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

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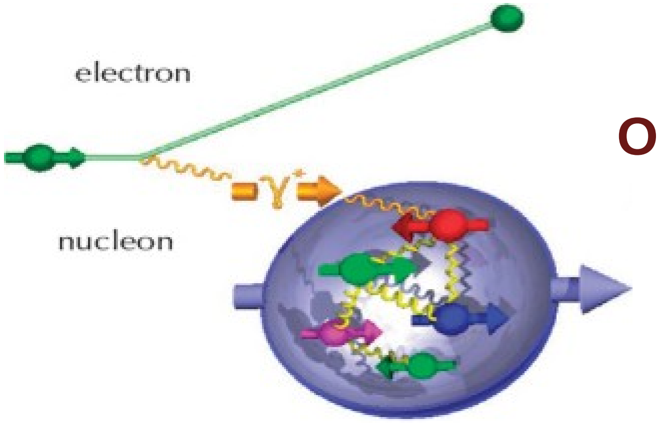
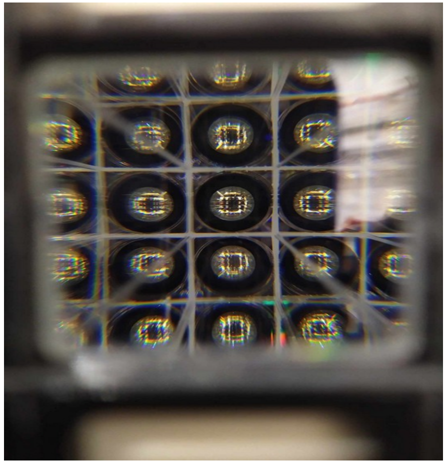
Tunisia

On behalf of the NPS Collaboration





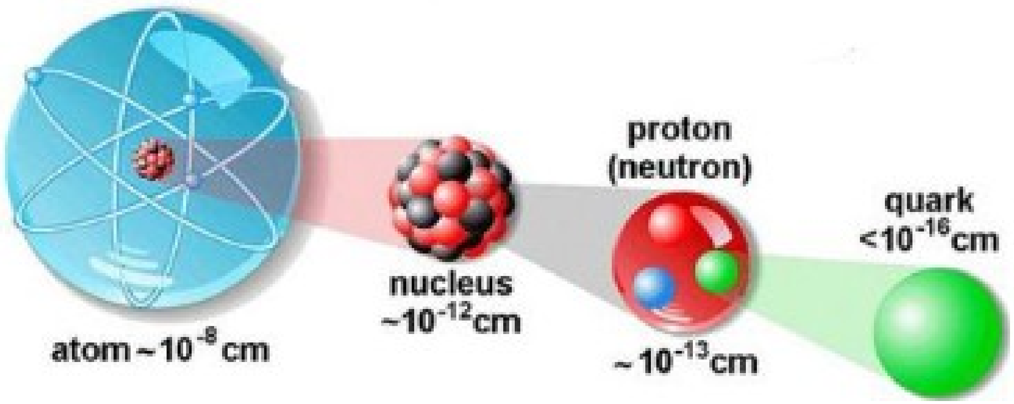
Towards Improved Hadron Tomography with Hard Exclusive Reactions

8th of August 2024, Trento, Italy

Outlines

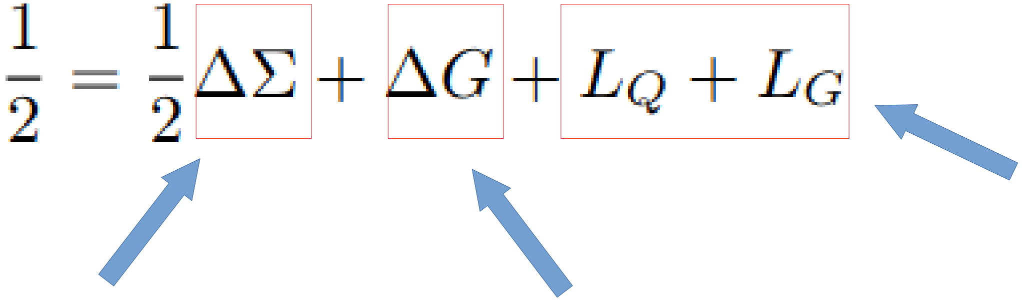
- Physics Motivation
- Experimental Setup
- Detector Performance
- Preliminary Physics Plots

Spin Crisis



½ = 

???



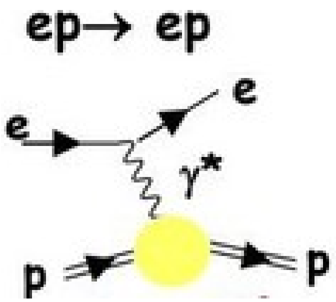
$$\frac{1}{2} = \frac{1}{2}\boxed{\Delta\Sigma} + \boxed{\Delta G} + \boxed{L_Q + L_G}$$

Quarks contribution (u,d,s)

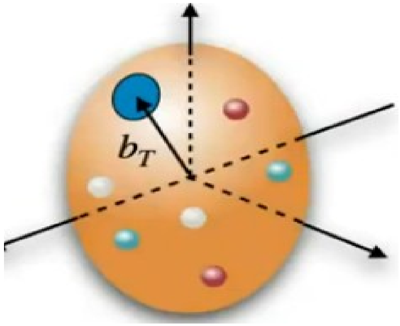
Gluons contribution

Orbital momentum of the quarks and gluons

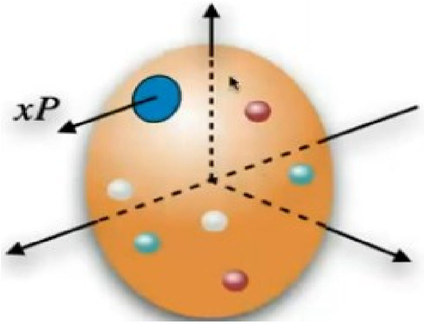
3D STRUCTURE OF THE NUCLEON

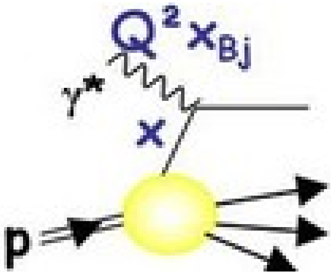


Form Factors



Partons Distribution Functions

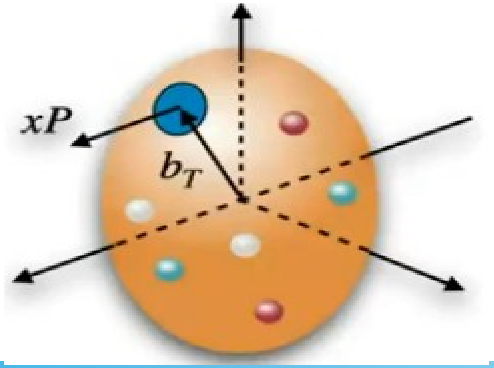




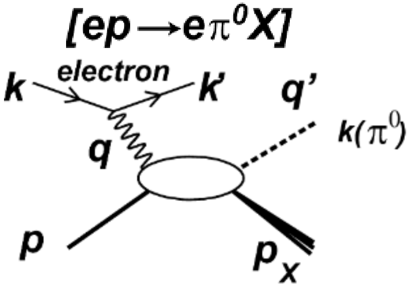
Elastic Scattering
(**ep**)

Deep Inelastic scattering
(**DIS**)

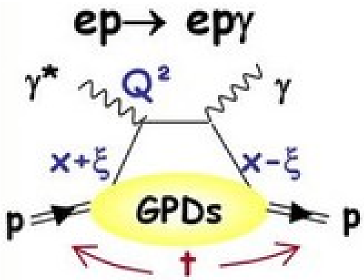
GPDs



Exclusive Pi0 Meson Electroproduction
(**DVMP**)

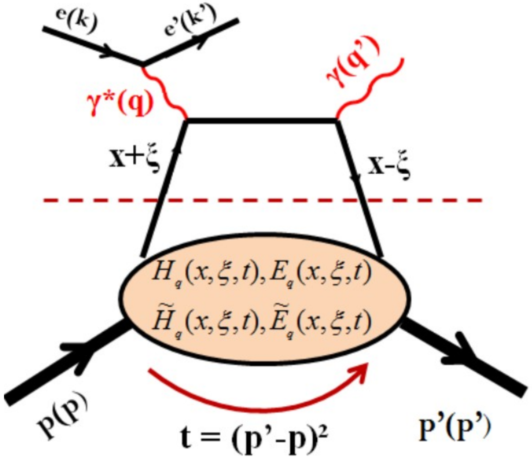


Deeply Virtual Compton Scattering
(**DVCS**)



From DVCS to GPDs

- **Factorization in Bjorken limit**



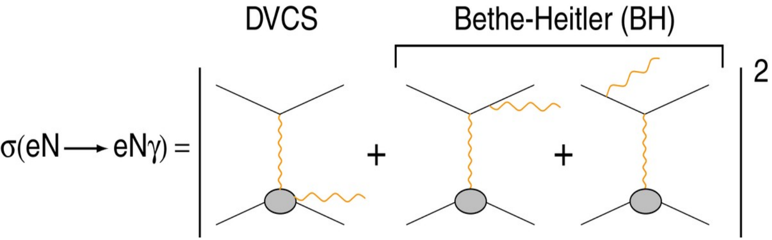
Handbag Diagram

Hard scattering process (Perturbative calculation)

PQCD factorization theorem

Soft process (non Perturbative calculation)

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



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

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

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

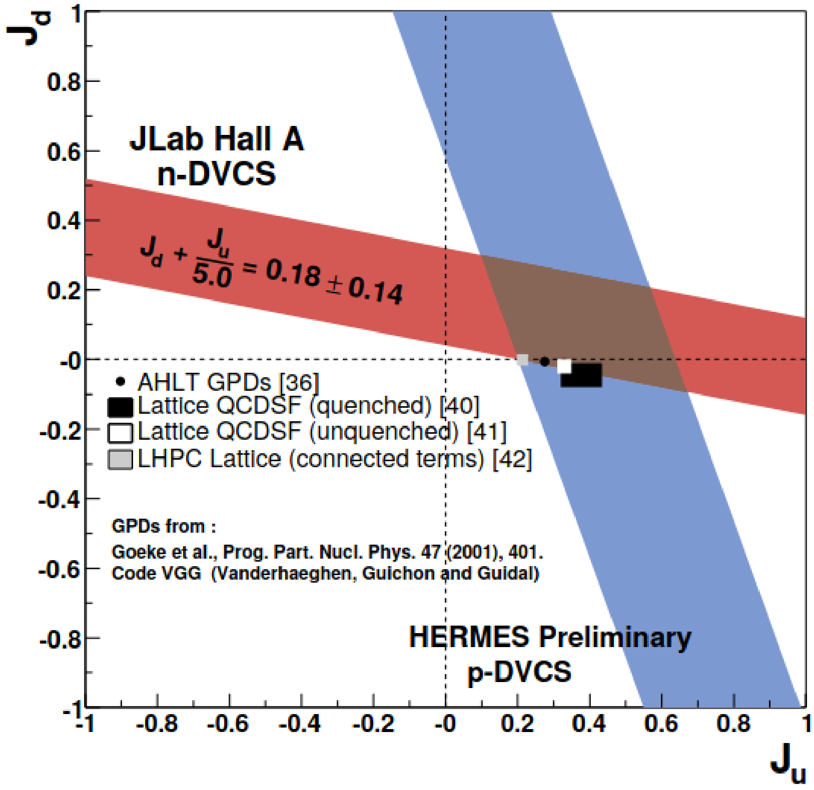
Why Neutron DVCS?

- 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:

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



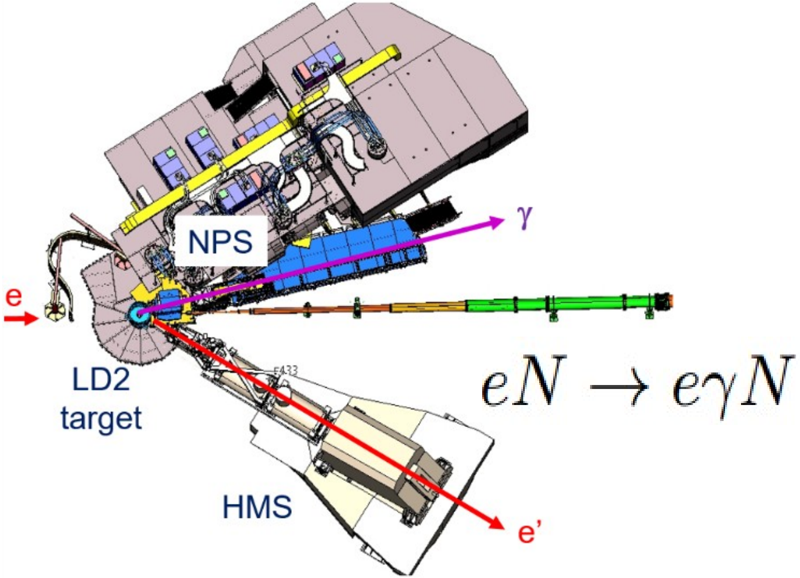
Mazouz et al. Physical review letters, 99(2007), 242501

Experimental Setup

- **The photons are detected by the NPS lead tungsten calorimeter**

- **The scattered electron are detected in the HMS**

- **The recoil particle off the LH2/LD2 target will be identified by missing mass**



$$eN \rightarrow e\gamma N$$

- 1080 $PbWO_4$ blocks:

- High energy resolution
- High light yield
- RadHard

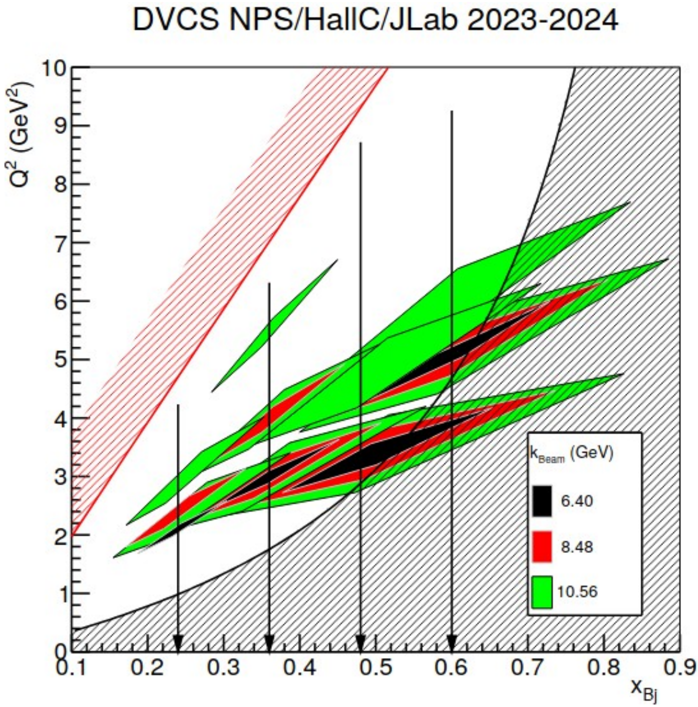
- 1080 Hamamatsu 4125 PMTs

n-DVCS Kinematics

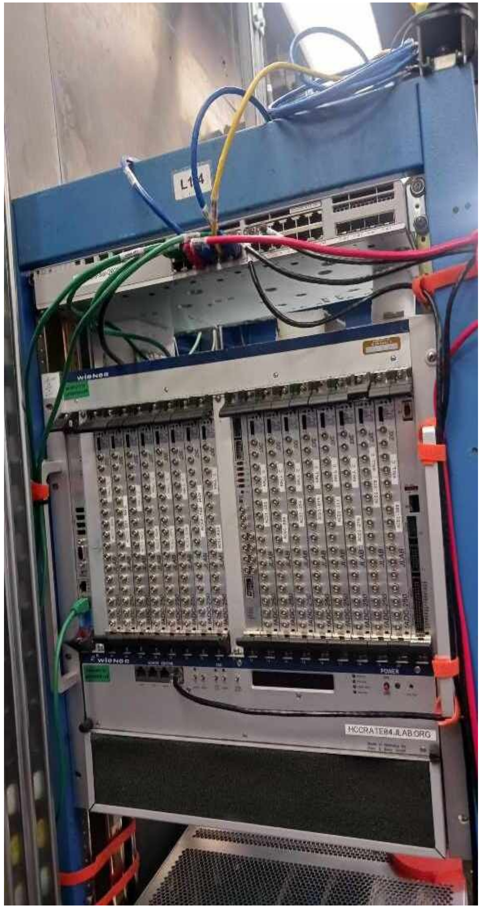
Data Taken in 2023 and 2024

X_bj	Beam energy (GeV)	Q2 (GeV2)
0.25	11	2.1
	11	2.4
	8.8	2.4
	6.6	3
0.36	11	3
	11	4
	8.8	3
	6.6	3
0.5	11	3.4
	11	4.8
	8.8	3.4
	6.6	3.4
0.6	11	5.1
	11	6
	8.8	5.1
	6.6	5.1

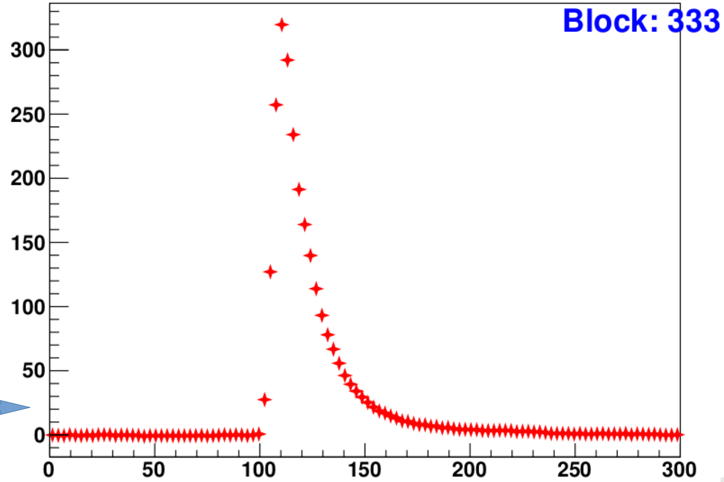
- **High xbj --> high |t|**
- **Different beam energies and Q2 will give a better extraction of the different CFFs from the DVCS cross sections**
- **To reduce systematic uncertainties, LH2 and LD2 run periods are interleaved frequently (every few hours)**



Data Acquisition



Data streamed every 4 ns to the VTP



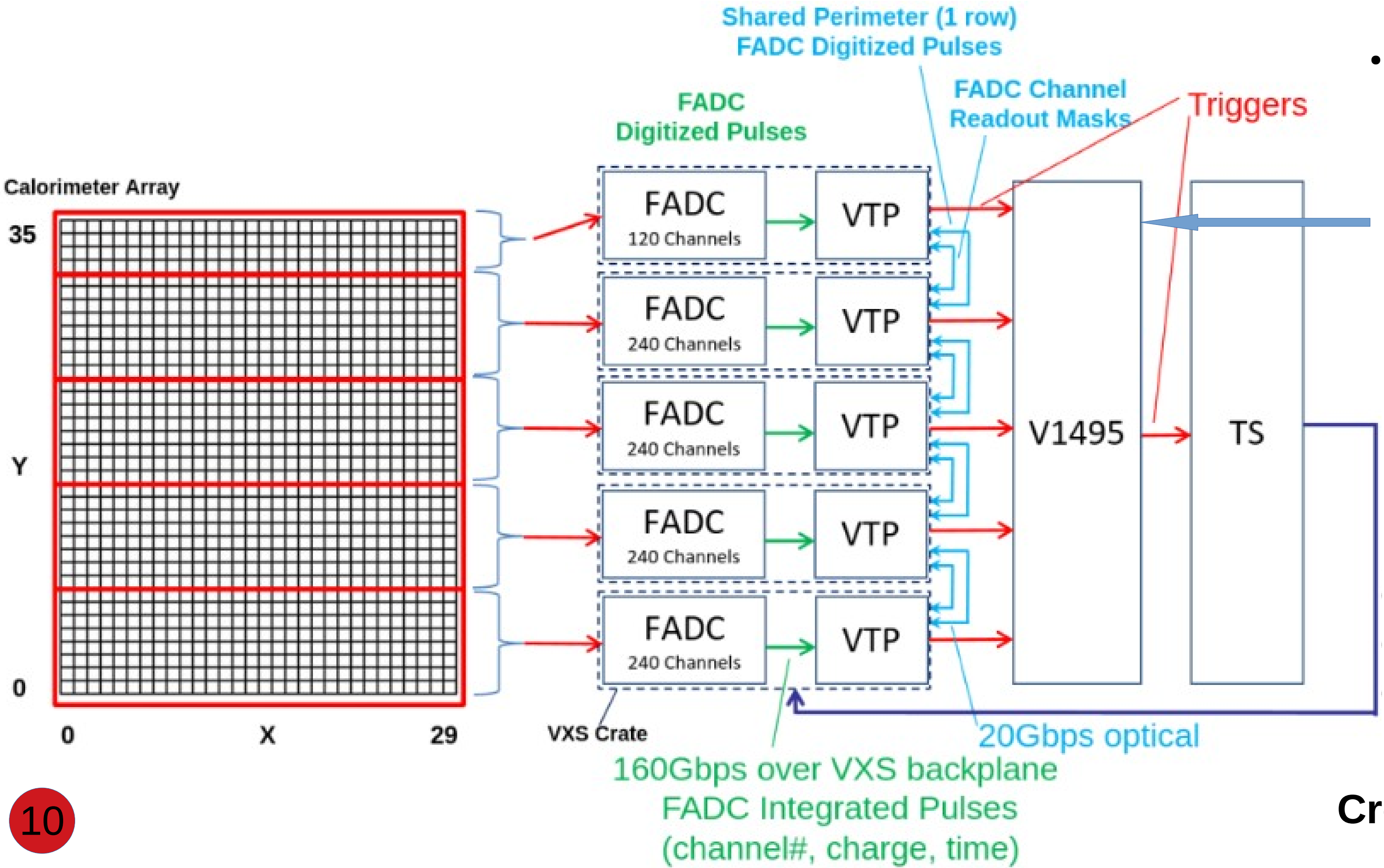
PEDESTAL
+
Threshold

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

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

Data Acquisition

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

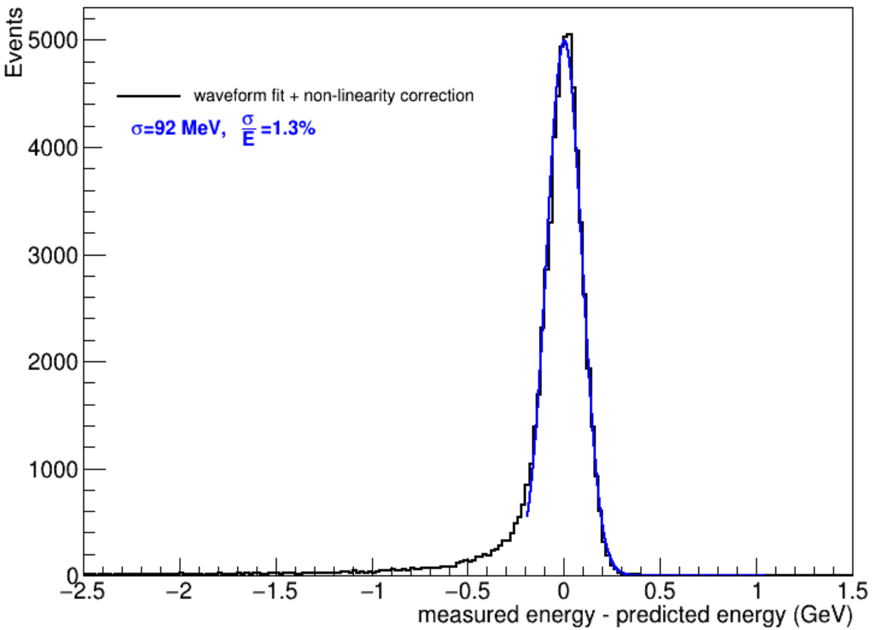


- **Compatible mezzanine connector exists that allow use of commercially available ECL/TTL/NIM/ADC/DAC modules**

Credits to Ben Raydo

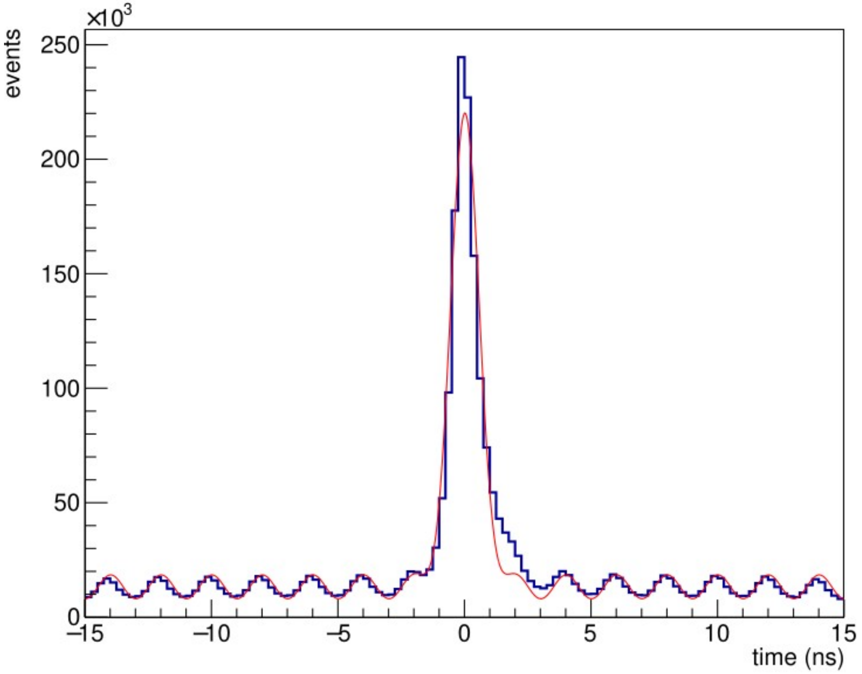
Detector Performance

Energy Resolution



- **1.3% energy resolution at 7.3 GeV from elastic $\mathrm{H}(e,e'_{Calo}p_{HMS})$ calibration run, applying waveform analysis and a and a non linearity correction to the photon cluster energy**

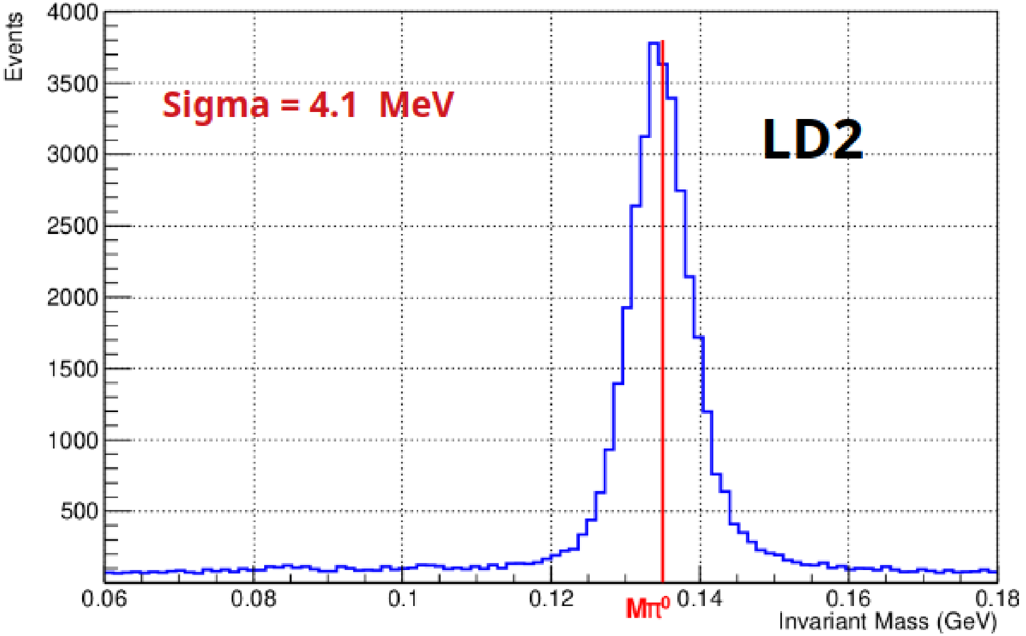
Time Resolution



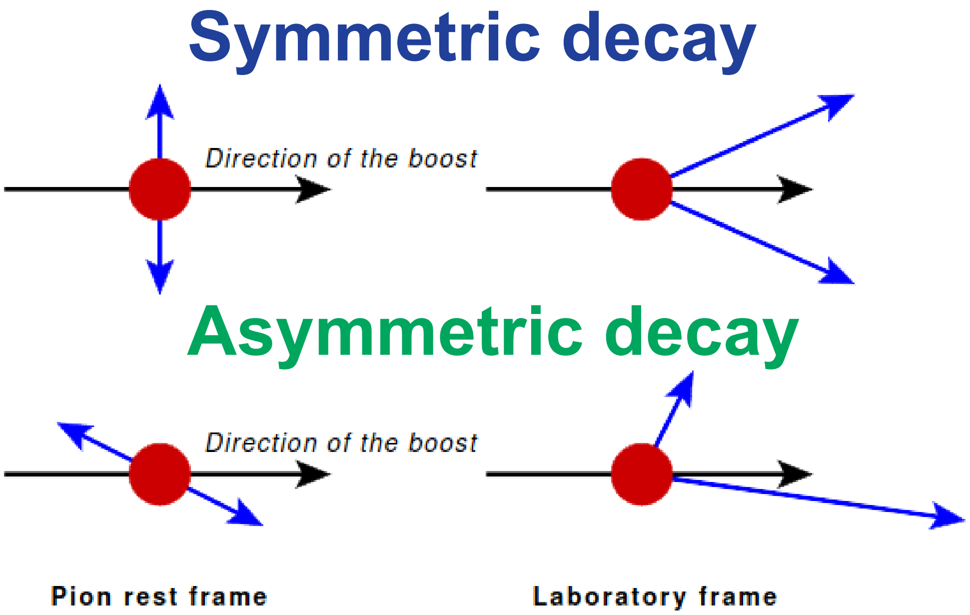
- **A good timing resolution (0.5 ns) is achieved**
- **True to accidentals ratio of 10:1 with a visible 2ns beam structure**

Preliminary Results

$\pi 0 \rightarrow \gamma\gamma$ reconstruction

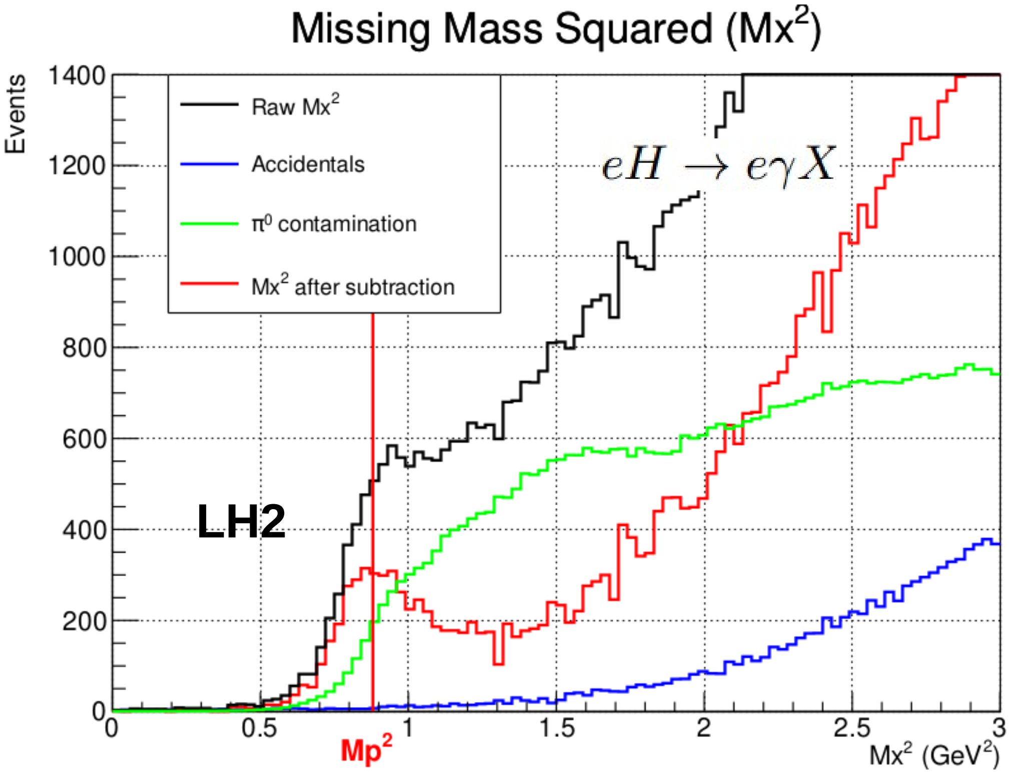


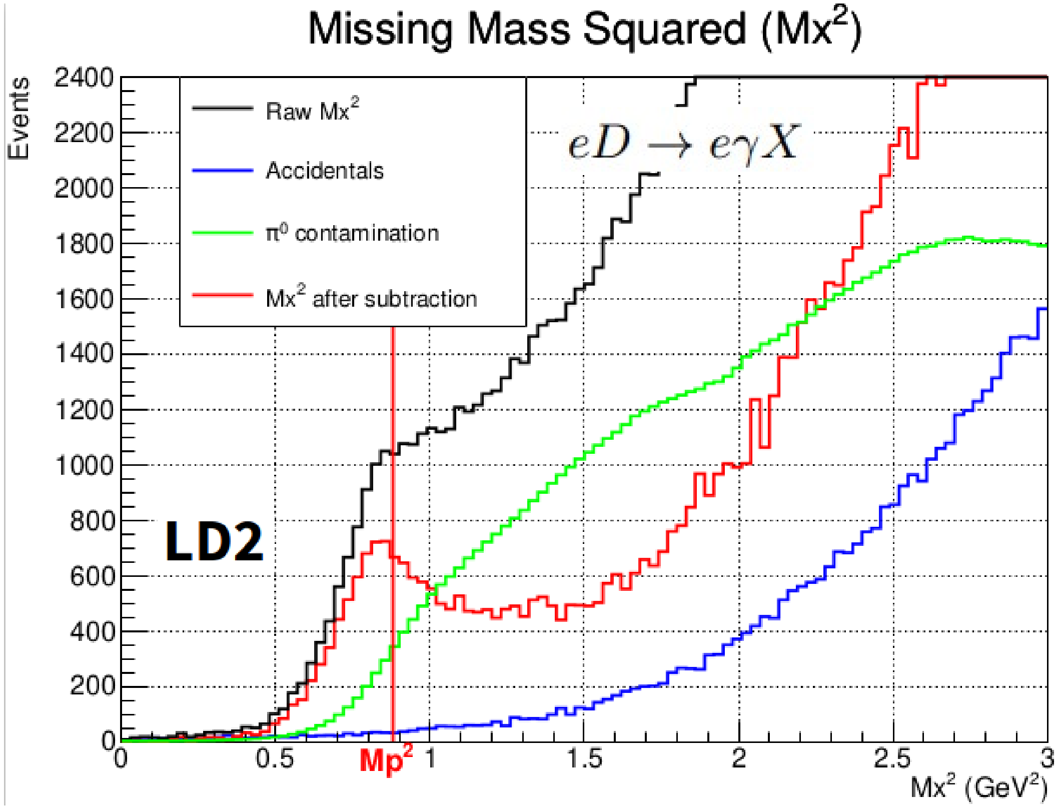
Exclusive neutral pion contamination



- **Better resolution** than the previous DVCS experiment in Hall A (**~7 MeV**) with **PbF2** calorimeter

Preliminary Results





n-DVCS and d-DVCS seperation (Hall A results and upcoming steps)

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

Coherent elastic channel

incoherent quasi-elastic channels

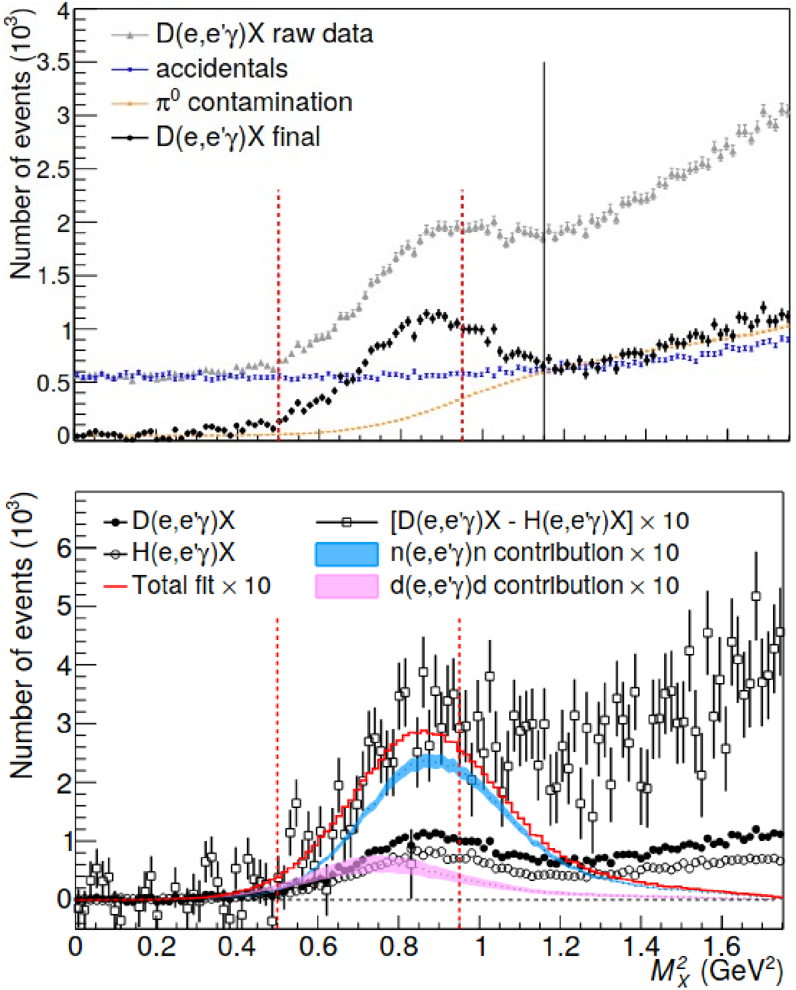
$$D(e,e'\gamma)X = d(e,e'\gamma)d + n(e,e'\gamma)n + p(e,e'\gamma)p$$

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'ɣ)n and coherent d(e,e'ɣ)d can be achieved with a fit of the exclusive region of the missing mass spectrum**



Benali et al. Nat Phys 16 (2020) 191

Summary

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

- Essential measurements of probing the flavor separation of GPDs

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

- The preliminary results showed an improved exclusivity and resolution with new PbWO4 calorimeter compared to previous PbF2, even at higher luminosity

Thank you for your attention!

Back up Slides

Waveform Analysis

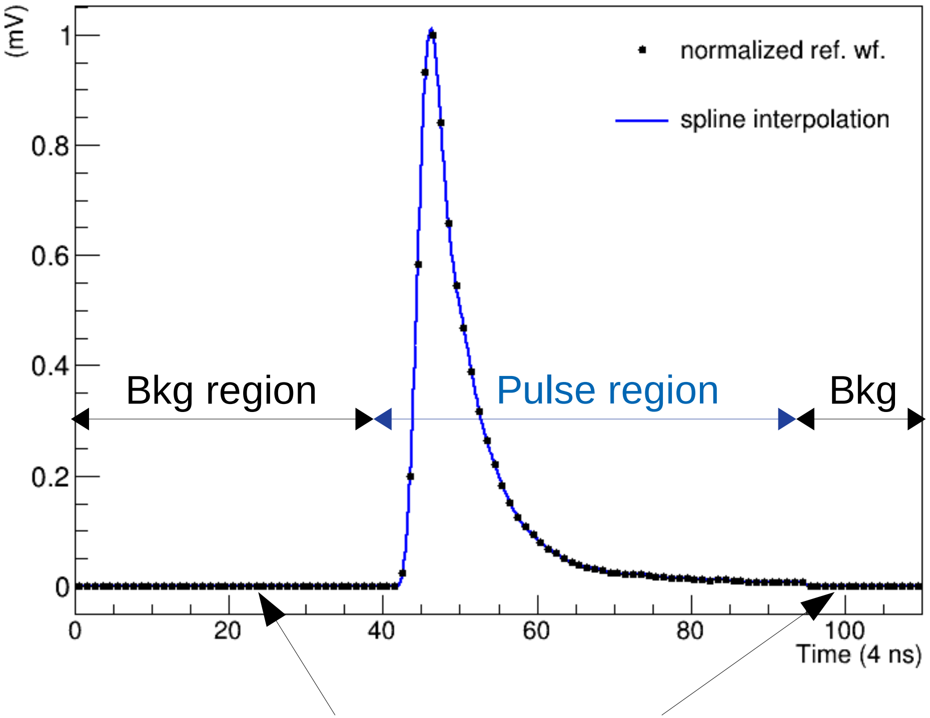
First step: Select from the elastic data a reference waveform for each NPS channel using certain criteria

- **Pulses should be:**

  - In Coincidence (+/- 5 samples)
  - Highest amplitude
  - Lowest noise in the Background
  - No multiples or pile-up

- **Add a constant vertical shift to have an average baseline equal to 0 mV**

- **Normalization of the ref. wf. to 1 mV amplitude**



Remove any fluctuation by setting all the ref. wf. samples to 0 mV in the bkg region

Waveform Analysis

Second step: Produce a Fit function for each block

- Interpolate the 110 samples of the ref. wf. with Spline to create a function ***f(t)***

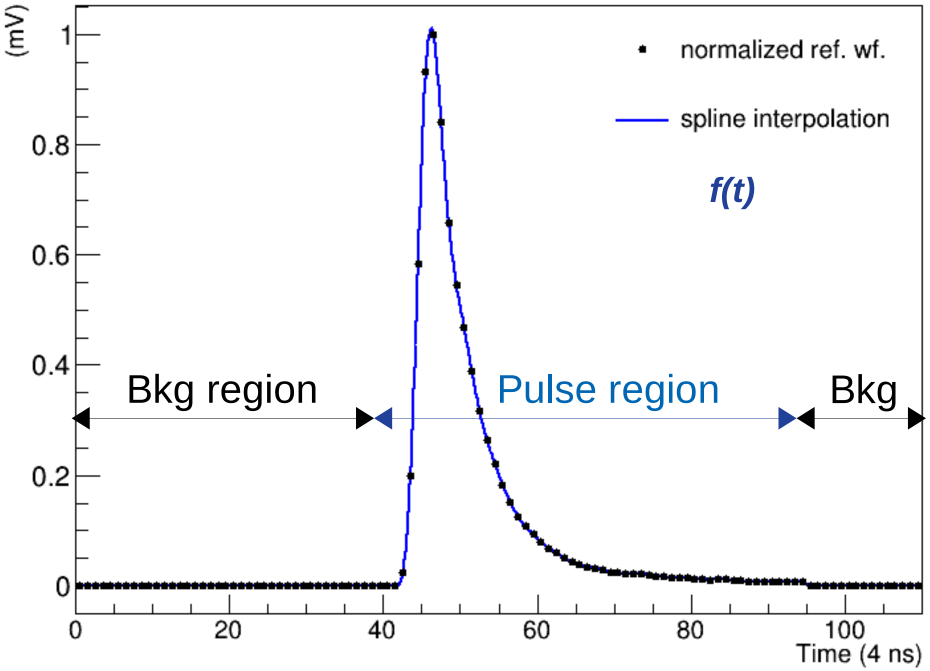
- The fit function:

$$F(t) = B + \sum_{i=1}^{Npulses} A_i \; f(t - t_i)$$

Baseline

Amplitude

Time of pulse #i (4*ns) relatively to the ref wf time

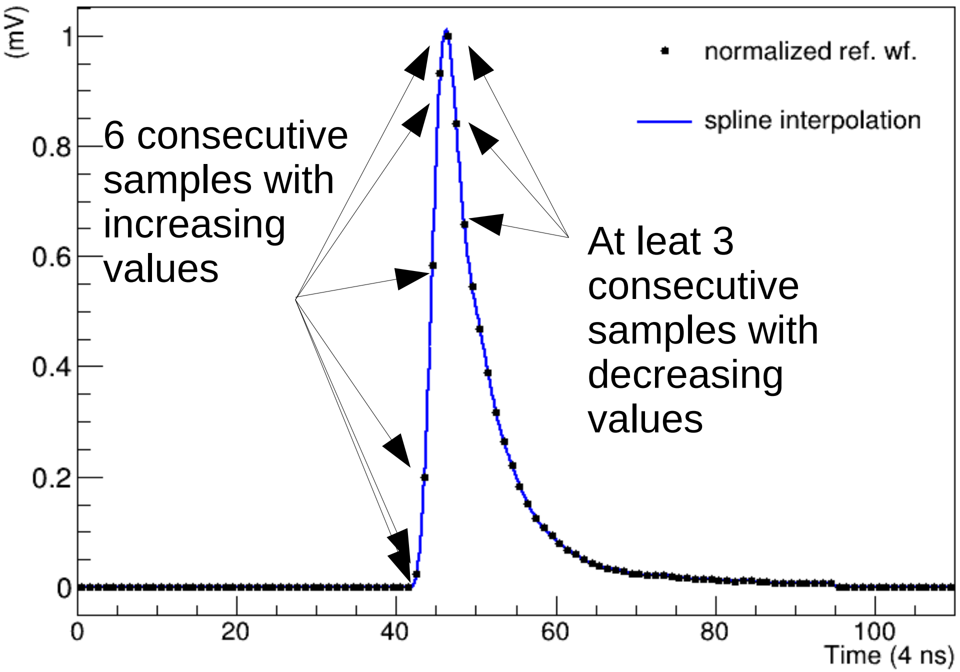


Waveform Analysis

Third step: Detect the number of pulses in the waveform, estimate the amplitude and time

- **The identification of a pulse is based on 4 consecutive samples with increasing values followed by 2 consecutive samples with decreasing values**

- **The time and the rough estimate of the amplitude of the pulses found are used to help the fit**

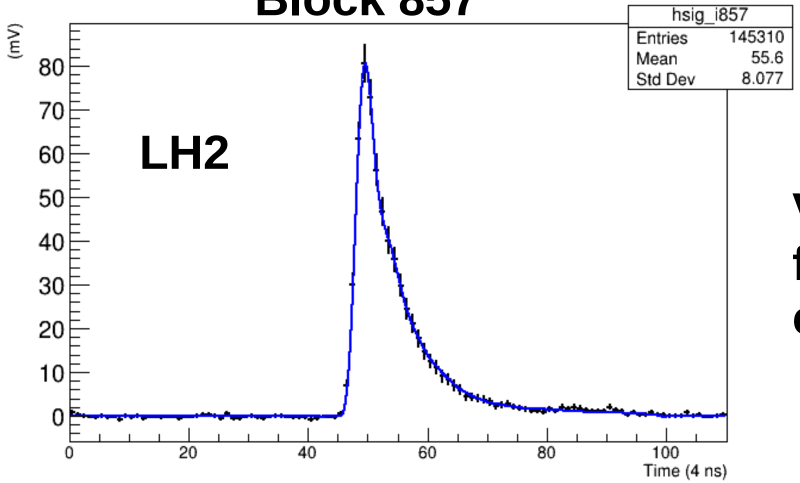


6 consecutive samples with increasing values

At leat 3 consecutive samples with decreasing values

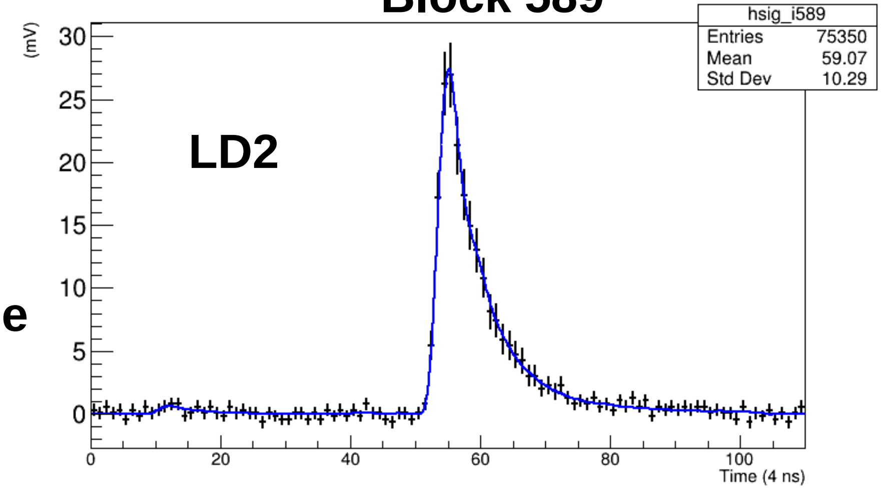
FITTED WAVEFORMS

Block 857

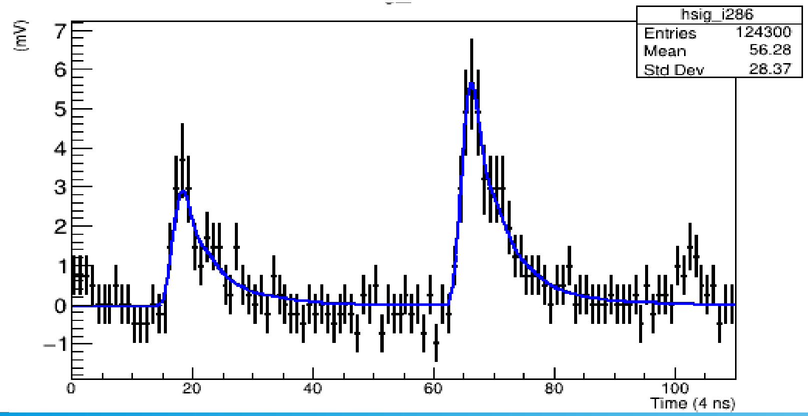


Very convenient fit for the coincidence pulse

Block 589

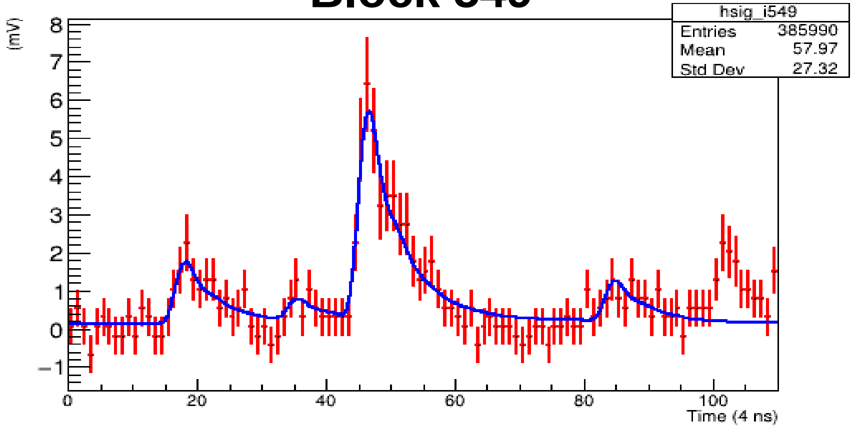


Block 286

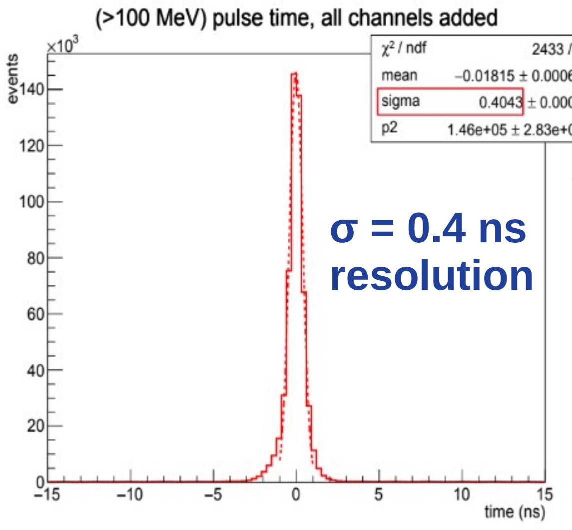


Multiple pulse fit

Block 549



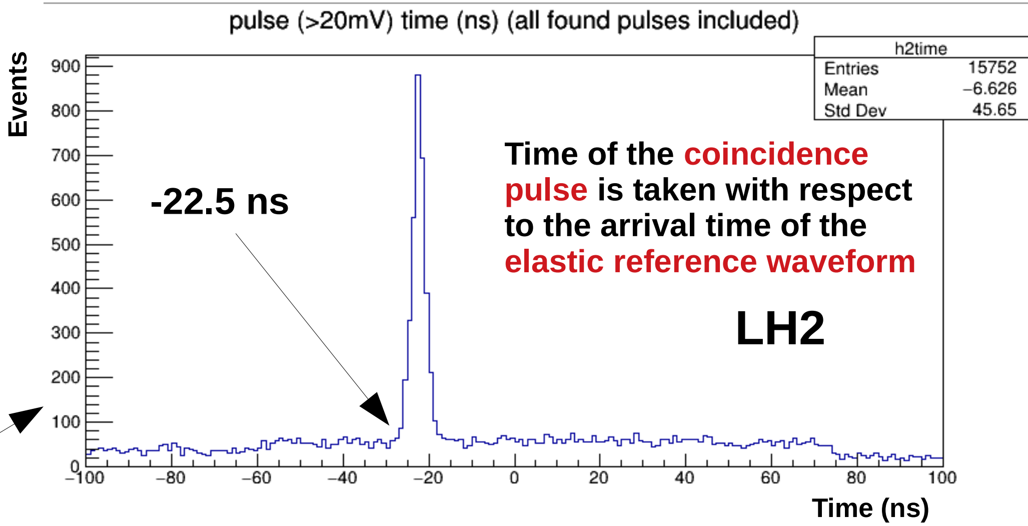
TIME RESOLUTION STUDY



σ = 0.4 ns resolution

Elastics data

Production data

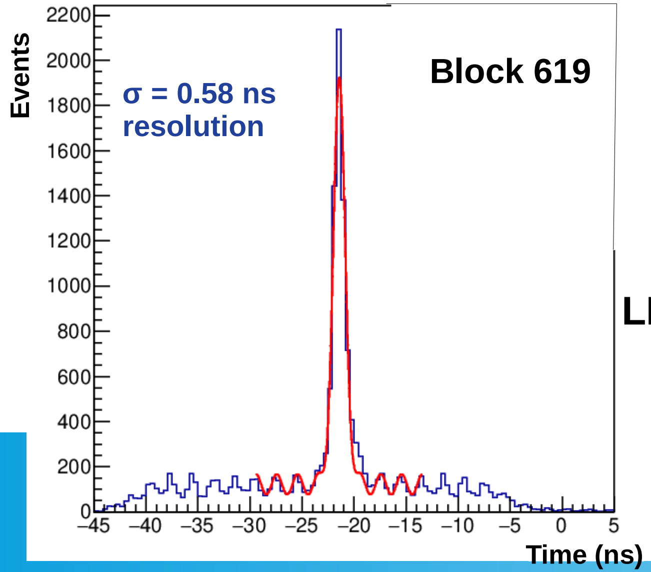


-22.5 ns

Time of the coincidence pulse is taken with respect to the arrival time of the elastic reference waveform

LH2

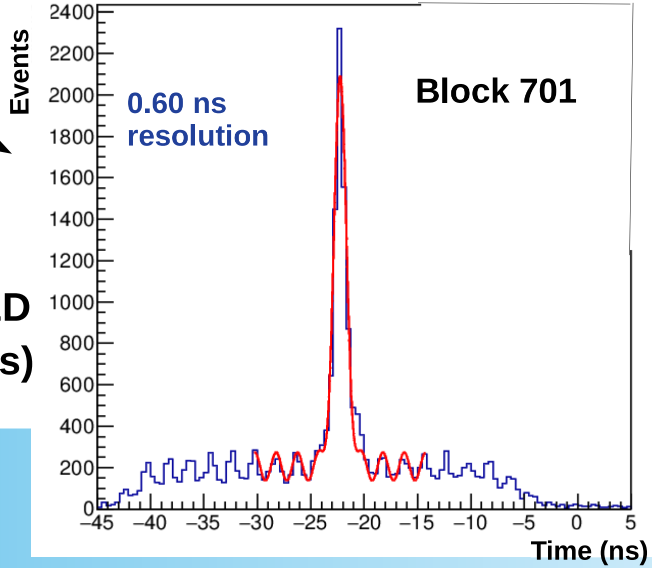
Pulses above 5 MeV



σ = 0.58 ns resolution

Block 619

LD2 +LH2 RUNS COMBINED (2 middle columns blocks)



0.60 ns resolution

Block 701

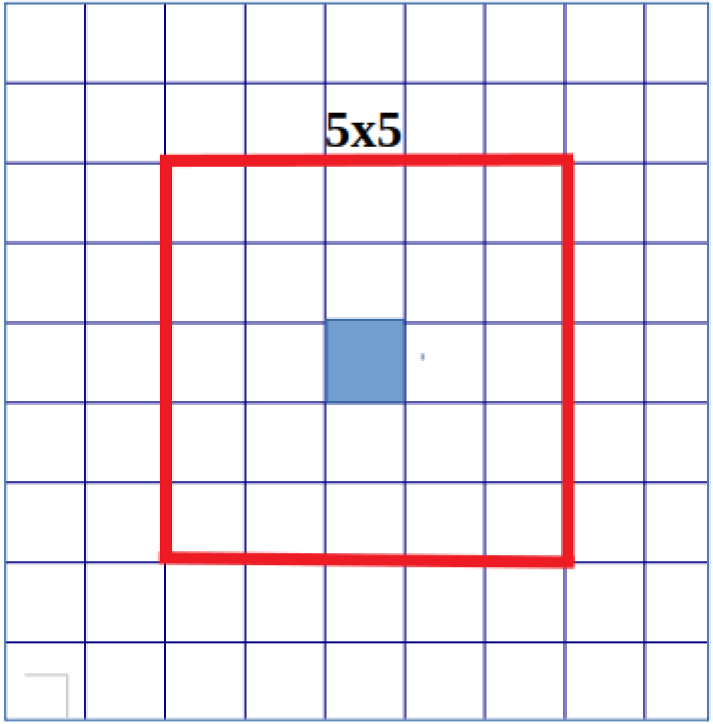
Clustering Scheme

Steps:

- **For each block:**

|time[i]|<5*rmstime[i]

- **Search for the seed block**
- **Apply the 5x5 clustering**
- **Calculate the cluster energy and the impact position:**



$$E_i = C_i A_i \quad / \quad \vec{x} = \frac{\sum_i w_i \, \vec{x}_i}{\sum_i w_i} \quad / \quad w_i = \max\left\{0, \left[W_0 + \ln\left(\frac{E_i}{E}\right)\right]\right\}$$

$$W_0 = \ln\left(\frac{100\, E(\mathrm{GeV})}{2.02\, e^{-\frac{d}{r_M}} + \left[4.98\, e^{-\frac{d}{r_M}} + 0.30\right] E(\mathrm{GeV})}\right)$$

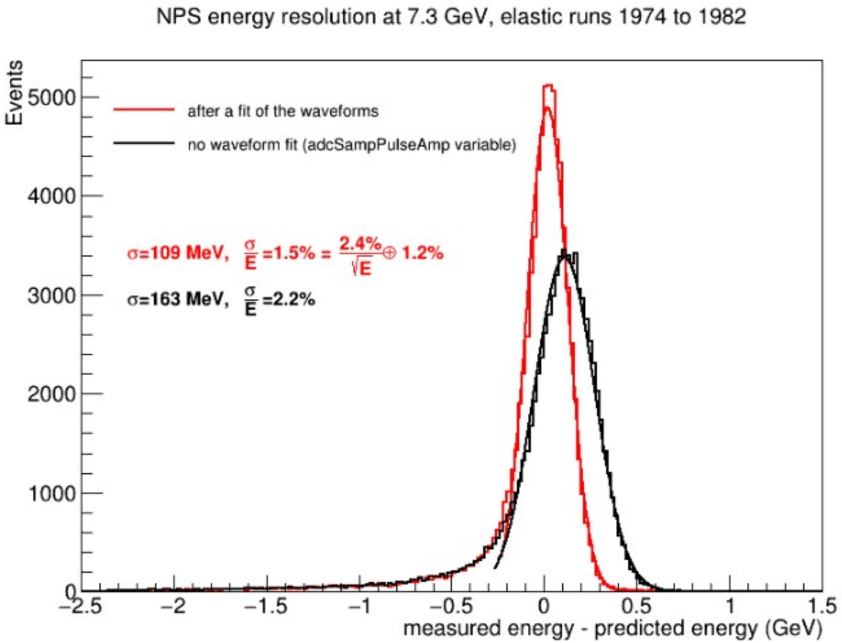
- **Calculate 4-vector using the shower depth (a) correction (G4 simulation)**

$$\longrightarrow a(cm) = \frac{0.00507955}{0.999238 - e^{(}0.0010705 \times \mathrm{E}(GeV))} + 9.31622$$

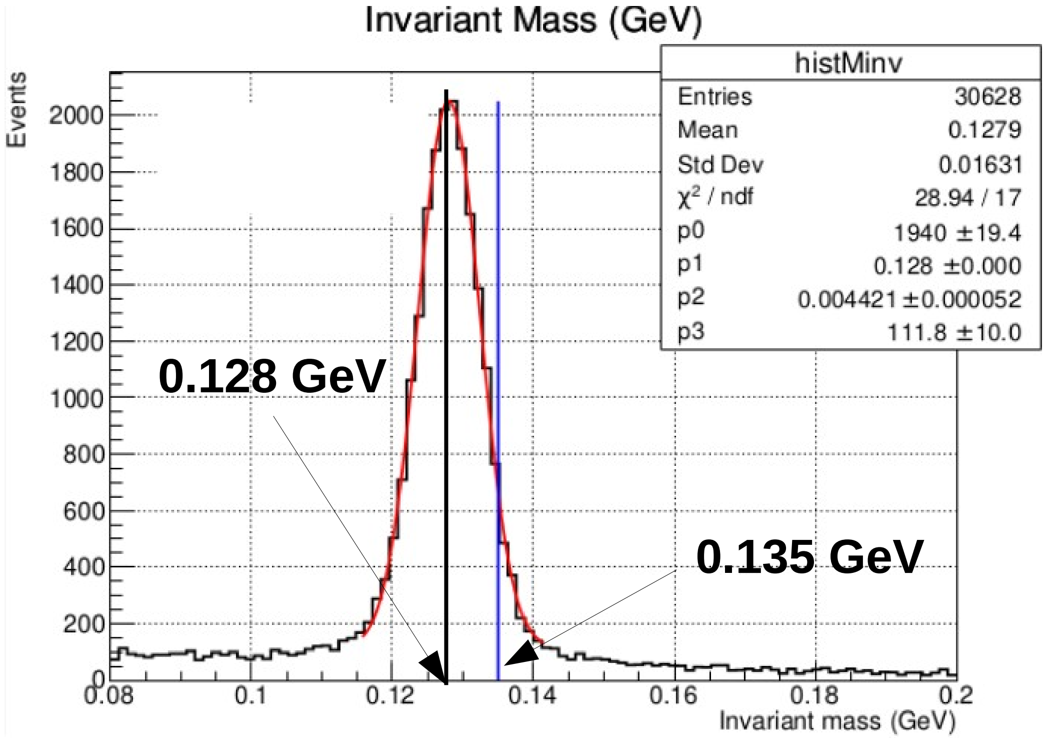
- **0.5 GeV as a cluster threshold**

Mazouz, M., L. Ghedira, and E. Voutier. "Determination of shower central position in laterally segmented lead-fluoride electromagnetic calorimeters." Journal of Instrumentation 11.07 (2016)

Energy Resolution



- **33% improvement** **in energy resolution at 7.3 GeV from elastic H(e,e'p) calibration runs after applying the waveform analysis**

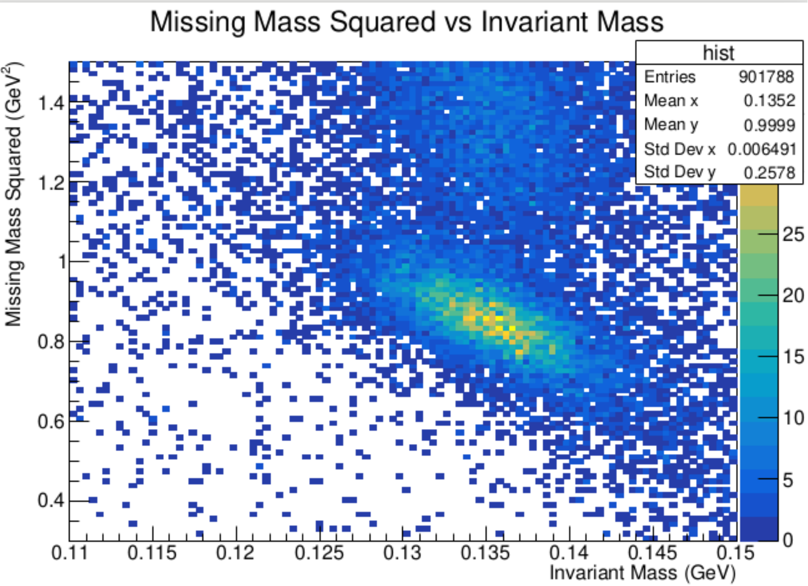


Not sufficient → **Calibration using π0 is needed**

π0 energy calibration

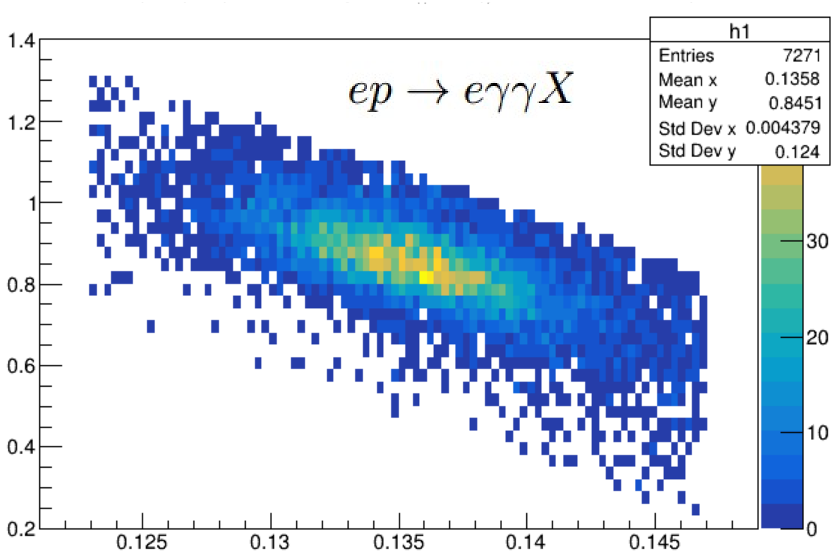
Method:

- With exclusive π0 events, the expected energy of the π0 can be calculated using its scattering angle. A minimization between the measured energy and the expected π0 energy allows to calibrate the NPS channels
- We usually do 3 to 4 iterations before converging to the most suitable calibration coefficients



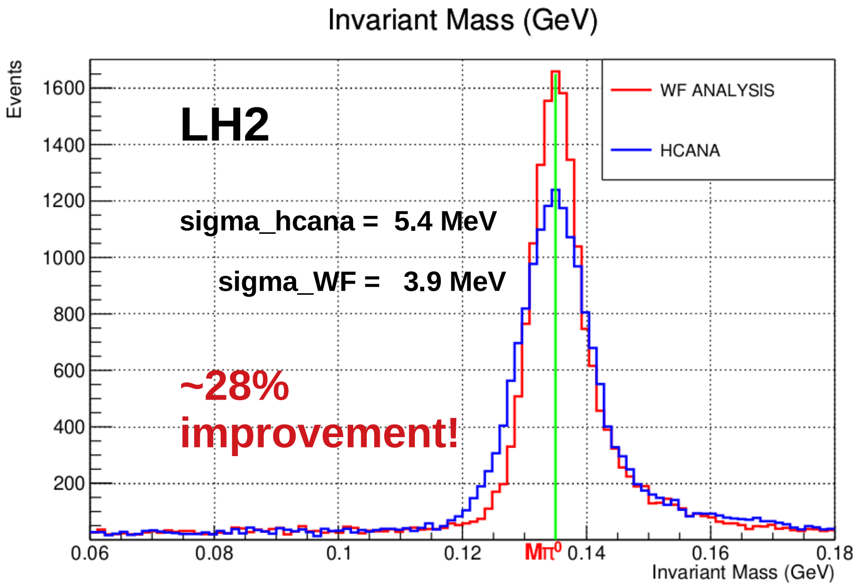
Exclusive events selection

2D cut



e p → e π0 p results

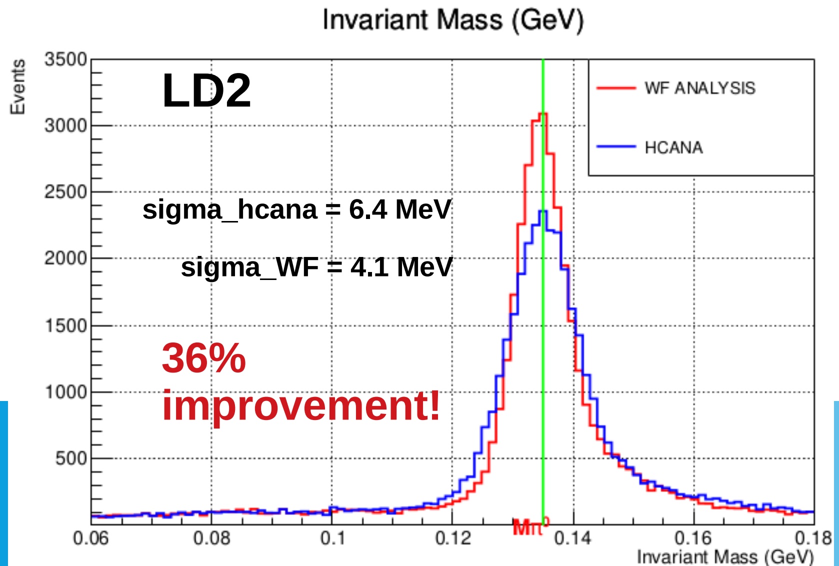
- **Kinematics: KinC_x60_3**
- **6 Runs for LH2: 2011, 2013, 2014, 2015, 2016 and 2017**
- **4 Runs for LD2: 1990, 1991, 1992 and 1993**
- **Only the basic HMS cuts :**
  |dp|<8% & |ph|<0.04 & |th|<0.08 & |react.z|<4



sigma_hcana = 5.4 MeV

sigma_WF = 3.9 MeV

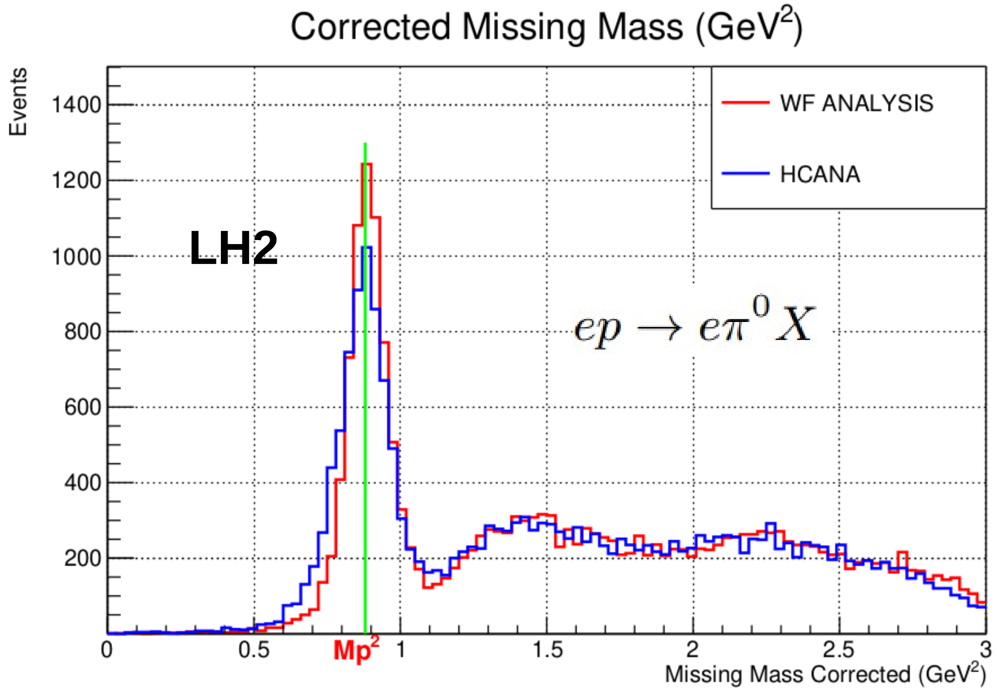
~28% improvement!



sigma_hcana = 6.4 MeV

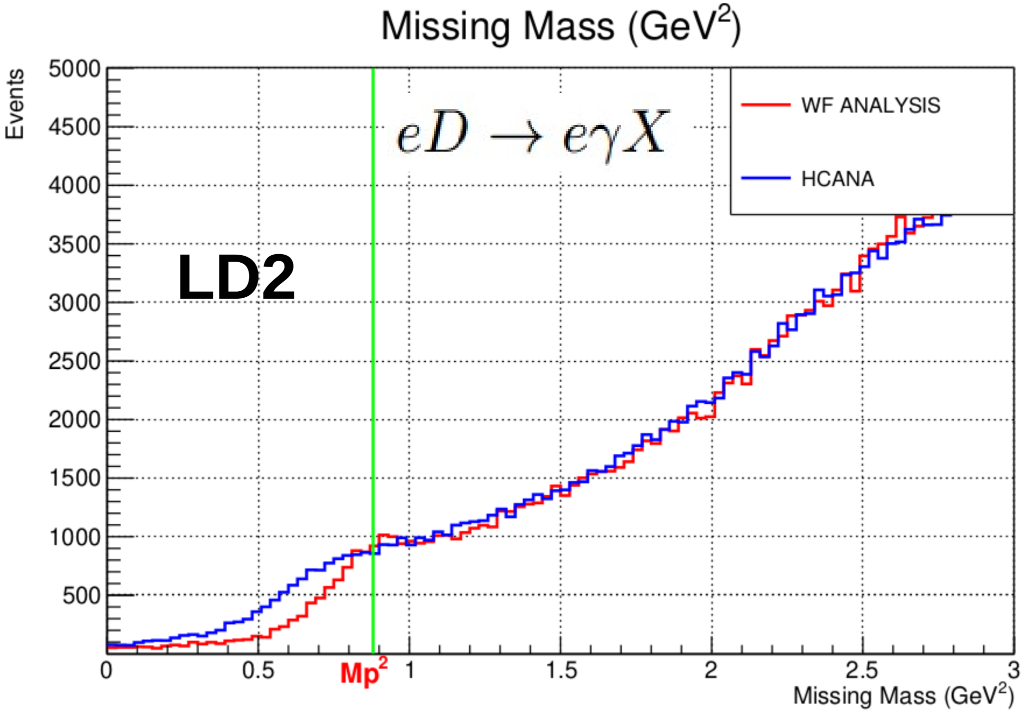
sigma_WF = 4.1 MeV

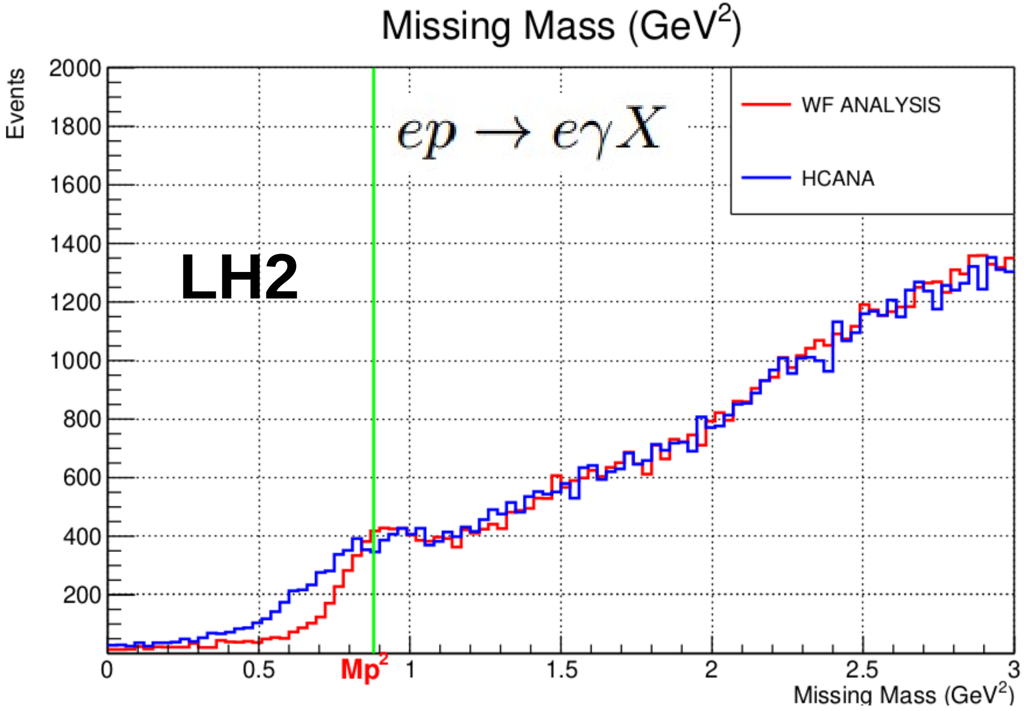
36% improvement!



- **Used the following relationship for the corrected missing mass: mm2+a*minv-b**

DVCS Missing Mass Plots





A noticeable improvement

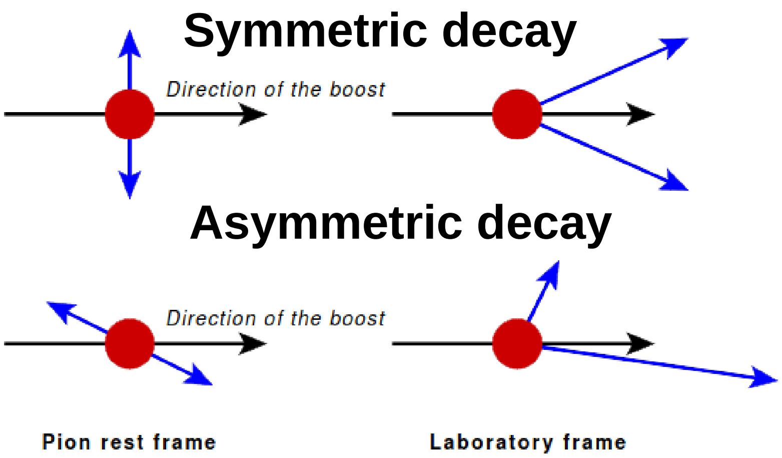
DVCS Analysis

(Pi0 Contamination)

Method:

- 3 Main criteria for the π0 events selected from data:

- No edge block clusters
- Energy of the photons is above the trigger threshold
- A correct invariant mass



- Simulate the decays of each detected π0 by randomizing the photon angles 5000 times in the c.m. frame:

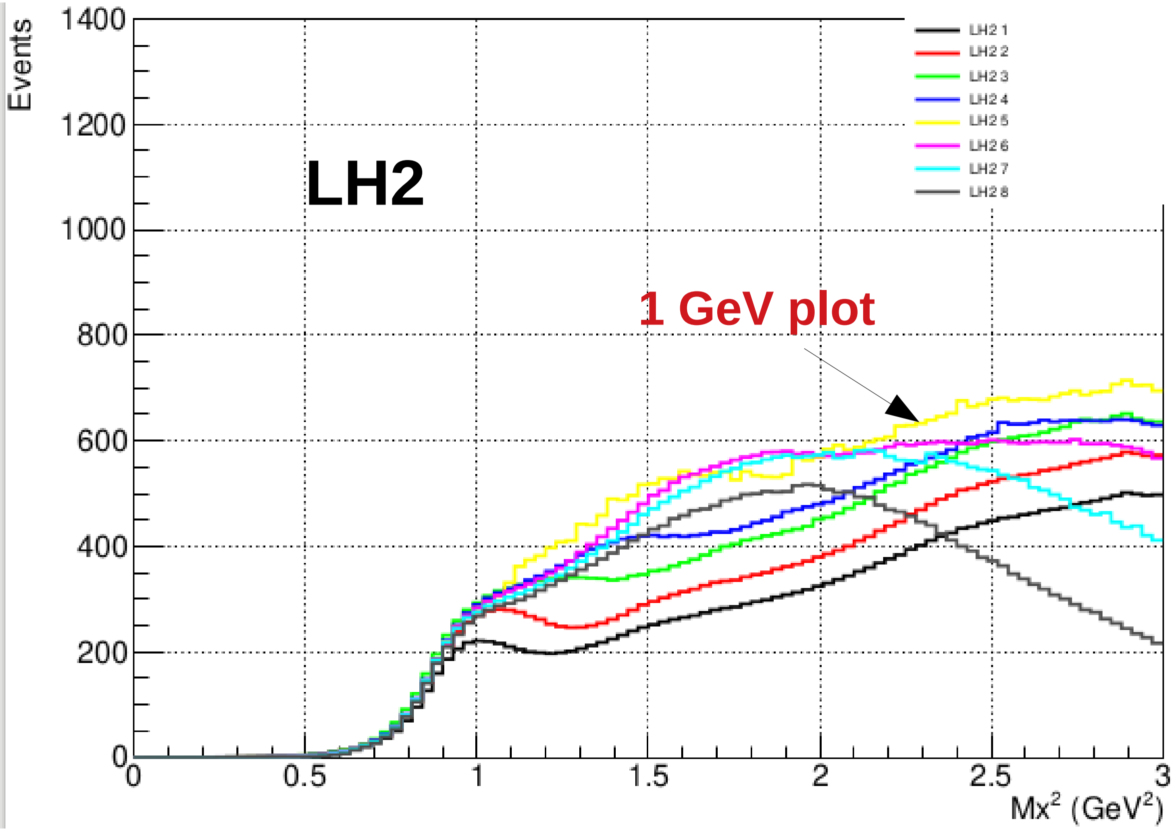
cos θ [-1, 1]
(θ= decay angle)

Azimuthal angle
[0, 2π]

- Divide the decays by number of photons generated:
  N0= events with no γ detected
  N1= events with 1 γ detected
  N2= events with 2 γ detected
- Each event with N1 is subtracted from the DVCS events and before hand multiplied by 2 factors:
  - a1 = 1/5000 and a2 =5000/N2 → W = a1*a2 = 1/N2

DVCS Analysis
(π0 Contamination)

Threshold Scan



- **Steps of 0.1 GeV for the π0 threshold from 0.6 GeV (black plot) to 1.3 GeV (Grey plot)**

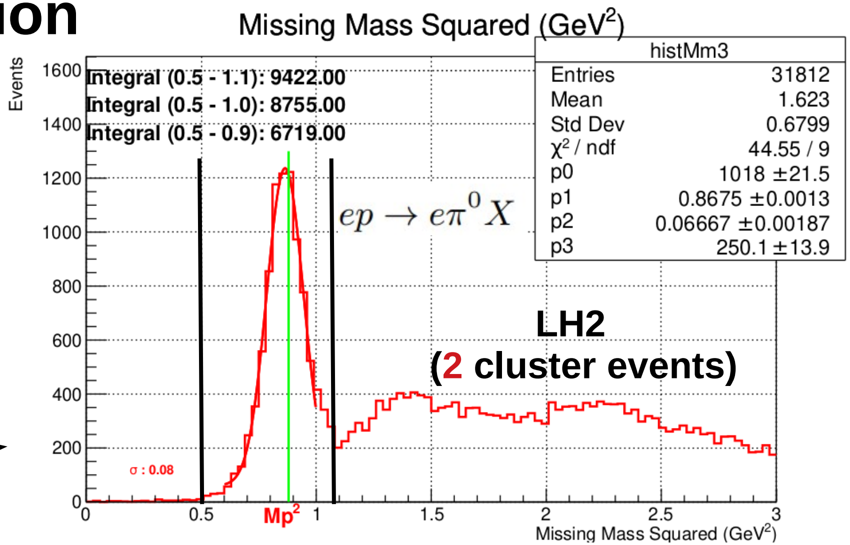
- **Chose the 1 GeV Threshold for both since it’s stable+higher in [0.5, 1.5] GeV2**
- **LH2 trigger threshold: 0.75 GeV**

DVCS Analysis

Multi-cluster correction

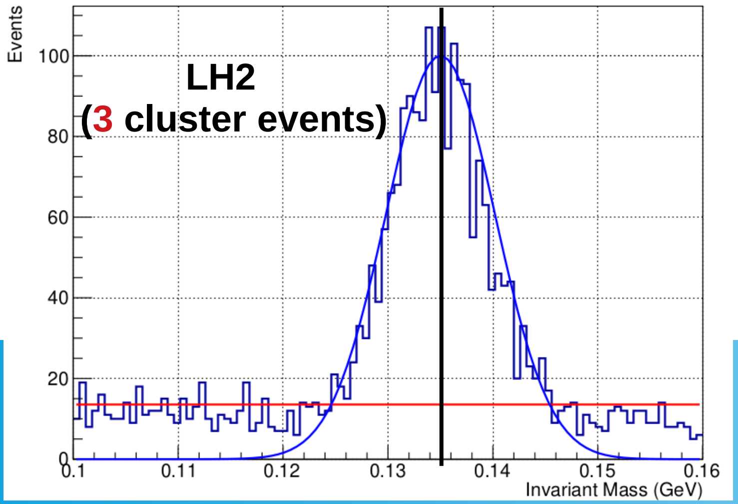
- **Calculated the yield of exclusive π0 events between 0.5 GeV2 and 1.1 GeV2 for the case of 2 cluster events ► 9422**

- **For 3 clusters event ► 598 (6.43%)**
- **For 4 clusters event ► 28 (0.29%)**
- **All the histogram of different contributions are added to the 2 cluster Mx2 raw spectrum** ►

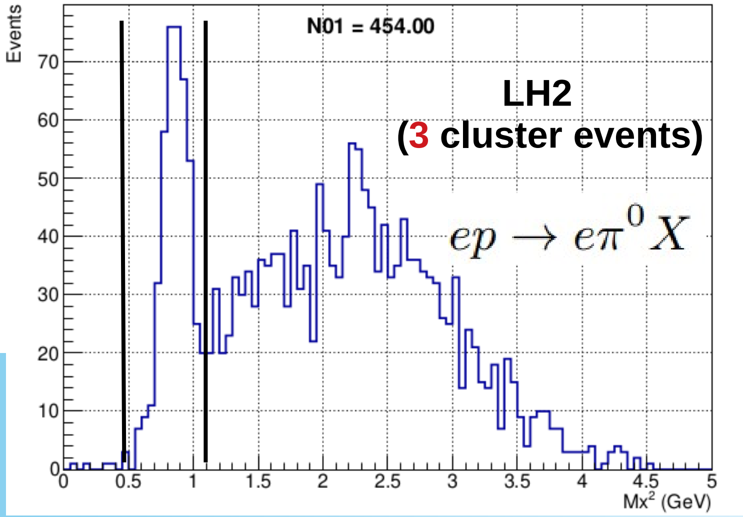


LH2
(2 cluster events)

One of the combinations: photon[0]+photon[1]
(E_photon[0]>E_photon[1]>E_photon[2])



LH2
(3 cluster events)



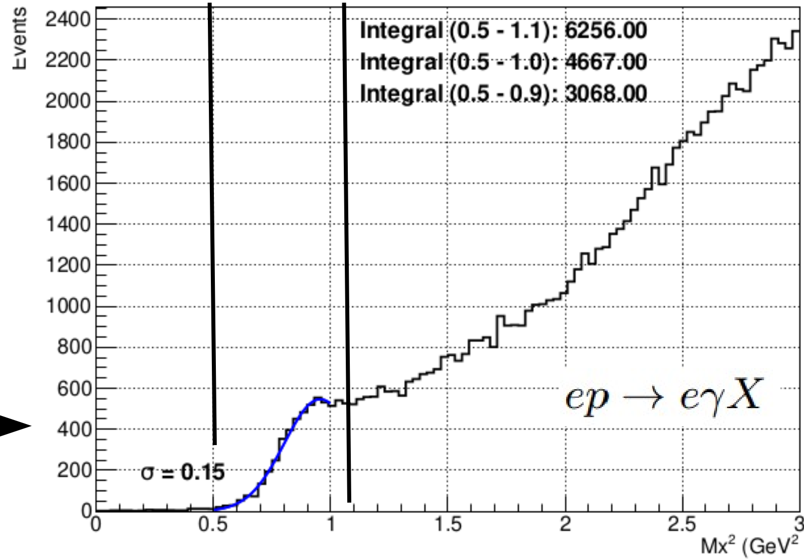
LH2
(3 cluster events)

DVCS Analysis

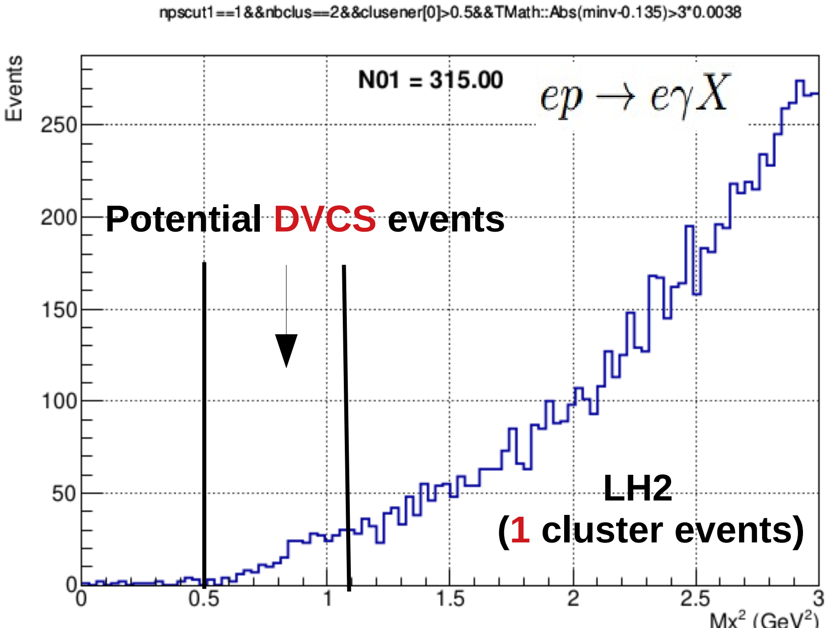
(DVCS Yield Study)

- **Calculated the yield of DVCS events between 0.5 GeV2 and 1.1 GeV2 for the case of 1 cluster events → 6256**

- **For 2 clusters events → 315 (5.03%)**
- **For 3 clusters events → 17 (0.27%)**
- **All the histogram of different contributions are added to the 1 cluster Mx2 raw spectrum →**



One Case:



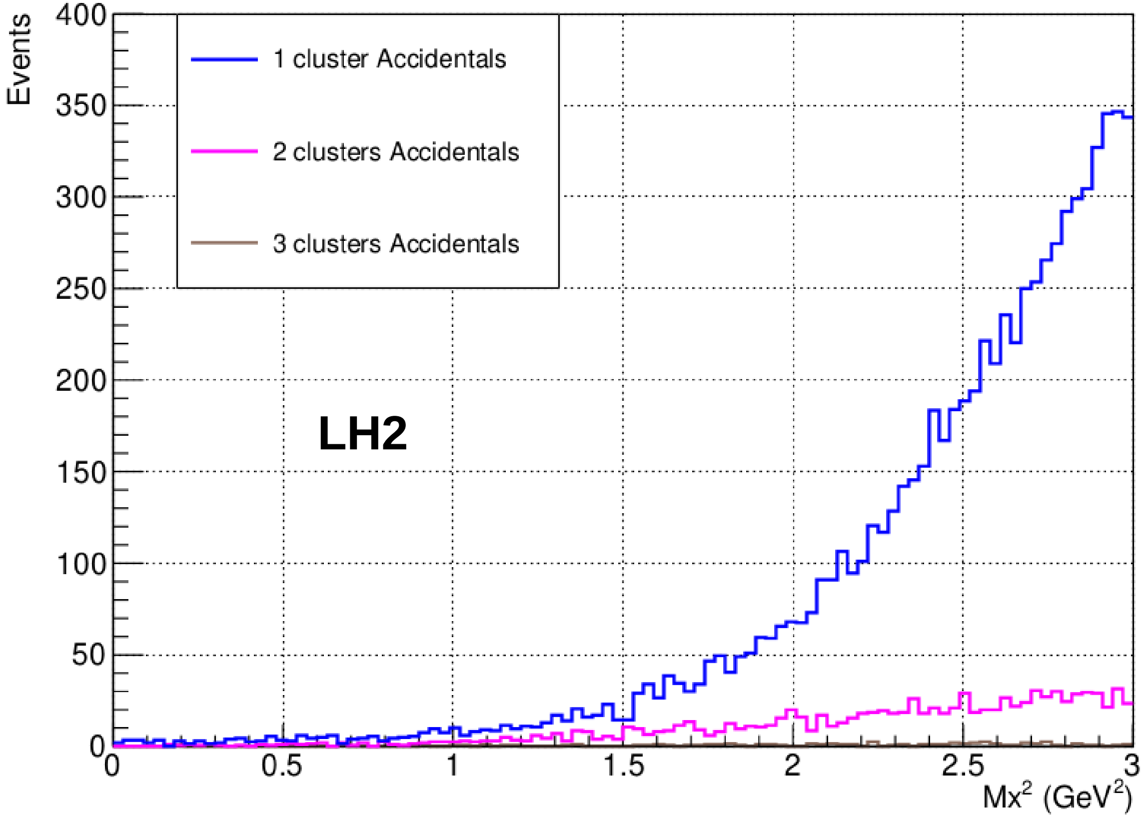
Potential DVCS events

LH2
(1 cluster events)

- **Each cluster in a multi-cluster event is systematically considered as a potential DVCS event if it does not originate from a π0 decay (the invariant mass of that photon when combined with another photon is different from the mass of π0)**

DVCS Analysis

(DVCS Accidentals)



- **Window: +/- 10 ns from the coincidence pulse time**

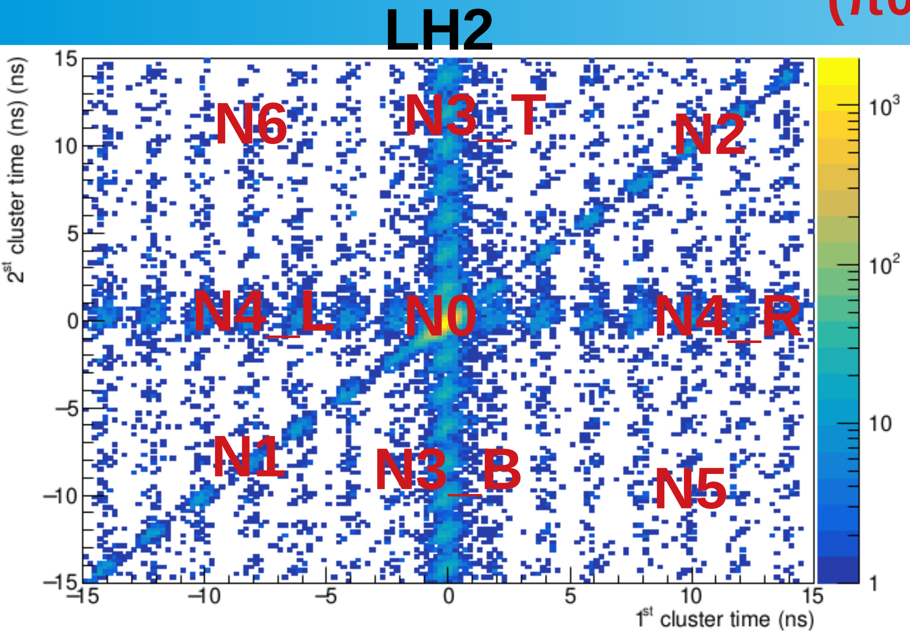
- **For each block:**
  |time[i]-10|<5*rmstime[i]
  |time[i]+10|<5*rmstime[i]

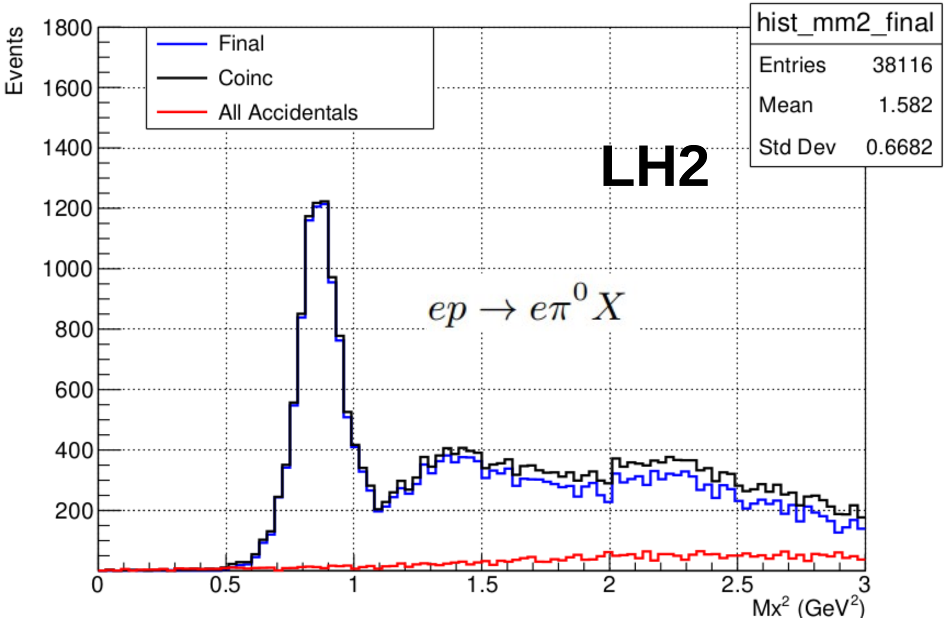
- **The accidentals are obtained with the same method used for the coincidence events :**

  - If cluster number 0 in 2-cluster events contributes to the coincidence Mx2 spectrum then its contribution is also determined and added to the total accidental Mx2 spectrum

DVCS Analysis

(π0 Accidentals)



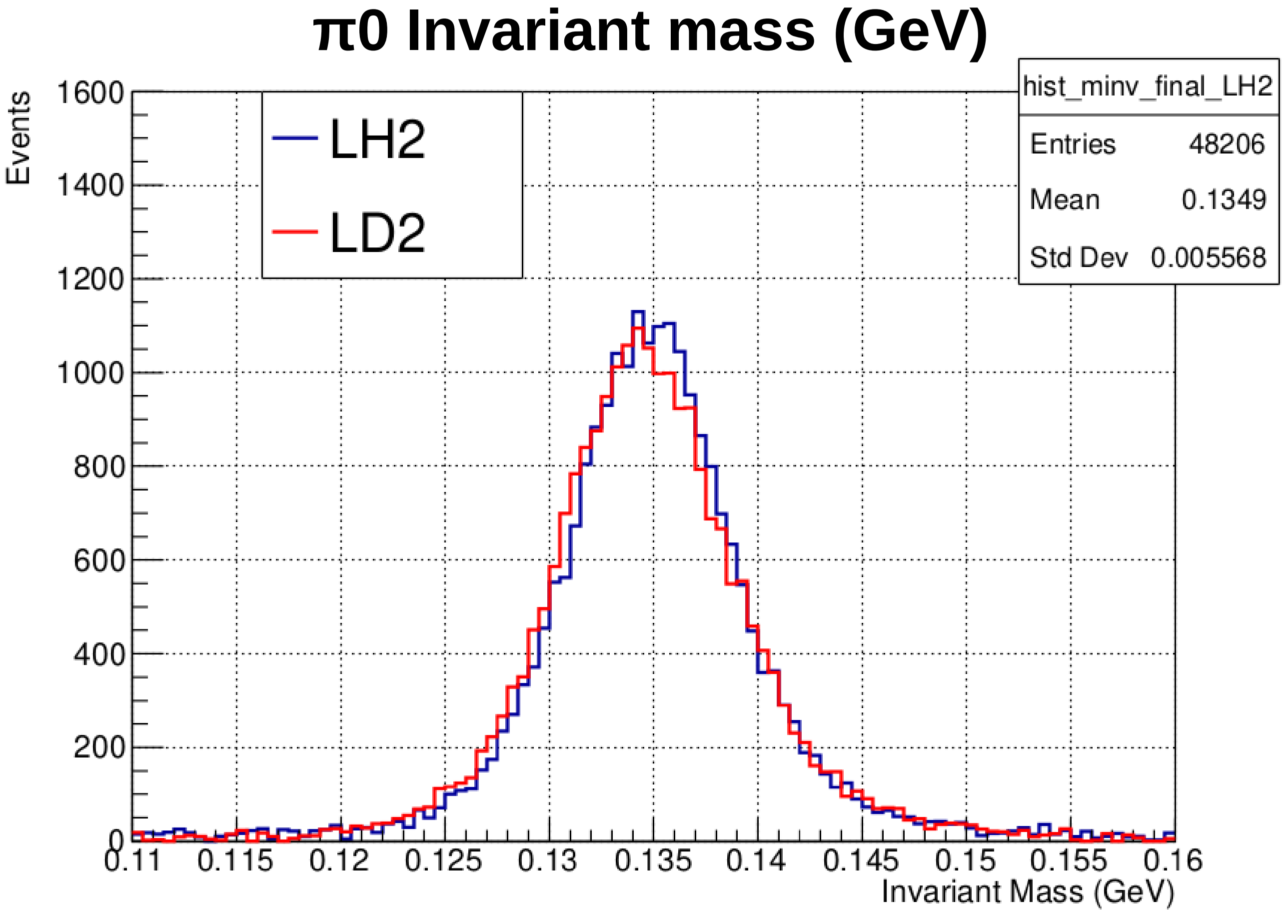


- **N0: 2 photons are in coincidence with each other and with the scattered electron**
- **N1 + N2: 2 photons are in coincidence with each other but not in coincidence with the scattered electron**
- **N3_T + N3_B + N4_L + N4_R: both photons are not in coincidence with each other and only one of them is in coincidence with the scattered electron**
- **N5 + N6: both photons are neither in coincidence with each other nor with the scattered electron**

- **3 time frames:**
  - **|time[i]|<5*rmstime[i]**
  - **|time[i]-10<5*rmstime[i]**
  - **|time[i]+10<5*rmstime[i]**

All Accidentals = 0.5 * (N1+N2+N3_B+N4_L+N3_T+N4_R) - (N5+N6)

DVCS Analysis
(π0 Resolution Check)



- **Small differences between the 2 resolutions of the π0 invariant mass**

- **Will be multiplying the cluster energy of LD2 in order to bring it up to the same resolution by the following ratio: mean_LH2/mean_LD2**

Fermi Smearing

LH2 not smeared → $$\boxed{M_x^2 = (P_p')^2 = (q+P-q')^2}$$ **How to smear it?**

- **For the DVCS off the deuteron reaction:**

$$\gamma^* + {}^2_1D \to \gamma + n' + p' \qquad P_d = (M_d, \mathbf{0})$$

Deuteron mass

Nucleon mass

$$\boxed{q + P_d = q' + P_n' + P_p'}$$

With $$= \left(\sqrt{M^2+\mathbf{P}_f^2}, \mathbf{P}_f\right) + \left(\sqrt{M^2+\mathbf{P}_f^2}, -\mathbf{P}_f\right) + \left(M_d - 2\sqrt{M_d^2+\mathbf{P}_f^2}, \mathbf{0}\right)$$

- **We can rewrite the previous equation as follows:**

$$\boxed{q + P_n + P_p + P_{add} = q' + P_n' + P_p'}$$

With $$P_{add} = \left(M_d - 2\sqrt{M_d^2+\mathbf{P}_f^2}, \mathbf{0}\right)$$

- **The missing mass of the deuteron can be then written as follows:**

$$\boxed{M_x^2 = (P_p' + P - P_p - P_{add})^2}$$

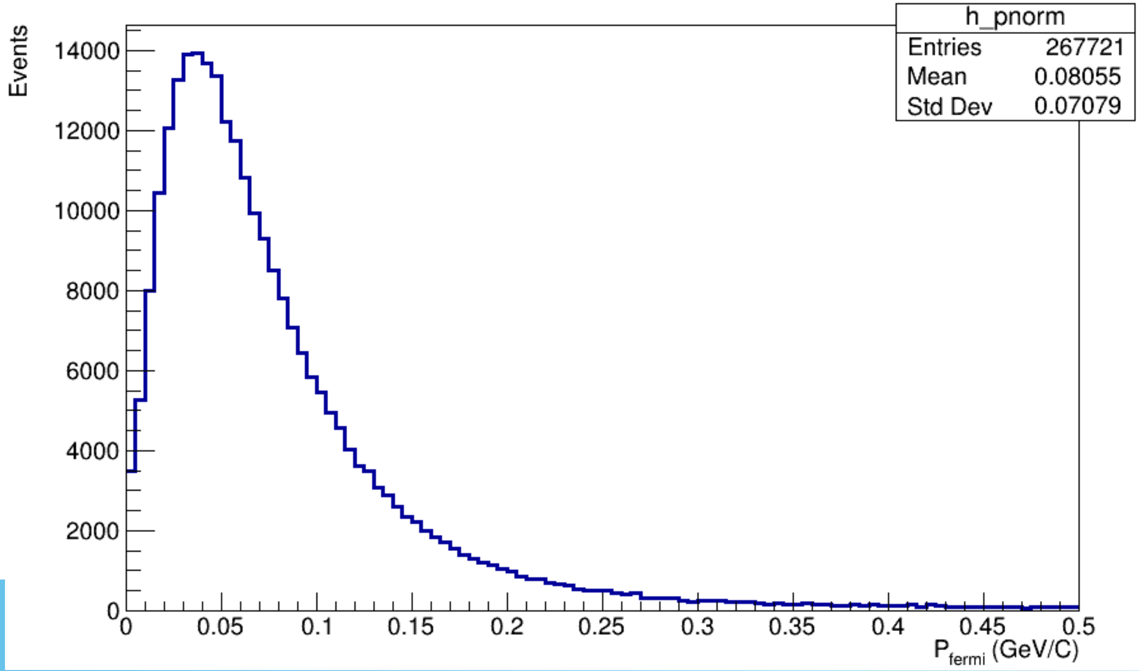
With $P = (M, \mathbf{0})$

- **Then we smear the LH2 data as follows:**

$$M_x^2 = \left(\boxed{q + P - q'} + \boxed{P - P_p - P_{add}}\right)^2$$

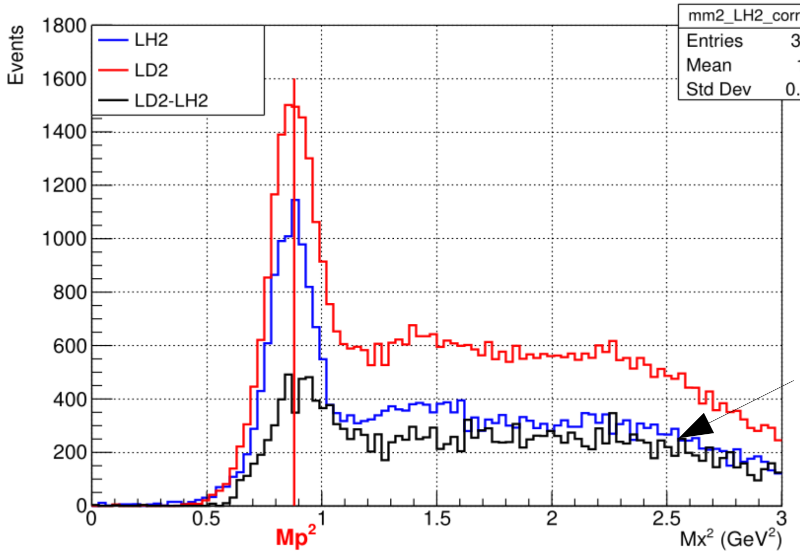
Smearing term

Fermi momentum distribution



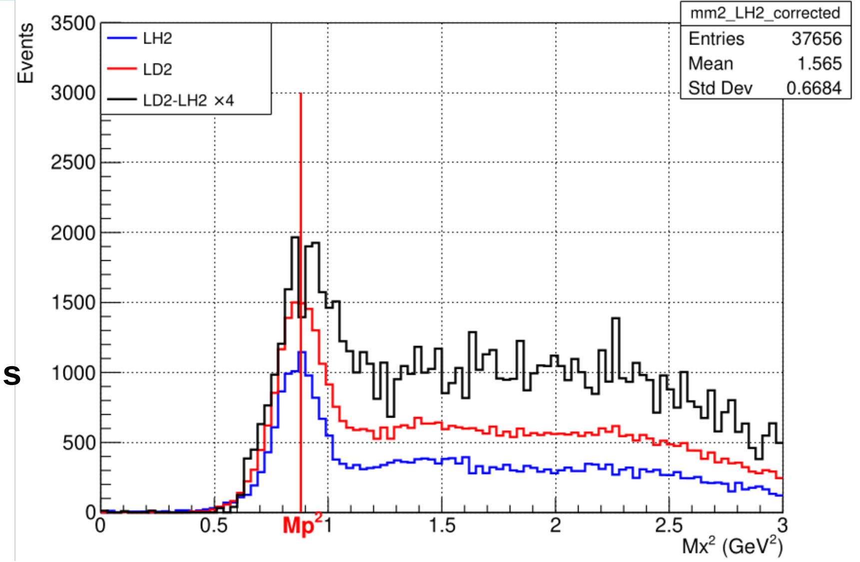
e N → e π0 N analysis

Corrected missing mass without any target correction



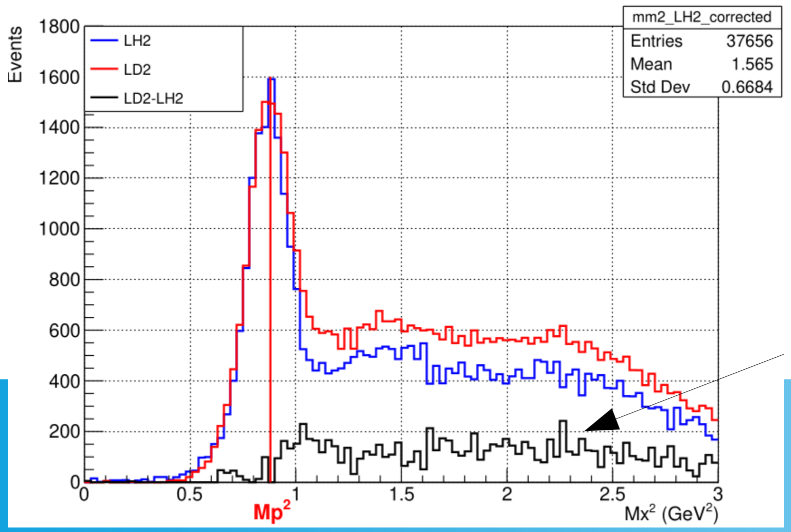
Multiplied the neutron peak by **4**

→



Neutron peak is **below** the proton peak

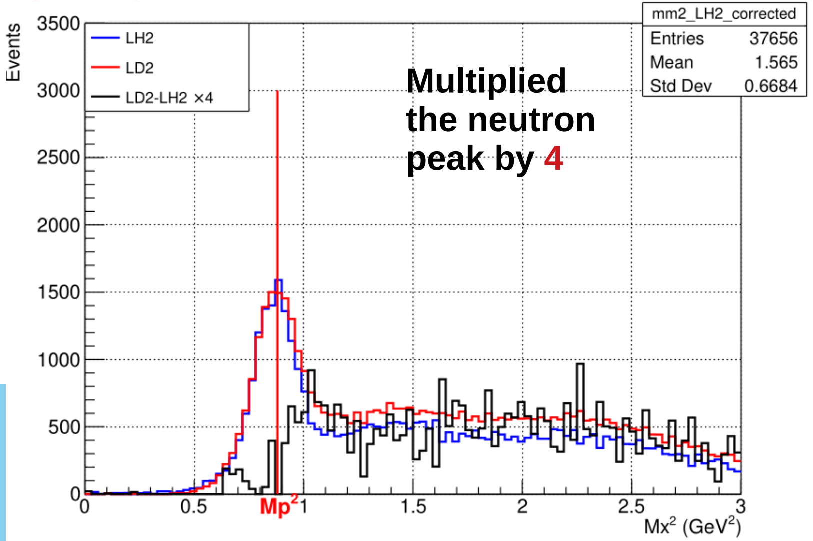
Corrected missing mass with (0.72) correction



Multiplied the neutron peak by **4**

→

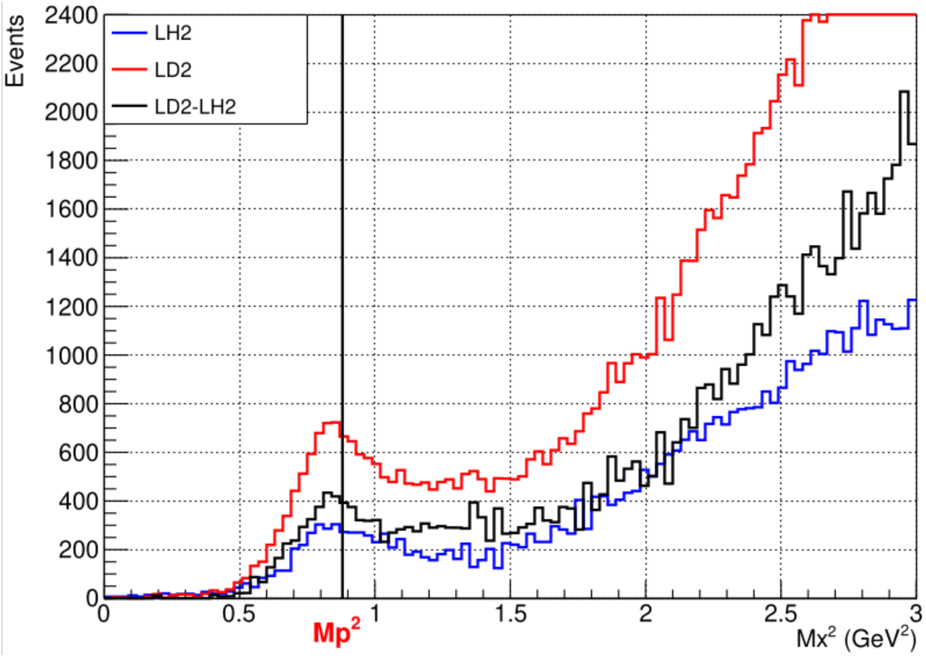
Neutron peak is **Disappeared**!



Multiplied the neutron peak by **4**

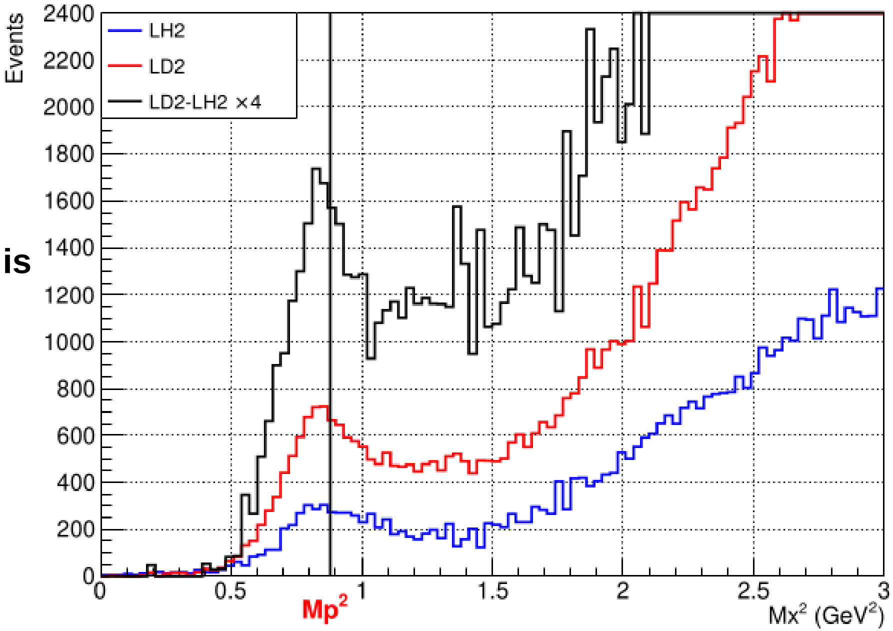
e **N** → e ɣ **N** analysis

DVCS missing mass squared without any correction

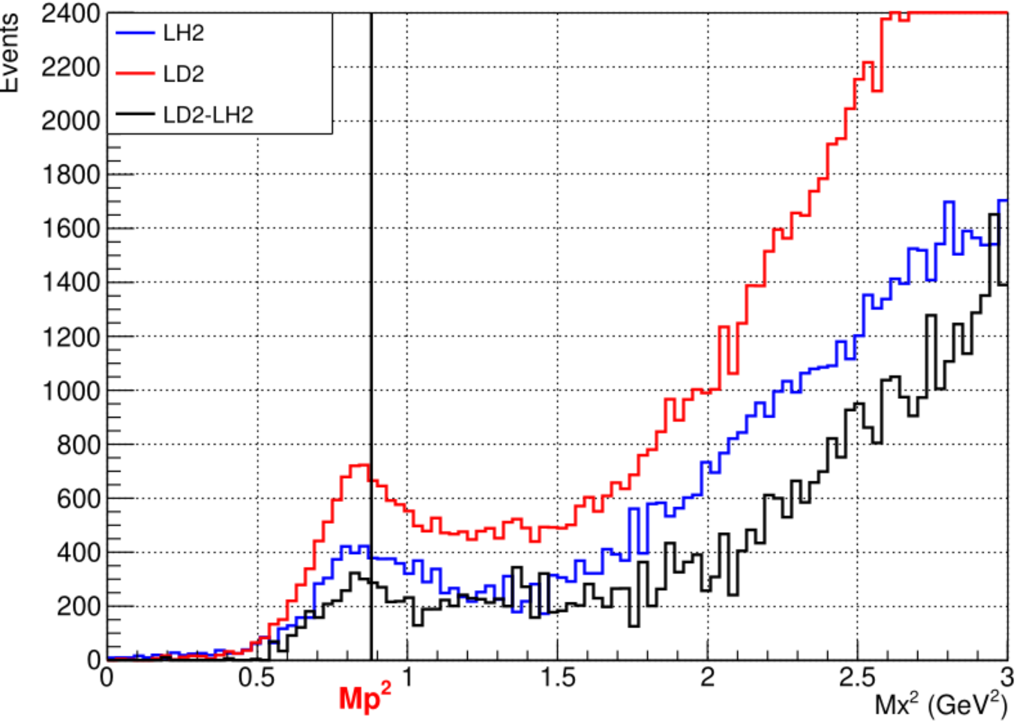


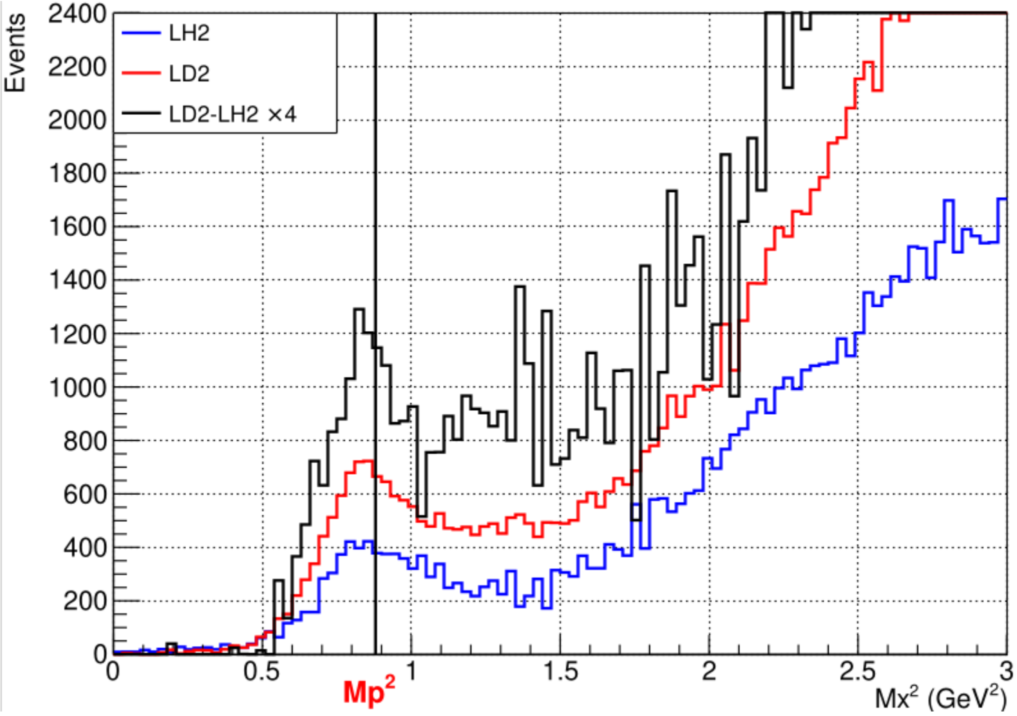
Multiplied the neutron peak by 4

Neutron peak is above the proton peak

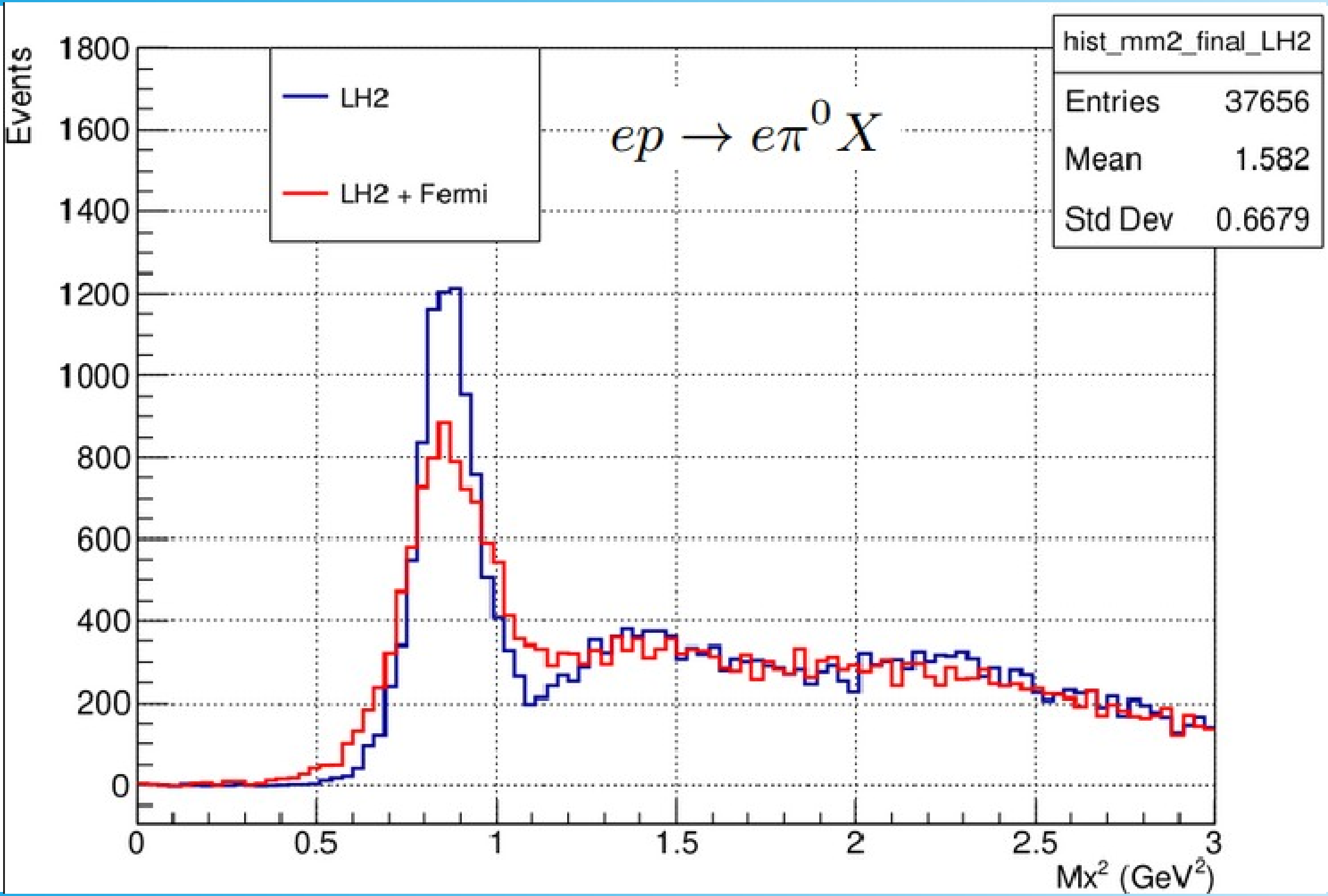


DVCS with (0.72) correction



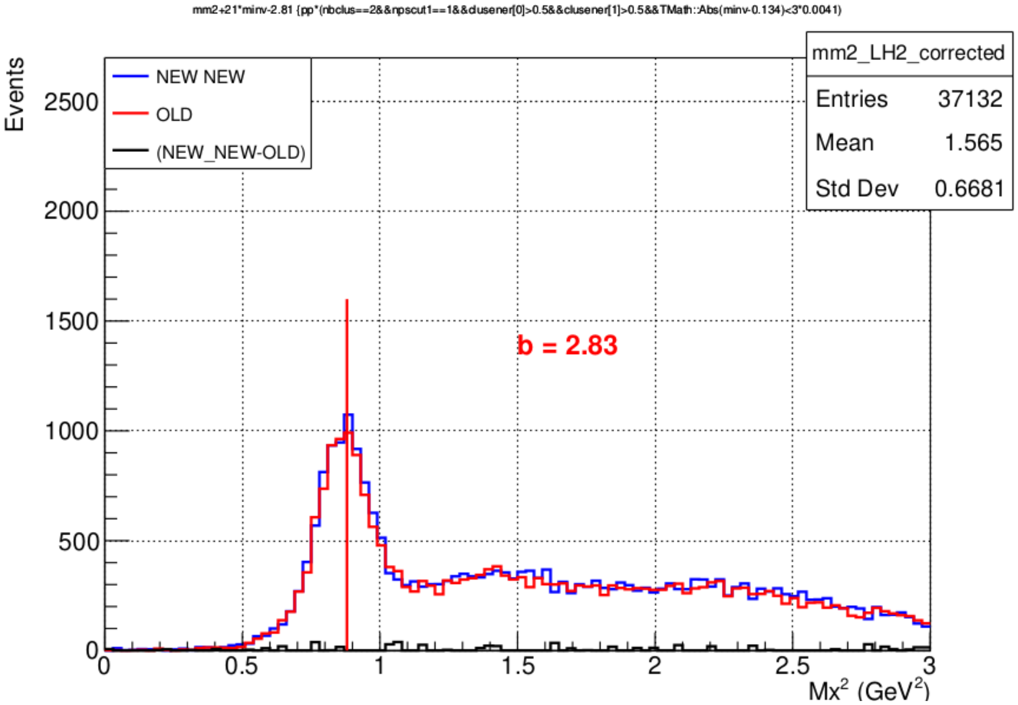


Fermi smearing effect

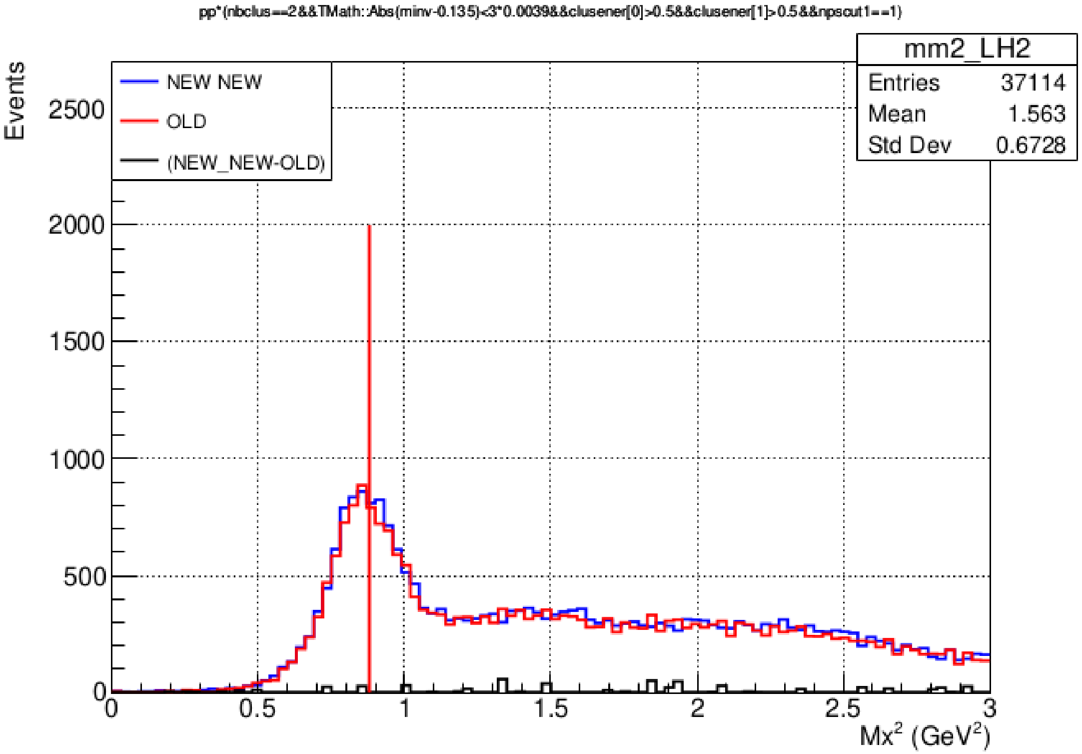


Comparison between old DVCS fermi smearing and the new method used

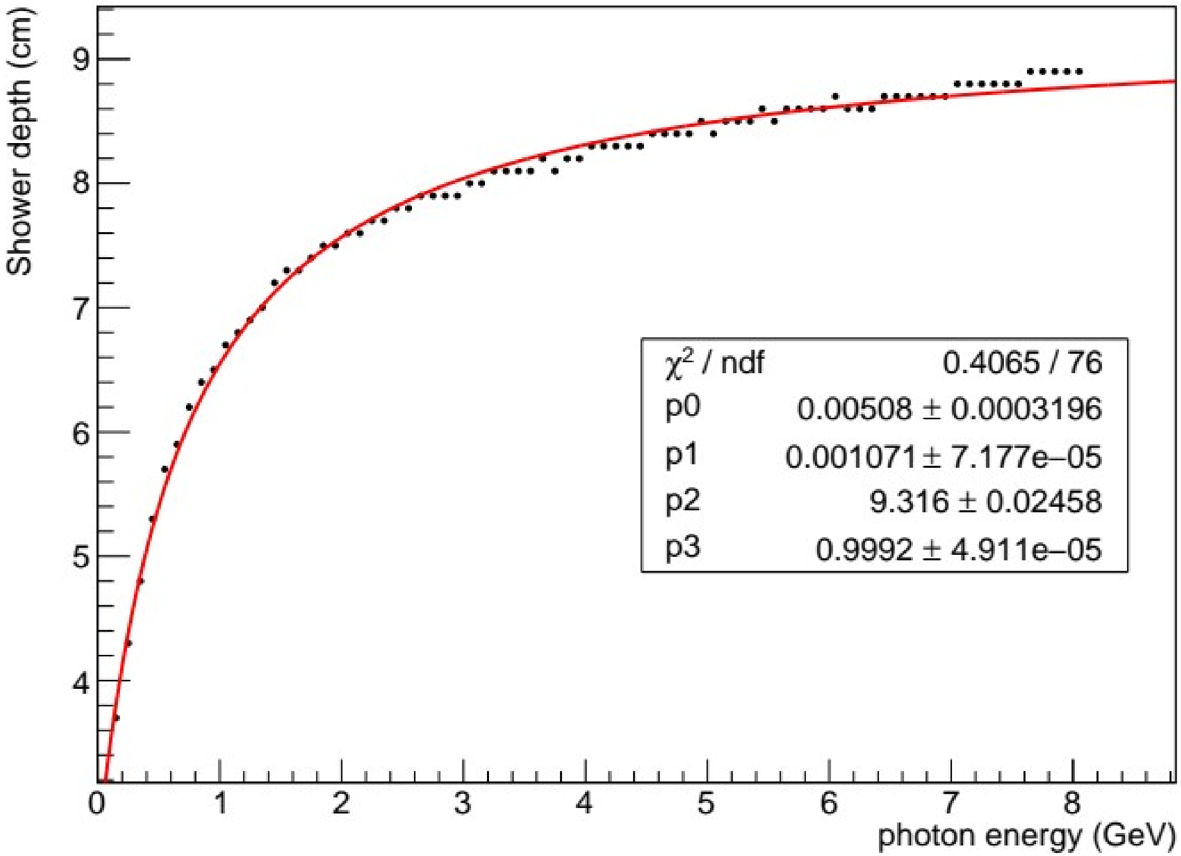
Corrected missing mass squared (GeV2)



Raw missing mass squared (GeV2)

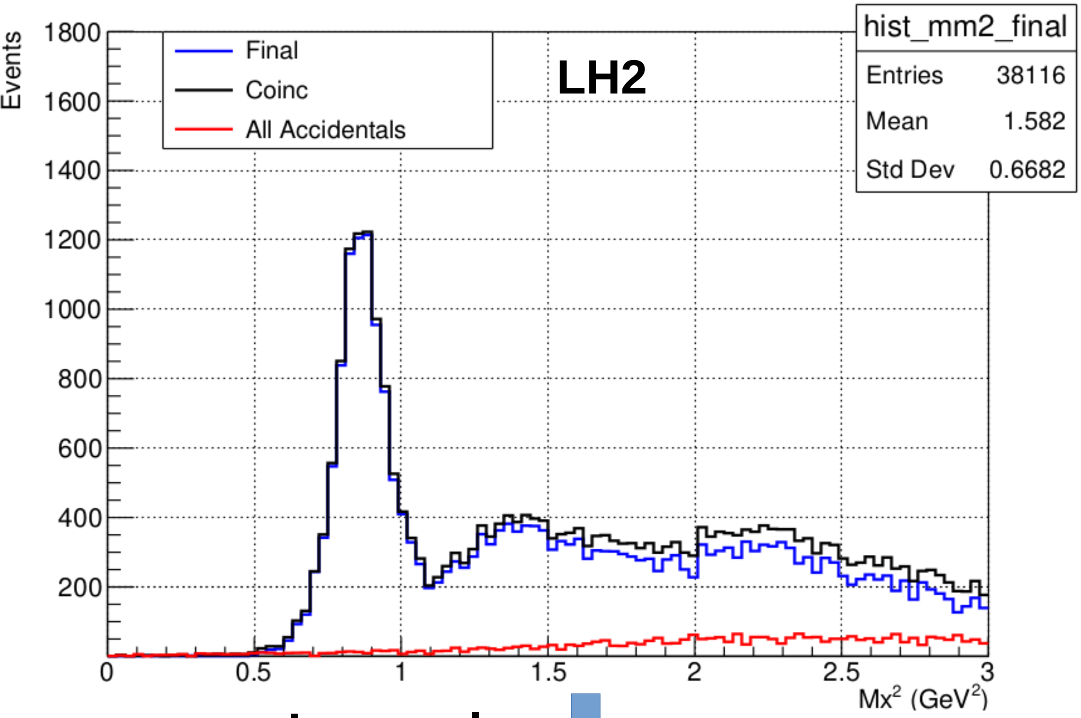


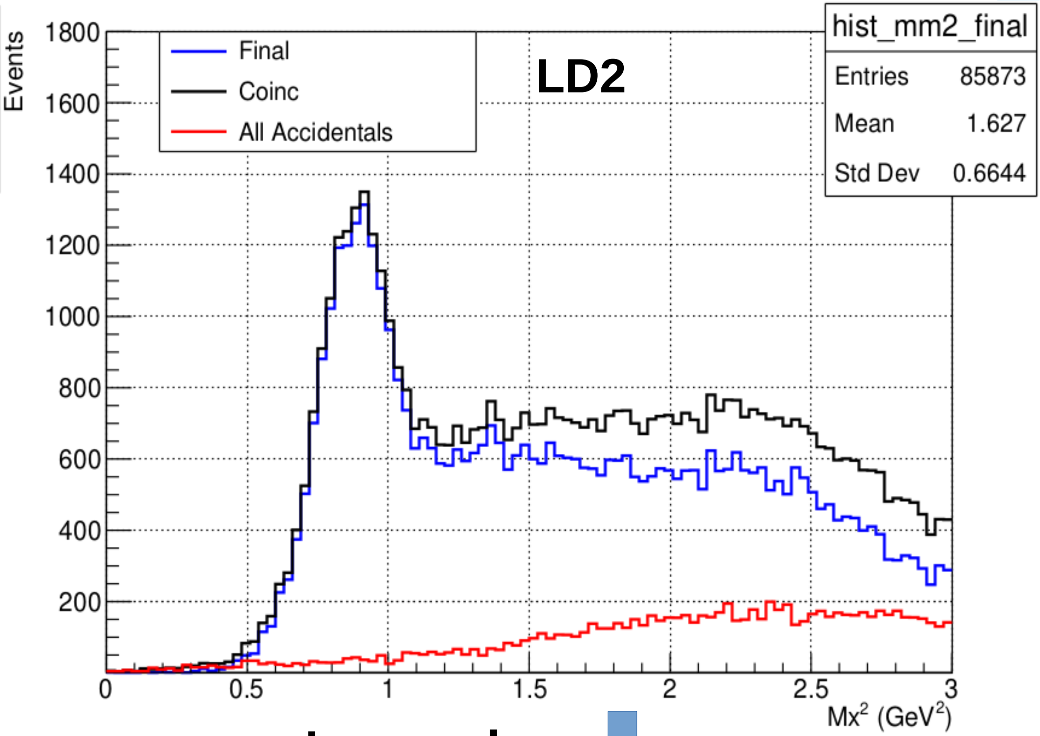
Shower depth correction



- **For each energy value, we determine “a” in such a way that the difference between the position xc (centroid position of the cluster) and x’c obtained by a Geante 4 simulation is centered around 0 and has the lowest RMS .**

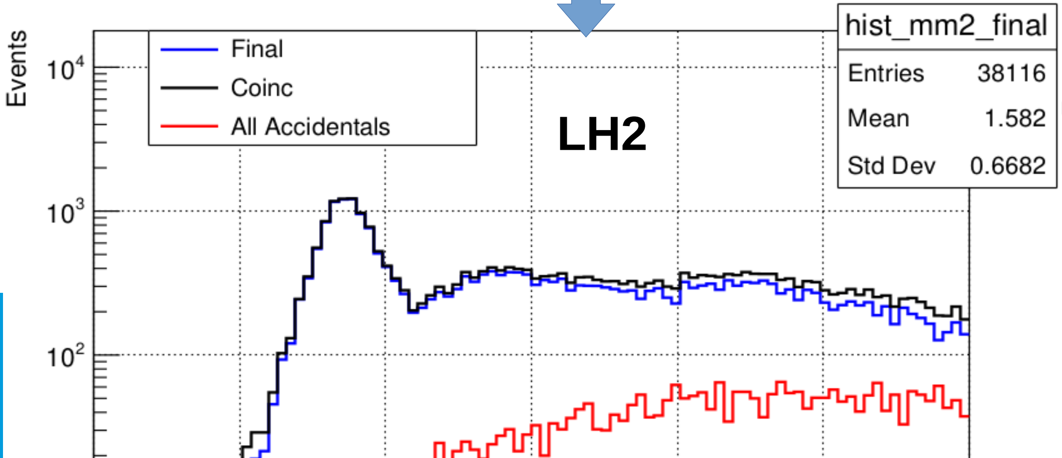
Exclusive Pi0 Missing Mass Squared

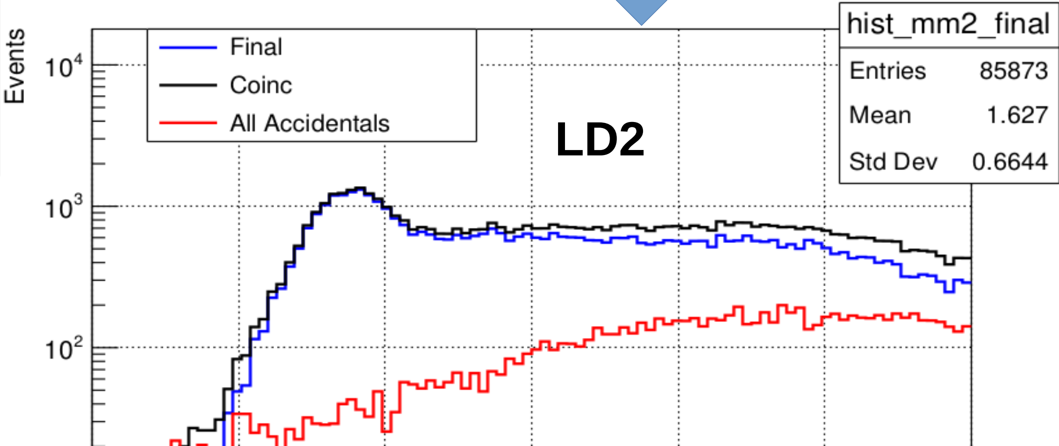




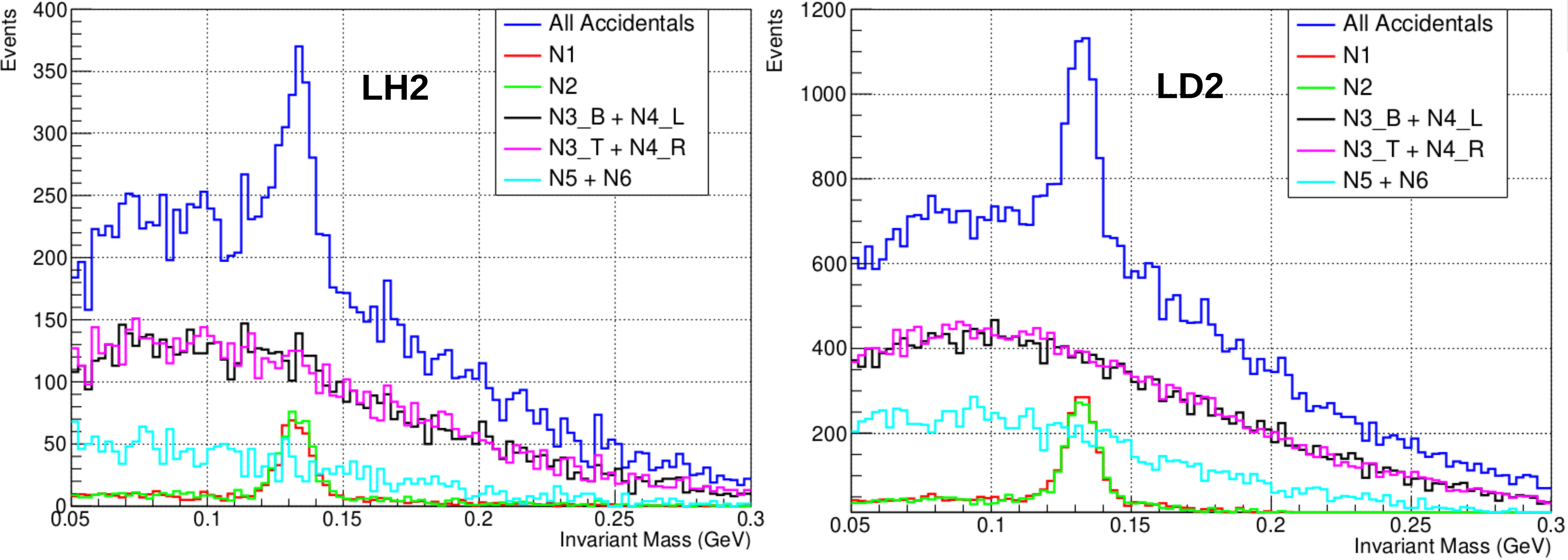
Log scale

Log scale



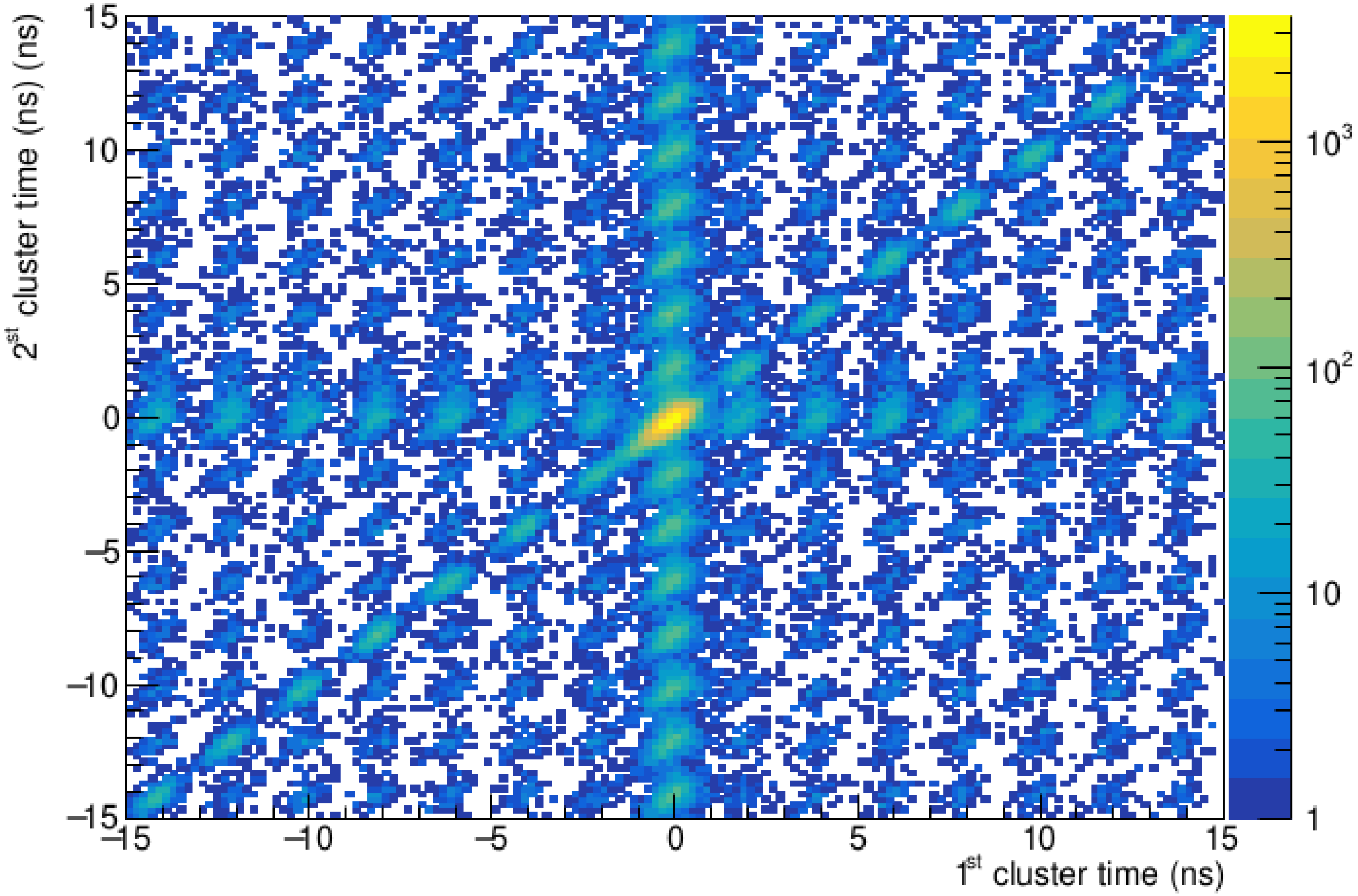


Exclusive Pi0 Invariant Mass

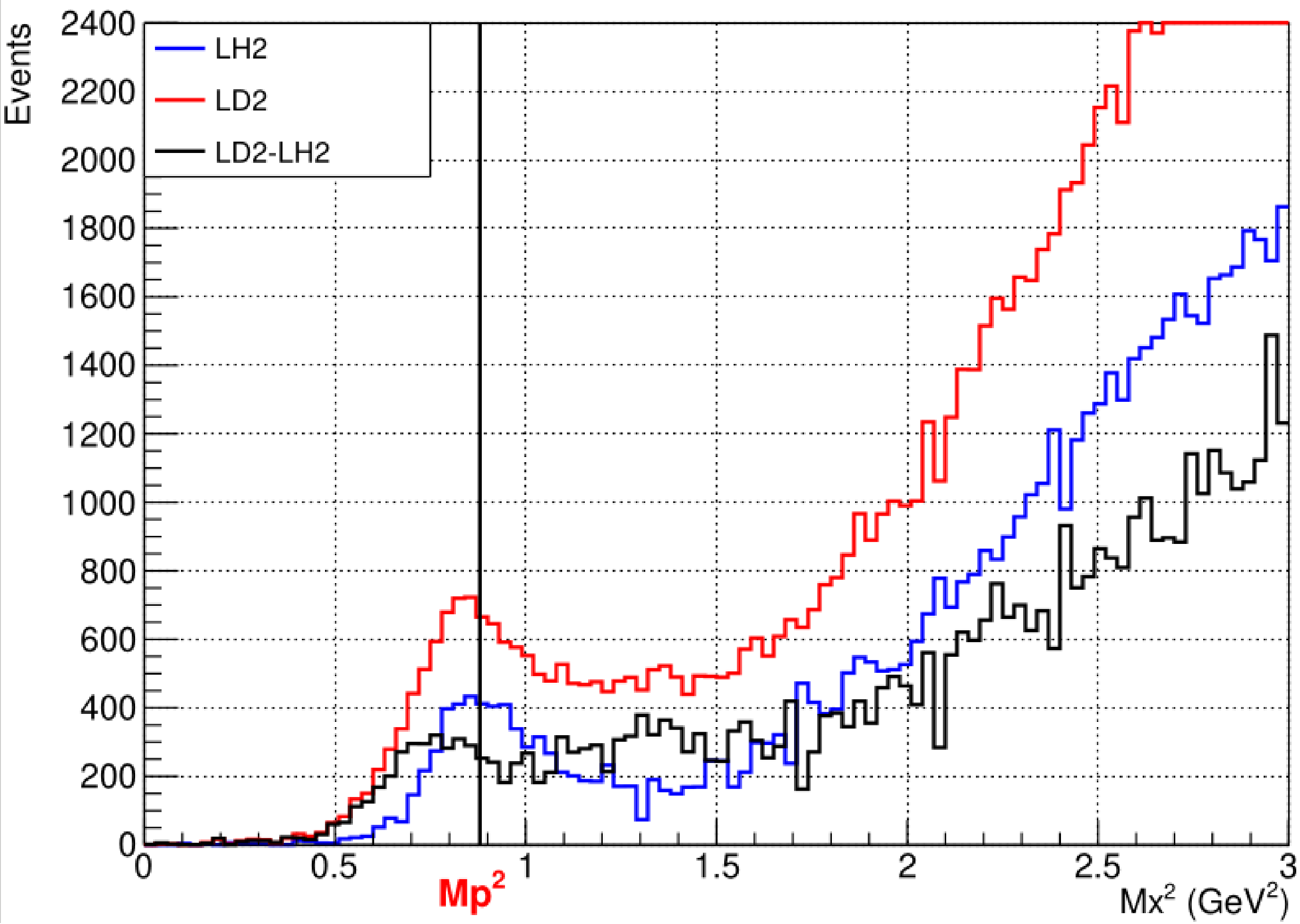


- **Red ==> N1**
- **Green ==> N2**
- **Black ==> N3_B (bottom) + N4_L (left)**
- **Pink ==> N3_T (Top) + N4_R (right)**
- **Sky Blue ==> N5 + N6**

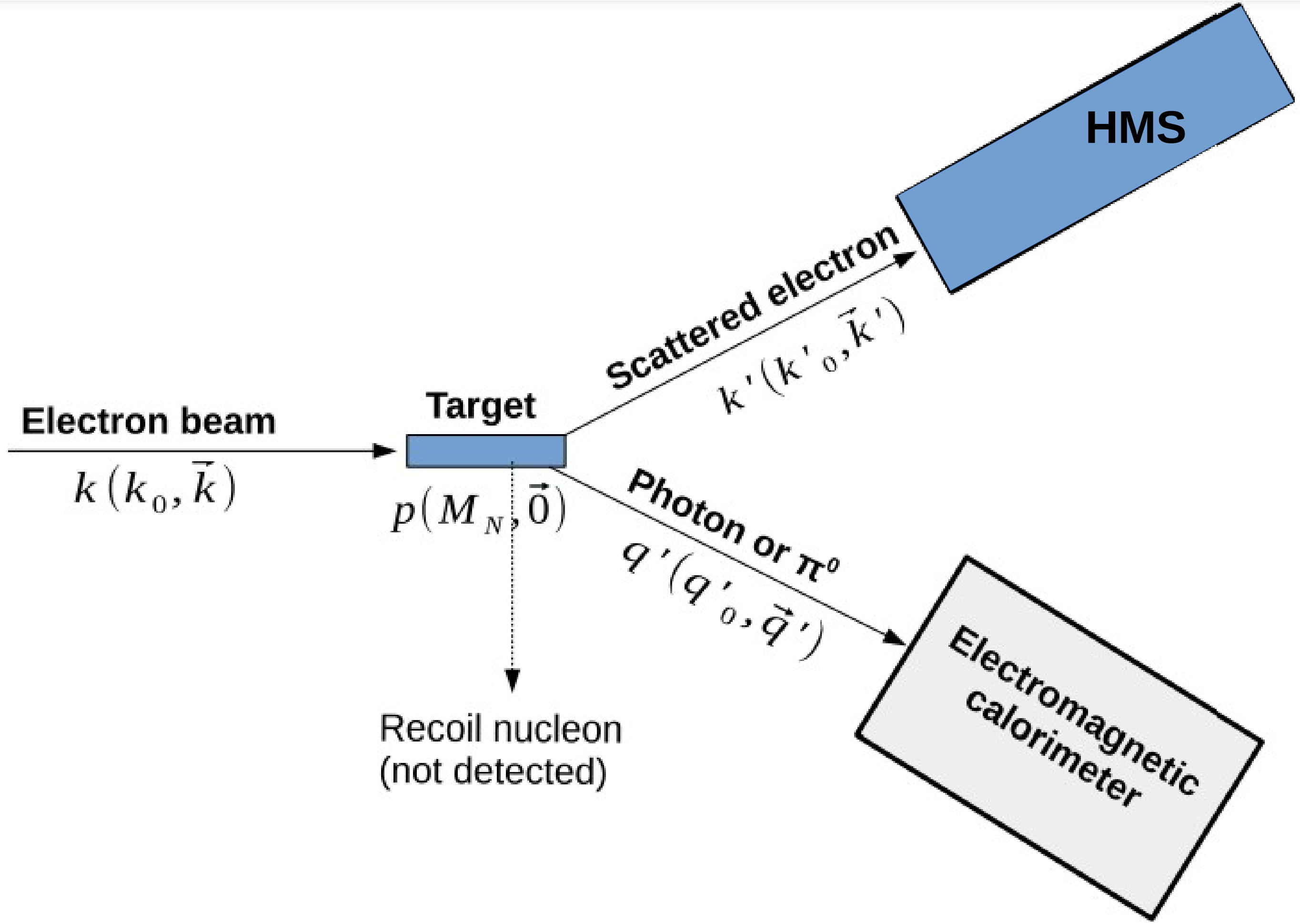
LD2 π0 ACCIDENTALS



DVCS missing mass squared with the factor 0.72 applied



π0 energy calibration



π0 energy calibration

Method:

$$E'_i(j) = C'_i A_i(j)$$ → $$E_i(j) = \epsilon_i C'_i A_i(j) = \epsilon_i E'_i(j)$$ **With** $$C_i = \epsilon_i C'_i$$ → **Corrected calibration coefficient**

Deposited energy

Corrected Energy

Correction factor

1) Identification of $eN \rightarrow eN\pi^0$ reaction:

$$\left|M_{\mathrm{inv}} - M_{\mathrm{peak}}\right| < 3\,\sigma_{M_{\mathrm{inv}}}$$ **+** $$M_x^2 < M_{\mathrm{peak}}^2 + \sigma_{M_x^2}$$ → **2 main cuts applied**

Missing mass squared resolution

With $$M_{\mathrm{inv}} = \sqrt{(q'_1 + q'_2)^2}$$

2) Calculate the expected Pi0 energy:

$$M_N^2 = (k + p - k' - q'_1 - q'_2)^2 = (k + p - k')^2 + M_{\pi^0}^2 - 2(k_0 - k'_0 + M_N)E_{\pi^0}^{\mathrm{cal}} + 2\|\vec{q}\|\sqrt{\left(E_{\pi^0}^{\mathrm{cal}}\right)^2 - M_{\pi^0}^2}\,\cos\theta$$

Solution: $E_{\pi^0}^{\mathrm{cal}} = \dfrac{-b + \sqrt{b^2 - 4ac}}{2a}$ **With**

$$a = 4\left(k_0 - k'_0 + M_N\right)^2 - 4\|\vec{q}\|^2 \cos^2\theta\,,$$

$$b = 4\left(k_0 - k'_0 + M_N\right)\left[M_N^2 - (k - k' + p)^2 - M_{\pi^0}^2\right],$$

$$c = 4M_{\pi^0}^2\|\vec{q}\|^2\cos^2\theta + \left[M_N^2 - (k - k' + p)^2 - M_{\pi^0}^2\right]^2.$$

Mazouz, M. Energy calibration of laterally segmented electromagnetic calorimeters based on neutral pion detection. Nucl. Sci. Tech. 28, 155 (2017)

π0 energy calibration

3) Minimization:

- **The following minimization between the calculated energy and the reconstructed one:**

$$\chi^2 = \sum_{j=1}^{N_{\pi^0}} \left(E_{\pi^0}^{\mathrm{cal}}(j) - E_{\pi^0}^{\mathrm{rec}}(j)\right)^2$$

With $N_{\pi^0} \longrightarrow$ **Number of Pi0 events**

$$E_{\pi^0}^{\mathrm{rec}}(j) = \sum_{i=1} \epsilon_i E_i'(j) d_i(j) \longrightarrow \text{Reconstructed energy}$$

- **We get the following linear set of equations:**

$$\sum_{i=1} \left[\sum_{j=1}^{N_{\pi^0}} E_i'(j) d_i(j) E_k'(j) d_k(j)\right] \epsilon_i = \sum_{j=1}^{N_{\pi^0}} E_{\pi^0}^{\mathrm{cal}}(j) E_k'(j) d_k(j)$$

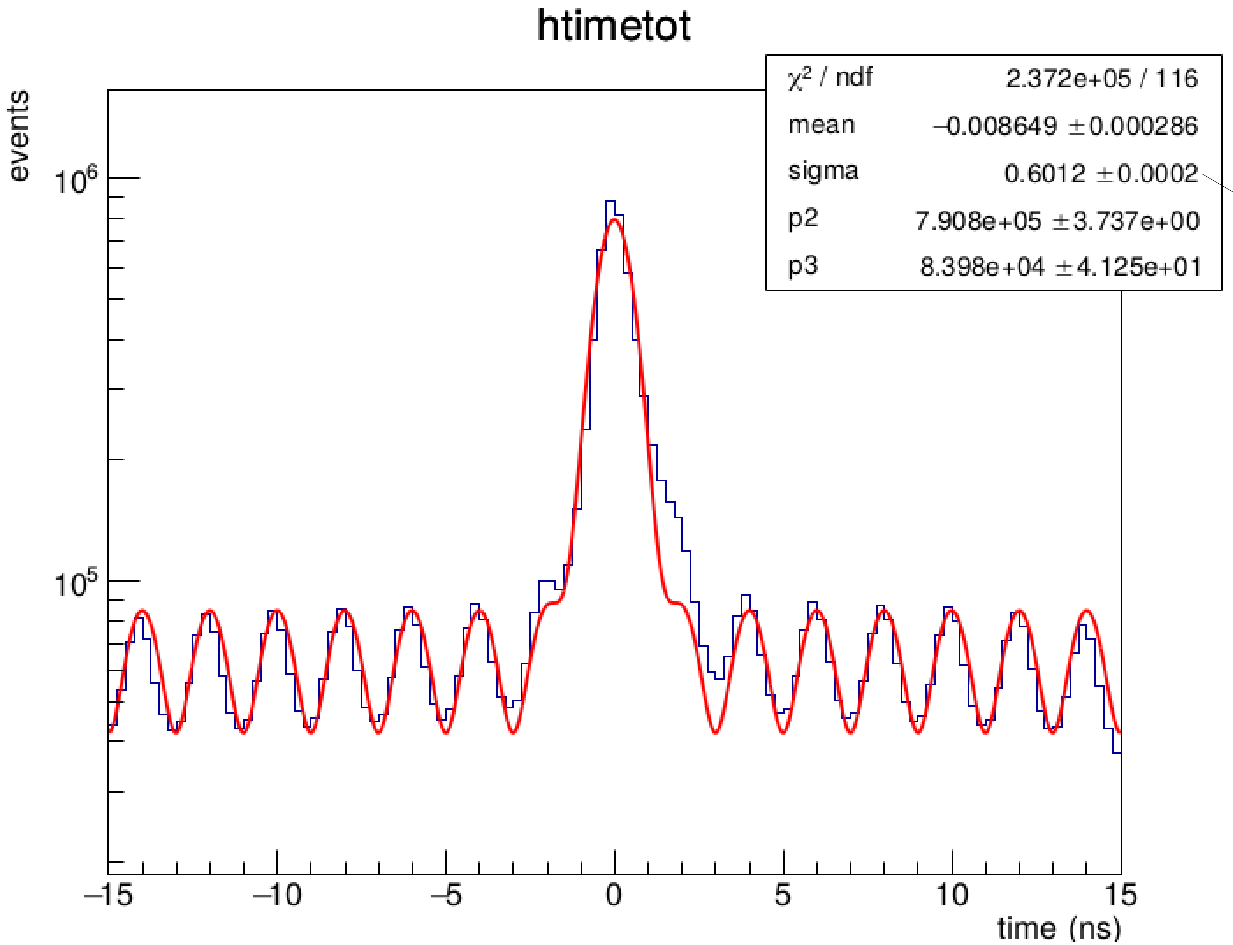
- **The correction factors are obtained by inverting the following matrix:**

$$\alpha_{ik} = \sum_{j=1}^{N_{\pi^0}} E_i'(j) d_i(j) E_k'(j) d_k(j)$$

Mazouz, M. Energy calibration of laterally segmented electromagnetic calorimeters based on neutral pion detection. Nucl. Sci. Tech. 28, 155 (2017)

TIME RESOLUTION STUDY

(LD2+LH2 RUNS COMBINED)



0.6 ns resolution

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

Dirac Matrix

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

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

In the infinite momentum reference frame

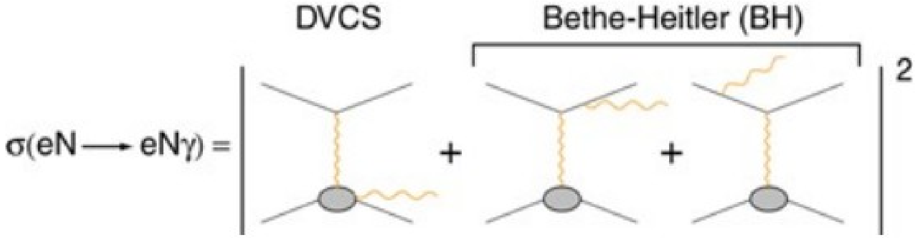
$$F_\Gamma^q(P,x,\Delta) = \frac{P^+}{4\pi} \int dz^- e^{ixP^+z^-} < p' | \boxed{\bar{\psi}(-z/2)\Gamma\psi(z/2)} | p > |_{z^+ = \vec{z}_\perp = 0}$$

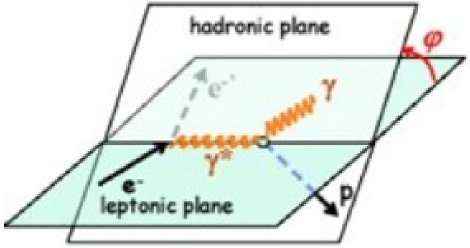
$$F_{\gamma^+}^q(x,\xi,t) = \boxed{H^q(x,\xi,t)}\bar{U}(p')\gamma^+U(p) + \boxed{E^q(x,\xi,t)}\bar{U}(p')\sigma^{+\nu}\frac{\Delta_\nu}{2M}U(p)$$

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

Particle with S = 1/2

DVCS Cross Section





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**

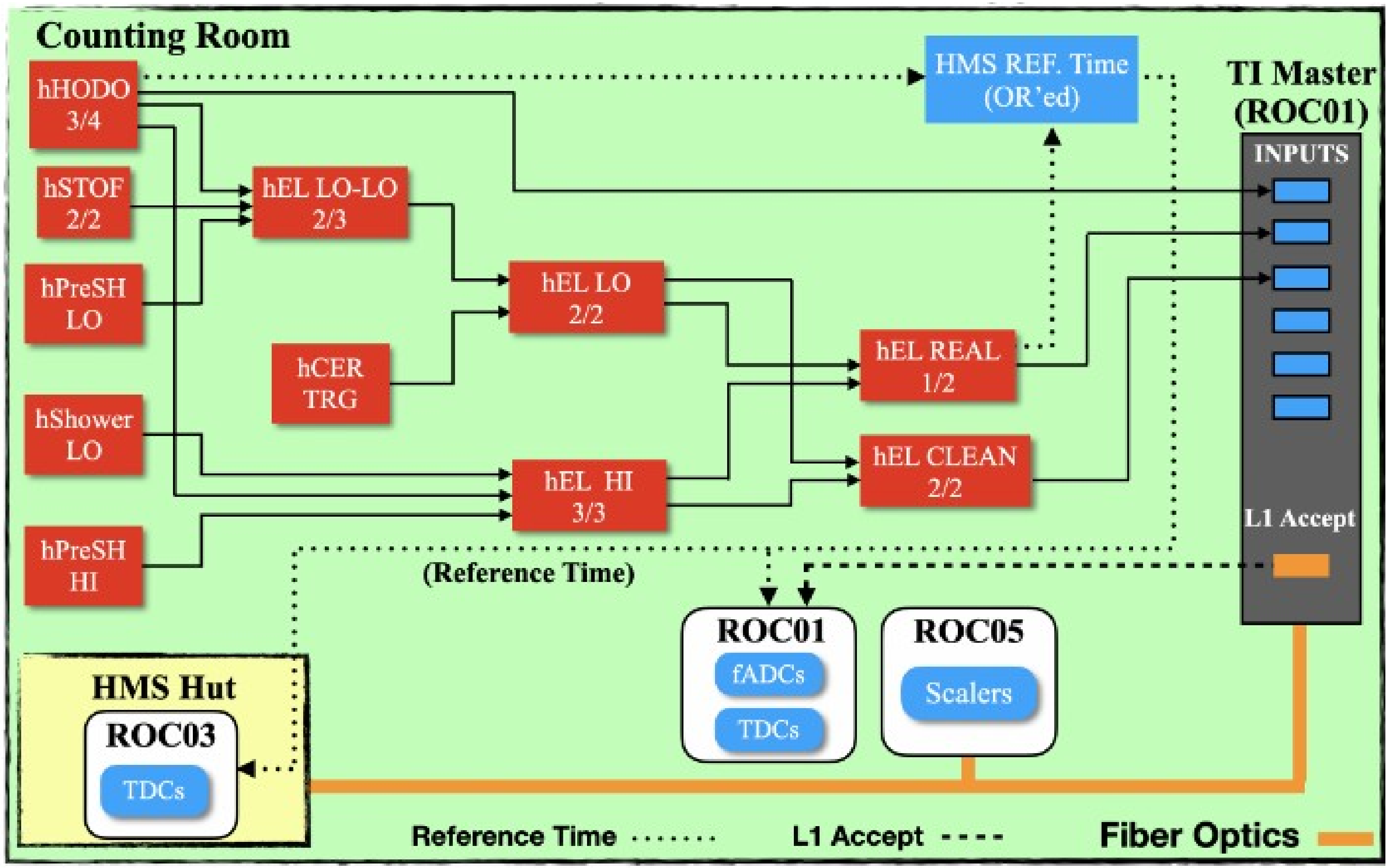
Small at Jlab enegies

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

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

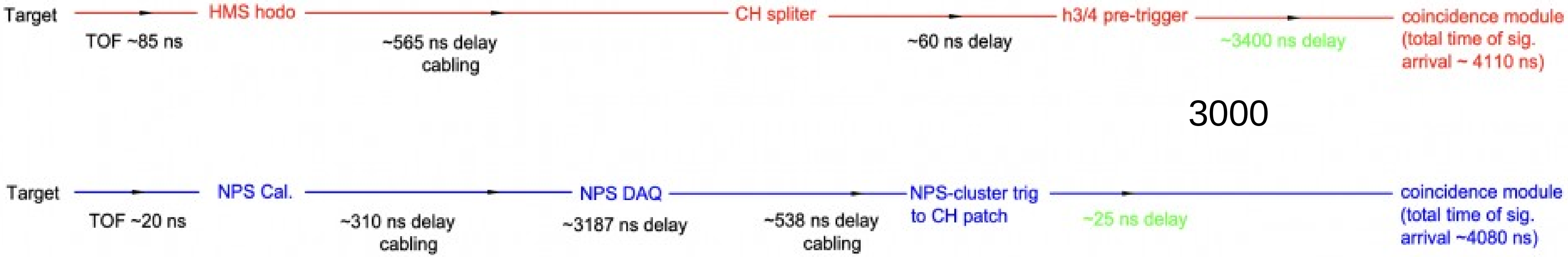
Kroll, Guichon, Diehl, Pire …

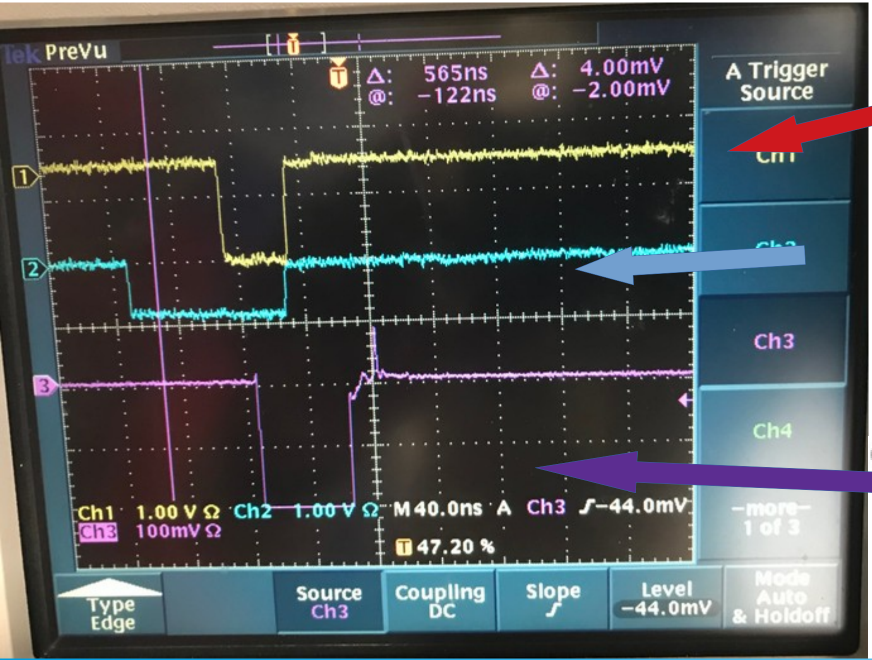
HMS Single Arm Pre-Trigger

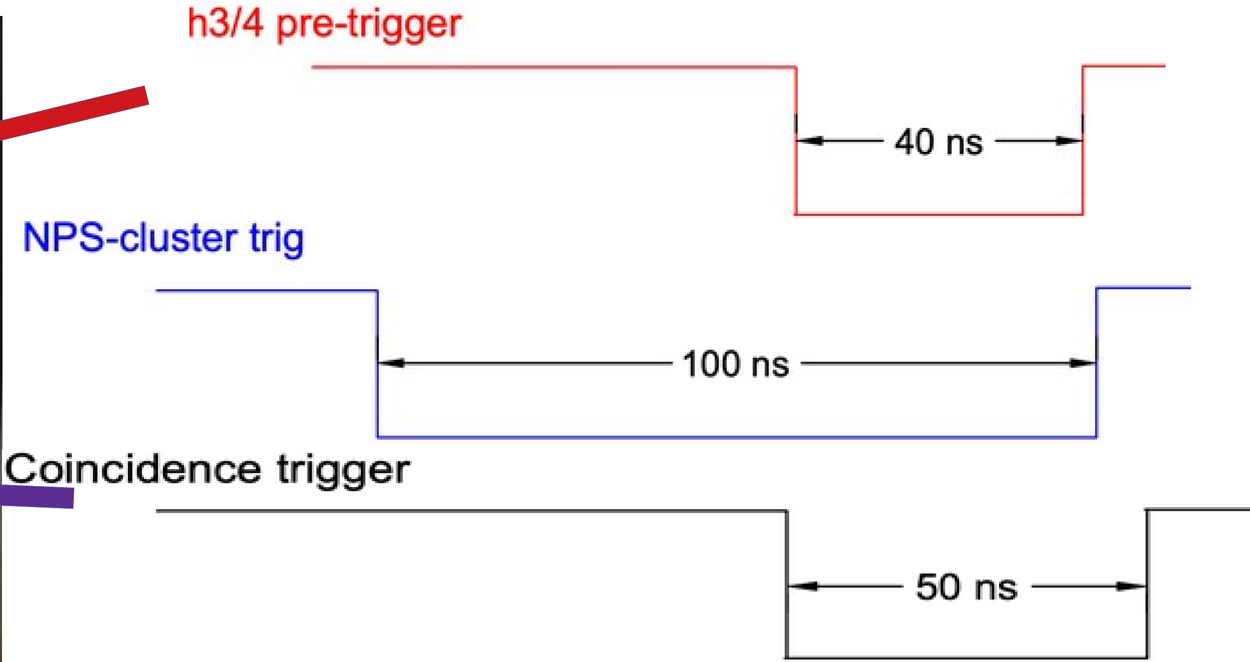


Credits to C.Yero

NPS/HMS Coincidence

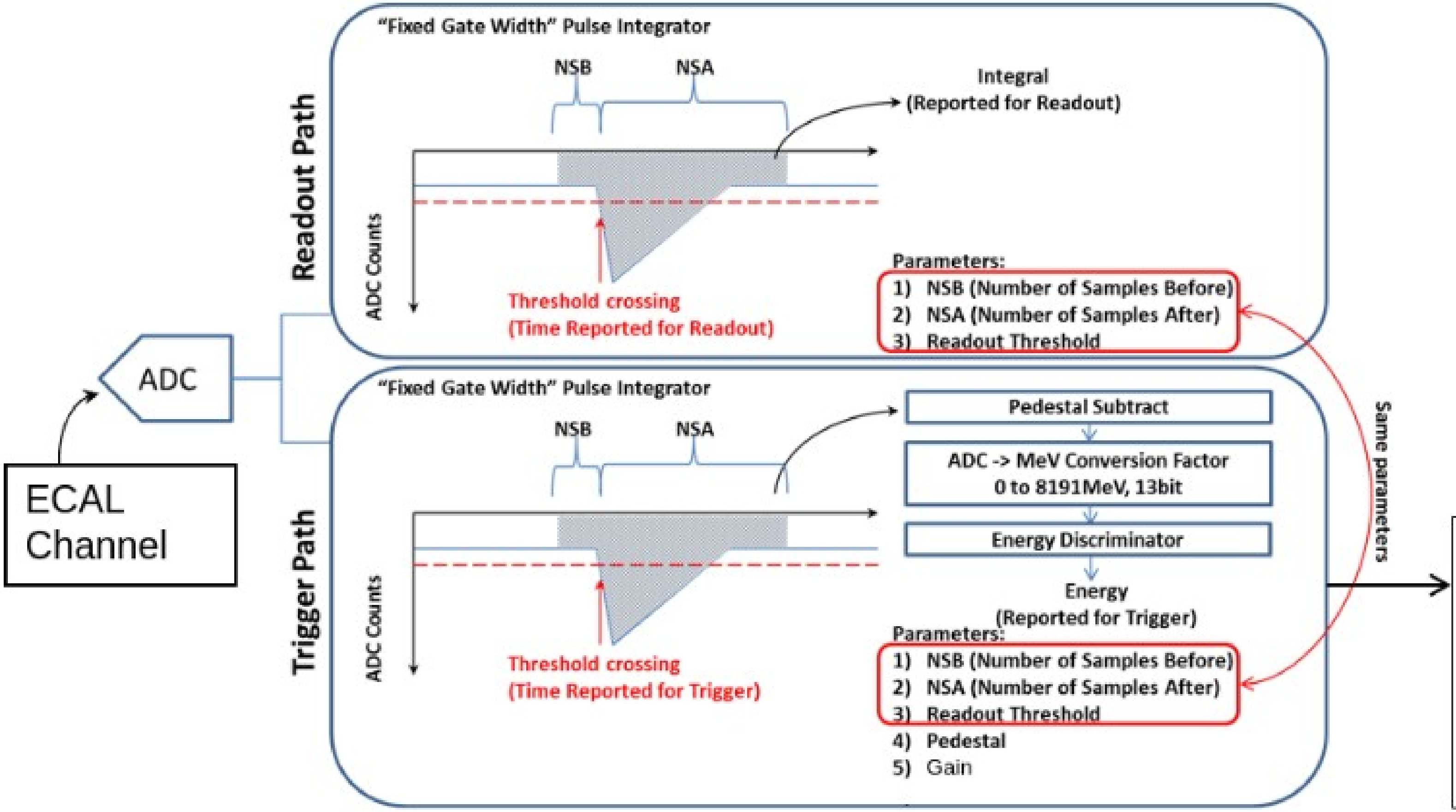






Credits to B.Michaels, J.Poudel, B.Raydo, C. Ghosh, Y. Zhang

FADC Data Stream



ECAL Channel

ADC

Readout Path

"Fixed Gate Width" Pulse Integrator

Integral (Reported for Readout)

Threshold crossing (Time Reported for Readout)

Parameters:

1) NSB (Number of Samples Before)
2) NSA (Number of Samples After)
3) Readout Threshold

Trigger Path

"Fixed Gate Width" Pulse Integrator

Pedestal Subtract

ADC -> MeV Conversion Factor 0 to 8191MeV, 13bit

Energy Discriminator

Energy (Reported for Trigger)

Threshold crossing (Time Reported for Trigger)

Parameters:

1) NSB (Number of Samples Before)
2) NSA (Number of Samples After)
3) Readout Threshold
4) Pedestal
5) Gain

Reports to VTP:

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

Cluster Trigger

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

1) The first Basic Steps by the VTP

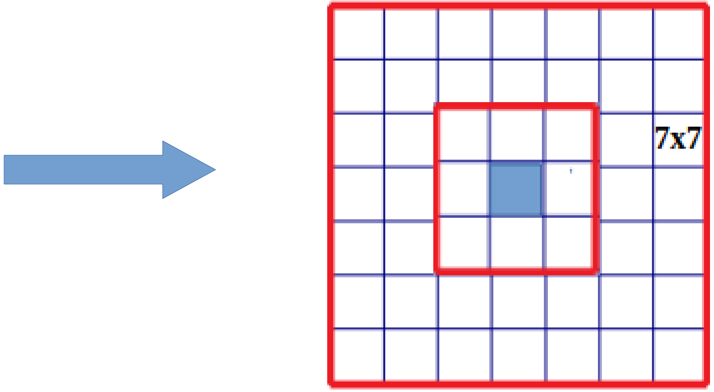
2) The Cluster Energy Is Above The S.P.T (1400 MeV)

==>> We have a DVCS cluster in hand

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

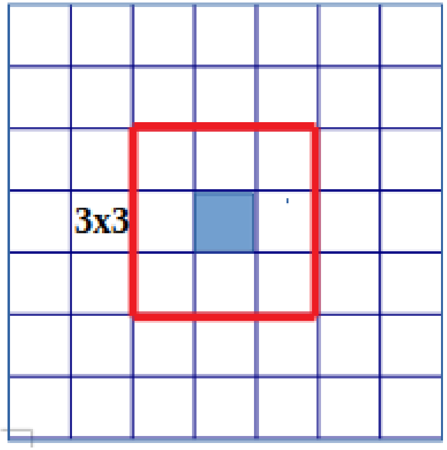
- We use the 7x7 Clustering around the seed block

- 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 and Clusters reconstruction

- **VTP BASIC STEPS:**



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

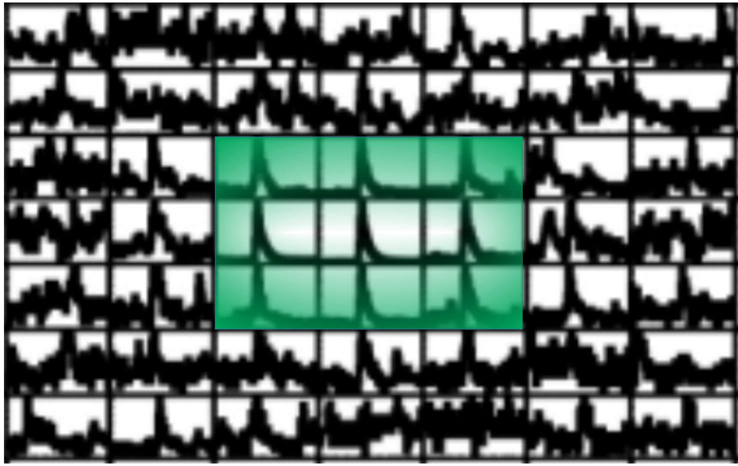
2) If the seed energy is a local maximum with respect to the 8 neighbors within the value of the time window (+- 20 ns from the seed) √

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



VTP Performance

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