Deeply Virtual Compton Scattering at Jlab: The 12GeV era

Hall A Running 2014/15

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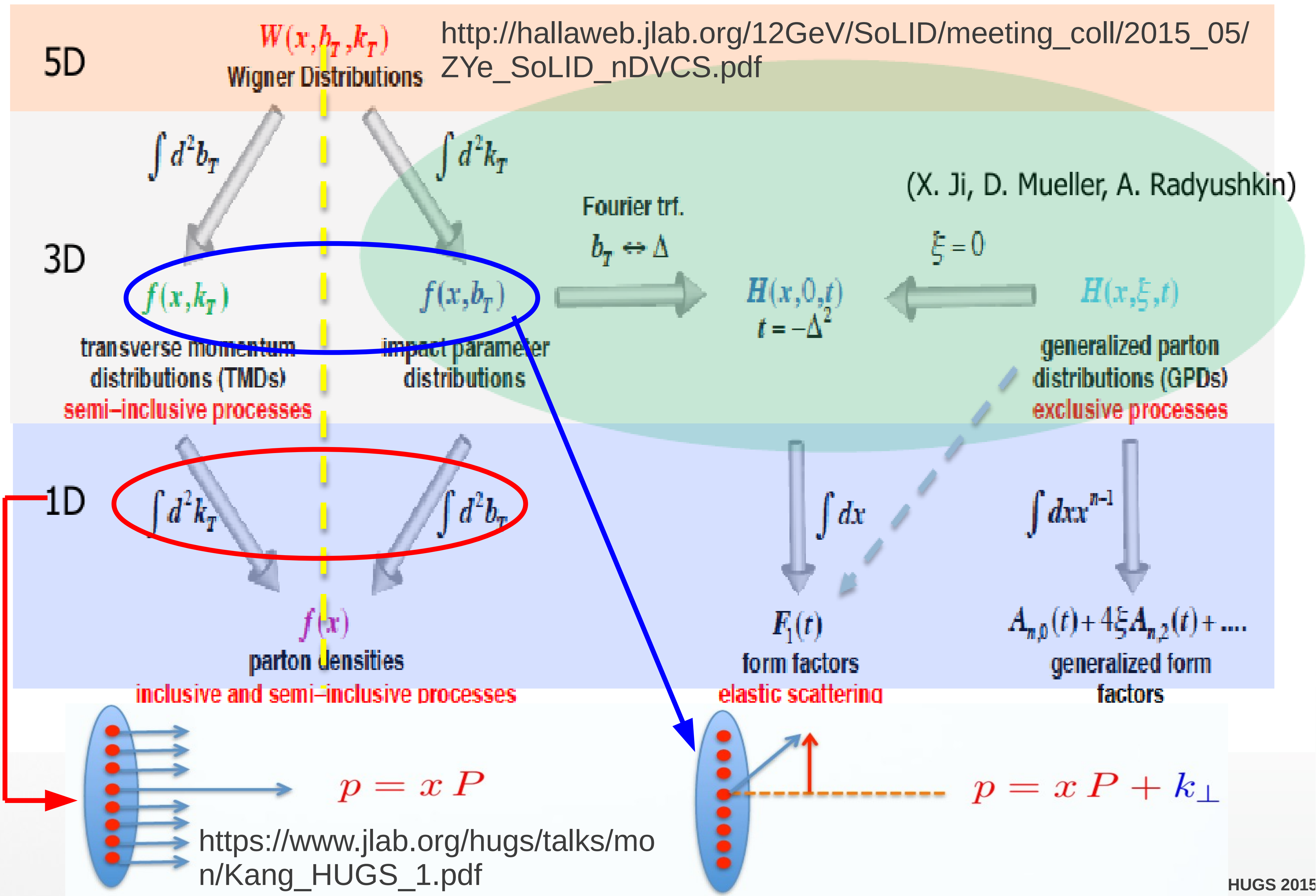
Talk outline:

- Generalized Parton Distributions and Deeply Virtual Compton Scattering
- DVCS at JLab 12GeV in Hall A: Experiment E12-04-144
    - Goals and kinematics
    - Instrumentation
        - Hall A's High Resolution Spectrometer(HRS)
        - Dedicated DVCS Calorimeter
    - Preliminary studies

Nucleon Structure: a unified view



Generalized Parton Distributions(GPDs)

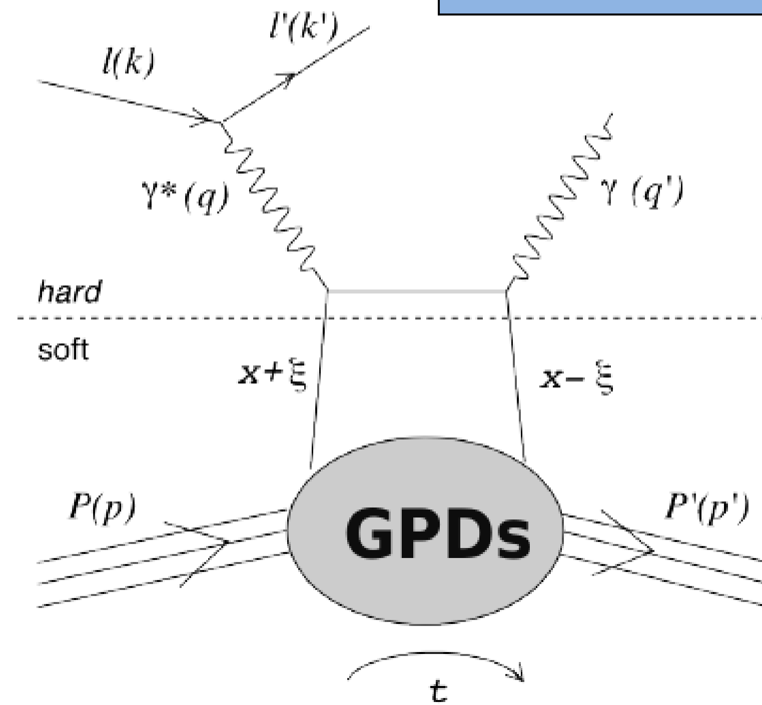
- Amplitude of removing a parton at an earlier time and putting it back later, with a final momentum fraction
- GPDs encode both position and momentum information of partons (quarks and gluons)
- Four quark or gluon GPDs parametrize nucleon structure at leading order and twist:
  - *H,E, (unpolarized)*
  - $\tilde{H},\tilde{E}(polarized)$
- Connect to FFs and PDFs:

$$\int_{-1}^{+1} dx H^q(x,\xi,t) = F_1^q(t)\,, \quad \int_{-1}^{+1} dx E^q(x,\xi,t) = F_2^q(t)\,,$$

$$\int_{-1}^{+1} dx \tilde{H}^q(x,\xi,t) = G_A^q(t)\,, \quad \int_{-1}^{+1} dx \tilde{E}^q(x,\xi,t) = G_P^q(t)\,.$$

DVCS is the cleanest way to measure GPDs.
DVMP has strongly interacting final meson which makes Factorization complex.

e P→e γ P



Deeply Virtual Compton Scattering

x : average longitudinal momentum fraction of the struck quark

ξ : longitudinal momentum transfer

t << Q'² : momentum transfer

Q'² >> 1 GeV² : hard scale

Images: https://www.jlab.org/highlights/images/physics/dvcs.jpg

GPDs: What can we learn from them?

1. Quark (Orbital) Angular Momentum of Nucleons and the spin puzzle

→ Considering Ji's decomposition of nucleon spin (Ji's Sum Rule):

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + L_q + \Delta G + L_g$$

Quark Spin ~30% (DIS)

Quark OAM

Gluon

Gluon OAM

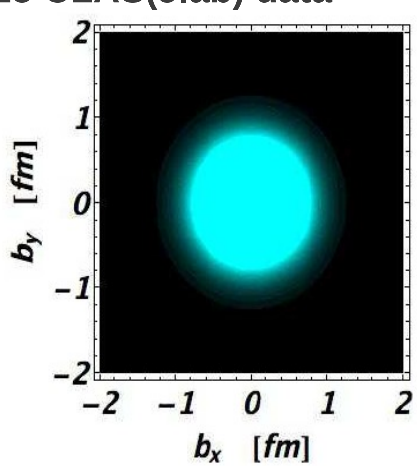
Where is the rest? → Quark OAM could tell us something

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

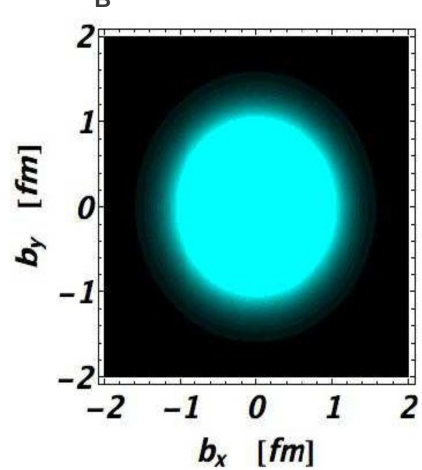
$$= \frac{1}{2}\Delta\Sigma^q + L^q$$

2. Transverse Imaging of Nucleon => 3D partonic picture of nucleons

.x_B = 0.25 CLAS(Jlab) data



.x_B = 0.09 HERMES data

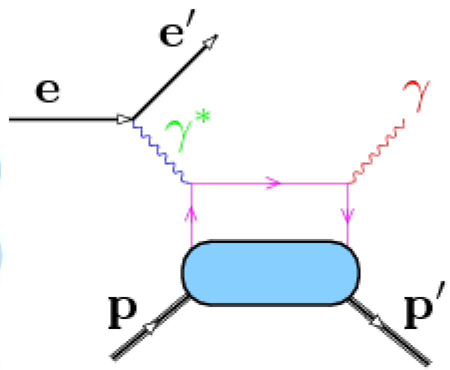


=> nucleon(proton) transverse size -depends on the players probed , i.e quarks or gluons

GPDs through DVCS

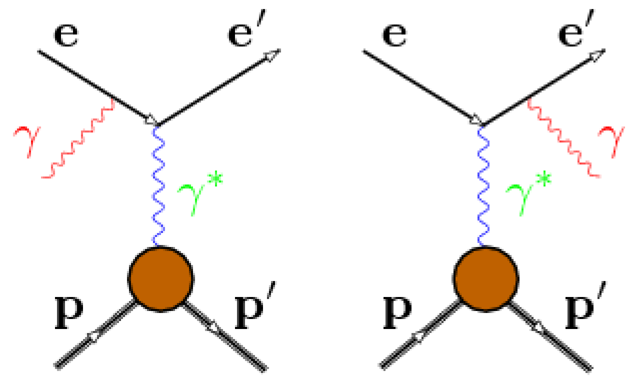
DVCS amplitude interferes with QED governed Bethe-Heitler process

σ(DVCS) α | (a) DVCS + (b) Bethe-Heitler |^2



(a)
DVCS

+

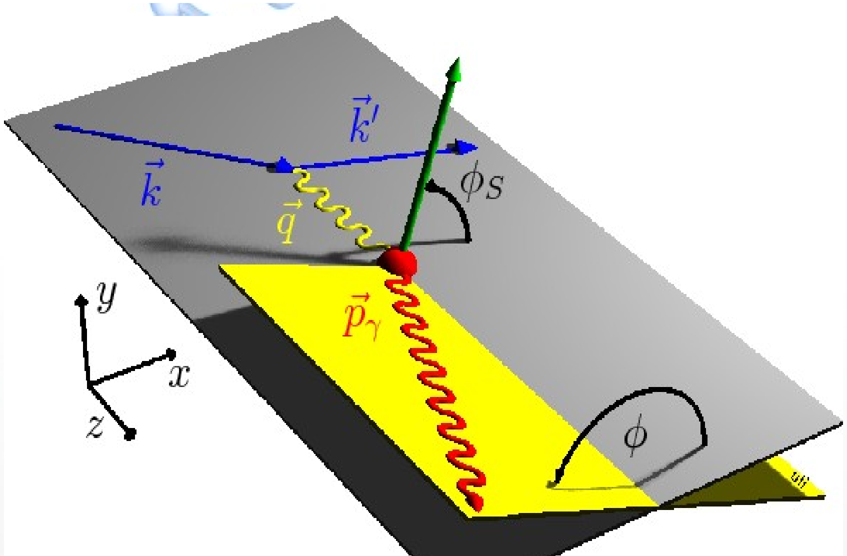


(b)
Bethe-Heitler

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

$$\mathcal{I} = \frac{\pm e^6}{x_B y^3 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ \mathcal{C}_0^{\mathcal{I}} + \sum_{n=1}^{3} [\mathcal{C}_n^{\mathcal{I}} cos(n\phi) + \mathcal{S}_n^{\mathcal{I}} sin(n\phi)] \right\}$$

$$|\mathcal{T}_{\mathcal{DVCS}}|^2 = \frac{e^6}{y^2 Q^2} \left\{ \mathcal{C}_0^{DVCS} + \sum_{n=1}^{2} [\mathcal{C}_n^{DVCS} cos(n\phi) + \mathcal{S}_n^{DVCS} sin(n\phi)] \right\}$$

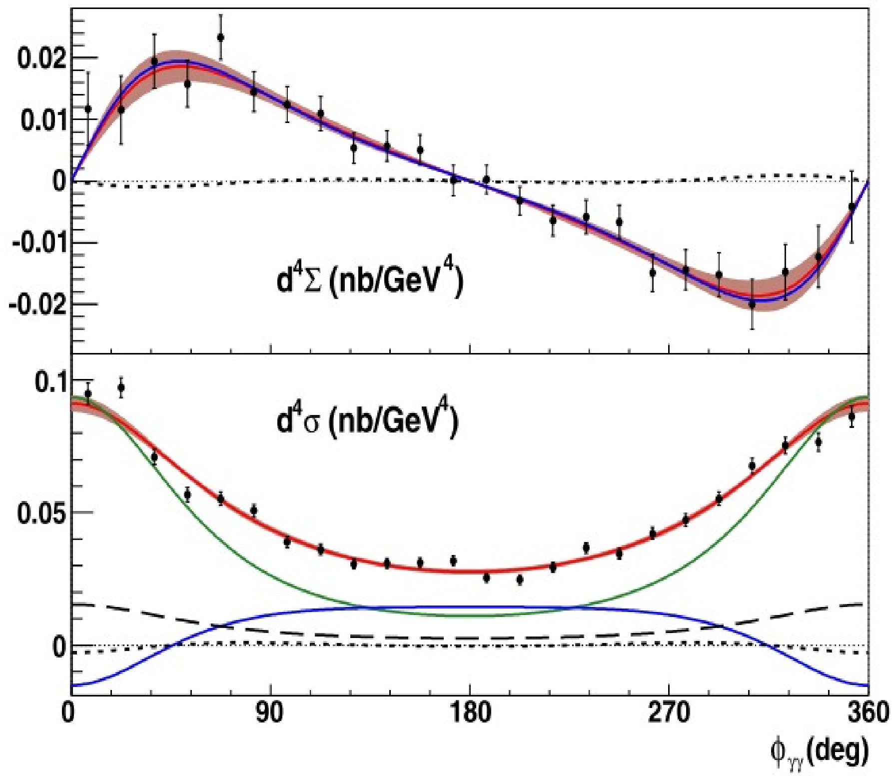


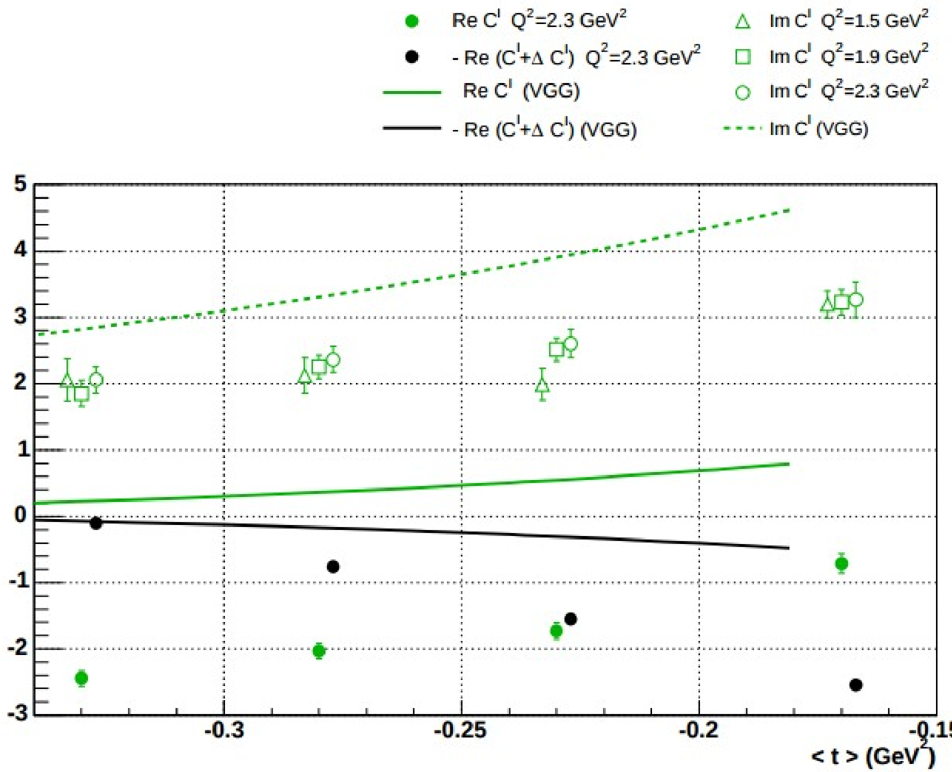
Nowak, arXiv:0812.2679 [hep-ph]

A convolution of GPD linear combinations

Results of DVCS at 6GeV, Hall A

[C. Munoz Camacho et al.,2005]





Helicity-dependent ($d^4\Sigma$) and helicity-independent ($d^4\sigma$) cross sections measured in E00-110 for $Q^2 = 2.3$ GeV^2 and $t = -0.28$ GeV^2 .

Fourier coefficients extracted from the E00-110 data

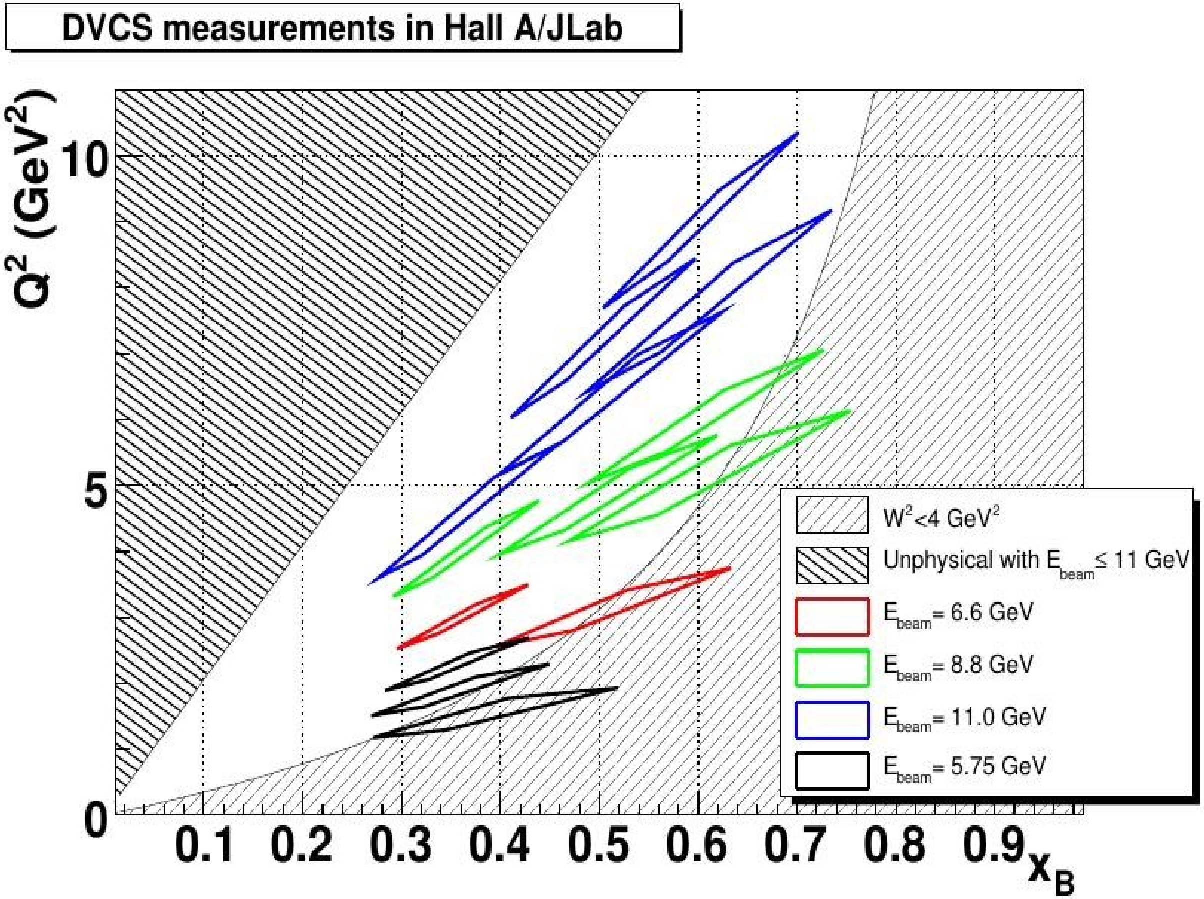
Experiment E12-04-144

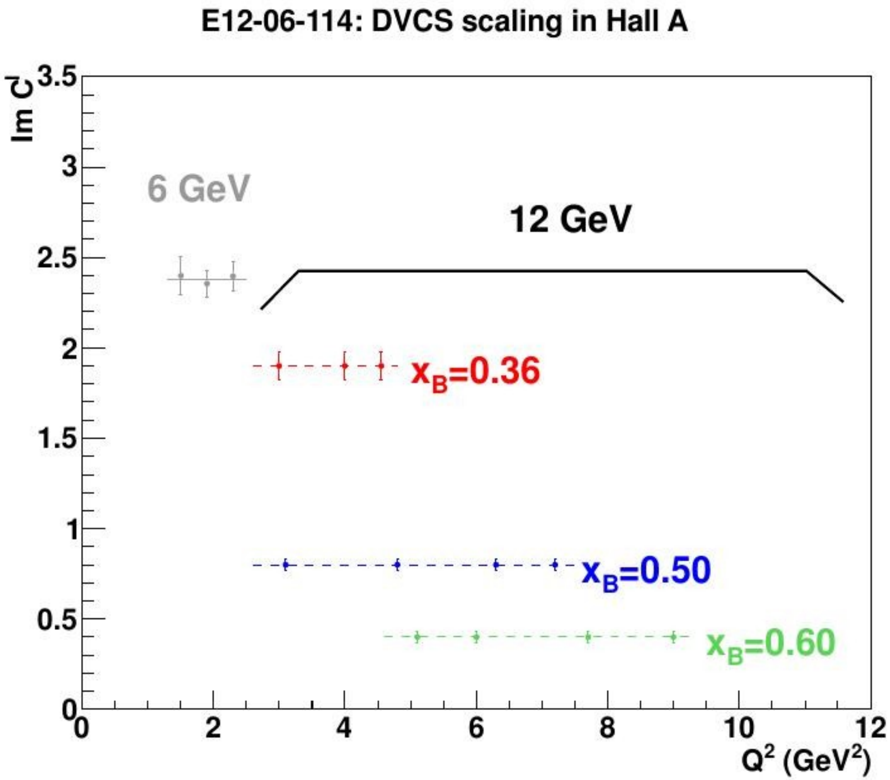
DVCS in Hall A of Jlab: 2014/15

→ Scaling test of DVCS cross-sections to 5% precision over large arm in Q^2

→ Separation of *Re* and *Im* part of DVCS amplitude (polarized and total cross section)

Proposed scans in Q^2 and x_{Bj}

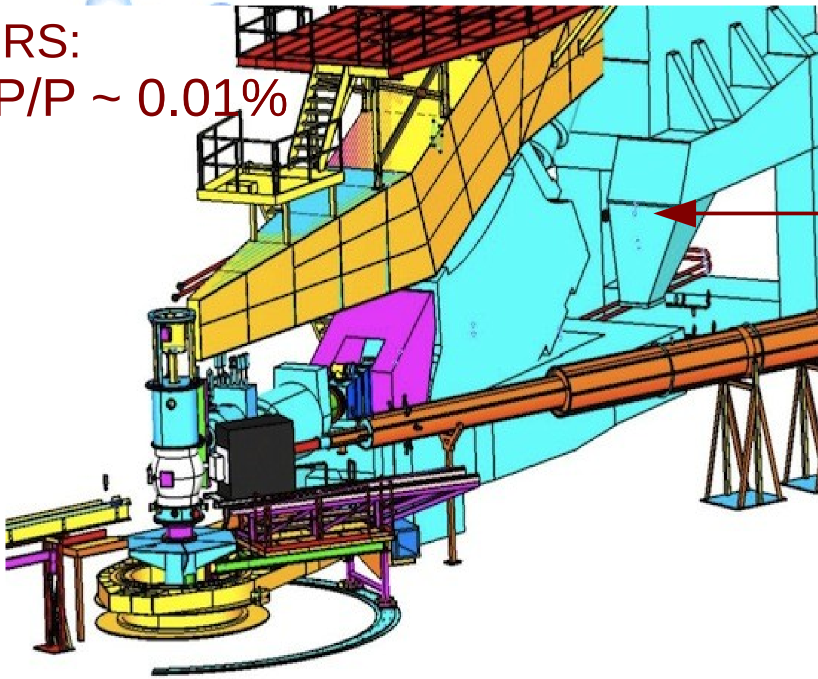


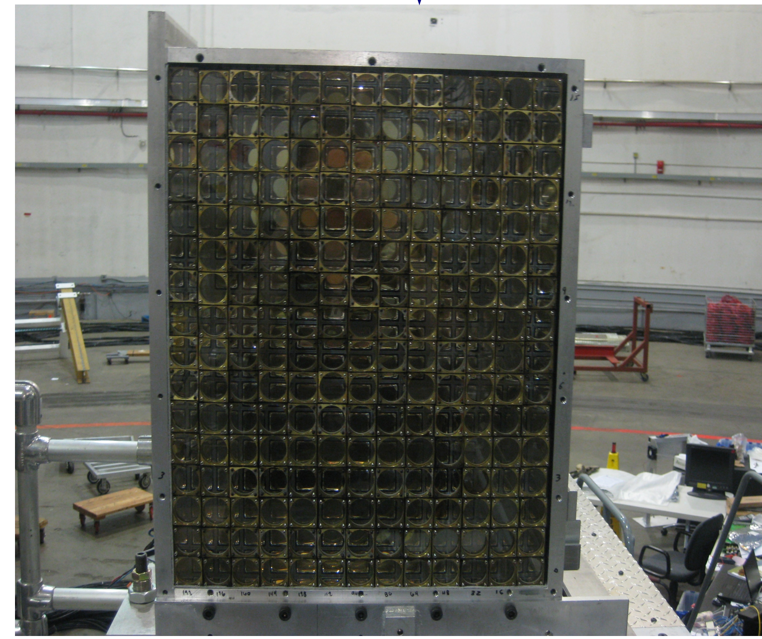


Previous experiments give hint of leading order domination. The present experiment aims to test this domination over an expanded arm in Q^2 and x_{Bj} scan.

Instrumentation: p(e,e'γ)p'

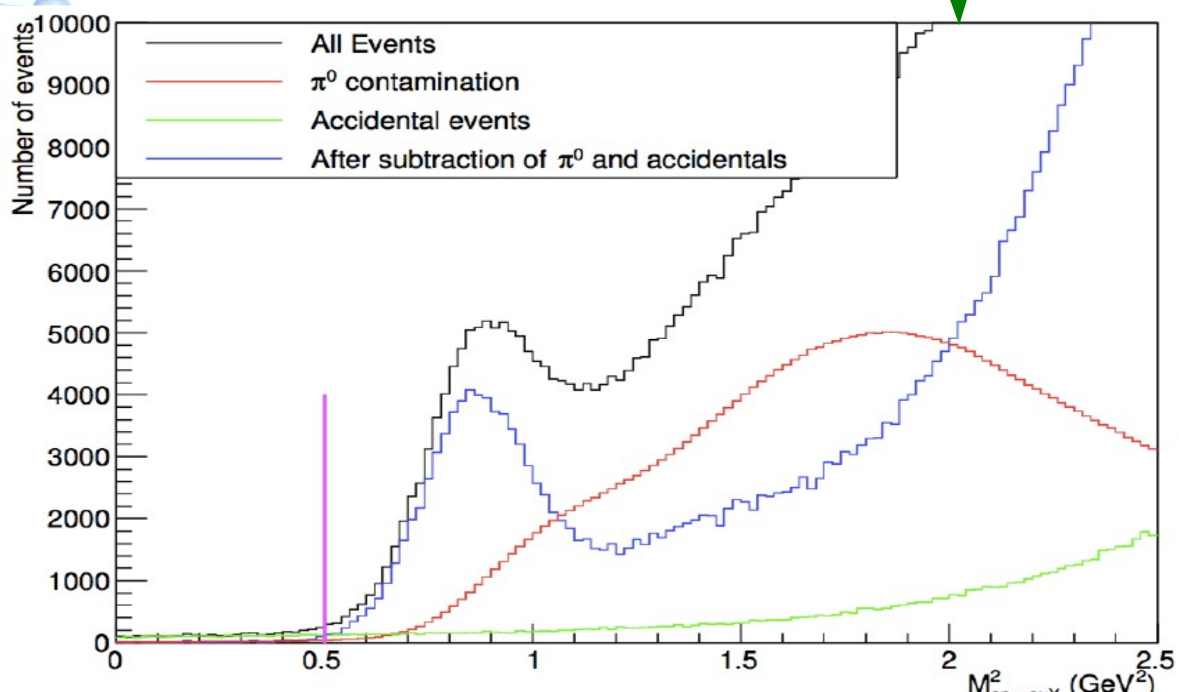
LHRS:
ΔP/P ~ 0.01%





208 Lead-Fluoride blocks
for calorimeter

Missing mass squared cut ensures exclusivity



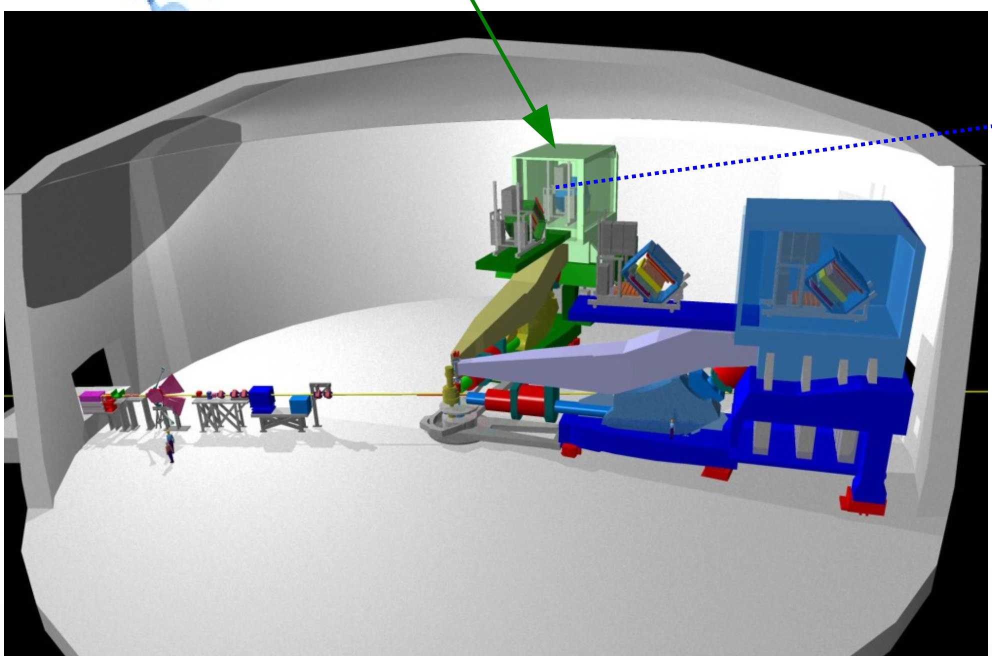
Δq/q ~ 3% ~ modest

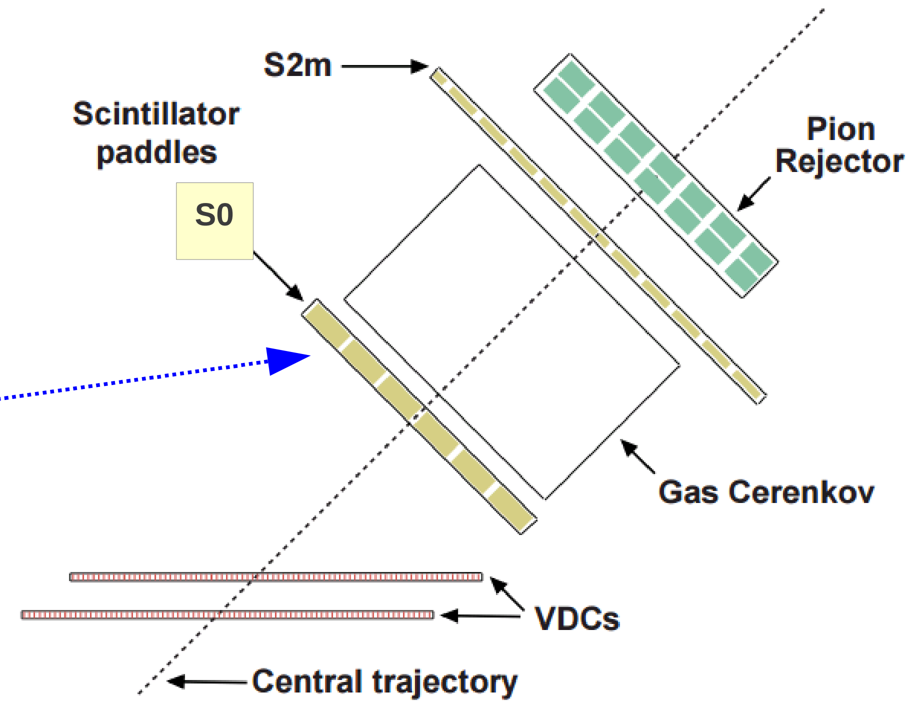
=> Calorimeter photon energy resolution is our limiting factor in the missing mass reconstruction

Instrumentation:

High Resolution Spectrometer

We use the Left HRS to detect the scattered electron





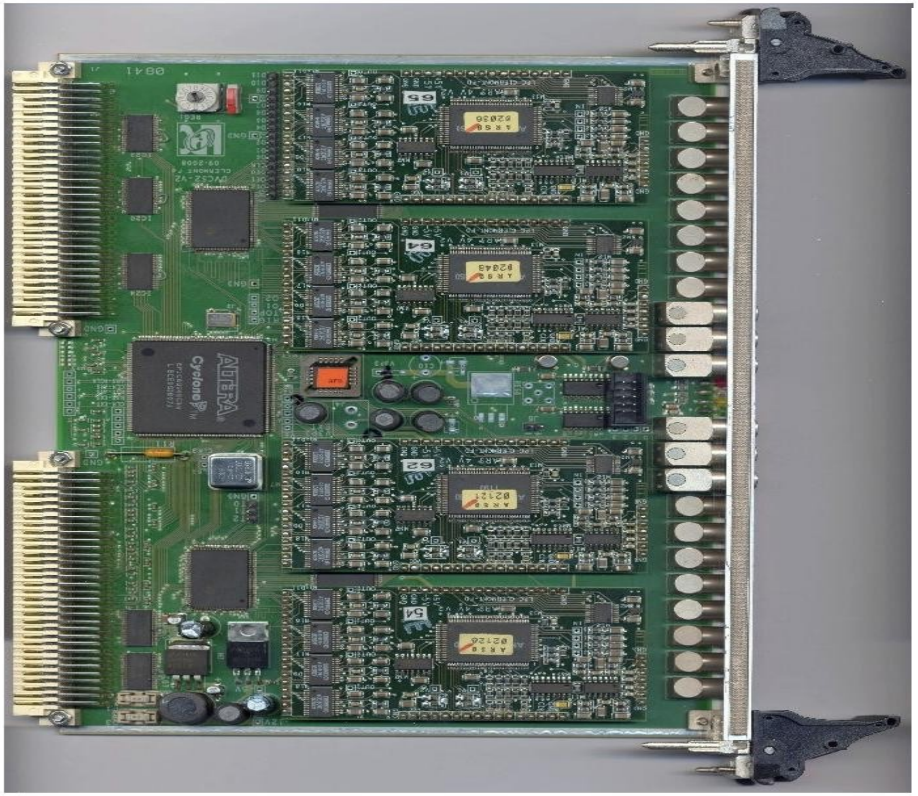
s2m and s0: scintillators for triggering

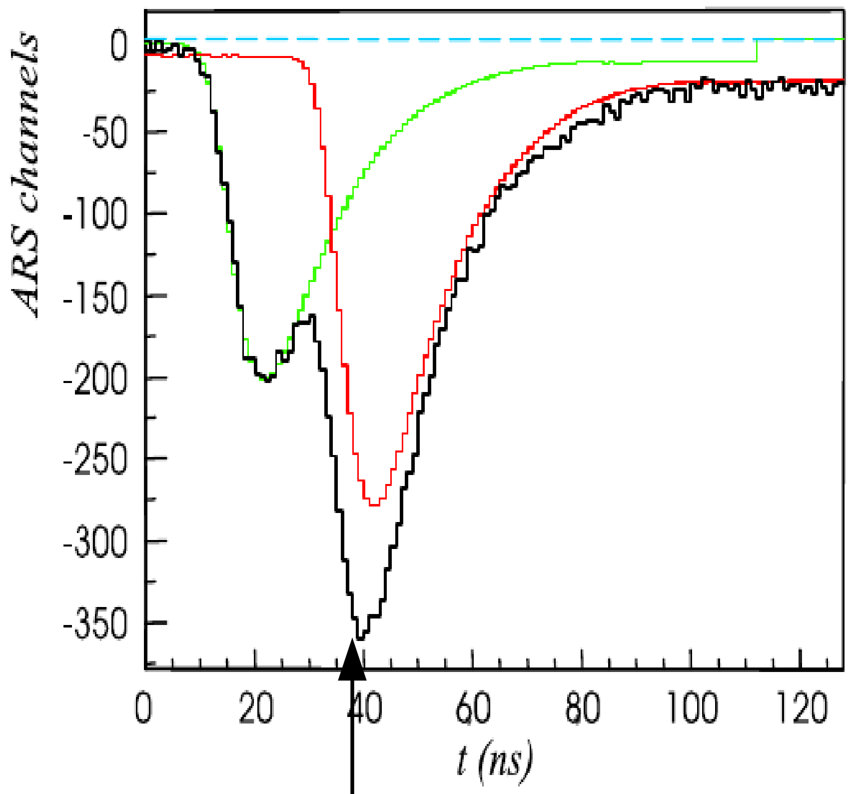
PID: Gas Cherenkov, Pion Rejector calorimeter

DVCS trigger: Gas Cerenkov & S2m

Instrumentation:

Dedicated DVCS Calorimeter





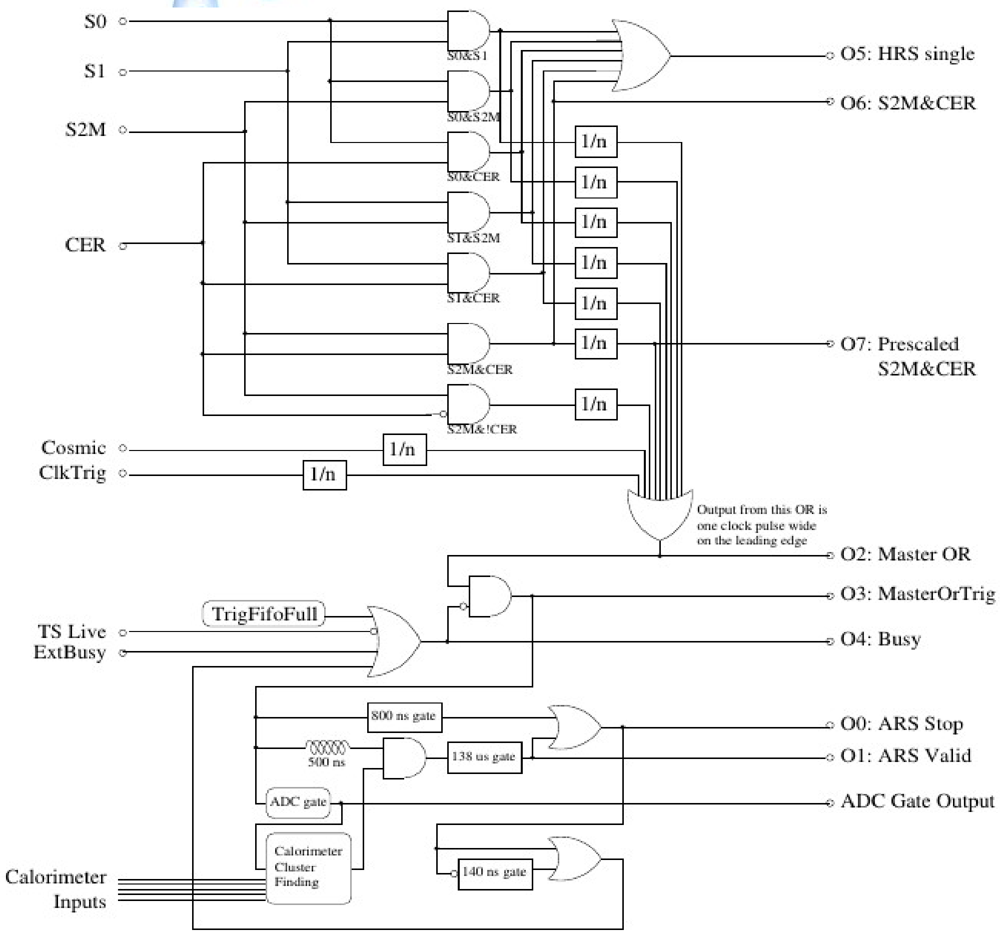
ARS system(for calorimeter signals):

→ 1 GHz sampling

→ Digitizes PMT signals, allowing off-line pile-up removal

→ Readout time = 128 μs

Instrumentation:



DVCS coincidence trigger module: (NEW FOR 2014-2015)

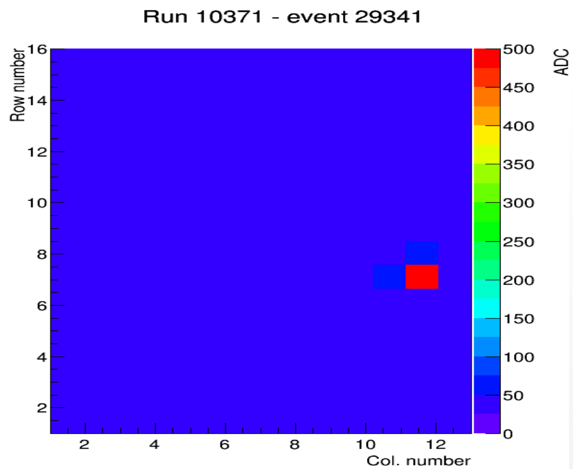
→ Is a second level trigger module
~800 ns decision time

→ HRS triggering in DVCS trigger module.

→ Selects a 2x2 block cluster above a programmable calorimeter energy threshold.

→ Can bypass cluster finding(autoval.) , to take DIS

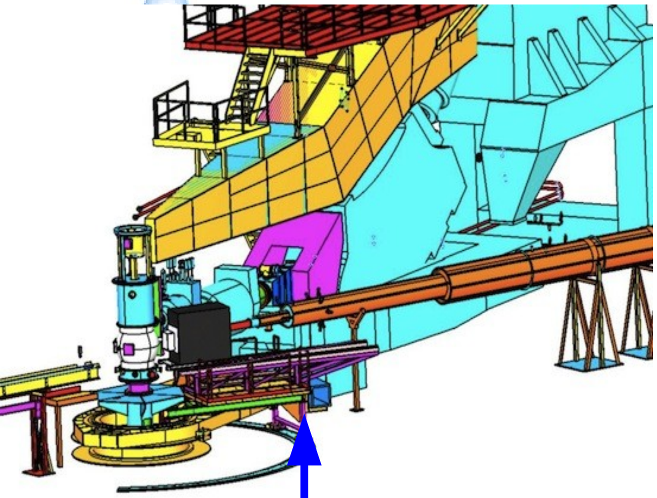
→ Simultaneous multiple triggers



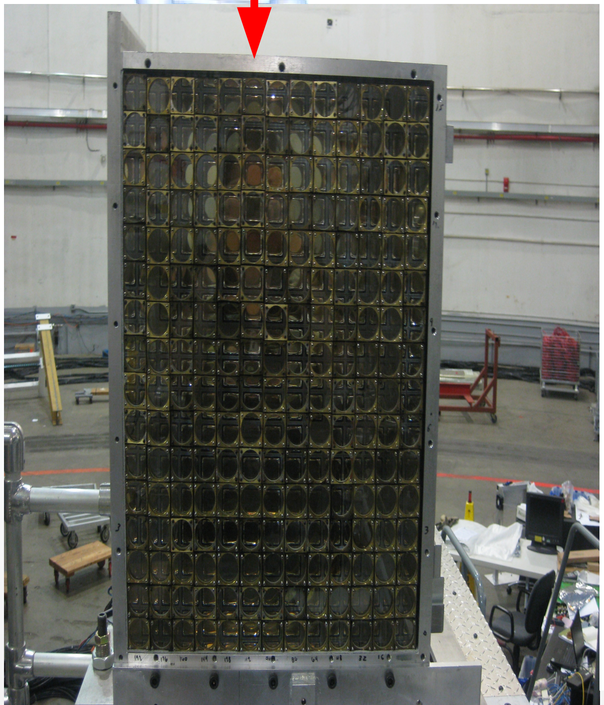
Preliminary Studies

Preliminary Studies:

Elastic calibration of DVCS calorimeter

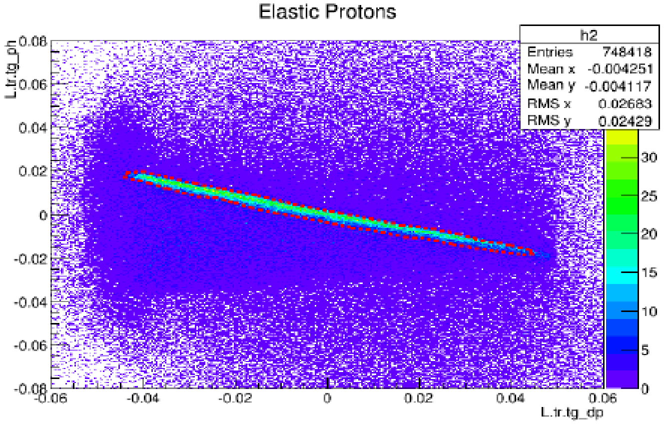


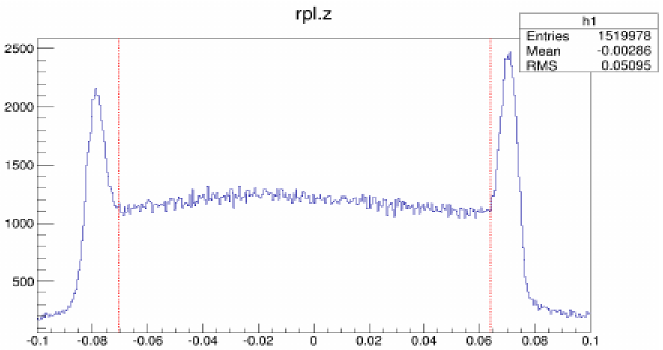
ep —> ep

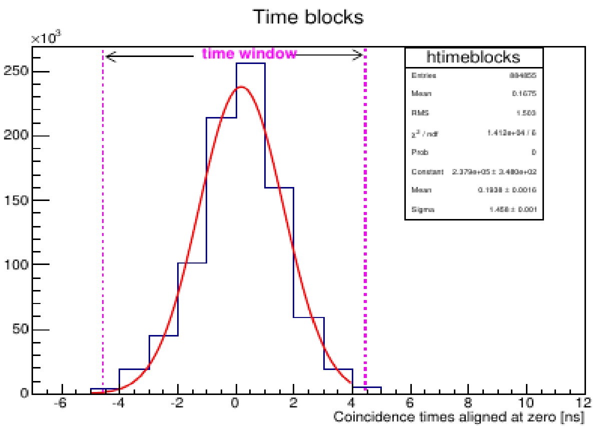


$$\chi^2 = \sum_{j=0}^{Nevents} \left(E_j - \sum_{i=0}^{Nblocks} (C_i A_i^j) \right)^2$$

$$\sum_{i}^{Nblocks} \left(\sum_{j=1}^{Nevents} A_j^k A_j^i \right) C_i = \sum_{j=1}^{Nevents} E_j A_j^k$$

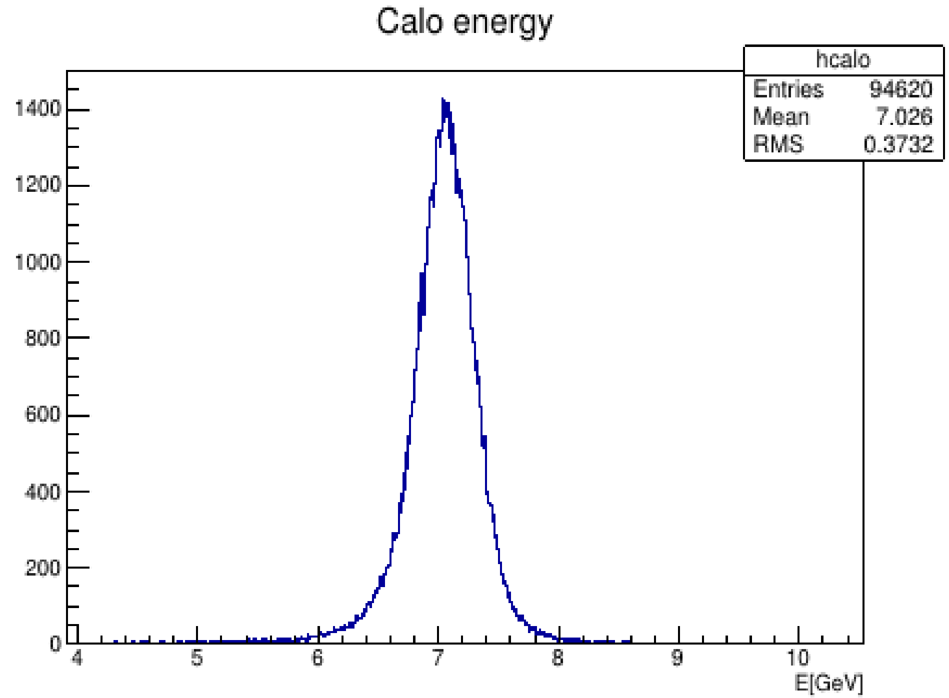


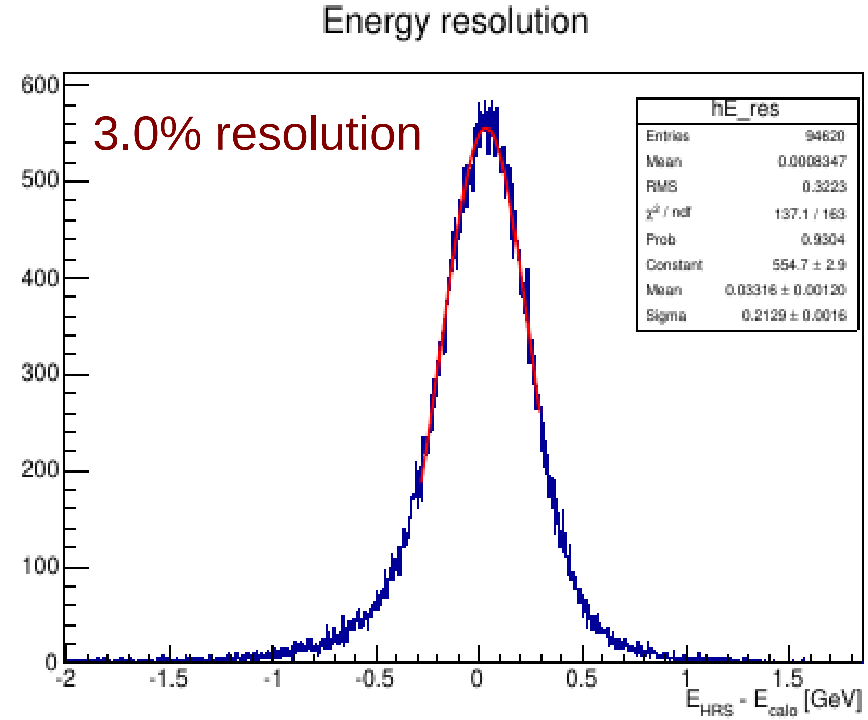


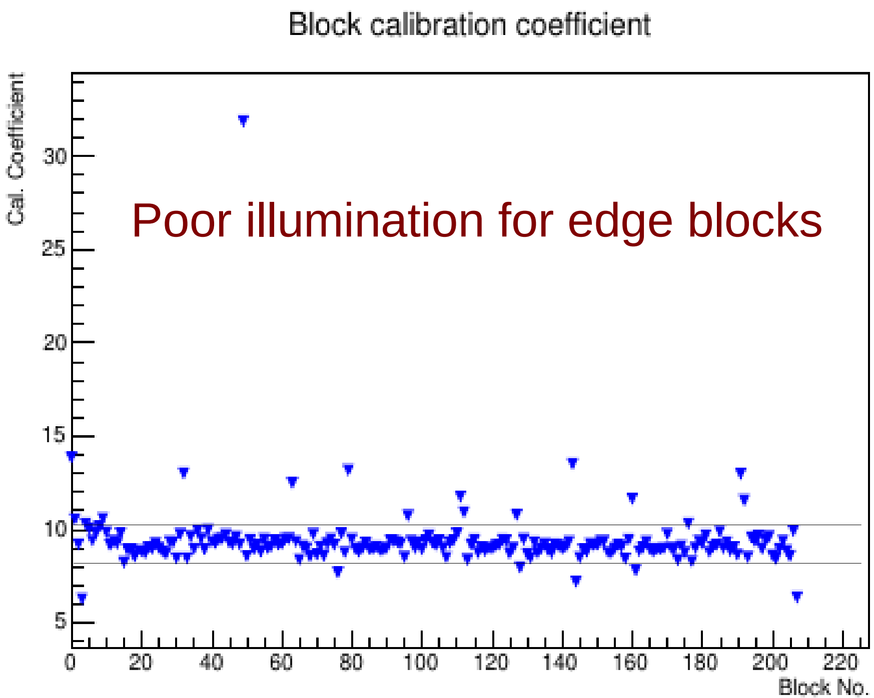


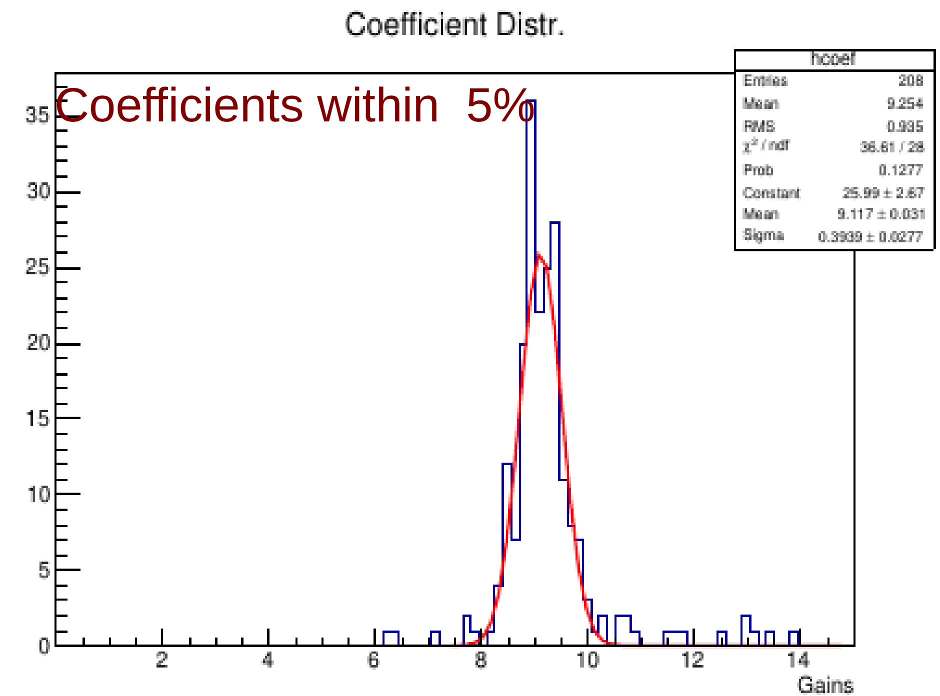
$$HV_2 = HV_1 \left(\frac{G_2}{G_1} \right)^{\frac{1}{\beta}},$$

Spring 2015 results



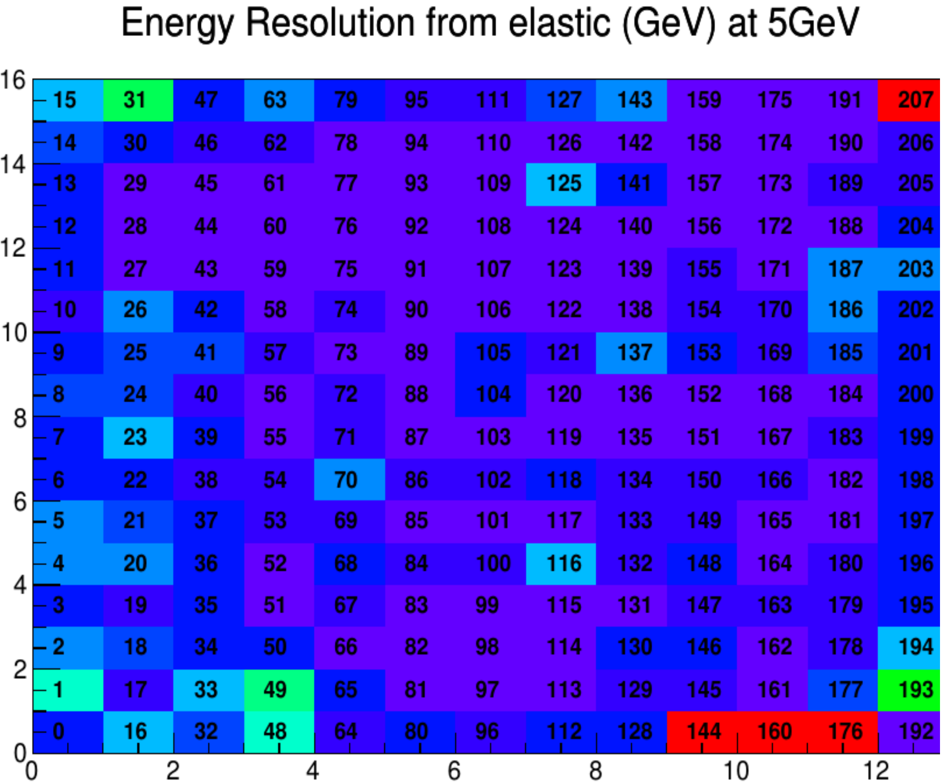


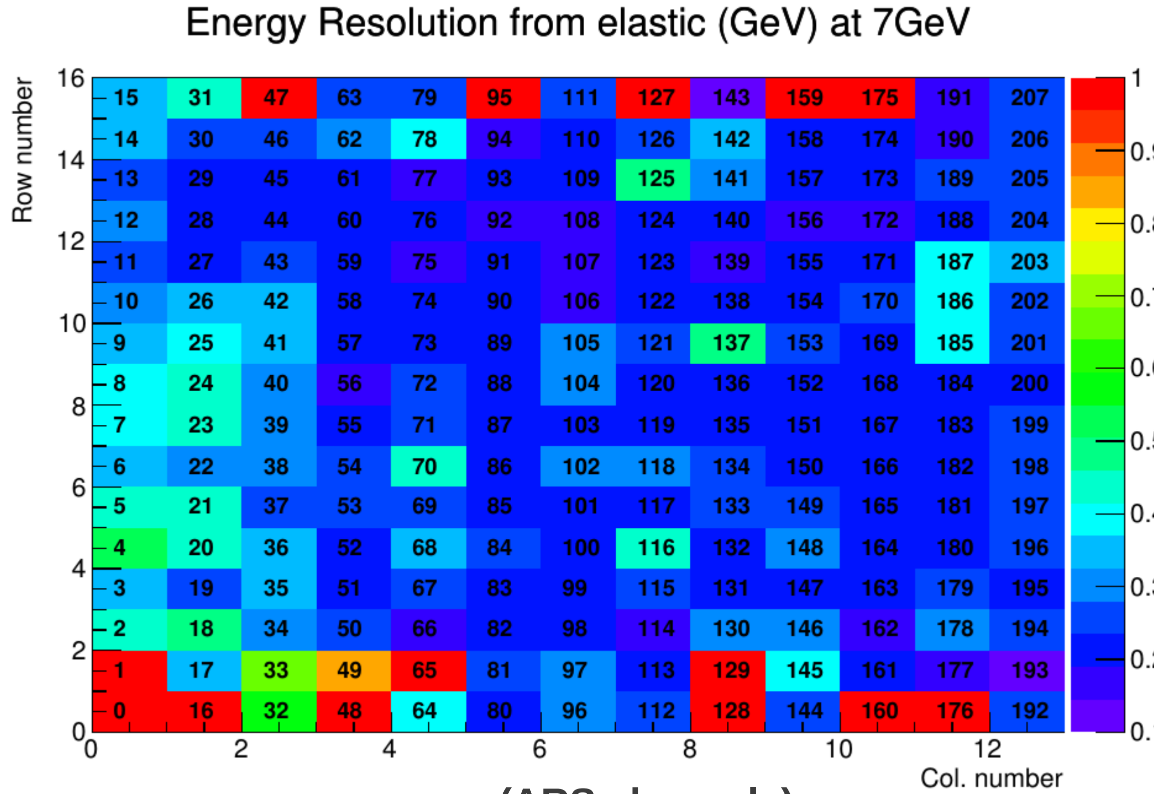




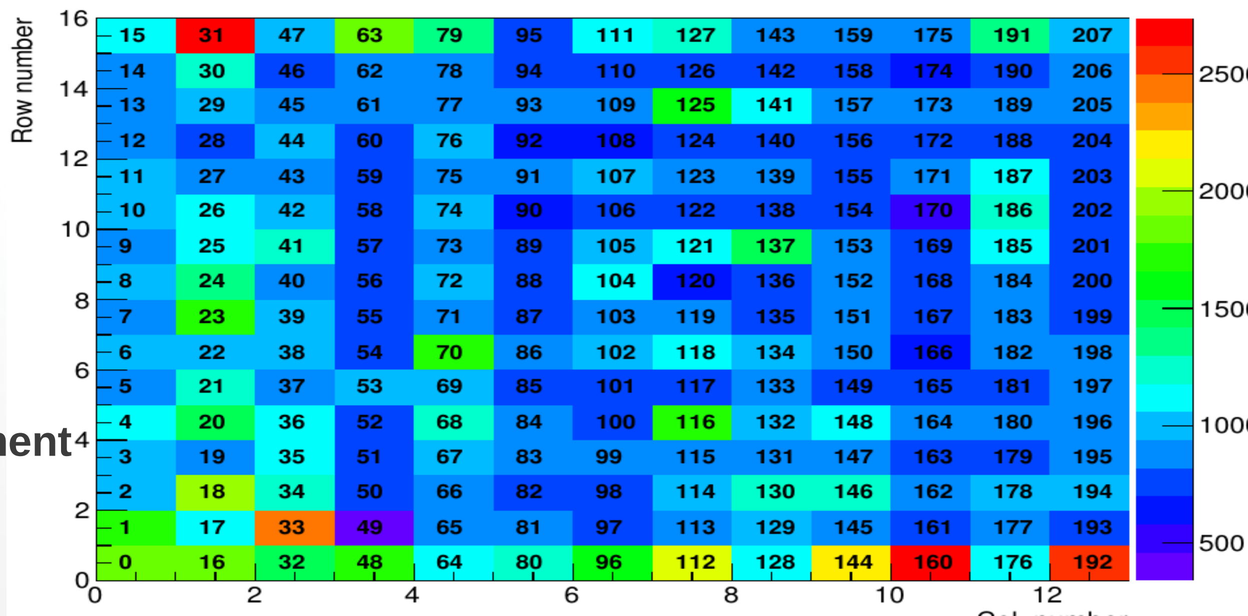
Preliminary Studies:

Energy resolution per block





Resolution with cosmics, run 11252 (ARS channels)



Resolution dominated by photon statistics

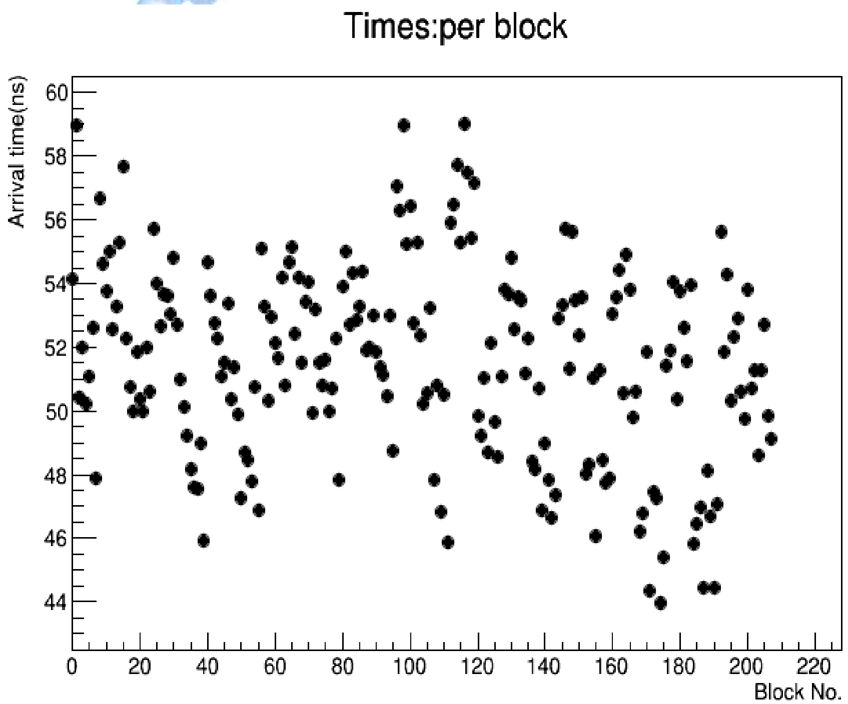
Res.~ √N ~ σ

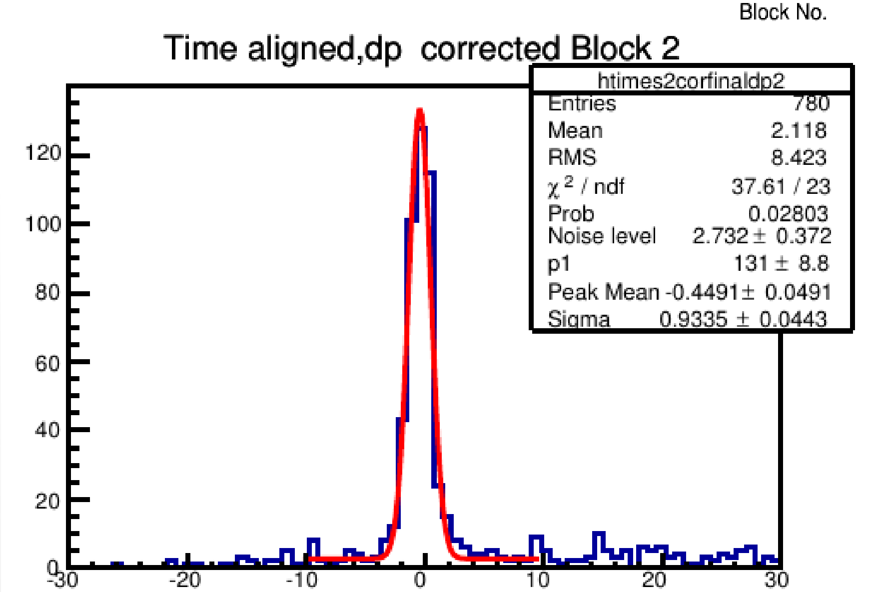
→ **low resolution to be Considered for replacement**

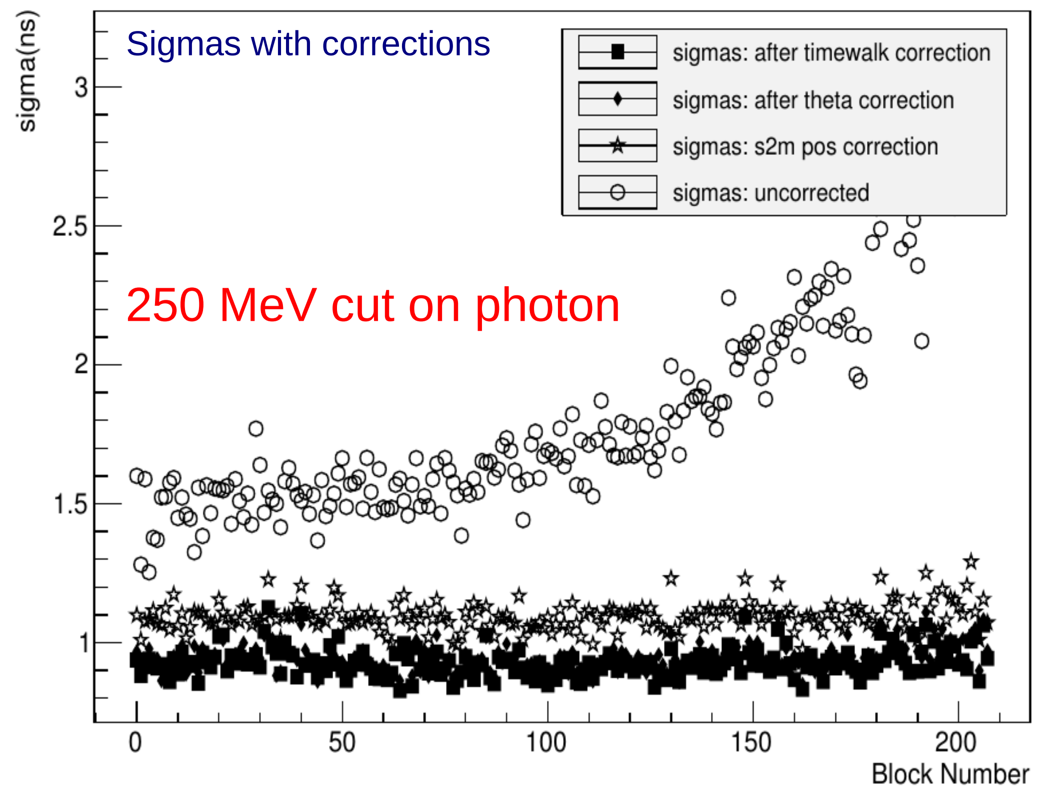
Preliminary Studies:

Coincidence time optimization

→ To improve calo energy resolution
→ close out accidentals and lower photon energy threshold







→ align all block times at zero to get a global Time window
→ consider calo time correlations with HRS Variables such as electron momentum, Scintillator timing, electron signal size, etc.
→ apply corrections
→ target was a sigma of at-most 1ns

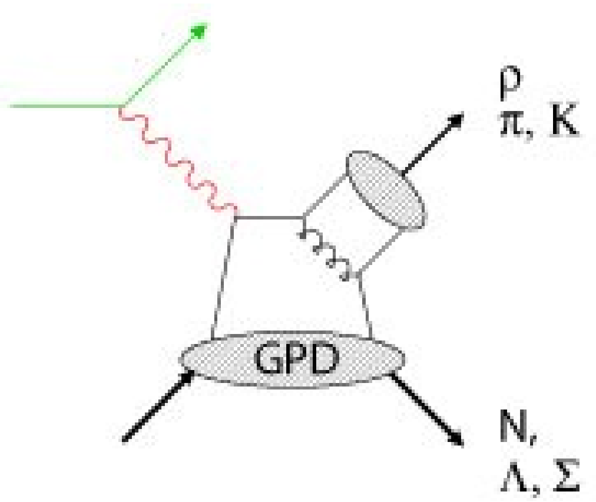
Status and conclusions

- Running to continue ...
- 100+ days approved
- Run time already scheduled/planned for 2016
- Scaling test of DVCS cross section for leading order factorization confirmation
- Preliminary analysis of data continues: waveform analysis of calorimeter data

Acknowledgements:
DVCS Collaboration
Hall A Collaboration

Thank you

Deeply virtual meson production (DVMP)



- Mesons select definite charge, spin, flavor component of GPD
- Quantum numbers in DVMP probe individual GPD components selectively
- Need good understanding of reaction mechanism
  - QCD factorization for mesons is complex (additional interaction of the produced meson)