Legacy of the Generic Detector R&D Program for the EIC

chatGPT did not get the logo right, sorry

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June 17, 2025

Brookhaven National Laboratory

World Wide R&D Efforts of Interest for the EIC

- Laboratory Directed Research & Development Programs (LDRDs) at National Labs in the US (BNL, JLAB, ANL)
- CERN
  - R&D program with partial match with EIC needs (e.g. RD51 Micro-Pattern Gas Detectors Technologies)
  - LHC Experiments R&D for phase-I upgrades, especially ALICE (TPC, ITS, SAMPA) and LHCb (RICH, trigger less DAQ). Now in production, R&D finished.
- R&D at Belle-II and Panda (crystals, DIRC, …)
- ILC related R&D

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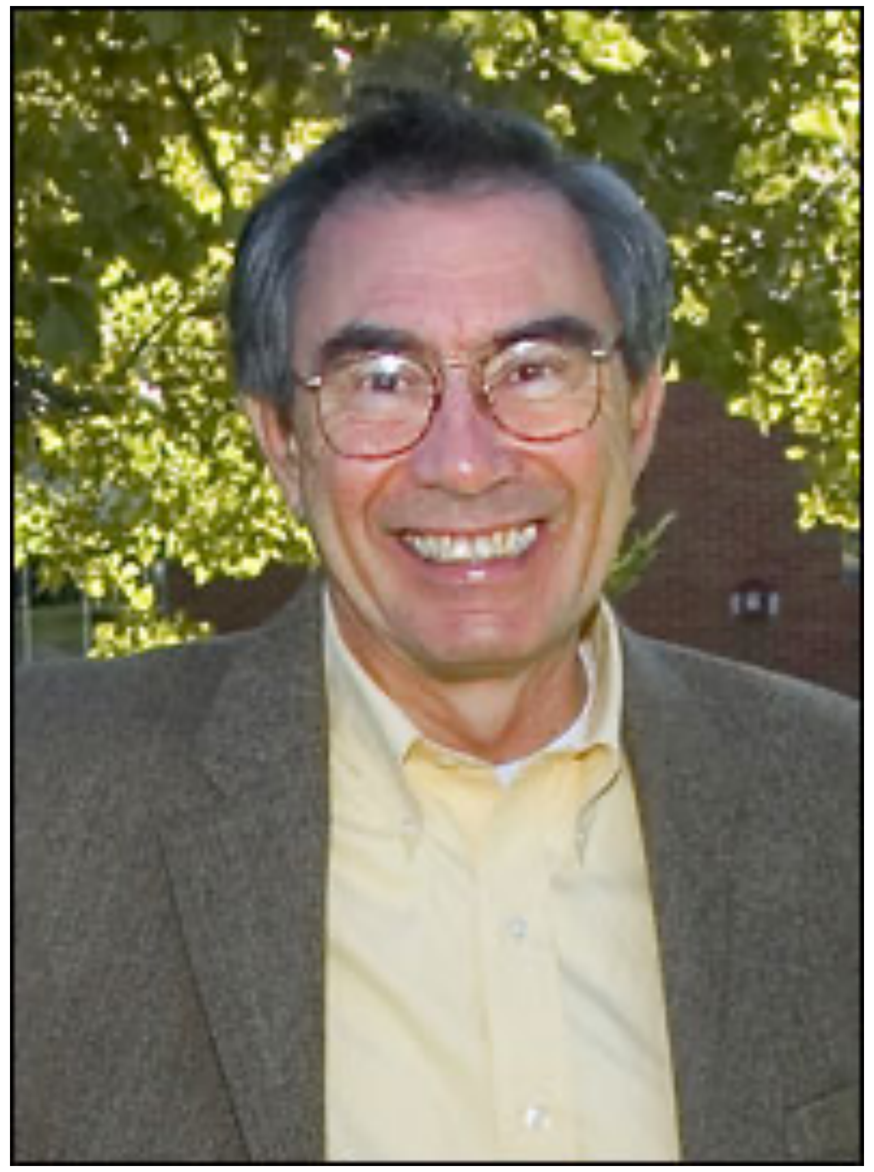


Clearly Not Enough !

This was realized by then ALD Steve Vigdor who acted using RICH R&D funds to create a generic R&D program. He asked Tom Ludlam to run the program. A year later Steve was instrumental in launching the EIC White Paper effort. We owe him big time.

Generic EIC Detector R&D Program

- Started 2011 BNL, in association with JLab and the DOE Office of NP
- Funded by DOE through RHIC operations funds
- Program explicitly open to international participation
- 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
- Focus initially on ‘generic’ R&D turning more targeted over the years

Program coordinator 2011-2014: Tom Ludlam
2014-2021: TU

Generic EIC Detector R&D Program

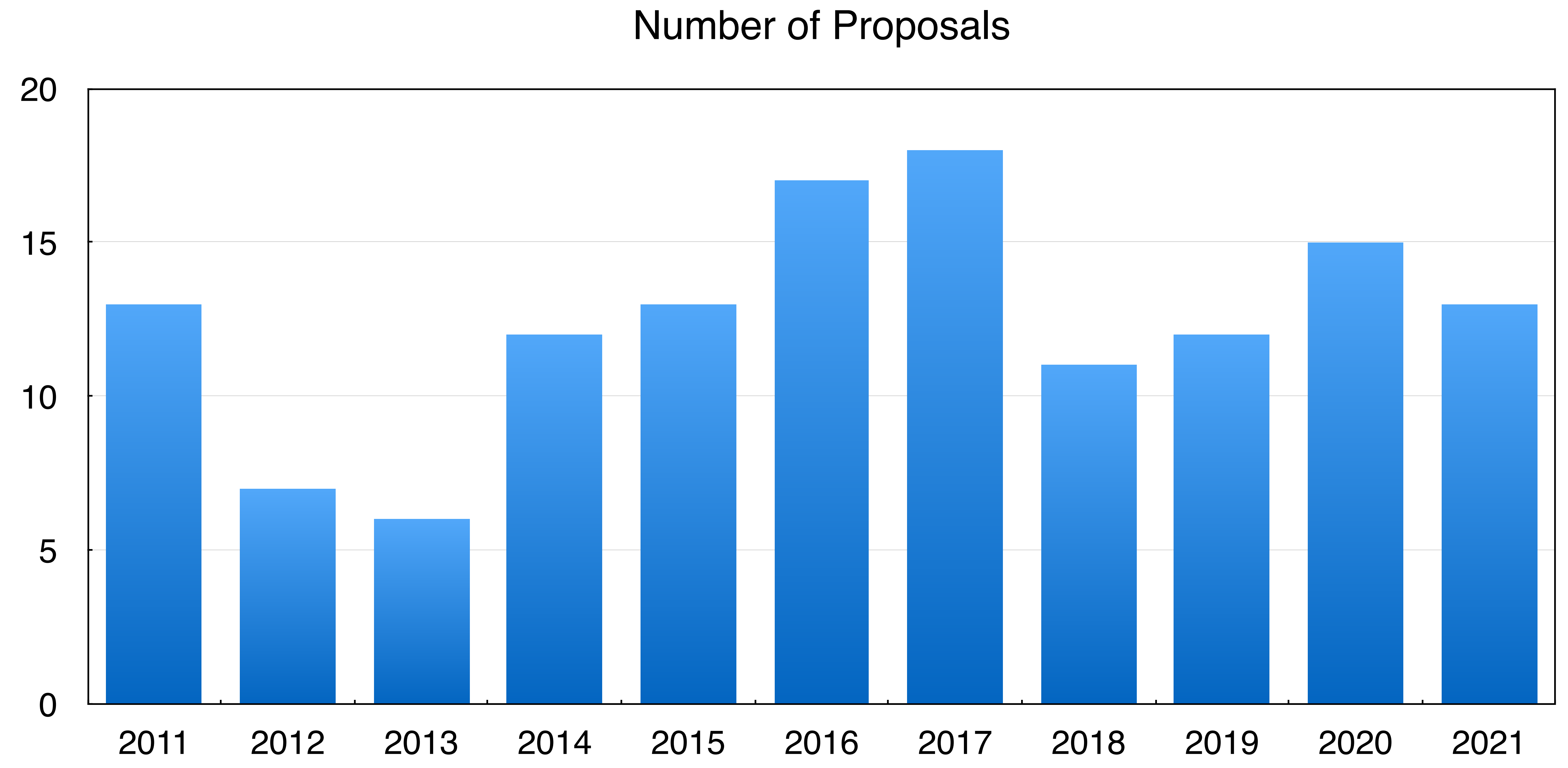
- Standing EIC Detector Advisory Committee consisted of internationally recognized experts in detector technology (almost no changes in 10y)
  - Meetings were twice a year, funding limited to one year (FY)
    - ~January: Review of ongoing projects
    - ~July: Review and new proposals
- Typical 10-11 projects supported per year (eRDNN)
- Consortia for Calorimetry, Tracking, PID, Si-Tracking
- Over 281 participants from 75 institutions (37 non-US)

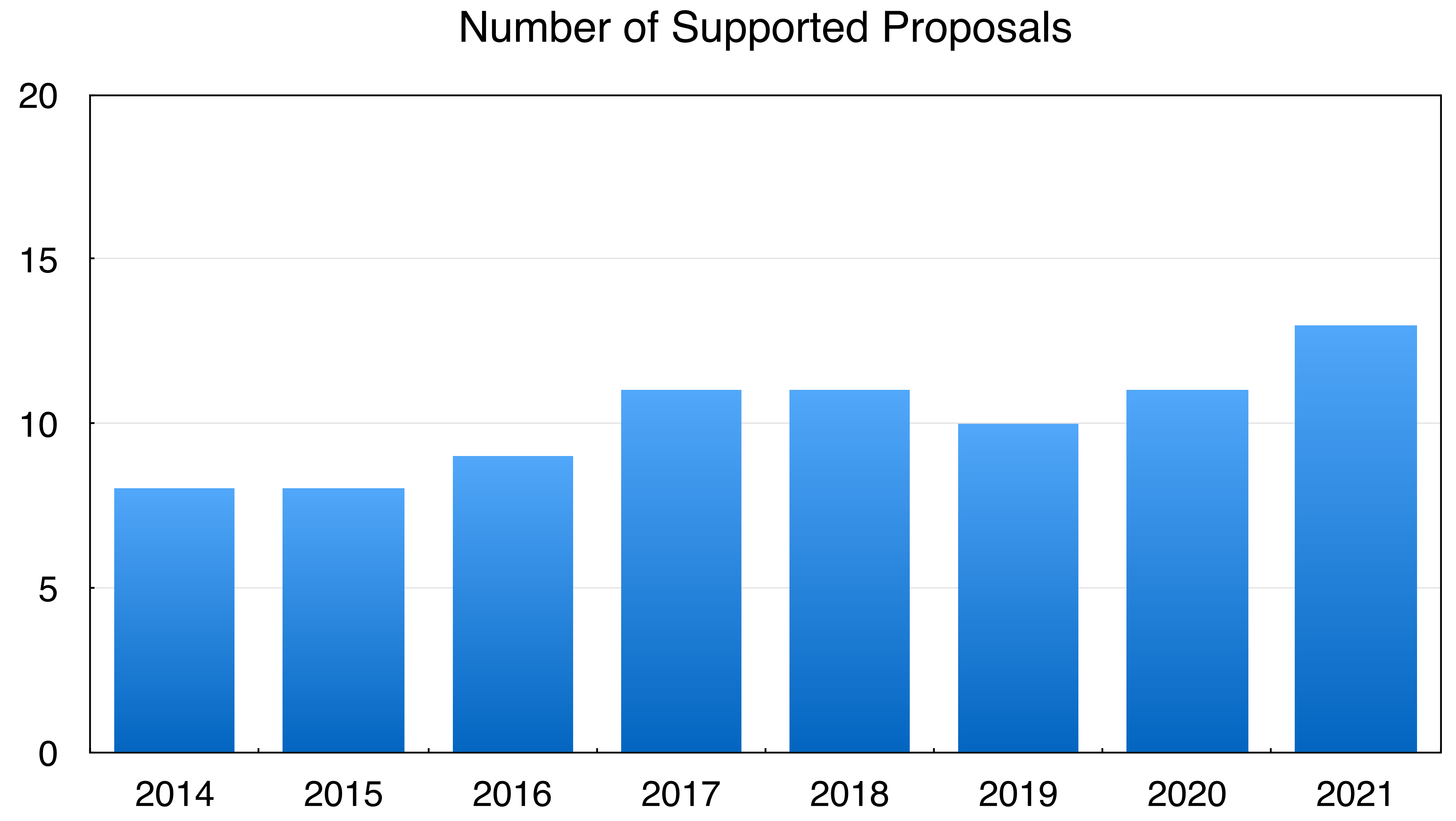
Current: Marcel Demarteau** (ORNL), Carl Haber (LBNL), Peter Krizan (Ljubljana), Ian Shipsey (Oxford), Rick Van Berg (UPenn), Jerry Va'vra (SLAC), Glenn Young (BNL)

**Chair

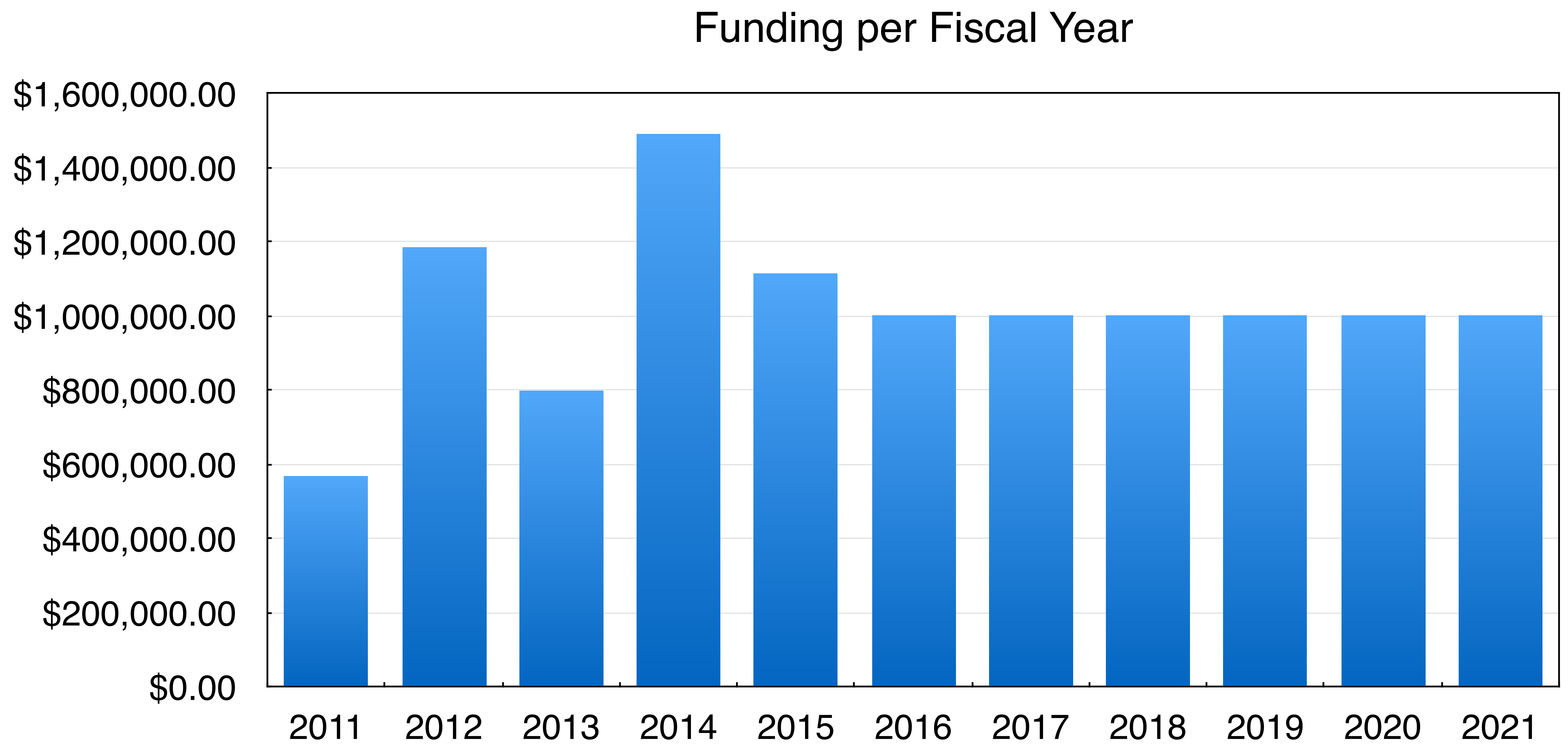
Retired:
Robert Klanner (Hamburg), Howard Wieman (LBL)

Statistics





- # of proposals affected by forming of consortia as well as release of LRP, NAS report, CD0
- Requested funds typically exceed available funds by factor 2
- Overall spread too thin affecting various critical projects
- FY21 was last year of this program



Generic R&D Projects 2014-2021

Project	Topic
eRD1	EIC Calorimeter Development
eRD2	A Compact Magnetic Field Cloaking Device
eRD3	Design and assembly of fast and lightweight forward tracking prototype systems
eRD6	Tracking and PID detector R&D towards an EIC detector
eRD10	(Sub) 10 Picosecond Timing Detectors at the EIC
eRD11	RICH detector for the EIC's forward region particle identification - Simulations
eRD12	Polarimeter, Luminosity Monitor and Low Q2-Tagger for Electron Beam
eRD14	An integrated program for particle identification (PID)
eRD15	R&D for a Compton Electron Detector
eRD16	Forward/Backward Tracking at EIC using MAPS Detectors
eRD17	BeAGLE: A Tool to Refine Detector Requirements for eA Collisions in the Nuclear Shadowing/Saturation Regime
eRD18	Precision Central Silicon Tracking & Vertexing
eRD19	Detailed Simulations of Machine Background Sources and the Impact to Detector Operations
eRD20	Developing Simulation and Analysis Tools for the EIC
eRD21	EIC Background Studies and the Impact on the IR and Detector design
eRD22	GEM based Transition Radiation Tracker R&D
eRD23	Streaming Readout for EIC Detectors
eRD24	Silicon Detectors with high Position and Timing Resolution as Roman Pots at EIC
eRD25	Si-Tracking
eRD26	Pulsed Laser System for Compton Polarimetry
eRD27	High Resolution ZDC
eRD28	Superconducting Nanowire Detectors
eRD29	Precision Timing Silicon Detectors for combined PID and Tracking System

Tracking | PID | Calorimetry | Software/Simulations | Other

One Legacy

There is almost a 1:1 match between many of the ePIC DSCs and the groups in the Generic R&D Program.

- The program was started at a time where meetings were in person and it formed a strong community
- The coordinator had enough freedom to accept efforts that were not convincing at first but helped in attracting groups that are now vital and strong
- The fact that it was international was key. This is not common.

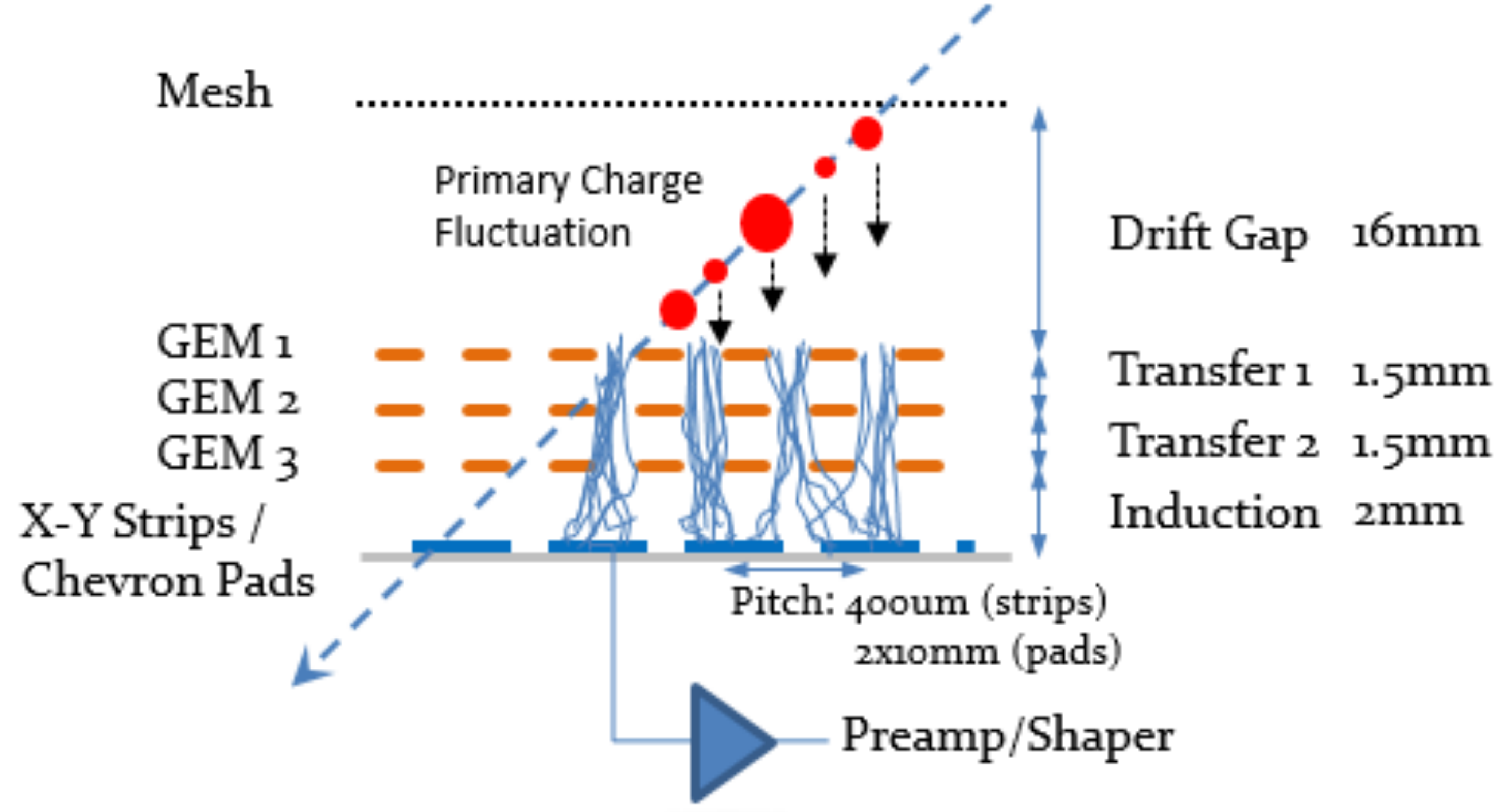
Many of the efforts made it but some not. That doesn’t make them in any shape or form less interesting.

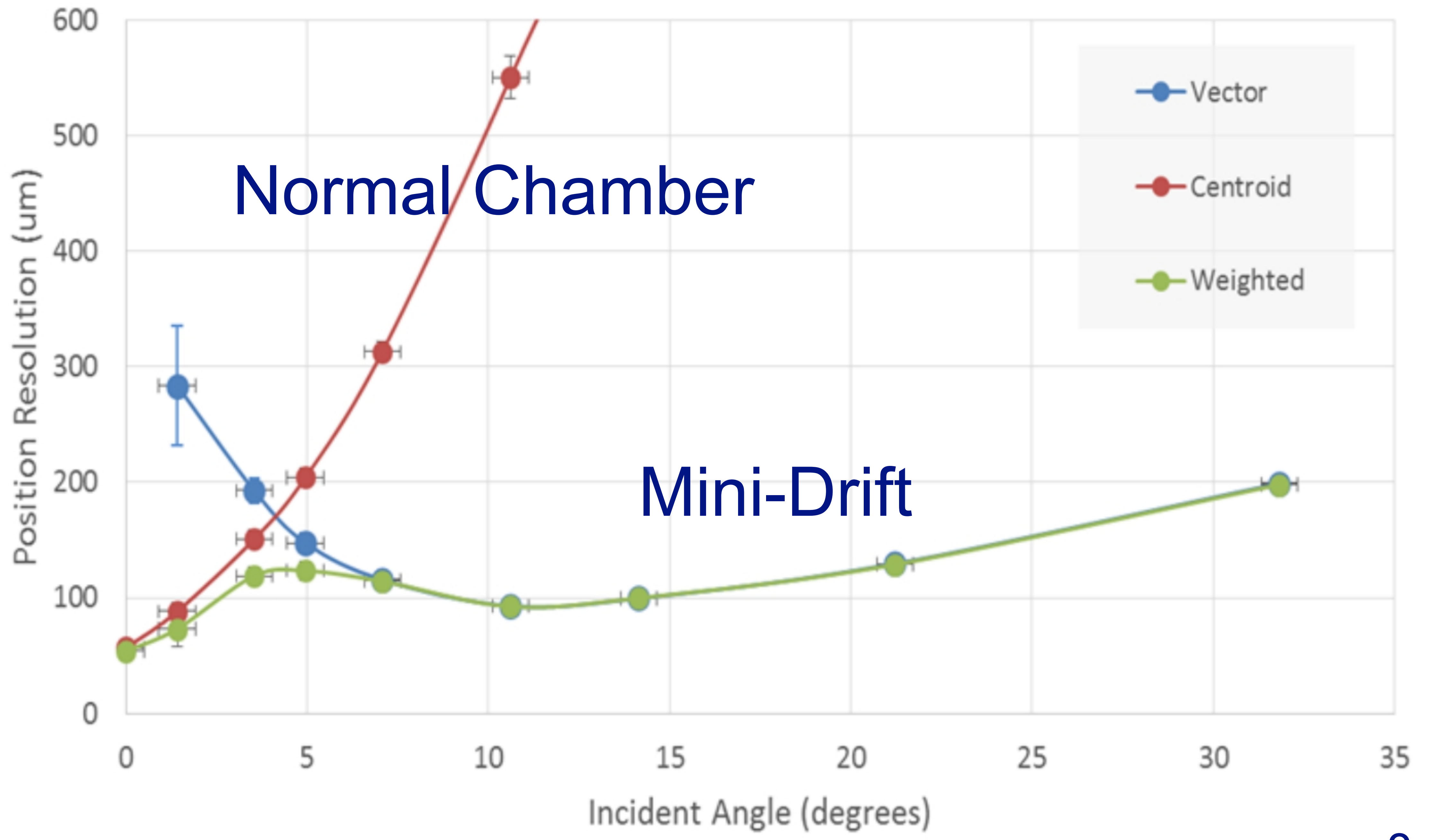
Here are some …

Example 1: Mini-Drift Tracking Detector (Mini TPC)

eRD6

- Triple GEM stack with a small (mini) drift region
- Position and arrival time of the charge deposited in the drift region is measured on the readout plane allowing reconstruction of track (vector) traversing the chamber
- Mini-Drift overcomes resolution degradation with increasing incident angles for conventional GEM tracker using only charge centroid information
- Compatible with all forms of planar GEM trackers





IEEE Transactions on Nuclear Science 63.3 (June 2016), pp. 1768-1776

Example 2: Large, Low-Mass Prototype GEMs (eRD6)

Initial assembly of carbon-fiber frame prototype and test

Encouraging:

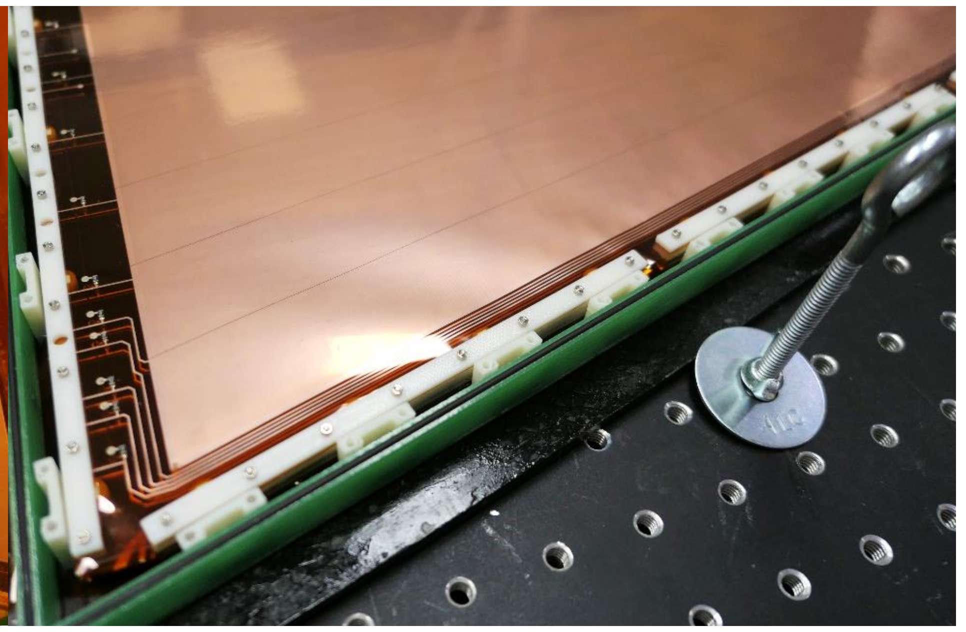
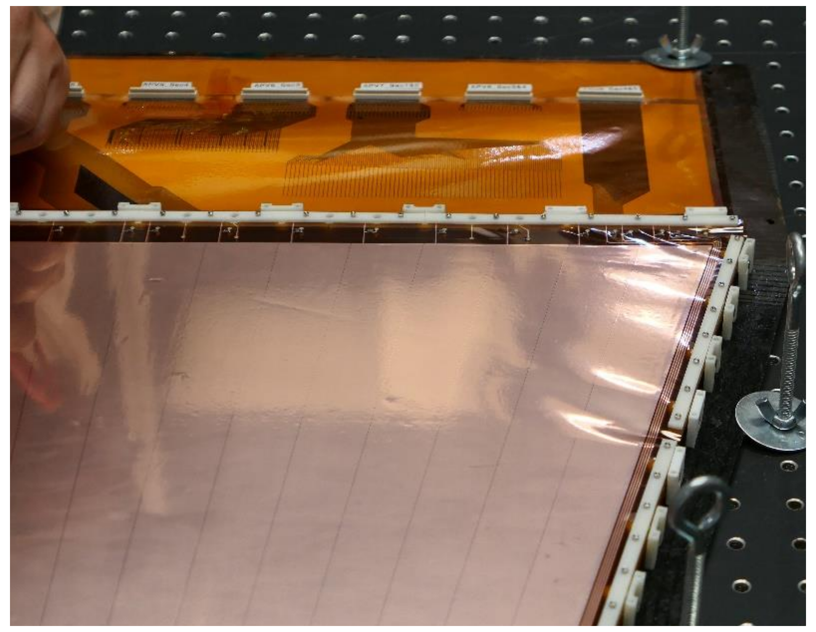
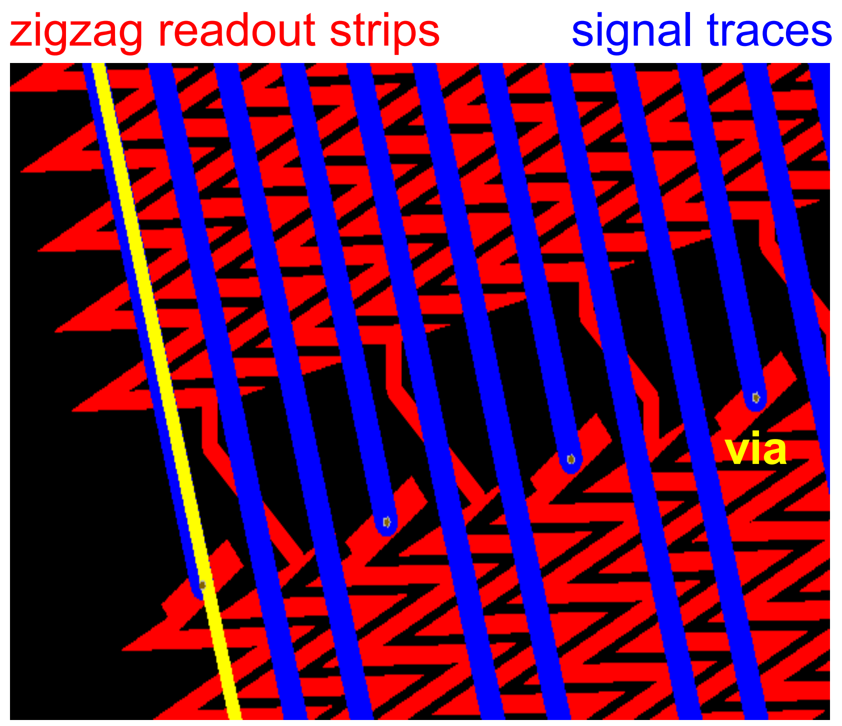
- CF frame doesn’t show any large deformation when stack is tensioned
- No issues with conductivity of CF
- Total chamber mass below 3 kg (w/ HV filter but w/o FE electronics)
- First data: Readout uses long zigzag strips, find low noise

Problematic:

- Detector had initial problems holding full voltage (HV trips) probably caused by on parts by insufficient stretching of the 5 foils in the stack

Remedies:

- Redesign and improvement of inner frames and pull outs
- Pull-outs with a more solid design (PolyEther Ether Ketone)

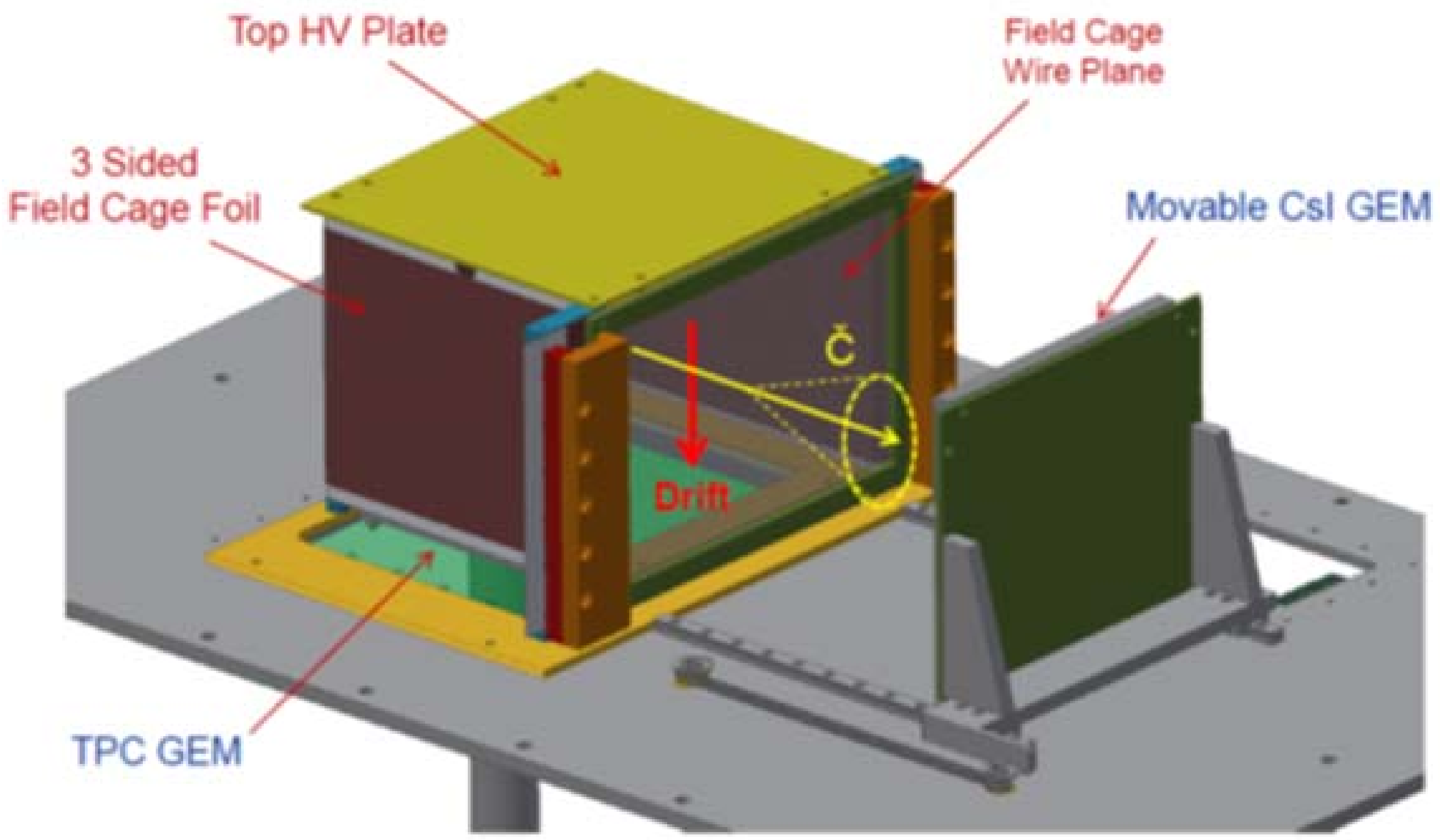
Example 3: Cherenkov TPC

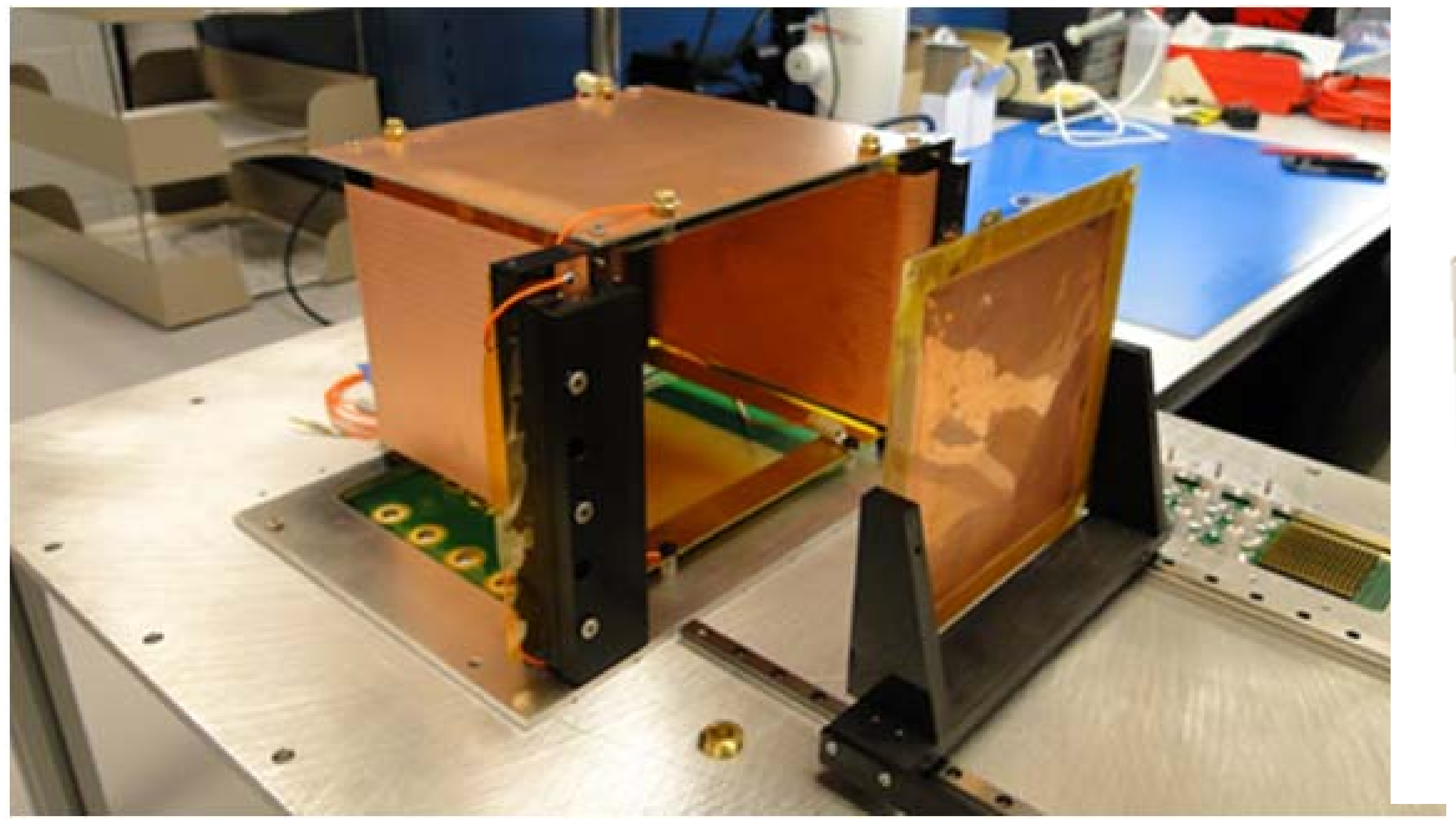
Combines the functions of a TPC for charged particle tracking and a Cherenkov detector for particle identification in same volume

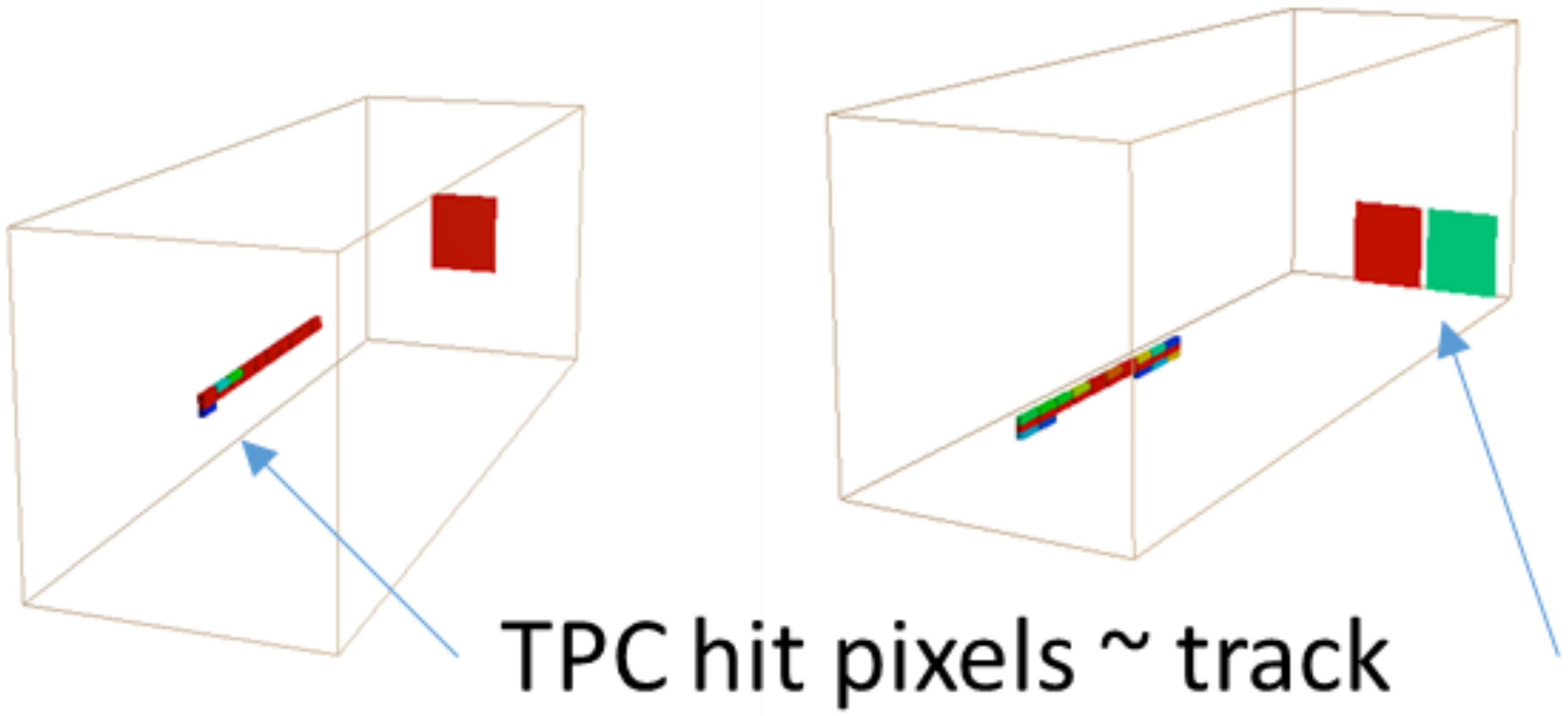
Prototype:

- TPC: 10cm drift + 10x10 cm^2 4 layer GEM
- Cherenkov: 3.3 x 3.3 cm^2 pad array + CsI + 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 - CTPC works!







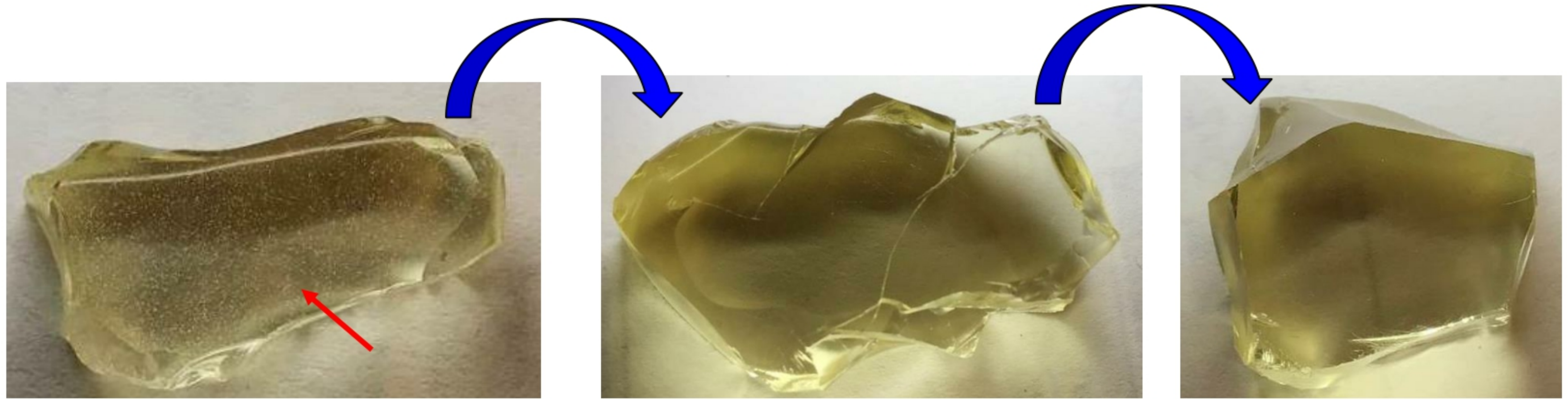
Cherenkov photons

IEEE Transactions on Nuclear Science 66.8 (Aug. 2019), pp. 1984

Example 4: Scintillating Glasses

- e-going direction needs high precision calorimetry ($\lesssim 2\%/\sqrt{E}$)
- Typically requires Lead Tungstate ($PbWO_4$) crystals
- Crystals are expensive, few vendors (SICCAS, CRYTUR)
  - Quality and QA issues
  - Moderate production capacity, raw material shortage

- New effort: Scintillating glasses (CUA/Vitreous State Laboratory)
  - Similar to lead glass in many properties but exhibit >10× the light yield per GeV
  - Nano-sized particles of $BaSi_2O_5$
    - Improve scintillation
    - Allows doping: Gd, Yb, Ce, ...

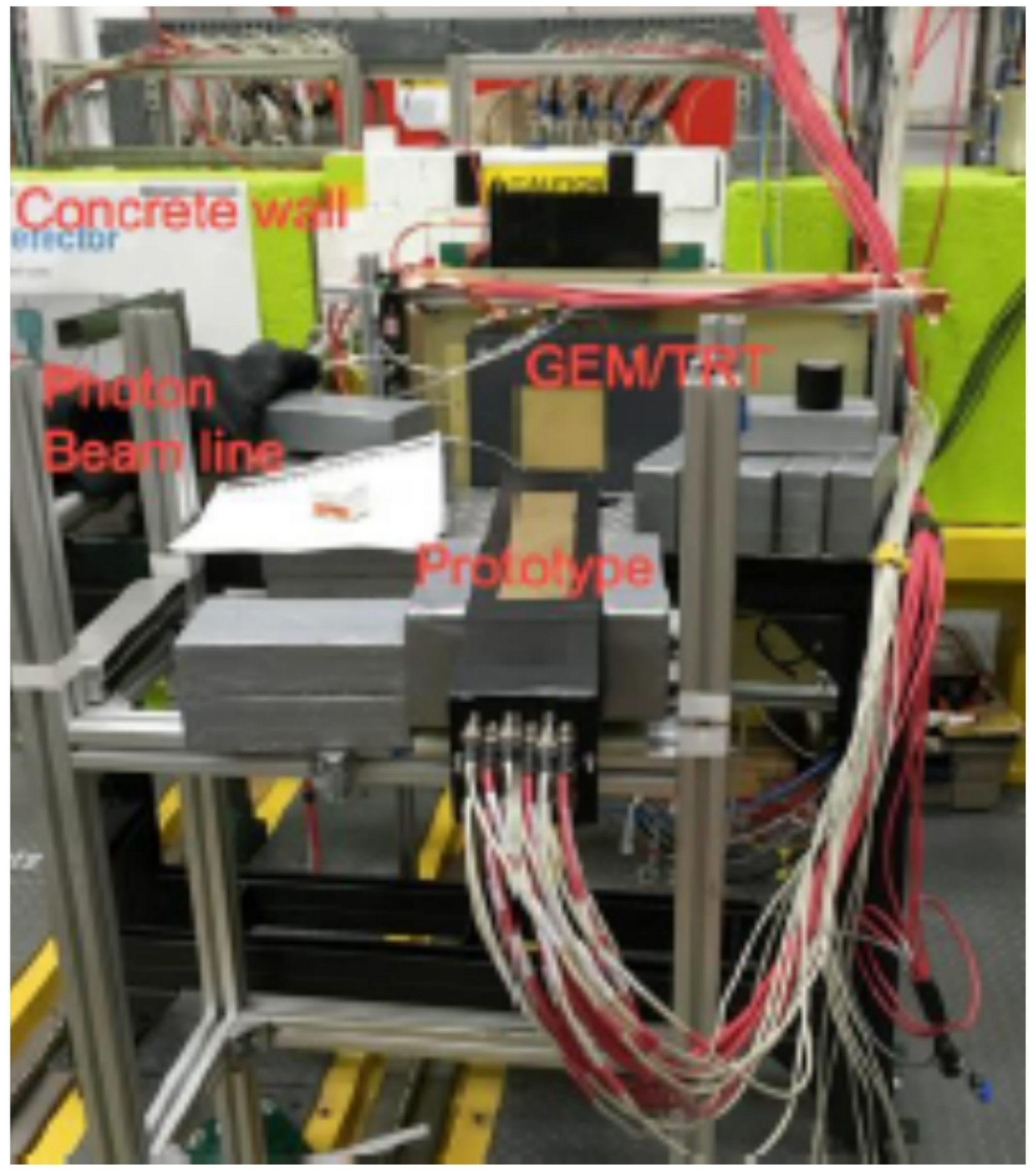


Samples made at CUA/VSL with new method.
35 times light output of $PbWO_4$

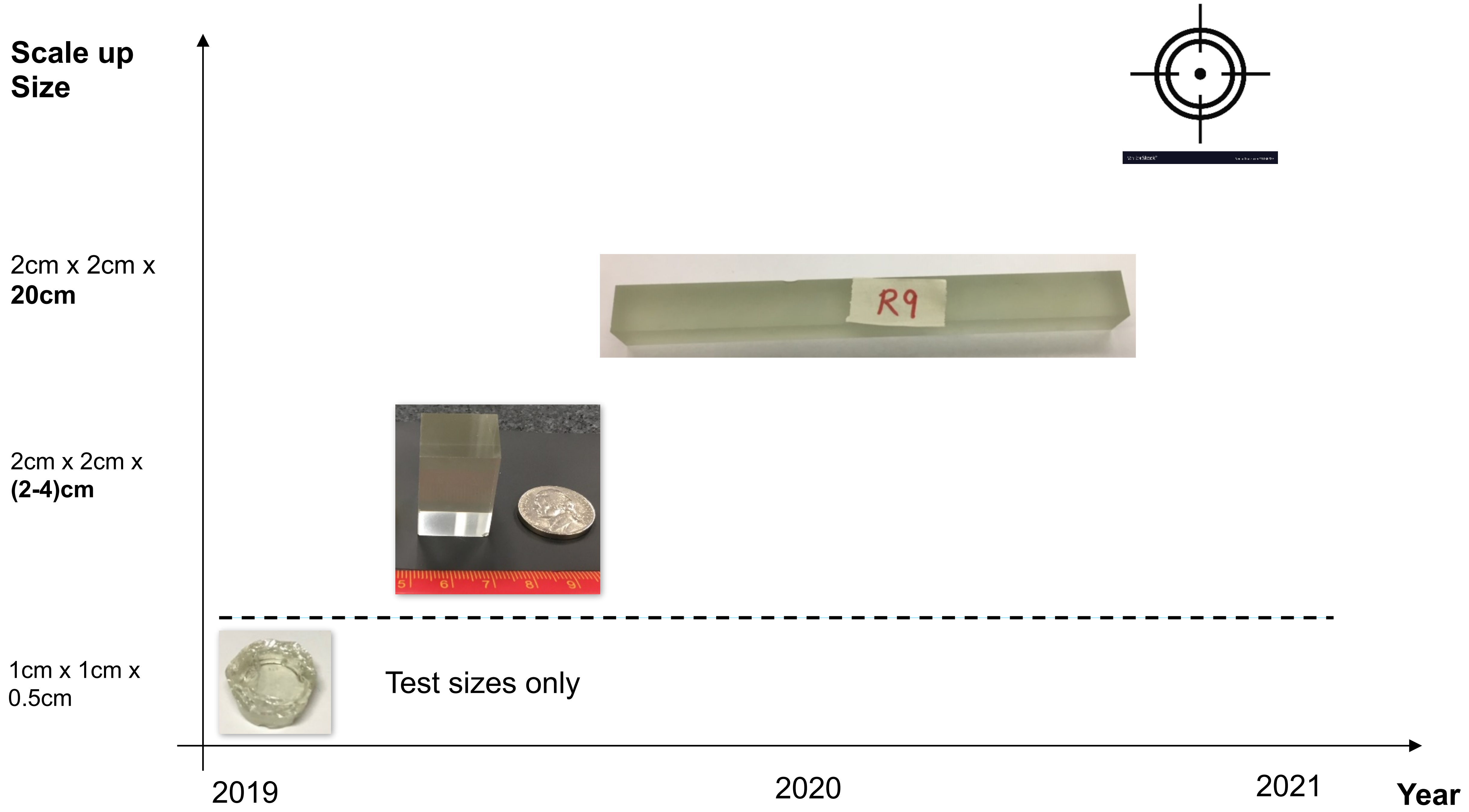
Example 4: Scintillating Glasses

- Early: Limited to small samples due to difficulties with scaling up while maintaining the required purity.
- Later: Possible path to inexpensive high resolution EM calorimeters
  - Simulation suggests a glass resolution comparable to $PbWO_4$
  - 40cm long bars match $PbWO_4$ resolution
  - Radiation test very positive (~1 MeV Co-60, 160 keV Xray, 40 MeV protons)

Beam and Lab test program:

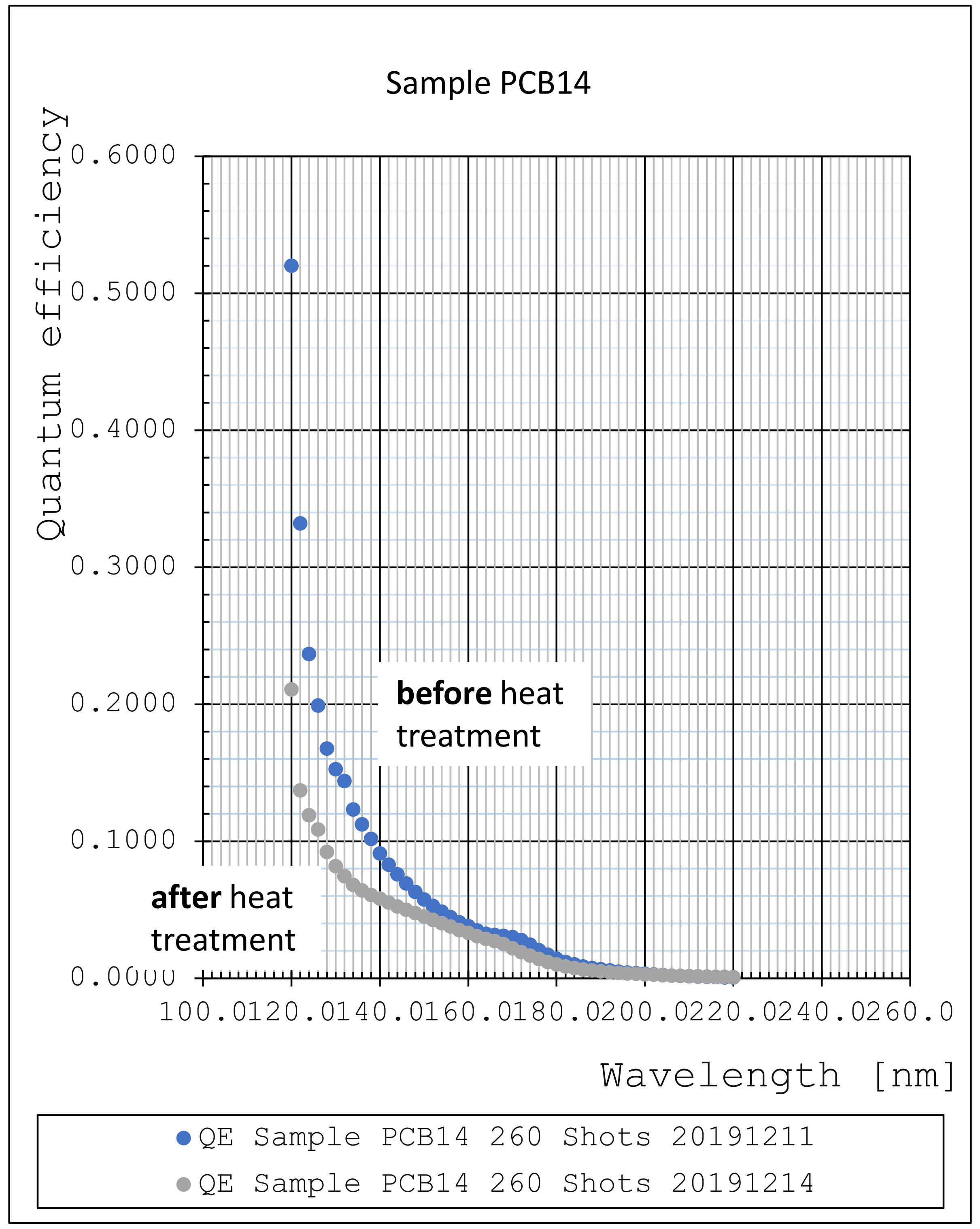


Nucl.Instrum.Meth. A 956 (2020) 163375

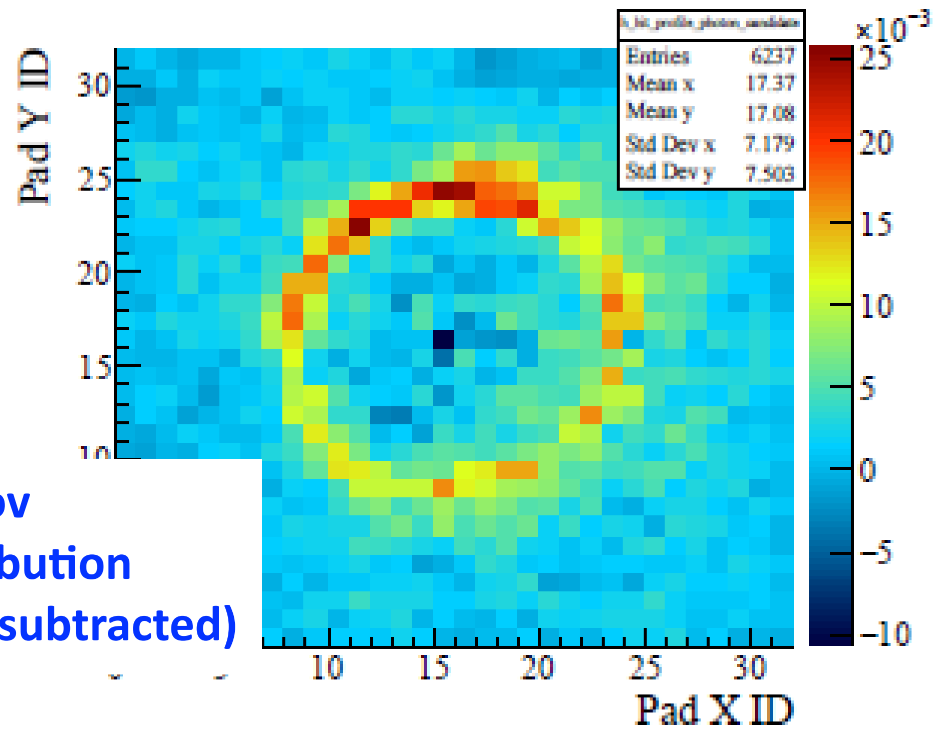


Example 5: R&D on MPGDs for RICH Detectors

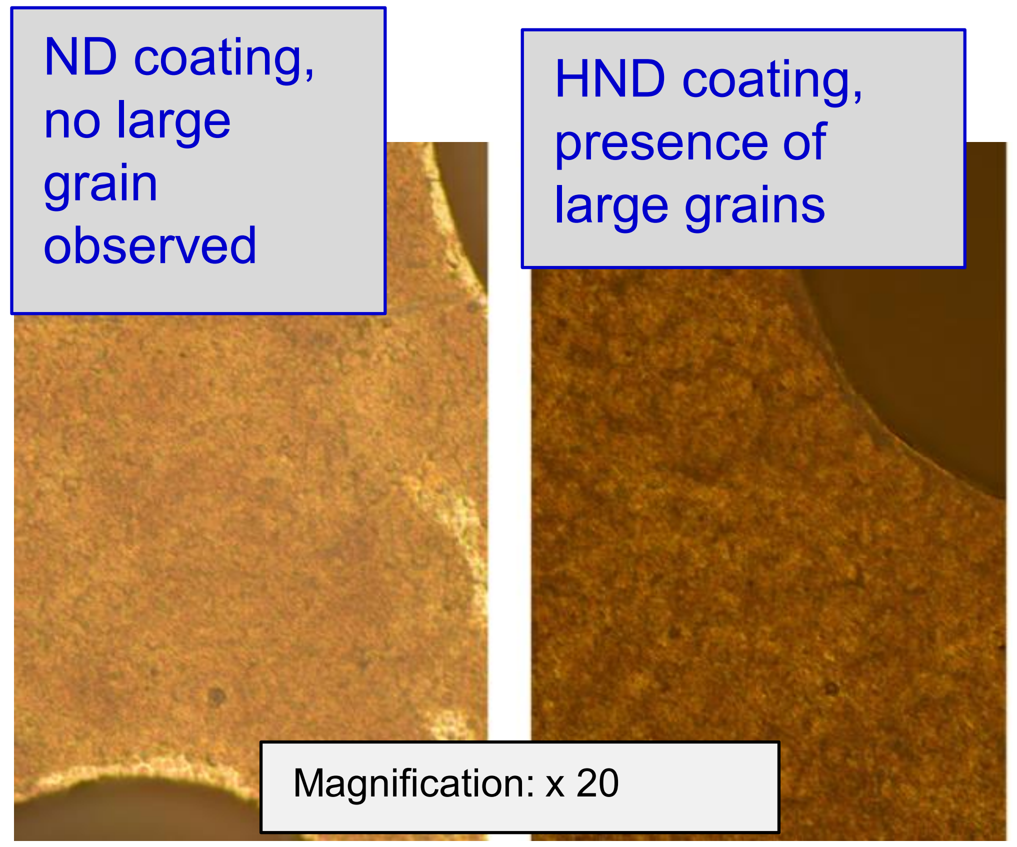
- Development of MPGD-based Photon Detectors
  - At high momenta: gas radiator is mandatory
  - Miniaturized pads
  - Operation in C-F gases
  - THGEM for optimal photoelectron collection
  - Use of innovative photocathode based on NanoDiamond (ND) particles coupled to MPGDs
- Current Efforts:
  - Construction and characterization of 2-layer THGEM with up-layer ND-coated
  - ND powered characteristics, QE studies



substrate type	sample label	coating material	number of spray shots
THGEM	TB IX	ND	300
THGEM	TB VIII	HND	140
THGEM	TB III	HND	43
THGEM	TB VII	HND	55
THGEM	TB XIX	HND	59
THGEM	TB XI	HND	250
disc	PBC1	ND	100
disc	PBC2	ND	100
disc	PBC3	ND	200
disc	PBC4	ND	200
disc	PBC5	ND	50
disc	PBC6	HND	50
disc	PBC9	HND	25
disc	PBC7	HND	50
disc	PBC10	HND	100
disc	PBC11	HND	200
disc	PBC8	HND	400



2-D Cherenkov photon distribution (background subtracted)



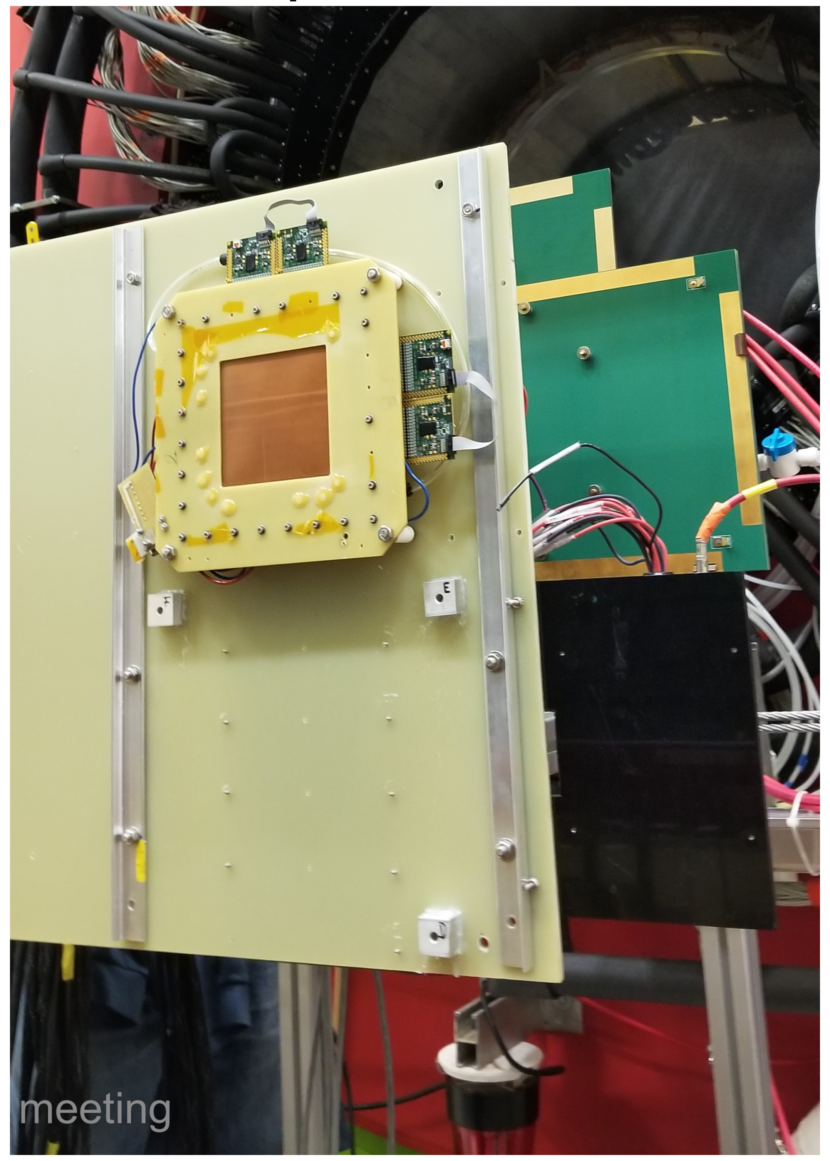
Example 6: GEM Based TRD

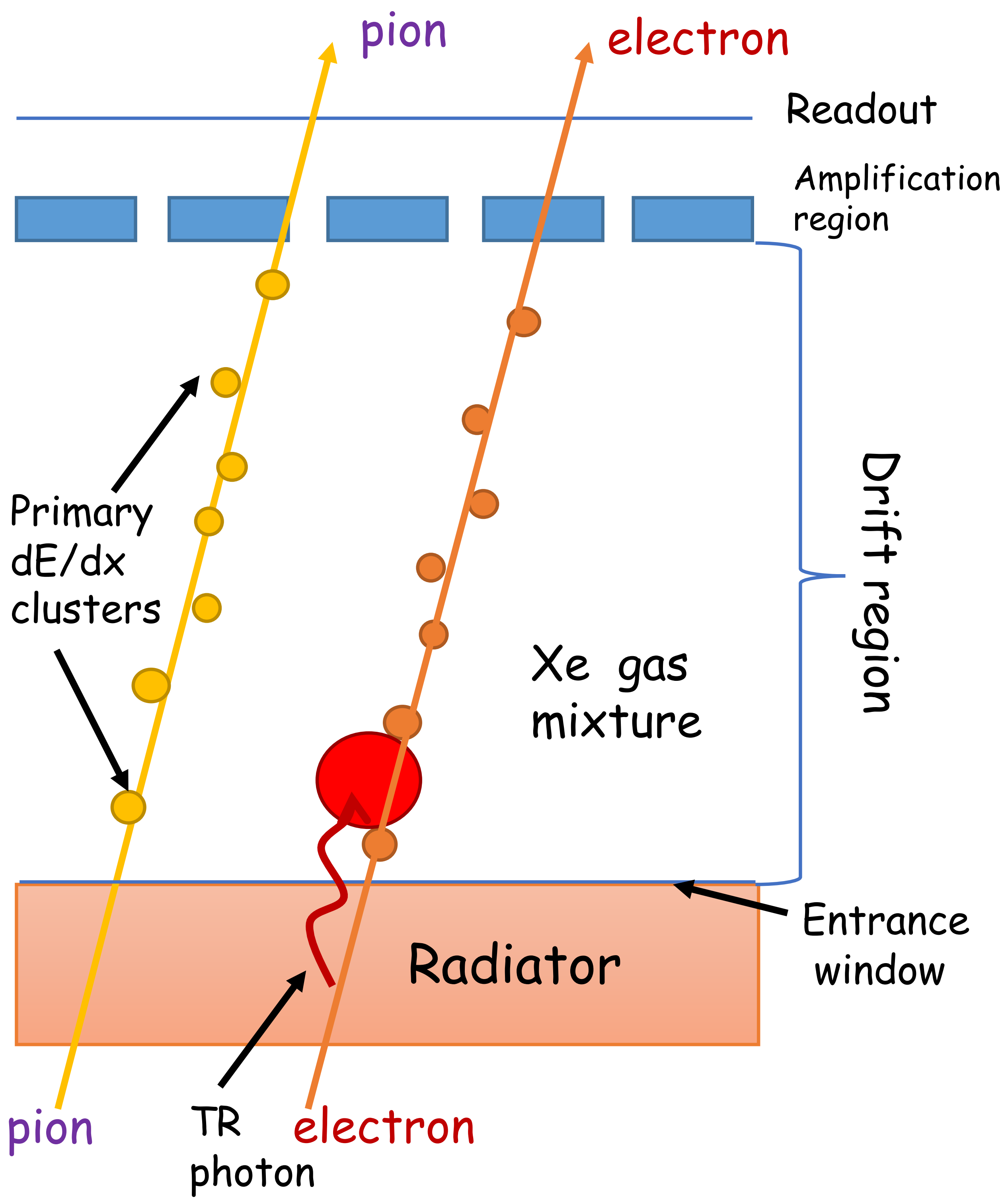
eRD22

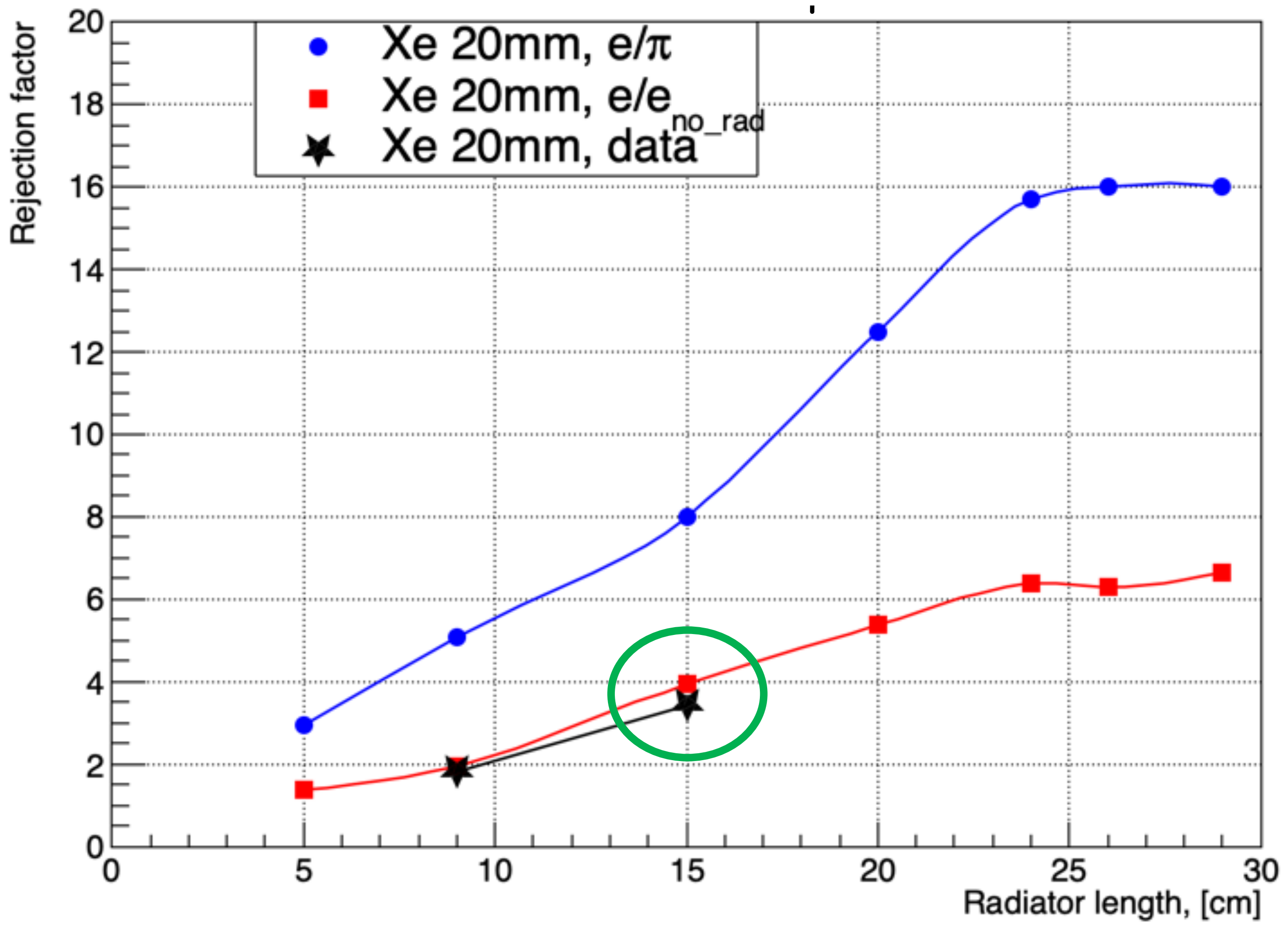
Goal: Electron identification (e/h separation) + tracking

- How to convert GEM tracker to TRD
  - Change from Argon to Xenon (for efficient absorption of X-rays)
  - Increase drift region up to 2-3 cm
  - Add a radiator in the front of each chamber
    - Best candidate so far is "Fleece" with excellent response, high TR-yield, soft and hard TR photon's spectrum
  - Number of layers depends on needs: single layer e/π rejection of 10 with ~90% electron efficiency

Test setup at GlueX@JLab







Test results in good agreement with simulations

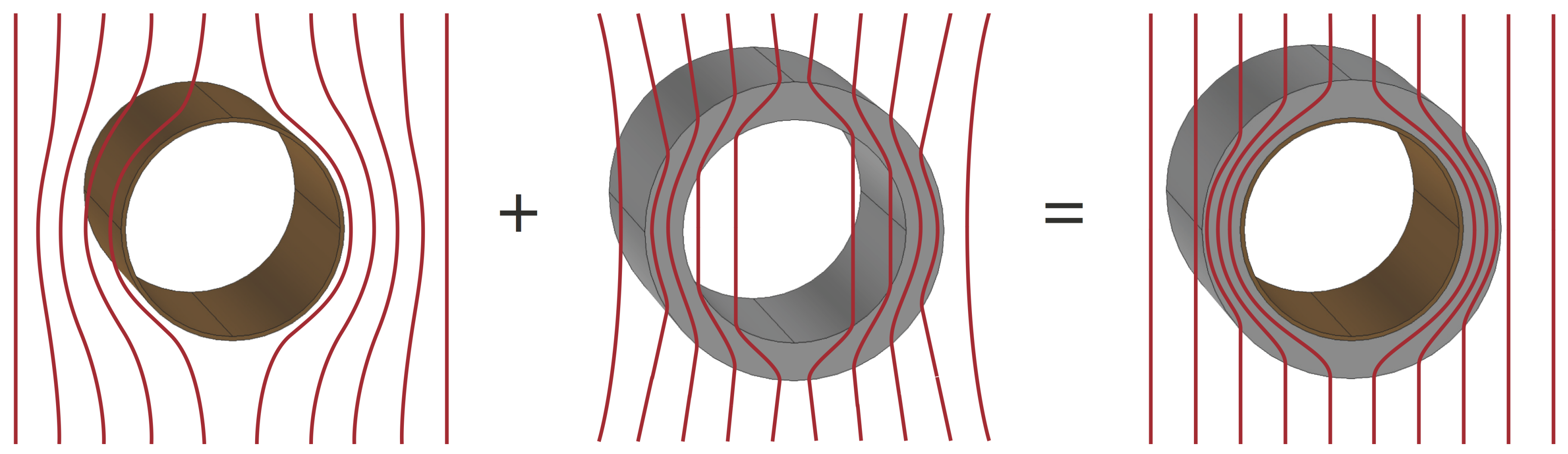
Example 7: A Magnetic Field Cloaking Device

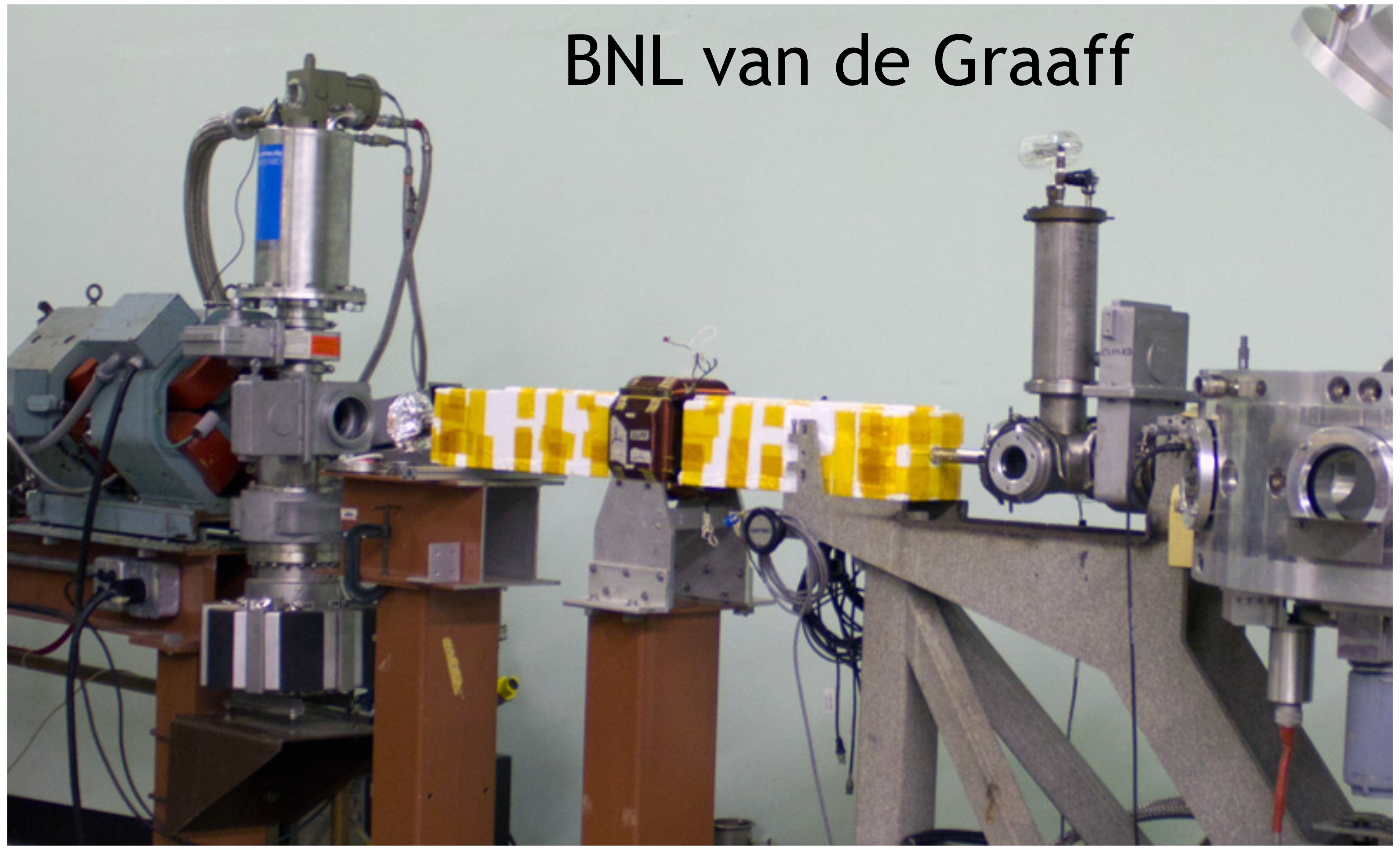
To retain good momentum resolution in the forward region, need dipole field

Dipole fields affect beam optics

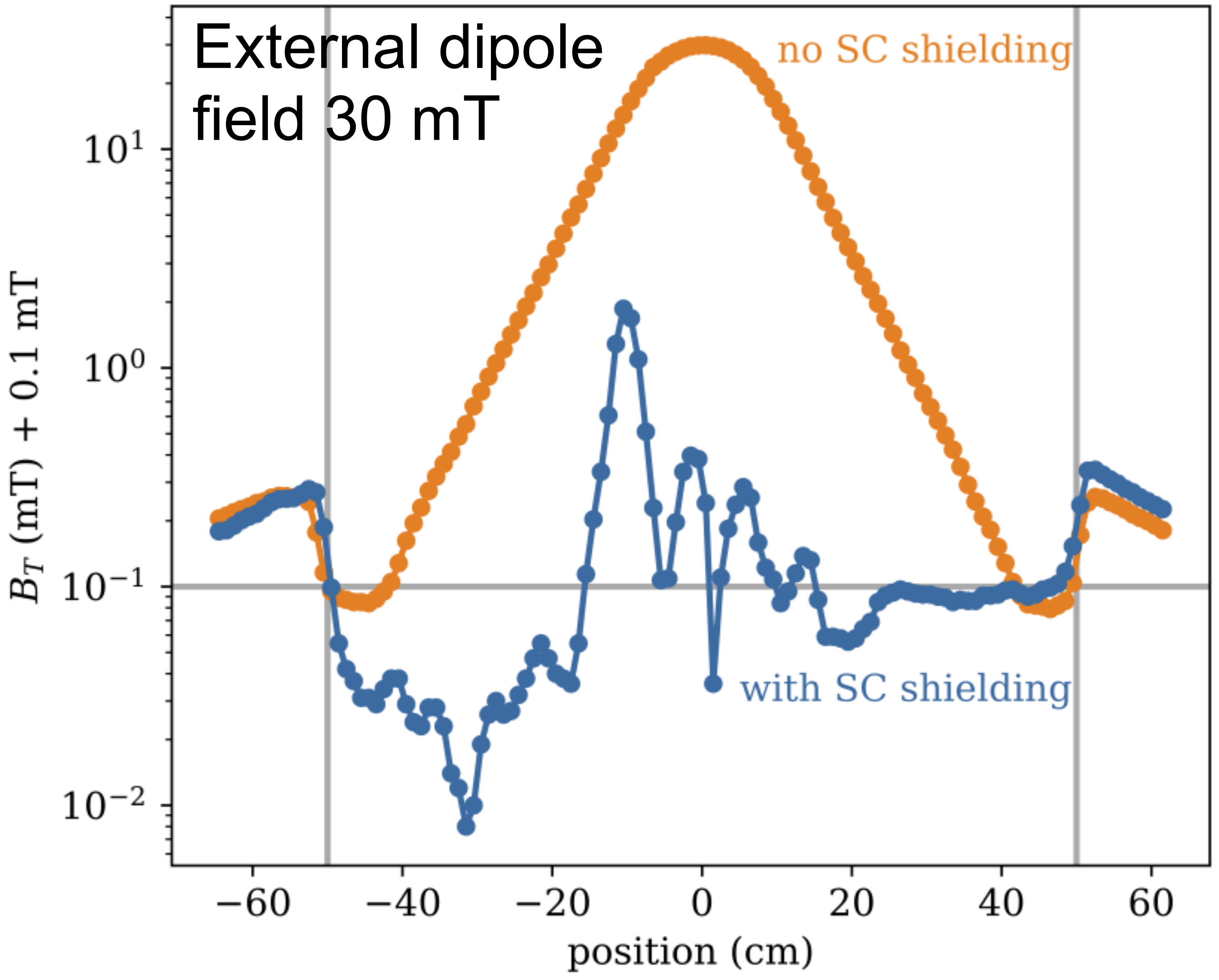
Develop magnetic cloak

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





- Beam shielding tests with the BNL Van de Graaff accelerator



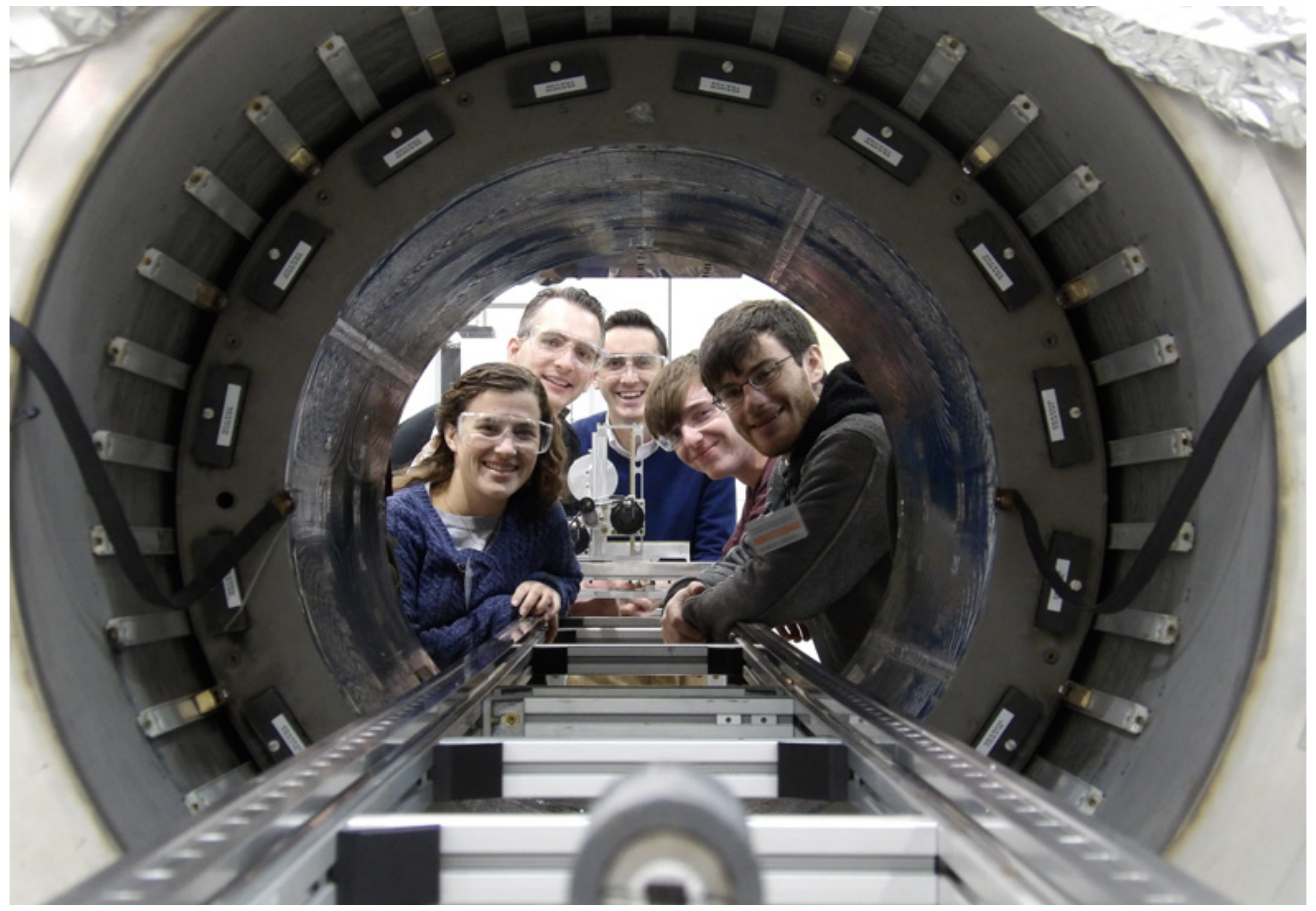
Institutions: Stony Brook, BNL, RIKEN

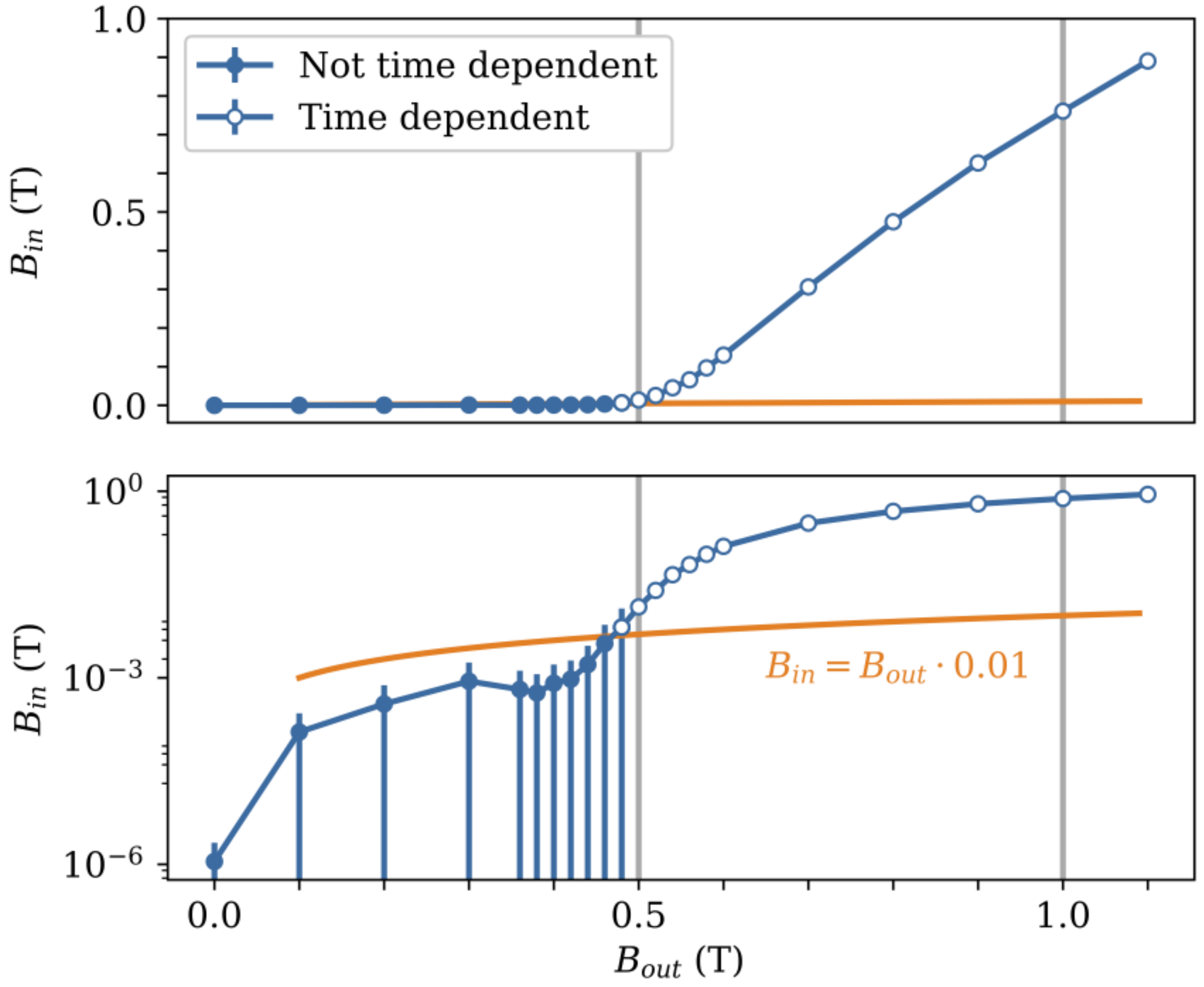
Magnetic Field Cloaking Device

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 (also NIM) - Project engaged many students

The Need for Continuing Generic R&D

- **ePIC Specific**
  - Need to continue developing technologies that are not ready for day-1 but that would offer *superior technologies down the road*
  - Support some *higher risk items*
  - Develop technology for *future upgrades* keeping the EIC on cutting-edge in the future and built on past investments
- For EIC to ever have a **2nd detector** we need a R&D program similar to that from 2011-2021. A EICUG working groups is by far not enough. We need to grow a community around a detector and dedicated R&D is doing just that. The current FCC-ee R&D efforts confirm that.
- **Broader Impact**
  - Develop more environmental-friendly technologies (e.g. fluorocarbon)
  - Brings benefit for other programs in NP, HEP, and medical application (e.g. PET w/ ToF)

New Round of Generic R&D

- **Generic R&D (2022-2024)**
  - After lots of efforts: Generic program reconstituted starting 2022
  - funded by DOE, coordinated by JLab
  - Mission: *This program will support advanced R&D on innovative, cost-effective detector concepts which reduce risk and that either the one detector in the project scope or a second detector could incorporate. (The term "generic" conveys this duality.) The EIC User Group-authored Yellow Report includes requirements for both detectors.*
  - total of 30 proposals received on July 25, 2022
  - total of 20 proposals received on July 15, 2023
  - https://www.jlab.org/research/eic_rd_prgm
  - Terminated 2024 by DOE

DOE Takes Over

From: 'Shinn, Michelle' via EICUG Steering Committee <eicug-sc@eicug.org>
Sent: Wednesday, October 2, 2024 5:19 PM
To: eicug-sc@eicug.org
Subject: [EXTERNAL] [eicug-sc] FY25 DOE Office of Science Notice of Funding Opportunity now includes EIC-related Generic Detector R&D

The FY 2025 Continuation of Solicitation for the Office of Science Financial Assistance Program Notice of Funding Opportunity (NOFO) (https://science.osti.gov/grants/FOAs/-/media/grants/pdf/foas/2024/DE-FOA-0003432.pdf) solicits proposals from eligible applicants for projects aligned with the goals ascribed for the Generic EIC Detector R&D Program described in section 6j. Note that the deadline for submission is **November 15, 2024**.
Regards,
Michelle Shinn

Michelle Shinn, Ph.D.
Program Manager for Industrial Concepts
Office of Nuclear Physics

DOE Takes Over

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Program Manager for Industrial Concepts
Office of Nuclear Physics

Several EIC related groups submitted their proposal

To my knowledge (?) we have not heard anything about this program after the new administration took over

The DOE Program lacks everything that had made the Generic R&D Program strong

- ➡ International contributions
- ➡ Freedom to prioritize community building over proposal strength
- ➡ Regular in Person meetings of all engaged groups

Observation: Limits of R&D

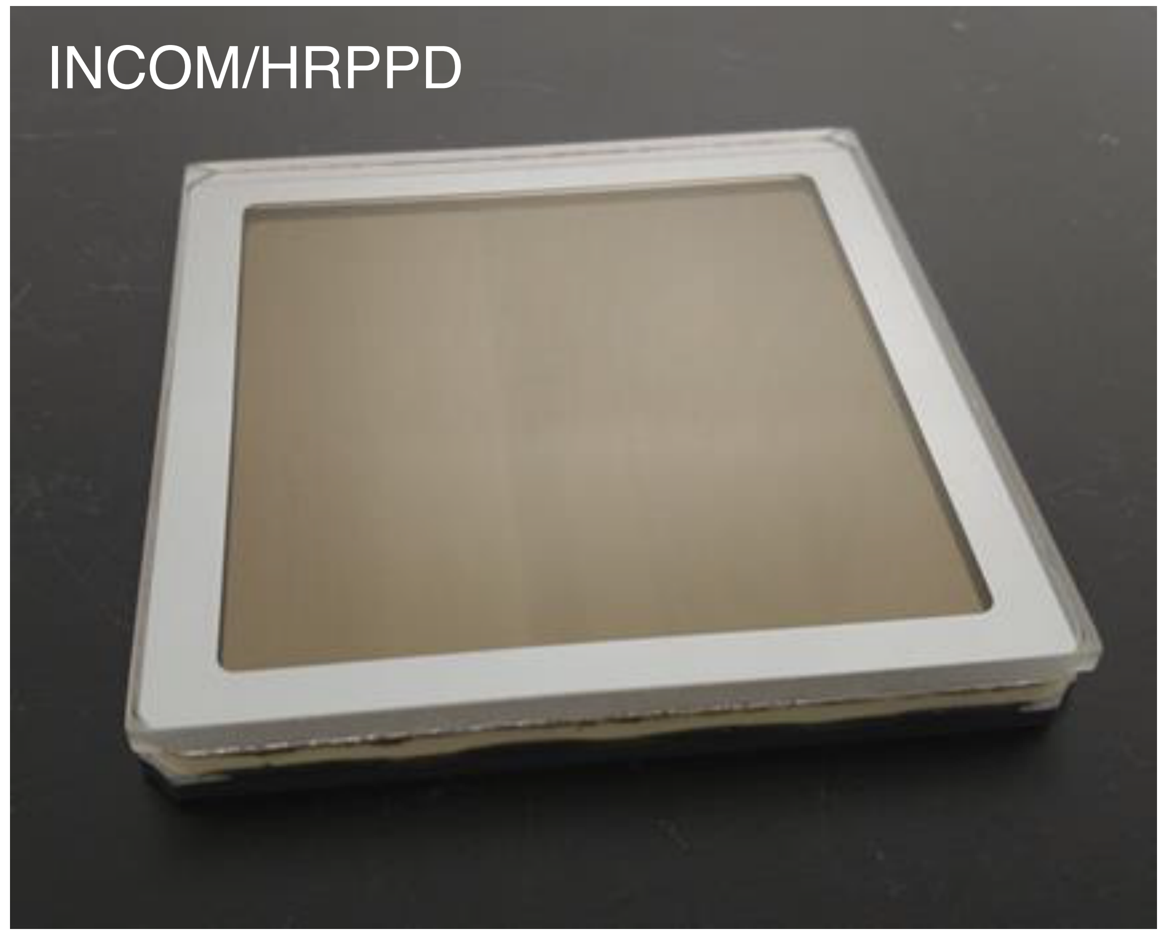
- As physics requirements become more challenging, technologies needed to meet them become more complex
- As a consequence the cost to develop them goes up
- Some key items are by now so cost and labor intensive that NP R&D alone cannot do it
- Cost are prohibitive on the scale of NPs capabilities
- It requires international and cross-field (e.g., NP-HEP) collaboration

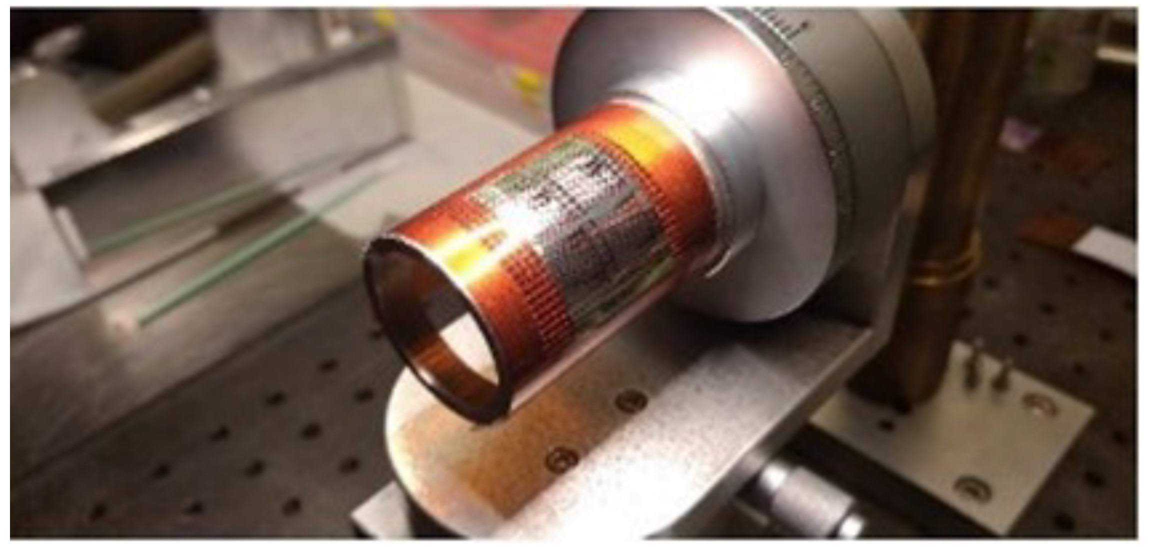
US NP Scale:

- RHIC R&D (1995): $15.6 M is ~$28 in 2023 $
- EIC Generic 2011-2021: $20 M in 2023 $

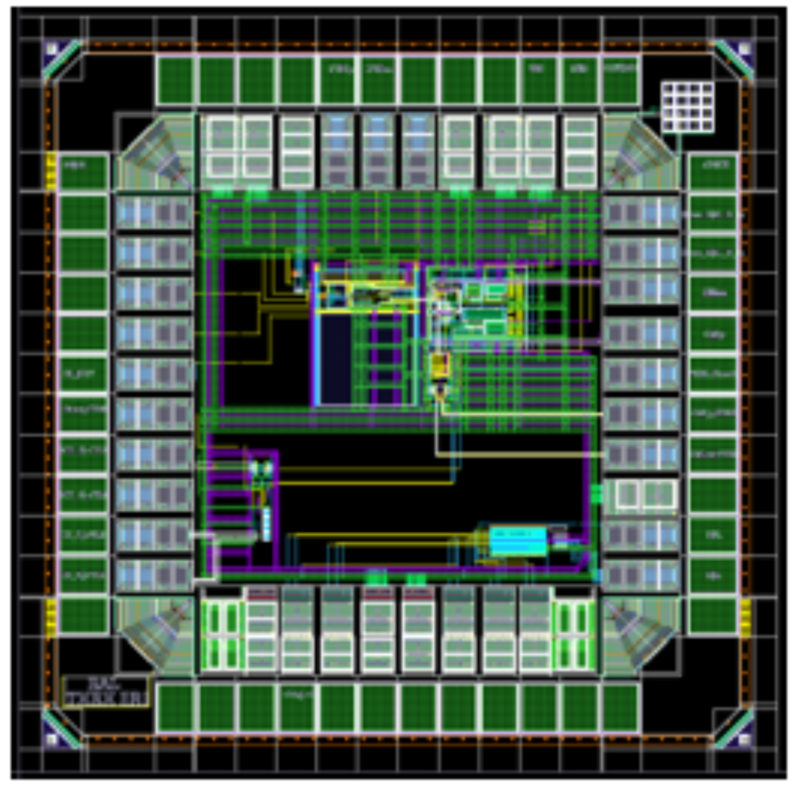
Observation 2: Limits of R&D (cont.)

- **Examples**
  - LAPPD/HRRP
    - benefit from a previous $20M investment by HEP through the LAPPD collaboration ➟ that's the equivalence of 10 years generic R&D
    - dedicated EIC version now used in pfRICH
  - ITS3/MAPS
    - Total cost of new MAPS development out of reach for EIC
    - Joining ALICE ITS3 collaboration to develop new generation MAPS sensors in 65 nm CMOS imaging technology was a great idea - in fact the only way (thank you Leo Greiner)
    - Leverage on a large effort at CERN (~30 FTE-years)
    - Strong EIC groups from UK, Italy, and US collaborating with CERN
    - Also growing interest from FCC-ee R&D community





APTS structure in curved geometry



ER1 layout

Legacy and Future

- The legacy of the generic R&D program is ePIC which is a great success and to a large extent the legacy of Steve Vigdor
- The absence of a strong generic R&D program is jeopardizing ePIC upgrades in the coming decade
- Efforts for 2nd EIC detector cannot be launched w/o a ‘dedicated’ generic R&D program
- There are big R&D projects we cannot do alone
  - Examples: monolithic LGADs
  - Ultra thin solenoids
  - Wireless technologies to reduce services (?)
  - MAPS with extremely fast timing
  - Breaking the $30\%/\sqrt{E}$ barrier in hadronic calorimetry
- Much to do for the next generation of physicist