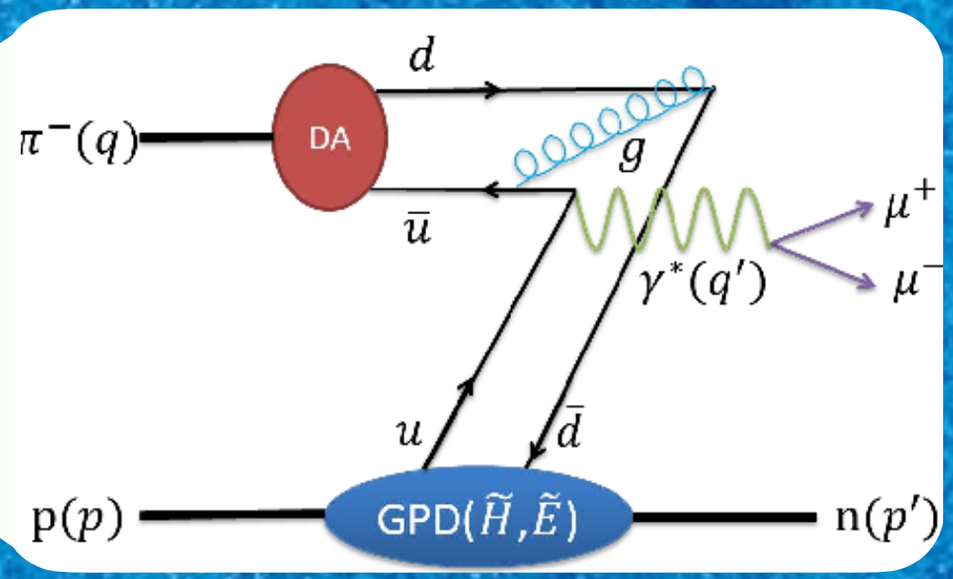




Proton tomography at K10

Yongsun Kim (Sejong University)

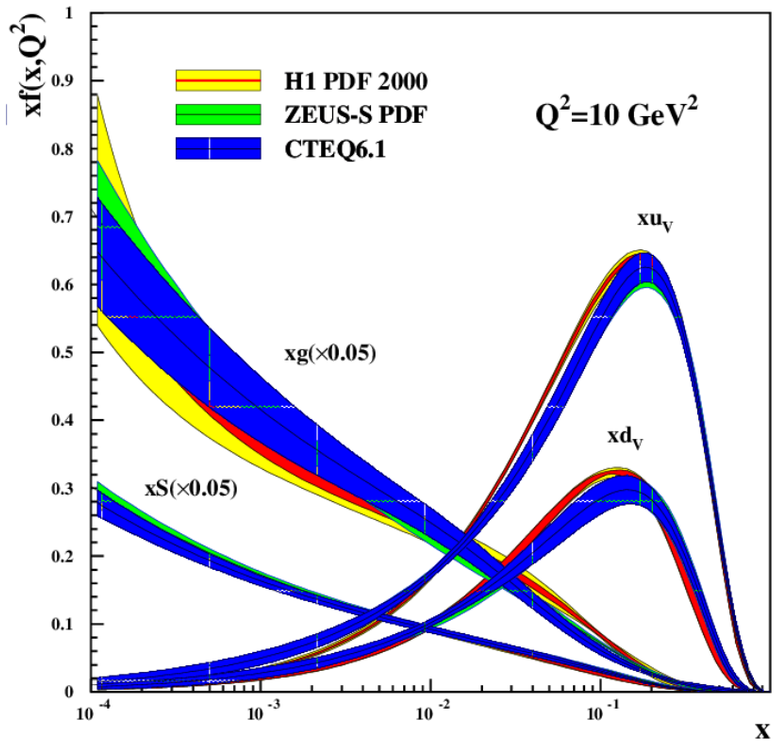
K10 Collaboration Meeting & Workshop, Oct 9 2026

Parton distributions in proton

The Parton distribution functions

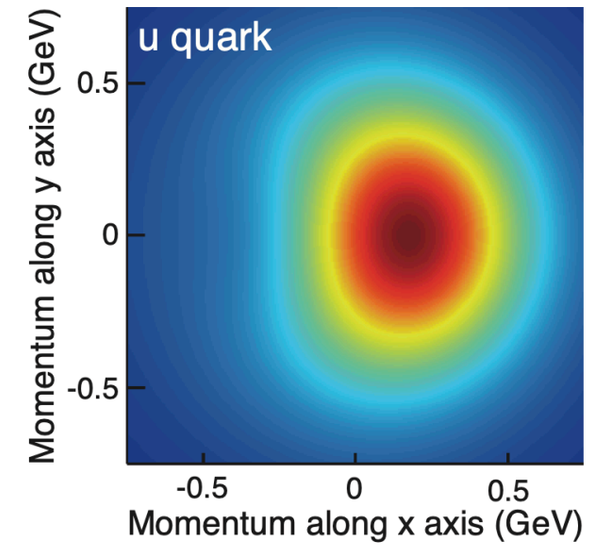
1-dim distribution

- **PDF** (Parton Distribution Function)
  - $f(x,Q^2)$
  - Probes the quark's probability distribution as a function of x
  - Measured since *1970s*

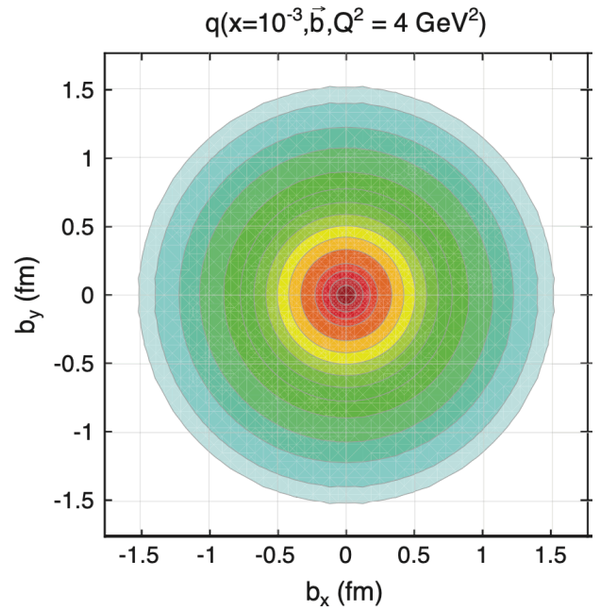


3-dim distribution

- **TMD** (Transverse Momentum Distribution)
  - $f(x, k_T, Q^2)$ measured
  - Transverse **momentum** information incl'd



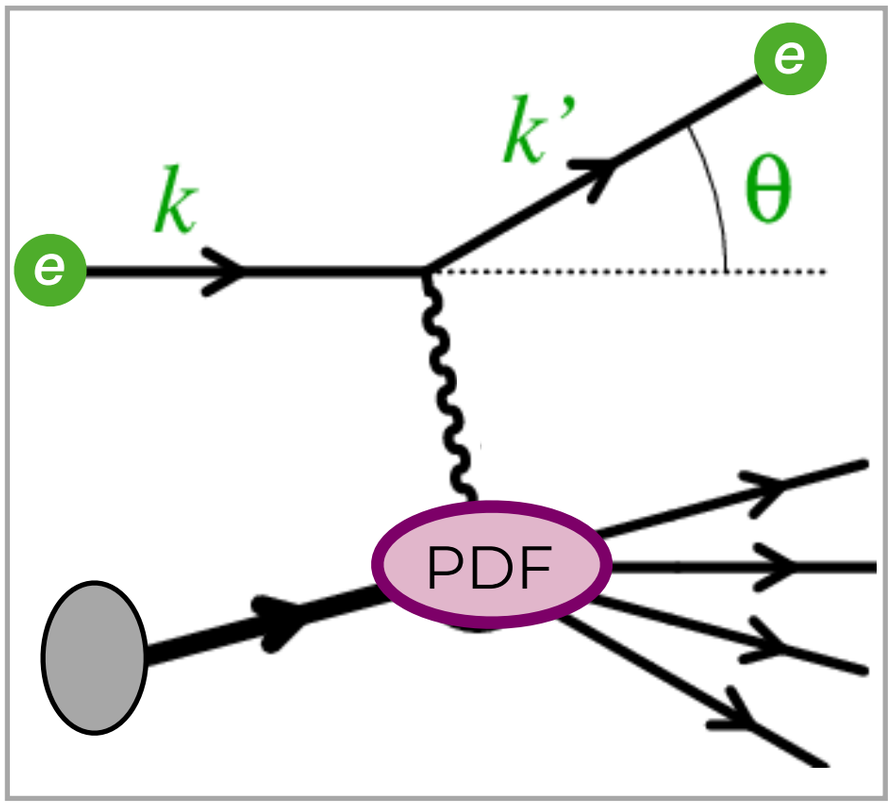
- **GPD** (Generalized Parton Distribution)
  - $f(x, b_T, Q^2)$
  - Transverse **position** information incl'd



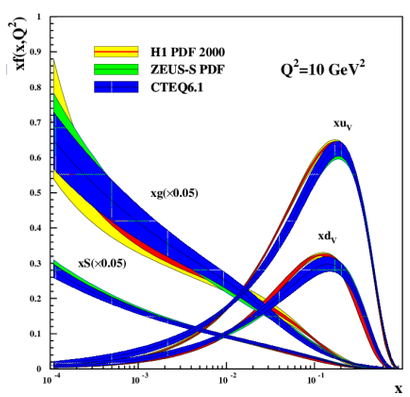
Inclusive vs Exclusive measurements

Inclusive DIS

$e + p \rightarrow e + X$



detector ... says Q^2 and x



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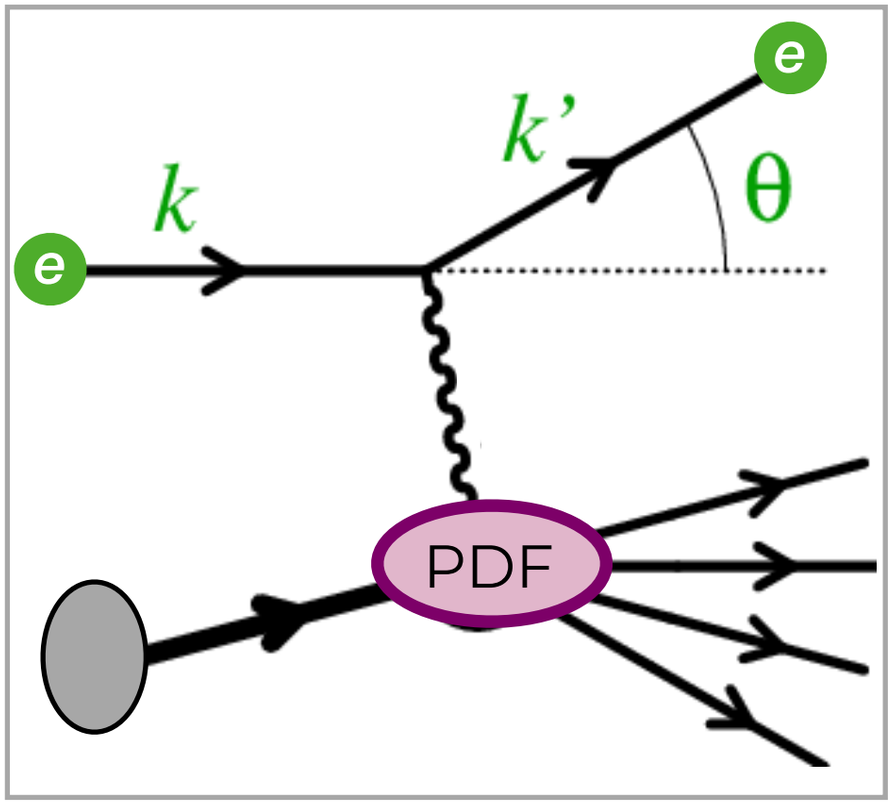
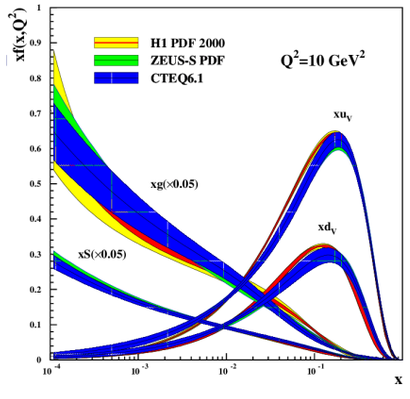
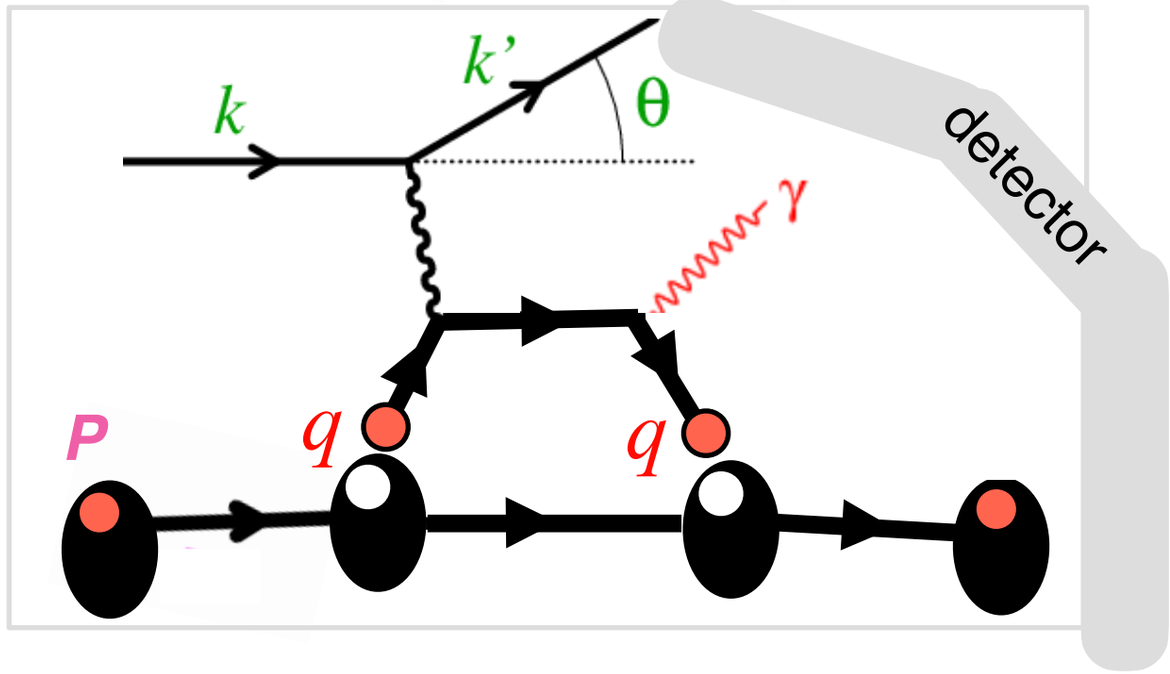




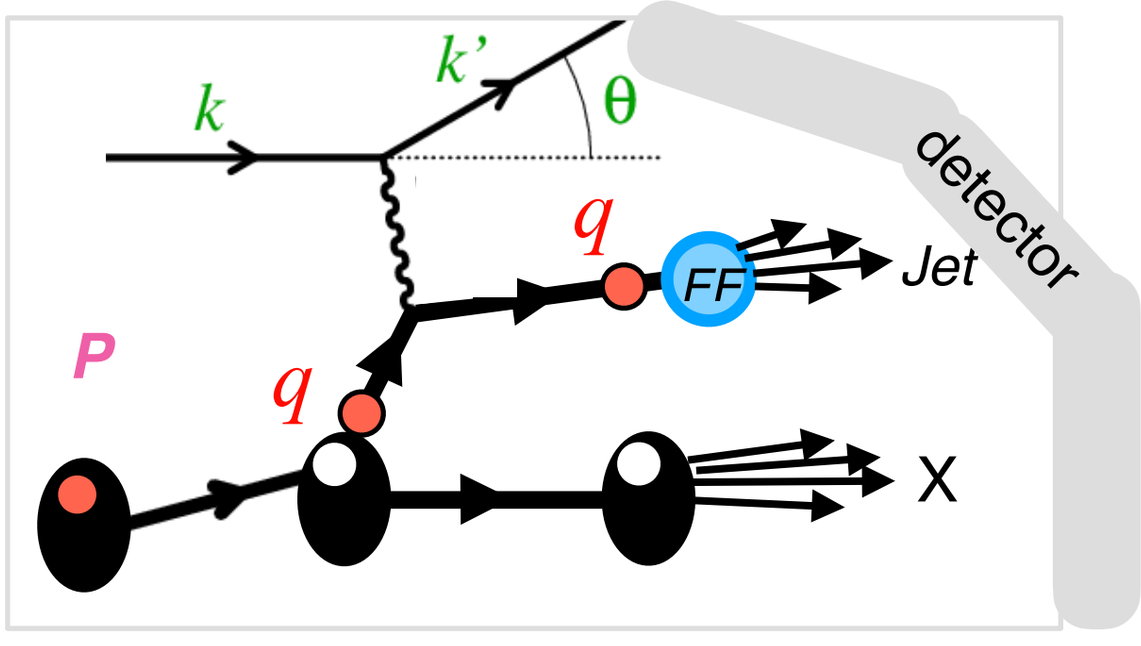
Deeply virtual Compton scattering **(DVCS)**

$e + p \rightarrow e + \gamma + p$



Semi-includie deep inelastic scattering **(SIDIS)**

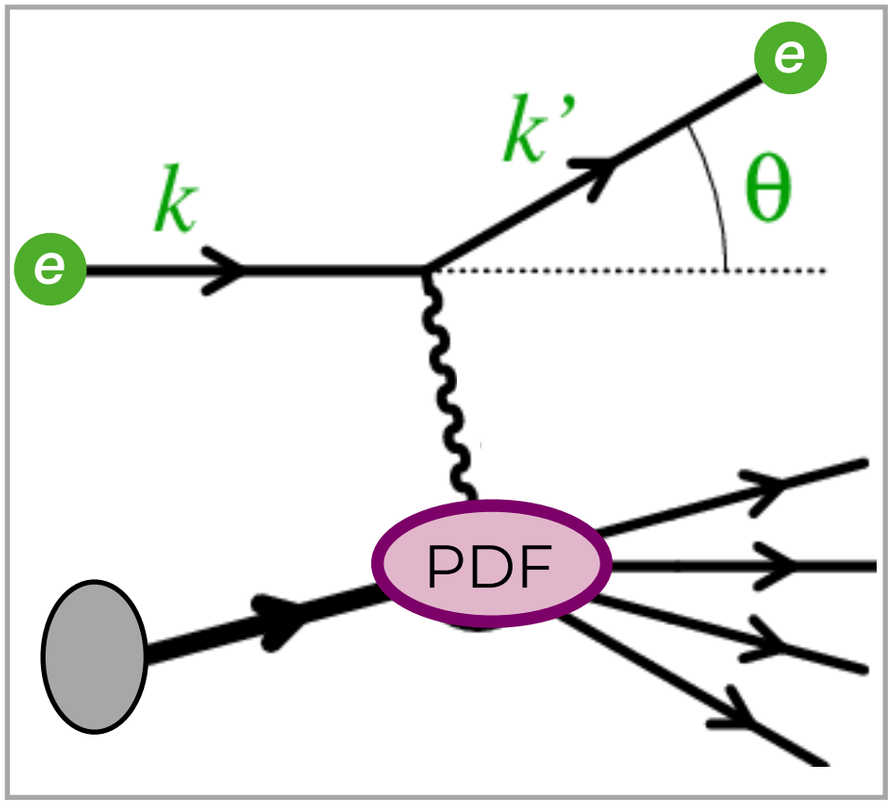
$e + p \rightarrow e + \text{jet} + \text{beam jet}$

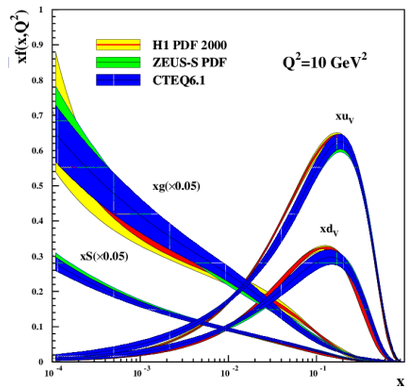


Inclusive vs Exclusive measurements

Inclusive DIS

$$e + p \rightarrow e + X$$





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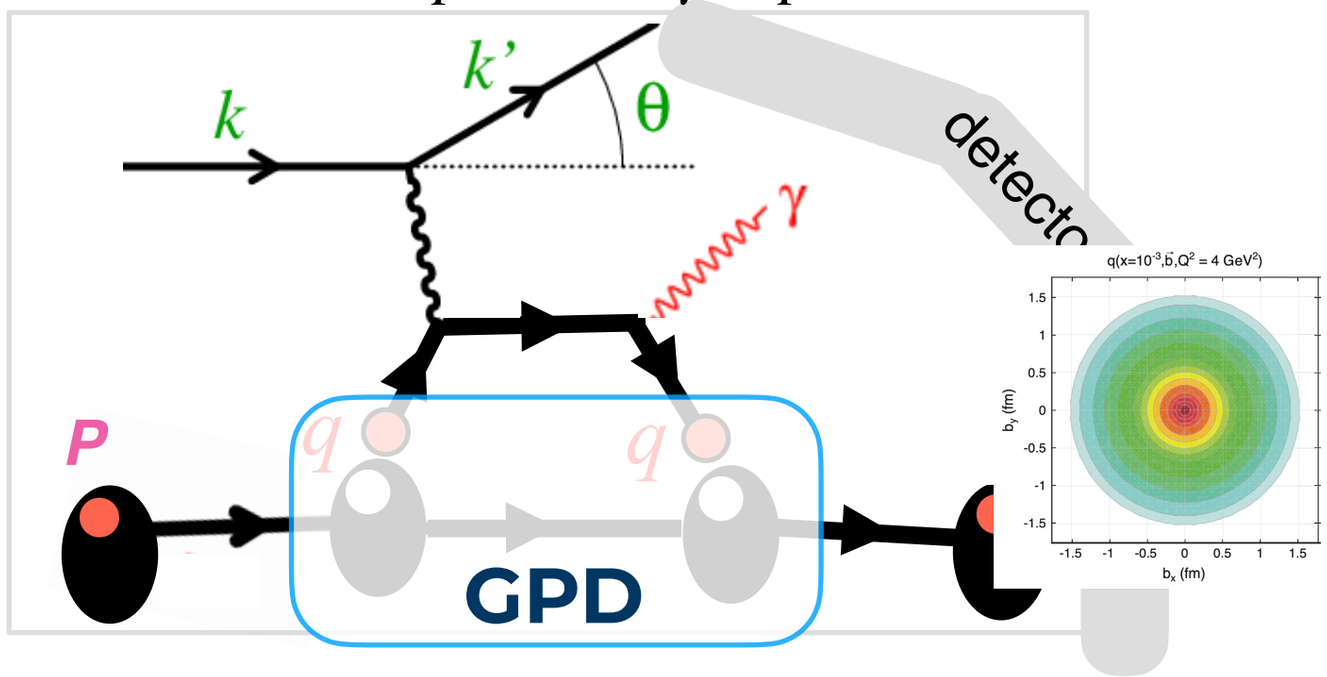

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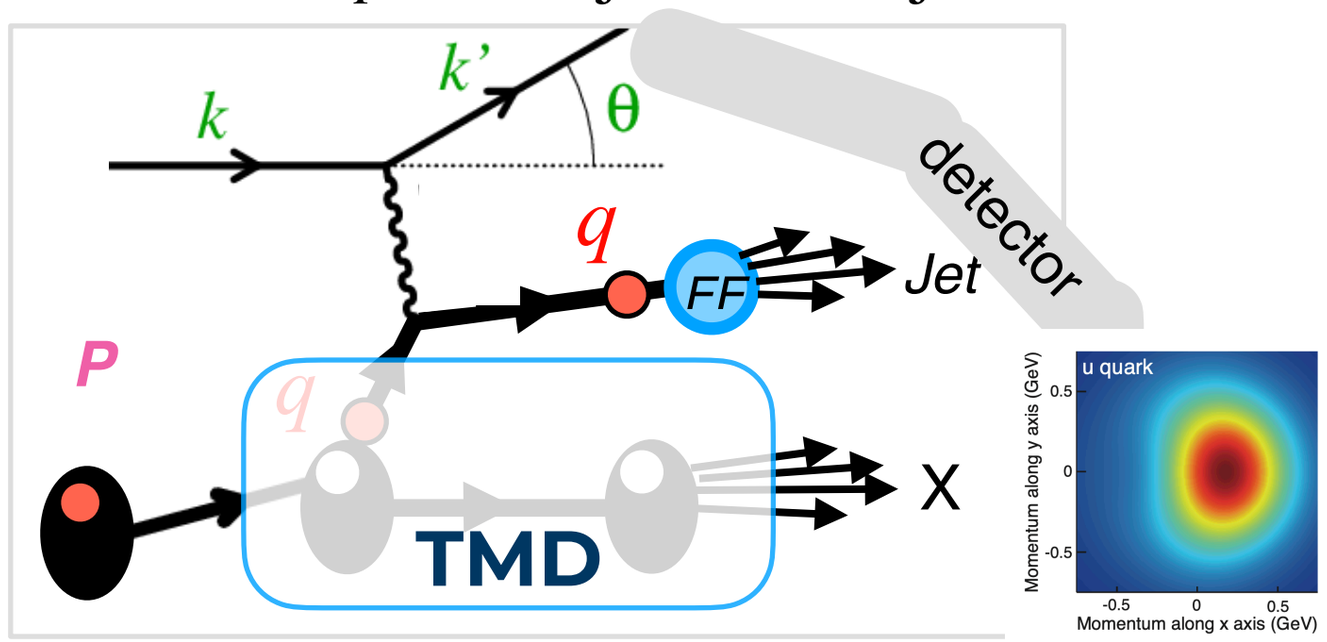
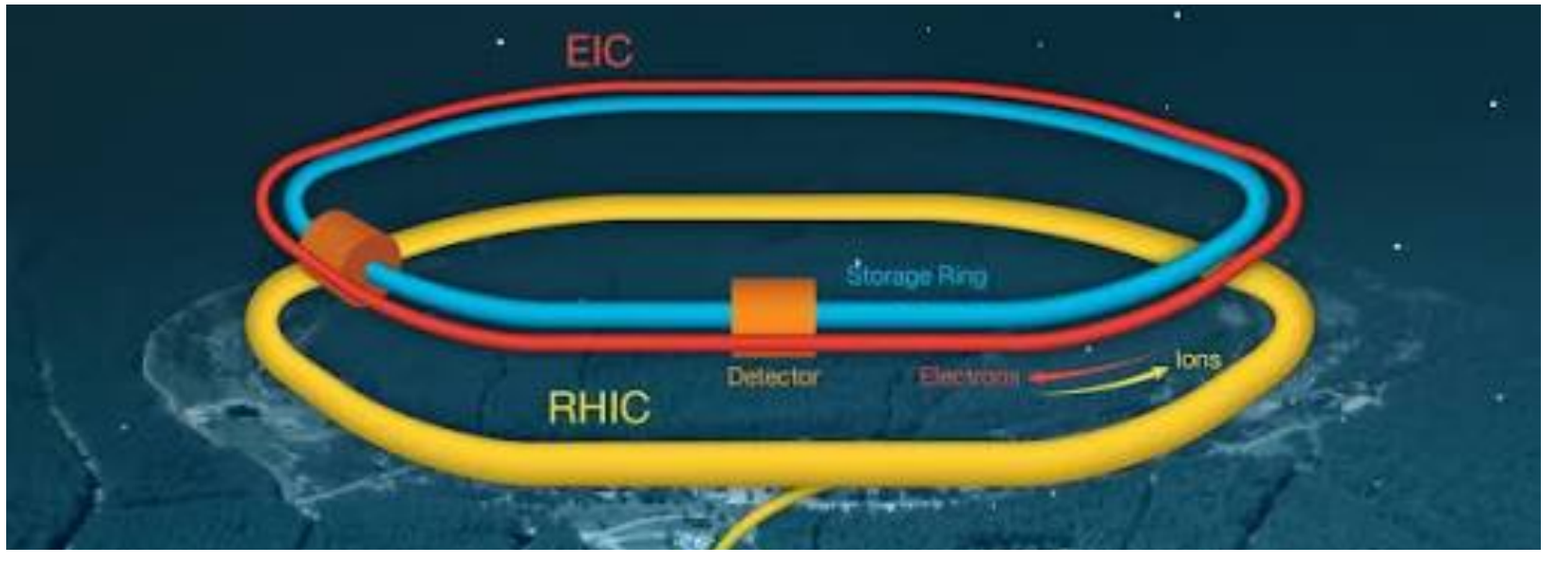


The Landscape of Structure Functions



The EIC will provide comprehensive insights into TMDs and GPDs in the future.

3-dim distribution		
	TMD (x, k_T)	**GPD** (x, Δ)

The Landscape of Structure Functions

1-dim distribution

From factor

PDF (x)

$\int d^2k_T$

$\Delta \to 0$

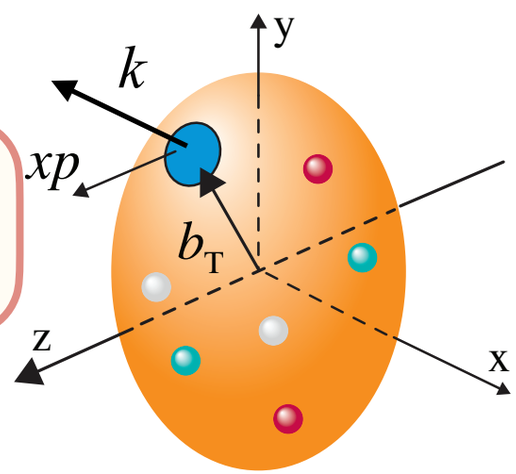
3-dim distribution

TMD (x, k_T)

GPD (x, Δ)

5-dim distribution

Wigner function (x, k_T, b_T)



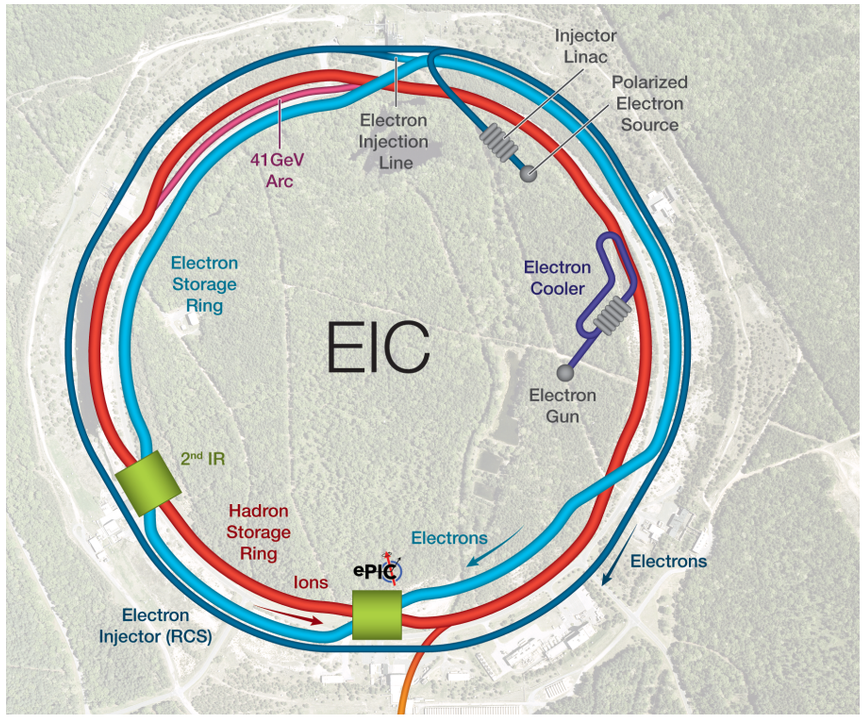
Electron-Ion Collider

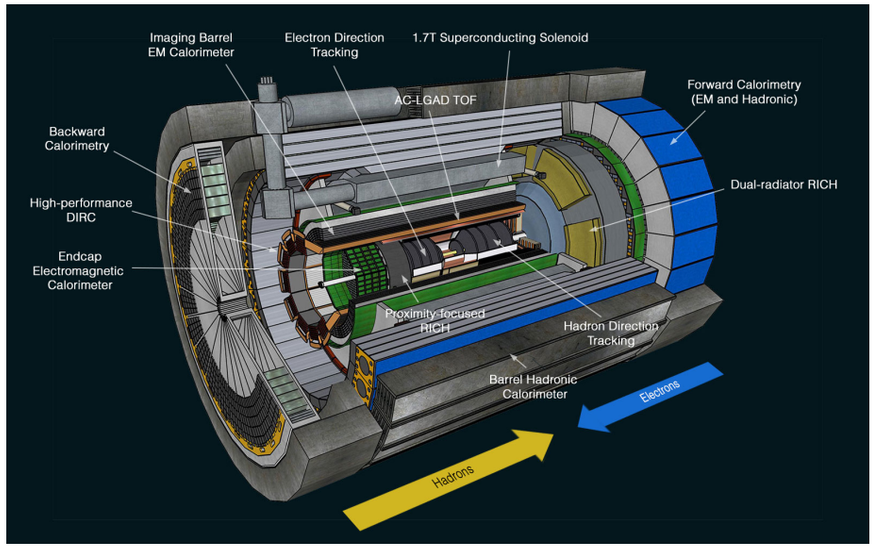
First Collider for Polarized e+p and e+A

- High luminosity ~ 10^{34} $cm^{-2}s^{-1}$
- E_{cm} : Up to ~140 GeV
- Highly polarized electron (~70%) and proton (~70%) beams
- To be constructed at BNL in ~2030

Science mission

- Precision 3D imaging of protons and nuclei
- Solving the proton spin puzzle
- Quark and gluon confinement
- PDF modification in nuclei

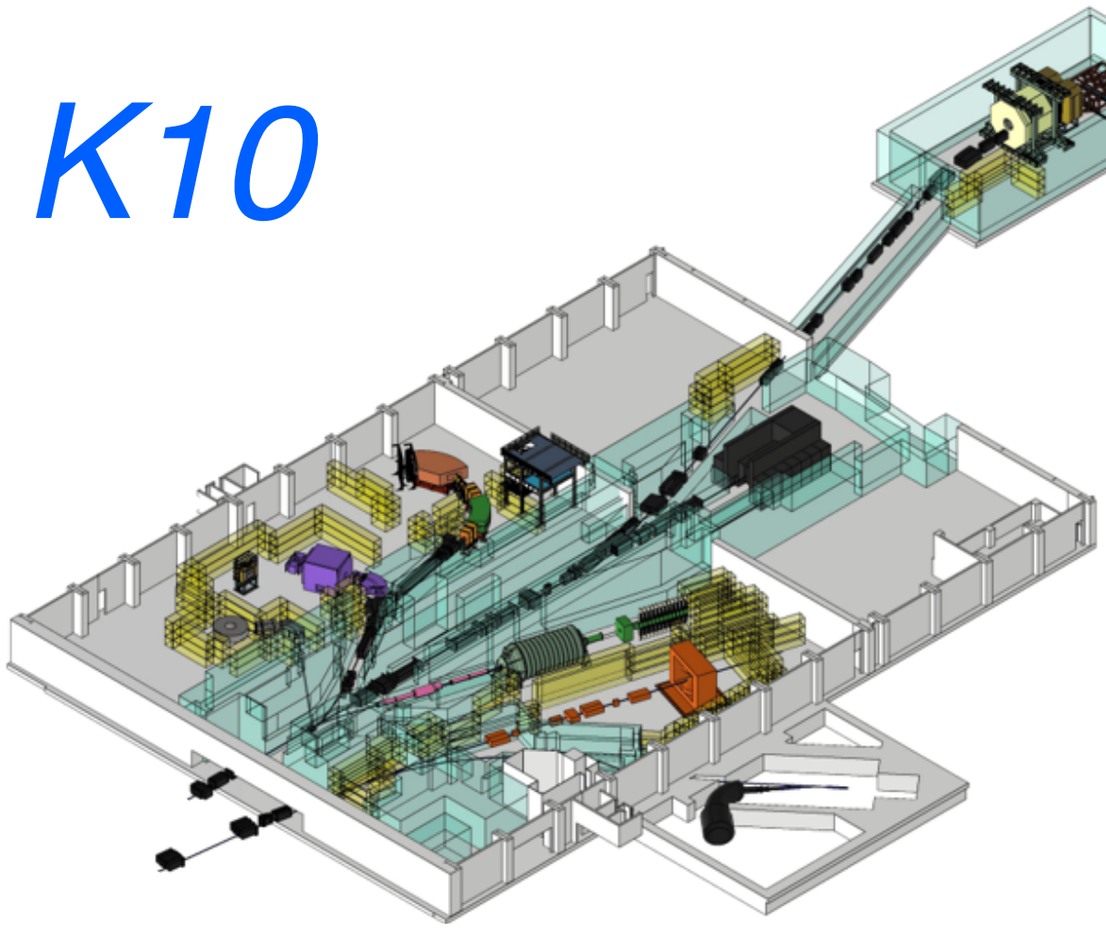


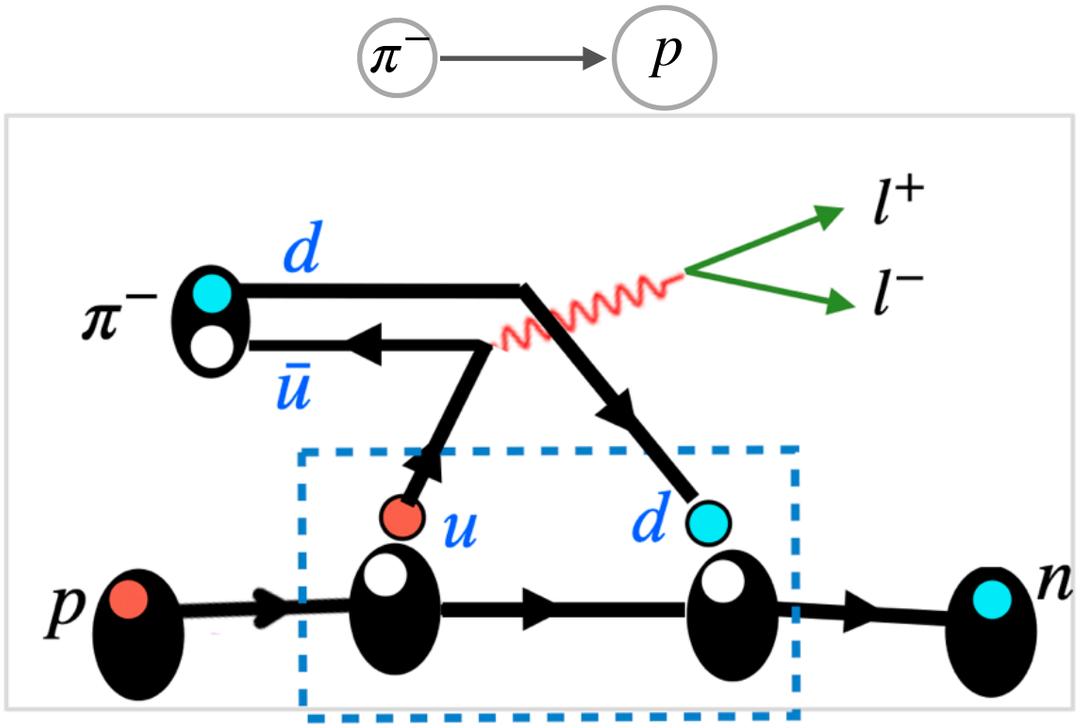


There is no doubt that the EIC will revolutionize our understanding of nuclear tomography.

… Yet, there is an untapped potential just near us!

K10



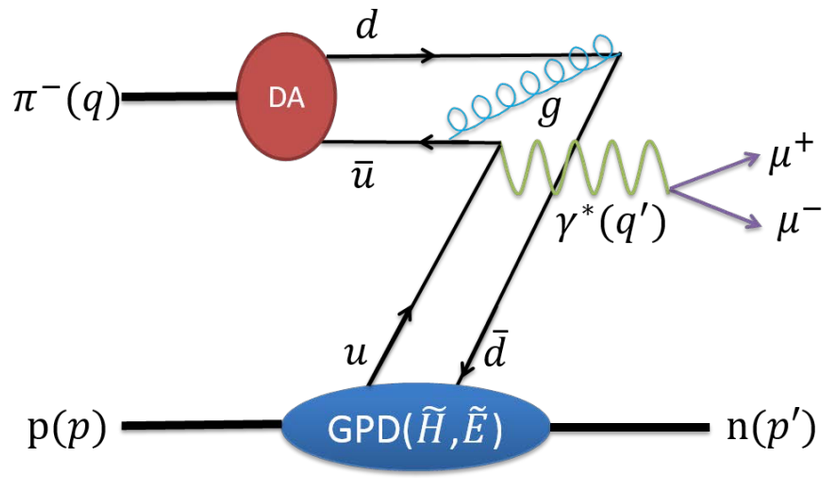


GPD (x, Δ)

What is K10's unique advantage in nucleon tomography alongside the EIC?

References

- **Exclusive Drell-Yan process**
  - $p + \pi^- \rightarrow n + \mu^+ + \mu^-$
  - Access for the **GPD** of proton
- This presentation is largely based on the 2018 Letter of Intent on the by the E50 Collaboration and colleagues



J-PARC LoI 2019-07

LETTER OF INTENT

Studying Generalized Parton Distributions with Exclusive Drell-Yan process at J- PARC

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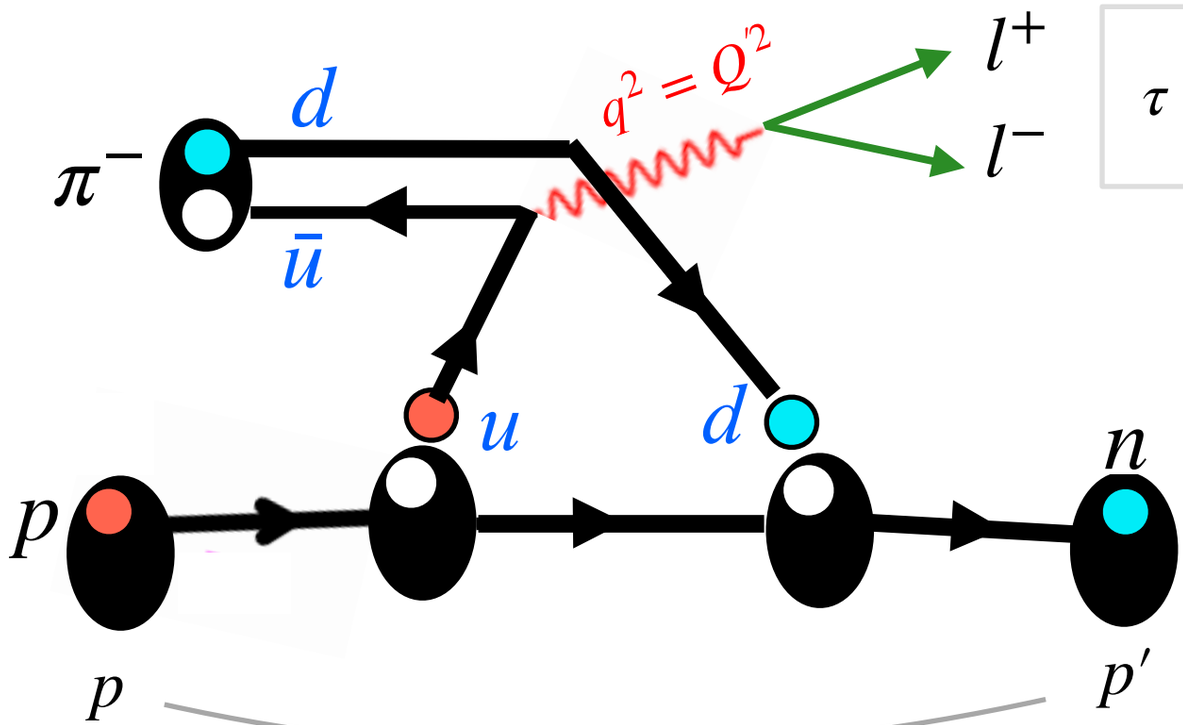
Exclusive Drell-Yan process at K10



$$\tau = \frac{Q'^2}{2p \cdot q}$$

$$\xi = \frac{Q'^2}{2s - Q'^2}$$

$$\Delta = -(p - p')^2 \quad (= -t)$$

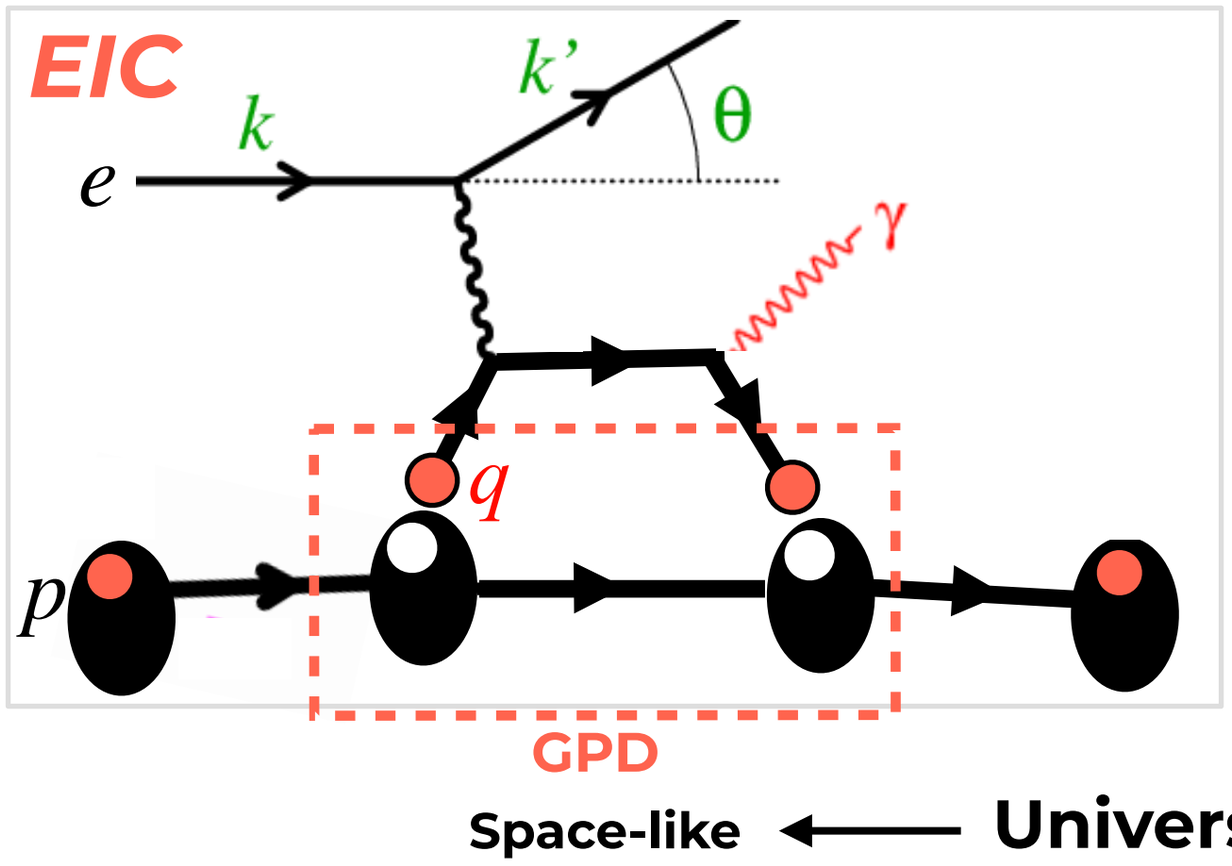
Experimental observable

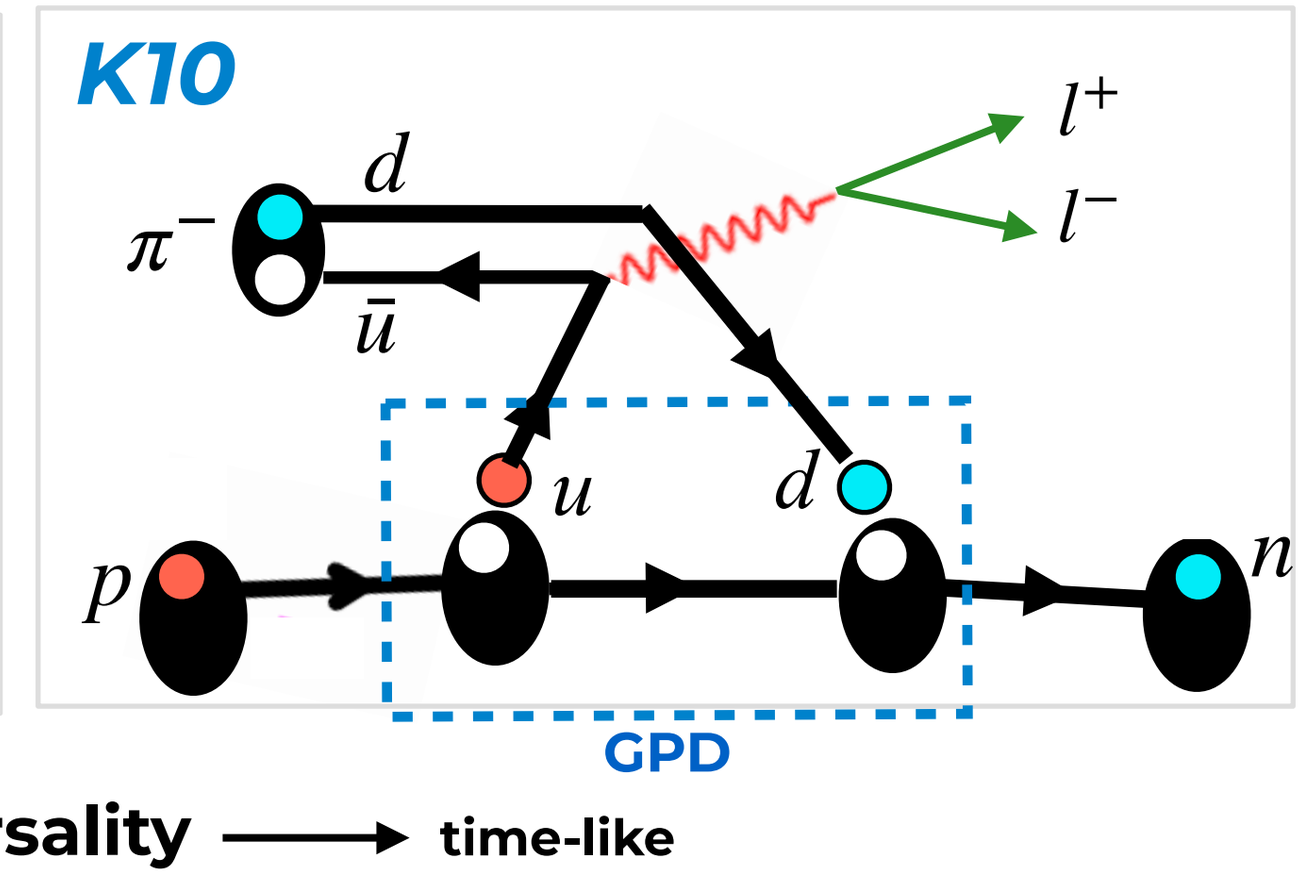
$$\left.\frac{d\sigma_L}{dt dQ'^2}\right|_\tau = \frac{4\pi\alpha_{\rm em}^2}{27}\frac{\tau^2}{Q'^8} f_\pi^2 \left[(1-\xi^2)|\tilde{\mathcal{H}}^{du}(\tilde{x},\xi,t)|^2 - 2\xi^2 \mathrm{Re}\left(\tilde{\mathcal{H}}^{du}(\tilde{x},\xi,t)^* \tilde{\mathcal{E}}^{du}(\tilde{x},\xi,t)\right) - \xi^2 \frac{t}{4m_N^2}|\tilde{\mathcal{E}}^{du}(\tilde{x},\xi,t)|^2\right]$$

$$, \text{ where } \tilde{x} = -(q+q')^2/(2(p+p')\cdot(q+q')) \approx -Q'^2/(2s - Q'^2) = -\xi$$

- Analogous to solving a system of equations, with each experiment providing one constraint
- In other words, **a single experiment is never sufficient** to fully determine GPDs
- A comprehensive theoretical analysis through global fits is essential

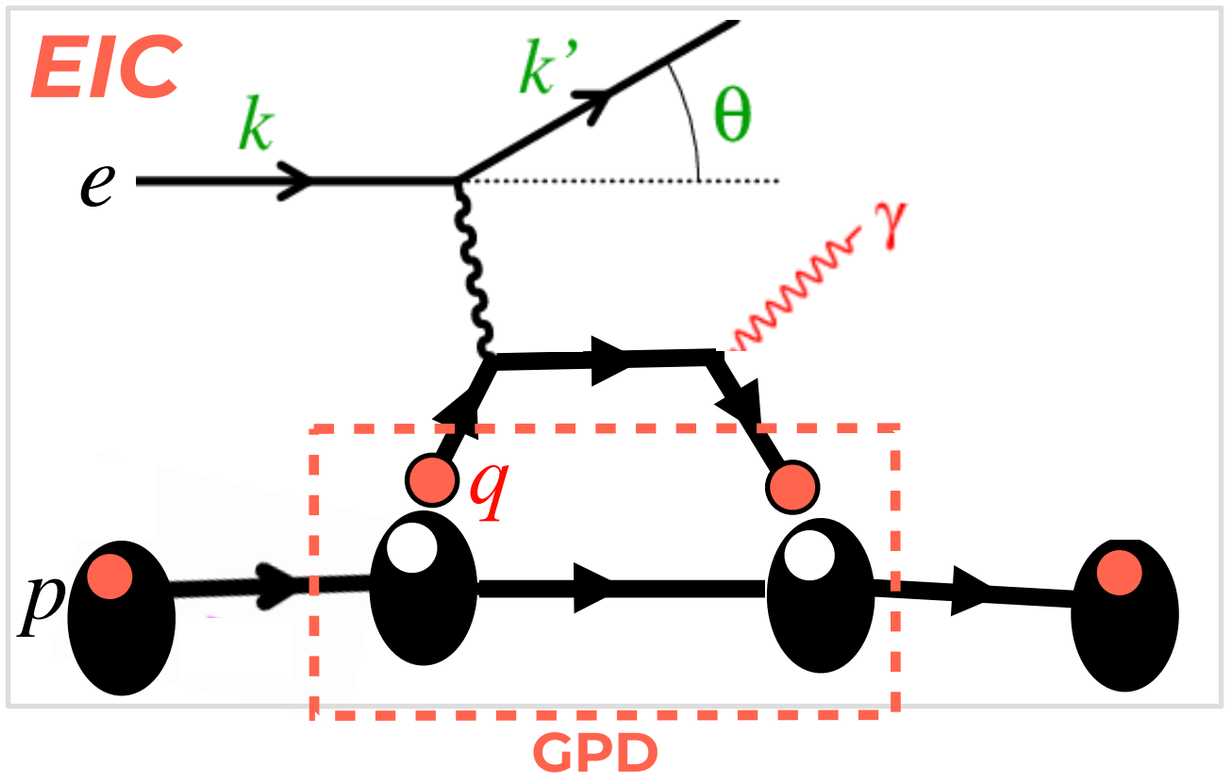
Complementarity between EIC and K10 (1)

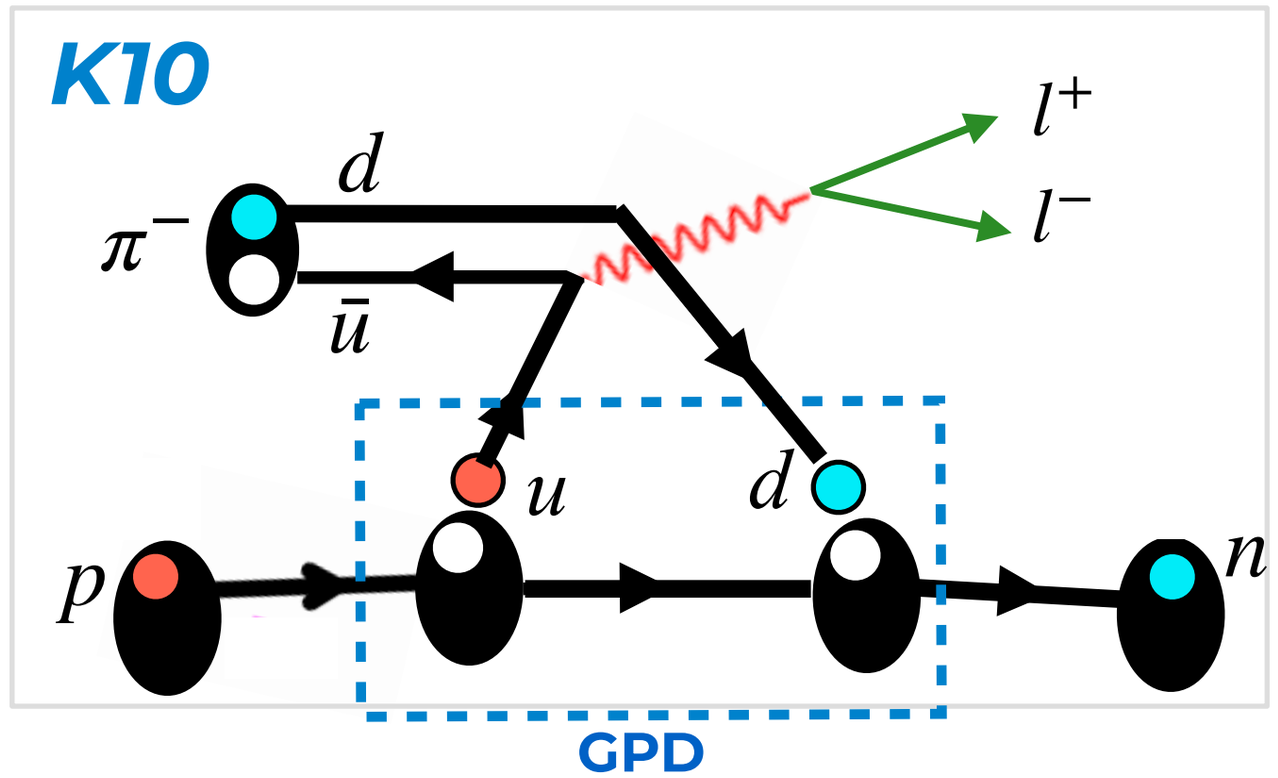




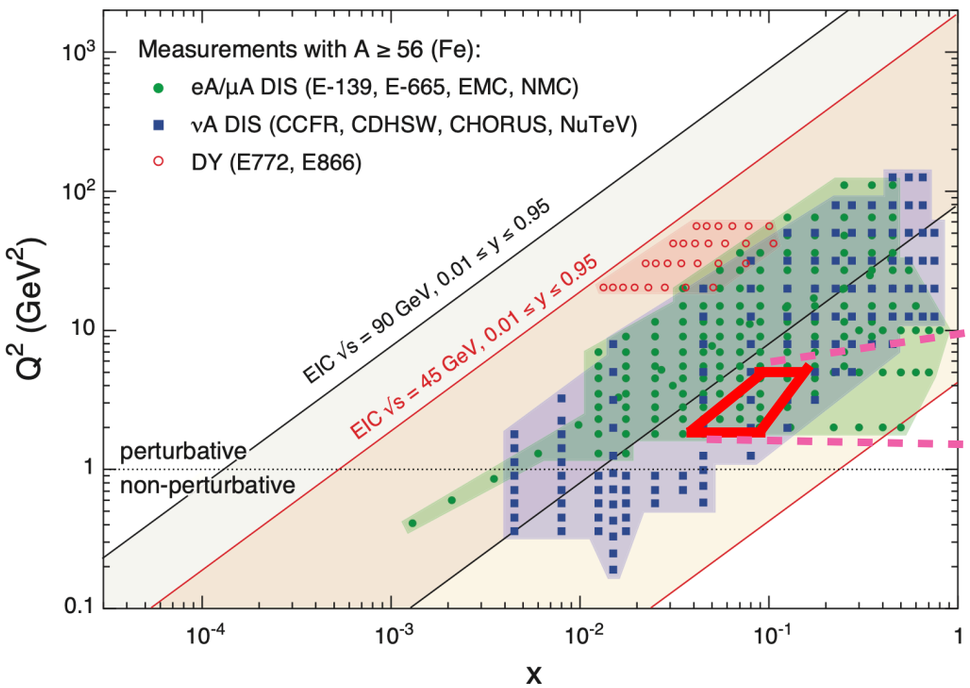
Space-like ⟵ **Universality** ⟶ **time-like**

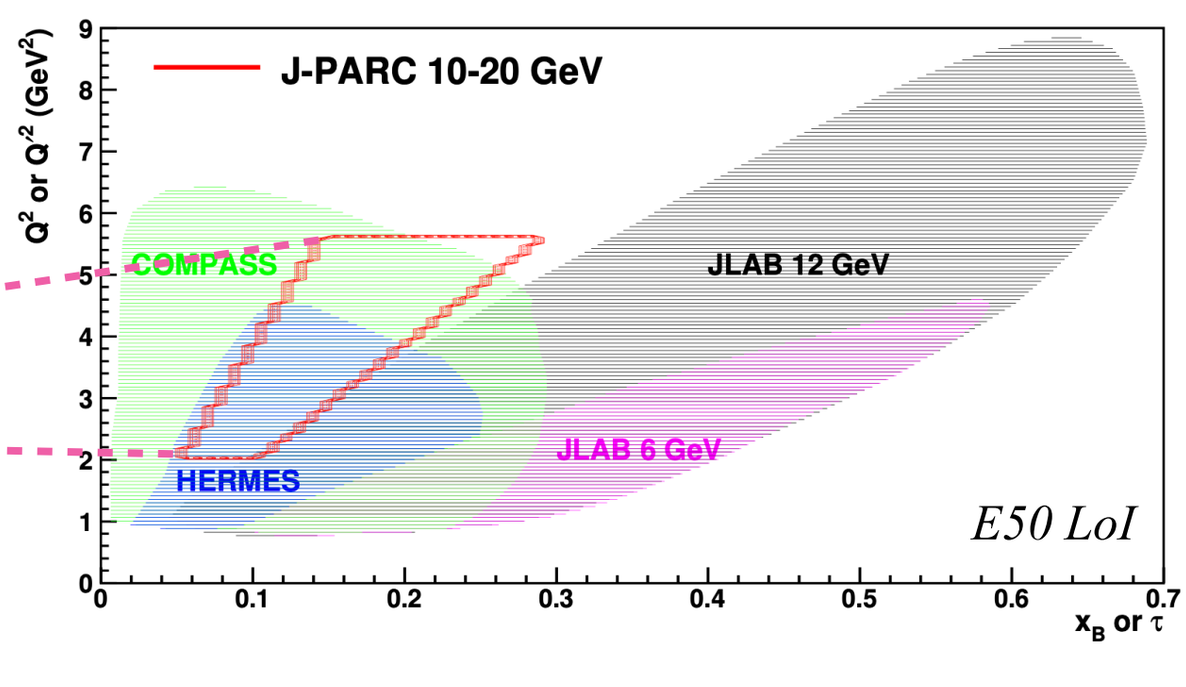
Complementarity between EIC and K10 (1)





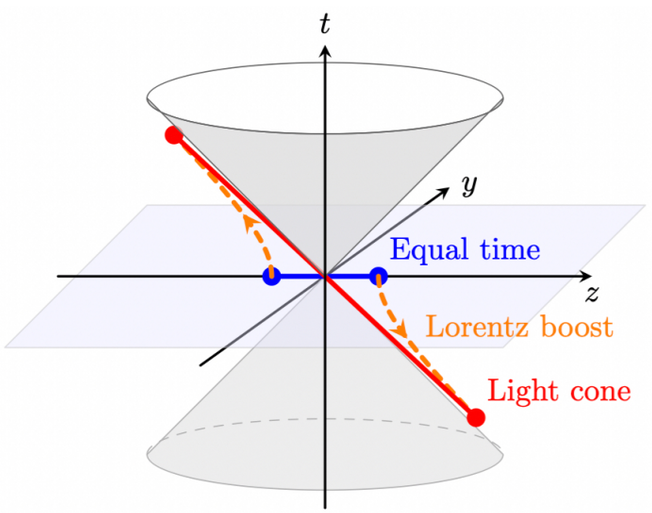
Space-like ⟵ **Universality** ⟶ **time-like**





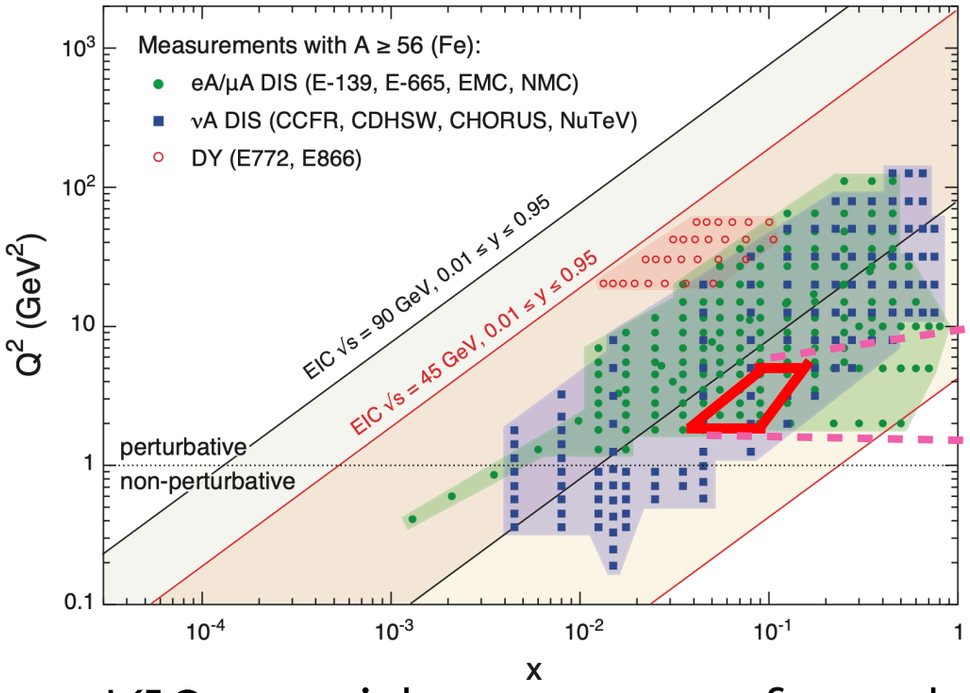
K10 provides a strong foundation for validating the EIC results in advance.

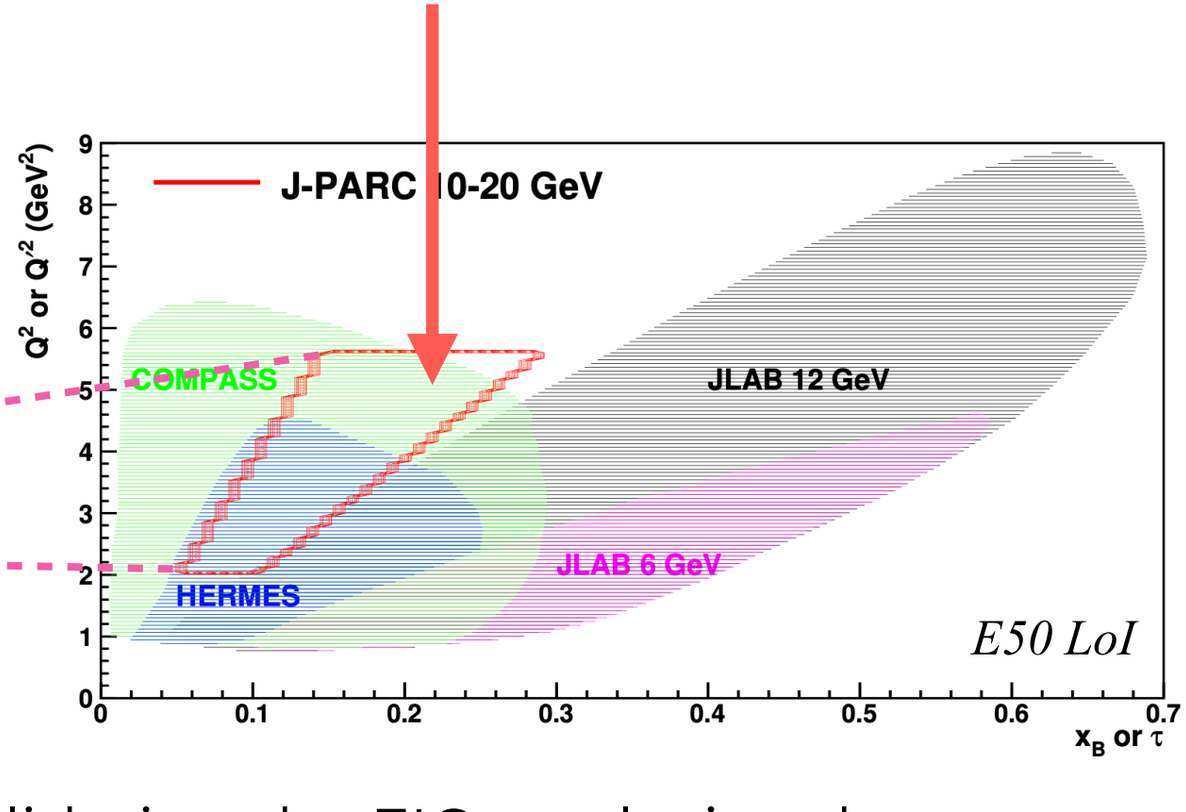
Complementarity between EIC and K10 (1)



LaMET (Large Momentum Effective Theory)

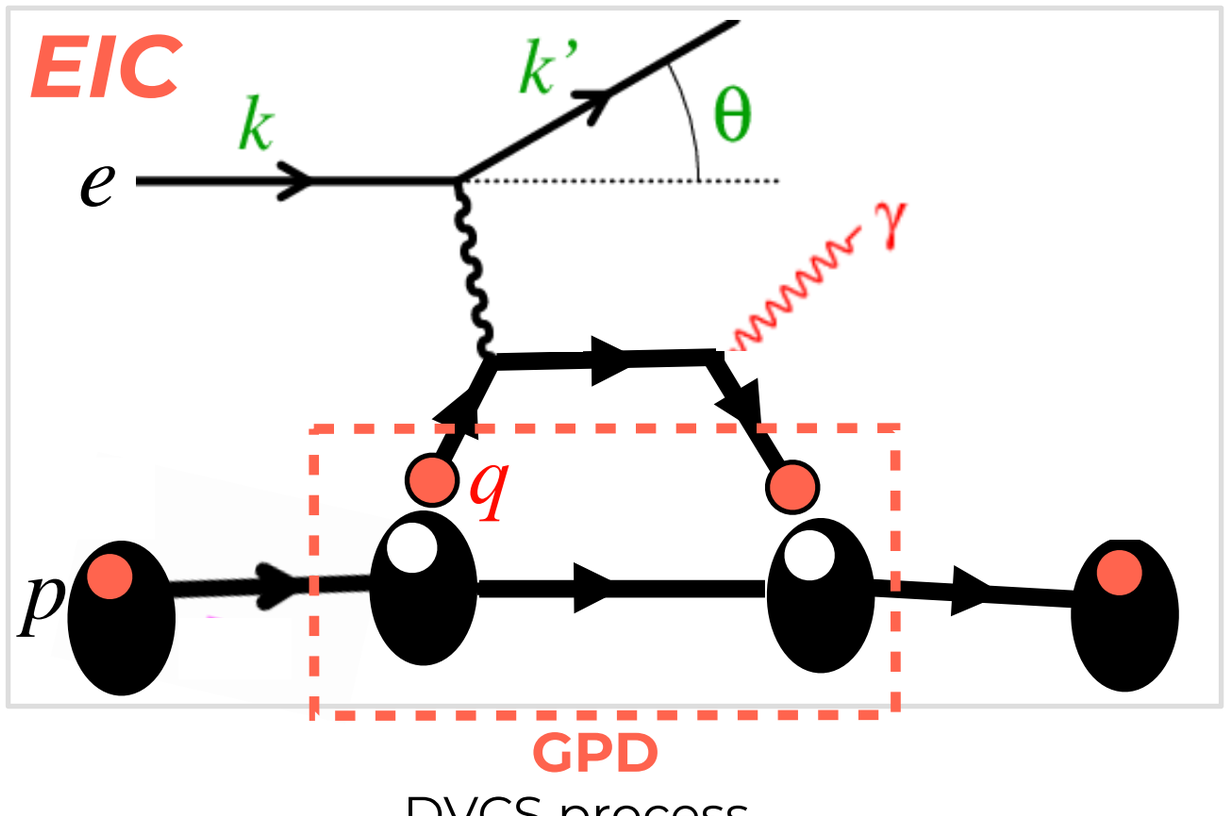
- New method to calculate the structure function *ab initio* (X. Ji, arXiv:1305.1539)
- LaMET is uniquely powerful in the high-x region (x ~ 0.1), aligning perfectly with the kinematic regime of J-PARC K10

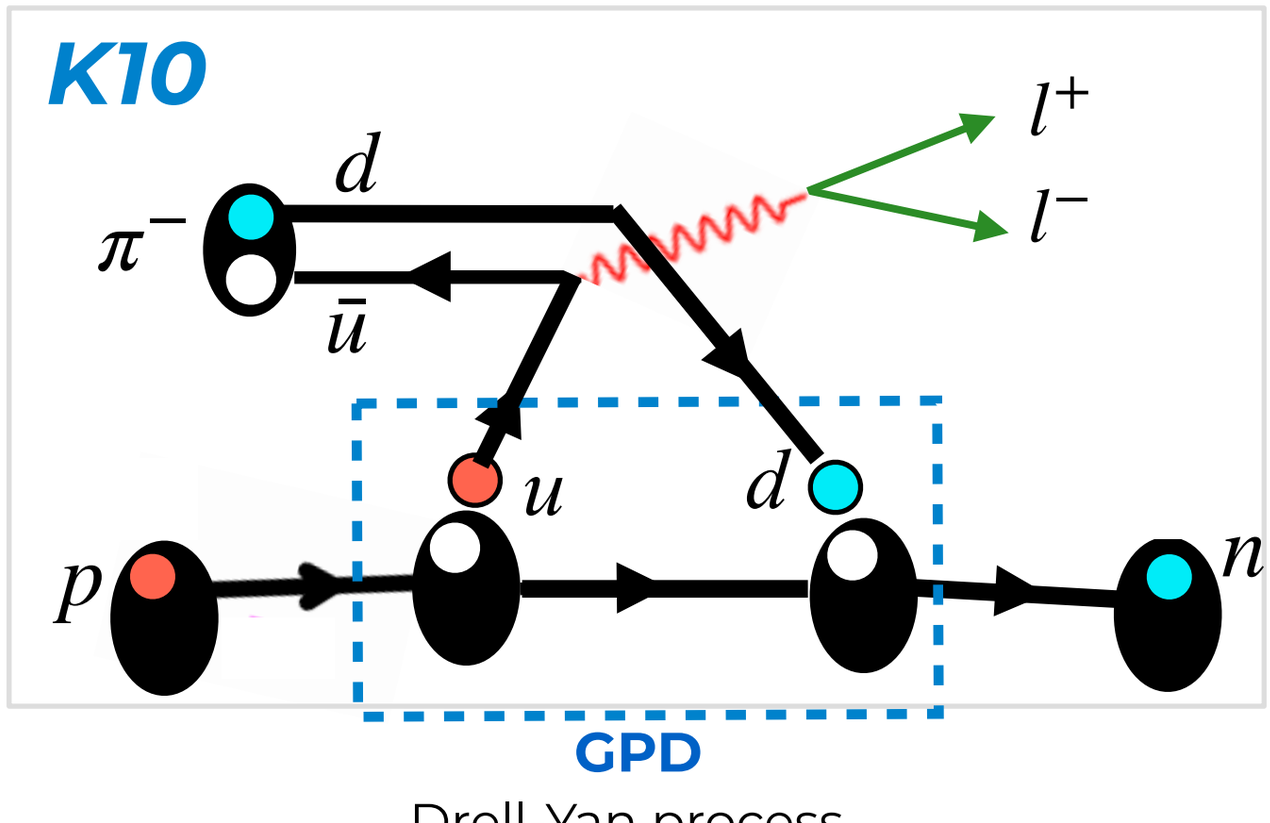




K10 provides a strong foundation for validating the EIC results in advance.

Complementarity between EIC and K10 (2)





DVCS process

$$\frac{4}{9}H^u(x,\xi,t)+\frac{1}{9}H^d(x,\xi,t)$$

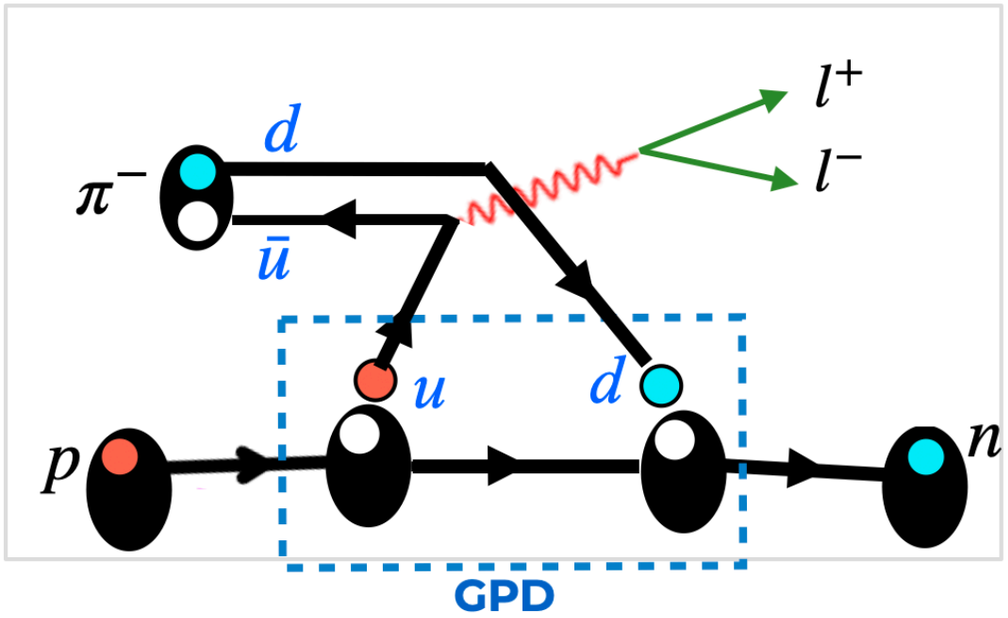
Drell-Yan process

$$\tilde{\mathcal{H}}^{du}(\tilde{x},\xi,t)=\frac{8}{3}\alpha_s\int_{-1}^{1}dz\,\frac{\phi_\pi(z)}{1-z^2}\times\int_{-1}^{1}dx\left(\frac{e_d}{\tilde{x}-x-i\epsilon}-\frac{e_u}{\tilde{x}+x-i\epsilon}\right)\left(\tilde{H}^d(x,\xi,t)-\tilde{H}^u(x,\xi,t)\right)$$

Orthogonal Constraints:

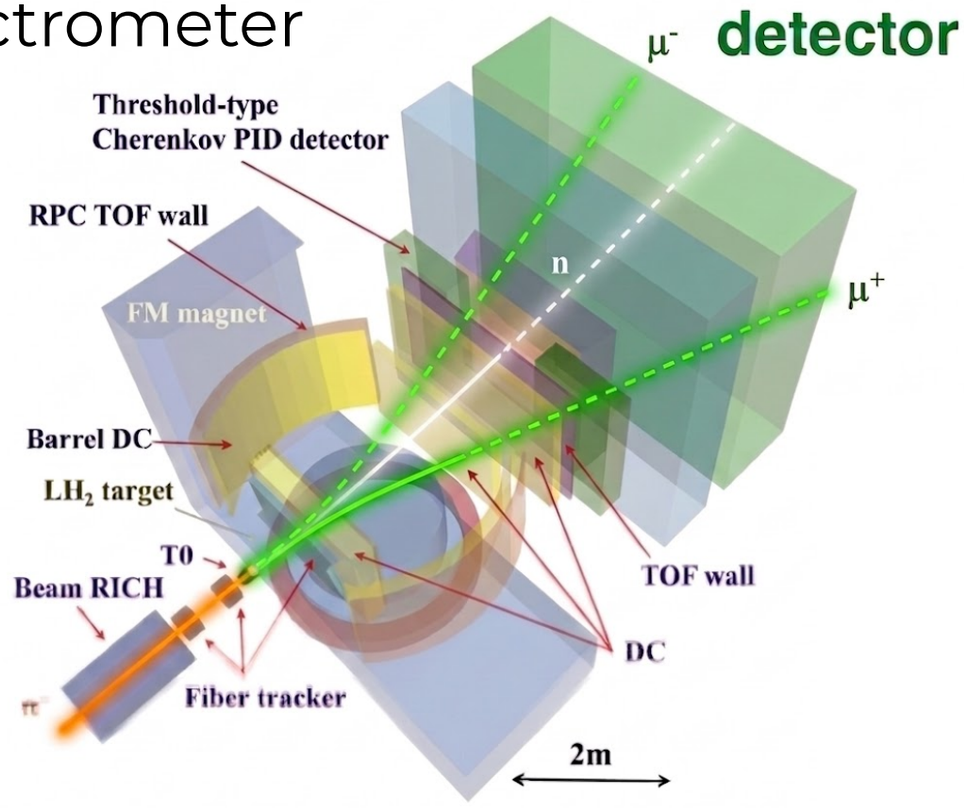
- EIC and K10 provide linearly independent values, thus allowing the **flavor-separated GPD**
- Unlike e+d scattering at EIC, K10 uses a free proton target, entirely avoiding systematic errors from Fermi motion
- While the EIC can probe timelike GPDs through Timelike Compton scattering (TCS), this channel inevitably suffers from Bethe-Heitler background

Detector development



MARQ
spectrometer

Muon detector



What would be the requirement for **KDREAM?**

- High resolution inner tracker (with pi, K identfication)
- A **Muon system** for PID and tigger
  - Seeking for funding for this in Korea as well
  - Potential options: μRWEll(+GEM) and RPC
- Muon ID will also largely extend the physics program for K10
  - Quarkonia and exotic hadrons (e.g. $P_{c\bar{c}}$, P_{cs})

Anticipated Performance at K10

Reconstructed neutron mass by missing mass technique

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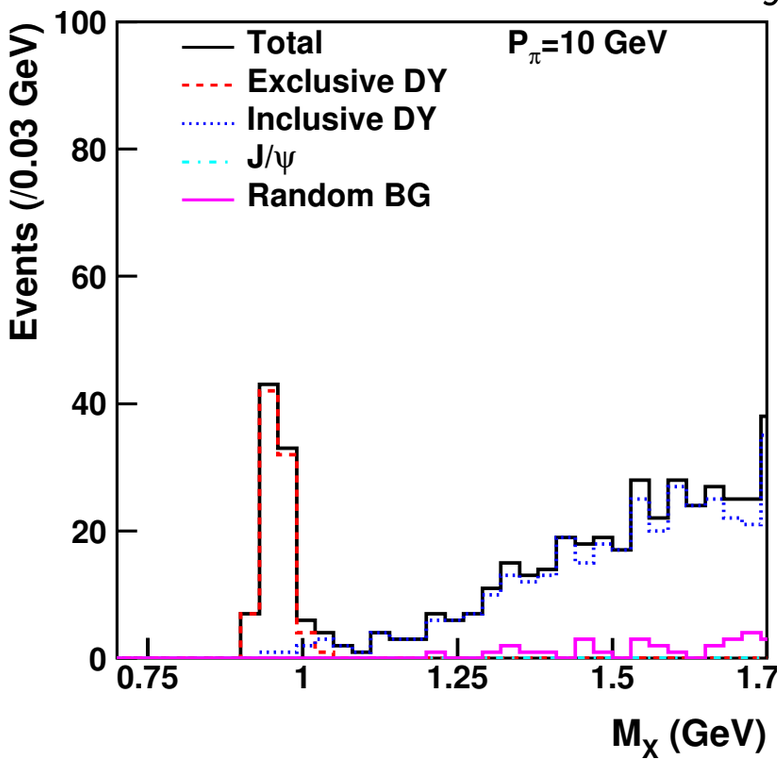
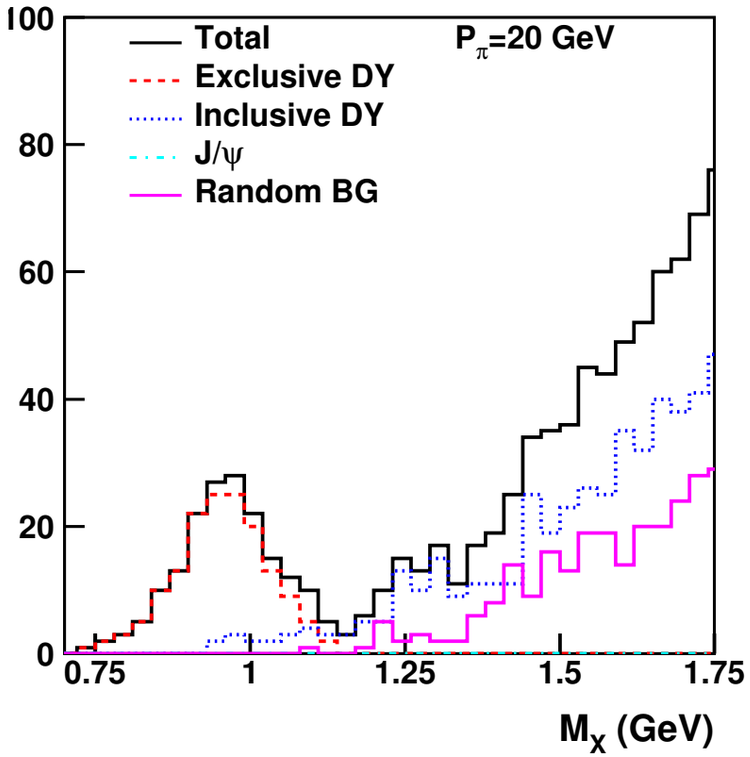
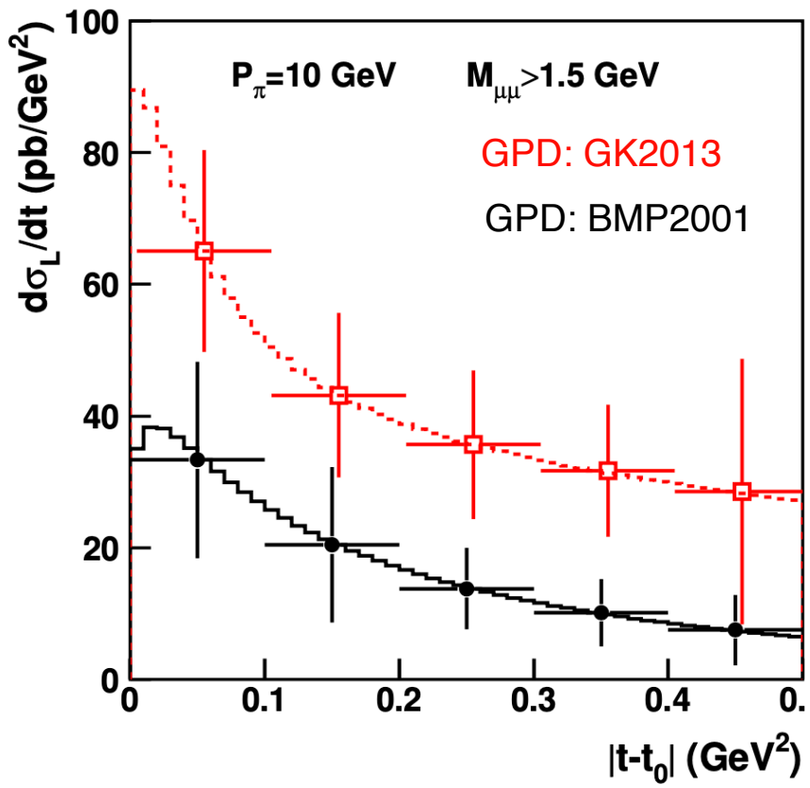
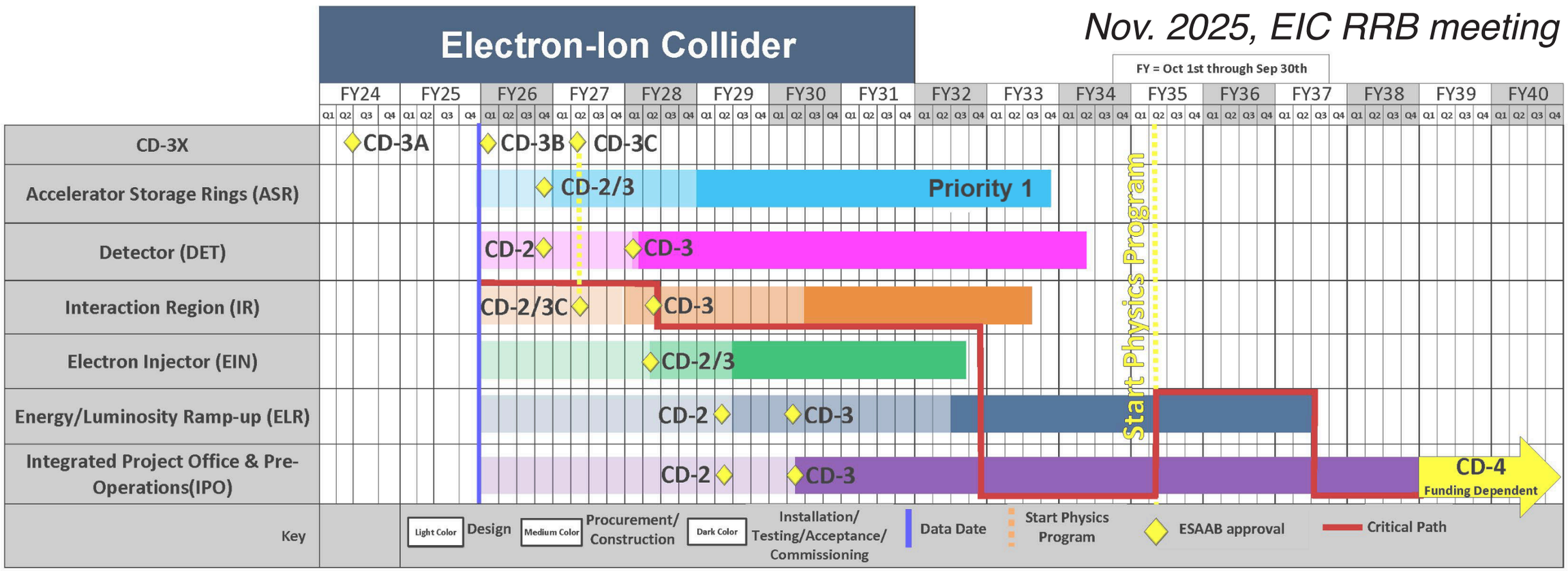






- GK2013, BMP2001 GPD parameterization was used for this simulation in this LoI
- Position resolution: 80μm *(Silicon strip),* 1 *mm (fiber tracker)*
- Backgrounds are from J/ψ and combinatorial bkg from minimum bias hadronic events
  - Simulation scenario for 50 days of data taking
  - Number of collisions: 1.83×10^7 (10 GeV) and 1×10^7 (20 GeV)

Next decade: golden time for K10



Pre-EIC gap

- Must maintain experimental momentum over the next decade
- Need complementary data to untangle EIC systematics (flavor separation, nuclear effects)

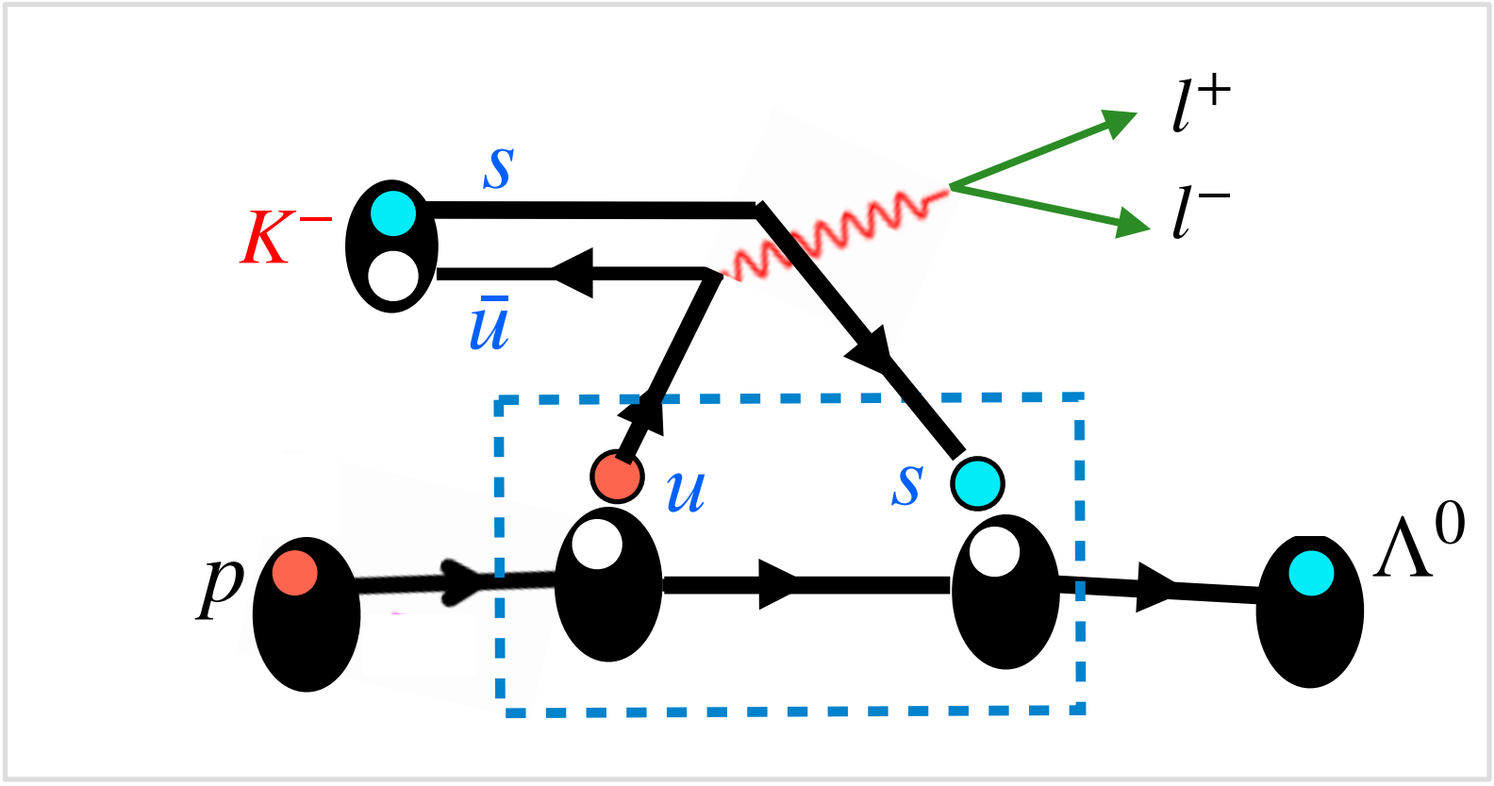
K10: The Ideal Proving Ground

- Immediate capabilities for exclusive Drell-Yan processes
- Mapping time-like GPDs years ahead of the EIC timeline to enable vital cross-checks
- Providing early, high-quality inputs for global fit analyses in the theory community

Strangeness: Unique Opportunity of K10

Probing s-quark GPDs using Kaon beam

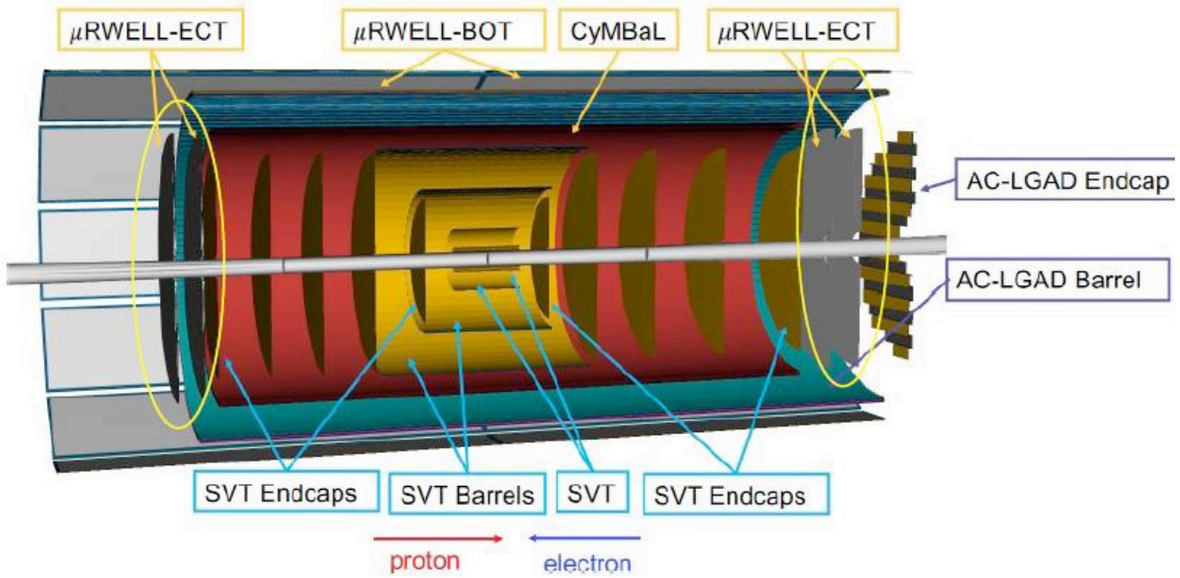
$$K^- + p \rightarrow \Lambda^0 + l^+ + l^-$$

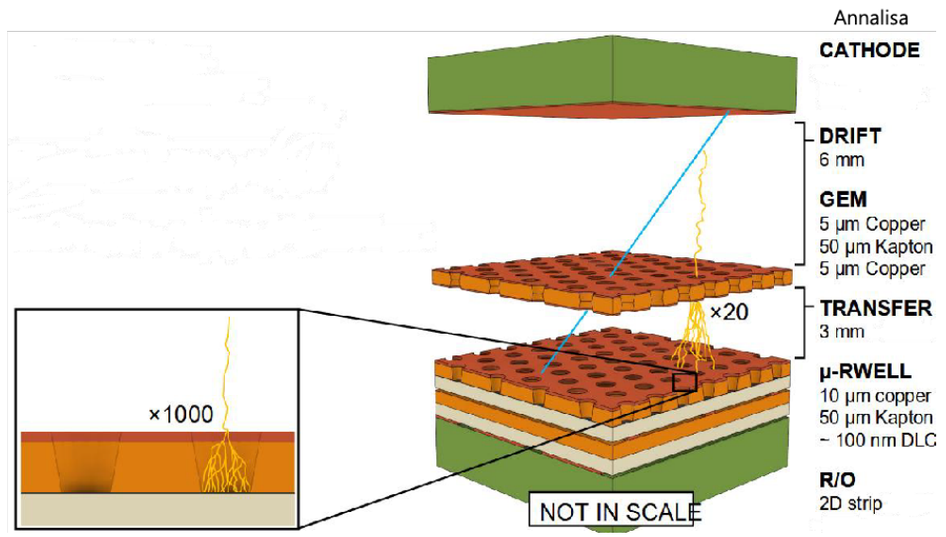


High energy K beam: Golden channel for strange quark

- Will be the first-ever experimental platform to map the 3D spatial distribution of strangeness in the nucleon
- $H^{u\rightarrow s}(x,\xi,t) = H^u(x,\xi,t) - H^s(x,\xi,t)$
- Directly probes the validity of flavor SU(3) symmetry breaking at the GPD level.
- Unique capability of K10 (Beyond EIC reach)
- Need a good detector to tag $\Lambda^0 \rightarrow n + \pi^0$ (or good missing mass technology)

GEM+μRwell R&D in Korea

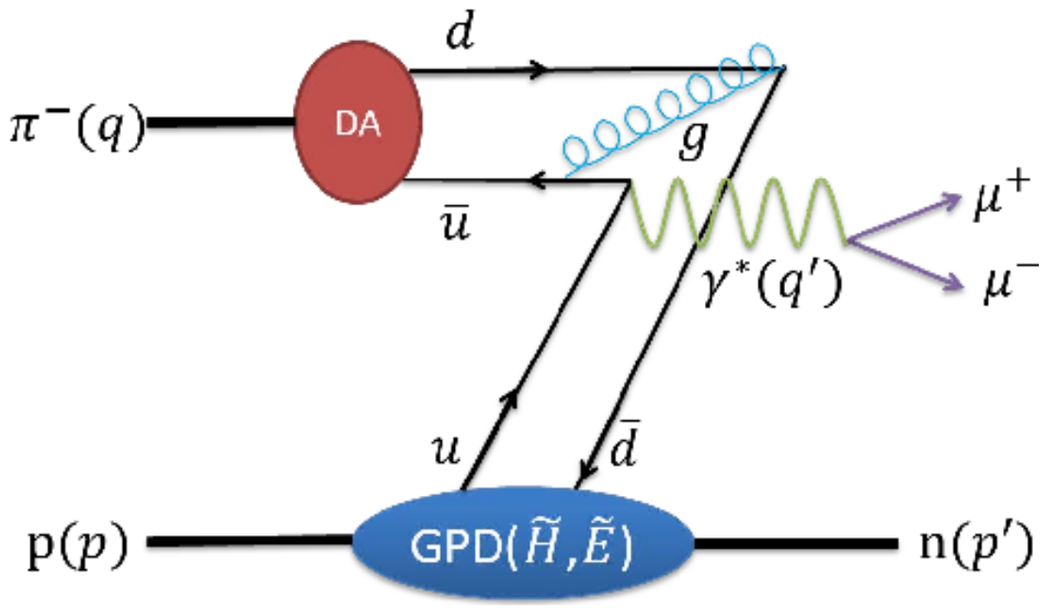


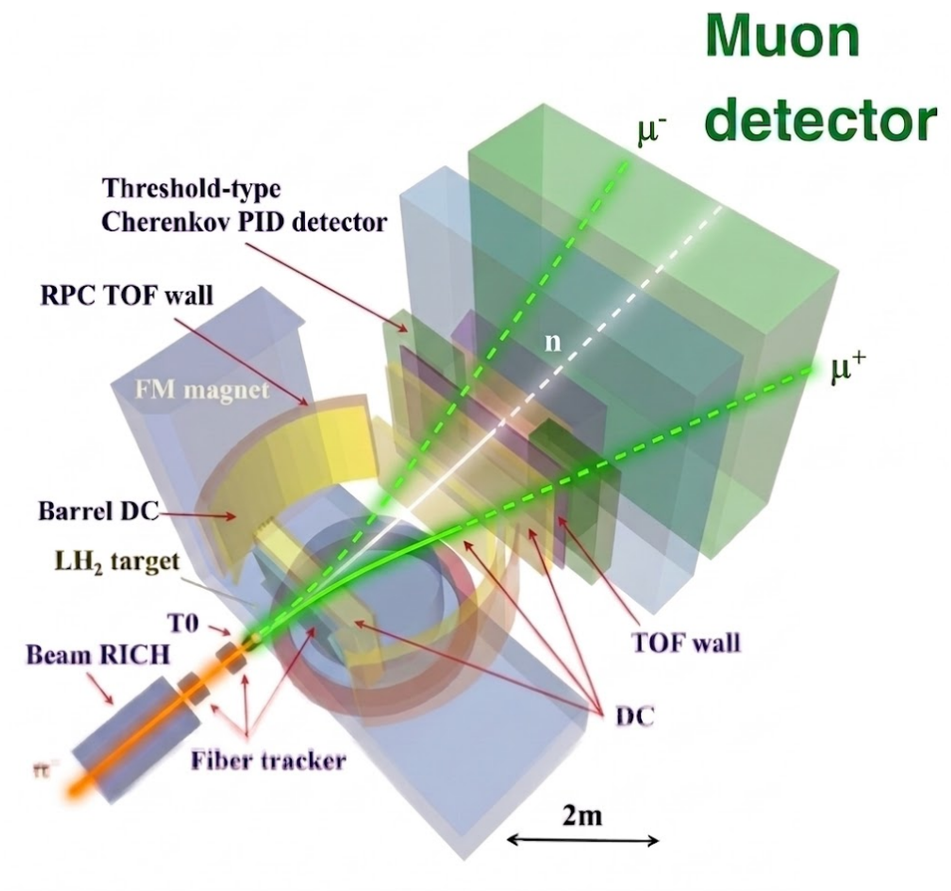


- After completing CMS production, Korean researchers are extending its expertise to μRWELL
  - Primary site of contribution: EIC/ePIC MPGD tracker
  - Projects to contribute to the EIC/ePIC experiment has begun
  - SNU, Sejong U, University of Seoul
- Great opportunity for Muon detector for K10 experiment

Summary

- The K10 Experiment will accelerate the Future of Hadron Physics
  - **Probing Proton Structure** using the **exclusive Drell-Yan process** for high-precision mapping.
  - **Synergy with the EIC:** Investigating complementary physics processes
  - Distinguishing PDF and GPD for u, d, and s quarks.
- Installation of muon detector will massively expand the physics program in K10, towards GPD and quarkonia





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