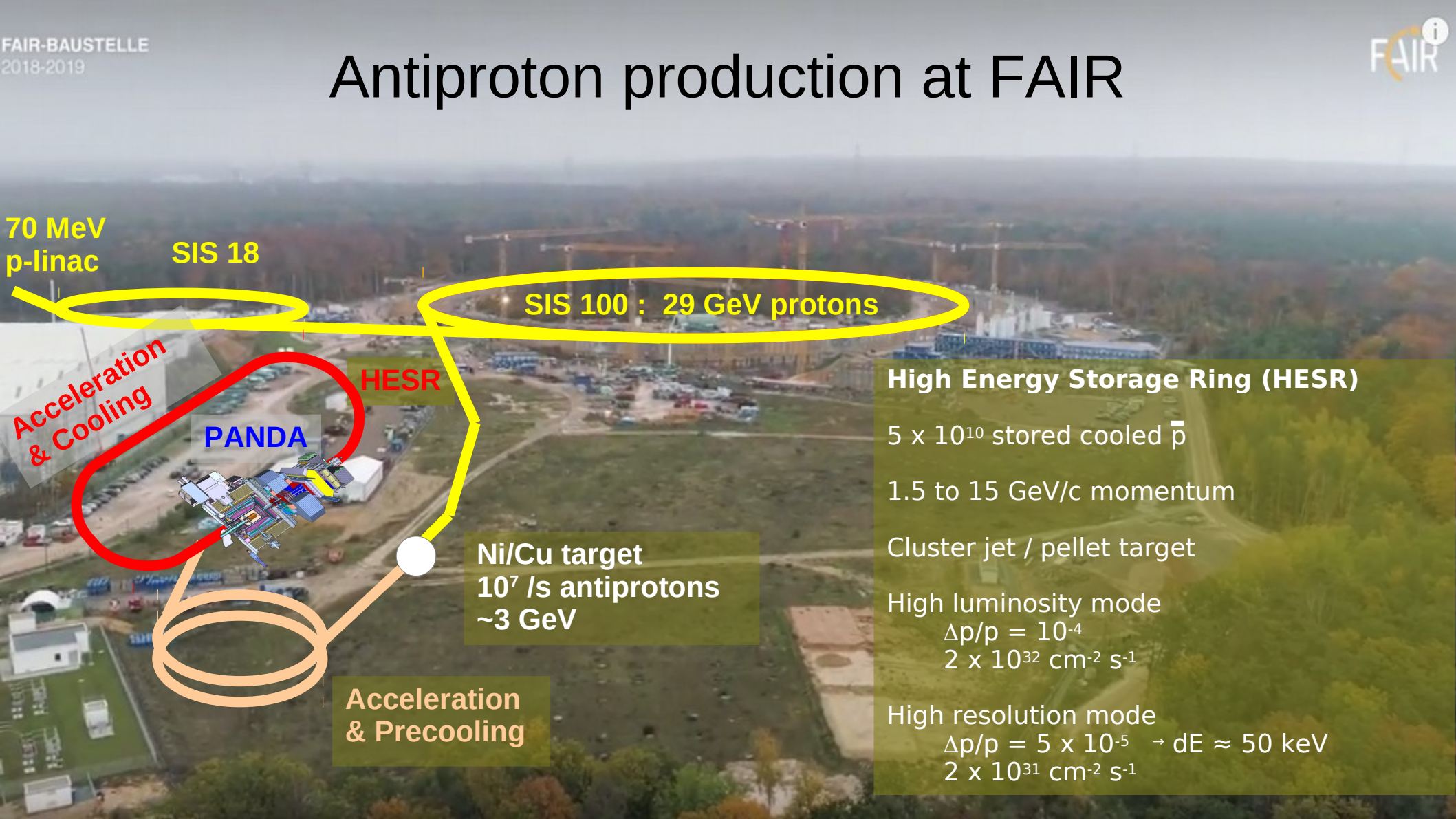




NUSTAR, PANDA, CBM, APPA
are fixed target experiments


SIS100
CRYO 2
APPA
CBM
S-FRS
NUSTAR LEB
NUSTAR HEB
FAIR in construction
April 2023

Antiproton production at FAIR



High Energy Storage Ring (HESR)

5×10^{10} stored cooled $\bar{p}$

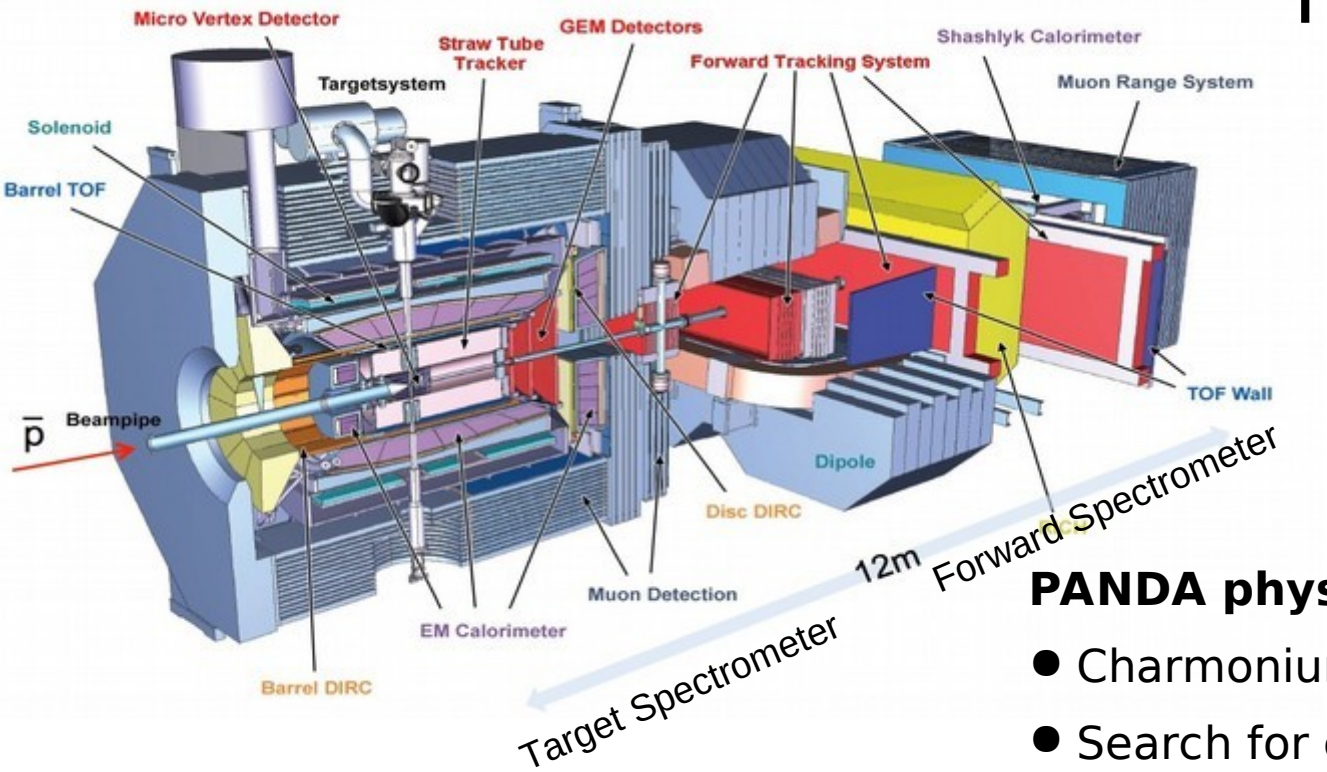
1.5 to 15 GeV/c momentum

Cluster jet / pellet target

High luminosity mode
$\Delta p/p = 10^{-4}$
2×10^{32} cm^{-2} s^{-1}

High resolution mode
$\Delta p/p = 5 \times 10^{-5}$ → dE ≈ 50 keV
2×10^{31} cm^{-2} s^{-1}

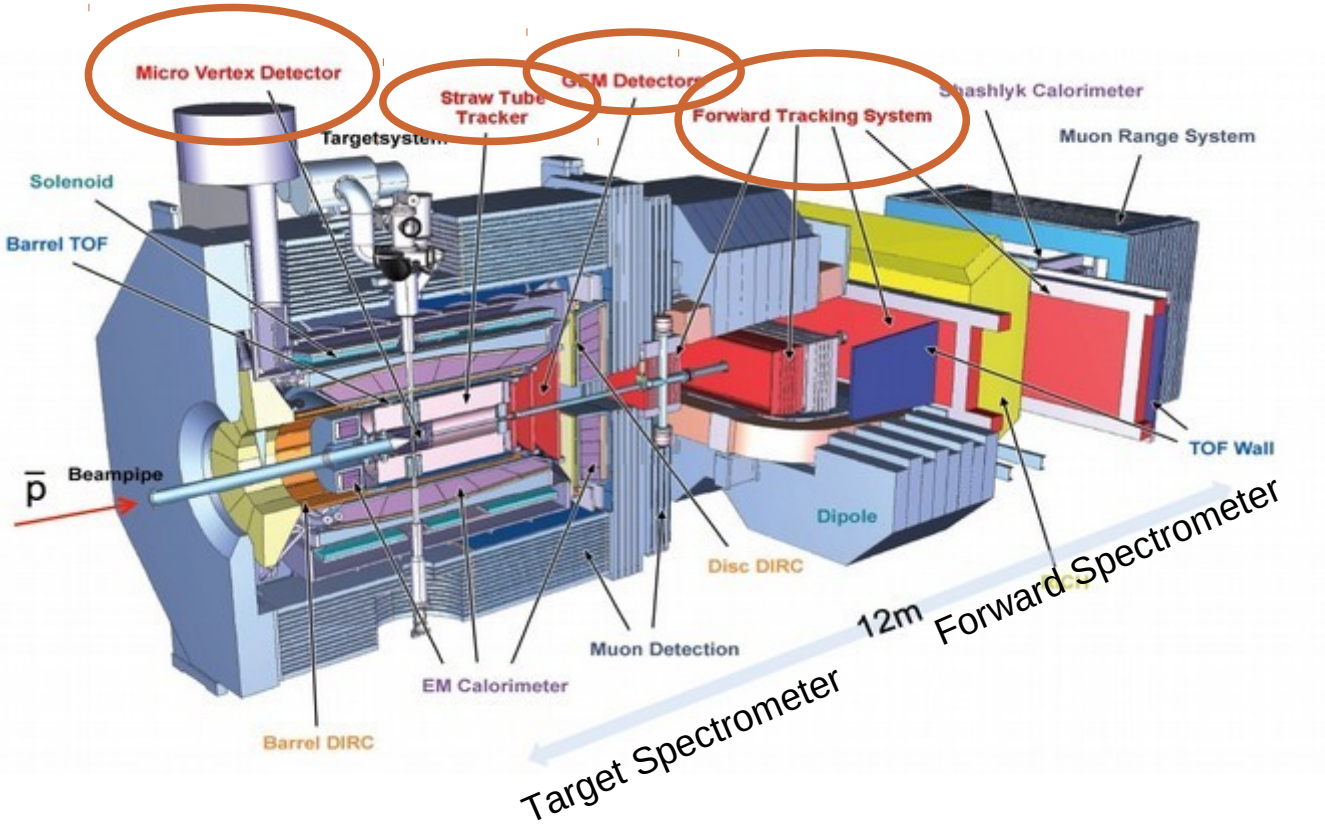
PANDA experiment



PANDA physics program

- Charmonium and open charm spectroscopy
- Search for charmed hybrids and glueballs
- Modification of charmed mesons in nuclear matter
- Hypernuclei
- Nucleon structure

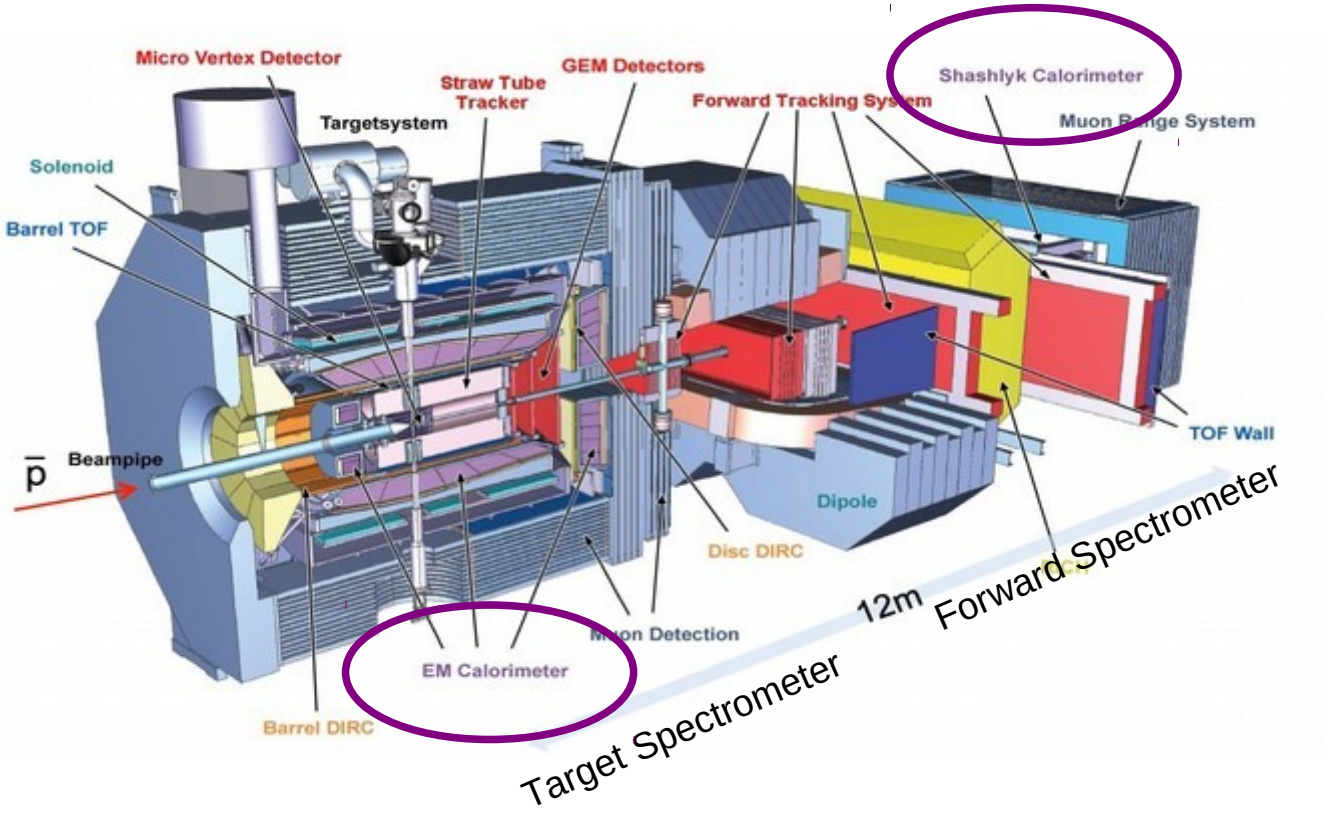
Excellent PID needed



Particle identification methods

momentum range:
0.2 GeV/c – 10GeV/c

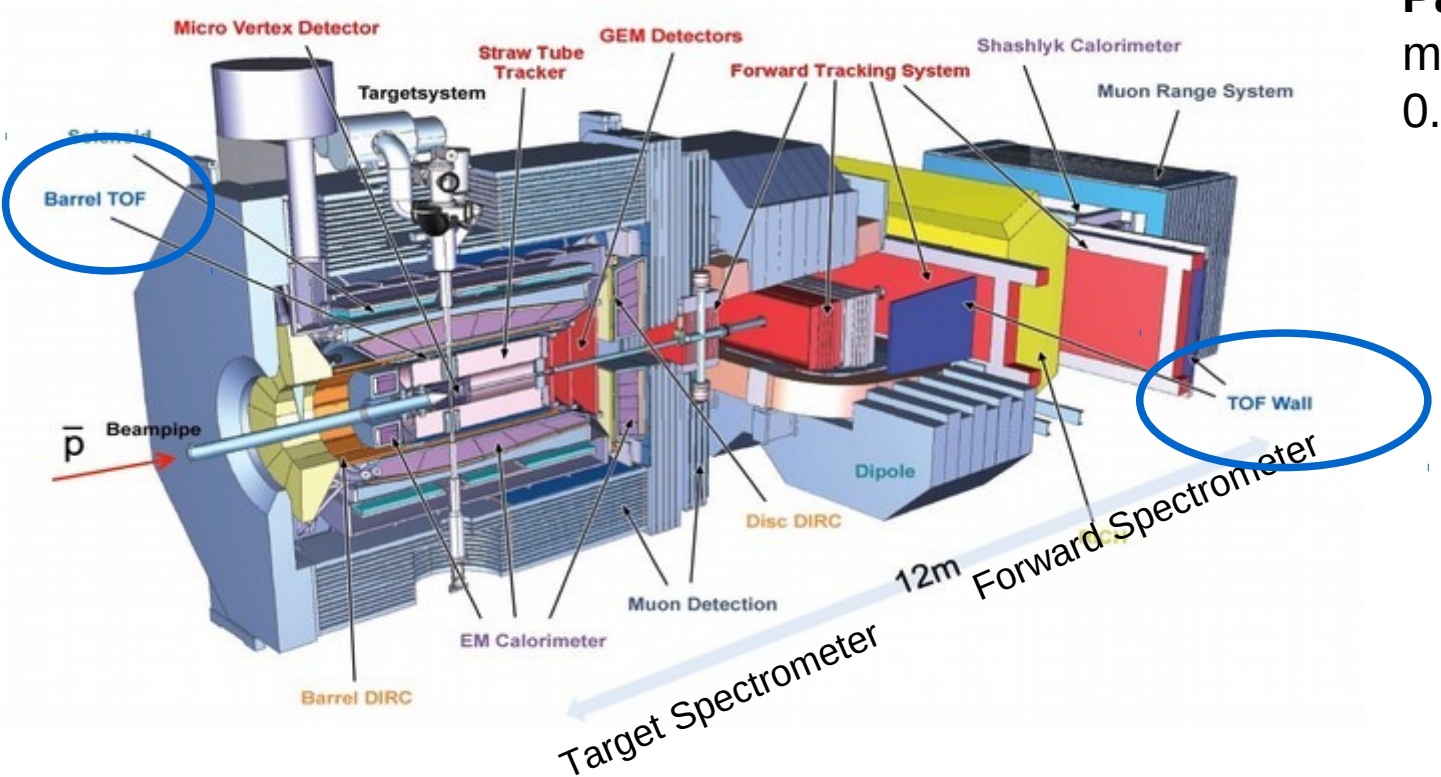
Energy loss



Particle identification methods

momentum range:
0.2 GeV/c – 10GeV/c

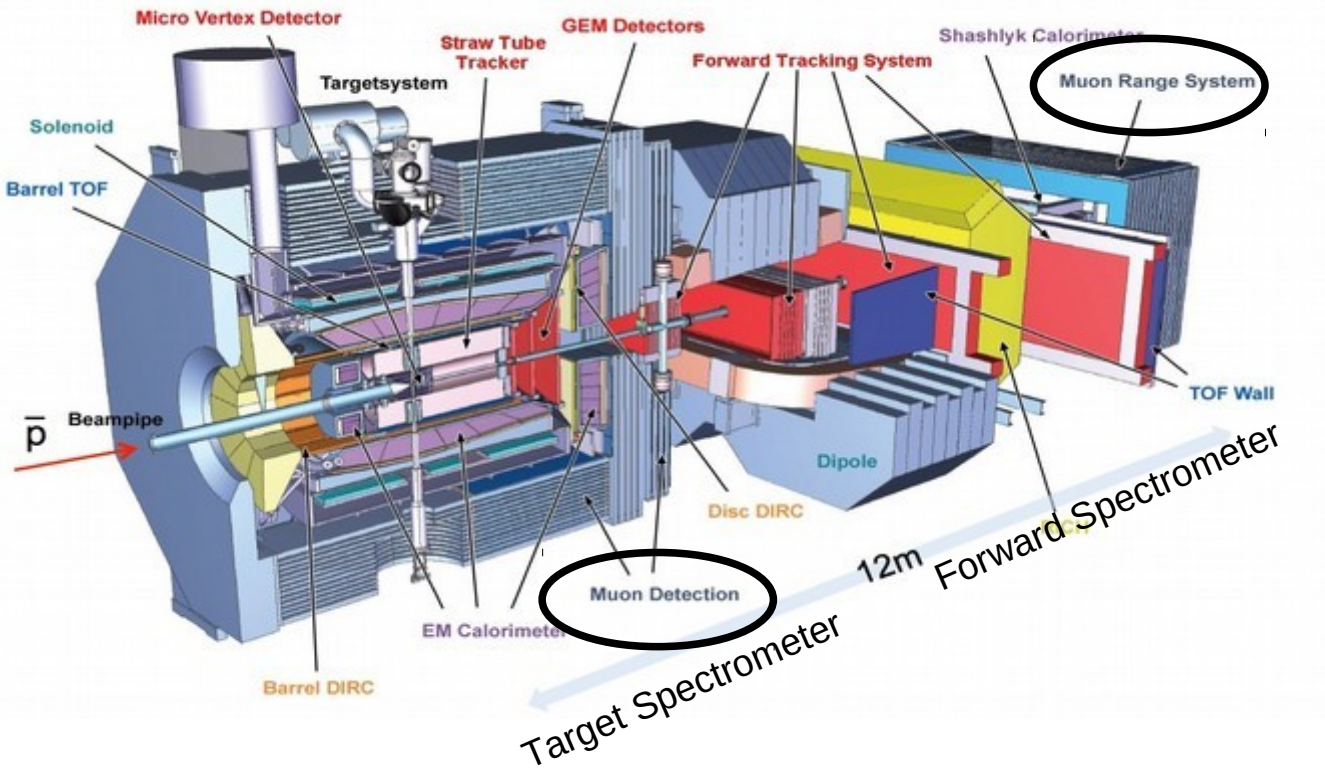
Energy loss
EM showers



Particle identification methods

momentum range:
0.2 GeV/c – 10GeV/c

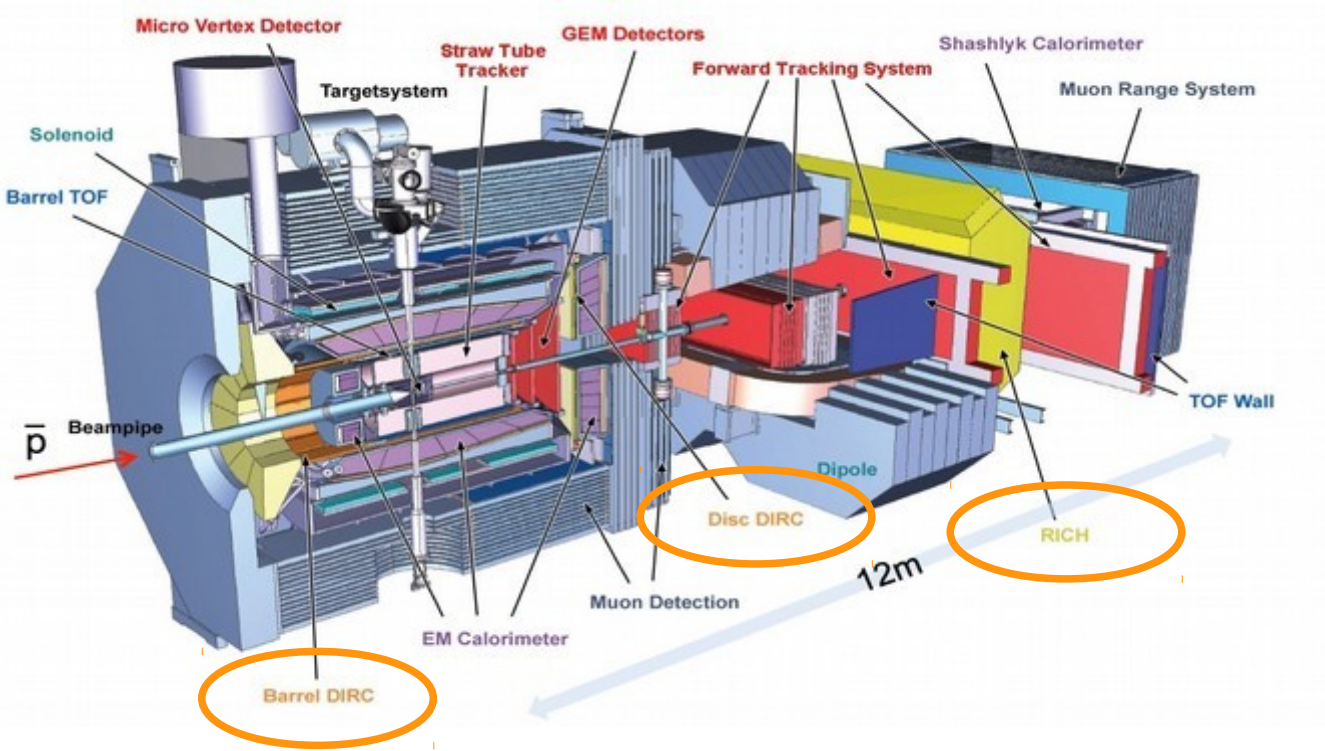
Energy loss
EM showers
Time of Flight



Particle identification methods

momentum range:
0.2 GeV/c – 10GeV/c

Energy loss
EM showers
Time of Flight
Muon Range System

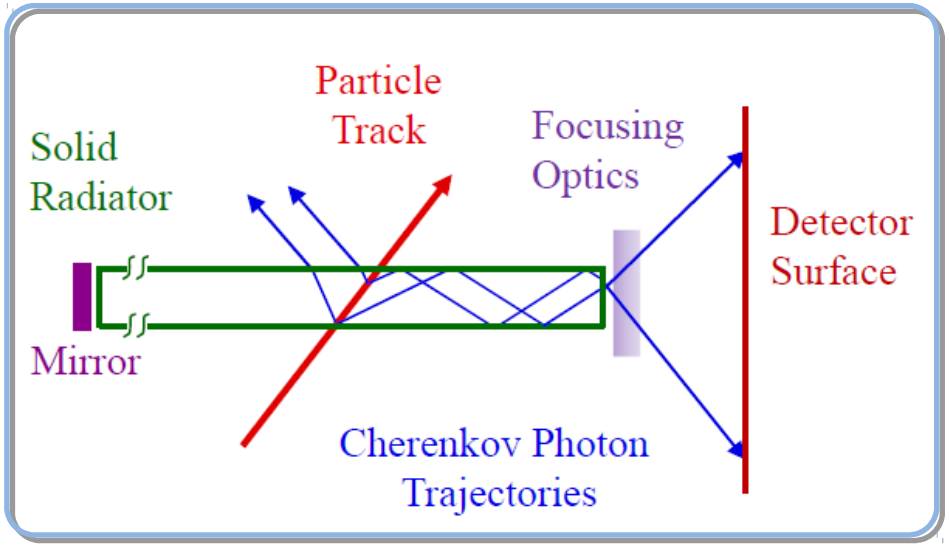


Particle identification methods

momentum range:
0.2 GeV/c – 10GeV/c

Energy loss
EM showers
Time of Flight
Muon Range System
Cherenkov

DIRC principle



Novel kind of
Ring **I**maging **Ch**erenkov Detector

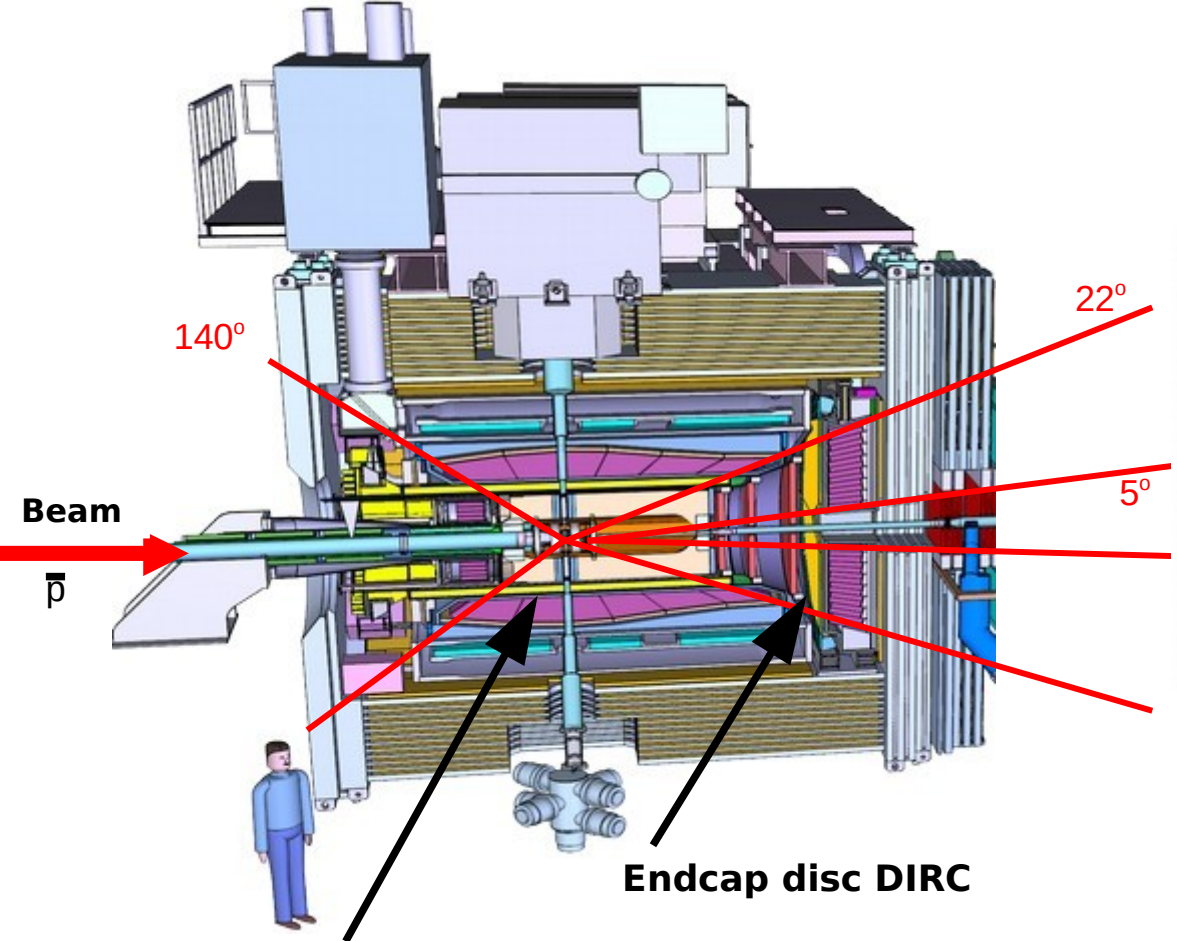
Detection of **I**nternally **R**eflected **C**herenkov Light

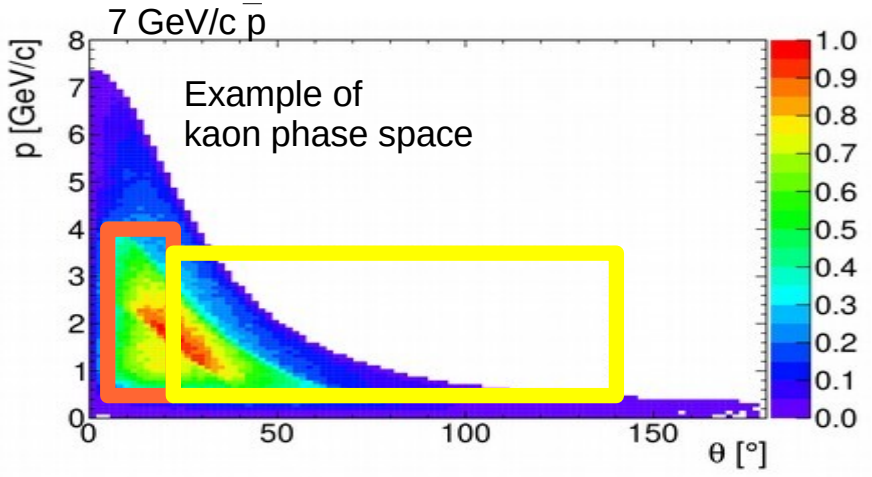
B.N. Ratcliff, SLAC-PUB-6047 (Jan. 1993)

Radiators with polished surfaces and orthogonal sides:

- For n>√2 some photons are always totally internally reflected for β≈1 tracks
- Magnitude of Cherenkov angle conserved during internal reflections
- Photons exit radiator via the (optional) **focusing optics** into **expansion region**, detected on **photon detector array**

PANDA Barrel DIRC





Barrel DIRC

Goal: 3 s.d. π/K separation
up to 3.5 GeV/c

Endcap disc DIRC

Goal: 3 s.d. π/K separation
up to 4 GeV/c

Barrel DIRC Design:

based on BABAR DIRC and SuperB FDIRC

with key improvements

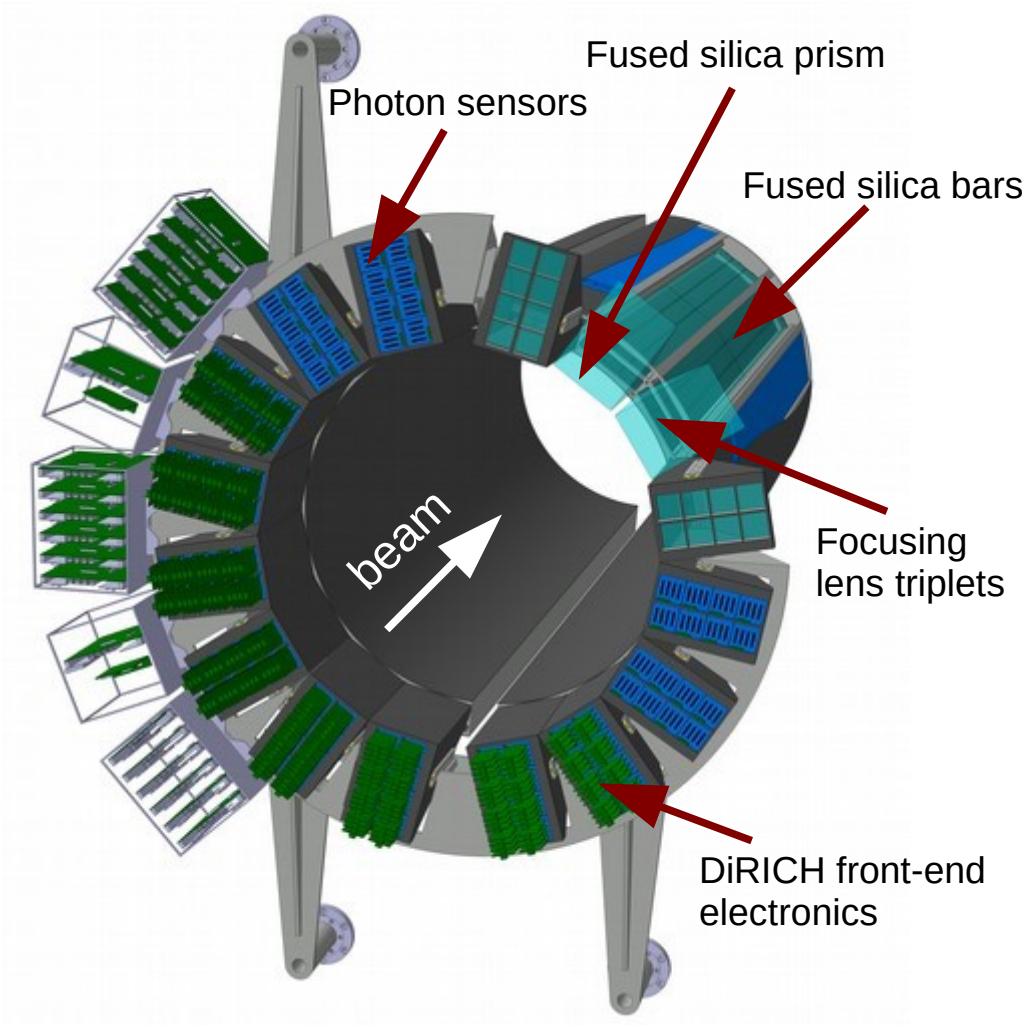
- Barrel radius ~48 cm;
- 48 narrow radiator bars, synthetic fused silica

  17 mm (T) x 53 mm (W) x 2400 mm (L).
- Compact photon detector:

  30 cm fused silica expansion volume
  8192 channels of MCP-PMTs
  in ~1T B field
- Focusing optics: spherical lens system
- Fast photon detection:

  fast TDC plus TOT electronics,

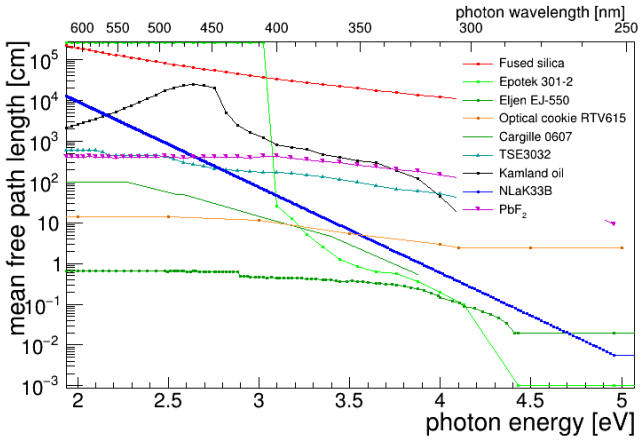
  → 100 ps timing

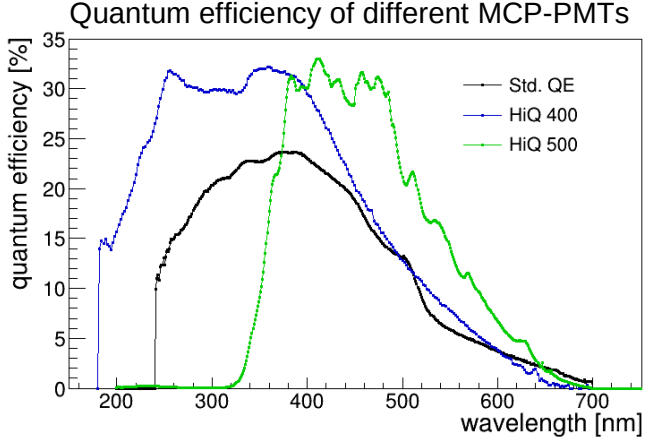


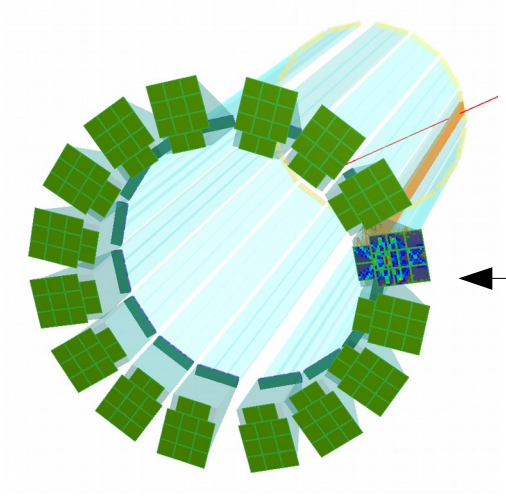
Expected performance

Geant4 simulations includes:

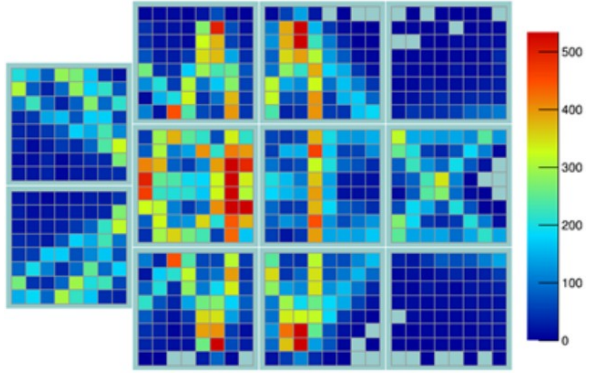
- Realistic materials properties
- Photons transport efficiency
- Single photon time resolution
- Quantum and collection efficiency
- Dark counts







Accumulated hit pattern from 1000 K^+ at 3.5 GeV/c and 25° polar angle



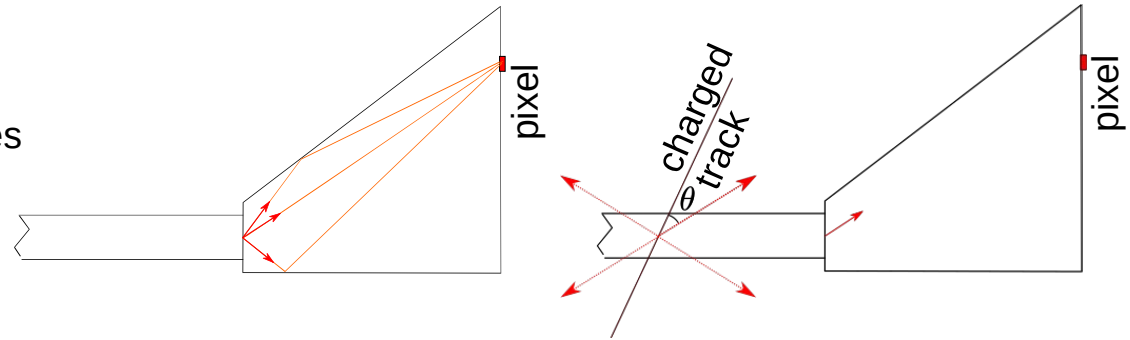
Two reconstruction methods
- geometric reconstruction (x,y)
- timing imaging (x,y,t)

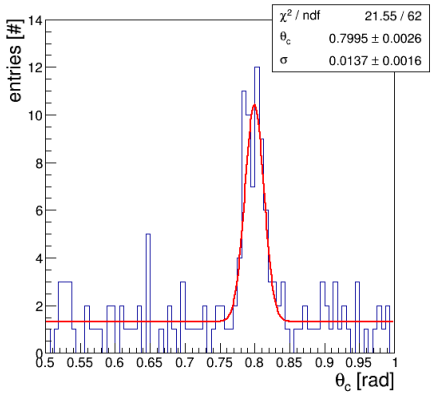
Roman Dzhygadlo IEEE-NS 2018

Reconstruction Methods

Geometrical

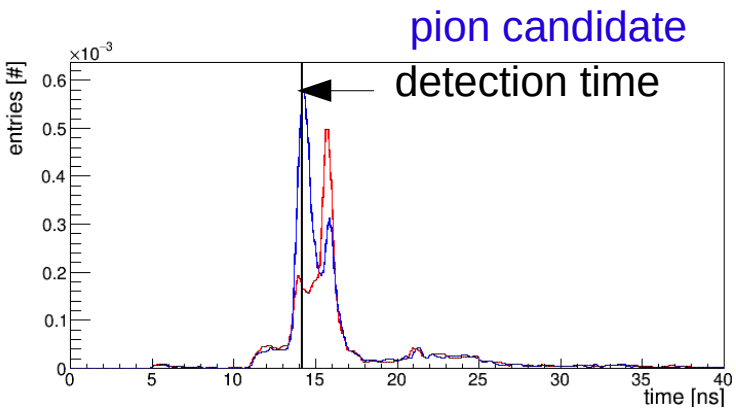
- BABAR-like
- Needs Look-Up Tables

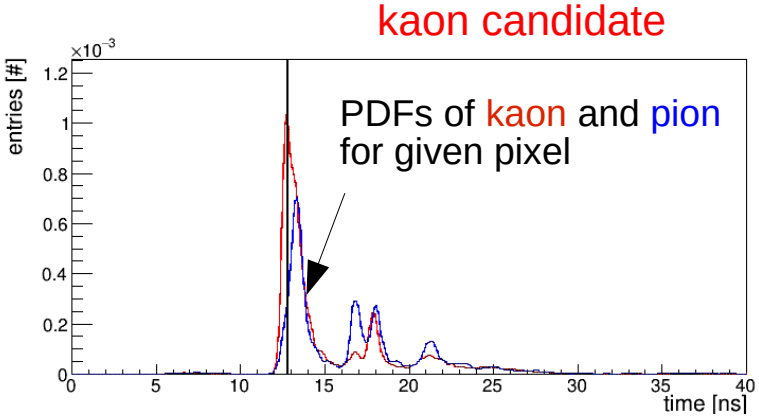




Time imaging

- Belle II TOP-like
- Needs Probability Density Functions of the propagation time

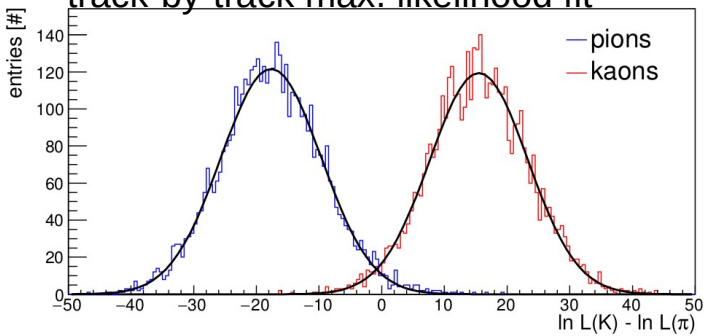




Roman Dzhygadlo IEEE-NS 2018

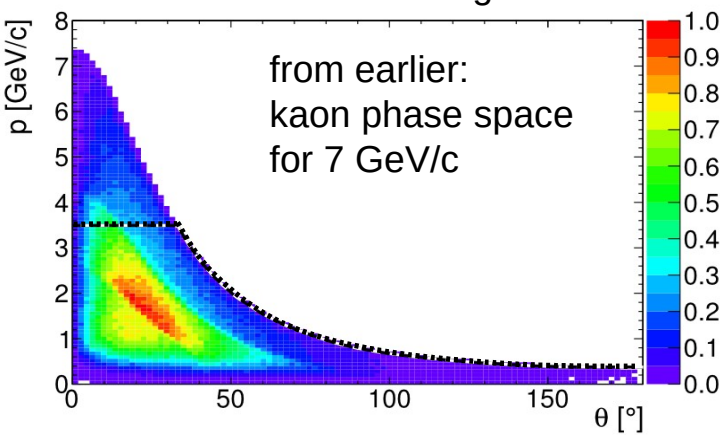
Expected Performance

track-by-track max. likelihood fit

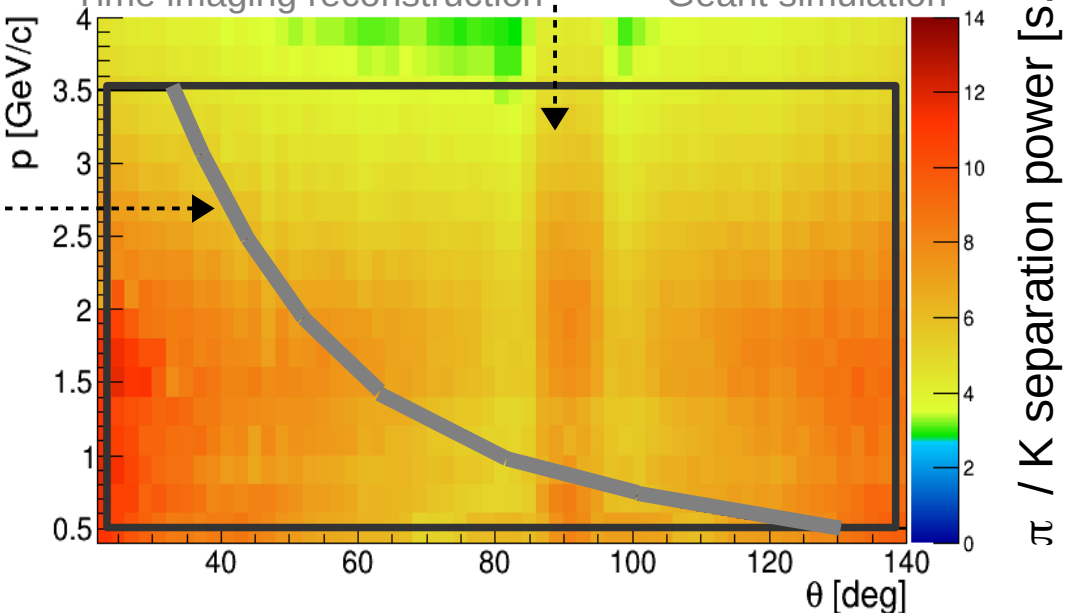


$$N_{\mathrm{sep}} = \frac{|\mu_1 - \mu_2|}{0.5(\sigma_1 + \sigma_2)}$$

Barrel DIRC PID 3 s.d. goal



Time imaging reconstruction — Geant simulation



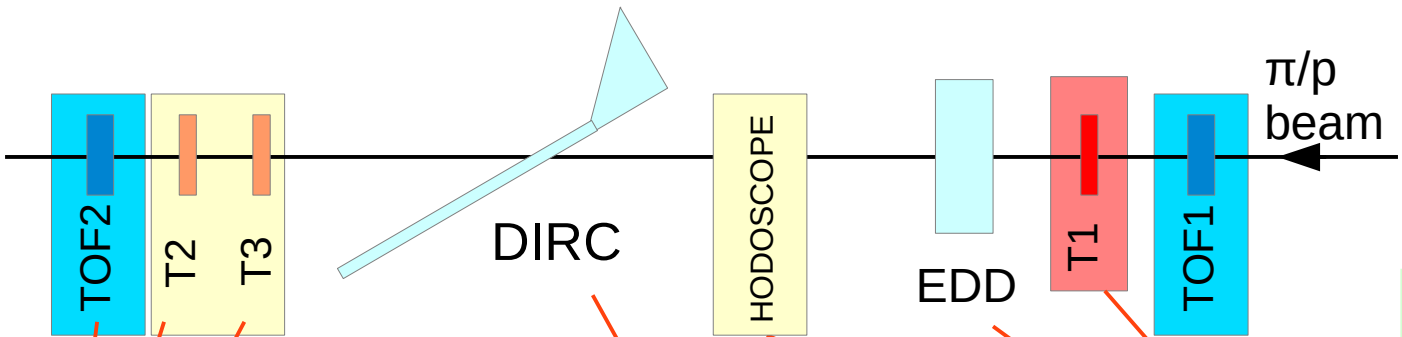
➡ Design meets and exceeds PID requirements

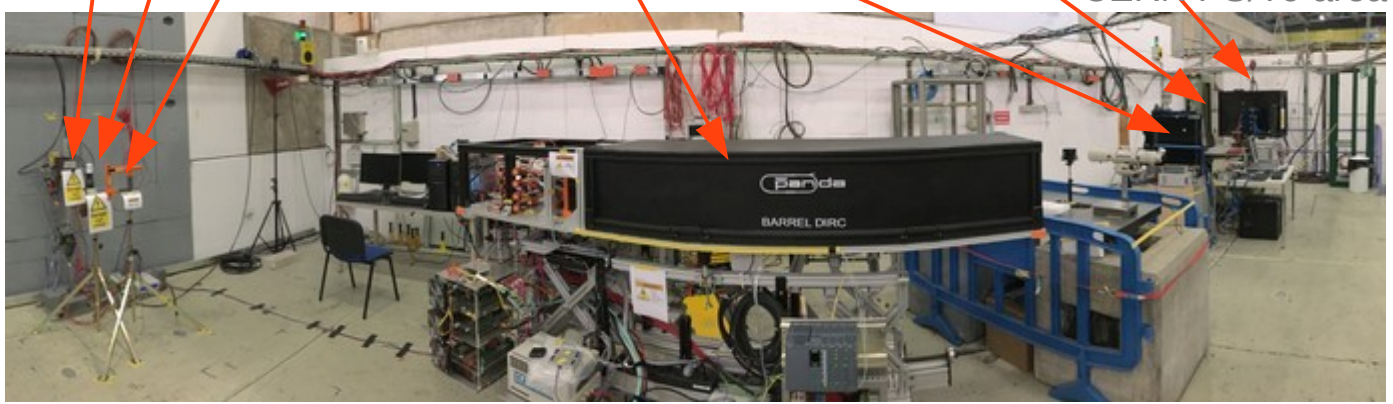
Beam test at CERN 2018

TOF particle identification

Beam profiling

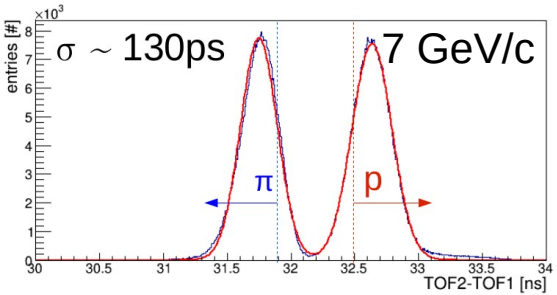
Trigger





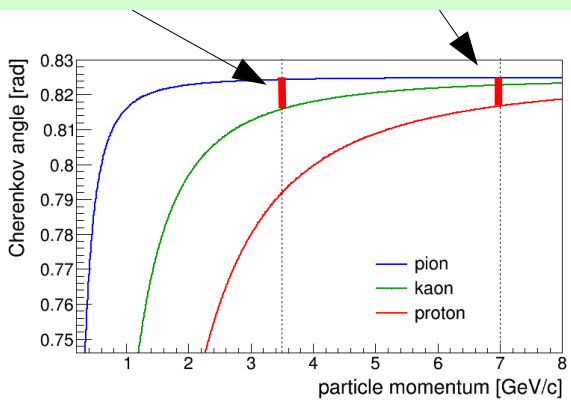
CERN PS/T9 area

External TOF PID

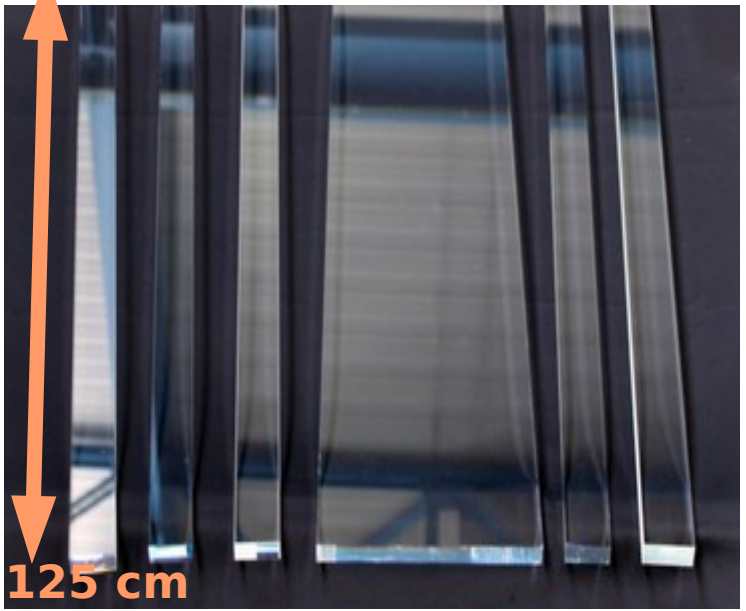


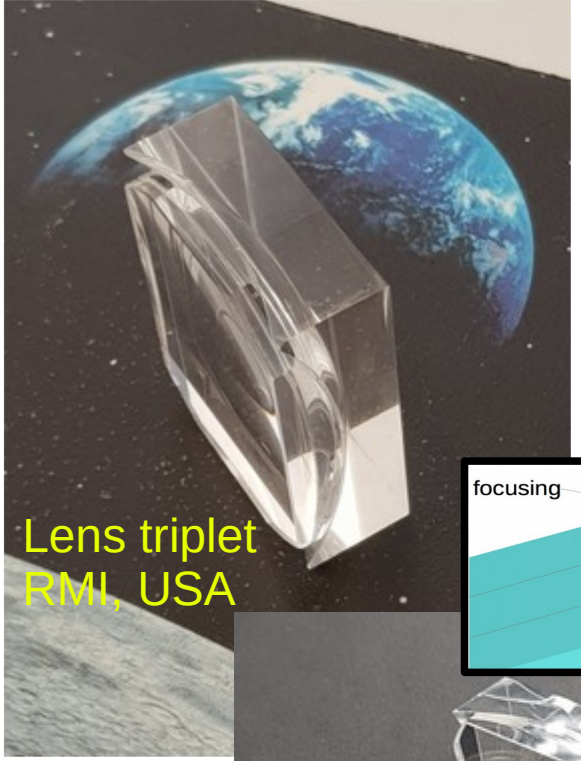
Most of the data taken at 7 GeV/c

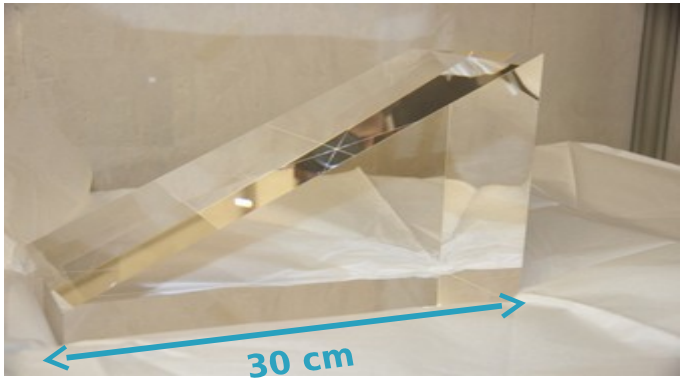
3.5 GeV/c π/K ≈ 7 GeV/c π/p sep.

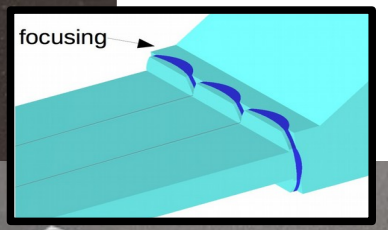


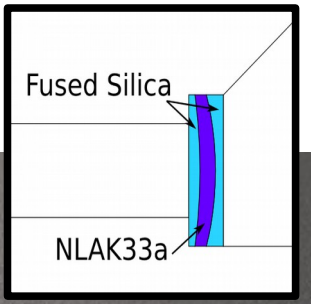
Optical components











Bars from AOS/Okamoto, InSync, Nikon, Zeiss, Zygo; Heraeus, Lytkarino LZOS, Schott Lithotec.

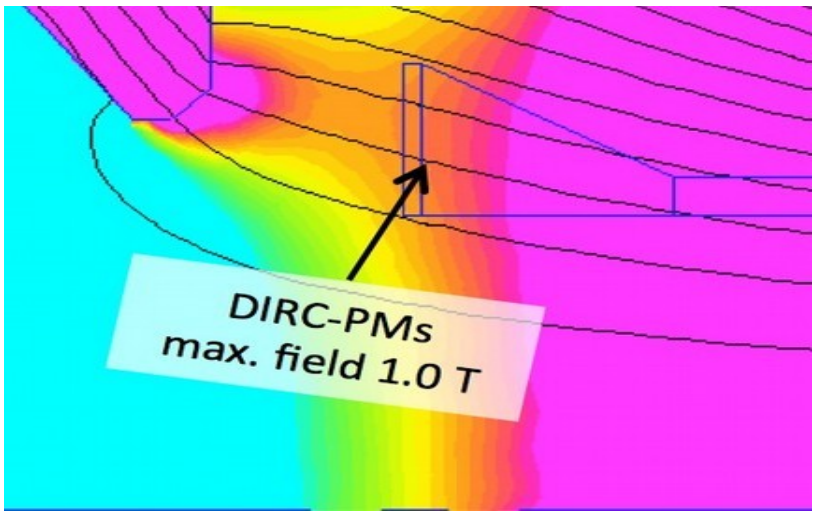
Plates from InSync, Nikon

Photon detector

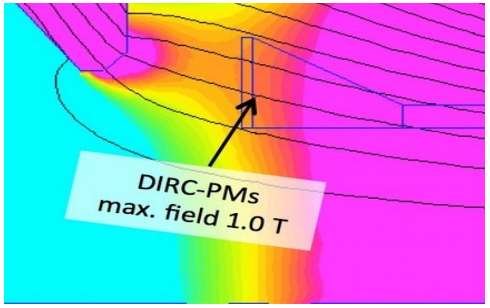
Requirements:

- **few mm** spatial resolution
- working in **magnetic field of 1 T**
- **~100 ps** timing resolution

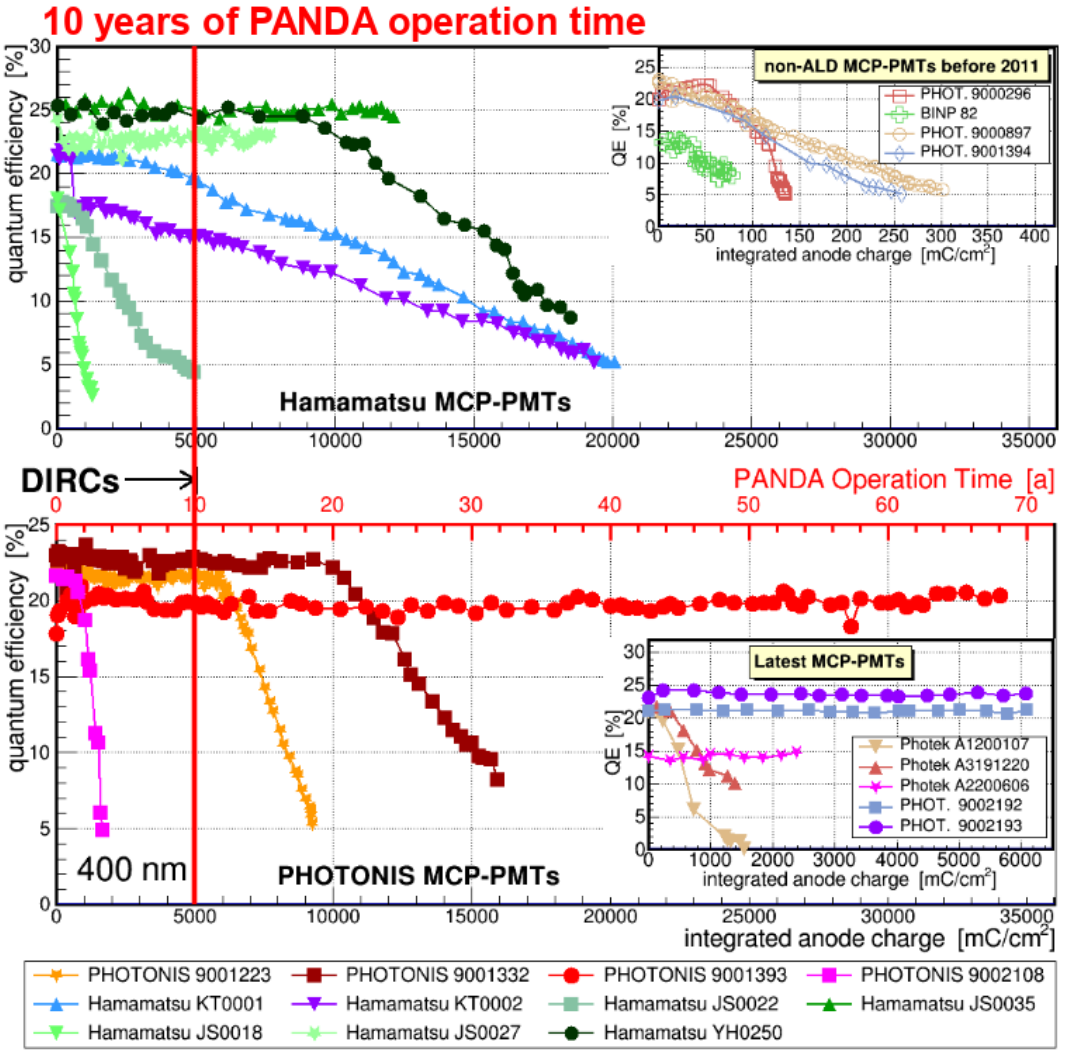
Sector:
8 MCP-PMT, each 8 x 8 pixels
(total 8 k readout channels)
with **pixel size 6 x 6 mm²**
work in **1T magnetic field**
survive **10 years** of PANDA (aging)



Photon detector



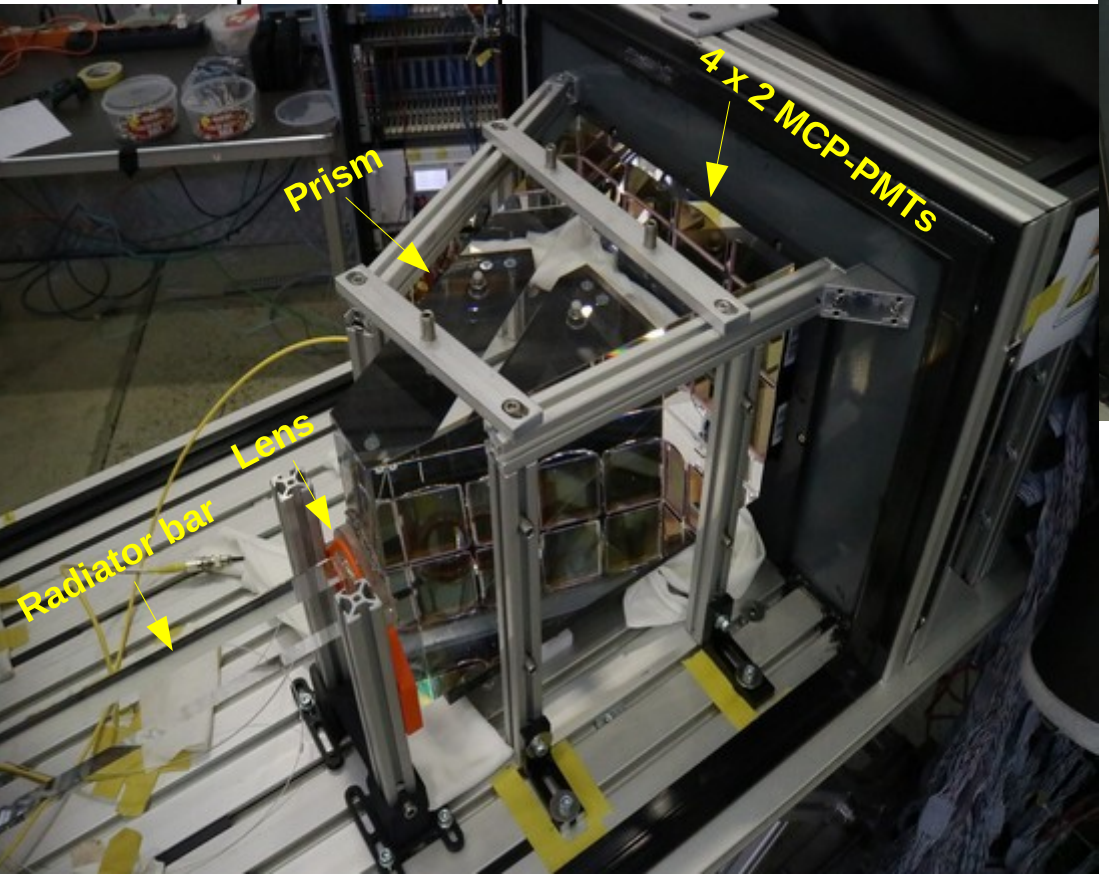
Sensors with **ALD coated** MCPs have **lifetime > 5 C/cm²**

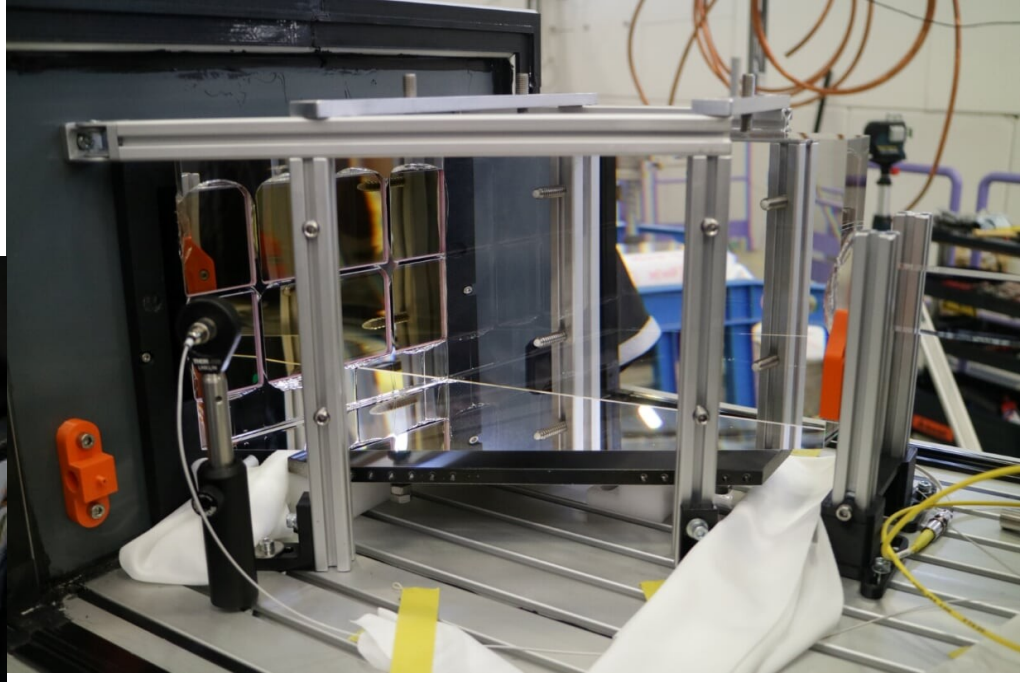


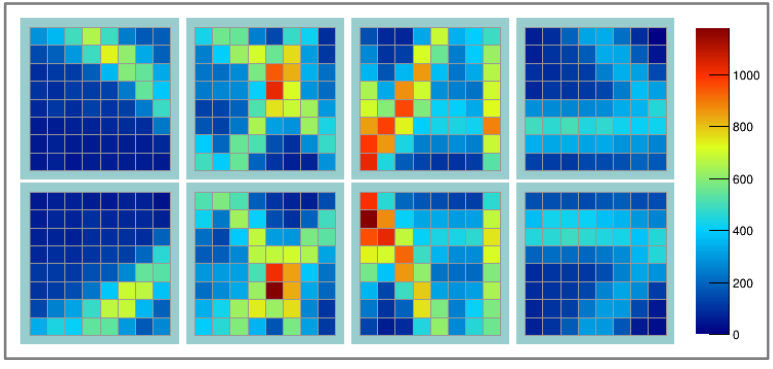
S. Krauss, RICH2022

Barrel DIRC setup
inside the dark box

with important components



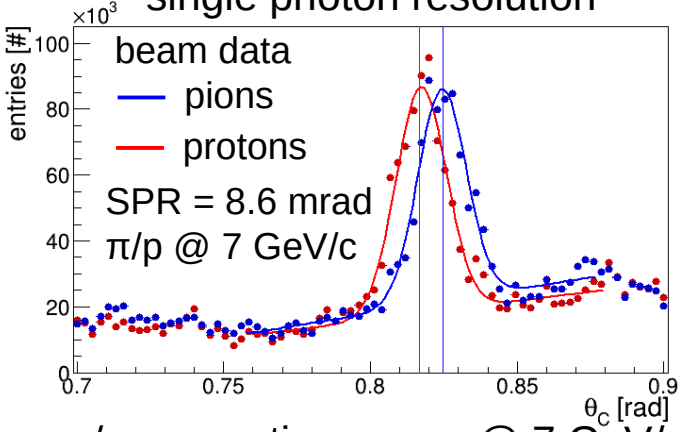


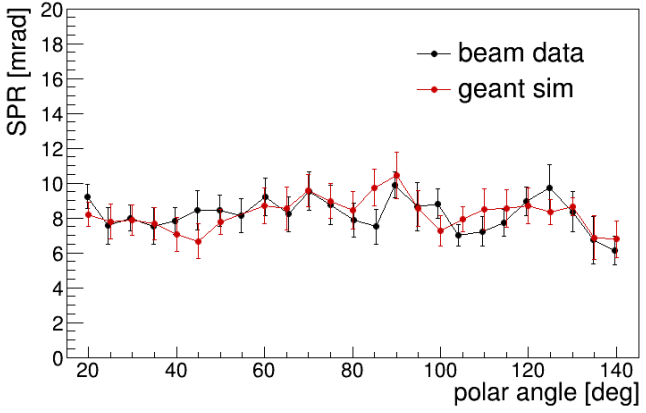


Barrel DIRC hit pattern at polar angle 20° of 7 GeV pions

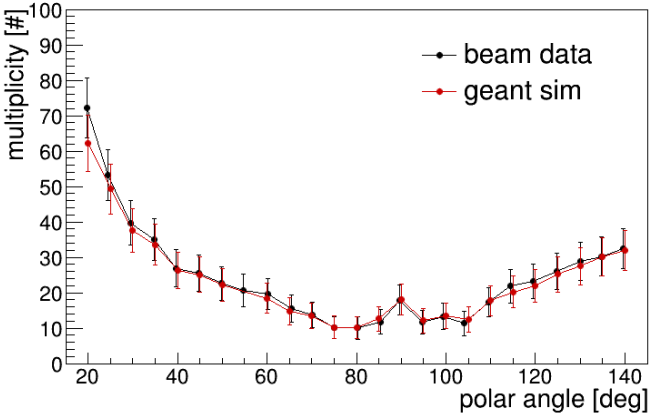
Beam test at CERN 2018

single photon resolution

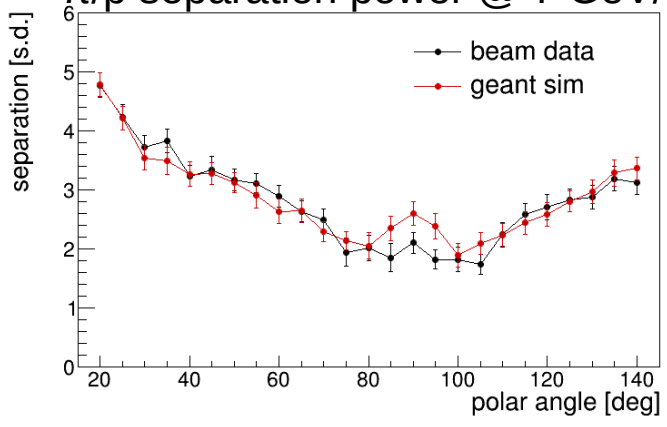




photon multiplicity



π/p separation power @ 7 GeV/c



➡ Good performance

Good agreement with Geant simulations

Design and simulation/reconstruction code validated

TDR: https://doi.org/10.48550/arXiv.1710.00684

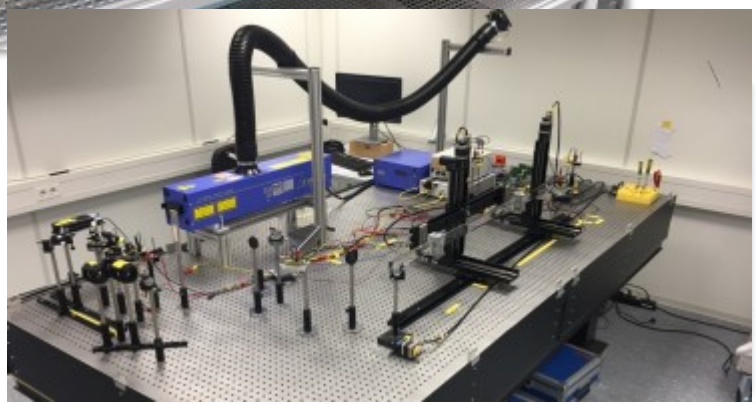
Series Production Status

Contract for DIRC bars awarded to Nikon Corp. in Sep. 2019

Series production of 112 bars completed in Feb. 2021, ahead of schedule

Quality assurance is in progress at GSI

Nikon DIRC bars at GSI



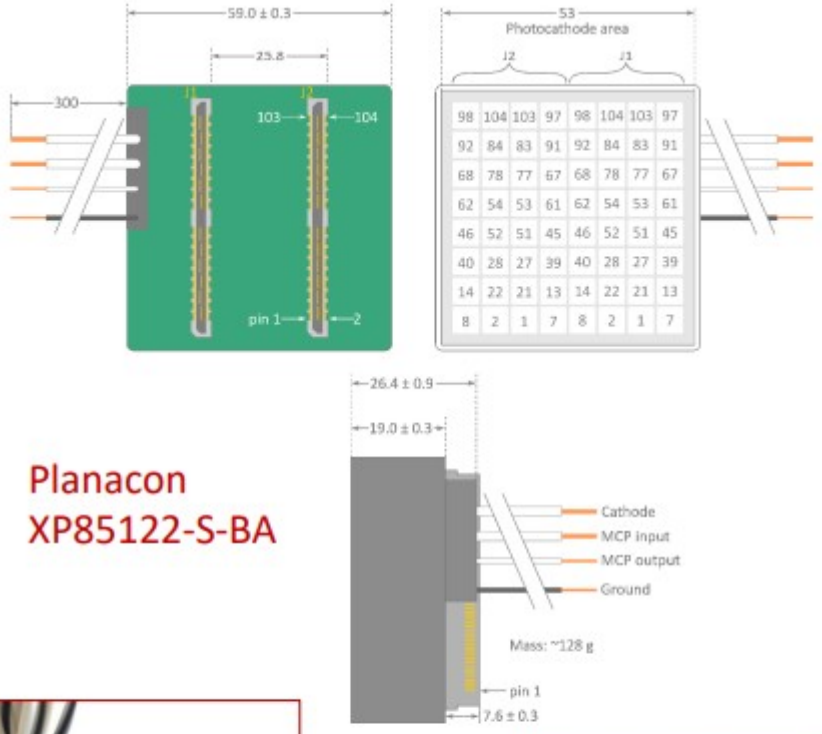
G. Schepers, GSI

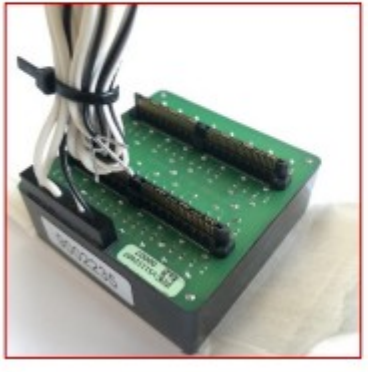
Series Production Status

Contract for MCP-PMTs awarded to Photonis NL in Dec. 2020
Order for 155 sensors total

Series production underway

QA done in University Erlangen





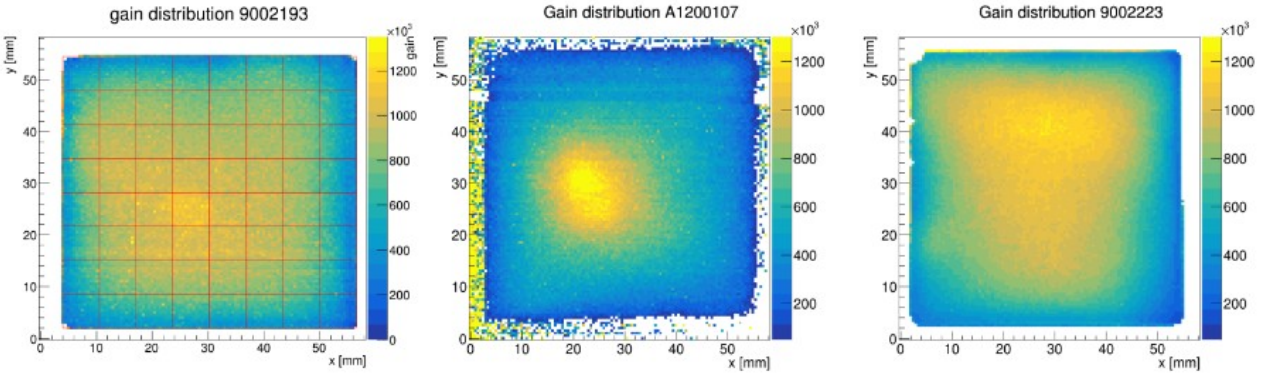
G. Schepers, GSI

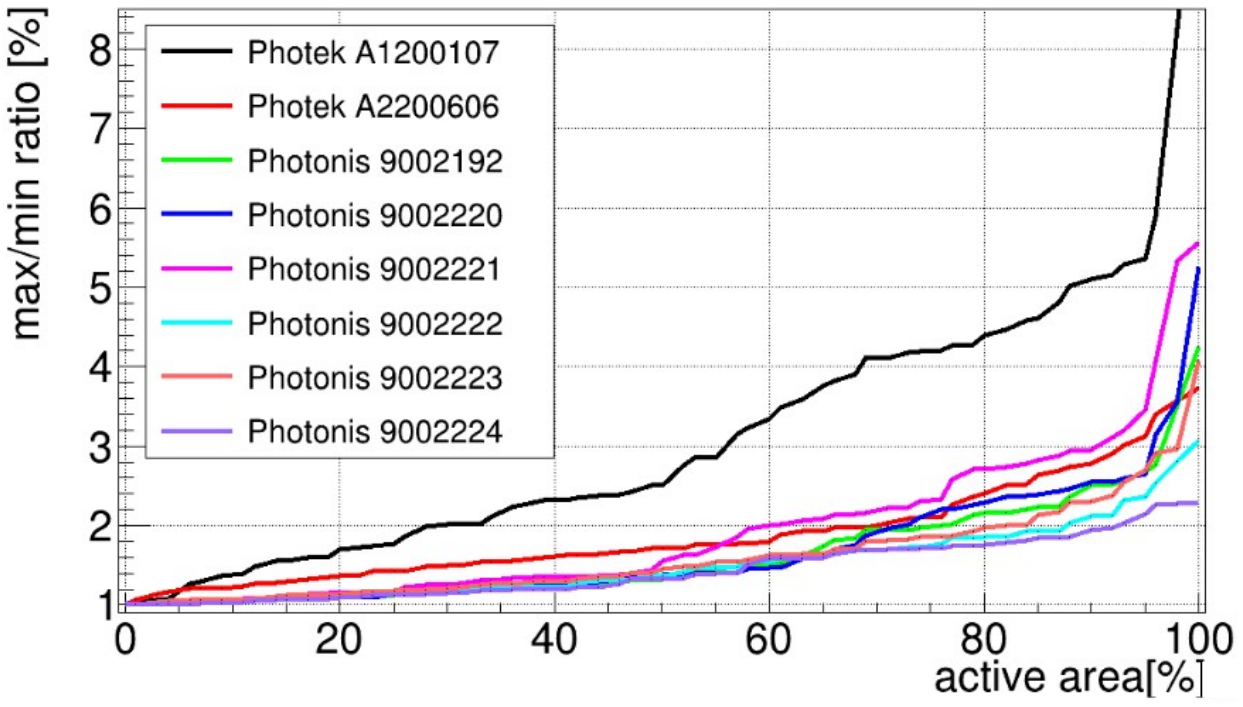
Gain homogeneity

Required spec:
max/min ratio <3
over whole active area

All Photonis tubes and latest Photek A2200606 are below max/min ratio of 3 for at least 90% of active area

Overall homogeneity ratio is within specs for Photonis tubes





S. Krauss, RICH2022

Current activities

Bar boxes and readout boxes

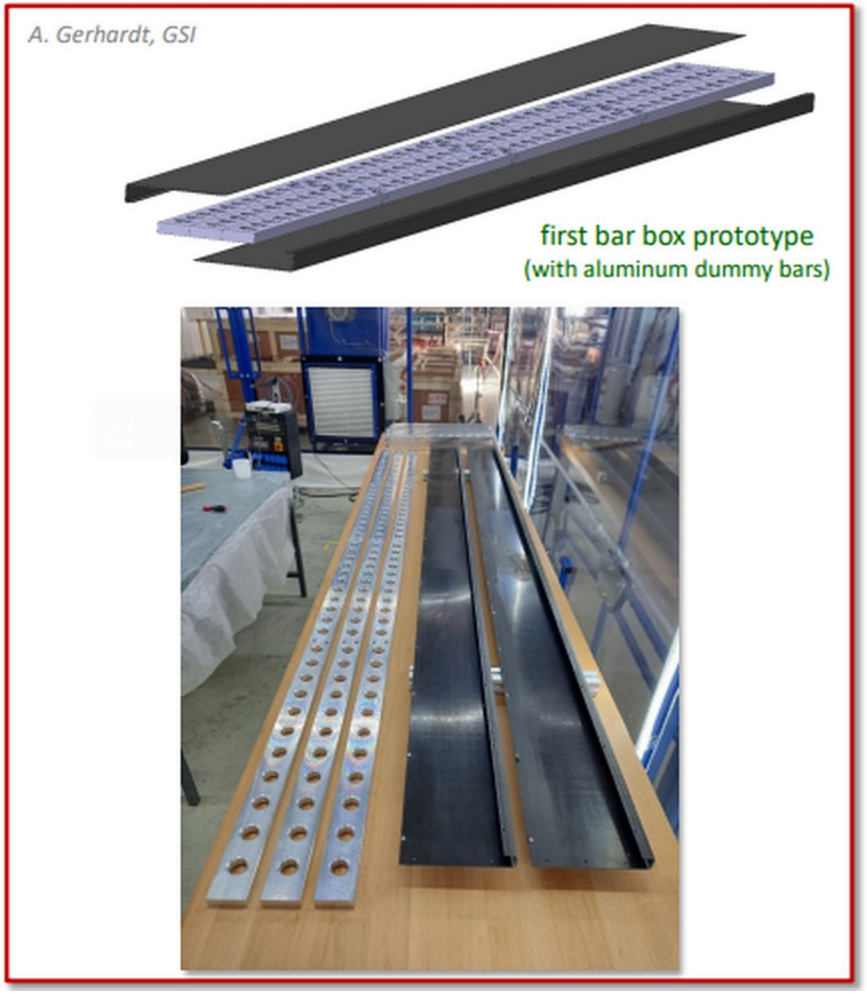
Modular DIRC support design based on detachable separate support structures for bars and prisms/MCP-PMTs

Components made of aluminum alloy and carbon fiber reinforced polymer (CFRP)

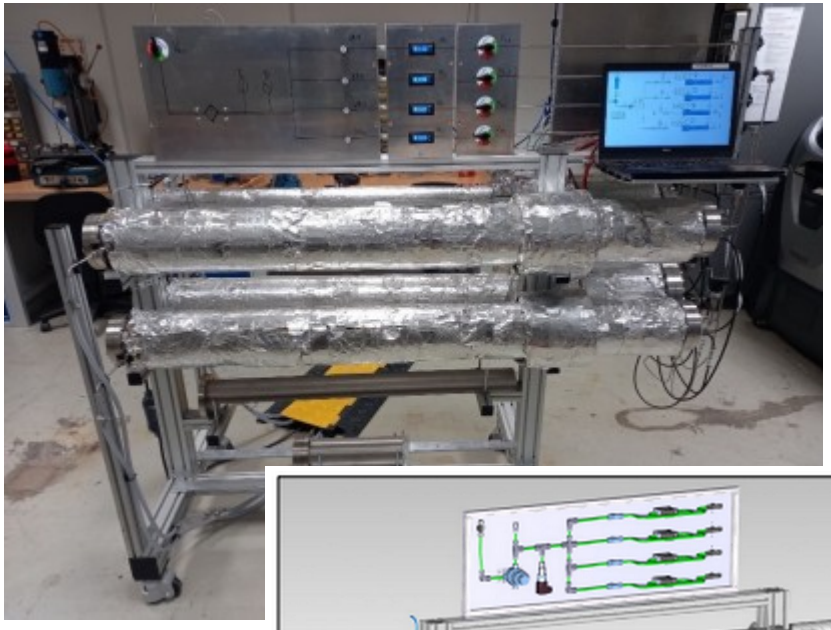
Barrel DIRC requires 16 light-tight bars boxes and readout boxes

First prototype bar box built by industry

Expect to procure second bar box prototype and first readout box prototype



Current activities

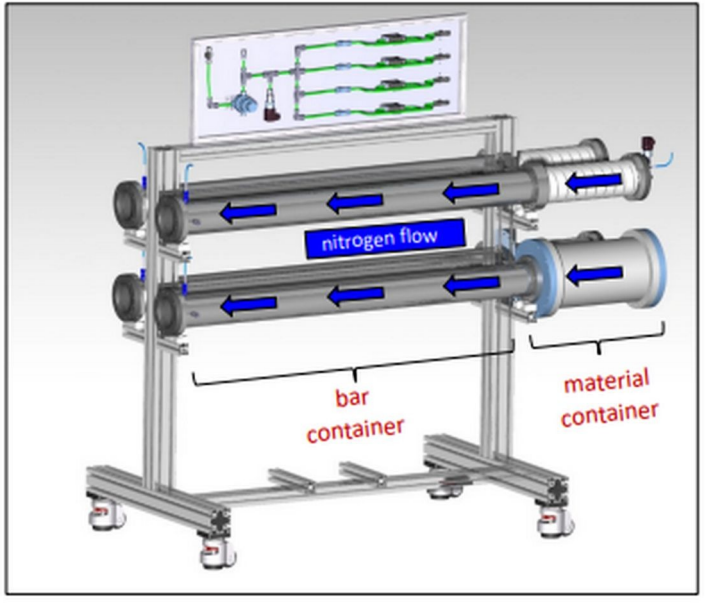


Material Screening

BaBar and Belle II DIRC bar boxes:
aluminum (hexcel honeycomb)

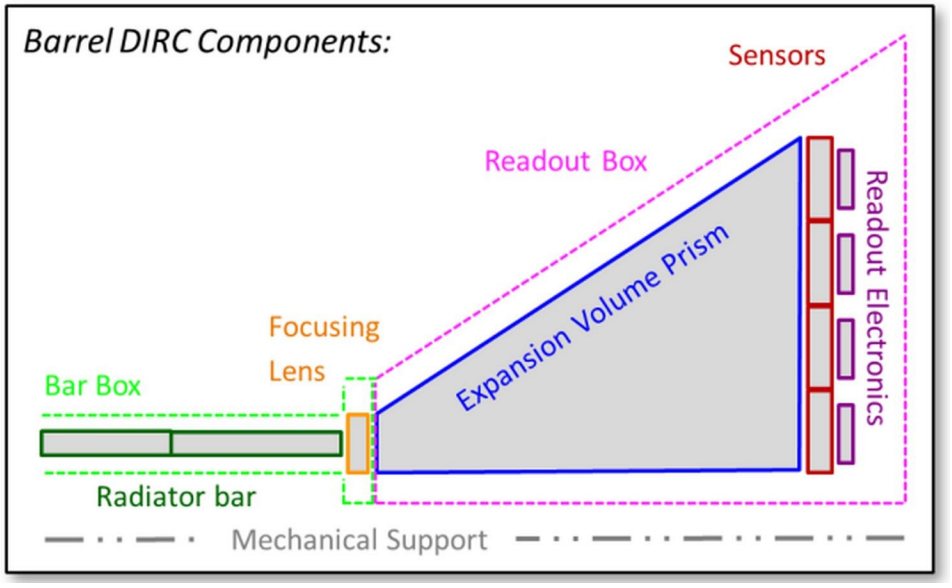
Need to confirm that CFRP and
other bar box materials are
safe to use
– particular concern about possible
outgassing of resin

Started tests, similar to BaBar DIRC approach,
to measure impact of material
outgassing on the bar surfaces



A. Gerhardt, GSI

Current activities



Mockup for prototyping
Sector #0

Glue bars and place 2-bar units at HI Mainz

Procure one set of pre-production prototype
bar/readout boxes

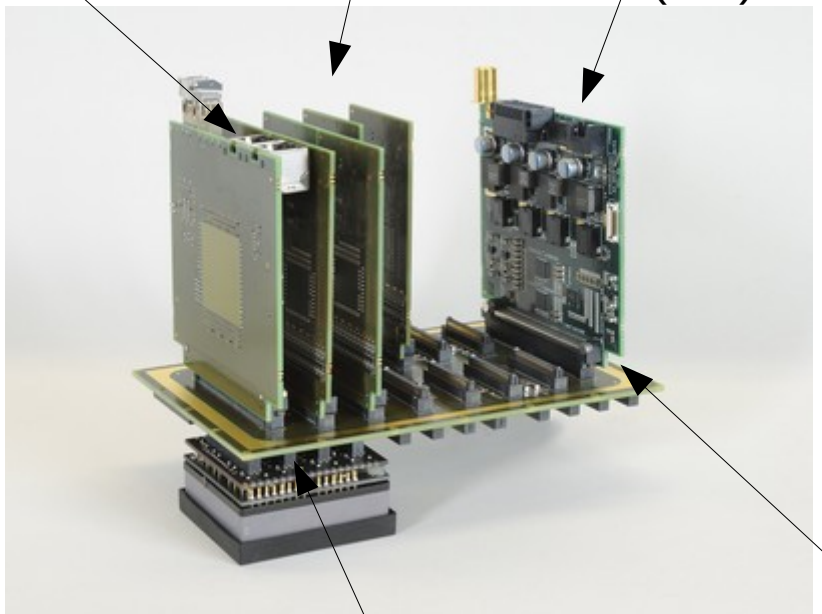
Glue and assemble first pre-production bar box at HI Mainz

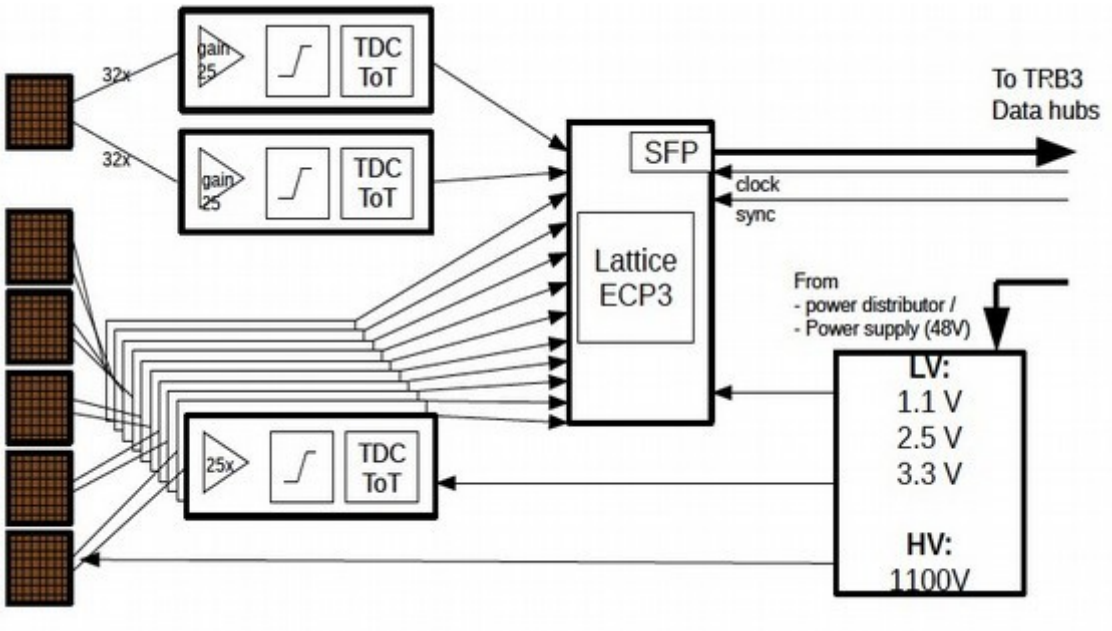
Assemble pre-production sector #0 available for
stand-alone tests with cosmics/beam

Current activities

DiRICH: PANDA-DIRC/CBM-RICH and HADES-RICH

Successor of PADIWA3 + TRB3

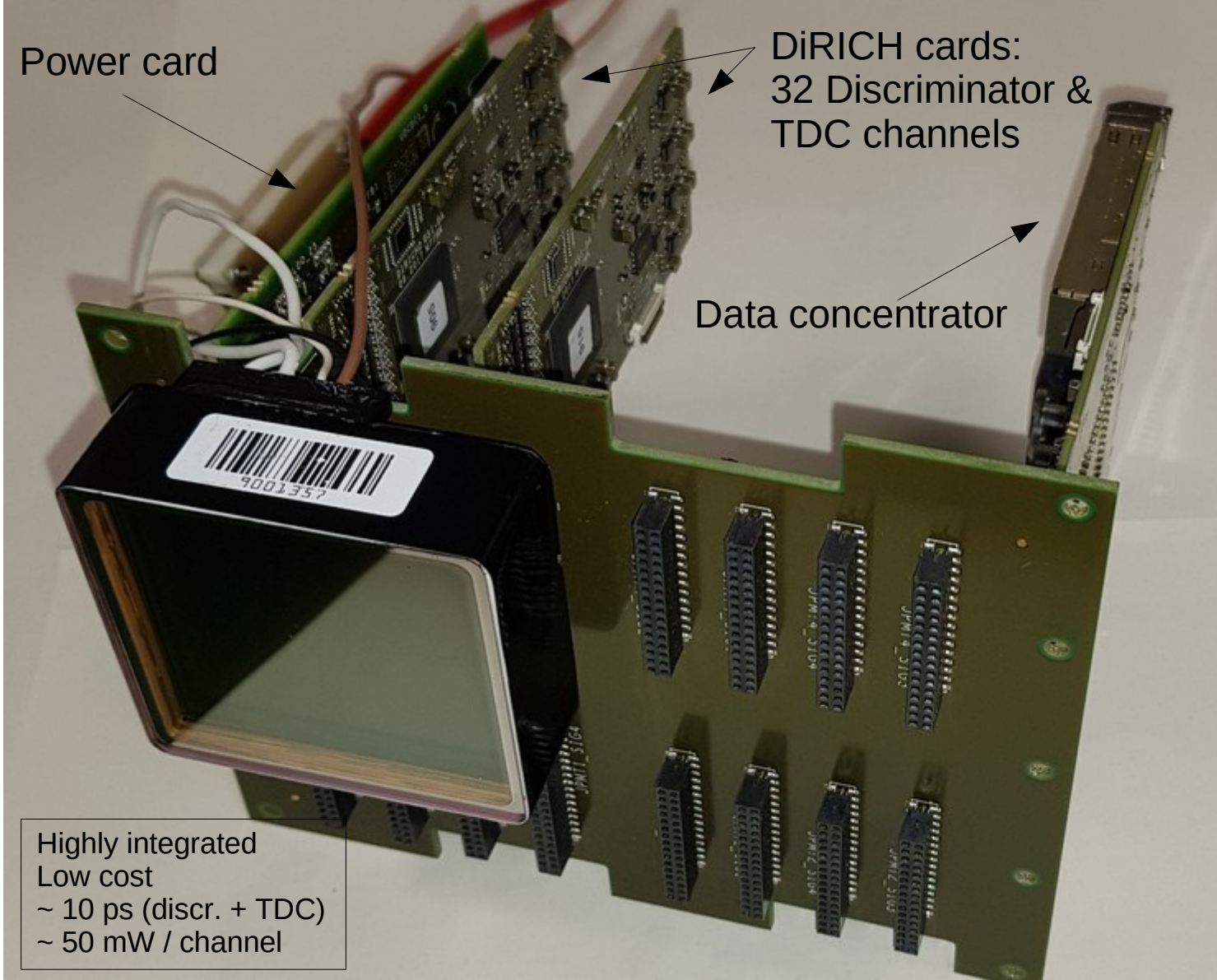




Current activities

DiRICH
Collaboration of
PANDA, CBM, HADES

Finalizing design
of next-gen DiRICH
modules/backplane



Summary

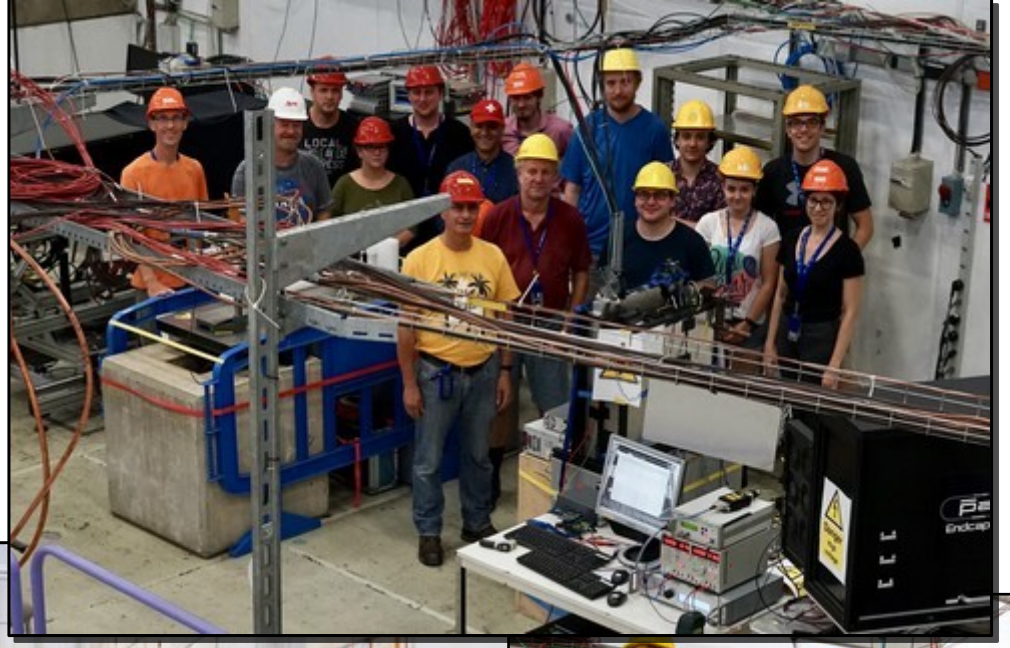
- The Barrel DIRC design with narrow bars, 3-layer spherical lens, and compact prisms meets or exceeds the PANDA PID requirements.

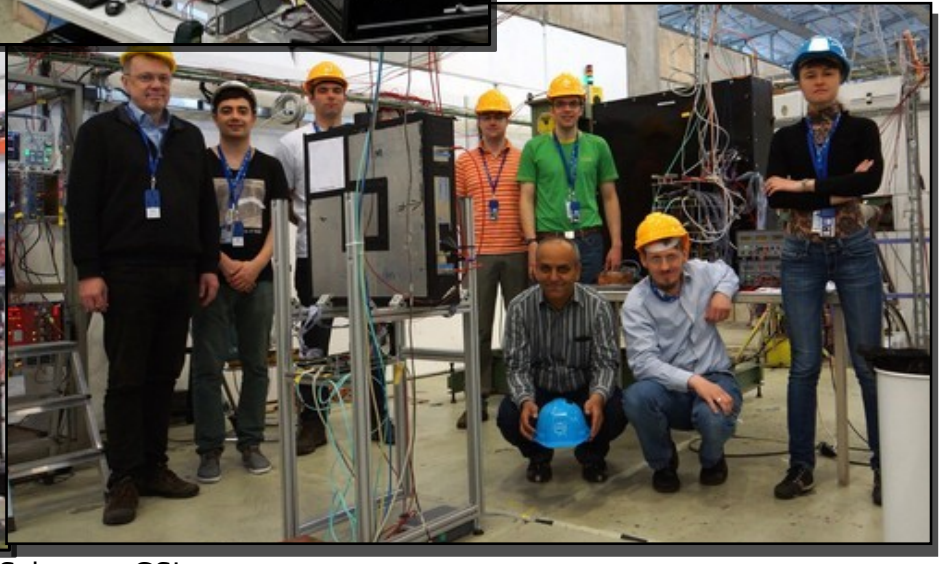
- The mass production of important components has started.
  - All bars are delivered by Nikon (2021).
  - 155 PHOTONIS MCP-PMTs are in production.

- Quality assurance of bars (GSI) and MCP-PMTs (FAU Erlangen) are ongoing.

- Prototype development for readout box holding the bars made from carbon fiber reinforced polymer (CFRP)
  - Started tests to measure impact of material outgassing on the bar surfaces

- Construction of #0 sector prototype
  - R&D for gluing two bars close to completed (HI Mainz)





Thank You