The ECCE Experiment

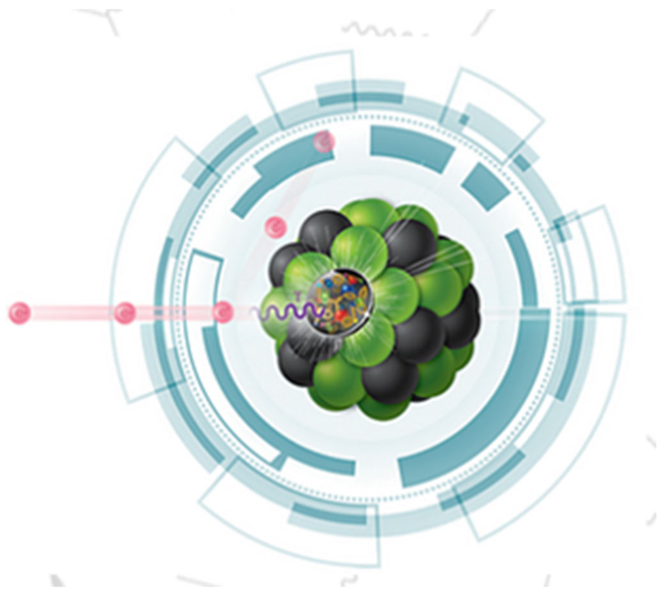
John Lajoie

Iowa State University

for the ECCE Consortium

ECCE 101

EIC Comprehensive Chromodynamics Experiment



- ECCE is 64 institutes (& counting) collaborating to design an EIC detector offering full kinematic coverage and an optimized far forward detector system
- ECCE is investigating a design which incorporates the existing 1.5T BaBar magnet, which will help reduce cost and risk, to allow it to be ready for first EIC detector operation (CD4a)
- ECCE is also investigating the costs and benefits associated with using either IP6 with 25 mrad crossing angle, or IP8 with 35 mrad
- ECCE is planning to submit a proposal to be the EIC project detector (“Detector 1”), which will address the complete science program outlined in the NAS report and Yellow Report
- ECCE is fully supportive of two detectors at the EIC, in both IR8 and IR6, to maximize the scientific output of the EIC
- ECCE is open to everyone in the community to participate, even if they wish to contribute to other proposals.

ECCE Consortium Structure

EIC Project POC
Rolf Ent (JLab)

ECCE Steering Committee
Or Hen (MIT)
Tanja Horn (CUA)
John Lajoie (ISU)

Institutional Board

Computing Team
Cristiano Fanelli (MIT)
David Lawrence (JLab)

Computing Working Groups:

- Artificial Intelligence
  William Phelps (CNU/JLab)
- Computing and Software
  Joe Osborn (ORNL)

Diversity, Equity and Inclusion
Narbe Kalantarians (VUU)
Simonetta Liuti (UVA)
Elena Long (UNH)
Christine Nattrass (UTK)

Detector Team
Doug Higinbotham (JLab)
Ken Read (ORNL)

Detector Working Groups:

- IP8/Equipment Re-use
  John Haggerty (BNL)
- Far Forward/Far Backward*
  Michael Murray (KU)
- Tracking
  Xuan Li (LANL), Nilange Liyanage (UVA)
- Calorimetry
  Friederike Bock (ORNL), Yongsun Kim (Sejong U.)
- Particle ID
  Greg Kalicy (CUA)
- Magnetic Field
  Paul Brindza (JLab), Renuka Rajput-Ghoshal (JLab)
- DAQ/Electronics/Readout
  Chris Cuevas (JLab)

***Alex Jentsch, Yulia Furletova**
(far-forward/backward POC)

Physics Benchmarks Team
Carlos Camacho (IJCLab-Orsay)
Rosi Reed (Lehigh U.)

Physics Working Groups:

- Simulations
  Cameron Dean (LANL), Jin Huang (BNL)
- Inclusive Processes
- Semi-Inclusive
  Ralf Seidl (RIKEN), Charlotte Van Hulse (Orsay)
- Exclusive
  Rachel Montgomery (Glasgow), Julie Roche (OU)
- Diffractive and Tagging
  Wenliang Li (W&M), Axel Schmidt (GWU)
- Jets and Heavy Flavor
  Cheuk-Ping Wong (LANL)
- BSM and Precision Electroweak
  Sonny Mantry (UNG), Xiaochao Zheng (UVa)

Editorial Team
Tom Cormier (ORNL)
Richard Milner (MIT)
Peter Steinberg (BNL)

Editorial Working Groups:

- Proposal Editing, Verification and Version Control
- Costing and Management

Website:
https://www.ecce-eic.org/

Mailing Lists:
https://lists.bnl.gov

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- ecce-eic-ib-l
- ecce-eic-comp-l
- ecce-eic-dei-l
- ecce-eic-det-l
- ecce-eic-phys-l
- ecce-eic-prop-l

Indico:
https://indico.bnl.gov/category/339/

ECCE is Growing…

ECCE Consortium: Feb. 26

1. AANL*
2. AUGIE
3. BGU*
4. BNL
5. Charles U*
6. Columbia
7. CUA
8. FIU
9. Georgia State
10. Glasgow*
11. GWU
12. IJCLab-Orsay*
13. Iowa State
14. IPAS*
15. JLab
16. LANL
17. Lehigh University
18. LLNL
19. MIT
20. NCKU*
21. NCU*
22. NRNU MEPhI*
23. NTHU*
24. NTU*
25. ODU
26. Ohio U
27. ORNL
28. PNNL
29. Rice
30. Rutgers
31. Saha*
32. SBU
33. TAU
34. CU Boulder
35. UConn
36. UIUC
37. UKY
38. UNH
39. UTSM*
40. UVA
41. Vanderbilt
42. Virginia Tech
43. Virginia Union
44. Wayne State
45. Weizmann*
46. Zagreb University*

*Non-US institutions (33%)

ECCE is Growing…

ECCE Consortium: April 26

Up by 40%!

1. AANL*
2. AUGIE
3. BGU*
4. BNL
5. CCNU*
6. Charles U.*
7. CNU
8. Columbia
9. CUA
10. Czech. Tech. Univ.*
11. Duke
12. FIU
13. Georgia State
14. Glasgow*
15. GSI*
16. GWU
17. HUJI*
18. IJCLab-Orsay*
19. IMP*
20. Iowa State
21. IPAS*
22. JLab
23. LANL
24. LBNL/Berkeley
25. Lehigh University
26. LLNL
27. Morehead State
28. MIT
29. MSU
30. NCKU*
31. NCU*
32. NMSU
33. NRNU MEPhI*
34. NTHU*
35. NTU*
36. ODU
37. Ohio U
38. ORNL
39. PNNL
40. Rice
41. RIKEN*
42. Rutgers
43. Saha*
44. SBU
45. SCNU*
46. TAU*
47. Tsukuba U.*
48. CU Boulder
49. UConn
50. UH
51. UIUC
52. UKY
53. UNH
54. USTC*
55. UTK
56. UTSM*
57. UVA
58. Vanderbilt
59. Virginia Tech
60. Virginia Union
61. Wayne State
62. WI*
63. York*
64. Zagreb U.*

*Non-US institutions (40%)

The EIC Call for Proposals

- A joint BNL/JLab call for Collaboration Proposals for Detectors at the EIC has been issued, deadline December 1, 2021 Call Collaboration Proposals
  - With input from DOE and EIC User's Group
- Detector 1 is within the scope of the project. US Federal funds are expected to support most but not all of the acquisition of Detector 1
- Detector 2 is not within the Project scope. Routes to make Detector 2 and a second interaction region possible are being explored
- Proposals should consider the siting scenario for the detectors described in the CDR.
  - Detector 1 is currently planned to be located at Interaction Point 6 (IP6) on the Relativistic Heavy-Ion Collider.
  - Other siting options are welcome but proposals that deviate from the CDR will need to address the implications to the EIC project.

The Science

- **Detector 1 should be based on the "reference" detector described by the EIC User Group (EICUG) in the Yellow Report (YR) and CDR**
  - Must address the EIC White Paper and NAS Report science case
  - The collaboration should propose a system that meets the performance requirements described in the EIC CDR and EICUG YR
  - The design should be compatible with that of the accelerator and interaction region layout of the CDR
  - Completion of detector construction must be achieved by Critical Decision (CD)-4A, the start of EIC accelerator operations.
- **Detector 2 could be a complementary detector that may focus on optimizing particular science topics or address science topics beyond those described in the White Paper and the National Academies of Science (NAS) 2018 report**
  - Completion at Critical Decision (CD)-4

ECCE Foundation

- Develop a detector capable of delivering the full EIC science mission
  - As outlined in the Yellow Report
- Appropriate utilization and/or upgrades of existing detectors and infrastructure
  - Reduce technical and schedule risks
  - Reinvest savings in detectors

Expression of Interest (EOI) for the EIC Collider Detector ("ECCE") Consortium

Contact persons for this submission:
Or Hen (hen@mit.edu)
Tanja Horn (hornt@cua.edu)
John Lajoie (lajoie@iastate.edu)

Institutions collectively involved in this submission of interest:
AANL/Armenia, Academia Sinica/Taiwan, BGU/Israel, BNL, CU Boulder, CUA, Charles U./Prague, Columbia, FIU, GWU, GSU, IJCLab-Orsay/France, ISU, JLab, Kentucky, LANL, LLNL, Lehigh, MIT, National Cheng Kung University/Taiwan, National Central University/Taiwan, National Taiwan University/Taiwan, National Tsing Hua University/Taiwan, ODU, Ohio University, ORNL, Rice, Rutgers, SBU, TAU/Israel, UConn, UIUC, UNH, UVA, Vanderbilt, Wayne State, and WI/Israel.

Items of interest for potential equipment cooperation:
The EIC enables an exciting research program which will advance our understanding of the structure of hadronic matter. A state-of-the-art collider detector for the EIC, which is needed to realize its physics program, will be extremely complex. It will require extensive infrastructure, and will need to be integrated into the operation of the accelerator to a very high degree. The technically driven reference schedule for the EIC project is aggressive and presents a significant challenge for an EIC detector to be designed, built, commissioned, and ready to start delivering science when the machine begins to deliver collisions. The substantial resources needed to construct a state-of-the-art detector for the EIC present an additional challenge. Time-tested strategies for addressing such challenges include the reuse of existing infrastructure where suitable and leveraging the hard-won expertise gained through previous successful projects.

The EIC Collider dEtector (ECCE) consortium comprises 36 institutions assembled around the idea of building on the foundation of existing infrastructure available at RHIC IP8 and experimental equipment available there and elsewhere at JLab and RHIC. The consortium includes institutions with wide-ranging world-class detector expertise, strong familiarity with the EIC-suitable characteristics of IP8, and an understanding of the approach to DOE project management. Appropriate use of existing infrastructure will help mitigate several technical and schedule risks of an EIC detector project. The technical expertise in the consortium can build on and extend upon the base provided by existing equipment to provide a complete detector with capabilities mandated by the EIC science requirements as defined by the recent EIC Yellow-Report community effort. The substantial project management experience of the involved institutions provides credible "out of the box" know-how for realizing such a sophisticated detector.

Our working principles in developing this consortium have been:

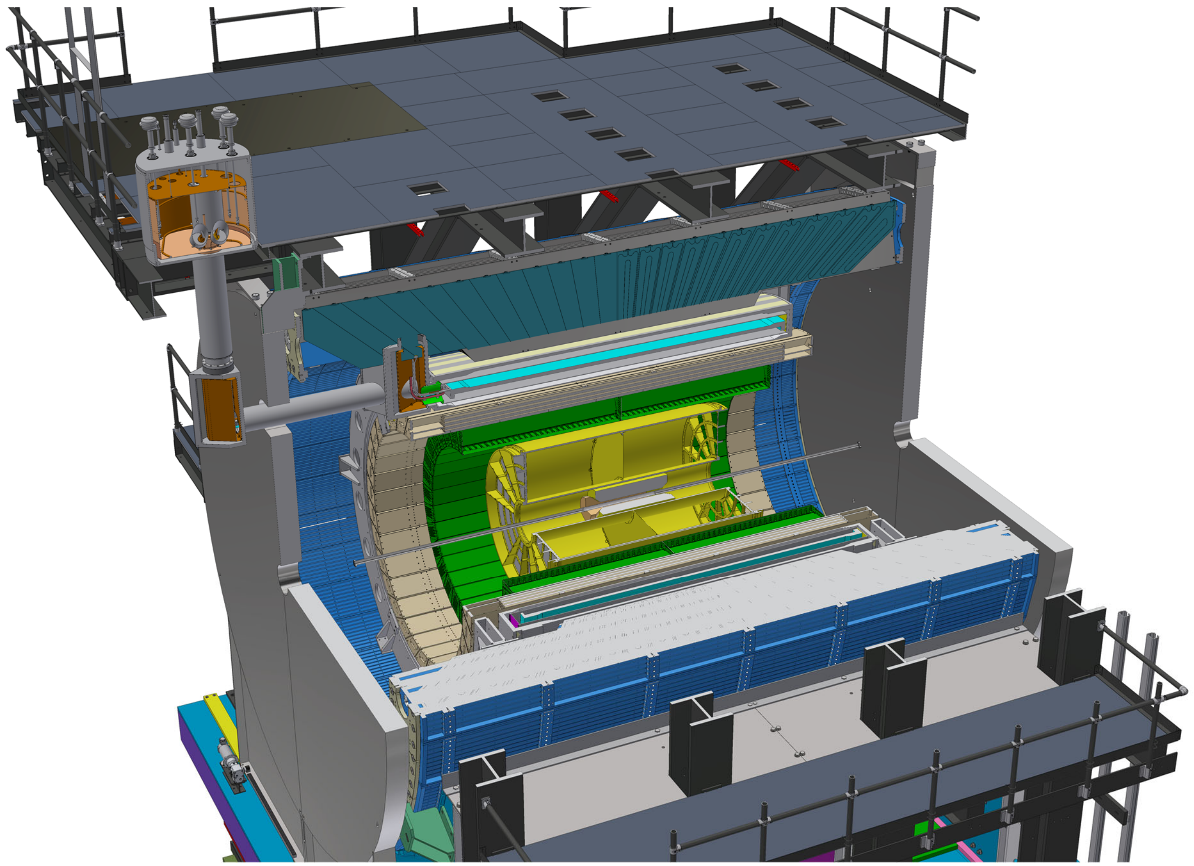
- To follow the guidance provided by the Yellow Report detector design study.

1

Existing Infrastructure

- Existing BaBar solenoid (1.5T), flux return and cradle
  - Substantial investment/risk reduction
- IP8 infrastructure
  - Cryogenic connection to RHIC
  - Racks, mechanical, safety, electrical, etc.
- Potential re-use/refurbish existing sPHENIX detectors as appropriate
- ECCE consortium has considerable recent DOE project experience

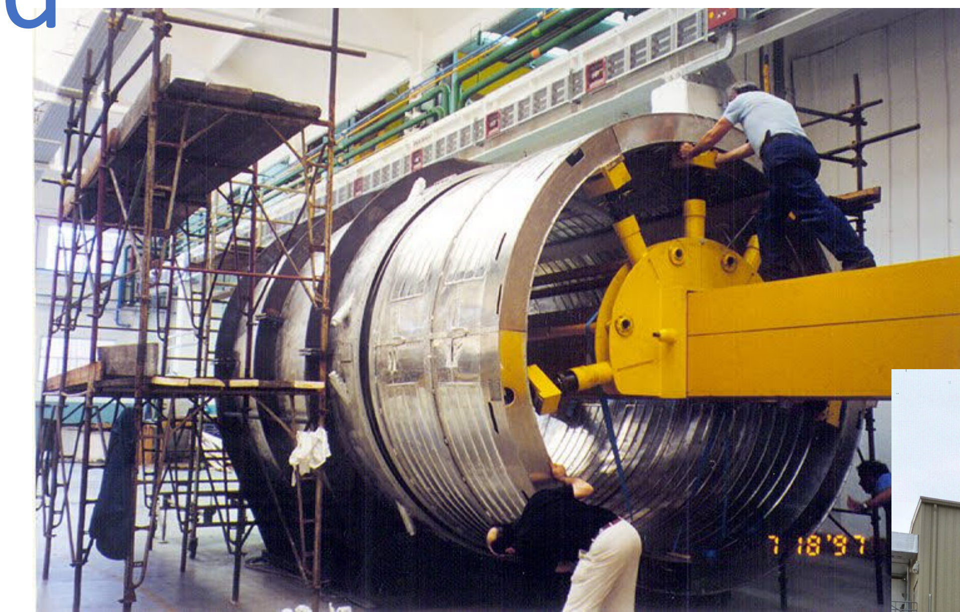
Currently under construction, sPHENIX represents a $27M investment by DOE (MIE)



1.5T BaBar Solenoid

- Built in 1997 (Ansaldo)
- Very conservative design
- 3.7m long,
  1.4m bore radius
- Designed for 1.5T @ 5kA
  - 20MJ stored energy
- Transported to BNL 2015
  - Successful low and high field tests
- Extensive risk analysis shows that the magnet is in excellent shape
  - Some refurbishment required

under construction



shipping to BNL

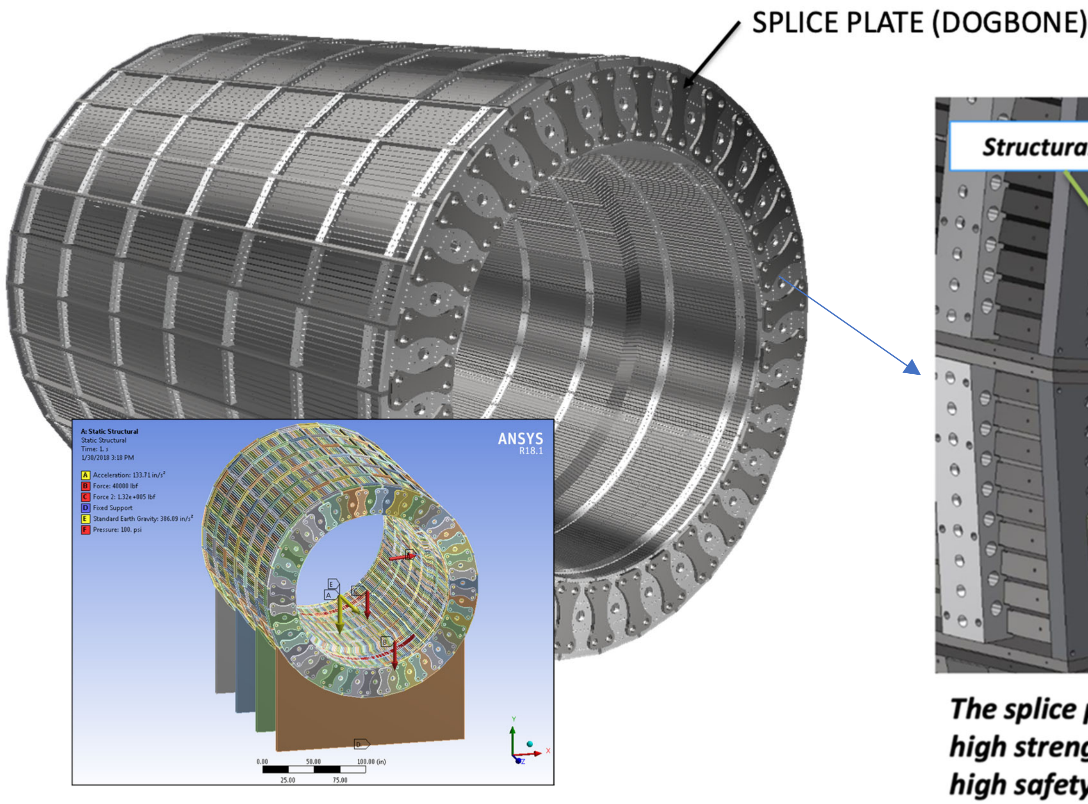
Pasquale Fabbricatore

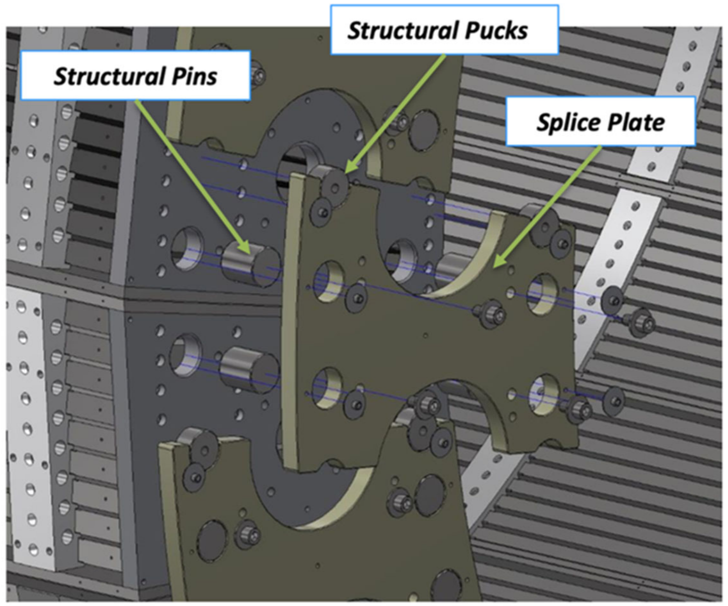
Designed BaBar and CMS 4T superconducting magnets

Recipient of IEEE Award for Continuing and Significant Contributions in the Field of Applied Superconductivity (2020)

Other Infrastructure…

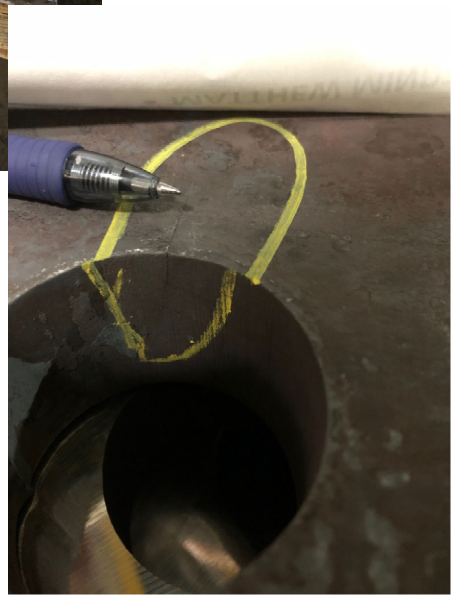
Multiple rounds of prototyping to adapt 4140 HT process to thick material:





The splice plates, pucks and pins are fabricated from high strength steel (AISI 4140 HT) to ensure there is a high safety factor for the oHCAL arch ring structure

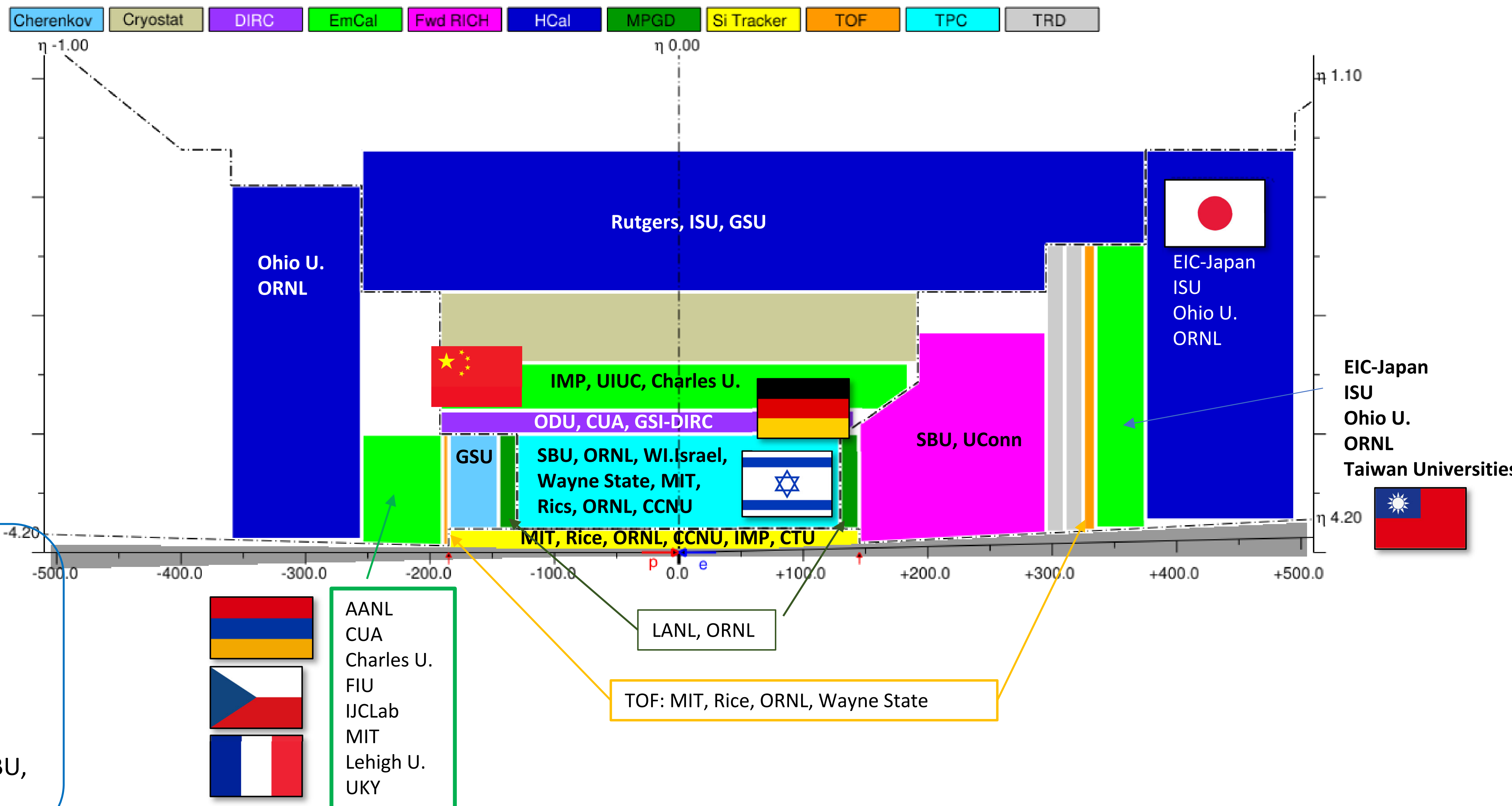
Initial attempt cracked when machined, required modified treatment and machining



engineering, FEA, reviews, prototyping, material choice, vendor selection, test fitting, and so on

8+ months to engineer and certify "dogbone" plates: reuse brings time and cost savings

Institution Interest - Barrel



Polarized Beam and polarimetry: MIT, UNH, SBU

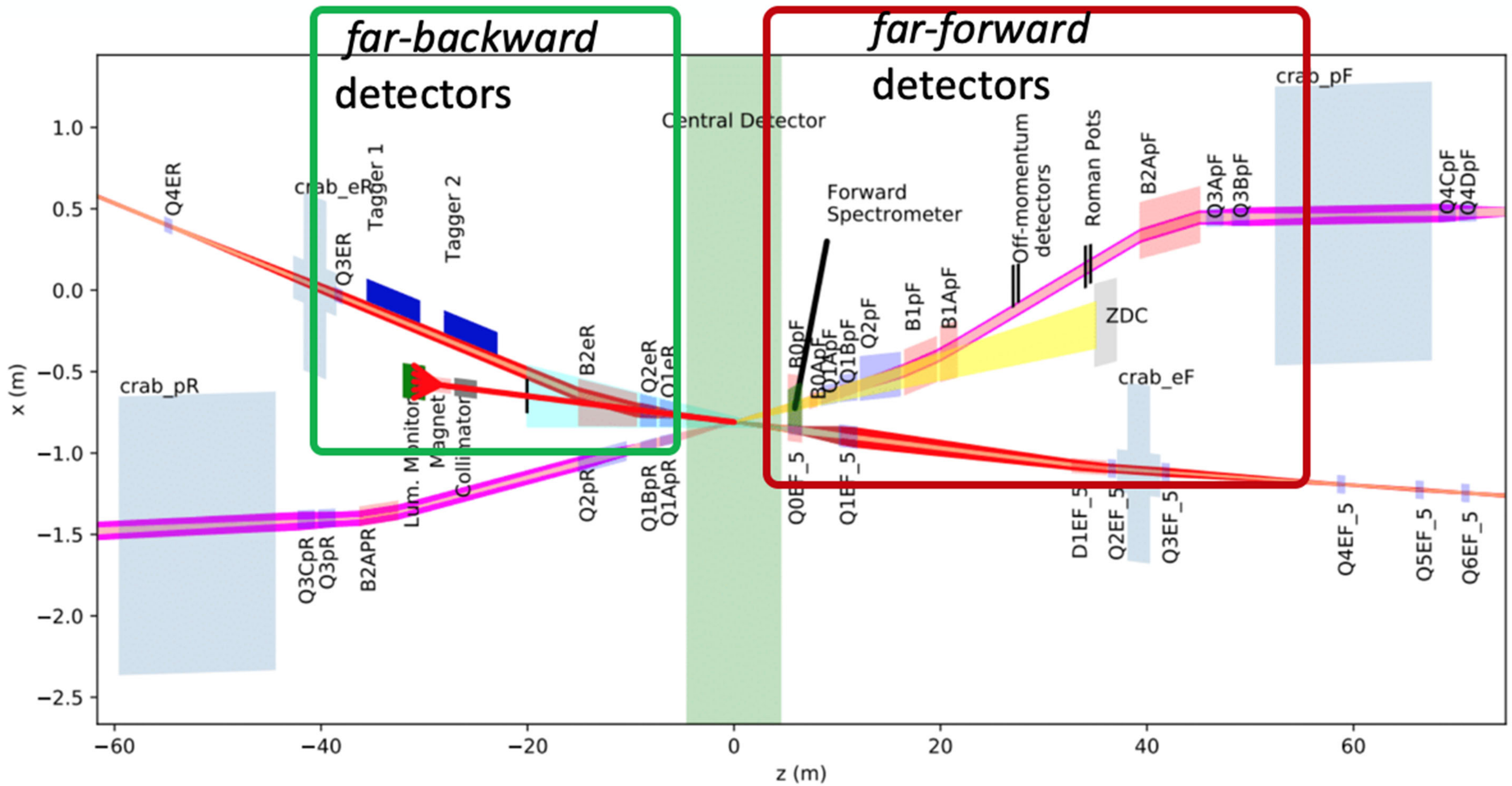
Electronics:
Columbia, ORNL, IMP

DAQ/Trigger: ISU, CU Boulder, OU, ORNL, SBU, UConn, LLNL

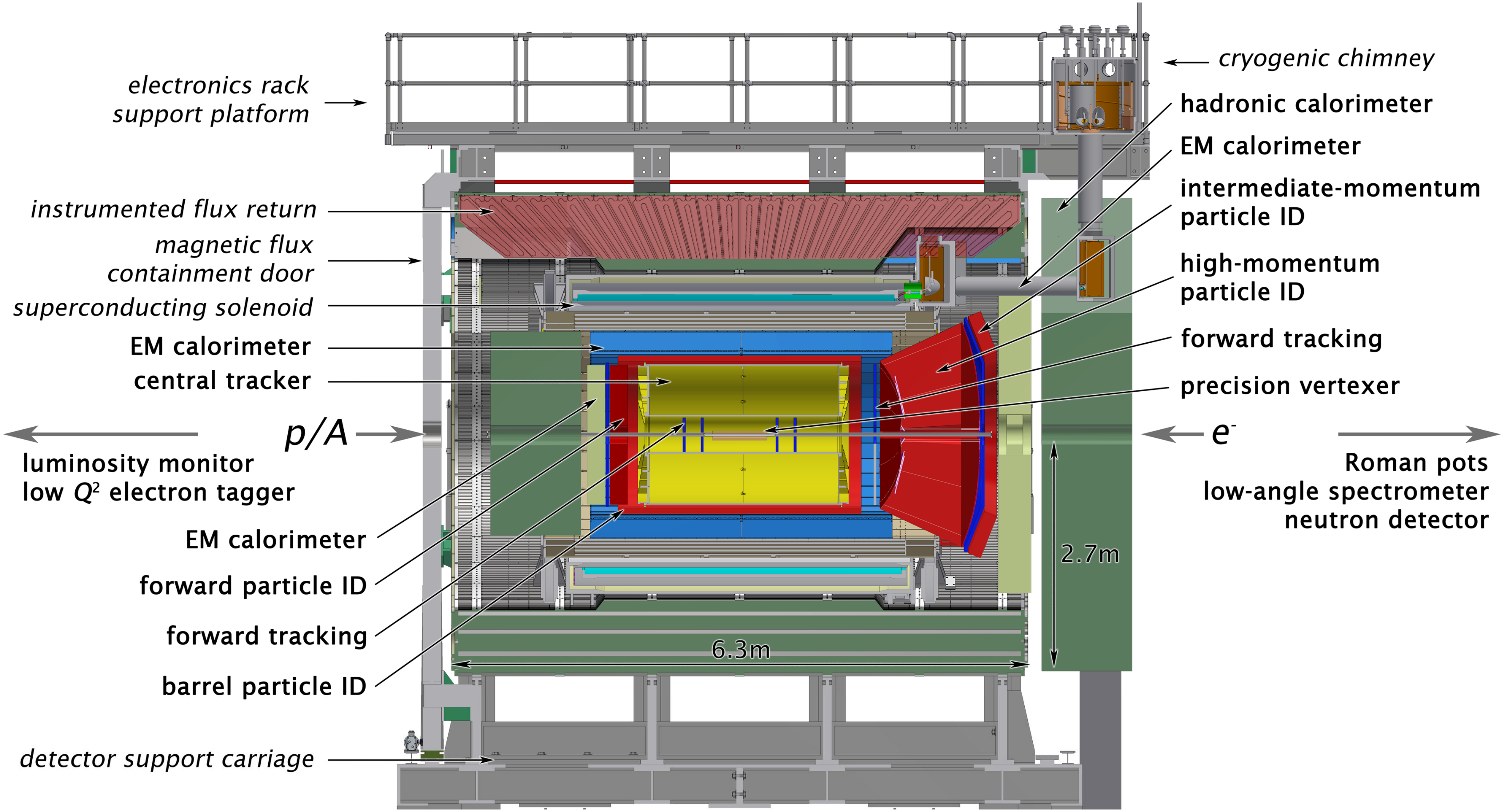
Institution Interest - Far Forward/Backward

Glasgow U., ODU

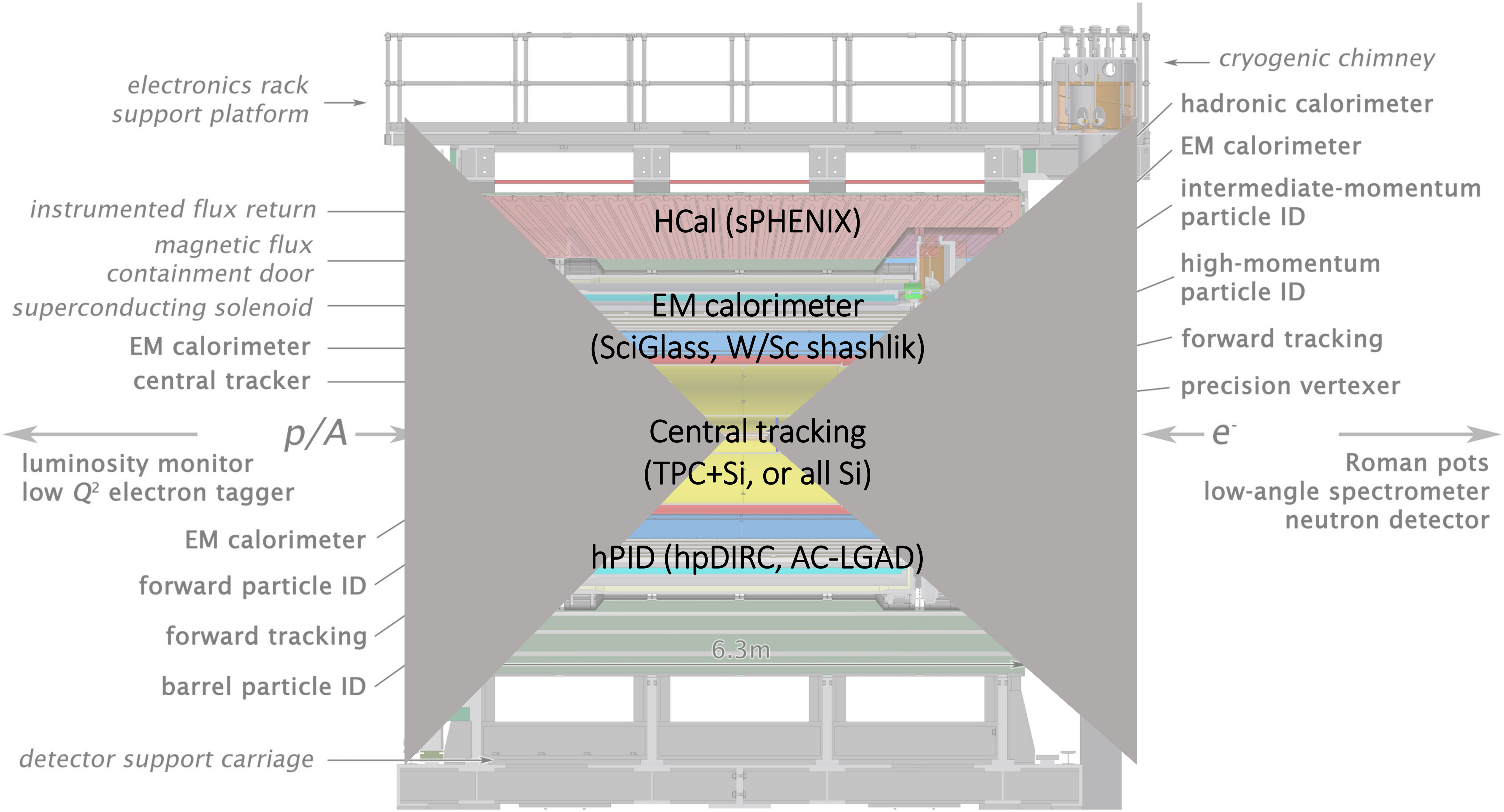
BGU/Israel, MIT, ORNL, UIUC, IJCLab-Orsay, EIC-Japan, TAU/Israel, UVA, GWU, MIT-BATES, HUIJ/Israel



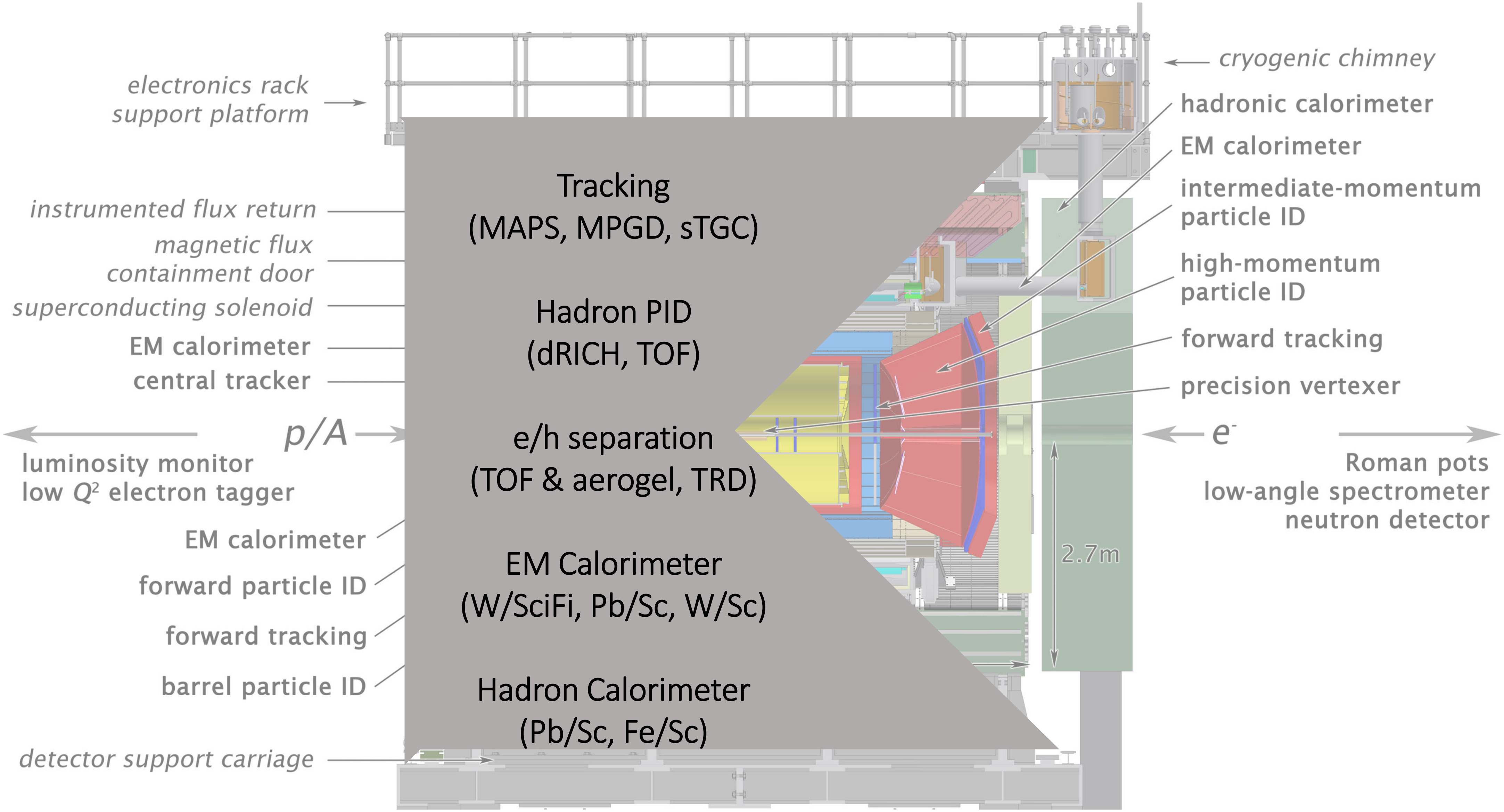
Evolution to a fully realized design



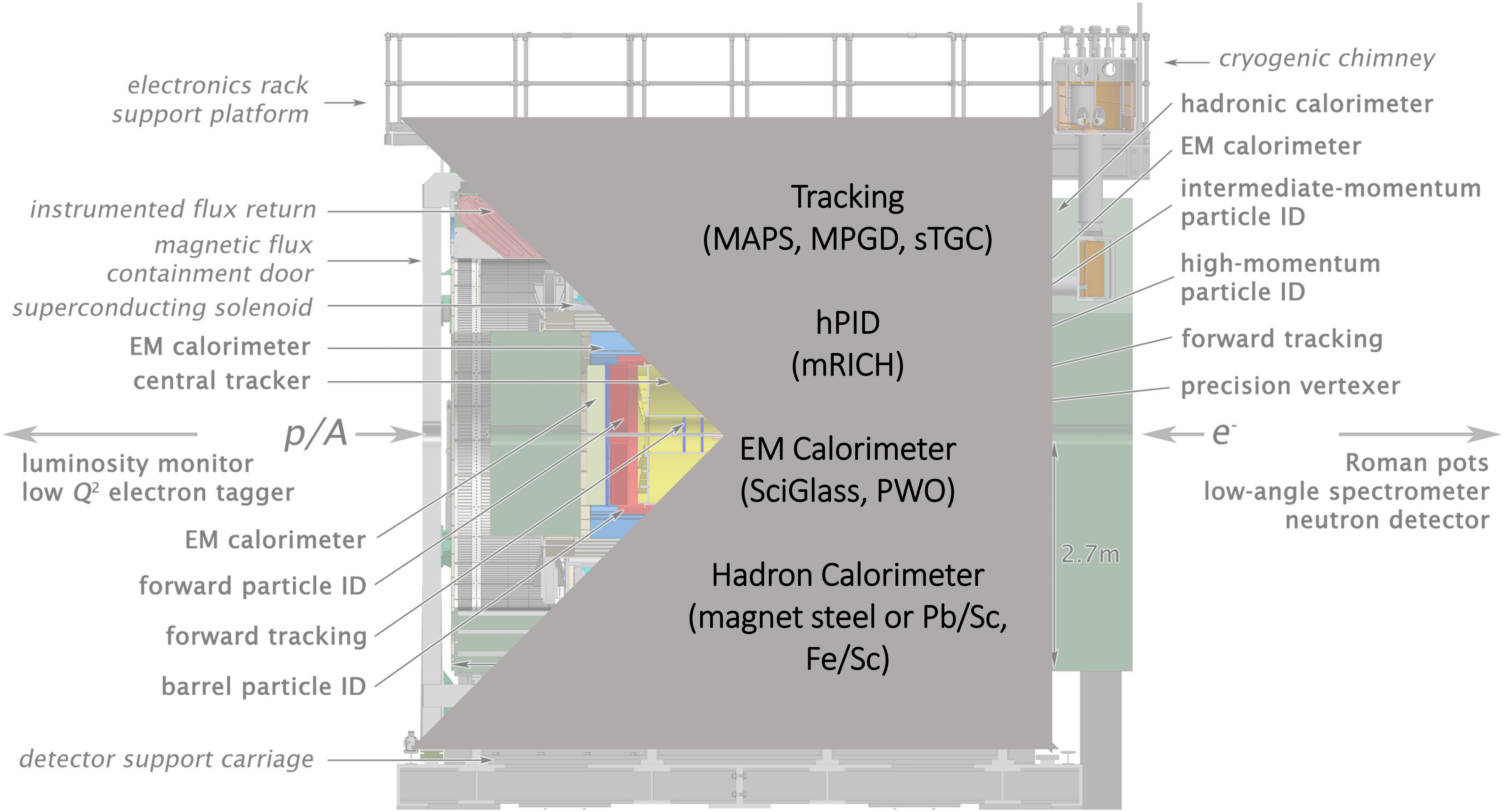
Central Barrel Technologies



Hadron Endcap Technologies



Electron Endcap Technologies

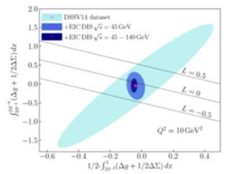


ECCE Physics Studies Focus: a first look

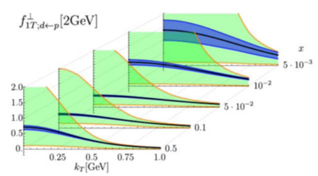
Studies to demonstrate EIC NAS Study, Yellow Report physics	**Studies to show unique ECCE strengths**

Studies to demonstrate EIC NAS Study, Yellow Report physics

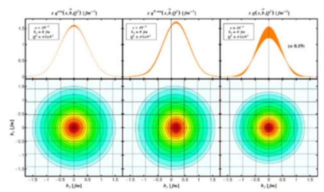
- Origin of Nucleon Spin



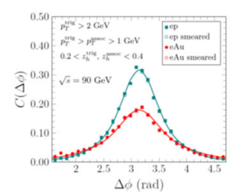
- Confined motion of partons



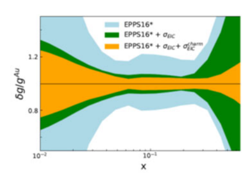
- 3D imaging quarks and gluons



- Nucleon mass
- High gluon densities in nuclei

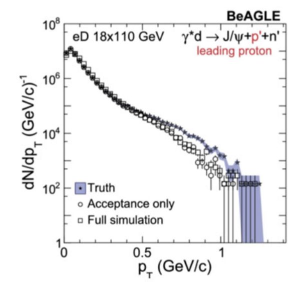


- Quarks and gluons in the nucleus

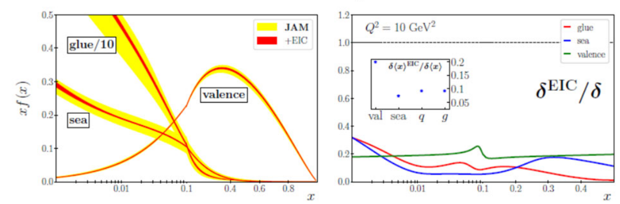


Studies to show unique ECCE strengths

- Light-ion tagging



- Pion/Kaon structure

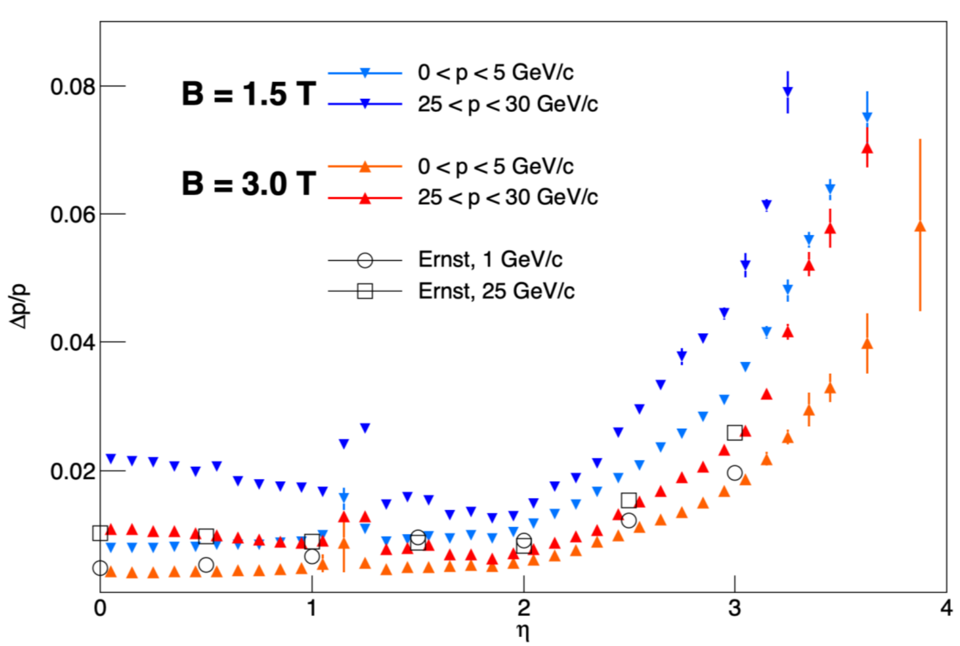


- Diffractive jets?
- Nuclear modifications and in-medium evolution
  - D/D* reconstruction and heavy-flavor in jets.

Challenges with B=1.5T

Resolution in forward region η > 2.5

- ❑ Jets and heavy flavor group requires higher resolution in forward hadron region.



Jets/HF WG (https://wiki.bnl.gov/eicug/index.php/Yellow_Report_Physics_Jets-HF)

Track Momentum Resolution

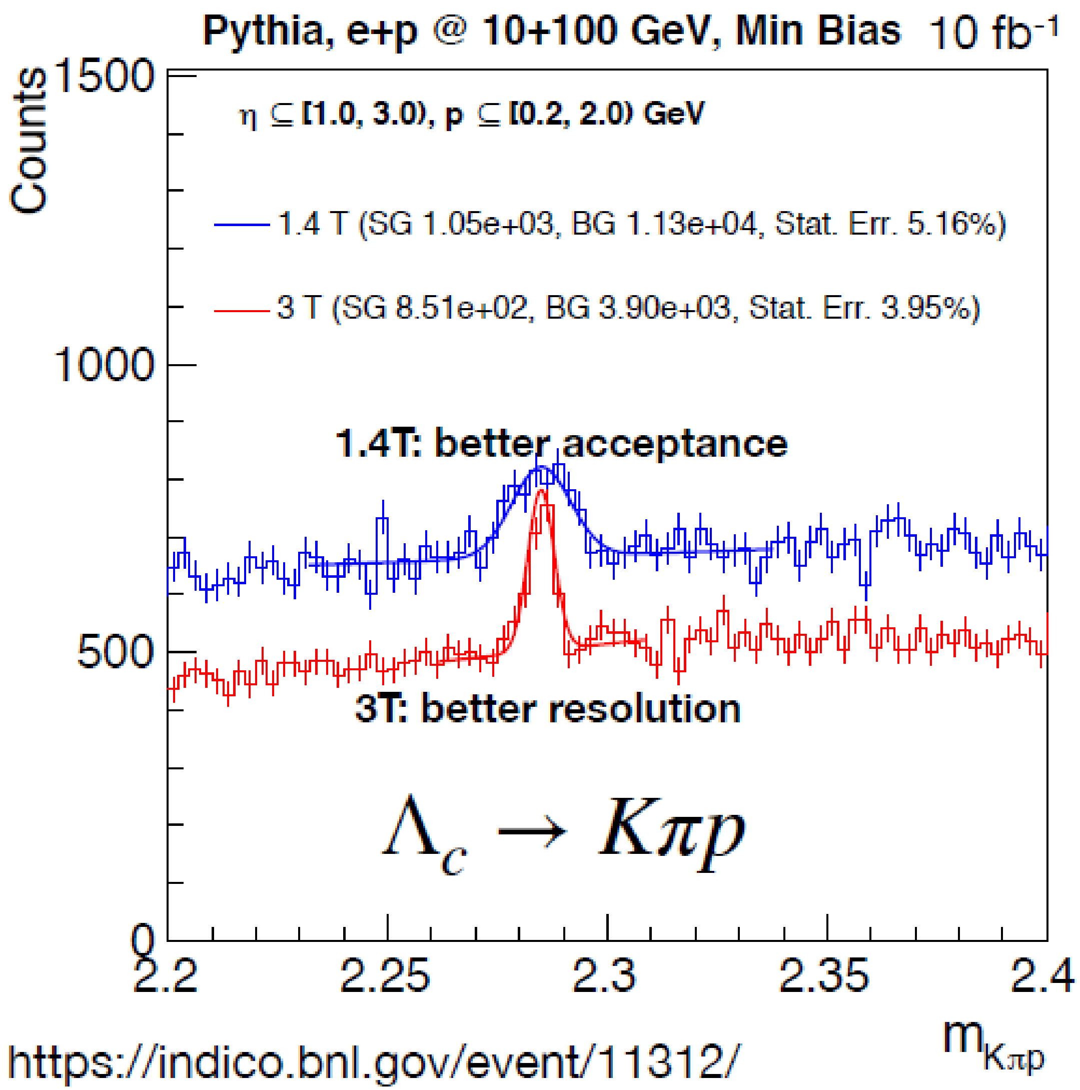
Eta Range	Default Resolution (σP/P)%	Requested (σP/P)%
-3.5 < η < -2.5	0.1%*P + 0.5%	Same
-2.5 < η < -2.0	0.1%*P + 0.5%	Same
-2.0 < η < -1.0	0.05%*P + 0.5%	Same
-1.0 < η < 1.0	0.05%*P + 0.5%	Same
1.0 < η < 2.5	0.05%*P + 1.0%	Same
2.5 < η < 3.5	0.1%*P + 2.0%	Same

Investigating options for field shaping.

- ❑ However, lower field can also be useful in tagging and reconstruction of certain heavy mesons (D*) – resolution vs. acceptance/efficiency balance

Pseudorapidity Range	Min p_T (3T) [MeV/c]	Min p_T (1.5T) [MeV/c]
$0.0 < \eta < 1.0$	400	200
$1.0 < \eta < 1.5$	300	150
$1.5 < \eta < 2.0$	160	70
$2.0 < \eta < 2.5$	220	130
$2.5 < \eta < 3.5$	150	100

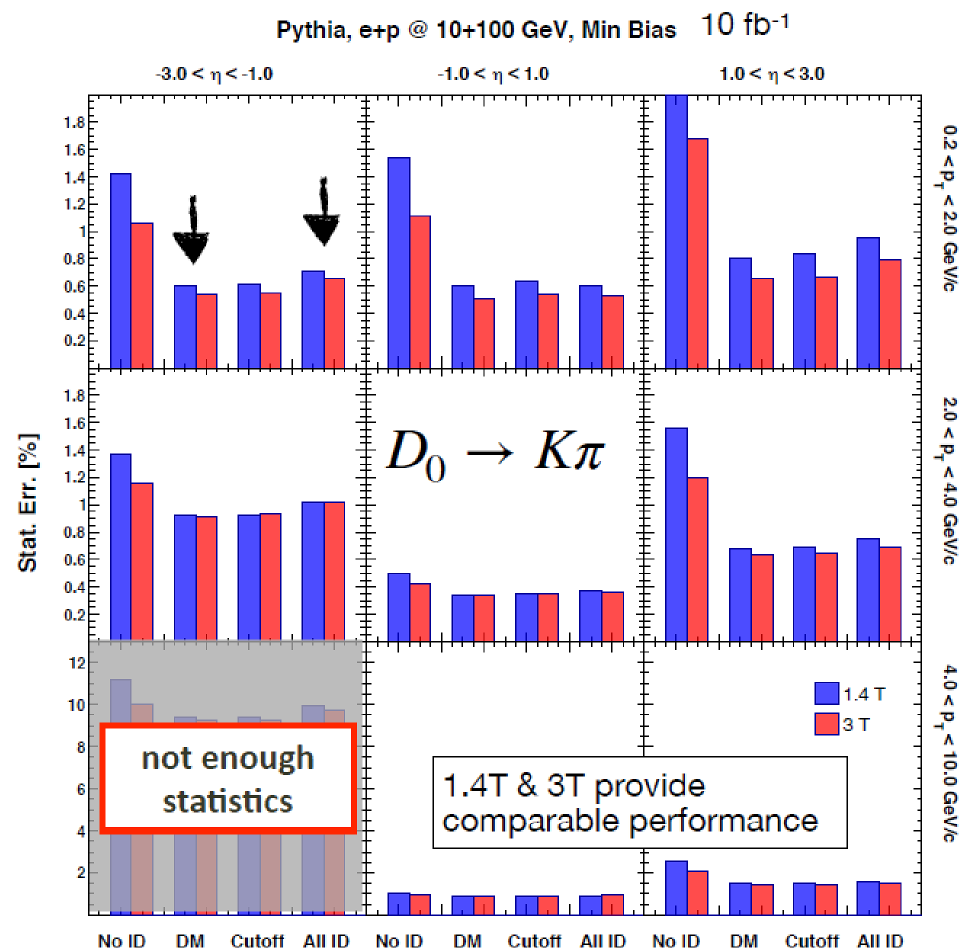
Heavy Flavor in ECCE



https://indico.bnl.gov/event/11312/

Recent Study by Wenqing Fan (LBNL)

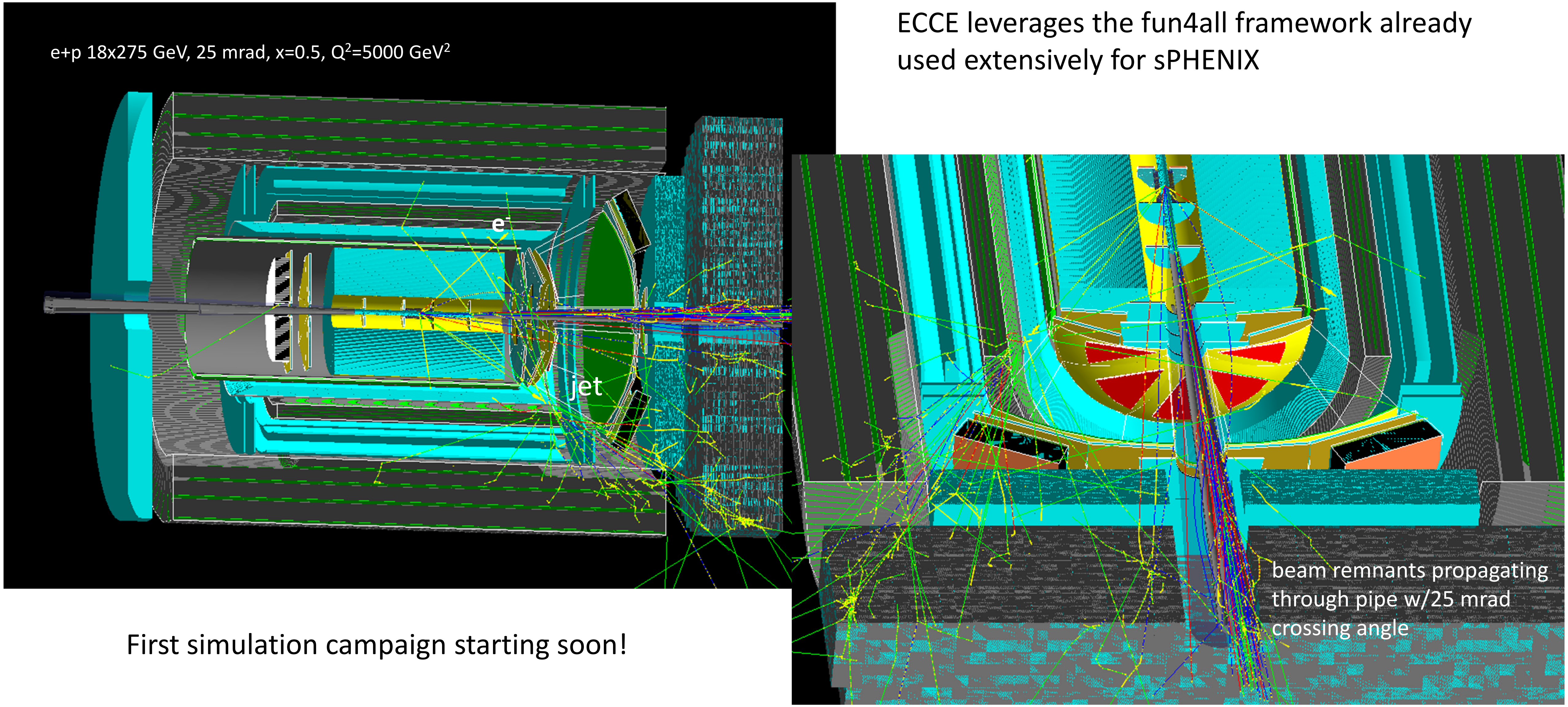
- *Fast simulation of PID, based on YR specifications*
- *Parallel effort ongoing with full detector G4 simulations*



G4 Simulations

https://ecce-eic.github.io

ECCE leverages the fun4all framework already used extensively for sPHENIX



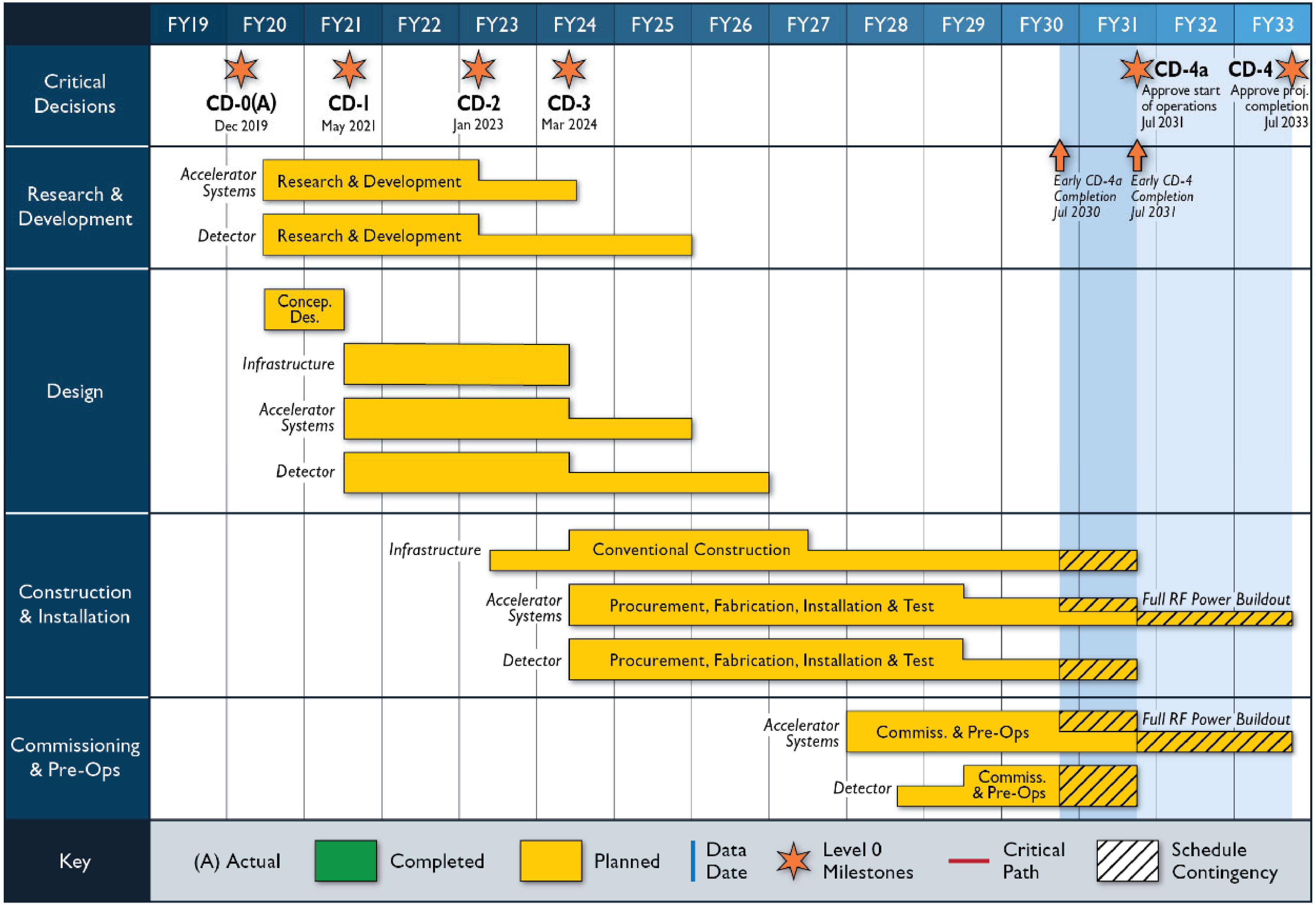
First simulation campaign starting soon!

Conclusions

- The ECCE consortium is 64 institutions (& growing) planning to design the EIC project detector based around the BaBar solenoid
- By reducing cost and risk, the plan is to be ready for physics by EIC CD4a, as soon as possible at the start of machine operations.
- The physics program spans the entirety of that outlined in the NAS study and the Yellow Report
- The detector design process has begun, in tandem with a wide range of full physics simulations

https://ecce-eic.org

BACKUP



From Jim Yeck
3/30/21

ECCE Timeline

Today, 28 April

Tasks	Duration (months)	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Startup	**1.5**									
Implement ECCE setup in Fun4All										
Agree on technology alternatives to study										
Agree on main physics studies										
Arrange required event generators										
First simulation campain & initial analysis	**1.5**									
Optimize										
Midterm activities	**1**									
Large scale simulations production										
Drafting Collaboration Structure part of the proposal										
Analysis of simulation data	**1.5**									
demonstrate physics extraction										
Start of Proposal Writing	**1.5**									
All physics plots are done										
Agree on technology selection based on physics studies										
Compose narrative around simulation results and selected technologies										
Proposal Review and final edits	**1**									
Review by external colleagues										
Final edits										
Proposal Submission (1 Dec. 2021)										

Central Barrel Space Constraints

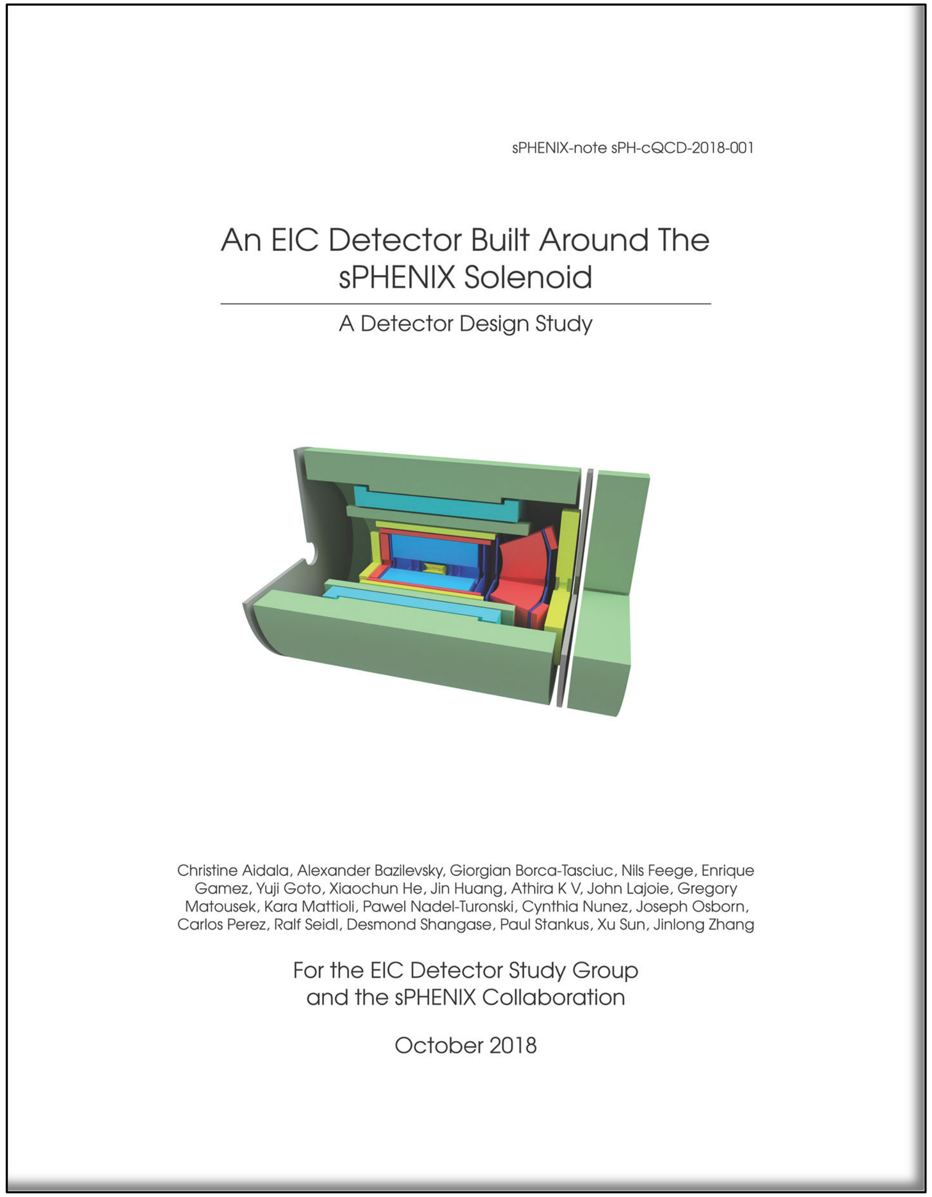
Tracking	all-Si maybe down to 50-60 cm, Si + TPC = 80 cm
Tracking support structure	5 cm
Hadron particle identification	DIRC only needs 10 cm, RICH 50 cm but better for uniformity
EM Calorimetry	50 cm for high-resolution, 30 cm for less-resolution (or costly)
PID & EMCal support structure	10-15 cm likely enough

Function	Minimum [cm]	Maximum [cm]	Minimum [cm]	Maximum [cm]
Tracking (includes 5 cm support)	All-Si		Si + TPC	
	65		85	
Hadron particle identification	RICH		DIRC	
	50		10	
EM Calorimetry	30	50	High-Resolution to achieve P < 2 GeV	
			50	
PID & EMCal support structure	10	15	10	15
Total	145	165	155	160

Need to discuss the fit of all detectors in the existing magnet with bore 2.8 meter - will be a tour de force and will require optimization.

From 4th YR Workshop – talk on magnet

Prior Design Studies


sPHENIX-note sPH-cQCD-2018-001

An EIC Detector Built Around The sPHENIX Solenoid

A Detector Design Study

Christine Aidala, Alexander Bazilevsky, Giorgian Borca-Tasciuc, Nils Feege, Enrique Gamez, Yuji Goto, Xiaochun He, Jin Huang, Athira K V, John Lajoie, Gregory Matousek, Kara Mattioli, Pawel Nadel-Turonski, Cynthia Nunez, Joseph Osborn, Carlos Perez, Ralf Seidl, Desmond Shangase, Paul Stankus, Xu Sun, Jinlong Zhang

For the EIC Detector Study Group and the sPHENIX Collaboration

October 2018

- Previous 2014/18 studies centered on BaBar solenoid
  - 2018 study in response to charge by BNL ALD
    (see talk by Christine Aidala)
  - Flexible, complete G4 simulation framework already exists for ECCE studies
    - Foundation for ECCE proposal work

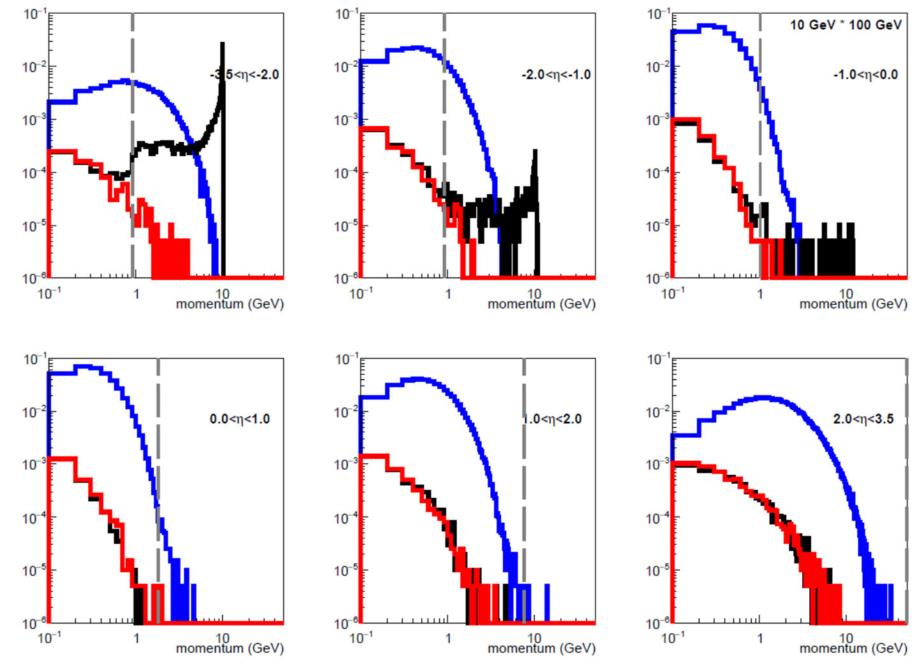
arXiv:1402.1209
https://indico.bnl.gov/event/5283/

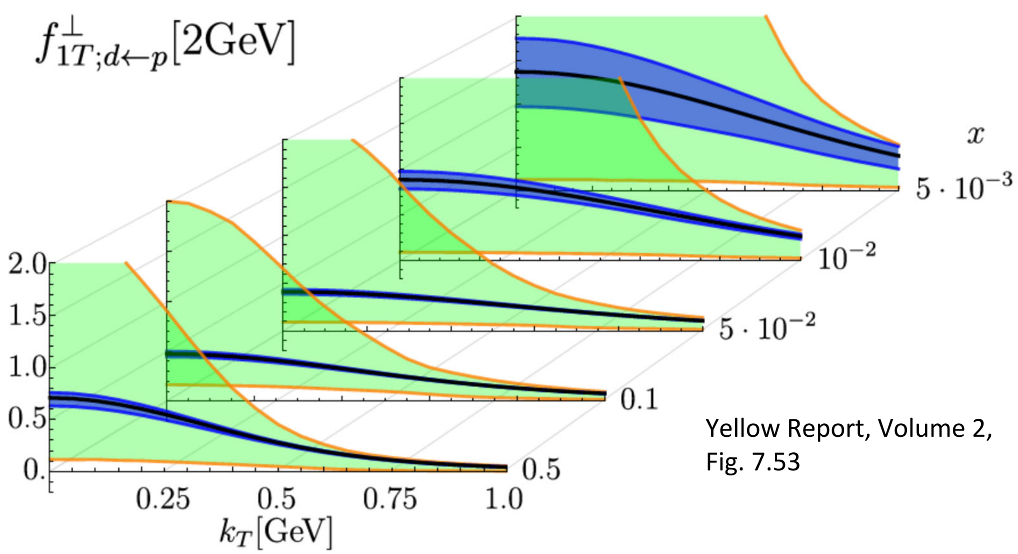
Example of ECCE Physics : Spin

Major requirements:
- ❑ Precision calorimetry in lepton endcap
- ❑ PID in barrel

ECCE:
- ❑ High resolution calorimetry in lepton endcap
- ❑ PID in barrel
- ❑ PID in forward endcap enables also TMDs

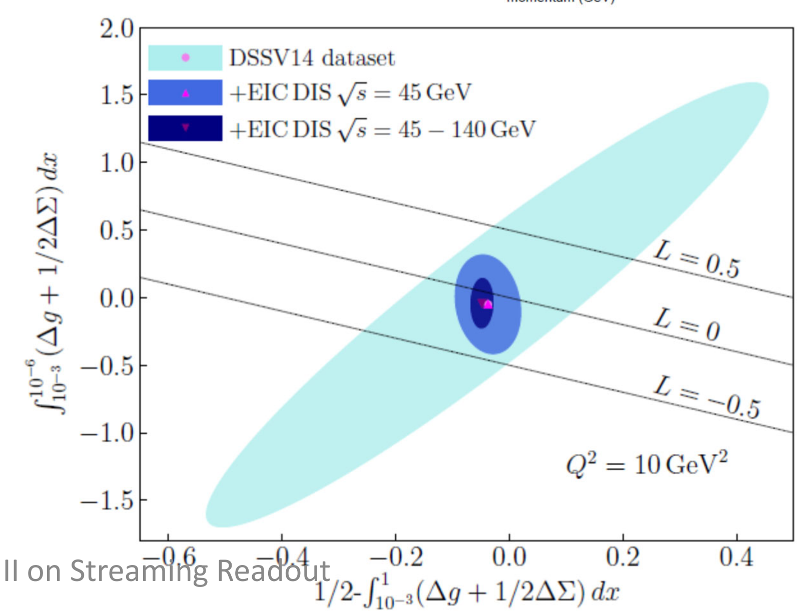
Scattered Electron Backgrounds





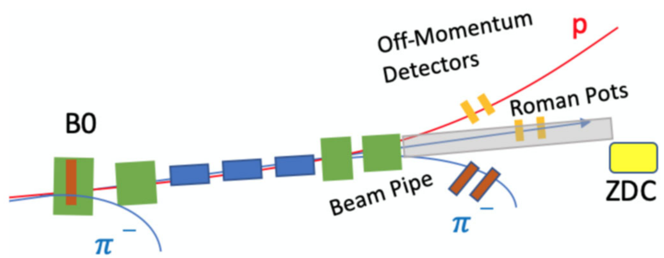
Yellow Report, Volume 2, Fig. 7.53

Yellow Report, Volume 2, Chapter 7



Yellow Report, Volume 2, Fig. 7.17 and 8.11

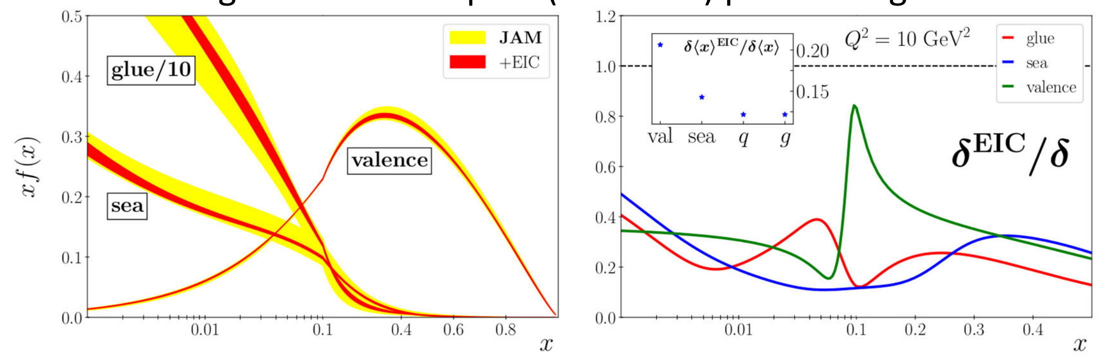
Example of ECCE Physics : Origin of Hadron Mass



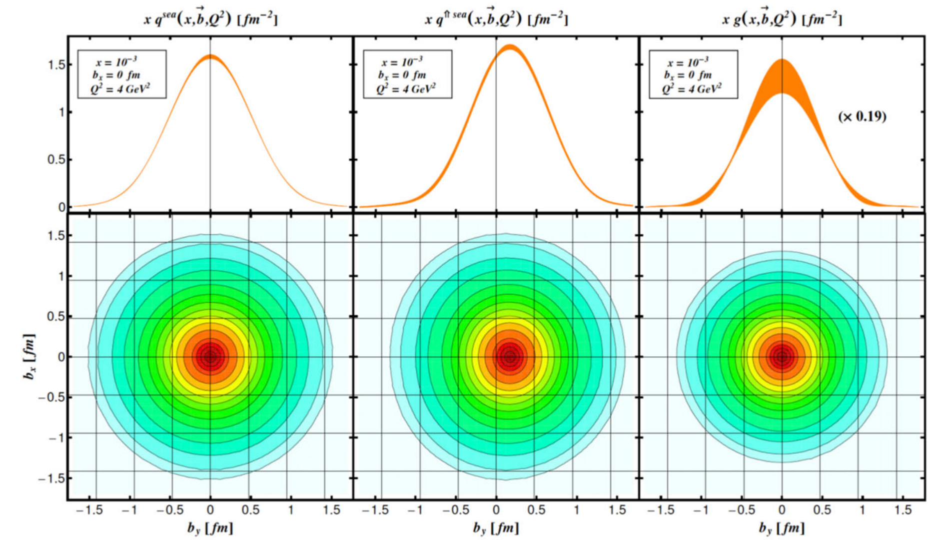
Major requirements

- Far-forward detection to tag n and Λ (or Σ°) (meson structure) and to tag p (for DVCS/3D).
- Scattered electron detection in electron endcap
- Good hadron endcap and far-forward calorimetry (goal: 35%/E, <50%/E acceptable)
- For pion form factor: pion in hadron endcap

Large reduction in pion (structure) pdfs through EIC



Yellow Report, Volume 2, Fig. 7.24



Yellow Report, Volume 2,Fig. 7.46

ECCE – physics reach enhanced in x_L and x_B with beam focus with dispersion – relevant for diffraction (e-p, e-A) and tagging (e-d, e-^{3}He, etc), and exclusive measurements

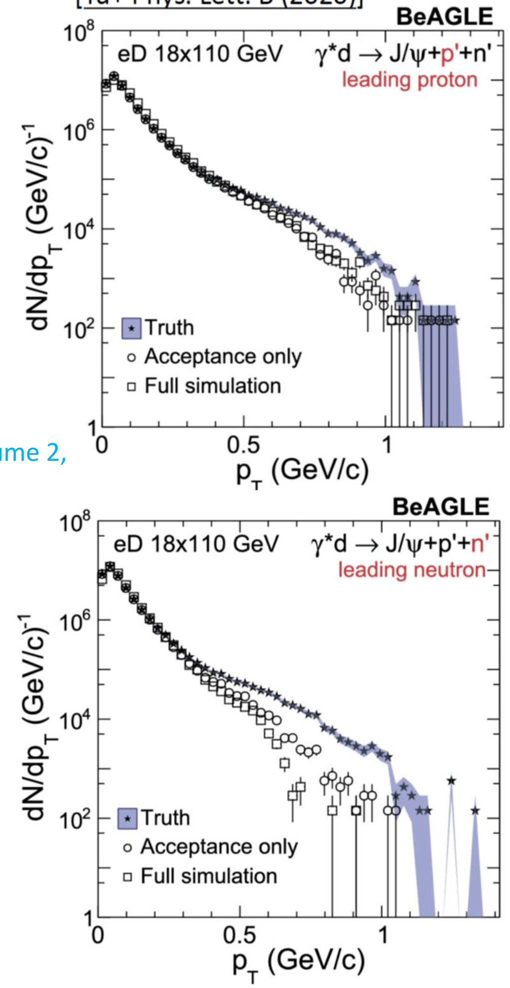
#	Parameter	EIC IR #1	EIC IR #2	Impact
8	Minimum $\Delta(B\rho)/(B\rho)$ allowing for detection of $p_T = 0$ fragments	0.1	$0.003 - 0.01$	Beam focus with dispersion, reach in x_L and p_T resolution, reach in x_B for exclusive processes

From 4th YR Workshop – talks on complementarity (Y. Zhang, V. Morozov)

Example of ECCE Physics : Nuclei

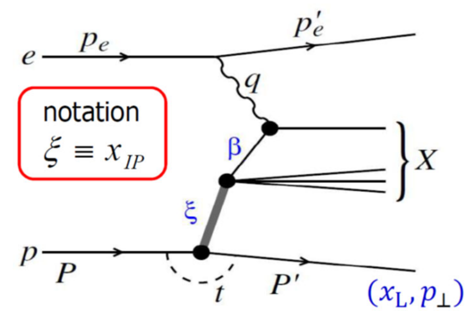
Incoherent diffractive J/Ψ production in e-d tagging

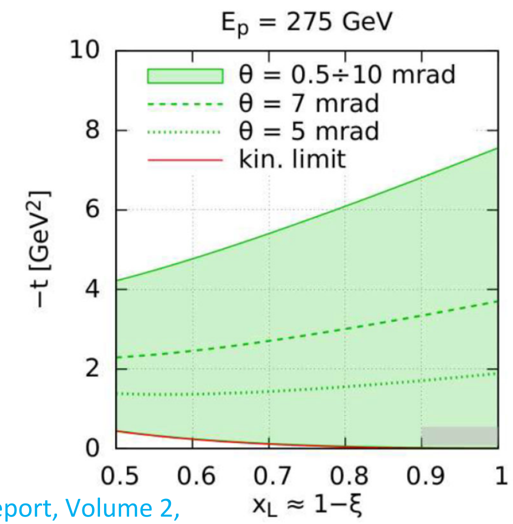
[Tu+ Phys. Lett. B (2020)]



Yellow Report, Volume 2, Fig. 7.73

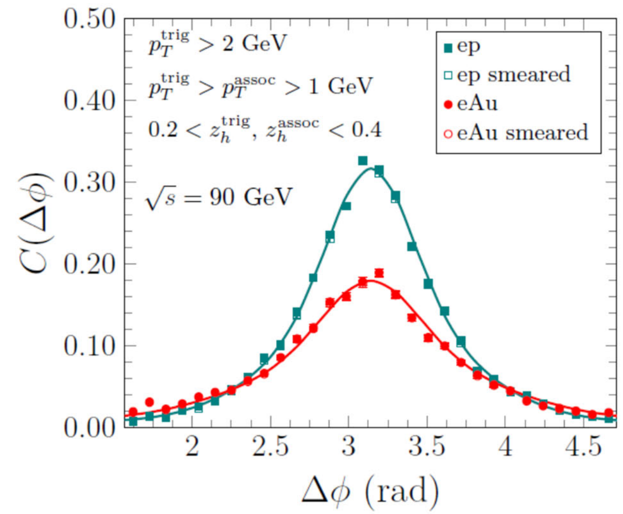
Inclusive diffraction in e-A



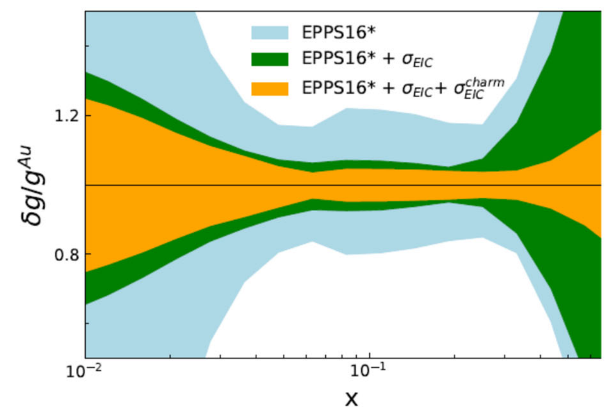


Yellow Report, Volume 2, Fig. 7.30

di-hadron azimuthal angle correlation, nuclear glue ratio through inclusive and open charm



Yellow Report, Volume 2, Fig. 7.63



Yellow Report, Volume 2, Fig. 7.69

ECCE – physics reach enhanced in x_L and x_B with beam focus with dispersion – relevant for diffraction (e-p, e-A) and tagging (e-d, e-^{3}He, etc), and exclusive measurements