Deeply Virtual Compton Scattering off the neutron with the Neutral Particle Spectrometer in Hall C

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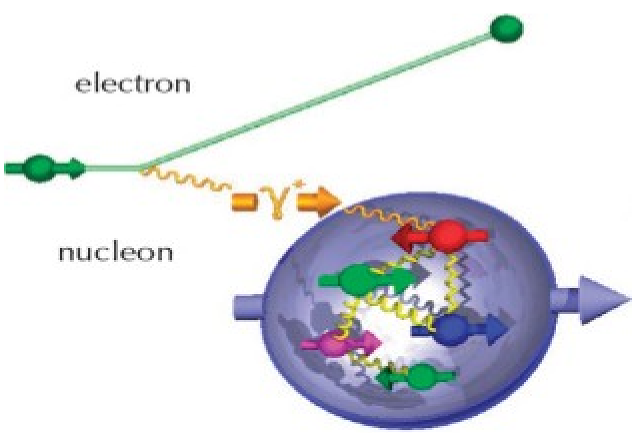
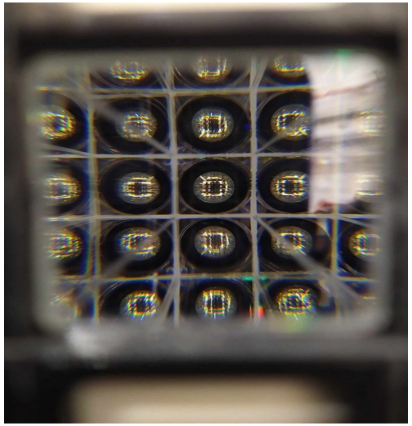
Tunisia





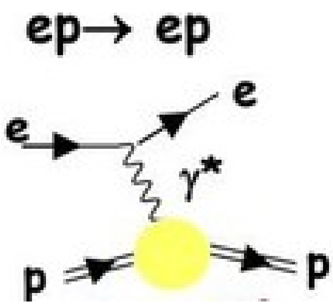
Hall C Winter Collaboration Meeting

19 January 2024

Outlines

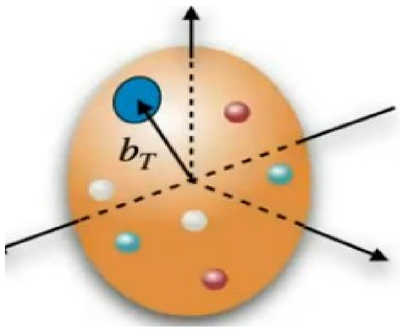
- **Physics Motivation**
- **Experimental setup**
- **Data Acquisition**
- **Preliminary Physics Plots**

3D STRUCTURE OF THE NUCLEON

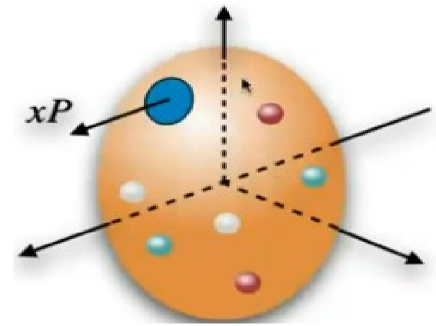


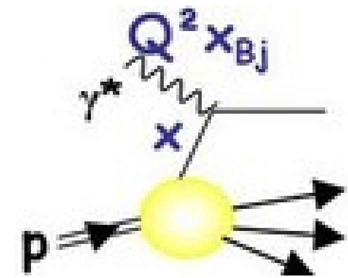
Elastic Scattering
(ep)

Form Factors

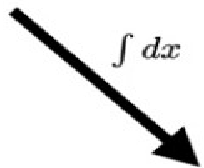


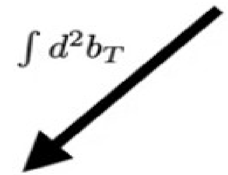
Partons Distribution Functions



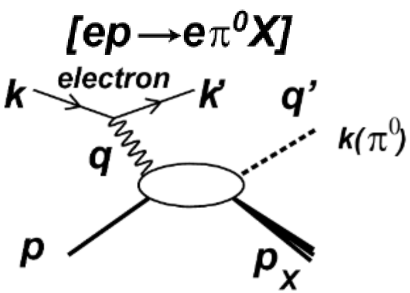


Deep Inelastic scattering
(DIS)

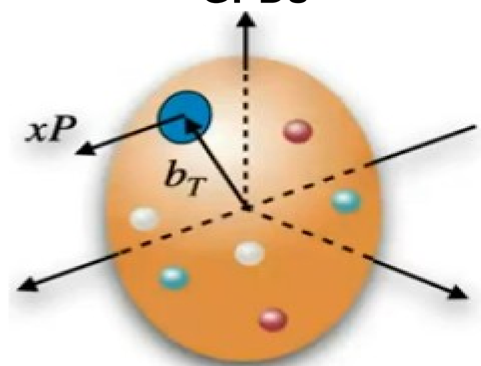




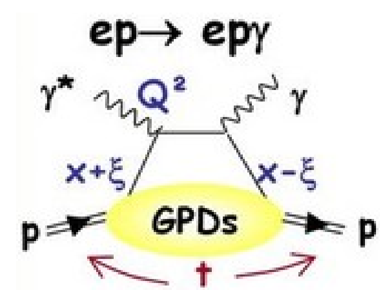
Exclusive Pi0 Meson
Electroproduction
(DVMP)



GPDs

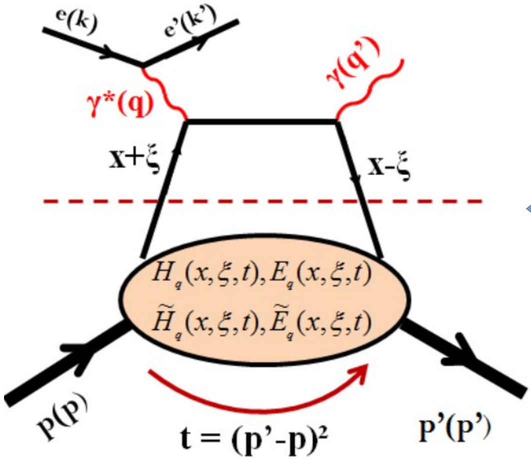


Deeply Virtual Compton
Scattering
(DVCS)



From DVCS to GPDs

- **Factorization in Bjorken limit**



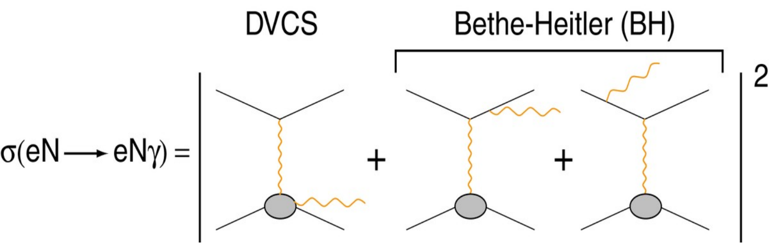
Handbag Diagram

Hard scattering process (Perturbative calculation)

PQCD factorization theorem

Soft process (non Perturbative calculation)

$$H^q, E^q, \tilde{H}^q, \tilde{E}^q(x,\xi,t)$$



$$|\mathcal{T}|^2 = (\mathcal{T}_{DVCS} + \mathcal{T}_{BH})^2 = |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \mathcal{I}$$

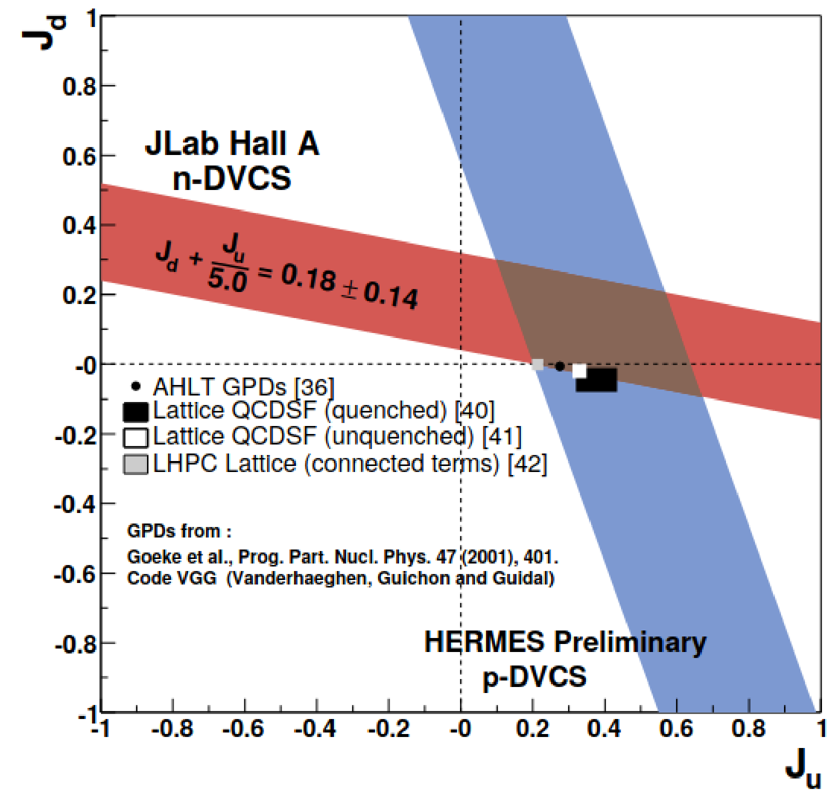
$$\Im m(\mathcal{T}_{DVCS}) \propto -i\pi \left(GPD(\xi,\xi,t) \pm GPD(-\xi,\xi,t) \right).$$

$$\Re e(\mathcal{T}_{DVCS}) \propto P \int_{-1}^{1} dx \left(\frac{1}{x-\xi} \pm \frac{1}{x+\xi} \right) GPD(x,\xi,t)$$

Why DVCS on the neutron?

- Using the **Approximate isospin symmetry of QCD** we obtain the simplest way to perform a **flavor decomposition** of the **u** and **d** quark GPDs:

$$H^p = \frac{4}{9}H^u + \frac{1}{9}H^d \qquad H^n = \frac{1}{9}H^u + \frac{4}{9}H^d$$



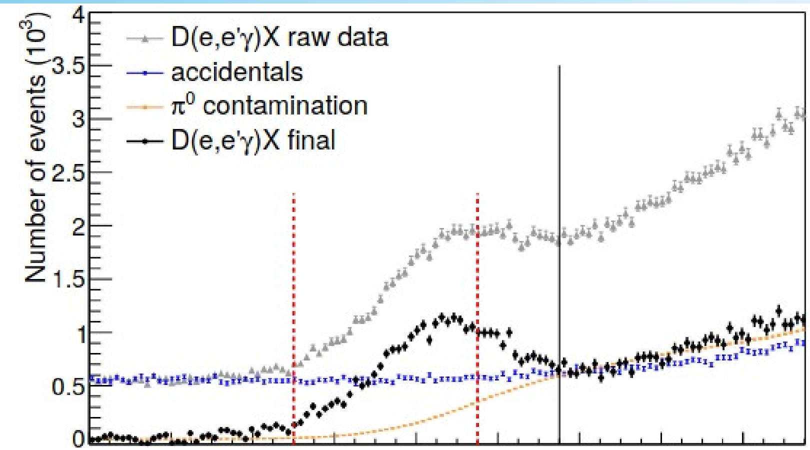
- The **unpolarized** "n-DVCS" cross sections at **low t** have a direct relevance in the determination of the quark angular momentum via **Ji's sum rule**:

$$J^q = \frac{1}{2}\int_{-1}^{1} x dx [H^q(x,\xi,t=0) + E^q(x,\xi,t=0)] \quad \forall\xi$$

Mazouz et al. Physical review letters, 99(2007), 242501

n-DVCS and d-DVCS seperation

- **Exclusive events are obtained with the missing mass technique after the subtraction of accidentals and neutral pions**



Coherent elastic channel

incoherent quasi-elastic channels

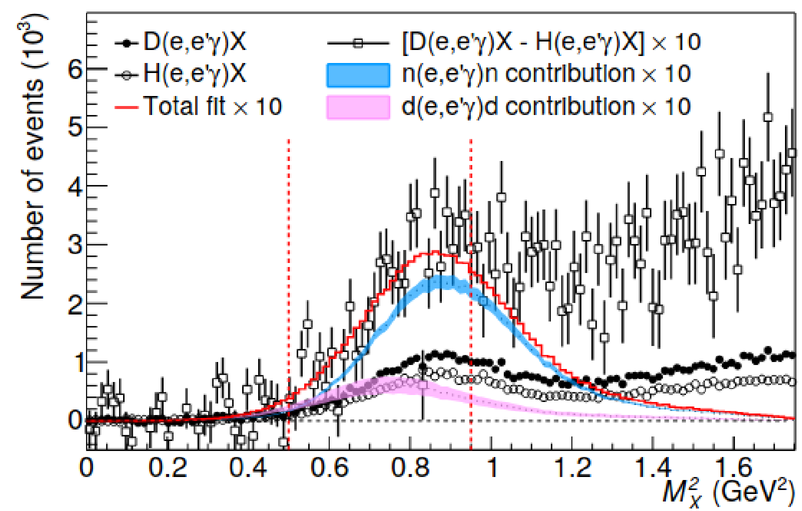
$$D(e,e'\gamma)X = d(e,e'\gamma)d + n(e,e'\gamma)n + p(e,e'\gamma)p$$

2 terms separated by missing mass

$$\Delta M_X^2 = t(1 - M_n/M_d) \approx t/2$$

Subtracted from the LH2 data interleaved

- **Separation between incoherent n(e,e'g)n and coherent d(e,e'g)d can be achieved with a fit of the exclusive region of the missing mass spectrum**



Benali et al. Nat Phys 16 (2020) 191

n-DVCS Kinematics

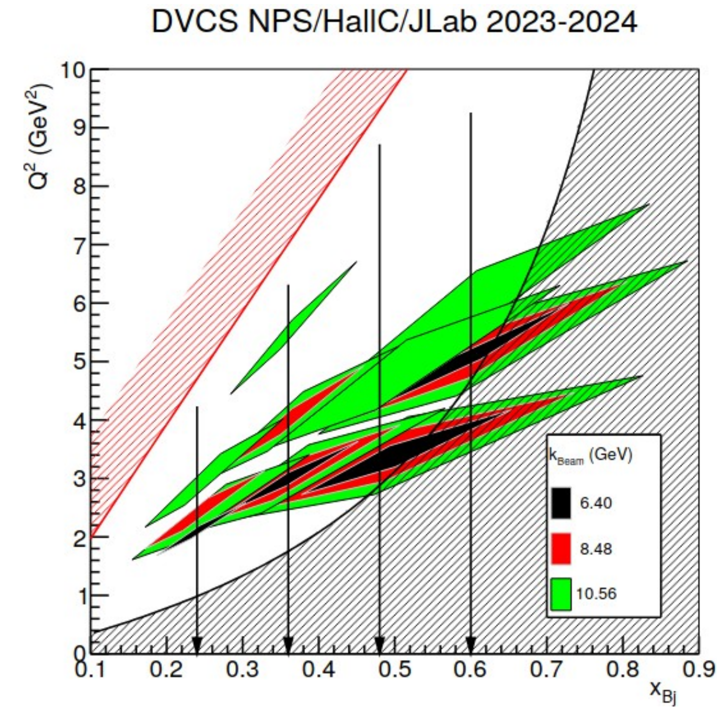
Data Taken in 2023

x_Bj	Kinematic Setting	Pass	Q2 (GeV^2)
0.36	KinC_x36_3	5	3.0
	KinC_x36_5	5	4.0
	KinC_x36_2	4	3.0
0.50	KinC_x50_2	5	3.4
	KinC_x50_3	5	4.8
	KinC_x50_1	4	3.4
0.6	KinC_x60_3	5	5.1
	KinC_x60_2	4	5.1

Data that will be taken in 2024

x_Bj	Kinematic Setting	Pass	Q2 (GeV^2)
0.25	KinC_x25_1	5	2.1
	KinC_x25_2	5	2.4
	KinC_x25_3	4	2.4
	KinC_x25_4	3	3.0
0.36	KinC_x36_6	5	5.5
	KinC_x36_4	4	4.0
	KinC_x36_1	3	3.0
0.5	KinC_x50_0	3	3.4
0.6	KinC_x60_4	5	6.0
	KinC_x60_1	3	5.1

- **High xbj --> high |t| --> better separation**
- **Different beam energies that will further give a better extraction of the different CFFs from the DVCS cross sections**
- **To reduce systematic uncertainties, LH2 and LD2 run periods are interleaved frequently (every few hours)**



- **Sharp drop of the deuteron form factors as |t| increases**

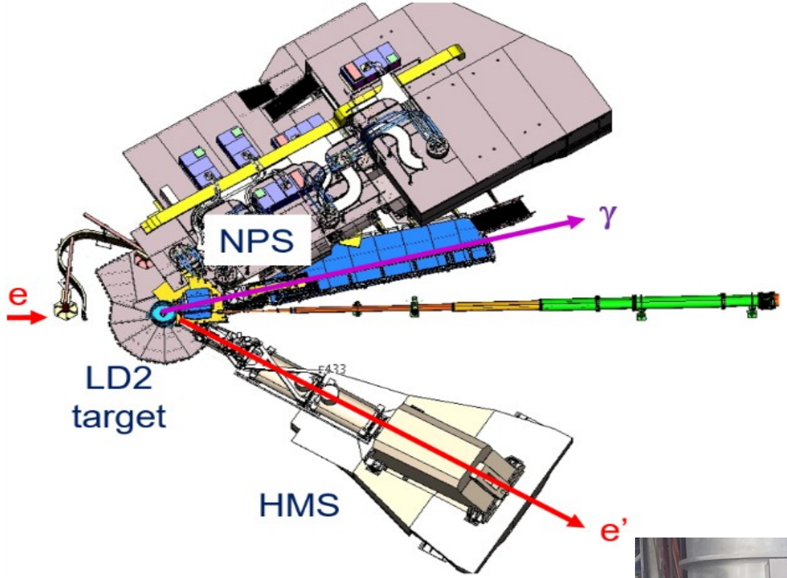
Credits to J.Crafts

Experimental Setup

- **The photon will be collected by the NPS lead tungsten calorimeter**

- **The scattered electron will be detected in the HMS**

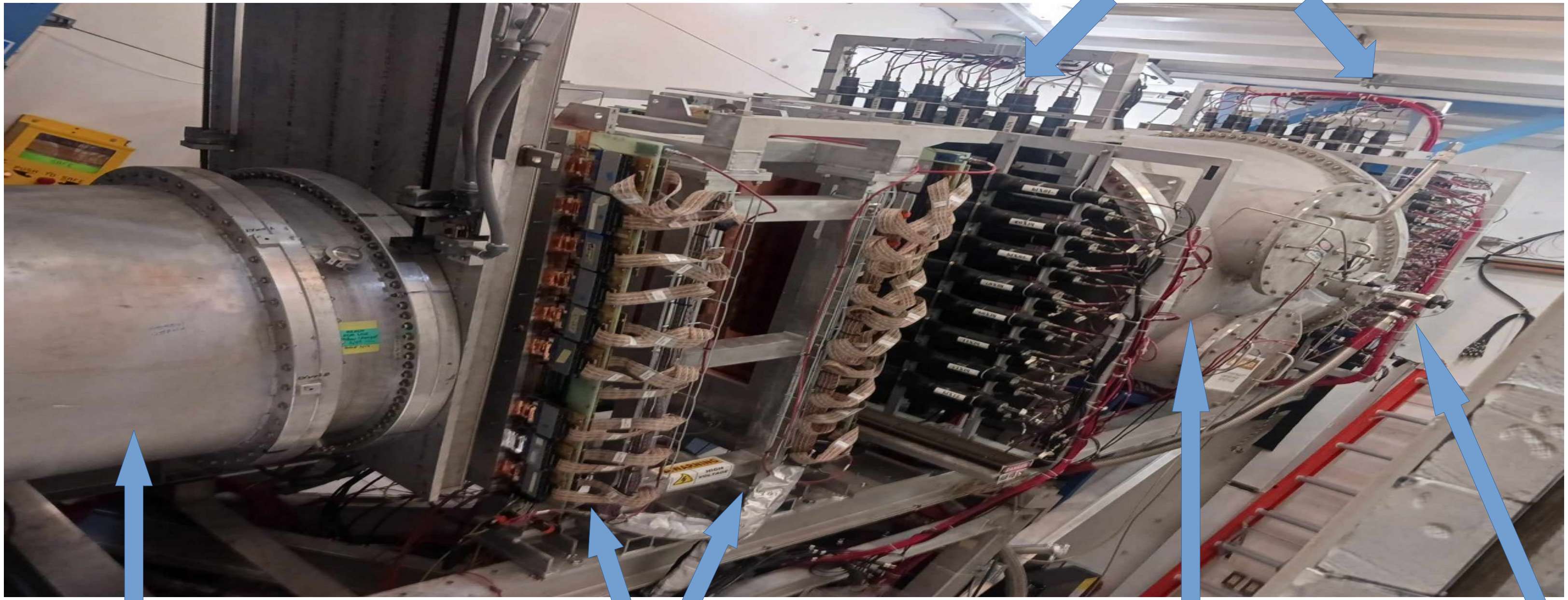
- **The recoil particle off the LD2 target will be identified by missing mass**



HMS Detectors

X-Y scintillators

e



Vacuum chamber

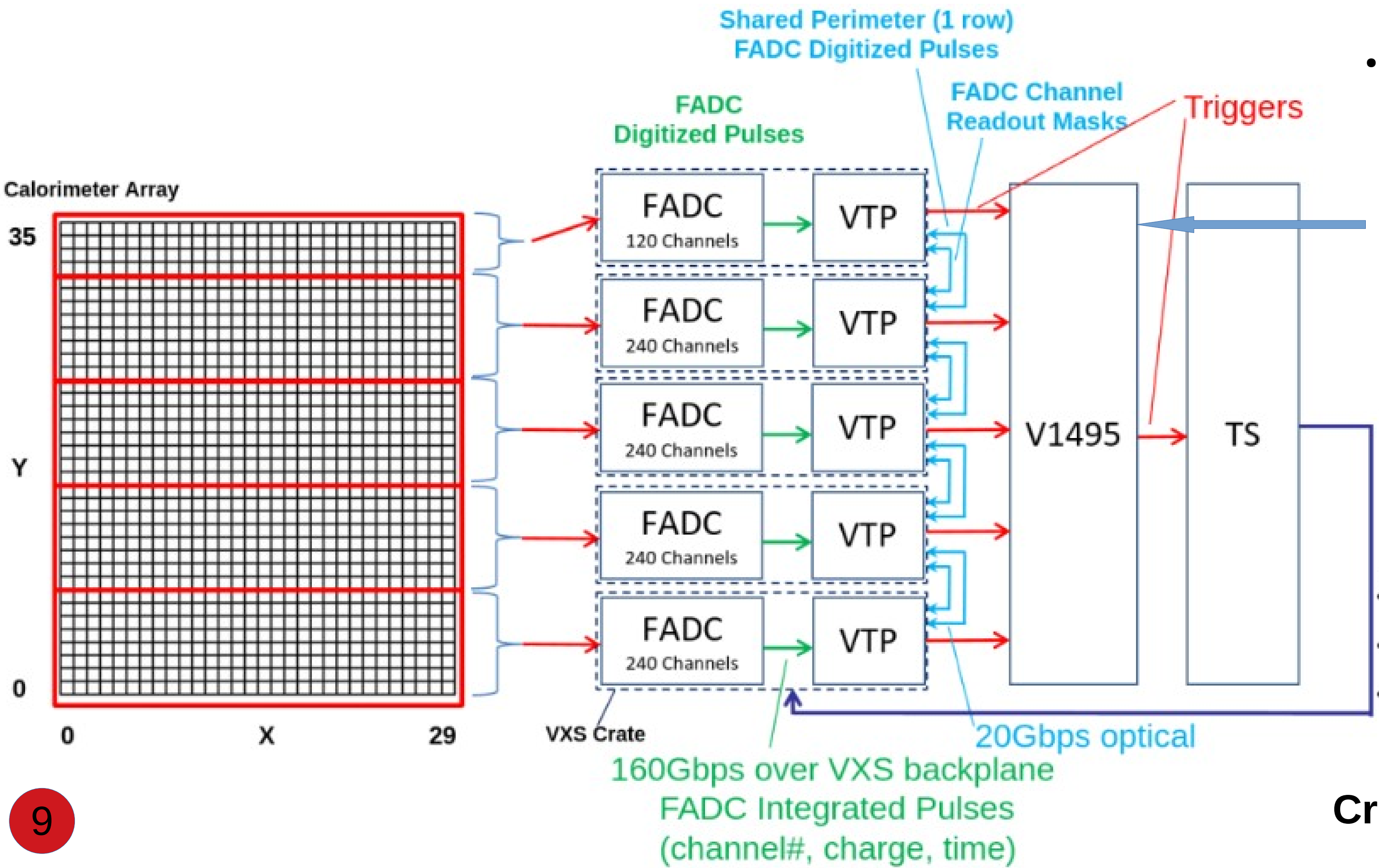
2 Drift Chambers

Heavy Gas
Cerenkov

Preshower
and shower
counters

Data Acquisition and electronics

- Flash Analog to Digital Converter (FADC)
- VXS Trigger Processor (VTP)



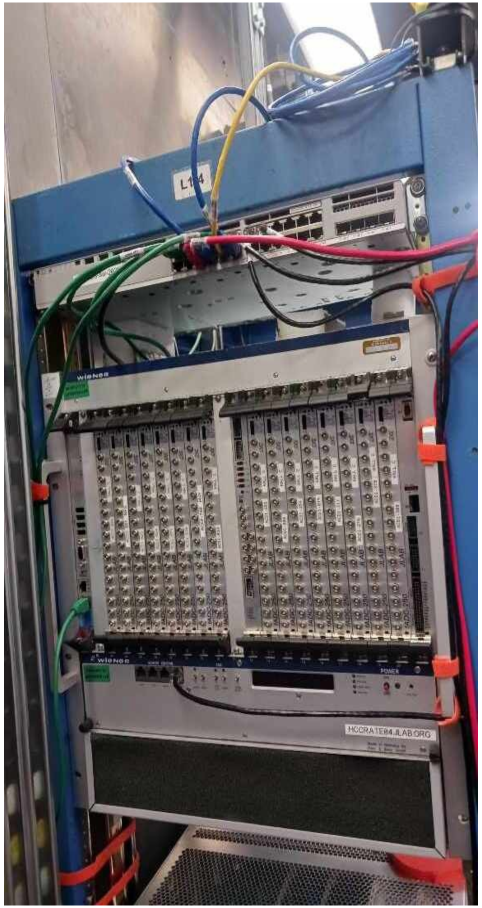
- Compatible mezzanine connector exists that allow use of commercially available ECL/TTL/NIM/ADC/DAC modules

L1A trigger latency estimated around 1μs

- Clustering of all views happens in parallel in about 64ns
- Most of the delay is in transporting information across the serial links
- L1A latency doesn't include additional delays due to TS->TI cable delays/latency settings

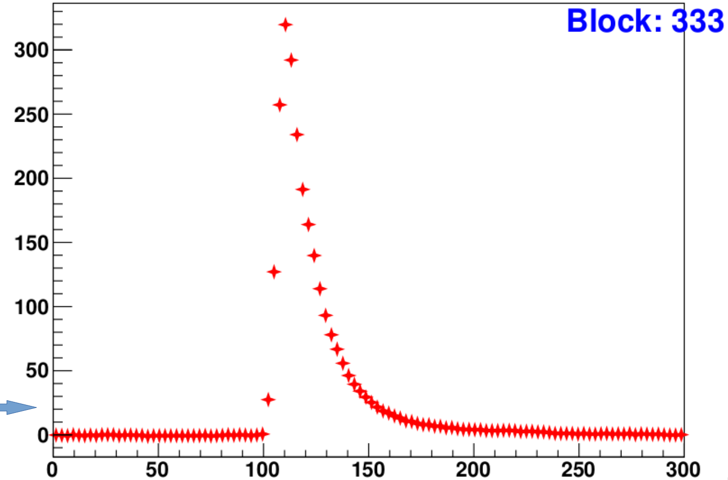
Credits to Ben Raydo

Data Stream



Data is stored in an 8 us buffer memory and always streamed (8GB/s) every 4 ns to the VTP

PEDESTAL
+
FADC
Threshold



If sample > PEDESTAL+ Threshold ==>> HIT detected in the FADC

FADC computes the integral+ PED substraction + Gain applied ==>> Energy in MeV (13 bit) streamed to the VTP

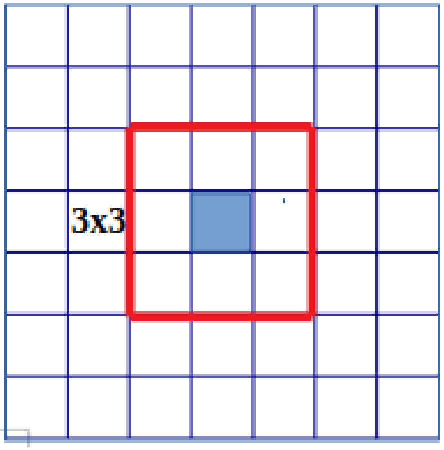
VTP and Clusters reconstruction

- **VTP BASIC STEPS:**

1) If the seed Energy is above the threshold value (70 MeV) √

2) If the seed energy is a local maximum with respect to the 8 neighbors within the value of the time window (+- 20 ns from the seed) √

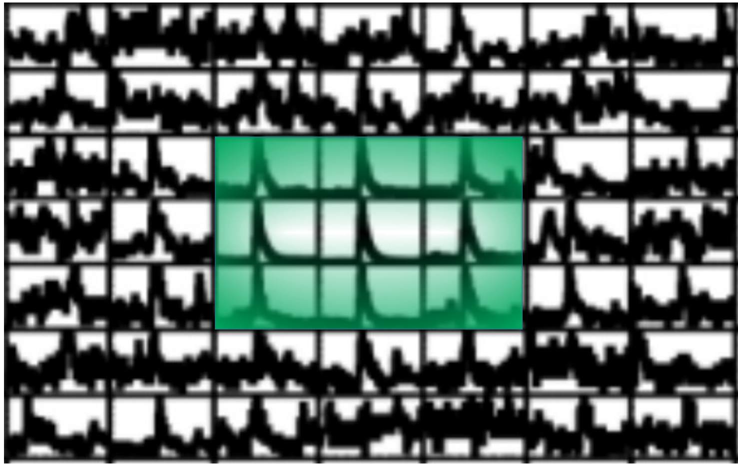
3) The Cluster Energy is calculated by summing up all the energies from the 9 blocks √



4) Information stored:

- **The x pos (column number), y pos (row number)**
- **Time of the seed block**
- **Total energy of the 3 by 3 cluster**

=> Coda file words => ROOTfile variables => Waveforms



Cluster Trigger

- Single photon cluster trigger (S.P.T):

1) The first Basic Steps by the VTP

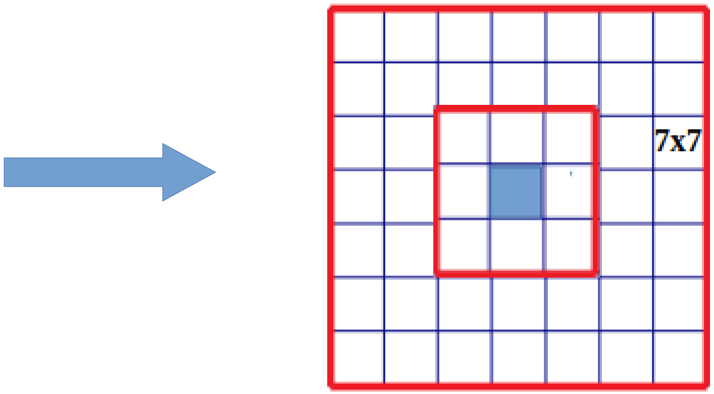
2) The Cluster Energy Is Above The S.P.T (1400 MeV)

==>> We have a DVCS cluster in hand

3) Readout threshold energy (500 MeV) is applied:

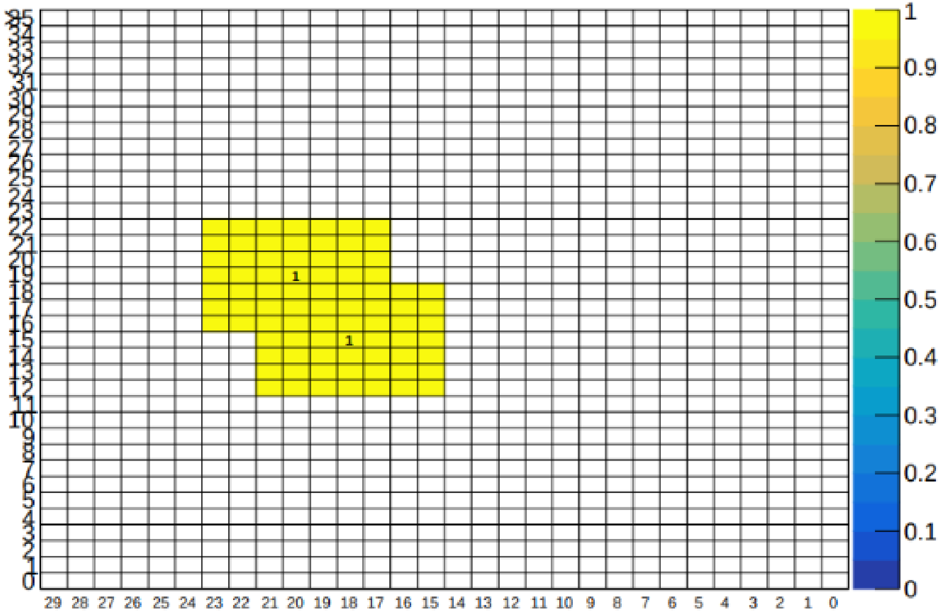
- We use the 7x7 Clustering around the seed block

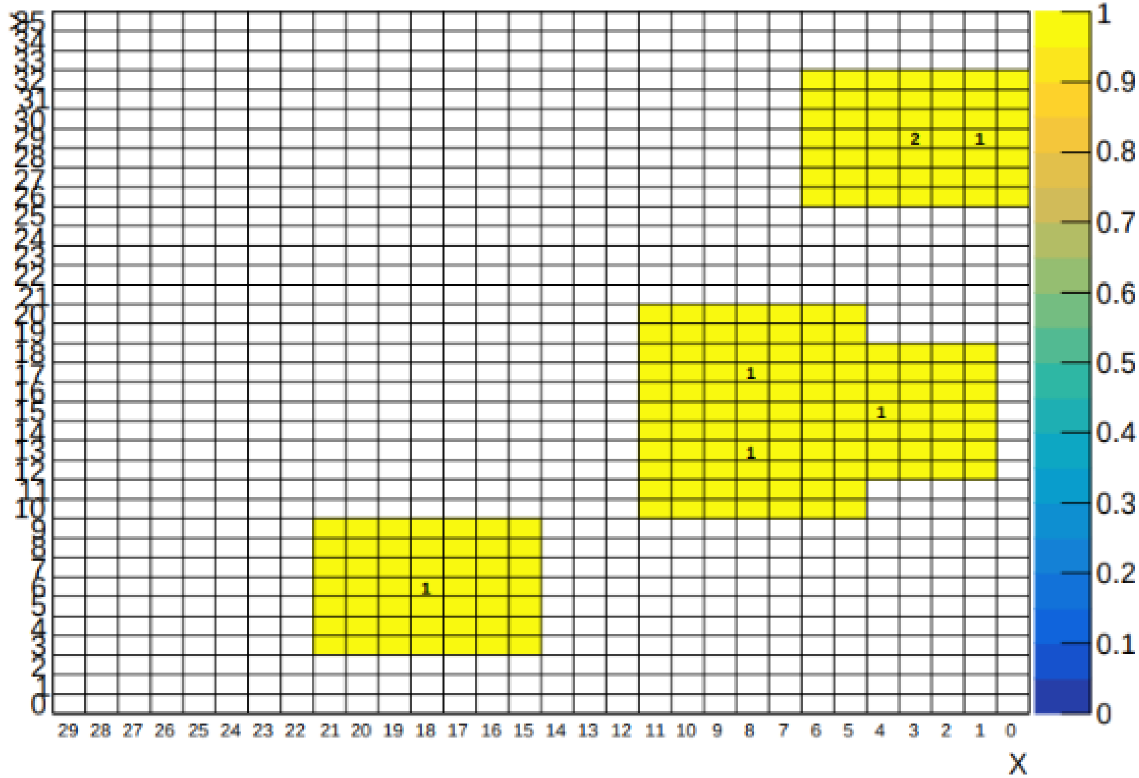
- The VTP sends the readout channels masks in the 7x7 to the FADC in order to read out the raw wavefoms of these channels



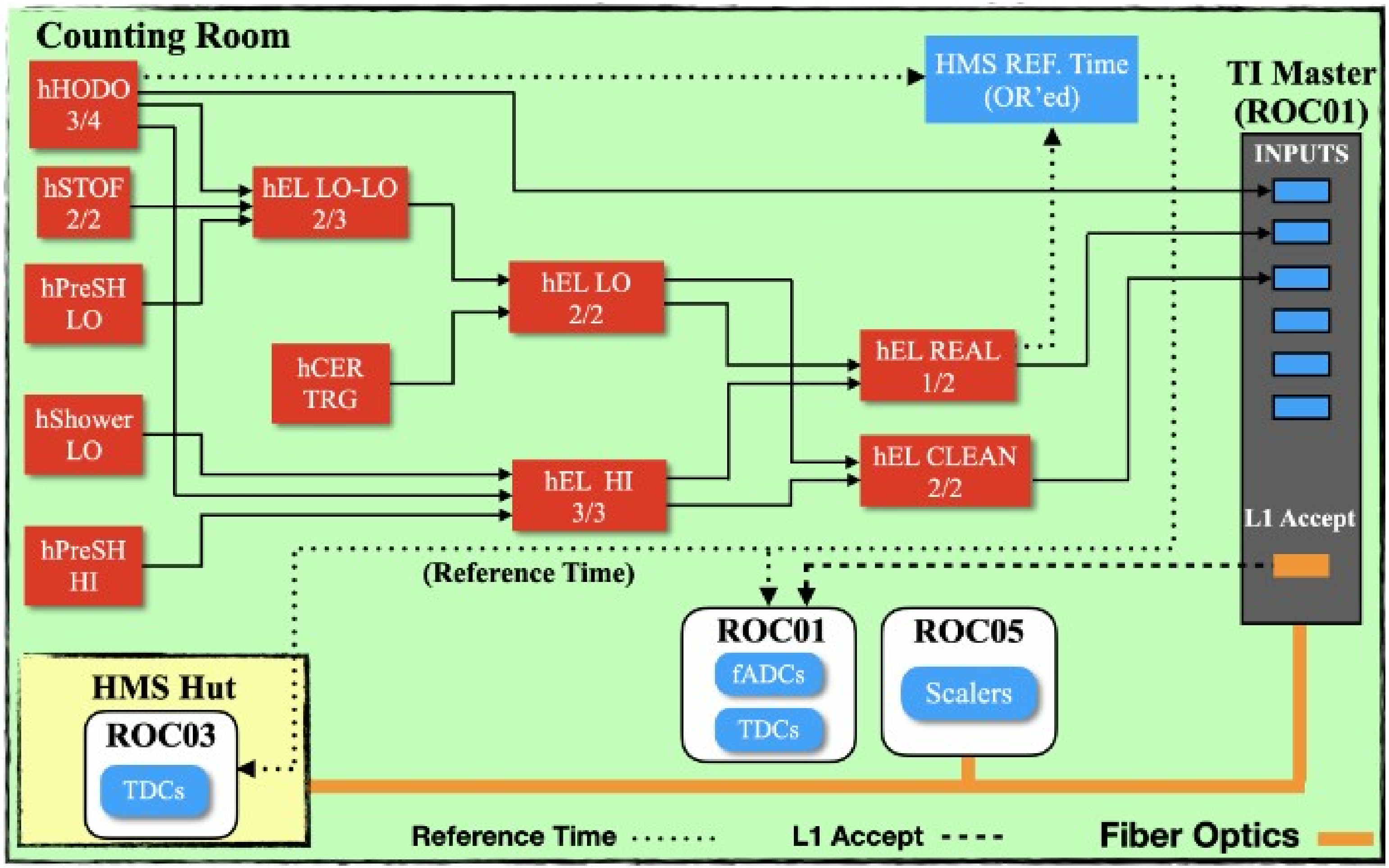
VTP Performance

- **7x7** readout patterns for **separate** and **overlapping** cluster events
- A **significant reduce** in terms of the **data** stored



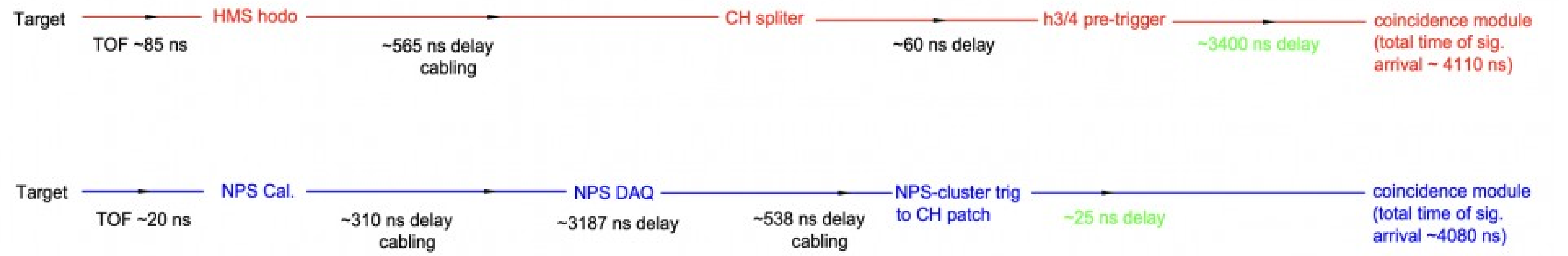


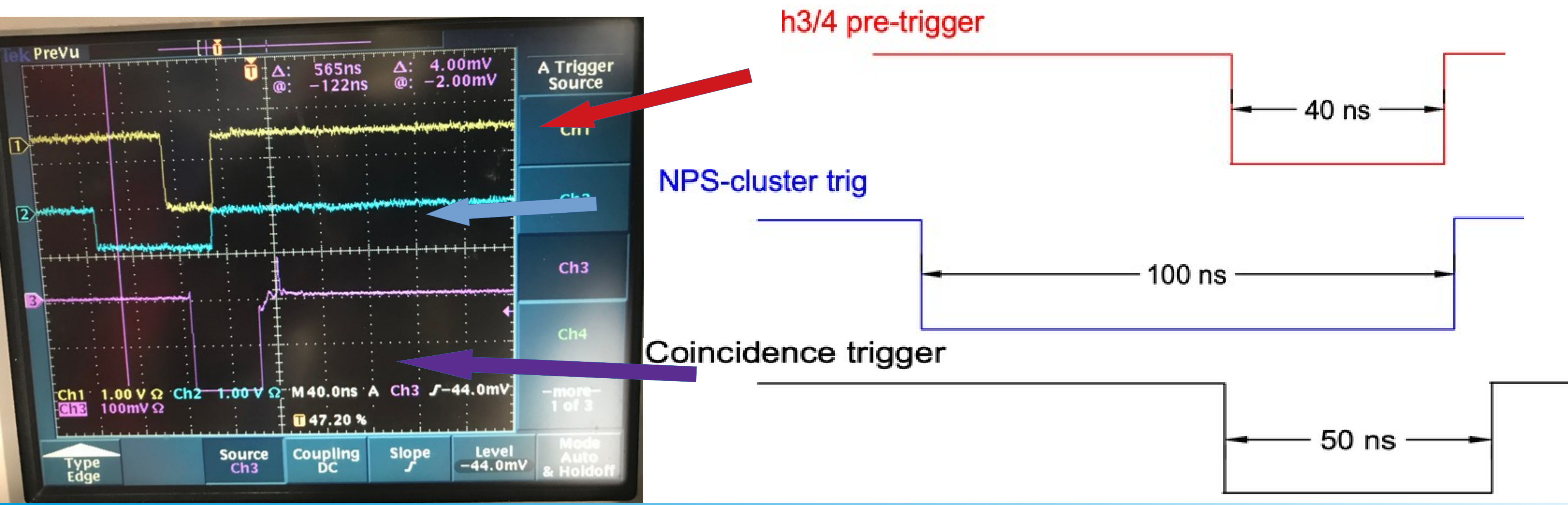
HMS Single Arm Pre-Trigger



Credits to C.Yero

NPS/HMS Coincidence





Credits to B.Michaels, J.Poudel, B.Raydo, C. Ghosh, Y. Zhang

Preliminary Physics Plots

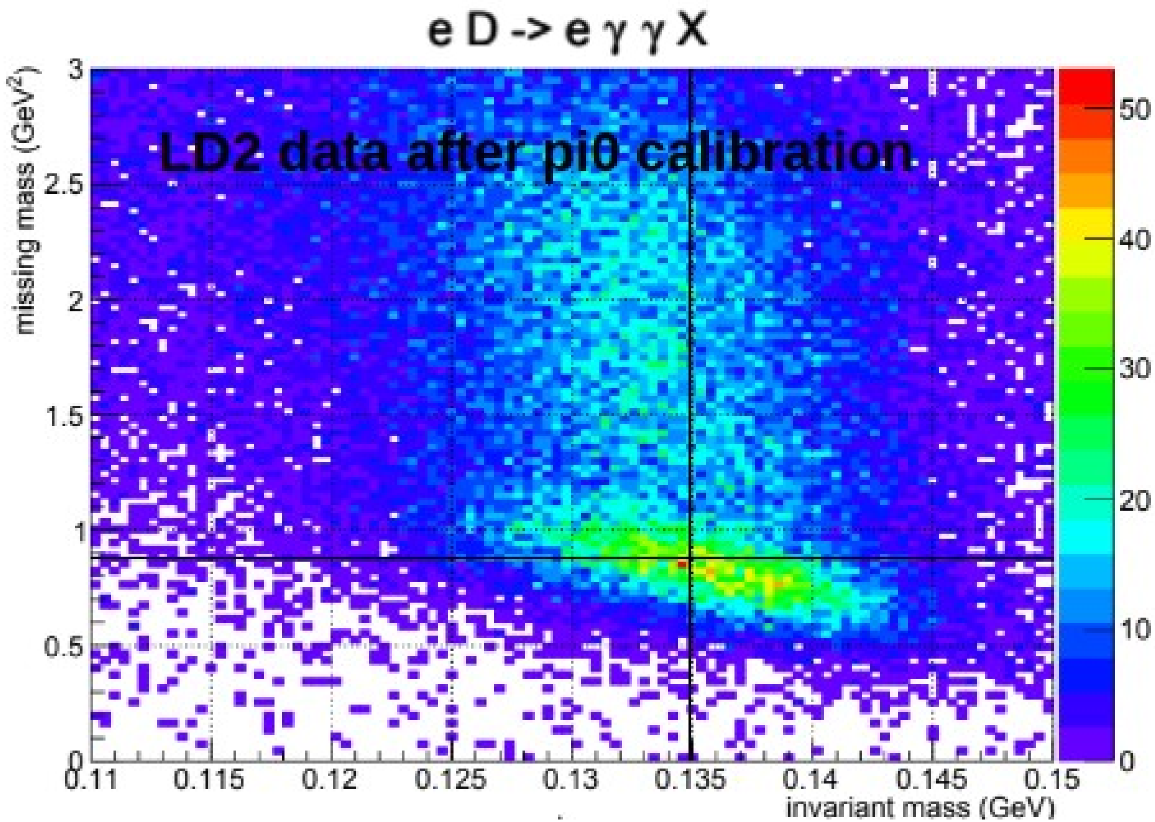
- **Correlation between the Exclusive Pi0 missing mass squared and invariant mass on the LD2 target**

- **Determination of the shower centroid coordinates with the center of gravity method**

$$E'_{\text{sh}} = \sum_{i}^{N_{\text{clus}}} E'_i.$$

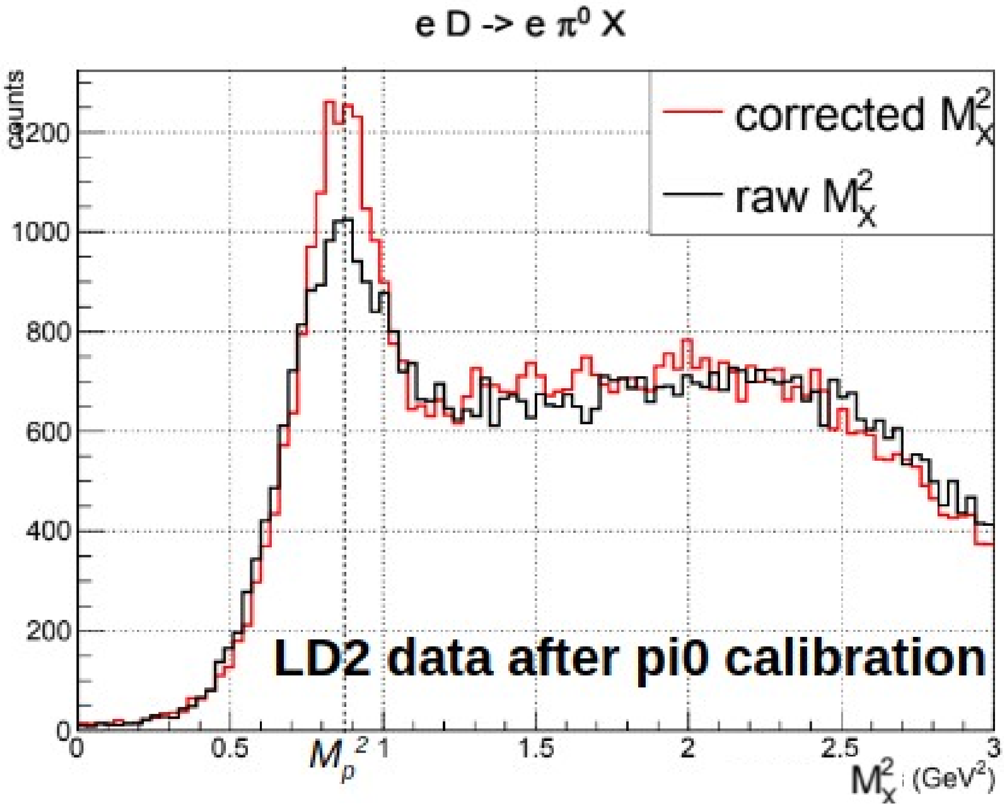
$$x_c = \frac{\sum_i w_i x_i}{\sum_i w_i}$$

$$w_i = \max\left\{0; W_0 + \ln\left(\frac{E'_i}{E'_{\text{sh}}}\right)\right\}$$

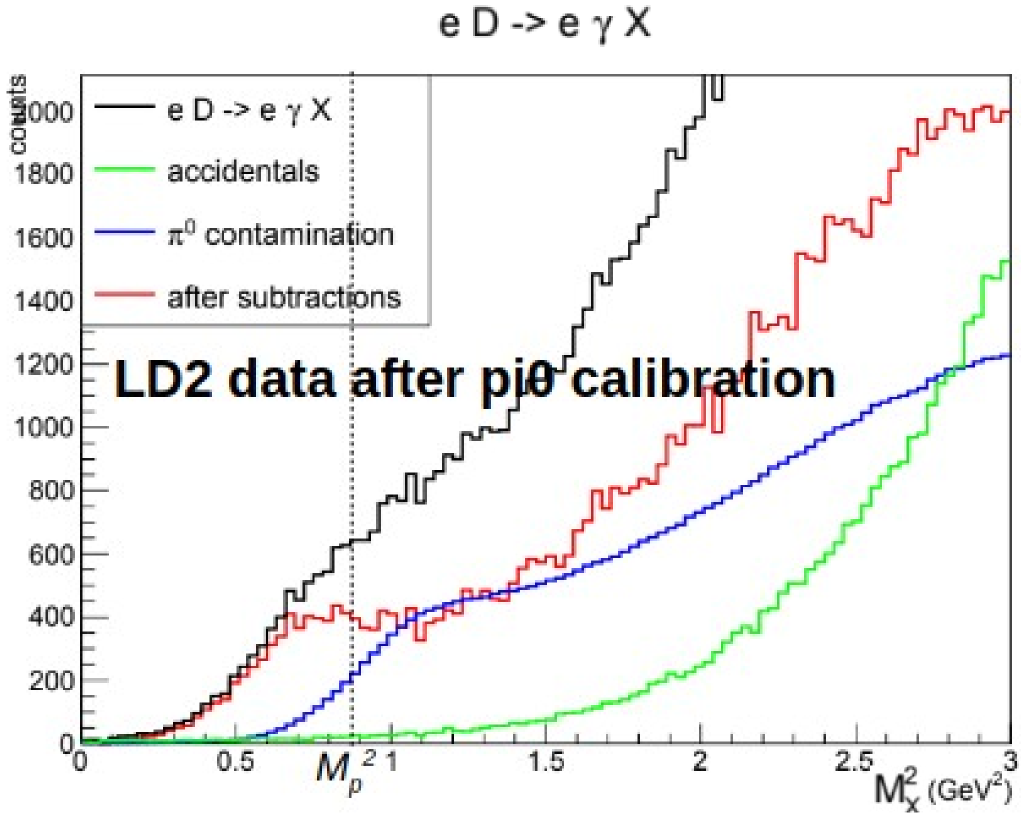


Very preliminary physics plots

- **Missing mass squared corrected by the correlation between the missing mass squared and the invariant mass**



- **Subtraction of Pi0 and accidentals**



Summary

- Measurements of the cross section over a wider kinematic domain reaction off quasi-free neutrons

- Essential measurements for probing the flavor separation of GPDs

- The Neutral Particle Spectrometer and the 12 GeV kinematics will significantly improve previous results on the n-DVCS experiments

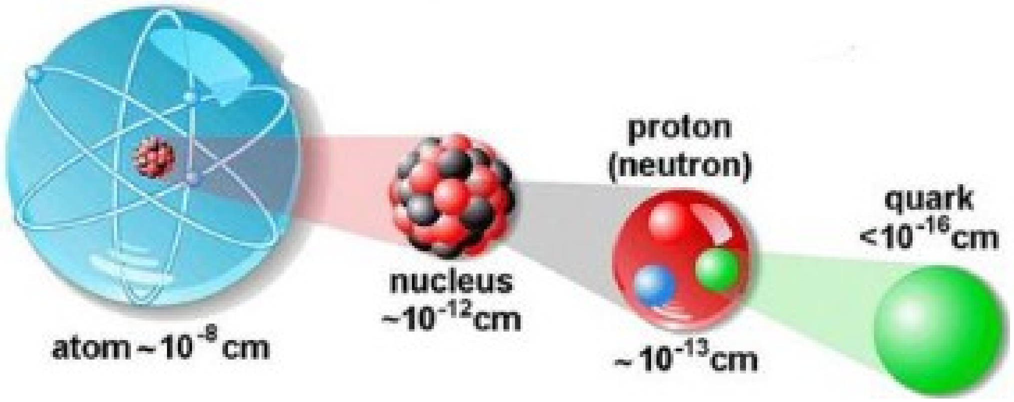
- A measurement of the exclusive $\pi 0$ electroproduction cross section off the neutron will also be measured

- Further Analysis will be conducted in the coming months to obtain the expected resolution

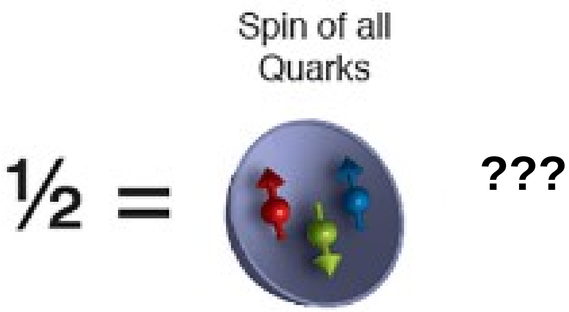
Thanks for everyone who contributed and still contributing to the experiment

Thank you for your attention!

Backup slides



Spin Crisis



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + L_Q + L_G$$

Orbital momentum of the quarks and gluons

Quarks contribution (u,d,s)

Gluons contribution

Wigner Distributions and GPDs

General formalism for a quantum system

$$W(r,p) = \int_{-\infty}^{+\infty} dz e^{ipz} \psi^*(r - z/2)\psi(r + z/2)$$

Wigner Distribution

For the case of relativistic quarks and gluons

$$W_\Gamma^q(r,k) = \frac{1}{2M}\int \frac{d^4q}{(2\pi)^4} < p'|\mathcal{W}_\Gamma^q(r,k)|p >$$

Dirac Matrix

$$\mathcal{W}_\Gamma^q(r,k) = \int d^4z e^{ikz}\bar{\psi}^q(r - z/2)\Gamma\psi^q(r + z/2)$$

In the infinite momentum reference frame

$$F_\Gamma^q(P,x,\Delta) = \frac{P^+}{4\pi}\int dz^- e^{ixP^+z^-} < p'|\bar{\psi}(-z/2)\Gamma\psi(z/2)|p > |_{z^+=\vec{z}_\perp=0}$$

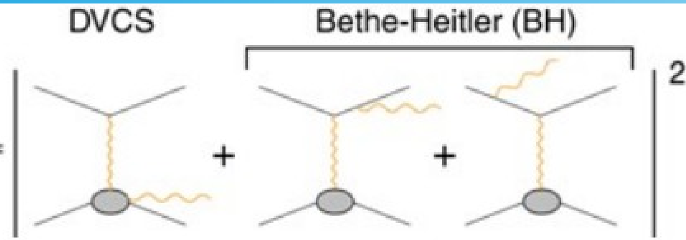
$$F^q_{\gamma^+}(x,\xi,t) = H^q(x,\xi,t)\bar{U}(p')\gamma^+U(p) + E^q(x,\xi,t)\bar{U}(p')\sigma^{+\nu}\frac{\Delta_\nu}{2M}U(p)$$

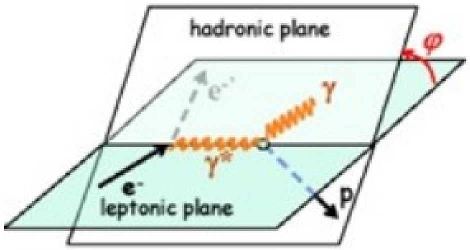
$$F^q_{\gamma^+\gamma^5}(x,\xi,t) = \tilde{H}^q(x,\xi,t)\bar{U}(p')\gamma^+\gamma^5U(p) + \tilde{E}^q(x,\xi,t)\bar{U}(p')\gamma^5\frac{\Delta^+}{2M}U(p)$$

Particle with S = 1/2

DVCS Cross Section

$\sigma(eN \longrightarrow eN\gamma) =$





But using a polarized electron beam: **Asymmetry appears in Φ**

$$d^5\vec{\sigma} - d^5\overleftarrow{\sigma} \approx 2\,\mathrm{Im}(T^{BH}.T^{DVCS}) + \left[\left|\vec{T}^{DVCS}\right|^2 - \left|\overleftarrow{T}^{DVCS}\right|^2 \right]$$

The **cross-section difference** accesses the Imaginary part of DVCS and therefore **GPDs at x=ξ**

Purely real and **fully calculable**

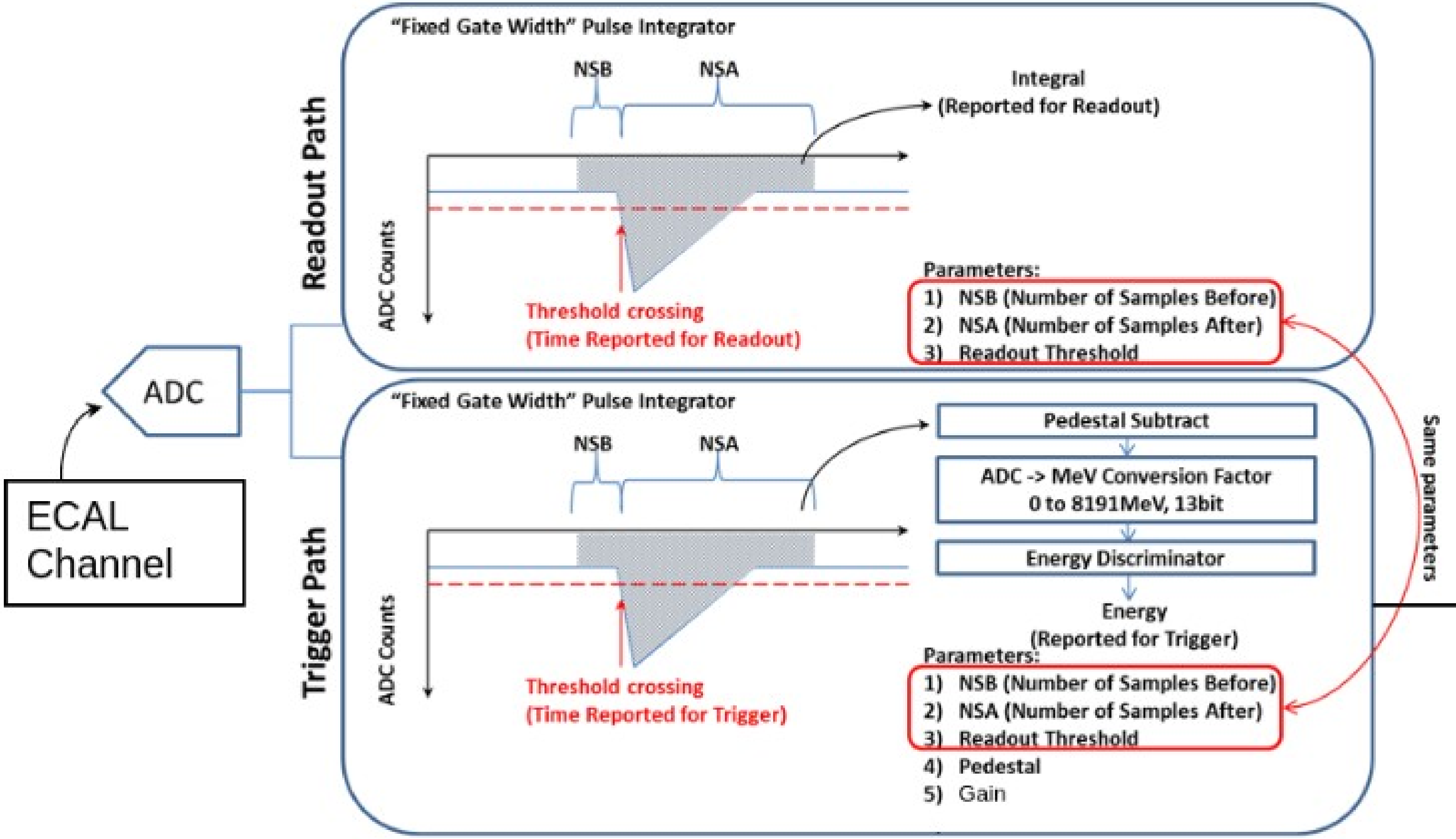
Small at Jlab enegies

$$d^5\sigma \approx \left|T^{BH}\right|^2 + 2T^{BH}.\mathrm{Re}(T^{DVCS}) + \left|T^{DVCS}\right|^2$$

The **total cross-section** accesses the real part of DVCS and therefore an **integral of GPDs over x**

Kroll, Guichon, Diehl, Pire …

FADC Data Stream



Reports to VTP:

- 13bit energy (in MeV)
- 4ns timing
- Channel number
- 32ns double pulse resolution

VTP Performance