The EIC Detector R&D Program

Status, Impact, and Needs

See also plenary talks by: Maxim Titov (MPGDs), Tom Hemmick (TPC), Paolo Cameron (MAPS) and Parallel 1 on Friday.

Thomas Ullrich, BNL/Yale
EIC User Meeting Trieste
July 20, 2017

Yale BROOKHAVEN NATIONAL LABORATORY

EIC Detector R&D Efforts

- Generic EIC Detector R&D Program (covered here)

- Other substantial efforts with impact on EIC
  - Laboratory Directed Research & Development Programs (LDRDs) at National Labs in the US (BNL, JLAB, ANL, …)
  - CERN supported detector R&D program with partial match with EIC needs (e.g. RD51 Micro-Pattern Gas Detectors Technologies) → Maxim's talk
  - LHC Experiments R&D for phase-I upgrades, especially ALICE (TPC, ITS, SAMPA, …) and LHCb (RICH, trigger less DAQ, electronics, …). Now in production, R&D finished.
  - R&D at Belle-II and Panda (crystals, DIRC, …)
  - ILC related R&D (TPC, …)
    - Rate and precision requirements compatible
    - Less emphasis on forward/backward instrumentation

Generic Detector R&D for an EIC

In January 2011 BNL, in association with JLab and the DOE Office of NP, announced a generic detector R&D program to address the scientific requirements for measurements at a future EIC

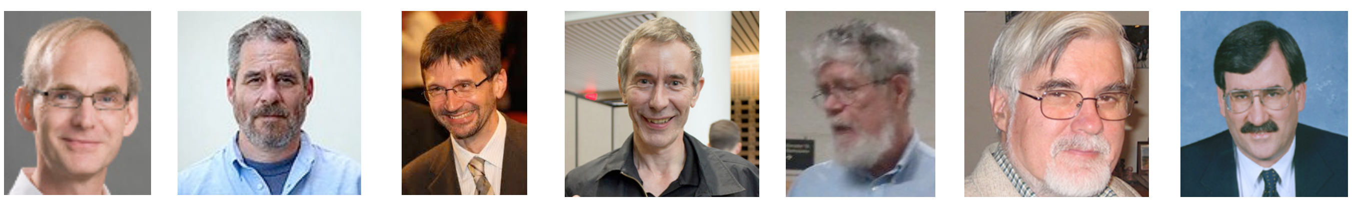
Goals of Effort

- Enable successful design and timely implementation of an EIC experimental program
  - Quantify the key physics measurements that drive instrumentation requirements
  - Develop instrumentation solutions that meet realistic cost expectations
- Stimulate the formation of user collaborations to design and build experiments

Program coordinator 2011-2014: Tom Ludlam
2014-present: TU

Generic Detector R&D for an EIC

- Funded by DOE through RHIC operations funds: ~$1M/year
- Program explicitly open to international participation
- Key to success: Standing EIC Detector Advisory Committee consisting of internationally recognized experts in detector technology and collider physics
    - Meets twice a year, funding limited to one year (FY)
        - ~January: Review of ongoing projects
        - ~July: Review and new proposals*



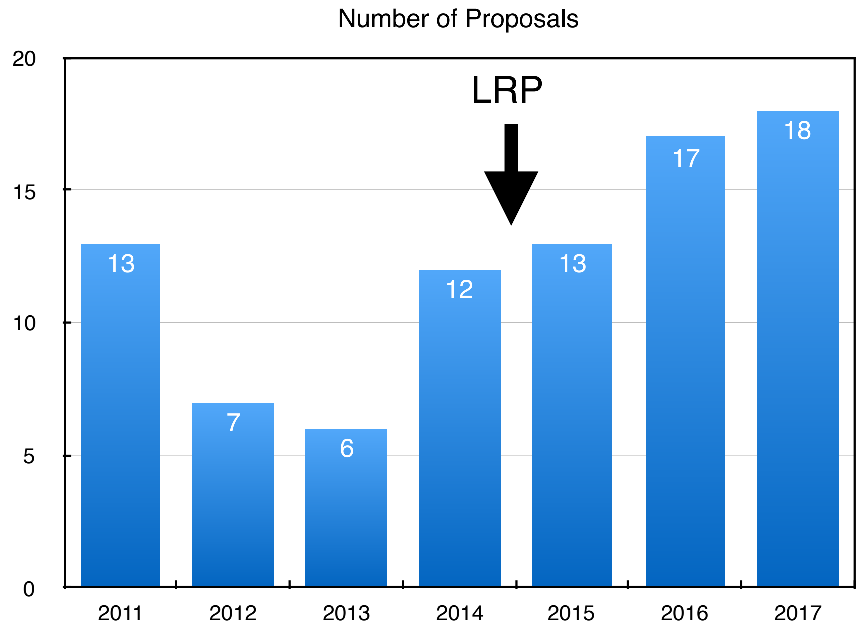
Current: Marcel Demarteau** (ANL), Carl Haber (LBNL), Peter Krizan (Ljubljana), Ian Shipsey (Oxford), Rick Van Berg (UPenn), Jerry Va'vra (SLAC), Glenn Young (JLab)

**Chair

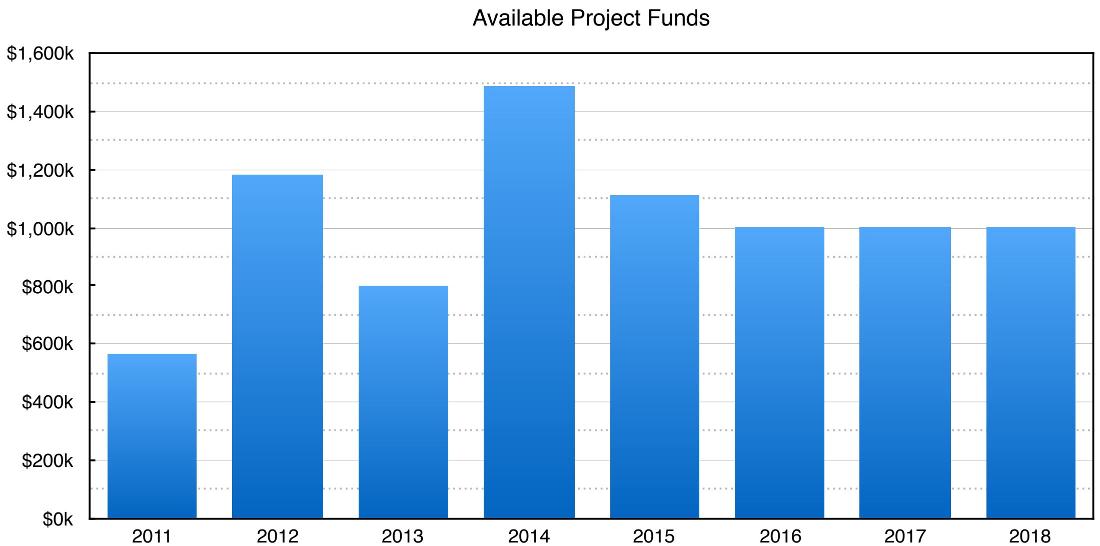
Retired:
Robert Klanner (Hamburg), Howard Wieman (LBL)

* During 2011-2014 new proposals were also accepted in the Winter meeting

EIC Detector R&D Program in Numbers



- FY18: Record participation this time (expected)
  - 9 new proposals
  - 9 existing projects requesting continuation
- FY16-now: flat funding
- FY17, FY18:
  - Total requested: ~$2.4M



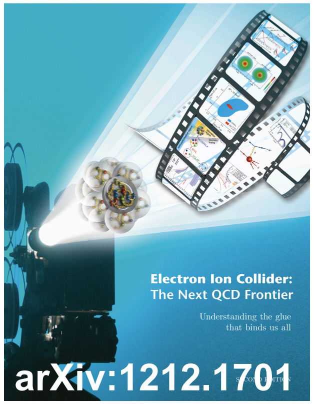
Investment in program so far ~$8M

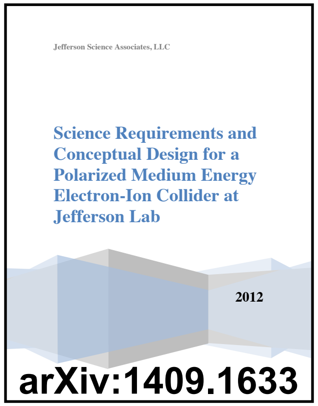
Detector Choices

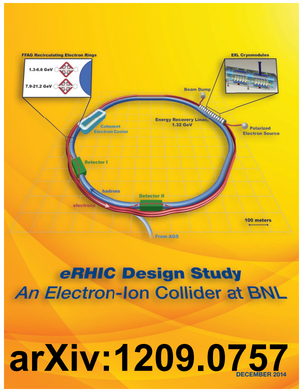
- General Purpose Detector
  - While relatively well studied, requirements spread over various documents and not always up-to-date. Focus of R&D efforts.
  - Design/Study efforts dominantly centered at JLAB and BNL
  - Many open question
    - 1 or 2 detectors; if 2, different emphasis
    - To fit into funding profile 2nd later?
- Specialized Detectors
  - Discussion has just started

EIC User Group needs to get involved.

Whatever choice, it has impact on the machine design as well. May be a workshop later this year?







Project: EIC Detector Handbook

- "Living" document on requirements, R&D needs, available technologies, EIC kinematics and more
- We started with a compilation of information that is available
- Update as things become more refined
- Right now: not even a draft

Electron-Ion Collider Detector Requirements and R&D Handbook

DRAFT - July 12, 2017

Editors:
Alexander Kiselev (BNL)
Thomas Ullrich (BNL)

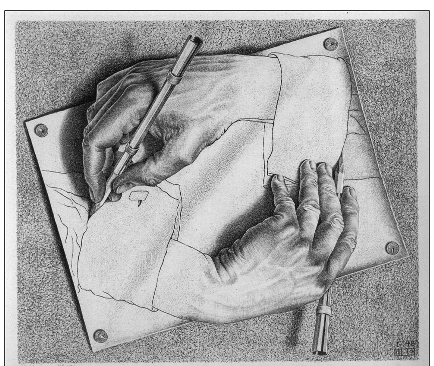


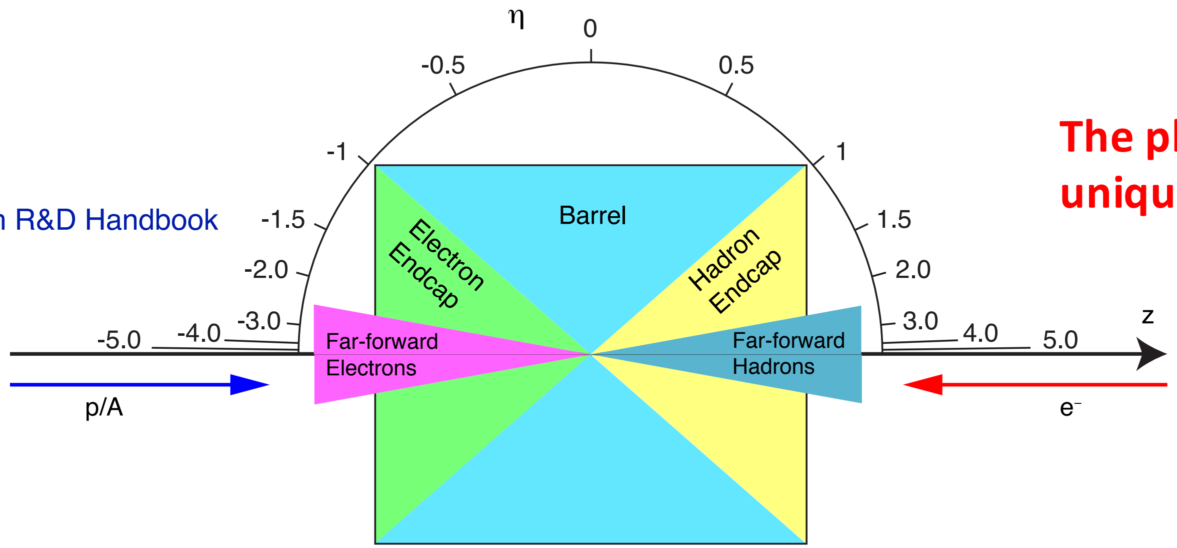
Table of Contents

- Current manpower: TU & A. Kiselev
- Volunteers are more than welcome

EIC Detector Requirements

Requirement are mostly site-independent with some slight differences in the forward region (IR integration)

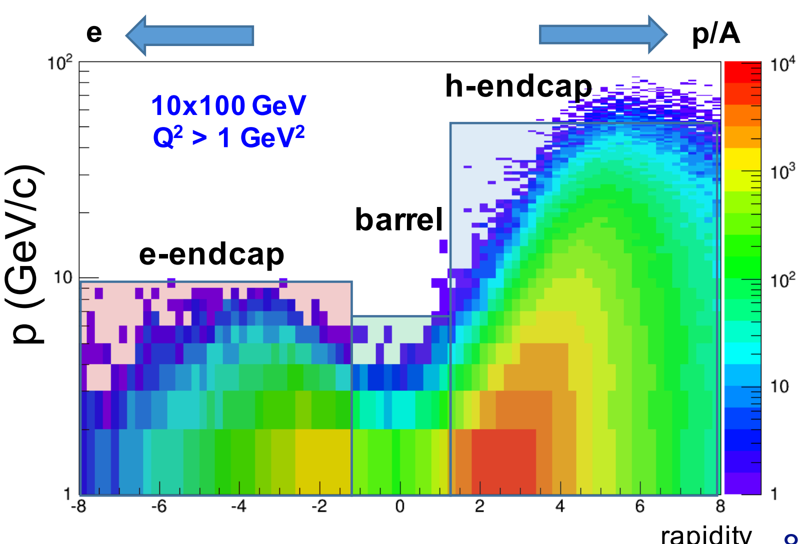
From R&D Handbook



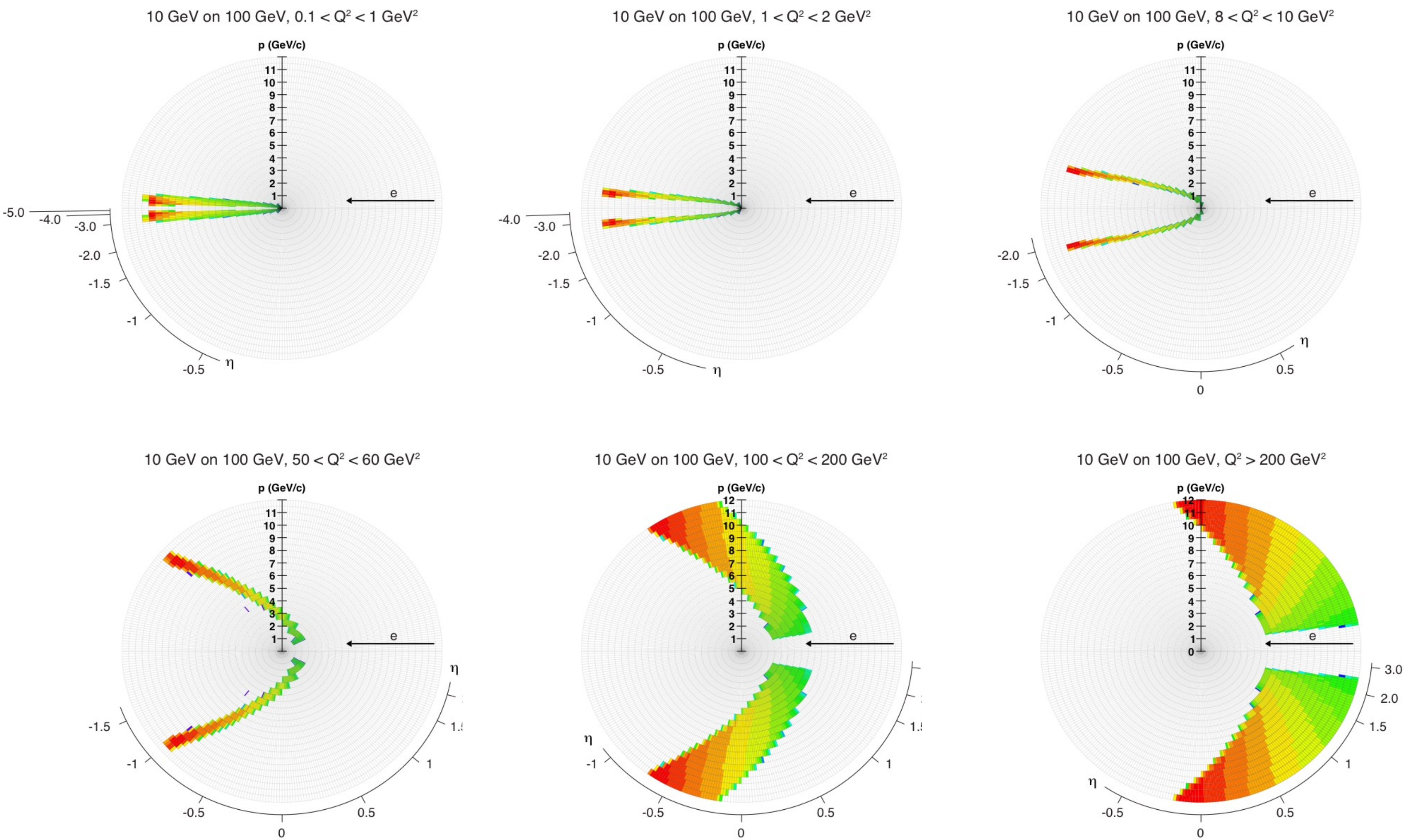
The physics characteristics bring unique challenges for an EIC detector

In Short:

- Hermetic detector, low mass inner tracking, good PID (e and π/K/p) in wide range, calorimetry, forward & backwards tracking
- Moderate radiation hardness requirements, low pile-up, low multiplicity



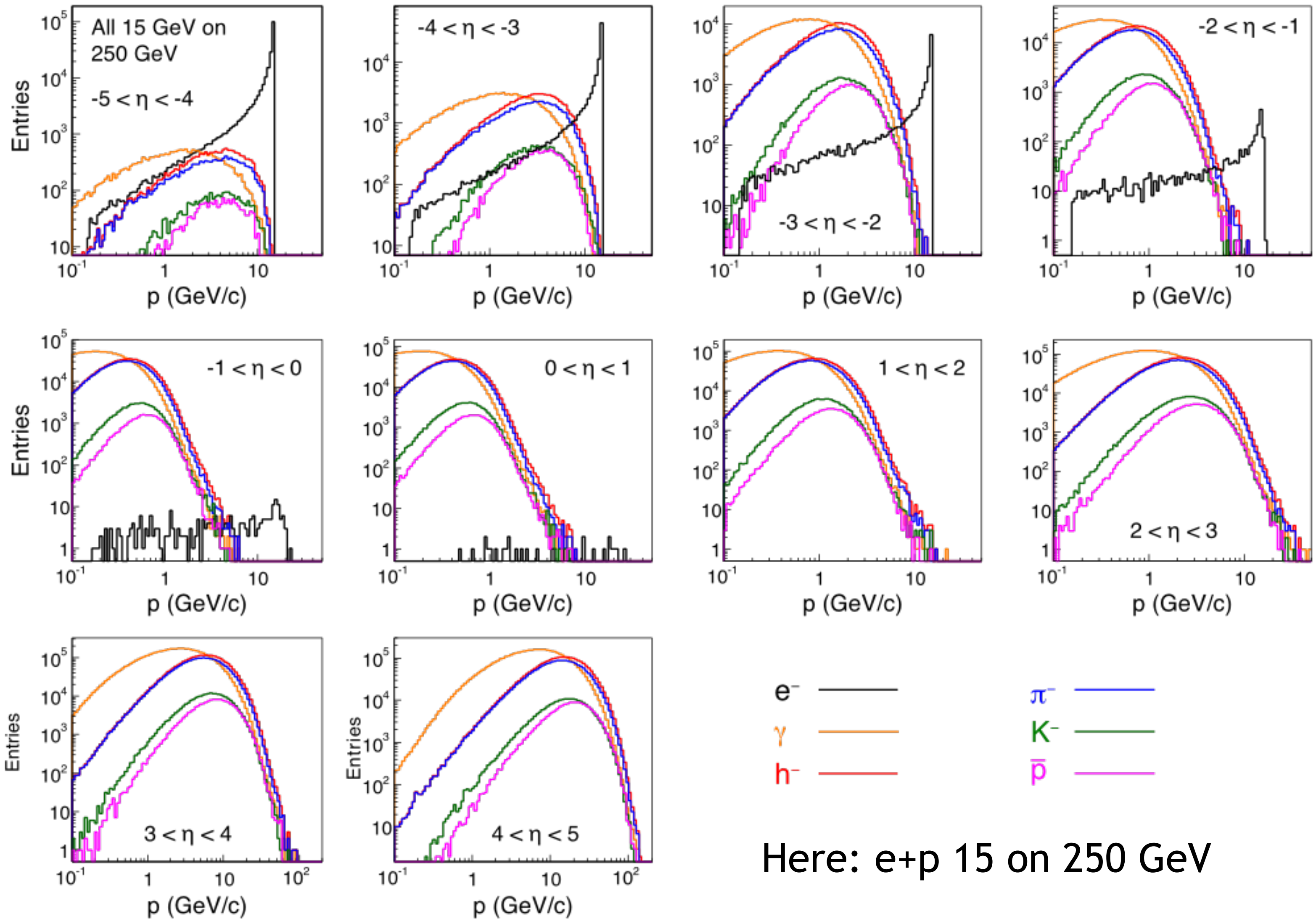
Electron Kinematics



From R&D Handbook

e+p: 10 on 100 GeV

Hadron Kinematics



From R&D Handbook

Here: e+p 15 on 250 GeV

PID is one of the challenges for an EIC detector ⇒ R&D

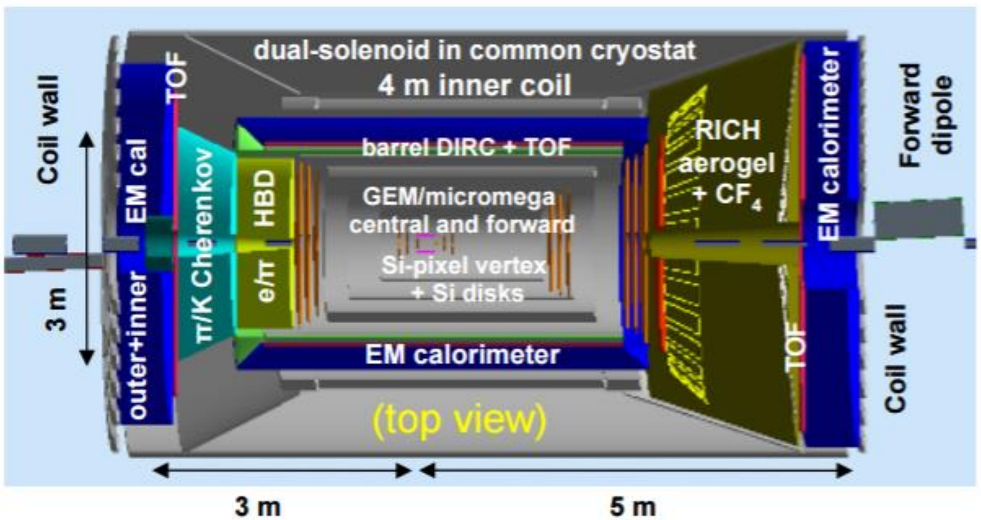
Compilation of EIC Detector Requirements

η	Nomenclature			Tracking			Electrons		π/K/p PID		HCAL	Muons
				Resolution	**Allowed X/X_0**	**Si-Vertex**	**Resolution σ_E/E**	**PID**	**p-Range (GeV/c)**	**Separation**	**Resolution σ_E/E**	
-6.9 — -5.8	↓ p/A	Auxiliary Detectors	low-Q^2 tagger	$\delta\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2								
…												
-4.5 — -4.0			Instrumentation to separate charged particles from photons				2%/√E					
-4.0 — -3.5												
-3.5 — -3.0		Central Detector	Backwards Detectors	$\sigma_p/p \sim 0.1\% \times p + 2.0\%$	~5% or less	TBD		π suppression up to 1:10^4	≤ 7 GeV/c	≥ 3σ	~50%/√E	
-3.0 — -2.5												
-2.5 — -2.0				$\sigma_p/p \sim 0.05\% \times p + 1.0\%$								
-2.0 — -1.5							7%/√E					
-1.5 — -1.0												
-1.0 — -0.5			Barrel	$\sigma_p/p \sim 0.05\% \times p + 0.5\%$		$\sigma_{xyz} \sim 20$ µm, $d_0(z) \sim d_0(r\phi) \sim 20/p_T$ GeV µm + 5 µm	(10-12)%/√E		≤ 5 GeV/c		TBD	TBD
-0.5 — 0.0												
0.0 — 0.5												
0.5 — 1.0												
1.0 — 1.5			Forward Detectors	$\sigma_p/p \sim 0.05\% \times p + 1.0\%$		TBD			≤ 8 GeV/c		~50%/√E	
1.5 — 2.0												
2.0 — 2.5									≤ 20 GeV/c			
2.5 — 3.0				$\sigma_p/p \sim 0.1\% \times p + 2.0\%$								
3.0 — 3.5									≤ 45 GeV/c			
3.5 — 4.0	↑e	Auxiliary Detectors	Instrumentation to separate charged particles from photons									
4.0 — 4.5												
…												
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\lvert t \rvert)/\lvert t \rvert < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c								

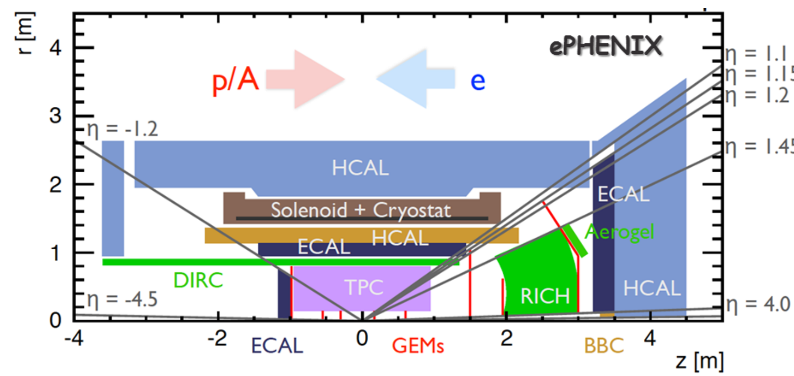
From R&D Handbook. Requirements as detailed in various documents (EIC WP, eRHIC and JEIC Design Reports).

Detector Concepts

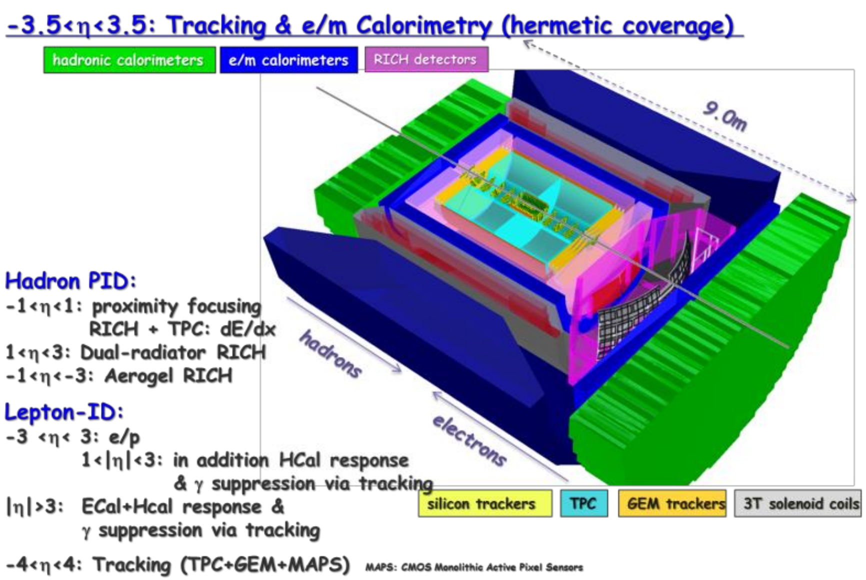
JLEIC Detector



ePHENIX



BeAST



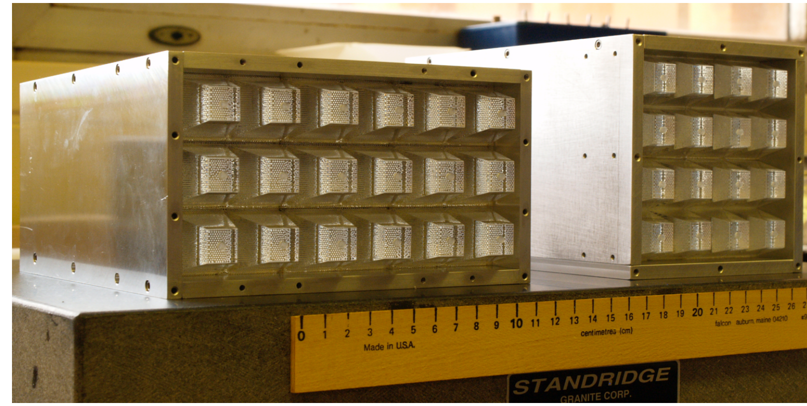
- **Concept Detectors**
  - Important as test bed for detector R&D
  - Each attempt to match requirements
  - Nothing is cast in stone
  - Will evolve as new concepts are developed

eRD1: Calorimetry

- **Goal:** Develop cost effective, flexible techniques to build compact sampling calorimeters that meet the EIC physics requirements.
- **Efforts:**
  - Tungsten-scintillating fiber EM calorimeter (SPACAL)
    - Compact calorimeter, developed at UCLA
    - Investigating high resolution version for e-going endcap
  - Crystal EMCal
    - Option for high resolution e-going endcap calorimeter
  - Shashlik EMCal
    - Option for h-going endcap calorimeter
  - HCal
    - Prototype development in collaboration with STAR forward upgrade and sPHENIX
  - Readout
    - SiPM and APDs, radiation studies and support electronics

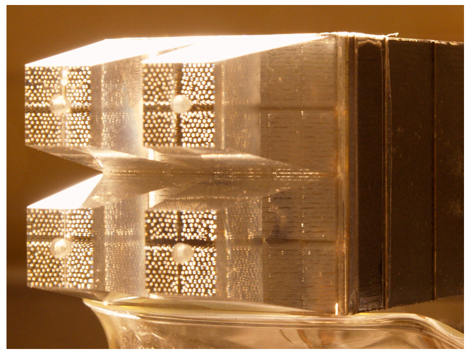
Participating institutions: BNL, Caltech, CUA, JLAB, IUCF, NPN Orsay, PSU, TAMU, UCLA, USTC, YPI

W-SciFi Calorimetry

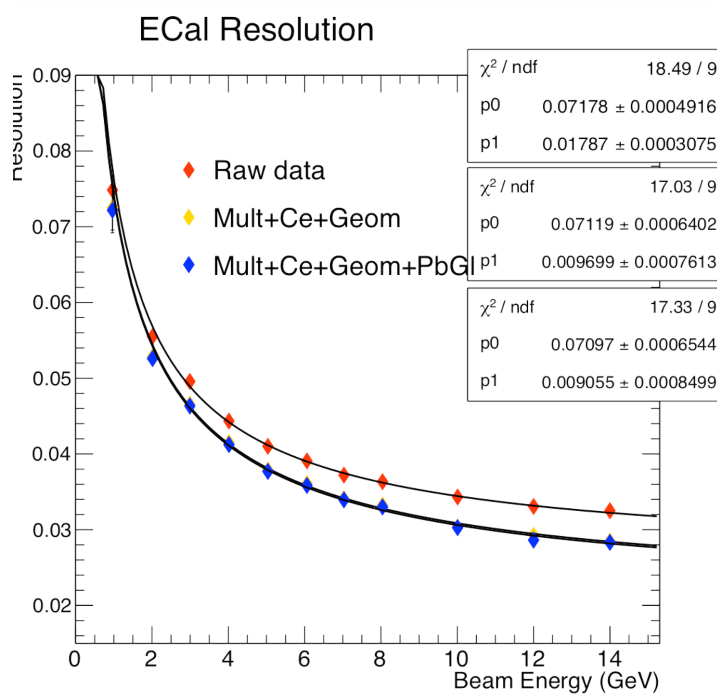


- Scintillating fibers embedded in composite absorber
- Round and square fibers tested

Detector	Fibers SCSF 78	Absorber
"Old" High sampling frequency	Round, 0.4mm	75% W 25% Sn
"Square" High sampling fraction	Square, 0.59 x 0.59 mm^2	100% W



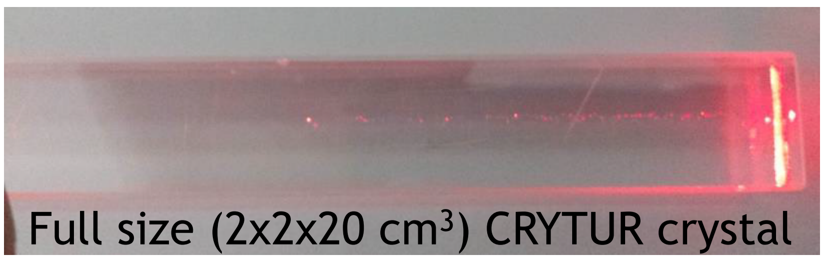
- Test beam campaigns in 2015 and 2016
- Square Fiber version achieves target of 7%/√E, with 1% constant term at 10^o, 2.9% at 4^o
- 2017: Optimizing light collection
- In RHIC beam in 2017, η=3.75, ~10^{11} n/cm^2)
- Issue: SiPM show non-homogeneous degradations, PM by PM. APD?



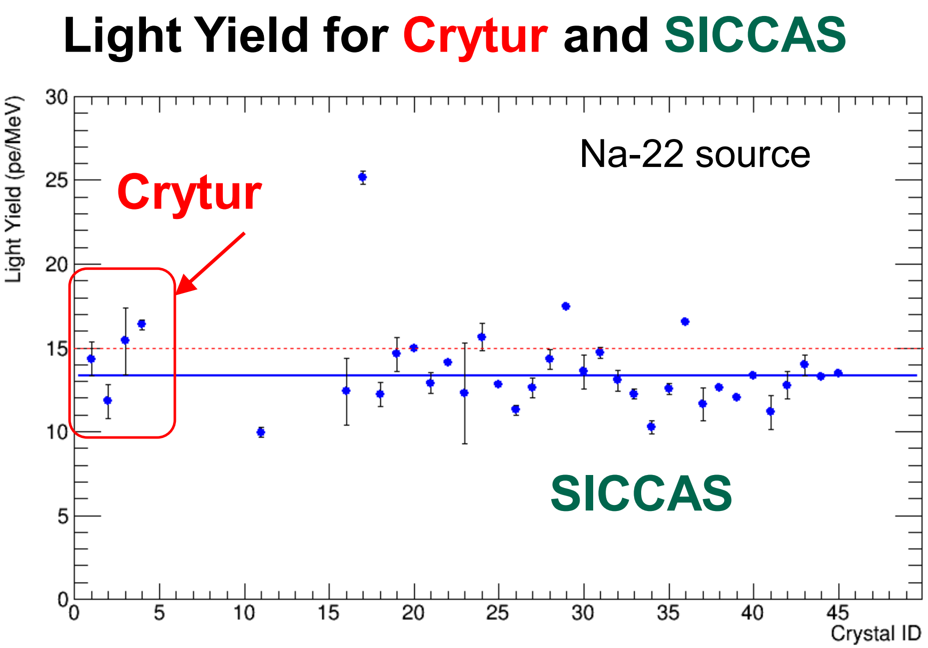
Crystal Calorimetry

See C. Munoz-Camacho , Parallel 1

- e-going direction needs high precision calorimetry (~2%/√E)
- PbWO calorimeter option for this role, extensively used for high precision calorimetry (CMS, JLab, PANDA…) because of its excellent energy and time resolutions and its radiation hardness
- BTCP (Russia) produced high quality crystals in the past but out of business
- SICCAS (China) has difficulties maintaining good crystal quality
- Collaborative effort with PANDA to qualify CRYTUR (Czech Republic)



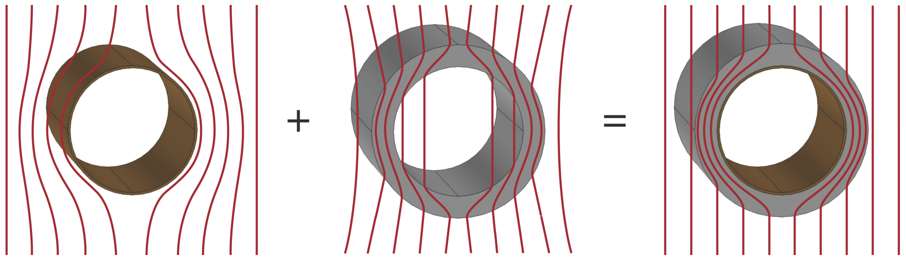
- 2017: chemical analysis ongoing
- CUA: growing crystals for faster turnaround time?



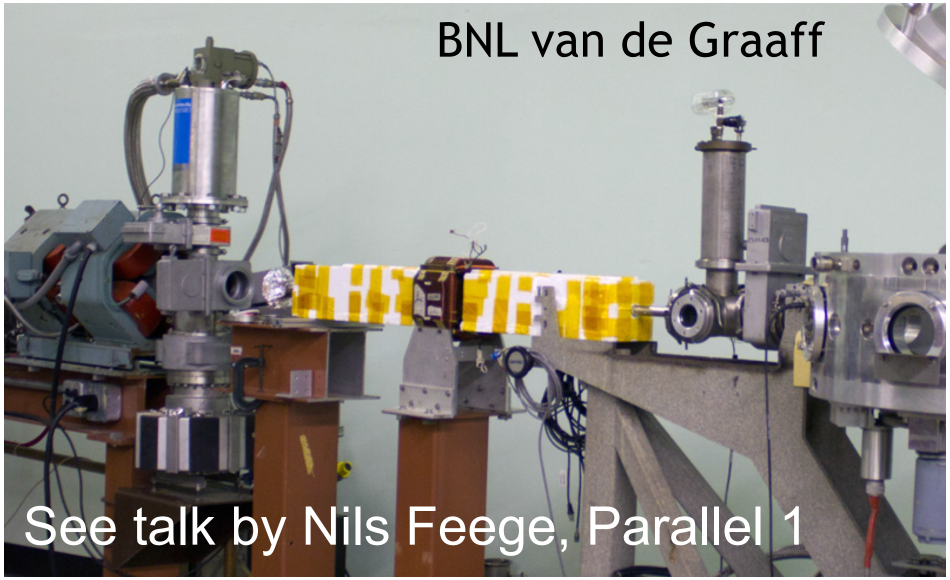
Participating institutions: YPI, CUA, IPN-Orsay, JLAB, BNL, Caltech

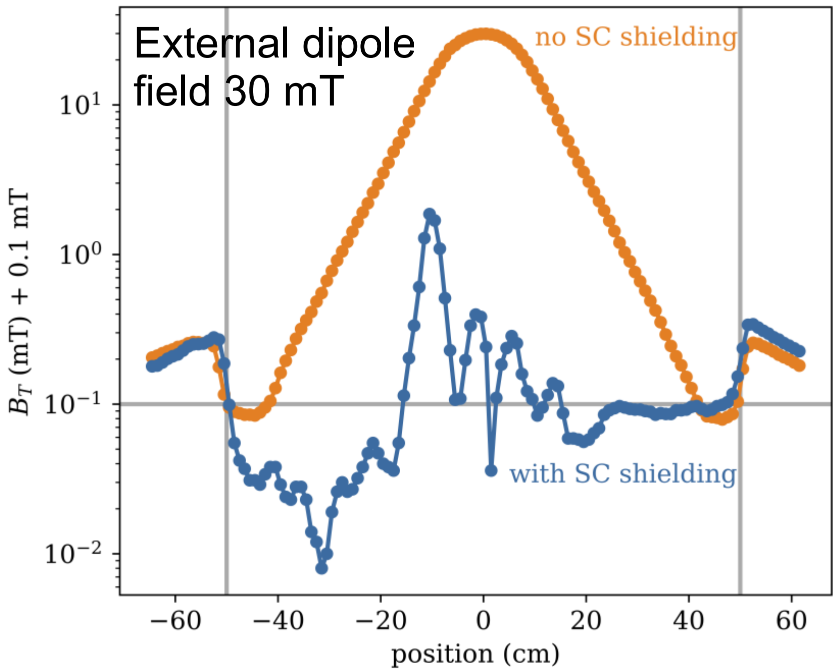
eRD2: A Magnetic Field Cloaking Device

- To retain good momentum resolution in the forward region, need dipole field
- Dipole fields affect beam optics
- Develop magnetic cloak
- Method: Wrapping layers of AMSC high-temperature superconductor around beam pipe



- Beam shielding tests with the BNL Van de Graaff accelerator

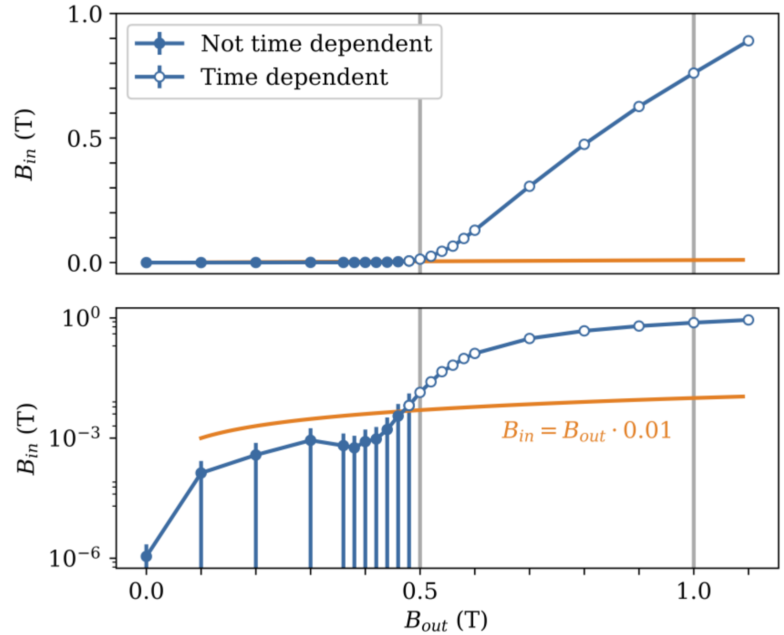




Institutions: Stony Brook, BNL, RIKEN

Magnetic Field Cloaking Device

- High-field shielding and cloaking tests with MRI magnet at ANL
- Shield a 0.5 T field with a 10 cm SC cylinder at liquid nitrogen temperature.
- Multi-layer shield

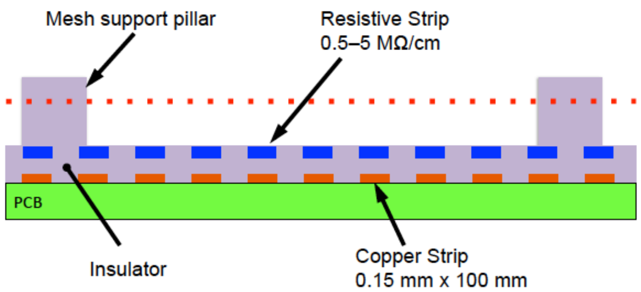


- Project has demonstrated magnetic field cloaking with 99% field shielding and 90% reduced field distortions next to the shield at 0.45 T
- Magnetic field cloak seems to be a viable option for EIC. Design parameters, fabrication, and limitations understood
- Project concluded: arXiv:1707.02361, submitted to NIM

eRD3: MPGD Based Tracking

- Development of intermediate tracking system
  - Barrel tracking system based on Micromegas; curved MM R&D program in close collaboration with Saclay
  - Forward/Backward tracking system based on triple-GEM
- Design and assembly of large cylindrical MM detector elements to demonstrate scaling of technology
- Test and characterization of MM chambers with full readout chain based on DREAM chip

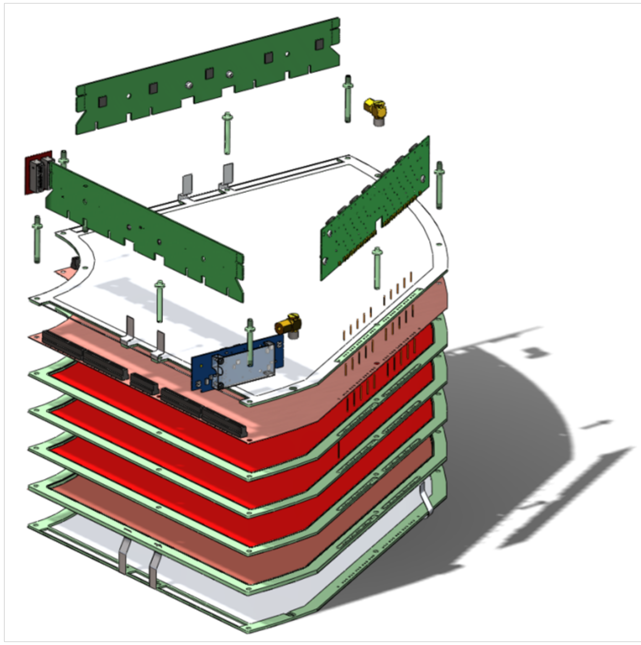
MicroMegas (MM):

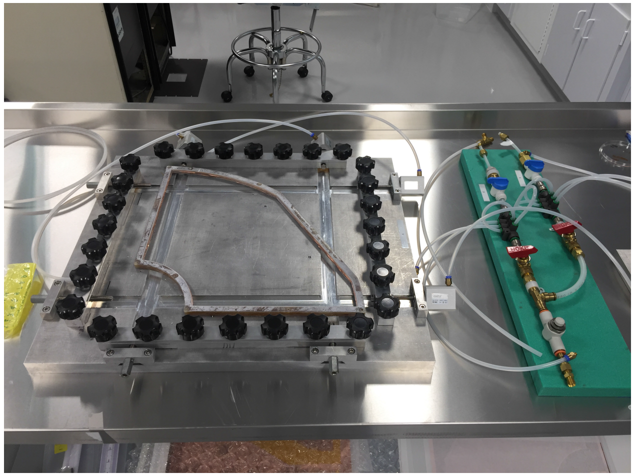


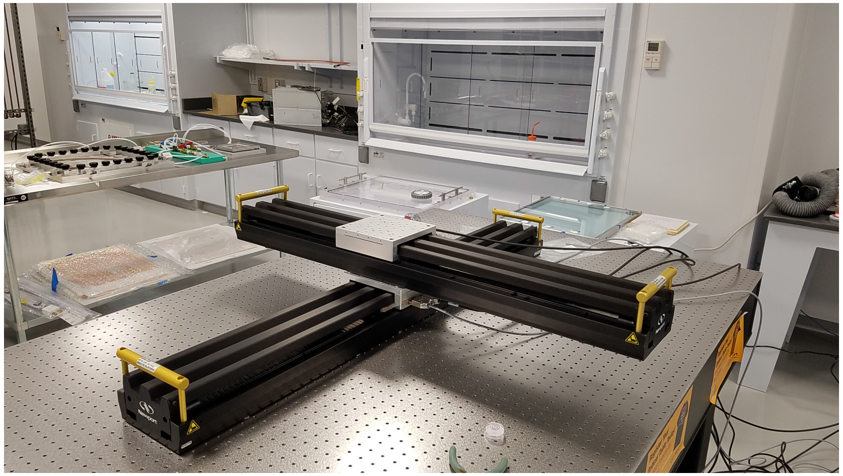
Participating Institutions:
Temple Univ., Saclay

MPGD Based Tracking

- Triple-GEM detector assembly 40x40cm designed
- GEM foils from TechEtch and CERN
- Close collaboration with industry (TechEtch)
- Quality assurance of GEM foils developed based on automatic CCD scanning system
- Assembly of triple-GEM chamber with full stacking and cosmic ray test with full readout chain

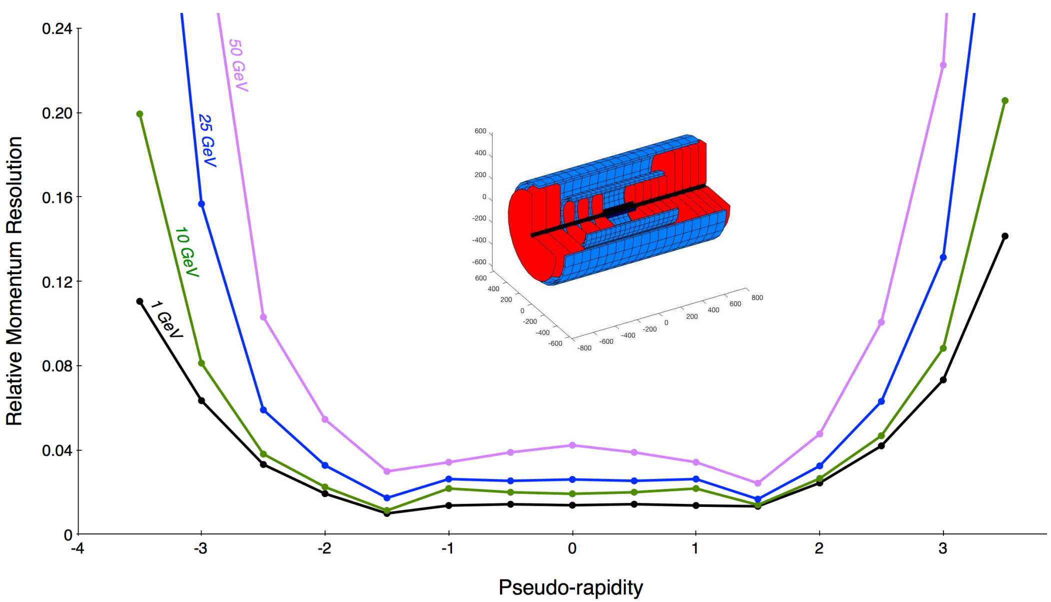






eRD16 & eRD18: Silicon Tracking

- Silicon Detector Layout Investigations
  - Performance requirements: numbers of layers, layout and spatial resolution of the pixel hits



A hypothetical all-Si tracker (> 10m²) in a 1.5T Solenoidal field.

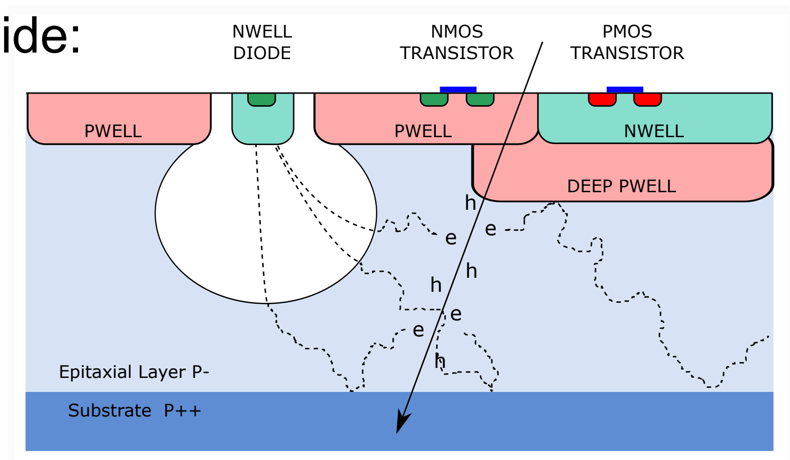
- **Studies**
  - Using toolset originally developed for ILC: Helix track model, multiple scattering, full track reconstruction from digitized hits using a Kalman filter.
  - Currently assuming ALPIDE chip
  - Study includes pileup (integration time)

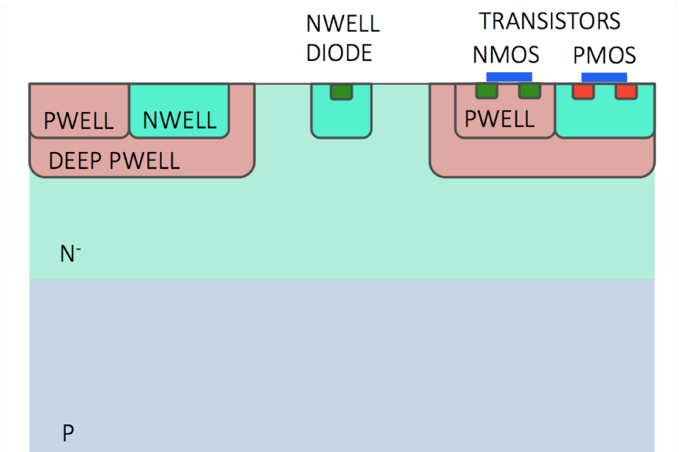
Institutions: eRD16: LBL, eRD18: Birmingham

eRD16 & eRD18: Silicon Tracking

- Sensor Development
  - Aim: to demonstrate high spatial resolution in a fully depleted sensor
  - Advantage of depletion = charge collection by drift
    $\Rightarrow$ larger Q, fast collection, small cluster multiplicity
  - Starting point: ALPIDE sensor (ALICE ITS)
  - TowerJazz modified process: First results indicate full depletion
  - Technology strong contender for dedicated EIC MAPS prototype
  - Exploit on-going ATLAS R&D in Birmingham

Alpide:



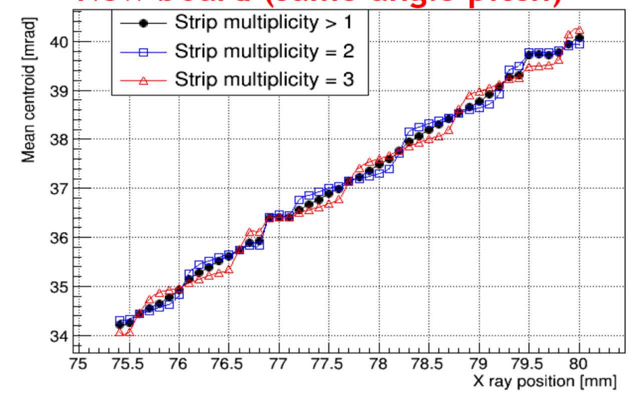


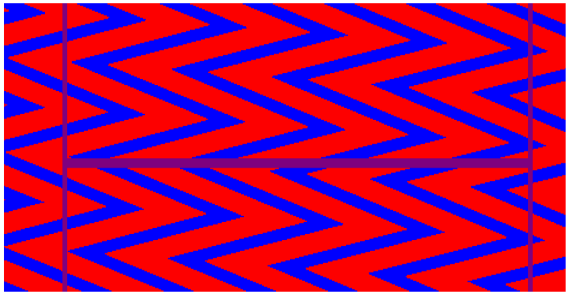
Modified pixel structure

eRD6: ZigZag Strip Readouts

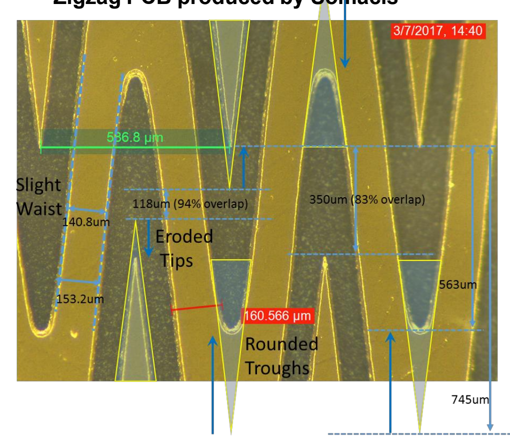
- Improve on the position resolution of GEM readout boards with novel design
  - Implement zig-zag readout; test with 3-GEM readout and X-ray source
  - Optimization of the zigzag pad readout pattern parameters, fabrication of PCB with this readout pattern and measurement of the relative position resolution in the lab
  - Recent: Scans of PCBs with improved zigzag strip design achieve < 70 µm spatial resolution
  - Still suffer from single pad hits in regions near center of pad (due to low gain, non-optimal interleaving, small transverse diffusion, etc)

New board (same angle pitch)



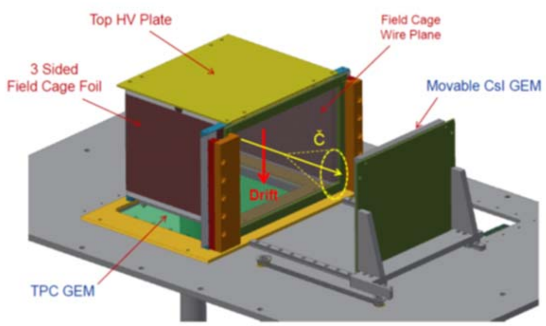


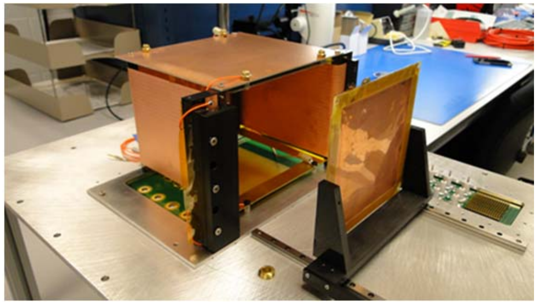
Zoomed in Microscope image of recent Zigzag PCB produced by Somacis

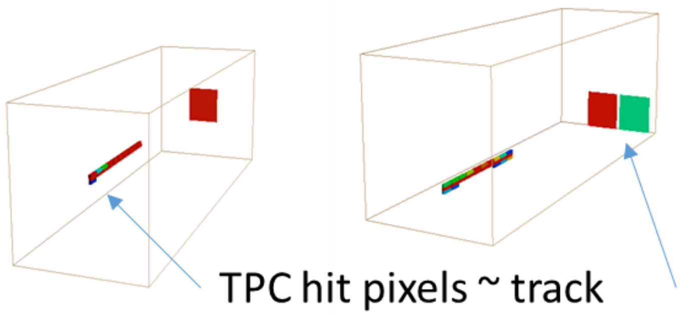


eRD6: Cherenkov TPC

- Combines the functions of a TPC for charged particle tracking and a Cherenkov detector for particle identification in same volume
- Prototype:
  - TPC: 10cm drift + 10x10 cm^2 4 layer GEM
  - Cherenkov: 3.3 x 3.3 cm^2 pad array + 10 x 10 cm^2 4 layer GEM
  - Common Gas: CF_4 (v_{drift} = 7.5 cm/μs & large N0)
- Successful demonstration of proof of principle - TPCC works!
- Finalizing performance specs on track resolution and Cherenkov light yield, paper in progress

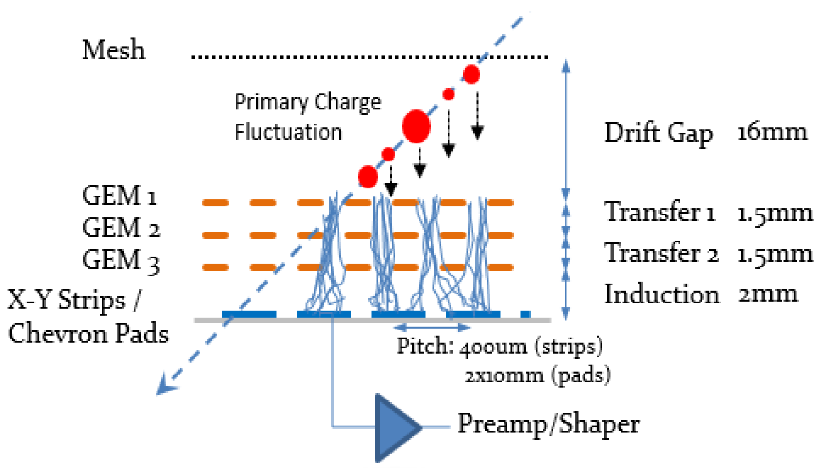


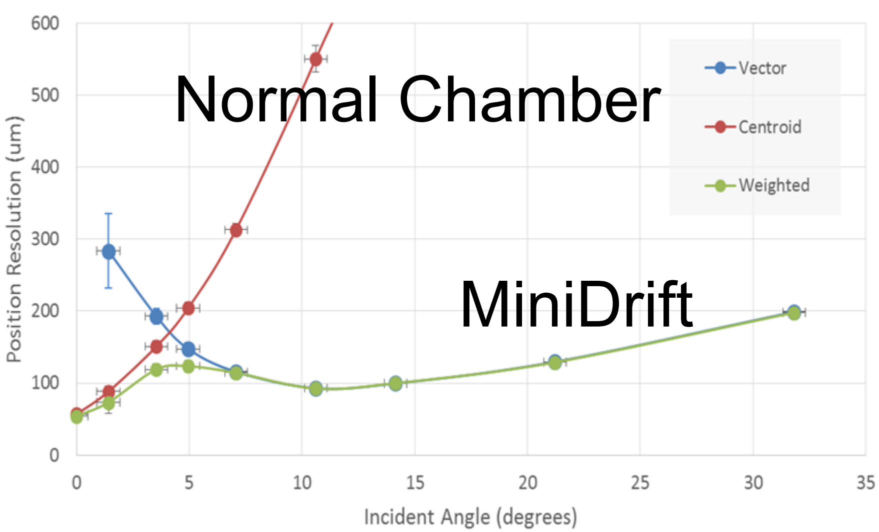




eRD6: Mini-Drift GEM Tracking Detector

- Triple GEM stack with a small drift region (mini TPC type configuration)
- Position and arrival time of the charge deposited in the drift region were measured on the readout plane allowing reconstruction of track traversing the chamber.
- Minidrift overcomes resolution degradation with incident angle for conventional GEM tracking detectors using only charge centroid information.
- Compatible with all forms of planar GEM tracker.





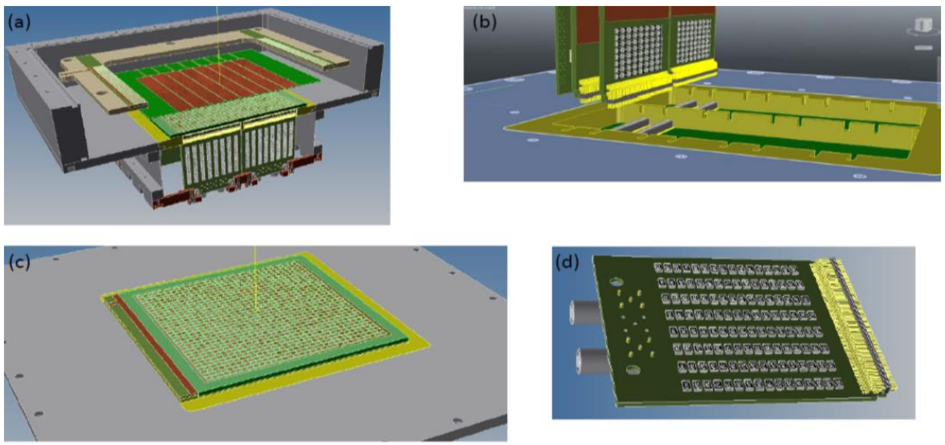
eRD6: MPGD-Based Photon Detector for RICHs

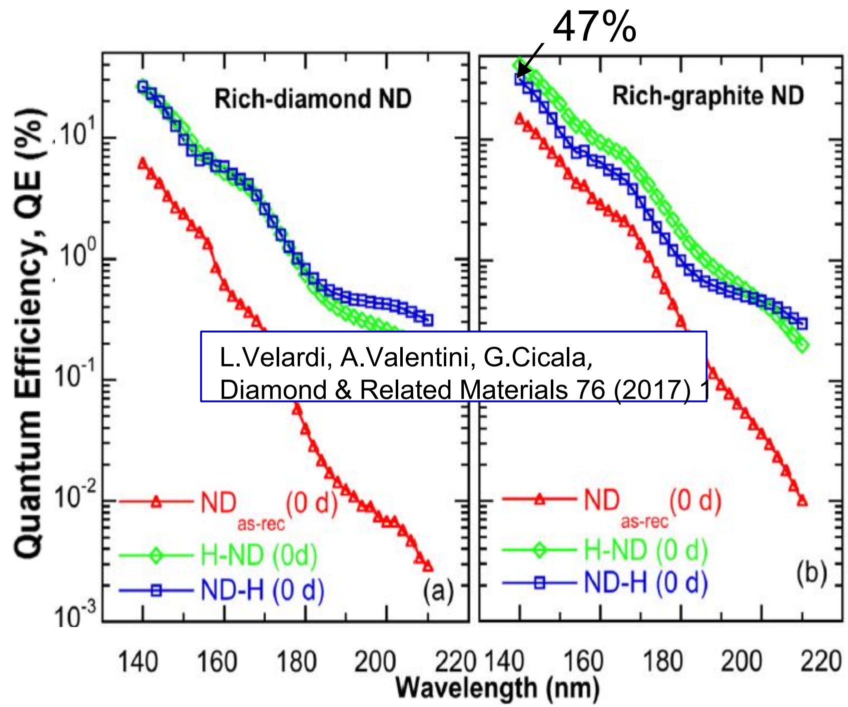
- Motivation
  - h-PID in the range $6 < p < 60$ GeV/c, a must for EIC
  - At high momenta: gas radiator is mandatory
  - Collider detector: short (~ 1 m) radiator length

- R&D program
  - Development of MPGD-based Photon Detectors
    - Miniaturized pads
    - Operation in C-F gases
    - THGEM vs GEM for optimal photoelectron collection
    - Ion BackFlow (IBF) control
    - Photocathodes: alternatives to CsI?
      - CsI: aging, doesn't tolerate water vapor, O^2

eRD6: MPGD-Based Photon Detector for RICHs

- New activity at INFN Trieste
  - Design of prototype of MM with resistive layer and miniaturized pad-size well advanced





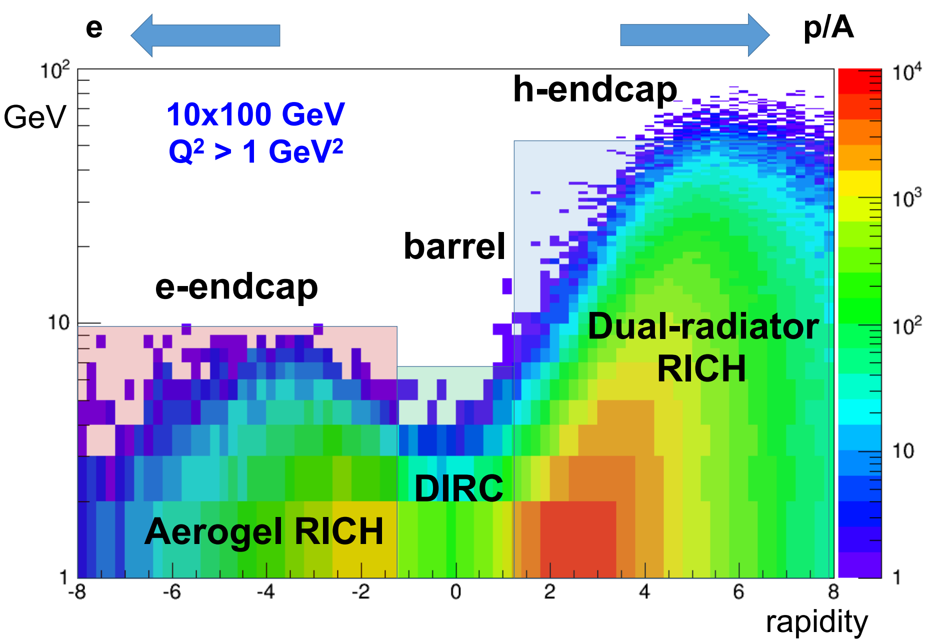
- New photocathode
  - Hydrogenated diamond film: Spray technique making use of NanoCrystals powder at T ~ 120° (instead of std >800°)
  - Next steps: Coupling of photo converter and MPGDs

see Stefano Levorato , Parallel 1

eRD14: PID Consortium

Particle ID is essential for EIC

- Developing a suite systems covering the full angular- and momentum range required Imaging Cherenkov detectors are the primary technology



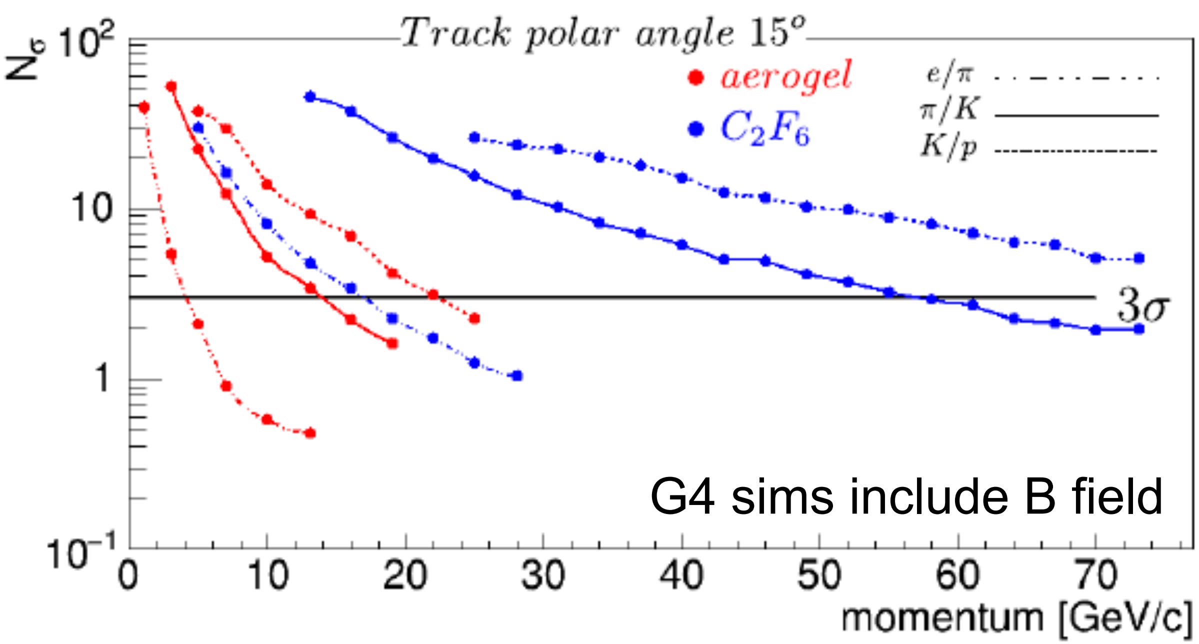
Institutes: ACU, ANL, BNL, CUA, William & Mary, Duke, GSU, GSI, Howard, INFN Ferrara, INFN Roma, ISS Rome, JLAB, LANL, ODU, USM, UIC, UNM, SC, Yale

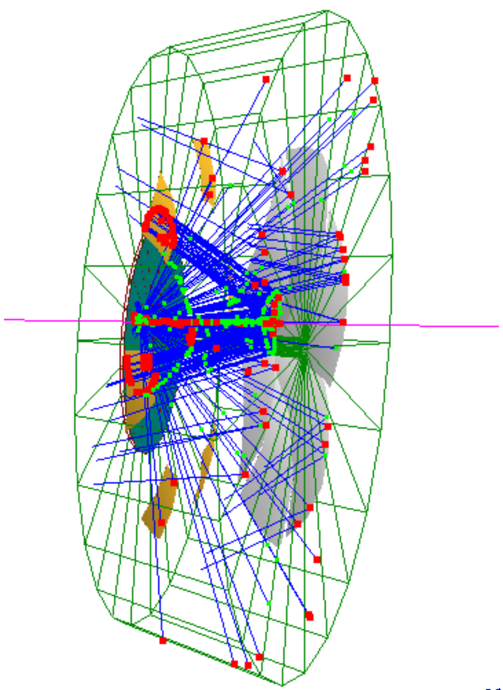
Current Projects

- h-side: RICH with two radiators (gas + aerogel) are needed to cover the full momentum range: more than 3 s.d. separation for π/K/p over 3-50 GeV/c
- e-side: Compact aerogel RICH covering up to 10 GeV/c (π/K/p) can provide the required PID optimized for EIC physics requirements
- Barrel:
  - DIRC is compact and can cover momenta up to 6-7 GeV/c
  - ToF issue with determining T_0

eRD14: dRICH

- First dual-radiator RICH developed for use with solenoidal detector
- Combination of C_2F_6 gas and n=1.02 aerogel leaves no gaps in coverage
- Outward-reflecting mirrors reduce backgrounds and (UV) scattering in aerogel
- 3D focusing reduces photosensor area
- Geant4 sims show excellent performance for hadron and lepton ID





See Alessio Del Dotto, Parallel 1

… and many more

- eRD6: Large forward GEM tracker prototype
- eRD6: Development of large cylindrical μ-RWELL
- eRD6: Chromium GEM foils
- eRD12: Electron polarimeter, luminosity monitor and a low Q2-tagger (concluded)
- eRD14: Modular aerogel RICH (mRICH) - see Cheuk-Ping Wong, Parallel 1
- eRD15: Compton electron detector for polarimetry - see Nicola Minafra, Parallel 1
- eRD17: BeAGLE, Tool to refine detector requirements for eA in the saturation regime
- eRD19 & New Proposal: Machine background studies
- eRD20 - Developing simulation and analysis tools - see Markus Diefenthaler, Parallel 1
- and then some …

Take Away Message

The Good

- The EIC physics has many characteristics that are unique to the environment and need dedicated R&D.
- High quality and highly relevant R&D being carried out within the EIC R&D program.
- Good involvement of universities and national laboratories; excellent student involvement, good publication record.

Take Away Message

The Good

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The Bad

- **The program is at the tipping point.** The number of proposals increases steadily while the funding stays flat. We either spread the funding thin (ineffective), or we fund fewer (discourages many, exclude groups we want on board). Neither option is good for the EIC.

Afterthoughts

- With the publication of the LRP came a significant increase in international and national participation.
- With a (hopefully) positive outcome of the NAS review the number of proposals and groups will certainly go up further.
- Many of the participating groups will be an important part in the formation of EIC collaborations and will likely be those that form detector groups.
- We suggested to DOE an increase towards a $3-4M/year level within 3-4 years if possible. International support will help, but the US has to take the lead (increased R&D funding was recommendation in LRP ’15)
- Strengthening the R&D program would ensure that the technologies exists and are mature enough to carry out the EIC physics program.