The EIC - a facility to unravel the secrets of nuclear matter

Elke-Caroline Aschenauer (BNL)

BROOKHAVEN NATIONAL LABORATORY
Jefferson Lab
U.S. DEPARTMENT OF ENERGY | Office of Science

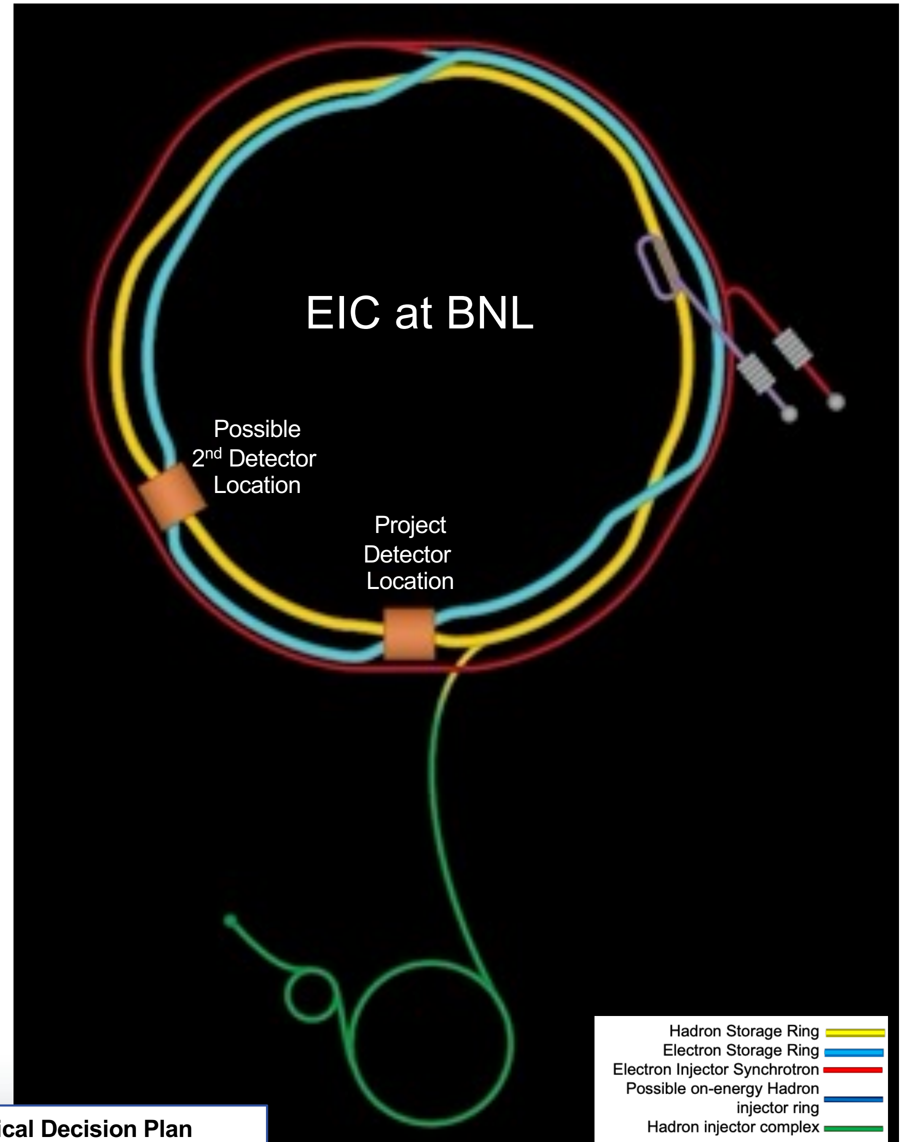
Facts about the EIC

What is the EIC:

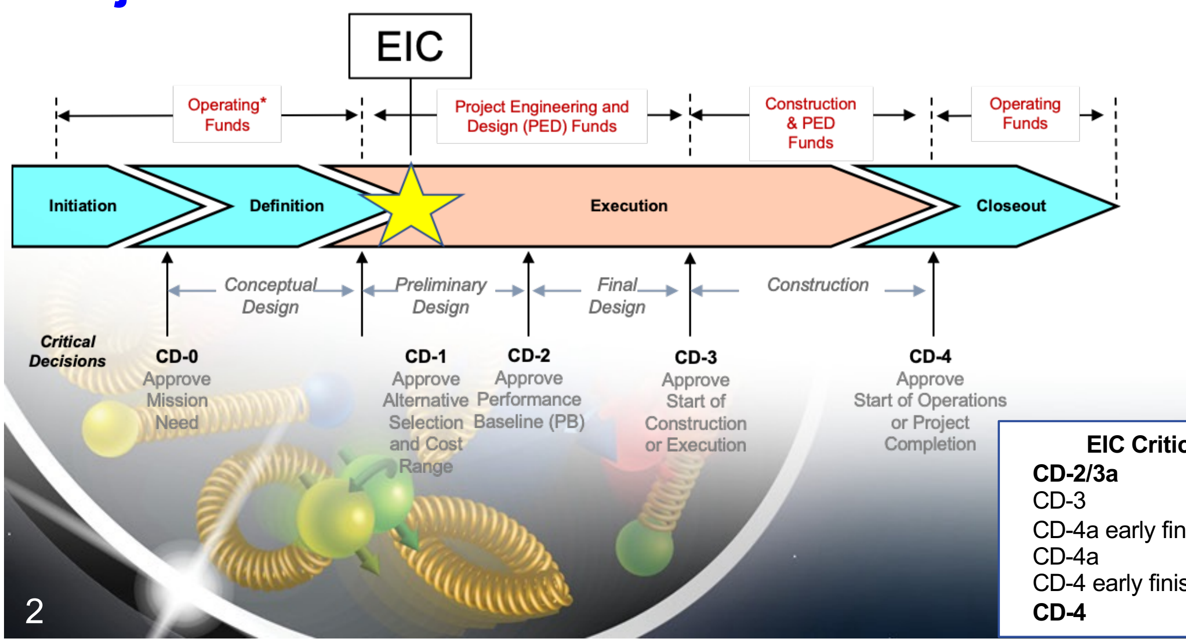
A high luminosity ($10^{33} – 10^{34}$ cm^{-2}s^{-1}) polarized electron proton / ion collider with $\sqrt{s_{ep}}$ = 28 – 140 GeV

What is new/different:

factor 100 to 1000 higher luminosity as HERA
both electrons and protons / light nuclei polarized,
nuclear beams: d to U
Fixed Target Facilities i.e.:
at minimum > 2 decades increase in kinematic coverage in x and Q^2



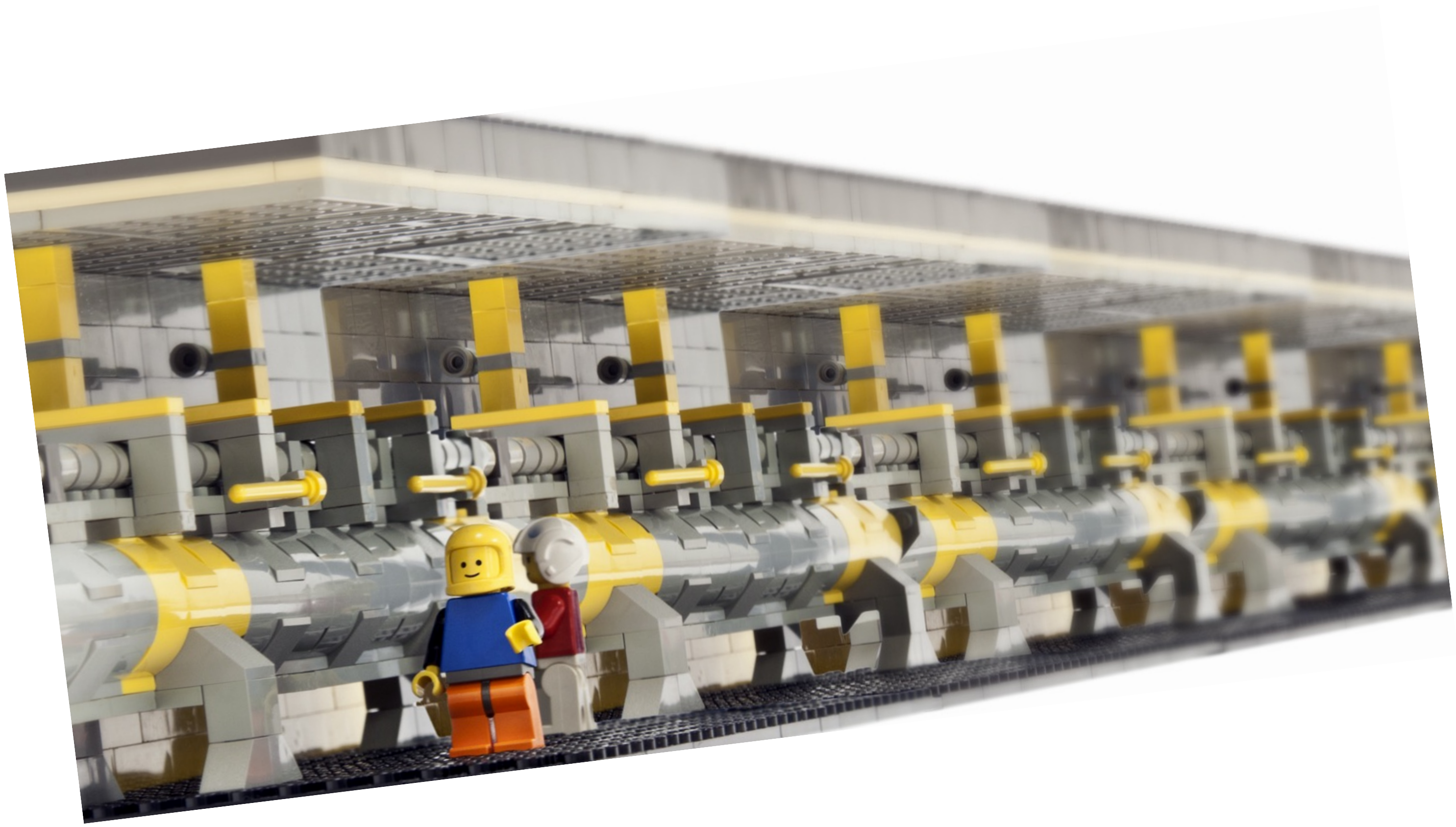
Project Status:



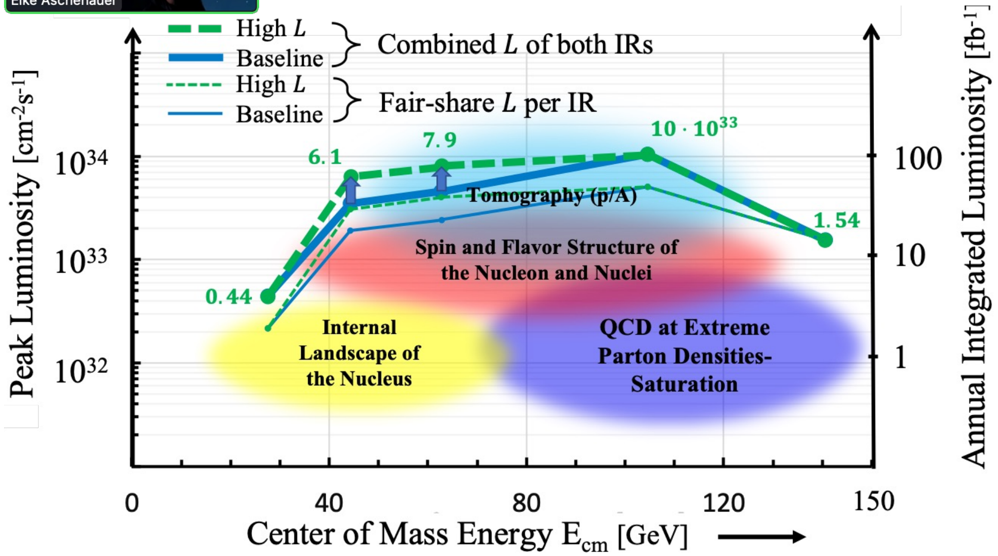
EIC Critical Decision Plan

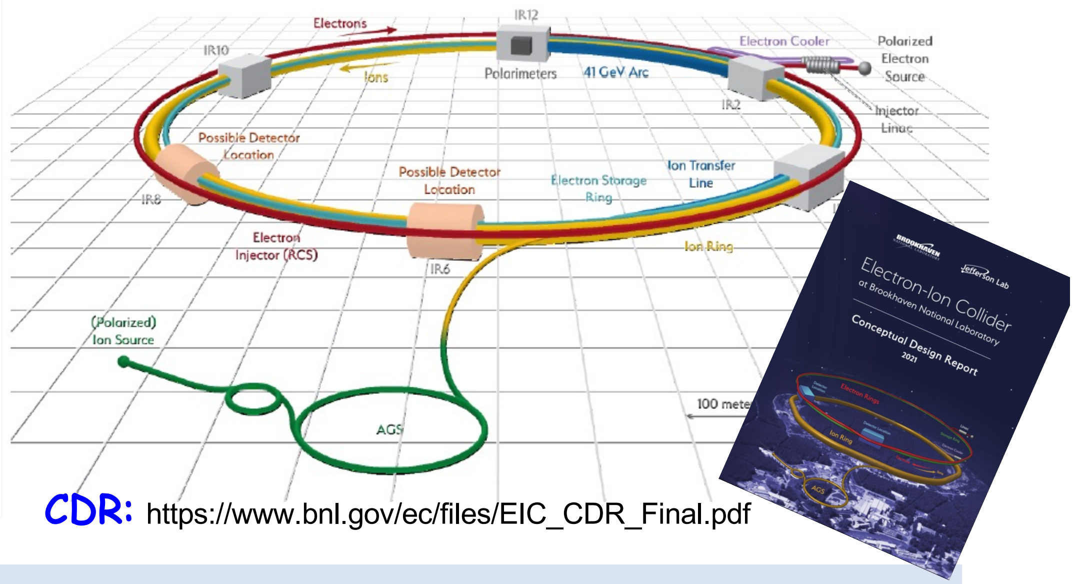
CD-2/3a	**January 2024**
CD-3	April 2025
CD-4a early finish	April 2031
CD-4a	April 2032
CD-4 early finish	April 2032
CD-4	**April 2034**

The EIC Accelerator



EIC Machine Parameters





CDR: https://www.bnl.gov/ec/files/EIC_CDR_Final.pdf

Double Ring Design Based on Existing RHIC Facilities	
Hadron Storage Ring: 40 - 275 GeV	**Electron Storage Ring: 5 - 18 GeV**
RHIC Ring and Injector Complex: p to Pb	Many Bunches, Large Beam Current - 2.5 A
1160 bunces @ 1A Beam Current 9 ns bunch spacing	9 MW Synchrotron Radiation
Light ion beams (p, d, ^{3}He) polarized (L,T)	Polarized electron beams
Nuclear beams: d to U	**Electron Rapid Cycling Synchrotron**
Requires Strong Cooling: new concept → CEC	Spin Transparent Due to High Periodicity
High Luminosity Interaction Region(s)	
25 mrad Crossing Angle with Crab Cavities	

The EIC: A Unique Collider

EIC

collide different beam species: ep & eA
→ consequences for beam backgrounds
  → hadron beam backgrounds, i.e. beam gas events
  → synchrotron radiation

asymmetric beam energies
→ boosted kinematics
  → high activity at high |η|

Small bunch spacing: >= 9ns

crossing angle: 25mrad

wide range in center of mass energies
→ factor 6

electron beam follows B-factory design parameters but polarized

both beams are polarized
→ stat uncertainty: ~ $1/(P_1 P_2 (\int L\, dt)^{1/2})$

LHC

collide the same beam species: pp, pA, AA
→ beam backgrounds
  → hadron beam backgrounds, i.e. beam gas events, high pile up

symmetric beam energies
→ kinematics is not boosted
  → most activity at midrapidity

moderate bunch spacing: 25 ns

no significant crossing angle yet (150 μrad now)

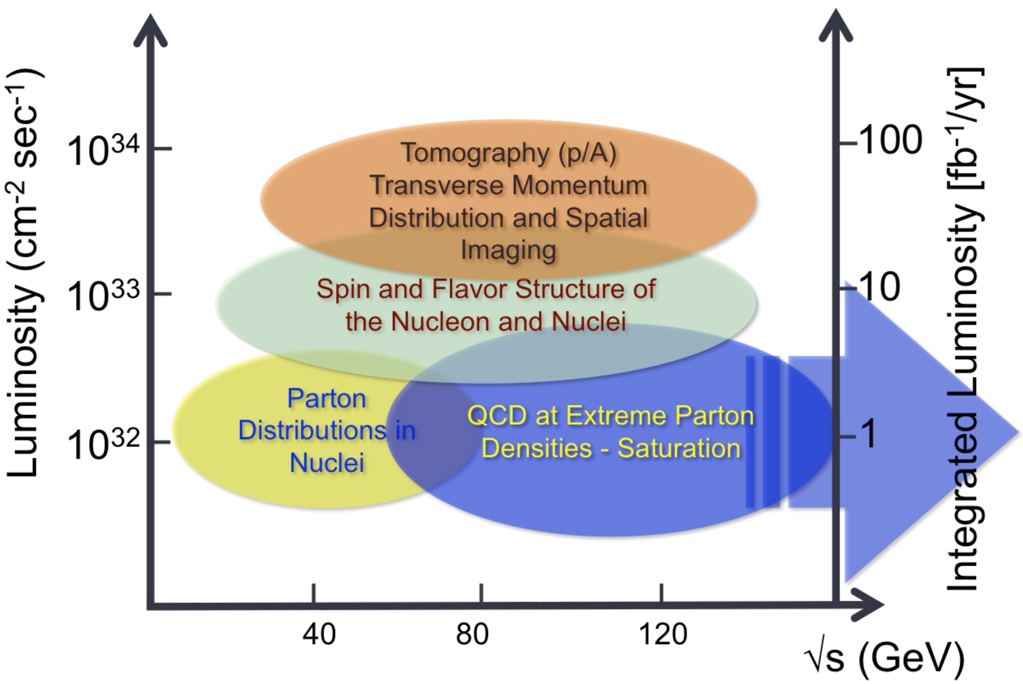
LHC limited range in center of mass energies
→ factor 2

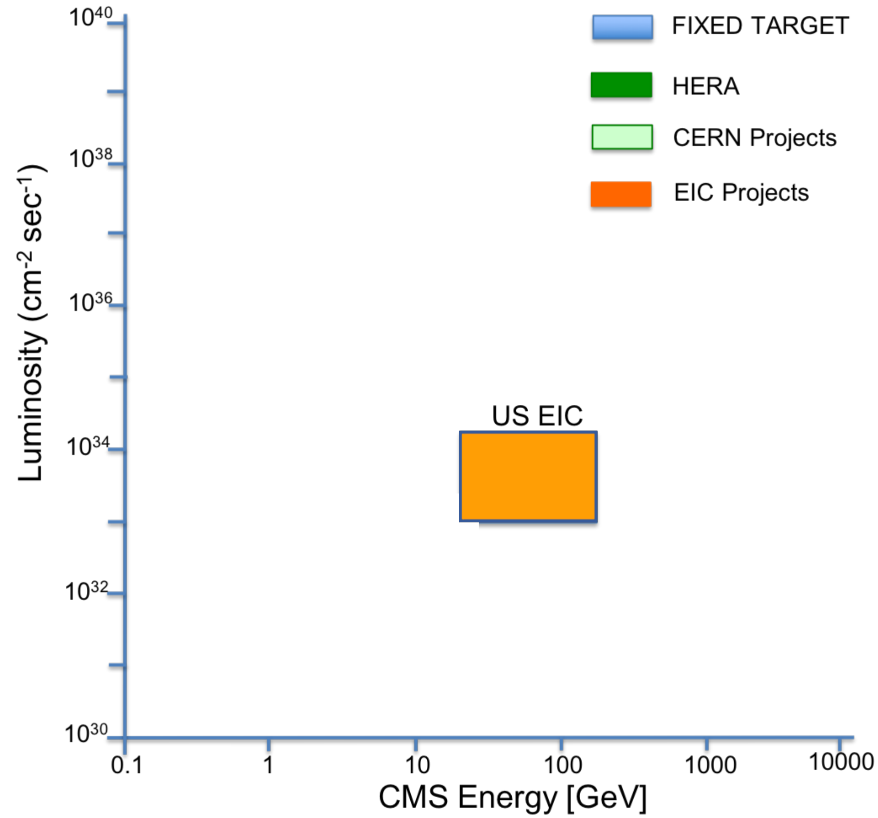
no beam polarization
→ stat uncertainty: ~$1/(\int L\, dt)^{1/2}$

Differences impact detector design, acceptance and possible technologies

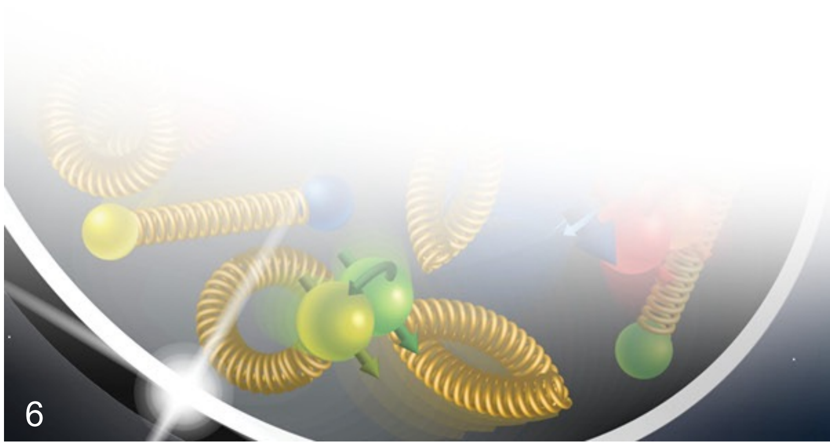
What is needed experimentally?

Luminosity - √s Energy and EIC Physics:





US-EIC:
polarization, ion species together with its luminosity and √s coverage makes it a completely unique machine world-wide.



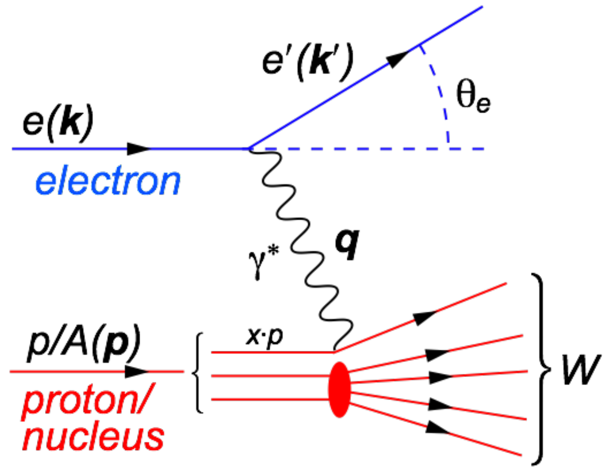
The EIC Science

What is needed to address the EIC Physics

The Golden Process:

Deep Inelastic Scattering (DIS):

- As a probe, electron beams provide unmatched precision of the electromagnetic interaction
- Direct, model independent determination of parton kinematics of physics processes



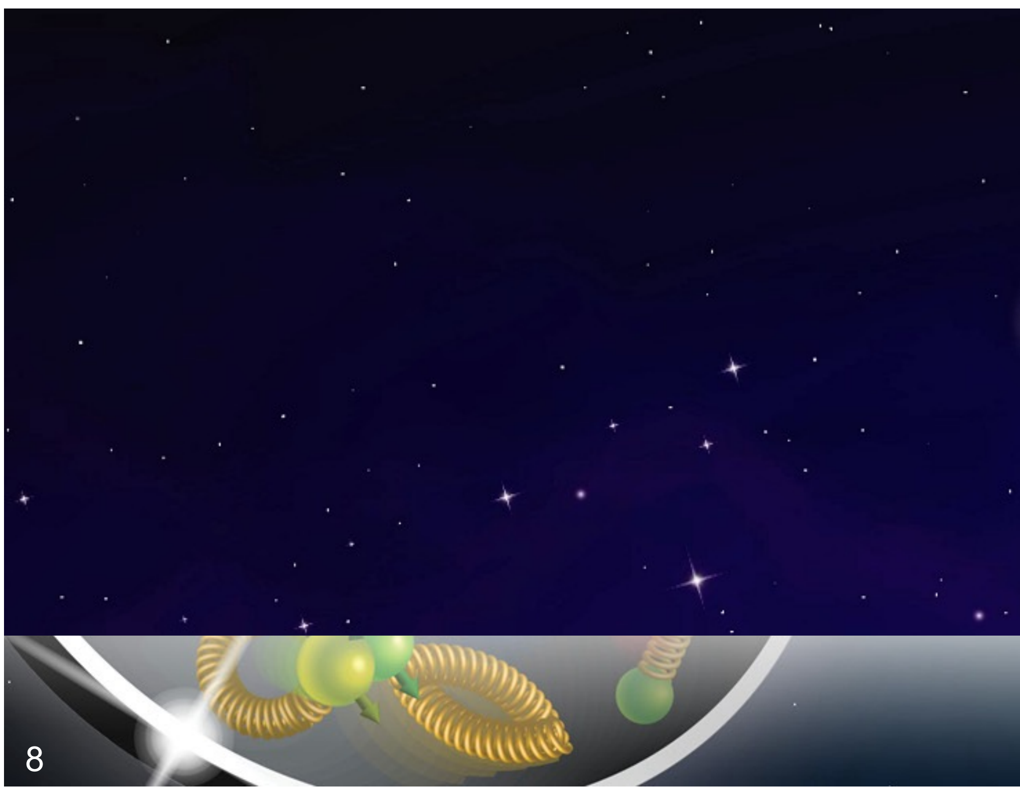
$$Q^2 = s \cdot x \cdot y$$

s: center-of-mass energy squared

Q^2: resolution power

x: the fraction of the nucleon's momentum carried by the struck quark (0<x<1)

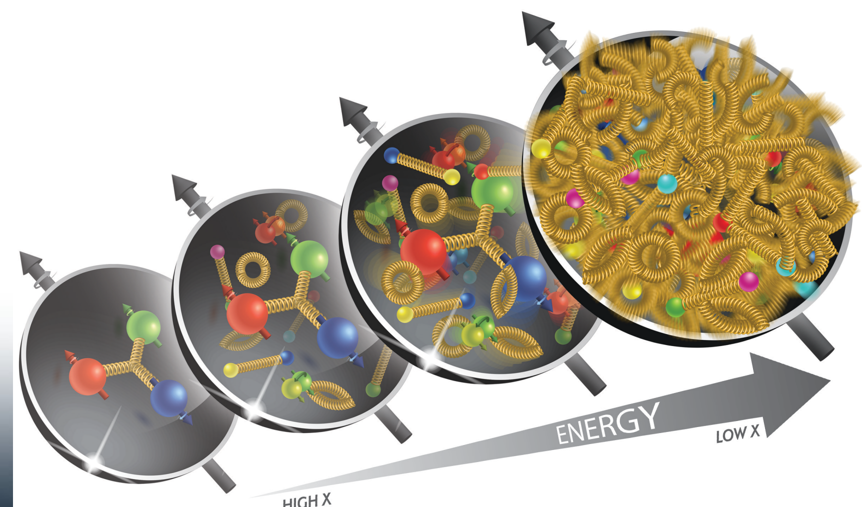
y: inelasticity



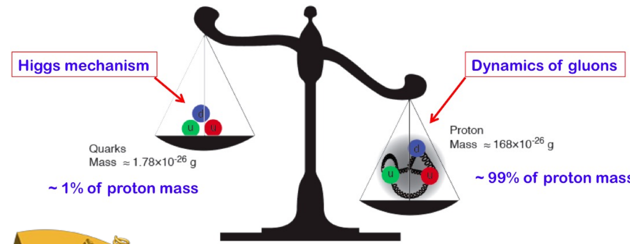
large kinematic coverage:

→ center-of-mass energy √s: 20 – 140 GeV

→ access to x and Q^2 over a wide range

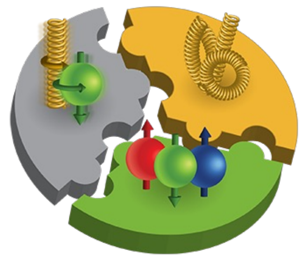


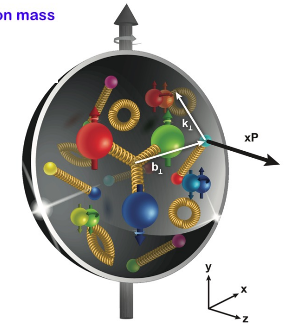
The EIC Physics



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?





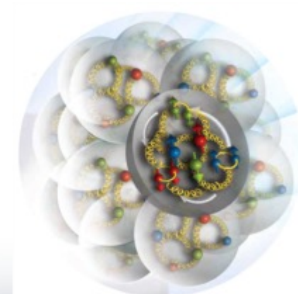
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium?

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

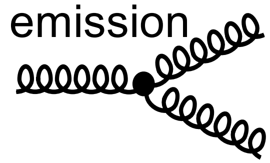
How do the quark-gluon interactions create nuclear binding?

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



?
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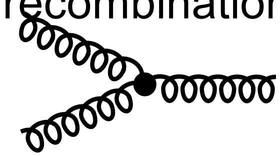
gluon recombination



Why are PDFs interesting?

- Two views of the proton
  - three quarks (spectroscopy, quark models)
  - many quarks, antiquarks, gluons (high-energy processes)

How are these two pictures and the underlying concepts related?

- simple (and often quoted) picture of nucleon:
  - ✓ three quarks at low resolution scale
  - ✓ gluons and sea quarks generated by perturbative splitting

BUT: 1d-PDF fits of Glueck, Reya et al. show that this is too simple

- must have gluons and sea quarks at non-perturbative scales

How can we understand their dynamical origin in QCD?
How do they relate to the valence quarks?

Gluons in DIS

Gluons manifest themselves through
the behavior of the cross section as function of x and Q^2

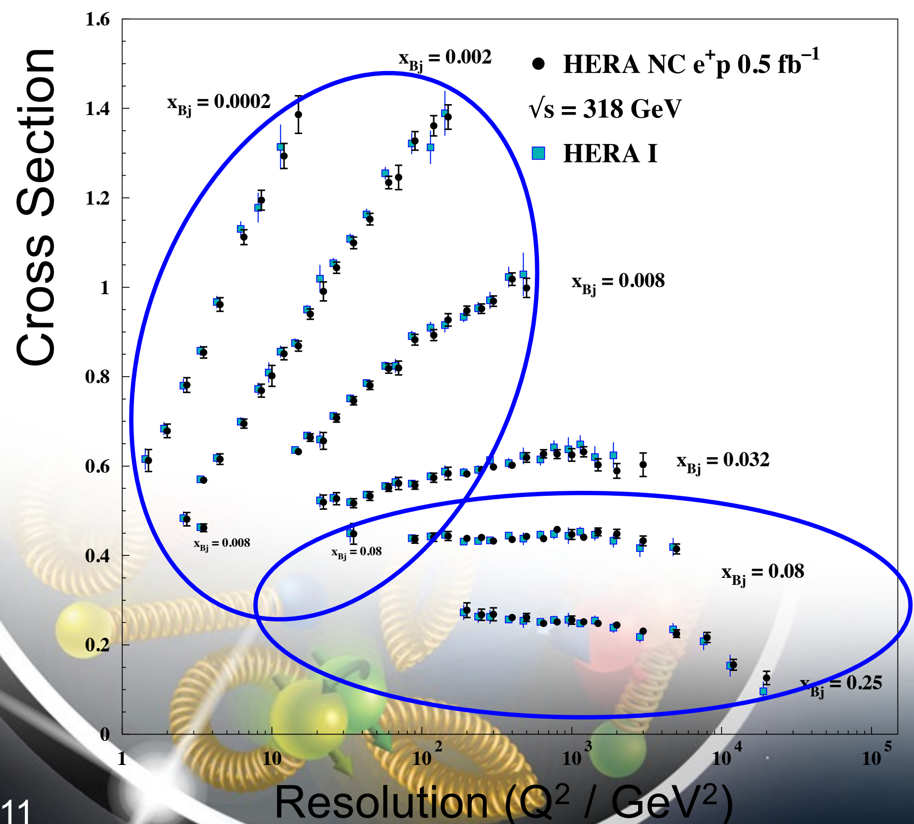
$$\frac{d^2\sigma^{ep\rightarrow eX}}{dxdQ^2} = \frac{4\pi\alpha^2_{e.m.}}{xQ^4}\left[\left(1 - y + \frac{y^2}{2}\right)F_2(x,Q^2) - \frac{y^2}{2}F_L(x,Q^2)\right]$$

quark+anti-quark momentum distributions (F_2)

gluon momentum distribution (F_L)

without gluons the cross section depends only on x, no dependence on Q^2 → $F_2(x)$

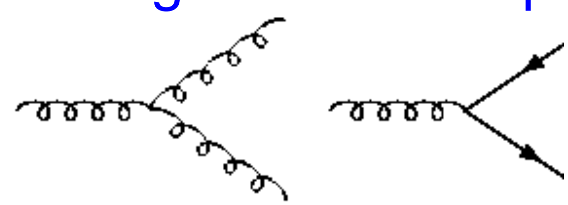
Bjorken scaling



BUT:

Observe strong rise of cross section with both x and Q^2

Because of gluon initiated processes

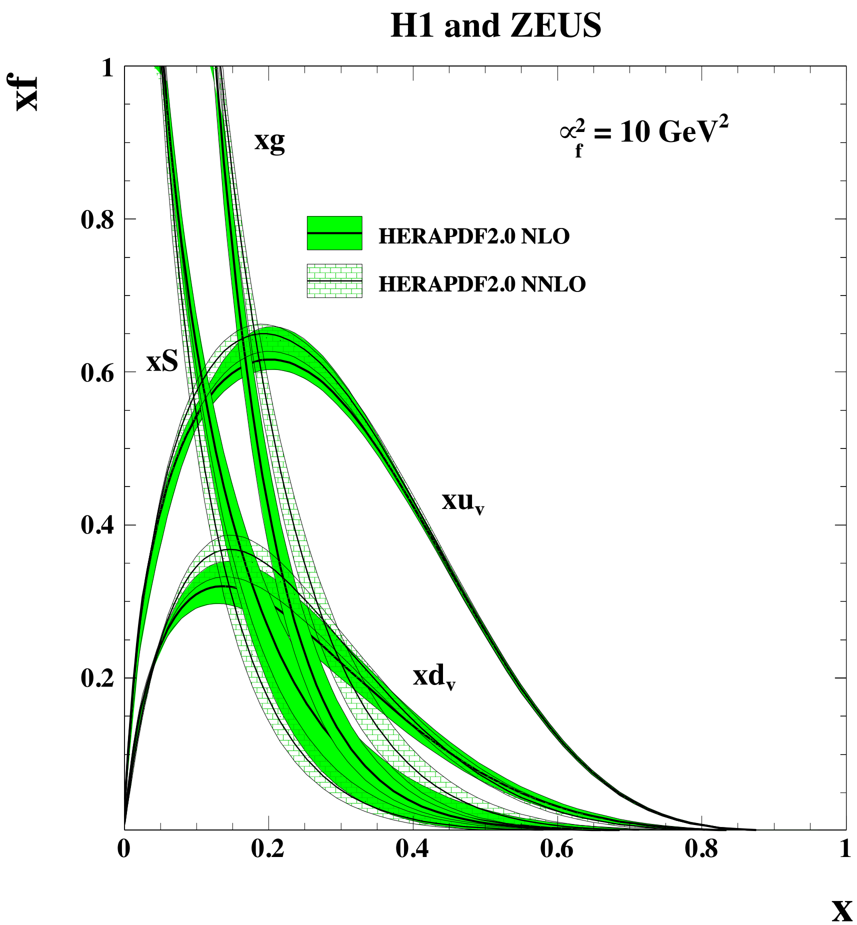


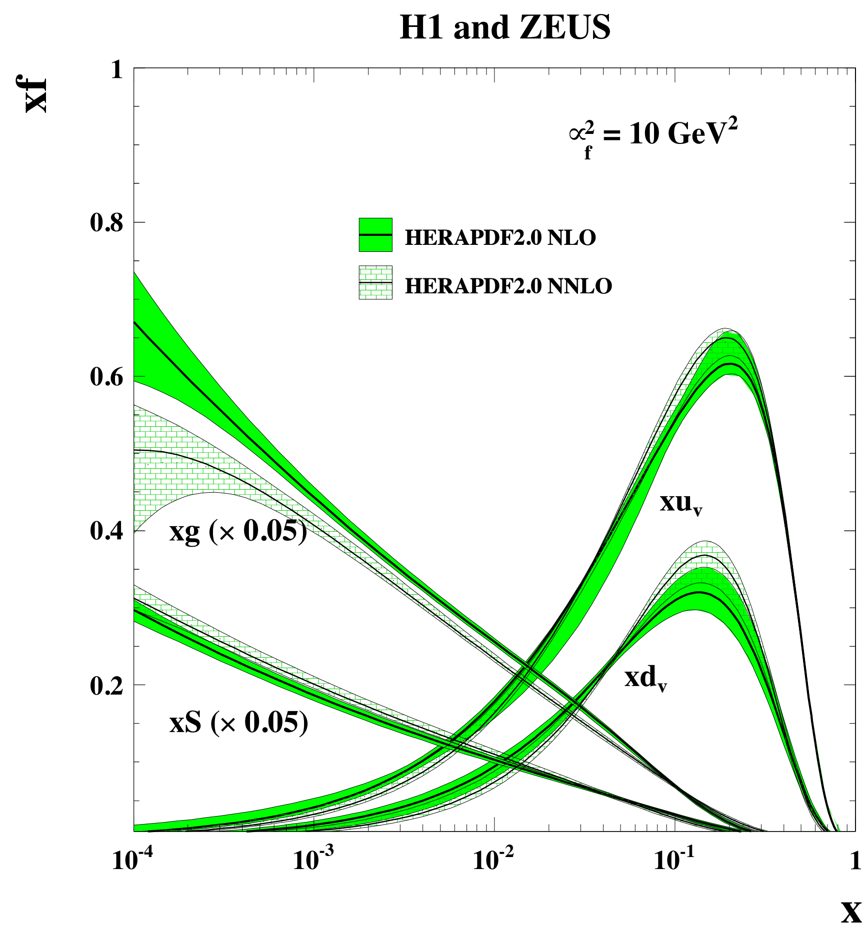
Scaling violation

→ Gluon Distribution:

$d\sigma(x,Q^2)/d\ln Q^2$

The unpolarized Proton PDFs





At x of 0.3 the proton is dominated by gluons and sea quarks
they should drive the inner structure of the proton

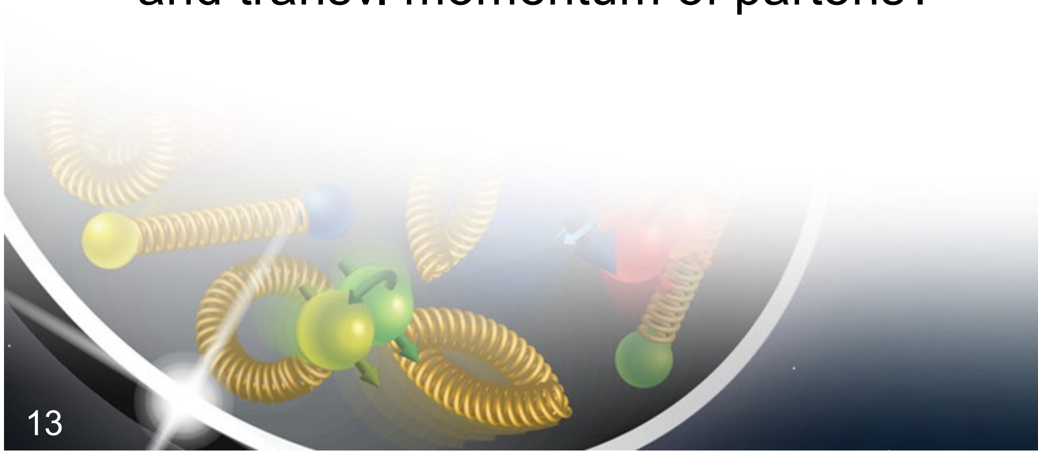
Why are PDFs interesting?

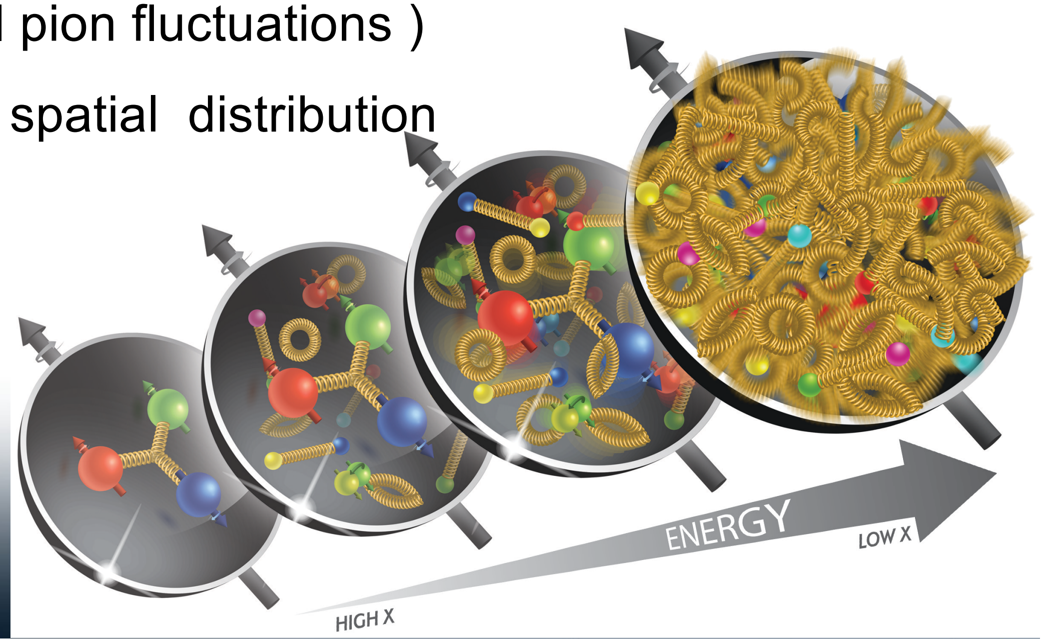
How can we understand their dynamical origin in QCD?
How do they relate to the valence quarks?

GOAL:

explore and quantify features of quarks, antiquarks and gluons in the proton that are suitable to guide theory

- How are quarks, antiquarks and gluons spatially distributed in a nucleon?
- How does this distribution change with momentum fraction x ?
  → difference between valence and sea quarks?
- What is the behavior at large transverse distances?
  → confinement, chiral dynamics (virtual pion fluctuations)
- What is the connection between transv. spatial distribution and transv. momentum of partons?





Why should we care about Spin?

SPIN is one of the fundamental properties of matter

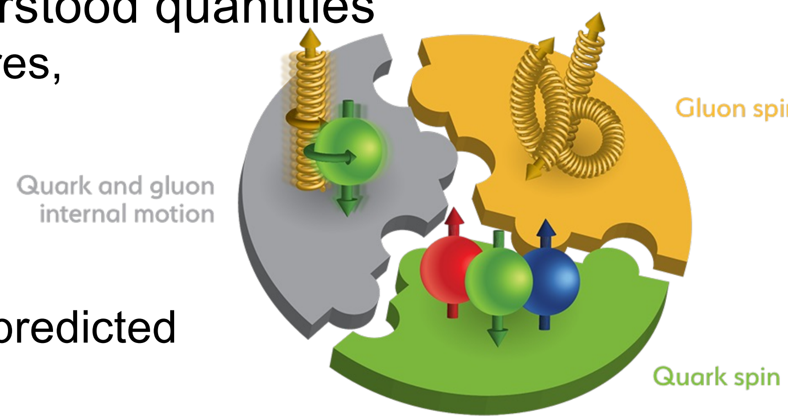
all elementary particles, but the Higgs carry spin

Spin cannot be explained by a static picture of the proton

It is more than the number ½ ! It is the interplay between the intrinsic properties and interactions of quarks and gluons

Despite decades of QCD – Spin one of the least understood quantities

→ Consequence very few models, but several physics pictures, which can be tested with high precision data



❑ the pion/kaon cloud model

- → rooted in deeper concepts → chiral symmetry
- → generated q-qbar pairs (sea quarks) at small(ish)-x are predicted to be unpolarized
- → gluons if generated from sea quarks unpolarised → spatial imaging
- → a high precision measurement of the flavor separated polarized quark and gluon distributions as fct. of x is a stringent way to test.

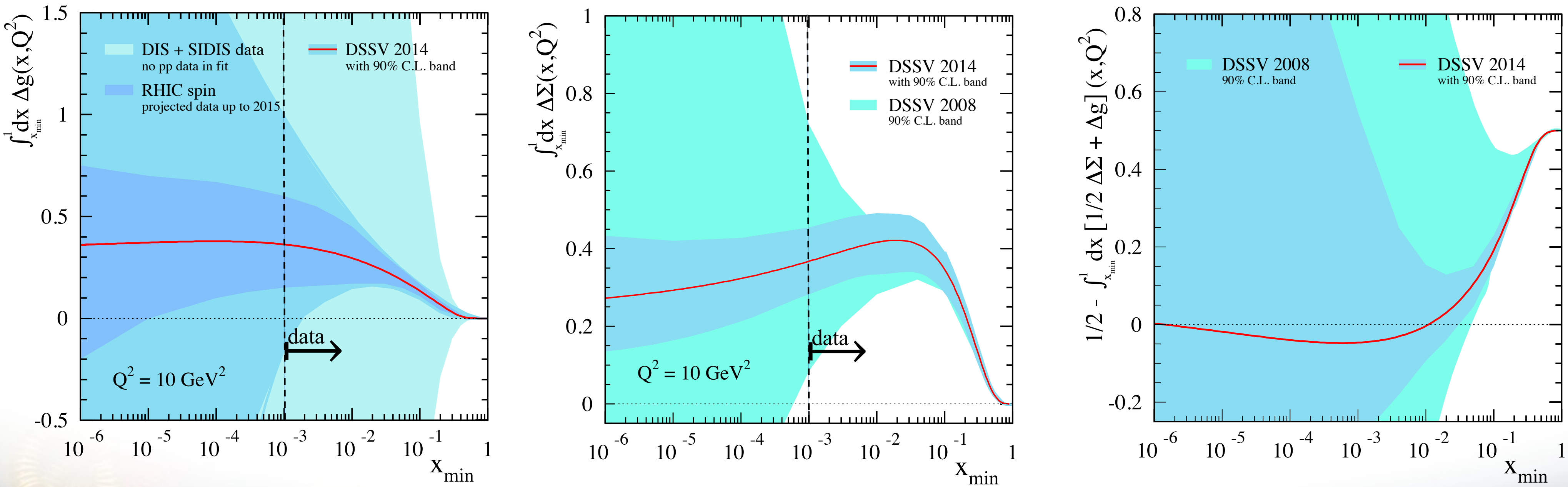
❑ the chiral quark-soliton model

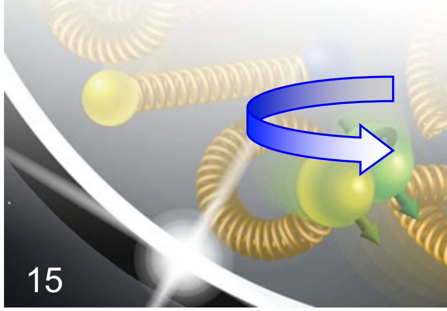
- → sea quarks are generated from a "Dirac sea" with a rich dynamical structure but excludes gluons at its starting scale
- → sea quarks are polarized → asymmetry
- → a high precision measurement of the flavor separated polarized quark as fct. of x is a stringent way to test

Spin Decomposition ala Jaffe-Manohar:

$$\frac{1}{2}\hbar = \left\langle P,\frac{1}{2}\,|\,J^z_{QCD}\,|\,P,\frac{1}{2}\right\rangle = \underbrace{\frac{1}{2}\int_0^1 dx\Delta\Sigma(x,Q^2)}_{\text{total quark spin}} + \underbrace{\int_0^1 dx\Delta G(x,Q^2)}_{\text{gluon spin}} + \underbrace{\int_0^1 dx\left(\sum_q L^z_q + L^z_g\right)}_{\text{angular momentum}}$$

Based on World DIS data and some RHIC pp-data





Current World DIS data → no constrain on $\Delta g(x,Q^2)$
need to measure more then just the integrals

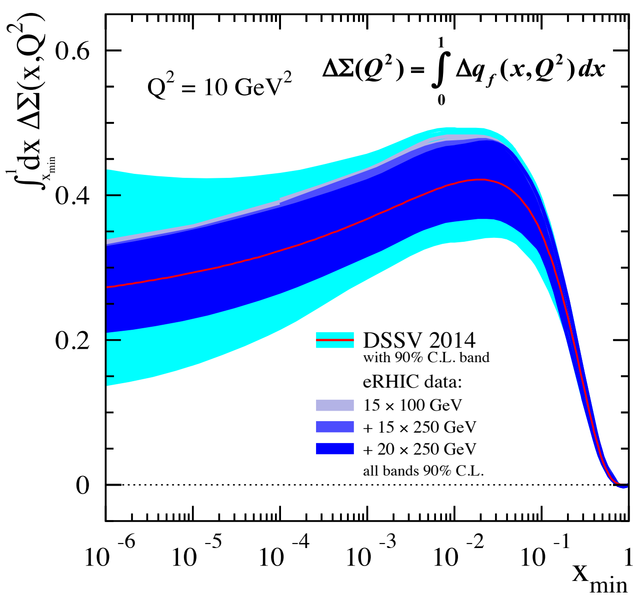
Why is separating quark flavors important?

Why is separating quark flavors important?

- nuclear structure is encoded in parton distribution functions
- understand dynamics of the quark-antiquark fluctuations
- flavor asymmetry in the light quark sea in the proton

unpolarized: ubar < dbar Helicity: Δubar > Δdbar TMDs: ?????

- shape of polarized sea-quark PDFs critical for quark contribution to spin



$$\int_{0.001}^{1} dx\Delta\Sigma \sim 0.366 \pm^{0.042}_{0.062} @10GeV^2$$

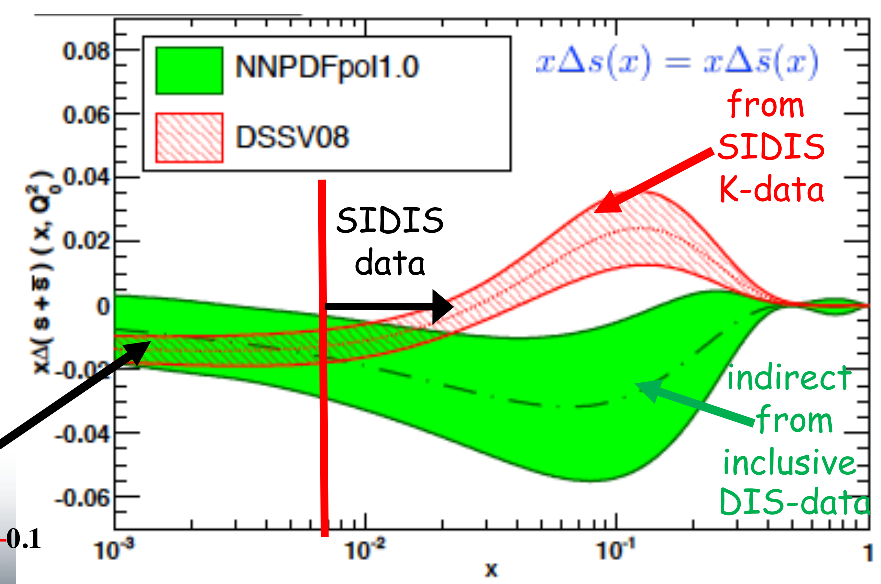
$$\int_{0}^{1} dx\Delta\Sigma \sim 0.242 @10GeV^2$$

ΔΣ does not converge at low x

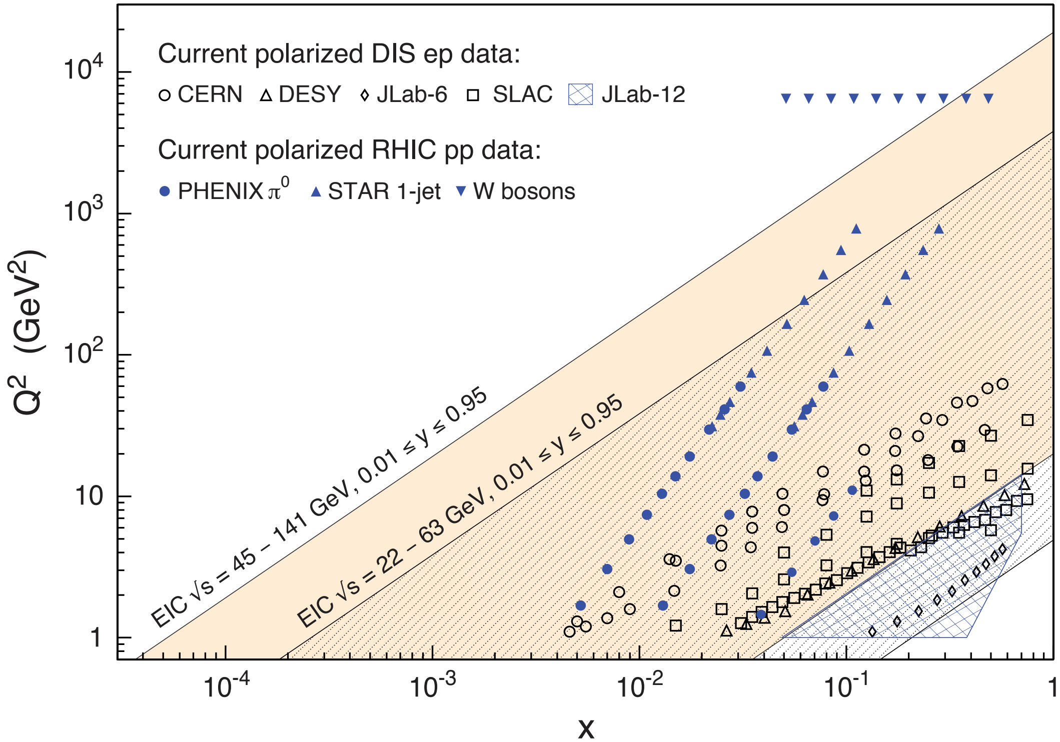
- due to current constrains put in the fits
- strangeness is one of the least known quantities
  - both unpolarized and polarized

1st moment constrained by 3F-D

$$\int_0^1 dx[\Delta s + \Delta\bar{s}](x) \simeq -0.1$$

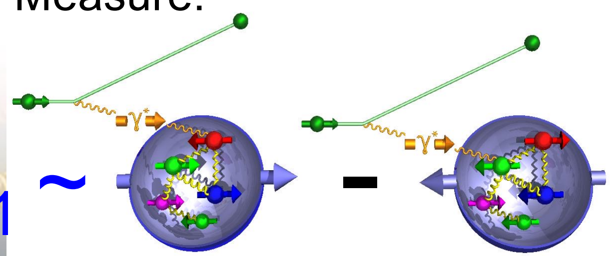


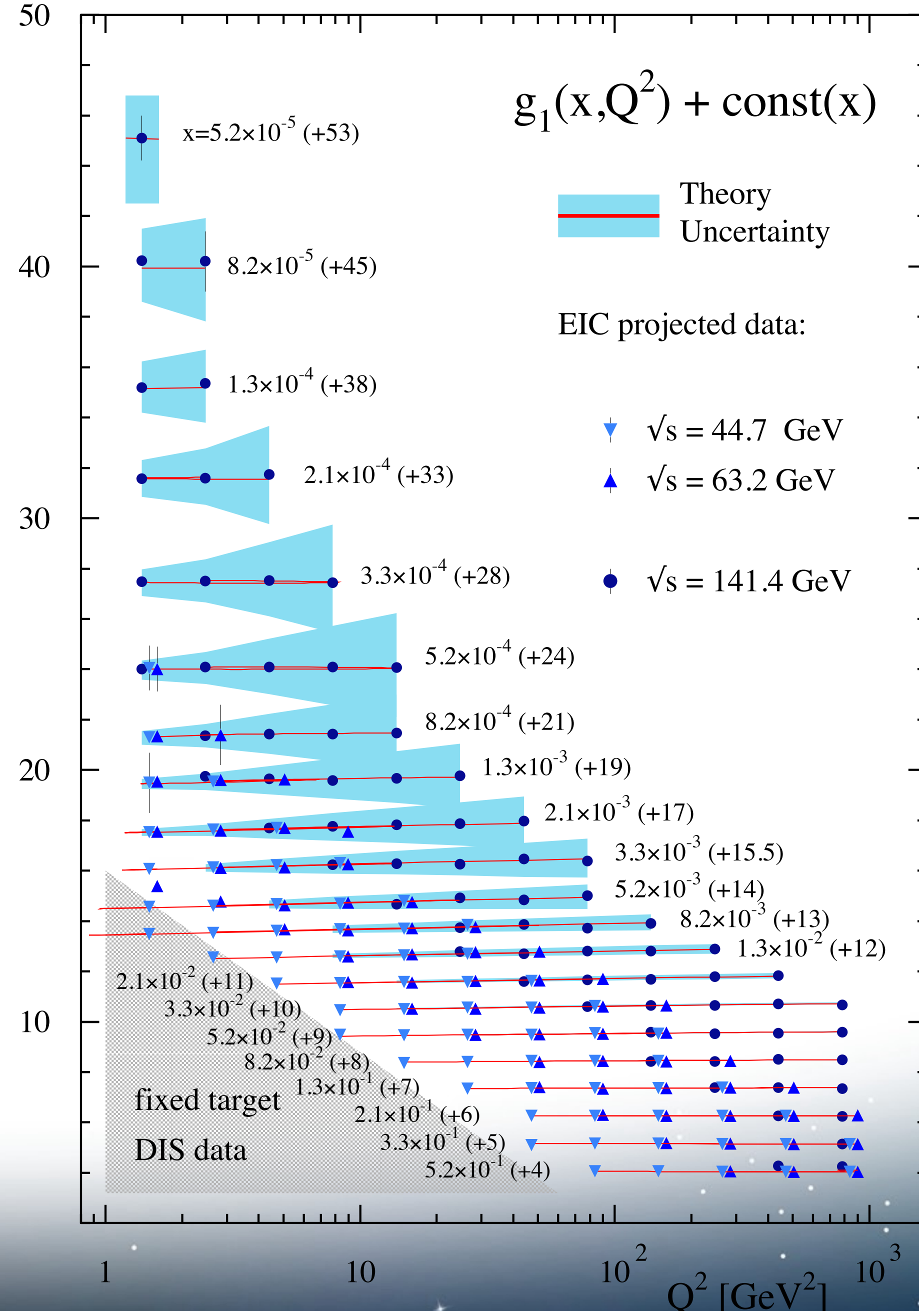
Most recent Study



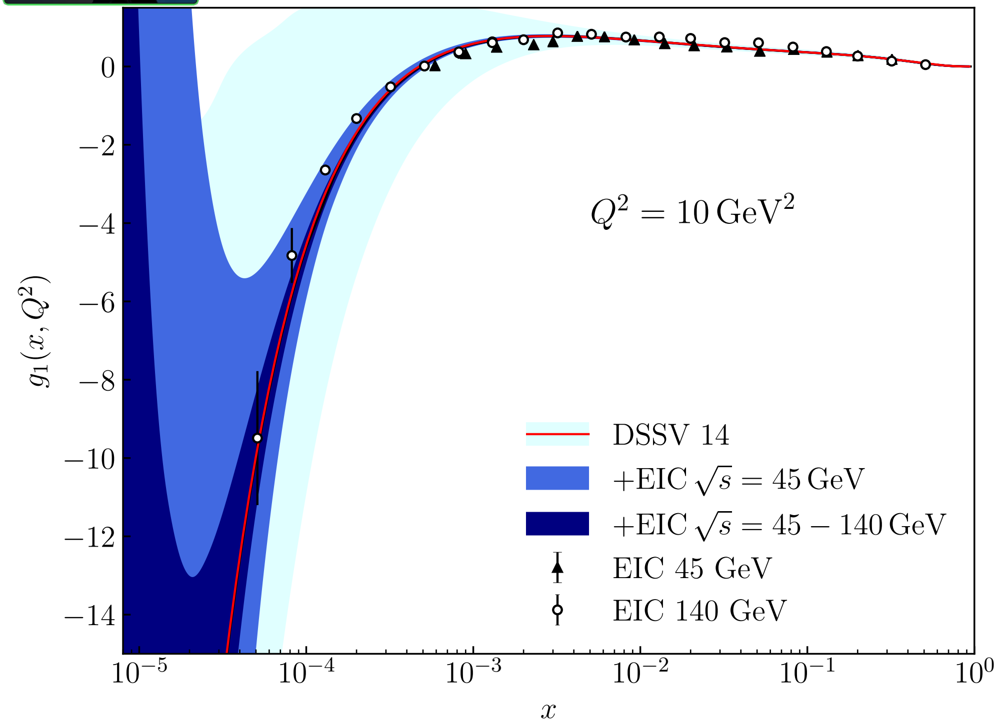
Inclusive and SIDIS Pseudo Data:
ep √s: 45 GeV and 141.4 GeV
eHe³ √s : 115.2 GeV
→ He-3 fully tagged → neutron target

→ Measure:

g_1 ~ 



Inclusive DIS

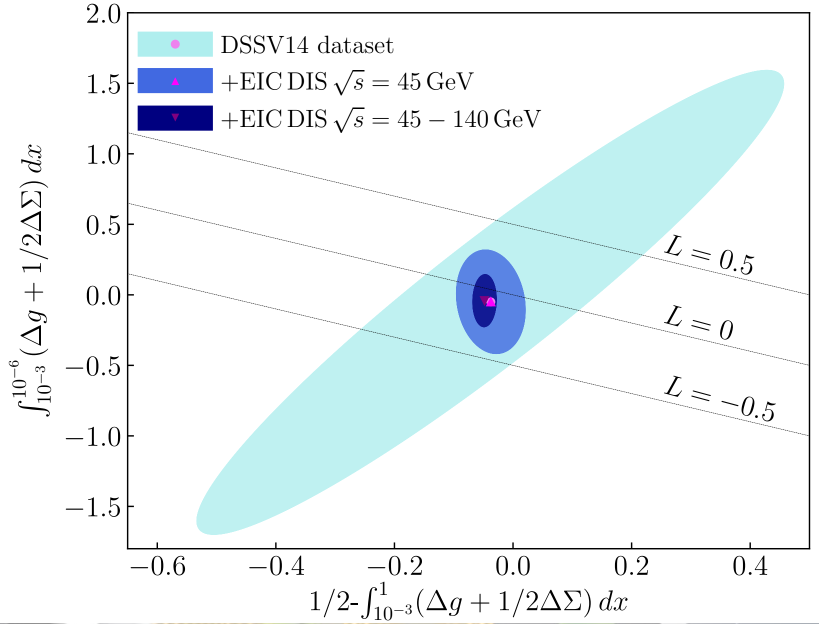


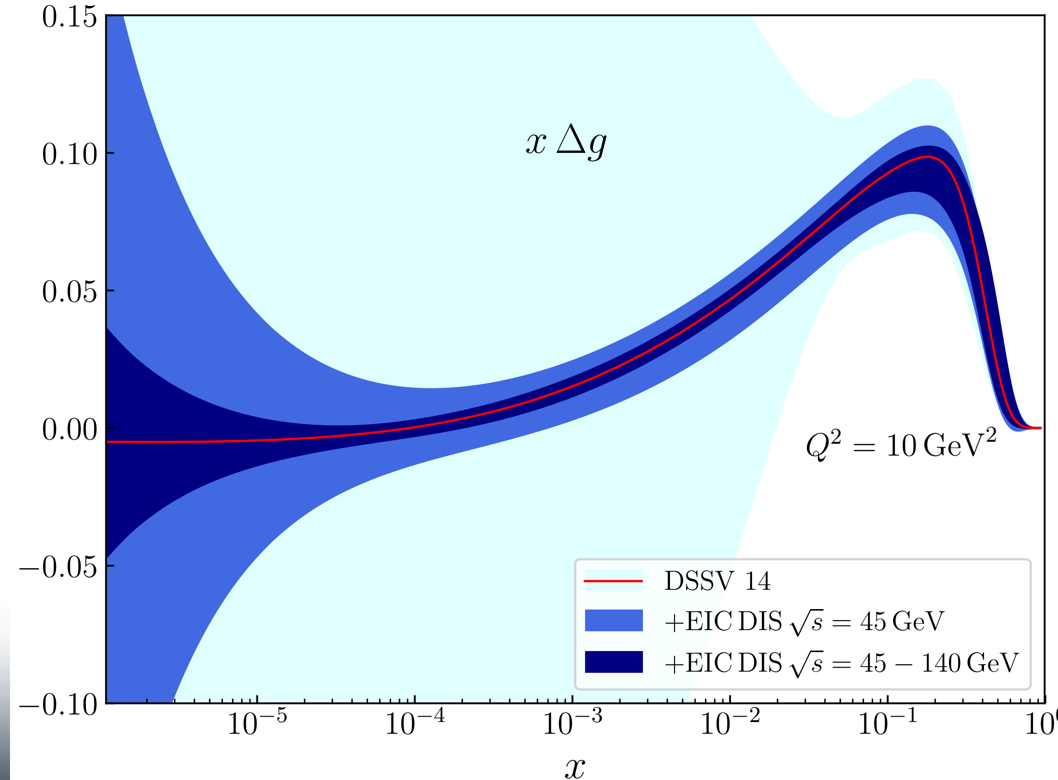
gluon contribution:

$dg_1(x,Q^2)/d\ln Q^2 \rightarrow \Delta g(x,Q^2)$

Inclusive data:

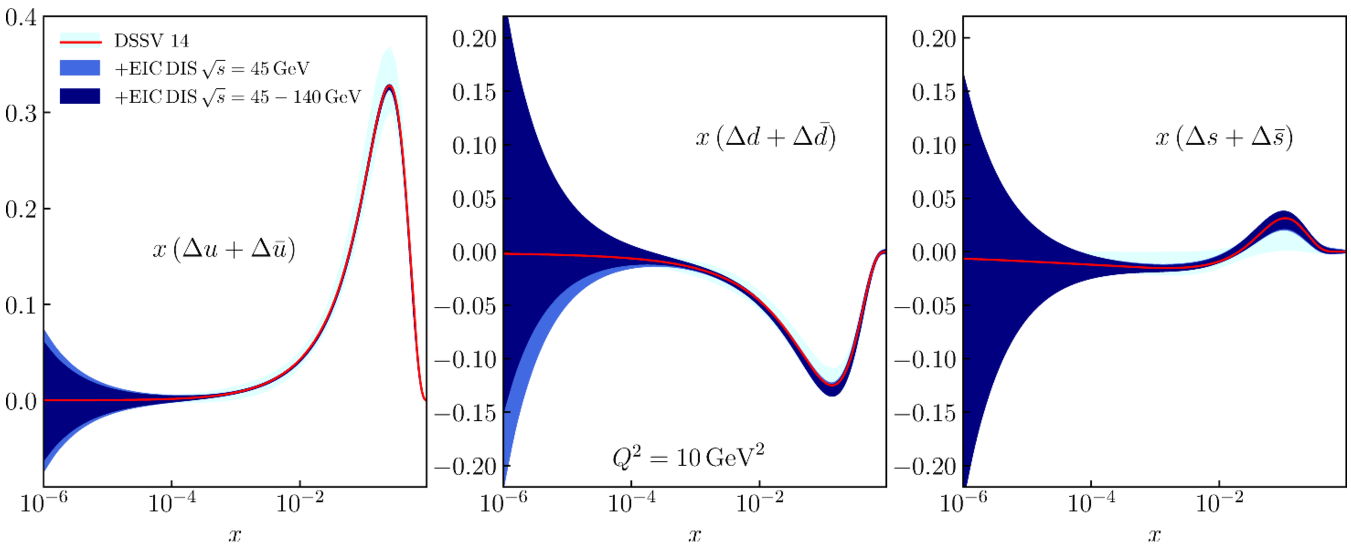
stringent constrain on Δg(x,Q2)





Impact from He-3 DIS Data

polarized PDFs from proton DIS

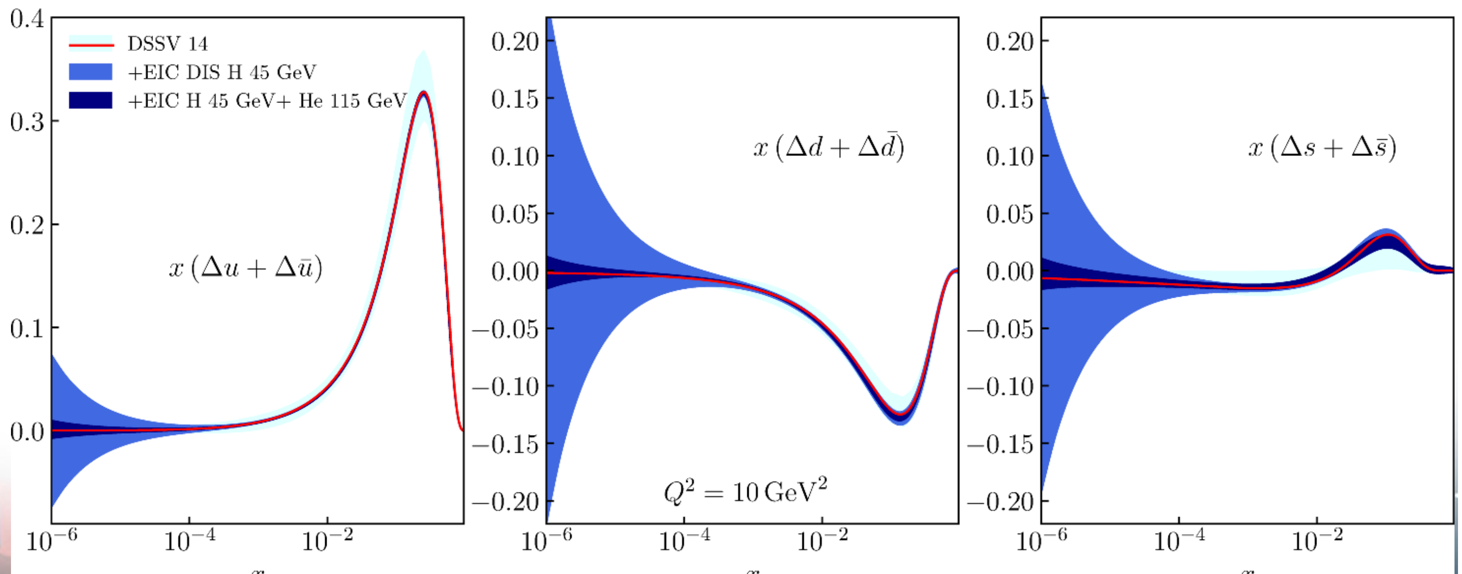


DIS-data:

- full flavor separation of Δqs not possible

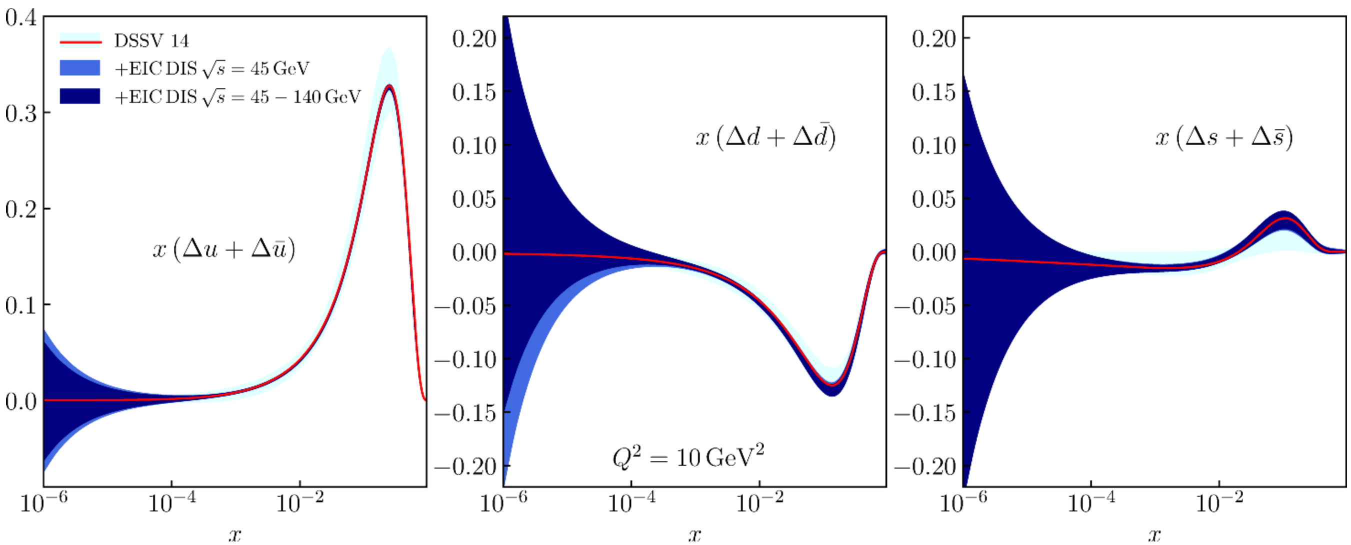
+ He^3 DIS-data:

- strong impact due to the more direct flavor separation



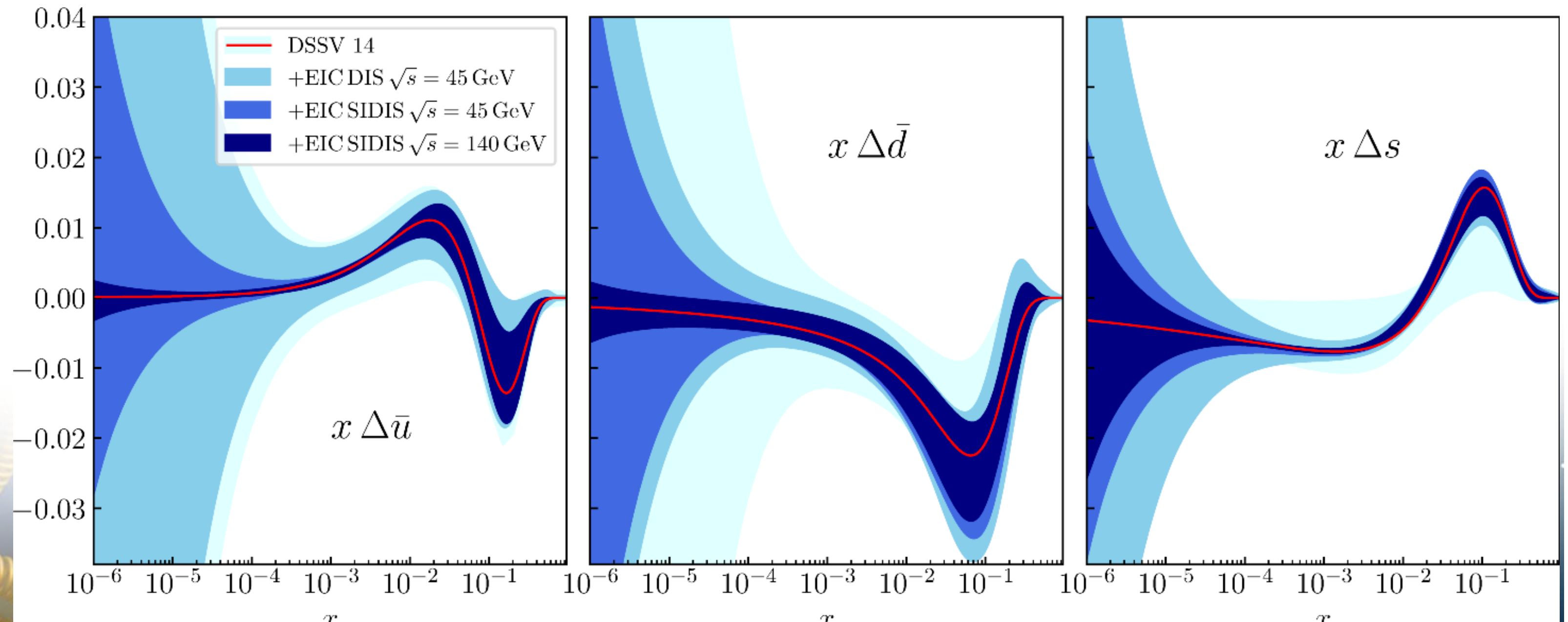
Impact from SIDIS Data

polarized PDFs from proton DIS



DIS-data:

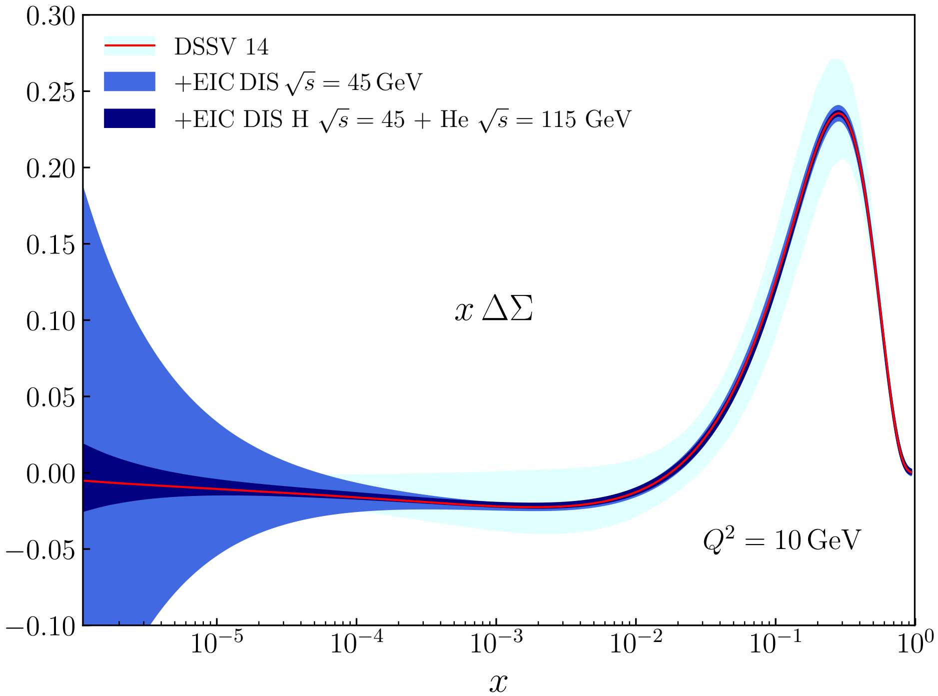
- full flavor separation of Δqs not possible



proton SIDIS-data:

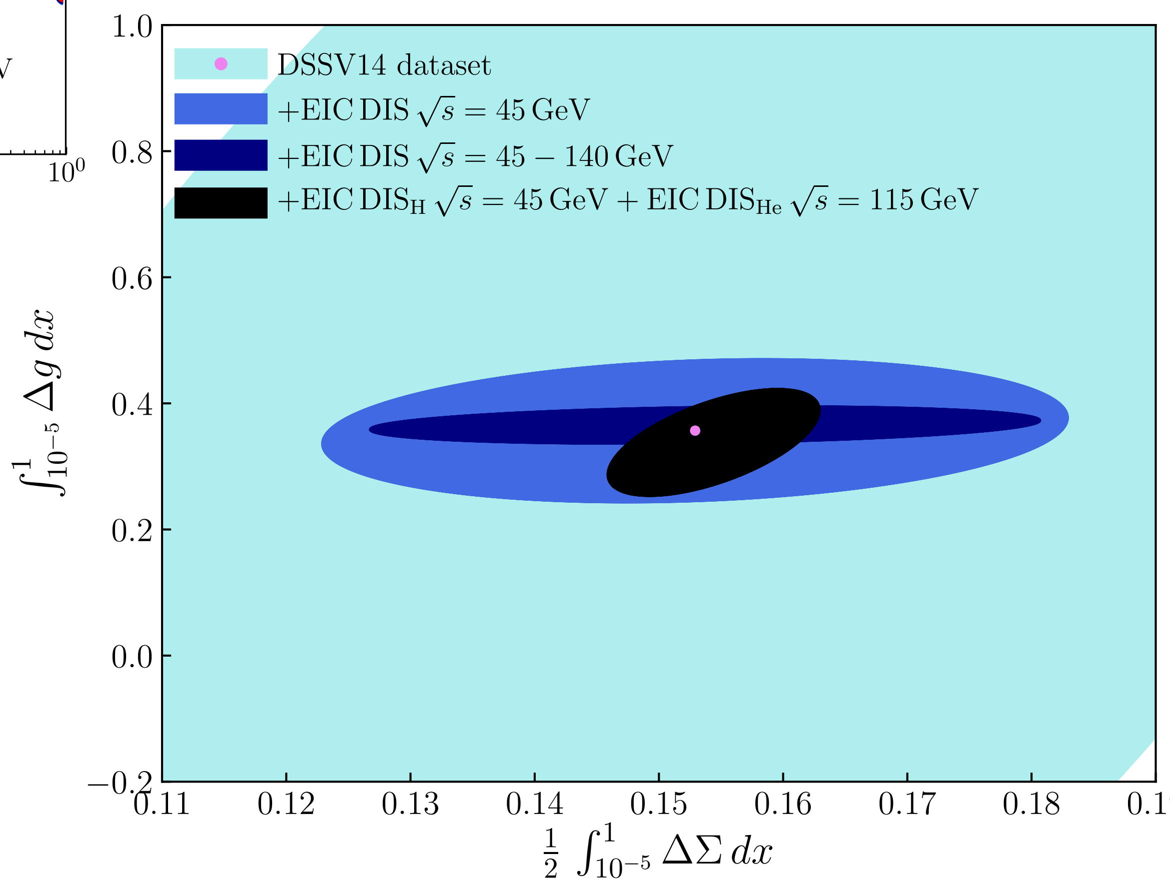
- flavor separated Δqs

Different Contributions to Proton Spin

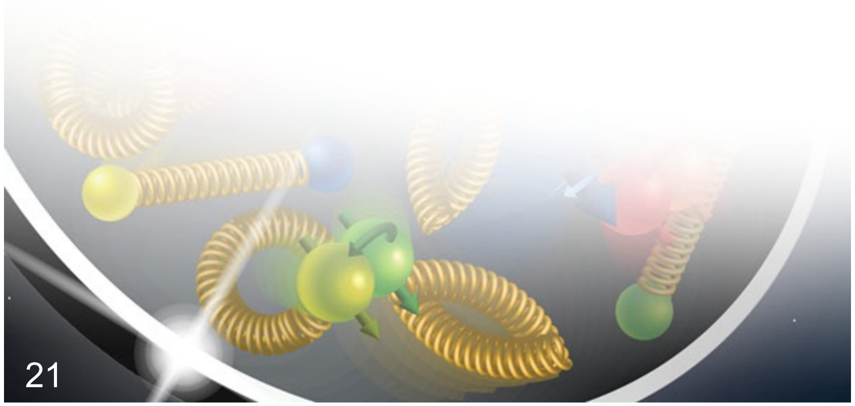


proton and He^3 DIS data provide excellent constrain of $\Delta\Sigma$ and ΔG

SIDIS Data are critical for a full flavor separation



What about L_z^q and L_z^g



Can we access the Orbital Angular Momentum

Jaffe-Manohar:

$$\frac{1}{2}\hbar = \left\langle P, \frac{1}{2} \middle| J^z_{QCD} \middle| P, \frac{1}{2} \right\rangle = \sum_q \underbrace{\frac{1}{2} S^z_q + S^z_g}_{} + \sum_q L^z_q + L^z_g$$

defined in $A^+=0$ gauge
Δq and Δg
→ density interpretation

- Orbital angular momentum: ½ - (ΔΣ + ΔG)
  - can lead to a misinterpretation as on does not measure (ΔΣ + ΔG) for x 0 to 1
- Alternative access orbital angular momentum through twist-3 GPDs
  - even more complicated then std GPDs → will come with large model uncertainties

Can we access the Orbital Angular Momentum

Ji:

$$\frac{1}{2} = J_q^z + J_g^z = \underbrace{\frac{1}{2}\Delta\Sigma + \sum_q \mathcal{L}_q^z + J_g^z}_{\text{through GPDs}}$$

$$\mathcal{L}_z = \frac{1}{2}\int dx\, x\left[H(x,0,0) + E(x,0,0)\right] - \frac{1}{2}\int dx\, \tilde{H}(x,0,0)$$

As of today:

- one can only extract Compton Form factors from data
  - unclear there is a unique relations between CFFs and GPDs
- there exists no study how to go from a GPD to $\mathcal{L}_z$ and what the model uncertainties would be

Further theoretical work will be absolutely critical to overcome these challenges

Spin as Vehicle to Image Quarks & Gluons

Wigner function → QCD genetic map

$W(x,b_T,k_T)$

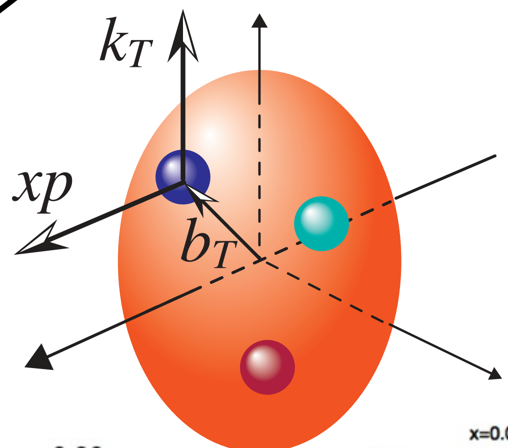
Momentum space

$\int d^2b_T$

$\int d^2k_T$

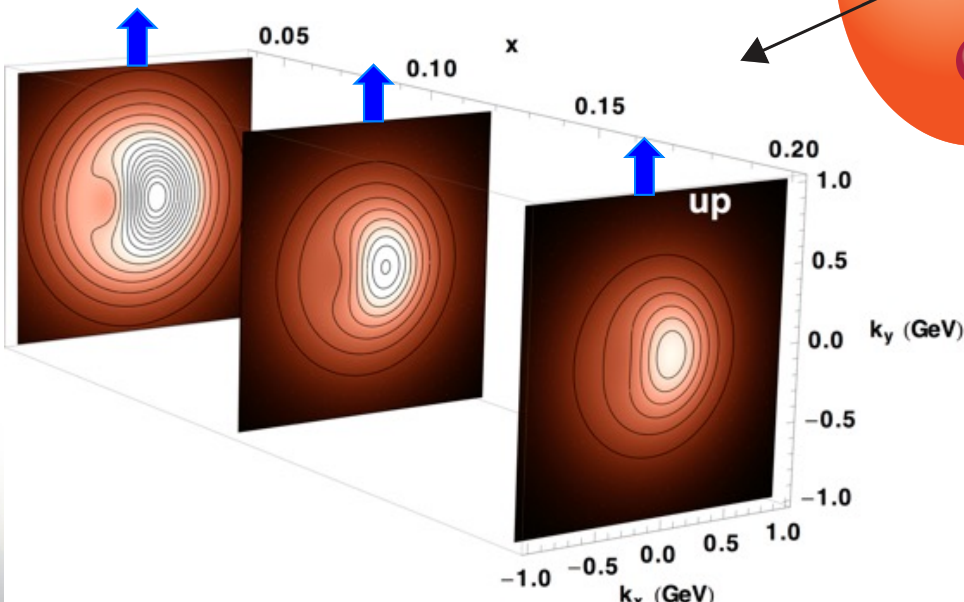
Coordinate space

$f(x,k_T)$

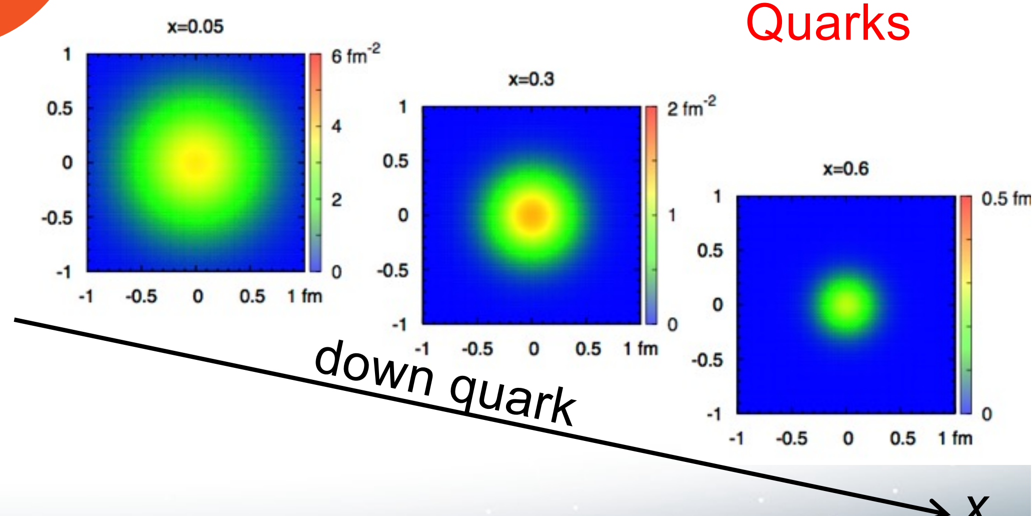


$f(x,b_T)$

Quarks



Quarks



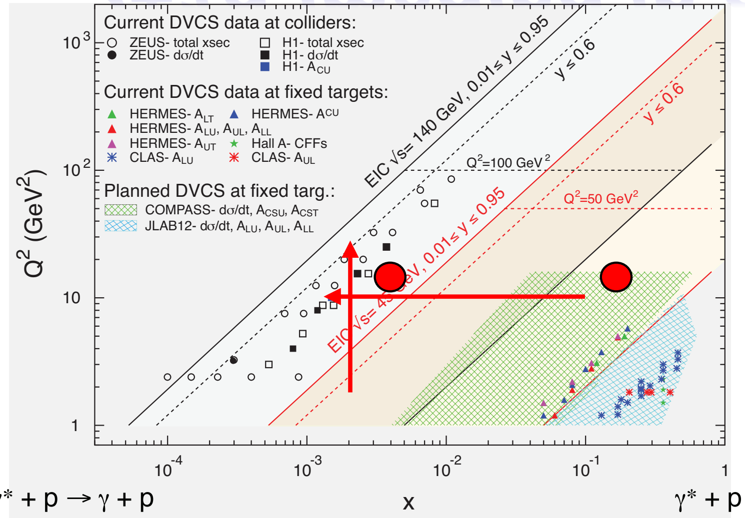
Spin-dependent 3D momentum space images from semi-inclusive scattering

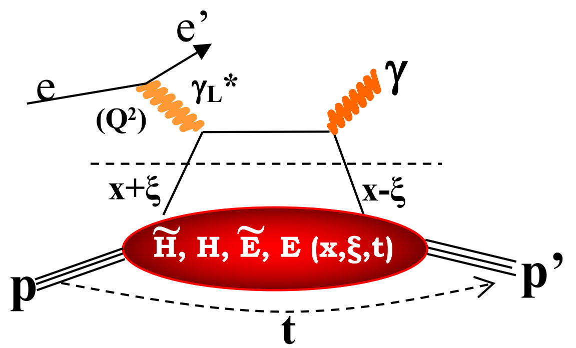
Spin-dependent 2+1D coordinate space images from exclusive scattering

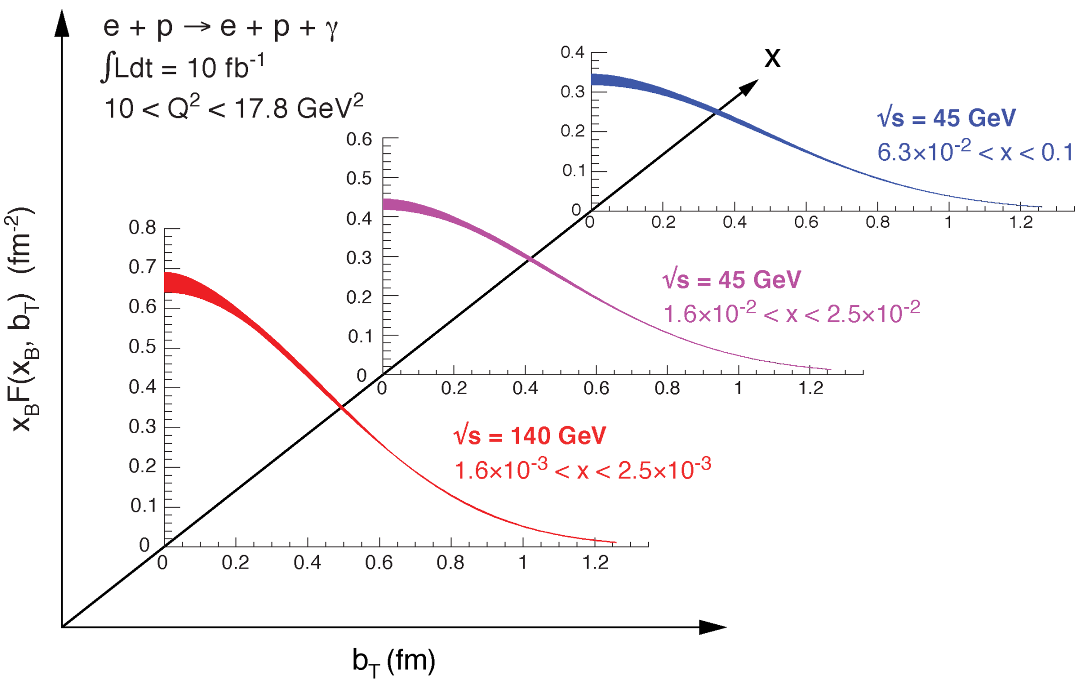
2+1d-Imaging in coordinate space

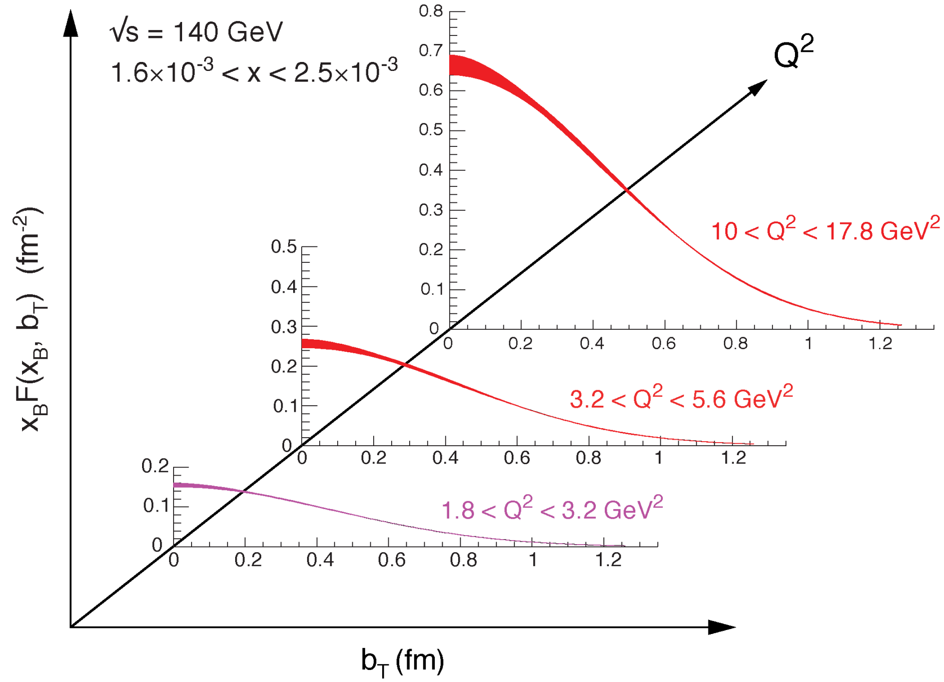
High precision imaging at EIC at low and high x

Golden channel: DVCS





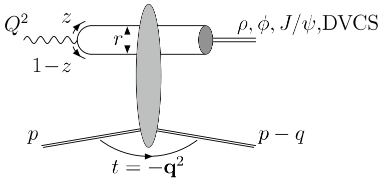


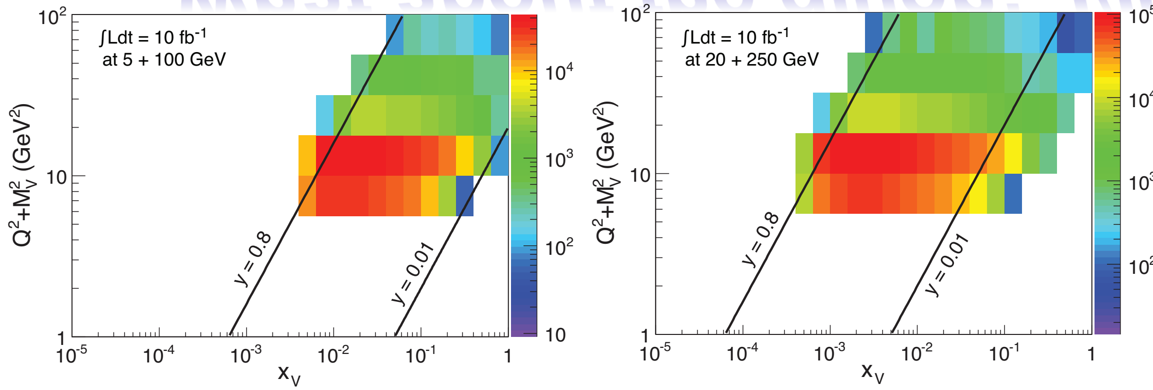


What about the gluon: J/ψ

To improve imaging on gluons
add J/ψ observables

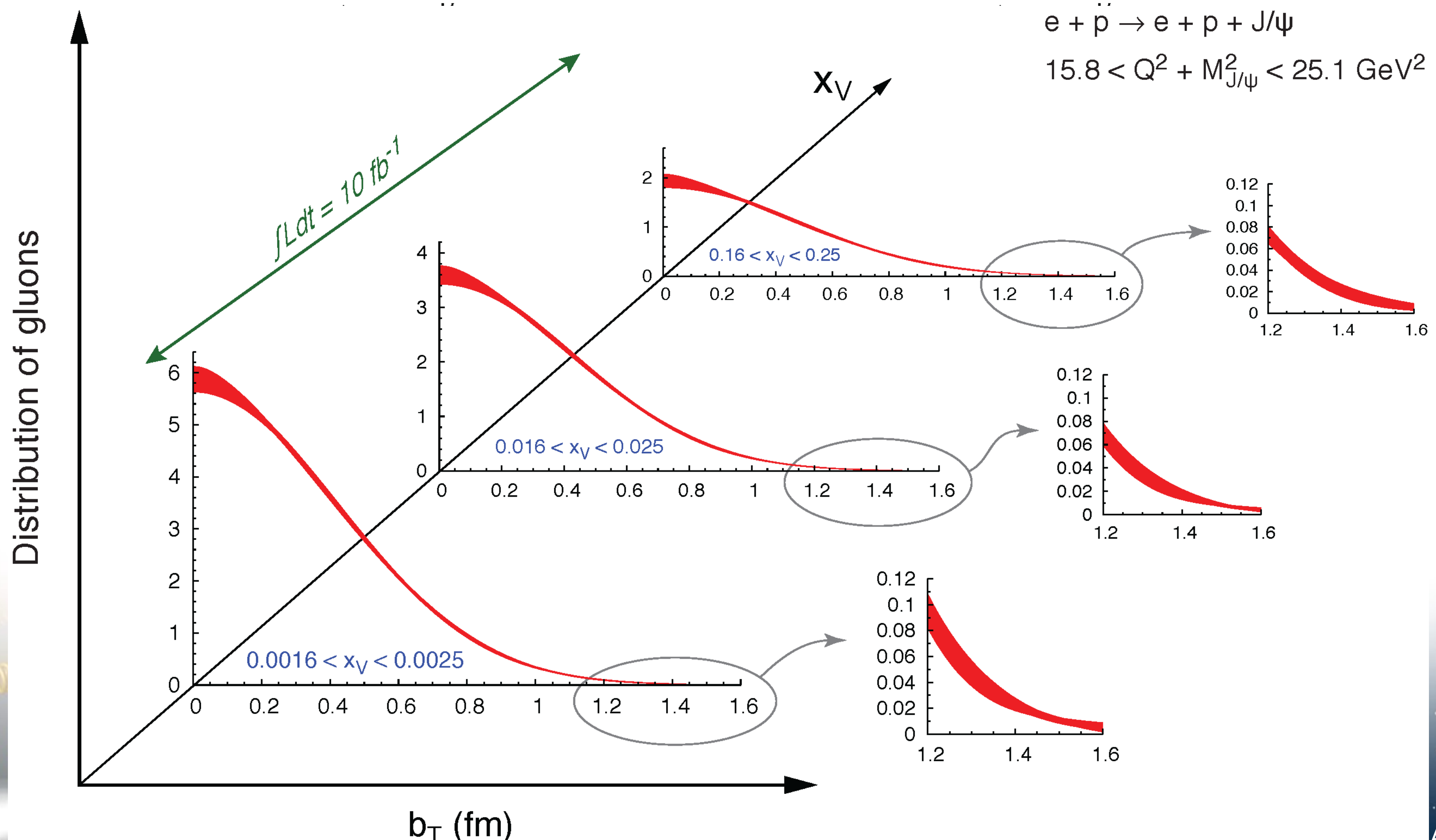
- ❑ cross section
- ❑ A_{UT}
- ❑ …..



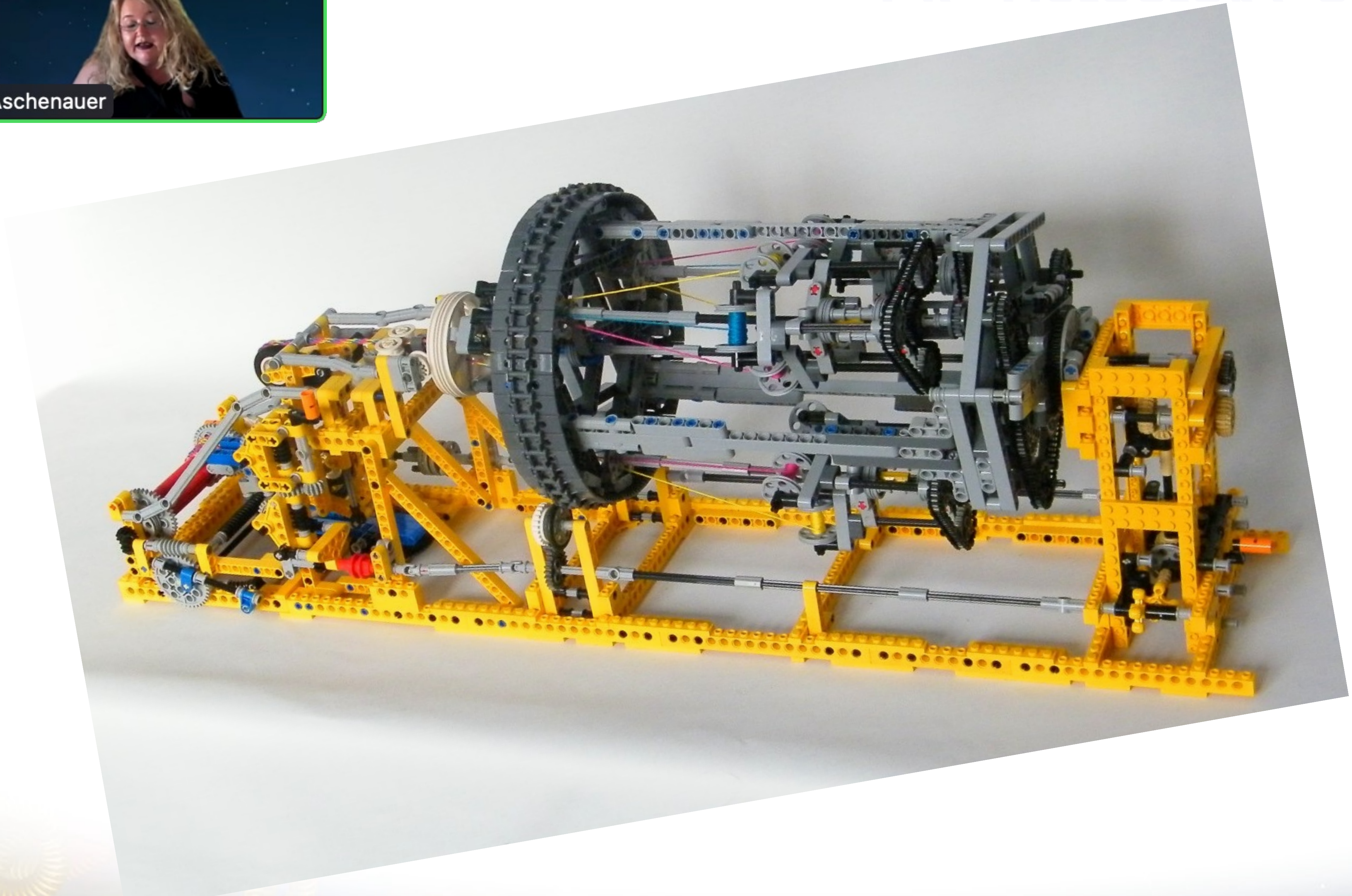


$e + p \rightarrow e + p + J/\psi$

$15.8 < Q^2 + M^2_{J/\psi} < 25.1$ GeV^2



EIC Detector Concept

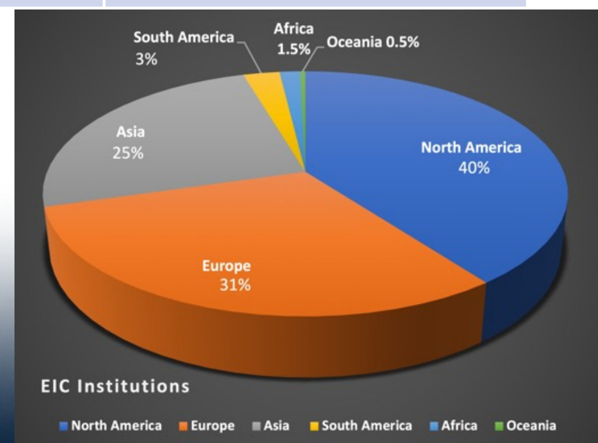


Experimental Program Preparation

Yellow Report and EIC Conceptual Design Report are both available and include a reference detector concept.

BNL and TJNAF Jointly Leading Process to Select Project Detector		
2020	Call for Expressions of Interest (EOI) https://www.bnl.gov/eic/EOI.php	May 2020
	EOI Responses Submitted	November 2020
	Assessment of EOI Responses	On-going
2021	Call for Collaboration Proposals for Detectors https://www.bnl.gov/eic/CFC.php	March 2021
	BNL/TJNAF Proposal Evaluation Committee	Spring 2021
	Collaboration Proposals for Detectors Submitted	December 2021
✓	Decision on Project Detector	March 2022

The EIC Users Group: EICUG.ORG
Formed 2016, Current Status
1330 collaborators, 36 countries, 267 institutions
(Experimentalists 830, Theory 327, Acc. Sci. 159)



Next Steps after DPAP

Great progress over the last months

ECCE is the reference design for an optimization and consolidation phase around a 1.5T solenoid, with goals to:

- integrate new collaborators in a manner that enables them to make contributions that impact the capabilities and success of the experiment in significant ways, including new collaborating individuals and groups into positions of responsibility and leadership
- integrate new experimental concepts and technologies that improve physics capabilities without introducing inappropriate risk
  - Have to consider science impact but also impact on cost, schedule and technical risk. The Project will have to make that call in the end
- advance the Project Detector to CD2/3a in a timely way (this includes starting a phase towards a pre-TDR for CD-2/3a and a TDR at CD-3)

Steps to formation of collaboration:

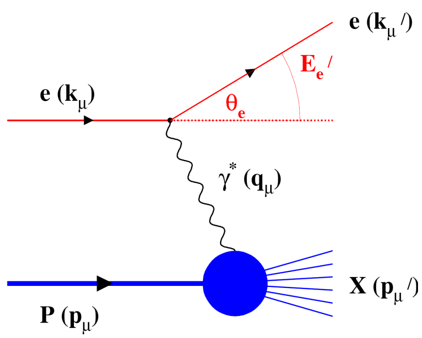
- Formed ATHENA and ECCE joint leadership team (Silvia Dalla Torre, Bernd Surrow, Or Hen, Tanja Horn, John Lajoie) together with physics and detector working groups
- Finish survey to confirm institutional interest in Detector-1
  - → form institutional board (IB) → to be finalized by EIC_UG meeting in July
  - IB appoints committee to write collaboration charter
  - After charter is established → elect collaboration management → goal: finalized by Oct/Nov 2022

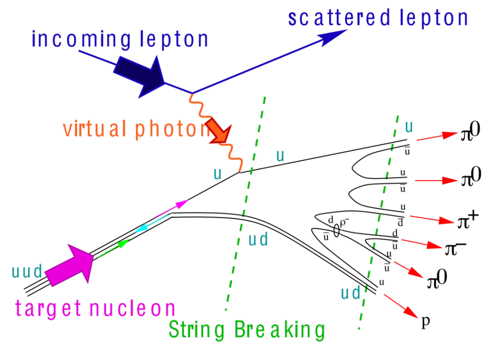
What is needed experimentally?

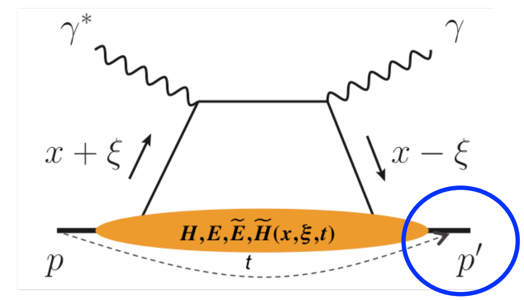
experimental measurements categories to address EIC physics:

Parton Distributions in nucleons and nuclei | **QCD at Extreme Parton Densities - Saturation** | **Spin and Flavor structure of nucleons and nuclei** | **Tomography Transverse Momentum Dist.**

QCD at Extreme Parton Densities - Saturation | **Tomography Spatial Imaging**







inclusive DIS

- measure scattered lepton

→ event kinematics
  - → e-ID: e/h separation
  - → reach to lowest x, Q^2 impacts Interaction Region design

semi-inclusive DIS

- measure scattered lepton and hadrons in coincidence
- multi-dimensional binning: x, Q^2, z, p_T, Θ
  - → particle identification over entire kinematic region is critical
  - → Jets: excellent E_T, jet-energy scale

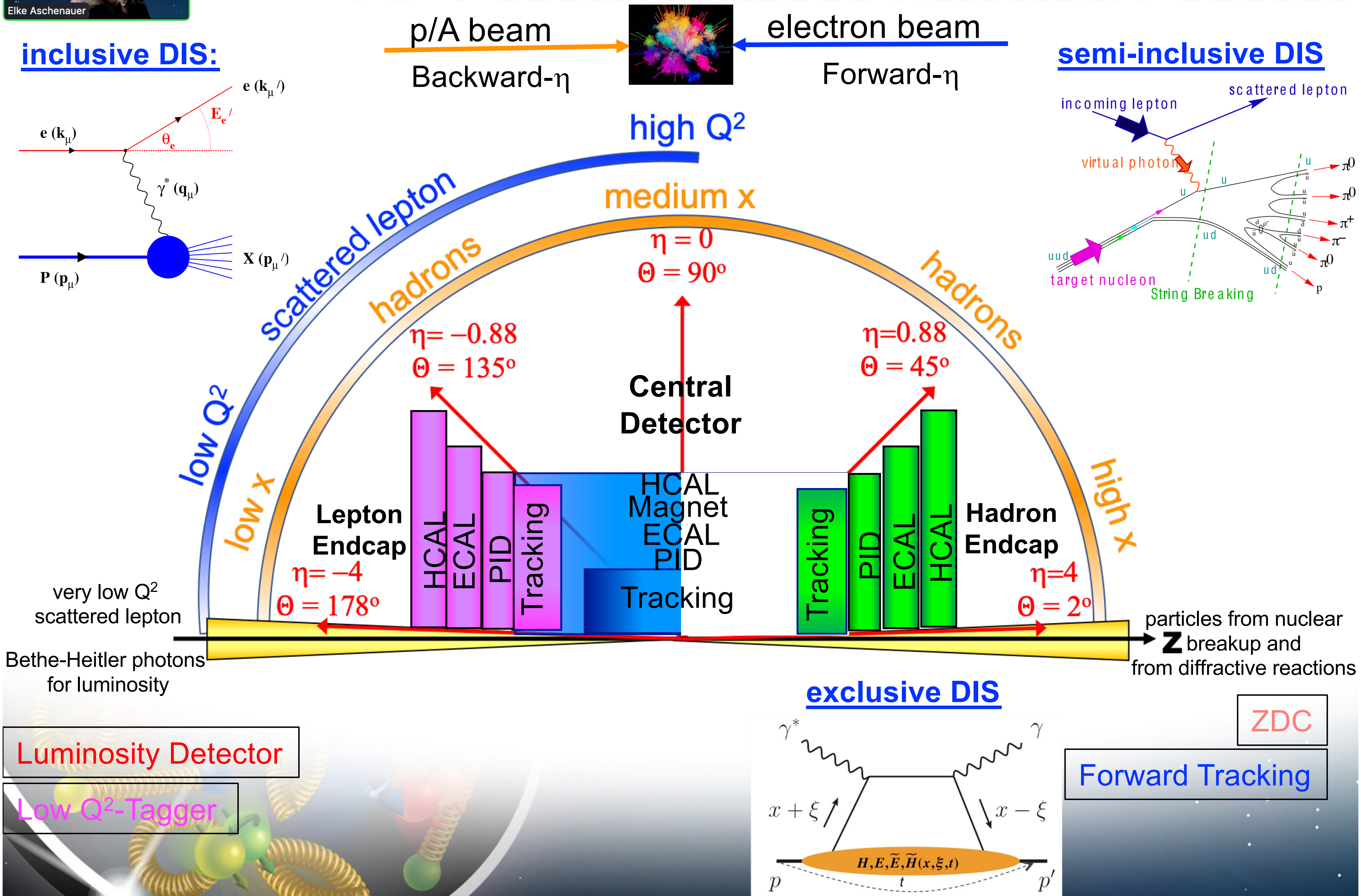
exclusive processes

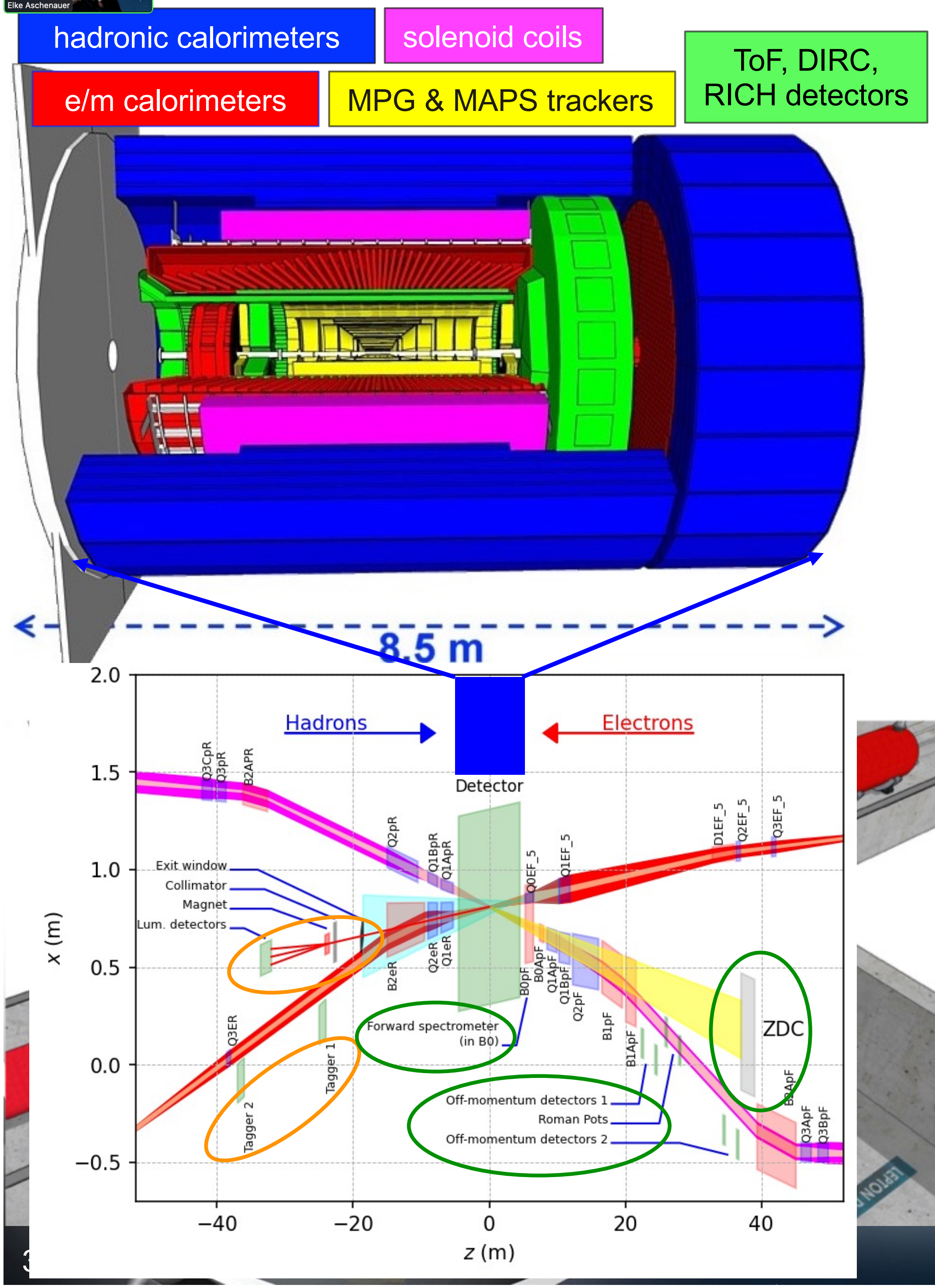
- measure all particles in event
- multi-dimensional binning: x, Q^2, t, Θ
- proton p_t: 0.2 - 1.3 GeV
  - → cannot be detected in main detector
  - → strong impact on Interaction Region design

$\int Ldt$: 1 fb^{-1} | 10 fb^{-1} | 10 - 100 fb^{-1}

machine & detector requirements

EIC General Purpose Detector: Concept





Experimental Equipment

Basis for EIC Project Detector

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

Overall detector requirements:

- Large rapidity ($-4 < \eta < 4$) coverage; and far beyond especially in far-forward detector regions
  - → Integration into IR from the beginning critical
  - Large acceptance for diffraction, tagging, neutrons from nuclear breakup: critical for physics program
    Many ancillary detector along the beam lines: low-Q^2 tagger, Roman Pots, Zero-Degree Calorimeter, ….
- High precision low mass tracking
  - small (μ-vertex Silicon) and large radius (gaseous-based) tracking
- Electromagnetic and Hadronic Calorimetry
  - equal coverage of tracking and EM-calorimetry
- High performance PID to separate e, π, K, p on track level
  - good e/h separation critical for scattered electron identification
- Maximum scientific flexibility
  - Streaming DAQ → integrating AI/ML
- High control of systematics
  - luminosity monitor, electron & hadron Polarimetry

What is new/special for a EIC GPD

Vertex detector → Identify primary and secondary vertices,
Low material budget: 0.05% X/X_0 per layer;
High spatial resolution: 10 μm pitch CMOS Monolithic Active Pixel Sensor (MAPS)
→ synergy with Alice ITS3

Central tracker → Measure charged track momenta
MAPS – tracking layers in combination with micro pattern gas detectors

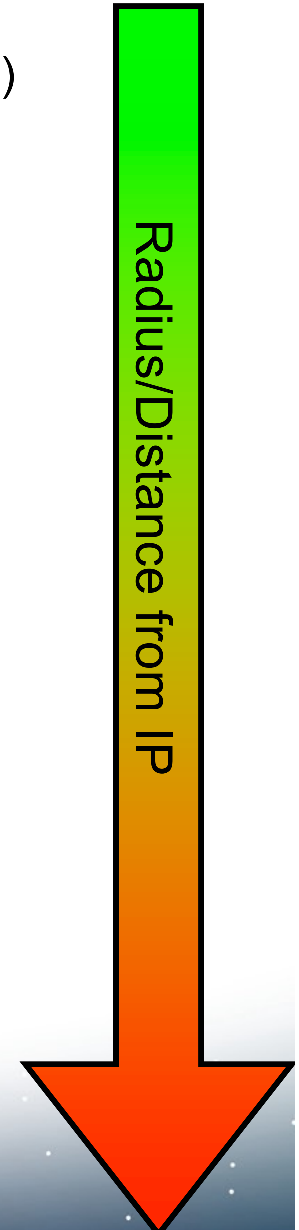
electron and hadron endcap tracker → Measure charged track momenta
MAPS – disks in combination with micro pattern gas detectors

Particle Identification → pion, kaon, proton separation
RICH detectors & Time-of-Flight
high resolution timing detectors (, LAPPS, LGAD) 10 – 30 ps
novel photon sensors: MCP-PMT / LAPPD

Electromagnetic calorimeter → Measure photons (E, angle), identify electrons
Crystals (backward), W/SciFi Spacal (forward)
Barrel: Pb/SciFi+imaging part or Scintillating glass → cost effective

Hadron calorimeter → Measure charged hadrons, neutrons and K_L^0
challenge achieve ~50%/√E + 10% for low E hadrons (<E> ~ 20 GeV)
Fe/Sc sandwich with longitudinal segmentation

DAQ & Readout Electronics: trigger-less / streaming DAQ
Integrate AI into DAQ → cognizant Detector



+ Beam pipe and very forward and backward detectors

Let's get to work and built the EIC

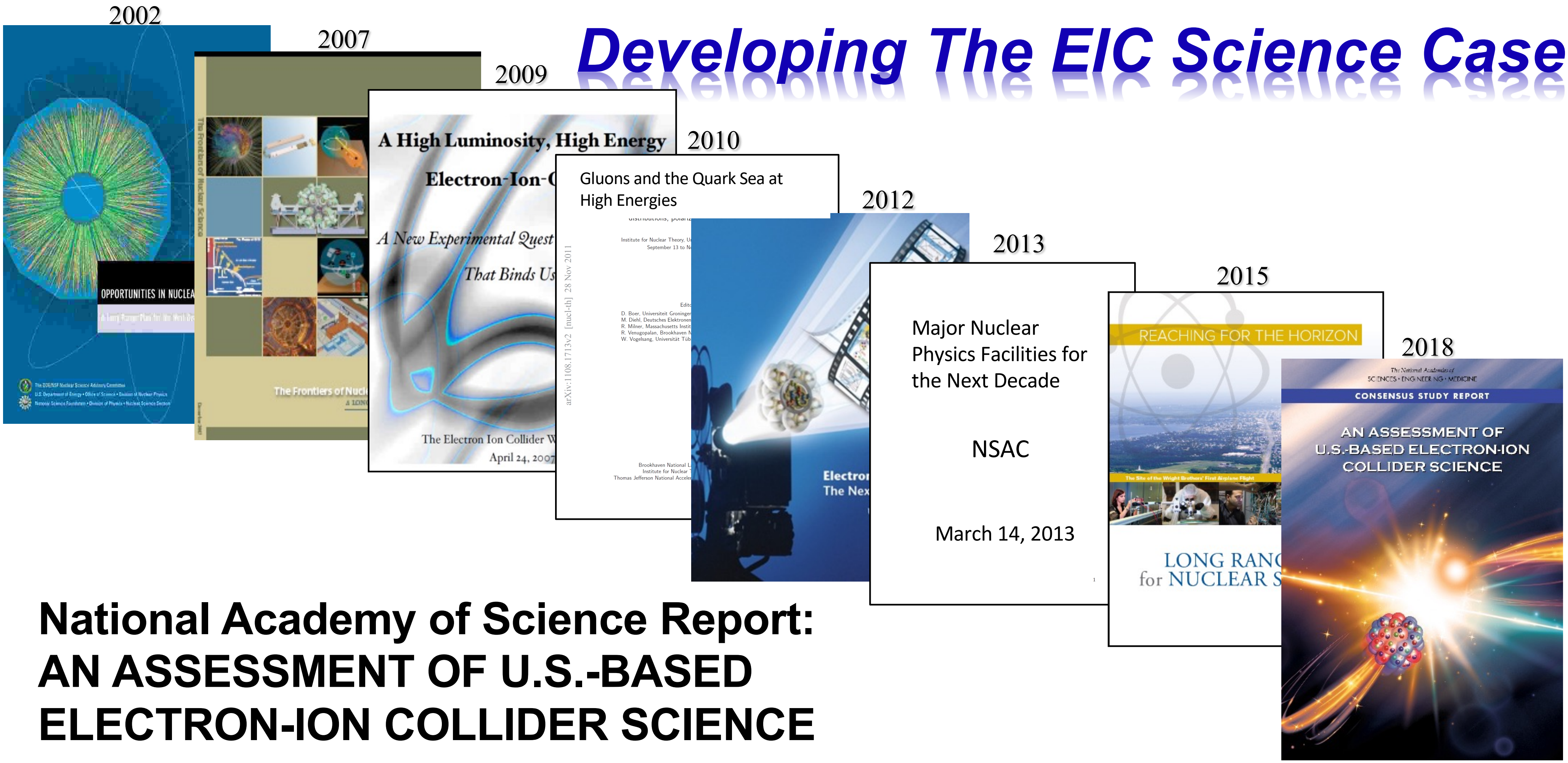
Please join us


Elke Aschenauer


BACK UP

The EIC Project

Developing The EIC Science Case



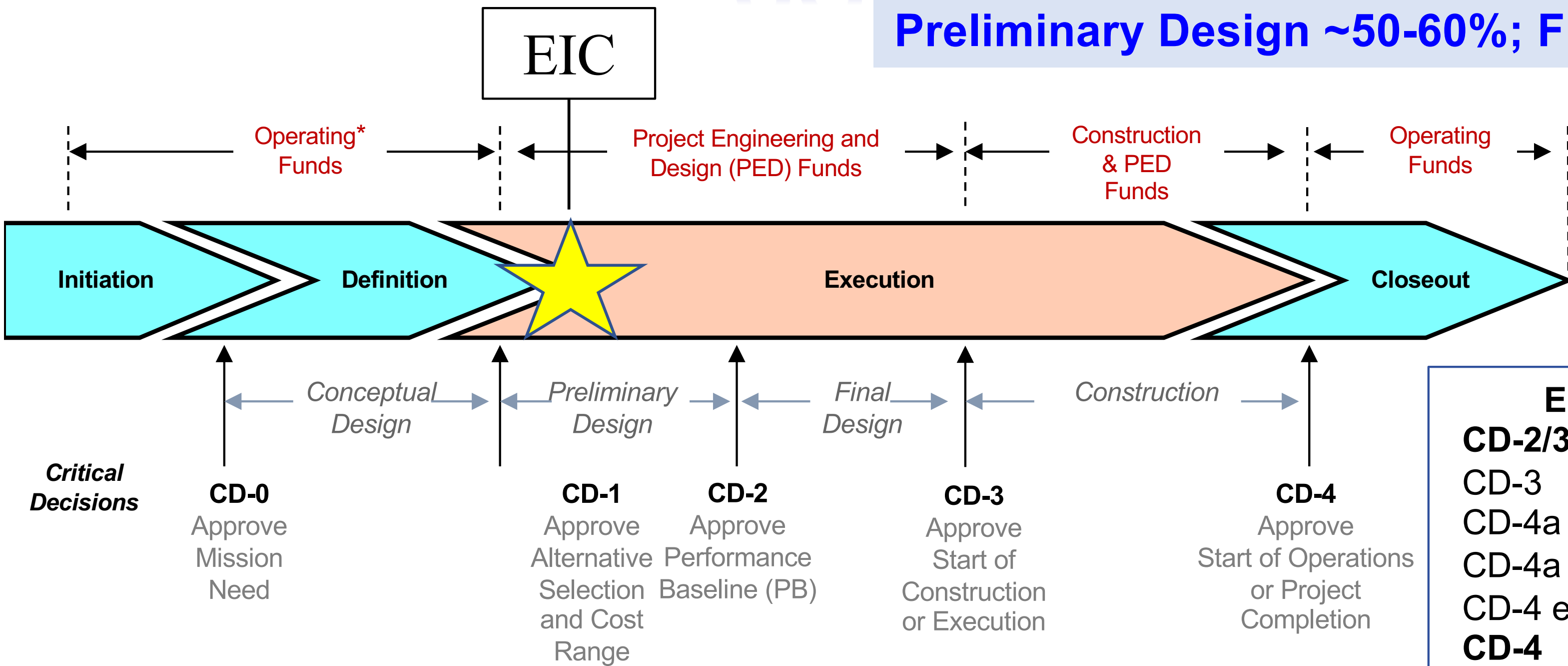
National Academy of Science Report:
AN ASSESSMENT OF U.S.-BASED ELECTRON-ION COLLIDER SCIENCE

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

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

DOE Project Decision Process

Preliminary Design ~50-60%; Final Design ≥ 85%



EIC Critical Decision Plan	
CD-2/3a	**January 2024**
CD-3	April 2025
CD-4a early finish	April 2031
CD-4a	April 2032
CD-4 early finish	April 2032
CD-4	**April 2034**

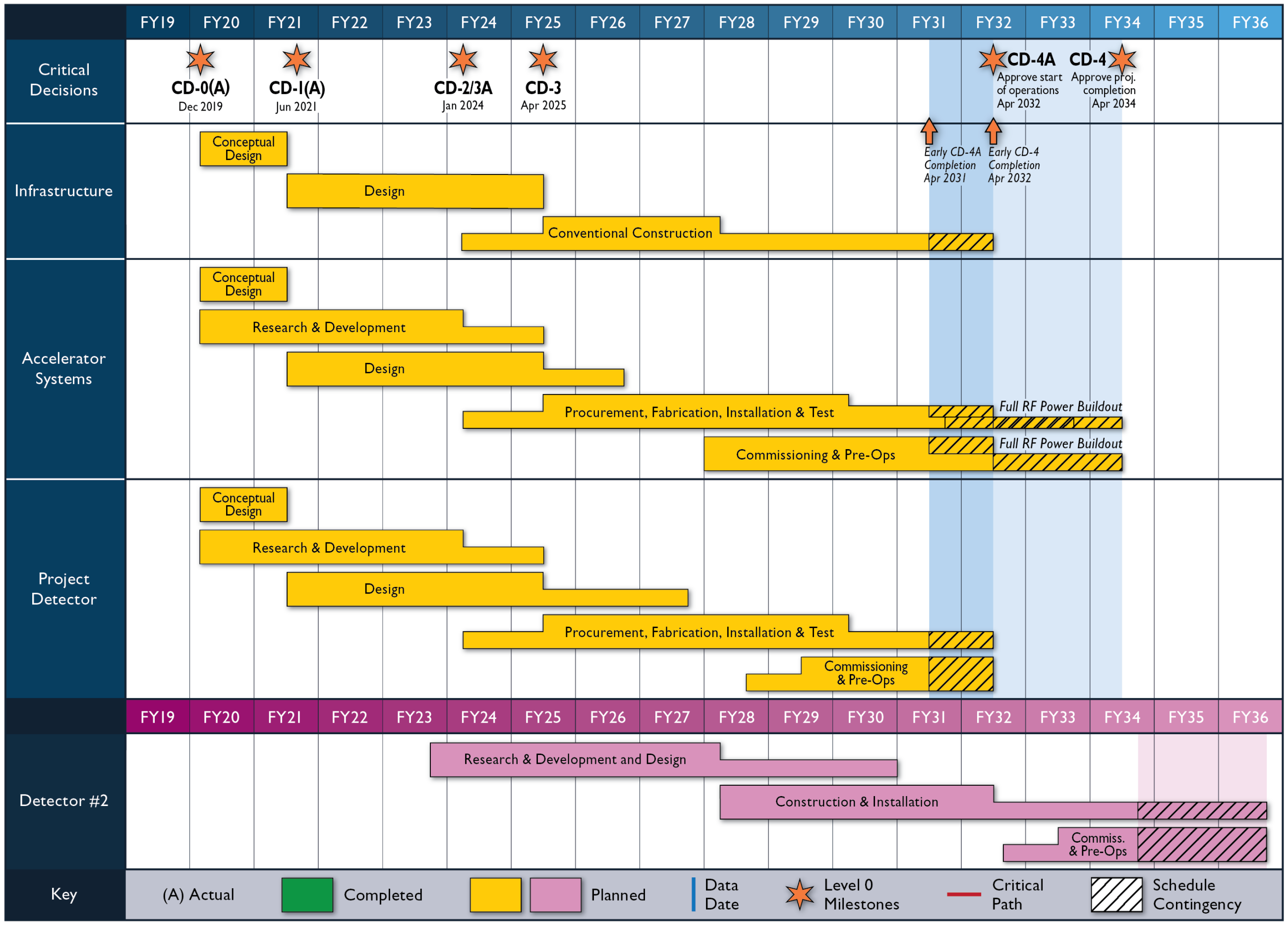
CD-2 – Approve Performance Baseline: CD-2 is an approval of the preliminary design of the project and the baseline scope, cost, and schedule. What is most relevant is that CD-2 means there is now a definitive plan that the project will be measured against in cost, schedule and technical performance.

→ pre-TDR is required for CD-2

CD-3 – Approve Start of Construction: CD-3 is an approval of the project's final design and authorizes release of funds for construction. What is most relevant is that projects can now proceed with construction related procurements and activities. CD-3 is sometimes split in CD-3A in a tailored approach to approve start construction for long-lead procurements.

→ TDR is required for CD-3

2nd Detector and IR



- Current assumption realization trailing ~3 – 5 years behind EIC Detector-1
- DOE is initiating generic EIC detector R&D program
  - focus on complementary technologies for 2nd Detector and future upgrades for Detector-1

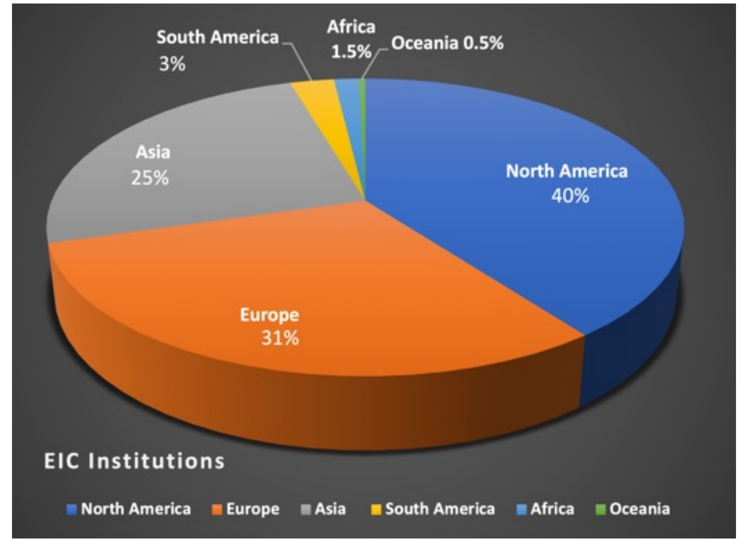
World-Wide Interest in EIC Physics

The EIC Users Group: EICUG.ORG

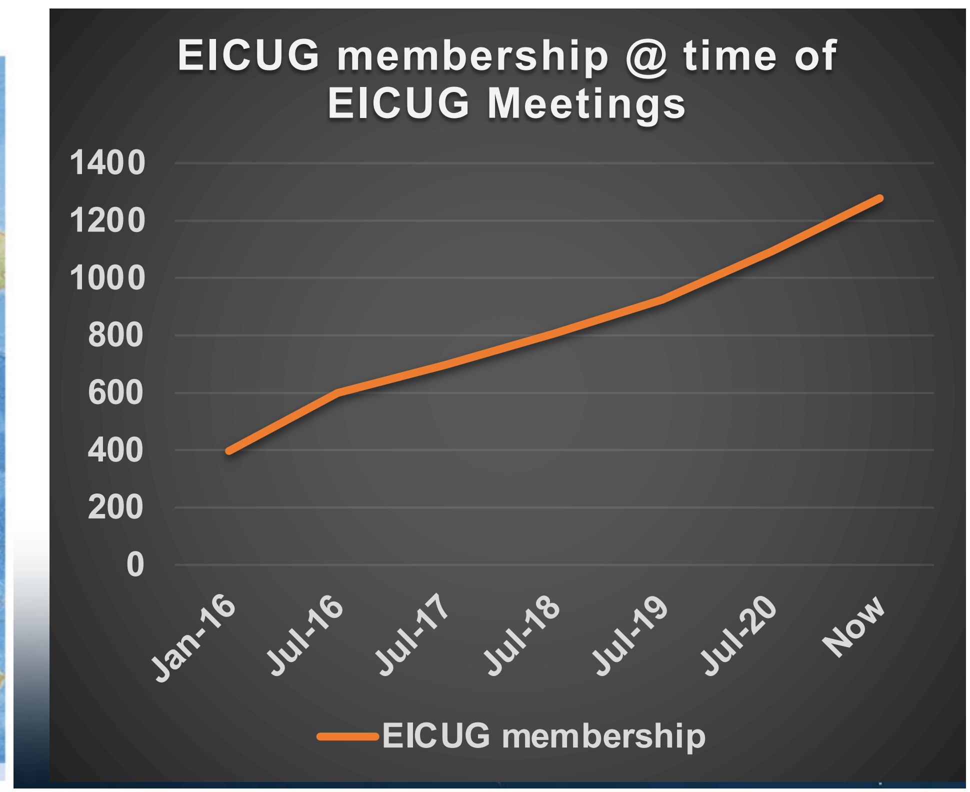
Formed 2016, Current Status

1330 collaborators, 36 countries, 267 institutions
(Experimentalists 830, Theory 327, Acc. Sci. 159)

- EICUG has continuously grown since its formation, notably after CD-0 and site-selection
- Growth will as EIC project moves into construction



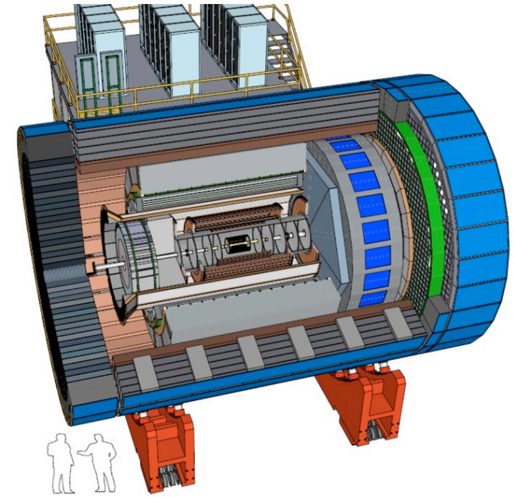
Location of Institutions



EIC Proto-Collaborations

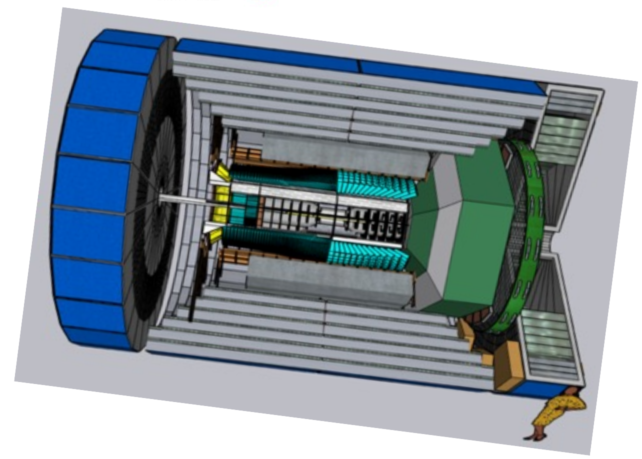
ATHENA (https://sites.temple.edu/eicatip6/)

- Focus on becoming the “project detector”@IP6
- New 3 T magnet and the YR Reference Detector
- Leadership: S. Dalla Torre (INFN Trieste, B. Surrow (Temple)
- ~117 collaborating institutions from Armenia, Canada, China, Czech, France, Germany, Italy, India, Poland, Romania, UK



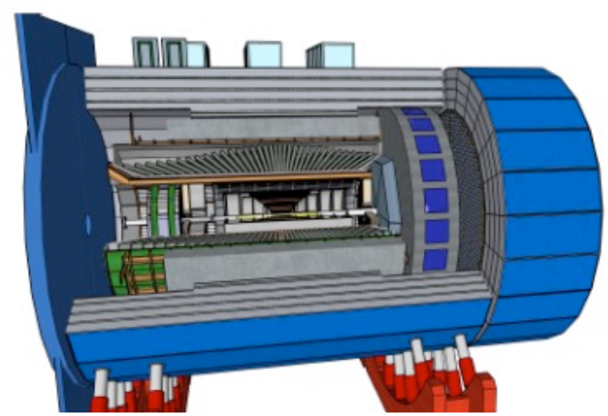
CORE (https://eic.jlab.org/core/)

- An EIC Detector proposal based on a new 3 T compact magnet for the 2nd EIC detector @ IP8
- Contacts: Ch. Hyde (ODU) and P. Nadel-Turonski (SBU)
- Smaller-scale effort, ~20-30 active collaborators



ECCE (https://www.ecce-eic.org)

- Project detector @IP6 or the 2nd EIC detector @ IP8 using existing 1.5T “Babar” solenoid
- Leadership: O. Hen (MIT), T. Horn (CUA), J. Lajoie (Iowa State)
- ~98 collaborating institutions from Armenia, Canada, Chile, Croatia, China, Czech, France, Germany, Israel, Japan, Senegal, Korea, Russia, Slovenia, Taiwan, UK



Detector Proposal Advisory Panel

- Reviewed detector proposals from the three proto-collaborations - all three proposals received high marks
- Concluded that ATHENA and ECCE satisfied the requirements
- Noted that many collaborators are involved in multiple proposals and none of the proto-collaborations are currently strong enough to build the project detector
- Strongly encouraged the three proto-collaborations to move forward together based on ECCE as the reference design for the project detector
- Expects the integration of new collaborators and new experimental concepts and technologies to improve physics capabilities, and to prepare the detector as part of the EIC project baseline, the next major DOE schedule milestone
- Enthusiastically supported a second detector as needed to take full advantage of the unique capabilities of EIC facility
- Expects the EIC User Community to come together in support of the project detector as well as a second detector

Agreements with International Partners

We are tracking closely what documents are required and what is in place

Documents needed by CD-2 for international collaboration Experimental Equipment

Country, Institution, Funding Agency	Gov. to Gov. / Agency to Agency		NP Program to Program Project Annex			Statement of Interest			Project-to-Project			DOE collaboration encouragement letter		EIC-Project collaboration encoragement letter	
	needed	existing	needed	in preparation	existing	needed	in preparation	existing	needed	in preparation	existing	requested	provided	requested	provided
Armenia															
Argentina															
Australia		in preparation													
Brasil															
Canada		SC with State initiating S&T agreement, followed by Agency to Agency													
CERN				in preparation											
Chile															
China															
Czech Rep.				in plan for next phase											
France-CEA				in preparation											
France-IN2P3															
Germany															
Hungary															
India				in plan for next phase											
Israel				in plan for next phase											
Italy															
Japan				in preparation											
Mexico		May be US-Canada-Mexico - Will check with GC if this can be used.													
Poland				Met with the funding agency											
Romania															
South Korea				in preparation											
Spain		in preparation													
Taiwan															
UK				in preparation											

Collaboration – Project

6.10 EIC Detector
Rolf & Elke
Level-2

- 6.10.01 Detector Management
- 6.10.08 Electronics
- 6.10.02 Detect. R&D & Physics Design
- 6.10.09 DAQ / Computing
- 6.10.03 Tracking
- 6.10.10 Detector Infrastructure
- 6.10.04 Particle Identification
- 6.10.11 IR Integration & Auxiliary Detectors
- 6.10.05 Electromagn. Calorimetry
- 6.10.12 Detector Pre-Ops & Commiss.
- 6.10.06 Hadronic Calorimetry
- 6.10.13 Detector #2 Development
- 6.10.07 Magnets
- 6.10.14 Polarimetry and Luminosity

6.10.04 Particle Identification Level-3

- 6.10.04.01 Backward RICH Level-4
- 6.10.04.02 Barrel DIRC Level-4
  - 6.10.04.01.01 DIRC-Photon-sensors Level-5
  - 6.10.04.01.02 DIRC-Quartz-bars Level-5
- 6.10.04.03 Forward RICH Level-4
- 6.10.04.04 Time-of-Flight Level-4

We need a control account manager (CAM) at each WBS level. WBS levels go down to where it is meaningful to accumulate cost and schedule variance. There can be many Work Packages below.

Integrating Collaborators:

- In-kind partners integrated into the project delivery organization and responsible for their project deliverables
- Close interaction between the project and the detector collaboration with collaborators taking lead roles on work packages and project deliverables

Fold in users/collaborators as

- L3/L4 point of contacts?
- L3/L4/L5 owners?
- Work Package owners

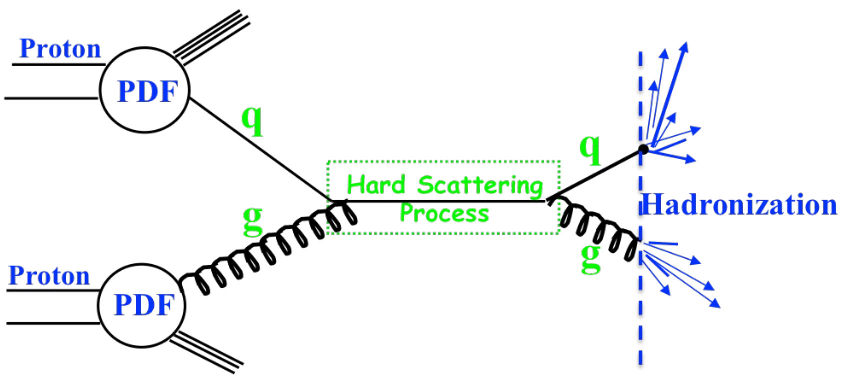
Why do we need different probes

Complementarity

QCD has two concepts which lay its foundation
factorization and universality

To tests these concepts and separate interaction dependent phenomena from intrinsic nuclear properties
different complementary probes are critical
Probes: high precision data from ep, pp, e+e-

Factorization

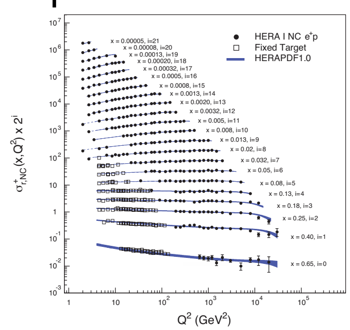


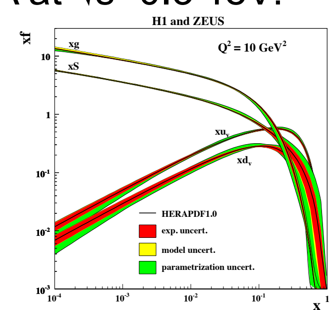
(un)polarized cross section ~
PDF $\otimes$ hard-scattering $\otimes$ Hadronization

hard-scattering : calculable in QCD
PDFs and Hadronization: need to be determined experimentaly

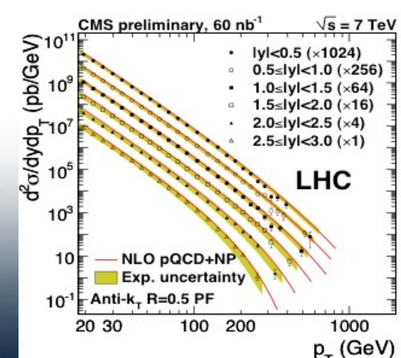
Universality

Example: Measure PDFs at HERA at $\sqrt{s}$=0.3 TeV:

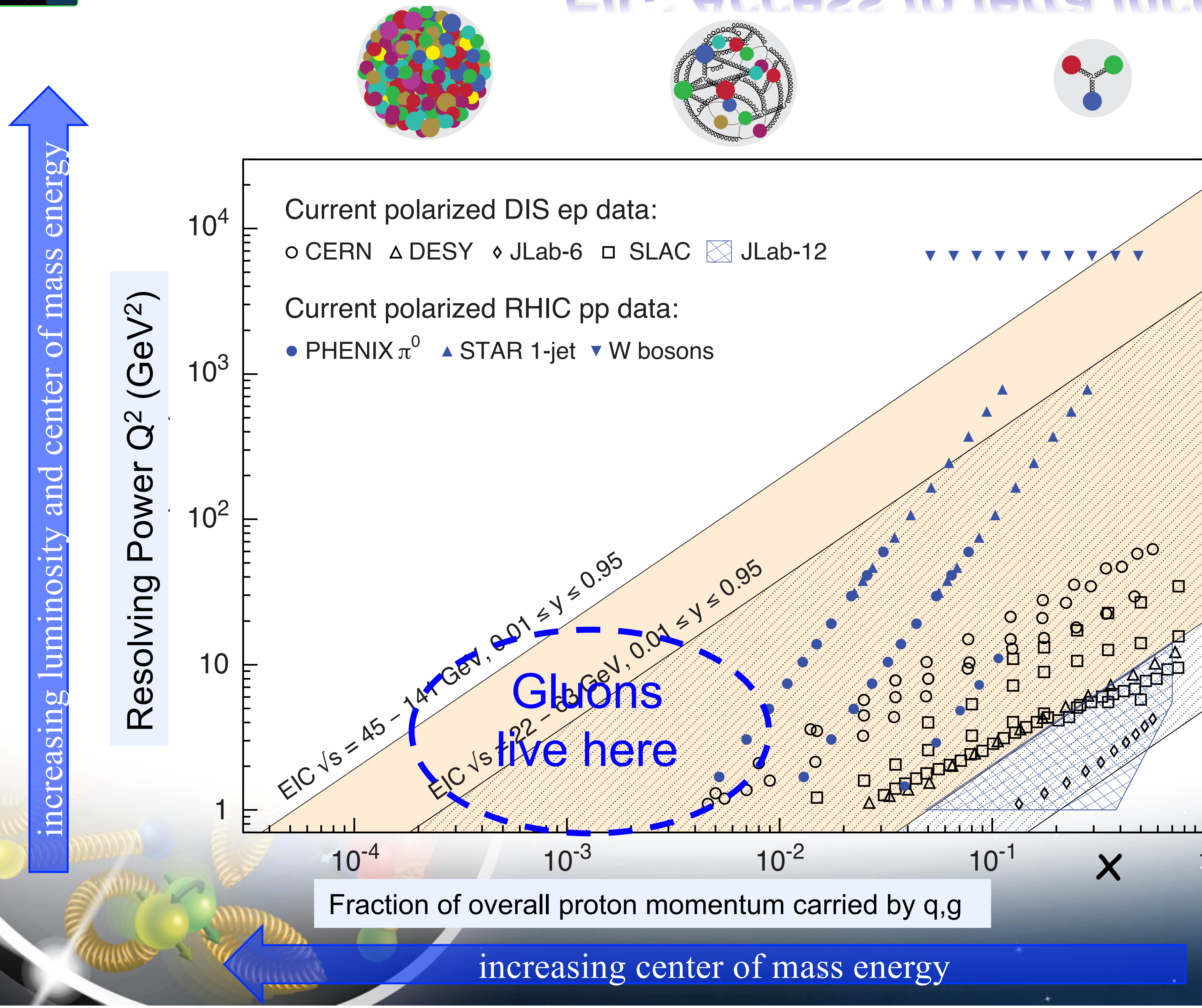




Predict pp and $p\bar{p}$ measurements at $\sqrt{s}$=0.2, 1.96 & 7 TeV

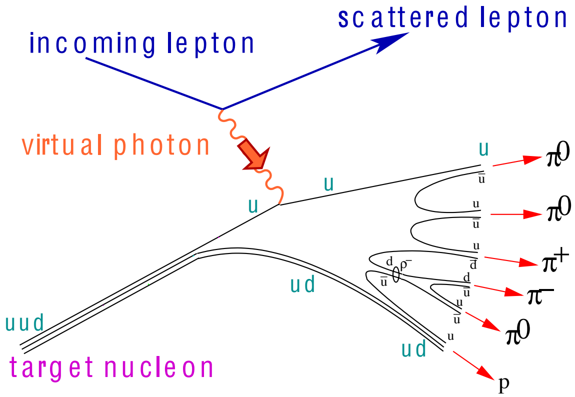


EIC: Access to terra incognita



HOW TO ACCESS PARTONS IN DIS

SIDIS:



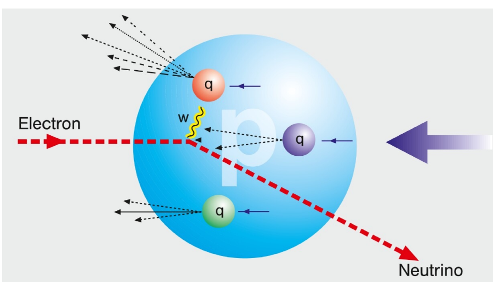
Detect scattered lepton (DIS) in coincidence with identified hadrons (SIDIS)

→ one can measure the correlation between different hadrons as fct. of p_t, z, η

→ needs fragmentation functions to correlate hadron type with parton

→ Detector: PID over a wide range of η and p

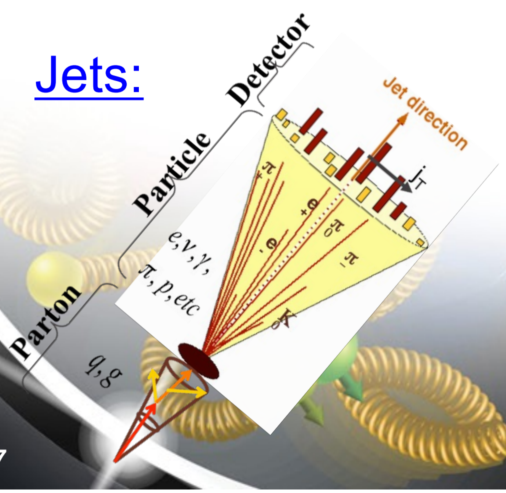
Charge Current:



W-exchange: direct access to the quark flavor
no FF – complementary to SIDIS

→ Detector: large rapidity coverage and large √s

Jets:



best observable to access parton kinematics
tag partons through the sub-processes and jet substructure

→ di-jets: relative p_t → correlated to k_t

→ tag on PGF

→ Detector: large rapidity coverage and PID

How to access Gluons in DIS

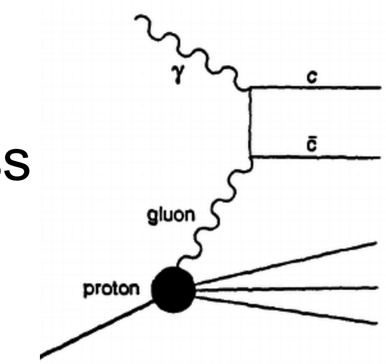
1. Gluons manifest themselves through
   the scaling violation of the cross section as function of x and Q^2
   $dF_2(x,Q^2)/d\ln Q^2 \rightarrow G(x,Q^2)$

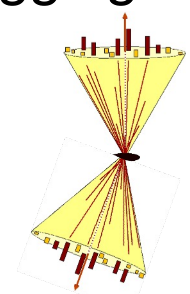
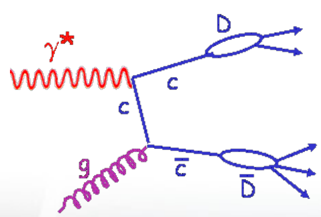
$$\frac{d^2\sigma^{ep\rightarrow eX}}{dxdQ^2} = \frac{4\pi\alpha^2_{e.m.}}{xQ^4}\left[\left(1-y+\frac{y^2}{2}\right)F_2(x,Q^2)-\frac{y^2}{2}F_L(x,Q^2)\right]$$

quark+anti-quark momentum distributions (F_2)

gluon momentum distribution (F_L)

2. Directly through the measurement of F_L



3. Through tagging of the photon gluon fusion process
   1. Di-jets
   
   2. charm production
   

All these process need a wide coverage in x and Q^2

EICUG: Yellow Report (YR) Initiative

The EIC Users Group: EICUG.ORG
Report: https://arxiv.org/abs/2103.05419

Detector requirements and design driven by EIC Physics program and defined by EIC Community

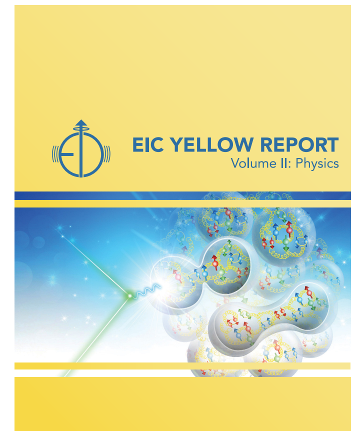
Physics Topics → Processes → Detector Requirements

Physics Working Group:

Inclusive Reactions
Semi-Inclusive Reactions
Jets, Heavy Quarks
Exclusive Reactions
Diffractive Reactions & Tagging

Detector Working Group:

Tracking + Vertexing
Particle ID
Calorimetry
DAQ/Electronics
Polarimetry/Ancillary Detectors
Central Detector: Integration & Magnet
Far- Forward Detector & IR Integration



Provides critical input for detector proposals

Background/Radiation

Important to note:

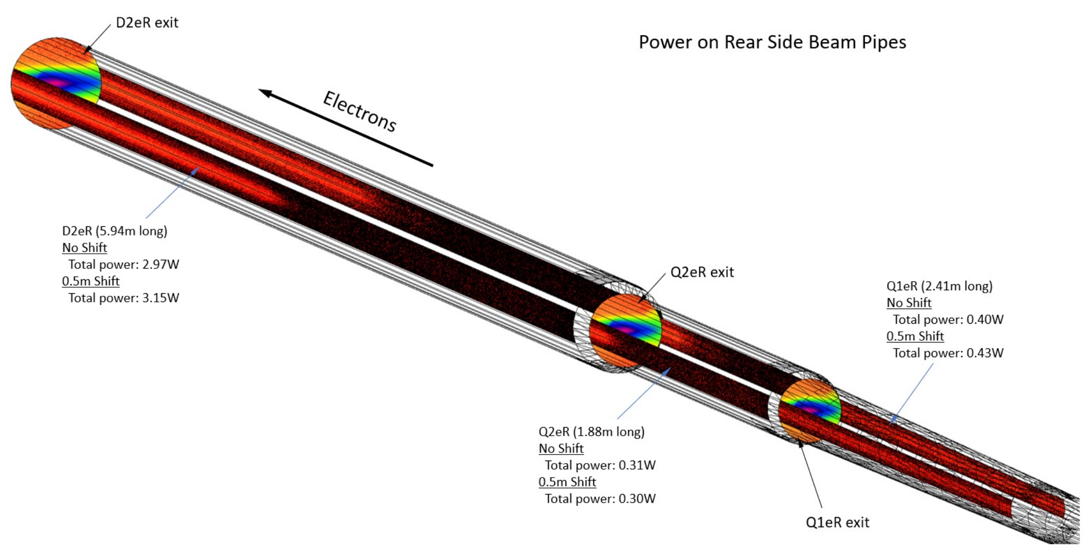
- low multiplicity per event: < 10 tracks
- $\eta > 2$: avg. hadron track momenta @ 141 GeV: ~20 GeV
- No pileup from collisions 500 kHz @10^{34} $cm^{-2}s^{-1}$ → coll. every 200 bunches
- radiation environment much less harsh than LHC → factor 100 less

The HERA and KEK experience show that having backgrounds under control is crucial for the EIC detector performance

- There are several background/radiation sources :
  - primary collisions
  - beam-gas induced
  - synchrotron radiation

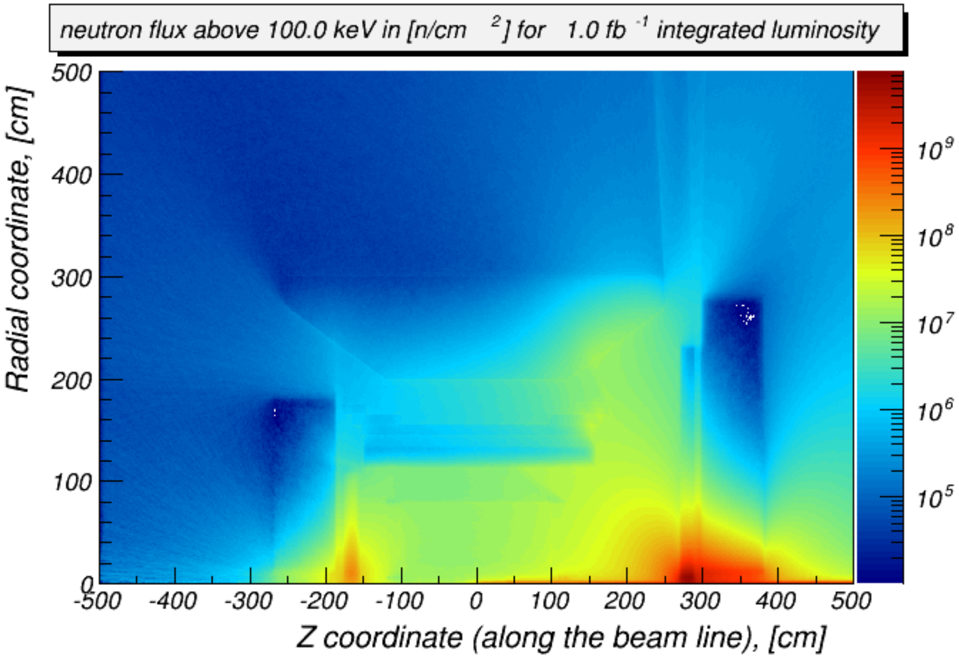
Synchrotron Radiation:

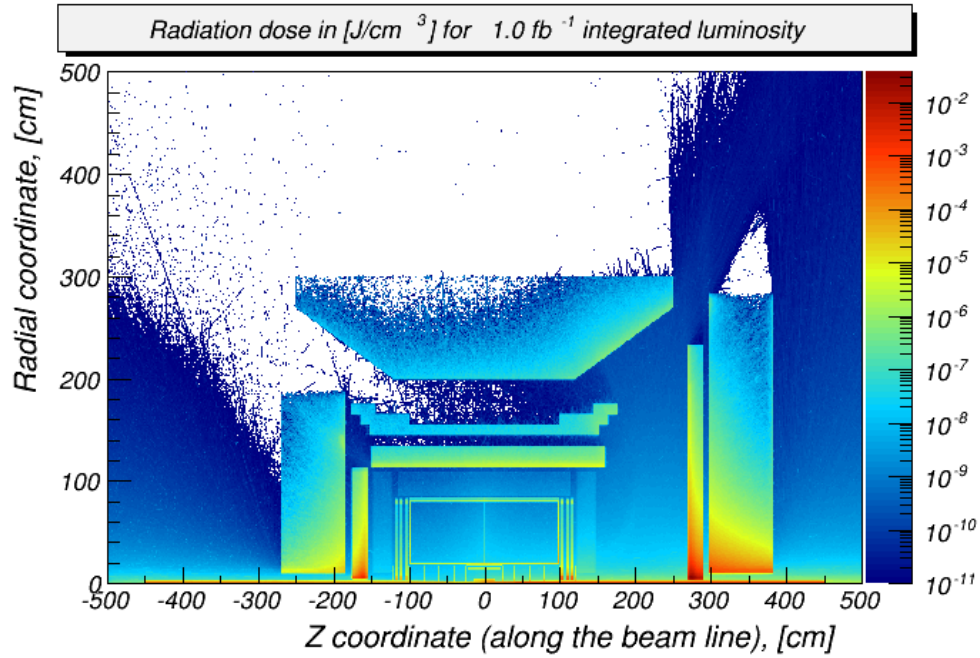
- Origin: quads and bending magnet upstream of IP
- Tails in electron bunches: can produce hard radiation
- Studied using Synrad3D



Background/Radiation

- Primary collisions contribute a substantial fraction of the ionizing radiation and low energy neutron fluence in the experimental hall





→forward EmCal: up to ~5*10^9 n/cm^2 per fb^{-1} (*inside the towers*); perhaps ~5 less at the SiPM location

→ backward EmCal: ~250 rad/year (at "nominal" luminosity ~10^{33} cm^{-2} s^{-1})

- Beam-gas interactions are one of the main sources of neutrons that thermalize within the detector hall and cause the damage.
- The current FLUKA simulations show that the EIC detector will obtain annual dose of 6*10^{10} n/cm^2 (1 MeV equivalent)
  → Impact on SiPMs and Silicon Vertex Tracker → suggested tolerance of 10^{14} n/cm^2

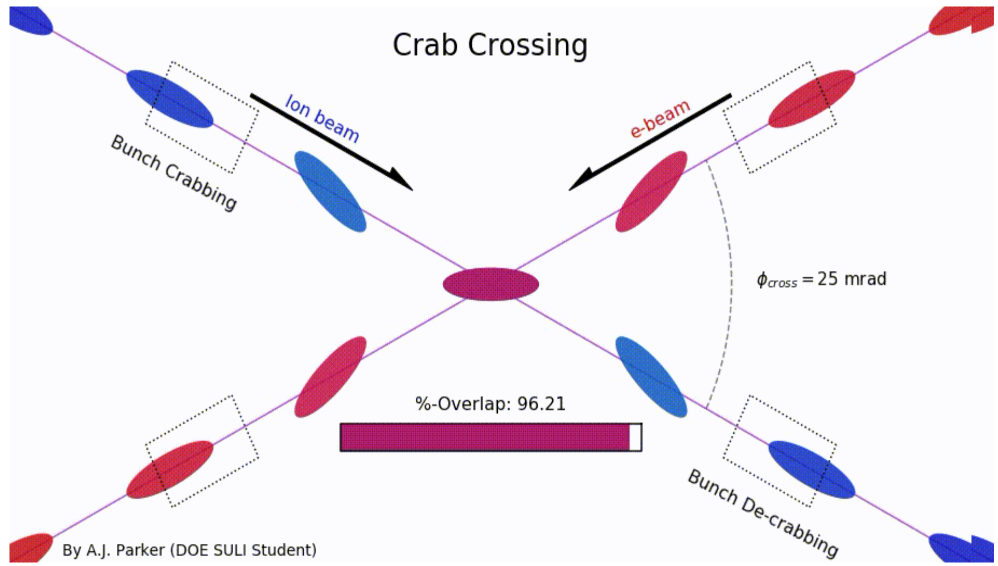
Why a Crossing Angle

- ❑ Brings focusing magnets close to IP
  → high luminosity
- ❑ Beam separation without separation dipoles
  → reduced synchrotron radiation

But significant loss of luminosity

Solution: Crab crossing

- ❑ Head-on collision geometry is restored by rotating the bunches before colliding ("crab crossing")
- ❑ Bunch rotation ("crabbing") is accomplished by transversely deflecting RF resonators ("crab cavities")
- ❑ Actual collision point moves laterally during bunch interaction
- ❑ Challenges
  - ➢ Bunch rotation (crabbing) is not linear due to finite wavelength of RF resonators (crab cavities)
  - ➢ Severe beam dynamics effects
  - ➢ Physical size of crab cavities

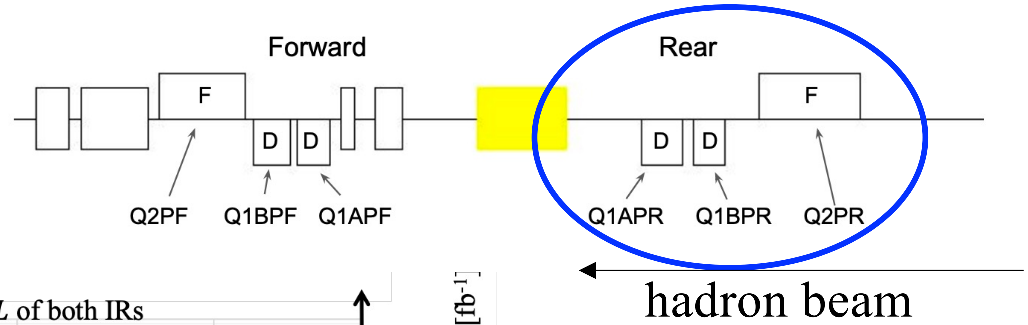


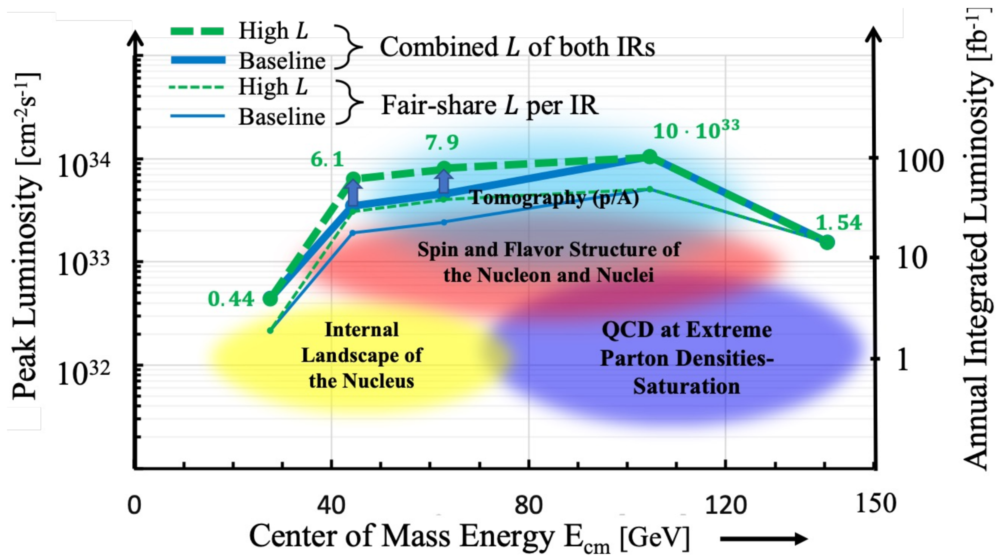
Significant impact on main and forward detector acceptance

Progress: Luminosity at lower E_{cm}

- Simplest way change focusing scheme of final focusing quads
  - Advantage independent of Interaction Region → can be done both at IP-6 and/or IP-8

change polarity of quads DDF to FDF
→ needs to be done only on the rear side (incom hadron beam) hadron quads
→ change polarity of quads at low E_{CM}

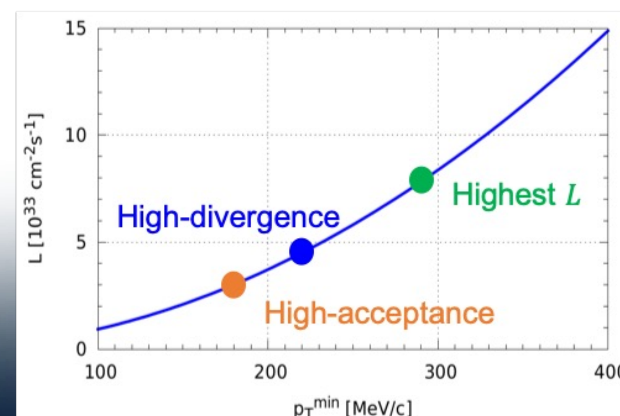




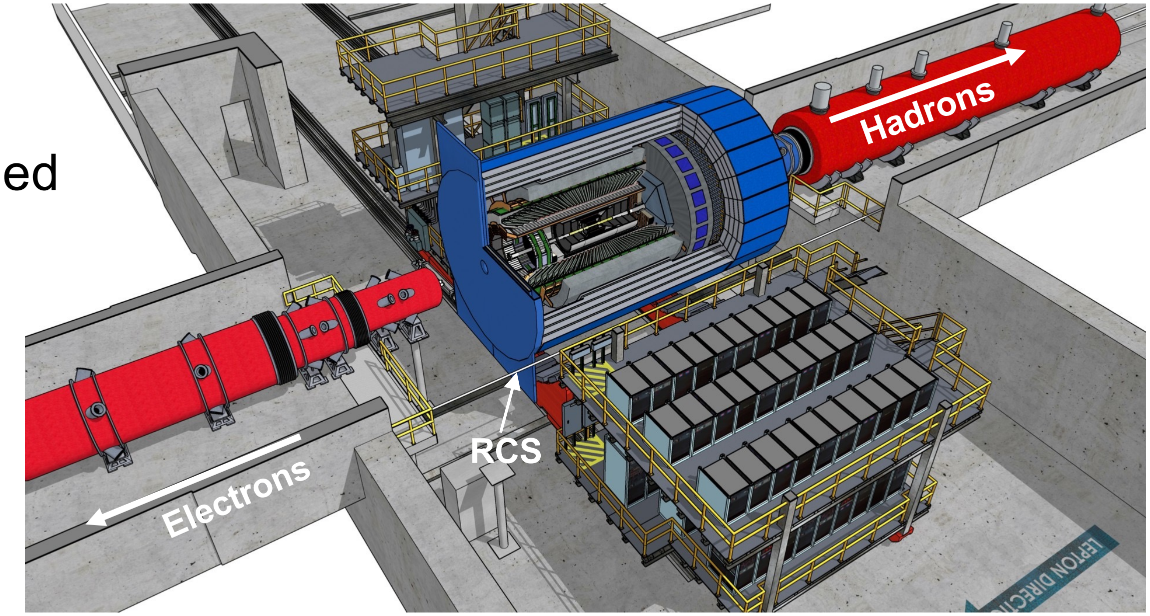
But nothing is for free, there is a direct impact on the low p_T acceptance for forward scattered particles ~β (at RP) x beam divergency σ'^{*}

Luminosity increases if β* ↓ & σ'^{*}↑

Highest luminosity → smallest low p_T acceptance at far forward



IR-Integration Requirements



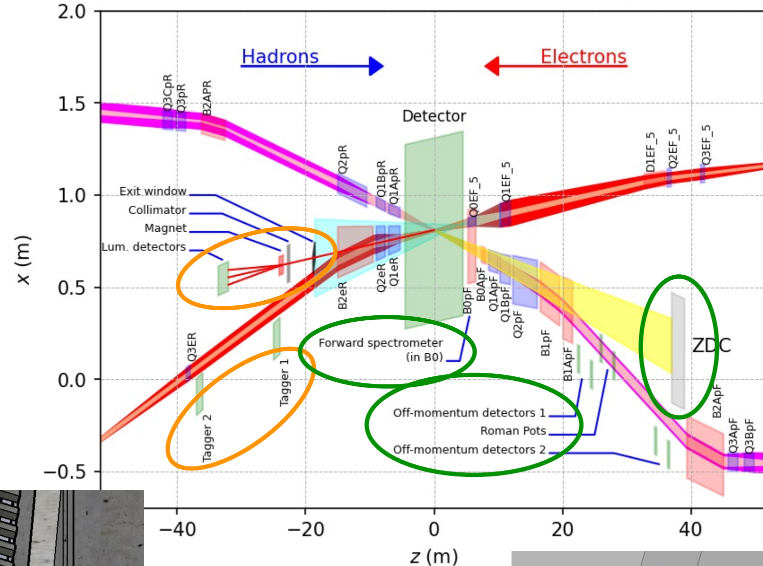
Space constrains for ECCE:

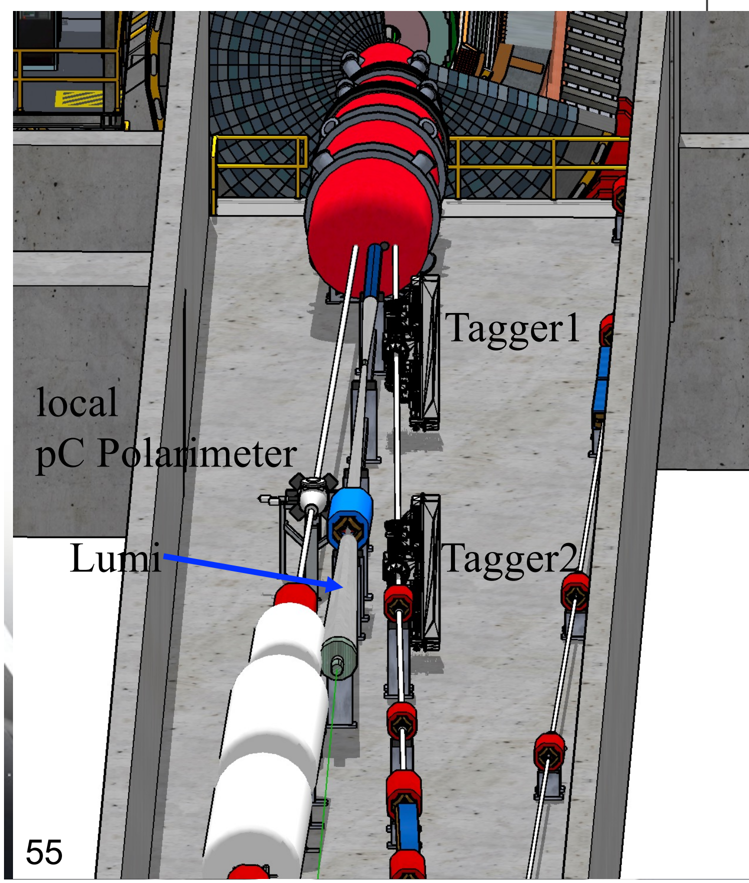
-4.5 m – IP – +5m not negotiable

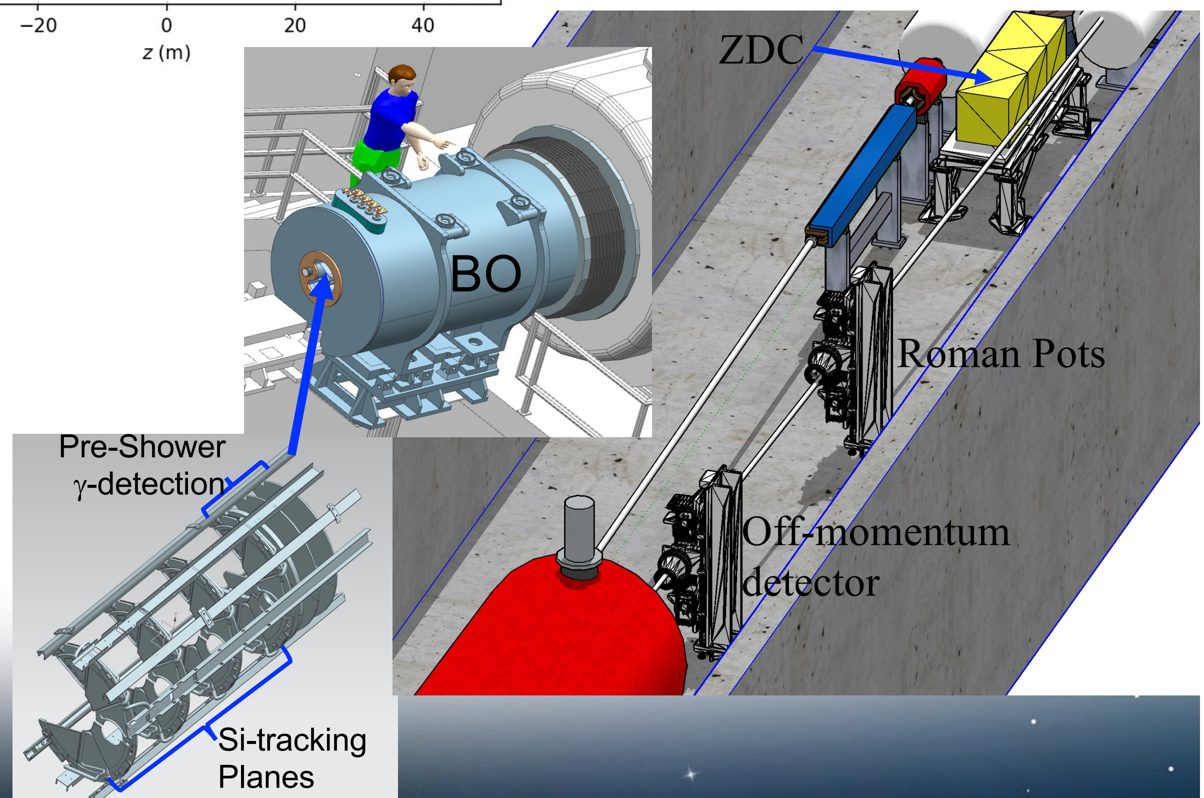
- ❑ 50 cm space to 1st IR-magnet occupied by vacuum pumps, valves, …..
- ❑ IP moved 81 cm towards ring inside compared to RHIC;
  y: 432 cm above floor
- ❑ 9.5 m long detector does not fit through the door
  - ➢ Door-Size: 823 cm x 823 cm
  - ➢ endcap hadron calorimeters need to stay in collider hall, if detector rolls in assembly hall
- ❑ RCS to IP: radial distance 335.2 cm at a height of 372 cm from floor
  - ➢ Maximum outer radius ~ 3.2 m
- ❑ Detector Solenoidal axis aligned with electron beam
- ❑ Fringe field requirements for solenoid under development
- ❑ Installation and Maintenance requirements defined

IR-Integration

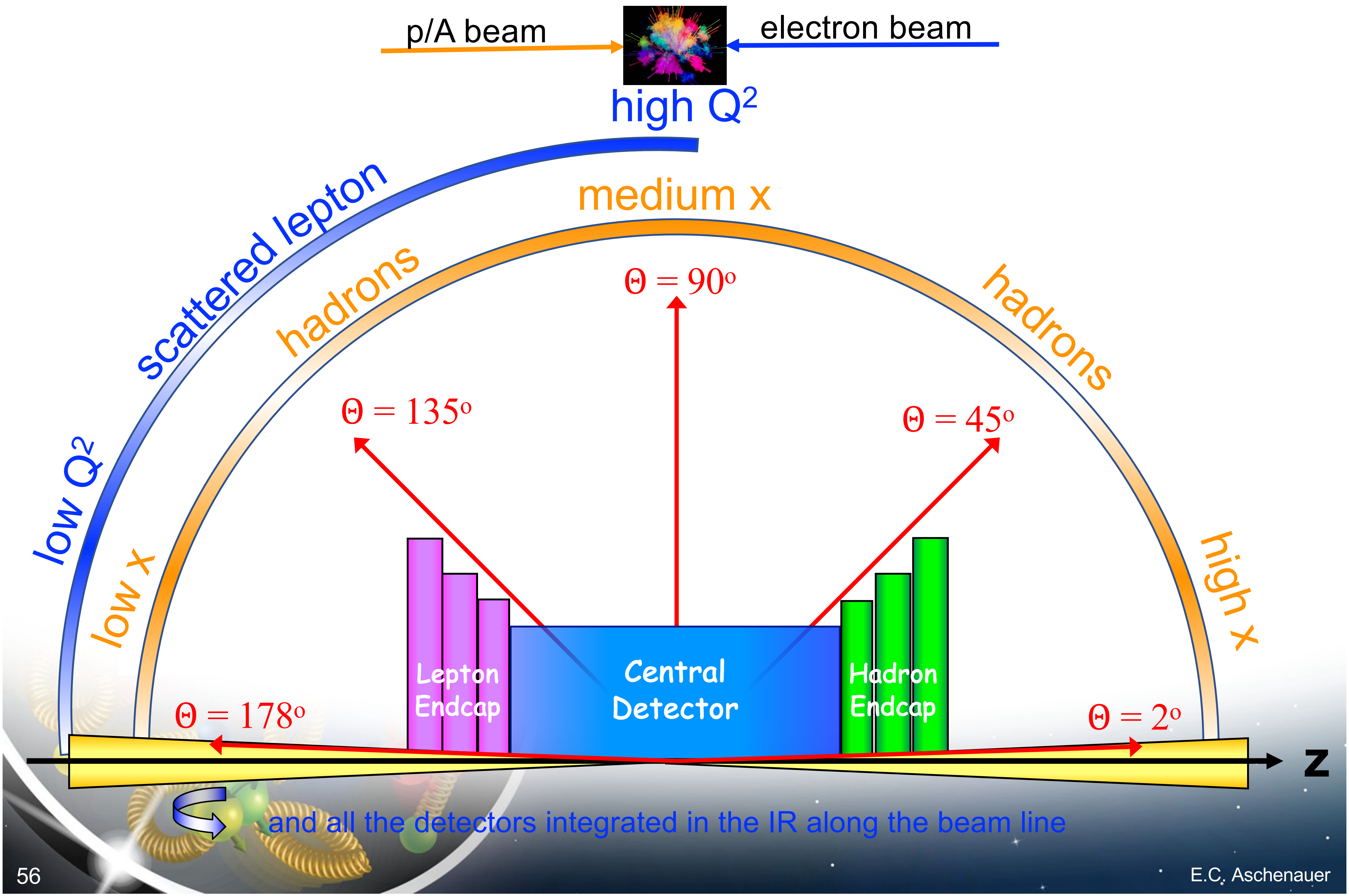
All far forward and backward subsystems are integrated in the Interaction region lattice





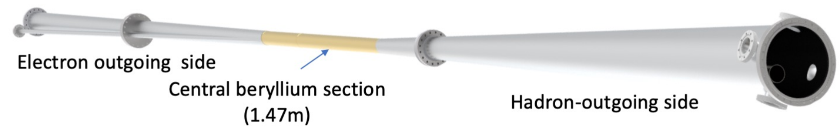


EIC General Purpose Detector: Concept

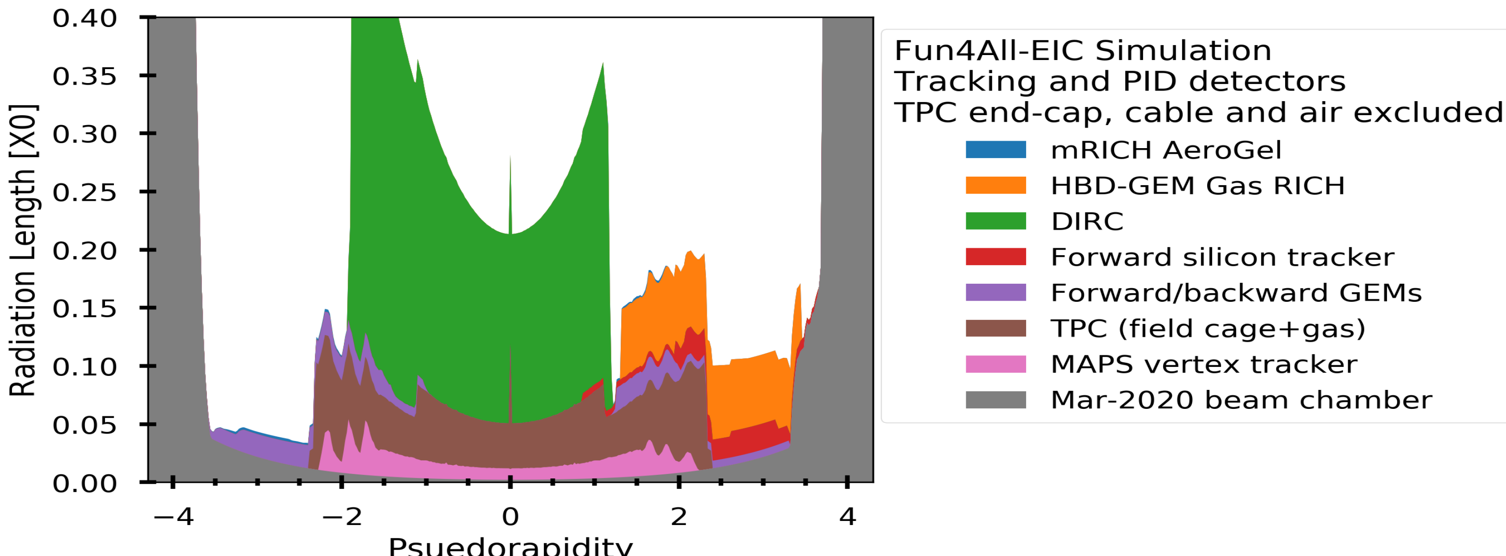


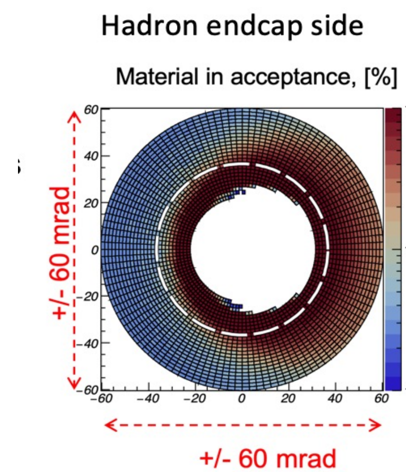
Tracking/Material Budget

- Vertex + central + forward / backward tracker layout (moderate momentum resolution, vertex resolution ~20 μm)
- At most 3T central solenoid field (maximize B*dl integral at high $|\eta|$)
- Low material budget
  - Minimize bremsstrahlung and conversions for primary particles
  - Improve tracking performance at large $|\eta|$ by minimizing multiple Coulomb scattering
  - Minimize the dead material in front of the high resolution e/m calorimeters



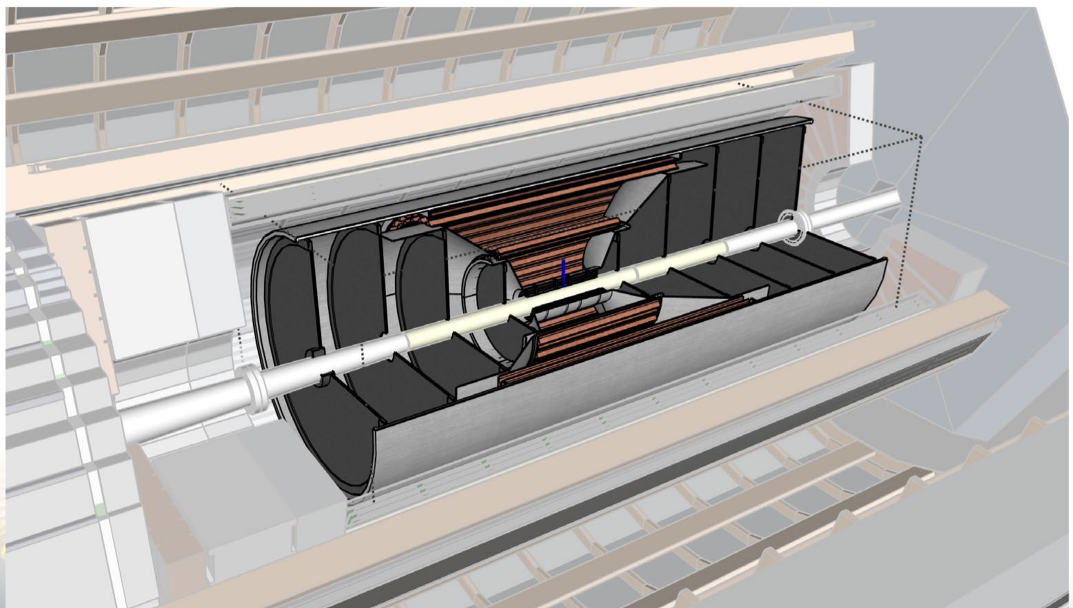
- ❑ Central area of beampipe (around IP): ~1.5m of beryllium to minimize multiple scattering for low Pt particles
- ❑ Low-mass exit window for far-forward particles
- ❑ Few % radiation length material thickness for the required angular range (low angle)

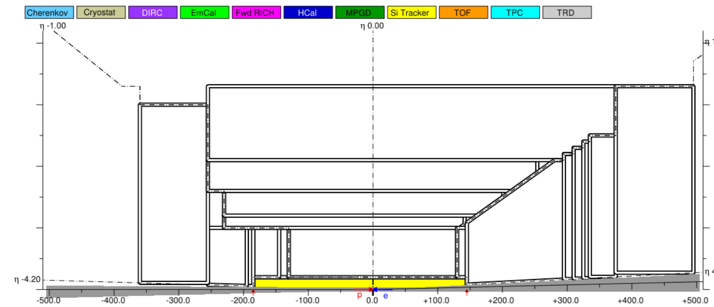


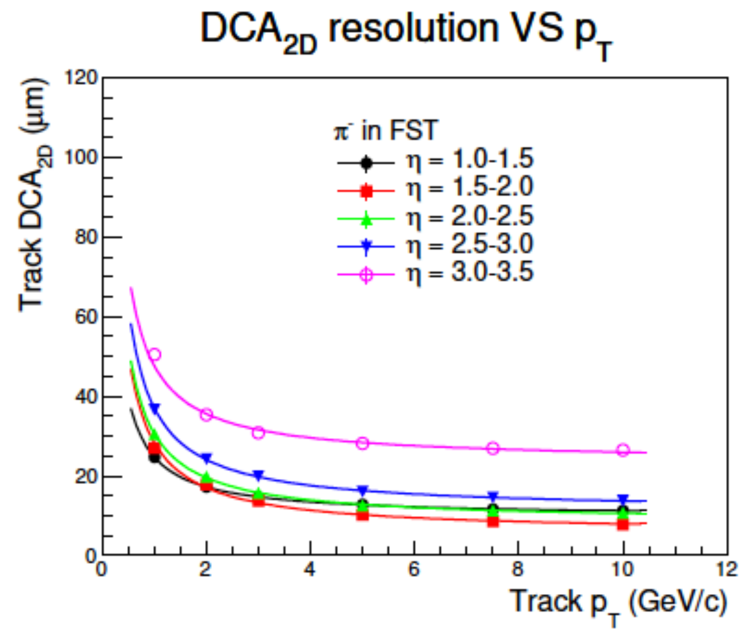


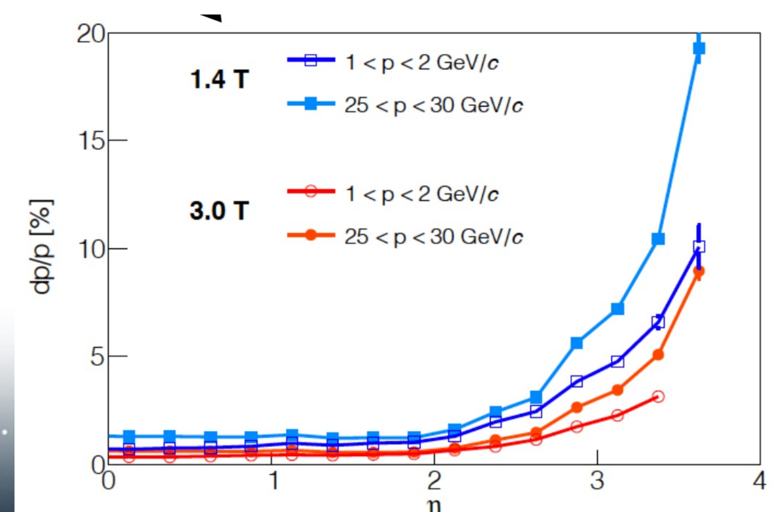
MAPS μVertex

- For primary and secondary vertex reconstruction
- Low material budget: 0.05% X/X_0 per layer
- High spatial resolution: 10 μm pitch MAPS
  → ref. Alice ITS3
- Compromise:
  20 μm (or smaller) pixels and ~0.3% X/X_0 per layer
- Configuration: Barrel+ Disks for endcaps

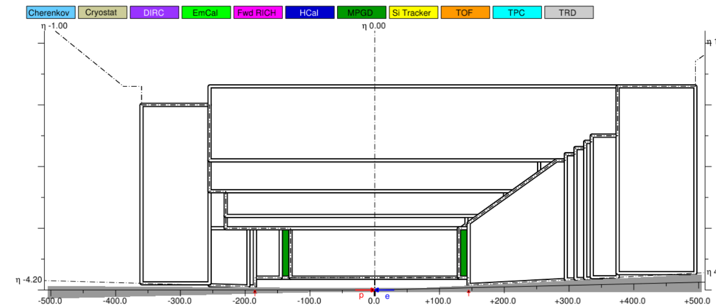




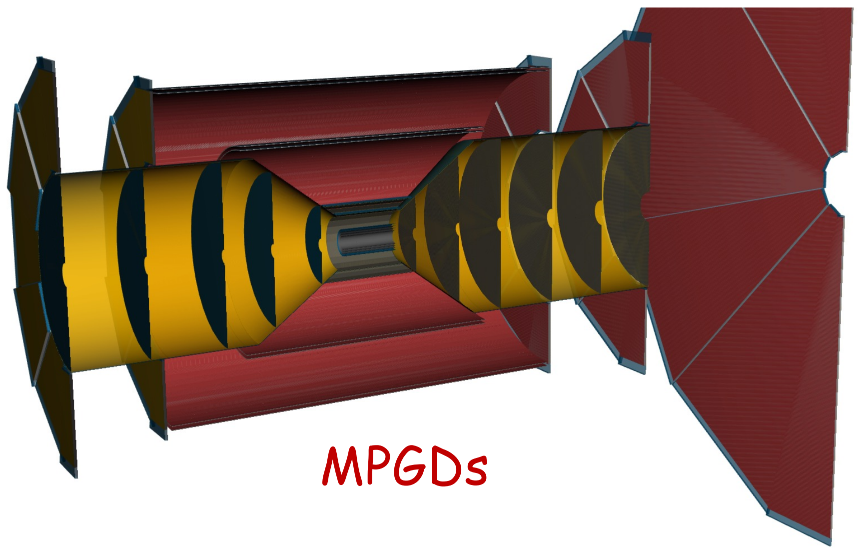


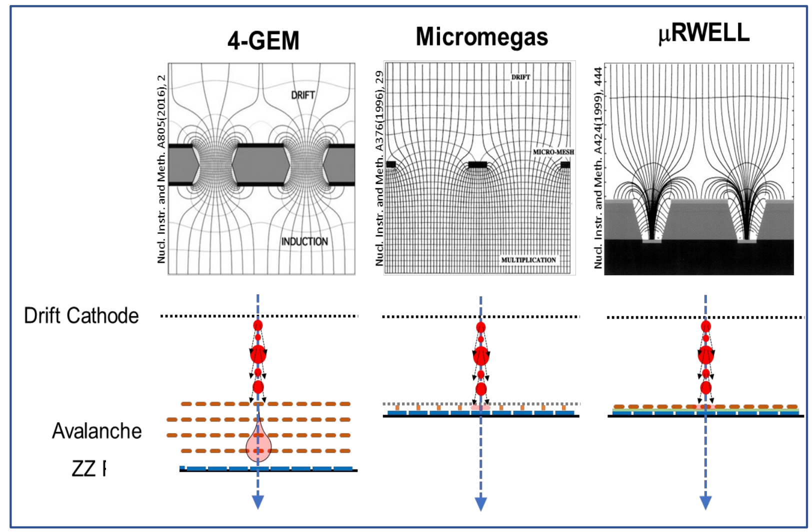


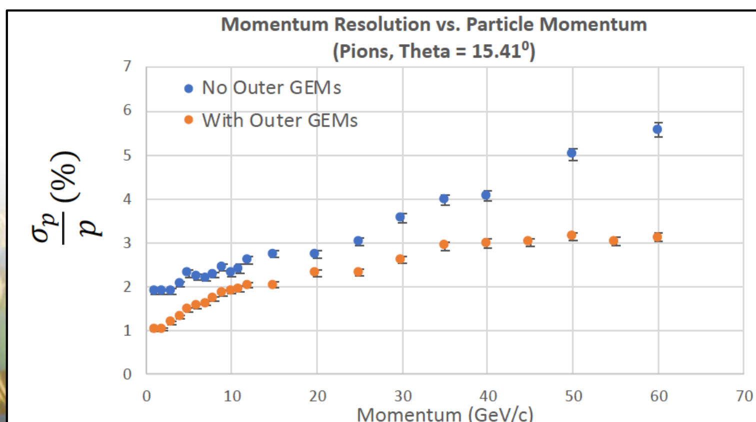
Micro Pattern Gas Detectors

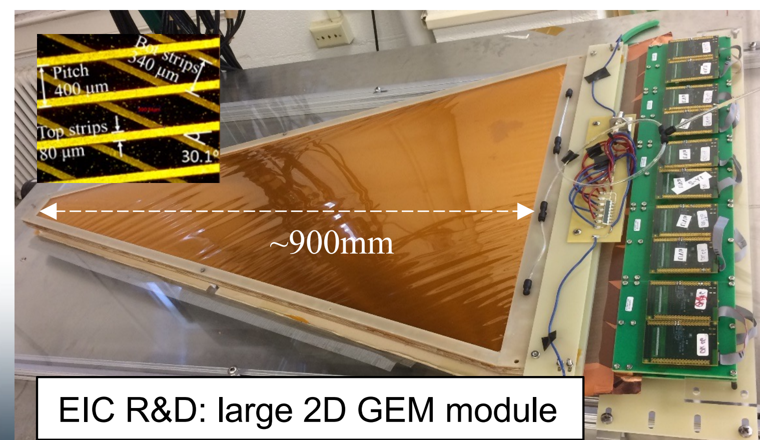


- To improve momentum resolution at large rapidities.
- Spatial resolution well below 100 μm
- Large-area detectors possible
- Cost efficient compared to silicon



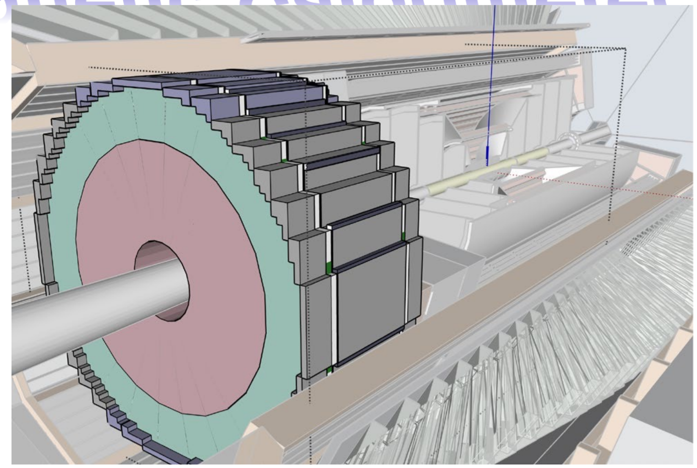






EIC R&D: large 2D GEM module

Electro-Magnetic Calorimeter



Applications:

- Scattered electron kinematics measurement at large |η| in the e-endcap
- Photon detection and energy measurement
- e/h separation (via E/p & cluster topology)
- π^0/γ separation

Anticipated stochastic term in energy resolution & π suppression

η	[-4 .. -2]	[-2 .. -1]	[-1 .. 1]	[1 .. 4]
σ_E/E	~2%/√E	~(4-8)%/√E	~(12-14)%/√E	~(4*-12)%/√E
π suppression	Up to 1:10^{-4}	Up to 1:10^{-3}-10^{-2}	Up to 1:10^{-2}	3σ e/π

Other considerations:

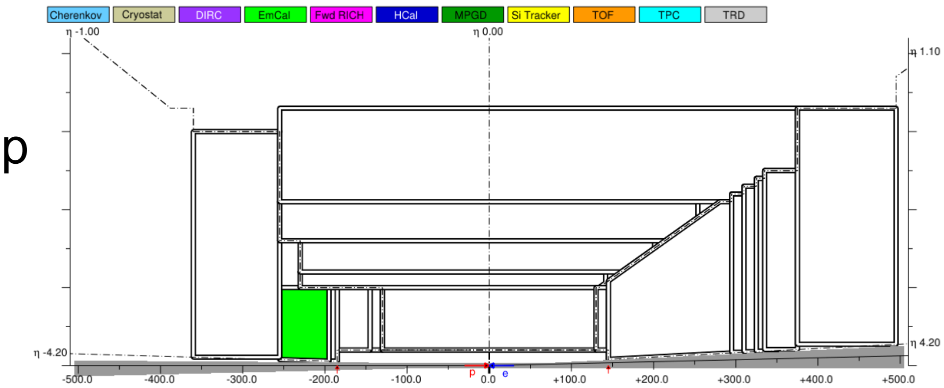
- Fast timing
- Compactness (small X_0 and R_M)
- Tower granularity
- Readout immune to the magnetic field

EIC Yellow Report

#	Type	samp-ling, mm	f_{samp}	X_0 mm	R_M mm	λ_I mm	cell mm^2	$\frac{X}{X_0}$	ΔZ cm	σ_E/E, % α	β
1	W/ScFi**	⌀0.47 ScFi W powd.	2%	7.0	19	200	25^2	20	30	2.5	13
2	$PbWO_4^{***}$	-	-	8.9	19.6	203	20^2	22.5	35	1.0	2.5
3	Shashlyk***	0.75 W/Cu[a] 1.5 Sc	16%	12.4	26	250	25^2	20	40	1.6	8.3
4	W/ScFi** with PMT	0.59^2 ScFi W powd.|	12%	13	28	280	25^2	20	43	1.7	7.1
5	Shashlyk***	0.8 Pb 1.55 Sc	20%	16.4	35	520	40^2	20	48	1.5	6
6	TF1 Pb glass***	-	-	28	37	380	40^2	20	71	1.0	5-6
7	Sc. glass*[b]	-	-	26	35	400	40^2	20	67	1.0	3-4

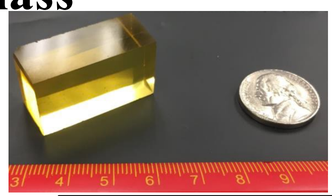
Crystals

- High resolution EmCal in the electron-endcap for the scattering electron measurements
- PWO where space is tight, and the highest possible energy resolution is required
- Scintillating glass (*EIC R&D*) otherwise
  - More cost efficient, easier manufacturing
  - Potentially better optical properties



Example: SC1 glass

2018: 1cm x 1cm x 1cm

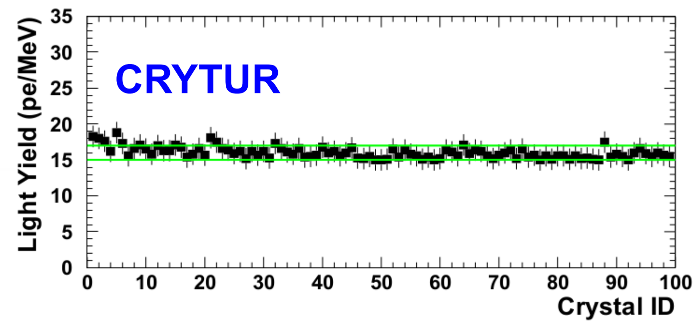


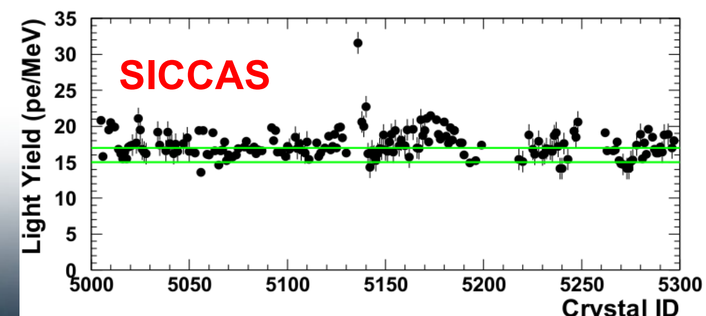
2019: 2cm x 2cm x 4cm

Feb 2020: 2cm x 2cm x 20cm (7 X0)

Dec 2020: 2cm x 2cm x 40cm (10-20 X0)

PWO: vendor characterization

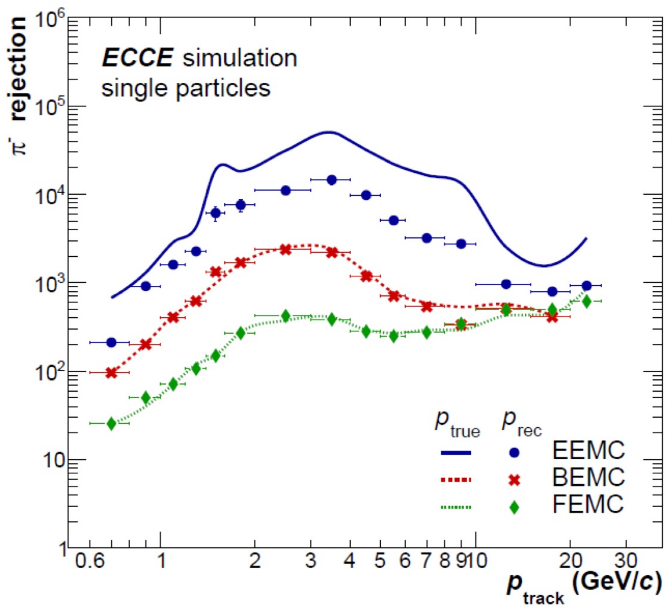




Barrel ECal ala ECCE

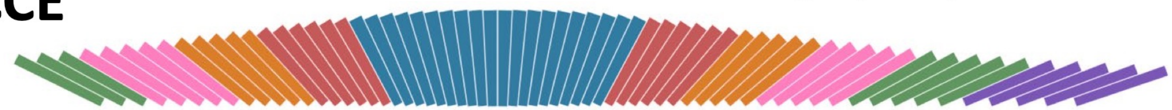
Homogeneous, projective calorimeter based on SciGlass, cost-effective alternative to crystals

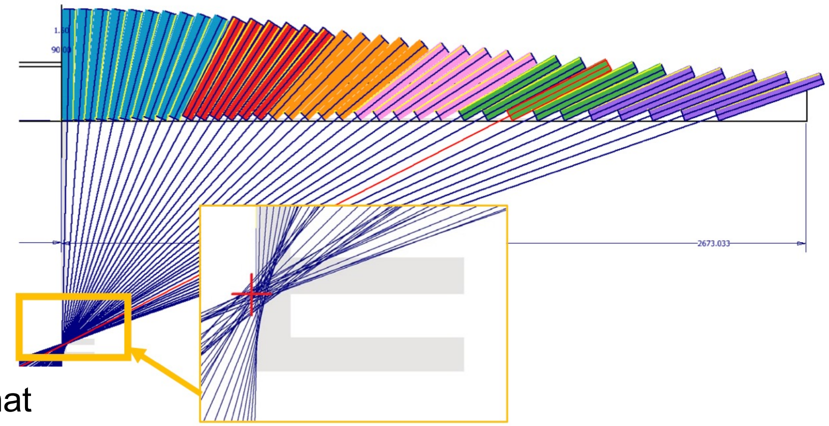
→ Design follows PANDA



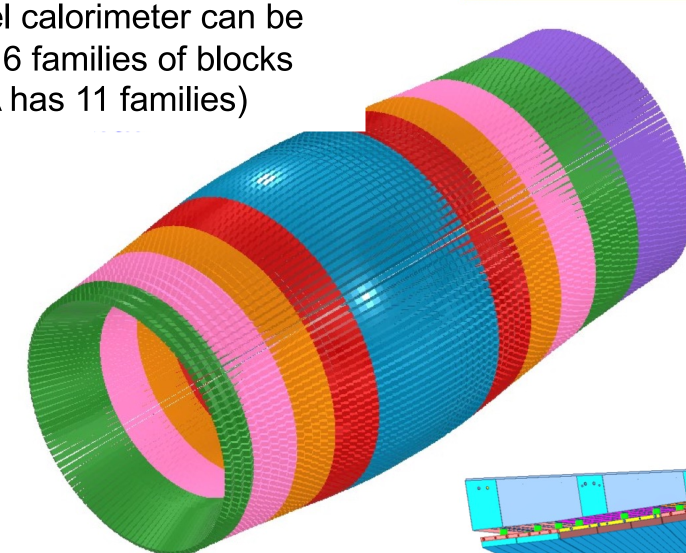
ECCE

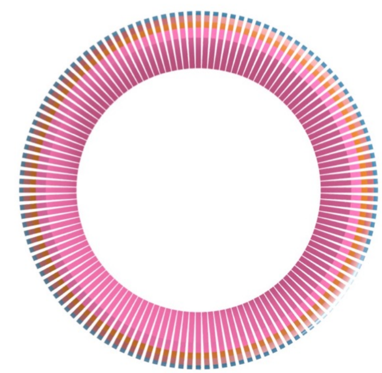
Based on realistic CAD design (CUA)

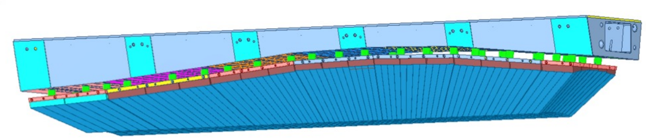




The geometry is optimized that ECCE barrel calorimeter can be made from 6 families of blocks (PANDA has 11 families)







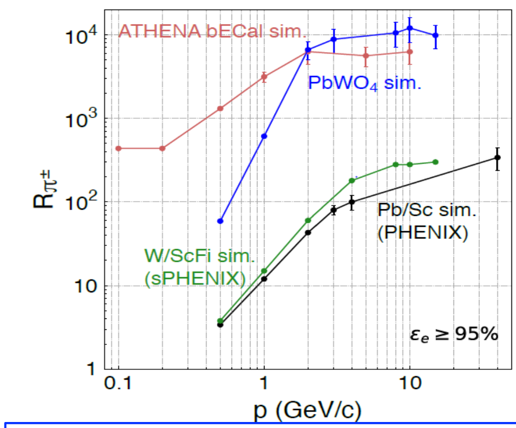
With these families any gap is already reduced both angular and radially between glass blocks to <5mm

Barrel – ECal ala ATHENA

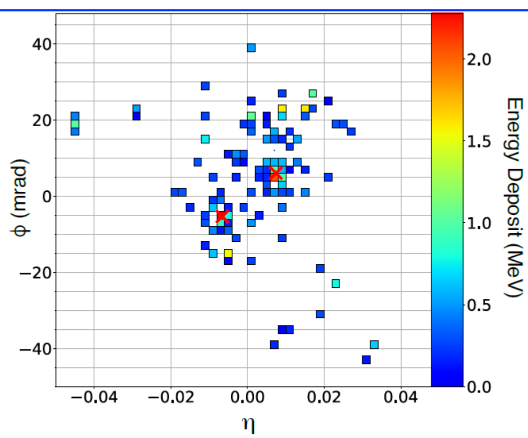
Hybrid concept:

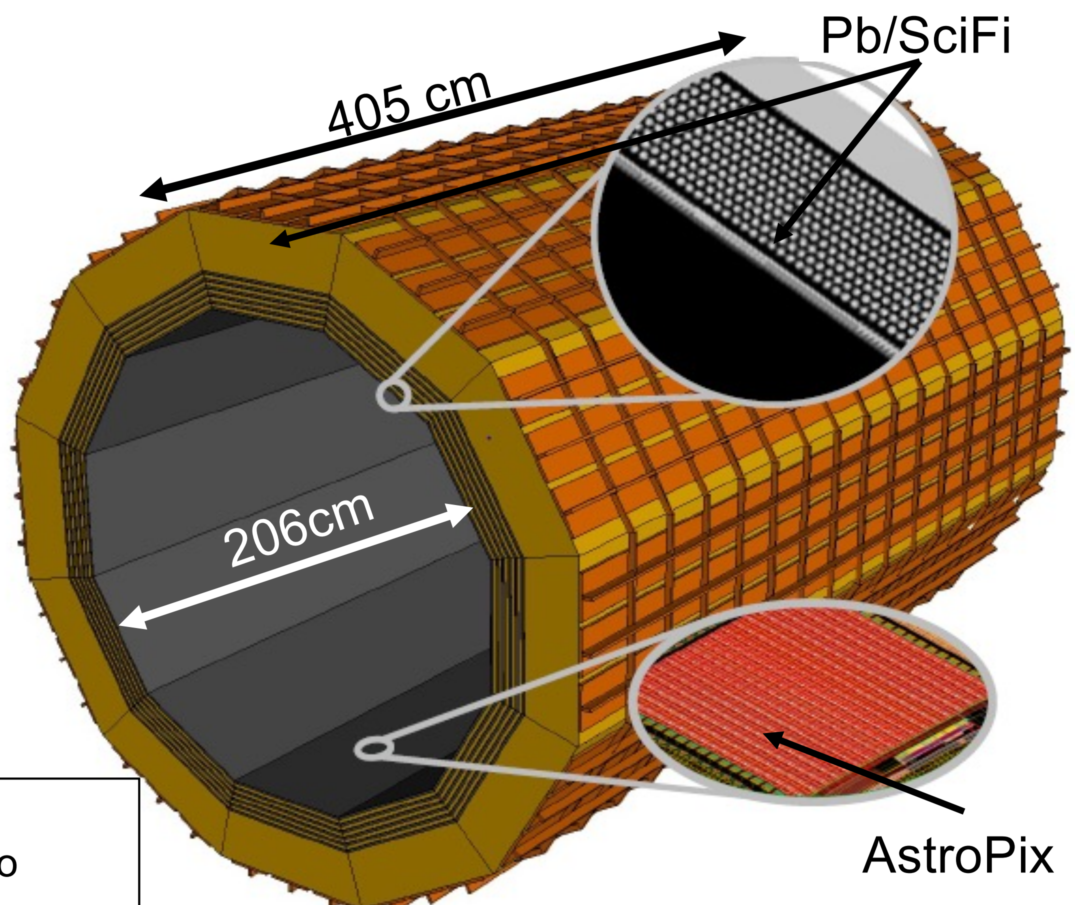
- 6 imaging layer: AstroPix and Pb/SciFi
  - AstroPix, monolithic Si sensor, dev
  - Pb/SciFi following KLOE, GlueX
- Reconstruct scattered and secondary electrons
- Separate e/π
- Identify and reconstruct g (also radiated from e)
- Identify π^0 also at high momenta

Separate e/π at low p



γ's from 15 GeV/c π^0 decay



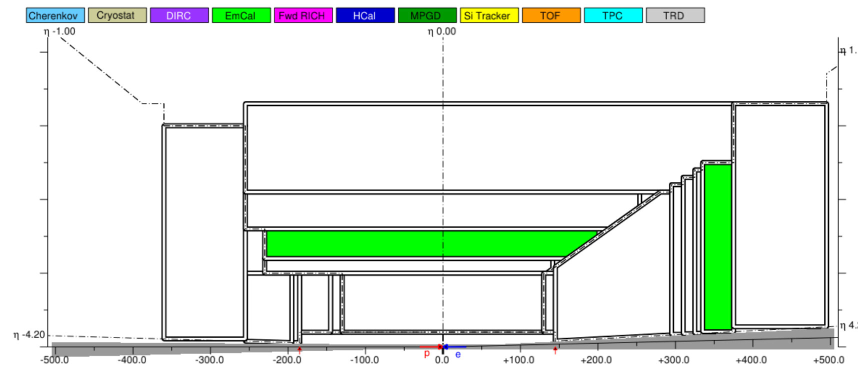


also >1 λ_I contributing to bHCal

expected performance

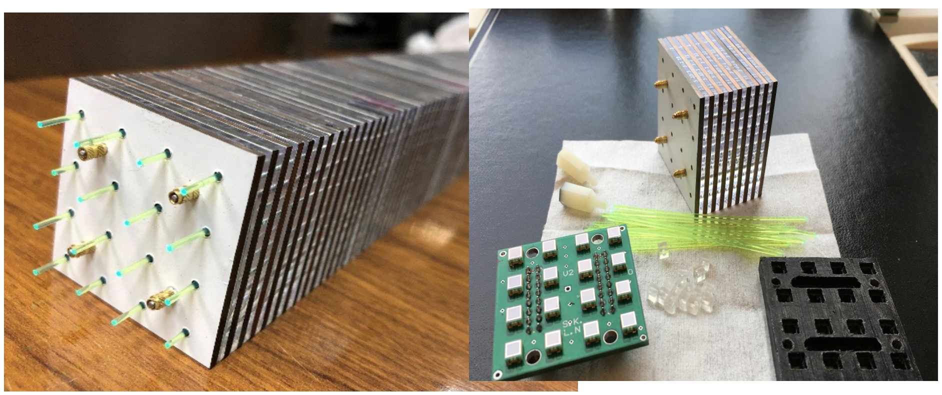
Energy Resolution	$5.5\%/\sqrt{E} \oplus 1\%^a$
e/π separation	$> 99.8\%$ pion rejection with 95% electron efficiency at $p \geq 0.1$ GeV/c^b.
E^{γ}_{min}	< 100 MeV^c
Spatial Resolution	Cluster position resolution for 5 GeV photons at normal incident angle is below $\sigma = 2$ mm (at the surface of the stave $r = 103$ cm) or 0.12°. For comparison, the minimal opening angle of photons from $\pi^0 \to \gamma\gamma$ at 15 GeV is $\sim 1.05°$ (about 19 mm – 37 pixels – of separation at $r = 103$ cm).

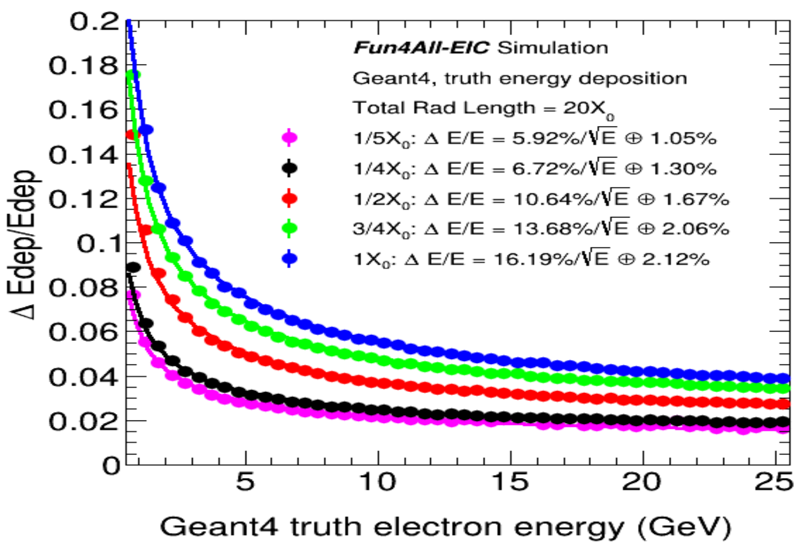
Sampling EmCal



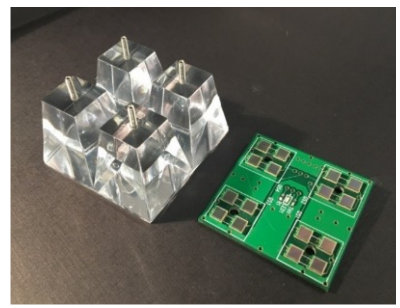
- Well established technology
  - HERA-B, ALICE, PHENIX, PANDA, …
- Medium energy resolution ~7..13%/√E
- Compact (X_0 ~7mm or less), cost efficient

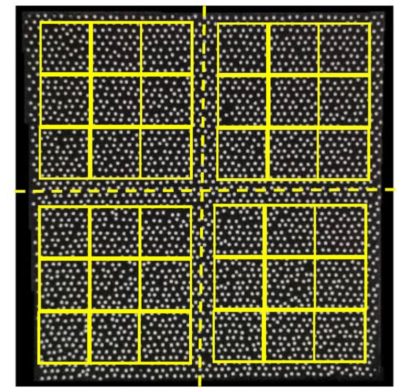
Pb/Sc shashlyk





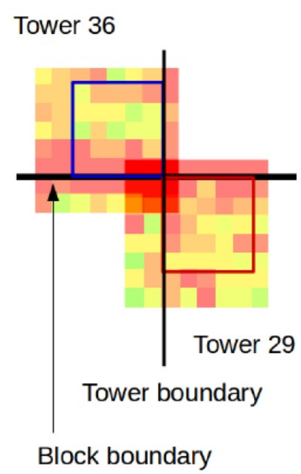
W/SciFi spacal

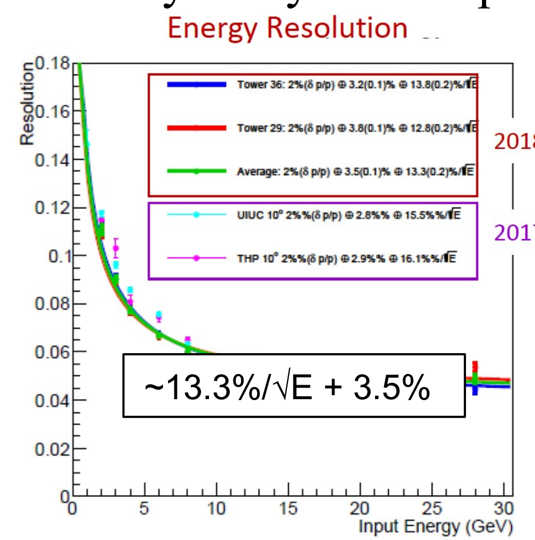




Scintillating Fibers embedded in a W/epoxy mix

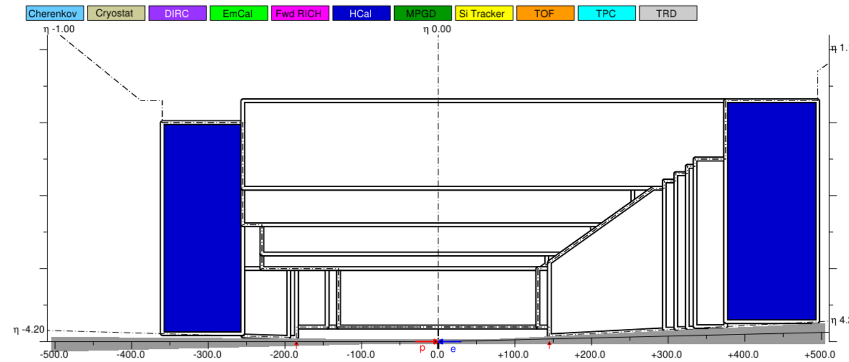
Light collection uniformity can yet be improved

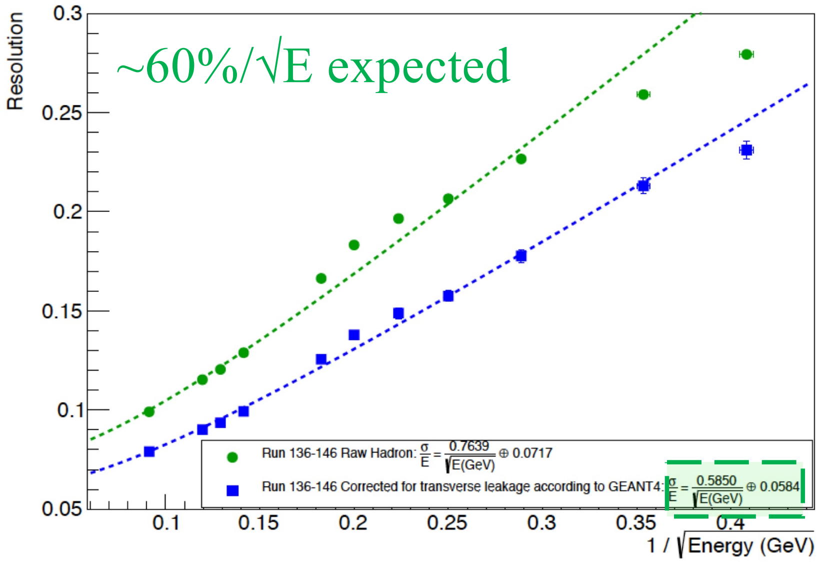


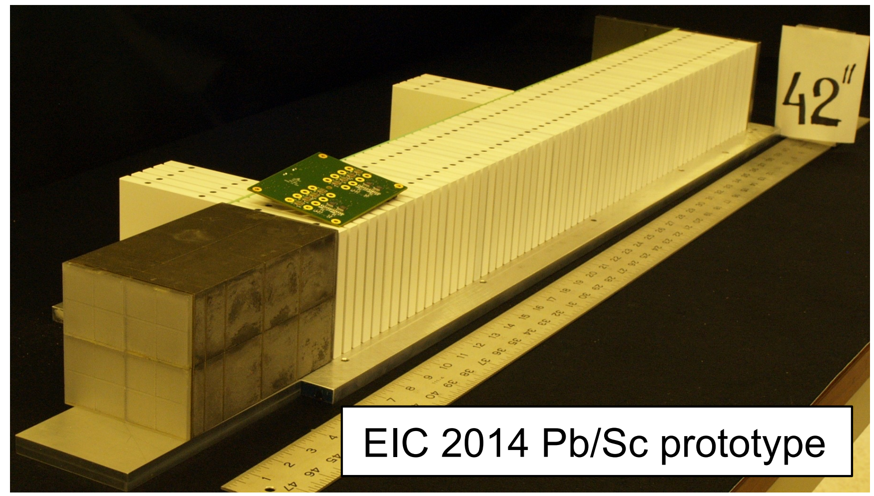


Fe/Sc sandwich

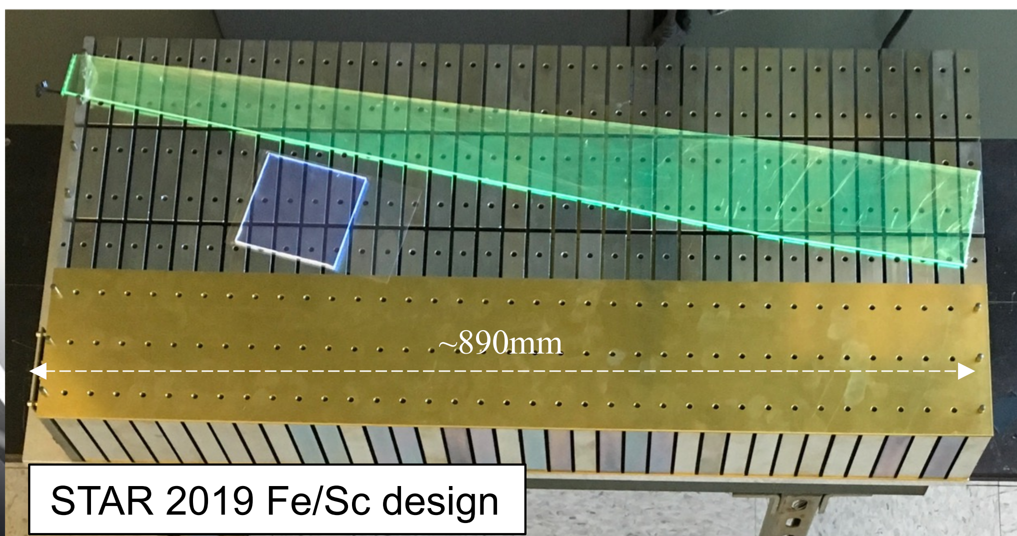
- HCAL in endcap
- Compact LEGO-style design
  - Can be used with a mixed Fe/Pb absorber



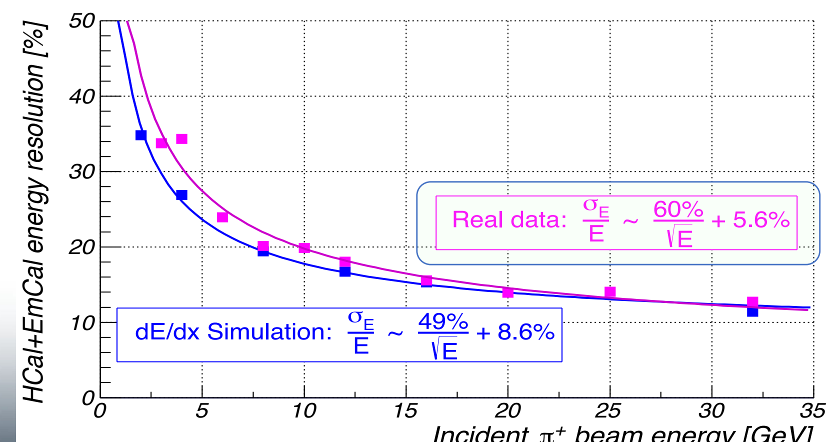




EIC 2014 Pb/Sc prototype

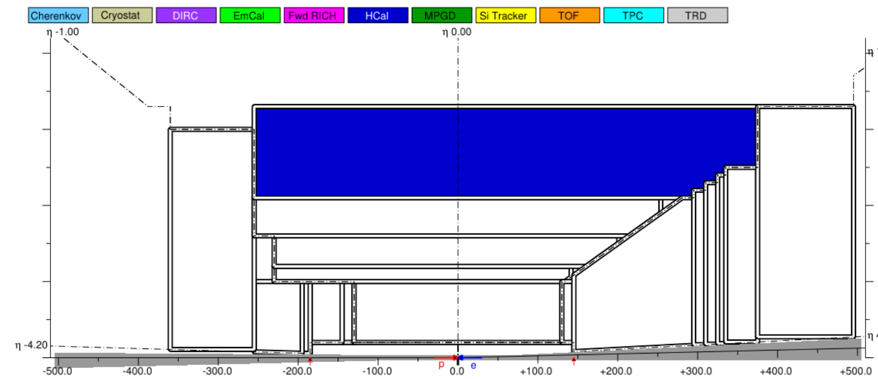


STAR 2019 Fe/Sc design

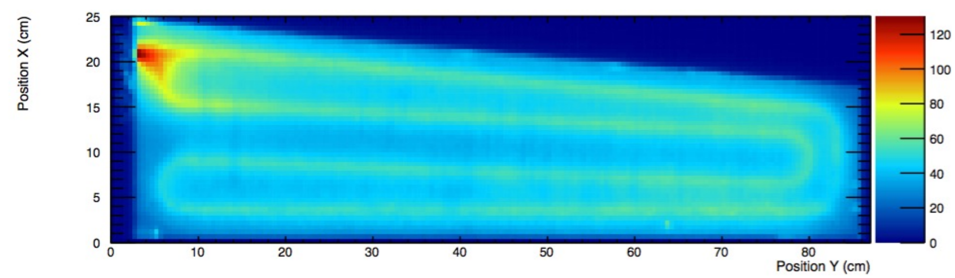


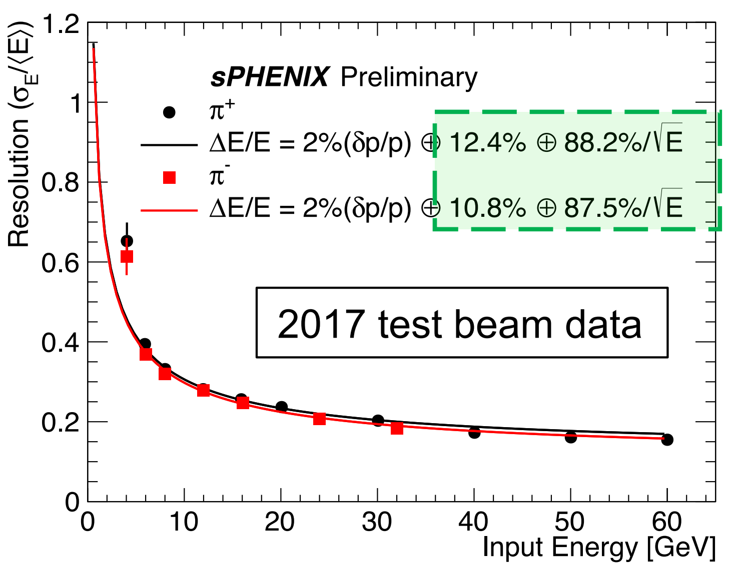
Fe/Sc (barrel)

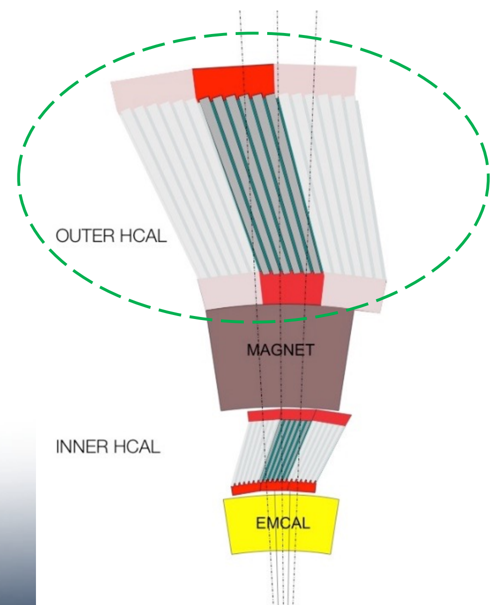
- Similar as used in sPHENIX
  - Solid 32-sector steel frame, but only ~3.5 λ_I
  - Moderate energy resolution



Scintillator plate with embedded WLS fiber







EIC PID

needs
are more demanding
then your
normal
collider detector

EIC

needs absolute
particle numbers at
high purity and low
contamination

Particle ID

- In general, need to separate:
  - Electrons from photons → 4π coverage in tracking
  - Electrons from charged hadrons → mostly provided by calorimetry
  - Charged pions, kaons and protons from each other → Cherenkov detectors
    - Cherenkov detectors, complemented by other technologies at lower momenta

Challenges:

- photon sensors in high magnetic field → SiPMs impact on streaming DAQ
- high performance aerogel radiator

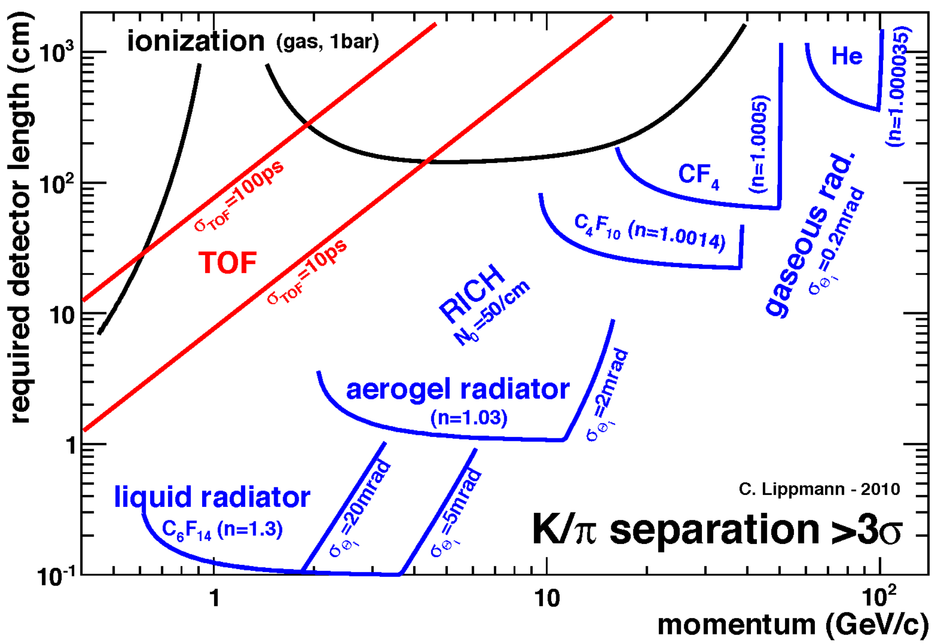
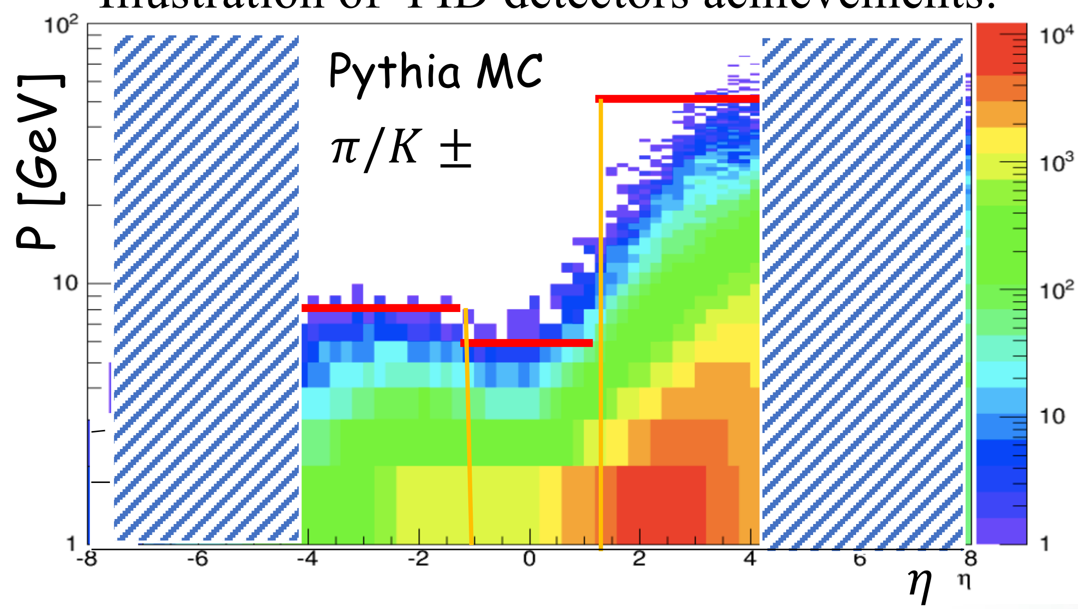


Illustration of PID detectors achievements:

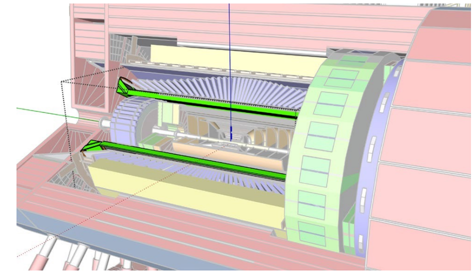


Need more than one technology to cover the entire momentum ranges at different rapidities

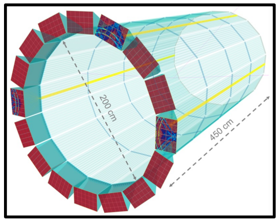
Physics requirements:

Rapidity	π/K/p and π0/γ	e/h	Min pT (E)
-3.5 – -1.0	7 GeV/c	18 GeV/c	100 MeV/c
-1.0 – 1.0	8-10 GeV/c	8 GeV/c	100 MeV/c
1.0 – 3.5	50 GeV/c	20 GeV/c	100 MeV/c

Hadron PID



Barrel

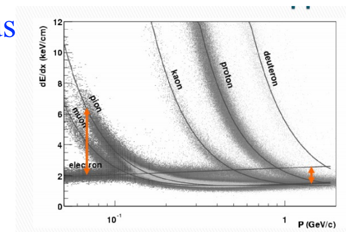


REFERENCE

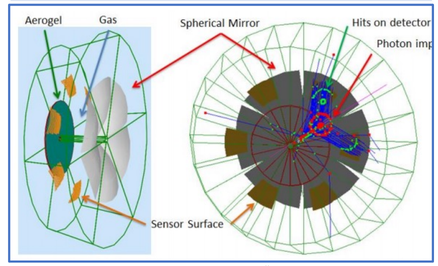
hpDIRC (High Performance DIRC)

- Quartz bar radiator, light detection with MCP-PMTs
- Fully focused
- p/K 3s sep. at 6 GeV/c
- Reuse of BABAR DIRC as alternative
- Integration into a 4π detector can be challenging

dE/dx from gaseous tracker, i.e. TPC complementary
STAR: ~ similar resolution expected



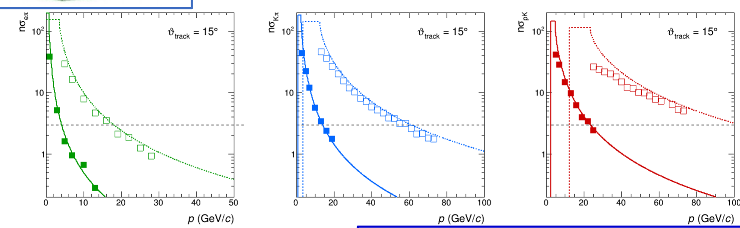
Forward Endcap



REFERENCE

dRICH (dual RICH)

- Aerogel and C-F gas radiators
- Full momentum range
- Sensor: Si PMs(TBC)
- p/K 3σ sep. at 50 GeV/c

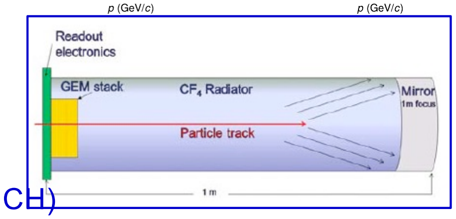


windowless RICH

- Gaseous sensors (MPGDs)
- CF_4 as radiator and sensor gas

Low p complements required:

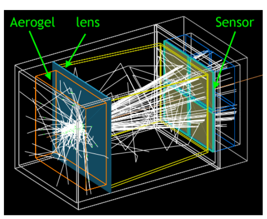
- TOF ~ 2.5m lever arm / Aerogel (mRICH)



HP-RICH (high pressure RICH)

- Eco-friendly alternative for dRICH/windowless RICH
- Ar @ 3. 5 bar ↔ C_4F_{10} @ 1 bar
- Ar @ 2 bar ↔ CF_4 @ 1 bar

Backward Endcap



Geant4 Simulation

With realistic material optical properties

REFERENCE

mRICH (Modular RICH)

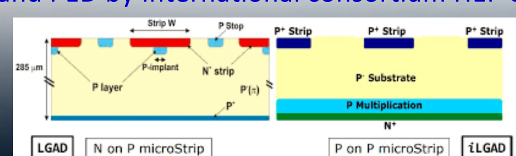
- Aerogel Cherenkov Det.
- Focused by Fresnel lens
- e, pi, K, p
- Sensor: SiPMs/ LAPPDs
- Adaptable to includeTOF
- π/K 3σ sep. at 10 GeV/c

Everywhere

TOF with short lever arm

LGAD (Low Gain Avalanche Detector)

- Silicon Avalanche
- 20-35 psec
- Accurate space point for tracking
- Relevant also to central barrel
- R&D and PED by International consortium HEP & NP



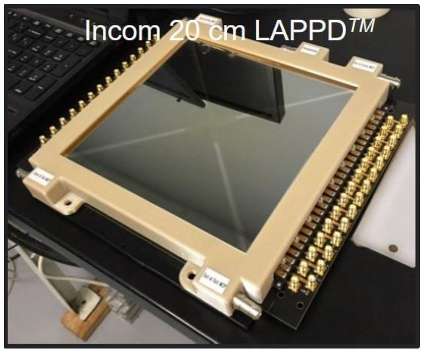
LAPPD (Large Area psec Photon Detector)

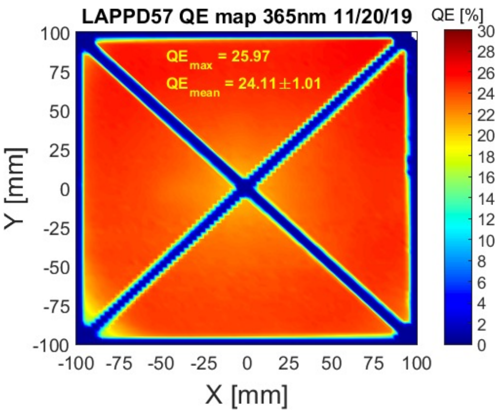
- MCP, Cherenkov in window
- 5-10 psec

→ supported by DOE SBIR program

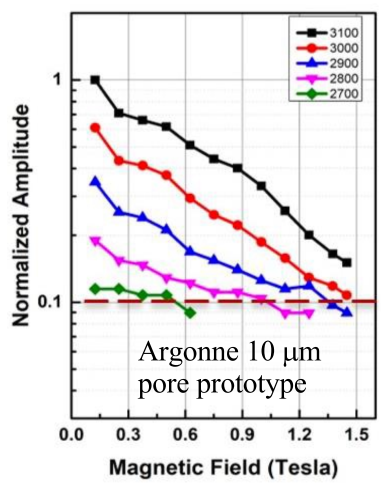
High resolution timing technologies

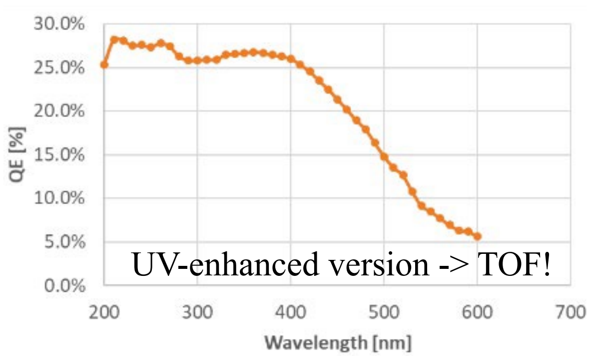
MCP-PMT / LAPPD





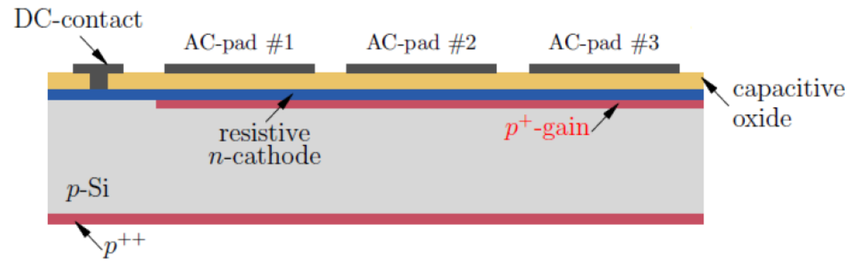
- QE routinely >20%
- >90% gain uniformity
- Single photon TTS <50 ps
- Performance in high B field is still of a concern

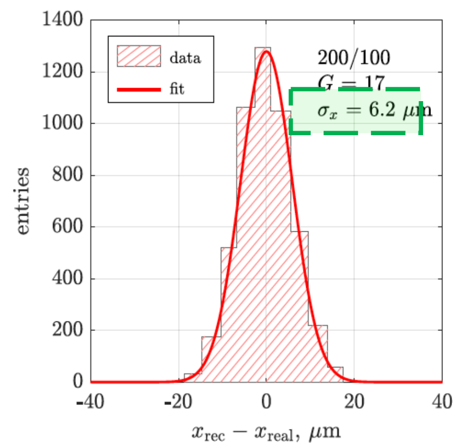


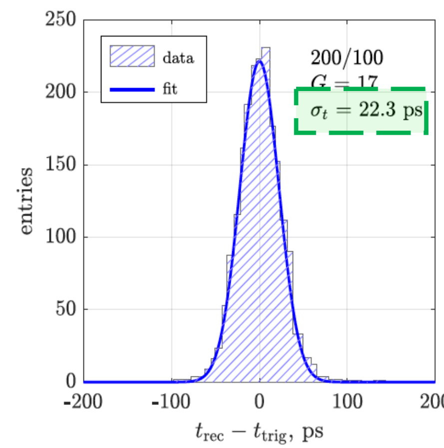


Expecting affordable detectors with <10ps timing on the EIC CD-2 time scale

(AC)-LGAD



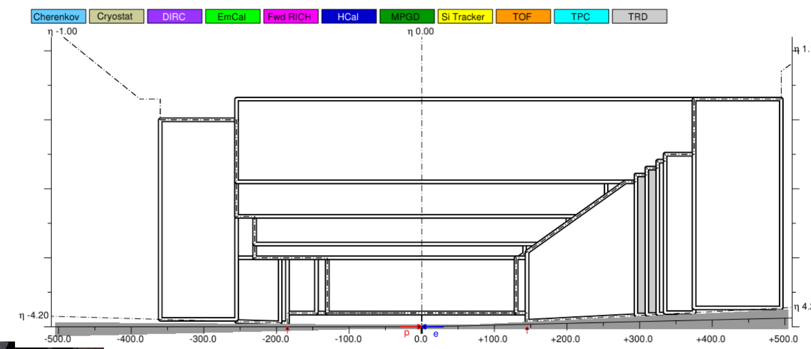


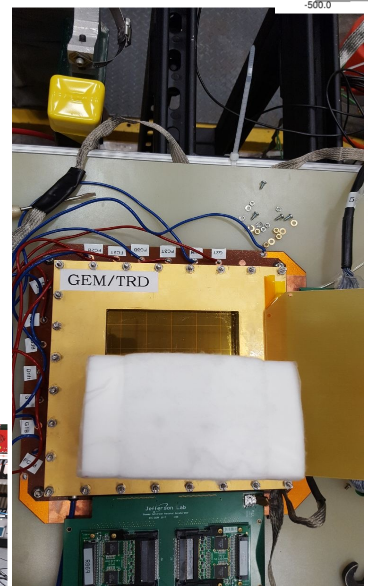


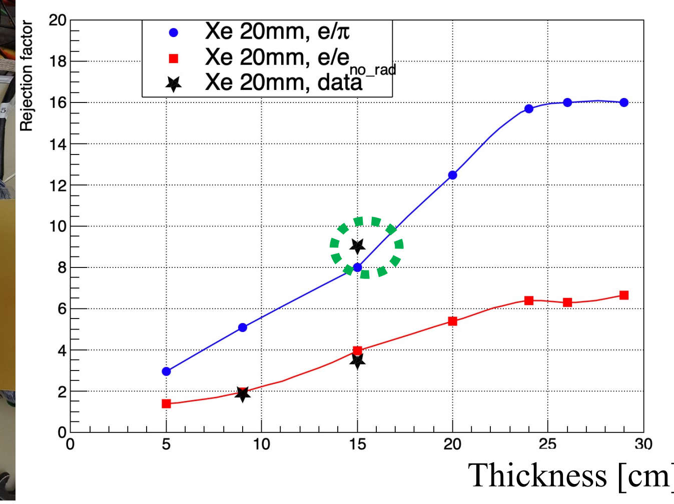
- Detectors can provide <20ps / layer
- AC-coupled variety gives 100% fill factor and potentially a high spatial resolution (dozens of microns) with >1mm large pixels

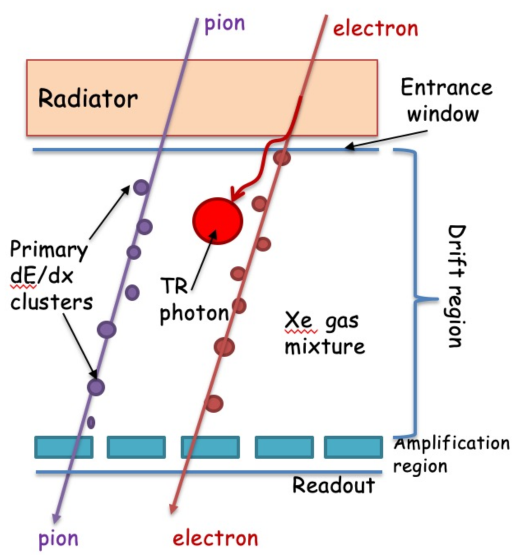
Additional e$^-$ ID

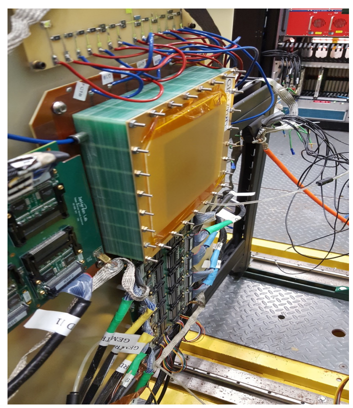
- To improve e-identification for leptonic/semi-leptonic decays.
- In addition to Calorimeters and Cherenkov detectors in the hadron-endcap considering TRD.
- GEM -TRD/Tracker :
  - e/π rejection factor ~10 for momenta between 2-100 GeV/c from a single ~15cm thick module.

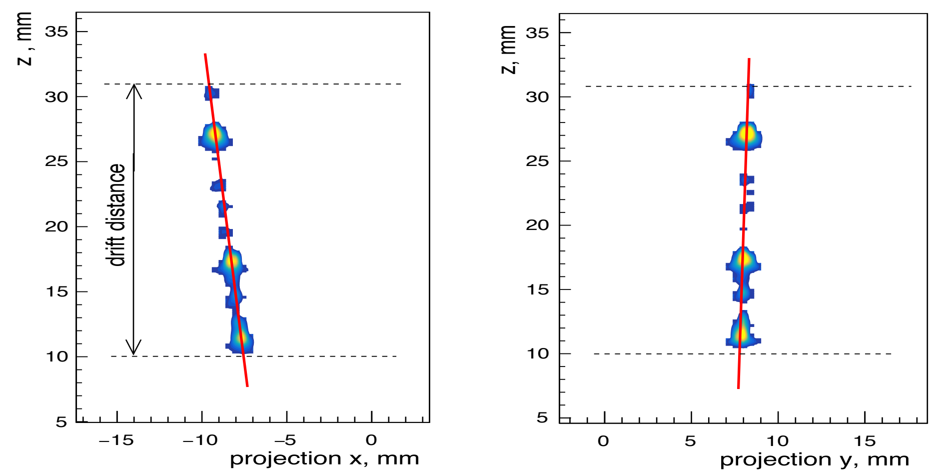








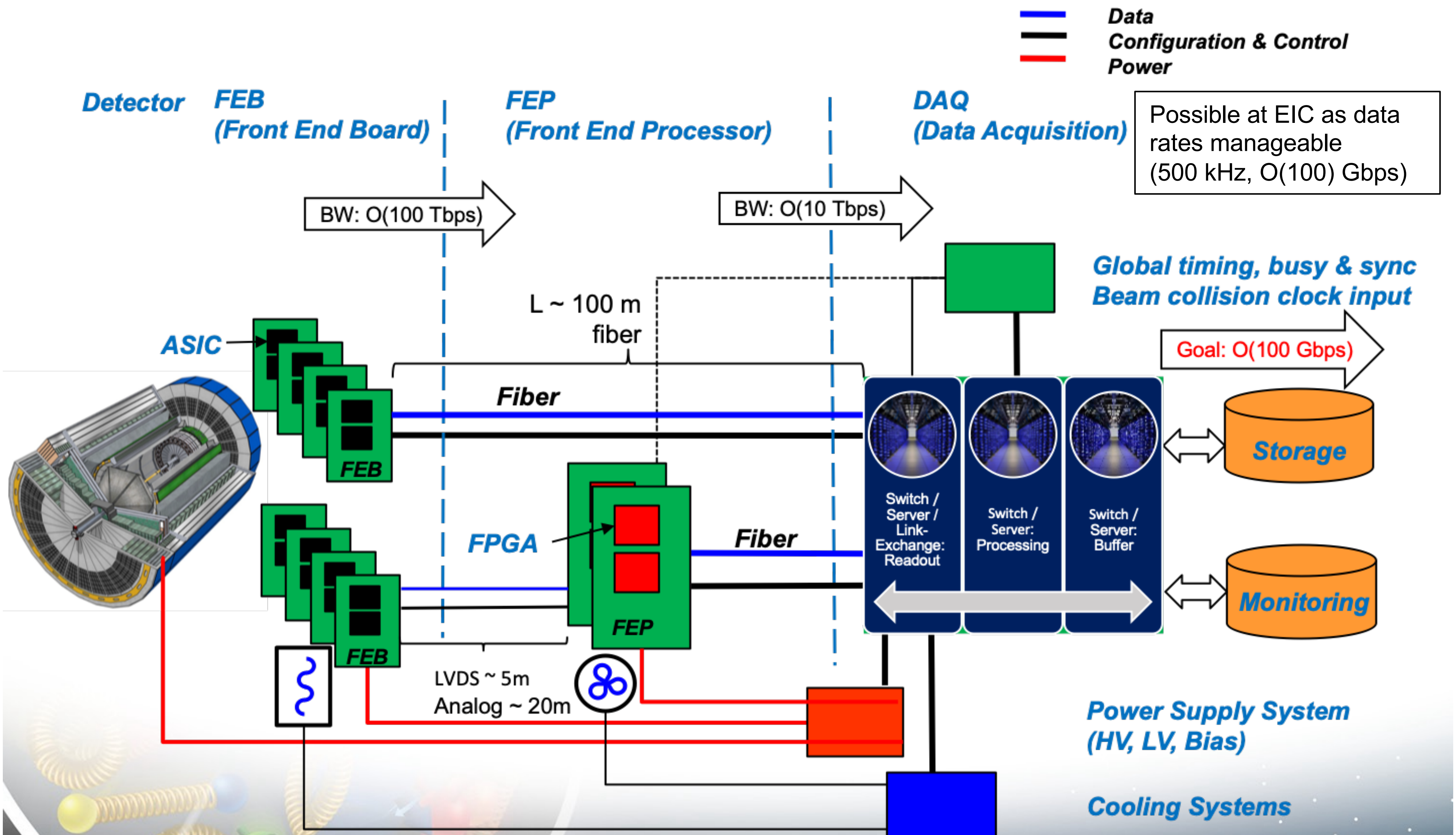




- Very precise Tracking segment behind dRICH:

E.C. Aschenauer

Streaming Readout Architecture



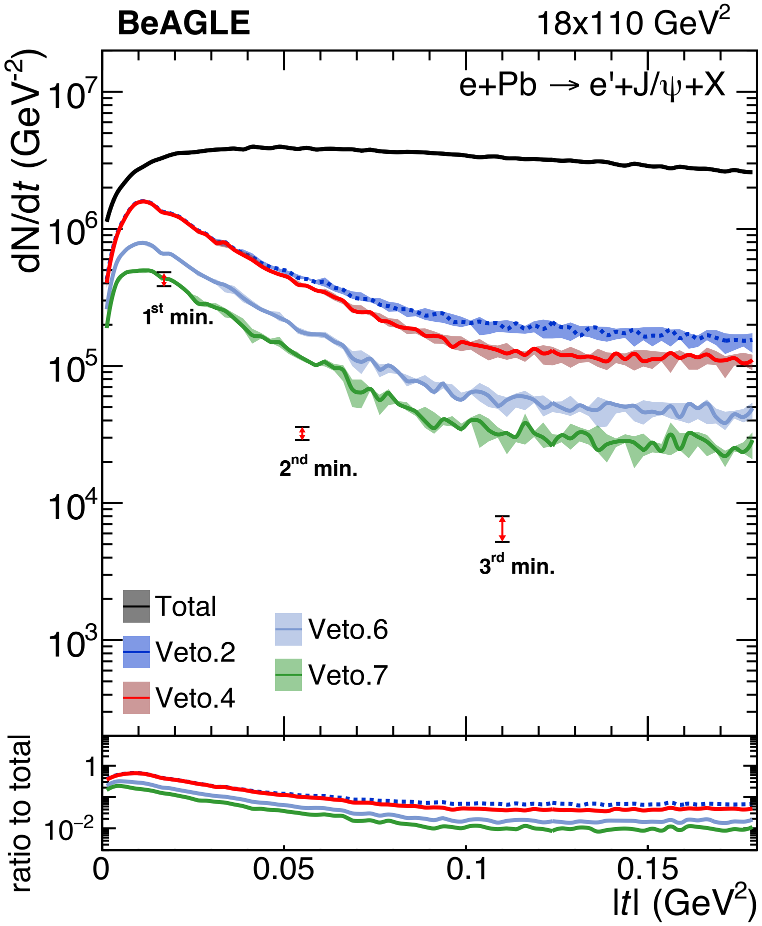
No trigger → much more flexibility to do physics not planned from the start

IR Requirements from Physics

	Hadron	Lepton
Machine element free region	High Luminosity → beam elements need to be close to IP EIC: +/- 4.5 m for main detector beam elements < 1.5° in main detector volume	
Beam pipe	Low mass material i.e. Beryllium	
Integration of Detectors	Local Polarimeter	Low Q^2-tagger Acceptance: $Q^2 <$ ~0.1 GeV
Zero Degree Calorimeter	60cm x 60cm x 2m @ ~30 m	
scattered proton/neutron acc. all energies for ep	Proton: 0.18 GeV $< p_t <$ 1.3 GeV $0.5 < x_L < 1$ ($x_L = E'_p/E_{Beam}$) Neutron: $p_t <$ 1.3 GeV	
scattered proton/neutron acc. all energies for eA	Proton and Neutron: $\Theta <$ 6 mrad ($\sqrt{s}$=50 GeV) $\Theta <$ 4 mrad ($\sqrt{s}$=100 GeV)	
Luminosity	Relative Luminosity: $R = L^{++/--}/L^{+-/-+} < 10^{-4}$ → Flexible spin patters for both beams 1: +-+--+-++-+- 2: -+-++-+--+-+ 3: ++--++--++-- 4: --++--++--++	
		γ acceptance: +/- 1 mrad → $\delta L/L <$ 1%

most demanding

Vetoing Incoherent Events



Veto.1:
- no neutron in ZDC

Veto.2:
- Veto1 + no proton in Roman Pots

Veto.3:
- Veto2 + no proton in off-momentum detector

Veto.4:
- Veto3 + no proton in B0

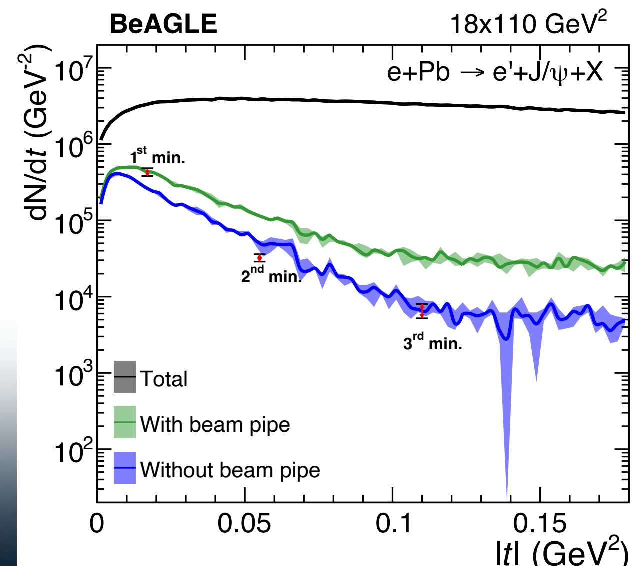
Veto.5:
- Veto4 + no anything in preshower

Veto.6:
- Veto5 + no photon ***E>50MeV*** in ZDC

Veto.7:
- Veto6 + no activities
  $(|\eta| < 4.0 \;\&\; p_T > 100\,\mathrm{MeV/c} \;\&\; E > 50\,\mathrm{MeV})$
  other than e- and J/ψ in the main detector

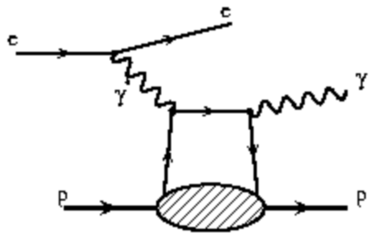
With these requirements, the rejection power is found to be not enough to reach the three minimum positions.

Beam pipe design and material critical to vetoing power

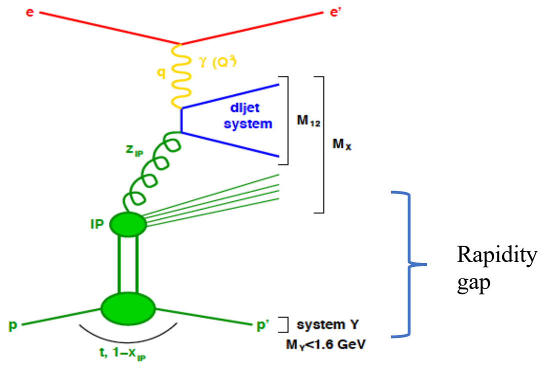


Far-forward physics at EIC

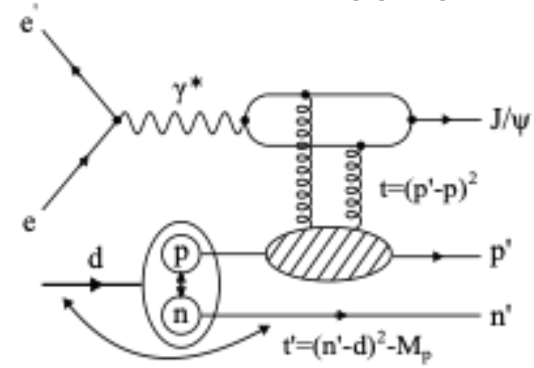
e+p DVCS events
with proton tagging.



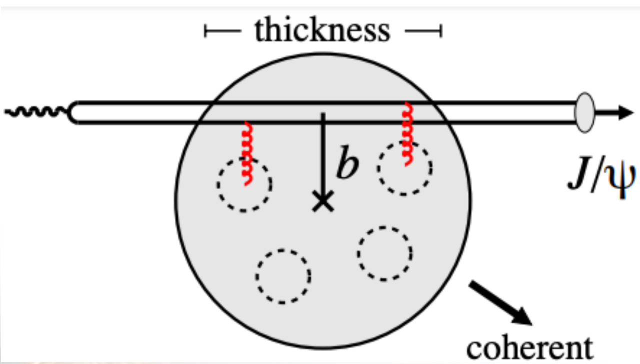
Diffraction



e+d incoherent J/Psi events with proton or neutron tagging

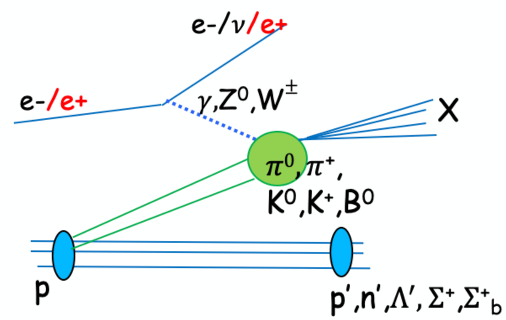


Saturation (coherent/incoherent J/ψ production)



Meson structure:

- with neutron tagging (ep→ (π) →e' n X)
- Lambda decays ($\Lambda \to p\pi^-$ and $\Lambda \to n\pi^0$)



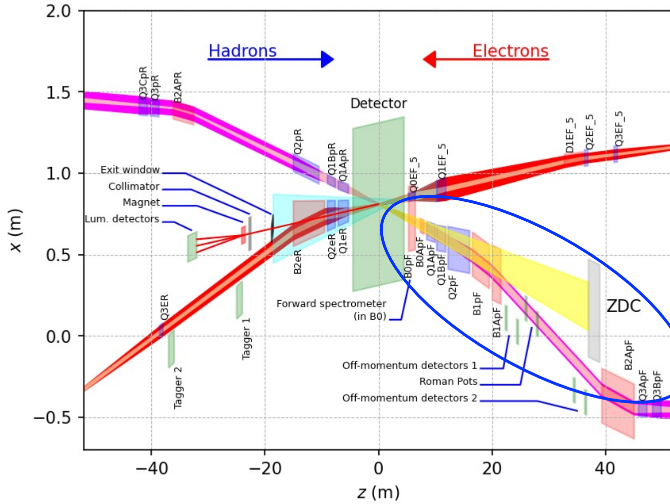
e+He3 with spectator proton tagging.

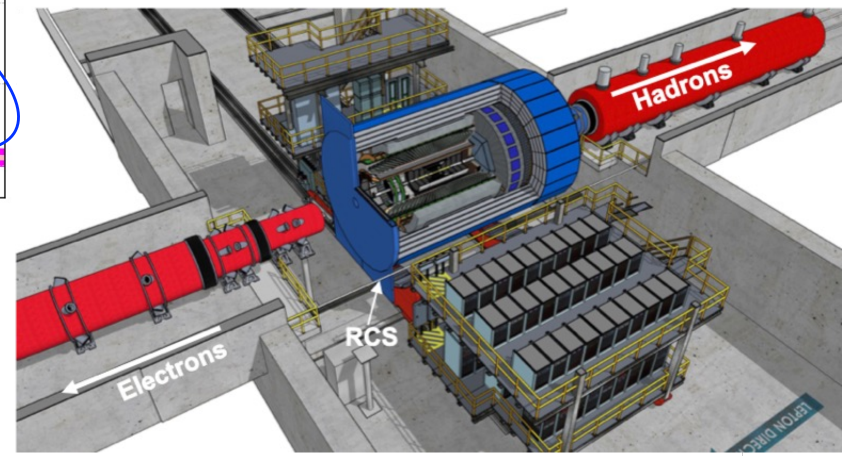
Tagging of coherent light ions (d, He3, He4) from coherent scattering.

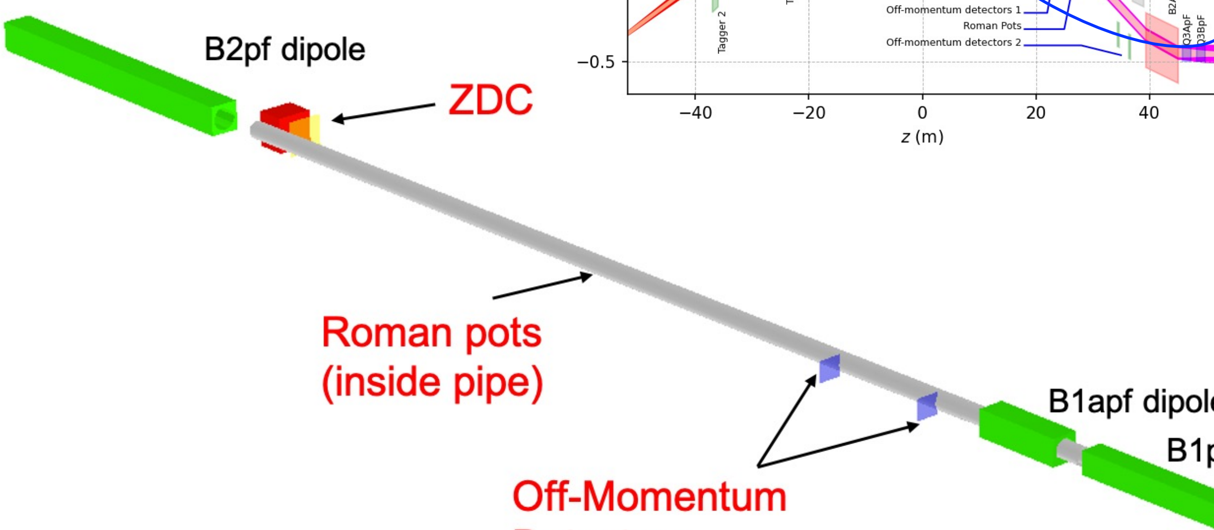
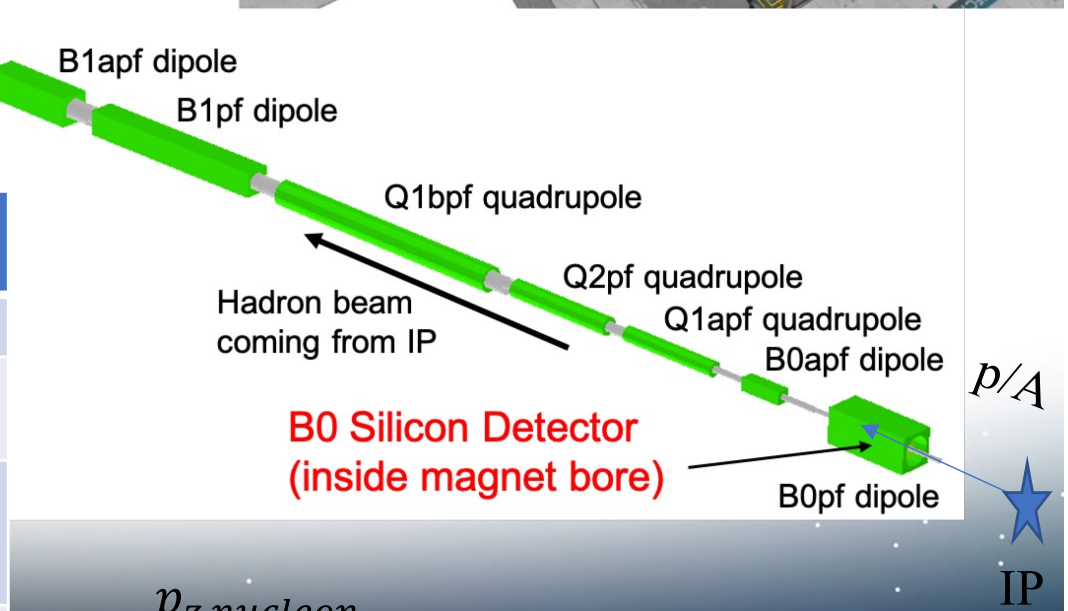
e+Au events with neutron tagging to veto breakup and photon acceptance.

….

Far forward (hadron going) region





Detector	Angular accept. [mrad]	P_T coverage
ZDC @ ~30m	θ<5.5 ($\eta > 6$)	pT<1.3 GeV
Roman Pots	0*<θ<5.0 ($\eta > 6$)	*Low p_T(t) cutoff (beam optics)
Off-Momentum Detectors	0.< θ < 5.0 ($\eta > 6$)	Low-rigidity particles from nuclear breakups
B0 forward spectrometer	$5.5 < \theta < 20.0$ (4.6< η < 5.9)	High p_T(t)

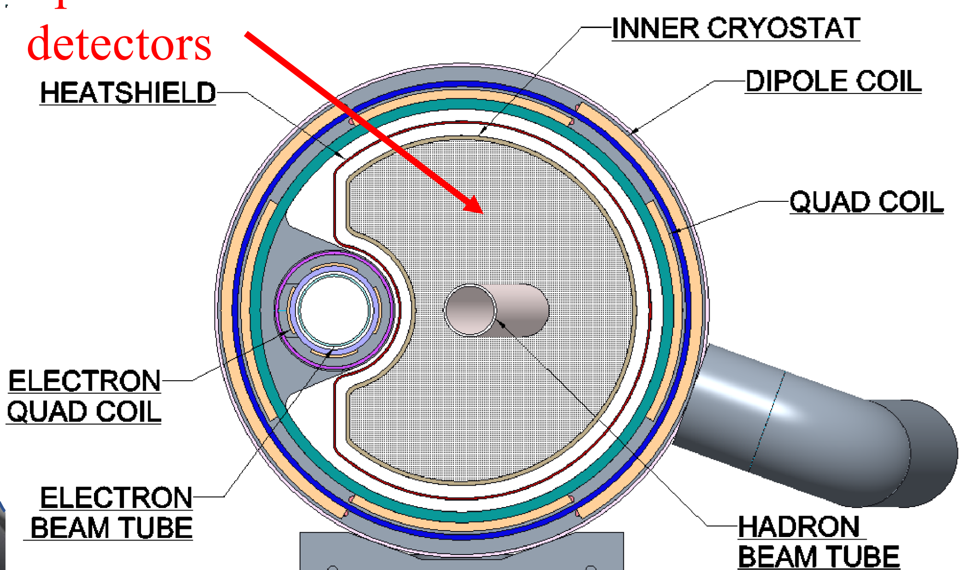
$$x_L = \frac{p_{z,nucleon}}{p_{z,beam}}$$

E.C. Aschenauer

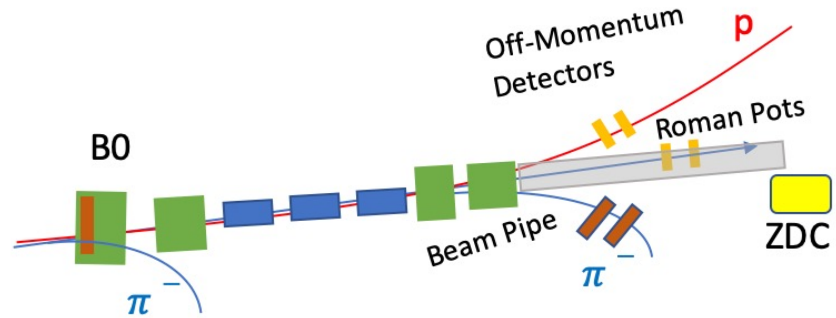
Far-forward detectors

B0-spectrometer (5.5 < θ < 20.0 mrad)

- Warm space for detector package insert located inside a vacuum vessel to isolate from insulating vacuum.
- Higher granularity detectors needed in this area (**MAPS**) with layers of fast-timing detectors (**LGADs**)
- Shape and coverage of B0 tracker needs to be further evaluated

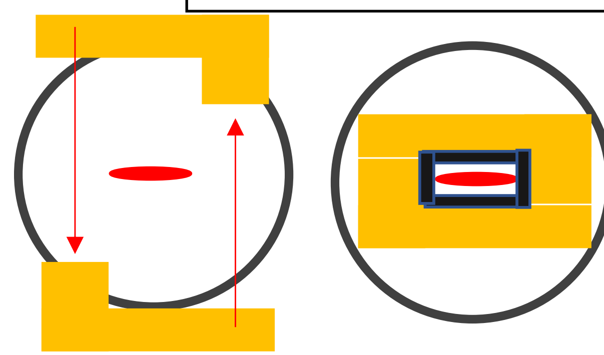


Roman-Pots and Off-momentum detectors 0.0* (10σ cut) < θ < 5.0 mrad



- Low Pt particles Pt < 1.3 GeV
- RPs: movable, integrated into the vacuum system
- Fast Timing and moderate granularity (500x500μm^2)
- **AC-LGADs**

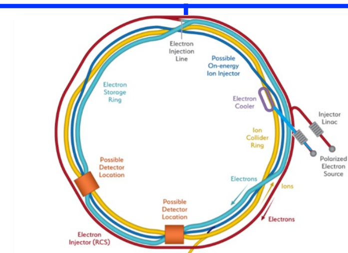
$$\sigma(z) = \sqrt{\varepsilon \cdot \beta(z))}$$



Complementarity for 1st-IR & 2nd-IR

Since CD-1 we made significant progress in the preliminary design for the 2nd IR with a focus on complementarity

	1st IR (IP-6)	2nd IR (IP-8)
Geometry:	ring inside to outside tunnel and assembly hall are larger Tunnel: ⦰ 7m +/- 140m	ring outside to inside tunnel and assembly hall are smaller Tunnel: ⦰ 6.3m to 60m then 5.3m
Crossing Angle:	25 mrad	35 mrad secondary focus



different blind spots
different forward detectors and acceptances
different acceptance of central detector

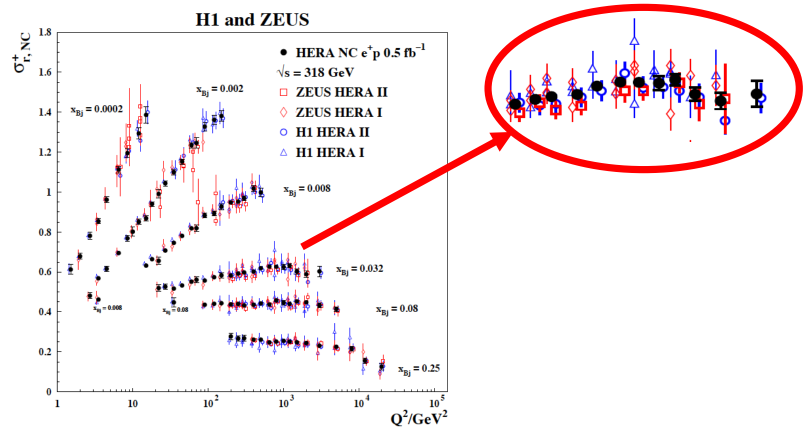
Luminosity:
more luminosity at lower E_{CM}
optimize Doublet focusing FDD vs. FDF
→ impact of far forward p_T acceptance

Experiment:
1.5 Tesla or 3 Tesla
different subdetector technologies

2^{nd} Detector: Complementary is Key

What do we want from “Complementary”

- **Cross-checking important results (obvious!)**
  - Many examples of wrong turns in history of nuclear and particle physics.
  - Independent cross checks (detector, community, analysis tools) are essential for timely verifications and corrections

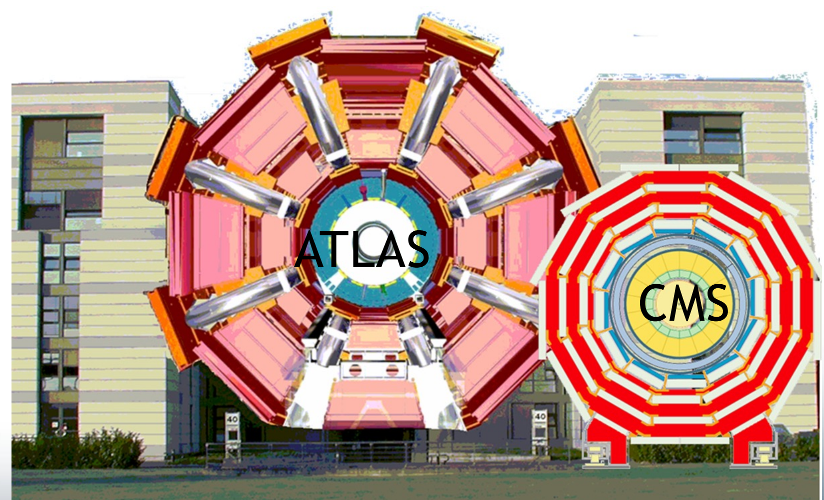


- **Cross Calibration**
  - Combining data gave well beyond the √2 statistical improvement …
  - Different dominating H1, ZEUS systematics…
  - Effectively use H1 electrons with ZEUS hadrons

  … not all optimal solutions have to be in one detector…

- **Technology Redundancy**

  ... by applying different detector technologies and philosophies to similar physics aims
  - mitigates technology risk vs. unforeseen backgrounds
  - differently optimizes precision and systematics



- **Different primary physics focuses**

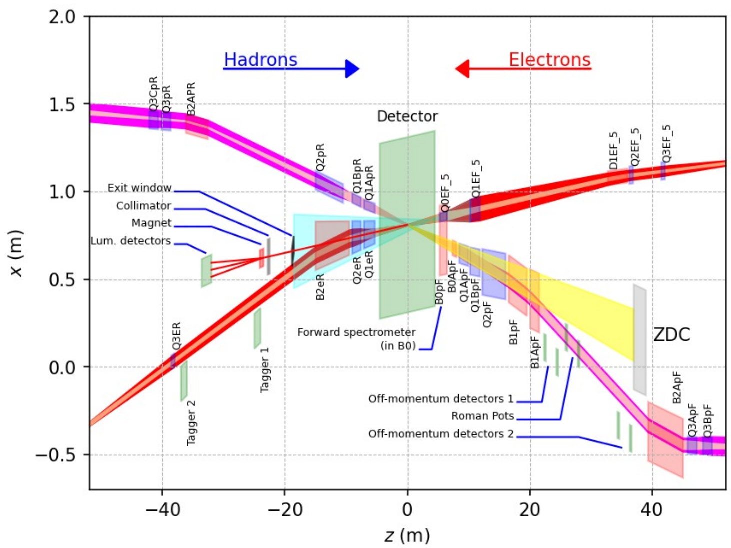
  ... EIC has unusually broad physics program (from exclusive single particle production to high multiplicity eA or γA with complex nuclear fragmentation)

  → Impossible to optimize for the full program in a single detector.

  → Impact on IR design

Progress – Interaction Region

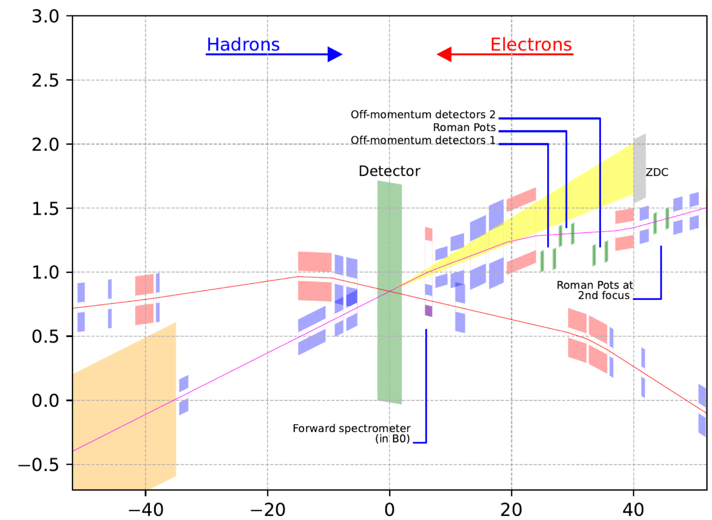
1st IR (IP-6)



IR Highlights and Challenges

- High Luminosity → High current (~ 2.5 A)
- High number of bunches (1160, ~10 ns separation)
  - Avoid parasitic collisions at IR
    - Crossing angle
    - Both focusing elements close to IP
- Small β^* values (h: 80/7.2 cm, e:45/5.6 cm)
  - Strong final focus magnets close to IR
  - Aperture: challenging magnet designs
- Polarization
  - Lattice constraints to enable polarized beams
  - Polarized hadrons / electons
    - Polarimetry (local and global)
    - Spin rotators & Snakes
  - electrons: Frequent on-energy bunch replacements
- Experimental detector
  - Forward detectors
  - Experimental solenoid & compensation

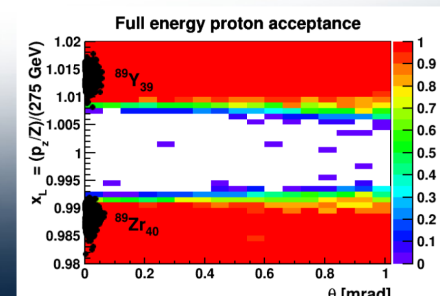
2nd IR (IP-8)



- The same highlights and challenges as IP-6
- Different: **pre-conceptual** design with 35mr crossing angle and secondary focus for science complementary checks.
- Further study needed for the feasibility of the IR magnets → Nb3Sn magnets are being evaluated as an option.

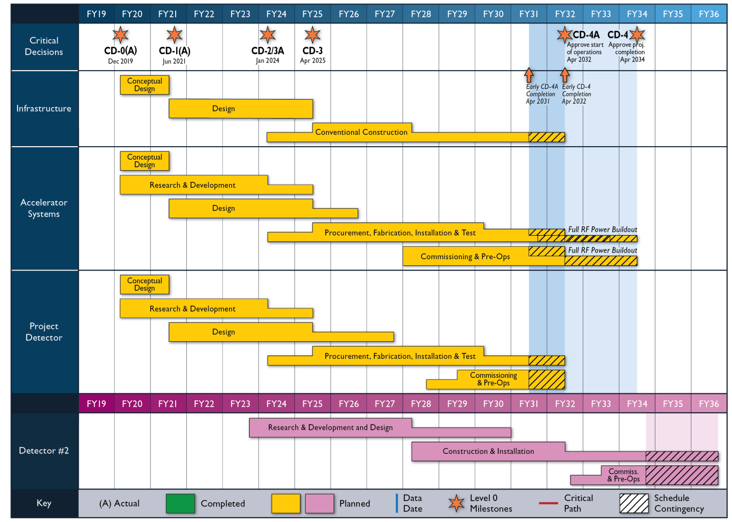
2nd focus enables:

enhanced low P_T acceptance, DVCS on nuclei, Light ion tagging, Diffraction, improved Gluon imaging by detection of (A-1) nuclei

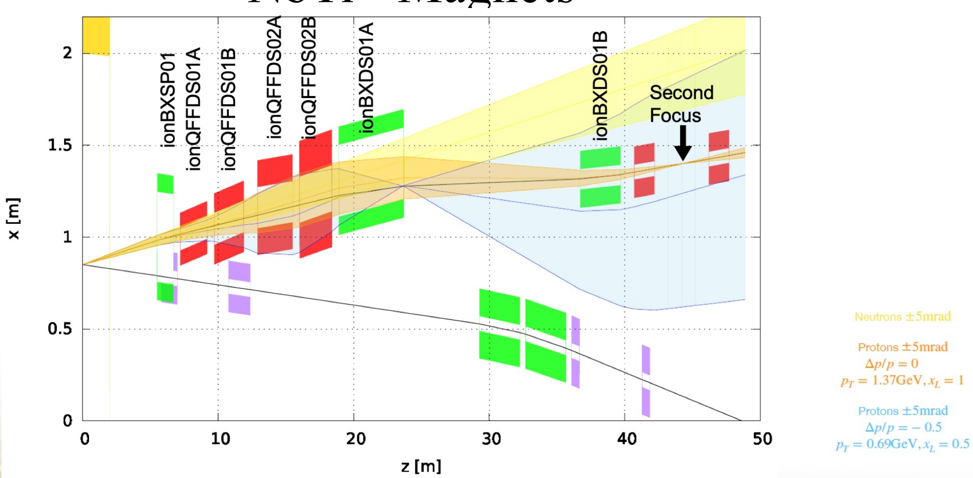


Enhance 2^{nd} IR complementarity: Nb_3Sn-Magnets

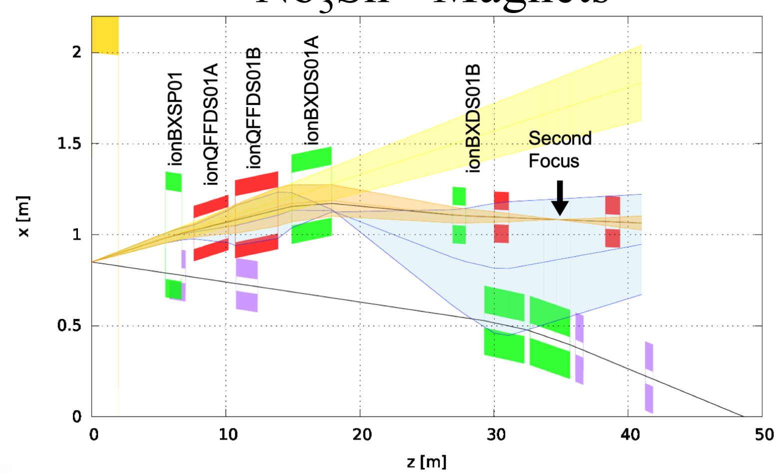
2^{nd} IR: 35 mrad crossing angle & secondary focus
Investigate Nb_3Sn magnets:
allow higher gradients → shorter L* → higher luminosity → compact IR
→ easier matching to existing RHIC arcs
→ technology challenge
- → Crosstalk: Greater crossing angle but shorter quadrupoles and stronger fields. NbTi version has 4 magnets at nearly full strength.



Present 2^{nd} IR pre-conceptual design
NbTi - Magnets



2^{nd} IR pre-conceptual design – v1
Nb_3Sn - Magnets



- Split ionQFFDS01A in 2 → Three magnets working as a doublet with the third powered off at low energy operation.
- Can reach smaller β^* with same β_{max} at low energies due to shorter focal length.
- Allows to tailor the apertures for acceptance better.