College of Natural Sciences and Mathematics
UNIVERSITY OF HOUSTON

Simulation studies of the luminosity detector for the ePIC experiment at the EIC

Physics Research Day - 2024

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Co-Advisor – Dr. Dhevan Gangadharan

Date - 24th Feb, 2024

Background

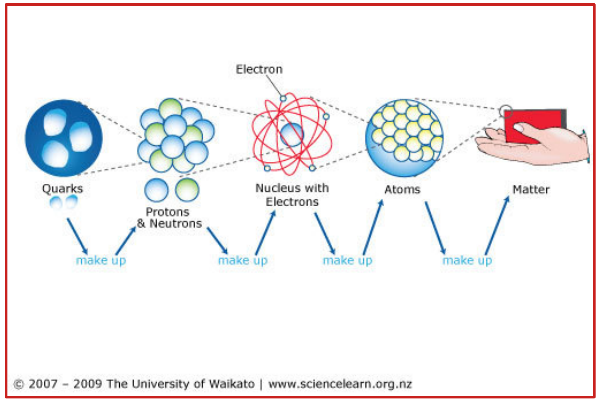


Fig. Diagram showing the matter composition

Observed Hadrons(Nucleons)

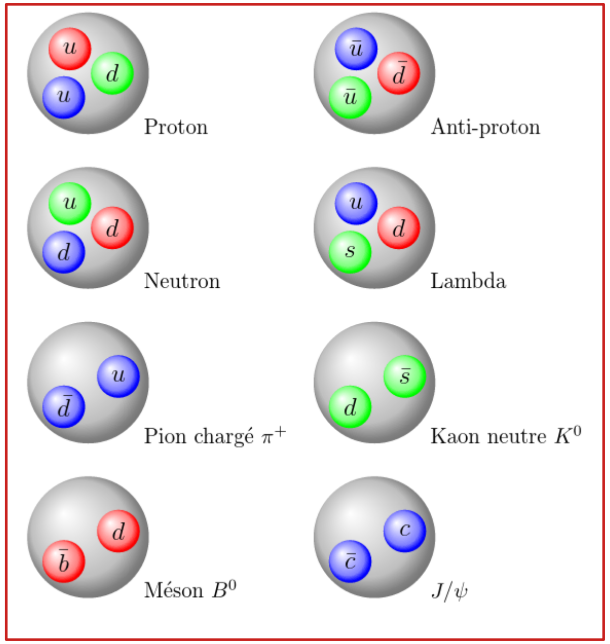


Fig. Picture showing the quark model of Baryons and meson, collectively hadrons.

Fundamental Force Particles

Force	Particles Experiencing	Force Carrier Particle	Range	Relative Strength*
Gravity acts between objects with mass	all particles with mass	graviton (not yet observed)	infinity	much weaker
Weak Force governs particle decay	quarks and leptons	W^+, W^-, Z^0 (W and Z)	short range	
Electromagnetism acts between electrically charged particles	electrically charged	γ (photon)	infinity	
Strong Force** binds quarks together	quarks and gluons	g (gluon)	short range	much stronger

Fig. Chart of four fundamental forces in nature

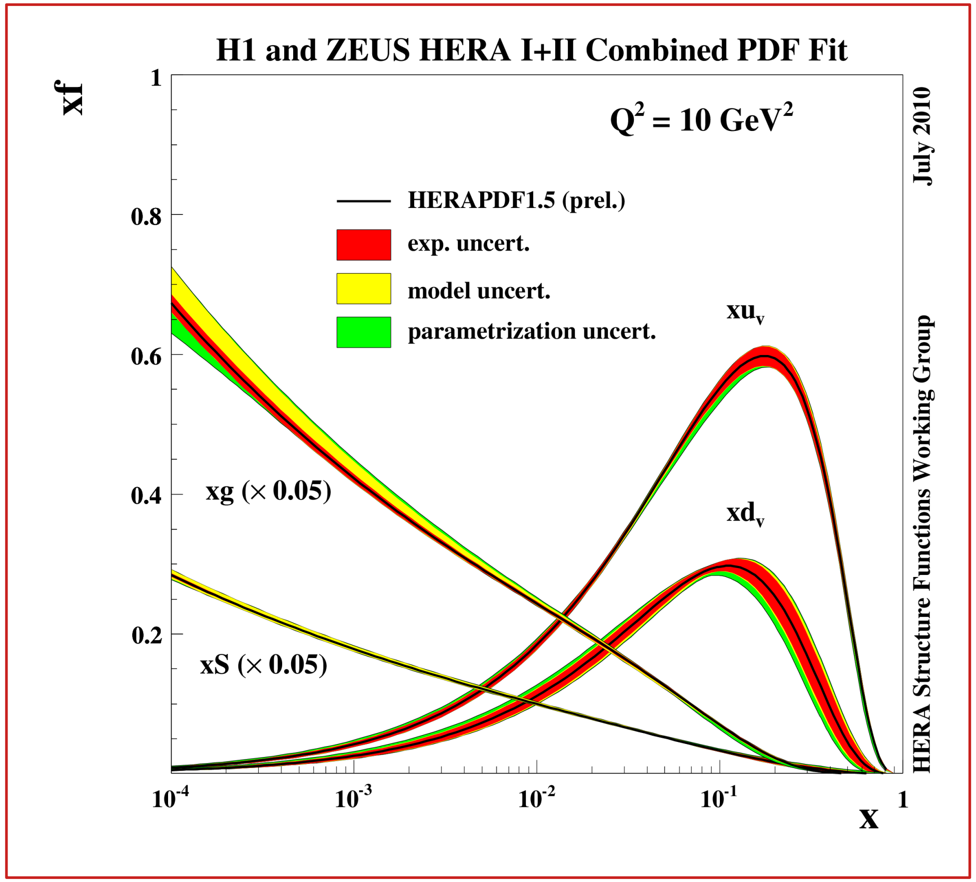
Deep Inelastic Scattering Timeline

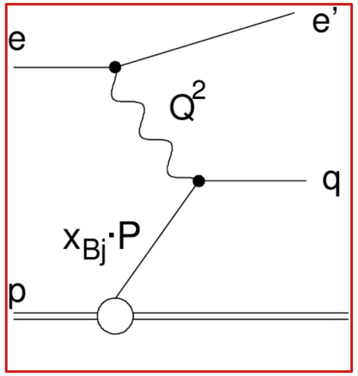
EIC - 2032

HERA - 2010

SLAC - 1967

Rutherford - 1911





DIS Feynman Diagram

https://www.desy.de/h1zeus/combined_results/index.php?do=proton_structure_fits2010_herapdf1.5_figures

The Electron Ion Collider

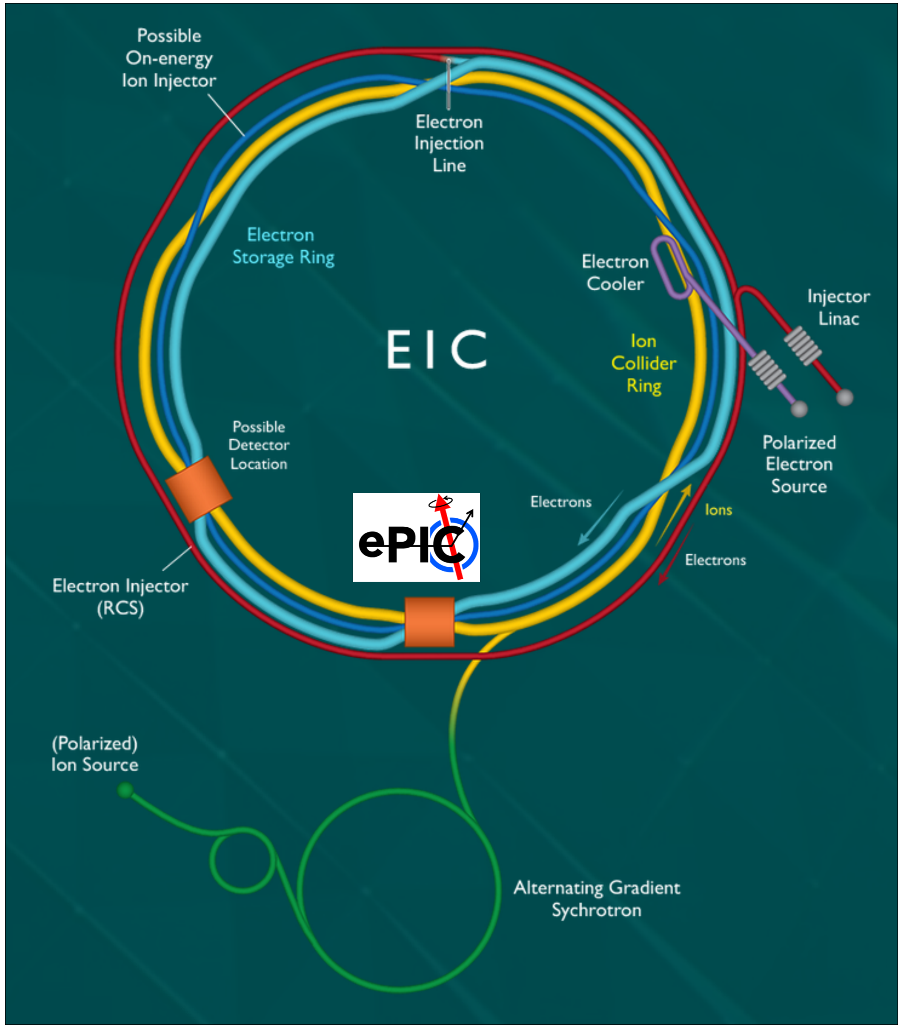


Fig. EIC Schematic diagram showing different components.

https://www.bnl.gov/eic/machine.php

The EIC Project – Kinematic Range

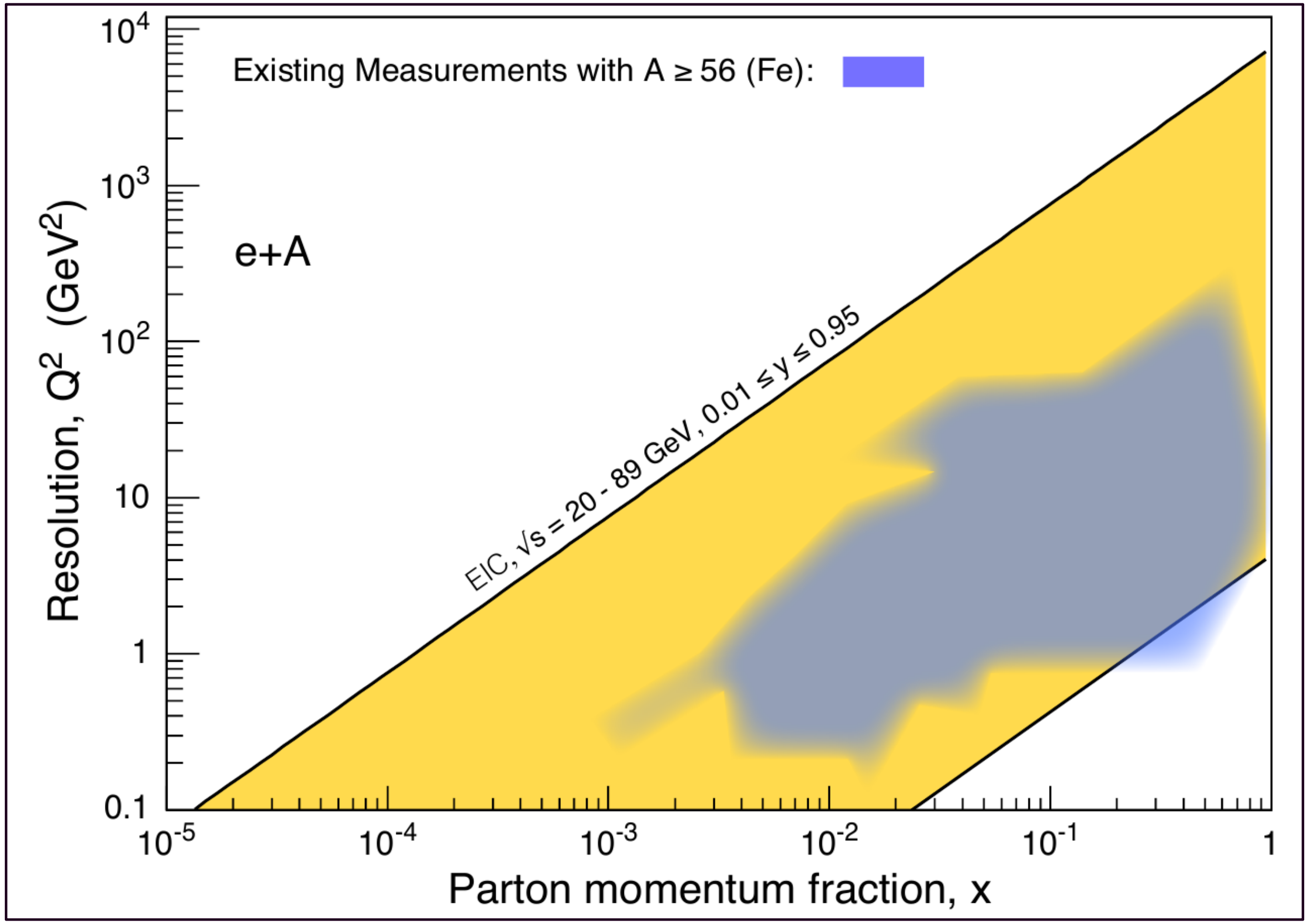
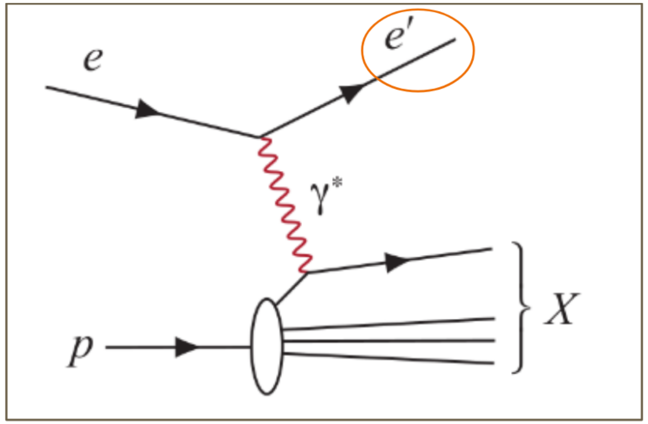


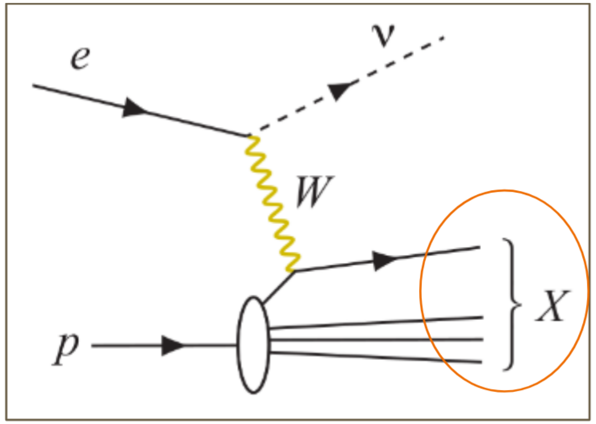
Fig. The x-Q2 range for e+A collisions for ions larger than iron (yellow) compared to existing world data.

https://doi.org/10.48550/arXiv.2103.05419

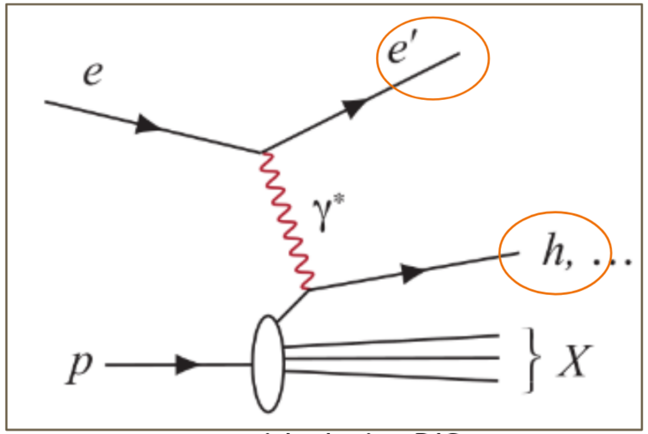
The EIC project – DIS processes under investigation



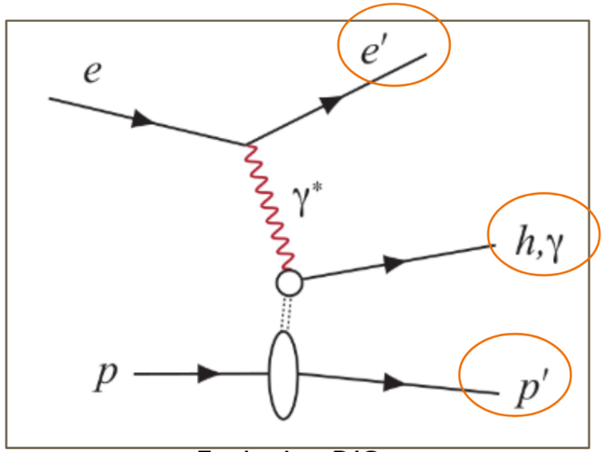
Neutral-current Inclusive DIS



Charged-current Inclusive DIS



semi-Inclusive DIS



Exclusive DIS

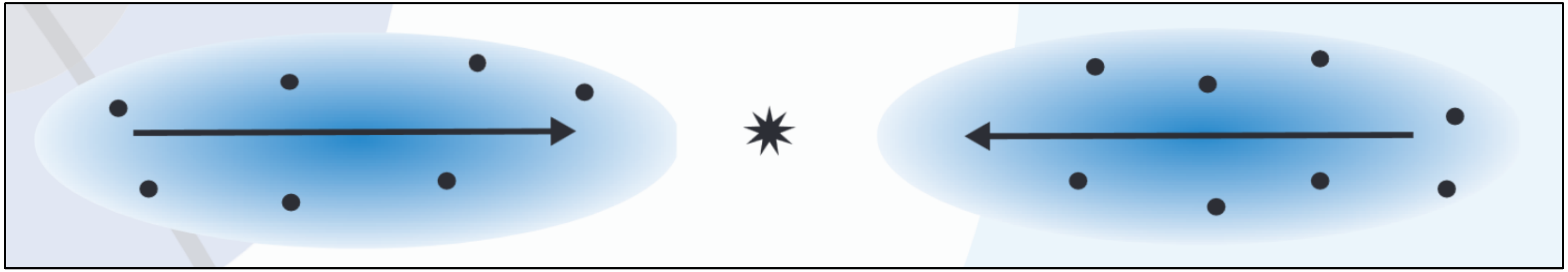
- e- : electron
- p : proton
- ν : neutrino
- h : hadrons
- X : final state particles
- W : W Boson
- γ : photon

https://indico.cern.ch/event/1005703/contributions/4221944/attachments/2184743/3923506/Schienbein_dis1_2021.pdf https://doi.org/10.1016/j.nuclphysa.2022.122447

Luminosity Detector - Introduction

Rate of an event during collision (R) = L · cross-section (σ_p) of the associated process

Luminosity is the maximum no. of collisions that can be produced in the collider per cm^2 per sec



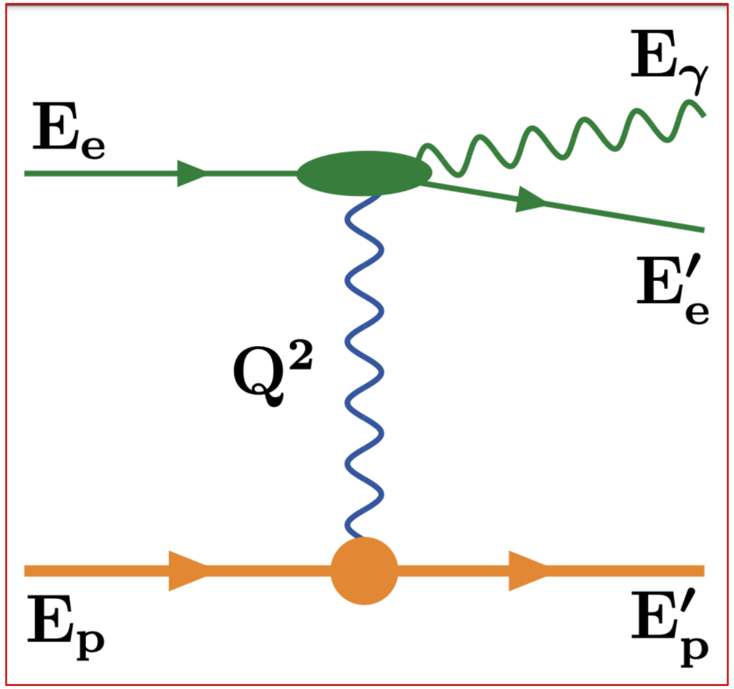
$$L = f\, N^2 / 4\, \pi r^2$$

https://www.lhc-closer.es/taking_a_closer_look_at_lhc/0.luminosity

Luminosity Detector – Bremsstrahlung Radiation

Radiation due to elastic scattering of electron near strong electric field (p / Nu).

$$L = R / \sigma_{BH}$$



- E_γ BH photon energy
- E_e Incoming e^- energy
- E_p Incoming p energy
- E_e` Outgoing e^- energy
- E_p` Outgoing p energy

At EIC, precision ~ 1% & High Luminosity ~ $10^{33\text{-}34}$ cm^{-2} s^{-1}

[1] https://arxiv.org/pdf/2106.08993.pdf [2] http://www-library.desy.de/preparch/desy/1992/desy92-066.kek.pdf

Luminosity Detector at ePIC

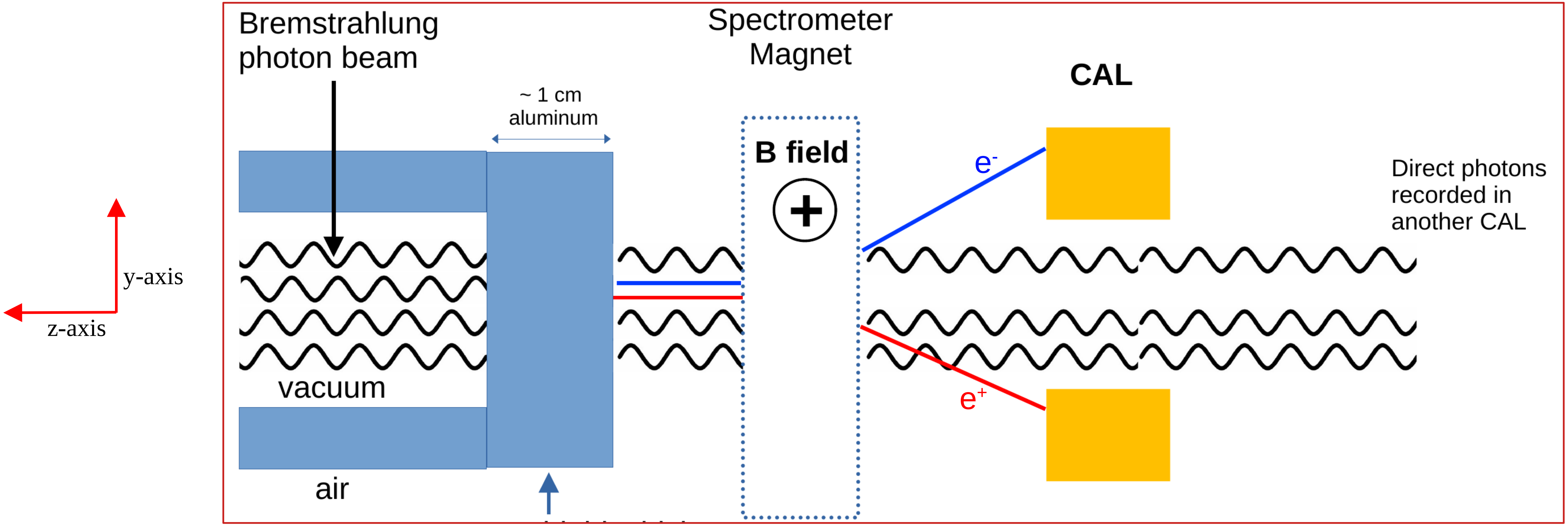
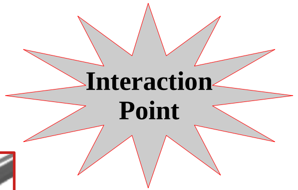


Fig. ePIC Pair Spectrometer Luminosity Detector pictorial design

Luminosity Detector in DD4hep



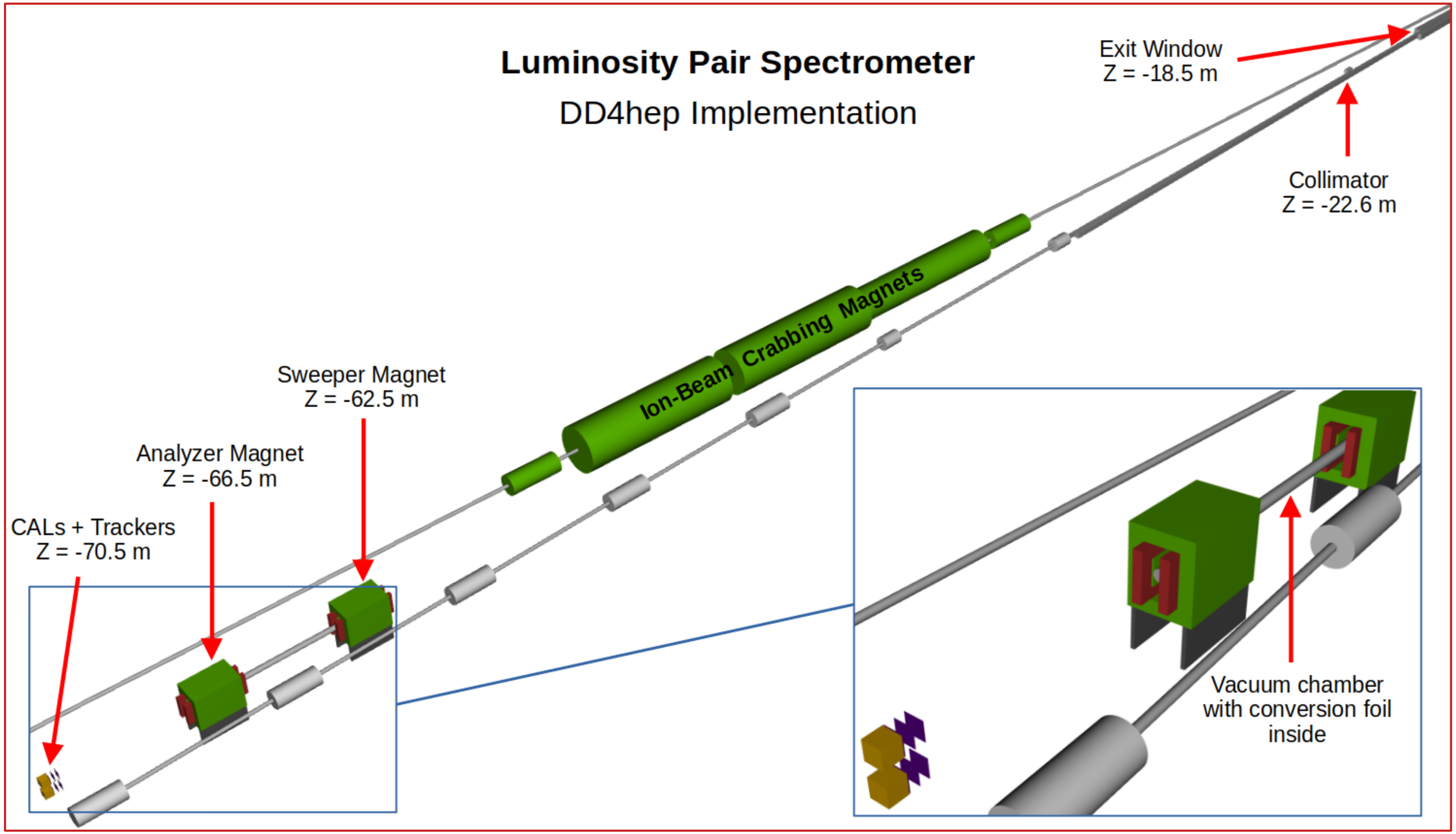


Fig. Current ePIC Luminosity Detector design with e^- and p beam pipes and magnets built by Dhevan G., Aranya G. & Justin C. in DD4hep. The placement of different component not fixed, changes according to experimental needs.

https://arxiv.org/pdf/2106.08993.pdf

Calorimeter - Introduction

Calorimeters are blocks of instrumented material in which particles to be measured are fully absorbed and their energy transformed into a measurable quantity.

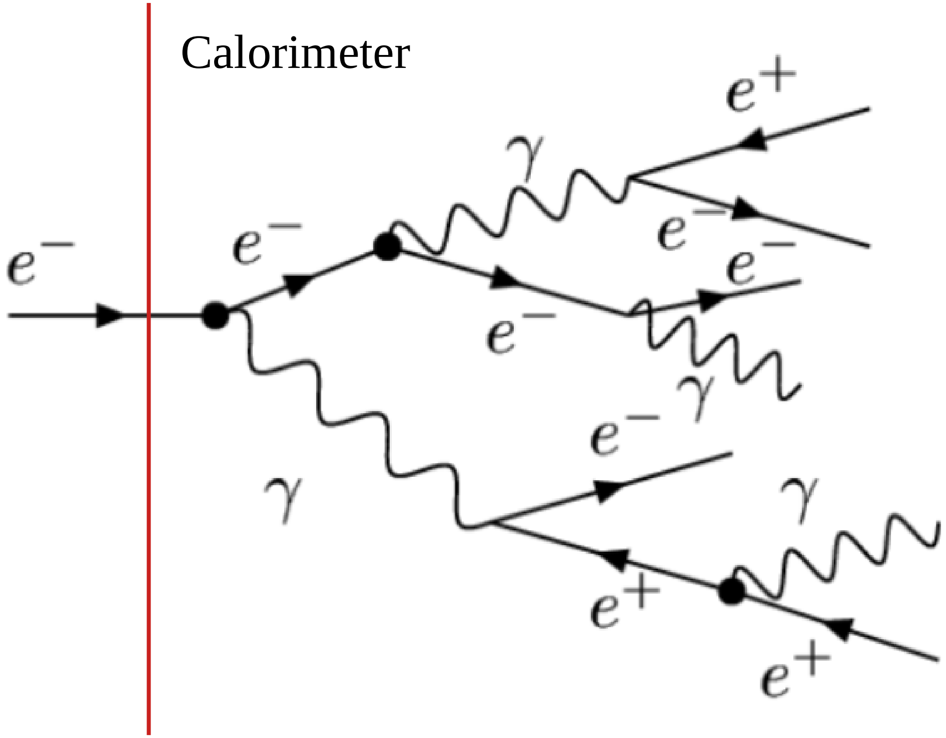


Fig. Electromagnetic shower propagation inside a electromagnetic calorimeter.

Inspiration of Design : [1] 10.1088/1742-6596/404/1/012023

Calorimeter - W-ScFi

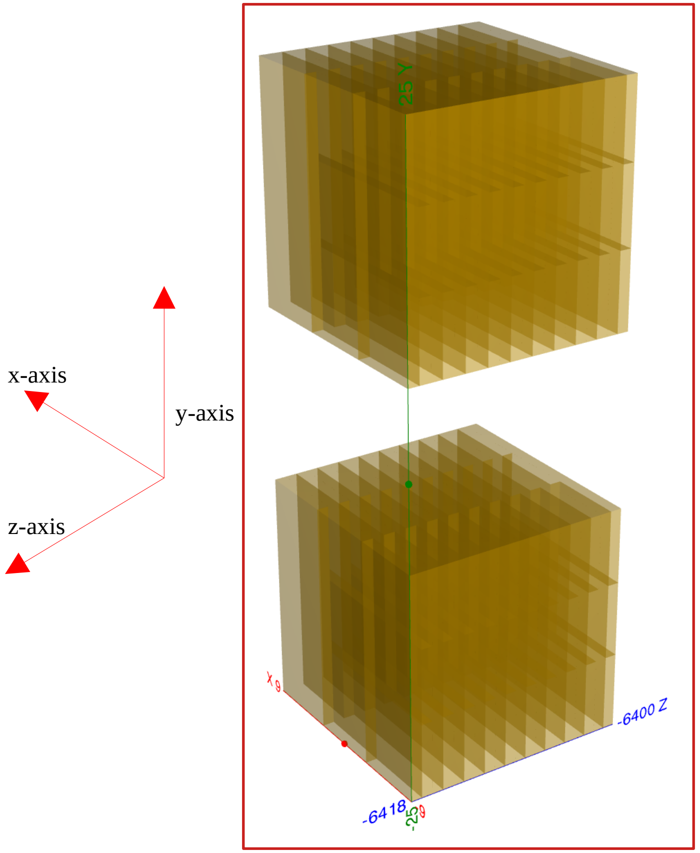


Fig. 2D W-ScFi calorimeter built in DD4hep

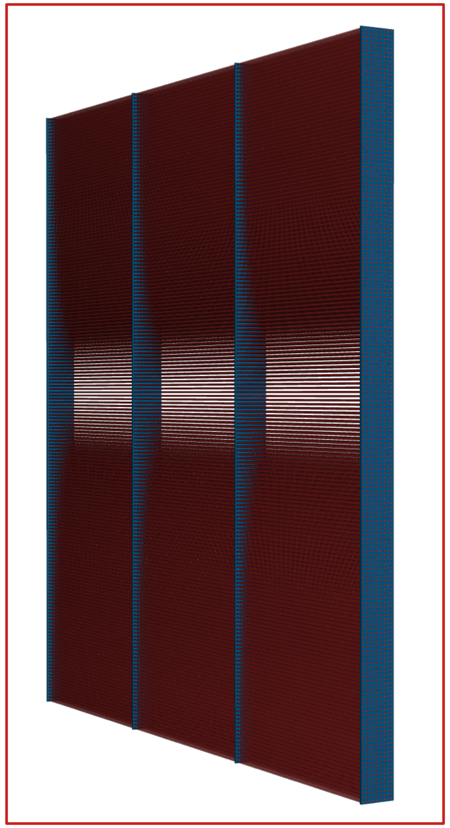
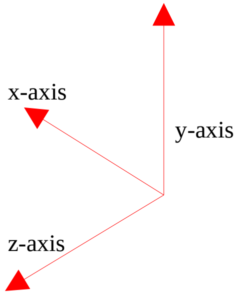


Fig. Each layers in CAL

- Sampling Electromagnetic Calorimeter (CAL)
- Detectors and absorber separated → only part of the energy in absorber is detected.
- Absorber – Hard Material like Pb, W
- Active Part – Scintillating fibers, crystals
- Excellent Spatial resolution but limited energy resolution
- Spaghetti CAL ~ W-Scintillator Fibers
- Alternating Layer of Y|| and X|| fibers

Inspiration of Design : [1] 10.1088/1742-6596/404/1/012023

Calorimeter - W-ScFi



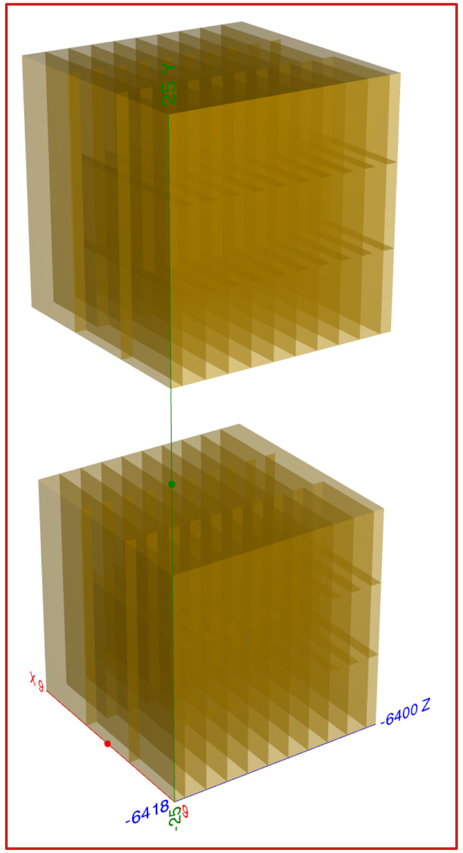


Fig. 2D W-ScFi calorimeter built in DD4hep

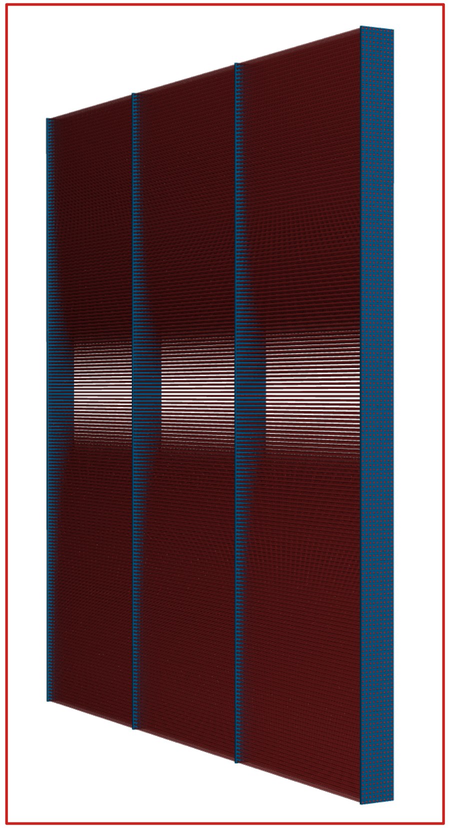


Fig. Each layers in CAL

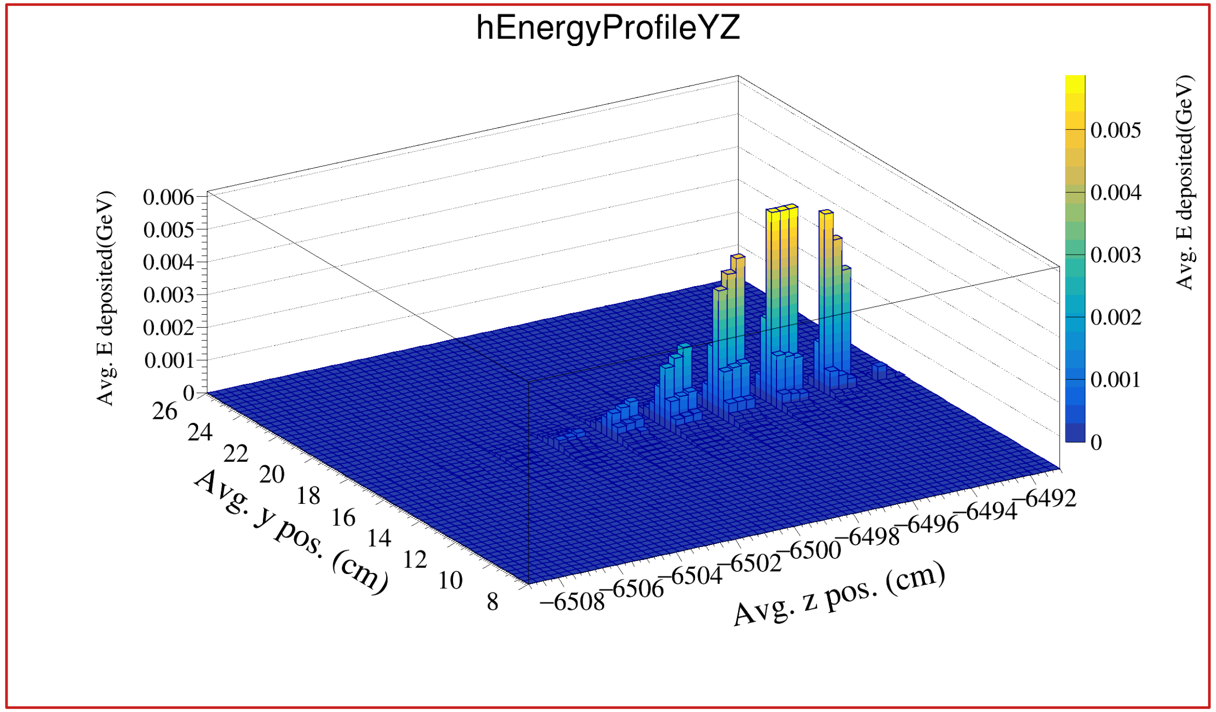


Fig. Shower energy profile of an e⁻ from all the X || layers in CAL

Inspiration of Design : [1] 10.1088/1742-6596/404/1/012023

W-SciFi CAL – Energy Resolution

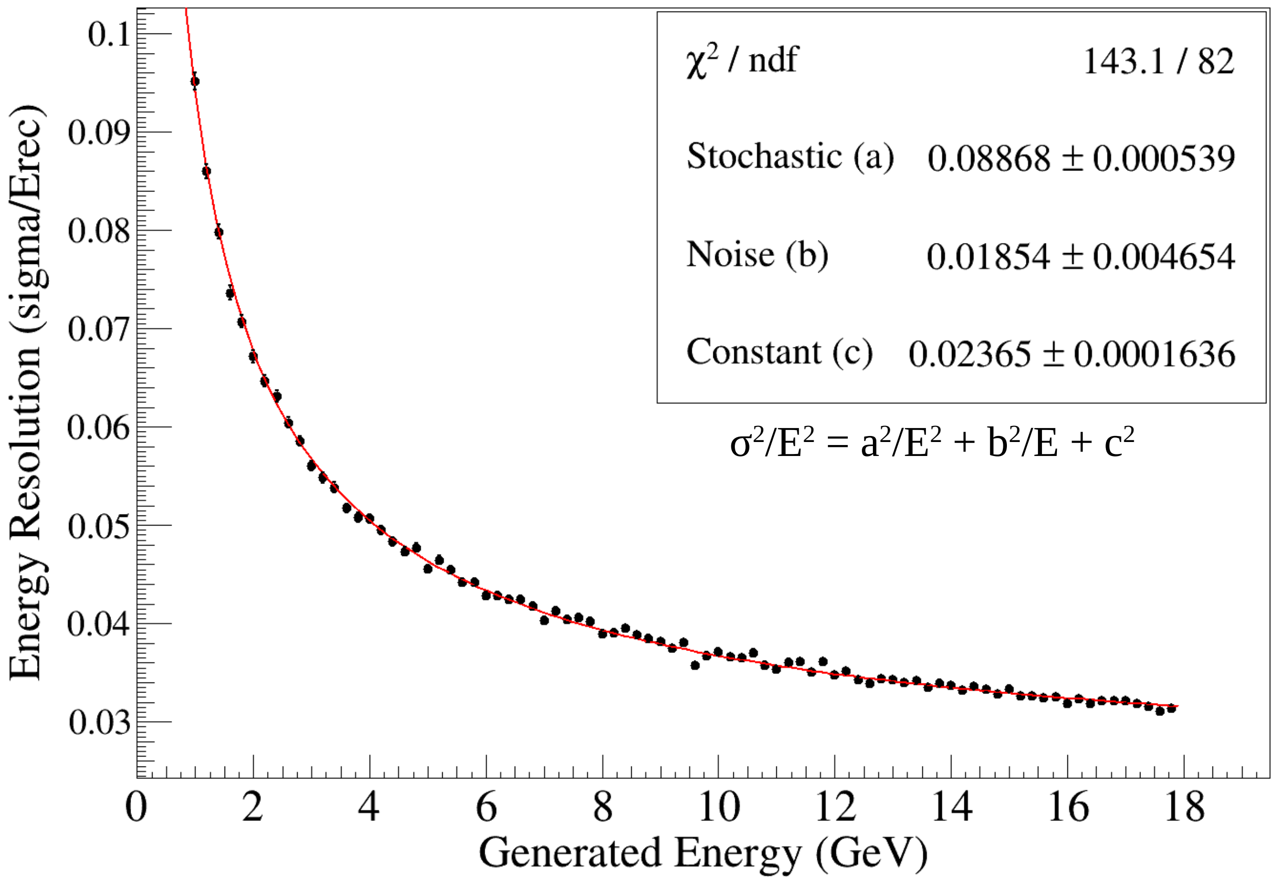
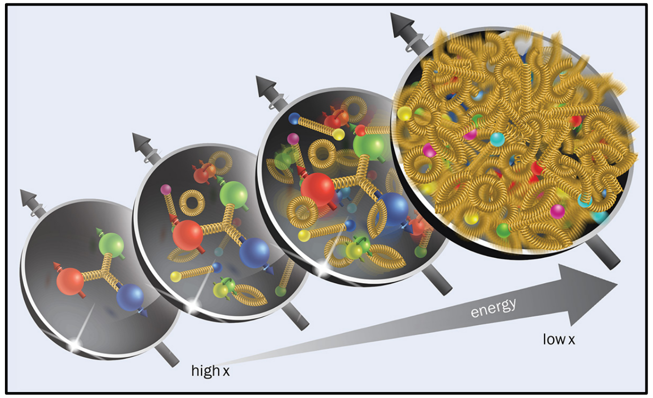
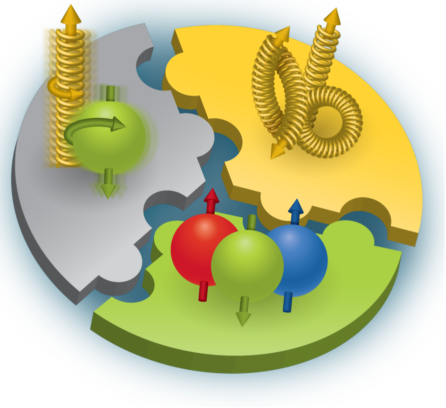


Fig. Standalone energy resolution of PS CALs, e- hit directly at a CAL.

W-SciFi CAL – Simulation results

Energy Resolution (Stochastic term)	8.8%
Position Resolution	1.6 mm
Moliere Radius	14.5 mm
Shower Depth	8.1 mm

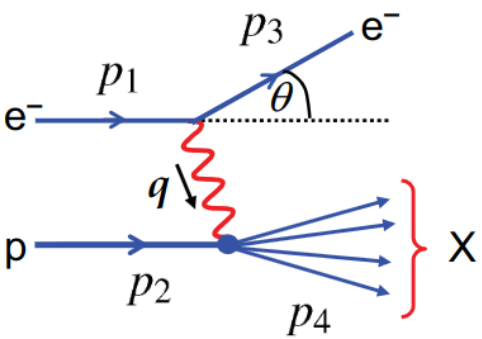


Thank You

Notations

Kinematics of Inelastic Scattering



- For inelastic scattering the mass of the final state hadronic system is no longer the proton mass, M
- The final state hadronic system must contain at least one baryon which implies the final state invariant mass $M_X > M$

$$M_X^2 = p_4^2 = (E_4^2 - |\vec{p}_4|^2)$$

✶ For inelastic scattering introduce four new kinematic variables: x, y, ν, Q^2

★ **Define:**

$$x \equiv \frac{Q^2}{2p_2.q}$$

Bjorken x (Lorentz Invariant)

where $Q^2 \equiv -q^2$ $\qquad Q^2 > 0$

- Here $M_X^2 = p_4^2 = (q + p_2)^2 = -Q^2 + 2p_2.q + M^2$

⇨ $Q^2 = 2p_2.q + M^2 - M_X^2$ ➡ $Q^2 \leq 2p_2.q$

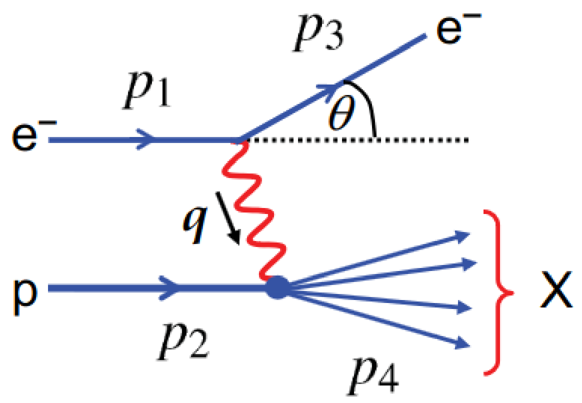
Note: in many text books W is often used in place of M_X

hence $0 < x < 1$ inelastic $\qquad x = 1$ elastic ← Proton intact $M_X = M$

https://www.hep.phy.cam.ac.uk/~thomson/partIIIparticles/handouts/Handout_6_2011.pdf

Notations

★ **Define:** $$y \equiv \frac{p_2 . q}{p_2 . p_1}$$ (Lorentz Invariant)



- In the Lab. Frame:

$$p_1 = (E_1, 0, 0, E_1) \quad p_2 = (M, 0, 0, 0)$$
$$q = (E_1 - E_3, \vec{p}_1 - \vec{p}_3)$$
$$\rightarrow \quad y = \frac{M(E_1 - E_3)}{ME_1} = 1 - \frac{E_3}{E_1}$$

So y is the fractional energy loss of the incoming particle

$$0 < y < 1$$

- In the C.o.M. Frame (neglecting the electron and proton masses):

$$p_1 = (E, 0, 0, E); \quad p_2 = (E, 0, 0, -E); \quad p_3 = (E, E\sin\theta^*, 0, E\cos\theta^*)$$
$$\rightarrow \quad y = \tfrac{1}{2}(1 - \cos\theta^*) \qquad \text{for } E \gg M$$

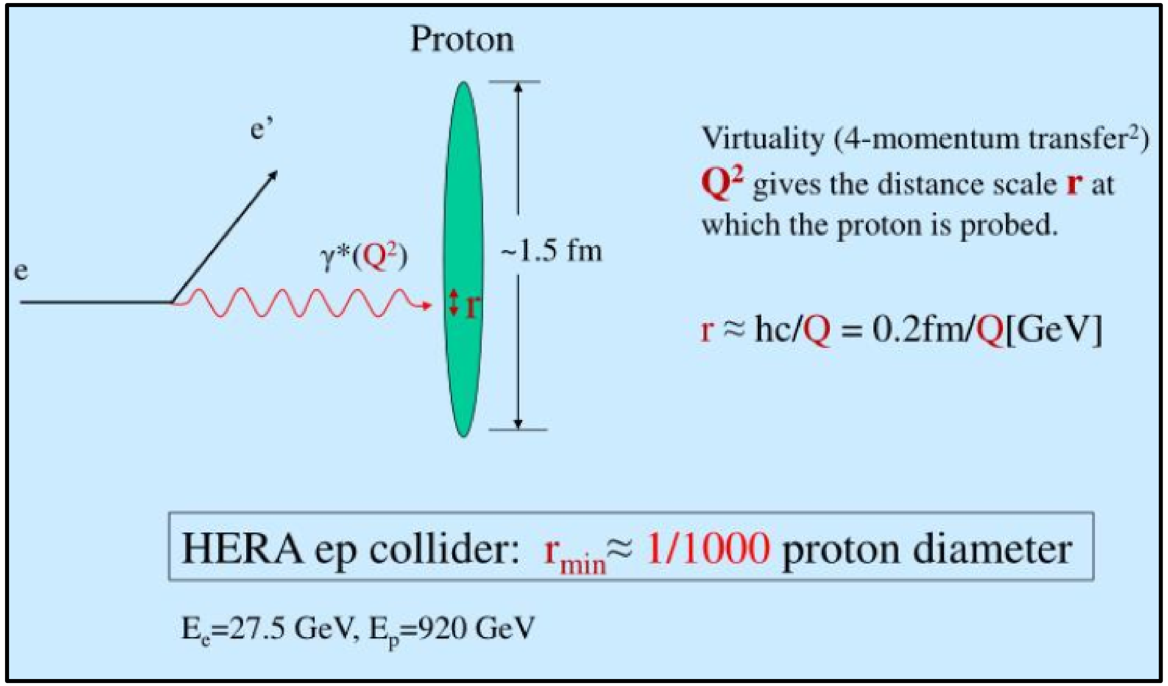
★ **Finally Define:** $$\nu \equiv \frac{p_2 . q}{M}$$ (Lorentz Invariant)

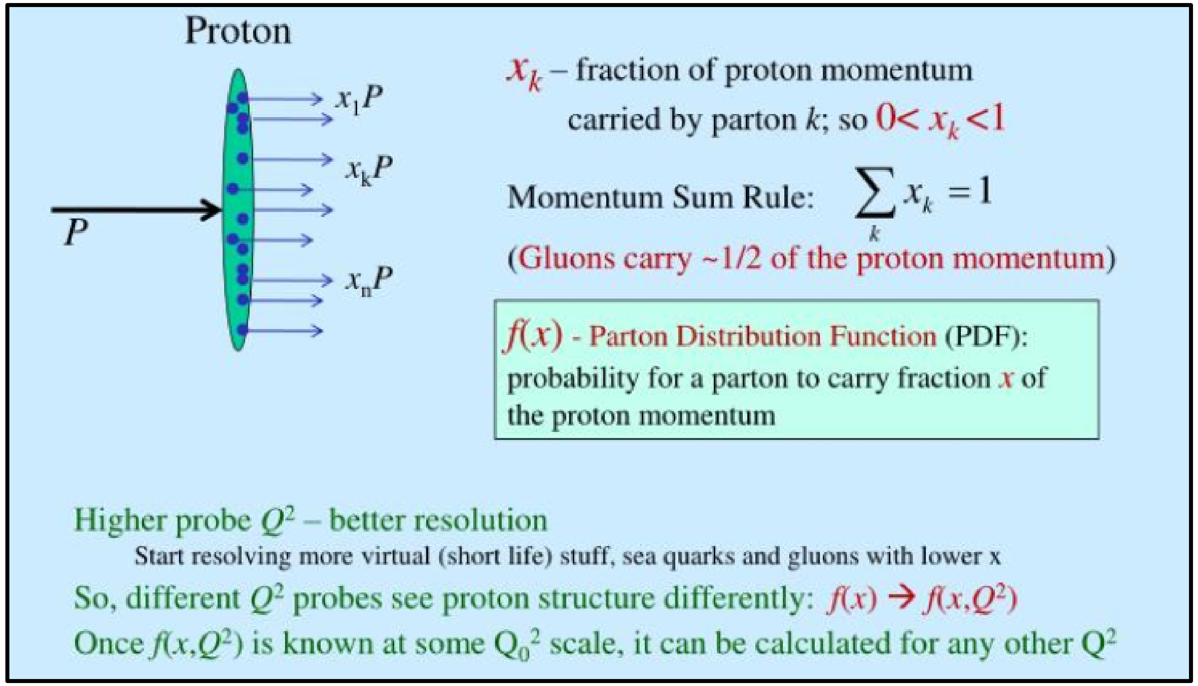
- In the Lab. Frame: $\nu = E_1 - E_3$

ν is the energy lost by the incoming particle

https://www.hep.phy.cam.ac.uk/~thomson/partIIIparticles/handouts/Handout_6_2011.pdf

Notations





https://www.slideserve.com/yama/do-gluons-carry-proton-spin-toward-resolving-the-spin-crisis

The EIC Project – Physics Questions to Address

Nuclear Spin

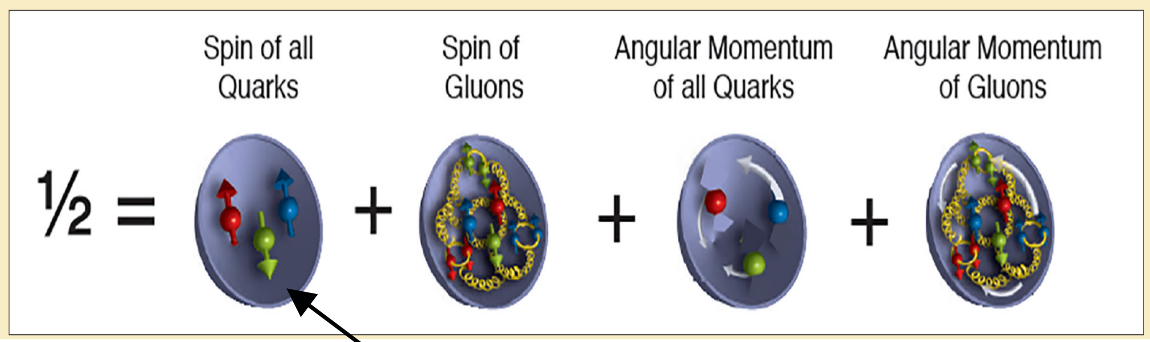


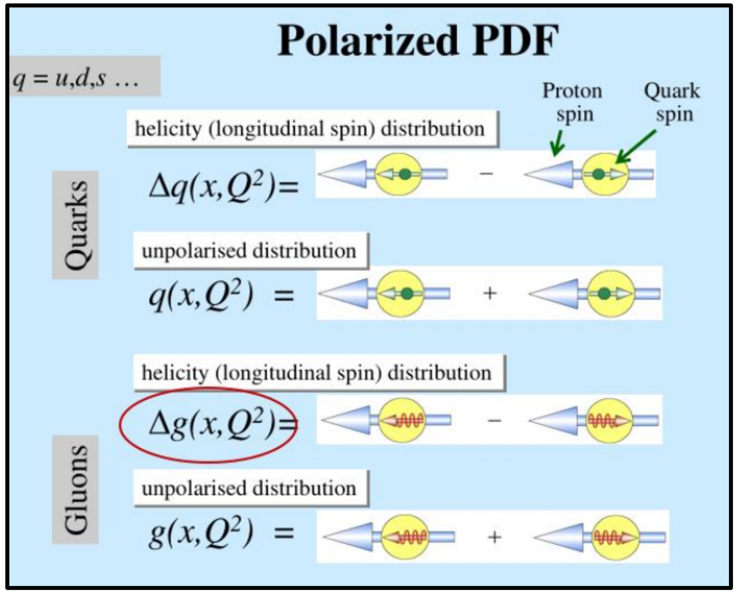
Fig. A schematic view of the proton and its potential spin contributions.

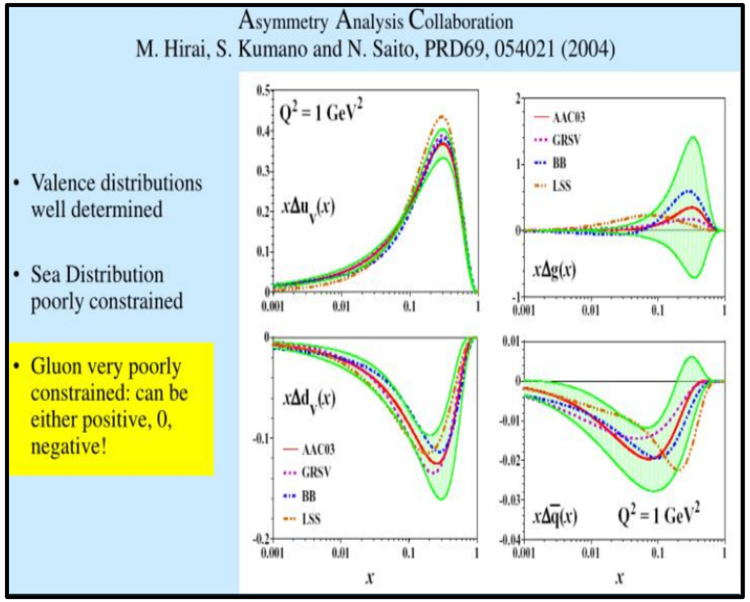
EMC (CERN) experiment:
Deep Inelastic Scattering (DIS) of high energy polarized muons on polarized protons

Quark (and anti-quark) contribution to proton spin is small:

ΔΣ=12 ±9(stat) ±14(syst) %

Nucl. Phys. B328, 1-35 (1989) – one of the most cited papers! >1200 citations





https://www.slideserve.com/yama/do-gluons-carry-proton-spin-toward-resolving-the-spin-crisis

The EIC Project – Physics Questions to Address

Behavior of quarks in nuclear medium

The EMC effect still puzzles after 30 years

26 April 2013

There is renewed interest in an old surprise.

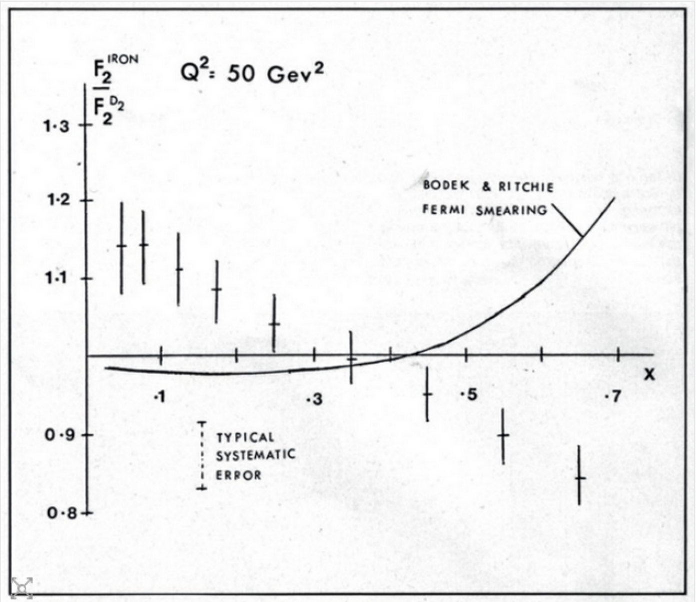
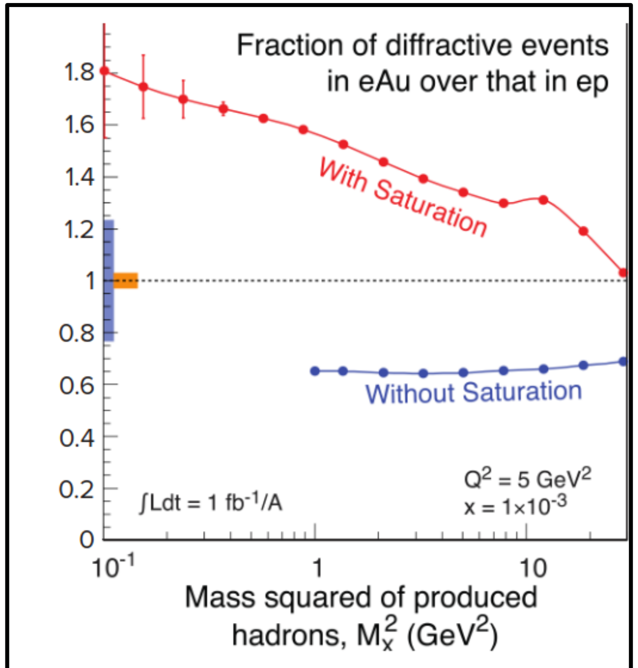


Fig. 1. A plot of the EMC data as it appeared in the November 1982 issue of *CERN Courier*. This image nearly derailed the highly cited refereed publication (Aubert *et al.* 1983) because the editor argued that the data had already been published.



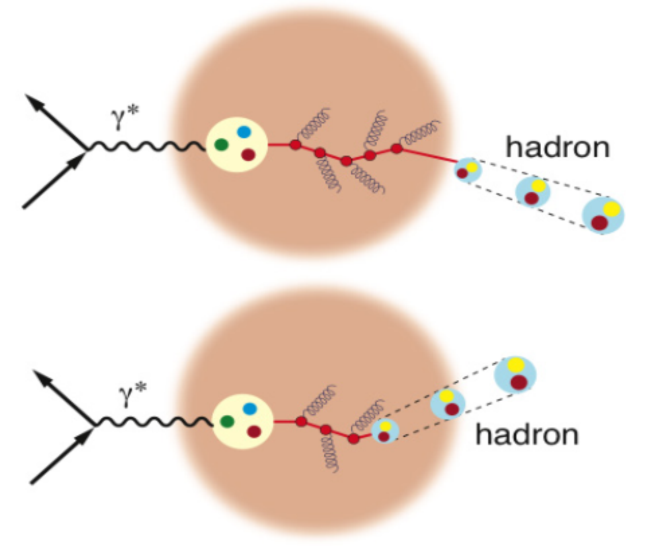
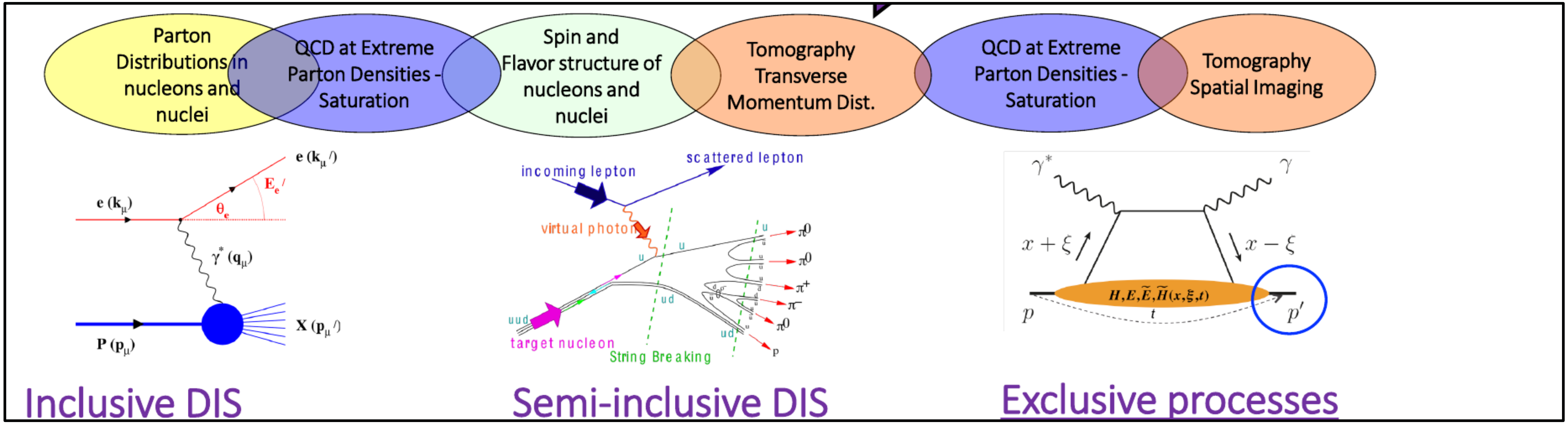


Figure 2.20: *A schematic illustrating the interaction of a struck parton moving through cold nuclear matter, with hadrons formed either outside (top) or inside (bottom) the nucleus.*

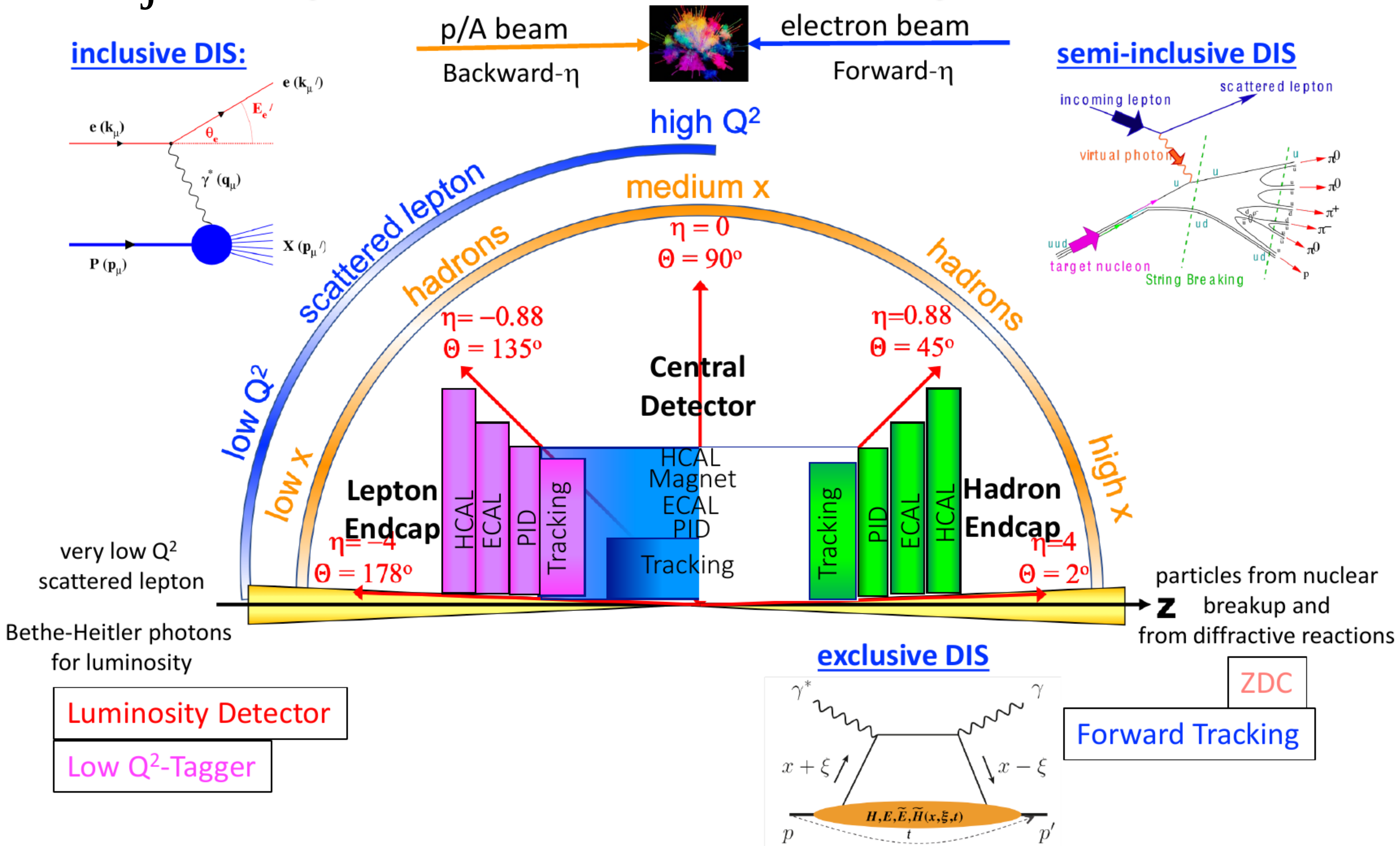
https://inspirehep.net/files/cb14a9bc2ce6ef53e56bf500efbc1126

The EIC Project



https://indico.jlab.org/event/344/contributions/10582/attachments/8367/11951/QNP2022-EIC-Horn-v1-nb.pdf

The EIC Project



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