Beam Spin Asymmetry measurement of Exclusive Φ production off the neutron

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Assemblée Générale – GDR QCD – 2023

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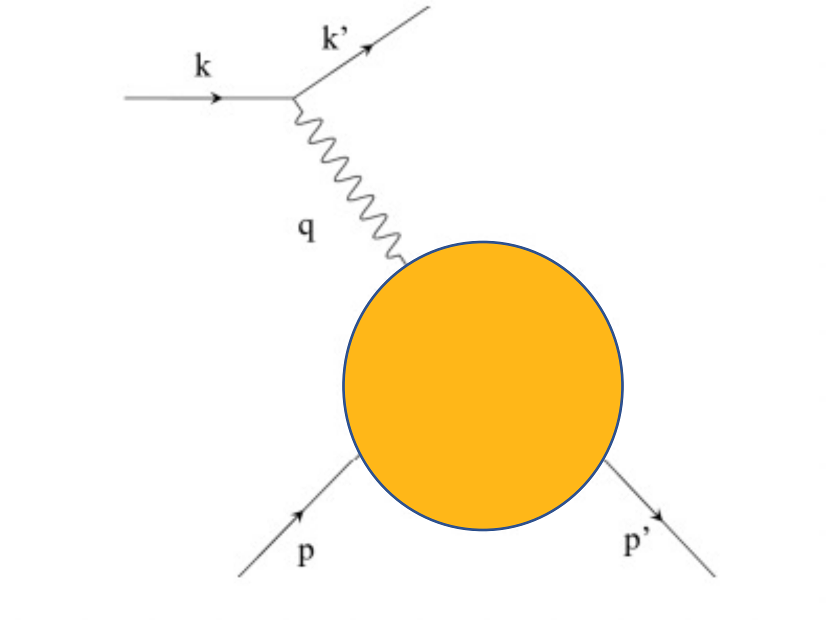
Understanding the structure of nucleon
Elastic Scattering

$$Q^2 = 4EE' \sin^2\left(\frac{\theta}{2}\right).$$



- gives access to transverse spatial distribution of partons
- Cross-section of this scattering, considering an extended nucleon is given by

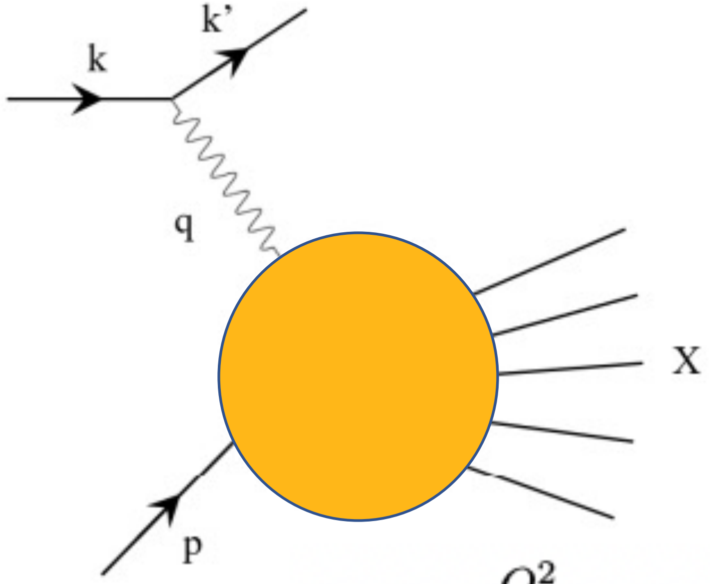
$$\left(\frac{d\sigma}{d\Omega}\right)_{Rosenbluth} = \left(\frac{d\sigma}{d\Omega}\right)_{Mott} \left\{F_1^2(Q^2) + \frac{Q^2}{4M^2}\left[F_2^2(Q^2) + 2\left(F_1(Q^2) + F_2(Q^2)\right)^2 \tan^2\left(\frac{\theta}{2}\right)\right]\right\}$$

F1 and F2 are Dirac and Pauli form factors which give the distribution of electric charge and current inside a nucleon.

Understanding the structure of nucleon

Deep-Inelastic Scattering

$$Q^2 = 4EE' \sin^2\left(\frac{\theta}{2}\right).$$



$$x_{Bj} = \frac{Q^2}{2M\nu}.$$

- gives access longitudinal momentum distribution of partons
- Cross-section of this scattering is given by

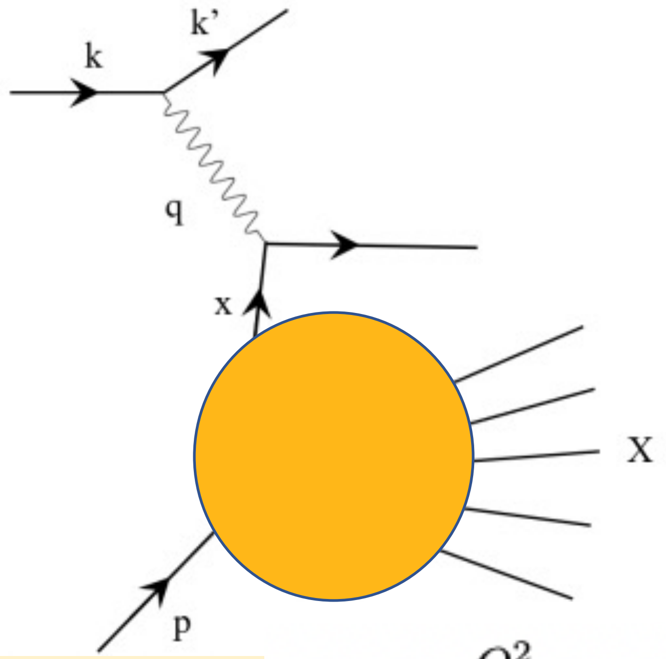
$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2 \cos^2\left(\frac{\theta}{2}\right)}{4E^2 \sin^4\left(\frac{\theta}{2}\right)} \left(\frac{F_2(x_{Bj}, Q^2)}{\nu} + \frac{2}{M} F_1(x_{Bj}, Q^2) \tan^2\left(\frac{\theta}{2}\right) \right).$$

F1 and F2 here are the structure functions of a nucleon and they depend on x and Q2.

Understanding the structure of nucleon

Deep-Inelastic Scattering (in briet frame)

$$Q^2 = 4EE' \sin^2\left(\frac{\theta}{2}\right).$$



- The virtual photon can be thought of to scatter off of a single parton carrying longitudinal momentum fraction x
- Cross-section is the

$$\frac{d^2\sigma}{d\Omega dE'} = \left\{\text{Cross-section of e over parton i}\right\}\left\{\text{Density of parton with momentum fraction x}\right\}$$

$$F_2(x_{Bj}) = x_{Bj} \sum e_i^2 q_i(x_{Bj}),$$

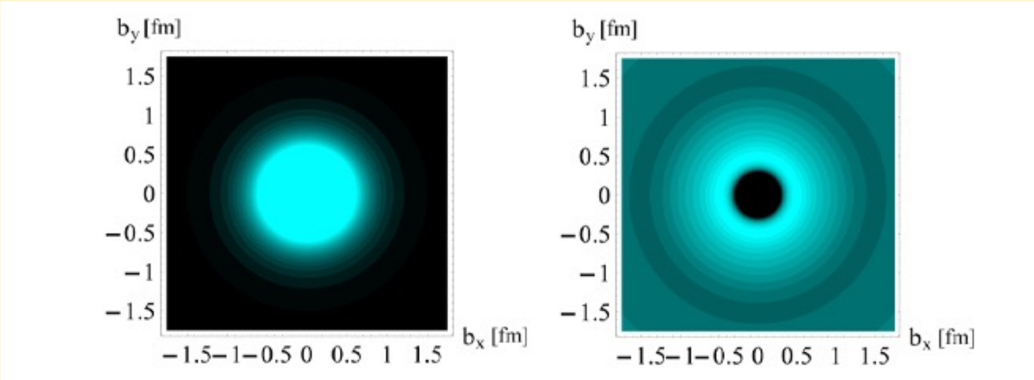
$$x_{Bj} = \frac{Q^2}{2M\nu}. \qquad x \approx \frac{Q^2}{2M\nu} = x_{Bj}.$$

where e_i is the charge of the parton i, in units of the proton charge, and $qi(x_{Bj})$ is the density of partons i with longitudinal momentum fraction x_{Bj} . These functions qi are called Parton Distribution Functions (PDFs).

Elastic Scattering

Form Factors

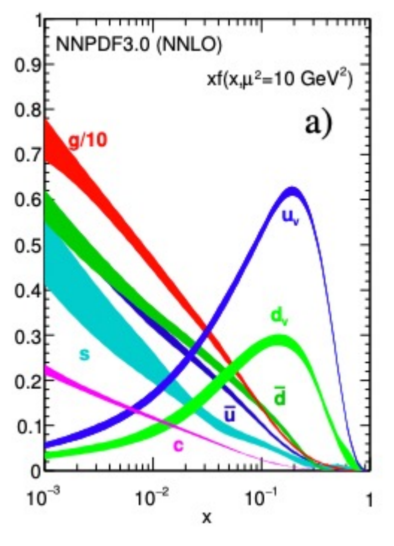
Transverse spatial distribution of partons



Deep Inelastic Scattering

Parton Distribution Functions

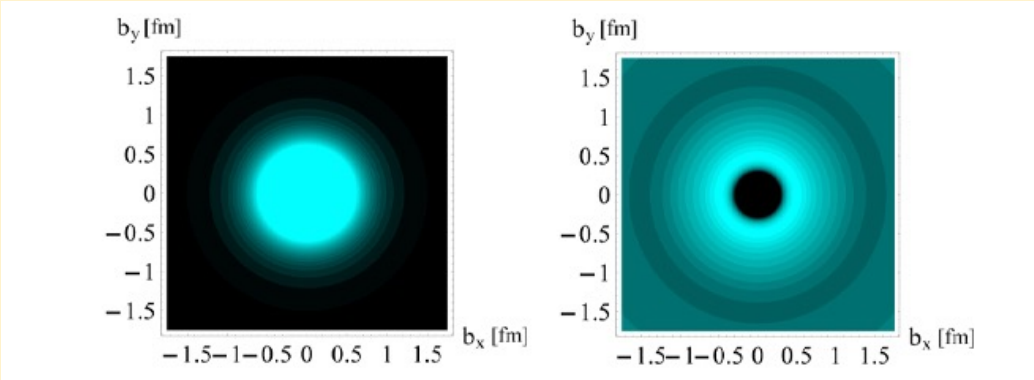
Longitudnal momentum distribution of partons



Elastic Scattering

Form Factors

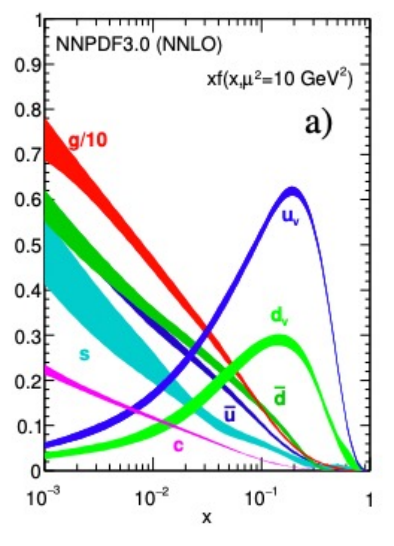
Transverse spatial distribution of partons



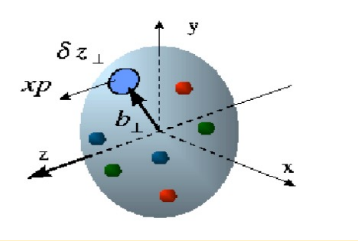
Deep Inelastic Scattering

Parton Distribution Functions

Longitudnal momentum distribution of partons



GPDs gives us the probability to find a quark which carries longitudinal momentum fraction *x* at a transverse position $\mathbf{b}_\perp$ in a nucleon



Genralised Parton Distributions

Form Factors

Transverse spatial distribution of partons

Parton Distribution Functions

Longitudnal momentum distribution of partons

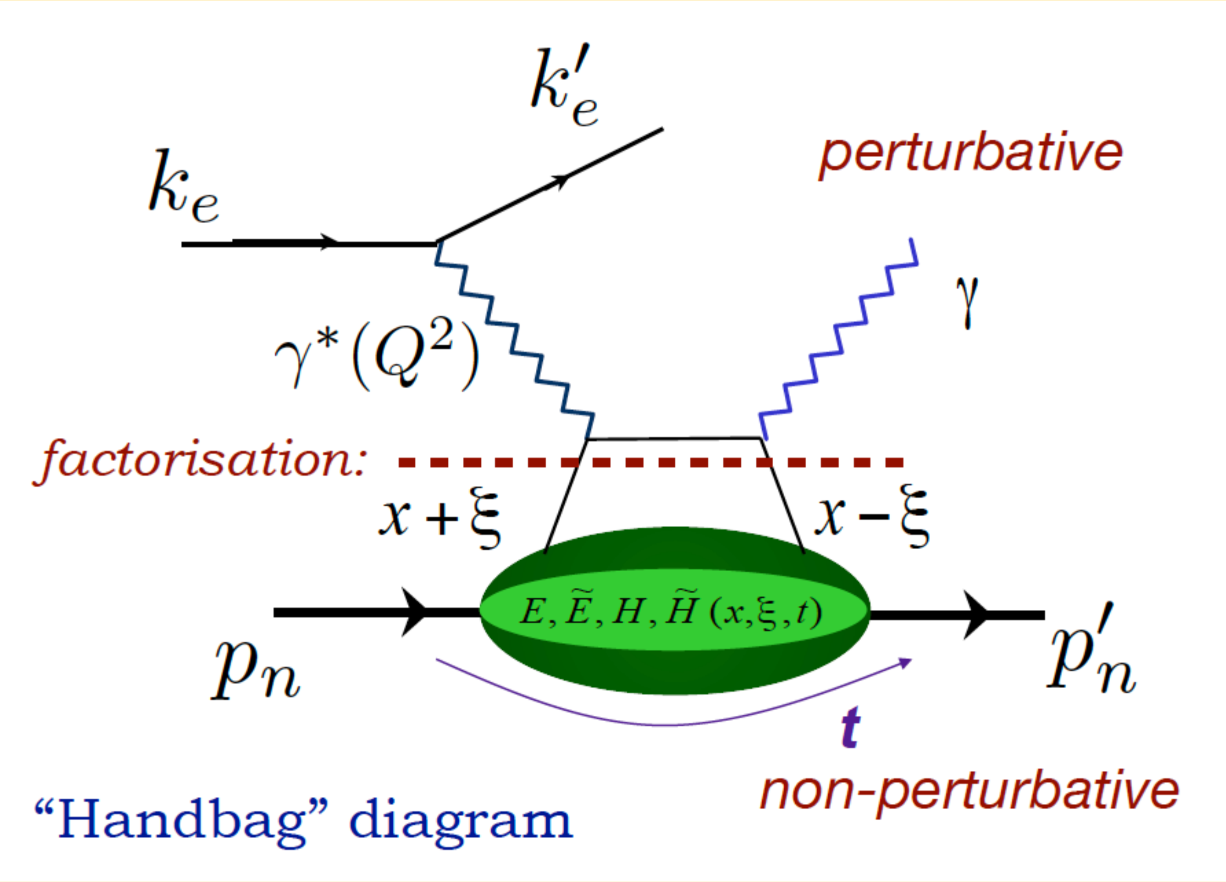
$$\int dx$$

$$\int d^2 b_T$$

longitudinal momentum fraction *x* at transverse position $\mathbf{b}_\perp$

Genralised Parton Distributions

Hard Exclusive Processess

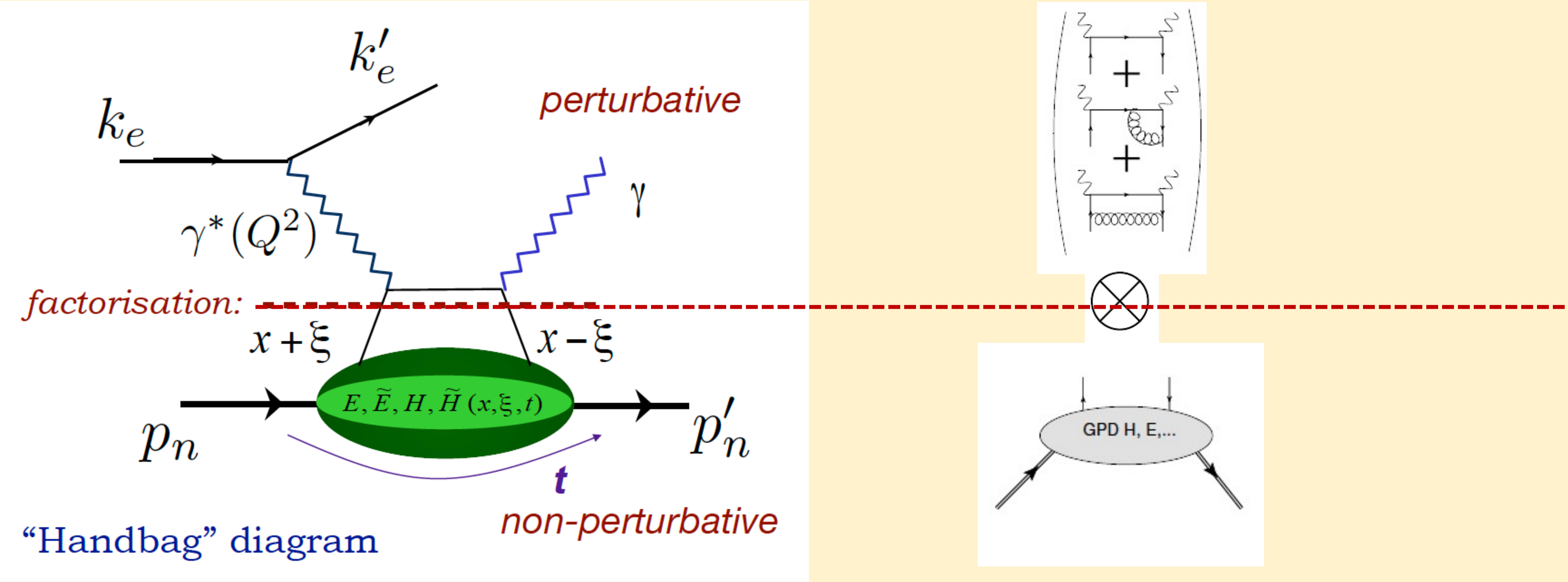


- ❖ interactions where the struck nucleon remains intact and final state particles are detected
- ❖ In such analysis, the final state particles are the deflected electron, deflected nucleon and other particles of interest (γ , π 0 , φ).

Studying in experiments

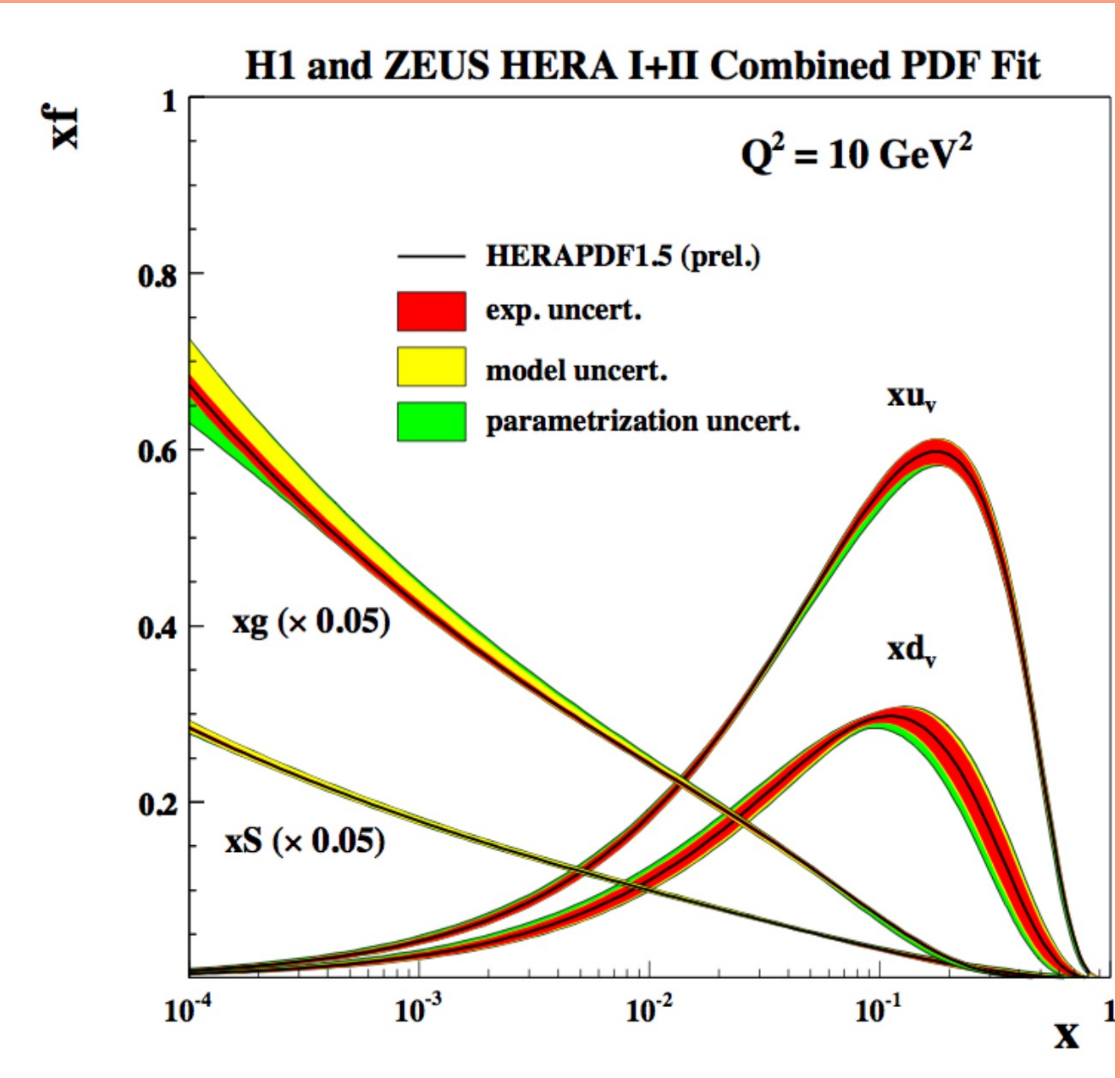
Genralised Parton Distributions

Hard Exclusive Processess

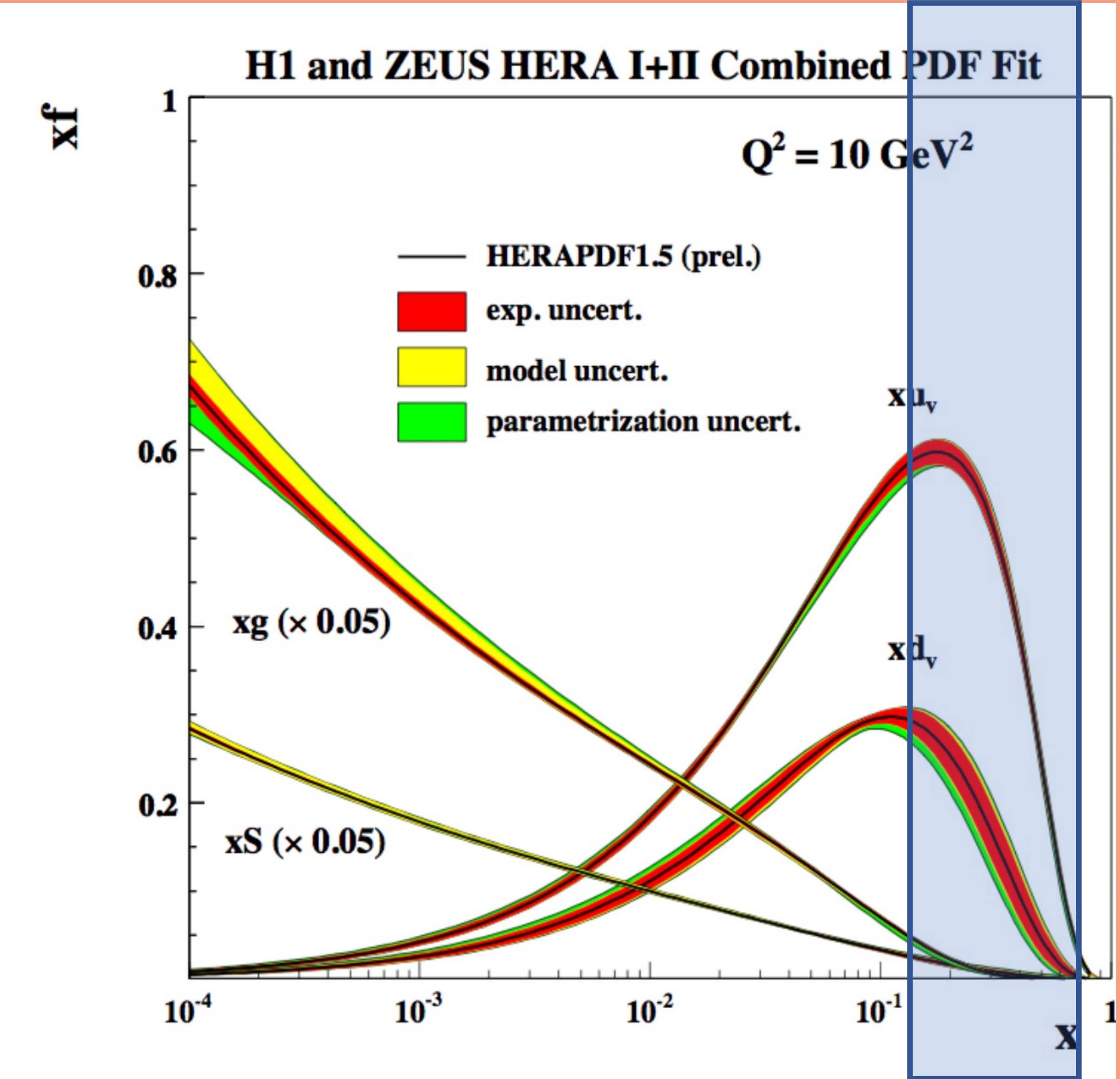


❖In the limit of high energy and high momentum transfer, these can be factorized into (i) calculable cross-section of interaction between the virtual photon and quark and (ii) the nucleon itself described by GPDs.

Acessing GPDs through different experiments



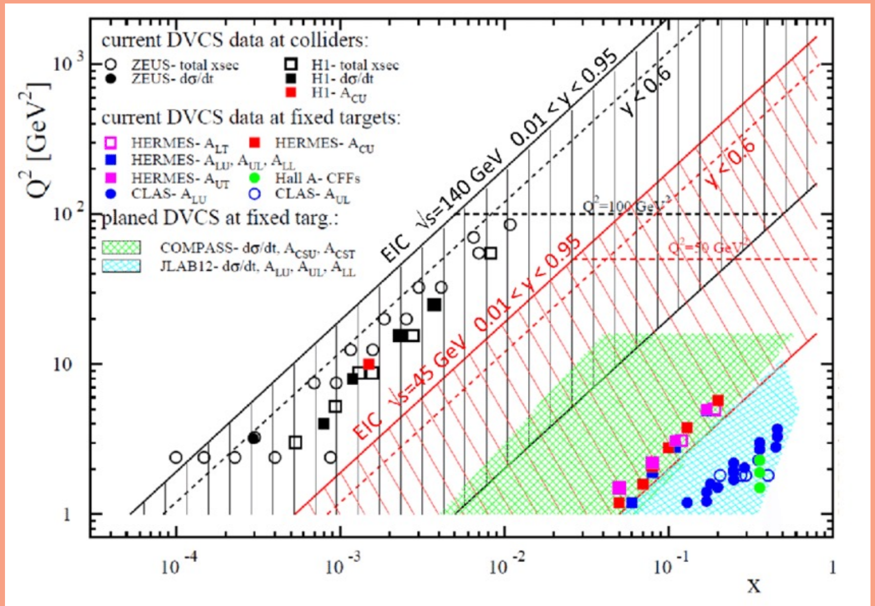
Acessing gluon GPDs through different experiments



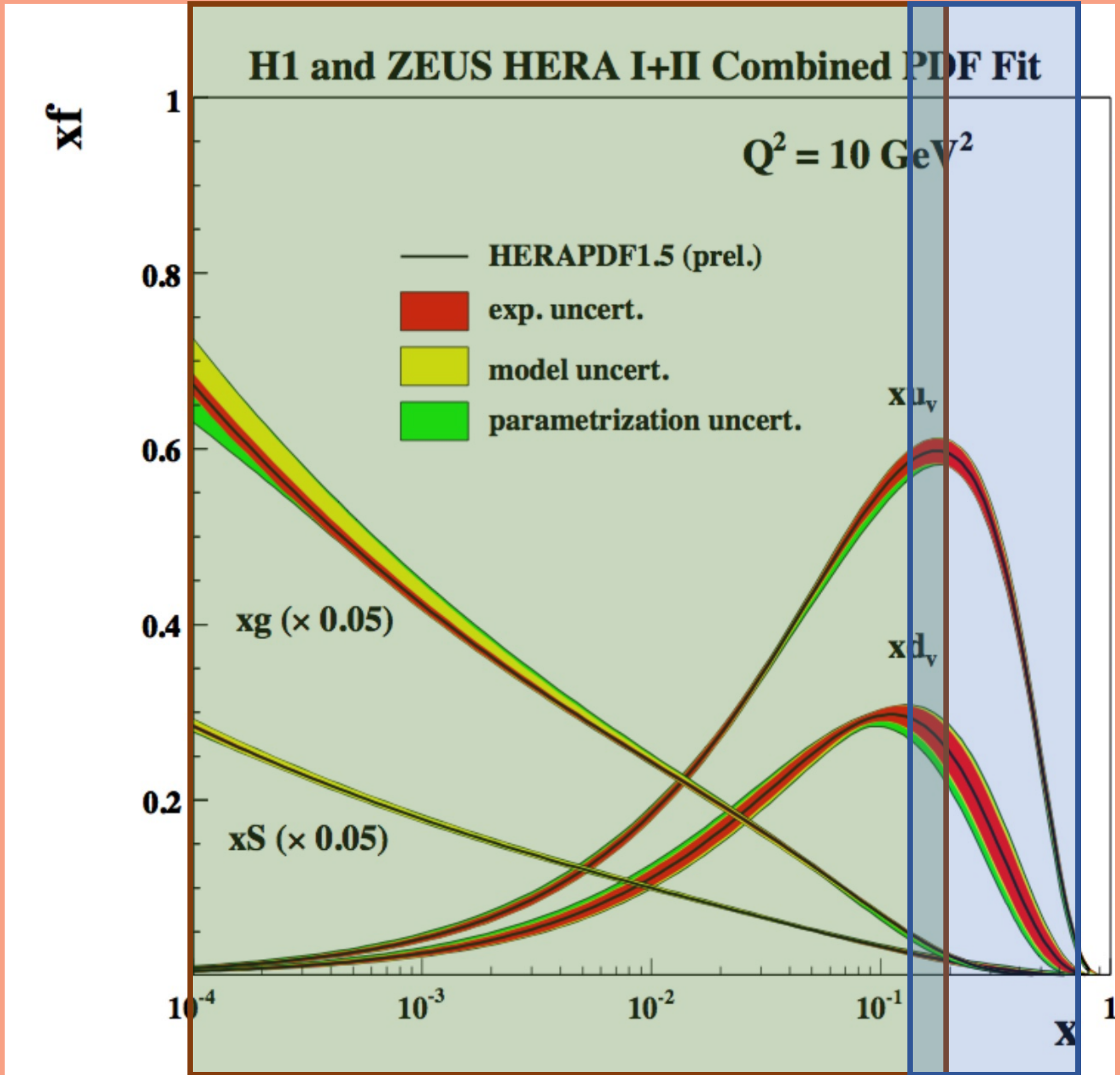
JLAB

$0.1 < x_b < 0.7$

DVCS at JLAB gives access to Quark GPDs



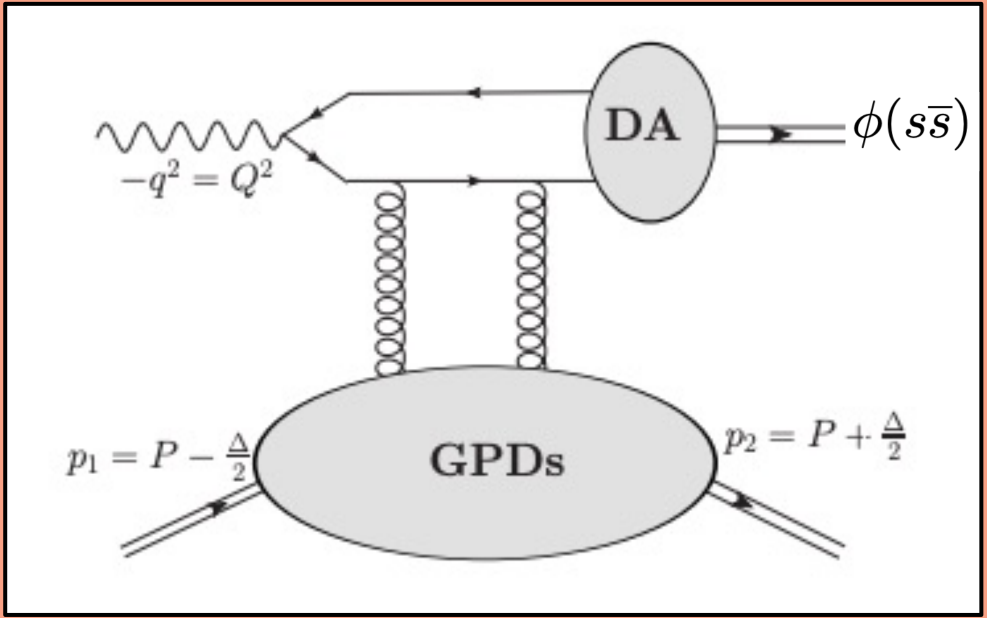
Acessing gluon GPDs through different experiments



JLAB	0.1 < x_b < 0.7
HERMES	0.02 < x_b < 0.3
COMPASS	0.01 < x_b < 0.1
ZEUS/H1	10^{-4} < x_b < 0.02
EIC	10^{-4} < x_b < 0.2 100-1000 times luminosity of HERA

Acessing gluon GPDs through different experiments

DVMP



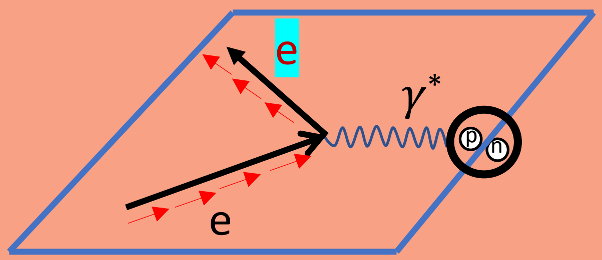
Φ meson is an $s\bar{s}$ particle

So at JLAB kinematics, Gluons and its GPDs are accessible even at tree level.

JLab-12 plans to carry out an extensive program of "3D nucleon imaging" with exclusive and semi–inclusive processes. DVCS and elastic nucleon form factors are sensitive mostly/only to the valence quark degrees of freedom [1]. The proposed ϕ electroproduction experiment offers a unique way to access the spatial distribution of gluonic degrees of freedom and thus provides a crucial missing piece in the nucleon imaging program.

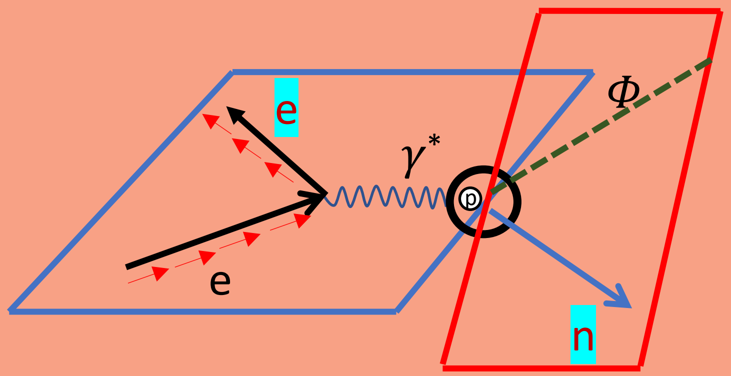
PAC39 : Exclusive Phi Meson Electroproductionhttps: //www.jlab.org/exp_prog/proposals/12/PR12- 12-007.pdf.

DVMP process at JLAB



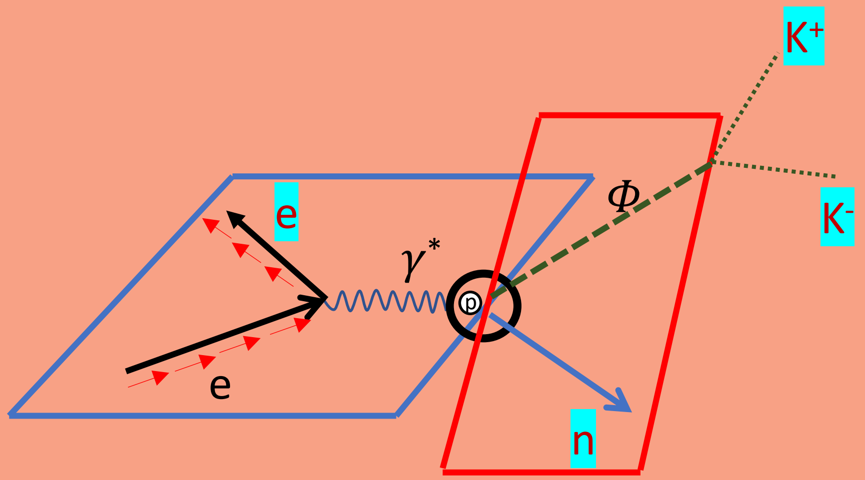
- Longitudinal beam of electron on fixed deuterium target

DVMP process at JLAB

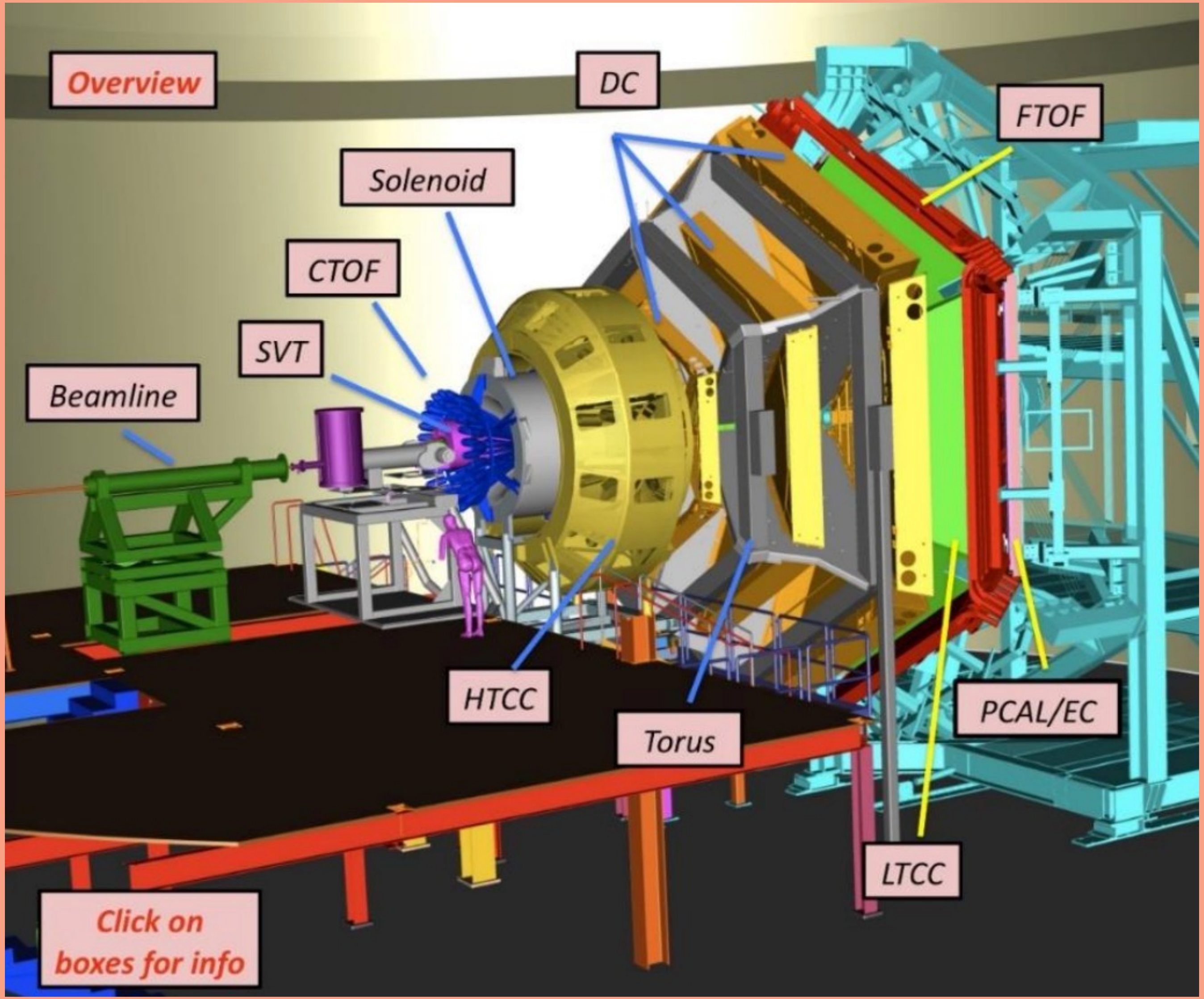


- Longitudinal beam of electron on fixed deuterium target
- Exclusive Phi produced off the neutron

DVMP process at JLAB



- Longitudinal beam of electron on fixed deuterium target
- Exclusive Phi produced off the neutron
- Looking at the decay channel of $\Phi \to K^+K^-$



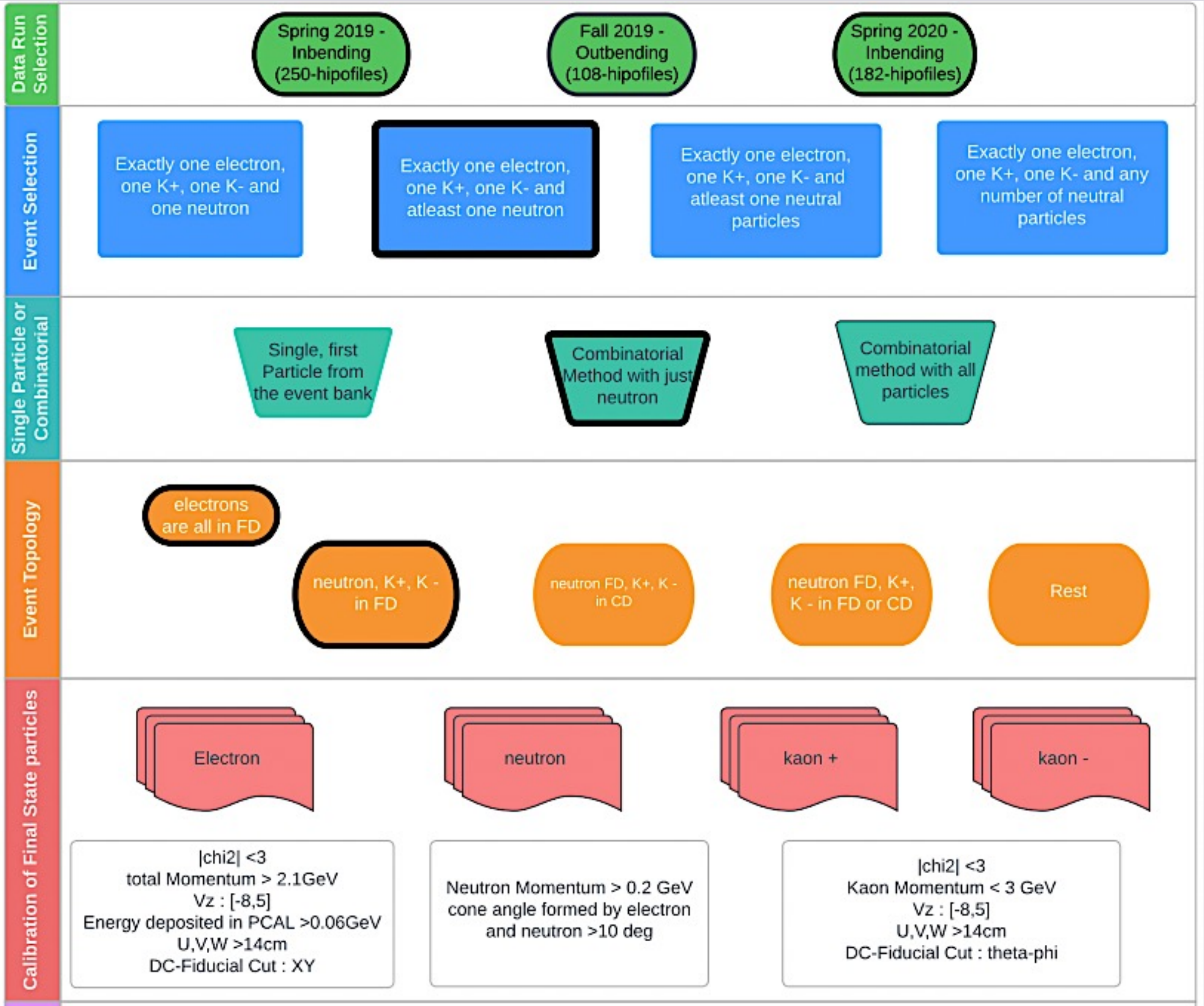
Why study φ off the neutron?

- As the φ accesses the gluon channel, we expect any measurement of this to be similar to that of proton. It would be a good validation check

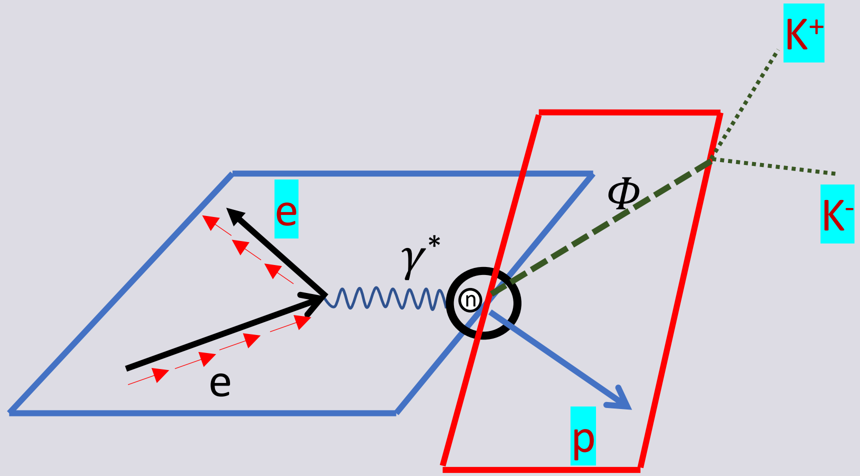
- If we are sentive to differences, that makes this an even more interesting channel to study.

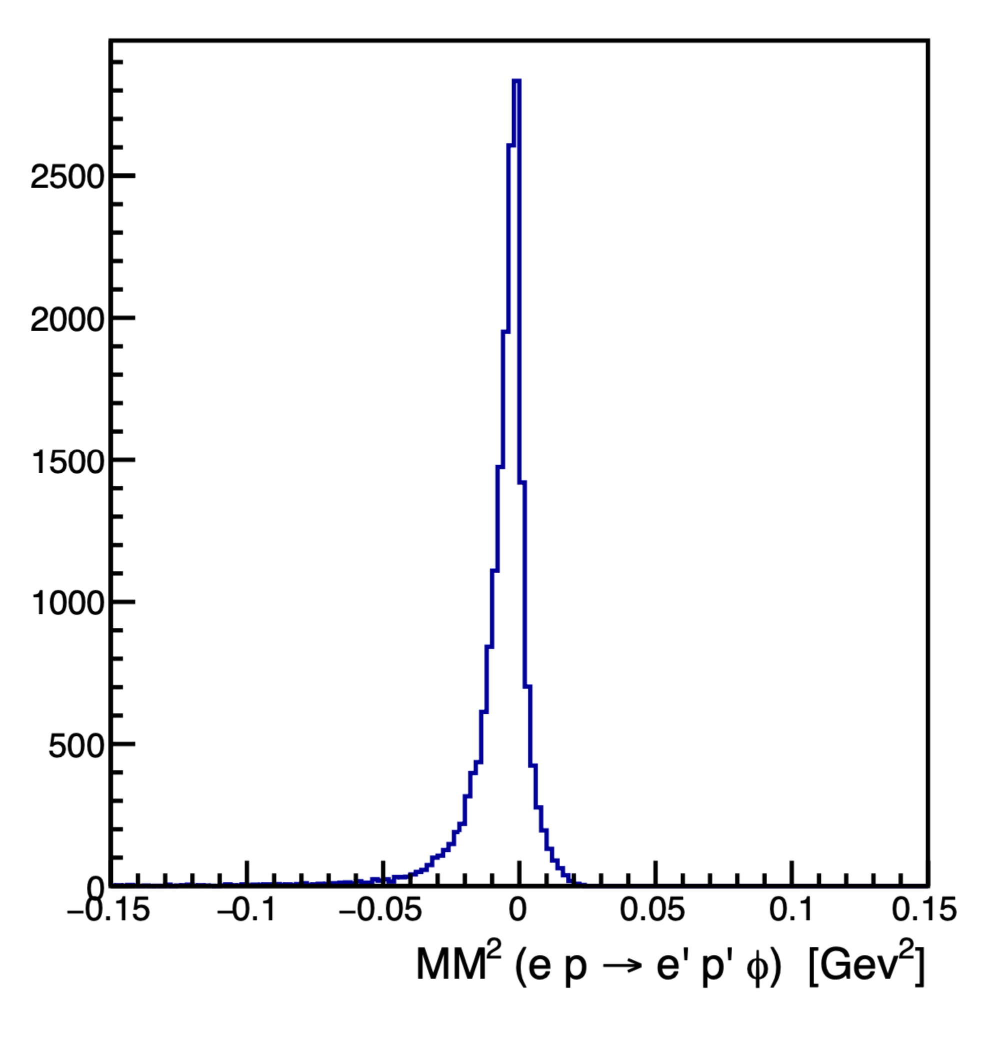
- Additional benefits could be comparing RGB and RGA channel to understand final state interactions in heavy meson production

Analysis Details and Flowchart



Analysis Details and Flowchart – Exclusivity Cuts



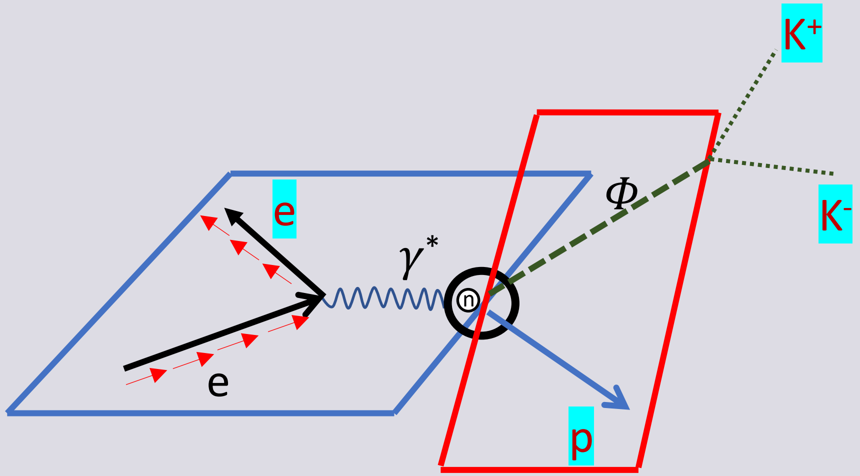


Exclusivity cuts : Using balance of equation to constraint that the event is purely exclusive, and not some semi-inclusive process with other particles undetected.

- $ep \rightarrow e'p'K^+K^-X$

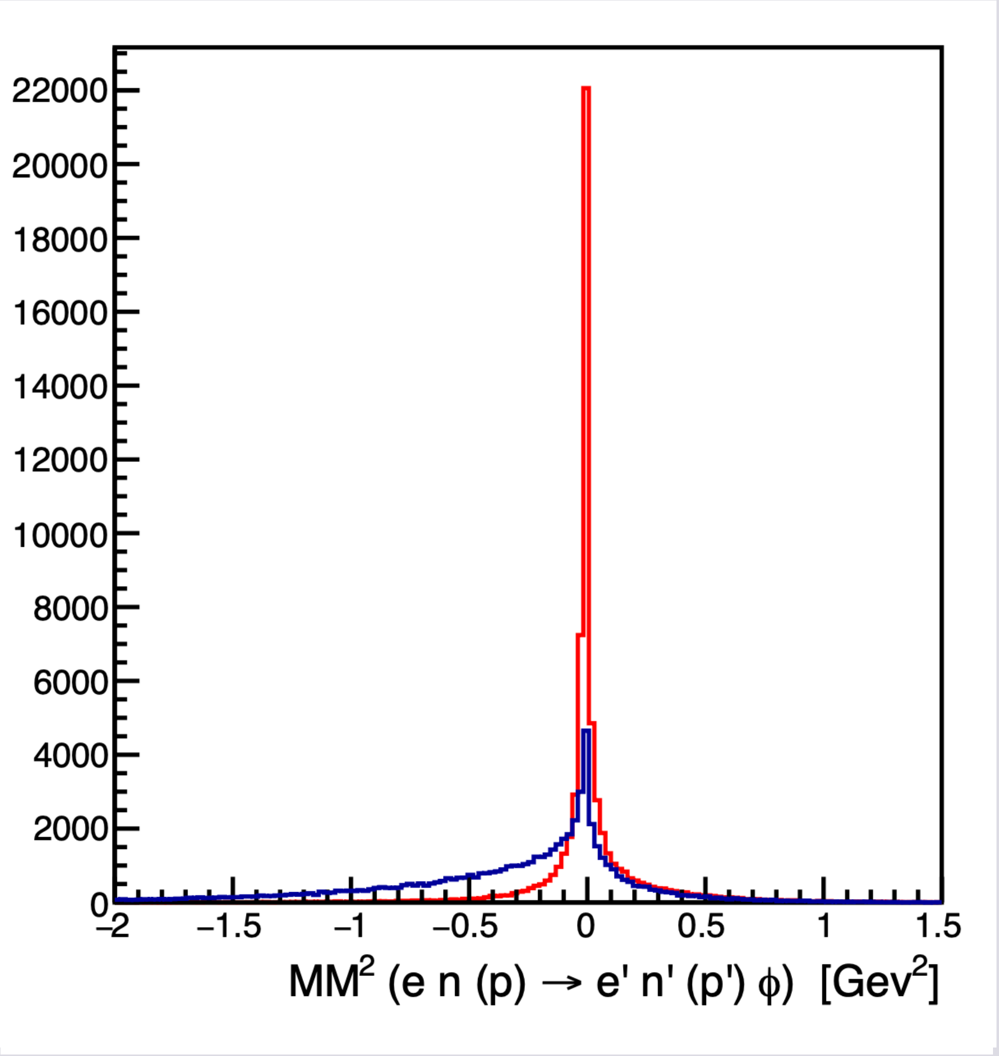
(beam + target) – (scatterted electron + scattered proton + Positive Kaon + Negative Kaon)

Analysis Details and Flowchart – Exclusivity Cuts

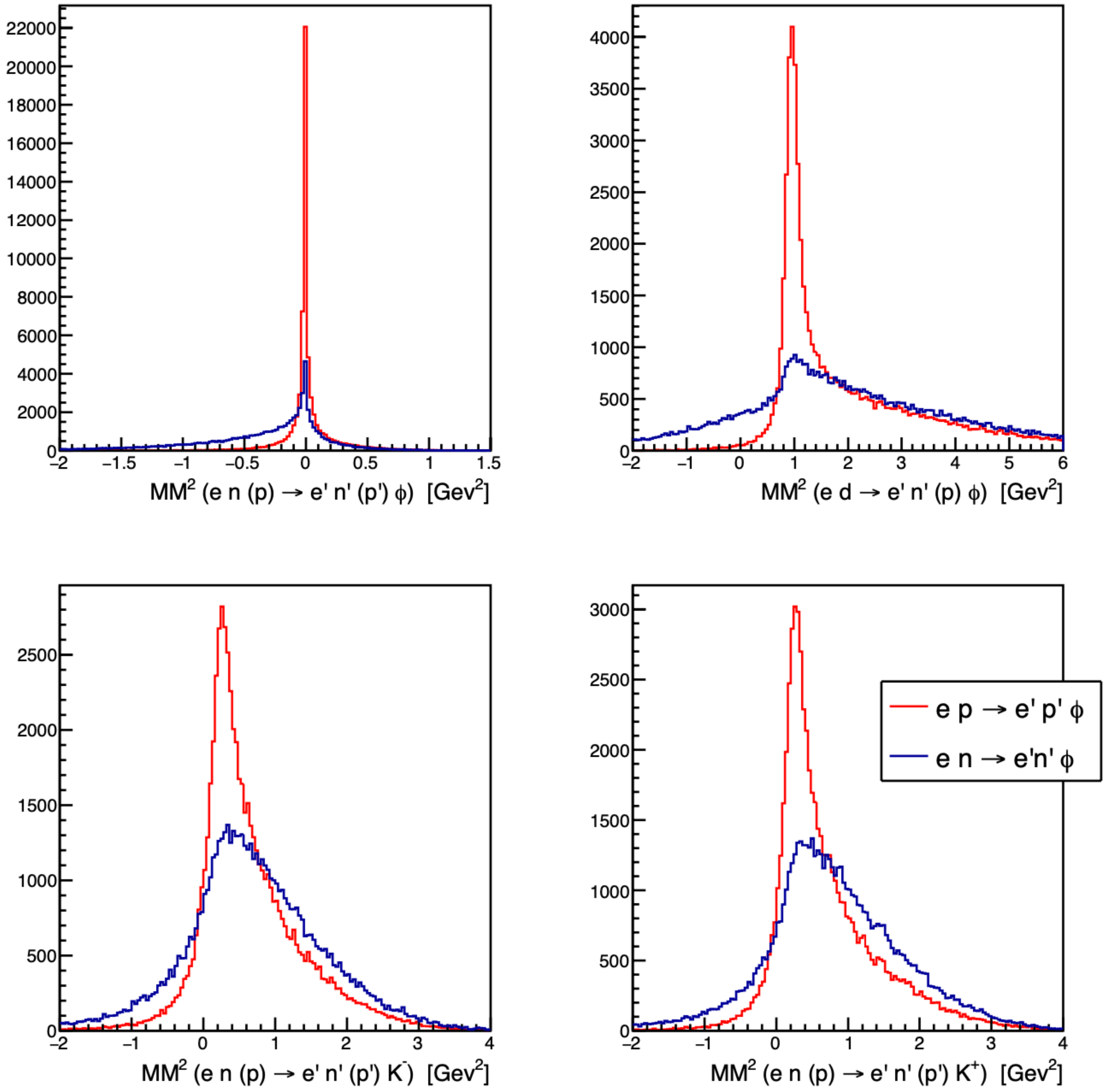


Exclusivity cuts : Using balance of equation to constraint that the event is purely exclusive, and not some semi-inclusive process with other particles undetected.

A neutron channel is far more challenging to study!

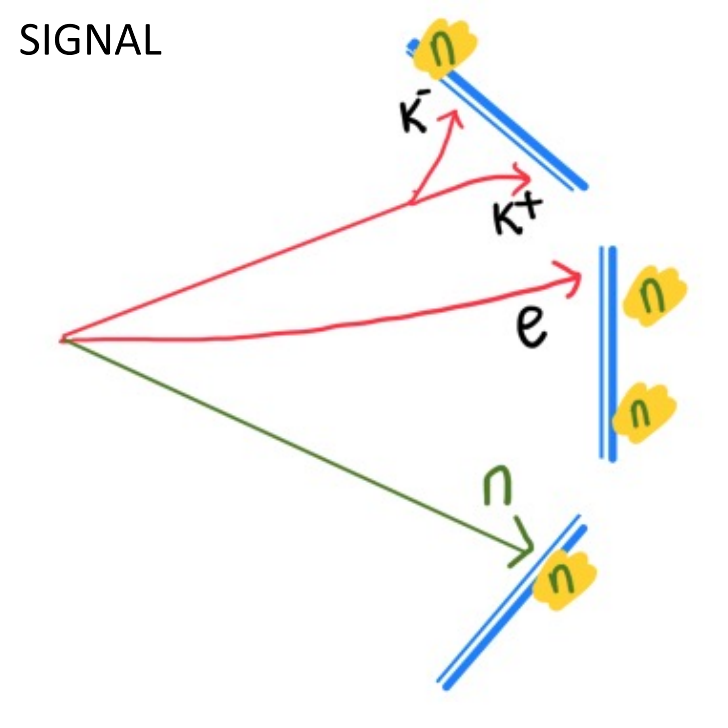


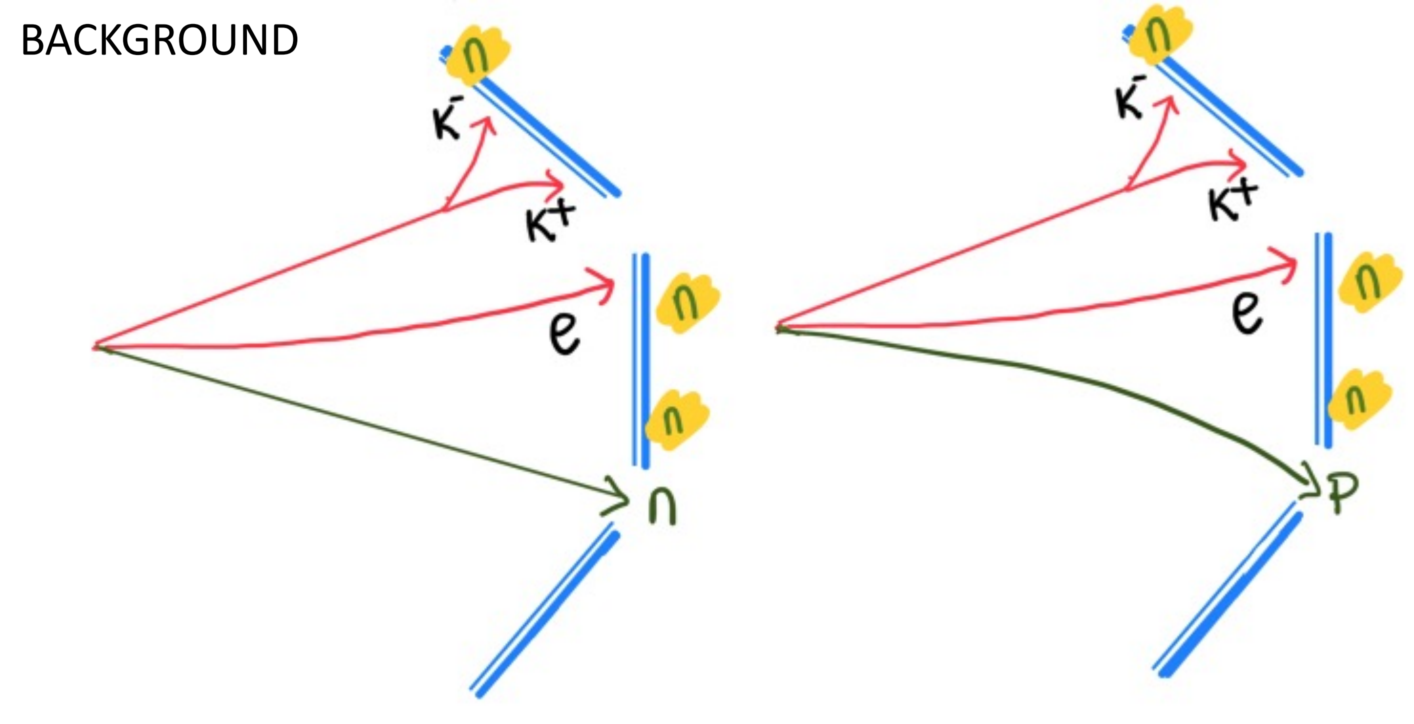
Analysis Details and Flowchart – Exclusivity Cuts



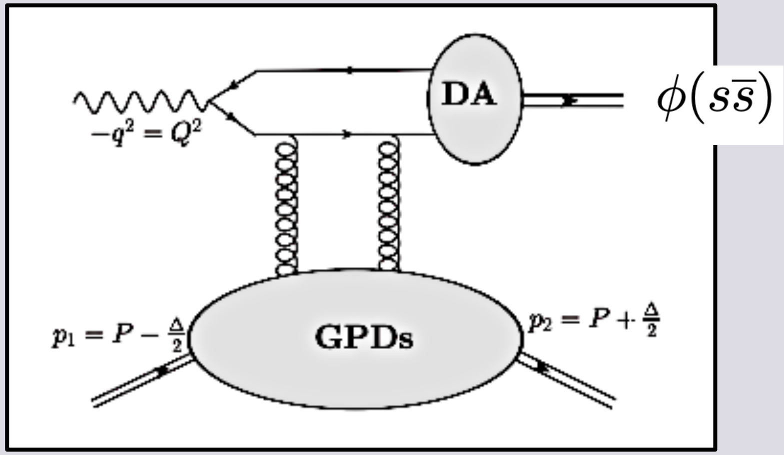
Analysis Details and Flowchart – Background Sources

Neutron detection efficiency is low as there is no dedicated detector

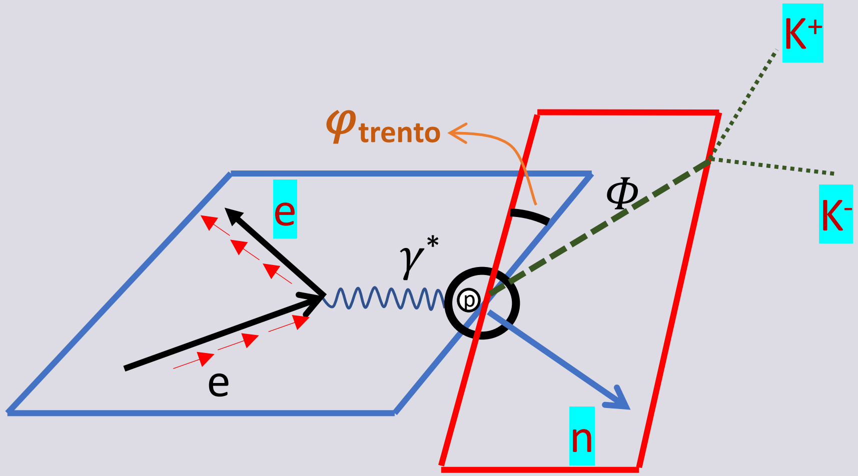




Beam Spin Assymmetry



Φ signal provides clean access to the gluons present in the nucleon



12GeV longitudnally polorized electron beam on a fixed deuterium target

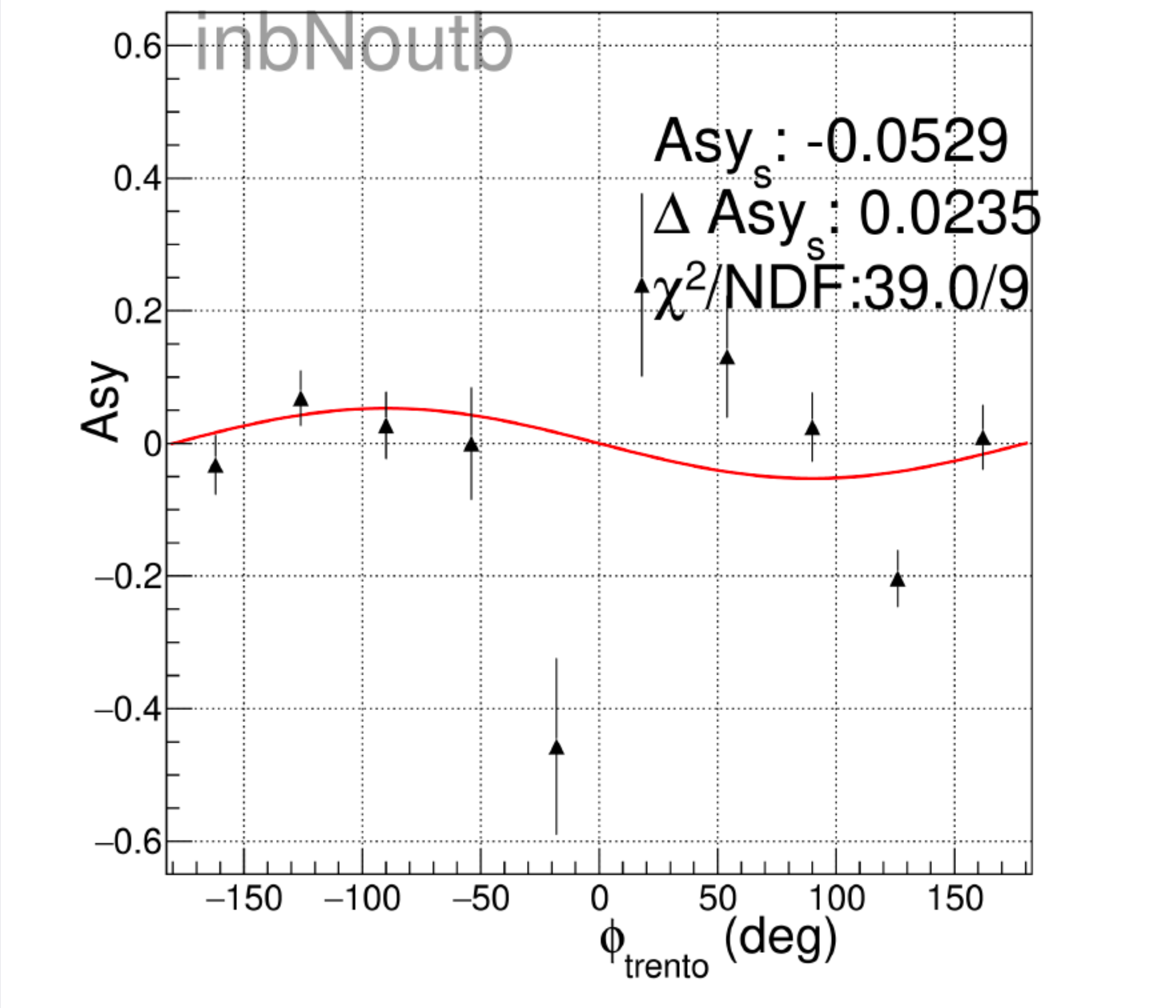
φ_{trento} = Angle between electron plane (electron and γ^*) and hadron plane (γ^* and Φ)

$$\frac{N_{\Phi}^{\rightarrow} - N_{\Phi}^{\leftarrow}}{N_{\Phi}^{\rightarrow} + N_{\Phi}^{\leftarrow}}$$

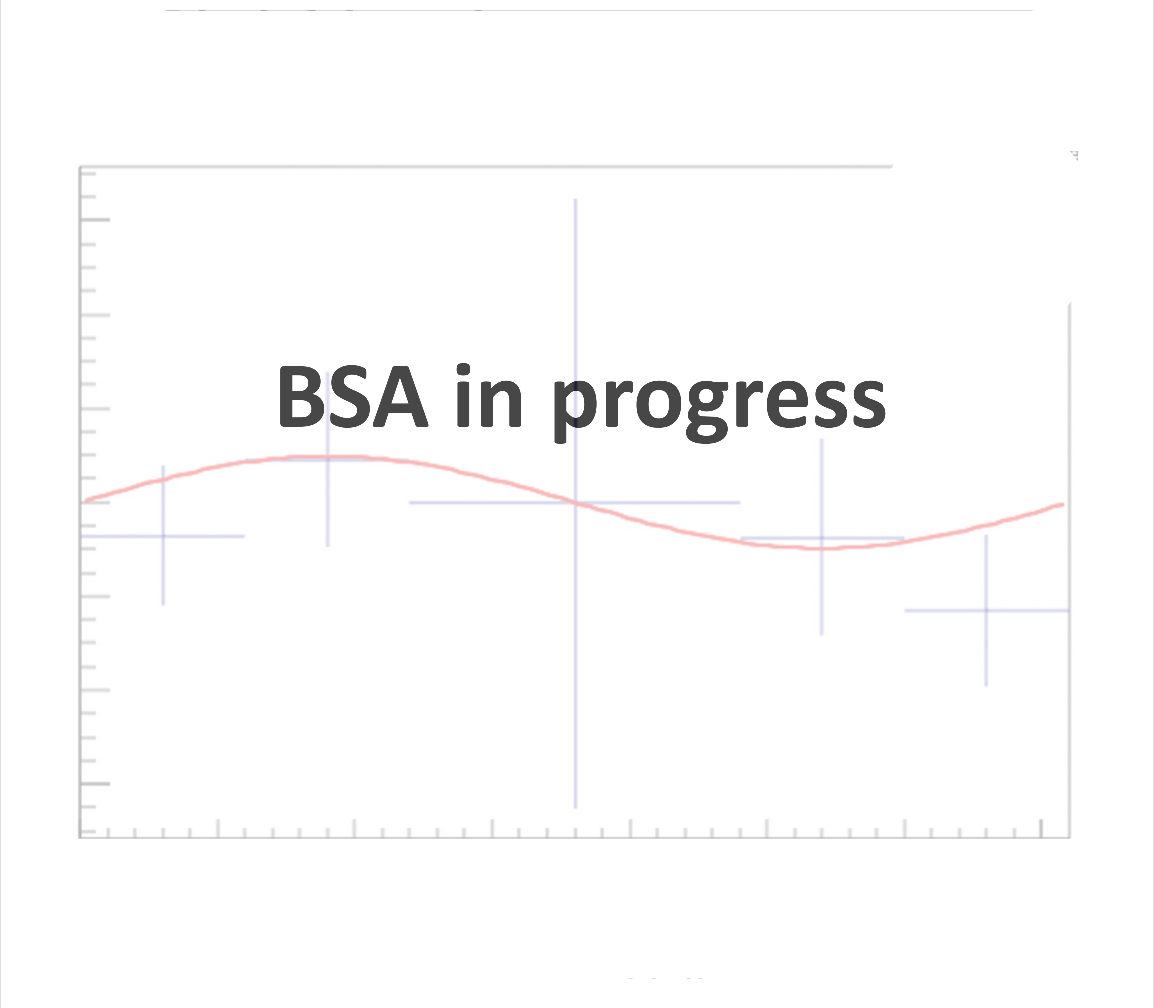
Plotting this in bins of φ_{trento}

Modulation in BSA gives access to the spatial distribution of Gluons in a nucleon

Beam Spin Assymmetry



Proton



Neutron

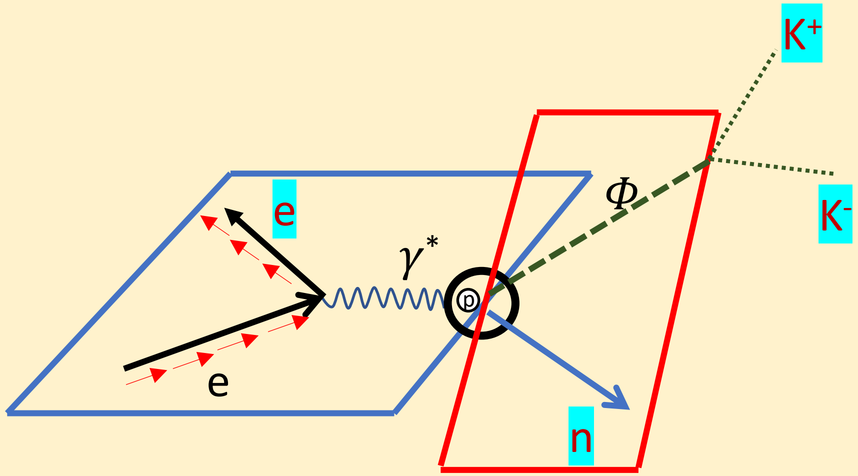
Summary and Ongoing task

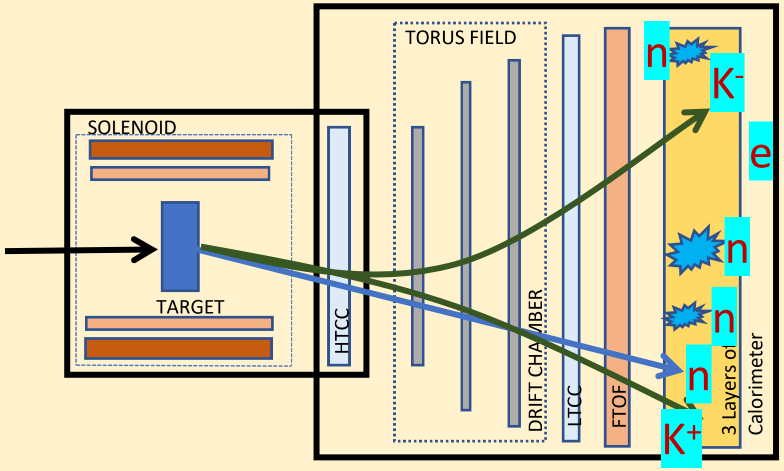
- Exclusive Φ production off of nucleon is a good way to extract gluon GPDs
- Crucial to study Beam spin asymmetery for the production off the proton and the neutron
- Neutron channel has many challenges, a lot of which has been overcome, but it is still highly limited by statistics.

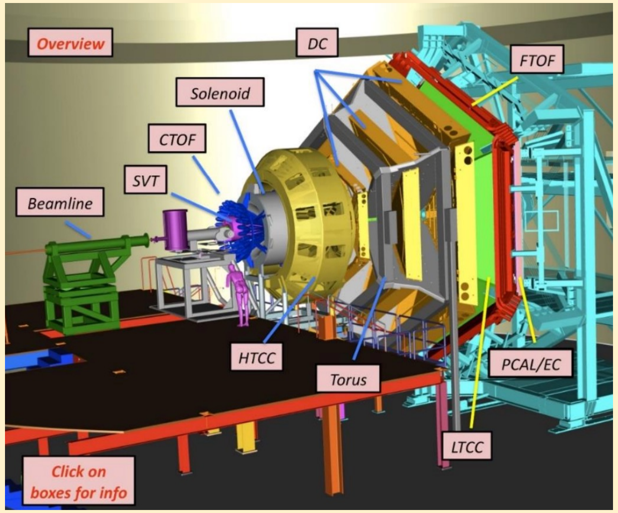
- Waiting for more statistics obtained by a more efficient reconstruction code for this run period ("pass2")
- Working on understanding and constraining the background contamination better

Merci Beaucoup pour votre attention

DVMP process at JLAB



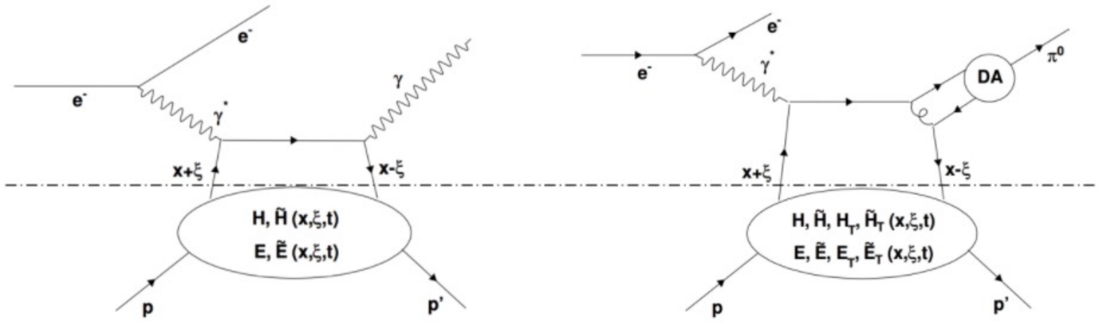




- Longitudinal beam of electron on fixed deuterium target
- Exclusive Phi produced off the neutron
- Looking at the decay channel of Φ -> K^+K^-

Accessing GPDs in spin ½ particle

- \- For each flavor of quarks, there are 8 GPDs each giving access to a specific combination of interplay between quark polorization and nucleon helicity.



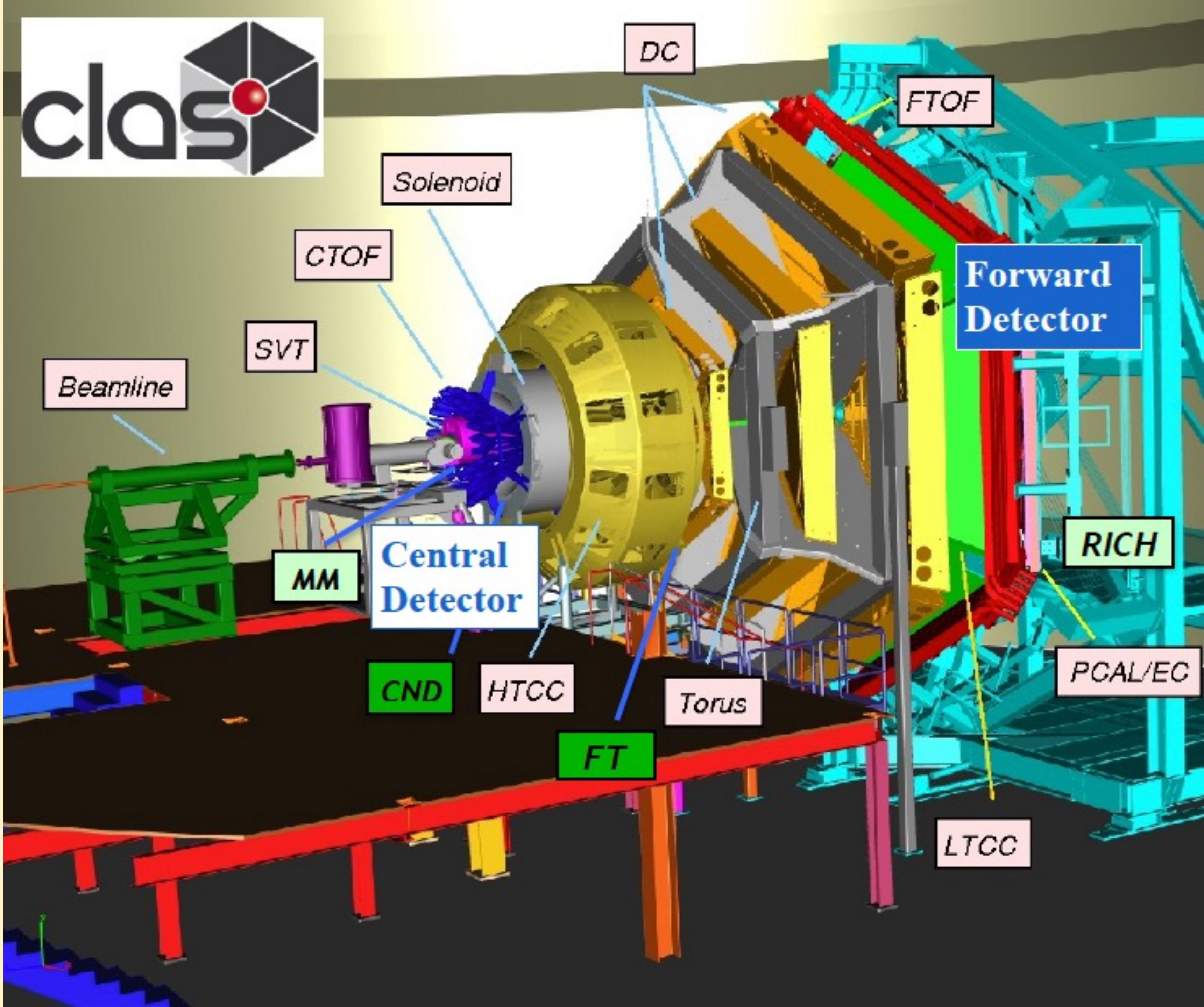
Chiral even GPDs:
(helicity of the parton is conserved)

	Nucleon Helicity	
	conserving	non-conserving
unpolarized GPD	H	E
polarized GPD	$\tilde{H}$	$\tilde{E}$

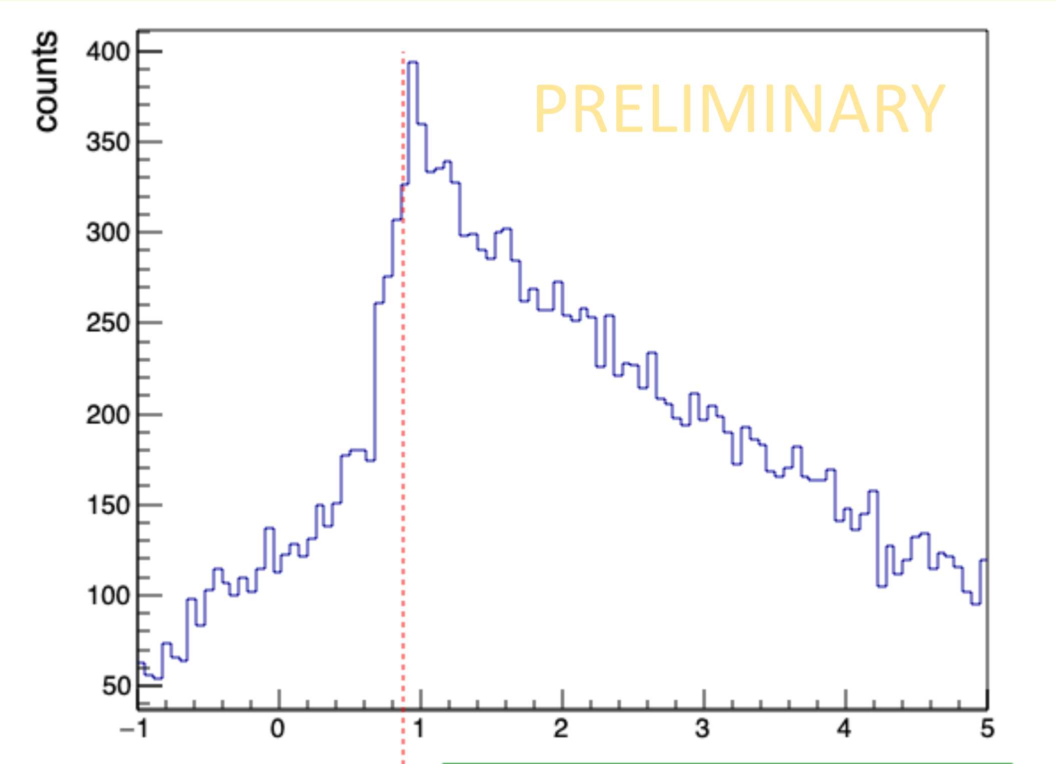
Chiral even GPDs
\+
Chiral-odd GPDs:
(helicity of the parton can flip)

	Meson	Flavor
$\mathcal{H}_T, \mathcal{E}_T$	π^+	$\Delta u - \Delta d$
	π^0	$2\Delta u + \Delta d$
	η	$2\Delta u - \Delta d + 2\Delta s$

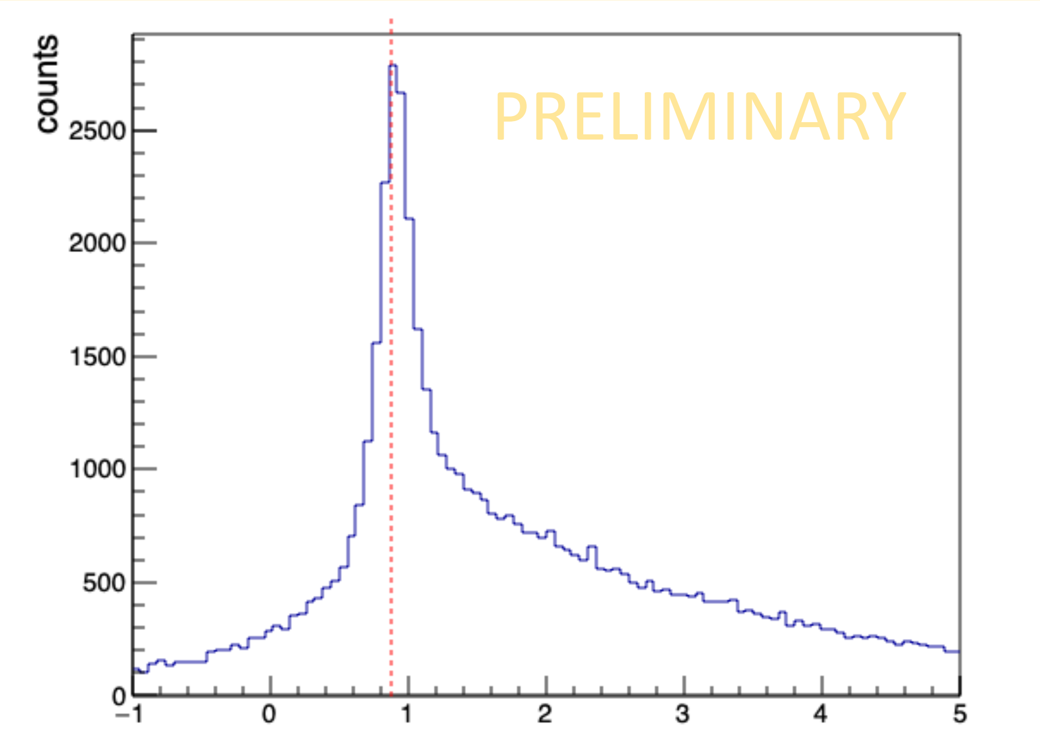
- Large acceptance spctrometer
- Has a dual magnet system (solenoid and toroidal)
- Divided into three large detector groups
    - Central detector
    - Forward detector
    - Forward tagger
- Concurrent measurement of exclusive, semi-inclusive and inclusive processes.



Comparing excluisivity cuts off the proton vs off the neutron in RGB dataset is one good way to see how much of the effect we see in our plots is from final state interactions (which impacts both) vs how much of this comes from neutron identification



$eD \to e'n'K^+K^-X$



$eD \to e'p'K^+K^-X$