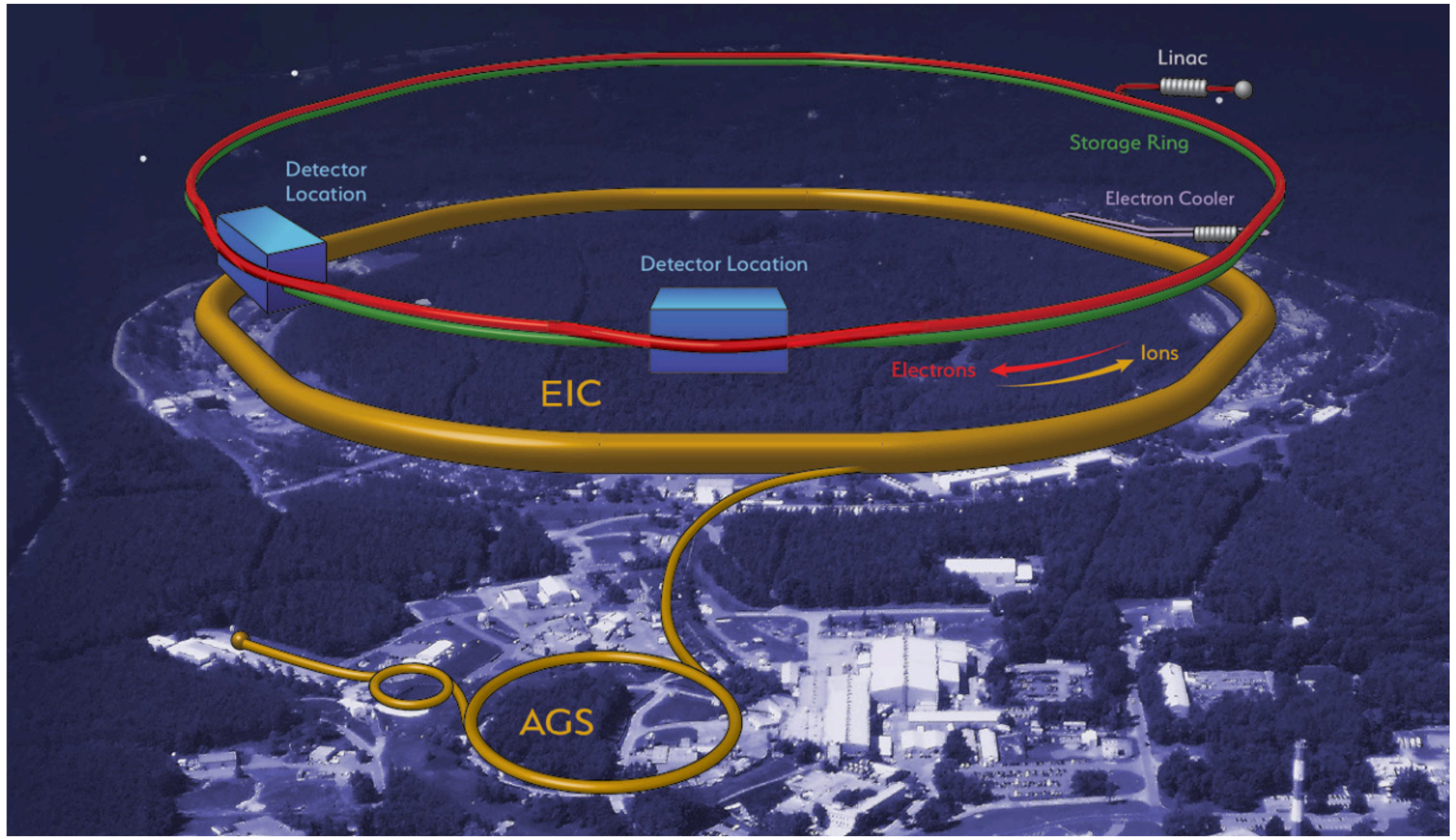
The EIC Community: Path Towards Detectors

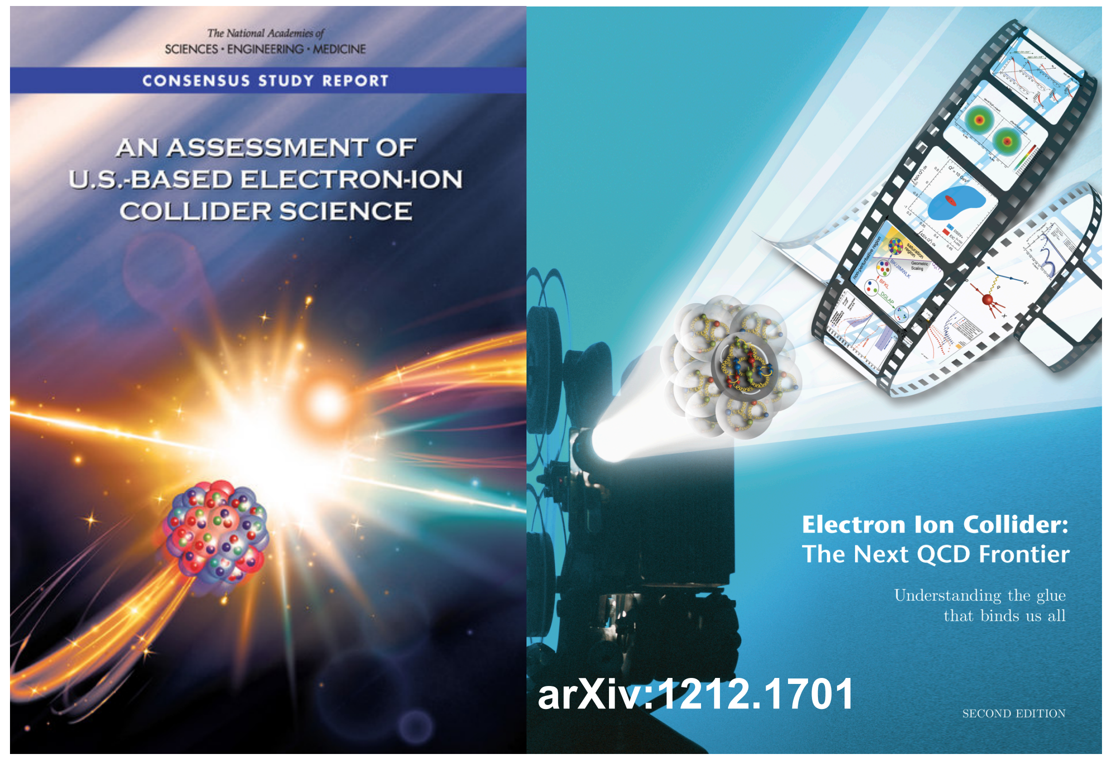


Thomas Ullrich
JLUO Annual Meeting
June 22-24, 2020

BROOKHAVEN NATIONAL LABORATORY

The Long Path to EIC Detectors

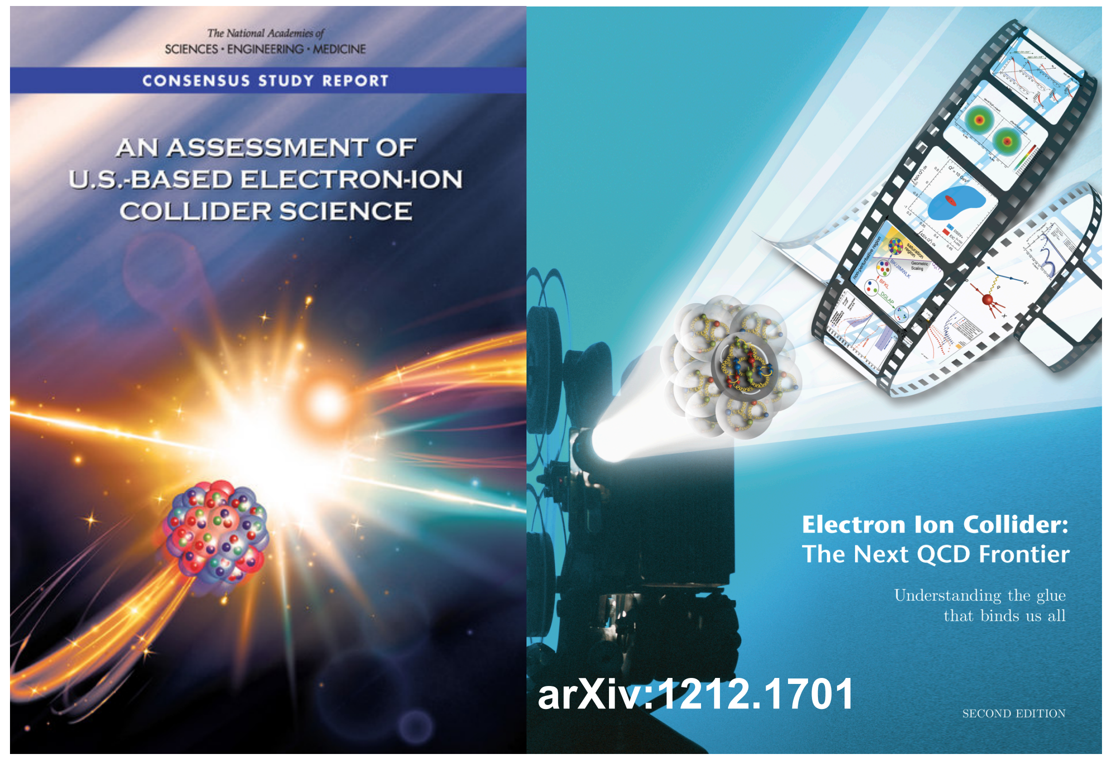
The Long Path to EIC Detectors



Big Questions & Physics Case

White Paper 2012 & NAS Report

The Long Path to EIC Detectors



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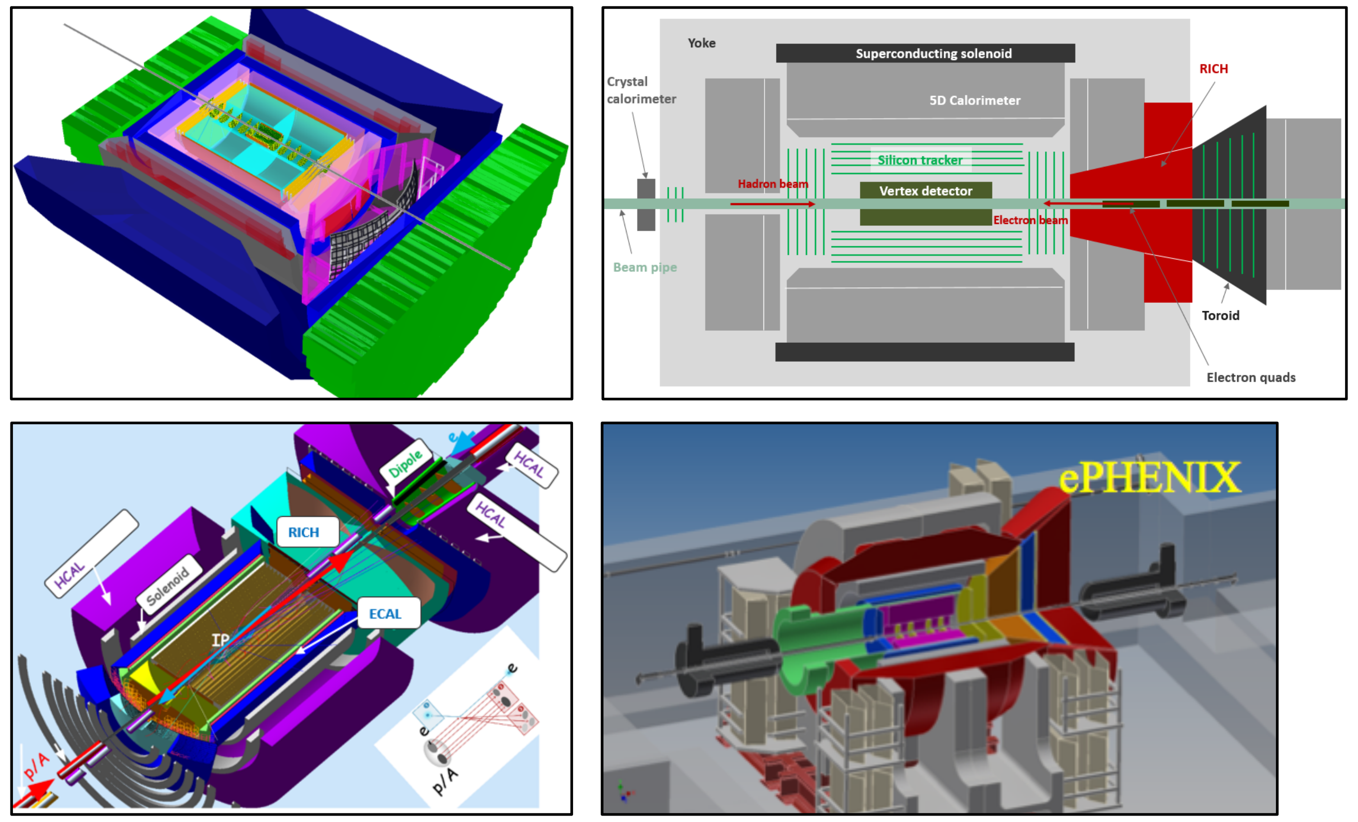
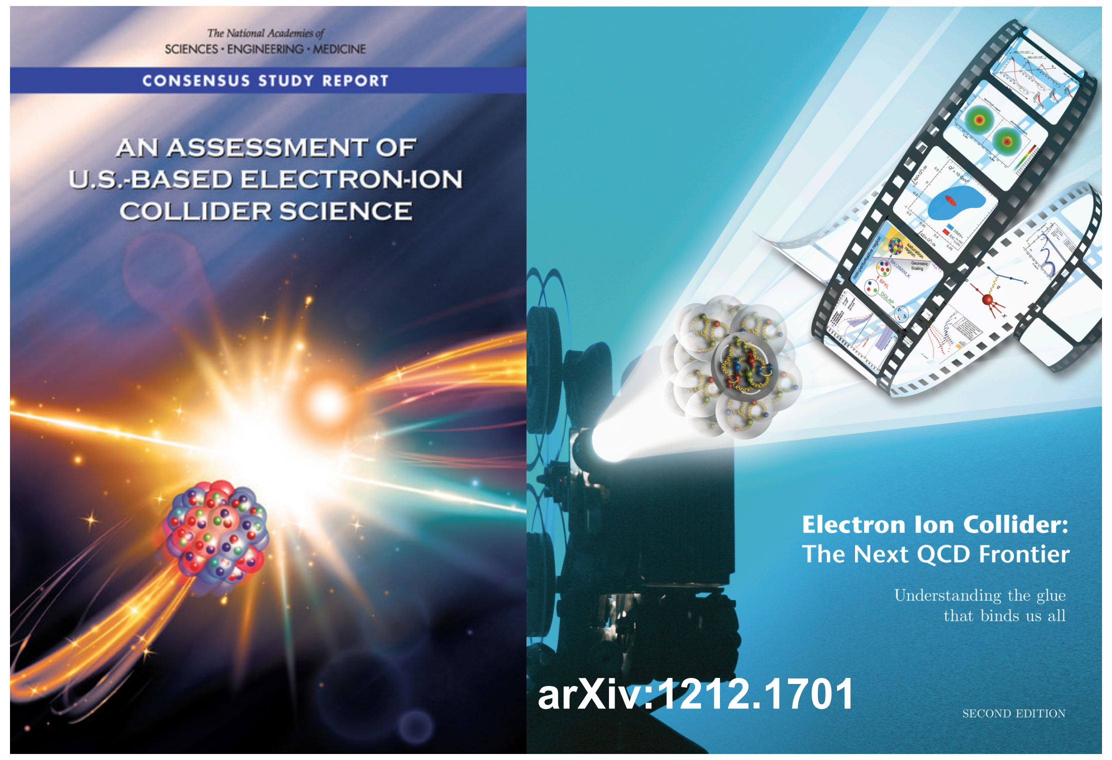


First Detector Ideas
& Concepts

The Long Path to EIC Detectors



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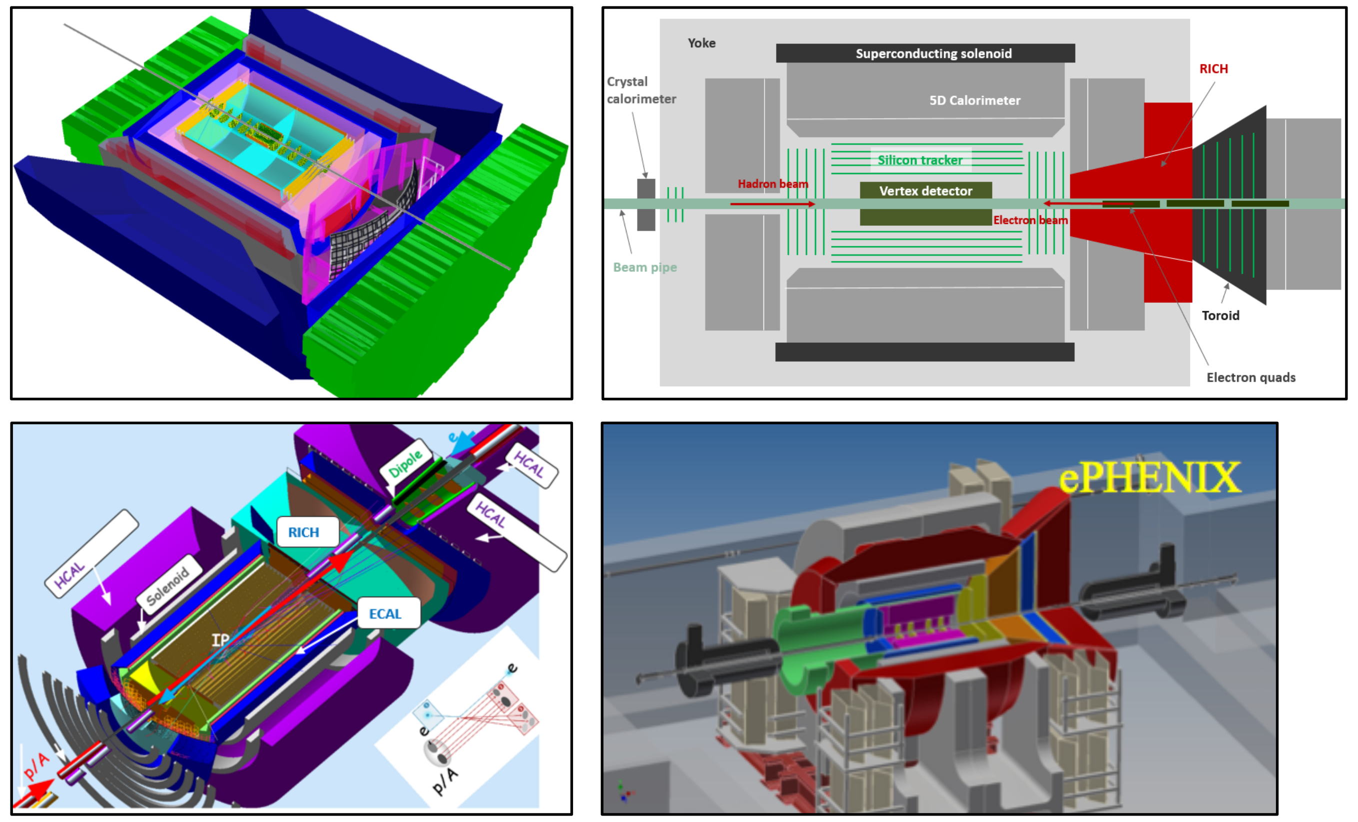
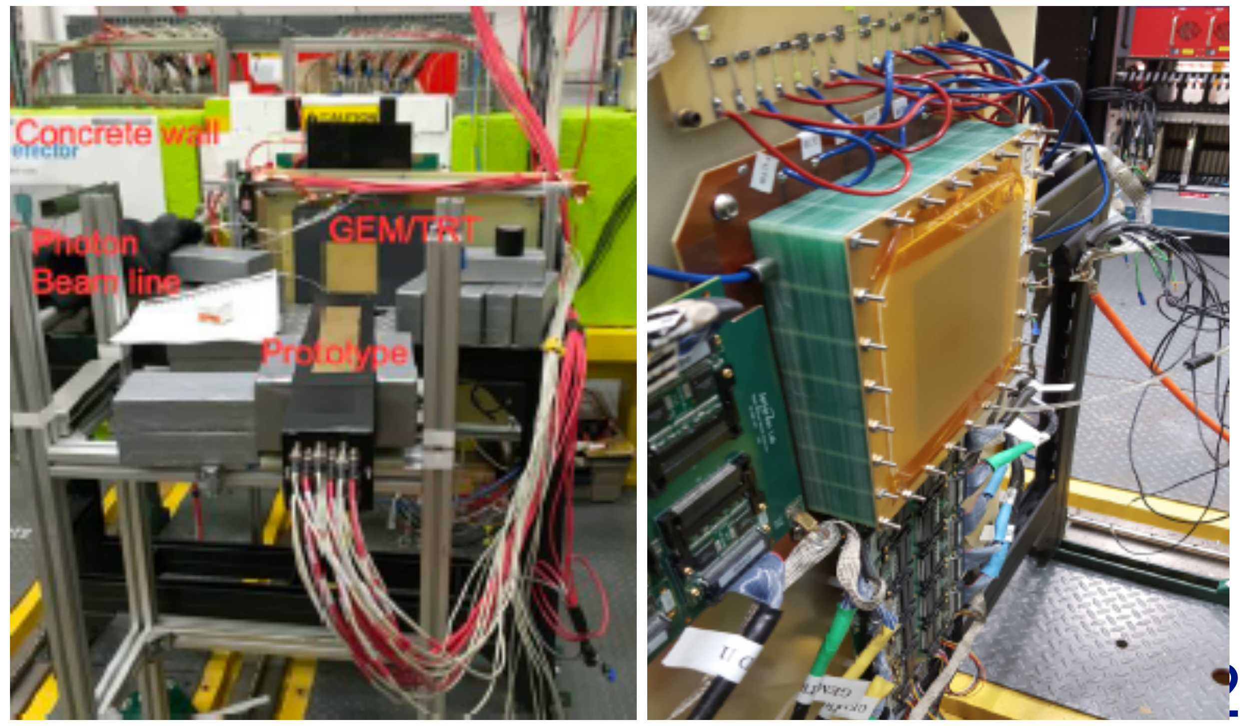


First Detector Ideas & Concepts

R&D, Prototypes



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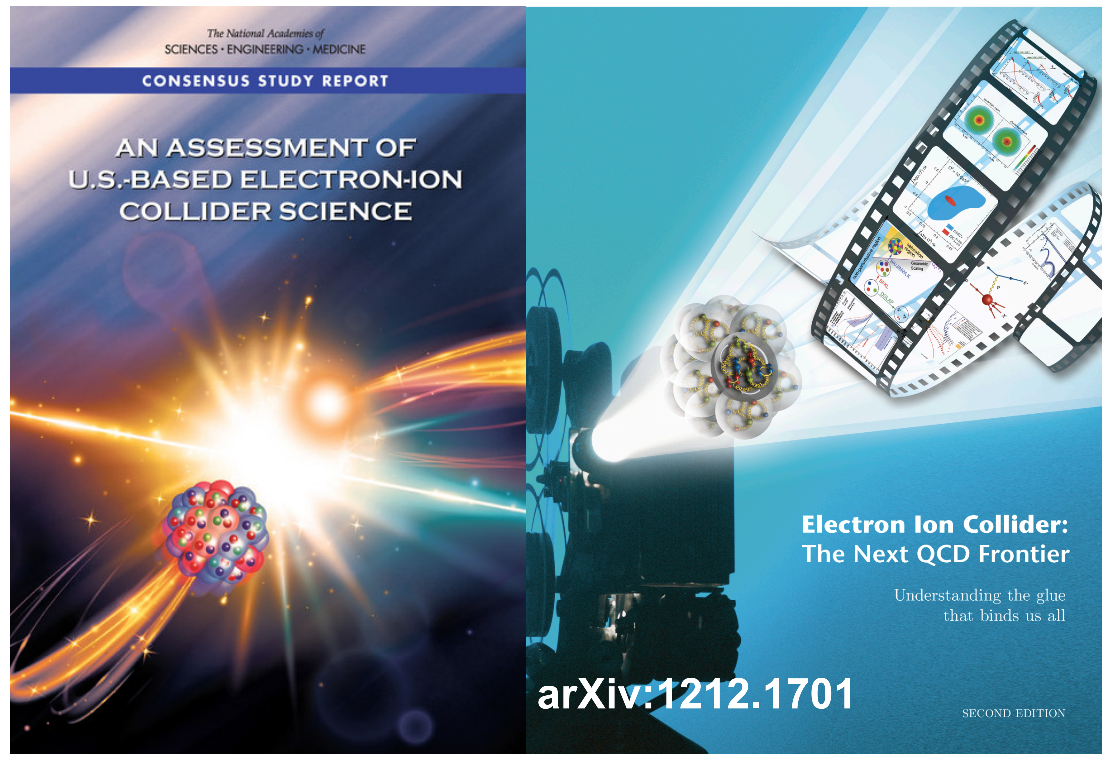

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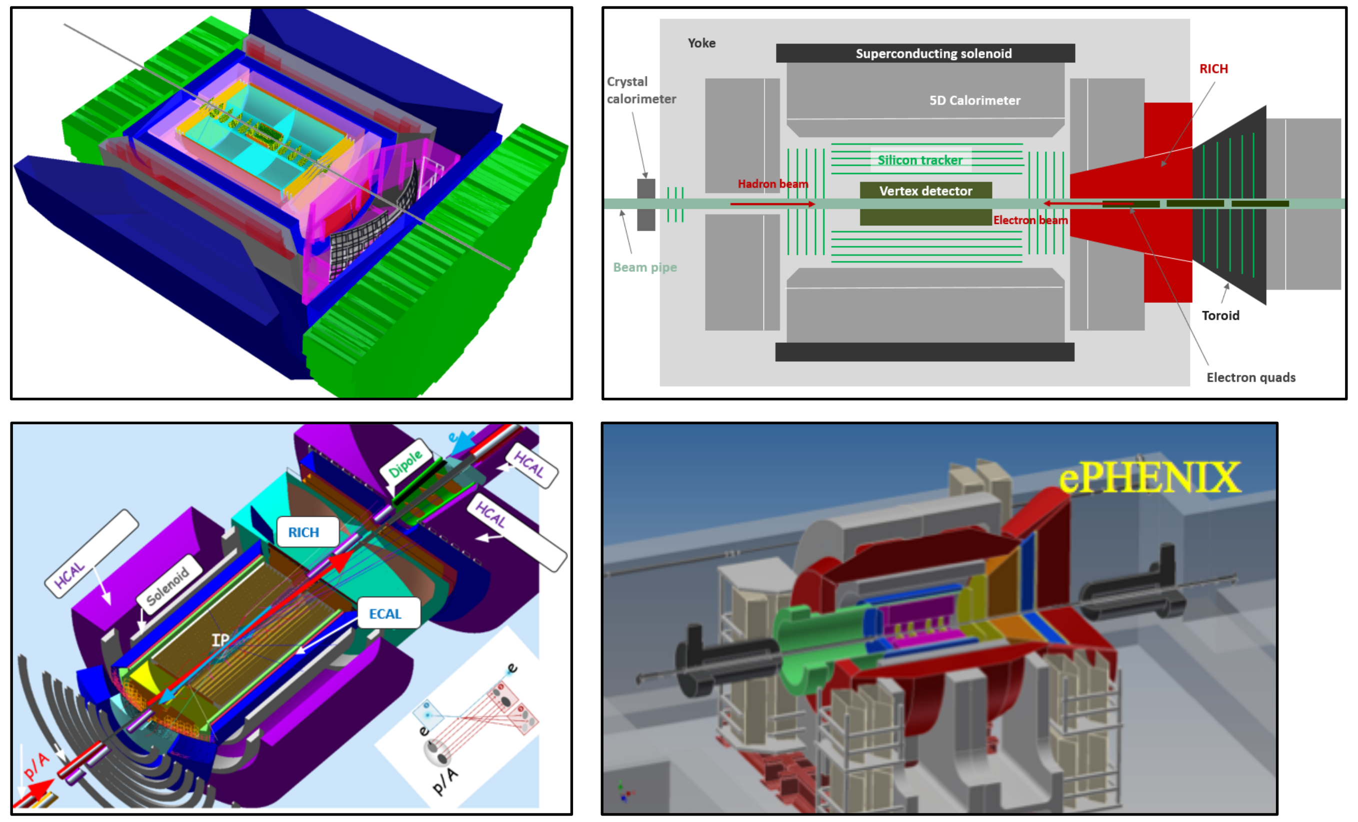

First Detector Ideas & Concepts

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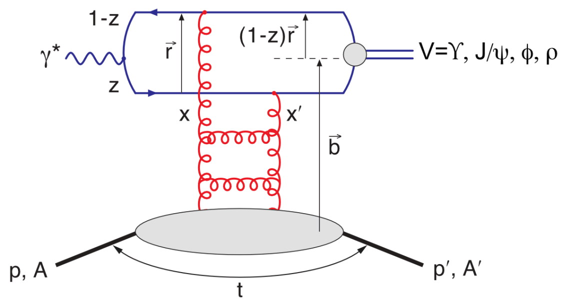
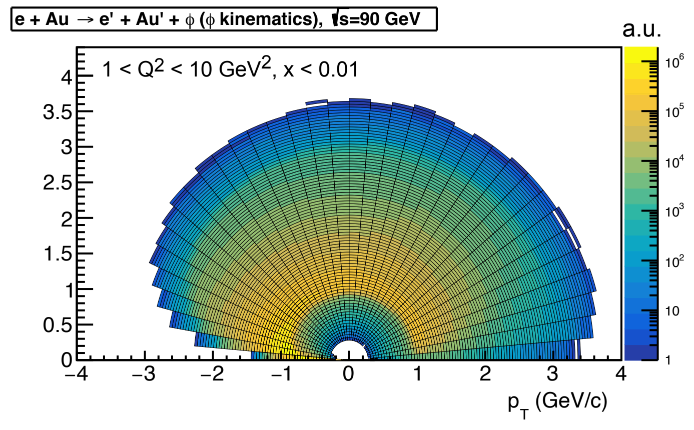
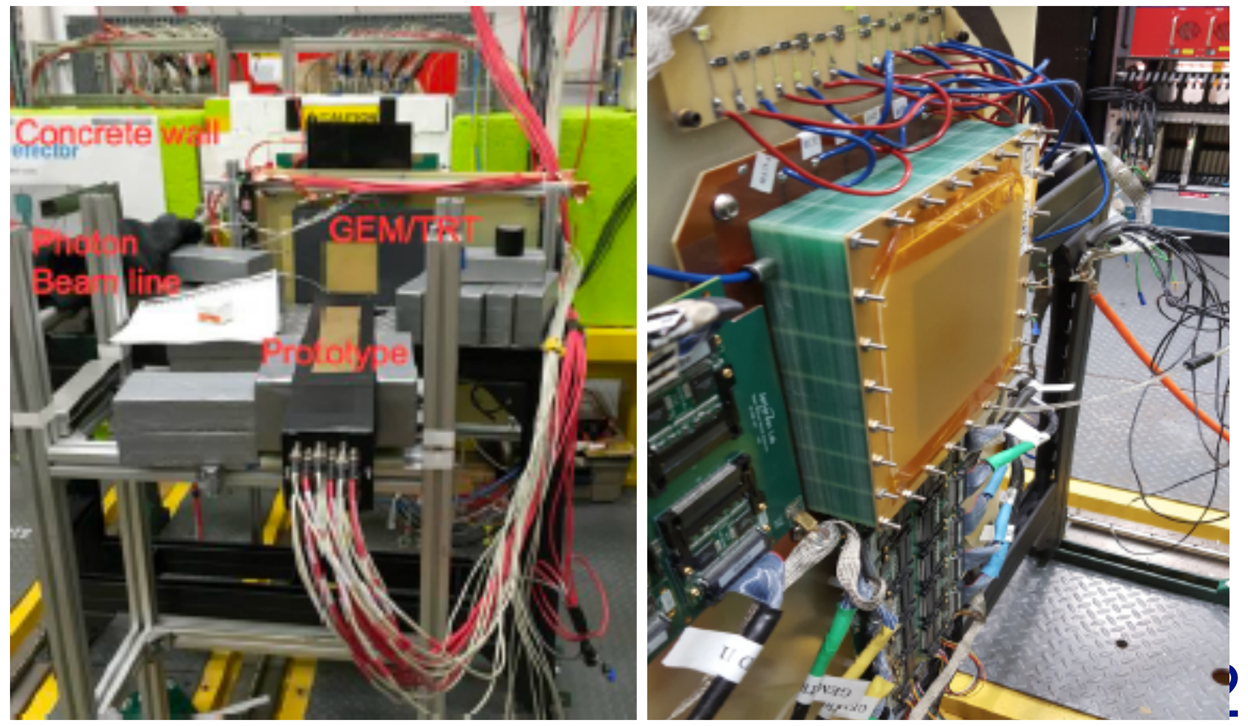
...												
-4.5 to -4.0			Instrumentation to separate charged particles from photons									
-4.0 to -3.5							2%/√E					
-3.5 to -3.0		Central Detector	Backward Detector	σ_p/p ~ 0.1%⊕0.5%								
-3.0 to -2.5												
-2.5 to -2.0				σ_p/p 0.1%⊕0.5%		TBD	2%/√E		≤ 7 GeV/c		~50%/√E	
-2.0 to -1.5				σ_p/p 0.05%⊕0.5%			7%/√E	π suppression up to 1:10[4]				
-1.5 to -1.0							7%/√E					
-1.0 to -0.5												
-0.5 to 0.0			Barrel	σ_p/p ~0.05%×p+0.5%	~5% or less X	σ_{xyz} ~ 20 μm, $d_0(z)$ ~ $d_0(r\Phi)$ ~ 20/p_T GeV μm + 5 μm			≤ 5 GeV/c	≥ 3 σ		TBD
0.0 to 0.5												
0.5 to 1.0												
1.0 to 1.5									≤ 8 GeV/c			
1.5 to 2.0			Forward Detectors	σ_p/p ~0.05%×p+1.0%								
2.0 to 2.5						TBD	(10-12)%/√E		≤ 20 GeV/c		~50%/√E	
2.5 to 3.0				σ_p/p ~ 0.1%×p+2.0%								
3.0 to 3.5									≤ 45 GeV/c			
3.5 to 4.0												
4.0 to 4.5			Instrumentation to separate charged particles from photons									
...	↑ e	Auxiliary Detectors	Neutron Detection									
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\|t\|)/\|t\|$ < 1%; Acceptance: 0.2 < p_t < 1.2 GeV/c								





Detailed Detector Requirements & Concepts

R&D, Prototypes



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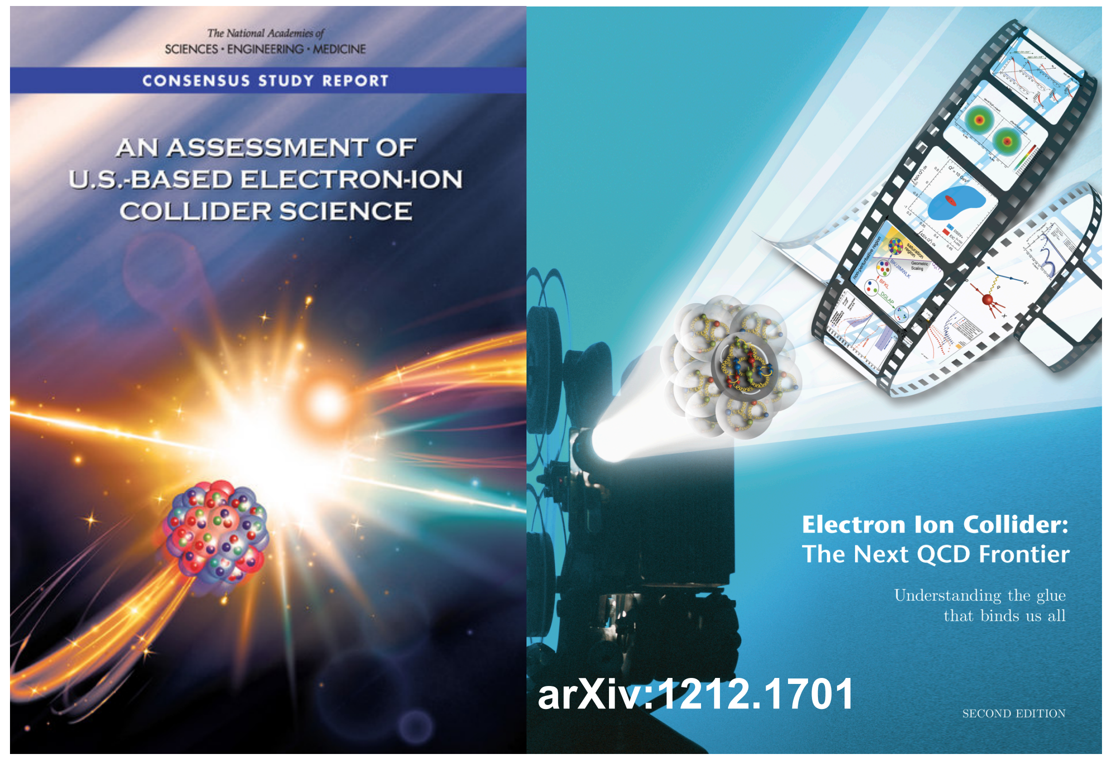
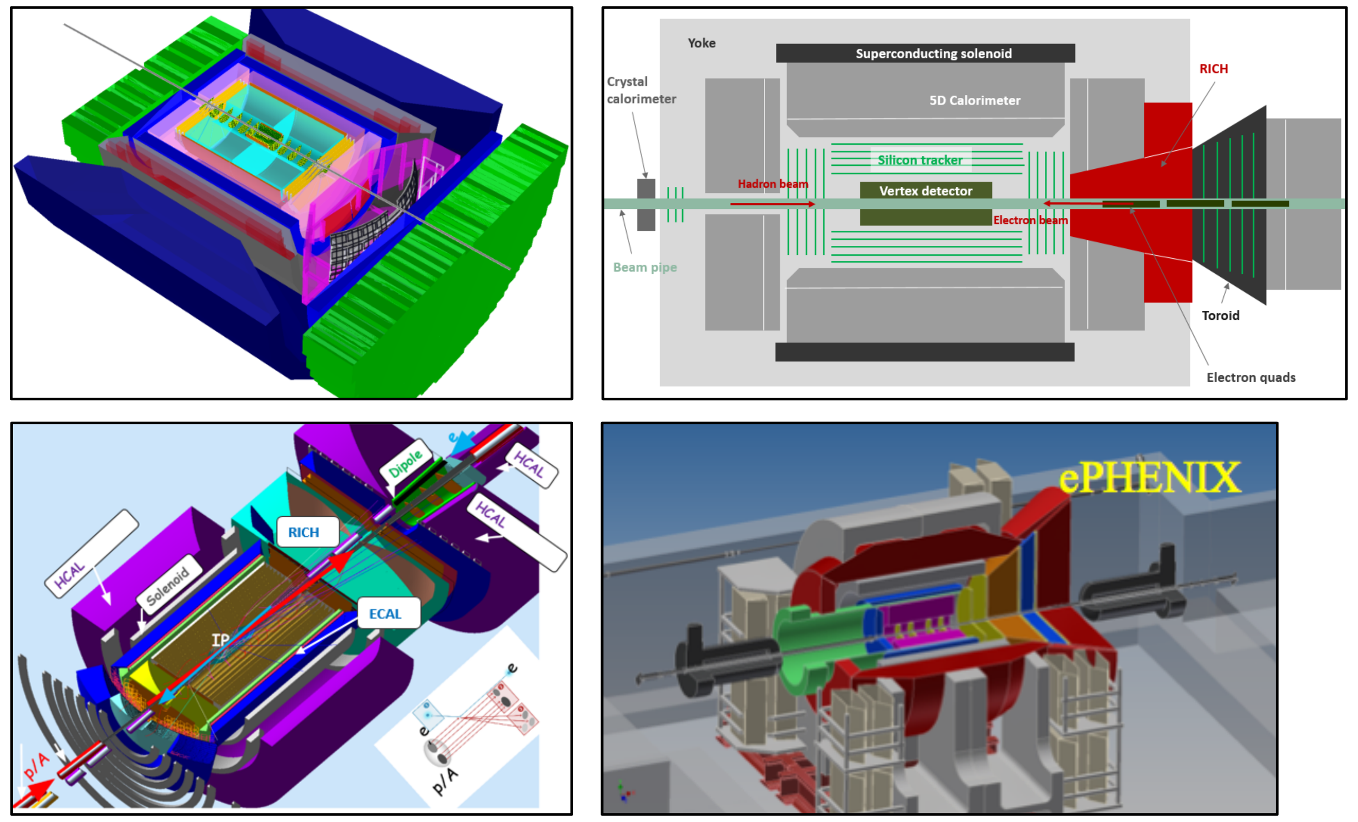


Big Questions & Physics Case

White Paper 2012 & NAS Report



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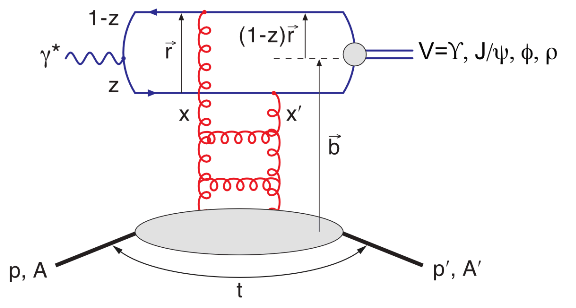
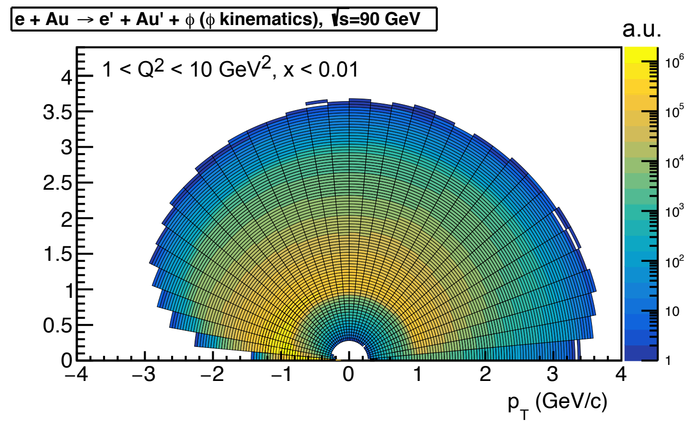
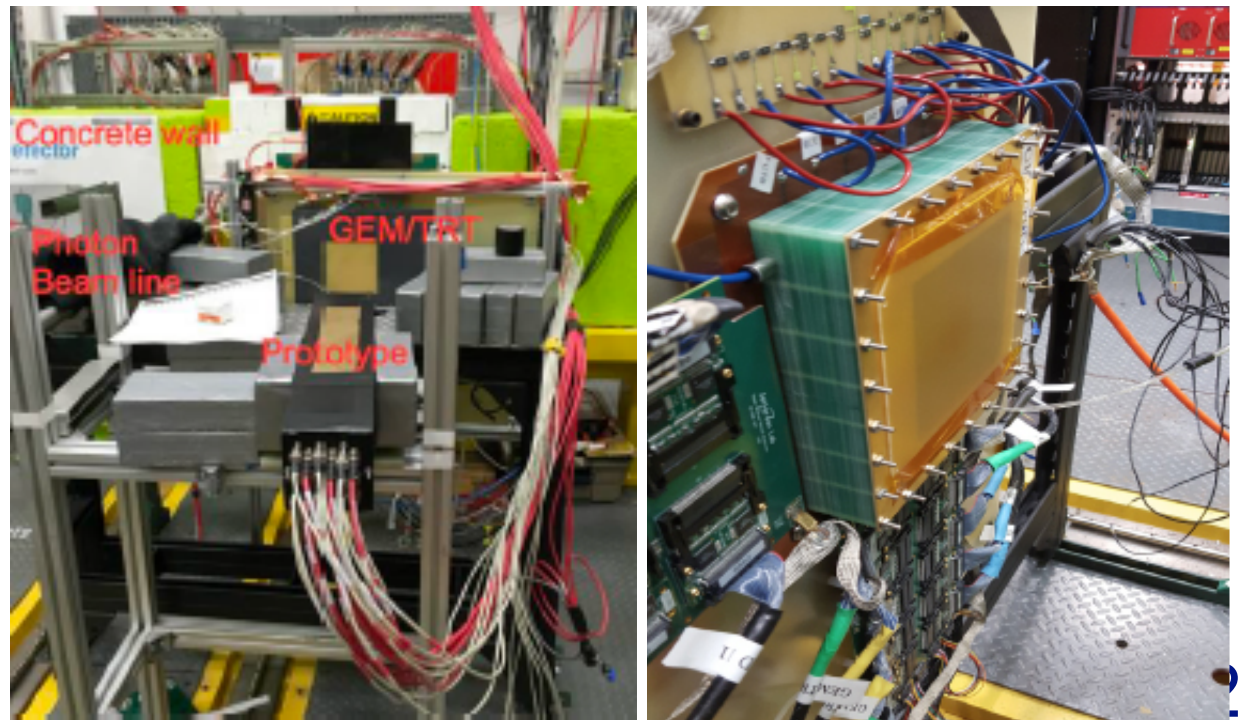




Detailed Detector Requirements & Concepts

Mature Detector Design

R&D, Prototypes



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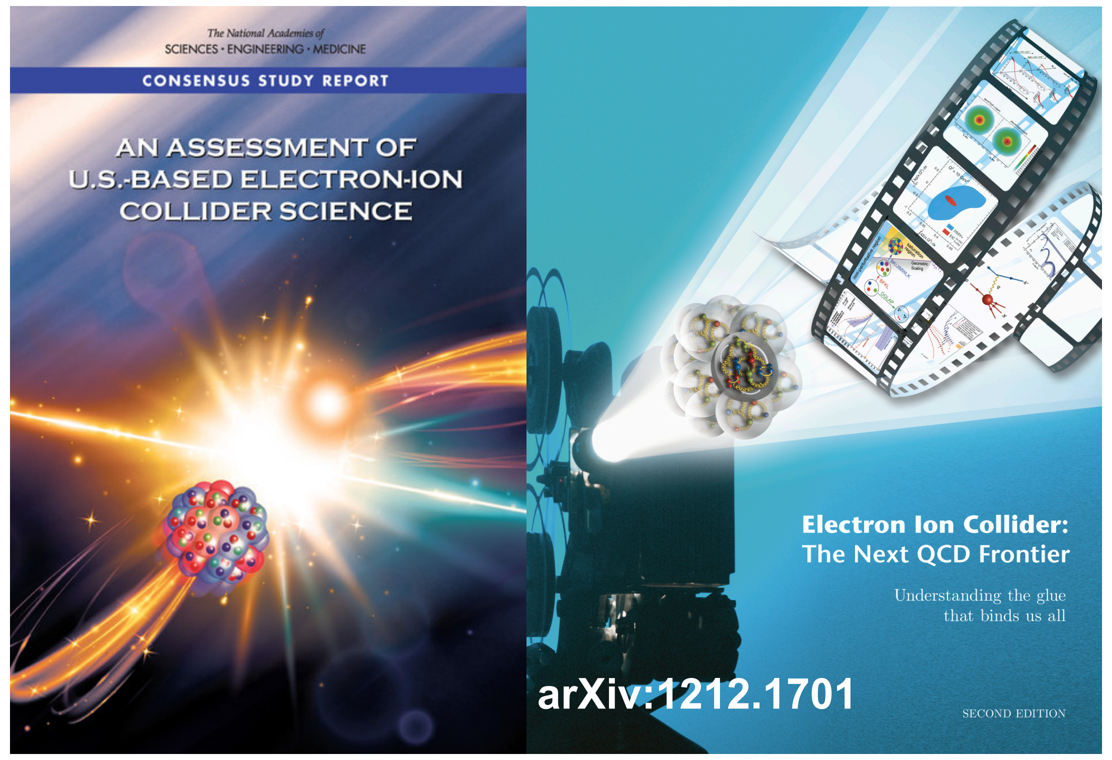

Big Questions &
Physics Case
White Paper 2012 &
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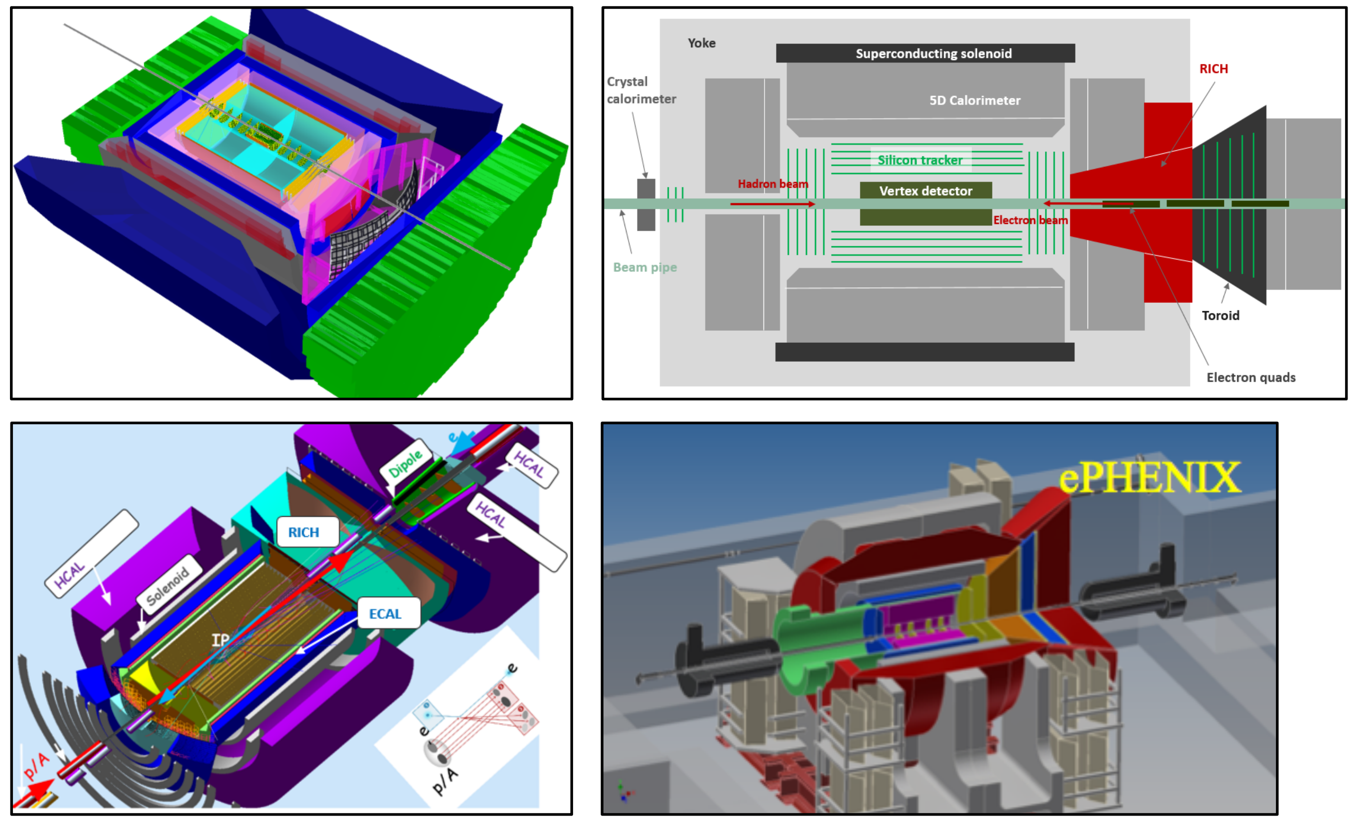
EIC User Group
(formal since 2016)



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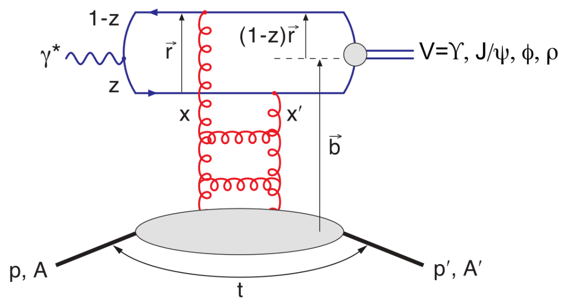
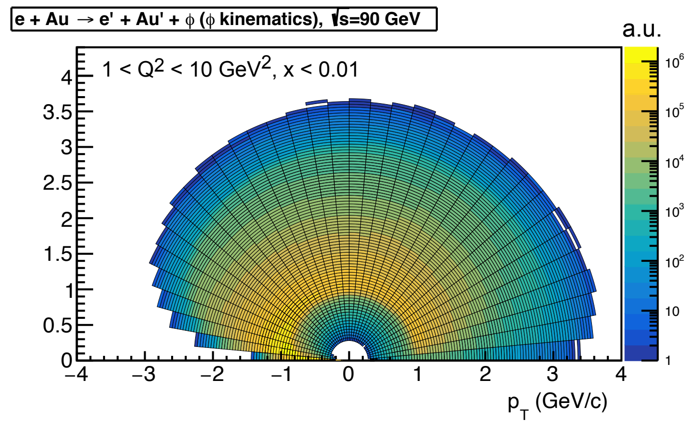
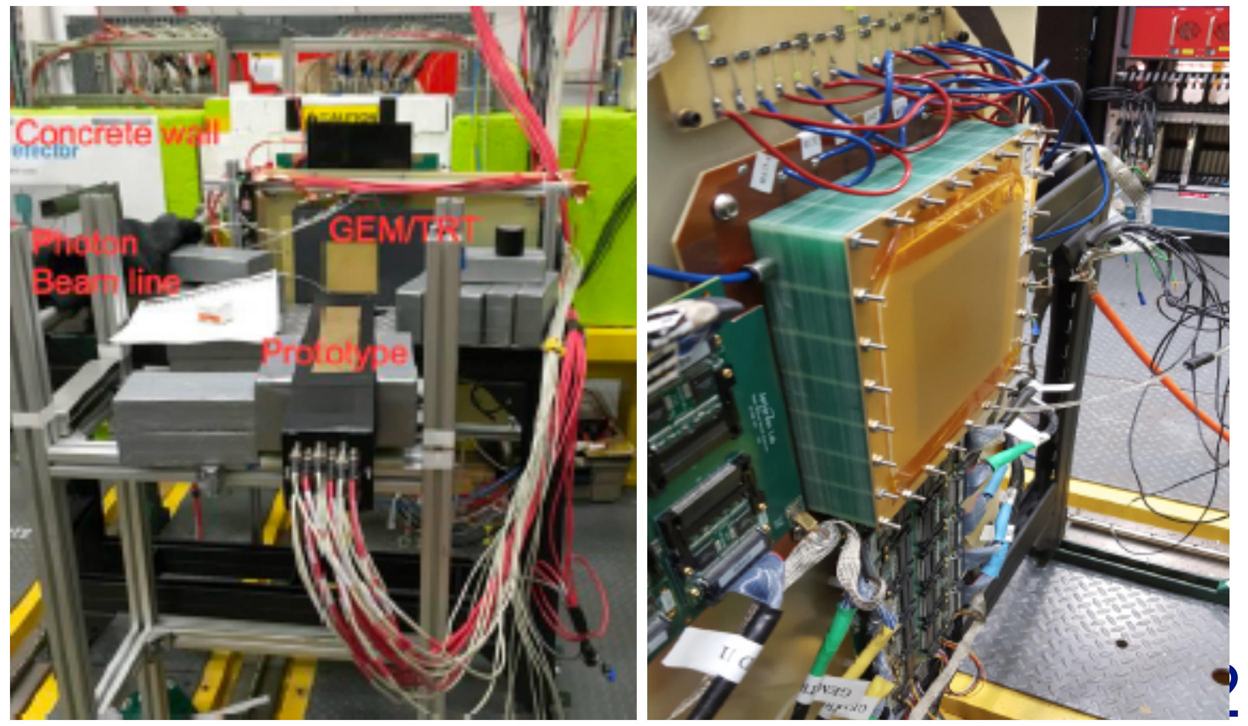




Detailed Detector
Requirements &
Concepts

Mature Detector
Design

R&D,
Prototypes



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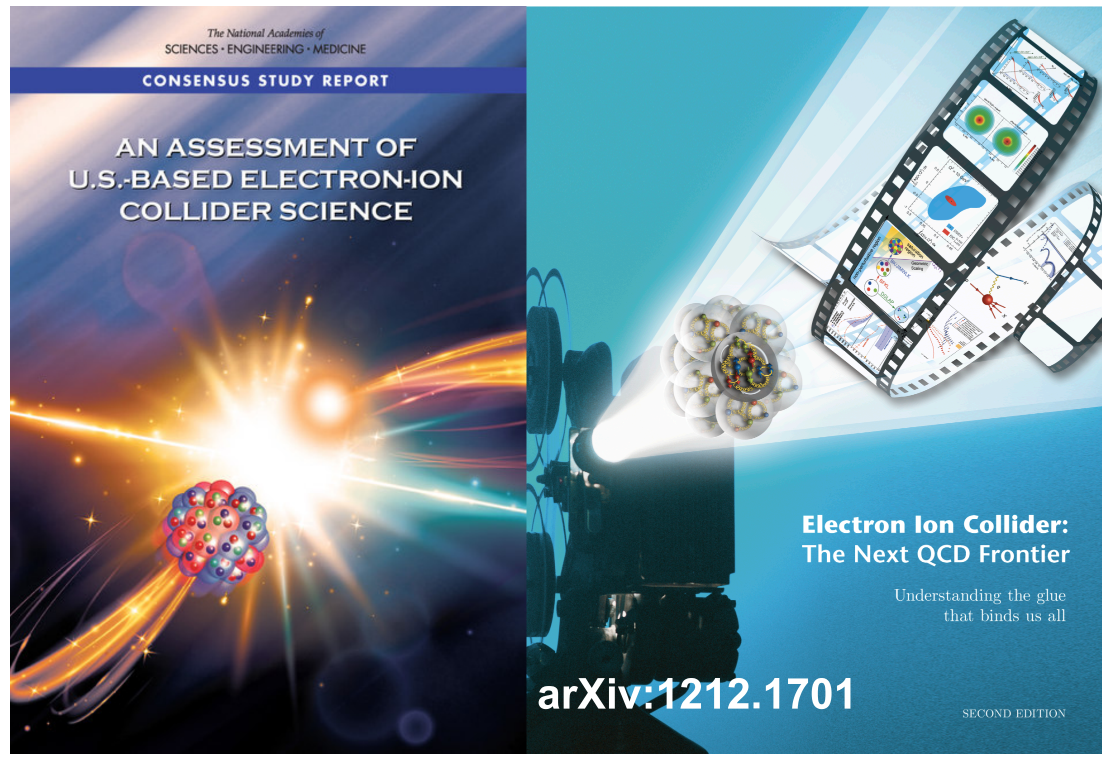

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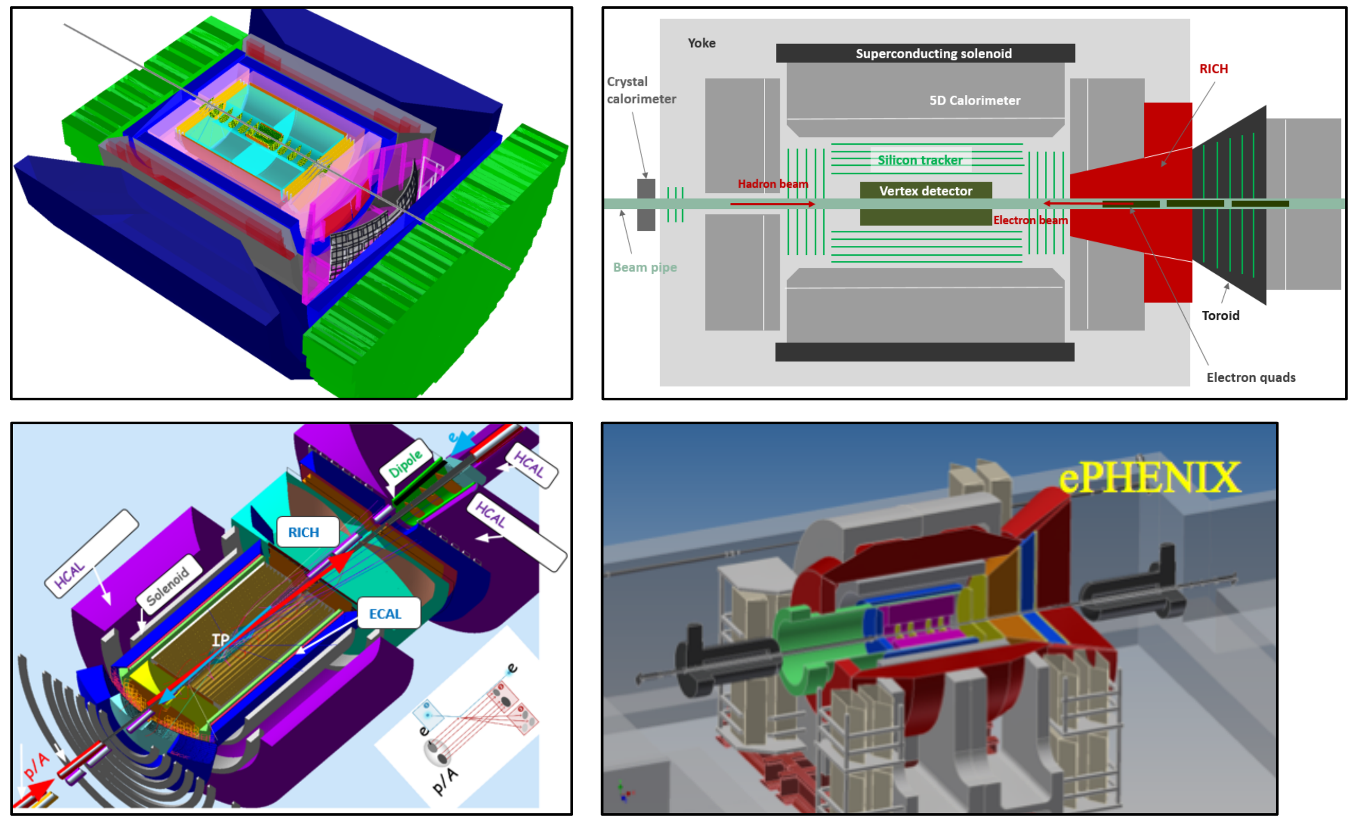
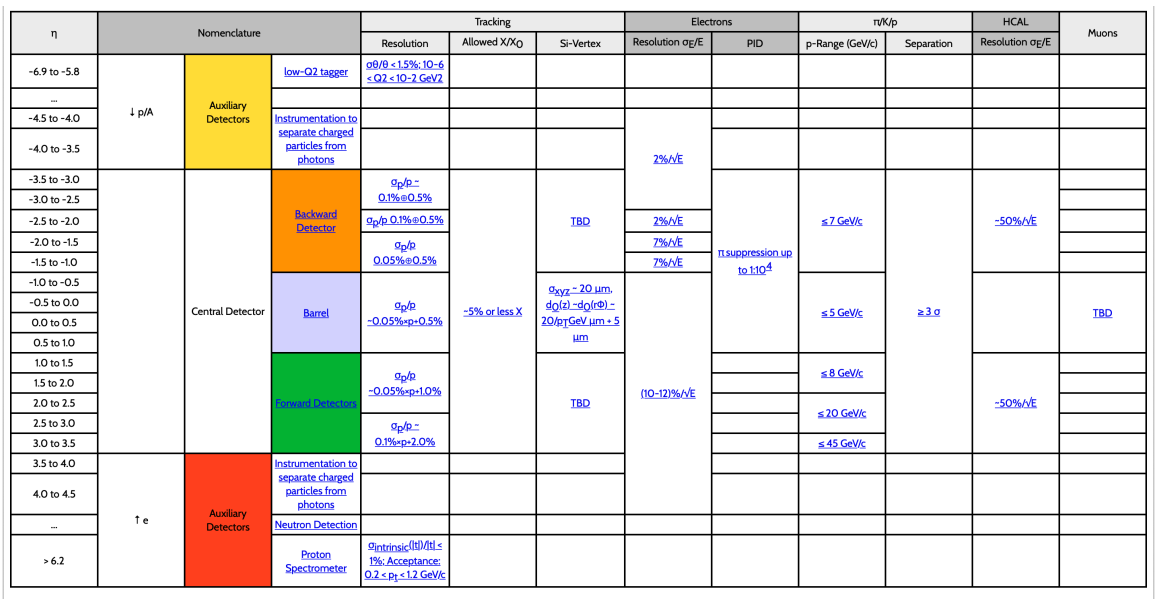


First Detector Ideas & Concepts



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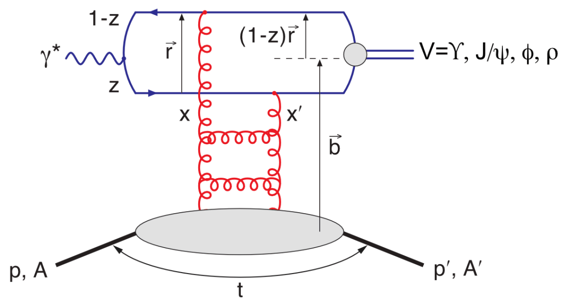
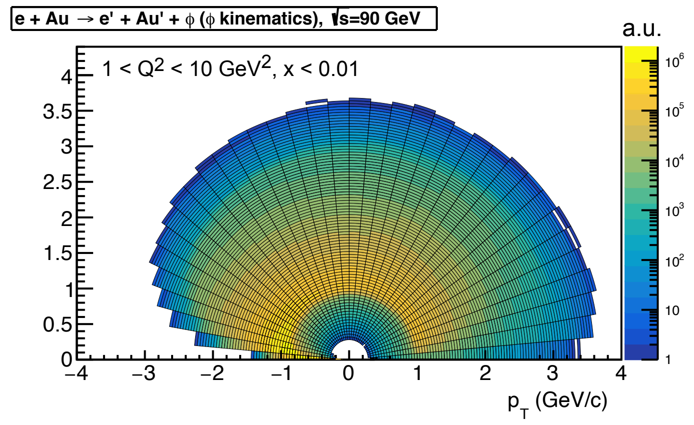


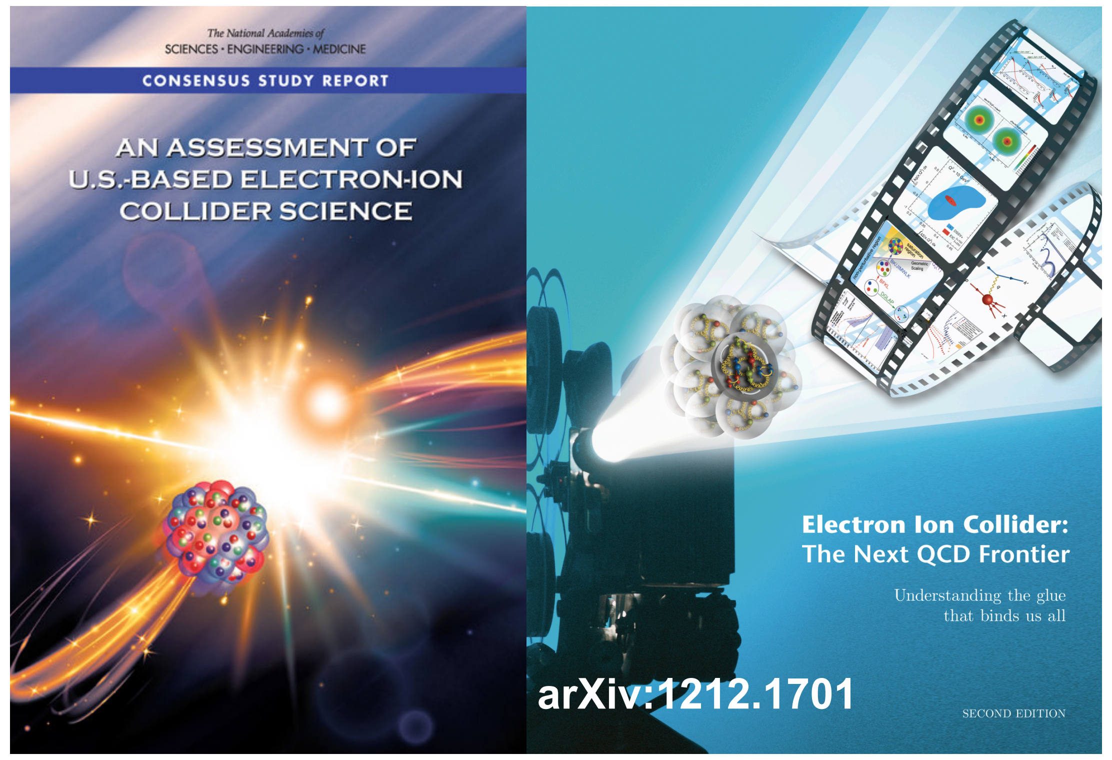


Mature Detector Design

EIC Detector R&D Program (> 2011)

R&D, Prototypes

The Long Path to EIC Detectors



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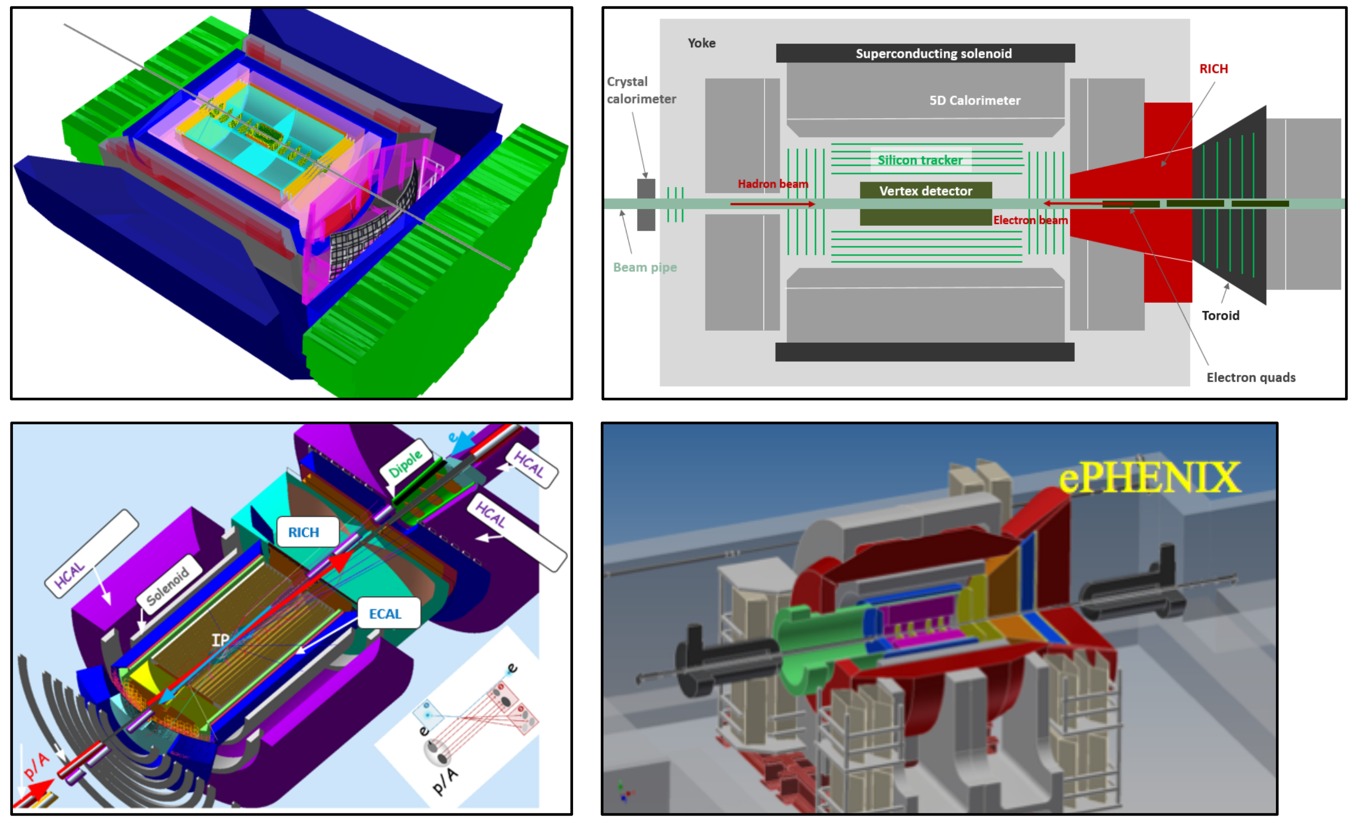


First Detector Ideas & Concepts

Yellow Report Initiative (2020)

Detailed Detector Requirements & Concepts

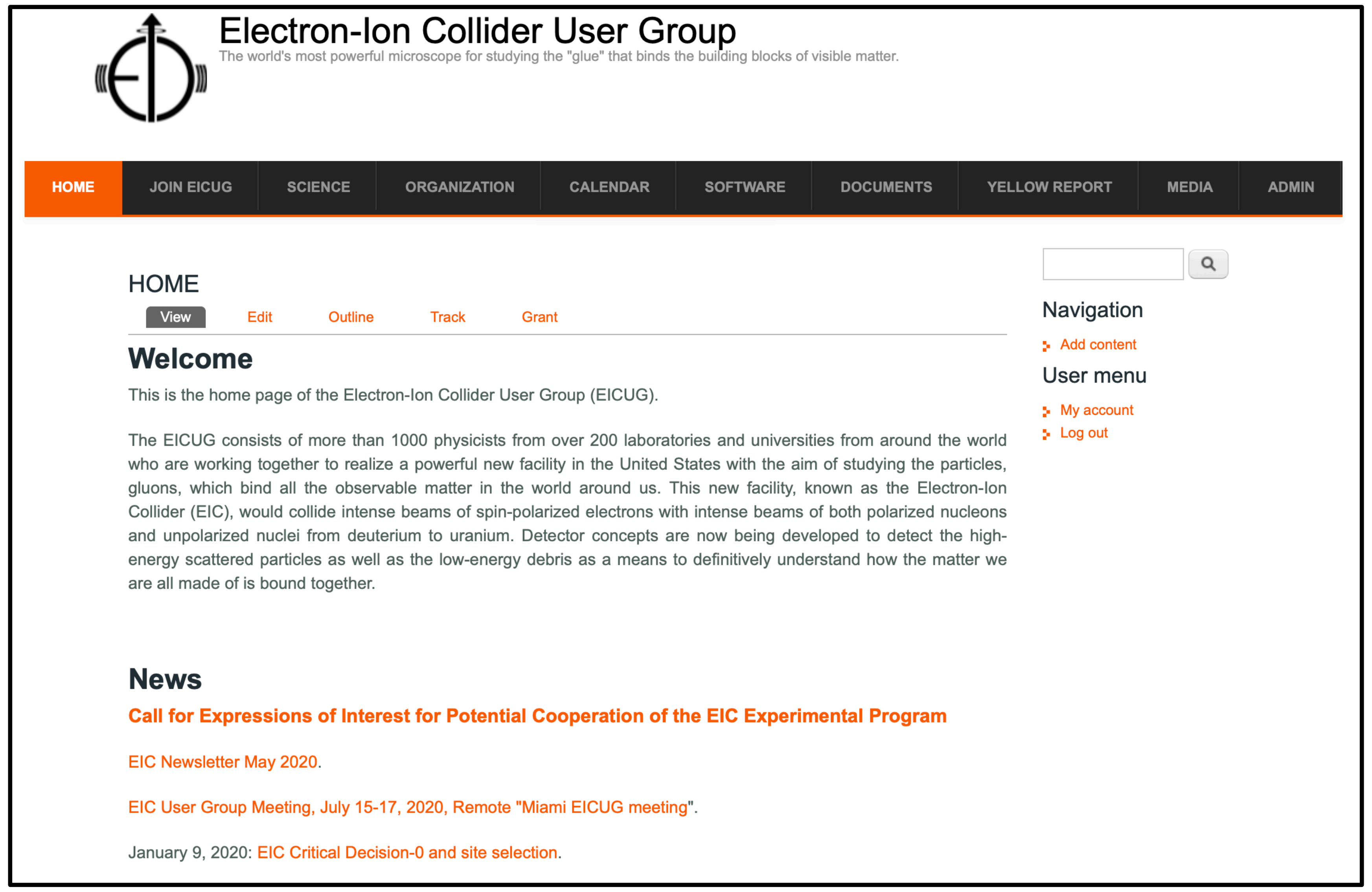
Mature Detector Design

EIC Detector R&D Program (> 2011)

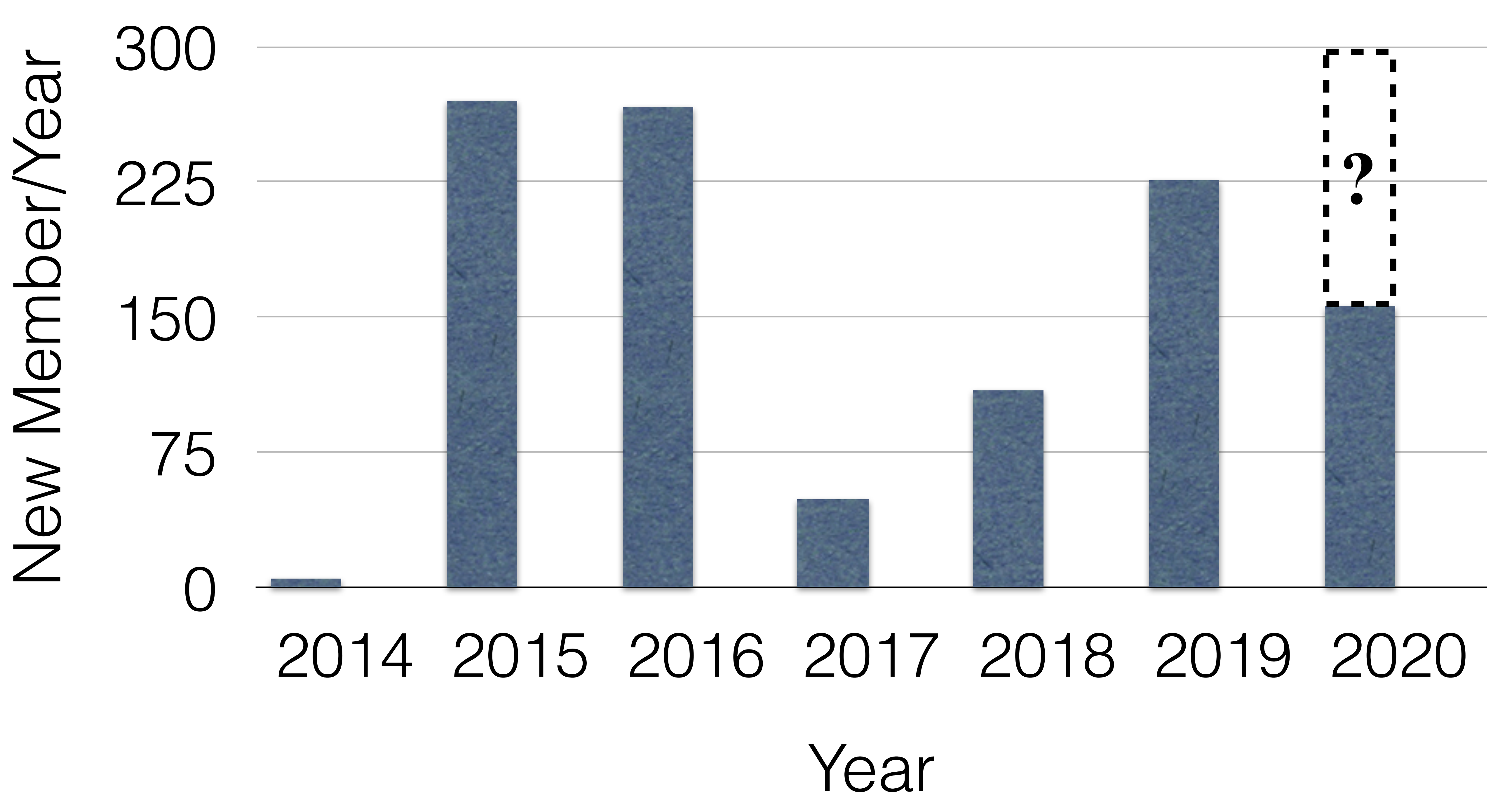
R&D, Prototypes

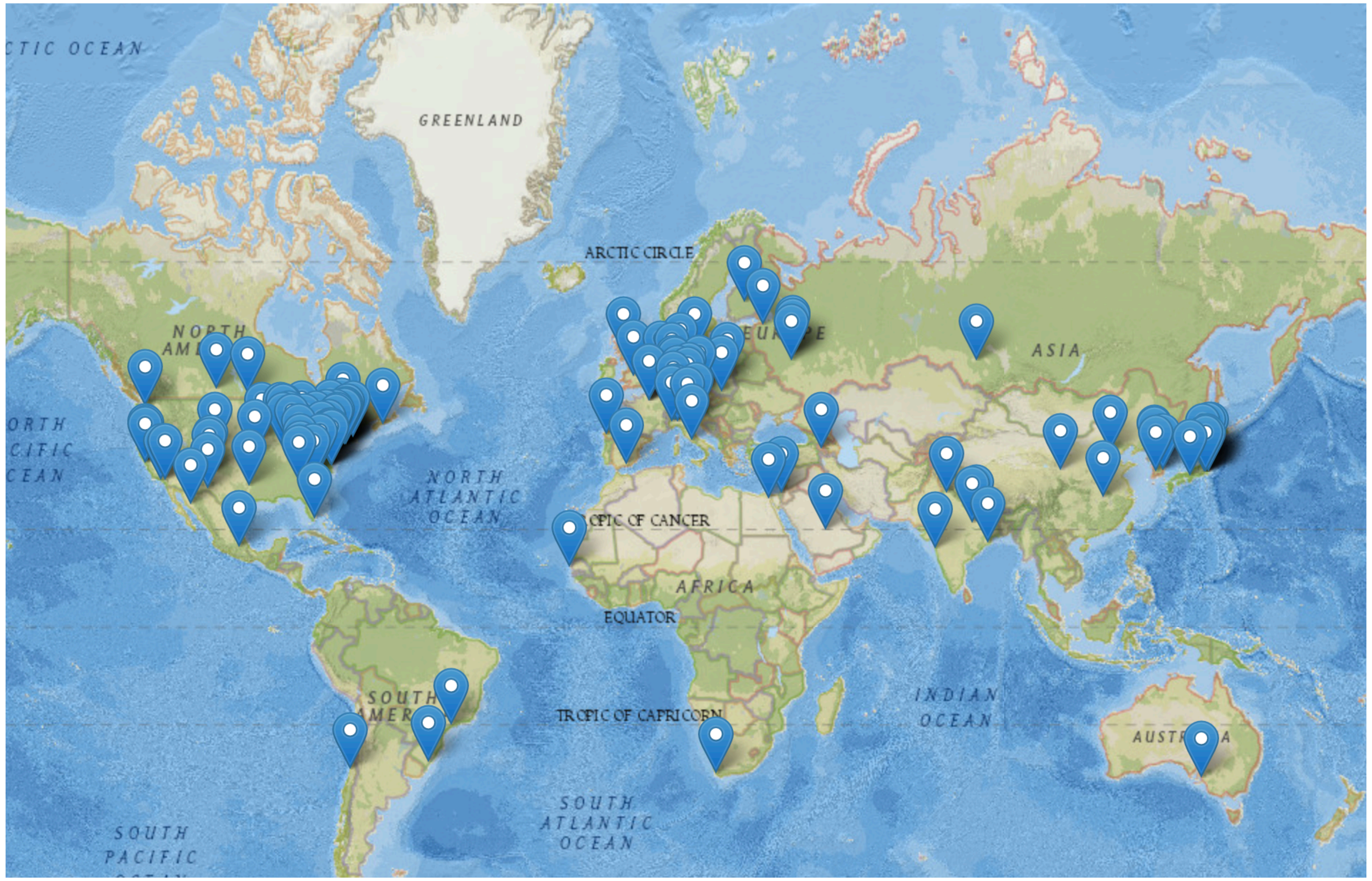
EIC User Group

- Involved community collaborating on EIC issues since early 2000
  - Focussed around “QCD Community” BNL & JLab and few universities
  - Substantial boosts in interest around 2007 & 2015 NSAC Long Range Plans
- First “User Meeting” at in Stony Brook, June 2014 (161 participants)
- Formation of a formal EIC User Group in 2014/2015
  - Charter approved June 2016
  - Institutional Board
  - Steering Committee
  - http://eicug.org
  - Organization of user meetings, newsletter, talks committees, working groups



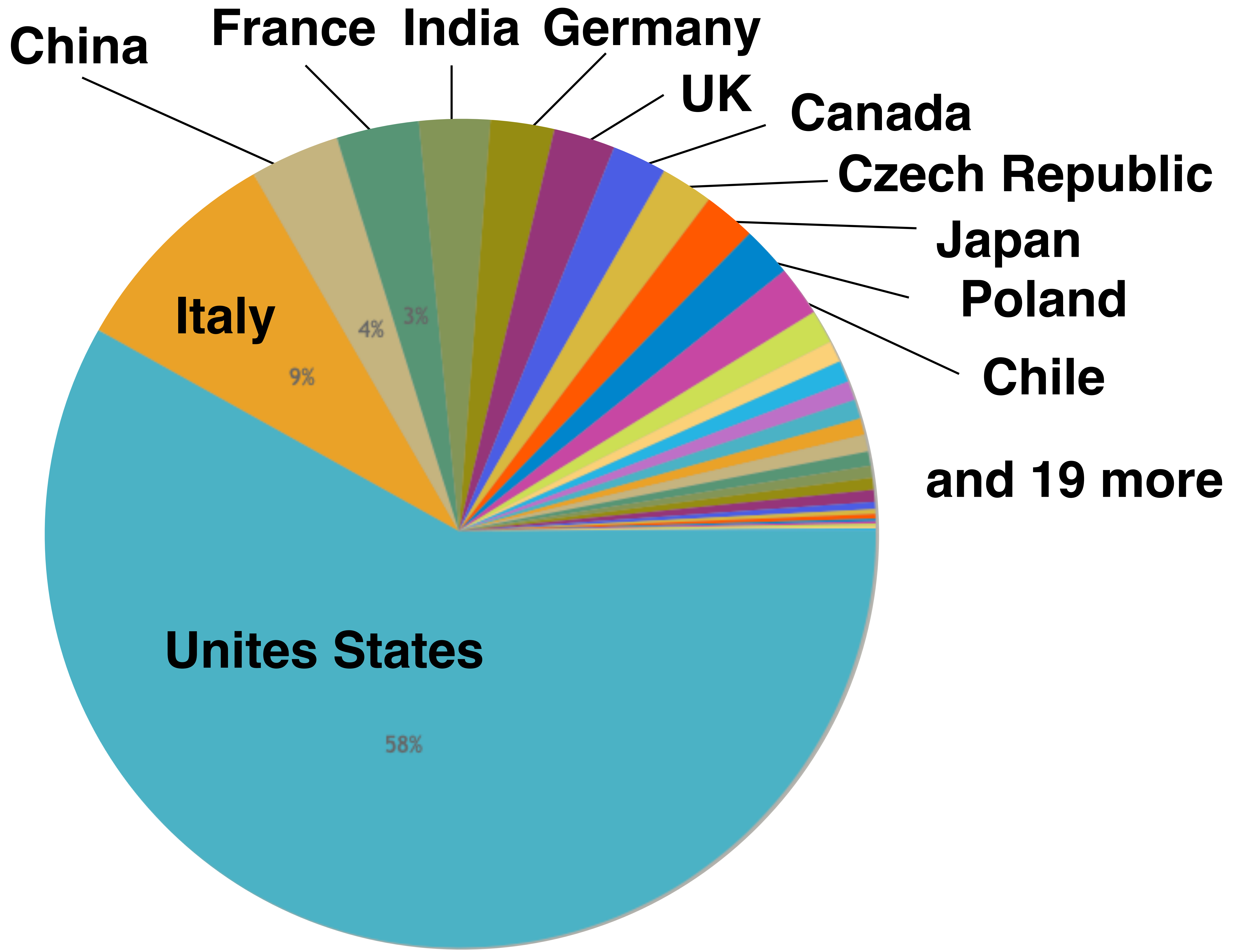
EIC User Group in Numbers and Graphs





- 1081 members (252 JLab)
- 224 institutions
- 31 countries
- 60% experimentalists
- 25% theorists
- 14% accelerator scientists
- 1% administration, computing

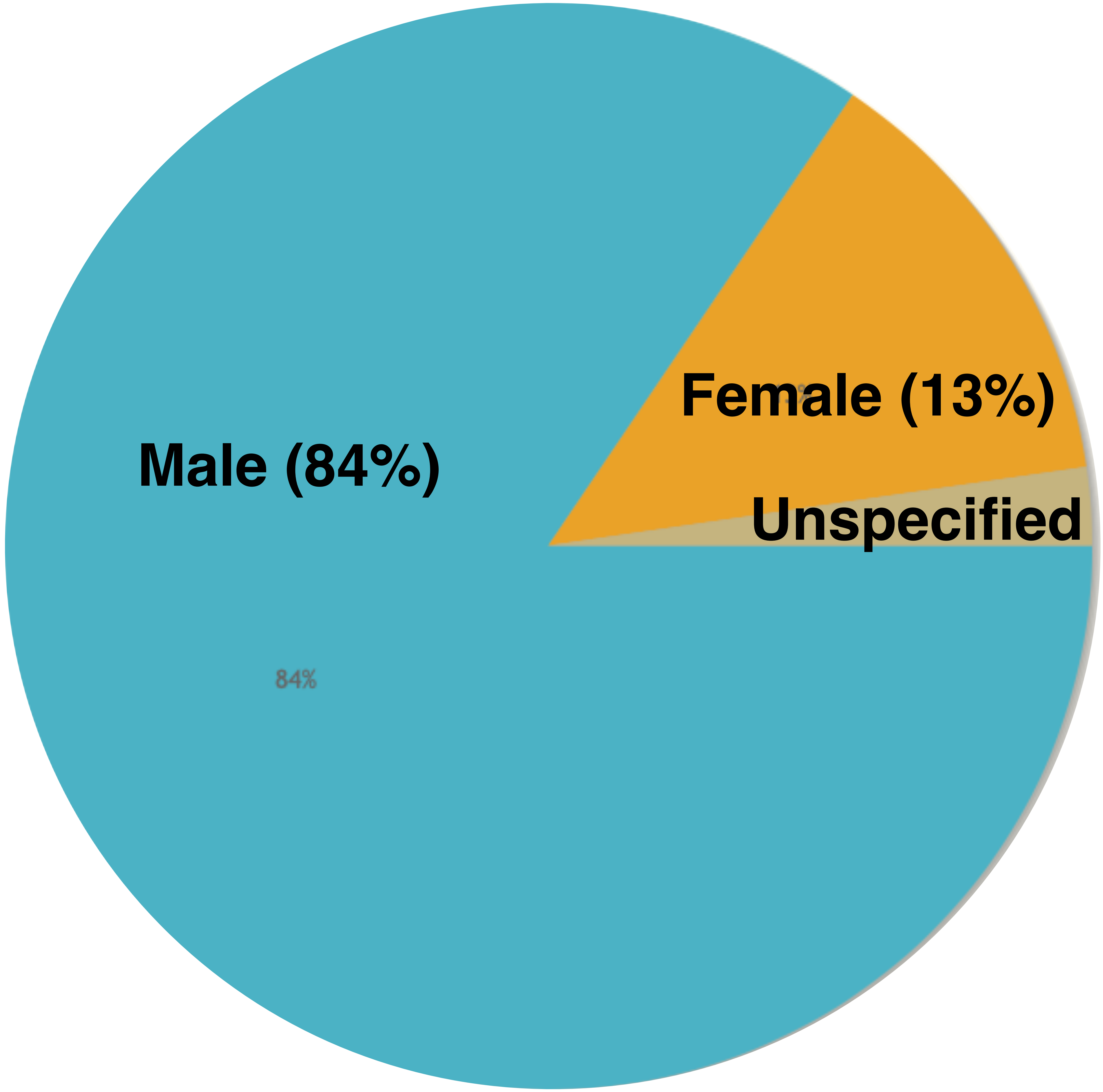
EIC User Group is International

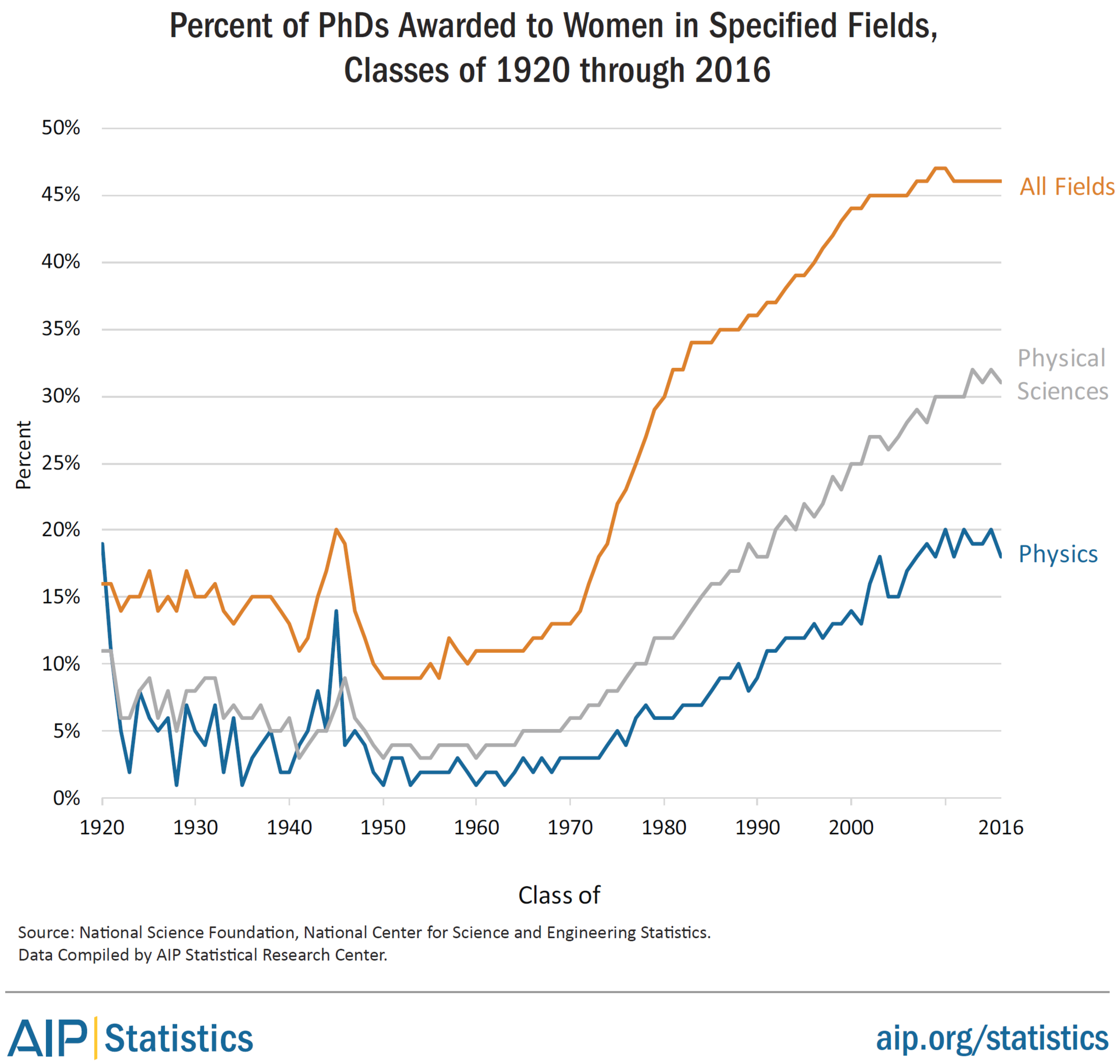


- N. America: 61%
- Europe: 26%
- Asia: 10%
- S. America: 2.5%
- Oceania: 0.8%
- Africa: 0.5%

Interesting Comparison:
~25% US participants in large LHC collaborations
- 20% in ATLAS
- 30% in CMS

Still work to do …





20%

- Behind the curve!

Current Activities

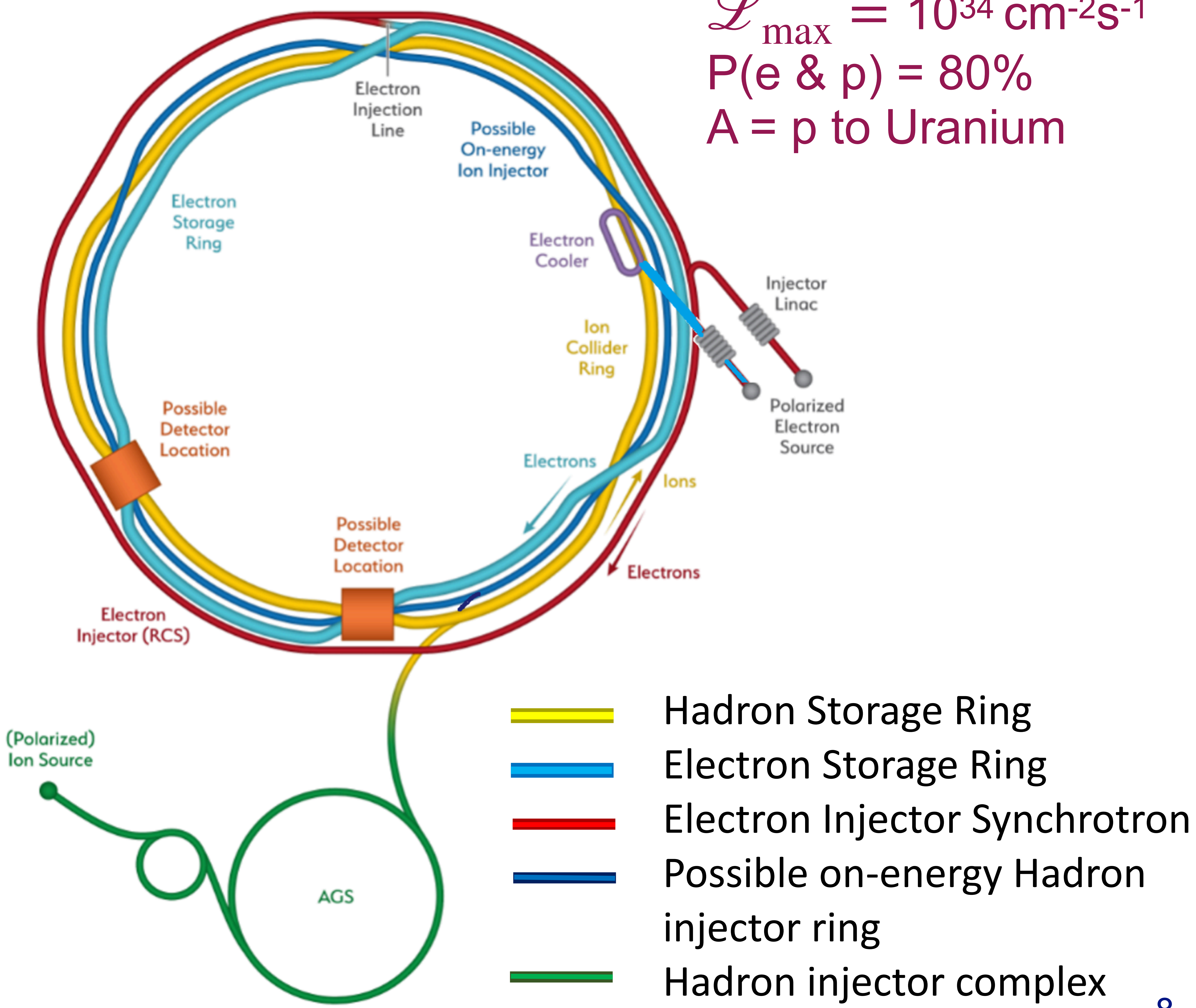
- Yellow Report Initiative (later)
- New charter
  - require new charter after CD-0/CD-1 (phase II/III)
  - charter writing committee in place
- Elections
  - International Representative on the EICUG Steering Committee
- Coordination of EIC efforts at Snowmass 2021
  - In-depth process by U.S. particle physics community to define the most important questions for our field and to identify the most promising opportunities to address these questions in a global context.
  - Coordinate with EIC community and Snowmass WGs
- Next EIC User Meeting July 15-17, 2020 (remote)
  - https://indico.bnl.gov/event/7352/

EIC Machine Overview

EIC design will meet NSAC and NAS requirements

$\sqrt{s}$ = 20 – 141 GeV
$\mathscr{L}_{max}$ = 10^{34} $cm^{-2}s^{-1}$
P(e & p) = 80%
A = p to Uranium

- Design using much of existing RHIC facility
- 3 accelerator rings:
  - Existing RHIC yellow ring (275 GeV)
  - New Rapid Cycling electron Synchrotron (18 GeV)
  - New Electron Storage Ring (18 GeV)
- 2 injector complexes:
  - Hadron injectors (existing)
  - Electron Injectors
- 2 detector halls
- Hadron Cooling Facility



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- Design u
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- 3 accele
  - Existin
  - New R
    Synchr
  - New El
- 2 injecto
  - Hadron
  - Electro
- 2 detector halls
- Hadron Cooling Facility

EIC: Not Your Standard Collider Setup

Constraining IR features, asymmetric beam energies, synchrotron backgrounds, crossing angle, and wide range of energies impact detector acceptance and detector technologies considerably

orage Ring

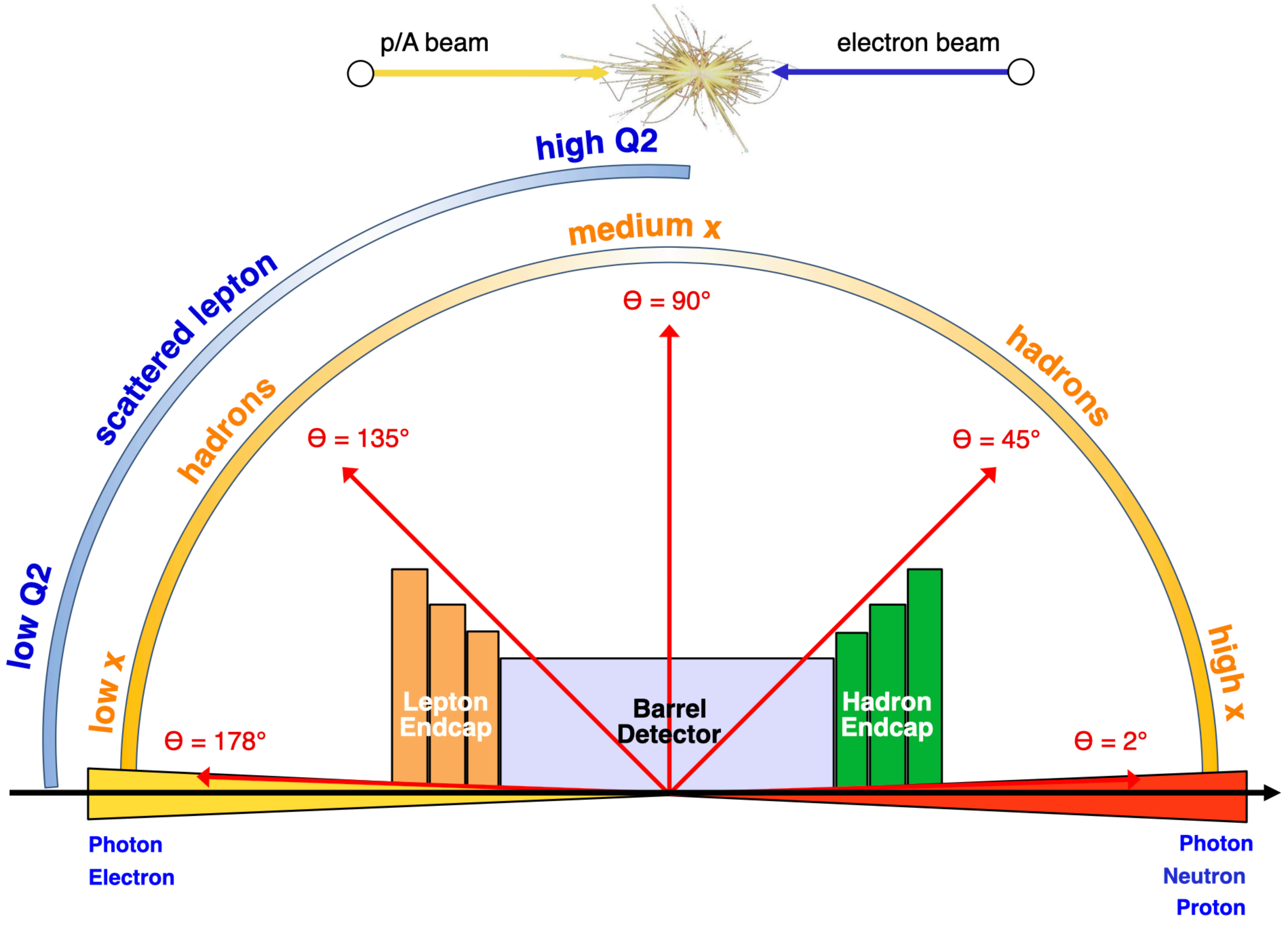
torage Ring

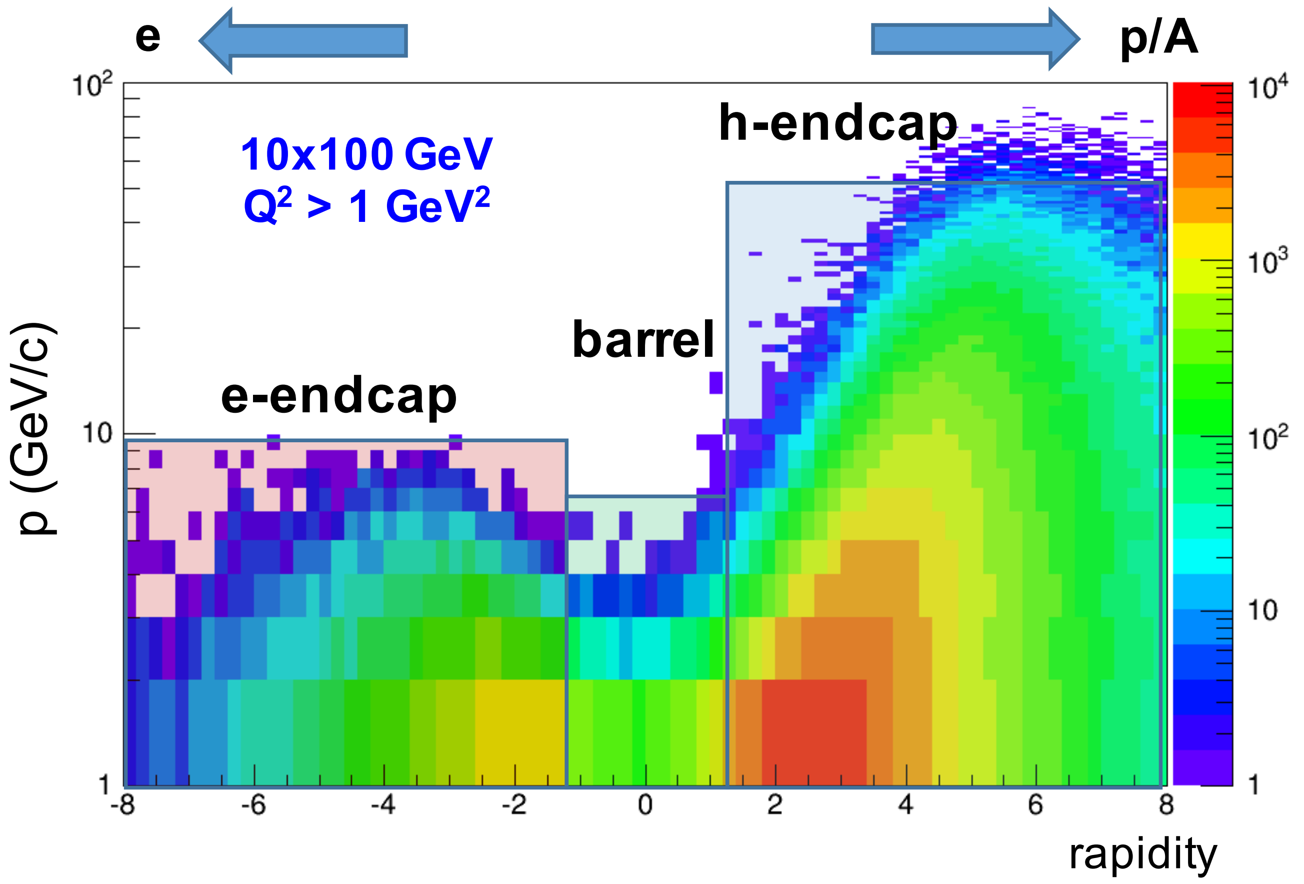
Electron Injector Synchrotron

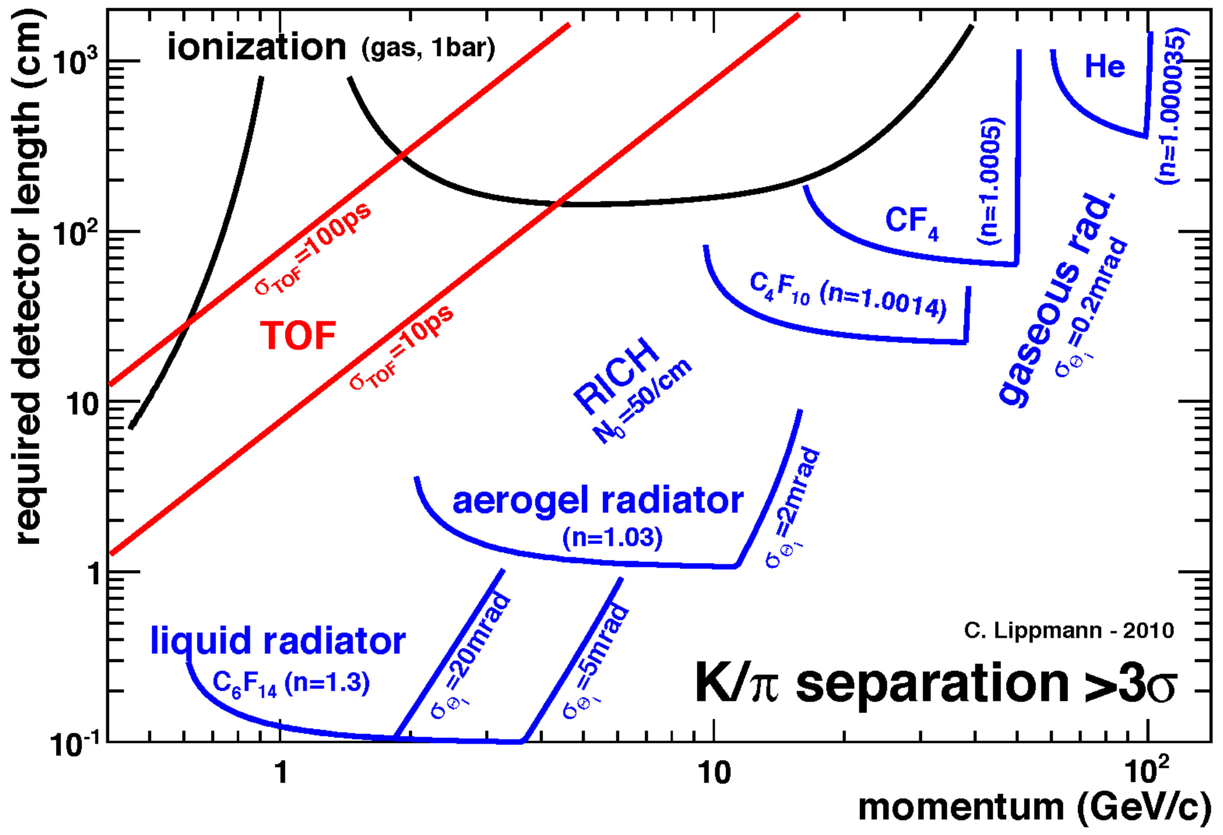
Possible on-energy Hadron injector ring

Hadron injector complex

EIC Detectors Illustrated



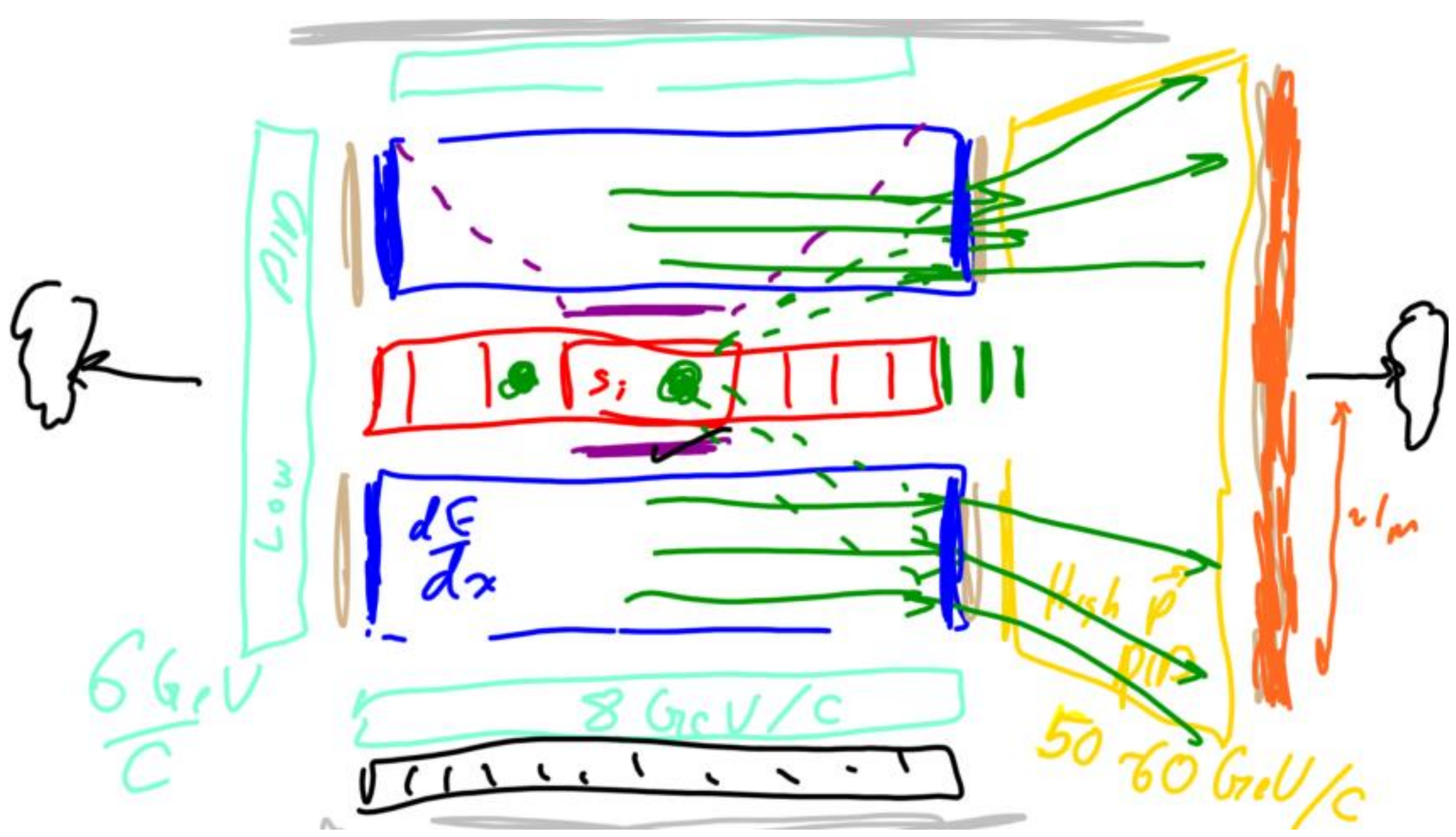


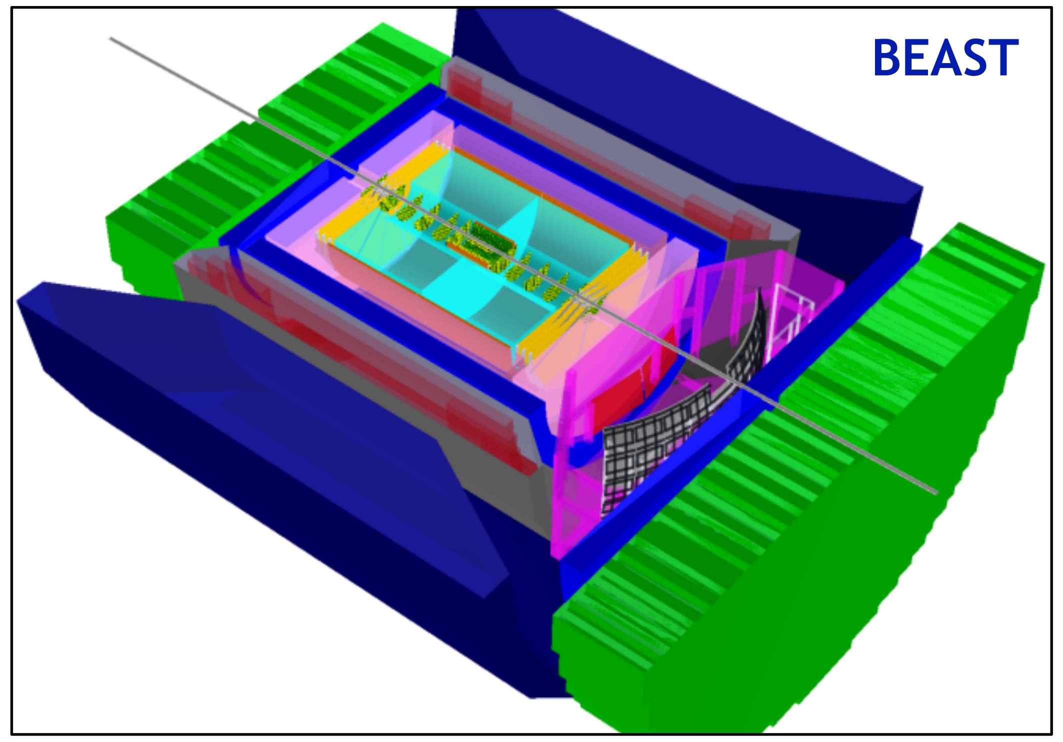


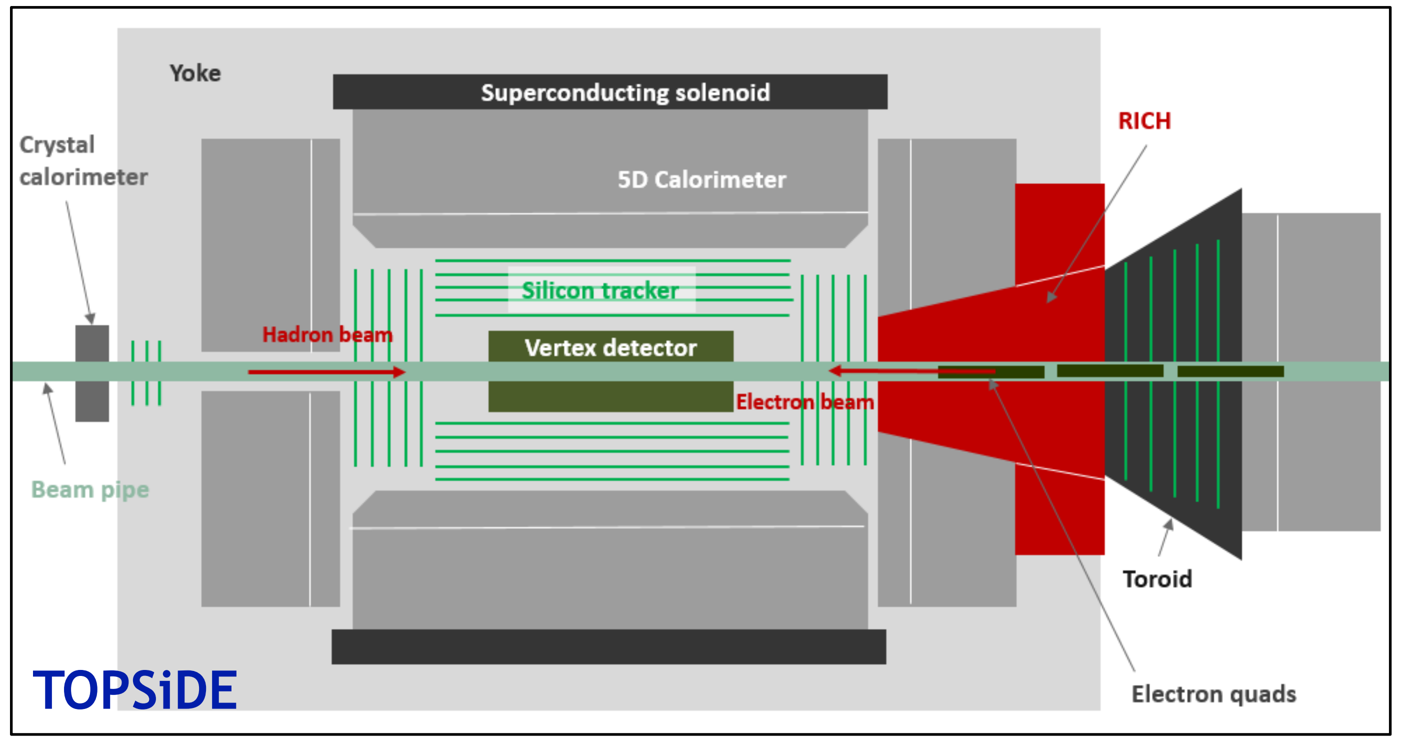
- Hermetic detector, low mass inner tracking
- Electron measurement & jets in wide rapidity range
- Good momentum resolution (x, Q^2)
- Good impact parameter resolution (heavy flavor)
- Excellent EM resolution, especially e-going direction
- Good hadronic energy resolution in h-going direction
- Excellent PID π/K/p
  - Forward: up to 50 GeV/c
  - Central: up to 7 GeV/c
  - Backward: up to 8 GeV/c

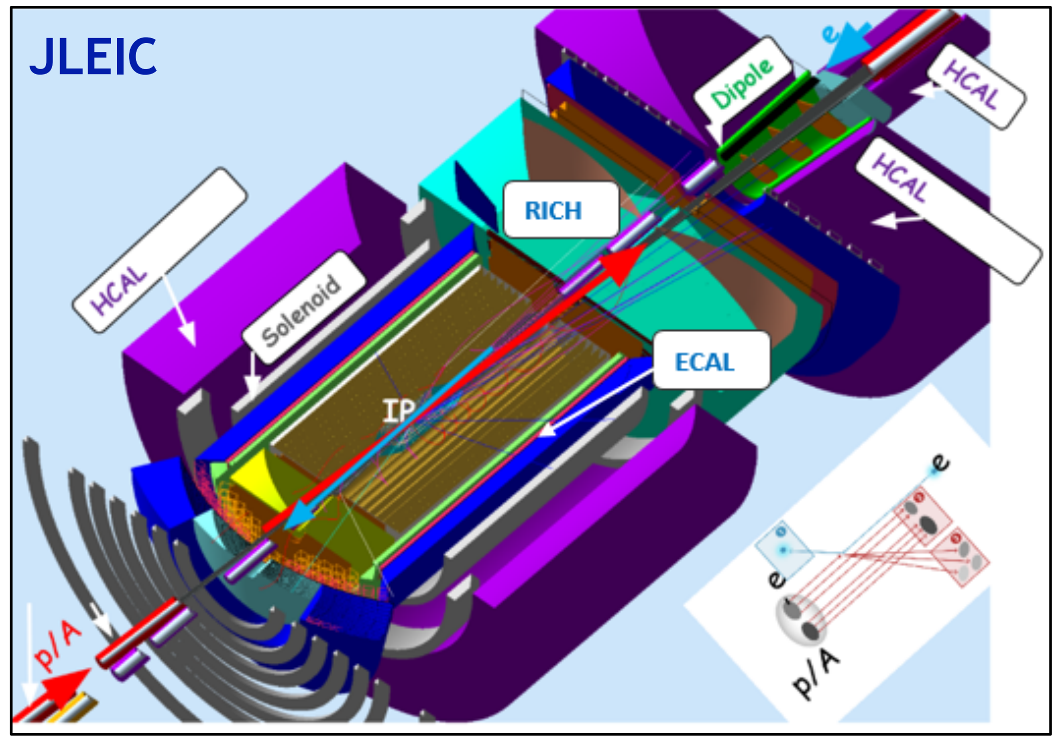
Vital: Early Generic EIC Detector Concepts

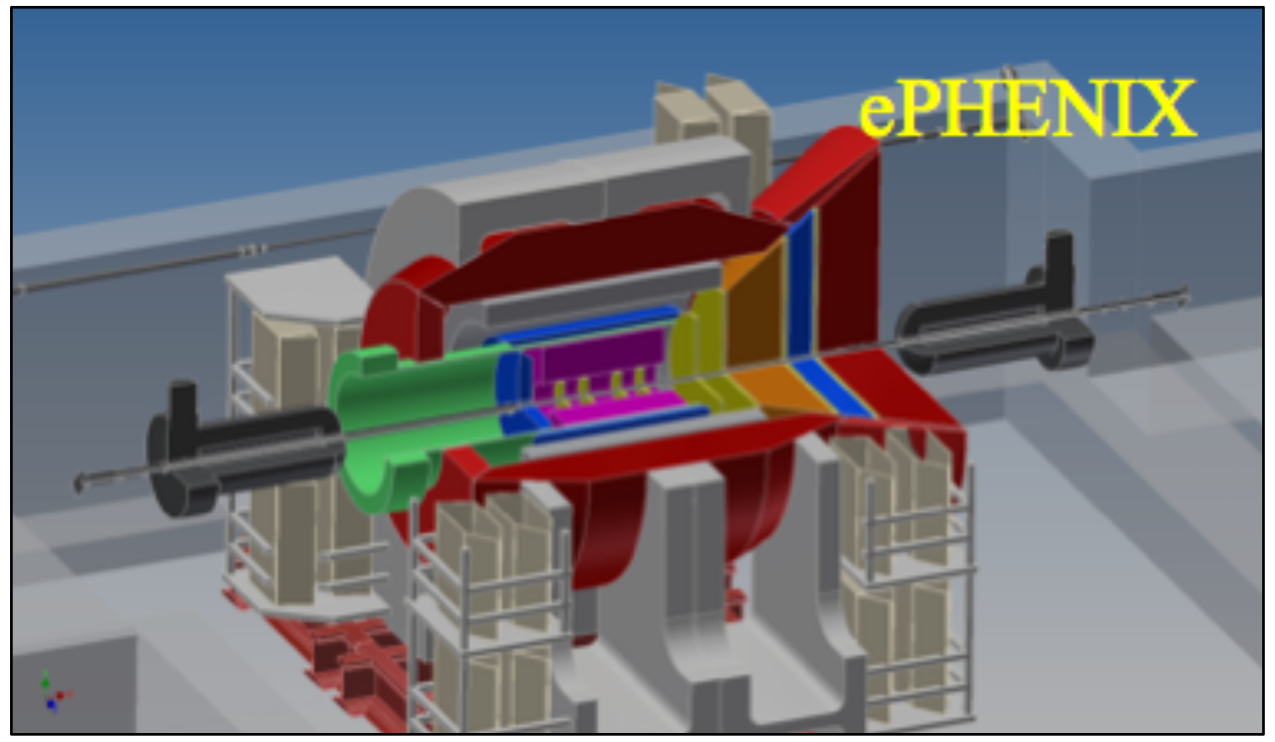
Courtesy eRD6











- Early concepts indicate
  - first feasibility test of measurements
  - estimate of achievable resolutions (and shortcomings)
  - mass distribution - hints were minimizing X/X_0 is needed
  - available space for subsystems
  - the need for R&D

Generic EIC Detector R&D Program

- Started 2011 in association with BNL, JLab and the DOE Office of NP
- Funded by DOE through RHIC operations funds
- Program explicitly open to international participation
- Standing EIC Detector Advisory Committee consisting of internationally recognized experts in detector technology

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

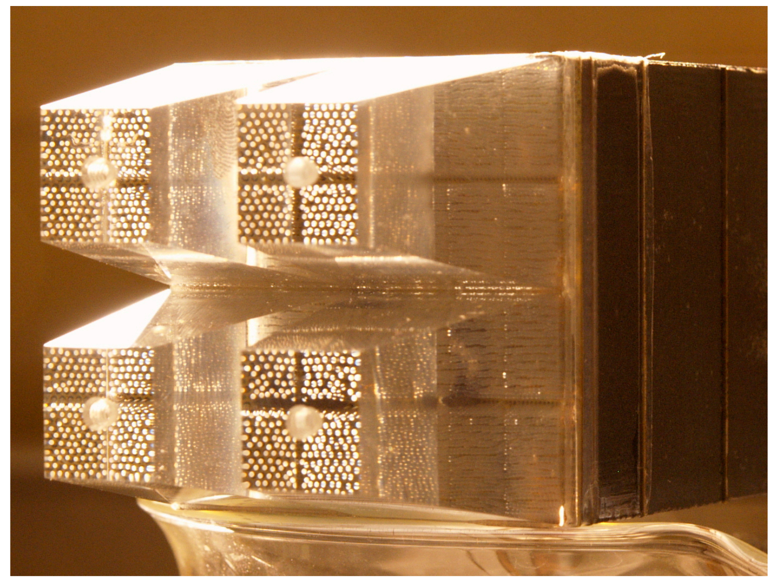
- Typical 10-11 projects supported per FY
- Consortia for Calorimetry, Tracking, PID
- Over 190 participants from 49 institutions (16 non-US)
  - not all are in the EICUG, e.g. colleagues from HEP

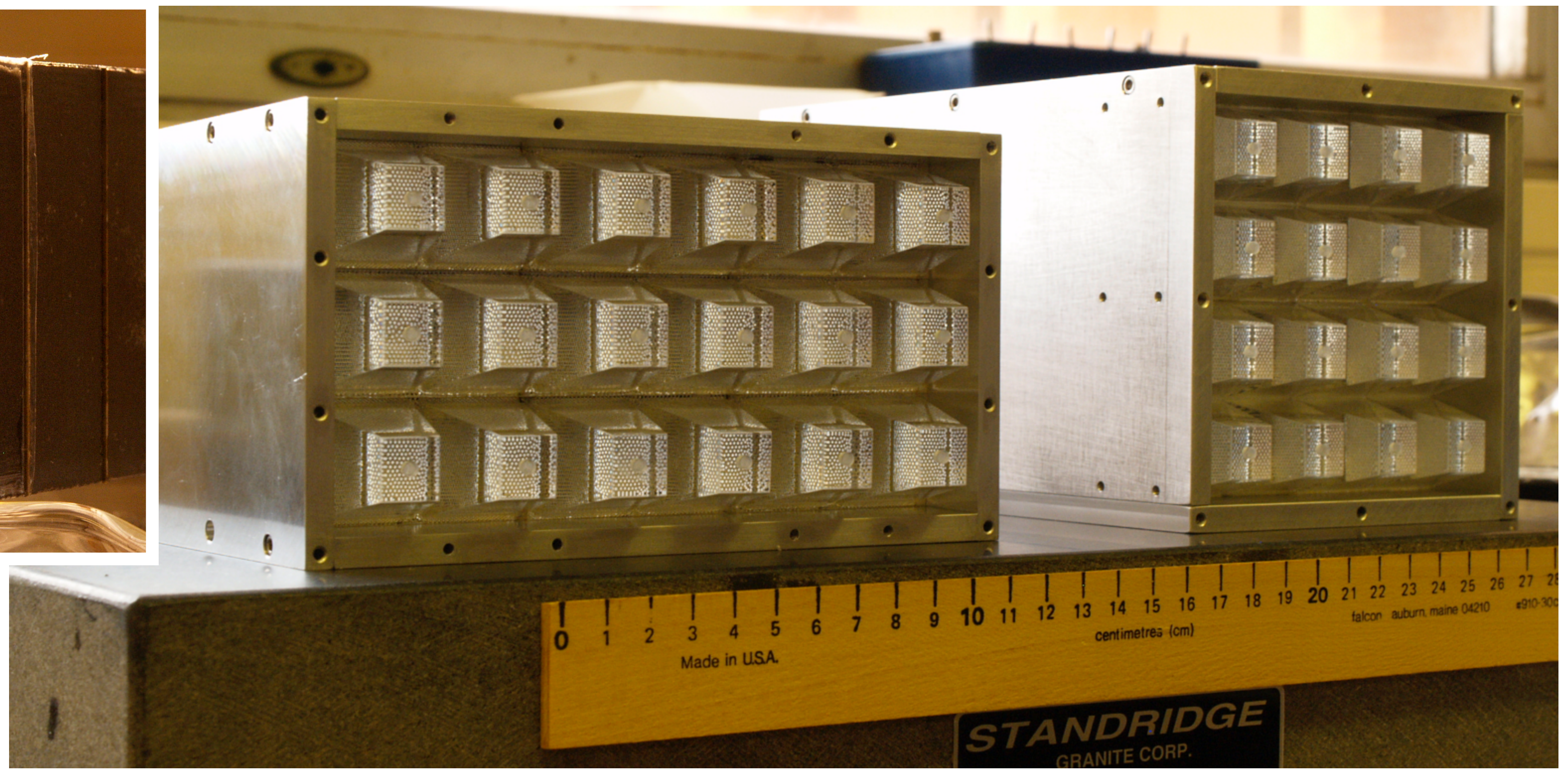
URL: https://wiki.bnl.gov/conferences/index.php/EIC_R%25D

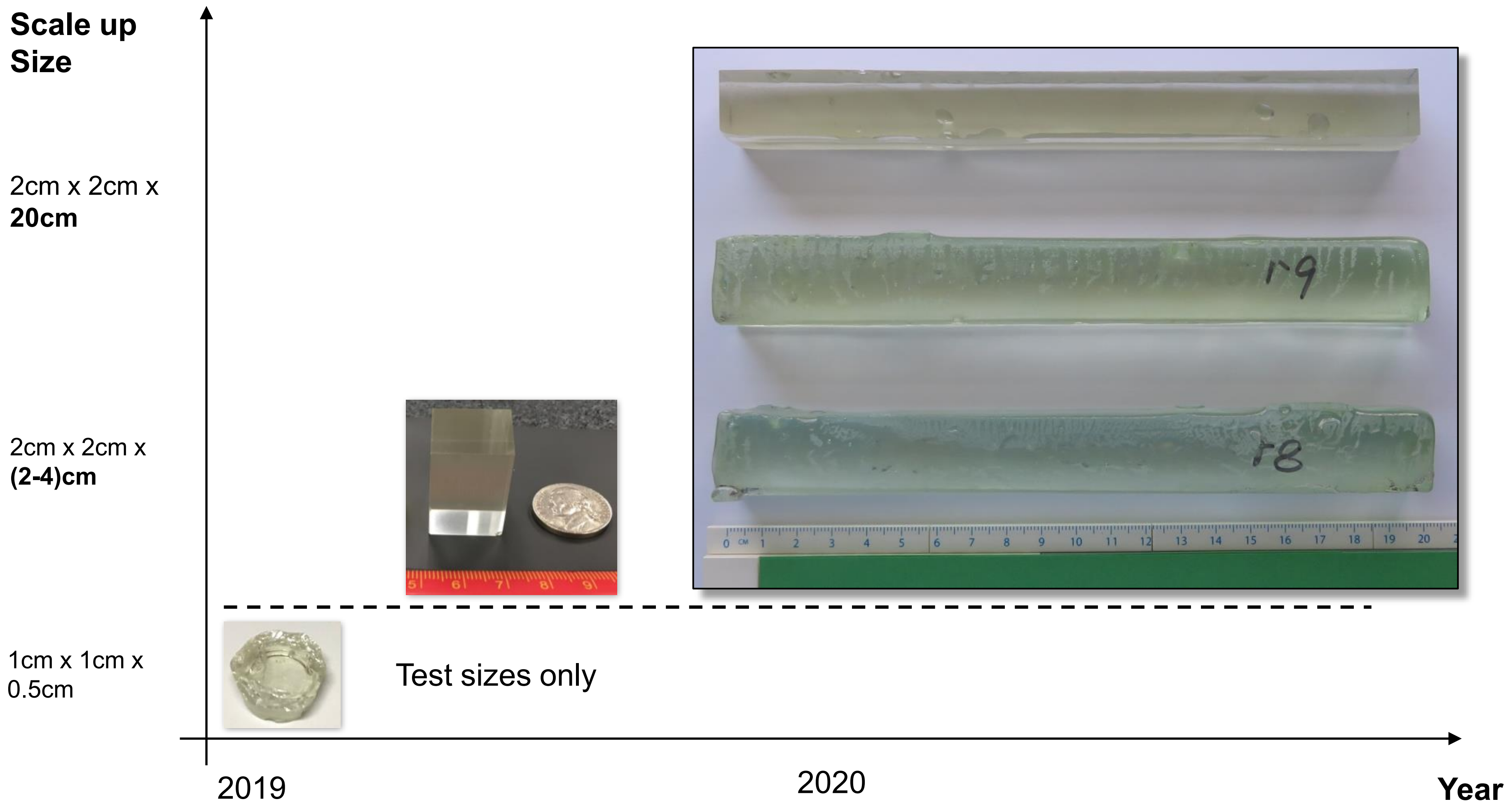
Examples: Calorimetry

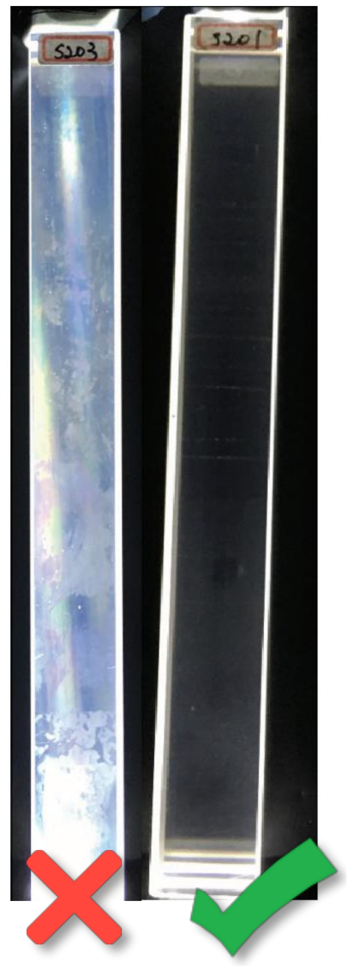
BNL, CalTech,CUA, JLab,, IU, UIUC, INFN Genova, IPN Orsay, UCLA, TAMU, UTFSM, MEPHI, Yerevan

- Scintillating fibers embedded in W-powder composite absorber, a.k.a W-SciFi
  - Development led to working prototypes with good energy & position resolutions that would result in a capable EM calorimeter for the barrel and hadron-going directions at an EIC
- Shashlik Calorimeters
- Lead Tungstate (PbWO4) crystals
- Scintillating Glasses
  - Similar to lead glass in many properties but exhibit >10× the light yield per GeV
  - Allows doping: Gd, Yb, Ce, …
  - Can now make reliably 20 cm bars
- Hadron Calorimetry (beginning)
- SiPM testing



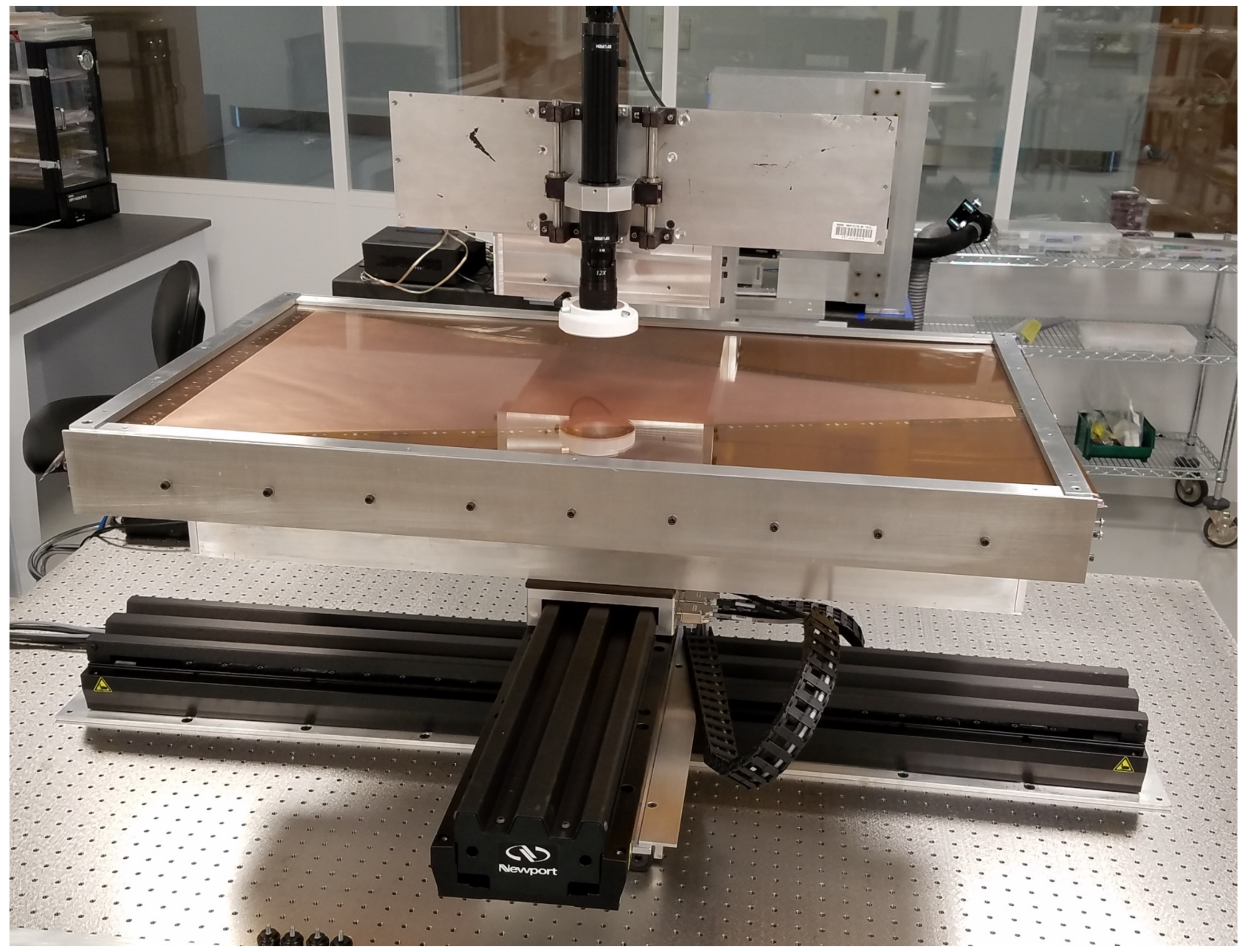




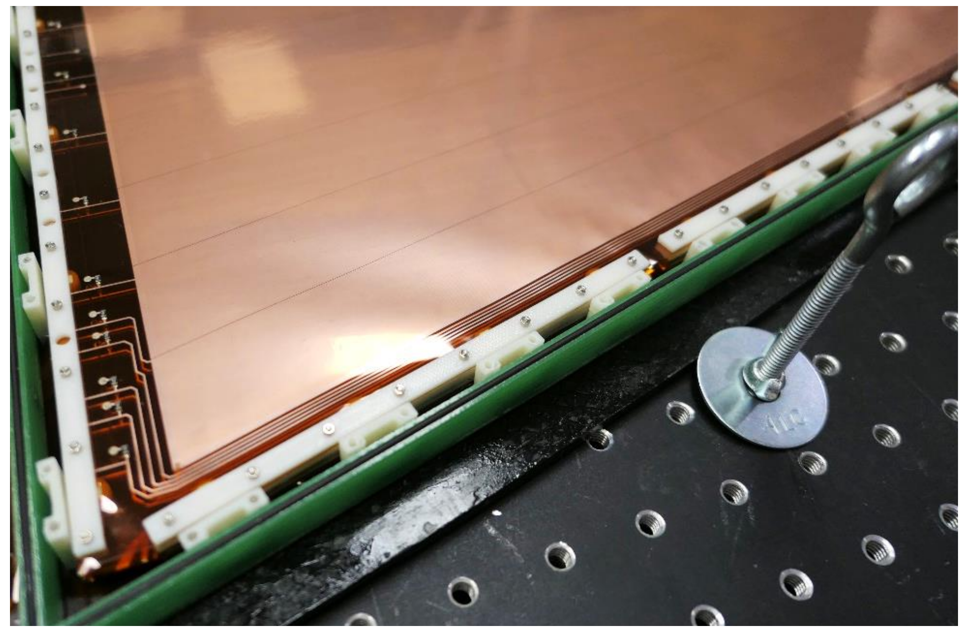


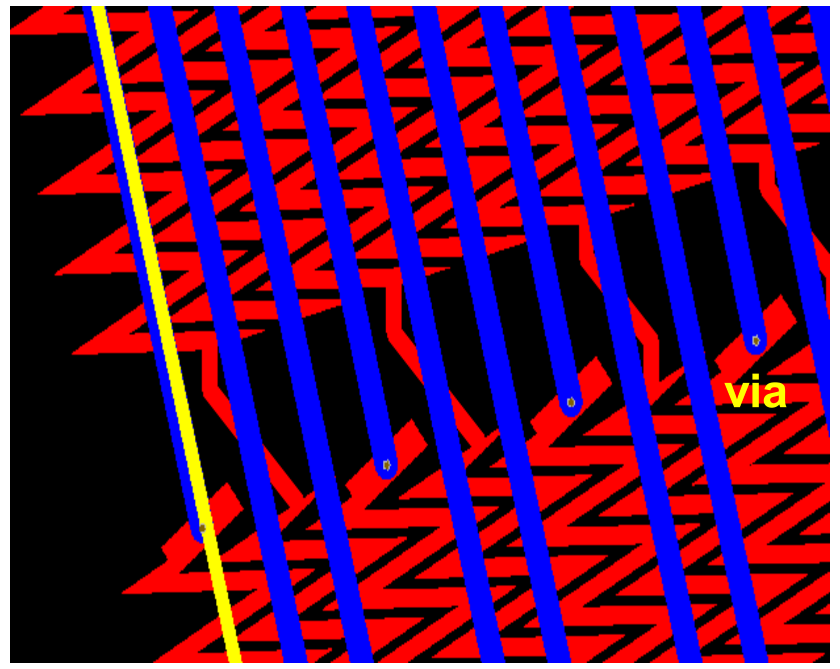
Examples: Tracking

FIT, UVa, BNL, SBU, Temple, Saclay, INFN Trieste, Yale

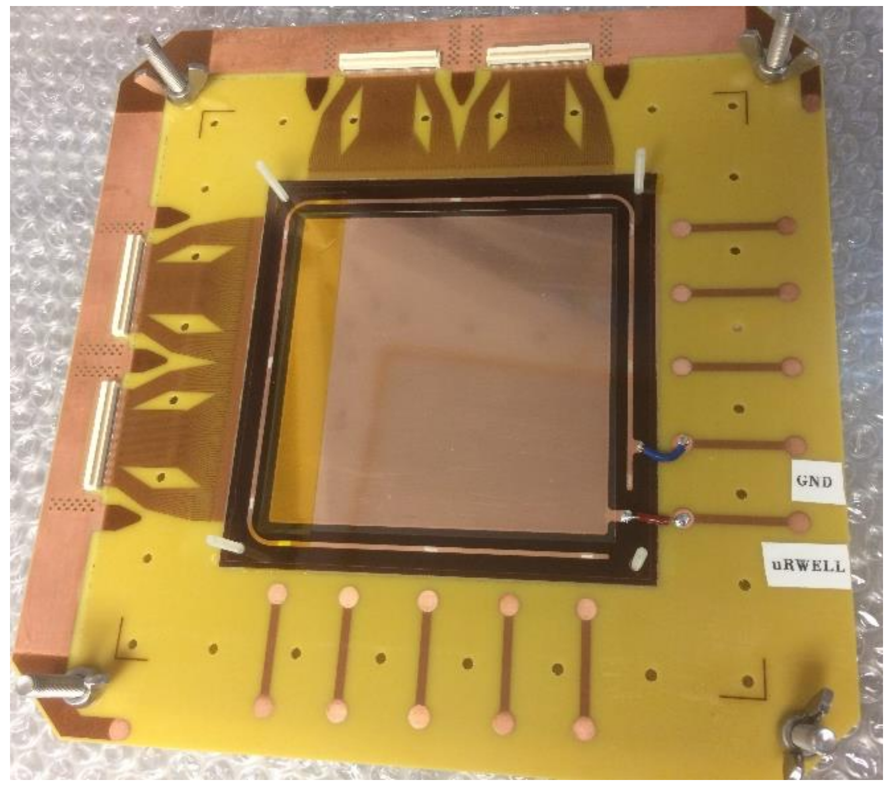


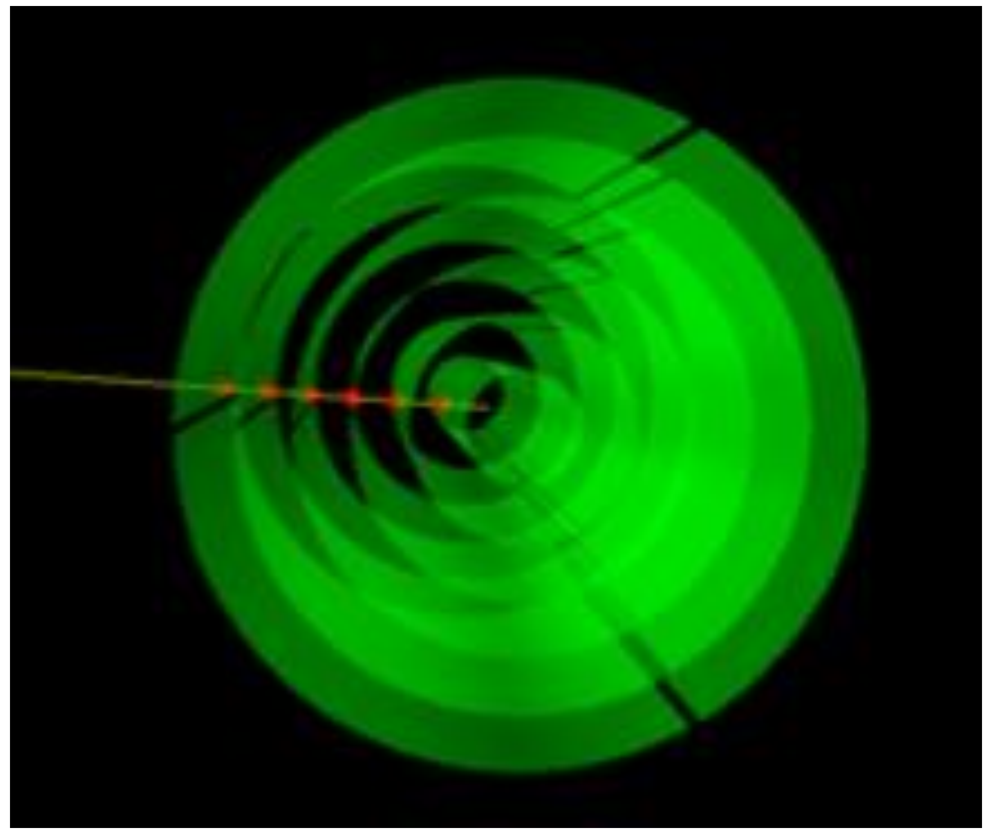
- GEMs & multi-layer GEMs & GEM + MMG
- Low-mass GEM tracker
- Resistive micro-well detector (µRWELL) detector
- Mini-TPC
  - Triple GEM stack with a small drift region
- Cherenkov-TPC
- Gaseous single-photon detection with MPGDs for high-p RICH - new photocathode based on NanoDiamond (ND) particles coupled to MMG
- TPC Readout Chambers, Zig-Zag RO boards





µRWELL with 2D X-Y readout

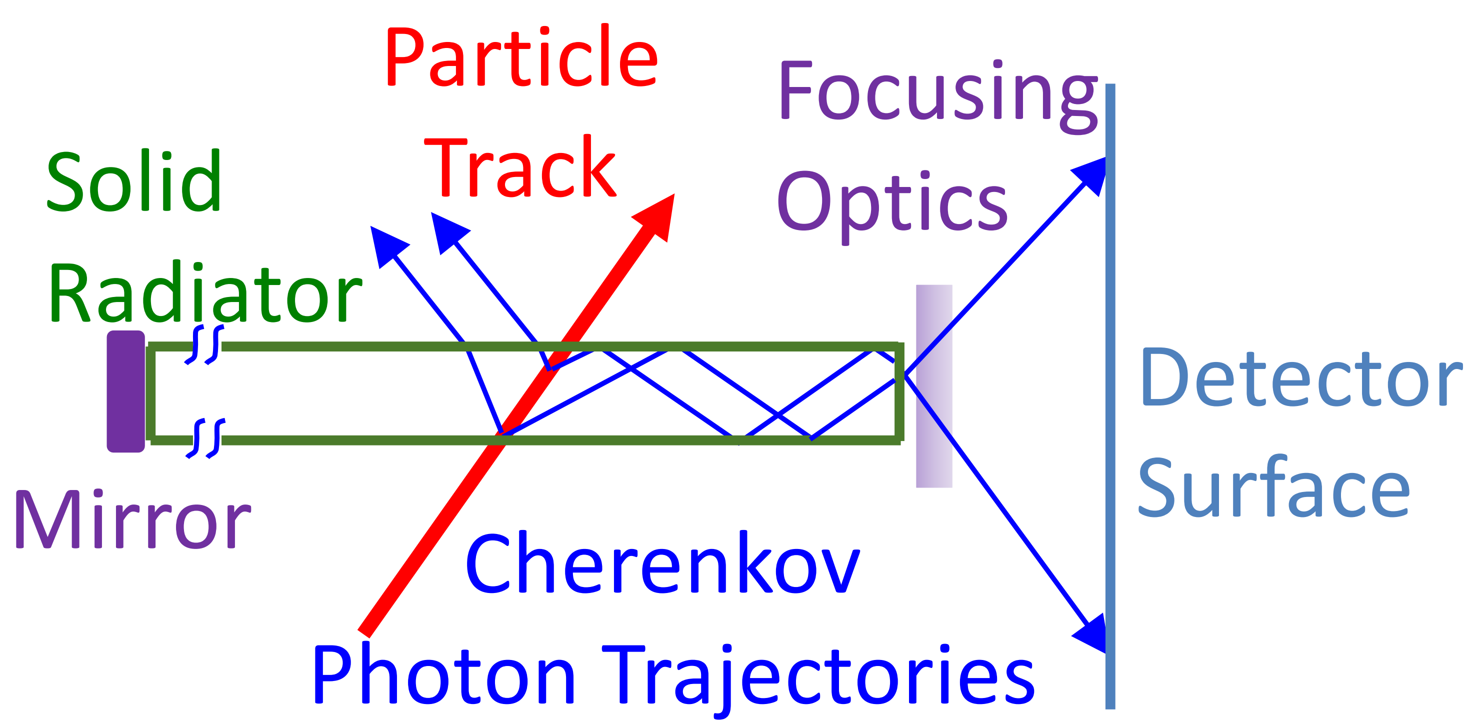


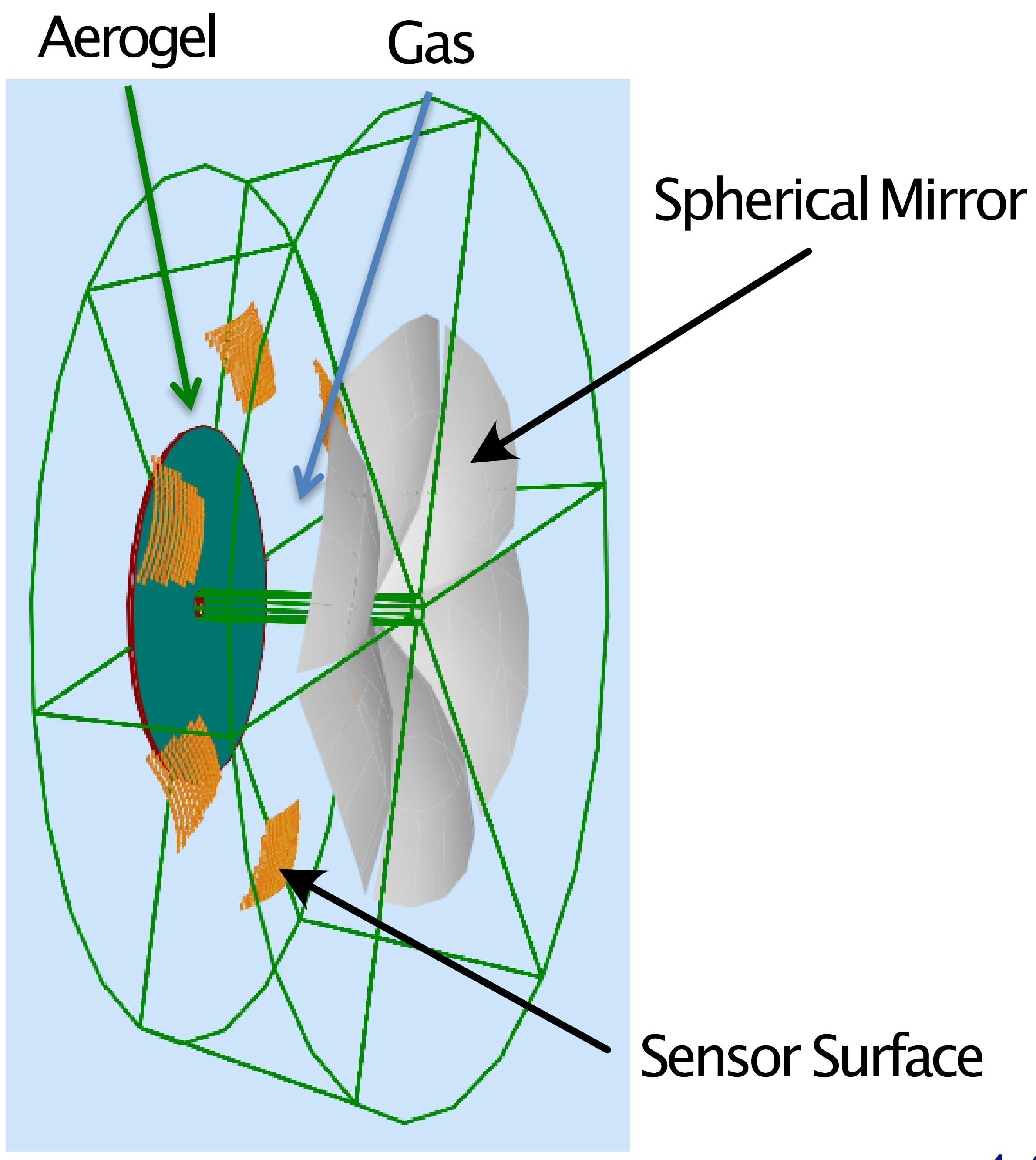


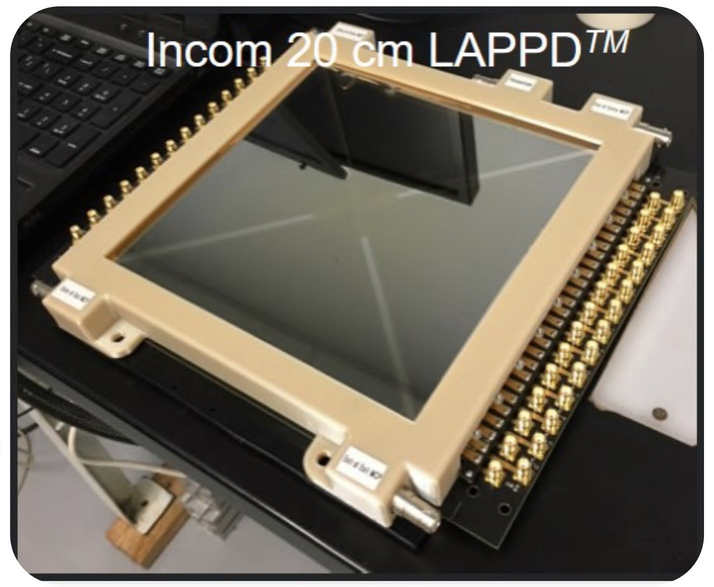
Examples: Particle ID

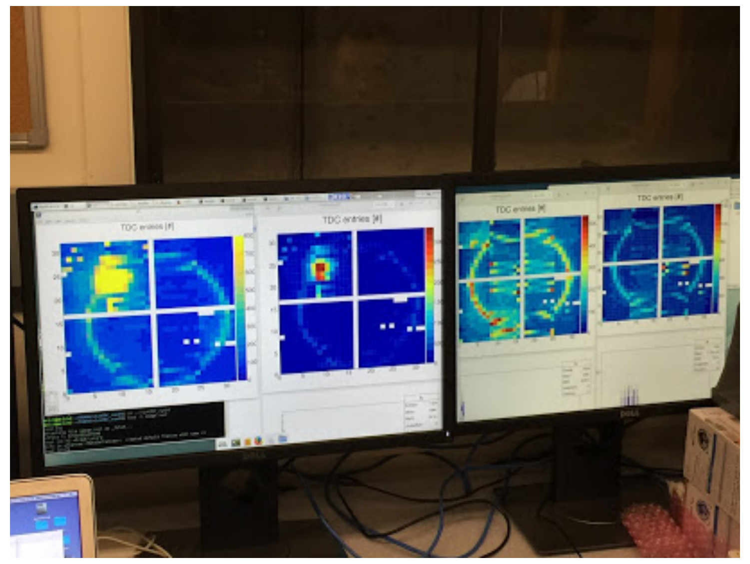
ACU, ANL, BNL, CUA, William & Mary, Duke, GSU, GSI, Howard, INFN Ferrara, INFN Roma, ISS Rome, JLAB, LANL, ODU, USM, UIC, UNM, SC

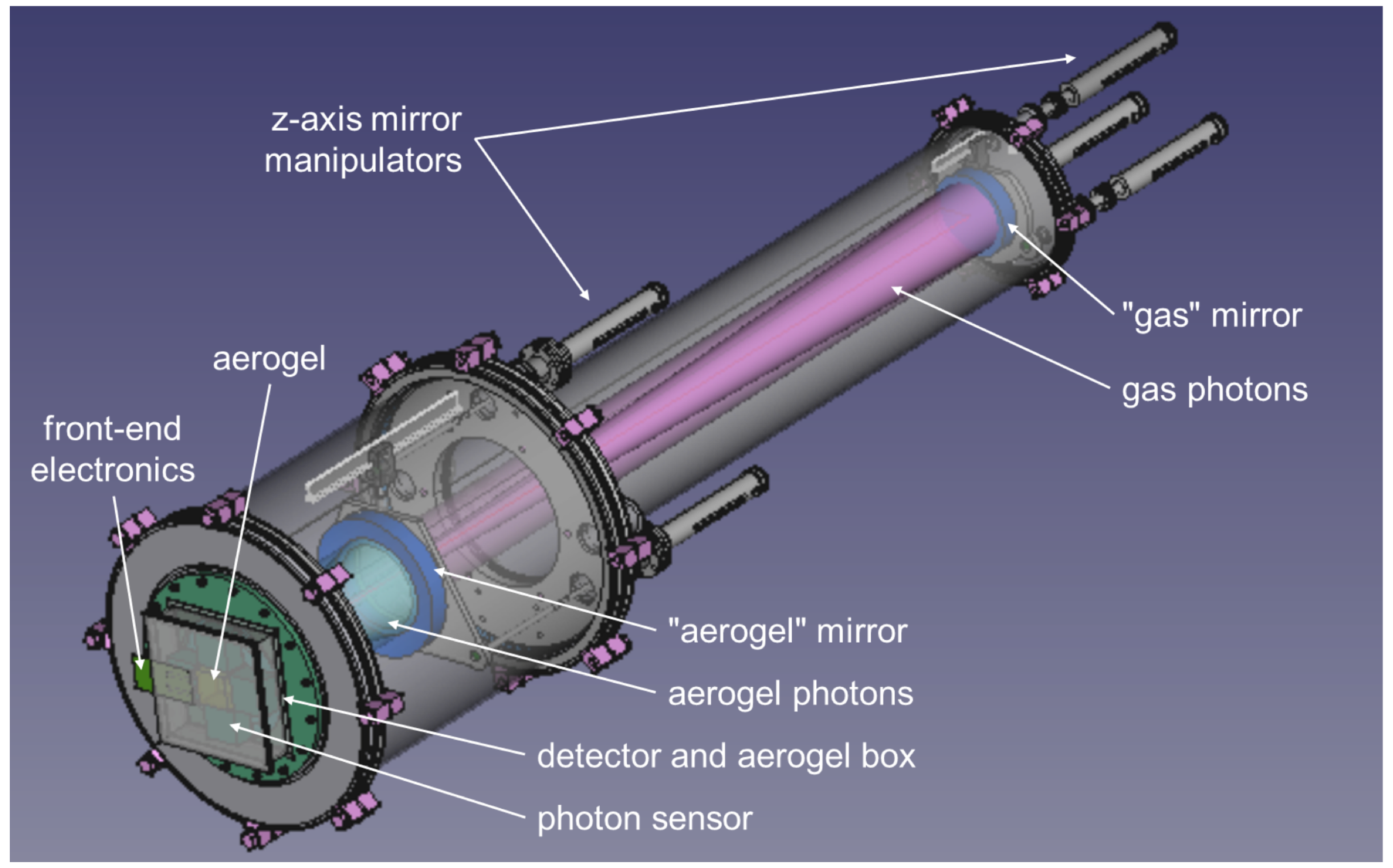
- DIRC (Detection of Internally Reflected Cherenkov light) for barrel region
- mRHIC: Compact aerogel RICH covering up to 10 GeV/c (π/K/p)
- dRICH: RICH with two radiators (gas + aerogel) to cover the full momentum range: more than 3 s.d. separation for π/K/p over 3-50 GeV/c in forward region (up to 15 GeV for e/π)
- Photosensors (SiPMT, MCP-PMT, LAPPD)
- High field tests
- Time-of-Flight (LGAD, LAPPD)



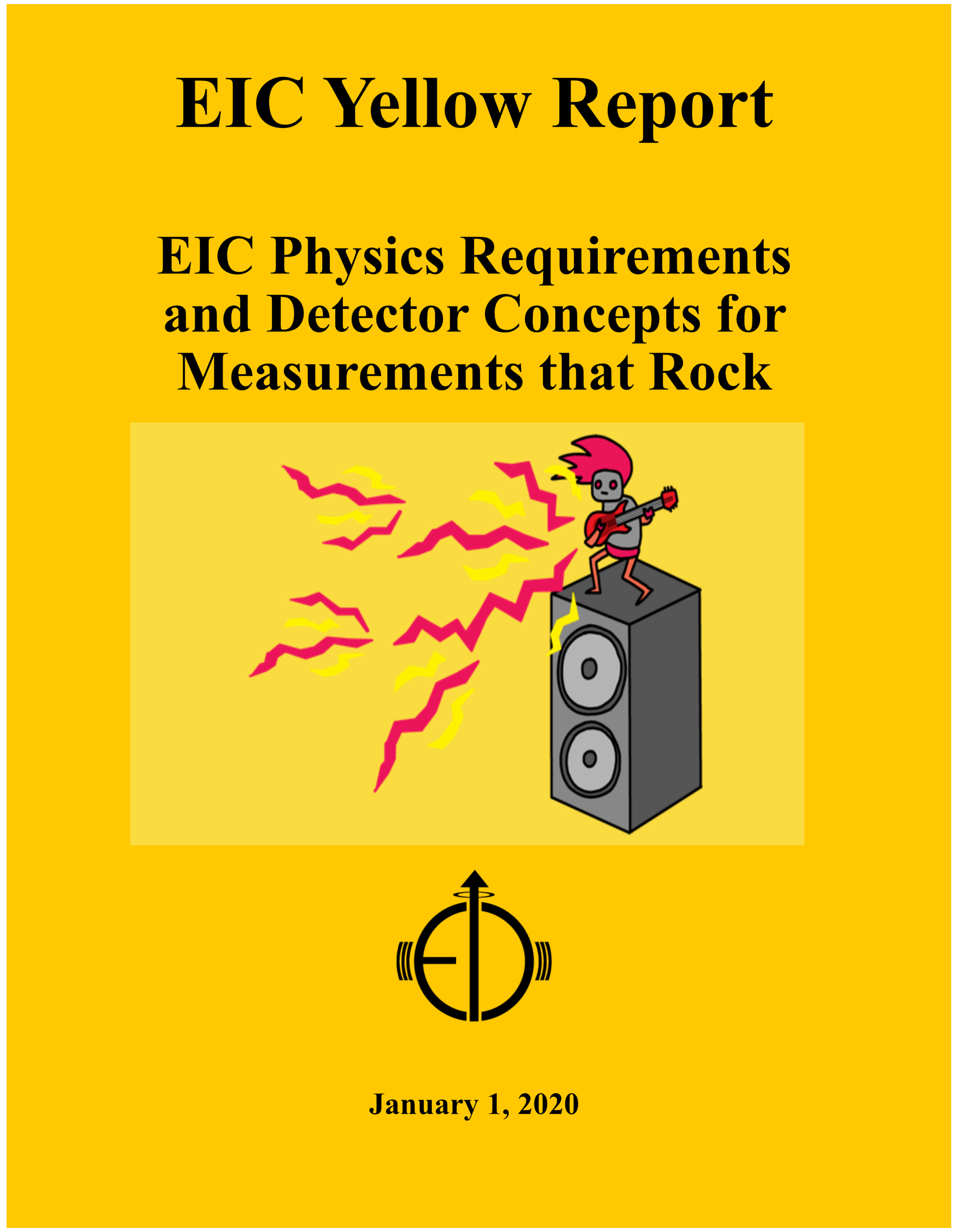








The Yellow Report Initiative



Name borrowed from CERN Yellow Reports series which includes reports on detectors and technical papers, criteria being that the audience should be large and the duration of interest long.

- The purpose is to advance the state and detail of:
  - documented physics studies with focus on detector requirements
  - detector concepts to match the requirements including the complementarity of two detectors towards future technical design reports
- Kick off meeting at MIT, Dec 12-13, 2019
- Timeline ~ 1 year driven by (among others):
  - CD-1: March 2021
  - CD-2: September 2022
- Expect effort to facilitate the formation of collaborations
- 4 Working Group Meetings in 2020
  - March (Temple), May (Pavia), September (CUA), November (UCB)

Organization of Yellow Report

EIC UG Steering Committee

Physics WG
Conveners:
- *Adrian Dumitru (Baruch)*
- *Olga Evdokimov (UIC)*
- *Andreas Metz (Temple)*
- *Carlos Muñoz Camacho (Orsay)*

Subgroups:
- Inclusive Reactions
- Semi-Inclusive Reactions
- Exclusive Reactions
- Jets & Heavy Flavor
- Diffractive Reactions & Tagging

Detector WG
Conveners:
- *Ken Barish (UC Riverside)*
- *Tanja Horn (CUA)*
- *Peter Jones (Birmingham)*
- *Silvia Dalla Torre (Trieste)*

Subgroups:
- Tracking (+vertexing)
- Particle ID
- Calorimetry (EM and Hadronic)
- Far-Forward Detectors
- DAQ/Electronics
- Polarimetry/Ancillary Detectors
- Central Detector/Integration & Magnet
- Forward Detector/IR Integration
- Infrastructure and Installation
- Detector Complementarity

Subgroups have 2-5 conveners each.
42 conveners in total

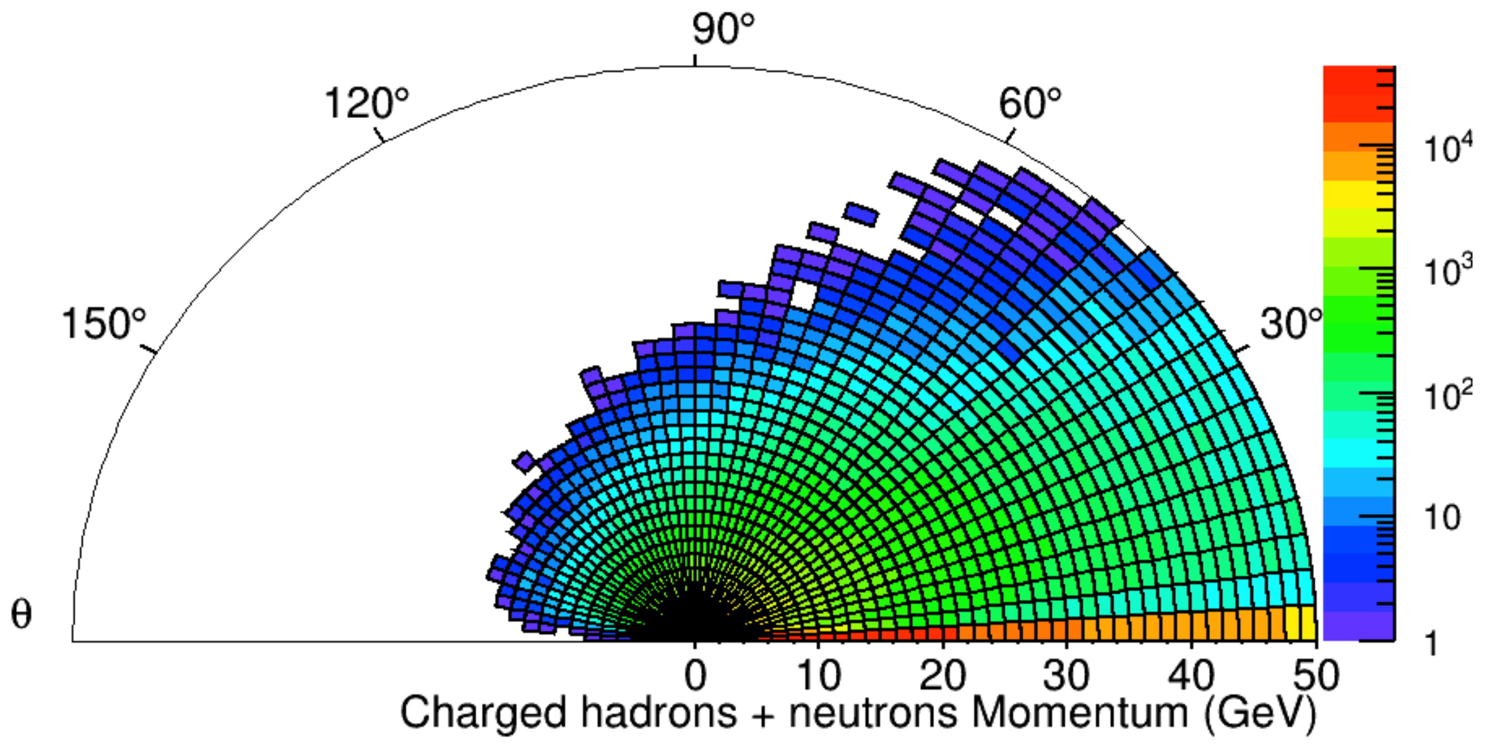
- Weekly meeting of each WG & joint meetings
- Regular meetings between PWG and DWG
- Many collaborative tools deployed by EICUG, BNL & JLab to support process: Indico, Email-groups, Dropbox, Wiki, Google calendar, Github, computing resources, …

Physics Working Group Efforts

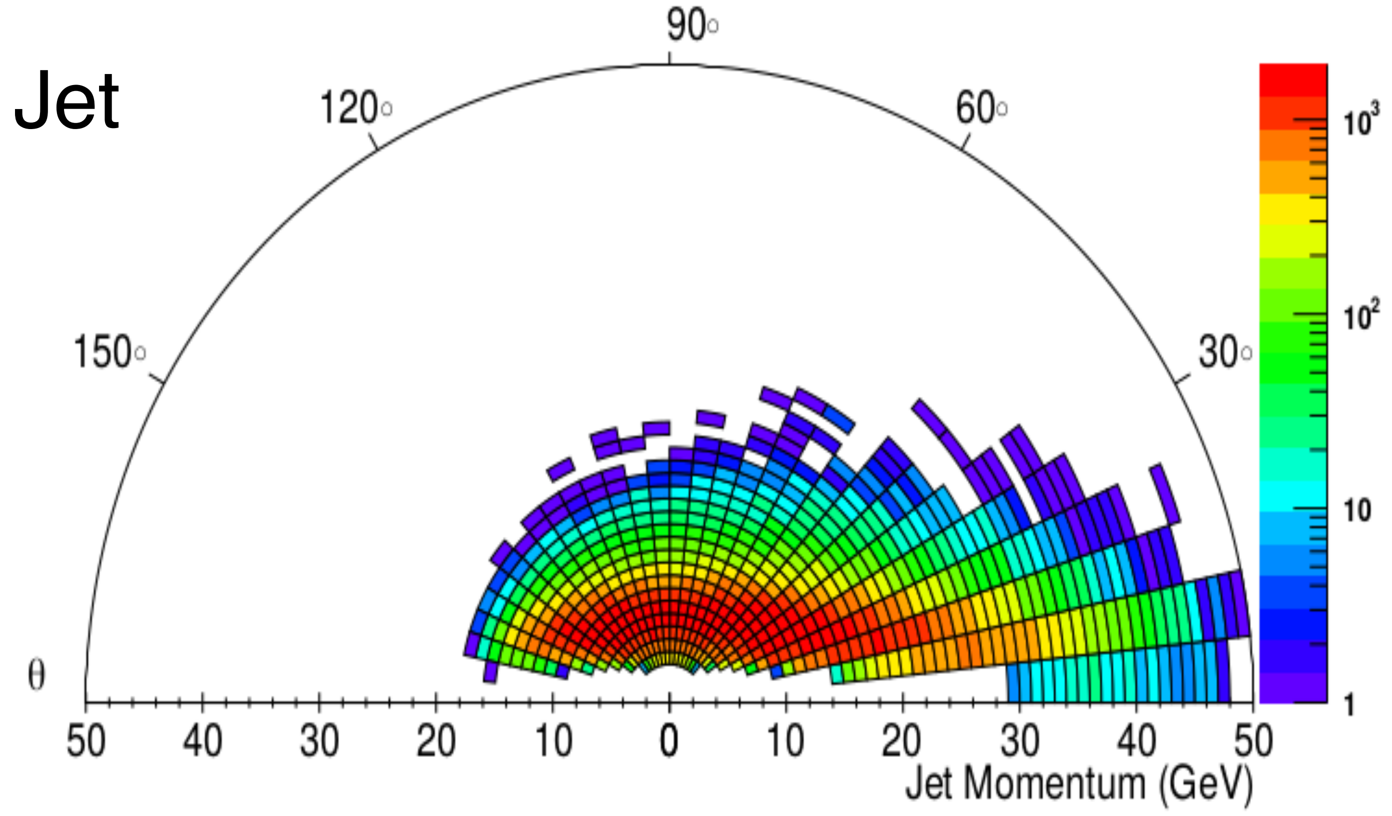
- Established simulation baseline parameters
  - ep, eA_{light}, eA_{heavy}, $E_e + E_h$ range, $\int Ldt$= 10 fb^{-1} and 100 fb^{-1}, $P_{e/p}$ = 70%
- Break-down physics deliverables into "physics objects" (PO): e, h, jets, …
  - map out kinematics for each PO
  - Cross-check PO maps across physics subgroups to determine the most challenging constraints in terms of detector design;
- Focus on fast simulations
  - determine the optimal/acceptable detector performance
  - confirm/check resulting impact on the rest of the measurements
- Many channels are under study, progressing well
- Many kinematic maps for physics objects completed/near completion
- Fast simulations of many channels are well underway
- Initial constraints on detectors are starting to come out (and being communicated to the DWG)

Physics Working Group - Examples

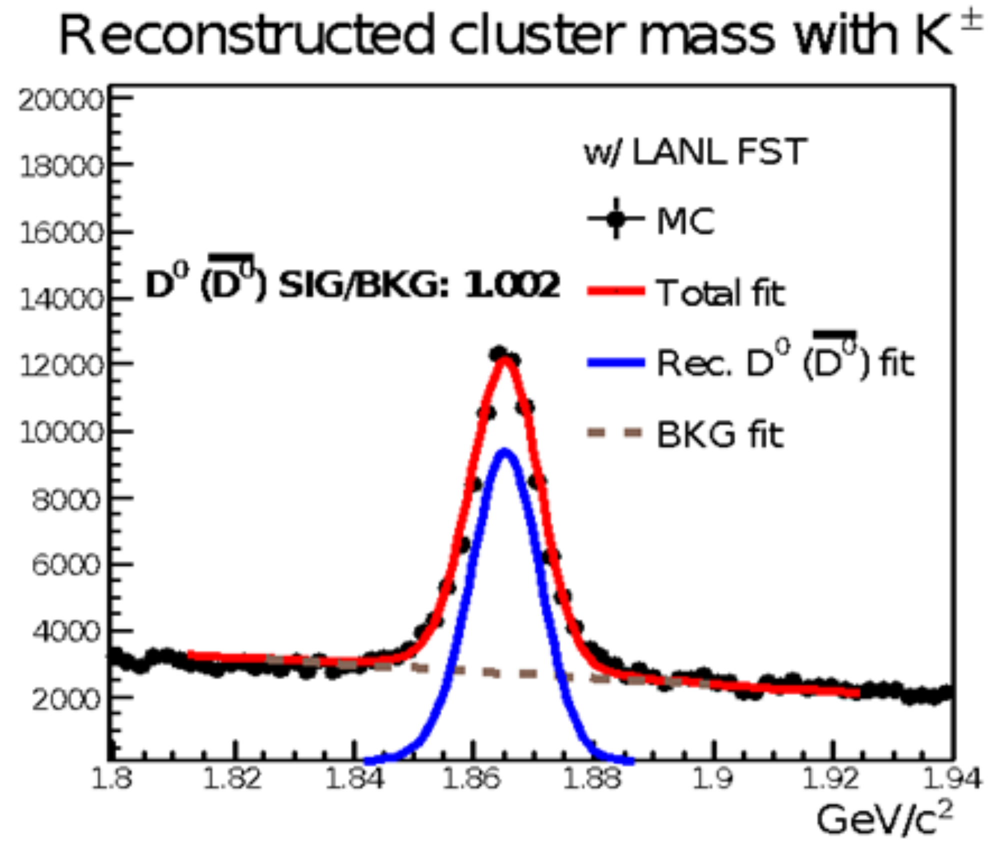
Inclusive WG: Charged Current



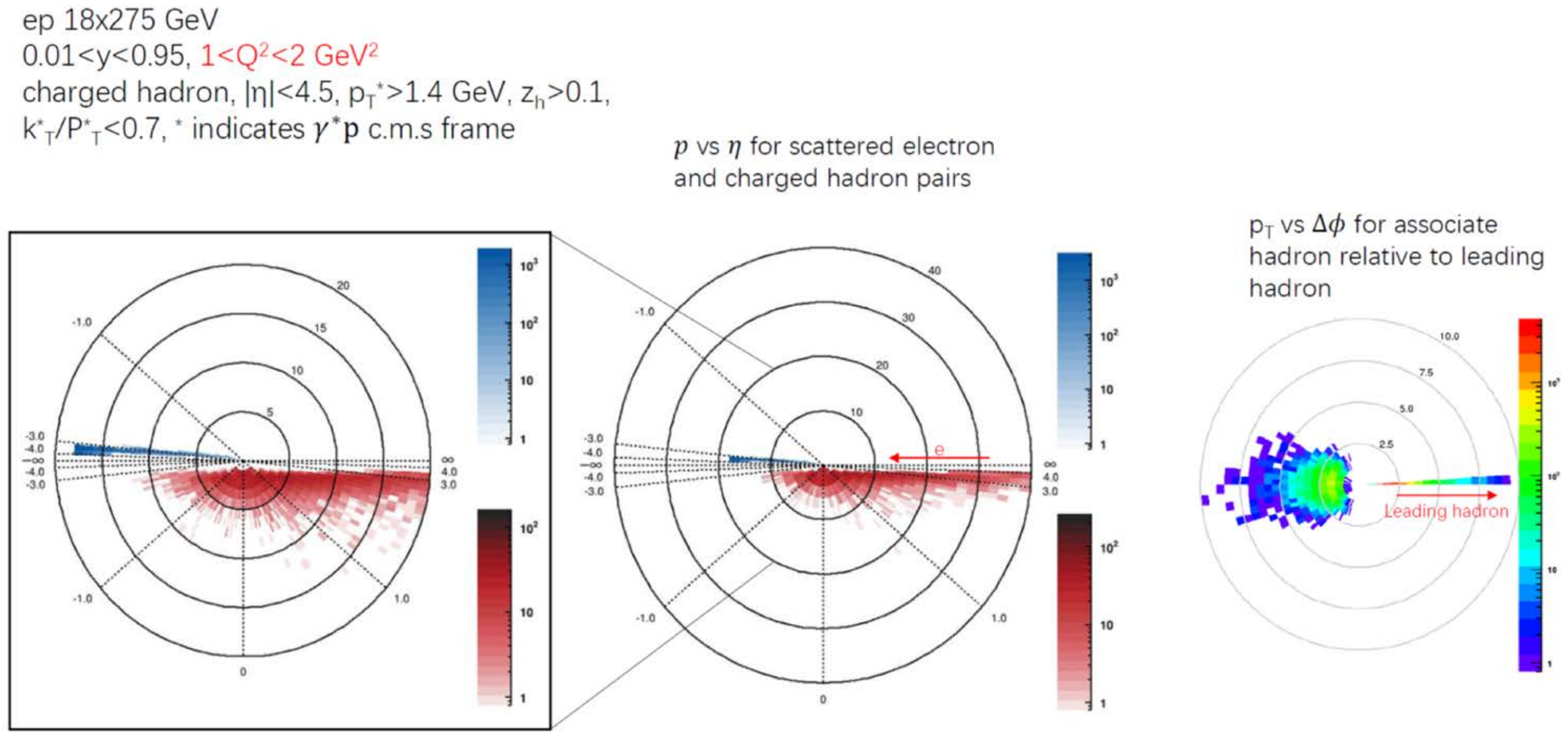
Exclusive WG: Diffractive dijet production



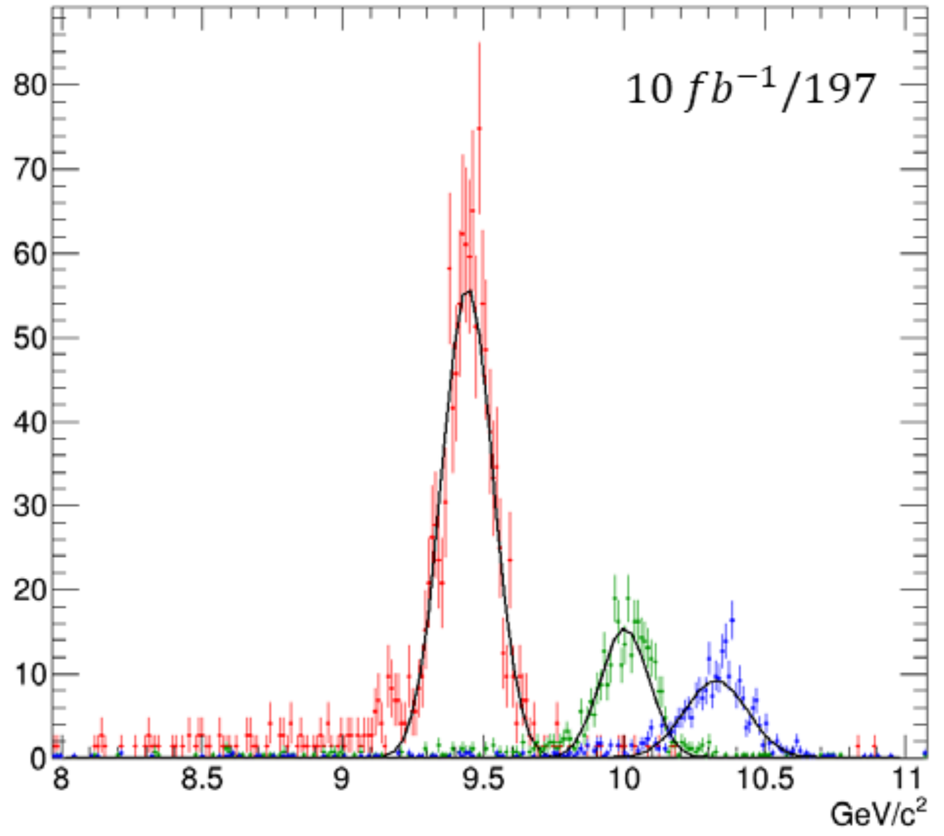
Jets & HF WG: D & B mesons



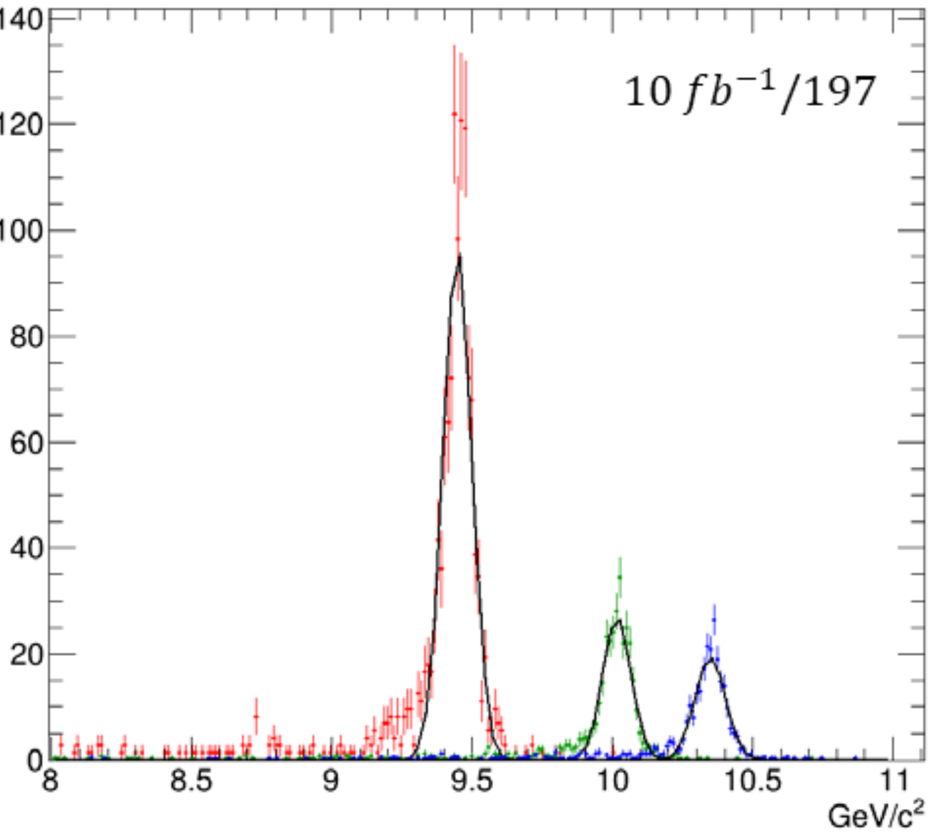
Semi-Inclusive WG: Gluon Sivers



Diffraction & Tagging WG: Diffractive ϒ production



1.5 Tesla



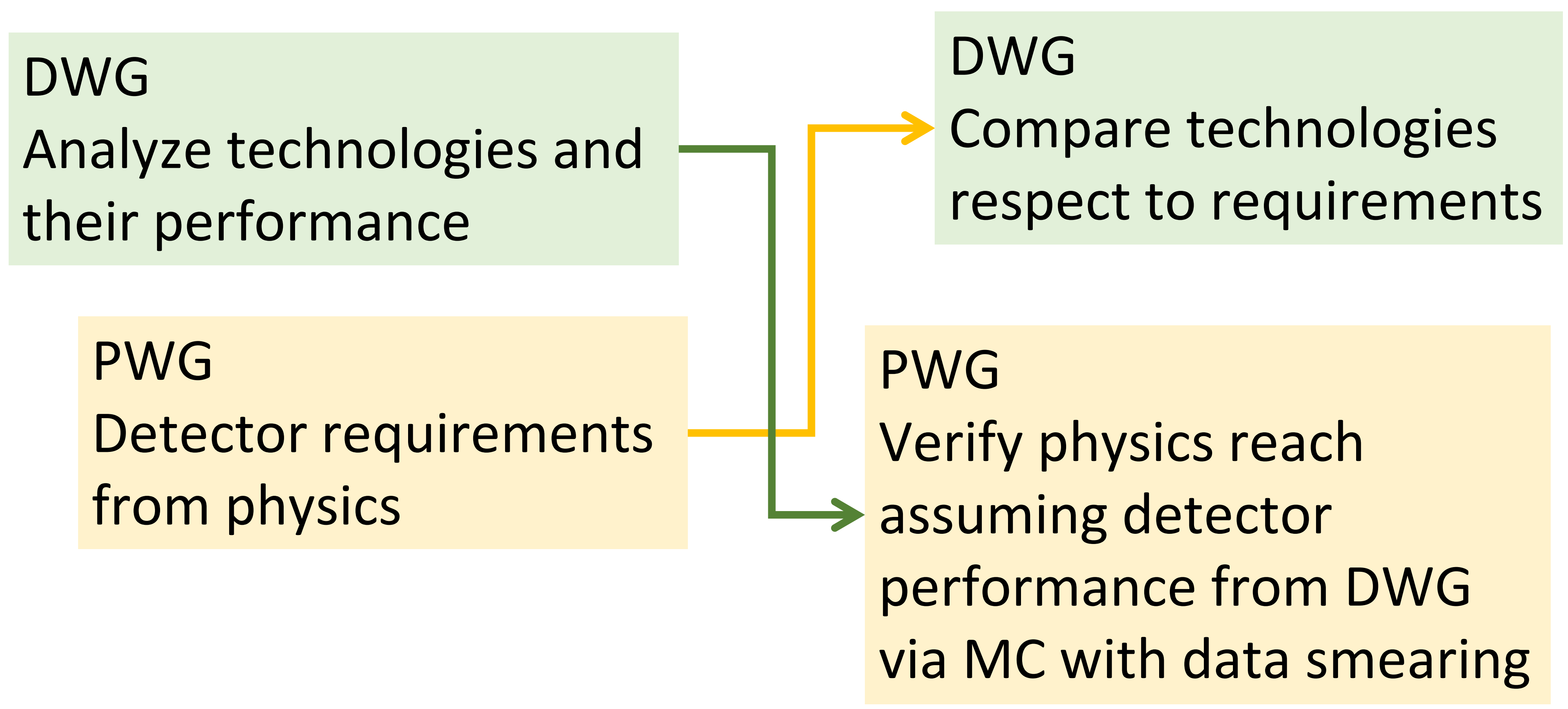
3.0 Tesla

Detector Working Group Efforts

- Main mandate of the Yellow Report is to consider and compare all possible technologies for two EIC detectors
- YR timeline short ⇒ balance between full Geant4 simulations and parametrizations
- Interactive Detector Matrix
  - Official set of physics requirements and technology parameters

η	Nomenclature			Tracking			Electrons		π/K/p		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 to -5.8			low-Q2 tagger	$\sigma\theta/\theta < 1.5\%$; $10^{-6} < Q^2 < 10^{-2}$ GeV^2								
...												
-4.5 to -4.0	↓ p/A	Auxiliary Detectors										
-4.0 to -3.5			Instrumentation to separate charged particles from photons				2%/√E					
-3.5 to -3.0				σ_p/p ~ 0.1%⊕0.5%								
-3.0 to -2.5												
-2.5 to -2.0			Backward Detector	σ_p/p 0.1%⊕0.5%		TBD	2%/√E		≤ 7 GeV/c		~50%/√E	
-2.0 to -1.5				σ_p/p 0.05%⊕0.5%			7%/√E	π suppression up to 1:10^4				
-1.5 to -1.0							7%/√E					
-1.0 to -0.5												
-0.5 to 0.0		Central Detector	Barrel	σ_p/p ~0.05%×p+0.5%	~5% or less X	σ_{xyz} ~ 20 µm, $d_0(z)$ ~ $d_0(r\Phi)$ ~ $20/p_T$ GeV µm + 5 µm			≤ 5 GeV/c	≥ 3 σ		TBD
0.0 to 0.5												
0.5 to 1.0												
1.0 to 1.5												
1.5 to 2.0				σ_p/p ~0.05%×p+1.0%					≤ 8 GeV/c			
2.0 to 2.5			Forward Detectors			TBD	(10-12)%/√E				~50%/√E	
2.5 to 3.0				σ_p/p ~ 0.1%×p+2.0%					≤ 20 GeV/c			
3.0 to 3.5									≤ 45 GeV/c			
3.5 to 4.0												
4.0 to 4.5			Instrumentation to separate charged particles from photons									
...	↑ e	Auxiliary Detectors	Neutron Detection									
> 6.2			Proton Spectrometer	$\sigma_{intrinsic}(\lvert t\rvert)/\lvert t\rvert < 1\%$; Acceptance: $0.2 < p_t < 1.2$ GeV/c								

Activity Flow



Detector Working Group - Examples

- Tracking
  - Hot: All-silicon vs hybrid (silicon & gaseous) trackers
  - Compare technologies

	TPC + Fast MPGD Layer	Cylindrical MPGD (Micromegas, μRWELL)	Drift Chambers / Straw Tubes	Planar MPGDs (GEM, Micromegas, μRWELL)	Small TGCs	MPGD-TRDs
Barrel region	Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel**	Pros: - Space point & angular res. - Time resolution (< 10 ns) - **Low material in End cap** - **Cost & robustness**	Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel**	Pros: - Alternative to cylindrical MPGDs arrangement in polygons - **Easier fabrication**	N/A	N/A Radiator size
	Cons: - **End cap material** - calibration space charge distortion	Cons: - Momentum res. - Fabrication challenges - **Material budget in barrel**	Cons: - **End cap material** - calibration - Stability issues	Cons: - Momentum res. - Detector space barrel - **Material budget in barrel**		
Hadron End Cap	N/A Only planar option		Pros: - momentum res.; - additional dE/dx; - **cost** - **Low material in barrel**	Pros: - Momentum & angular res. - Low material (<0.4%) - **Cost & robustness**	Pros: - Momentum & angular res. - **Cost & robustness**	Pros: - Additional tracking - Angular res. for RICH - **Additional e/π PID**
			Cons: - **Material budget** - calibration - Stability issues	Cons: - **?**	Cons: - **Material budget**	Cons: - Radiator size
Electron End Cap	N/A Only planar option		N/A	Pros: - Momentum & angular res. - Low material (<0.4%) - **Cost & robustness**	N/A Mainly because of material budget	Pros: - Additional tracking - **Complement main e PID in electron end cap**
				Cons: - **?**		Cons: - Radiator size?

Detector Working Group - Examples

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	P Range	Contr. ϑ_c	Param.	Pro/Con	Ext. Const	MONTECARLO Sim.
psec TOF LGAD TOF	Up to 10 Depending on the σ_T and L	NO	~YES	YES	~ YES	NO
dual RICH (aerogel, gas)	2-60 @ 1.6 m	YES • Chroma • Emission • Pixel • Field • Tracking	YES	YES	YES • Simulated constant w/ momentum	YES • GEMC/Geant4 • AI-driven Optimization
GEM RICH (Gas Electron Multipliers)	20-50 @1m	• Chroma • (Emission) • Pixel • Tracking	YES	YES	YES	YES (Simplified)
modular RICH (mRICH)	2-10 @ 3 cm	YES • Chroma • Emission • Pixel • Tracking	~YES	YES	YES (tracking)	~YES • GEMC/Geant4 work in progress
DIRC	2-6 @ 1.7 cm	YES • Tracking • Mult. Scat • Chrom, Emis, pix	YES 18	YES	YES	YES • GEMC/Geant4 without B field

Detector Working Group - Examples

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  - Study many options including crystals, glass, W/ SciFi, Shashlyk, Pb/Sc, PbGl, etc.

η	Nomenclature	EmCal						HCal			
		Energy resolution %	Spatial resolution mm	Granularity cm^2	Min photon energy MeV	PID e/π πsuppression	Technology examples*	Energy resolution %	Spatial resolution mm	Granularity cm^2	Technology solution
-3.5 : -2	backward	2/√E ⊕ 1	3/√E ⊕ 1	2x2	50	100	$PbWO_4$	50/√E⊕10	50/√E ⊕ 30	10x10	Fe/Sc
-2 : -1	backward	7/√E ⊕ 1.5	3(6)/√E ⊕ 1	2.5x2.5 (4x4)	100	100	DSB:Ce glass; Shashlik; Lead glass	50/√E⊕10	50/√E ⊕ 30	10x10	Fe/Sc
-1 : 1	barrel	(10-12) /√E ⊕ 2	3/√E ⊕ 1	2.5x2.5	100	100	W/ScFi	100/√E⊕ 10	50/√E ⊕ 30	10x10	Fe/Sc
1 : 3.5	forward	(10-12) /√E ⊕ 2	3/√E ⊕ 1	2.5x2.5 (4x4)	100	100	W/ScFi Shashlyk, glass	50/√E⊕ 10	50/√E ⊕ 30	10x10	Fe/Sc

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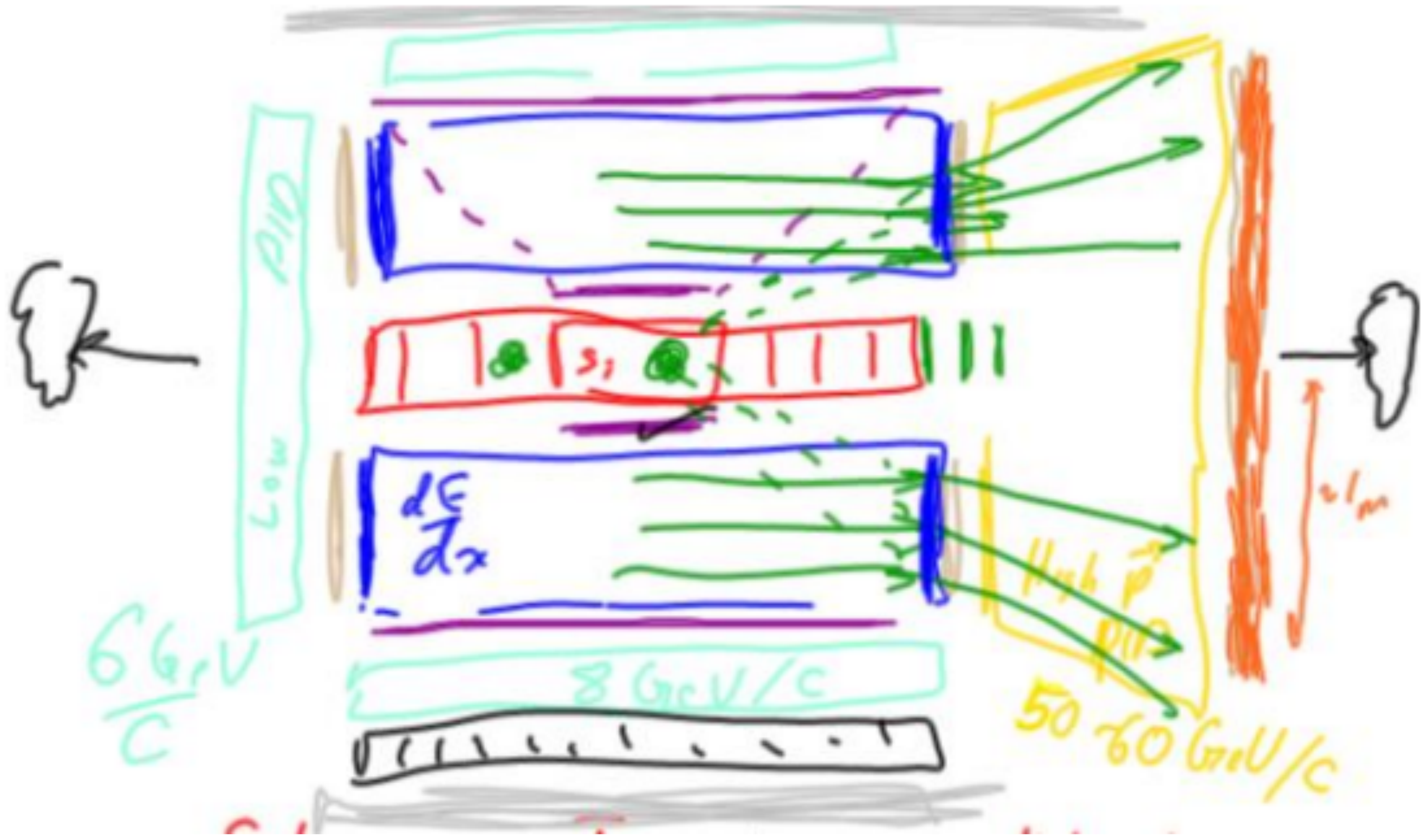

- All DWG are making fantastic progress - more input from PWG is coming

Take Away Message

- EIC User Group
  - Vibrant, international, active, steadily increasing community
  - Good communication with project, labs, and DOE
  - Coordination of European and US Strategy efforts
  - Seed for collaborations

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Then we only have to built it - but this is another (much longer) talk