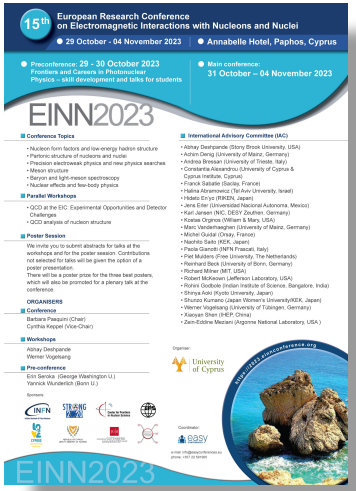
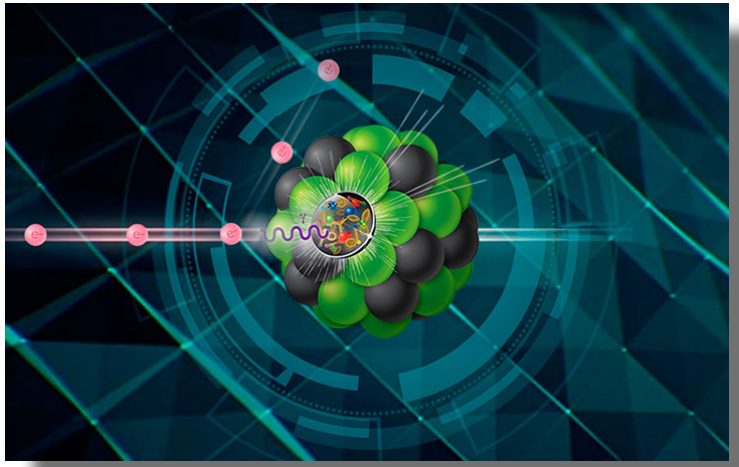
Design Philosophy
ePIC
(electron-Proton/Ion Collider)
Detector and Collaboration

Bernd Surrow

(surrow@temple.edu)

TEMPLE UNIVERSITY®

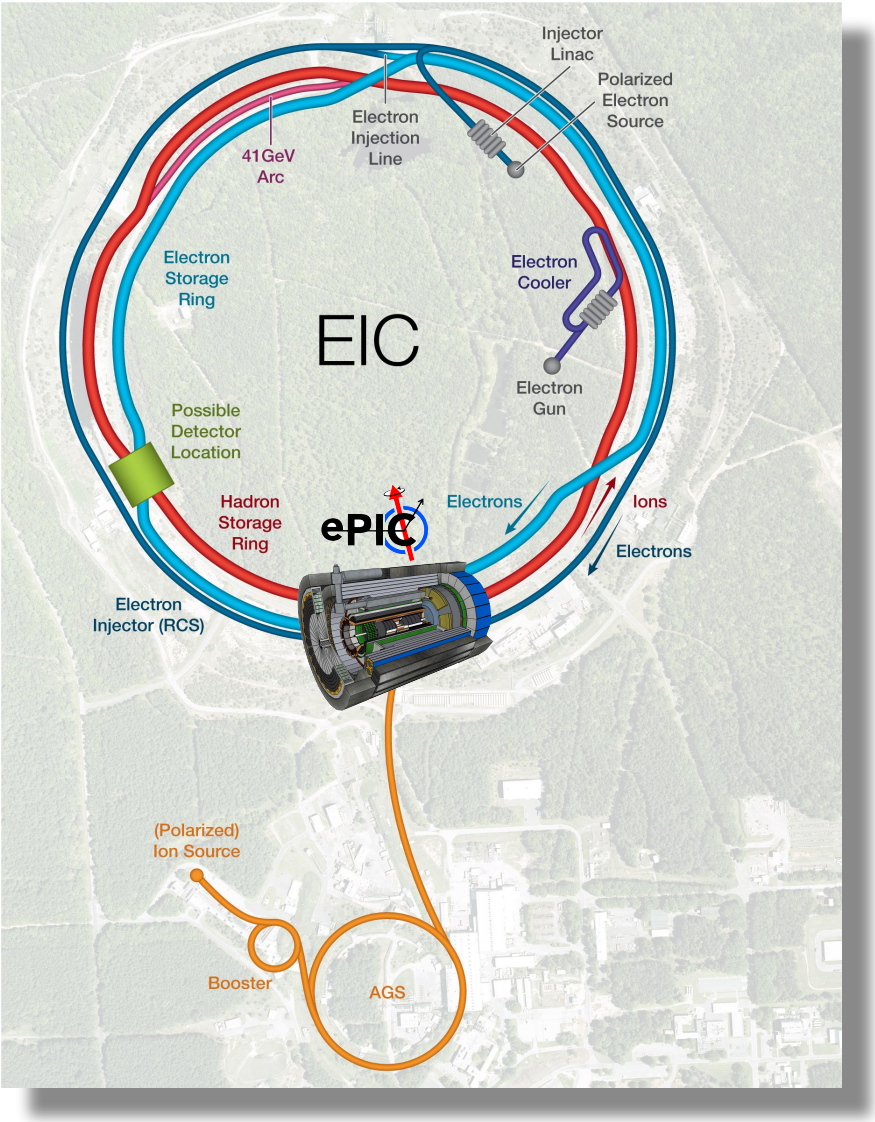




U.S. DEPARTMENT OF ENERGY | Office of Science

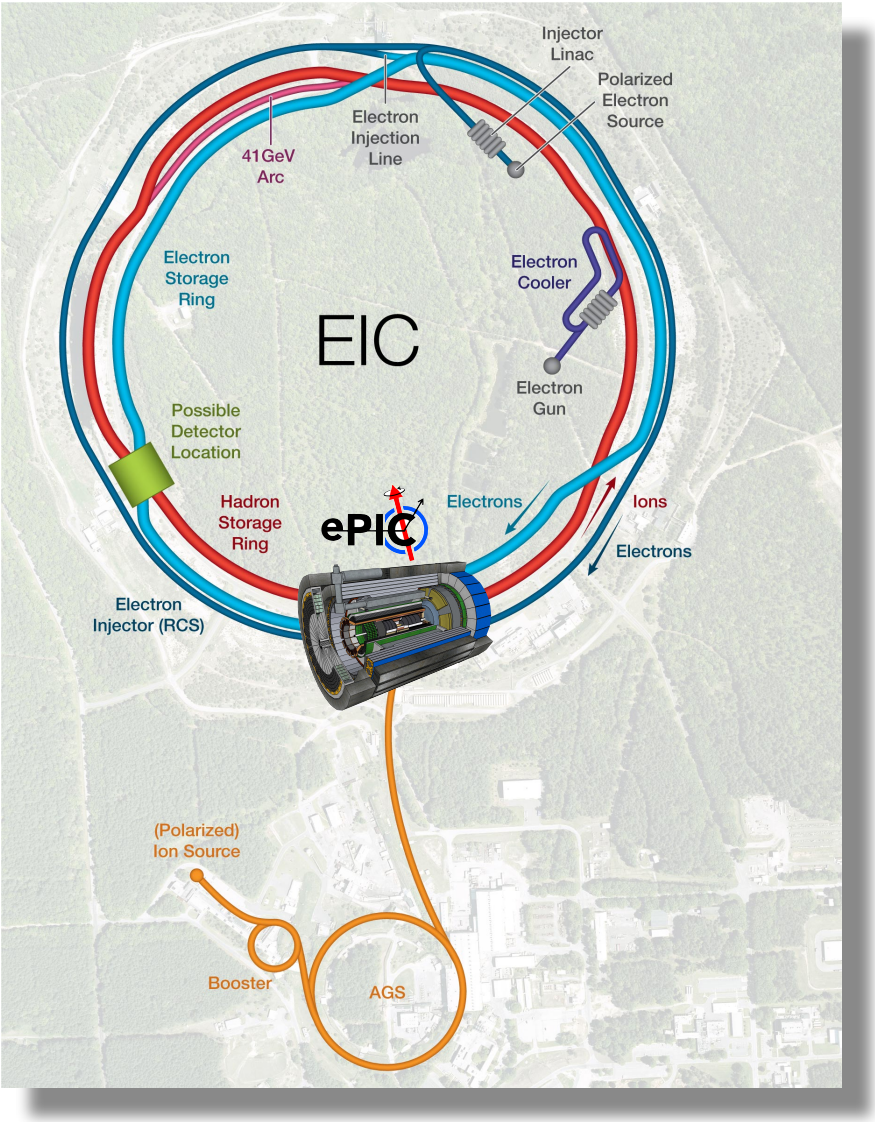
DOE NP contract: DE-SC0013405

Outline


Injector Linac
Polarized Electron Source
Electron Injection Line
41GeV Arc
Electron Storage Ring
Electron Cooler
EIC
Electron Gun
Possible Detector Location
Hadron Storage Ring
ePIC
Electrons
Ions
Electrons
Electron Injector (RCS)
(Polarized) Ion Source
Booster
AGS

Outline

- EIC Project Development



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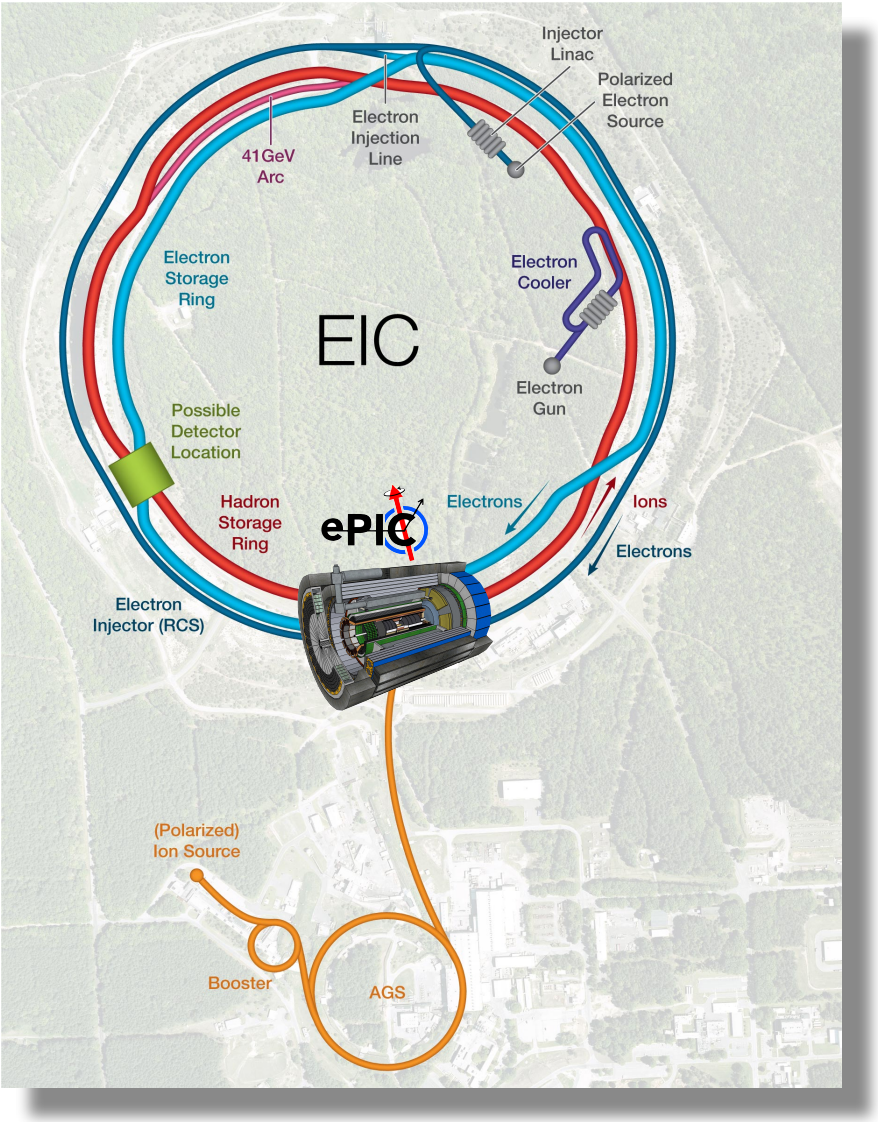

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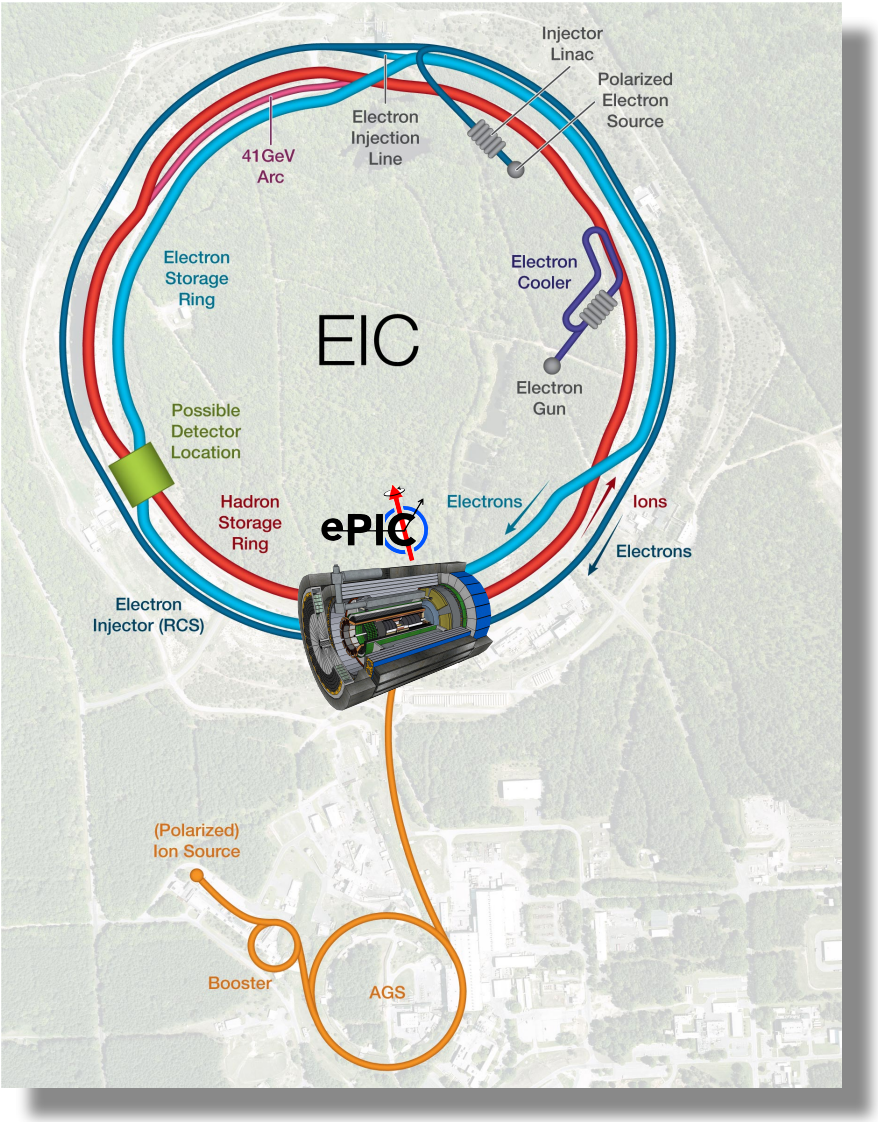

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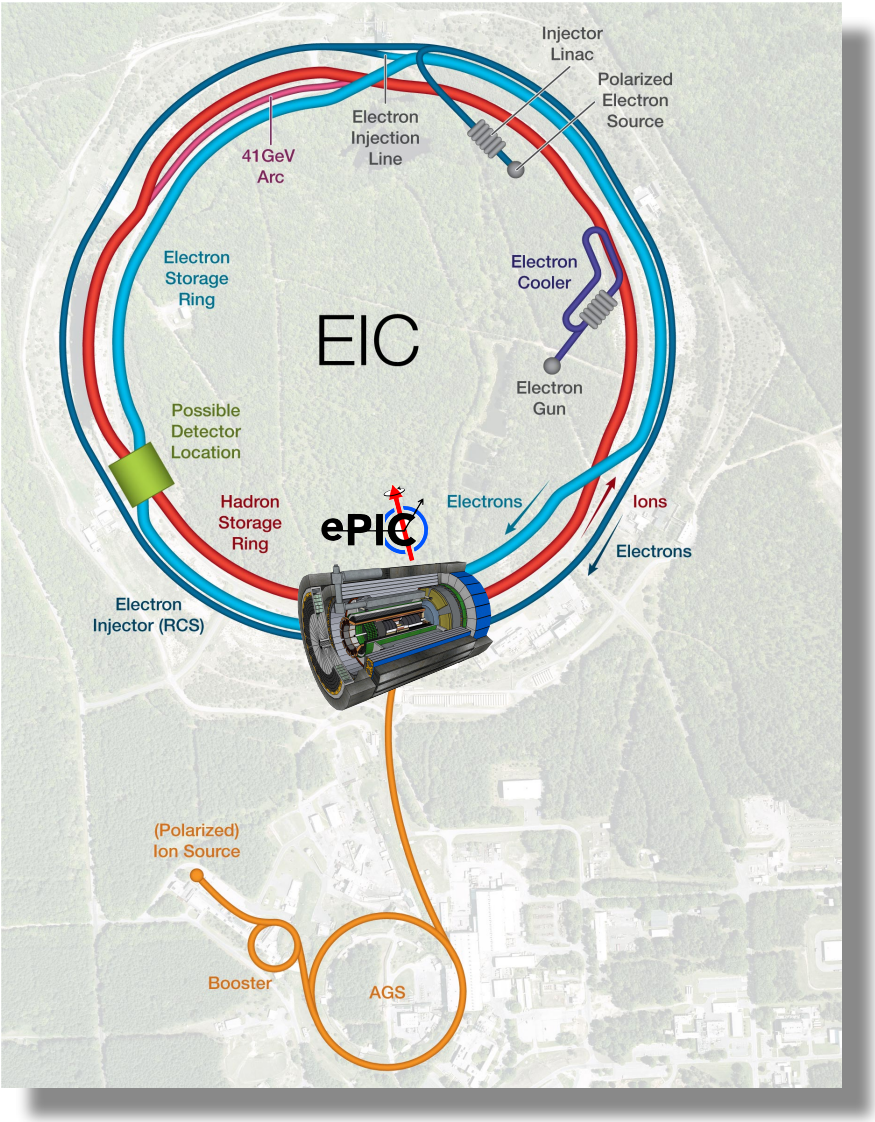
- ePIC Collaboration
- Summary And Next Steps



EIC Project Development

EIC Project Development

- EIC: Study
  structure and
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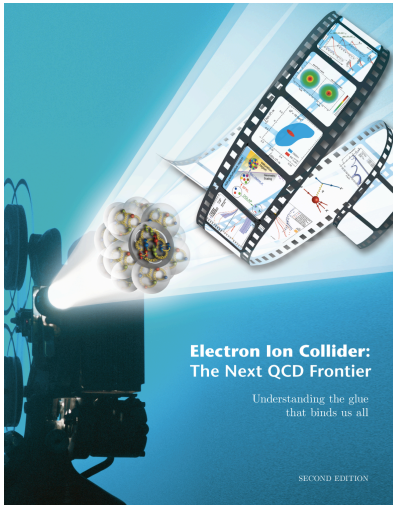
arXiv:1212.1701



Understanding the glue that binds as all!

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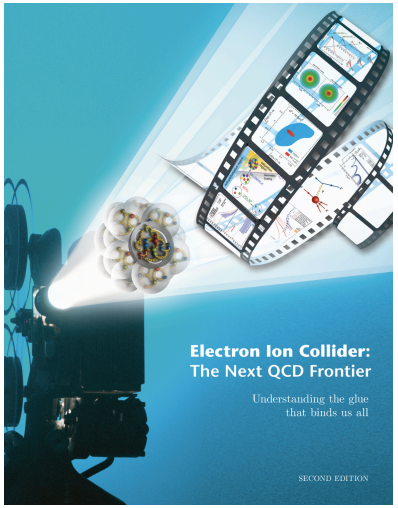

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Parton Distributions in Nuclei

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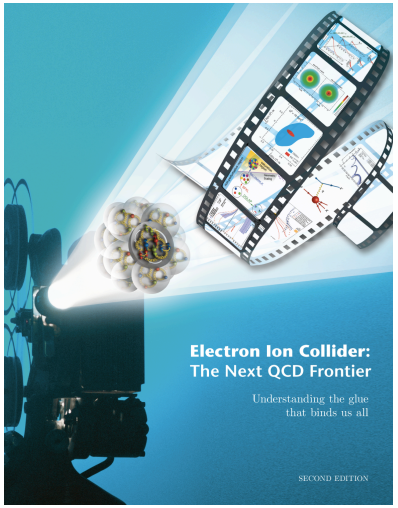

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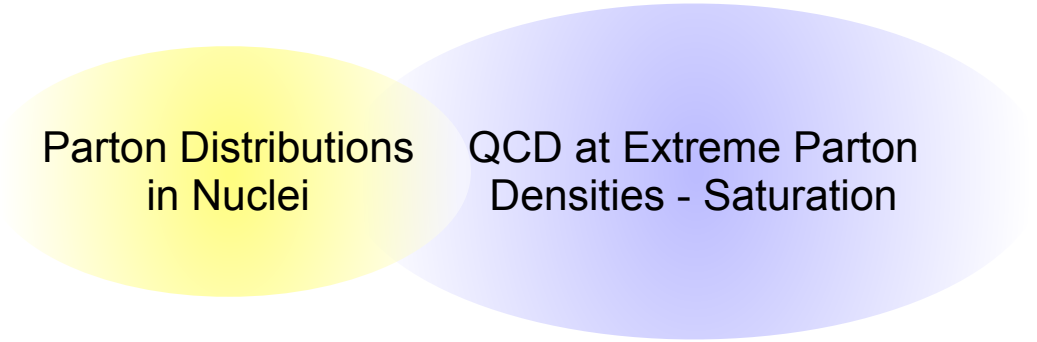

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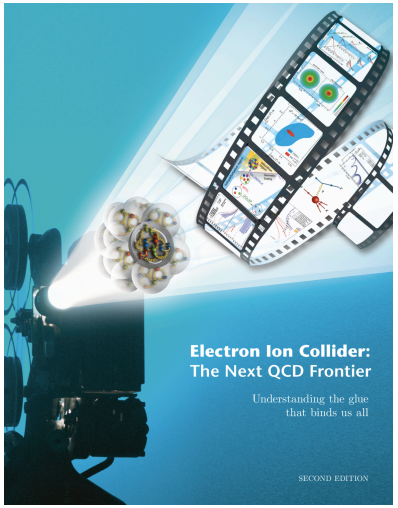

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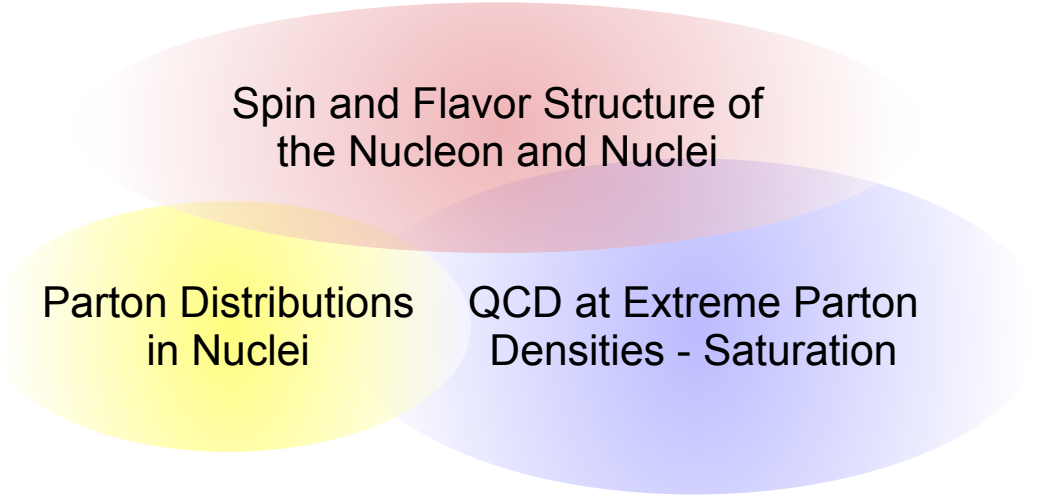

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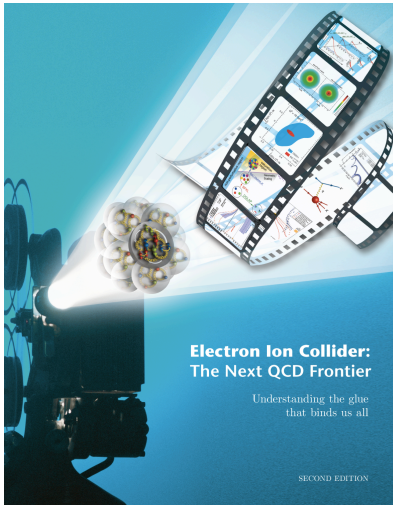

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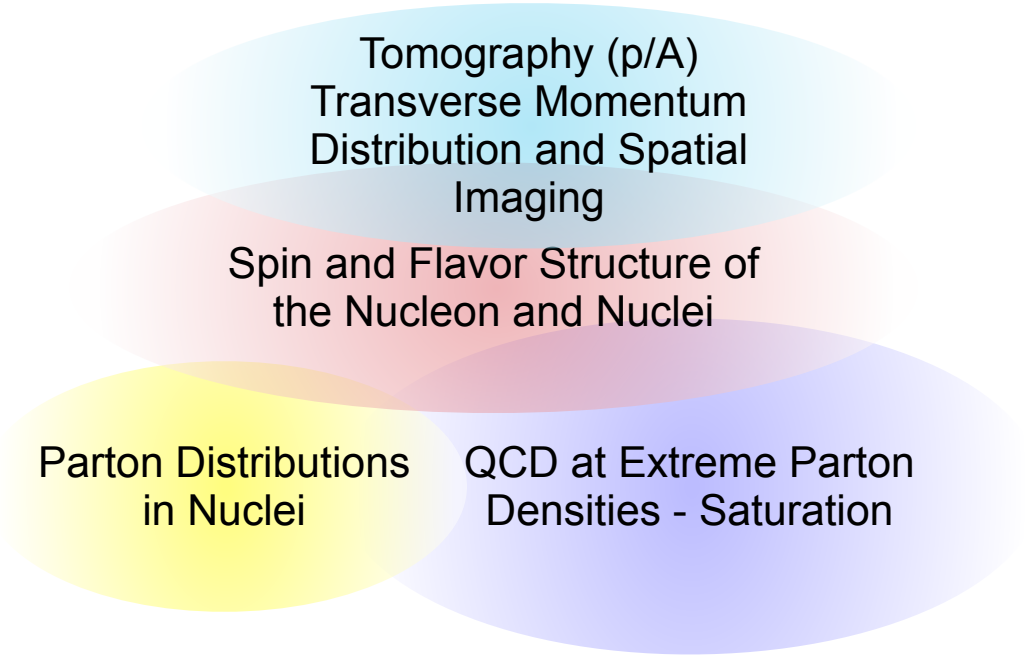

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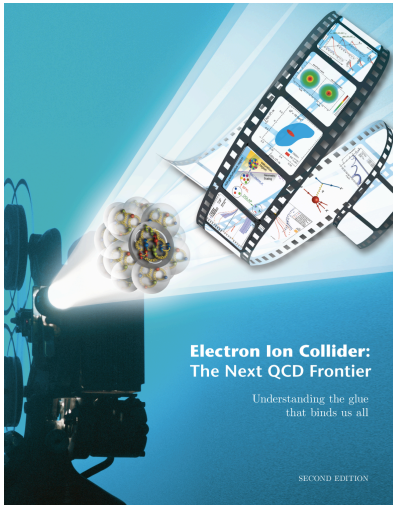

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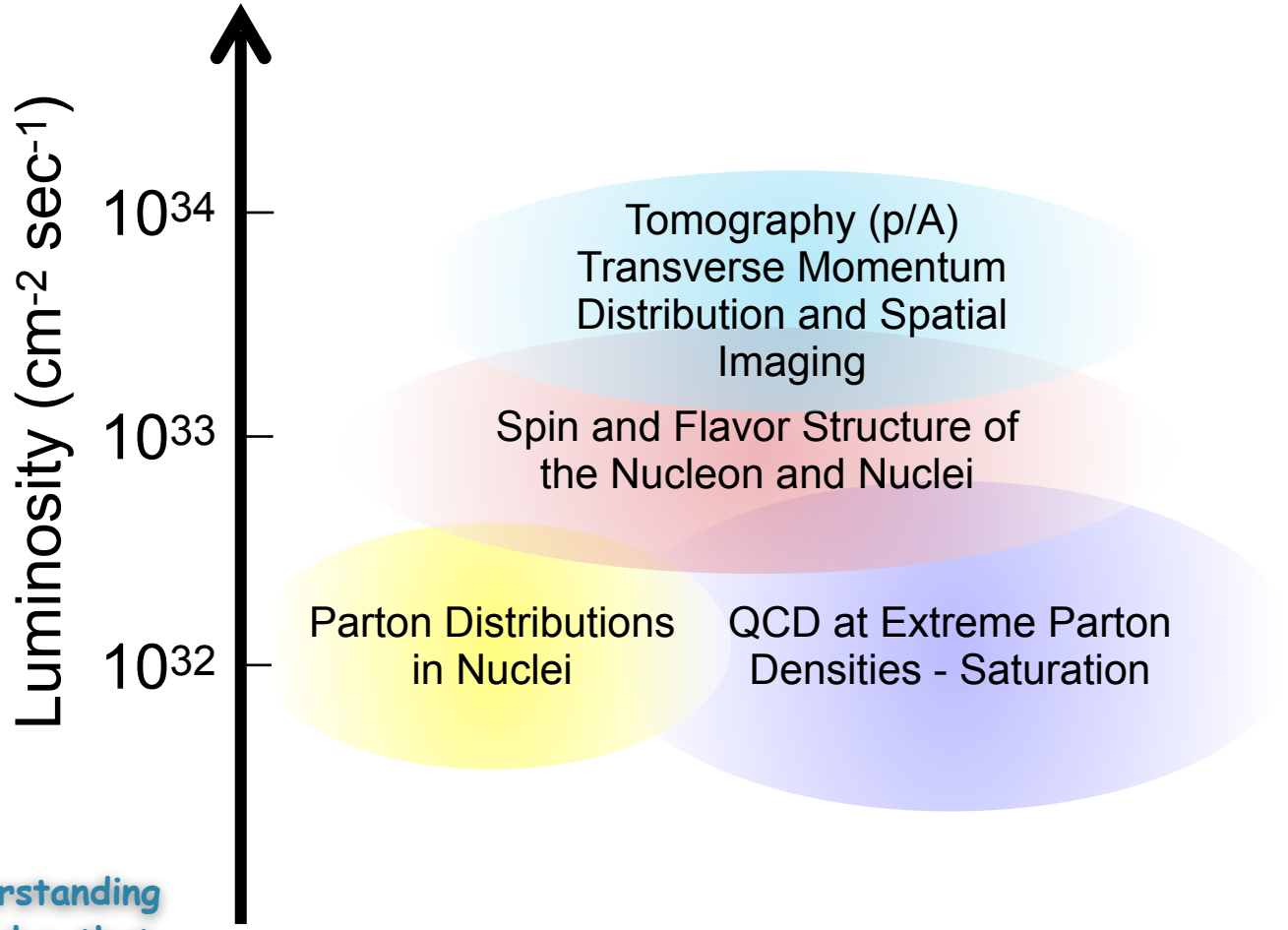

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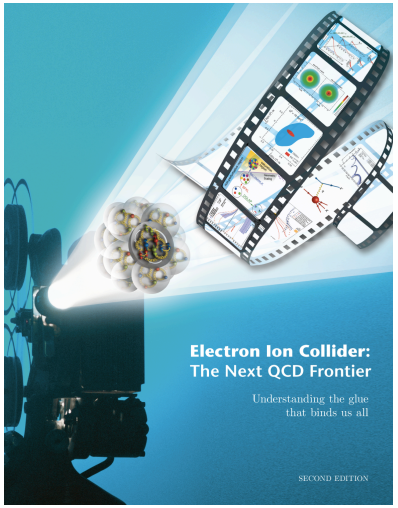

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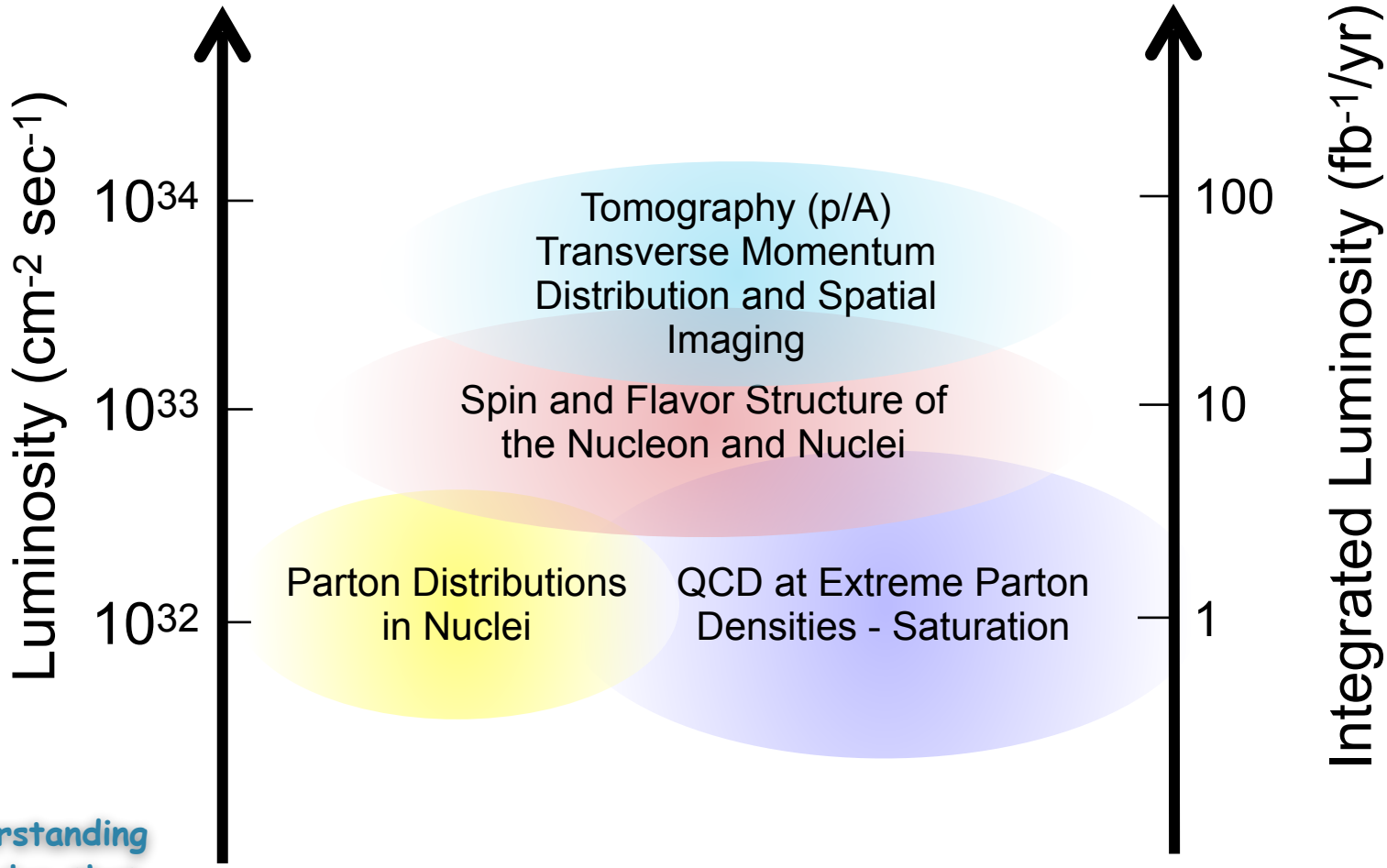

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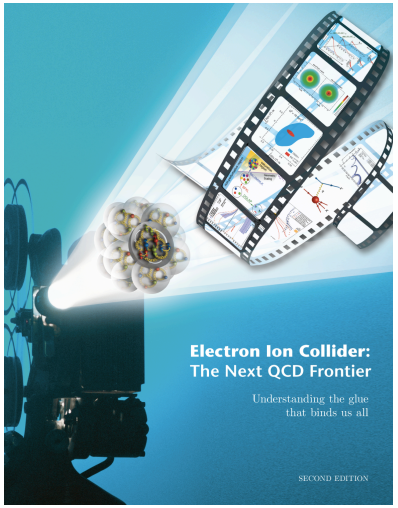

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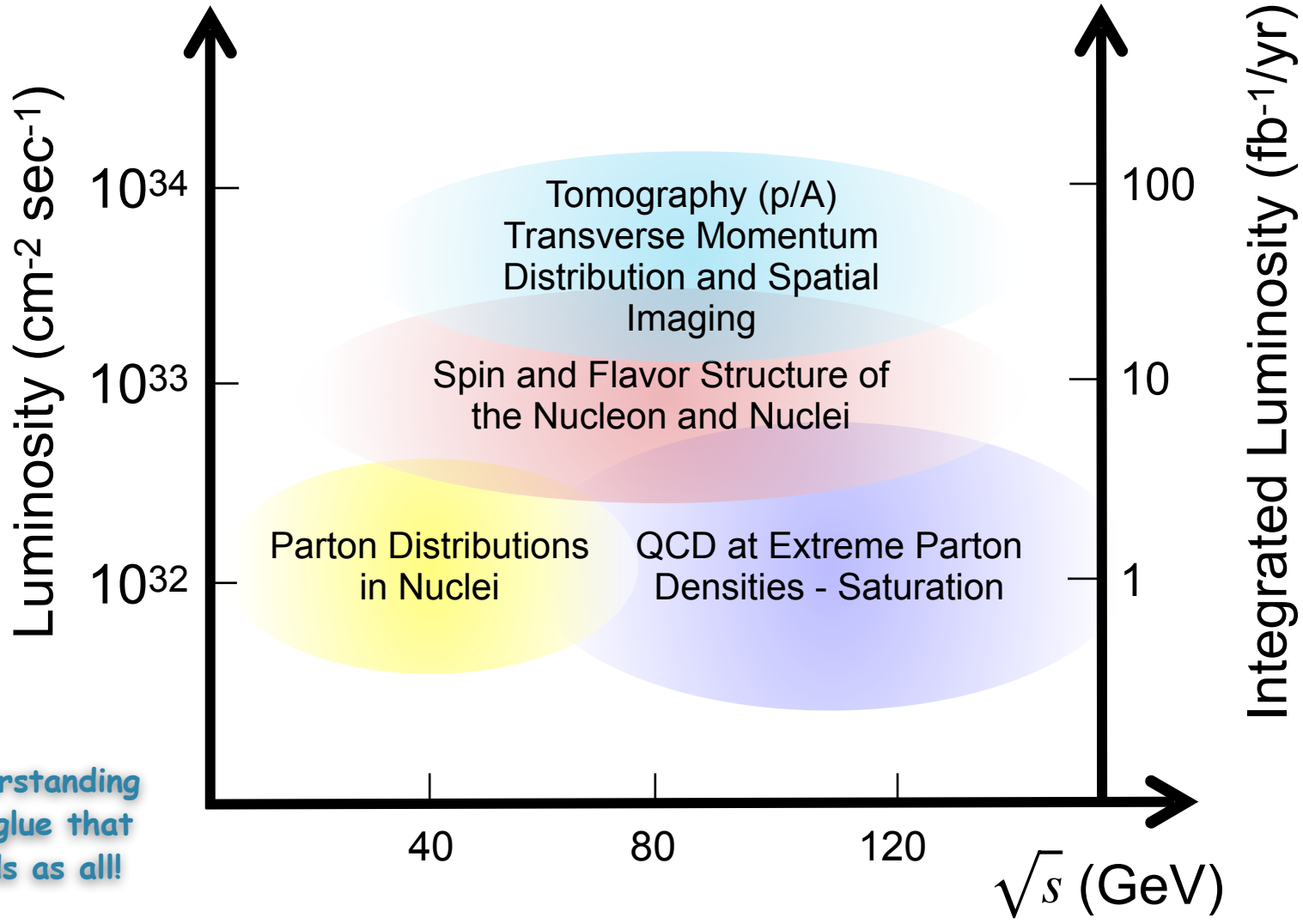

EIC Project Development

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- Requirements

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    - High luminosity: 10^{33}cm^{-2}s^{-1} - 10^{34}cm^{-2}s^{-1}
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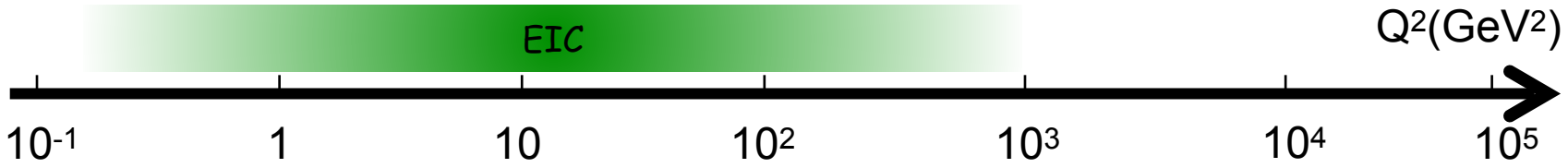

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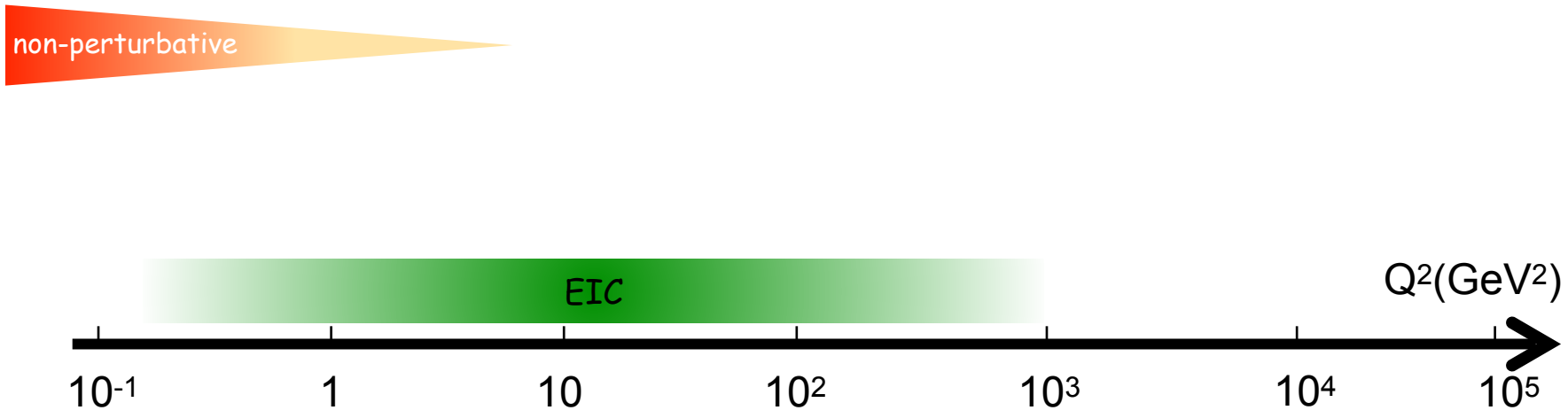

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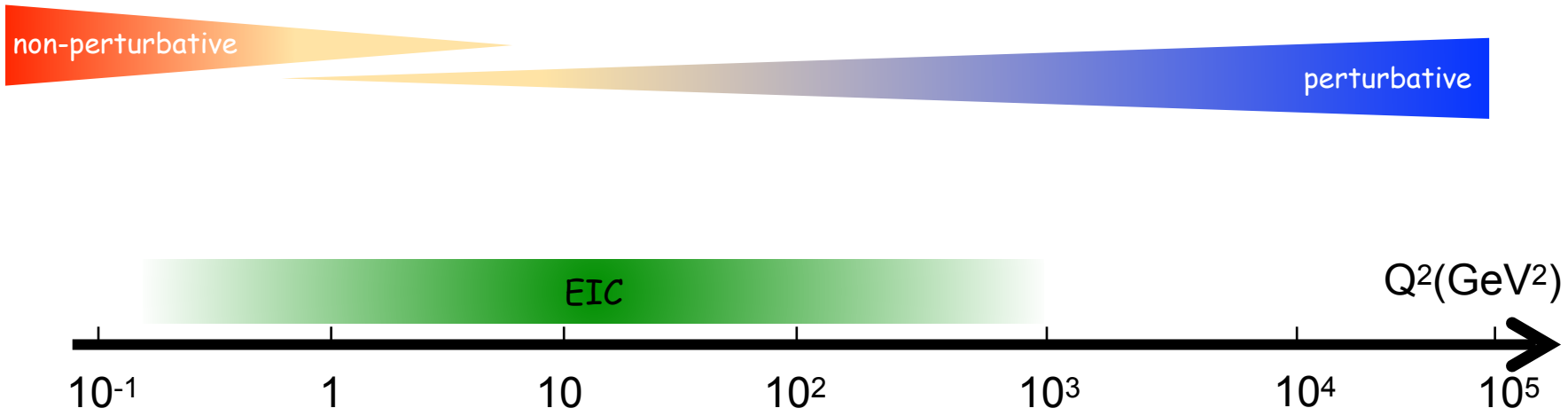

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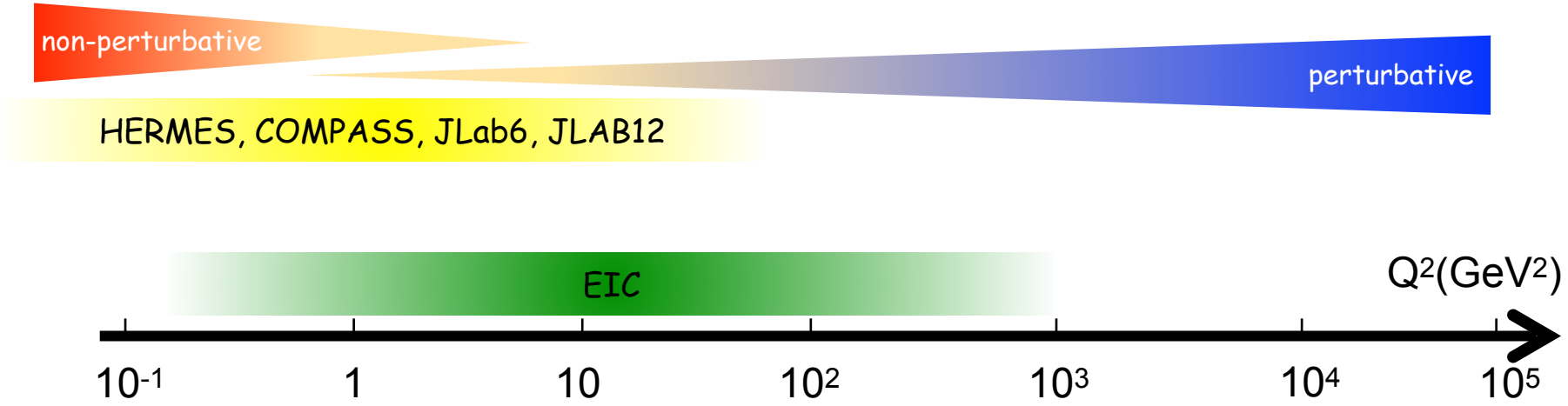

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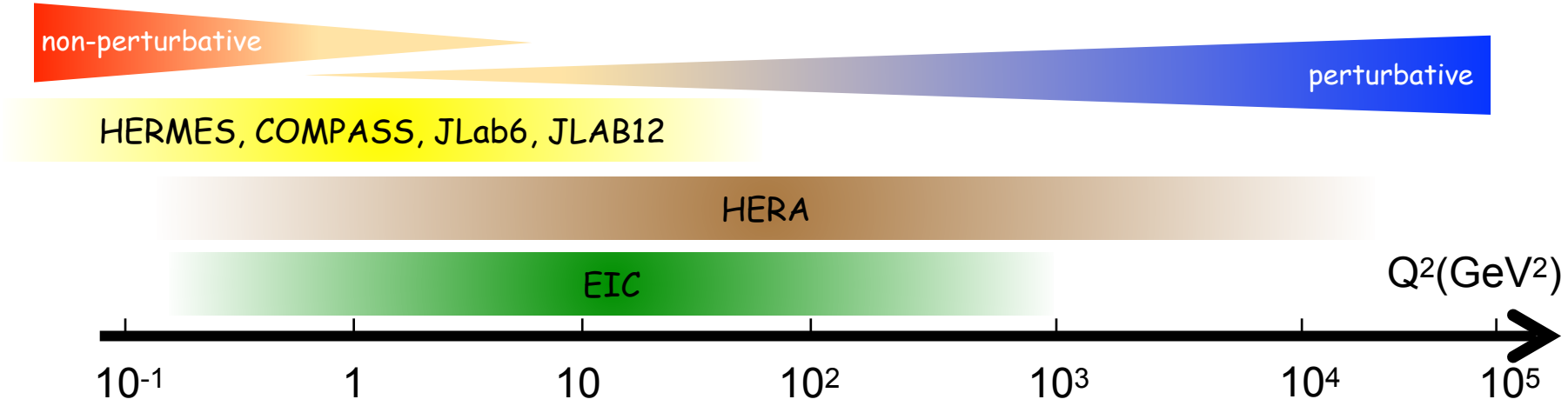

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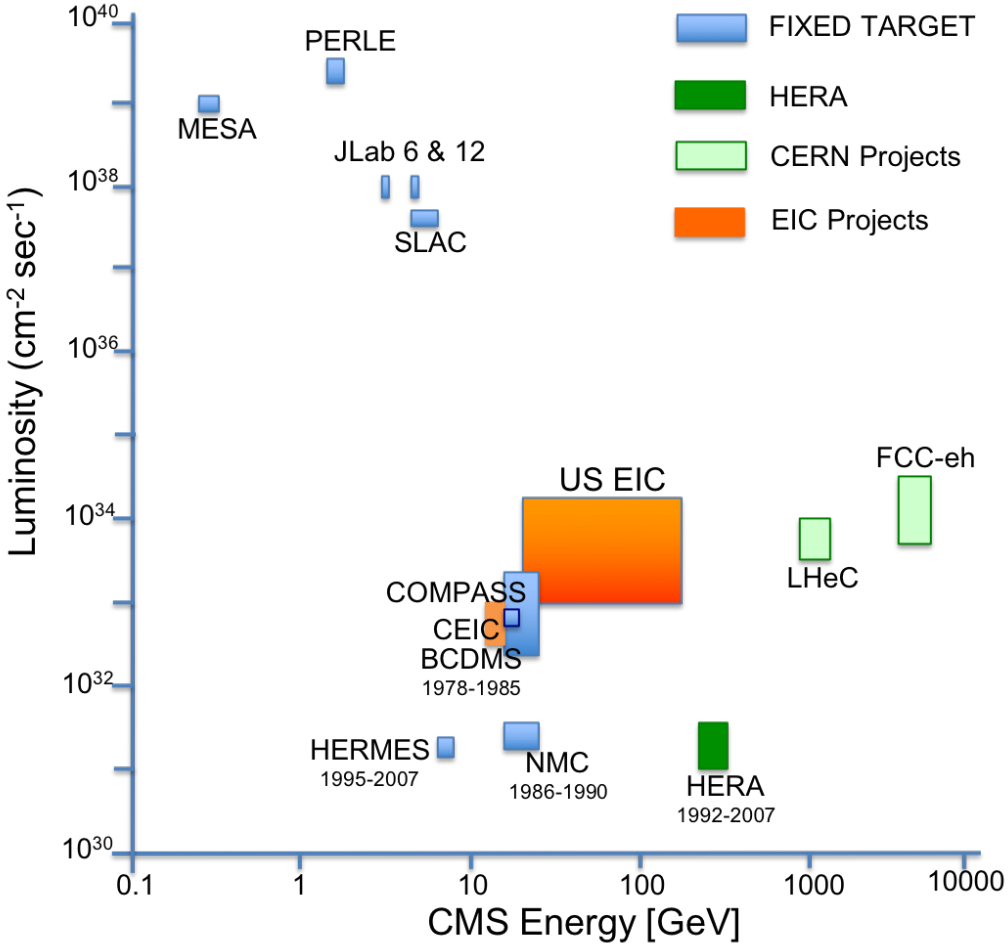

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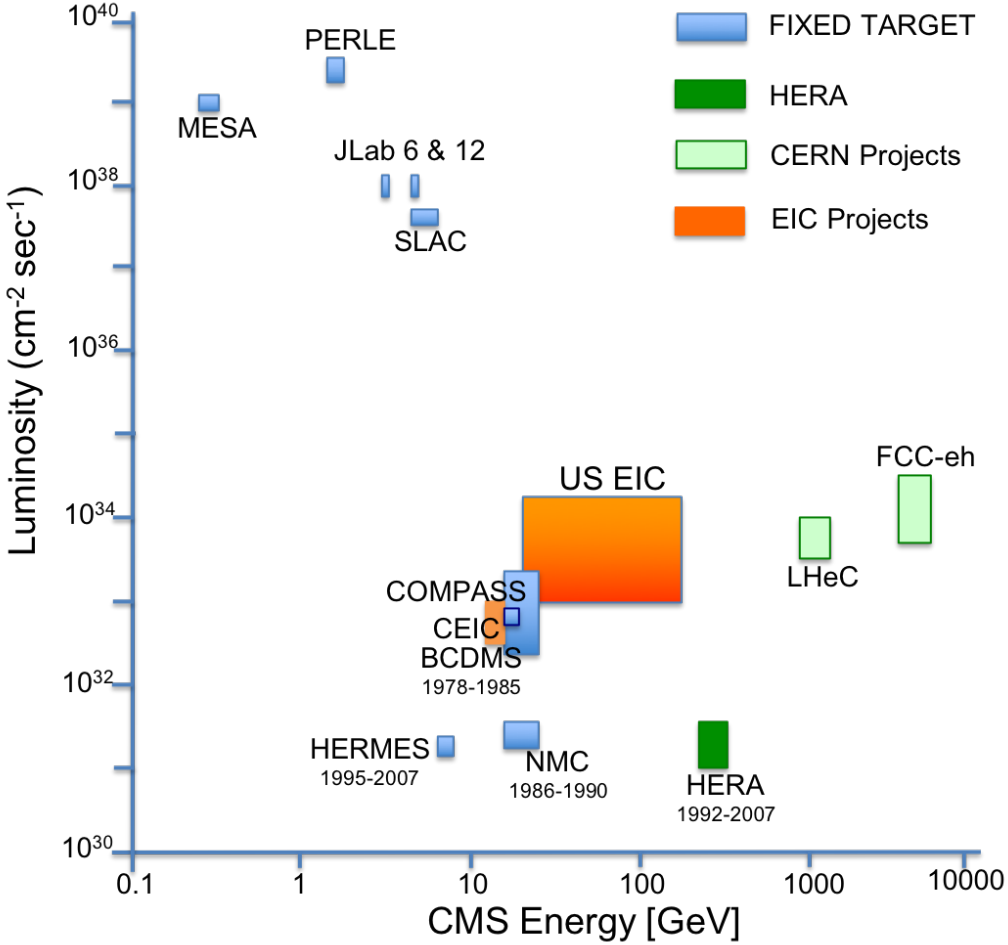

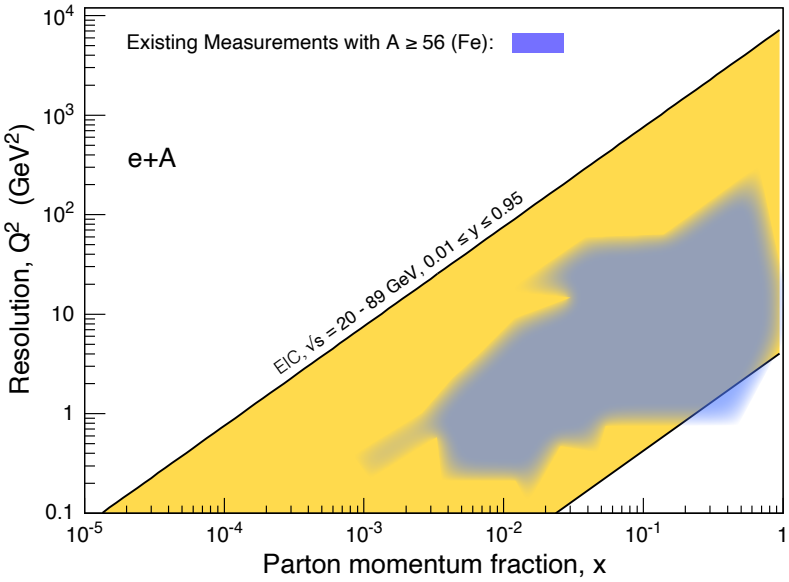

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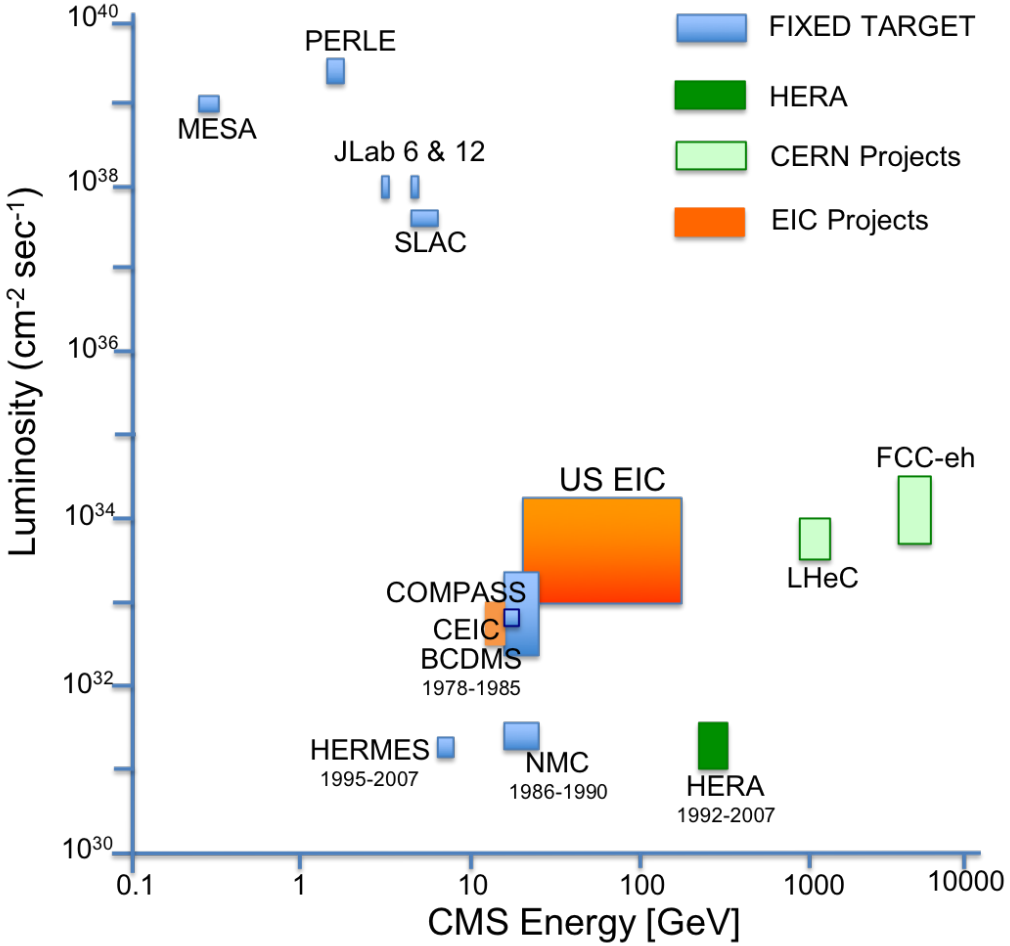

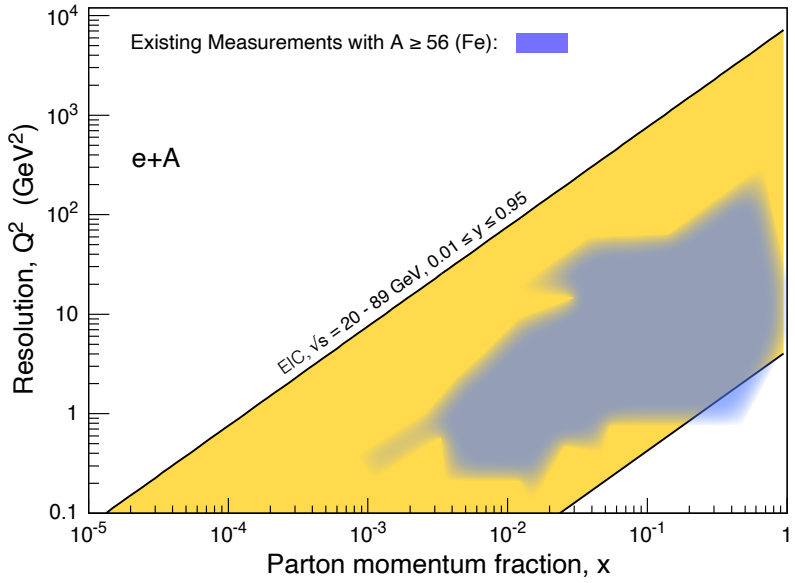

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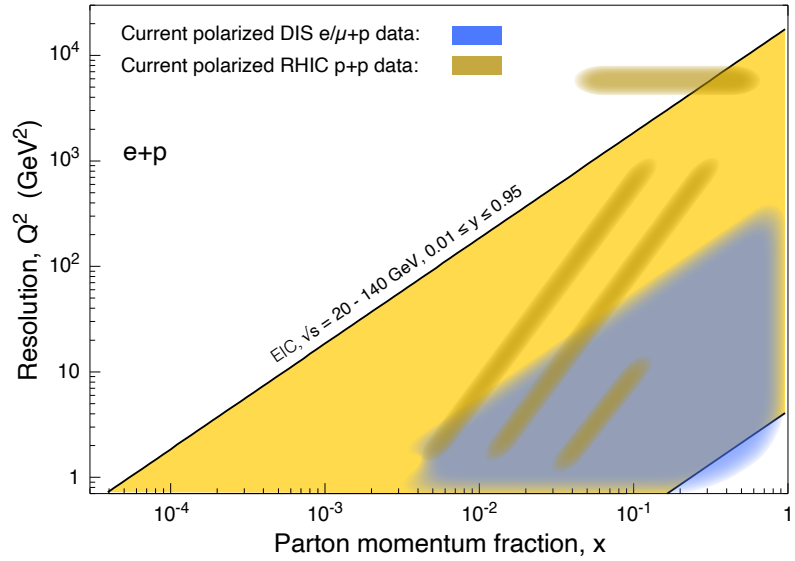

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- Critical steps over the last couple of years
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    - INT Workshop: 2010
    - WP: 2012, updated in 2014 for LRP

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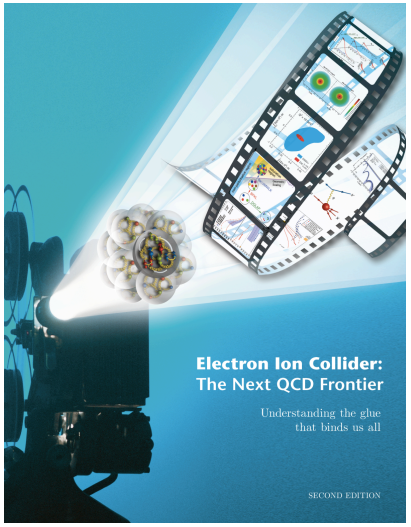

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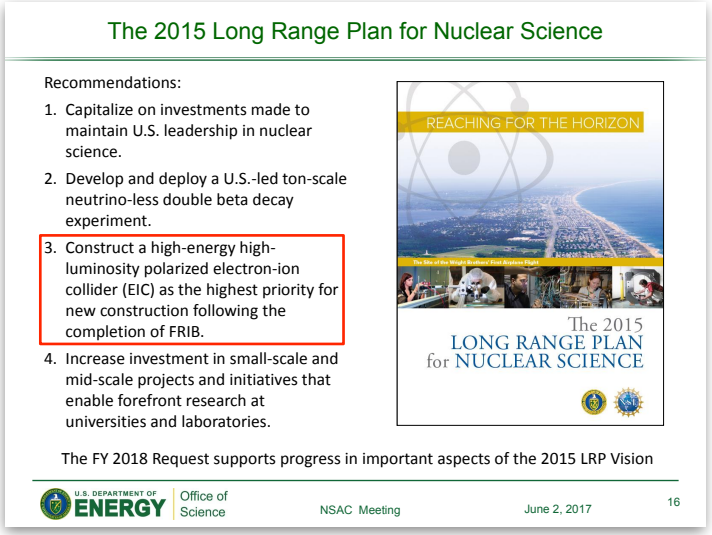

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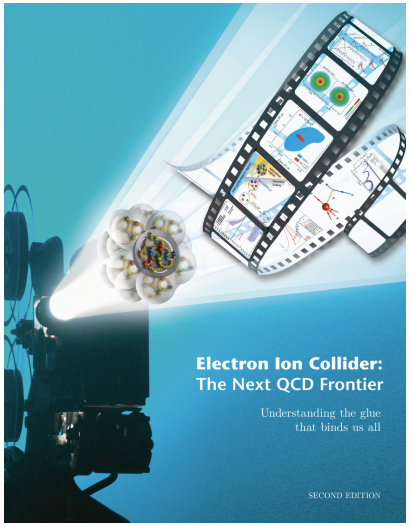

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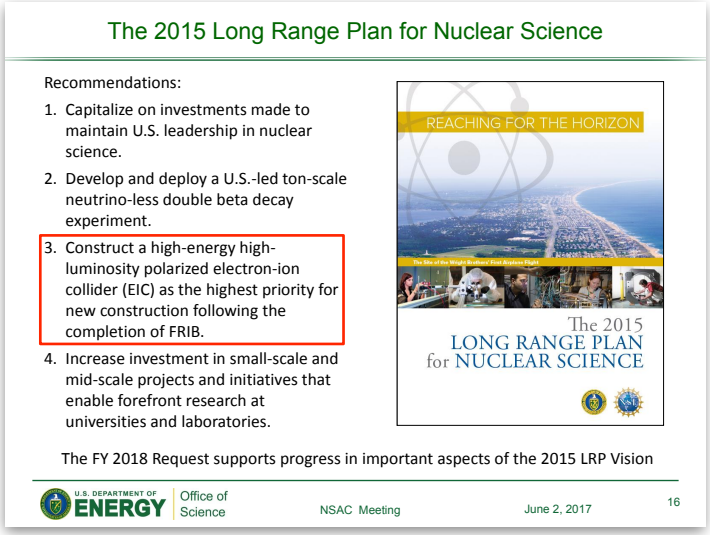

  - Request to review EIC Science Case by National Academy of Sciences, Engineering, and Medicine (NAS)

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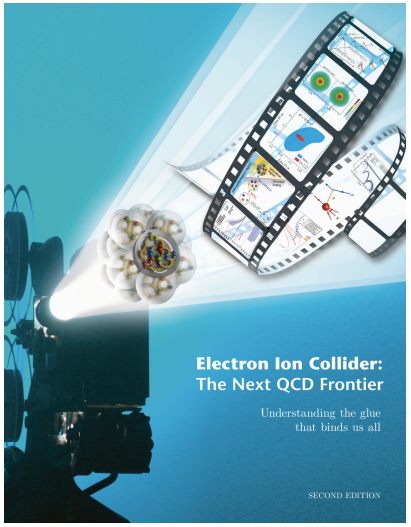

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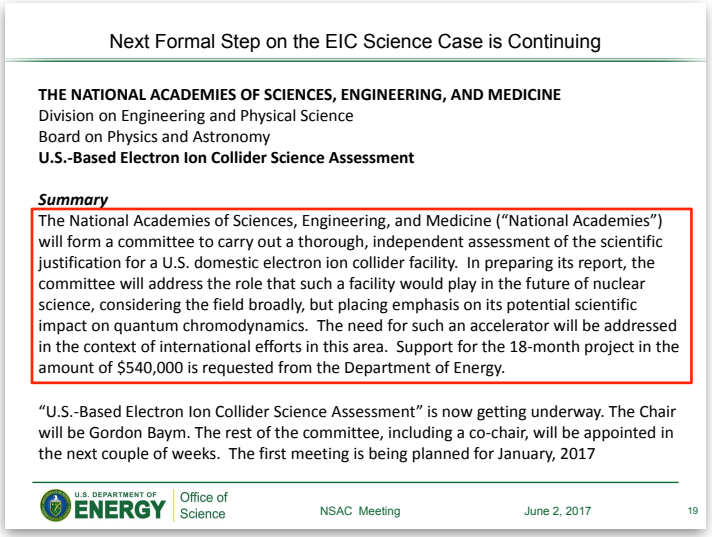

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- Slides from Webinar: https://www.nap.edu/resource/25171/eic-public-briefing-slides.pdf

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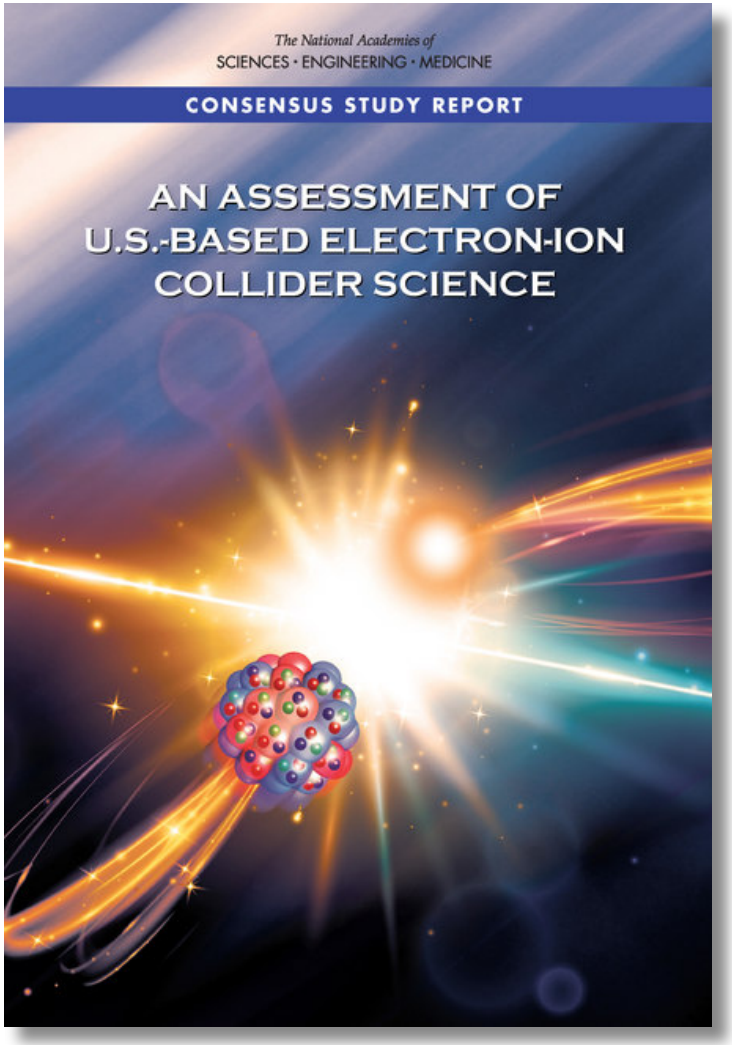
- Slides from Webinar: https://www.nap.edu/resource/25171/eic-public-briefing-slides.pdf
- Glowing" report on a US-based EIC facility!

EIC Project Development

- NAS Webinar and NAS report release: 07/24/2018

https://www.nap.edu/catalog/25171/an-assessment-of-us-based-electron-ion-collider-science

Download pdf-file of final report!



- Webinar on Tuesday, July 24, 2018 - Public presentation and report release
- Gordon Baym (Co-chair): Webinar presentation

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EIC Project Development

- Site Selection and award of DOE Critical Decisions 0 (CD-0) and 1 (CD-1)

https://www.energy.gov/articles/us-department-energy-selects-brookhaven-national-laboratory-host-major-new-nuclear-physics

Department of Energy

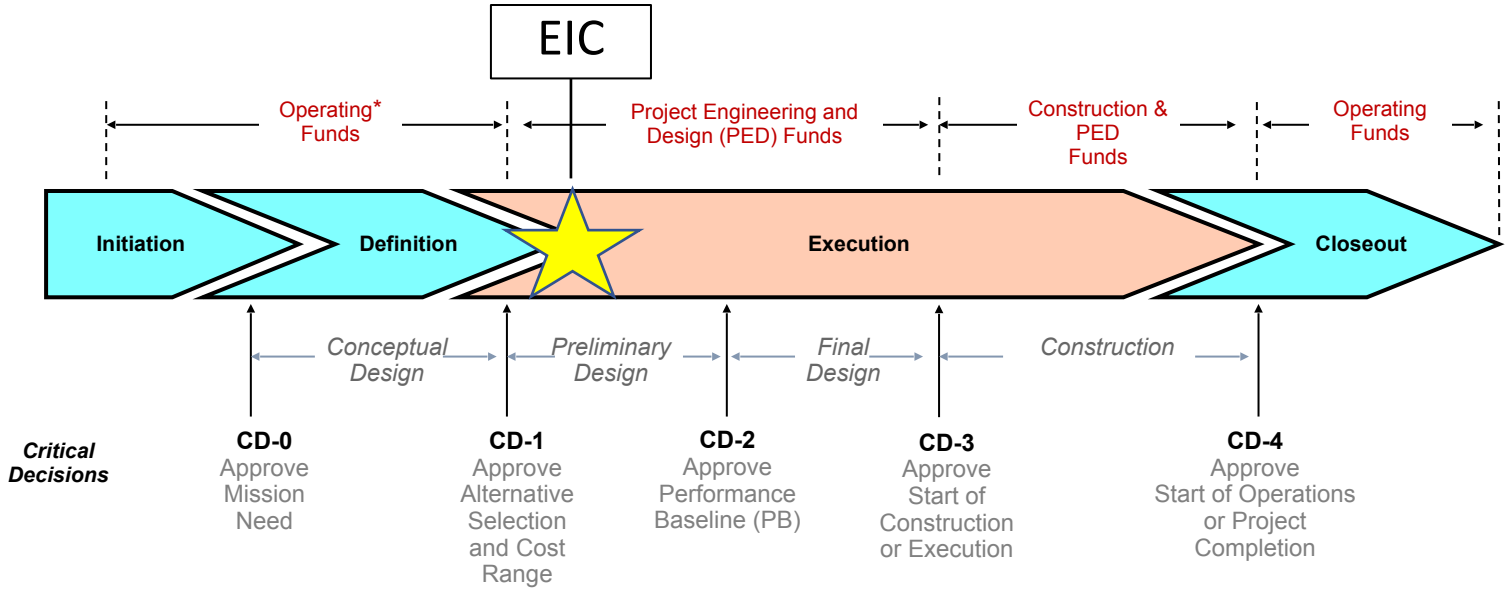
U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

WASHINGTON, D.C. – Today, the U.S. Department of Energy (DOE) announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility. The Electron Ion Collider (EIC), to be designed and constructed over ten years at an estimated cost between $1.6 and $2.6 billion, will smash electrons into protons and heavier atomic nuclei in an effort to penetrate the mysteries of the "strong force" that binds the atomic nucleus together.

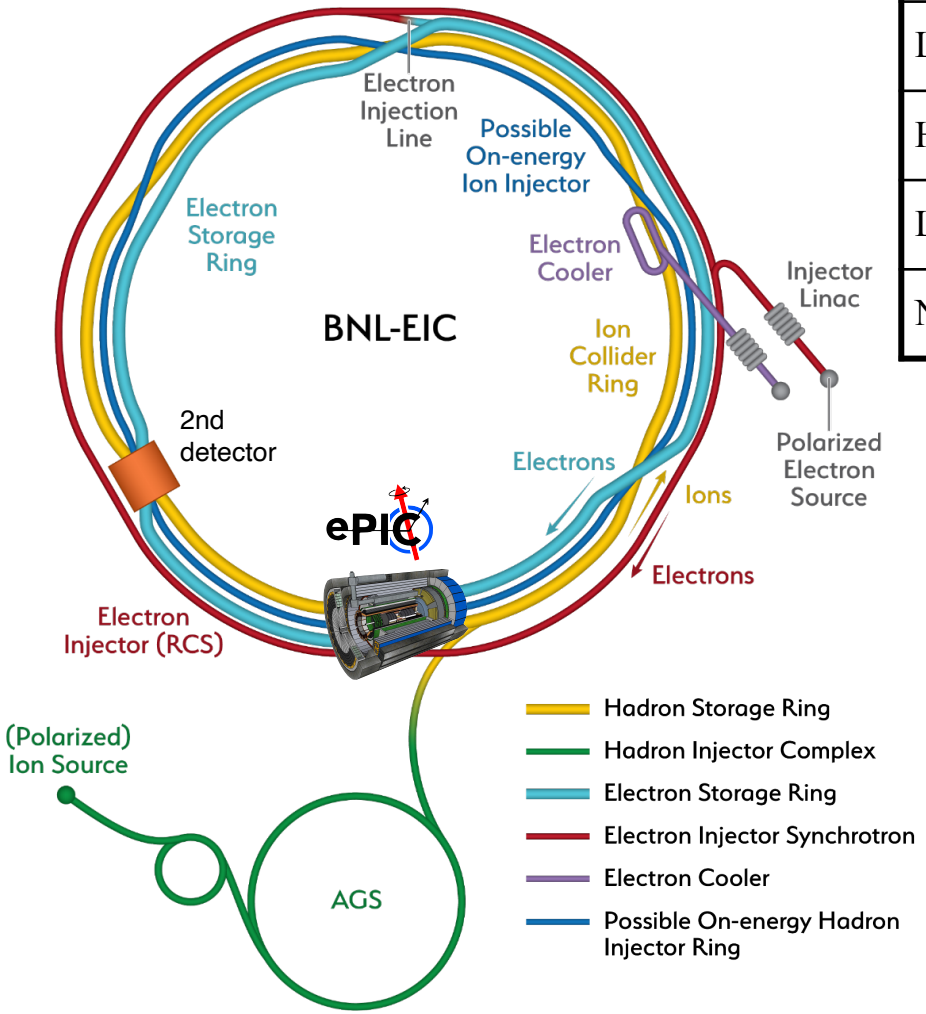
Critical Decision-0 (CD-0), "Approve Mission Need", approved for the EIC on December 19, 2019.

Critical Decision-1 (CD-1), "Approve Alternative Selection and Cost Range", was awarded for the EIC on June 29, 2021.

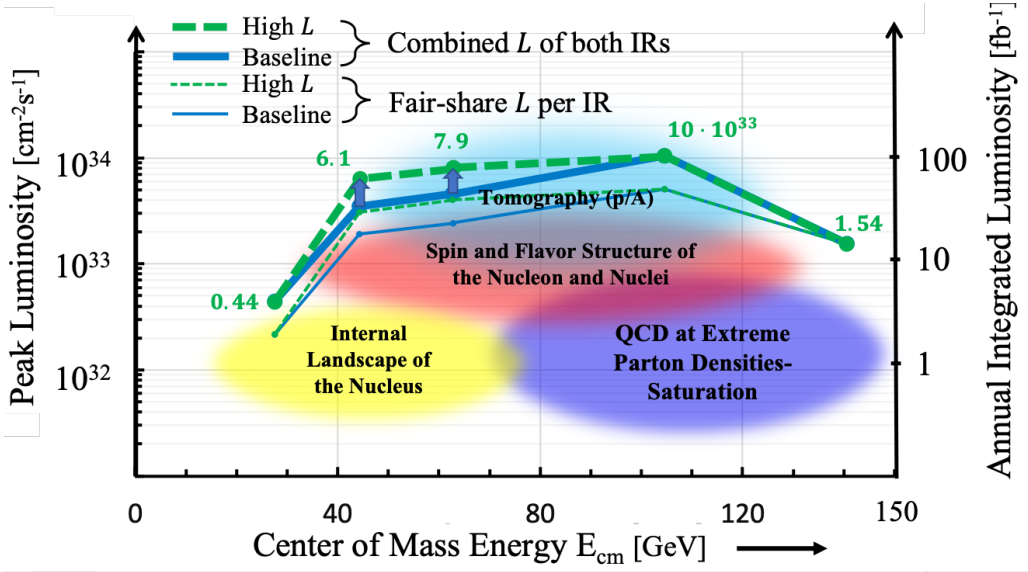


EIC Project Development

EIC accelerator design



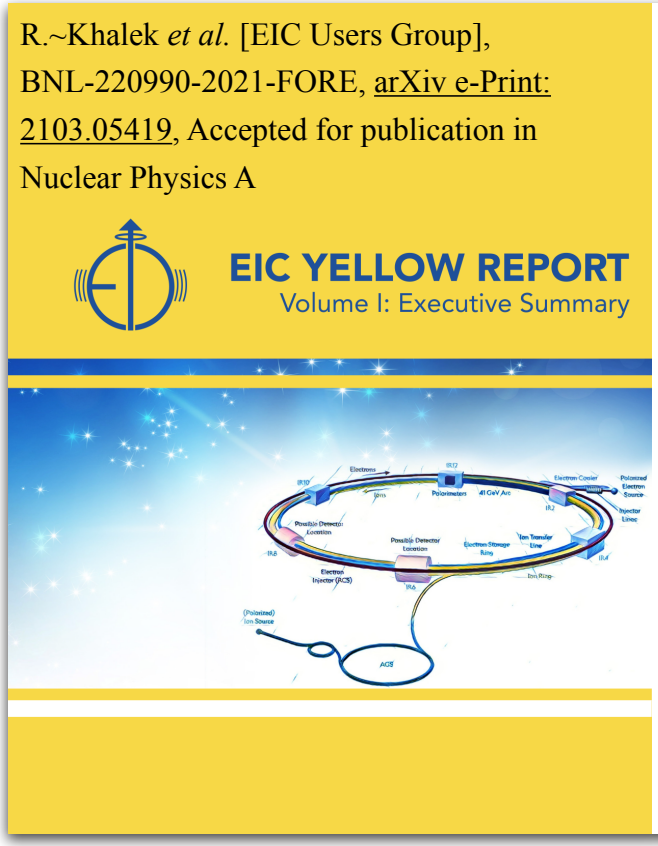
Center of Mass Energies:	20GeV - 140GeV
Luminosity:	10^{33} - 10^{34} $cm^{-2}s^{-1}$ / 10-100fb^{-1} / year
Highly Polarized Beams:	70%
Large Ion Species Range:	p to U
Number of Interaction Regions:	Up to 2!

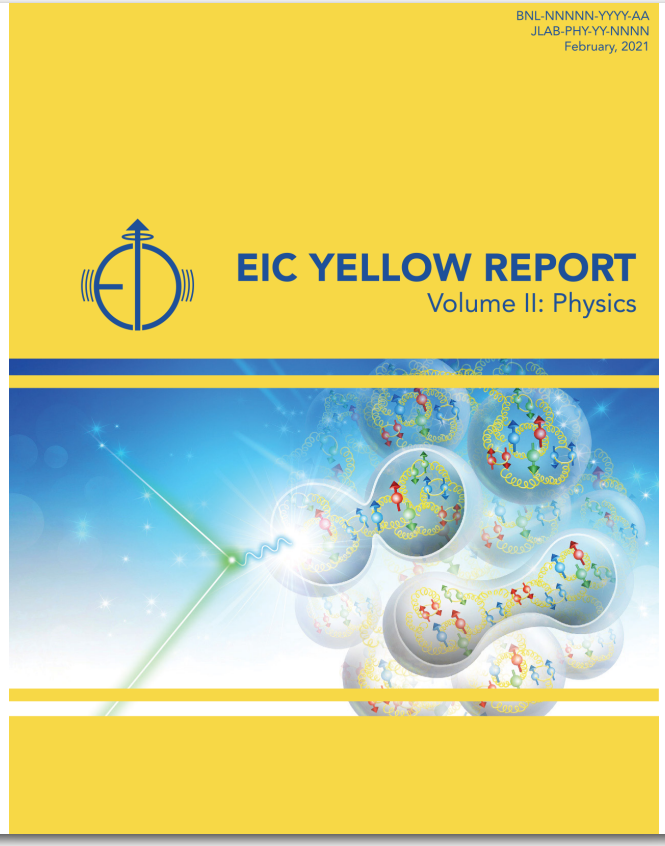


EIC Project Development

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

R.~Khalek *et al.* [EIC Users Group], BNL-220990-2021-FORE, arXiv e-Print: 2103.05419, Accepted for publication in Nuclear Physics A





- ~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

EIC Project Development

- Open Call for Detector Proposals

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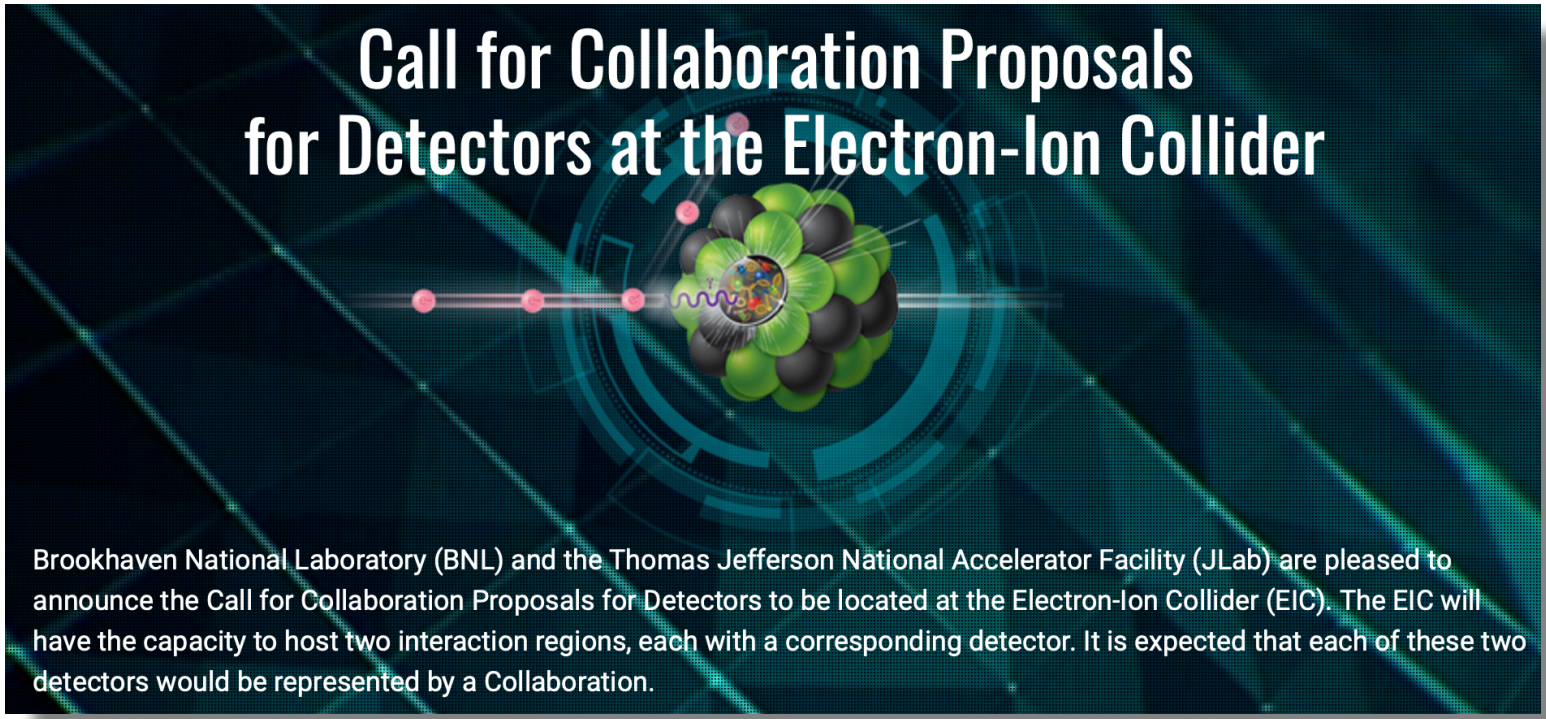

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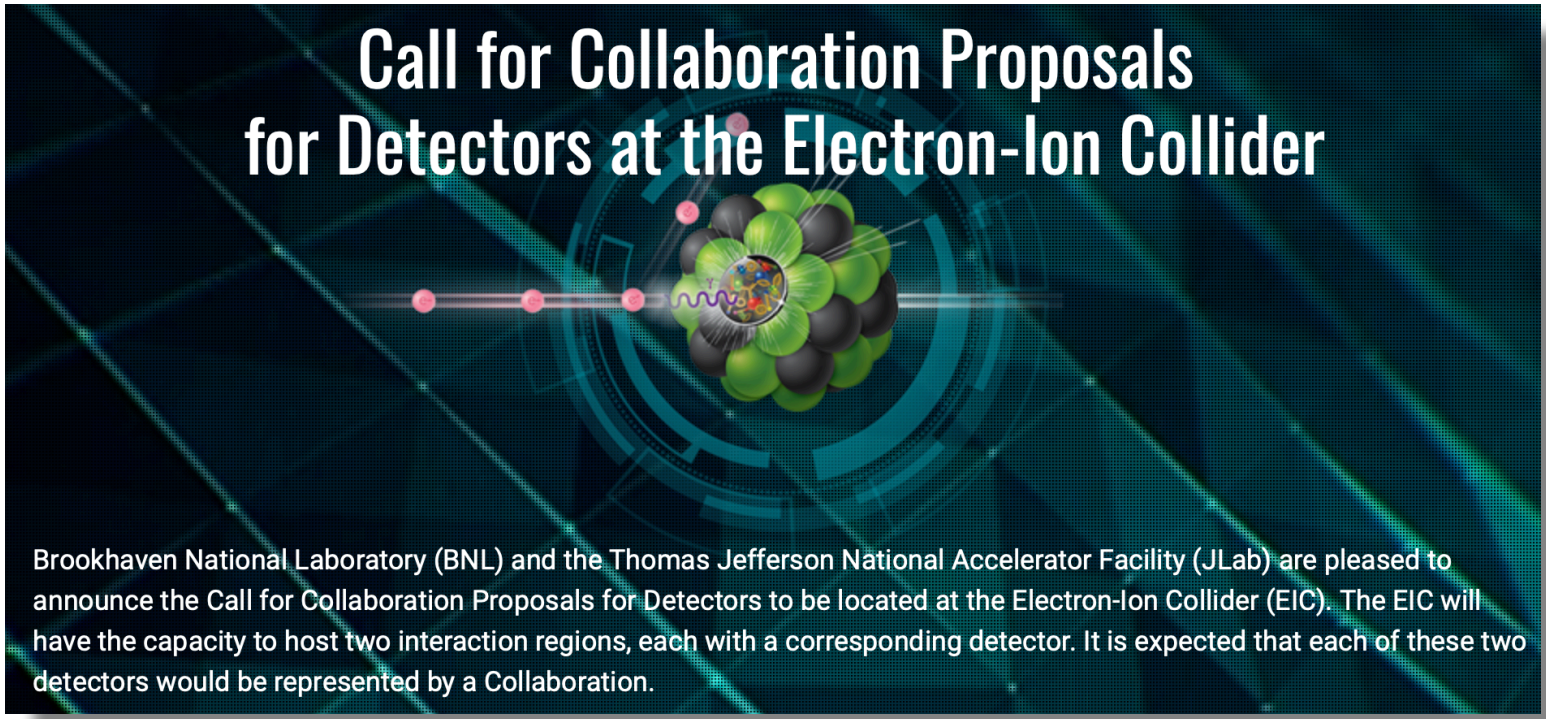

ATHENA: A Totally Hermetic Electron-Nucleus Apparatus

Concept: General purpose detector inspired by the YR studies based on a new central magnet of up to 3T

WWW-page: https://www.athena-eic.org

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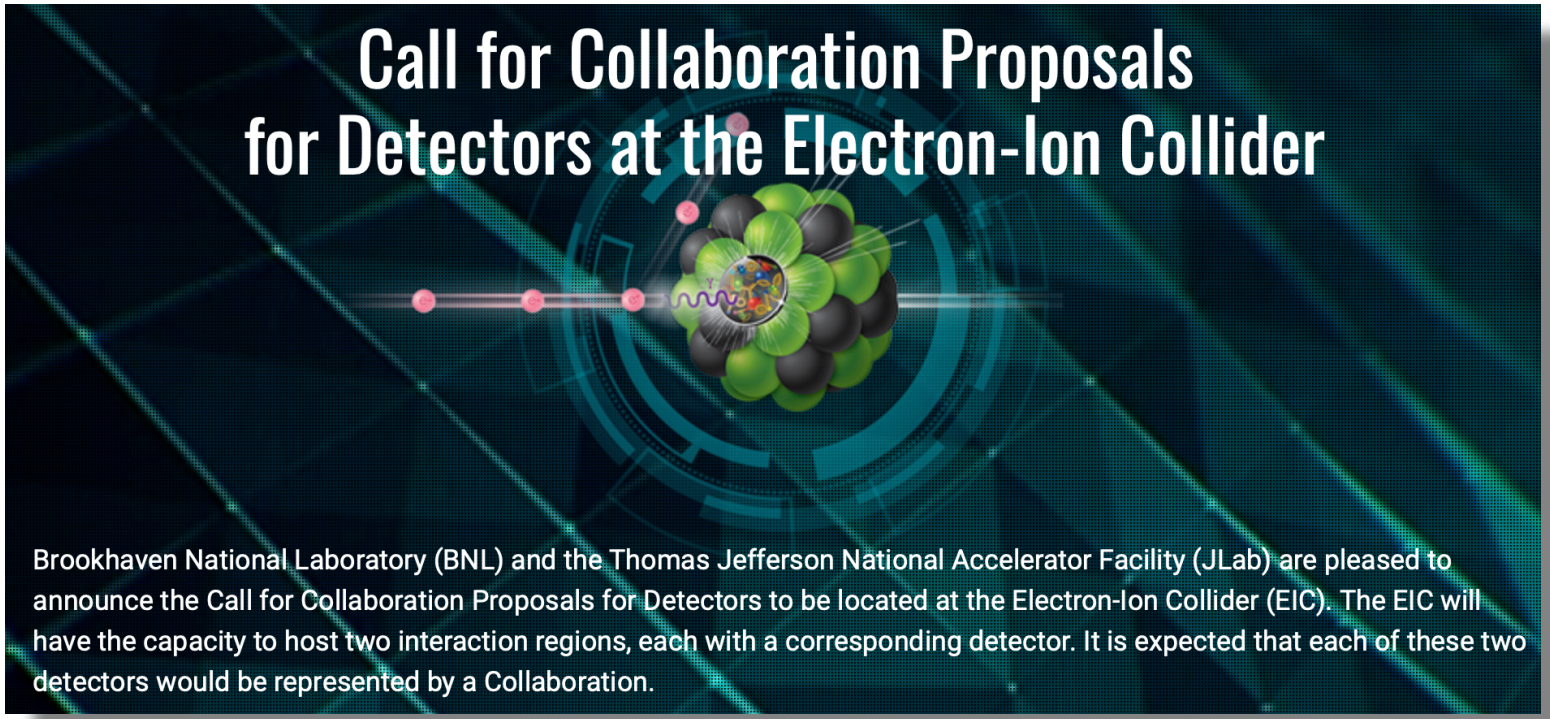

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Concept: Nearly hermetic, general-purpose compact detector, 3T baseline
WWW-page: https://userweb.jlab.org/~hyde/EIC-CORE/

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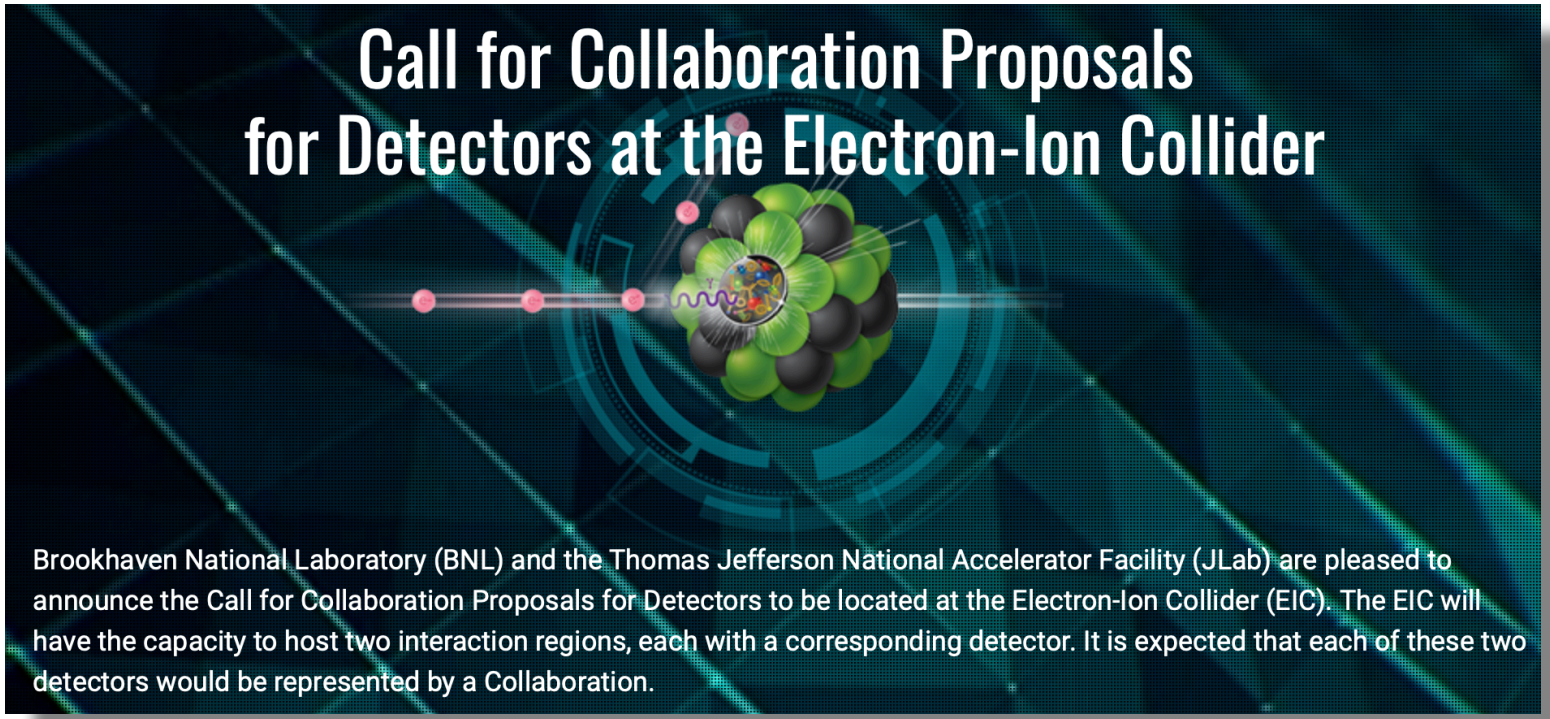

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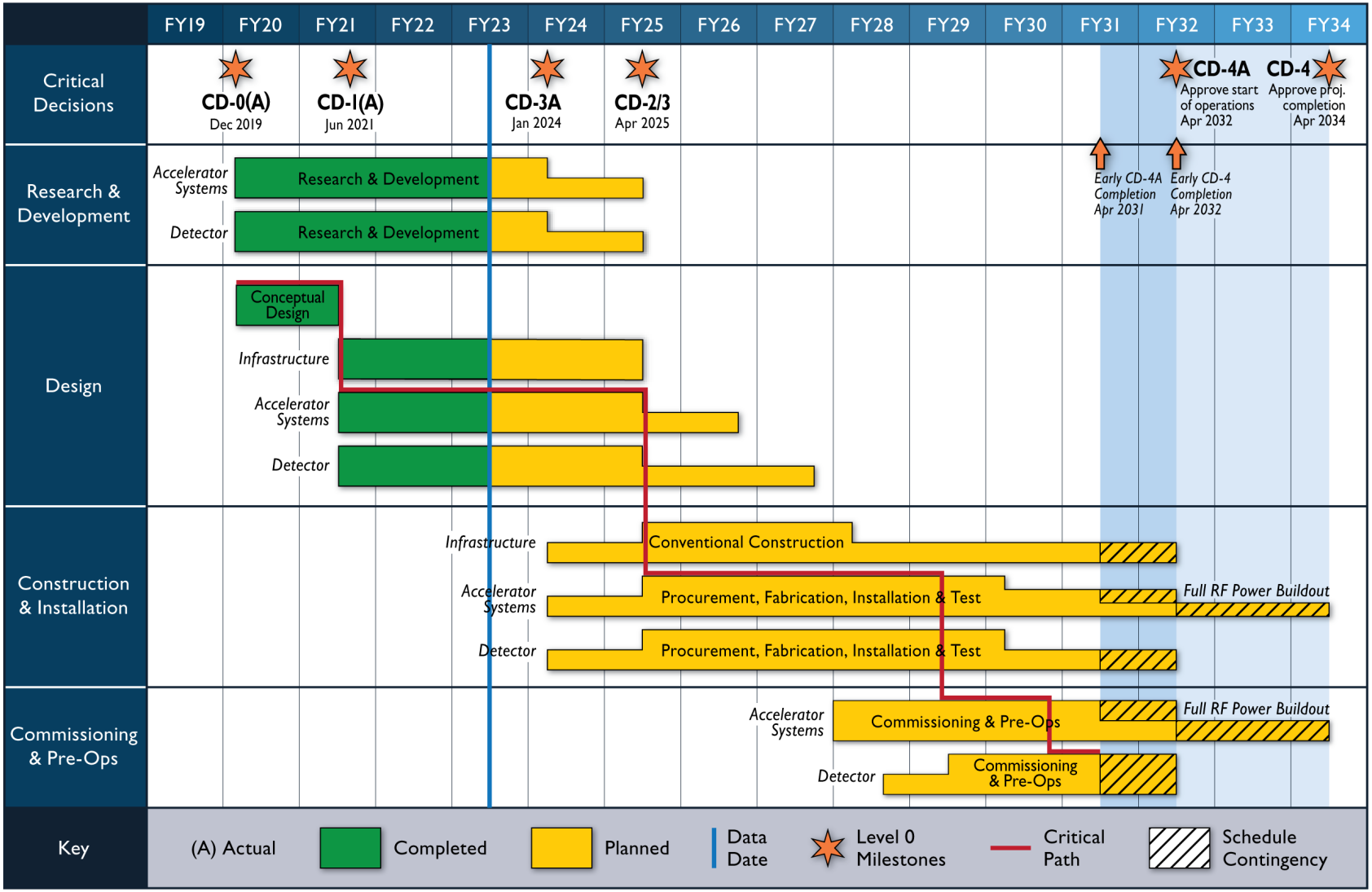
ECCE: EIC Comprehensive Chromodynamics Experiment
Concept: General purpose detector based on 1.5T BaBar magnet
WWW-page: https://www.ecce-eic.org

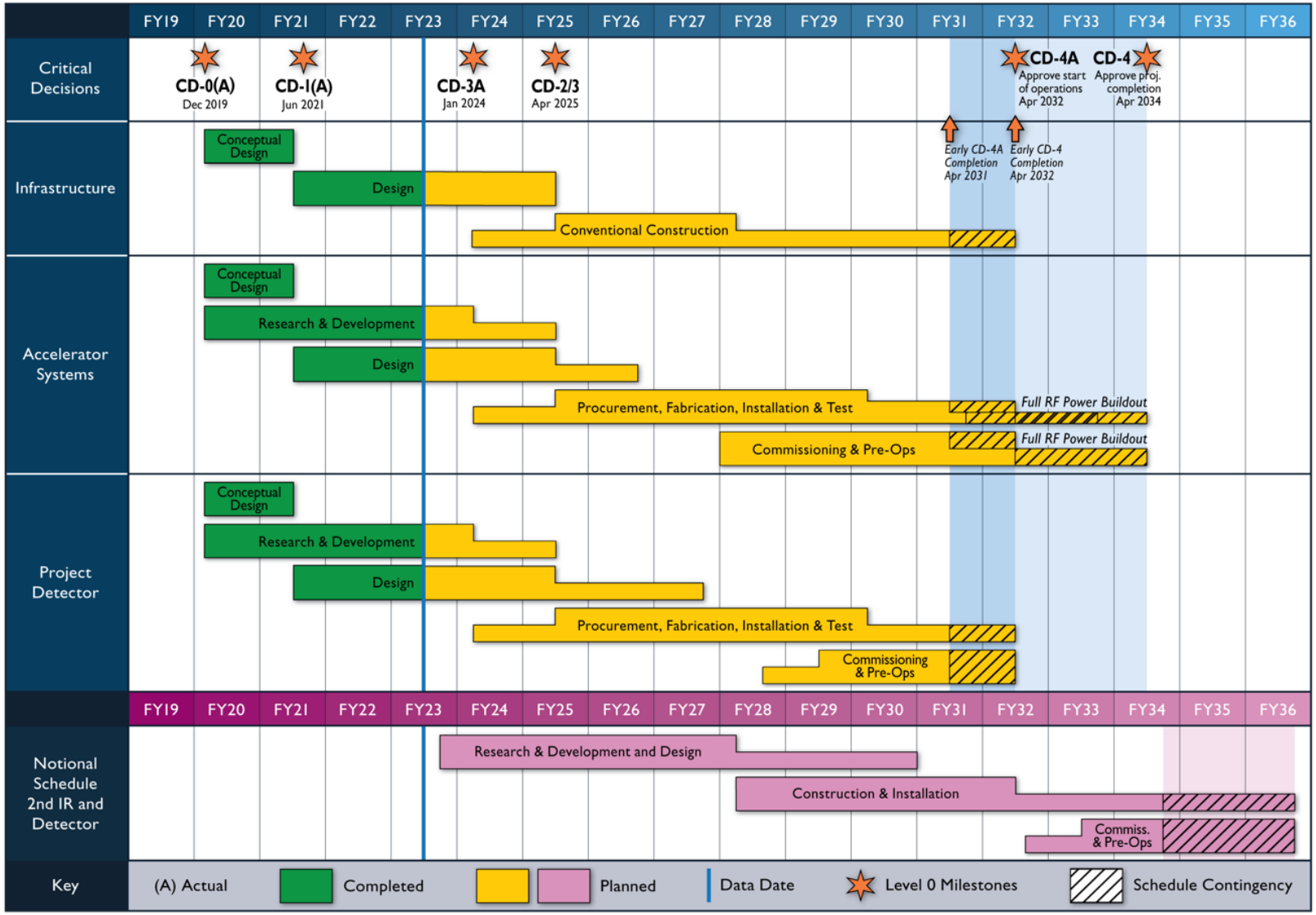
EIC Project Development

- Schedule: EIC Project Detector at IP 6 / ePIC



EIC Project Development

- Reference Schedule for 2nd IR and Detector



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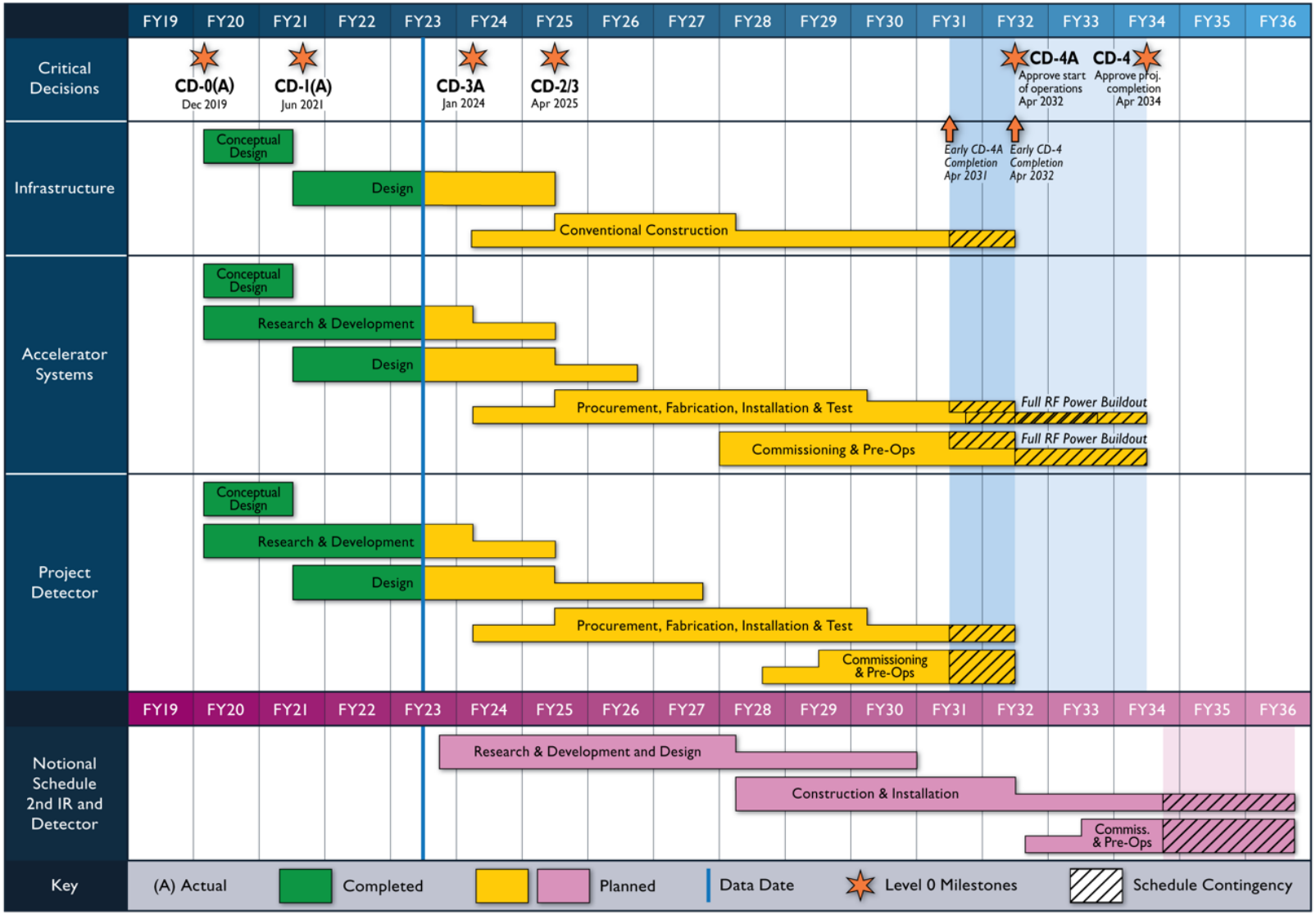
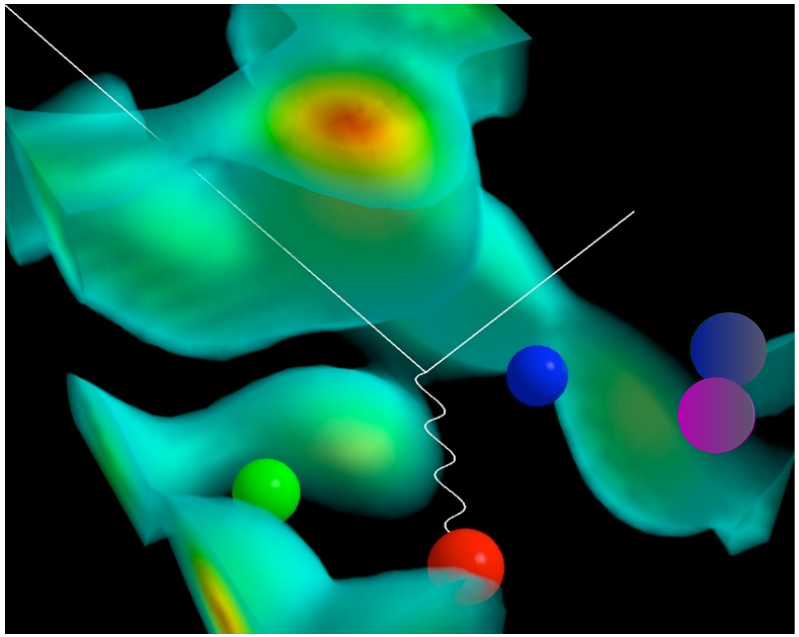


Talk by Abhay Deshpande / TR 03:00 PM: Case for the 2nd detector

Talk by Pawel Nadel-Turonski / TR 03:30 PM: Designing the 2nd IR and detector

ePIC Detector Design Philosophy

- DIS - Kinematics



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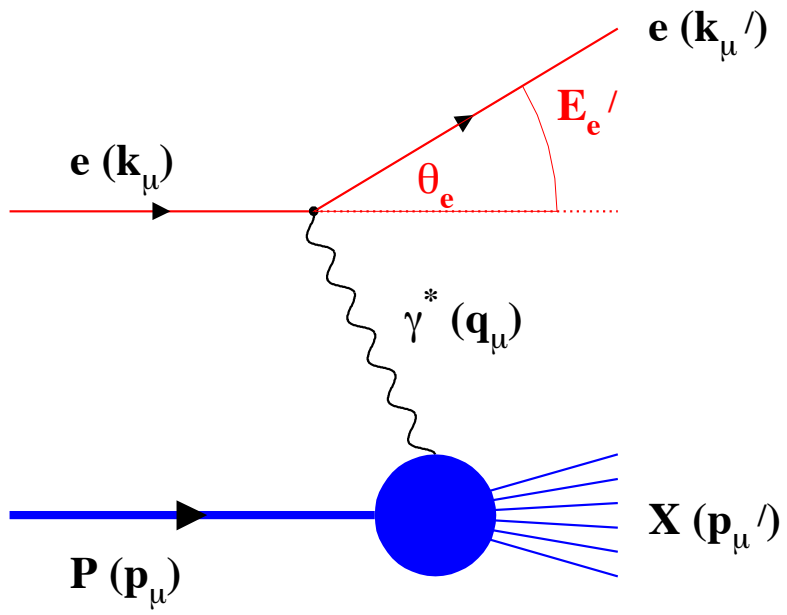

ePIC Detector Design Philosophy

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$$k = \begin{pmatrix} E_e \\ 0 \\ 0 \\ -E_e \end{pmatrix}$$

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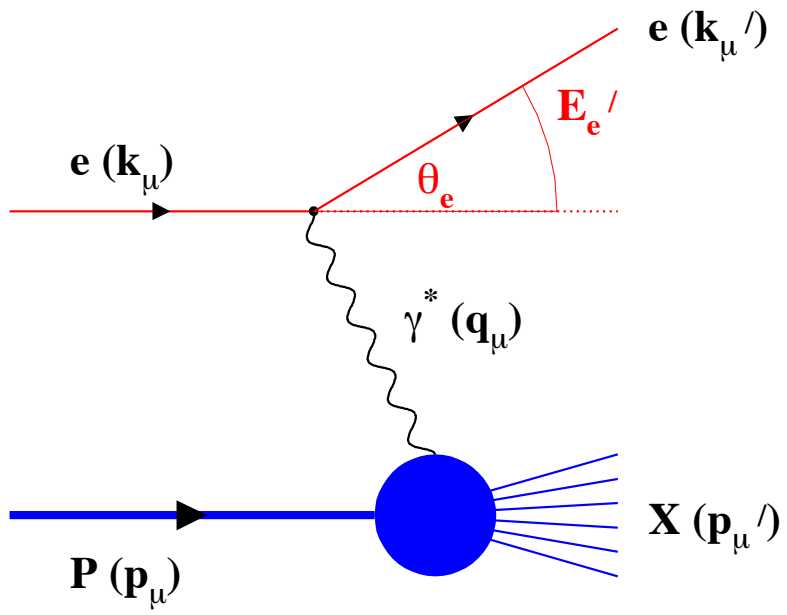

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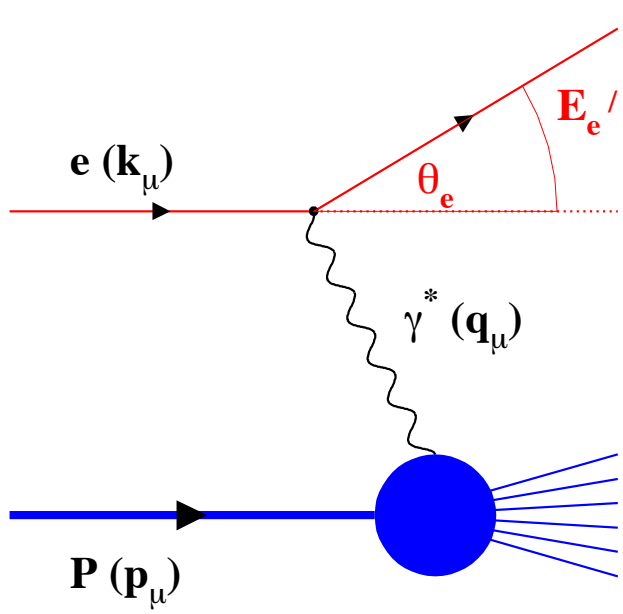

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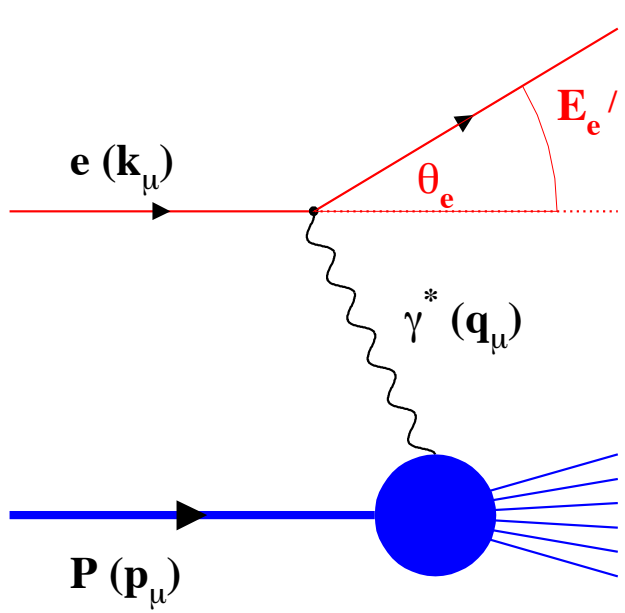

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$Q^2 = -(k - k')^2 = -q^2$	Measure of resolution power
$x = \dfrac{Q^2}{2(p \cdot q)}$	Measure of momentum fraction by struck quark
$y = \dfrac{p \cdot q}{p \cdot k}$	Measure of inelasticity

ePIC Detector Design Philosophy

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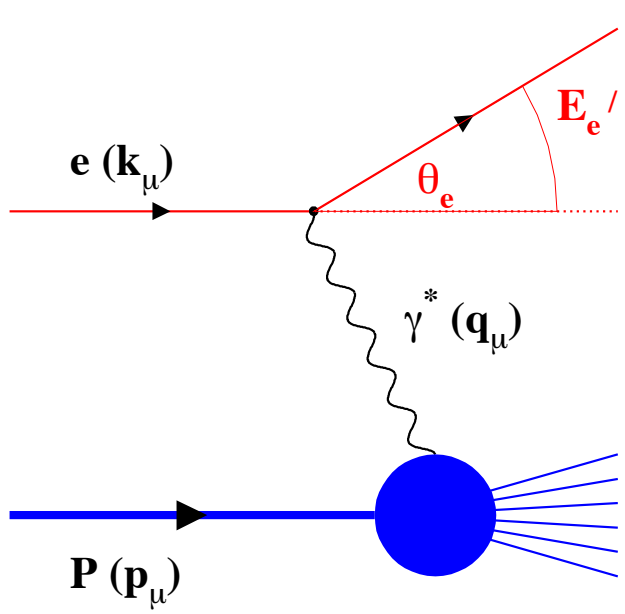

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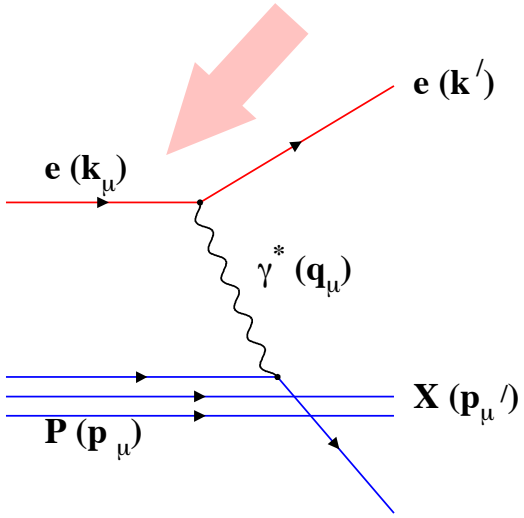

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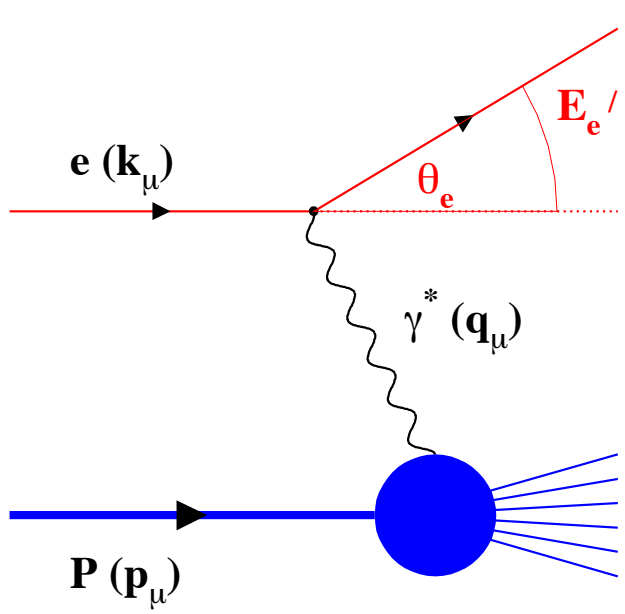

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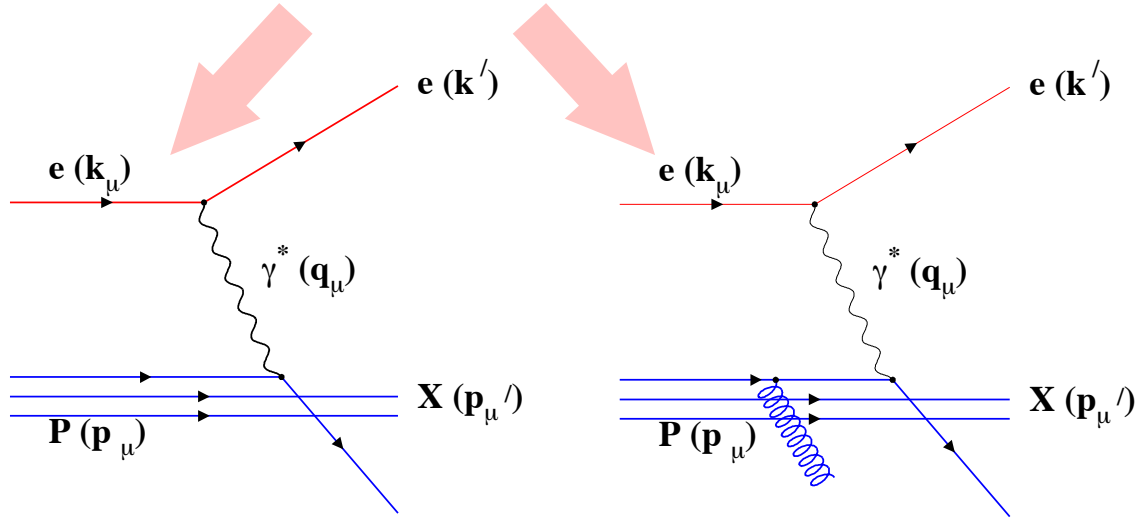

ePIC Detector Design Philosophy

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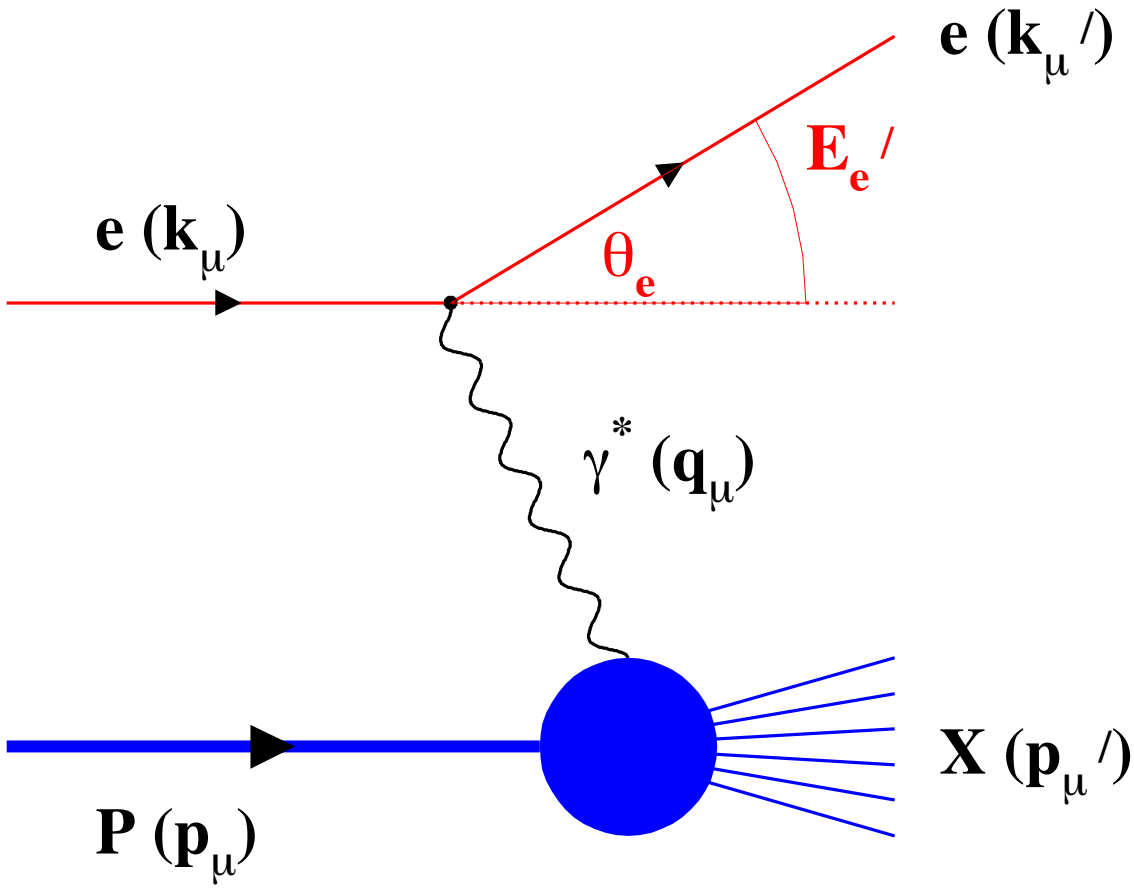
- Importance of EIC / Kinematics found On every-day products…



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$E_e = 10\,\mathrm{GeV}$ →

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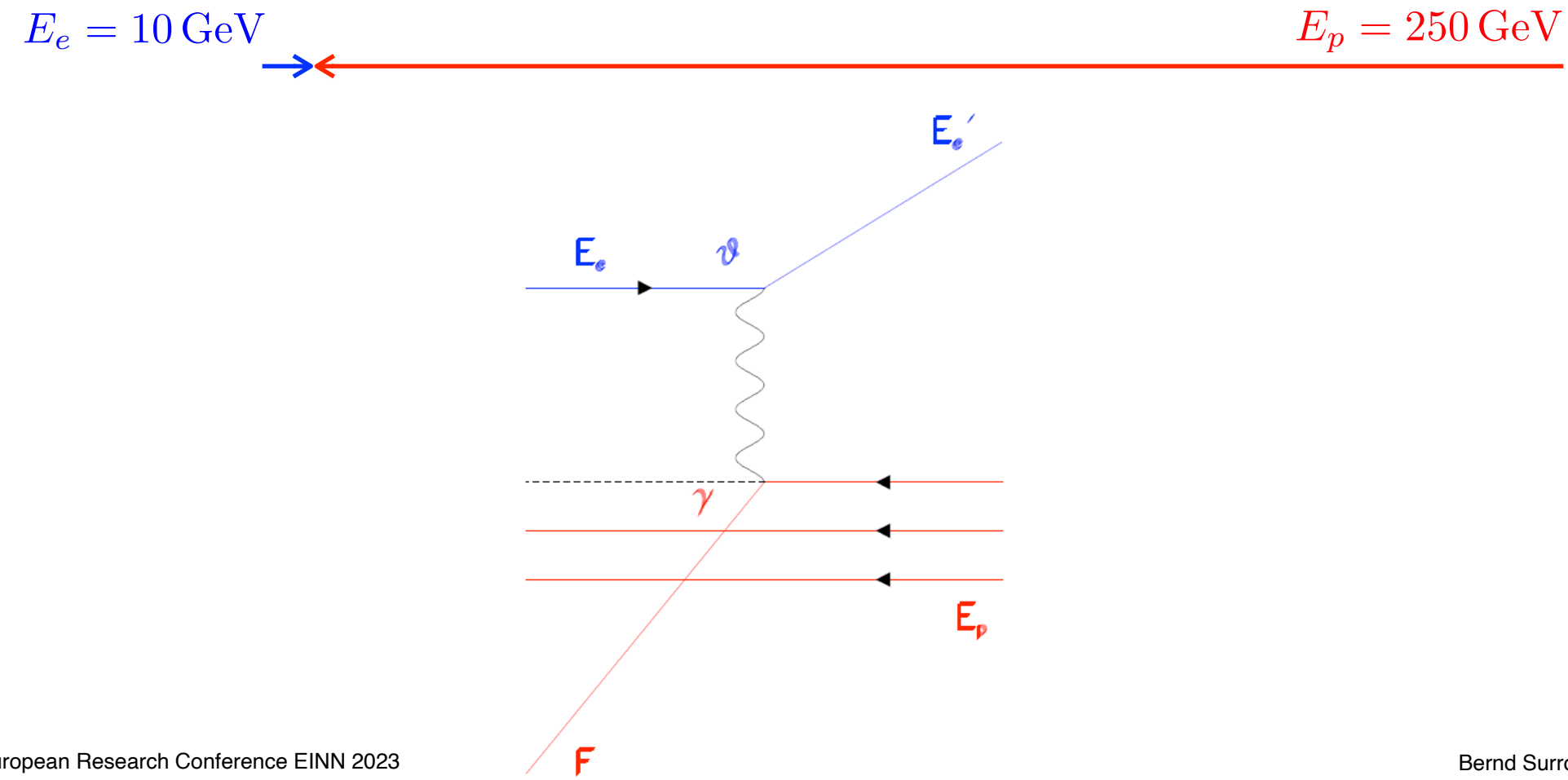

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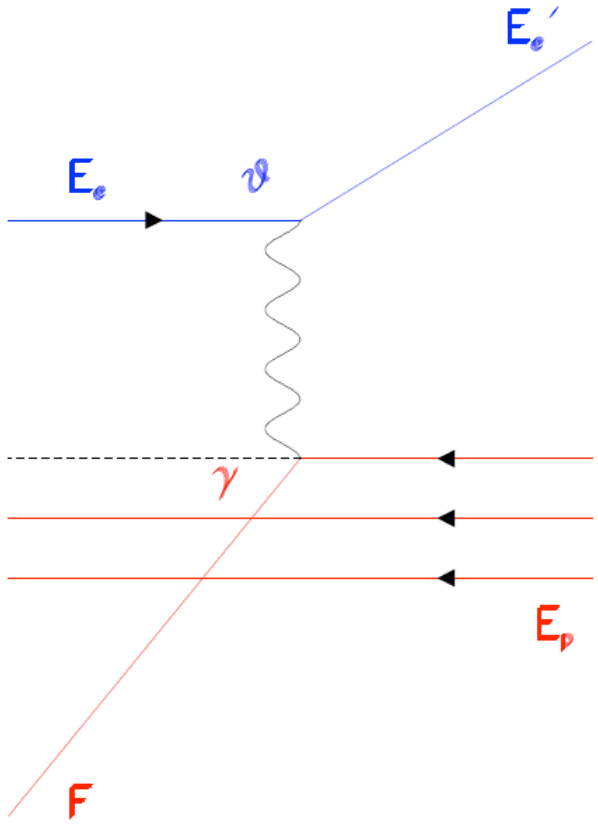

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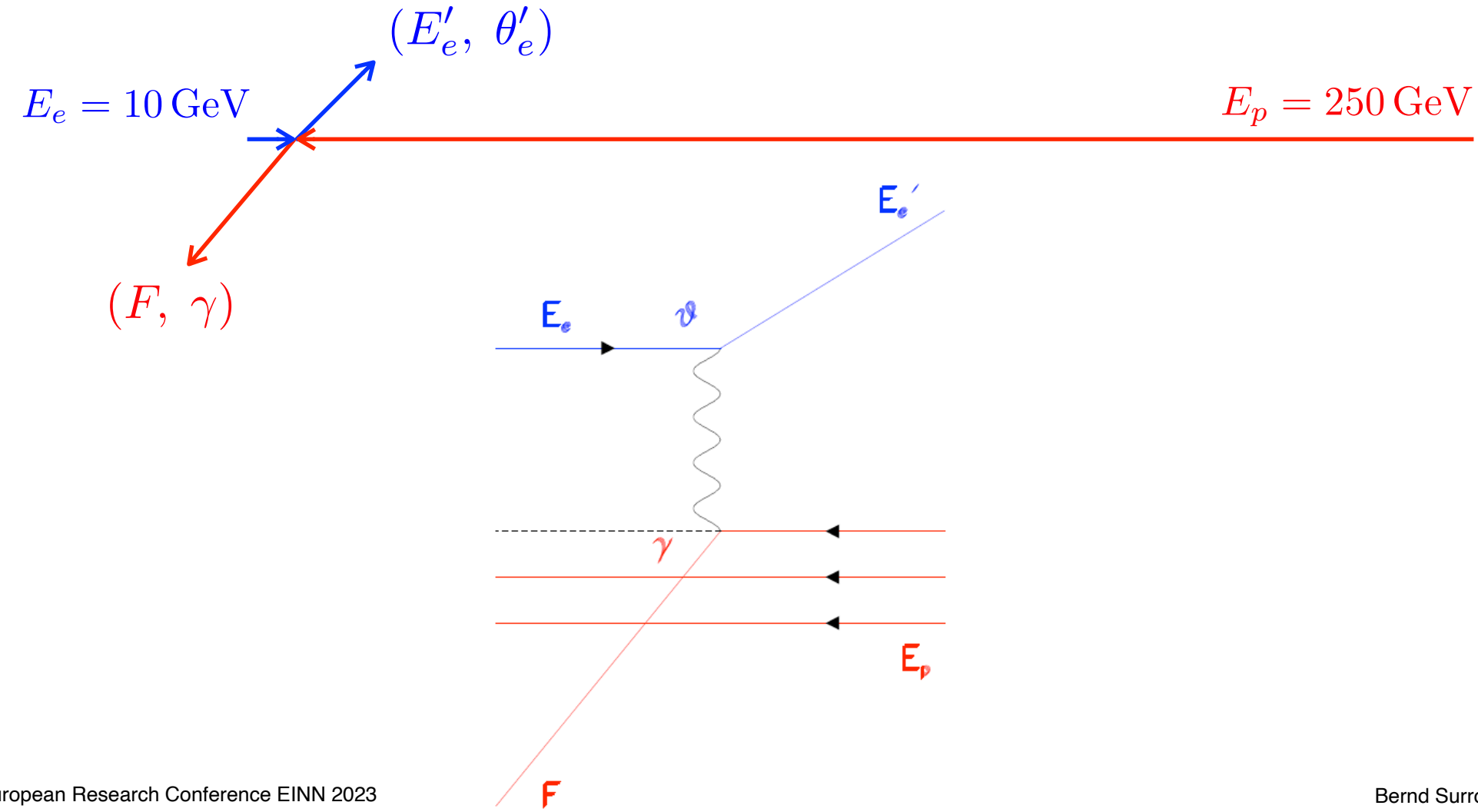

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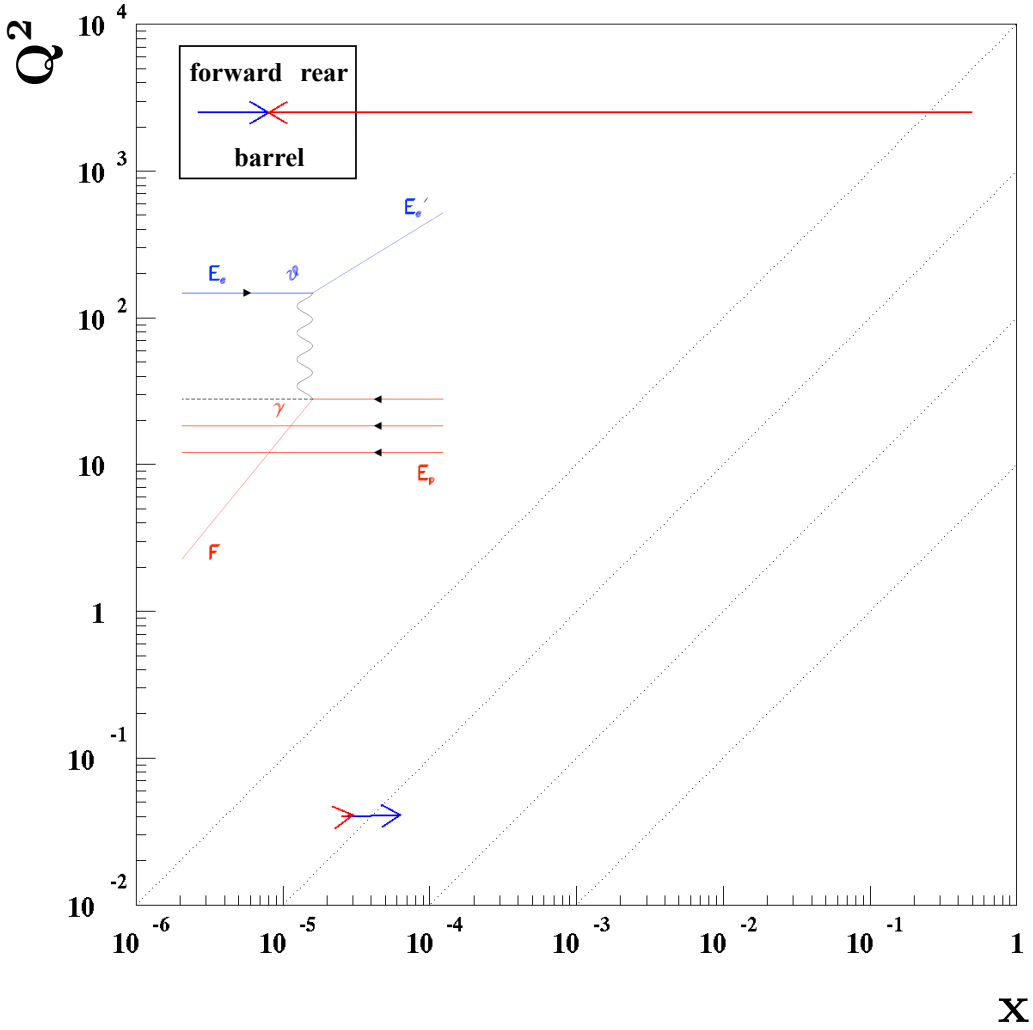

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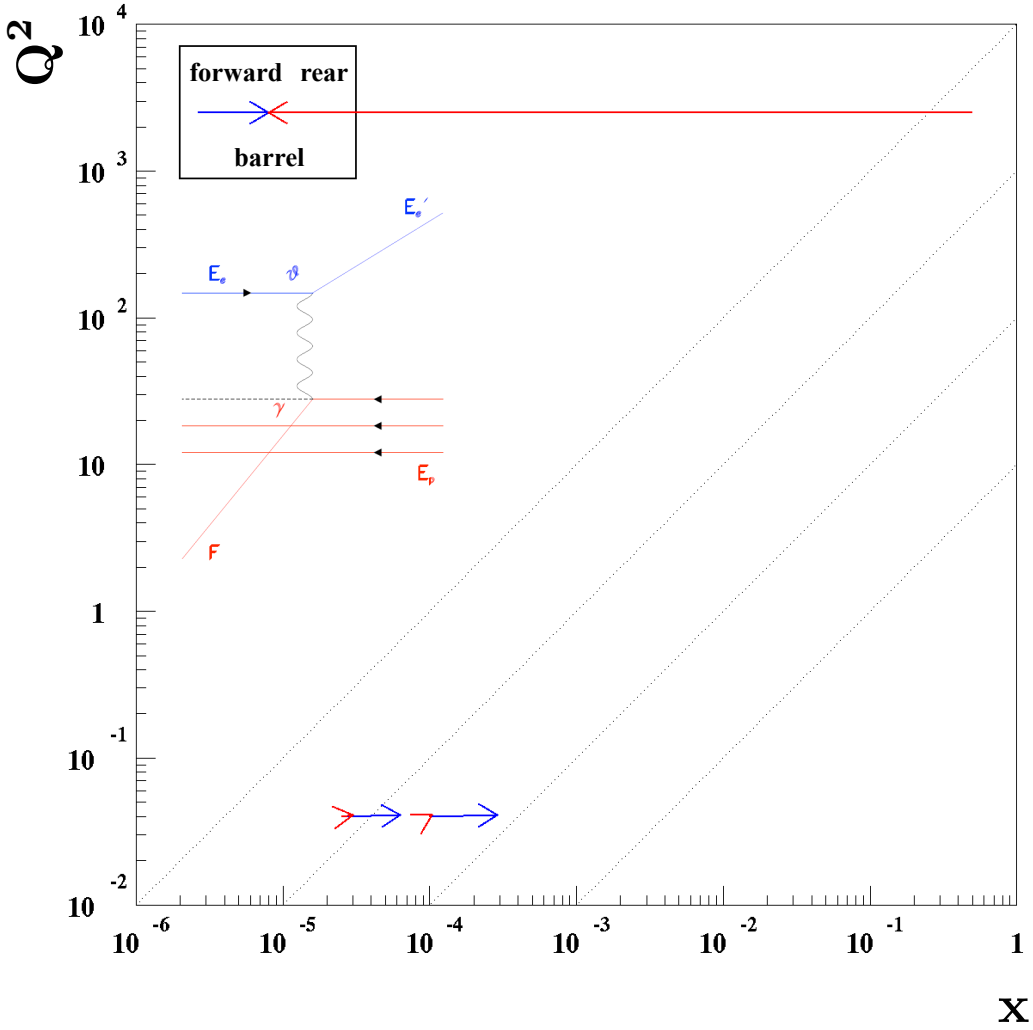

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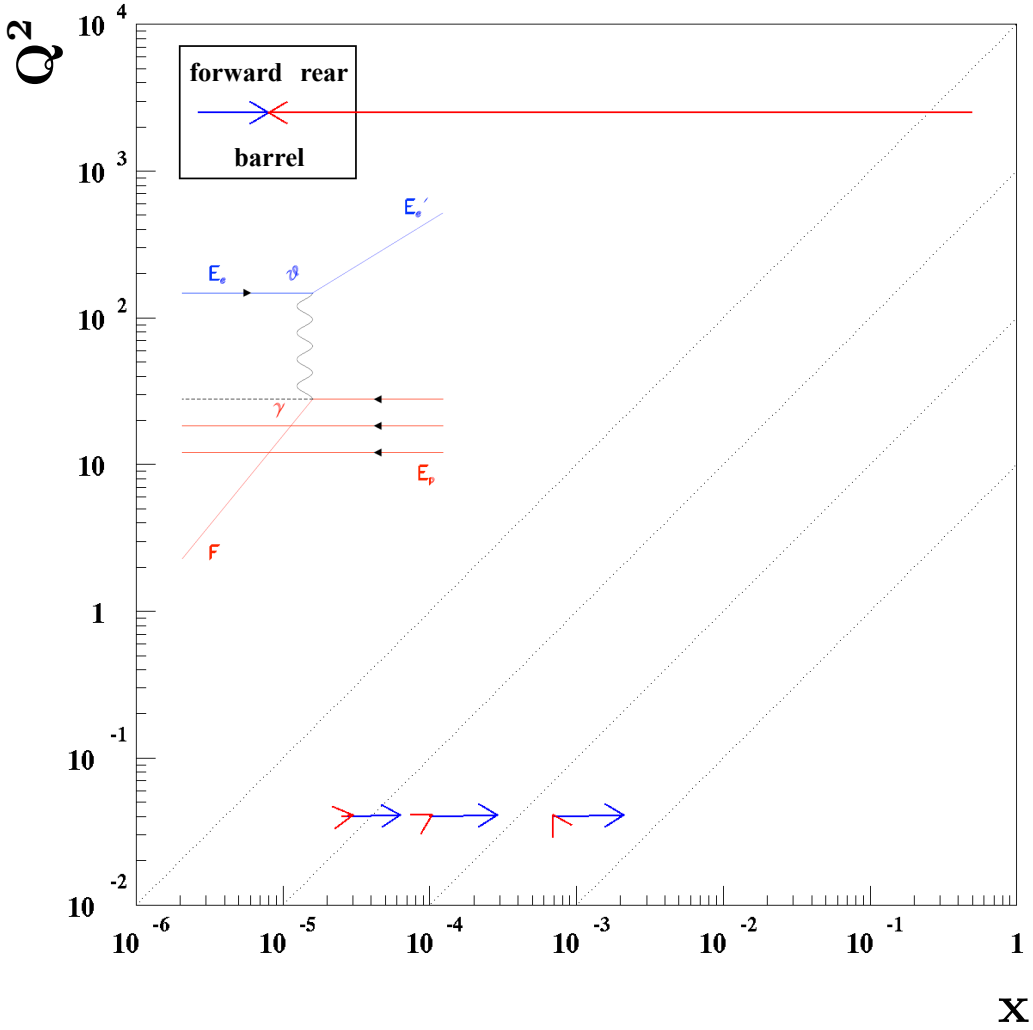

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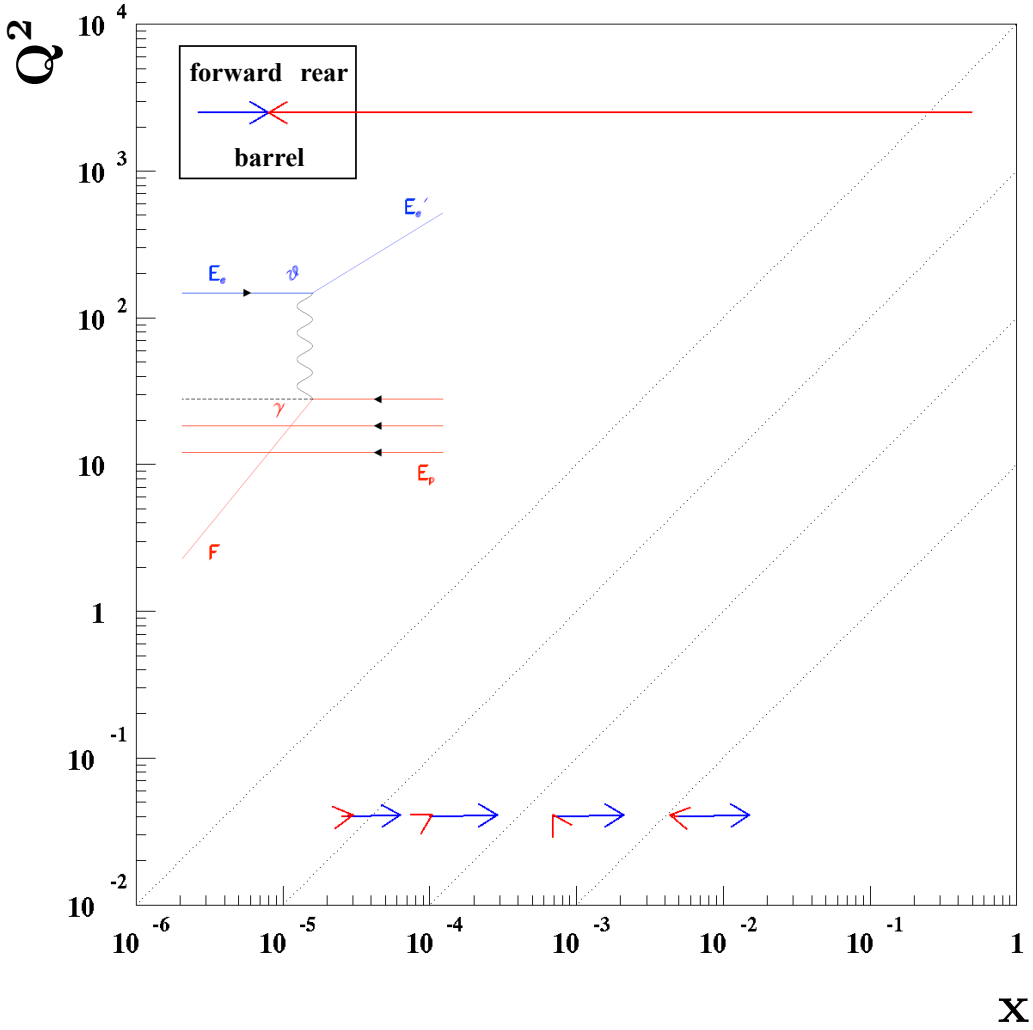

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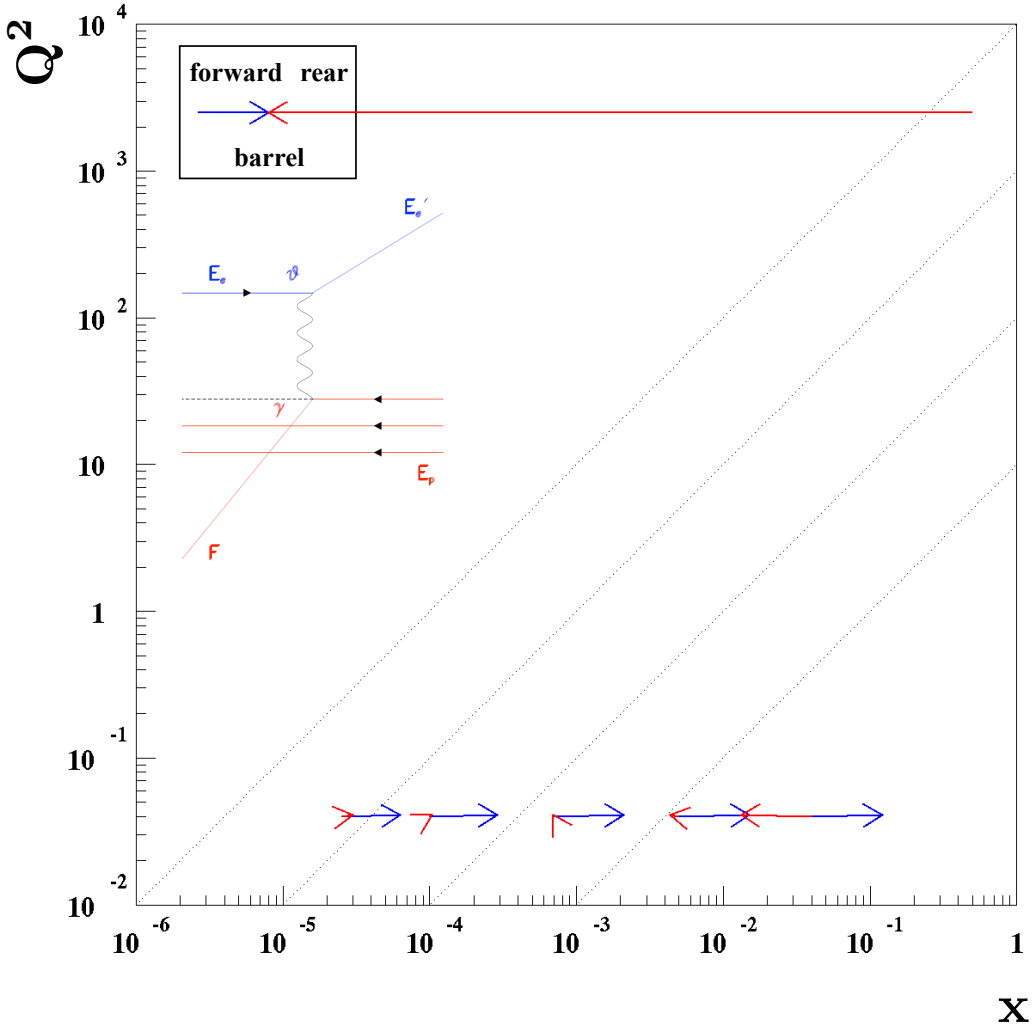

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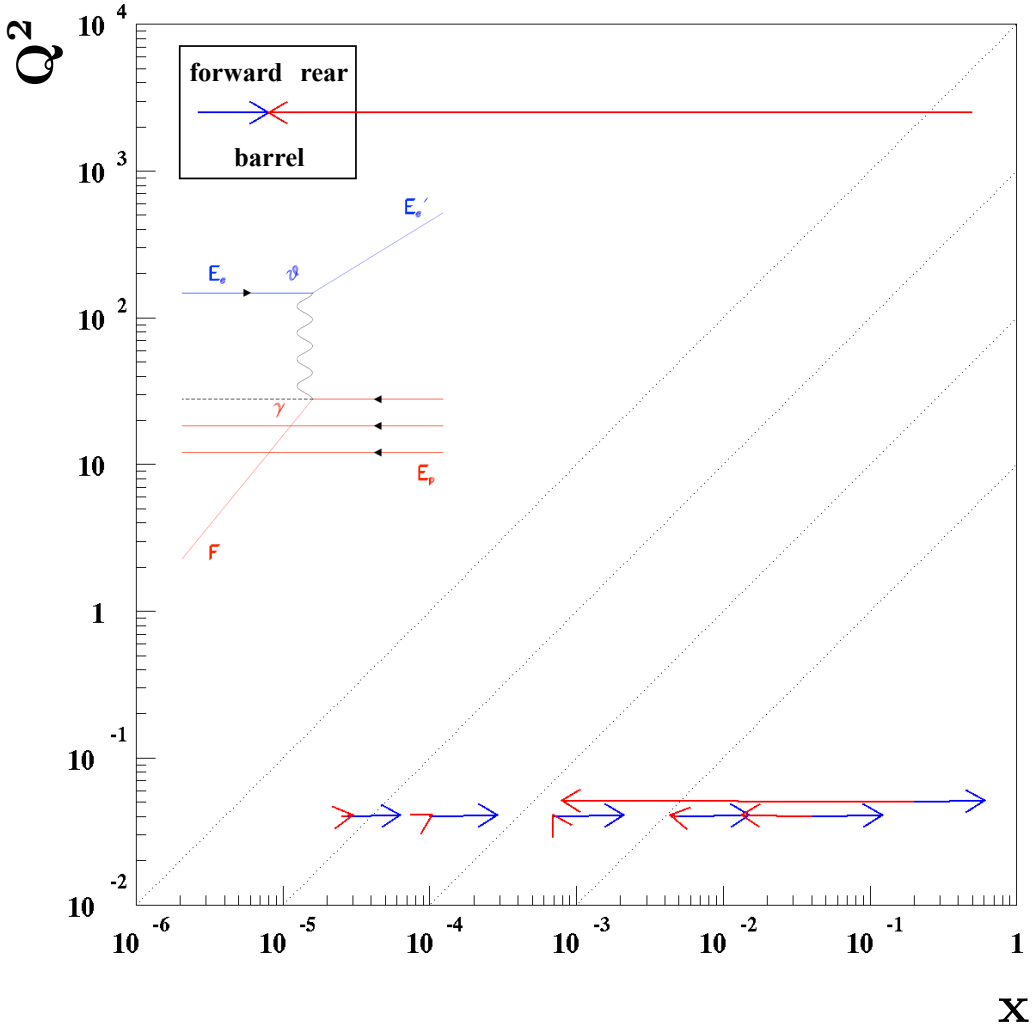

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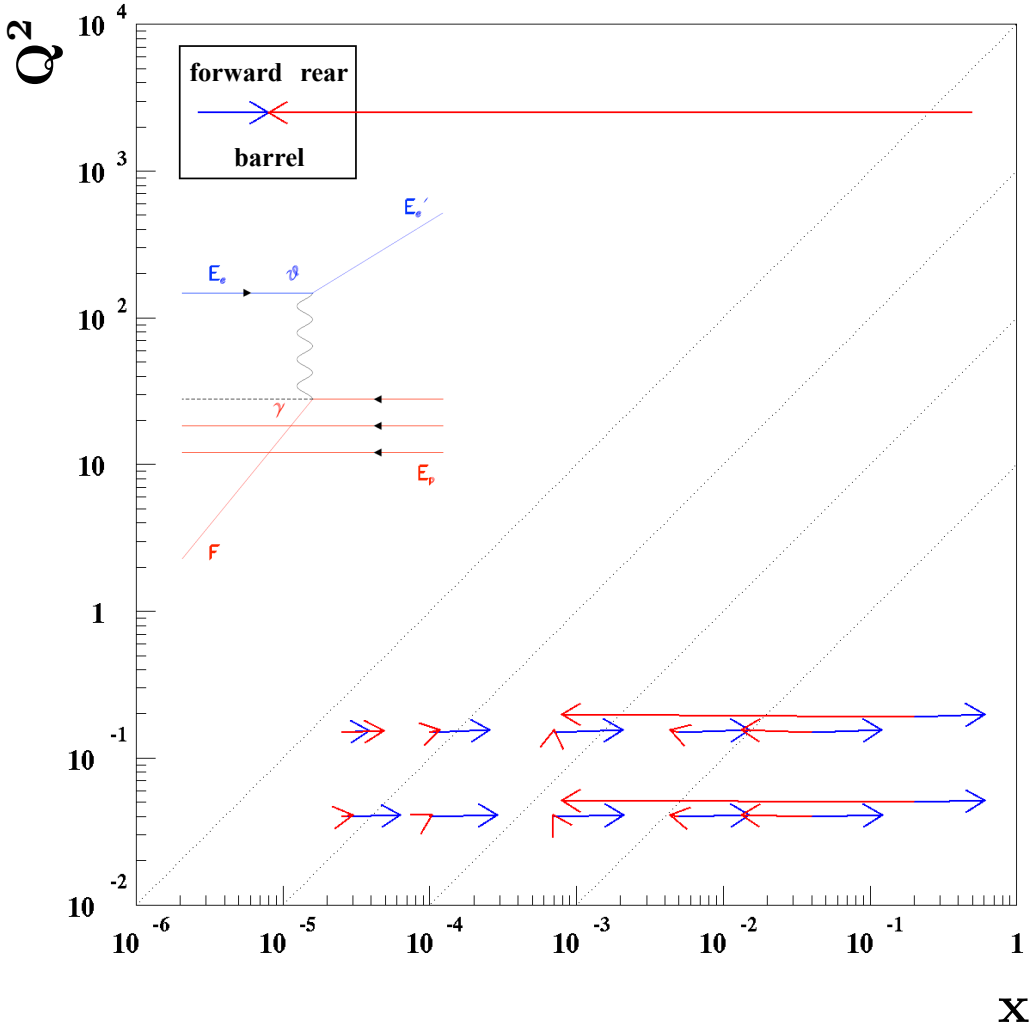

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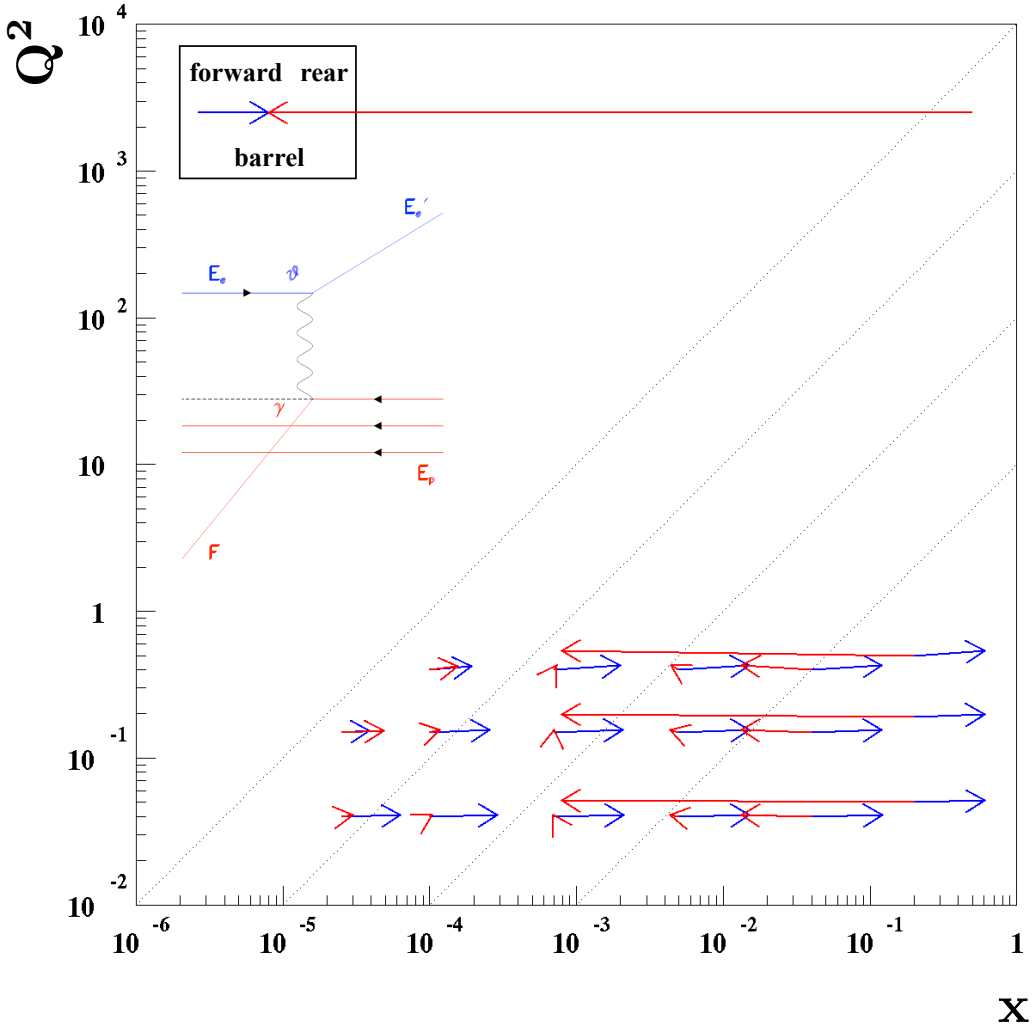

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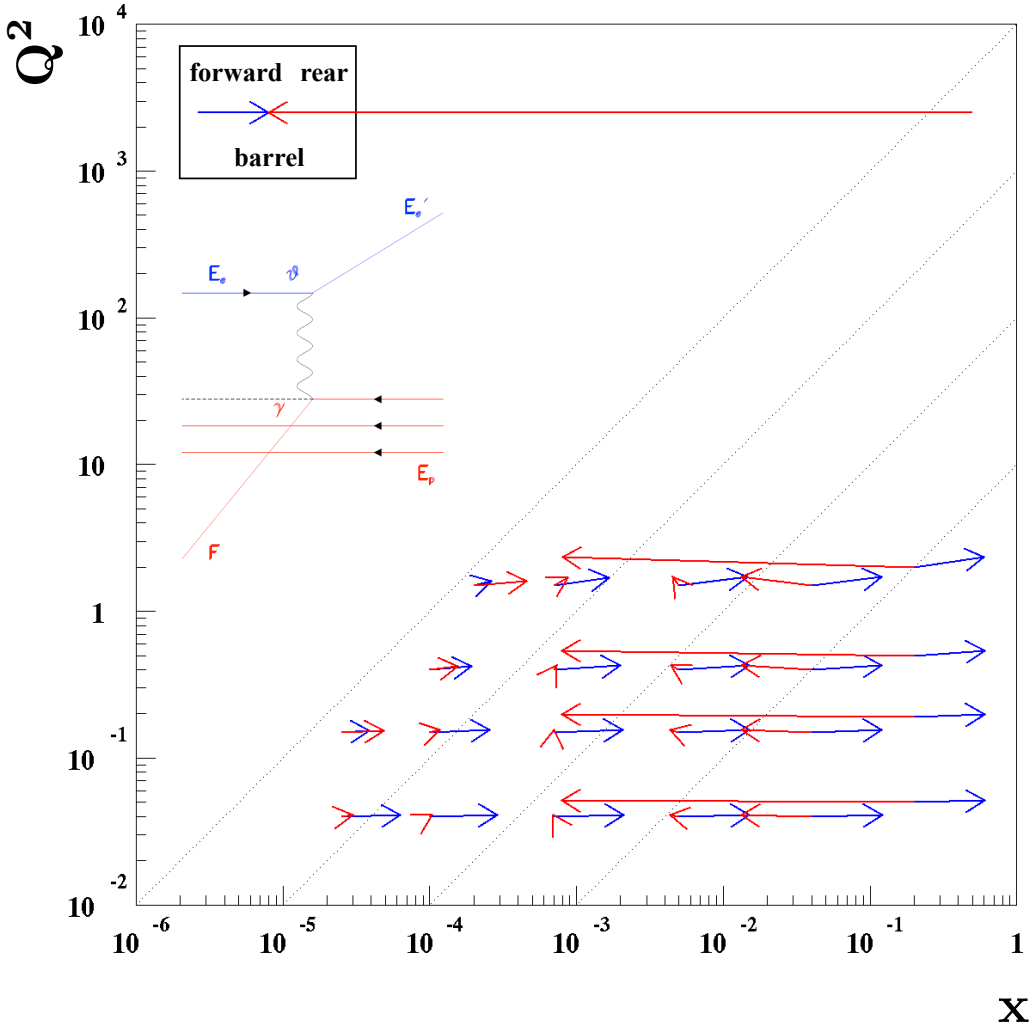

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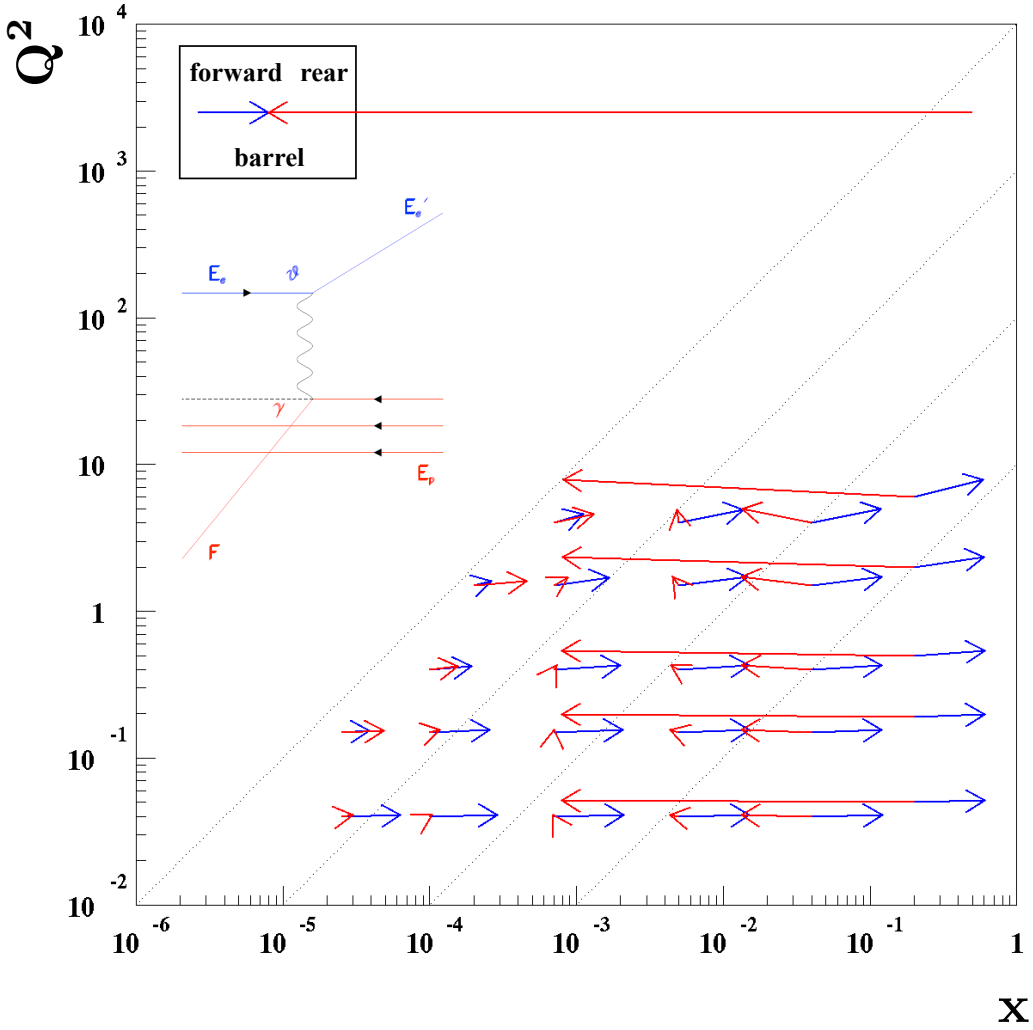

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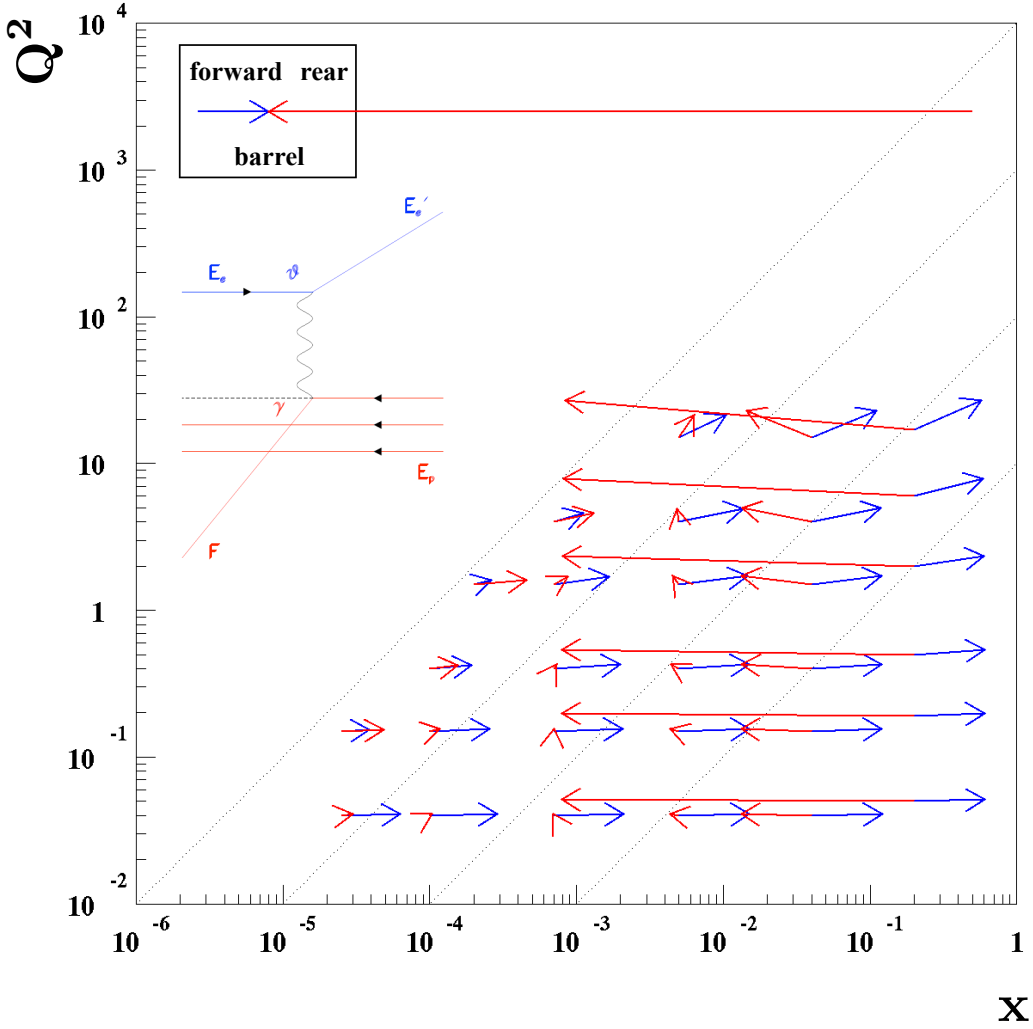

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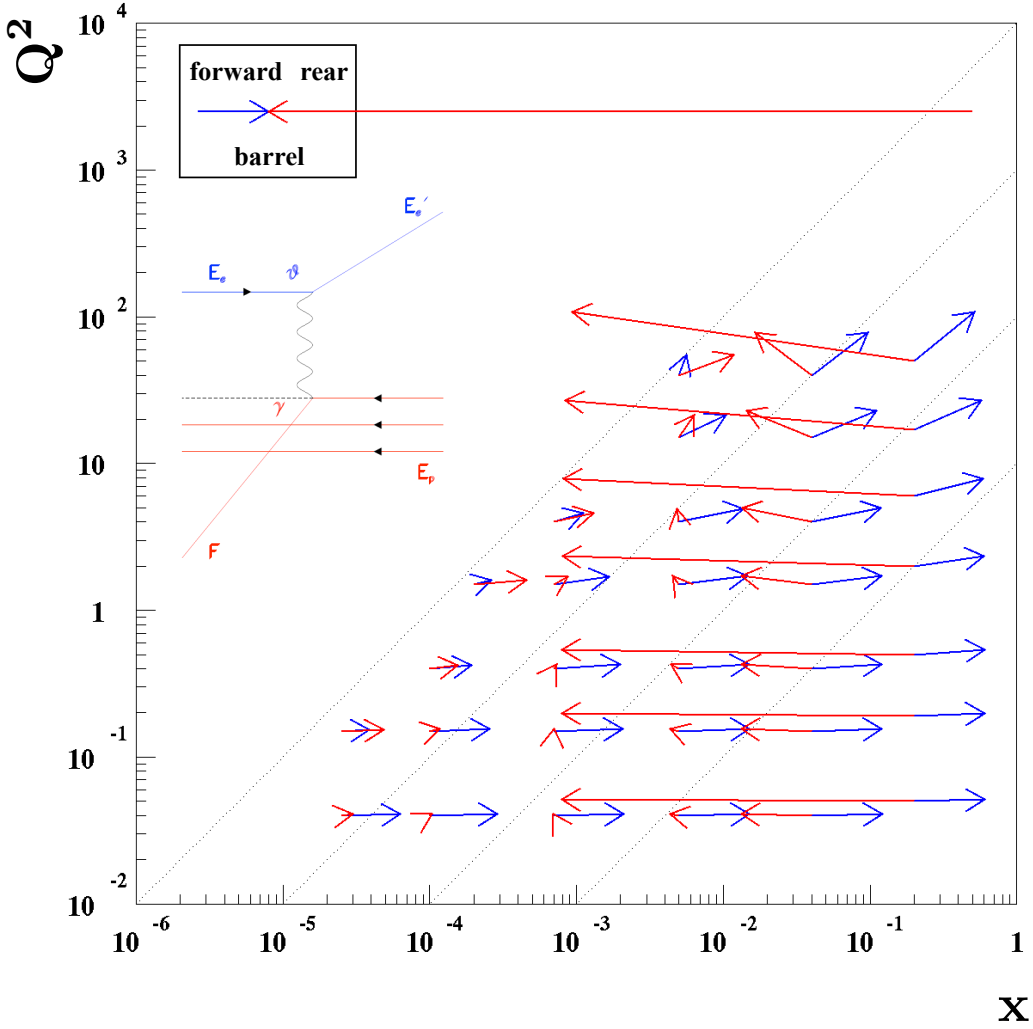

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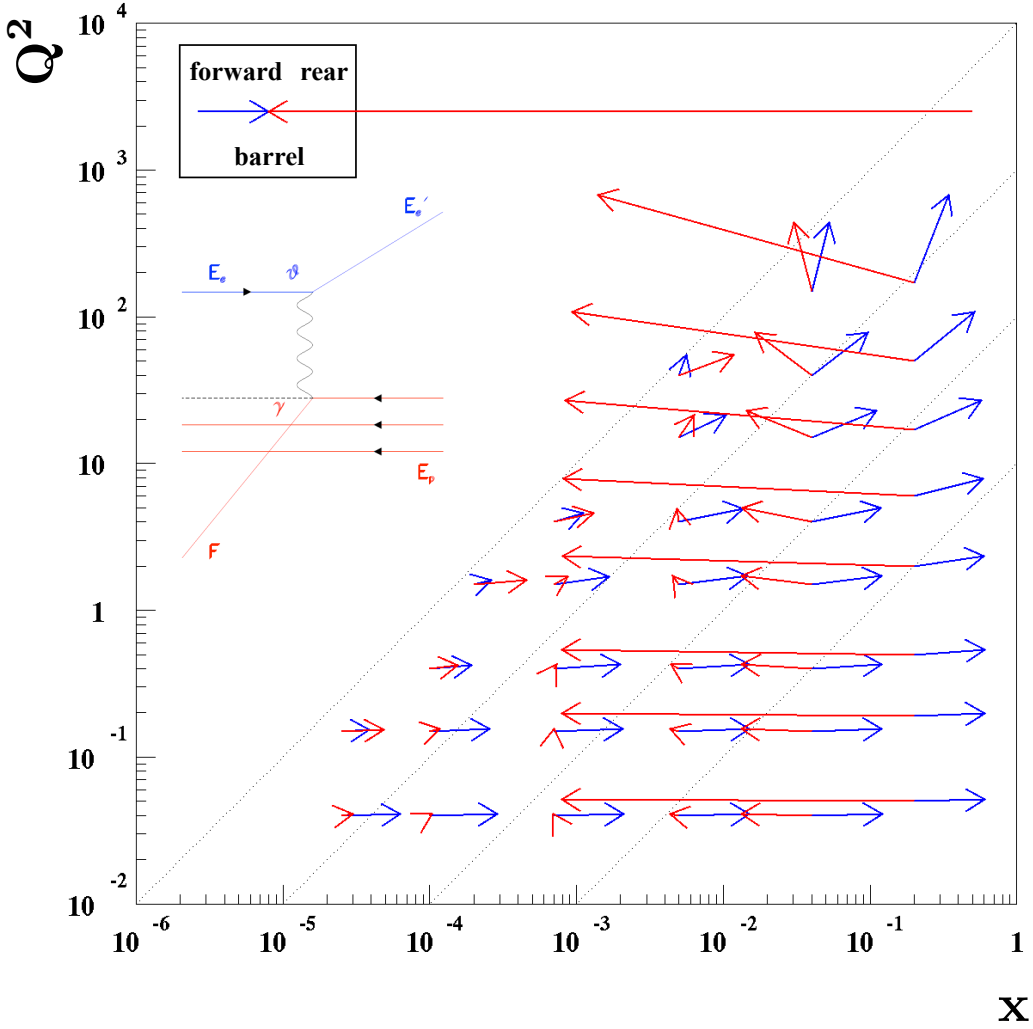

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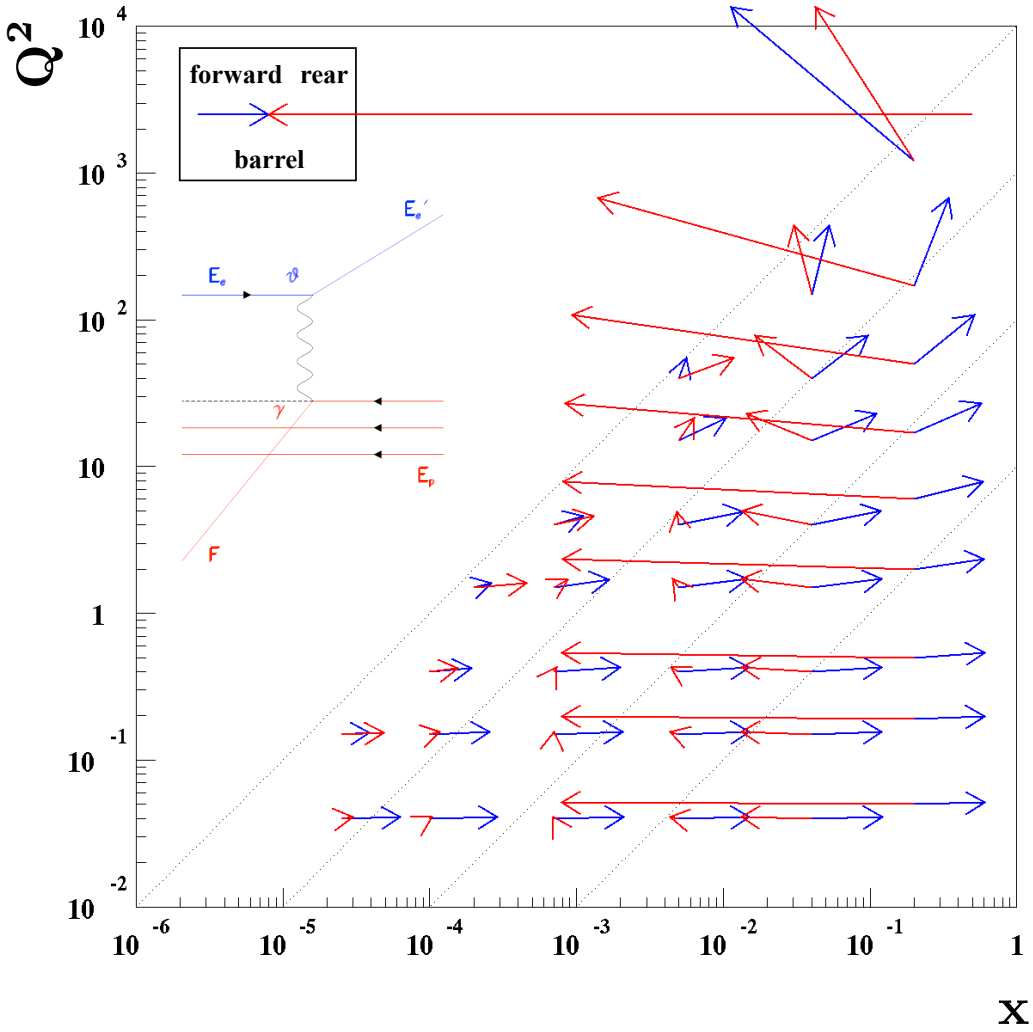

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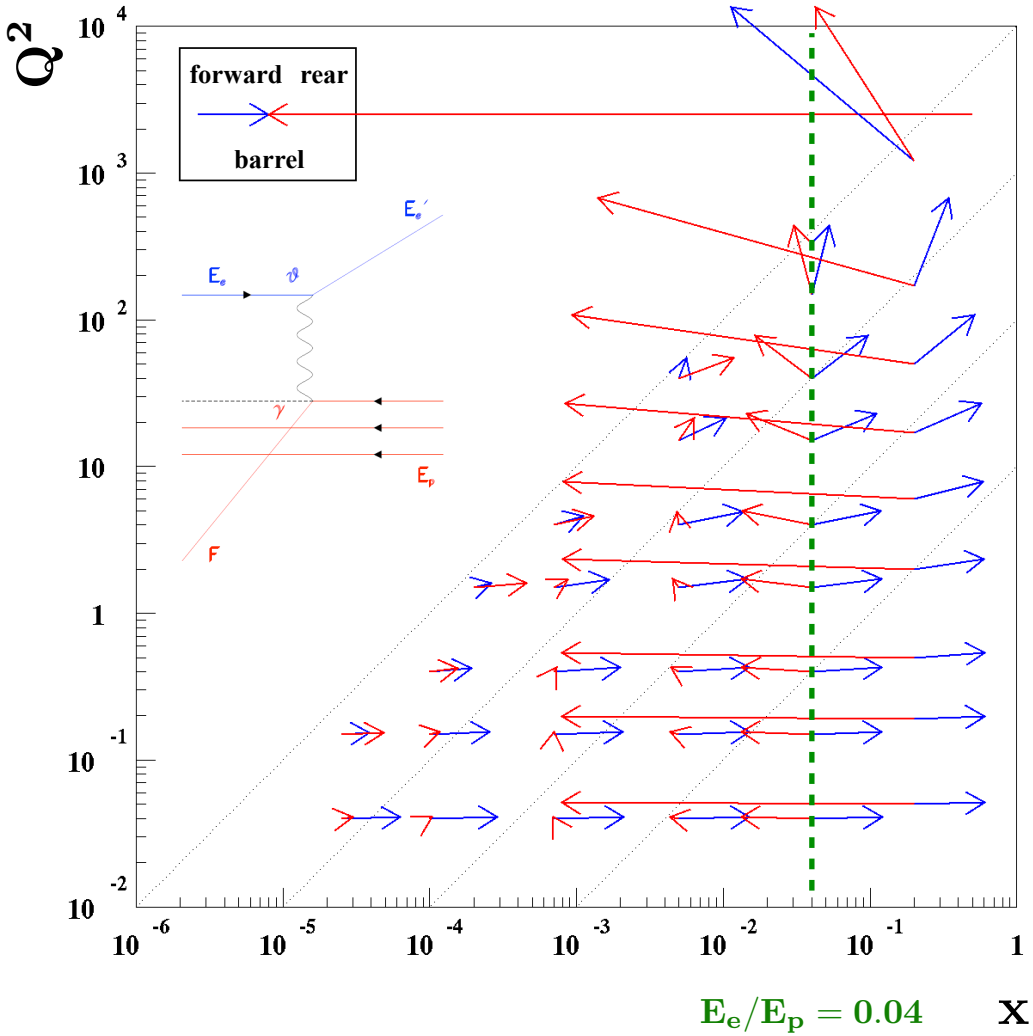

Kinematic peak location!

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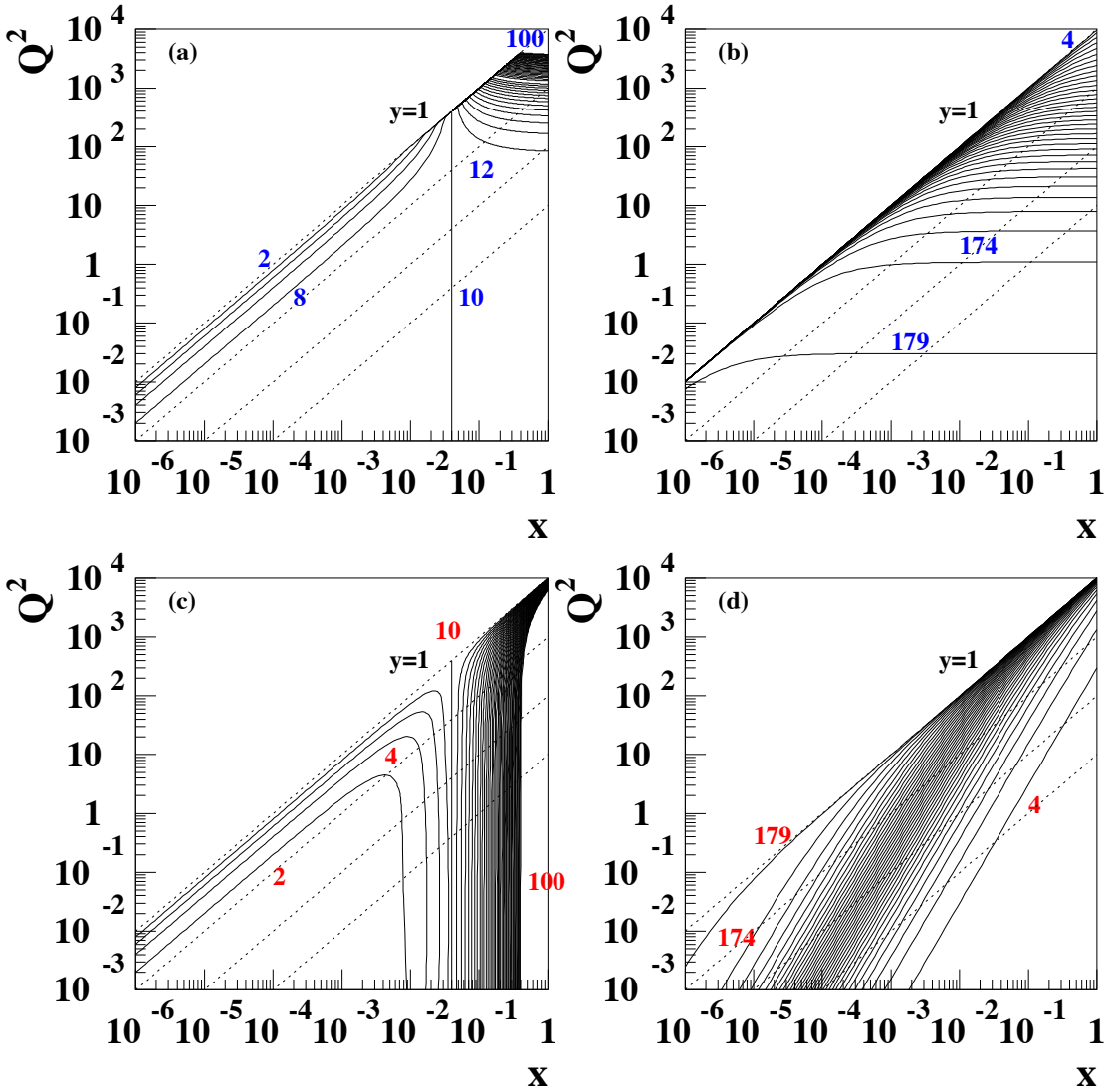

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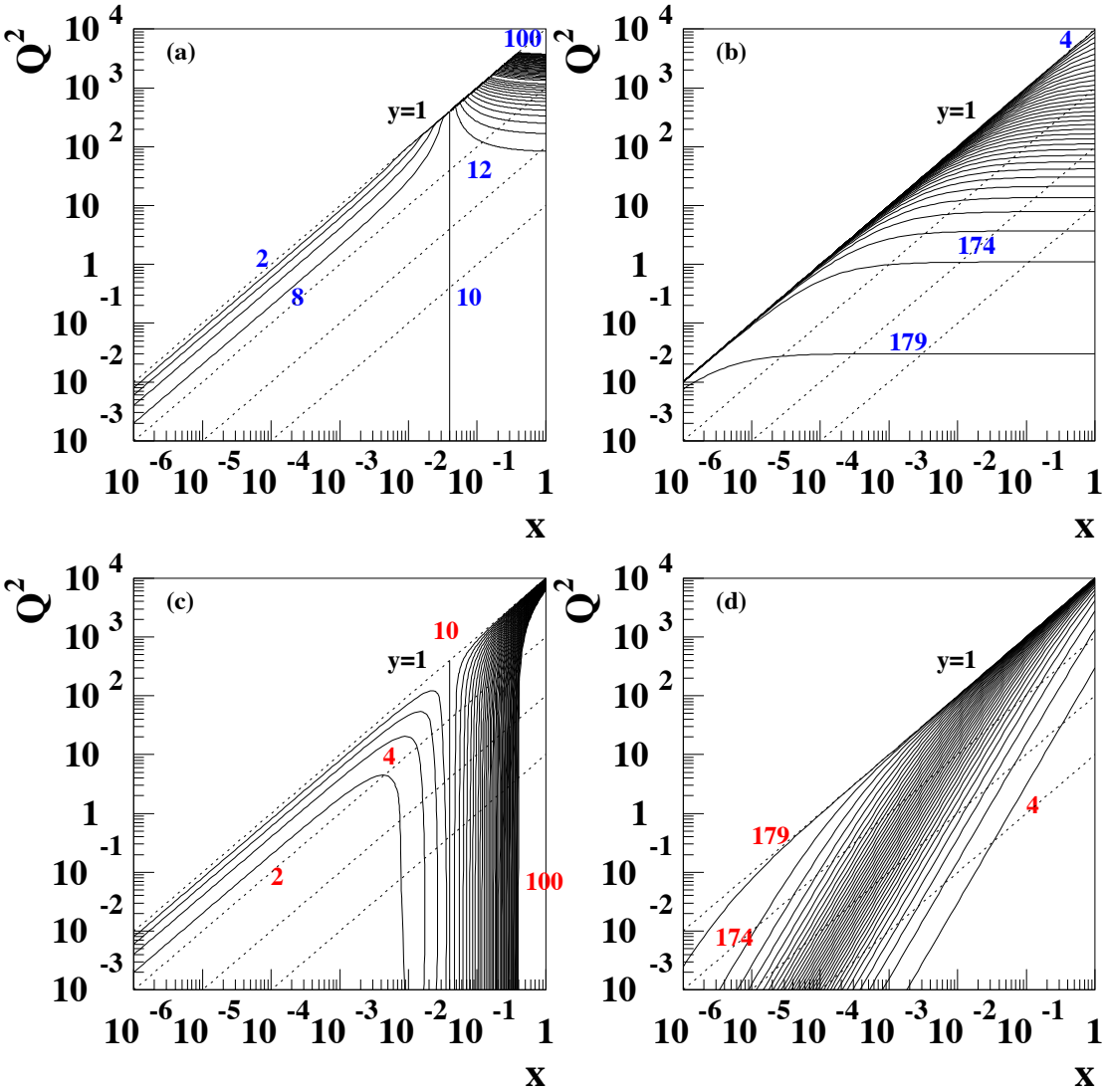
Fixed E'_e

2GeV steps:
2GeV-100GeV



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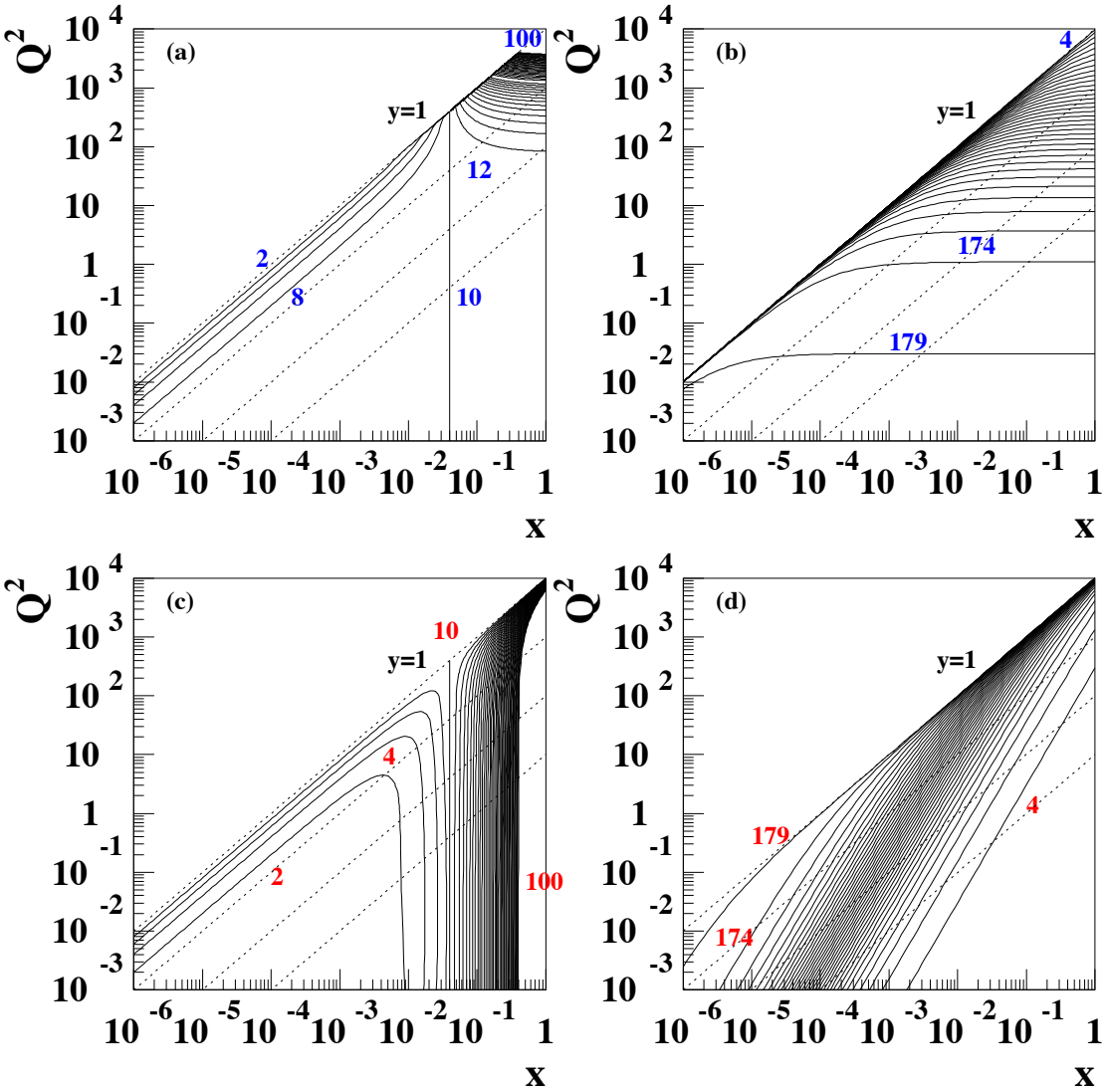

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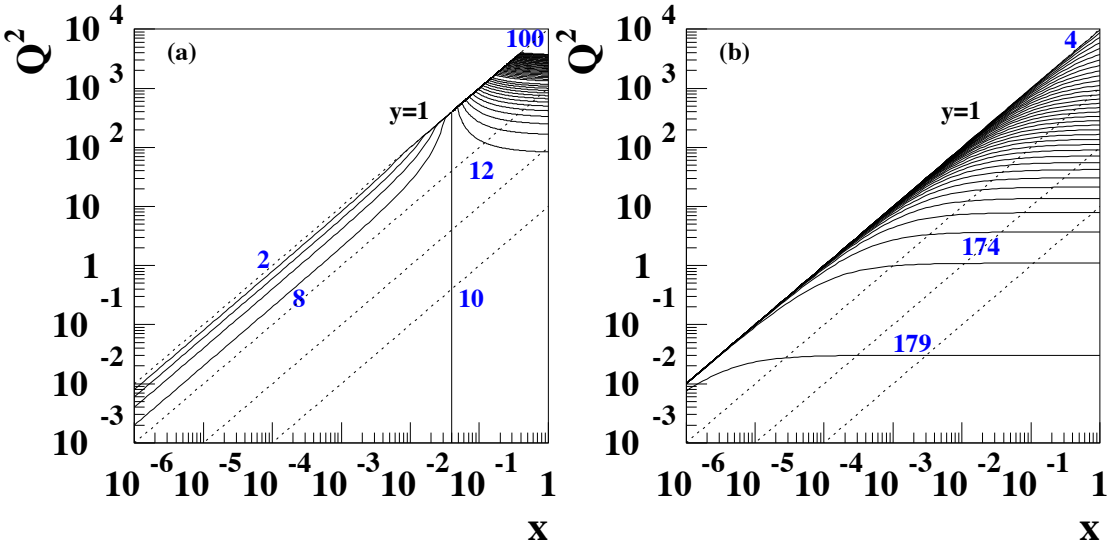

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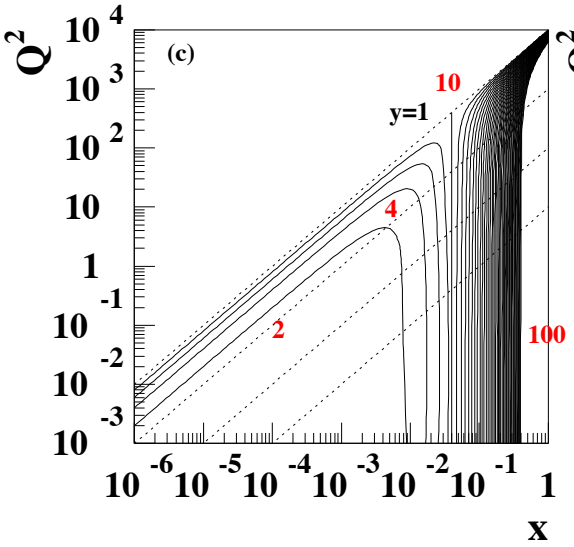

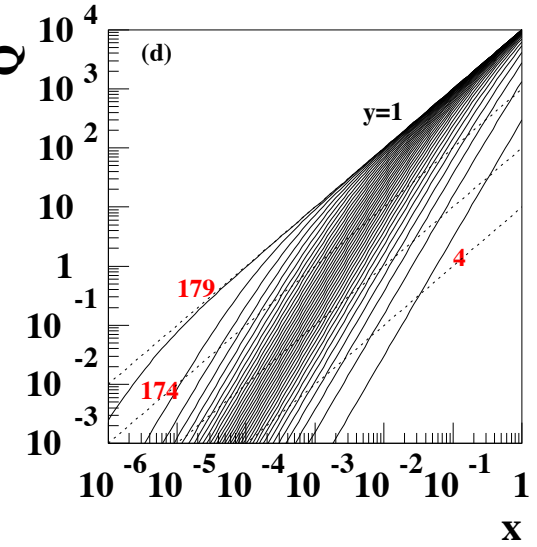

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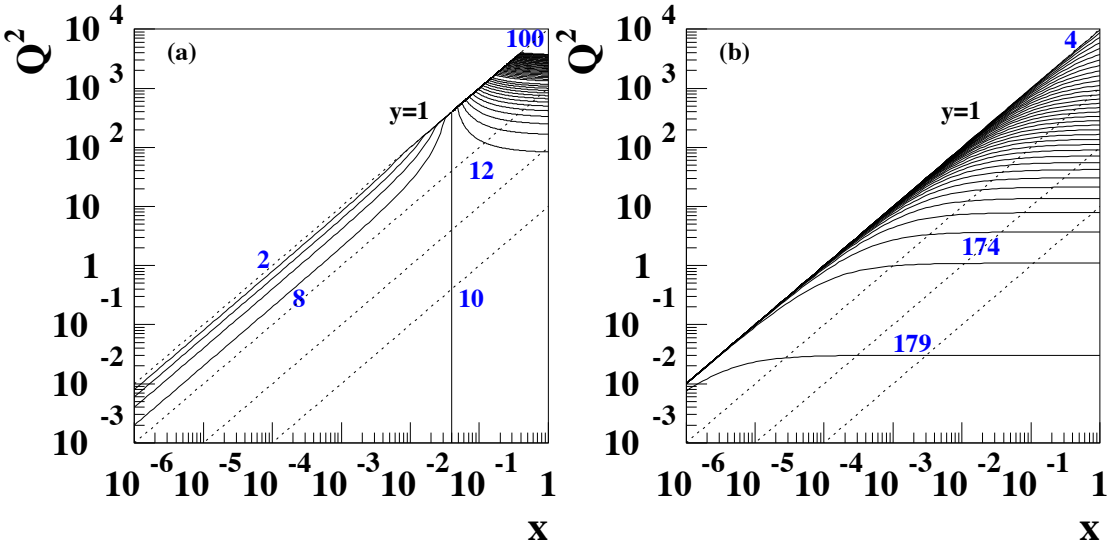

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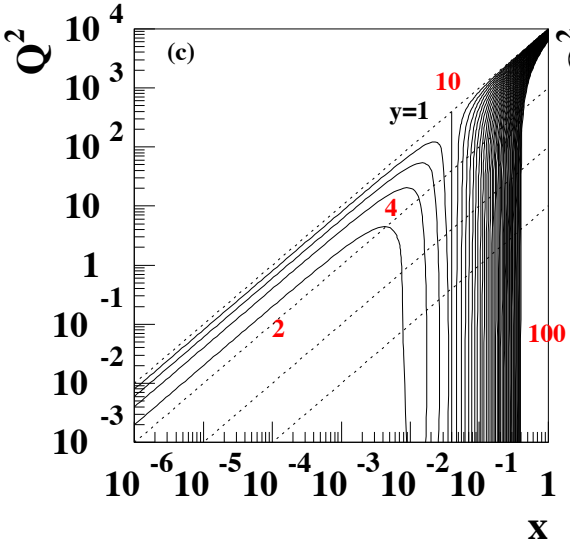

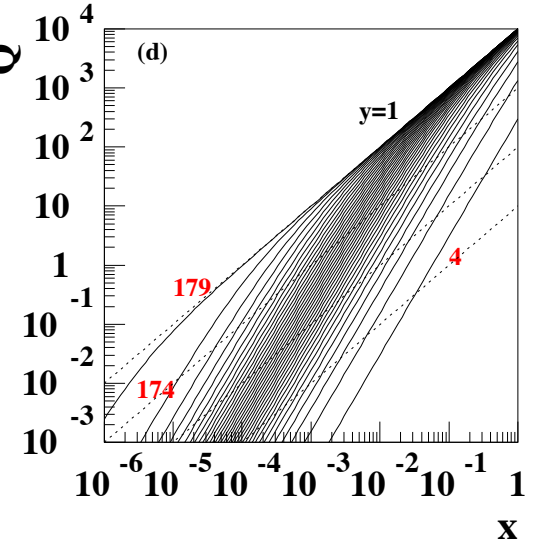

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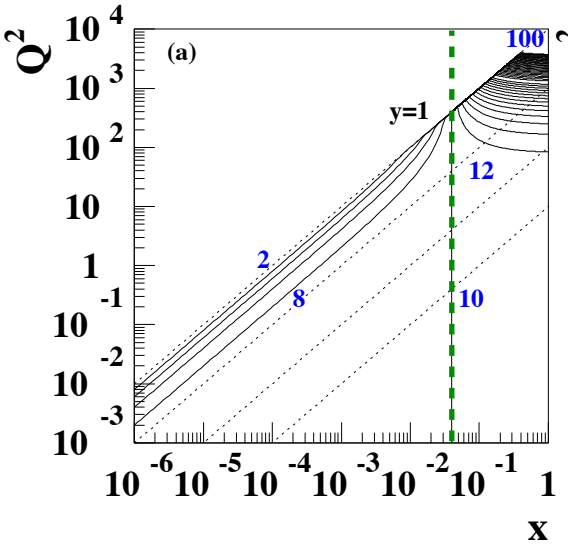

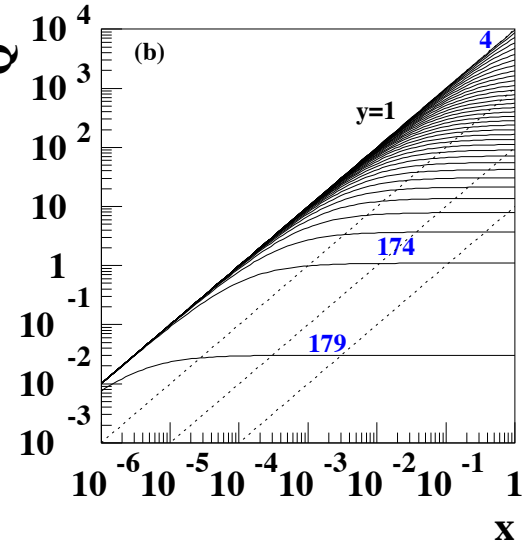

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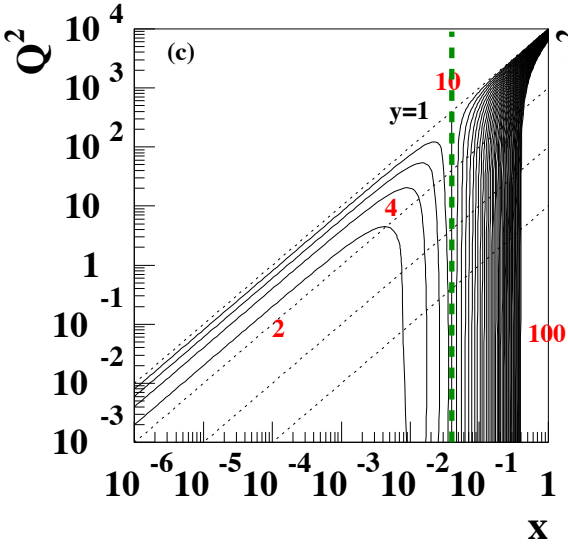

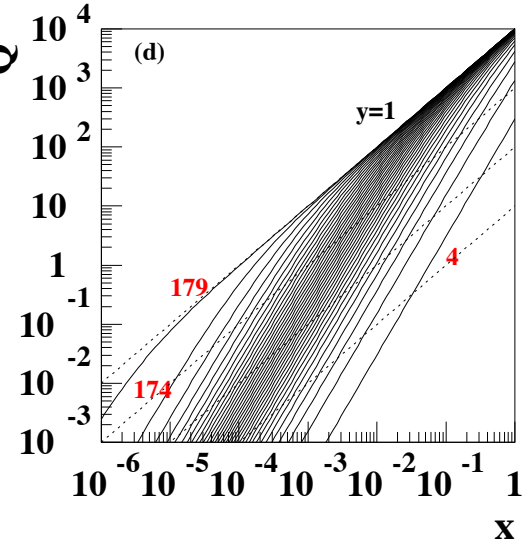

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ePIC Detector Design Philosophy

- Overview of processes and final states

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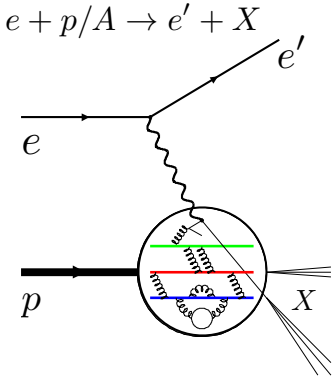


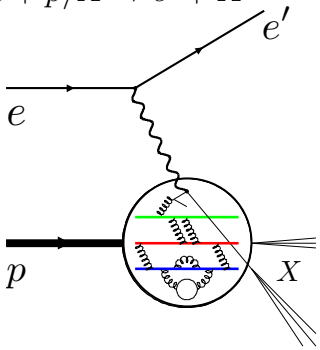
Inclusive DIS

- Inclusive: Unpolarized $f_i(x,Q^2)$ and helicity distribution $\Delta f_i(x,Q^2)$ functions through unpolarized and polarized structure function measurements (F_2, F_L, g_1)
- Define kinematics (x, y, Q^2) through electron (e-ID and energy+angular measurement critical) / hadron final state or combination of both depending on kinematic x-Q^2 region

ePIC Detector Design Philosophy

Overview of processes and final states

$e + p/A \rightarrow e' + X$



Inclusive DIS

Semi-Inclusive DIS (SDIS)

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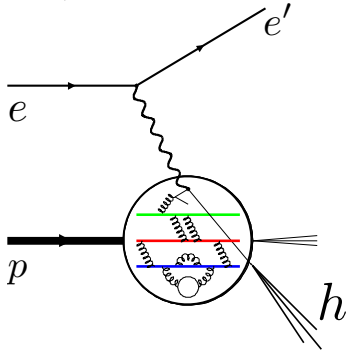

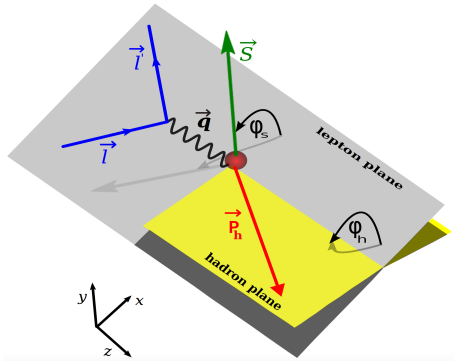

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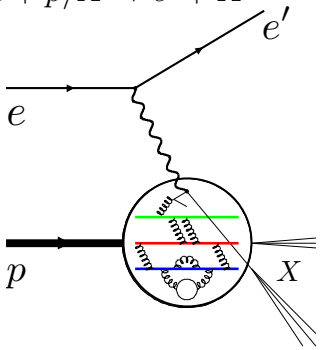

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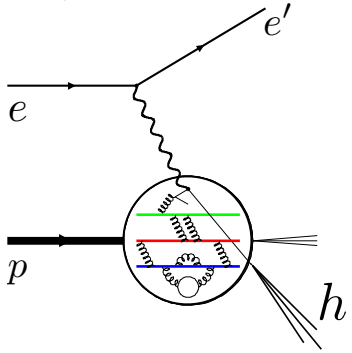

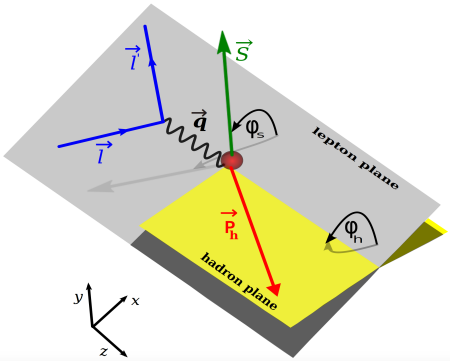

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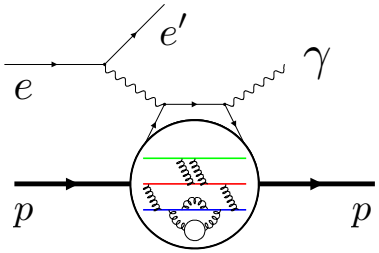


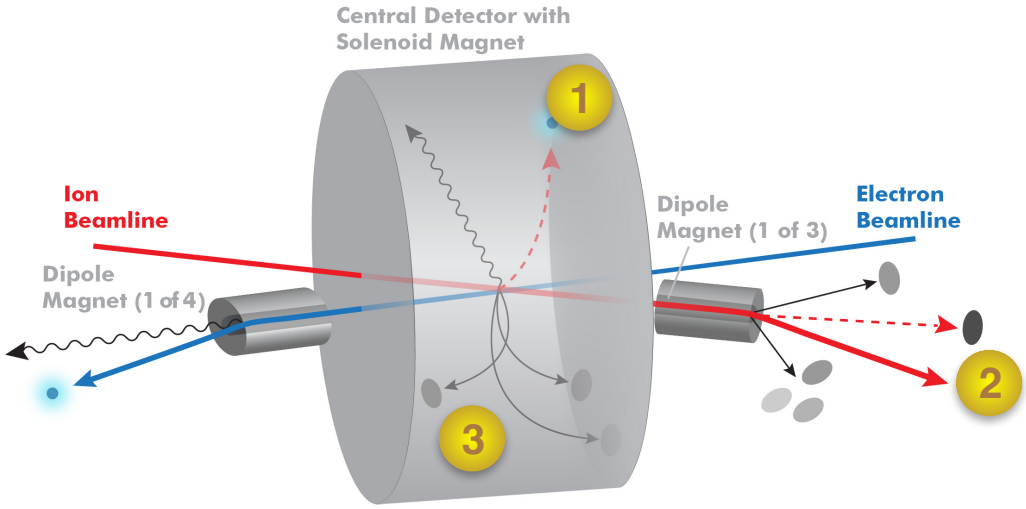
Deeply-Virtual Compton Scattering (DVCS)

- Exclusive: Tagging of final state proton using Roman pot system studying GPD's (Impact parameter, b_T, dependence) using DVCS and VM production
- eA: Impact parameter determination / Neutron tagging using Zero-Degree Calorimeter (ZDC)

ePIC Detector Design Philosophy

- Overview of general requirements

arXiv:1212.1701



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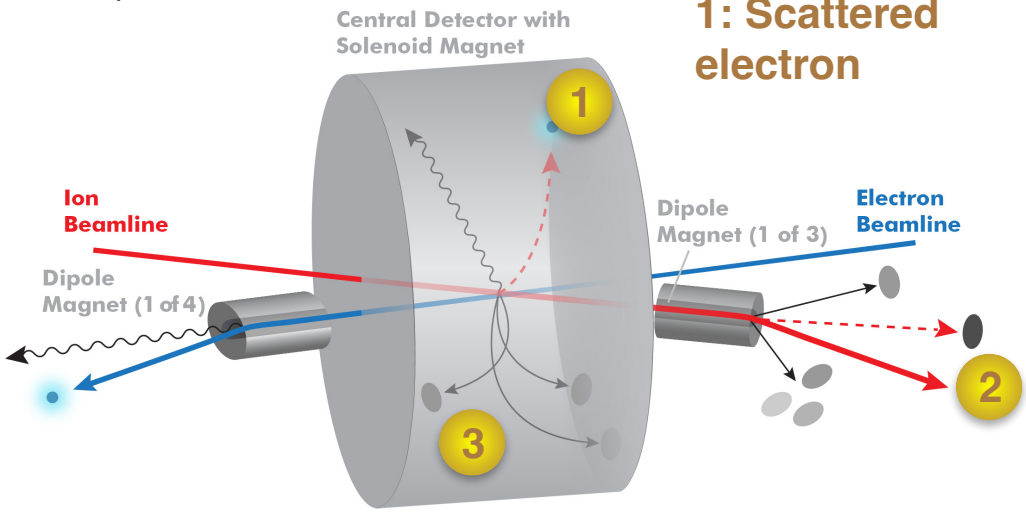

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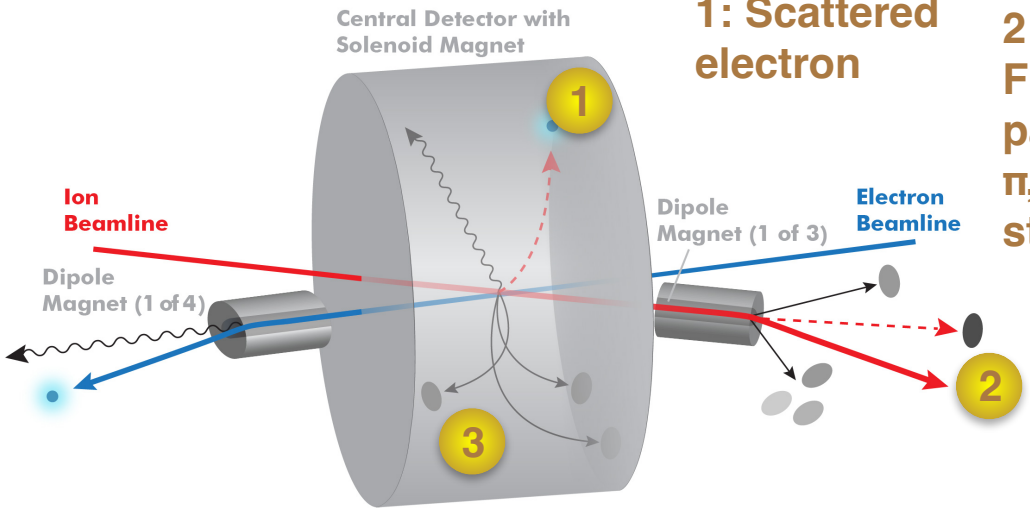

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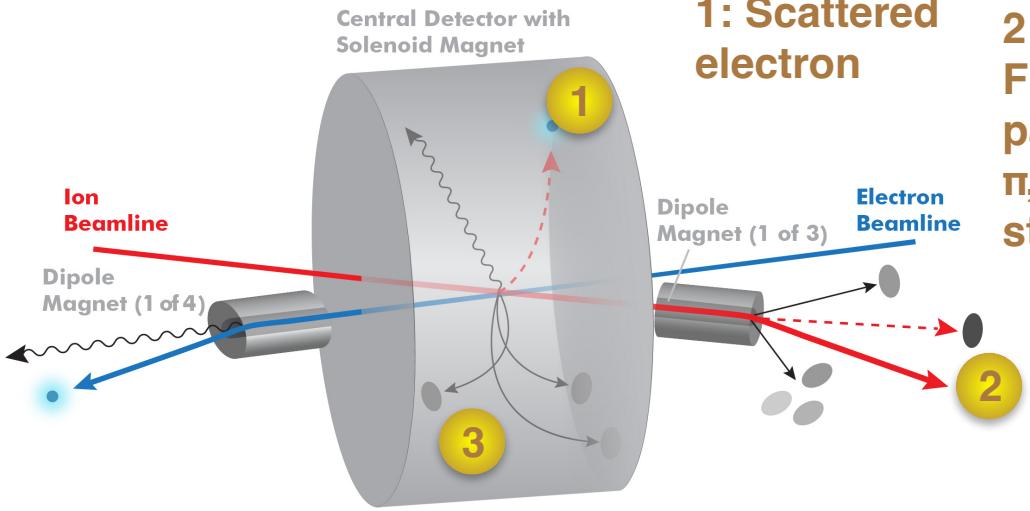

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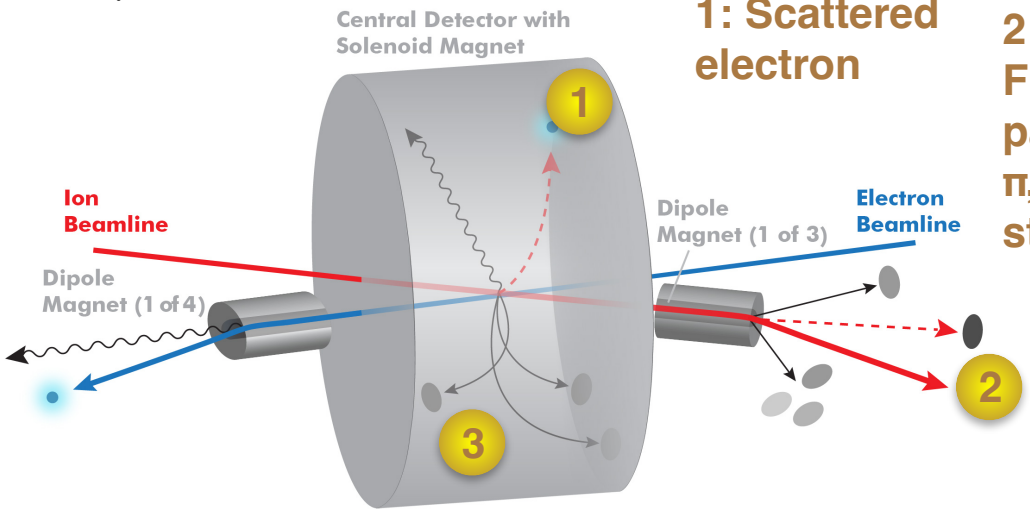

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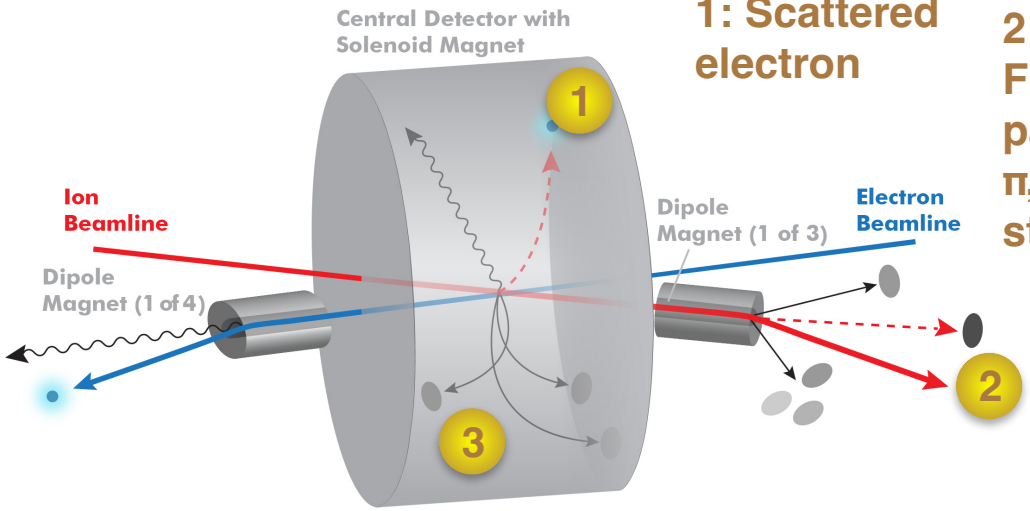

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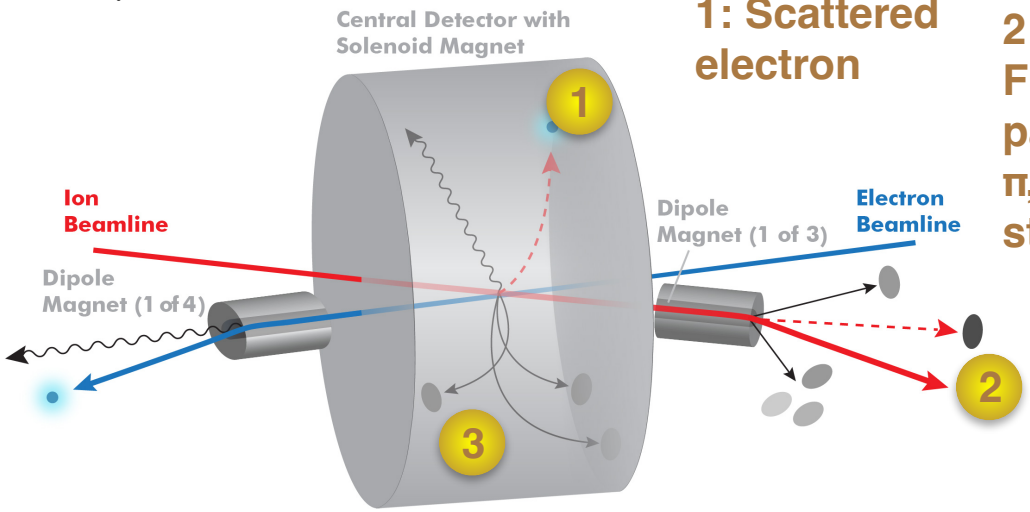

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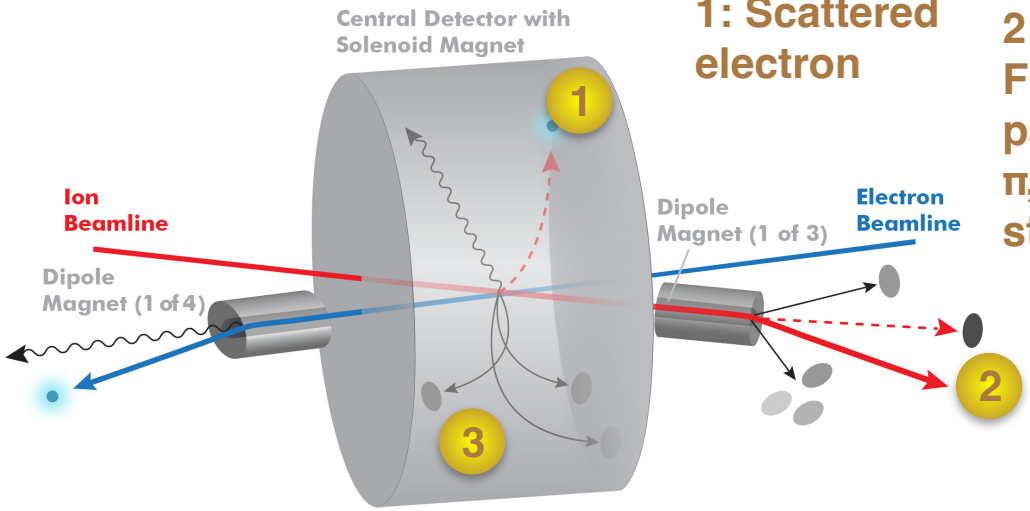

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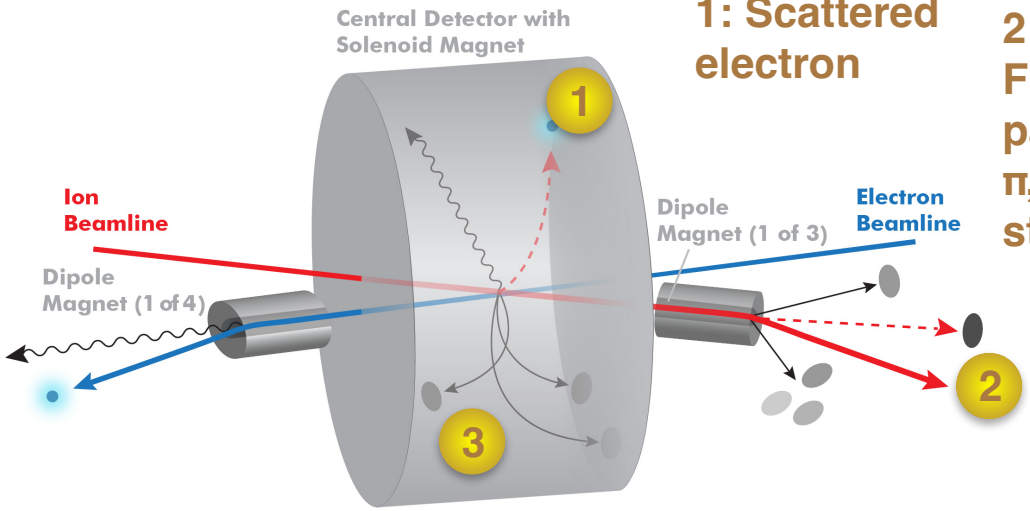

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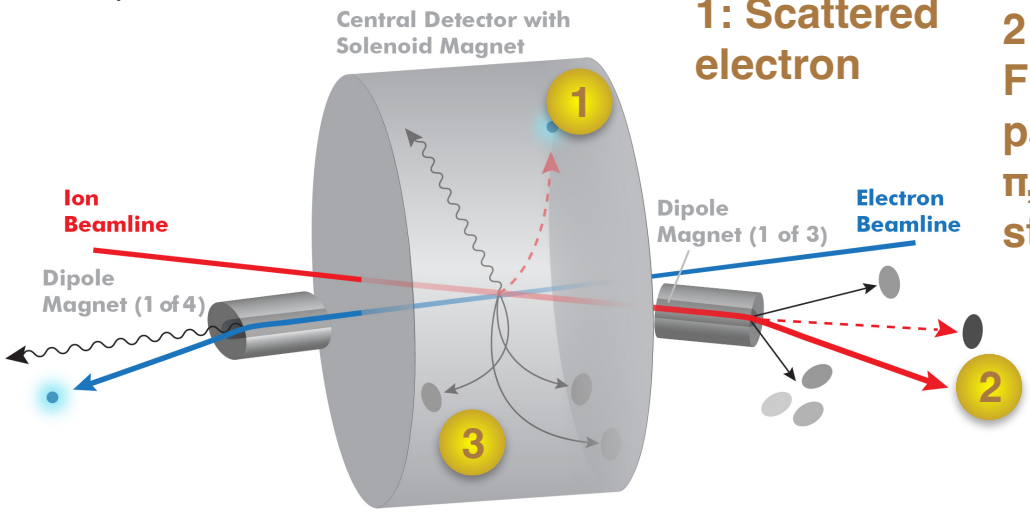

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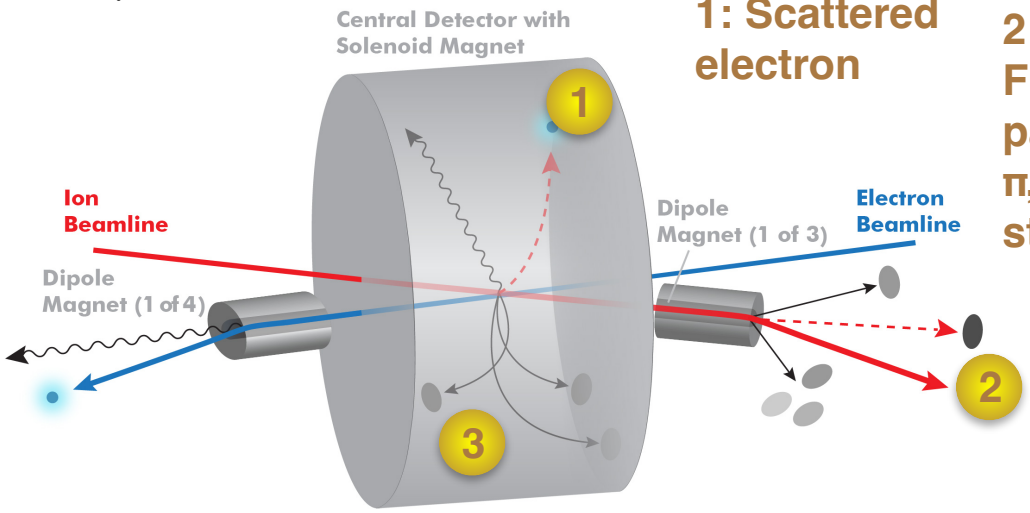

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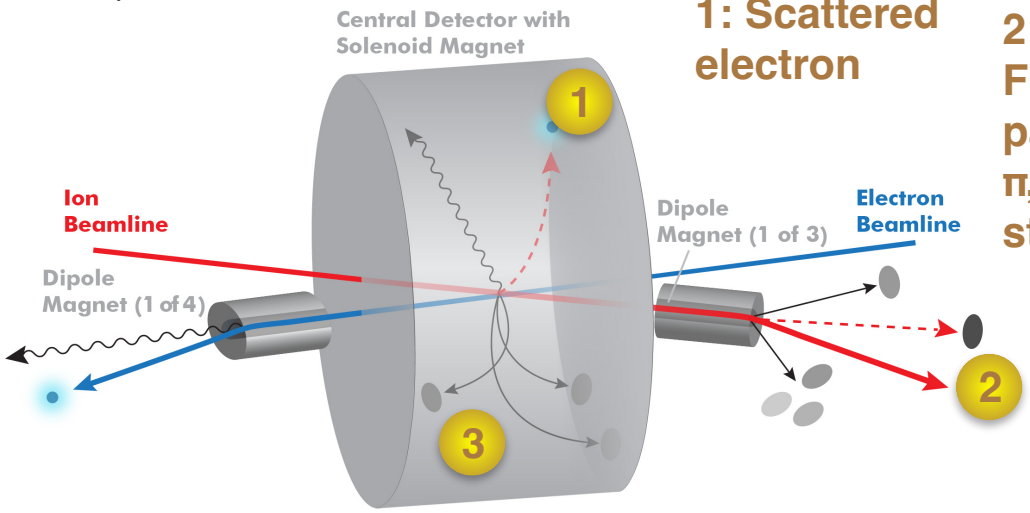
- Low-angel taggers:
  - Forward proton / A fragment spectrometer (Roman pots)
  - Low Q^2 tagger
  - Neutrons on hadron direction

ePIC Detector Design Philosophy

- Overview of general requirements

arXiv:1212.1701

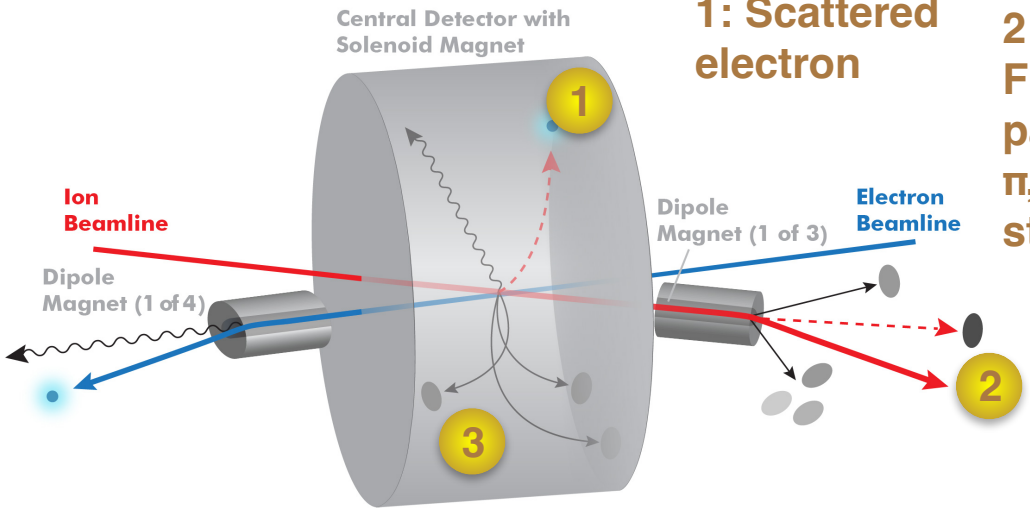


- Acceptance: Close to 4π coverage with a η-coverage ($\eta = -\ln(\tan(\theta/2))$ of approximately $\eta < |3.5|$ combined calorimetry (EM CAL and hadron CAL at least in forward direction) and tracking coverage
- Low dead material budget in particular in rear direction (~10% X/X_0)
- Good momentum resolution $\Delta p/p$ ~ few %
- Electron ID for e/h separation varies with θ / η at the level of 1:10^4 / ~2-3%/√E for η<-2 and ~7%/√E for -2<η<1
- Particle ID for π/K/p separation over wide momentum range (Forward η up to ~50GeV/c / Barrel η up to ~4GeV/c / Rear η up to ~6 GeV/c)
- High spatial vertex resolution ~ 10-20μm for vertex reconstruction
- Low-angel taggers:
  - Forward proton / A fragment spectrometer (Roman pots)
  - Low Q^2 tagger
  - Neutrons on hadron direction
- Luminosity (Absolute and relative) and local polarization direction measurement

ePIC Detector Design Philosophy

- Overview of general requirements

arXiv:1212.1701



1: Scattered electron

2: Fragmented particles (e.g. π, K, p) of struck quark

3: Nuclear and nucleonic fragments / scattered proton

Talk by Dave Gaskell / W 03:30 PM: Electron and Hadron Beam Polarimetry

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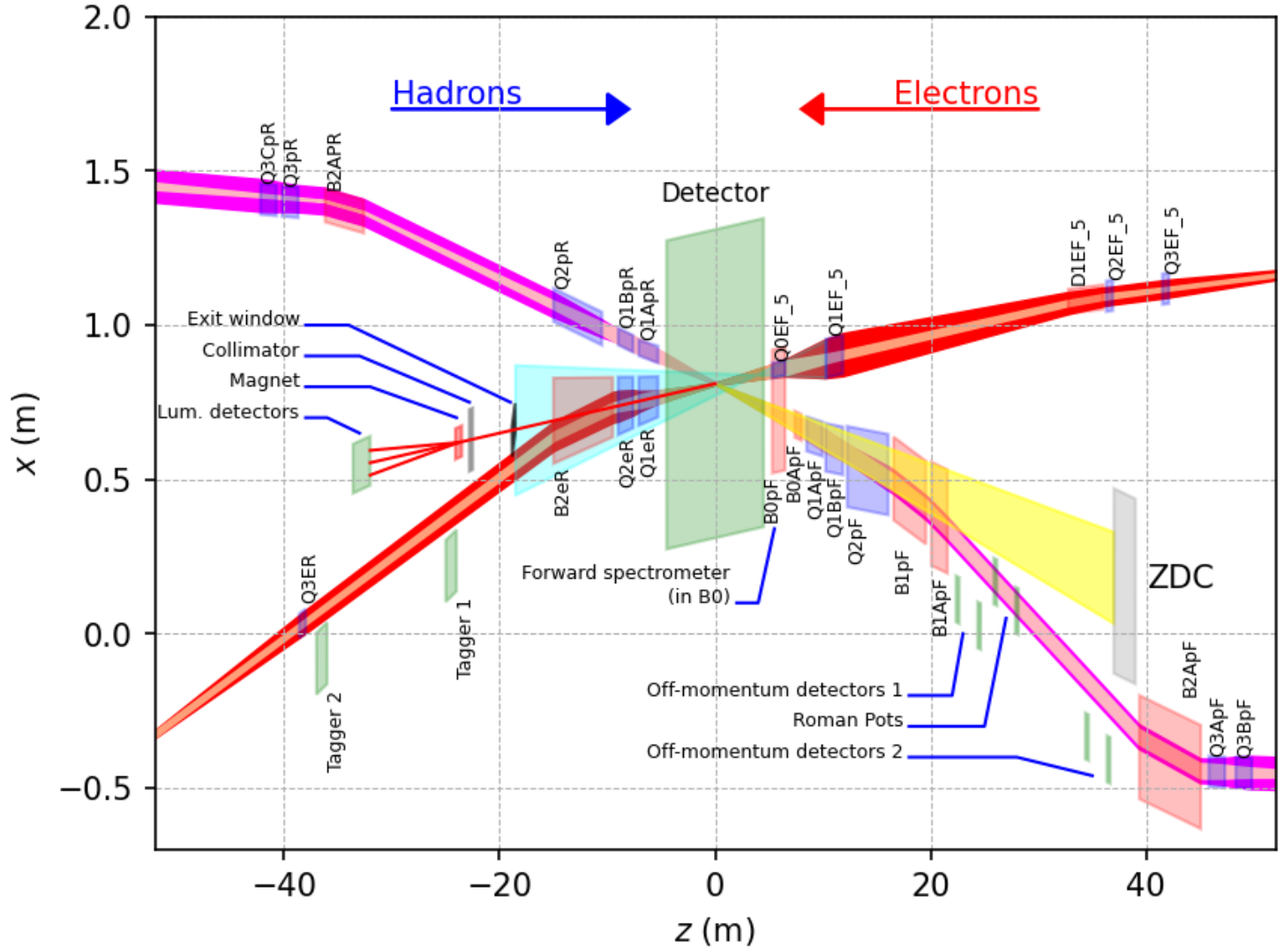
ePIC Detector Design Philosophy

- Global ePIC design overview



ePIC Detector Design Philosophy

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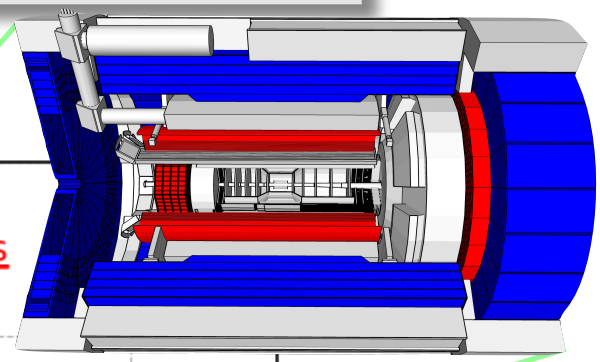

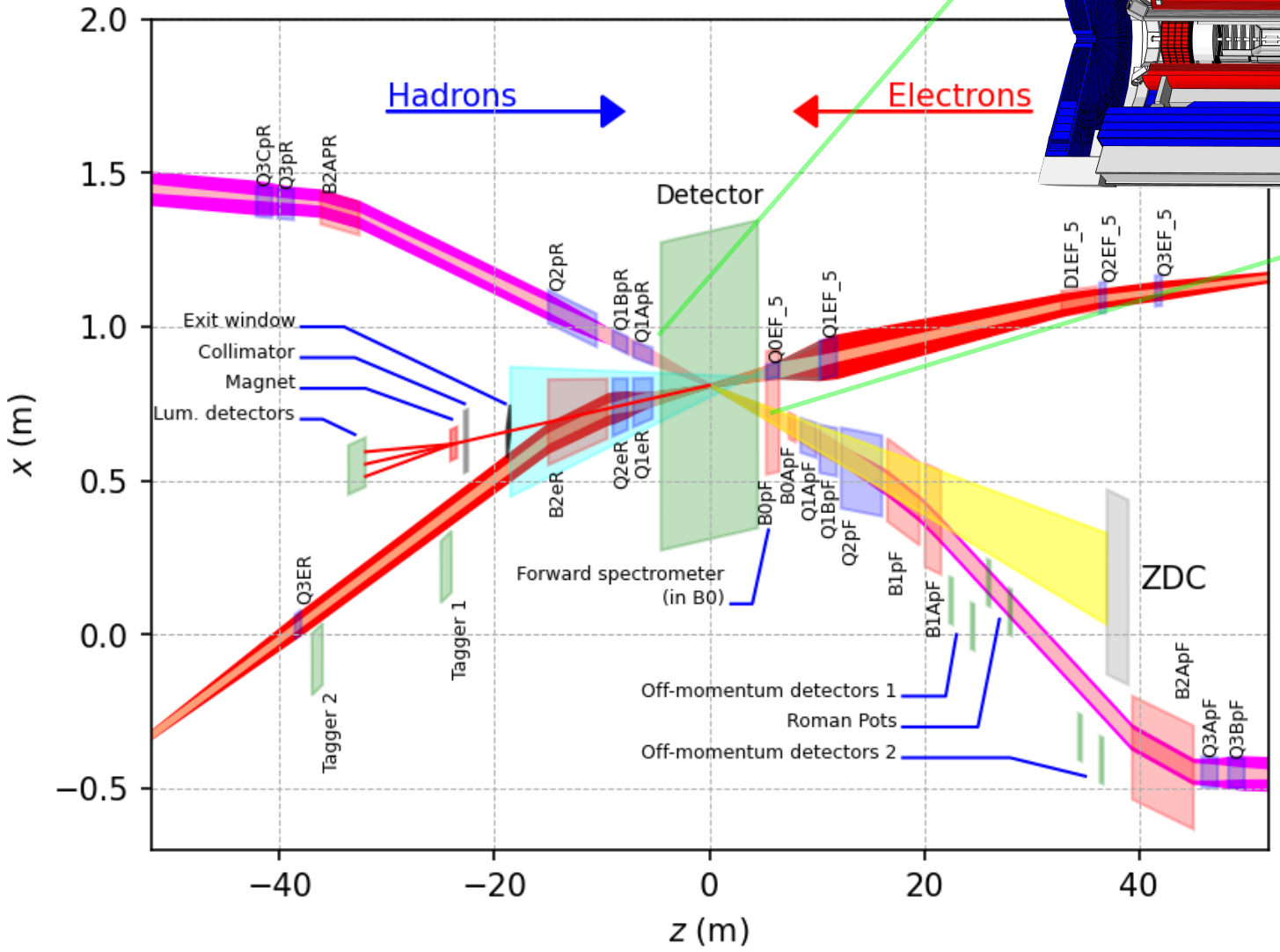

ePIC Detector Design Philosophy

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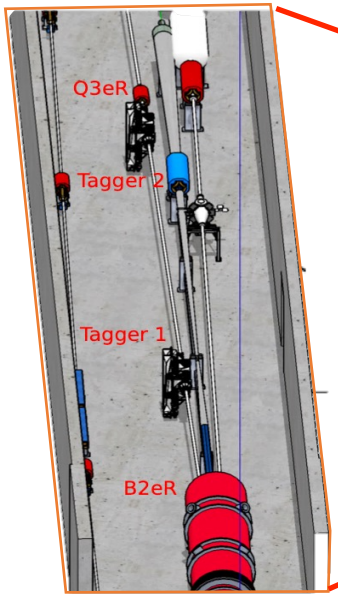
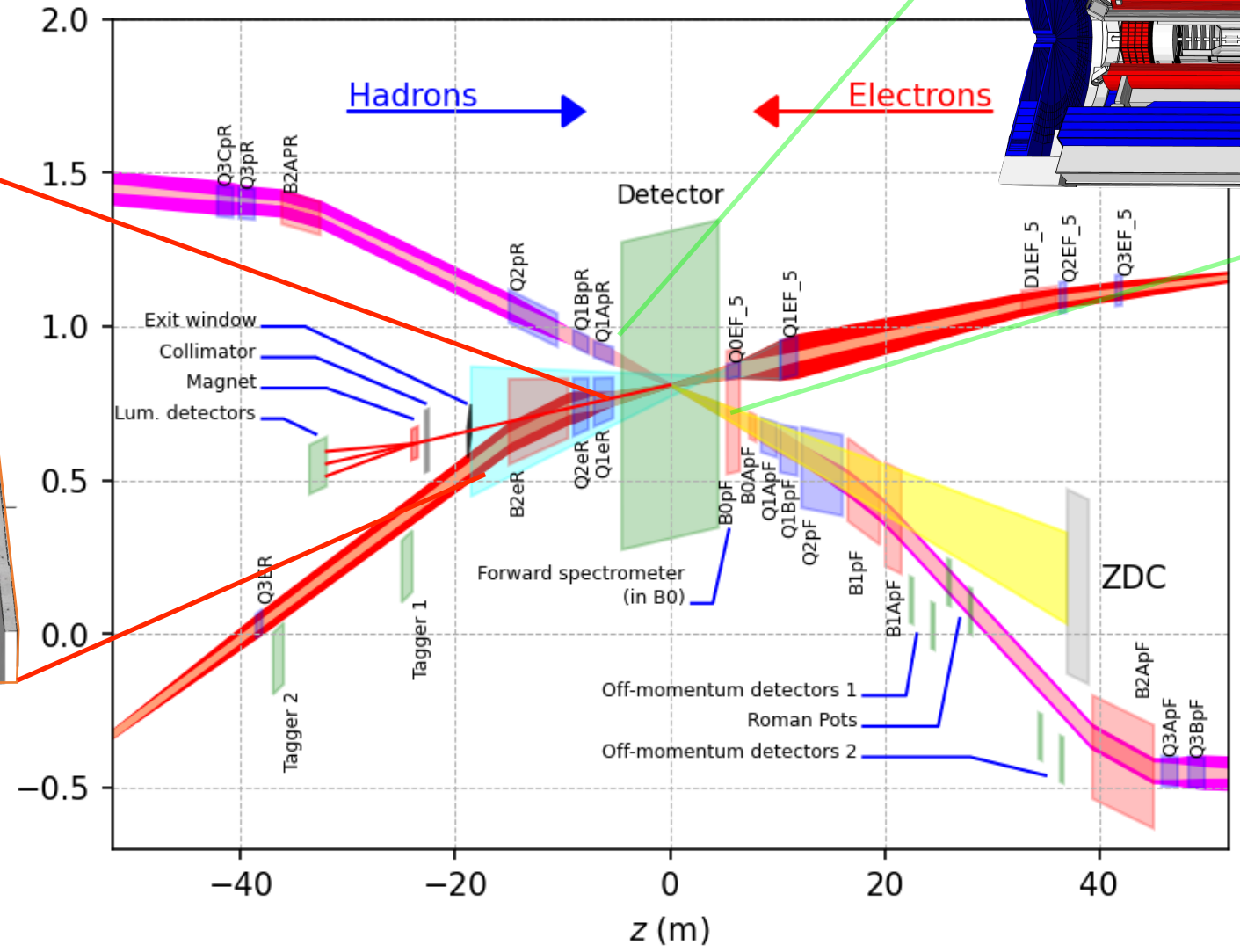
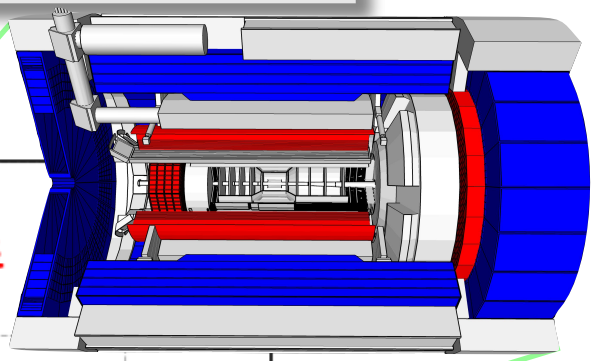


Far Backward Detectors

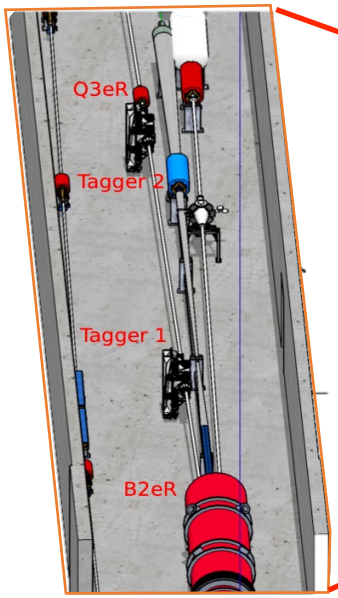




Central Detectors

ePIC Detector Design Philosophy

- Global ePIC design overview



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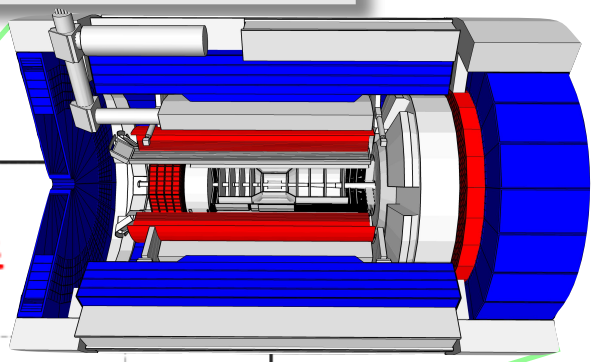

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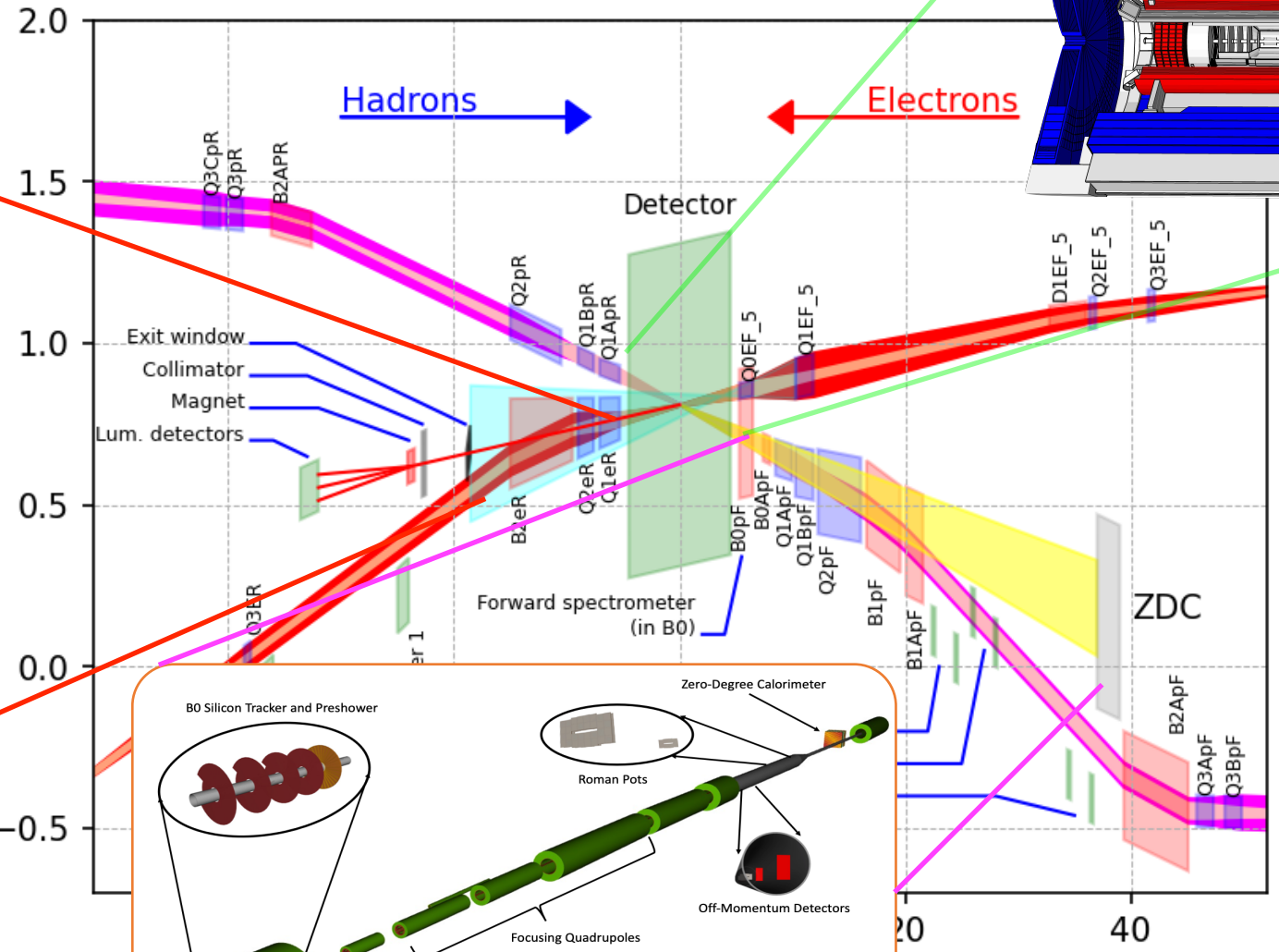
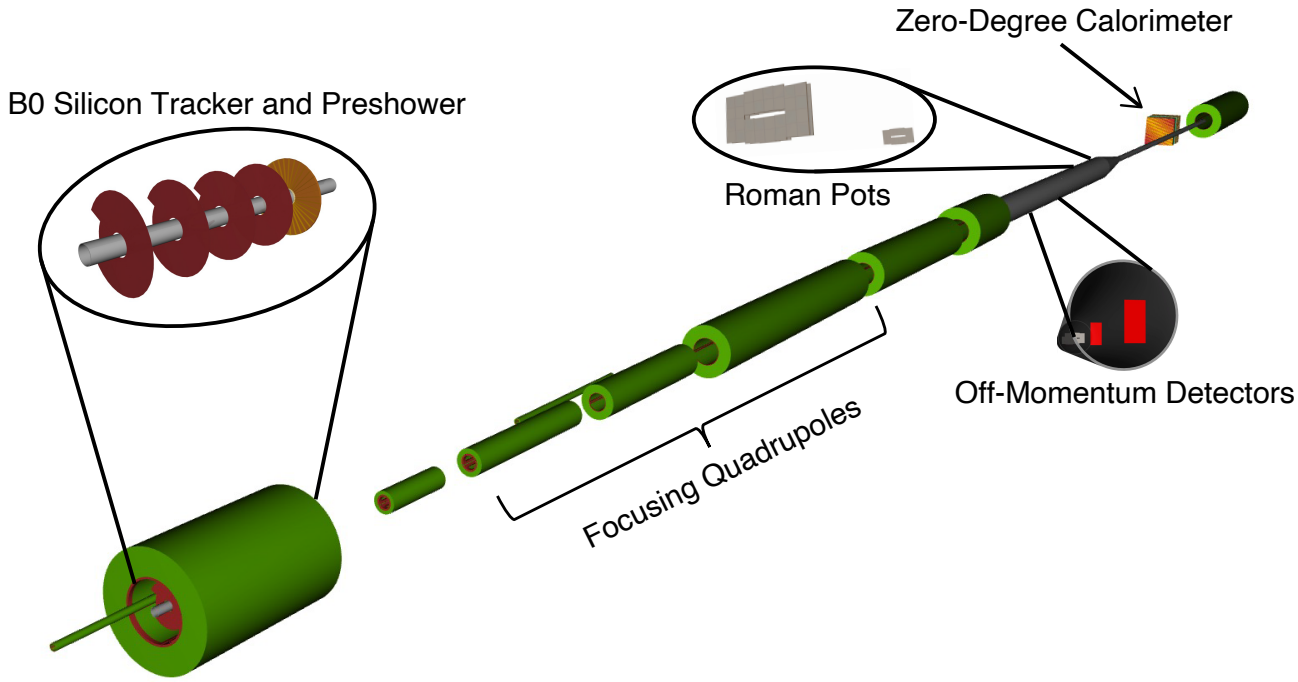


Far Forward Detectors

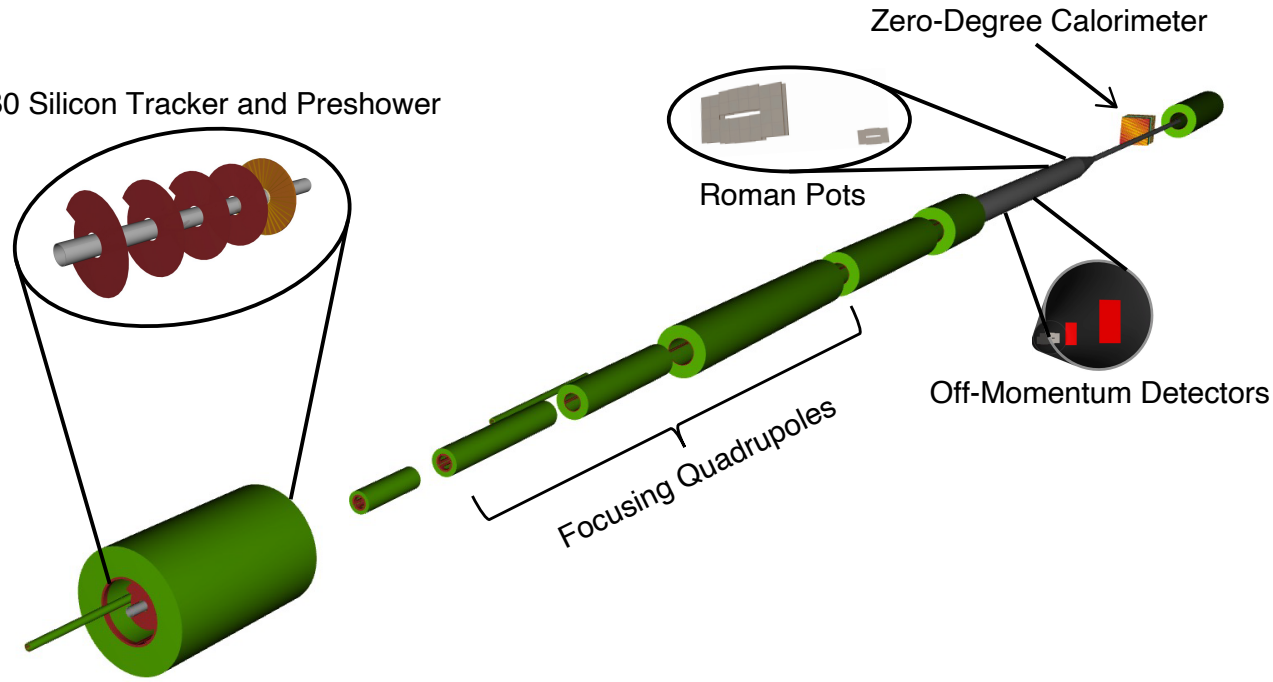
ePIC Detector Design Philosophy

- FarForward detector system



ePIC Detector Design Philosophy

- FarForward detector system
  - FarForward detector system to measure very forward neutral and charged particle production: 4 detector systems



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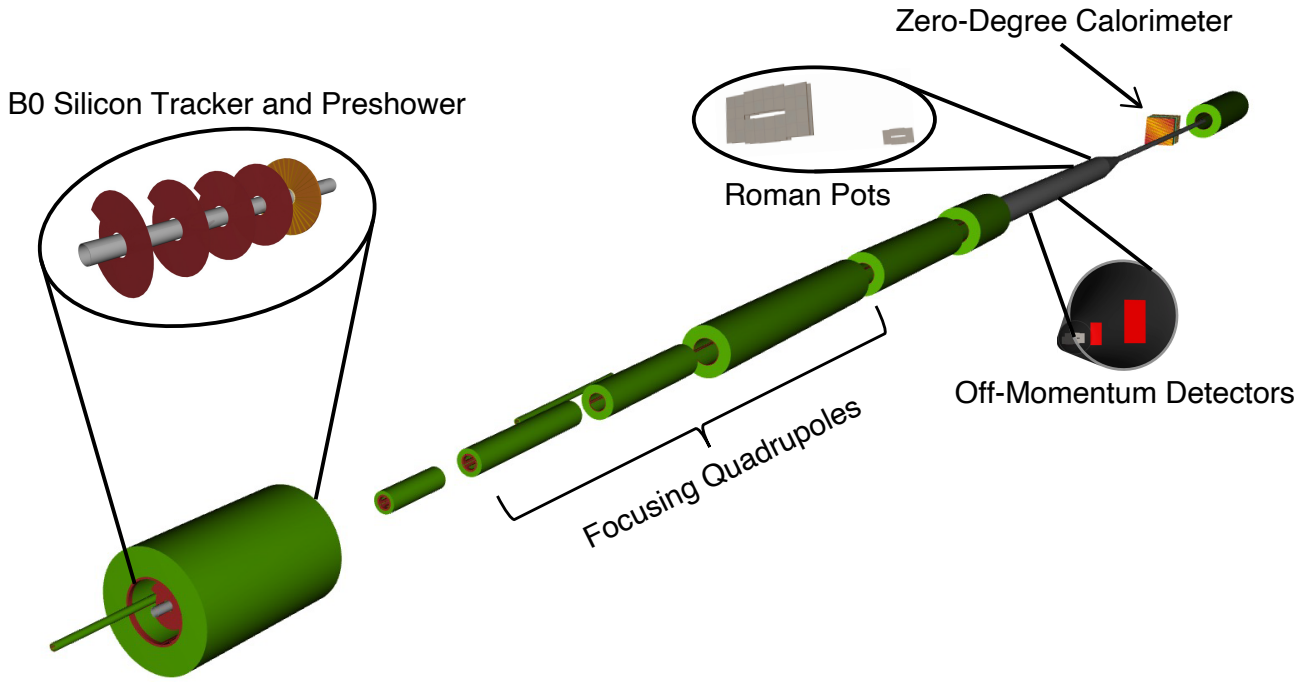

Detector	θ accep. [mrad]	Rigidity accep.	Particles	Technology
B0 tracker	5.5–20.0	N/A	Charged particles Tagged photons	MAPS AC-LGAD
Off-Momentum Detector	0.0–5.0	45%–65%	Charged particles	AC-LGAD
Roman Pots	0.0–5.0	60%–95%*	Protons Light nuclei	AC-LGAD
Zero-Degree Calorimeter	0.0–4.0	N/A	Neutrons Photons	W/SciFi (ECal) Pb/Sci (HCal)

ePIC Detector Design Philosophy

FarForward detector system

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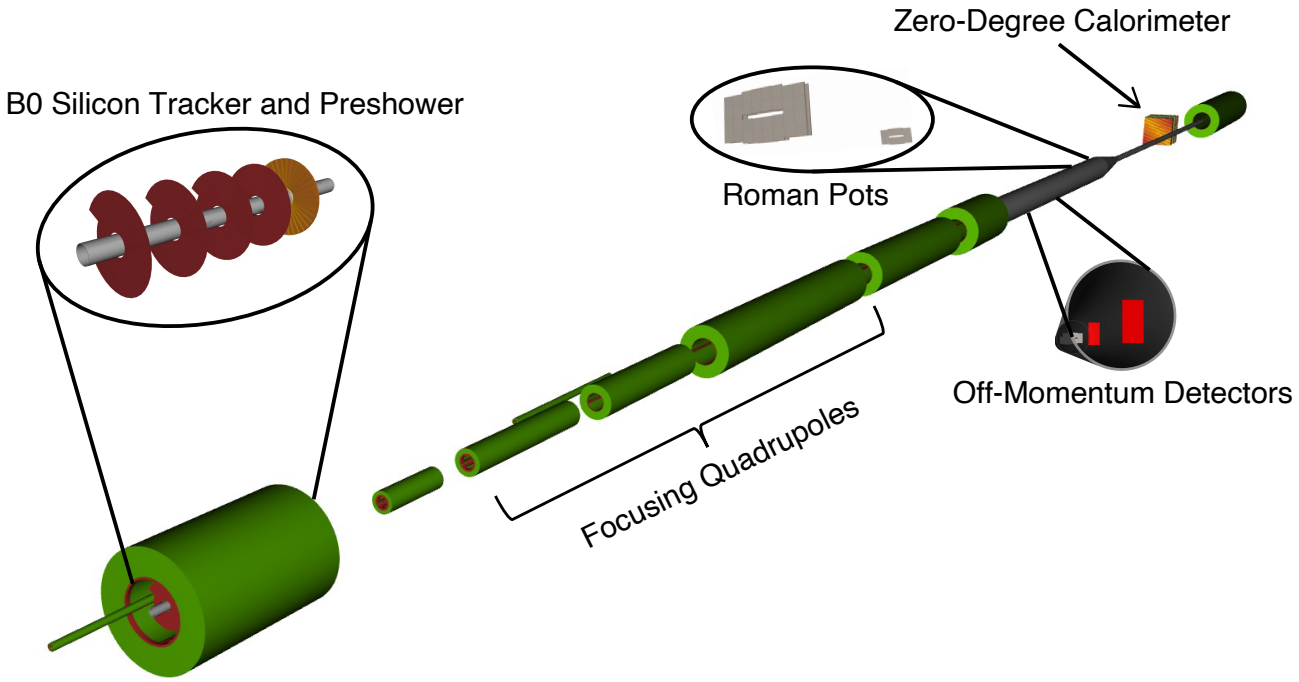
- B0 system: Measures charged particles in the forward direction and tags neutral particles



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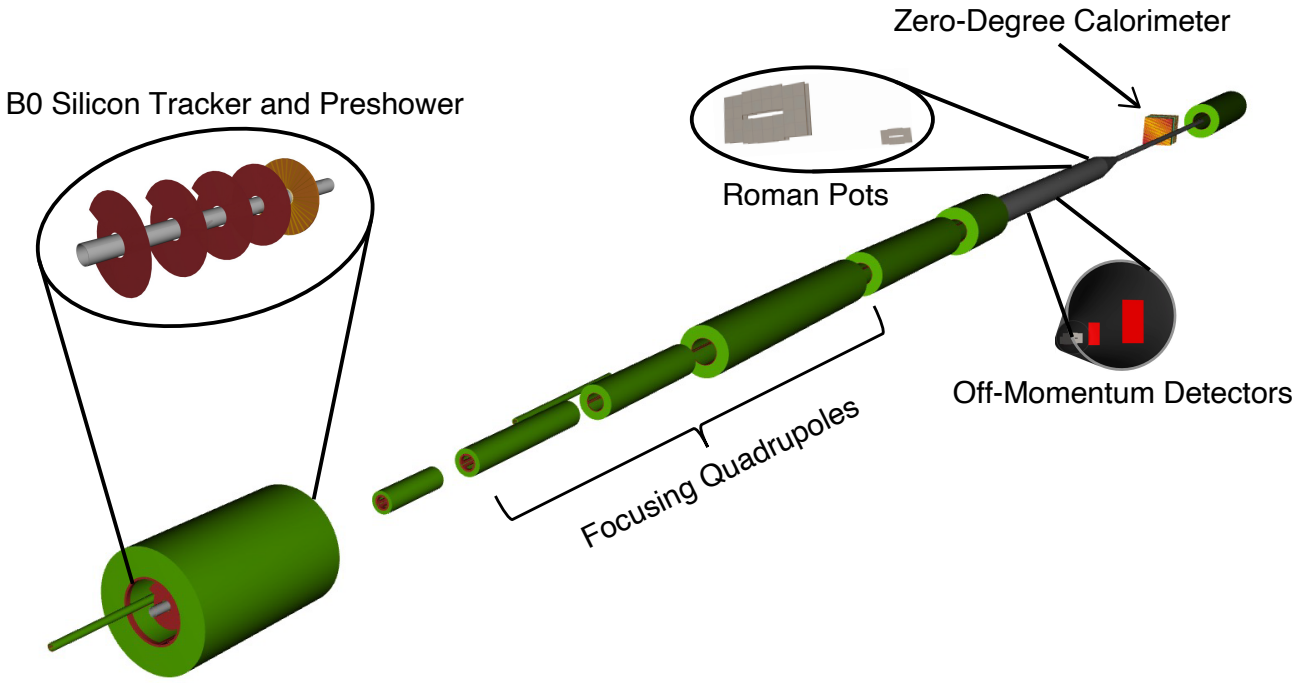

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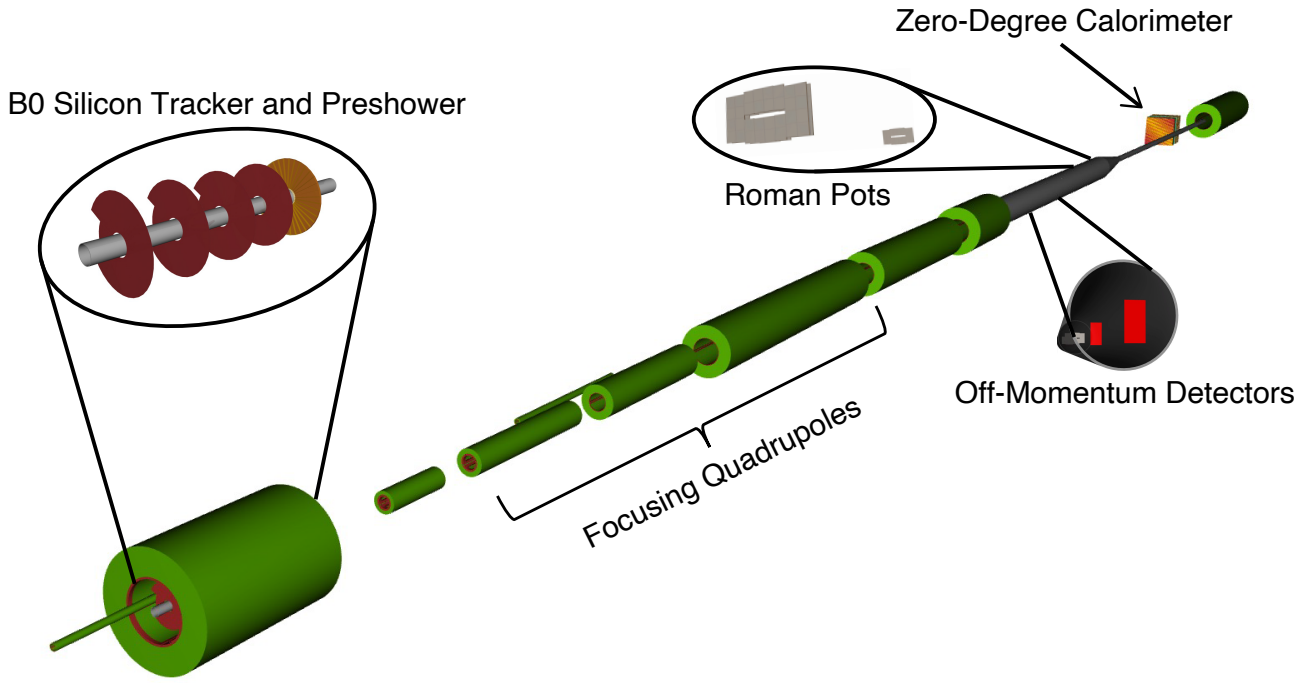

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ePIC Detector Design Philosophy

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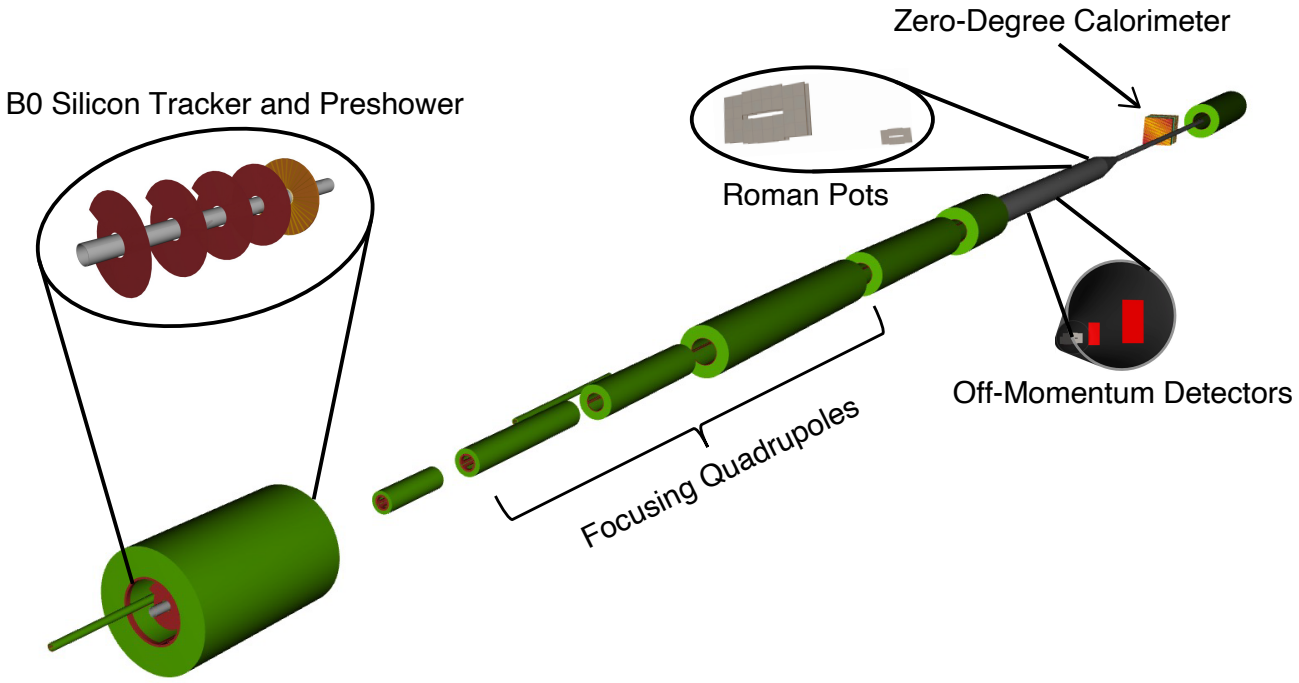
- Roman pot detectors: Measure charged particles near the beam
- Zero-degree calorimeter: Measures neutral particles at small angles



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ePIC Detector Design Philosophy

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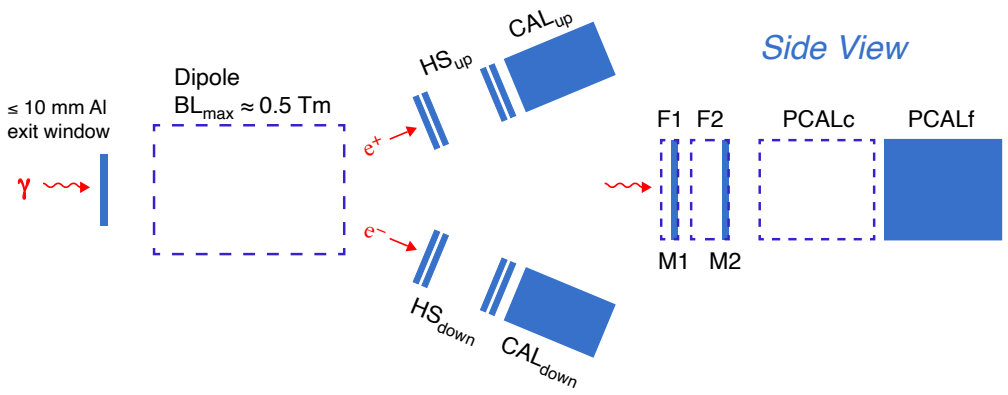
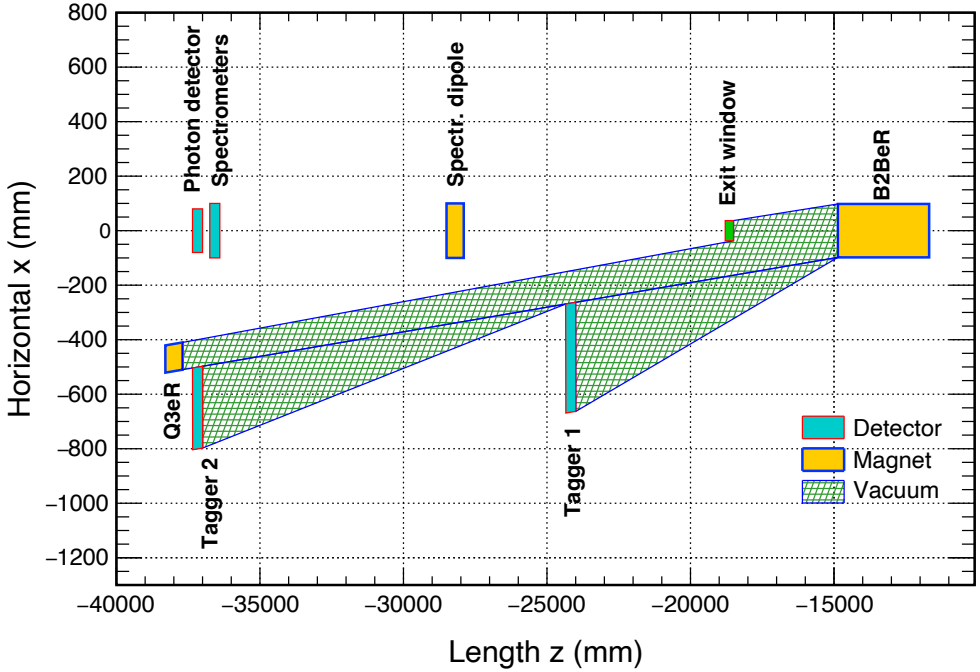
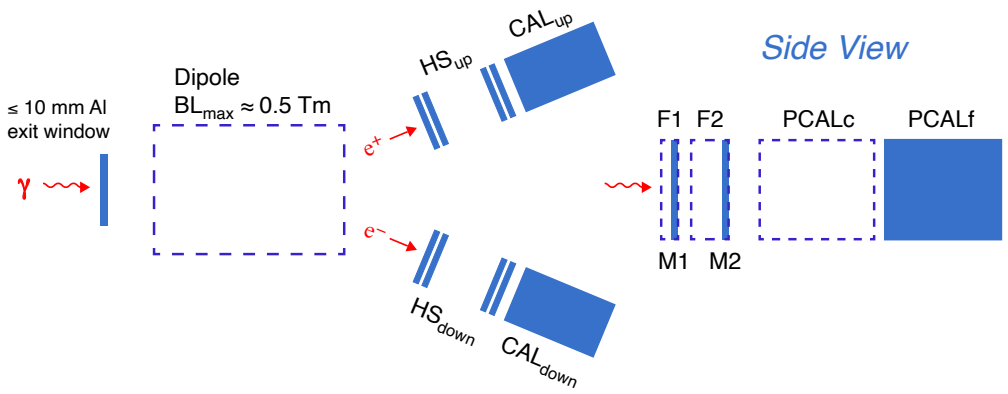


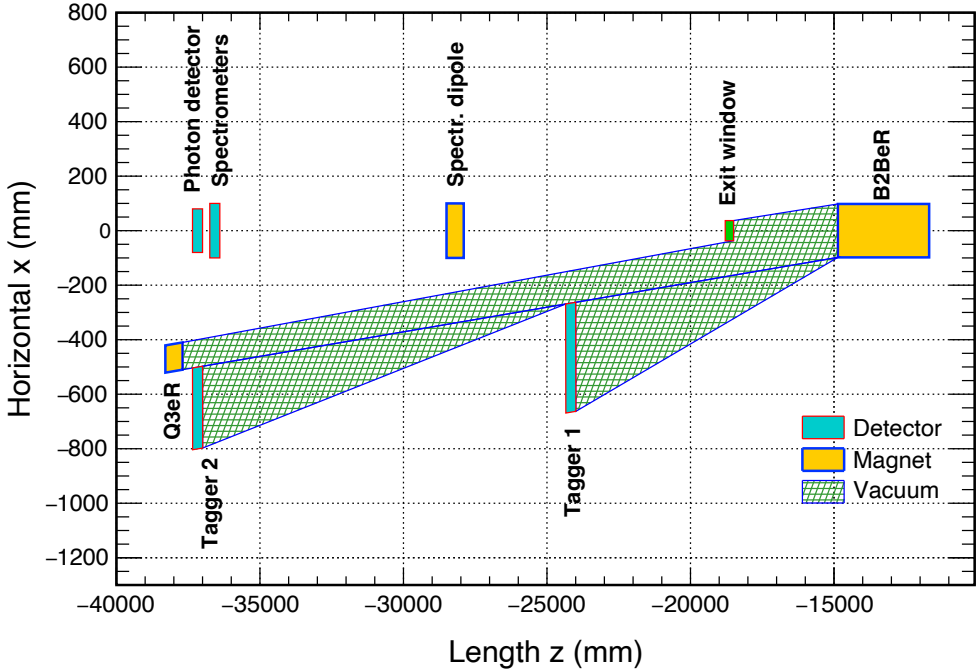


Talk by Krzysztof Piotrzkowski / W 04:00 PM: EIC Luminosity Measurement

ePIC Detector Design Philosophy

- FarBackward system





- High precision luminosity measurement at 1% level for absolute luminosity and 0.01% for relative luminosity measurement using several methods based on the Bremsstrahlung process:
  1. Counting photons converted in thin exit window using dipole field and measuring e^+e^- pairs
  2. Energy measurement of unconverted photons
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Talk by Krzysztof Piotrzkowski / W 04:00 PM: EIC Luminosity Measurement

ePIC Detector Design Philosophy

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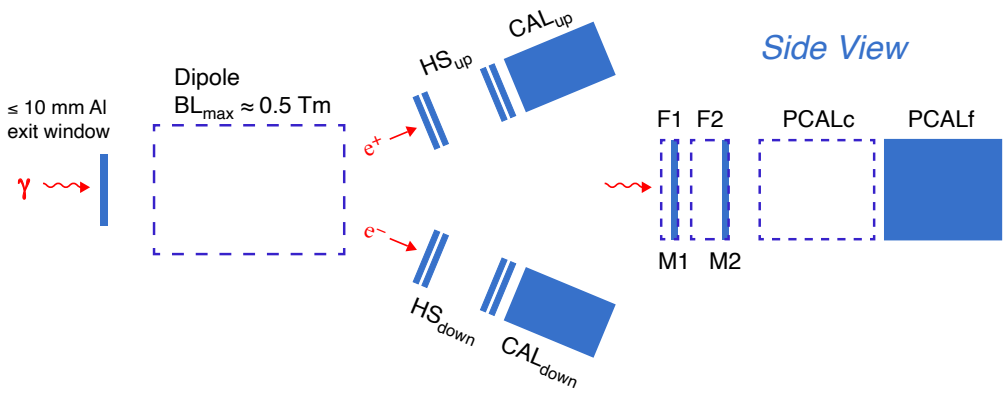

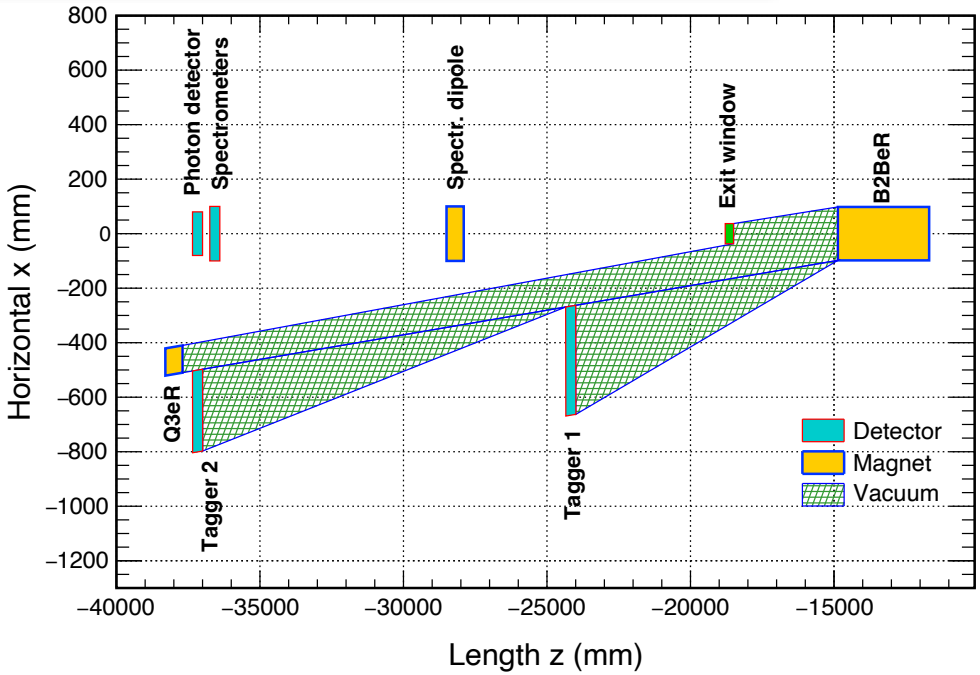

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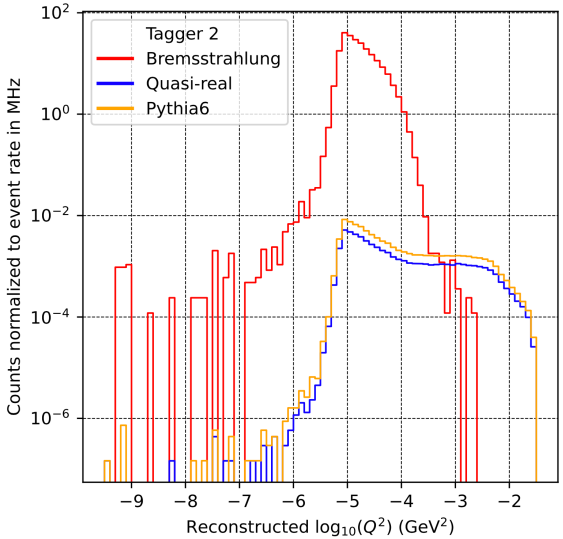
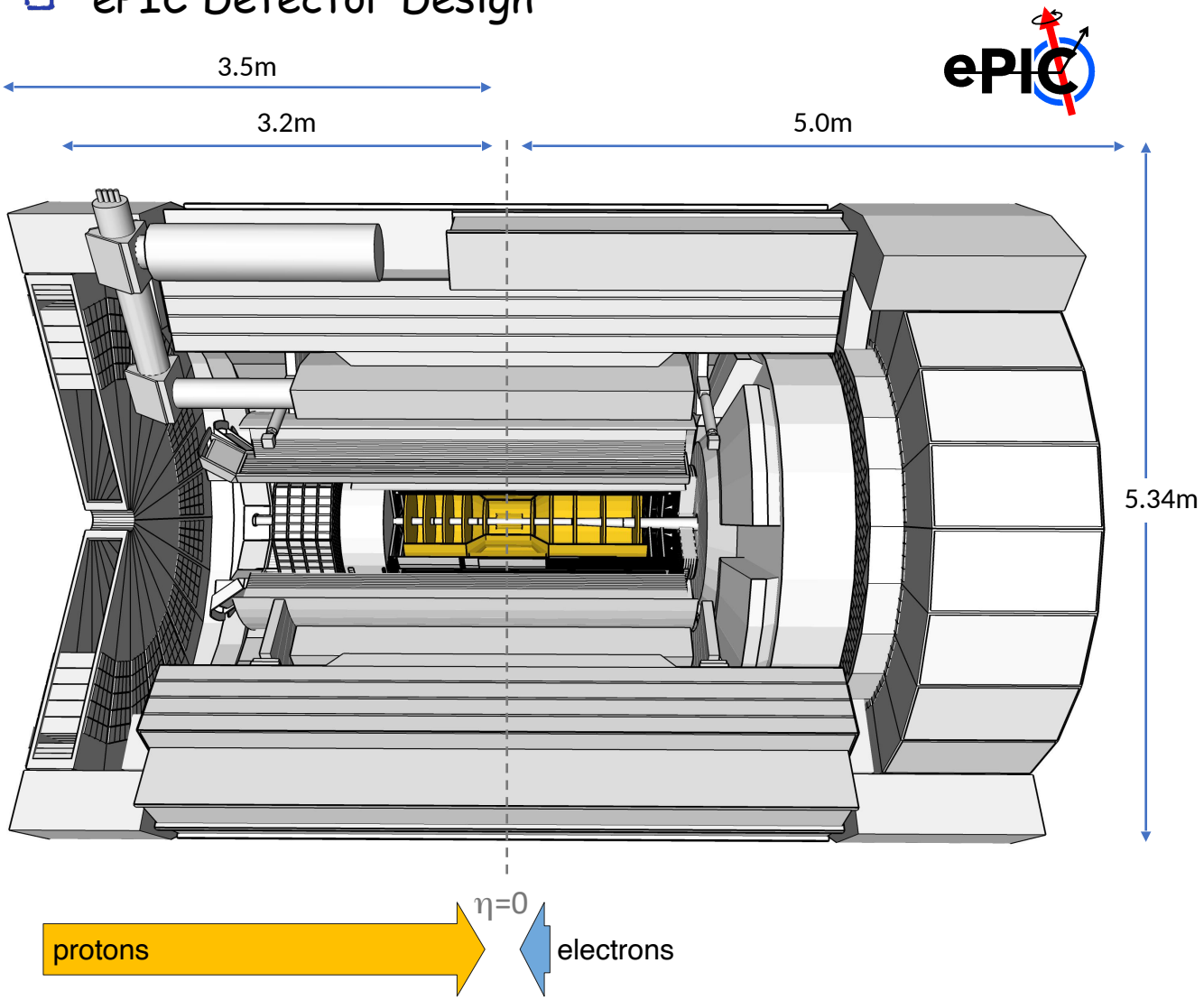
- Low Q2 taggers - PHP tagger



Talk by Krzysztof Piotrzkowski / W 04:00 PM: EIC Luminosity Measurement

ePIC Detector Design Philosophy

ePIC Detector Design



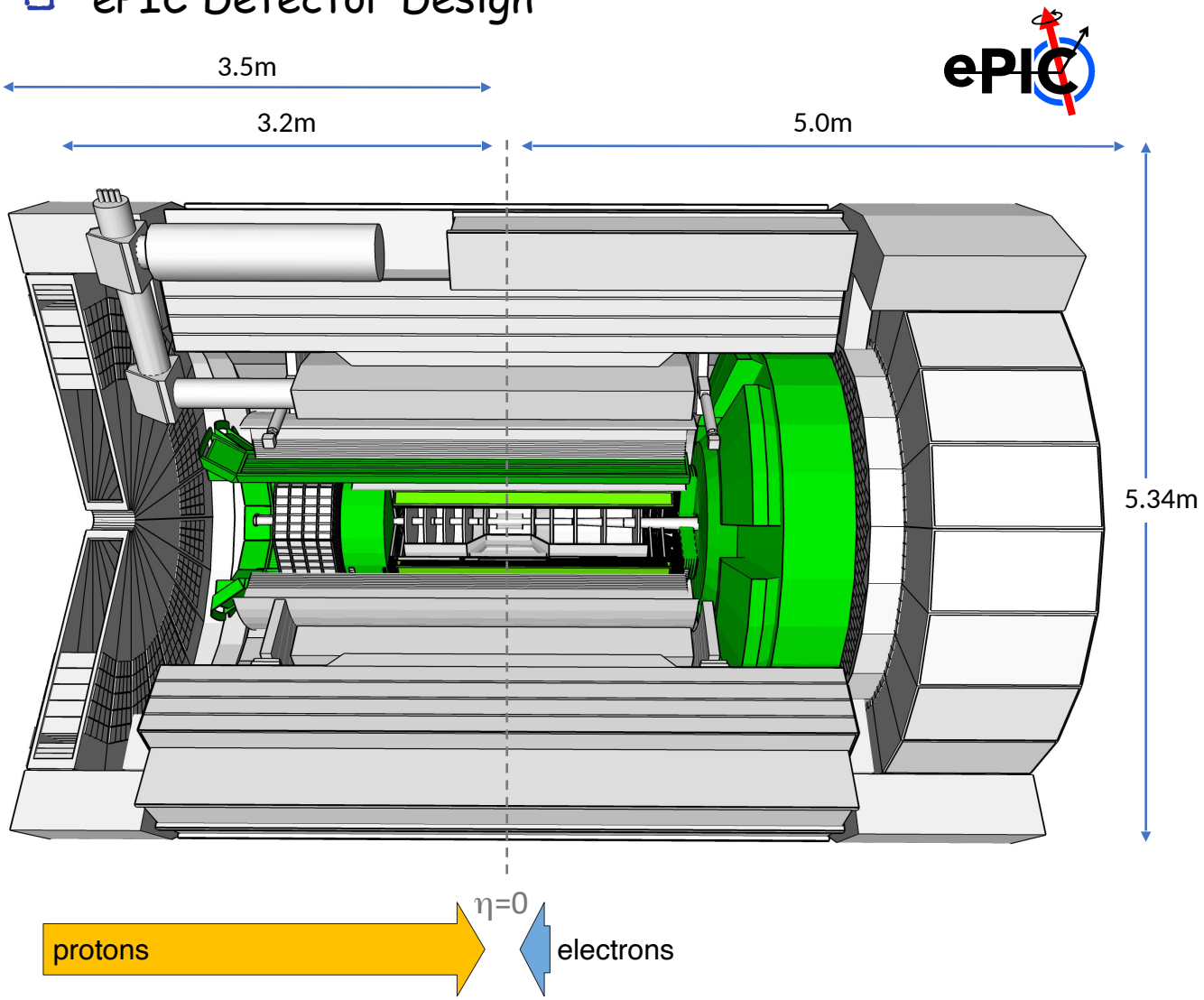
Tracking:

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

PID:

ePIC Detector Design Philosophy

ePIC Detector Design



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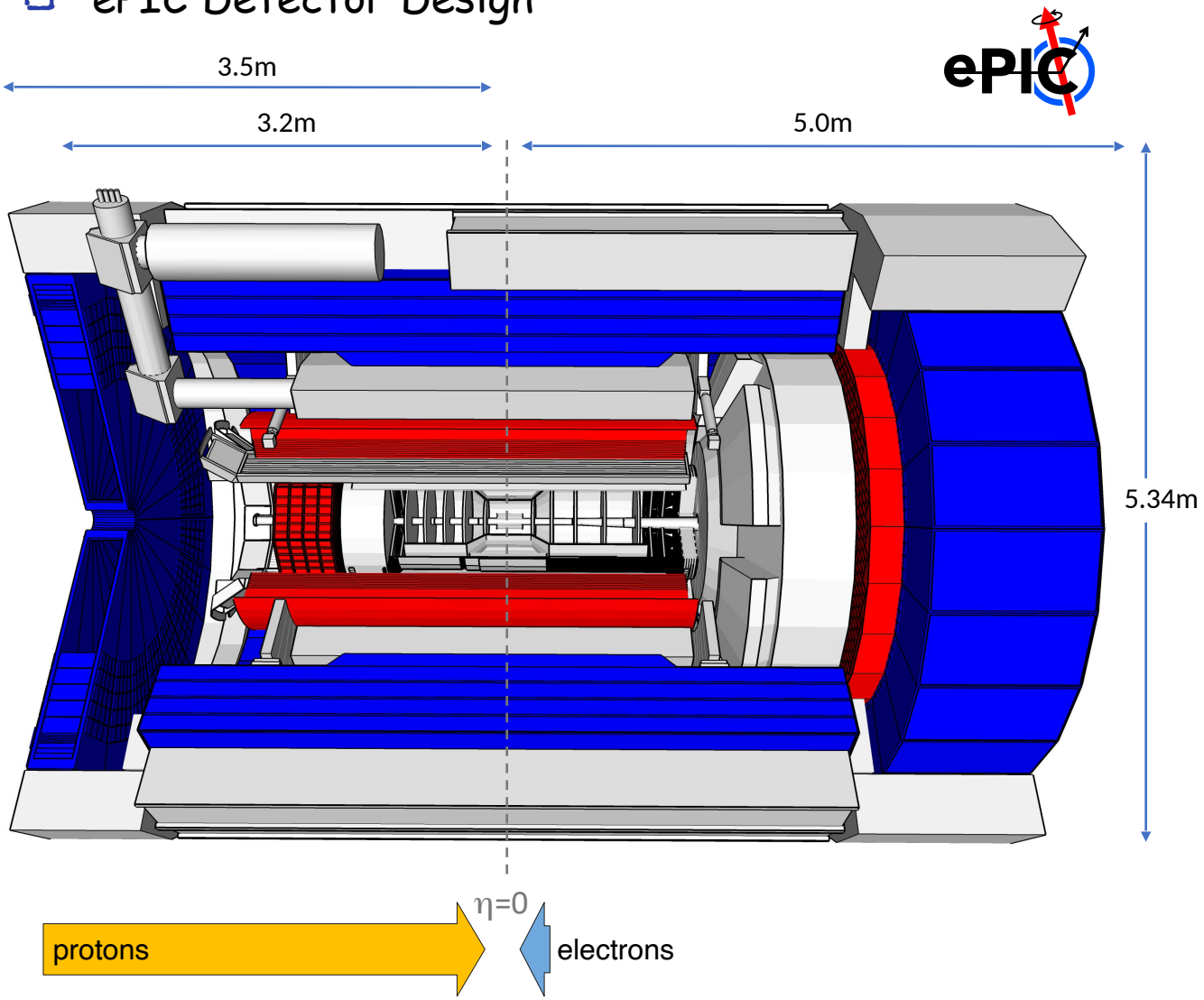
- hpDIRC
- pfRICH
- dRICH
- AC-LGAD (~30ps TOF)

Calorimetry:

- Imaging Barrel EMCal

ePIC Detector Design Philosophy

ePIC Detector Design



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PID:

- hpDIRC
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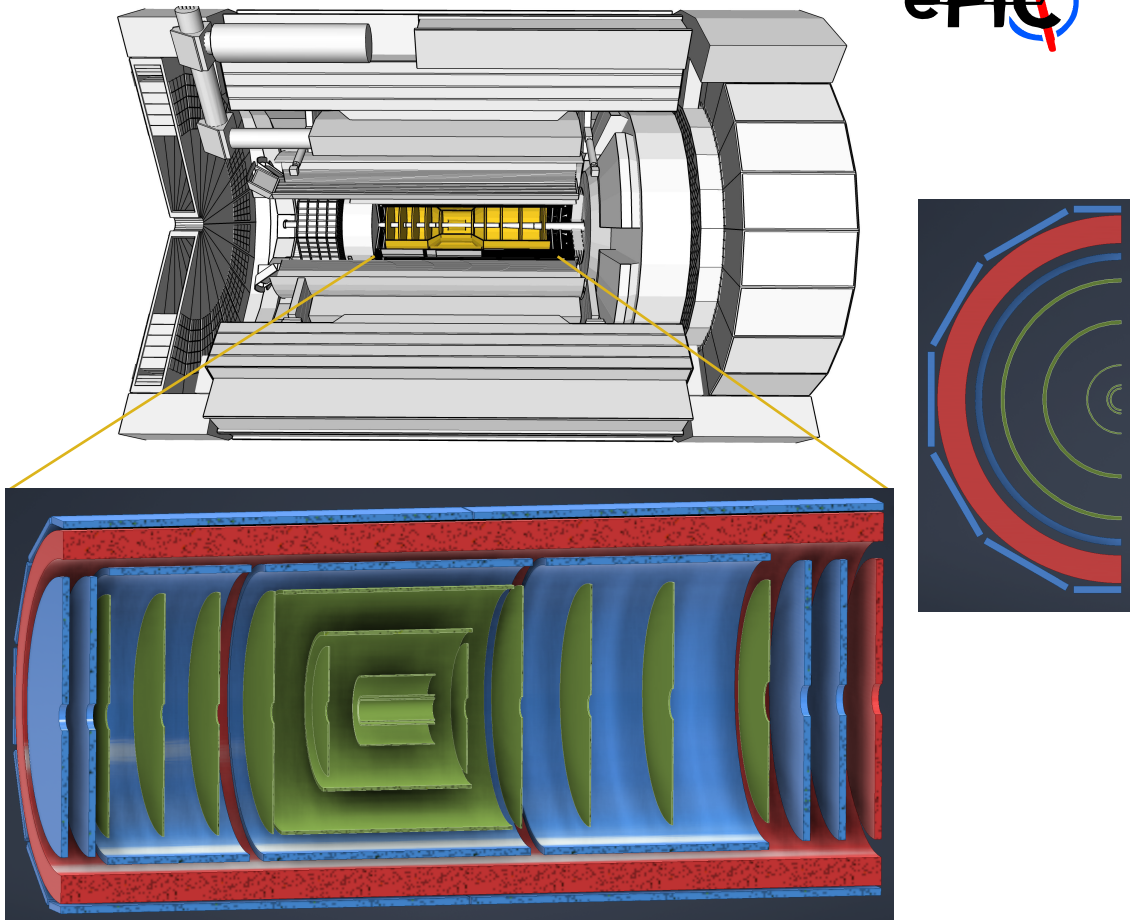
- AC-LGAD (~30ps TOF)

Calorimetry:

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

ePIC Detector Design Philosophy

- ePIC Tracking Detectors: Layout

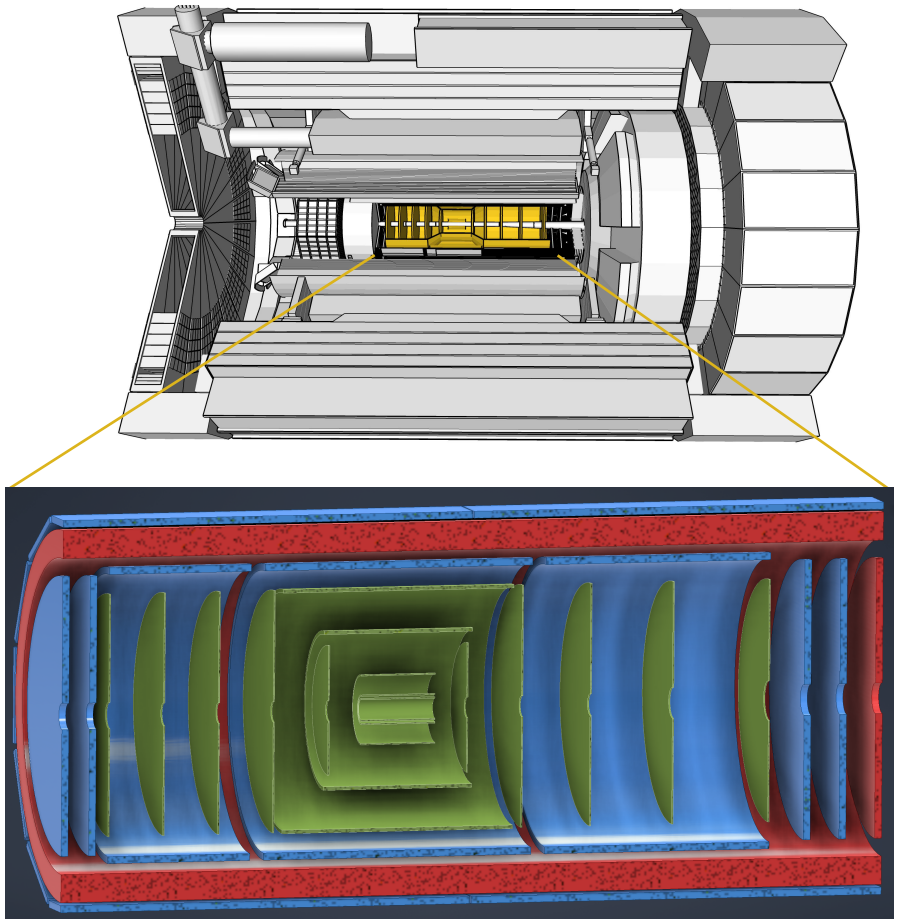


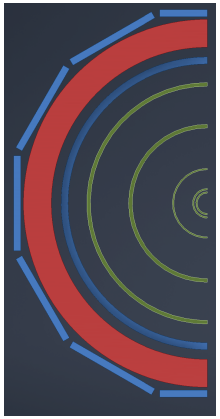
- MAPS Barrel + Disks
- MPGD Barrels + Disks
- AC-LGAD based ToF

Talk by Matt Posik / 05:00 PM: ePIC Tracking System Overview and Performance

ePIC Detector Design Philosophy

- ePIC Tracking Detectors: Layout





- MAPS Tracker:
  - Small pixels (20 μm), low power consumption (<20 mW/cm^2) and material budget (0.05% to 0.55% X/X_0) per layer
  - Based on ALICE ITS3 development
  - Vertex layers optimized for beam pipe bake-out and ITS-3 sensor size
  - Forward and backward disks
- MPGD Layers:
  - Provide timing and pattern recognition
  - Cylindrical μMEGAs
  - Planar μRWell's before hpDIRC - Impact point and direction for ring seeding
- AC-LGAD TOF and AstroPix (BECAL):
  - Additional space point for pattern recognition / redundancy
  - Fast hit point / Low p PID

- MAPS Barrel + Disks
- MPGD Barrels + Disks
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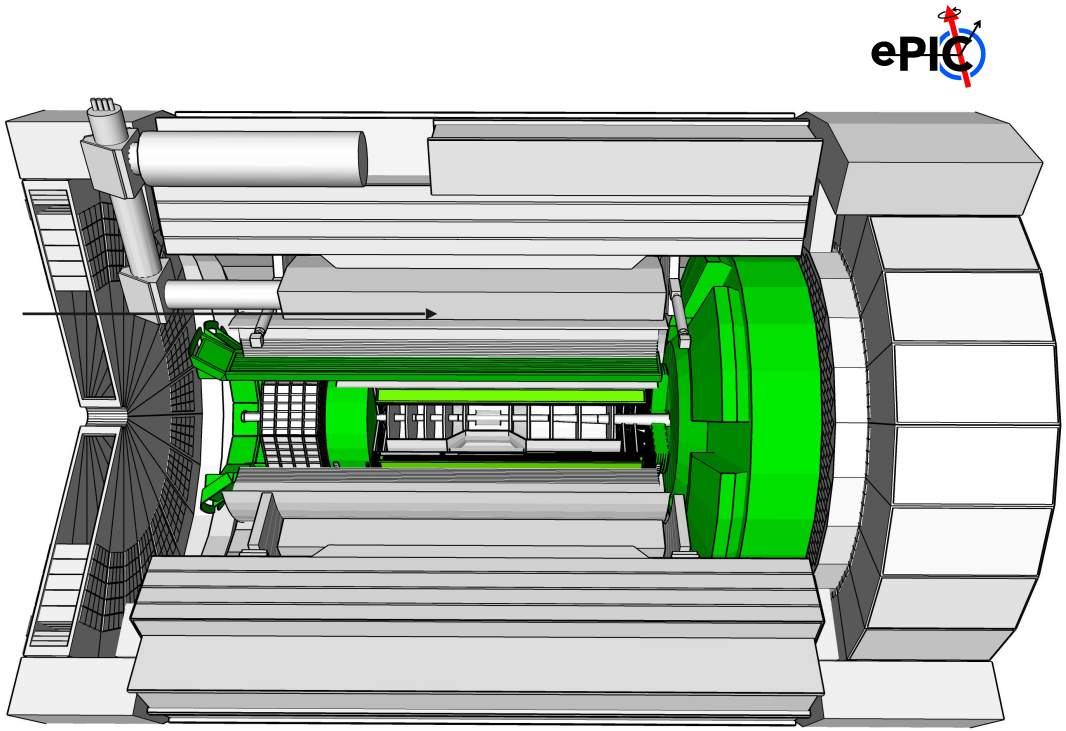
Talk by Matt Posik / 05:00 PM: ePIC Tracking System Overview and Performance

ePIC Detector Design Philosophy

- ePIC PID Detectors: Layout



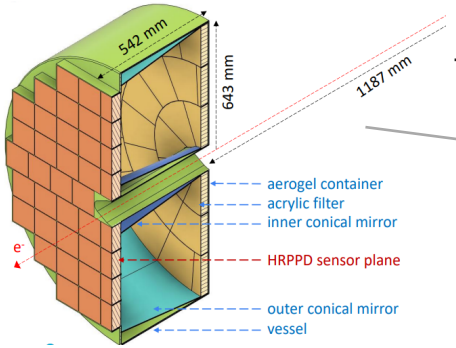
Talk by Roberto Preghenella / 05:30 PM: Particle Identification with the ePIC detector at the EIC

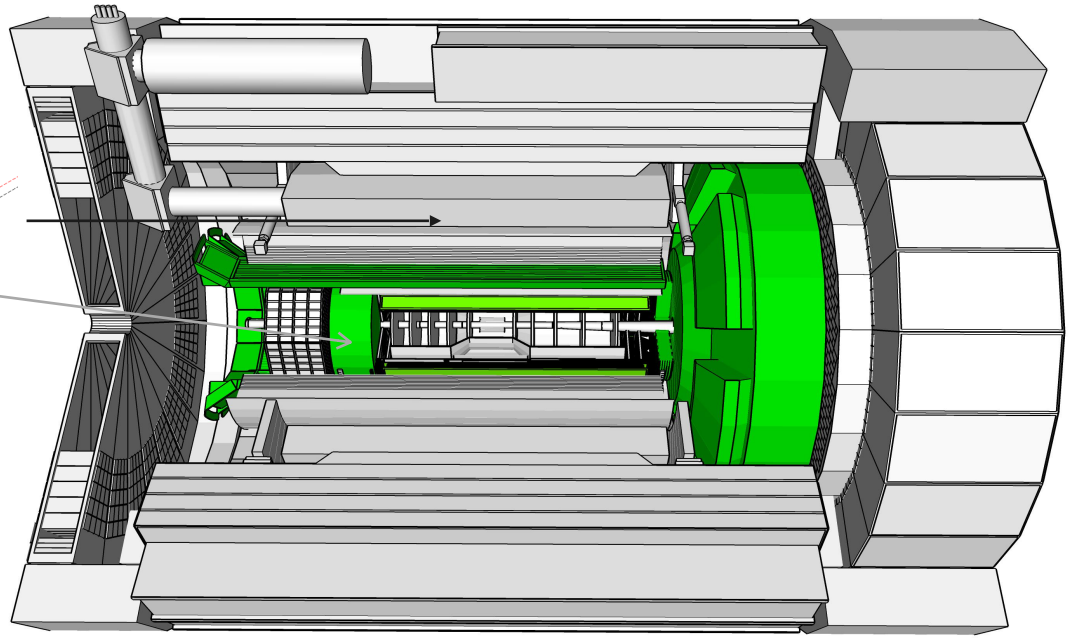
ePIC Detector Design Philosophy

ePIC PID Detectors: Layout

Proximity Focused (pfRICH)

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





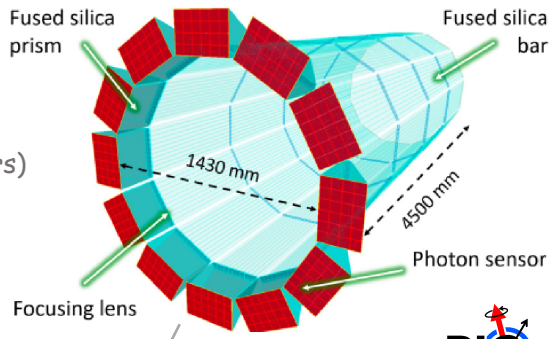
Talk by Roberto Preghenella / 05:30 PM: Particle Identification with the ePIC detector at the EIC

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



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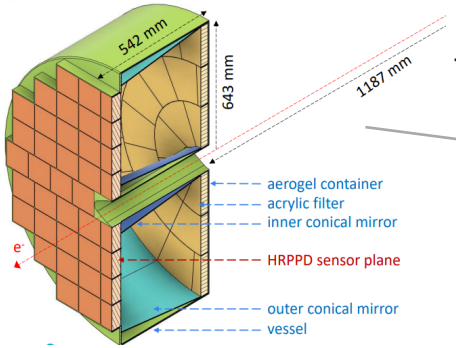

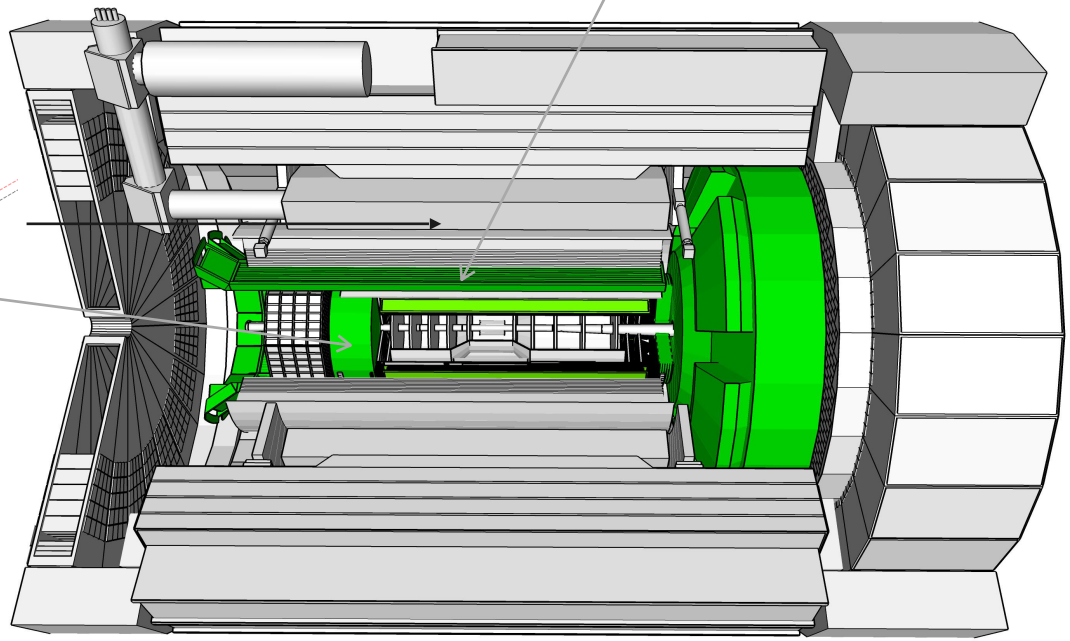

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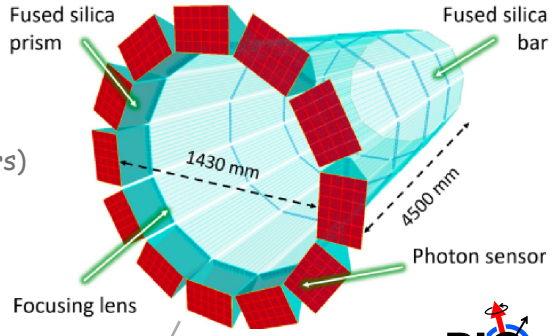
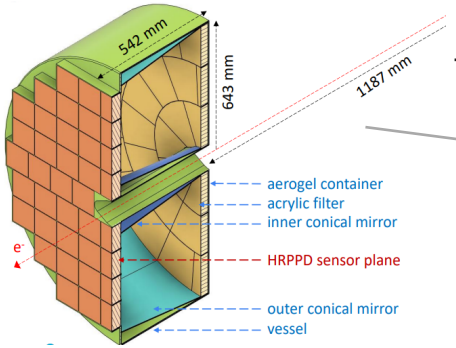
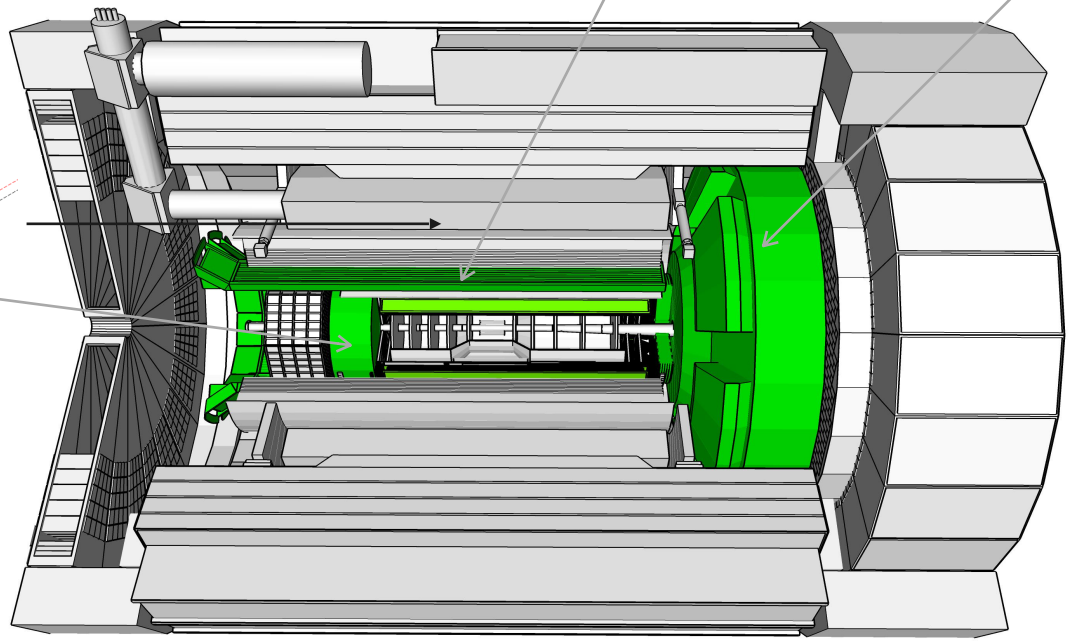


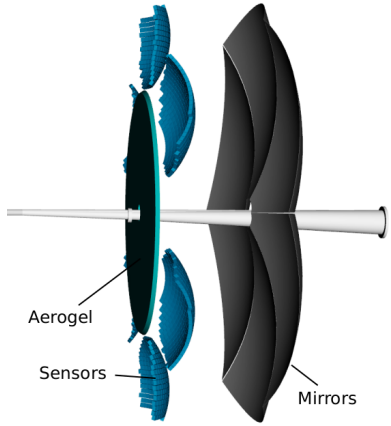
Proximity Focused (pfRICH)

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





Dual-Radiator RICH (dRICH)



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

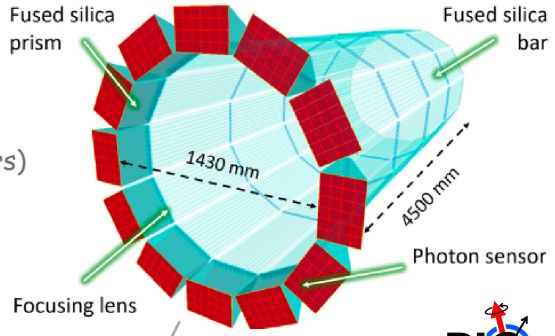
Talk by Roberto Preghenella / 05:30 PM: Particle Identification with the ePIC detector at the EIC

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



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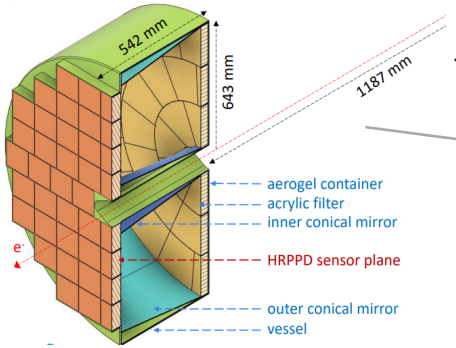

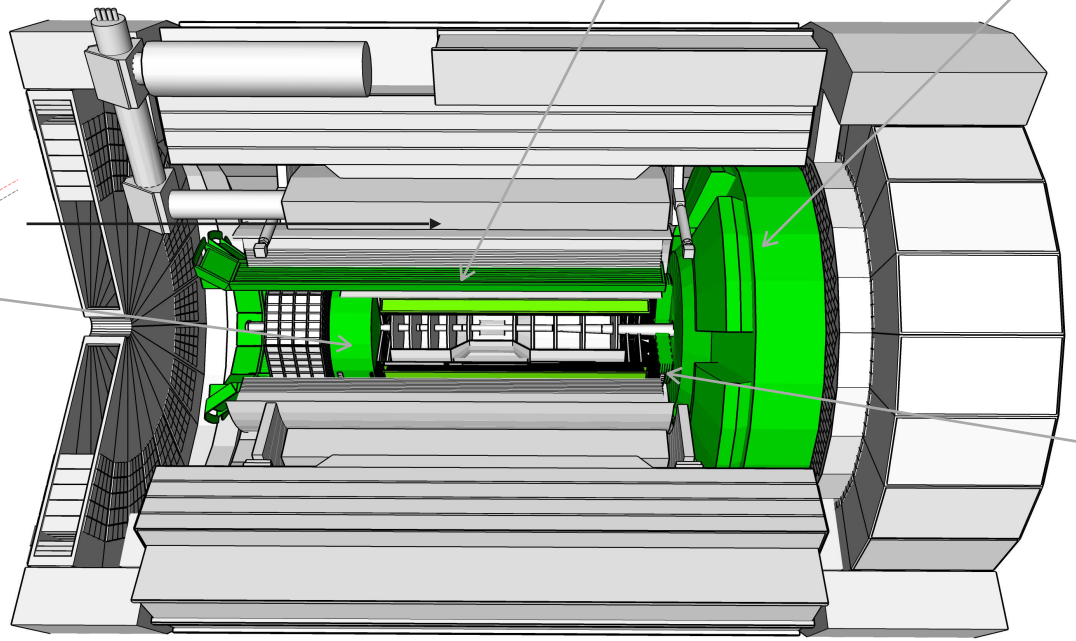

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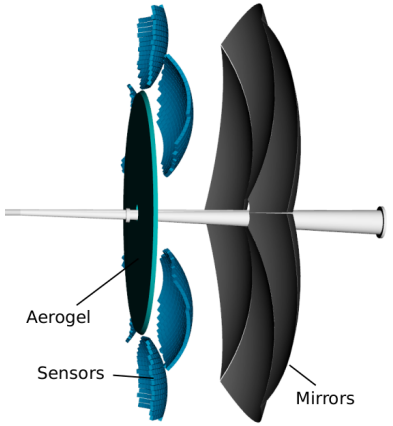

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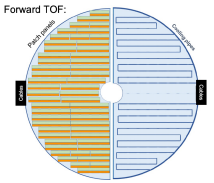
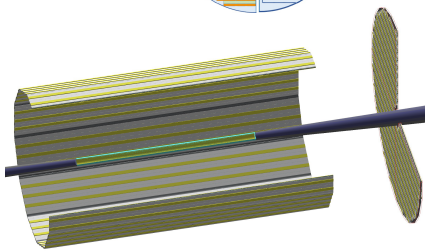
- Sensors tiled on spheres (SiPMs)
- π/K 3σ sep. at 50 GeV/c

AC-LGAD TOF (~30ps)



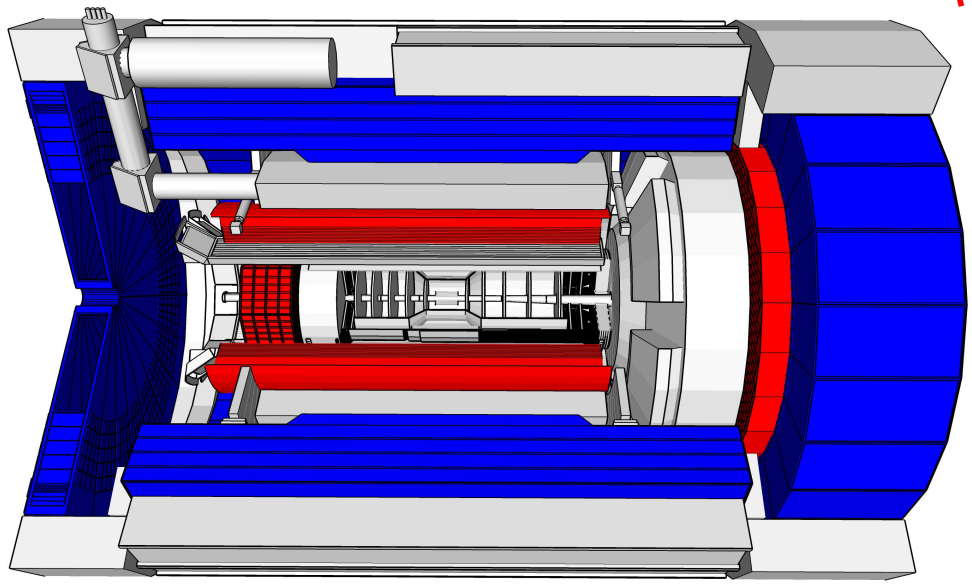


- Accurate space point for tracking / Low p PID
- Forward disk and central barrel

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

ePIC Detector Design Philosophy

- ePIC Calorimeter Detectors: Layout



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

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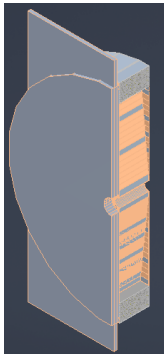
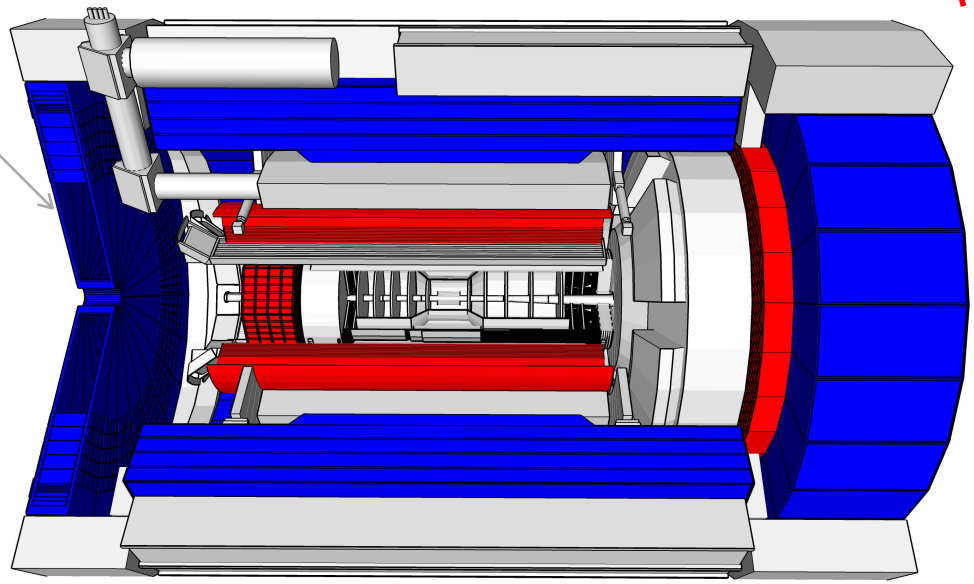


Backwards HCal
Steel/Sc Sandwich tail catcher



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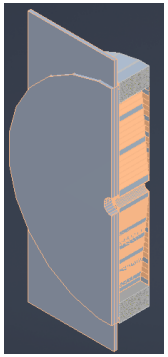

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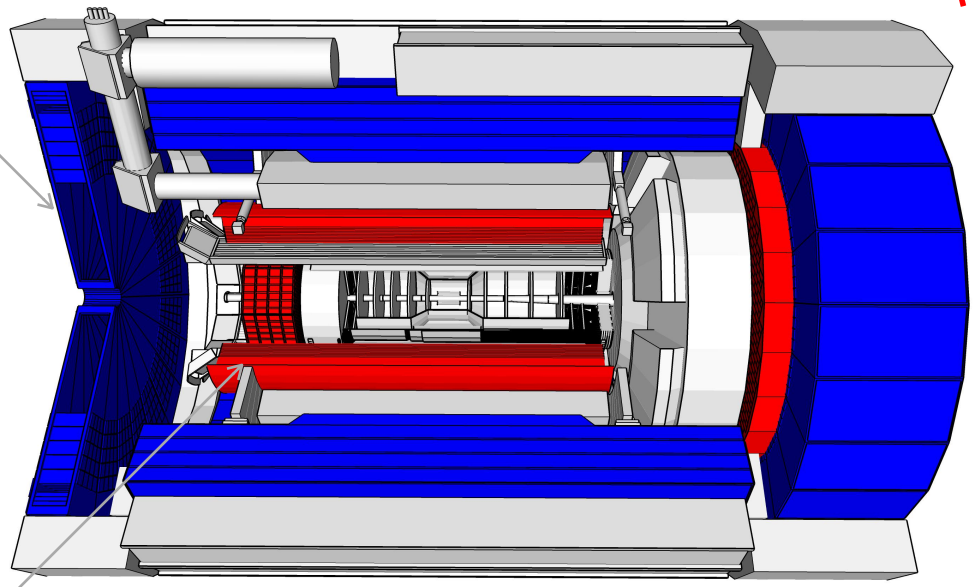

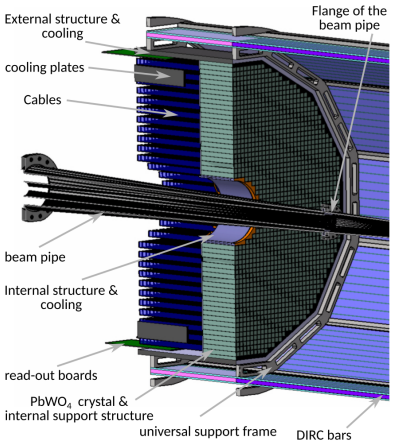

Backwards EMCal

PbW04 crystals, SiPM photosensor

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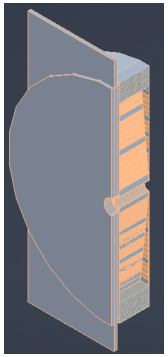

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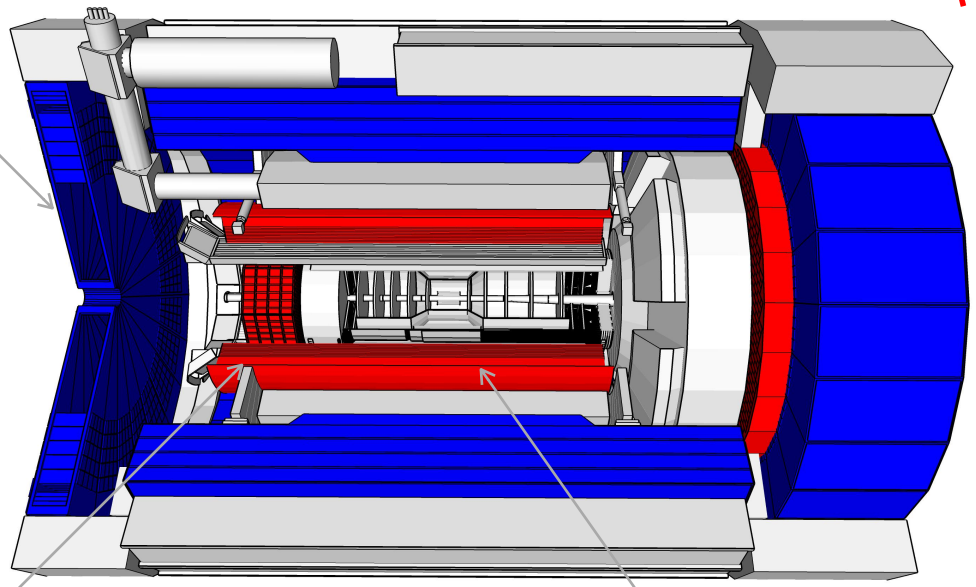

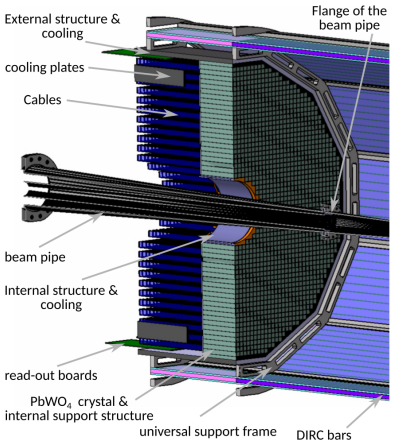

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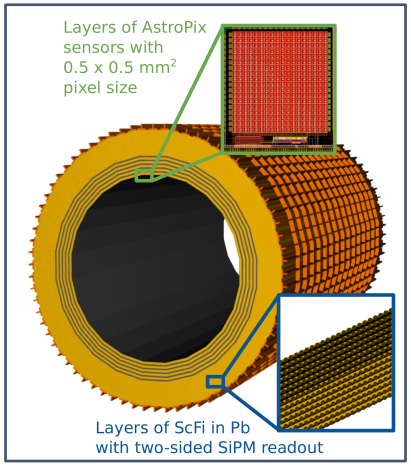
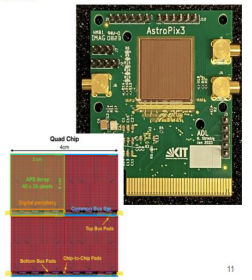


Barrel BECAL

AstroPix v3: Design and Fabrication

Pixel Matrix:

- 500um² Pixel Pitch, 300um² Pixel Size
- 35 x 35 pixels
- first 3 cols PMOS amplifier others NMOS
- Pixel Comparator Outputs Row/ Column OR wired
- Goal:
  - Pixel Dynamic Range 20keV - 700keV
  - Noise Floor 5 keV (2%@662keV)

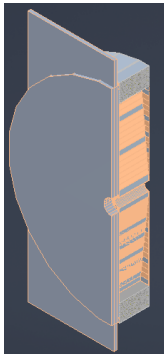


ASTROPIX

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

ePIC Detector Design Philosophy

ePIC Calorimeter Detectors: Layout



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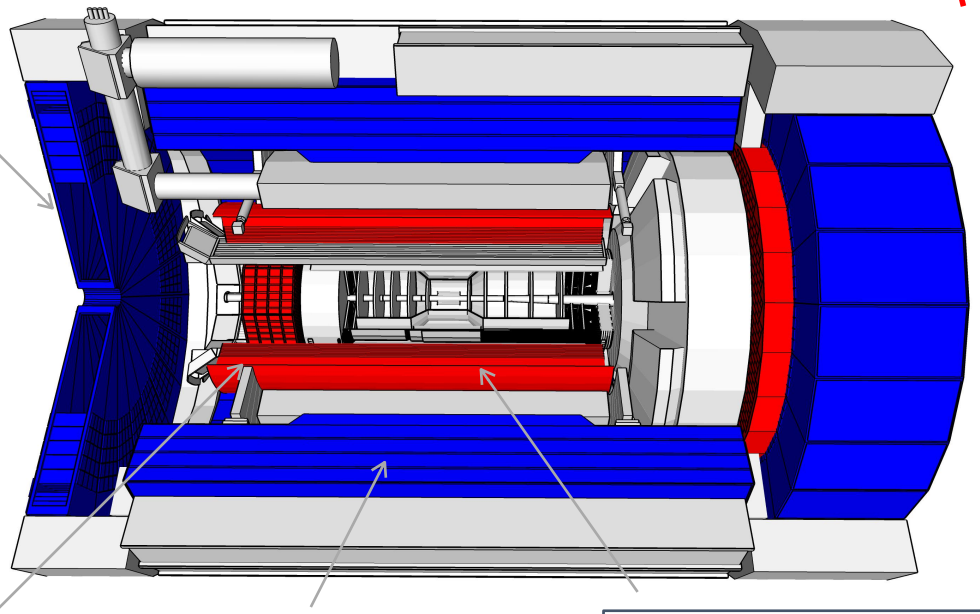

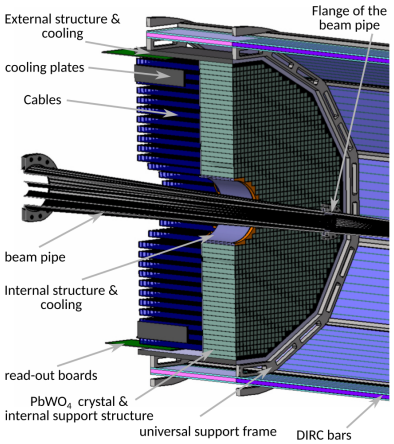

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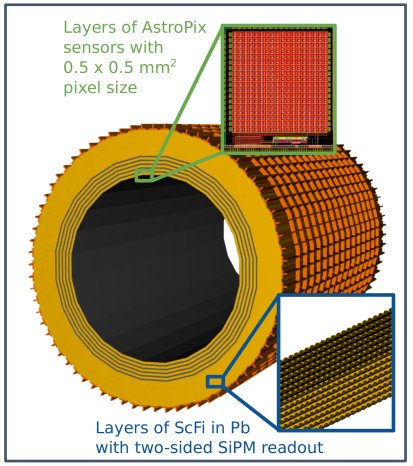
PbW04 crystals, SiPM photosensor

Barrel HCAL
(sPHENIX re-use)



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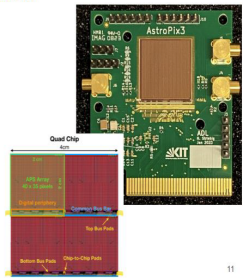

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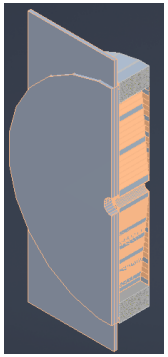

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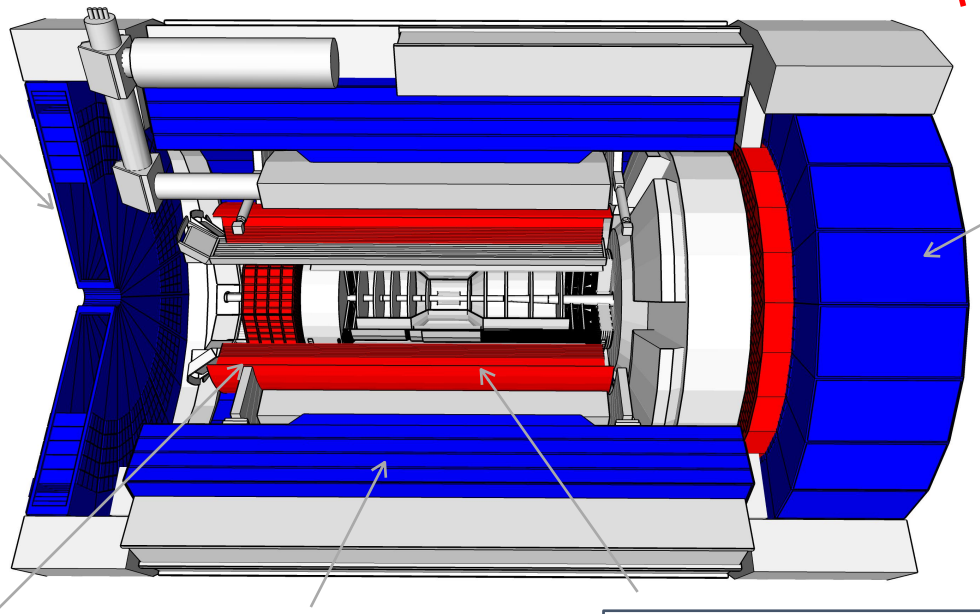
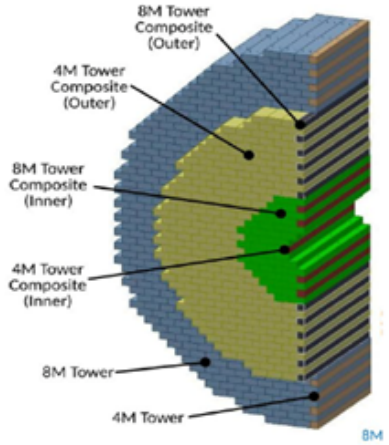
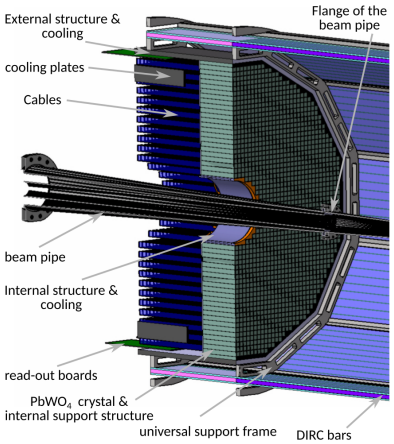




High granularity W/SciFi **EMCal**
Longitudinally separated **HCAL** with high-η insert



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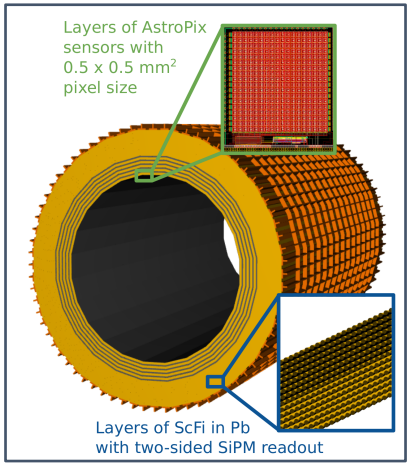

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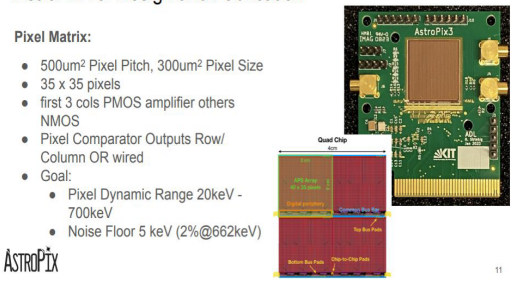
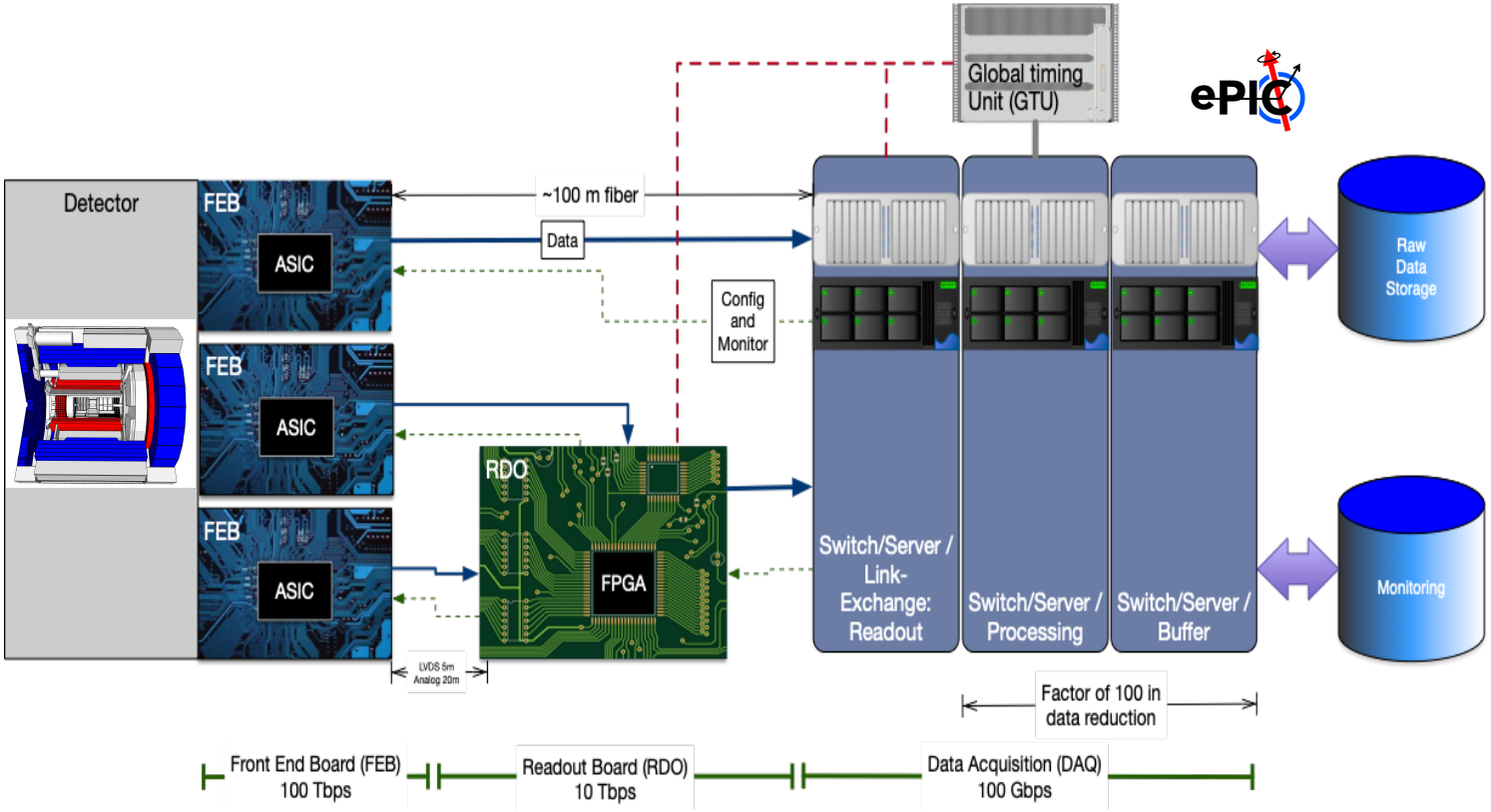


Talk by David Hornidge / 06:00 PM:
Calorimetry with the ePIC Project

ePIC Detector Design Philosophy

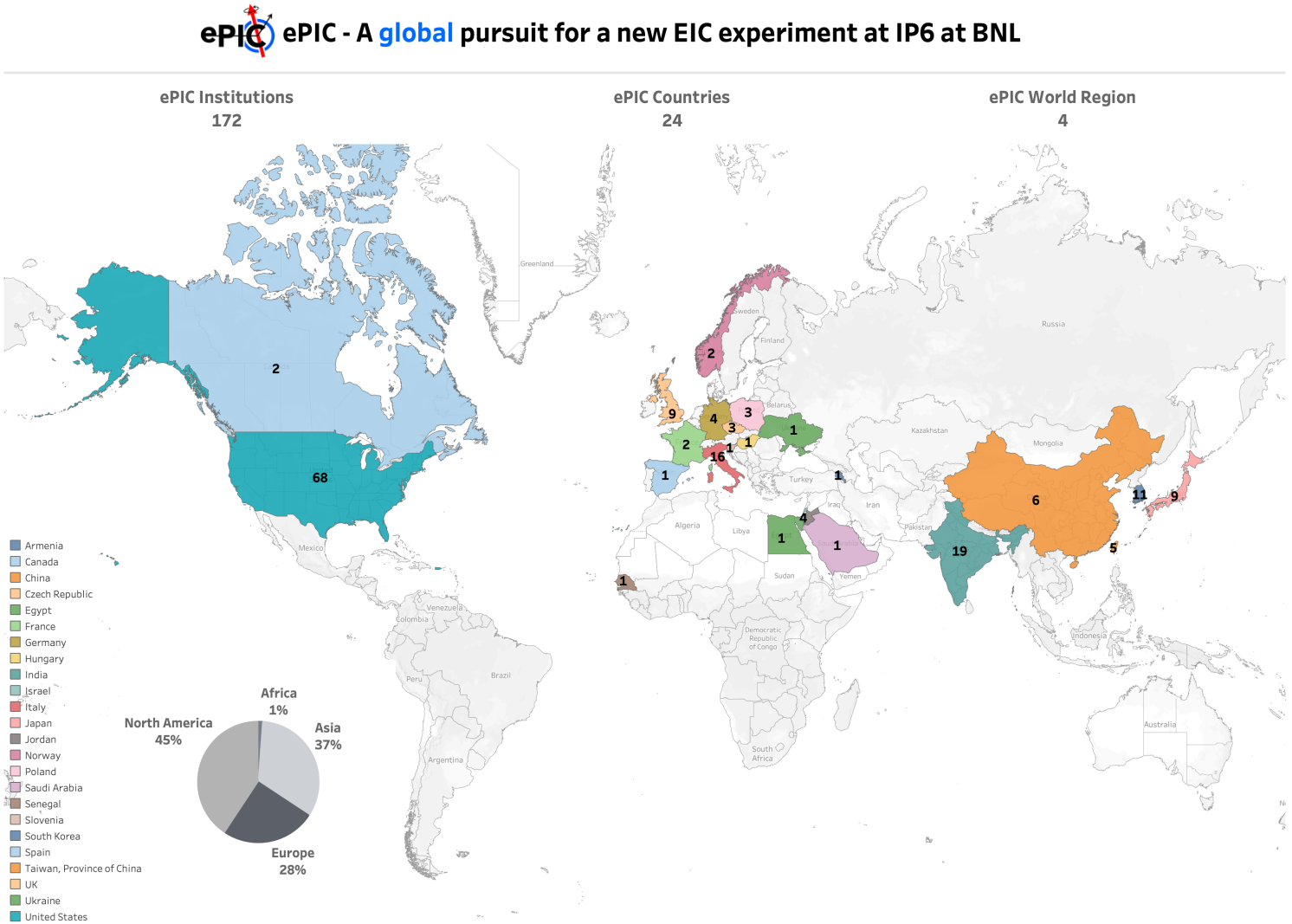
- ePIC Streaming DAQ system



- No External trigger
- All collision data digitized, but zero suppressed at FEB
- Low / zero dead-time
- Event selection can be based on full data from all detectors (in real-time, or later)
- Collision data flow is independent and unidirectional ➜ no global latency requirements
- Avoiding hardware triggers avoids complex custom hardware and firmware
- Data volume is reduced as much as possible at each stage

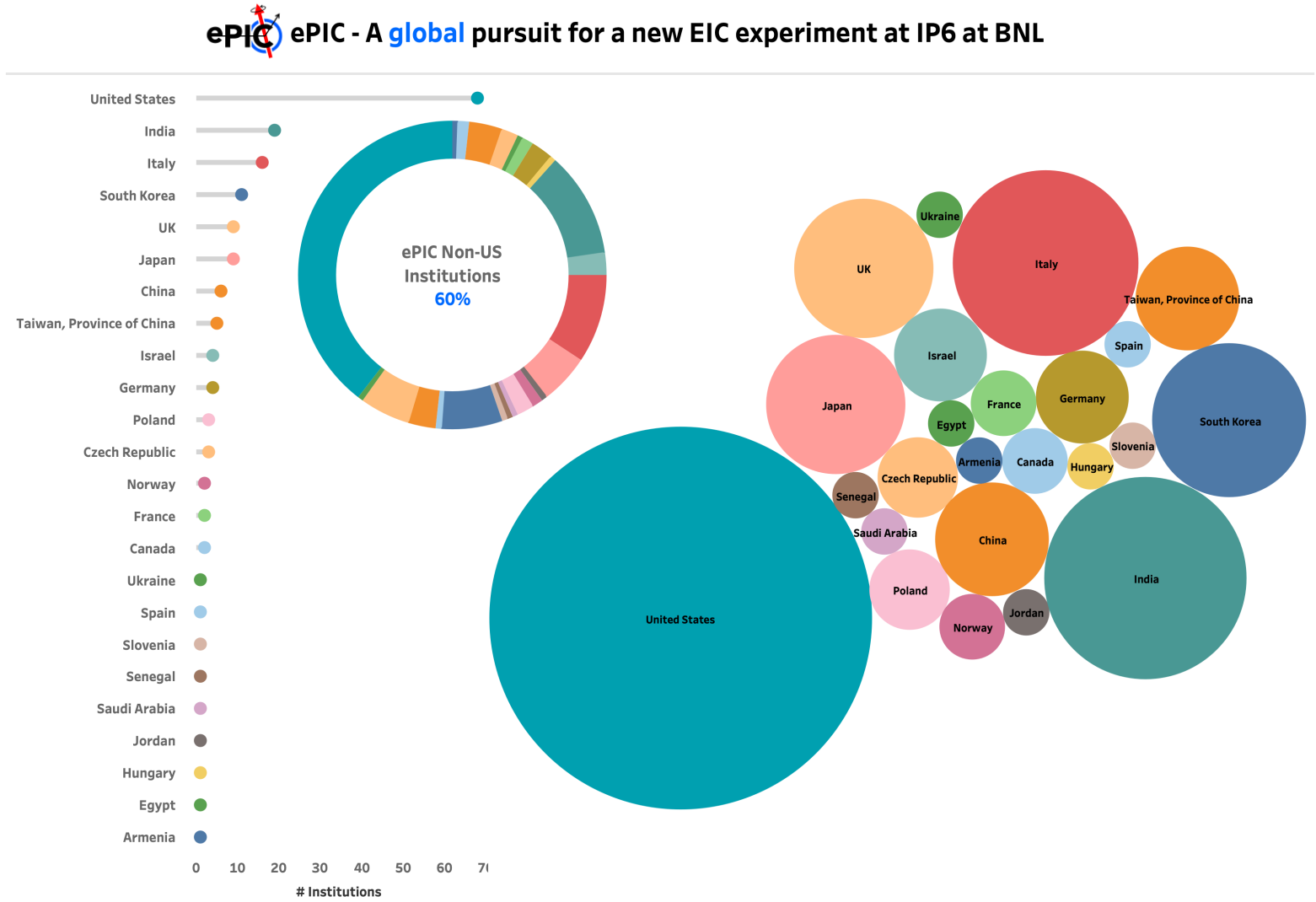
ePIC Collaboration

World Map - Institutions



ePIC Collaboration

- Number of Institutions



Summary and Next Steps

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- Over two decades, the nuclear physics community has developed the scientific and technical case for the Electron-Ion Collider, to push the frontiers of human understanding of the fundamental structure and dynamics of matter ➜ Emergent phenomena in QCD!

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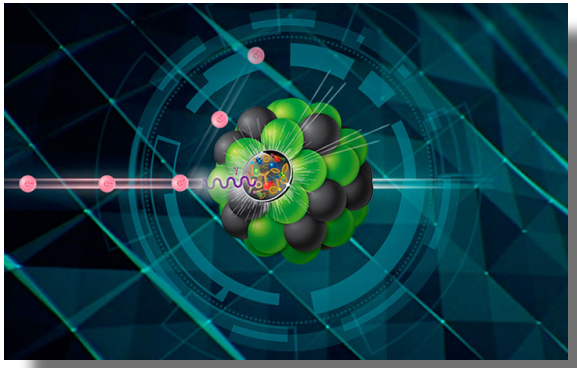
- Successful merging of several proposal efforts, forming a new collaboration in 2022/2023: ePIC collaboration
- A very exciting time is ahead of us to explore the structure and dynamics of matter at a new ep/eA collider facility following years of preparation - Join us!



Summary and Next Steps

- Schedule: EIC Project Detector at IP 6 / ePIC