EIC Detector R&D

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EIC User Meeting
ANL
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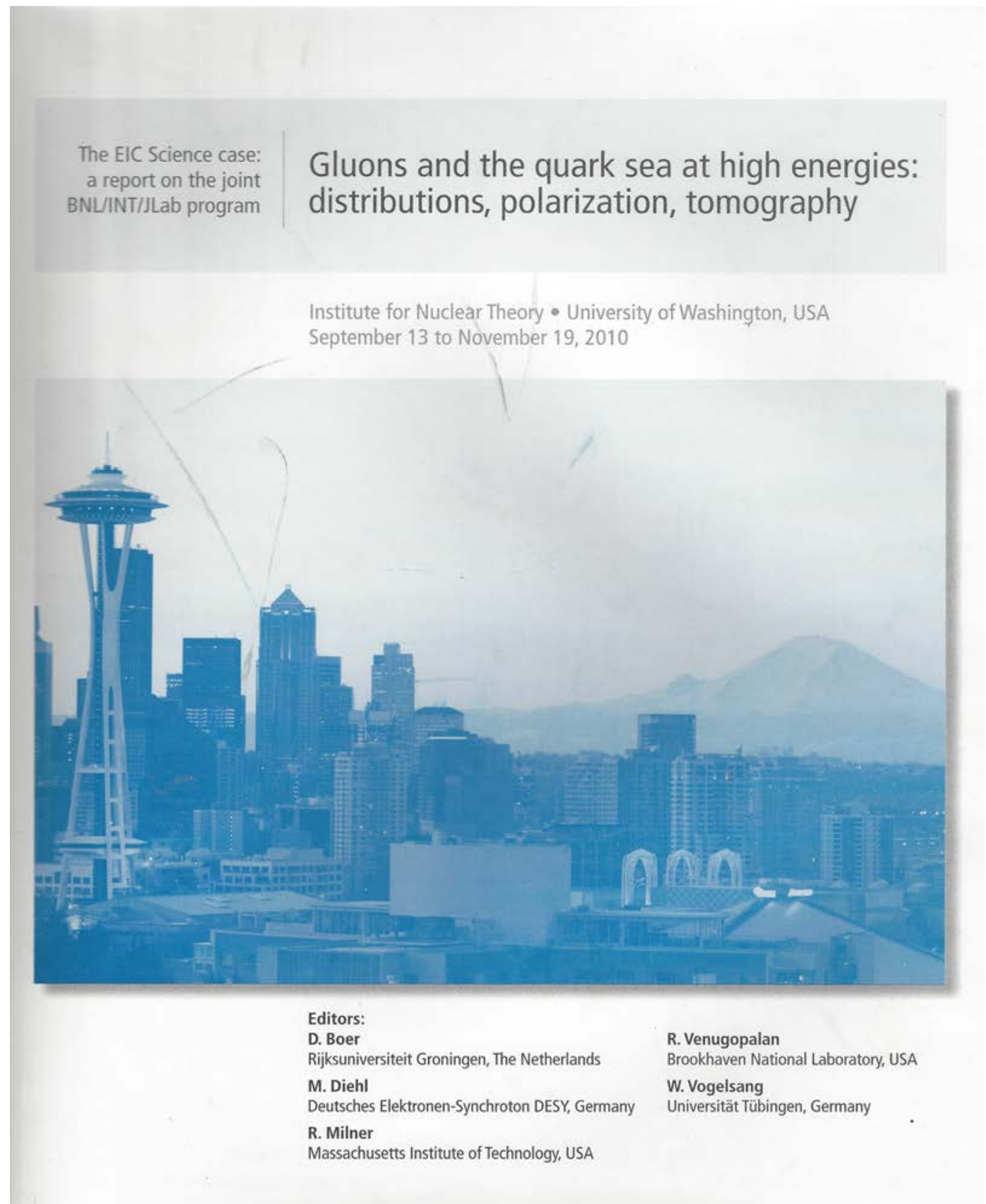
BROOKHAVEN
NATIONAL LABORATORY

2010/2011 - EIC Key Years

- Last LRP (2007) had good words for an EIC but no recommendation
  - “An EIC with polarized beams has been embraced by the U.S. nuclear science community as embodying the vision for reaching the next QCD frontier.”
  - “We recommend the allocation of resources to develop accelerator and detector technology necessary to lay the foundation for a polarized Electron-Ion Collider.”
- No funding efforts of DOE for detector R&D
- Fall 2010 INT Workshop “Gluons and the quark sea at high energies distributions, polarization, tomography”
  - 551 page writeup in August 2011



2010/2011 - EIC Key Years

- Work on the EIC White Paper started
  - Working groups of few enthusiast
- Few experimentalists from universities involved (although many were interested)
- No organized user group in sight
- Machine design at JLAB and BNL well underway
- No detector design(s) nor R&D efforts

2010/2011 the need to get the ball rolling was apparent

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
- Develop instrumentation solutions that meet realistic cost expectations
- Stimulate the formation of user collaborations to design and build experiments

Peer-Reviewed program established in 2011 to enable EIC experiments

Initiator, driver, and coordinator until 2014: Tom Ludlam

Generic Detector R&D for an EIC

- Funded by DOE, managed by BNL: 1M$-1.5M$/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
    - ~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)

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

Consortia

Committee was and is supporting the formation of consortia

- Combining efforts of groups from universities and labs with similar targets
  - encourage close collaboration
  - sharing of resources, some freedom in distribution of funds
- Currently:
  - Tracking consortium - 7 institutions
  - Calorimeter consortium - 12 institutions
  - PID consortium - 20 institutions
- Potential future candidates:
  - Si Vertex consortium
  - Software and Computing consortium

First step toward building scientific collaborations to successfully build EIC detector components

Reminder: EIC Detector Requirements

There are site-dependent requirements but overall they are rather similar:

- $-3.5 < \eta < 3.5$ is sufficient for the central detector
  - try to get to $\eta = -4$ if possible
- Material budget of $\lesssim 5\%\ X/X_0$
- Momentum resolution on a (few) % level is fine
  - no need to do better at a cost of higher X/X_0
- Electron ID
  - $-3.5 < \eta < 1$; π suppression up to $1{:}10^4$
  - ~2%/√E energy resolution (and low constant term) for $\eta < -2$
  - ~7%/√E energy resolution for $-2<\eta< 1$
  - ~10-12%/√E in barrel
- π/K/p separation
  - momentum distributions are very η-dependent
    - Forward η: up to ~50 GeV/c
    - Central η: up to ~4++ GeV/c
    - Backward η: up to ~5-6 GeV/c
  - suppression factors ~100 required
- Spatial resolution of primary vertex
  - ~10-20 μm
- Jets
  - HCAL needed at forward η; at mid-η no HCAL needed

EIC Detector Requirements and R&D in Context

In Short:

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

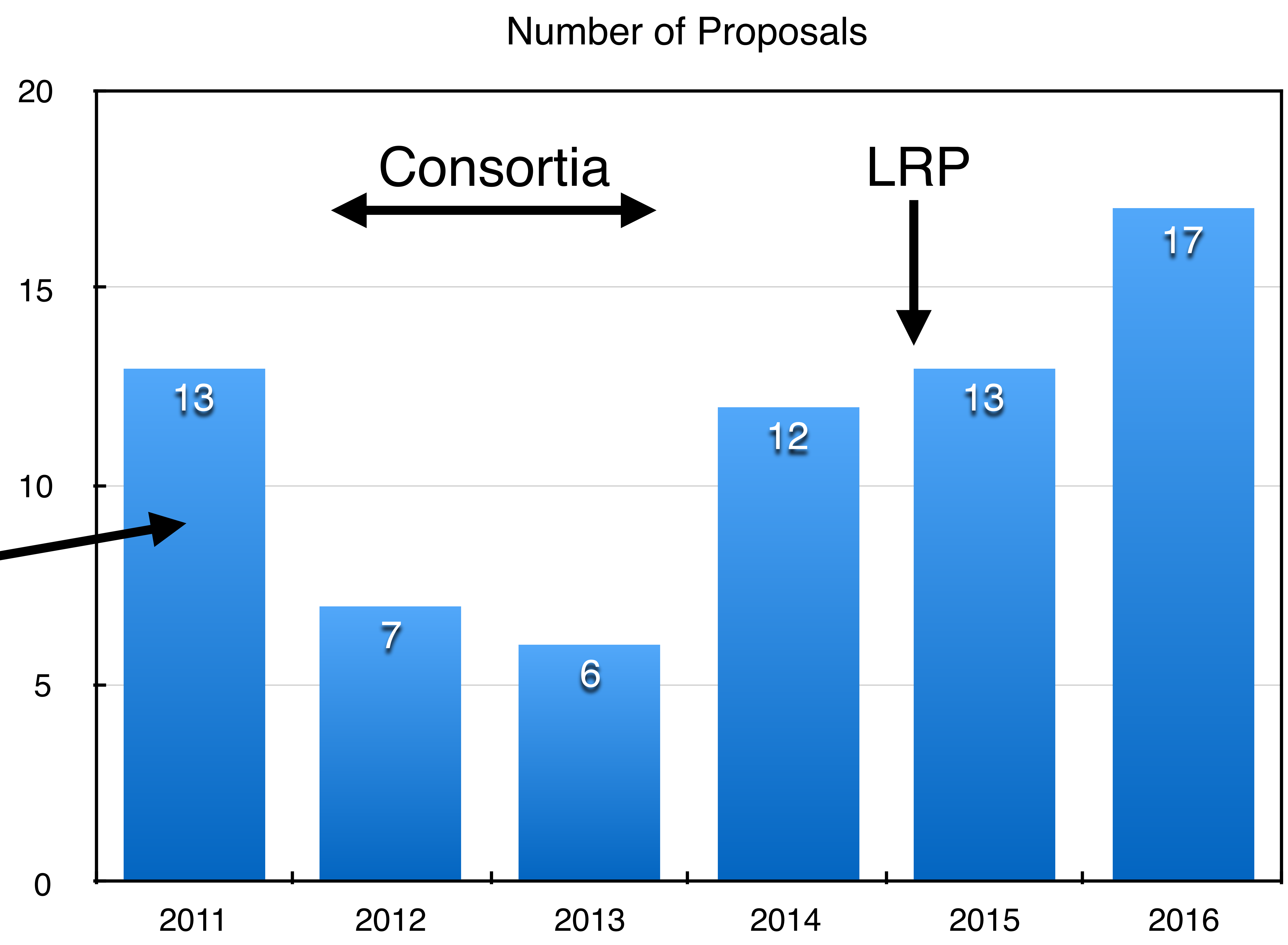
Comparison:

- Majority of R&D in HEP and HENP is currently related to LHC phase-I and phase-II upgrades
- 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-TPC will stop

Specific requirements for an EIC demand R&D that is not covered by main stream HEP, HENP R&D - we have to drive it ourselves

Some Statistics (I)

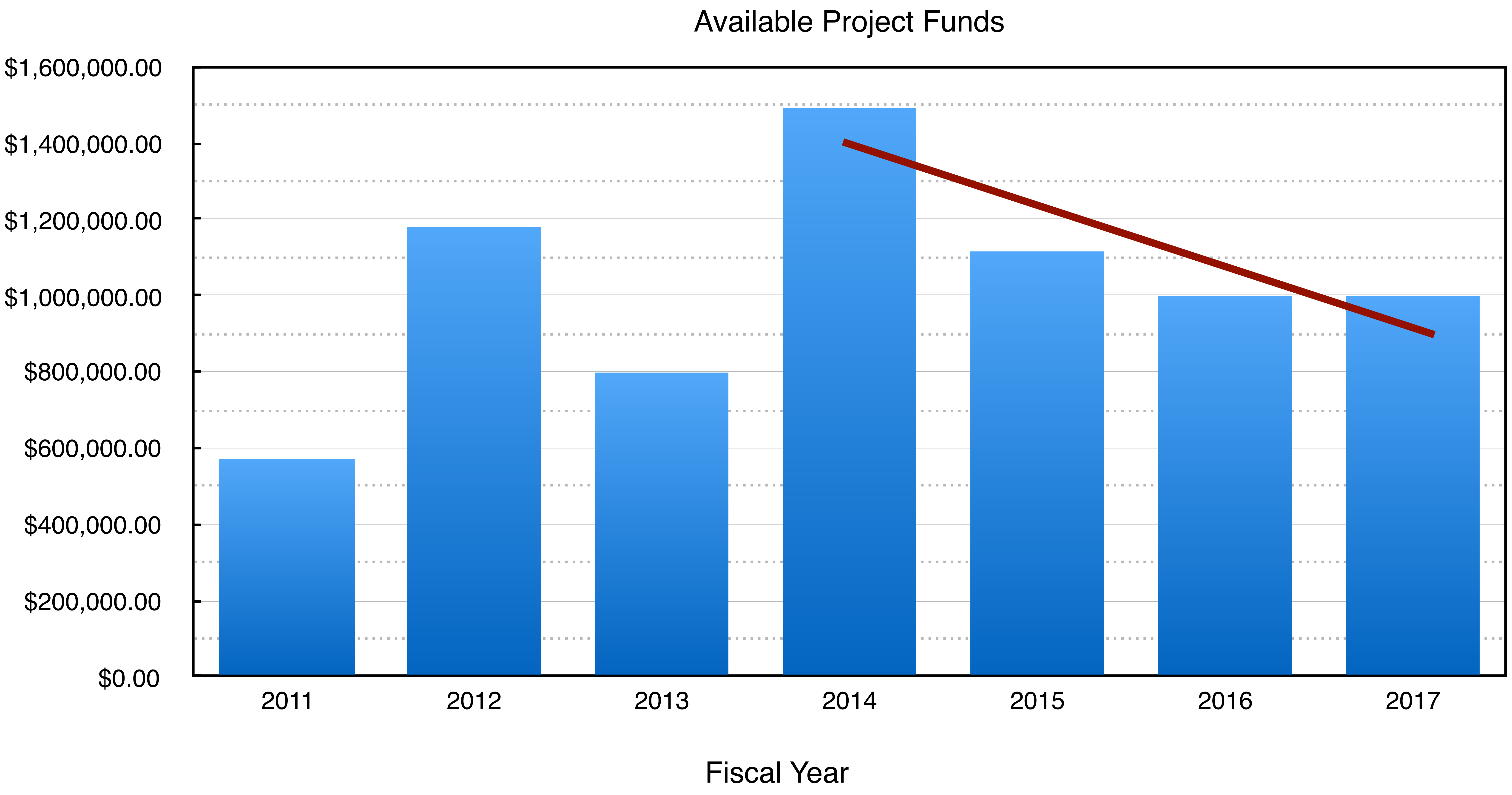
Note: < 2014 proposals were considered every 1/2 year. Those are added up.

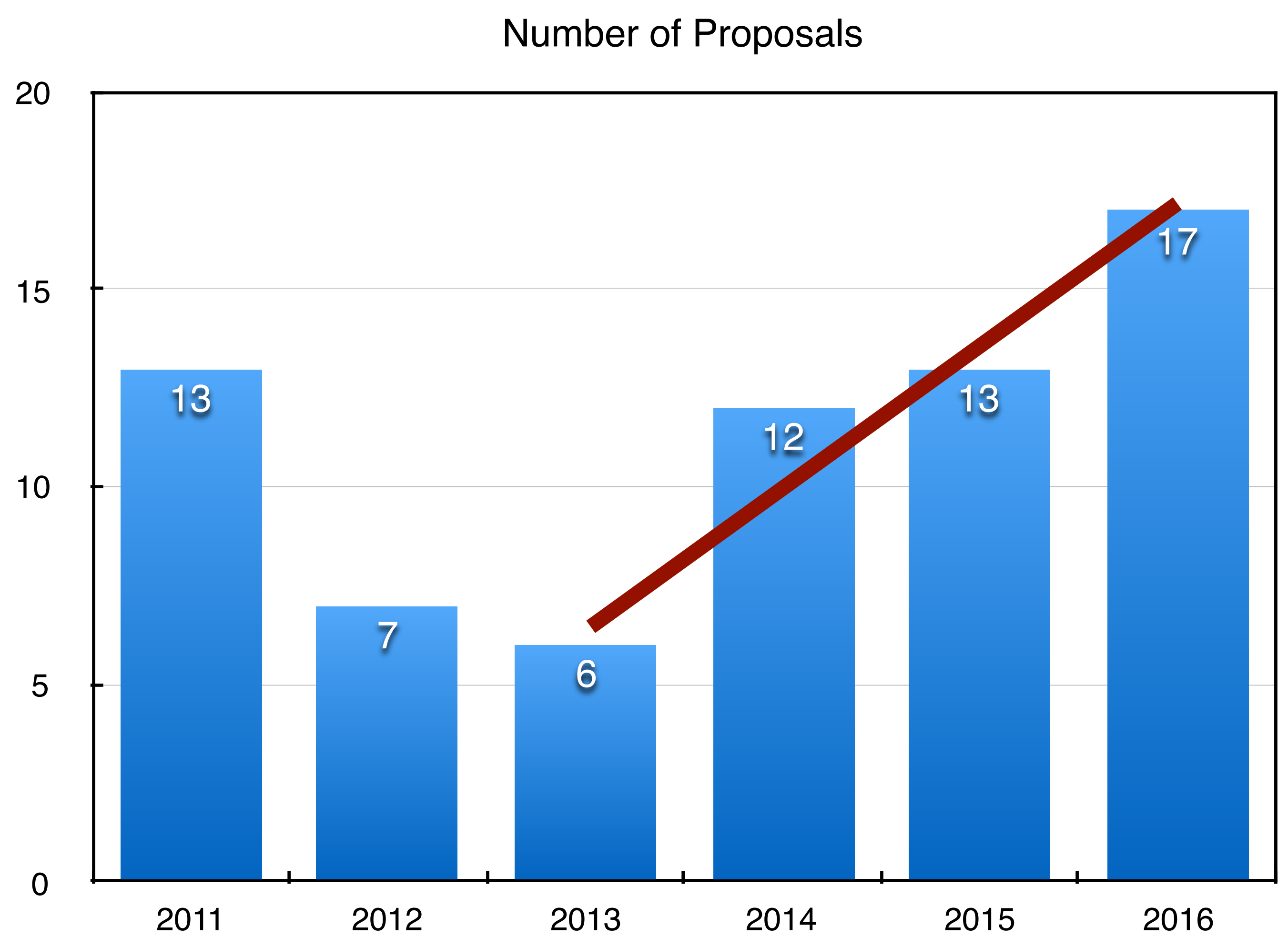


First year: moderate requests in terms of funding

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

Some Statistics (II)





- Total since 2011: $7,721,740
- Total funds requested: $2.45M: worst ratio of available/requested funds ~ 0.41
- Need to work on this together with DOE and EIC User Group SC

EIC R&D Examples

eRD1: Calorimeter Consortium

- **Goal:** Develop simple, cost effective, flexible techniques to build compact sampling calorimeters with good characteristics.
- **Efforts:**
  - Sci-fiber EM calorimeter (SPACAL)
    - Compact W-scifi 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
  - Sensor
    - SiPM and APDs, radiation studies and support electronics

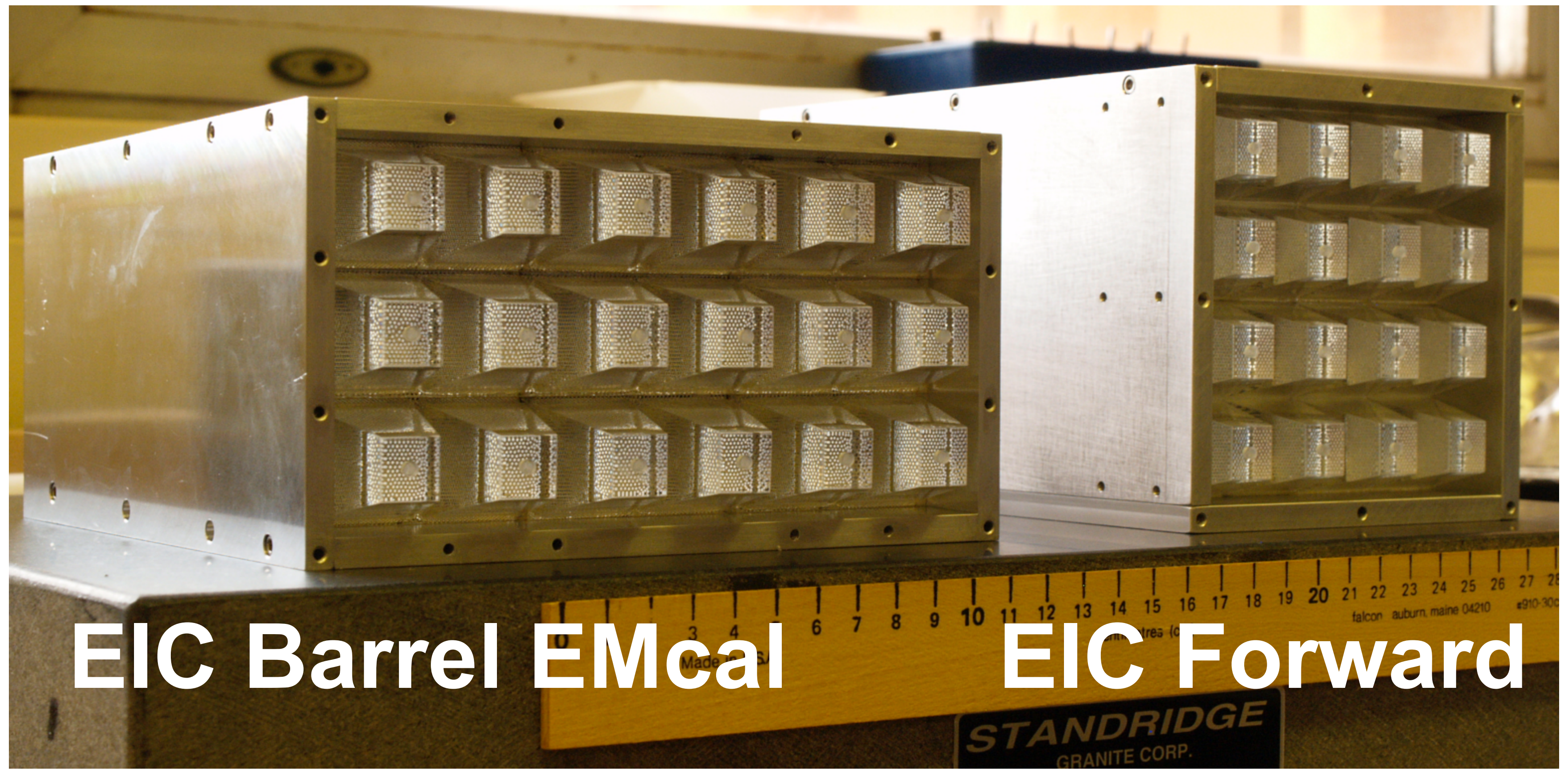
BNL, CALTECH, CUA, JLAB, IUCF, NPN Orsay, PSU, TAMU, UCLA, USTC, YPI

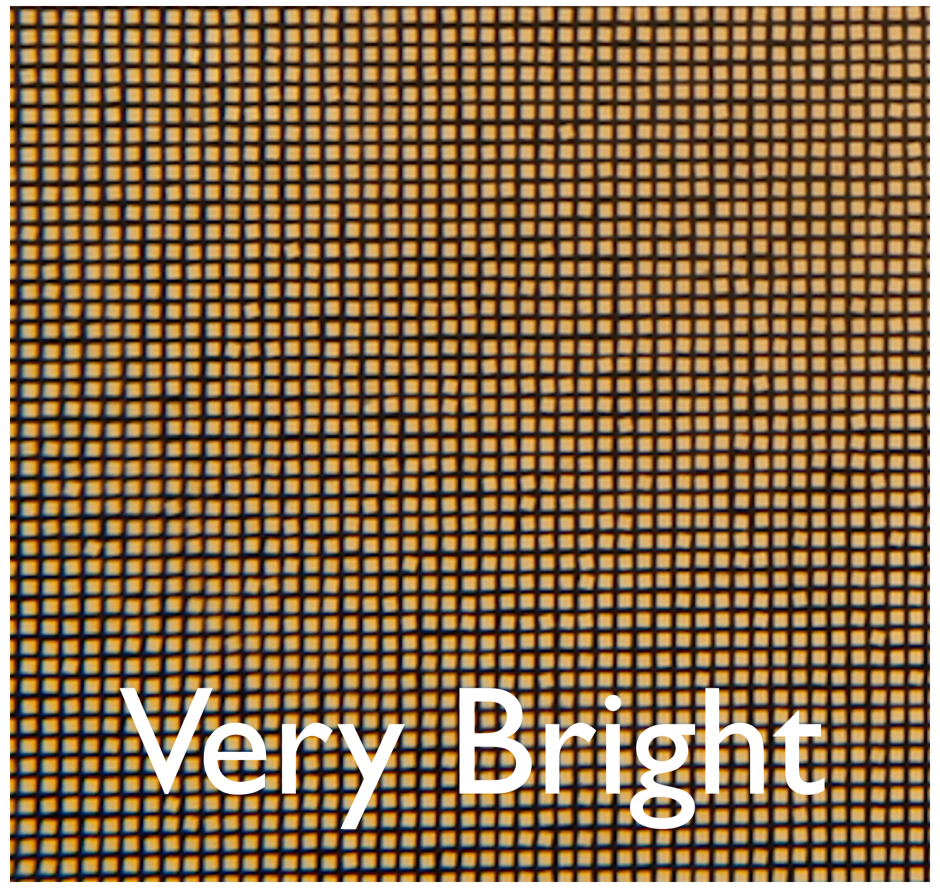
eRD1: W-SciFi SPACAL - EIC Forward

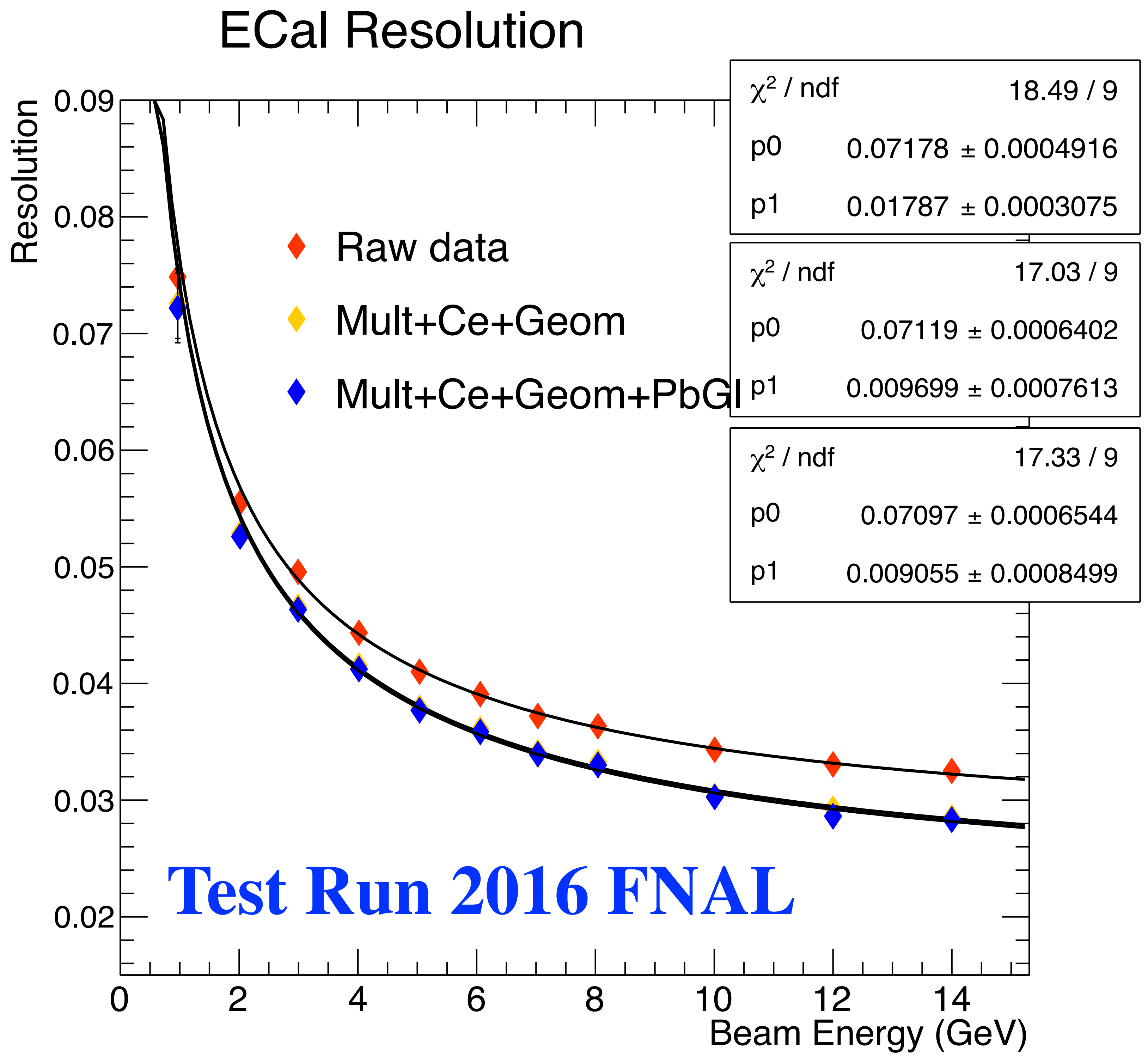
- **Thin fibers embedded in composite absorber**
  - Two versions 'O' (old) and 'S' (square)

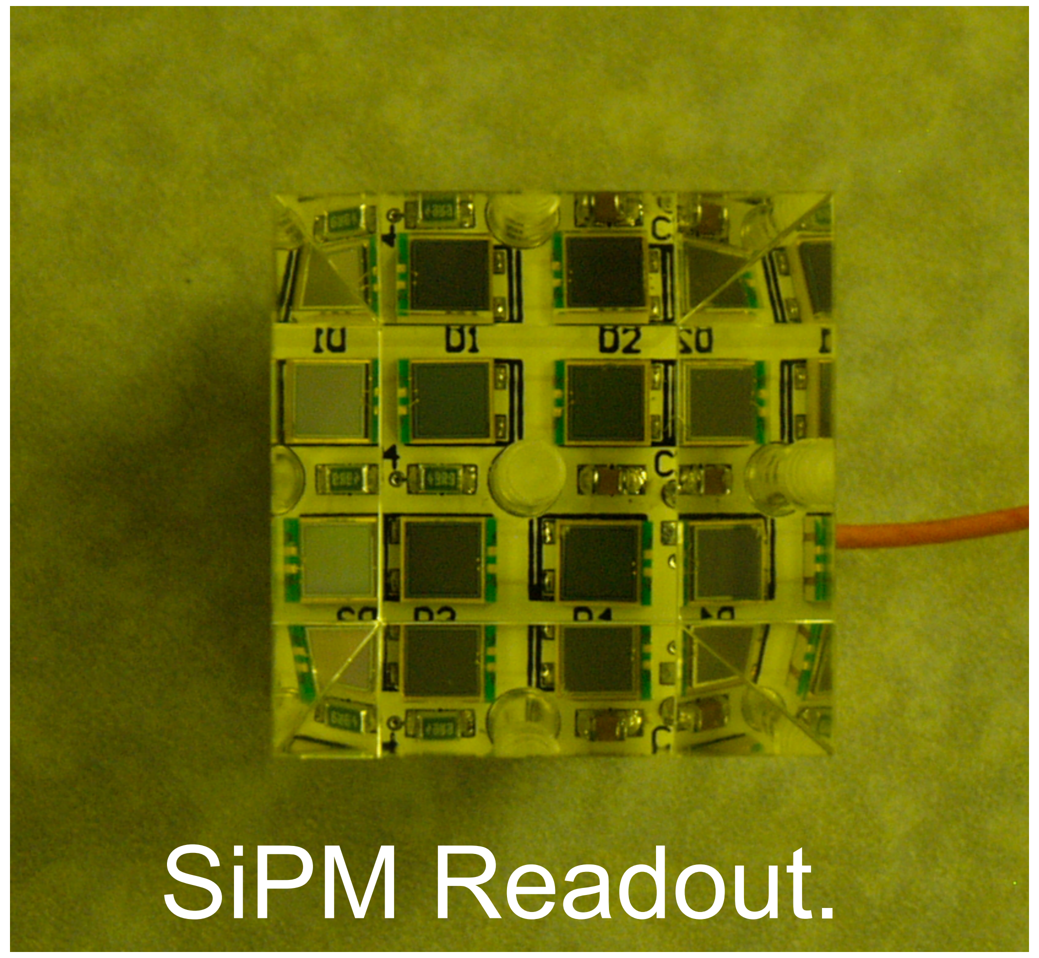
Detector	Fibers SCSF 78	Absorber	Sampling Frequency	Composition by weight	Number of fibers in superblock
"Old" High sampling frequency	Round, 0.4mm	75% W 25% Sn	0.671 mm Staggered Pattern	W -0.665 Sn – 0.222 Sc – 0.057 Epoxy- 0.056	25112 Damaged 3
"Square" High sampling fraction	Square, 0.59 x 0.59 mm²	100% W	0.904 mm Square Pattern	W – 0.858 Sc- 0.075 Epoxy- 0.067	11664 Damaged 0

  - 'S' version: Achieve target of 7%/√E with constant term ~ 1% constant term at 10°, 2.9% at 4°
- **Next:** Systematic study of behavior of Si sensors in realistic conditions, R&D on efficient and compact light collection scheme







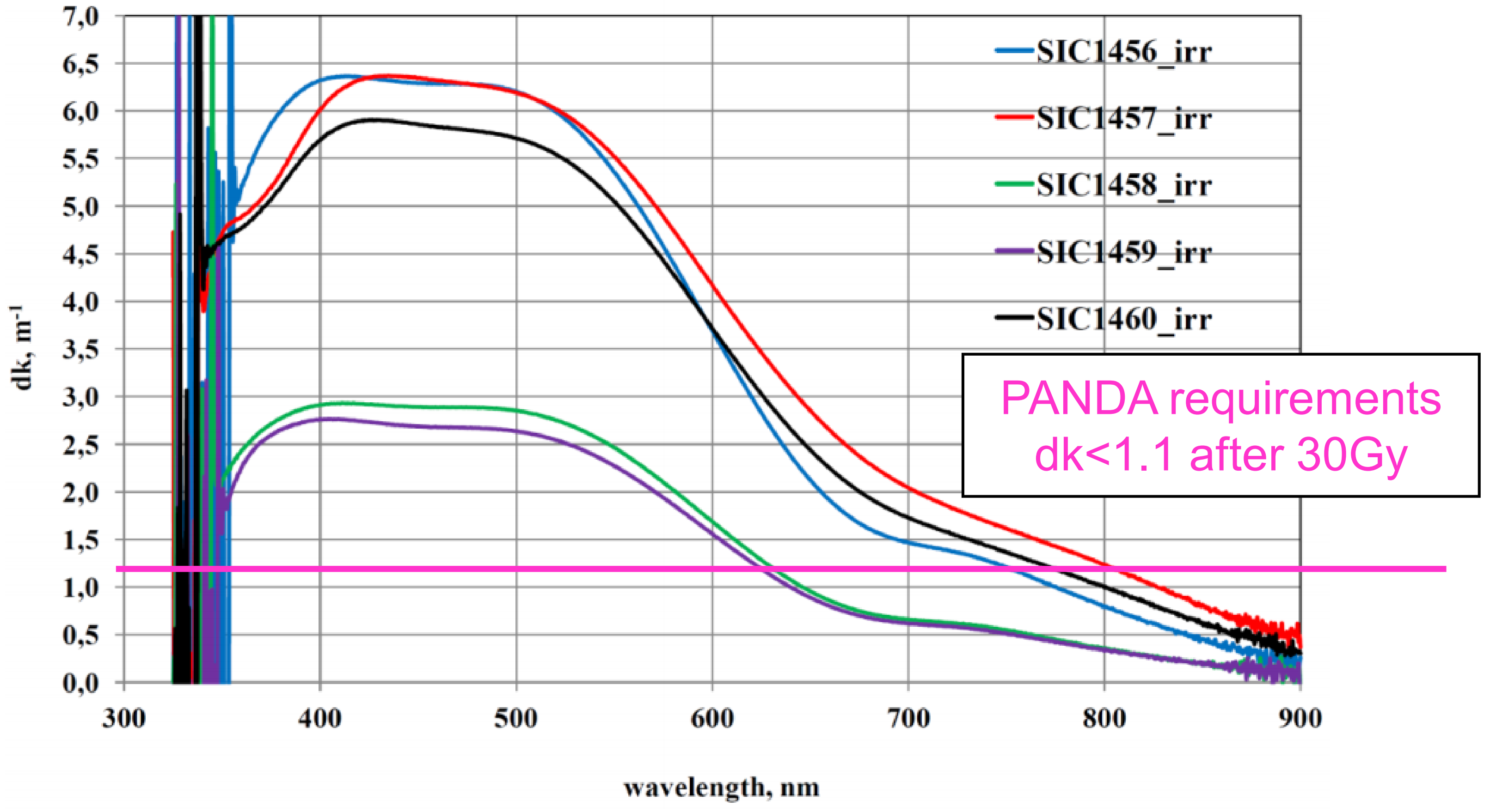


$$f(E) = \sqrt{\frac{p_0^2}{E} + p_1^2 + 0.01875^2}$$

eRD1: Crystal Calorimeter

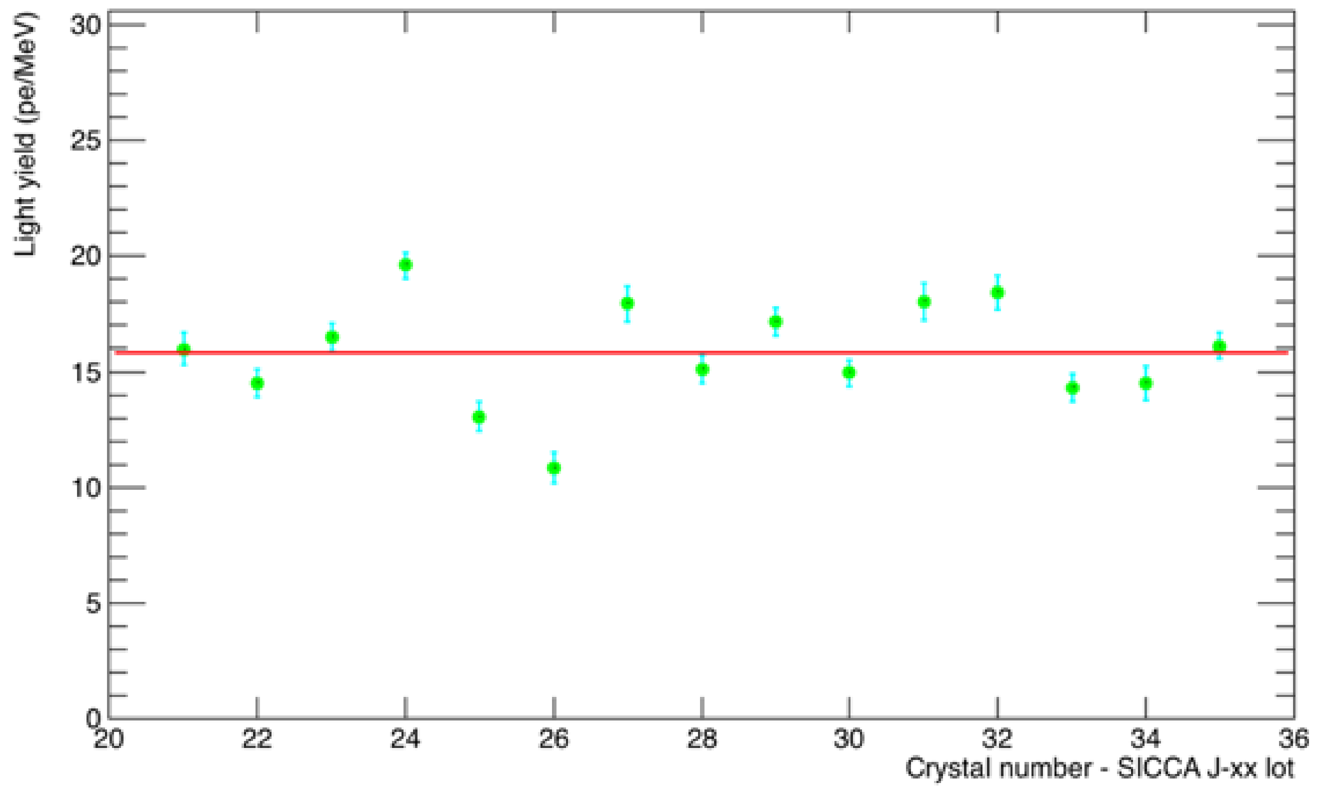
- e-going direction needs high precision calorimetry (few%/√E)
- PbWO4 calorimeter desired for this role, extensively used for high precision calorimetry (CMS, JLab, PANDA…) because of its energy and time resolutions and its radiation hardness
- BTCP (Russia) produced high quality crystals in the past but out of business
- SICCAS (China) problems maintaining good crystal quality
- New potential candidate: CRYTUR, Czech Republic

$$dk = \frac{\ln(T_{bef} / T_{aft})}{D}$$ Radiation induced absorption coefficient



Radiation hardness of recent SICCAS crystals

Light yield: large variations crystal to crystal

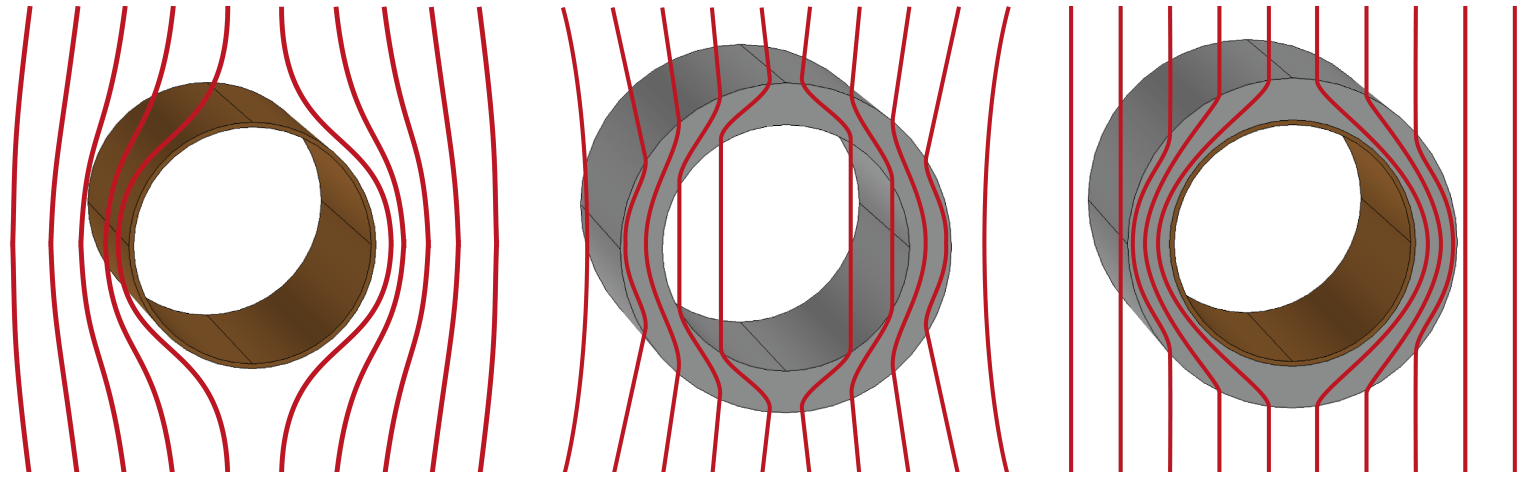


Goal:

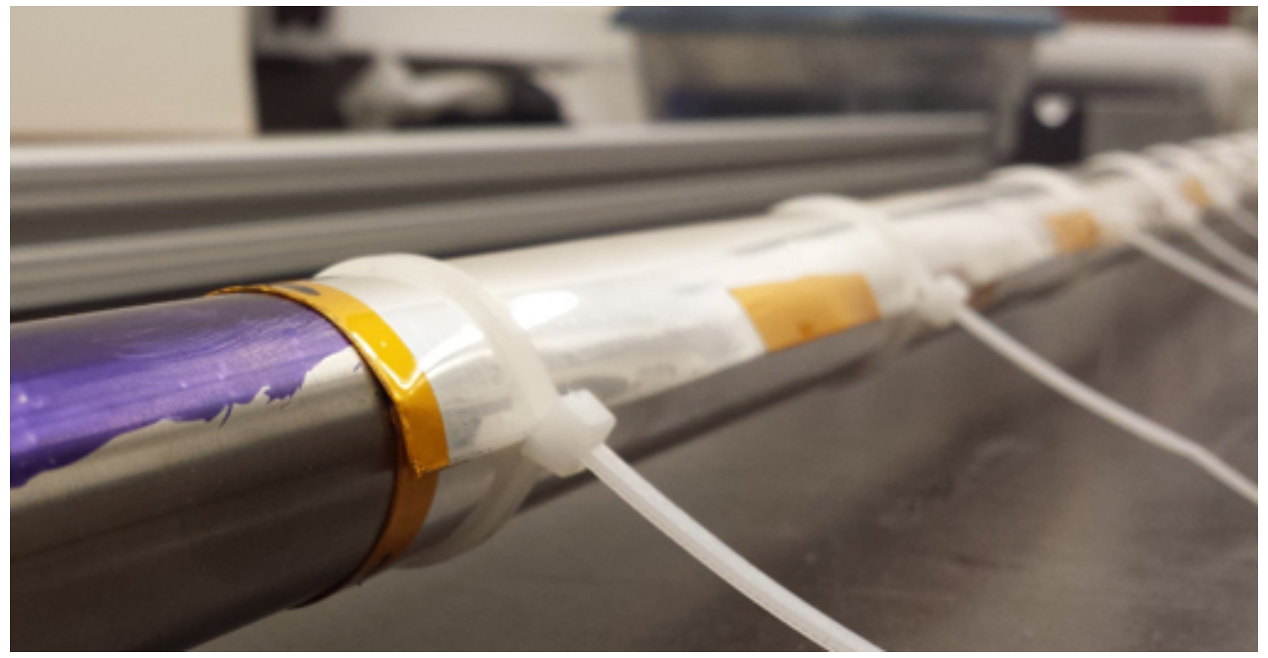
- Develop process towards acceptable crystals quality assurance towards EIC needs
- Develop an alternate supplier of PbWO4 (CRYTUR) - evaluate quality, work with manufacturers to improve quality

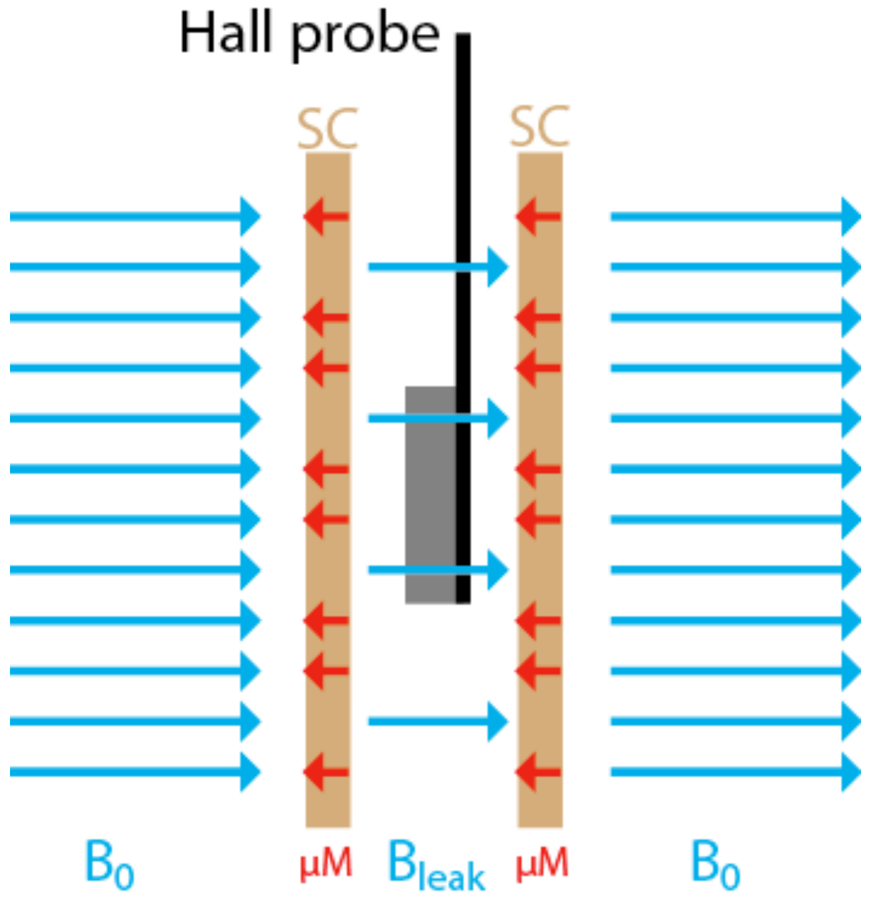
eRD2: A Magnetic Field Cloaking Device

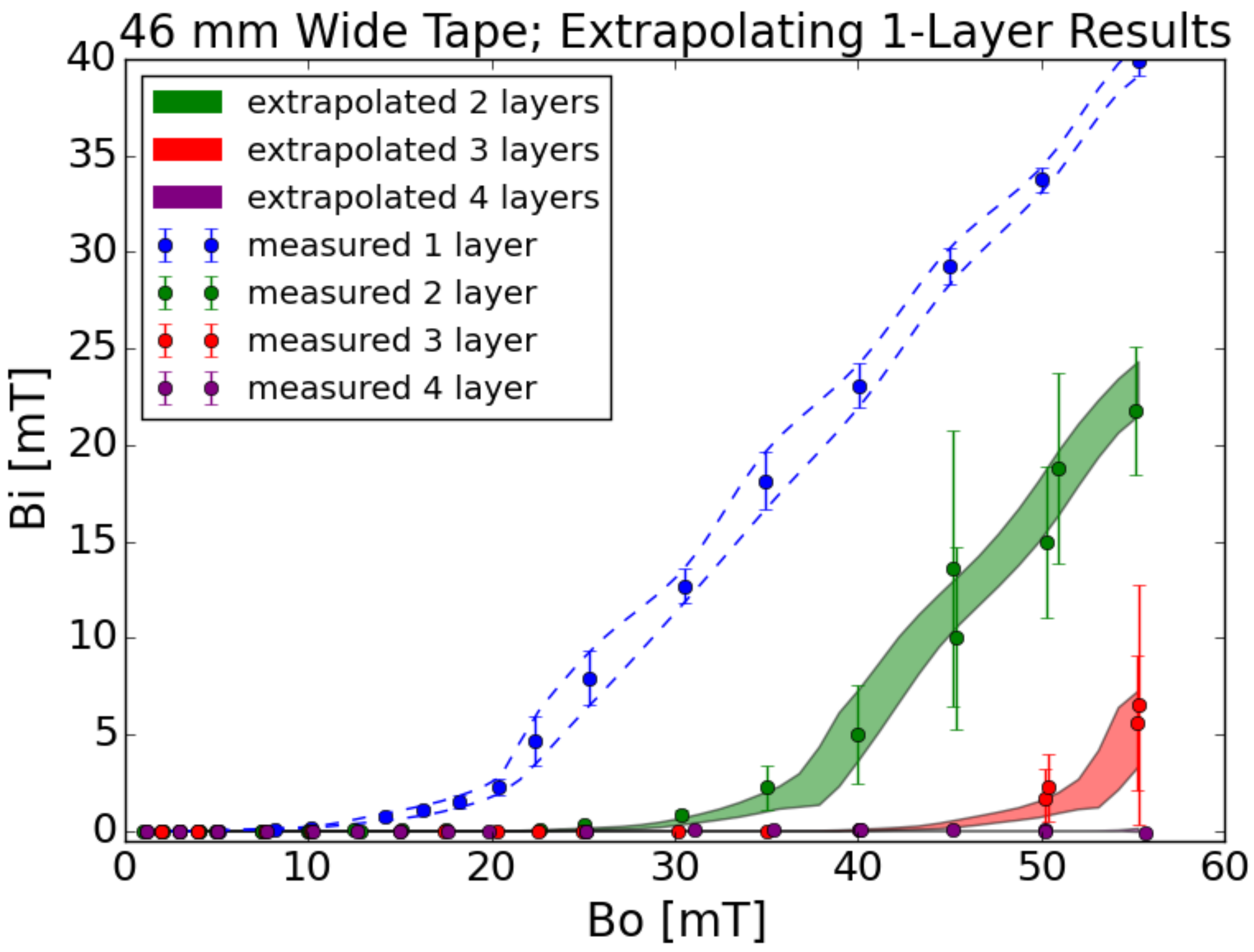
- **Issue:** Strong dipole magnets in forward/backward direction affect beam optics.
- **Goal:** Shield beam pipe and allows beam to tunnel through magnetic fields w/o disturbance of outside fields



- **Method:** Wrapping layers of layers of AMSC high-temperature superconductor around beam pipe



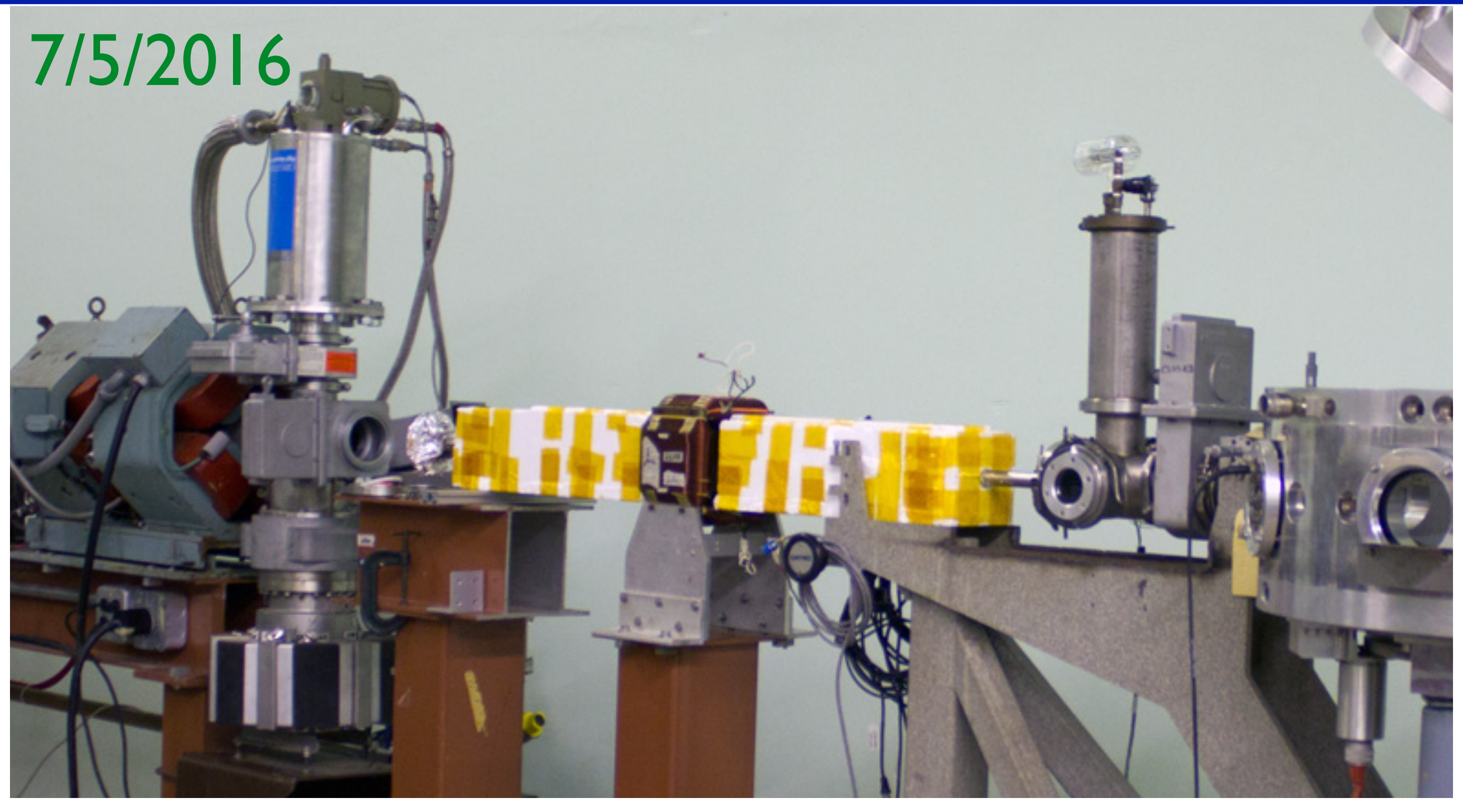


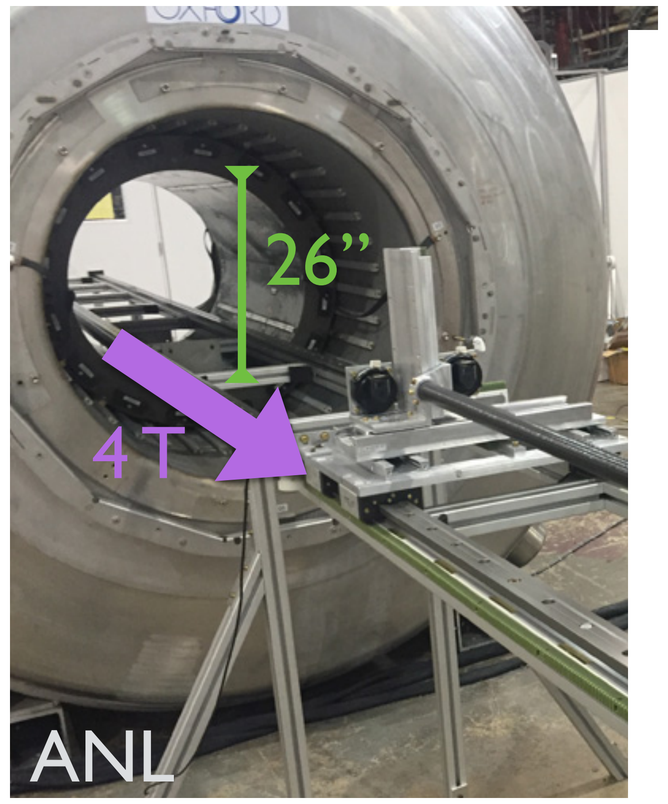


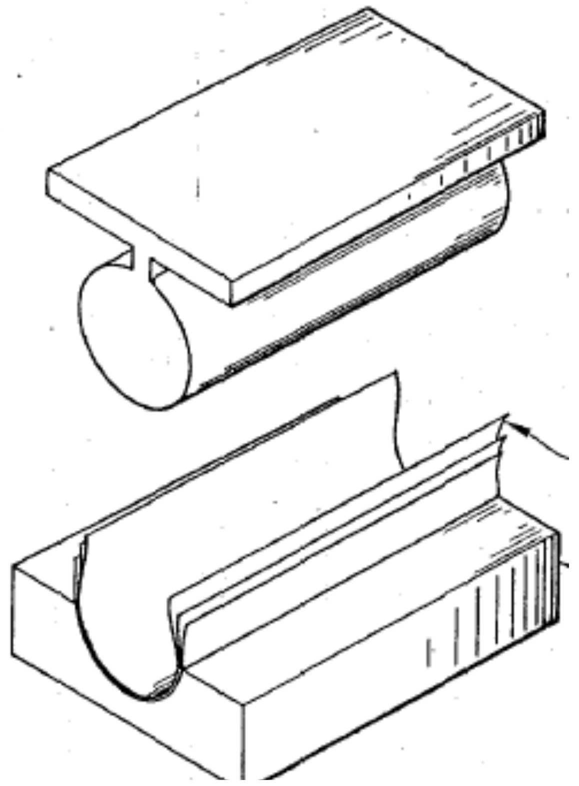
45 layers → 0.5T

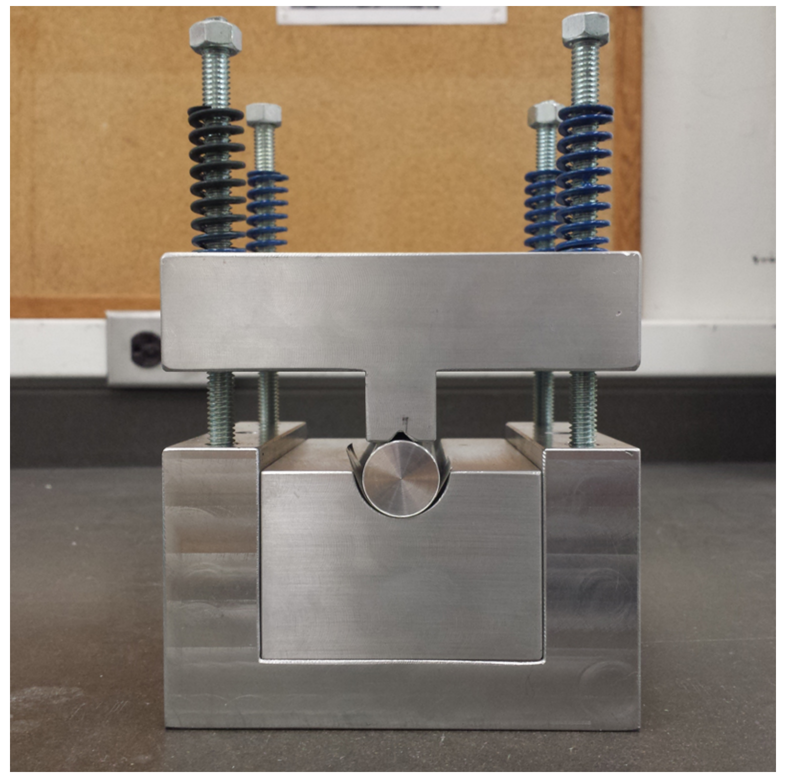
SUNY, RIKEN, BNL

eRD2: A Magnetic Field Cloaking Device







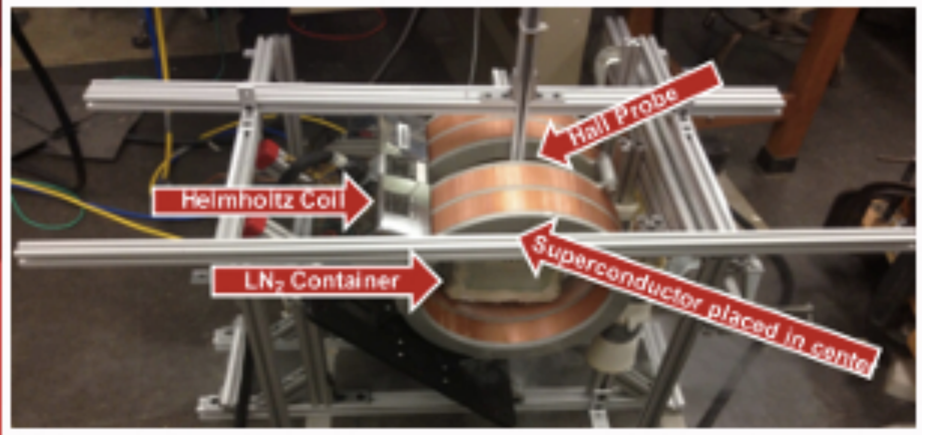


- Beam tests in progress:
  - BNL, Van de Graaff beam line
  - Shield beam from a transverse magnetic field with a 1.3 m SC cylinder at liquid nitrogen temperature
- Coming up:
  - High-field shielding test with MRI magnet at ANL
  - Shield a 0.5 T field with a 10 cm SC cylinder at liquid nitrogen temperature.
- Producing multi-layer shield
  - Successful first soldering and performance test with miniature version of shield

EIC R&D: Involving HS Students Successfully in eRD2

"Most Outstanding Exhibit in Computer Science, Engineering, Physics or Chemistry"

Ayesha Chhugani



High School Senior, Ayesha Chhugani, under the guidance of Prof. Abhay Deshpande receives 1st place at NYSSEF as well as the Yale Science & Engineering Association Award

Simons Program Student Receives 1st Place at NYSSEF and the Yale Science & Engineering Association Award

Ayesha Chhugani, a senior at Herricks High School, conducted Physics research as part of the Simons Program under the guidance of Professor Deshpande's Laboratory Group. She applied to the Simons Program to conduct independent research as part of Herricks' 4 year Science Research Program under the direction of Mrs. Renée Barcia. With direct support from Professor Deshpande, Post Doc Nils Feege, and Master's student Raphael Cervantes, Ayesha learned about superconductor physics and applied such knowledge to a project involving the study of trapped magnetic fields within superconductors. She learned not only the technicalities of superconductor physics, but learned what it means to be a researcher and actually implement the scientific method to discover something new.

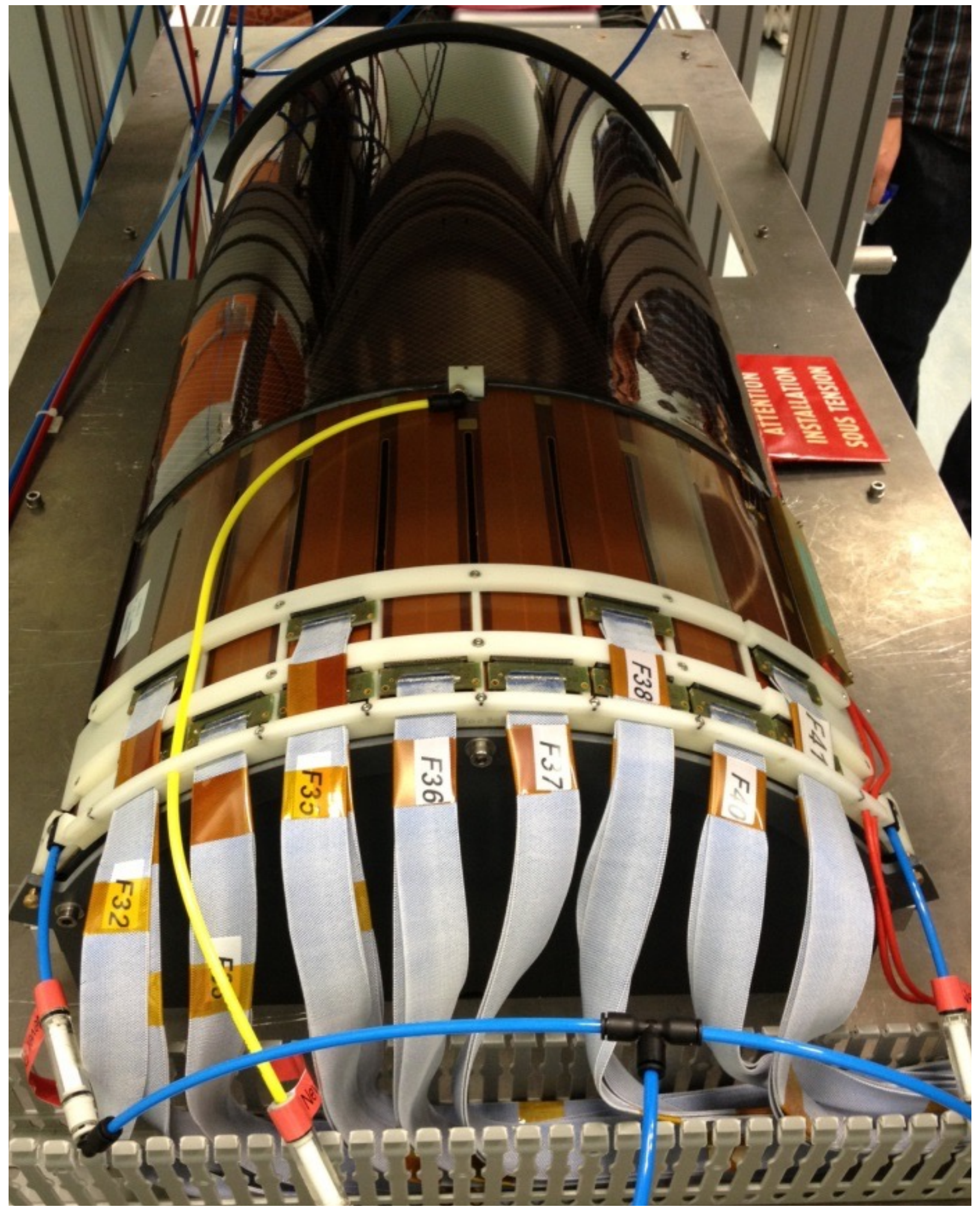
With her research report, "A Novel Magnetic Field Trap Using Superconductors for Transporting Polarized Ions for Medical Imaging", Ayesha was named as a Siemens Competition Semifinalist, Intel Science Talent Search Semifinalist, and was awarded 1st place in the Physics category at NYSSEF (New York State Science and Engineering Fair) along with the Yale Science & Engineering Association Award for "Most Outstanding Exhibit in Computer Science, Engineering, Physics or Chemistry."

Semi-finalist:

Fall 2016: Egleston Research Scholar at Columbia University-Fu Foundation School of Engineering

eRD3: Micro-Pattern EIC Tracking System

- R&D effort focuses on intermediate tracking system
  - Barrel tracking system based on MM detectors (Dedicated barrel / curved MM EIC R&D program) manufactured as cylindrical shell elements and
  - Forward/Backward tracking system based on triple-GEM detectors manufactured as planar segments (Collaboration with eRD6 FIT/UVA)
- R&D strategy:
  - Design and assembly of large cylindrical MM detector elements and large planar triple-GEM detectors
  - Test and characterization of MicroMegas and triple-GEM prototype detectors
  - Utilization of light-weight materials
  - Development and commercial fabrication of various critical detector elements

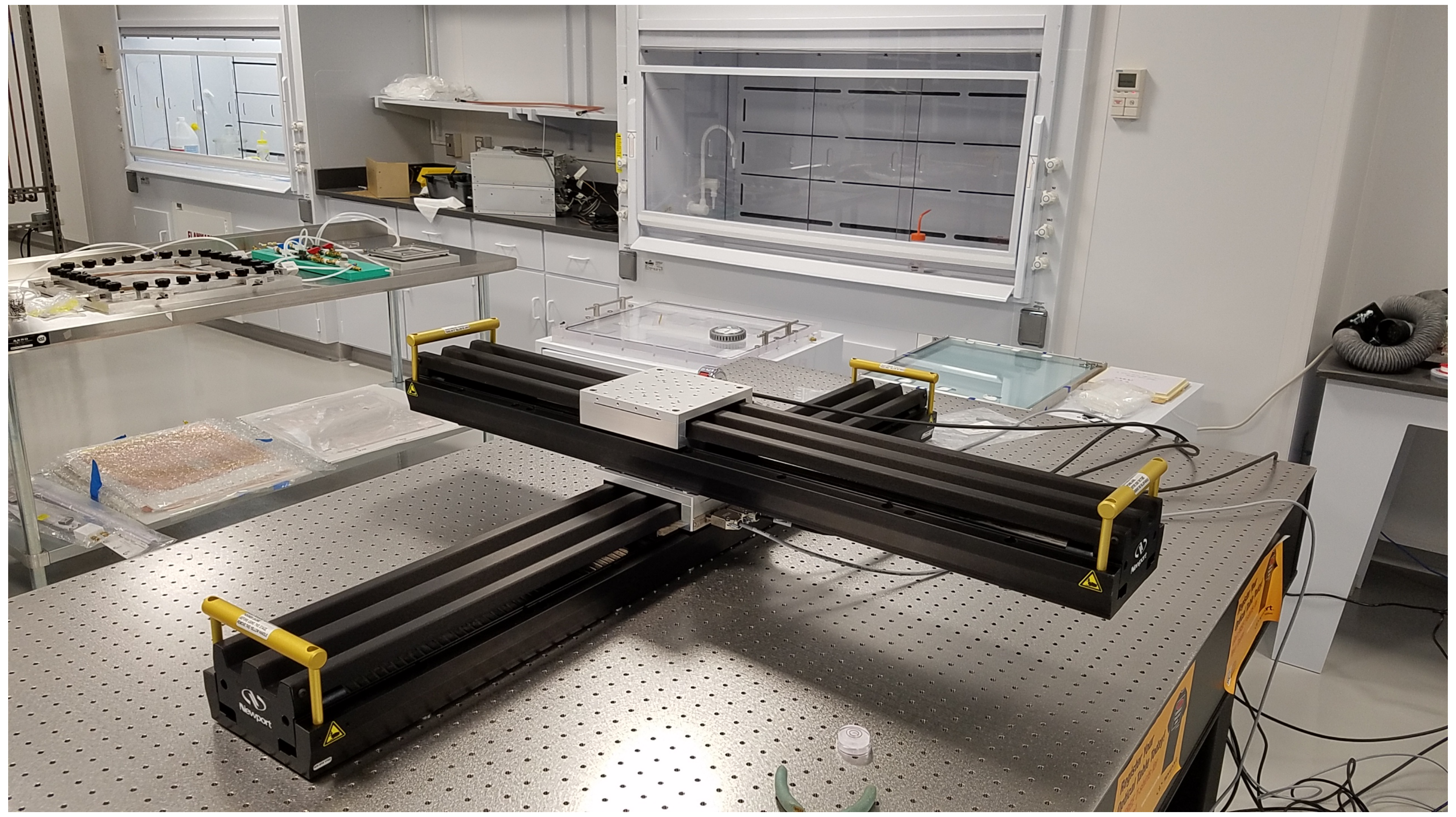


Temple, Saclay

eRD3: Micro-Pattern EIC Tracking System

Highlights:

- Substantial facility development at Saclay (Assembly and testing of MM detector) and Temple University (Assembly and testing of GEM detectors) for micro-pattern detectors
- Work on commercial development of various components including GEM foils and 2D readout foils
  - Commercialization of GEM foils is issue

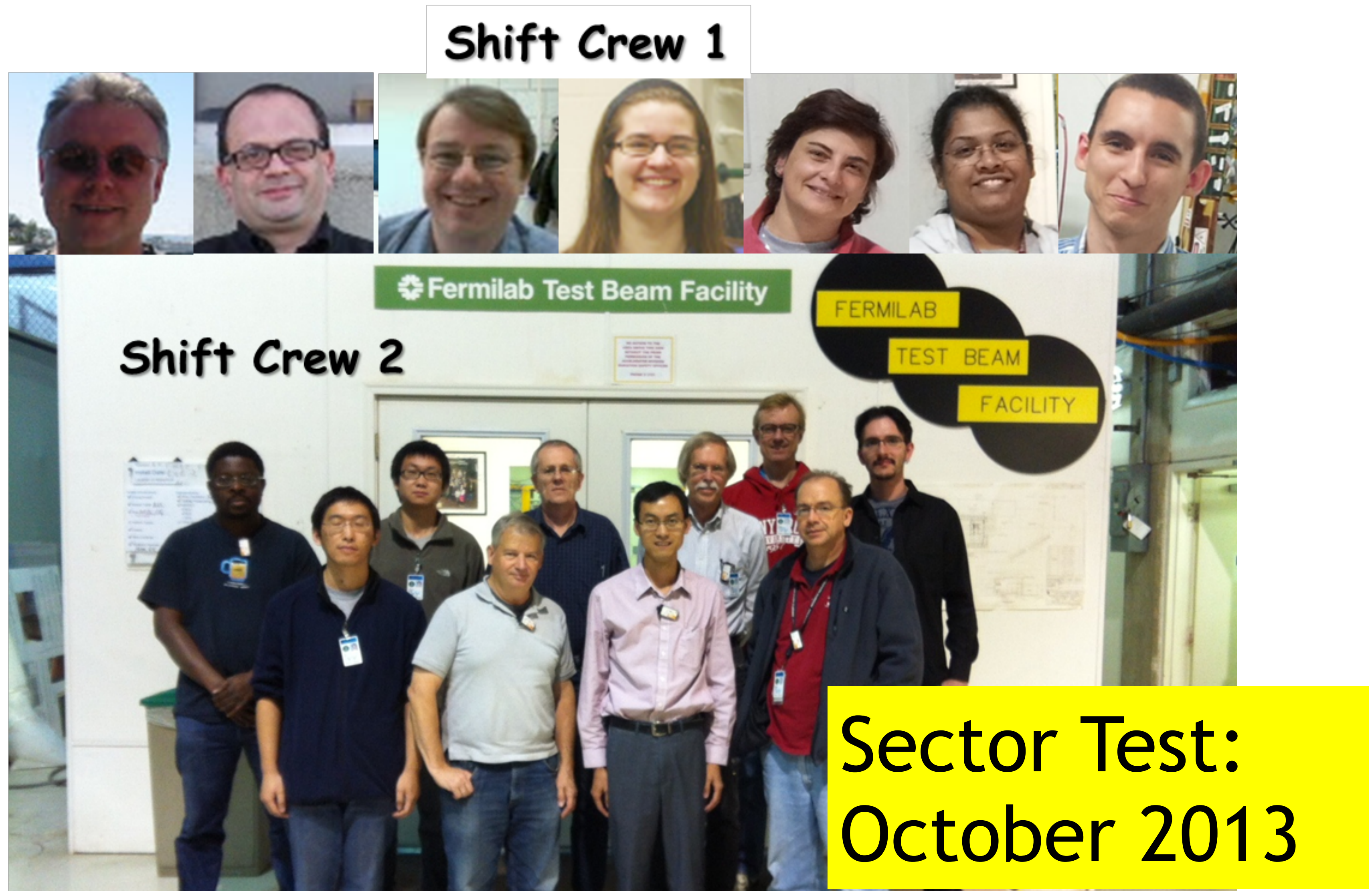


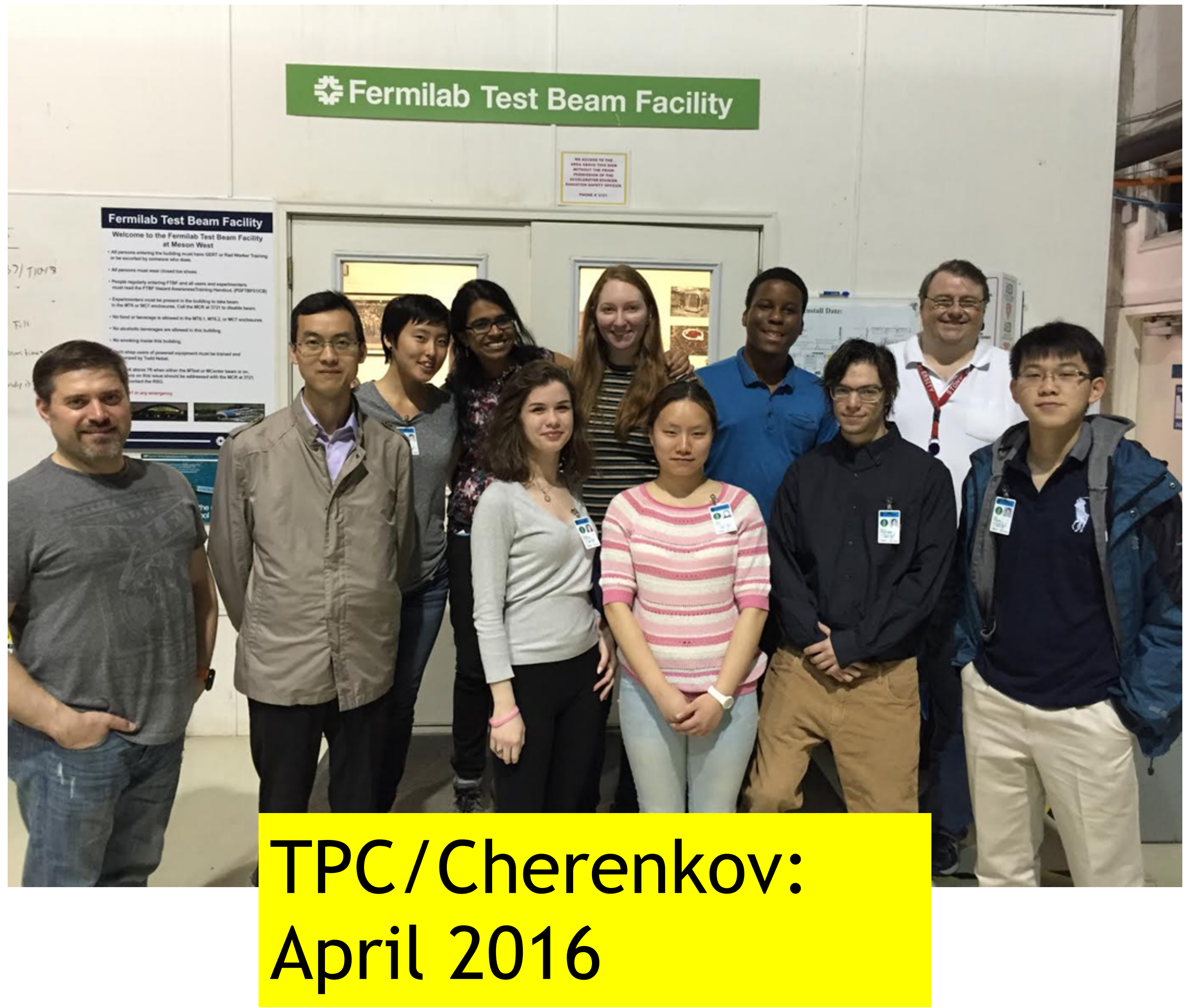
CCD GEM scanning setup inside TU Micro-Pattern Detector Clean Room Facility

- Successful development and application of a dedicated new chip readout system (DREAM chip) for micro-pattern detectors
- Remaining program plans to focus on assembly and testing of larger detector elements using X-ray and cosmic-ray scans using novel assembly techniques

eRD6: Tracking/PID Consortium

- Existing Since 1st Round of EIC R&D
  - Brookhaven National Lab: MiniDrift & TPCC
  - Florida Institute of Technology: ZigZag Planar GEMs
  - Stony Brook University: RICH & TPCC
  - University of Virginia: Stereo-COMPASS Planar GEMs
  - Yale University: 2Gem+μMEGA
- Recent Additions
  - INFN Trieste: RICH PID
  - Weizmann Institute of Science: EIC TPC
- Largest experiment at Fermilab Test Beam Facility with 19 detector stations in single experiment

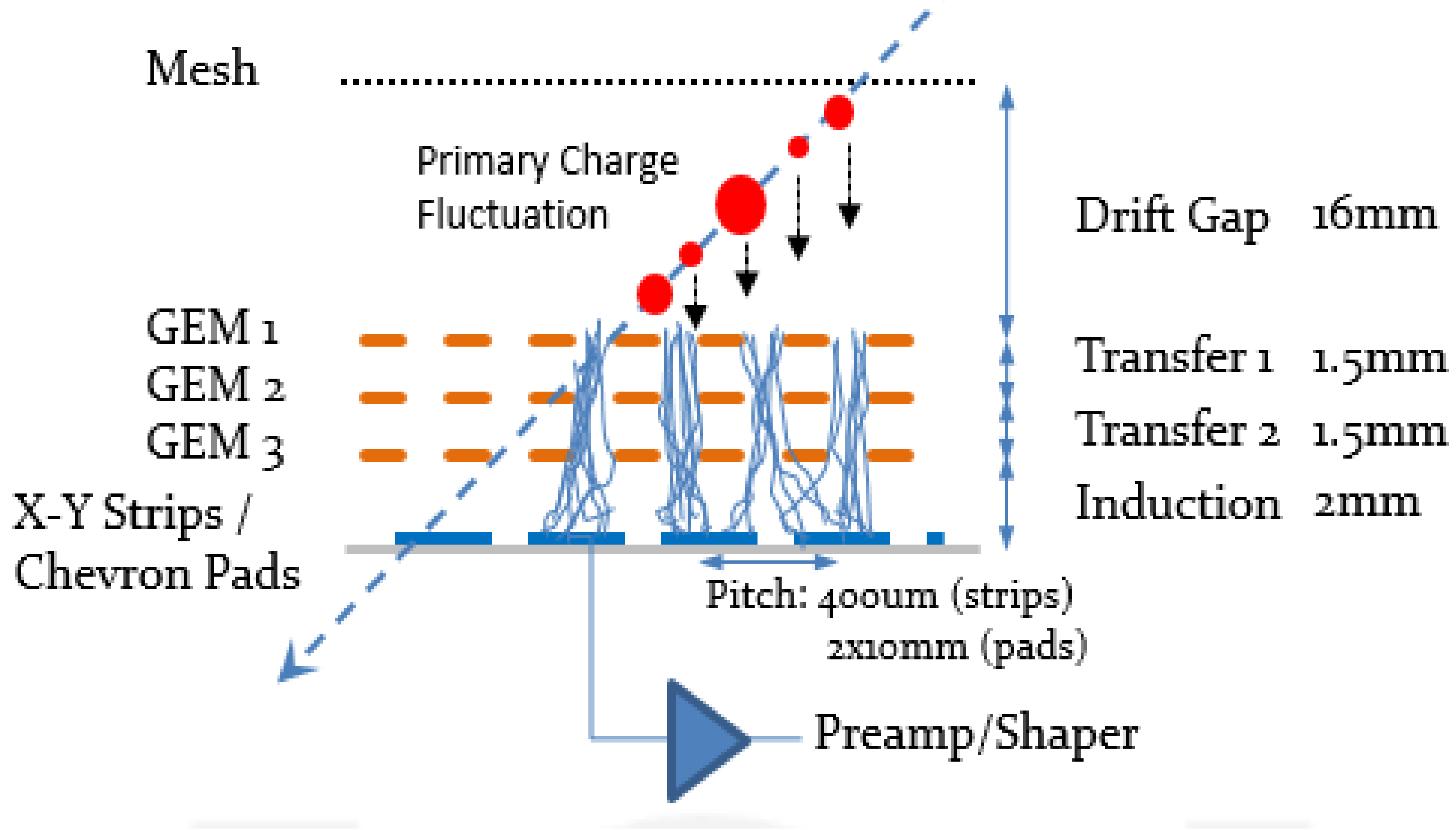


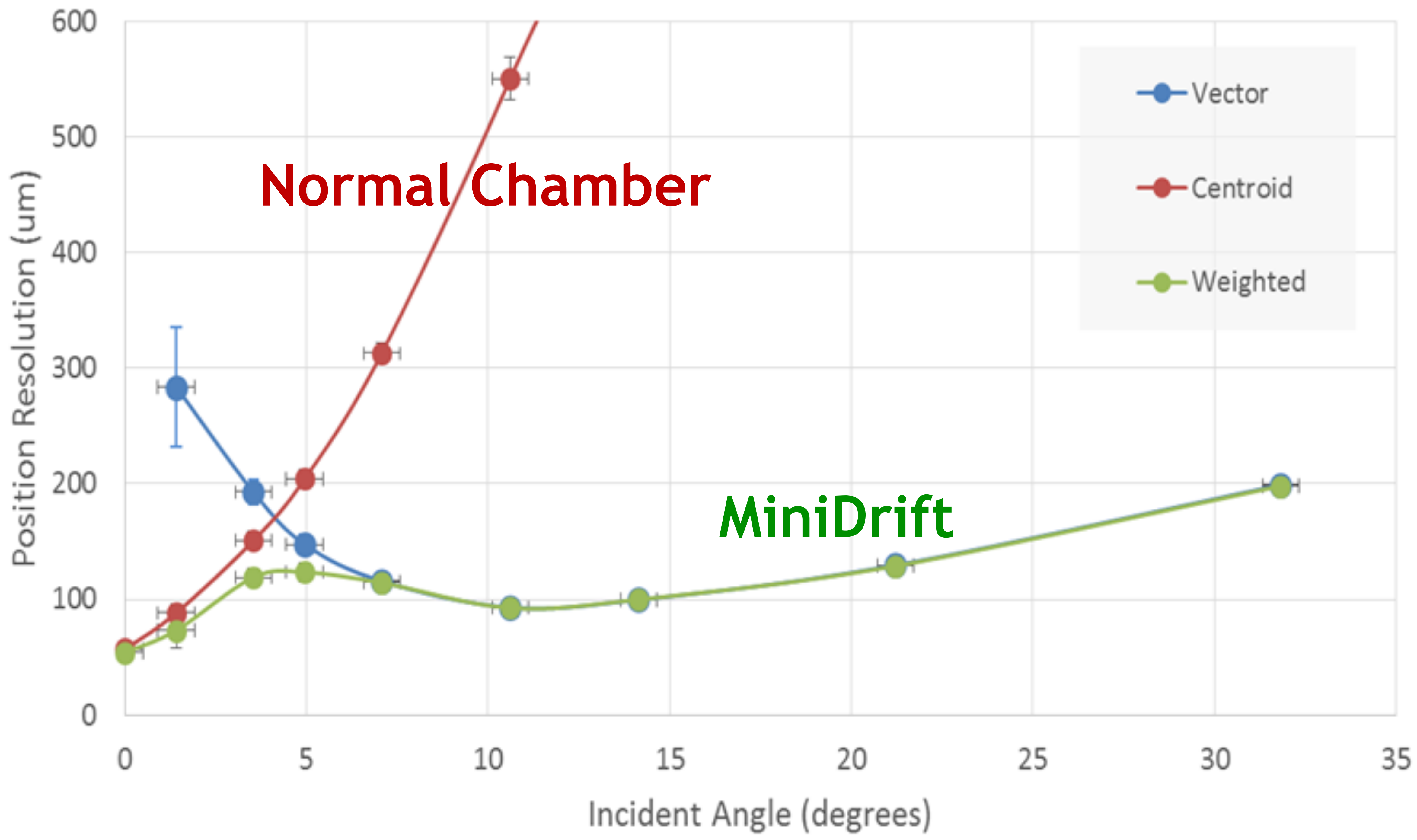


BNL, FIT, INFN Trieste, SUNY, UV, WIS, Yale

eRD6: Mini-Drift GEM Tracking Detector

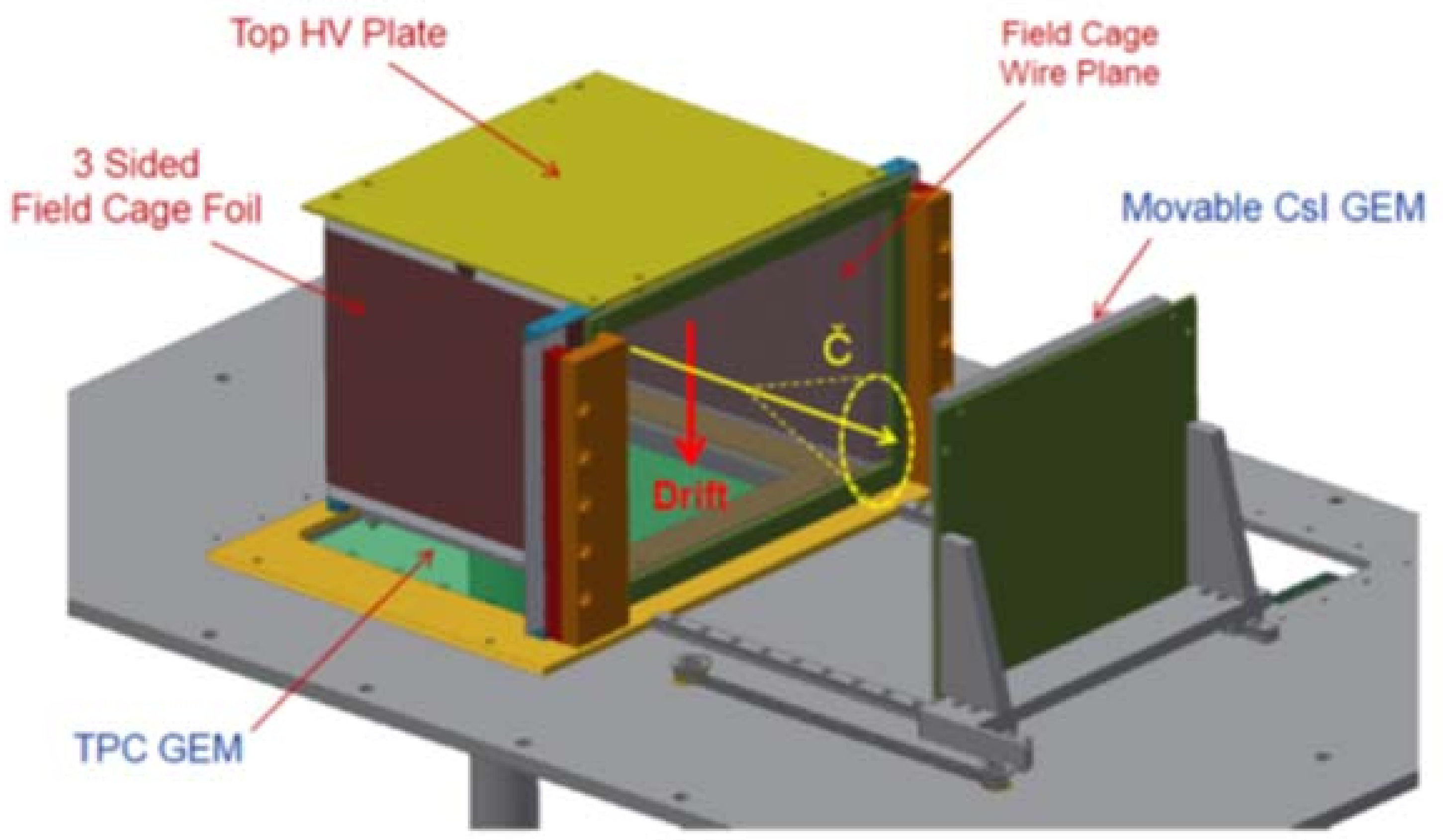
- Triple GEM stack with a small drift region (mini TPC type configuration)
- Position and arrival time of the charge deposited in the drift region were measured on the readout plane allowing reconstruction of track traversing the chamber.
- Minidrift overcomes resolution degradation with incident angle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

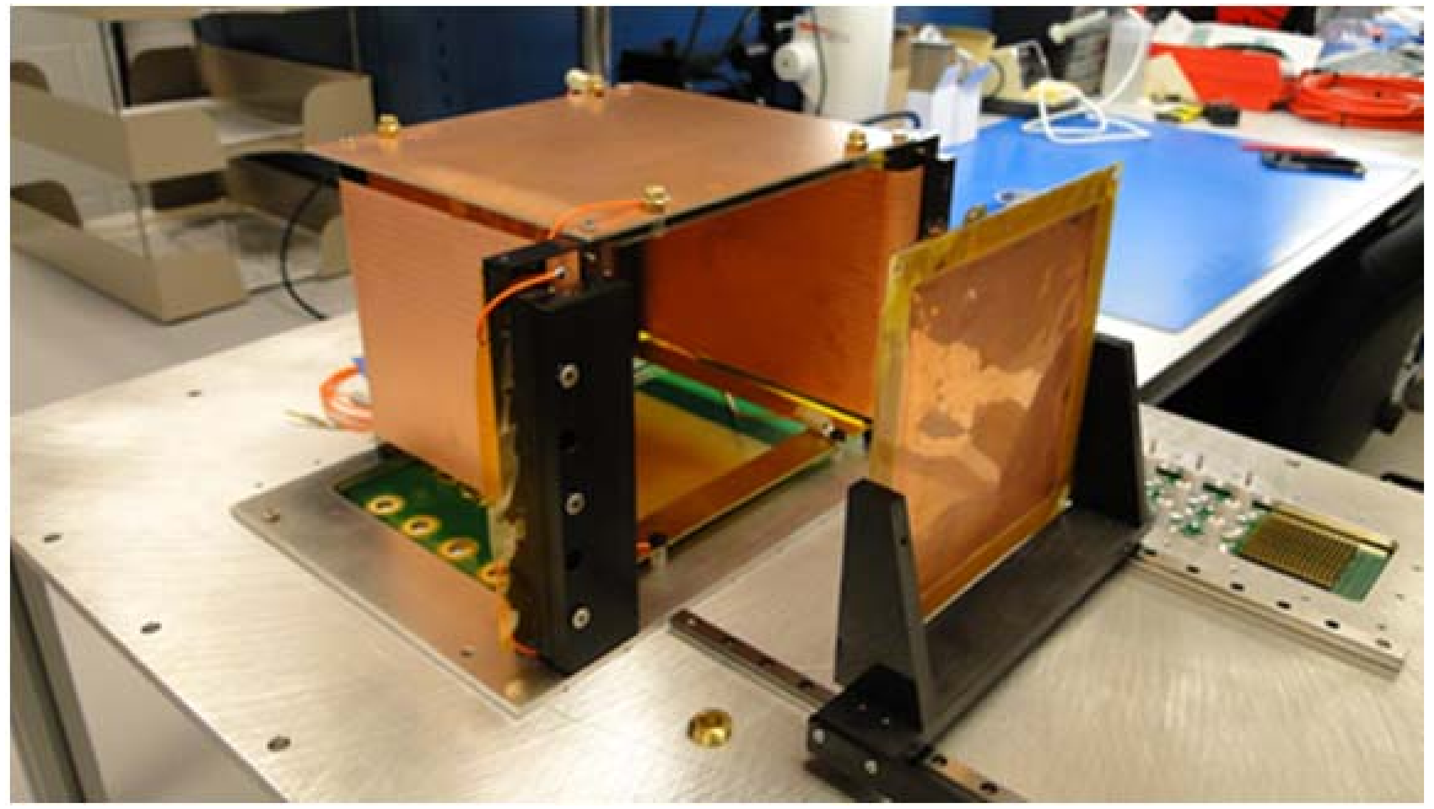


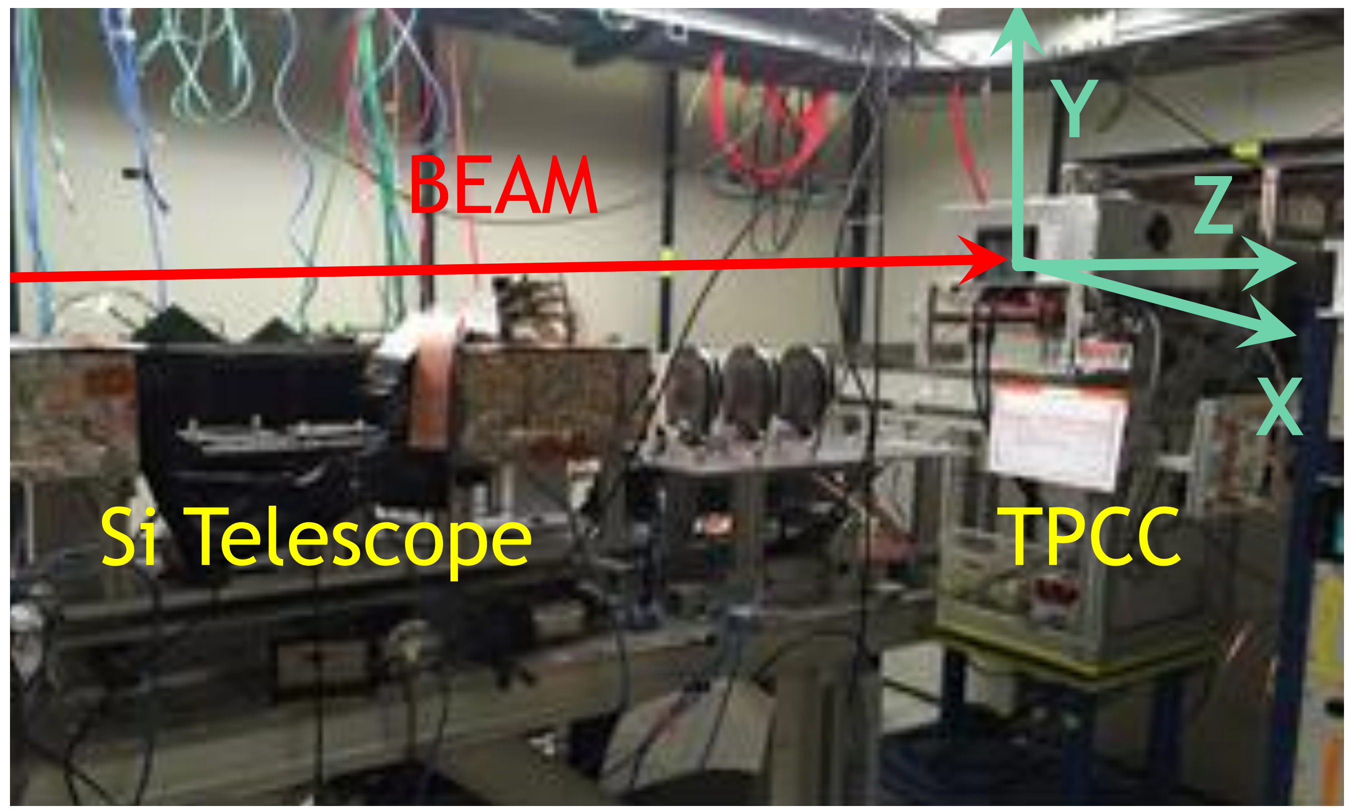


eRD6: Cherenkov TPC

- Combines the functions of a TPC for charged particle tracking and a Cherenkov detector for particle identification in same volume
- Prototype:
  - TPC: 10cm drift + 10x10cm2 4GEM
  - Cherenkov: 3.3x3.3cm2 pad array + 10cmx10cm 4GEM
  - Common Gas: CF_4 (v_{drift} = 7.5cm/μs & large N_0)
- Successful demonstration of proof of principle - TPCC works!
- Quantified performance specs like track resolution and Cherenkov light yield

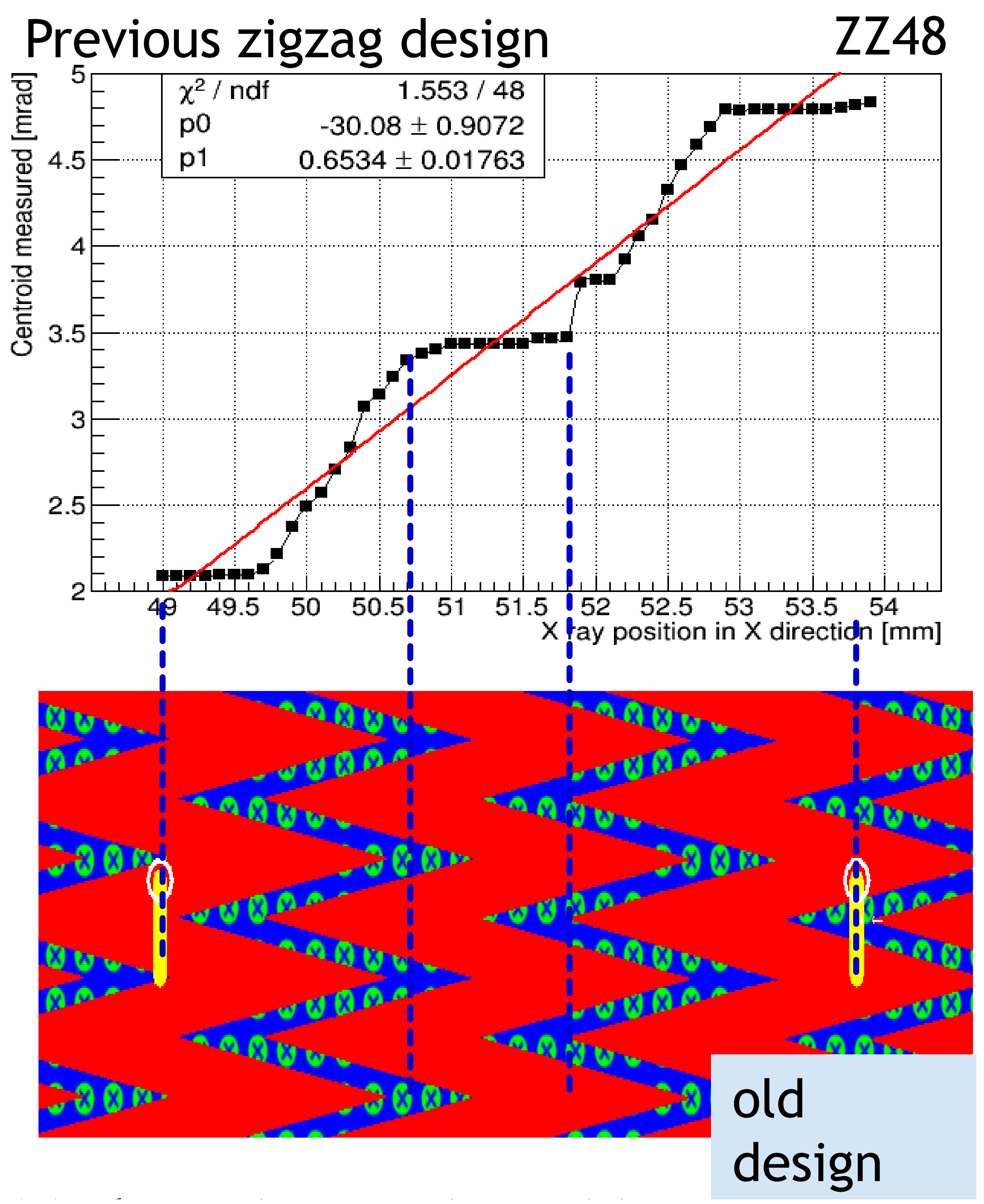


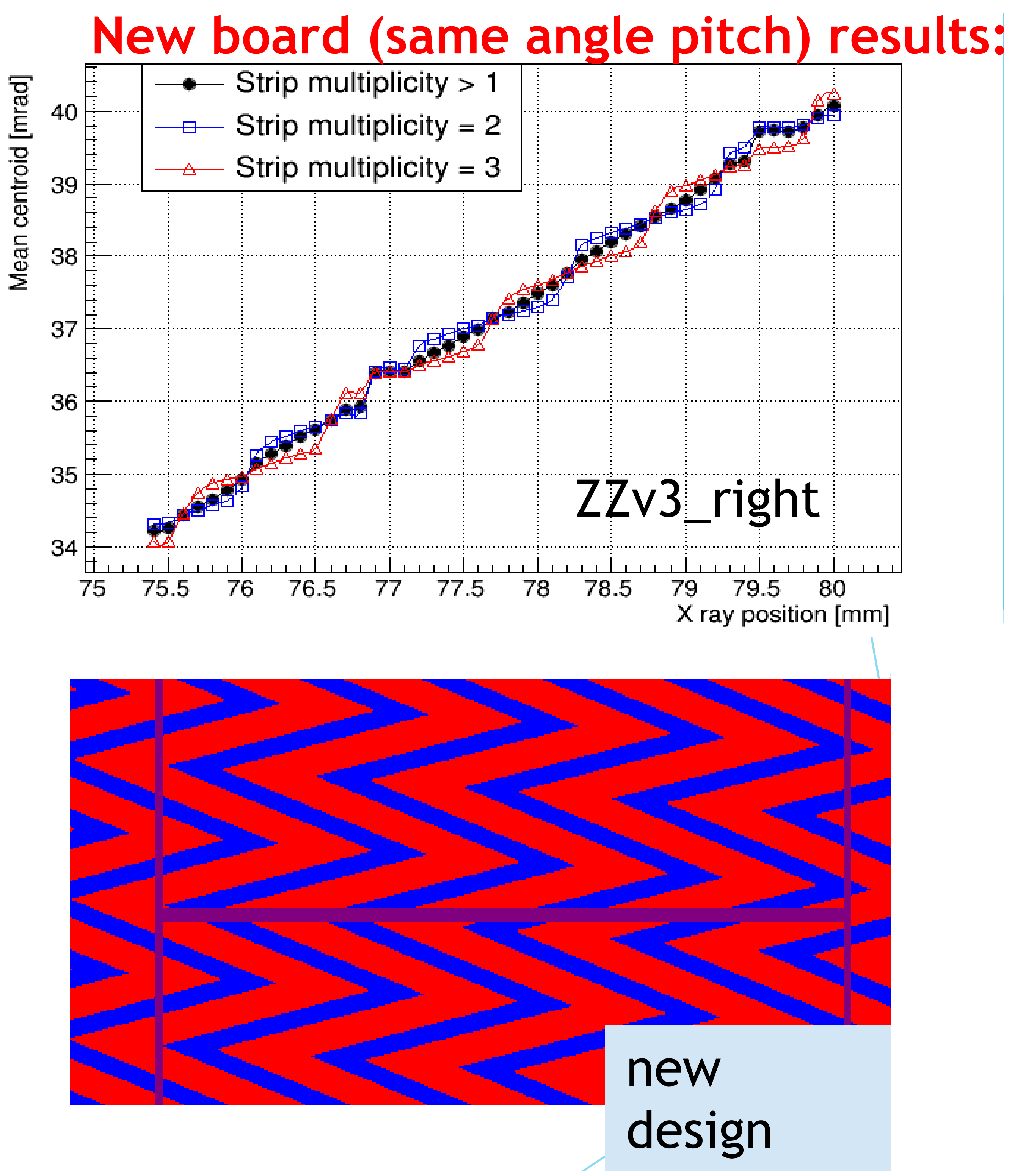




eRD6: ZigZag Strip Readouts

- Goal: Improve common readout boards with more complex zigzag design
- Test with 3GEM readout and X-ray source
- Early results of boards tested at FNAL showed non-linear behavior
- Recent: Scans of PCBs with improved zigzag strip design aiming to reduce non-linear response and achieve <100 μm spatial resolution

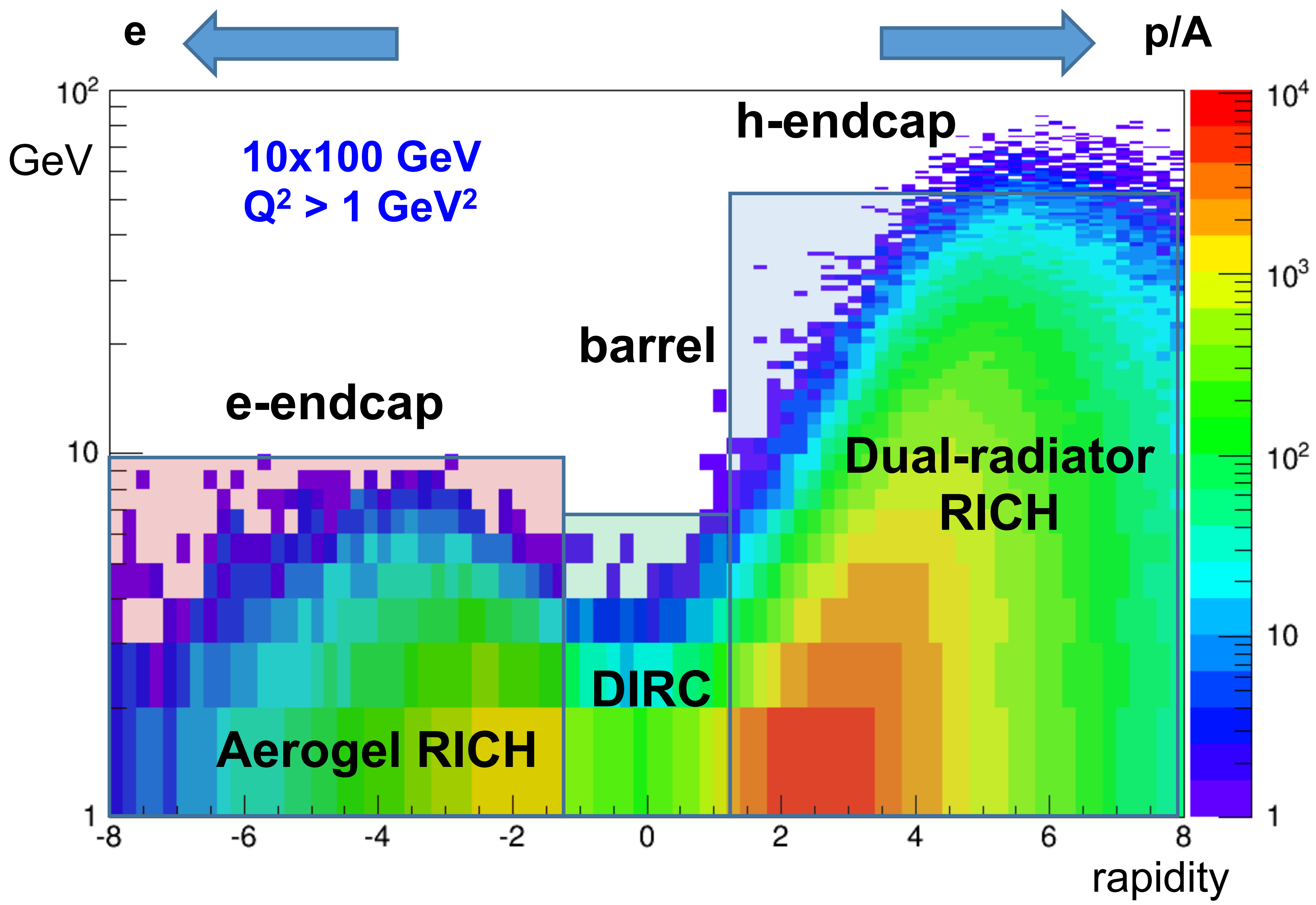




- Vastly improved
- Linear response over whole range
- > 95% events fire 2 or 3 strips (before mostly 1)
- Continue work with company to further improve PCBs

eRD14: PID Consortium

- **Particle ID is essential for EIC**
- eRD14 is developing a suite of detector systems covering the full angular- and momentum range required for an EIC
  - Imaging Cherenkov detectors are the primary technology



Current Projects:

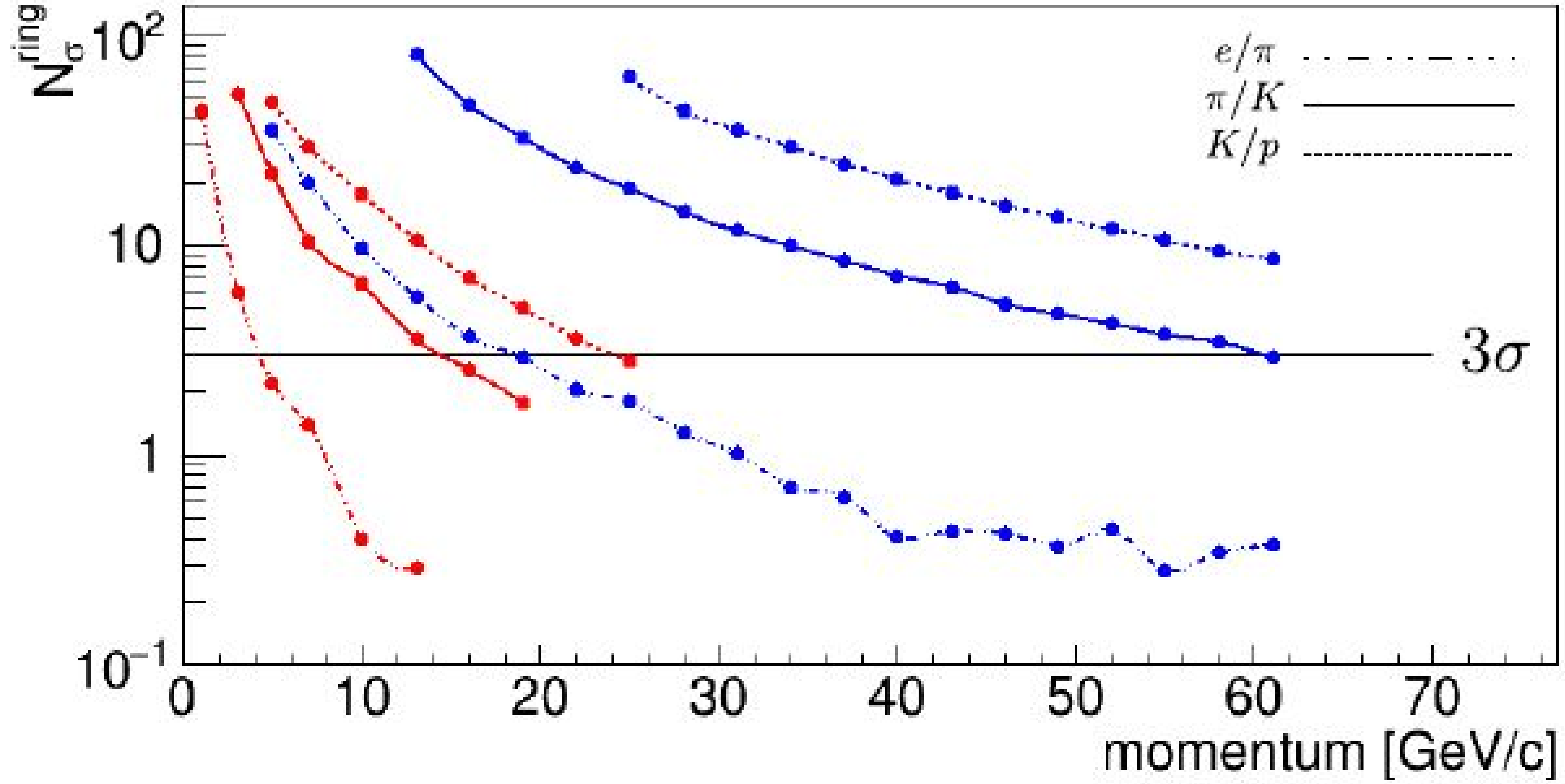
- h-side: RICH with two radiators (gas + aerogel) are needed to cover the full momentum range: more than 3 s.d. separation for π/K/p over 3-50 GeV/c
- e-side: Compact aerogel RICH covering up to 10 GeV/c (π/K/p) can provide the required PID and allow for an endcap design optimized for EIC physics requirements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

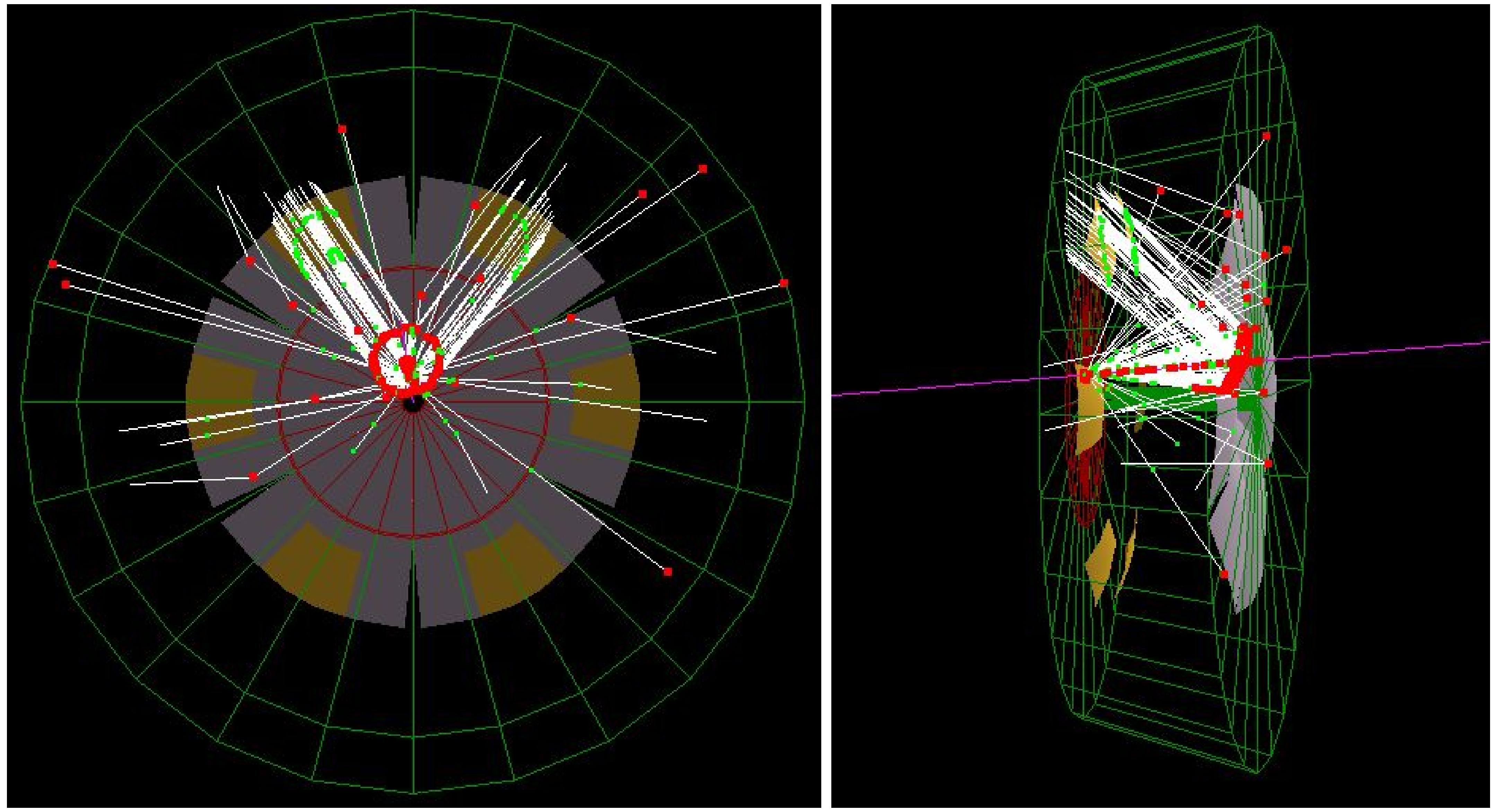
ACU, ANL, BNL, CUA, William & Mary, Duke, GSU, GSI, Howard, INFN Ferrara, INFN Roma, ISS Rome, JLAB, LANL, ODU, USM, UIC, UNM, SC, Yale

eRD14: Dual Radiator RICH Detectors

- First dual-radiator RICH developed for use with a 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 simulations show excellent performance for both hadron and lepton ID

Particle separation power for tracks with 15° polar angle





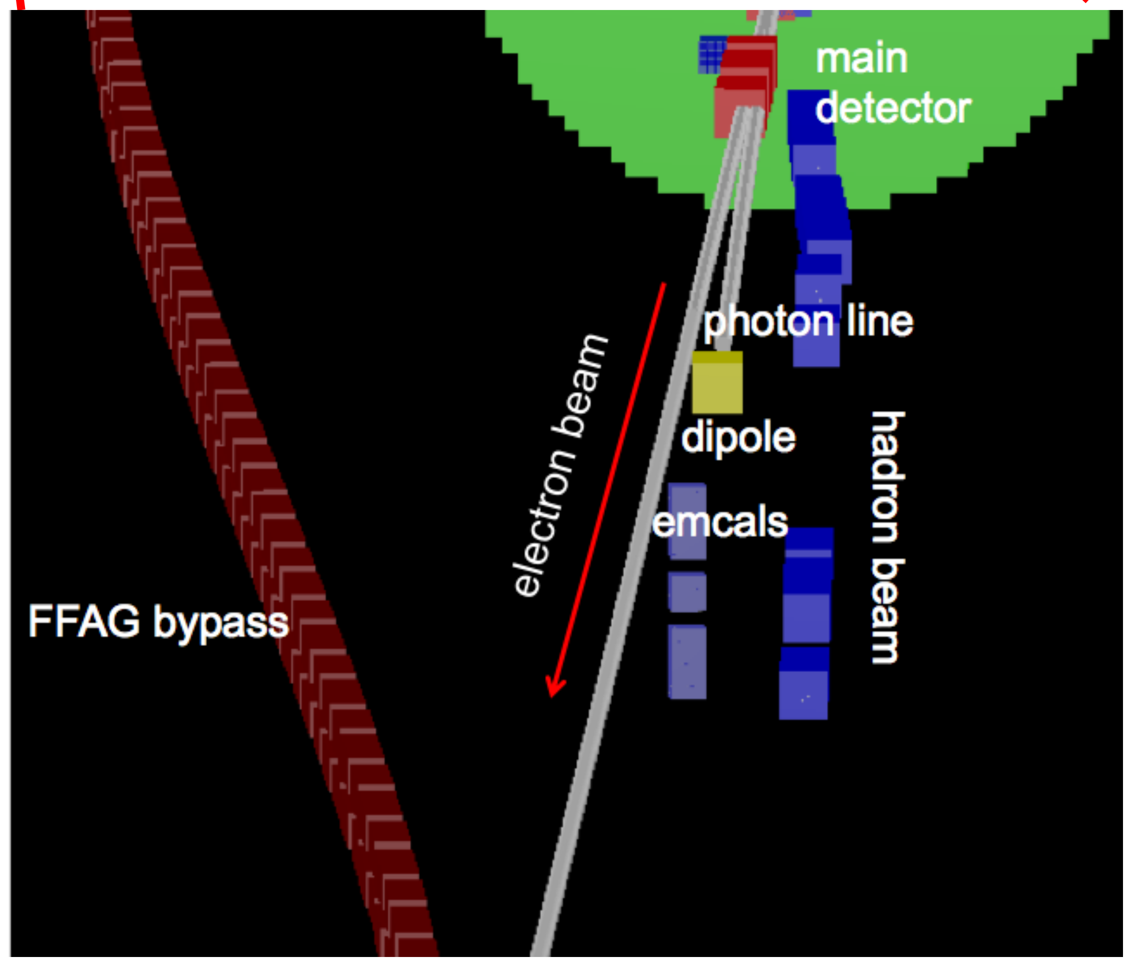
eRD12: Low Q^2-Tagger, Luminosity Monitor & e-Beam Polarimeter

Successful conclusion of project:

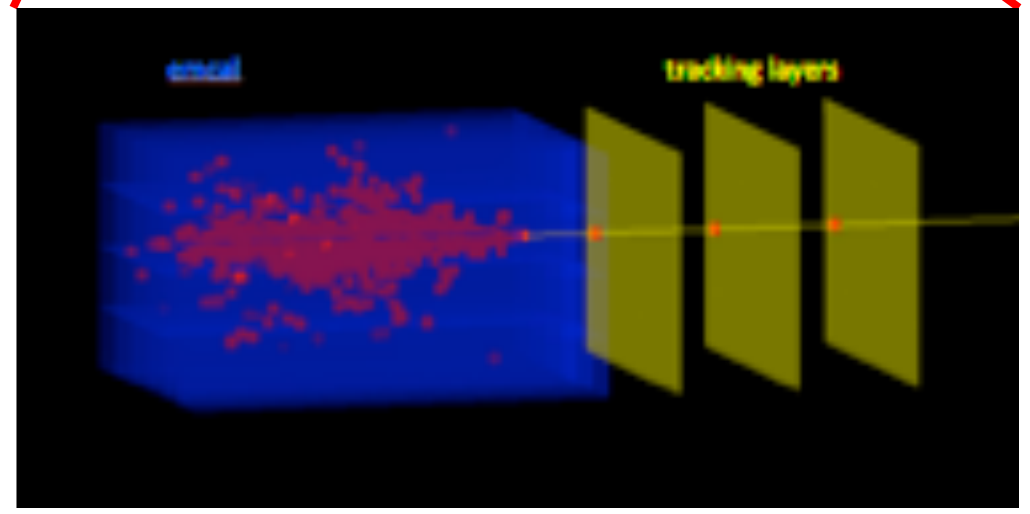
Initial design and integration into the IR completed

- Optimized the IR design to integrate:
  - Luminosity monitor
  - Lepton polarimeter
  - Low Q^2-tagger
- Developed a Monte Carlo code for Bremsstrahlung taking into account the polarization dependence of the Bremsstrahlung cross section
- Integrate a first layout into the EicRoot simulation package
  - Develop a dedicated e-polarimeter simulation package
  - Determine detector performance requirements based on physics and machine backgrounds
- Targeted Detector R&D which fulfills the determined requirements

eRD12: Low Q^2-Tagger, Luminosity Monitor & e-Beam Polarimeter

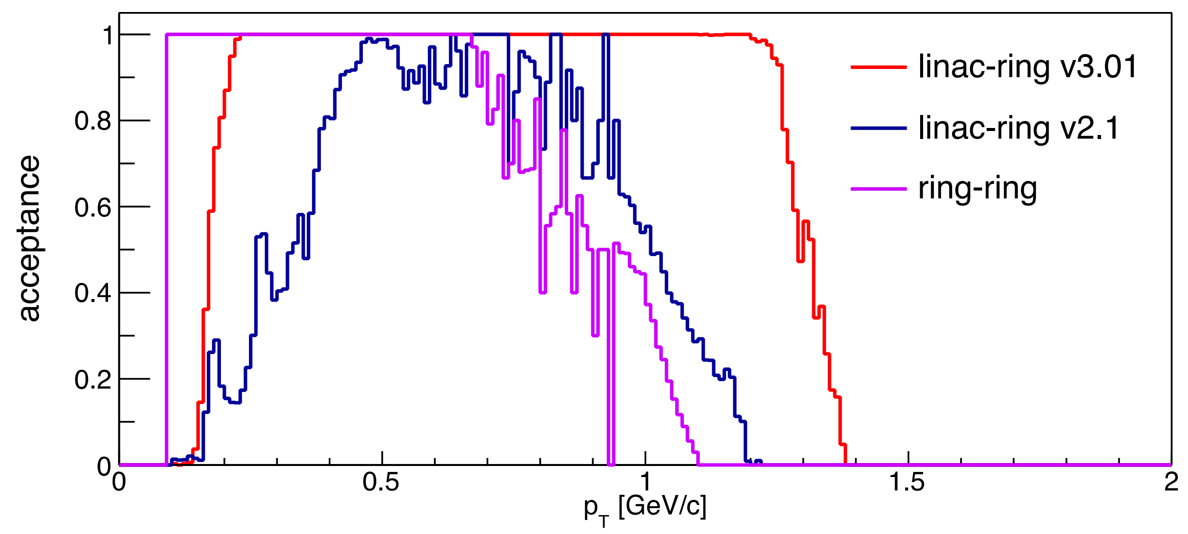


Lumi Monitor
- Integrated into IR
- Includes a pair spectrometer
- Effect of beam optics studies
- Angular divergence dominates the acceptance, current parameters are ok



Low Q^2-tagger
- Tracking code to calculate scattering angle of electron
- Iterate with machine designers to improve IR design
- Pythia studies show acceptance down to Q^2 $O(10^{-5}$ $GeV^2)$

Forward Proton Spectrometer
- Important for DVCS
- Roman Pot integrated into IR
- Studied the acceptance of protons through the lattice
- Feedback to machine designers to push for next iteration



Electron polarimetry
- Identified the space in the tunnel
- Estimated constraints on the laser (cathode by cathode measurement in about 2 minutes)

General Remarks from the Committee

- It is great to see proposals come to a conclusion with a deliverable that is of general value for the EIC development (e.g. eRD12)
- Field is getting more crowded and level of funding will not change in the near future. The protocol for proposal submission will be modified and proposals will have to address different funding levels: 100% +/- 25%.
- Given the severe financial constraints, a guideline of one year of support per postdoc will be implemented; this hopefully will encourage securing matching support by the proponents.
- EIC R&D funding is NOT base funding, but should be considered as supplemental funding to initiate new directions.
- There seems to be a tendency of some of collaborations that have been in existence for a longer time to move in the direction of (value) engineering. The committee feels that it is too early for this (R&D versus PED)

General Remarks from the Project Coordinator

- It is great and rewarding to see the program grows and mature
- Program has participants from 43 institutions (11 non-US)
- The number of peer reviewed publication grows steadily
- Certainly in the near future funding is not expected to increase stressing the project (and the committee)
- We will make some changes to the proposal format (include different funding levels) and apply new rules (e.g. only support for 1 year/postdoc) to mitigate some funding issues
- Need to work with DOE to implement LRP recommendation and increase funding.
- The program needs to have room (i.e. funds) for further grow