ePIC General meeting

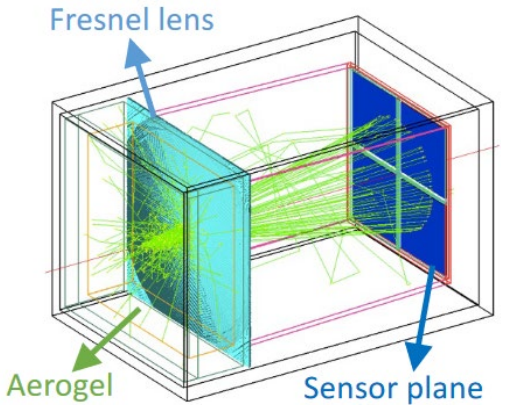
Backward RICH recommendation

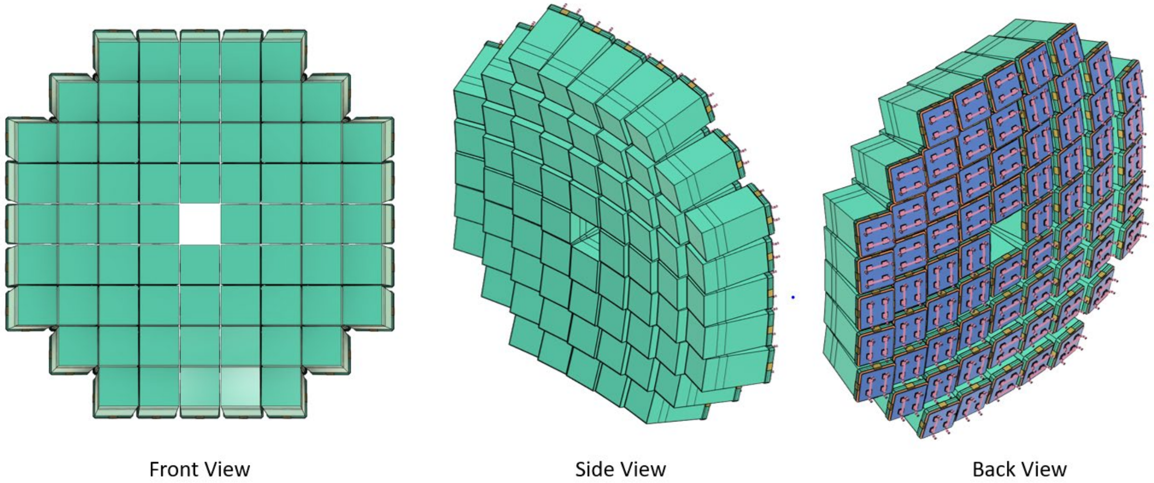
John Lajoie and Silvia Dalla Torre

April 14, 2023

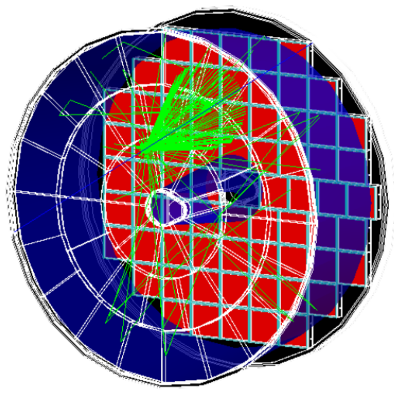
REMINDER: the two alternative designs

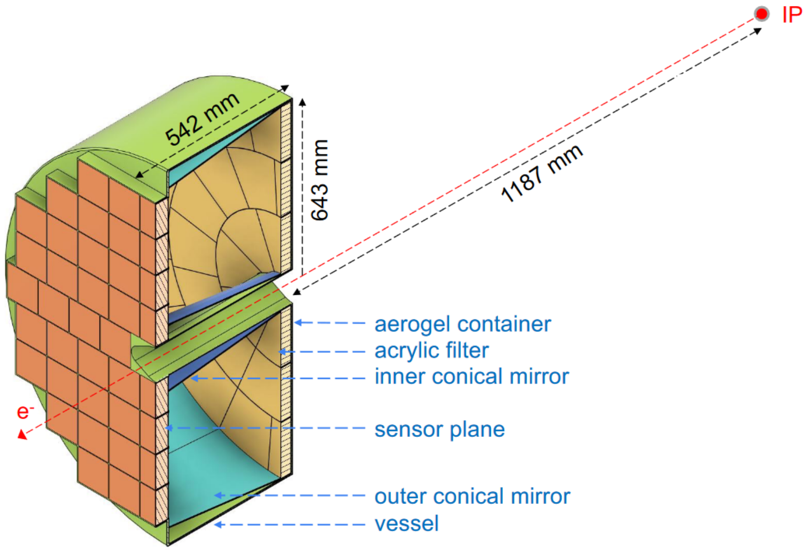
mRICH





pfRICH





INPUT USED

- Reports at the review (March 20-21, 2023)
- Report by the reviewers
- Feedback to the reviewing committee by the proponents of the two designs
- Other material received contacting the proponents
- Cost information solicited from the EIC Project
- pfRICH CDR
- Inputs from the discussion at the EB meeting on April 7

Thank You !

- EB members (meeting April 7)

- Review board (with internal members from GD/I and external international experts)

Ichiro Adachi (KEK)
Roberta Cardinale (University of Genova)
Carmelo D'Ambrosio (CERN)
Antonello DiMauro (CERN)
Jin Huang (BNL)
Richard Milner (MIT)
Carlos Munoz Camacho (IJCLab Orsay)
Joe Osborn (BNL, chair)
Beni Zihlmann (Jefferson Laboratory, ex-oficio)

- The proponents and speakers at the review

The committee congratulates both design proponents for the excellent presentations and the high level of discussions. We highly appreciate the efforts of both groups and the ePIC collaboration in preparing for this review. We hope this report will help the collaboration in making a decision in the technology choice for the ePIC backwards RICH detector.

SCRUTINIZED ITEMS

- Performance for PID
  - Expected **resolution from simulations**:
    - this figure dictates the π/κ and e/π separation range
  - π/κ separation range
  - e/π separation range
  - Acceptance

In the following, a reminder of the major points

More, in the backup slides at the end of this file
Much more in the review material:
https://indico.bnl.gov/event/18499/

- Holistic view
  - Device length and tracking lever arm
- Costing
- Risks and mitigations

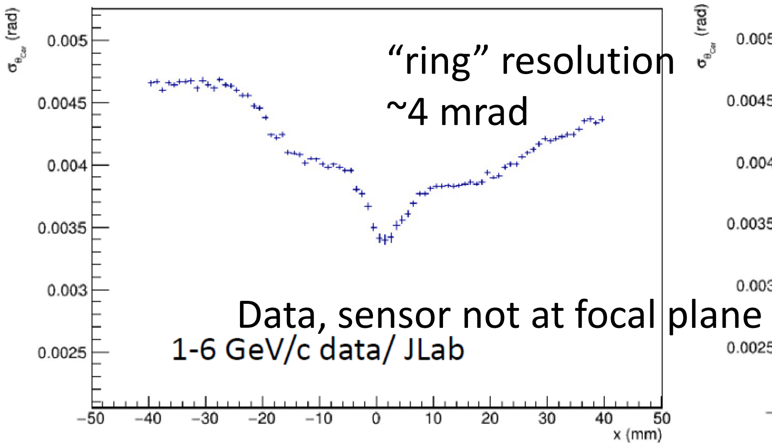
SCRUTINIZED ITEMS

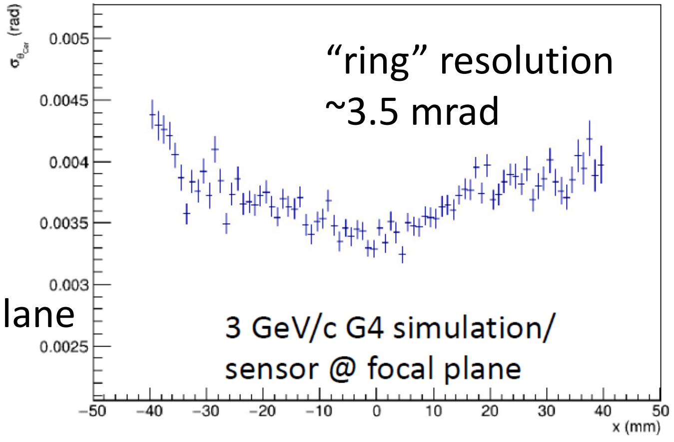
- Performance for PID
  - Expected **resolution from simulations**:
    - this figure dictates the π/κ and e/π separation range
  - π/κ separation range
  - e/π separation range
  - Acceptance
- Holistic view
  - Device length and tracking lever arm
- Costing
- Risks and mitigations

RESOLUTION

mRICH, from test beam and simulation

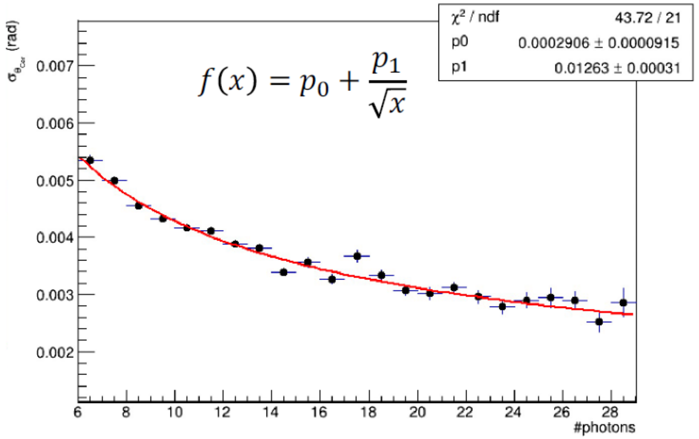
JLab Beam Test: Results

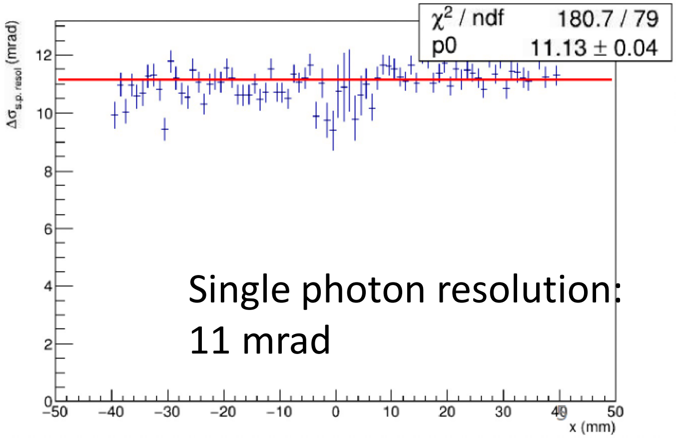




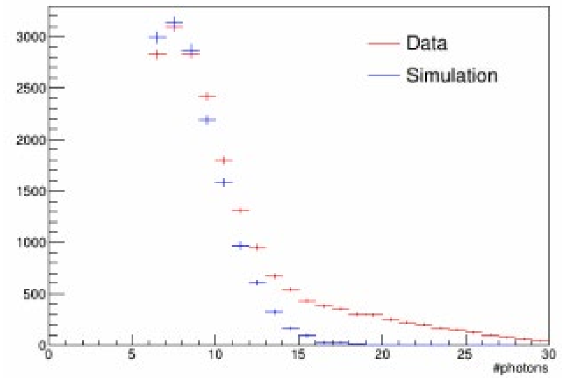
- More photons optimizing the aerogel thickness.
- Improved resolution claimed with sensor at the focal plane.

Proving all this requires further R&D.

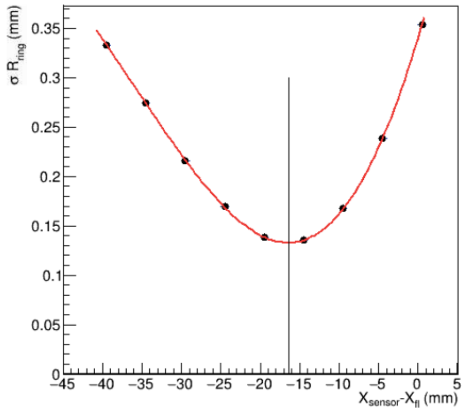




n. of Photons per ring
From JLab test beam



“ring” resolution
vs sensor plane position
w/o including pixel size



QUANTUM EFFICIENCY in SIMULATION STUDIES

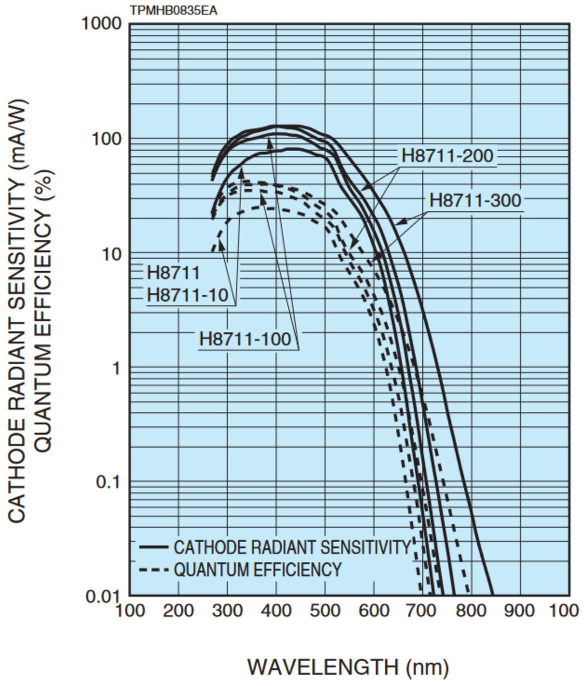
From E-mail by Xiaochun He on March 23

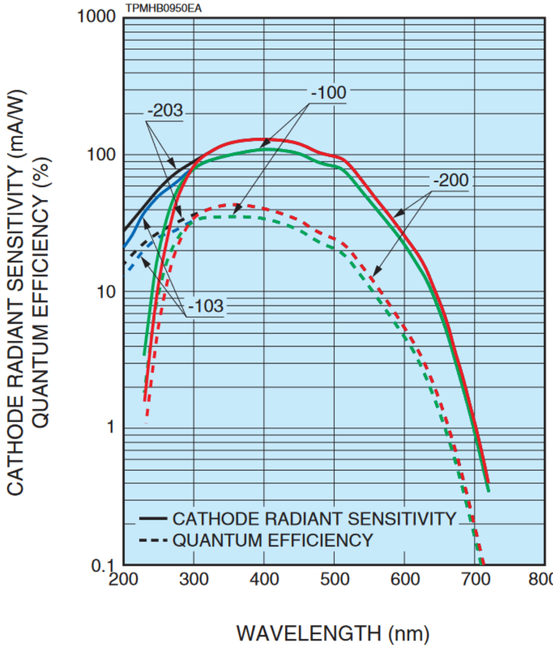
We did, however, implement an accurate digitization reflecting the pixelization as well as Q.E. but shifted the Q.E. distribution to start above 350 nm but with a maximum value of 38% at ~500 nm which has a similar distribution in shape to LAPPD.

mRICH

A **photocathode with QE~ 38% at 500 nm** is not at hands. Hamamatsu reference plot copied here (more examples available in literature).

any possible R&D dedicated to the development and engineering of a different photocathode would have a time-scale incompatible with the project timelines (90% readiness for CD3)



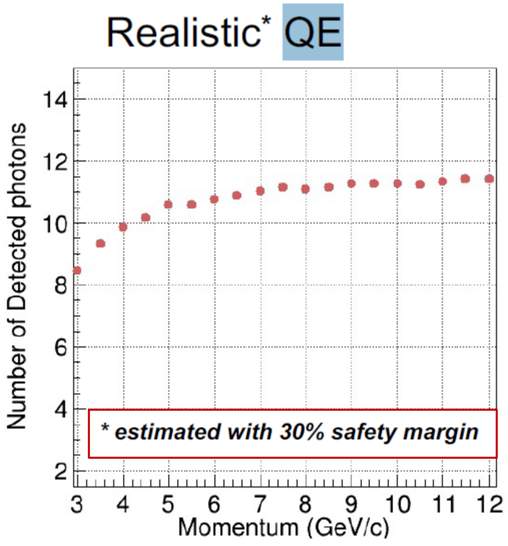


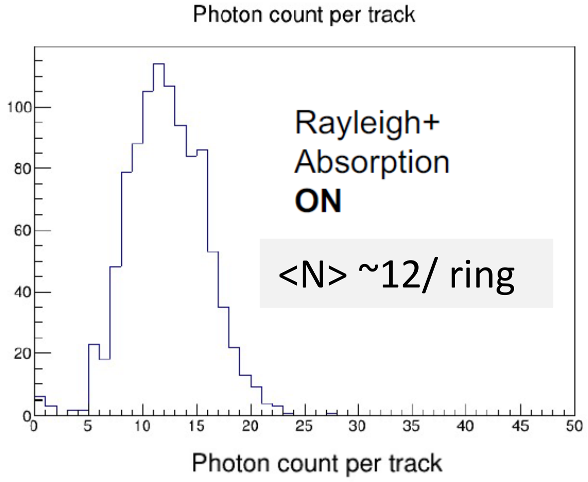
NUMBER OF DETECTED PHOTOELECTRONS **pfRICH**

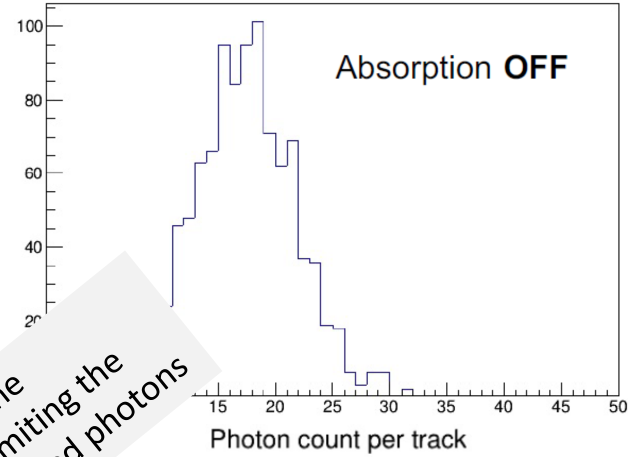
Ingredients:

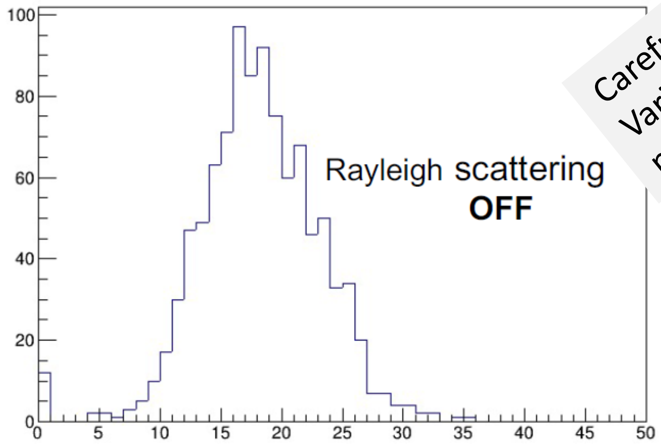
Conservative QE, **aerogel properties (BELLE II A-RICH measured parameters used),** further **safety factor** for conservative estimate: assume 70 % of the detected photoelectrons as provided by the full Monte Carlo simulation

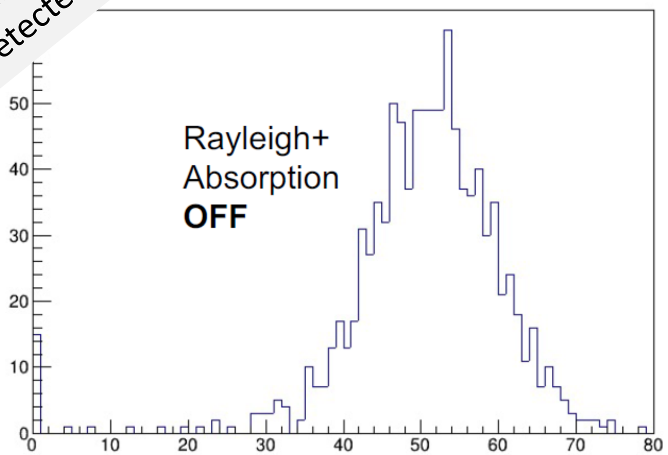
- 2.5 cm thick Belle II type tiles possible (as communicated by the manufacturer)







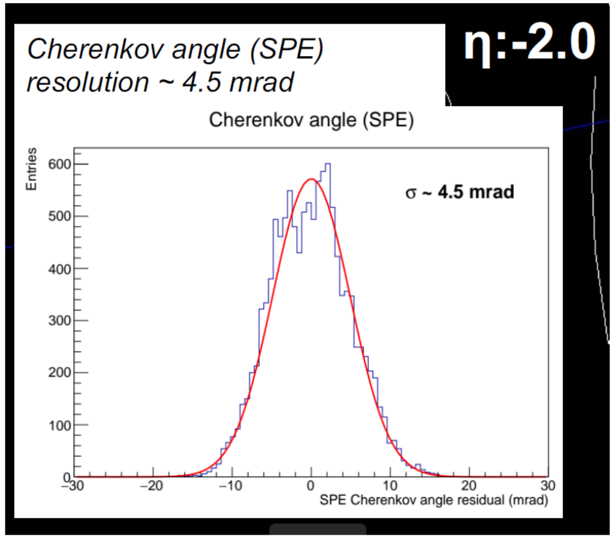




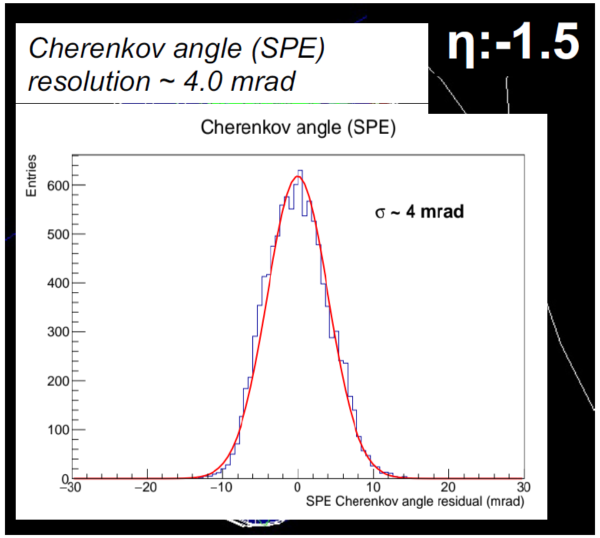
Careful study of the Various effect limiting the number of detected photons

RESOLUTION

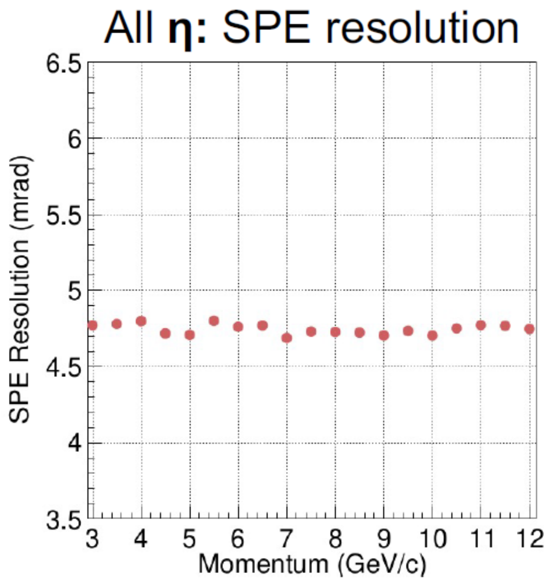
pfRICH, from simulation

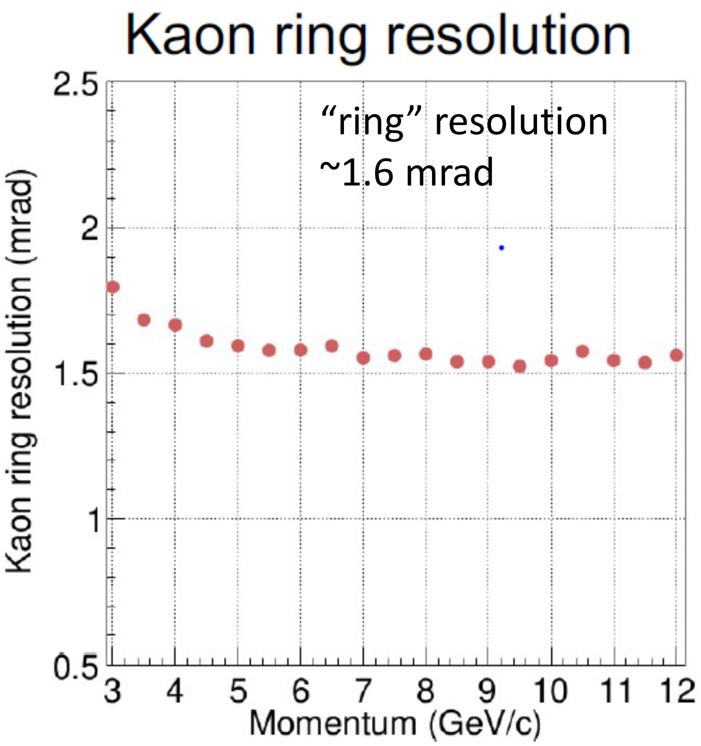


Center of pfRICH



Edge of pfRICH





RESOLUTION in the report

mRICH

(1) a ring resolution of 3-4 mrad measured in test beam, and implemented in simulation, leading to a K/pi separation beyond the YR requirement was presented. Potential improvement via an optimization of the sensor position with respect to the focal lens was also presented.

pfRICH

Based on the current simulation study, the proponents showed a ring resolution of 1-2 mrad and that the expected performance exceeds the YR requirement.

SCRUTINIZED ITEMS

- Performance for PID
  - Expected **resolution from simulations**:
    - this figure dictates the π/κ and e/π separation range
  - π/κ separation range
  - e/π separation range
  - Acceptance
- Holistic view
  - Device length and tracking lever arm
- Costing
- Risks and mitigations

π/κ separation range requested (YR)

Backward endcap:

π/κ separation $\geq$ 3σ up to 7 GeV/c

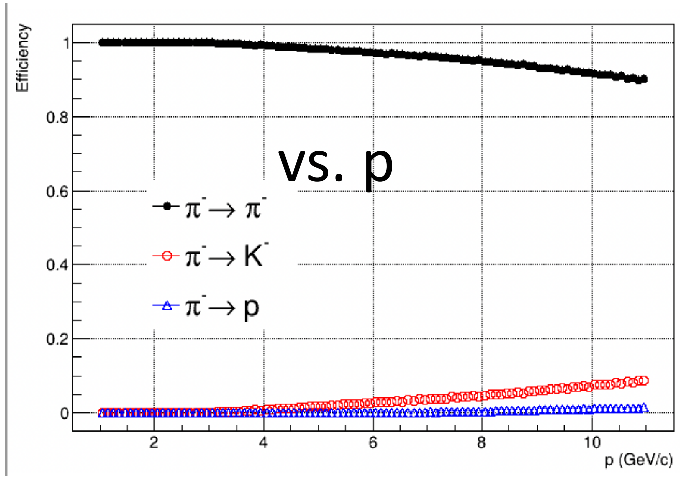
HADRON PID PERFORMANCE

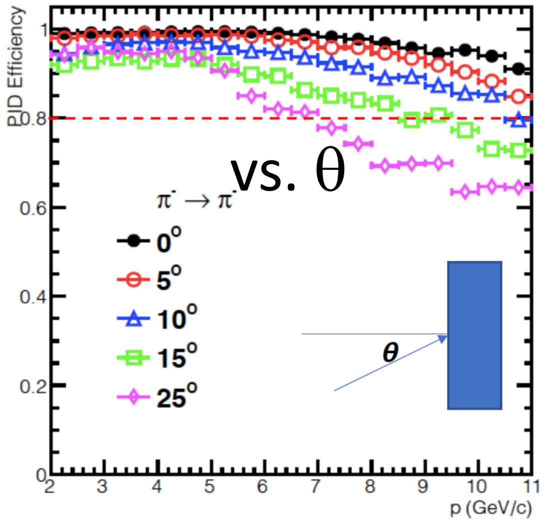
mRICH

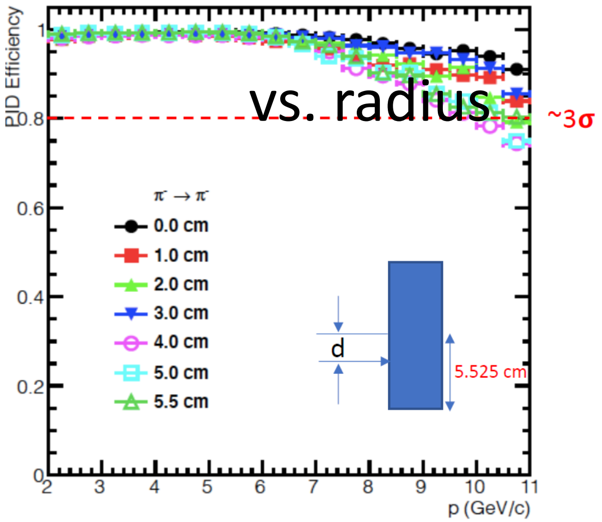
Efficiency and purity

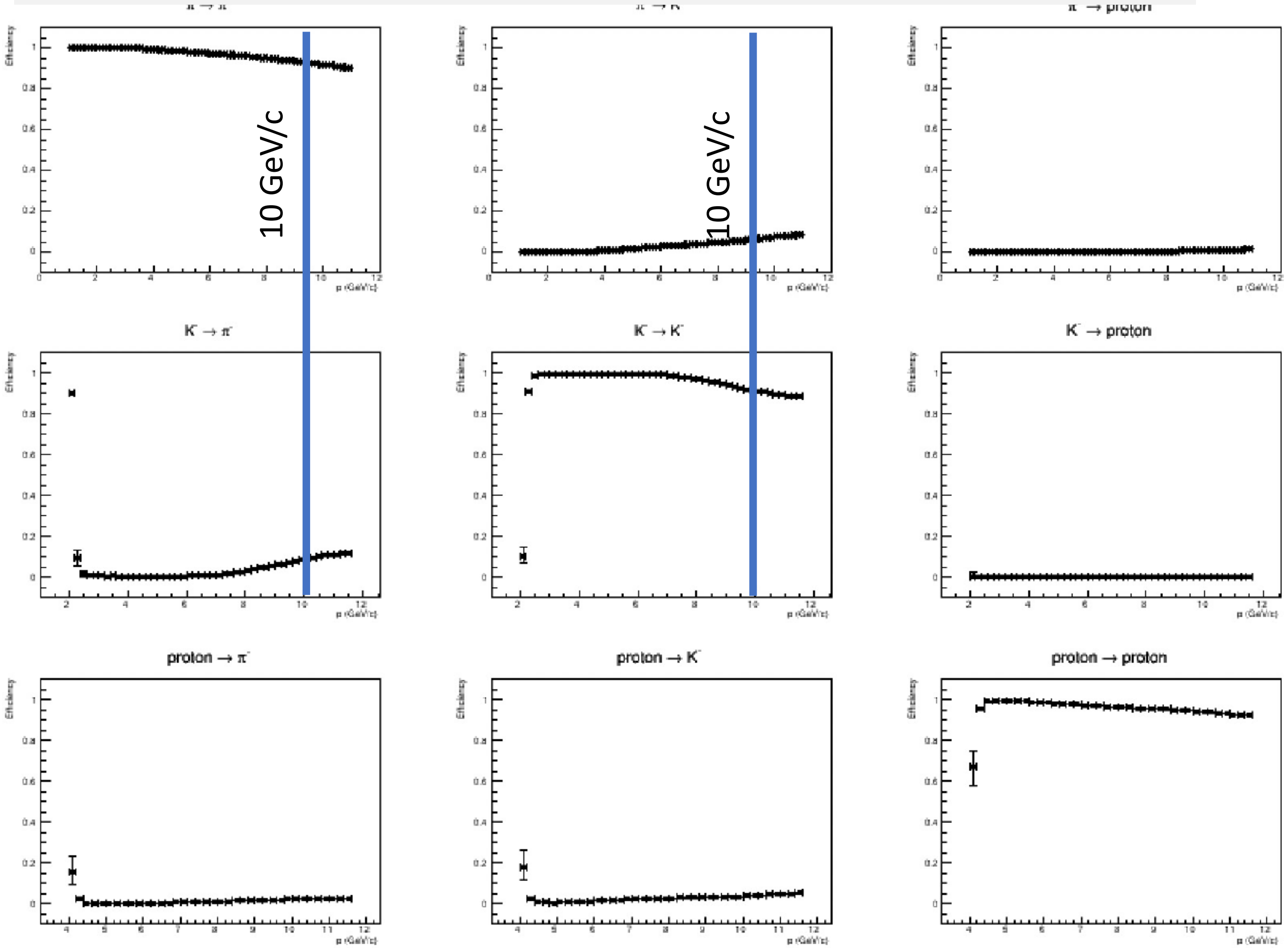
✓K/pi separation up to 10 GeV/c

Parameters still subject to R&D assumed (as QE spectrum and Number of photons from ticker aerogel tiles)









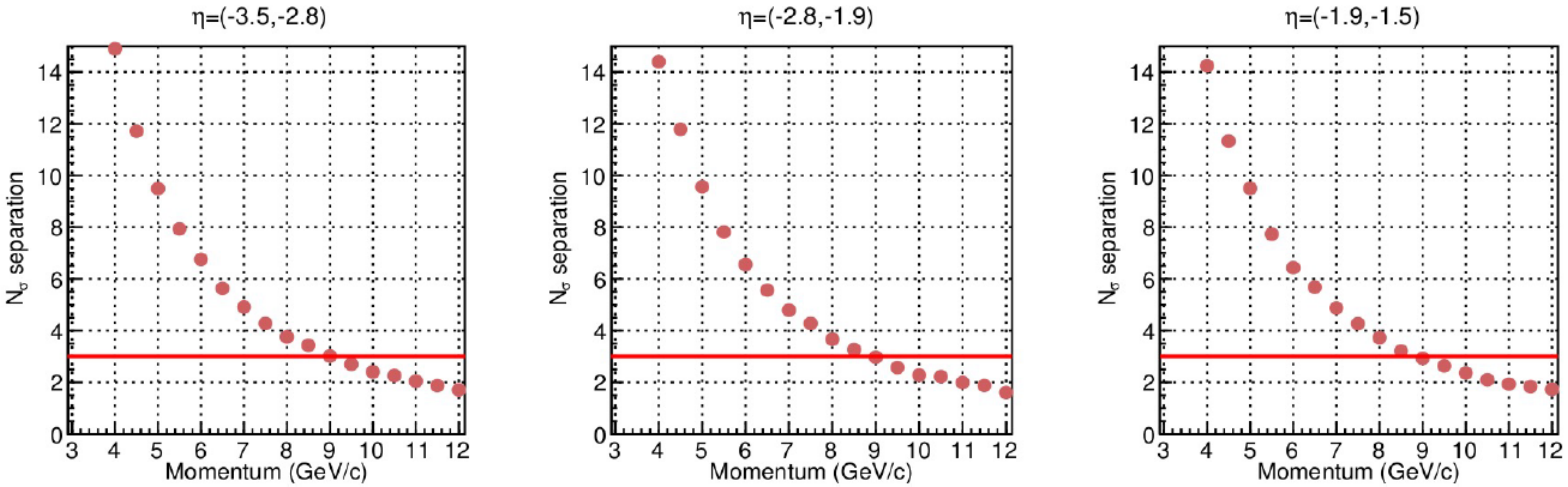
HADRON PID PERFORMANCE

pfRICH

FROM ring resolution

π/k separation : $3\sigma \rightarrow p$ = 9.0 GeV

π/k



3σ at ~9.0 GeV

19

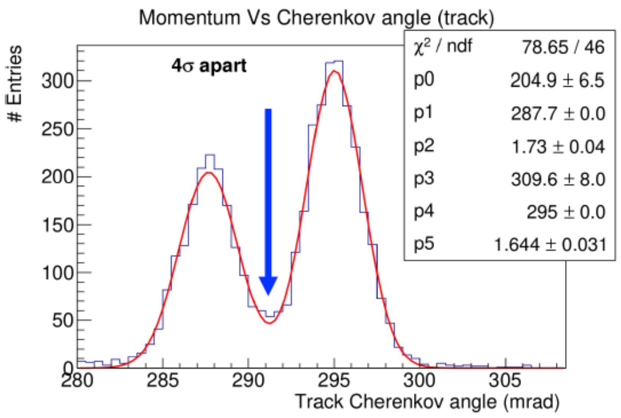
HADRON PID PERFORMANCE

pfRICH

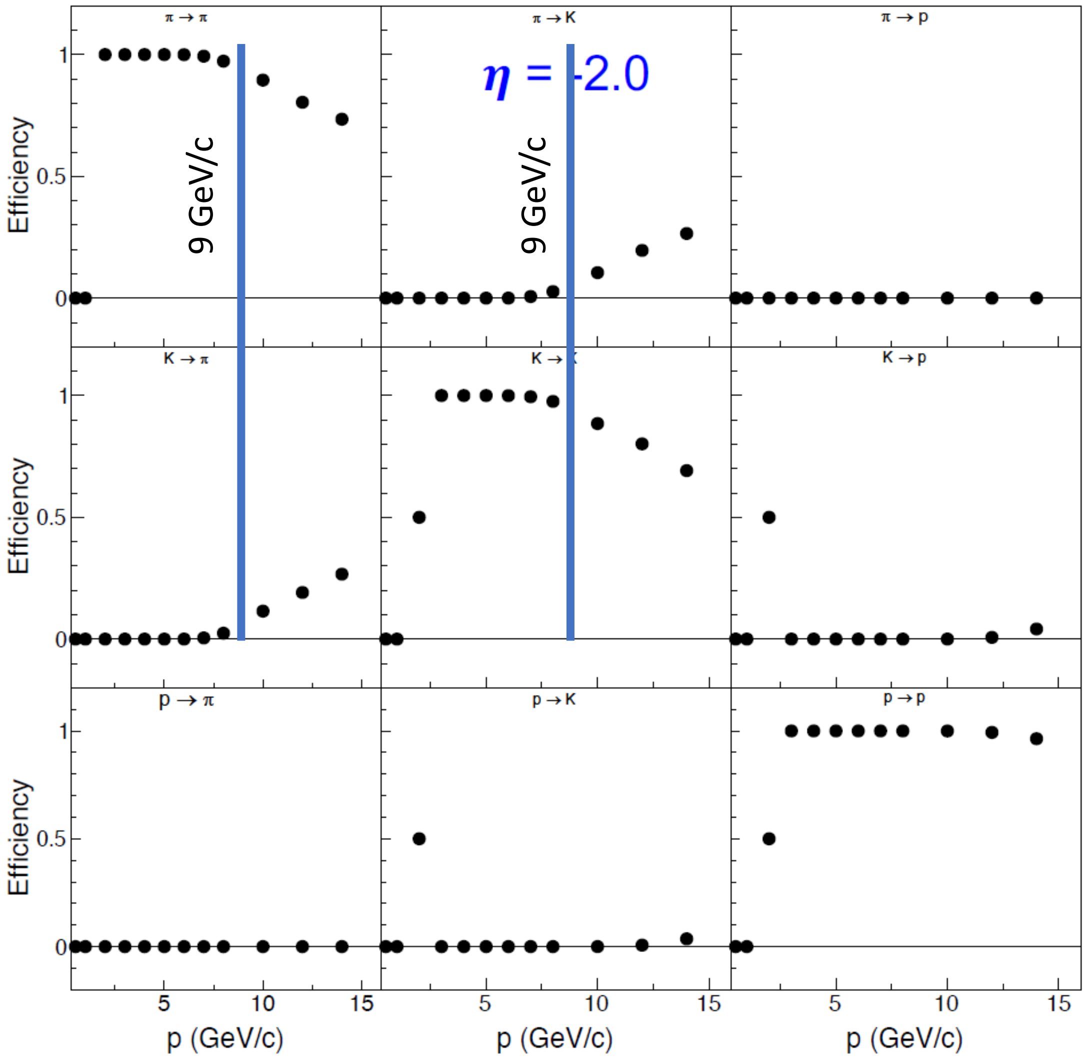
Efficiency and purity

C. π/k/*p* Efficiency

- Efficiency = PID probability for **π/k/*p* → π/k/*p* (3x3)**
- Nominal selection: place **Cherenkov angle cut at the Gaussian overlap.**



example

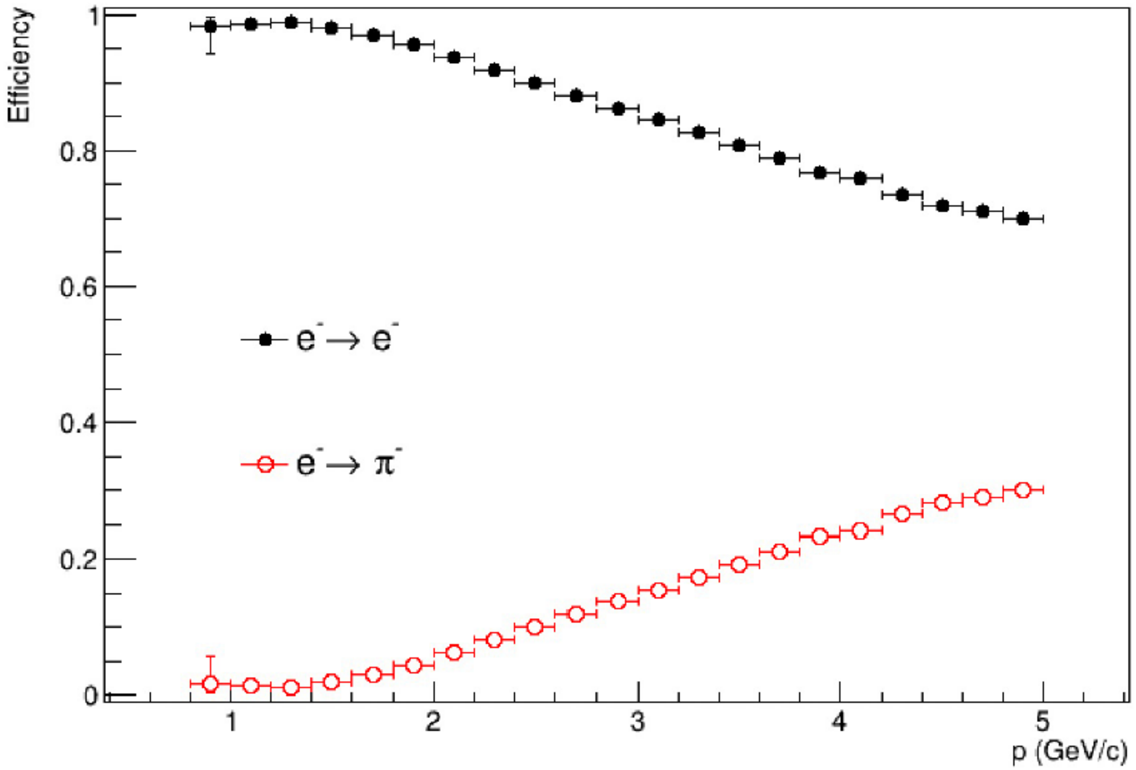


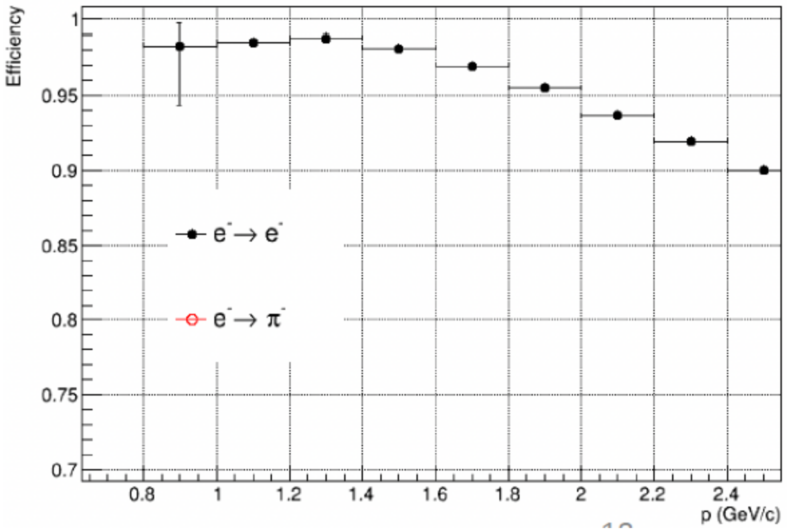
SCRUTINIZED ITEMS

- Performance for PID
  - Expected **resolution from simulations**:
    - this figure dictates the π/κ and e/π separation range
  - π/κ separation range
  - e/π separation range
  - Acceptance
- Holistic view
  - Device length and tracking lever arm
- Costing
- Risks and mitigations

e-π SEPARATION

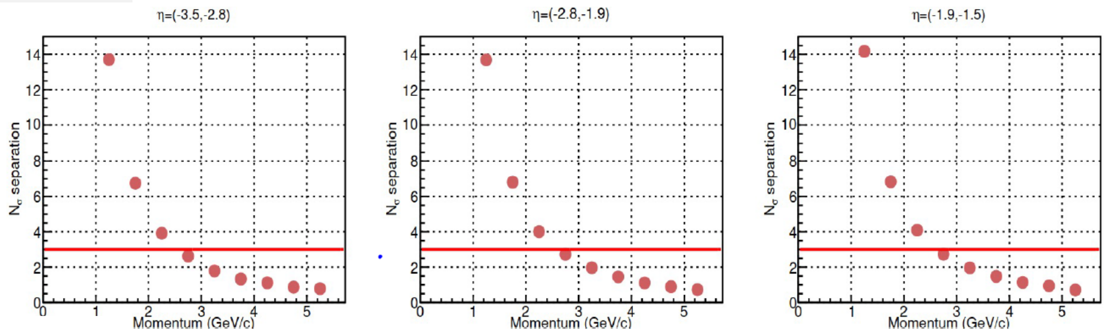
mRICH





e-π SEPARATION **pfRICH**

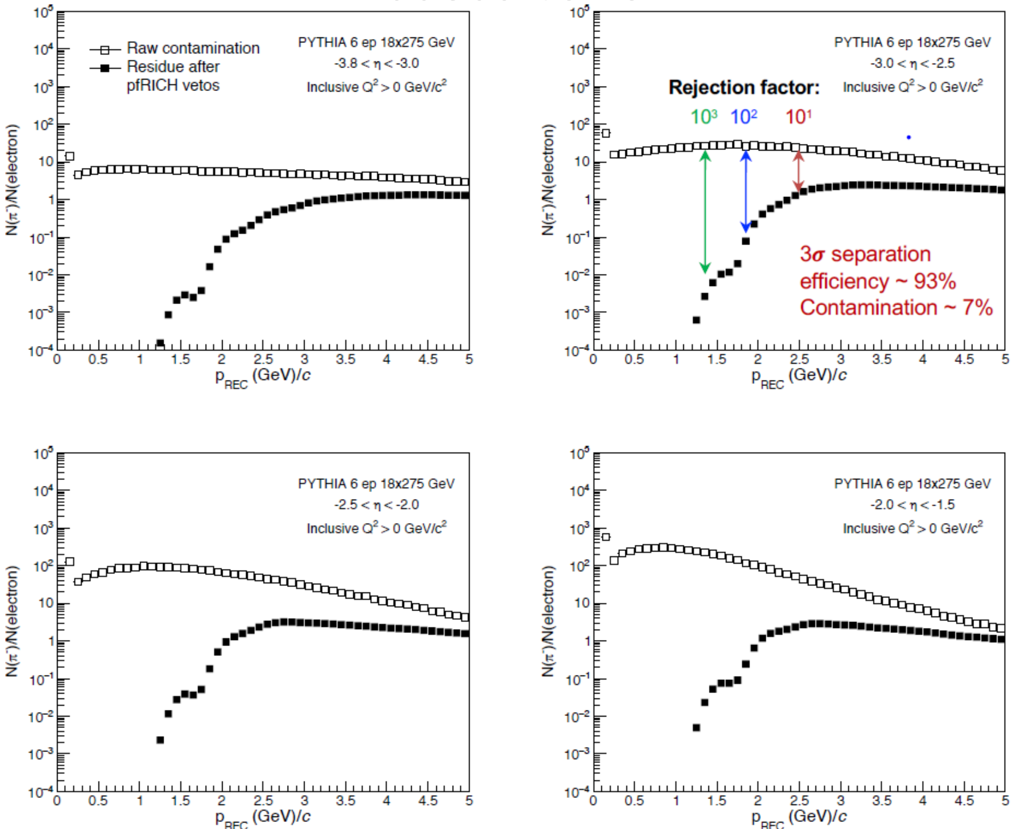
e/π



3σ at ~2.5 GeV

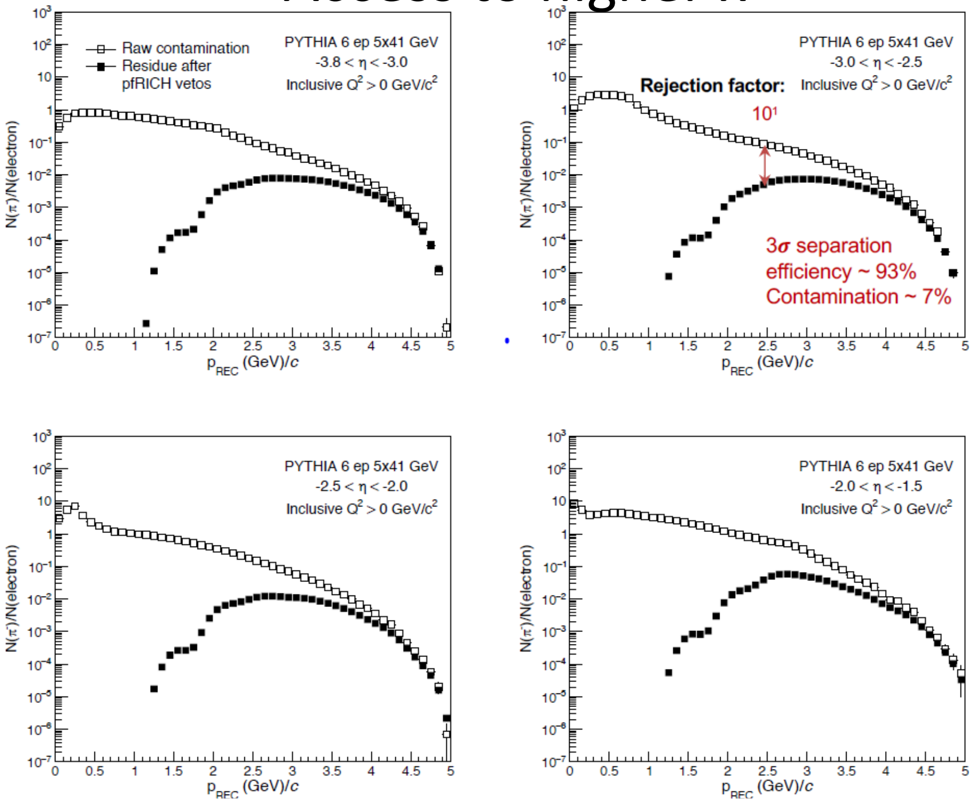
ep 18x275 (high energy)

Access to low x



ep 5x41 (low energy)

Access to higher x

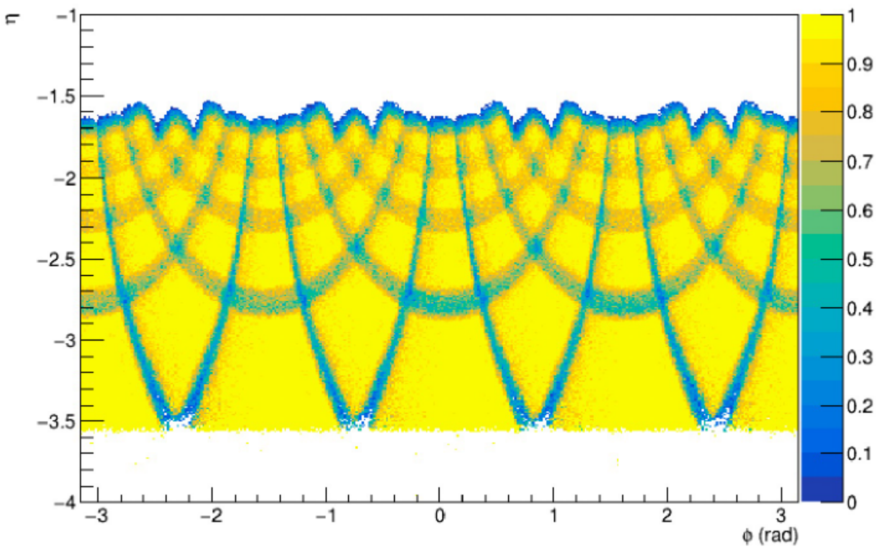


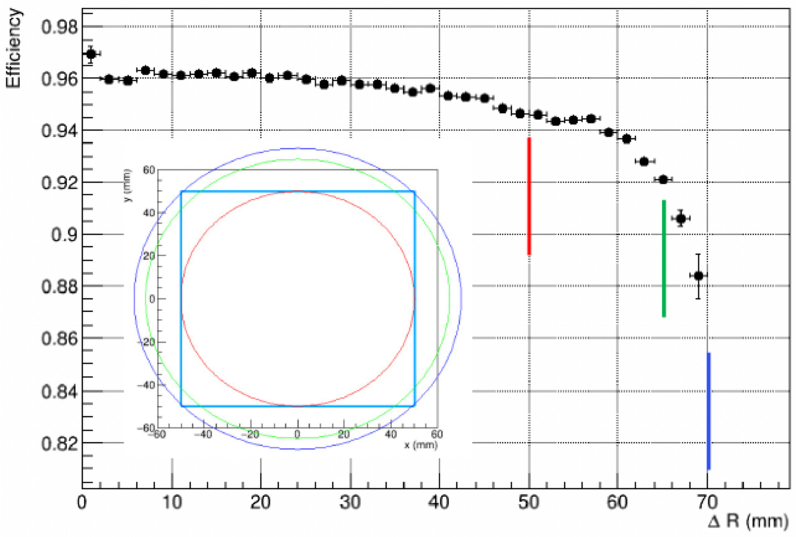
SCRUTINIZED ITEMS

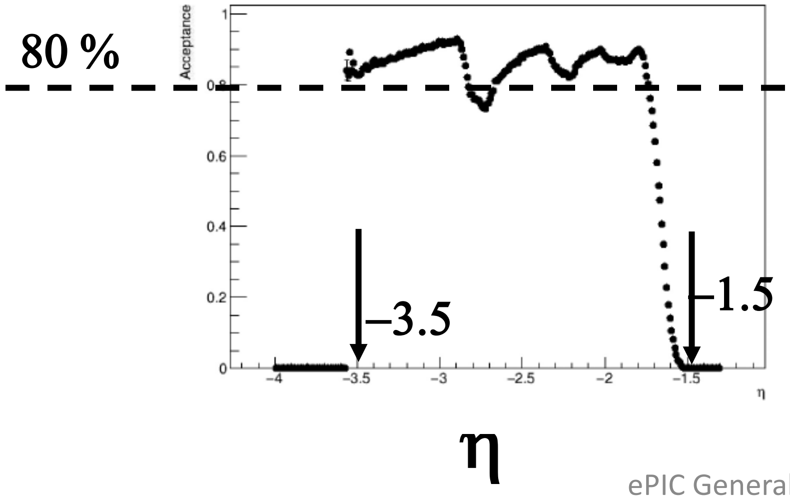
- Performance for PID
  - Expected **resolution from simulations**:
    - this figure dictates the π/κ and e/π separation range
  - π/κ separation range
  - e/π separation range
  - Acceptance
- Holistic view
  - Device length and tracking lever arm
- Costing
- Risks and mitigations

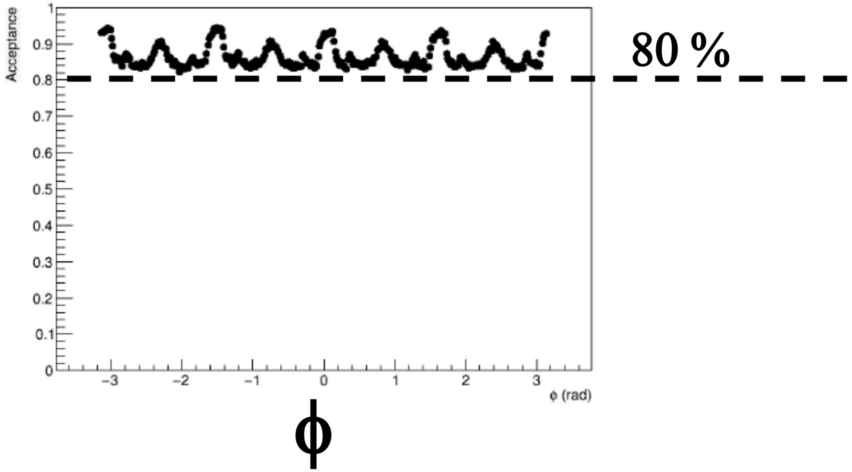
PID Acceptance

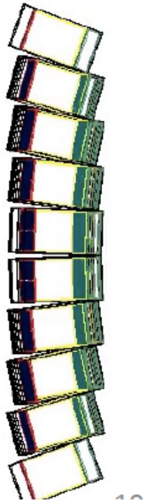
mRICH





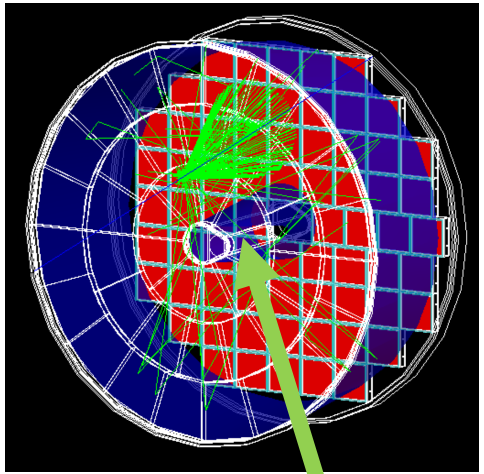




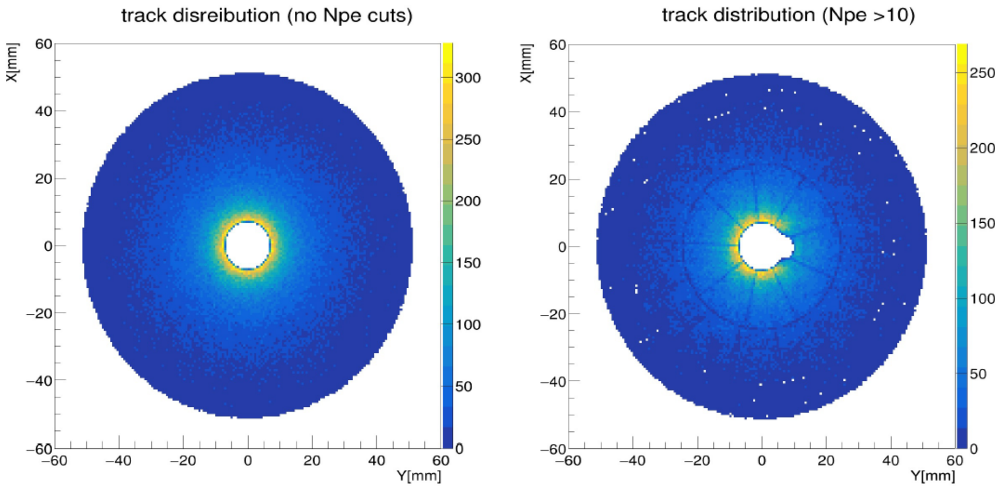


PID Acceptance

pfRICH



7 GeV pions $\langle N_{pe} \rangle \sim 12$

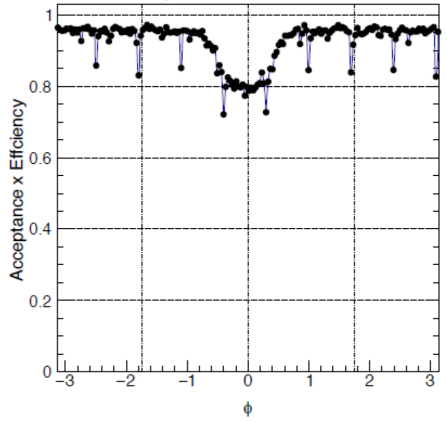


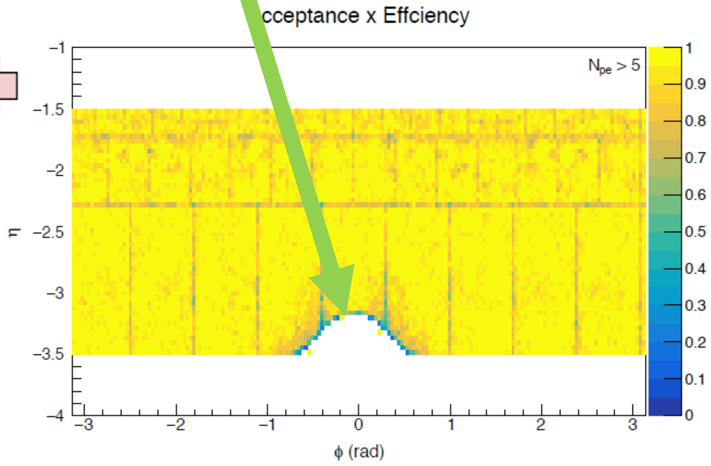
Uniform track distribution w/o N_{pe} cut

Track distribution with more than **10 photons**

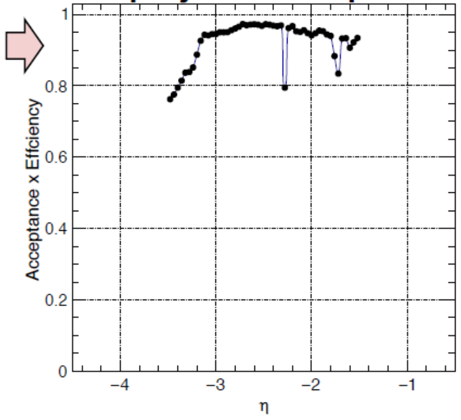
Acceptance x Efficiency (N_{pe} > 5)

1D projection to ϕ





1D projection to η



⟨Acceptance⟩ > 95 % for -3.5 < **η** < -1.5

ACCEPTANCE from the report

mRICH

more prominent acceptance gaps at the module or shoebox boundaries

pfRICH

The wall structure separating aerogel blocks leads to some loss in acceptance, although less than the case for mRICH.

SCRUTINIZED ITEMS

- Performance for PID
  - Expected **resolution from simulations**:
    - this figure dictates the π/κ and e/π separation range
  - π/κ separation range
  - e/π separation range
  - Acceptance
- Holistic view
  - Device length and tracking lever arm
- Costing
- Risks and mitigations

Backward RICH geometry and tracking layout

mRICH length: 272 mm (222 mm with minimum performance loss)

pfRICH length: 542 mm (492 mm with minimum performance loss)

pfRICH about 25 cm longer → impact on the resolution provided by tracking

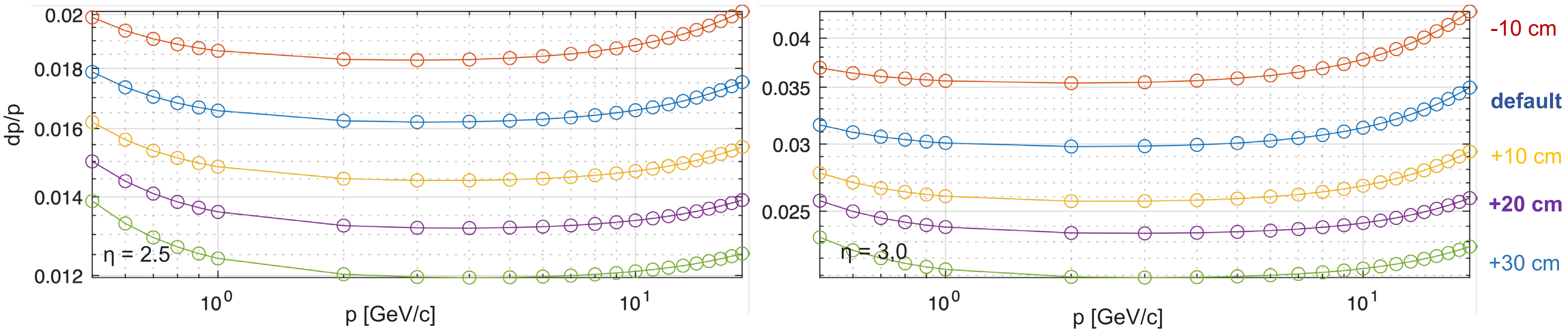
Impact from backward PID envelopes on dp/p from tracking

The envelope of the backward PID system affects the space available for tracking,

The reference MAPS implementation respects the pfRICH envelope in its default form; the mRICH envelope is anticipated to be smaller, thus leaving more space for tracking,

It is thus meaningful to ask what effect additional or reduced space has on dp/p resolution,

Shown here are representative results for **η = 2.5** and **η = 3.0** for different lengths of the disk array; tracks with η = 2.5 traverse all five disks in the array, whereas tracks with η = 3.0 escape through the beam opening of the innermost disk at z = -25 cm.



The default **length L** of the traversed five (four) disk array is **90 (70) cm**,

Results for a change in L by -10, +10, +20, and +30 cm are shown from **fast simulations**,

An increase in lever arm is clearly beneficial to momentum resolution, but this does not scale as L^2 as would be expected from point resolution alone due to multiple scattering. The physics impact of this loss or gain in dp/p is not assessed here.

SCRUTINIZED ITEMS

- Performance for PID
  - Expected **resolution from simulations**:
    - this figure dictates the π/κ and e/π separation range
  - π/κ separation range
  - Acceptance
- Holistic view
  - Device length and tracking lever arm
- Costing
- Risks and mitigations

Costing considerations

mRICH and pfRICH have **the most expensive components in common**:

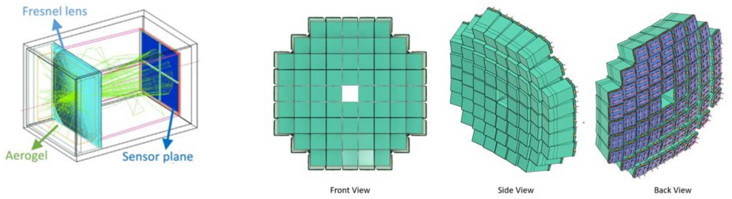
- Sensors, electronics and cooling (~ same instrumeted area)

Small cost difference come from:

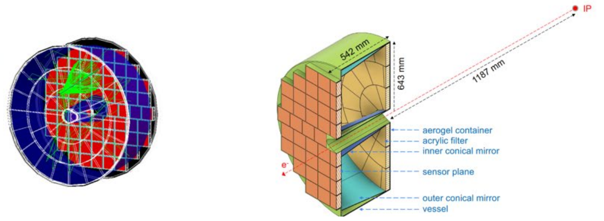
- Different aerogel thickness and refractive index
- Different mechanical design
- Different characteristics of the mirrors

→ the resulting costs are the same within the present resolution

mRICH



pfRICH



The use of HRPPD does not increase the cost respect to the costing info from P6 based on DPAP information

mRICH (with SiPMs) in P6 (escalated): 6.256 k$
pfRICH (non-escalated): 5.270 k$

SCRUTINIZED ITEMS

- Performance for PID
  - Expected **resolution from simulations**:
    - this figure dictates the π/κ and e/π separation range
  - π/κ separation range
  - e/π separation range
  - Acceptance
- Holistic view
  - Device length and tracking lever arm
- Costing
- Risks and mitigations

RISKS AND MITIGATION

- The **uncertainty associated with the photodetector HRPPD** is the most critical issue in both designs (as recognized in the review report). The risk mitigation in both cases involves the use of MCP-PMT's, which are substantially more expensive. The use of Si-PM's is not an option as it will not fulfill the requirement to provide timing information.

  - For the mRICH, the instrumented area is fixed. If risk mitigation for the HRPPD's is required the only option to reduce the cost associated with the MCP-PMT's cost will be to reduce acceptance.

  - The pfRICH has the capability to reduce the instrumented area without reducing acceptance by changing the inclination of the mirrors. This offers substantial additional flexibility if the risk associated with HRPPD's is realized.

- The mRICH design carries a larger unknown, given that it is the **first use of a design with Fresnel lenses** in a large experiment (a substantial risk underlined in the report of the review panel).

Draft Recommendation

Recommendation

- The mRICH design carries a larger unknown, given that it is the **first use of a design with Fresnel lenses** in a large experiment (a substantial risk underlined in the report of the review panel).
- The backward RICH design is envisioned to be compatible with LAPPD photosensor readout to fulfill the desired double particle identification and timing purpose.
- The **peak QE value** assumed by the mRICH is at variance with respect to the response of LAPPD's/HRPPD's manufactured by Incom. This would imply additional R&D that may be lengthy.
- The **uncertainty associated with the photodetector HRPPD** is the most critical issue in both designs. The risk mitigation in both cases involves the use of MCP-PMT's, which are substantially more expensive. The use of Si-PM's is not an option as it will not fulfill the requirement to provide timing information.
  - For the mRICH, the instrumented area is fixed. If risk mitigation for the HRPPD's is required the only option to reduce the cost associated with the MCP-PMT's cost will be to reduce acceptance.
  - The pfRICH has the capability to reduce the instrumented area without reducing acceptance by changing the inclination of the mirrors. This offers substantial additional flexibility if the risk associated with HRPPD's is realized.
- The **estimated cost** for the two design **is the same** within the present resolution and fully compatible with the Project P6 envelope (mRICH with SiPMs).

Recommendation: mRICH and pfRICH costs are nearly the same, but pfRICH carriers a lower risk, thus ePIC should initiate the change control process to make the pfRICH the baseline technology selection for the backward RICH.

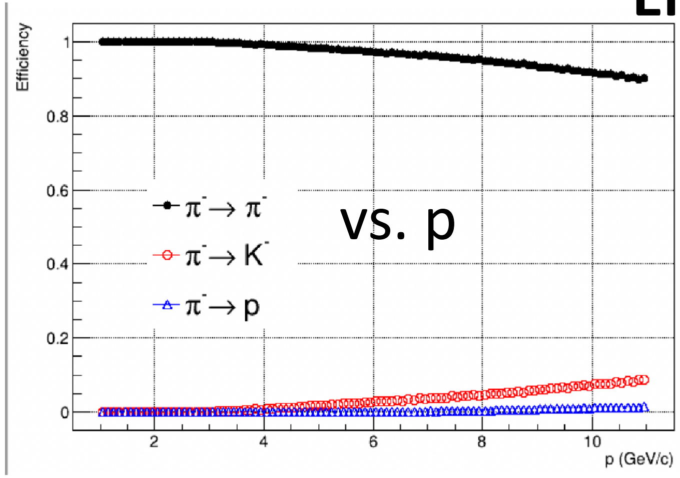
The recommendation of the pfRICH design for the ePIC backwards PID detector has the unanimous support of the Executive Board.

BACKUP SLIDES

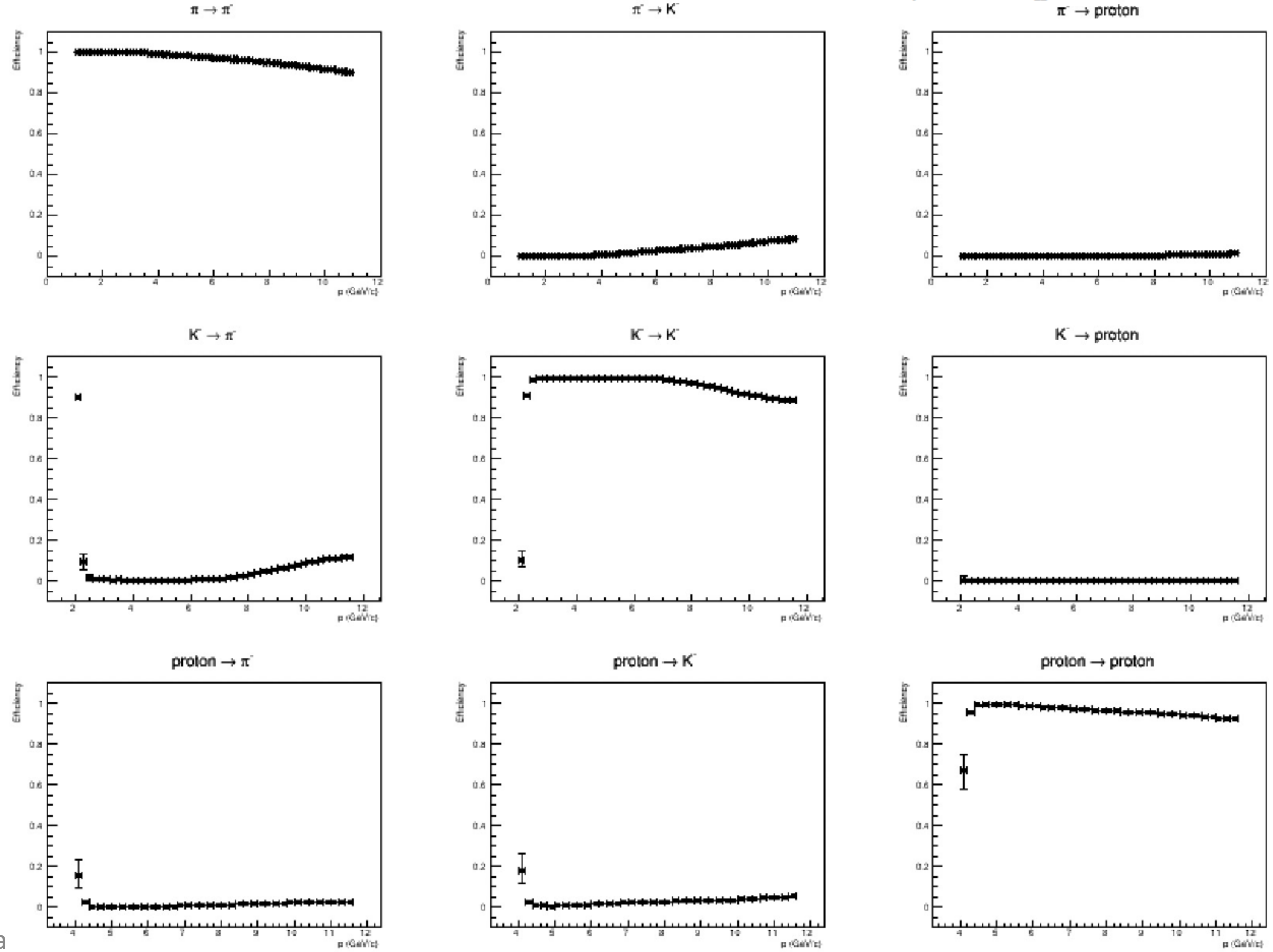
HADRON PID PERFORMANCE

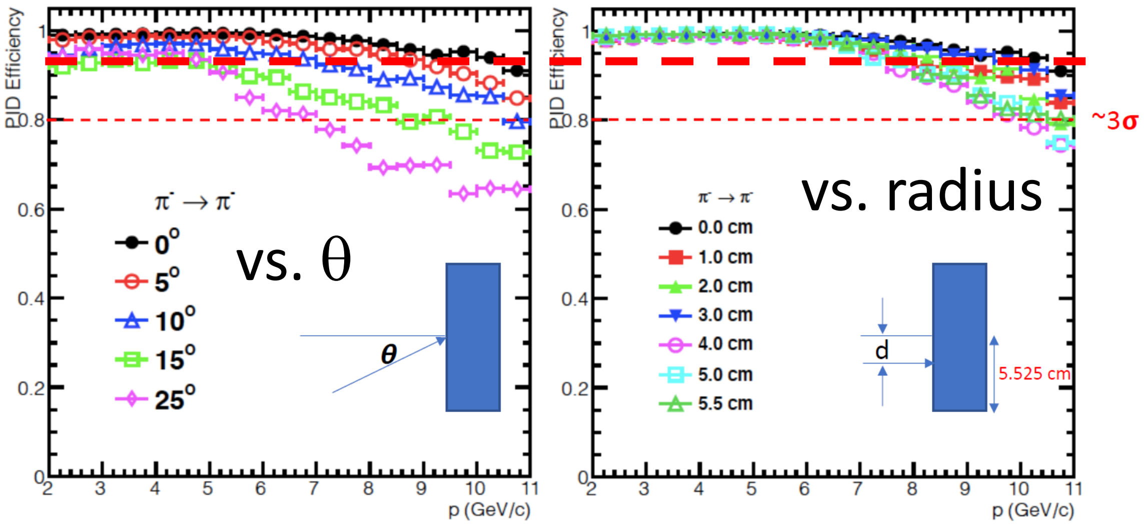
mRICH

Efficiency and purity



Efficiency figures: single particle Pi/Kaon/Proton identified as Pi/Kaon/Proton as a function of the truth momentum in a 3x3-panel figure?



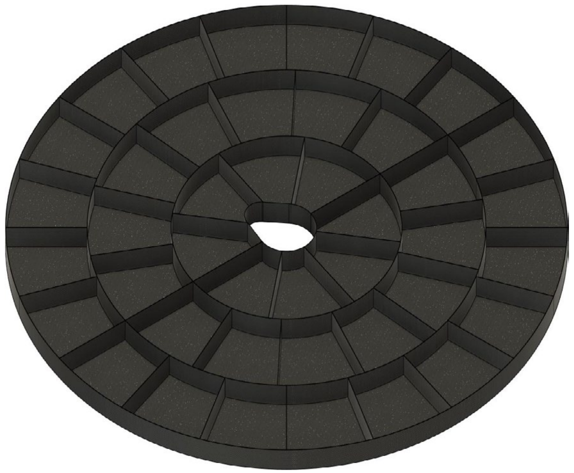


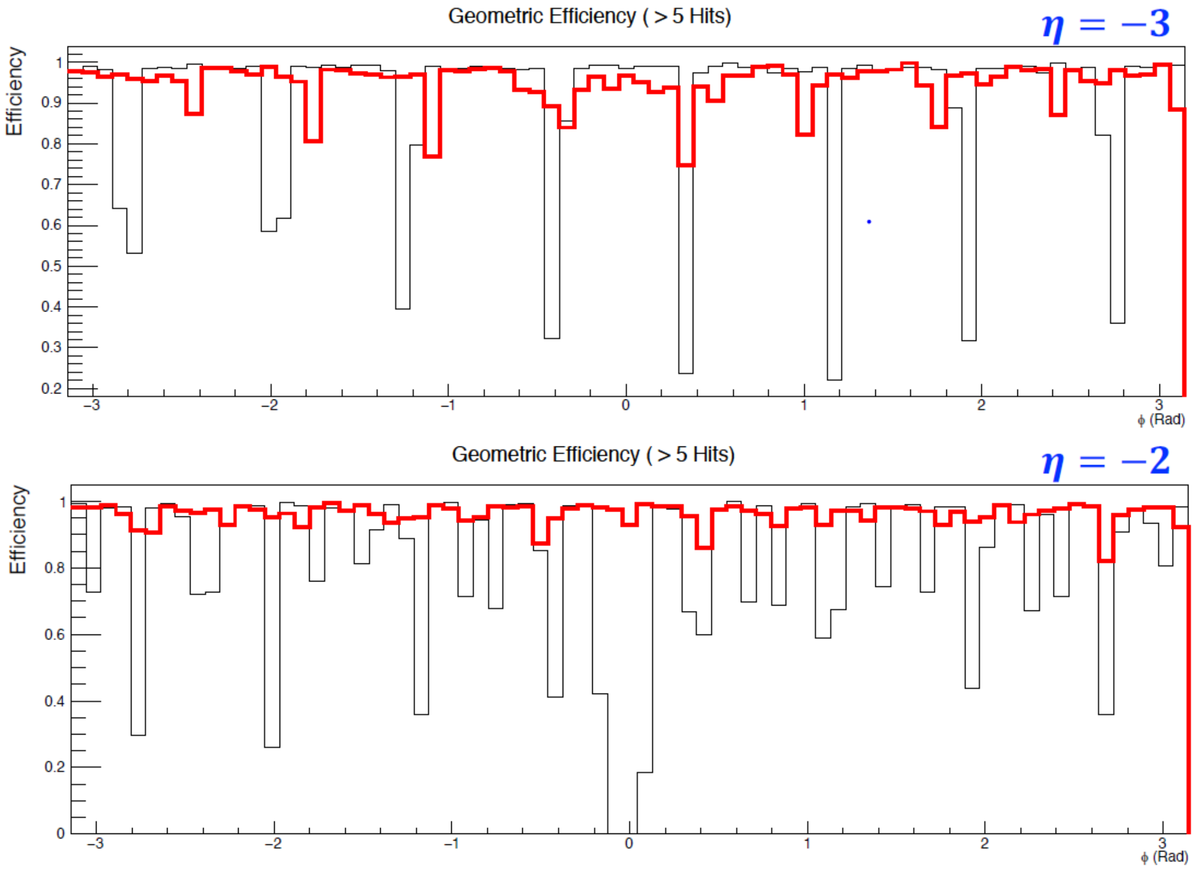
The standard definition of 3σ separations corresponds to an efficiency = 93 %

Timing Acceptance

pfRICH

Geometric ToF Efficiency vs. φ





N_{Hits}	Window	Aerogel
>1	95%	99%
>2	94%	99%
>3	93%	99%
>4	91%	98%
>5	90%	96%

Using Photons from LAPPD Window **Only**

Using Photons from Aerogel **Only**

N_{Hits}	Window	Aerogel
>1	90%	99%
>2	87%	99%
>3	84%	99%
>4	83%	98%
>5	81%	96%

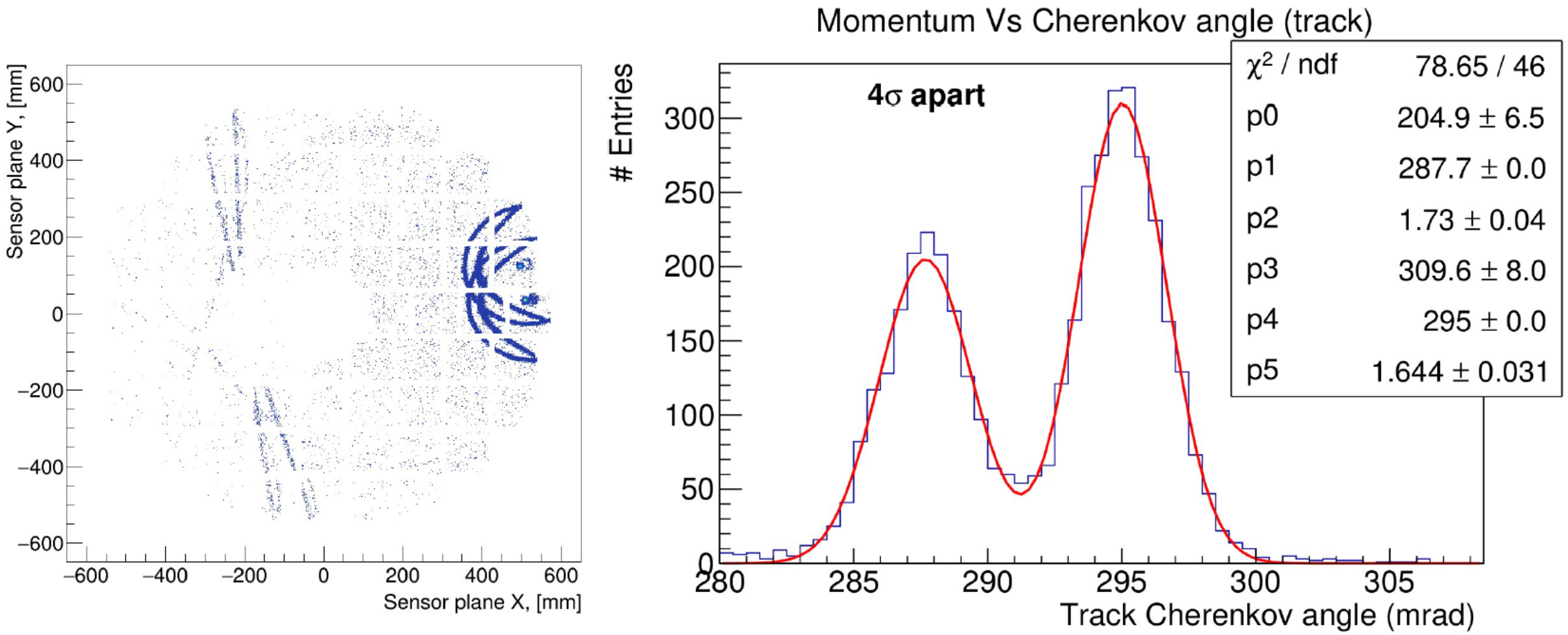
Approaching the performance in a realistic environment

mRICH

No double particle studies available, either in test beam or by simulations

pfRICH

pfRICH can separate extreme multi-particle cases



- **π** and kaon generated in same event.
- particle ϕ angle chosen to have overlapping rings at border pseudorapidity
- Event-based χ^2 model has a **95% accuracy** separating multi-particles

TECHNICAL RISKS

- The **major technical risk: HRPPDs** not becoming mature and industrially available in due time, or yield issues, or production delays.

- Recognized in the report:

  The committee finds that the uncertainty associated with the photodetector is the most critical issue in both designs. The baseline photodetector is the HRPPD, a common technology for both, and recent developments in the HRPPD and LAPPD by Incom are presented by each group. The committee understands that significant studies of the HRPPD performance characterizations at the lab bench as well as in test beam should be performed. In addition, more technical information such as on the HRPPD production yield at Incom should be closely tracked.

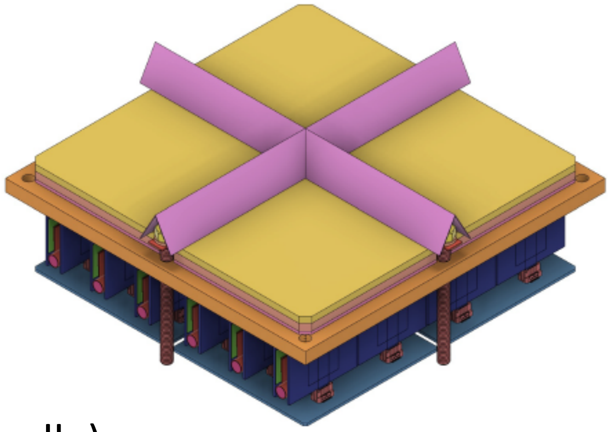
- Moreover, the report suggests:

  Both teams should consider alternative options such as SiPM or Planacon MCP-PMT, as these alternative options may mitigate risk in the photodetector.

HRPPD RISK MITIGATION IN **pfRICH**

- **Alternative solutions**
  - Capacitively coupled HRPPDs is still an option

  - Other commercially available MCP-PMTs (like PHOTONIS Planacon)
    - One seemingly can over-tilt the outer conical mirror, give up η acceptance above -1.65, and reduce the sensor plane by a factor of 2-3
    - Occupancy stays the same (or becomes even better) since a 2" Planacon has 32x32 pixel segmentation
    - Interfacing without dead zones becomes an issue …
    - .. yet may want to consider funneling pyramid mirrors around dead zones



  - SiPMs
    - Noise is becoming an issue
    - Cooling system is certainly more involved
    - Less space left for the expansion volume

(~15 cm more space in z, according to Roberto Preghenella)

OTHER TECHNICAL RISKS from report analysis

2.5.1 mRICH design

The committee thinks that Fresnel lenses represent a very interesting and elegant solution to improve Cherenkov angle resolution in RICH detectors planned for applications where the particle multiplicity is low. The committee also notes that this design carries higher risk, given that it is the first use of such a design in a large experiment. The information on the optical quality provided by the supplier is sufficient for a first rough assessment and validation of the concept; however, the usage in a large RICH system at a collider experiment requires a more detailed characterization of such a device. In particular, the optical properties should be measured on a large sample (and eventually on all parts that will be installed) to verify the photons transmission, scattering, and focusing. In addition, one should carefully study the performance dependence on lens alignment with respect to the photodetector, and on particle impact position with respect to the lens center. The comparison between simulation and beam test performance should not be limited only to ring images and include quantitative estimates of the number of detected photons, homogeneity of radius along the ring, and Cherenkov angle accuracy. A further validation concerns the performance in a real environment, to be assessed by simulations of collision events including, possibly, beam background.

The committee considers the procurement of aerogel tiles from a supplier in Russia risky considering the global political situation, and other companies should be considered. In addition, the design based on 5 cm thick tiles could be modified to adopt smaller thickness in case of optical quality improvement, which could be achieved by dedicated development or is available at other suppliers.

As already mentioned in 2.2.1, the committee suggests implementing gas purging (with N2 or Ar) of the boxes to control the environmental conditions and prevent aerogel aging due to moisture or other volatile substances included in the assembly.

OTHER TECHNICAL RISKS from report analysis

2.5.2 pfRICH design

The committee finds that technical and cost risks are appropriately identified in the pfRICH system.

Risk Mitigation

- Technology risks
  - Low photoelectron output (lower aerogel transparency, lower HRPPD QE or CE, etc.):
    - Install funneling mirrors and/or use dual aerogel radiator configuration
  - HRPPDs are not available, or the first samples do not meet the specifications:
    - Over-tilt the conical mirrors, shrink the sensor area, and use PHOTONIS Planacon or other 2" MCP-PMTs
    - Reduce the expansion volume length and use the SiPMs
  - EICROC ASIC is not available in a 256-channel configuration:
    - Consider unlikely, but can use 64-channel ASICs (4x4 per sensor) without changing anything else in the setup
  - Aerogel is not available or does not meet the specifications:
    - Consider unlikely
- Cost increase risks:
    - Provide a realistic breakdown of costs early & keep control of the main items (photosensors)
- Schedule risks:
    - Proceed with the Final Design and construction the earliest the EIC schedule allows (and construction time is small)