The EIC Detector R&D Program

The Program Coordinator View

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https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

BROOKHAVEN NATIONAL LABORATORY

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Office of Science
U.S. DEPARTMENT OF ENERGY

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: Thomas Ullrich

Generic Detector R&D for an EIC

- Currently funded out of RHIC operations funds: $1-1.5M/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)

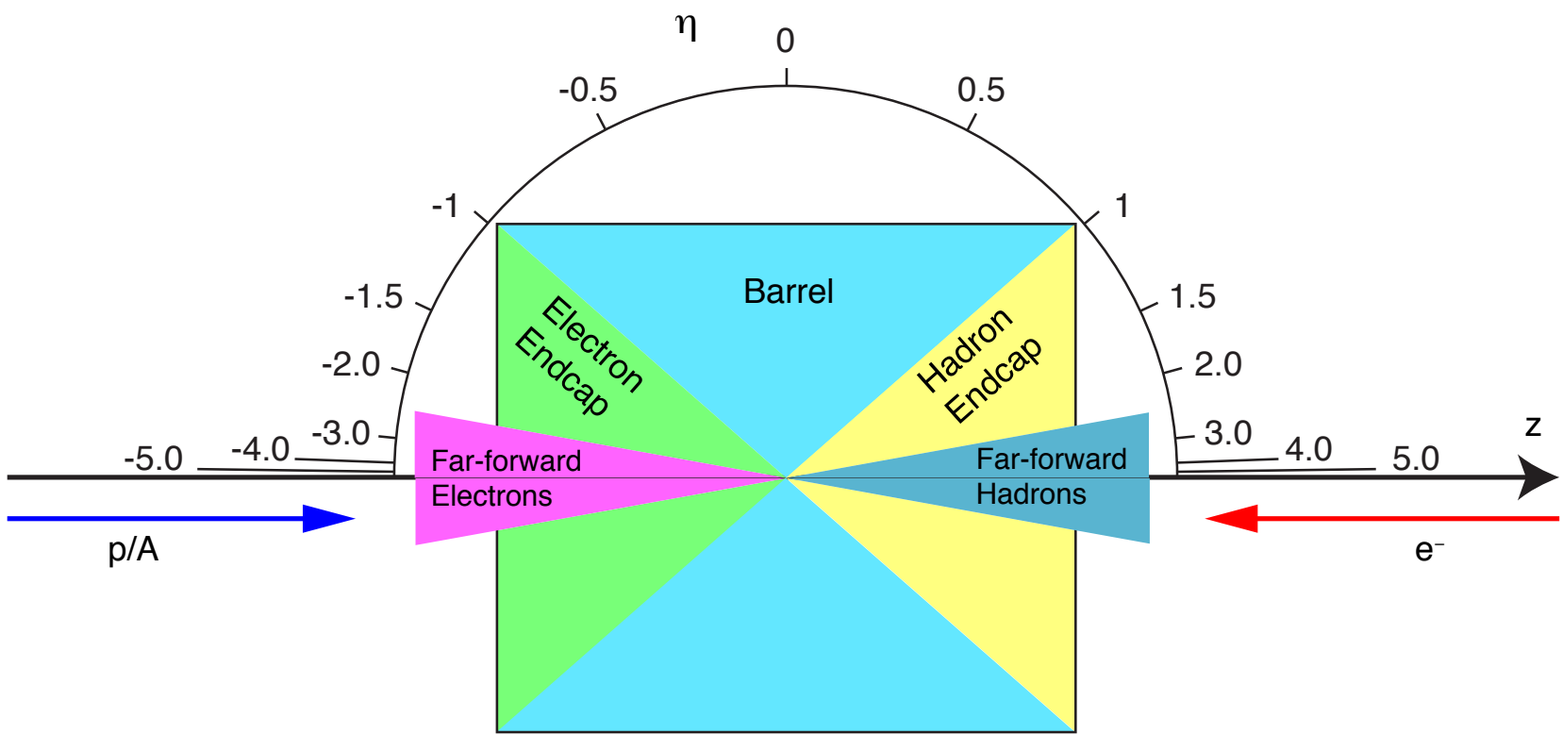
* During 2011-2014 new proposals were also accepted in the Winter meeting

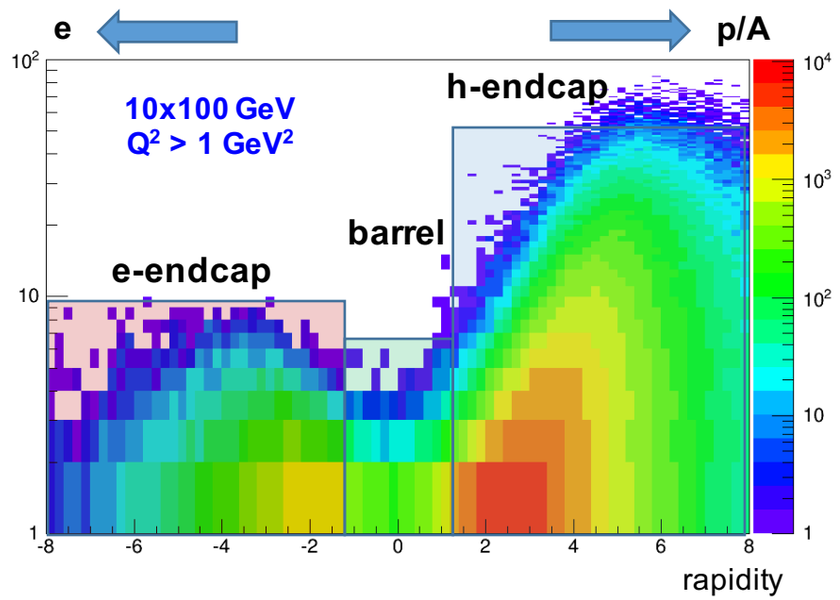
EIC Detector Requirements (I)

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

In Short:

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





EIC Detector Requirements (II)

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												
-2.0 — -1.5				$\sigma_p/p \sim 0.05\% \times p + 1.0\%$			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				$\sigma_p/p \sim 0.1\% \times p + 2.0\%$					≤ 20 GeV/c			
2.5 — 3.0												
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	$\sigma_{intrinsic}(1/t)/1/t < 1\%$; Acceptance: $0.2 < p_T < 1.2$ GeV/c								

Details are refined continuously. Requirements details in various documents (EIC WP, eRHIC and JEIC Design Reports). A comprehensive R&D Handbook is in the works.

Detector R&D in Context

LHC:

- Majority of detector R&D is currently related to LHC phase-I (ALICE, LHCb) and phase-II upgrades (ATLAS, CMS)
- Radiation hardness and rate are top R&D items for pp. Less emphasis on PID (notable exceptions is LHCb). High multiplicity and high data taking rate for AA (ALICE).
- With end of phase-I R&D efforts on MAPS, PID, GEM/MMG-TPC will cease.

ILC:

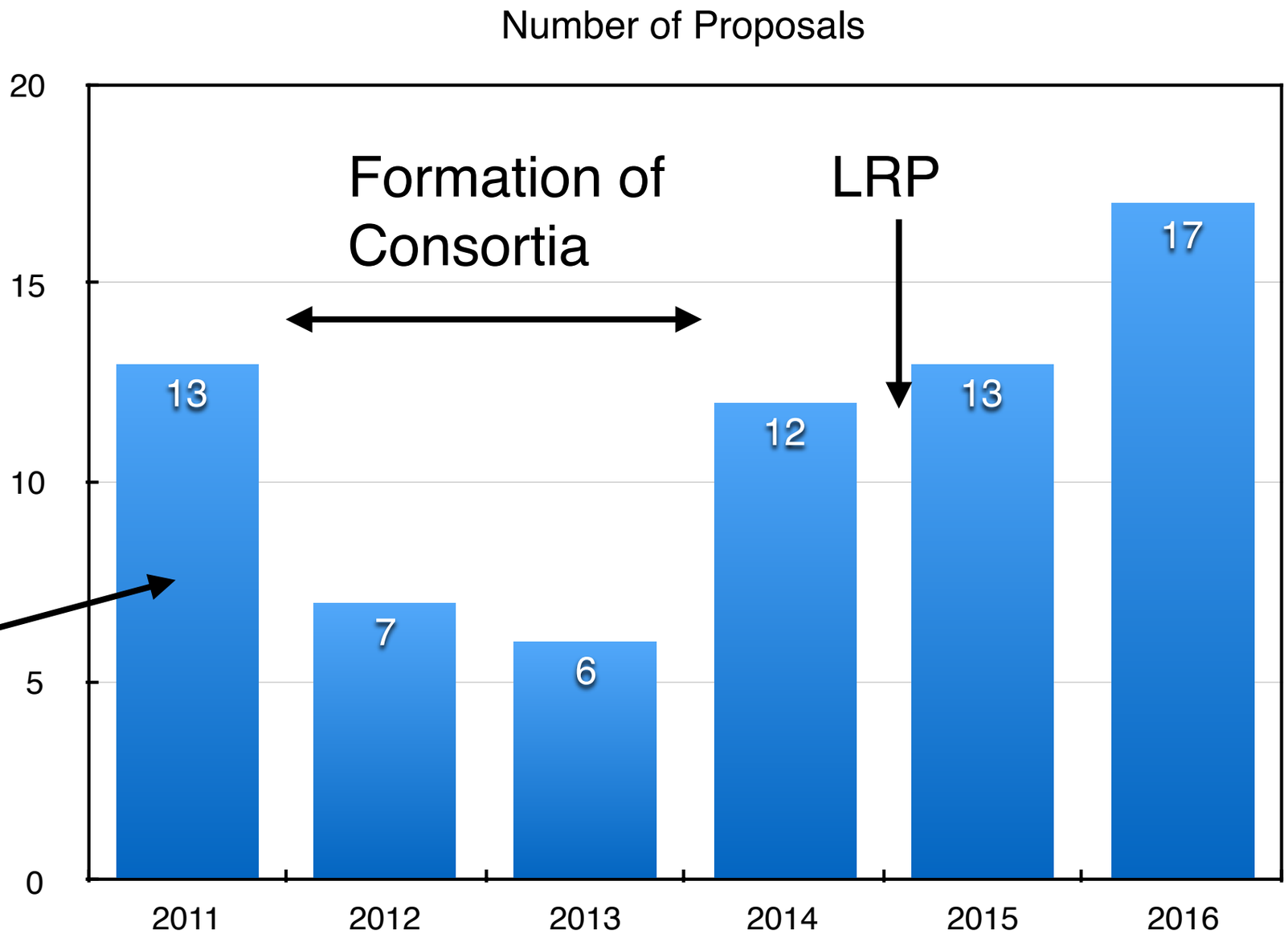
- Rate and precision requirements compatible
- Less emphasis on forward/backward instrumentation

Others:

- Some overlap with Belle-II, Panda

Program has to drive specific R&D that is not covered by main stream HEP R&D.

Statistics (I)

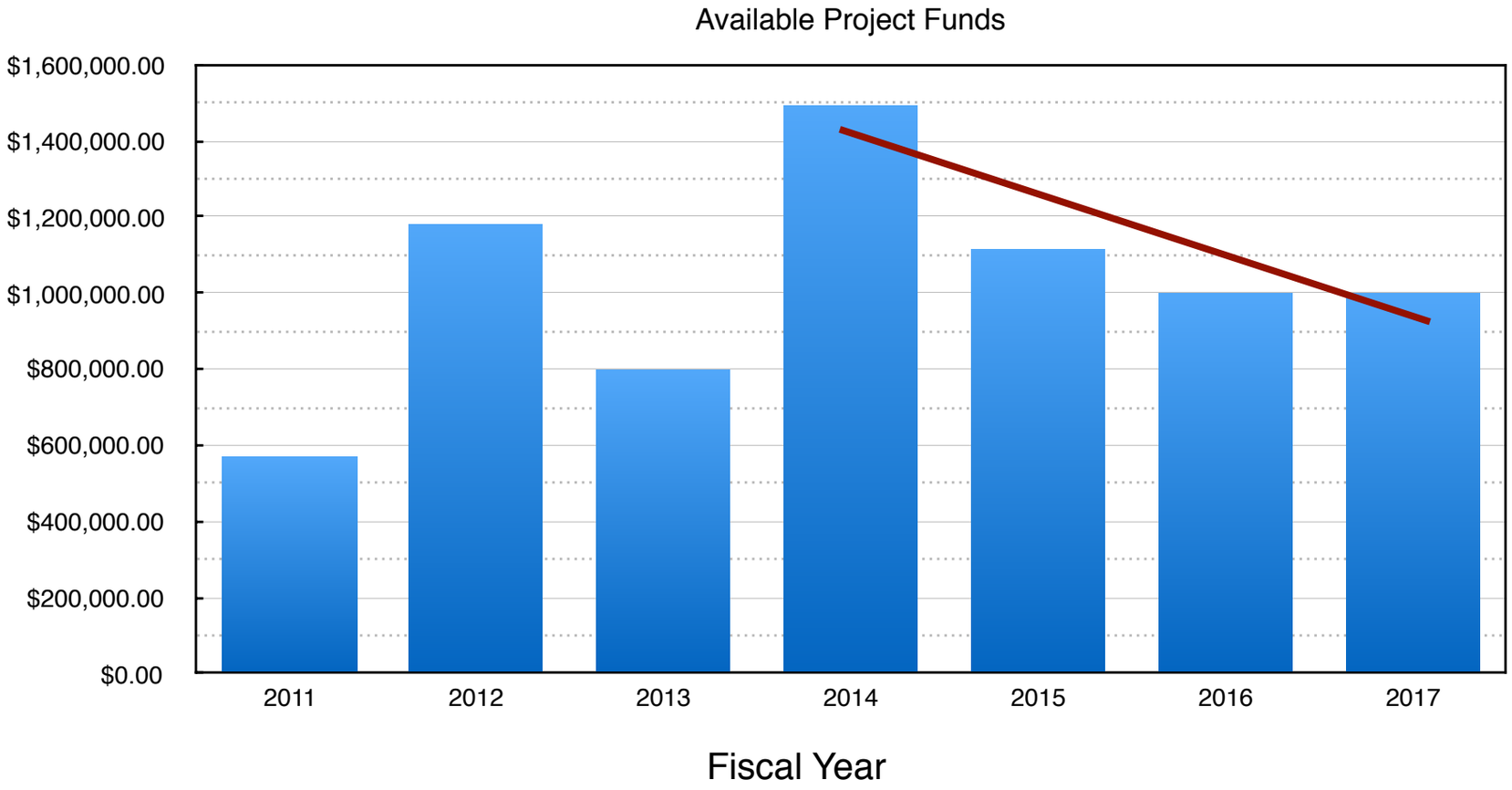


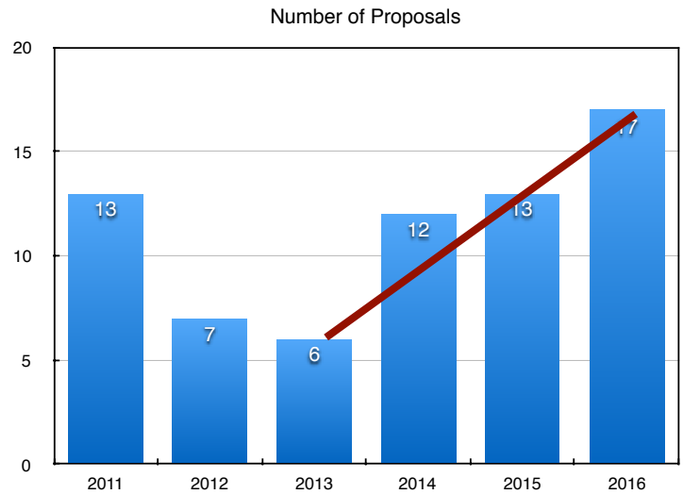
First year: moderate requests in terms of funding

Note: < 2014 proposals were considered every 1/2 year. Those are added up.

- FY17: Record participation this time (expected)
  - 8 new proposals, new strong international groups

Statistics (II)





- Funding
  - Total since 2011: $7,721,740
  - Total funds requested for FY17: $2.45M: worst ratio of available/requested funds ~ 0.41
- Participation (present)
  - 48 institutions (11 non US)
  - ~140 participants

The R&D Program: Calorimetry

- 2011: Development of a new detector technology for fiber sampling calorimeters for EIC and STAR (UCLA, Texas A&M, Penn State)
- 2011: Liquid scintillator calorimetry for the Electron Ion Collider (Ohio University)
- 2011: Crystal R&D proposal for a forward calorimeter at EIC (USTC, UCLA)
- 2012: Pre-shower detector for forward EM calorimeters (Univ. Tecnica Valparaiso)
- 2012: Develop Calorimeters for EIC (BNL, Indiana University, Penn State Univ., UCLA, USTC, TAMU)
- 2013: Dead area free planar silicon sensors with improved radiation hardness for tracking and calorimetry applications at EIC (BNL, Younsei University)
- 2013: Proposal for Generic R&D on EIC Detectors (ECAL)
- 2014: Zero-degree high-precision hadronic calorimetry (Iowa State University, Jefferson Lab, Old Dominion University)
- 2016: Proposal to Develop Imaging Hadron Calorimetry (ANL)

All calorimeter related R&D is now performed by the **eRD1** consortium (12 institutions, 36 participants, PI: C Woody (BNL), H. Huang (UCLA))
Focus: Sci-fiber EM calorimeter (SPACAL), Crystal ($PbWO_4$) EMCal

The R&D Program: Tracking

- 2011: Letter of Intent for Detector R&D towards an EIC detector (BNL, Florida Inst. Of Technology, Iowa State Univ., LBNL, LANL, MIT, Riken BNL Res. Cntr., Stony Brook Univ., Univ. Virginia, Yale Univ.)
- 2011: Proposal for very forward tracking in STAR (ANL)
- 2011: Design and Assembly of fast and lightweight barrel and forward tracking prototype for an EIC (CEA Saclay, MIT, Temple Univ.)

Tracking consortium **eRD6*** Consortium (7 institutions, >30 participants, PI: Klaus Dehmelt, Thomas Hemmick (SUNY))
Focus: MiniDrift TPC, TPCC, ZigZag Planar GEMs, RICH, Stereo-COMPASS Planar GEMs, 2GEM+µMEGA TPC RO Chambers

Project **eRD3** (2 institutions, ~5 participants, PI: Bernd Surrow (Temple), Franck Sabbatie (Saclay)), in future merged with eRD6
Focus: curved MicroMega Barrel tracker, Forward/Backward tracking system based on triple-GEM detector, detailed GEM foil studies

*eRD6 is largest experiment at Fermilab Test Beam Facility with 19 detector stations in single experiment

The R&D Program: Vertex Tracking

- 2012: R&D of a Silicon-based tracker system for EIC detector (Jlab, Moscow State Univ., Univ. New Hampshire)
- 2015: Forward/Backward Tracking at EIC using MAPS Detectors (LBNL)
- 2016: Precision Central Silicon Tracking & Vertexing for the EIC (University of Birmingham)

eRD16 (LBL, PI: B. Jacak, E. Sichtermann)
Focus: Forward tracker based on MAPS, simulations & requirements

eRD18 (U Birmingham, PI: Peter Jones)
Focus: Central barrel tracker, simulations & requirements, sensor development

The R&D Program: PID

- 2011: DIRC-based PID for the EIC Central Detector (Catholic University of America, Old Dominion University, Jefferson Lab, GSI)
- 2011: Endcap TOF and TRD for identifying electrons at EIC (BNL, Indiana Univ., Rice Univ. UT-Austin, USTC, VECC, Yale, MIT)
- 2012: RICH detector for the EIC forward detector (Jlab, INFN Frascati, INFN Ferrara, Ch. Newport Univ., Univ. Tecnica Valparaiso)
- 2012: GEM based TRD for Identiying electrons at EIC (BNL, Indiana Univ., USTC, VECC, ANL)
- 2013: RICH detector for the EIC forward region PID region (JLab, Argonne, INFN Ferrara, Los Alamos)
- 2013: R&D Proposal for 10 Picosecond TOF PID at an EIC (Brookhaven National Laboratory, Howard University, Muhlenberg College, University of Illinois at Urbana-Champaign, University of Massachusetts at Amherst, Yale)
- 2015: Proposal for an integrated program of Particle Identification (PID) challenges and opportunities for a future Electron Ion Collider (BNL, Howard University, University of Illinois at UrbanaChampaign, Abilene Christian University, ANL, Georgia State, INFN, Sezione di Ferrara, Jefferson Lab, LANL, Duke, The University of New Mexico, Universidad Tecnica Federico Santa Maria, Old Dominion University, University of South Carolina, GSI, The Catholic University of America, Yale)

Most PID related R&D is now performed by the **eRD14** consortium (20 institutions, 65 participants, PI: P. Nadel-Turonski, Y. Ilieva (SC))
Focus: Dual radiator RICH, Modular Aerogel RICH (mRICH) ,DIRC, High-resolution Time-of-Flight, Photosensors & Electronics (Sensors in High-B, LAPPDs, GEM photocathodes)

The R&D Program: Polarimetry & Luminosity

- 2012: Development of a Spin Light Polarimeter for the EIC (Mississippi State, College of Wm. & Mary, Stony Brook, Mainz, UV-Charlottesville, ANL, JLab)
- 2013: R&D Proposal for an electron polarimeter, a luminosity monitor and a low Q2-tagger (Brookhaven National Laboratory (Physics & CAD), Cracow University of Technology, Byelorussian State University)
- 2013: 2. A proposal for Compton Electron Detector R&D (Thomas Jefferson National Accelerator Facility, University of Manitoba, Idaho State University, Mississippi State University, University of Virginia, Stony Brook University, Carnegie Mellon University, College of William and Mary, SEDI CEA Saclay)

eRD12 provided complete study and design for electron polarimeter, a luminosity monitor and a low Q2-tagger (BNL, PI: E. Aschenauer) concluded

eRD15 Compton Electron Detector R&D for precision polarimetry (5 institutions, PI: A. Camsonne (JLAB))

The R&D Program: Physics Studies (Software)

- 2011: Physics simulations to establish and refine detector requirements and detector design for the EIC (BNL)
- 2011: Improved energy loss calculations for GEANT4 simulations (Univ. Washington)
- 2015: DPMJetHybrid Upgrade: A Tool to Refine Detector Requirements for eA Collisions in the Nuclear Shadowing / Saturation Regime (BNL, MDB Physics and Detector Simulation LLC, Central China Normal University in Wuhan)
- 2016: R&D Proposal for Detailed Simulations of Machine Background Sources and the Impact to Detector Operations (BNL)
- 2016: Developing Analysis Tools and Techniques for the EIC (ANL, BNL, INFN Trieste, SLAC, JLab
- 2016: Performance characteristics of the SiD detector for deep inelastic events at the electron-ion collider (Argonne National Laboratory

RD 2012-5 provided physics generators that defined the diffractive physics program (WP) and corresponding requirements (PI: TU (BNL))

eRD17 is working on eA event generator including nuclear shadowing & parton saturation. Essential in establishing detector requirements (PI: M. Baker)

eRD18 to establish long missing details on background sources and their impact (PI: E. Aschenauer (BNL))

eRD20: software simulation and analysis consortium (PI: M. Diefenthaler (JLAB), A. Kiselev (BNL))

The R&D Program: Electronics & Sensors

- 2011: Front end readout module for detector data acquisition and trigger system (Jefferson Lab)
- 2011: Proposal to test improved radiation tolerant silicon photomultipliers (Jefferson Lab)
- 2014: EIC Proposal for a Scalable, Deadtime-free, Trigger-less Readout Scheme(MIT)
- 2016: Proposal to Realize Radiation Tolerant Magnetic Immune Radiation Detector Readout Using Optical Phase-modulation-based Electro-optical Coupling (JLab)
- 2016: 4D Tracking Detectors: Monolithic Fast Timing Silicon Detectors (Argonne National Laboratory)

No past or ongoing project

Some dedicated tests (LAPPDs, SiPM, APD) are included in tracking, calorimetry, and PID consortia.

The R&D Program: Miscellaneous

- 2013: A Compact Magnetic Field Cloaking Device (Institutes: Stony Brook University, RIKEN Nishina Center for Accelerator-Based Science, BNL)
- 2014: 6. EIC Proposal for R&D of Micromegas Detectors (New) (MIT)
- 2016: Precision Timing at the Electron Ion Collider (University of Kansas)

eRD2: Develop magnetic field cloaking to shield transverse fields to avoid deflection and depolarization (3 institutions, PI: AD (SUNY))
Focus: Beam test up to 0.5T and over >1m using HTSC

Publications

After an initial slow start, all projects now have a solid publication record. Focus is on NIM, IEEE, and JINST. Large amount of presentations and posters at conferences. Many students involved.

RD 2012-5

Tobias Toll, Thomas Ullrich: *The dipole model Monte Carlo generator Sartre 1*; arXiv: 1307.8059 [hep-ph], Comput. Phys. Commun. 185 (2014) 1835-1853.

Tobias Toll, Thomas Ullrich: *Exclusive diffractive processes in electron-ion collisions*; arXiv:1211.3048 [hep-ph], Phys. Rev. C87 (2013) 2, 024913.

RD 2012-15

S. Yang et al.: *Cosmic Ray Test of Mini-drift Thick Gas Electron Multiplier Chamber for Transition Radiation Detector*; arXiv:1412.4769 [physics.ins-det], Nucl. Instrum. Meth. A785 (2015) 33-39.

eRD1

C.Woody et.al., *Status and New Results for the sPHENIX Calorimeter Systems*; proceedings of the CALOR 2016 Conference, submitted to the Journal of Physics Conference Series (in process).

C. Munoz-Camacho et al., *R&D for high resolution calorimetry at the future Electron-Ion Collider*; proceedings of the CALOR 2016 Conference, submitted to the Journal of Physics Conference Series (in process).

O. D. Tsai, et.al.: *Development of a forward calorimeter system for the STAR experiment*; Journal of Physics: Conference Series 587 (2015) 01205.

C. Woody and E. Kistenev: *Design Studies of the Calorimeter Systems for the sPHENIX Experiment at RHIC and Future Upgrade Plans*; Journal of Physics: Conference Series 587(2015) 011001.

Y. Fisyak et.al.: *Thermal neutron flux measurements in the STAR experimental hall*; NIM A 756(2014) 68-72.

O. D. Tsai, et.al.: *Results of R&D on a new construction technique for W/ScFi Calorimeters*; Journal of Physics: Conference Series 404 (2012) 012023.

C. Woody and E. Kistenev: *The Calorimeter Systems for the sPHENIX Experiment at RHIC*; Proceedings of CALOR 2012 International Conference on Calorimetry in High Energy Physics, Journal of Physics Conference Series, Vol 404,(2012) 012054.

eRD2

K. G. Capobianco-Hogan et al.: *Magnetic cloaking of charged particle beams*; Proc. 2nd North American Particle Accelerator Conf. (NA-PAC'16), Chicago, IL, USA, Oct. 2016, paper TUPOB43.

eRD3

M. Posik and B. Surrow: *Construction of Triple-GEM Detectors Using Commercially Manufactured Large GEM Foils*; Conference Record to IEEE Nucl. Sci. Symposium, Strasbourg, France [submission in progress] (2016).

M. Posik and B. Surrow: *R&D of Commercially Manufactured Large GEM Foils*; Conference Record to IEEE Nucl. Sci. Symposium, San Diego, CA, C15-10-31 (2015).

M. Posik and B. Surrow: *Optical and electrical performance of commercially manufactured large GEM foils;* Nucl. Instrum. Meth. A 802, 10-15 (2015).

M. Posik and B. Surrow: *Research and Development of Commercially Manufactured Large GEM Foils*; Conference Record to IEEE Nucl. Sci. Symposium, Seattle, WA, C14-11-08 (2014).

eRD6

A. Zhang et al.: *Study of non-linear response of a GEM read out with radial zigzag strips*; has been presented on the IEEE NSS/MIC conference 2016 and to be submitted to NIM A.

K. Gnanvo et al., *Performance in Test Beam of a Large-area and Light-weight GEM detector with 2D Stereo-Angle (U-V) Strip Readout*; Nucl. Inst. and Meth. A808 (2016), pp. 83-92.

S. Aiola, R.J. Ehlers, S. Gu, J.W. Harris, R. Majka, J.D. Mulligan, M. Oliver, J. Schambach and N. Smirnov: *Combination of Two Gas Electron Multipliers and a Micromegas as Gain Elements for a Time Projection Chamber*; Nucl. Instr. Meth. Phys. Res. A. 834 (2016) 149.

B. Azmoun et al., *A Study of a Mini-drift GEM Tracking Detector*; IEEE Transactions on Nuclear Science (Volume: 63, Issue: 3, June 2016).

A. Zhang et al.: *Performance of a large-area GEM detector readout with wide radial zigzag strips*; NIM A 811 (2016) 30-41.

A. Zhang and M. Hohlmann: *Accuracy of the geometric-mean method for determining spatial resolutions of tracking detectors in the presence of multiple Coulomb scattering*; JINST 11 P06012 (2016), June 21, 2016.

A. Zhang et al.: *R&D on GEM detectors for forward tracking at a future Electron-Ion Collider*; Proc. of IEEE Nuclear Science Symposium 2015, San Diego, CA, Nov 24, 2015 (arXiv: 1511.07913).

M. Blatnik et al.: *Performance of a Quintuple-GEM Based RICH Detector Prototype*; IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 62, NO. 6, DECEMBER 2015.

M. Blatnik et al.: *Performance of a Quintuple-GEM Based RICH Detector Prototype*, Nuclear Science Symposium Conference Record, 2015, IEEE

K. Gnanvo et al.: *Large Size GEM for Super Bigbite Spectrometer (SBS) Polarimeter for Hall A 12 GeV program at JLab*; Nucl. Inst. and Meth. A782, 77-86 (2015).

C. Woody et.al.: *A Prototype Combination TPC Cherenkov Detector with GEM Readout for Tracking and Particle Identification and its Potential Use at an Electron Ion Collider*, Conference Proceedings of the 2015 Micropattern Gas Detector Conference, Trieste, Italy, October 12-15, 2015 (submitted).

M.L. Purschke: *Test Beam Study of a Short Drift GEM Tracking Detector*; Conference Record Proceedings of the 2013 IEEE Nuclear Science Symposium and Medical Imaging Conference, October 27-Nov 2, 2013, Seoul, Korea

eRD12

R. Petti: *Interaction region design and auxiliary detector systems for an EIEPJ Web of Conferences, Volume 112, 2016, 6th International Conference on Physics Opportunities at an Electron-Ion Collider.*

eRD14

G. Kalicy et al.: DIRC detector for the future Electron Ion Collider experiment; Proceedings of the DIRC2015 Workshop, 11 - 13 November, Giessen, Germany, Journal of Instrumentation, Volume 11, March 2016.

Y. Ilieva et al.: *MCP-PMT studies at the High-B test facility at Jefferson Lab*; Proceedings of the DIRC2015 Workshop, 11 - 13 November, Giessen, Germany; Journal of Instrumentation, Volume 11, March 2016.

J. Xie et al.: *Development of a low-cost fast-timing microchannel plate photodetector*; Nucl. Instrum. Meth. A 824 (2016) 159.

L. Allison: *High-performance DIRC detector for use in an Electron-Ion Collider*, Proceedings for ICHEP2016 (38th International Conference on High Energy Physics), August 3-10, 2016, Chicago, IL, submitted to Proceedings of Science.

G. Kalicy: *PID systems for the JLab EIC full-acceptance detector*, Proceedings for ICHEP2016 (38th International Conference on High Energy Physics), August 3-10, 2016, Chicago, IL, submitted to Proceedings of Science.

A. Del Dotto et al.: *Design and R&D of RICH detectors for EIC experiments*, poster at RICH2016 (9th International Workshop on Ring Imaging Cherenkov Detectors), September 5-9, 2016, Bled, Slovenia, submitted to Nucl. Instrum. Meth. A.

R. Dharmapalan et al: *MCP-based photodetectors for cryogenic applications*; Journal of Instrumentation, 11, C02019 (2016).

J. Xie et al. (LAPPD collaboration): *Design and fabrication of prototype 6×6 cm2 microchannel plate photodetector with bialkali photocathode for fast timing applications*; Nucl. Instrum. Meth. A 784 (2015) 242.

J. Wang et al.: *Development and testing of cost effective, 6cm× 6cm MCP based Photodetectors for fast timing applications*; Nucl. Instrum. Meth. A 804 (2015) 84.

eRD15

A. Camsonne: *The low Q2 chicane and Compton polarimeter at the JLab EIC*; Proceedings of POETIC 2015 (EPJ Web Conf. 112), EPJ Web of Conferences (2016) Refereed Page(s) 01007.

Take Away Message

- The EIC R&D Program is successfully running since 2011
- The program is mature and is growing after the 2015 LRP
- Critical projects were added (Si-Vertex, PID)
- Currently 48 institutions (11 non US) are involved
- The program is currently oversubscribed, many projects that are vital for an EIC are underfunded
- Program management in collaboration with Committee is implementing new guidelines (funding requests, postdocs) to mitigate the funding situation and enforce prioritization
- Committee & Management are now enforcing the shift from “generic” R&D to more “targeted” program (w/o encouraging PED) whose priorities are aligned with the need for a realistic EIC detector
- Management, committee, and participant need guidance from the Office of Science on the future of the program
- Detector R&D program will need to get up to the $4M/year funding level within the next 4 years to reach past RHIC detector R&D levels (Generic R&D FY90: $1.35M, FY91: $1.95M)

Comparison - RHIC R&D

Detector R&D Funding Summary

R&D Effort	FY 90 $	FY 91 $	FY 92 $	FY 93 $	FY 94 $	FY 95 Plan	Total
Total Generic	1,121,437	1,620,751	215,000	20,000	50,000		3,027,188
Total STAR			1,125,000	1,267,000	1,467,365	1,100,000	4,959,365
Total PHENIX			1,200,523	1,463,984	1,147,300	1,000,000	4,811,807
Total PHOBOS				288,000	340,000	200,000	828,000
Total Allocations	1,121,437	1,620,751	2,540,523	3,038,984	3,004,665	2,300,000	13,626,360
Administration & BNL Support	228,563	331,249	269,477	376,016	450,335	296,000	1,951,640
R&D Total	1,350,000	1,952,000	2,810,000	3,415,000	3,455,000	2,596,000	15,578,000