Center for Frontiers in Nuclear Science

Experimental Challenges and Opportunities at the EIC

Summary of Workshop 1 at EINN2023

It is impossible to cover every talk with equal weight

Abhay Deshpande

Ex-Chair i.e Chair of the infamous “Online” EINN2021

November 4, 2023

Who is this summary for?

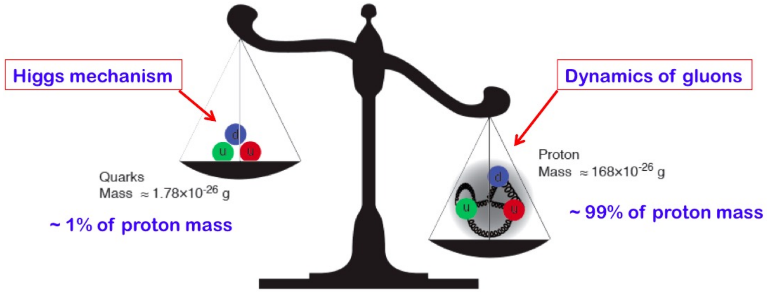
- Those who attended the WS1 don’t need this summary
- Those who presented detailed talks also don’t need this summary

This summary is for:

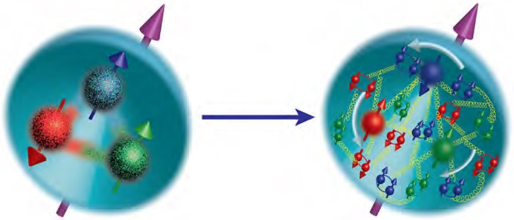
- Those who attended WS2 which ran parallel to WS1 (this)
- Those who chose to attend to the beaches, boats and para-gliders…

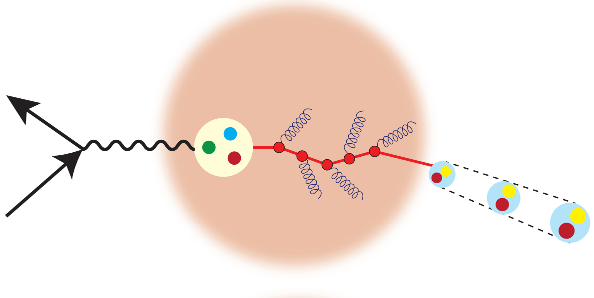
EIC Physics at-a-Glance

Eur. Phys. J. A 52 (2016) 9, 268 arXiv:1212.1701 (nucl-ex)



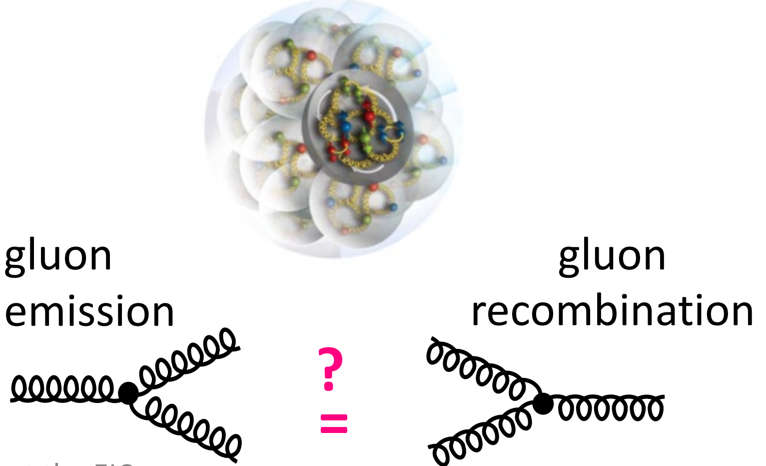
How are the sea quarks and gluons, and their spins, distributed in space and momentum inside the nucleon? How do the nucleon properties (mass & spin) emerge from their interactions?





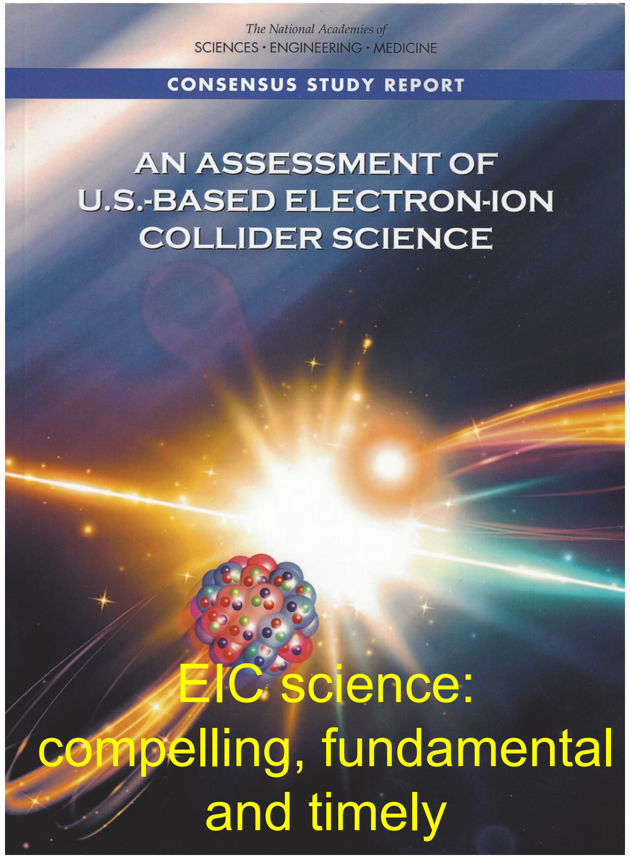
How do color-charged quarks and gluons, and colorless jets, interact with a nuclear medium? How do the confined hadronic states emerge from these quarks and gluons? How do the quark-gluon interactions create nuclear binding?

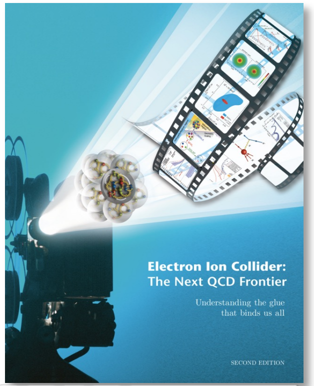
How does a dense nuclear environment affect the quark- and gluon- distributions? What happens to the gluon density in nuclei? Does it saturate at high energy, giving rise to a gluonic matter with universal properties in all nuclei, even the proton?

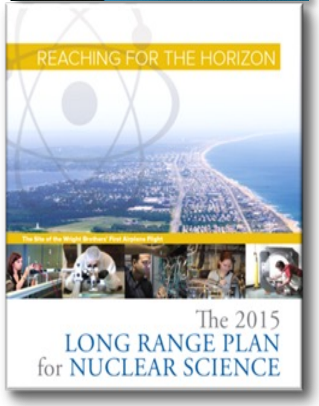


National Academy of Science, Engineering and Medicine

Assessment July 2018







Physics of EIC

- Emergence of Spin
- Emergence of Mass
- Physics of high-density gluon fields

Machine Design Parameters:

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

Day 1: EIC Introduction

- EIC project (Yech), Accelerator (Montag) & Detector design philosophy (Surrow)
- ePIC: Tracking (Posik), Particle ID (Preghenella), Calorimetry (Hornidge)

Day 2: EIC Detector 1: ePIC detector, measurements & challenges

- Measurements: GPD's (Niccolai), polarimetry (Gaskell), Luminosity (Piotrzkowsky)
- Measurements: high Q^2 (Puckett), TMDs (Surrow) and Meson structure (Briscoe)

Day 3: Second detector?

- Why? (Deshpande) and How? (preliminary ideas and discussion) (Nadel-Turonski)

14 talks in all, one remote (Yech)

All excellent talks, good discussions
Also, a special thanks to the Early Career Chairs
(Saskia Plura, Yasemin Schelhaas and Yannick Wunderlich)

EIC Workshop 1: Experimental Opportunities & Challenges

Day 1: EIC project and ePIC detector

Session 1: Yeck, Montag, Surrow

Session 2: Posik, Preghenella, Hornidge


Brookhaven National Laboratory
Jefferson Lab
U.S. DEPARTMENT OF ENERGY
Electron-Ion Collider Progress & Plans
Jim Yeck
EIC Project Director
BNL Associate Director
Parallel Workshop #1
EINN 2023
October 31, 2023
Electron-Ion Collider
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Project Organization – Level 1/2

- BNL/TJNAF Partnership
- OBS maps into WBS L1-Ln
- International Governance

Elaborated on the next slides

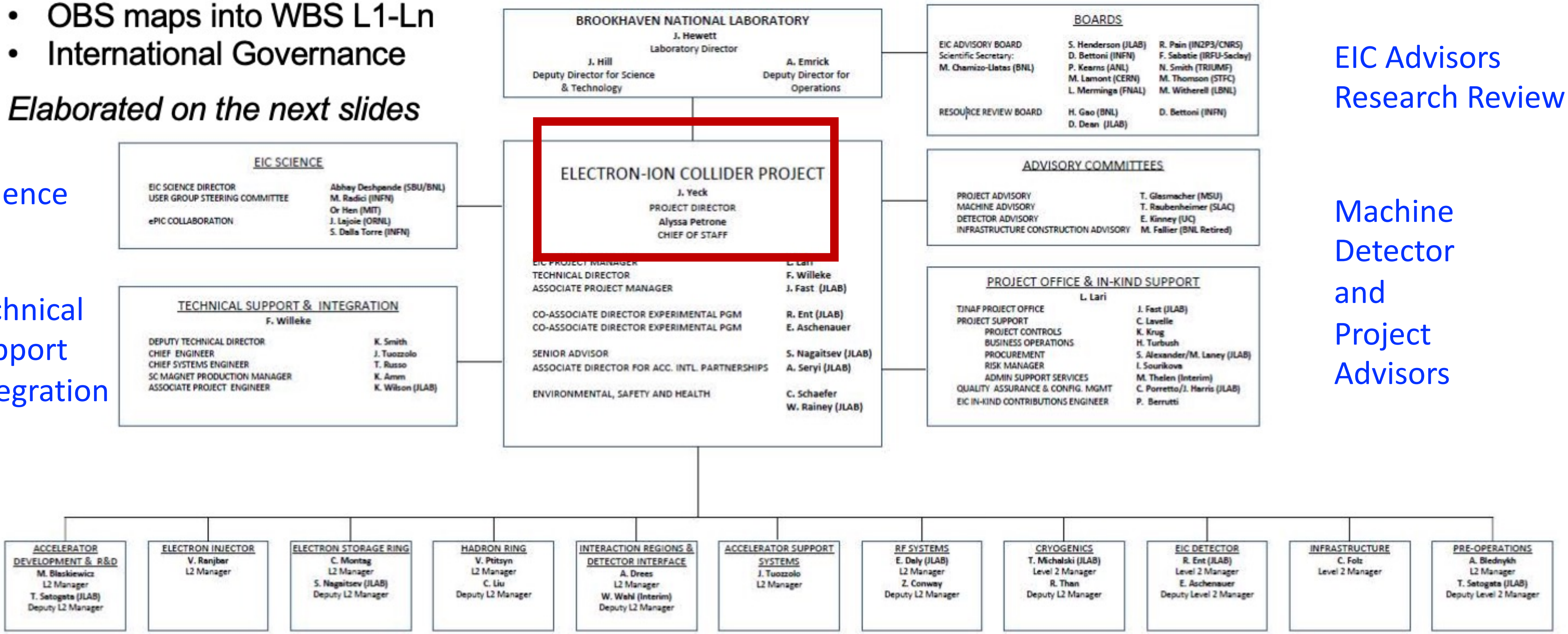
BNL DIrector

EIC Advisors
Research Review Board

Science

Technical
Support
Integration

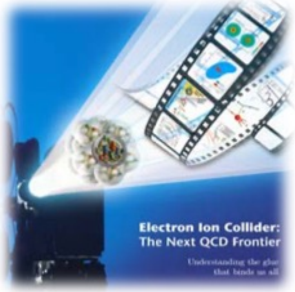
Machine
Detector
and
Project
Advisors



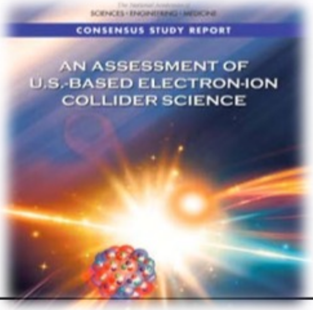
Project Requirements

Facility Performance Goals

- High Luminosity: $L = 10^{33} - 10^{34} cm^{-2} sec^{-1}$, 10 – 100 fb^{-1}/year
- Highly Polarized Beams: 70%
- Large Center of Mass Energy Range: E_{cm} = 20 – 140 GeV
- Large Ion Species Range: protons – Uranium
- Large Detector Acceptance and Good Background Conditions
- Accommodate a Second Interaction Region (IR)



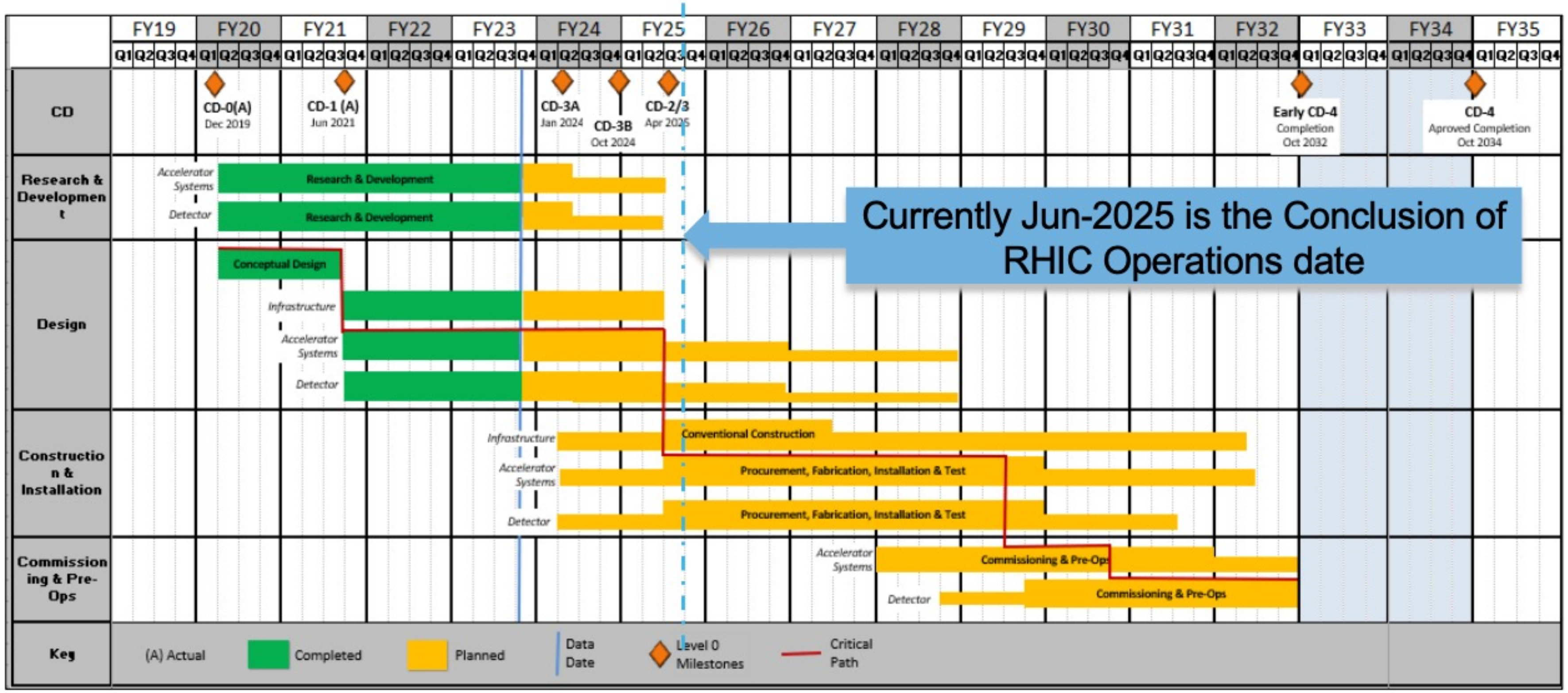
Conceptual design scope and expected performance meet or exceed the Nuclear Science Advisory Committee (NSAC) Long Range Plan (2015) and the EIC White Paper requirements endorsed by the National Academy of Sciences (2018).



Electron-Ion Collider
EINN 2023 J. Yeck 5

Schedule

Under finalization for CD-2; Mostly Technically Driven



Since CD-1, the critical path is on the Interaction Region Superconducting magnets.

Perhaps the most challenging machine ever built.

Montag

EIC Design Concept

- EIC is based on the RHIC complex: Hadron Storage Ring (HSR), injectors, ion sources, infrastructure; needs only relatively few modifications and upgrades
- Today's RHIC beam parameters are close to what is required for EIC (except number of bunches, 3 times higher beam current, and vertical emittance)
- Add a 5 to18 GeV electron storage ring & its injector complex to the RHIC facility ➔ E_{cm} = 29-141 GeV
- Design and built a suitable interaction region

Electron-Ion Collider

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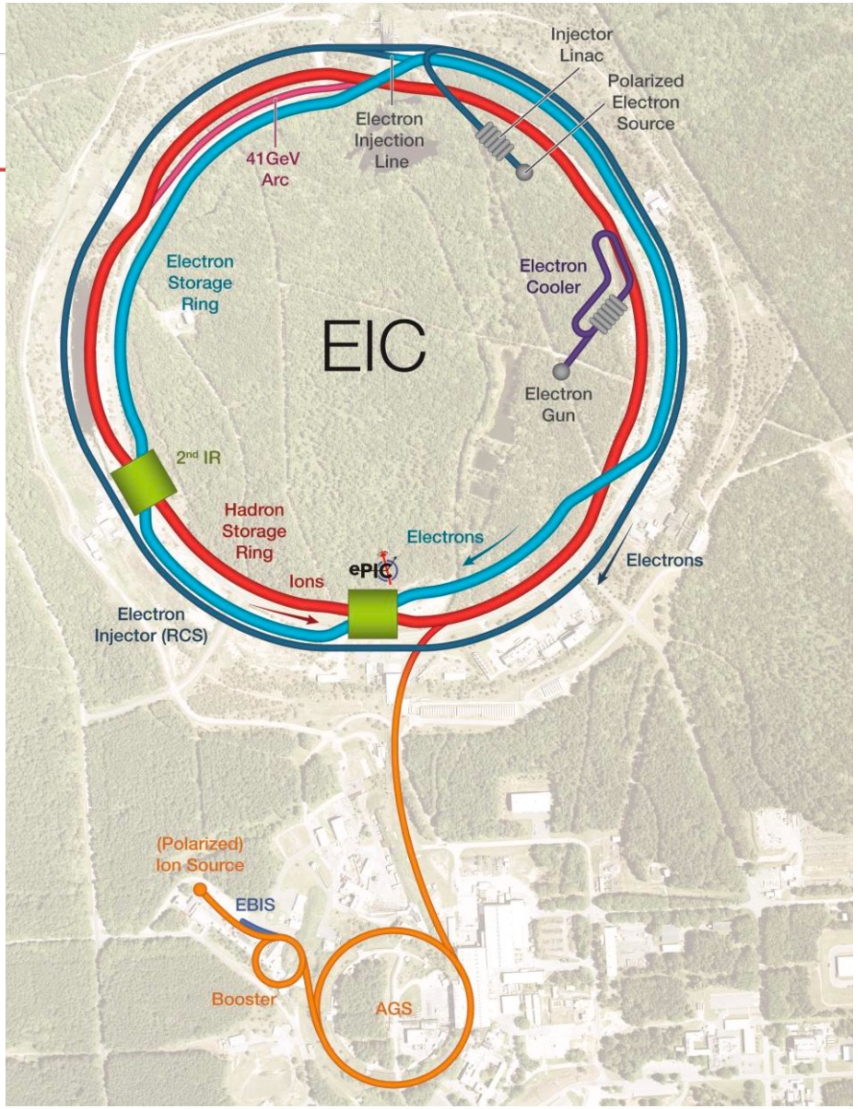


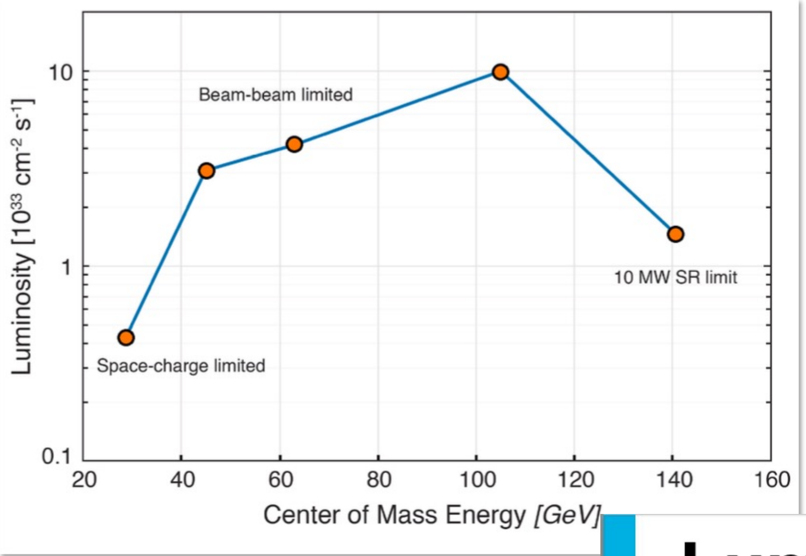
Parameters for Highest e-p Luminosity

	proton	electron
no. of bunches	1160	
energy [GeV]	275	10
bunch intensity [10^{10}]	6.9	17.2
beam current [A]	1.0	2.5
ϵ_{RMS} hor./vert. [nm]	9.6/1.5	20.0/1.2
$\beta^*_{x,y}$ [cm]	90/4	43/5
b.-b. param. hor./vert.	0.014/0.007	0.073/0.100
σ_s [cm]	6	2
$\sigma_{dp/p}$ [10^{-4}]	6.8	5.8
τ_{IBS} long./transv. [h]	3.4/2.0	N/A
L [$10^{33}\,cm^{-2}sec^{-1}$]	10.05	

RHIC ~ 120

- Hadron beam parameters similar to present RHIC, but smaller vertical emittance and many more bunches
- 2 hour IBS growth time requires strong hadron cooling
- Electron beam parameters resemble a B-Factory

e-p Luminosity versus Center-of-Mass Energy



Electron-nucleon luminosities in e-A collisions are similar within a factor of 2 to 3

Relevant in the discussion of two interaction regions (later)

Electron-Ion Collider

Luminosity Sharing with two IRs

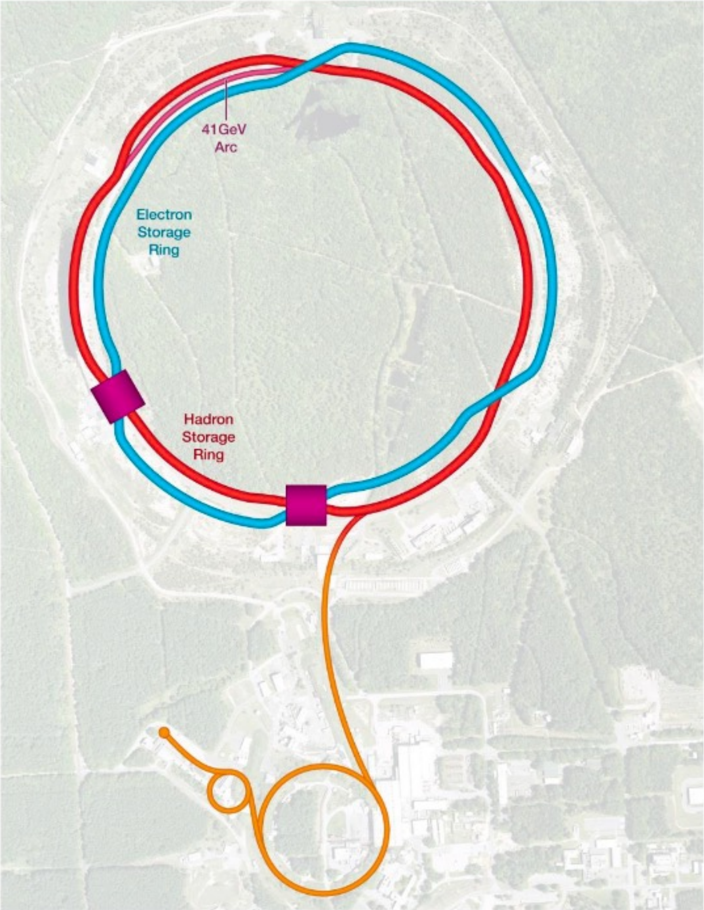
- Both electrons and hadrons are at the beam-beam limit with one collision point – they would not “survive” a second IR
- To enable two collision points, both electron and hadron bunch intensity would have to be reduced by a factor two – resulting luminosity at each IR would be factor 4 smaller
- Instead, we modify the fill pattern such that half the bunches collide in IR6, while the other half collides in IR8
- As a result, total luminosity is preserved, and each detector gets half of the total

Examples of ingenuity of accelerator scientists amongst many others

Hadron Storage Ring

Collision Synchronization

- HSR needs to operate over a wide energy range
- Changing the beam energy in the HSR causes a significant velocity change
- To keep the two beams in collision, they have to be synchronized so bunches arrive at the detector(s) at the same time
- Synchronization accomplished by path length change
- Between 100 and 275 GeV (protons), this can be done by a small radial shift – there is enough room in the beampipe
- For lower energies, use an inner instead of an outer arc as a shortcut. 90 cm path length difference corresponds to 41 GeV proton beam energy



Electron-Ion Collider

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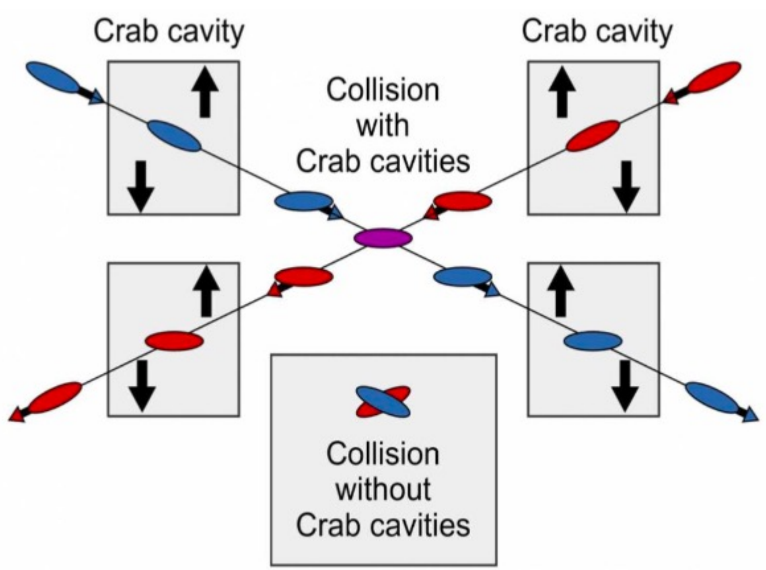
Examples of technical challenges

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 – to be taken into account in analysis



Electrons: has history from BELLE
Proton/nuclei : new but R&D synergy with LHC

Electron-Ion Collider

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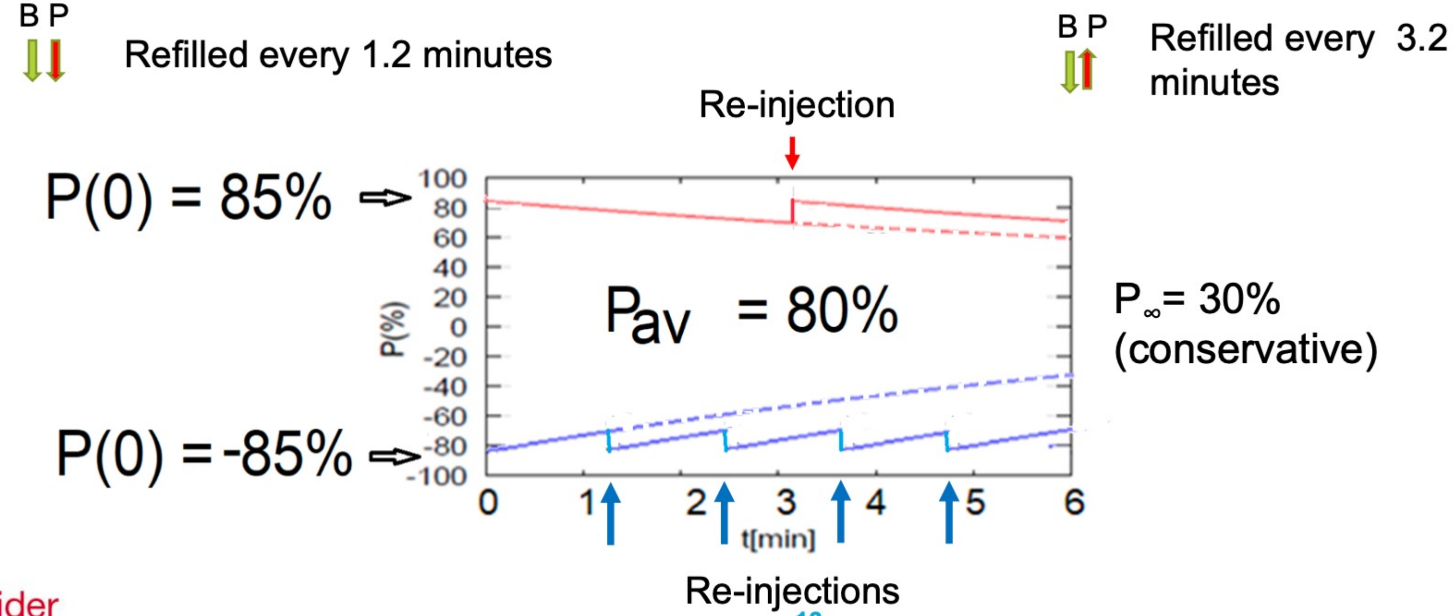
High Average Electron Polarization

- Frequent injection of bunches with high initial polarization of 85%
- Initial polarization decays towards P_∞
- At 18 GeV, every bunch is replaced (on average) after 2.2 min with RCS cycling rate of 1Hz



Detector and Measurements

- Electron and hadron beam polarimetry (Gaskell)
- Measurement of luminosity (Piotrzkowsky)

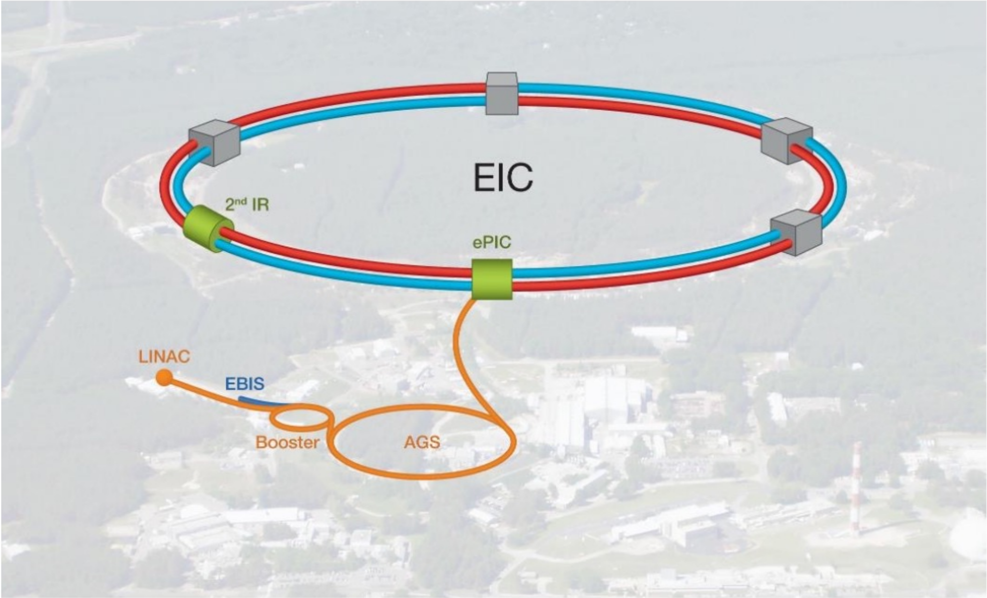
- Detector design philosophy and ePIC detector design (Surrow)
  - Tracker subsystem (Posik)
  - Particle Identification (Preghenella)
  - Calorimetry (Hornidge)

Electron and Hadron Beam Polarimetry at EIC

Dave Gaskell

Jefferson Lab

- Polarimetry at EIC
- Electron Polarimetry
  - Mott Polarimeters
  - ESR Compton
  - RCS Compton
- Hadron Polarimetry
  - p-Carbon Polarimeter
  - H-Jet Polarimeter



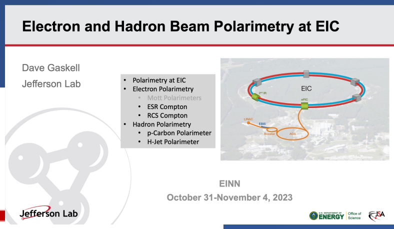
EINN

October 31-November 4, 2023

Jefferson Lab

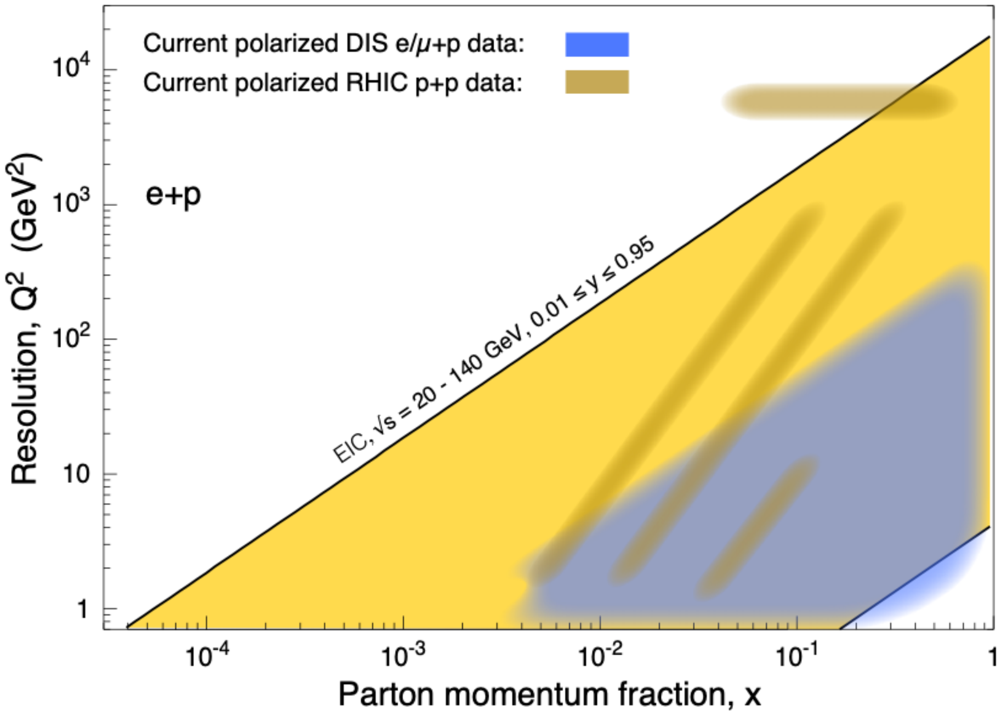
U.S. DEPARTMENT OF ENERGY Office of Science

JSA



Physics from Polarized Beams at EIC

- EIC will provide an enormous amount of information in many reaction channels to elucidate the quark/gluon structure of nucleons and nuclei
- ***Polarized beams*** a crucial requirement for achieving physics goals
- 1D polarized quark distributions via inclusive and SIDIS measurements (double-spin asymmetries)
- Access to transverse momentum distributions (TMDs) via SIDIS (single-spin, double-spin asymmetries)
- Total angular momentum in nucleon (GPDs) via exclusive reactions (single-spin, double-spin asymmetries)
- Physics beyond the Standard Model using PV processes



EIC will provide unprecedented statistical precision in many reaction channels due to its high luminosity

→ Require systematic precision to match

2 Jefferson Lab

EIC Beam Properties and Polarimetry Challenges

EIC will provide unique challenges for both electron and hadron polarimetry

Common to both:
→ Small spacing between electron/hadron bunches (10 ns) at high luminosity configuration (~40 ns at higher CM configuration)
→ Intense beams (0.26 to 2.5 A)
  → Large synchrotron radiation from electron beam results in large effects at detectors
  → Hadron beam intensity results in challenges for polarimeter targets

Polarimetry systematics:
Goal is ***dP/P = 1%*** or better for both electrons and hadrons

Table 1.1: Maximum luminosity parameters.

Parameter	hadron	electron
Center-of-mass energy [GeV]	104.9	
Energy [GeV]	275	10
Number of bunches	1160	
Particles per bunch [10^{10}]	6.9	17.2
Beam current [A]	1.0	2.5
Horizontal emittance [nm]	11.3	20.0
Vertical emittance [nm]	1.0	1.3
Horizontal β-function at IP β_x^* [cm]	80	45
Vertical β-function at IP β_y^* [cm]	7.2	5.6
Horizontal/Vertical fractional betatron tunes	0.228/0.210	0.08/0.06
Horizontal divergence at IP $\sigma_{x'}^*$ [mrad]	0.119	0.211
Vertical divergence at IP $\sigma_{y'}^*$ [mrad]	0.119	0.152
Horizontal beam-beam parameter ξ_x	0.012	0.072
Vertical beam-beam parameter ξ_y	0.012	0.1
IBS growth time longitudinal/horizontal [hr]	2.9/2.0	-
Synchrotron radiation power [MW]	-	9.0
Bunch length [cm]	6	0.7
Hourglass and crab reduction factor [17]	0.94	
Luminosity [10^{34} cm^{-2} s^{-1}]	1.0	

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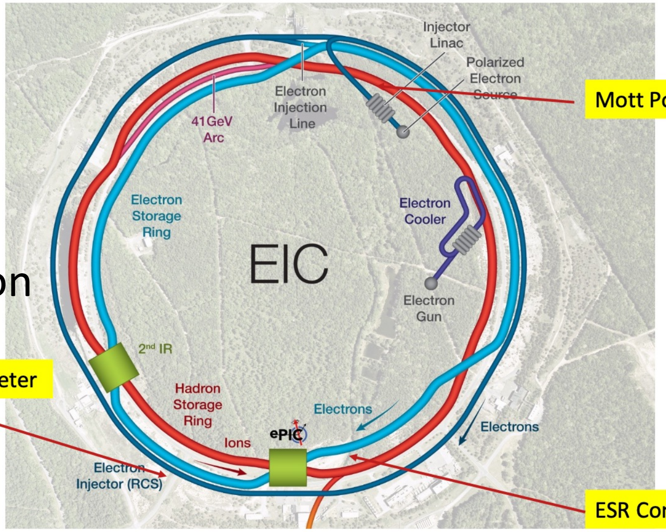
Jefferson Lab

EIC Electron Polarimeter Map

Rapid Cycling Synchrotron



Electron Storage RIng

Mott Polarimeters

RCS Compton polarimeter

ESR Compton polarimeter

ESR Compton Polarimeter

Compton polarimetry ideal technique for storage rings
→ Non-destructive
→ Can be used for both longitudinal and transverse polarization

Planned Compton polarimeter location upstream of detector IP

At Compton interaction point, electrons have both longitudinal and transverse (horizontal) components
→ Longitudinal polarization measured via asymmetry as a function of backscattered photon/scattered electron energy
→ Transverse polarization from left-right asymmetry

Beam energy	P_L	P_T
5 GeV	96.5%	26.1%
10 GeV	86.4%	50.4%
18 GeV	58.1%	81.4%

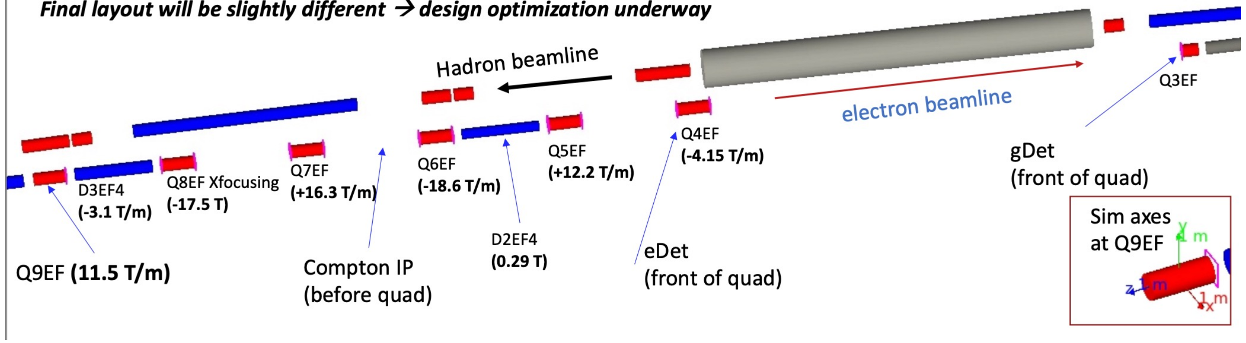
Polarization Components at Compton

Beam polarization will be fully longitudinal at detector IP, but accurate measurement of absolute polarization will require ***simultaneous*** measurement of P_L and P_T at Compton polarimeter

EIC Compton will provide first high precision measurement of P_L and P_T at the same time

Compton Placement

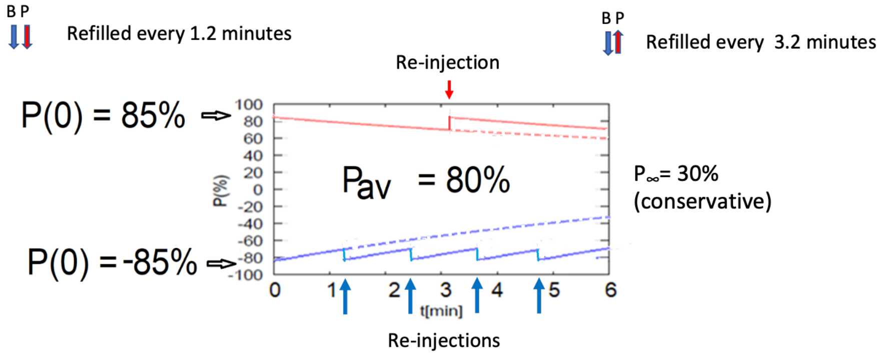
Final layout will be slightly different → design optimization underway



Various difficulties and challenges discussed see the talk for details and their mitigation

Polarization Time Dependence - electrons

- Electrons injected into the storage ring at full polarization (85%)
- Sokolov-Ternov effect (self-polarization) will re-orient spins to be anti-parallel to main dipole field → electrons will have different lifetime depending on polarization
- Bunches must be replaced relatively often to keep average polarization high
- Bunch-by-bunch polarization measurement required



Bunches will be replaced about every 50 minutes at 5 and 10 GeV
→ 1-3 minutes at 18 GeV

Sets requirement for measurement time scale

Electron Polarimetry Systematics

Beam energy	P_L	P_T
5 GeV	96.5%	26.1%
10 GeV	86.4%	50.4%
18 GeV	58.1%	81.4%

State of the art for Compton polarimetry:

Longitudinal:

SLD @ SLAC: dP/P=0.5% → Electron detector in multi-photon mode

Q-Weak in Hall C @ JLab: dP/P=0.59% → Electron detector, counting mode

CREX in Hall A @ JLab: dP/P=0.44% → Photon detector, integrating mode

Transverse:

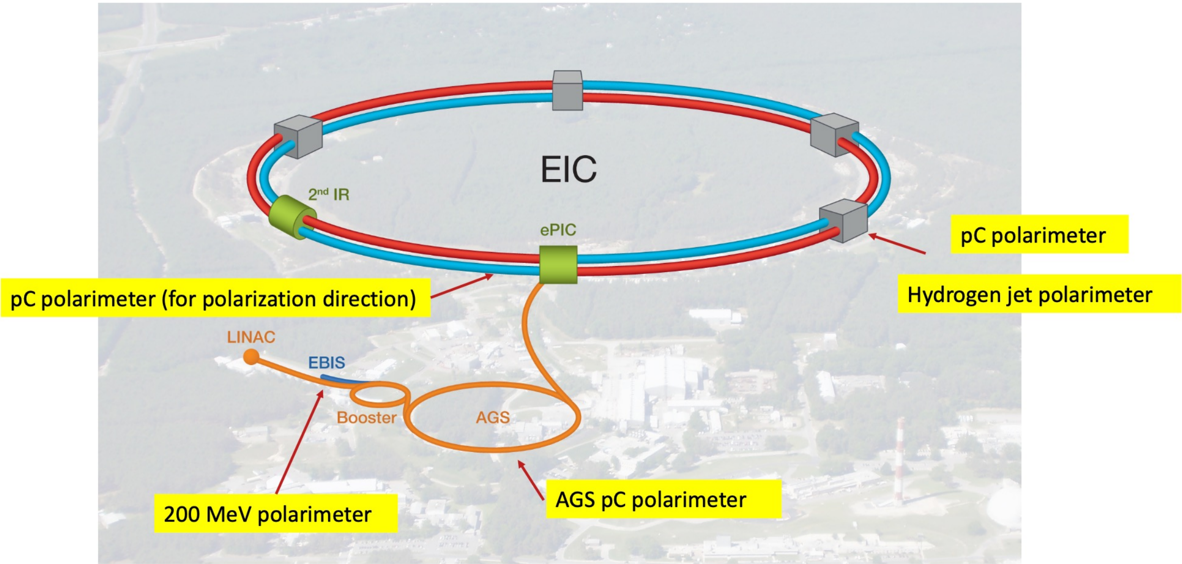
TPOL @ HERA: dP/P=1.87% → Photon detector in counting mode

Total polarization extraction will rely on two quasi-independent measurements

While 0.5% for P_L is plausible, P_T is less certain → 1%?

At 18 GeV this results in dP/P=0.86% at 18 GeV

Hadron Polarimeter Map

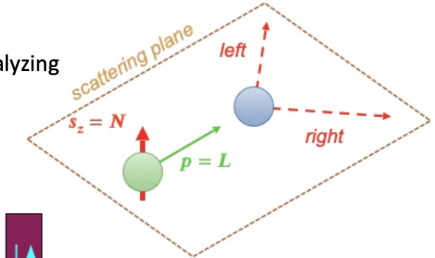


Measurement of Absolute Polarization

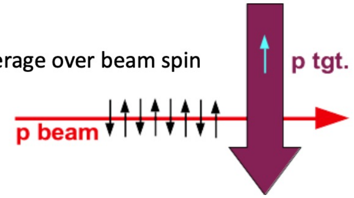
Electron polarimetry benefits from known QED processes (Compton, Møller scattering)
→ No equivalent processes for hadrons to measure absolute polarization → analyzing power a priori unknown

Use of polarized target with polarized beam bypasses need to determine analyzing power from first principles

$$\epsilon = \frac{N_R - N_L}{N_R + N_L} = A_N P$$

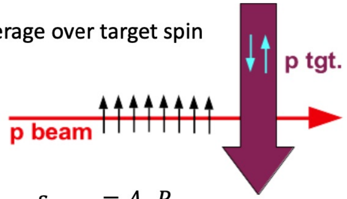


Average over beam spin



$$\varepsilon_{target} = A_N P_{target}$$

Average over target spin

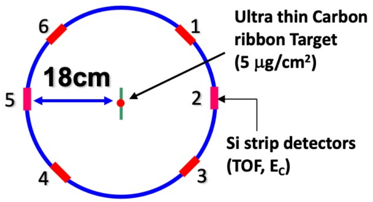


$$\varepsilon_{beam} = A_N P_{beam}$$

$$\Rightarrow P_{beam} = \frac{\varepsilon_{beam}}{\varepsilon_{target}} P_{target}$$

p-Carbon Polarimeter

p-Carbon polarimeter also uses elastic scattering in CNI region
→ Provides rapid, ***relative*** measurement of proton polarization
→ Uses thin carbon ribbon
→ Very low energy, recoiling carbon detected in silicon strip detectors
→ Polarization extracted via L-R asymmetry
2 p-Carbon polarimeters at RHIC → vertical and horizontal target to characterize beam profile



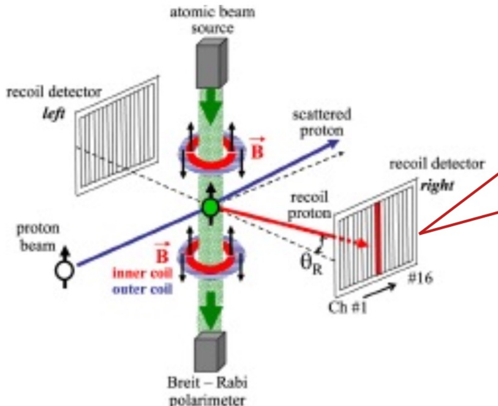
Nominal target size:
2.5 cm · 10 μ · 50 nm

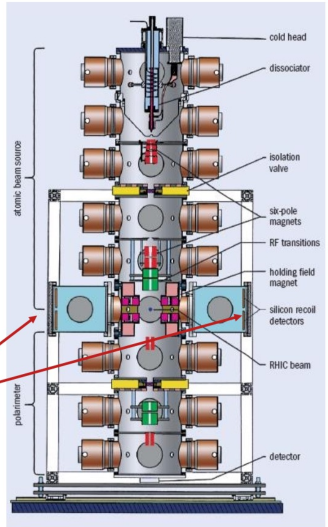
Passed across beam & back
~2-5 sec. in beam each pass
lifetime: few - few hundred passes

Hydrogen-Jet Polarimeter at RHIC

H-Jet Polarimeter (presently) installed at IP12
→ Uses elastic p-p scattering in the Coulomb-nuclear interference (CNI) region
→ Polarized atomic H source, 1.2·10^{12} atoms/cm2
→ Target polarization measured w/ Breit-Rabi polarimeter, P_{target} ≈ 96%

→ Silicon strip detectors, 12 strips 3.75 mm pitch
→ H-Jet has achieved high precision at RHIC: $(dP/P)_{syst}$=0.6%
→ Measurements time consuming: $(dP/P)_{stat}$ ~ 2% for 8-hour period





Summary

- EIC goal is to measure both electron and hadron beam polarization to 1%
- Compton polarimeter for electrons
  - ESR Compton must measure both P_L and P_T simultaneously since Compton not at IP
  - High current, short bunch separation pose challenges
  - P_T measurement may be biggest challenge for <1% polarimetry
- Hadron polarimetry will use combination of:
  - H-Jet (absolute)
    - Has achieved dP/P=0.6%
  - p-Carbon (relative)
    - Can measure polarization profile (transverse and longitudinal)
  - Both polarimeters must overcome issues with background rejection
    - Must find new target for p-Carbon polarimeter

Luminosity measurements @EIC – guided

Krzysztof PIOTRZKOWSKI

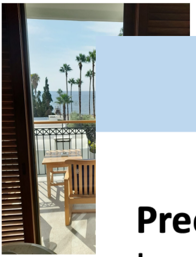
AGH University of Science and Technology

Although we are building up substantially over what we had in HERA, EIC presents new and fundamental technical and intellectual challenges (opportunities) because of its

- *high luminosity*
- *diverse species of nuclei and*
- *variable center of mass energies.*

Preamble: LEP luminosity analysis recently (after 20 yrs) published new data, that improved the by a factor ~two and even the central value changed. Impacting the number of light neutrinos from hadronic cross section measurement at Z peak. Some 2sigma discrepancies are done.

Krzysztof PIOTRZKOWSKI
H University of Science and Technolog



EIC luminosity challenge

Precise cross-section measurements are the corner stone of physics program at the EIC, hence very demanding requirements for the EIC luminosity measurement:

- **Absolute $\mathcal{L}$ precision of** **1%** or better
- "Bunch-to-bunch" **relative $\mathcal{L}$ measurements** with very high precision of **$\lesssim 10^{-4}$**

27.5 GeV e × 820 GeV p

Acceptance error	0.8%
Cross section calculation	0.5% ←
e gas background substr.	0.1%
Multiple event correction	0.03%
Energy scale error	0.5%
Total error	1.05%

EIC luminosity challenge:

HERA recipe: use very precise measurement of bremsstrahlung rate R: $\mathcal{L} = R/\sigma$

However: nominal EIC *ep* luminosity will be almost **1000 times bigger** than that at HERA I, and thanks to 10 times smaller bunch spacing event pileup will be only partially mitigated – for E_γ/E_e > 1%, σ_{BH} = 0.23 b at E_e = 10 GeV; but **as event pileup scales roughly as Z²/2A** hence for *eAu* case, instead of **23** hard photons every 10 ns, more than **300** photons (σ_{BH} = 1.4 kb) will hit detectors, corresponding to **>30 GHz total event rate**!

HERA II big challenges: luminosity > 5 × higher (→ event pileup) + **very hard synchrotron radiation** (→ strong SR filtering needed) ⇒ two complementary methods used by ZEUS, but still only 2% precision achieved

H1 using only one ("PCAL") bremsstrahlung measurement, https://doi.org/10.1016/j.nima.2010.12.219, achieved 3% absolute precision – for overall normalization the Compton scattering was used, https://dx.doi.org/10.1140/epjc/s10052-012-2163-2, resulting in final uncertainty of 2.7%

For example, at the EIC, for E_e = 18 GeV, E_p = 275 GeV and E_γ = 1 GeV, one gets the minimal longitudinal momentum transfer, *in the proton rest-frame*, $\Delta p_z = |q_{min}|/c$ = 0.00073 eV/c. The corresponding (kinetic) energy transfer = $(\Delta p)^2/2M \approx 3.10^{-16}$ eV!

From the uncertainty principle Δp_z corresponds to the longitudinal distance $\approx \hbar/\Delta p_z$ of **0.3 mm** whereas in the transverse plane the impact parameters can be even larger.

Higher beam energies/lower photon energy ⇒ **more** extreme it becomes!

Measurements of Beam-Size Effects @ EIC

Letter Open Access

https://doi.org/10.1103/PhysRevD.103.L051901

When invariable cross sections change: The Electron-Ion Collider case

Krzysztof Piotrzkowski and Mariusz Przybycien
Phys. Rev. D **103**, L051901 – Published 5 March 2021

JINST **16** (2021) 09, P09023
https://doi.org/10.1088/1748-0221/16/09/P09023

For **direct photon measurement** bremsstrahlung pileup is huge at EIC and photon counting is not possible, instead, **total photon energy per bunch crossing** can be measured, ⇒⇒ which is directly proportional to $\mathcal{L}$

For nominal *eAu* collisions it is equivalent to measuring total photon energy ≈ 600 GeV !

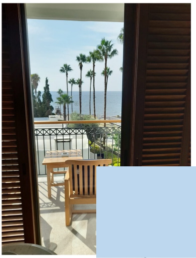
ABSTRACT

In everyday research, it is tacitly assumed that scattering cross sections have fixed values for a given particle species, center-of-mass energy, and particle polarization. However, this assumption has been called into question after several observations of suppression of high-energy bremsstrahlung. This process will play a major role in experiments at the future Electron-Ion Collider, and we show how variations of the bremsstrahlung cross section can be profoundly studied there using the lateral beam displacements. In particular, we predict a very strong increase of the observed cross sections for large beam separations. We also discuss the relation of these elusive effects to other quantum phenomena occurring over macroscopic distances. In this context, spectacular and possibly useful properties of the coherent bremsstrahlung at the Electron-Ion Collider are also evaluated.

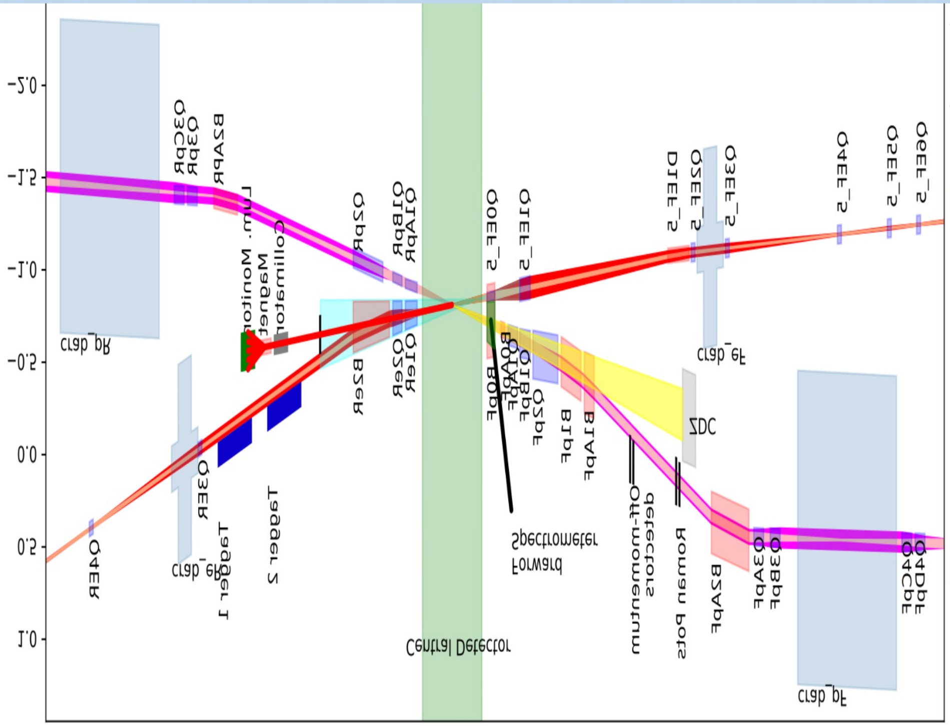
Other complications:

- Bunch by bunch intensity (luminosity) variation
- How well can that be constrained…. For spin measurements?

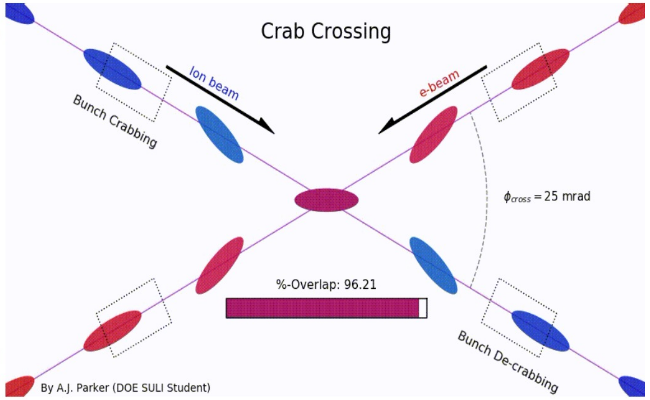
Krzysztof PIOTRZKOWSKI
H University of Science and Technolog



Interaction Region at the EIC



Vertex drift has negligible effect on γ–acceptance (in contrast to forward *p/e* tracking), as **all photons with polar angle < 1 mrad should be detected**



https://www.bnl.gov/ec/files/EIC_CDR_Final.pdf
https://wiki.bnl.gov/eic/

K. Piotrzkowski (AGH UST), Paphos - EINN 2023 13

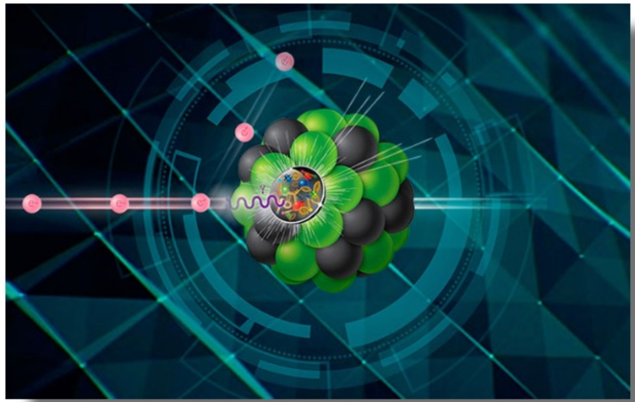
Great deal of things to be learnt and done… investigated and "lumino-meter" designed and implemented reliably

Design Philosophy
ePIC
(electron-Proton/Ion Collider)
Detector and Collaboration

Bernd Surrow

(surrow@temple.edu)

TEMPLE UNIVERSITY



15th European Research Conference EINN 2023
Paphos, Cyprus, October 31 - November 4, 2023

U.S. DEPARTMENT OF ENERGY | Office of Science

DOE NP contract: DE-SC0013405

Bernd Surrow

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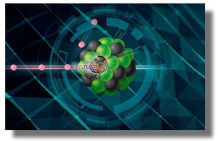
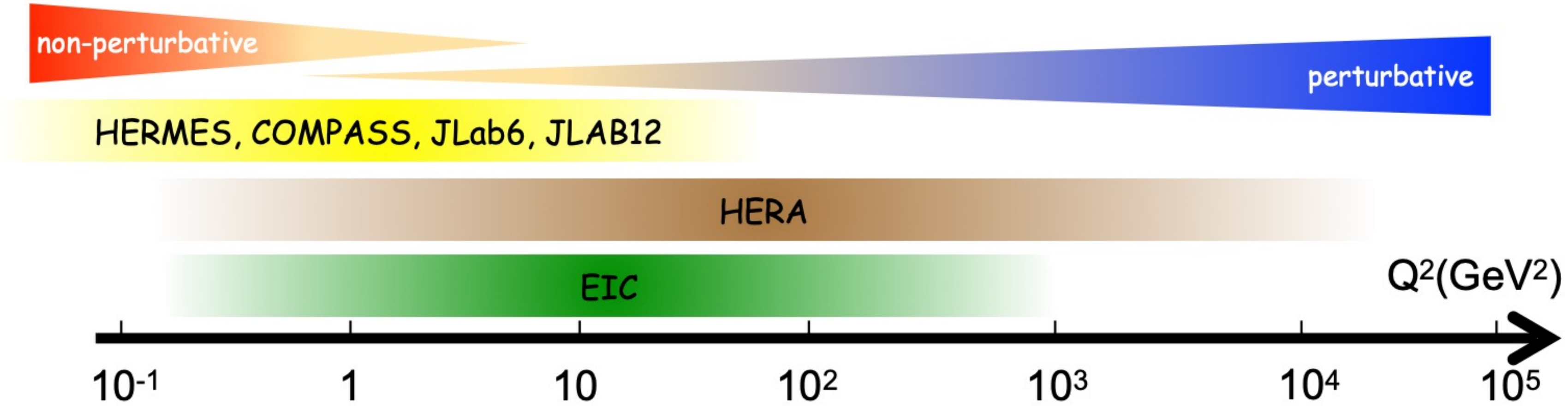
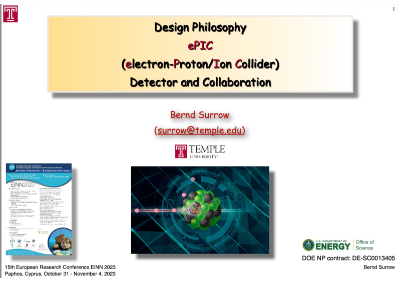


U.S. DEPARTMENT OF ENERGY Office of Science
DOE NP contract: DE-SC0013405
Bernd Surrow

EIC Project Development

- **Requirements**
  - **Machine:**
    - High luminosity: $10^{33}cm^{-2}s^{-1}$ - $10^{34}cm^{-2}s^{-1}$
    - Flexible center-of-mass energy $\sqrt{s} = \sqrt{4 E_e E_p}$: Wide kinematic range $Q^2 = s\,x\,y$
    - Highly polarized electron (0.8) and proton / light ion (0.7) beams: Spin structure studies
    - Wide range of nuclear beams (d to Pb/U): High gluon density
  - **Detector:**
    - Wide acceptance detector system including particle ID (e/h separation & π, K, p ID - flavor tagging)
    - Instrumentation for tagging of protons from elastic reactions and neutrons from nuclear breakup: Target / nuclear fragments in addition to low Q^2 tagger / polarimetry and luminosity (abs. and rel.) measurement





EIC Project Development

- Yellow Report Activity - Critical EIC Community activity for CD-1

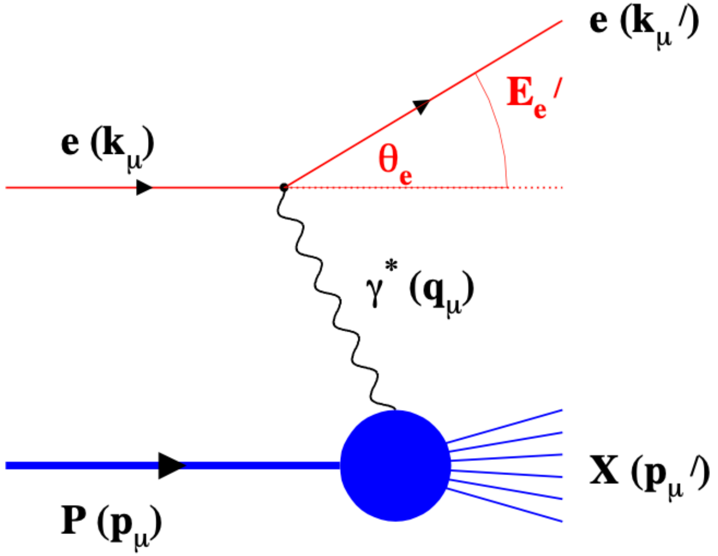
- ~400 authors / ~150 institutions / ~900 pages with strong international contributions!
- Review: Community review within EICUG and external readers (~30) worldwide covering physics and detector expert fields!
- Available on archive: Nucl. Phys. A 1026 (2022) 122447 / https://arxiv.org/abs/2103.05419

Bernd Surrow
(surrow@temple.edu)
TEMPLE UNIVERSITY

ePIC Detector Design Philosophy

- DIS - Kinematics

$$k = \begin{pmatrix} E_e \\ 0 \\ 0 \\ -E_e \end{pmatrix} \qquad k' = \begin{pmatrix} E'_e \\ E'_e \sin\theta'_e \cos\phi'_e \\ E'_e \sin\theta'_e \sin\phi'_e \\ E'_e \cos\theta'_e \end{pmatrix}$$

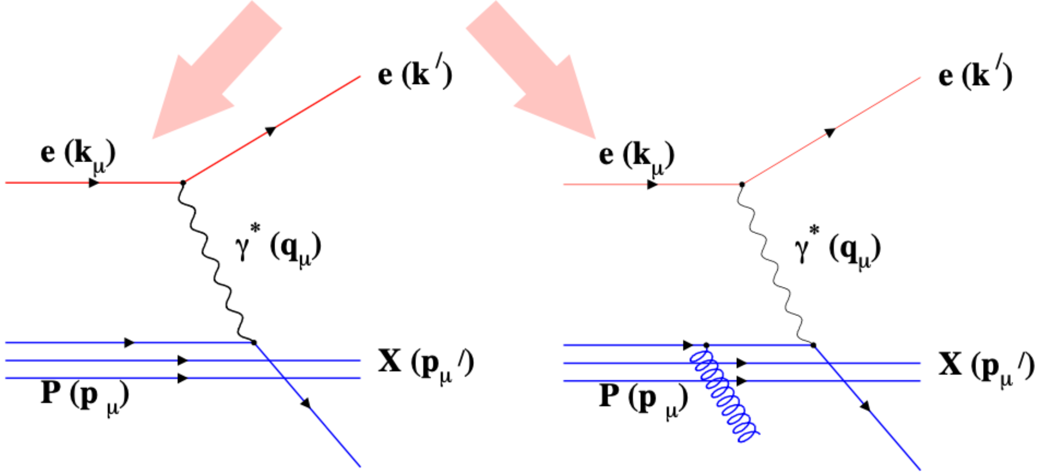


$$p = \begin{pmatrix} E_P \\ 0 \\ 0 \\ E_P \end{pmatrix} \qquad p' = \begin{pmatrix} \sum_h E_h \\ \sum_h p_{X,h} \\ \sum_h p_{Y,h} \\ \sum_h p_{Z,h} \end{pmatrix}$$

$$Q^2 = -(k - k')^2 = -q^2$$ Measure of resolution power

$$x = \frac{Q^2}{2(p \cdot q)}$$ Measure of momentum fraction by struck quark

$$y = \frac{p \cdot q}{p \cdot k}$$ Measure of inelasticity



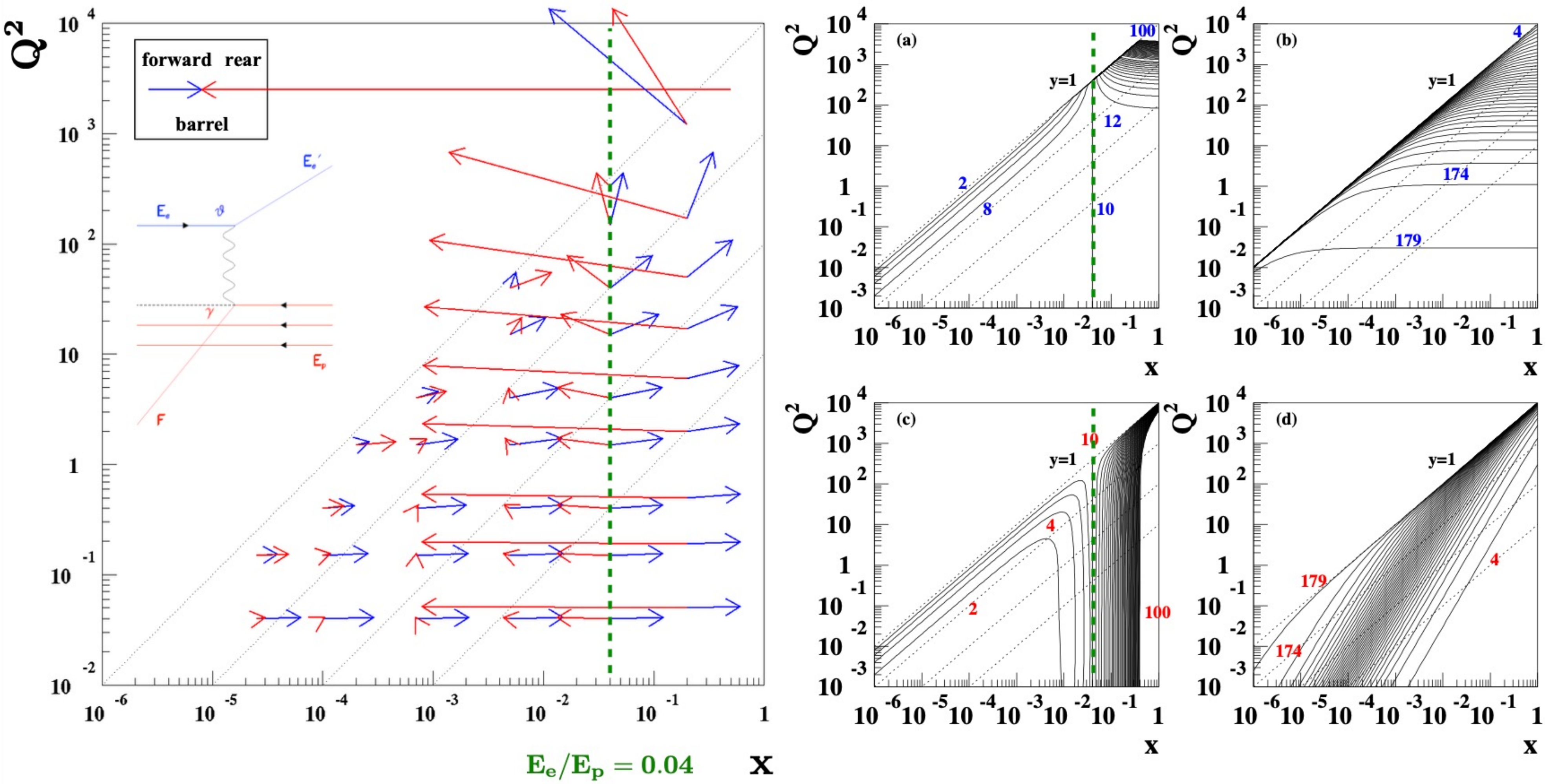
DIS kinematics

Advantages off an e-A collider over A-A collider

Precision and control

ePIC Detector Design Philosophy

- EIC kinematic considerations: E_e=10GeV X E_p=250GeV ($\sqrt{s}$=100GeV)



Kinematic peak location!

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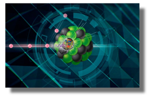
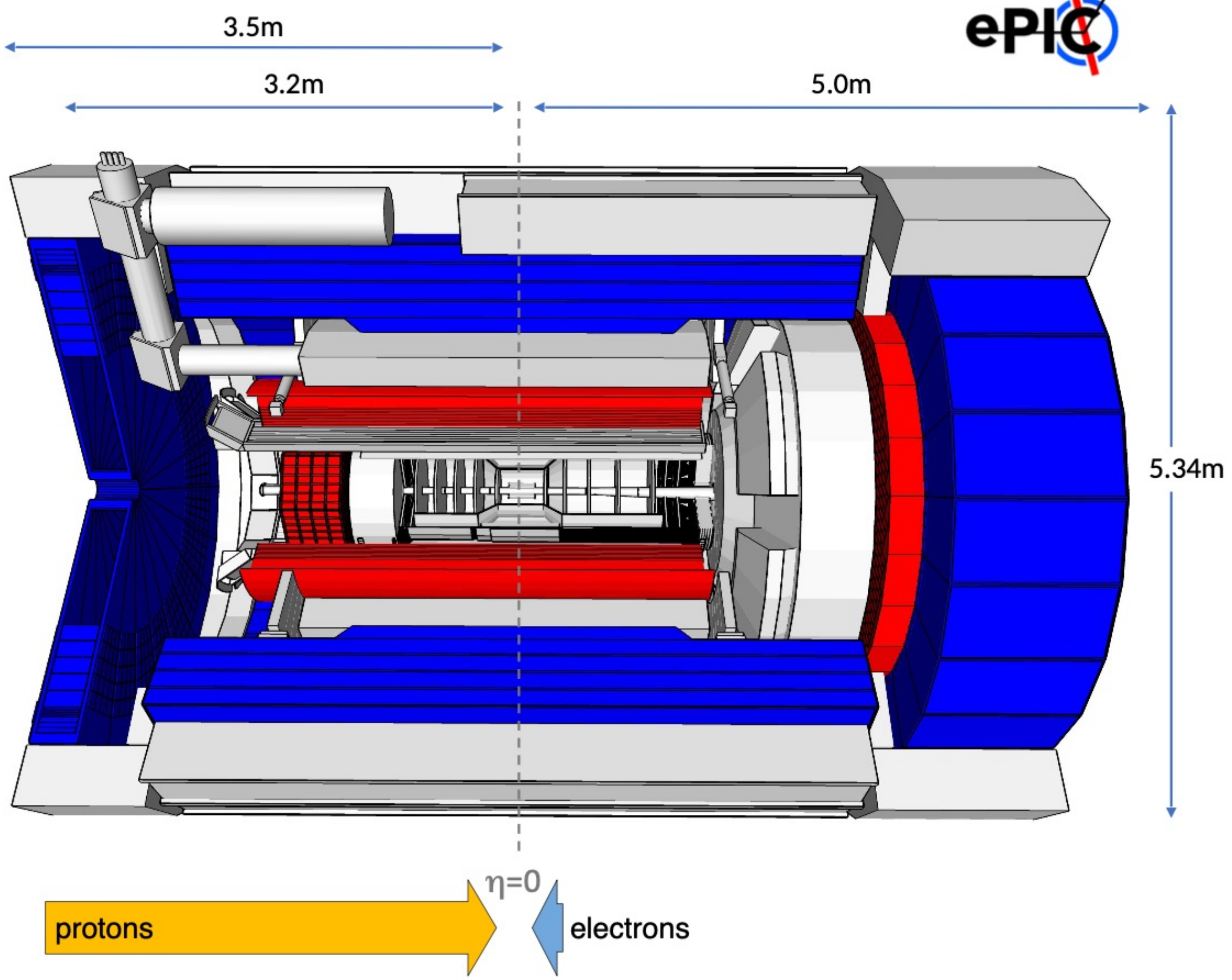
TEMPLE



ePIC Detector Design Philosophy

- ePIC Detector Design



Tracking: Posik
- New 1.7T solenoid
- Si MAPS Tracker
- MPGDs (μRWELL/μMegas)

PID: Preghenella
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry: Hornidge
- Imaging Barrel EMCal
- PbWO4 EMCal in backward direction
- Finely segmented EMCal +HCal in forward direction
- Outer HCal (sPHENIX re-use)
- Backwards HCal (tail-catcher)

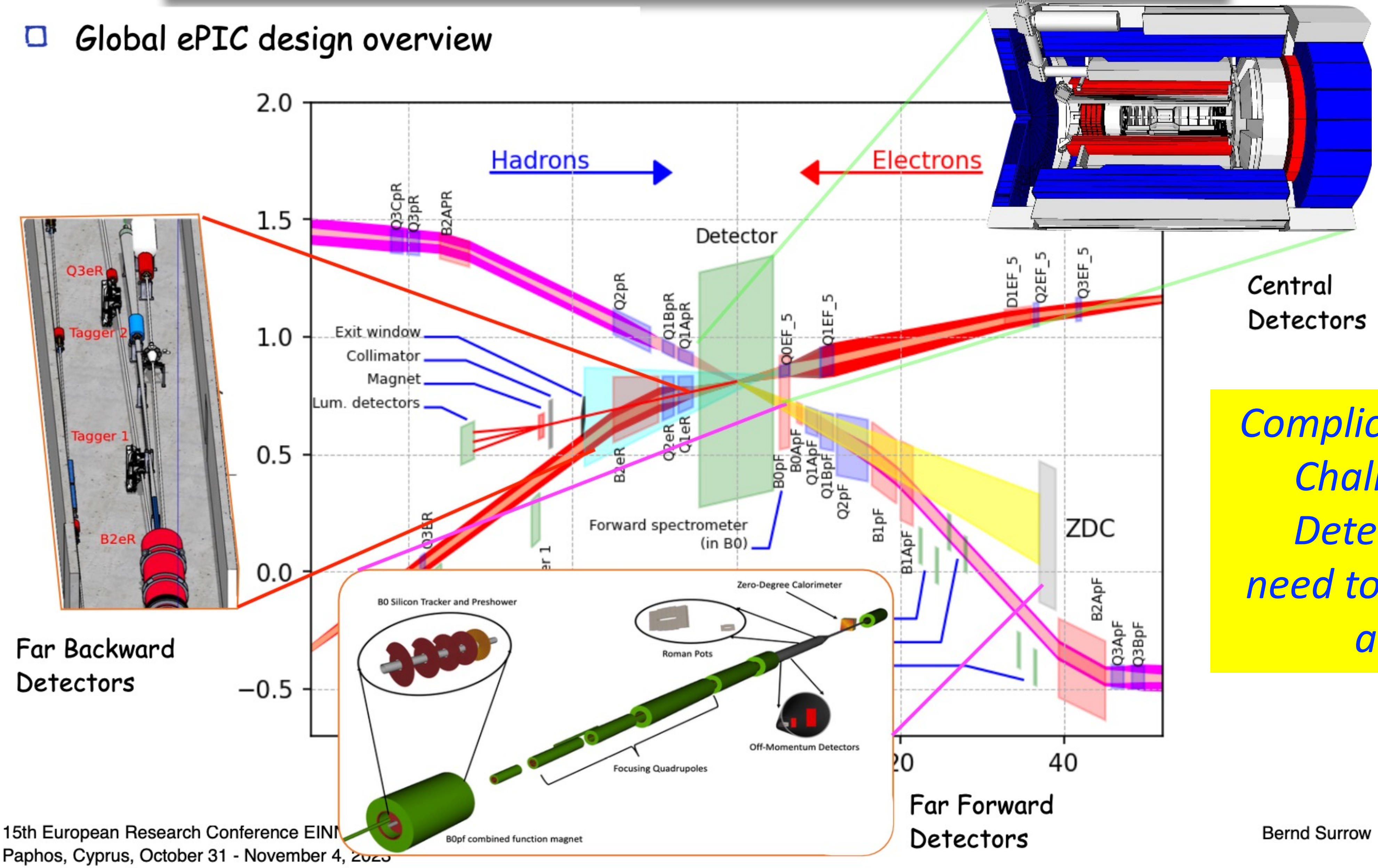
Small

Radius

Large

ePIC Detector Design Philosophy

- Global ePIC design overview



Complicated Accelerator
Challenging IR design
Detector components need to be embedded in accelerator lattice

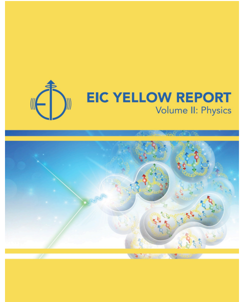
ePIC Tracking System Overview and Performance

Matt Posik
Temple University

Innermost detector
Smallest radius
Closes to the beam pipe

1

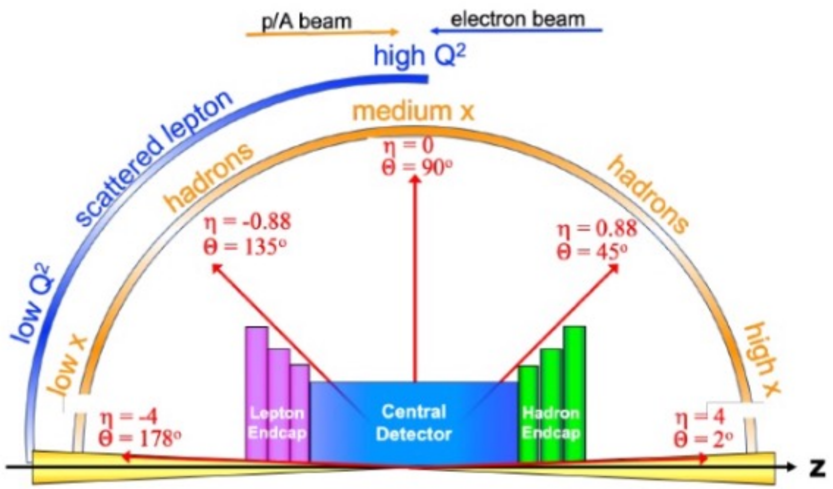
Electron-Ion Collider Tracking Requirements



- High point resolution and low material budget are critical to meeting physics requirements.
- Most challenging requirements
  - High granularity
  - Minimal material from mechanics, cooling, power, and data distribution

Tracking requirements from PWGs						
			Momentum res.	Material budget	Minimum pT	Transverse pointing res.
η						
-3.5 to -3.0	Central Detector	Backward Detector	σp/p ~ 0.1%×p ⊕ 0.5%	~5% X0 or less (~MAPS + MPGD trackers)	100-150 MeV/c	
-3.0 to -2.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
-2.5 to -2.0			σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
-2.0 to -1.5					100-150 MeV/c	
-1.5 to -1.0					100-150 MeV/c	
-1.0 to -0.5		Barrel	σp/p ~ 0.05%×p ⊕ 0.5%		100-150 MeV/c	dca(xy) ~ 20/pT µm ⊕ 5 µm
-0.5 to 0						
0 to 0.5						
0.5 to 1.0						
1.0 to 1.5		Forward Detector	σp/p ~ 0.05%×p ⊕ 1%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 20 µm
1.5 to 2.0					100-150 MeV/c	
2.0 to 2.5					100-150 MeV/c	
2.5 to 3.0			σp/p ~ 0.1%×p ⊕ 2%		100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 40 µm
3.0 to 3.5					100-150 MeV/c	dca(xy) ~ 30/pT µm ⊕ 60 µm

YR, Table 11.2



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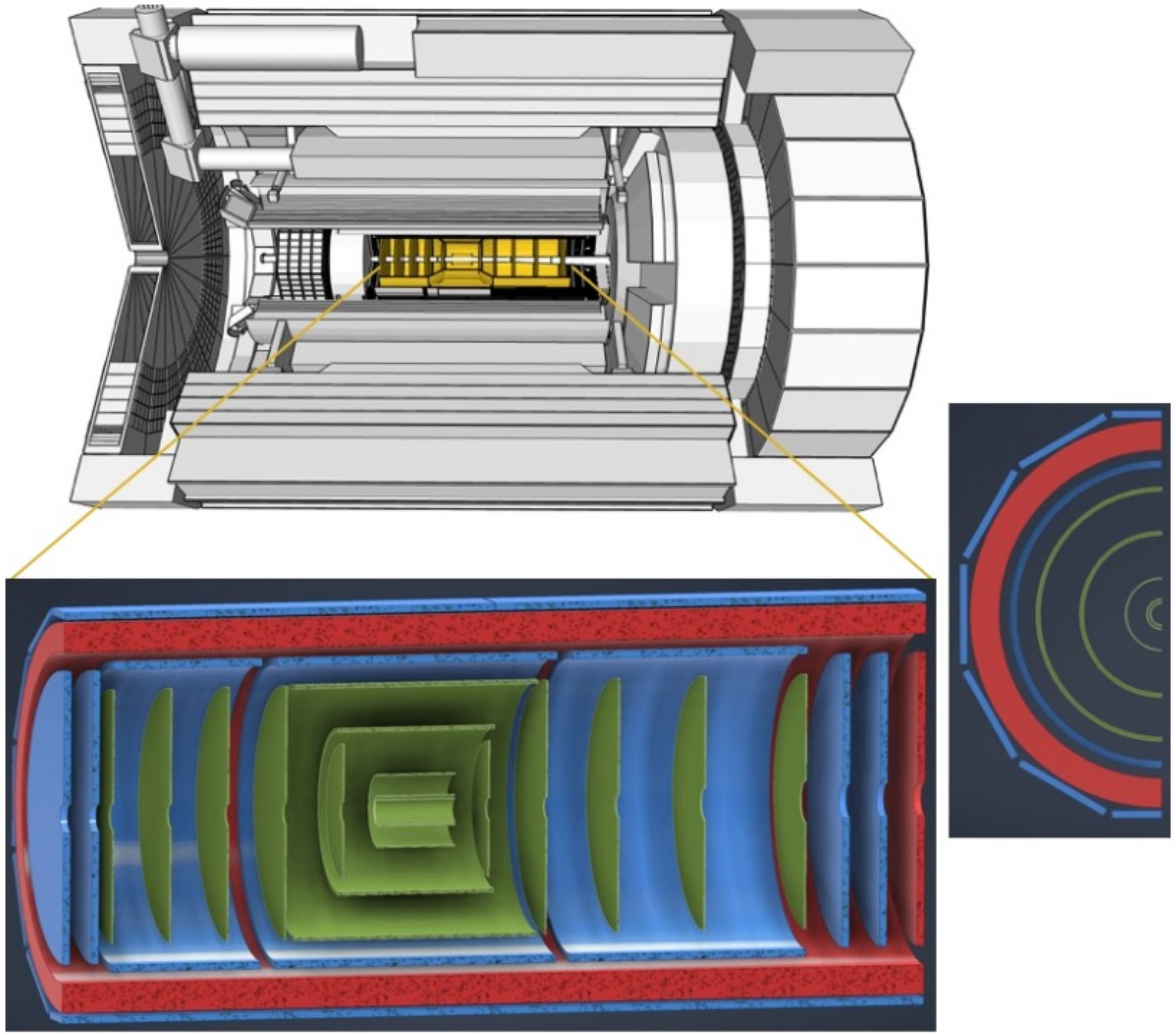
ePIC Central Tracking Layout Overview



■ MAPS Barrel + Disks ■ MPGD Barrels + Disks ■ AC-LGAD based ToF

- ePIC tracking system is a hybrid of silicon and gaseous technologies

- **MAPS Layers**
  - Make up inner tracking volume
  - Highly granular and low mass layers to provide excellent momentum resolution and precision pointing resolution

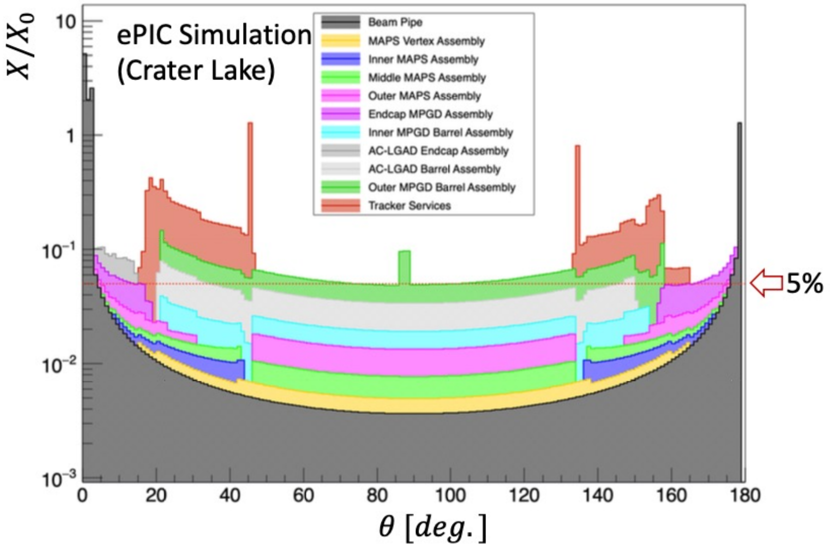
- **MPGD Layers**
  - Large area detectors are instrumented in the outer tracking volume
  - Provide timing and pattern recognition
  - Planar detectors can provide impact point and direction for PID seeding

- **AC-LGAD**
  - Fast detector to provide low momentum PID.
  - Can provide an additional space point for pattern recognition/redundancy

ePIC Tracking System Overview and Performance

Matt Posik
Temple University

ePIC Tracking: Material Budget



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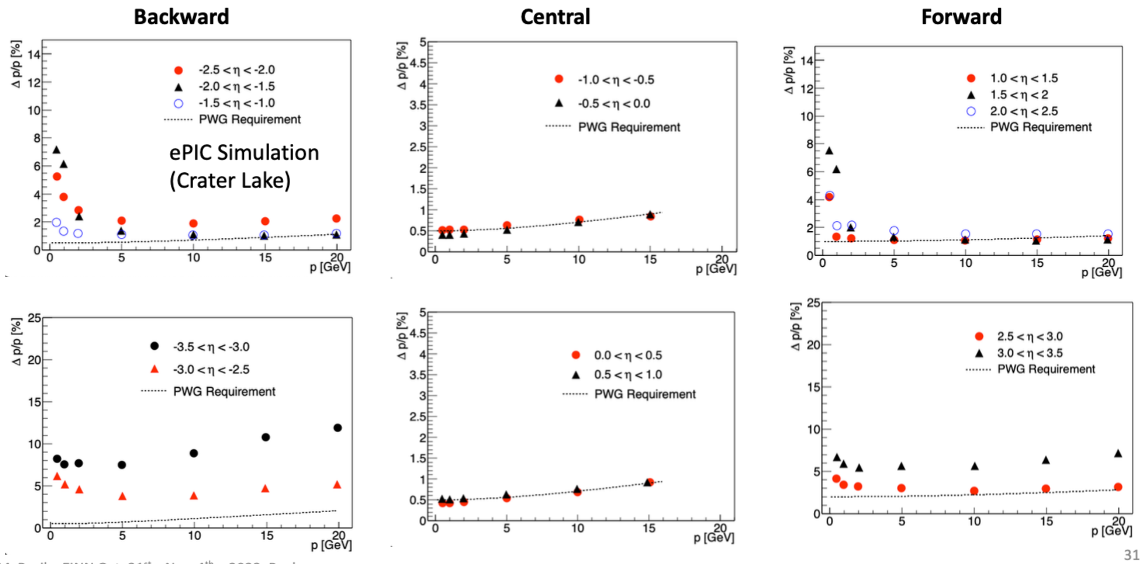
Simulation Studies

Simulated Tracking Performance: Momentum Resolution

- Simulated performance: Truth Seeding (ePIC Simulation, Crater Lake) -- Pions



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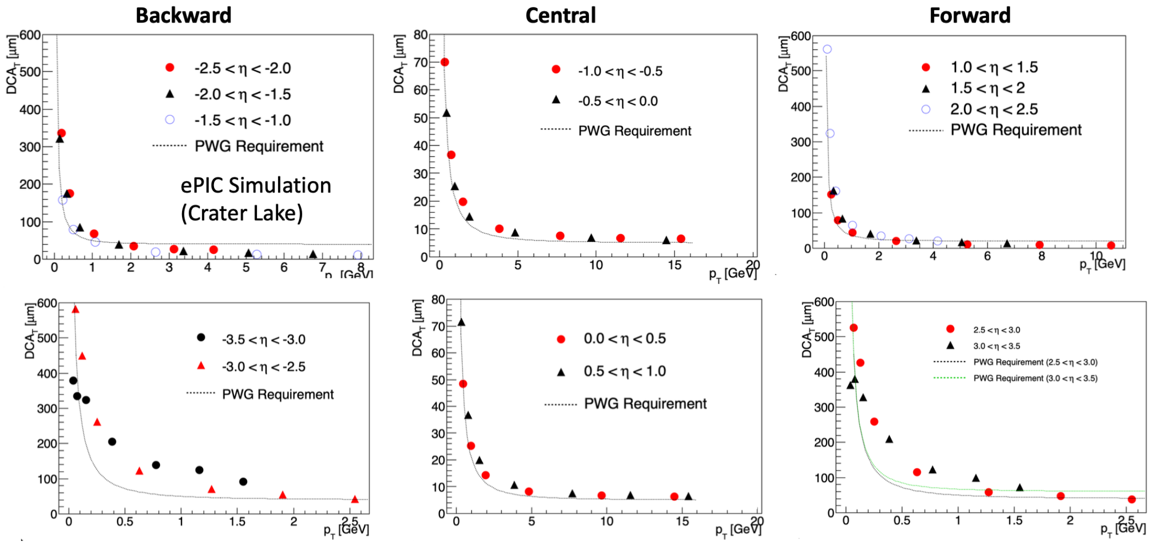
ePIC Simulated Tracking Performance: DCA

- Simulated performance: Truth Seeding (ePIC Simulation, Crater Lake) -- Pions



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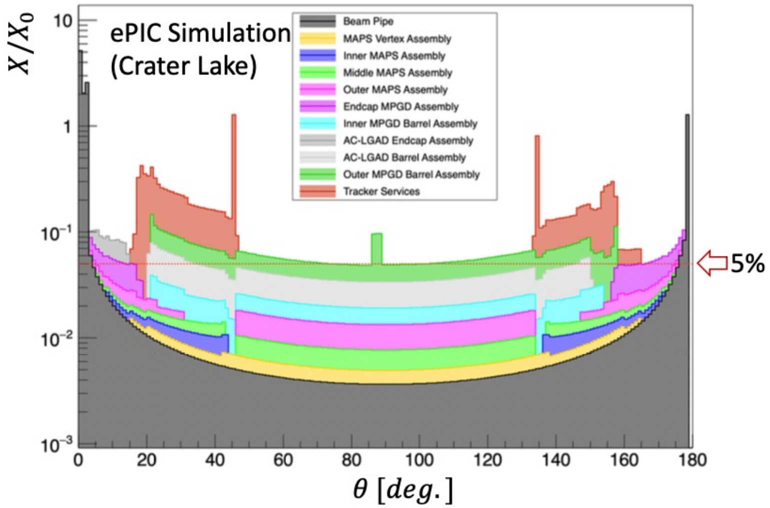
ePIC Tracking System Overview and Performance

Matt Posik
Temple University

EINN 2023
15th European Research Conference on Electromagnetic Interactions with Nucleons and Nuclei

ePIC Tracking: Material Budget



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Summary

- ePIC central tracking system integrates both state of the art silicon and gaseous detector technologies
- Silicon based MAPS detector provides precision momentum resolution and excellent pointing resolution
- $\mu RWELL$ and $\mu Megas$ MPGD based tracking detectors provide good space point and timing resolution over a large area in the outer tracking volume aiding in pattern recognition and informing seeding for PID
- Yellow Report requirements met in most regions
- Integration of other detector information (e.g. EM calorimeter) should help with overall performance, in particular the backward region.

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Challenging but achievable tracking performance.

Particle identification with the ePIC detector at the EIC

Roberto Preghenella
INFN Bologna
on behalf of the ePIC Collaboration

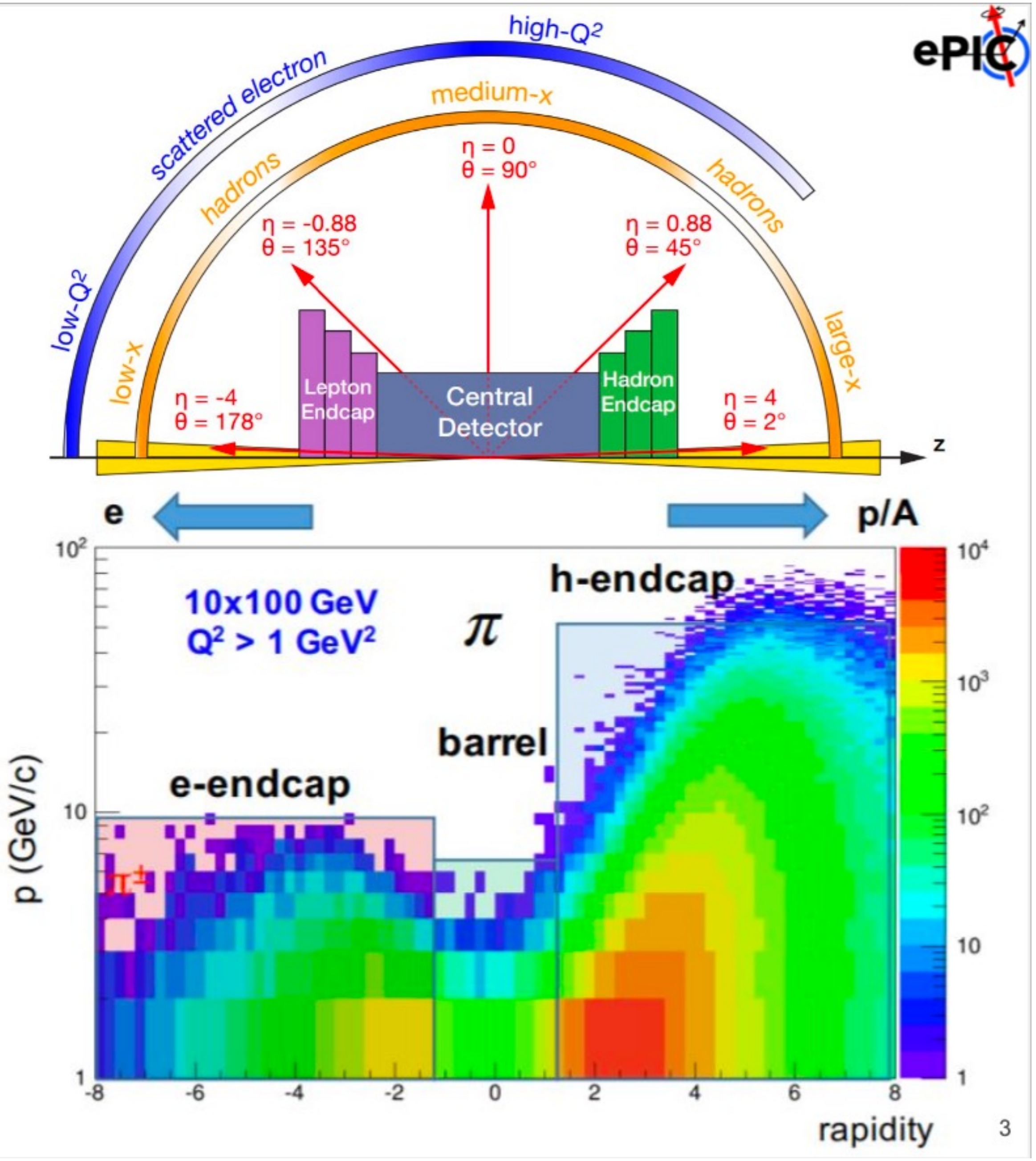
EINN 2023
15th European Research Conference on
Electromagnetic Interactions with Nucleons and Nuclei
31 October - 4 November 2023, Paphos

preghenella@bo.infn.it

Particle identification at EIC

one of the major challenges for the detector

- **physics requirements**
  - pion, kaon and proton ID
  - over a wide range $|\eta| \leq 3.5$
  - with better than 3σ separation
  - significant pion/electron suppression
- **momentum-rapidity coverage**
  - forward: up to 50 GeV/c
  - central: up to 6 GeV/c
  - backward: up to 10 GeV/c
- **demands different technologies**

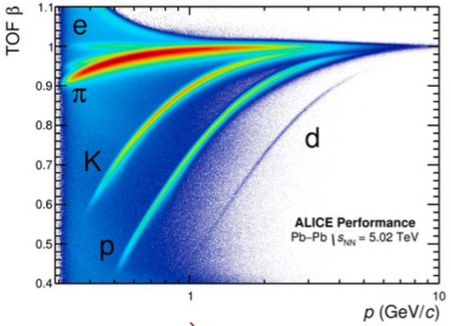


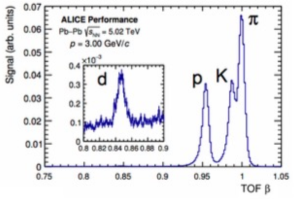
www.bnl.gov/eic

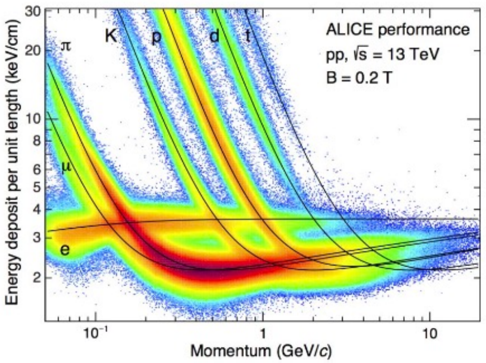
Particle identification ~ particle velocity

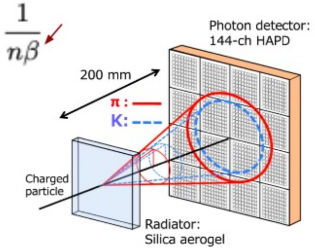
particle velocity + momentum (from tracking) or energy (from calo) = PID

- **velocity measurement yields mass**
  - $p = m\,\beta\gamma$
  - $E = m\,\gamma$
- **direct velocity measurement**
  - time-of-flight
    - record time signal at multiple locations: $\Delta t = t_{stop} - t_{start}$
    - measure trajectory length and calculate: $\beta c = L / \Delta t$
- **velocity-dependent interactions**
  - specific energy loss $$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$
  - Cherenkov radiation $$\cos\theta = \frac{1}{n\beta}$$
    - θ_C measured wrt. track direction
    - performance also depends on tracking
- **other techniques for e-ID**
  - Brehmsstralung
  - transition radiation $$I = \frac{z^2 e^2 \gamma \omega_p}{3c}$$
  - calorimetry: E/p









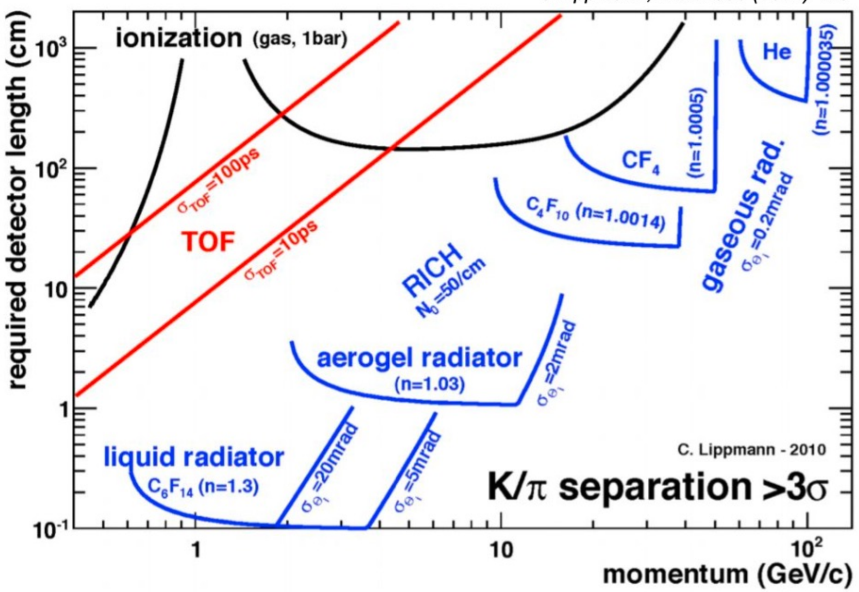
Particle ID techniques and how it works and where the limitations come from?

Particle identification techniques

EIC detector need more than one technique to cover the entire momentum ranges

- **central (< 6 GeV/c)**
  - TOF, DIRC
- **backward (< 10 GeV/c)**
  - aerogel RICH
- **forward (< 50 GeV/c)**
  - gaseous RICH

C.Lippmann, NIMA 666 (2012) 148



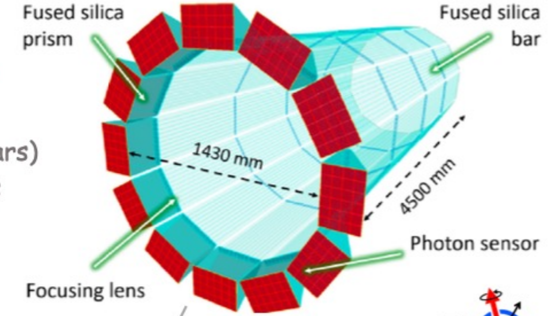
Particle identifica
the ePIC detector a
Roberto Preghene
INFN Bologna
on behalf of the ePIC Collaboration
EINN
15th European Research Co
Electromagnetic Interactions with Nucleons
31 October - 4 November 20
preghenella@bo.infn.it

ePIC Detector Design Philosophy

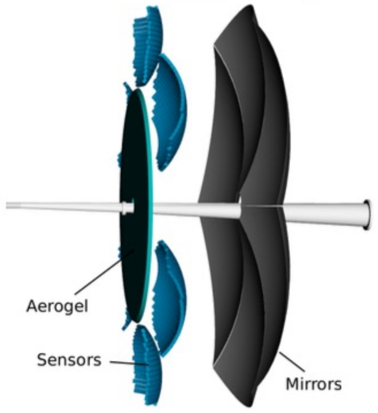
ePIC PID Detectors: Layout

High-Performance DIRC

- Quartz bar radiator (BaBAR bars)
- light detection with MCP-PMTs
- Fully focused
- π/K 36 separation at 6 GeV/c



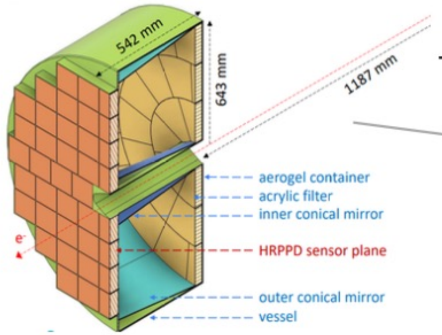
Dual-Radiator RICH (dRICH)

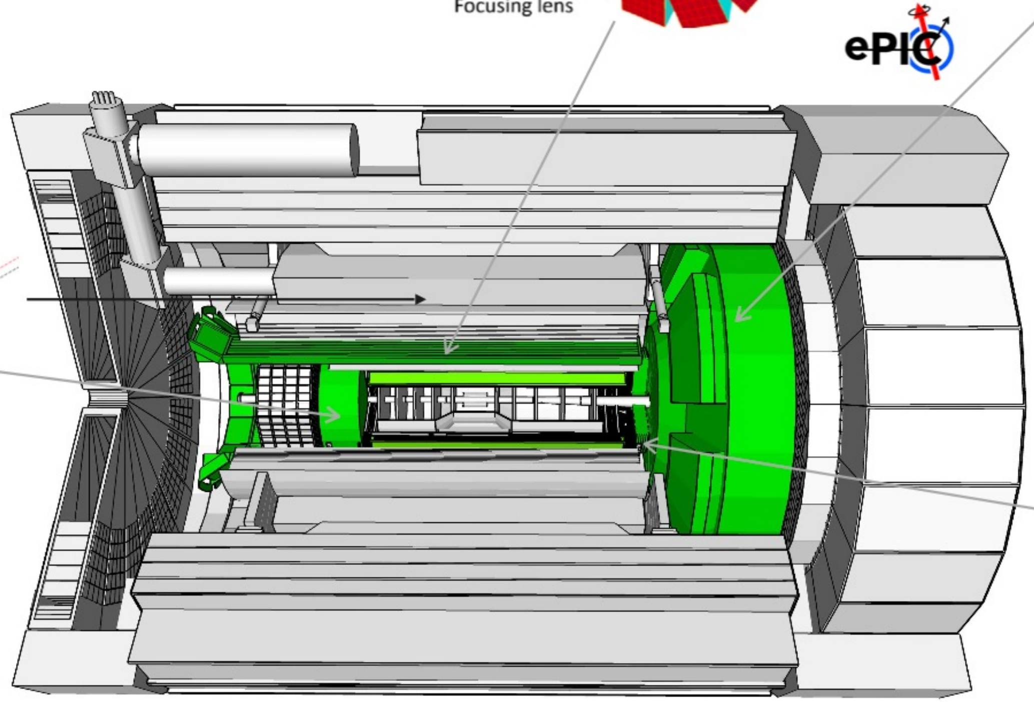


- C_2F_6 Gas Volume and Aerogel
- Sensors tiled on spheres (SiPMs)
- π/K 3σ sep. at 50 GeV/c

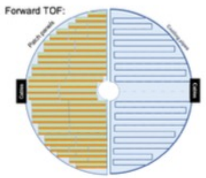
Proximity Focused (pfRICH)

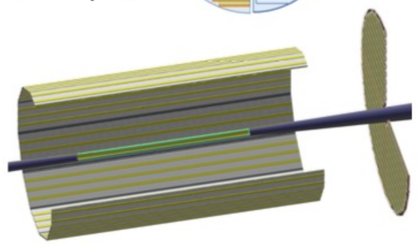
- Long proximity gap (~40 cm)
- Sensor: LAPPDs
- up to 9 GeV/c 36 π/K sep.





AC-LGAD TOF (~30ps)





- Accurate space point for tracking / Low p PID
- Forward disk and central barrel

Talk by Roberto Preghenella / 05:30 PM: Particle Identification with the ePIC detector at the EIC

INFN

ePIC

Particle identification with the ePIC detector at the EIC

Roberto Preghenella
INFN Bologna
on behalf of the ePIC Collaboration
preghenella@bo.infn.it

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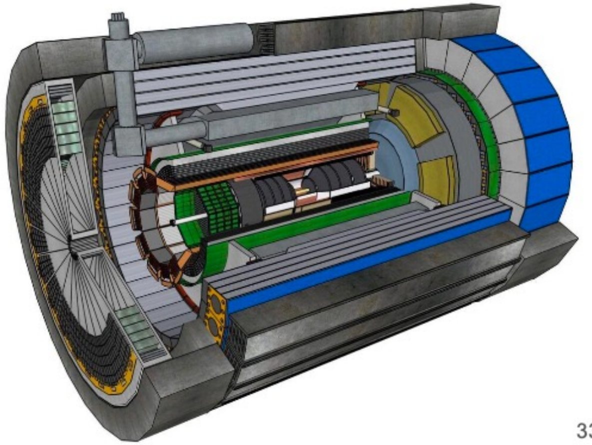
See RP's talk for all details of the detailed of design and construction details and challenges, readout / chips plan, proto-type , radiation studies, test beam results: All of which builds the confidence that the ePIC PID will work!

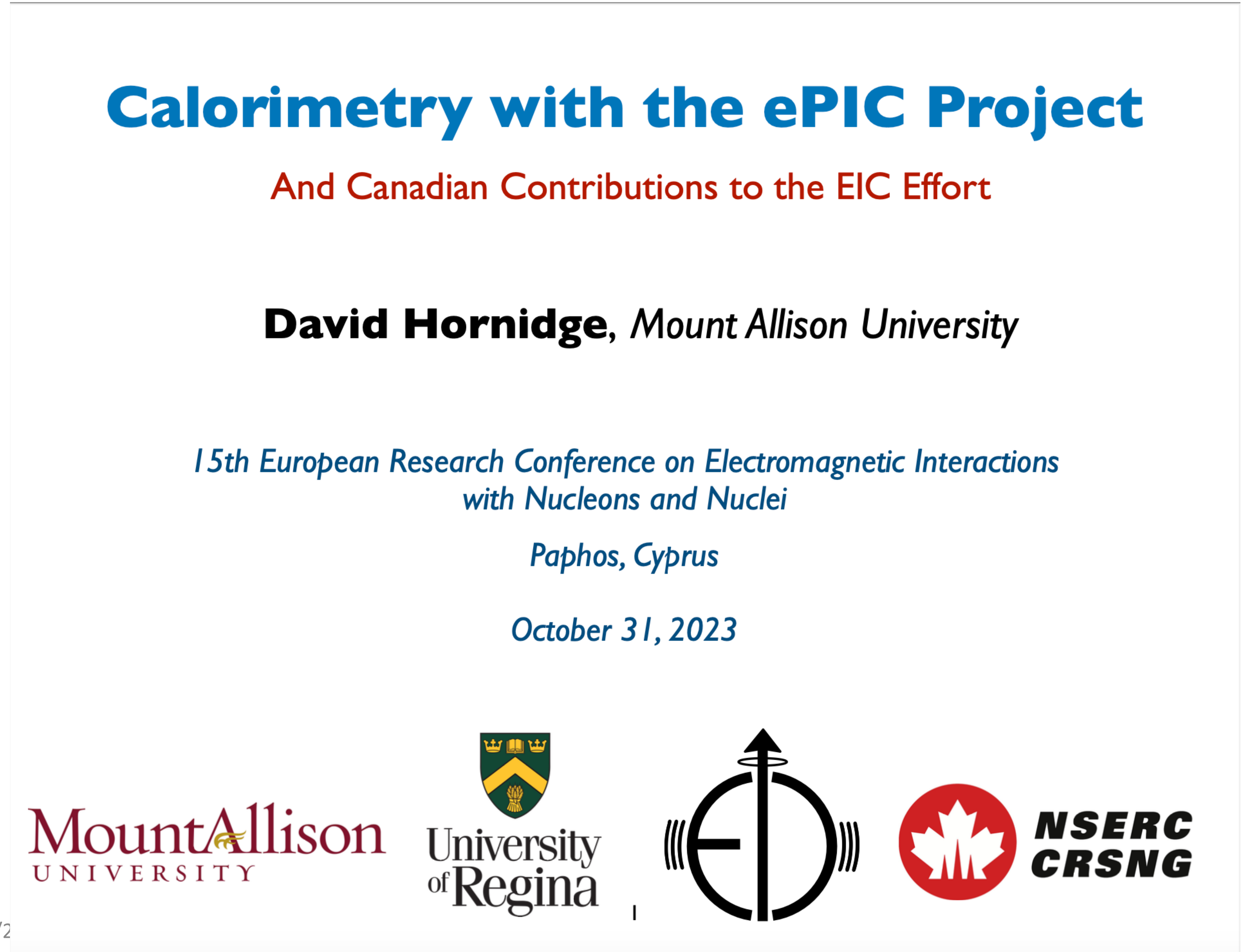
ePIC

Summary

ePIC meets EIC PID needs with advanced detector technology

- **PID is one of the major challenges for the ePIC detector at the EIC**
  - physics requires high-purity π K p over large phase-space
  - multiple techniques needed
    - time-of-flight, ring imaging Cherenkov
    - calorimetry for e (μ) identification
- **selected detector technologies meet the requirements**
  - AC-LGAD TOF
  - high-performance DIRC
  - dual-radiator RICH
  - proximity-focusing RICH
- **ongoing R&D and engineering activities**
  - risk reduction
  - optimisation of technologies




Calorimetry with the ePIC Project

And Canadian Contributions to the EIC Effort

David Hornidge, *Mount Allison University*

15th European Research Conference on Electromagnetic Interactions with Nucleons and Nuclei

Paphos, Cyprus

October 31, 2023

MountAllison UNIVERSITY

University of Regina

NSERC CRSNG

Gave an overview of Canadian scientific, technical interest in the EIC Project as a whole and an overview of various group activities

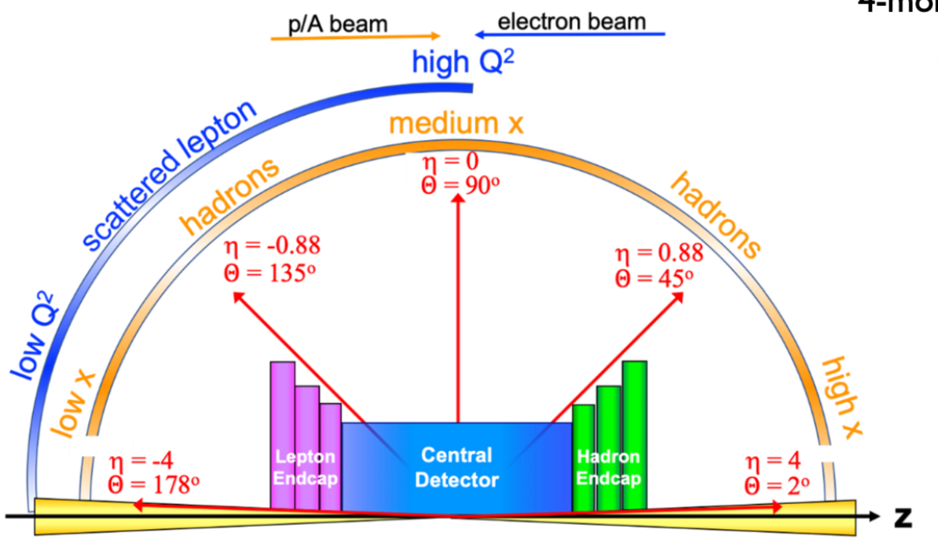
Calorimetry for the ePIC Detector

Electromagnetic calorimeter:

- Measure E, θ for photons and identify electrons.
- Backward: $PbWO_4$ Crystals
- Forward: W/SciFi
- Barrel: Pb/SciFi + Imaging

Hadronic calorimeter:

- Measure energy and position of charged hadrons, neutrons, and K_L^0
- Main challenge is resolution for low-E hadrons
- Fe/Scintillator sandwich with longitudinal segmentation



4-mom transfer of virtual photon

$$Q^2 = -q^2 = -(k - k')^2$$

Momentum fraction

$$x = \frac{Q^2}{2M\nu}$$

Pseudo rapidity

$$\eta = -\ln\left[\tan\left(\frac{\theta}{2}\right)\right]$$

D. Hornidge

Note: The Barrel has a very wide kinematic coverage!

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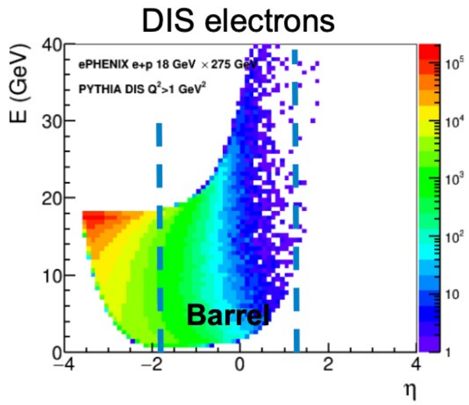
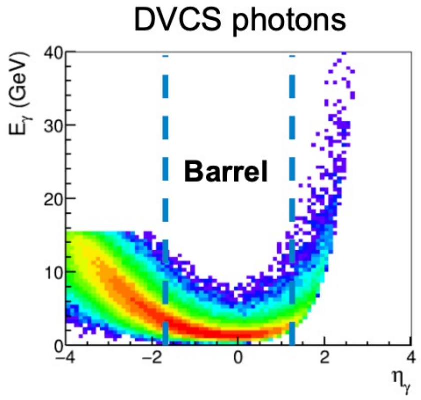
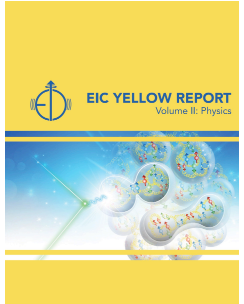
Calorimetry Requirements for BIC

EIC Yellow Report:

- Detection of **e** and **γ** to measure **energy** and **position**
- Require **moderate energy resolution** $(7-10)\,\%/\sqrt{E} \oplus (1-3\%)$
- Require **e/π separation** up to **10^4** at low momenta in combination with other detectors
- Discriminate between **π^0 decays** and **single γs** up to **~10 GeV**
- **Low-energy photon** reconstruction **~100 MeV**







Challenges:

- **e/π** PID
- **γ/π⁰** discrimination
- Dynamic range of sensors
- Available space

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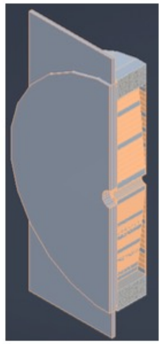
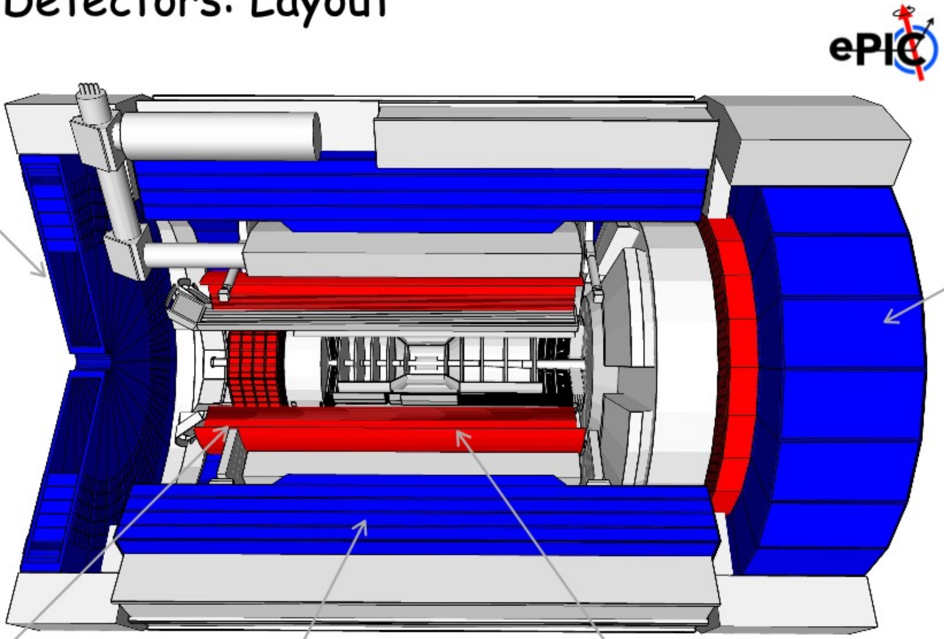
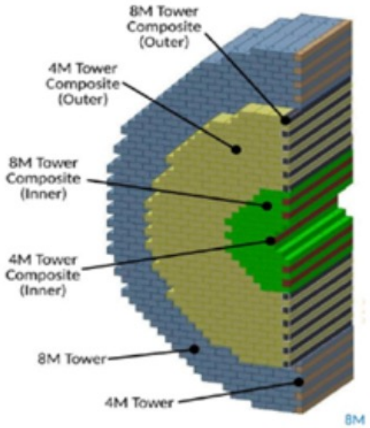
ePIC Detector Design Philosophy

❑ ePIC Calorimeter Detectors: Layout

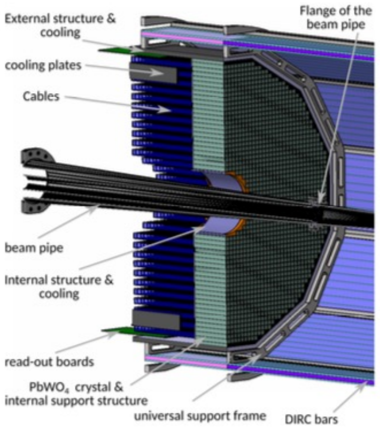


Backwards HCal
Steel/Sc Sandwich tail catcher



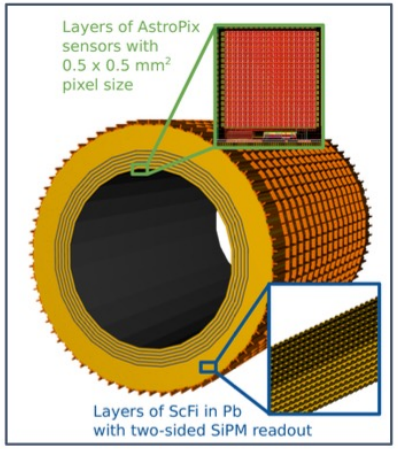


High granularity W/SciFi **EMCal**
Longitudinally separated **HCAL** with high-η insert

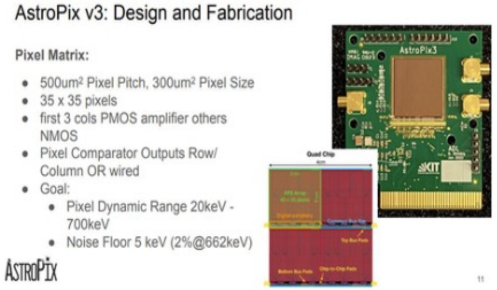


Backwards EMCal
PbW04 crystals, SiPM photosensor

Barrel HCAL
(sPHENIX re-use)



Barrel BECAL



Talk by David Hornidge / 06:00 PM: Calorimetry with the ePIC Project

15th European Research Conference EINN 2023
Paphos, Cyprus, October 31 - November 4, 2023

Bernd Surrow

BIC Consortium

USA
- Argonne National Laboratory
- NASA Goddard Space Flight Center
- Oklahome State University
- University of Connecticut
- University of California Santa Cruz

Canada
- University of Manitoba
- University of Regina
- Mount Allison University
- NSERC
- Canada Fund for Innovation

Korea
- Kyungpook National University
- Yonsei University
- University of Seoul
- Pusan National University
- Korea University
- Sungkyunkwan University
- Hanyang University
- Gangneung-Wonju National University

Germany
- Karlsruhe Institute of Technology
- University of Giessen

ePIC BIC Detector Subsystem Collaboration

D. Hornidge 11

Electron-Ion Collider Collaboration Canada

University of Manitoba
- Wouter Deconinck
- Michael Gericke
- Juliette Mammei
- Savino Longo

University of Regina
- Garth Huber
- Zisis Papandreou

Mount Allison University
- DLH

TRIUMF

Also presently 4 PDFs, 14 grad students, and one undergrad.

Collaboration is growing!

EIC User Group
- 31 members from Canada, including theoretical, experimental, and accelerator physicists.
- 7 institutions from Canada.
- 8th largest country by member count
- Deconinck elected as international representative on global Steering Committee (2020–2021).

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Mount Allison University

New Brunswick

Population: 840,000
Area: 72,908 km²

English and French

Lobster, Lumber, and High Tides

Mount Allison University
- 2,250 students
- Undergrads only

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Canadian Interests/Contributions at the EIC near term

- Extend Pion and Kaon Form-Factor Studies
- *XYZ* Spectroscopy
- Extend Studies of Leptoquark sensitivity
- PVES to determine interference structure functions
- Machine Learning for calorimeter design optimization
- Compton polarimetry
- HV-MAPS electron detector
- BIC

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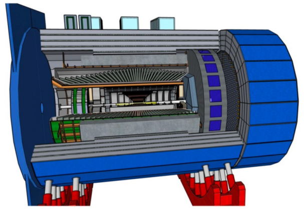
Major Detector Construction In Canada



Electromagnetic Calorimetry:
- Major components of the ePIC Barrel Imaging Calorimeter will be built by U. Regina (end-of-sector readout box) and U. Manitoba (Pb/SciFi layers)
- Calorimeter pulse-shape discrimination in the electron endcap (PbWO4 technology).
- Positioning for CFI IF 2025 application for calorimeter construction.

Compton Polarimetry for EIC Electron Beam:
- HV-MAPS technology at U. Manitoba for Compton polarimeters at JLab, KEK.
- Photon polarimetry based on MOLLER and Belle II experience (U. Manitoba).

Online/Offline Production Software:
- Experience throughout JLab and EIC programs, including proposal stages.

Much of this work will be undertaken with help from TRIUMF.

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Bay of Fundy

Highest tides in the world — 16 m!

$\tau \approx 12.5 - 12.7$ h Bay	$N_2 \approx 12.66$ h Moon

D. Hornidge 3

EIC Experimental Opportunities and Challenges

Day 3: 2nd Detector and prospects

Session:

Deshpande,

Nadel-Turonski

Why a second detector at the EIC?

Abhay Deshpande

EIC Workshop 1: Experimental Opportunities and Challenges Workshop

November 2, 2023

These are my personal thoughts, not "the opinion" of the EIC Project
(although they should be ;-))

Why a 2nd detector at the EIC?

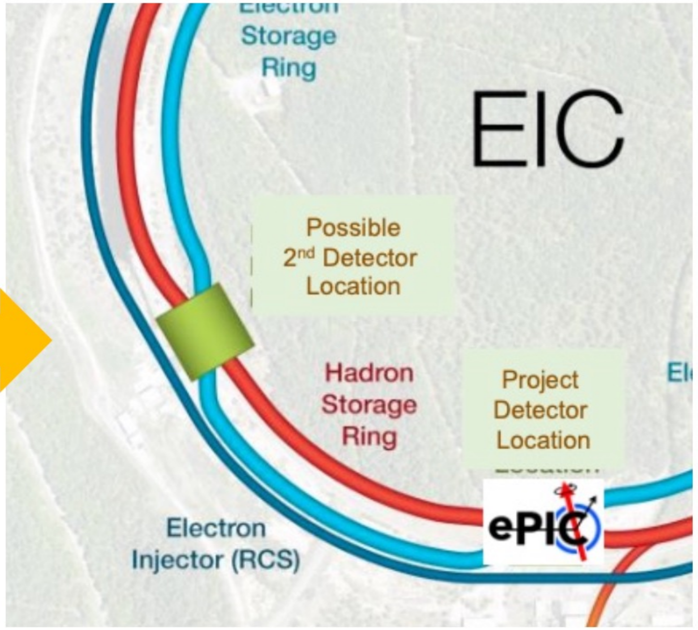
Why a second detector at the EIC?

EIC Workshop 1: Experime

These are my personal
(alt

Stony Brook University

The 2nd detector



NSAC documents 2015: talk about possibly ~4 detectors

NAS Report 2018 : planning for up to 2 well-integrated detectors

EICUG 2018 – Present : desires 2 Detectors

EIC Project funds support: 1 Machine, 1 Interaction Region and 1 Detector
without negating the possibility of the 2nd IR/Detector

Cost? = cost of IR infrastructure + a new Detector

History: Discoveries established with **more than one** detectors in Nuclear Science

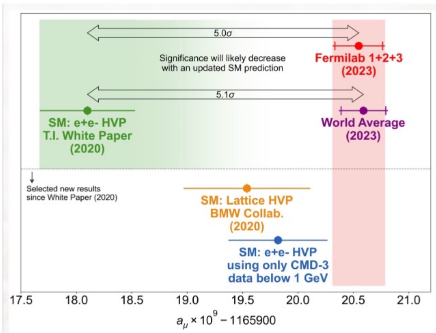
- Discovery of gluon : TASSO, JADE, Mark J, and PLUTO @ DESY
- H1 and ZEUS at Rise of F_2 and hence the gluon dominance at low-x
- BRAHMS, PHOBOS, PHENIX and STAR Discovery and establishing the existence of Quark Gluon Plasma
- Measurements at DESY and JLab eventually led to "parton imaging"

- EMC/CERN discovered and then SMC/CERN and EXXX/SLAC established nucleon spin crisis (low-x) & EMC discovered and then NMC/CERN & E865/FNAL established nuclear effects on nucleon PDFs (also low-x)

11/1/23 Why a 2nd detector at the EIC? 14

Tension: take-home message #1 g-2 (after 10/2023)

Systematic/statistical error ratios: lattice ≈2; R-ratio ≈4

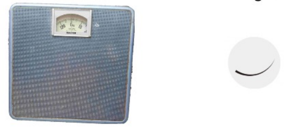


Experimental result

- Recent result at Fermilab (2023)

$$a_\mu(\text{FNAL}) = 11\,659\,205.5(2.4)\cdot 10^{-10} \quad (0.20\,\text{ppm})$$

- Equivalent to: bathroom scale sensitive to weight of a single eyelash.



- Fully agrees with the BNL E821 measurement

$$a_\mu(\text{BNL}) = 11\,659\,209.1(6.3)\cdot 10^{-10} \quad (0.54\,\text{ppm})$$
$$a_\mu(\text{combined}) = 11\,659\,205.9(2.2)\cdot 10^{-10} \quad (0.19\,\text{ppm})$$

- Final target uncertainty (1.6)
- J-PARC experiment very different systematics but same accuracy (2027)

Muon g-2… example presented by Prof. Fodor

11/1/23 Why a 2nd detector at the EIC? 15

Building Trust

- Quark Gluon Plasma: RHIC Experiments
- Discovery of Top Quark D0/CDF
- Discovery of Higgs Boson: ATLAS and CMS
- Gravitational Waves: LIGO and VIRGO
- Neutrino oscillations

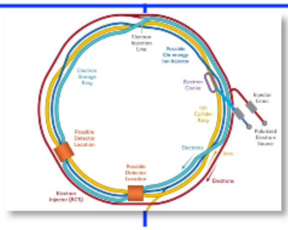
Mistakes or misinterpretations:

- Cold fusion
- 17 KeV neutrinos in Tritium
- Superluminal neutrinos
- Leptoquarks
- Pentaquarks from 2000's

Opportunity for complementary detector designs for different IRs exists!

Complementarity for 1st-IR & 2nd-IR

	1st IR (IP-6) ePIC	2nd IR (IP-8)
Geometry:	tunnel and assembly hall are larger Tunnel: ⌀ 7m +/- 140m	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	
Focusing:	Optimize Doublet focusing FDD vs. FDF → impact of far forward p_T acceptance	
Experiment:	1.7 Tesla	or 2-3 (?) Tesla



Potential Physics topics beyond EPIC detector's mandate?

Focus first on Physics beyond the EIC's core (CD0) science

Physics with nucleons and nuclear Fragments: e-A light and heavy nuclei

- Connecting to low energy nuclear physics (exotic nuclei): studying the shapes of nuclei and their internal substructure
- Set novel concepts of entanglement & entropy in DIS, as major goals
- Nuclear and proton fragmentation, hadronization and such phenomena
- Quark **Exotica**: 4,5,6 quark systems…? Much interest after recent **LHCb** led results.

Precision electroweak and BSM physics:

- Electroweak physics & searches beyond the SM: Parity, charge symmetry, lepton flavor violation
- LHC-EIC Synergies & complementarity: (**muon detectors** were of particular interest)

New Studies with proton or neutron target: (mostly overlapping?)

- Impact of precision measurements of unpolarized PDFs at high x/Q^2, on LHC-Upgrade results(?)
- Precision calculation of α_S : higher order pQCD calculations, twist 3
- Heavy quark and quarkonia (c, b quarks) studies with 1000 times lumi of HERA (and polarization)

Detector technologies EIC & LHC:

Many EIC collaborators already part of RD51 (and family) at CERN & vice-versa.

- MAPS μVertex for primary/secondary vtx: barrel & end-caps (ALICE ITS3)
- Micro Pattern Gas Detectors: large rapidity, spatial resolution ~100 μm
- Electromagnetic Calorimetry for kinematic reconstruction, precise energy measurements e, γ; e/π & π^0/γ separation. Various technologies at various locations:
  - W/SciFi w/o PMT, PbWO4, SiGlass; AstroPix & Pb/SciFi
  - High resolution Crystal Cal for e-endcap
  - Barrel EMCal 6 layers AstroPix and Pb/SciFi
- Particle Identification – extremely important for most EIC physics
  - K/pi separation over a wide range 1-20 GeV/c
  - Hadron ID: hpDIRC in Barrel, forward EndCap: duel RICH, backward Endcap: modular RICH or pF RICH, also TOF for short lever arm : LGAD, LAPPD
- Streaming Readout

Connect to new fields

- *High energy particle physics*
- *Low energy nuclear physics*
- *Explore other connections*

(see NAS Report)

Vision for the 2nd detector: C²C

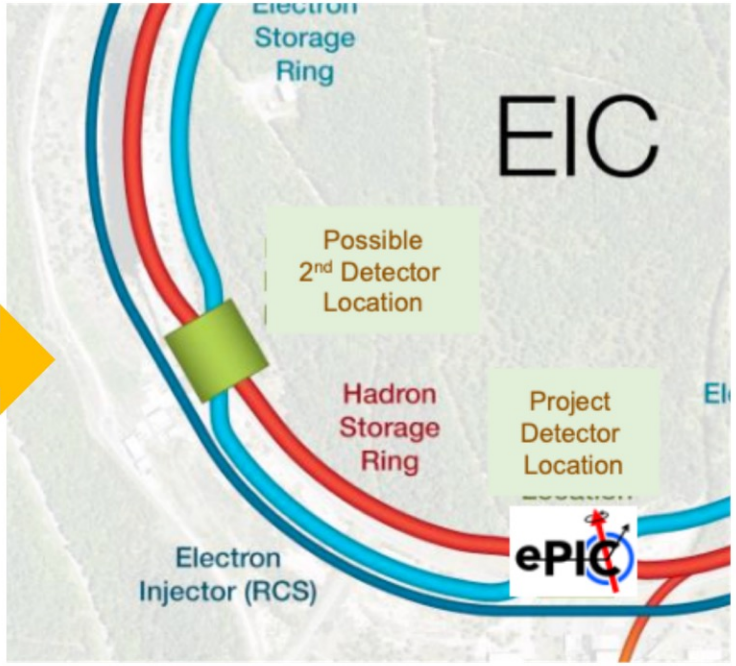
- Complementary (IR, detector technologies & design)
  - Continue to explore complementary ready and not-yet-ready technologies
  - Generic detector R&D program
- Complementary (physics)
  - A significant list of physics topics exists (some-exclusive to IR8 (2nd IR) and some-overlapping with ePIC/IR6)
  - Which of those can *develop into strong pillars of science for the 2nd detector?*
  - New physics developing around the world: we need to monitor constantly
- Complementary (people)
  - New non-US/outside groups who may bring new interests & funding in future
  - New US groups – other than those with significant responsibilities in ePIC
  - Impact of different perspectives that different collaborators bring to the same problem.
  - Complementary analyses strategies build confidence in conclusions

Designing the 2nd interaction region and detector

Pawel Nadel-Turonski

CFNS Stony Brook University

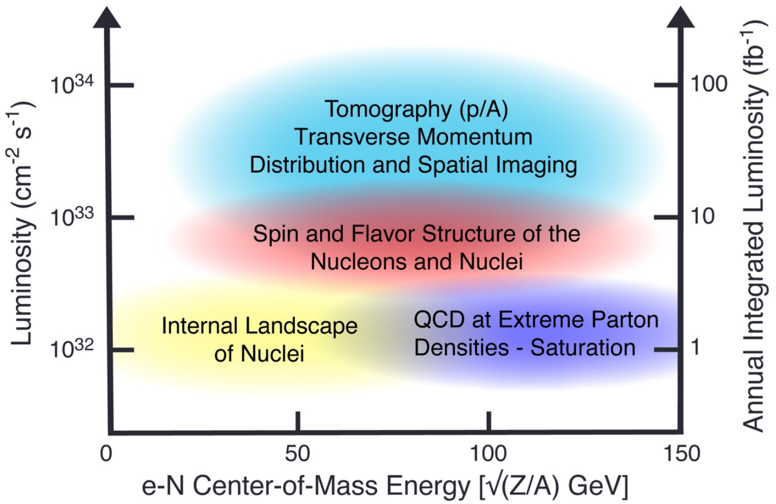
The 2nd detector



EINN, Paphos, Cyprus, 31 October - 4 November, 2023

Luminosity, acceptance, and systematics

Pawel Nadel-Turonski



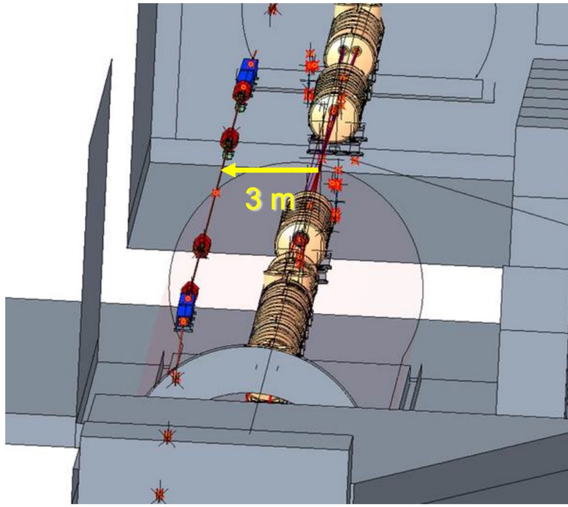
- Tomography / imaging requires a high **luminosity** – but also excellent far-forward **acceptance**
- When the EIC reaches its design luminosity, measurements in these categories will mostly become **systematics** limited, greatly benefitting from two detectors.

A 2nd detector with improved forward acceptance will have a large impact on all aspects of the EIC physics program.

Rapid Cycling Synchrotron (RCS)
Hadron Storage Ring (HSR)

Constraints, complementarity, and synergies

- The 2nd detector will be located in IR8, and has to fit some external **constraints**.
- For example, the RCS line will run 3 m to the side, and requires B to be essentially zero there.
  - This sets a constraint on the *outer size* of a detector - or requires the RCS line to go through it
- **Complementarity** with ePIC can go beyond subsystems to subsystem comparisons.
- Several measurements critically depend on a combination of capabilities.
- There are many natural **synergies** with a 2nd focus.



RCS line (left) in IR8

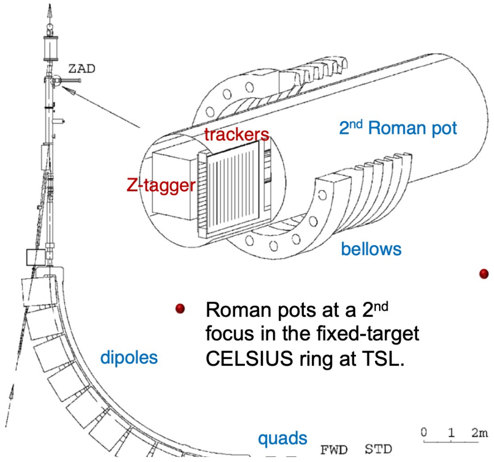
So what is a 2nd focus and what does it do?

$$\sigma = \sqrt{\beta\epsilon + \left(D\frac{\Delta p}{p}\right)^2}$$

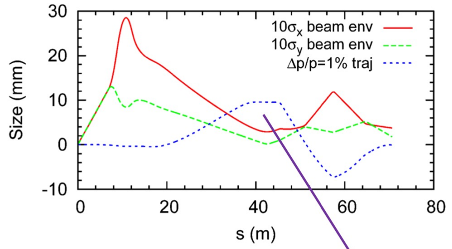
Three are mutually supportive strategies for detecting forward particles

- **Drift**
  - A particle scattered at a small angle will eventually leave the beam (which could be far away).
  - When using *only* this method, the scattering angle has to be larger than the angular spread (divergence) of the beam, which is determined by the strength of the focus at the collision point (β^*).
- **Dispersion** (D) translates a longitudinal momentum loss into a transverse displacement
  - dx = D dp/p , where dx is the transverse displacement at $p_T = 0$
  - With D = 0.4 m, dp/p = 0.01, and $p_T = 0$, the transverse displacement for would be **0.4 cm**
- **A 2nd focus** can reduce the (10σ) beam size at the detection point
  - Enables detectors to be placed closer to the beam – very effective in combination with dispersion
  - Without a 2nd focus (IR6): **4 cm** (high luminosity / divergence), **2 cm** (low luminosity / divergence)
  - With a 2nd focus (IR8): **0.2 cm** (high luminosity / divergence)

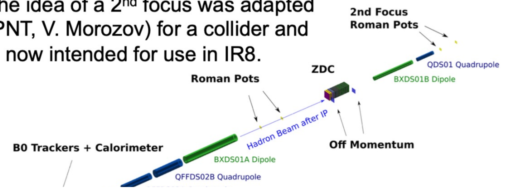
Optics for a 2nd EIC detector were inspired by the CELSIUS ring in Uppsala



- Roman pots at a 2nd focus in the fixed-target CELSIUS ring at TSL.

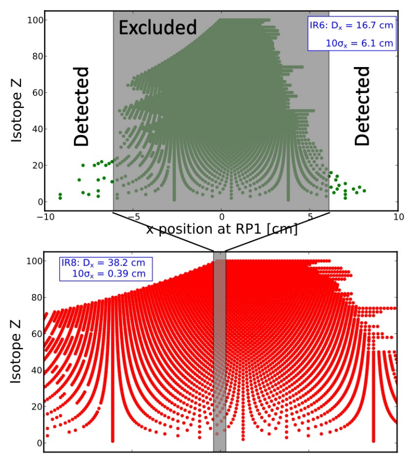


- The idea of a 2nd focus was adapted (PNT, V. Morozov) for a collider and is now intended for use in IR8.



EIC far-forward acceptance with and without a 2nd focus

Ion fragments from ^{238}U



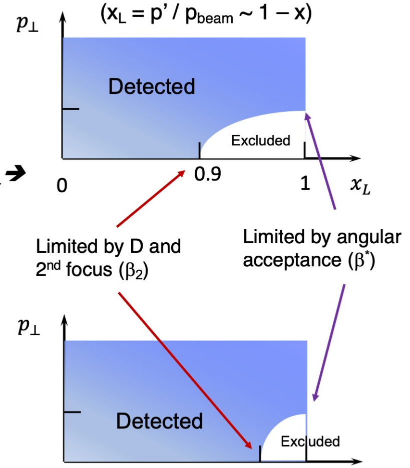
Without 2nd focus: (EPIC @IR6)

← Z' vs x_{RP} $p_\perp$ vs x_L →

With 2nd focus: (Detector 2 @ IR8)

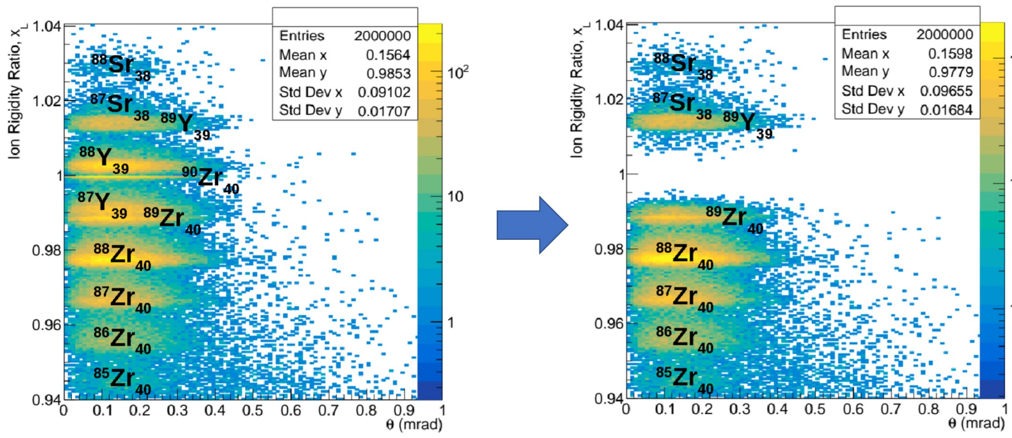
Order-of-magnitude improvement in forward acceptance

Exclusive protons ($x_L = p' / p_{beam} \sim 1 - x$)



Example: A-1 tagging with 2nd focus using a ^{90}Zr beam

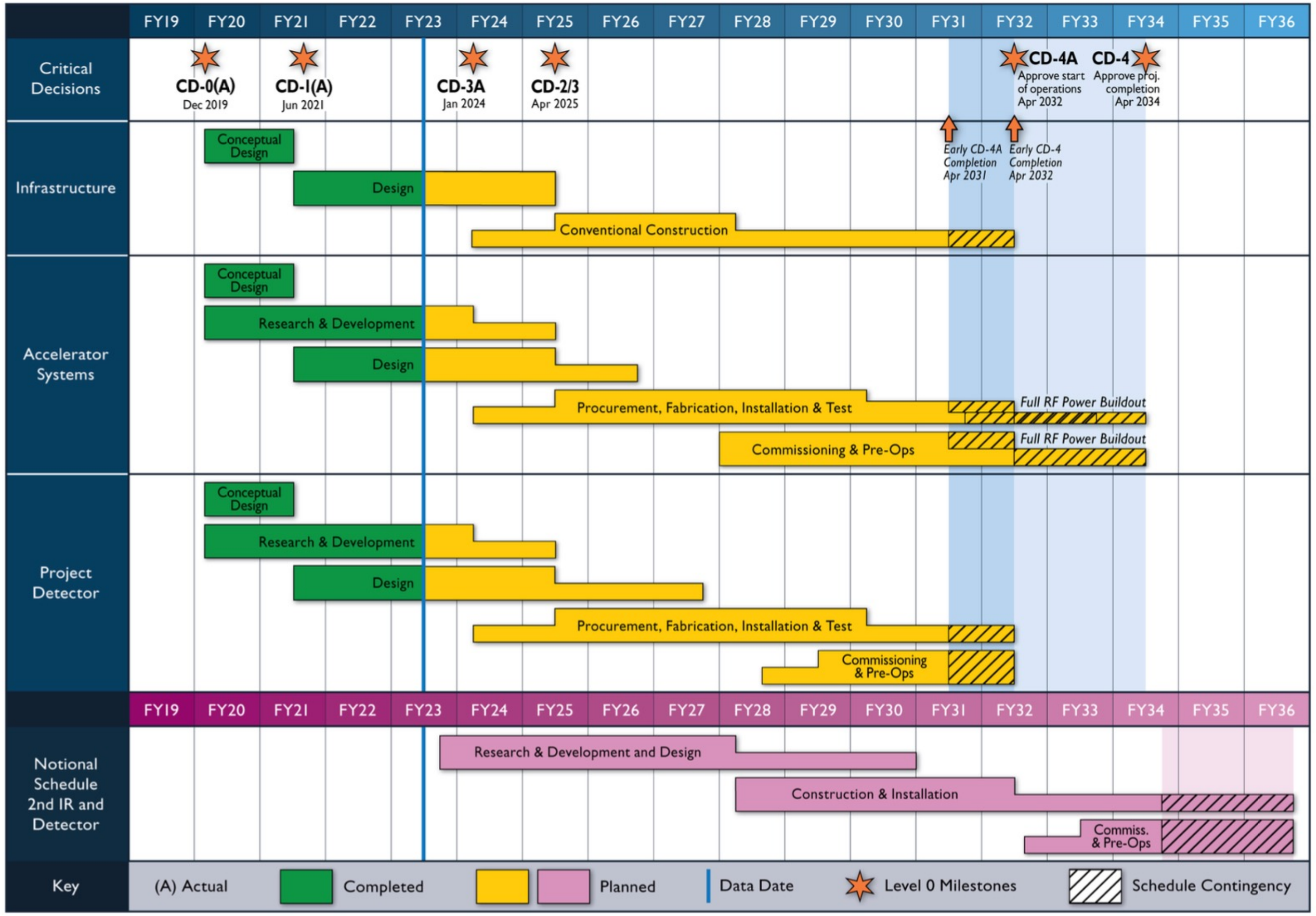
arxiv:2208.14575



generated (BeAGLE)   detected (Geant)

Reference schedule for a 2nd IR and Detector

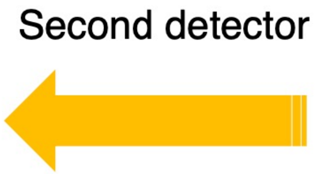
Jim Yeck, EIC 2nd detector WS, May 2023



Detector Concepts and new ideas being pursued through the EIC Users Group

Note: IR Design, 2nd focus and details shown so far are VERY preliminary and needs significant technical effort.

2nd IR is outside the purview of the EIC project.
-- A strong science case, complementary and some overlapping
-- complementary design
-- complementary leadership and contributions



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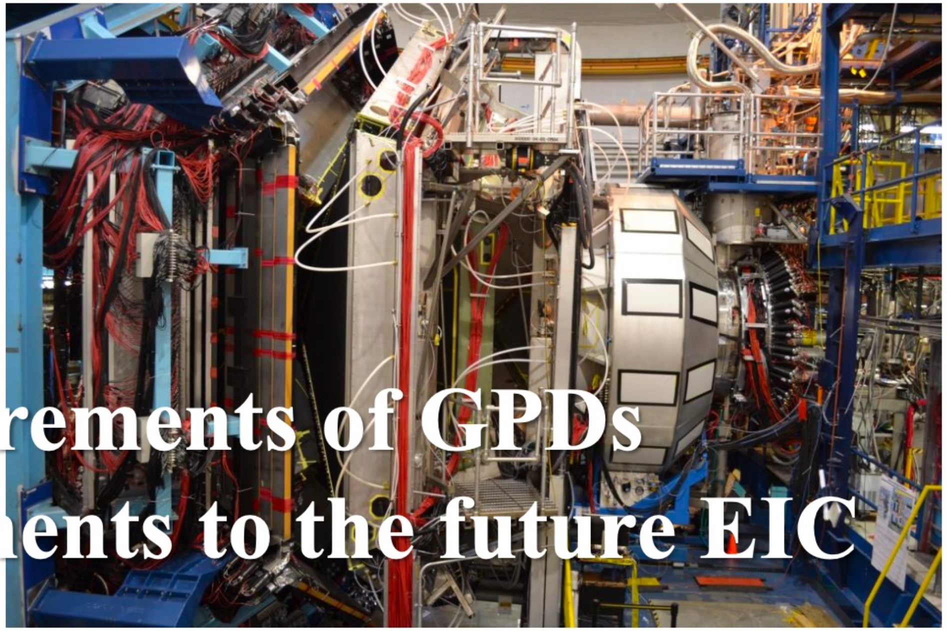
Physics Measurements:

Niccolai, Puckett, Briscoe and Surrow



Experimental measurements of GPDs
From fixed target experiments to the future EIC

Silvia Niccolai, IJClab Orsay & CLAS Collaboration

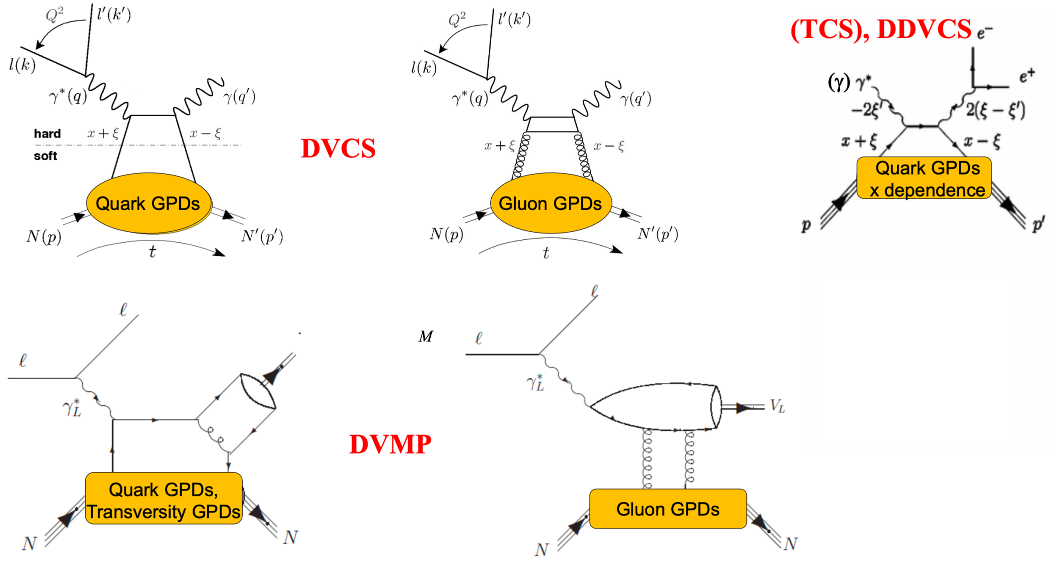
EINN2023, Paphos, (Cyprus), 1/11/2023

IJCLab Irène Joliot-Curie Laboratoire de Physique des 2 Infinis

clas CEBAF Large Acceptance Spectrometer

1

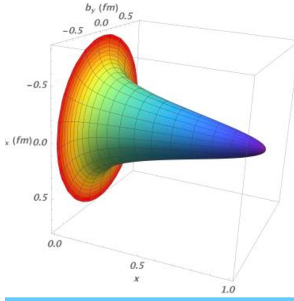
Exclusive reactions giving access to GPDs



2

What have we learned from the first generation of DVCS results?

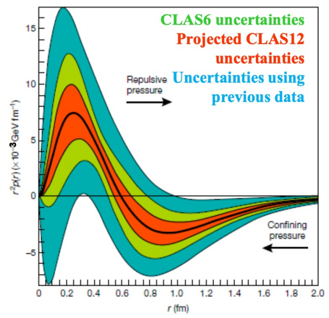
Proton tomography from *local fits* to HERMES, CLAS, and Hall-A data (**ImH+ model dependent** assumptions for x dependence)



High-momentum quarks (valence) are at the core of the nucleon, low-momentum quarks (sea) spread to its periphery

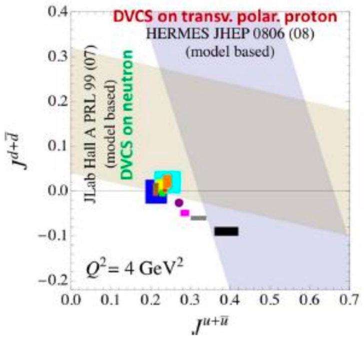
R. Dupré, M. Guidal, M.Vanderhaeghen, PRD95 (2017)

From **H-only fit** of DVCS BSA and cross section from CLAS@6 GeV **(model dependent): an insight in the pressure distribution in the proton**



V. Burkert, L. Elouadrhiri, F.X. Girod, Nature 557, 396-399 (2018)

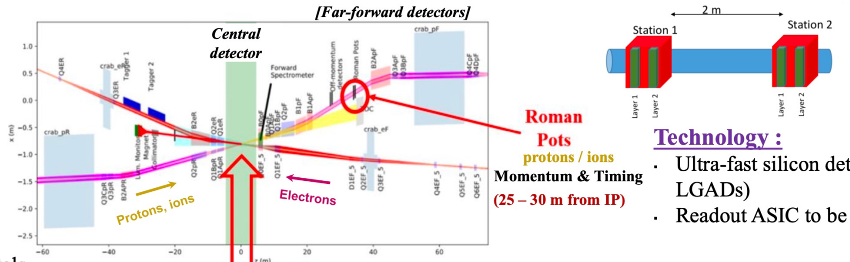
Importance of **neutron-DVCS** and **transversely-polarized proton-DVCS** to constrain J_u and J_d



M. Mazouz et al., PRL 99 (2007) 242501

6

How to measure DVCS at EIC: EMCal, Roman Pots

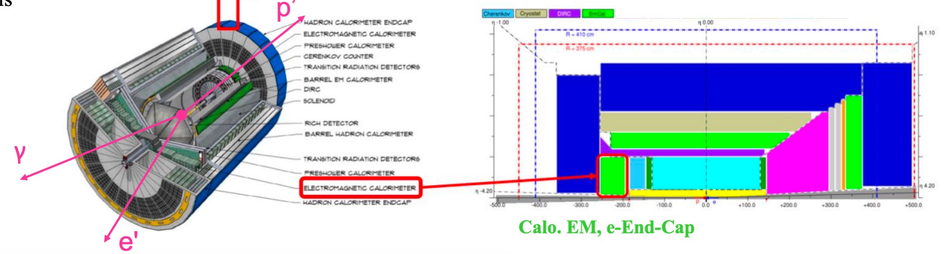


Technology :

- Ultra-fast silicon detectors (AC-LGADs)
- Readout ASIC to be developed

Technology :

- PbWO4 crystals
- SiPM readout (or APDs)



Calo. EM, e-End-Cap

These are the R&D projects ongoing in my lab, IJCLab Orsay ☺

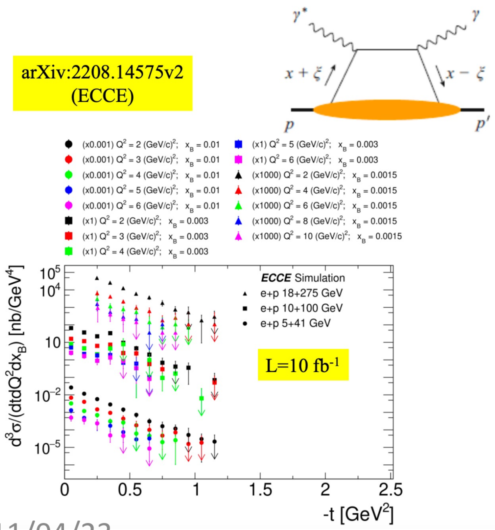
Work by P.K.Wang and N. Pilleux

2

GPDs with ePIC@EIC – DVCS and DVMP

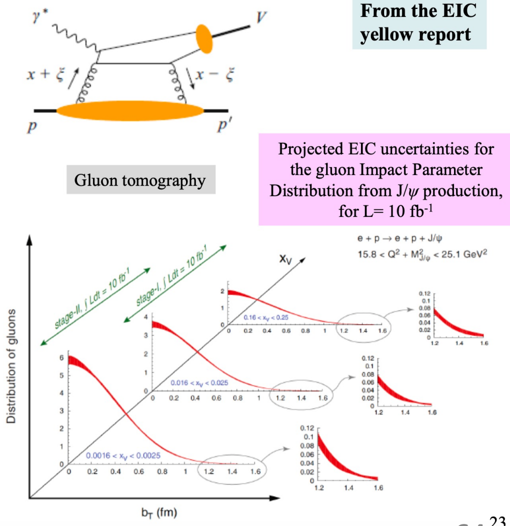
arXiv:2208.14575v2 (ECCE)

From the EIC yellow report



Gluon tomography

Projected EIC uncertainties for the gluon Impact Parameter Distribution from J/ψ production, for L= 10 fb^{-1}



Status of High-Momentum Transfer Form Factor Program at JLab and EIC

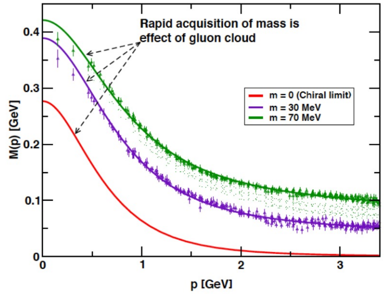
Prof. Andrew Puckett
University of Connecticut

EINN2023, Paphos, Cyprus
November 1, 2023

UCONN

Continued relevance of high-Q^2 FF measurements

- For Q ~ few GeV and higher we are probing the theoretically challenging region of transition between non-perturbative QCD, strong-coupling, and confinement to weak-coupling, asymptotic freedom, and pQCD.
- Precise FF knowledge is required both to directly constrain GPD moments and to interpret DVCS experiments
- Quark flavor separation to very large momentum reveals role of diquark correlations: PPNP 116, 103835 (2021), https://doi.org/10.1016/j.ppnp.2020.103835



- Comparison of continuum and Lattice results for M(p)

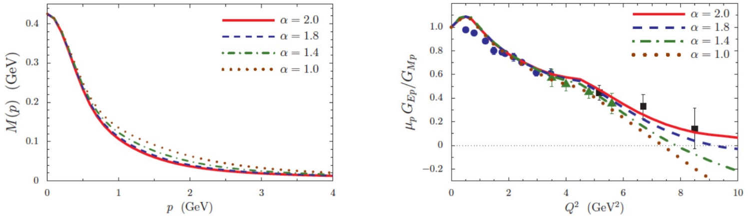


Figure 7.1: *Left panel.* Dressed-quark mass function employed in Ref. [89]. $\alpha = 1$ specifies the reference form and increasing α diminishes the domain upon which DCSB is active. *Right panel.* Response of $\mu_p G_E/G_M$ to increasing α; i.e., to an increasingly rapid transition between constituent- and parton-like behaviour of the dressed-quarks. Data are from Refs. [301, 312–316].

- High-Q^2 form factor behavior highly sensitive to M(p) in Dyson-Schwinger Equation (DSE) framework
- Cloet and Roberts, PPNP 77, 1 (2014)

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Positrons @JLab

- https://inspirehep.net/literature/1809448

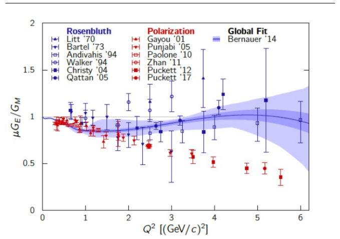

Fig. 1 A representative sample of the world data on the proton's form factor ratio, $\mu_p G_E/G_M$ shown as a function of squared four-momentum transfer, Q^2. Rosenbluth separations of unpolarized cross sections are shown in blue [48, 49, 50, 51, 52, 53]. Polarized measurements are shown in red [35, 36, 37, 38, 39, 40]. A global fit to unpolarized cross sections [59] is shown, along with statistical and systematic uncertainties, by a blue curve with light blue bands.

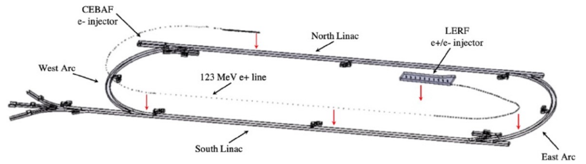

Figure 44: A new tunnel and beam line (shown raised) connects the LERF to CEBAF and transports the 123 MeV e^+ beam for injection and acceleration into CEBAF 12 GeV.

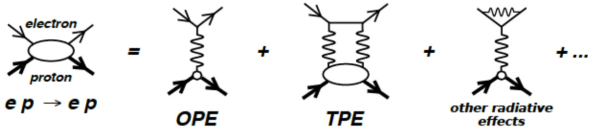

Fig. 2 Feynman diagram series for elastic electron-proton scattering. The two-photon exchange amplitude contributes at the same order as several other radiative processes.

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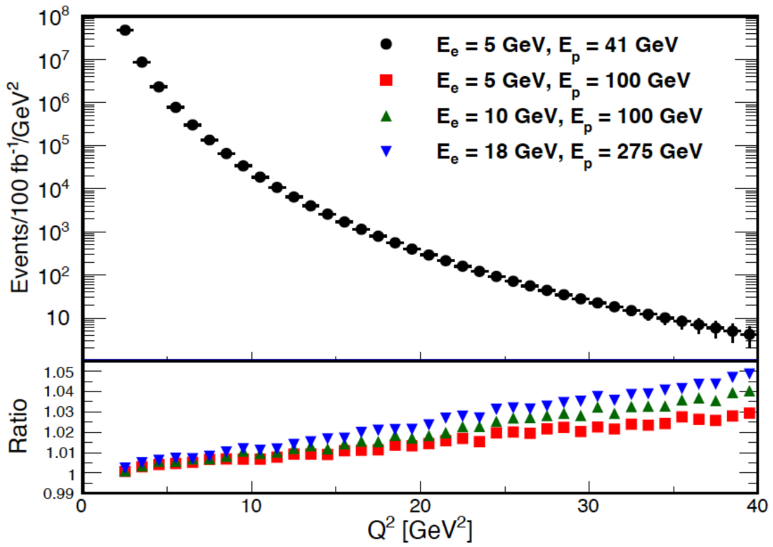
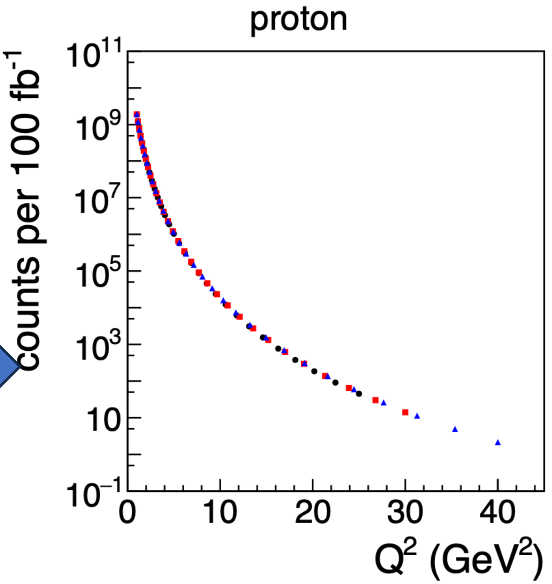


EIC with the planned ePIC Detector

- Schmookler *et al.*, "High-Q^2 Electron-Proton E Scattering at the Future Electron-Ion Collider https://inspirehep.net/literature/2108947

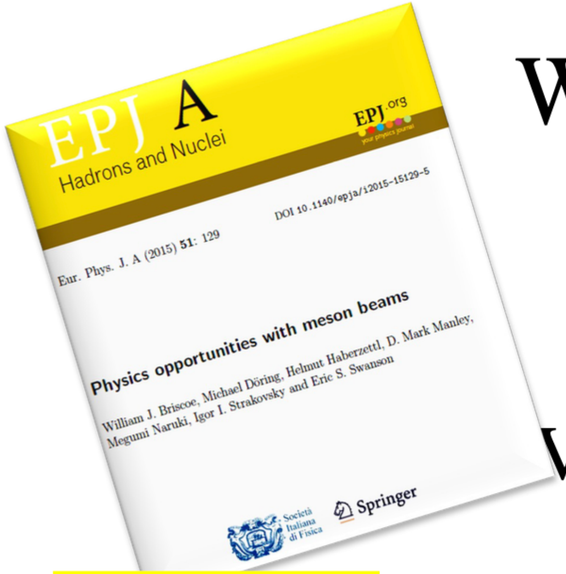
JLAB22



Post EIC Project Era idea (?)

- JLab high luminosity provides plenty of count rate up to max. accessible Q^2
- EIC ~100 fb^{-1} per YEAR (best-case)

Experimental Opportunities in for Meson Beams at EIC

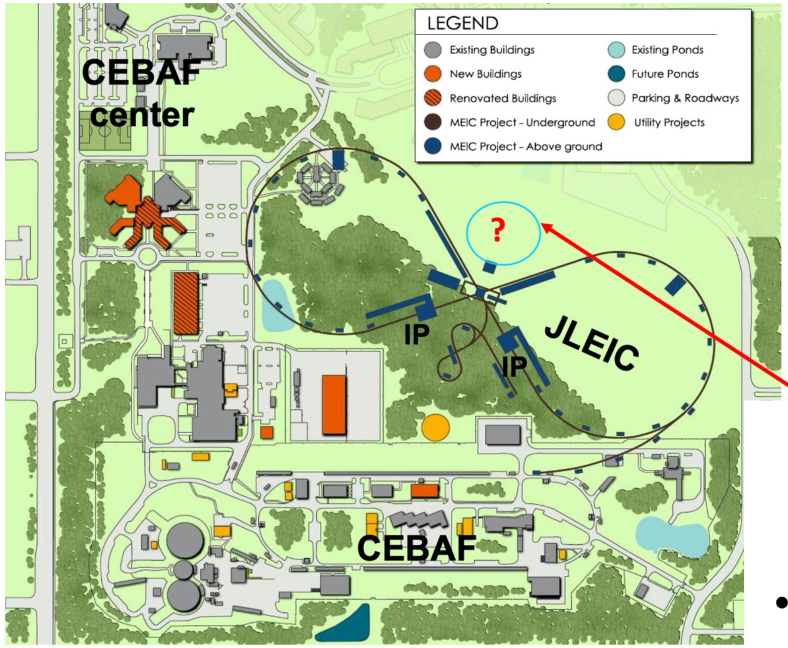

EPJ A
Hadrons and Nuclei
EPJ .org
Eur. Phys. J. A (2015) 51: 129
DOI 10.1140/epja/i2015-15129-5
Physics opportunities with meson beams
William J. Briscoe, Michael Döring, Helmut Haberzettl, D. Mark Manley, Megumi Naruki, Igor I. Strakovsky and Eric S. Swanson
Società Italiana di Fisica
Springer

2015 White Paper
135 endorsers from 77 labs worldwide

W.J. Briscoe and Igor Strakovsky

Department of Physics
The George Washington University
Virginia Science and Technology Campus
Ashburn, VA 20147

JLab Campus Layout



JLEIC:
- W = 15 – 65 GeV.
- *Protons*: 20 – 100 GeV.
- *Luminosity*: 10^{33} to 10^{34} $cm^{-2}s^{-1}$ per IP.
- 2.2 km.

Ion Booster:
- *Protons*: 8 GeV.
- Booster design based on super-ferric magnet technology.
- 313.5 m.

It would have gone here!

High energy pion, kaon beam impinging on various targets (fixed)

Will require hadron beam extraction from the current RHIC ring, and a fixed target experimental hall.

A post EIC era idea

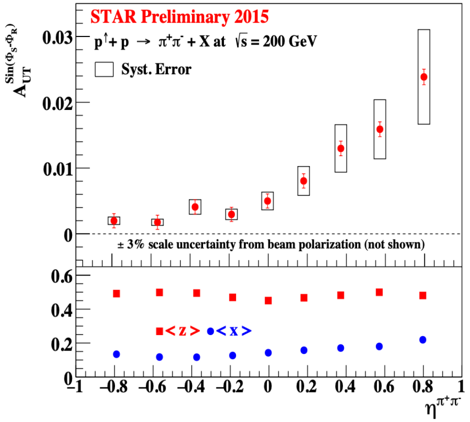
What Would a Modern Meson Facility Be?

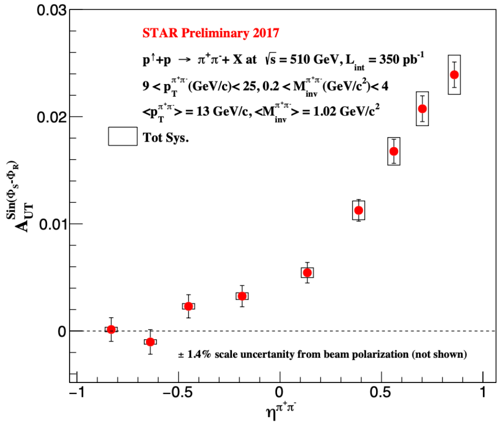
- It would have a CM energy range of at least 2.5 GeV to exploit the physics opportunities with pion and kaon beams complementary to EM programs at facilities: JLab, MAMI, ELSA, SPring-8, and BEPC.
- New higher energy and intensity meson facilities can contribute to the fuller understanding of recent high-quality EM data.
- This is not a competing effort, but an experimental program that
  - provides the hadronic complement of ongoing EM programs and
  - provides common ground for better, more reliable, phenomenological and theoretical analyses. [1,2]

➢ Refs available online with supplemental.

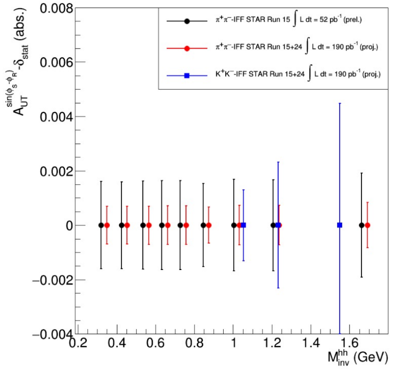
$\pi^+\pi^-$ Asymmetry Results

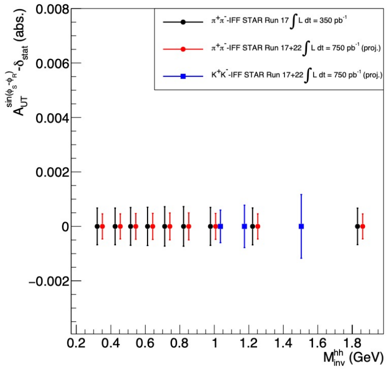
- Asymmetry vs. pseudo-rapidity $\eta^{\pi^+\pi^-}$ at 200GeV and 510GeV





- Outlook
  - Precision measurement of IFF asymmetries for pions / kaons from 2015+2024 at 200GeV and 2017+2022 at 510GeV
  - Planned cross-section measurements for pions at 510GeV and Kaons at 200/510GeV



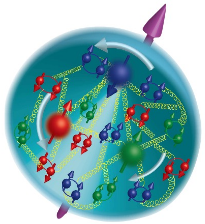


Measurements of Transverse Spin Dependent $\pi^+\pi^-$ Azimuthal Correlation Asymmetry and Unpolarized $\pi^+\pi^-$ Cross Section in p+p Collisions at STAR at RHIC

Bernd Surrow

TEMPLE UNIVERSITY

(On behalf of the STAR Collaboration)



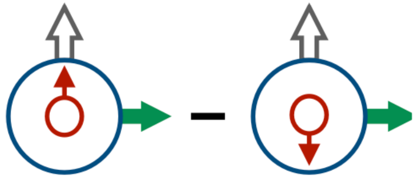
U.S. DEPARTMENT OF ENERGY | Office of Science

DOE NP contract: DE-SC0013405

15th European Research Conference EINN 2023
Paphos, Cyprus, October 31 - November 4, 2023

Bernd Surrow

Transversity



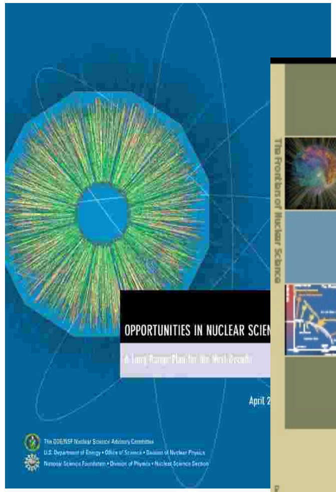
First proof of principle measurement

Outlook

- A high luminosity polarized e-p/e-A collider with variable center of mass energy, will be built in the next 10 years and will operate for next two decades -- addressing some of the most profound questions in QCD.
- A large user group and a collaboration is gathering around the project to realize it with BNL and Jefferson Lab. Supported by the US DOE (NP) and with many international partner funding agencies.
- Great opportunities for scientist from around the world to contribute & lead explored and unexplored avenues on the scientific and technical front.

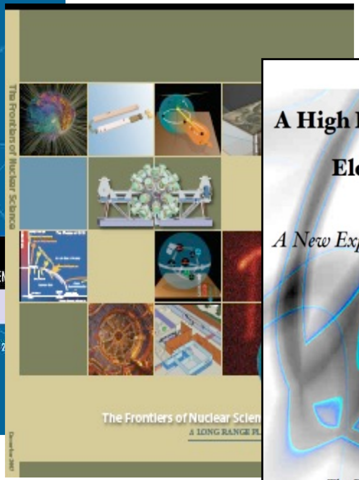
The Scientific Foundation for an EIC was Built Over Two Decades

2002



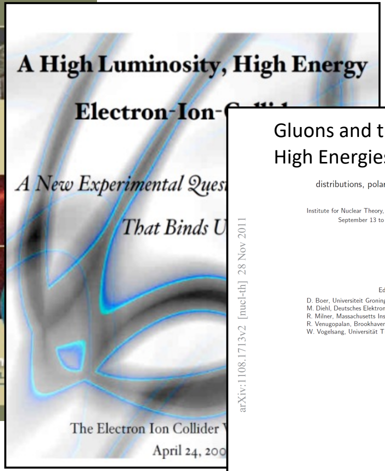
"…essential accelerator and detector R&D [for EIC] should be given very high priority in the short term."

2007



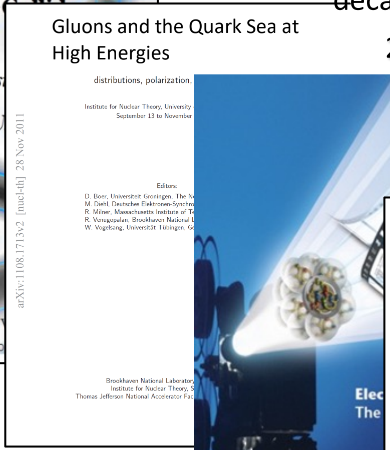
"We recommend the allocation of resources …to lay the foundation for a polarized Electron-Ion Collider…"

2009



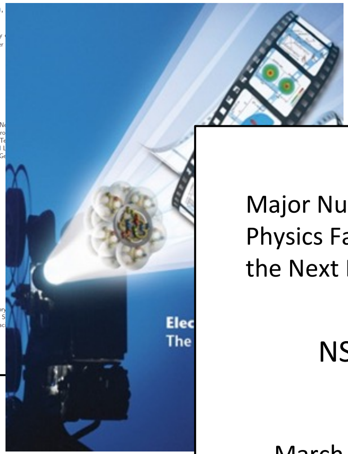
"..a new dedicated facility will be essential for answering some of the most central questions."

2010



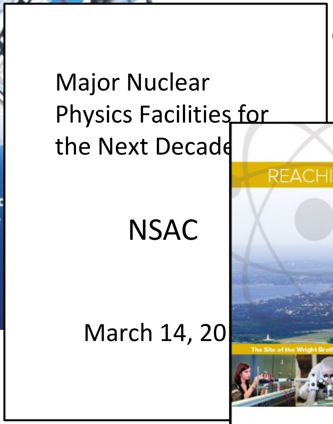
"The quantitative study of matter in this new regime [where abundant gluons dominate] requires a new experimental facility: an Electron Ion Collider.."

2012



Electron-Ion Collider..*absolutely central* to the nuclear science program of the next decade.

2013



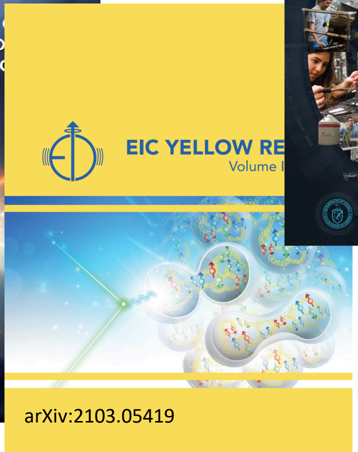
"a high-energy high-luminosity polarized EIC [is] the highest priority for new facility construction following the completion of FRIB."

2015

The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today."

2018

2021



Science Requirements and Detector Concepts for the EIC – Drives the requirements of EIC detectors

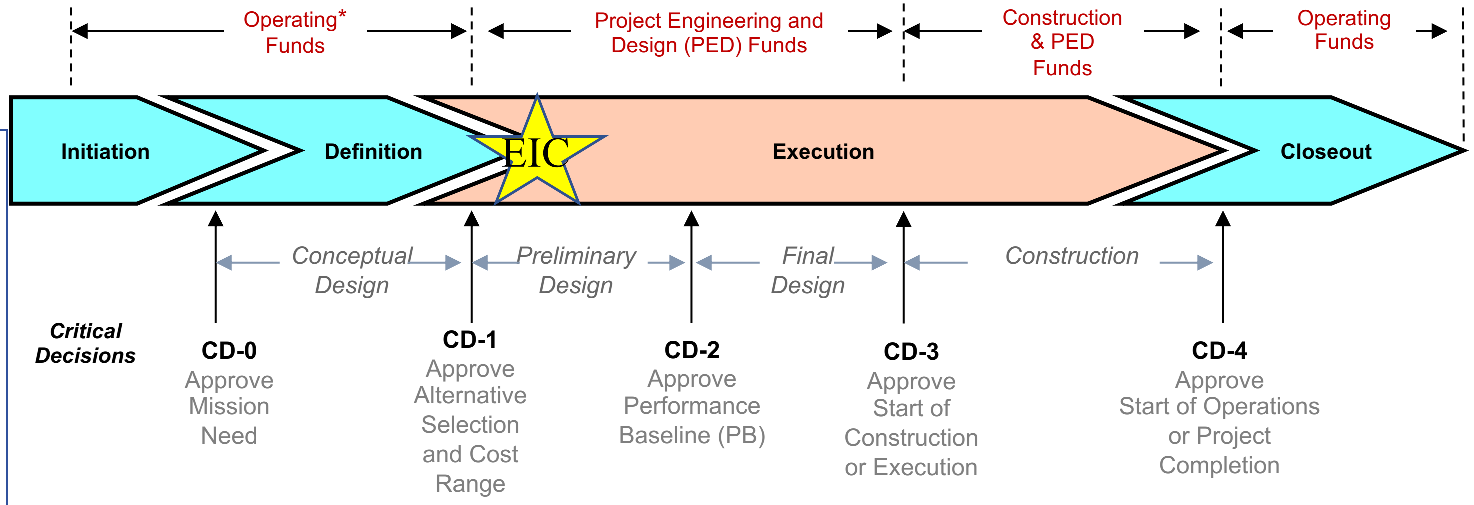
2023

Build expeditiously

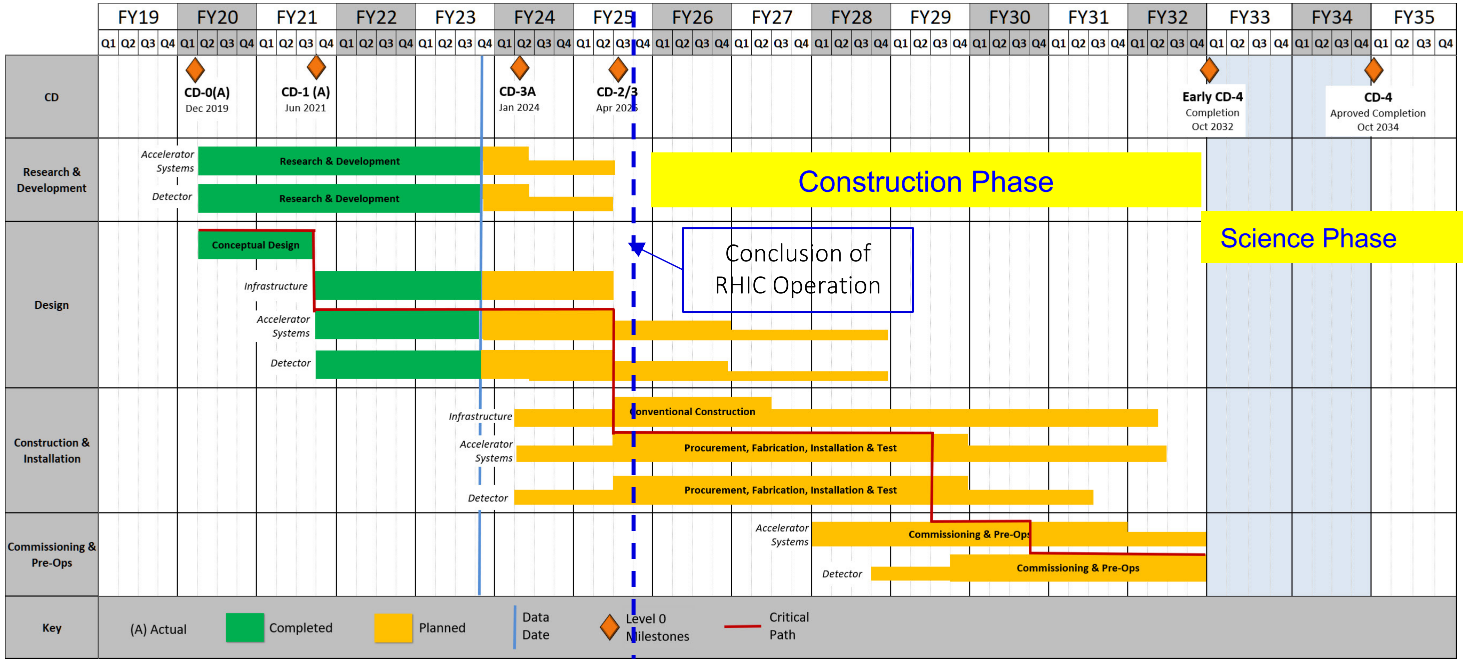
Timeline:

EIC Critical Decision Plan

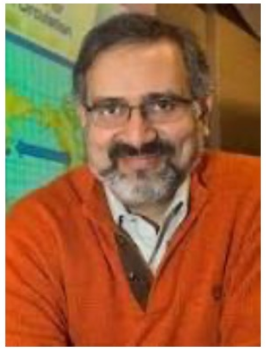
CD-0/Site Selection	December 2019 ✓
CD-1	June 2021 ✓
CD-3A	**January 2024**
CD-2/3	**April 2025**
CD-4A	October 2032
CD-4	**October 2034**



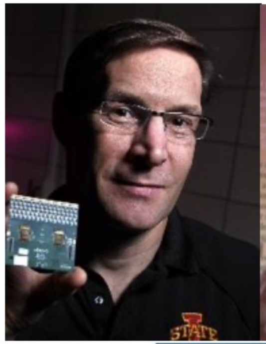
CD-3A: (review mid-November)
Define Baseline:
technologies, Scope, Cost & Schedule
Long Lead Procurement (LLP) items
Design Maturity: ~90%
Plan is tracked through EVMS
& Change control process
Start of construction for LLPs












BROOKHAVEN NATIONAL LABORATORY
D. Gibbs
Laboratory Director
R. Tribble
Deputy Director for Science & Technology
J. Anderson
Deputy Director for Operations

EIC BOARDS
EIC Advisory Board
S. Henderson, TJ Director, Chair
EIC Resource Review Board
H. Gao, BNL Associate Lab Director for Nuclear & Particle Physics
D. Dean, TJ Deputy Director for Science
TBD Co-Chair, International Funding Agency

ELECTRON-ION COLLIDER PROJECT

J. Yeck (BNL), Project Director
F. Willeke (BNL), Deputy Project Director and Technical Director
K. Smith (BNL), Deputy Technical Director

R. Ent (TJ), Co-Associate Director for the Experimental Program
E. Aschenauer (BNL), Co Associate Director for the Experimental Program
Technical Integration

A. Lung (TJ), Deputy Project Director for TJNAF Partnership
A. Seryi (TJ), Associate Director for Accelerator Systems & International Partnership

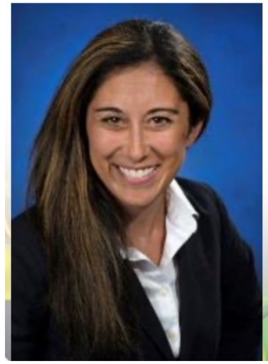
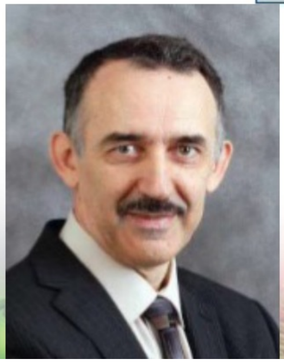
L. Lari (BNL), Project Manager

A. Deshpande (BNL)
EIC Science Director

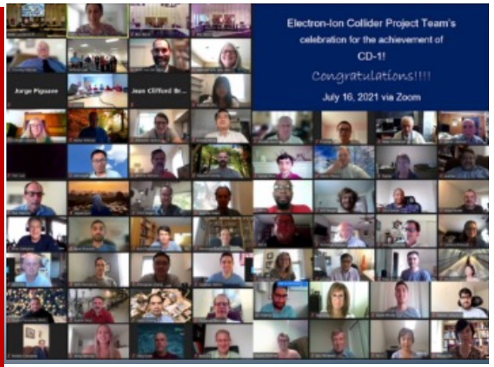
M. Chamizo Llatas (BNL)
EIC In-Kind Manager
K. Amm (BNL)
EIC SC Magnet Production Manager

EIC COMMITTEES
Project Advisory Committee
T. Glasmacher, Chair
Machine Advisory Committee
T. Raubenheimer, Chair
Detector Advisory Committee
E. Kinney, Chair
Infrastructure Construction Advisory Committee
M. Fallier, Chair

EIC USERS
EIC User Group Steering Committee
R. Fatemi, Chair
M. Radici, Co-Chair
ePIC Collaboration
TBD – Spokesperson





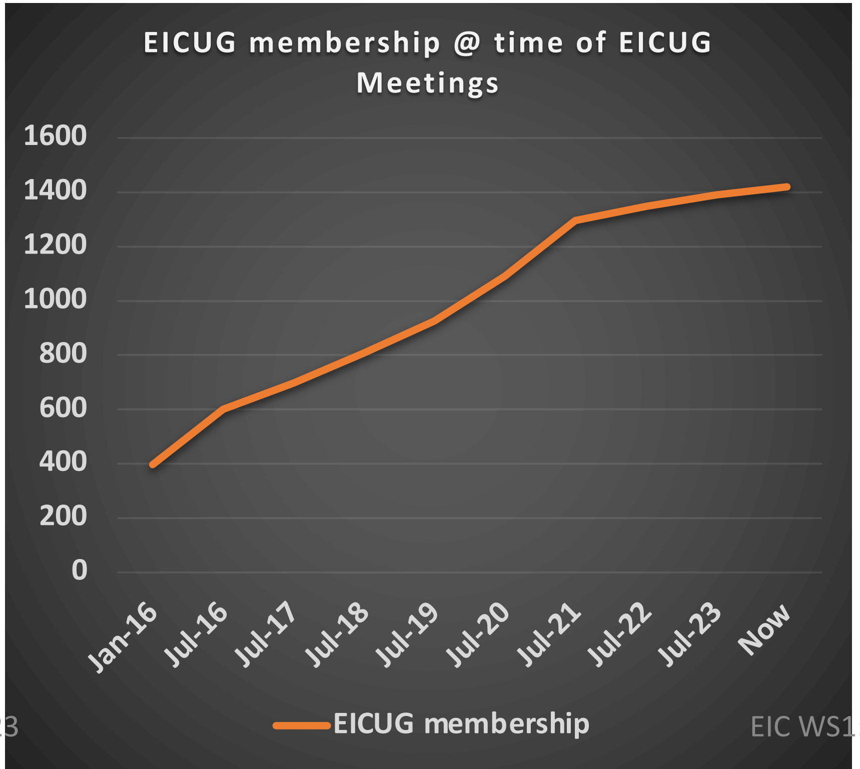
Jim Yeck

Worldwide Interest in EIC

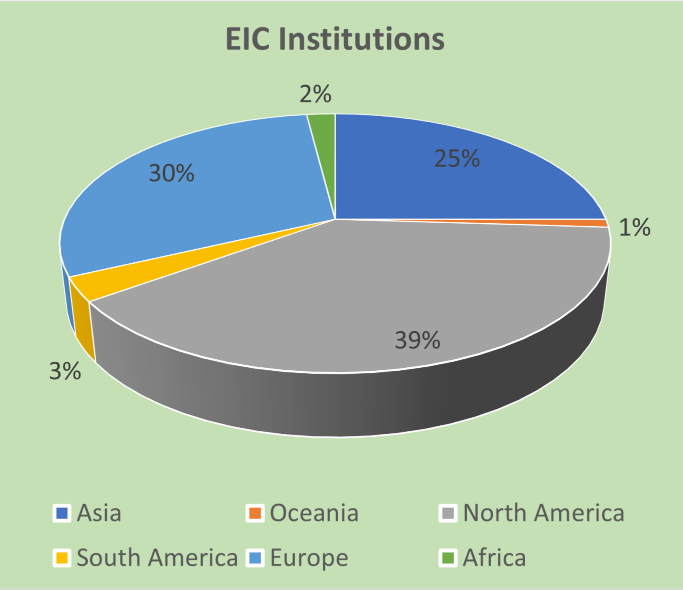
The EIC User Group:
https://eicug.github.io/

Formed 2016 –
- **1417 collaborators,**
- **37 countries,**
- **285 institutions**

as of October 02, 2023.
Strong International Participation.



Annual EICUG meeting
2016 UC Berkeley, CA
2016 Argonne, IL
2017 Trieste, Italy
2018 CUA, Washington, DC
2019 Paris, France
2020 FIU, Miami, FL
2021 VUU, VA & UCR, CA
2022 Stony Brook U, NY
2023 Warsaw, Poland
2024 Lehigh U, PA



Two documents: with overlapping arguments

Ent and Milner et al for the EICUG SC

JLAB-PHY-23-3761

Motivation for Two Detectors at a Particle Physics Collider

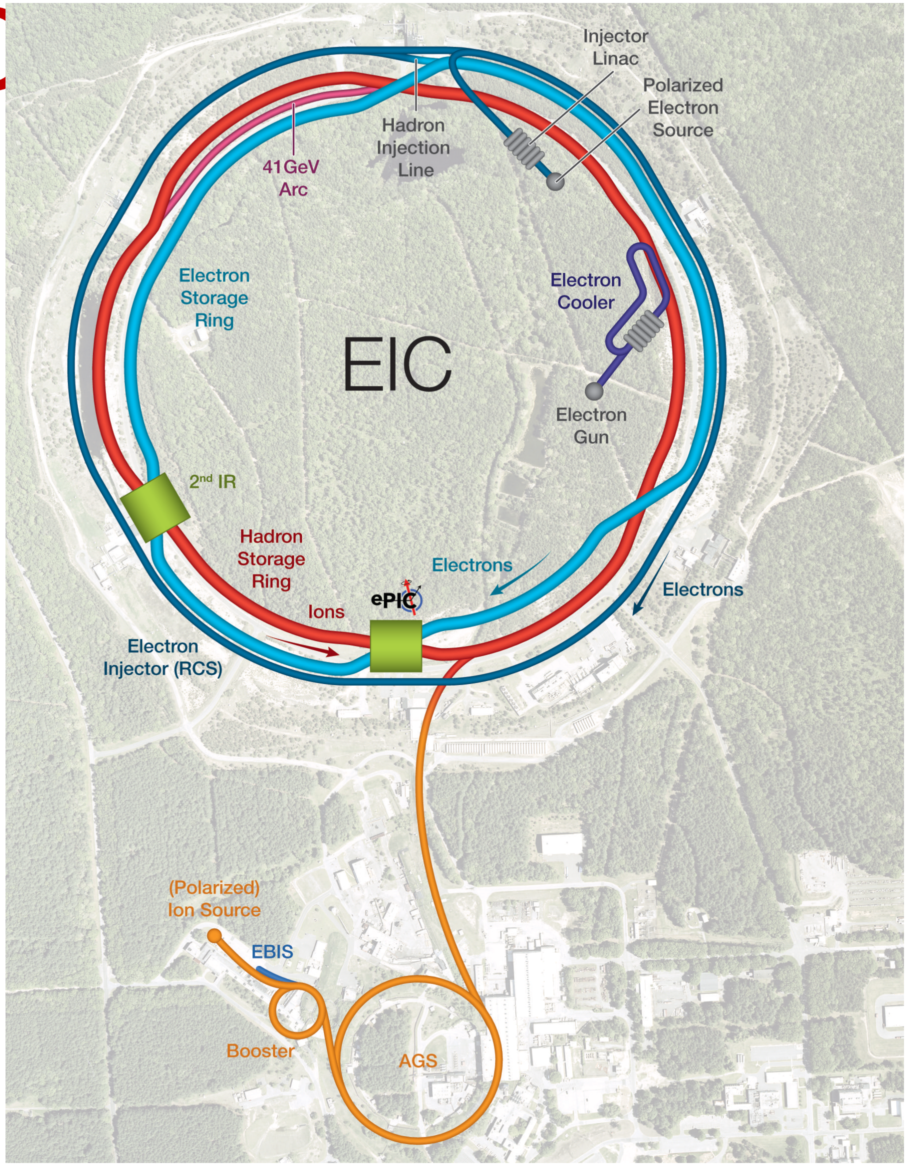
Paul D. Grannis* and Hugh E. Montgomery†
(Dated: March 27, 2023)

It is generally accepted that it is preferable to build two general purpose detectors at any given collider facility. We reinforce this point by discussing a number of aspects and particular instances in which this has been important. The examples are taken mainly, but not exclusively, from experience at the Tevatron collider.

arXiv: 2303.08228v2 March 24, 20234

Case for two detectors being made from **Nuclear** and **Particle** Physics

EIC Accelerator D



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