Muon Detection: *Its Significance and Strategy for the* DDVCS Experiment at Hall C

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Goal

GPDs

DDVCS

EXPERIMENTAL SETUP

Muon Detector

PLAN TO MOVE FORWARD

Accessing GPDs through exclusive reactions

Compton like reactions

Meson production

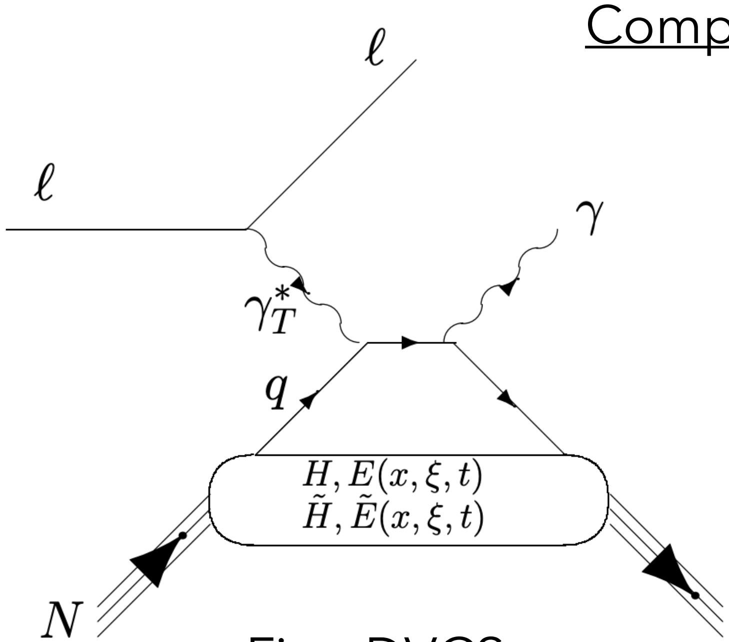


Fig : DVCS

https://arxiv.org/pdf/1511.04535.pdf

(measure in multiple experiment)

GPDs

Physics information : Transverse position of the partons and the quark-hadron densities (In PDF's the transverse informations are integrated over the Parton densities)

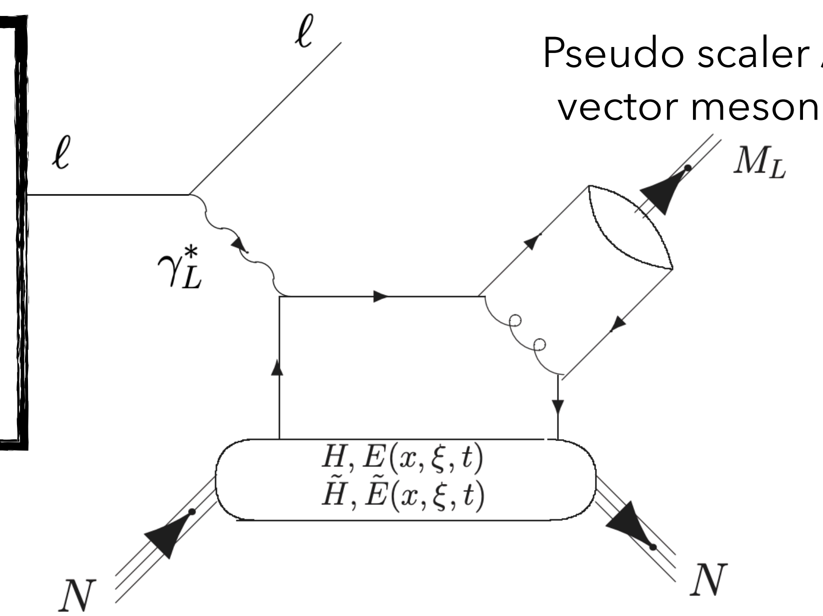


Fig : DVMP (quark Subprocess)

https://arxiv.org/pdf/1511.04535.pdf

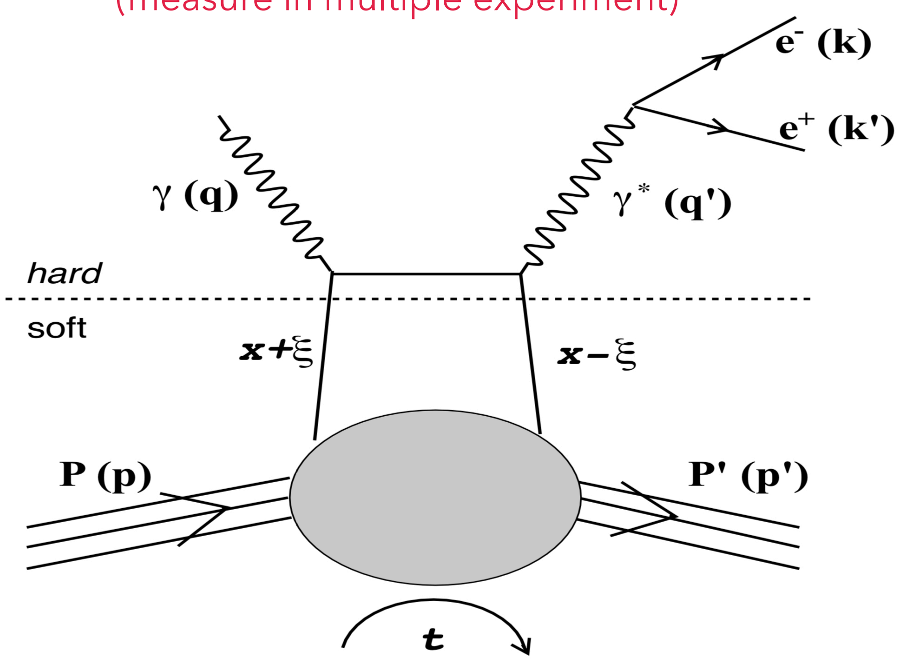


Fig : TCS

Source : M, Boer. et.al. Eur. Phys. J. A (2015) 51: 103

(measure for the first time at JLab)

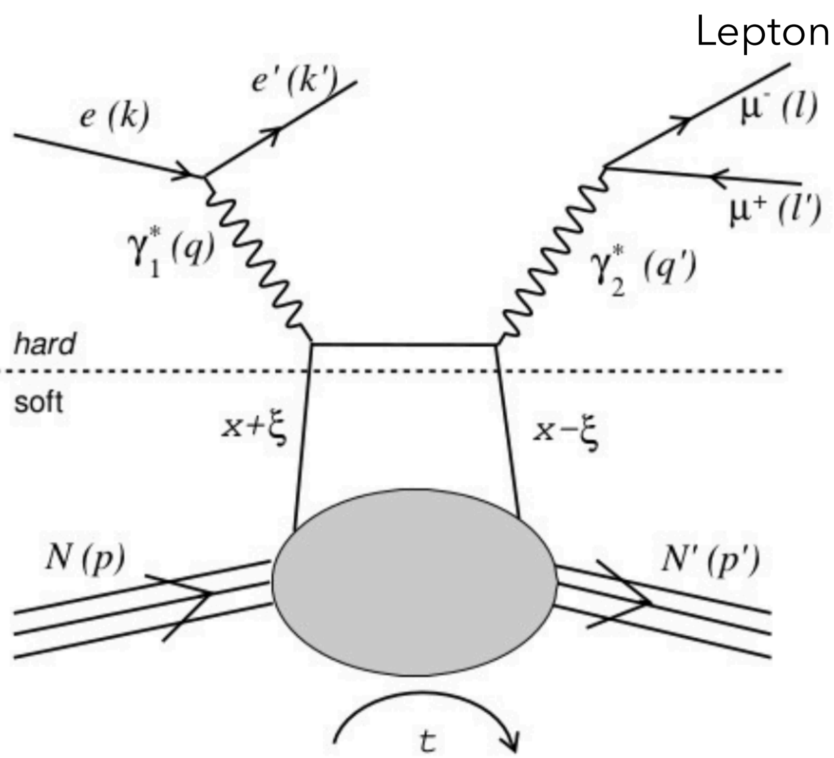


Fig : DDVCS

Source : M, Boer. et.al. Eur. Phys. J. A (2015) 51: 103

(no experiment yet)

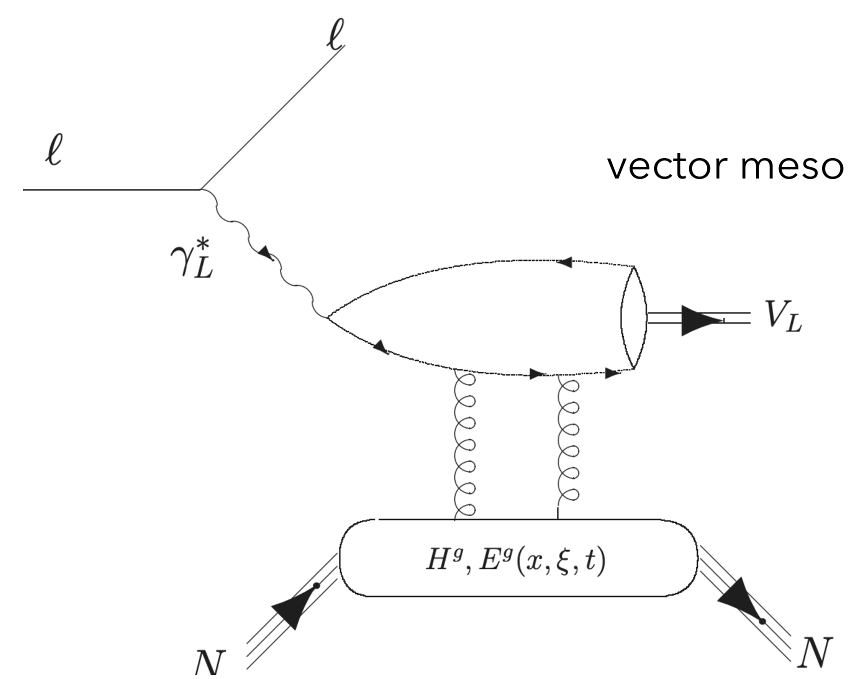


Fig : DVMP (gluon subprocess)

https://arxiv.org/pdf/1511.04535.pdf

DDVCS

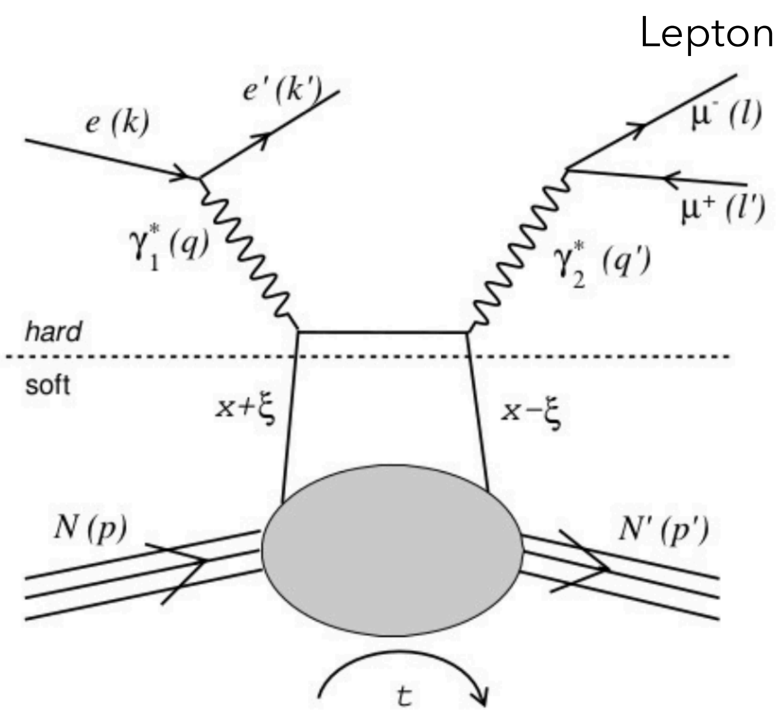


Fig1: DDVCS

Source : M, Boer. et.al. Eur. Phys. J. A (2015) 51:

WHY DDVCS ?

1. The incoming and outgoing photon virtualities : $Q^2 = -q^2, Q'^2 = -q'2$

2. The four momentum transfer to nucleon : $\Delta = q - q'$

3. $t = \Delta^2$

4. Decomposition of the skewness variables in terms of virtualities and Δ

$$\xi = \frac{Q^2 - Q'^2 + (\Delta^2/2)}{2(Q^2/x_B) - Q^2 - Q'^2 + \Delta^2}, \xi' = -\frac{Q^2 + Q'^2}{2(Q^2/x_B) - Q^2 - Q'^2 + \Delta^2}$$

5. Q'^2 dependence of the numerators enables us to access the off diagonal Phase space , in the contrary for TCS and DVCS $\xi = \xi'$

WHY $\mu^+ + \mu^-$ final state ?

$eN \rightarrow e'N'l^+l^-$

Due to anti-symmetrization and beam electrons : final state electrons are indistinguishable from the beam electrons

So, we rely on the muons at the final state

WHY HALL C ?

1. High luminosity helps in obtaining precise DDVCS measurement

2. Cross sections can be measure (not only asymmetry) with sufficient resolution ->helps to examine the GPD evolution

3. All these together help to deconvolute the kinematic variables ->essential for the proton's tomographic picture

Experimental Setup : Di-Lepton Spectrometer

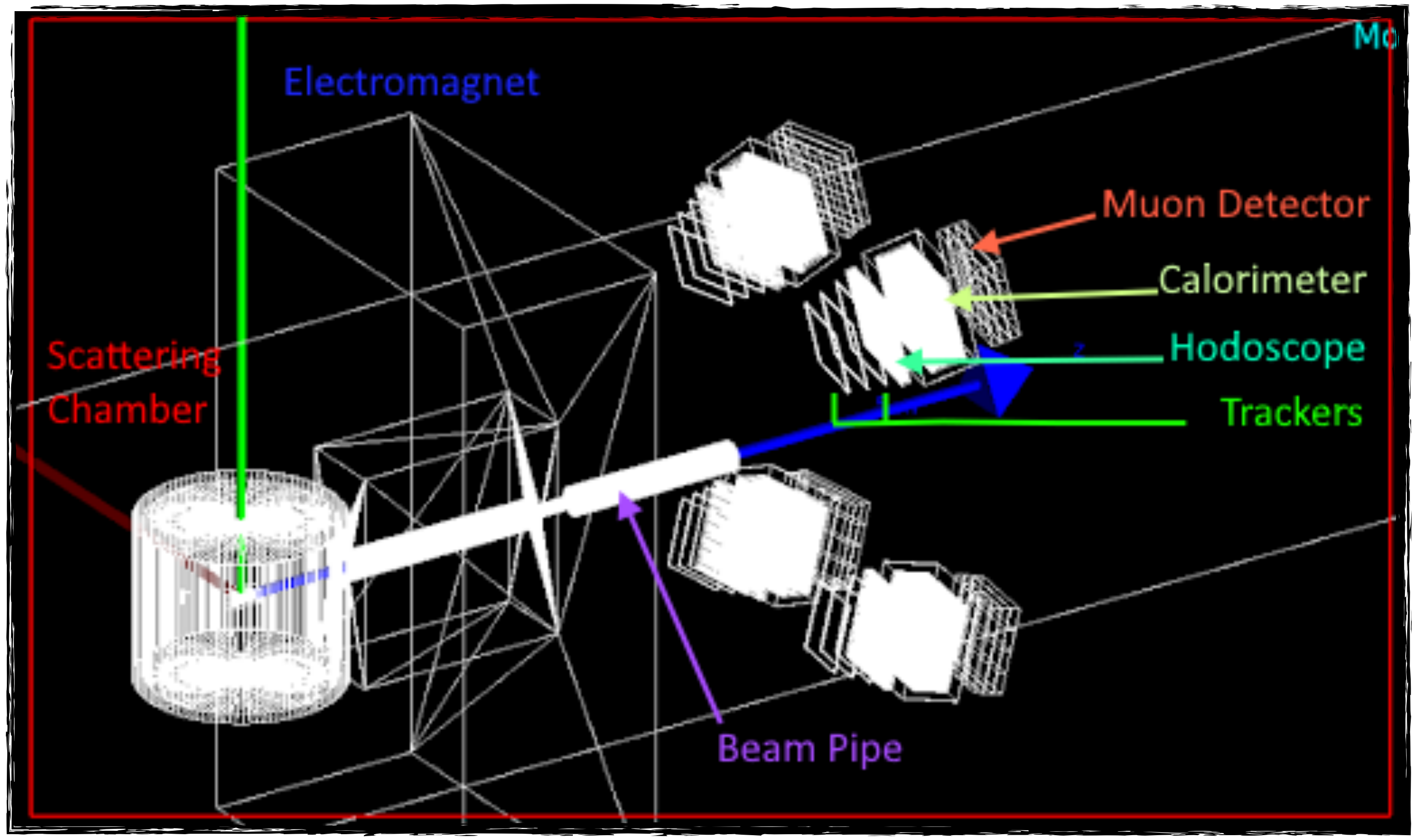
1. Current Hall C setup is not suitable for this kind of measurement

2. To do an exclusive measurement a new di-lepton spectrometer is needed

3. The same detector design can be adopted as shown in the previous talk for unpolarized TCS measurements if a muon detector is added to the setup

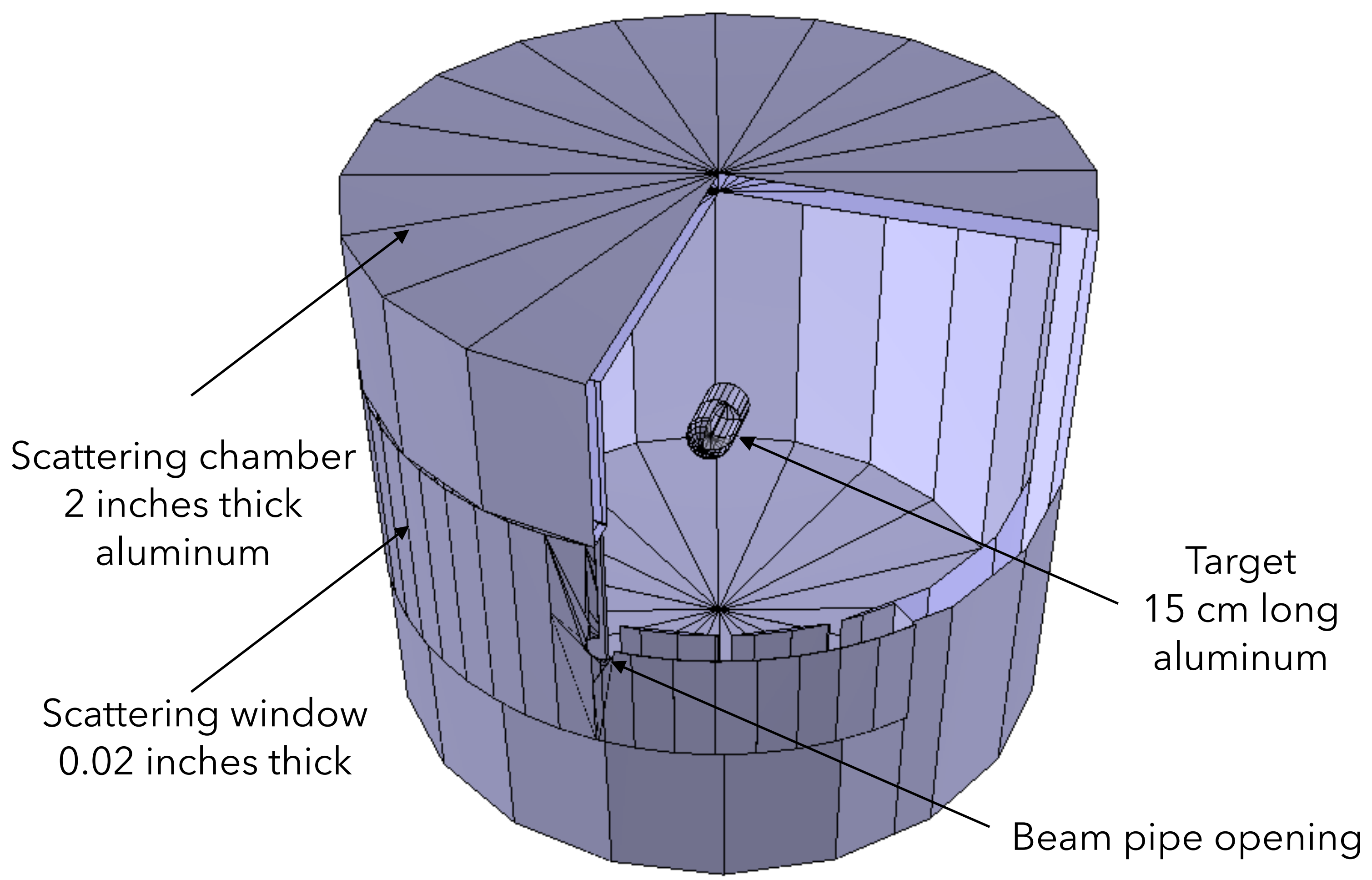
4. A dipole magnet is placed right after the scattering chamber to spatially separate μ^+ and μ^-

5. Detectors are placed in 4 quadrants
    1. Trackers (e.g. GEMs)
    2. Hodoscope (e.g. Scintillators)
    3. Calorimeter (e.g. NPS)
    4. Muon Detectors



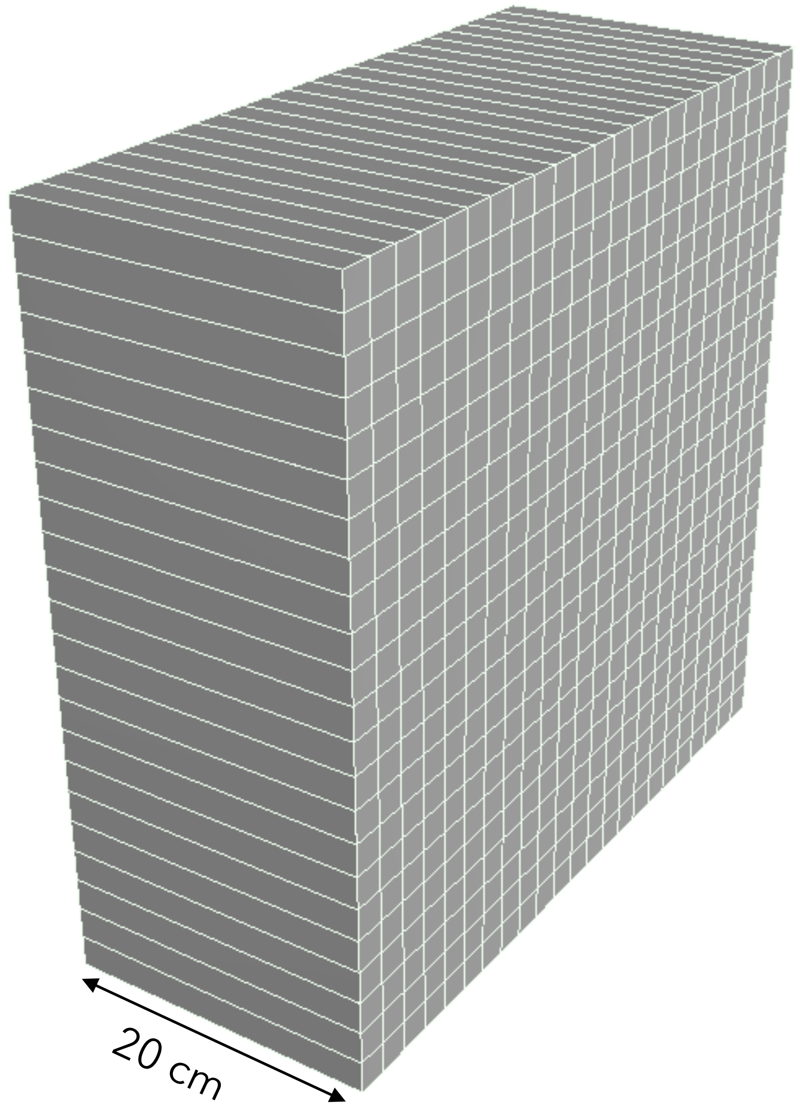
Scattering Chamber & Target

Calorimeter



Geant4 simulation of scattering chamber and target

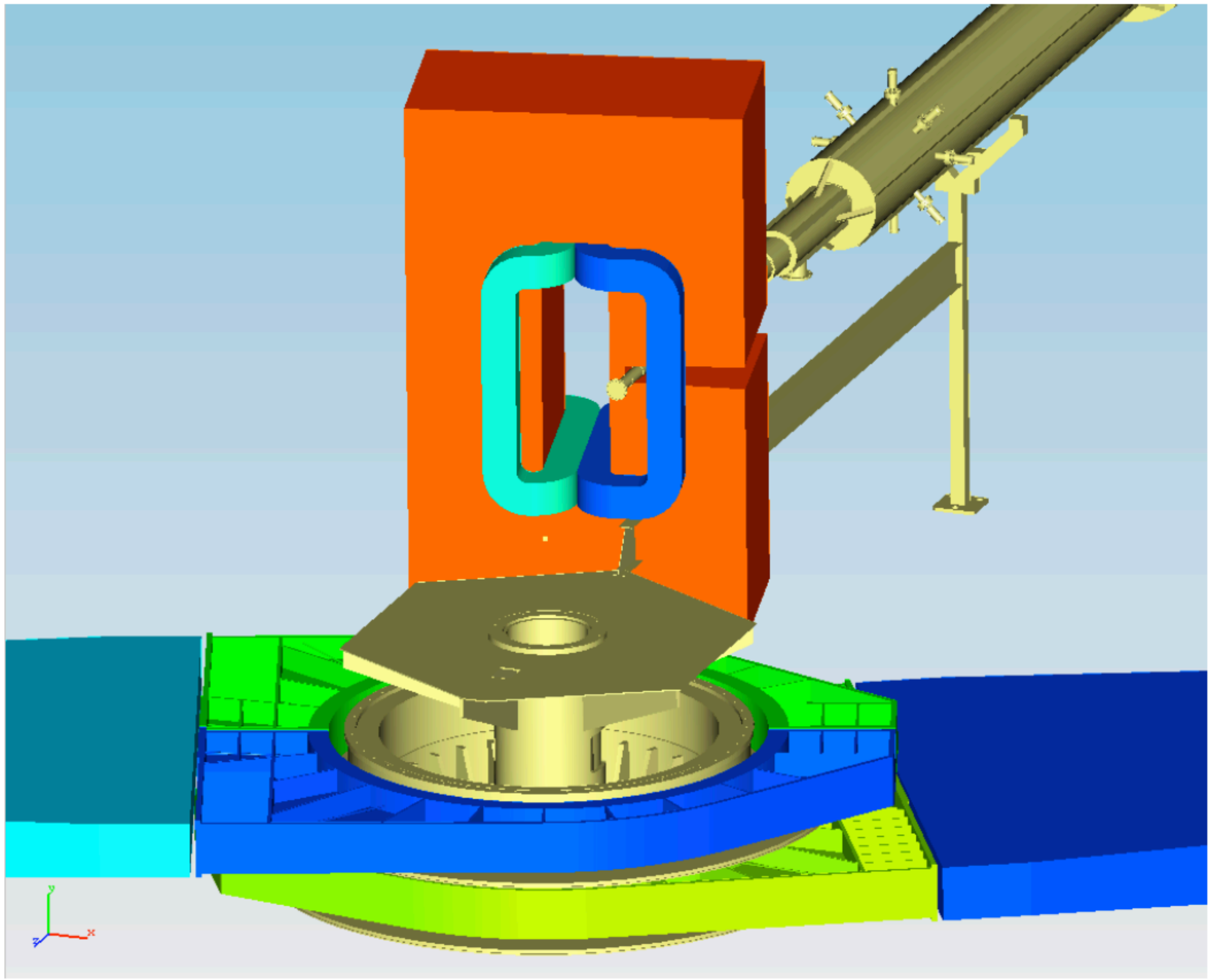
1. Scattering chamber inner diameter = 41 inches
2. Scattering chamber outer diameter = 45 inches
3. Angular range : horizontal HMS : 3.2 to 77.0 degrees
4. Angular range : SHMS : 3.2 to 47.0 degrees
5. Vertical angular range : ±17.3 degrees
6. Target thickness of Entrance and exit cap = 0.1778 cm
7. Target cell wall thickness = 0.0254 cm



Geant4 simulation calorimeter

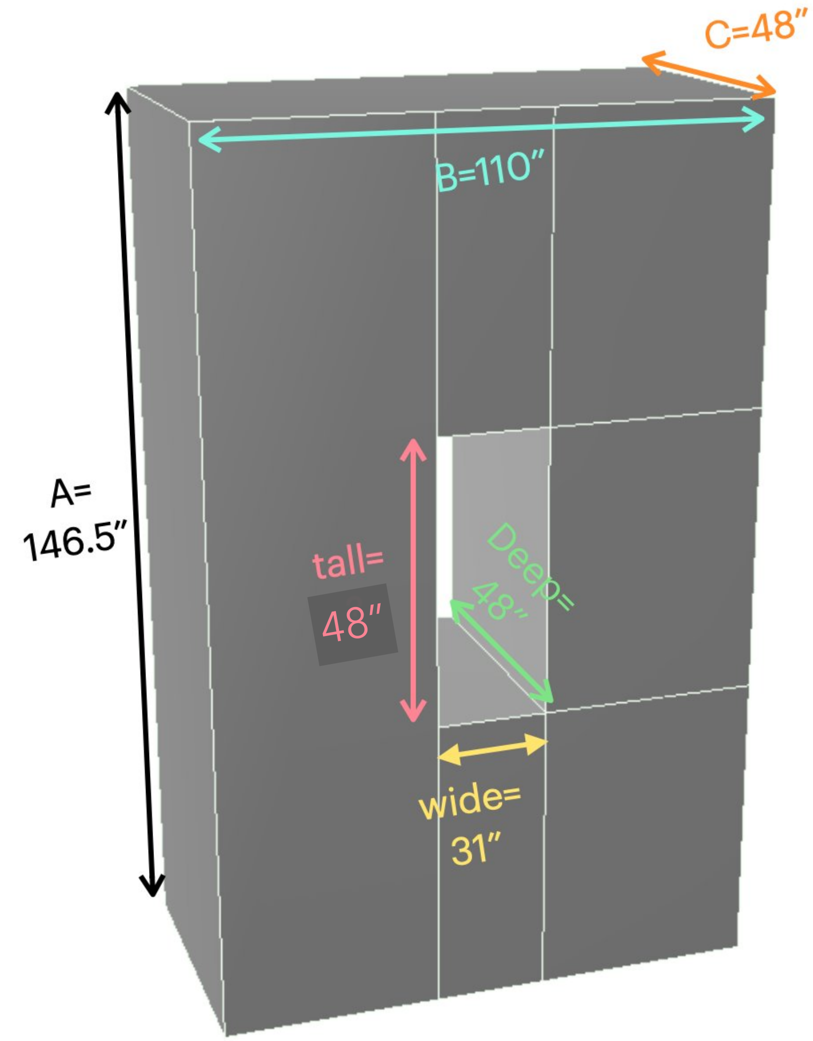
1. e^-, e^+, P detection and PID
2. Clones of the NPS calorimeter at Hall C
3. 2x2x20 cm^2 PBWO4 scintillator crystal
4. Expected energy resolution $\frac{2.5\,\%}{\sqrt{E}} + 1\,\%$
5. Coordinate resolution ~3 mm at 1 GeV
6. Fly's eye assembly of 23x23 matrix of total 2116 modules

Magnet : Separate the outgoing particles



CAD Drawing for Super Bigbite Magnet

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



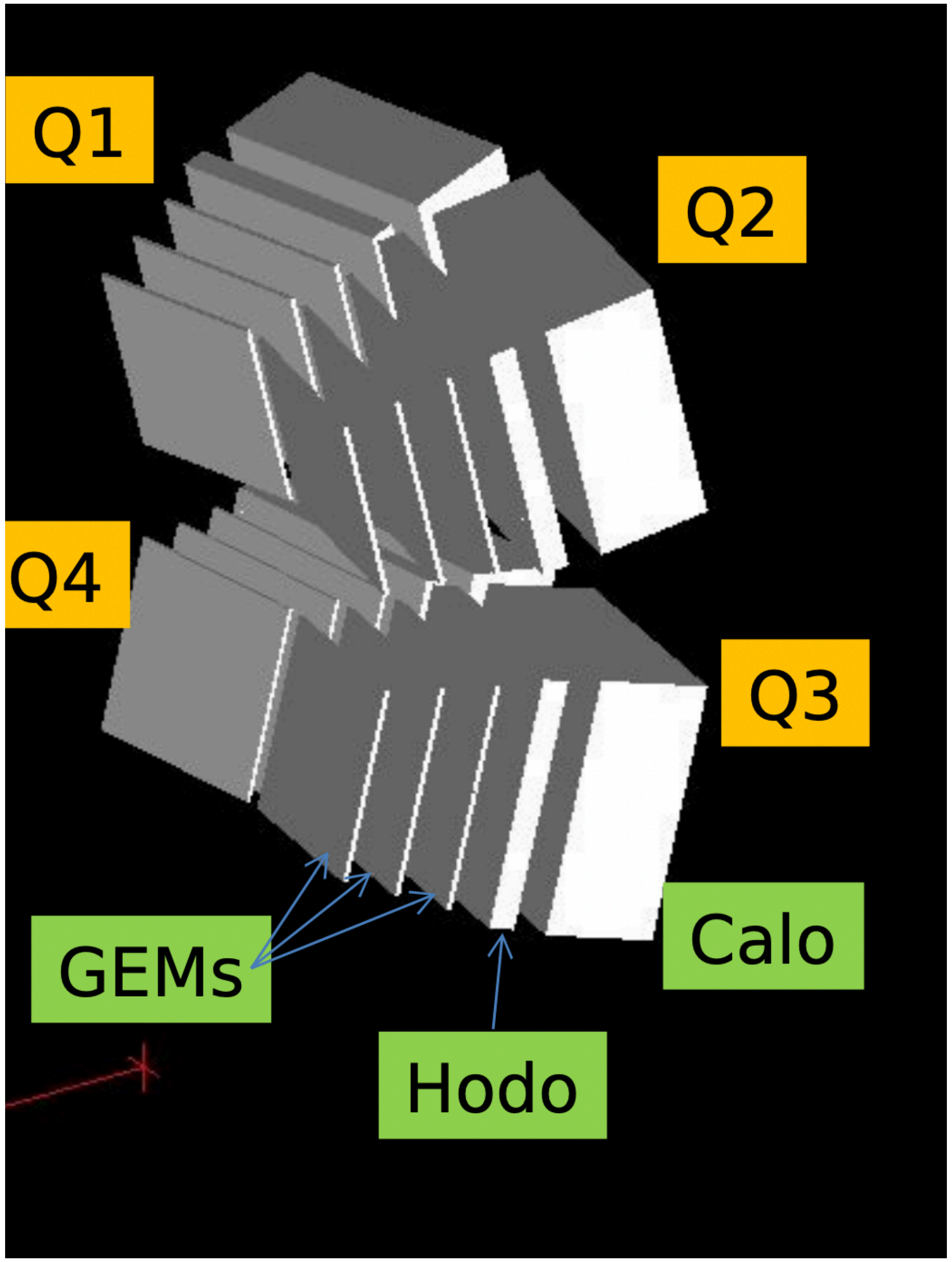
Geant4 simulation of simple magnet geometry

1. The field integral is 2.0 Tesla-meter with 1.2 m long pole

GEM Tracker

Hodoscopes

1. GEM tracker will be used to track e^{-}, e^{+}, P
2. Coordinate reconstruction accuracy ~80 μm
3. Background rate tolerance up to 106 Hz/mm^2
4. Minimum material thickness along particle pass
5. Big size manufacturing
   Use at Jlab: SBS, SoLID DDVCS, Prad

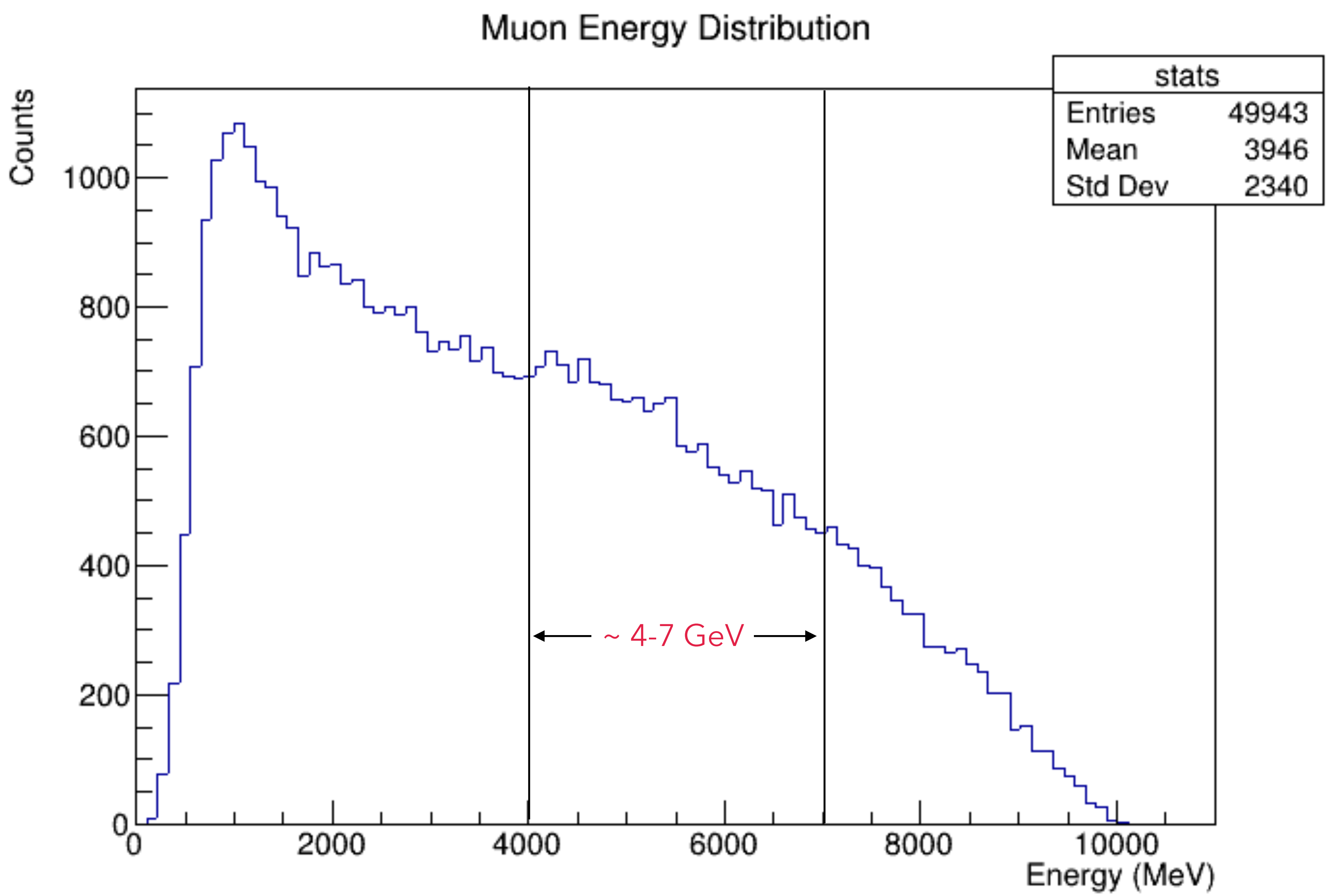


1. For recoil proton detection and and PID
2. To provide dE/dX signal from low momentum recoil protons
3. 2x2x5 cm^3 scintillators arranged in “Fly’s eye” hodoscopic construction

Muon Energy - from generated events

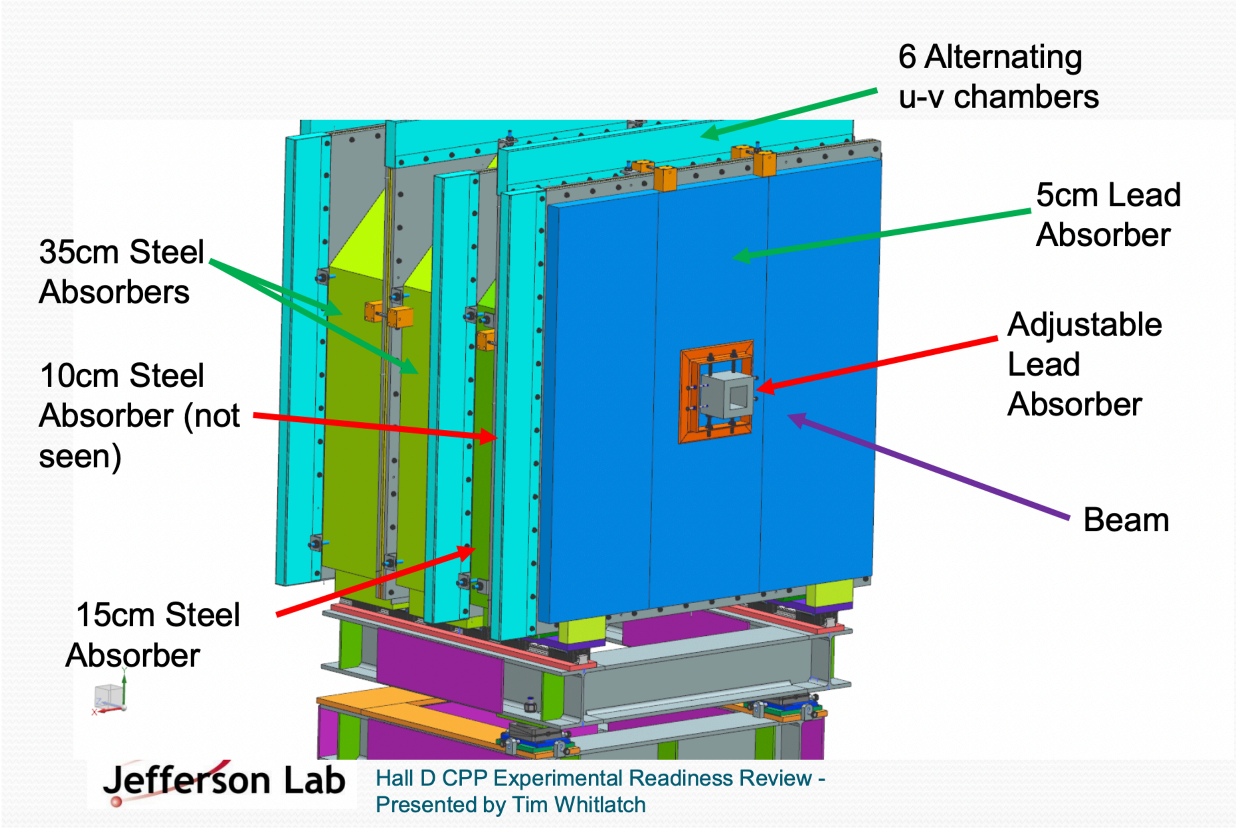
1. DEEPGEN (by M. Boer) event generator is used to simulate the DDVCS events

2. To consider more symmetric muon pairs above 2 GeV invariant mass, more natural cut for maximum number of muons becomes ~4-7 GeV



How to Detect Muons ?

1. World Wide Experiments
    1. Belle Experiment K_L^0 and Muon Subsystem
    2. CLEOII
    3. EIC KLM Proposal
    4. CPP experiment at Hall D etc…
2. Main theme of any muon detector : multiple layers of background absorber and active material (to pick up signal) placed alternatively
3. For example : The Hall D muon detector is composed of six layers of MWPC (U-V layers) and five layer of absorbers arranged in this order : 5 cm Pb , U-V layer, 10 cm steel, U-V layer, 15 cm steel, U-V layer, 35 cm steel, U-V layer, 35 cm steel, U-V layer, U-V layer.
4. Hall C :
    1. Large pion background, di-lepton spectrometer is a 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

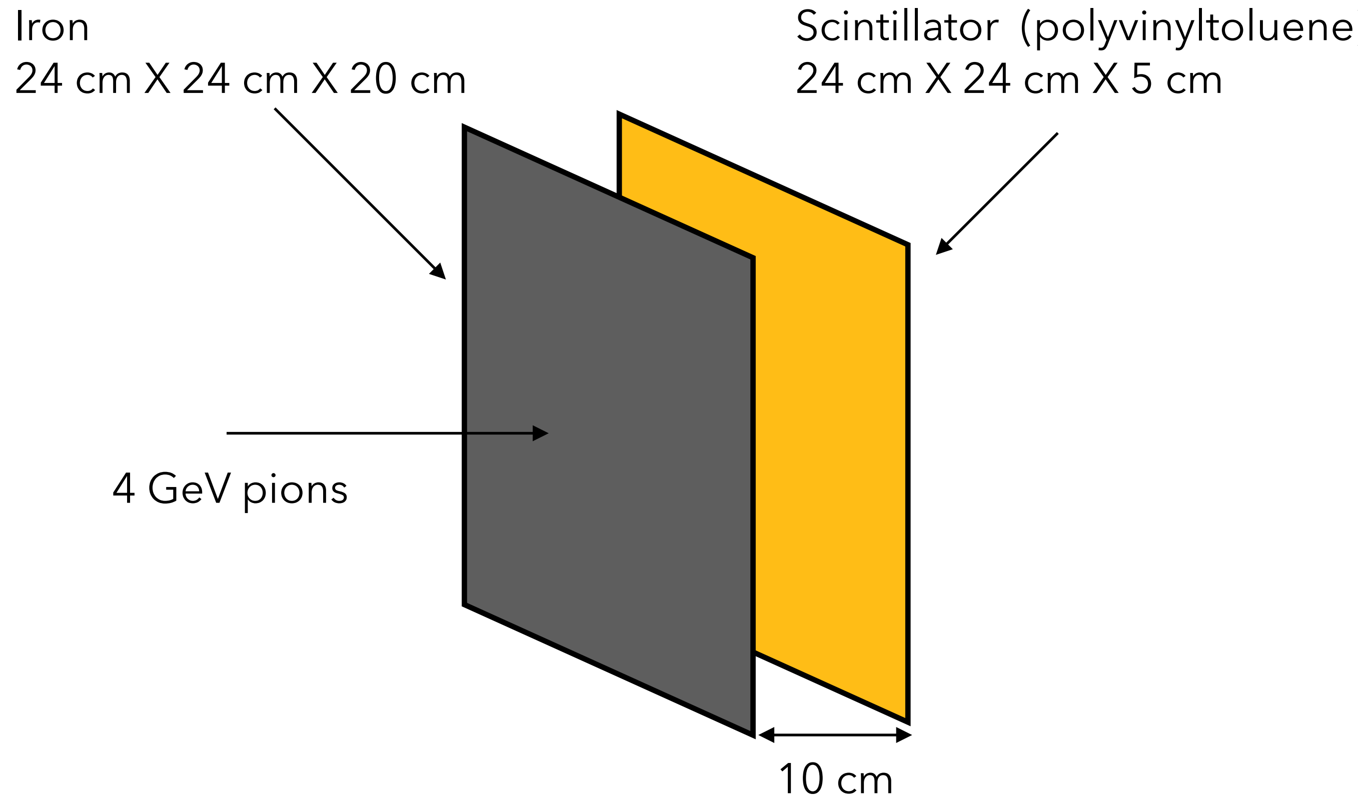


Source : https://halldweb.jlab.org/DocDB/0049/004903/002/CPP_ERR_Eng_Feb_2021_v4.pdf

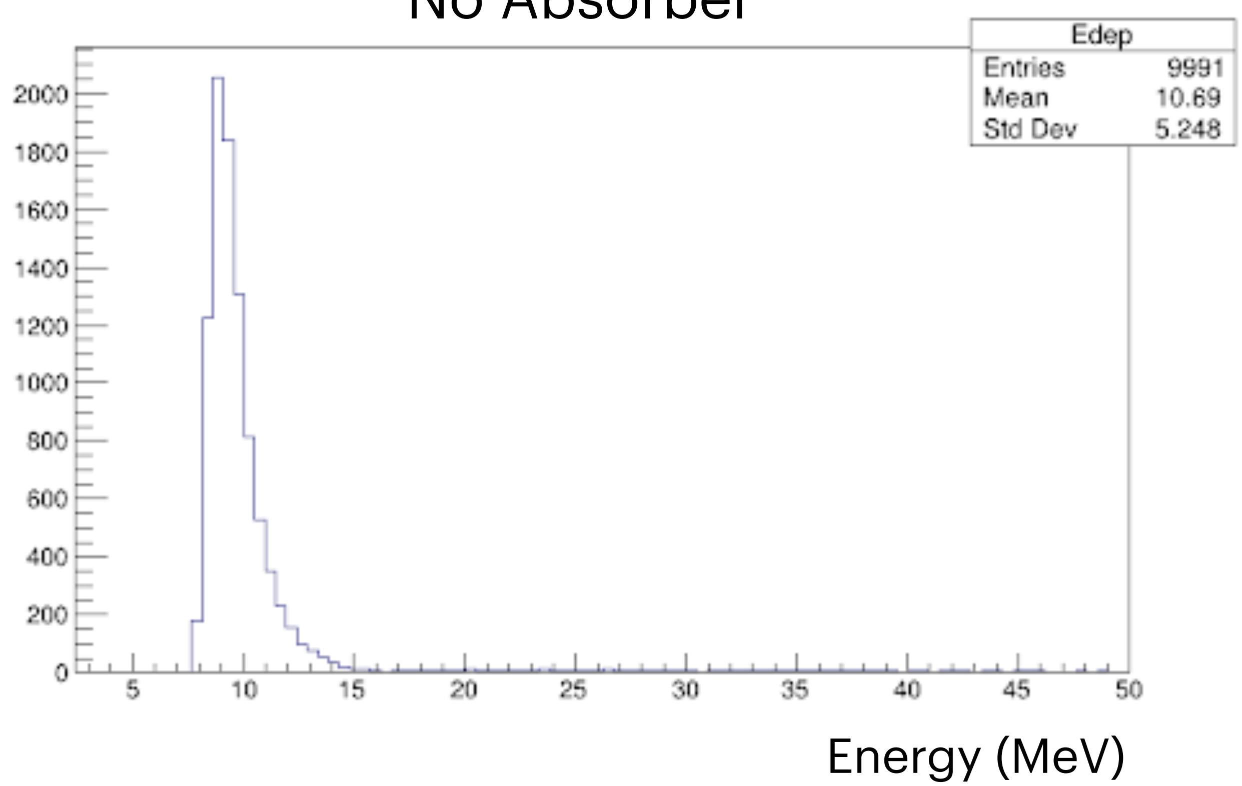
GlueX Experiment Document 4903-v2, by Timothy Whittch

Pion signal w and w/o an absorber in front of scintillator

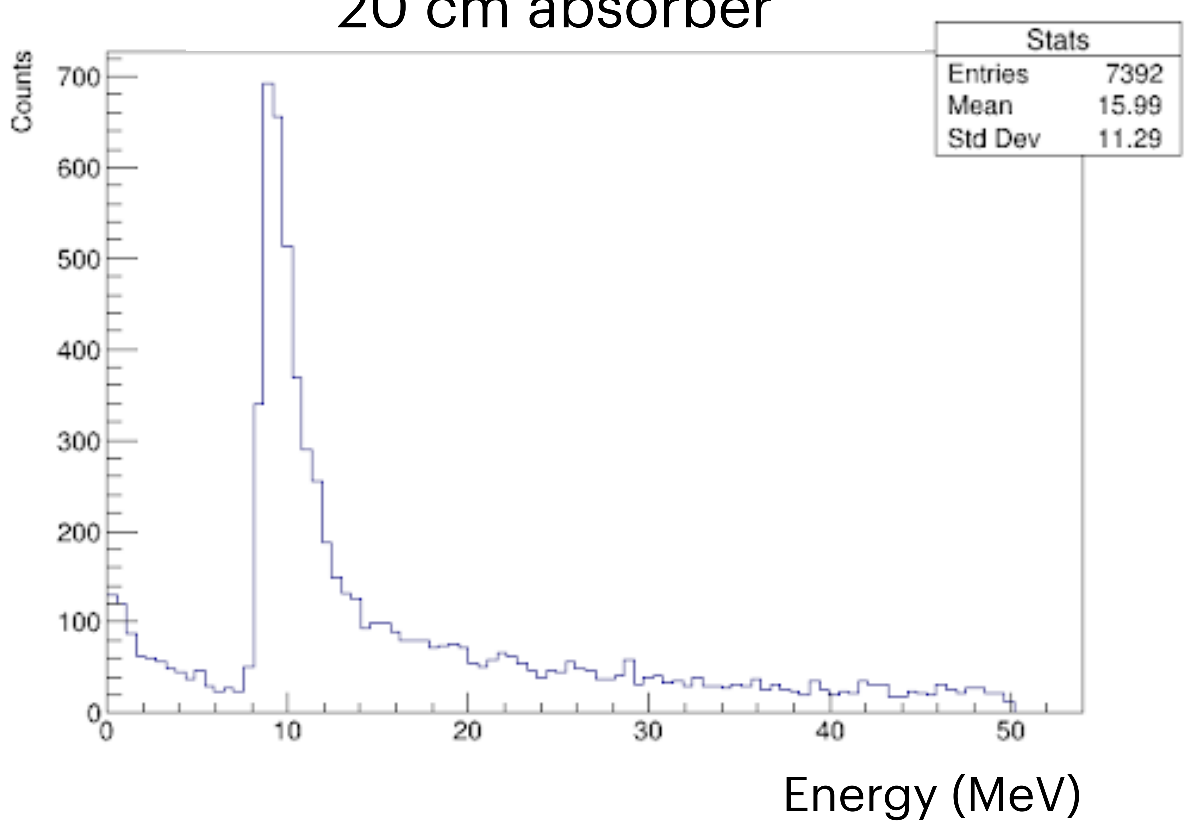
1. 1 absorber - 1 scintillator
2. 4 GeV pions were fired from a particle gun
3. Energy deposited by pions and all other particles generated in the interaction is histogrammed (w and w/o absorber)
4. Distinctive low energy secondary peak (from hadronic interaction of pions with the absorber) emerges in presence of the absorber



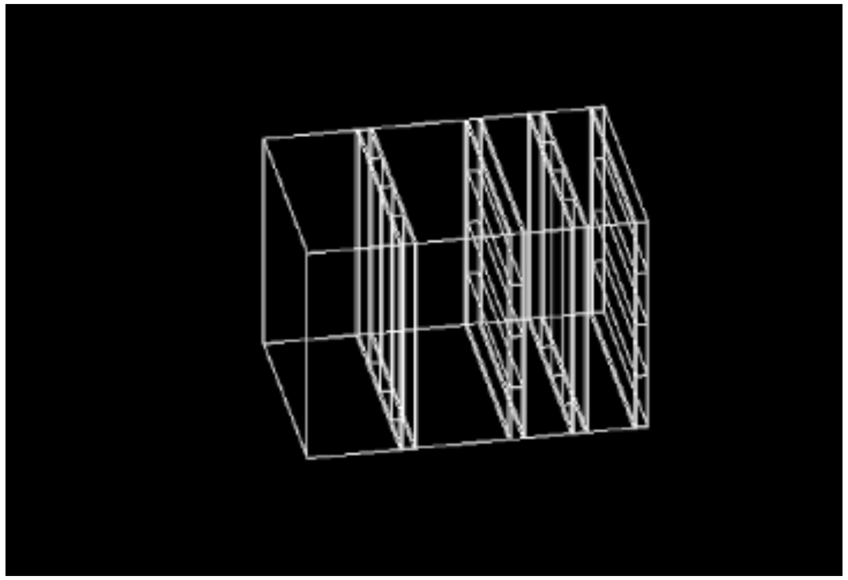
No Absorber



20 cm absorber



Multiple absorber-scintillator



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

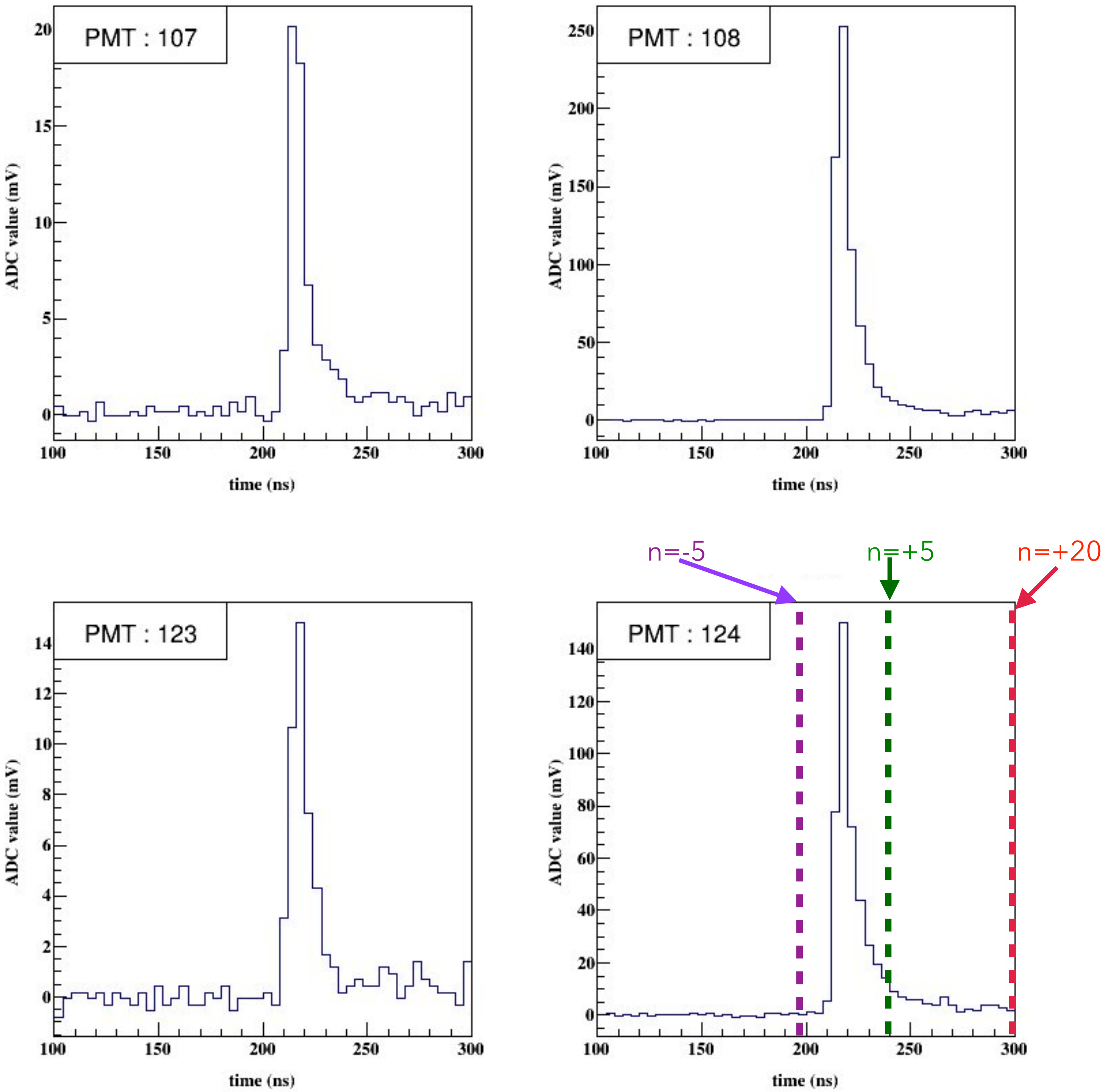
40 cm lead -scint 1 - 40 cm lead - scint 2 - 20 cm lead - scint 3 - 20 cm lead - Scint 4

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

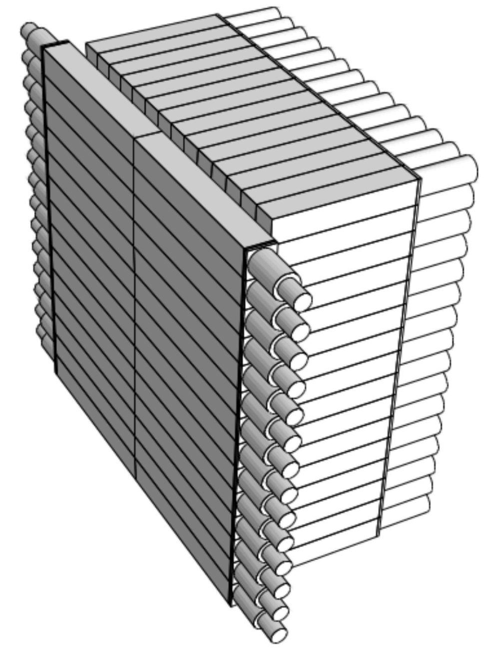
hits in each layer of scintillator				6 GeV
particle	scint 1	scint 2	scint 3	scint 4
mu-	10000	9997	9996	9994
pi+	3001	417	146	50

1. Of course this is 1st (or even 0th) order of study
2. Interactions below some threshold will not be detected
3. Multiple scattering of same particle within a time interval of O(10 ns) cannot be resolved
4. Comprehensive study of the DDVCS background is needed with more realistic Geant4 simulation

Pulse Shape Discrimination : e^{-}/π PID



ADC values (mV) [pedestal subtracted] vs time (ns)

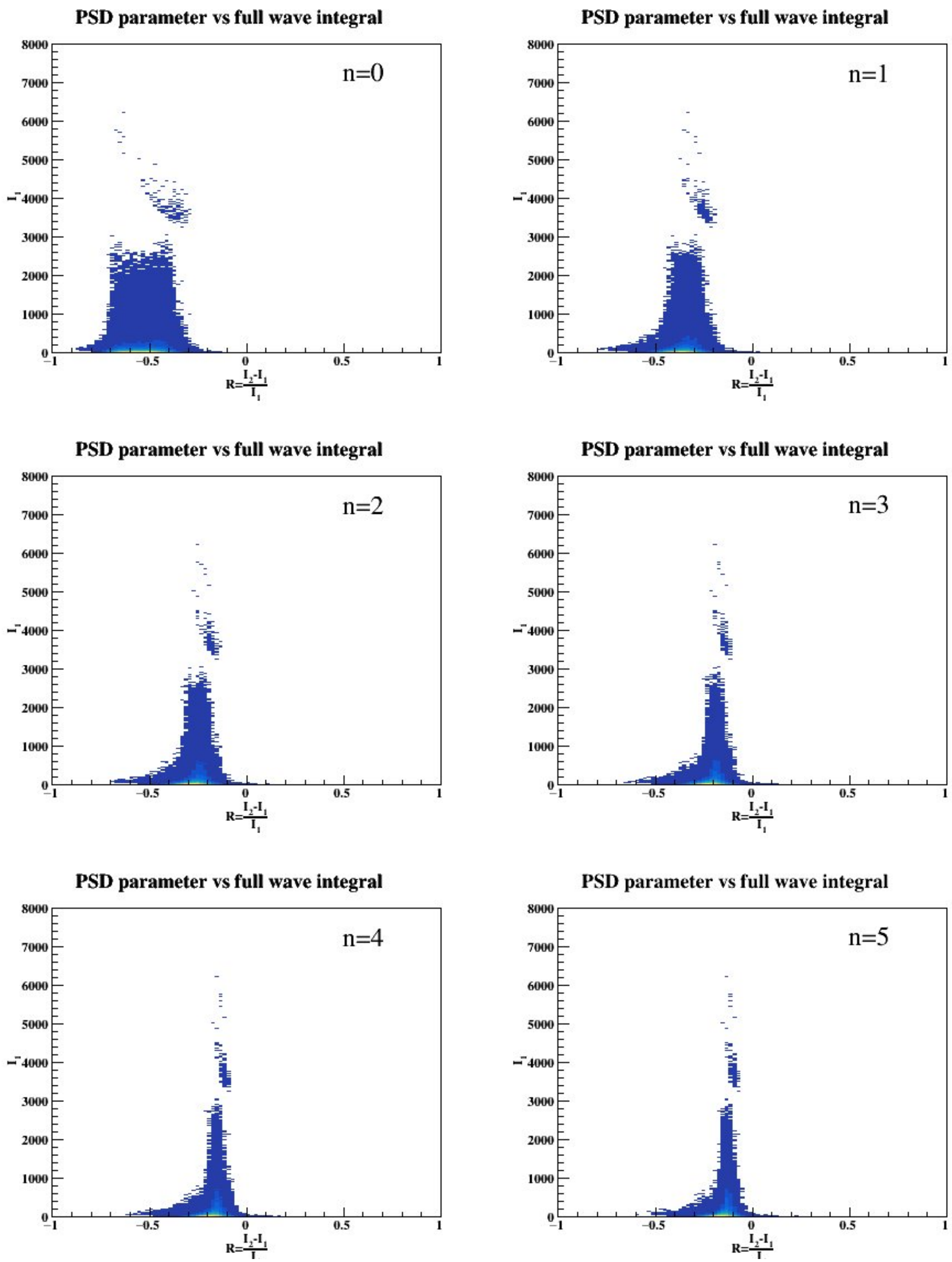


SHMS Calorimeter : shower counter
F-101 type lead glass blocks

1. FADC250 mode 10 full waveform data
2. Records the ADC value in every 4 nS

I_1 = Full wave integral (bin_{max} - 5 : bin_{max} + 20)
I_2 = Prompt wave integral (bin_{max} - 5 : bin_{max} + n)
N = 0, 1, 2, 3, 4, 5
PSD Parameter : $R = (I_2 - I_1)/I_1$

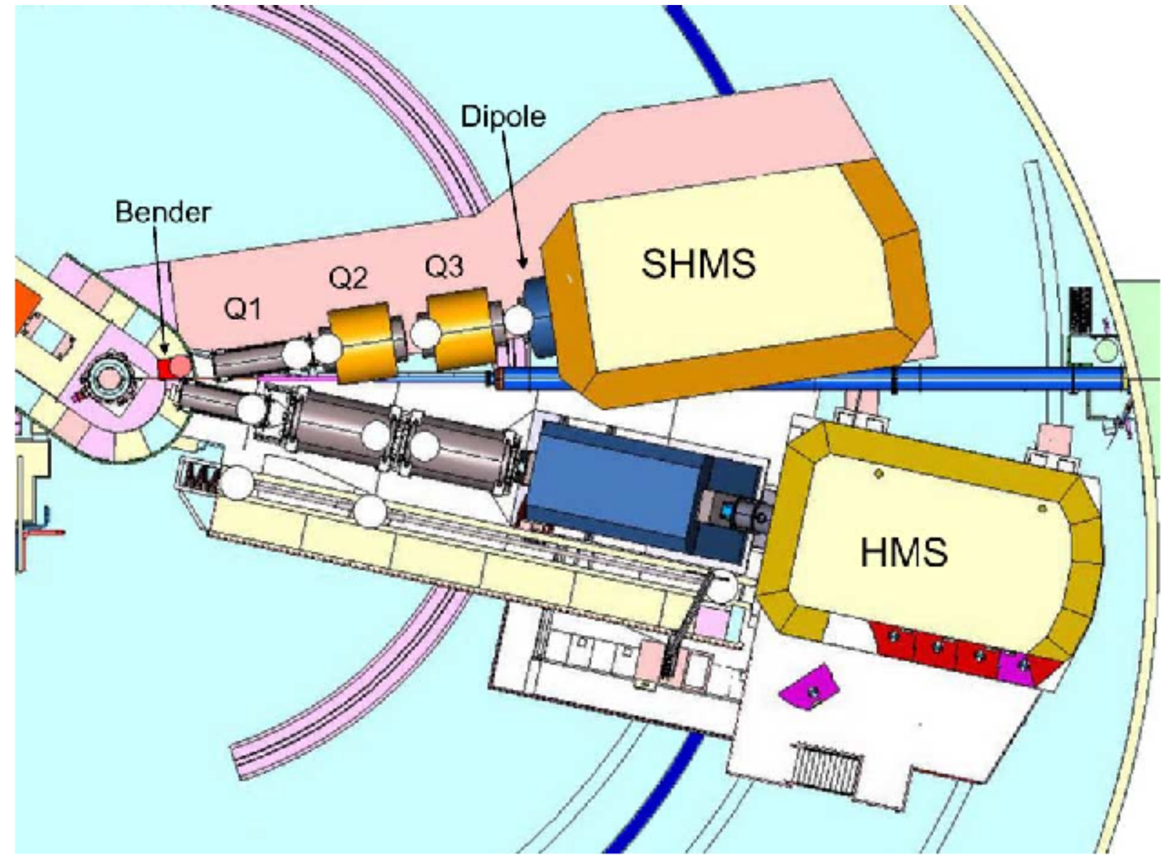
Pulse Shape Discrimination : e^-/π PID

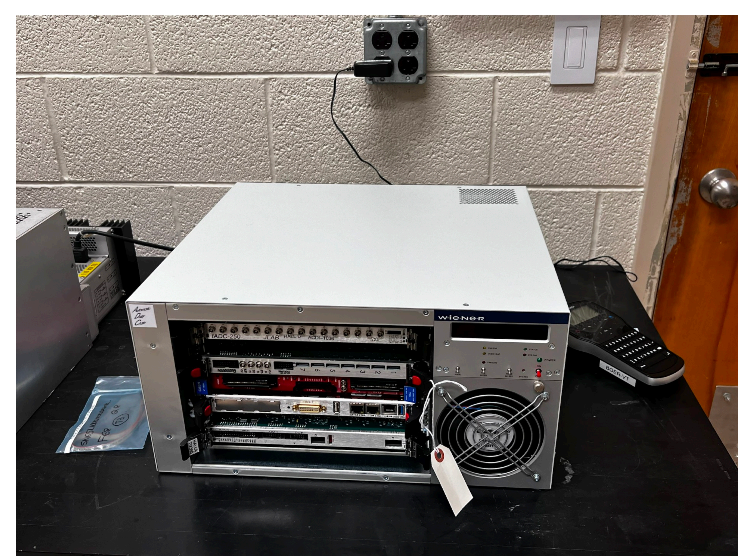


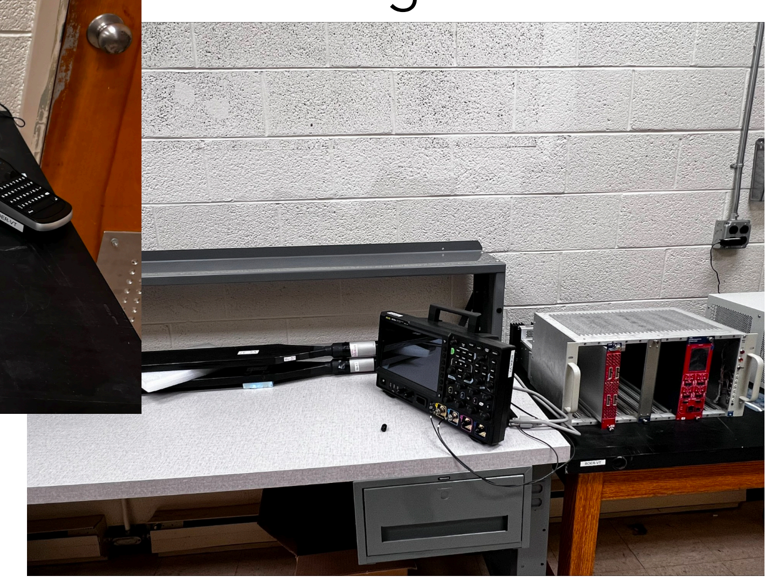
1. No separation is seen along R direction
2. So, PSD is not very useful for SHMS calorimeter data
3. Does not produce much scintillation light component
4. Other detectors :
    1. BigByte ?
    2. Gluex ?
    3. Class12 ?
    4. NPS Lead Tungstate ($PbWO_4$) : RG1 data not useful for e^-/π separation, as only neutral particles reach the spectrometer. Probably γ/π^0 separation can be checked.
    5. LAD Scintillator detector : If some data were taken in FADC250 mode 10 , it will be useful for PSD analysis

Prototype

1. No Geant4 simulation can100% mimic the experimental reality
2. So, at some point we should think of making and testing a prototype in real hall environment
3. Making a prototype is comparatively easy , testing is not !
4. Data taking with the prototype need to be non invasive to current Hall setup
5. The test run should be parasitic to other approved experiments
6. Placing the prototype anywhere on the hall floor 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
7. 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 for this conditions

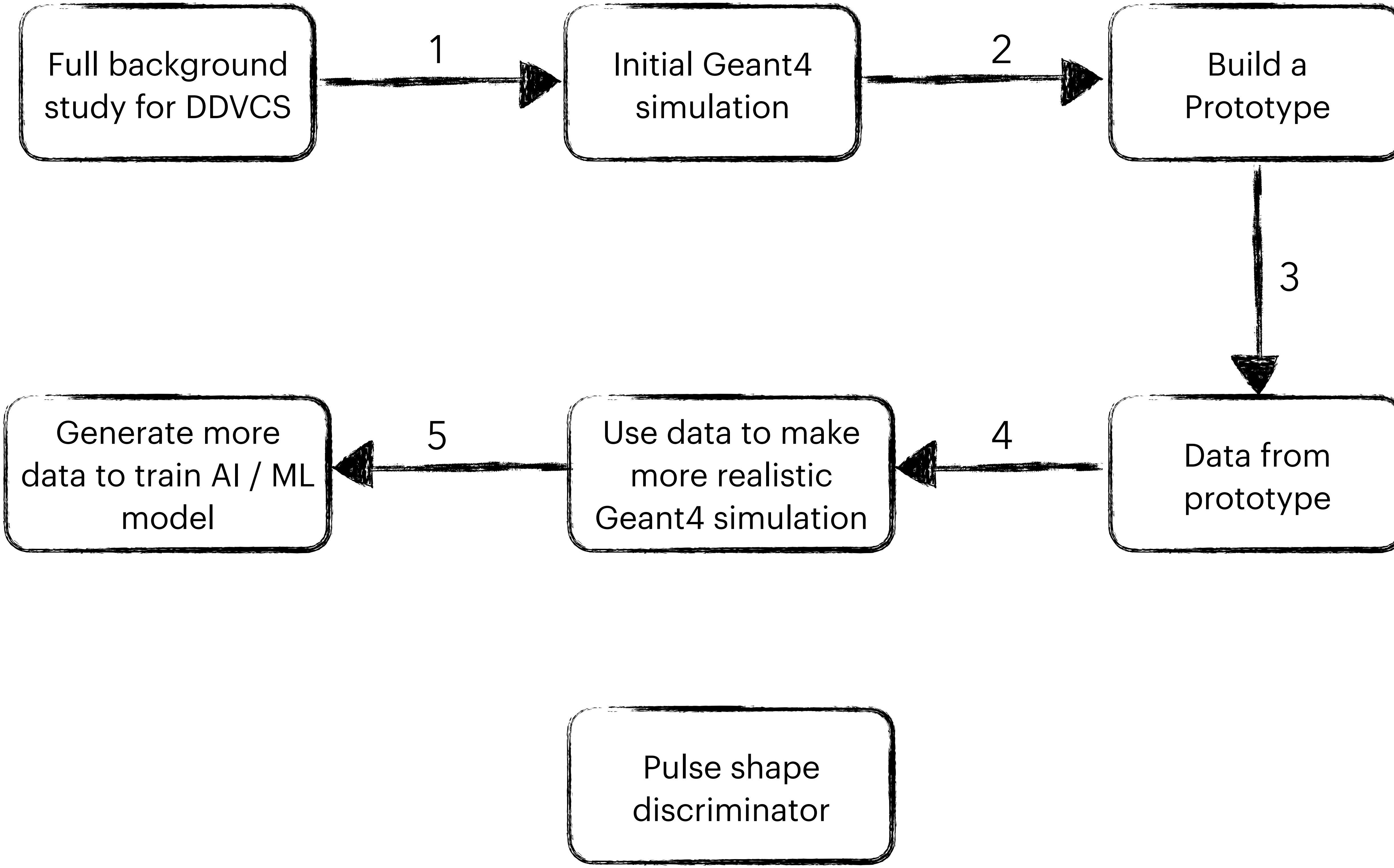






DAQ for prototype at Virginia Tech

Plan for moving forward



Summary

1. DDVCS is important to access the off diagonal terms of GPDs

2. The muon channel is need to be investigated for DDVCS reaction

3. The di-lepton spectrometer design for unpol. TCS program can be adopted if we add a Muon Detector

4. Muon Detector : Constrains :
    1. Large pion background
    2. Space Constraint to use large shielding materials
    3. Budget

5. To Do List :
    1. Full DDVCS background study
    2. Finalize the Geant4 Simulation
    3. Building the prototype and testing
    4. Finding other PID methods (e.g. PSD)
    5. How AI/ML can help in the design