ePIC CC meeting

Detector recommendations

John Lajoie and Silvia Dalla Torre

April 21, 2023

ePIC Internal Review Process

- March 13, 2022 – EIC Project encourages proto-collaboration to "… *integrate new experimental concepts and technologies that improve physics capabilities without introducing inappropriate risk*."
- Spring/Summer 2022 – Barrel ECal and backwards PID identified by GD/I as consolidation items requiring additional scrutiny.
- October '22 – March '23:
  - First ePIC simulation campaign with two geometry concepts (Arches and Bryce Canyon) to support simulation studies for competing technologies
  - Barrel ECal and backwards PID guidance to proponents, committee charge developed.
  - External review committee members identified.
  - GD/I review preparation meetings:
    - (ECal) https://indico.bnl.gov/event/17940/
    - (bRICH) https://indico.bnl.gov/event/18140/, https://indico.bnl.gov/event/18221/

Barrel ECal Committee Charge

Review Committee was GD/I (Richard Milner excused himself) with external reviewers. Sasha Bazilevsky present as observer (L3 CAM).

Many thanks to our external reviewers:

Etiennette Auffray (CERN)
Tom LeCompte (SLAC)
Rainer Novotny (Univ. Giessen)

https://indico.bnl.gov/event/18517/

ePIC Barrel ECAL Technology Review

Charge to the Committee

The scope of this review is to gather information and feedback on the anticipated performance, cost and risk of two proposed technology choices (scintillating glass and imaging calorimeter) for the ePIC barrel electromagnetic calorimetry system. This review should include both the detector itself and the required readout and digitization electronics.

It is understood that both technology choices are currently evolving from advanced conceptual designs to full technical designs and should be evaluated with this level of development in mind. For the ePIC Barrel ECAL Technology Review, you are asked to address the following questions for each of the two technology options:

1. Is the anticipated performance, as demonstrated by simulations, test beam, R&D, etc. realistic given existing experience? Is the anticipated performance adequate to address the full EIC science program, as outlined in the National Academy (link) report and the EICUG Yellow Report (link)?
2. Are the plans for the detector front-end electronics realistic and well-matched to the sensor properties? Is the detector readout compatible with a streaming readout DAQ, as planned for ePIC?
3. Does the mechanical integration of the detector present any unique challenges?
4. Is there an adequate workforce to build, commission and maintain the detector, or are there adequate plans to evolve the workforce towards these goals?
5. Is the cost and schedule presented realistic? Are the production capabilities of vendors fully understood and consistent with the schedule?
6. Have the proponents adequately identified technical, cost and schedule risks? Are appropriate risk mitigations identified?

Please address the above questions point-by-point.

Backwards PID Committee Charge

Review Committee was GD/I (Silvia Dalla Torre and Thomas Ullrich excused themselves) with external reviewers. Beni Zihlmann present as an observer (L3 CAM).

Many thanks to our external reviewers:

Ichiro Adachi (KEK)
Roberta Cardinale (U. Genova)
Carmelo D'Ambrosio (CERN)
Antonello Di Mauro (CERN)

https://indico.bnl.gov/event/18499/

ePIC Backwards PID Technology Review

Charge to the Committee

The scope of this review is to gather information and feedback on the anticipated performance, cost and risk of two proposed technology choices (the modular RICH and proximity-focused RICH) for the ePIC backwards particle identification system. This review should focus primarily on the detector performance and integration issues.

It is understood that both technology choices are currently evolving from advanced conceptual designs to full technical designs and should be evaluated with this level of development in mind. For the ePIC Backwards PID Technology Review, you are asked to address the following questions for each of the two technology options:

1. Is the anticipated performance, as demonstrated by simulations, test beam, R&D, etc. realistic given existing experience? Is the anticipated performance adequate to address the full EIC science program, as outlined in the National Academy (link) report and the EICUG Yellow Report (link)?
2. Does the mechanical integration of the detector present any unique challenges?
3. Is there an adequate workforce to build, commission and maintain the detector, or are there adequate plans to evolve the workforce towards these goals?
4. Is the cost and schedule presented realistic? Are the production capabilities of vendors fully understood and consistent with the schedule?
5. Have the proponents adequately identified technical, cost and schedule risks? Are appropriate risk mitigations identified? Please comment on production and performance uncertainties for both the aerogel and the LAPPD’s.

Please address the above questions point-by-point.

EB Meeting 4/7/2023

- As discussed at the CC Meeting on 3/31, the Spokesperson's Office convened a meeting of the Executive Board:
  - EB discussion of recommendations for technology selections for BEMCal and backwards particle ID needed
  - Included temporary members pending election of CC – elected members

- First meeting of ePIC proto Executive Board (proto-EB):
  - **Members:** J. Lajoie, S. Dalla Torre, K. Dehmelt, M. Diefenthaler, R. Reed, S. Fazio
  - **CC Chair/Vice Chair (invited):** E. Sichtermann, B. Surrow *(invited, non-voting)*
  - **Temporary EB Members:** B. Jacak, O. Evdokimov, T. Gunji, D. Higinbotham
  - **External Input Solicited:** P. Jones, P. Newman

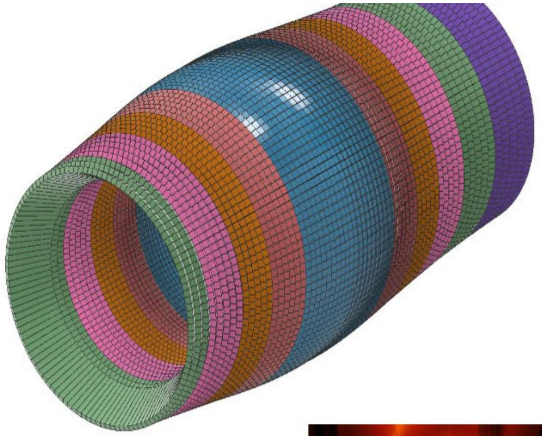
Detail presentations of the selection process

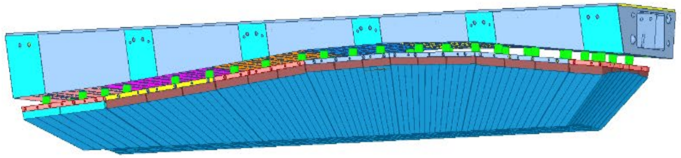
- At the ePIC CC meetingon April 14, 2023
  - Agenda and slides: https://indico.bnl.gov/event/18688/
  - Recording : https://youtu.be/T6lsTWbWcrc

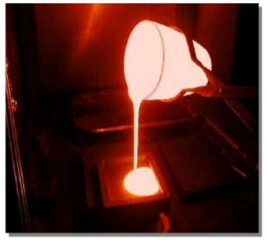
Barrel ECal

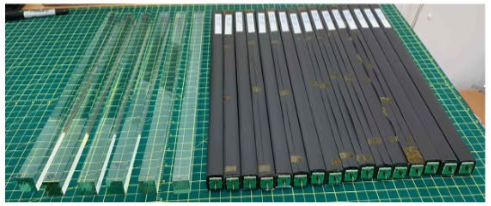
REMINDER: the two alternative designs

SciGlass

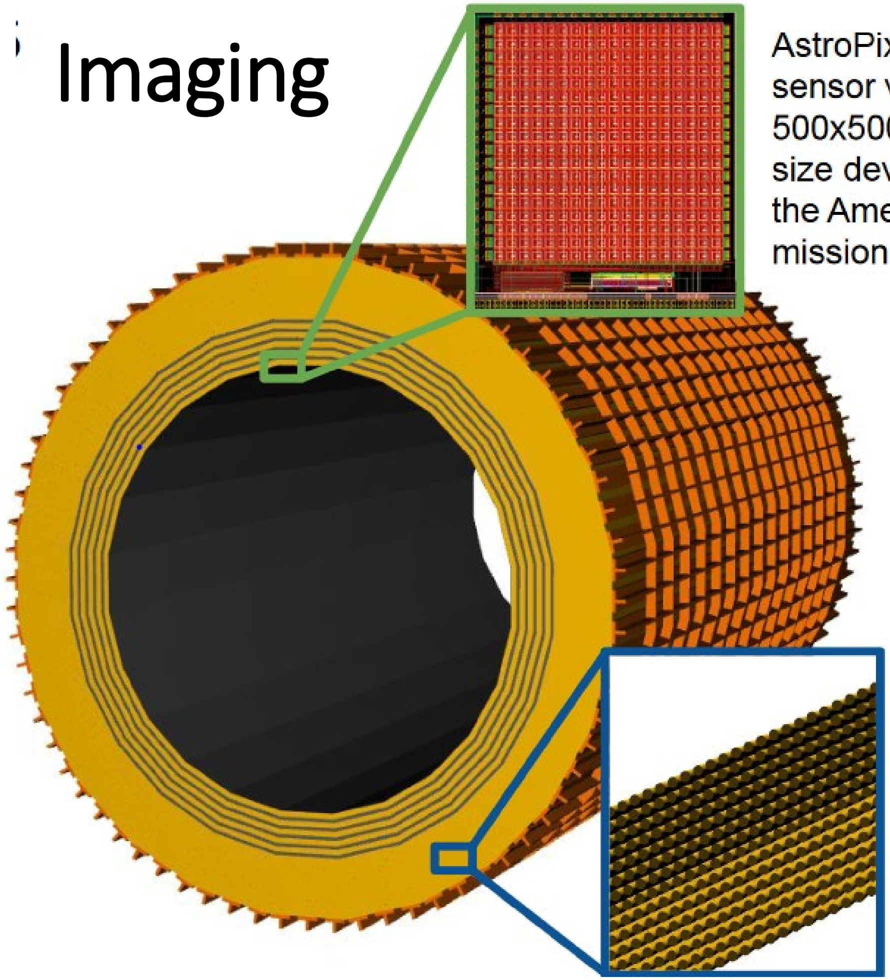








Imaging



AstroPix: silicon sensor with $500x500\mu m^2$ pixel size developed for the Amego-X NASA mission

ScFi Layers with two-sided SiPM readout

INPUT USED

- The BECal review material and committee report https://indico.bnl.gov/event/18517/
- Conversations with committee members
- Conversations with proponents
- Additional material (solicited and unsolicited) from proponents
- Cost information solicited from the EIC Project
- Input from EB discussions

Summary of the presentation on April 14

- **Physics Performance**
  - Resolution
  - e/π separation
  - γ/π^0 separation

  → Both calorimeter designs are in principle capable of achieving the EIC science program, at the level of realism included in the current simulations, assuming performance as indicated in simulations

- **SciGlass Concerns**
  - Important properties of SciGlass that affect the simulated physics performance are not well-known
  - **There is a risk that the required SciGlass R&D is not compatible with EIC project timelines.** In addition, if risks are realized too late it may be extremely difficult to mitigate those risks without impacting project timelines.

- **Imaging Calorimeter Concerns**
  - **Imaging EMCal can replace the outer MPGD layer**
  - The **AstroPix chip hit buffer** will drop hits if it gets full; unlikely, mitigation with more concentrators
  - The SciFi technology is well-demonstrated and presents little technical risk. The **imaging layers represent a large overall area of Si detectors**, use a novel sensor in development, and this represents a ***technical, cost and schedule*** risk.
  - No studies shown at the review that demonstrate the optimal number of imaging layers: **4 layers is the minimal number to guarantee a coordinate measurement after the DIRC and imaging capailities**

- **Cost Comparison**

  → Within the uncertainties in this comparison, the costs of the SciGlass and Imaging calorimeters are similar.

Draft Recommendation

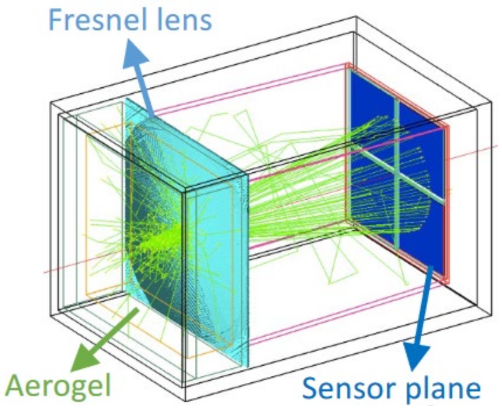
Recommendation

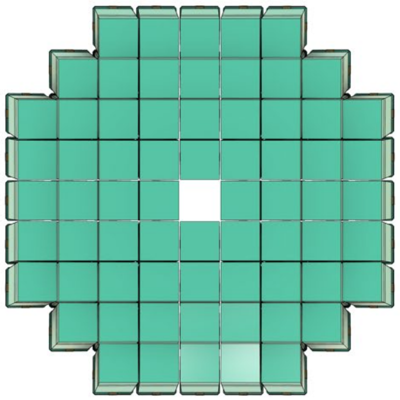
- The SciGlass EMCal implementation carries substantial risk based on the need for continued R&D to determine the SciGlass characteristics
  - This risk is fundamental to the technology choice and difficult to mitigate if realized.
- The Imaging EMCal with four imaging layers meets or exceeds the performance requirements
  - The detector can be built to accommodate additional AstroPix layers as a potential upgrade
- **Recommendation:** ePIC should initiate the EIC change control process to make the Imaging Barrel EMCal with four imaging layers the baseline technology selection. The design should be upgradeable to six layers as a future (off-project) upgrade.
- This recommendation was <u>unanimously</u> endorsed by the Executive Board.

Backward RICH

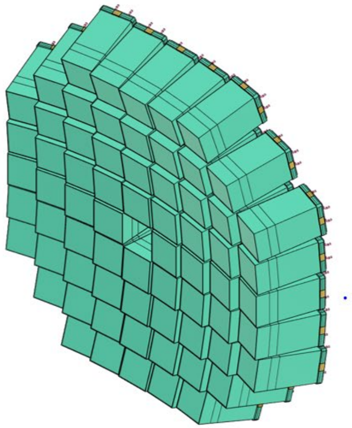
REMINDER: the two alternative designs

mRICH

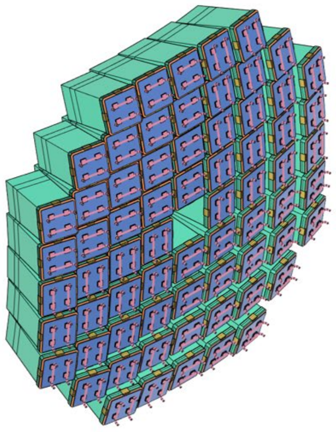




Front View

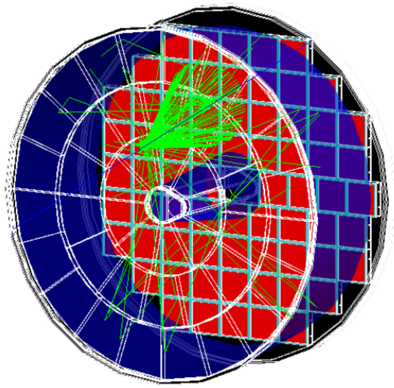


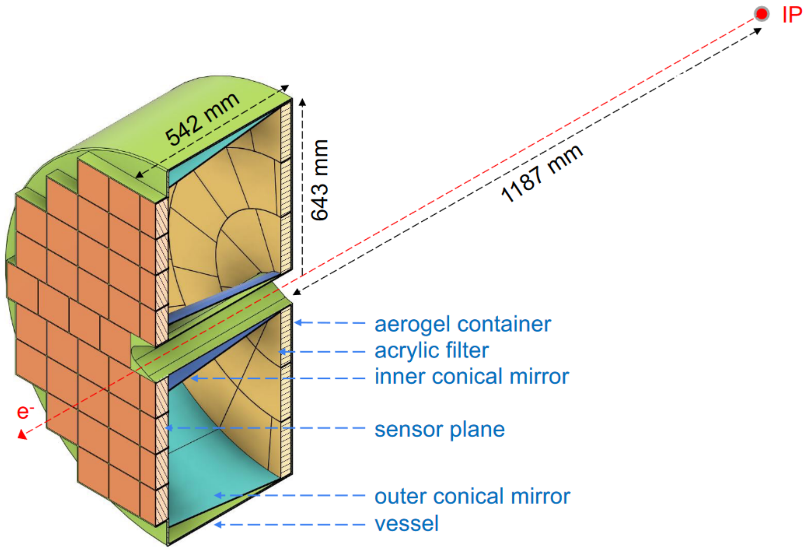
Side View



Back View

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

Summary of the presentation on April 14

- **Performance for PID**
  - Resolution
  - π/κ separation
  - e/π separation

→ Both RICH designs are in principle capable of achieving the EIC science program, assuming performance as indicated in simulations

- **Holistic view**
  - Device length and tracking lever arm: the longer lever arm compatible with the mRICH design does not change substantially the tracking capabilities in the backward telescope

- **Concerns**
  - The most relevant **risks are associated with the photosensors** (HRPPDs)
  - **Mitigation by commercial MCP-PMT** covering a smaller area due to cost constrains; for mRICH this imposes a smaller acceptance; pfRICH can operate with the same acceptance also with reduced sensor area by a more pronounced mirror inclination
  - **QE spectrum assumed in mRICH simulations at variance with HRPPD one**; additional and lengthy R&D needed.

- **Costing**

→ Within the present uncertainties, the costs of the mRICH and pfRICH are very similar.

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

Barrel ECal presentation at ePIC general meeting

on April 14, 2023

ePIC Barrel ECal Spokesperson's Office Recommendation

J. Lajoie, S. Dalla Torre

April 14, 2023

Introduction

- The presentation was prepared from:
  - The BECal review material and committee report
    - https://indico.bnl.gov/event/18517/
  - Conversations with committee members
  - Conversations with proponents
  - Additional material (solicited and unsolicited) from proponents
    - This is noted throughout the presentation
  - Cost information solicited from the EIC Project
  - Input from EB discussions
- This evaluation is broken into sections:
  - Physics Performance
  - SciGlass Concerns
  - Imaging Calorimeter Concerns
  - Cost Comparison
  - Draft Recommendation

Barrel ECal Physics Performance Metrics

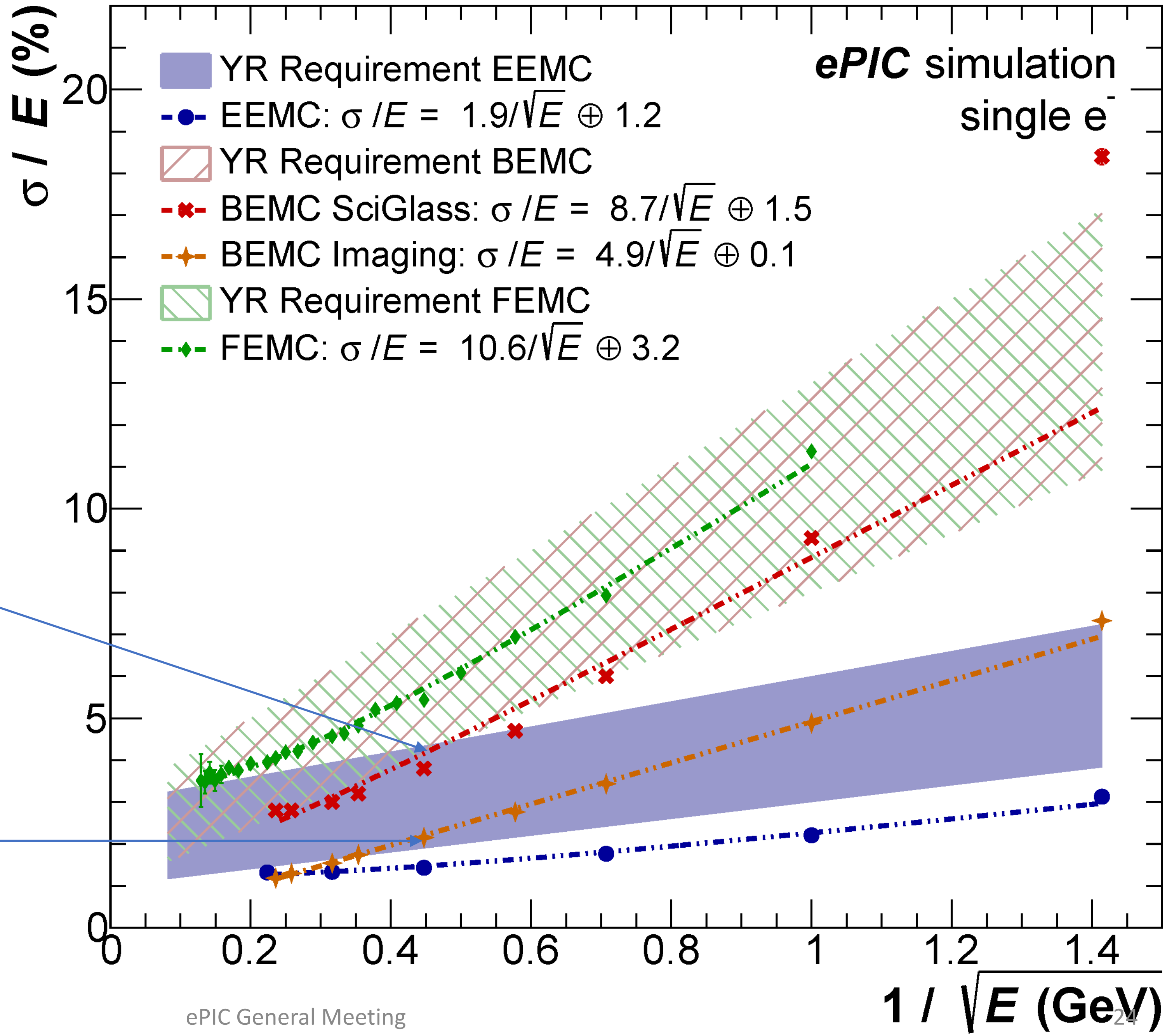
- The required physics performance is defined:
  - "This detector must satisfy the requirements of the EIC "mission need" statement based on the EIC community White Paper and the National Academies of Science (NAS) 2018 report." – from the EIC Call for Detector Proposals
- Barrel EMCal Performance Criteria (Yellow Report)
  - EM energy resolution: $10-12\%/\sqrt{E}$
  - Pion rejection: "up to" 10^4 (set by inclusive measurements)
    - Review evaluated pion contamination in inclusive measurement using rejection at 95% efficiency. Goal is less than 10% pion contamination in all bins.
  - Gamma separation from neutral pion decays as needed by DVCS

EMCal energy resolution plot from Fredierike Bock 3/30/2023

Both calorimeters meet the YR energy resolution requirement

SciGlass easily meets the YR requirement

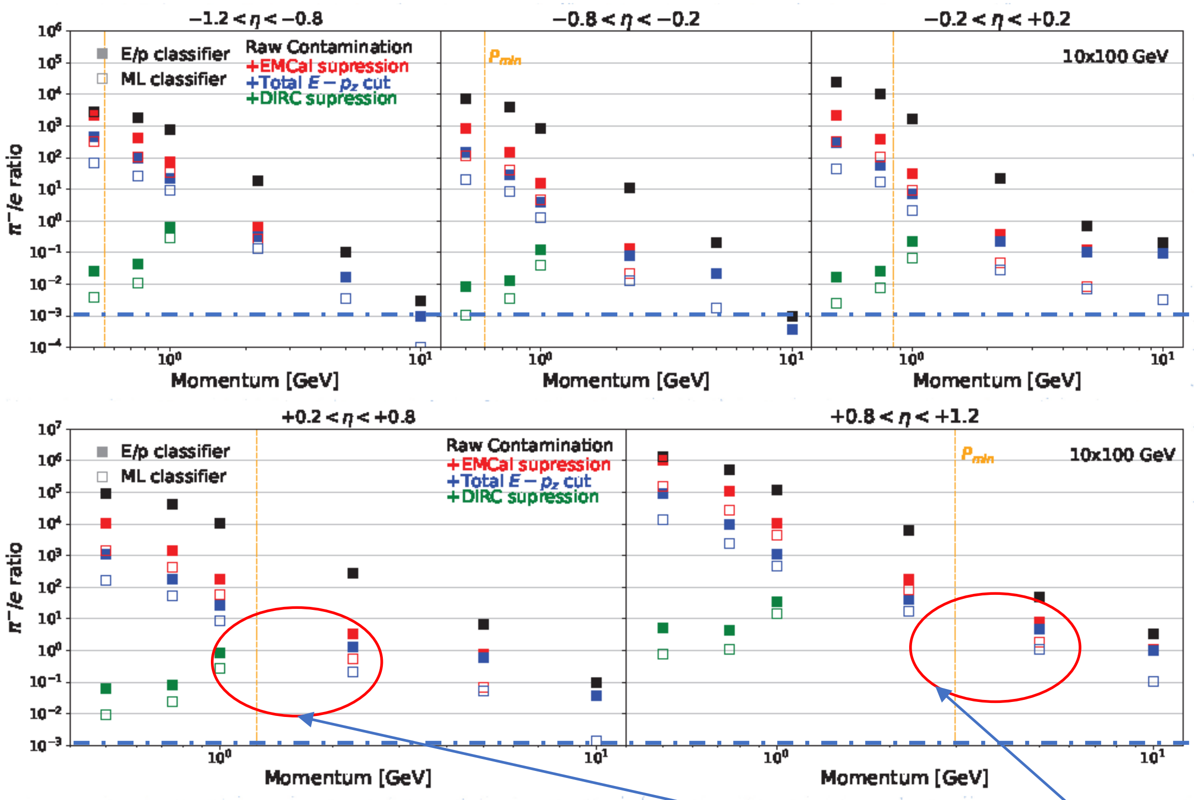
Imaging EMCal does substantially better than the YR requirement



10 x 100 GeV

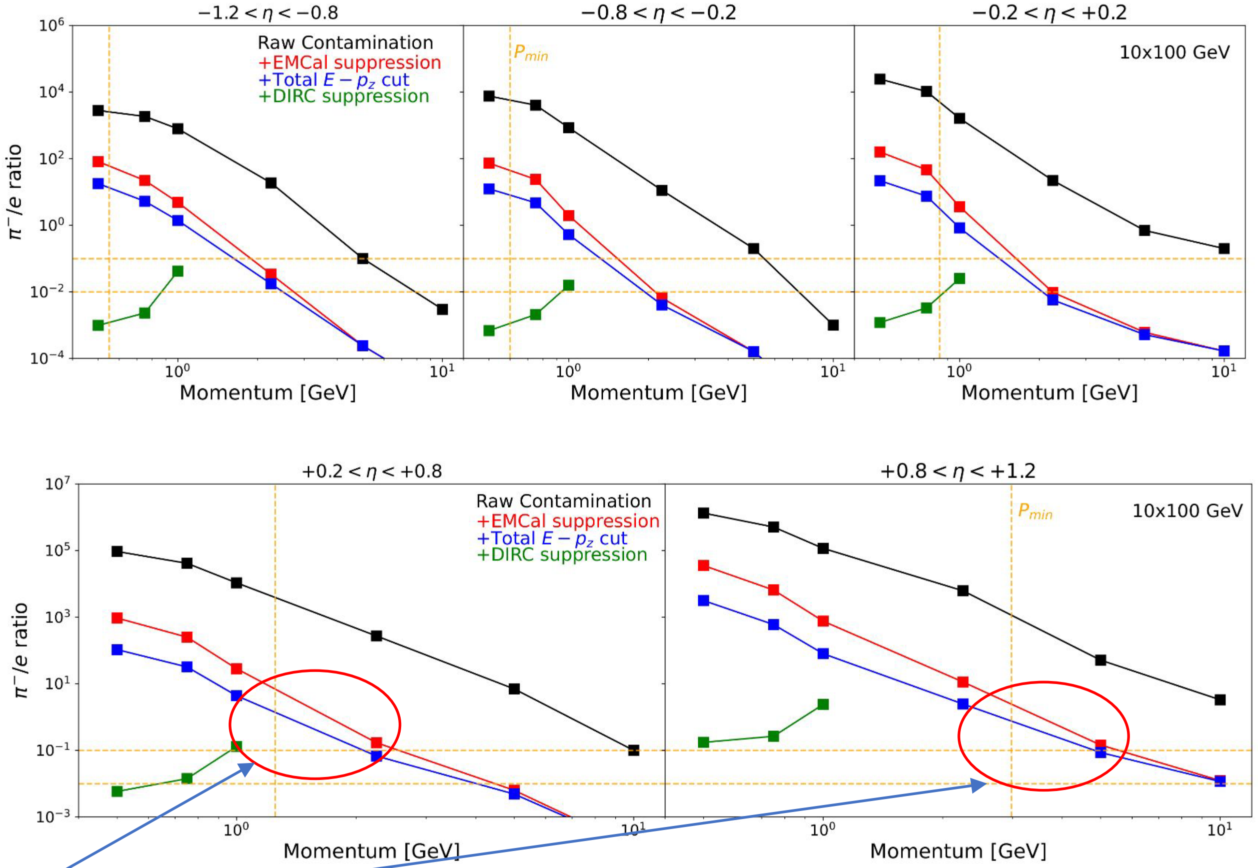
Plots use pion rejection at 95% electron efficiency

SciGlass EMCal Results (from review)



(Analysis by Claire Gwenlan, Tyler Kutz, Paul Newman, and Barak Schmookler)

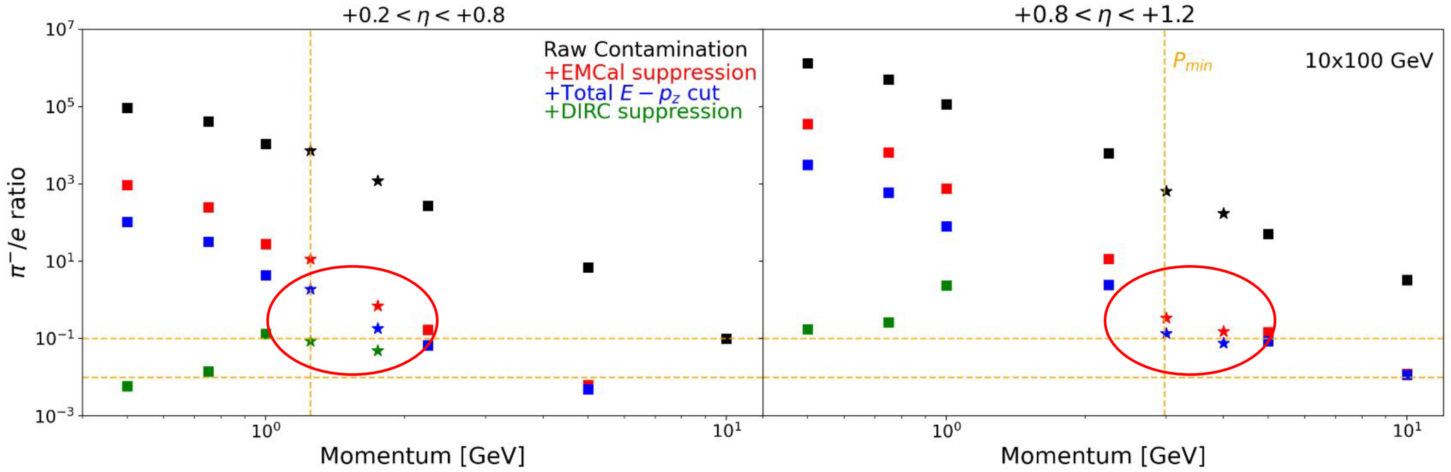
Imaging EMCal Results (from review)



Challenges at positive pseudorapidity, low p_T for both calorimeters

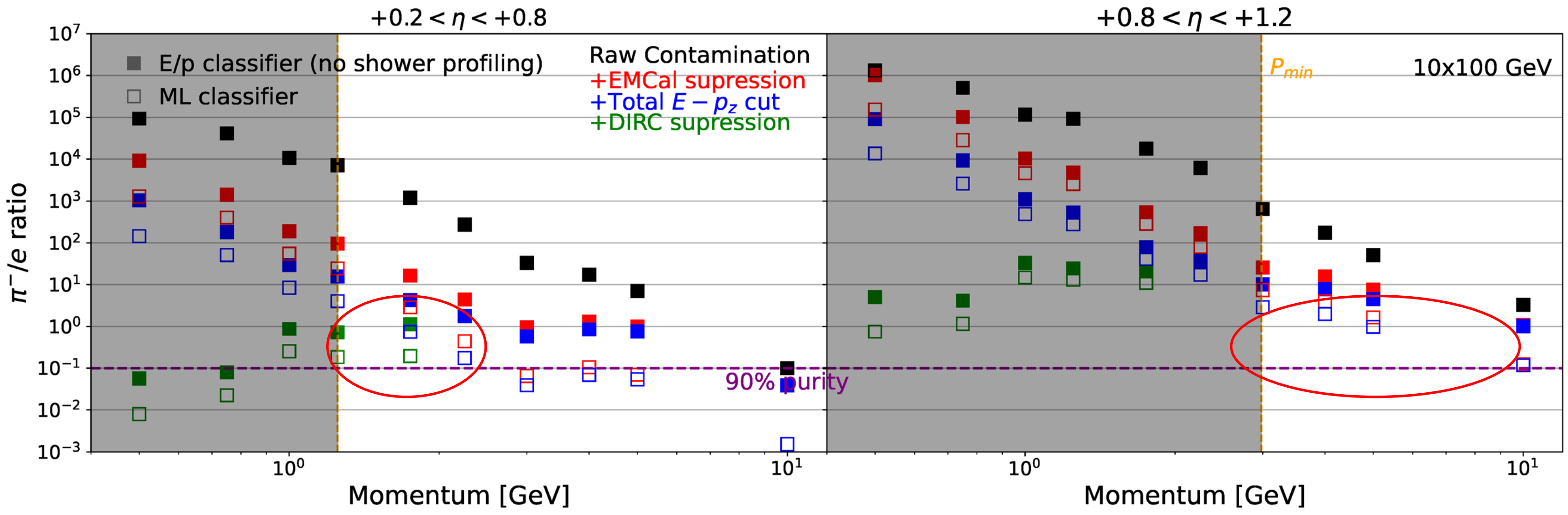
10 x 100 GeV

Imaging EMCal Results (from M. Zurek, email to committee, 3/17/2023) – additional points near p_{min} for positive pseudorapidity



Barak Schmookler confirmed 3/29/2023 that hpDIRC parametrization goes up to 2 GeV @ 95% efficiency, but agreed performance limit is 1.2 GeV (G. Kalicy 4/14/2023)

SciGlass EMCal Results (from D. Kalinkin, 4/3/2023)

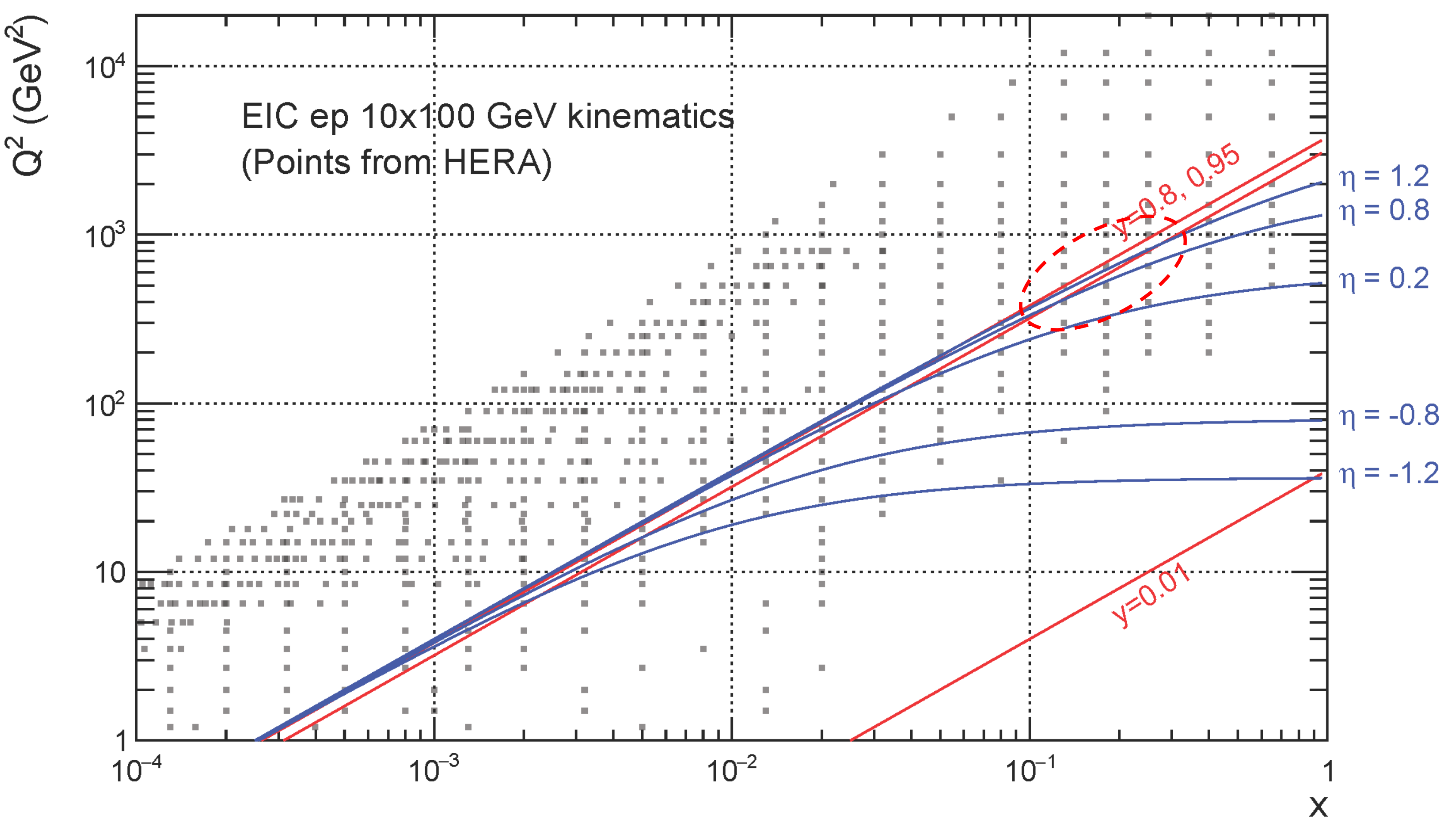


Performance Impact (10 x 100 GeV)

From Tyler Kutz – 4/12/2023

Band shows rapidity range in barrel overlaid with HERA data points.

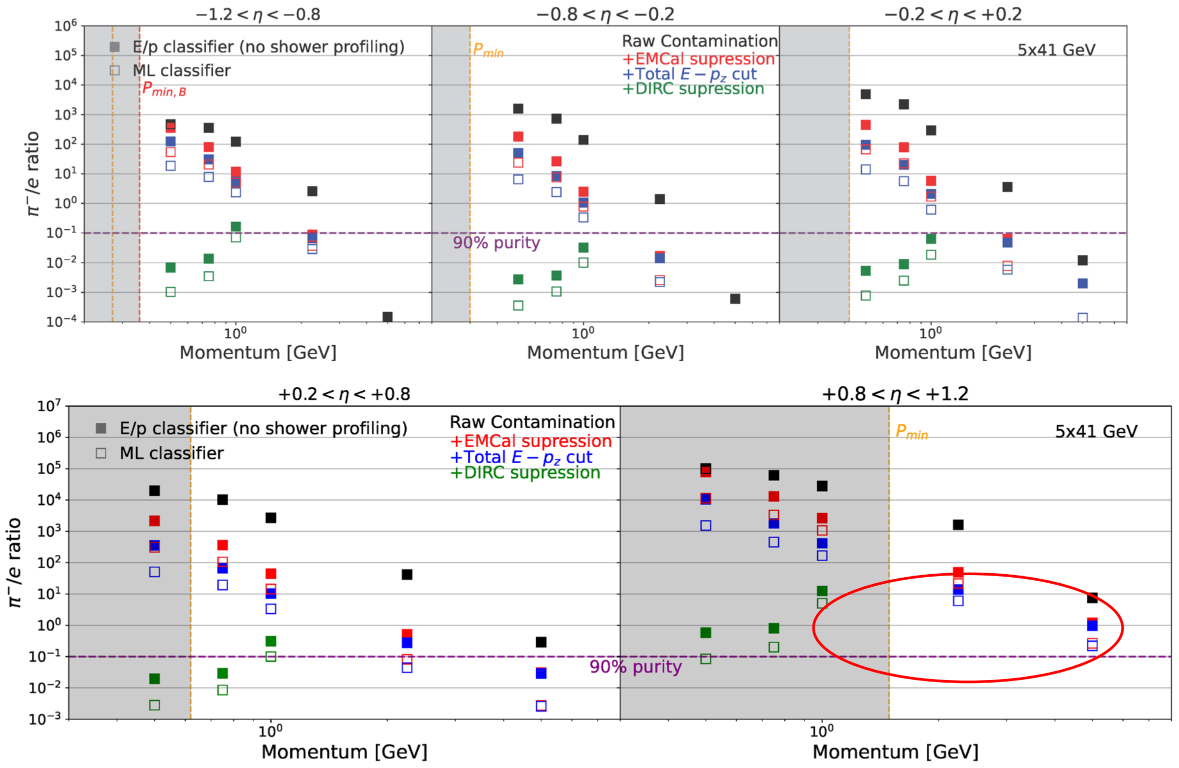
The region +0.2 < η < +1.2 and electron energy of ~2 GeV is (y~0.8) is in region well-covered by HERA



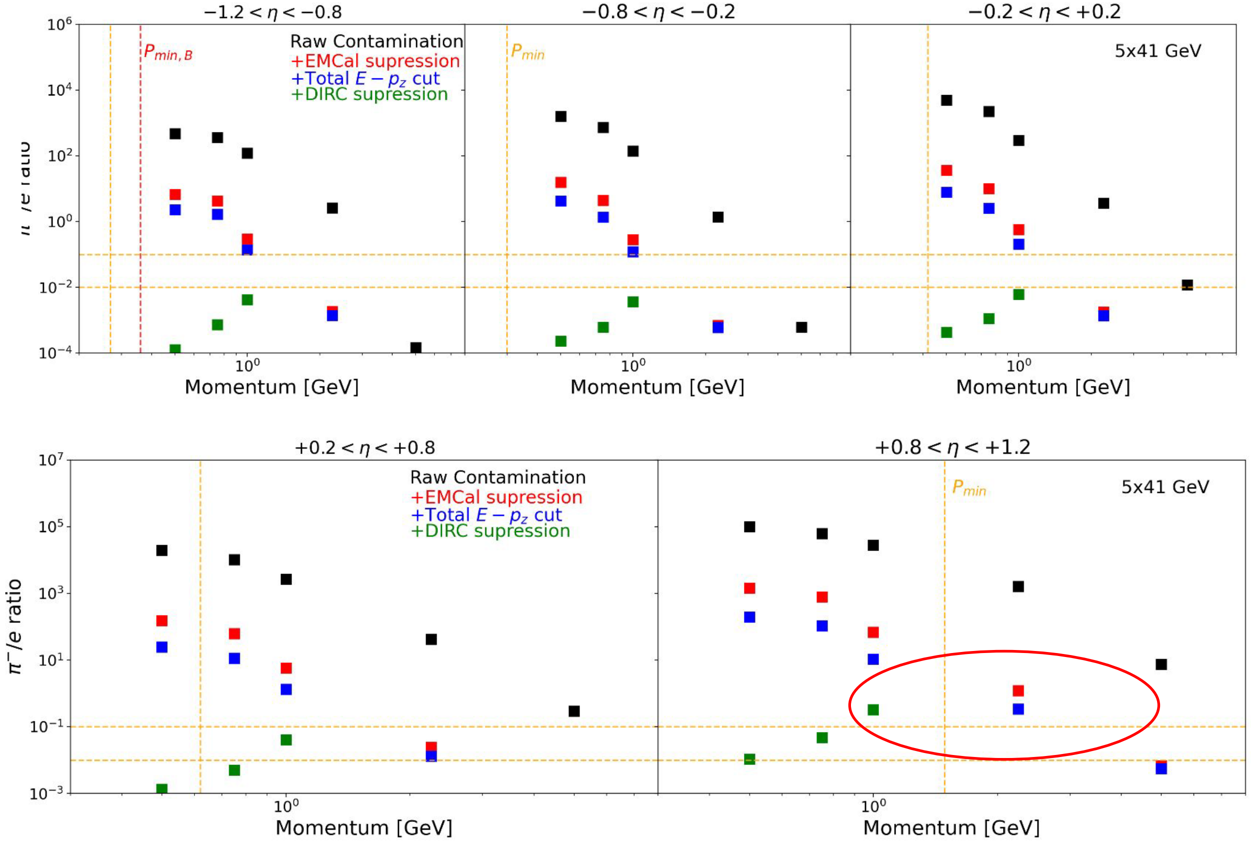
5 x 41 GeV

Note that the 5x41 GeV plots do not take advantage of the extended hpDIRC coverage

SciGlass EMCal Results
(from D. Kalinkin, 4/3/2023)



Imaging EMCal Results
(from M. Zurek, 4/6/2023)

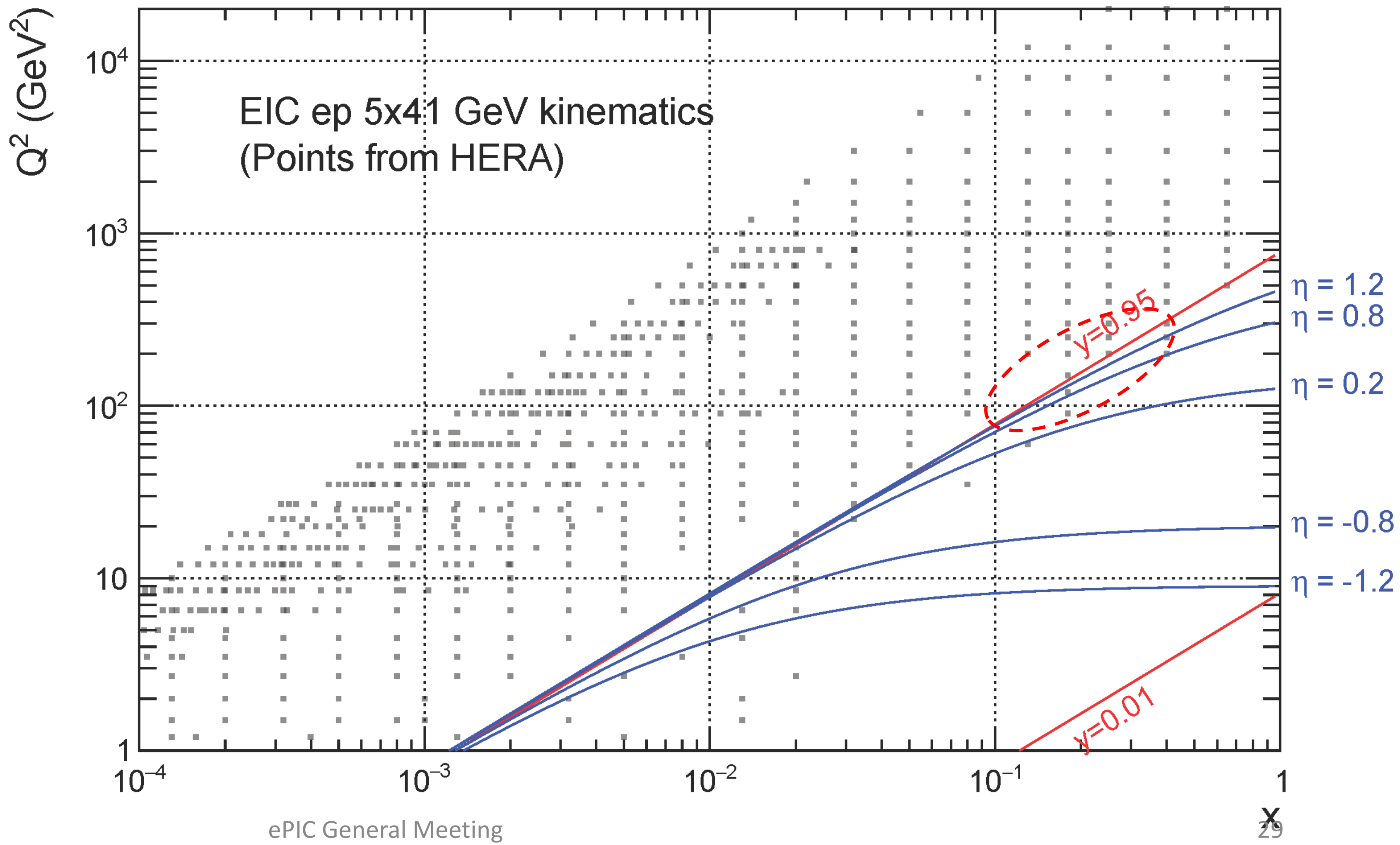


Performance Impact (5 x 41 GeV)

From Tyler Kutz – 4/2/2023

Band shows rapidity range in barrel overlaid with HERA data points.

The region +0.2 < η < +1.2 and electron energy of ~2 GeV is (y~0.8) is in region at the edge of what is covered by HERA

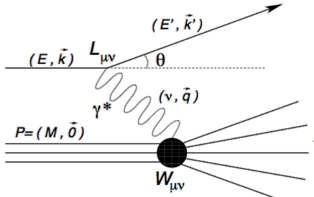


EM Calorimetry Requirements

DVCS photons that go into the Barrel EMCal are at predominantly low energies but plot is at generator level (no crossing angle). DVMP more important at higher positive pseudorapidity (higher x_B).

Electron/photon PID, energy, angle/position:

Coverage (in rapidity and energy), resolution, e/π, granularity, projectivity



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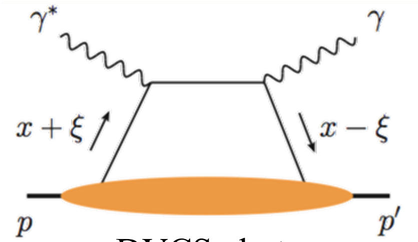
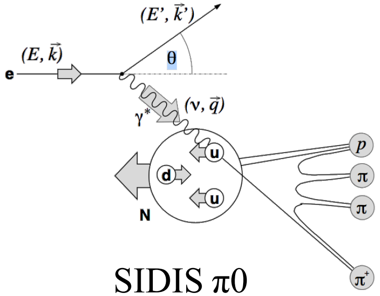
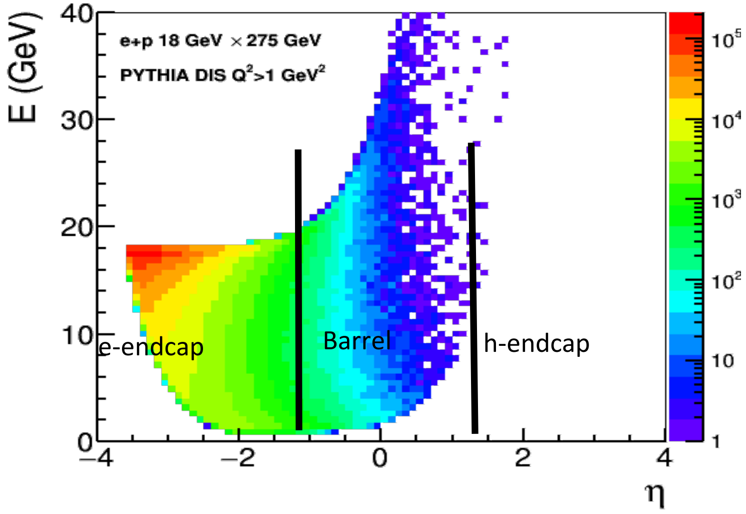
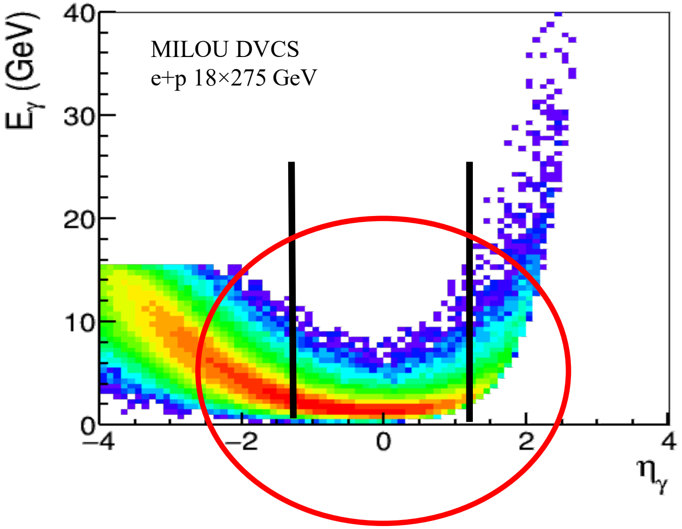


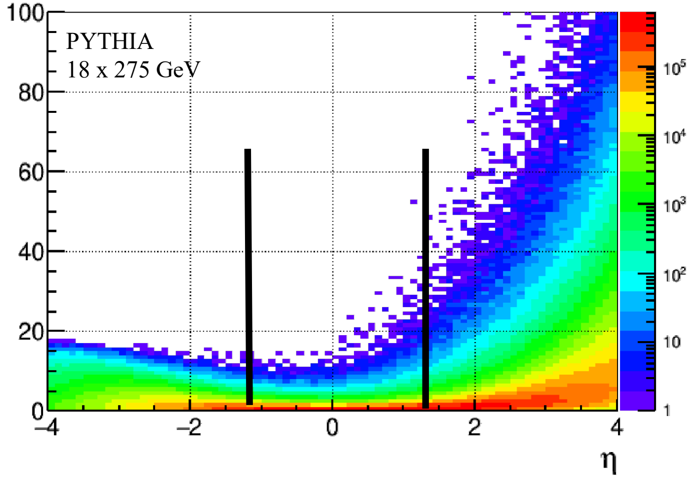
DVCS photons



SIDIS π0



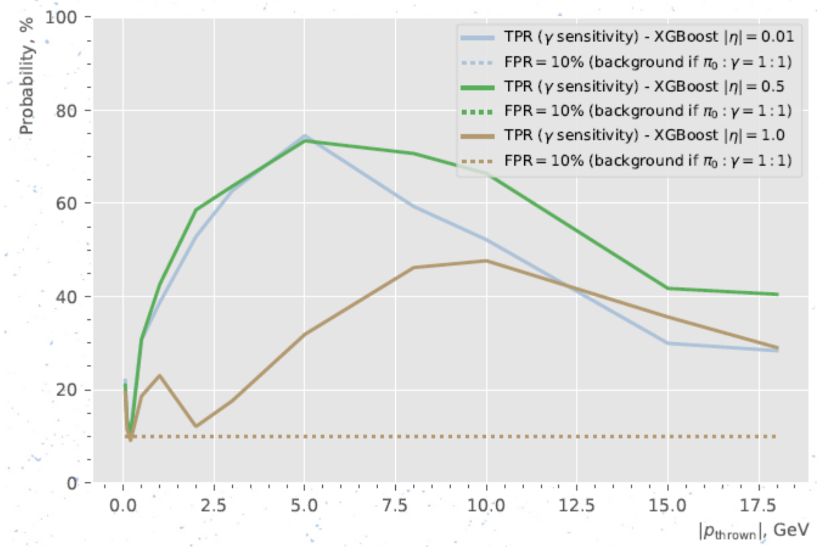




π^0/gamma Separation

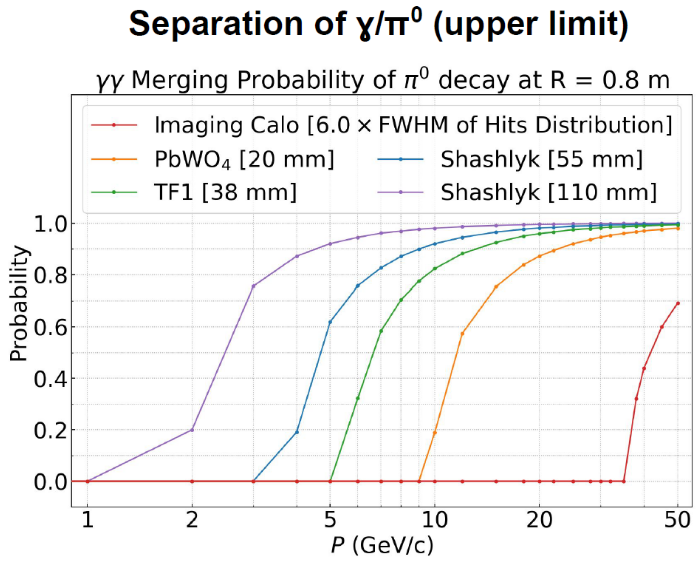
Additional work post-review to compare SciGlass and Imaging EMCal on the same footing!

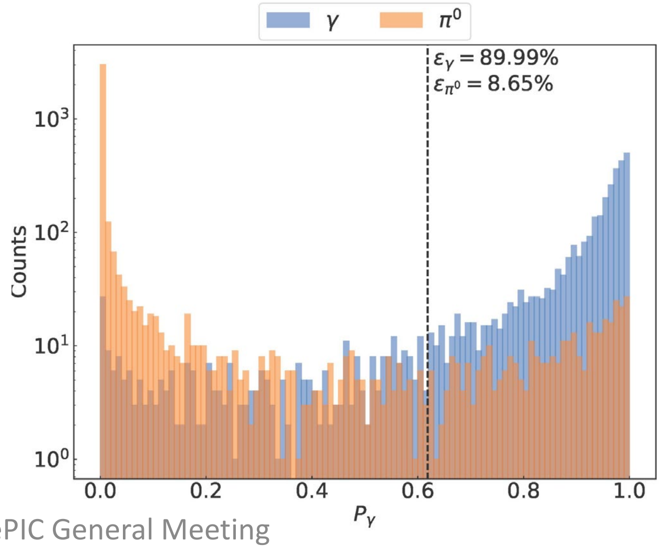
From D. Kalinkin 4/13/2023: Photon probability (efficiency) for 10% pion false positive.



SciGlass results for ML @ η=0 and 10 GeV: photon efficiency ~45% for 10% π^0 false positive.

From review:





Imaging EMCal results for CNN @ η=0 and 10 GeV: photon efficiency 90% for 8.65% π^0 false positive.

Physics Capabilities: Conclusion

- Both calorimeter designs are in principle capable of achieving the EIC science program, at the level of realism included in the current simulations, assuming performance as indicated in simulations:
  - CAVEAT: Gamma/π^0 rejection performance calls for an evaluation extended to physics performance:
    - The overall effect on DVCS/DVMP measurements should be quantified in the future in a full physics simulation
  - CAVEAT: Beam gas backgrounds not included
  - CAVEAT: Both designs need realistic implementations of detector noise, etc. (following beam tests)

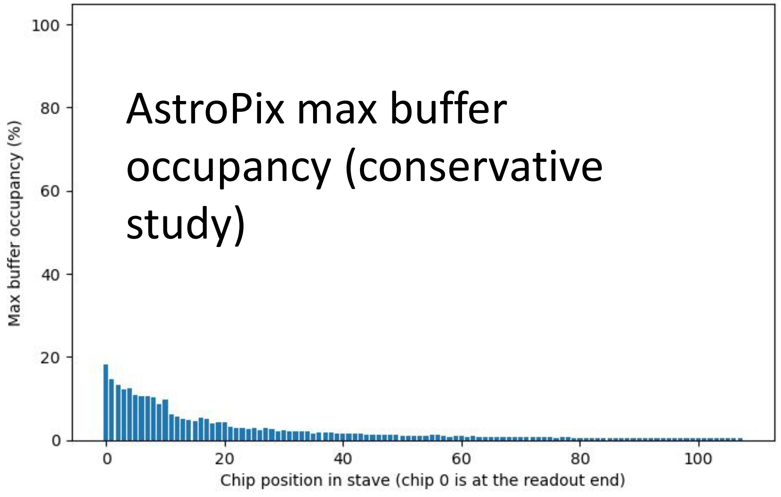
Scintillating Glass Concerns

- Important properties of SciGlass that affect the simulated physics performance are not well-known:
  - The review committee pointed out that a detailed characterization of the SciGlass material has not been presented (transmission and emission spectra, slow components of light output, non-uniformity along depth, etc.). In particular the transmittance and uniformity as a function of depth along the tower length is necessary to characterize linearity of response.
    - This has important implications for the simulated pion rejection. In particular the linearity of response could make the pion rejection substantially worse.
    - It was pointed out during the review that the transmittance could be adjusted by tuning the dopant, if necessary. However, this extends the R&D time required before SciGlass can go into production and creates schedule risk.
    - Hadron response is not known/constrained
  - The existing beam tests of the 3x3 20cm ($7X_0$) blocks that are compared to simulation results are leakage dominated, and therefore tell us little about how well the characteristics of the SciGlass are reproduced in simulation.
- There is a risk that the required SciGlass R&D is not compatible with EIC project timelines. In addition, if risks are realized too late it may be extremely difficult to mitigate those risks without impacting project timelines.

Imaging EMCal Concerns (I)

- Can the Imaging EMCal replace the outer MPGD layer?
  - AstroPix hit resolution σ~500μm (pixel size)/sqrt(12) = 144μm
    - MPGD position resolution is σ~100-150μm (angle dependent)
    - AstroPix also potentially offers a good time resolution (needs further study)
  - Imaging EMCal should be able to replace the MPGD layer with similar performance for both momentum resolution, pattern recognition, and angular resolution at hpDIRC
- The AstroPix chip hit buffer will drop hits if it gets full:
  - Data is daisy-chained from chip to chip
  - Plausible argument this is OK for a full stave at EIC multiplicities
    - Mitigation is to use more aggregators (small effect on cost)

From S. Joosten 4/13/2023



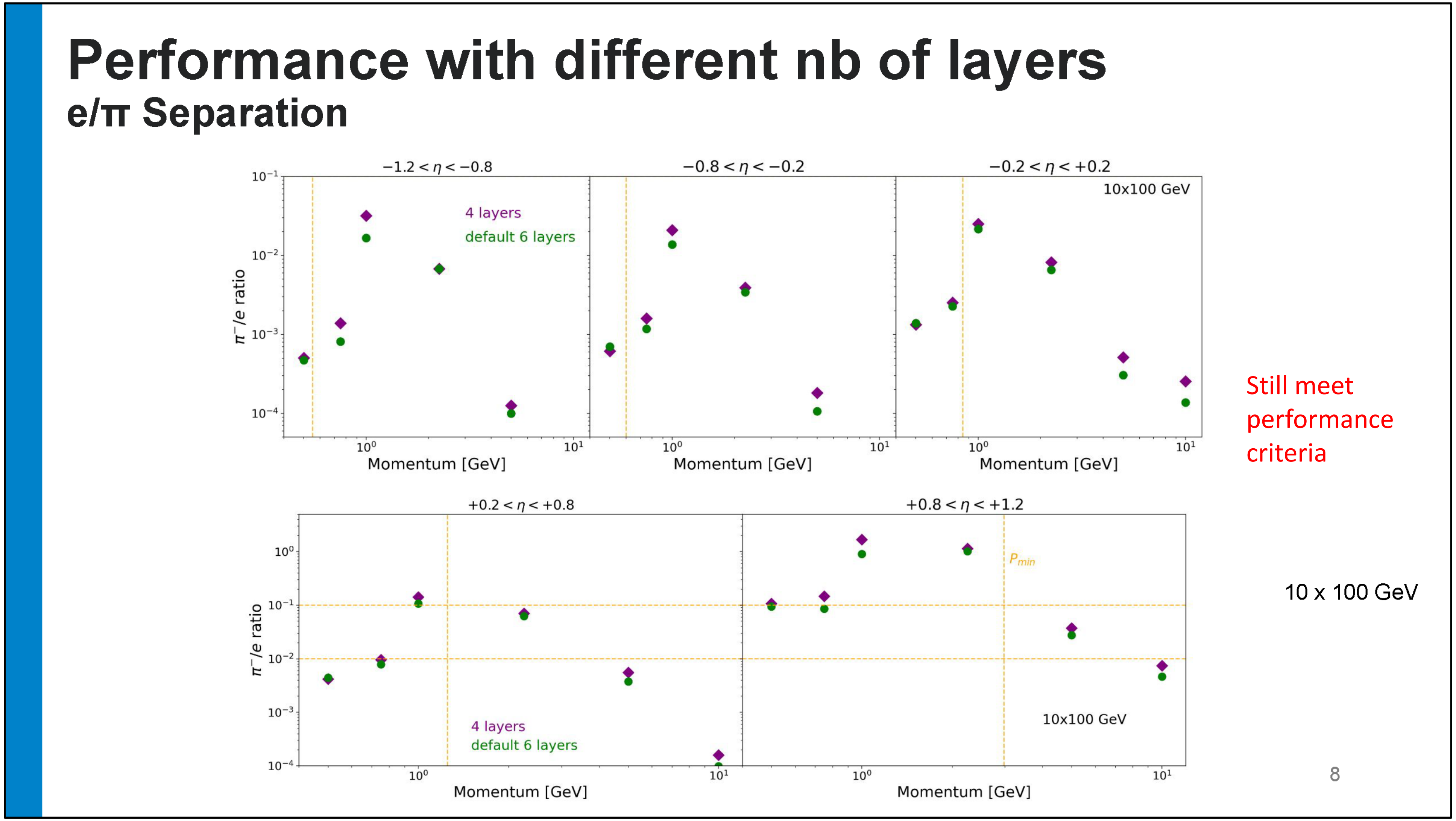
Imaging EMCal Concerns (II)

- The SciFi technology is well-demonstrated and presents little technical risk. The imaging layers represent a large overall area of Si detectors, use a novel sensor in development, and this represents a ***technical, cost and schedule*** risk.
- No studies shown at the review that demonstrate the optimal number of imaging layers:
  - The current design over-performs for the physics performance requirements
  - What is the minimal number of imaging layers required to achieve the physics goals of the EIC White Paper and NAS report, with any potential benefit of additional layers being reserved for an upgrade of the detector?
  - Proponents note that imaging layers important to both pion rejection and gamma/π^0 separation.
  - Reducing the number of layers reduces risk.

From Sylvester and Maria 4/6/2023

Performance includes all components – plots focus near p_{min}.

Performance at 10x100 still adequate.



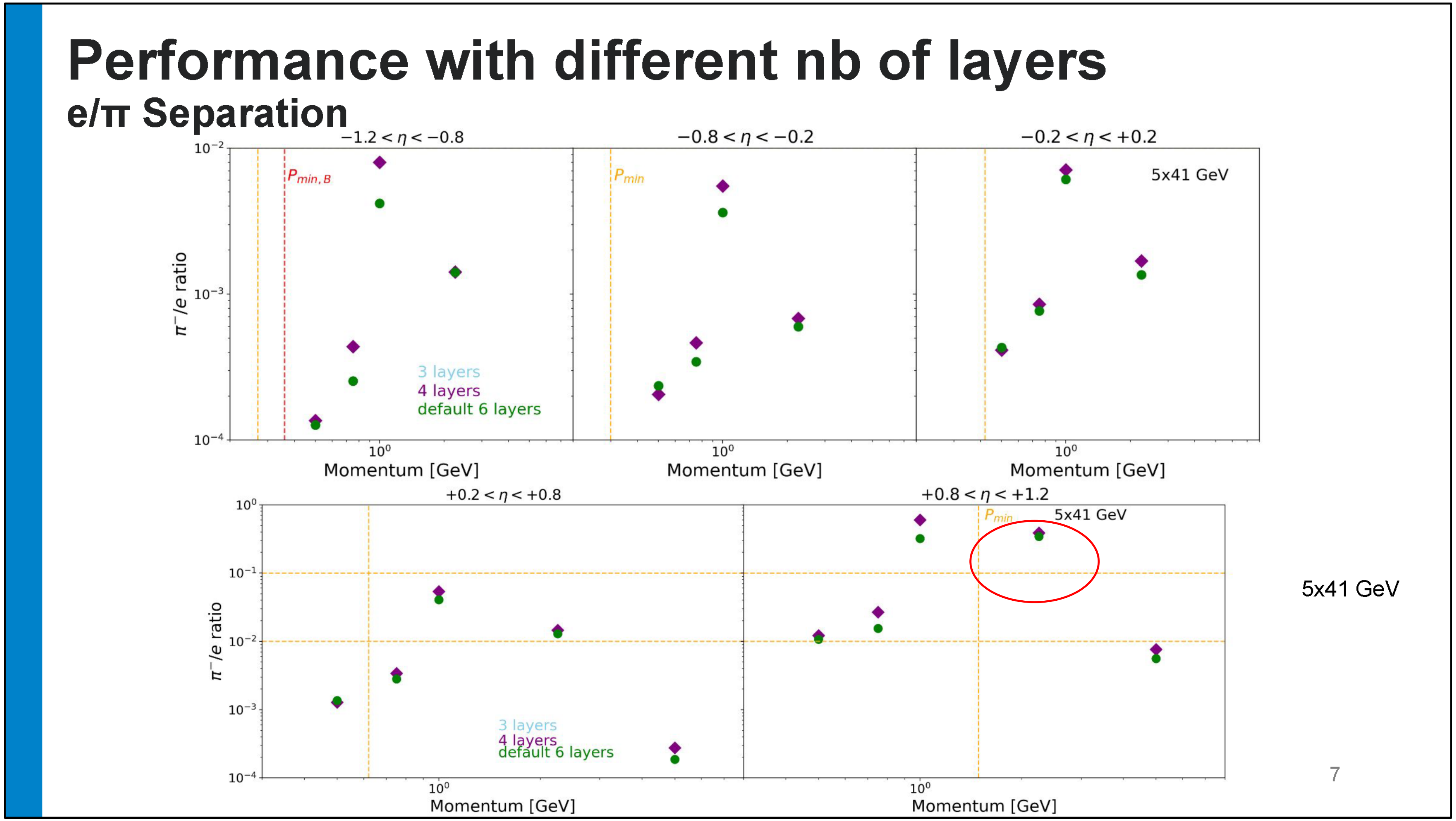
Still meet performance criteria

10 x 100 GeV

From Sylvester and Maria 4/6/2023

Performance includes all components – plots focus near p_{min}.

Performance at 5x41 still struggles just above p_{min} at highest rapidity – but no worse.

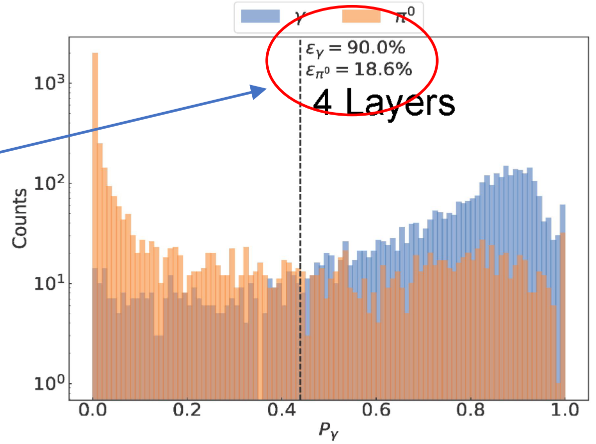


From Sylvester and Maria 4/6/2023

Performance with reduced number of layers

γ/π^0 separation

Momentum	Configuration	γ efficiency	π^0 rejection
10 GeV/c	6-layer default	90%	11.5
10 GeV/c	4-layer alternate	90%	5.4



π^0 background at 10 GeV increases by x2

Significant reduction in π^0 rejection at larger energies when reducing the number of layers (where π^0 rejection is the hardest).

4-layer configuration, sees a reduction in π^0 rejection at high energies by a factor of 2.

4-layer alternate is workable (still better than theoretical limit on a crystal calorimeter!), but significantly reduced π^0 performance versus the default 6-layer configuration.

5

Cost Comparison

SciGlass:

Costs provided by Project (P6) 4/10/23:
(burdened and escalated)

SciGlass:	
Material	17797393
Labor	1254229
Electronics	1482911
DAQ	40200
Total	**20574733**

Outer MPGD Tracker	
Material	661500
Labor	506738
Electronics	1650000
DAQ	32600
Total	**2850838**

SciGlass EMCal + Outer MPGD Tracker: **$23.4M**

- Does not include additional **$4.5M** in increased SciGlass material costs (Dec 2022 review). These cannot be trivially added to escalated numbers.

Imaging:

Costs provided by proponents, using DPAP costing guidelines (no escalation):

Base Cost (6 layers): $27M

- Remove two imaging layers:
  - -$2.15M (AstroPix staves)
  - -$0.5M (testing stations)
- Add electronics:
  - $1M SiPM readout, AstroPix aggregators

Imaging EMCal: **$25.4M**

- This is not an escalated number!
- Escalation depends on profile and things like long-lead procurements, cannot be trivially estimated!

Cost Comparison

SciGlass:

Costs provided by Project (P6) 4/10/23:
(burdened and escalated)

SciGlass:

Material
Labor
Electronics
DAQ
Total

Outer MPGD Tracker

SciGlass EM

- Does no
  increased SciGlass material costs
  (Dec 2022 review). These cannot be trivially
  added to escalated numbers.

Imaging:

Costs provided by proponents, using DPAP costing guidelines (no escalation):

Base Cost (6 layers): $27M

x

- This is not an escalated number!
- Escalation depends on profile and things like long-lead procurements, cannot be trivially estimated!

Conclusion:

Within the uncertainties in this comparison, the costs of the SciGlass and Imaging calorimeters are similar.

Thanks and Congratulations!

- The SP Office would like to thank:
  - The detector proponents
  - The GD/I Convenors
  - The external reviewers
  - All the ePIC collaborators who contributed to develop and improve the simulations and analysis software
- The amount of effort that went into the reviews was enormous, and this work is greatly appreciated by the collaboration!

- This was a long process, but the ePIC collaboration came together to explore the options and followed a prescribed procedure to make a decision in the best interest of ePIC.

Recommendation

- The SciGlass EMCal implementation carries substantial risk based on the need for continued R&D to determine the SciGlass characteristics
  - This risk is fundamental to the technology choice and difficult to mitigate if realized.
- The Imaging EMCal with four imaging layers meets or exceeds the performance requirements
  - The detector can be built to accommodate additional AstroPix layers as a potential upgrade
- **Recommendation:** ePIC should initiate the EIC change control process to make the Imaging Barrel EMCal with four imaging layers the baseline technology selection. The design should be upgradeable to six layers as a future (off-project) upgrade.
- This recommendation was unanimously endorsed by the Executive Board.

A New Challenge

- From the review committee report, regarding the Imaging EMCal:

"The schedule presented is very aggressive and the committee is concerned about possible delays that may impact the ePIC detector as a whole, as well as the EIC project."

- It will take an immediate, concerted effort on the part of the institutions working on the imaging EMCal to engage with the EIC Project to avoid delays:
  - Identify any long-lead procurements for CD-3A
  - Work out integration issues
  - Integrate new collaborators and enlarge the workforce
  - Rapidly develop ePIC expertise with AstroPix sensors


BACK UP

Email from Tom LeCompte

Here are some technical thoughts I have on SciGlass, if the collaboration decided to go this direction. It's not meant to be in the actual report, as that should be consensus based. These are just my thoughts.

(1) If e/h is the problem, cerium is the problem. Z=58 is tough to get around. Playing with gap geometry is nibbling around the edges - fundamentally the issue is the material and its low electron density.

(2) A 6mm sensor throws away a lot of light. If you can afford to do this, you can afford to use lead, no?

(3) E-705 was clobbered by long-lived light components. We never characterized the light, but it was at least microsecond-scale. It manifested itself as a pedestal shift, one that varoied throughout the spill. You probably don't want pedestals changing bunch-by-bunch and with beam species.

(4) E-705 was also clobbered by opacity. The thinking was that it was OK, because we had a preconverter, so we could tell when the showers developed. The problem with that is that when you linearize the equations, you realize you are double (or more) weighting the preconverter energy, so your resolution suffers. EPIC not having a preconverter makes this worse.

If someone were to put a gun to my head and say you must use cerium, and you must use tiny SiPMs and you must make this work somehow, I'd put multiple SiPMs on each block, with different wavelength filters on each one - certainly one to get the scintillation light, one to get more Cerenkov light, and whatever else I could do. (Wigmans published on this, which he called "dual readout", although this is more mult-redaout) The idea is that color would help you address points 3 and 4. It also collects more photons. However, this would not be my first choice.

Backward RICH presentation at ePIC general meeting

on April 14, 2023

ePIC General meeting

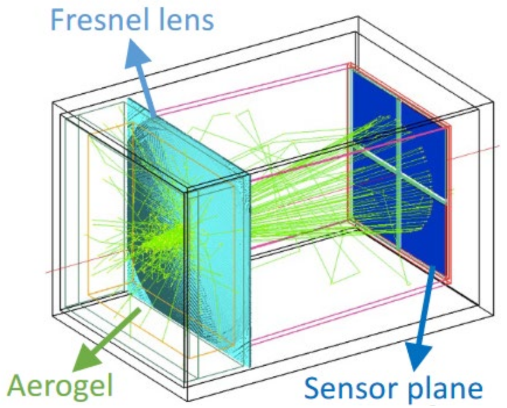
Backward RICH recommendation

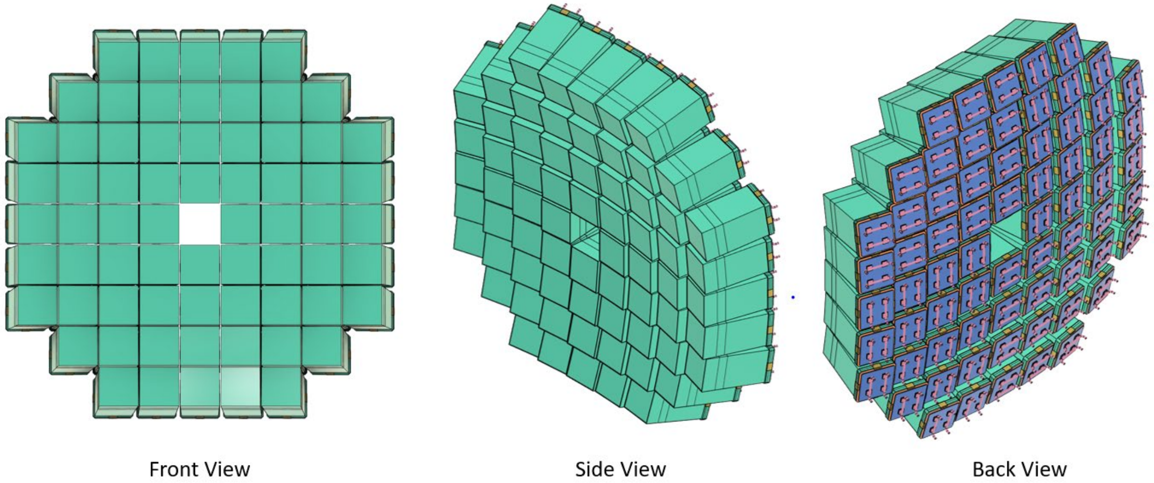
John Lajoie and Silvia Dalla Torre

April 14, 2023

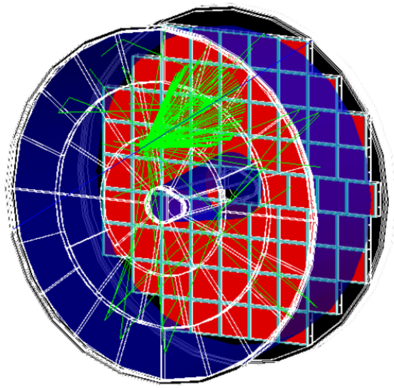
REMINDER: the two alternative designs

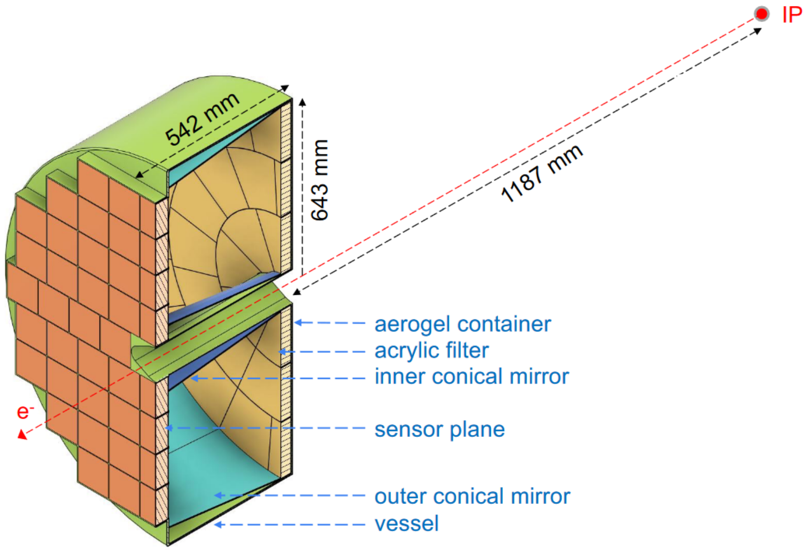
mRICH





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

- Holistic view
  - Device length and tracking lever arm

- Costing

- Risks and mitigations

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/

SCRUTINIZED ITEMS

- Performance for PID
  - Expected **resolution from simulations**:
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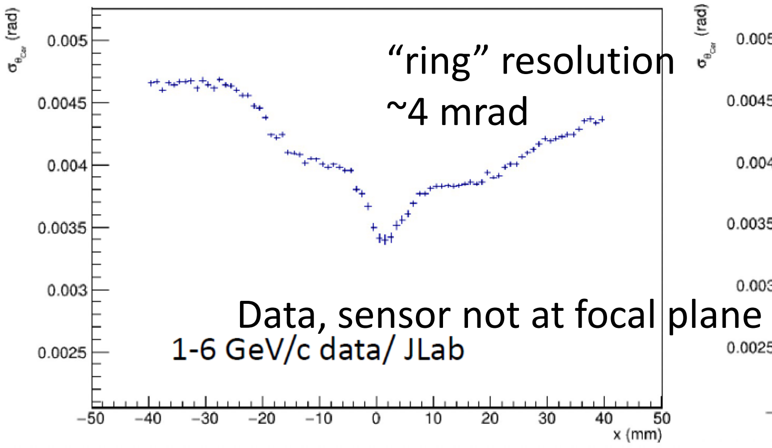
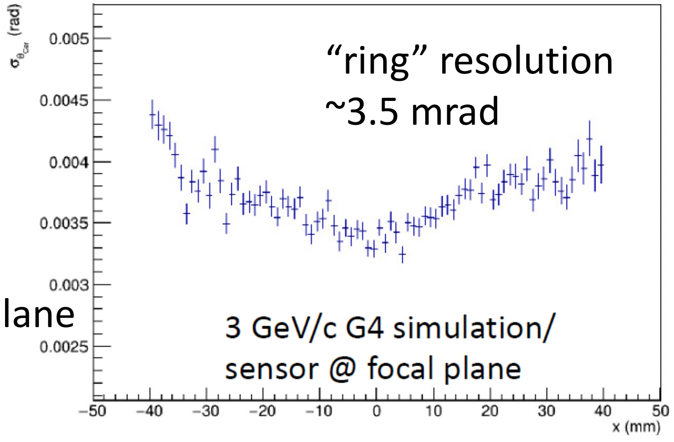
RESOLUTION

mRICH, from test beam and simulation

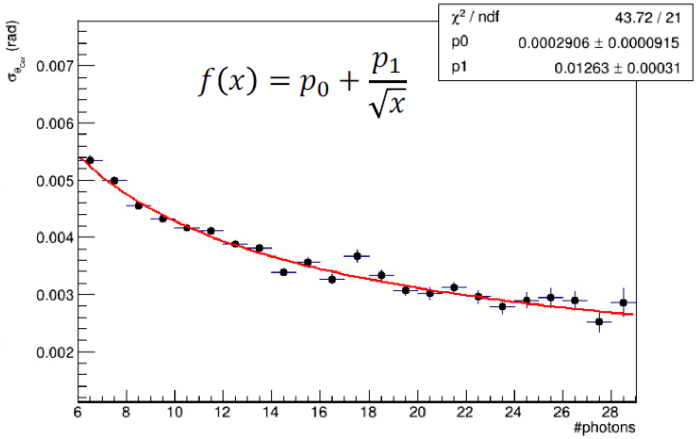
JLab Beam Test: Results

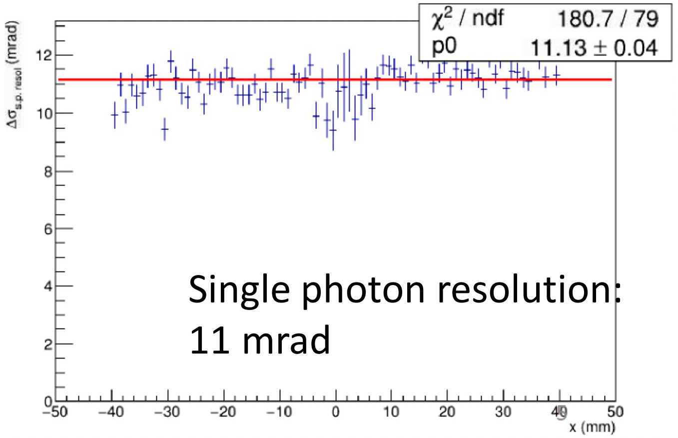




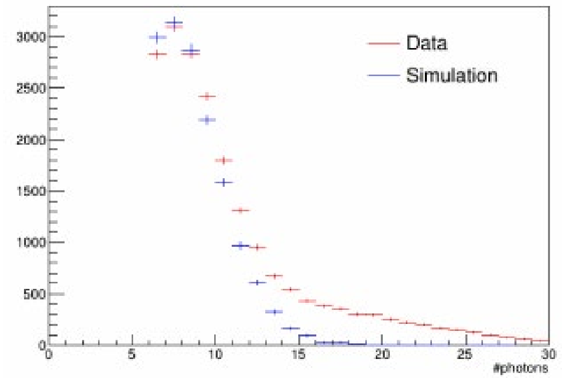
- More photons optimizing the aerogel thickness.
- Improved resolution claimed with sensor at the focal plane.

Proving all this requires further R&D.

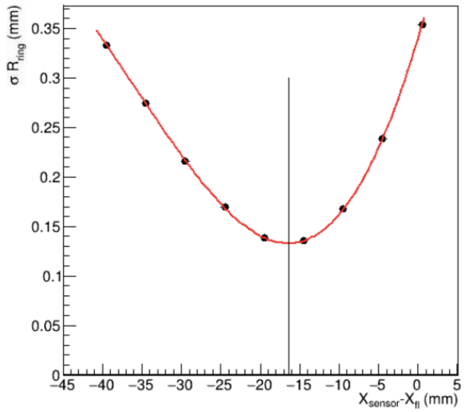




n. of Photons per ring
From JLab test beam



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



QUANTUM EFFICIENCY in SIMULATION STUDIES

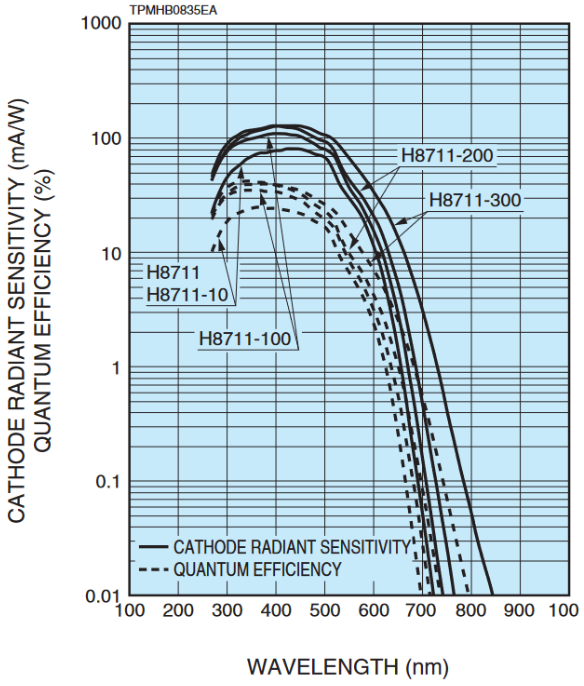
From E-mail by Xiaochun He on March 23

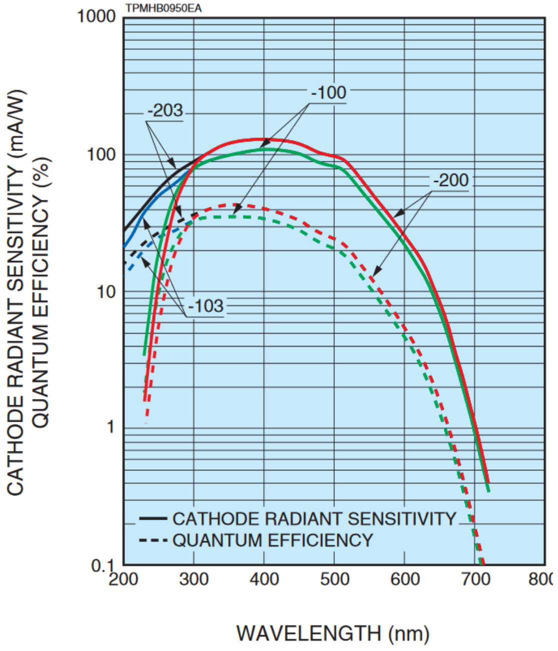
We did, however, implement an accurate digitization reflecting the pixelization as well as Q.E. but shifted the Q.E. distribution to start above 350 nm but with a maximum value of 38% at ~500 nm which has a similar distribution in shape to LAPPD.

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)



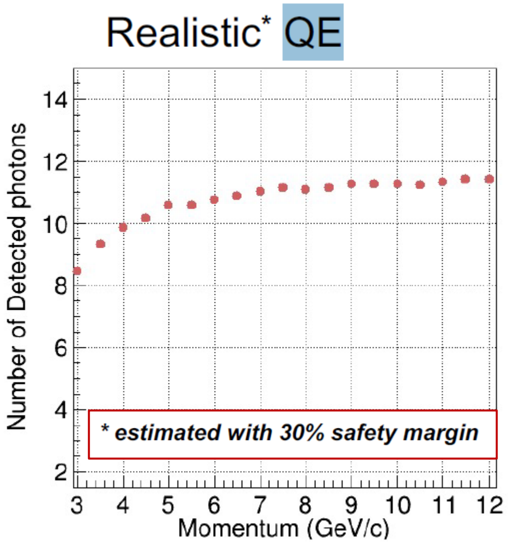


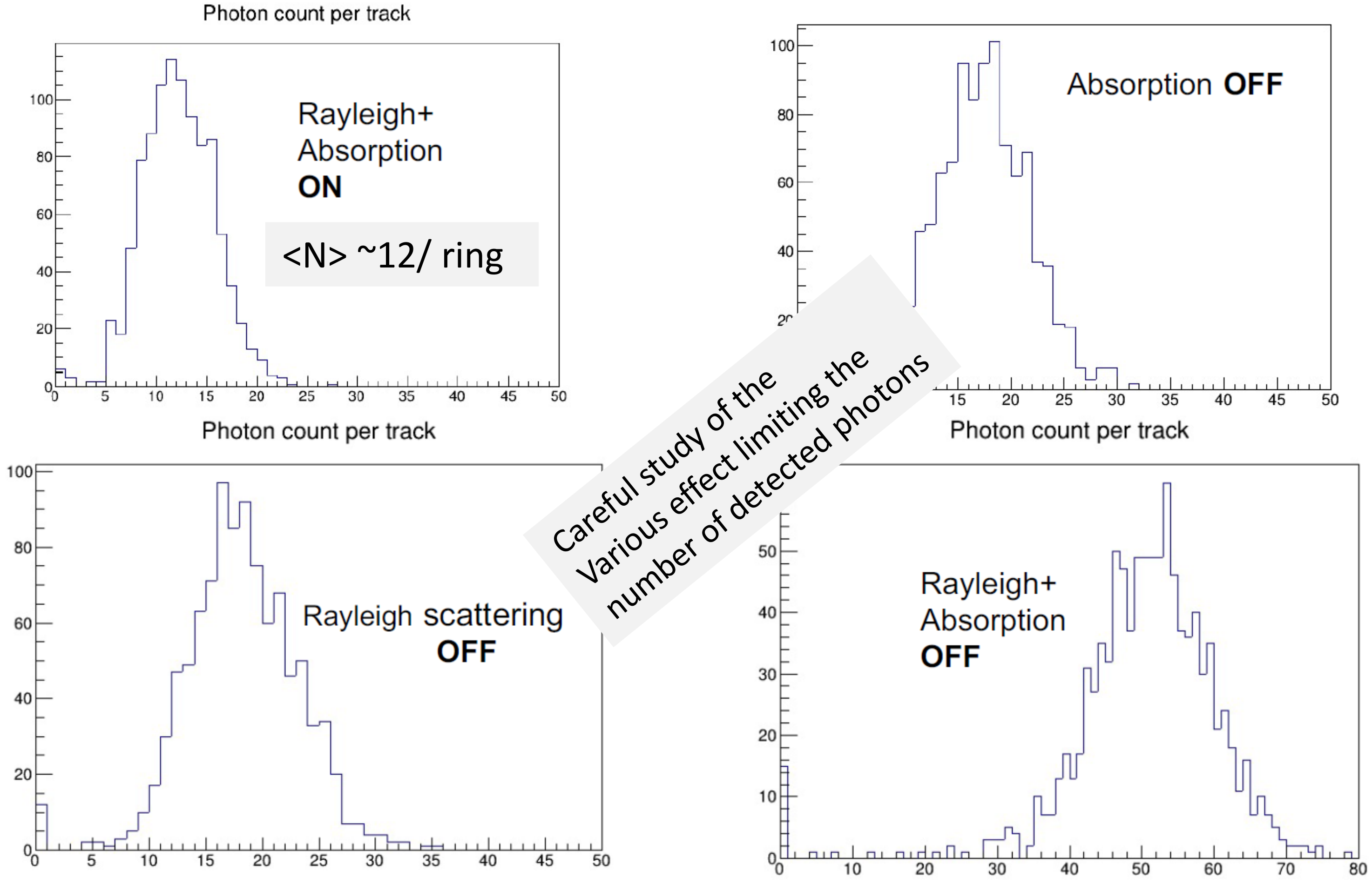
NUMBER OF DETECTED PHOTOELECTRONS **pfRICH**

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)

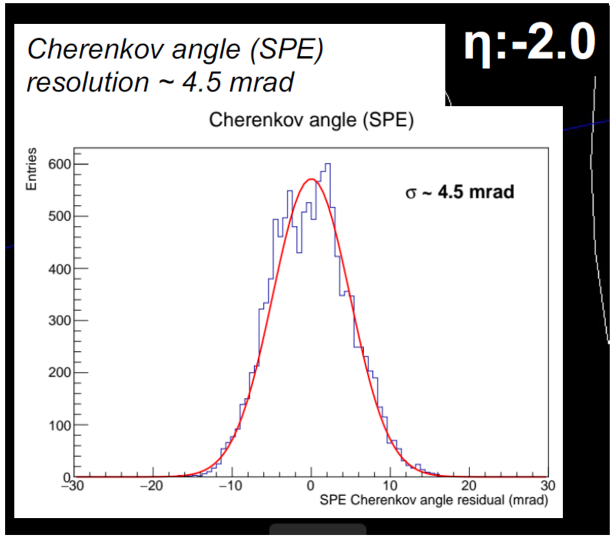




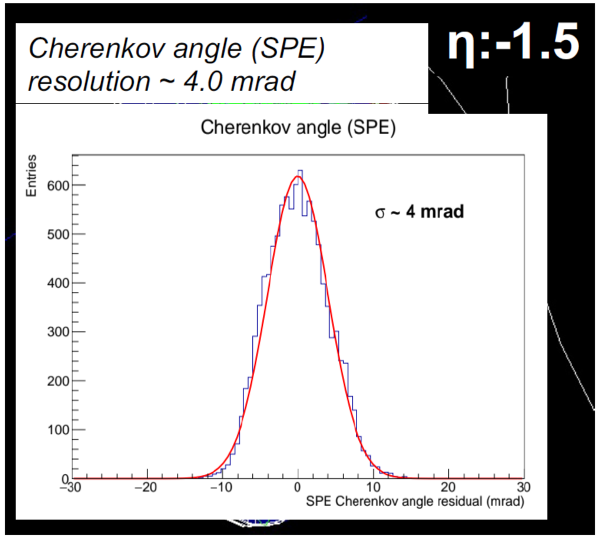
Careful study of the Various effect limiting the number of detected photons

RESOLUTION

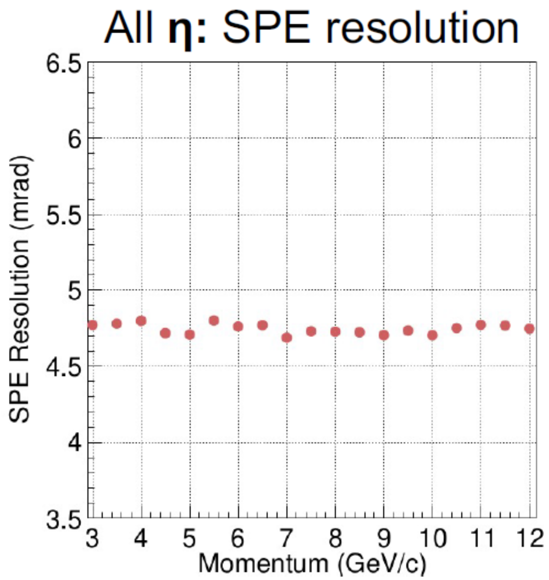
pfRICH, from simulation

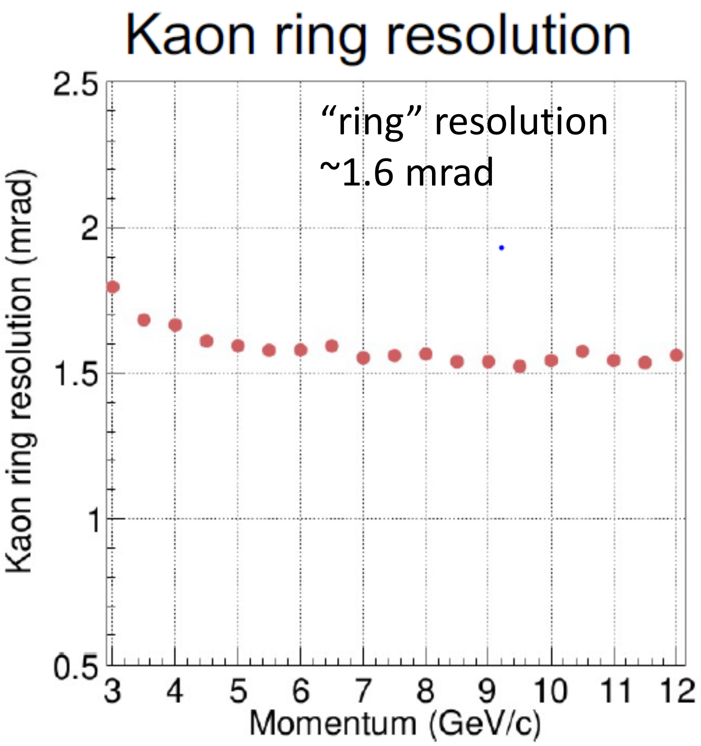


Center of pfRICH



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
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  - 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

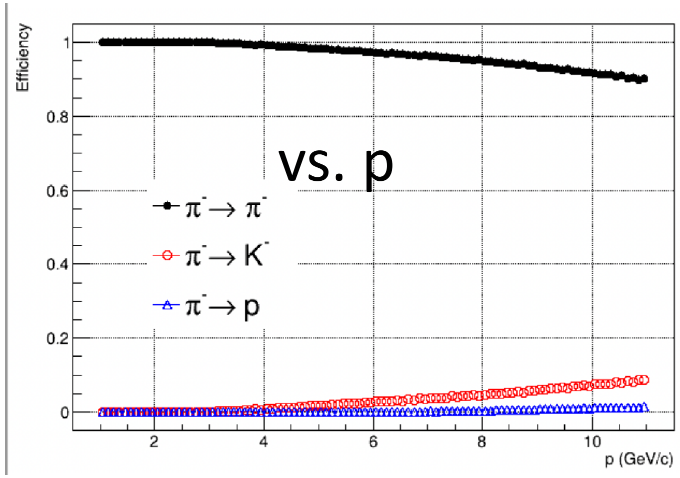
HADRON PID PERFORMANCE

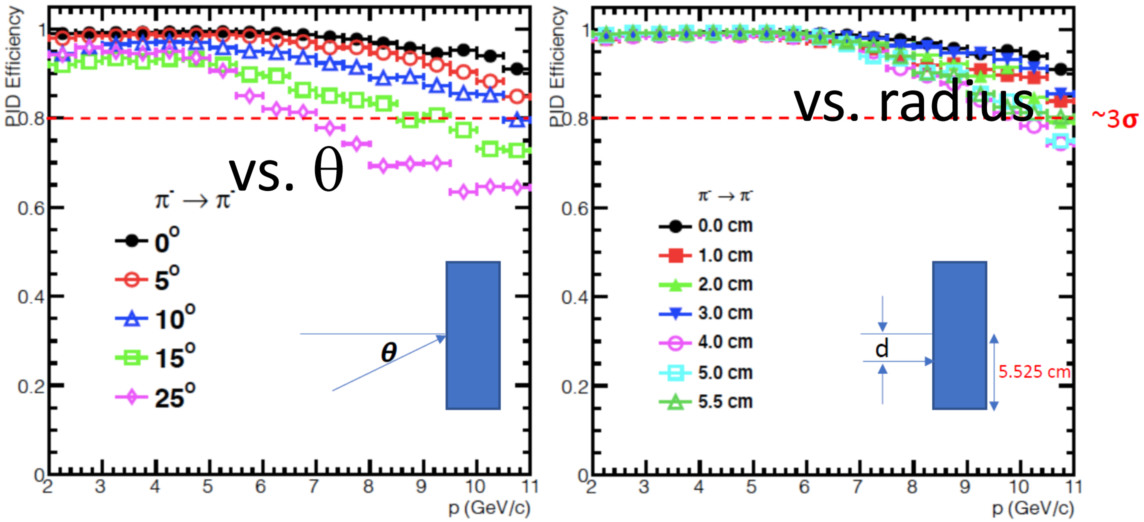
mRICH

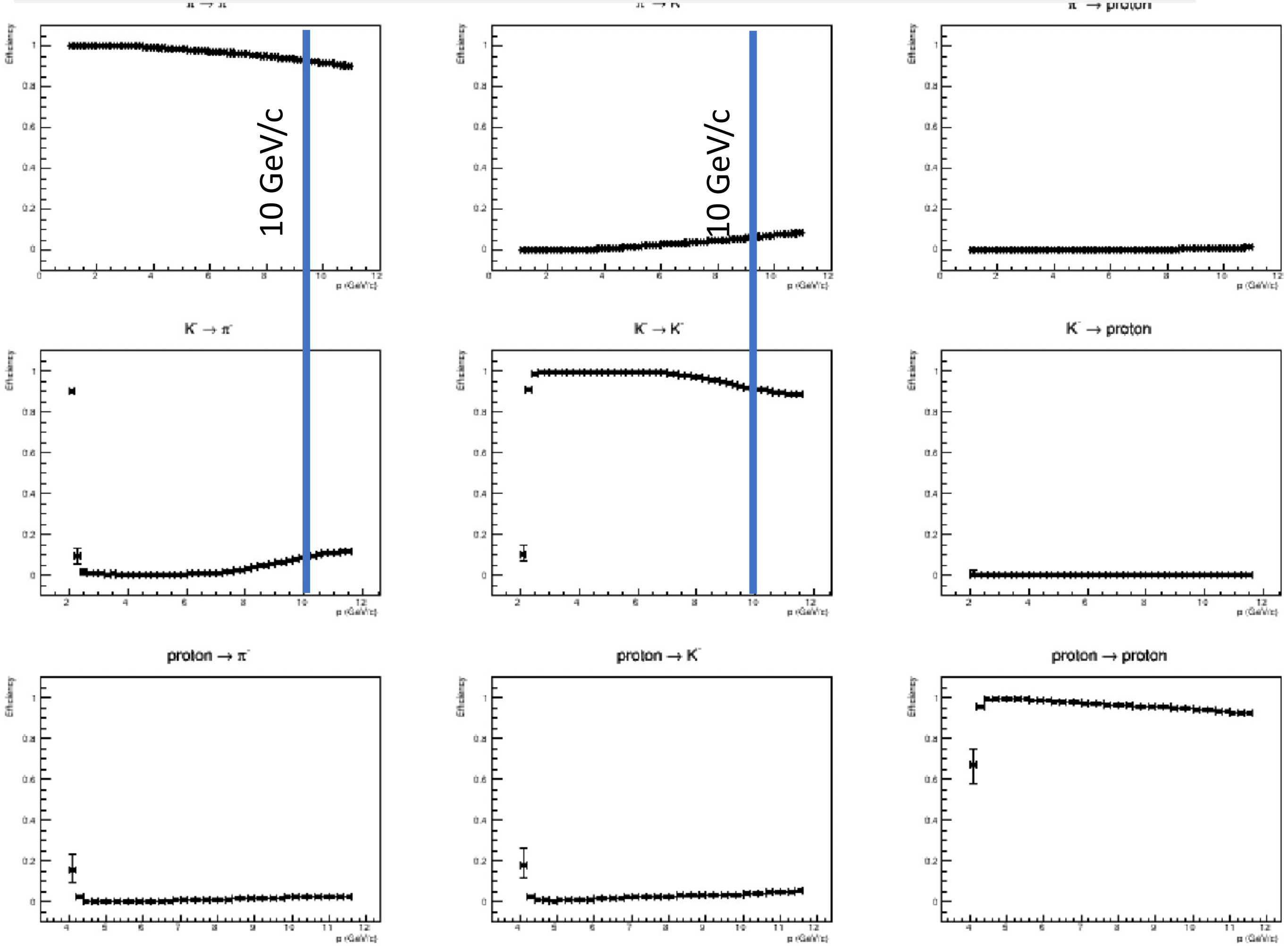
Efficiency and purity

✓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)







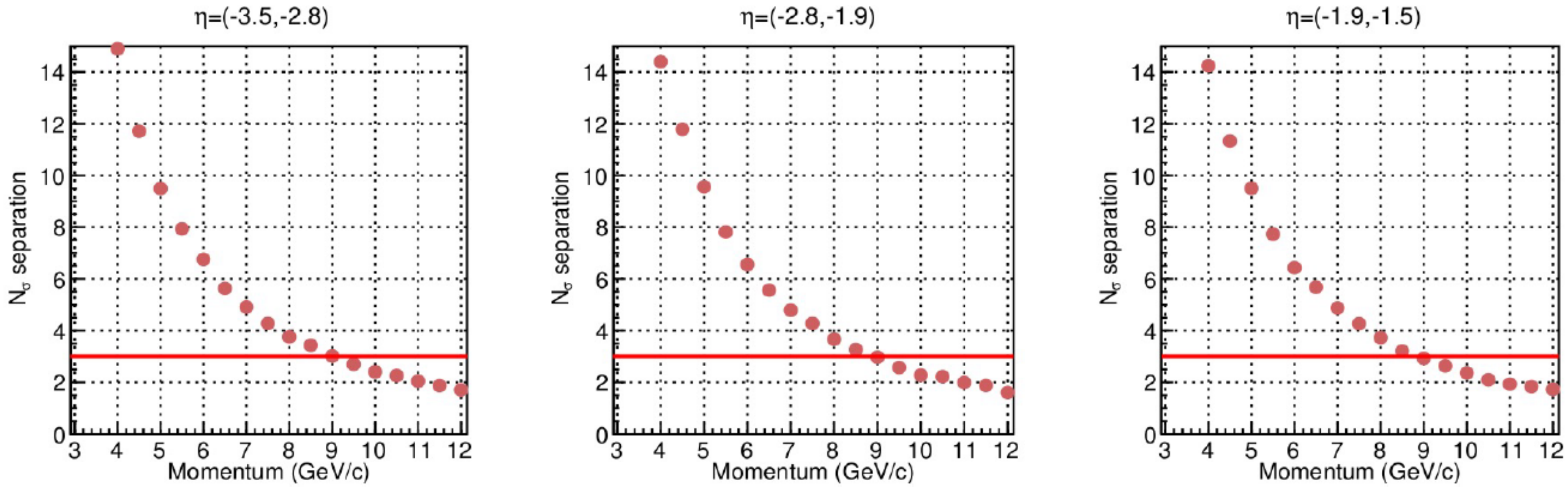
HADRON PID PERFORMANCE

pfRICH

FROM ring resolution

π/k separation : 3$\boldsymbol{\sigma}$ → p = 9.0 GeV

π/k



3$\boldsymbol{\sigma}$ at ~9.0 GeV

19

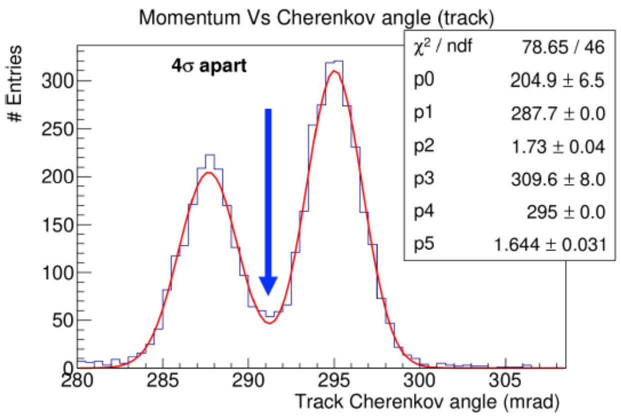
HADRON PID PERFORMANCE

pfRICH

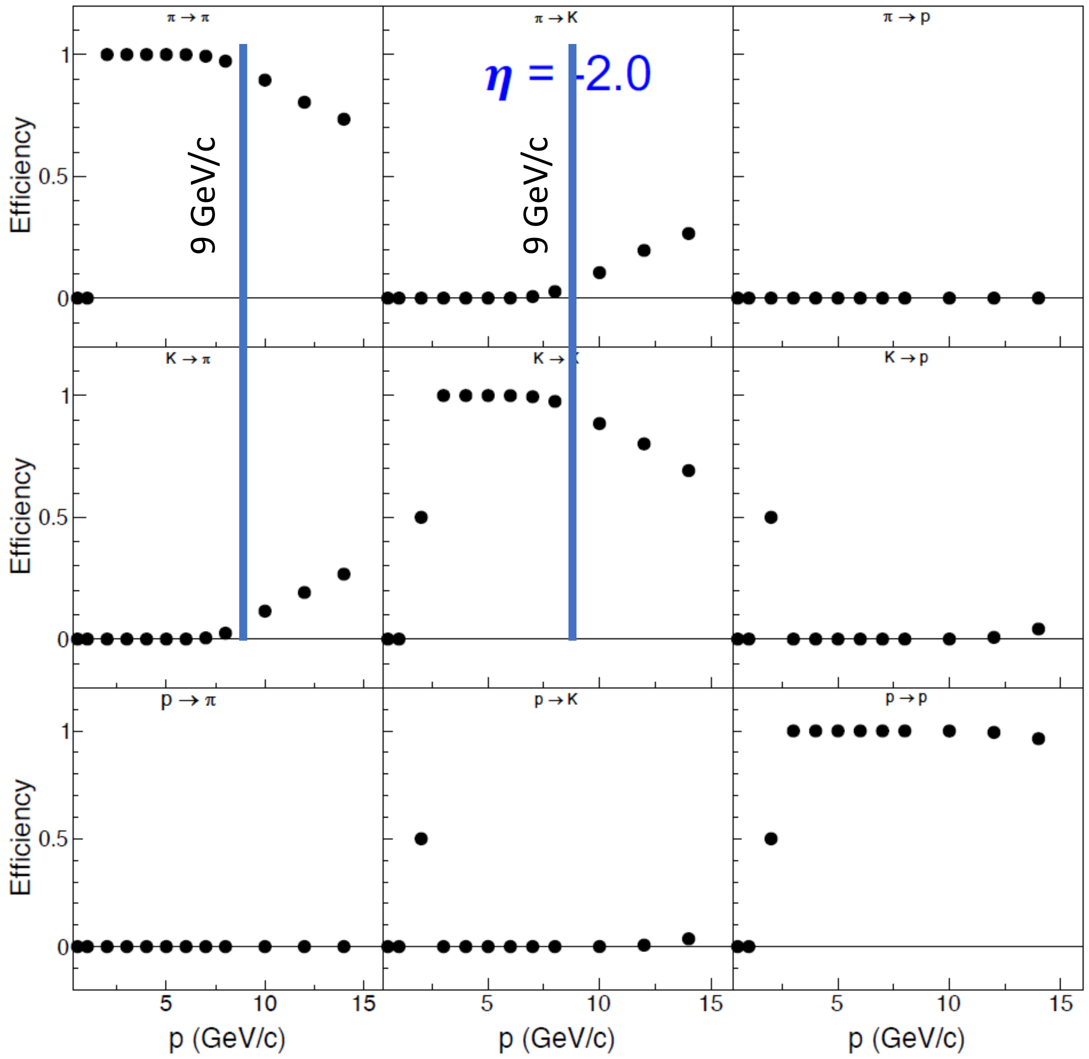
Efficiency and purity

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

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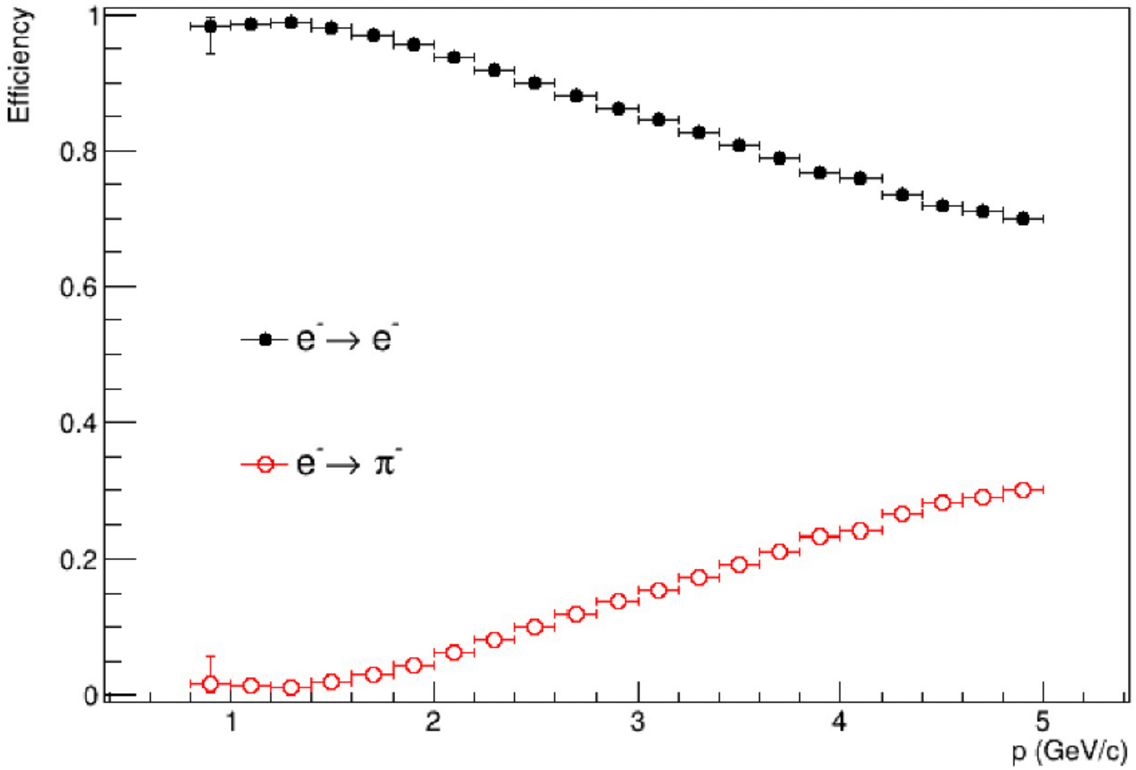
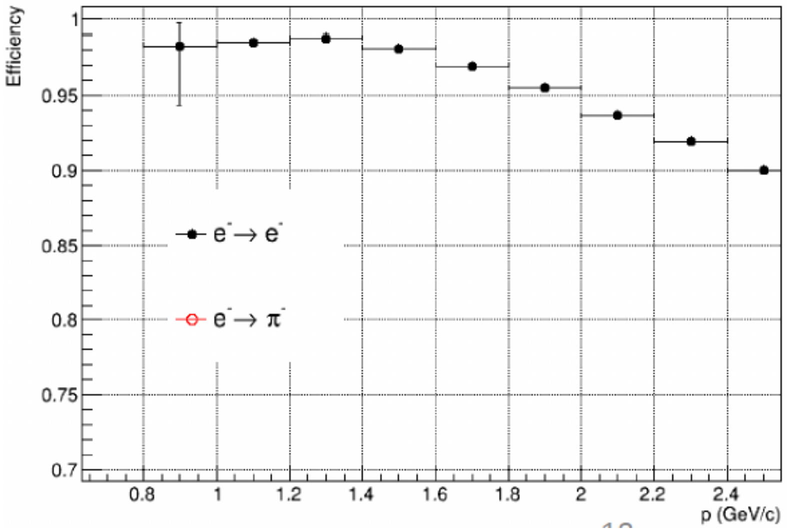
e-π SEPARATION

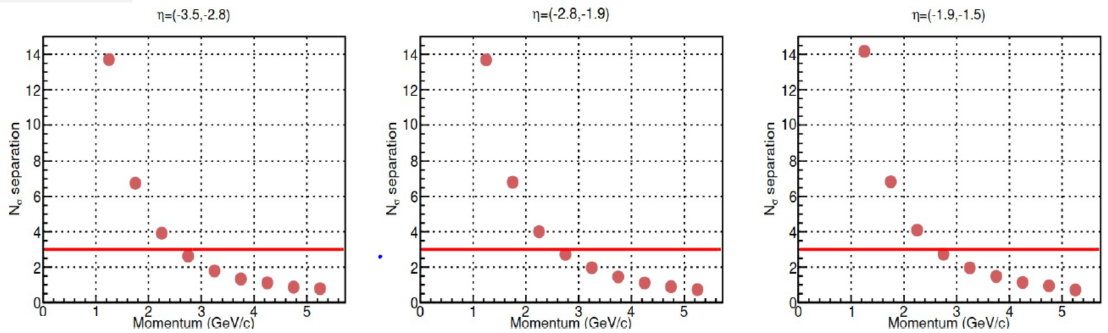
mRICH





e-π SEPARATION **pfRICH**

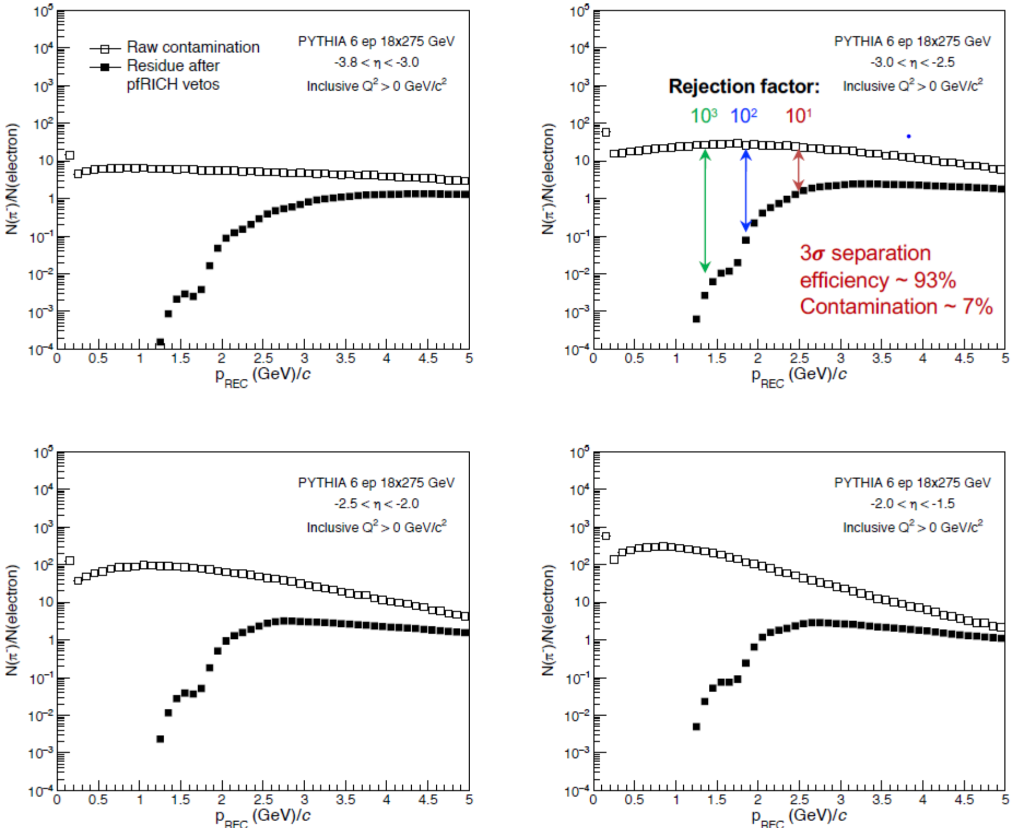
e/π



3σ at ~2.5 GeV

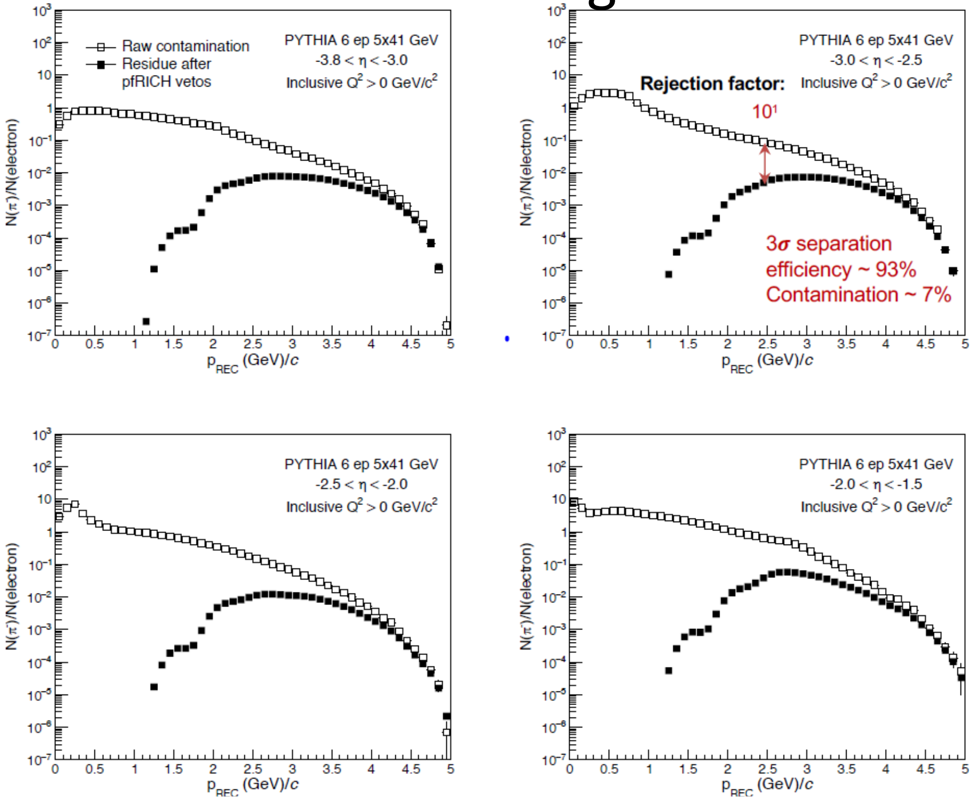
ep 18x275 (high energy)

Access to low x



ep 5x41 (low energy)

Access to higher x



SCRUTINIZED ITEMS

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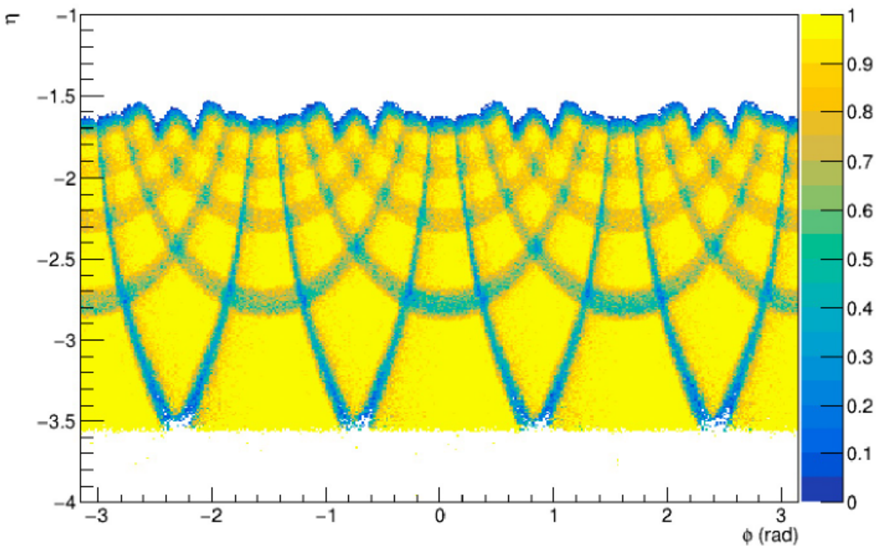
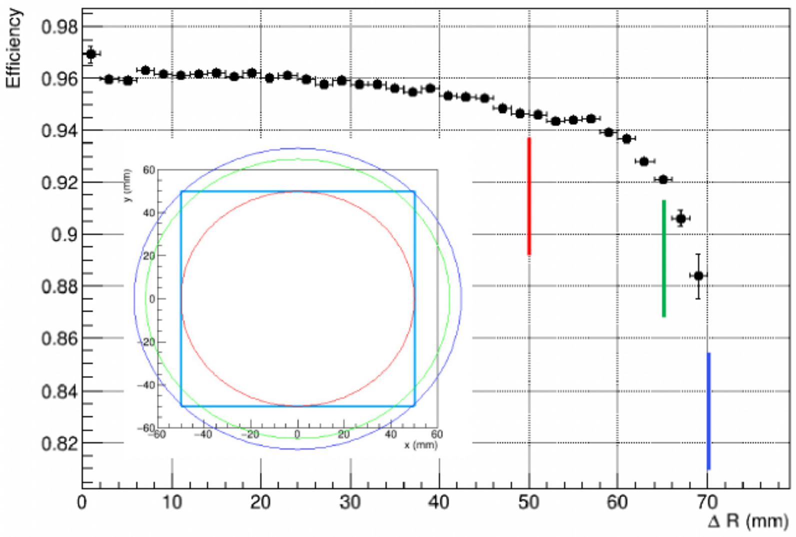
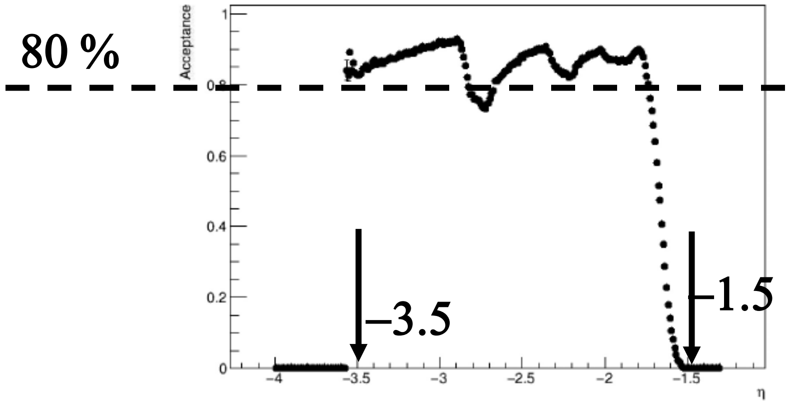
PID Acceptance

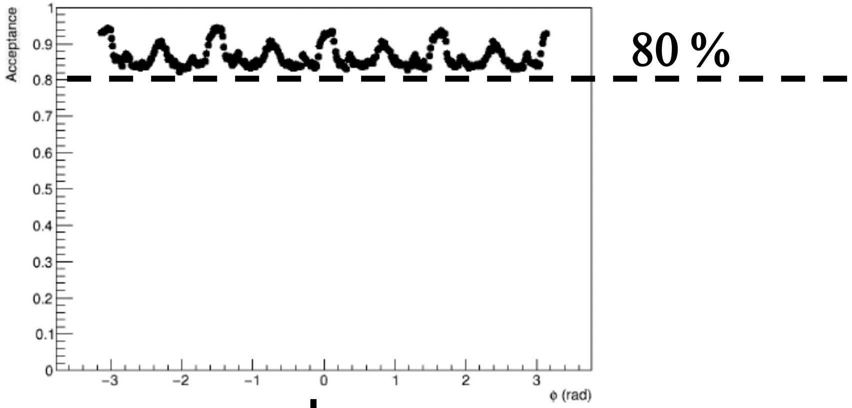
mRICH







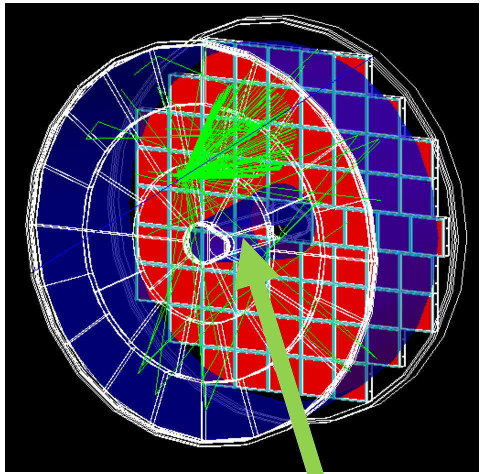
η



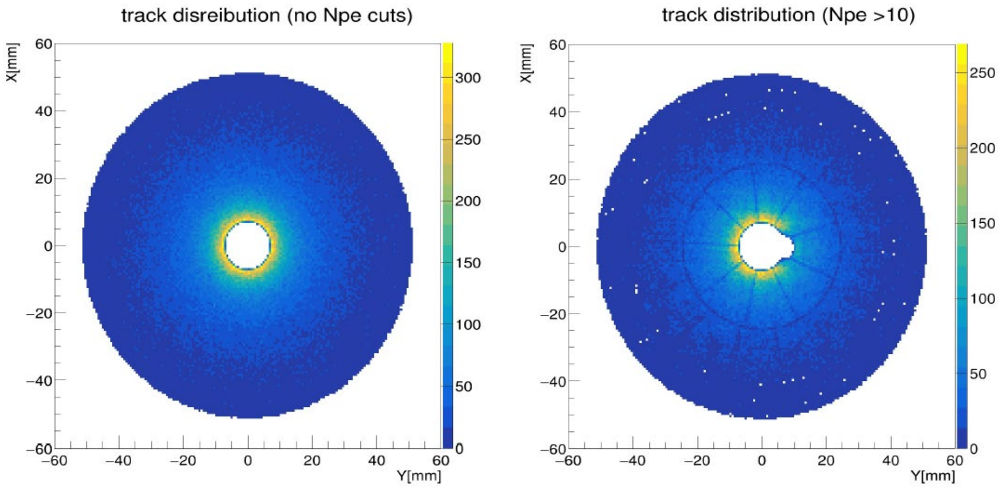
ϕ

PID Acceptance

pfRICH



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

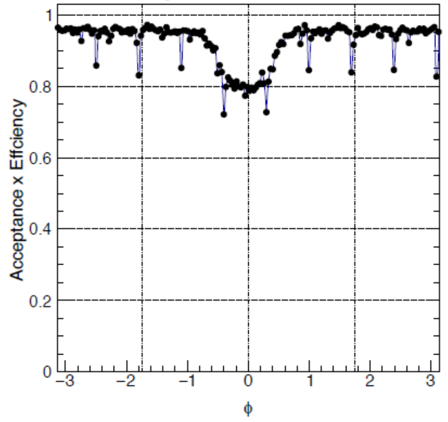


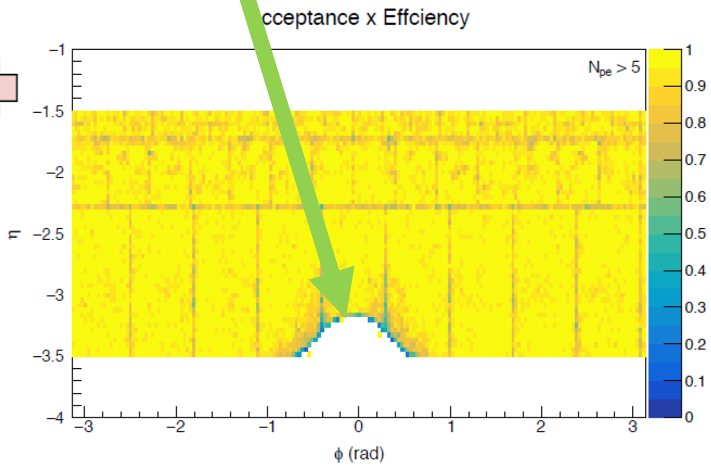
Uniform track distribution w/o N_{pe} cut

Track distribution with more than **10 photons**

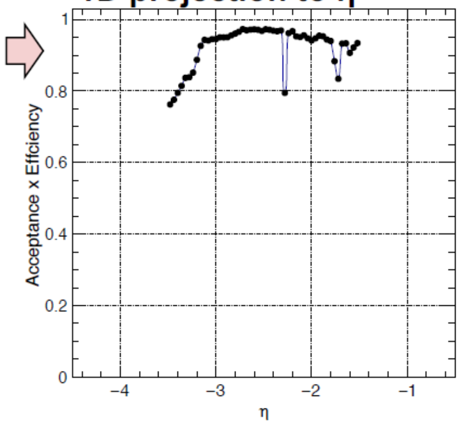
Acceptance x Efficiency (N_{pe} > 5)

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

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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

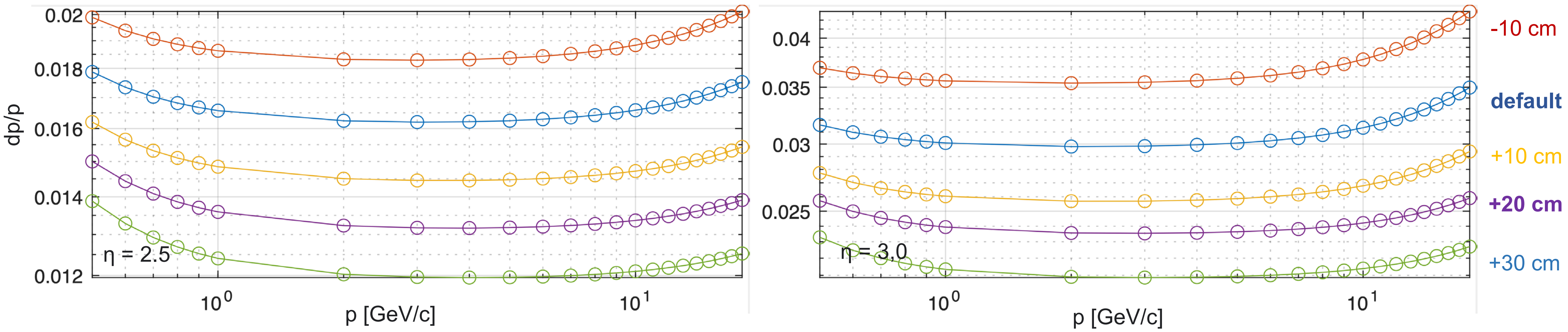
Impact from backward PID envelopes on dp/p from tracking

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**:

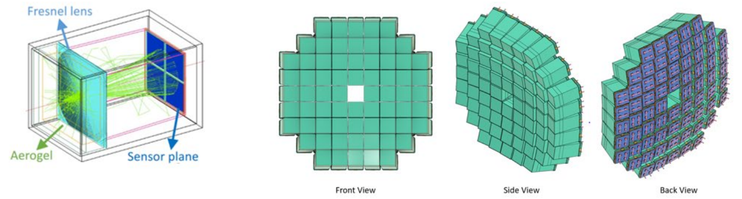
- Sensors, electronics and cooling (~ same instrumeted area)

Small cost difference come from:

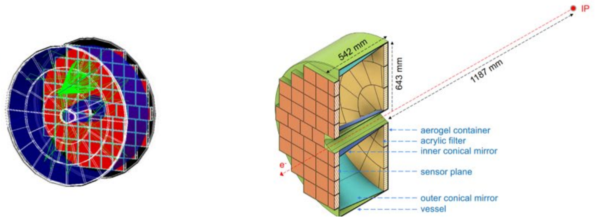
- Different aerogel thickness and refractive index
- Different mechanical design
- Different characteristics of the mirrors

→ 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.

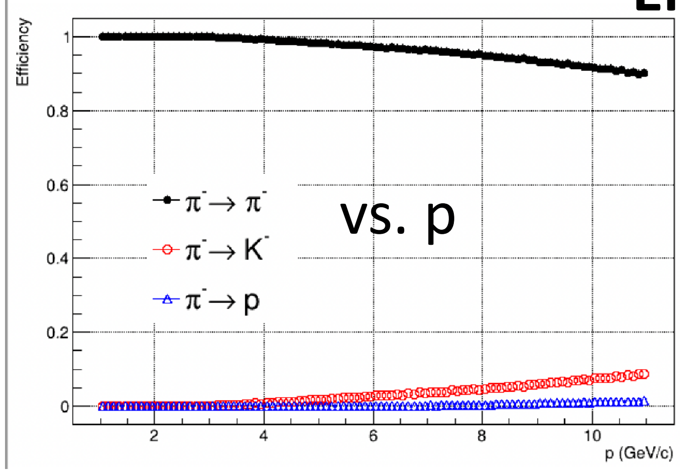
The recommendation of the pfRICH design for the ePIC backwards PID detector has the unanimous support of the Executive Board.

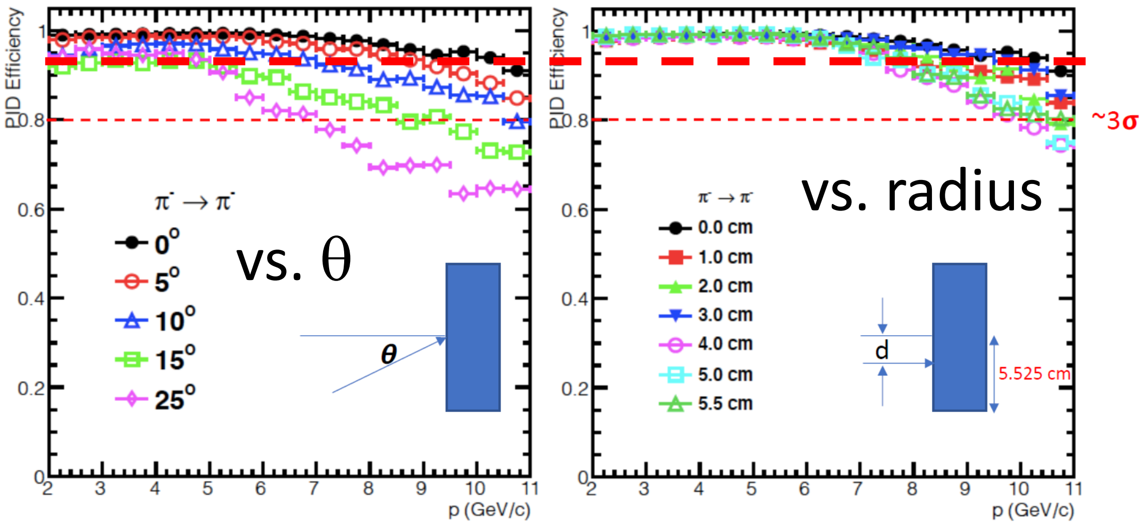
BACKUP SLIDES

HADRON PID PERFORMANCE

mRICH

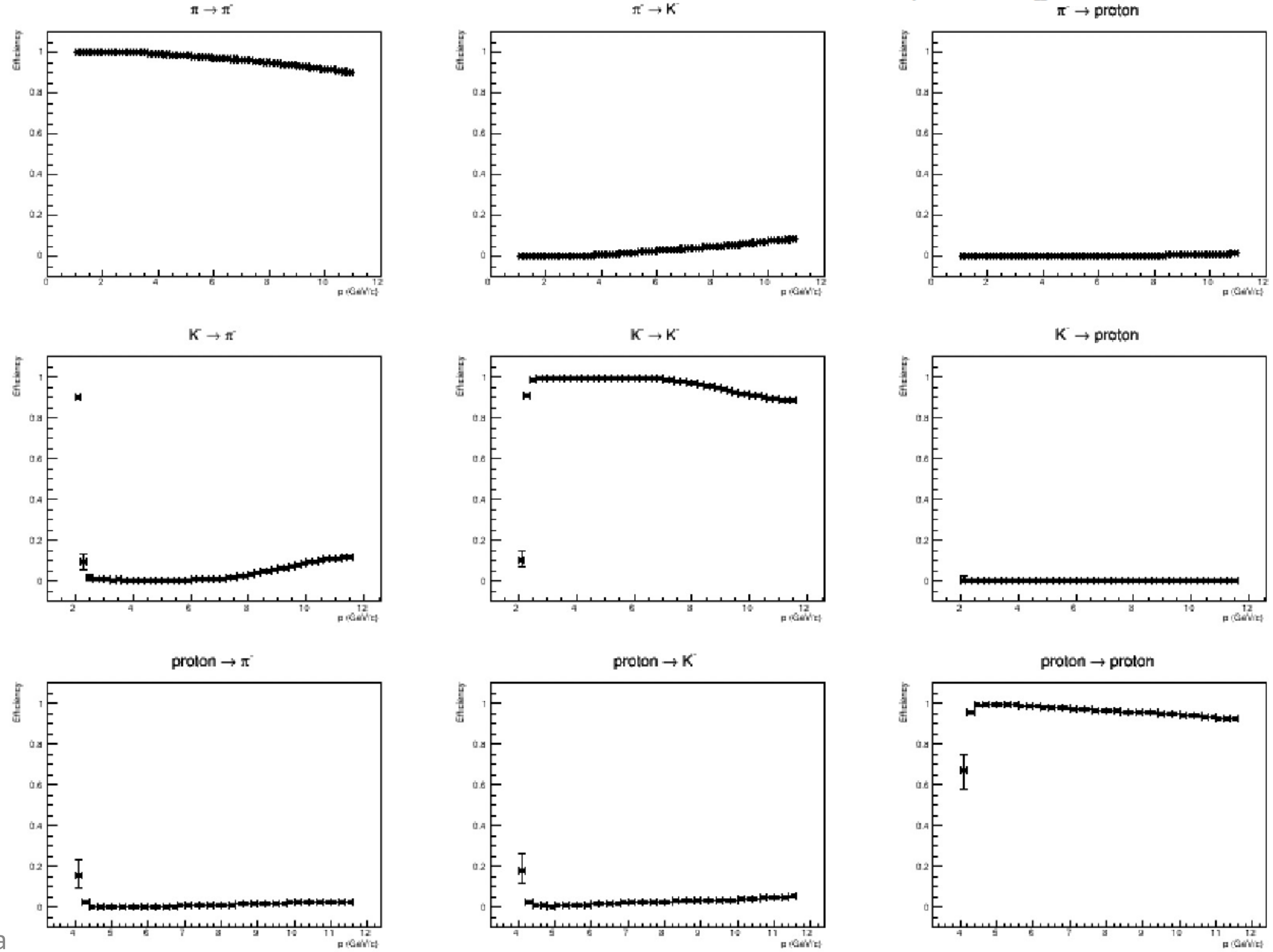
Efficiency and purity





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

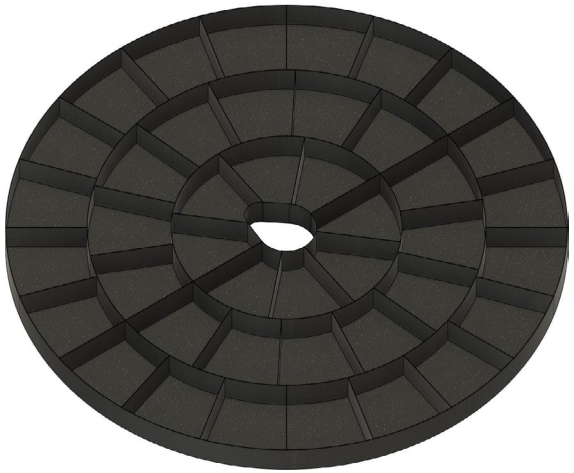
Efficiency figures: single particle Pi/Kaon/Proton identified as Pi/Kaon/Proton as a function of the truth momentum in a 3x3-panel figure?

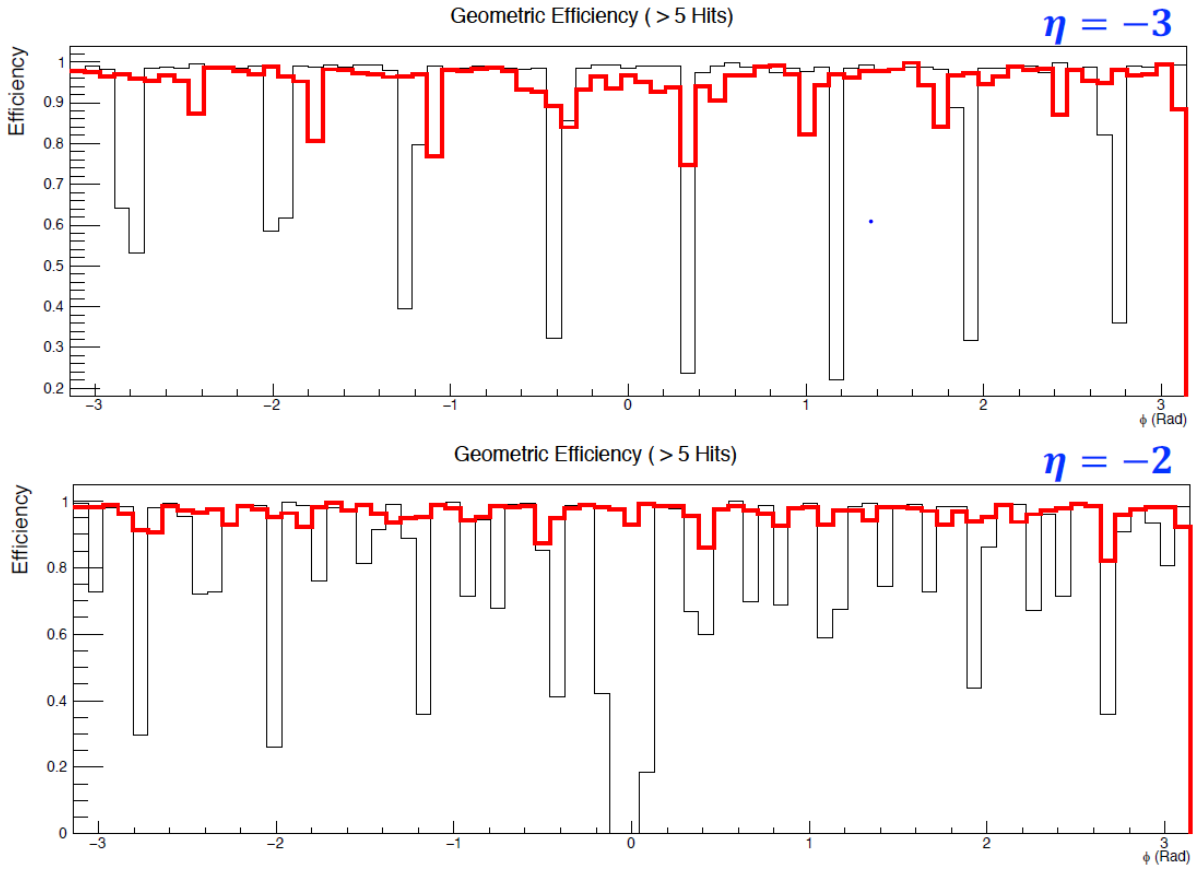


Timing Acceptance

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%

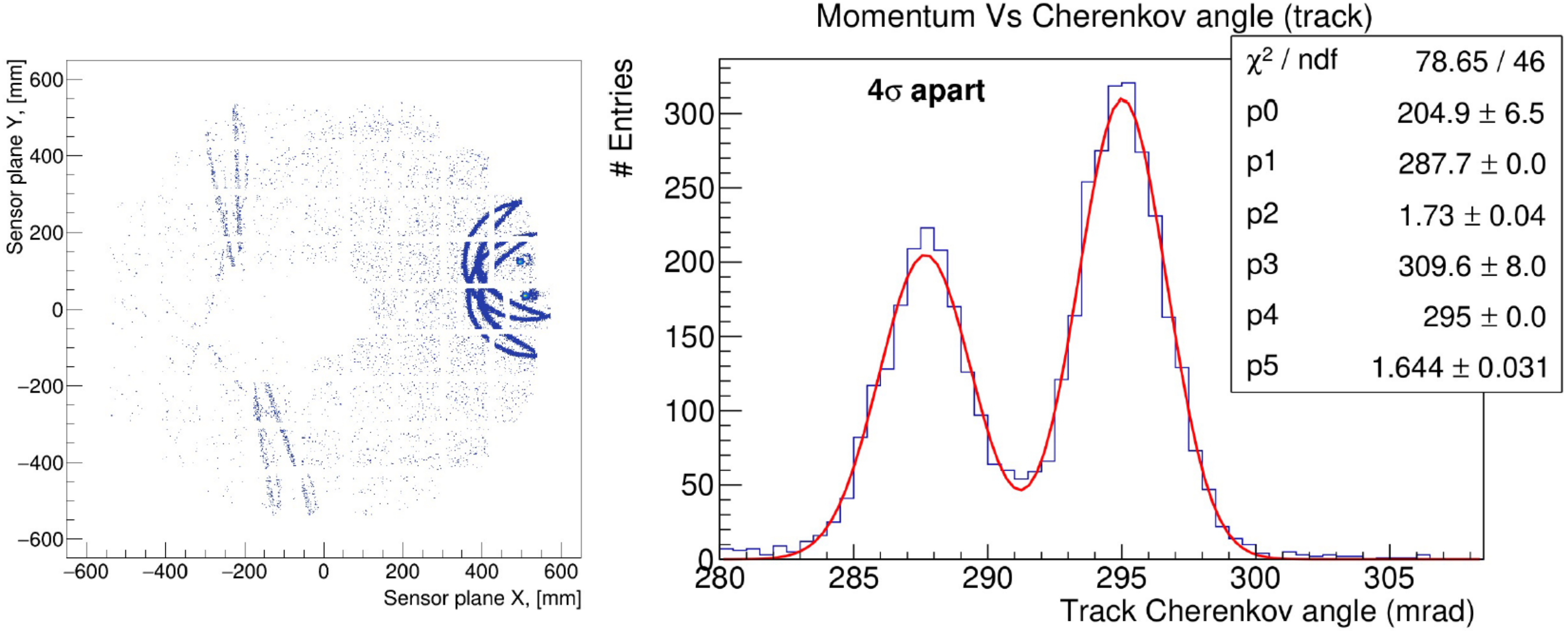
Approaching the performance in a realistic environment

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:

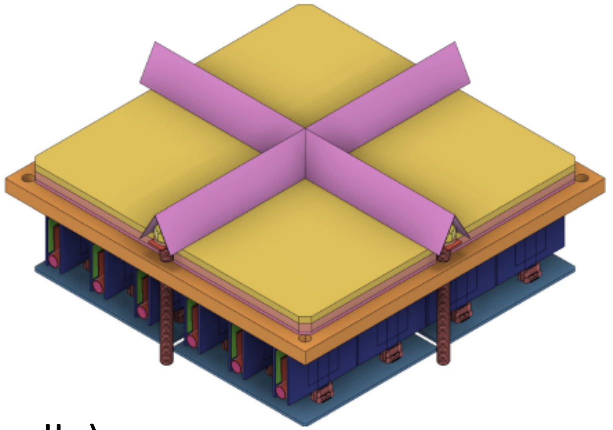
  Both teams should consider alternative options such as SiPM or Planacon MCP-PMT, as these alternative options may mitigate risk in the photodetector.

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)