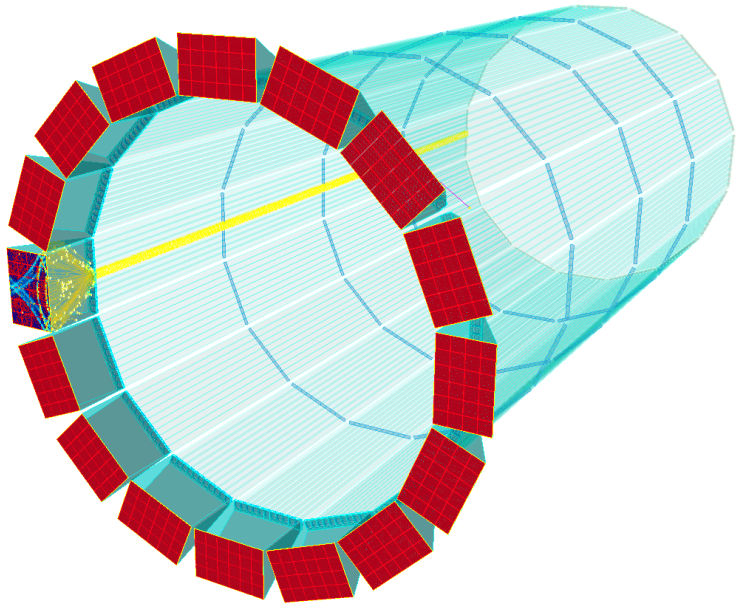
Development of a Novel Readout Concept for an EIC DIRC

Generic R&D for EIC: EICGENRandD ID 12



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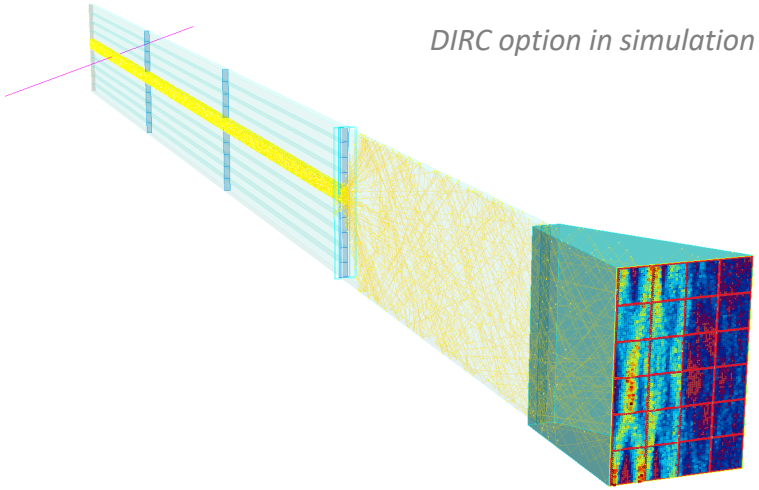
OUTLINE

Objective: Explore innovate optical DIRC configurations to create opportunities for cost reduction, performance improvement, and complementarity

- Reminder: ePIC hpDIRC design and performance
- Proposed generic R&D topics
  - Novel hybrid optics
    - Cost reduction
    - Potential use of SiPM
    - Complementarity
  - Thinner bars for low-mass DIRC
    - Reduced impact of DIRC material on EMCal
    - Improved DIRC e/π performance at low momentum
    - Complementarity
- Deliverables and budget

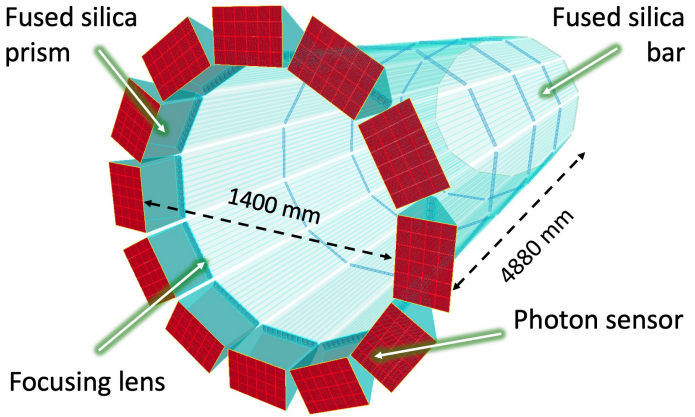


DIRC option in simulation

HPDIRC CONCEPT

hpDIRC R&D programs

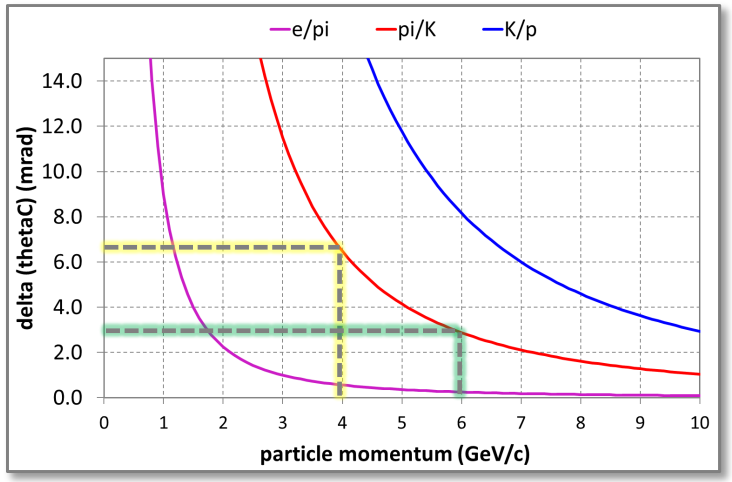
- Concept developed as part of previous Generic R&D program (eRD14)
- Finalizing design, validating components as part of Project R&D (eRD103)
- Future innovate optical DIRC configurations in new Generic R&D program



hpDIRC Concept:

- Fast focusing DIRC, utilizing high-resolution 3D (x,y,t) reconstruction
- Design based on BaBar DIRC, R&D for SuperB FDIRC, PANDA Barrel DIRC
- Radiator/light guide: narrow fused silica bars (radius/length flexible)
- Innovative 3-layer spherical lenses
- Compact fused silica prisms as expansion volumes
- Fast photon detection: small-pixel MCP-PMTs and high-density readout electronics
- Detailed Geant4 simulation: ≥ 3 s.d. π/K separation at 6 GeV/c,
  ≥ 3 s.d. e/π separation at 1.2 GeV/c

DIRC Cherenkov angle difference vs. momentum



BASELINE HPDIRC DESIGN FOR EPIC

- Radiator bars:
  - Size: 4580mm x 35mm x 17mm (L x W x T)
  - Barrel: 715mm radius, 12 bar boxes, 10 long bars per bar box

    long bar: 4 bars glued end-to-end, flat mirror on far end

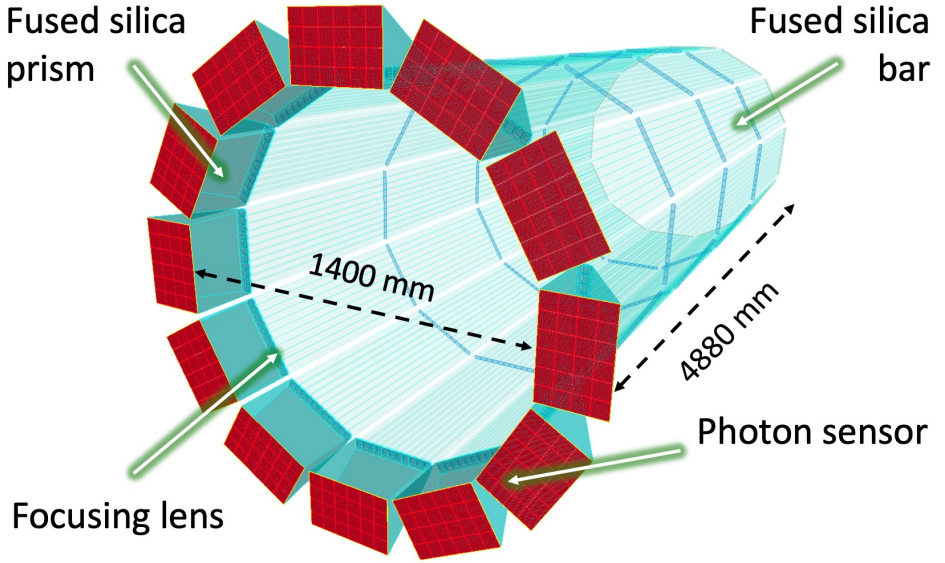
    baseline design: reuse of BaBar DIRC bars (R&D started)
- Focusing optics:

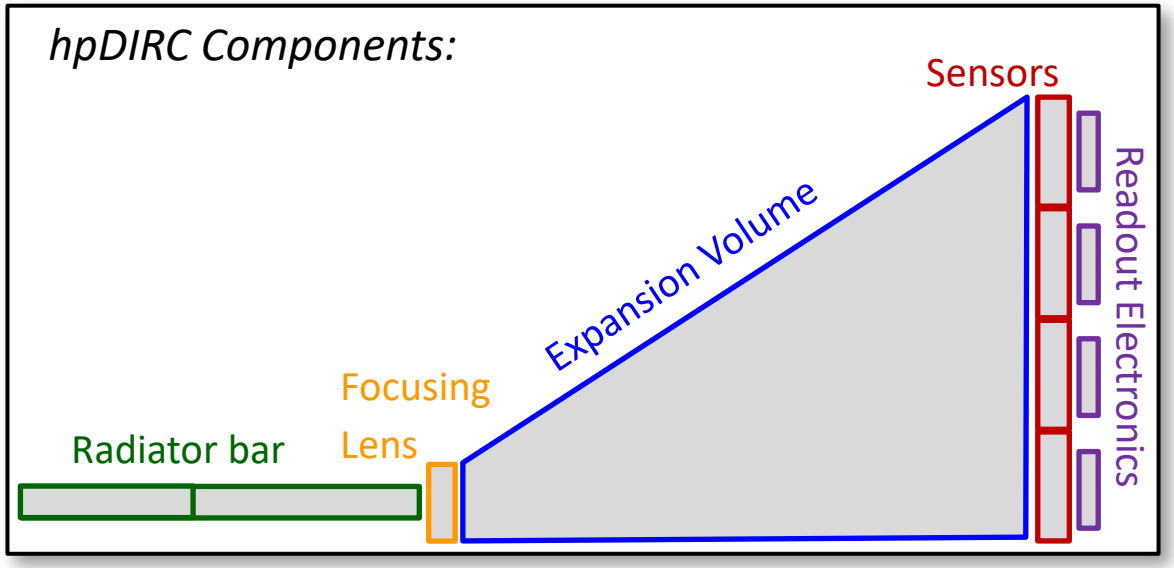
  Radiation-hard 3-layer spherical lens (sapphire or PbF_2)
- Expansion volume:

  Solid fused silica prism: 240 x 360 x 300 mm^3 (H x W x L)
- Readout system:

  MCP-PMT Sensors (e.g. Photek/Photonis/Incom)

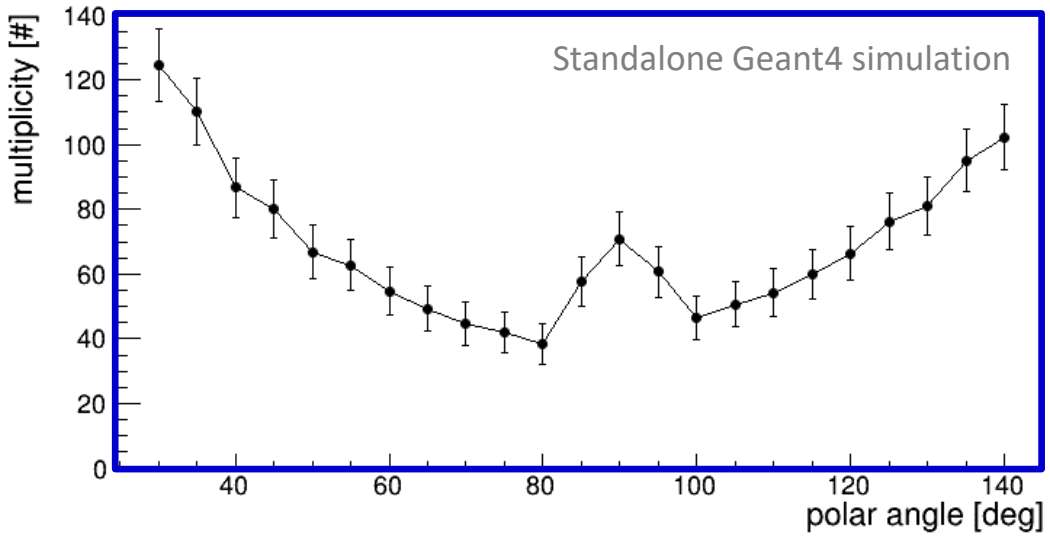
  ASIC-based Electronics (e.g UH/Nalu Scientific)
- Several core design aspects, as well as detailed Geant simulation, validated in PANDA Barrel DIRC beam tests (prototype tests in cosmic rays and test beams in preparation)



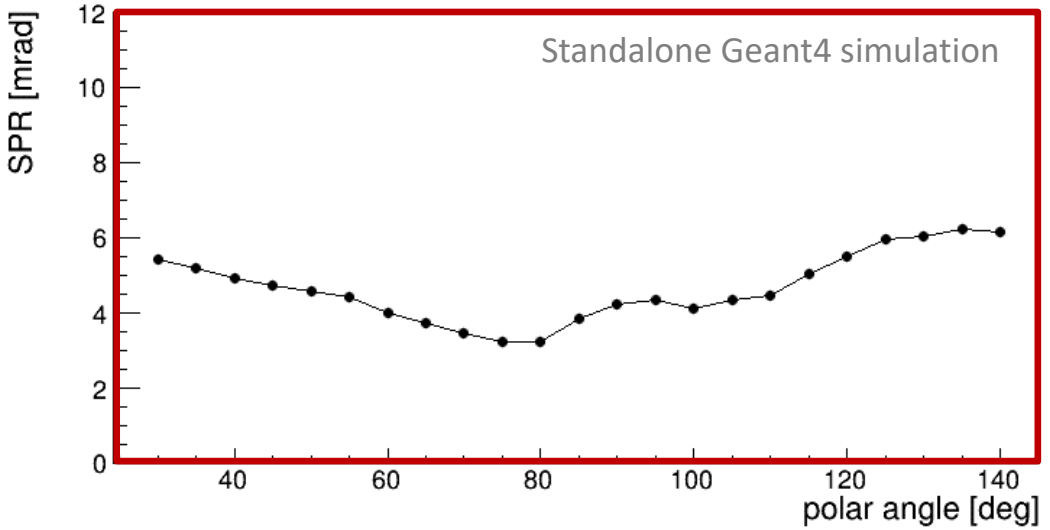


EXPECTED HPDIRC PERFORMANCE

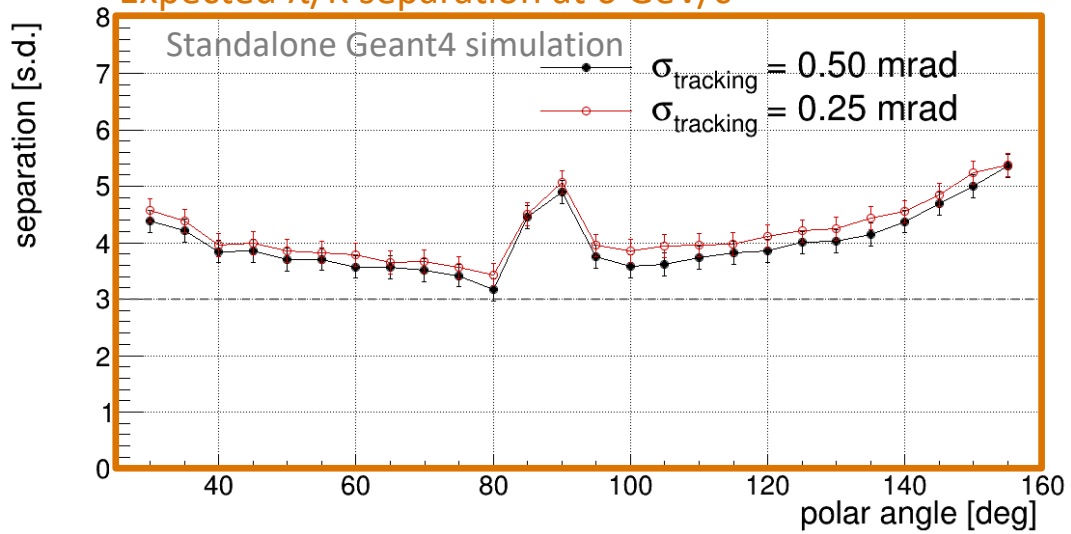
Photon yield per particle



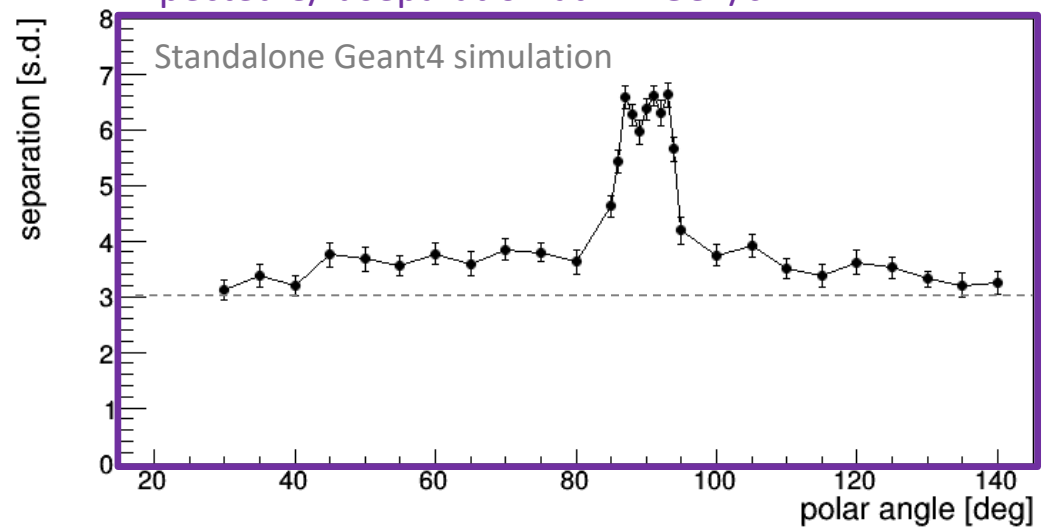
Cherenkov angle resolution per photon (SPR)



Expected π/K separation at 6 GeV/c



Expected e/π separation at 1.2 GeV/c



→ expect 3 s.d. separation for π/K up to at least 6 GeV/c and for e/π up to 1.2 GeV/c

ERD103 R&D PLANS

Validation of the BaBar DIRC bar reuse (JLab activity):

- BaBar bar box transfer from SLAC to JLab
- Disassembly of the bars
- Validation of mechanical and optical bar quality in QA laser setup

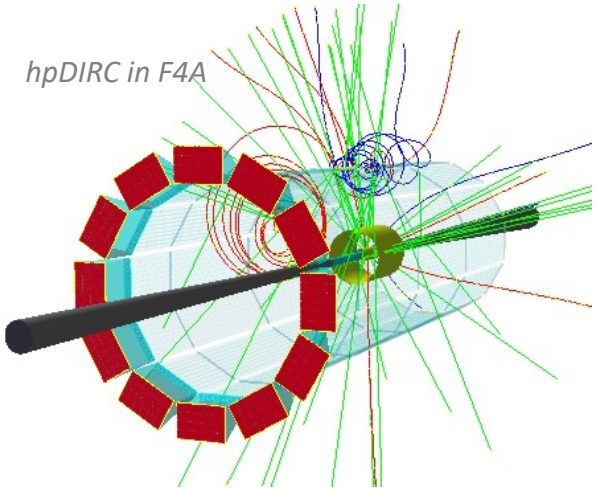
BaBar DIRC bars

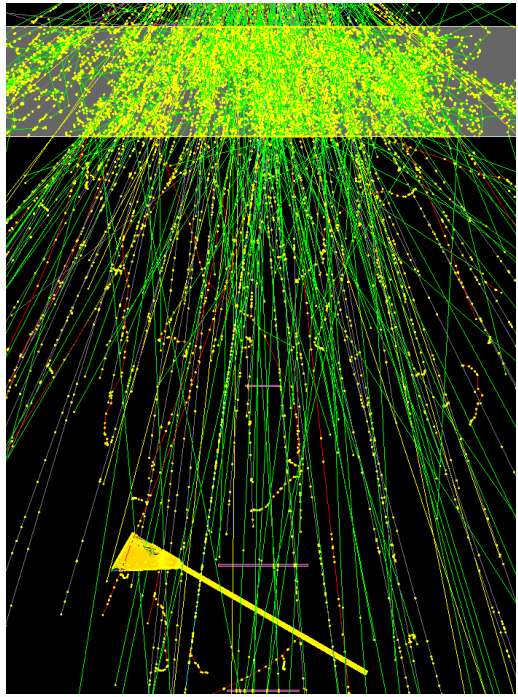
DIRC barboxes in SLAC

hpDIRC studies in simulation:

- Study of the hpDIRC performance with background and magnetic field in the full ePIC simulation

hpDIRC in F4A





hpDIRC prototype program:

- Modular hpDIRC prototype in Cosmic Ray Telescope at SBU
- Incremental hpDIRC optical components integration and evaluation
- Adaptation and evaluation of sensors and readout electronics in hpDIRC prototype
- Conclusion of prototype program with final cost/performance-optimized hpDIRC design

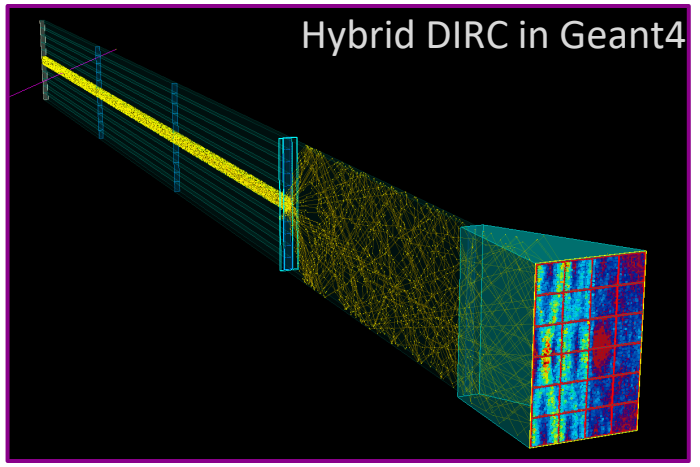
DIRC lab/CRT space at SBU

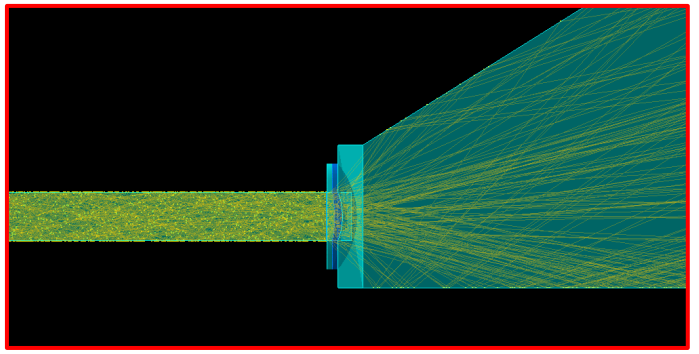
xpDIRC R&D Overview

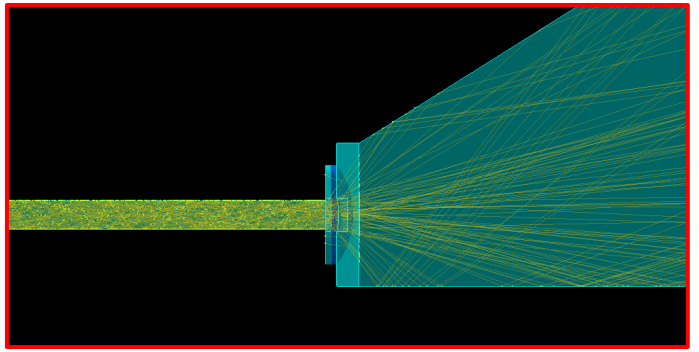
hpDIRC baseline design performance matches requirements for ePIC.

Reuse of BaBar DIRC bars limits ePIC hpDIRC design options, propose to explore novel optical designs ("xpDIRC") in generic R&D program.

- Hybrid optics in different focusing lens configurations
  - Reduce cost
  - Potential for smaller prism (may enable SiPM application)
  - Potentially improve DIRC performance at high momentum
  - Provide complimentarity to ePIC hpDIRC
- Thinner bars
  - Improve DIRC performance at low momentum
  - Reduce impact on EMCal performance
  - Provide complimentarity to ePIC hpDIRC





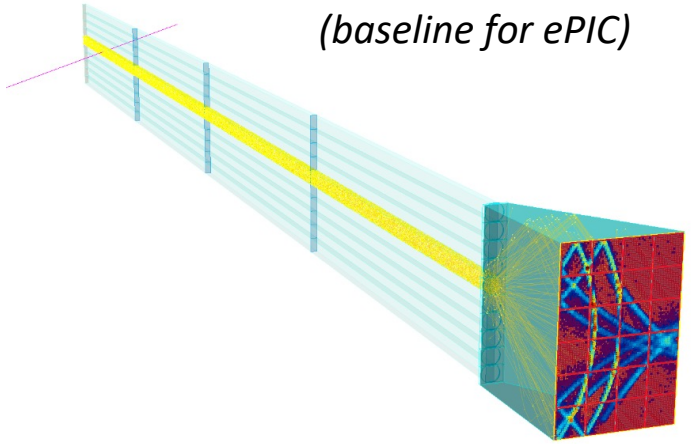


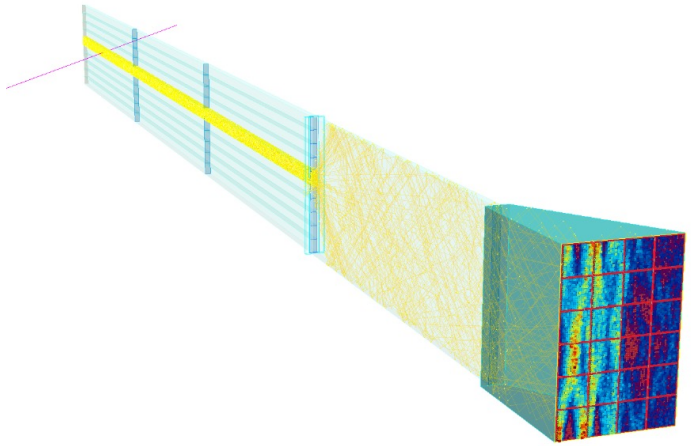
LIGHT GUIDE SECTION

- ePIC detector barrel length requires additional fused silica bars or plate ("light guide") to connect BaBar DIRC bars to prism
- Narrow bars could be ordered from industry or, possibly, produced by cutting and repolishing BaBar DIRC bars
- Alternative: one single short wide plate as transition light guide between BaBar DIRC bars and prism
- Plate would significantly reduce cost compared to new narrow bars and potentially improve hpDIRC performance

Geant4 visualization of the two options

Narrow bars in each sector
(baseline for ePIC)



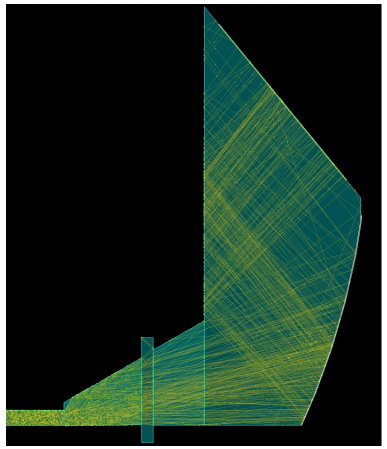


Hybrid of bars and plate in each sector

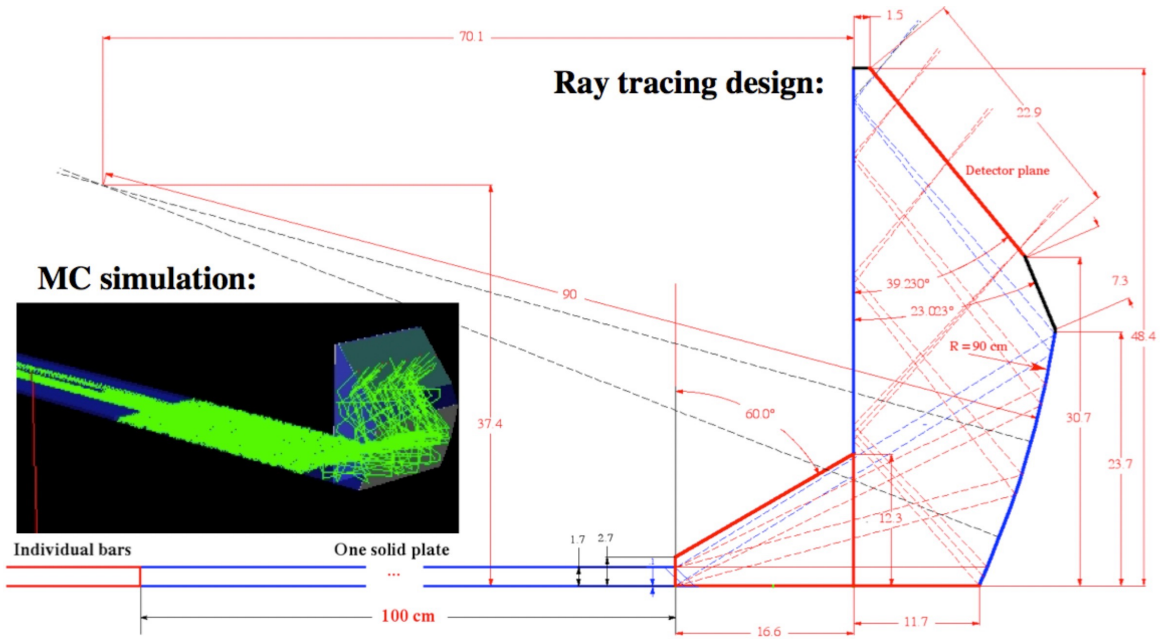
LIGHT GUIDE SECTION

- The ultimate fDIRC concept introduced for SuperB in 2016
- BaBar DIRC bars + wide plate + focusing block
- Narrow bars in "active area" ensure robust performance in multi-track events
- Wide plate as "light guide" section effectively part of the expansion volume in horizontal direction, provides better angular precision
- Simulation performance promising, experimental validation needed
- DIRC@EIC considers lens focusing and prism instead of mirror focusing and block from ultimate fDIRC

Geant4 visualization of ultimate fDIRC



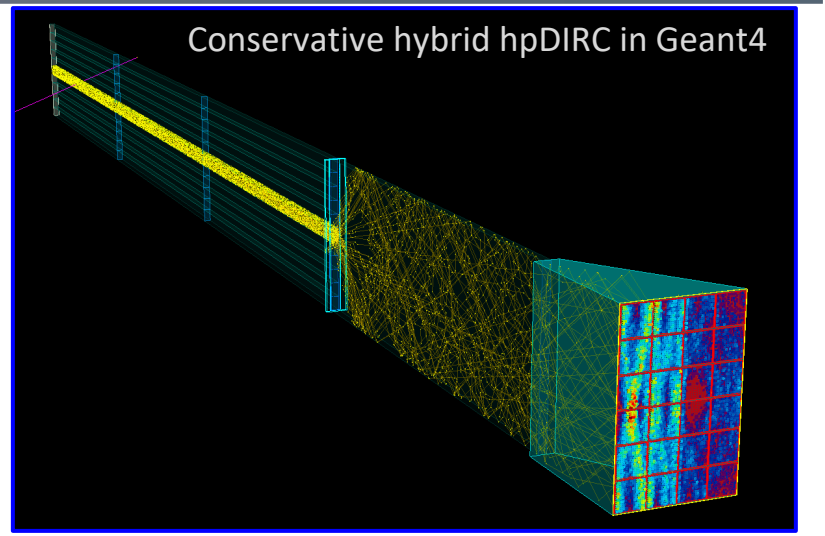
J. Va'vra et al., RICH 2016, doi.org/10.1016/j.nima.2017.02.044

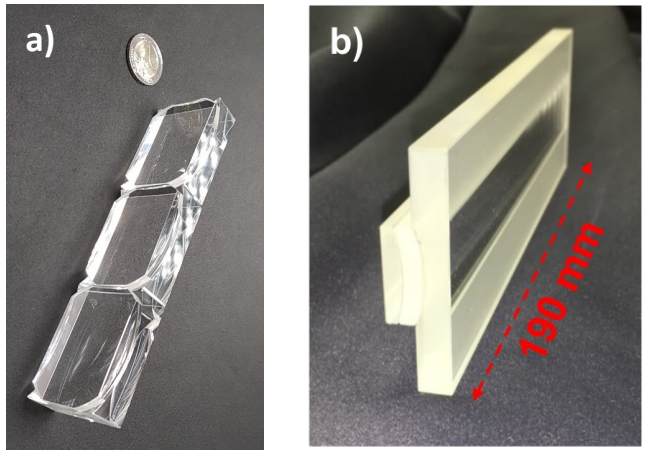


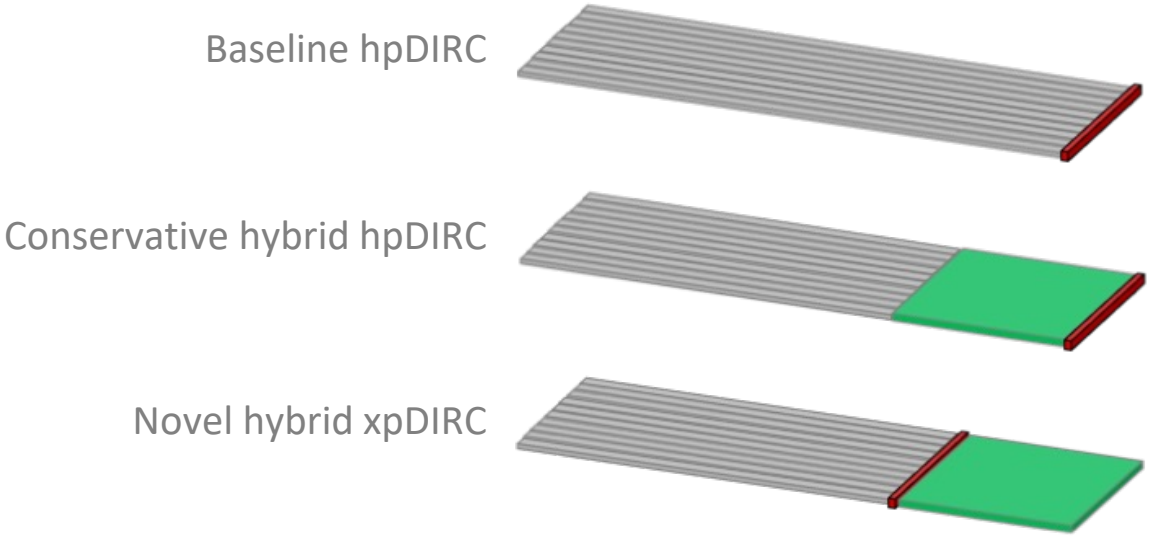
B. Ratcliff, J. Va'vra, doi.org/10.1016/j.nima.2020.163442

Novel Hybrid DIRC Design

- Lens position:
  - Conservative hybrid hpDIRC: bar-plate-lens configuration
  - Novel hybrid xpDIRC: bar-lens-plate configuration
- Plate serving as pre-expansion volume may allow smaller prism, decrease material budget and improve integration
- Two options for xpDIRC focusing: spherical or cylindrical

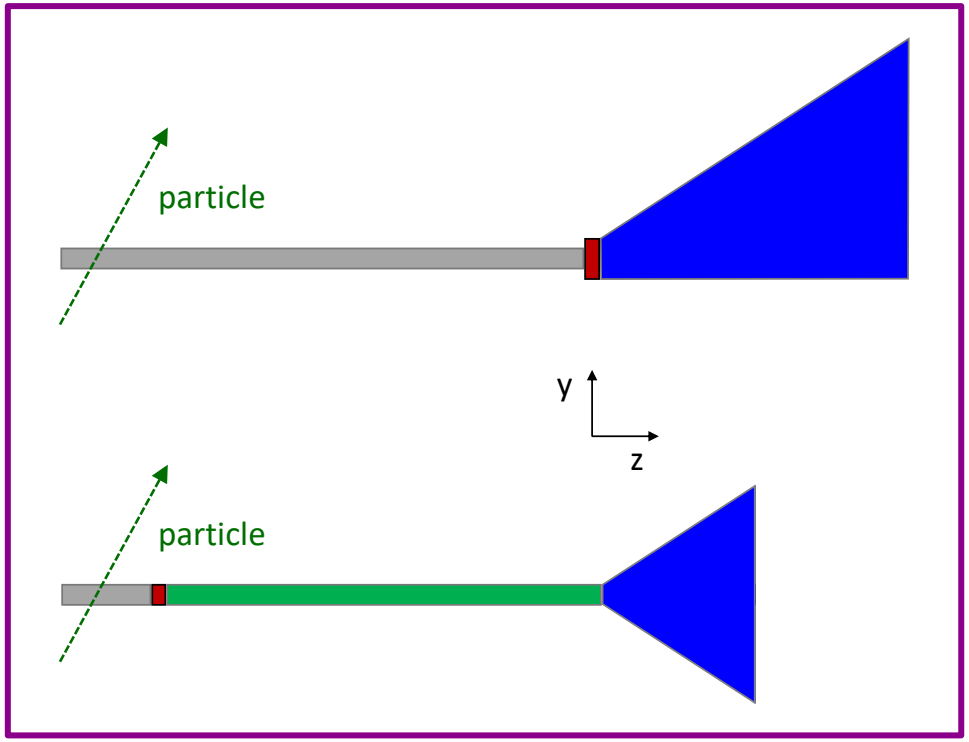


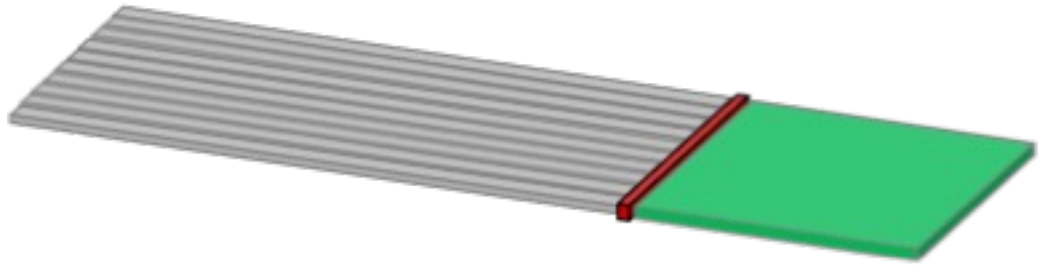




Novel Hybrid xpDIRC Design

- Bar-lens-plate option increases the effective expansion distance
- Potential performance improvement
- Spherical and cylindrical focusing lens options possible
- Potential redesign of the prism: change opening angle and/or decrease prism length - reduce material budget and sensor area
- SiPM may become a more realistic option for DIRC
- The reconstruction algorithms will require adjustment to deal with more complex hit patterns
- Plate thickness may need to be increased to retain photon yield

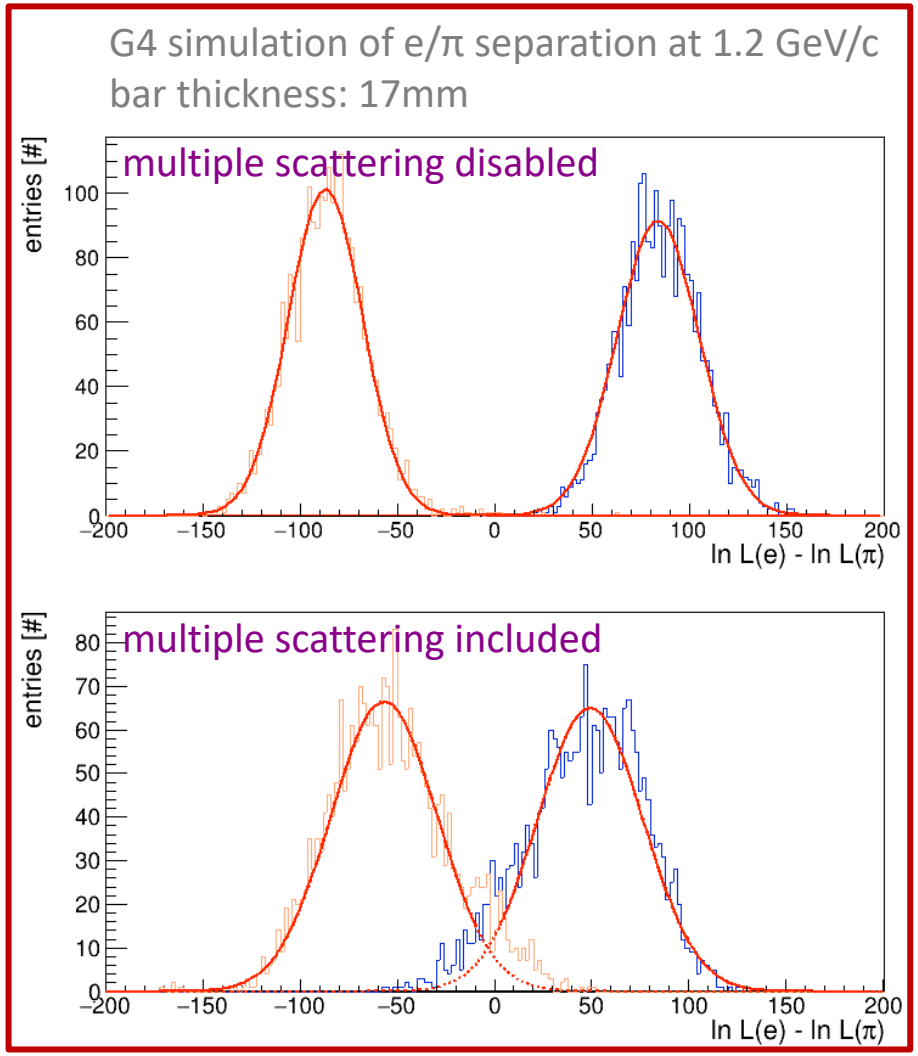




Low-Mass Thin xpDIRC

Key features of low-mass thin xpDIRC *(10mm example):*

- 41% reduction in mass benefits the EMCal performance
- Multiple scattering in the DIRC bar limiting factor for hpDIRC performance at lower momentum and at high momentum
- Potential for significant e/π ID improvement around 1 GeV/c, without significantly affecting π/K ID above 4 GeV/c
- Smaller bar thickness simplifies focusing lens design/performance



Challenges:

- Lower photon yield
- More complicated fabrication – but production of large 10 mm-thin fused silica radiator bars/plate by industry feasible (1250 x 660 x 10 mm^3 prototype plate produced by Nikon for LHCb TORCH DIRC

LOW-MASS THIN XPDIRC

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- Multiple scattering in the DIRC bar limiting factor for hpDIRC performance at lower momentum and at high momentum
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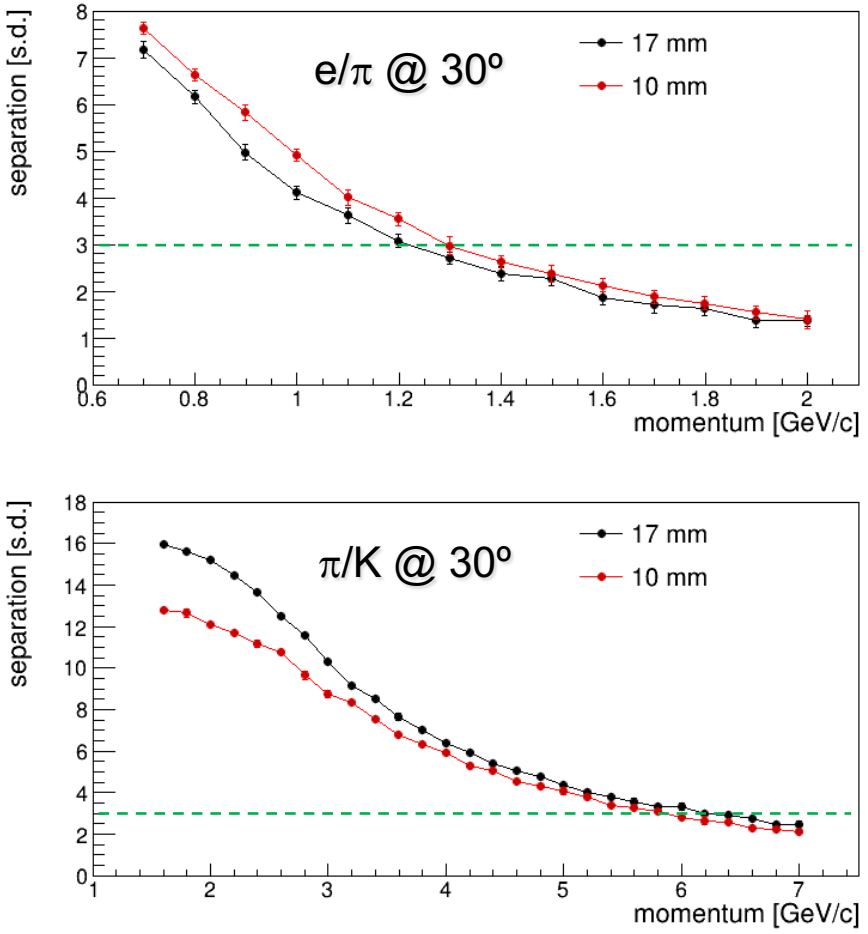
- Smaller bar thickness simplifies focusing lens design/performance

Challenges:

- Lower photon yield
- More complicated fabrication – but production of large 10 mm-thin fused silica radiator bars/plate by industry feasible (1250 x 660 x 10 mm^3 prototype plate produced by Nikon for LHCb TORCH DIRC

G4 simulation performance of 10mm and 17mm options of hpDIRC (CORE scenario)



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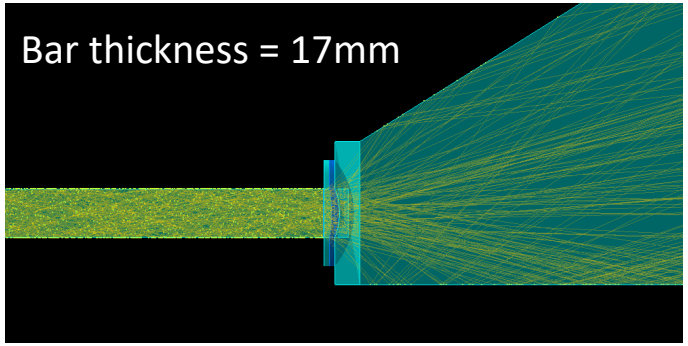

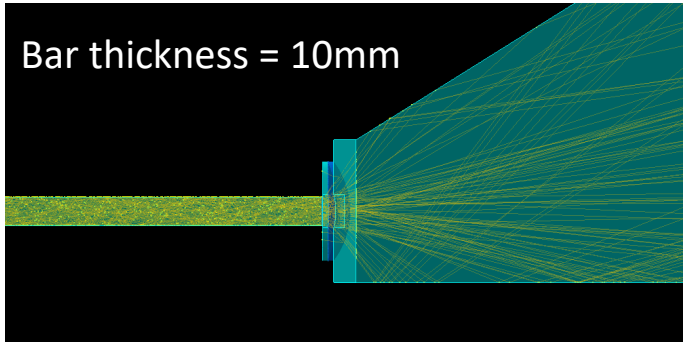

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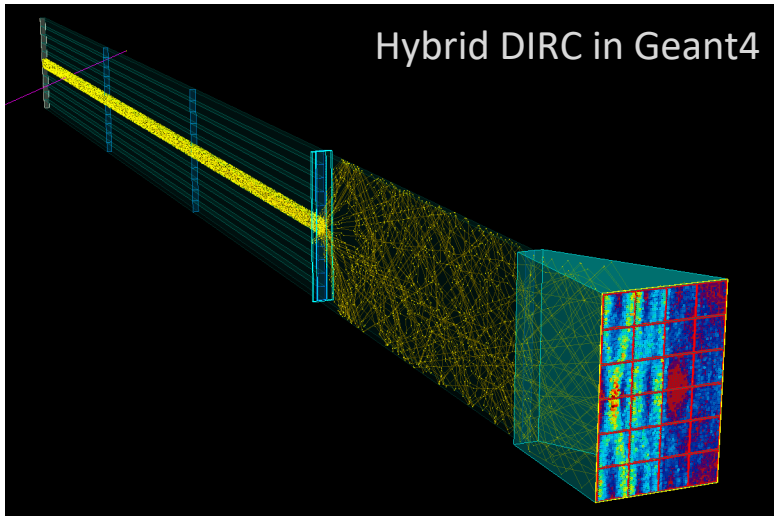
10 mm–thick LHCb TORCH prototype

xpDIRC R&D Activities

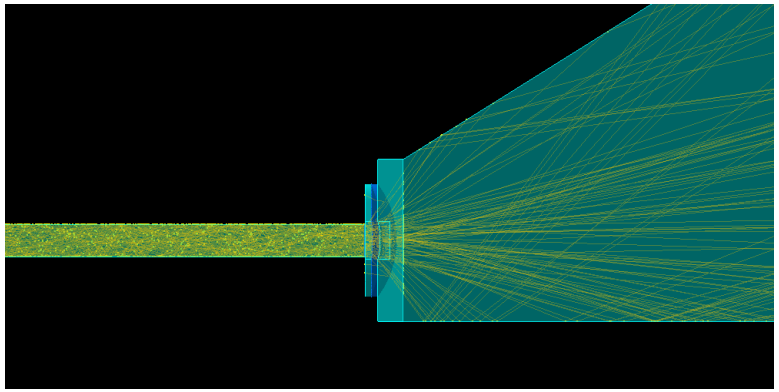
FY 23

- Evaluation of the performance of the hpDIRC/xpDIRC hybrid geometry (G4)
  - Narrow bars with wide plate, impact on light-guide section decision for Detector-1
  - Narrow bars with wide plate and new focusing optics, impact on design of xpDIRC for Detector-2



FY 24

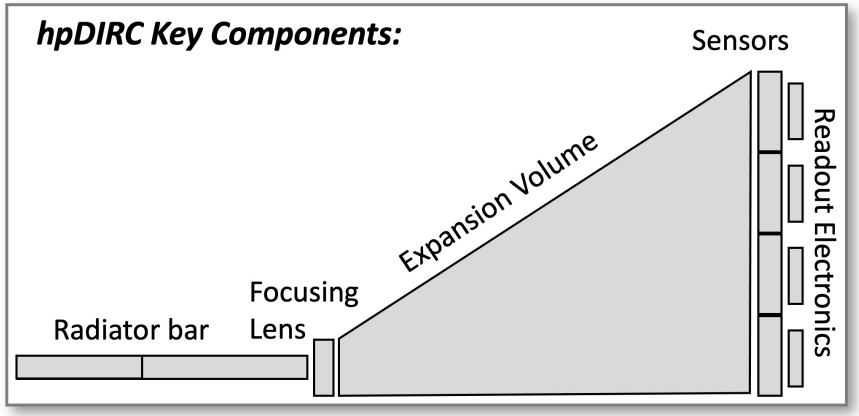
- Evaluation of the DIRC performance with thinner bars (G4)
- Evaluation of the performance of the xpDIRC geometry with a small and/or narrow expansion volume, with SiPM readout (G4)
  (modeling of SiPM response to radiation damage based on input from experts, cooling annealing requirements)

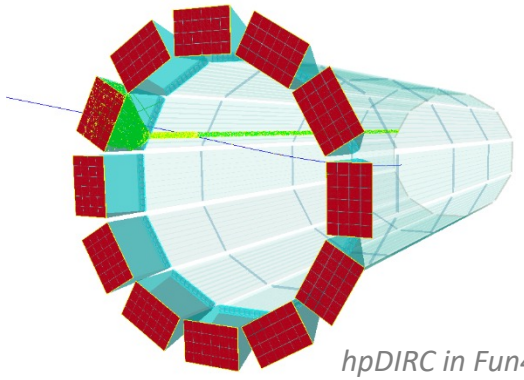


FY 25

- Requirements of SiPM performance parameters (dark noise and after-pulsing) for xpDIRC with SiPM readout (G4)
- Experimental validation of xpDIRC geometry aspects (eRD103 synergy) using available lenses/prisms (or procuring new components)

HPDIRC ROADMAP TOWARDS TDR READINESS





hpDIRC in Fun4All

Category	Subject	Comments	Program
Design in simulation	Lightguide section	Narrow bar vs. wide plate	Generic R&D
	Cost/performance optimization	Sensor coverage	eRD103
	Expansion volume	Geometry details	eRD103, Generic R&D
Optics	Radiator bars	Reuse of BaBar bars	JLab DSG and CUA
	Focusing optics	Radiation-hard 3-layer lens	eRD14, eRD103
Readout	Sensors	Baseline identified, alternatives being studied	eRD14, eRD110, Incom SBIR, eRD103, (Generic R&D)
	Readout electronics	UH/Nalu solution based on Belle II TOP	Nalu and Incom SBIRs, eRD109, eRD103
Construction	Mechanical design	Materials and integration	Synergy with PANDA Barrel DIRC

FY23 Budget Request

2023 Plan:

- Adding and training new member(s) to DIRC@EIC group
- Developing simulation based on existing standalone Geant4 framework
- Working on the reconstruction algorithms to deal with more complex hit patterns
- Evaluation of the hpDIRC/xpDIRC hybrid geometry:
  - Narrow bars with wide plate (impact on light-guide section decision for Detector-1)
  - Narrow bars with wide plate and new focusing optics (impact on design of possible DIRC for Detector-2)

	100%	80%	60%
Postdoc, CUA, 50%	\$70k	\$0	\$0
Graduate student, CUA, 100%	\$0k	\$50k	\$50k
Undergraduate student, CUA, 100%	\$15k	\$15k	\$15k
Travel, CUA/GSI	\$10k	\$10k	\$0
Total	\$95k	\$85k	\$75k

QUESTIONS FROM THE COMMITTEE

Q1. How will the performance (in all respects) of the new geometry be assessed, relative to the baseline for Detector 1?

A1. We plan to perform the feasibility study and initial evaluation with the standalone simulation, which has been prepared to be used for this study. We will use the set of ”the usual” DIRC variables, from the single photon Cherenkov angle resolution and photon yield to the separation power. At a later state we plan to extend the study to include Fun4All or DD4Hep. This will allow us to add the PID efficiency and mis-ID as observables (which will be particularly relevant for the thinner bars, which reduce the effect of non-Gaussian tails from multiple scattering), to study the impact of multiple physics tracks in a plate, and to provide the geometry to the calorimeter groups for their study of the impact of the DIRC material.

QUESTIONS FROM THE COMMITTEE

Q2. Could you sketch out the cost-benefit analysis of how the pi/K separation power, smaller pixel array, SiPM usage, and impact on calorimetry (e.g. thinner bars) could be weighted in design choices?

A2. Given the exploratory nature of the proposed R&D, it is difficult to come up with a cost-benefit analysis scenario. Ultimately, the Detector-1 and -2 working groups will be involved in the decision, in particular when it comes to the impact on the calorimetry.

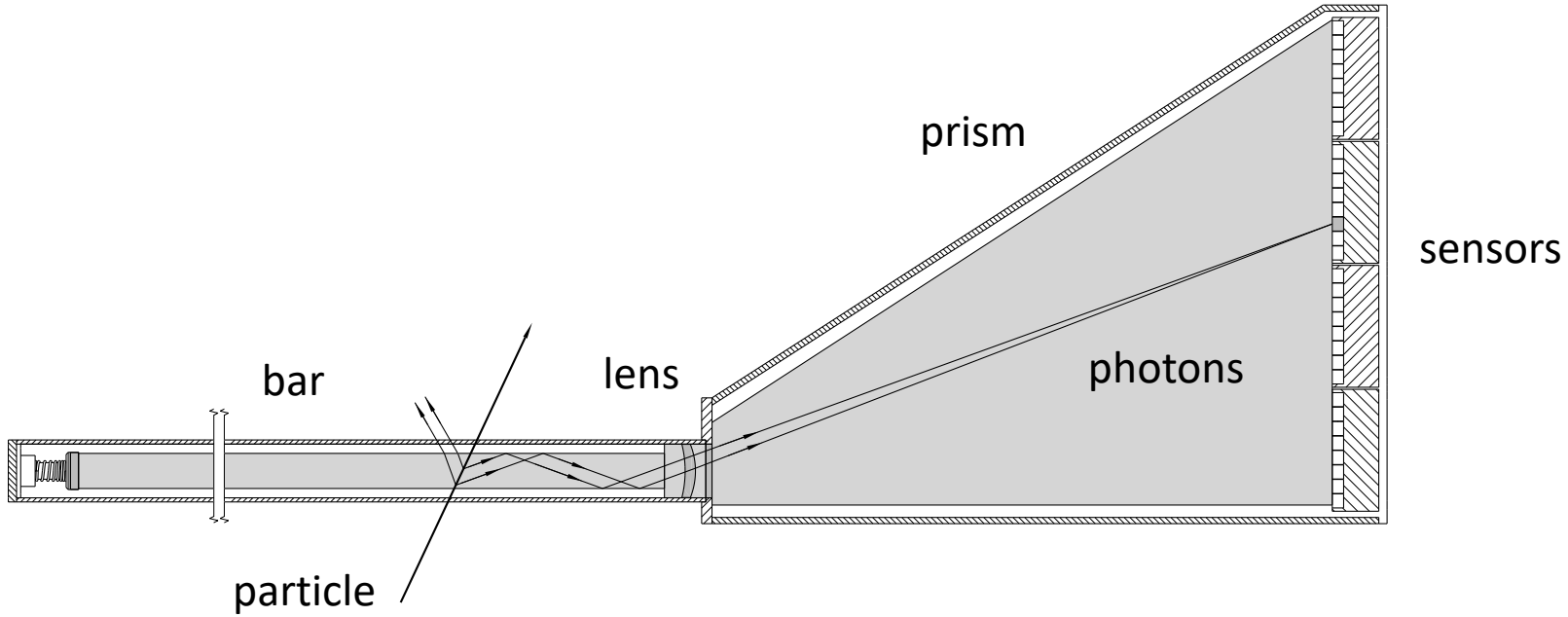
Q3. What cost reduction might be achieved in the best-case scenario?

A3. The outcome of the proposed R&D is difficult to predict. The cost reduction depends on details of the DIRC design for Detector-2. Savings will be larger for a longer ATHENA-type hpDIRC at larger radius, smaller for a CORE-type DIRC.

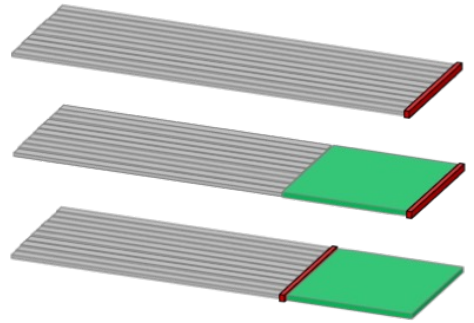
QUESTIONS FROM THE COMMITTEE

Q4. Can you sketch on Figure 2 the path of the Cherenkov photons along the midline of the bar? (The effect of the lens is not very obvious from the text.)

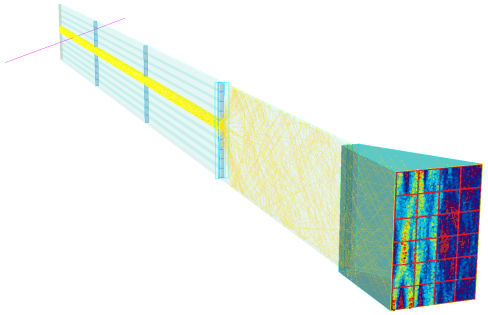
A4. In the side view sketch (updated with a coordinate system and a particle track direction) the focusing always starts at the lens. Due to the small size of the sketch, we did not manage to draw photon tracks into the bar/plate/lens/prism. We hope that the example of a larger sketch for the hpDIRC configuration is helpful to show the typical paths.



SUMMARY AND OUTLOOK



- Performance of hpDIRC baseline design good match to ePIC PID requirements
  but planned reuse of BaBar DIRC bars limits ePIC hpDIRC design options
- New proposal for generic DIRC R&D to explore innovate optical DIRC configurations
  to create opportunities for cost reduction, performance improvement, and complementarity
- Narrow bar/wide plate hybrid could reduce cost of light guides and improve the performance
- Novel hybrid lens configurations (xpDIRC) may enable designs with more compact prisms,
  reducing the material budget, potentially making SiPM a viable option for the xpDIRC
- Thinner bars reduce the DIRC material budget, lowering the impact on the EMCal;
  reduction of multiple scattering inside the bar could improve the DIRC e/π separation



Thank you all for your attention