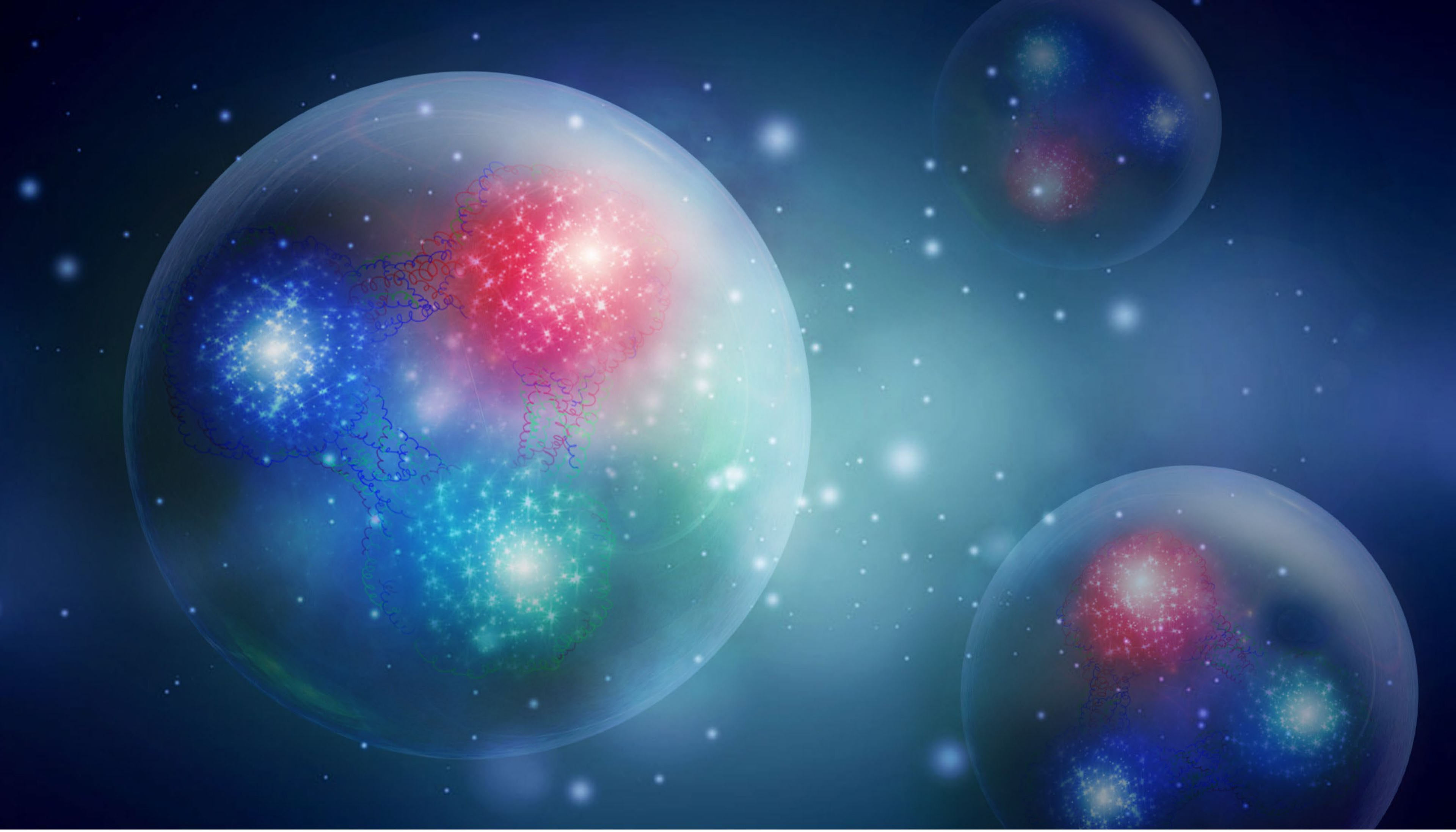


Electron-Ion Collider

NNPSS Lectures 2017 (Day 3) Rik Yoshida, Jefferson Lab

Plan for the Lectures

Day 1:

- Prologue
- Some History
- Deep Inelastic Scattering and Parton Distributions (I)

Day 2:

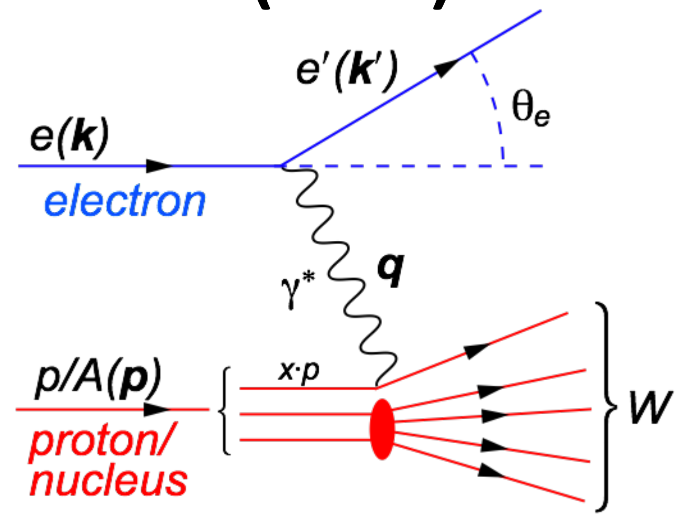
- DIS and PDF (II)
- Beyond parton distributions.

Day 3:

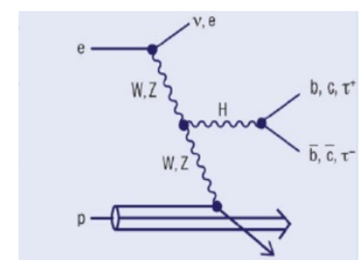
- **EIC accelerator and detector realizations**
- **Other facilities and EIC physics topics.**
- **EIC and physics topic at other facilities.**
- **EIC and the future of Nuclear Physics.**
- **Epilogue**

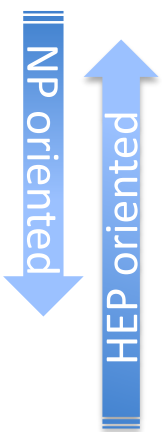
EIC REALIZATION PLANS AND DETECTOR DESIGN

Electron Ion Collider (EIC)



- Electron Ion Collider (EIC)
  - It is a Deep Inelastic Scattering Collider
  - Point-like probe interacts with p/A
  - Science aims of the EIC
    - Probe Nuclear and Nucleon Structure
    - Laboratory for Quantum Chromo Dynamics.
    - Search for certain types of BSM particles (e.g. Leptoquarks)
    - Higgs Factory with excellent kinematic control. (Scattered electron fixes the kinematics)

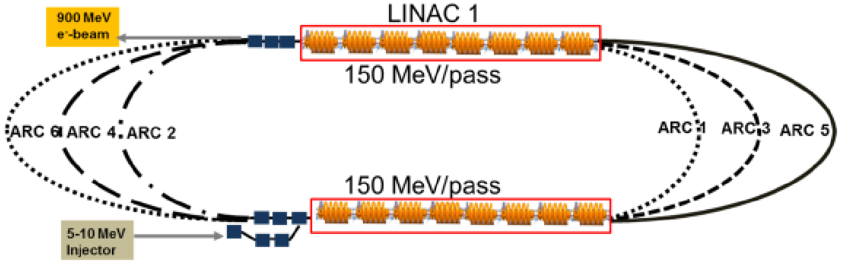


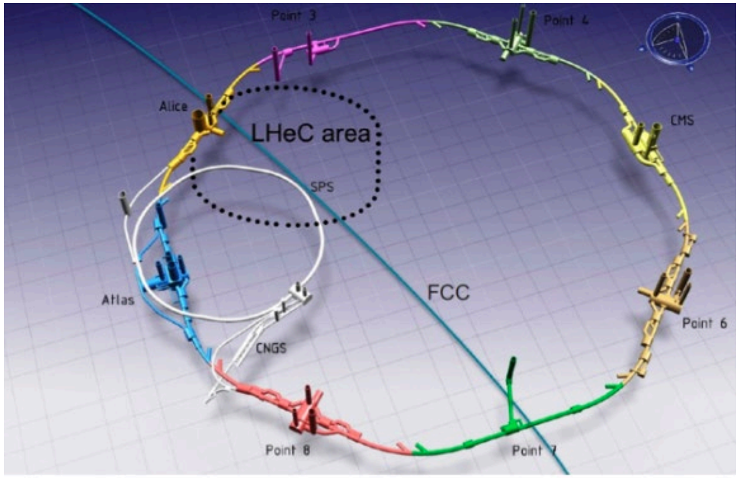


Which aims play the primary role depends on the parameters of the EIC, such as the center-of-mass energy, luminosity, etc.

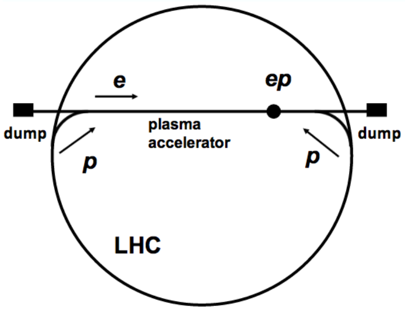
World-Wide Concepts for Electron-Ion Colliders

- High Energy Physics oriented EICs
  - LHeC/FCC-eh: Build 60 (120) GeV electron ERL at CERN and collide with LHC/FCC hadrons.
    - $\sqrt{s}$ = 1.3/3.5 (1.6/7.0) TeV
    - Luminosity = 10^{34} cm^{-2}s^{-1}





    - Information
    - Studies continuing to EU2019 planning cycle.
  - Very High Energy Electron Proton Collider (VHEeP): Use proton beam driven plasma accelerator (AWAKE) at the LHC to produce 3 TeV electron beams and collide with the LHC beam.
    - $\sqrt{s}$ = 9 TeV
    - Luminosity = 4×10^{28} cm^{-2}s^{-1}
    - Very early concept stage: Workshop, Munich June 1,2 2017



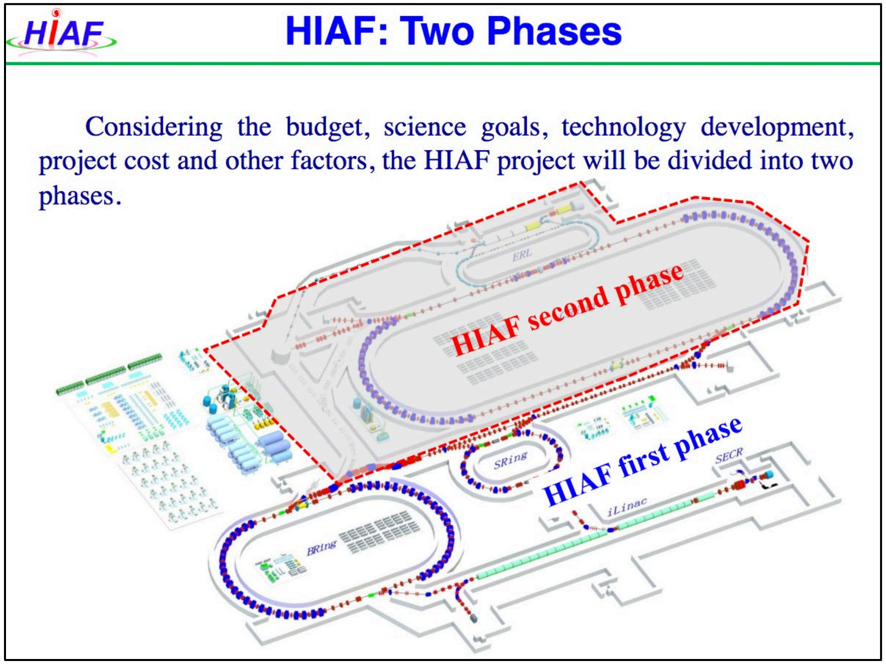
  - CepC × SppC?

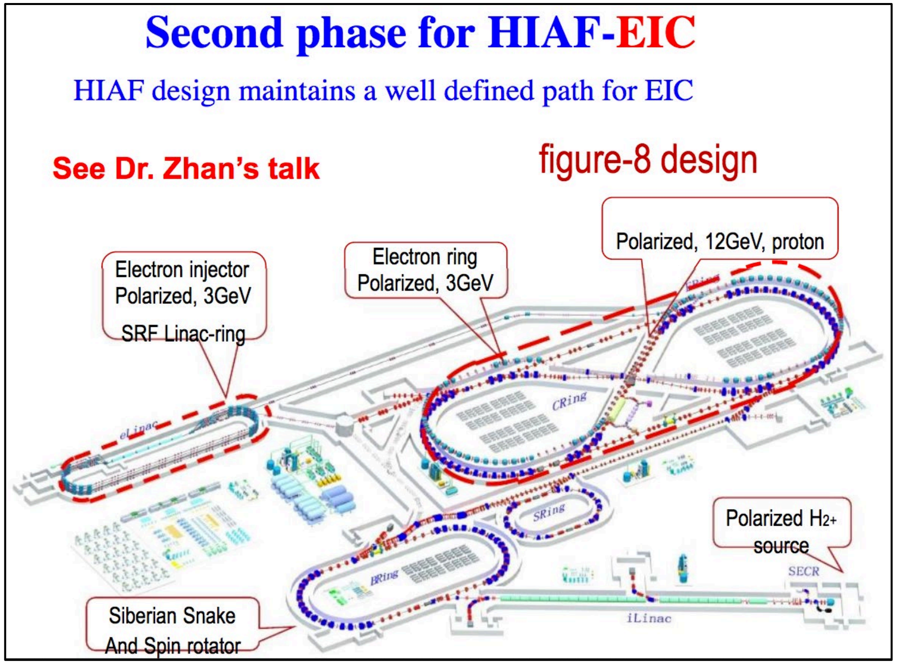
World-wide Concepts for Electron-Ion Colliders

- Nuclear Physics oriented EICs
  - EIC@HIAF (Phase 2 HIAF)
    - √s = 15 GeV
    - Luminosity: 3-5×10^{32} cm^{-2} s^{-1}
    - Polarized beams

Taken from Xurong Chen talk at the 8th Workshop on Hadron Physics in China

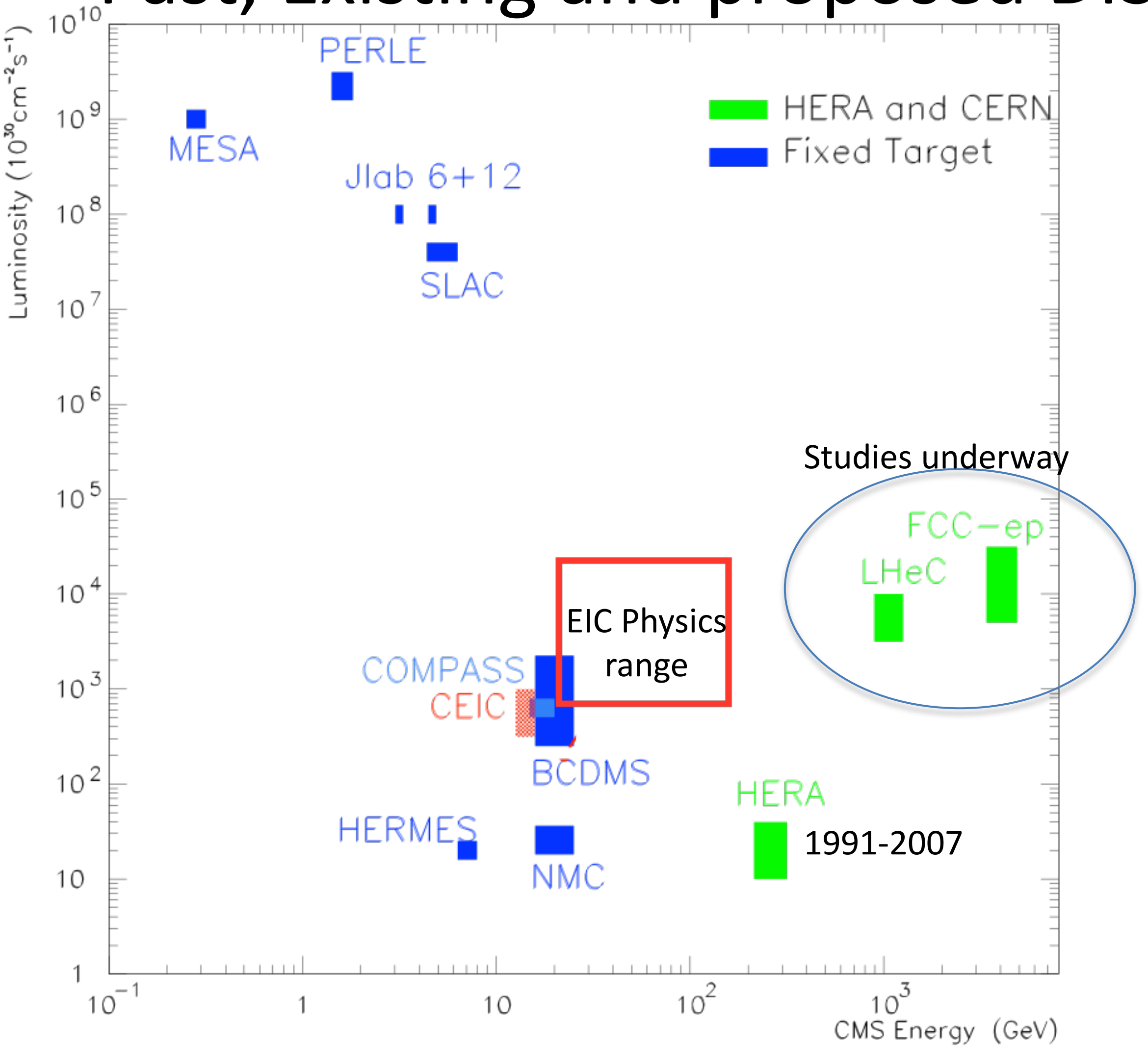
9th Workshop on H.P. in China
Nanjing, July 24-28, 2017





Heavy Intensity Heavy Ion Accelerator Facility (HIAF)
Phase 1 approved 2015

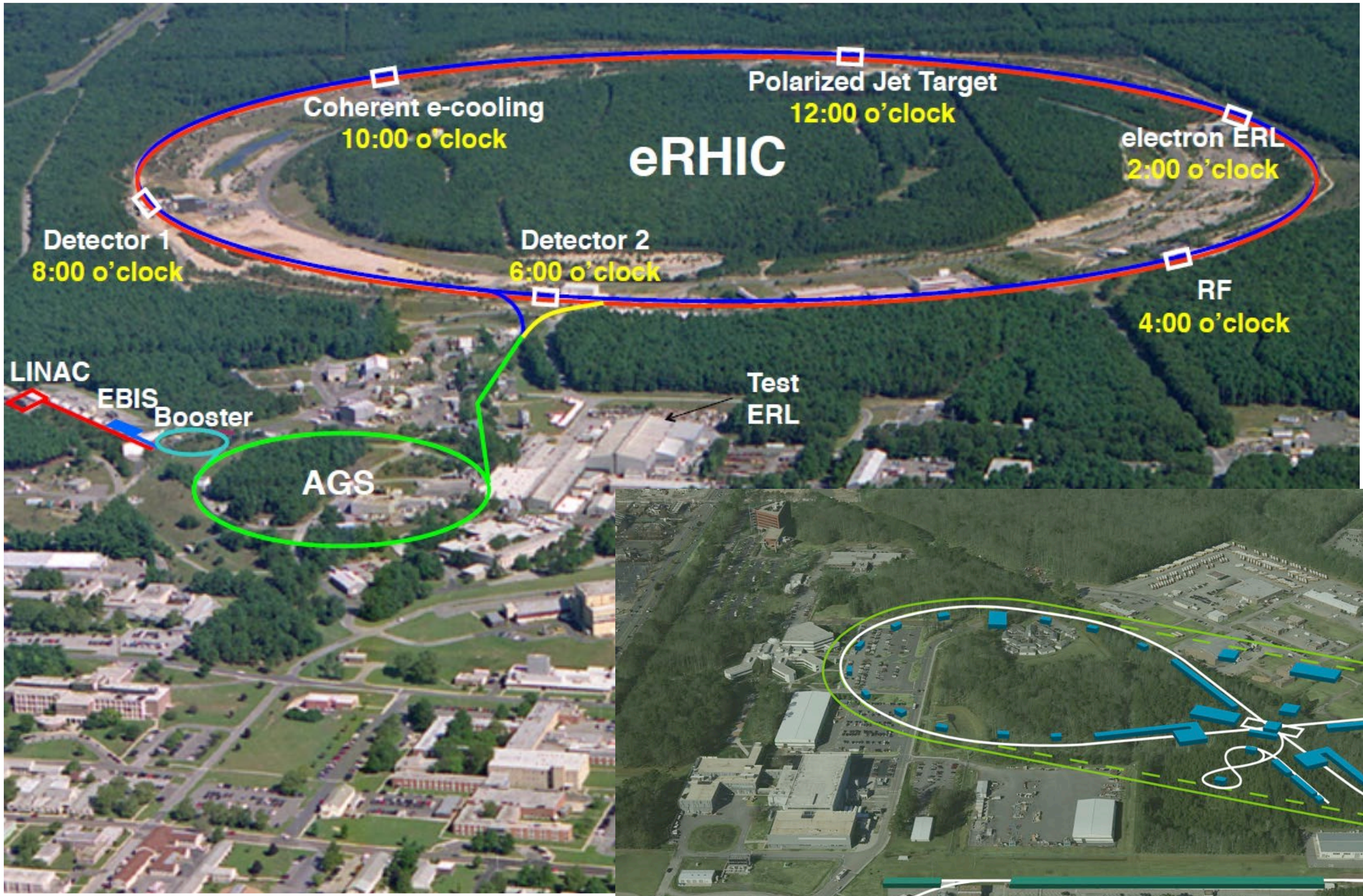
Past, Existing and proposed DIS Facilities



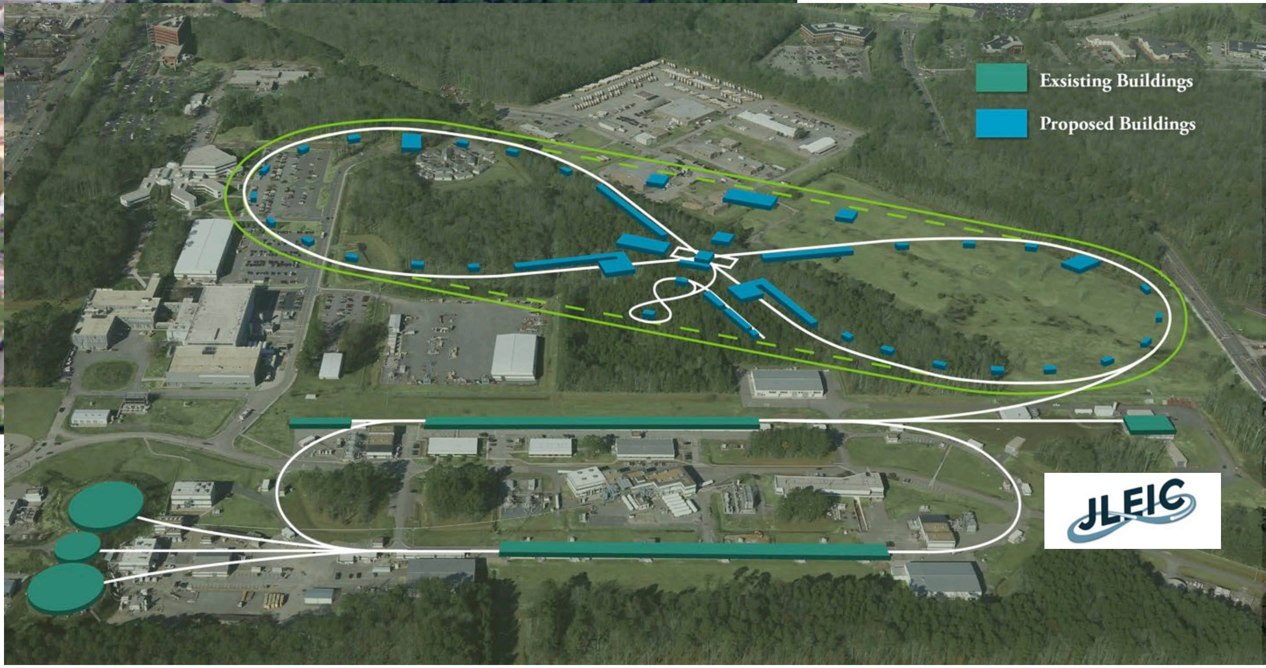
US EIC will be a unique facility.

No other machine, existing or planned can address the physics of interest satisfactorily.

US-Based EIC Proposals



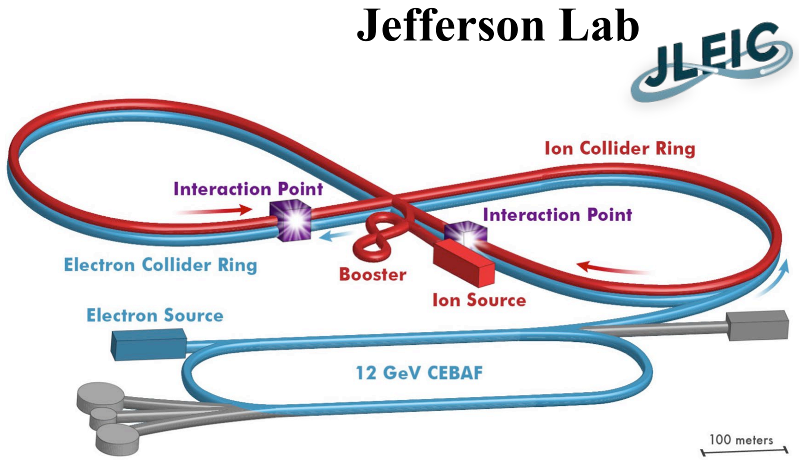
Brookhaven Lab
Long Island, NY

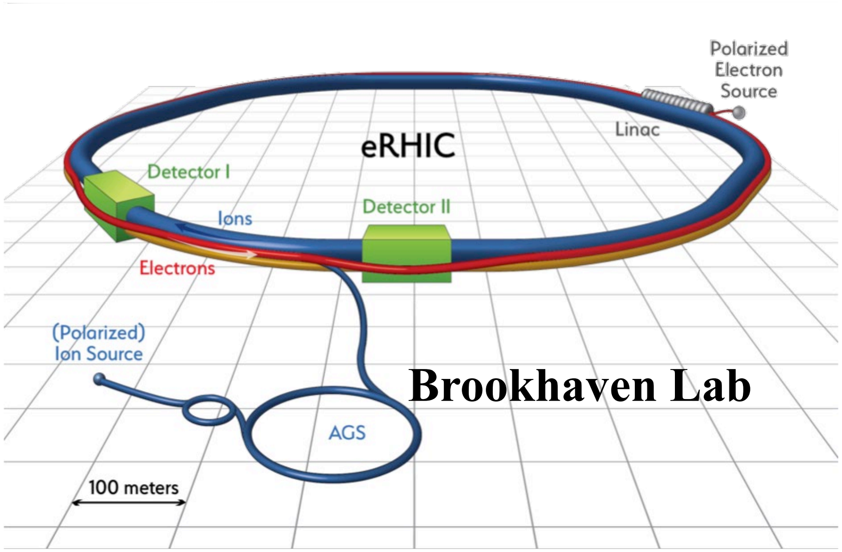


Jefferson Lab
Newport News, VA

US EIC Parameters and Realization Plans

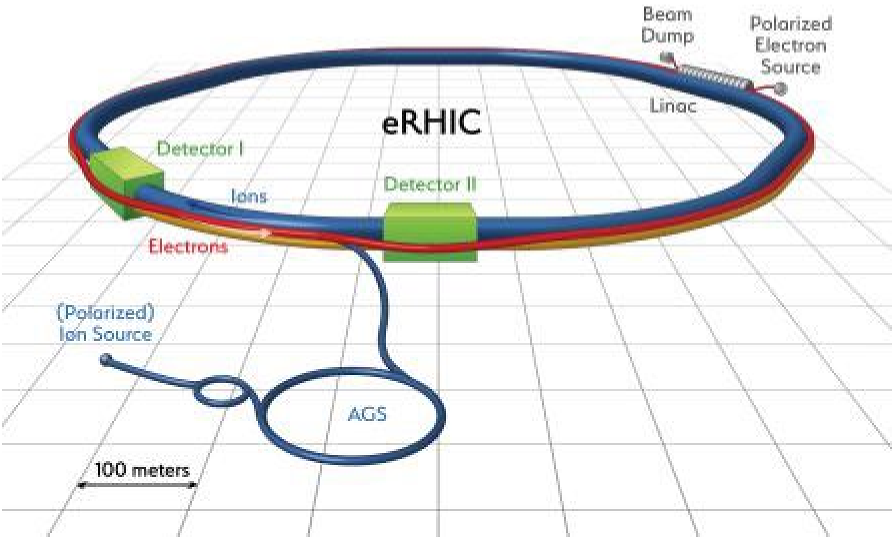
- US EIC Machine design aims from the EIC Whitepaper
  - Highly polarized (~70%) electron and nucleon beams.
  - Ion beams from deuterons to the heaviest nuclei (uranium or lead).
  - Variable center of mass energies from ~20 - ~ 100 GeV, upgradable to ~140 GeV.
  - High luminosity: ~$10^{33\text{-}34}$ cm^{-2} s^{-1}
  - Possibility of having more than one interaction region.
- Two proposed realization plans
  - Jefferson Lab: building on the existing 12 GeV CEBAF. JLEIC Design.
  - BNL: building on the existing RHIC. eRHIC Design.
  - Recent review of acc. R&D
- Similar performances, cost according to LRP assessment.
- US EIC will likely be down-selected from one of these proposals.





From F. Willecke, BNL

eRHIC design strategy

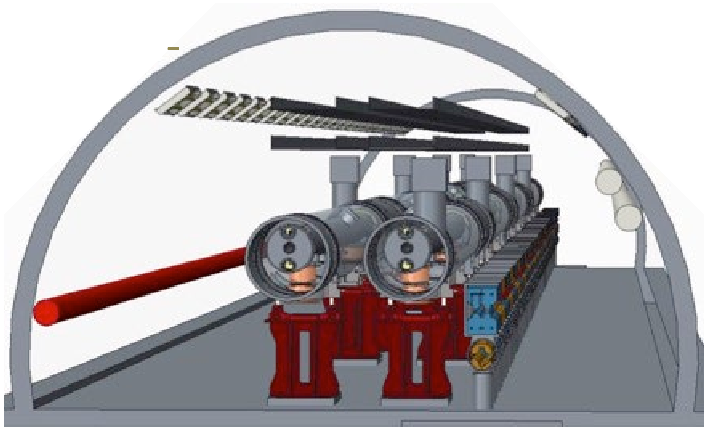


Exploiting RHIC with its
- superconducting magnets, 275 GeV protons
- its large accelerator tunnel and
- its long straight sections
- its existing Hadron injector complex

by

adding an electron accelerator

of 18 GeV in the same tunnel
- high energy reach in e-Ion collisions
- with modest synchrotron radiation, (low operating cost)
- making use of - superconducting LINAC technology -
and multi-turn recirculation
- using either the energy recovery (ERL) concept
or a high intensity electron storage ring
- achieve high luminosity electron-Hadron collisions
over a large range of CM Energies



JLEIC Design Update (Apr. **2017**)

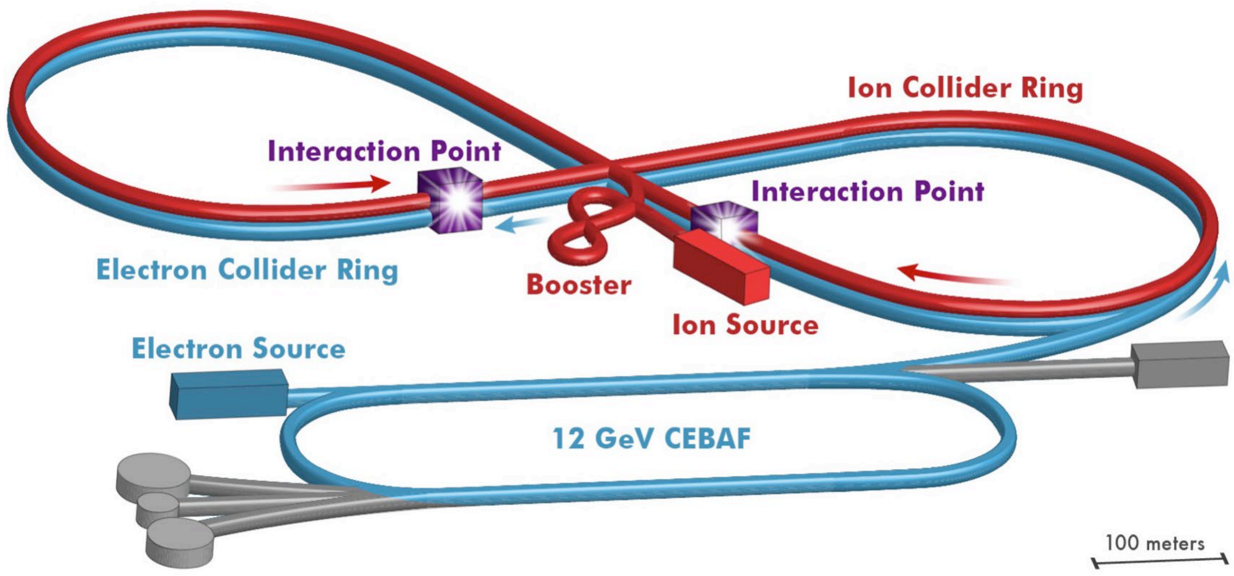
energy range:

E_e: 3 to 12 GeV

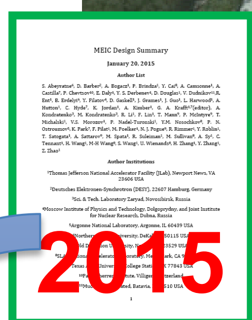
E_p: 40 to 100-400 GeV

√s: 20 to 65- 140 GeV

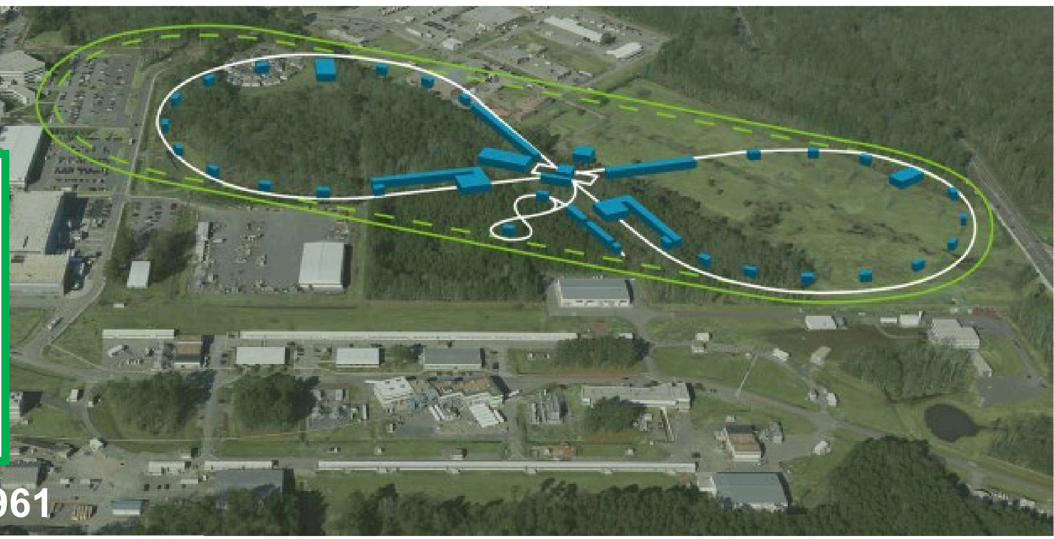
(upper limit depends on magnet tech. choice)



- **Electron complex**
  - CEBAF
  - Electron collider ring
- **Ion complex**
  - Ion source
  - SRF linac
  - Booster
  - Ion collider ring
- Fully integrated IR and **detector**
- DC and bunched beam **coolers**



arXiv:1504.07961

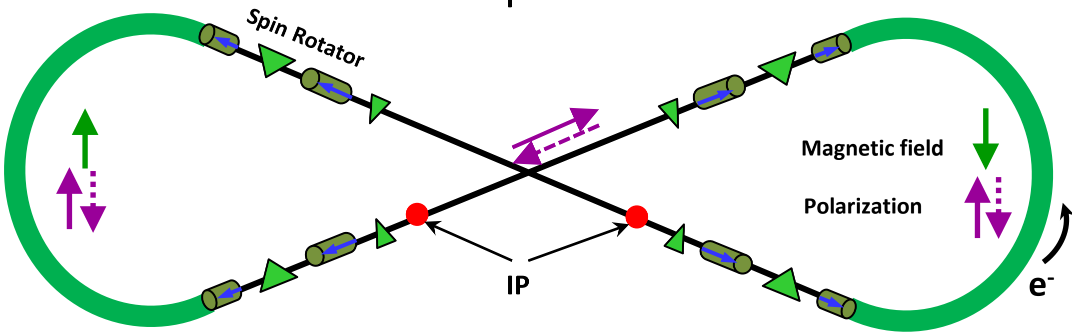


April 2017 Update

High polarization: Figure-8

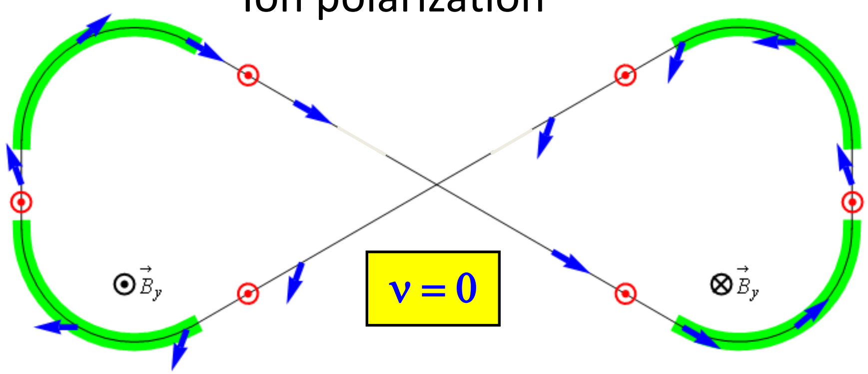
- **Figure-8** concept: spin precession in one arc is exactly cancelled in the other
- **Spin stabilization by small fields**: ~3 Tm vs. ~ 400 Tm for **deuterons** at 100 GeV
  - Criterion: induced spin rotation >> spin rotation due to orbit errors
- **Polarized deuterons possible**
- **3D spin rotator**: combination of small rotations about different axes provides any polarization orientation at any point in the collider ring
- No effect on the orbit
- Adiabatic spin flips
- **Spin tracking** in progress

Electron polarization

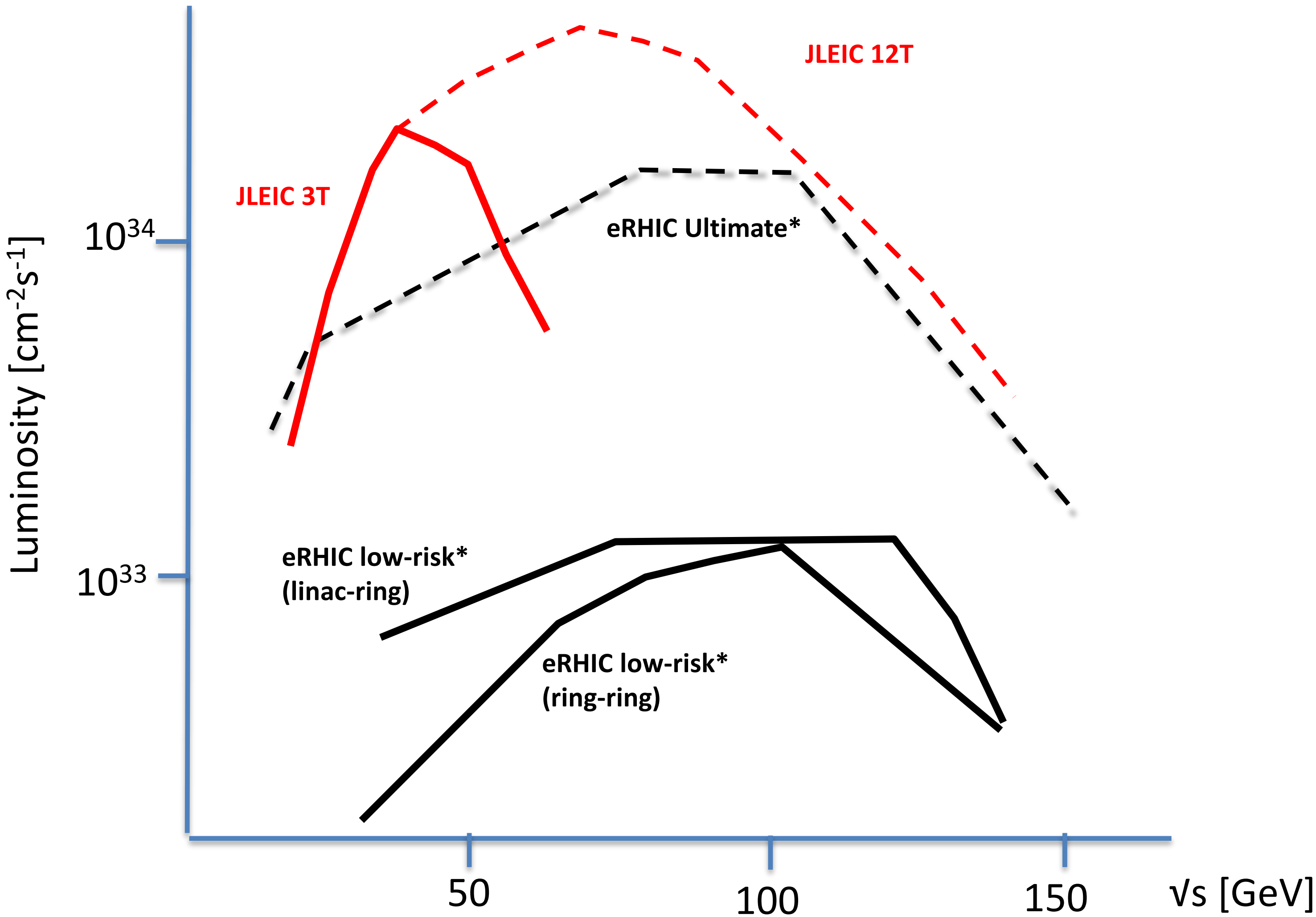


E- energy (GeV)	3	5	7	9	10
Estimated Pol. Lifetime (hours)	66	5.2	2.2	1.3	0.8

Ion polarization



Comparison JLEIC and eRHIC (Jan. 2017)

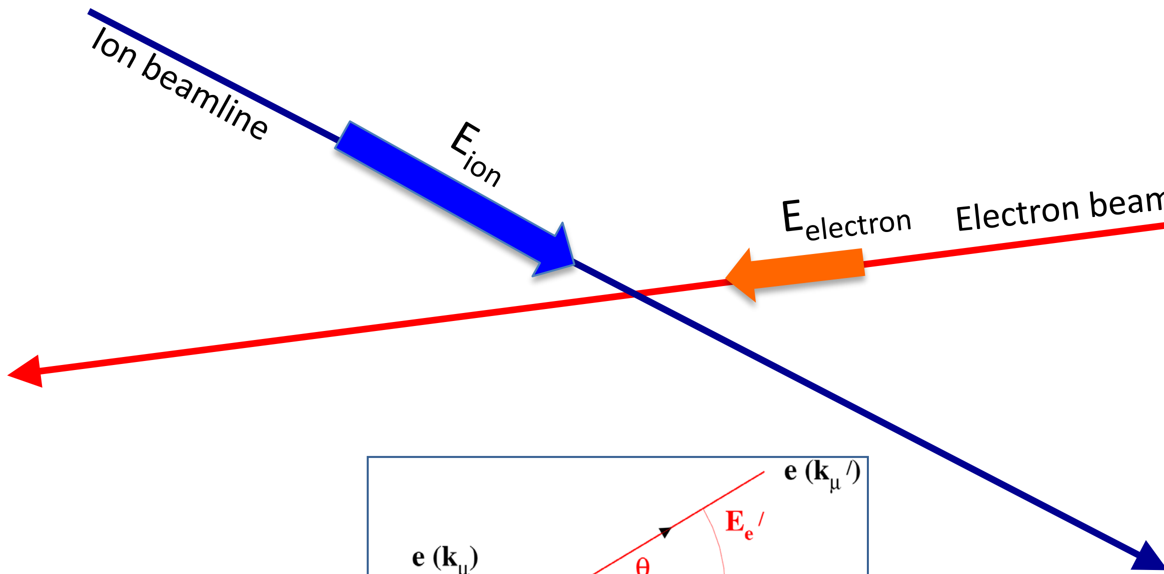


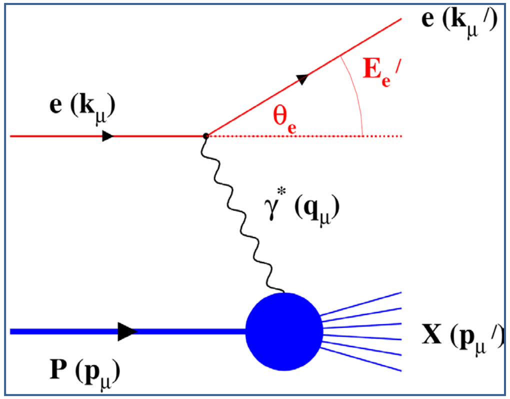
*eRHIC parameters taken from F. Willike slides (F. Pilat talk) from EIC opportunities meeting for INFN, Genova (17 January, 2017)
JLEIC parameters can be found at eic.jlab.org/wiki (January, 2017 update)

DETECTOR DESIGN CONSIDERATIONS

DIS and Final State Particles

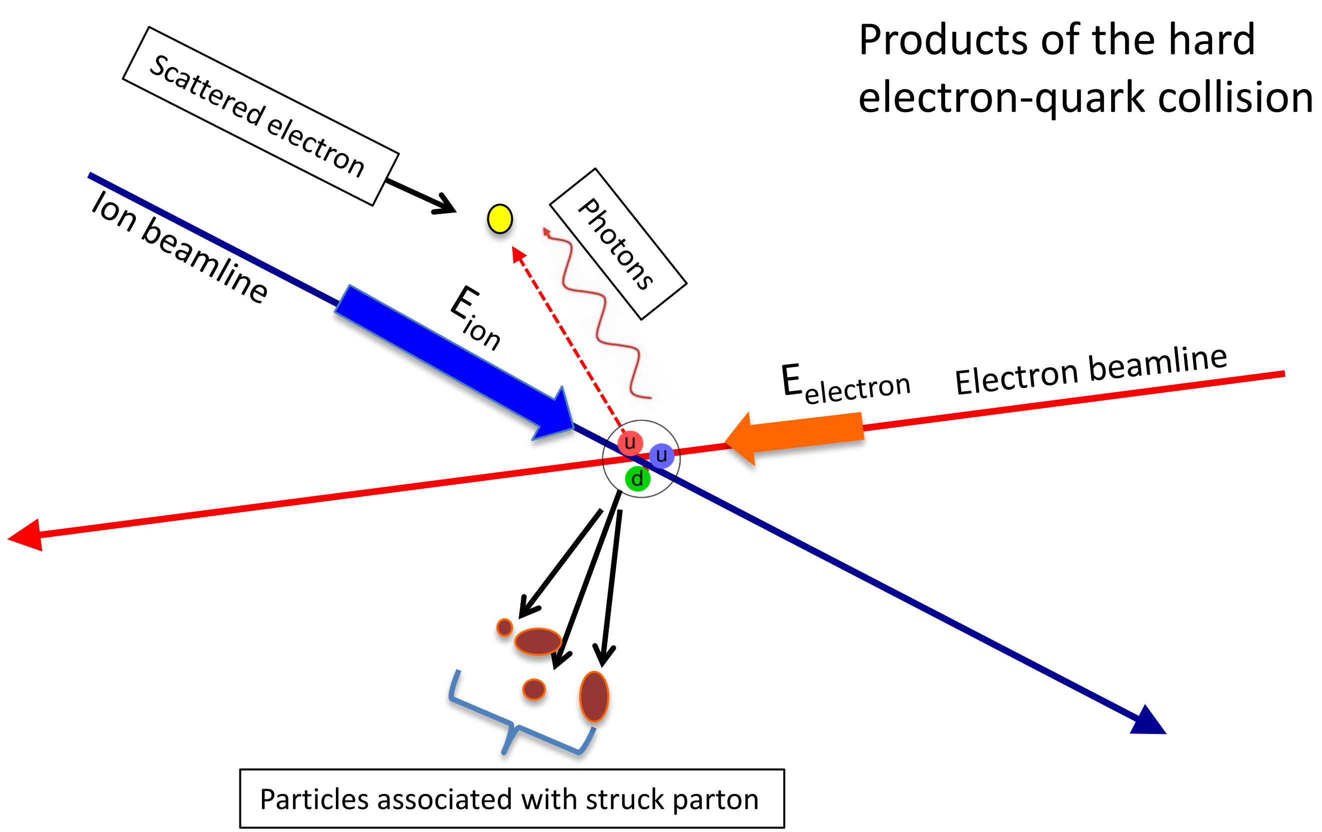
Aim of EIC is nucleon and nuclear structure beyond the longitudinal description. This makes the requirements for the machine and detector different from all previous colliders **including HERA**.





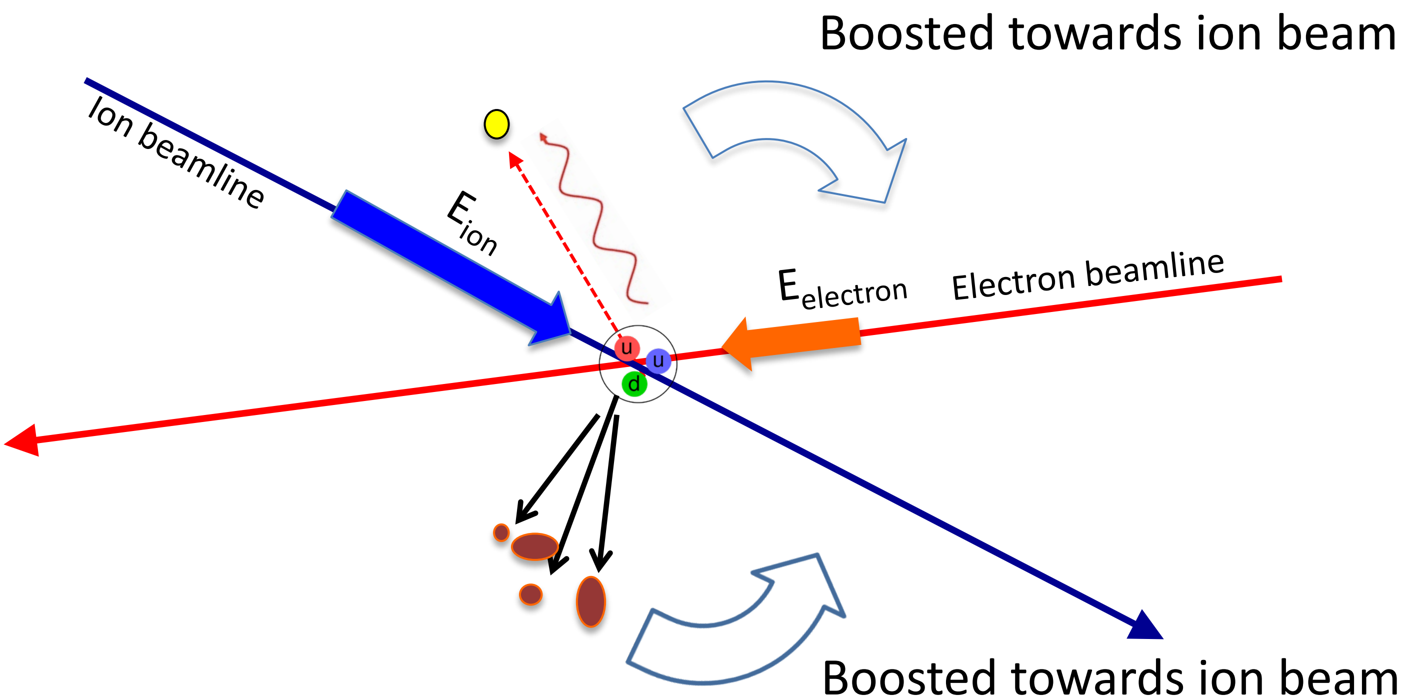
Need more than this

Final State Particles in the Central Rapidity



Transverse and flavor structure measurement of the nucleon and nuclei: The particles associated with struck parton must have its species identified and measured. **Particle ID much more important than at HERA**

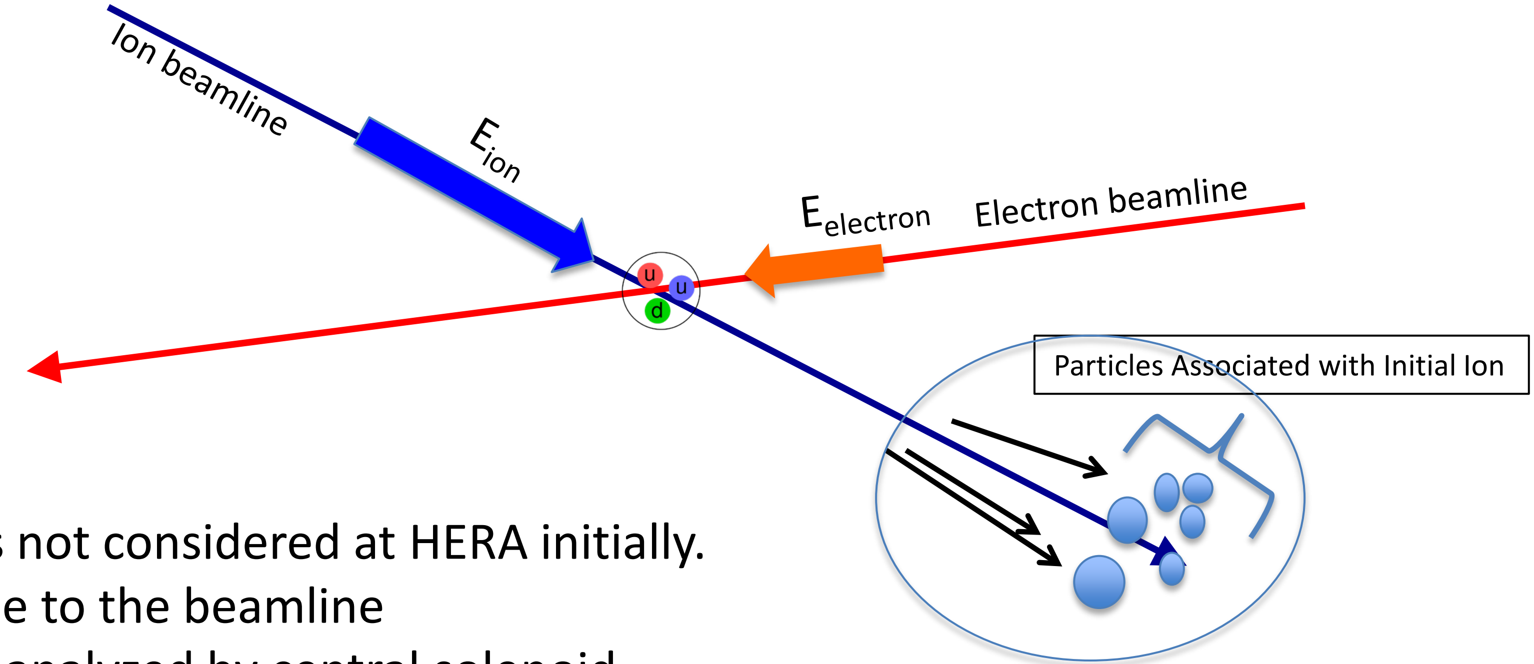
Final State Particles in the Central Rapidity



Asymmetric collision energies will boost the final state particles in the ion beam direction: **Detector requirements change as a function of rapidity**

Particles Associated with the Initial Ion

For EIC, particles of the “target remnant” is as important as the struck parton



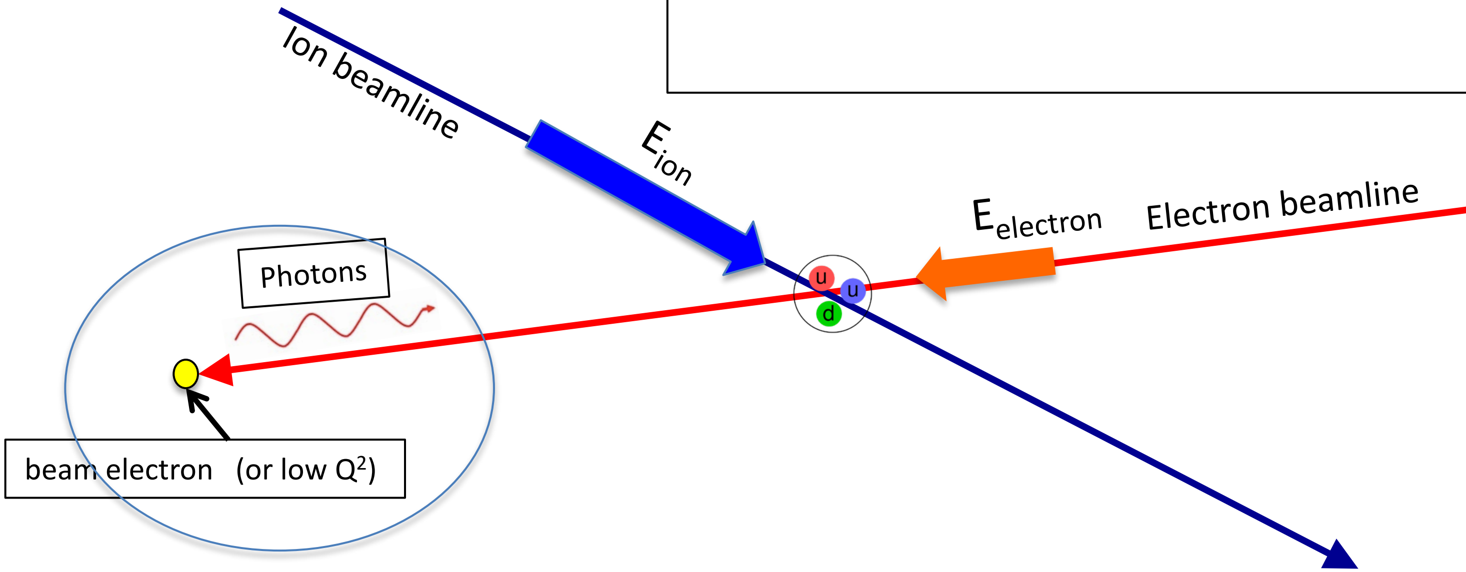
- Was not considered at HERA initially.
- Close to the beamline
- Not analyzed by central solenoid.
- **Aim for ~100% acceptance and good resolution at EIC.**

Remember acceptance is equally important as luminosity!

Particles Associated with the Initial Electron

Forward Electron area:

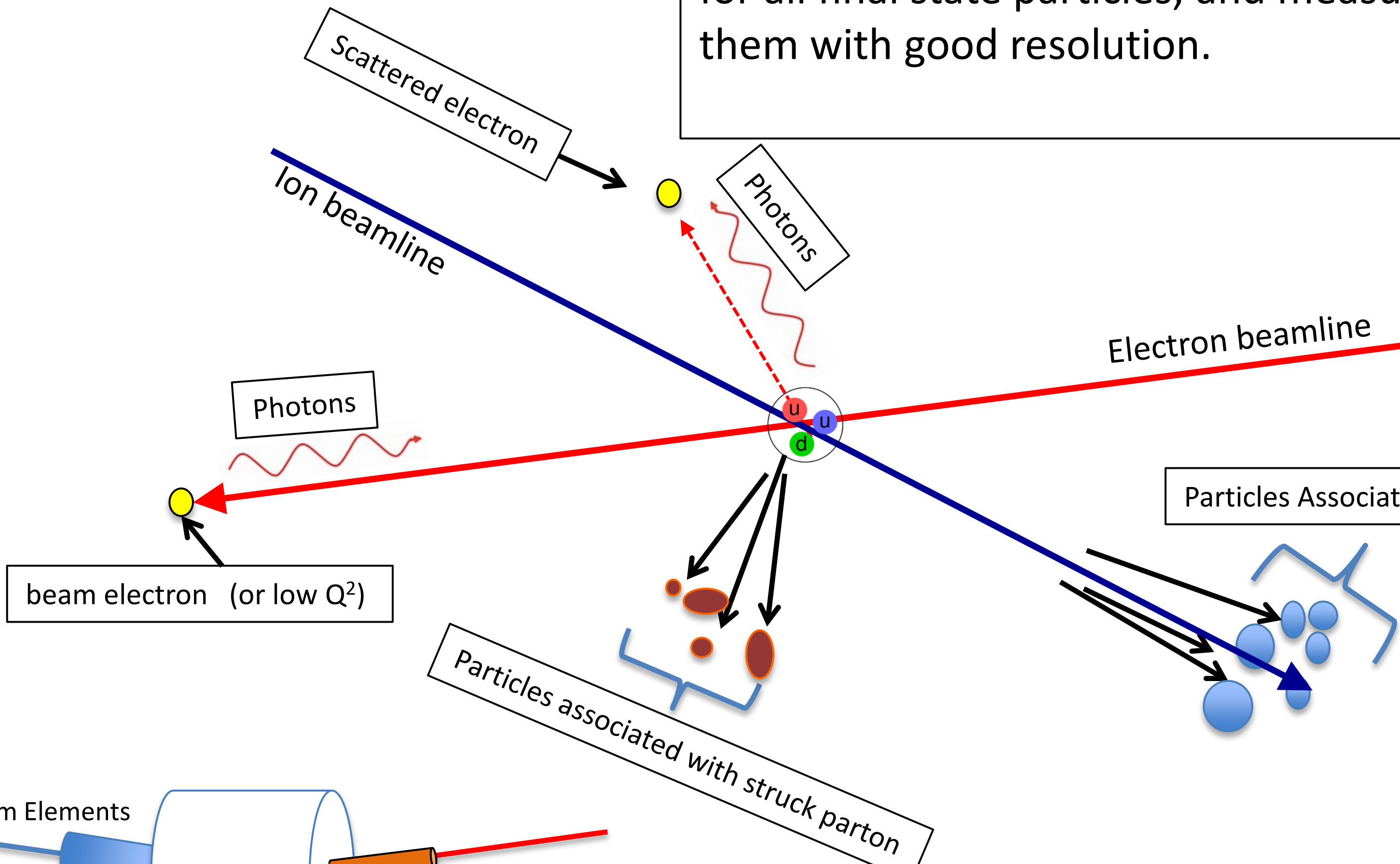
- Tag photoproduction ($Q^2 \approx 0$)
- Measure Luminosity
- Measure electron polarization

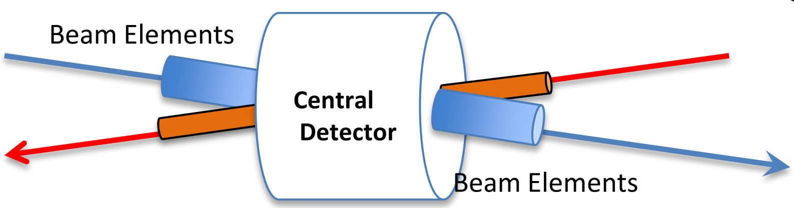


Apply lessons from HERA, JLab and elsewhere

Final State Particles

The aim is to get ~100% acceptance for all final state particles, and measure them with good resolution.

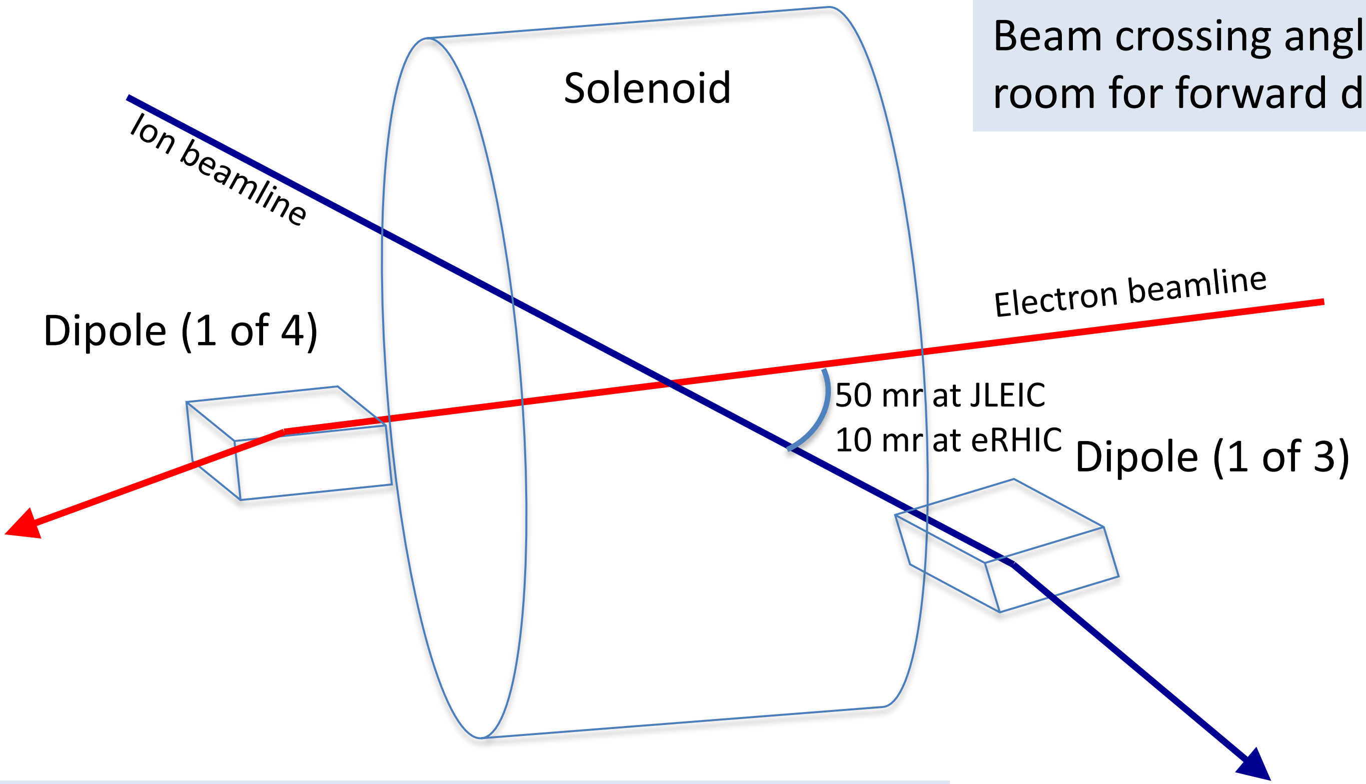




Beam elements limit forward acceptance
Central Solenoid not effective for forward

Interaction Region Concept

NOT TO SCALE!

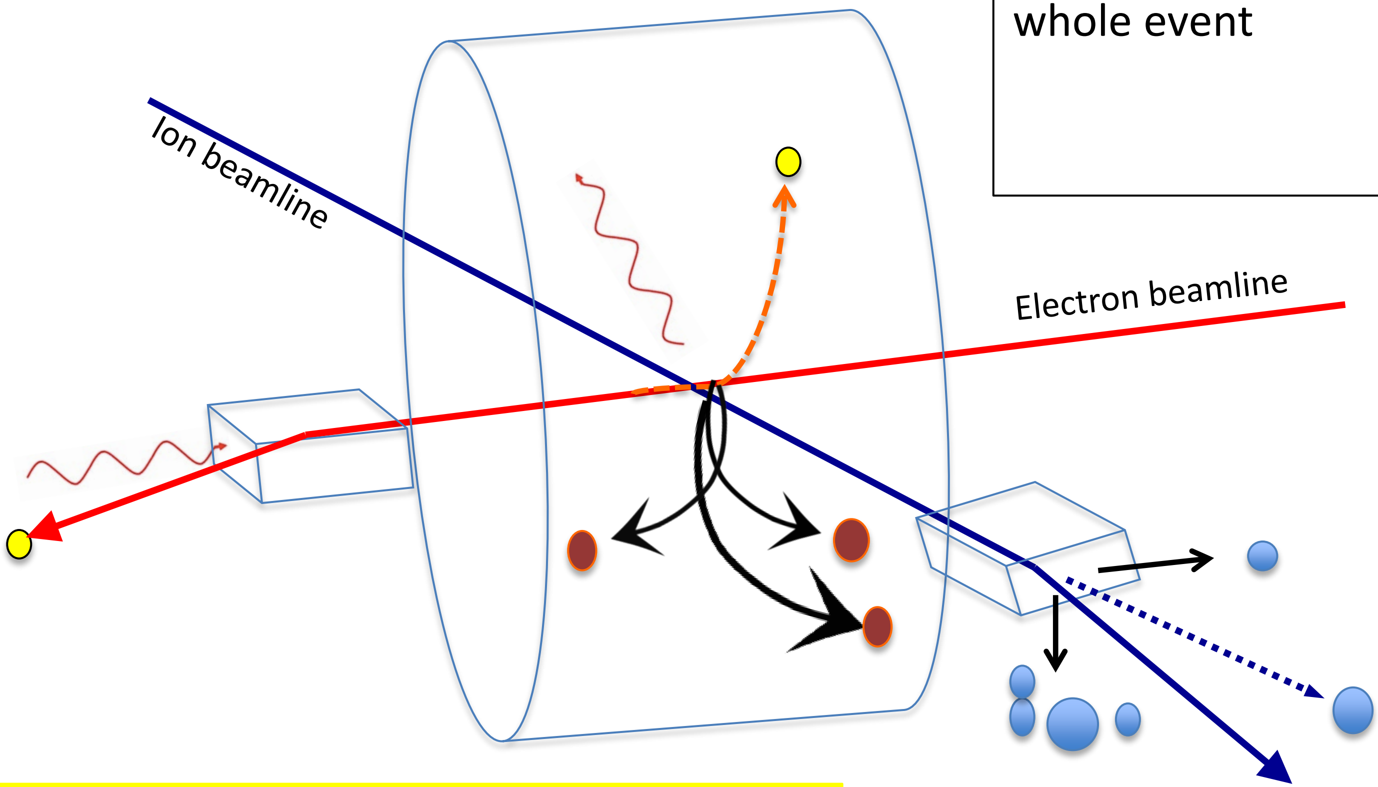


Beam crossing angle creates room for forward dipoles

Dipoles analyze the forward particles
and create space for detectors in the forward direction

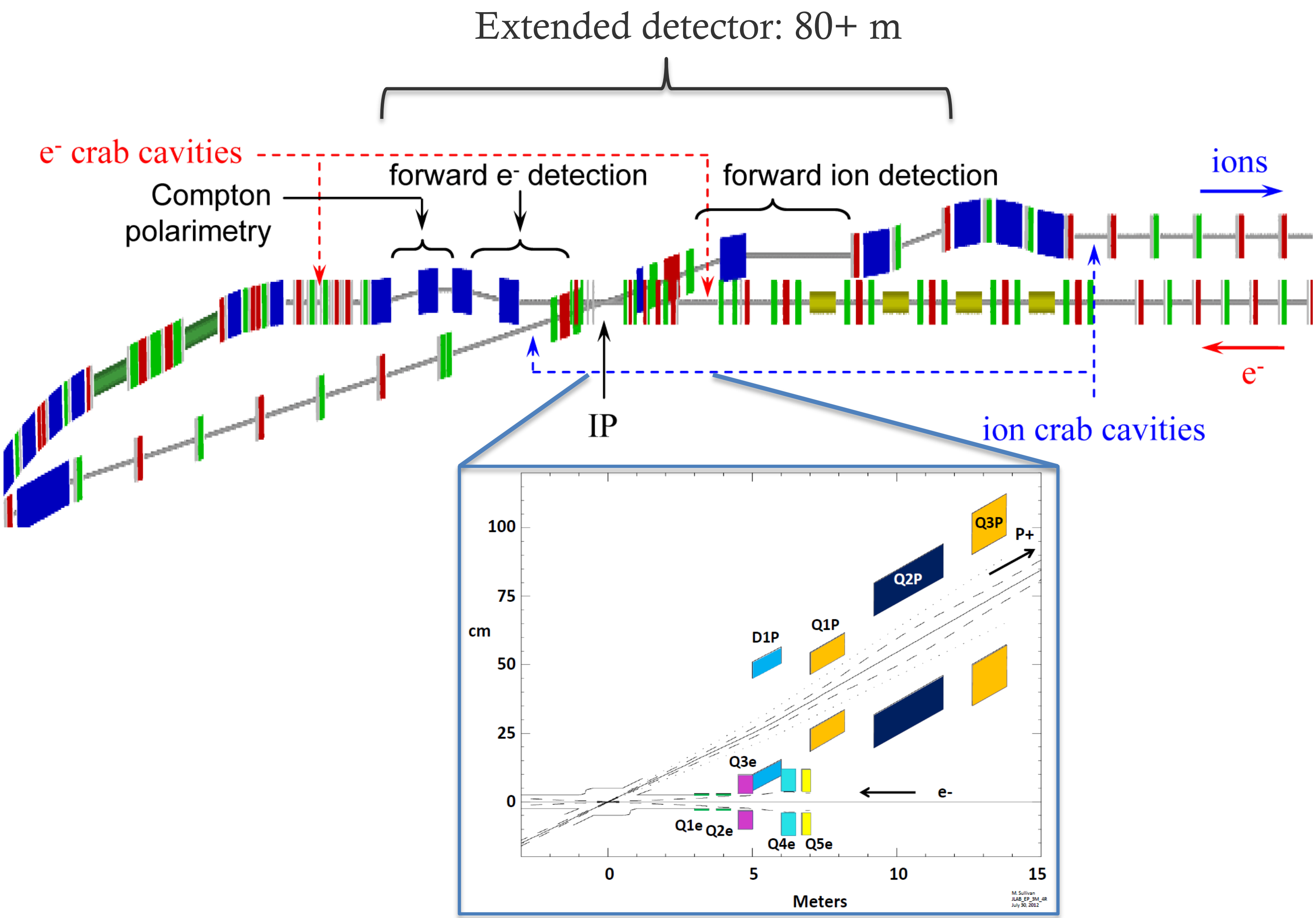
Interaction Region Concept

Possible to get ~100% acceptance for the whole event



Total acceptance detector (and IR)

JLEIC IR Layout

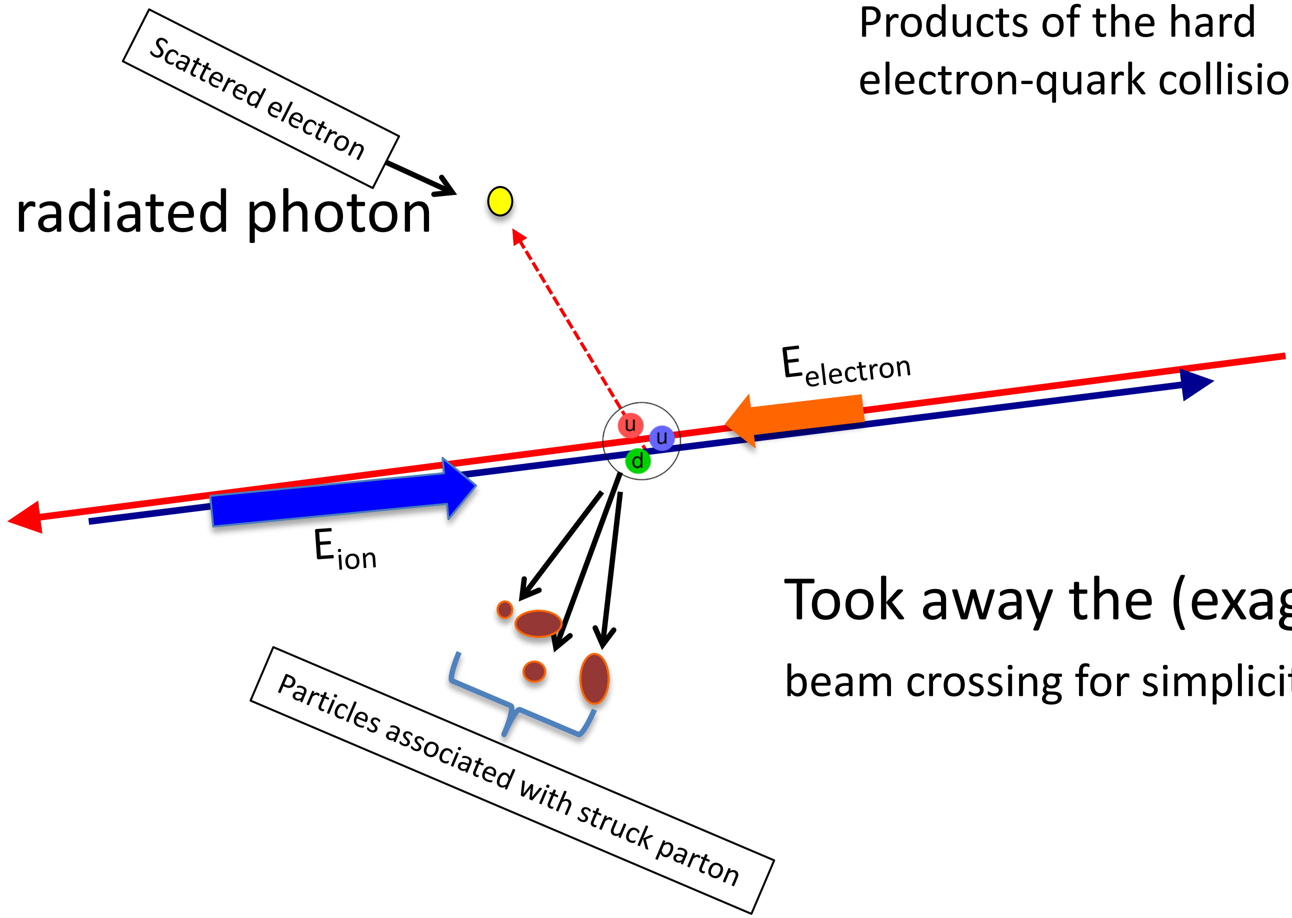


CENTRAL DETECTOR

Final State Particles in the Central Detector

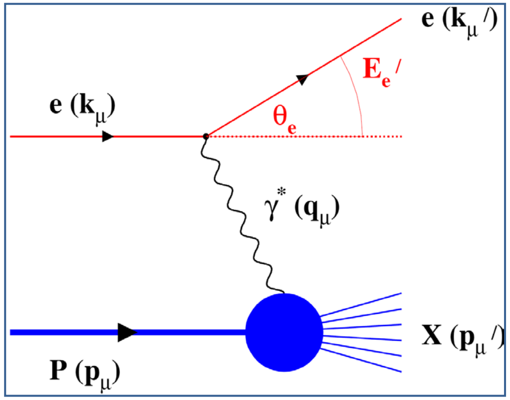
Products of the hard
electron-quark collision

Took away radiated photon
for simplicity



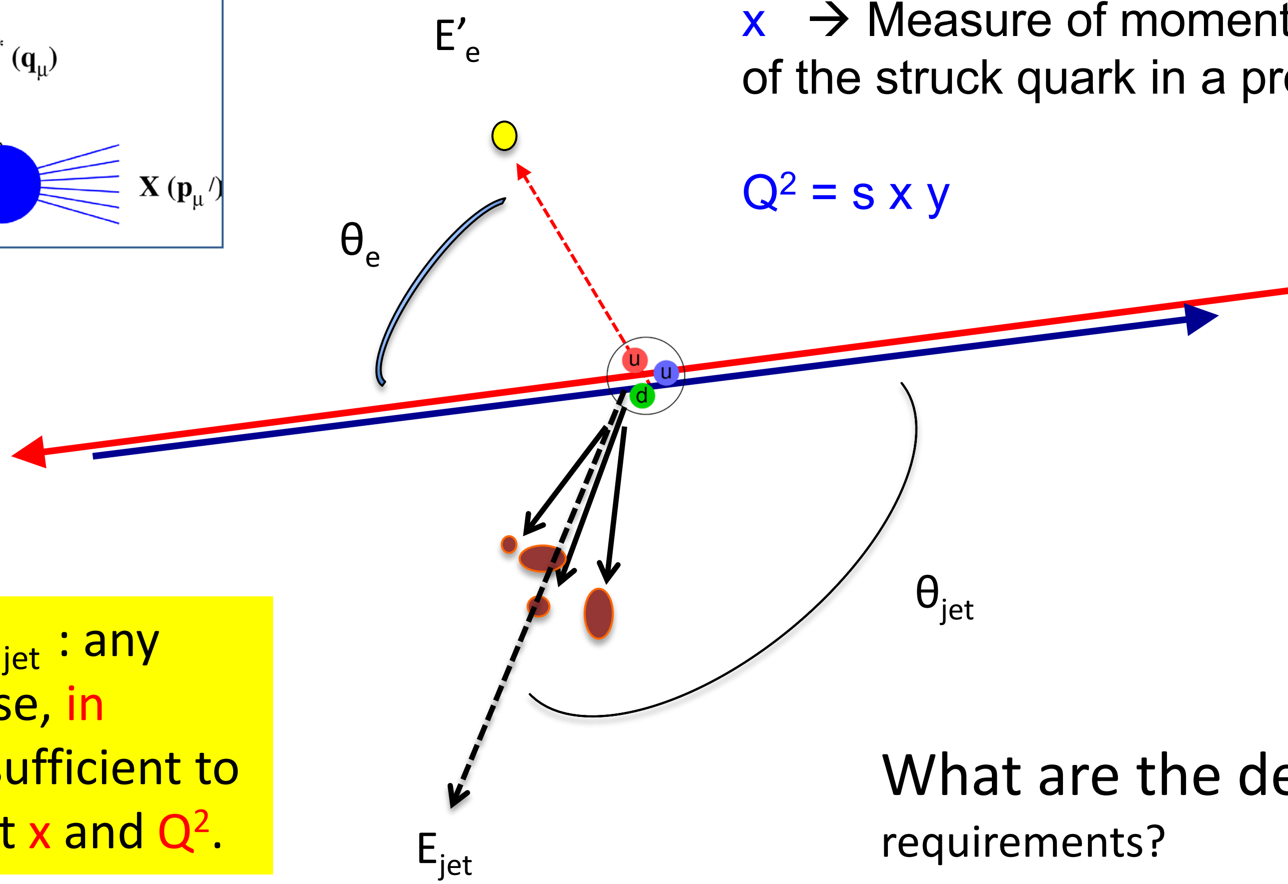
Took away the (exaggerated)
beam crossing for simplicity

Basic Kinematic Reconstruction



Q^2 → Measure of resolution
y → Measure of inelasticity
x → Measure of momentum fraction of the struck quark in a proton

$Q^2 = s\,x\,y$

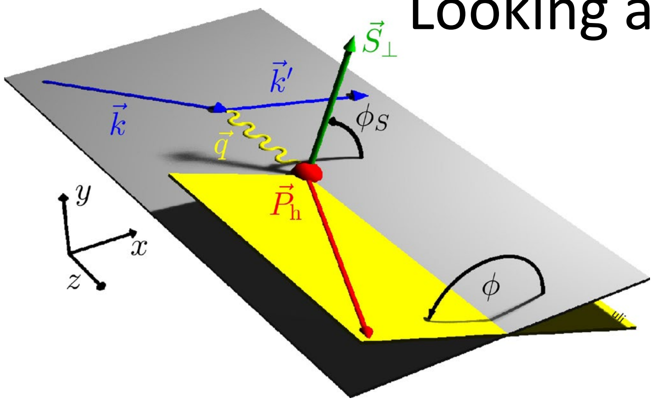


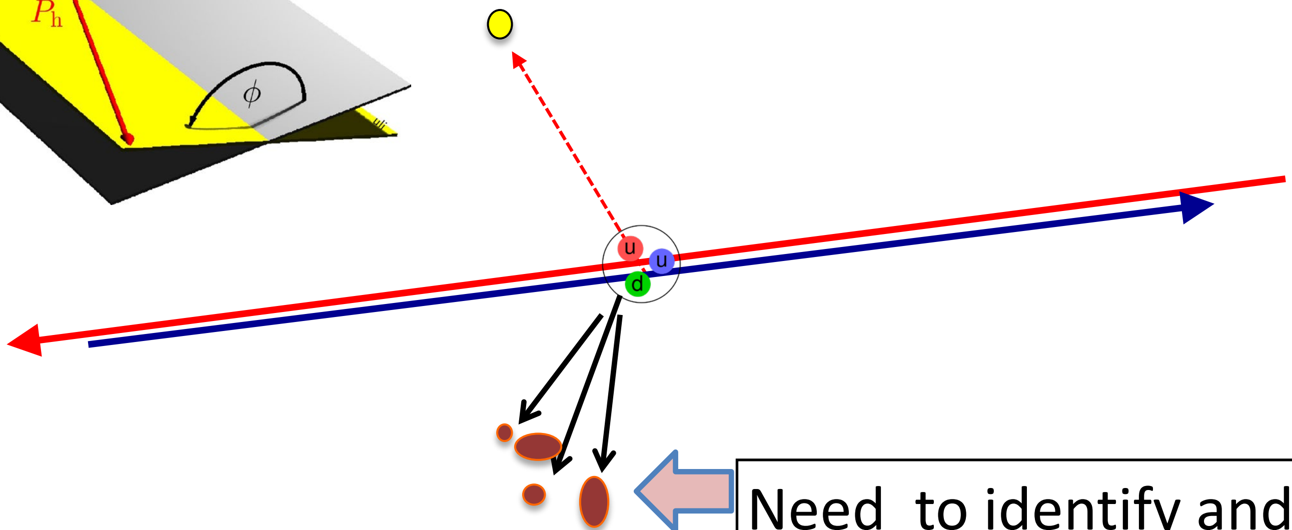
$E'_e, \theta_e, E_{jet}, \theta_{jet}$: any two of these, in principle, sufficient to reconstruct x and Q^2.

What are the detector requirements?

Reconstruction for Transvers Structure

Looking at out-of –plane component in the final state





Need to identify and measure these particles

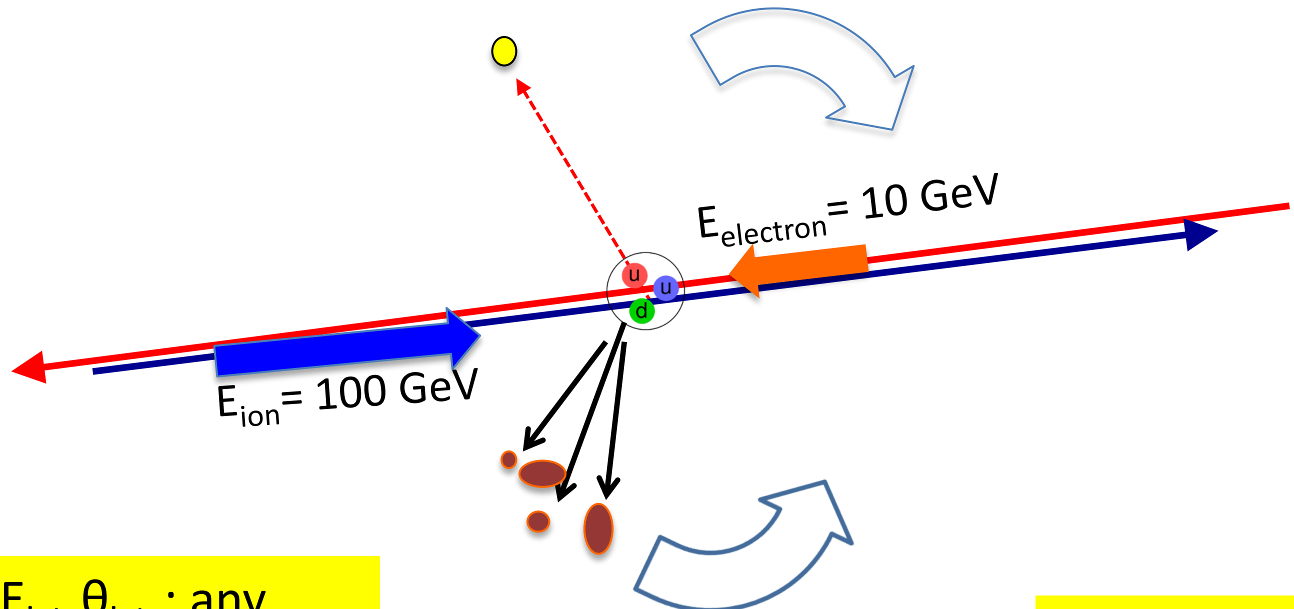
What are the detector requirements?

Note: multiplicities are low (~20 for ep)
Cross-sec x Lumi < 0.01 x HLLHC
< 0.1 interaction/crossing

How Boosted is the Final State?

No Monte Carlo needed to Determine

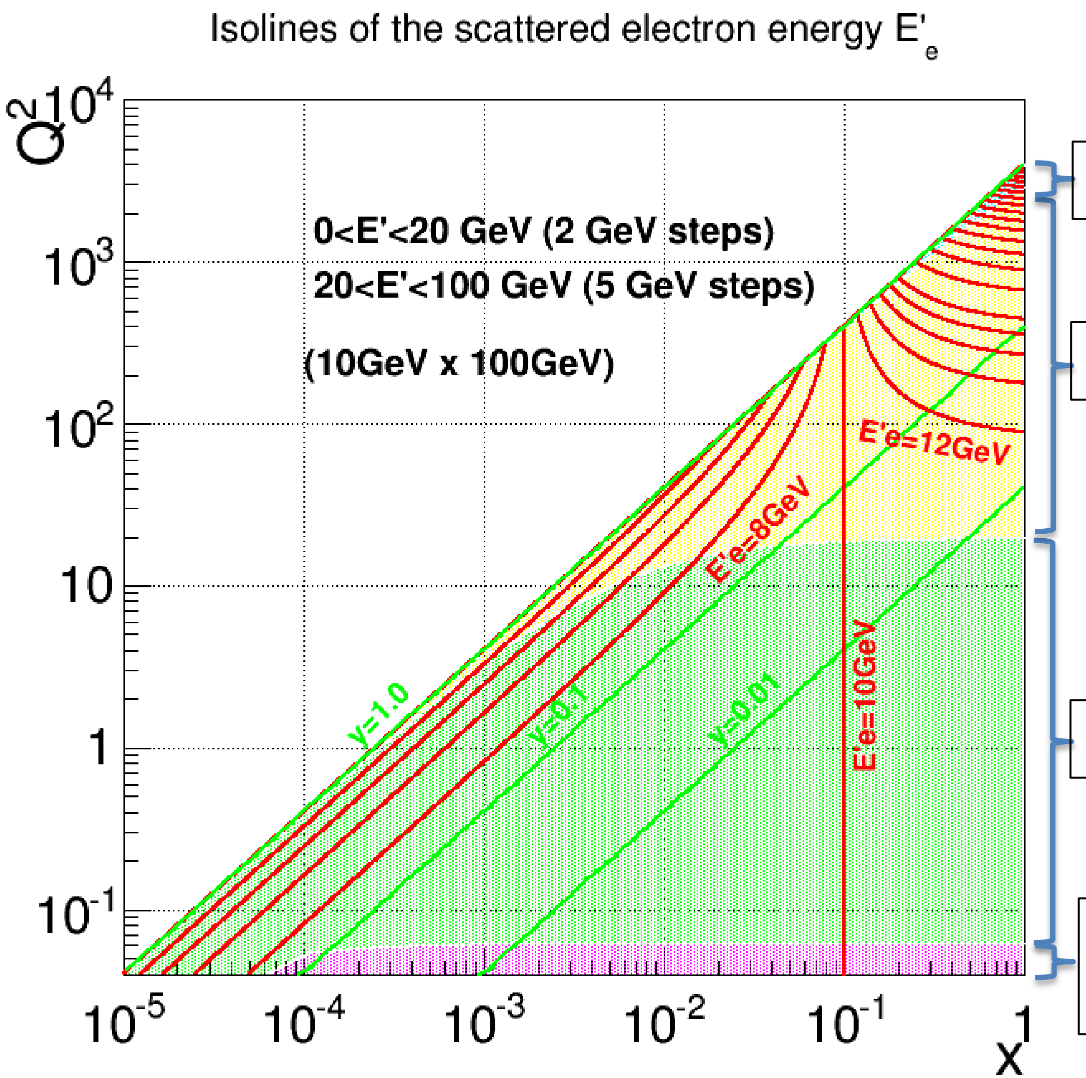
Boosted towards ion beam

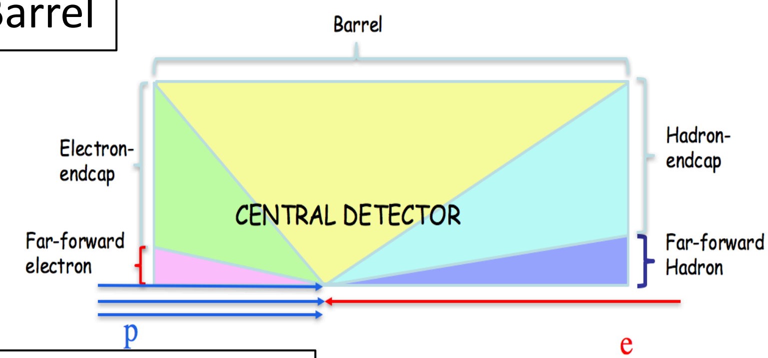


$E'_{e}, \theta_{e}, E_{jet}, \theta_{jet}$: any two of these, in principle, sufficient to reconstruct x and Q^2.

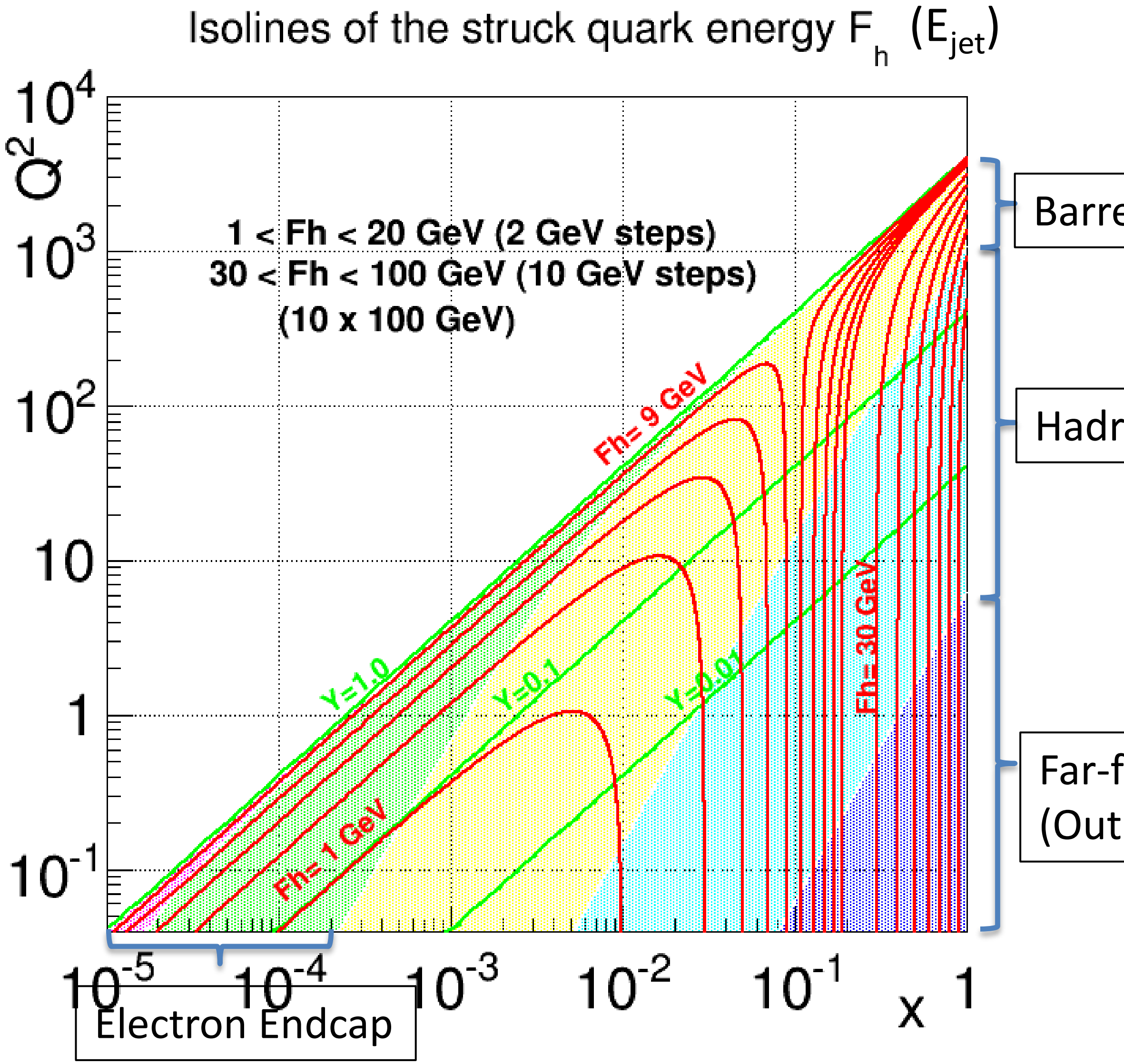
Given x and Q^2, $E'_{e}, \theta_{e}, E_{jet}, \theta_{jet}$ are all fixed

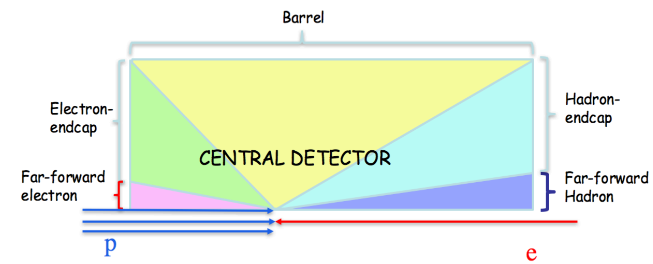
Electron Isoline Plot





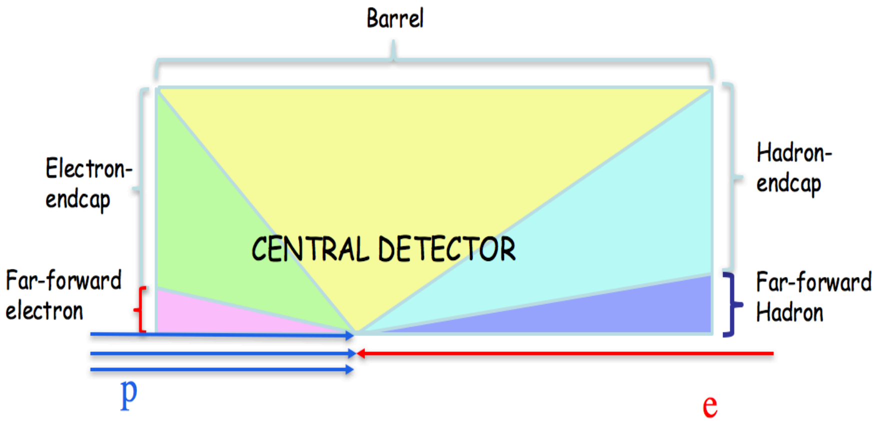
Quark(Jet) Isoline Plot

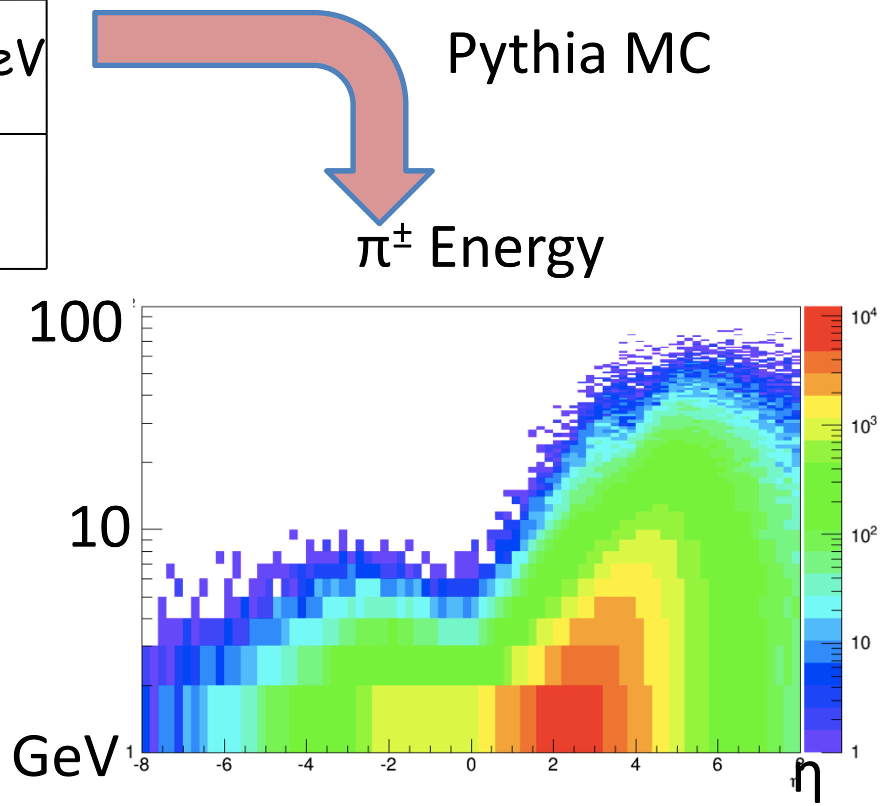




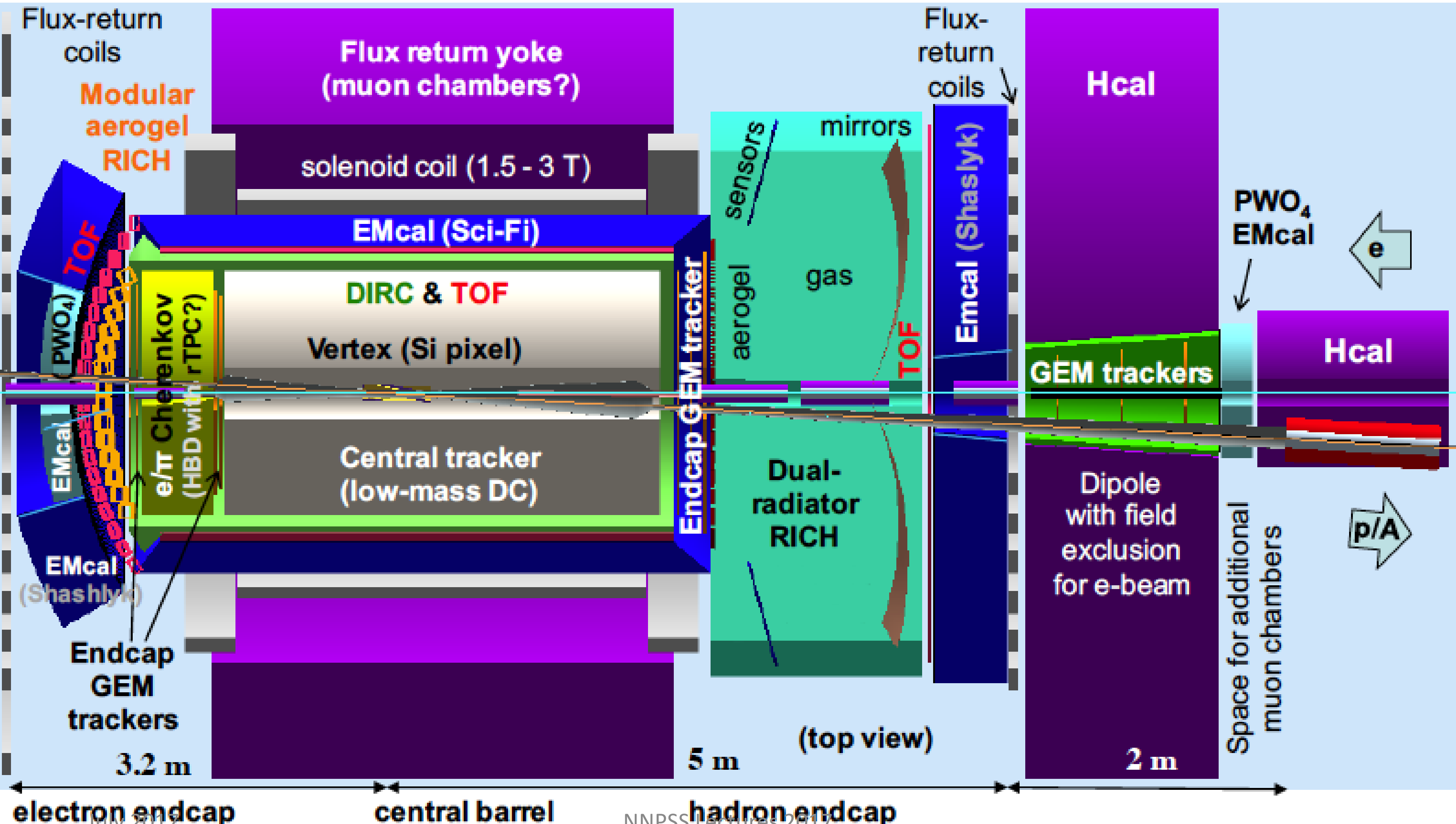
Particle Distribution

	E-endcap	Barrel	H-endcap
E'e	<8 GeV	8-50 GeV	>50 GeV
Ejet	<10 GeV	~10-50 GeV	20-100 GeV
E,hadrons	<10 GeV	<15 GeV	~15-50 GeV
occupancy	low	medium	high





Current JLEIC Concept

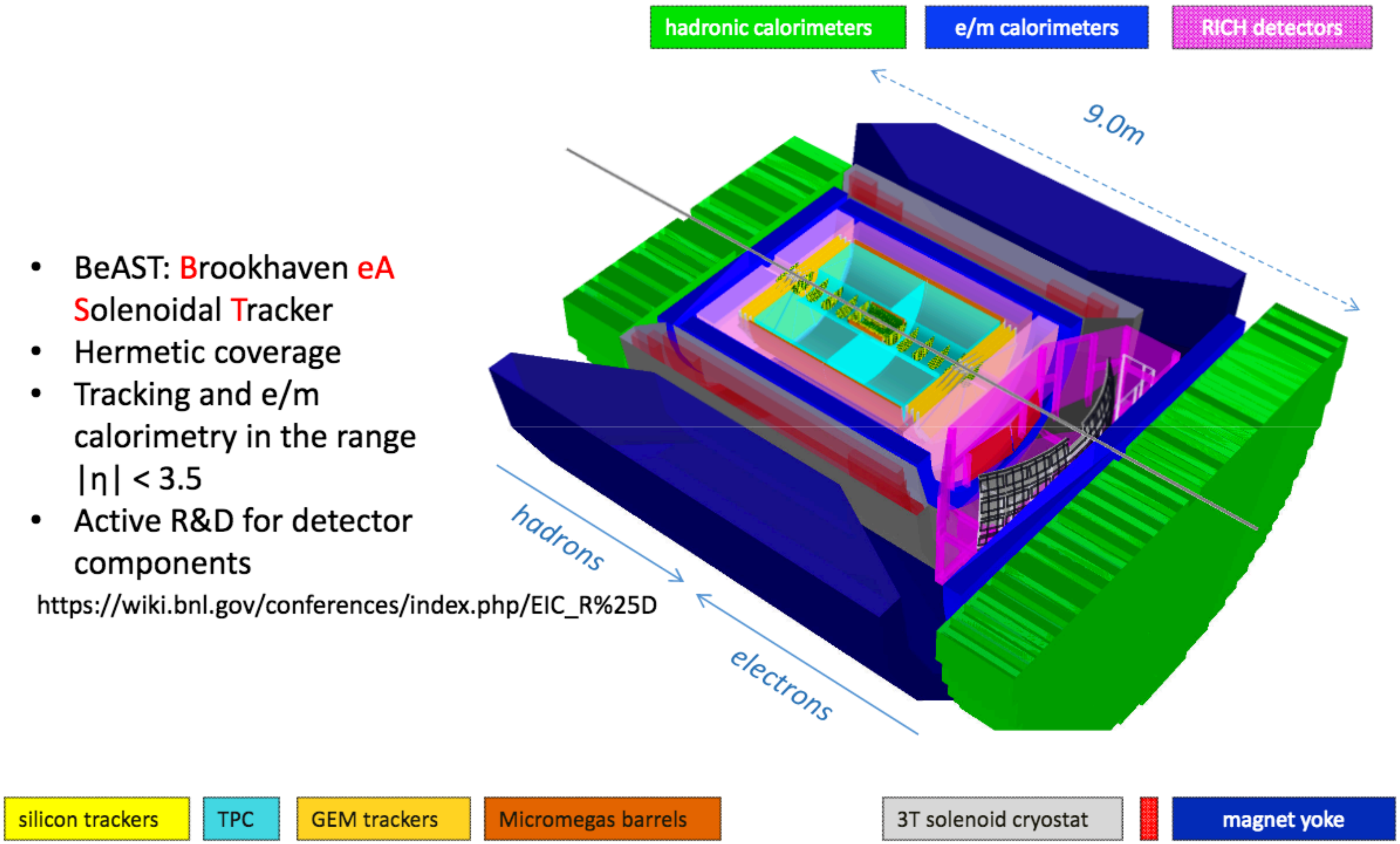


BNL Reference Detector

Reference detector layout: BeAST

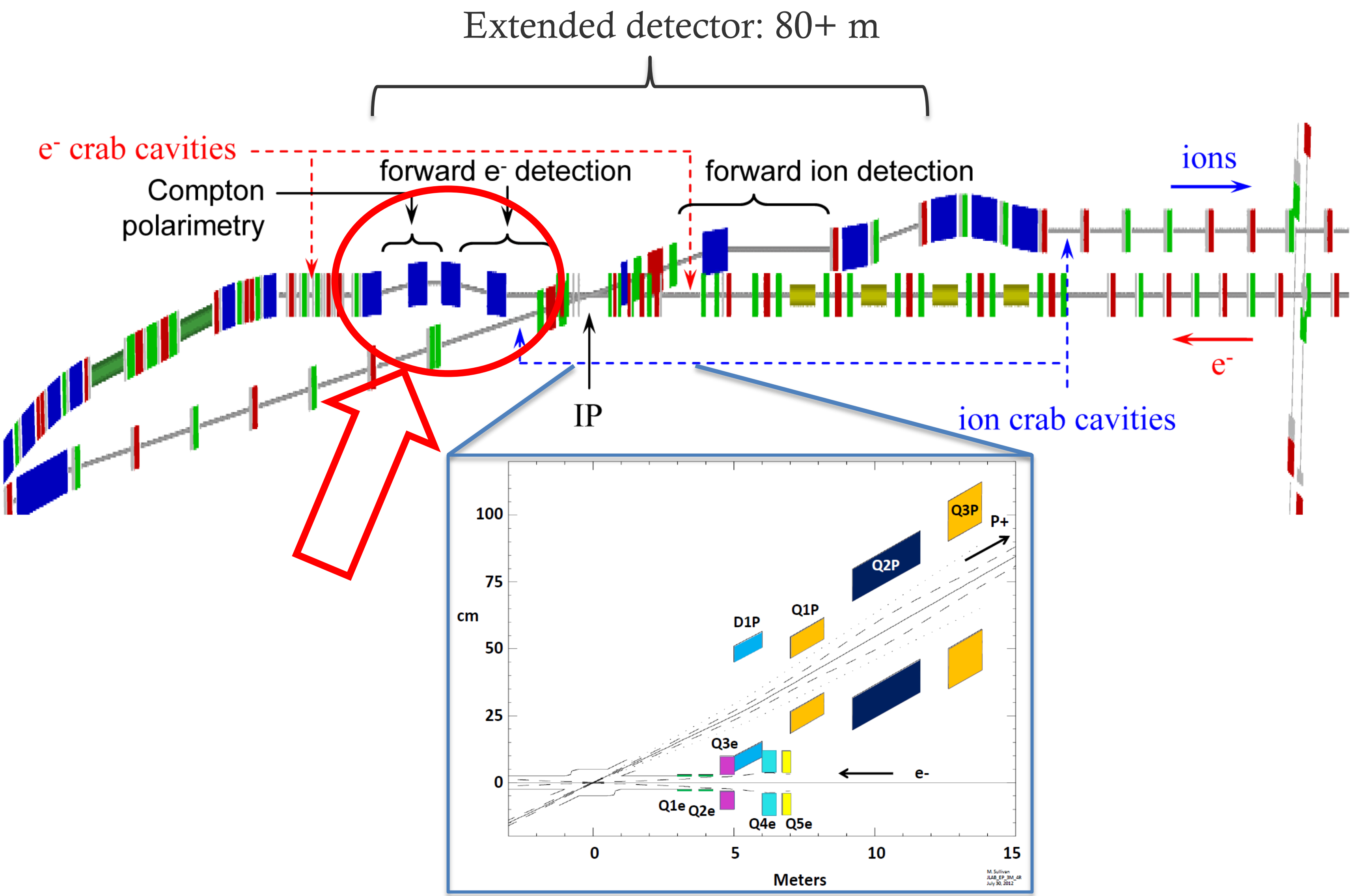
- BeAST: Brookhaven eA Solenoidal Tracker
- Hermetic coverage
- Tracking and e/m calorimetry in the range $|\eta| < 3.5$
- Active R&D for detector components

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



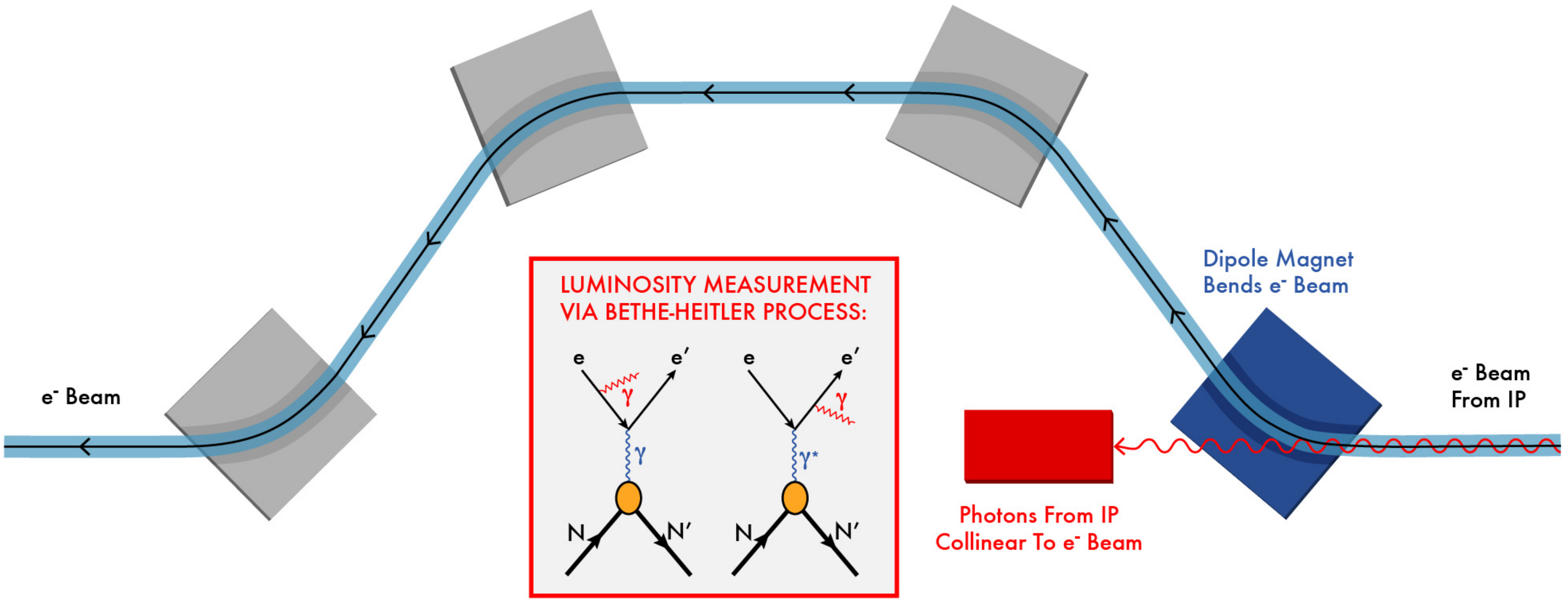
ELECTRON-BEAM DIRECTION

Chicane for Electron Forward Area

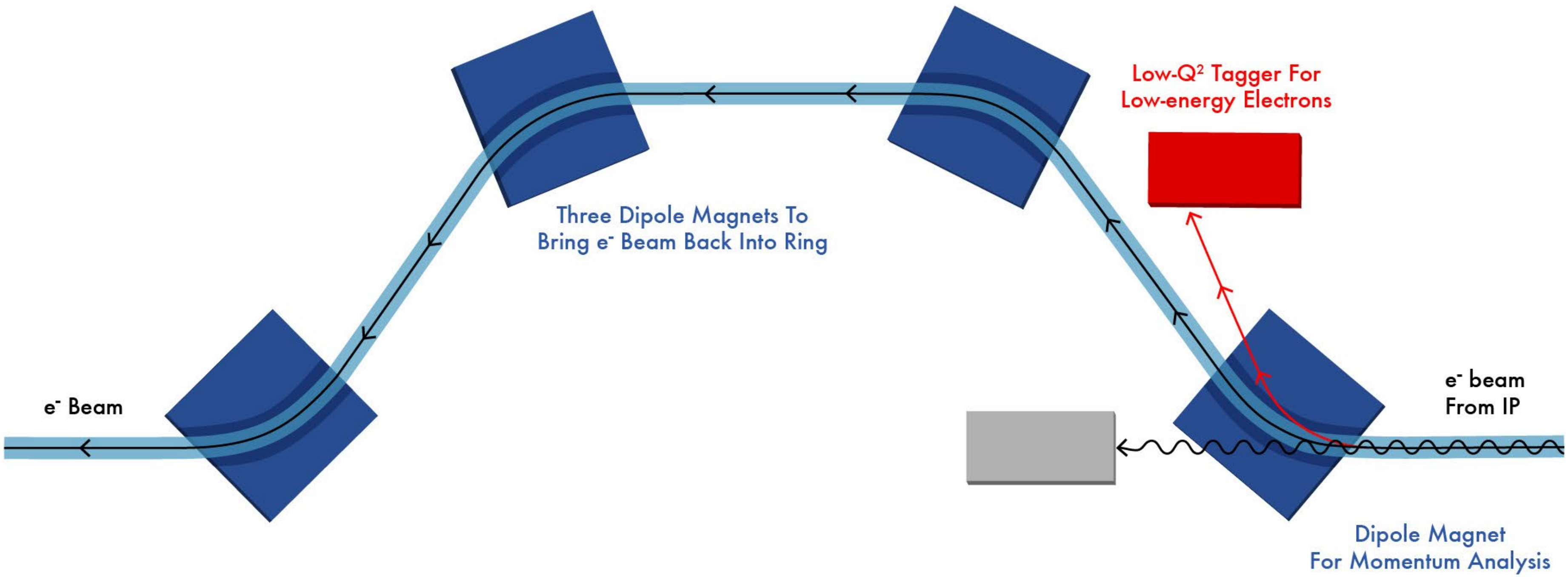


Luminosity Measurement

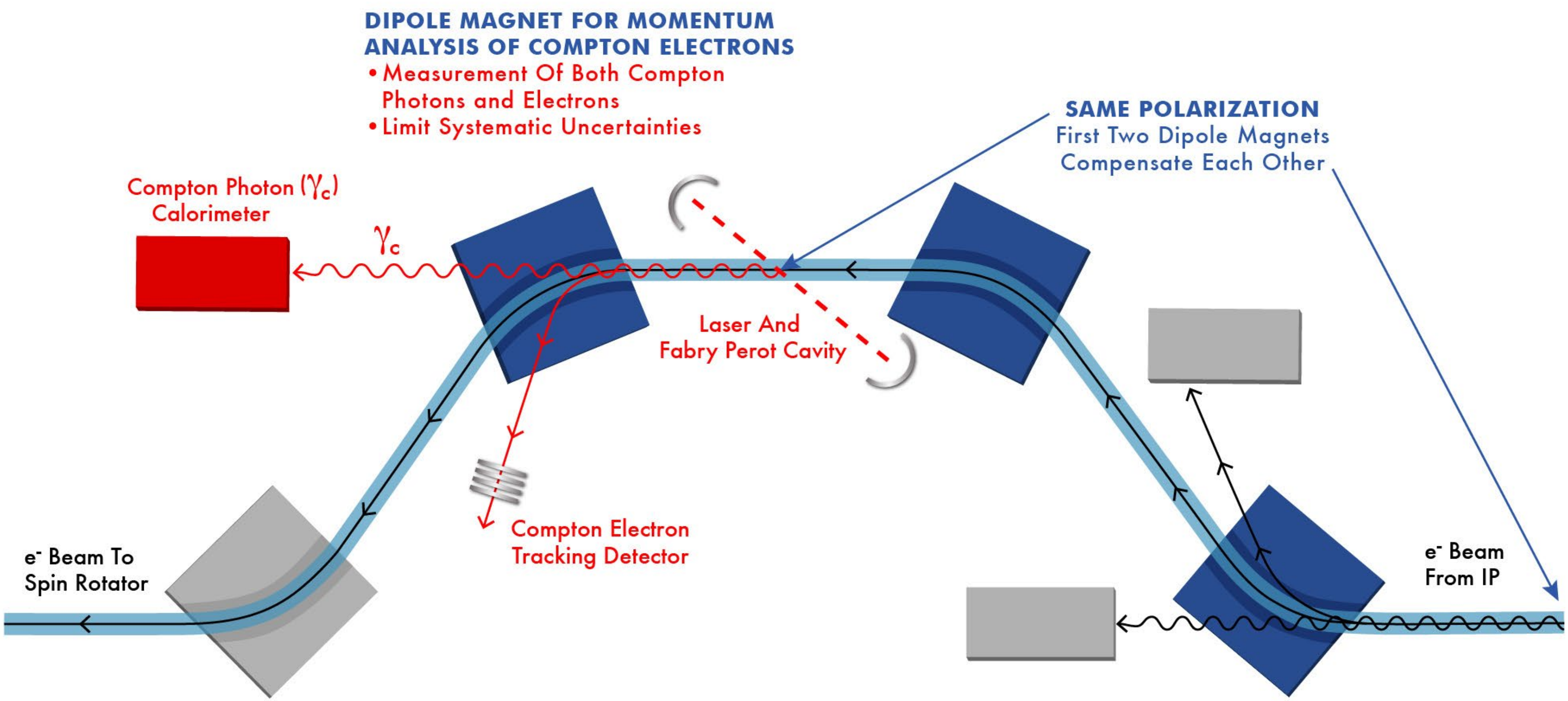
Use Bethe-Heitler process to monitor luminosity: same as HERA



Low Q^2 Tagger

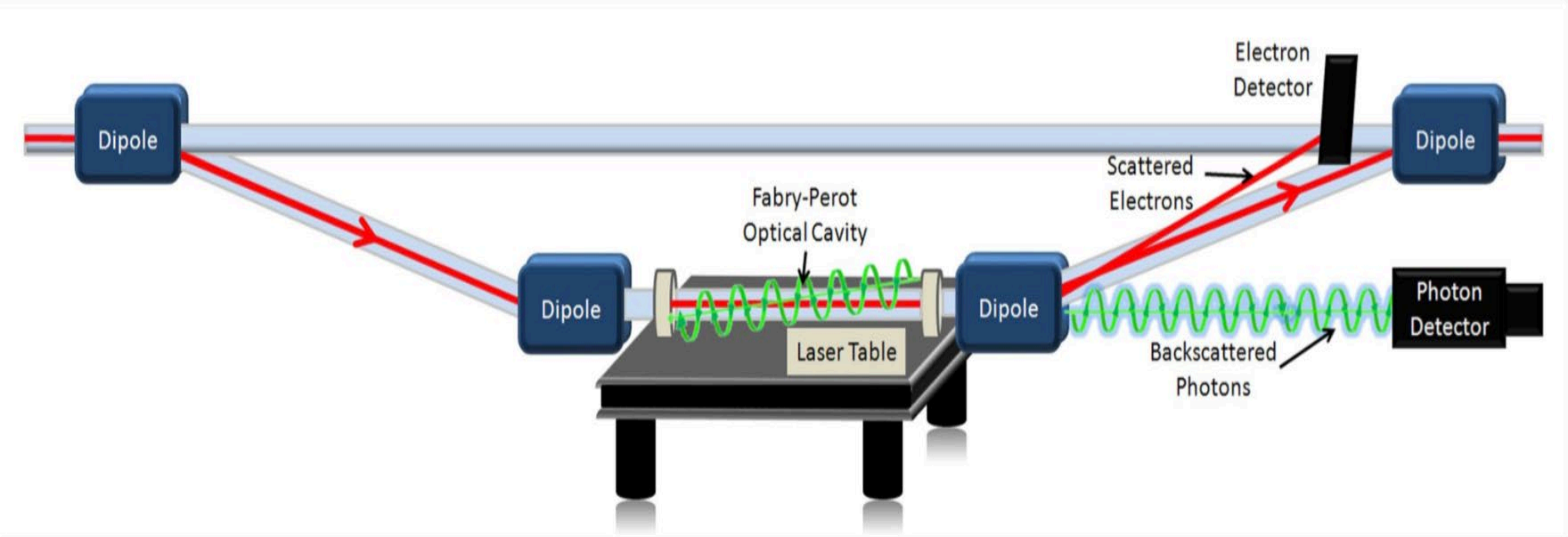


Polarization Measurement



Note the off-momentum electrons from IP does not enter the
Compton tracker for polarimetry.

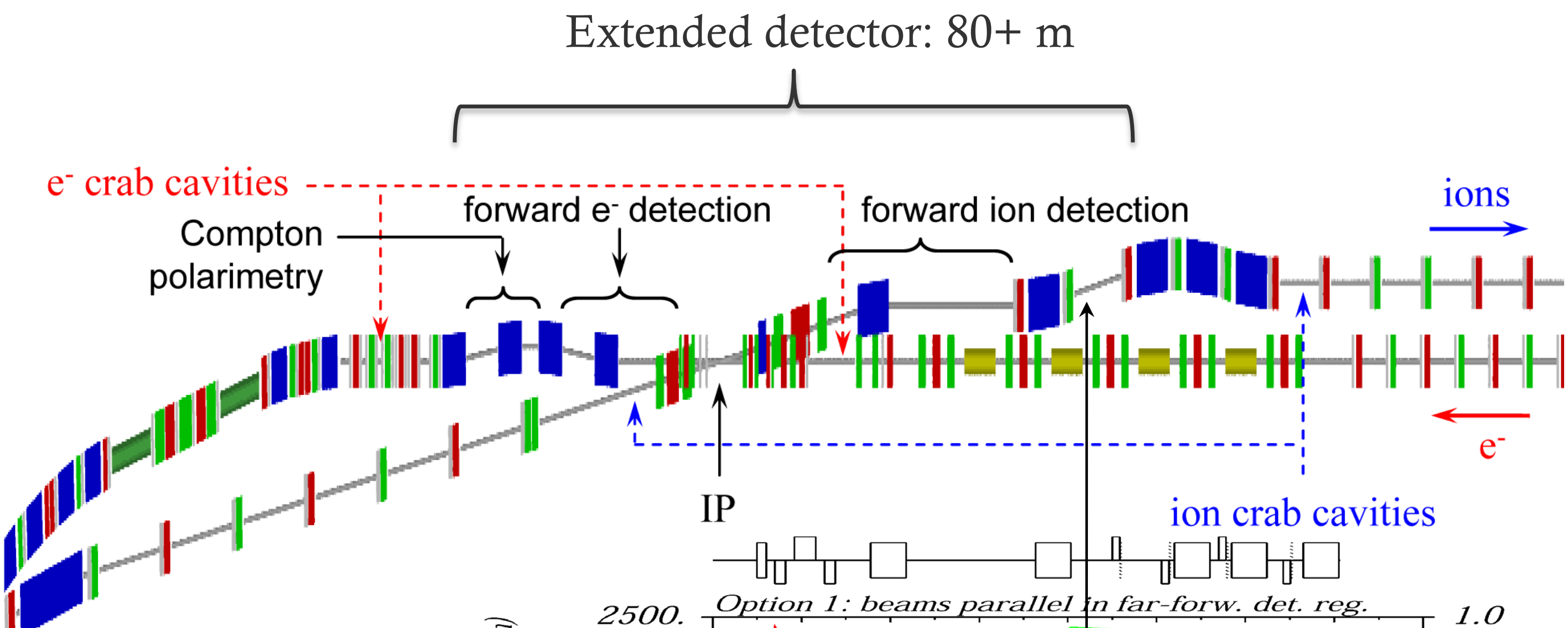
Compton Polarimetry



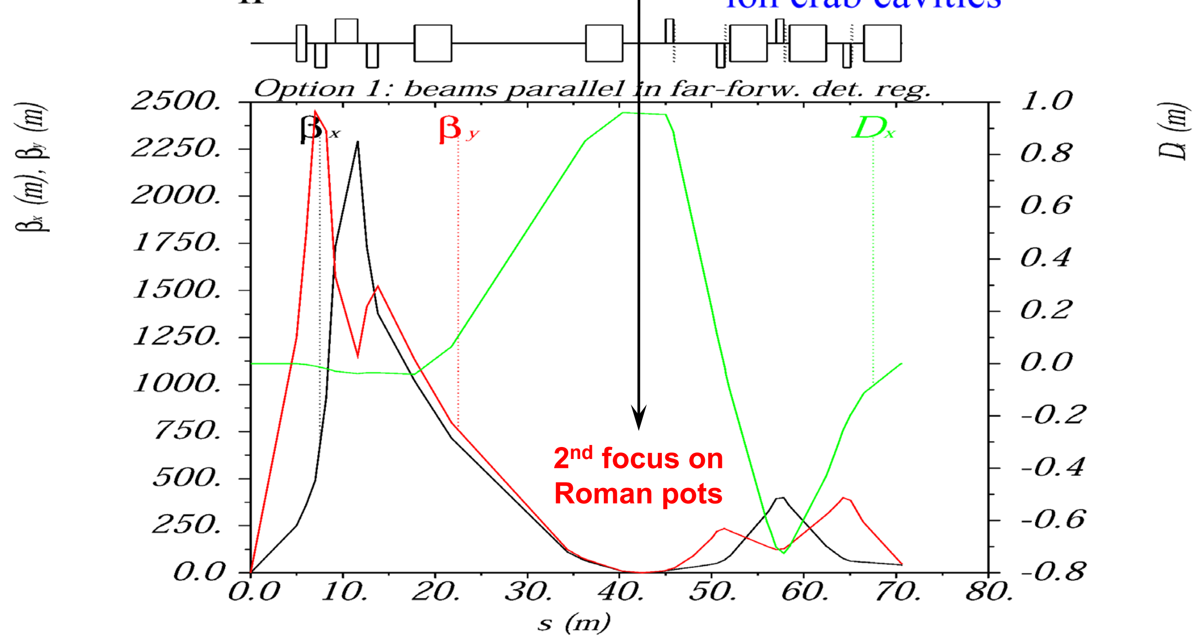
Existing Polarimeter in Hall C at JLab: Achieved 1% Precision

ION-BEAM DIRECTION

Ion optics for near-beam detection



- A large ***dispersion*** at the detection point separates scattered (off-momentum) particles from the beam.
- A ***second focus*** and small emittance (cooling) allows moving detectors closer to the beam



EIC forward detection requirements

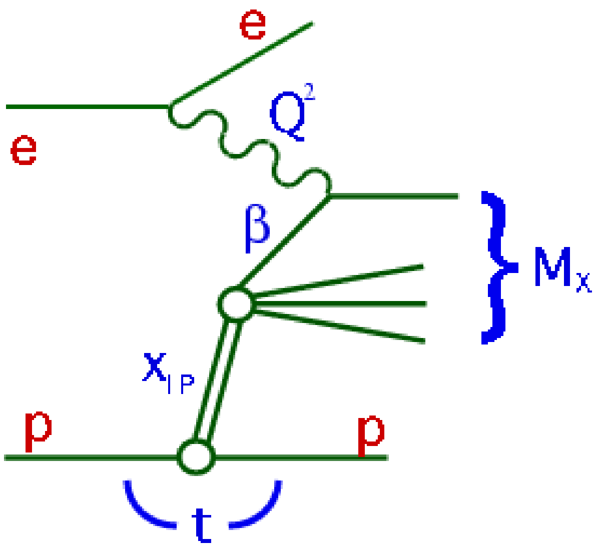
- Good acceptance for recoil nucleons (rigidity close to beam)
  - **Diffractive processes on nucleon, coherent nuclear reactions**
  - Small beam size at detection point (to get close to the beam)
    Secondary focus on roman pots, small beam emmittance (cooling)
  - Large dispersion (to separate scattered particles from the beam)

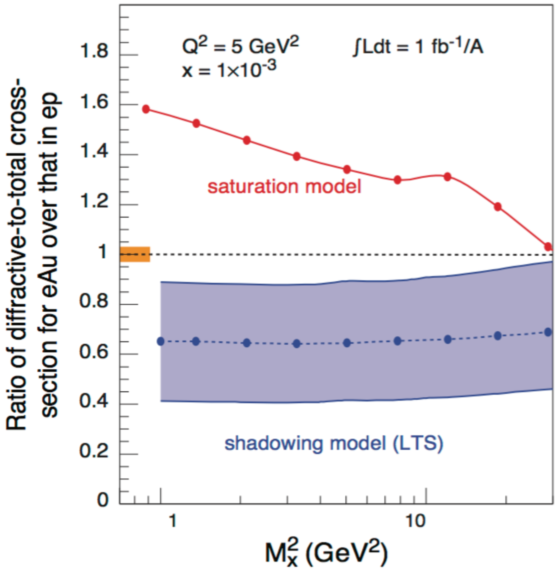
- Good acceptance for fragments (rigidity different than beam)
  - **Tagging in light and heavy nuclei, nuclear diffraction**
  - Large magnet apertures (low gradients)
  - Detection at several points along a long, aperture-free drift region

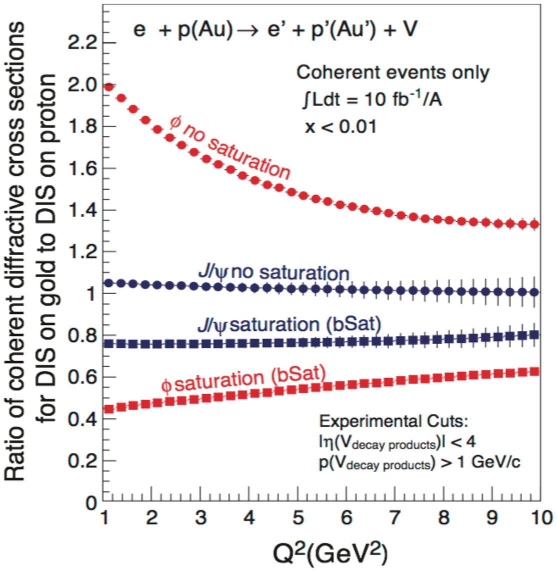
- Good momentum- and angular resolution
  - **Free neutron structure through spectator tagging, imaging**
  - Both in roman pots and fixed detectors

An Example: Diffractive DIS

Signature for Saturation (among other things)



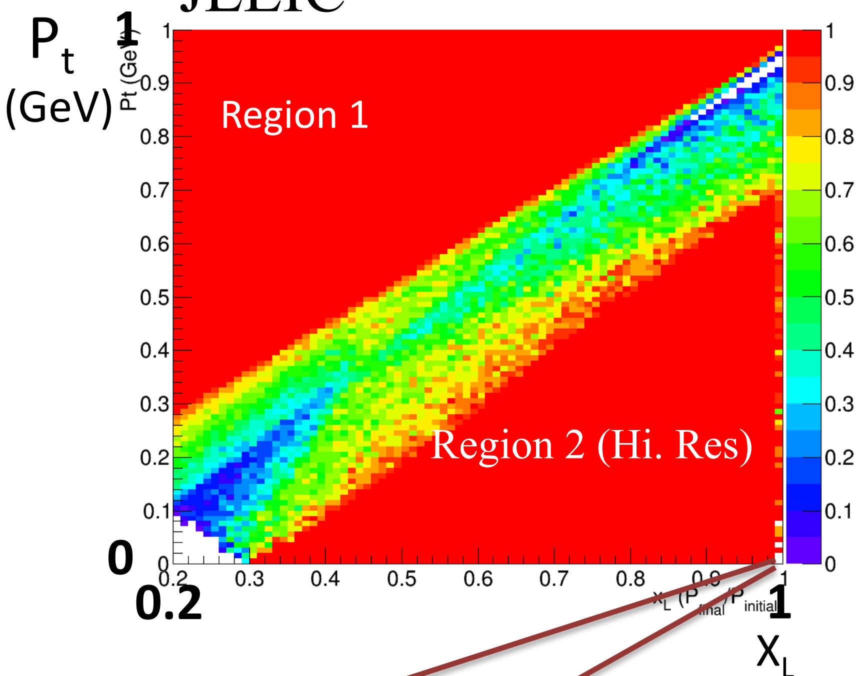


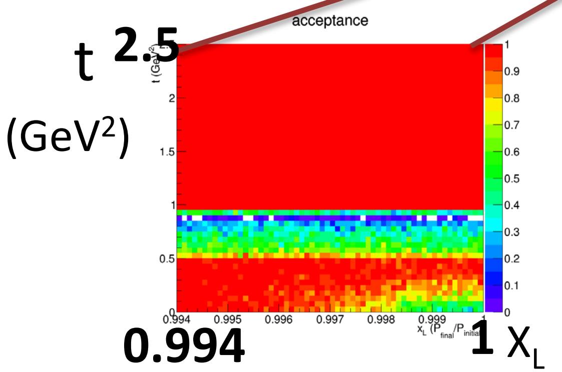


Identify the scattered proton: distinguish from proton dissociation
Measure $\mathbf{X_L = E_p'/E_p}$, and $\mathbf{P_t}$ (or **t**) (equiv. to measuring M_x)

Acceptance for p' in DDIS

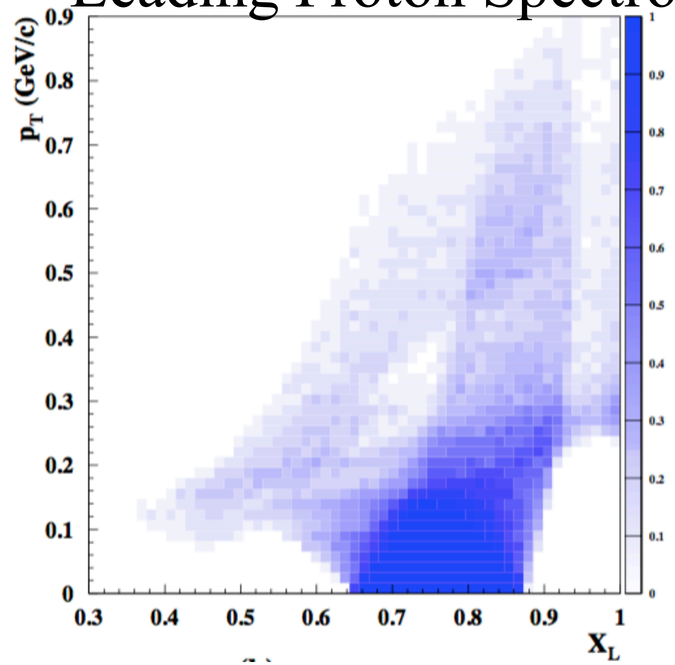
JLEIC





ZEUS

Leading Proton Spectrometer



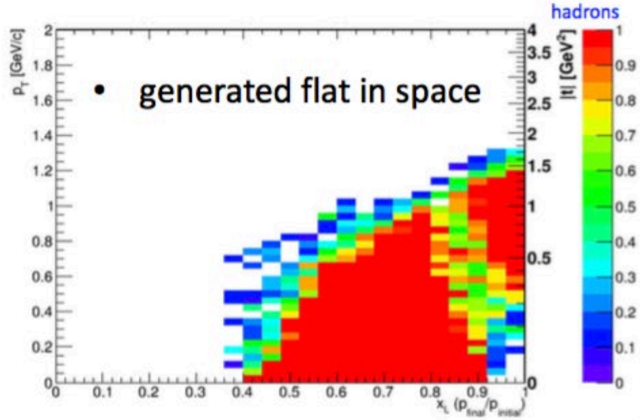
Acceptance in diffractive peak (X_L>~.98)

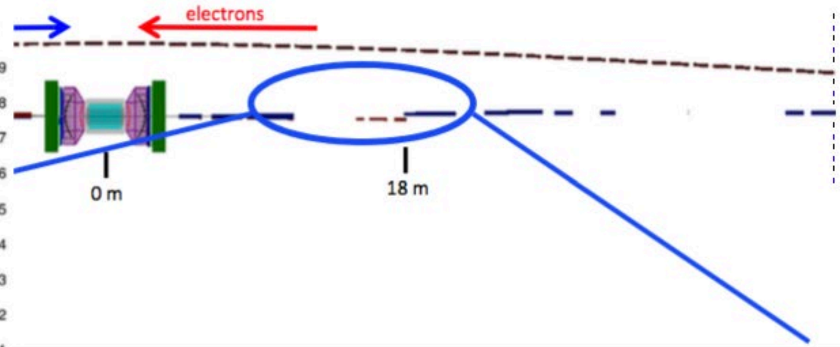
ZEUS: ~2%

JLEIC: ~100%

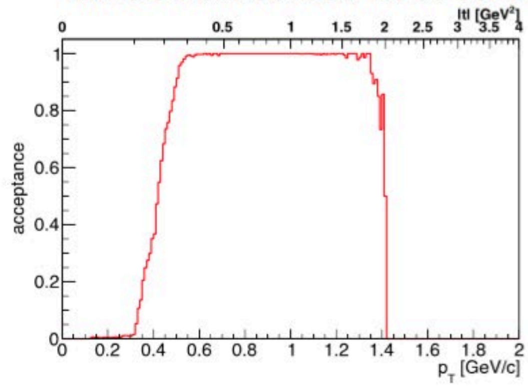
eRHIC Forward Hadron Detector

Auxiliary Detectors and the IR





- One station at ~20 m
- MILOU 20x250 GeV DVCS sent into sim

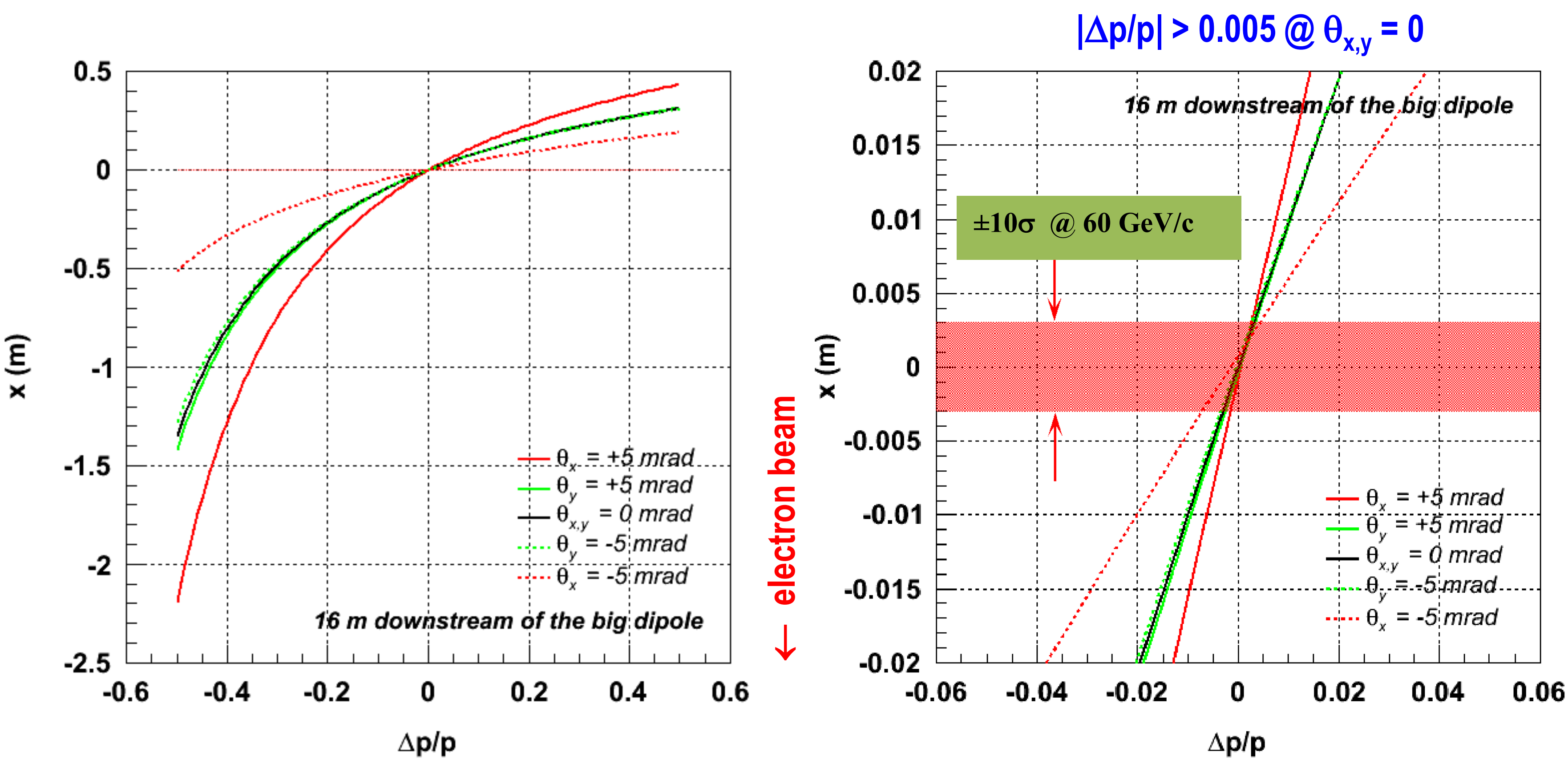


- Roman Pots
- Sensors integrated into the vacuum system
- Retractable to move into the beam after stable
- Allows to move sensors as close to beam as possible
  - Typically around 10sigma beam width
  - Defined by beam optics (beta function) at the location of the roman pot
  - Want small beta function with large dispersion to pull scattered protons out of the beam
- Ongoing R&D with machine developers to give access

Richard Petti Spin 2016

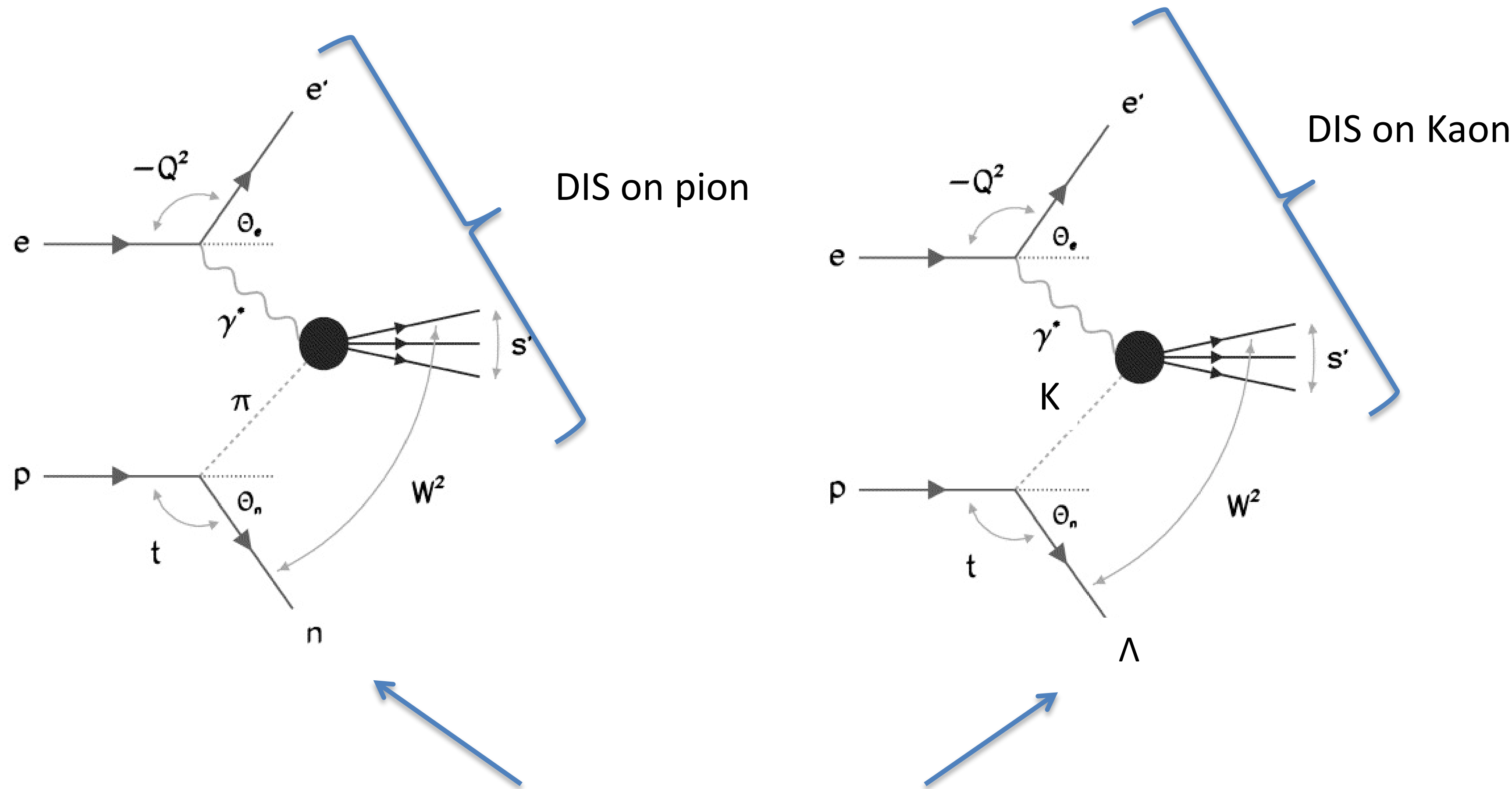
Forward Ion Momentum & Angle Resolution

- **Protons with Δp/p spread launched at different angles to nominal trajectory**



For ZEUS LPS: resolution in X_L was about 0.5% and Pt resolution was 5 MeV

Another example: Kaon and Pion Structure at an EIC



Need to measure these

Detection of $^{1}H(e,e'K^{+})\Lambda$

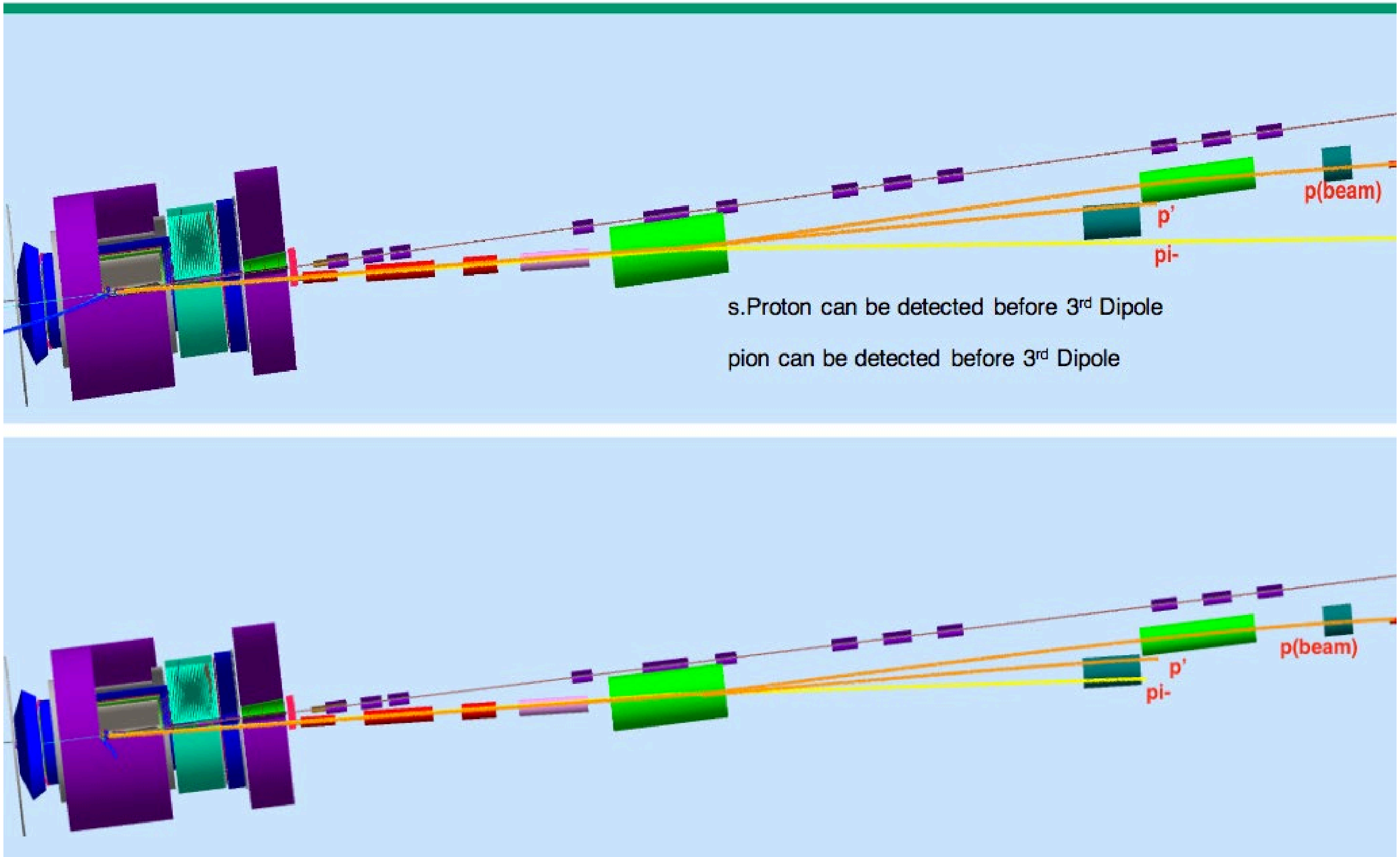
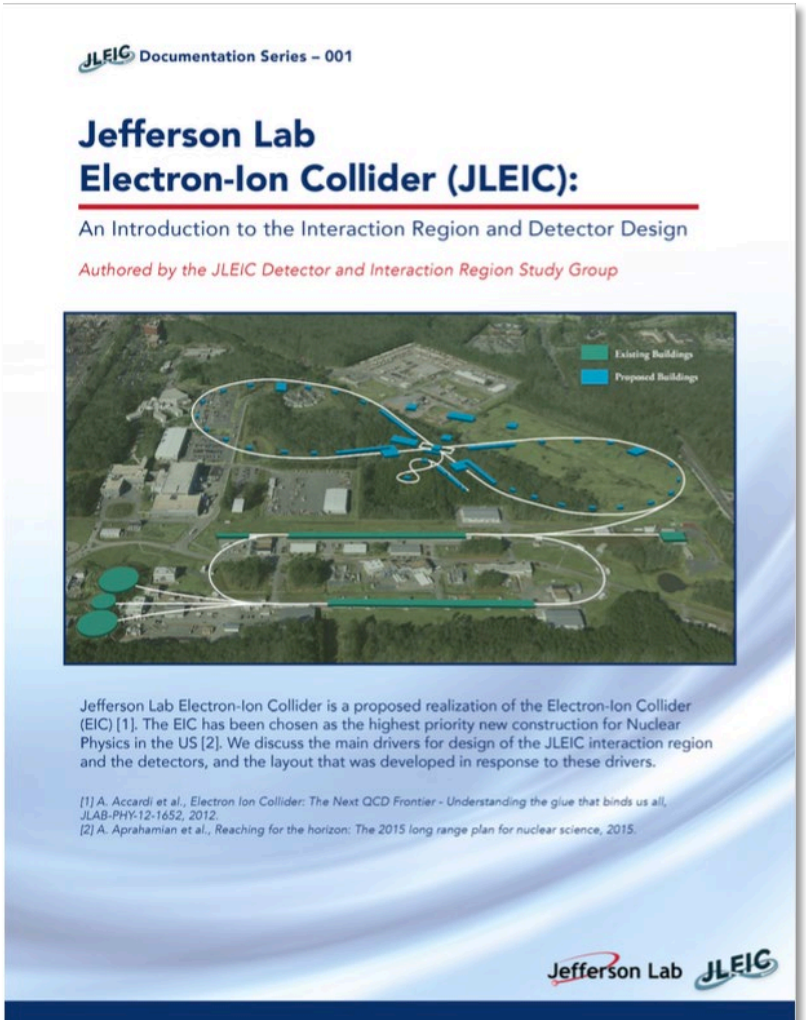


Figure from K.Park

12

How efficiently can we do this?

JLEIC Detector and IR Document



Can be found at the JLEIC Public Wiki page at: https://eic.jlab.org/wiki

This a short 9-page general introduction for people new to JLEIC.

More specific and detailed documents to follow.

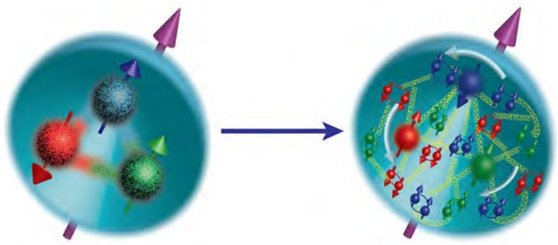
OTHER FACILITIES AND EIC PHYSICS TOPICS

Quark and Gluon Structure in 3D

EIC Science Goal

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

How do the nucleon properties emerge from them and their interactions?



Complementary measurements at other facilities.

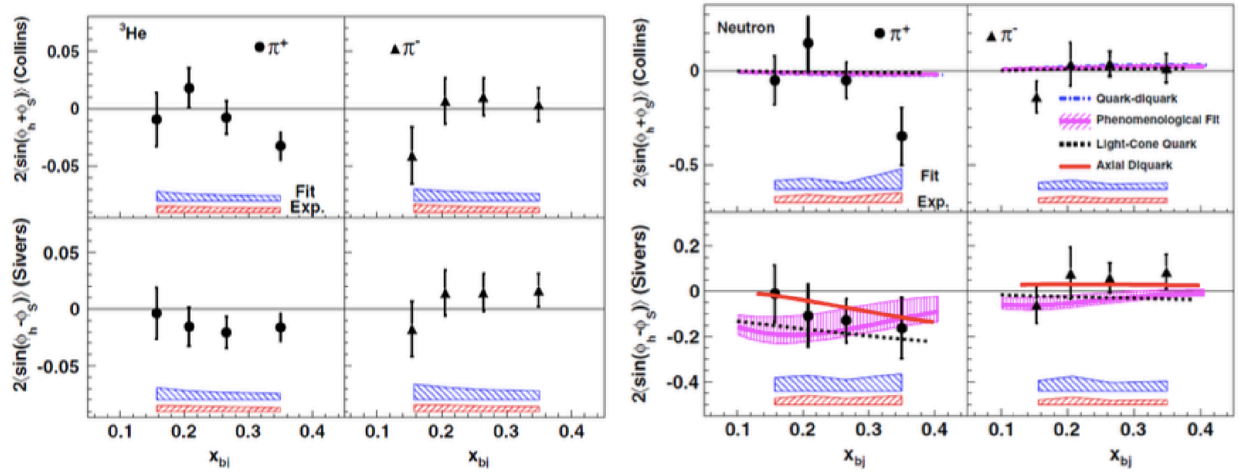
- **JLAB 12, COMPASS, *HIAF-EIC*: Measure at high x and lower Q^2 (1D & 3D)**
- ***LHeC, VHEeP, FCC-eh*: Measure at lower x (mainly 1D)**
- **LHC, HL-LHC, RHIC;**
  - **Ultra-peripheral collisions. mostly low $Q^2 \sim 0$, but high energy (1D & 3D)**
  - **Parton distributions using q-q, q-g or g-g interactions (mainly 1D)**

Other facilities are limited either in kinematic coverage or 3D measurement capability. They will be able to extend EIC data in certain kinematic regions.

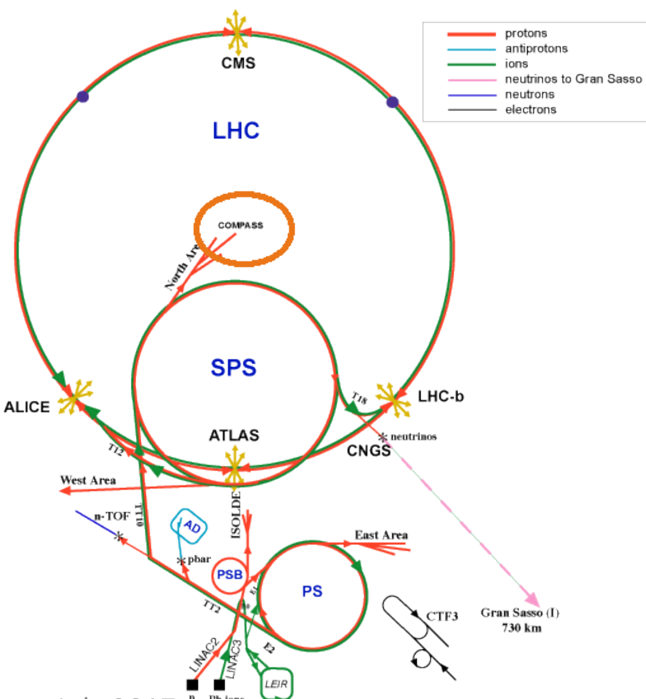
HIAF-EIC, LHeC, VHEeP, FCC-eh: Facility concepts

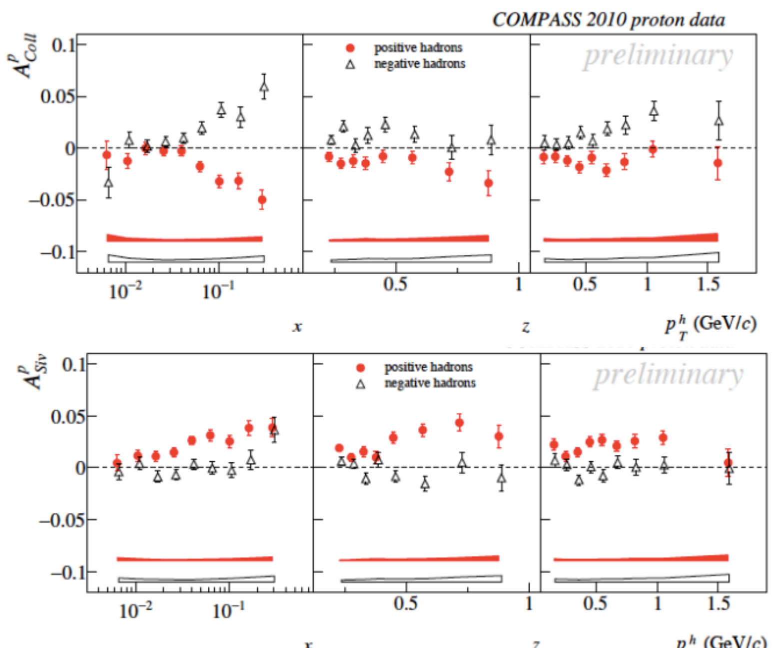
JLAB

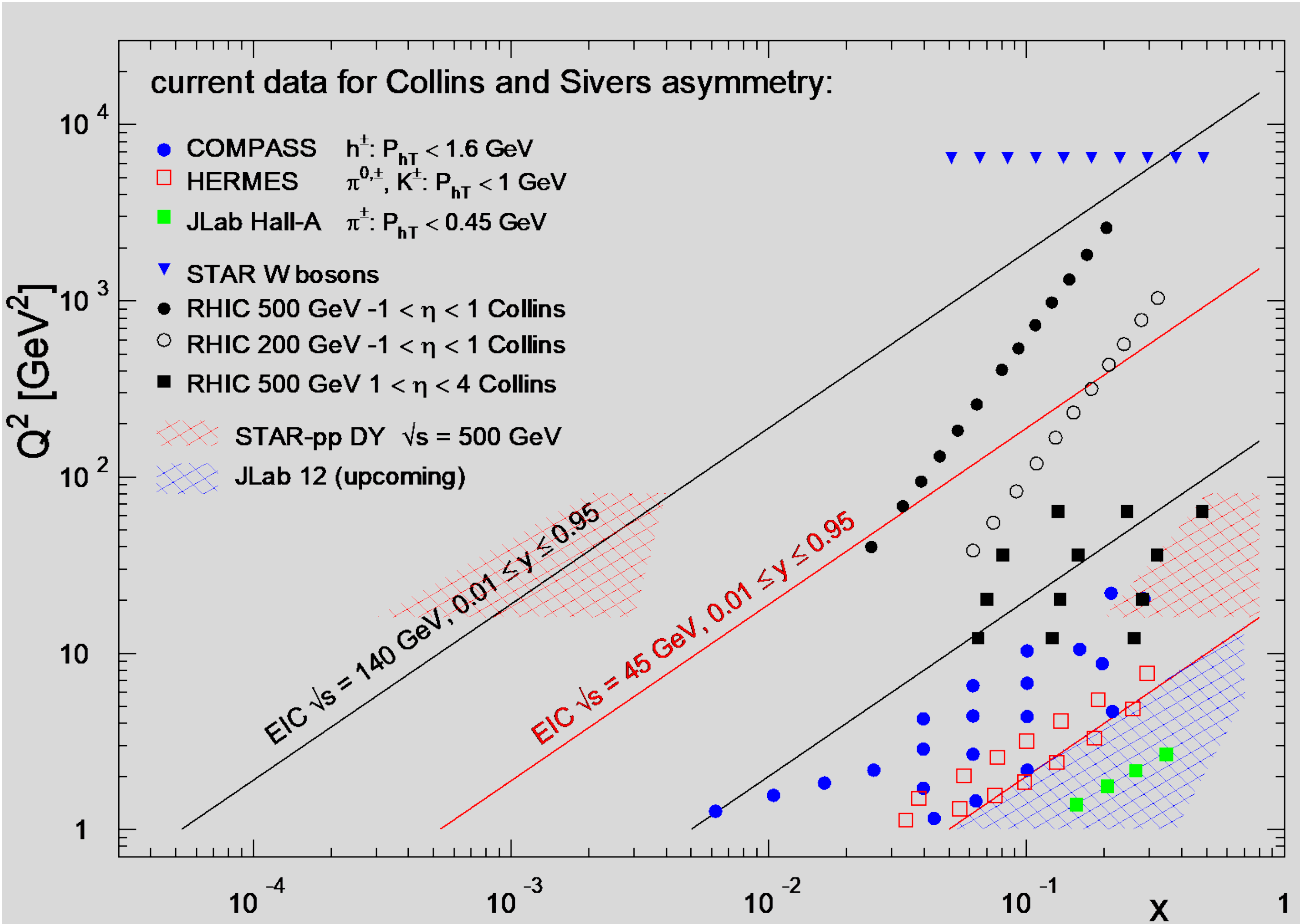
Collins and Sivers effects: *PRL 107, 072003 (2011)*



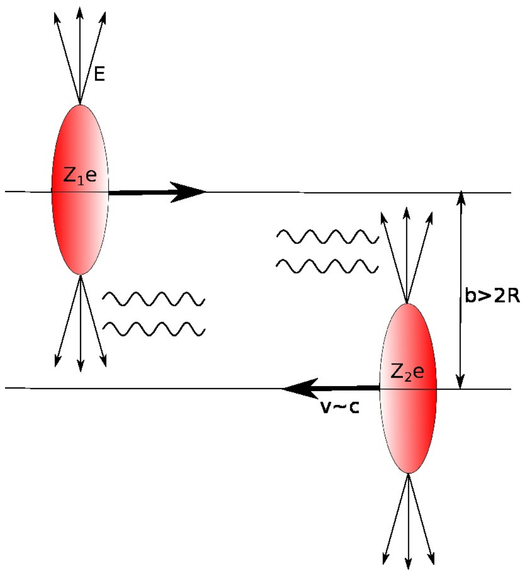
COMPASS

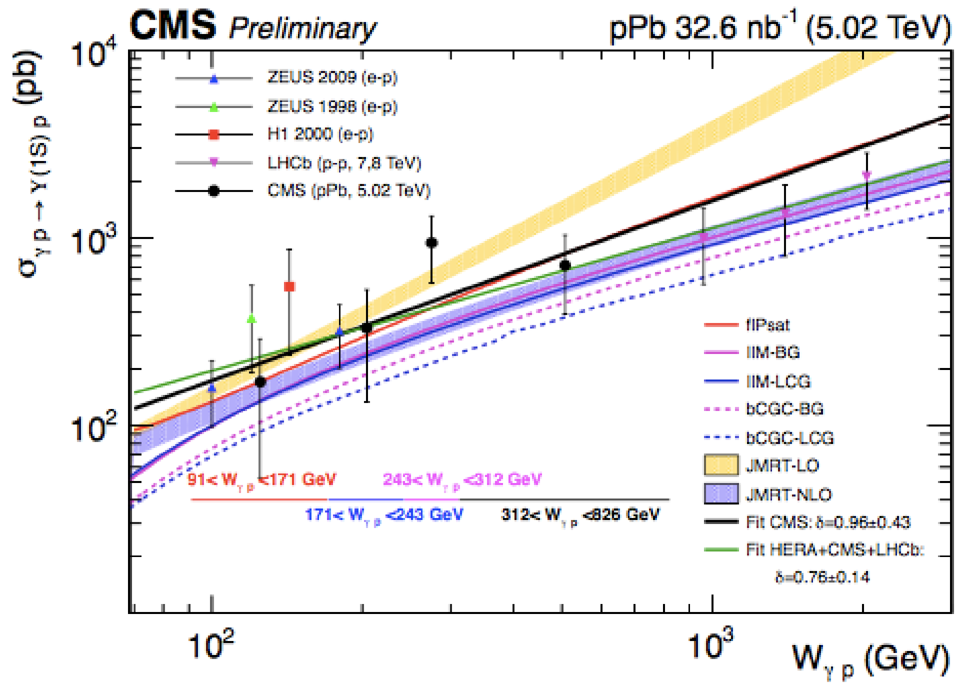





current data for Collins and Sivers asymmetry:
COMPASS h±: P_hT < 1.6 GeV
HERMES π0,±, K±: P_hT < 1 GeV
JLab Hall-A π±: P_hT < 0.45 GeV
STAR W bosons
RHIC 500 GeV -1 < η < 1 Collins
RHIC 200 GeV -1 < η < 1 Collins
RHIC 500 GeV 1 < η < 4 Collins
STAR-pp DY √s = 500 GeV
JLab 12 (upcoming)
EIC √s = 140 GeV, 0.01 ≤ y ≤ 0.95
EIC √s = 45 GeV, 0.01 ≤ y ≤ 0.95
Q2 [GeV2]
x
10 4
10 3
10 2
10
1
10 -4
10 -3
10 -2
10 -1
1

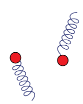
Ultra-peripheral Collisions





LHC pA and AA collisions.   RHIC

Propagation of Color in Cold QCD and Emergence of Hadrons



EIC Science Goal

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?

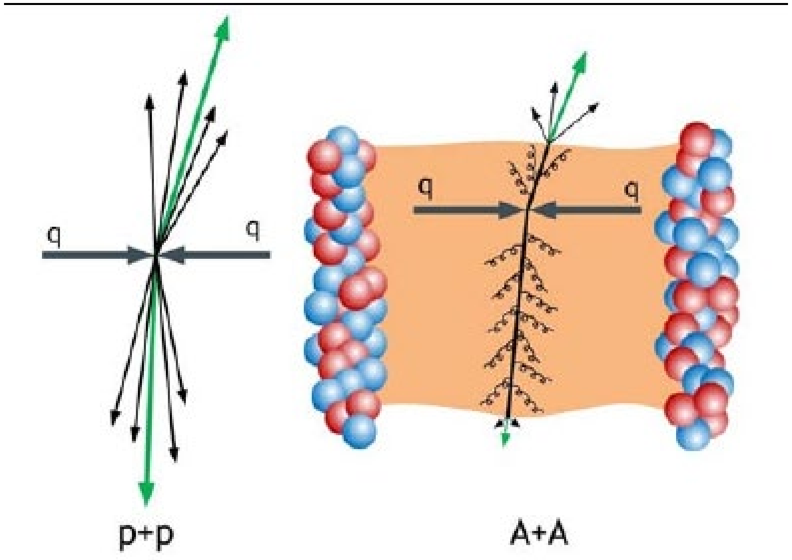
How do the quark-gluon interactions create nuclear binding?

Complementary measurements at other facilities.

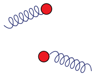
- **LHC, HL-LHC, RHIC: propagation of color in hot and cold QCD**
- **FRIB, ATLAS, FAIR, HIAF and other nuclear structure facilities:**
  - **Nuclear structure data complements and informs EIC measurements.**

The EIC science will build a bridge between hot and cold QCD as well as between low energy nuclear structure and quark-gluon structure of nuclei.

Jet Quenching in hot QCD vs cold QCD



EIC Only



How are these three different?

QCD at Extremes

EIC Physics Goal

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?

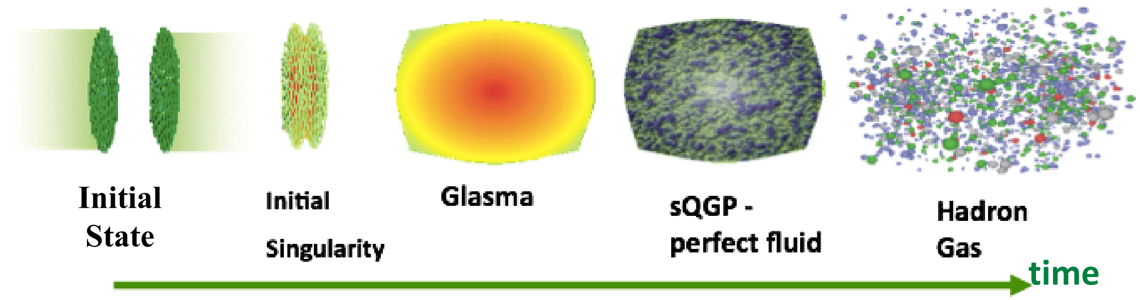
Complementary measurements at other facilities.

- **LHC, HL-LHC, RHIC:**
    - **study saturation in pA collisions: UPC, di-hadron correlations, open charm at forward rapidities (lower x) → universality**
    - **Effects of saturation on ion-ion collisions.**
- ***LHeC, VHEeP, FCC-eh*: Access lower x.**

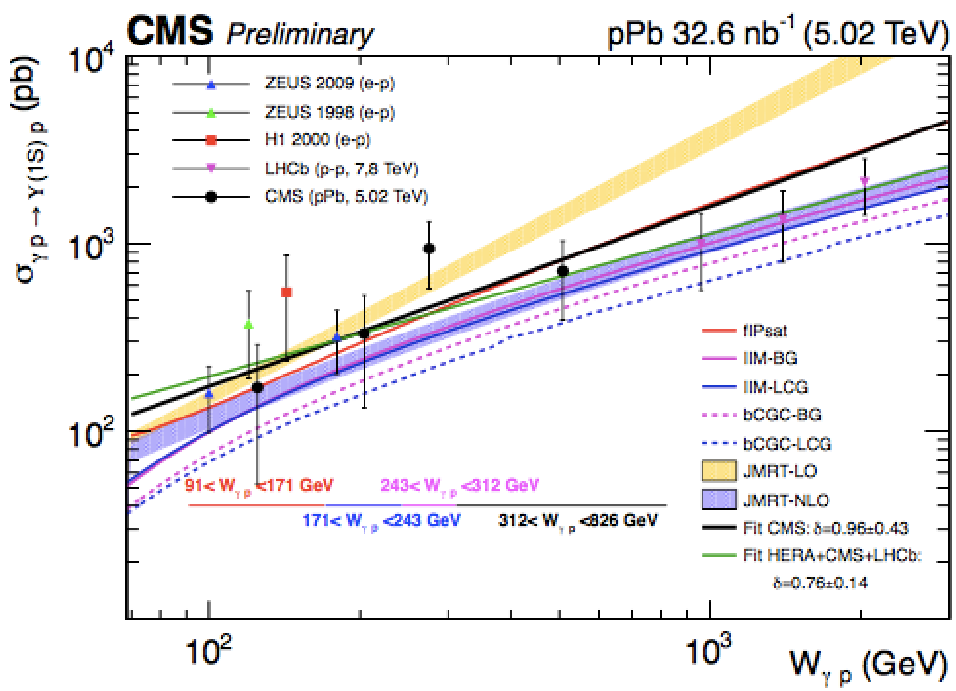
EIC studies the transition between a non-saturated and saturated regime with high precision, making use of a large range of nuclei and spin

LHeC, VHEeP, FCC-eh: Facility concepts

Saturation and heavy ions



Effects due to gluon saturation in HI collisions: particle production and distribution.

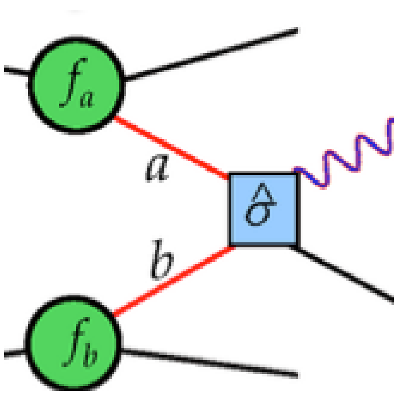


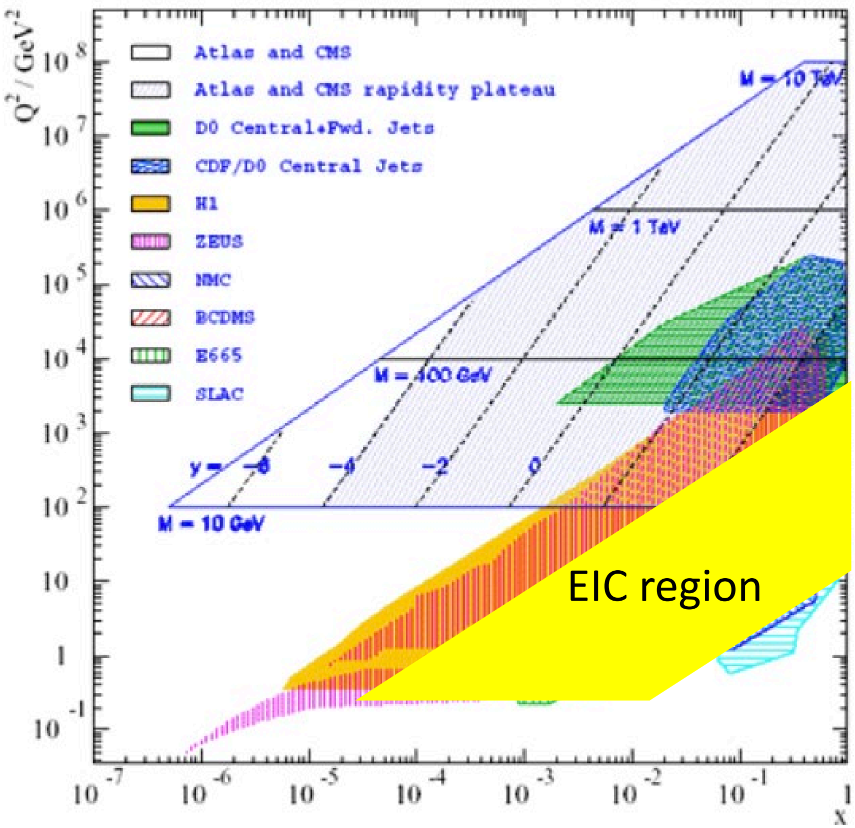
Also UPC probe low x

EIC AND PHYSICS TOPICS AT OTHER FACILITIES

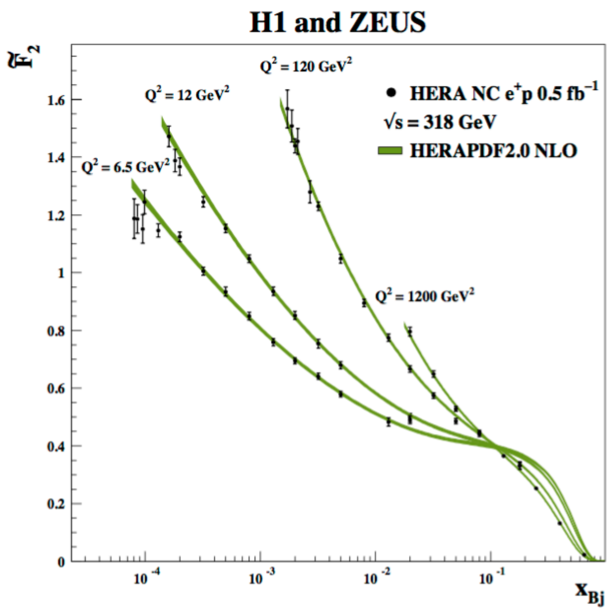
Search for Beyond the Standard Model at LHC (HL-LHC)

Collisions between high-x partons give the highest energy reach.

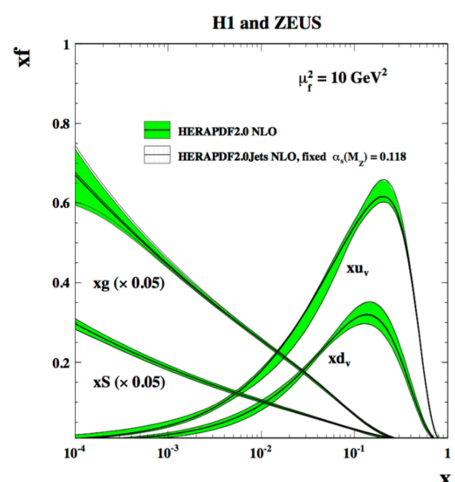




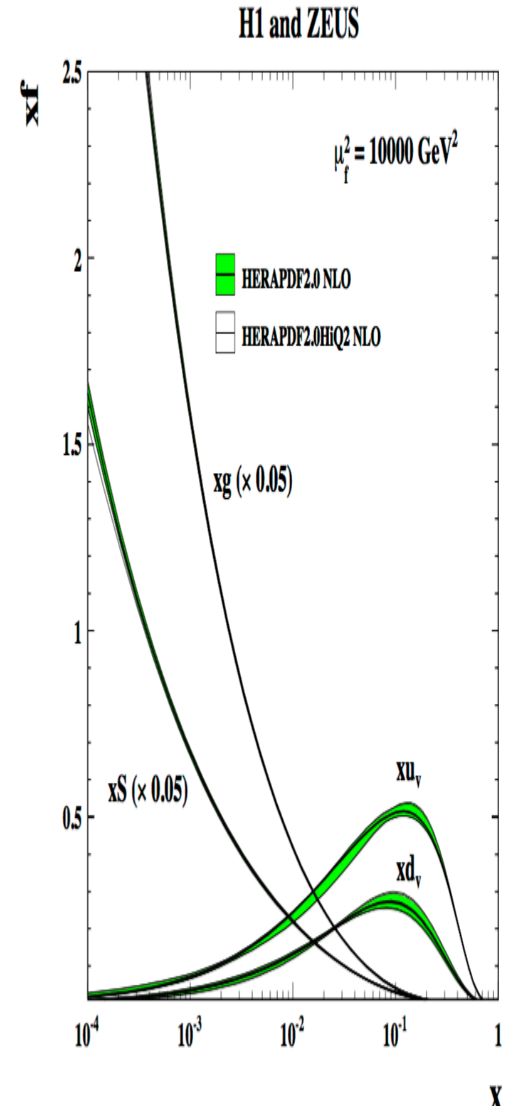
How this works



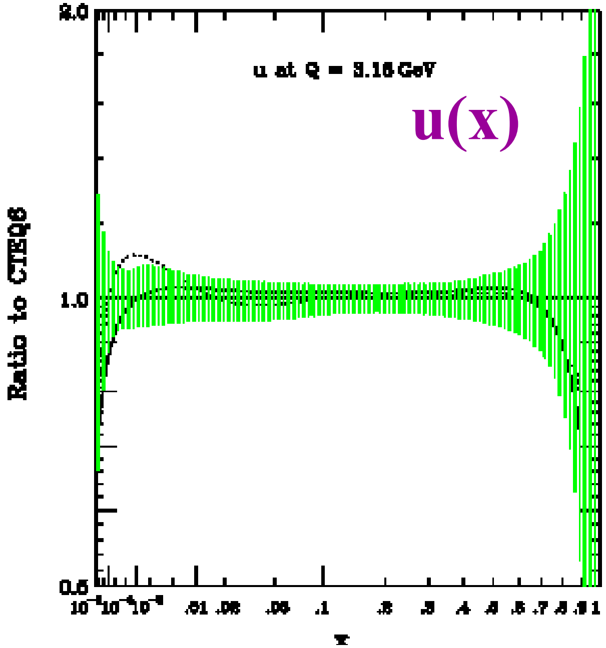
do a fit to get q_f and g

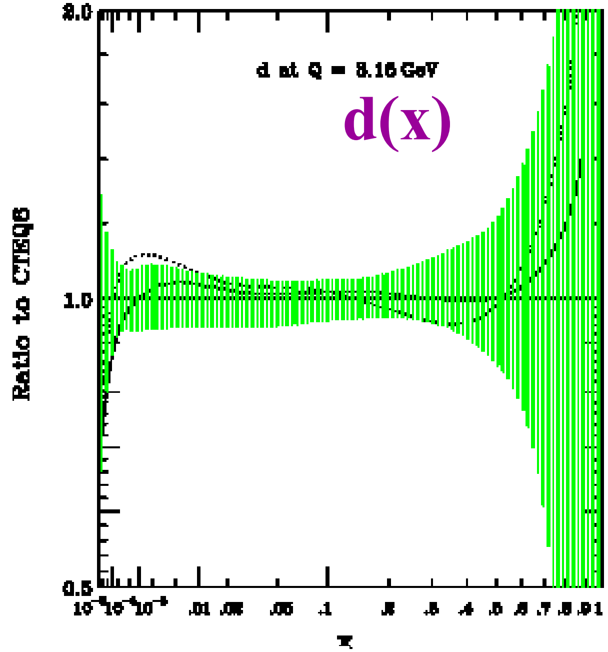


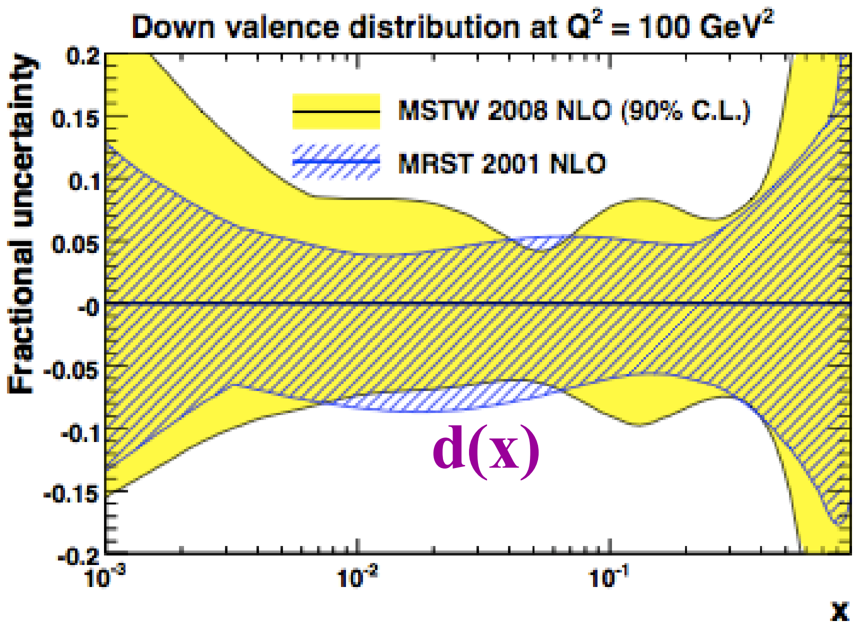
Q^2 (or μ^2) evolution

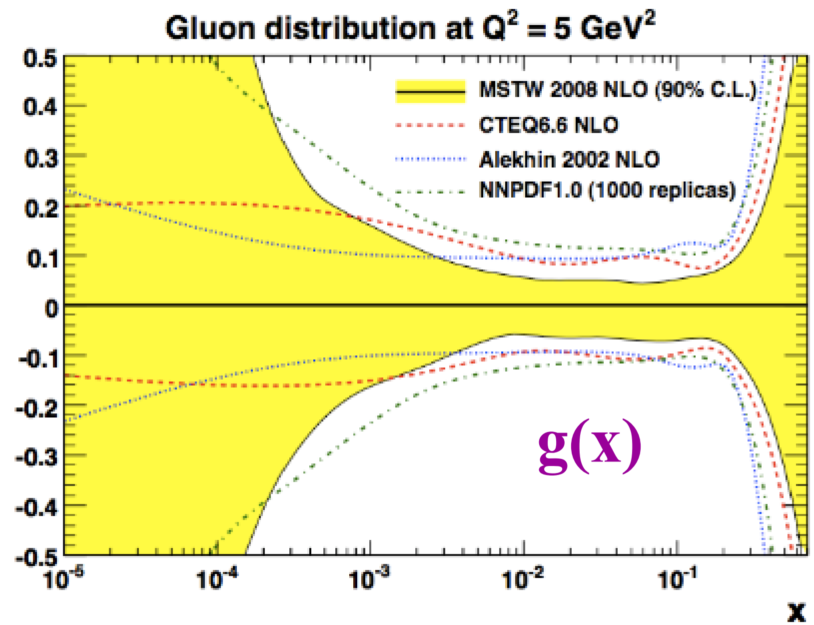


Large x (x > 0.05) -> Large PDF Uncertainties

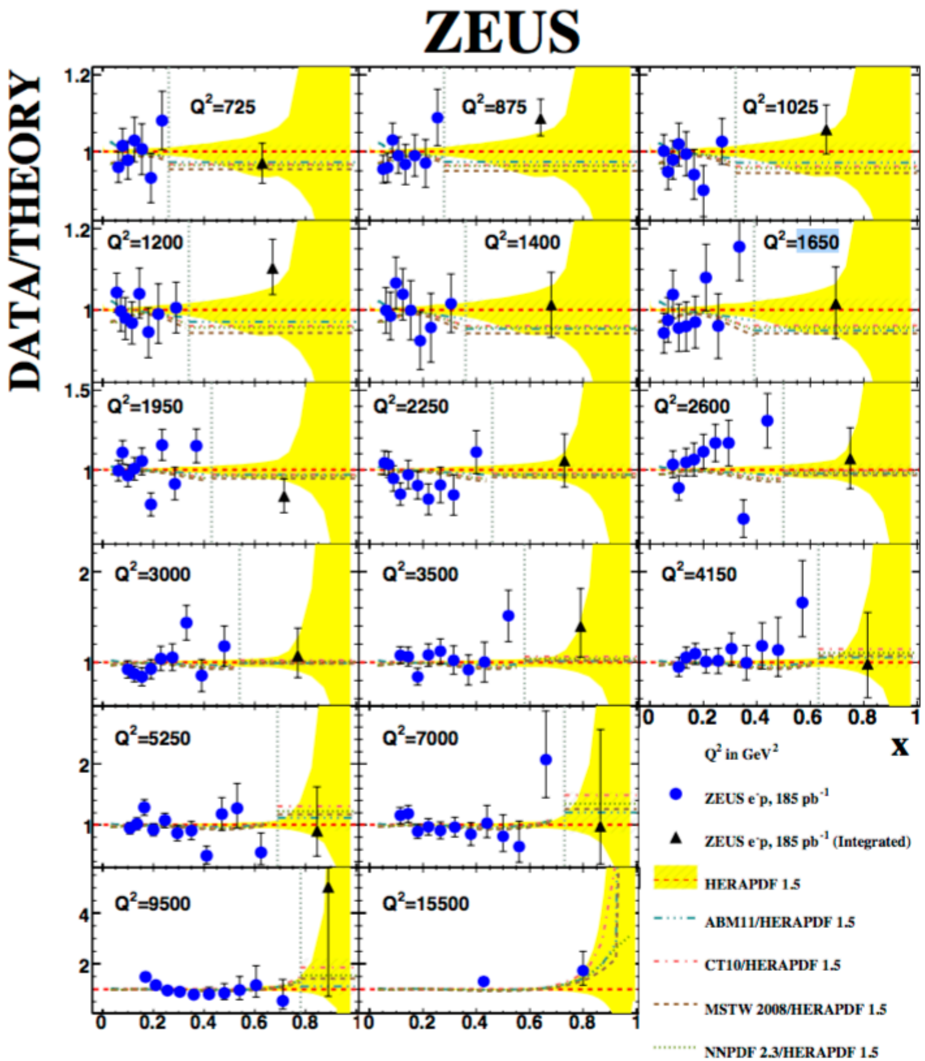


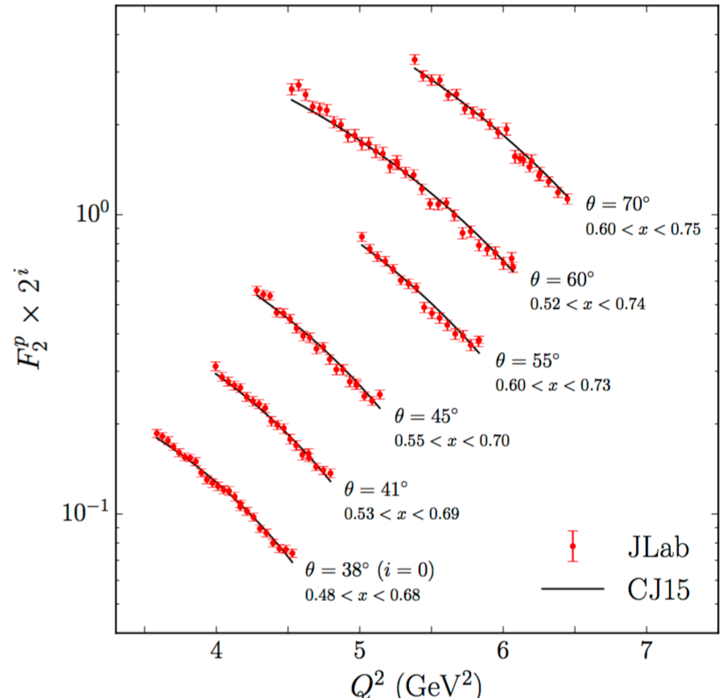






Existing High-x measurements

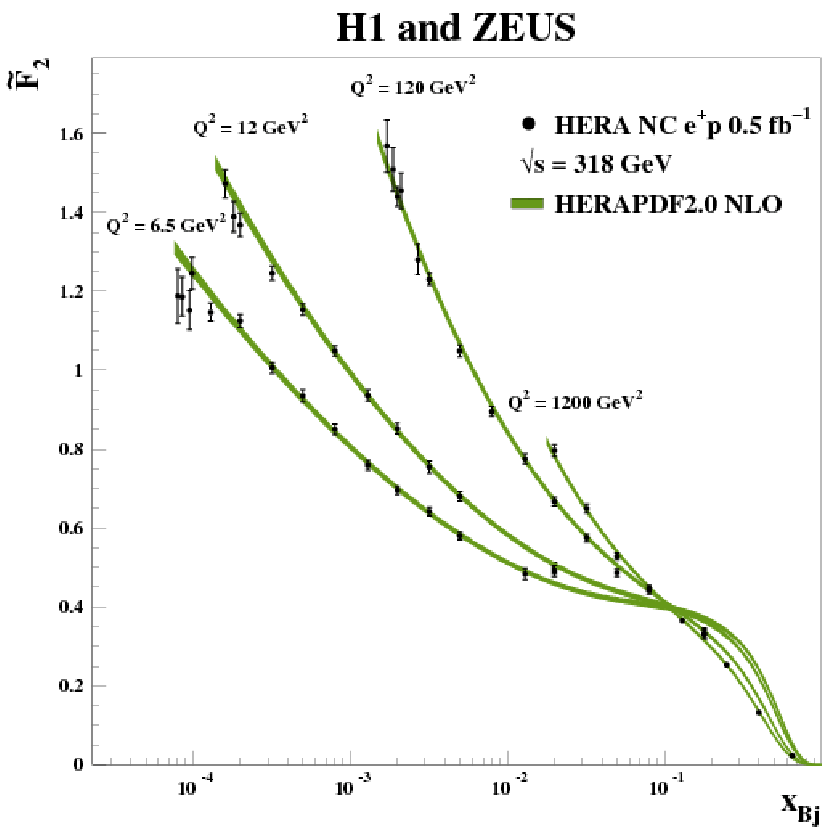


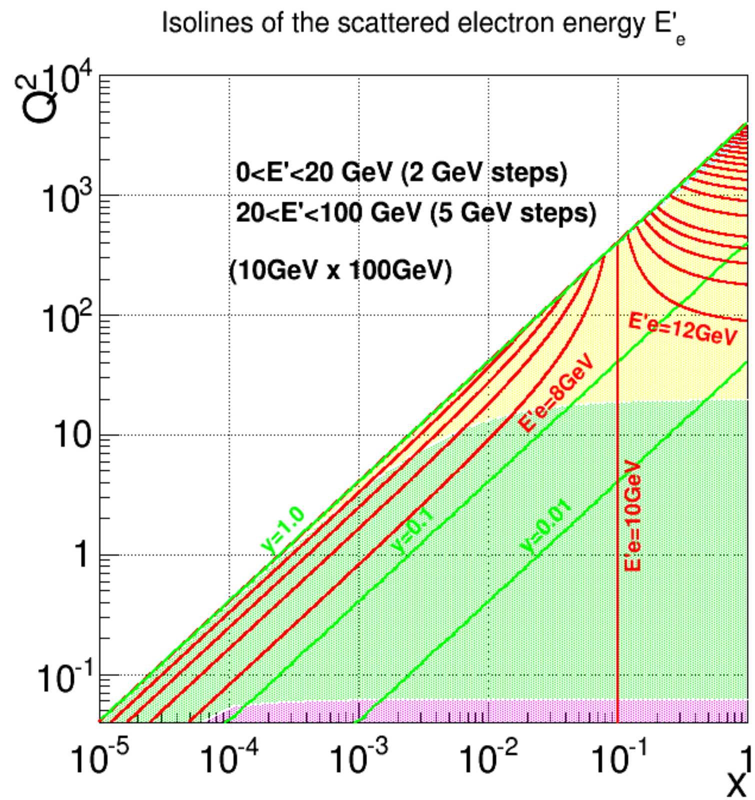


JLAB 12 measurements will push to higher Q^2 but…

Could EIC fill the high Q^2 (10-1000 GeV^2) high-x (>0.5) gap in the data with precision measurements?

Cross-sections



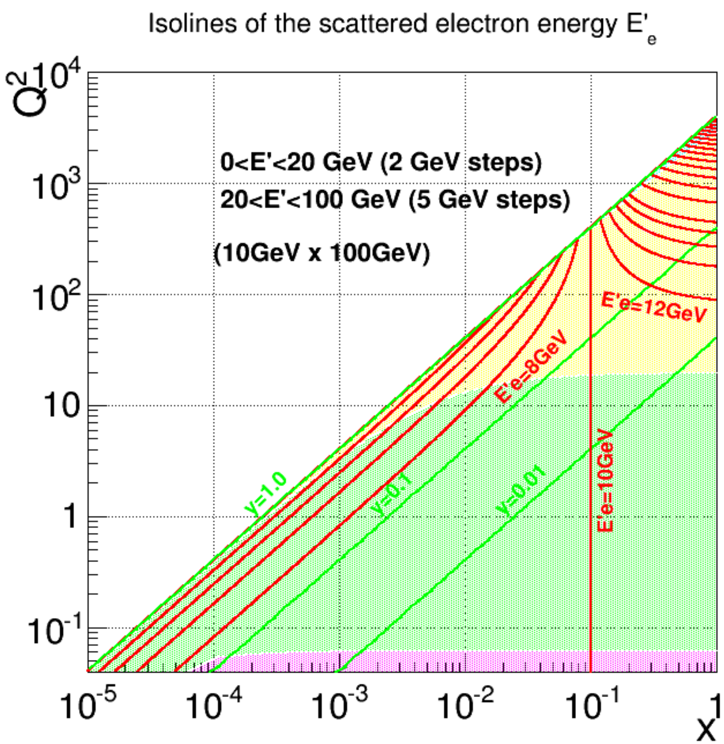


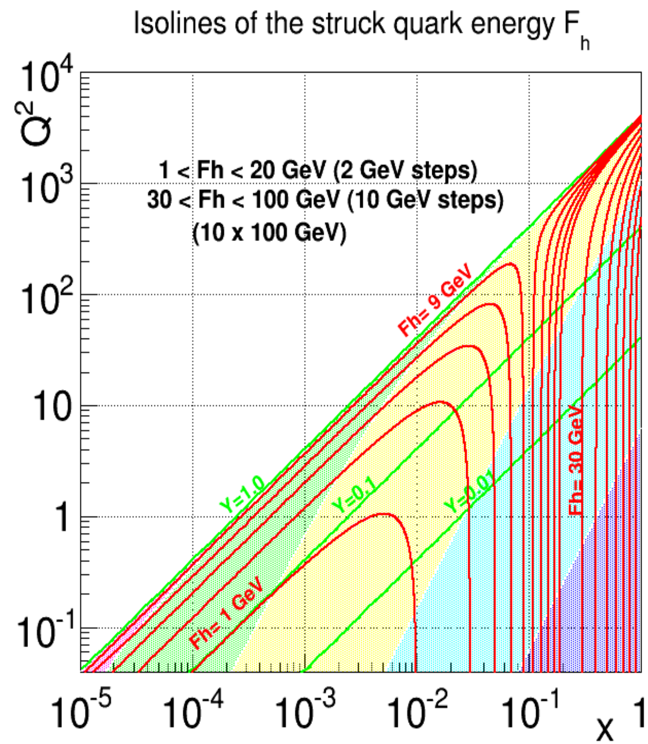
$1/Q^4$

$\sim(1-x)^3$

Best statistics at lower Q^2 (but must be "high enough") ➔ Low y

Resolutions





$$\left.\frac{\partial x}{x}\right|_{E_e} = \frac{1}{y}\frac{dE_e}{E_e}$$

$$\left.\frac{\partial x}{x}\right|_{F_h} = \frac{1}{(1-y)}\frac{dF_h}{F_h}$$

Resolutions

Say, Q^2 = 20 GeV^2, x= 0.7 (y=0.01)

$$\left.\frac{\partial x}{x}\right|_{E_e} = \frac{1}{y}\frac{dE_e}{E_e}$$

if dE/E = 1%, then dx/x = 100%

$$\left.\frac{\partial x}{x}\right|_{F_h} = \frac{1}{(1-y)}\frac{dF_h}{F_h}$$

if dF/F= 10% then dx/x = 10.1%

.. need jet energy resolution of ~85%/√F

Need to measure jet energies (forward calorimeters)?
How precisely?
Lower E_p?

Questions you might ask..

- What is the measurable range?
  - What are the resolutions really needed?
  - How low in the jet angle can we measure?
- What is the relation between
  - Luminosity available
  - Acceptance
  - Optimum beam energies (more than one?)
  - Measurement technique
- What is the right detector technology for this measurement?
- Can we optimize for the high-x and also for other measurements at the EIC with the same detector?

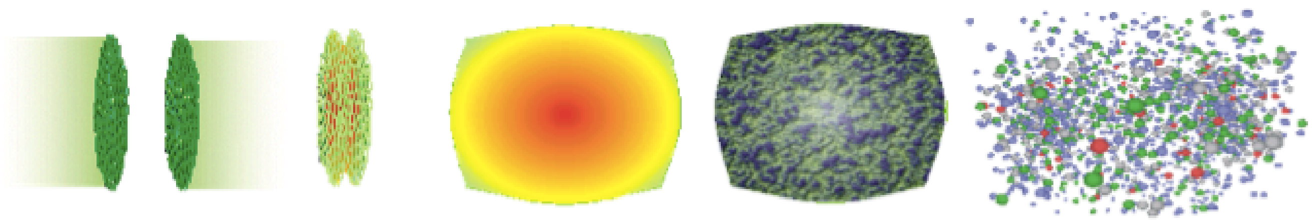
Physics Beyond the Standard Model

- Discovery of BSM physics at LHC (or any other energy frontier machine, e.g. FCC, or SppC) means looking for:
  - σ_{SM}(PDF(hadron 1), PDF(hadron 2)) $\neq \sigma_{measured}$
    - The mass reach of the search becomes higher as x→1 for the PDFs.
    - Uncertainty in the knowledge of Parton Distribution Functions (PDFs) limits the reach of the search.
    - LHC (or any other similar machine) cannot disentangle PDF from new physics—using its own measurements.
- Complementary measurements at EIC:

  EIC can measure PDFs at high-x relevant for LHC searches at a lower $\sqrt{s}$ where it is known that physics obeys SM.

EIC has the potential to considerably extend the discovery reach of the LHC, HL-LHC and other frontier energy machines with a precise measurement of PDFs at high-x.

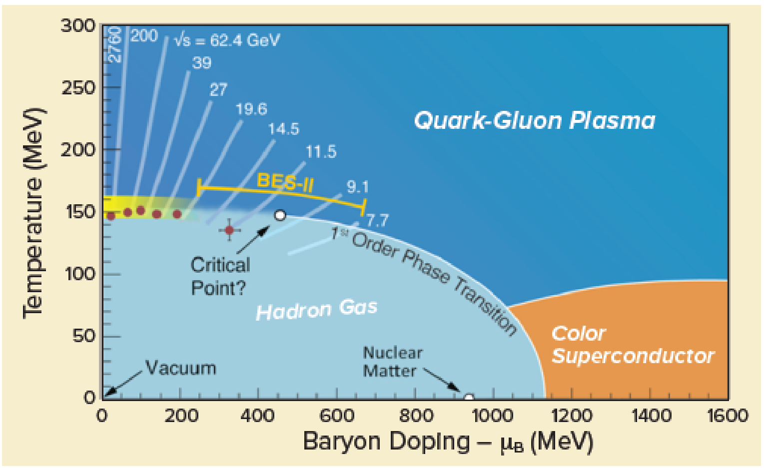
Quark-Gluon Plasma



Initial State | Initial Singularity | Glasma | sQGP - perfect fluid | Hadron Gas

time

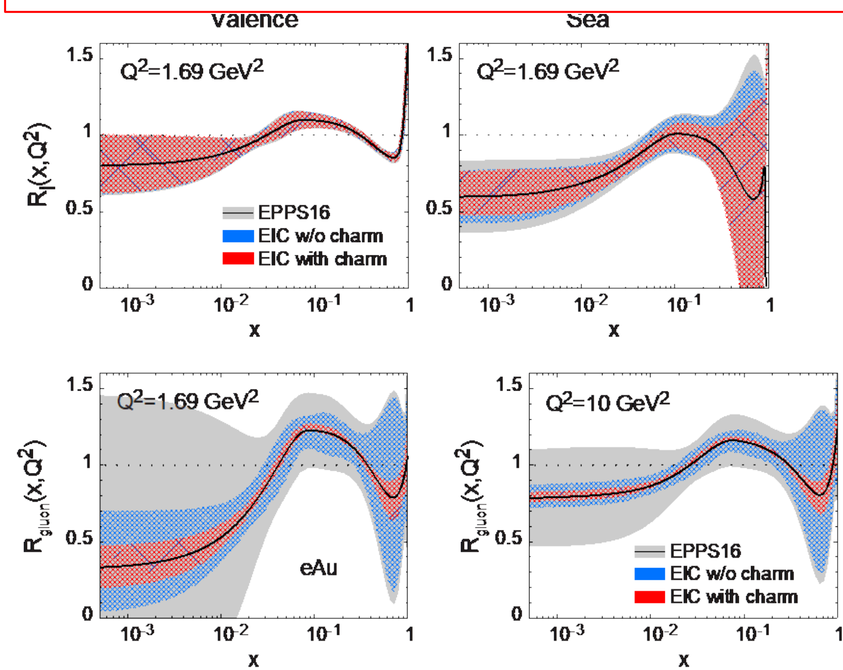
What is the initial State?

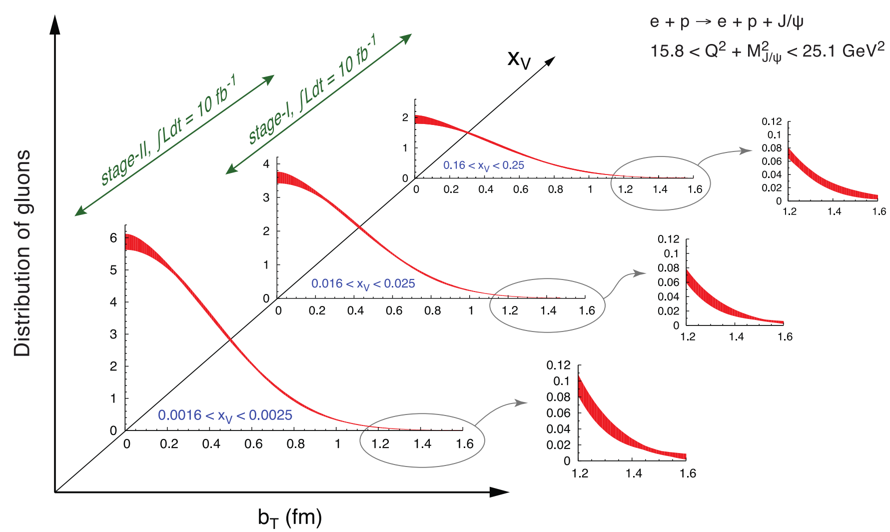


Quark-Gluon Plasma

Our understanding of fundamental properties of the Glasma, sQGP and Hadron Gas depend on our knowledge of the initial state!

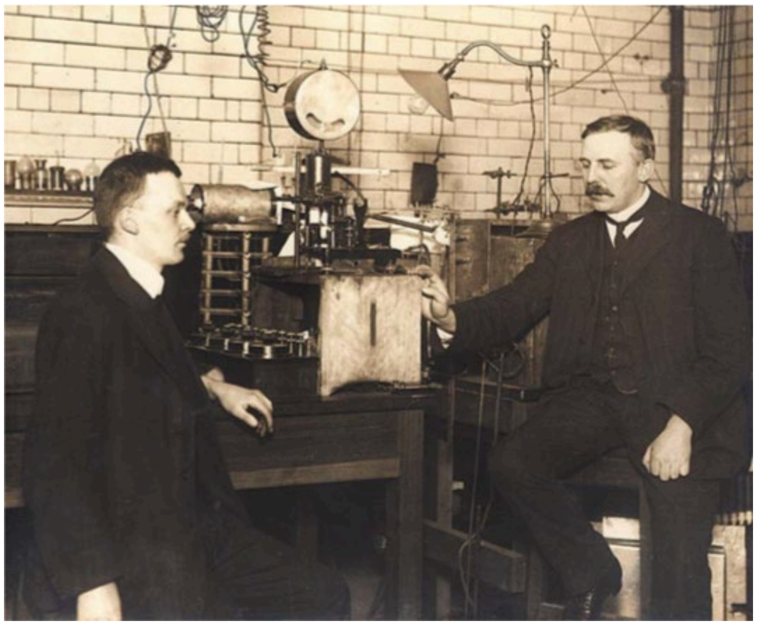
EIC: Measure nuclear PDFs and map out quark and gluon structure in 3D.

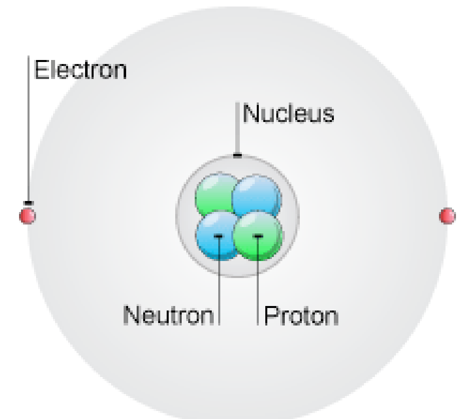




FUTURE OF NUCLEAR PHYSICS AND THE EIC

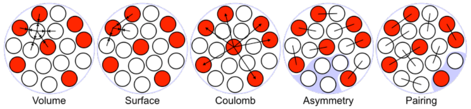
Where it began.

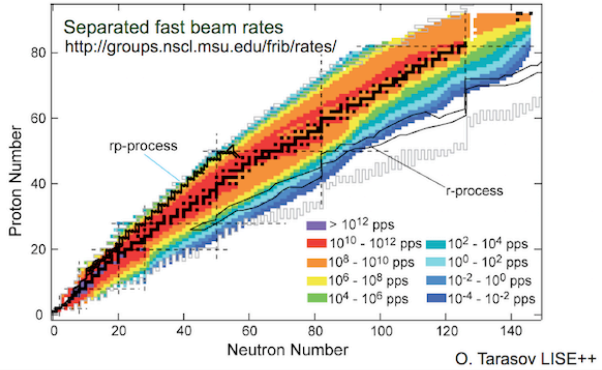


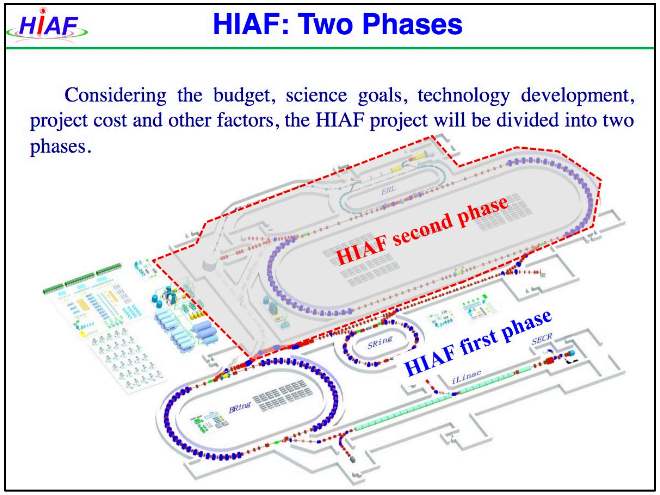


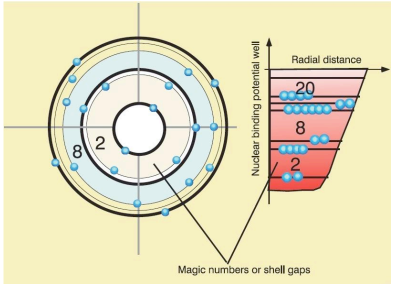
Nuclei made of protons and neutrons

Leads to effort to understand Nuclei in terms of NN interactions: Nuclear Structure Theory





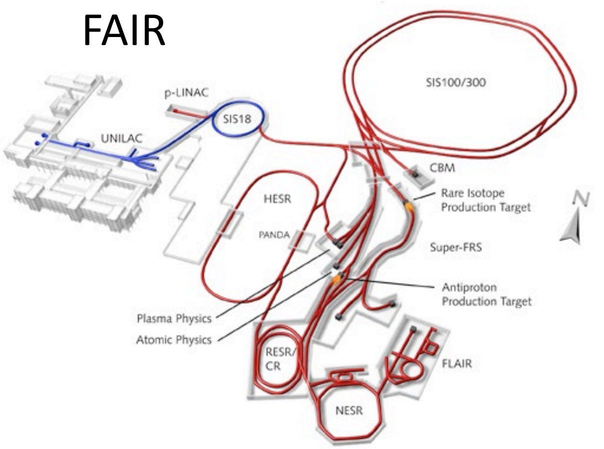




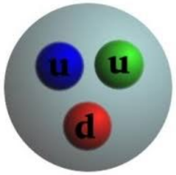
Low –energy nuclear facilities coming on line in the next decades

FRIB

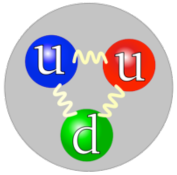
FAIR



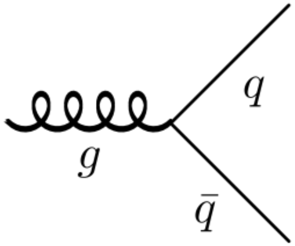
QCD and nucleons



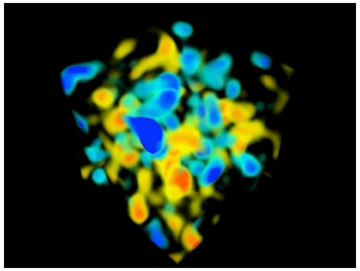
Quark Model: hadrons are made of quarks.



Quantum Chromodynamics: theory of quark and gluon interaction.



QCD is a strongly interacting theory except at short distances..
perturbative QCD: ok at short distances

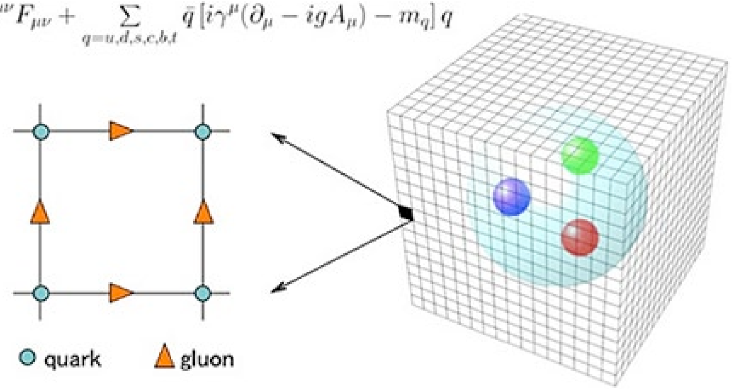


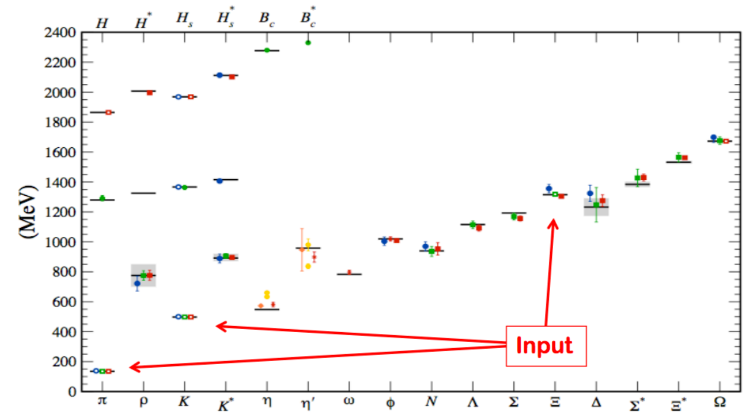
But nucleon size is long-distance in this scale:
perturbative theory (on it's own)
cannot tell us about how nucleons
come about from quarks and gluons.

Lattice QCD: one way to work with strong-coupling

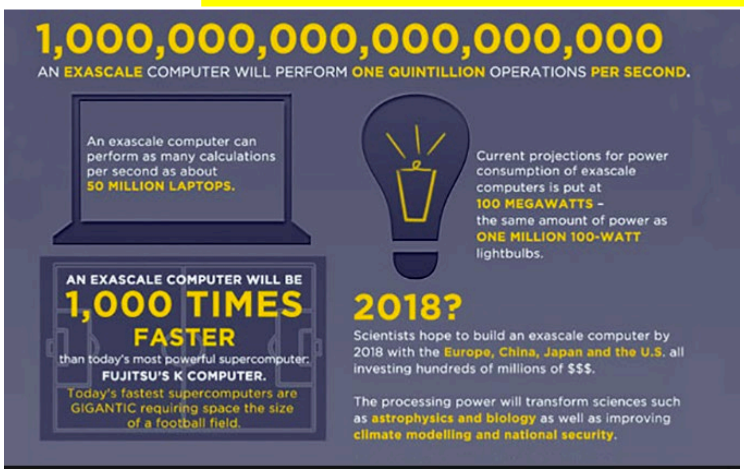
QCD Lagrangian

$$\mathcal{L} = -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \sum_{q=u,d,s,c,b,t} \bar{q}\left[i\gamma^{\mu}(\partial_{\mu} - igA_{\mu}) - m_q\right]q$$

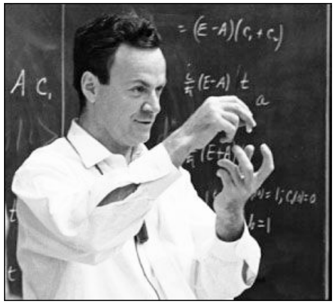




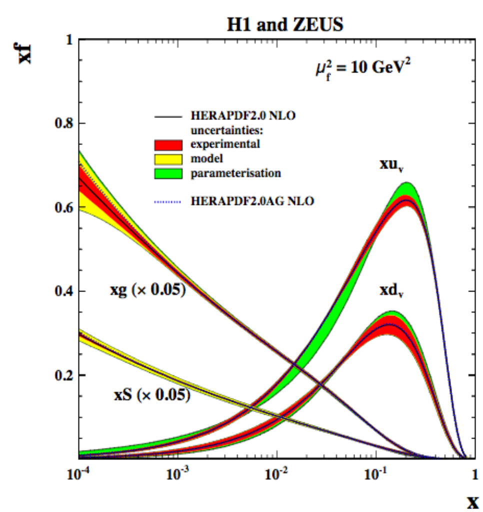
EXASCALE Computing is coming in the next decade

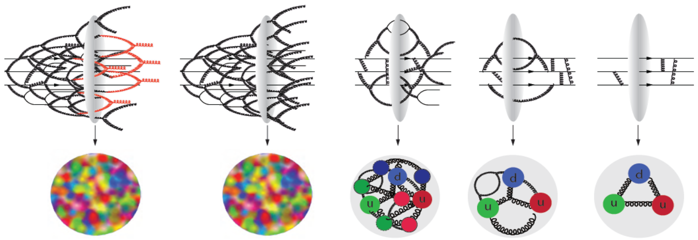


Longitudinal PDFs

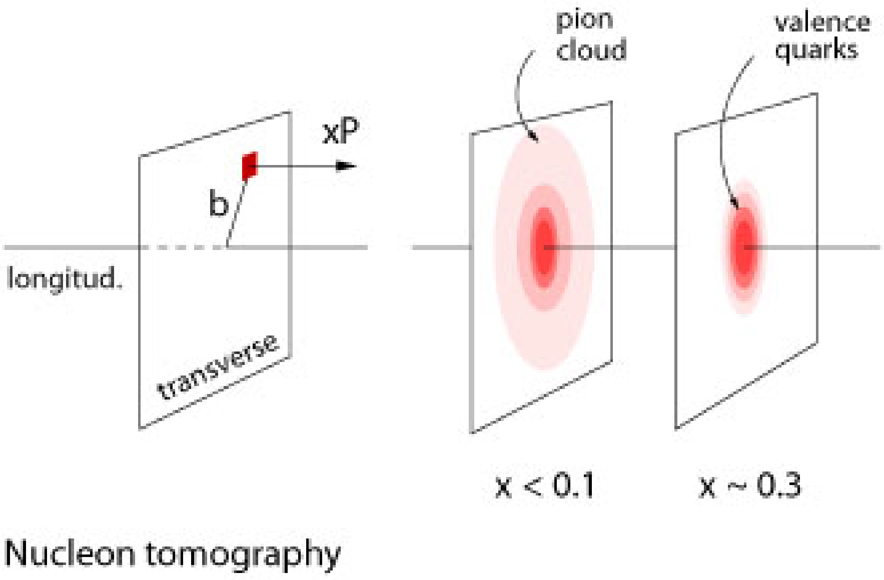


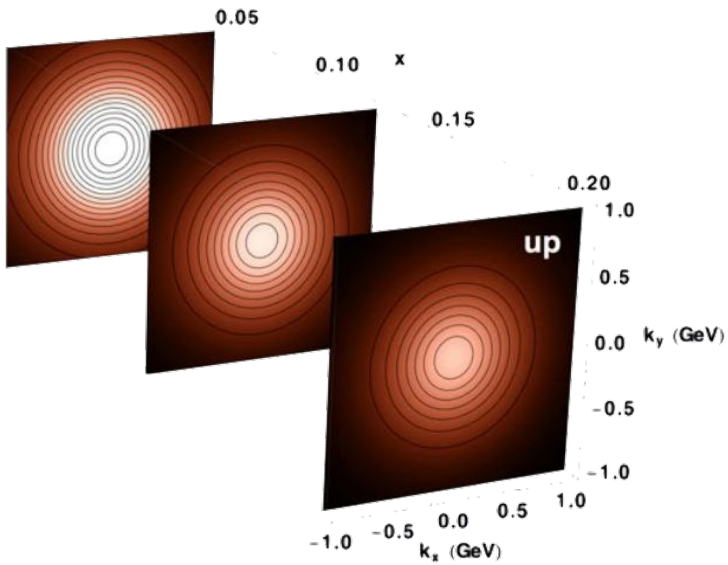
- Feynman’s parton model
- Asymptotic freedom → pQCD
- Factorization allows measurement to extract non-perturbative PDFs.
- However: incomplete as a description of the proton





3D structures of nucleons and nuclei is a new frontier (at JLAB 12 and elsewhere)

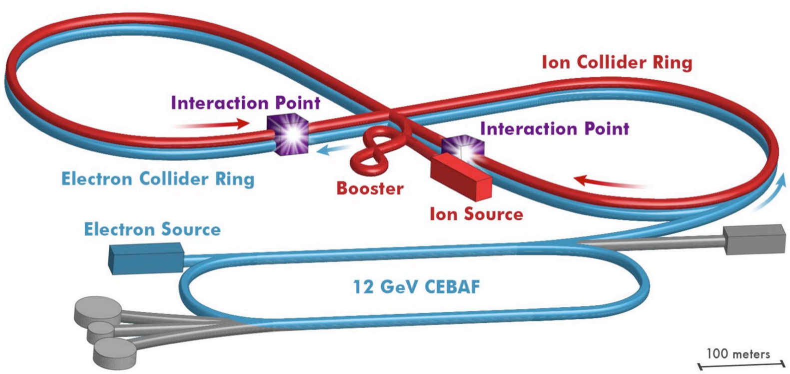


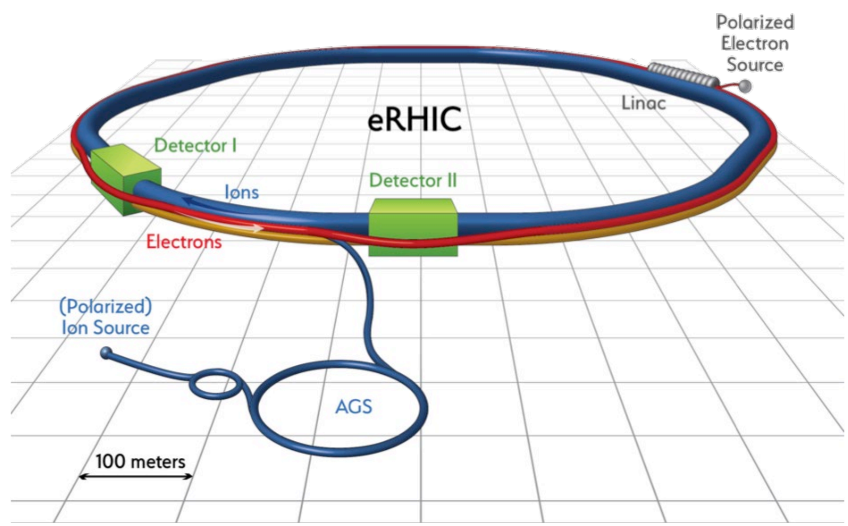


- Enabled by theoretical developments → TMD, GPD, Factorization II

Electron-Ion Collider

- We know the right kinematic region to measure the quark and gluon structures of nucleon and nuclei.
- The advances in accelerator technologies (and existing infrastructure) enable us to build an EIC, with the right characteristics in the US.

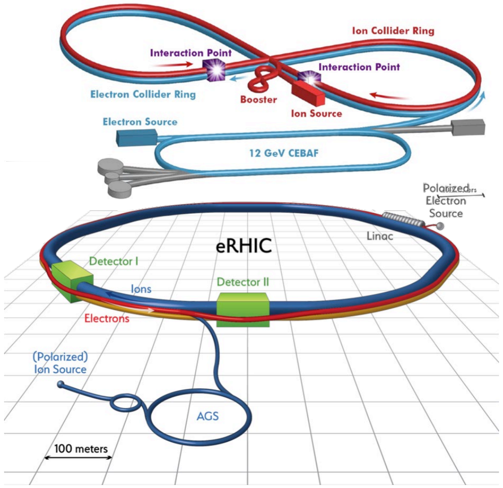




Timescale: ~2025-2030

Nuclear Physics Research Landscape: ca. 2030

EIC/ Quark-gluon Structure

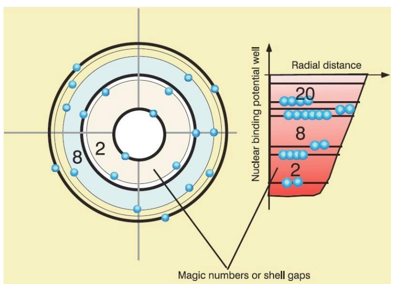


FRIB/Nuclear Structure Science

LQCD

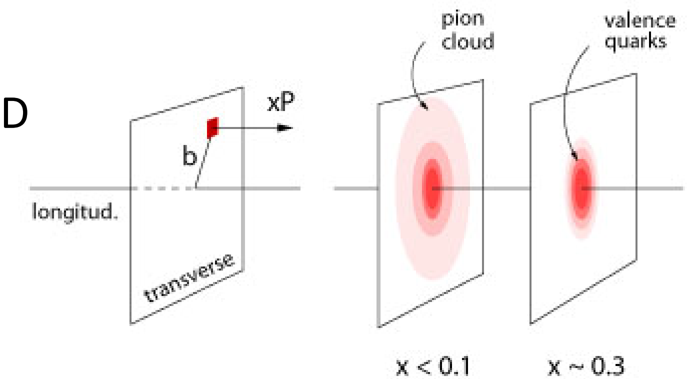
Three powerful tools
to understand nuclear matter

Towards a unified description of nuclear matter?

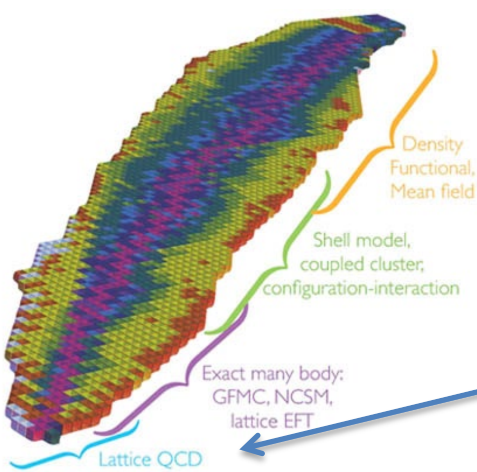


Nuclear Structure

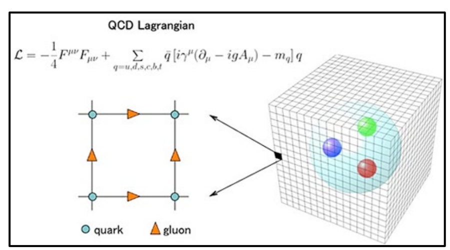
pQCD



Nucleon tomography



LQCD



Structure Functions

A Goal of Nuclear Physics

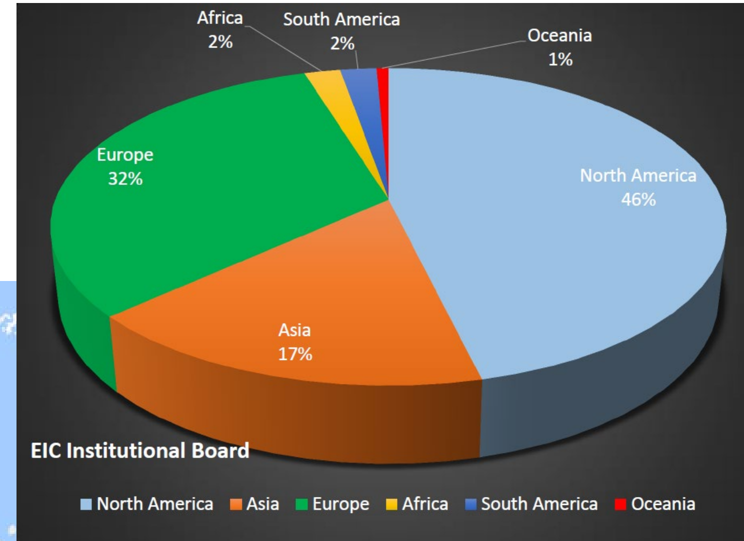
- **To understand the nucleus, nuclei and QCD at the same level at the least as we understand atoms and electromagnetism.**
- Nuclear Physics Community has started this quest in three different ways.
  - Nuclear structure theory and low energy nuclear physics.
      - FRIB, FAIR …
  - Lattice QCD
      - Exascale Computing
  - Perturbative QCD and partonic quarks and gluons
    - Quark-gluon plasma and hot QCD
      - RHIC, ALICE
    - Quark-gluon structure of cold QCD
      - JLab12
- In the end, all of three ways need to be reconciled in order to achieve our goal.
- Progress in pQCD Theory → JLAB 12 and other program starts this reconciliation.
- EIC makes the exploration of all relevant regions possible.

Worldwide Interest in EIC Physics

The EIC Users Group: EICUG.ORG

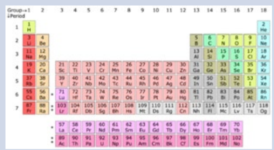
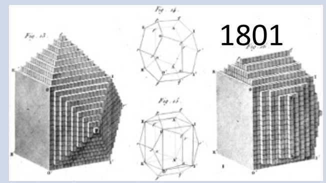
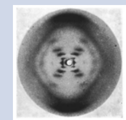
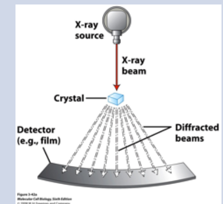
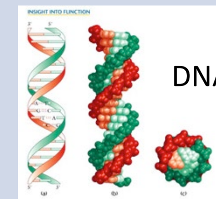
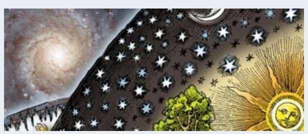
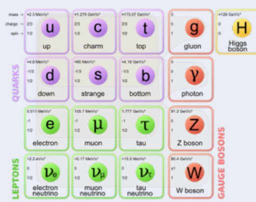
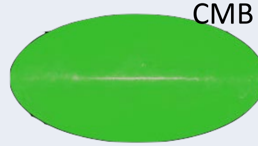
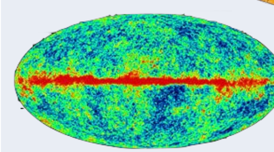
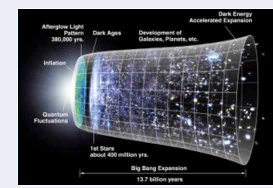
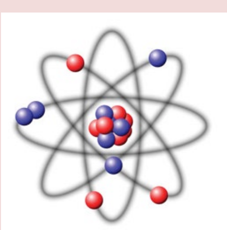
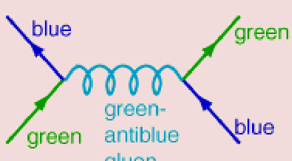
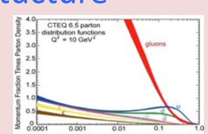
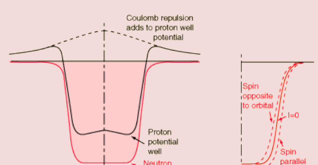
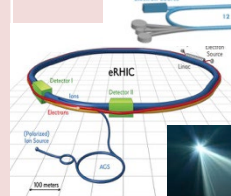
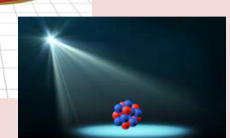
(no students included as of yet)

692 collaborators, 29 countries, 157 institutions... (June 7, 2017)



EPILOGUE

EIC: A Portal to a New Frontier

Dynamical System	Fundamental Knowns	Unknowns	Breakthrough Structure Probes (Date)	New Sciences, New Frontiers
Solids 	Electromagnetism Atoms 	Structure  1801	X-ray Diffraction (~1920)  	Solid state physics Molecular biology 
Universe 	General Relativity Standard Model 	Quantum Gravity, Dark matter, Dark energy. Structure  CMB 1965	Large Scale Surveys CMB Probes (~2000)  	Precision Observational Cosmology 
Nuclei and Nucleons 	Perturbative QCD Quarks and Gluons $\mathcal{L}_{QCD} = \overline{\psi}(i\partial\!\!\!/ - gA\!\!\!/)\psi - \frac{1}{2}\mathrm{tr}\, F_{\mu\nu}F^{\mu\nu}$ 	Non-perturbative QCD Stucture  2017 	Electron-Ion Collider (2030)   	Structural QCD Nuclear Physics 

Conclusion

- EIC Program aim: Revolutionize the understanding of nucleon and nuclear structure and associated dynamics. Explore new states of QCD.
- For the first time, EIC will enable us to study the nucleon and the nucleus at the scale of quarks and gluons, over (arguably) all of the kinematic range that are relevant for exploring the nuclear and nucleon structure and the associated QCD dynamics.
- Outstanding questions raised both by the science at RHIC/HERA/LHC and at HERMES/COMPASS/Jefferson Lab, have **naturally led to the science and design parameters of the EIC.**
- There exists **world wide interest** in collaborating on the EIC. Now we must turn this into real participation!
- In the next decades, with the advent of EIC, a new window will open to the quark-gluon structure of ordinary QCD matter.

The future of science demands an Electron Ion Collider