Double Deeply Virtual Compton Scattering (DDVCS) at 22 GeV

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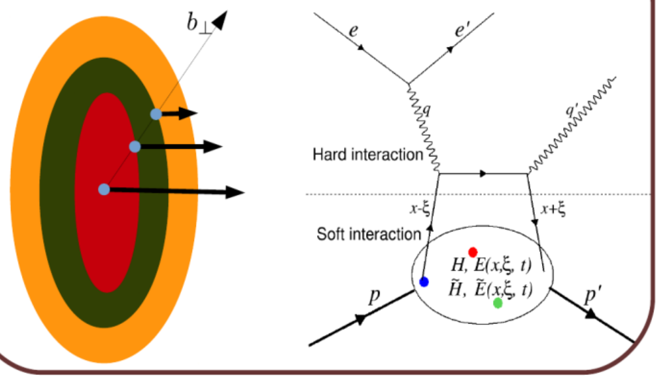
Introduction

Generalized Parton Distributions (GPDs)

Hard Exclusive processes

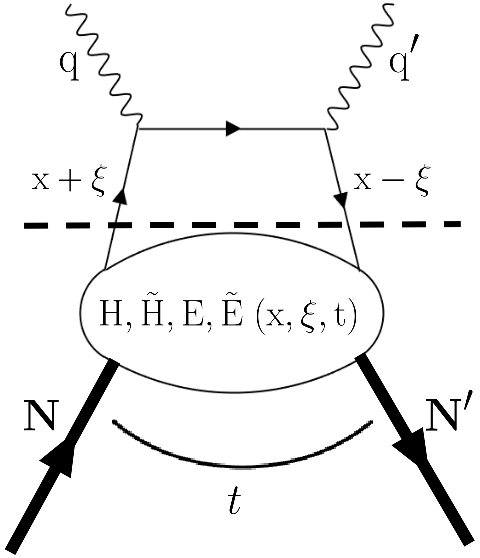


3D Description:

Spatial (2D) + longitudinal momentum (1D) distribution of partons inside the nucleon.

One of Flagship programs of JLab at 6 GeV and 12 GeV .

More than a dozen of dedicated experiments (completed and planned), @ 6 GeV, @12 GeV and w/ e+ beam.



Factorization works if there is a hard scale and relatively small 4 momentum transfer to the hadron

$$\frac{t}{Q^2 \text{ or } Q'^2} << 1$$

Depend on three variables **x**, ***ξ*** and **t**

In the forward limit ($\xi \to 0$, $t \to 0$) they reduce to PDFs.

$$\mathrm{H^q(x,0,0) = q(x) - \bar{q}(x)}$$
$$\mathrm{\tilde{H}^q(x,0,0) = \Delta q(x) - \Delta\bar{q}(x)}$$

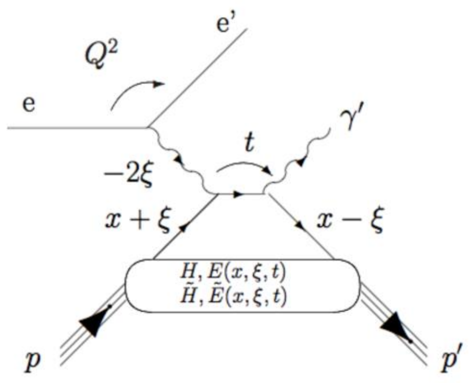
First moments of quark GPDs are related to the Dirac, Pauli, axial, and pseudoscalar form factors

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

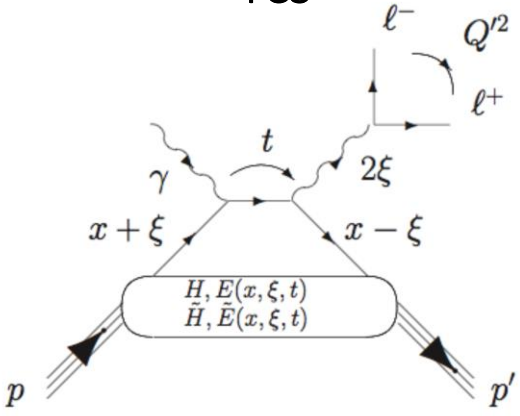
$$\int_{-1}^{1} \mathrm{dx \tilde{H}^q(x,\xi,t) = g_A^q(t)} \qquad \int_{-1}^{1} \mathrm{dx \tilde{E}^q(x,\xi,t) = h_A^q(t)}$$

How to access GPDs experimentally

DVCS



TCS



- First measurement reported **in 2001**: *Phys.Rev.Lett.* 87 (2001) 182002

Followed measurements:

- JLab (Halls A, B and C) + HERMES + COMPASS
- Beam and Target Spin asymmetries
- X-sec measurements
- Nuclear targets
- Different reactions: DVCS, DVMP, TCS

However, Extraction of GPDs from measurements is challenging.

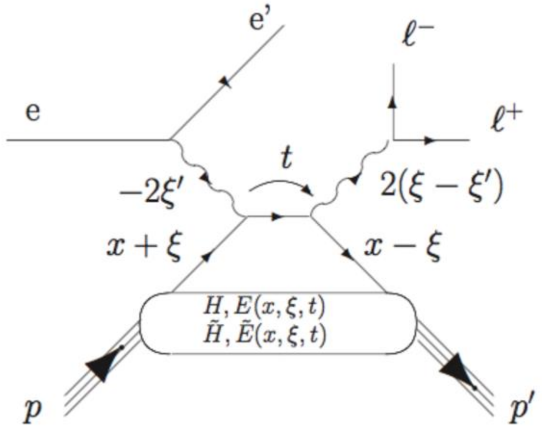
DVCS/TCS amplitudes are proportional to

$$\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\epsilon} + \cdots \text{ Same for } (\tilde{H}, E, \tilde{E}) \qquad PV\left(\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}\right) - i\pi H(\xi,\xi,t)$$

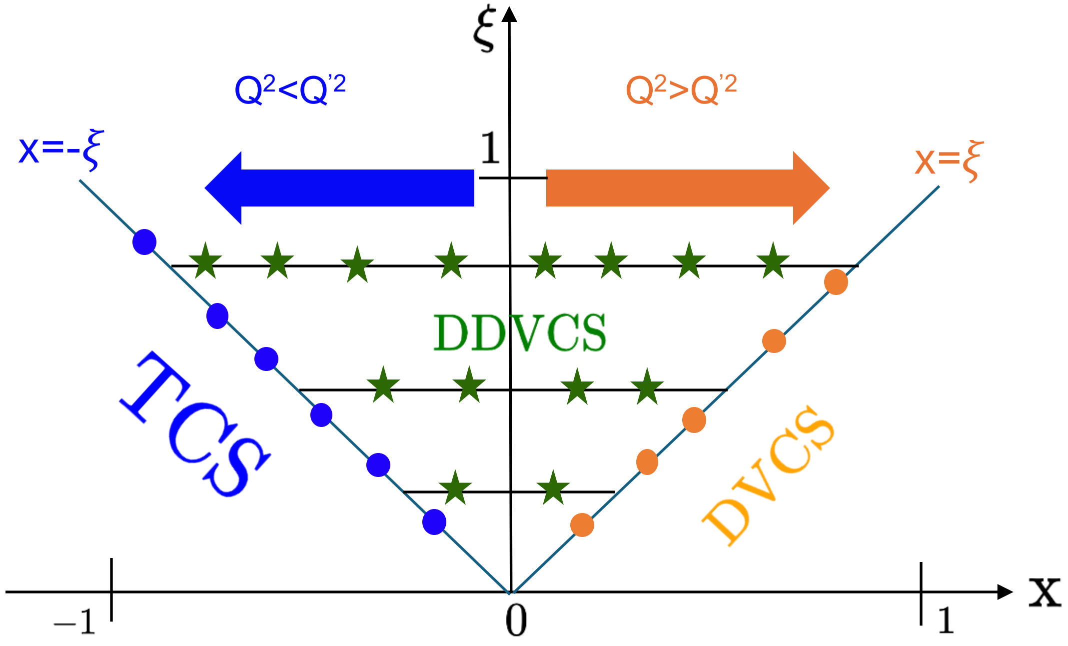
- GPDs enter observables as an integral over **x**, with an exception when the observable is proportional to the Im part of the scattering amplitude.
- There one access GPDs at x=ξ
- Certainly, an important gain of information, however, not enough to independently map out GPDs.

The way to avoid integration over x outside the x=ξ phase space is DDVCS, which allows mapping GPDs along all three variables (x, ξ, and t) independently.

Double **DVCS**: accessing GPDs at x≠ξ point



Kinematics of two photons are described by ξ and ξ'.



$$\xi' = \frac{x_B}{2 - x_B}$$

$$\xi = \xi' \frac{Q^2}{Q^2 + Q'^2}$$

$$x = 2\xi' - \xi$$

Quark propagators between two photons now reads as:

$$\frac{1}{x - (2\xi' - \xi) + i\epsilon} + \frac{1}{x + (2\xi' - \xi) - i\epsilon}$$

Observables (e.g. BSA) proportional to the Im part of the amplitude, allow direct measurement of GPDs at ($x=2\xi' - \xi$, ξ, t) points.

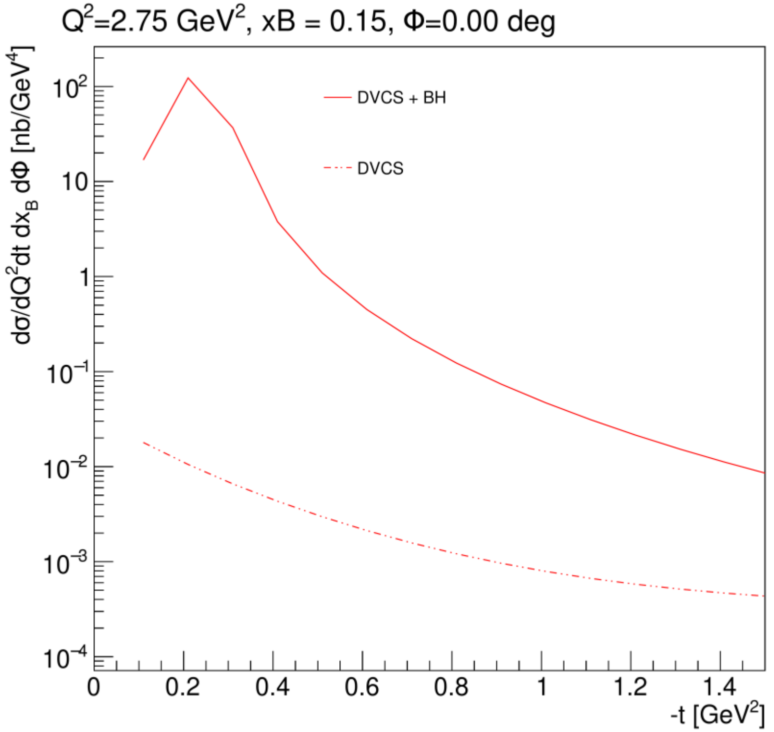
Here one can get away from the $x=\xi$ line by varying virtualities of incoming and outgoing photons

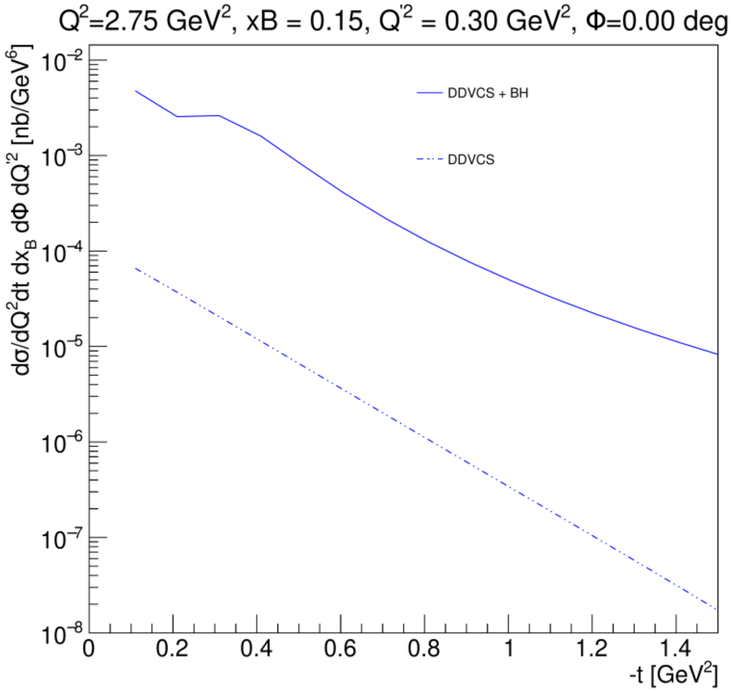
Cross-sections

The challenge of the DDVCS is it involves an additional α which makes the DDVCS cross-section 2-3 orders of magnitude smaller than the DVCS cross-section.

With standard CLAS12 detector package it is unrealistic to get sufficient statistics in a reasonable data taking time

12 GeV kinematics





Using M. Guidal's code

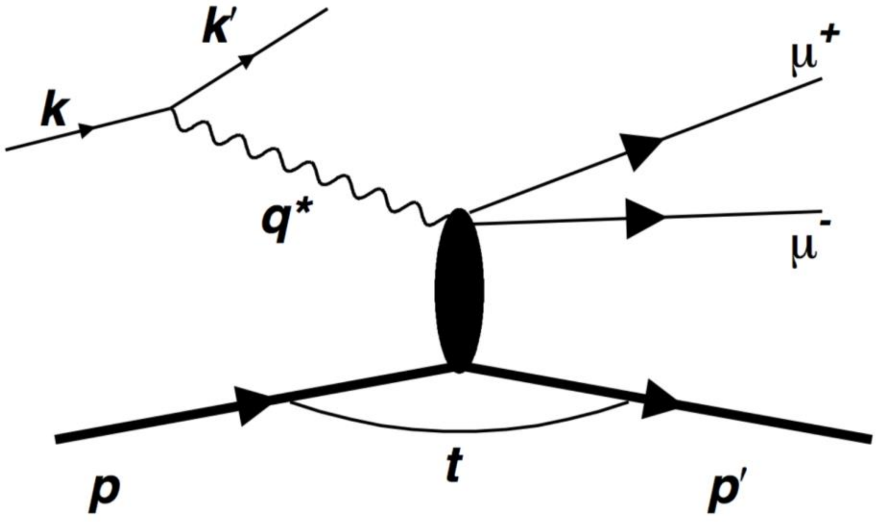
Luminosity upgrade is a must for a DDVCS measurement.

The proposed measurement

- SoLid and High Lumi upgraded CLAS12 are ideal place to carry out the experiment.
  - **High Lumi (>10^{37}cm^{-2}s^{-1})**
  - **Large acceptance**
- DDVCS with μCLAS12: LOI12-16-004
- DDVCS with SoLID: LOI12-23-012

Both experiments will detect same final state.

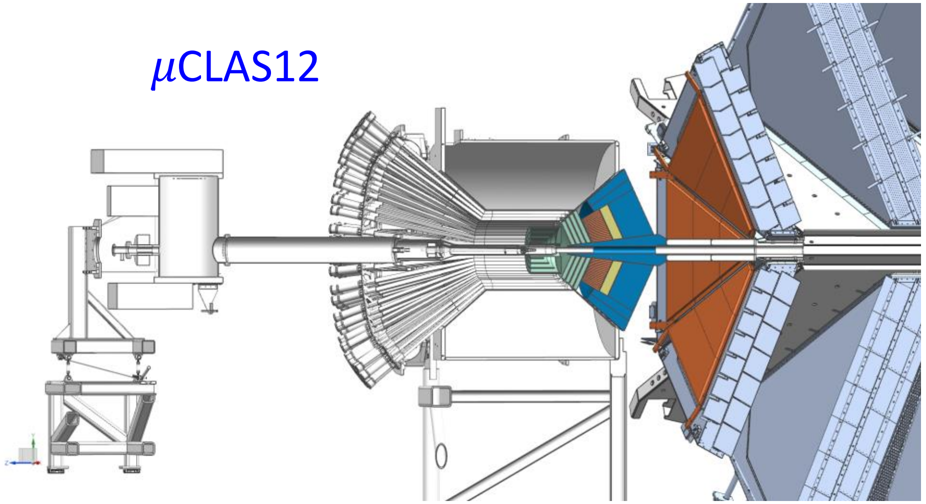
The reaction of interest is ep → e′$\boldsymbol{\mu}^{-}\boldsymbol{\mu}^{+}$p



- The timelike photon is identified through the detection of $\boldsymbol{\mu}^{-}\boldsymbol{\mu}^{+}$ pair (to avoid the Interference between the beam and the decay electron.)
  - Requires a muon detection
- Proposed Luminosity: 10^{37} cm^{-2}s^{-1}.
- We plan to detect at least e′$\boldsymbol{\mu}^{-}\boldsymbol{\mu}^{+}$, and the proton kinematics will be deduced from the missing momentum analysis, when the proton is outside of the acceptance.

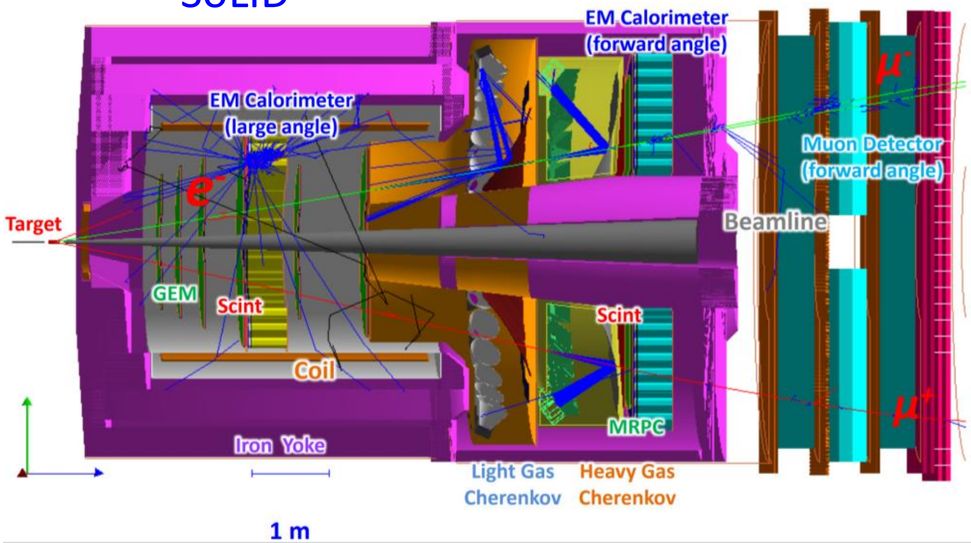
Detector configurations

μCLAS12



- Modest modification of the CLAS12 detector
- Take out HTCC, CVT and CTOF
- New Electromagnetic calorimeter for electron detection
- New Tungsten absorbers for suppressing all electromagnetic background coming from the target
- Electron polar angle (7°-30°), full azimuthal coverage
- Muons starting 7° up to around 40°.

SoLID



SoLId picture from Z. Zhao

The SoLID apparatus completed with muon detectors at forward angle, enables DDVCS measurements with both polarized electron and Positron beams at 11 and 22GeV

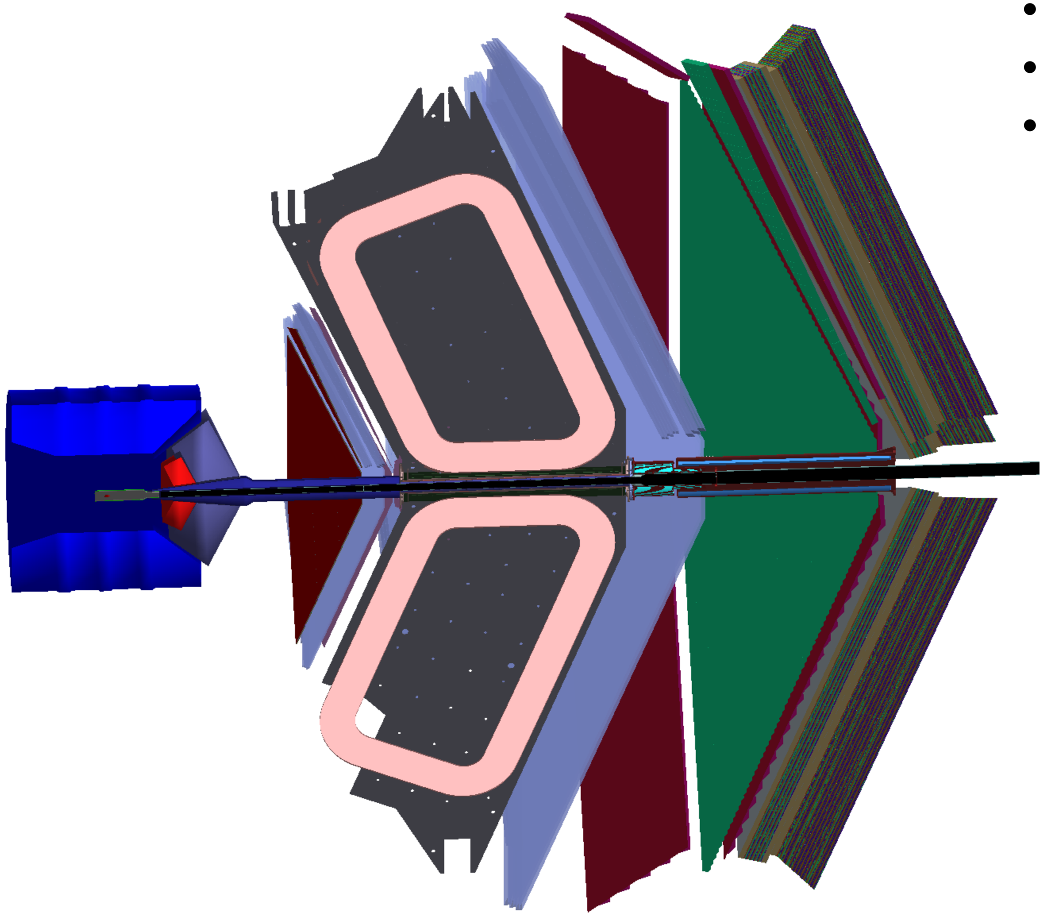
- Lumi > $10^{37} cm^{-2} s^{-1}$
- Electron polar angle 8°-28°
- Muon polar angle 8°-15°
- Full azimuthal coverage

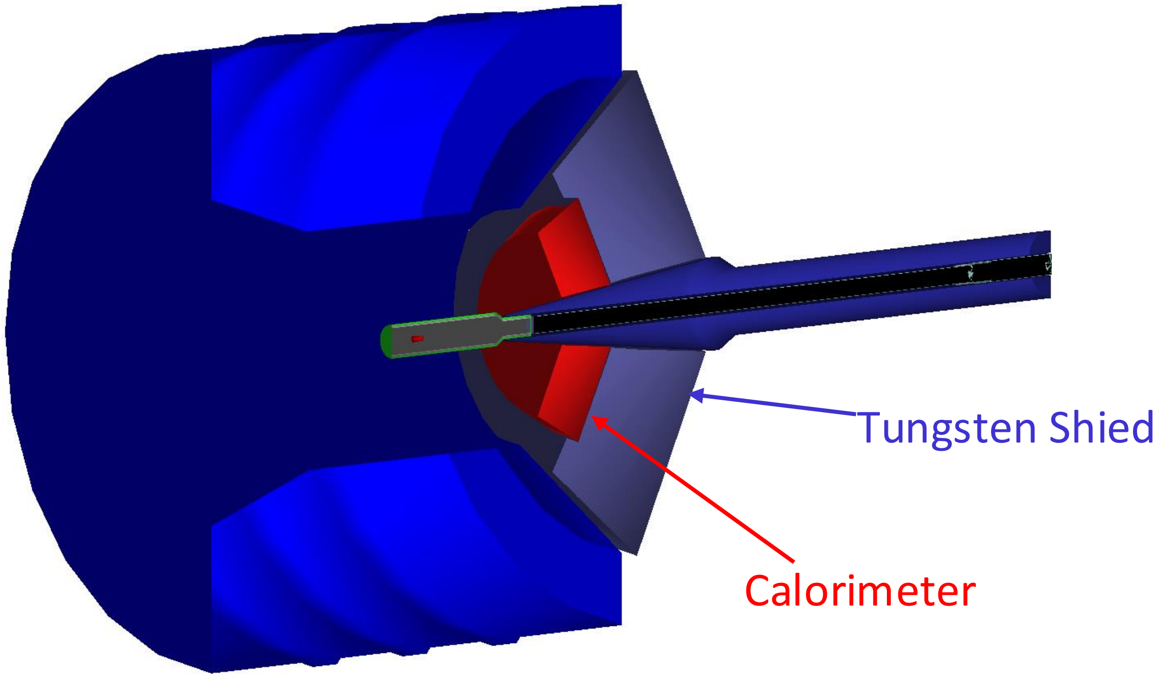
Geant4 simulations

- The detector model is in GEMC (Thanks to Mauri and Raffaella)
- Reconstruction of muons is done through full CLAS12 offline reconstruction software (coatjava)

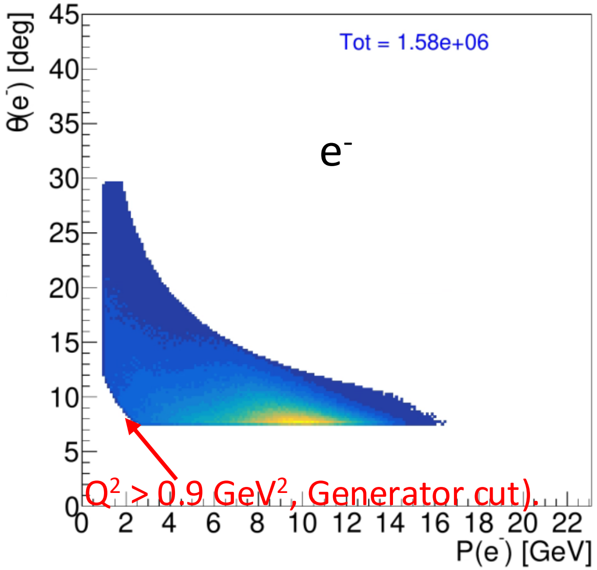
- BH: $ep \to \mu^- \mu^+ p$
- Quasi-elastic dileptons: $ep \to \mu^- \mu^+ pX$
- $ep \to \boldsymbol{\rho}(\hookrightarrow \mu^- \mu^+)p$
- $ep \to \boldsymbol{\rho}(\hookrightarrow \pi^- \pi^+)p$

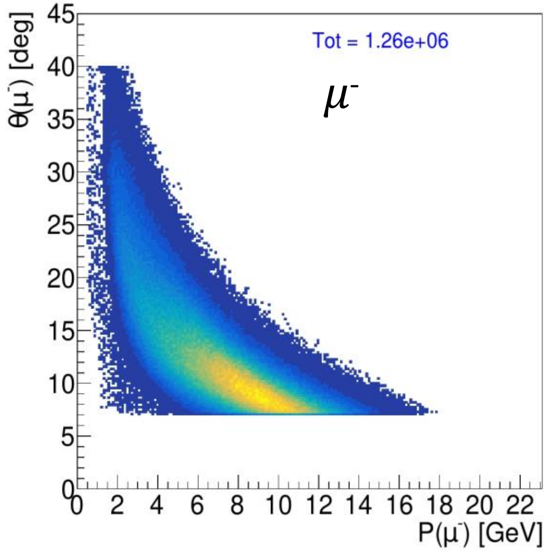
Thanks to Harut

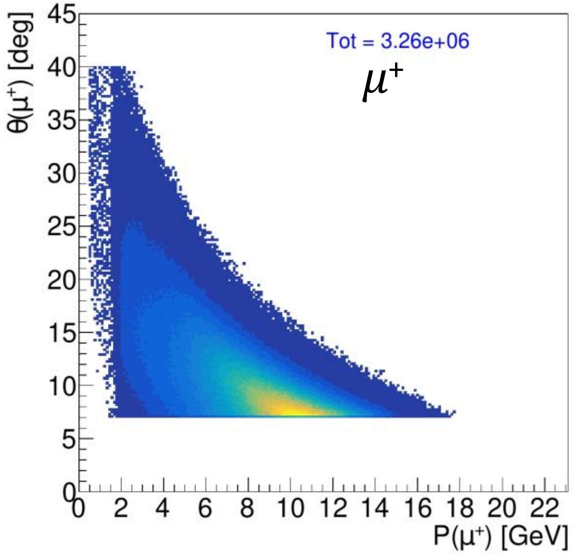


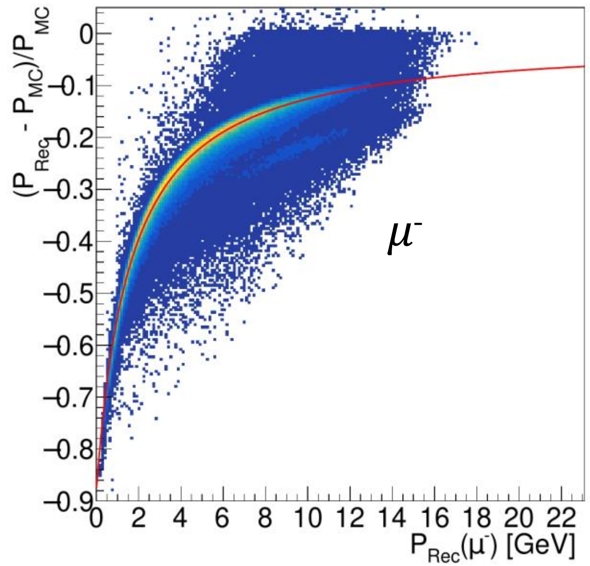


Reconstruction: 22 GeV simulations



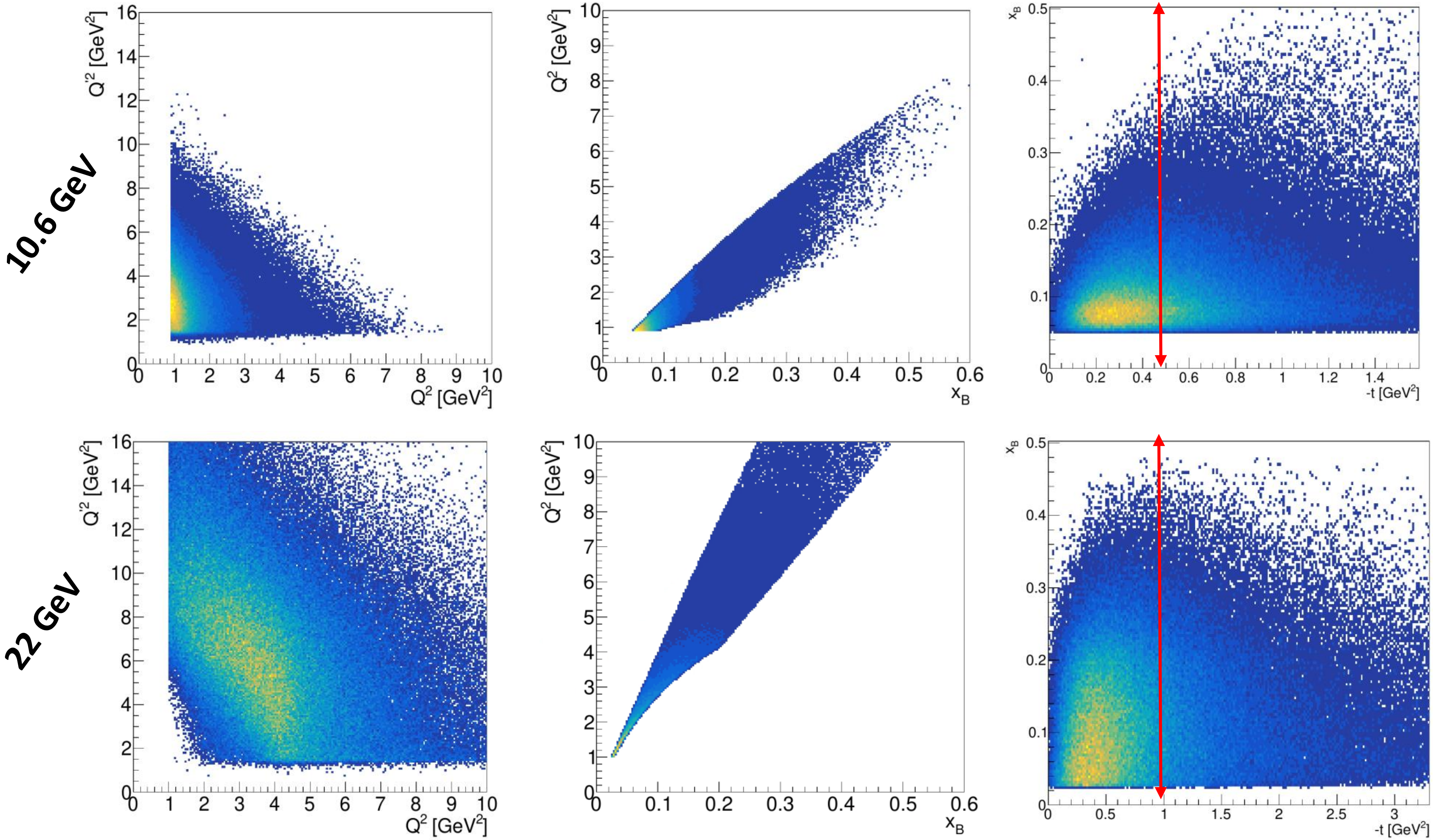






- As it is not surprising there is a big energy loss.
- Each muon momentum is corrected accordingly
- Generated muon angles used, as tracking detectors close to the vertex will provide precise angular measurements.

Kinematic distributions

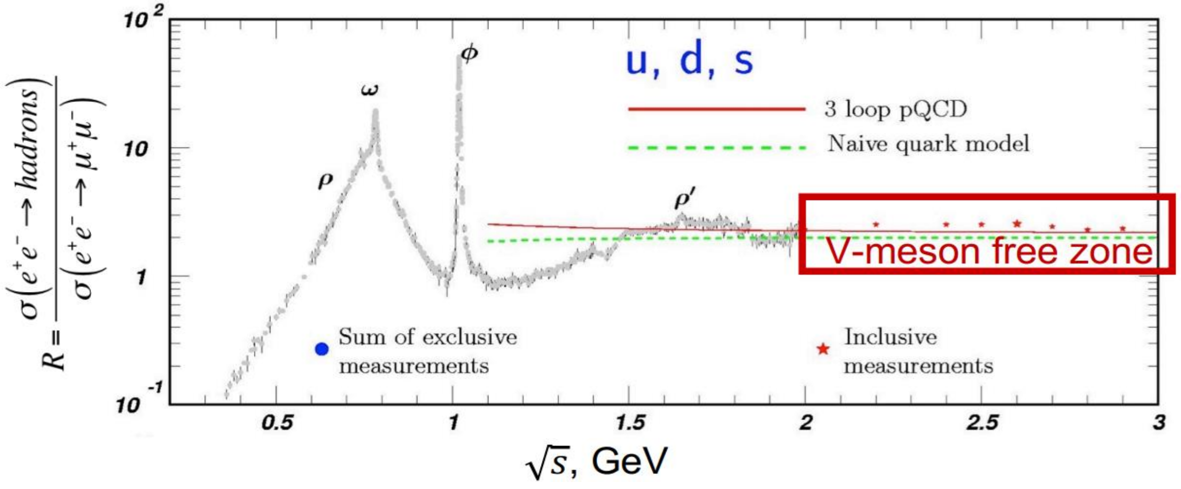


22 GeV covers larger kinematic region.

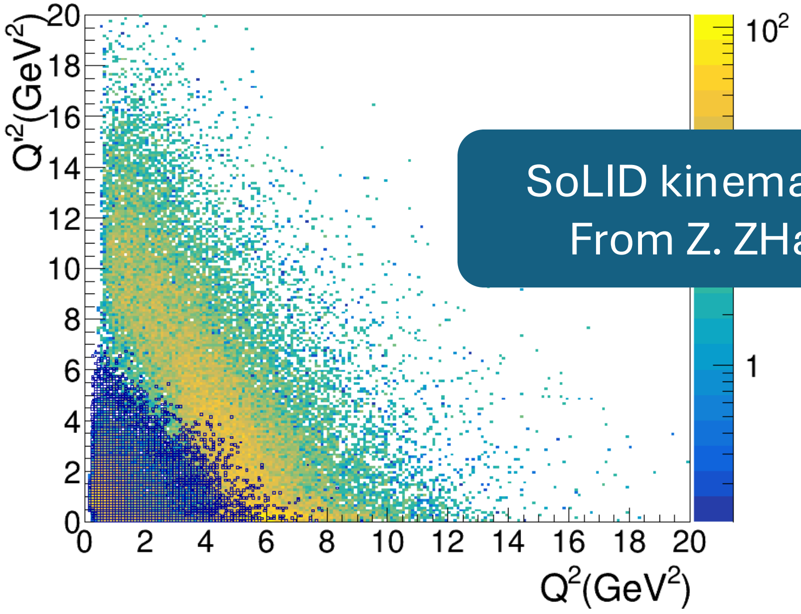
$-t < 0.5$ GeV^2 for 10.6 GeV

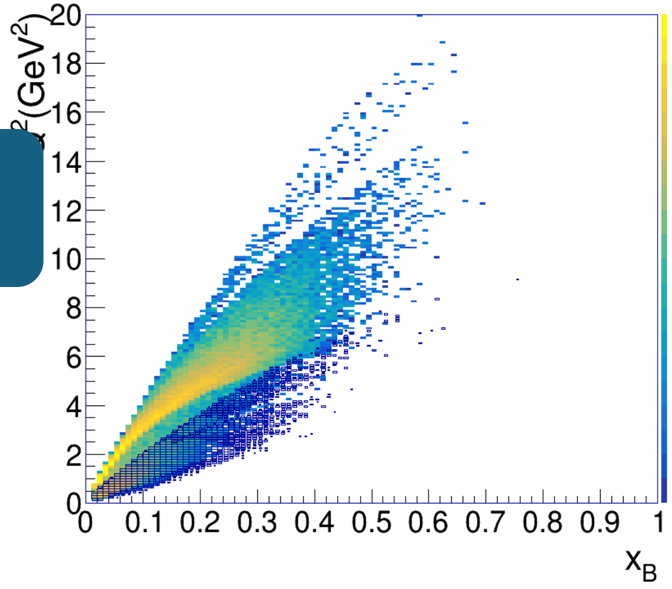
$-t < 1$ GeV^2 for 22 GeV

Why do DDVCS at 22 GeV



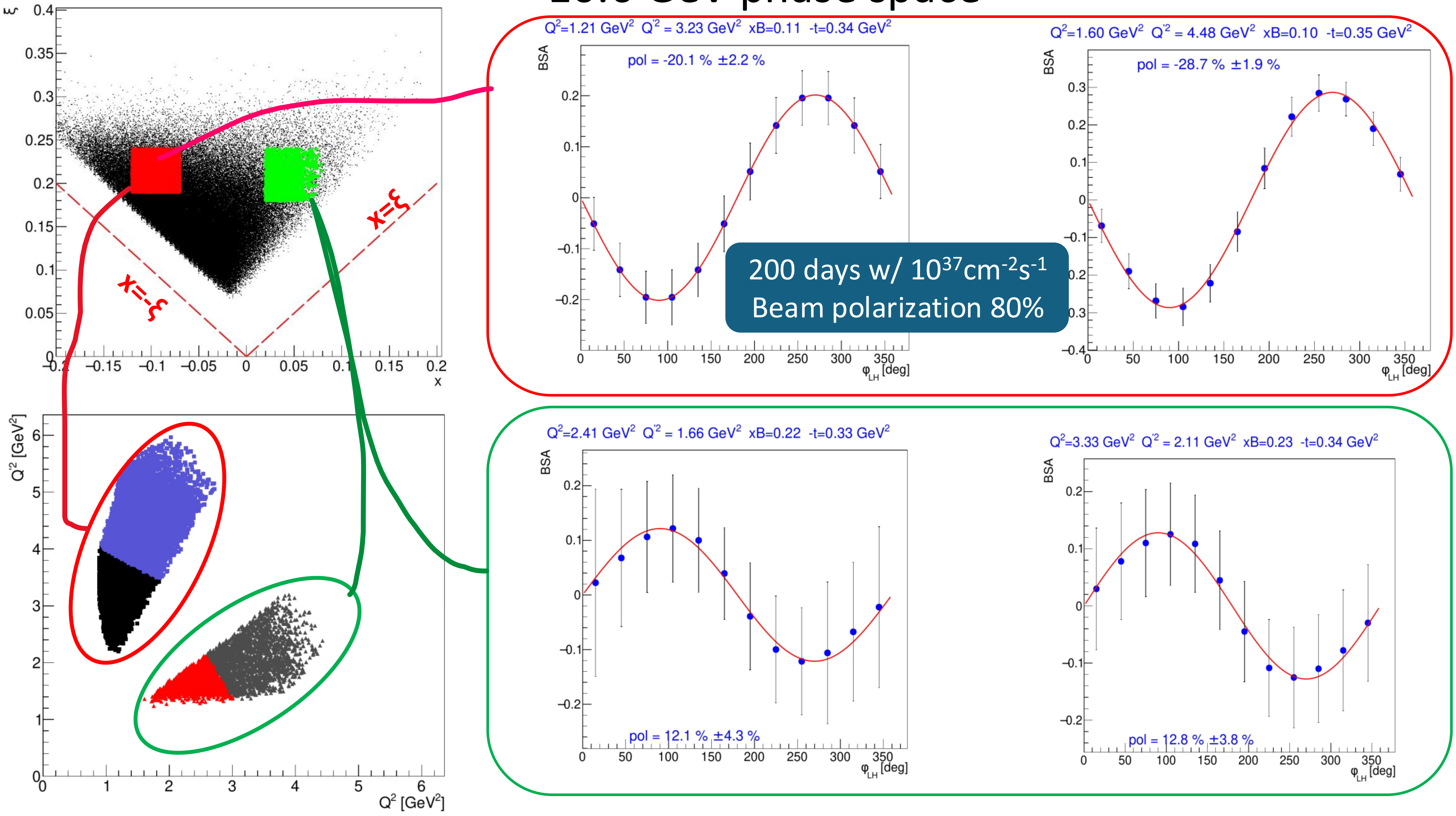
- With 22 GeV The resonance free [2 – 3] GeV region is more accessible.
- 22 GeV provides larger coverage on Q2 as well.
- Allows to test the scaling and evolution of GPDs
- Study higher twist effects



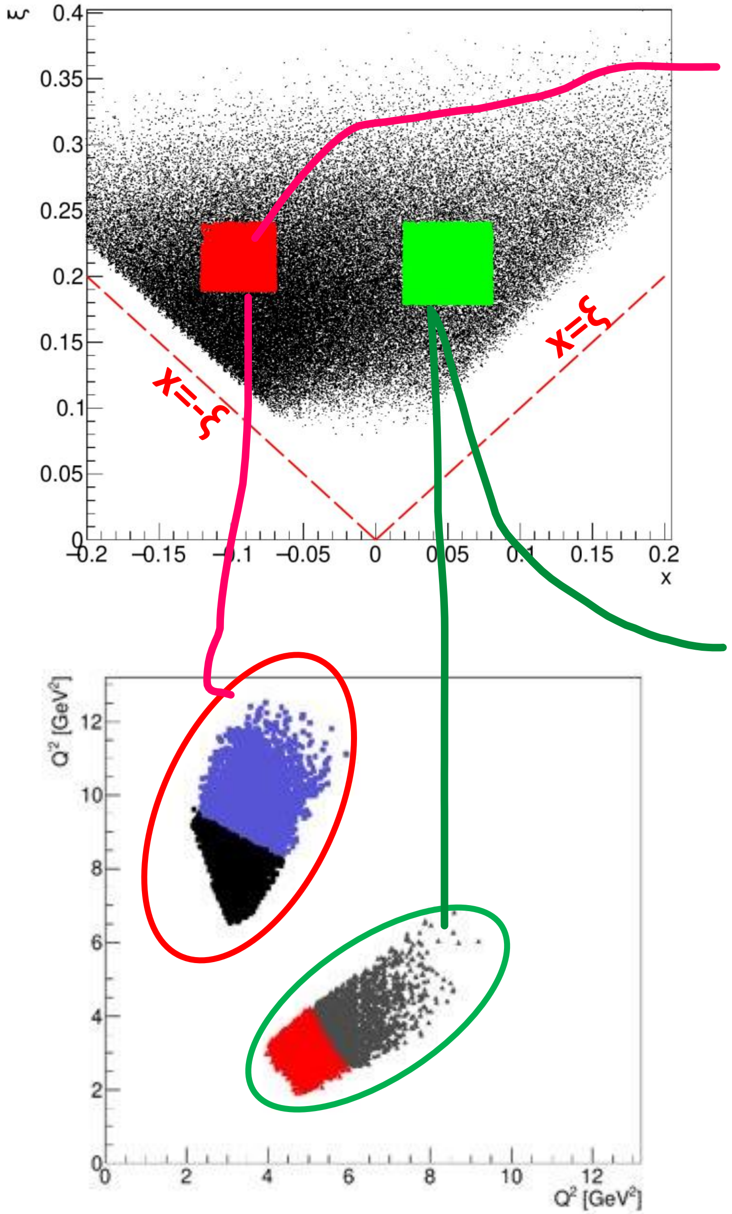


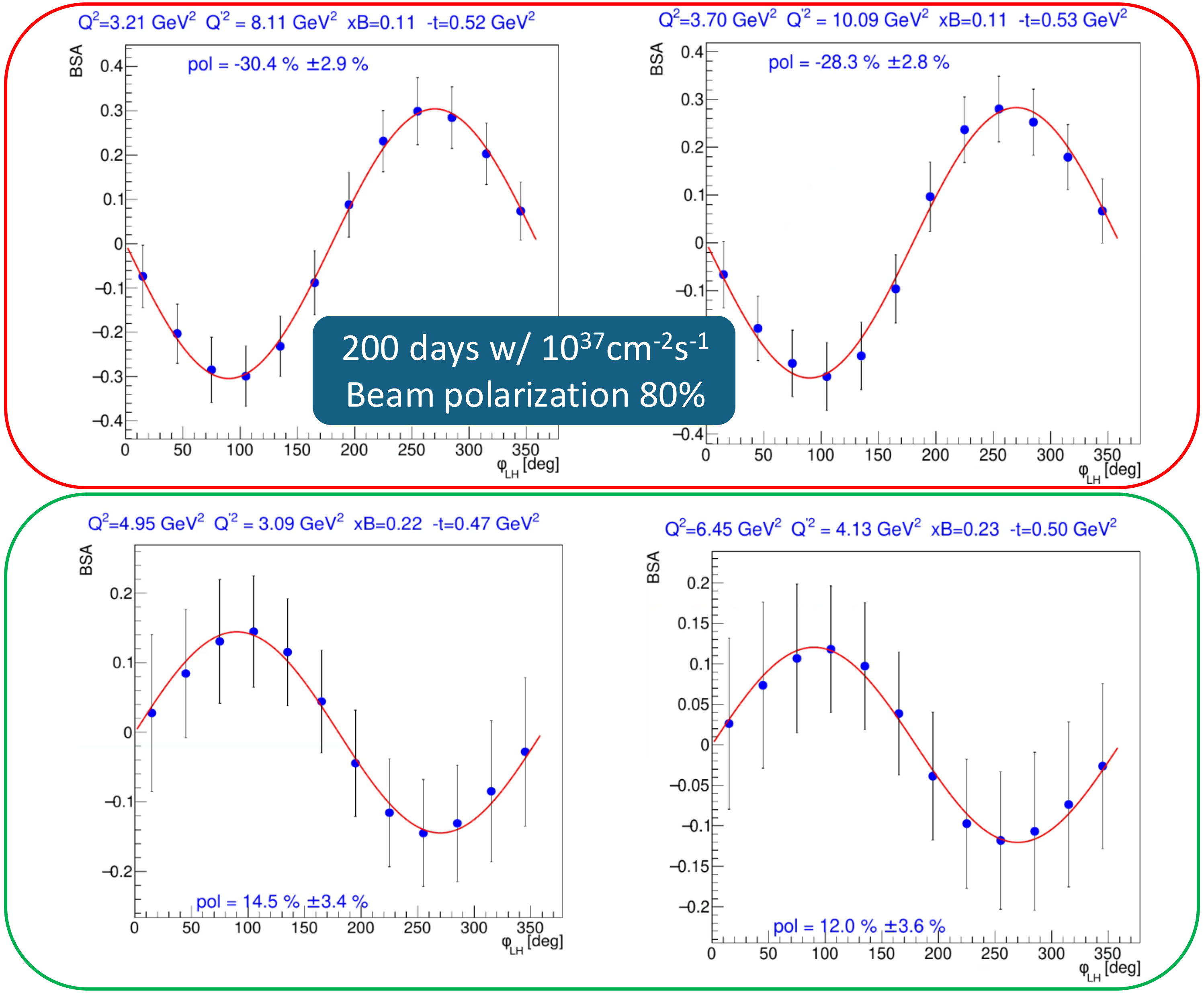
SoLID kinematics
From Z. ZHao

10.6 GeV phase space



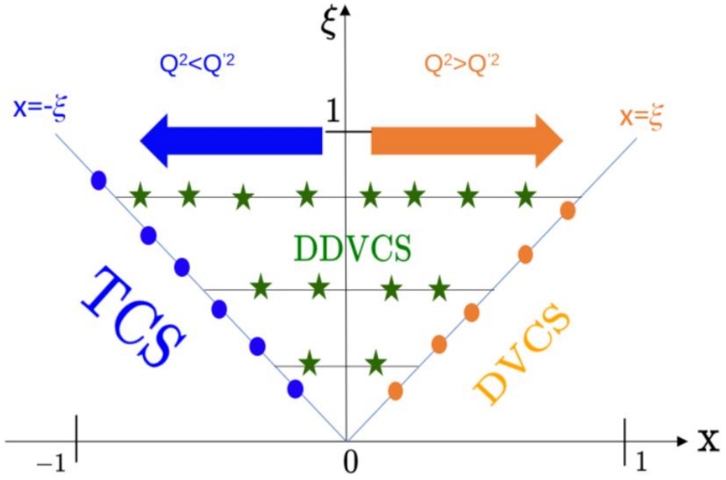
22 GeV phase space

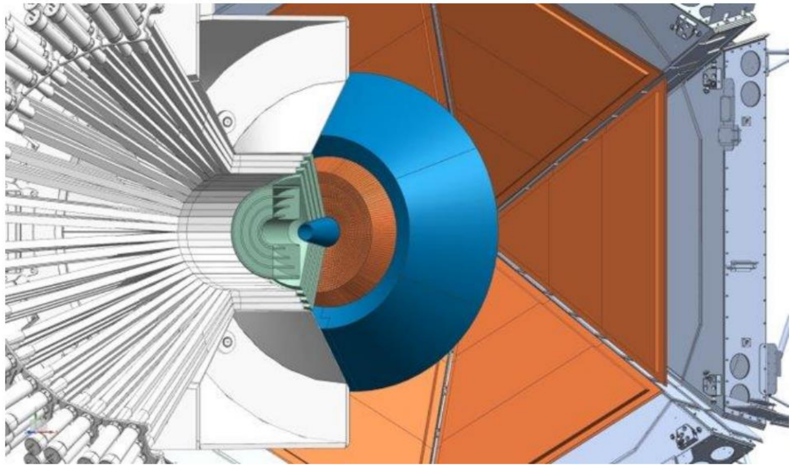


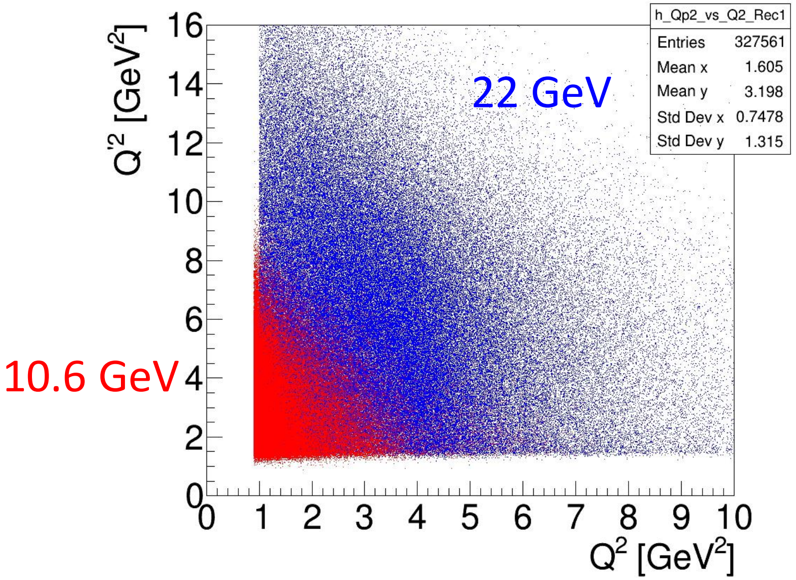


Summary

- DDVCS is an important process which allows to access GPDs away from the x=±ξ line
- Has never been measured because of its very small cross section.
- JLab with High Luminosity facilities (CLAS12 and SoLID) is an ideal place to carry out the experiment.
- Detectors will not need upgrade to go from 10 GeV to 22 GeV.
- 20+ GeV upgrade allows to reach higher Q2 .
  - Test evolution and scaling of GPDs
  - Study higher twist effects

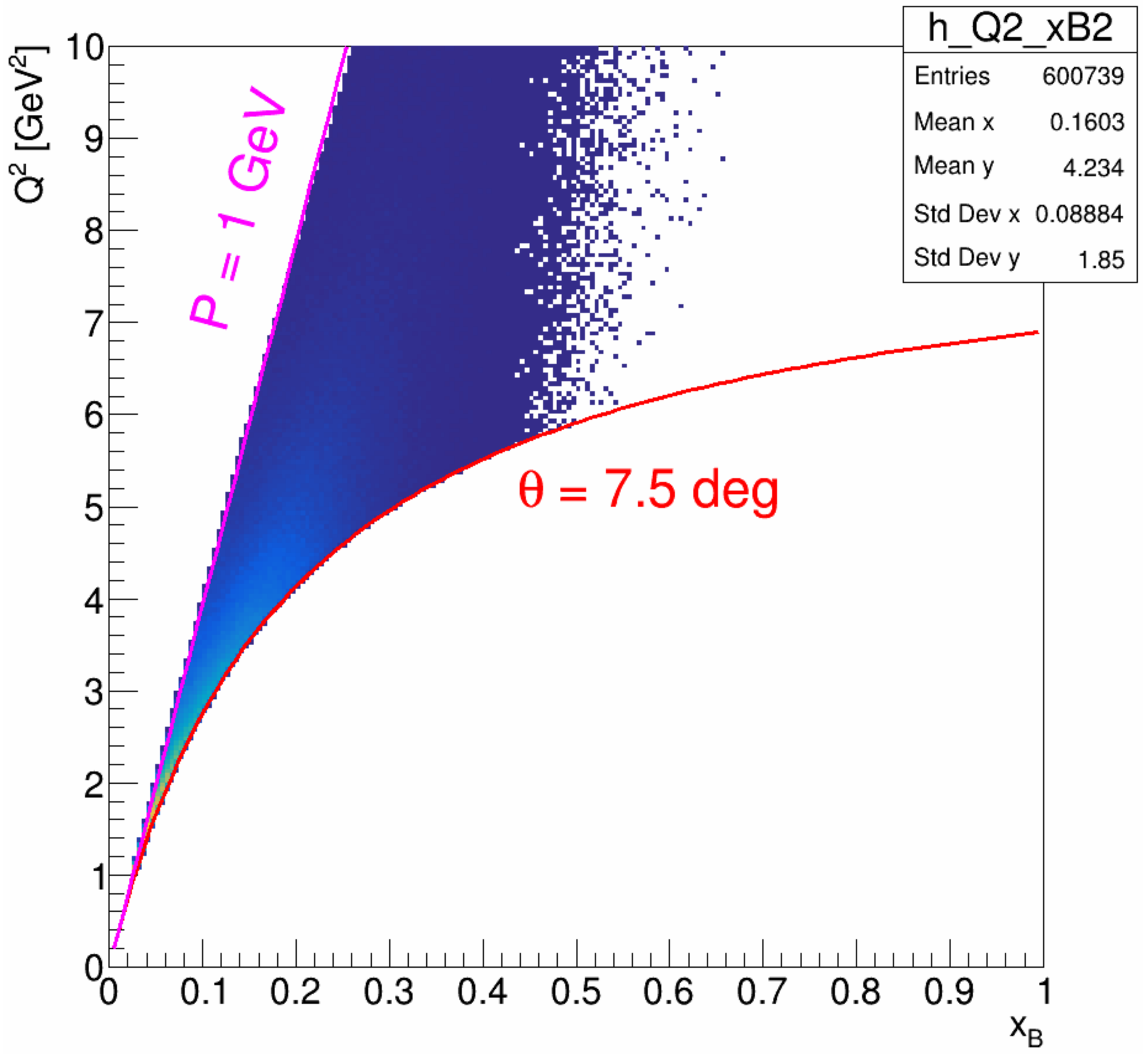


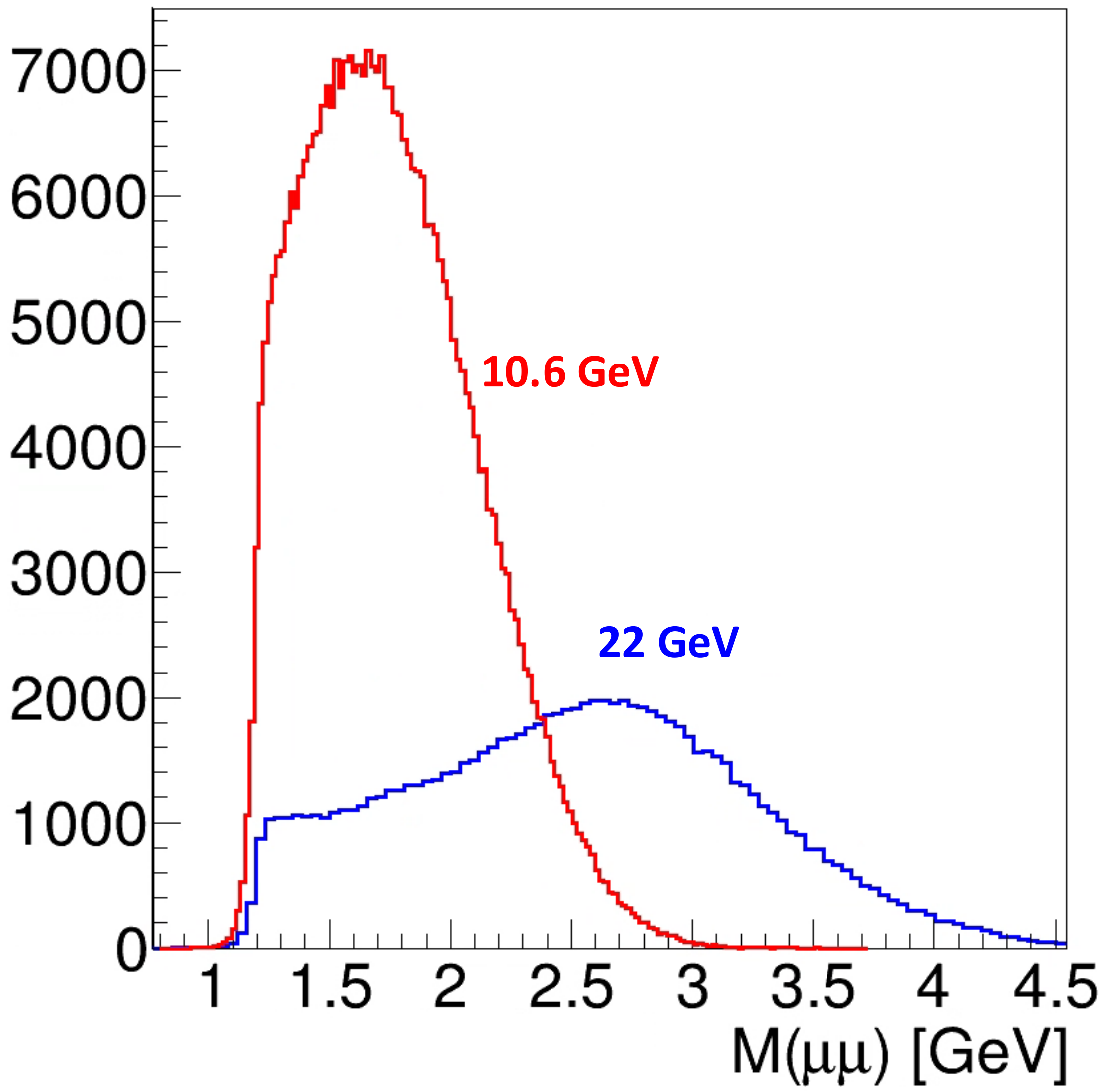


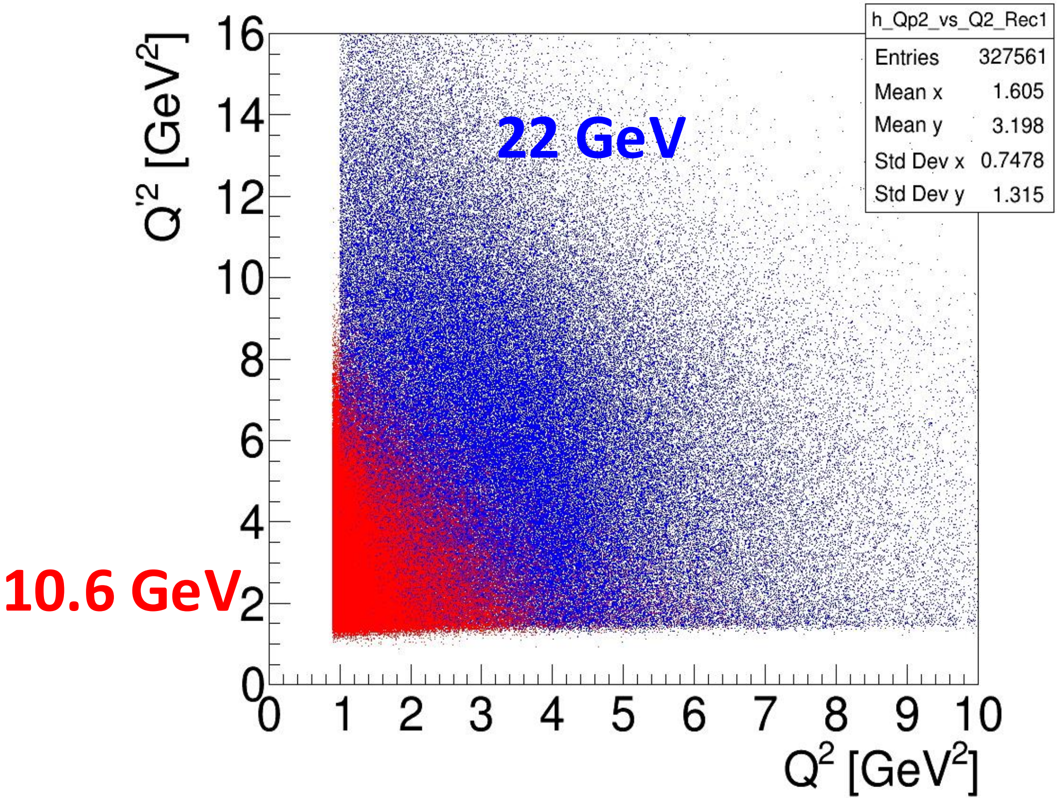


Backup

22 GeV kinematics

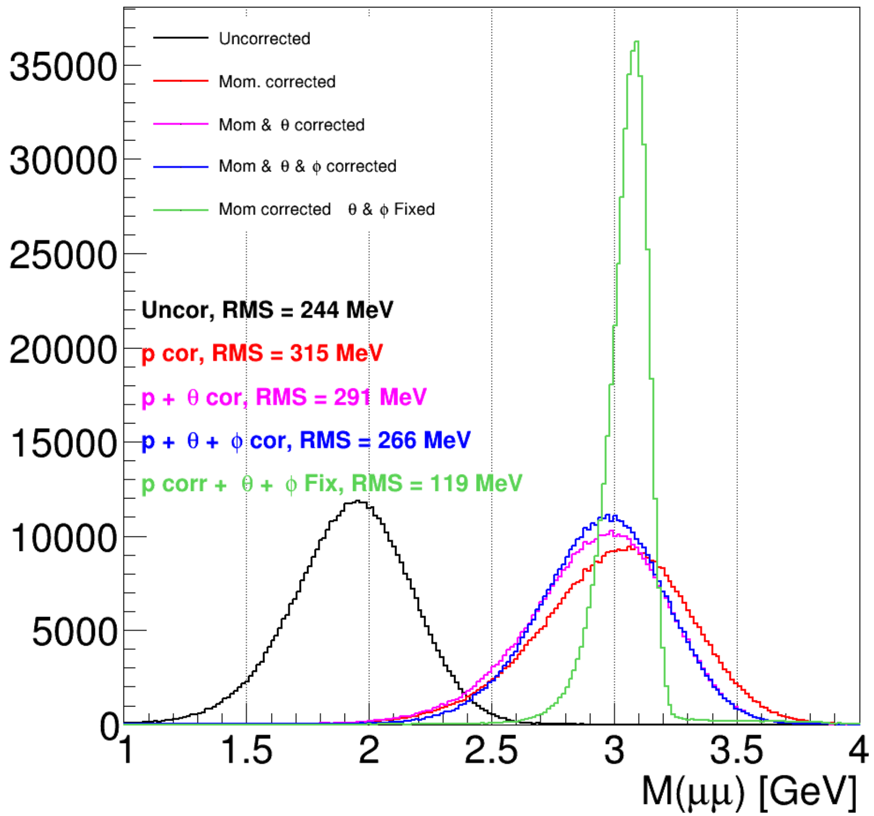



7000
6000
5000
4000
3000
2000
1000
0
1
1.5
2
2.5
3
3.5
4
4.5
M(μμ) [GeV]
10.6 GeV
22 GeV

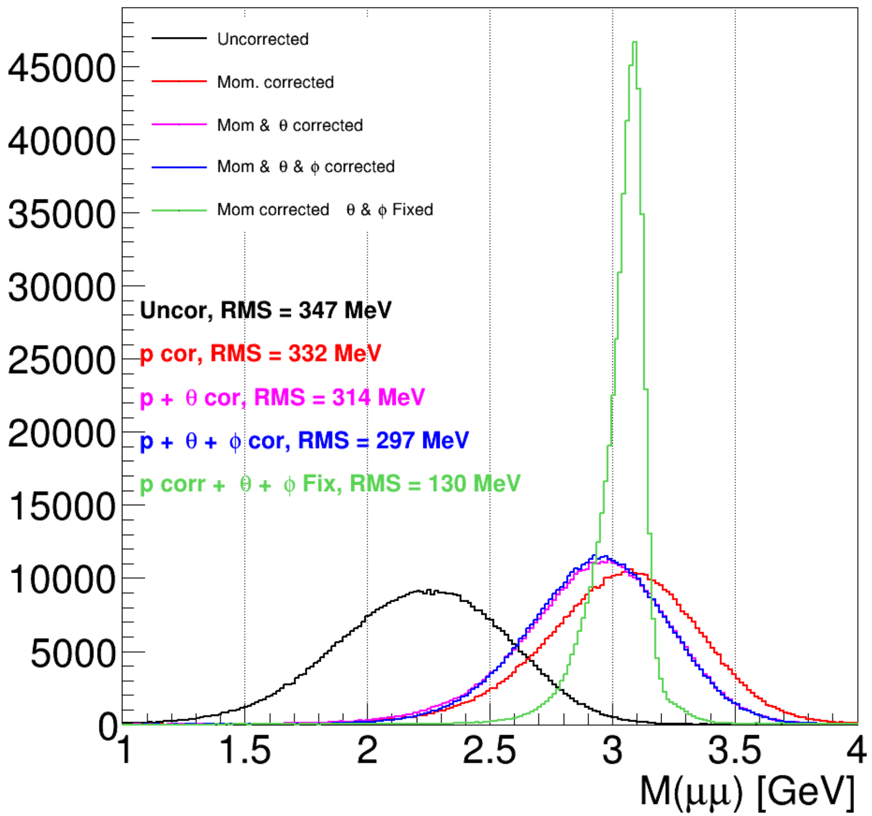

h_Qp2_vs_Q2_Rec1
Entries 327561
Mean x 1.605
Mean y 3.198
Std Dev x 0.7478
Std Dev y 1.315
Q'2 [GeV2]
Q2 [GeV2]
22 GeV
10.6 GeV
0
2
4
6
8
10
12
14
16
1
3
5
7
9

J/psi

Eb = 10.6 GeV

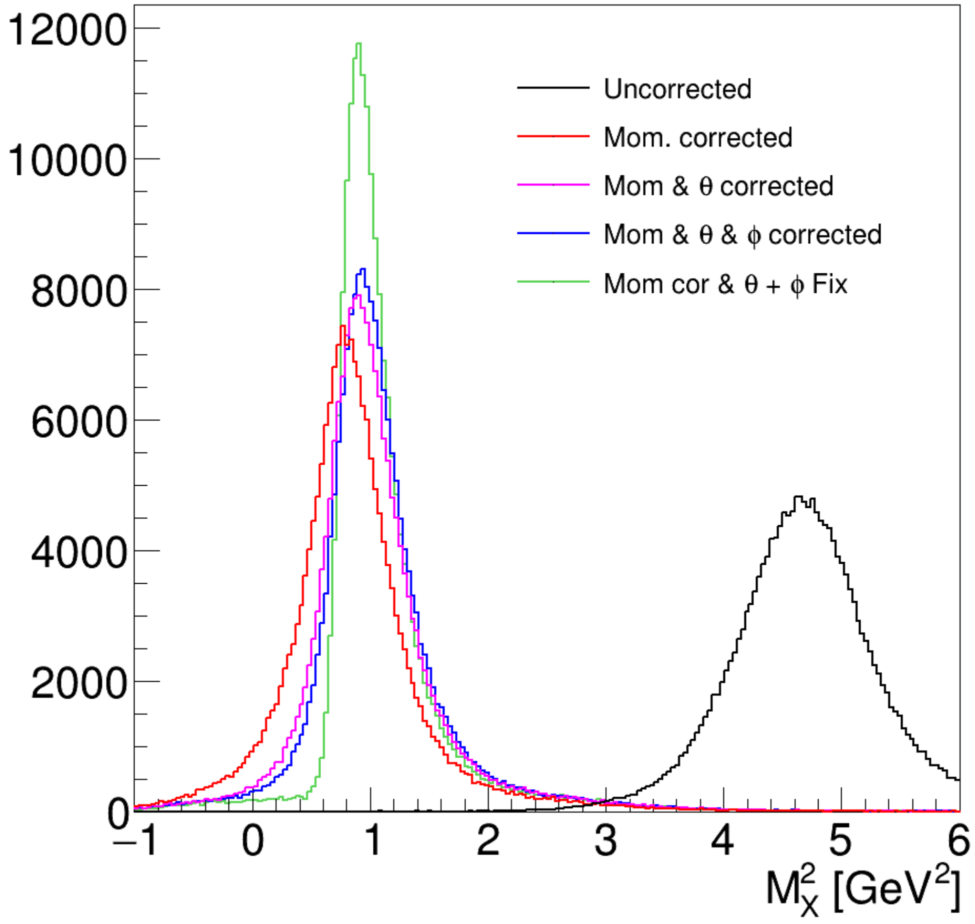


Eb = 22 GeV



With tracking detectors in front of the target, we should be able to significantly improve the mass resolution

Missing mass

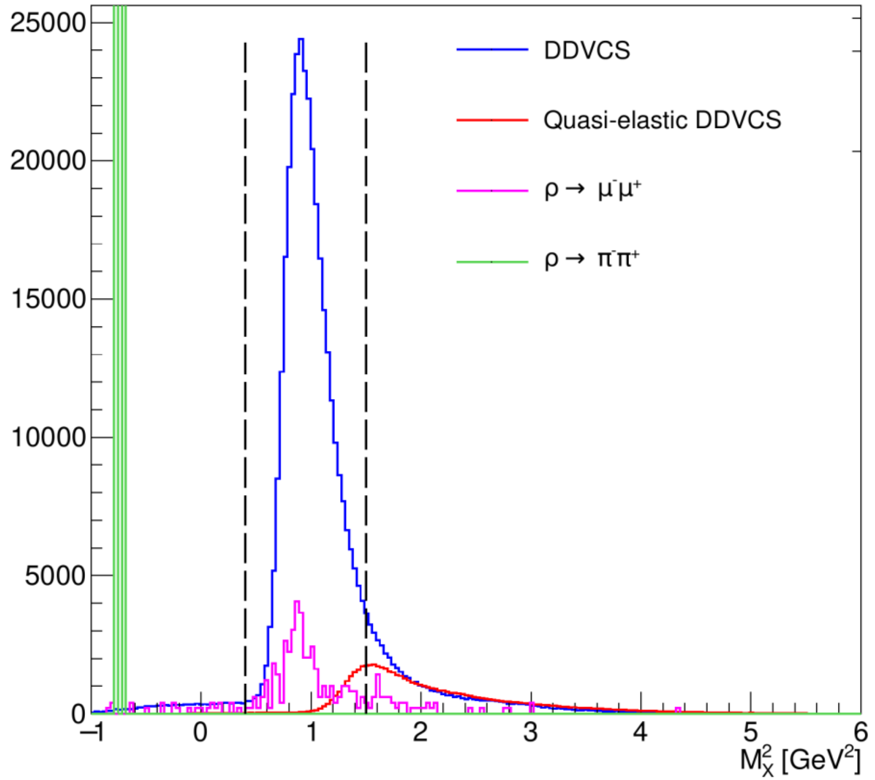


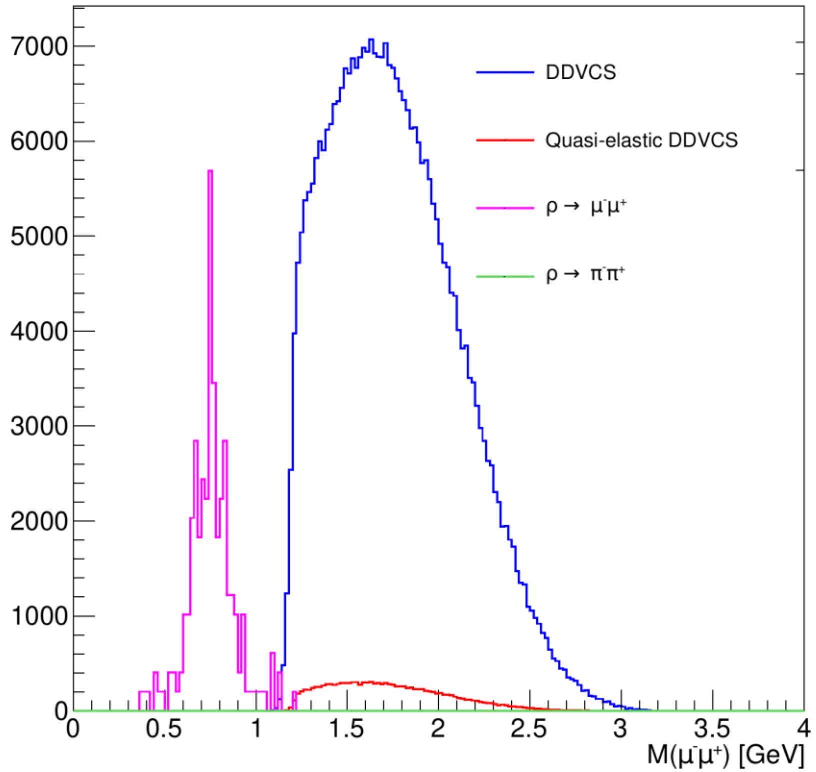
- The effect of the momentum correction is huge (as it is expected)
- Assuming no vertex detectors, angular corrections also improve the missing mass resolution, but not too much
- Installing vertex detectors will significantly improve the missing mass.

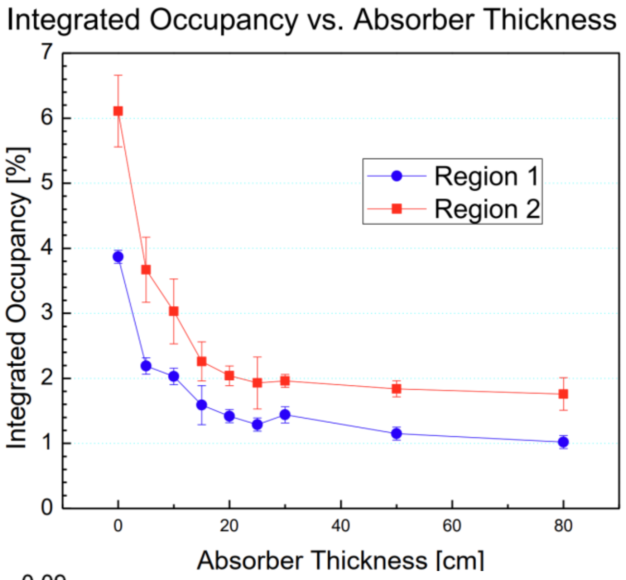
Applying the missing mass cut

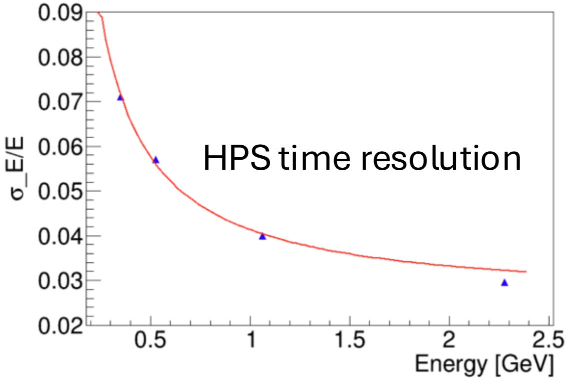
All simulations are normalized by their x-sec and 200 days of running at $10^{37} cm^{-2} s^{-1}$.

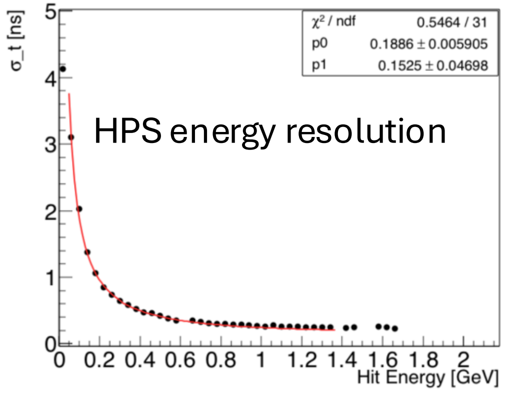
- ρ->π-π+ : No event pass the missing mass cut.
- ρ->μ-μ+ : They are well inside the missing mass cut, however no contributions above M > 1.2 GeV.
- Quasi-elastic: about 30% of quasi-elastic leak into the missing mass cut, making about 5% contamination. Those are mainly π^0s, and can be accounted for in a similar way as in DVCS analysis.











Particle Rates

- An absorber with a thickness of 30 cm was used to bring DC occupancies to an acceptable level.
- Rates were studied for protons, pions, electrons and photons by placing a scoring plane between 4.8° and 35° at 40 cm from the target.
  - The tot rate from all particles at 5° is less than 0.5 MHz/cm^2.
- Trigger rate:
  - Requiring 5 hits FDC AND MIP signature in calorimeter have 75/95 KHz for positive/negative single tracks:
  - Using a 50 ns coincidence time this translates into about 360 Hz

Electromagnetic calorimeter

- Serves as an additional shielding for EM background.
- 7° – 12°, crystals are 13 mm x 13 mm to keep rates per crystal at an acceptable level
- Above 12°, crystals 20mm x 20 mm will be used
- Readout: APD from the downstream face of crystals
- Similar crystals and readout were used during the DVCS calorimeter, and HPS electromagnetic calorimeter
- Expected rates at 7° is around 1.5 MHz
  - Similar rates were observed in HPS experiment on close to the beam crystals.

Rates on MPGD trackers

- Highest rates at 7° is less than < 0.6 MHz/cm^2