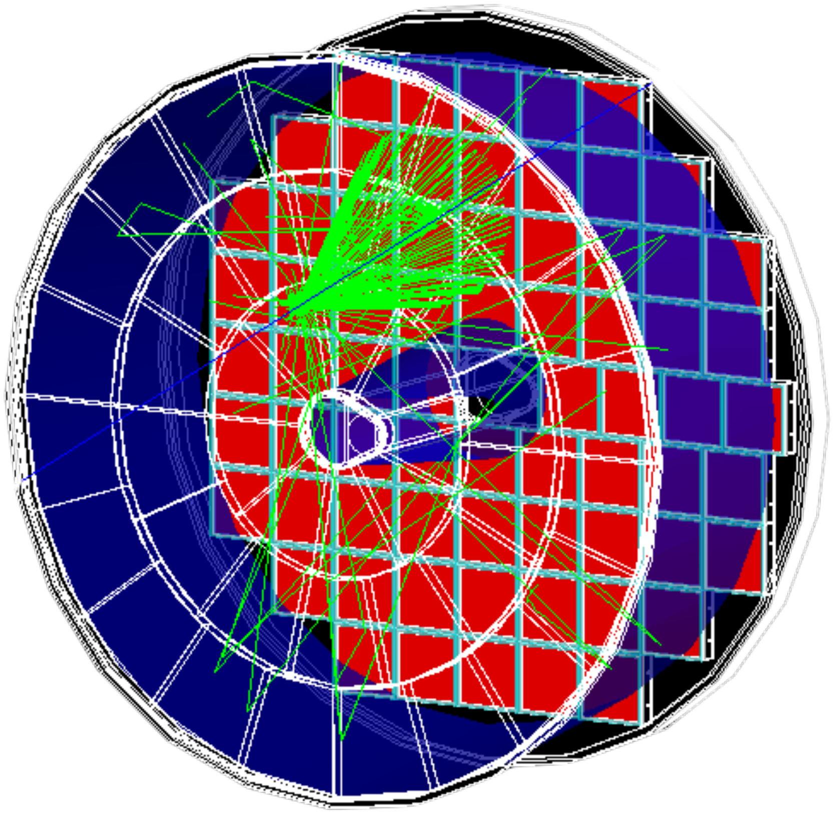
pfRICH: Overview and input information



ePIC pfRICH:

- A classical proximity focusing RICH
- Pseudorapidity coverage: $-3.5 < \eta < -1.5$
- Uniform performance in the whole $\{\eta,\phi\}$ range
- π/K separation: above 3σ up to ~ 9.0 GeV/c
- t_0 reference with a ~100% geometric efficiency

Alexander Kiselev (BNL)

Agenda

March 20

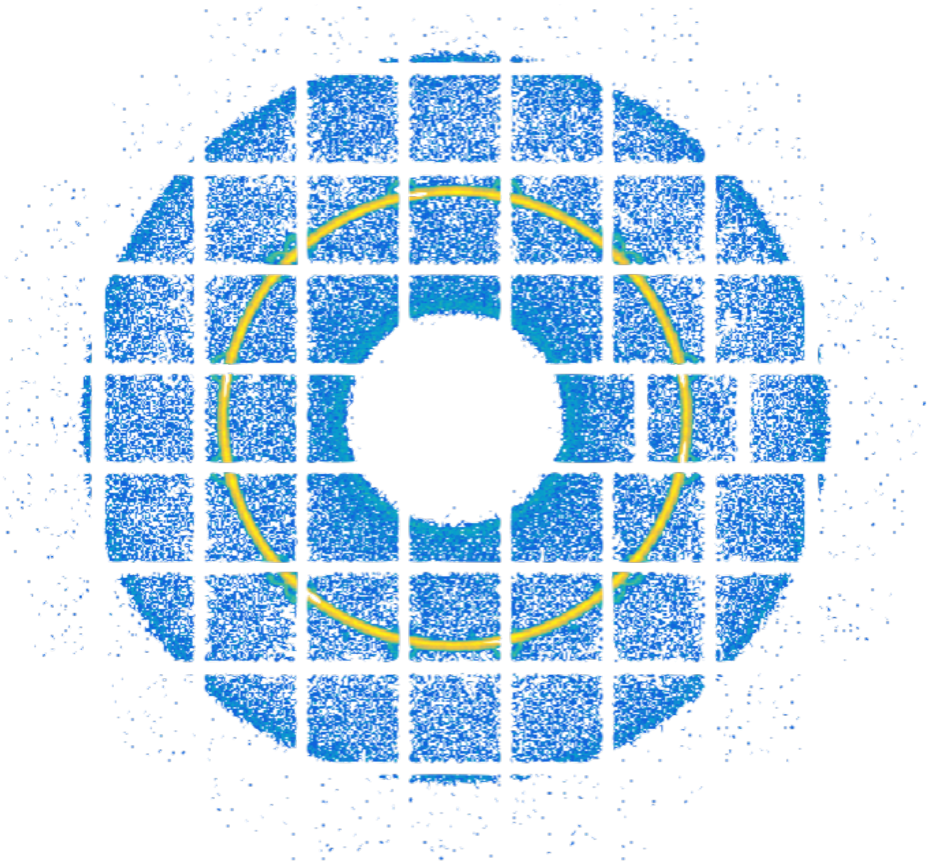
	pfRICH: Overview & Input Information	*Alexander Kiselev*	08:30 - 09:00
09:00	**pfRICH: Sensors and FEE**	*Alexander Kiselev*	09:00 - 09:20
	pfRICH: Performance Studies	*Chandradoy Chatterjee et al.*	09:20 - 10:00

March 21

07:00	**pfRICH: Mechanical Design, Aerogel, and Integration**	*Alex Eslinger et al.*	06:50 - 07:15
	pfRICH: Workforce, Cost and Schedule, Risk Mitigation	*Bernd Surrow*	07:15 - 07:40

Backup slides are color coded to show which charge questions are addressed in which talk

- (blue) Charge question **#1, #2.1, #2.2**
- (purple) Charge question **#2.2**, **#5**
- (green) Charge question **#3**
- (orange) Charge question **#4, #6**
- (yellow) Charge question **#7, #8**



Design Overview

Physics requirements

- 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 < η < 3.5 by tracking, calorimetry and PID detectors

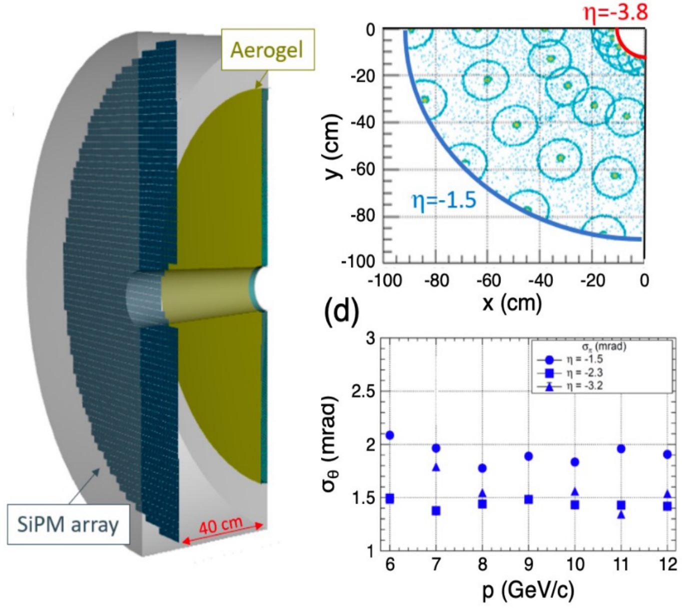
- Yellow report requirement: **3σ π/K separation up to 7 GeV/c**

- A new requirement: provide **~20 ps timing reference** for ePIC ToF detectors

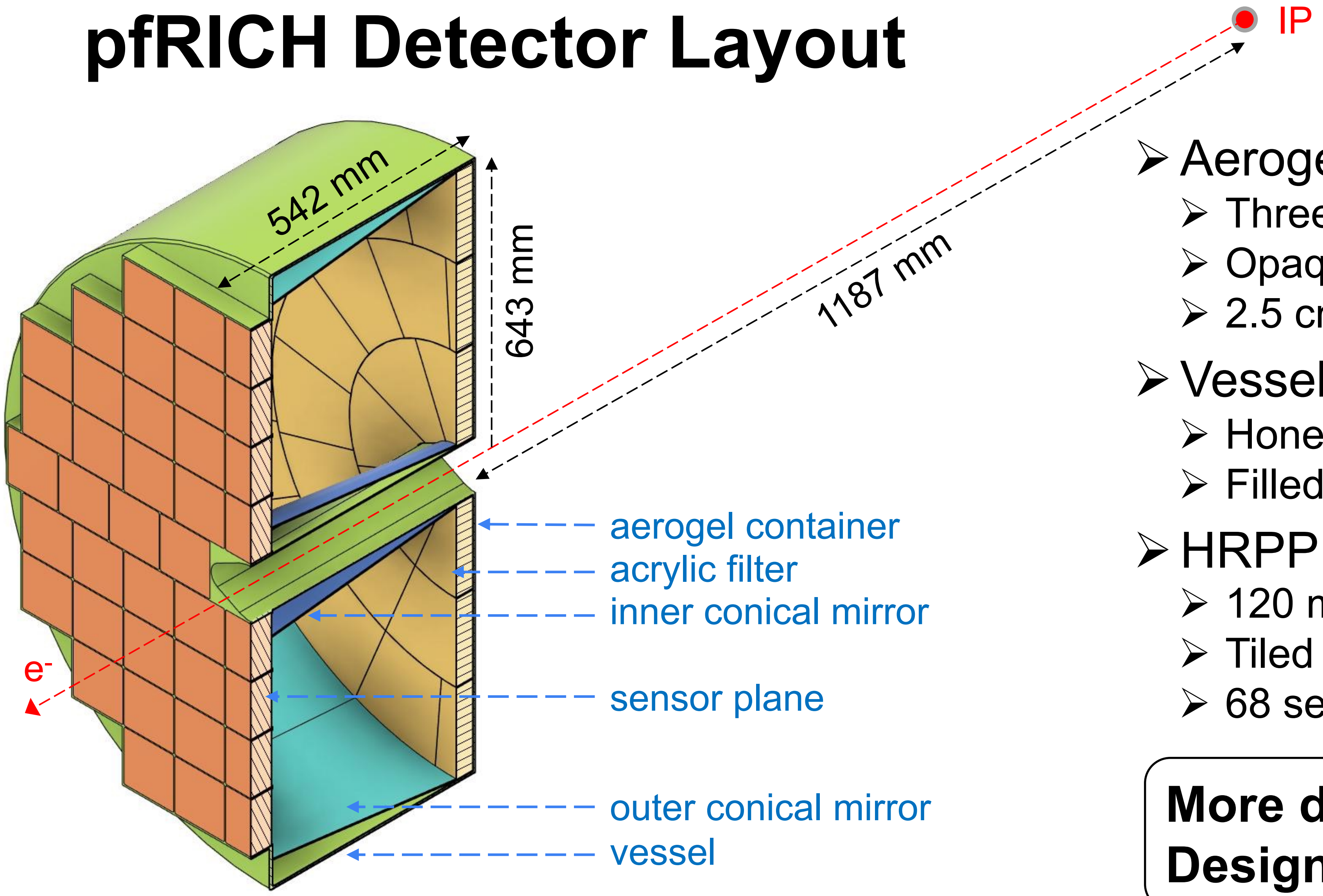
ePIC pfRICH concept evolution

- Based on the **concept** developed for ATHENA proposal in late 2021:
  - A conventional proximity focusing RICH
  - High geometric efficiency
  - Uniform performance in the whole acceptance
  - SiPMs, CLAS12 aerogel parameterization with <n> ~ 1.020
- (Re)started in October 2022
  - A proximity focusing RICH with Gen II HRPPD photosensors
  - WFD ASIC for high resolution timing, vertical integration
- November 2022
  - Belle II aerogel parameterization with <n> ~ 1.045
- February 2023
  - DC-coupled HRPPDs, EICROC ASIC, flat sensor-to-ASIC integration

ATHENA proposal (2021)



pfRICH Detector Layout

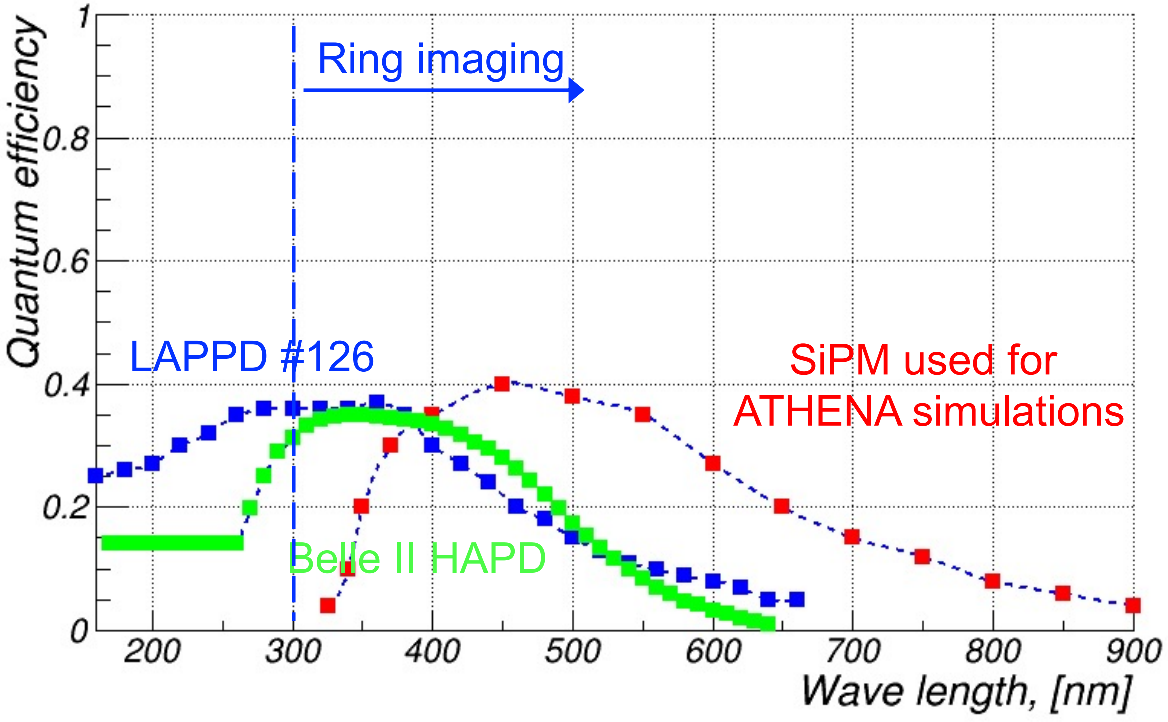


- Aerogel
  - Three radial bands
  - Opaque dividers
  - 2.5 cm thick, 42 tiles total
- Vessel
  - Honeycomb carbon fiber sandwich
  - Filled with nitrogen
- HRPPD photosensors
  - 120 mm size
  - Tiled with a 1.5mm gap
  - 68 sensors total

More details by talk on Design & Integration

Choice of aerogel

- HRPPD PDE is expected to be substantially smaller than of the SiPMs
  - And peak value shifted to the UV range, where it cannot be used for ring imaging
- Therefore working with <n> ~ 1.020 does not look feasible (<N_{pe}> too small)
- **Consider using n ~ 1.040 … 1.050**
  - 300 nm acrylic filter cutoff for imaging
  - <N_{pe}> ~ 11-12
  - *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)



More details by talk on Design & Integration

Choice of the photosensors & ASIC

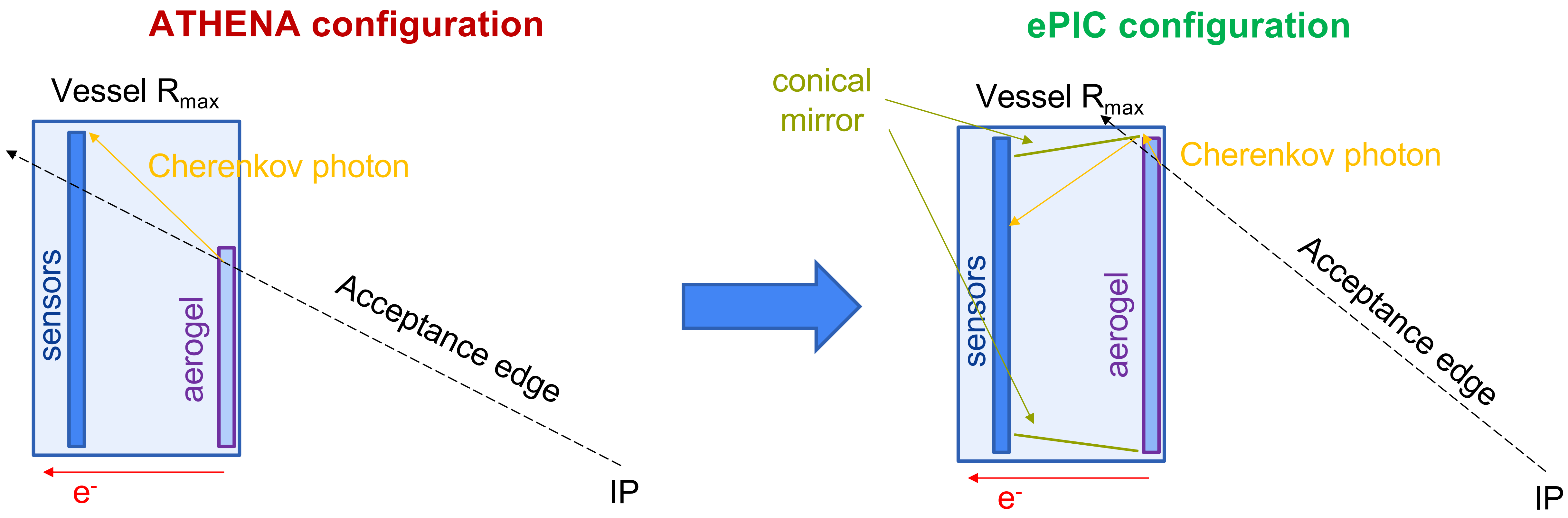
- Basic requirements:
  - Provide a timing reference better than ~20 ps for the barrel and forward ToF subsystems
  - Provide spatial resolution ~1mm
  - Have small Dark Count Rate
  - Have reasonable power dissipation in mW per channel
    - to allow for a low material budget cooling system in front of the PWO EmCal
    - to have 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

More details by talk on Photosensors & ASIC

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

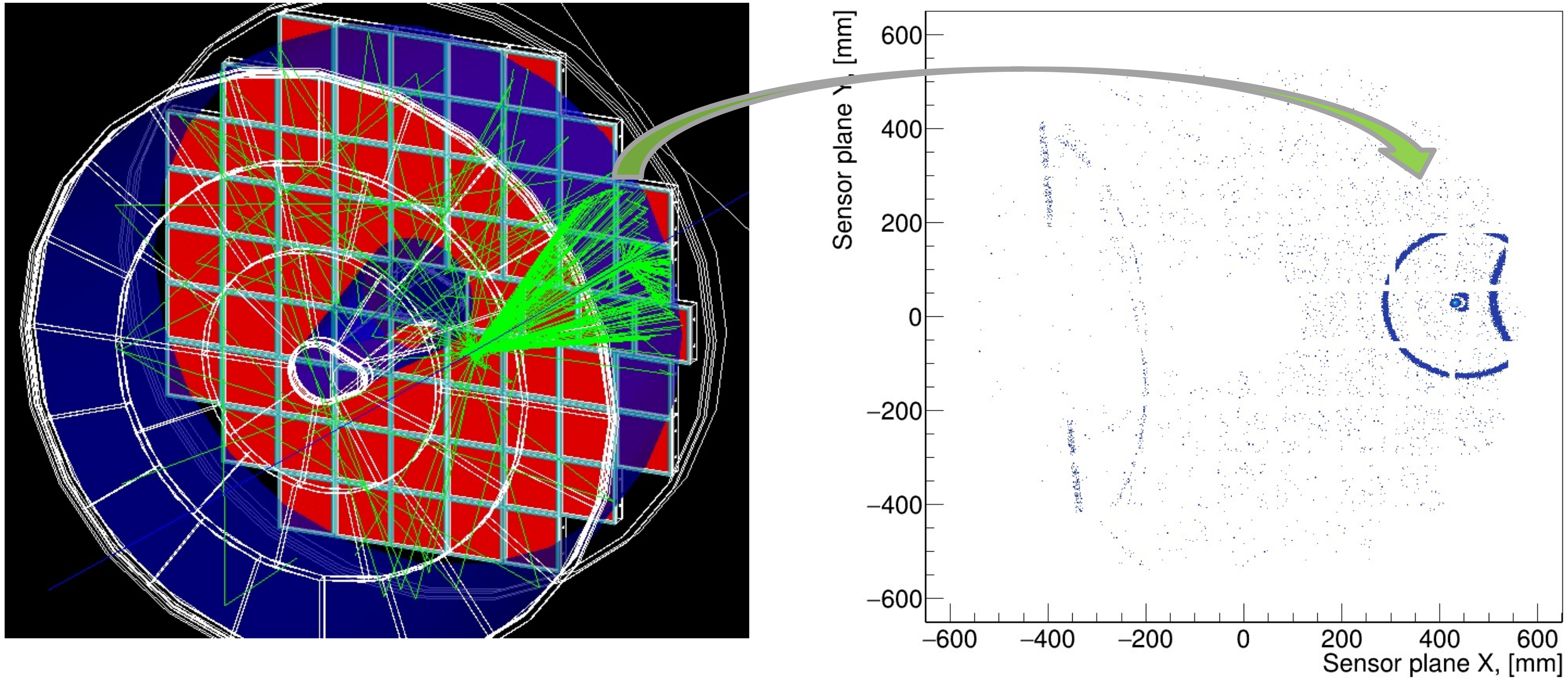
- **ASIC: EICROC by OMEGA group**
  - Meets the requirements
  - Will be available in 256+ channel configuration
  - Will be developed for ePIC AC-LGADs anyway

Angular acceptance optimization

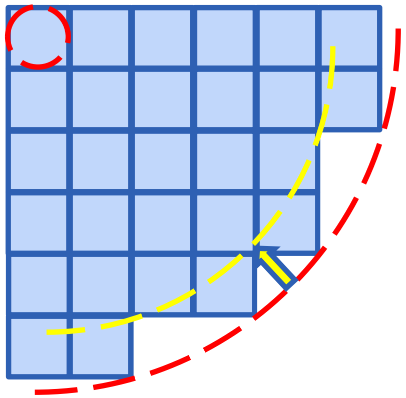


- Use side wall mirrors to increase η acceptance
  - Achieve $-3.5 < \eta < -1.5$ coverage
  - Make mirrors conical to avoid inefficiency on the sensor plane

Angular acceptance optimization



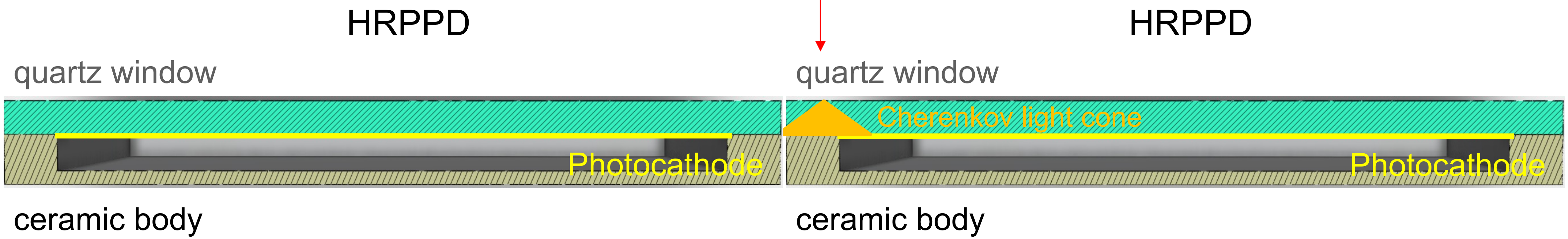
- Use side wall mirrors to increase η acceptance
  - Achieve -3.5 < η < -1.5 coverage
  - Make mirrors *conical* to avoid inefficiency on the sensor plane



Geometric efficiency optimization for t_0 measurement

High energy charged particle produces dozens of p.e.'s in the HRPPD window

charged particle (missing the "active" area)

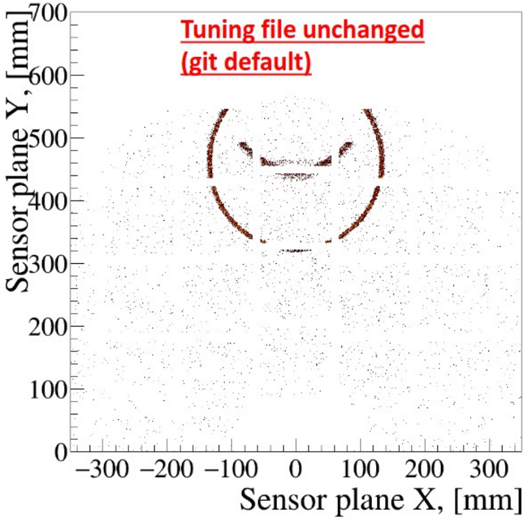


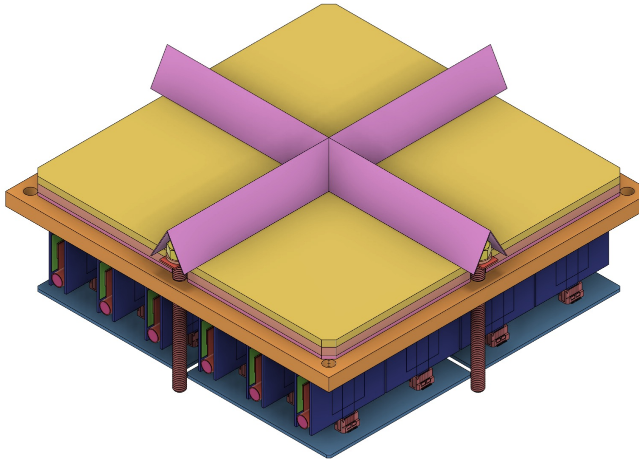
- Cherenkov light cone produced in the window creates a ~12mm spot on the photocathode
- Tiling HRPPDs as a "flat wall" with minimal gaps provides >90% geometric efficiency …
- … and it is complemented by timing from ring imaging photoelectrons to achieve ~100%

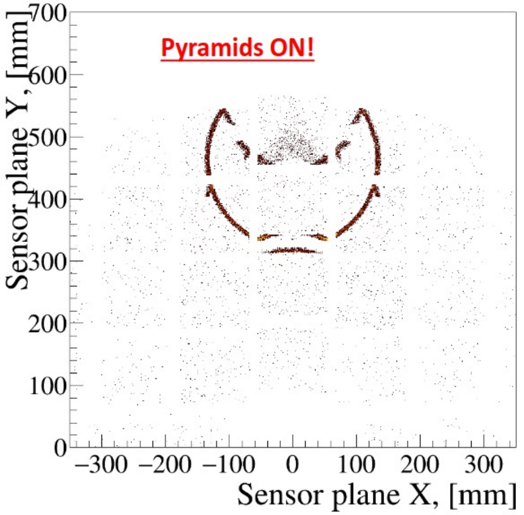
More details by talk on Performance

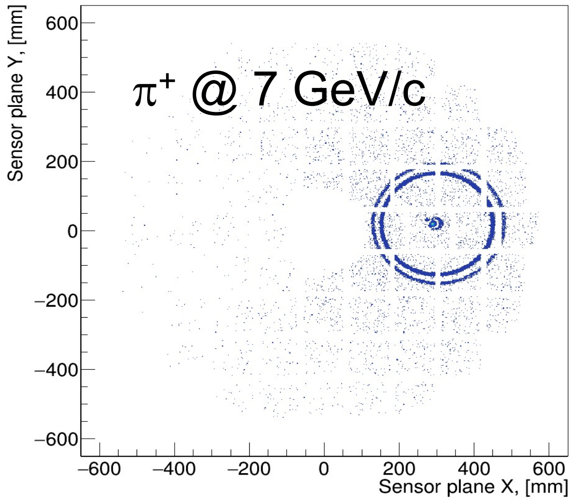
Other design choices & potential upgrades

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









- Use of a dual aerogel configuration
  - Both options implemented in software
  - Each of them can give up a substantial increase in photon yield
  - **Not present in the baseline configuration** (considered as risk mitigation options)

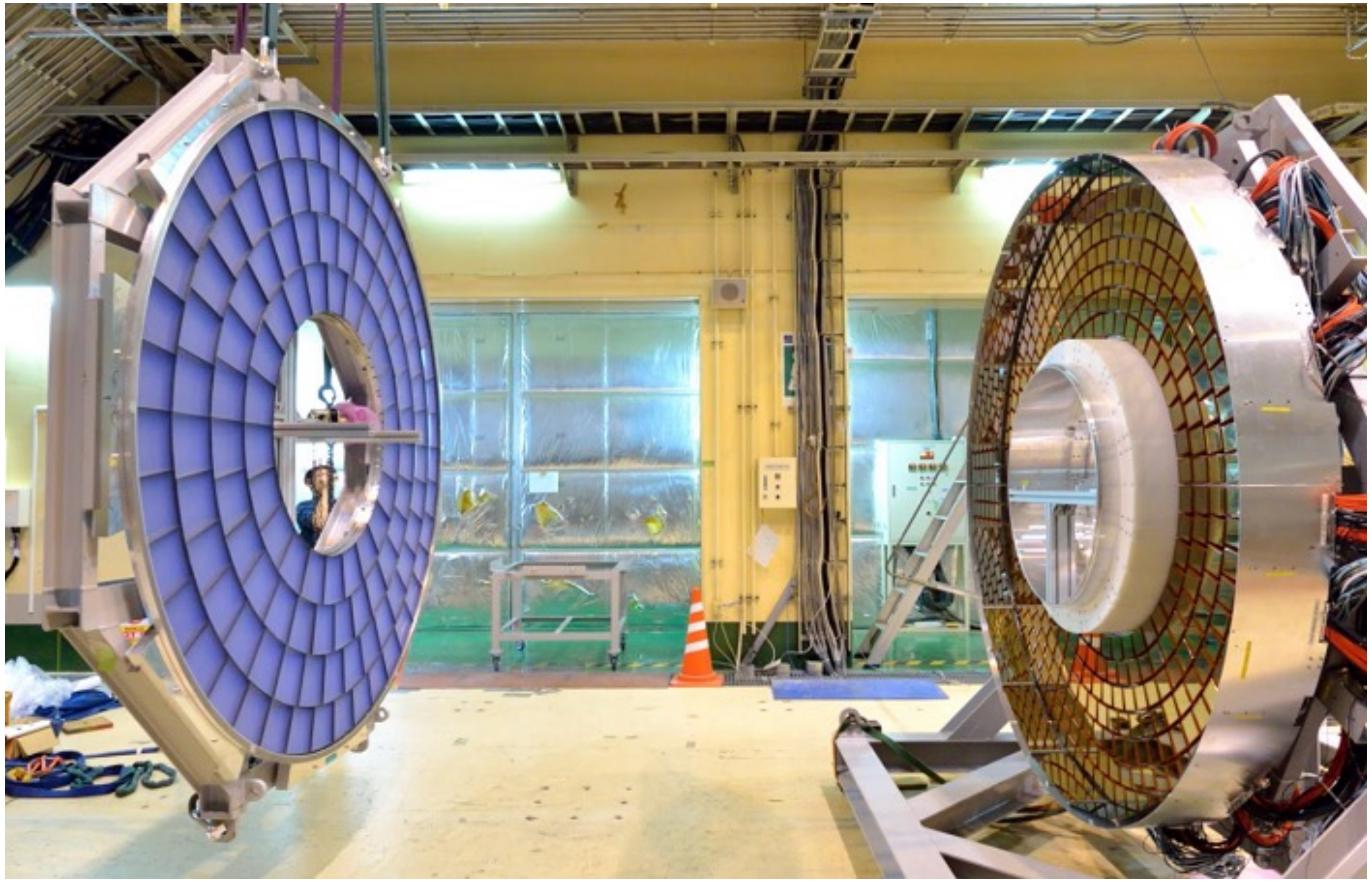
Other design choices & potential upgrades

- Gas radiator: *nitrogen*
  - "Safe" choice for the time being
  - e/π separation provided by ring imaging (aerogel)
  - May still consider a fluorocarbon gas in the future*

- Overall philosophy: do not overdesign the detector at this early stage

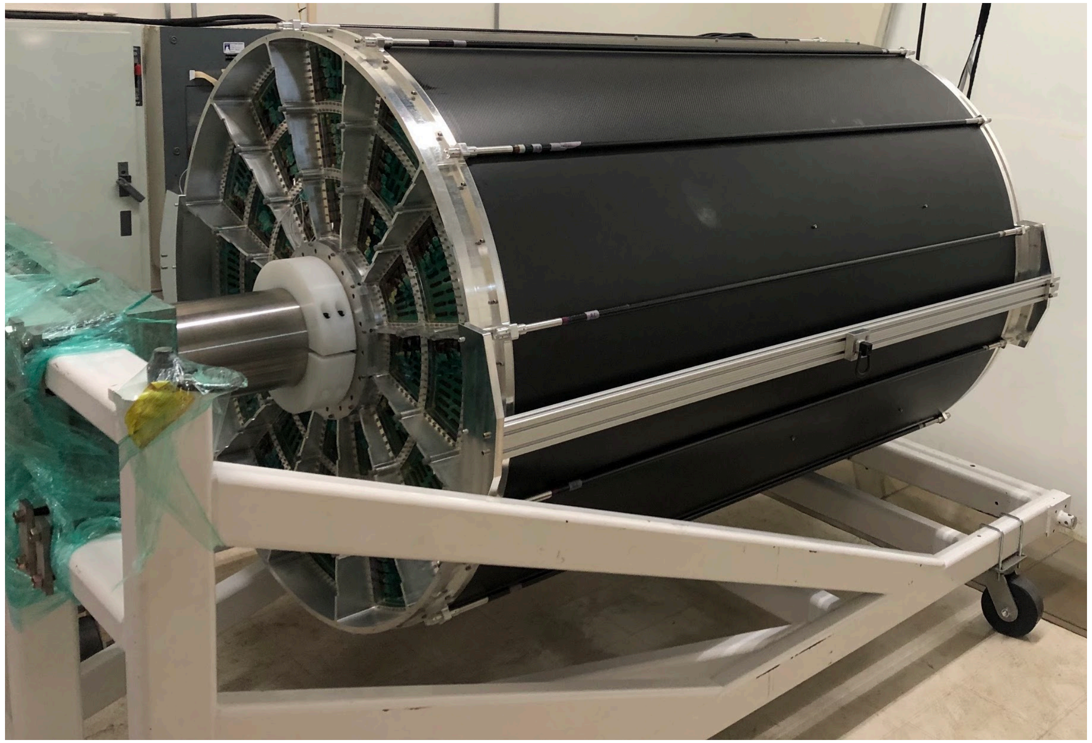
see a supplementary study provided in this talk

Closest ePIC pfRICH predecessor: Belle II ARICH



- Very short expansion volume
  - Yet achieved ~3σ π/K separation up to ~4 GeV/c
- Aerogel tiles segmented in {r,ϕ}
- Dual aerogel configuration
- Detected ~15 p.e. from a pair of 2 cm thick aerogel layers, using a photosensor with a similar QE as the HRPPDs
- Used side mirrors to increase the η acceptance

Construction ideas from other experiments



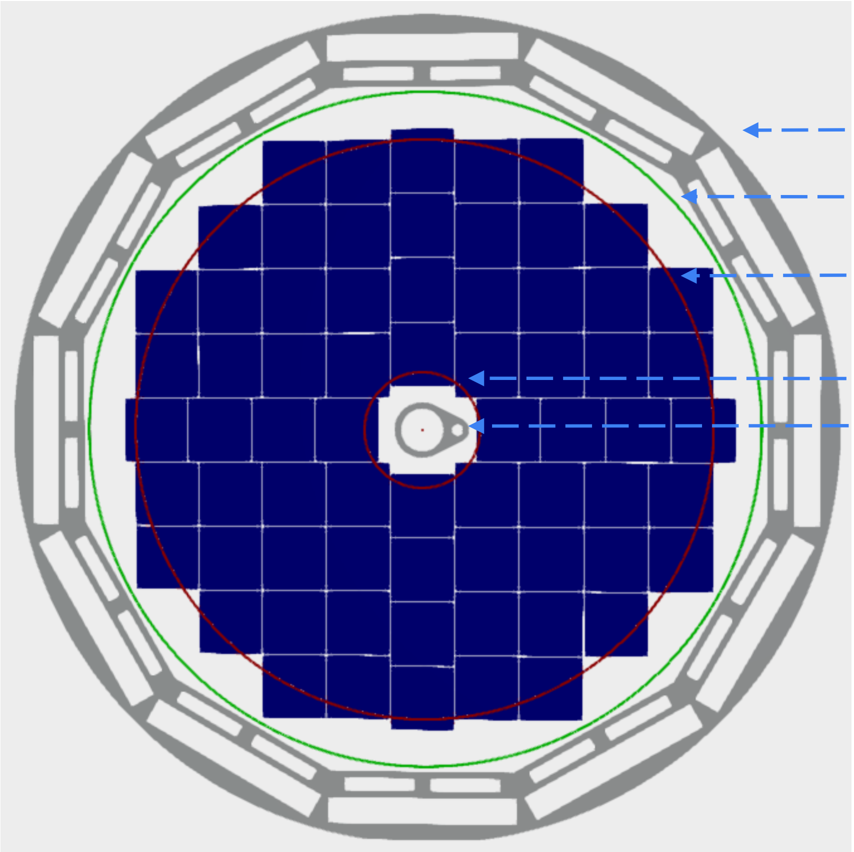
- ***sPHENIX TPC vessel***
  - Honeycomb carbon fiber sandwich

- ***AMS RICH conical mirror***
  - Carbon Fiber Reinforced Composite substrate

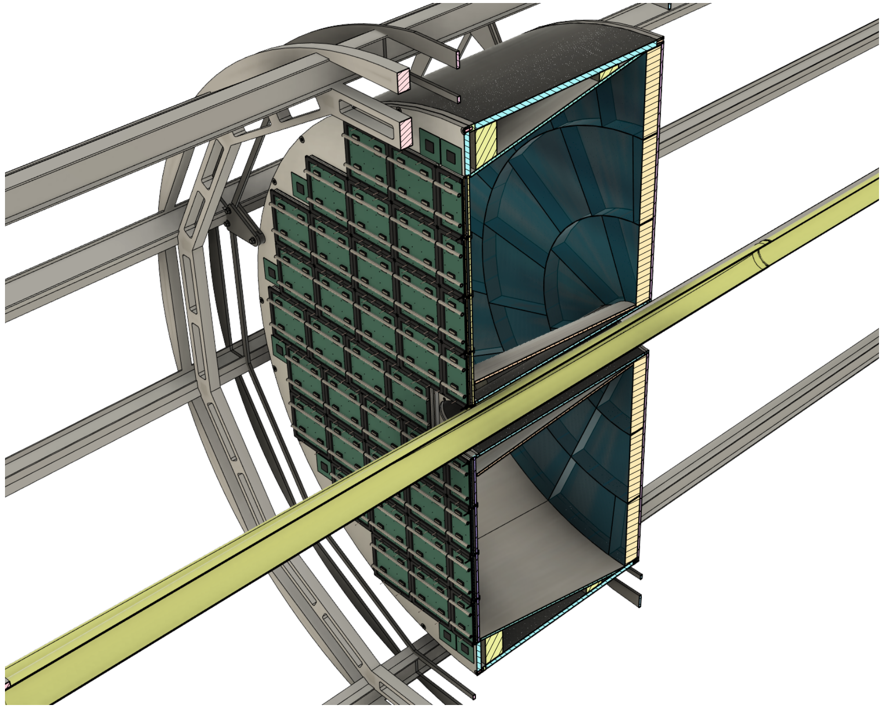
Both options implemented in GEANT and costed accordingly

Compliance with the IR and other subsystem constraints

Sensor plane tiling scheme



- Maintain GEANT model, CAD model and services description as coherent as possible



- 5 mm clearance to the beam pipe flange
- 8 mm clearance to the DIRC support frame

Subsystems

- Essential details of the HV, LV & Cooling systems are reflected in GEANT and / or CAD models
- Costing sheets are available to the reviewers

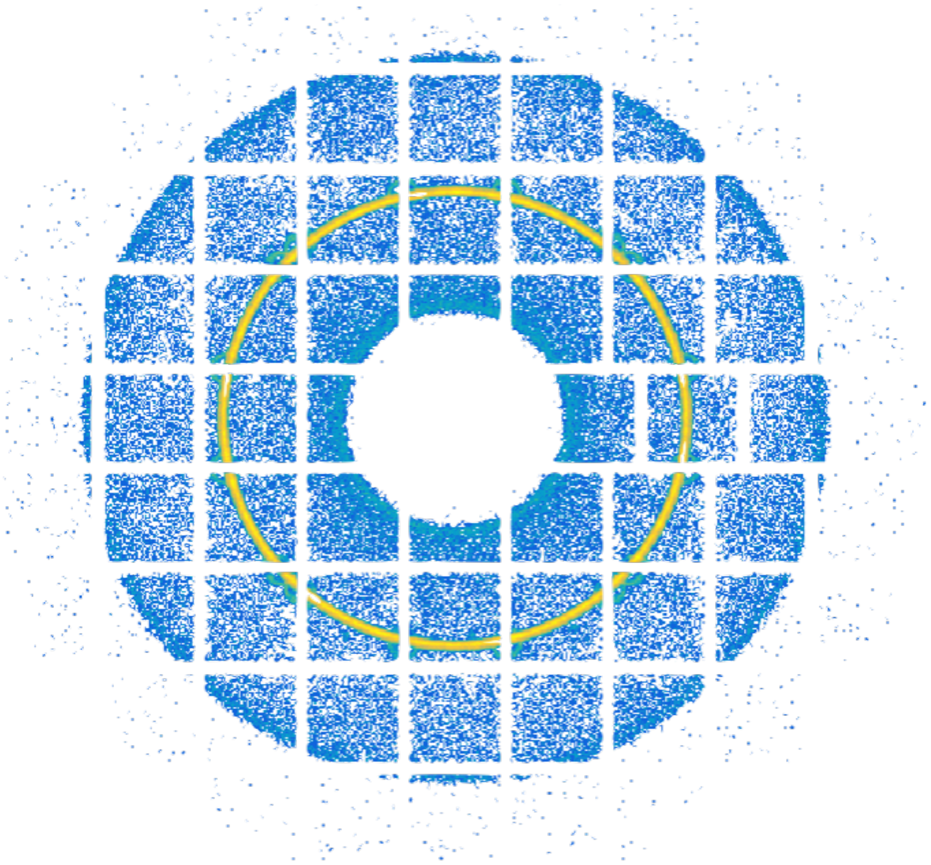
- High Voltage
  - Preliminary design stage
  - Fully costed (vendor quotes)
- Low Voltage
  - Preliminary design stage
  - Fully costed (prior experience)
- Gas
  - Conceptual design stage
  - Fully costed (expert opinion)
- Cooling
  - Preliminary design stage
  - Fully costed (catalogue items)

More details by talk on Design & Integration

Synergy with other ePIC subdetector systems

- DIRC
  - HRPPD photosensors
  - Cross-calibration (overlap in η acceptance)
- dRICH
  - Ring imaging reconstruction software
  - Aerogel procurement and QA

All three DSSCs will be involved in creating a unified PID environment for ePIC



Prototyping and beam tests

Prototyping, QA stations, beam tests in 2023-2024

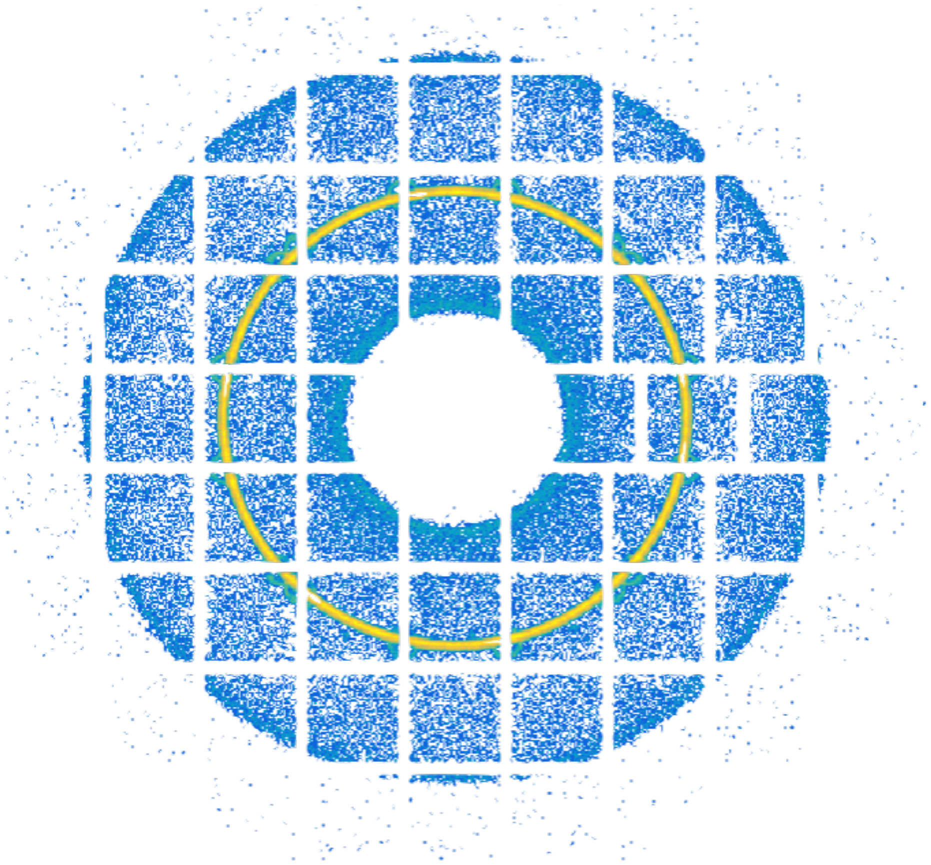
- BNL and INFN Trieste are two of the few groups worldwide with a close relationship to the photosensor manufacturer (Incom) and well developed LAPPD test station setups
- Several pfRICH groups have LAPPD beam test experience either at Fermilab or at CERN (BNL, INFN Trieste, INFN Genova, MSU, SBU)
- On behalf of the EIC project pfRICH members work with Chiba University on a contract to produce first aerogel samples of a type required by ePIC RICH groups

- Aerogel QA test station will be built at Temple University
- HRPPD QA test station (replica of Incom's one) will be built at BNL

Prototyping, QA stations, beam tests in 2023-2024

- Work with Incom within the scope of eRD110 consortium (photosensors)
  - Validation of the DC-coupled HRPPDs for use in EIC
  - Development of the pixelated interface for DC-coupled HRPPDs
  - Formulation of EIC-Incom PED contract for 2023-2024
  - Bench tests and a beam test at Fermilab in Winter 2023/24 to confirm the performance parameters of the first five HRPPDs Incom is re-designing for EIC
- Work with eRD109 consortium (electronics) and eRD107 (LFHCAL)
  - ASIC interface development for a small scale pfRICH prototype
  - Beam test at Fermilab with this prototype in Spring 2024 as a demonstration of a π/K separation reach

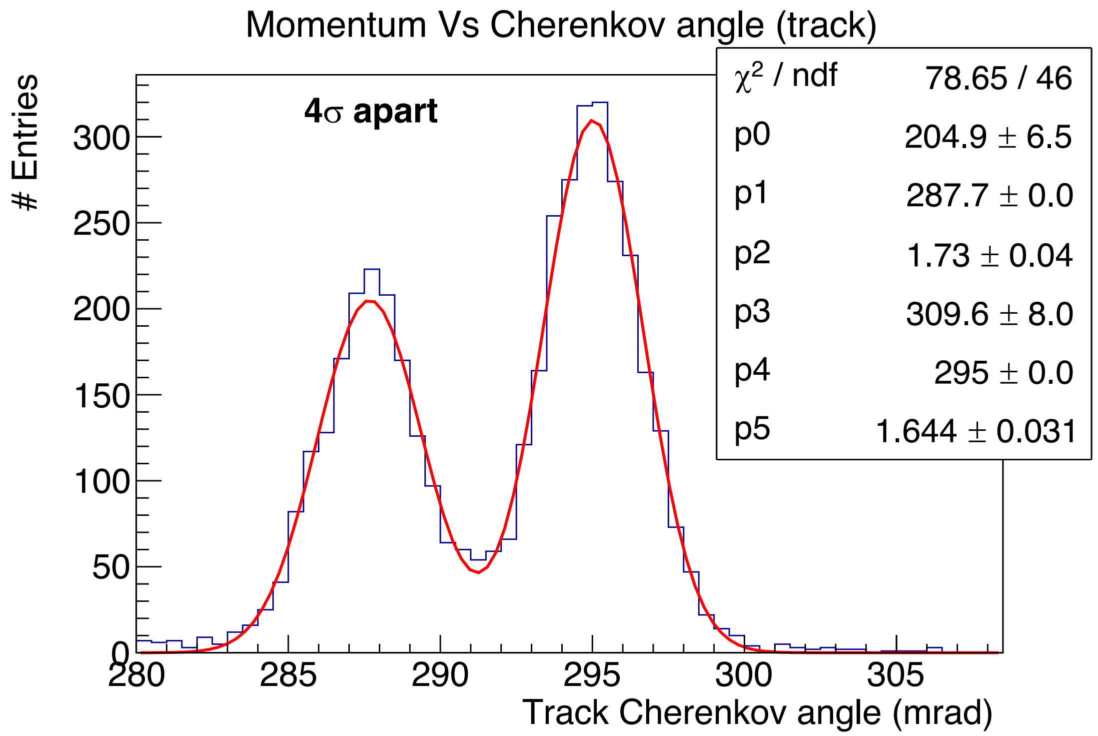
More details by talk on Photosensors & ASIC



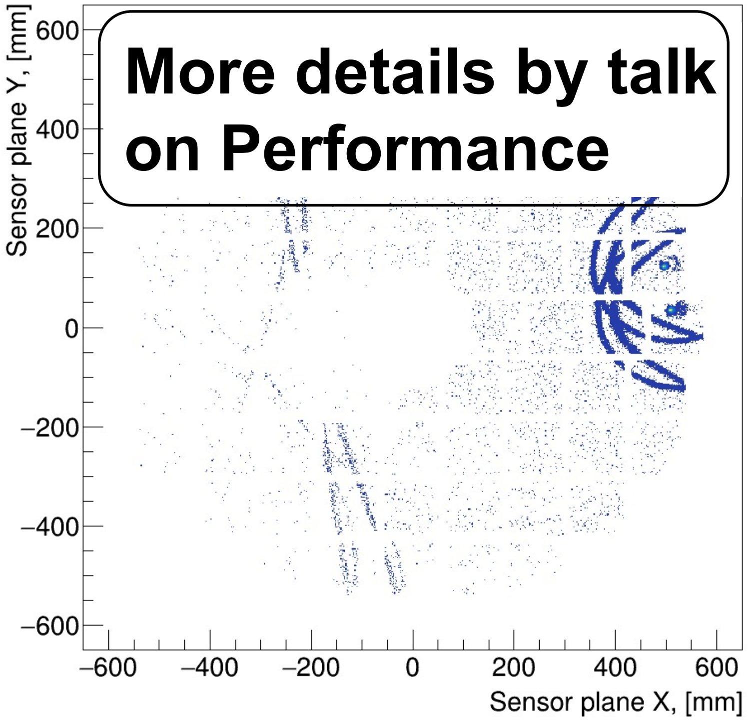
Performance studies

Software & pfRICH Performance Highlights

- Use standalone GEANT4 code with interfaces to ePIC software stack
- Simulation, and event-level digitization / reconstruction chain implemented



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)

pfRICH Performance Studies Dictionary

- Core performance studies → **talk by C. Chatterjee and Z. Tu**

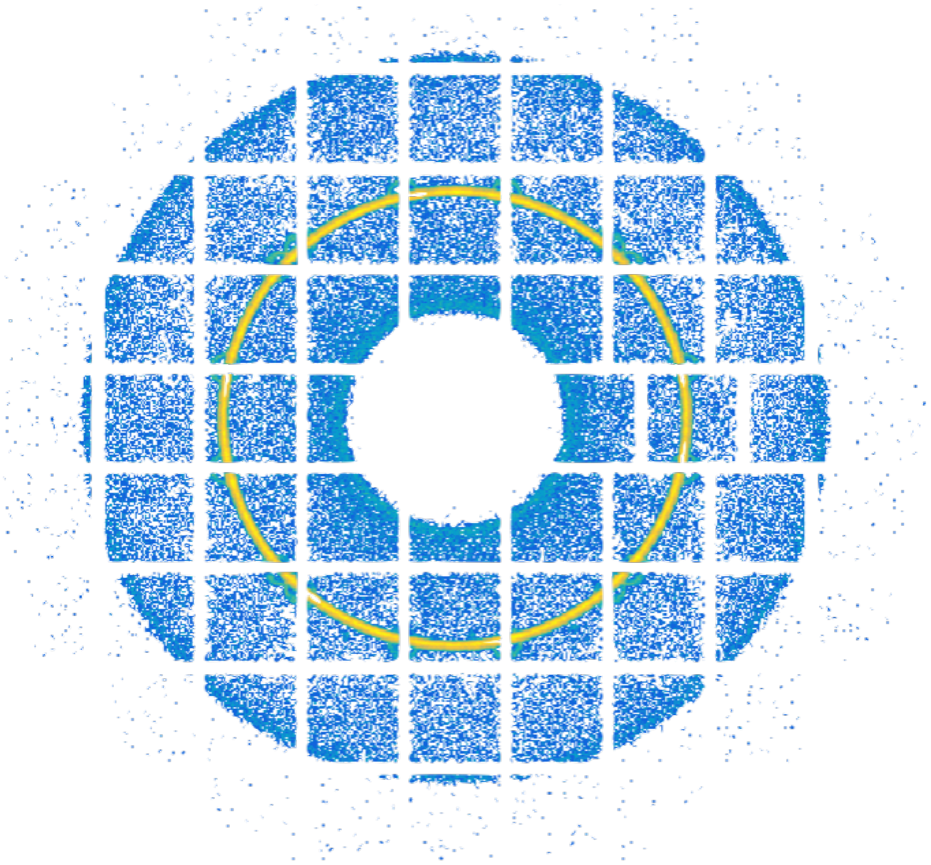
- Material effects on backward EmCal
- Central tracker performance

→ **integration talk tomorrow**

- pfRICH with a C_4F_{10} radiator
- Particle occupancy studies in ePIC e-endcap
- Photocathode refractive index effects
- Geometry exchange with dd4hep

→ **extra slides to this presentation**

- HRPPD performance in magnetic field → **photosensor talk**



Cost, schedule, workforce

Institutional commitments to date

- Currently pfRICH Detector SubSystem Collaboration includes strong groups and members from
  - Brookhaven Lab
  - Chiba University
  - Duke University
  - INFN Trieste *[not for construction]*
  - INFN Genova *[not for construction]*
  - Jefferson Lab *[project engineer support]*
  - Ljubljana University and JSI *[as experts]*
  - Mississippi State University
  - Stony Brook University
  - Temple University
  - Yale University

- It is expected that INFN colleagues will **not** be able to contribute during the construction phase, since their main focus will be ePIC dRICH

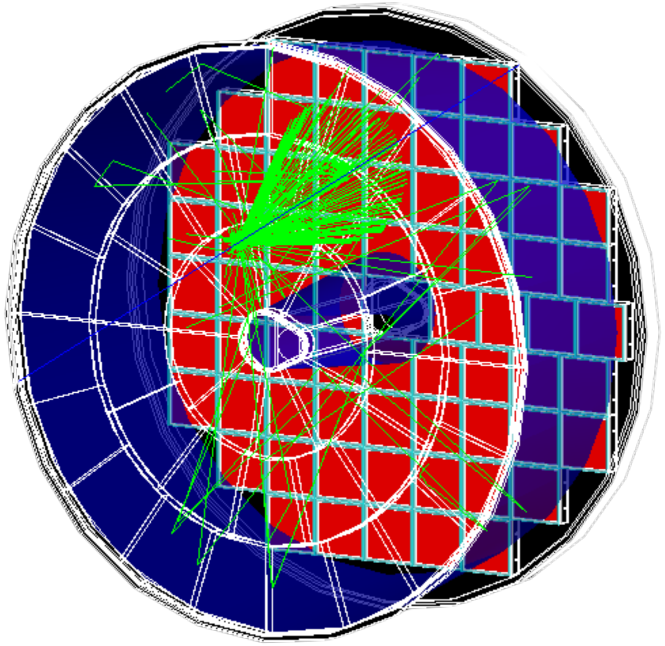
- The doors are open for new groups, especially those who can provide young scientist workforce for modeling, prototyping and participation in beam tests *now*

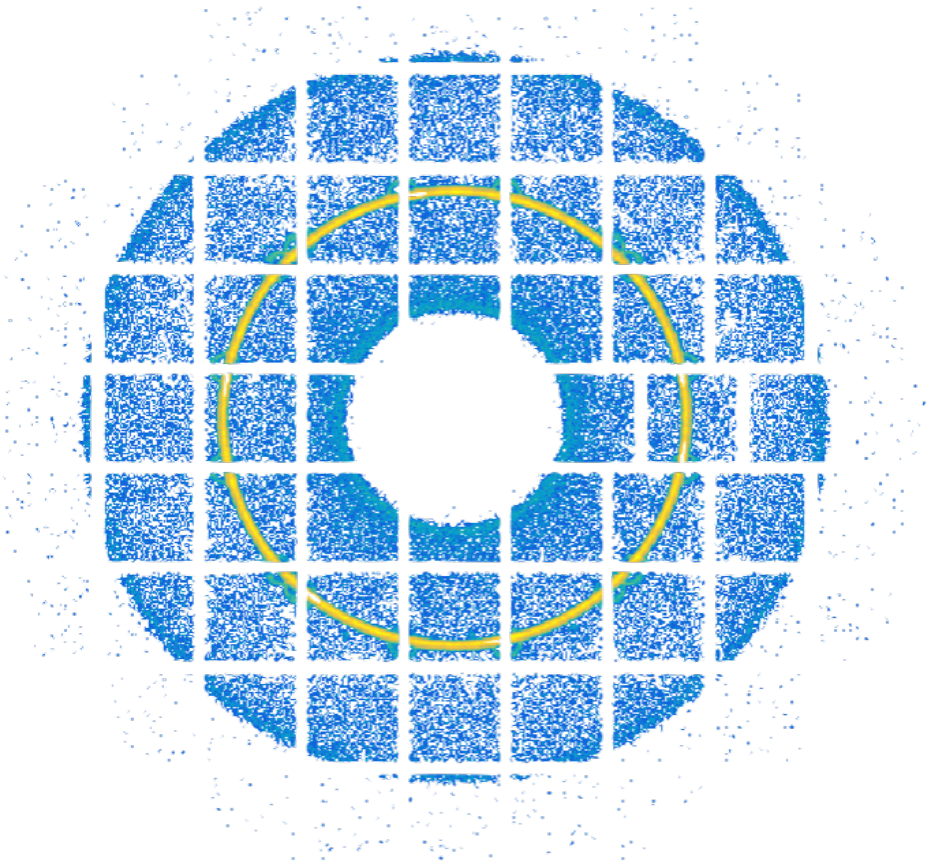
More details by talk on Workforce, Cost & Risk

Summary: pfRICH for backward PID in ePIC

- Performance studies show that ePIC pfRICH design **exceeds the Yellow Report** requirements

- Progress achieved over the first five months assures that the final design will be successfully completed by CD-2 / CD-3
- There is a core of **strong institutions** behind this effort to push it to the construction stage
- Detector concept, performance and its expected role in ePIC already attracted **several young scientists** working together as a team
- Nothing is carved in stone, and **new groups are more than welcome!**



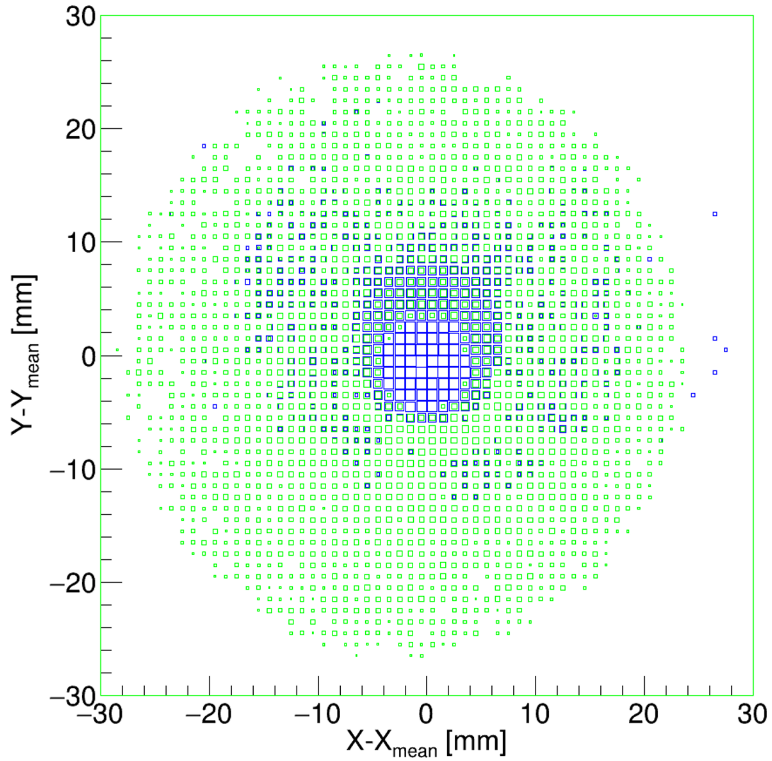


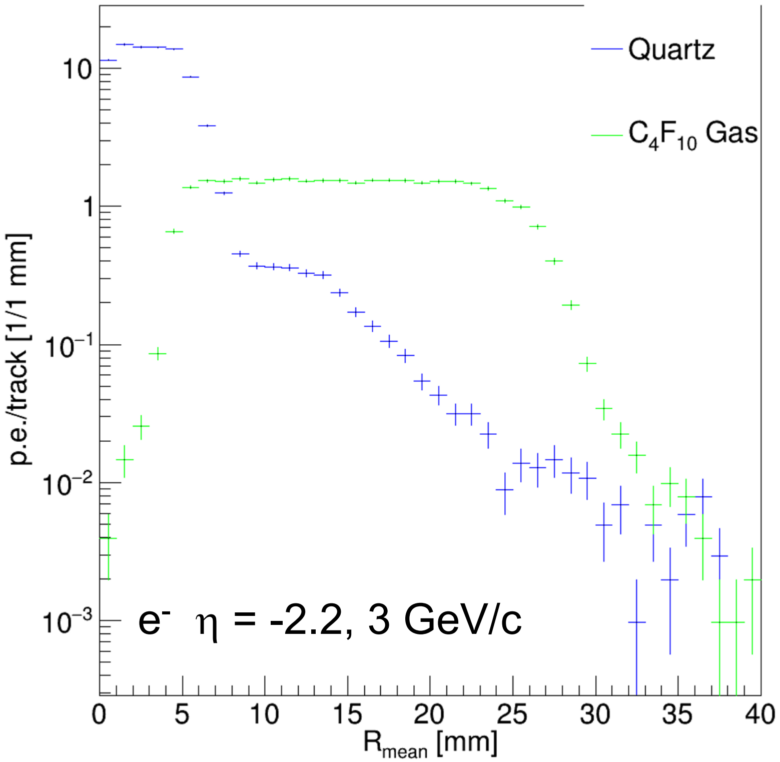
Extra slides

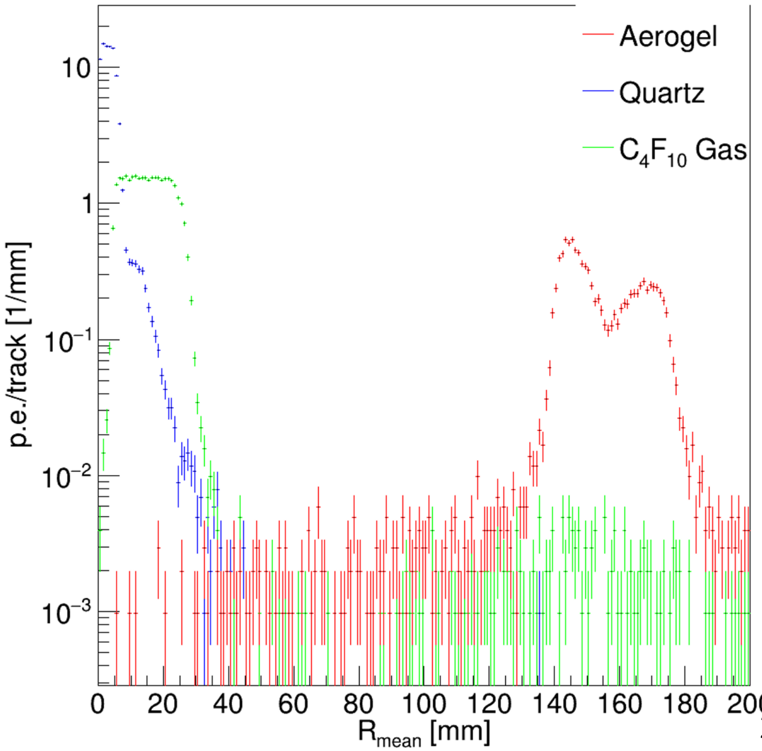
Case for a C_4F_{10} Radiator instead of Nitrogen

- pfRICH has ~45 cm of expansion volume, and Cherenkov radiation in gas can be used for e/π-sepation
- pion Cherenkov threshold P>2.7 GeV (but near threshold at 3 GeV pion radius is small)
- e^- track gives 33 photo-electrons in gas - compare with 85 p.e. from HRPPD quartz window
- radius of quartz window spot is 7 mm, but with multiple internal reflections extends to 40 mm
- applying a cut on radius R>8 mm provides 29 gas p.e. on top of 4 window p.e. ⇒ >4 sigma separation
- contamination in Aerogel radius region is about <2% of p.e.

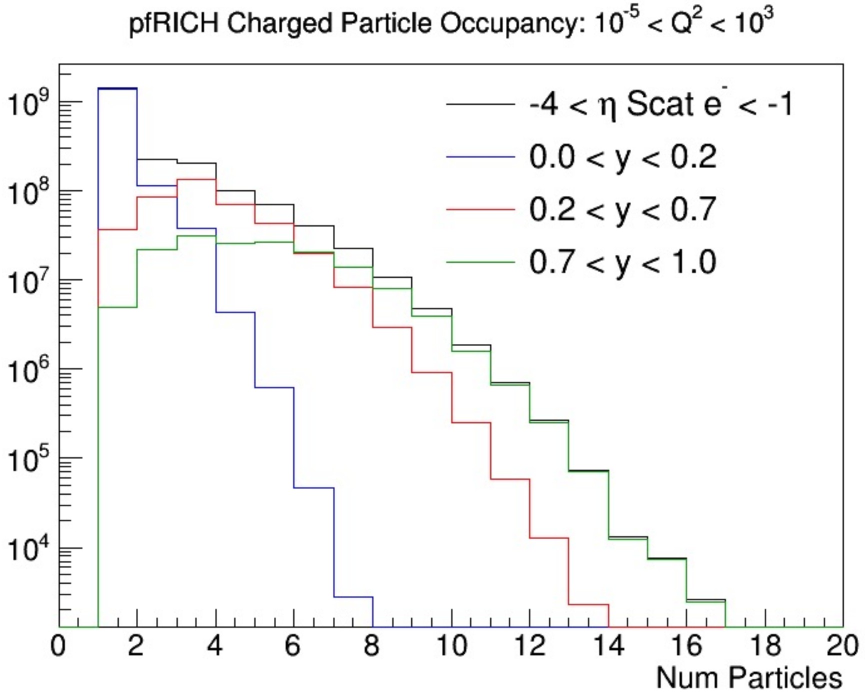
by Mikhail Osipenko (INFN Genova)

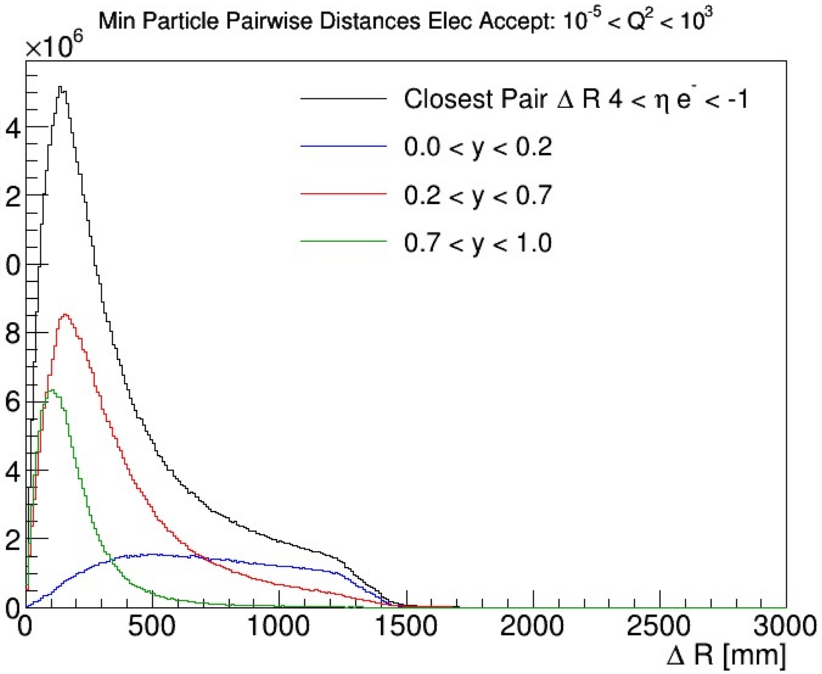






pfRICH Particle Occupancy Studies





by Brian Page (BNL)

- ❑ For events with two or more particles in pfRICH acceptance find distance between closest pair
- ❑ Distance measured at pfRICH sensor plane
- ❑ Minimum distance between particles decreases as inelasticity, thus occupancy, increases

- ❑ Plot number of charged particles in $-4 < \eta < -1$ for different inelasticity bins and scattered beam electron in acceptance
- ❑ Sample scaled such that curves can be read as number of events expected with given number of particles per fb^{-1}
- ❑ Most events have few charged particles in addition to electron

Conclusion: both ring multiplicity and overlap probability in pfRICH will be small

Photocathode Refractive Index Effects

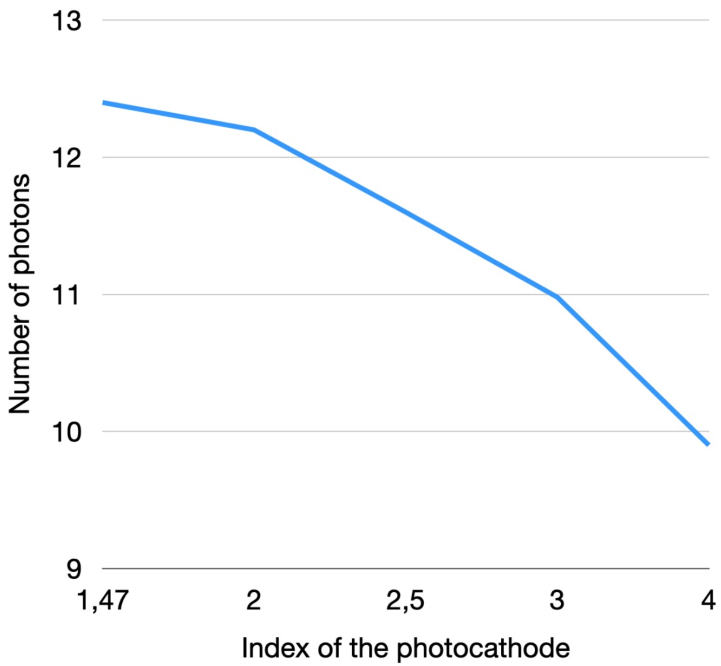
by Charles Neim (Stony Brook)

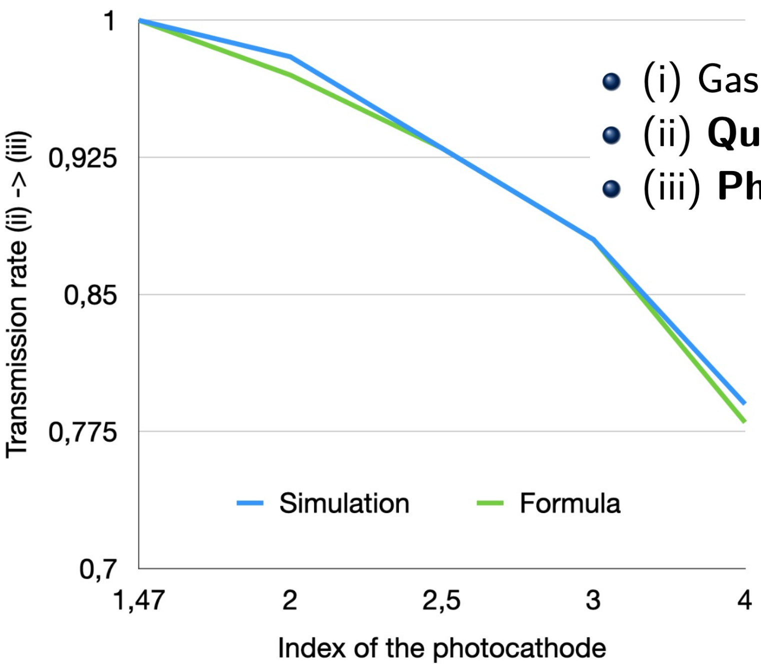
Goal:

- Evaluate the number of photons transmitted between the quartz window and the photocathode.

Methods:

- **Frenel's laws and energy conservation formula**;
- **pfRICH simulation based on GEANT4**.





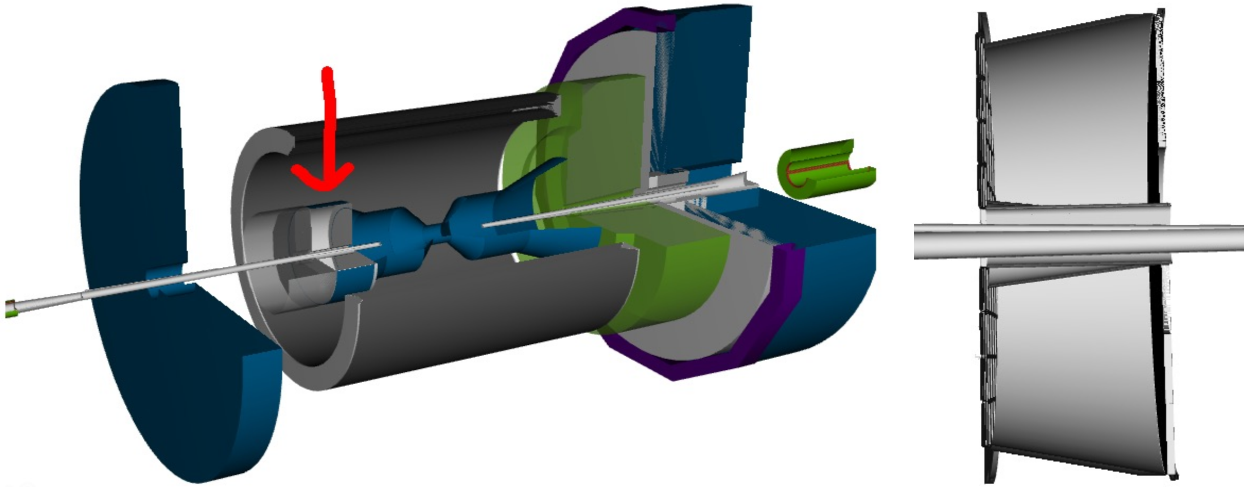
- (i) Gas index: $n_1 = 1$;
- (ii) **Quartz windows index**: $n_2 = 1.45$;
- (iii) **Photocathode index**: $n_3 \in (1.47, 2.00, 2.50, 3.00, 3.50, 4)$;

Conclusion: setting photocathode refractive index high in the simulation requires renormalization of the measured Quantum Efficiency

Geometry Exchange with ePIC dd4hep Framework

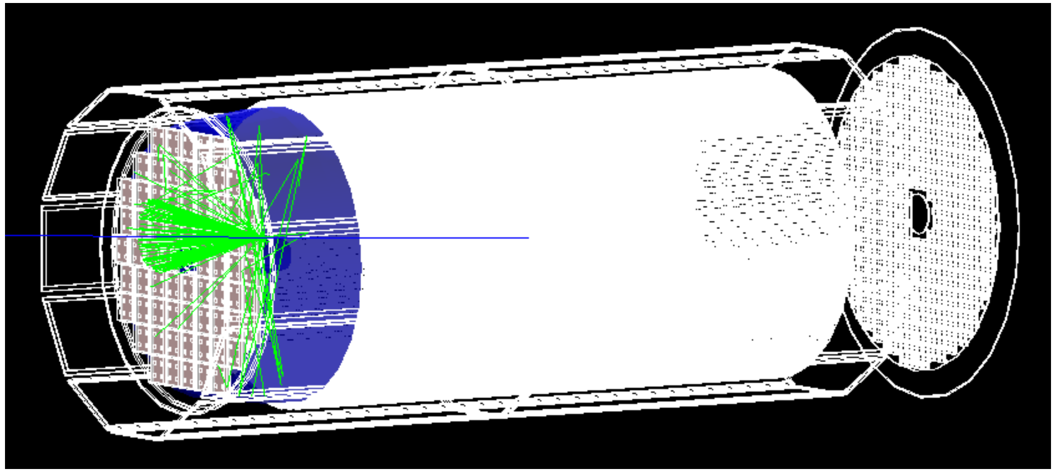
- GDML import / export was tuned to exchange the models
- pfRICH simulations were performed *without ePIC tracker material in front of it* though
  - This material does not show any visible effect on performance
  - Sows down the processing substantially

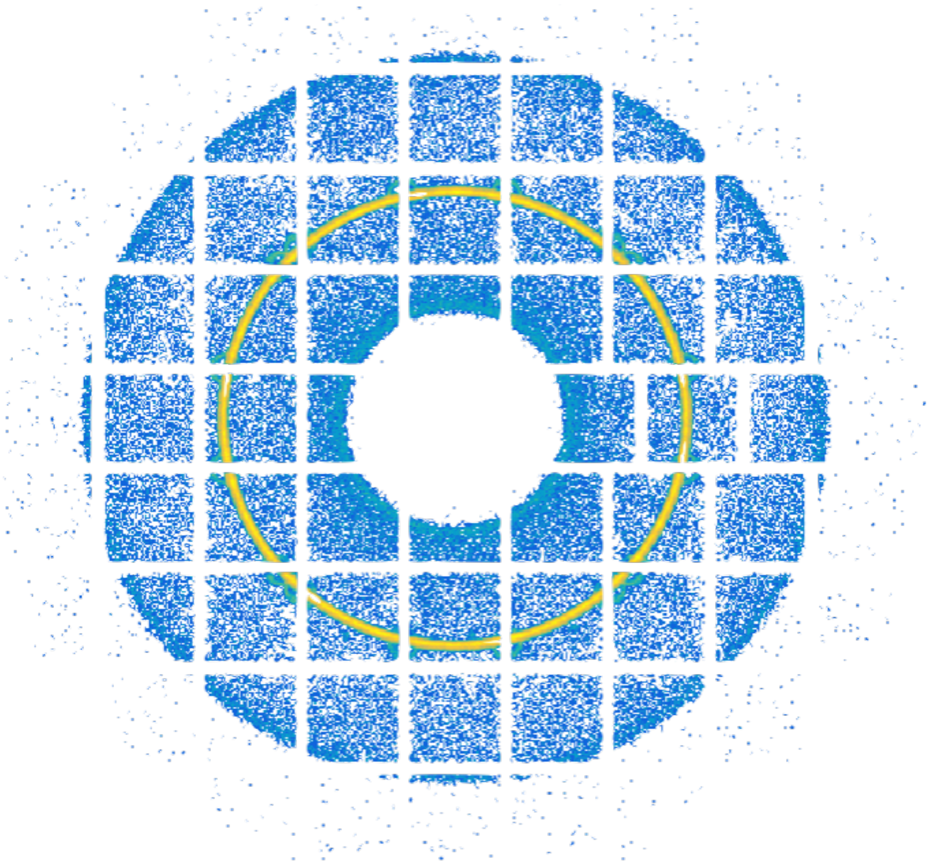
by Chris Dilks (Duke)



pfRICH in ePIC event display

pfRICH & ePIC tracker in our standalone GEANT simulation





Backup

Charge to the proponents

1. Reminder of the proposed **detector configuration** for the use in the ePIC detector.
2. **Input information**:
   1. Pertinent **information on similar technology/design** that is used by other experiments or R&D efforts (example references could be literature or conference talks).
   2. **Prototypes and their tests**: done so far, ongoing effort, future planning (with timelines); results from prototypes and their tests
   3. **Simulation studies**: already performed, ongoing and planned (with timelines); results from the simulations; particular care in (i) showing how realistic the parameters used in simulations are and (ii) reporting what is missing for a fully realistic simulation (backgrounds, specific event categories, …) (iii) Does the simulation take into account the **realistic response of the selected photosensors and related FEE**?

Charge to the proponents

3. **Performance**:
    1. Comparison of the **present assessment of the Cherenkov PID detector performance compared with the YR requirements**?
    2. Performance perspectives **beyond the YR requirements (if any)** ?
    3. **Efficiency** figures: single particle Pi/Kaon/Proton identified as Pi/Kaon/Proton as a function of the truth momentum in a 3x3-panel figure?
    4. **Please quantify the performance for electron/hadron separation**
    5. **Active area** or /dead area as 2D function of eta and phi; and comment on the edge effects?
    6. **Performance or potential as timing detector, providing both timing resolution and acceptance coverage in eta and phi.**
    7. **Under the coordination of the SIDIS working group, provide Kaon Purity in the kinematic region of (x. .. Q2…) via parameterized hadron PID performance.**

Charge to the proponents

4. **Aerogel Radiator**
   1. Status of **radiator selection**
   2. **Status of the radiator** development and related potential issues?
   3. **Perspectives of radiator mass production** and timelines for the production period?
5. **Sensors and FEE**:
   1. Status of **photosensor selection** (a single consolidated option, more options under consideration); please provide photo sensor and pixel segmentation characteristics?
   2. **Status of the sensor** development and related potential issues?
   3. **Perspectives of sensor mass production** and timelines for the production period?
   4. **Characteristics of the ASIC and FEEs** considered?
   5. Status of **FEE identification** (a single consolidated option, more options under consideration)? Present a plan for realization on the FEE development in the context of technology choice and in conjunction with the project.
   6. Status of the **FEE development** and related potential issues?
   7. Perspectives of **FEE mass production** and timelines for the production period?

Charge to the proponents

6. **Integration**:
    1. **Status of the proposed detector integration** into the current baseline detector?
        1. z-space and effect to tracking: in coordination with the tracking DWG, produce backward momentum resolution for the tracker that fit into the z-spaced allowed by the proposed RICH detector
        2. Material effect to backward EMCal: in coordination with the calorimeter DWG, produces electron lineshape in the backward EMCal with the proposed RICH detector in front.
    2. Status of the **design of the electrical/electronic infrastructure** (channels, power supplies, heat, rate)?
    3. **Cooling** strategies?
7. **Workforce:**
    1. **List of groups** engaged in the proposed detectors and of other groups potentially interested;
    2. **Workforce needed with timelines and qualification of the required professional profiles;** please, include also physicists needed for dedicated simulation studies;
    3. **Available workforce** (specifying: granted, expected, possible) by the groups proposing the detector;
8. **Cost and scheduling**:
    1. up-to-date cost estimate for the different components and expenditure categories;
    2. In-kind contributions (specifying: granted, expected, possible).
    3. Envisioned schedule for full scale production
9. **Envisioned risk and risk mitigation strategy**