Development (setup) of new muon detector for DDVCS experiment at JLab Hall C

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PARTONIC STRUCTURE OF THE HADRONS

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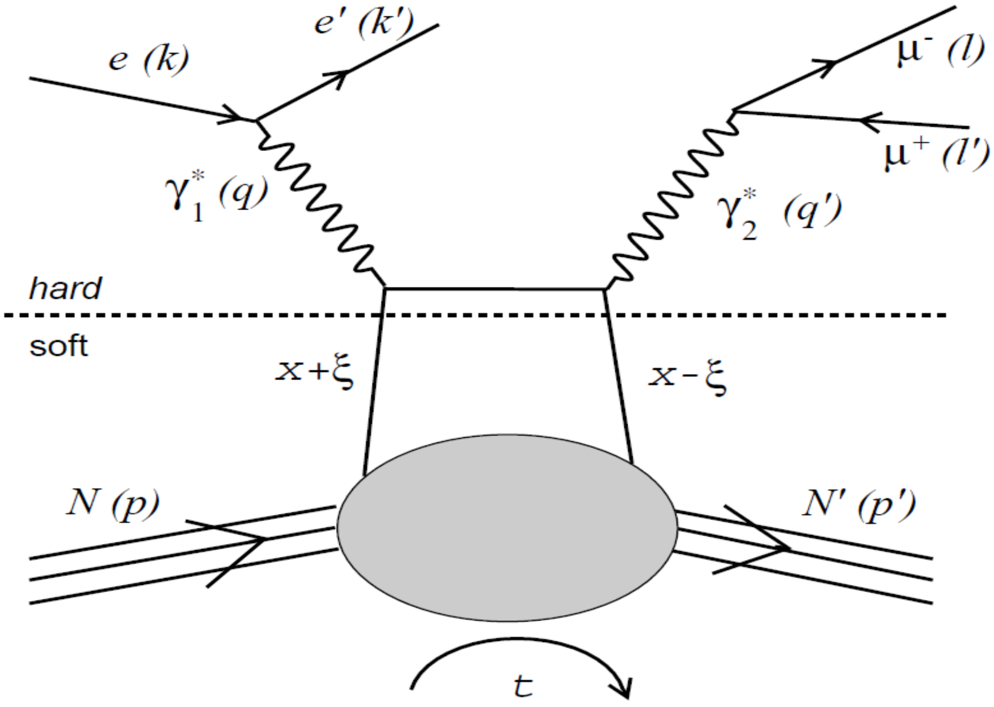
Physics Goals

Double Deeply Virtual Compton Scattering



- Goal: extraction of the Generalized Parton Distributions (GPDs)

- GPDs at $x \neq \pm\xi$

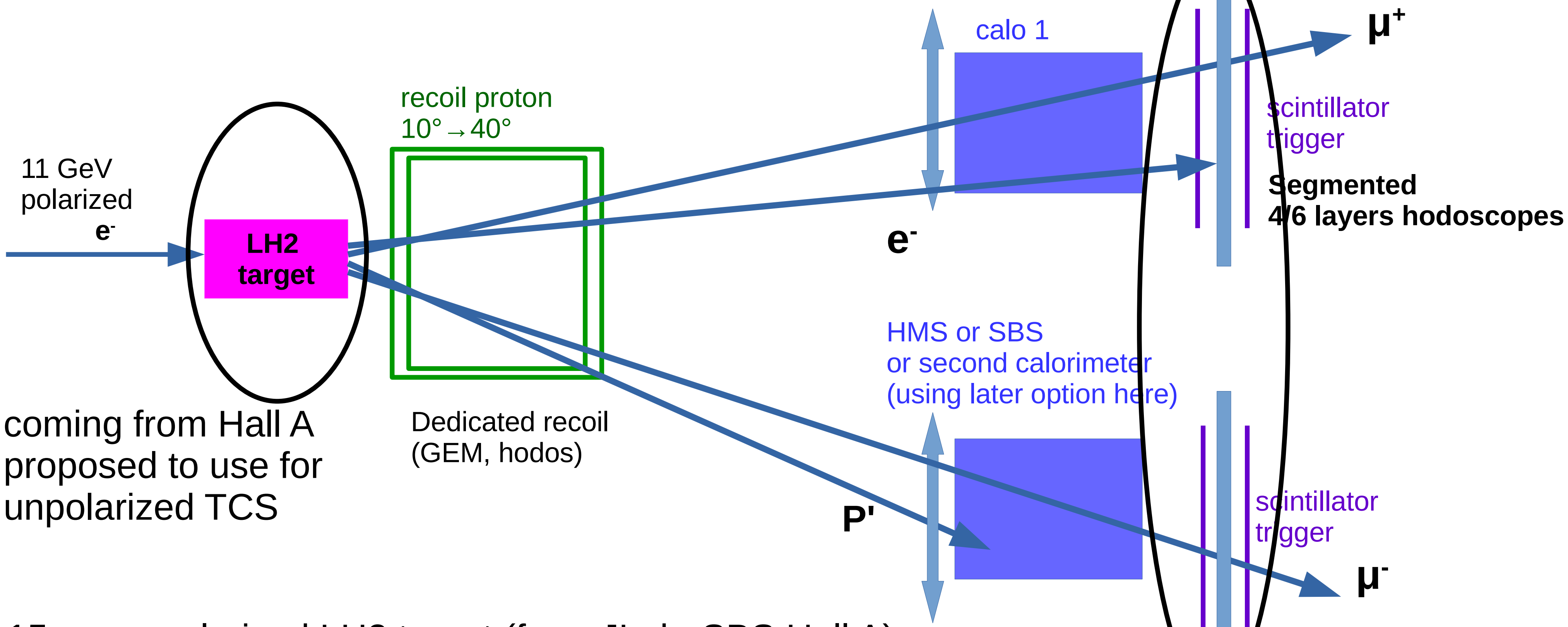
- We have 4 final particles: e', P', and a lepton pair

- We can't reconstruct it with an electron pair, due to beam and scattered electrons having the same kinematics, and to avoid extra anti-symmetrization terms (complicating interpretation and extraction of GPDs)

- Therefore we want to detect a muon pair

$$e(k) - e'(k') + p(p_1) \equiv \gamma^\star(q_1) + p(p_1) \rightarrow p'(p_2) + \gamma^\star(q_2) \rightarrow p'(p_2) + \mu^+(l^+) + \mu^-(l^-)$$

Proposed setup for JLab Hall C

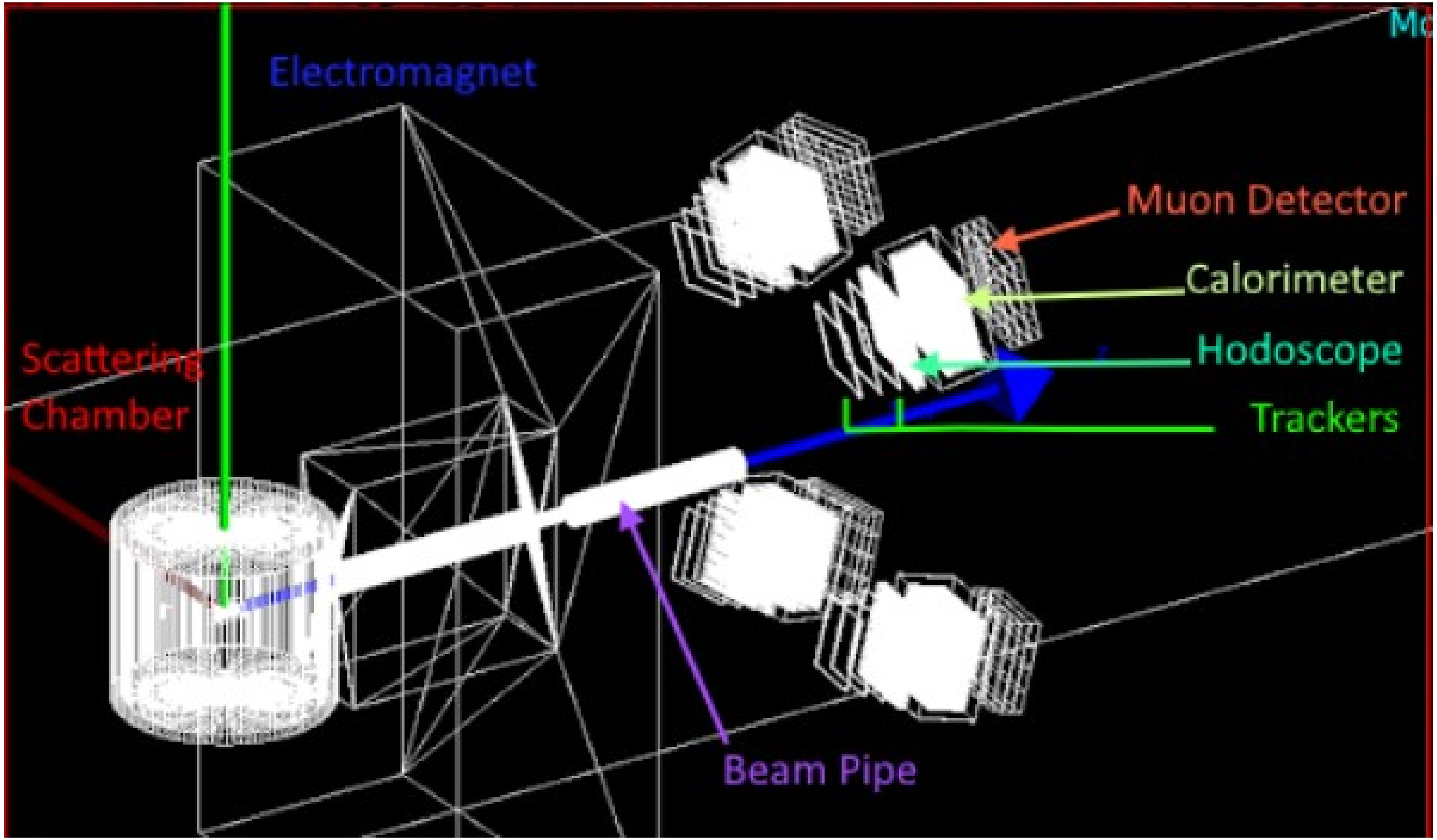


- 15 cm unpolarized LH2 target (from JLab, SBS Hall A)
- Magnet: dipole with 2.4 Tesla-meter (from SBS)

Muon detector, what we want to develop

Central part: intend to use setup from proposed (un)-polarized TCS
Muon detector part: we will show details

Proposed setup for JLab Hall C (3D GEANT4 simulations)



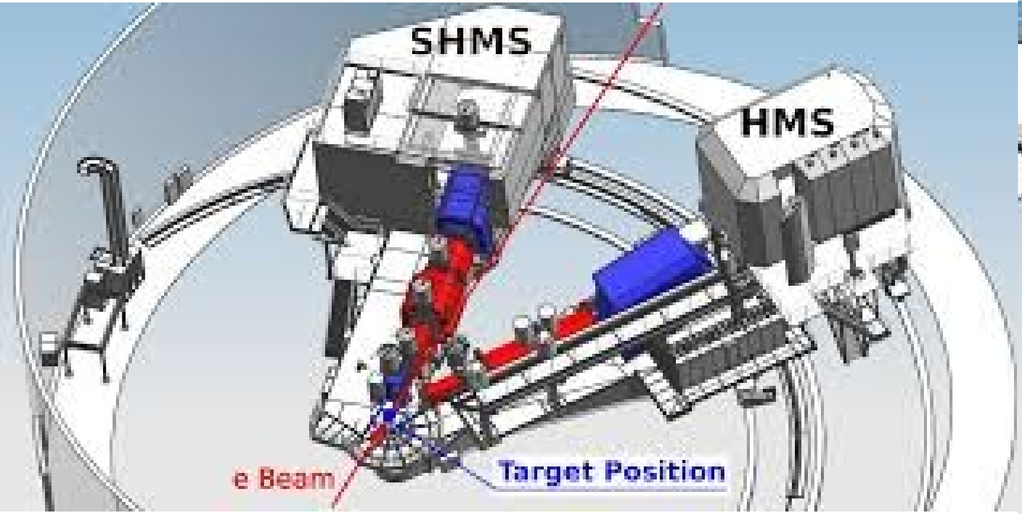
Detectors are placed in 4 quadrants:

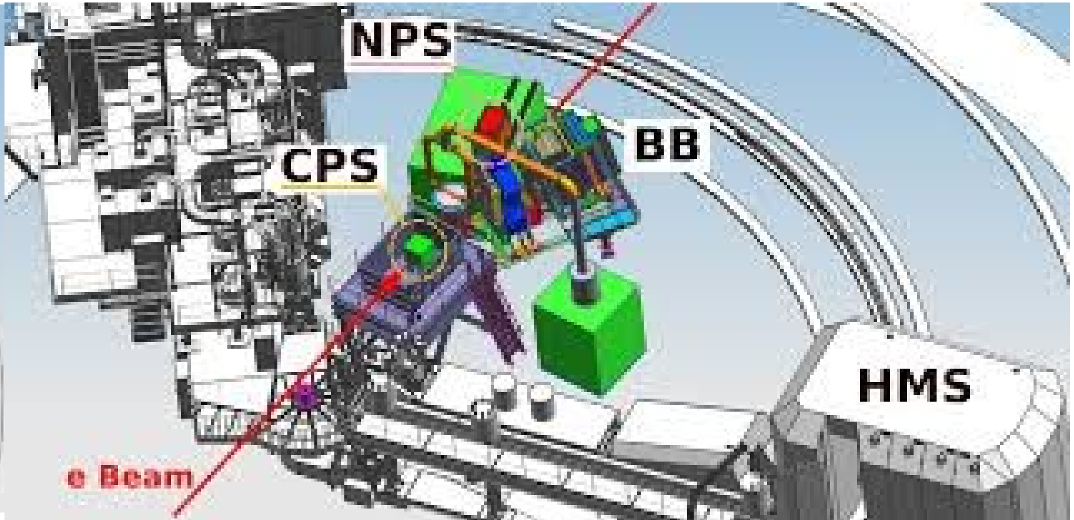
Why this choice of setup?

Current spectrometers in Hall C at JLab: HMS and SHMS.
Possible spectrometers in Hall C: SBS, currently used in Hall A (it has wider acceptance, at a small cost in terms of resolution)

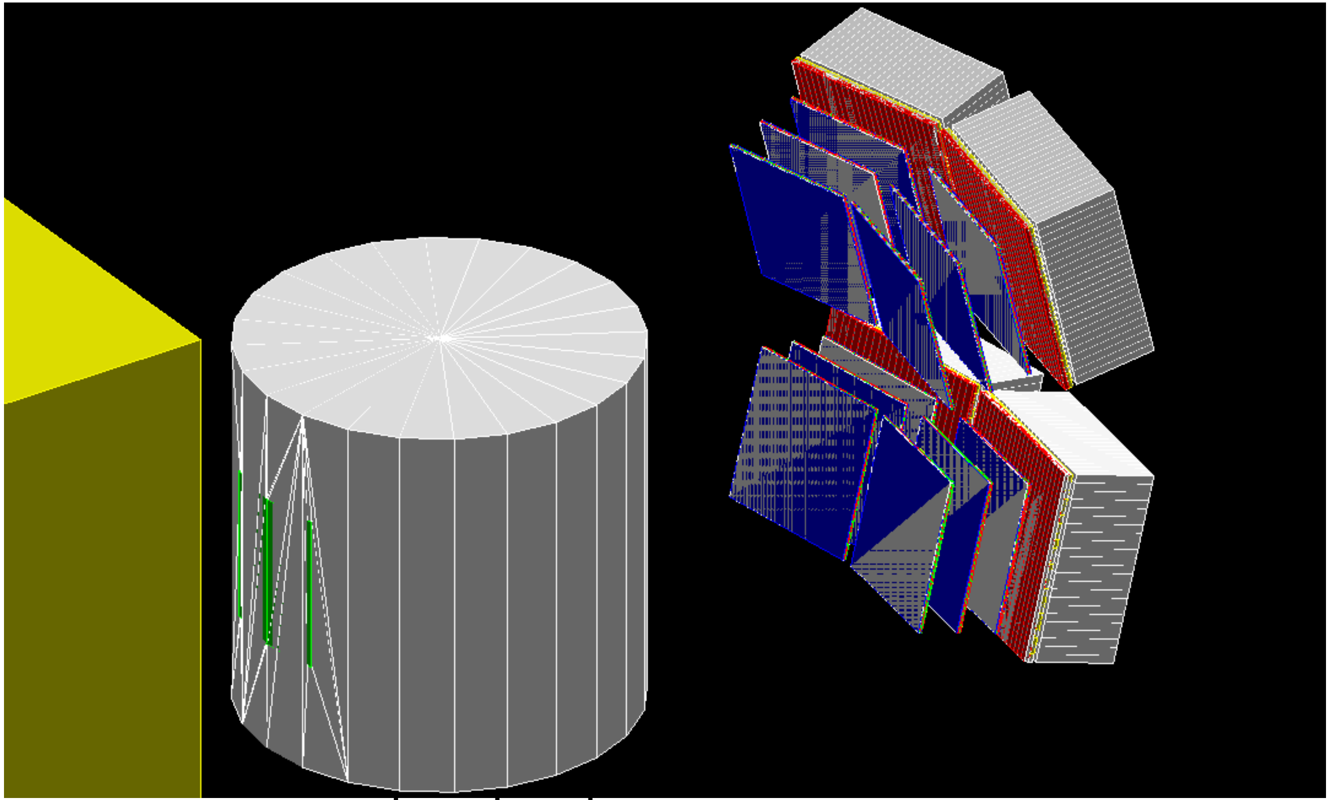
Our plan: HMS (SHMS) or SBS still have a limited acceptance, DDVCS needs to optimize statitics, therefore we chose a wider acceptance option

In 2024, Hall C successfully ran DVCS experiment using a new electromagnetic calorimeter (NPS) providing great resolution and quite wide acceptance for scattered electrons





Central part: proton and scattered electron detection

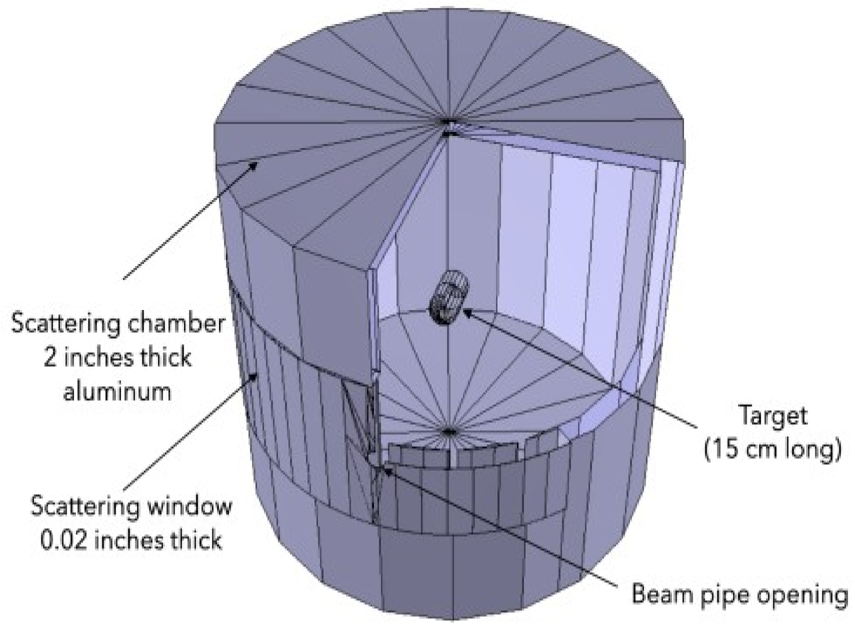


4 identical quadrant:
3 layers hodoscopes
3 layers GEMs
aray of calorimeter blocks
(lead tungstate)

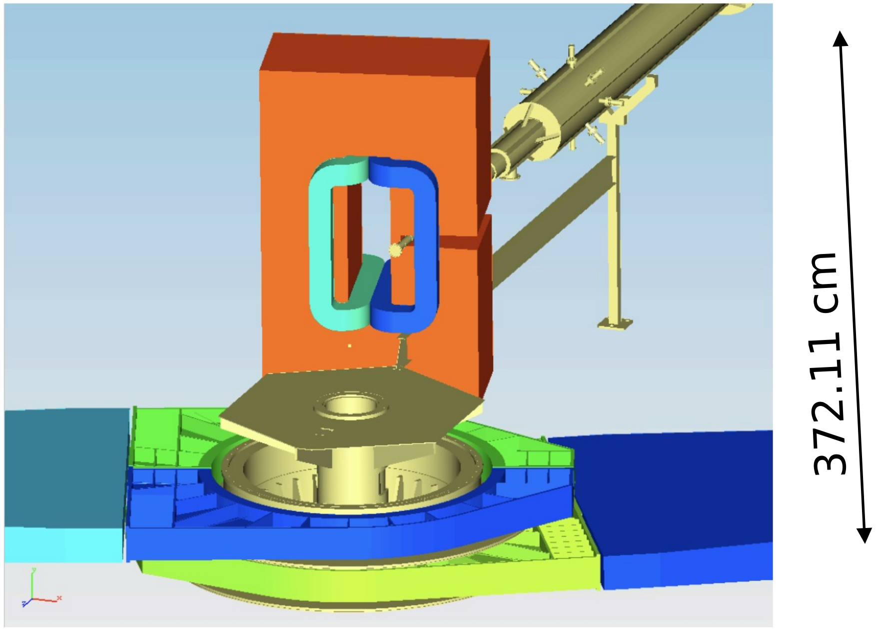
scattering chamber
(replaced here by SBS target
and magnet)

From previously proposed polarized TCS experiment (see Deb's talk)

Scattering Chamber and SBS Magnet (detailed in Deb's Slides)



target and scattering chamber



CAD Drawing for Super Bigbite Magnet

Source : https://userweb.jlab.org/~bogdanw/SBS-general.pdf

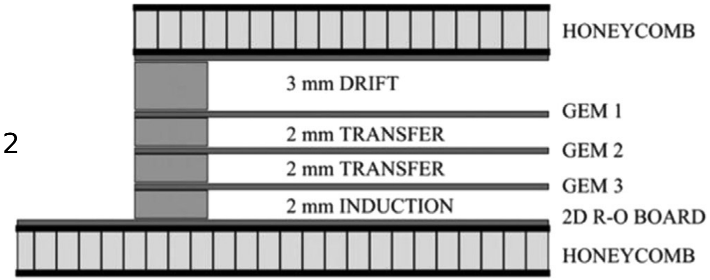
1. The field integral is 2.4 Tesla-meter with 1.2 m long pole

Proton tracking: GEMs and Hodoscopes (discussed in Deb's slide)

GEM trackers:

- Coordinate reconstruction accuracy better than 100 μm
- Background rate tolerance up to 10^6 Hz/mm^2
- Magnetic field tolerance up to 1.4 T
- Good radiation resistance
- Minimum material thickness along particle pass
- Big size manufacturing

Use at Jlab: SBS, SoLID DDVCS, Prad



Layout of COMPASS GEM-s (*F.Sauli, NIMA 805 (2016) 12-24*)

Hodoscopes:

- To provide dE/dX signal from low momentum recoil protons
- 2x2x5 cm^3 scintillators arranged in “Fly's eye” hodoscopic construction
- Light detectors attached to the rear side of scintillators

Detection of scattered electron – can detect other lepton for other measurements (TCS...)

Detect and identify leptons, measure energy and coordinates. Define Q'^2, x, ξ.

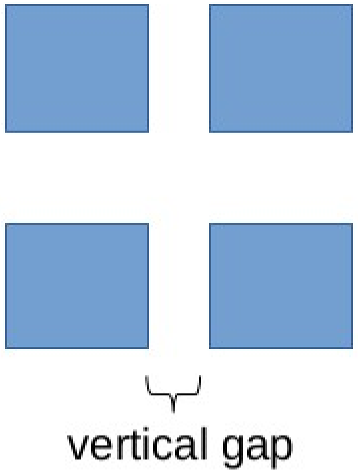
Modular construction, similar to the NPS calorimeter:

- 2x2x20 cm^2 **$PBWO_4$ scin. crystals**, optically isolated
- Hamamatsu **R4125 PMTs** (¾”, bialcali photocathode) for light collection
- **Active devider** linear up to 1 MHz rate.
- Modules arranged in a mesh of μ-metal
- Expected **energy resolution** 2.5%/√E + 1%
- Expected **coordinate resolution** ~3 mm at 1 GeV.

For TCS case, modules arranged in 4 “fly’s eye” assemblies

of 23x23 matrix.
Total number of modules needed **2116**.

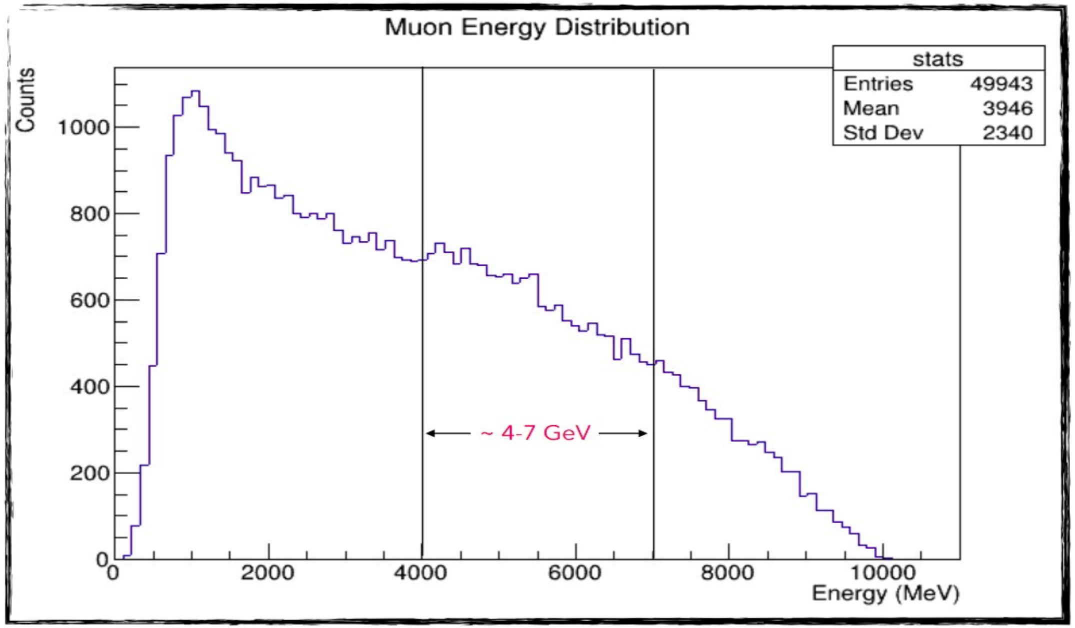
4 symmetrical parts:



NPS calorimeter has successfully been used in DVCS experiment
in Hall C in 2024

We plan twice this surface. Reusing this detector enables larger acceptance

Muon Energy: from generated events



- DEEPGEN (by M. Boer) event generator was used to simulate DDVCS events.
- Consideration for more symmetric muon pairs > 2 GeV invariant mass,
- More natural cut for maximum number of muons becomes ~4–7 GeV

Muon Detection

- **Main theme of any muon detector:** multi layers of background absorber and active material placed alternatively.
- **Challenges:**

  1. Large pion background, di-lepton spectrometer is an open geometry model, no shielding around

  2. Comparable mass of muon (105.7 MeV) and pion (139.570 MeV) makes it harder for traditional SHMS/HMS PID (e.g. cannot tune Cherenkov to one particle and not for the other)

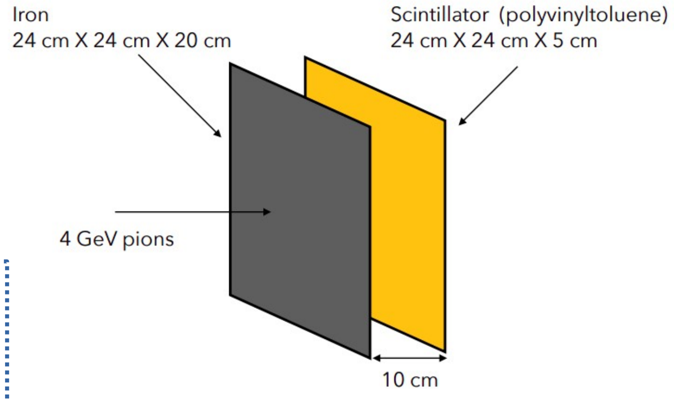
  3. Space constraint: No space for large detector array

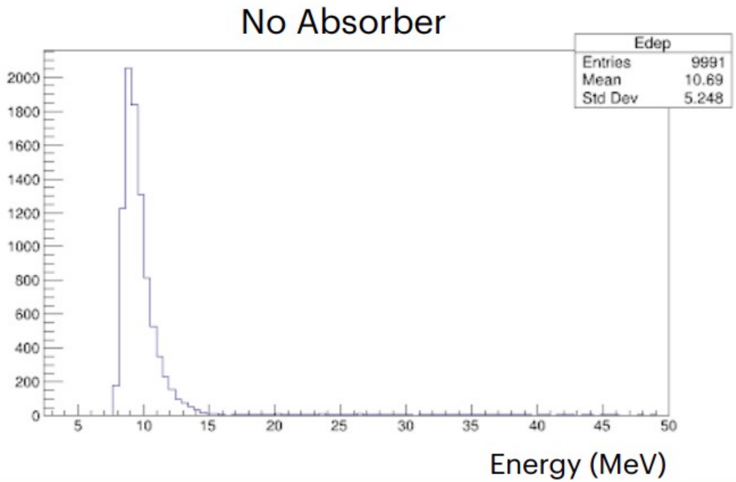
  4. Engineering constraint: How to hold bulky detectors in four quadrants

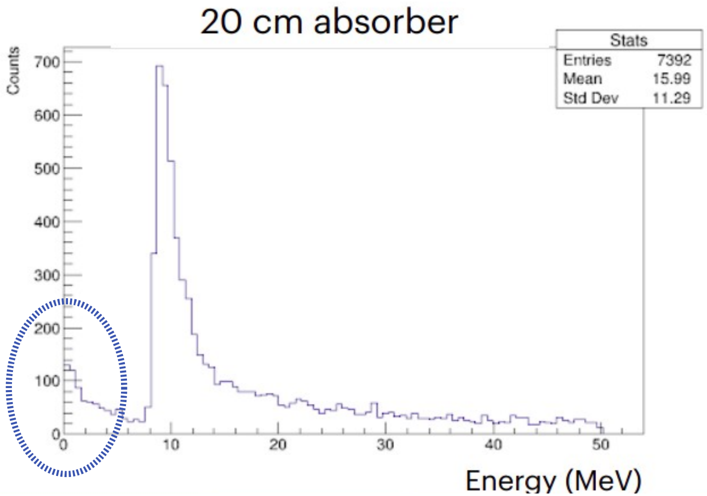
  5. Money constraint: Can’t be too expensive

Pion Signal: w and w/o absorber in front of scintillator

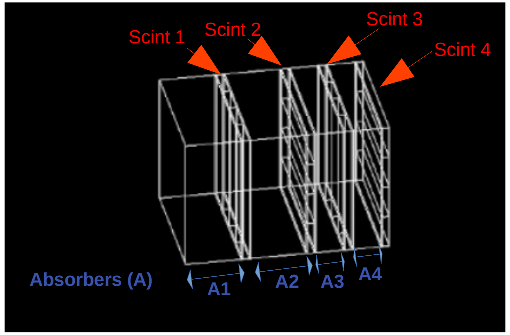
- 1 absorber – 1 scintillator
- 4 GeV pions were fired from a particle gun
- Energy deposited by pions and other particles generated in the interaction are shown
- Distinctive low energy secondary peak (from hadronic interaction of pions with the absorber) emerges in presence of the absorber







Multiple absorber-scintilator



1. Next step : From simple 1 absorber and 1 scintillator model to 4 absorber (iron / lead) - 4 scintillator model
2. Different combinations of absorber widths were tried, e.g. 20 cm-20cm-20cm-20cm; 40cm-20cm-20cm-20cm; 40cm-40cm-20cm-20cm
3. 10,000 Pions and muons were shot from a particle gun
4. Total number of interactions from only pions / muons were counted in each of the scintillator
5. 40cm-40cm-20cm-20cm turns out to be the most effective in blocking pions

40 cm iron -scint 1 - 40 cm iron - scint 2 -
20 cm iron - scint 3 - 20 cm iron - Scint 4

hits in each layer of scintillator				**4 GeV**
particle	**scint 1**	**scint 2**	**scint 3**	**scint 4**
mu-	9998	9998	9998	9998
pi+	3088	452	132	48

hits in each layer of scintillator				**6 GeV**
particle	**scint 1**	**scint 2**	**scint 3**	**scint 4**
mu-	9997	9996	9996	9996
pi+	4618	797	281	103

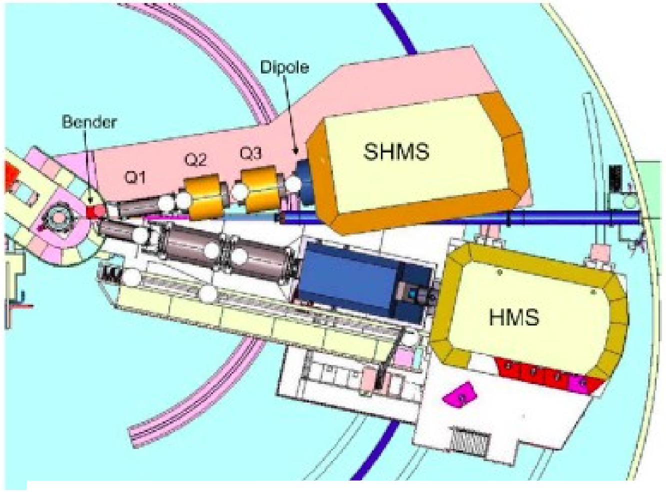
40 cm lead -scint 1 - 40 cm lead - scint 2 -
20 cm lead - scint 3 - 20 cm lead - Scint 4

hits in each layer of scintillator				**4 GeV**
particle	**scint 1**	**scint 2**	**scint 3**	**scint 4**
mu-	10000	10000	9999	9997
pi+	2028	245	66	18

hits in each layer of scintillator				**6 GeV**
particle	**scint 1**	**scint 2**	**scint 3**	**scint 4**
mu-	10000	9997	9996	9994
pi+	3001	417	146	50

Prototype

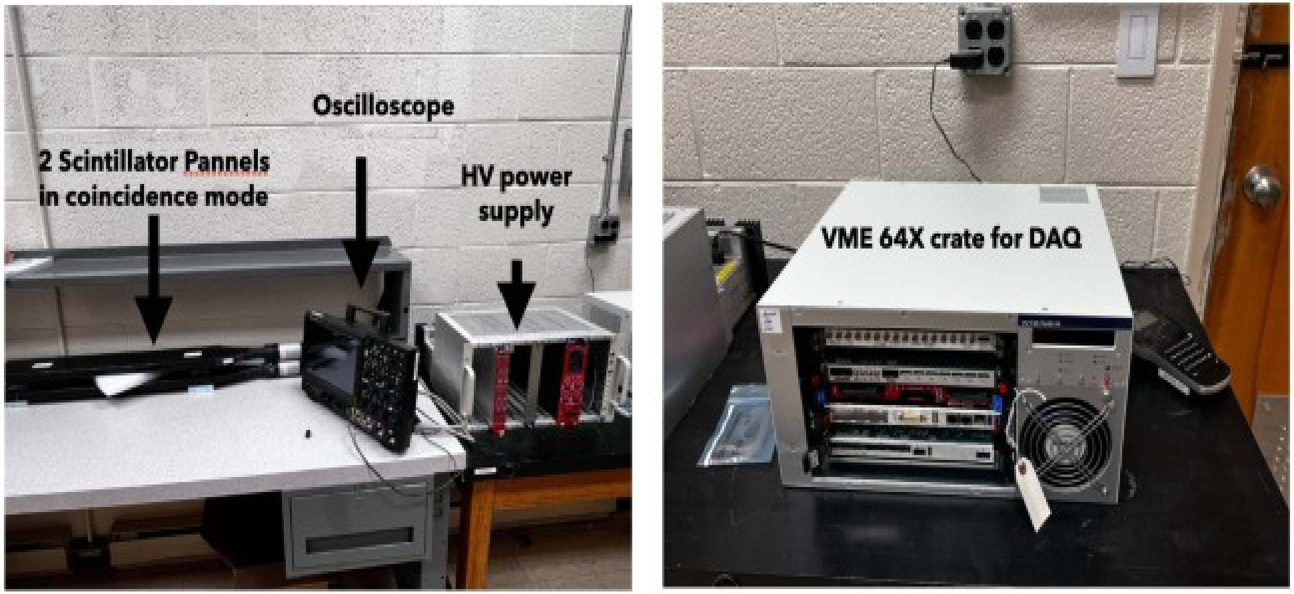
- Making a prototype may be comparatively easy, testing is not!
- Data taking with the prototype need to be non invasive to current Hall setup
- The test run should be parasitic to other approved experiments
- Placing the prototype anywhere on the hall is not an option:
    1. Then no control over the particles going into the detector
    2. Cannot determine the momentum/energy of the particle
    3. Will flood the detector with huge background
- Can we think of any platform behind the SHMS (or another existing spectrometer in Hall A or C) to place the prototype?
    1. In that case most of the backgrounds will be shielded by the spectrometer
    2. Particle momentum will be known using the SHMS magnet, data will be interpretable
    3. Then we can think of optimizing the Geant4 simulation this conditions



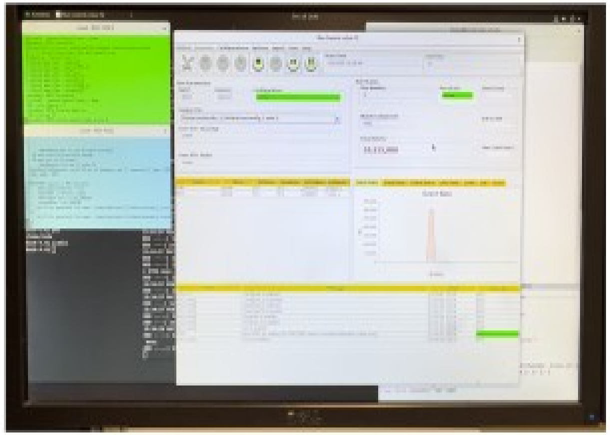
DAQ for prototype at Virginia Tech

DAQ and prototype preparation at Virginia Tech

Here is the basic setup we started with in our lab at VT.
DAQ/CODA based on JLab software – plan to test at JLab during another run.



(a)

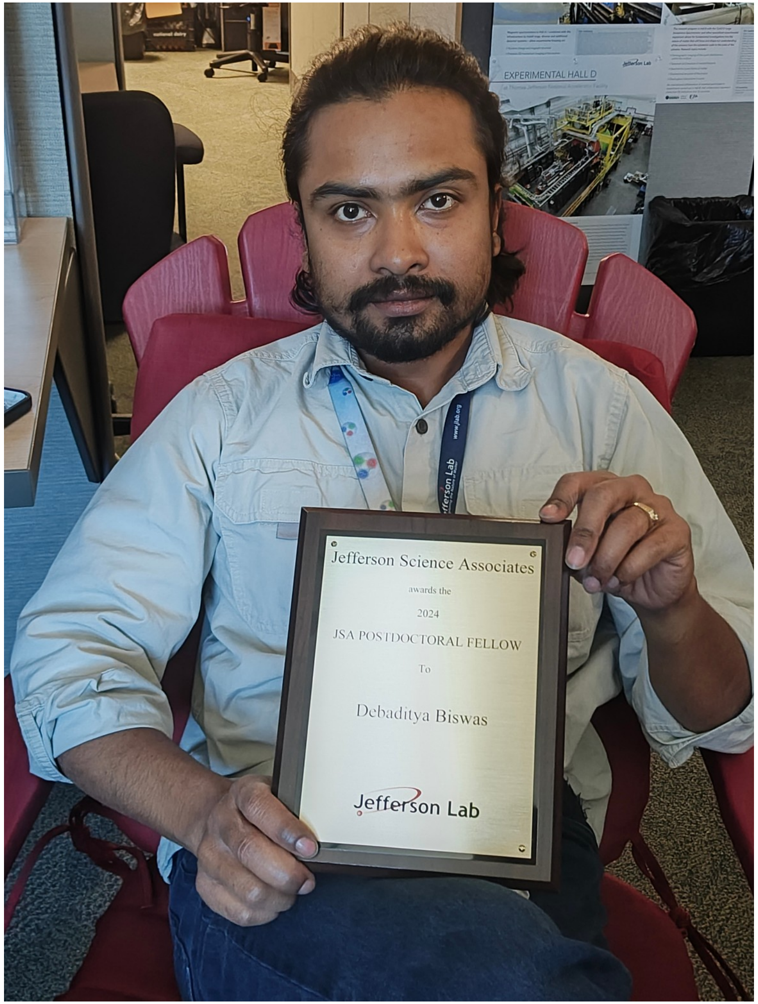


(b)

We are setting up DAQ, then we plan to move towards building a simple prototype.
We have DOE support for making a prototype to be later tested at JLab
Once proof of principle, we will start preparation of a full scale muon detector for Hall C (and A)

Summary

- DDVCS requires muon detector to the TCS experiment setup.
- Absorber-scintillator multi-layers for muon detector.
- Assembling a prototype (after more simulation and optimization of model) and DAQ system (ongoing) at Virginia Tech.
- R&D done in parallel for Hall C and for SoLID (Hall A)
- Undergraduate students working on this project. Debaditya Biswas (postdoc) got JSA postdoc prize last year on this project



Deb (postdoc), Arna, Ryan, Keagan (undergraduates)

Thank you