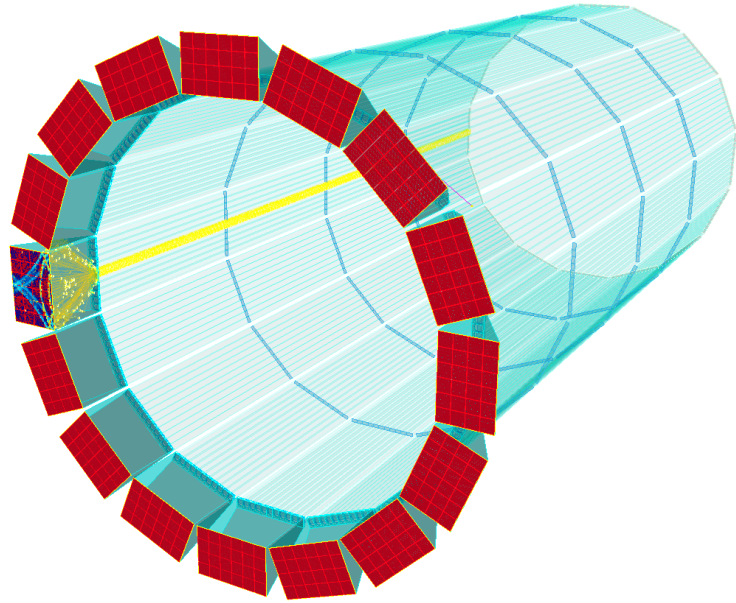
THE HIGH-PERFORMANCE DIRC FOR THE EIC



Jochen Schwiening

GSI Helmholtzzentrum für Schwerionenforschung GmbH

for the eRD14 hpDIRC group

- Status of the hpDIRC Activity
- Progress in 2020, Covid-19 Impact
- FY21 Plan and Budget Request

eRD14 – EIC PID consortium

An integrated program for particle identification (PID) for a future Electron-Ion Collider (EIC) detector

A suite of detector systems covering the full angular- and momentum range required for an EIC detector

- Different technologies in different parts of the detector
- Focus on hadron ID with an electron ID capability

A cost-effective sensor and electronics solution

- Development and testing of photosensors (to satisfy EIC requirements)
- Development of readout electronics needed for prototyping

Consortium synergies (including reduction of overall R&D costs)

- Close collaboration within the consortium, with coordinated goals and timelines (*e.g.*, DIRC & LAPPD, mRICH & dRICH, sensors and readout for prototype tests, etc).
- Strong synergies with non-EIC experiments and R&D programs (PANDA, CLAS12, GlueX, PHENIX, commercial LAPPDs) result in large savings.

Slide from P. Nadel-Turonski, R&D Committee Meeting, BNL, July 2019

eRD14 – EIC PID consortium

An integrated program for particle identification (PID)

for a future Electron-Ion Collider (EIC) detector

M. Alfred[1], P. Antonioli[32], W. Armstrong[11], B. Azmoun[2], F. Barbosa[3], L. Barion[8], W. Brooks[4], T. Cao[5], P. Chao[11], M. Chiosso[33], M. Chiu[2], E. Cisbani[6,7], M. Contalbrigo[8], S. Danagoulian[9], M.D. Da Rocha Rolo[33], A. Datta[10], A. Del Dotto[6], A. Denisov[13], J.M. Durham[14], A. Durum[13], R. Dzhygadlo[15], C. Fanelli[3,16], D. Fields[10], Y. Furletova[3], C. Gleason[18], M. Grosse-Perdekamp[19], J. Harris[20], M. Hattawy[21], X. He[22], H. van Hecke[14], T. Horn[23], J. Huang[2], C. Hyde[20], Y. Ilieva[24], S. Joosten[11], G. Kalicy[23], A. Kebede[9], B. Kim[25], J. Kim[11], E. Kistenev[2], A. Lehmann[29], M. Liu[14], R. Majka[20], J. McKisson[3], R. Mendez[4], M. Mirazita[34], I. Mostafanezhad[26,31], A. Movsisyan[8], P. Nadel-Turonski[12], M. Patsyuk[30], K. Peters[15], R. Pisani[2], R. Preghenella[32], W. Roh[22], P. Rossi[3], M. Sarsour[22], C. Schwarz[15], J. Schwiening[15], C.L. da Silva[16], N. Smirnov[20], J. Stevens[28], A. Sukhanov[2], X. Sun[22], S. Syed[22], R. Towell[10], Sh. Tripathi[26], C. Tuve[35], G. Varner[26], R. Wagner[11], N. Wickramaarachchi[23], C.-P. Wong[22], J. Xie[11], Z.W. Zhao[17], B. Zihlmann[3], C. Zorn[3]

Contacts: P. Nadel-Turonski, Y. Ilieva

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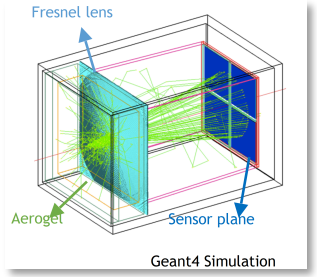
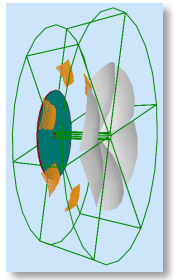
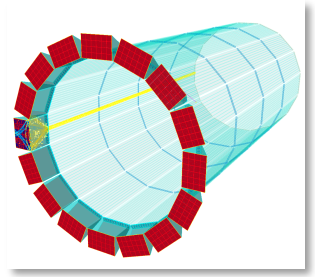
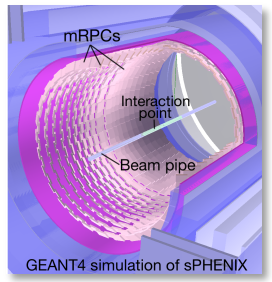
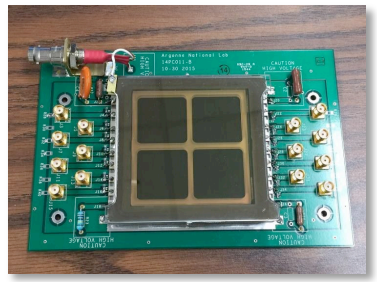
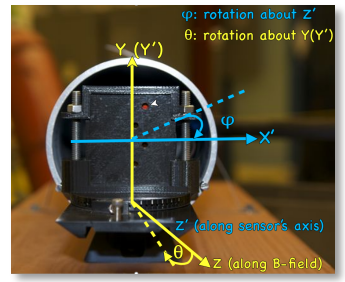


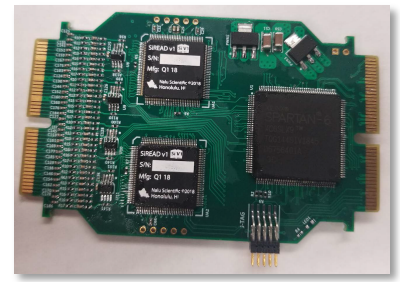








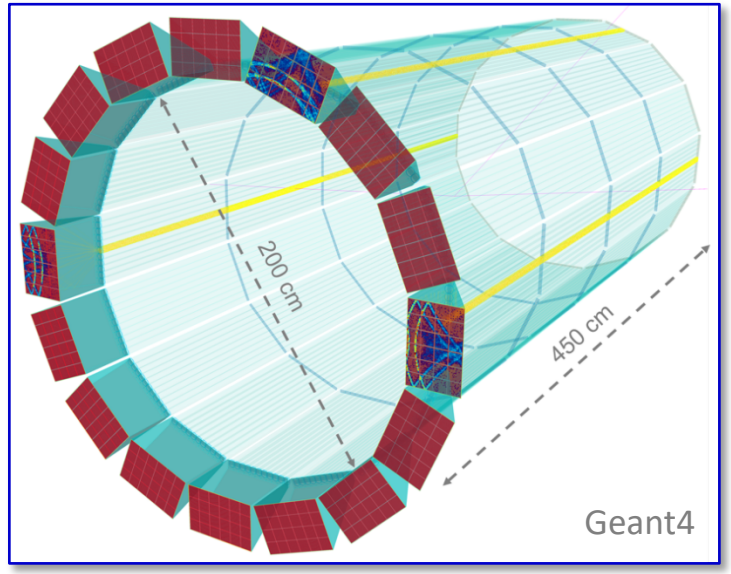




HPDIRC OVERVIEW

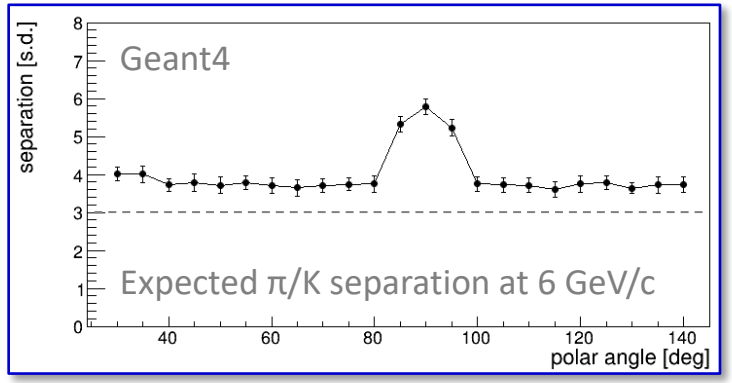
High-Performance DIRC Goal:

- To develop a very compact barrel EIC PID detector with momentum coverage reaching 6 GeV/c for π/K, pushing the performance well beyond the state-of-the-art for DIRC counters.



Concept:

- Fast focusing DIRC, utilizing high-resolution 3D (x,y,t) reconstruction
- Initial generic design: narrow fused silica bars, 1m barrel radius, 4.5m barrel length
  (barrel length and radius to be optimized for detector integration - no impact on DIRC PID)
- Innovative 3-layer spherical lenses, compact fused silica expansion volumes
- Fast photon detection using small-pixel MCP-PMTs *(eRD14)* and high-density readout electronics *(eRD14)*
- Detailed Geant4 simulation:
  40-120 detected photons per particle, ≥ 3 s.d. π/K separation at 6 GeV/c



HPDIRC GROUP

hpDIRC: part of the EIC Generic Detector R&D program since day one

- 2011-2015: eRD4 - DIRC-based PID for the EIC
- 2015-now: hpDIRC activity in eRD14

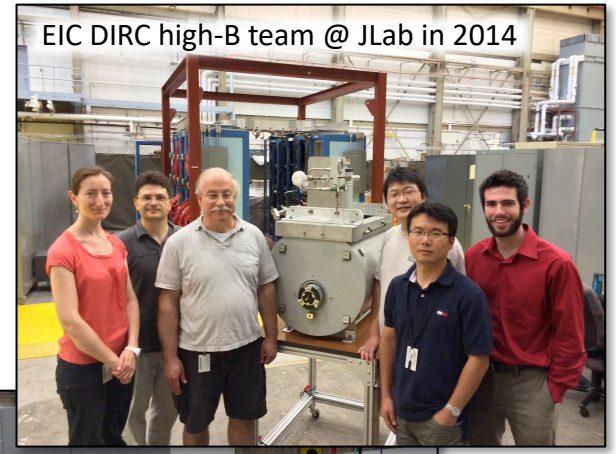
Cooperation between groups from USA and Germany

R. Dzhygadlo, Y. Ilieva, T. Hartlove, C. Hyde, G. Kalicy, A. Lehmann, P. Nadel-Turonski, M. Patsyuk, K. Peters, C. Schwarz, J. Schwiening, N. Wickramaarachchi, C. Zorn

CUA, FAU Friedrich-Alexander Universität Erlangen-Nürnberg, GSI, Jefferson Lab, Old Dominion University, University of South Carolina, Stony Brook University

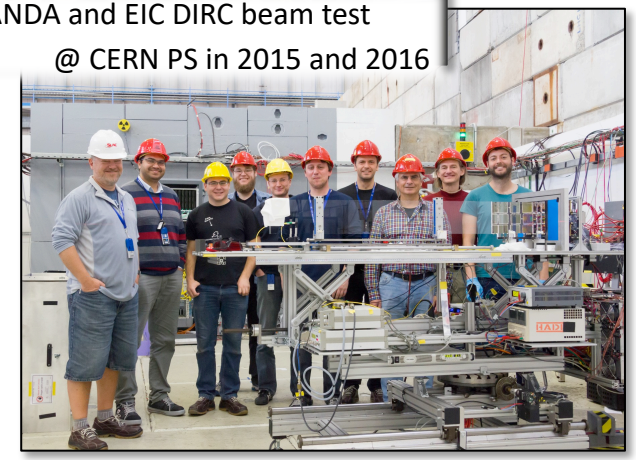
New members (since Sept. 2019 review)

- Albert Lehmann (Erlangen), MCP-PMT and DIRC expert, advising hpDIRC and high-B effort
- Nilanga Wickramaarachchi (CUA), new PostDoc, started June 2020, responsibilities: simulation, prototype evaluation, lens properties; funded (50%) by this program
- Maria Patsyuk (JINR Dubna), DIRC software expert (PANDA and GlueX), will start in September, specific simulation work package contracts from CUA; funded by this program



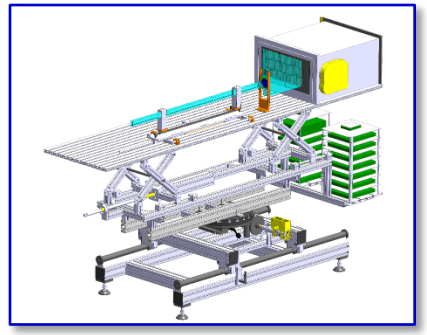
EIC DIRC high-B team @ JLab in 2014

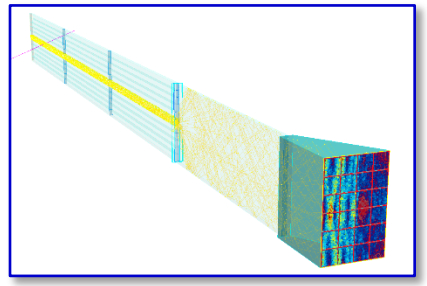
PANDA and EIC DIRC beam test @ CERN PS in 2015 and 2016



HPDIRC ACTIVITY OVERVIEW

FY 20 Activities proposed at July/Sep 2019 meetings:





- Strengthen DIRC team, add new PostDoc for simulation, prototype evaluation
- Transfer of PANDA DIRC prototype from Germany to the U.S.
- Finalize radiation hardness study of candidate lens materials using neutron and gamma sources
- Upgrade laser setup for characterization of the lens prototypes
- Develop Geant simulation of alternative hpDIRC designs and hpDIRC prototype in beam test environment
- Study feasibility of "mini-DIRC" for near-beam ion identification

Committee findings and recommendations from Sep 2019 and Jan 2020 reports (highlights):

- Complete transfer of prototype to U.S., investigate "ultimate DIRC" design option, postpone "mini-DIRC" study
- Prior to planned prototype beam tests: sharpen focus, define planned measurements and required components
- Investigate use of Cosmic Ray Telescope facility as alternative to particle beams

HPDIRC ACTIVITY OVERVIEW

FY 20 Activities proposed at July/Sep 2019 meetings:

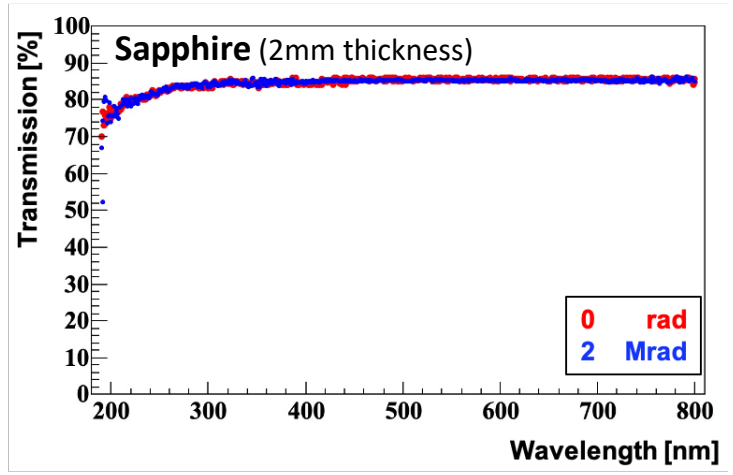
- Strengthen DIRC team, add new PostDoc for simulation, prototype evaluation — completed
- Transfer of PANDA DIRC prototype from Germany to the U.S. — progress, delayed
- Finalize radiation hardness study of candidate lens materials using neutron and gamma sources — progress, ongoing
- Upgrade laser setup for characterization of the lens prototypes — progress, near complete
- Develop Geant simulation of alternative hpDIRC designs and hpDIRC prototype in beam test environment — delayed, starting now
- Study feasibility of "mini-DIRC" for near-beam ion identification — postponed
- Important contributions to EIC Yellow Report PID detector working group — additional task

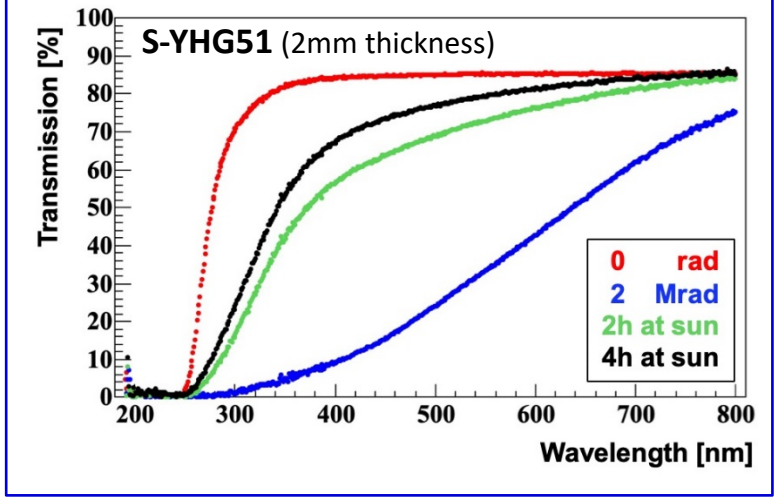
Committee findings and recommendations from Sep 2019 and Jan 2020 reports (highlights):

- Complete transfer of prototype to U.S., investigate "ultimate DIRC" design option, postpone "mini-DIRC" study ☑
- Prior to planned prototype beam tests: sharpen focus, define planned measurements and required components ☑
- Investigate use of Cosmic Ray Telescope facility as alternative to particle beams

Hardware: Lens radiation hardness evaluation

- Study of lens material candidates with ^{60}Co source and monochromator at BNL close to complete
- Materials exposed to doses up to 2 Mrad
- Radiation hardness of Sapphire and PbF_2 confirmed *(previously reported)*
- Initial photo-annealing and luminescence observations require follow-up measurements this summer and in FY21
- Neutron damage study up next, preparing run at Fast Neutron Irradiation Facility at University of Massachusetts Lowell this summer/fall
- Transmission after neutron irradiation will be measured at BNL, followed by additional ^{60}Co gamma irradiation to investigate possible combined effects
- Significant Covid-19 delay but still on track for journal publication in FY21

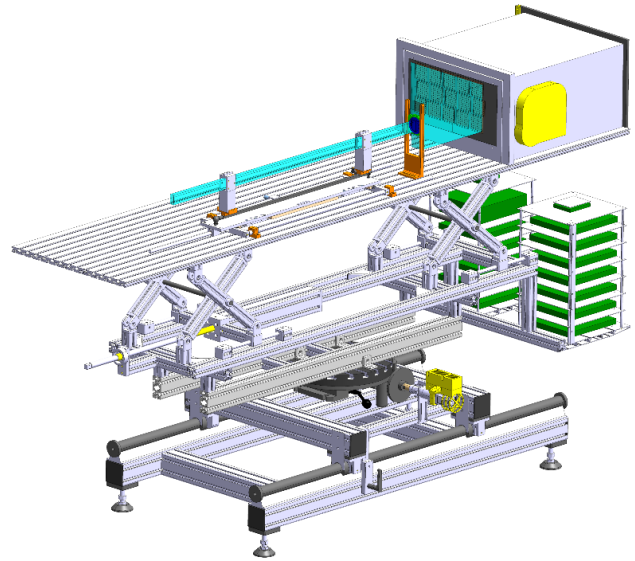




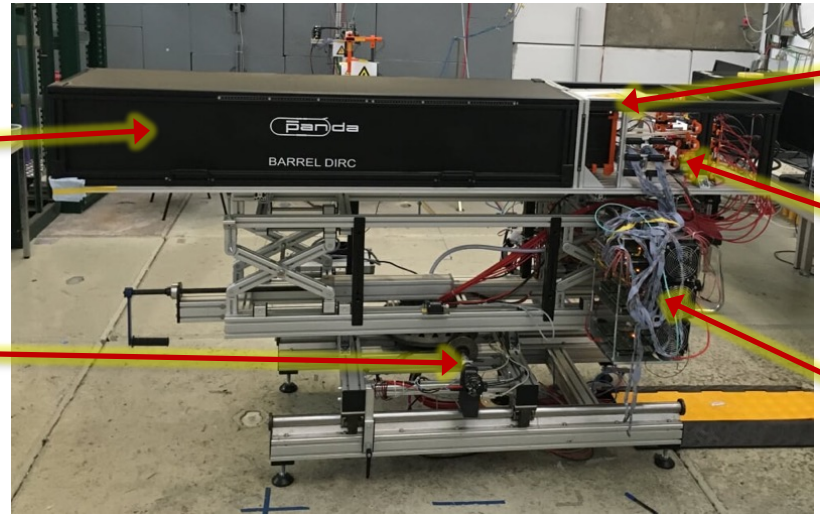
Work supported by Jim Kierstead (BNL)

HPDIRC 2020 HIGHLIGHTS

Hardware: Transfer of the PANDA barrel DIRC prototype



- Preparing the transfer from GSI to Stony Brook, lab space at SBU identified
- Components selected: fused silica bar and plate, fused silica prism, lenses, mechanical system, dark box, several Planacon MCP-PMTs (8x8, 6.5mm pixel pitch, 25µm pores) with PANDA DAQ cards (PADIWA/TRB, $\sigma_t \approx 200$ps), DAQ PC with software, HV/LV supplies
- Upgraded rotation stage at GSI in preparation for transfer
- Paperwork for loan agreement under review at ODU – significant administrative delays due to Covid-19, still hope to ship prototype this (fiscal) year



Hardware: Upgrade of laser setup at ODU

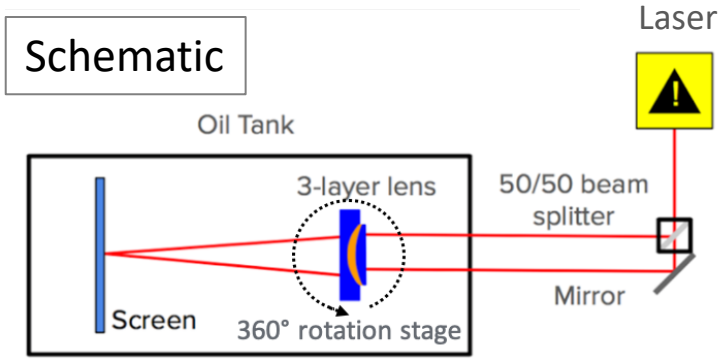
- Setup for evaluation of the shape of the focal plane of prototype lenses
- Performing upgrade to improve precision and speed of measurements
- Better quality of parallel laser beams with new laser and beamsplitter
- More repeatable lens and screen placement with new mechanical system
- Camera and digital image processing to calculate focal length

- Good progress despite delays due to Covid-19 (closure of ODU, no access to laser lab for several months, now reopening)

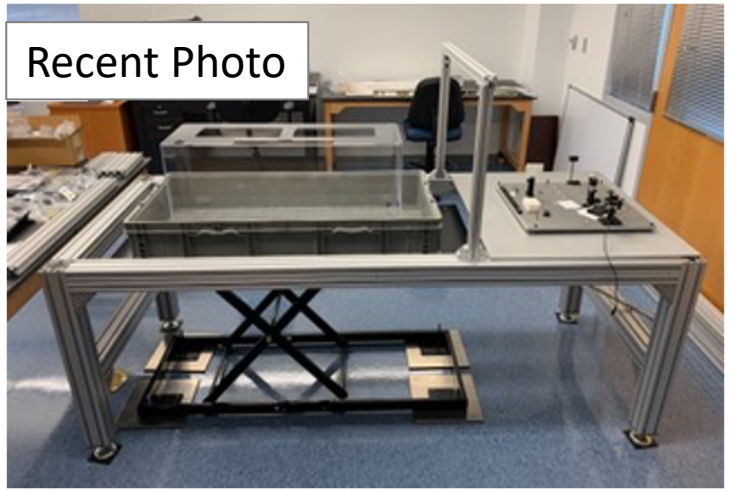
- Expect upgrade to be completed before the end of this fiscal year
- Several prototype lenses available for evaluation, including sapphire prototype (PbF_2 prototype lens production at the Harbin Institute of Technology, China, delayed due to Covid-19, fabrication recently restarted)

- Measurements to start this fall, still on track for journal publication in FY21

Schematic



Recent Photo



Software: Reprioritized simulation projects

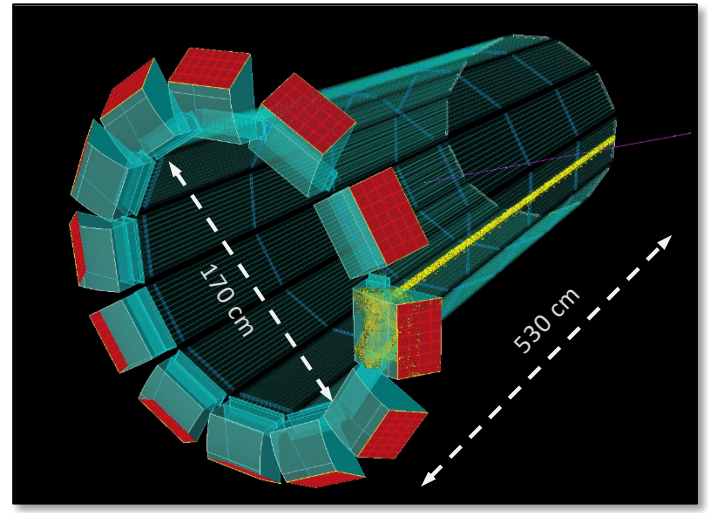
Reevaluation of simulation work package priorities and overall beam test plan in response to

- Covid-19 impact (cancellation of 2020 FTBF beam tests, delays in hiring of new PostDoc and paperwork for transfer of prototype)
- Rapid development of the EIC project schedule (EIC Users Group Yellow Report)

Simulation of the FDIRC geometry, reusing BaBar DIRC bar boxes

- Urgent request from EIC UG YR effort in the spring of 2020:
  study reuse of BaBar DIRC bar boxes for EIC, compare performance to hpDIRC
- Implemented unmodified BaBar DIRC bar boxes and SLAC FDIRC focusing in Geant4
- Improvement of reconstruction algorithm required
  (to deal with additional reflections in focusing block and impact of wedge bottom angle)
- Additional YR request in summer 2020: study performance of hpDIRC design
  using disassembled BaBar DIRC bar boxes
- Expect initial PID performance estimate later this fiscal year,
  studies will continue in FY21

EIC FDIRC geometry with unmodified BaBar DIRC bar boxes in Geant4



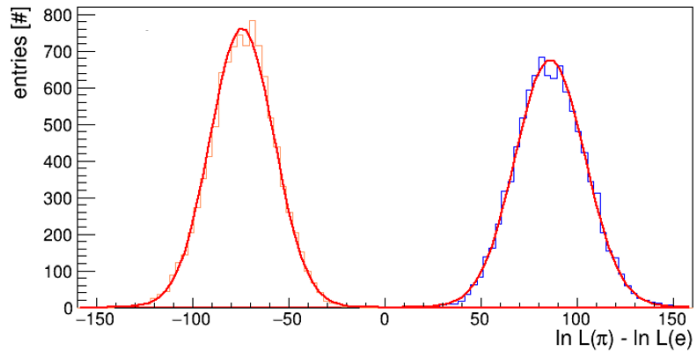
Software: Reprioritized simulation projects

Evaluation of the hpDIRC e/π separation at low momentum

- High pion background problematic for electron ID below 4 GeV/c
- EIC UG YR effort requested study of supplemental e/π separation from PID systems
- Started hpDIRC study for realistic EIC tracking system options
  (0.8mrad – 2.2mrad angular resolution at ~1GeV/c momentum)
- hpDIRC e/π performance at low momentum dominated by multiple scattering and EM showers in DIRC bars
- First results: 4-8 s.d. e/π separation at 1 GeV/c, depending on polar angle
  (challenging non-Gaussian tails, especially for steeper polar angles)
- Study of momentum dependence, potential improvements from ring center fit or from optional additional tracking layer outside DIRC radius will continue in FY21

Simulated hpDIRC e/π separation
at 1 GeV/c momentum, 30° polar angle,
for 0.8mrad tracking resolution

without multiple scattering: ~9 s.d.



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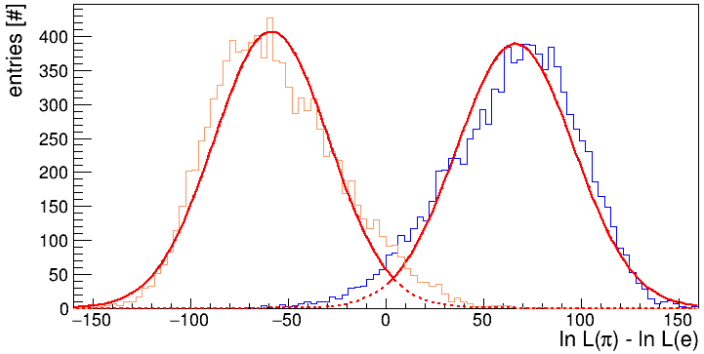

HPDIRC 2020 SCHEDULE

Software/Hardware: Decided to postpone first beam test to 2022

- Cancellation of approved test experiments at Fermilab in 2020 due to Covid-19 pandemic makes approval of the initially planned hpDIRC beam test in 2021 very unlikely
- Prototype transfer delayed by 4-6 months; prototype unlikely to be ready for a spring 2021 beam test
- Flat FY21 R&D budget – required large hpDIRC budget increase in FY21&FY22 to fully equip the hpDIRC prototype with small-pixels sensors and compact readout electronics by 2022 (described in Sep 2019 presentation) is unlikely
- New plan: First hpDIRC beam test in spring 2022, second (final) beam test in spring 2023
  - More time for new PostDoc to develop prototype simulation, validate prototype setup and prepare DAQ system
  - Properly define the beam test goals and beam/instrumentation requirements, coordinate beam test effort
  - Flatten funding profile: Start with incremental upgrade of prototype in FY21, partial coverage with small-pixel sensors and compact readout electronics, larger request in FY22&FY23 for full coverage for spring 2023
    (budget request for two commercial small-pixel MCP-PMTs, configured as 16x16 anodes, ~3mmx3mm pixels)
- We agree with the committee that a Cosmic Ray Telescope could be very helpful, especially in the current situation; a concept for a new CRT at Stony Book has been proposed (discussion is ongoing, including meeting earlier this week)

HPDIRC 2020 SCHEDULE

Impact of work package reprioritization

in response to Covid-19 pandemic

and required work on Yellow Report

- More realistic schedule for prototype hardware and software work
- Better match to R&D funding profile
- TDR readiness in 2024 still in reach

Old September 2019 schedule

assumed milestones (2019 plan)

		2019	2020	2021	2022	2023	2024
			FY20	FY21	FY22	FY23	FY24
Software	Simulation: Prototype, beam line		★				
	Simulation: Explore hpDIRC design options						
	Simulation: Cost/performance optimization						
	Simulation: Intregrated PID performance study						
	Reconstruction: Prototype analysis code						
	Reconstruction: hpDIRC time imaging optimization						
Prototype	Transfer from GSI to CUA/SBU		★				
	Initial protoype commissioning at SBU						
	Prototype upgrade and commissioning						
Beam test	Beam test at FTBF			★	★		
	Beam test data analysis						
Lens evaluation	Upgrade of ODU setup						
	Characterization of FY20 lenses						
	Neutron irradiation and analysis						

New July 2020 schedule

assumed milestones (2020 plan)

		2019	2020	2021	2022	2023	2024
			FY20	FY21	FY22	FY23	FY24
Software	Simulation: Prototype, beam line		★				
	Simulation: Explore hpDIRC design options						
	Simulation: Cost/performance optimization						
	Simulation: Intregrated PID performance study						
	Reconstruction: Prototype analysis code						
	Reconstruction: hpDIRC time imaging optimization						
Prototype	Transfer from GSI to CUA/SBU		★				
	Initial protoype commissioning at SBU						
	Prototype upgrade and commissioning						
Beam test	Beam test at FTBF				★	★	
	Beam test data analysis						
Lens evaluation	Upgrade of ODU setup						
	Characterization of FY20 lenses						
	Neutron irradiation and analysis						

hpDIRC Summary and Budget Request

FY 21 Plan:

- Nilanga, new PostDoc responsible for simulation and prototyping, started June 1st ⇒ budget request to extend contract
- Incremental upgrade of prototype with small-pixel commercial MCP-PMTs ⇒ budget request for two new sensors
- Complete transfer of prototype, evaluate performance at SBU ⇒ budget request for travel (CUA, GSI) to SBU
- Complete radiation hardness study with neutron irradiation ⇒ budget request for procurement of samples
- Complete evaluation of prototype lenses in upgraded ODU laser setup
- Develop prototype simulation, define beam test plan and deliverables, identify required beam instrumentation
- Optimize hpDIRC geometry (bar size, pixel size, sensor coverage)
- Resume/continue hpDIRC simulation projects
  - "ultimate DIRC" and wide plate design options
  - hpDIRC with reused BaBar DIRC bars
  - hpDIRC e/π separation at low momentum

	100%	80%	60%
Postdoc, CUA, 50%	\$60k	\$60k	\$60k
Small-Pixel MCP-PMT Sensors	\$40k	\$20k	\$0
Prototype Evaluation (Travel, CUA)	\$15k	\$15k	\$15k
Prototype Equipment	\$5k	\$5k	\$2k
Radiation Hardness test	\$1k	\$1k	\$1k
Travel, CUA/GSI	\$9k	\$9k	\$6k
Total	\$130k	\$110k	\$84k

hpDIRC Summary and Budget Request

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- Complete radiation hardness study with neutron irradiation ⇒ budget request for procurement of samples
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  - hpDIRC with reused BaBar DIRC bars
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Thank you for your attention