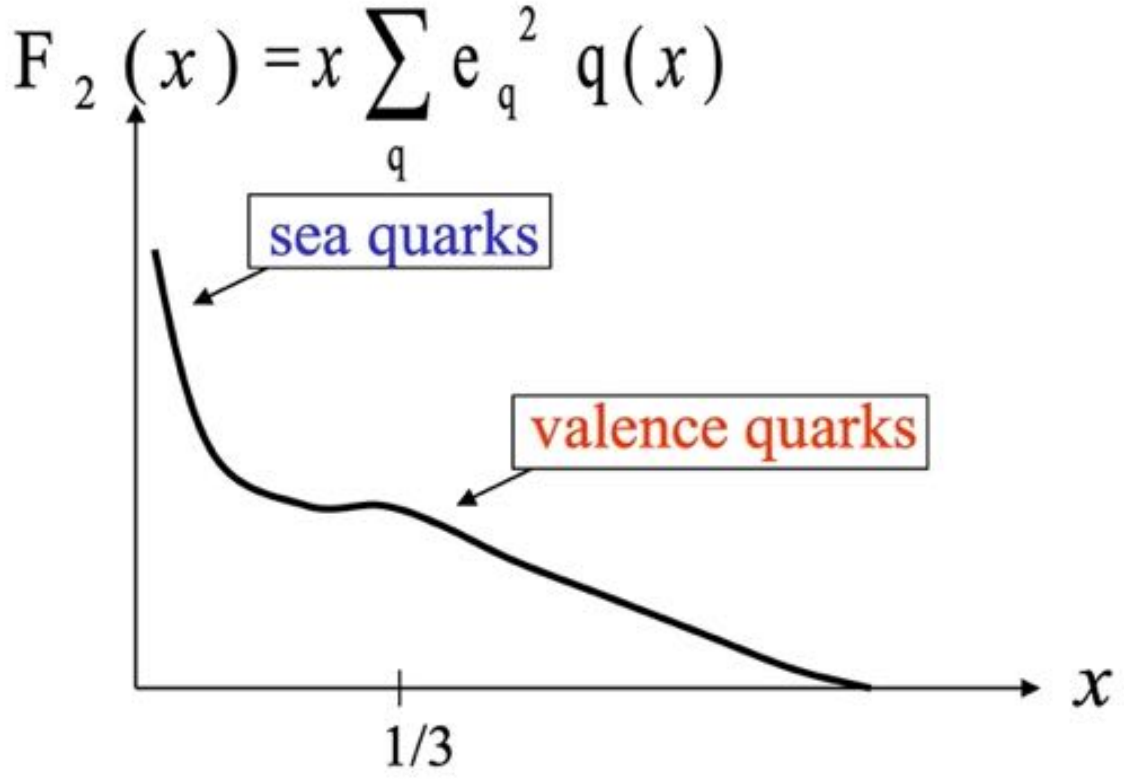
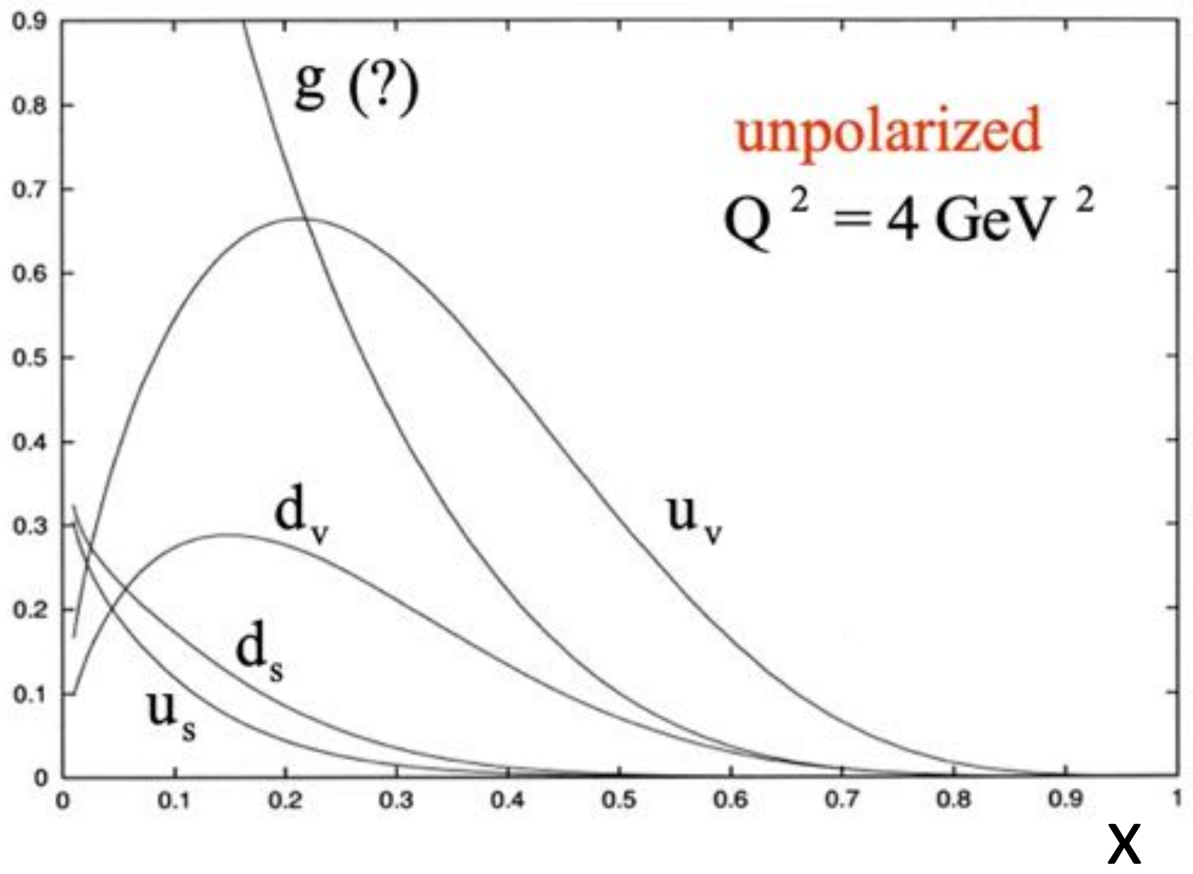
Unpolarized quark distributions: valence quarks and sea quarks

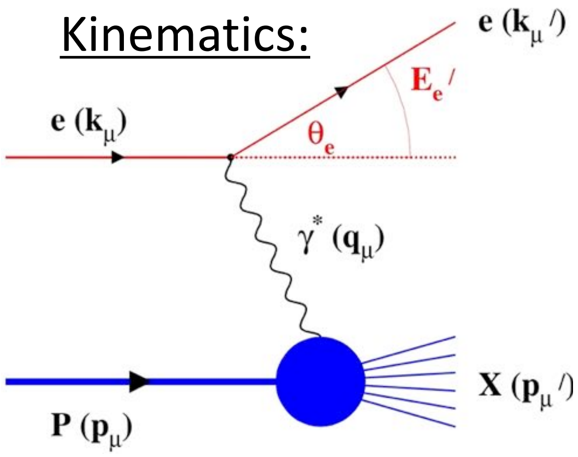




X here is x-bjorken.
In DIS it can be measured explicitly event by event
In p-p scattering it is not possible to use it, but can be inferenced from MC events generation.

Deep Inelastic Scattering: Precision and control

Kinematics:



$$Q^2 = -q^2 = -(k_\mu - k'_\mu)^2$$

$$Q^2 = 2E_e E'_e (1 - \cos\Theta_{e'})$$

Measure of resolution power

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$x = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

Hadron :

$$z = \frac{E_h}{\nu}; p_t$$ with respect to γ^*

$$s = 4 E_h E_e$$

High lumi & acceptance

Low lumi & acceptance

Exclusive DIS

detect & identify *everything* e+p/A → e'+h(π,K,p,jet)+…

Semi-inclusive events:

e+p/A → e'+h(π,K,p,jet)+X

detect the scattered lepton in coincidence with identified hadrons/jets

Inclusive events:

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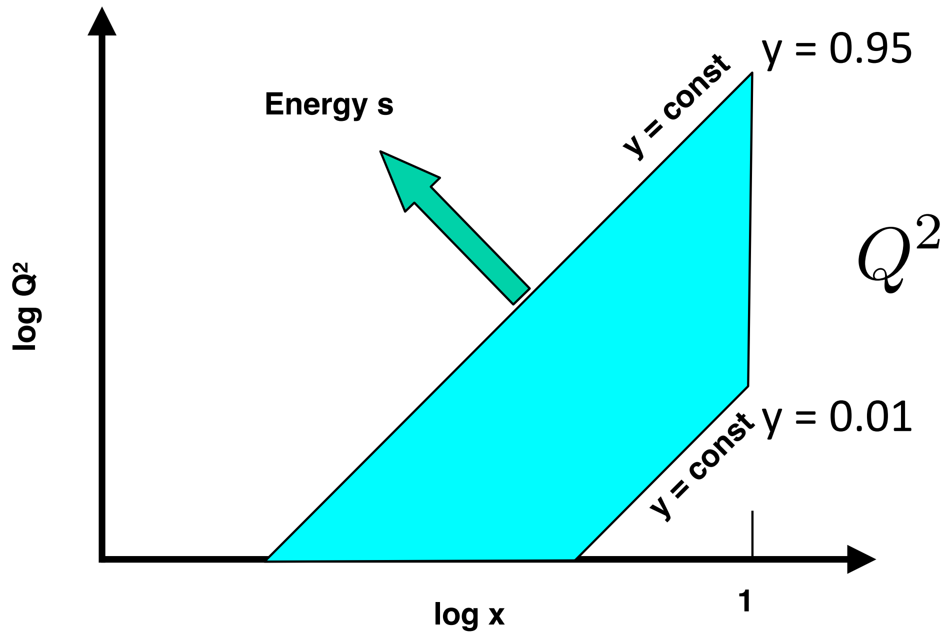
detect *only the scattered lepton* in the detector

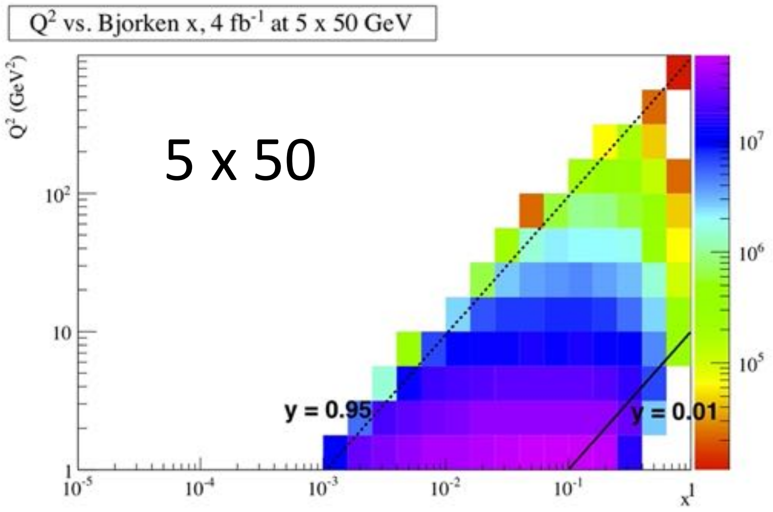
The x-Q^2 plane…

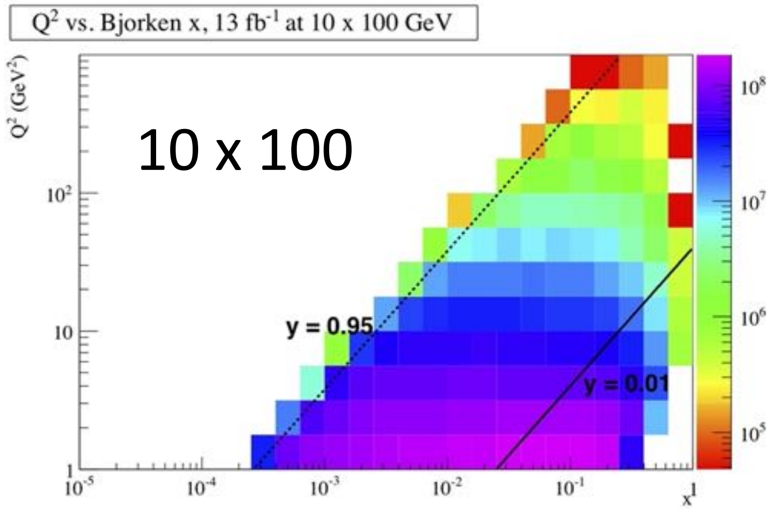


$$Q^2 \approx s \cdot x \cdot y$$

- Low-x reach requires large $\sqrt{s}$
- Large-Q^2 reach requires large $\sqrt{s}$
- *y* at colliders typically limited to $0.95 < y < 0.01$

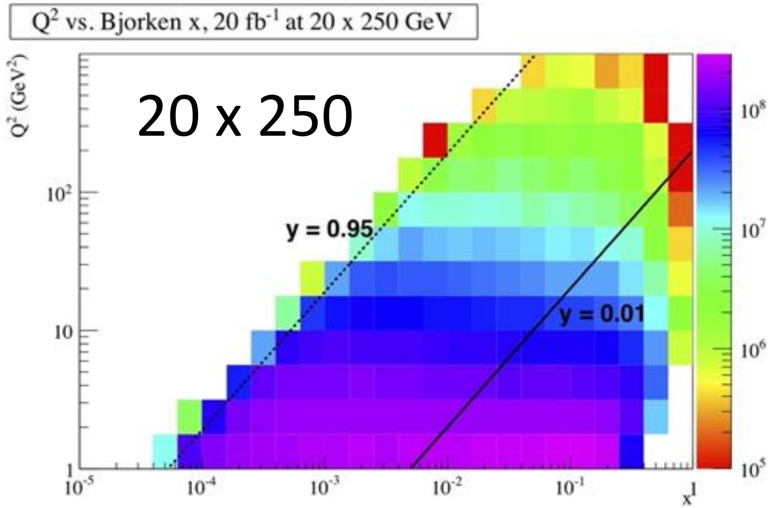
Kinematic coverage as a function of energy of collisions



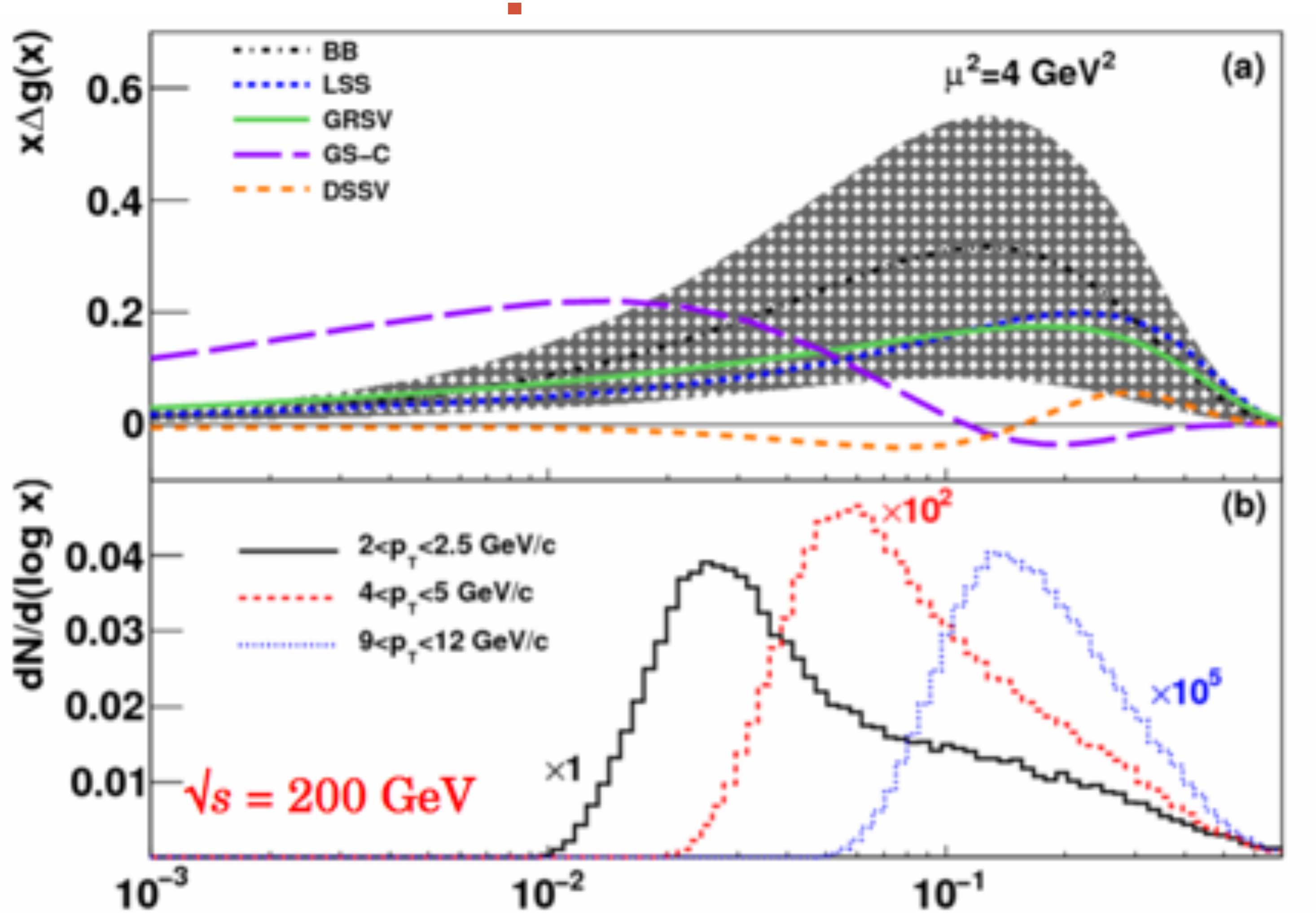


As beam energies increase, so does the x, Q^2 coverage of the collider: 5, 10 and 20 GeV electrons colliding with 50, 100 and 250 GeV protons

y = 0.95 and 0.01 are shown on all plots (they too shift as function of energy of collisions)



Monte Carlo Generated events: for a pT range of pions produced what is the x of the leading parton that created the pion p+p → pi + X



Start with any polarized gluon distribution and produce P_T distribution of pions or gamma distribution.

See bottom.

For any pT range, one see one sees the x distribution of the originating partons associated with it.

There is a large overlap. The lowest pT distribution end at 10^{-2}.

Any thing significantly less than pT of 2 is going to be difficult to measure and identify in detectors.

Electron Ion Collider

Lecture 3 of 3

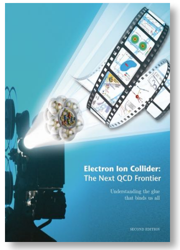
Abhay Deshpande

Overview of these lectures:
Understanding the structure of matter

Lecture 3: Electron Ion Collider: Frontiers in investigations of QCD

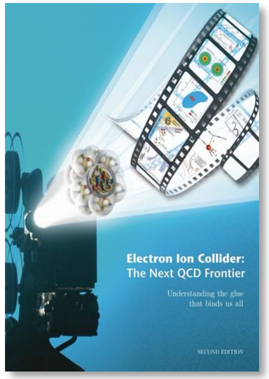
- Solving the spin puzzle ➔ **3D imaging** of the nucleon
- Gluons in nuclei: what role in nuclei? Do they **saturate**?

- Designing an EIC detector and Interaction Region (IR)
- EIC: Status and prospects
  - What can you do for the US EIC?

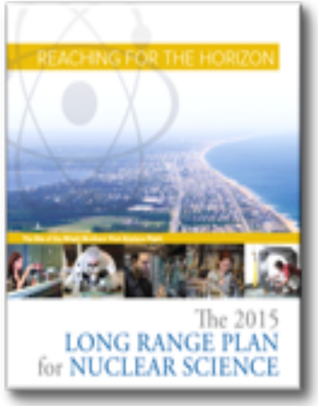


Electron Ion Collider:
Science, Status & Prospects

2015

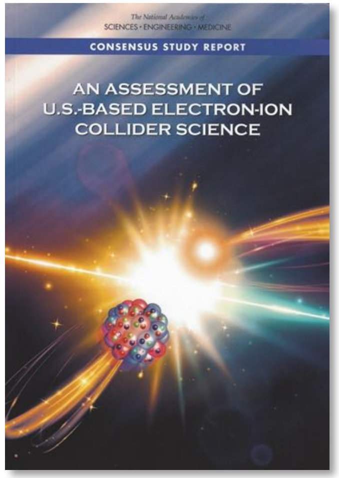


2016



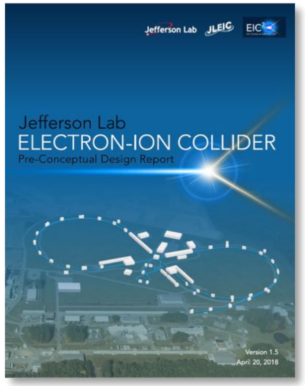
Physics of EIC

2018

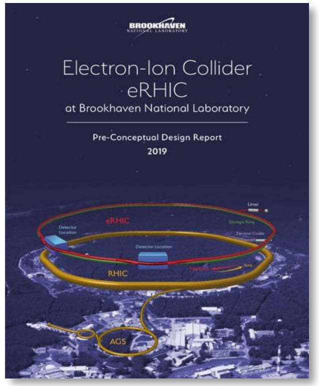


Evaluation

2019



2019 - future



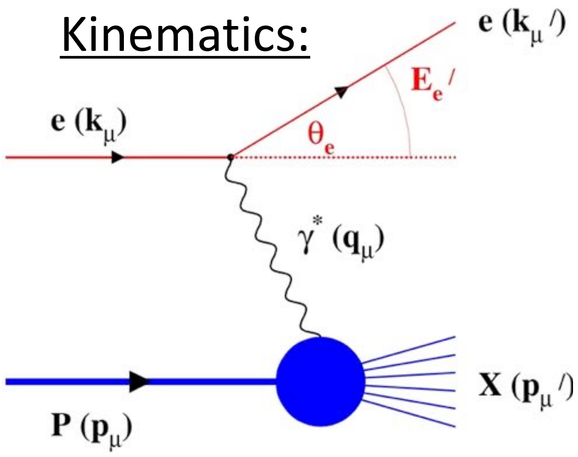
Realization

On the menu today:

- Highlights of the Electron Ion Collider science
- The EIC project setup
  - Machine, detector & call for proposal
- EIC Users Group aspirations & recent developments
  - Proto-Collaborations/consortia…
- Realization and the path forward (particularly for experiments)

Deep Inelastic Scattering: Precision and control

Kinematics:



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detect the scattered lepton in coincidence with identified hadrons/jets

Inclusive events:

e+p/A → e'+X

detect *only the scattered lepton* in the detector

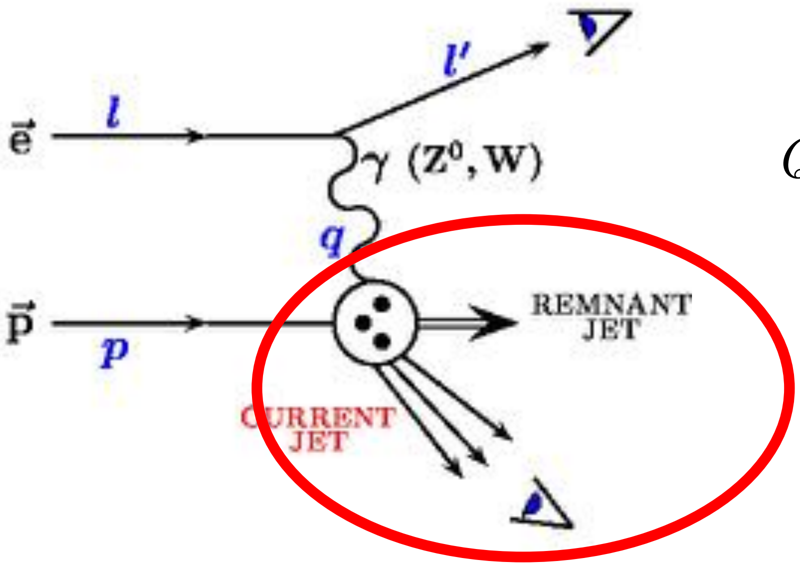
Some times scattered electron can't be measured….

Reason:

1) Scattering angle so small that it is too close to the beam pipe

2) Radiative correction too large, i.e. electron lost its energy due to Initial State Radiation or Brehmstrahlung through material -- So the kinematic reconstruction unreliable.

What to do? Then see if we can reconstruct the hadronic final state?



$$x = \frac{E_j}{2E_p}(1 + cos\theta_j)/(1 - y)$$

$$y = \frac{E_j}{2E_e}(1 - cos\theta_j)$$

$$Q^2 = E_j^2 sin^2\theta_j/(1 - y)$$

$$E_j = yE_e + x(1 - y)E_p$$

$$cos\theta_j = \frac{-yE_e + (1-y)xE_p}{y\,E_e + (1-y)xE_p}$$

$$E_j^2 sin^2\theta_j = 4\,xy(1-y)E_eE_p = Q^2\,(1-y)$$

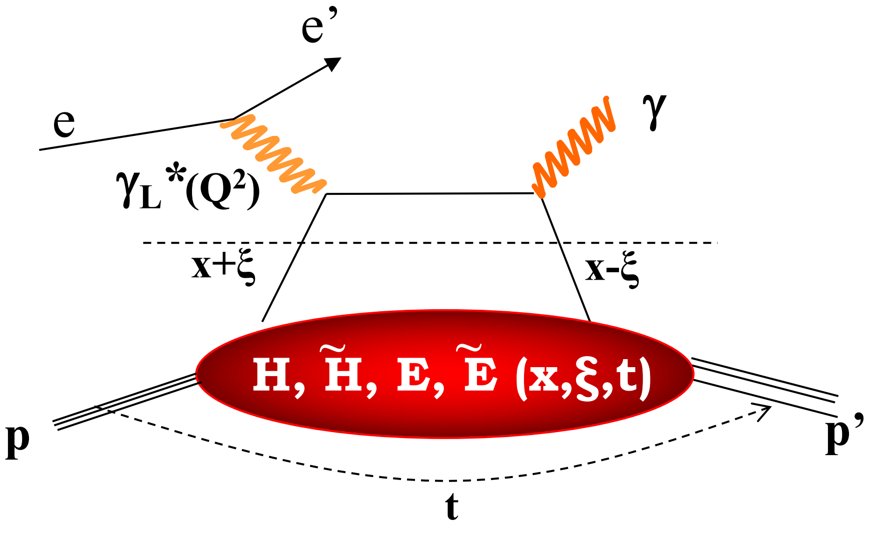
$$y_{JB} = \frac{1}{2E_e}\sum_h (E_h - p_{Zh})$$

$$Q^2_{JB} = \frac{(\sum_h p_{Xh})^2 + (\sum_h p_{Yh})^2}{1 - y_{JB}}$$

$$x_{JB} = Q^2_{JB}/(y_{JB}s)$$

Deep Inelastic Scattering: Deeply Virtual Compton Scattering

Kinematics:



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$$Q^2 = 2E_e E'_e(1-\cos\Theta_{e'})$$

$$y = \frac{pq}{pk} = 1 - \frac{E'_e}{E_e}\cos^2\left(\frac{\theta'_e}{2}\right)$$

Measure of inelasticity

$$x_B = \frac{Q^2}{2pq} = \frac{Q^2}{sy}$$

Measure of momentum fraction of struck quark

$$t = (p-p')^2, \xi = \frac{x_B}{2-x_B}$$

Exclusive measurement:

e + **(p/A)** → e'+ **(p'/A')**+ γ / J/ψ / ρ / ϕ

detect **all** event products in the detector

Special sub-event category rapidity gap events

e + **(p/A)** → e' + γ / J/ψ / ρ / ϕ / jet

Don't detect **(p'/A') in final state**

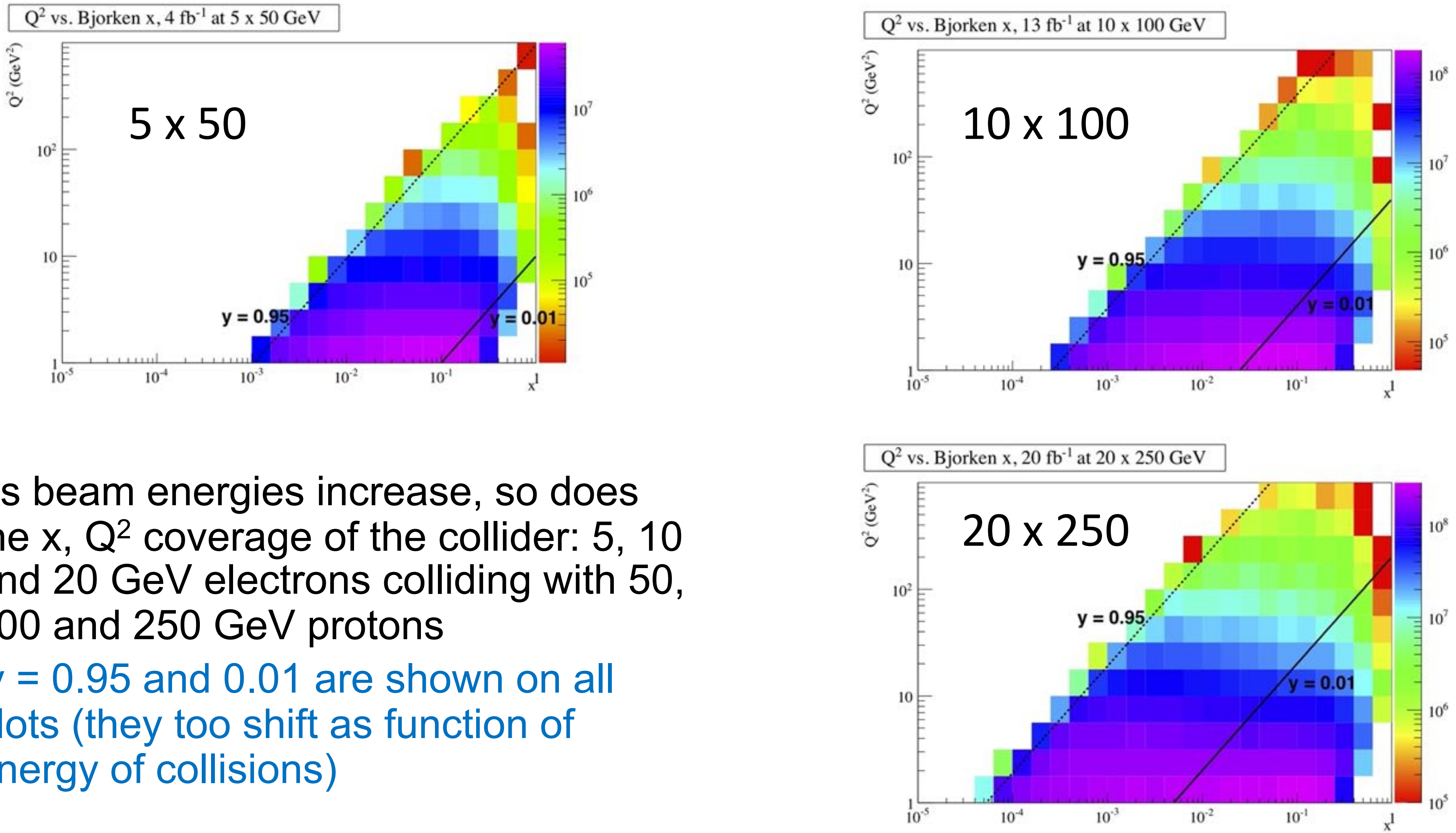
Complete set of variables for DIS e-p:

https://core.ac.uk/download/pdf/25211047.pdf

We will use some of these more often than others, you should know them all.

E_p	proton beam energy
E_e	electron beam energy
$p = (0, 0, E_p, E_p)$	four momentum of incoming proton with mass m_p
$e = (0, 0, -E_e, E_e)$	four momentum of incoming electron
$e' = (E'_e sin\theta'_e, 0, E'_e cos\theta'_e, E'_e)$	four momentum of scattered electron
$s = (e + p)^2 = 4E_pE_e$	square of total ep c.m. energy
$q^2 = (e - e')^2 = -Q^2$	mass squared of exchanged current J
	$=$ square of four momentum transfer
$\nu = q \cdot p/m_p$	energy transfer by J in p rest system
$\nu_{max} = s/(2m_p)$	maximum energy transfer
$y = (q \cdot p)/(e \cdot p) = \nu/\nu_{max}$	fraction of energy transfer
$x = Q^2/(2q \cdot p) = Q^2/(ys)$	Bjorken scaling variable
$q_c = x \cdot p + (e - e')$	four momentum of current quark
$M^2 = (e' + q_c)^2 = x \cdot s$	mass squared of electron - current quark system.

Kinematic coverage as a function of energy of collisions

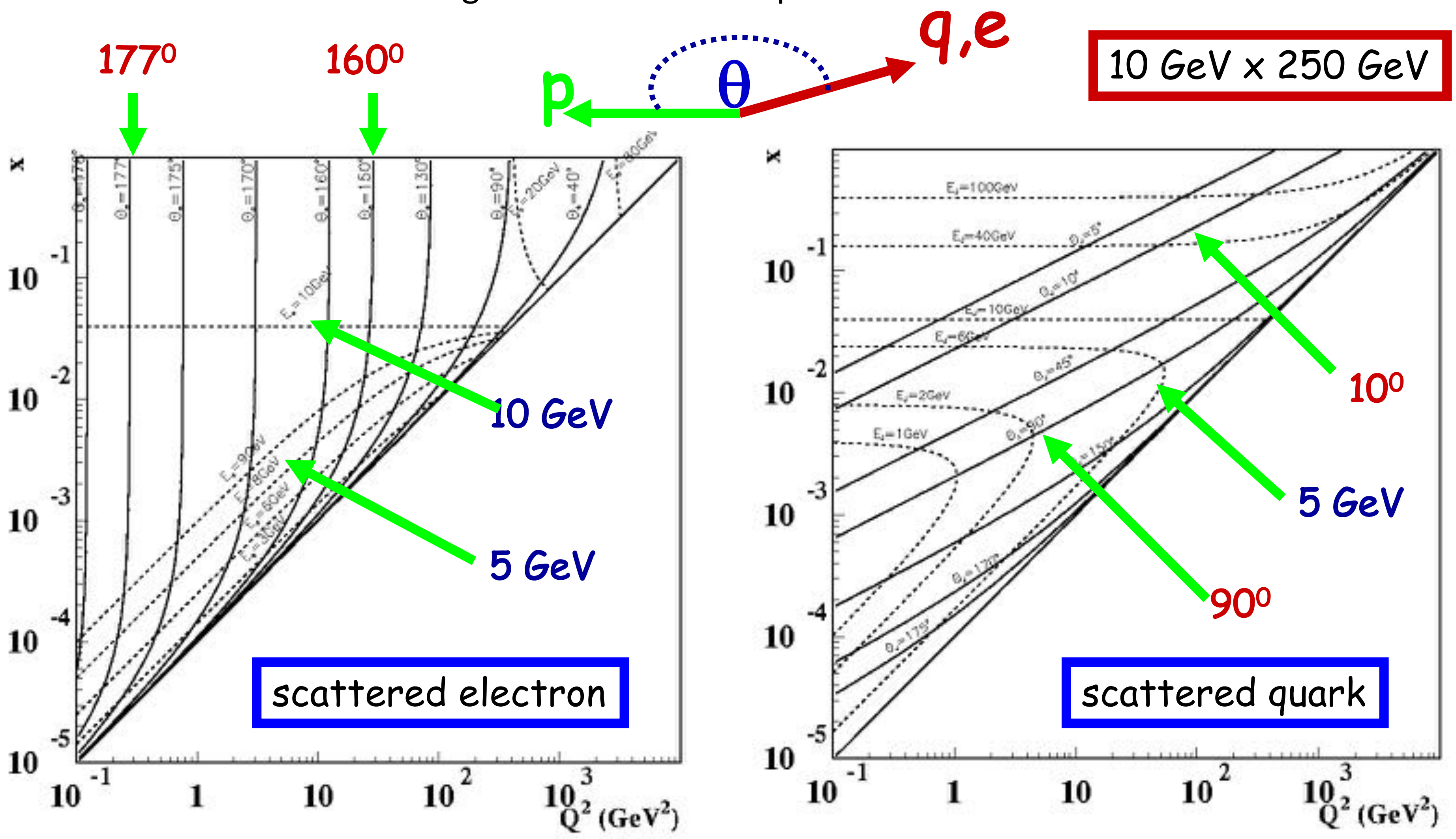


As beam energies increase, so does the x, Q^2 coverage of the collider: 5, 10 and 20 GeV electrons colliding with 50, 100 and 250 GeV protons

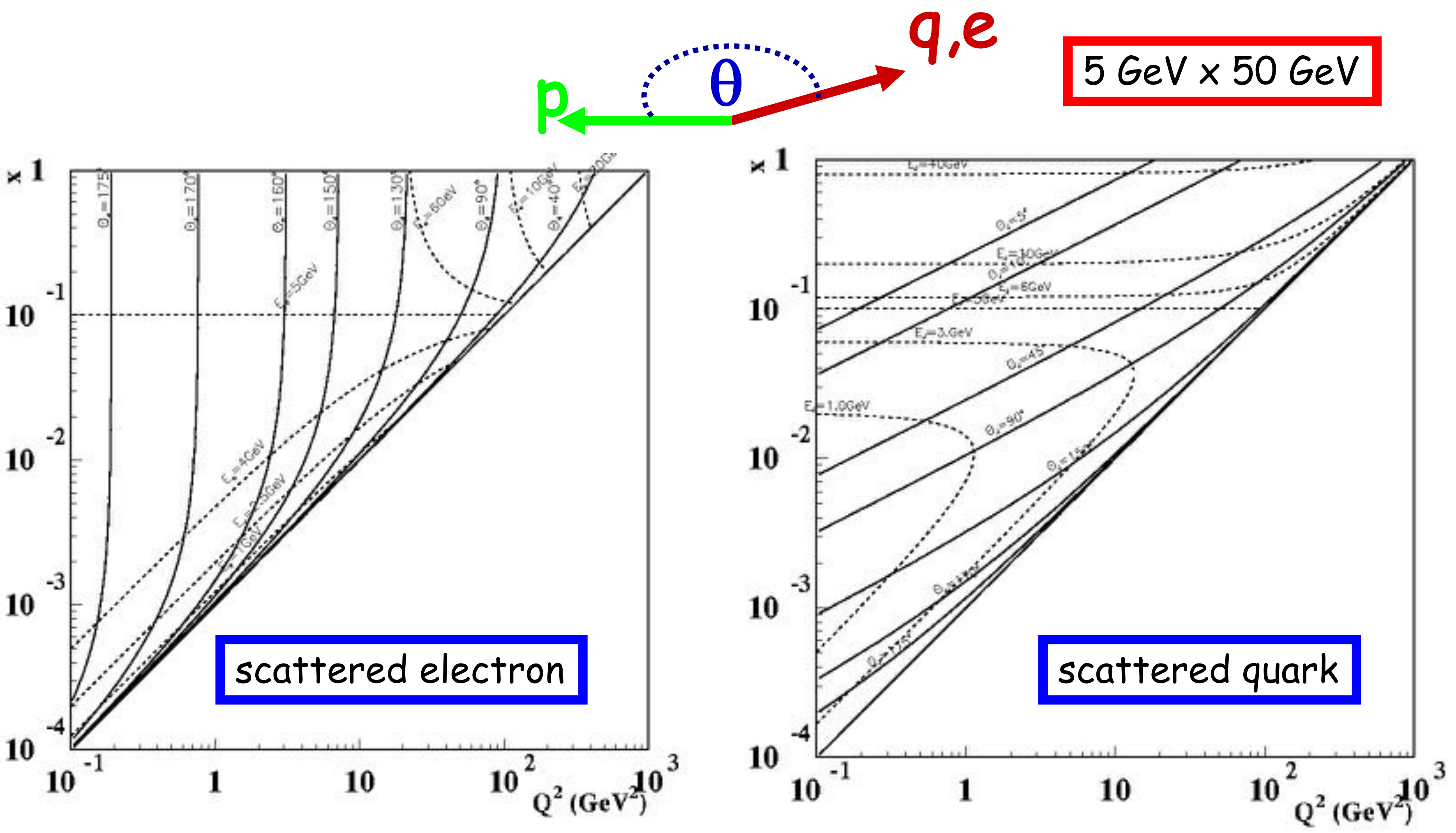
y = 0.95 and 0.01 are shown on all plots (they too shift as function of energy of collisions)

Home Work: Where do electrons and quarks go?

Angles measured w.r.t. proton direction



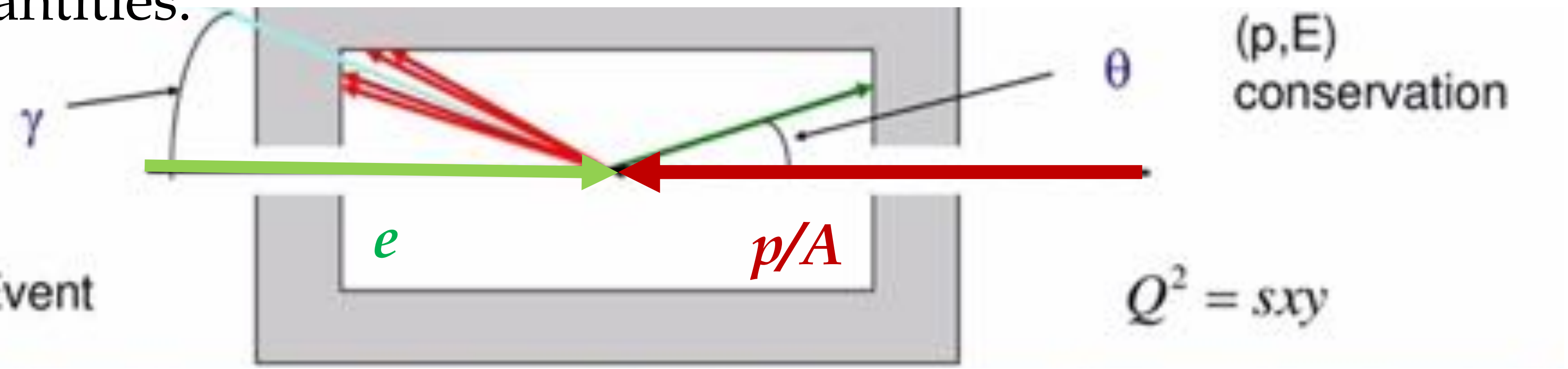
Electron, Quark Kinematics



There are multiple ways to reconstruct events:

Four measured quantities:

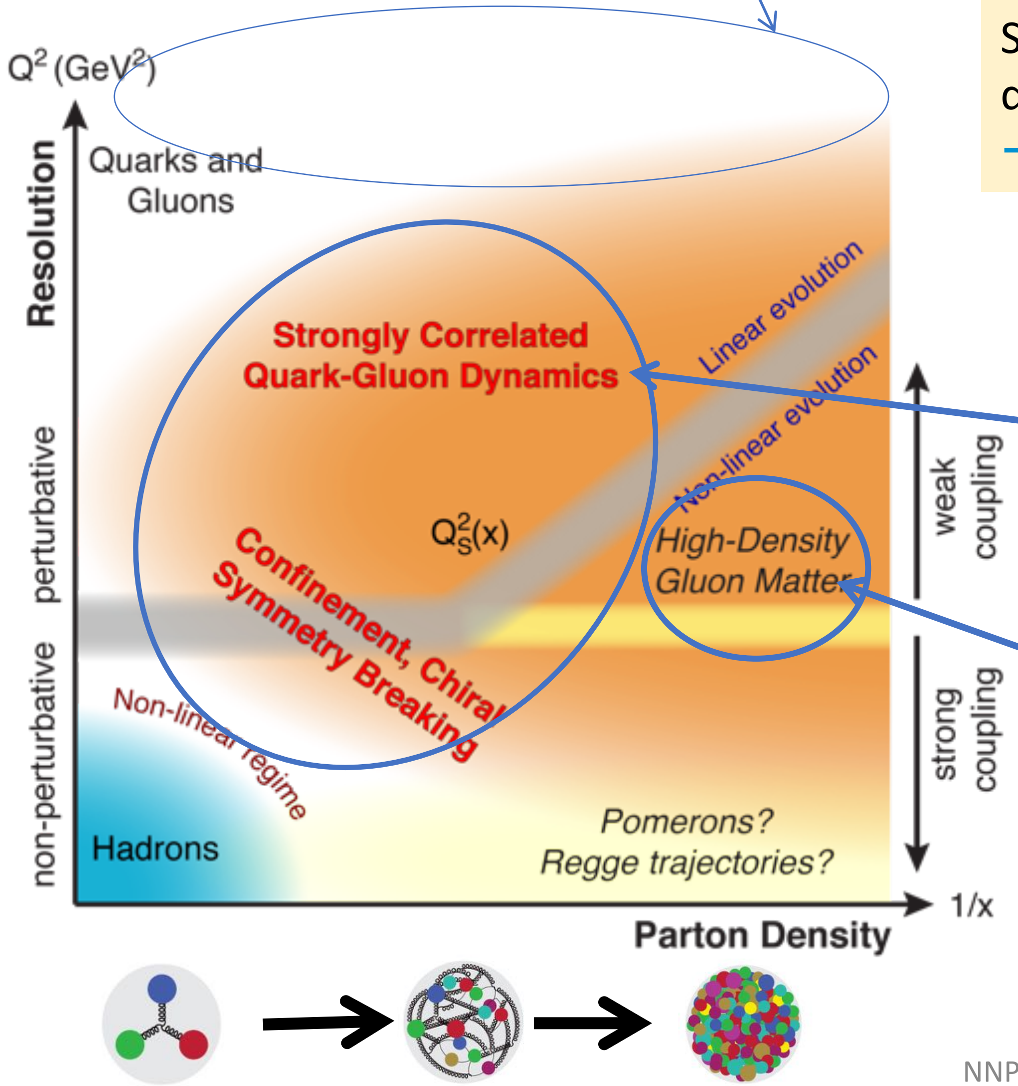
$$E'_e, \theta, E_h, \gamma$$



QCD Landscape to be explored by a future facility

QCD at high resolution (Q^2) — weakly correlated quarks and gluons are well-described

Strong QCD dynamics creates many-body correlations between quarks and gluons
→ hadron structure emerges

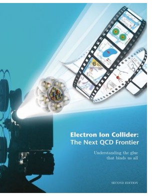


arXiv: 1708.01527

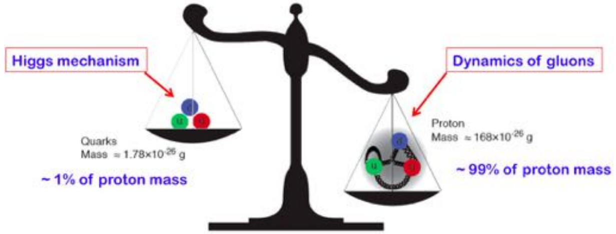
Systematically explore correlations in this region.

An exciting opportunity: Observation of a new regime in QCD of weakly coupled high-density matter

Need Precision and Control

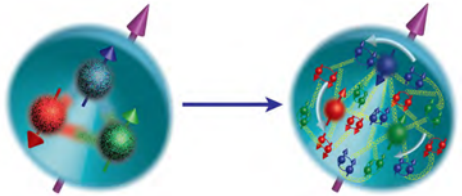


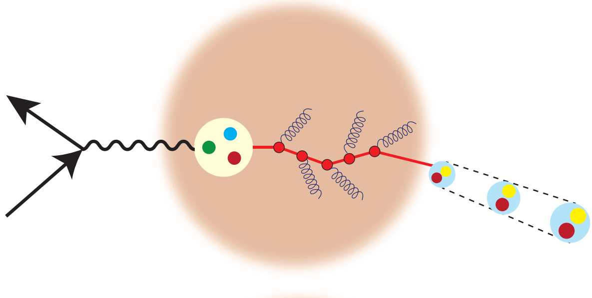
EIC Physics at-a-Glance



How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon?

How do the nucleon properties (mass & spin) emerge from their interactions?





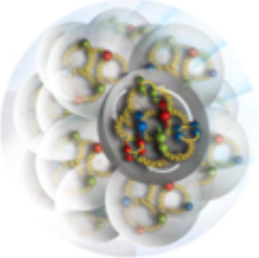
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

How do the confined hadronic states emerge from these quarks and gluons?

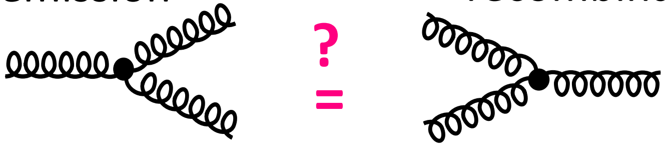
How do the quark-gluon interactions create nuclear binding?

How does a dense nuclear environment affect the quarks and gluons, their correlations, and their interactions?

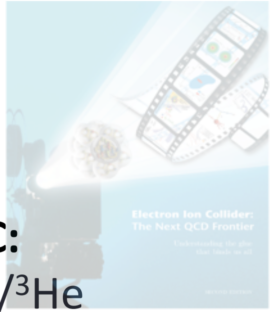
What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?

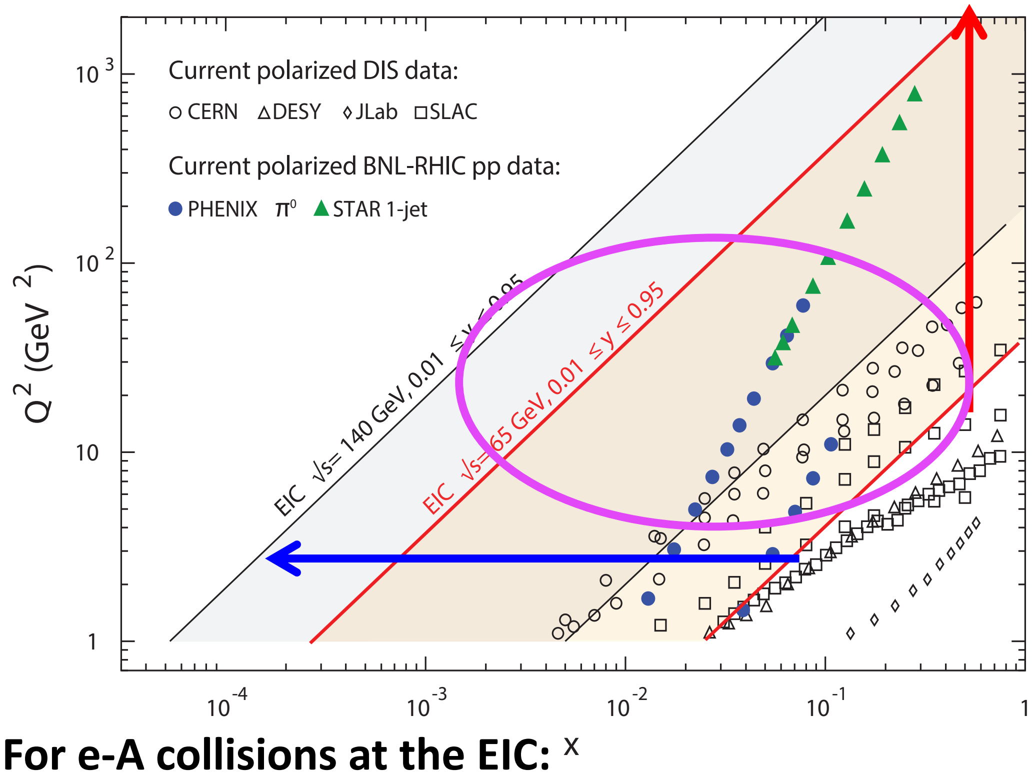


gluon emission ?= gluon recombination



EIC: Kinematic reach & properties



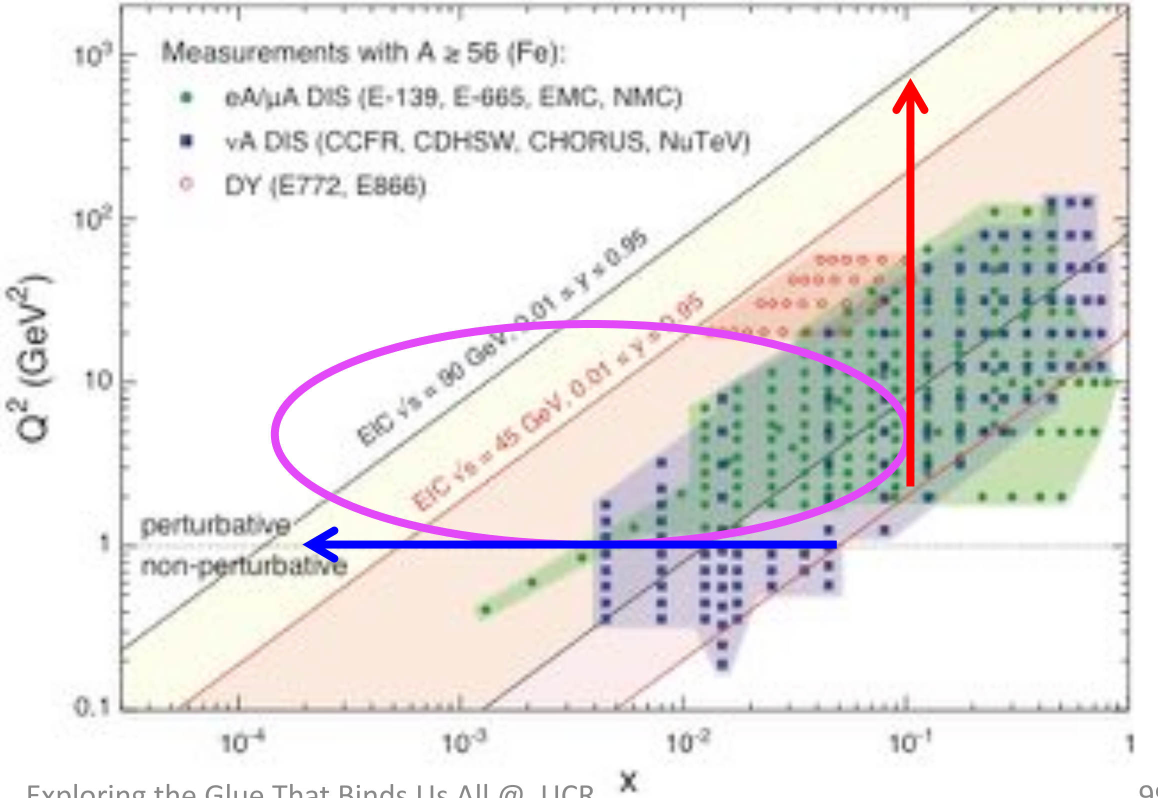


For e-N collisions at the EIC:

- ✓ **Polarized** beams: e, p, d/^{3}He
- ✓ Variable center of mass energy
- ✓ Wide Q^2 range → evolution
- ✓ Wide x range → spanning valence to low-x physics

For e-A collisions at the EIC:

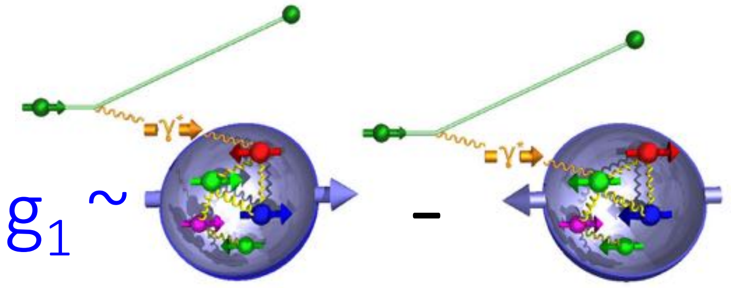
- ✓ **Wide range in nuclei**
- ✓ Lum. per nucleon same as e-p
- ✓ Variable center of mass energy
- ✓ Wide x range (evolution)
- ✓ Wide x region (reach high gluon densities)



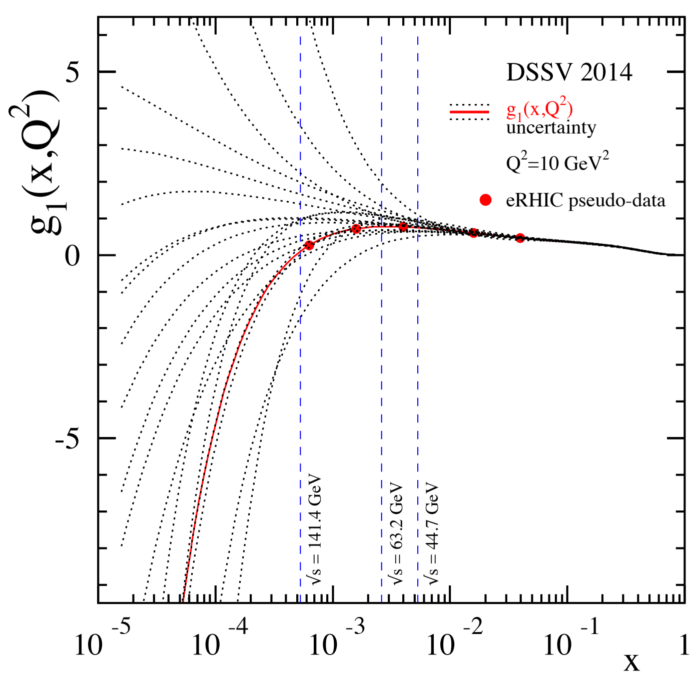
Nucleon Spin: Precision with EIC

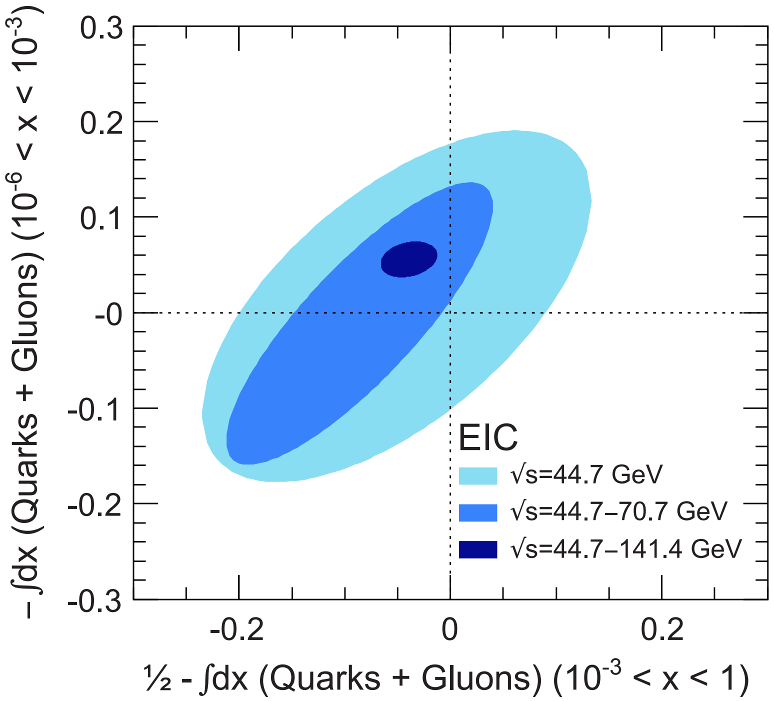
$$\frac{1}{2} = \left[\frac{1}{2}\Delta\Sigma + L_Q\right] + \left[\Delta g + L_G\right]$$

$\Delta\Sigma/2$ = Quark contribution to Proton Spin
Δg = Gluon contribution to Proton Spin
L_Q = Quark Orbital Ang. Mom
L_G = Gluon Orbital Ang. Mom



Spin structure function g_1 needs to be measured over a large range in x-Q^2





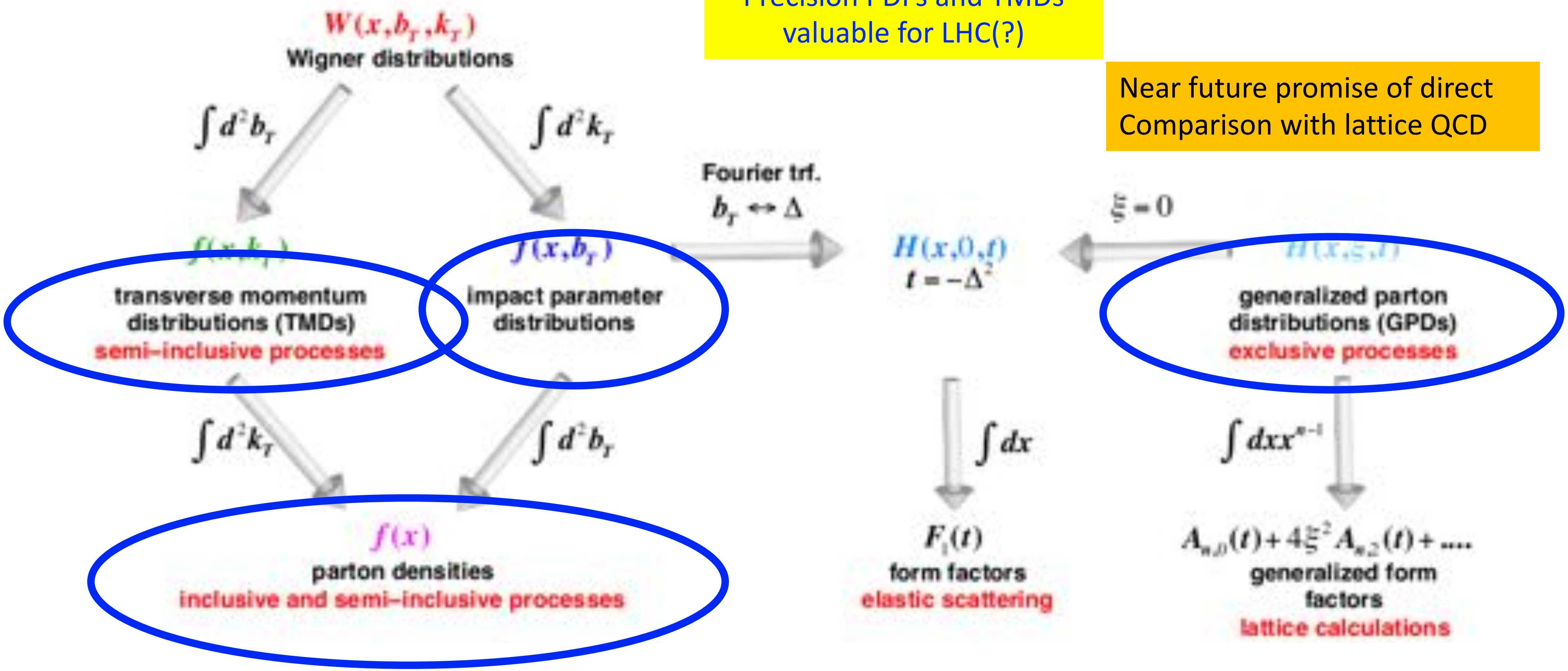
Precision in $\Delta\Sigma$ and Δg ➔ A clear idea Of the magnitude of L_Q+L_G = L

SIDIS: strange and charm quark spin contributions

2+1D Imaging of hadrons: beyond precision PDFs

Precision PDFs and TMDs valuable for LHC(?)

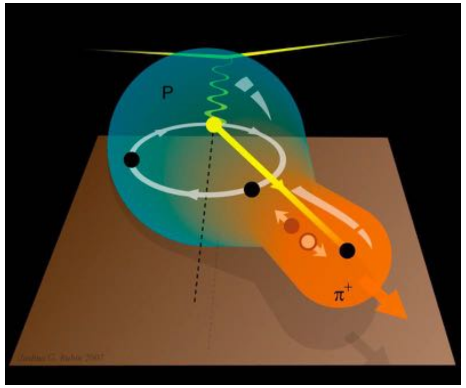
Near future promise of direct Comparison with lattice QCD



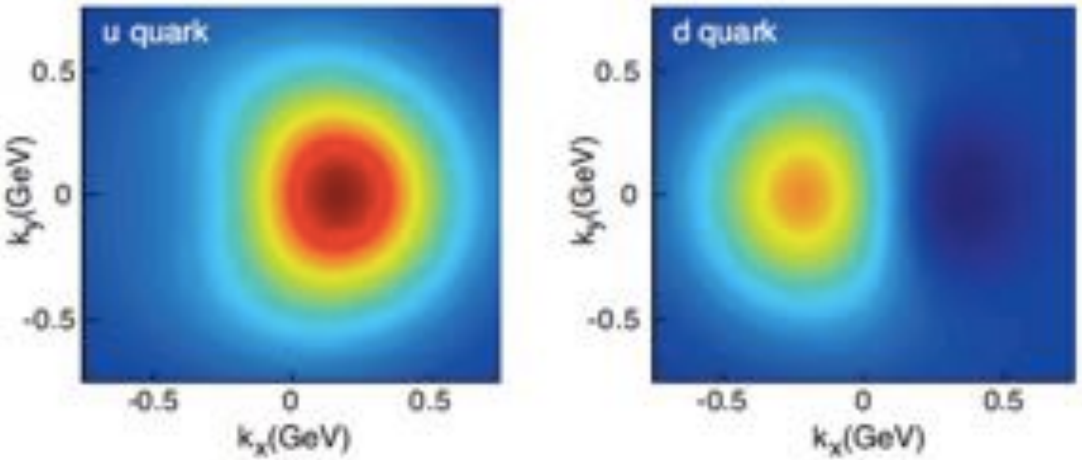
2+1 D partonic image of the proton with the EIC

Spin-dependent 3D momentum space images from semi-inclusive scattering (SIDS)

Transverse Momentum Distributions



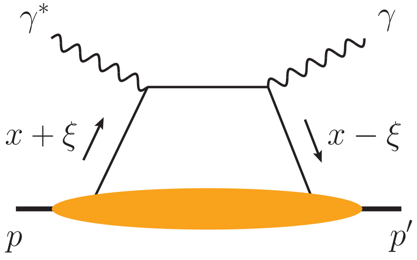
Possible measurements of K (s) and D (c)

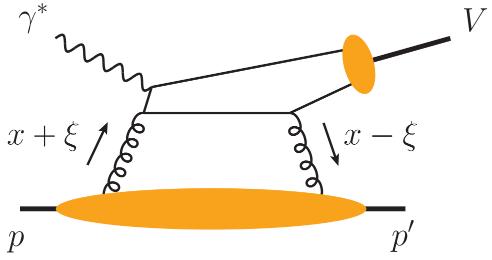


Spin-dependent 2D coordinate space (transverse) + 1D (longitudinal momentum) images from exclusive scattering

Transverse Position Distributions

Quarks Motion





Gluons: Only @ Collider

Deeply Virtual Compton Scattering

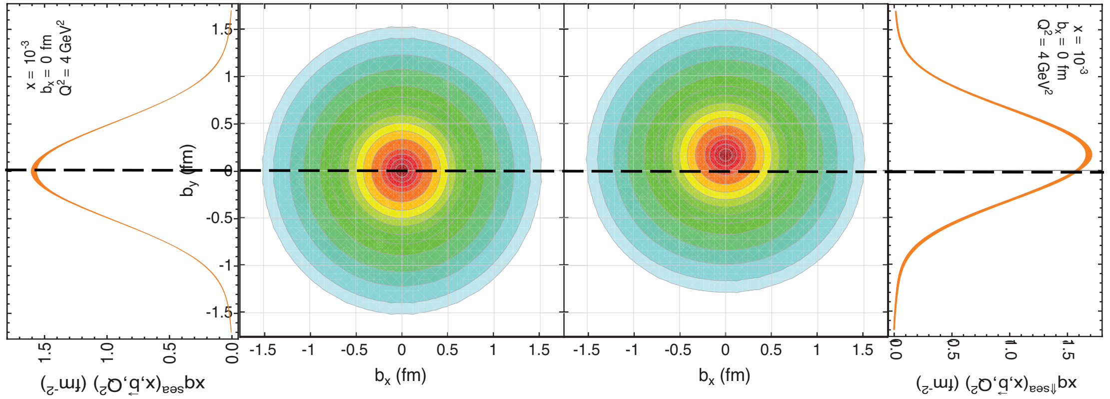
Measure all three final states

e + **p** → e’+ **p’**+ γ

Fourier transform of momentum transferred=(p-p’) → Spatial distribution

2D position distribution for sea-quarks

unpolarized polarized



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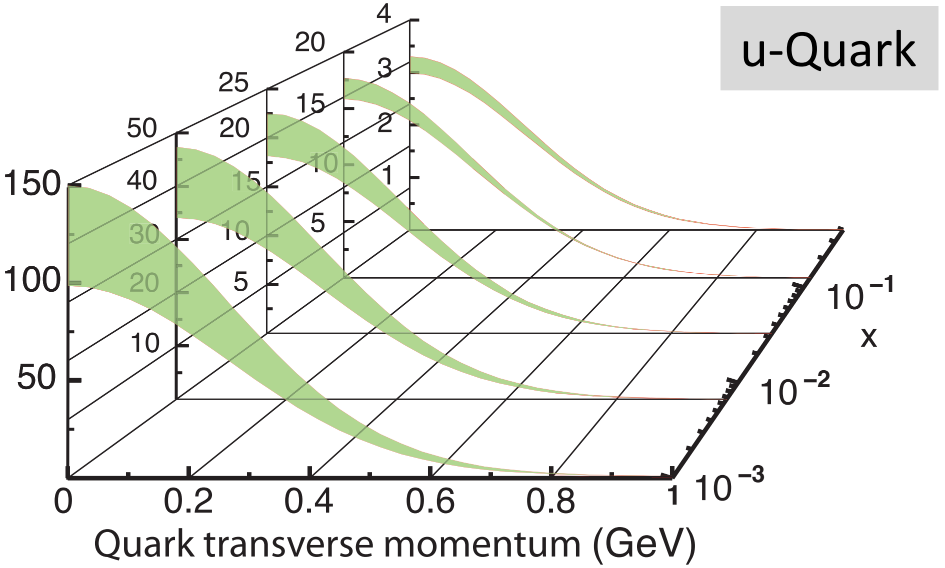

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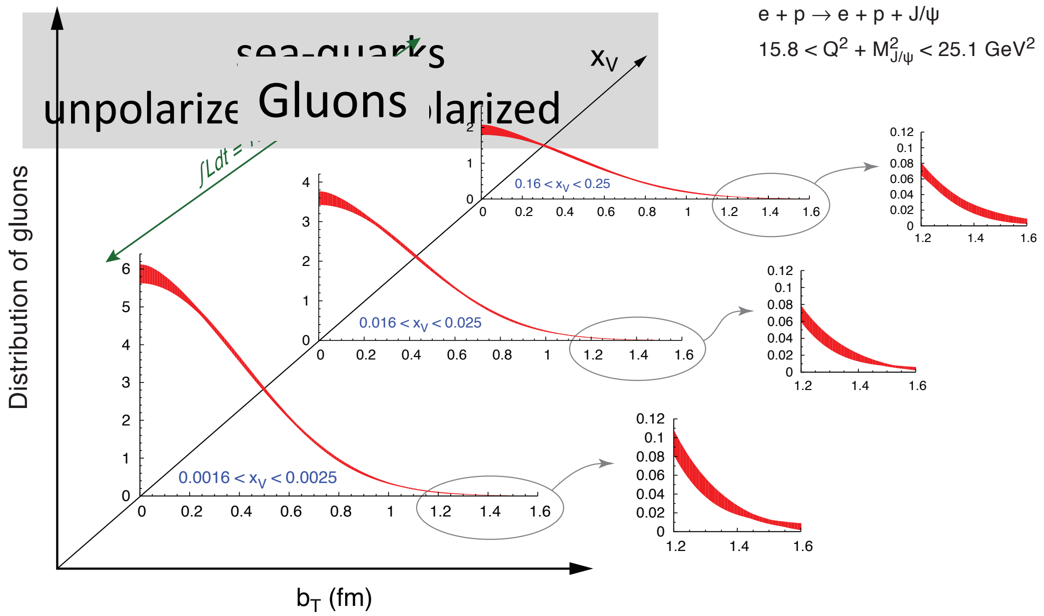


Study of internal structure of a watermelon:

A-A (RHIC)

1) Violent collision of melons

2) Cutting the watermelon with a knife

Violent DIS e-A (EIC)

3) MRI of a watermelon

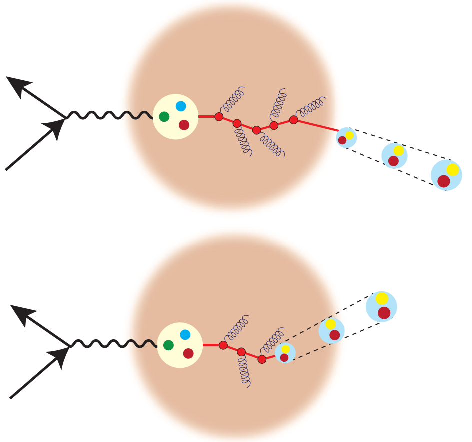
Non-Violent e-A (EIC)

Emergence of Hadrons from Partons

Nucleus as a Femtometer sized filter

Unprecedented ν, the virtual photon energy range
@ EIC : *precision & control*

$$\nu = \frac{Q^2}{2mx}$$

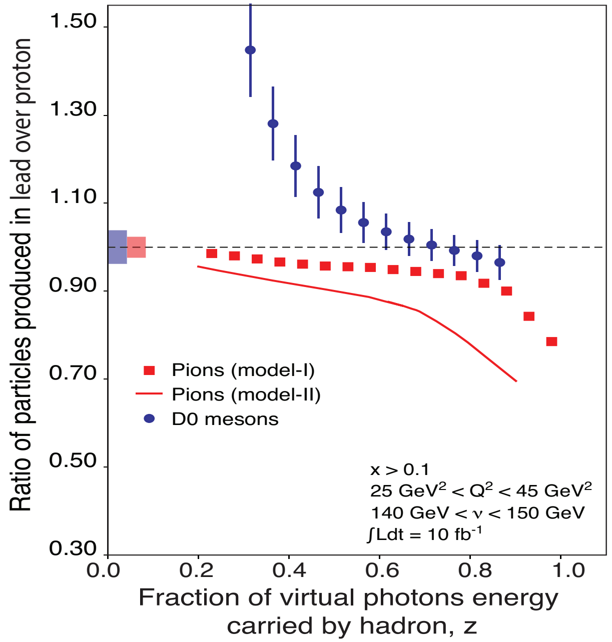


Study in light quarks
vs.
heavy quarks

Control of ν by selecting kinematics;
Also under control the nuclear size.

(colored) Quark passing through cold QCD matter emerges as color-neutral hadron ➔
Clues to color-confinement?

Energy loss by light vs. heavy quarks:

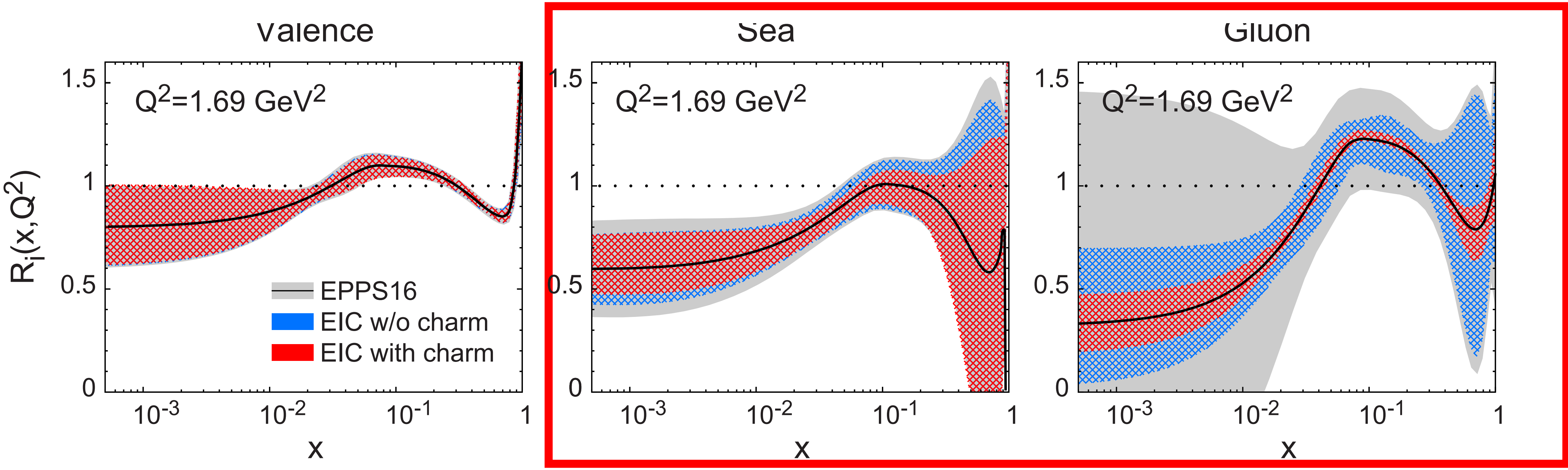


Identify π vs. D^0 **(charm)** mesons in e-A collisions:

Understand energy loss of light vs. heavy quarks
traversing the cold nuclear matter:
Connect to energy loss in Hot QCD

Need the collider energy of EIC and its control on parton kinematics

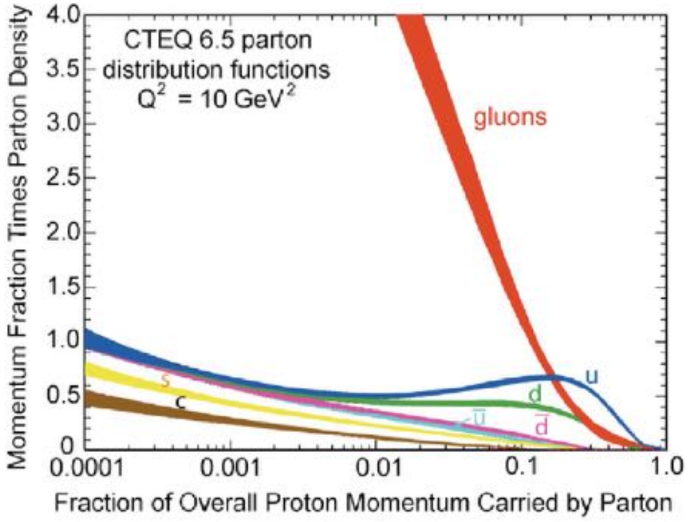
EIC: impact on the knowledge of 1D Nuclear PDFs

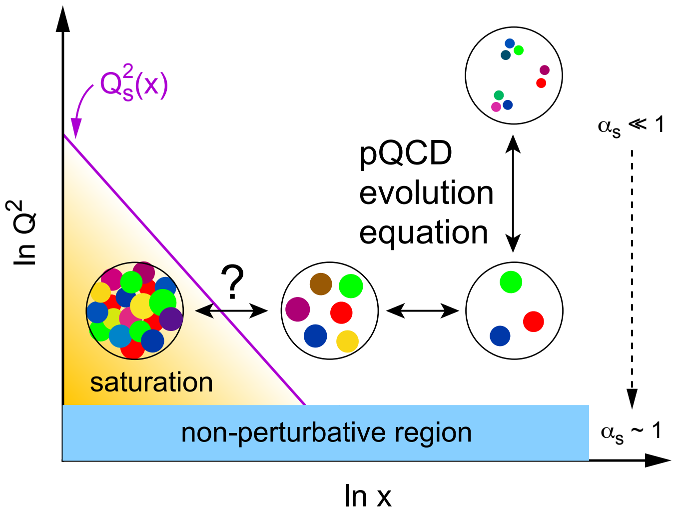


Ratio of Parton Distribution Functions of Pb over Proton:

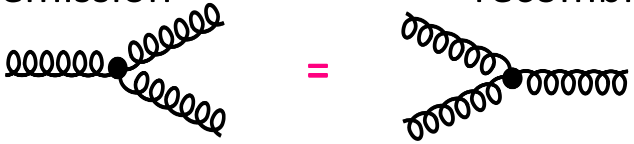
- ❖Without EIC, large uncertainties in **nuclear sea quarks and gluons** ➔With EIC significantly reduced uncertainties
- ❖Complementary to RHIC and LHC pA data. Provides information on initial state for heavy ion collisions.
- ❖Does the nucleus behave like a proton at low-x? ➔ such color correlations relevant to the understanding of astronomical objects

Low x physics with nuclei

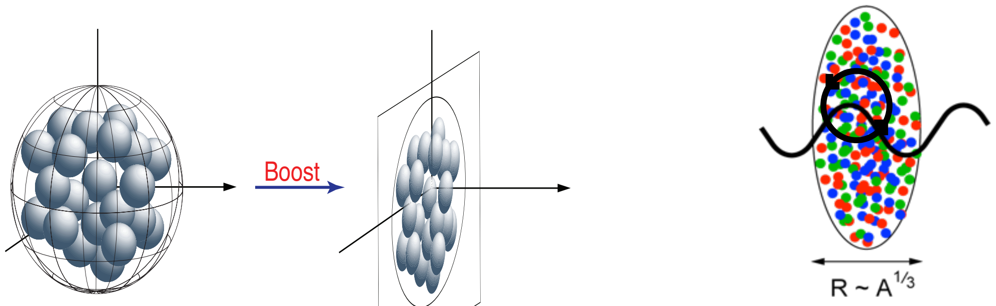




gluon emission = gluon recombination



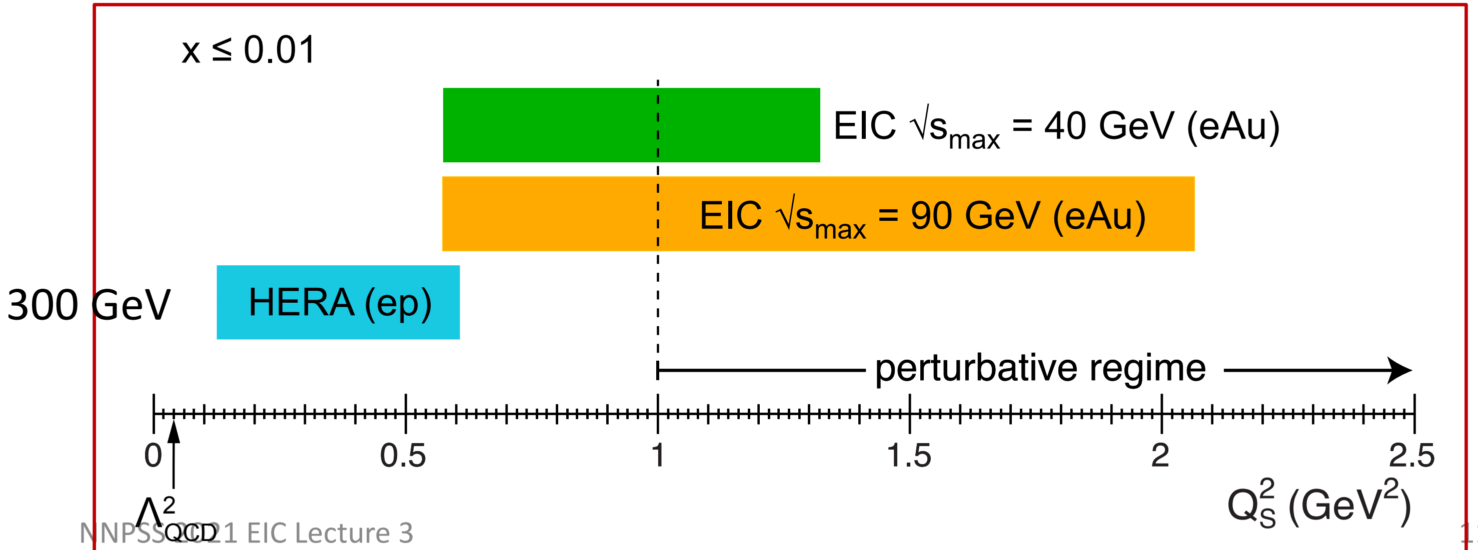
At Q_S



$$(Q_s^A)^2 \approx cQ_0^2 \left[\frac{A}{x}\right]^{1/3}$$

$L \sim (2m_N x)^{-1} > 2 R_A \sim A^{1/3}$

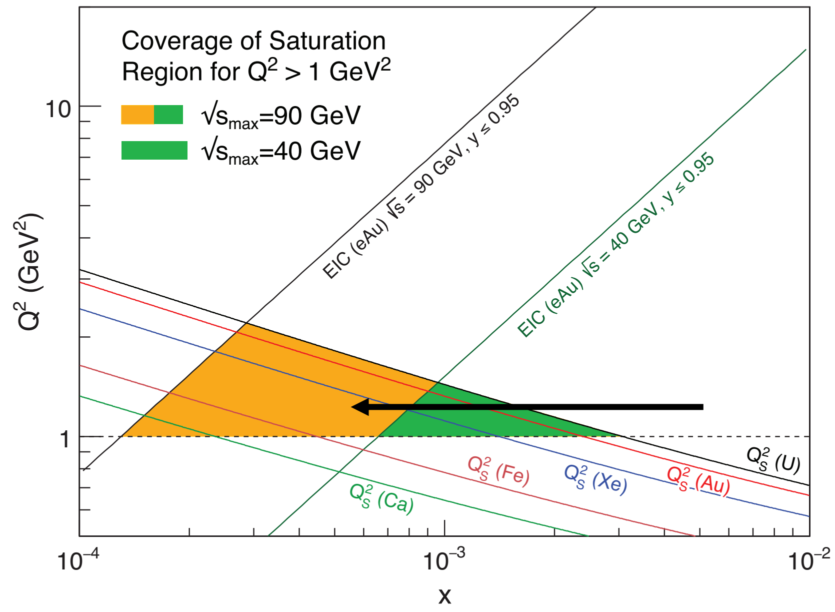
Accessible range of saturation scale $Q_s{}^2$ at the EIC with e+A collisions.
arXiv:1708.01527



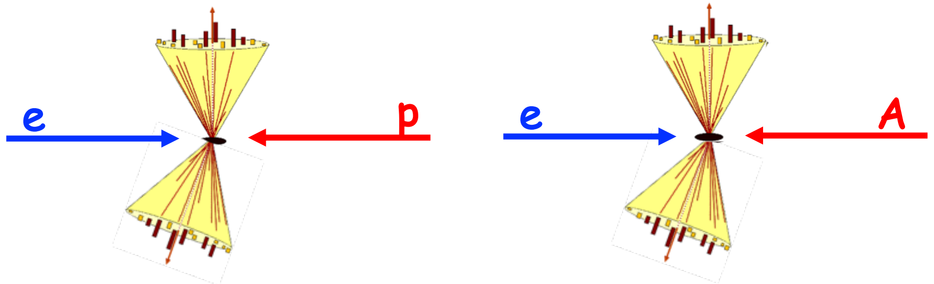
Can EIC discover a new state of matter?

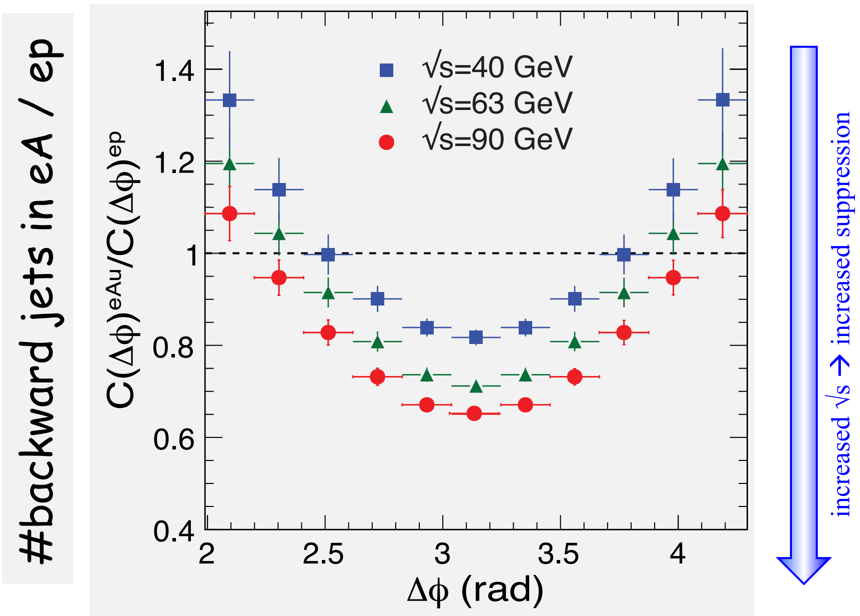
EIC provides an absolutely unique opportunity to have very high gluon densities
→ electron – lead collisions
combined with an unambiguous observable

EIC will allow to unambiguously map the transition from a non-saturated to saturated regime



counting experiment of Di-jets in ep and eA
Saturation:
Disappearance of backward jet in eA



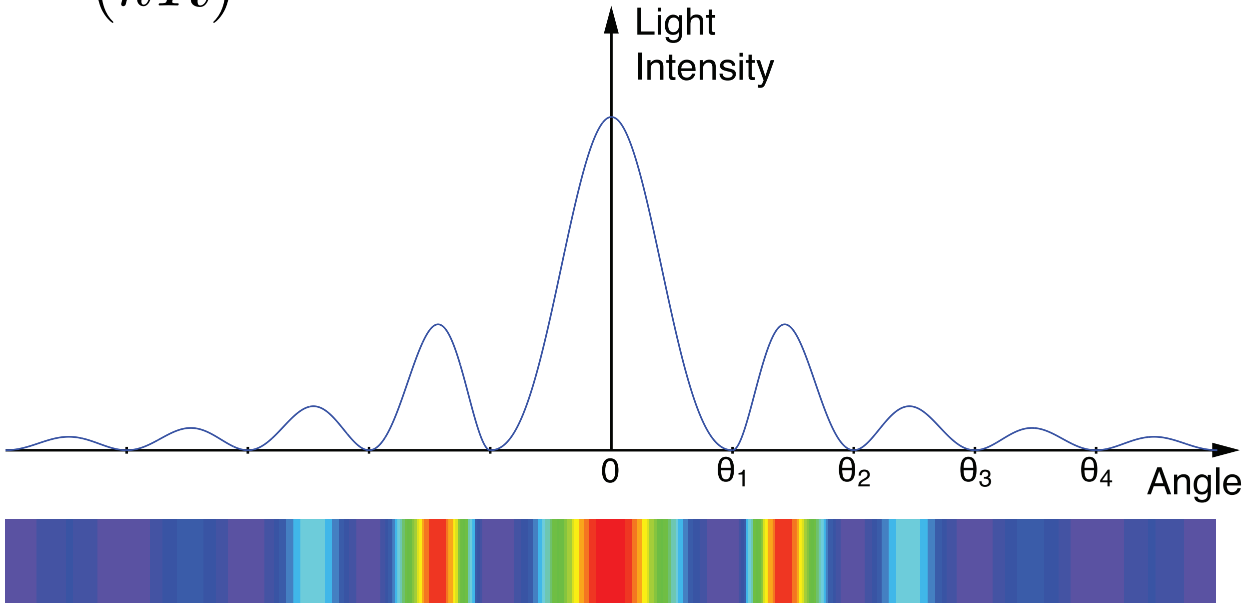


Diffraction in Optics and high energy scattering

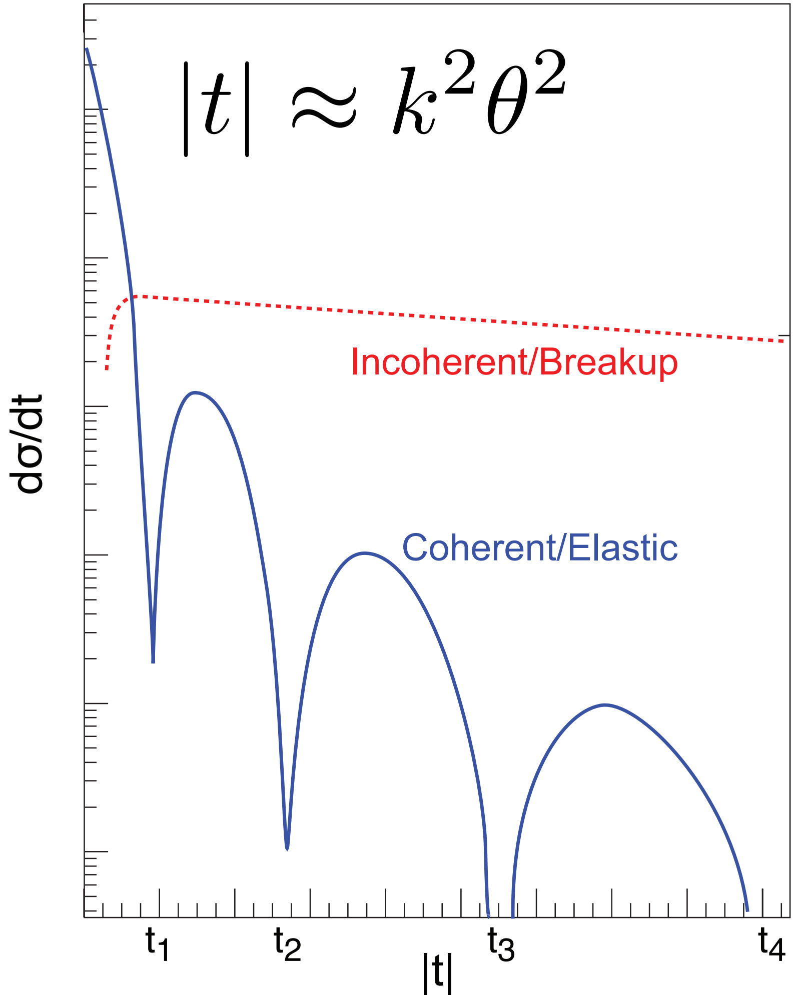
Light with wavelength λ obstructed by an opaque disk of radius R suffers diffraction:

k → wave number

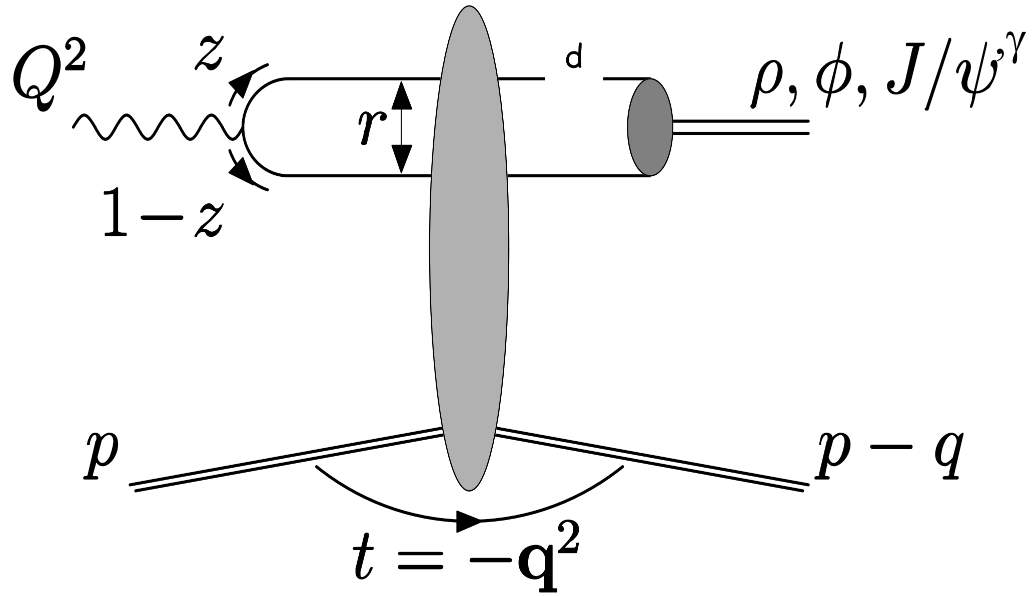
$$\theta_i \sim \frac{1}{(kR)}$$



Calculation of e-A diffraction

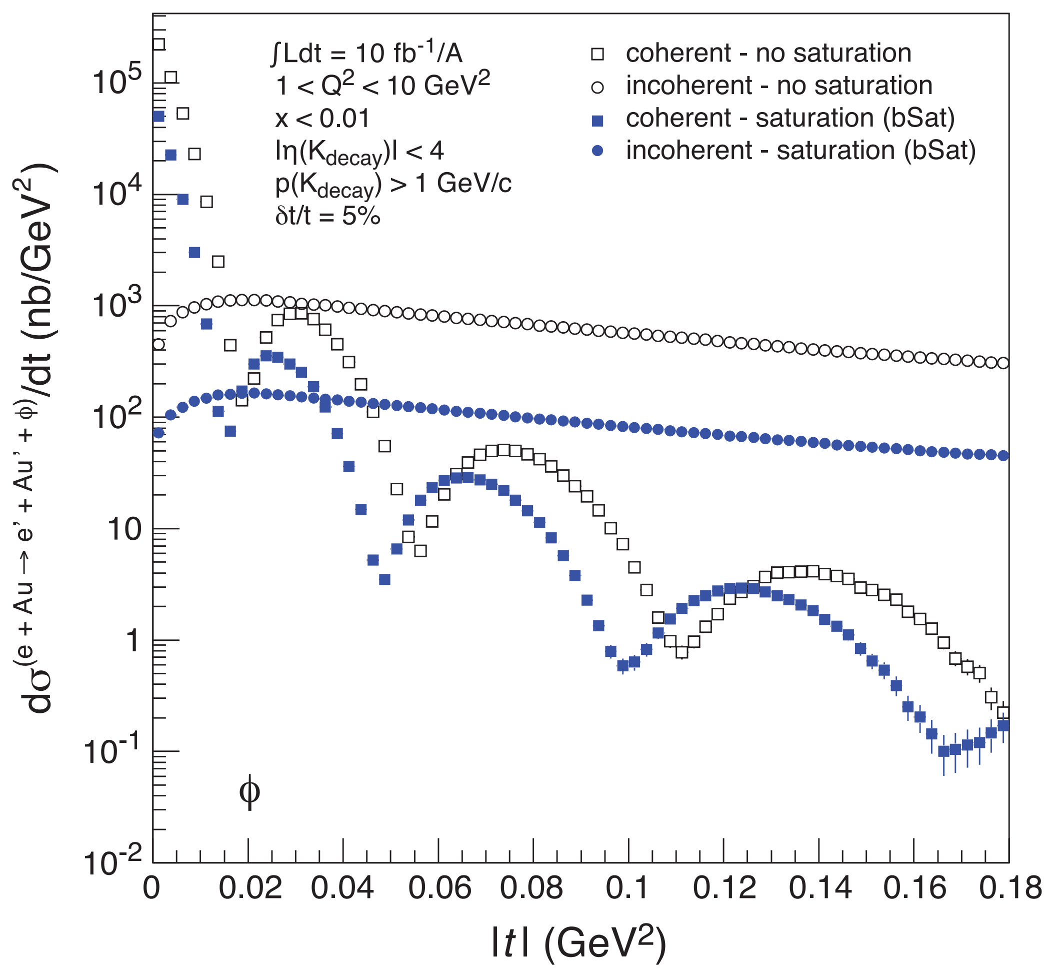


Transverse imaging of the gluons nuclei



Diffractive vector meson production in **e-Au**

Diff. MC: "Sartre"

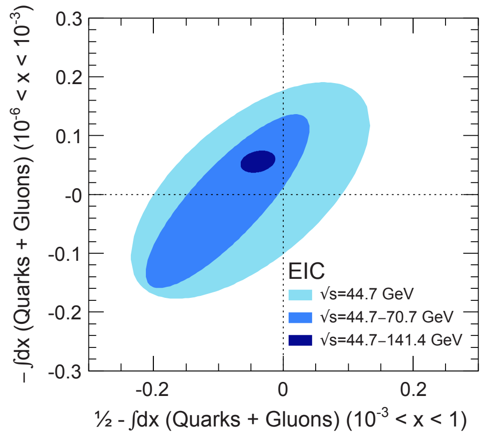


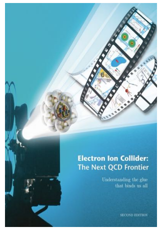
Simulation study by Toll & Ullrich

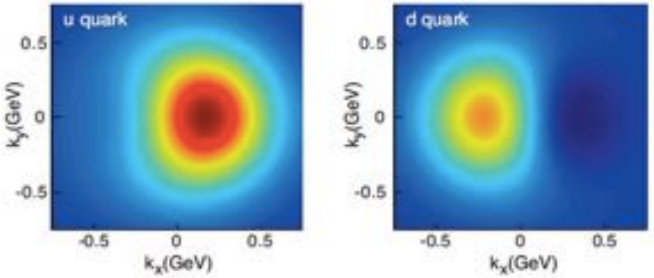
➔Does low x dynamics (Saturation) modify the transverse gluon distribution?

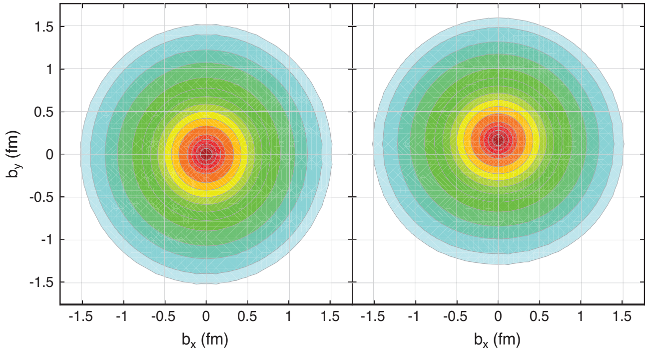
Experimental challenges being studied.

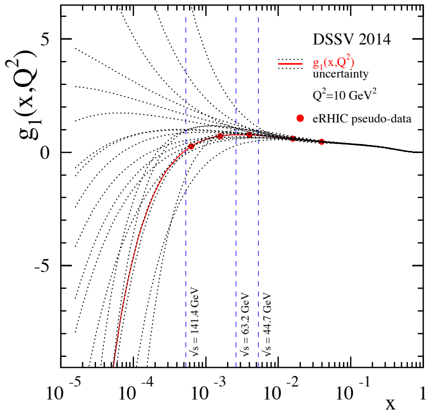
EIC science highlights

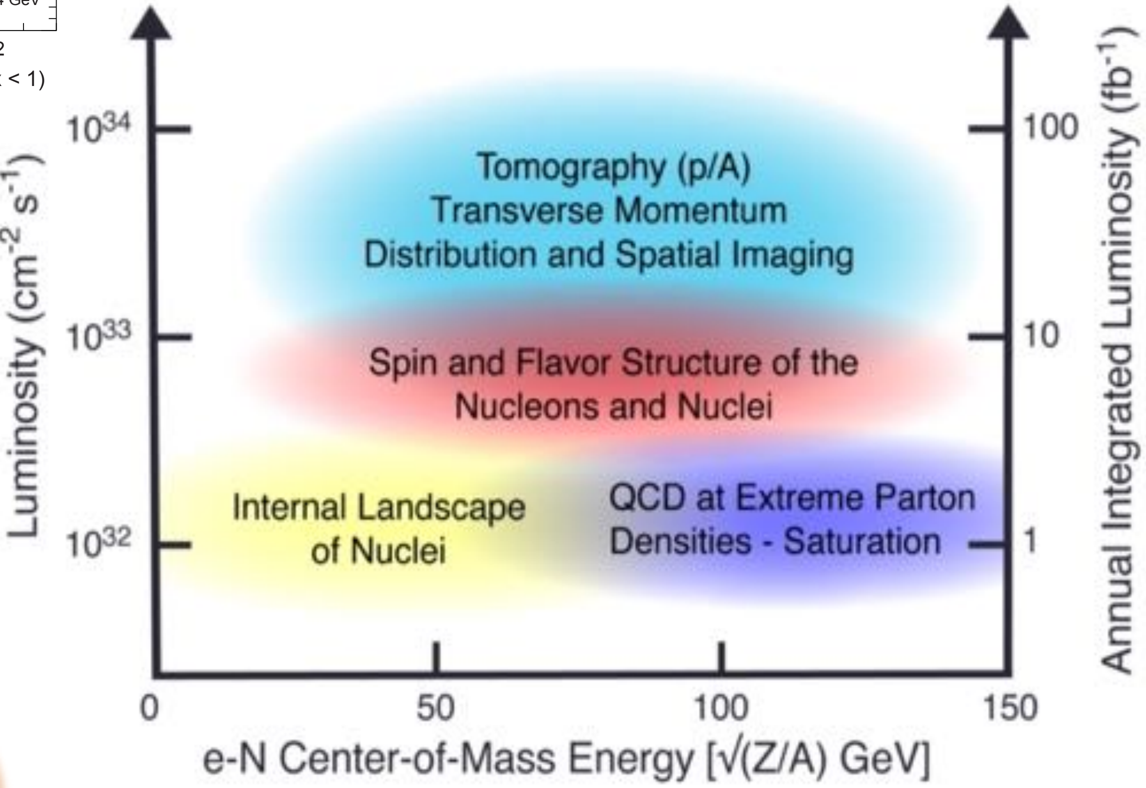


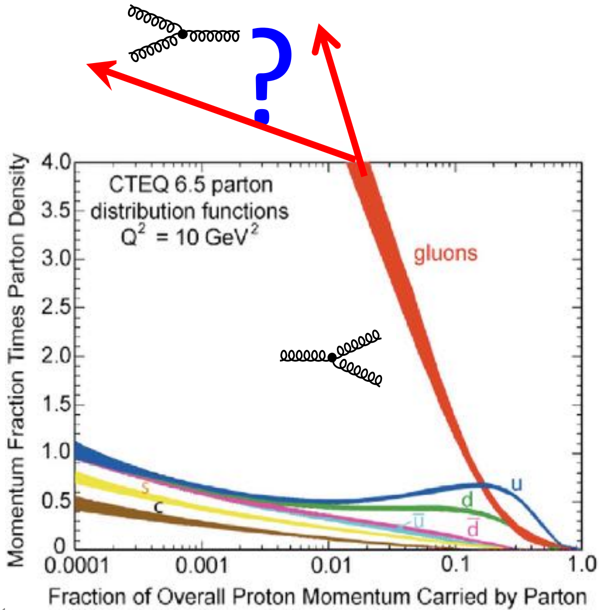


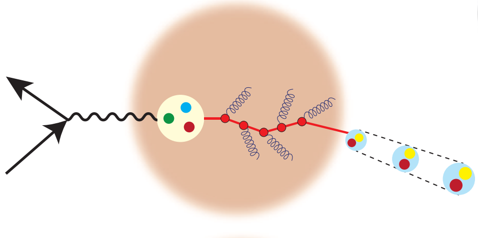


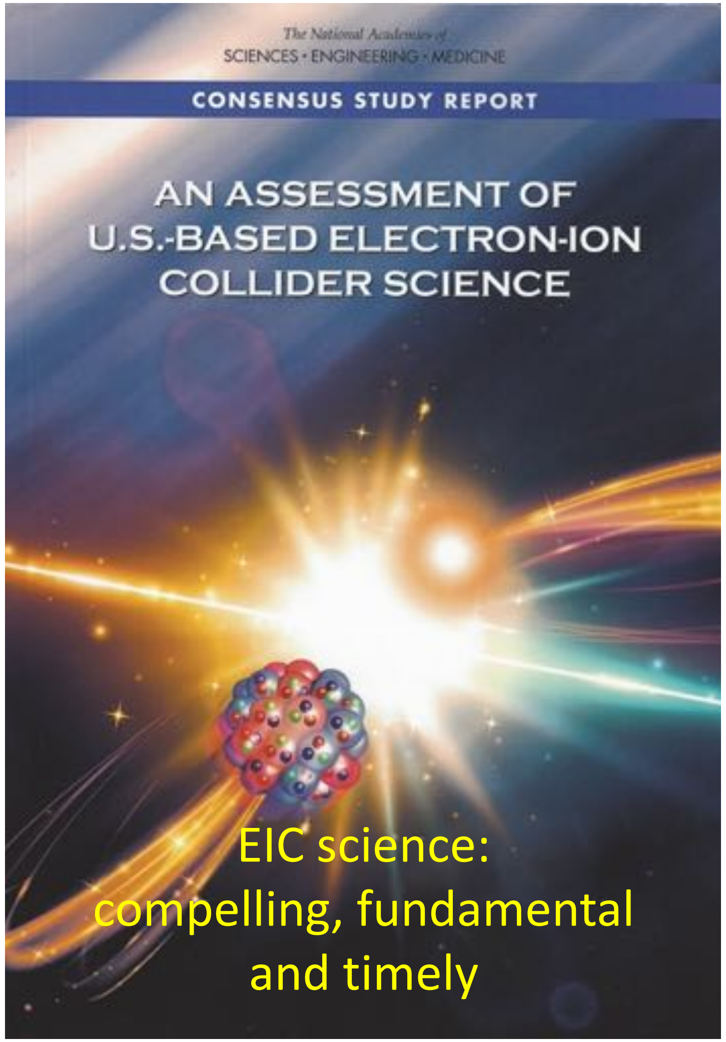










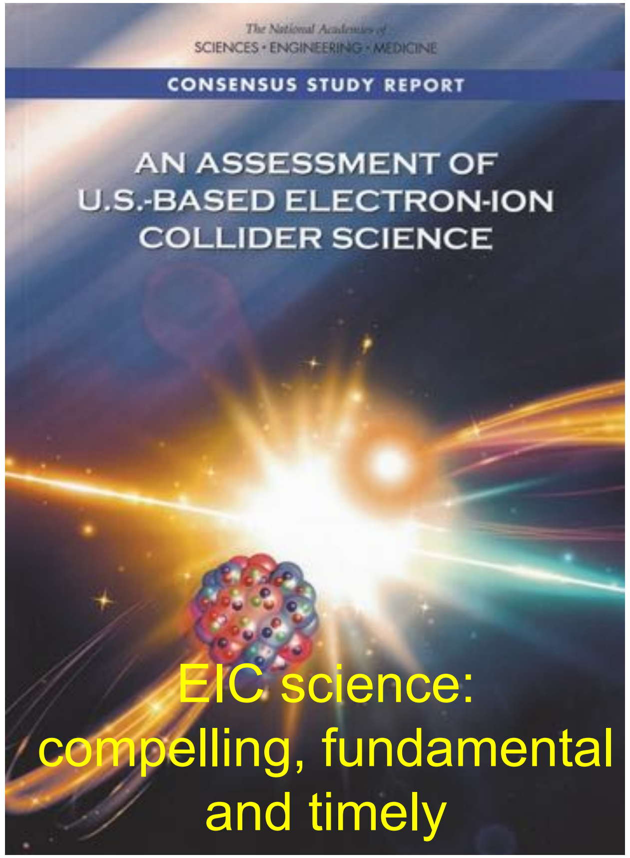


Consensus Study Report on the US based Electron Ion Collider

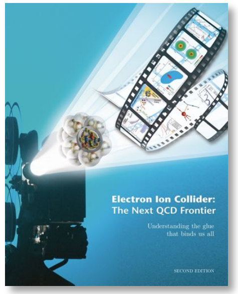
Summary:

The science questions that an EIC will answer *are central* to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today. In addition, the development of an EIC would *advance accelerator science and technology* in nuclear science; it would as well *benefit other fields of accelerator based science and society*, from medicine through materials science to elementary particle physics

National Academy's Assessment

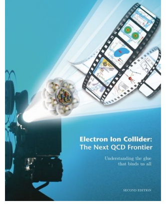


EIC science: compelling, fundamental and timely



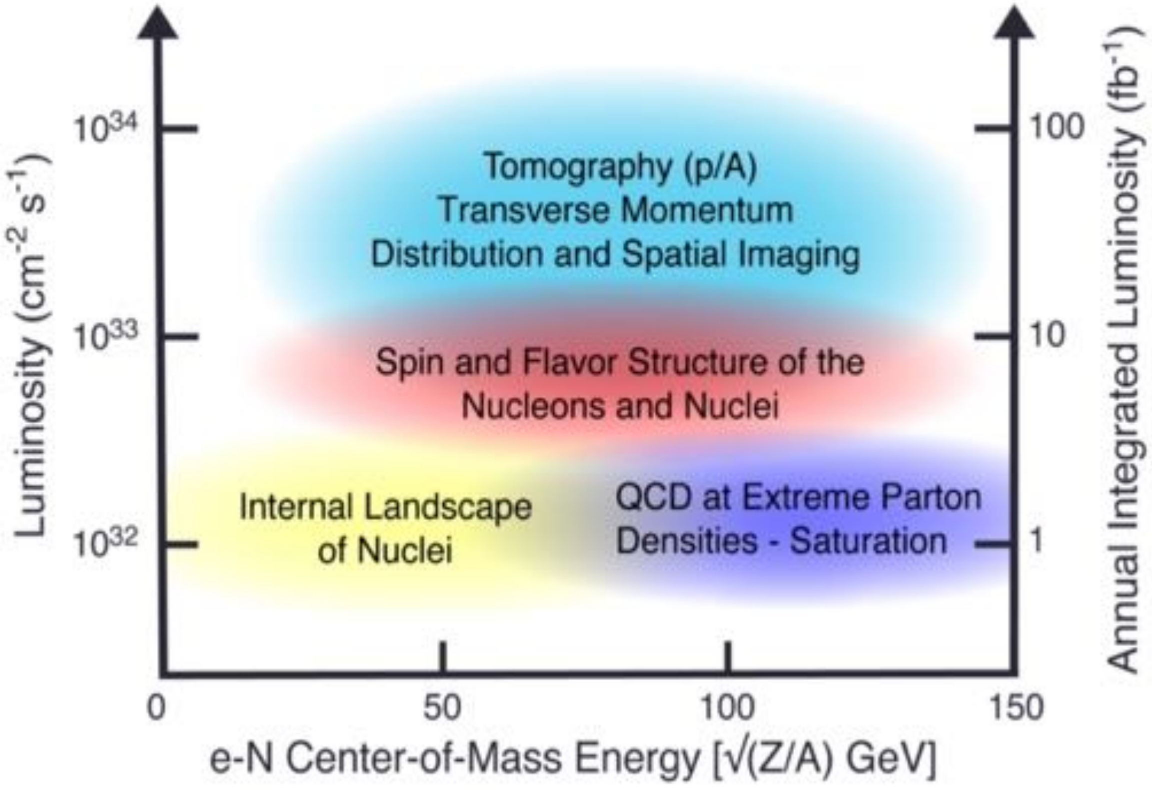
Machine Design Parameters:

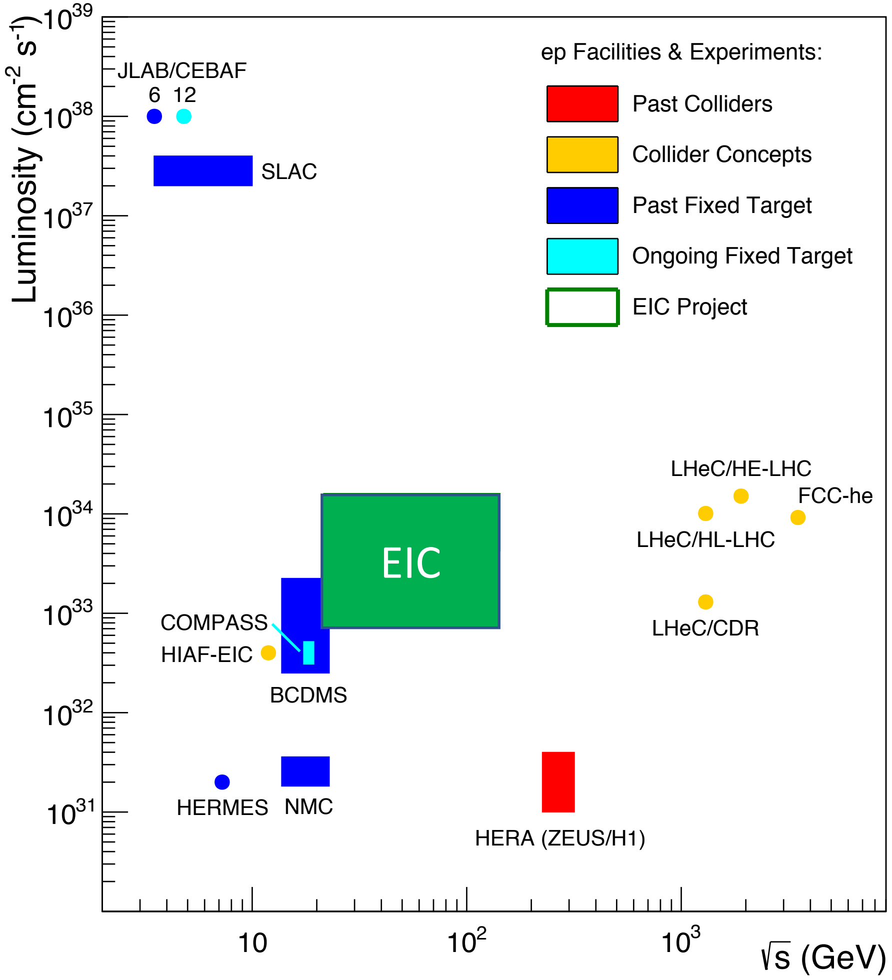
- High luminosity: up to 10^{33}-10^{34} cm^{-2}sec^{-1}
  - a factor ~100-1000 times HERA
- Broad range in center-of-mass energy: ~20-100 GeV upgradable to 140 GeV
- Polarized beams e-, p, and light ion beams with flexible spin patterns/orientation
- Broad range in hadron species: protons…. Uranium
- Up to two detectors well-integrated detector(s) into the machine lattice



EIC Physics and the machine parameters

CM vs. Luminosity vs. Integrated luminosity

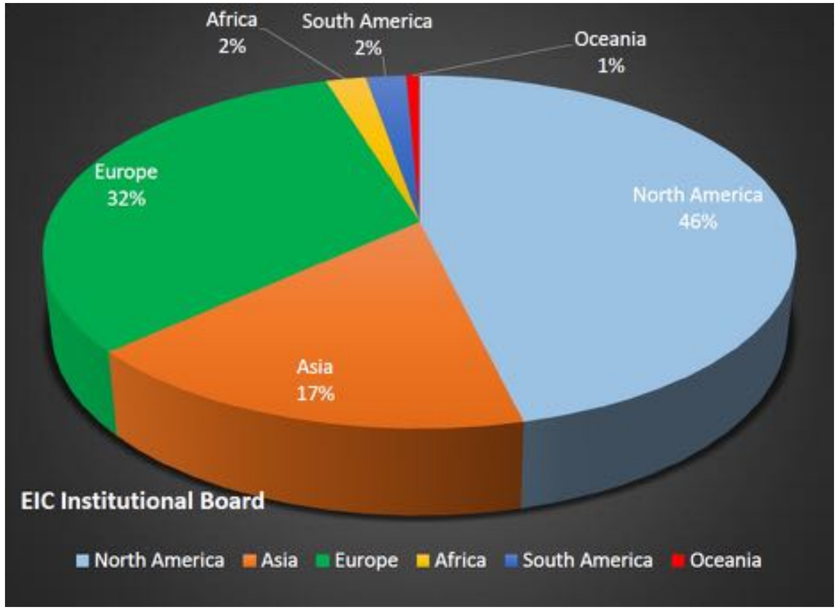




The US EIC with a wide range in $\sqrt{s}$, polarized electron, proton and light nuclear beams and luminosity makes it a unique machine in the world.

The EIC Users Group: EICUG.ORG

Formally established in 2016, now we have:
~1300 Ph.D. Members from 34 countries, 254 institutions
New members welcome



New:
Center for Frontiers in Nuclear Science (at Stony Brook/BNL)
EIC² at Jefferson Laboratory

EICUG Structures in place and active:
EIC UG Steering Committee, Institutional Board, Speaker's Committee, Election & Nominations Committee

Year long workshops: Yellow Reports for detector design

Annual meetings: Stony Brook (2014), Berkeley (2015), **ANL (2016)**, **Trieste (2017)**, **CAU (2018)**, **Paris (2019)**, **FIU (2020)**, **Remote (2021)**, **Warsaw (2022)**

Physics @ the US EIC beyond the EIC's core science

New Studies with proton or neutron target:

- Impact of precision measurements of unpolarized PDFs at high x/Q^2, on LHC-Upgrade results(?)
- What role would TMDs in e-p play in W-Production at LHC? Gluon TMDs at low-x!
- Heavy quark and quarkonia (c, b quarks) studies with 100-1000 times lumi of HERA
- Does polarization of play a role (in all or many of these?)

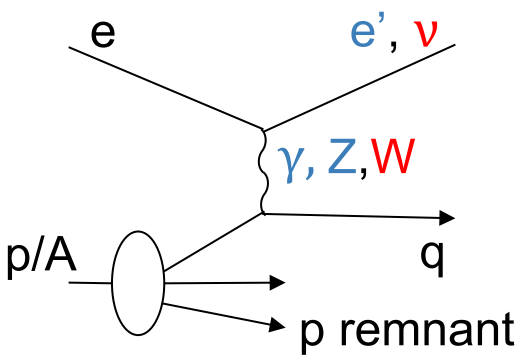
Physics with nucleons and nuclear targets:

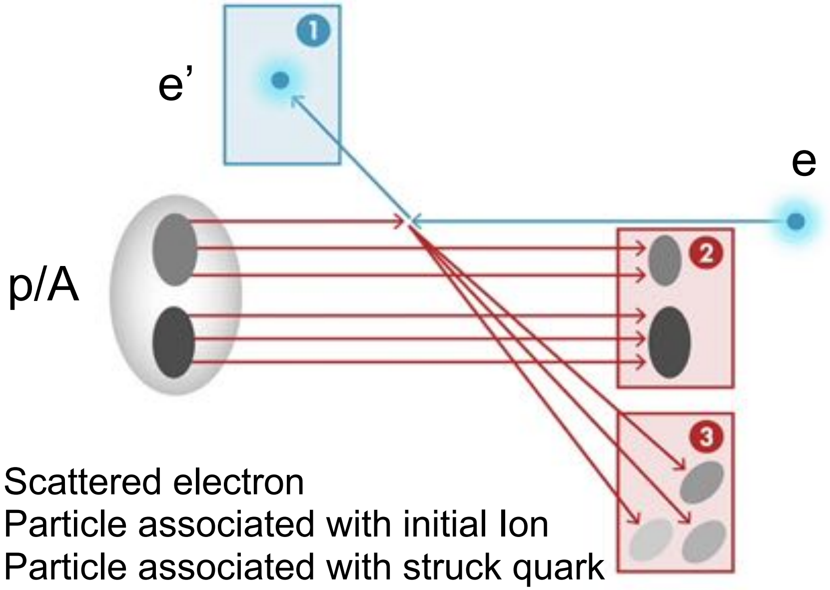
- Quark Exotica: 4,5,6 quark systems…? Much interest after recent LHCb led results.
- Physic of and with jets with EIC as a precision QCD machine:
  - Internal structure of jets : novel new observables, energy variability, polarization, beam species
  - Entanglement, entropy, connections to fragmentation, hadronization and confinement
  - Studies with jets: Jet propagation in nuclei… energy loss in cold QCD medium
- Connection to p-A, d-A, A-A at RHIC and LHC
- Polarized light nuclei in the EIC

Precision electroweak and BSM physics:

- Electroweak physics & searches beyond the SM: Parity, charge symmetry, lepton flavor violation

Detector Challenge of the EIC





1. Scattered electron
2. Particle associated with initial Ion
3. Particle associated with struck quark (or associated gluon)

Aim of EIC is 3D nucleon and nuclear structure beyond the longitudinal description.

This makes the requirements for the machine and detector different from all previous colliders.

"Statistics"=Luminosity × Acceptance

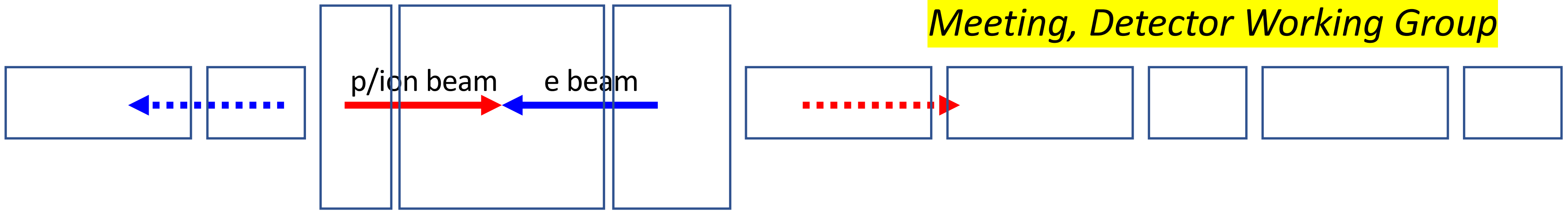
EIC Physics demands ~100% acceptance for all final state particles (including particles associated with initial ion)

Ion remnant is particularly challenging
- not a usual concern at colliders
- at EIC integrated from the start with a highly integrated (and complex) detector and interaction region scheme.

Cartoon/Model of the Extended Detector and IR

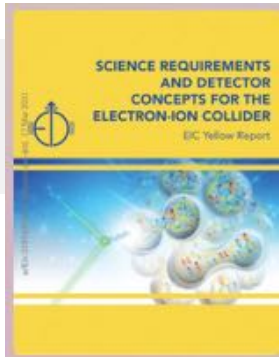
- ❑ EIC physics covers the entire region (backward, central, forward)
- ❑ Many EIC science processes rely on excellent and fully integrated forward detection scheme

Adapted from 2nd Yellow Report Meeting, Detector Working Group



far-backward e-detection	e final-focus quads	"Central detector", includes e-endcap, central, and p/ion endcap detectors	forward dipole incl. h detection	Ion final-focus quads	forward dipole	far-forward h-detection	far-forward h-detection
Low-Q^2 spectroscopy		Inclusive Structure Functions, TMDs, heavy flavors and jets, electrons for GPDs	GPDs/DVCS, tagging, diffraction, high-medium t			Baryon decay π/K structure evaporated n	GPDs, tagging, diffraction, lowest-t
GEMs Diamond detectors?		Vertex and Tracking detectors, particle identification detectors, calorimetry detectors, muon detectors, etc.	Si/GEMs Roman pots, e/γ calorim.			GEMs Roman pots e/γ calorim.	Roman pots ZDCs

physics examples (green row) | detector examples (yellow row)



Resulting Experimental Requirements

More and more demanding moving from inclusive to fully exclusive scattering

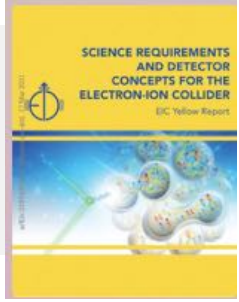
- **Inclusive measurements (DIS), required:**
  - Precise scattered electron identification (e.m. calorimetry, e/h PID) and extremely fine resolution in the measurement of its angle (tracking) and energy (calorimetry)
- **Semi-inclusive measurements (SI-DIS), also required:**
  - excellent hadron identification over a wide momentum and rapidity range (h-PID)
  - full 2π acceptance for tracking (tracking) and momentum analysis (central magnet)
  - excellent vertex resolution (low-mass vertex detector)
- **Exclusive measurements also required:**
  - Tracker with excellent space-point resolution (high resolution vertex) and momentum measurement (tracking),
  - Jet energy measurements (h calorimetry)
  - very forward detectors also to detect n and neutral decay products (Roman pots, large acceptance zero-degree calorimetry)
- **And luminosity control, e and A polarimeters, r-o electronics, DAQ, data handing**

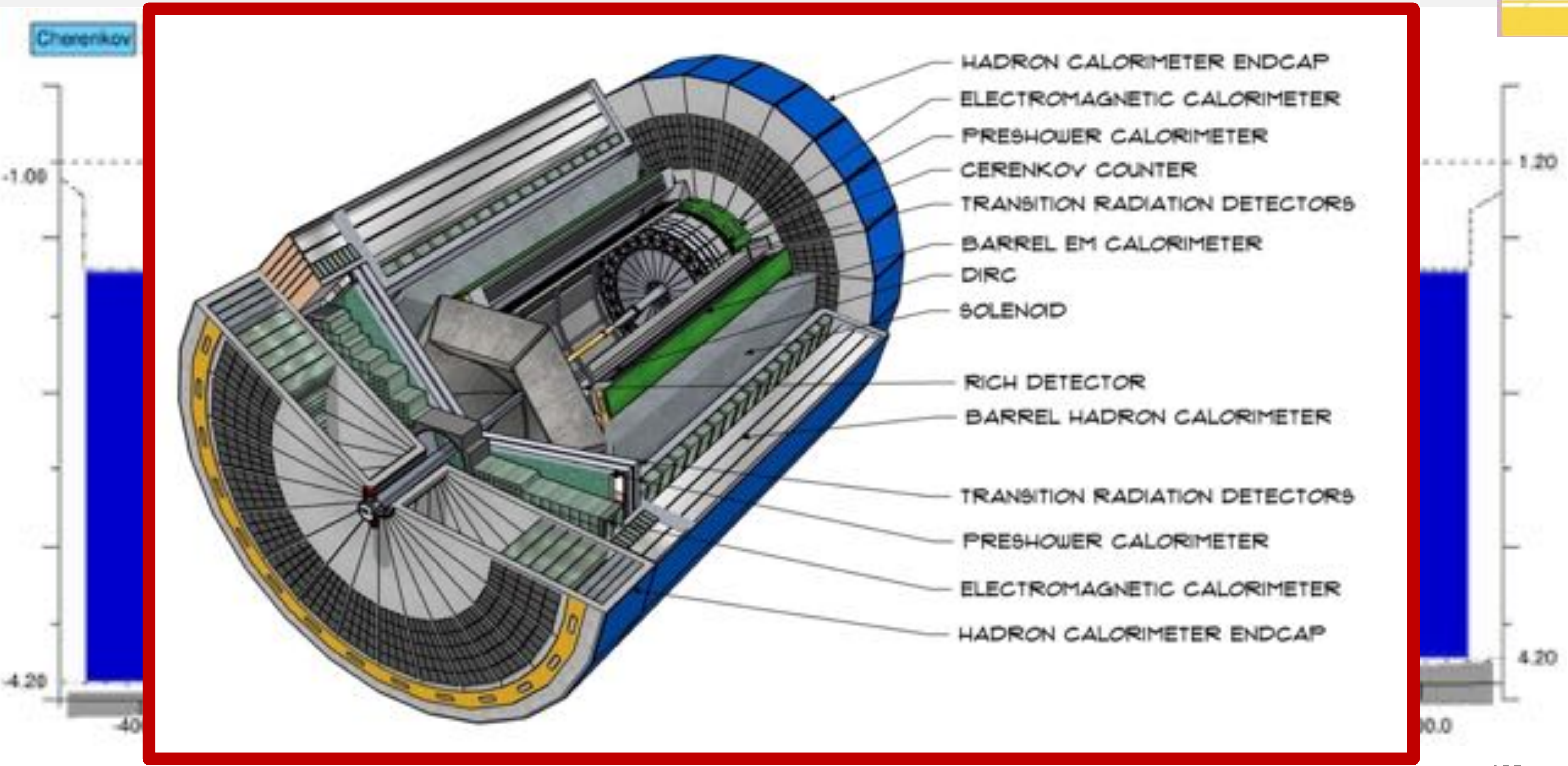
EIC Detector Advisory Committee (DAC) Meeting, 28-29 September 2020

S. Dalla Torre (INFN) & T. Horn (CUA)

Concept DETECTOR

This detector concept was included in the EIC CDR prepared for the CD1 Review



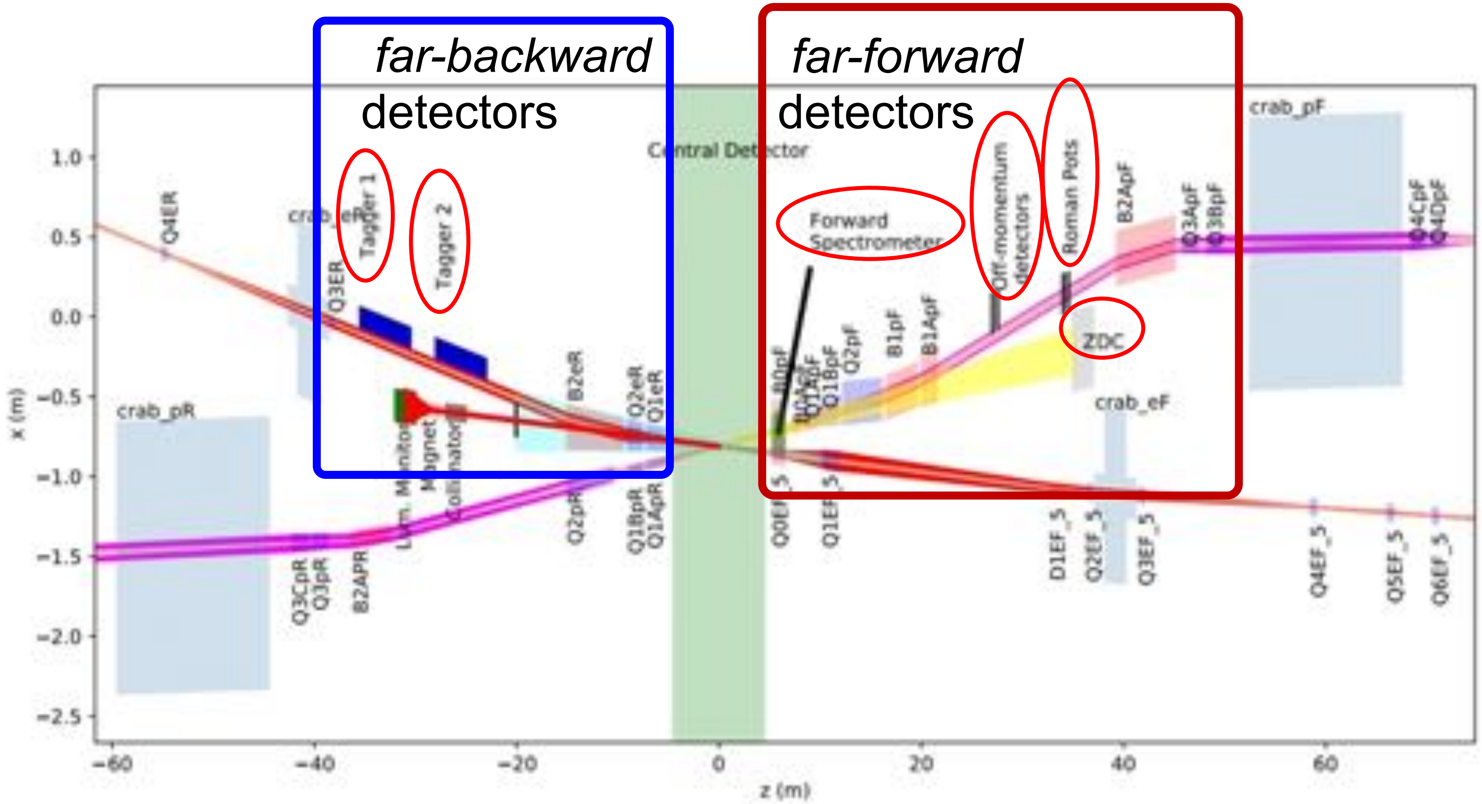


Reference Detector – Backward/Forward Detectors

Highly Integrated detector system: ~75m
1. Central detector: ~10m
2. Backward electron detection: ~35m
3. Forward hadron spectrometer: ~40m

Lesson learned from HERA – ensure low-Q^2 coverage

Various stage detector to capture forward-going protons and neutrons, and also decay products (Δ, Λ).



EIC moved forward…. A major step!

- DOE announced: January 9, 2020
- CD0 December 19, 2019
- Site of EIC: Brookhaven National Laboratory
- BNL and JLab realize EIC as partners

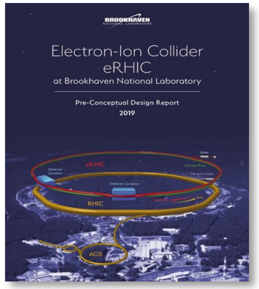
- A formal EIC project is now setup at BNL
- BNL+Jlab management & scientists are working together to realize it on a fast timeline.

- CD1 anticipated June 28, 2021
- CD2 Approval 1st Quarter FY2023
- CD3 4th Quarter FY2023 (start construction)
- EIC CD4A Early Finish 4thQ FY2029
- EIC CD4B 3rdQ FY 2032

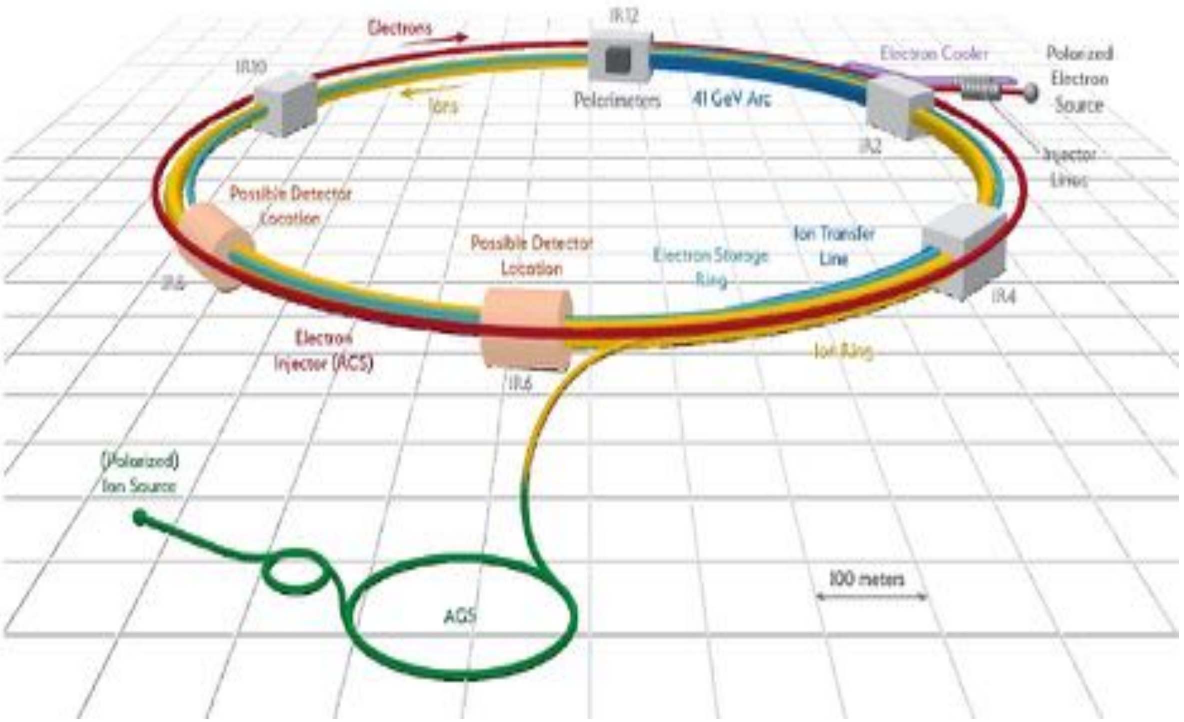
EIC Project and Experimental Program

Credits: Slides in this section are taken from various public presentations by J. Jeck, F. Willeke, R. Ent & E. Aschenauer

Some are minimally modified for compactness by me.



The US Electron Ion Collider



- ❖ Electron storage ring with frequent injection of fresh polarized electron bunches
- ❖ Hadron storage ring with strong cooling or frequent injection of hadron bunches

Hadrons up to 275 GeV

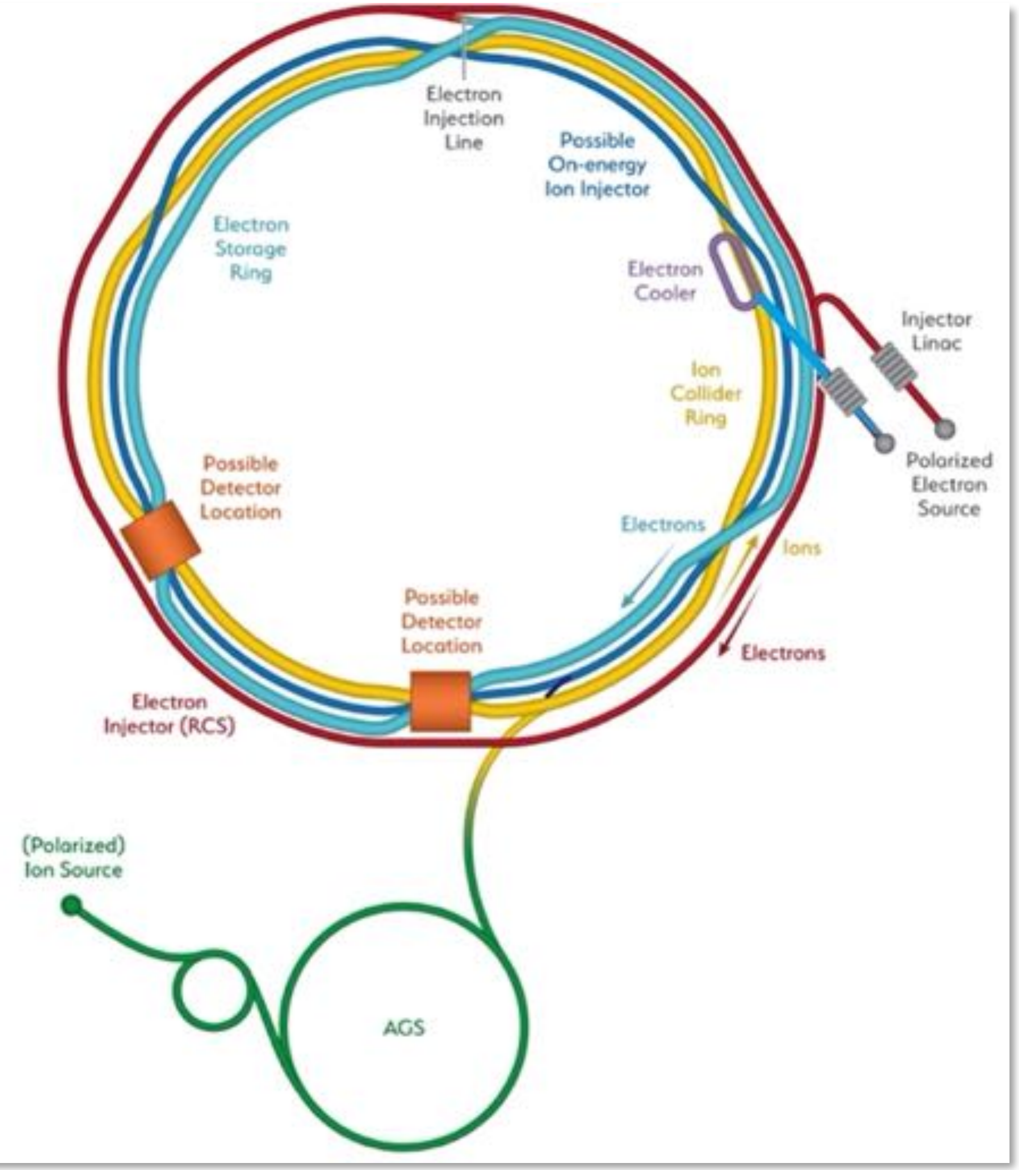
- ➢ Existing RHIC complex: Storage (Yellow), injectors (source, booster, AGS)
- ➢ Need few modifications
- ➢ RHIC beam parameters fairly close to those required for EIC@BNL

Electrons up to 18 GeV

- ➢ Storage ring, provides the range sqrt(s) = 20-140 GeV. Beam current limited by RF power of 10 MW
- ➢ Electron beam with variable spin pattern (s) accelerated in on-energy, spin transparent injector (Rapid-Cycling-Synchrotron) with 1-2 Hz cycle frequency
- ➢ Polarized e-source and a 400 MeV s-band injector LINAC in the existing tunnel

Design optimized to reach 10^{34} $cm^{-2}sec^{-1}$

Reference Detector – Location



Two possible locations – IP6 and IP8 – for detectors and Interaction Regions.

IP6 is the assumed detector location from project risk view (mainly schedule).

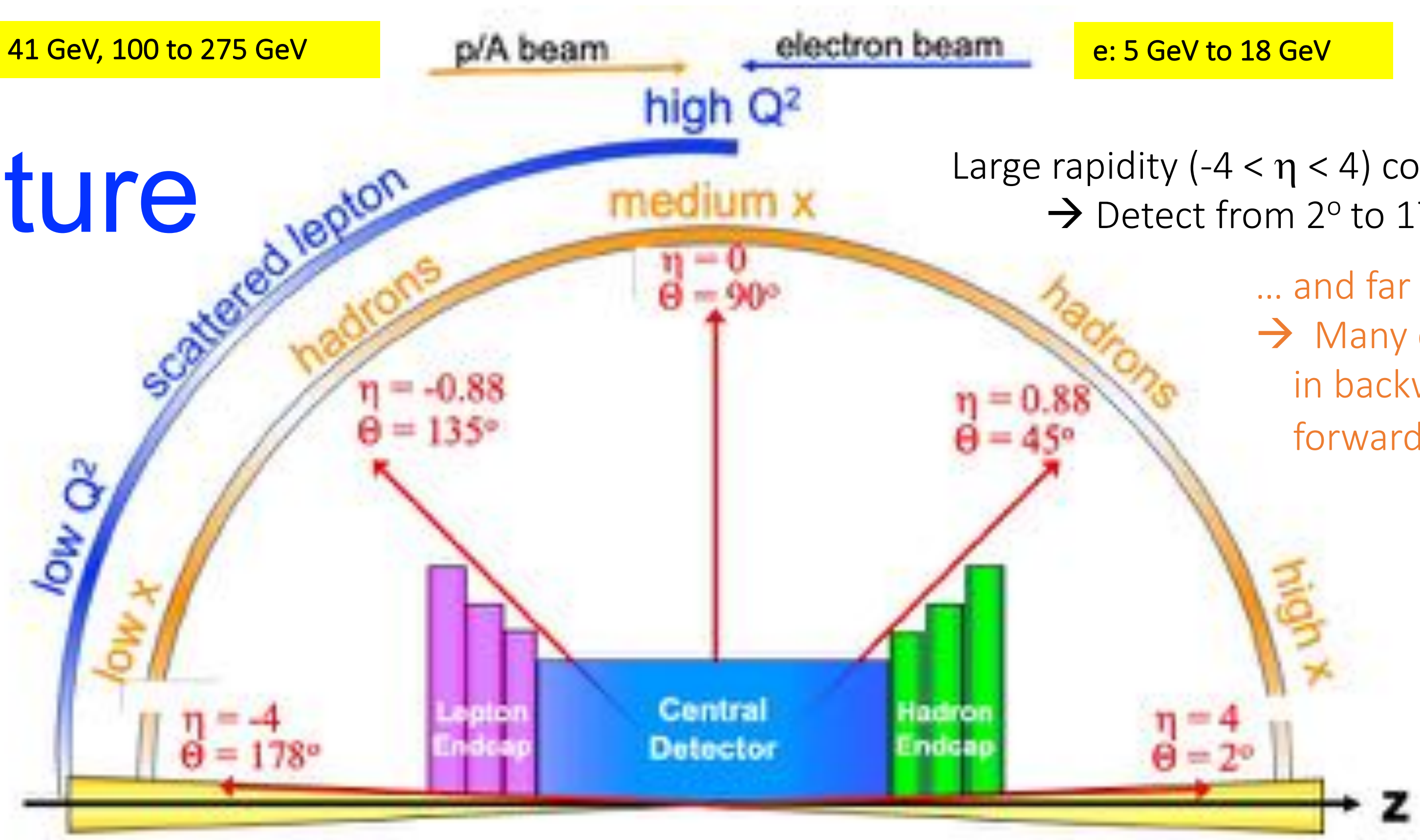
- **IP8 is also suitable.**

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

Nomenclature

p: 41 GeV, 100 to 275 GeV

e: 5 GeV to 18 GeV



Large rapidity ($-4 < \eta < 4$) coverage
→ Detect from 2° to 178°…

… and far beyond
→ Many detectors in backward + forward region

low Q^2 scattered electrons
Bethe-Heitler photons
for luminosity

Backward

Main detector =
Barrel +
Lepton Endcap +
Hadron Endcap

particles from nuclear breakup, i.e. neutrons, scattered protons, and ions from diffractive reactions

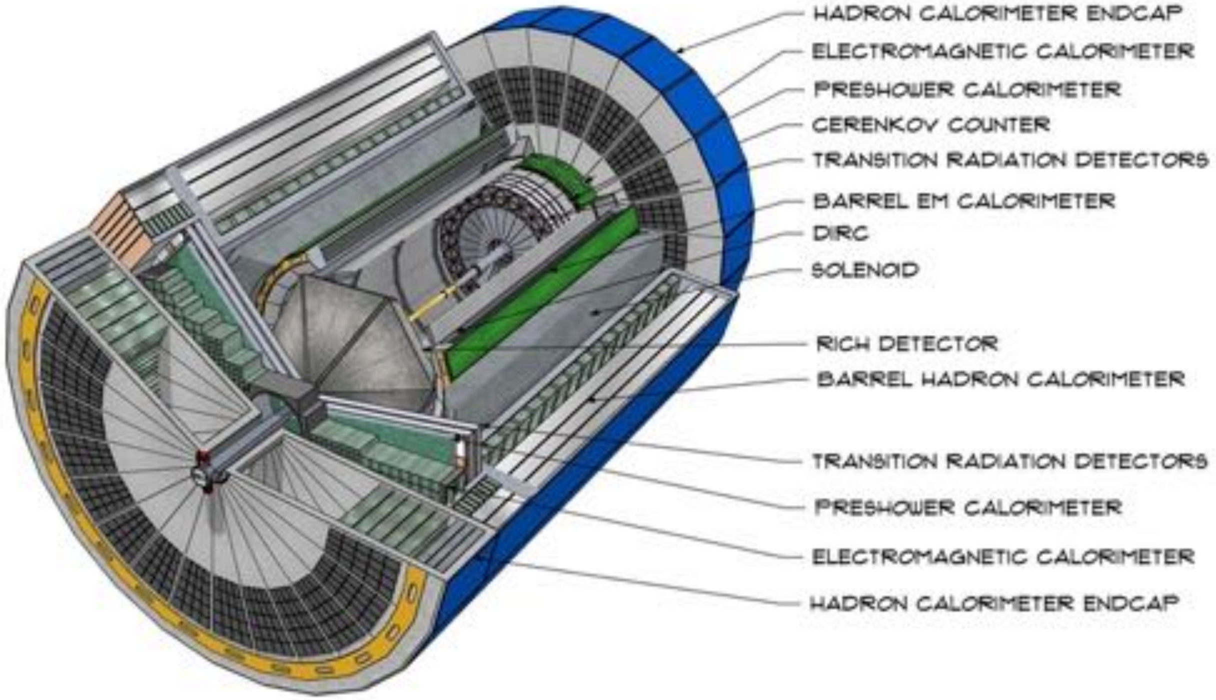
Forward

Endcaps critical because of largely asymmetric beam energies (with different beams).
Similar large impact on IR/accelerator.

EIC Experimental Equipment Requirements

Any general purpose EIC Detector is complex

Overall detector requirements:
- ❑ Large rapidity ($-4 < \eta < 4$) coverage; and far beyond in especially far-forward detector regions
- ❑ High precision low mass tracking
  - o small (μ-vertex) and large radius (gaseous-based) tracking



- ❑ Electromagnetic and Hadronic Calorimetry
  - o equal coverage of tracking and EM-calorimetry
- ❑ High performance PID to separate π, K, p on track level
  - o also need good e/π separation for electron-scattering
- ❑ Large acceptance for diffraction, tagging, neutrons from nuclear breakup: critical for physics program
  - o Many ancillary detector integrated in the beam line: low-Q^2 tagger, Roman Pots, Zero-Degree Calorimeter, ….
- ❑ High control of systematics
  - o luminosity monitors, electron & hadron Polarimetry

Integration into Interaction Region is critical

Reference Detector – technologies

system	system components	reference detectors	detectors, alternative options considered by the community		
tracking	vertex	MAPS, 20 um pitch	MAPS, 10 um pitch		
	barrel	TPC	TPC[a]	MAPS, 20 um pitch	MICROMEGAS[b]
	forward & backward	MAPS, 20 um pitch & sTGCs[c]	GEMs	GEMs with Cr electrodes	
	very far forward & far backward	MAPS, 20 um pitch & AC-LGAD[d]	TimePix (very far backward)		
ECal	barrel	W powder/SciFi or Pb/Sc Shashlyk	SciGlass	W/Sc Shashlyk	
	forward	W powder/SciFi	SciGlass	PbGl	Pb/Sc Shashlyk or W/Sc Shashlyk
	backward, inner	$PbWO_4$	SciGlass		
	backward, outer	SciGlass	$PbWO_4$	PbGl	W powder/SciFi or W/Sc Shashlyk[e]
	very far forward	Si/W	W powder/SciFi	crystals[f]	SciGlass
h-PID	barrel	High performance DIRC & dE/dx (TPC)	reuse of BABAR DIRC bars	fine resolution TOF	
	forward, high p	double radiator RICH (fluorocarbon gas, aerogel)	fluorocarbon gaseous RICH	high pressure Ar RICH	
	forward, medium p		aerogel		
	forward, low p	TOF	dE/dx		
	backward	modular RICH (aerogel)	proximity focusing aerogel		
e/h separation at low p	barrel	hpDIRC & dE/dx (TPC)	very fine resolution TOF		
	forward	TOF & aerogel			
	backward	modular RICH	adding TRD	Hadron Blind Detector	
HCal	barrel	Fe/Sc	RPC/DHCAL	Pb/Sc	
	forward	Fe/Sc	RPC/DHCAL	Pb/Sc	
	backward	Fe/Sc	RPC/DHCAL	Pb/Sc	
	very far forward	quartz fibers/ scintillators			

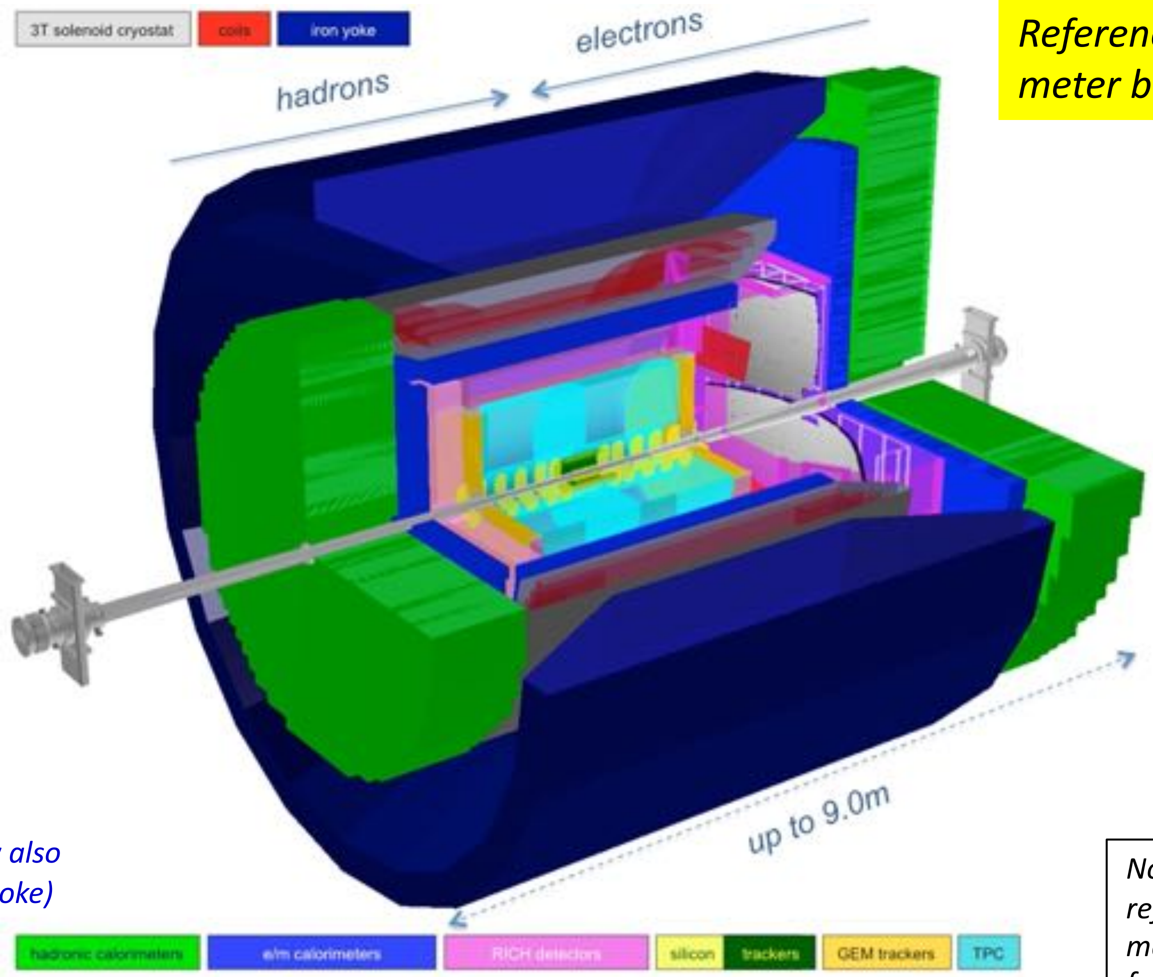
[a] TPC surrounded by a micro-RWELL tracker
[b] set of coaxial cylindrical MICROMEGAS
[c] Small-Strip Thin Gas Chamber (sTGC)
[d] MAPS for B0 and off-momentum poarticles, LGAD for Roman Pots
[e] also Pb/Sc Shashlyk
[f] alternative options: $PbWO_4$, LYSO, GSO, LSO

Table from CDR based on Yellow Report initiative

We used the first column as reference detector but also consider alternate detector technologies as options for risk reduction, as the final call comes from the community detector proposals. The context of this was mentioned in CDR Section 8.1 “Realization of the Experimental Equipment in the National and International Context”.

Reference General-Purpose EIC Detector

6.10.07 Magnets



Reference detector magnet = 3T, with 3.2 meter bore and 3.84 meter cryostat length

(Hadronic calorimetry also integrated with iron yoke)

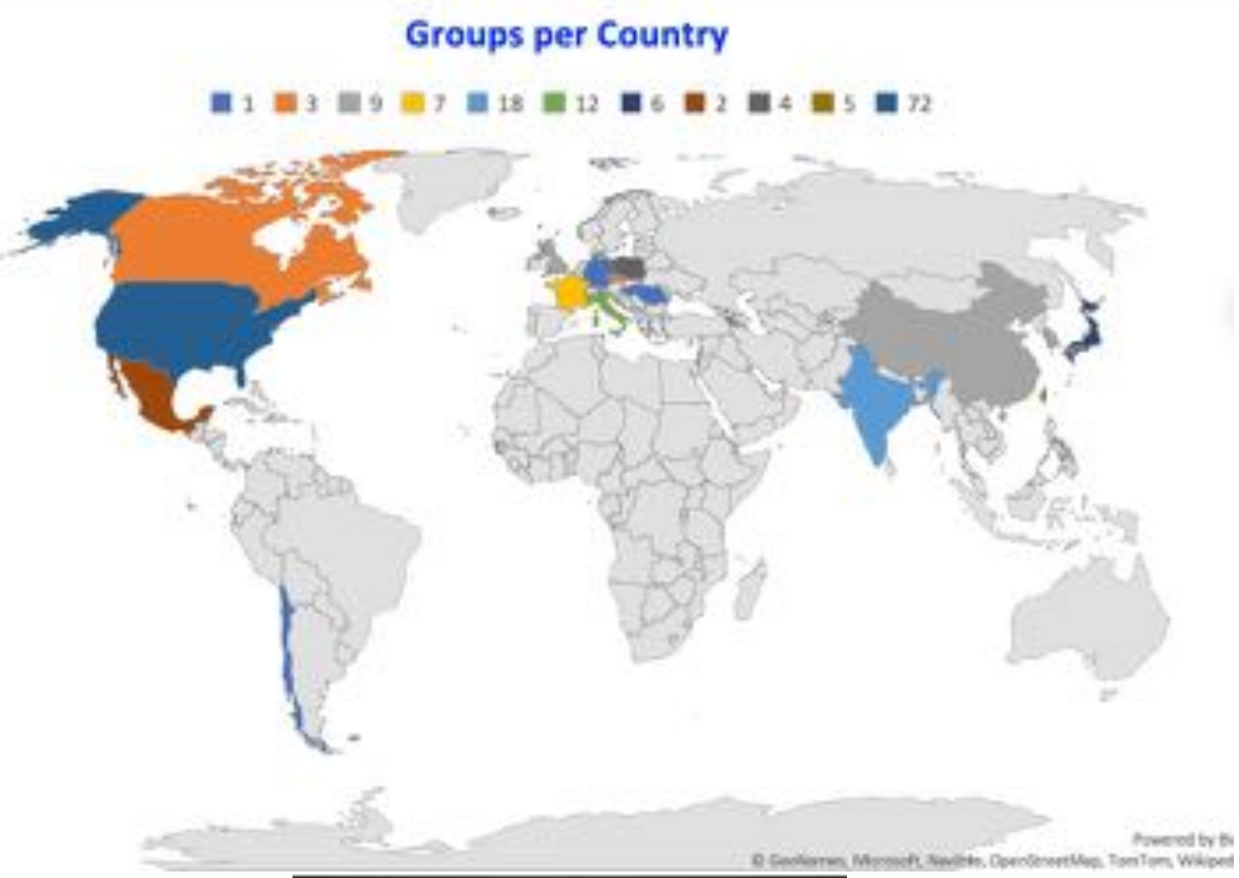
6.10.06 Hadronic Calorimetry

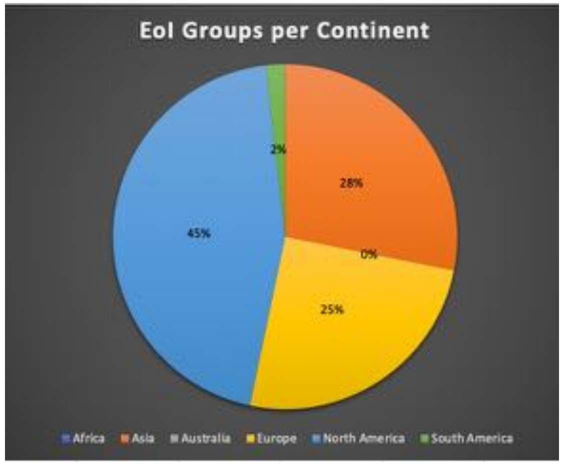
6.10.05 EM Calorimetry

6.10.04 Particle Identification

6.10.03 Tracking

Note: this is NOT the final reference detector, but many of us use this figure for the talks as it gives an easy direct snapshot.





Expressions of Interests Received

- 47 Expressions of Interest received
- There is clearly large interest in EIC science and experimental equipment
  - Both domestically among universities and national labs
  - And international, with many countries represented (Canada, China, Czech, France, India, Italy, Japan, Korea, Poland, UK and institutional EoIs of Chile, Hungary, Mexico, Rumania, and group EoIs with Armenia, Israel, Saudi Arabia and Taiwan as members)
- With EIC science still a *decade* away, impressively many are committed to work on EIC.
  - ~500 FTEs annually, $50-100M non-DOE in-kind
- In-kind contributions suffice to maintain low-risk for a general-purpose EIC detector.
- It is clear we need to remain vigilant and follow up to secure in-kind contributions and even argue
- if we want to be able to secure a second detector, with crisp arguments on why.
- Make the case for collaboration internationally

Pre-proposals ➔ detector collaborations…

- ECCE IP8 or IP6 ➔ **E**IC **C**ollider **E**xperiment:
  - Or Hen, Tanja Horn, John Lejoie

- ATHENA ➔ at IP6
  - Silvia Dalla Torre, Abhay Deshpande, Yulia Ferlatova, Olga Evdokimov, Barbara Jacak, Alexander Kiselev, Franck Sabatie, Bernd Surrow,
- CORE: at IP7
  - a COmpact detectoR for the Eic: Charles Hyde, Pavel Nadol-Turonski

- HL-LCM (“IR2”) White Paper: Volker Burkert, Latifa Eloudrihiri, and Marco Contalbrigo, John Arrington, Franck Sabatie, Abhay Deshpande, Richard Milner, Todd Satogata, Xiangdong Ji

ECCE 101

- 77 inst … far forwar…
- Based … ginning of EIC
- ECCE … EIC physic… ("Dete…
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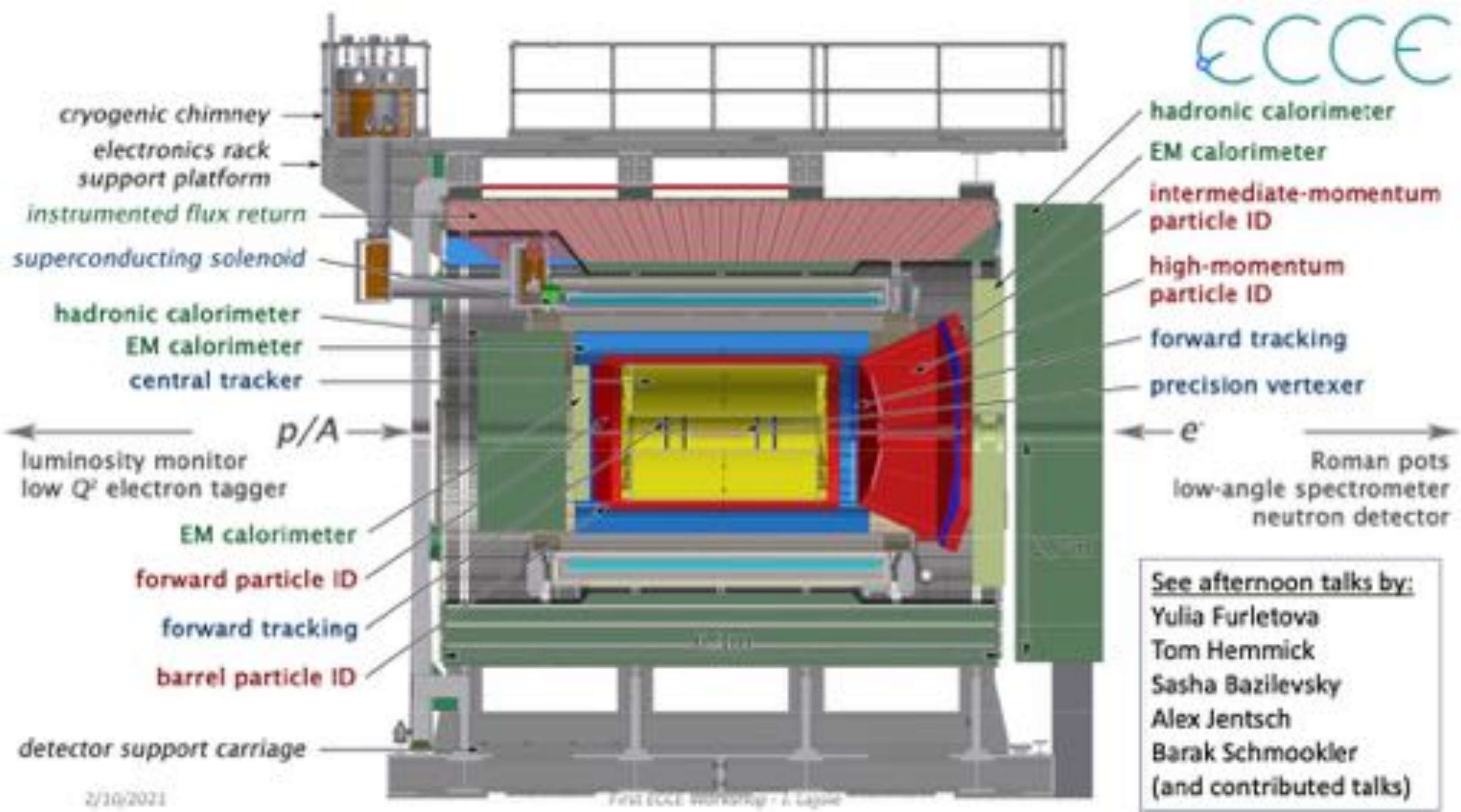
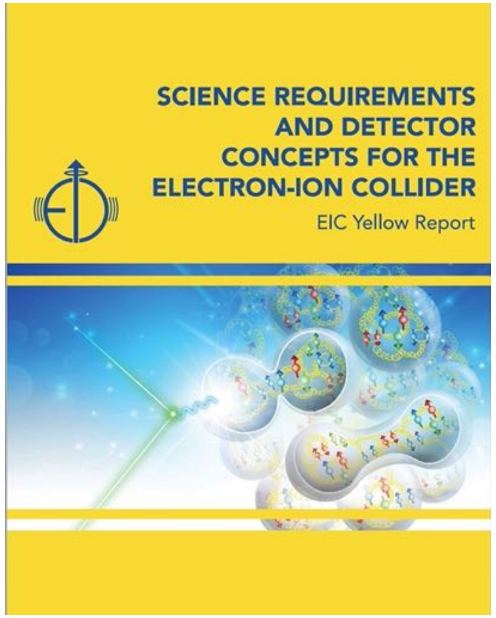
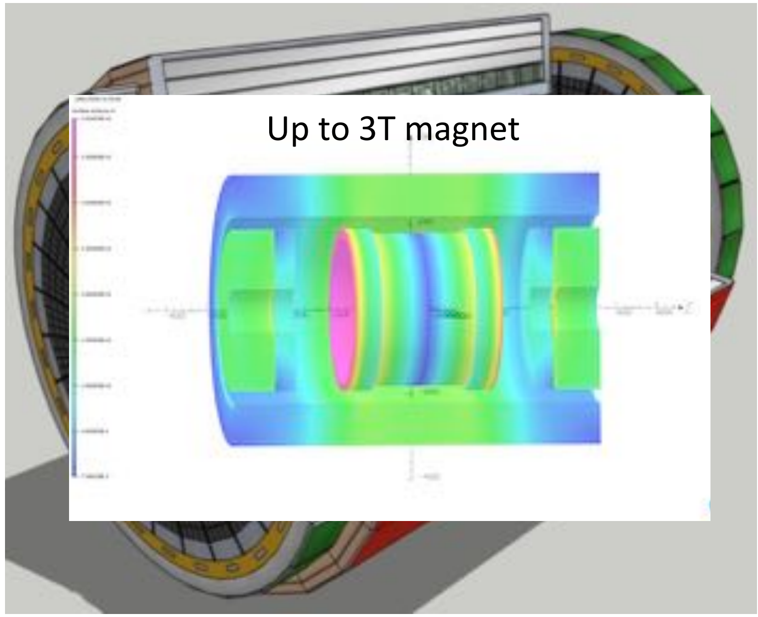
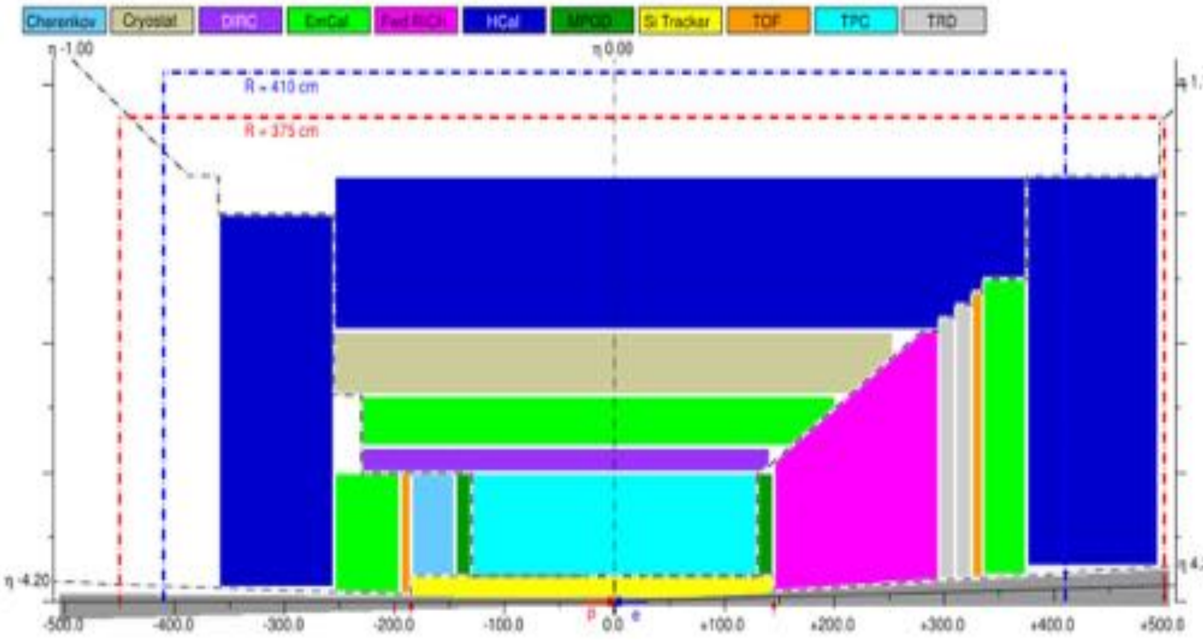


- ECCE is open to all to participate - freedom of choice to also work on other proposals

- ATHENA pre-collaboration is open to the whole EICUG community
- Web-page: https://sites.temple.edu/eicatip6
- Mailing lists: https://lists.bnl.gov/mailman/listinfo/
- Join EIC@IP6 on Slack: link
- The coordination committee: Silvia Dalla Torre, Abhay Deshpande, Olga Evdokimov, Yulia Furletova , Barbara Jacak, Alexander Kiselev, Franck Sabatie, Bernd Surrow
- Institutional board, charter committee, proposal committee, Working Groups for detector and physics in place.
- **94+ institutions contributing to the effort**

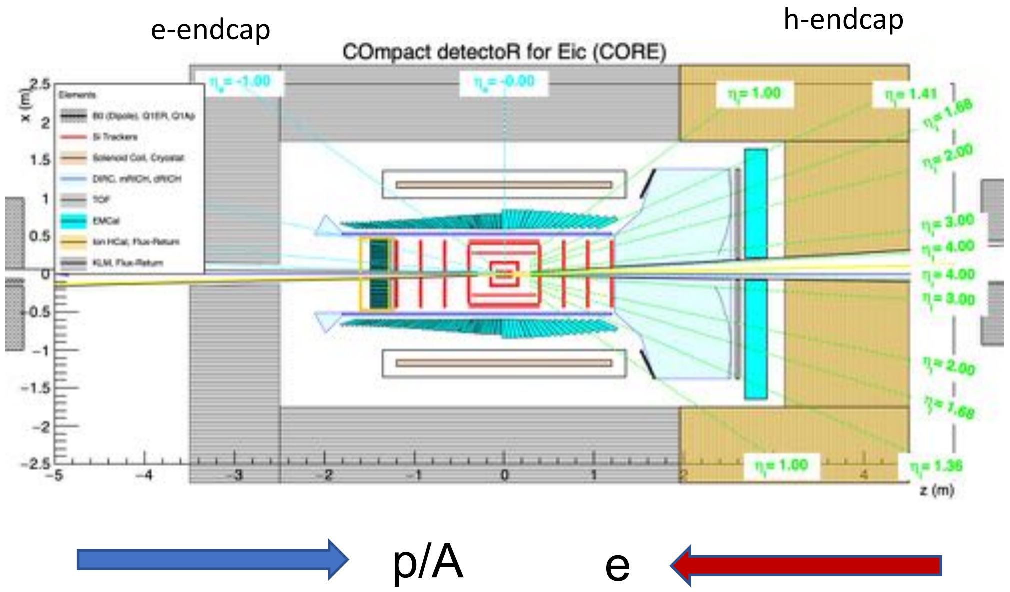






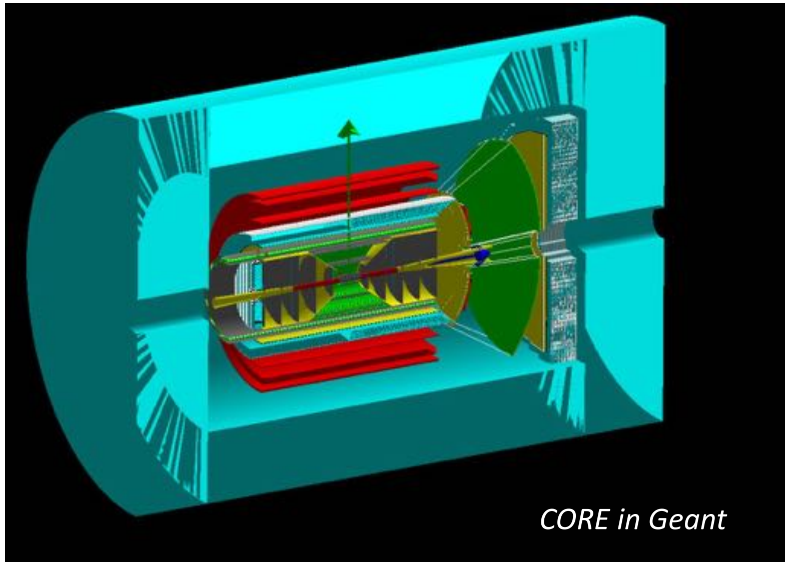
CORE: a COmpact detectoR for the EIC

- CORE is a hermetic general-purpose detector that fulfills the EIC physics requirements.
  - outlined in the Yellow Report. White Paper, etc.
- The compact size has several advantages, including.
  - higher luminosity for all c.m. energies
  - reduced cost allowing investment in critical components



Main systems

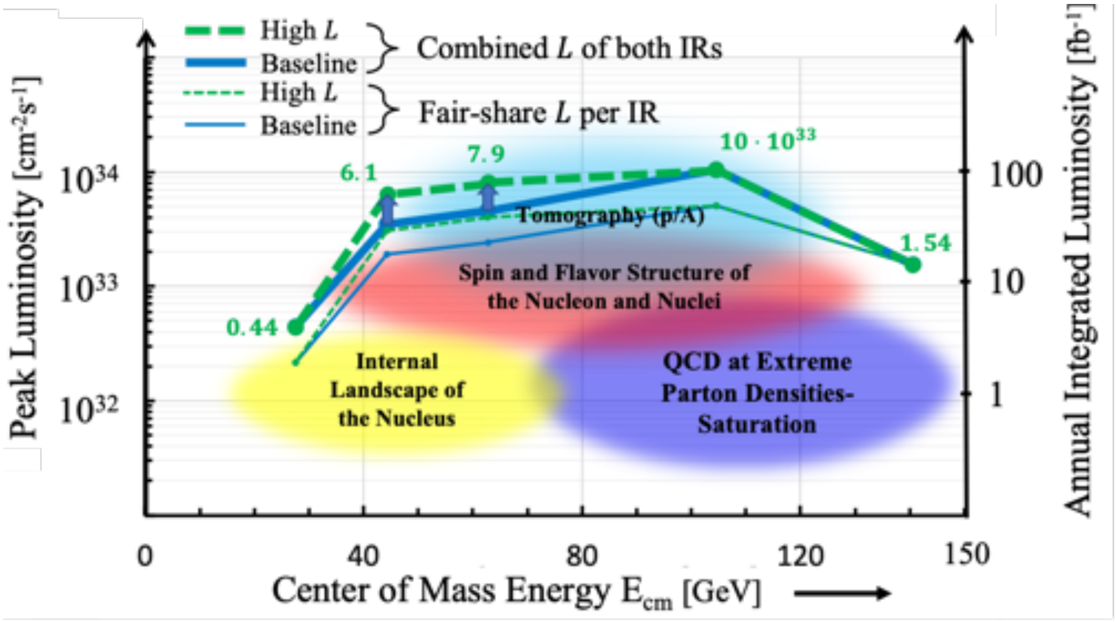
- New 2.5 T solenoid (2.5 m long, 1 m inner radius)
- Central all-Si tracker (+ GEM in h-endcap)
- PID: DIRC in barrel, dual-radiator RICH in h-endcap, LGAD TOF in e-endcap
- EMcal: PWO for $\eta < 0$ and W-Shashlyk for $\eta > 0$
- Hcal and K_L-μ (KLM) detectors integrated with the magnetic flux return of the solenoid



P. Nadel-Turonski

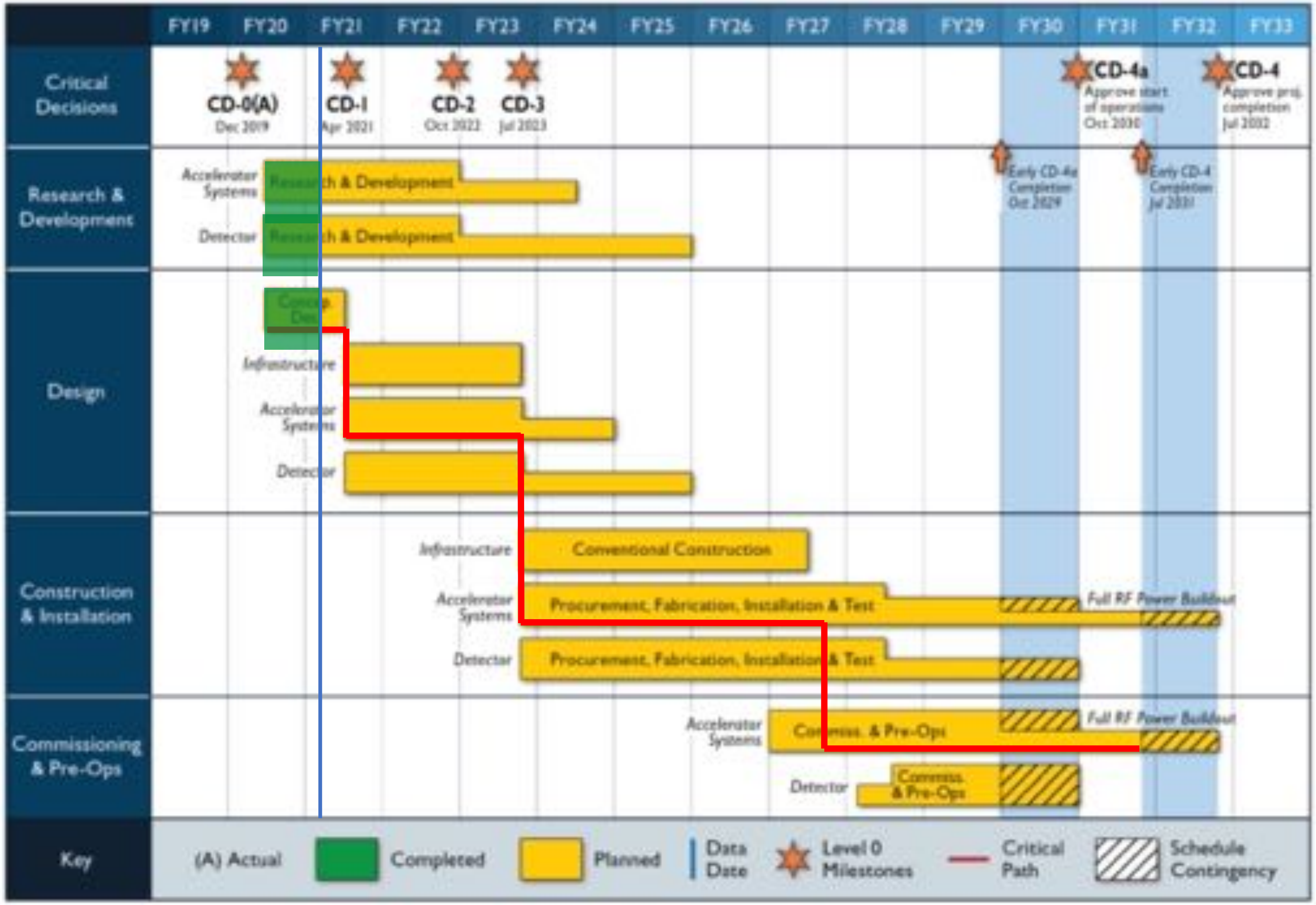
Physics at Low CM-High Lumi IR: A separate detector?

- Aim: to produce a White Paper to highlight the science at the EIC with a **high-luminosity at low-CM energy Interaction Region.**
  - DES, SIDIS, Jets, HF, Spectroscopy, various researches with light nuclei
  - Contact: Volker Burkert, Latifa Elouadrhiri, AD
- Conditions from the Call for proposal for the 2nd detector:
  - D2/IR2 complementary to D1/IR1, physics focus beyond EIC WP, and possibly modified IR2 design (compatible with IR1 and machine operations)
- Series of Center for Frontiers In Nuclear Science Workshops: 1st @ CFNS, 2nd @ ANL-CFNS, 3rd APCTP=CFNS, 4th CNF-CFNS (DC).



Recent machine development and studies
Possible to get high luminosity by only adjusting magnetic polarities of near-IR magnets

Proposed Schedule



Detector 1 needs to be ready by CD4A to help with initial collider operations. This is the 1st (left) CD4A blue band (uncertainty)

Detector 2 ideally should be ready by CD4 (about 2 yrs later, the 2nd blue band on right)

Summary: Challenging but EXCITING times ahead

EIC Science : enthusiastically supported by NAS & 1300+ (growing) users, 254 institutions and 34 countries

EIC Project is a very large one within DOE NP and Office of SC

- International partners are significant component of the success: DOE actively pursuing contacts and collaborators
- BNL and JLab managements are working together to realize the EIC

EIC Detector: unique in its demanding : IR integration

- Encouraged by the international interest: Large Users Group assembled and organized
- R&D program absorbed by the Detector Advisory Committee
- Yellow report produced a concept of an ideal reference detector

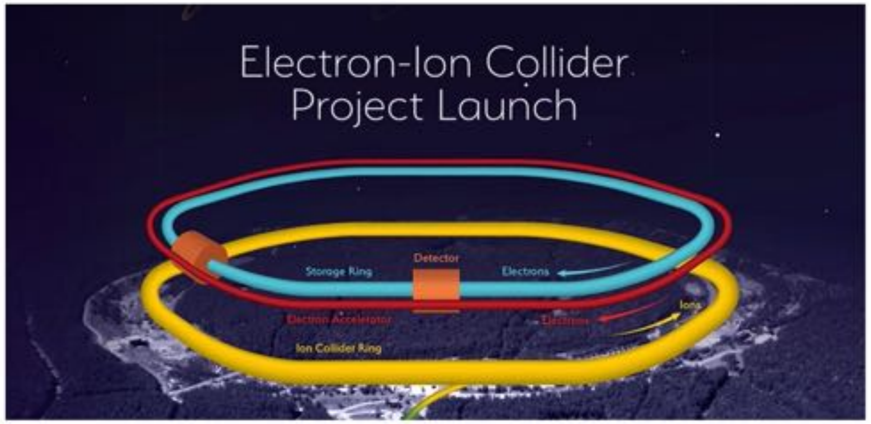
Emerging detector collaborations will realize the promise of EIC

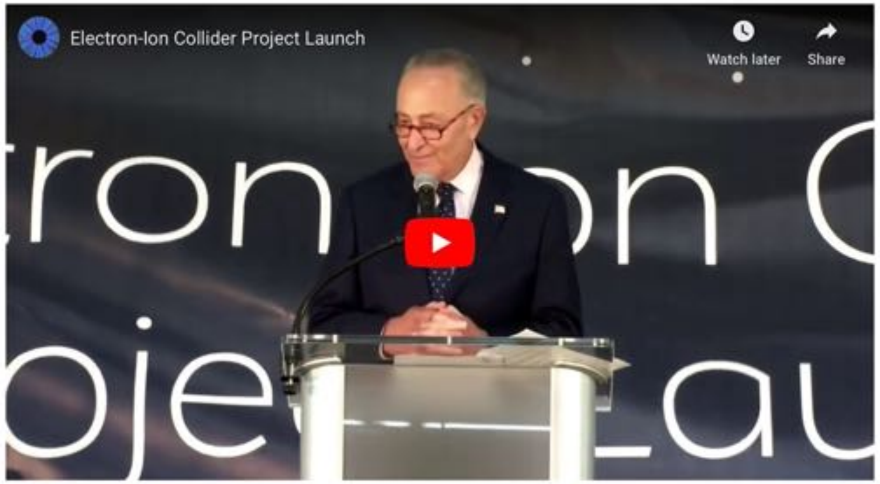
https://www.bnl.gov/newsroom/news.php?a=117399

Key Partners Mark Launch of Electron-Ion Collider Project

State-of-the-art facility and partnership among DOE, NYS, Brookhaven Lab, and Jefferson Lab will open a new frontier in nuclear physics, a field essential to our understanding of the visible universe with applications in national security, human health, and more

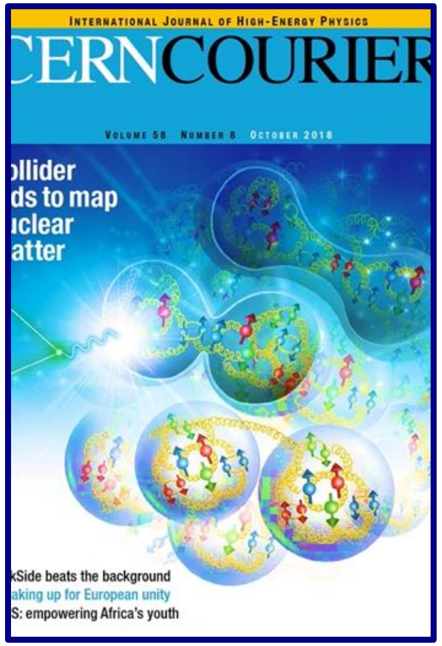
September 18, 2020





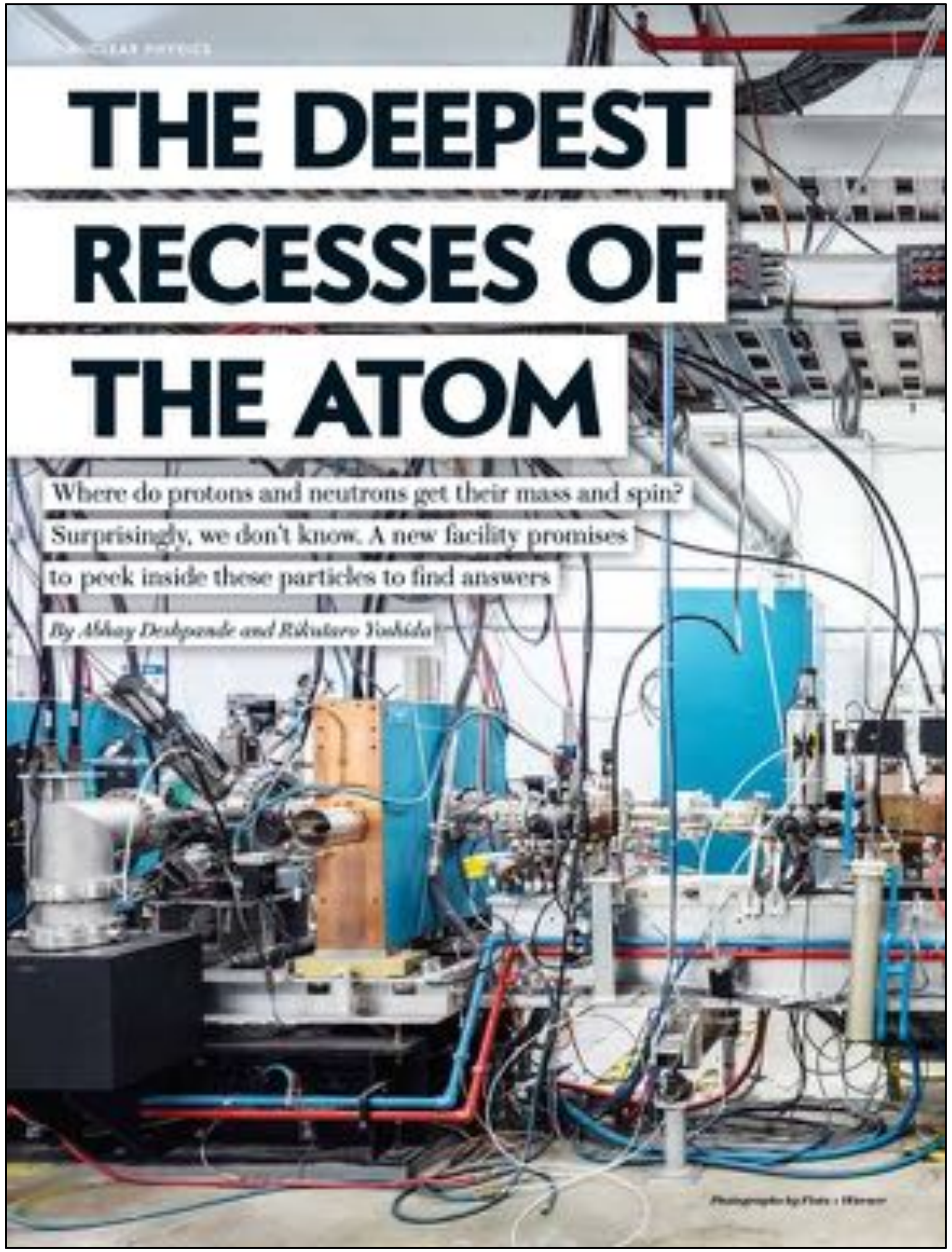
Replay of Electron-Ion Collider project launch event at Brookhaven Lab, September 18, 2020

R. Ent, T. Ullrich, R. Venugopalan
Scientific American (2015)
Translated into multiple languages



E. Aschenauer
R. Ent
October 2018

A. Deshpande
& R. Yoshida
June 2019
Translated in to multiple languages



Thank you!