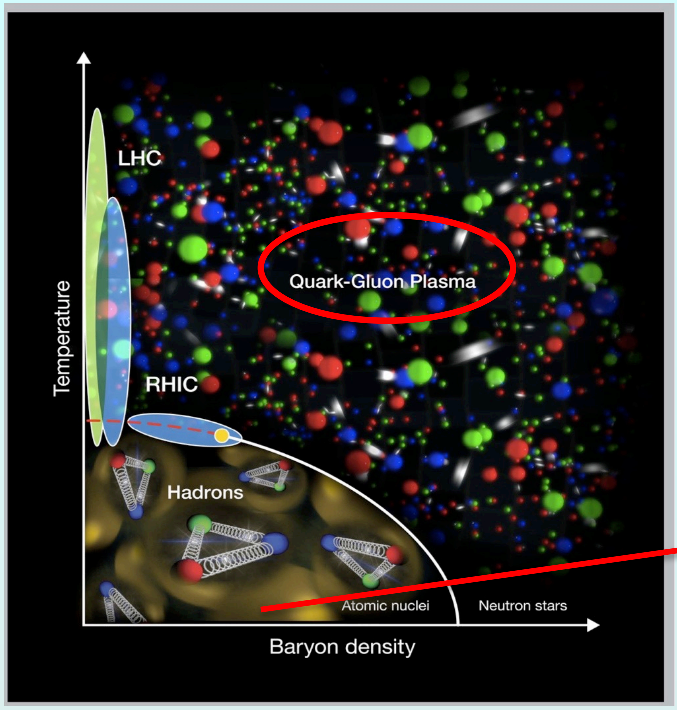
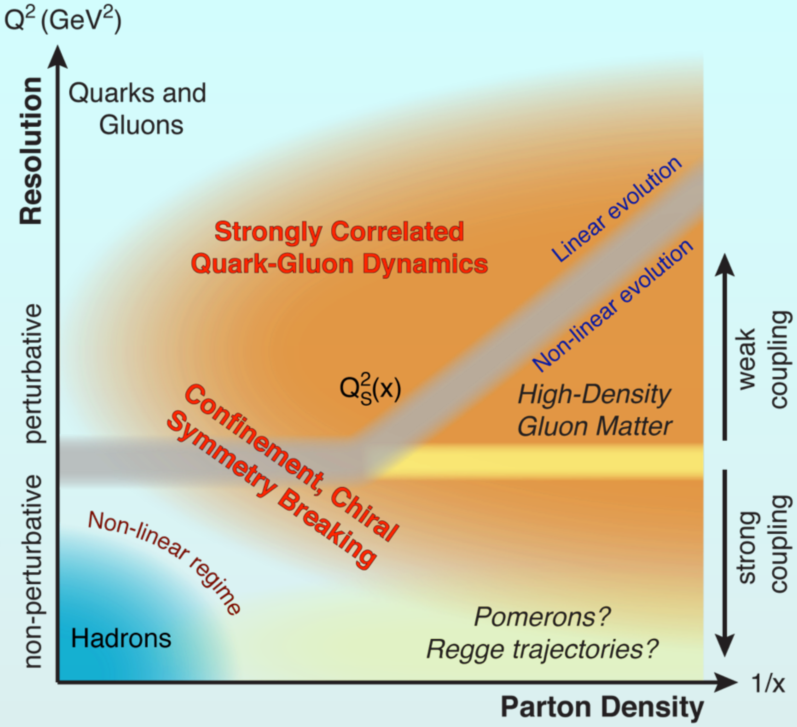
EIC Project Overview



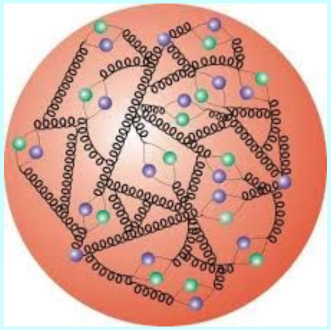


Barbara Jacak

UC Berkeley & LBNL

July 18, 2022

A key goal: small x in e+p & e+A



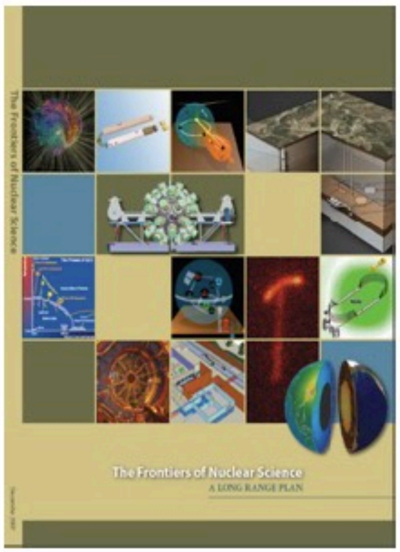
Density of gluons increases
as $x = p_g/p_N$ gets smaller

- Measure low x parton density & spin asymmetry
- To probe the small x region in e+A, excite a small x parton and see how its fate depends on A
  (➔ vary the path length, density)
- Look as a function of x and Q^2
  (➔ vary medium density & the probe)
- Use data + theory to extract transport parameters.

The Electron-Ion Collider – The Next QCD Frontier

2018 NAS Report : An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:

- How does the **mass** of the nucleon arise?
- How does the **spin** of the nucleon arise?
- What are the emergent properties of dense systems of gluons?



NSAC LRP 2007


The EIC Science case: a report on the joint BNL/INT/JLab program

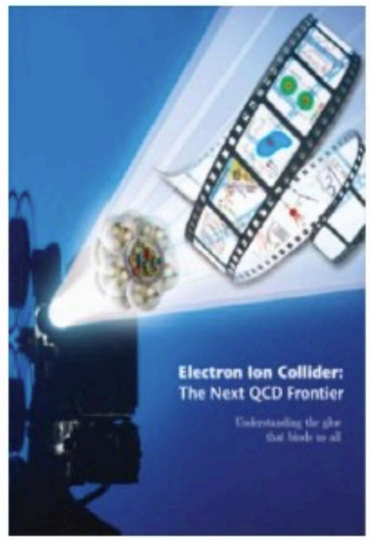
Gluons and the quark sea at high energies: distributions, polarization, tomography

Institute for Nuclear Theory, University of Washington, USA
September 13 to November 18, 2010

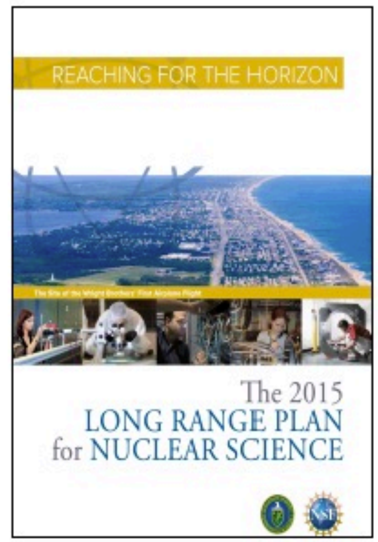
Editors:
D. Boer, Universität Groningen, The Netherlands
M. Diehl, Deutsches Elektronen-Synchroton DESY, Germany
R. Milner, Massachusetts Institute of Technology, USA
R. Venugopalan, Brookhaven National Laboratory, USA
W. Vogelsang, Universität Tübingen, Germany

Brookhaven National Laboratory, Upton, NY
Institute for Nuclear Theory, Seattle, WA
Thomas Jefferson National Accelerator Facility, Newport News, VA

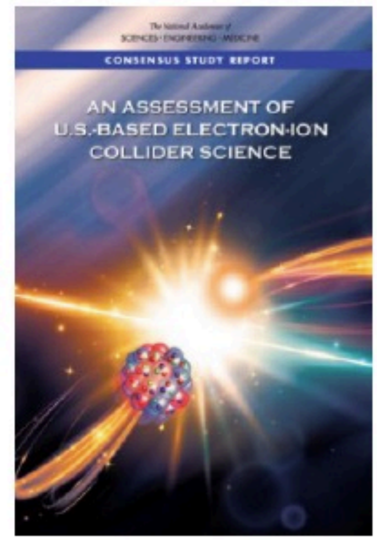
EIC INT Report 2011



EIC White Paper 2015



NSAC LRP 2015

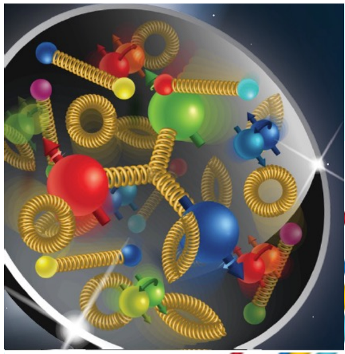


NAS Report 2018

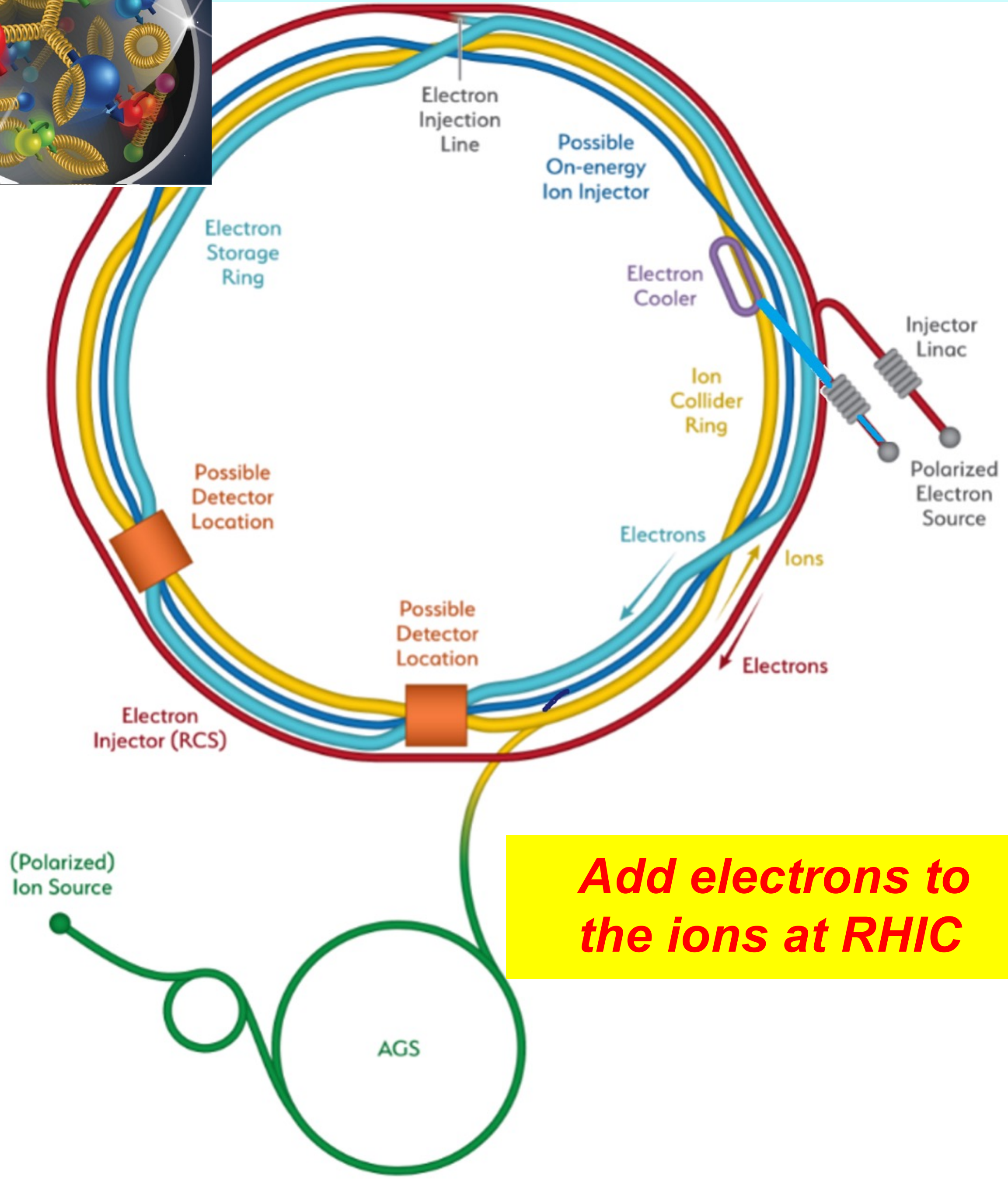
Brookhaven National Laboratory

A long journey with years of community effort – the DOE announced the selection of BNL as the site for the EIC on Jan 9, 2020
CD-1 June 2021, partnership between BNL and Jefferson Lab

Haiyan Gao

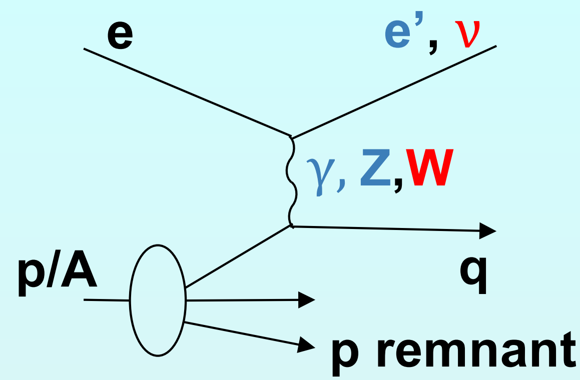


Electron-ion collider at Brookhaven



Add electrons to the ions at RHIC

Scatter electrons from nuclei



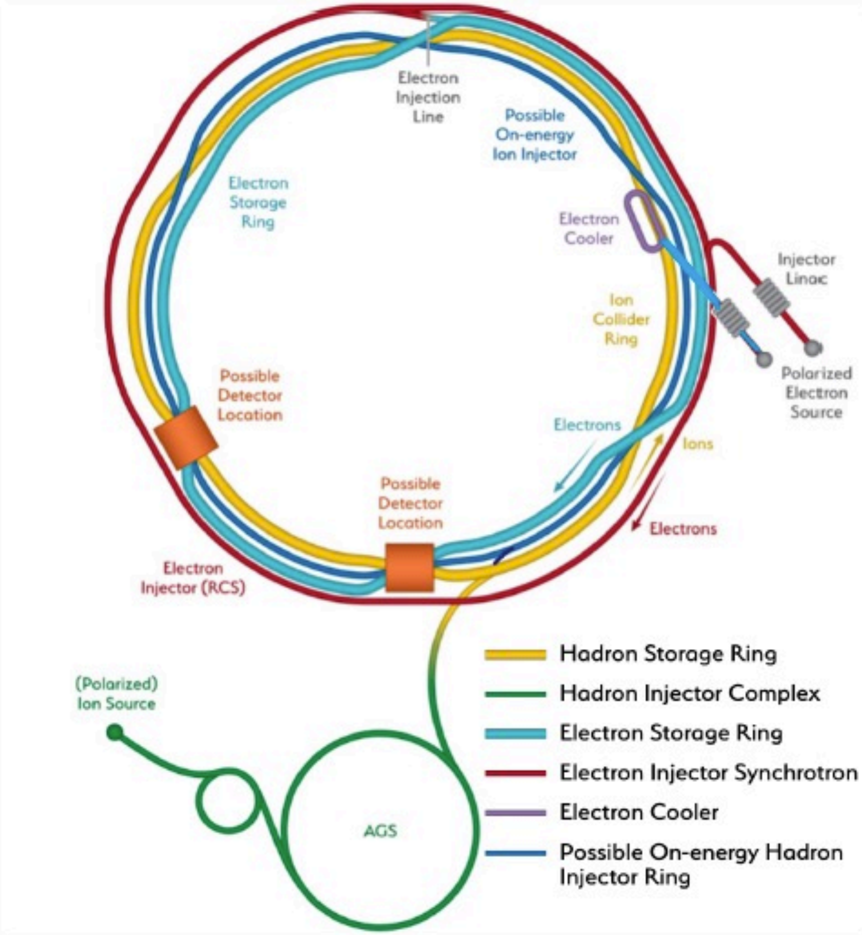
- $\sqrt{s}$ = 30 to 140 GeV

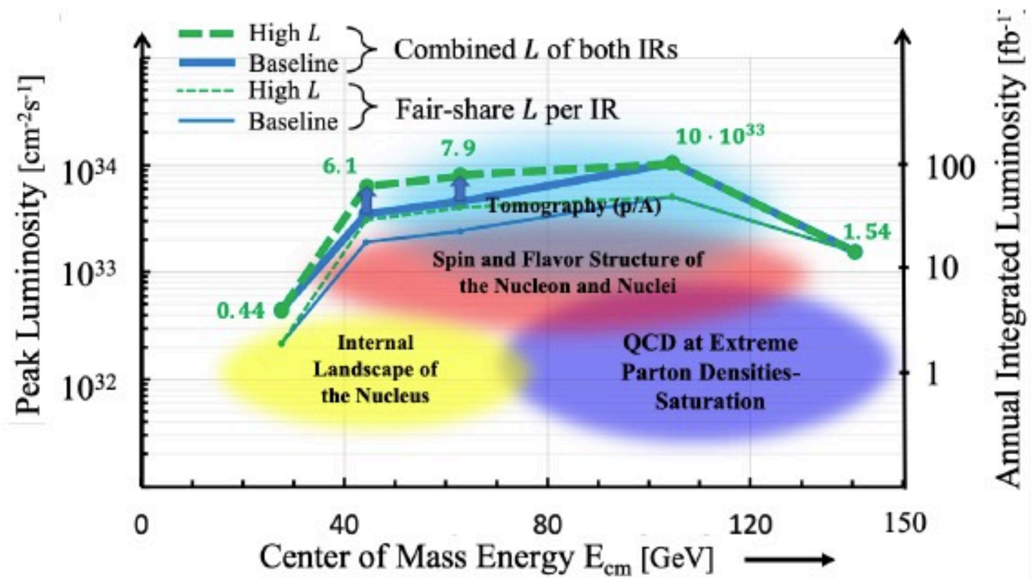
Hadron Storage Ring
Electron Storage Ring
Electron Injector Synchrotron
Possible on-energy Hadron injector ring
Hadron injector complex

EIC Accelerator Design

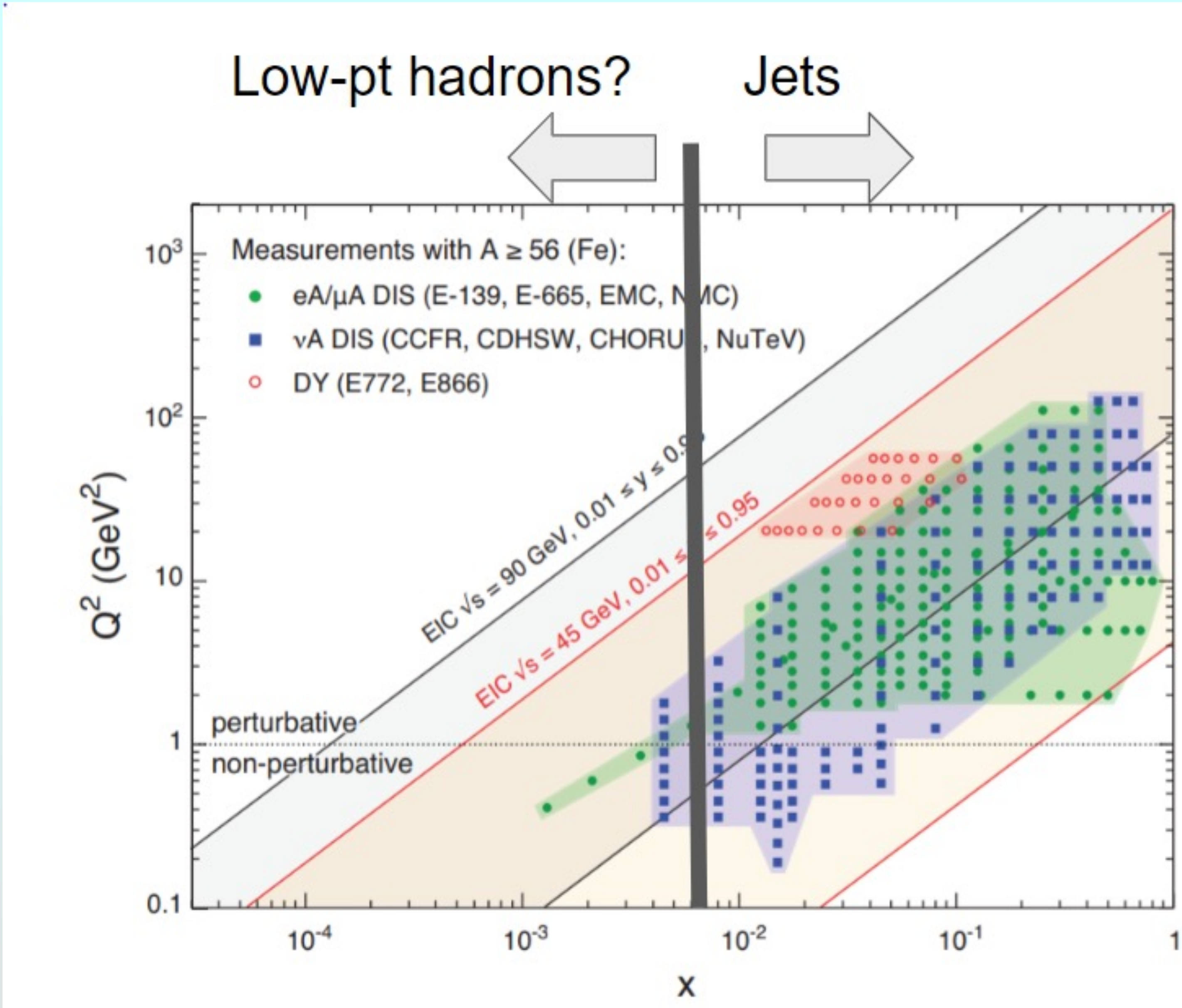
10

Center of Mass Energies:	20GeV - 140GeV
Luminosity:	10^{33} - 10^{34} $cm^{-2}s^{-1}$ / 10-100fb^{-1} / year
Highly Polarized Beams:	70%
Large Ion Species Range:	p to U
Number of Interaction Regions:	Up to 2!





To reach low x where gluons are dense



use single hadrons

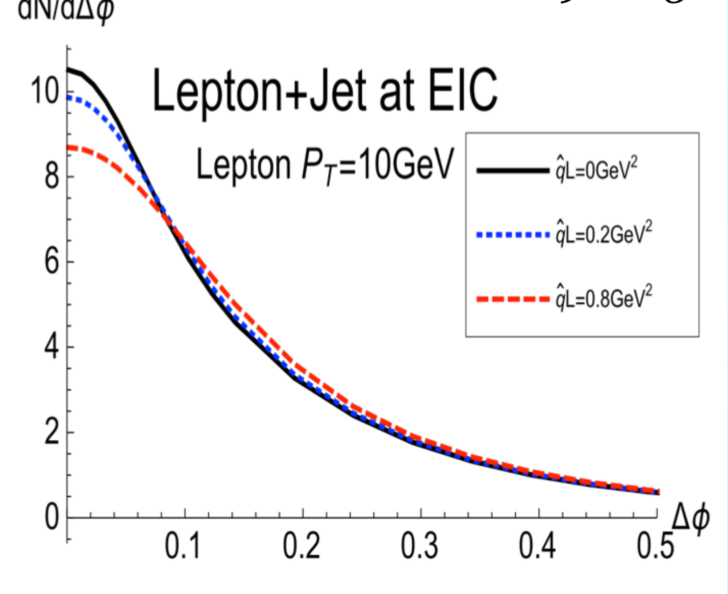
NB: jets are better!

energy loss & medium modification observables

- **Energy balance**
  via lepton-jet correlations

- **medium effects -> jet p_T broadening**
  multiple scatter
  induced radiation
  fragmentation function modified

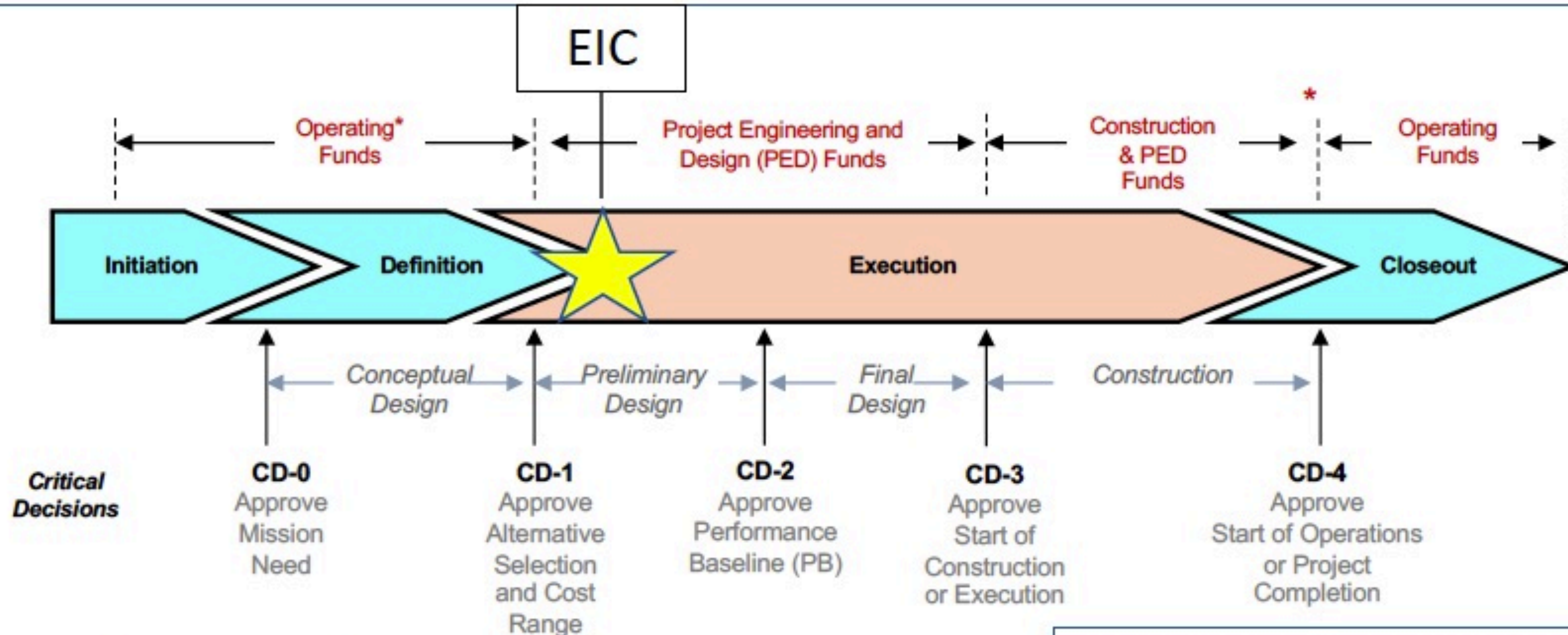
PRL 122 192003



- **Energy flow/shower development**
  Hadron formation in jets
  …

- **Di-jet correlations**

DOE Project Decision Process



Formal Process of Gateway Reviews

- CD-0, Mission Need
- CD-1, Alternative Selection and Cost Range
- CD-2, Performance Baseline
- CD-3a, Long Lead Procurement

EIC Critical Decision Plan at CD-1	
CD-2/3a	April 2023
CD-3	July 2024
CD-4a early finish	July 2030
CD-4a	July 2031
CD-4 early finish	July 2031
CD-4	July 2033

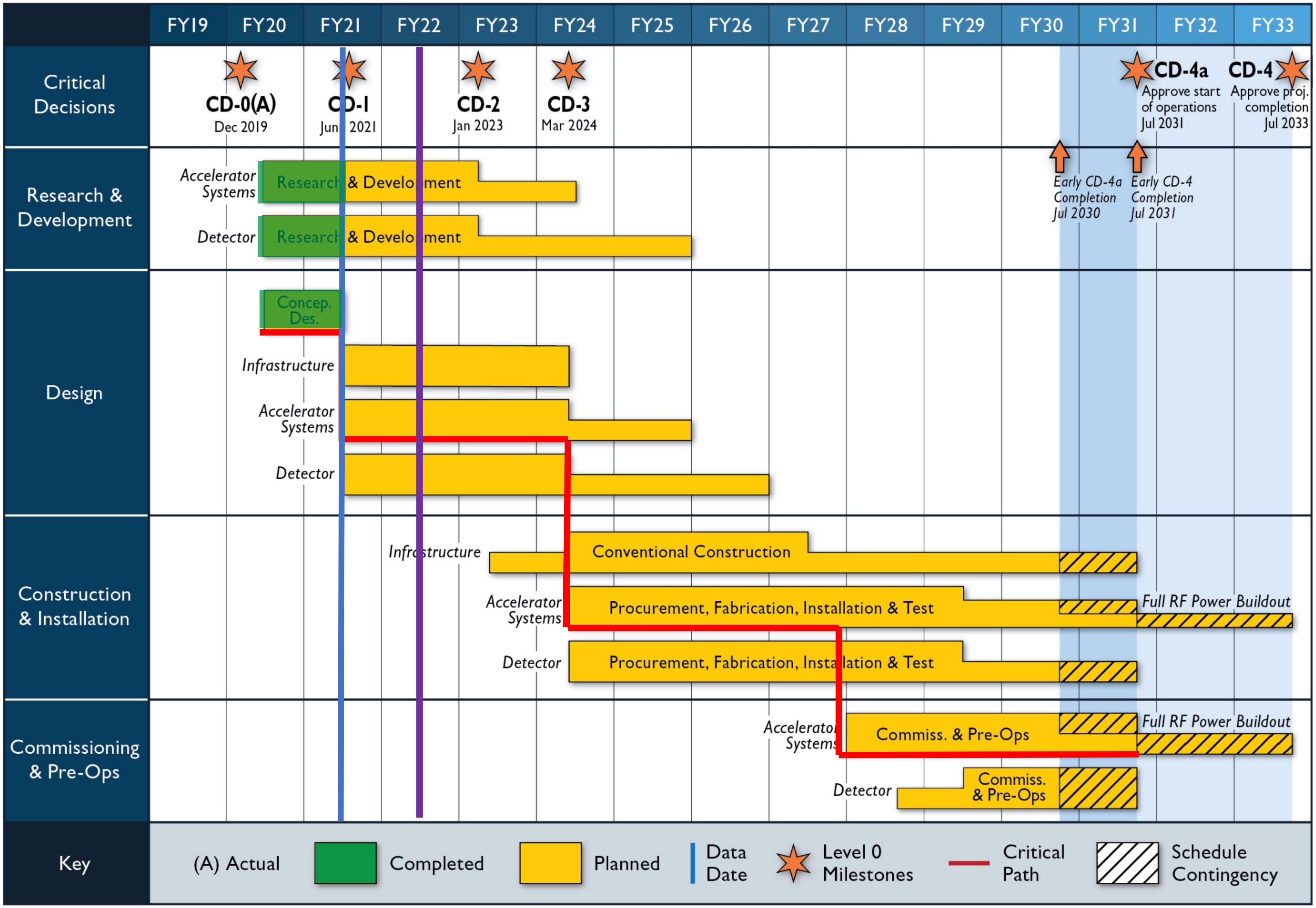
Total Project Cost (without contingency)

WBS	Description	Total M$	DOE M$
6	**Electron-Ion Collider**	**$ 1,848**	**$ 1,606**
6.01	Project Management	$ 103	$ 103
6.02	Accelerator Dev & R&D	$ 70	$ 70
6.03	Electron Injector	$ 195	$ 171
6.04	Electron Storage Ring	$ 310	$ 285
6.05	Hadron Ring	$ 199	$ 199
6.06	Interaction Regions & Detector Interface	$ 195	$ 195
6.07	Accelerator Support Systems	$ 230	$ 230
6.08	Infrastructure	$ 210	$ 110
6.09	Pre-Operations	$ 80	$ 80
6.10	EIC Detector	$ 255	$ 162

$100M New York State
$ ~93M Detector In-kind
$ ~49M Accelerator In-kind

- ***$1,606 + ~40% = $2,249M***

Schedule


FY19
FY20
FY21
FY22
FY23
FY24
FY25
FY26
FY27
FY28
FY29
FY30
FY31
FY32
FY33
Critical Decisions
CD-0(A)
Dec 2019
CD-1
Jun 2021
CD-2
Jan 2023
CD-3
Mar 2024
CD-4a
Approve start of operations
Jul 2031
CD-4
Approve proj. completion
Jul 2033
Research & Development
Accelerator Systems
Research & Development
Detector
Research & Development
Early CD-4a Completion Jul 2030
Early CD-4 Completion Jul 2031
Design
Concep. Des.
Infrastructure
Accelerator Systems
Detector
Construction & Installation
Infrastructure
Conventional Construction
Accelerator Systems
Procurement, Fabrication, Installation & Test
Full RF Power Buildout
Detector
Procurement, Fabrication, Installation & Test
Commissioning & Pre-Ops
Accelerator Systems
Commiss. & Pre-Ops
Full RF Power Buildout
Detector
Commiss. & Pre-Ops
Key
(A) Actual
Completed
Planned
Data Date
Level 0 Milestones
Critical Path
Schedule Contingency

FY22 Funding Update

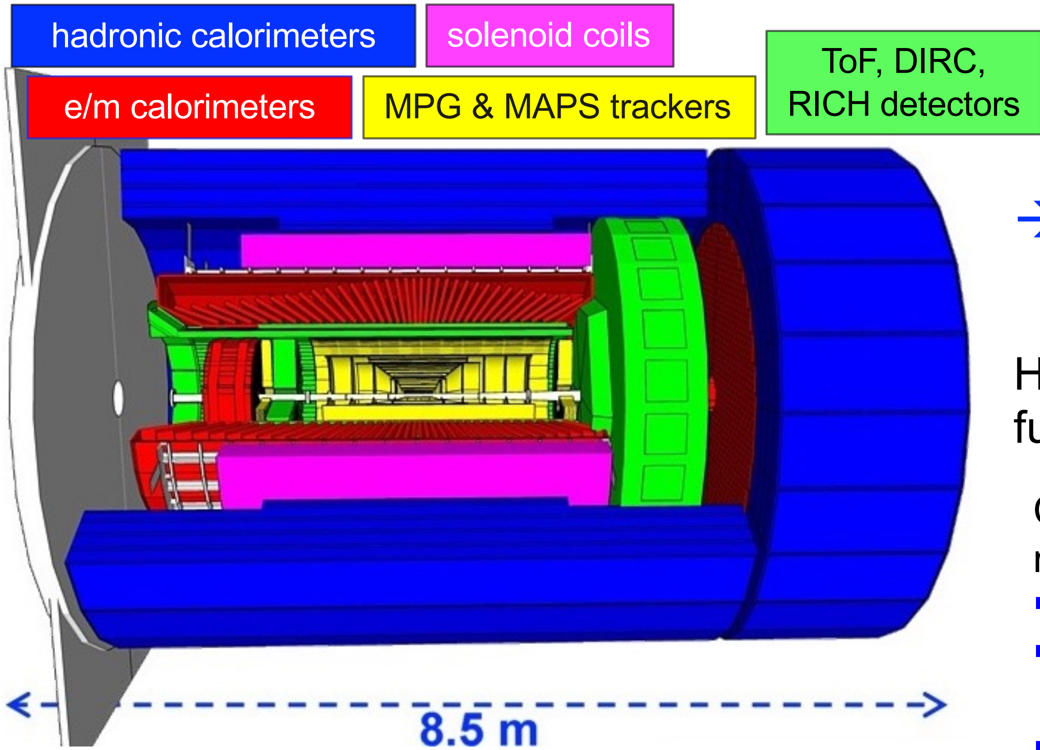
- The Continuing Resolution (CR) was over after almost six months.
- EIC funding will be a minimum of $45M, less than the reference funding profile but more than the CR.
- EIC can move forward with design, critical R&D, some hiring and planning activities to prepare for CD-2/3A
- The plan for CD-2/3A approval and the reference schedules is being revised.
- Start EIC Detector R&D!
- Indication from DOE/NP to resume generic detector R&D program in FY22, similar as program that was successfully hosted for a decade through BNL.

Timeline – What Is Coming

CD-0 approval	December 19, 2019
Community-wide Yellow Report effort	Dec. 2019 – Feb. 2021
CD-1 review (includes CDR)	January 26-29, 2021
Call for Collaboration Proposals for Detectors	March 6, 2021
CD-1 approval	June 29, 2021
DOE/OPA Status Review	October 19-21, 2021
Status Update to Federal Project Director	June 28-30, 2022, @BNL
Cost and Schedule Event(s)	May-June 2022
Technical Subsystem Reviews	January – December 2022
OPA Status Review	January 2023
Preliminary Design Complete & Review	May 2023
Final Design/Maturity Readiness for CD-3A Items	May 2023
CD-2/3A review (expectation), requires pre-TDR	~October 2023
CD-2/3A (expectation)	~January 2024
CD-3 review (expectation)	~January 2025
CD-3 (expectation), requires TDR	~April 2025

Elke Aschenauer

Experimental Equipment Status Update



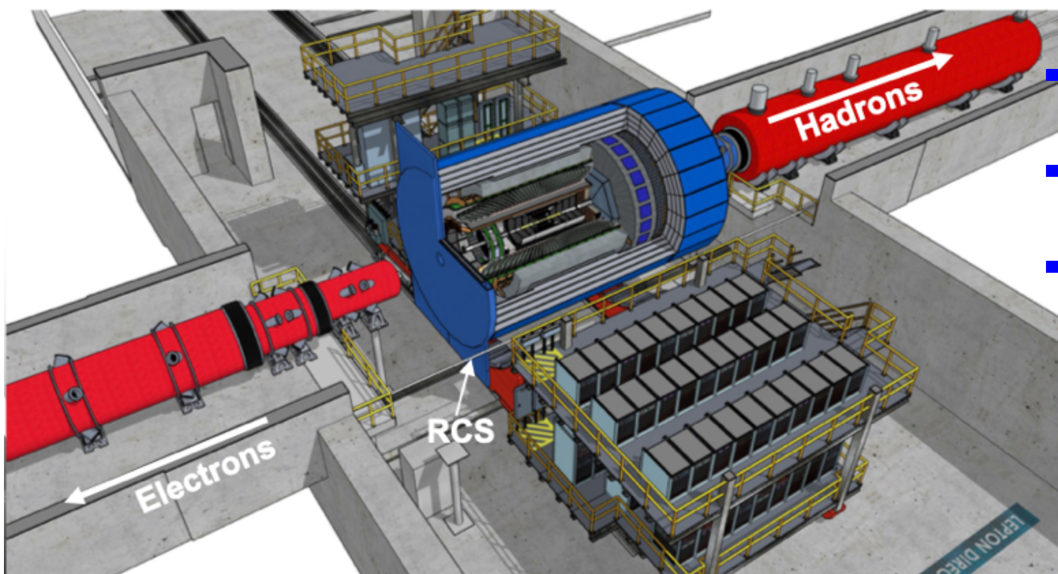
Finalized Project Detector selection process 8th of March 2022

→ ECCE general-purpose Detector around the BaBAR 1.5 T Solenoid

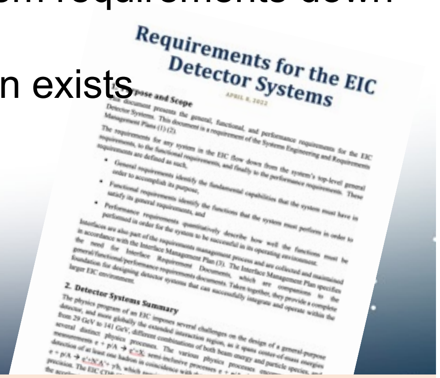
Hermetic coverage:
full Φ-coverage in $2^o < \Theta < 178^o$ ($-4<\eta<4$)

Consolidation of ECCE and ATHENA in full swing, make integration of all groups as welcoming as possible

- Combined Leadership Team formed
- Combined Physics and Technical WG formed

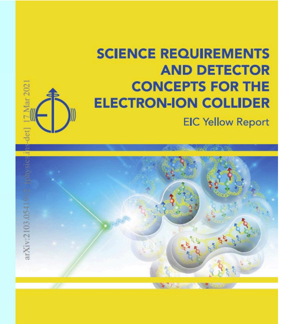


- Updating P6 cost and schedule based on ECCE as reference detector in the next month
- R&D rolled out to Users and P6 updated with & respective milestones
- Defined and documented system requirements down to L4
- 3D pdf of full Interaction Region exists


Requirements for the EIC Detector Systems

More detail in Barak's talk

Detector requirements from the EIC yellow report

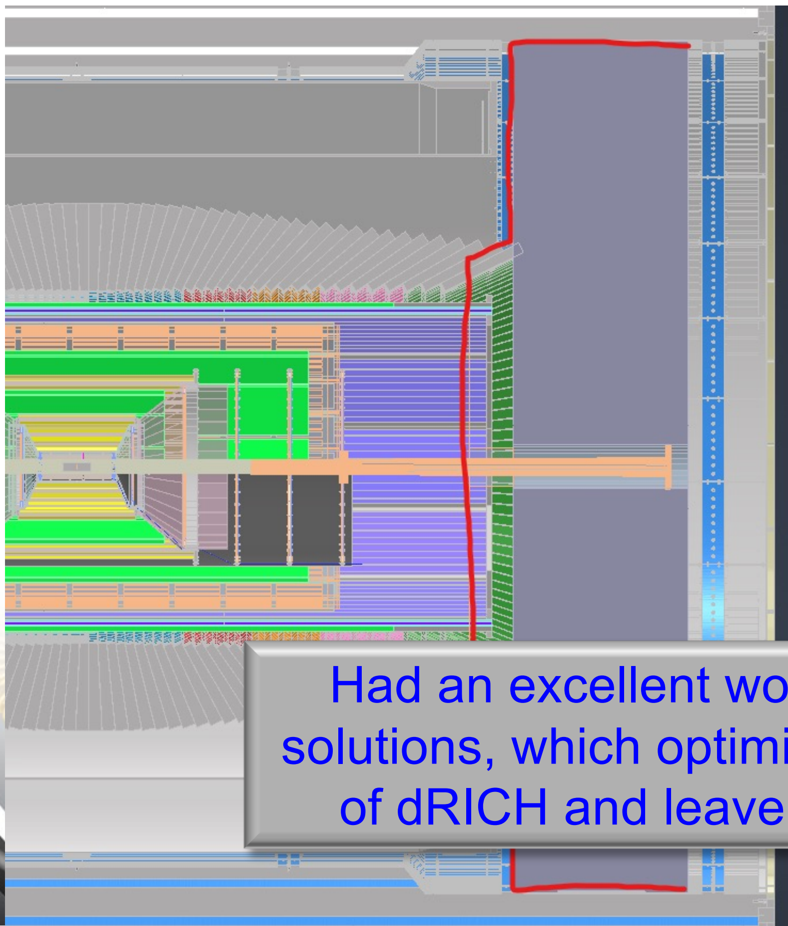


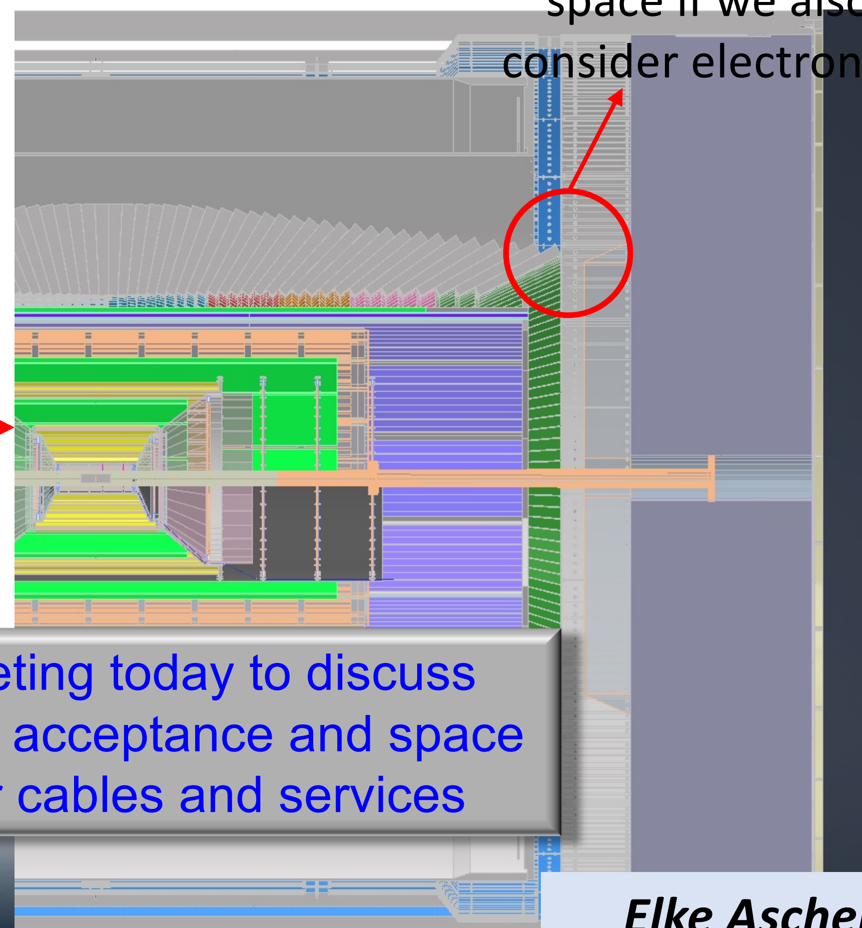
η	Nomenclature			Tracking: Resolution	Tracking: Allowed	Tracking: minimum-pT	Tracking: Si-Vertex	Electrons and Photons: Resolution	Electrons and Photons: PID	Electrons and Photons: min E	π/K/p: p-Range (GeV/c)	π/K/p: Separati	HCAL: Resolution σE/E	HCAL: Energy	Muons
-6.9 to -5.8	↓ p/A	Auxiliary Detectors	low-Q2 tagger	σθ/θ < 1.5%; 10-6 < Q2 < 10-2 GeV2											
-5.0 to -4.5						300 MeV pions									
-4.5 to -4.0			Instrumentation to separate charged particles from photons			300 MeV pions		2%/√E(+1-3%)		50 MeV					
-4.0 to -3.5						<100MeV pions, 135MeV kaons				50 MeV			~50%/√E + 6%		
-3.5 to -3.0		Central Detector	Backward Detector		~5% or less X	<100MeV pions, 135MeV kaons			π suppression up to 1:1E-4	50 MeV	≤ 7 GeV/c	≥ 3 σ	~45%/√E+6%	~500 MeV	muons useful for bkg, improve resolution
-3.0 to -2.5				σp/p ~ 0.1%⊕0.5%		<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT µm + 40 µm			50 MeV					
-2.5 to -2.0				σp/p 0.1%⊕0.5%		<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT µm + 20 µm	2%/√E(+1-3%)		50 MeV					
-2.0 to -1.5				σp/p 0.05%⊕0.5%		<100MeV pions, 135MeV kaons		7%/√E(+1-3%)		50 MeV					
-1.5 to -1.0						<100MeV pions, 135MeV kaons		7%/√E(+1-3%)		50 MeV					
-1.0 to -0.5			Barrel	σp/p ~0.05%×p+0.5%		<100MeV pions, 135MeV kaons	σxyz ~ 20 µm, d0(z) ~d0(rΦ) ~ 20/pTGeV µm + 5 µm	(10-12)%/√E (+1-3%)		50 MeV	≤ 10 GeV/c		~85%/√E+7%		
-0.5 to 0.0						<100MeV pions, 135MeV kaons				50 MeV			~85%/√E+7%		
0.0 to 0.5						<100MeV pions, 135MeV kaons				50 MeV			~85%/√E+7%		
0.5 to 1.0						<100MeV pions, 135MeV kaons				50 MeV	≤ 15 GeV/c		~85%/√E+7%		
1.0 to 1.5			Forward Detectors	σp/p ~0.05%×p+1.0%		<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT µm + 20 µm		3σ e/π	50 MeV	≤ 30 GeV/c		35%/√E		
1.5 to 2.0						<100MeV pions, 135MeV kaons				50 MeV	≤ 50 GeV/c				
2.0 to 2.5						<100MeV pions, 135MeV kaons				50 MeV					
2.5 to 3.0				σp/p ~ 0.1%×p+2.0%		<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT µm + 40 µm			50 MeV	≤ 30 GeV/c				
3.0 to 3.5						<100MeV pions, 135MeV kaons	σ_xy ~ 30/pT µm + 60 µm			50 MeV	≤ 45 GeV/c				
3.5 to 4.0	↑ e	Auxiliary Detectors	Instrumentation to separate charged particles from photons			<100MeV pions, 135MeV kaons				50 MeV					
4.0 to 4.5						300 MeV pions				50 MeV					
4.5 to 5.0			Neutron Detection			300 MeV pions		4.5%/√E for photon energy > 20 GeV	<= 3 cm granularity	50 MeV			35%/√E (goal), <50%/√E (acceptable)+, 3mrad/√E (goal)		
> 6.2			Proton Spectrometer	σintrinsic($\lvert t \rvert$)/$\lvert t \rvert$ < 1%; Acceptance: 0.2 < pt < 1.2 GeV/c											

Integration

- Working on next stage of conflicts between subdetectors (recall the hpDIRC/MPGD frame fixes before)

➢ bEcal and dRICH overlap
➢ DIRC and dRICH aerogel – snout overlap
→ shift dRICH by 35 cm → limits any further dRICH performance optimization
→ 10 cm space for services and cables
Or alternately drop some bECAL rows

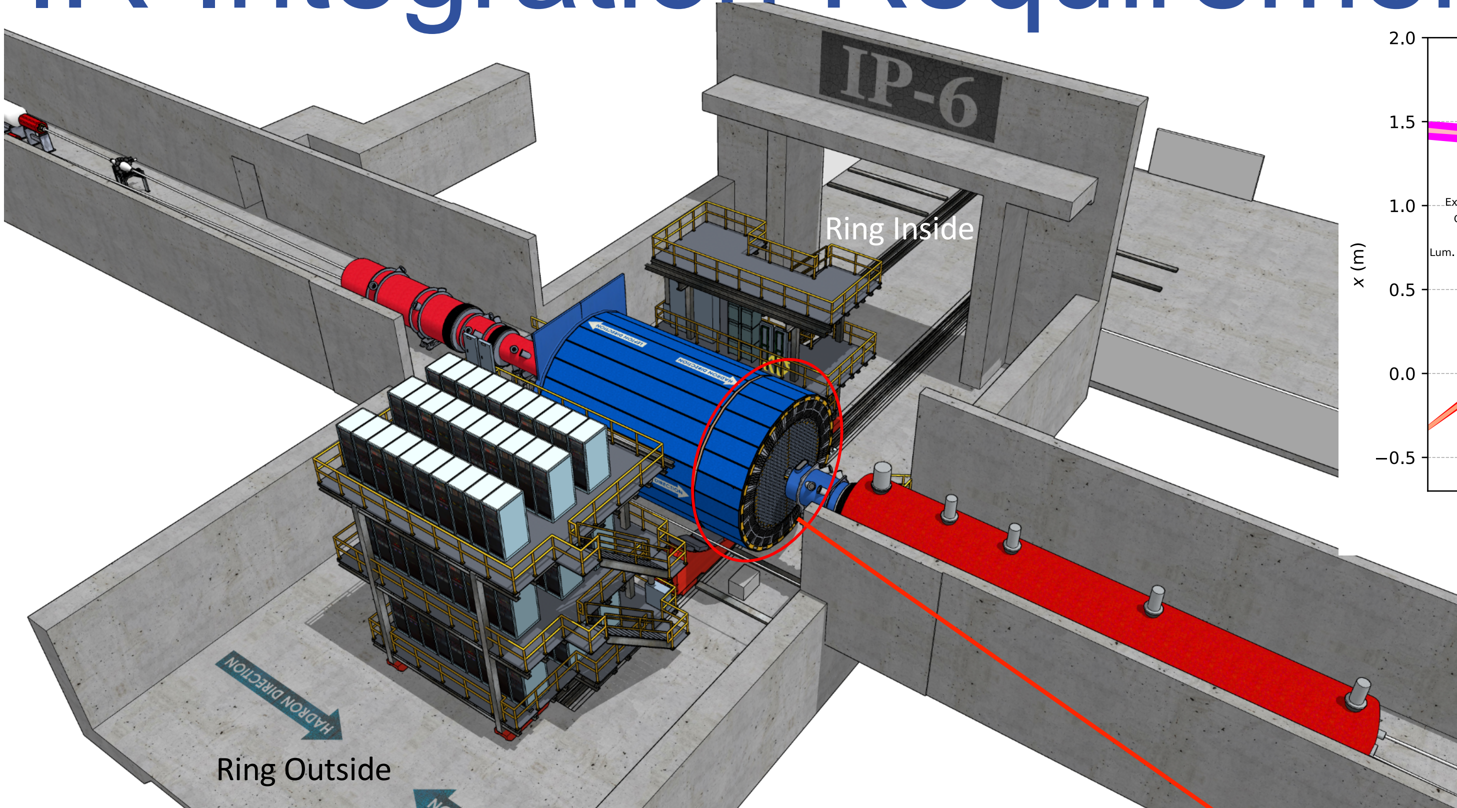


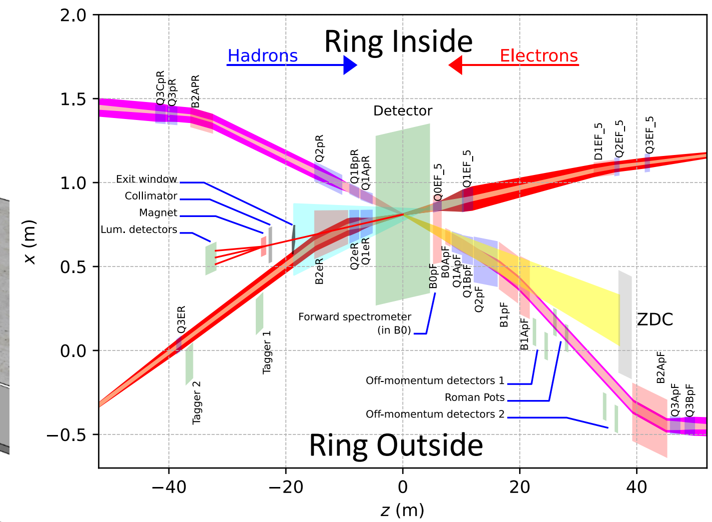


Had an excellent working meeting today to discuss solutions, which optimize bECal acceptance and space of dRICH and leave room for cables and services

Elke Aschenaur

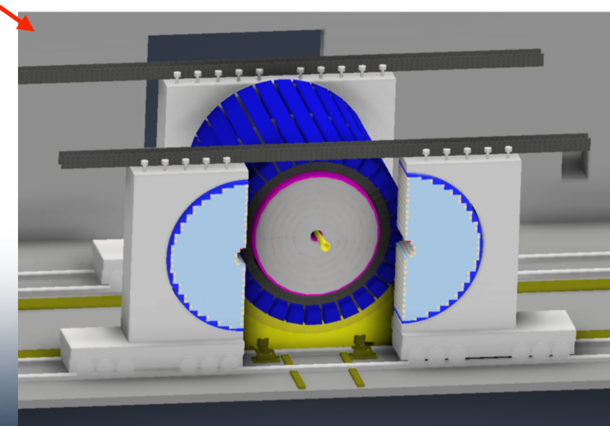
IR-Integration Requirements





Installation and Maintenance :

- ❑ limited installation possible in collider hall
- ➢ endcap hadron calorimeters need to be split transverse to beam pipe
- ➢ RCS vacuum needs to be broken
- ➢ central detector maintenance only possible in assembly hall → requires to break vacuum → central beam pipe moves with detector → requires bake-out before operation



EIC Project Detector R&D Program

Large international components to EIC Project R&D:
in-kind contributions from Italy/INFN, France/IRFU, France/IN2P3, UK/STFC

https://wiki.bnl.gov/conferences/index.php/ProjectRandDFY22

2022												
Project:	**eRD101**	**eRD102**	**eRD103**	**eRD104**	**eRD105**	**eRD106**	**eRD107**	**eRD108**	**eRD109**	**eRD110**	**eRD111**	**eRD112**
Title:	mRICH	dRICH	hpDIRC	Silicon Service reduction	SciGlass	Forward ECal	Forward HCal	Cylindrical MPGD	ASIC/Electronics	Photosensors	Si-Vertex	AC-LGAD
Contact:	X. He (GSU), M.Contalbrigo (U. Ferrara)	E. Cisbani (INFN-RM1), M.Contalbrigo (U. Ferrara), A. Vossen (Duke)	G. Kalicy (CUA), J. Schwiening (GSI)	L. Gonella (B'ham), I. Sedgwick (RAL), E.P. Sichtermann (LBL), Leo Greiner (LBL), Giacomo Contin (LBL), Domenico Elia (INFN, Bari) and Grzegorz Deptuch (BNL)	T. Horn and .L. Pegg (CUA)	H.Z. Huang (UCLA), O. Tsai (UCLA)	H.Z. Huang (UCLA), O. Tsai (UCLA)	K. Gnanvo (UVA)		Y. Ilieva (SC), C. Zorn (JLab), J. Xie (ANL), A. Kiselev (BNL), Pietro Antonioli (INFN)	L. Gonella (B'ham), I. Sedgwick (RAL), E.P. Sichtermann (LBL), Leo Greiner (LBL), Giacomo Contin (LBL), Domenico Elia (INFN, Bari) and Grzegorz Deptuch (BNL)	Zh. Ye (UIC)
Proposal:	V1 (pdf), V2 (PDF)	V1 (pdf), V2 (PDF)	V1 (pdf), V2 (PDF)	V1 (pdf) V2)PDF)	V1 (pdf), V2 (DOCX)	V1 (pdf), V2 (DOCX)	V1 (pdf), V2 (DOCX)	V1 (pdf), V2 (pdf)		V1 (pdf), V2 (pdf)	V1 (pdf), V2 (pdf)	V1 (pdf), V2 (pdf), V3 (pdf)
Presentation:	PDF	PDF	PDF-v1, PDF-v2	PPTX	PDF	PDF	PDF	V1-PDF, V2-PDF		PDF-1, PDF-2	PPTX	PDF

on hold until technology choices are finalized

will be started after subsystem review

Strong synergies with CERN

CERN – EIC R&D Day November 2021 https://indico.cern.ch/event/1063927/

- MAPS: ALICE-3 – ITS-3 development
- PID: LHC-b and ALICE-3
- Photon-sensors: LAPPDs with LHC-b
- MPGD: long-term CERN R&D program RD51
- DAQ: strong developments on streaming DAQs for all LHC experiments
- AI/ML and high-performance distributed computing

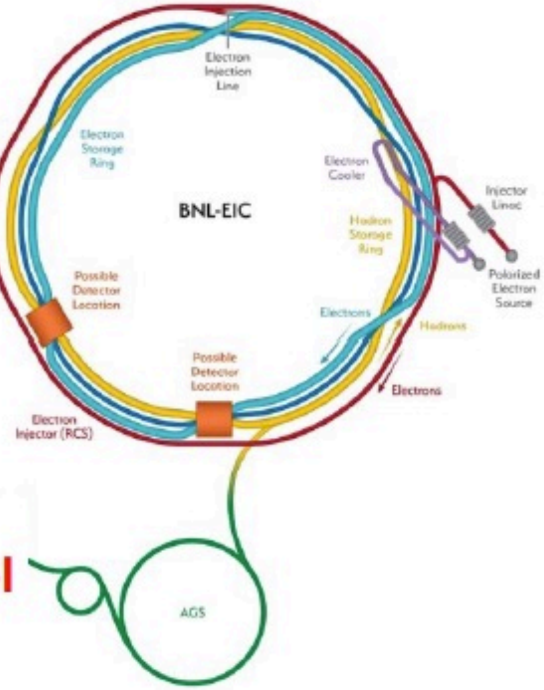
Generic R&D Program

- DOE NP is restarting the EIC generic R&D program in FY22 of scale $2M.
- Such a program would look at new cost-effective detector capabilities for either the detector-1 in the project scope or of use for a detector-2.
- The generic detector R&D program is expected to be governed similar as the successful generic EIC-related detector R&D program that ran through BNL from 2011-2021.
- It will be managed by Jefferson Lab, drawing deeply on BNL's extensive experience managing the previous version of the program.
- The PI will be David Mack (TJNAF). The Program Manager is David Dean (TJNAF).

- **Backup**

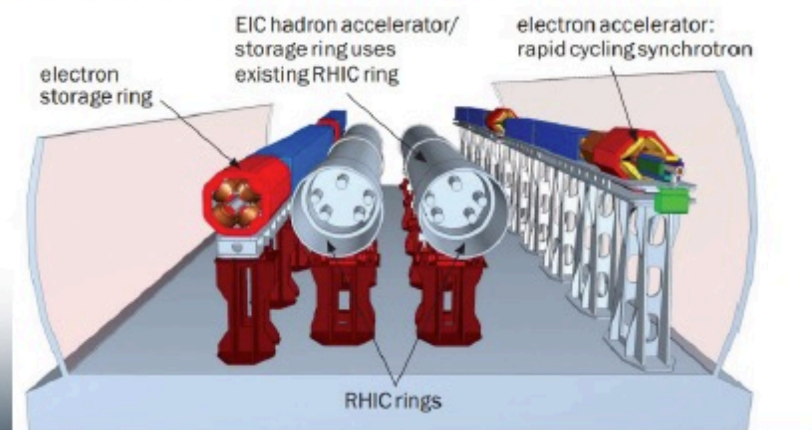
EIC Accelerator

Design based on **existing RHIC Complex**
RHIC is well-maintained, operating at peak performance



- **Hadron storage ring 40-275 GeV**

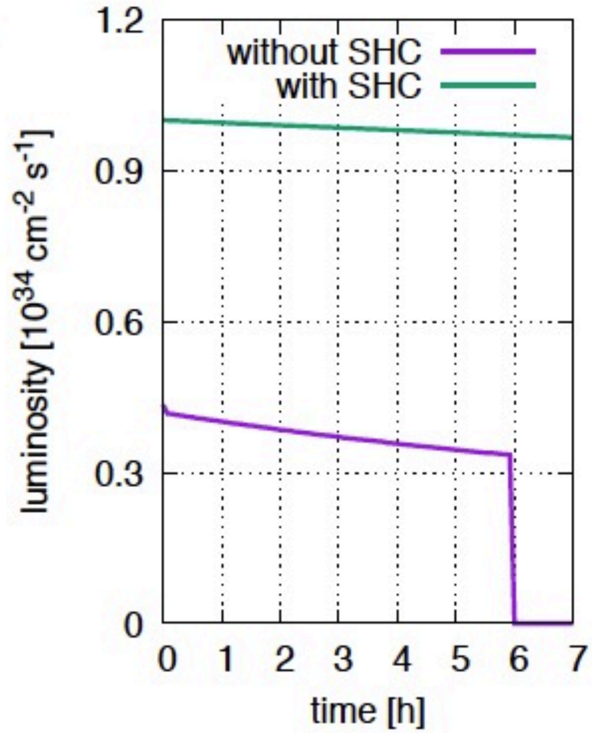
  based on existing RHIC
  - 1160 bunches, 1A beam current (3 x RHIC
  - Bright vertical beam emittance 1.5 nm
  - Strong hadron cooling (coherent electron cooling)
- **Electron storage ring 2.5–18 GeV new ring in RHIC tunnel**
  - 1160 bunches
  - Large beam current, 2.5 A ➔ 9 MW S.R. power
  - SRF cavities
- **Electron rapid cycling synchrotron 0.4- 18 GeV new ring in RHIC tunnel**
  - 2 x 28 nC bunches, 1 Hz cycle time
  - Use spin transparency for high polarization
- **High luminosity interaction region(s) new**
  - $L = 10^{34}\ cm^{-2}s^{-1}$, Superconducting magnets
  - 25 mrad crossing angle with crab cavities
  - Spin rotators (longitudinal electron spin)
  - Forward hadron instrumentation for tagging



EIC Requires Strong Hadron Cooling to Deliver Science Program

- Performance metric: **average luminosity**
  - Intrinsic ion **emittance growth** limits achievable initial and average luminosity
  - Reduces average luminosity by at least factor 2-3 unless **counteracted by strong hadron cooling** (SHC)
  - Ultimate performance peak luminosity of 10^{34} cm^{-2} s^{-1} requires hadron beam cooling

- SHC is **required to deliver the EIC physics program** in a reasonable time



Assumption: electron collision beam size matches ion beam evolution

Transport properties of QCD matter

- **Transport of particles: diffusion**
  heavy quark diffusion
  parton shower development inside jets

- **Transport of energy: thermal conductivity**
  energy loss – how much and how? R_{AA}
  where does it go? ***Medium response to jets***
  what does pQCD get right? ***IR safe jet substructure***

- **Transport of** p_T **(viscosity)**
  Particle flow; flow fluctuations & correlations

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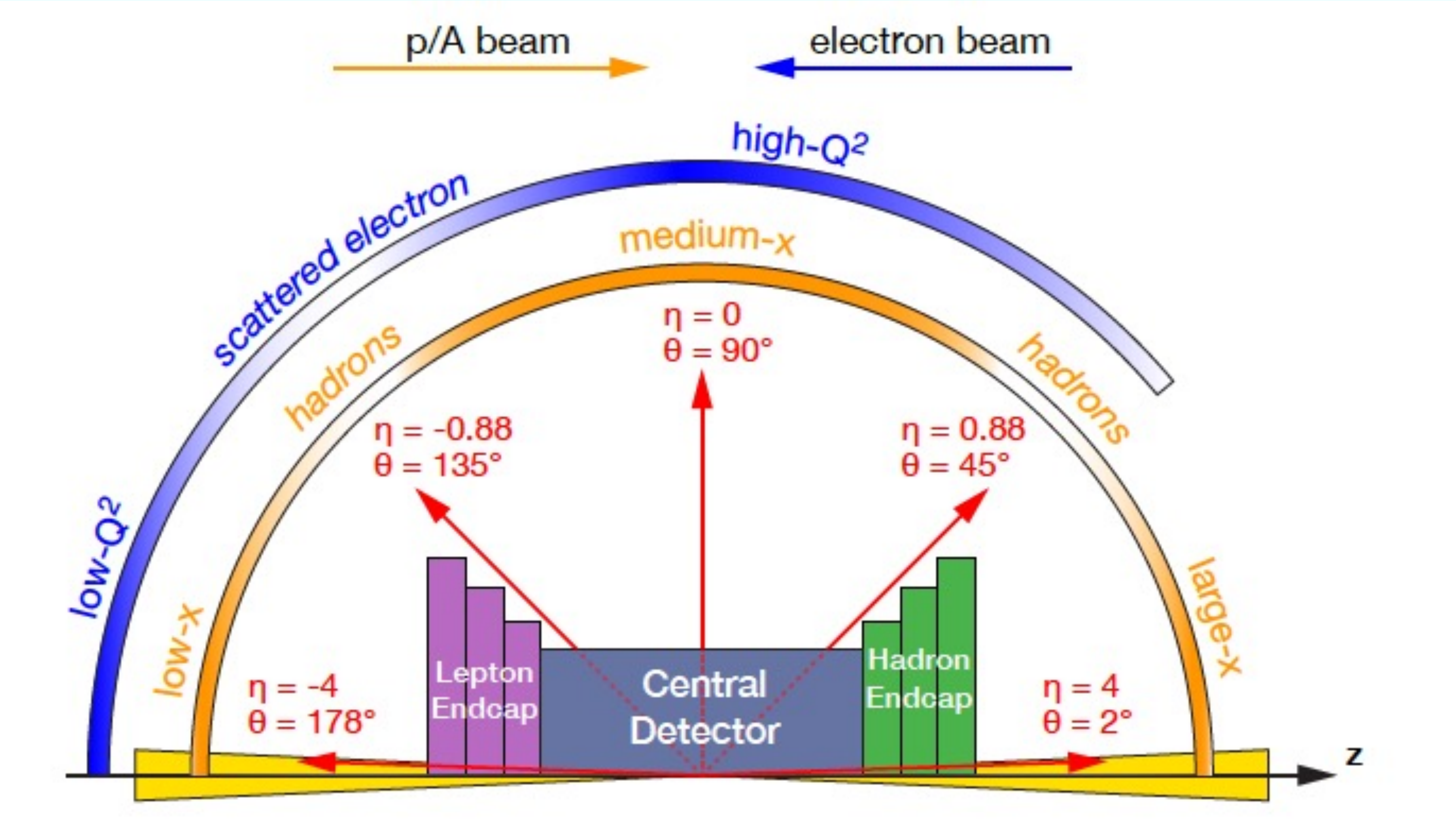
  Particle flow; flow fluctuations & correlations

- **Transport of particles: diffusion**
  heavy quark diffusion

- **Transport of energy: thermal conductivity**
  energy loss – how much and how? R_{AA}
  where does it go?
  Parton shower development
  Medium response to jets
  what does pQCD get right?
  IR safe jet substructure observables

- ***Transport in cold QCD matter at the EIC***
- ***Hadronization***

What goes where



The Questions for small x

- **Does the gluon density saturate?**

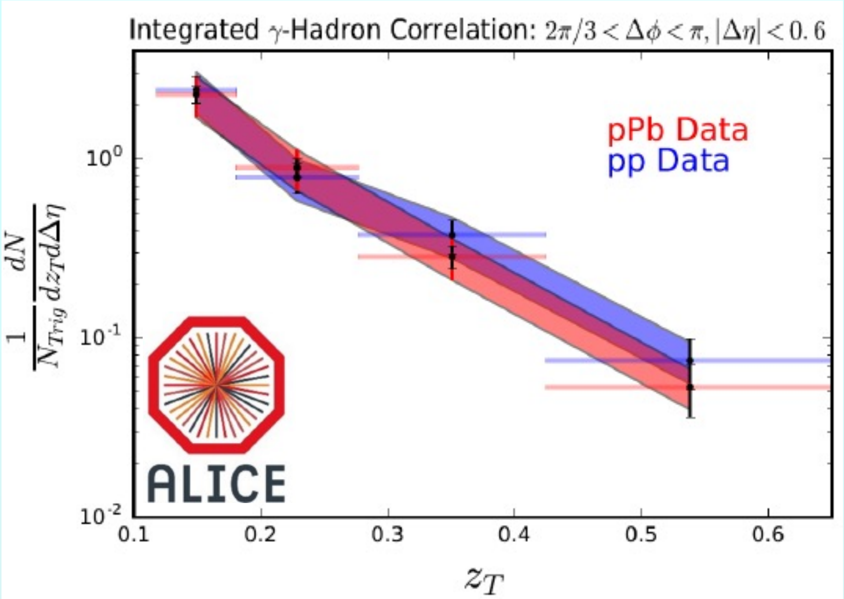
- **How does a parton shower evolve?**
  Use precision of EIC e+p to study QCD

- **How do partons interact inside dense QCD matter?**
  Energy loss & transport in dense QCD matter
  Medium modification of jet substructure
  Heavy flavor jets for exquisite control

- **How do hadrons emerge from a bunch of partons?**
  Use nuclei as a variable size filter

Evolution observables

- **Jet Fragmentation Function**
  $z = p_{T,hadron}/p_{T,jet}$
  or $p_\gamma/p_{T,jet}$ in pp γ-hadron



Needs better precision!

Do via hadron-in-jet at EIC

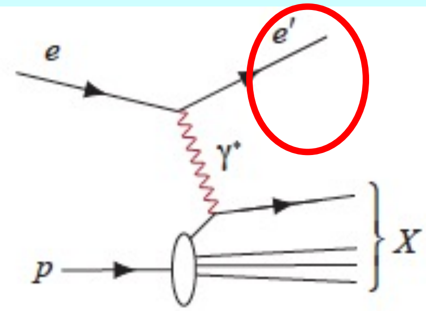
-> hadronization corrections

other jet evolution observables:

- **Angularity**
- **(groomed) Jet substructure e.g. jet mass, z_g**
- **Jet axis differences**

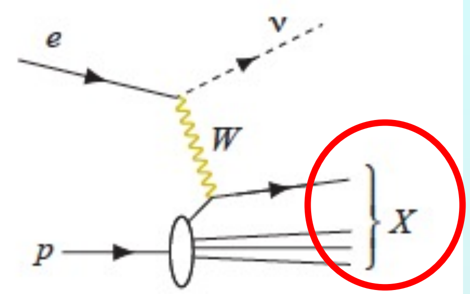
Processes in e + p/A scattering

Neutral-current Inclusive DIS: $e + p/A \longrightarrow e' + X$; for this process, it is essential to detect the scattered electron, e', with high precision. All other final state particles (X) are ignored. The scattered electron is critical for all processes to determine the event kinematics.

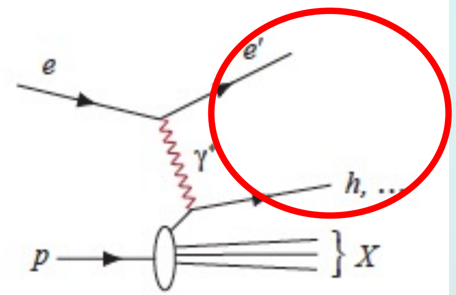


What is measured

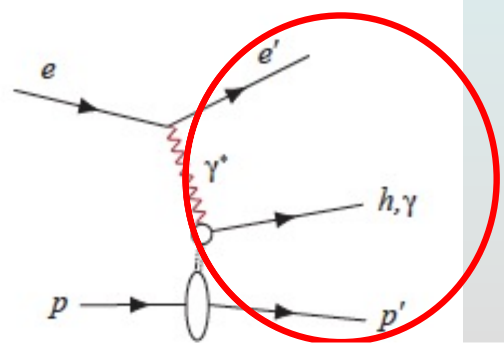
Charged-current Inclusive DIS: $e + p/A \longrightarrow \nu + X$; at high enough momentum transfer Q^2, the electron-quark interaction is mediated by the exchange of a $W^{\pm}$ gauge boson instead of the virtual photon. In this case the event kinematic cannot be reconstructed from the scattered electron, but needs to be reconstructed from the final state particles.



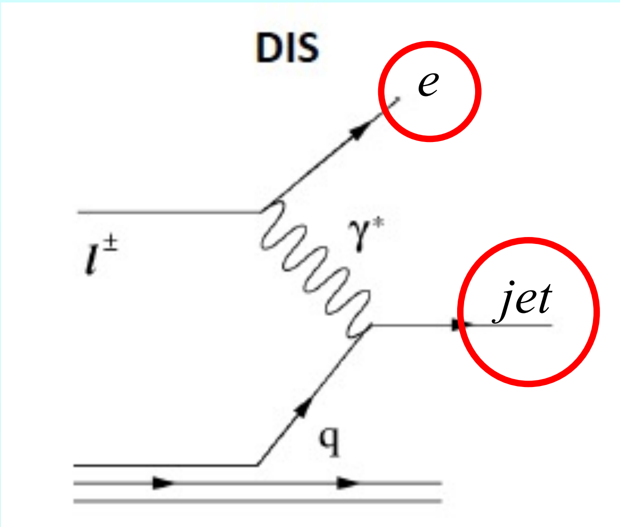
Semi-inclusive DIS: $e + p/A \longrightarrow e' + h^{\pm,0} + X$, which requires measurement of *at least one* identified hadron in coincidence with the scattered electron.

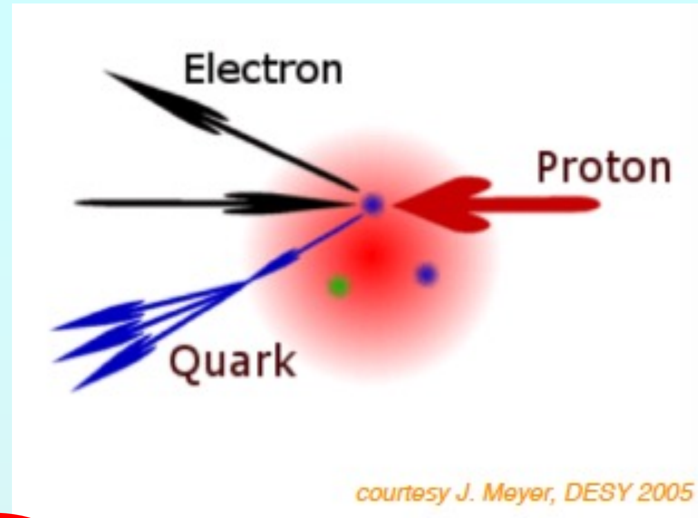


Exclusive DIS: $e + p/A \longrightarrow e' + p'/A' + \gamma/h^{\pm,0}/VM$, which require the measurement of *all* particles in the event with high precision.



Deep Inelastic Scatter off low-x partons

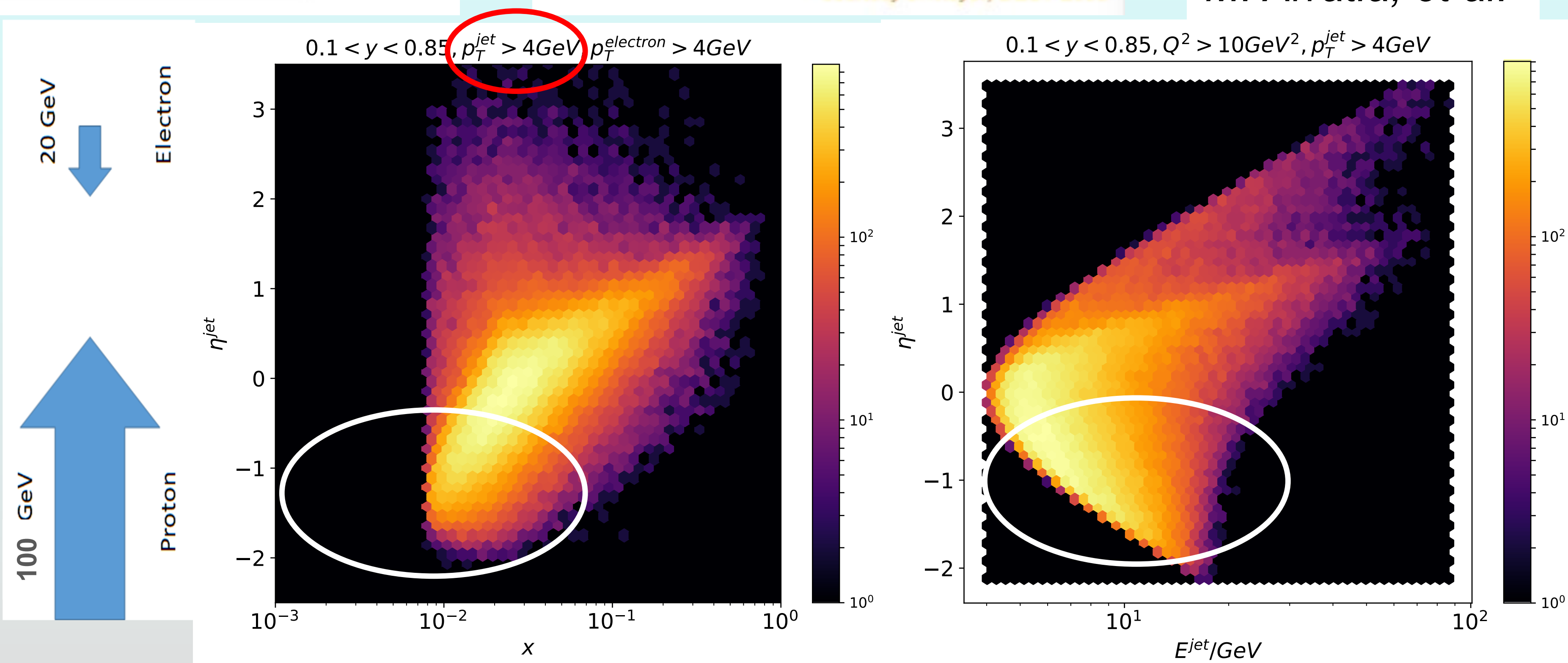




Probe parton at $x=10^{-2}$ (almost a fixed target)

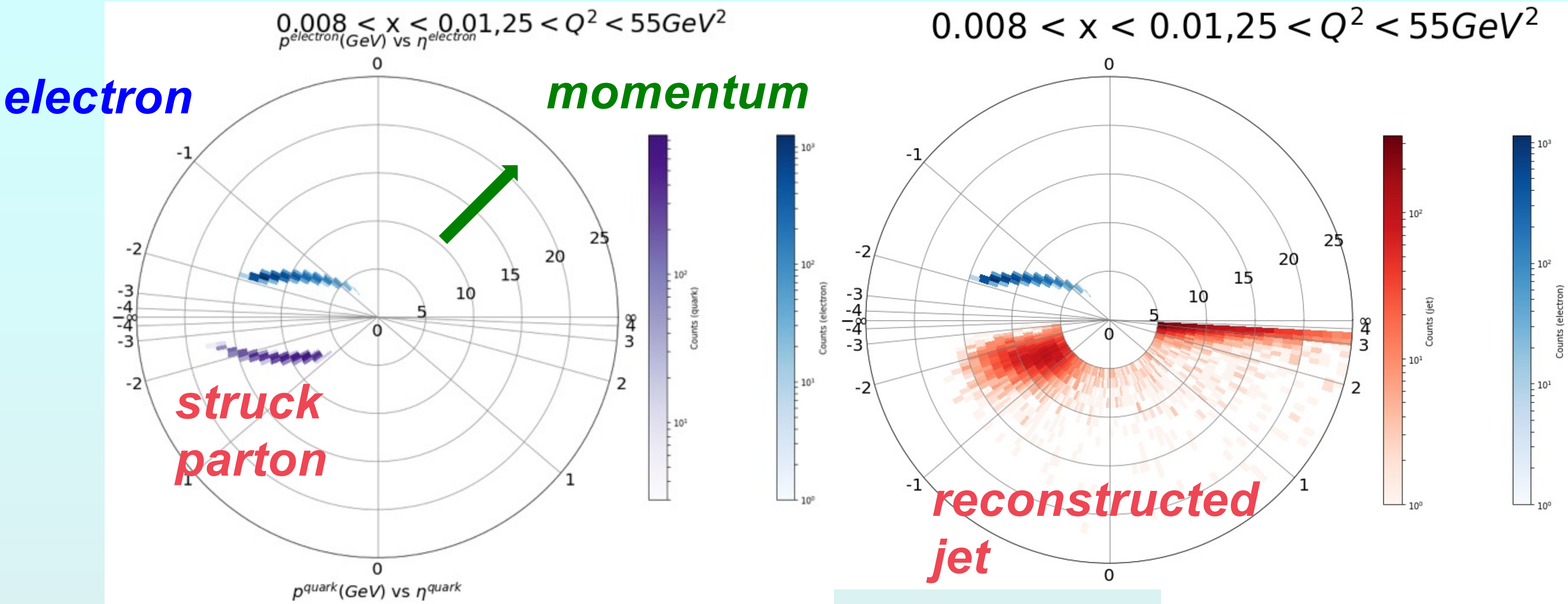
-> 5-15 GeV jets

M. Arratia, et al.



Electron tags original jet energy, angle

e+p, DIS; Pythia 8. Require W^2 > 4 GeV^2, jet R=1.0



Youqi Song, M. Arratia

🡐 electron direction

proton/ion 🡒 direction

In R=1 jets hadronization uncertainties are small

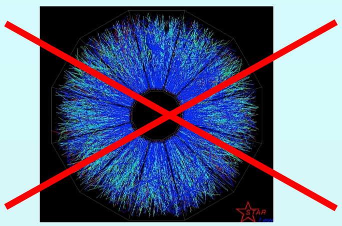
jet approximates the parton well; calculable with pQCD

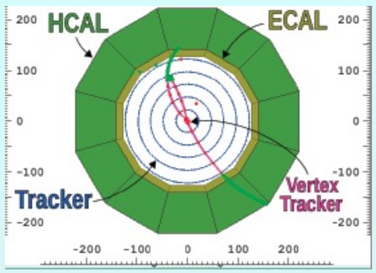
Directly measure energy lost to dense matter at small x

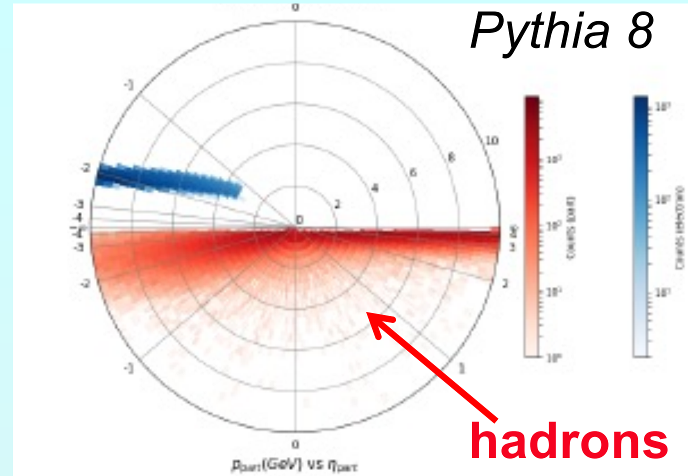
Use substructure observables! NB: Q^2 >25 GeV^2

Measuring these jets

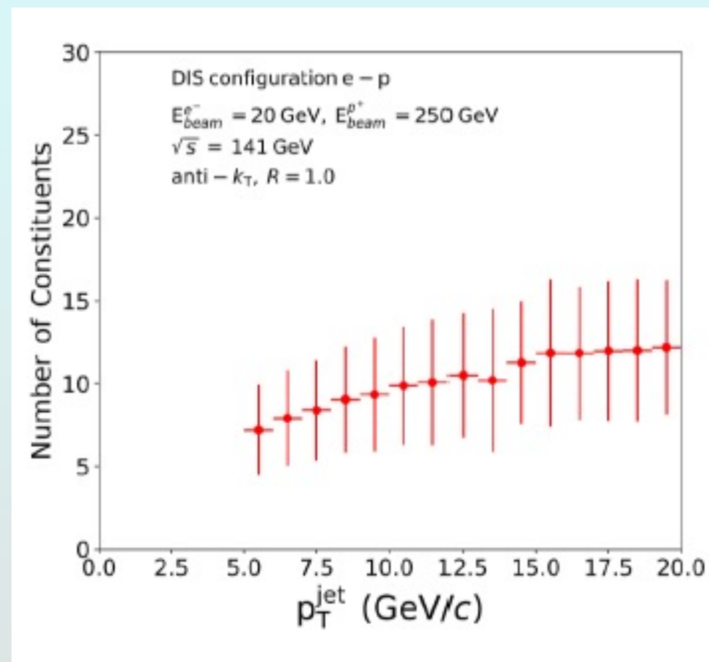
- **Is easy!**
  Underlying event is small
  MPI effects smaller than pp and pA





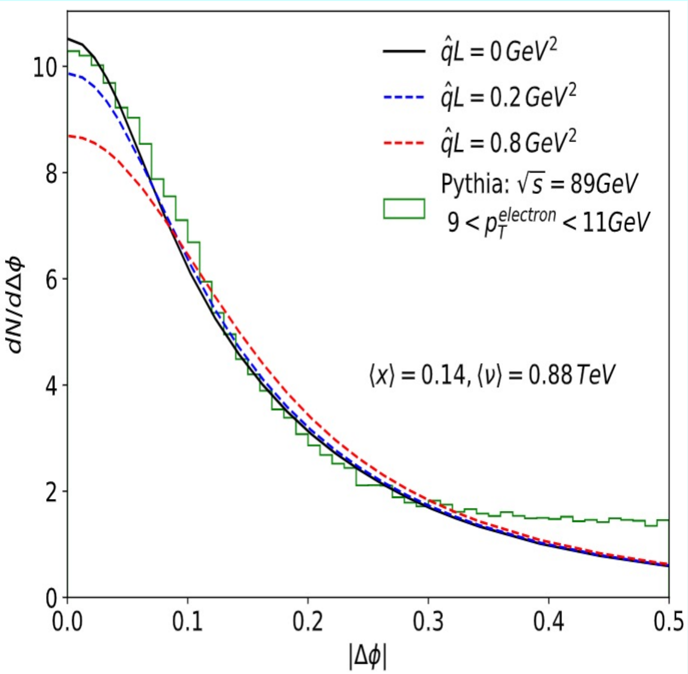


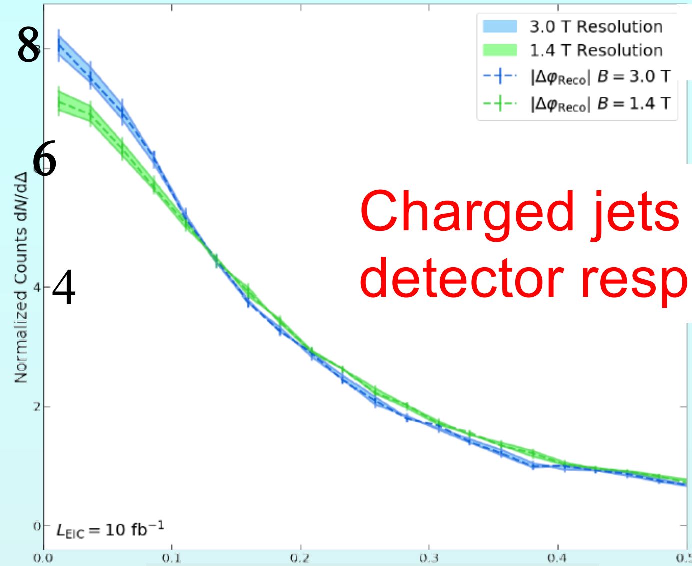
- **Is hard!**
  The jets are very soft
  Small number of constituents
  But we have practice at RHIC
  - under tougher conditions!
  Look at charged & full jets



Lepton-jet correlations

Imbalance due to intrinsic quark k_T and soft radiation.

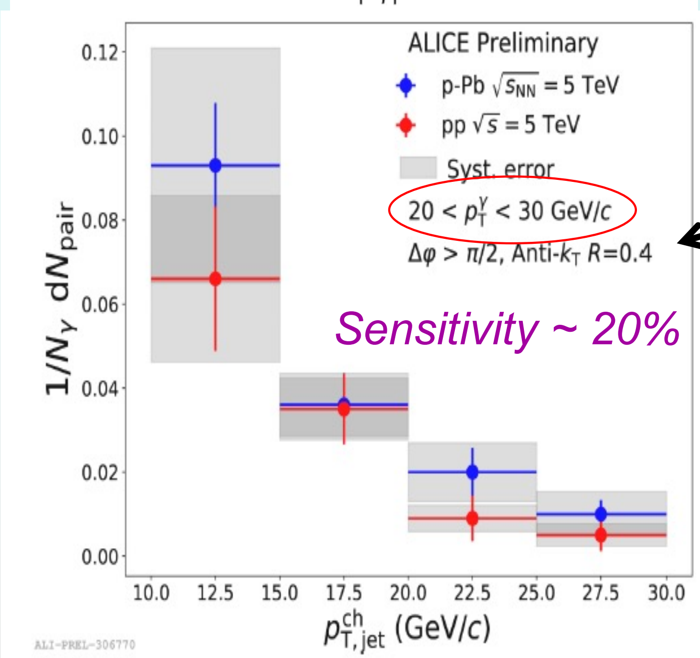




Fernando Torales Acosta

Charged jets with EIC detector response

$|\Delta\phi| = |\phi^{jet} - \phi^{e} - \pi|$



Soft γ-jet at LHC

Precision at EIC (statistics)