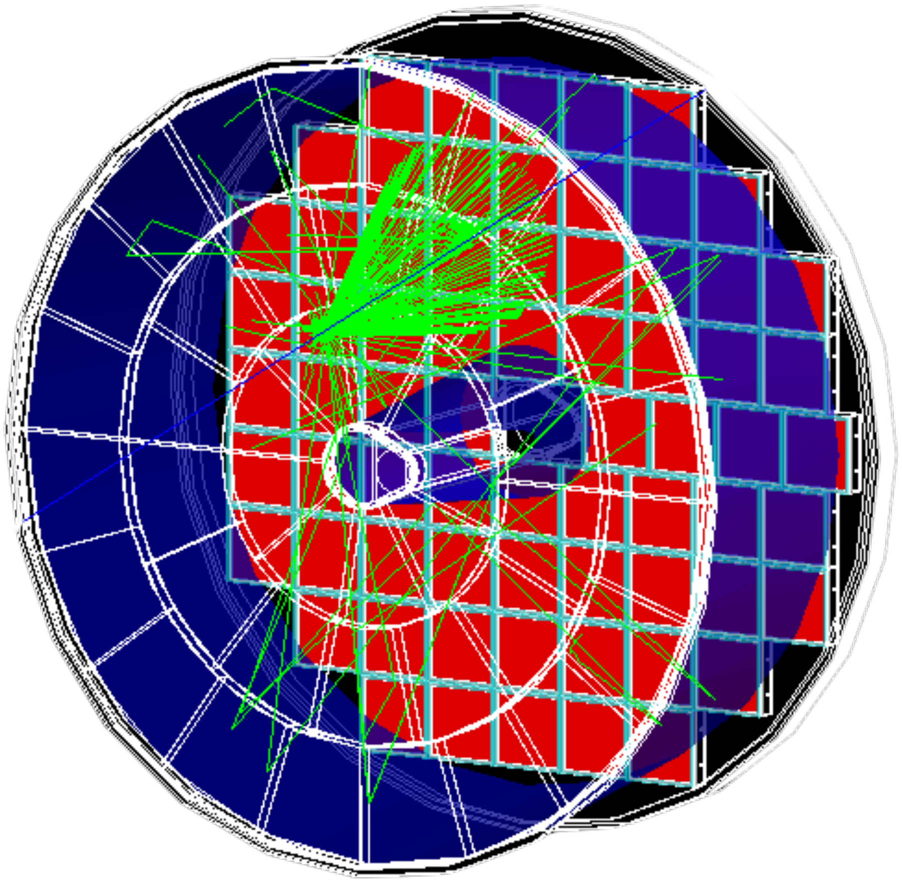


The ePIC Backward RICH Detector

Brian Page (BNL)

EICUG 2023

Outline

- ❑ Introduction and requirements
- ❑ Components and design
- ❑ Simulation
- ❑ DSC Organization

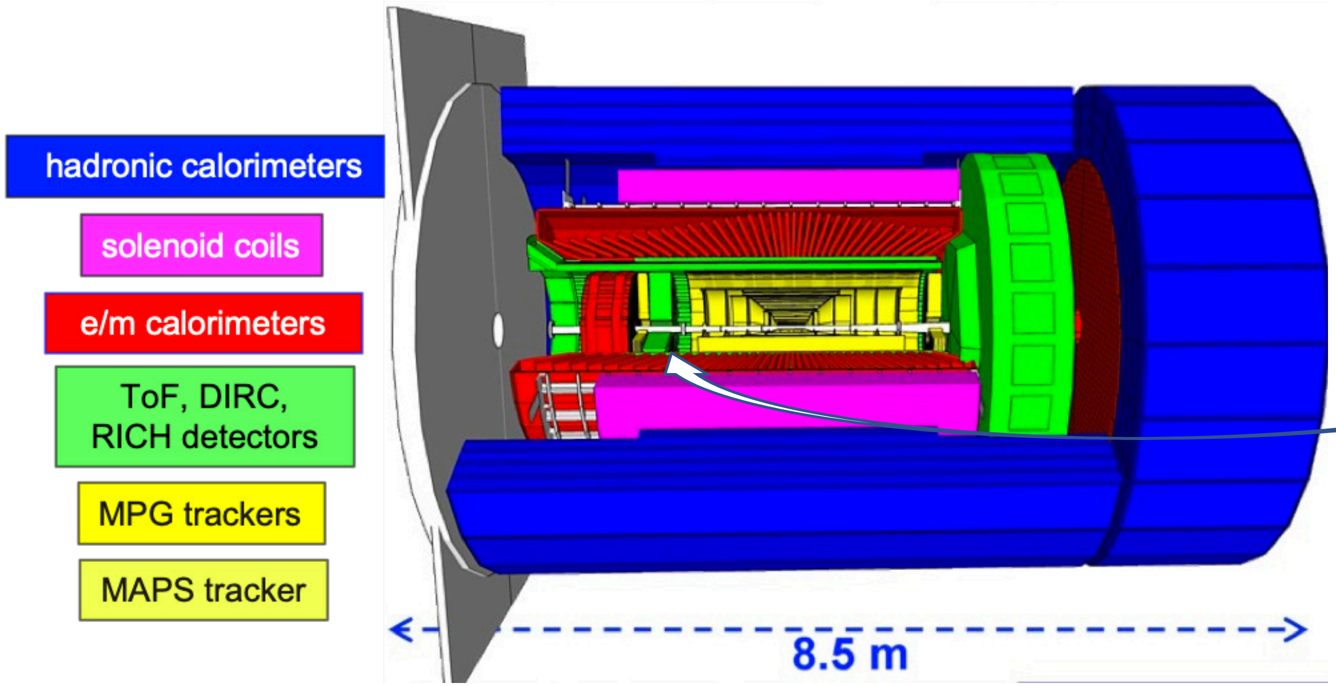
Requirements

SCIENCE REQUIREMENTS AND DETECTOR CONCEPTS FOR THE ELECTRON-ION COLLIDER

EIC Yellow Report

- ePIC backward RICH must provide PID coverage in the η range determined by the reach of the barrel DIRC and the acceptance of the crystal calorimeter in the e-endcap, therefore ~ -3.5 < η < ~ -1.65, at a minimum
- This part of the detector acceptance corresponds to the current fragmentation and low x physics, and is essential to support the claim of a complete hermetic coverage of the pseudorapidity range $-3.5 < \eta < 3.5$ by tracking, calorimetry and PID detectors
- Yellow report requirement: 3σ π/K separation up to 7 GeV/c
- Additional requirement: provide ~20 ps timing reference for ePIC ToF detectors

Integration within ePIC



Tracking:

- New 1.7 T solenoid magnet
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID:

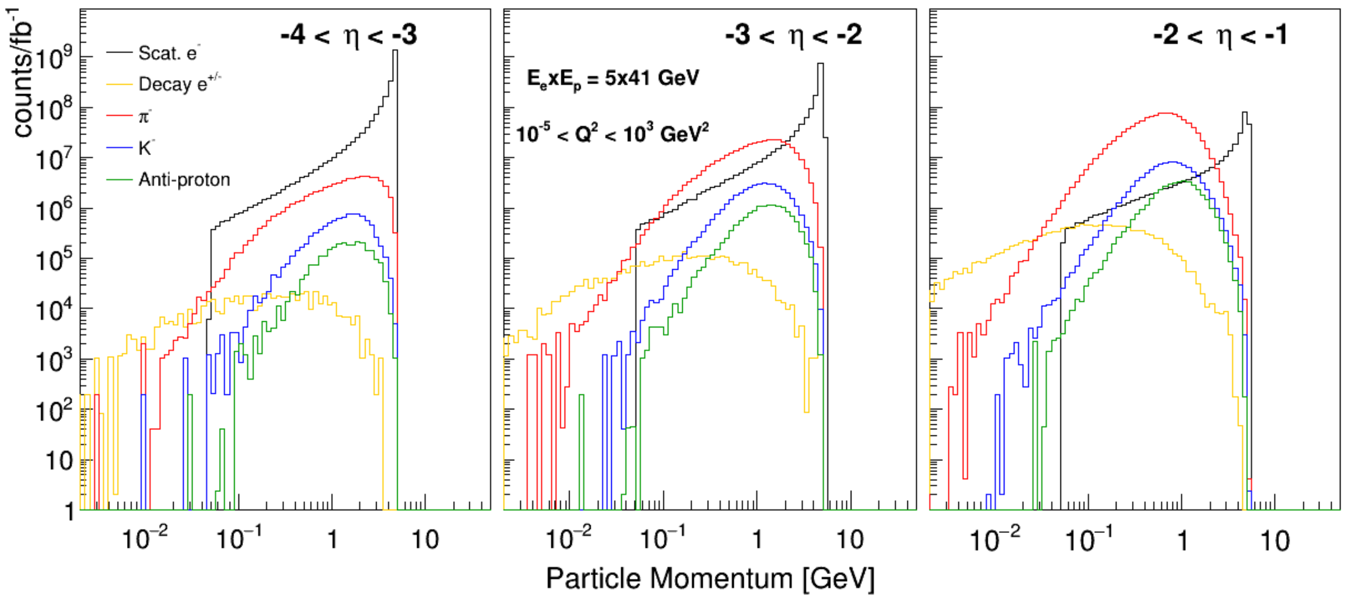
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:

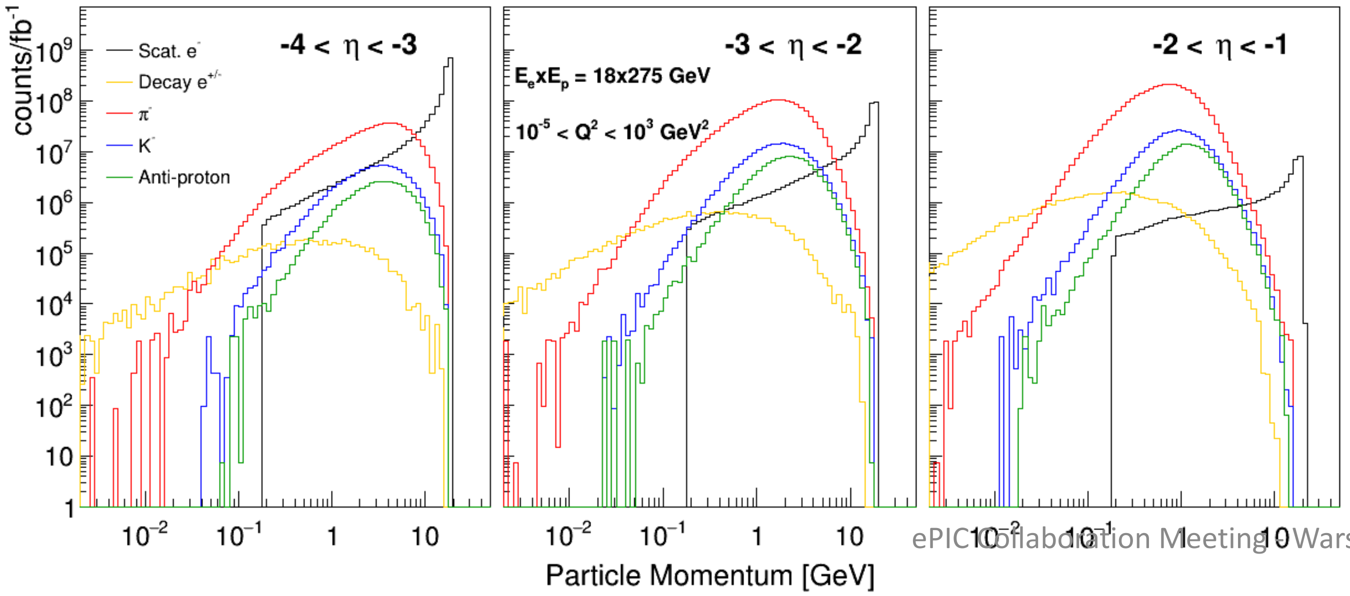
- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal + HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

- ❑ A compact central detector with several subsystems
- ❑ (Almost) hermetic coverage in tracking, calorimetry & PID $-3.5 < \eta < +3.5$

Particle Distributions in the e-Endcap



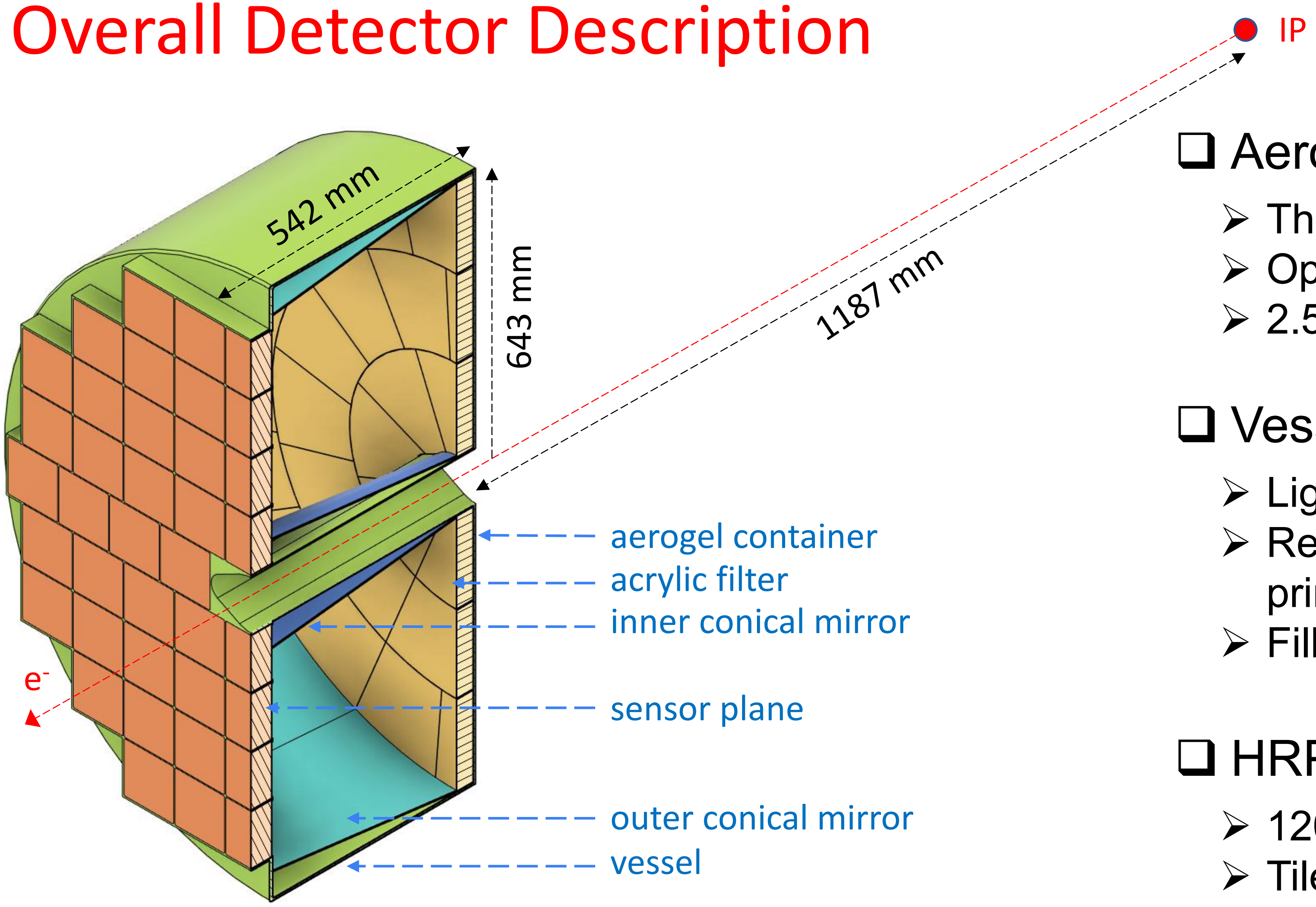
5 x 41 GeV



18 x 275 GeV

- ❑ Momentum dependency of π/K/p distributions is similar
  - ➢ With a π:K ratio ~3
- ❑ There is not much above ~7 GeV/c, especially at lower beam energies

Overall Detector Description



❑ Aerogel

- Three radial bands
- Opaque dividers
- 2.5 cm thick, 42 tiles total

❑ Vessel

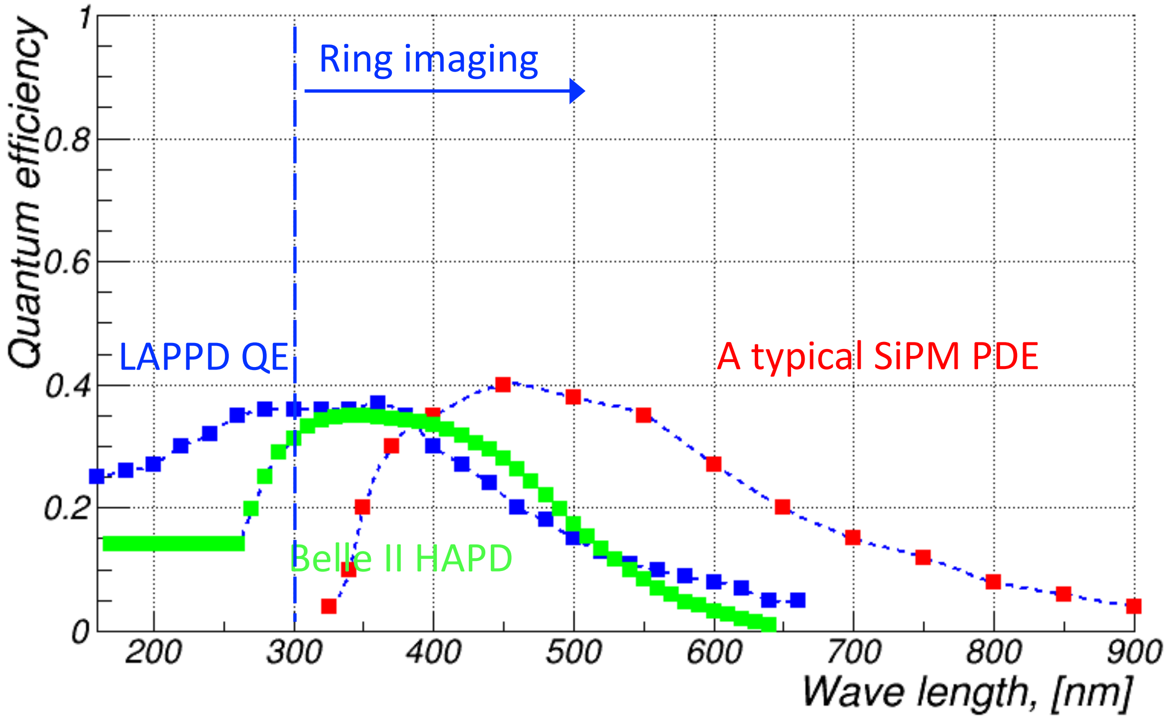
- Lightweight structure
- Reinforced carbon fiber and 3D printed materials
- Filled with nitrogen

❑ HRPPD photosensors

- 120 mm size
- Tiled with a 1.5mm gap
- 68 sensors total

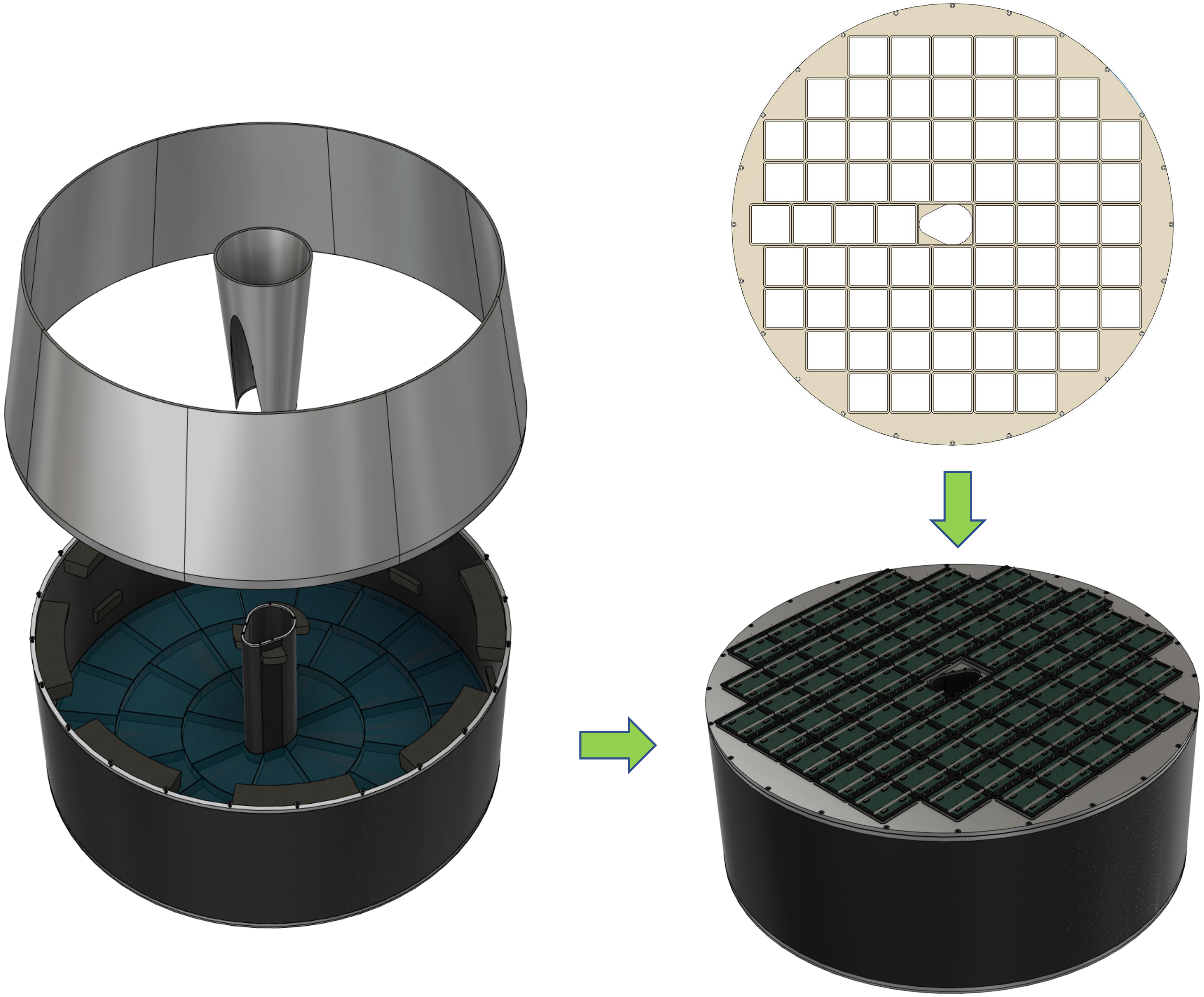
Aerogel

- ❑ A relatively moderate momentum reach is required for this RICH detector
- ❑ HRPPD PDE is expected to be substantially smaller than of the SiPMs
  - ➢ Peak value shifted to the UV range, where it cannot be used for ring imaging
- ❑ Consider using aerogel with high n (1.040 … 1.050)
  - ➢ 300 nm acrylic filter cutoff for imaging
  - ➢ $\langle N_{pe} \rangle \sim 11\text{-}12$
  - ➢ *For ToF still make use of the UV range for abundant Cherenkov light produced in the window*
  - ➢ Natural choice for simulations: Belle II (n ~ 1.045)
  - ➢ Natural hardware reference: Chiba University aerogel recently produced for J-PARC (n = 1.040)
  - ➢ Test samples will be produced by the end of 2023



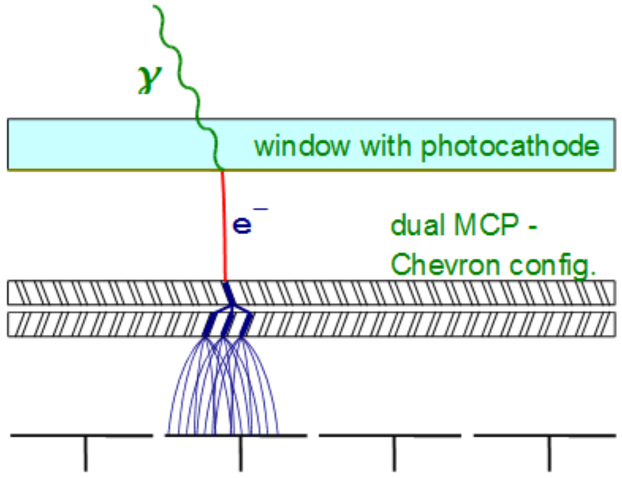
Vessel and Mirrors

- ❑ Outer vessel shell
  - ➢ Honeycomb carbon fiber sandwich
- ❑ Inner shell
  - ➢ Molded prepreg laminate
- ❑ Front (aerogel support) wall
  - ➢ Molded prepreg laminate
- ❑ Rear (sensor support) plate
  - ➢ 3D printed using reinforced carbon
- ❑ Mirrors
  - ➢ Molded laminate substrate
  - ➢ Aluminum evaporation + coating

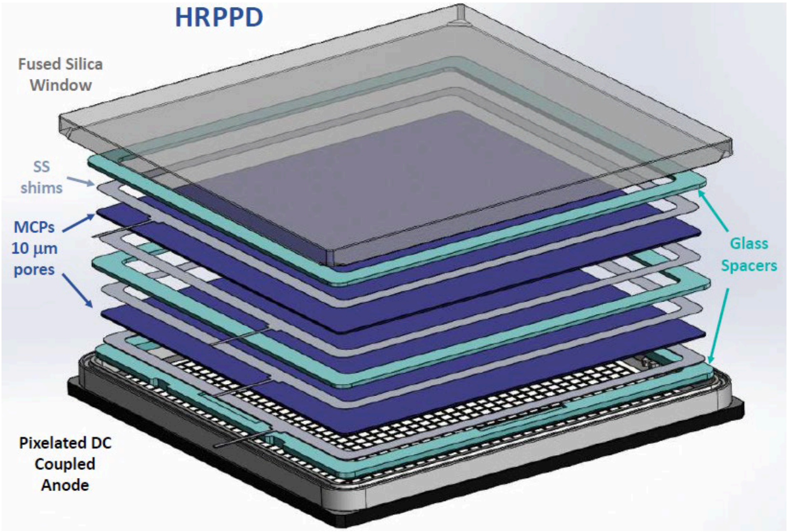


All built in-house by the pfRICH DSC member groups

Photosensors and Electronics



- Basic requirements:
  - Provide a timing reference better than ~20 ps for the barrel and forward ToF subsystems
  - Provide spatial resolution ~1mm
  - Have small Dark Count Rate
  - Have reasonable power dissipation in mW per channel
    - A low material budget cooling system in front of the PWO EmCal
    - As little influence on the thermal environment around the EmCal as possible
  - Allow for a compact solution to leave more space for the proximity gap

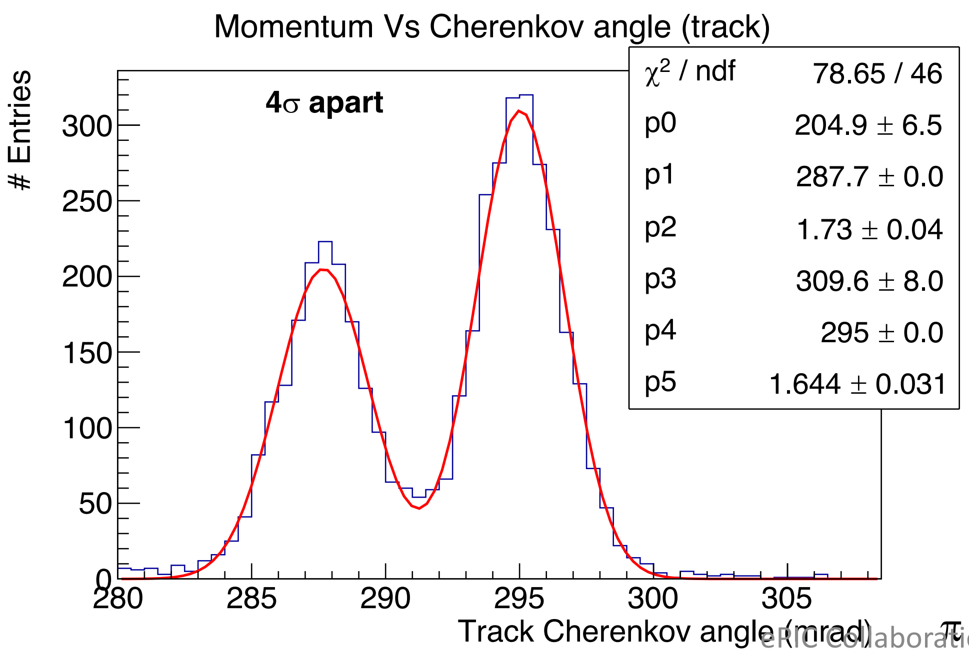


- Photosensor: HRPPD by Incom Inc.
  - High intrinsic SPE timing resolution
  - Low Dark Count Rate (compared to SiPMs)
  - Low cost (compared to other MCP-PMTs)

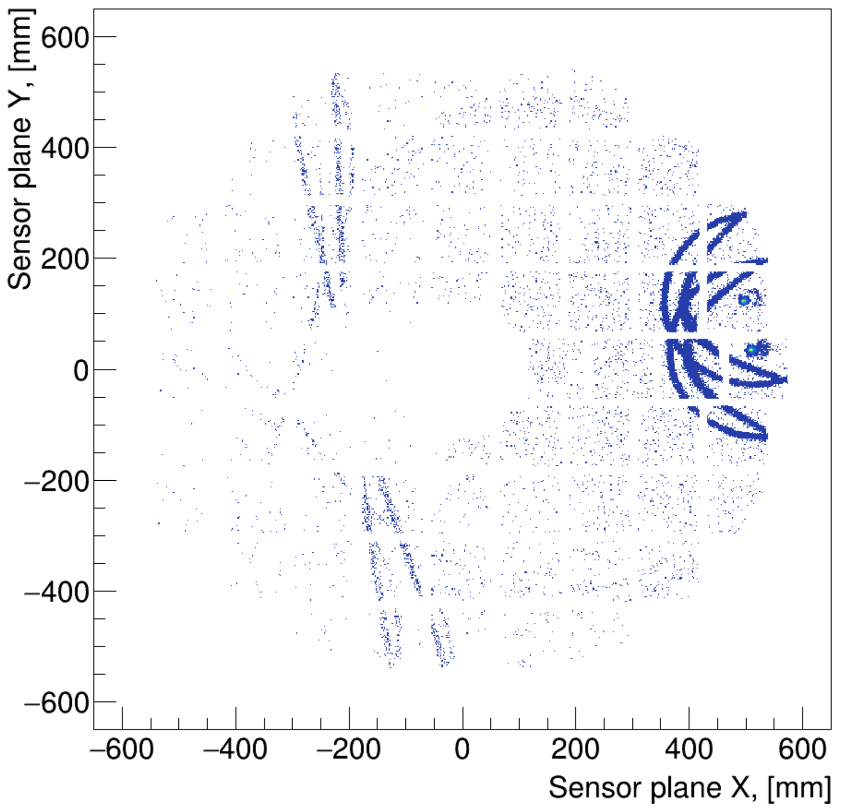
- ASIC: EICROC by OMEGA group
  - Meets the requirements
  - Will be available in 256+ channel configuration
  - Will be developed for ePIC AC-LGADs anyway

Simulation Framework

- ❑ Standalone GEANT4 code with particle gun or HepMC3 import
- ❑ (Almost) All optical effects included
- ❑ Event-level digitization / reconstruction chain
  - ❑ χ^2 based algorithm with a full combinatorial hit-to-track ambiguity resolution

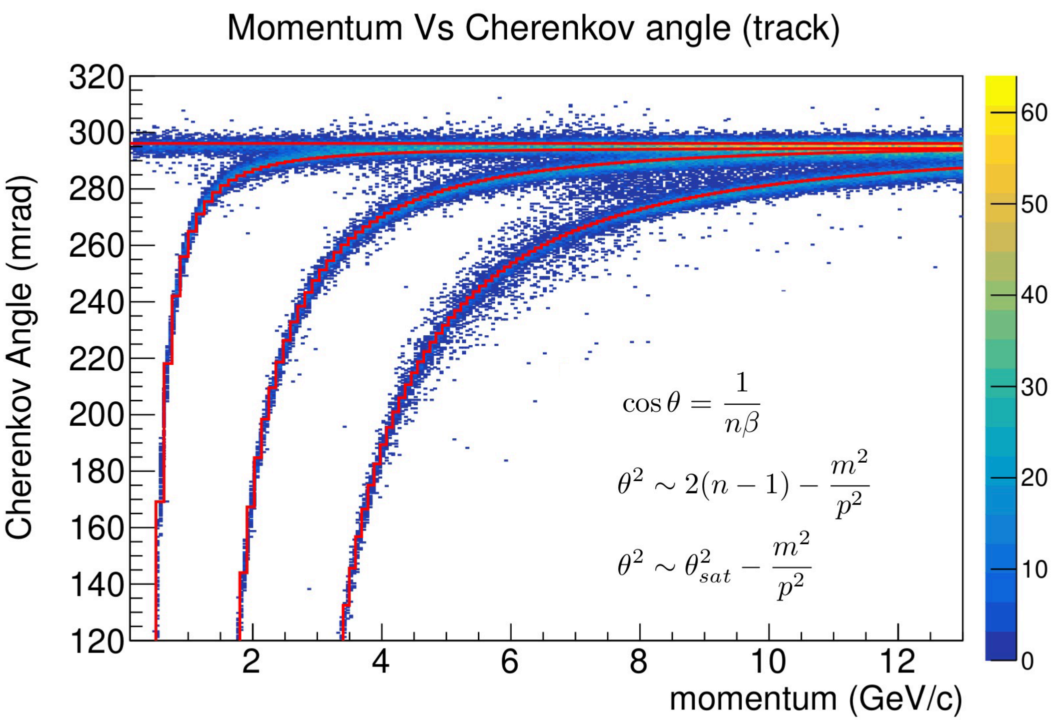


π and K @ 7.25 GeV/c: >4 σ separation

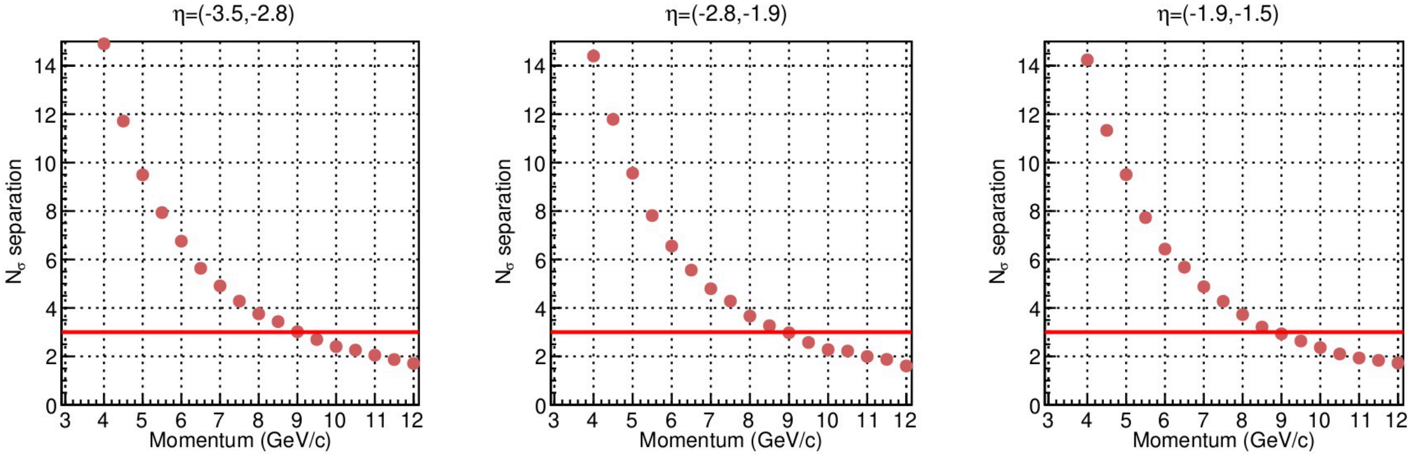


7 GeV/c π and K @ η = -1.9: <5% misidentification rate
(plot accumulated over 1000 two-track events)

(e/)π/K/p Separation Power



e/π/K/p response integrated over the whole η acceptance

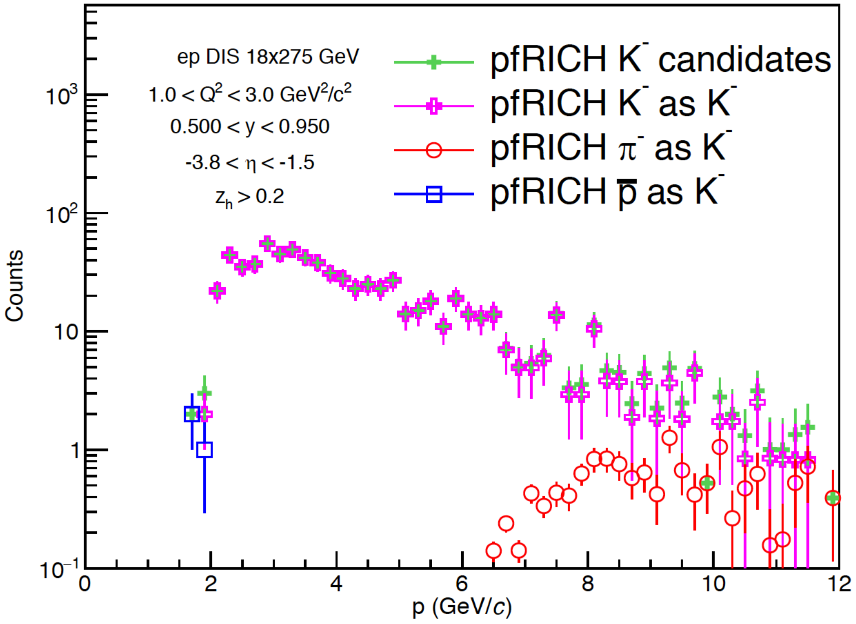


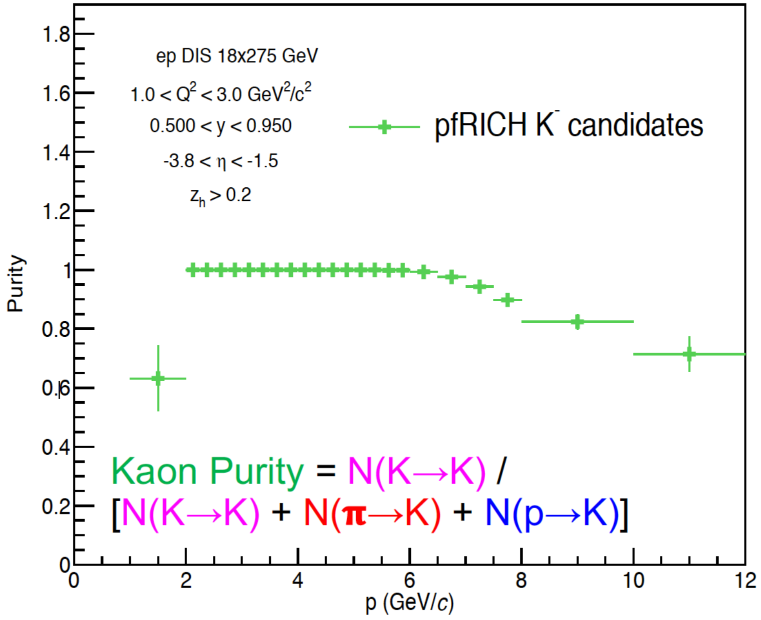
π/K N_σ separation in η bins

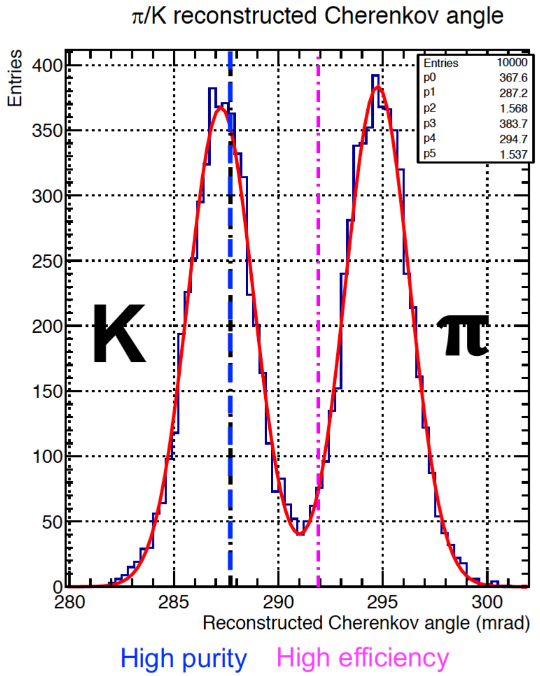
- Comfortably reach 7+ GeV/c momentum range with a higher than 3σ π/K separation level

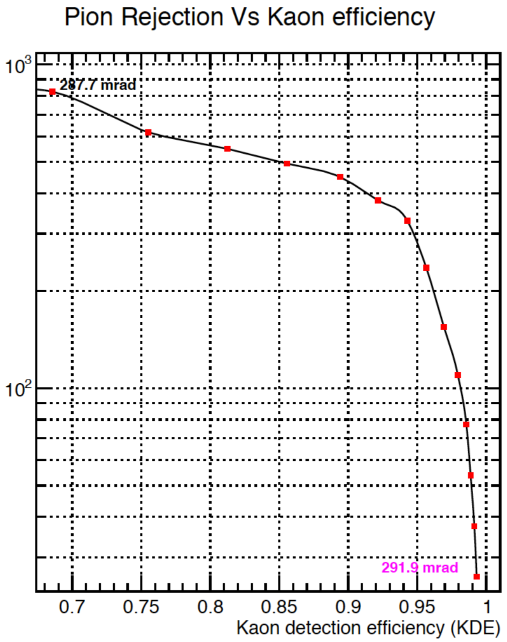
SIDIS Performance

- ❑ PYTHIA 18 x 275 GeV simulation
- ❑ Parameterized pfRICH hadron PID response, assuming 100% kaon detection efficiency









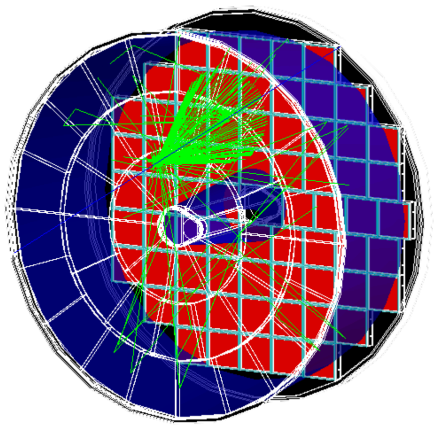
High Kaon Purity ~ 95% at 7 GeV/c
→ this **goes beyond** the requirement of SIDIS physics in the YR

- ❑ Can tune cut on Cherenkov angle to vary Kaon purity vs pion rejection

pfRICH Detector Subsystem Collaboration (DSC)

Institution	Main focus	Comments
Brookhaven Lab	HRPPD integration, ASIC interface, detector and physic modeling, engineering support	
Chiba University	Aerogel production	No institutional commitment
Duke University	Software support	
INFN Genova	HRPPD evaluation, modeling	Synergetic activities with
INFN Trieste	HRPPD evaluation, modeling	dRICH (aerogel, software)
Jefferson Lab	Engineering support, test beam data analysis	
Ljubljana University		Participating as experts
Purdue University	Vessel & mirror design and construction	
Stony Brook University	Vessel & mirror design and construction	
Temple University	Aerogel QA station	
University of Glasgow	HRPPD & MCP-PMT evaluation	
Yale University	HRPPD QA station	

A Proximity-Focusing RICH for the ePIC Experiment
– Conceptual Design Report –
(Draft 1.1)



Babak Azmoun[1], Deb Sankar Bhattacharya[2], Daniel Cacace[1], Helen Caines[3], Chandradoy Chatterjee[2], Jaydeep Datta[4], Abhay Deshpande[4], Christopher Dilks[5,6], James Dunlop[1], Alex Eslinger[6], Prakhar Garg[4,3], Tom Hemmick[4], Alexander Jentsch[*,1], Alexander Kiselev[*,1], Henry Klest[4], Samo Korpar[7], Peter Križan[7], Jeffery Landgraf[1], Saverio Minutoli[8], Charles-Joseph Naïm[4], Mikhail Osipenko[8], Brian Page[*,1], Sanghwa Park[9], Matt Posik[10], Rok Pestotnik[7], Andrej Seljak[7], Prashanth Shanmuganathan[1], Nikolai Smirnov[3], Bernd Surrow[10], Makoto Tabata[11], Silvia Dalla Torre[2], Zhoudunming Tu[*,1], Thomas Ullrich[*,1,3], Jan Vanek[1], Anselm Vossen[5,6], Craig Woody[1], and Zhengqiao Zhang[1]

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[11]Chiba University, Chiba, Japan[¶]

pfRICH Work Packages

Fabrication and Construction

- Engineering design oversight
- Vessel & mirrors: 3D printing & molding
- Vessel: other components & assembly
- Mirrors: aluminum coating & QA
- Construction oversight

Component Testing

- HRPPD QA station
- Aerogel QA station

Software

- Detector level software & modeling
- Physics modeling
- Integration into ePIC framework
- DAQ software

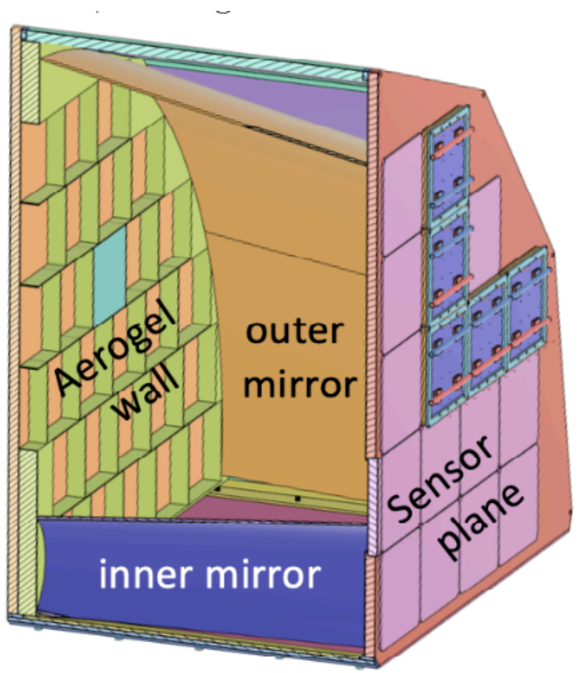
Service Systems

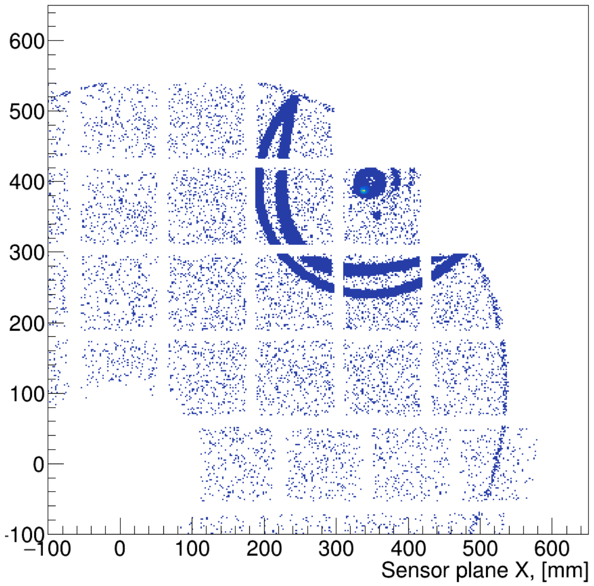
- Gas system
- HV & LV systems
- Cooling system
- Light monitoring system
- On-board Electronics

Blue: person identified
Green: person available after current commitments
Red: searching

Detector Prototype and Beam Tests FY24

- ❑ Propose construction of a pfRICH quadrant prototype using materials and techniques proposed for full scale system
  - ➢ Verify composite and 3D printed materials used in vessel design
  - ➢ Develop construction ”know-how”
- ❑ Evaluate prototype at Fermilab Test Beam Facility in FY24
  - ➢ Quantify π/K separation performance
  - ➢ Verify single and multi-photon timing performance
  - ➢ Evaluate Chiba Aerogel Factory tiles for pfRICH usage
  - ➢ Make use of the first five HRPPDs produced by Incom, in a fully integrated on-board ASIC configuration
  - ➢ Evaluate conical mirror performance
  - ➢ Check detector component integration



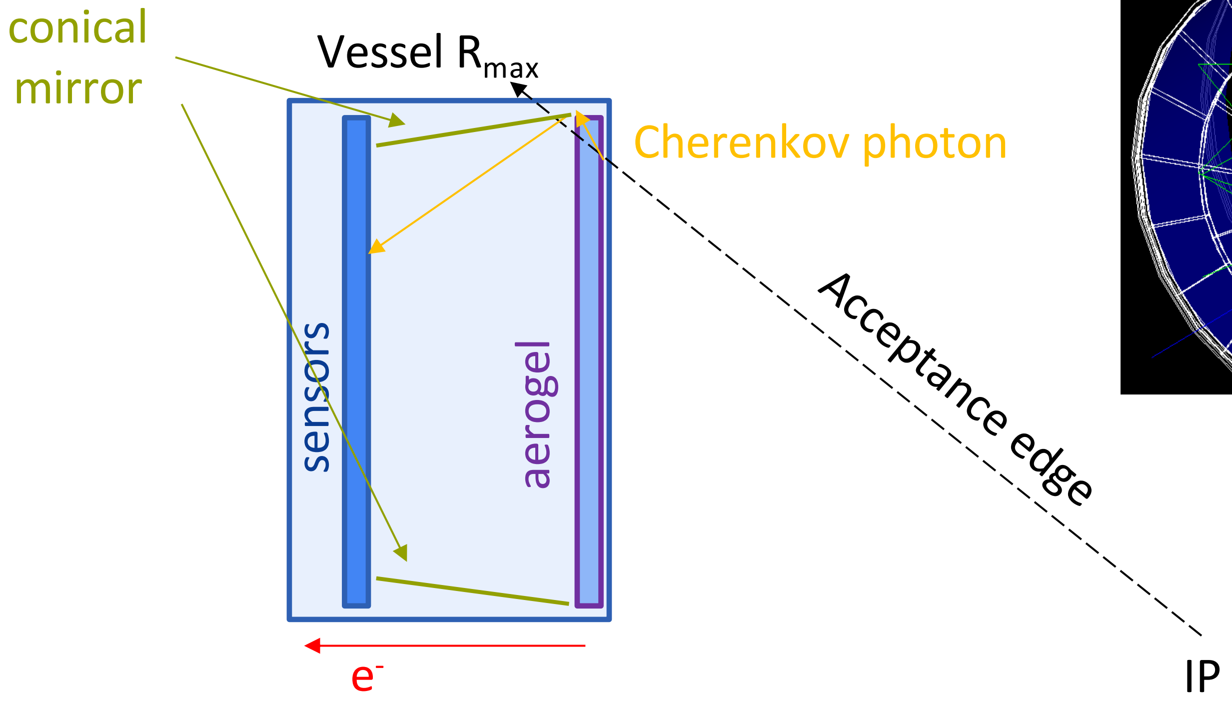


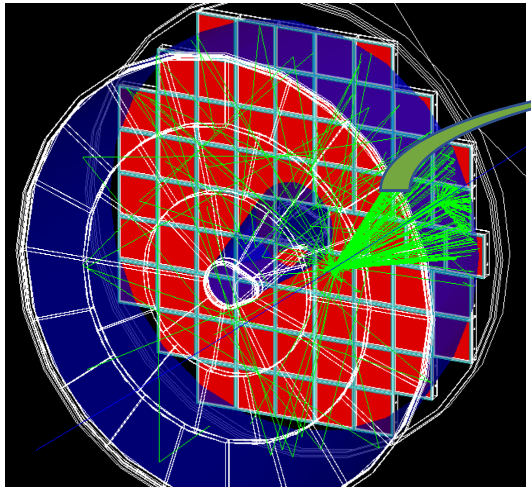
Summary

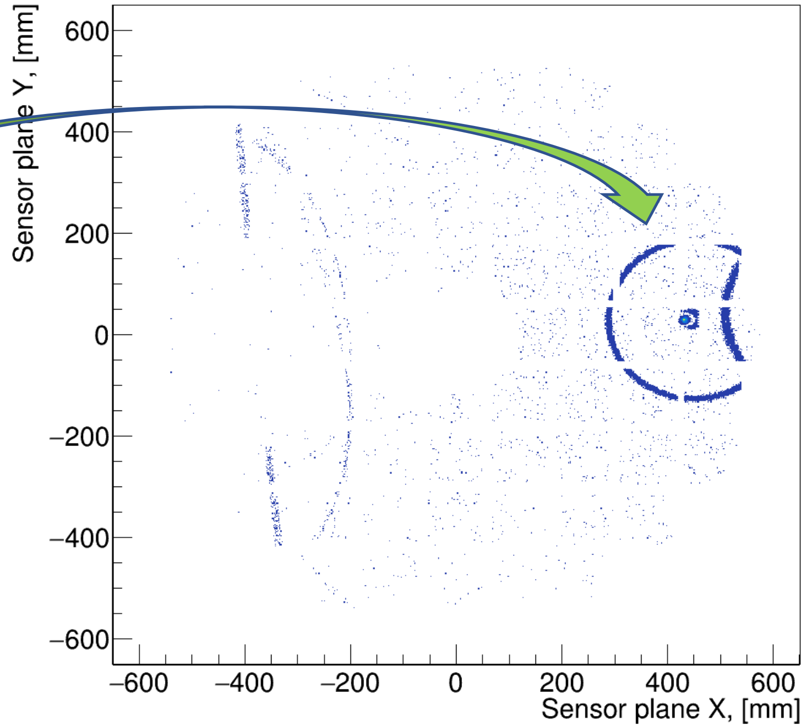
- A proximity focusing RICH with HRPPD photosensors has been selected for the baseline ePIC configuration
  - Ring imaging and high resolution timing in one detector
- Major subsystem components have been chosen and costed and integration, fabrication, and assembly plans have been defined
- Monte-Carlo modeling shows that Yellow Report requirements are met
  - Track-level p/K/p identification up to 7 GeV/c (or higher, if efficiency can be somewhat sacrificed)
- Prototype beam test expected in approximately one year
  - Confirm p/K separation reach (ring imaging) and high resolution timing performance at once
  - Provide insight and experience for fabrication of full detector

Backup

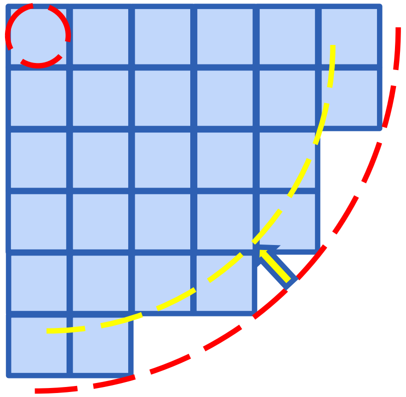
Angular acceptance optimization







- Use side wall mirrors to increase η acceptance
  - Achieve $-3.5 < \eta < -1.5$ coverage (hence overlap with the DIRC)
  - Make mirrors *conical* to avoid inefficiency on the sensor plane



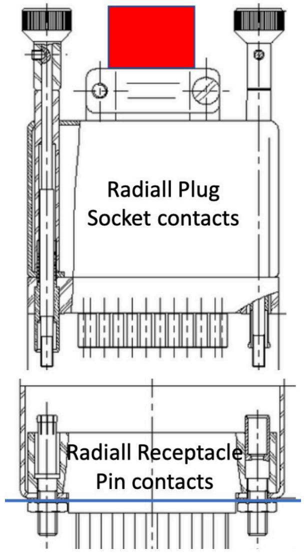
18

HV system

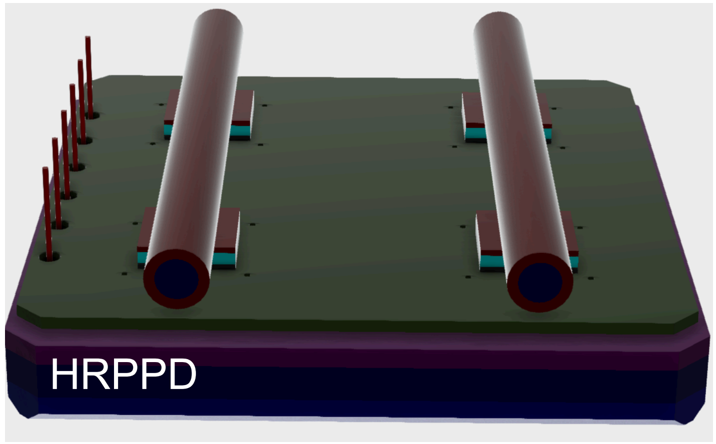
- CAEN HV mainframes and *stackable* HV modules
- CERN-approved Radiall connectors

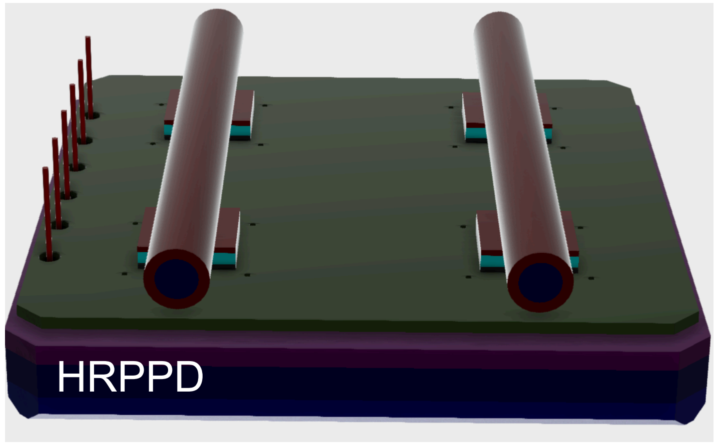
23x A1515BV's

From PSUs
56 wires HV cable



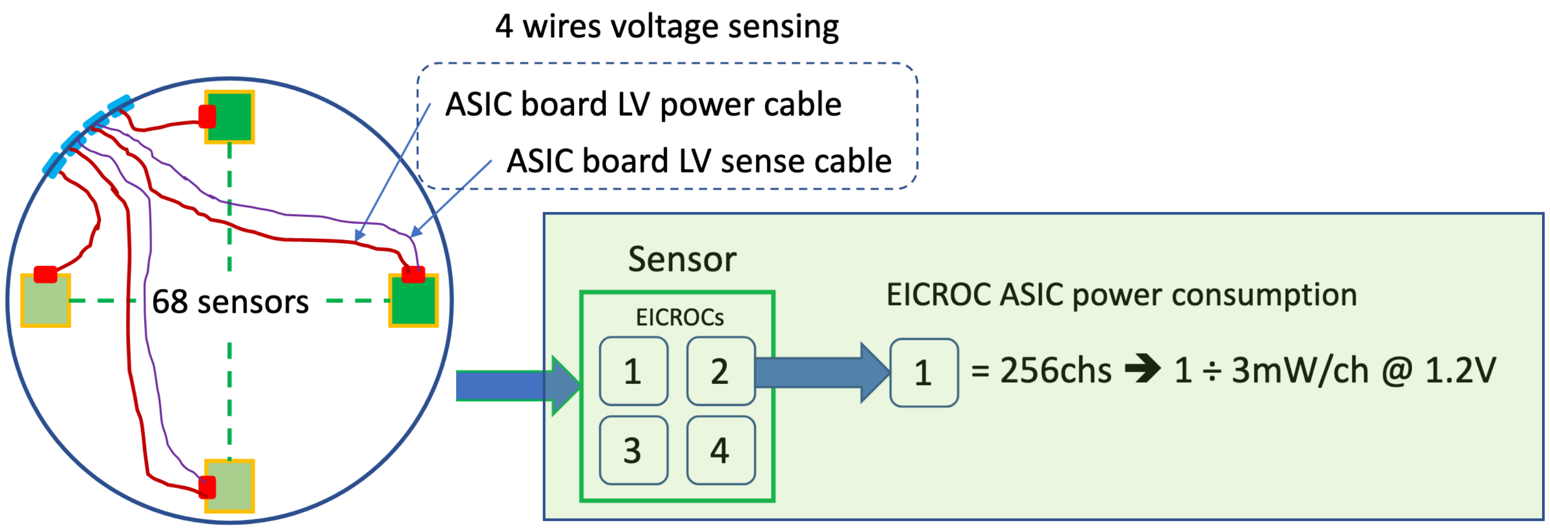
On-detector part





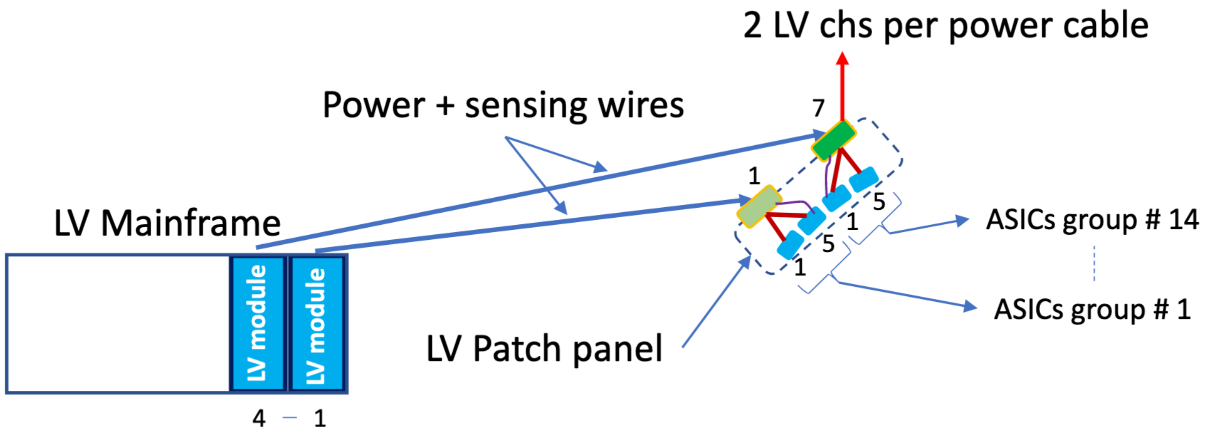
six Teflon coated wires per HRPPD

LV system



Wiener LV mainframe and modules

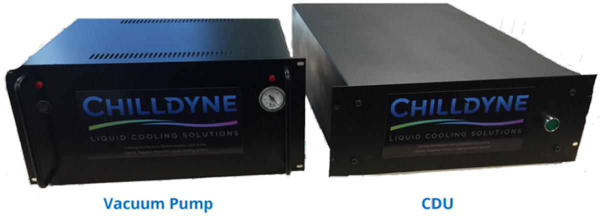
- Each Sensor
  - 4EICROCs x 256chs = 1024chs/sensor ➔ @3mW/ch ➔ ~3W/se
- Whole detector
  - 68sensors x 2.5A ➔ 170A@1.2V ➔ 204W
  - Add 20% extra current for the ancillary electronic components
    - 170A + 20% = 204A@1.2V ➔ 245W
  - Add 20% extra current for safety margin
    - 204A + 20% = **245A@1.2V** ➔ **294W**



Cooling system

Off Detector

- Chilldyne Circulator
  - 8 lpm
  - -10 psi
  - 5°C to 40°C



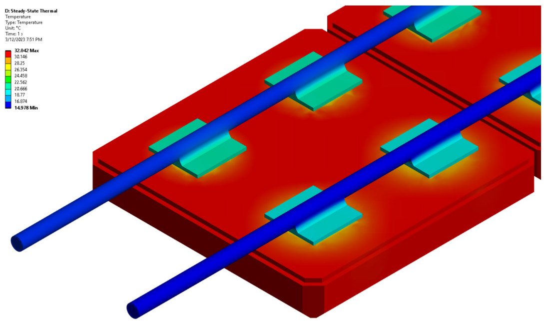
- Polyscience Chiller
  - 9.8 l/min @ 43.4 psi
  - -20°C to 40°C ±0.1°C
  - 800 W @ 10°C

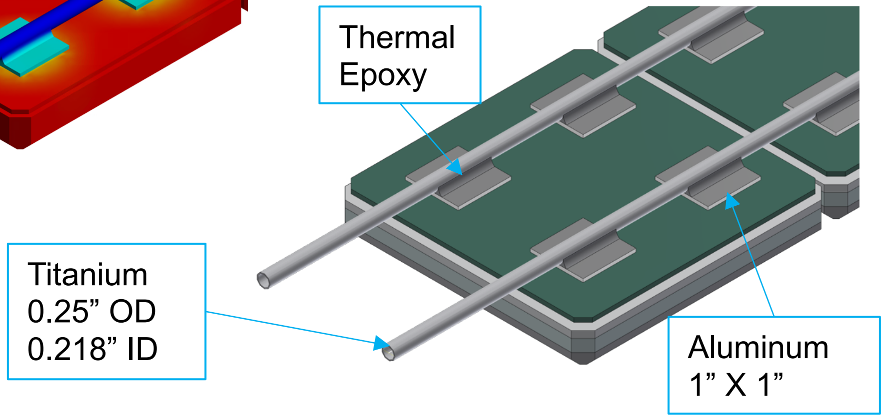
- Distribution Panel
  - Flowmeters
  - Flow Transmitters

On Detector

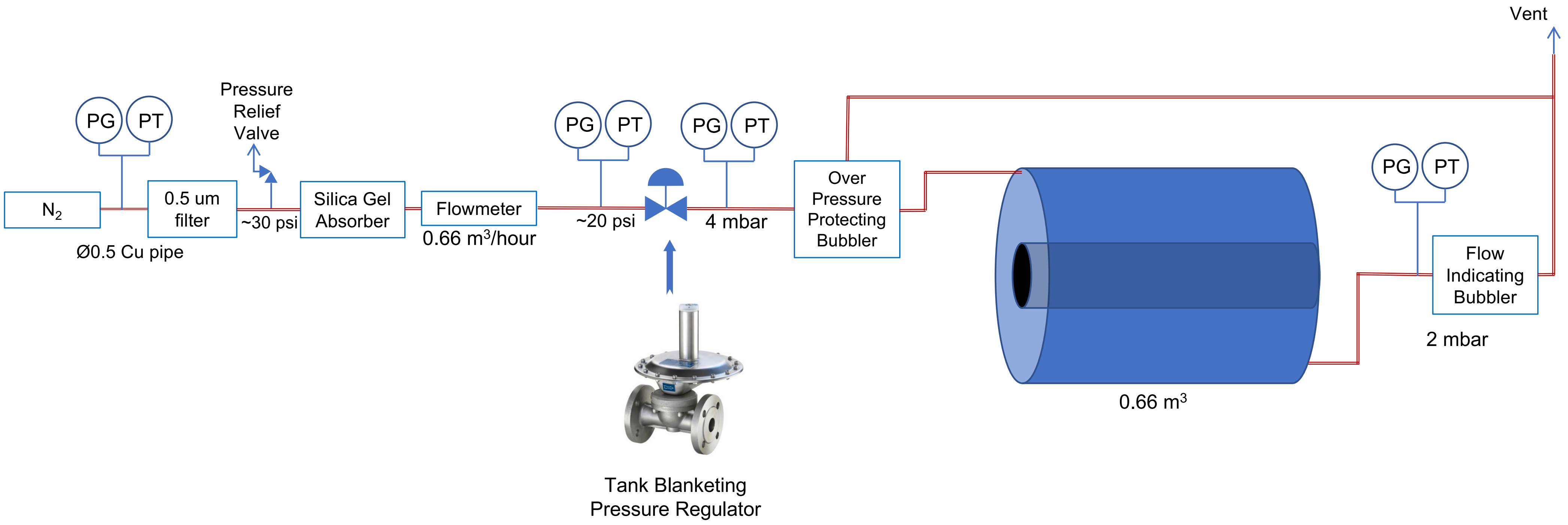
- Heat dissipation: 400W
- Tube @ Δ2°C: ~3 lpm
- ΔP ~0.25 psi

- 9 Modules:
  - ~50W,
  - ~Δ17°C
  - Water ~Δ1.2°C



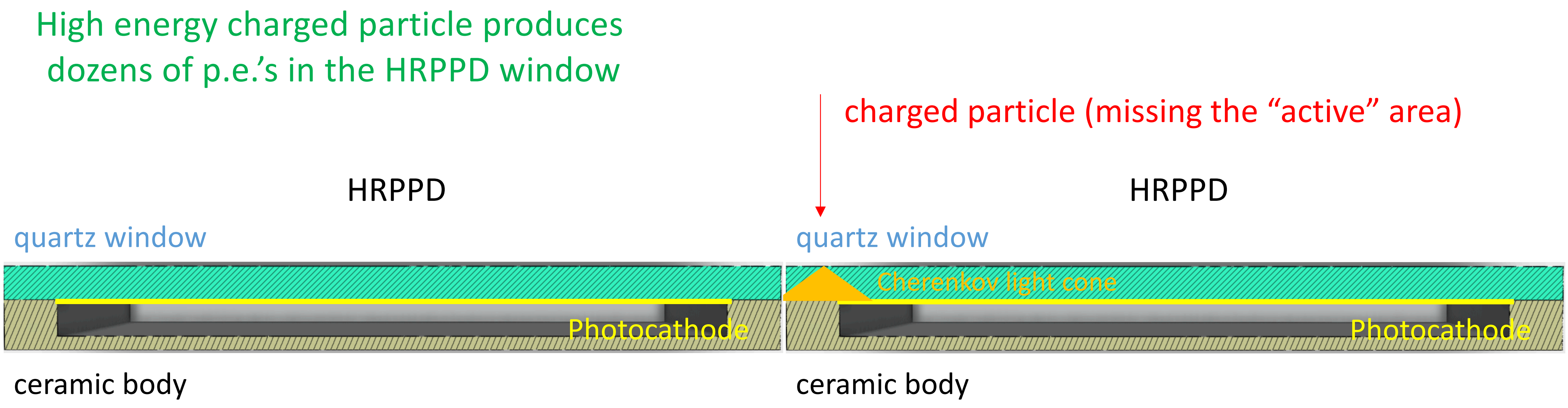


Gas system



- Assume nitrogen only configuration
- One volume exchange per hour at a pressure 2-4 mbar
- Gas quality (industrial, ultra-pure,…) needs to be finalized

Geometric efficiency for timing purposes



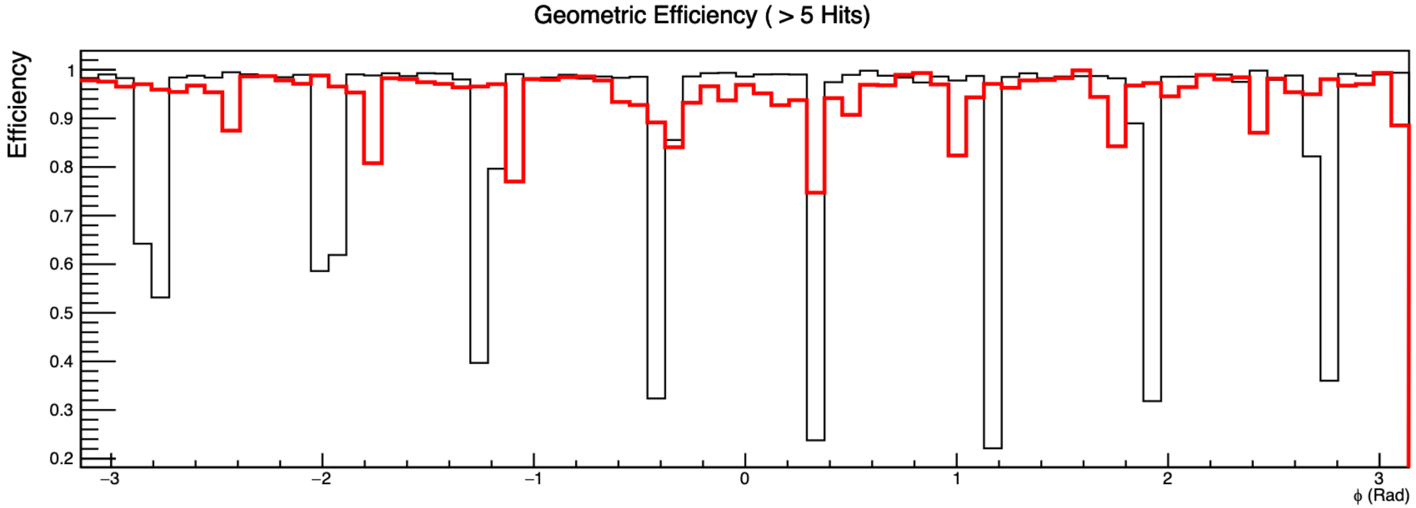
- Cherenkov light cone produced in the window creates a ~12mm spot on the photocathode

- Tiling HRPPDs as a "flat wall" with minimal gaps provides >90% geometric efficiency …
- … and it is complemented by timing from ring imaging photoelectrons to achieve ~100%

Geometric efficiency for timing purposes

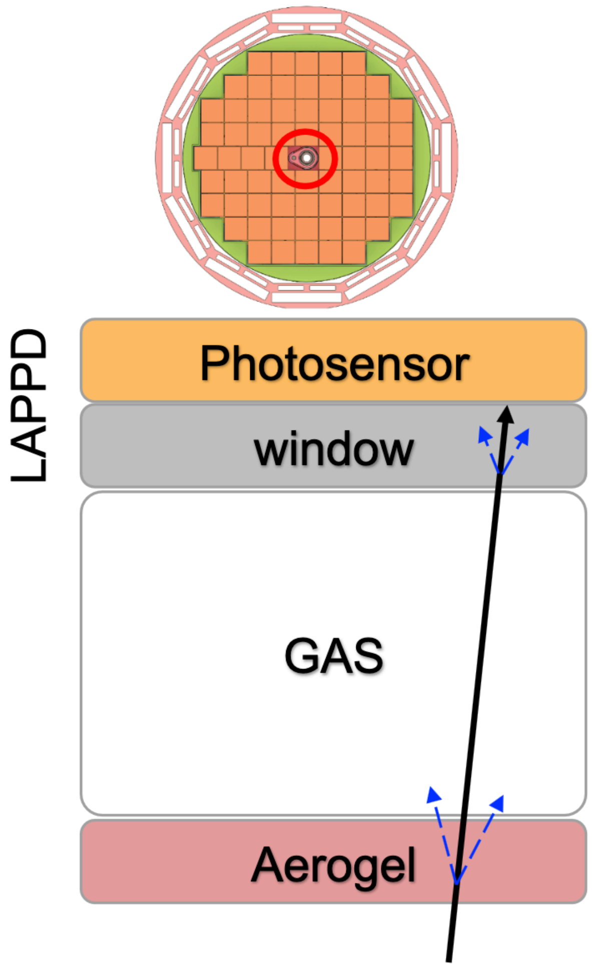
- Timing provided by both aerogel (<N_{pe}> ~12) and HRPPD window photons (<N_{pe}> above 80)
  - Their combined geometric acceptance will be ~100%

- **ToF** meas. ← # photon hits created by particles
  - pfRICH receives photon hits from aerogel, acrylic filter, gas in expansion volume, and **LAPPD window**
- **Efficiency** (η, ϕ): prob. of particle creating N_{pe} > 5.
  - **20 ps t_0 resolution** by having 6 photons, assuming 50 ps single photon time resolution (timing resolution **20ps = 50ps / $\sqrt{6}$**).



Red dips → ribs from Aerogel wall

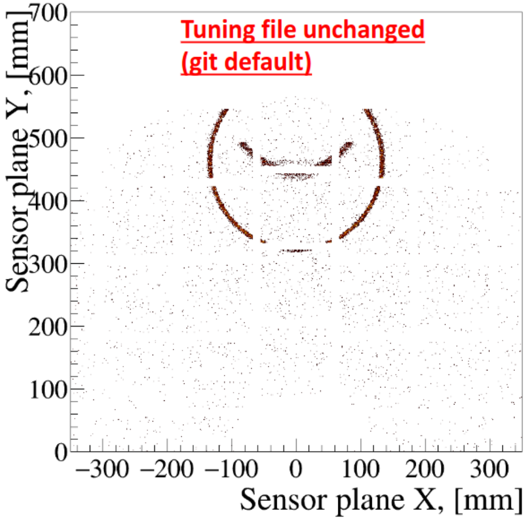
Black dips → ribs from window ceramic boundary

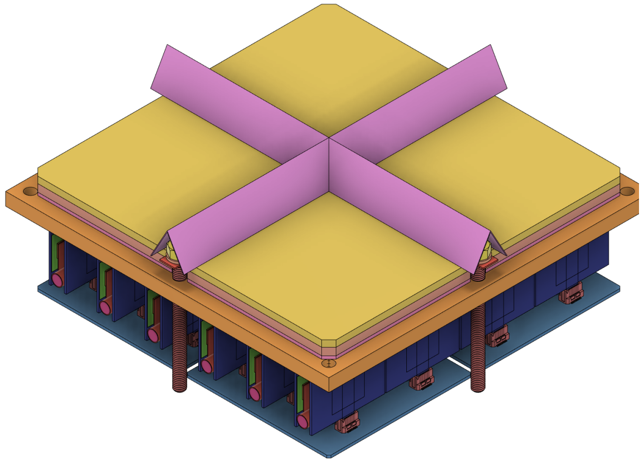


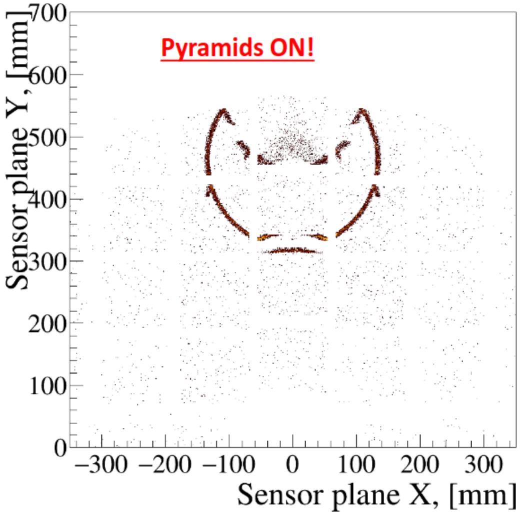
Single Particles fired at $\eta = -3$

Performance enhancements

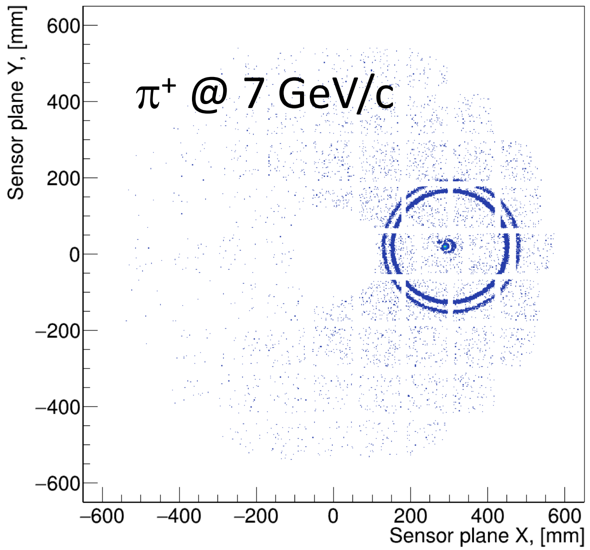
- Installation of small funneling mirrors around each sensor dead area boundaries







- Use of a dual aerogel configuration



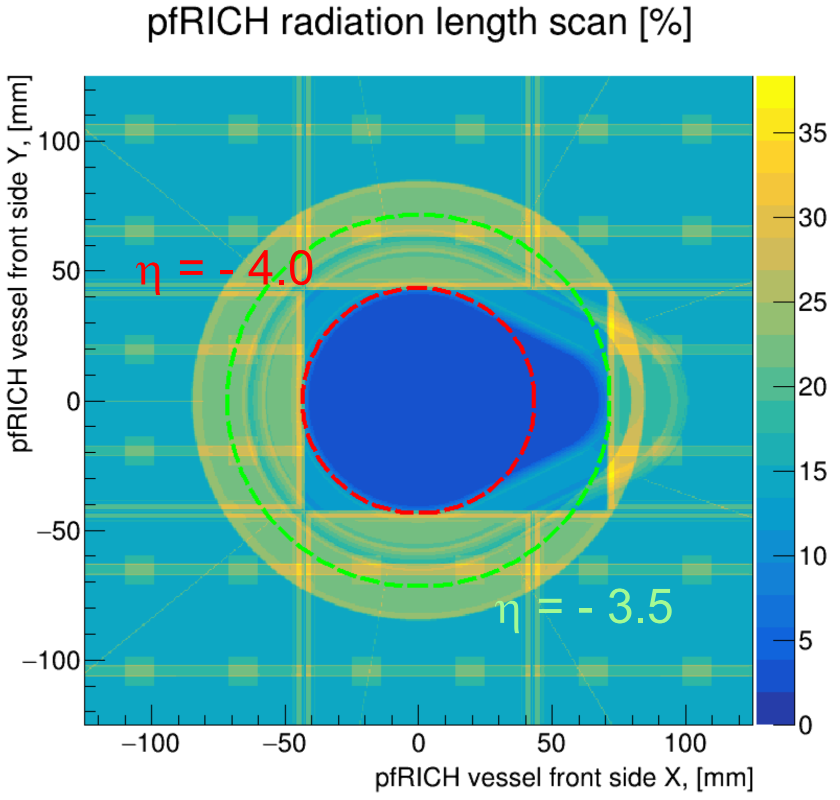
- Both options implemented in software
- Both give a substantial increase in photon yield

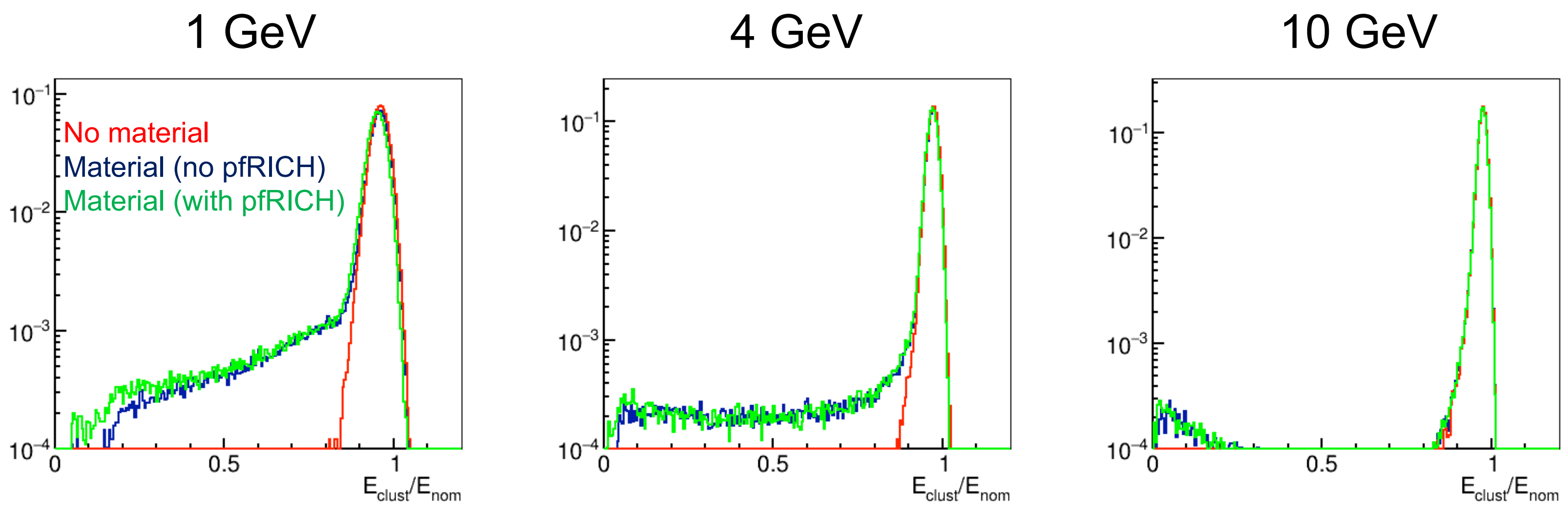
- Recently added to the baseline configuration as a consequence of a complex ePIC detector tracker optimization (pfRICH expansion volume was shortened by ~5cm)

pfRICH material effect on the backward EmCal

- pfRICH GEANT implementation imported in ePIC framework as a GDML file
  - Material implemented to the best of our knowledge (vessel, HRPPDs, cooling system, etc)

-3.3 < η < -1.9





- No effect on (~gaussian) peak width
- Lower energy tails (the largest at 1 GeV)
- No effect for high energy electrons (10 GeV)

- Minimal effect from pfRICH overall