MUON DETECTION AT HALL C, JLAB

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Goal

I'll try not to hold you too long before your coffee break.

By the end of the talk, you may have more questions than answers!

Why Detect Muons? GPD & DDVCS

PDFs

Physics information : Longitudinal momentum of partons inside a fast moving hadron
Transverse informations are integrated in the parton densities
Golden Channel : Deep Inelastic Scattering (DIS)

GPDs

Physics information : Transverse position of partons and quark-hadron densities
Golden Channels :

<u>Compton Like Scatterings</u>
DVCS (measure in multiple experiment)
TCS (measured for first time at JLab)
DDVCS (no experiment yet)

<u>Meson Productions</u>
DVMP

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

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

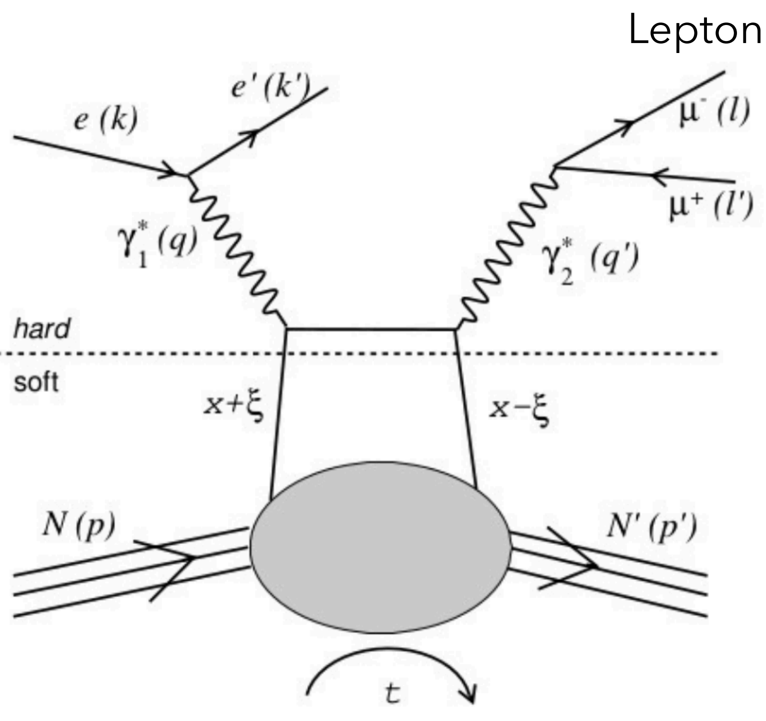
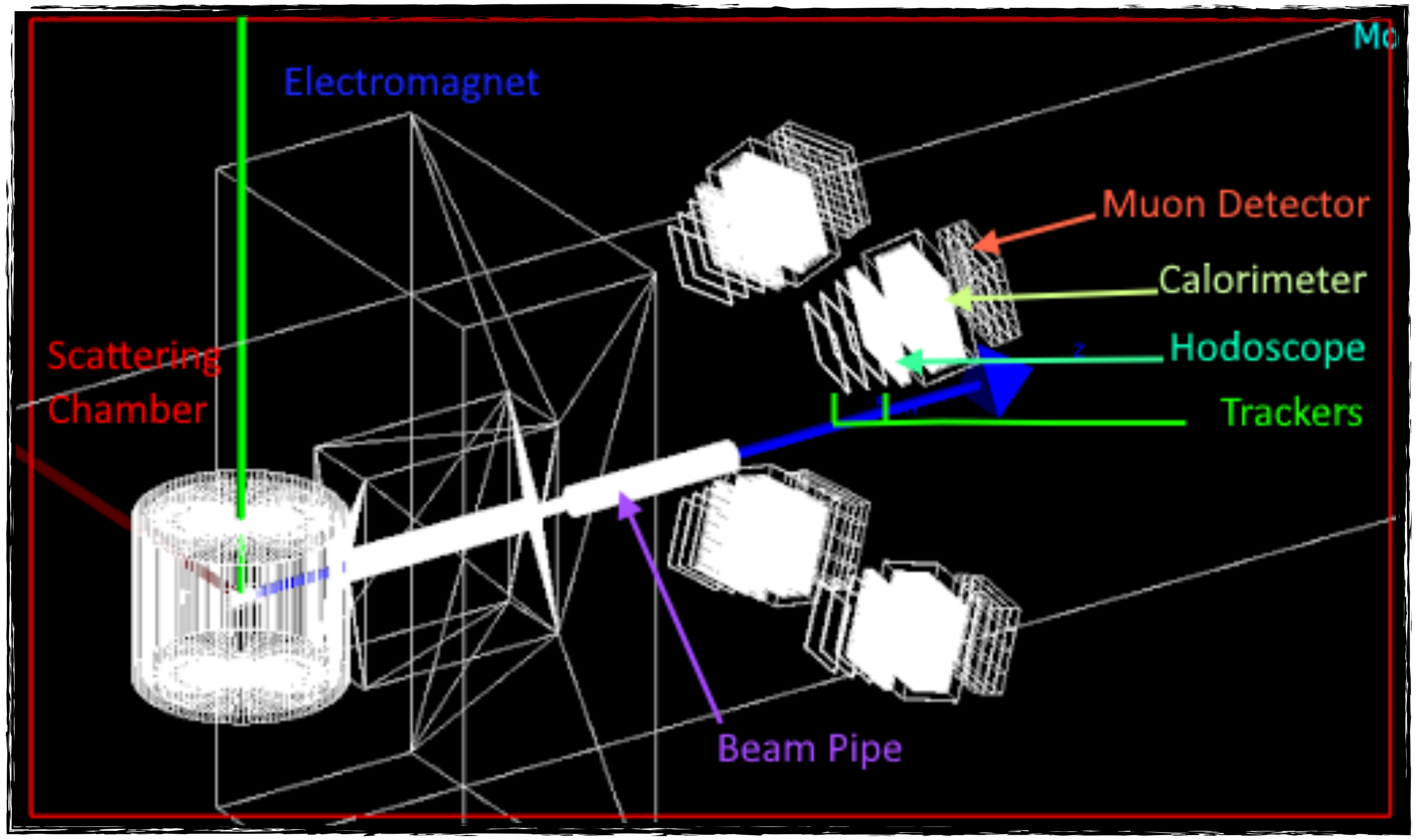


Fig1: DDVCS
Source : M, Boer. et.al. Eur. Phys. J. A (2015) 51:

Hall C advantages :
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

Di-Lepton Spectrometer

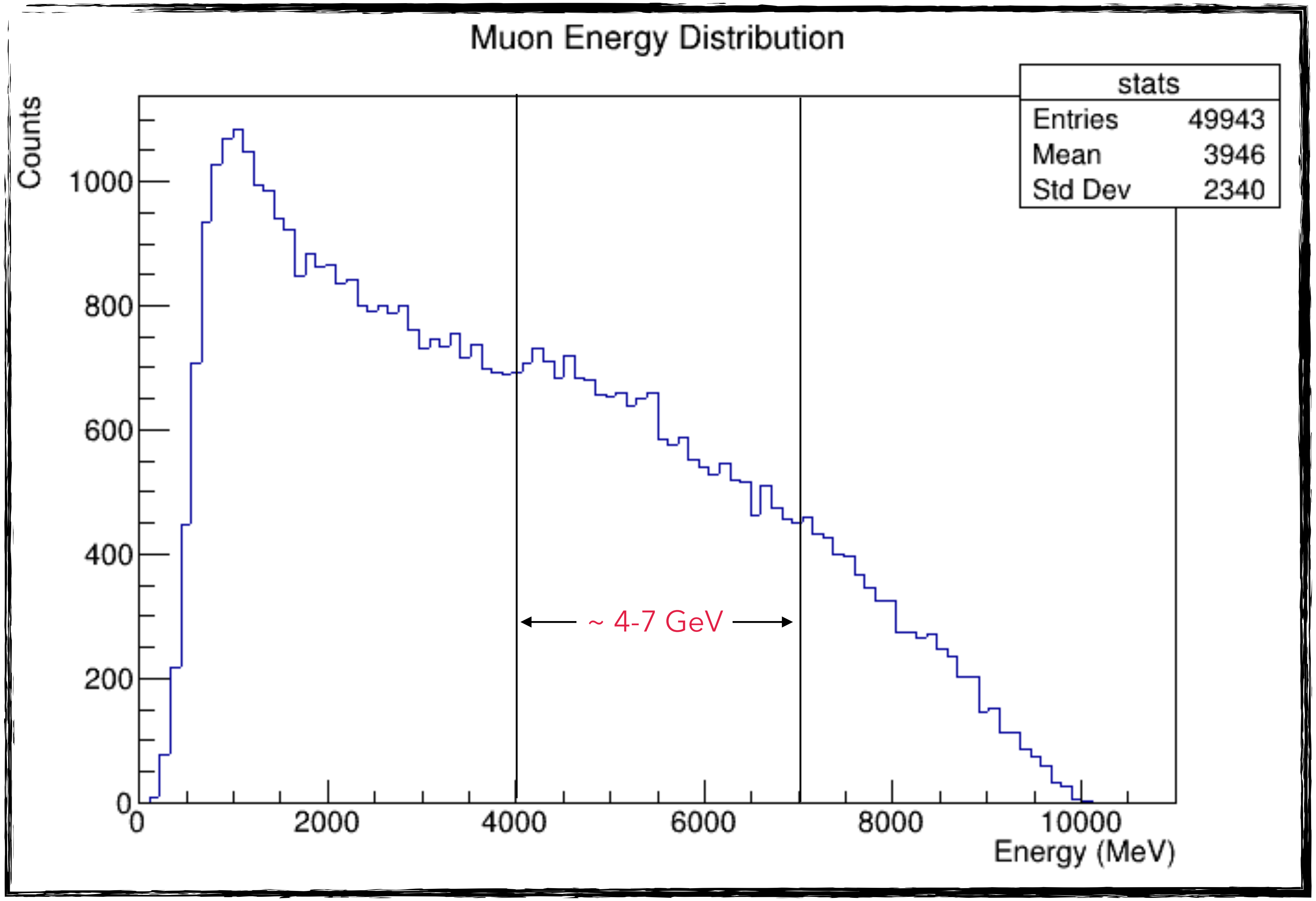
1. Current Hall C setup is not suitable for this kind of measurement
2. To do an exclusive measurement a new di-lepton spectrometer is needed
3. A dipole magnet is placed right after the scattering chamber to spatially separate μ^+ and μ^-
4. Detectors are placed in 4 quadrants
    1. Trackers (e.g. GEMs)
    2. Hodoscope (e.g. Scintillators)
    3. Calorimeter (e.g. NPS)
    4. Muon Detectors
5. This di-lepton spectrometer will also be helpful (with some modifications) for the measurement of TCS (polarized / unpolarized)



Muon Energy - from generated events

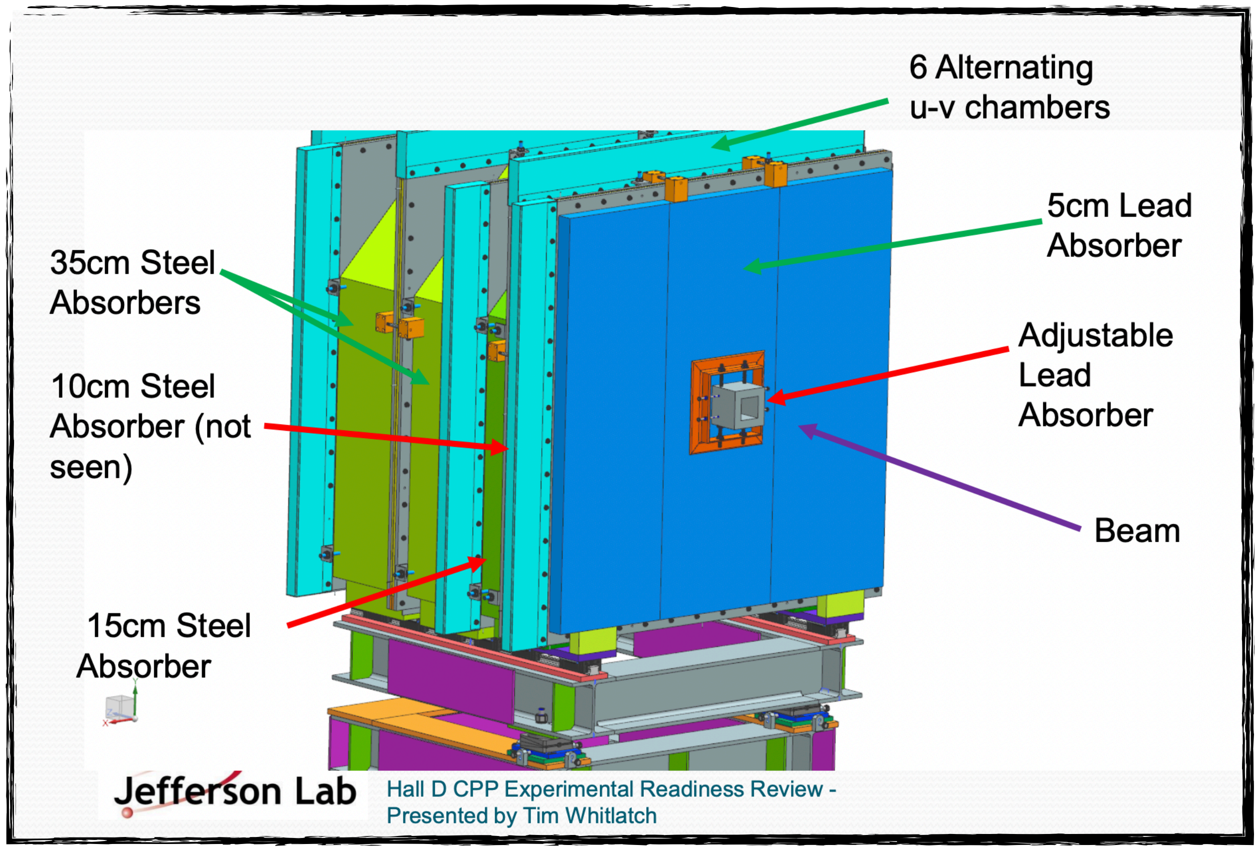
1. DEEPGEN (by M. Boer) event generator is used to simulate the DDVCS events

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

Good Luck ! Just for comic relief

Deb : I am thinking of designing a muon detector for Hall C ?
General answer : GOOD LUCK !

Question: How did Enrico Fermi handle hard problems he couldn't solve? ★

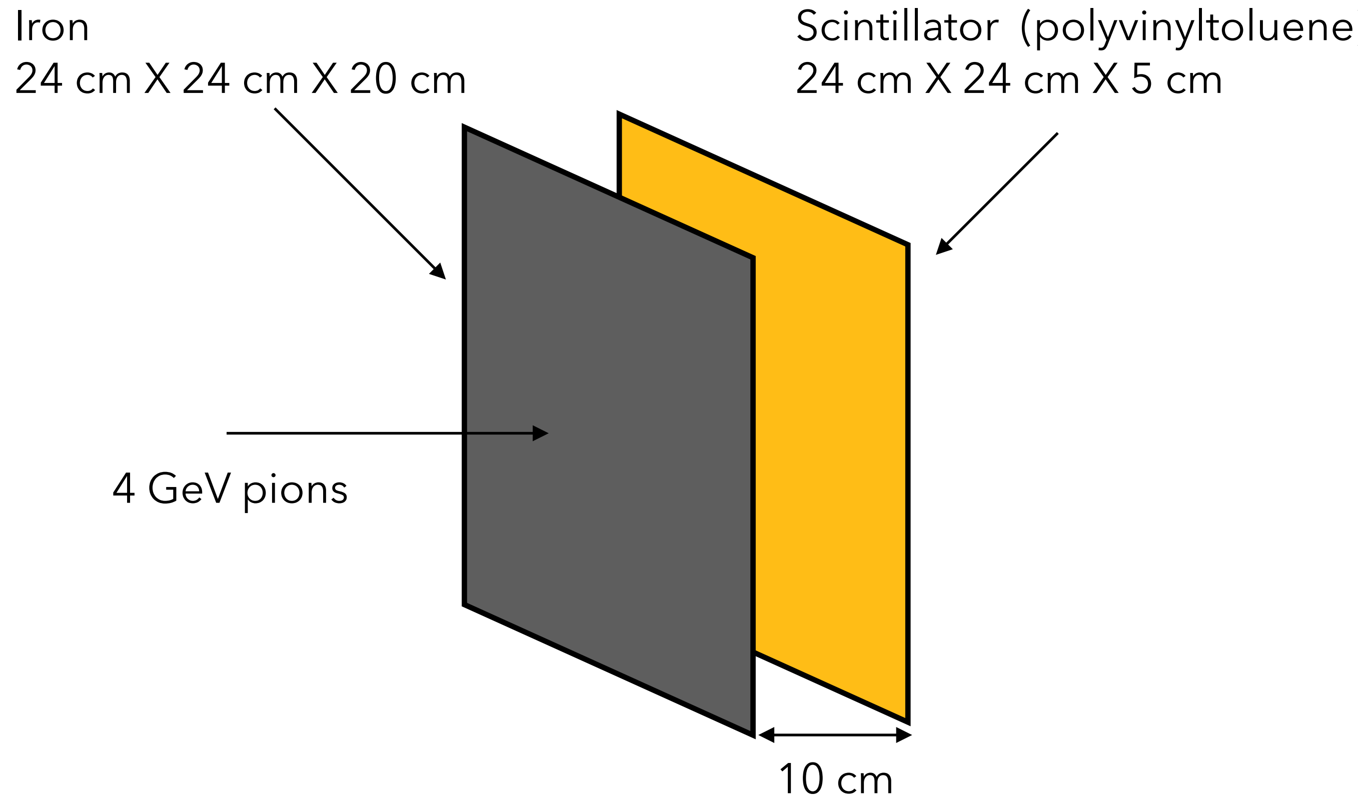
Answer: Enrico Fermi reportedly said that when faced with hard problems he couldn't solve, he would give them to his graduate students, who often managed to solve them under the pressure of exams.

So, I made a one semester undergraduate project out of it and gave it to a Virginia Tech Undergraduate Keagan Bell (supported by M. Boer).

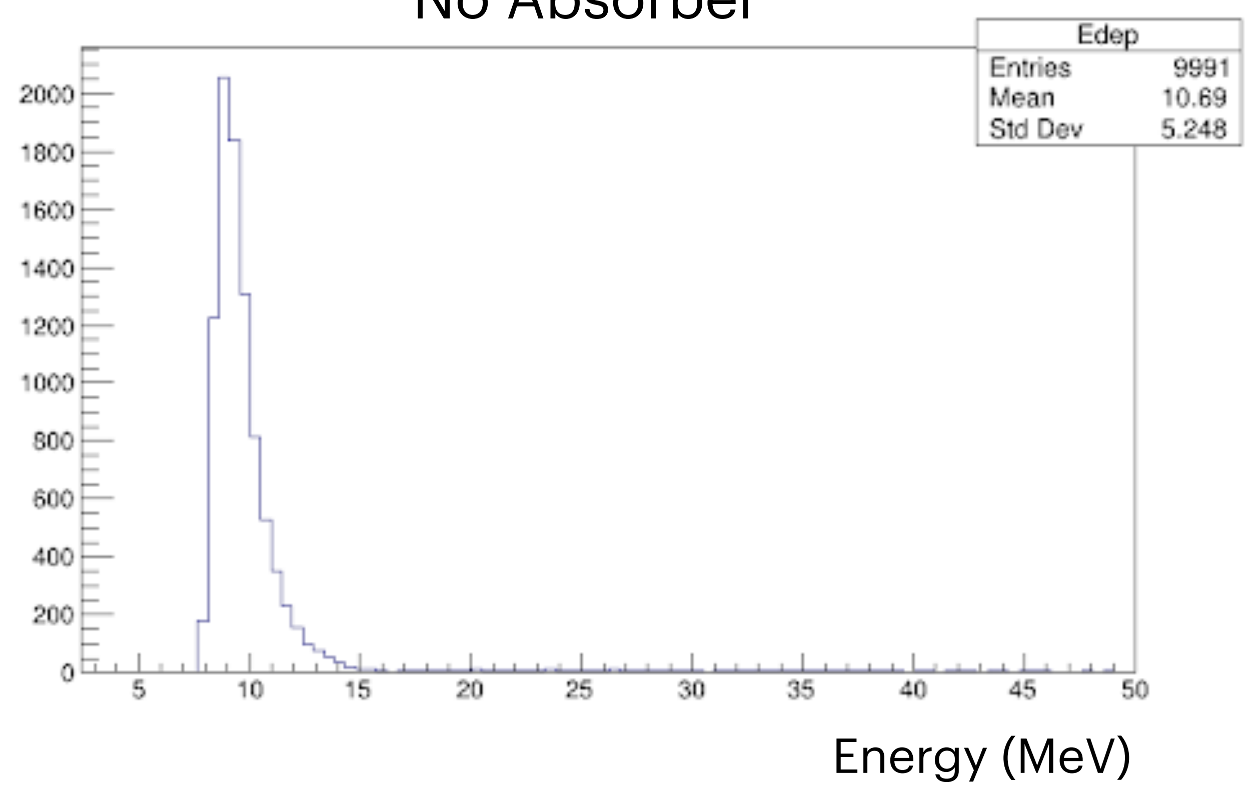
★ Even if the story is not true or wrongly attributed to Enrico Fermi, it remains a useful and insightful anecdote!

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

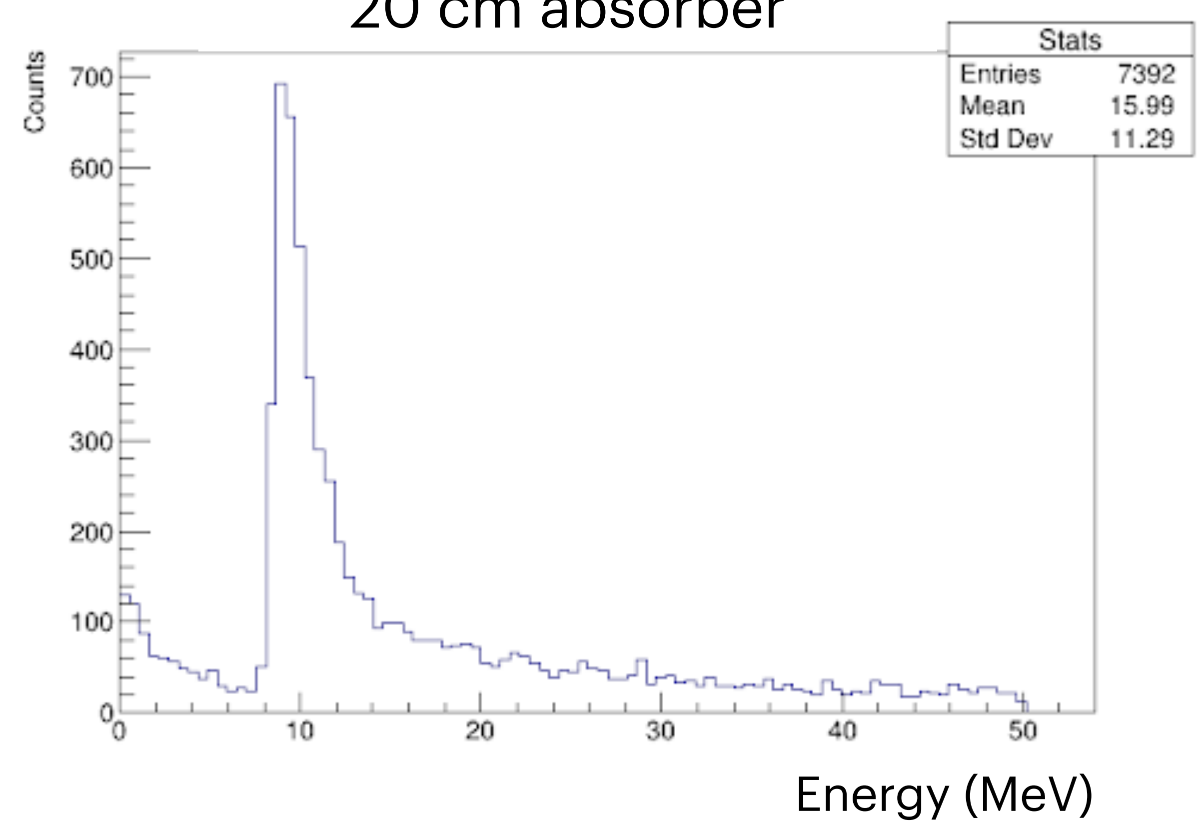
1. 1 absorber - 1 scintillator
2. 4 GeV pions were fired from a particle gun
3. Energy deposited by pions and all other particles generated in the interaction is histogrammed (w and w/o absorber)
4. Distinctive low energy secondary peak (from hadronic interaction of pions with the absorber) emerges in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



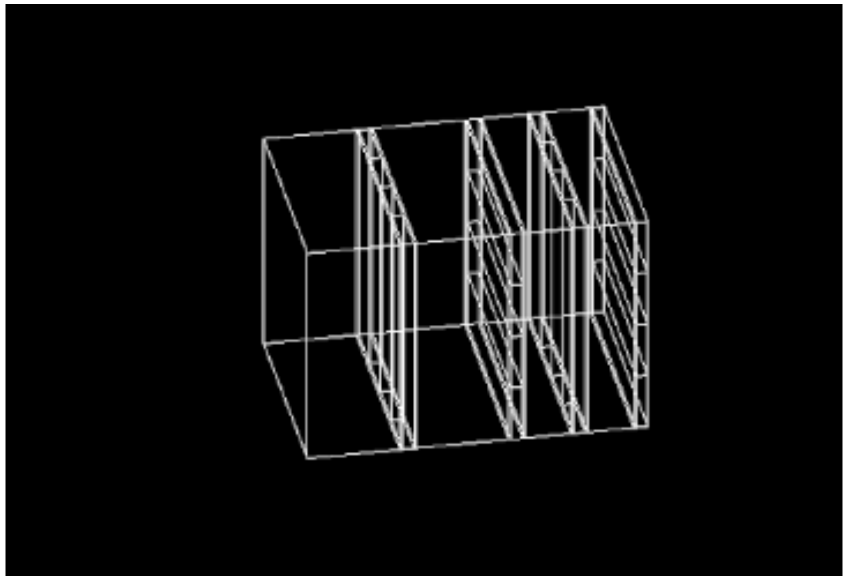
No Absorber



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

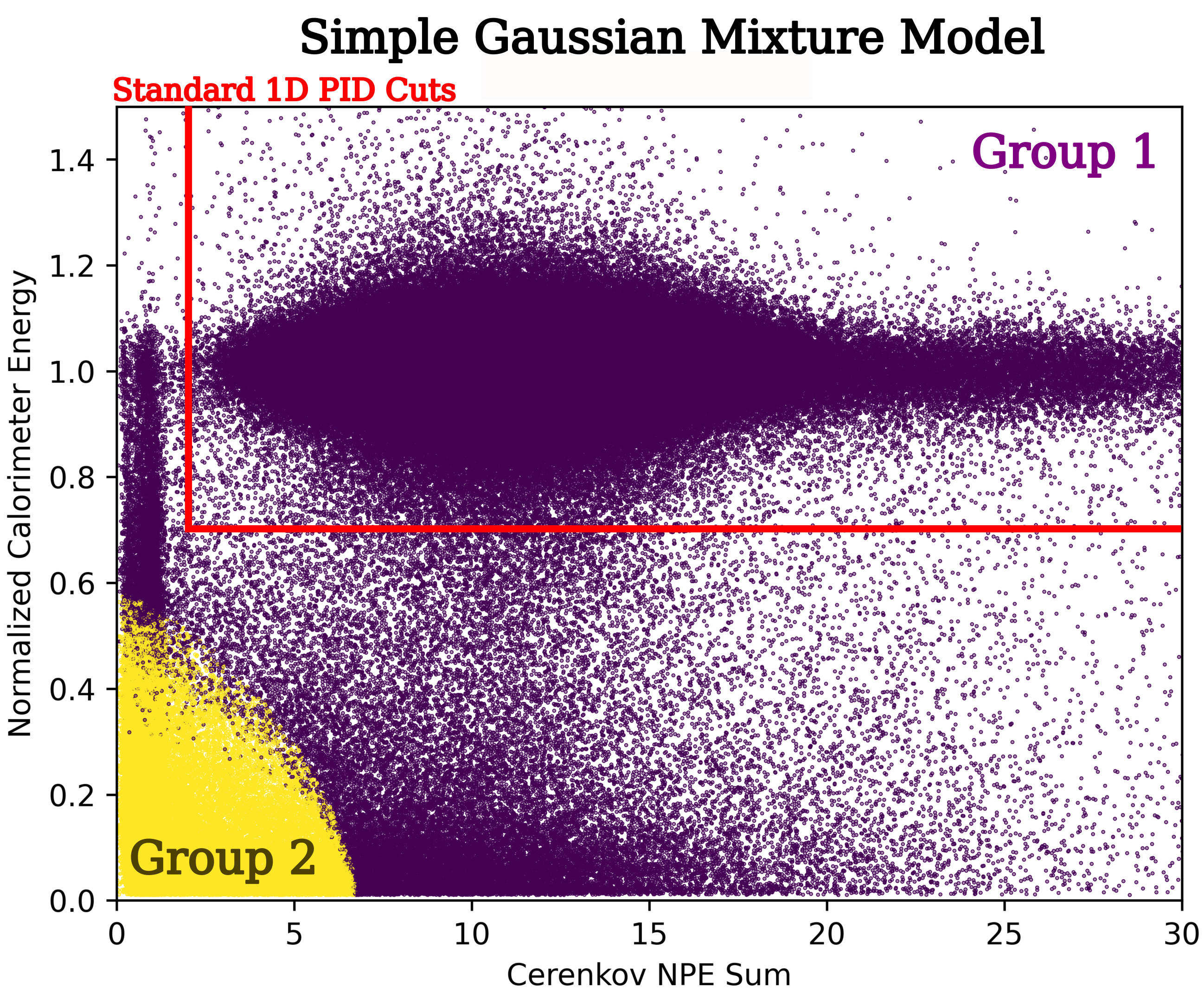
hits in each layer of scintillator				6 GeV
particle	scint 1	scint 2	scint 3	scint 4
mu-	10000	9997	9996	9994
pi+	3001	417	146	50

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

AI/ML can machine learning provide some solution ?

1. Using machine learning algorithm is gaining popularity in recent years both at JLAB / EIC for PID
2. Many people / group trying their own way
3. Camerons 1 week fun project with Hall C data
    1. Uses multilayered calorimeter and Cherenkov data
    2. Simple Gaussian Mixture Model
    3. Unsupervised learning : the particles are not labelled in Hall C simulation
    4. Shows promise despite not being super successful
4. Hall D also using machine learning for PID : I would like to learn more about their progress
5. aligned with the ongoing efforts of the AI4HallC Working Group dedicated to Hall C
6. Where is the training data for muon detector for muon-pion PID ?

Electron - pion PID using machine learning



From : Cameron Cotton

Pulse Shape Discrimination

1. Some scintillator materials show a slow (delayed fluorescence) component along with a fast (prompt fluorescence) decay component

2. Light from the delayed fluorescence depends on the rate of energy loss dE/dx; light response will be greater for the particles with greater dE/dx

3. i.e. this depends on the nature of the incoming particle

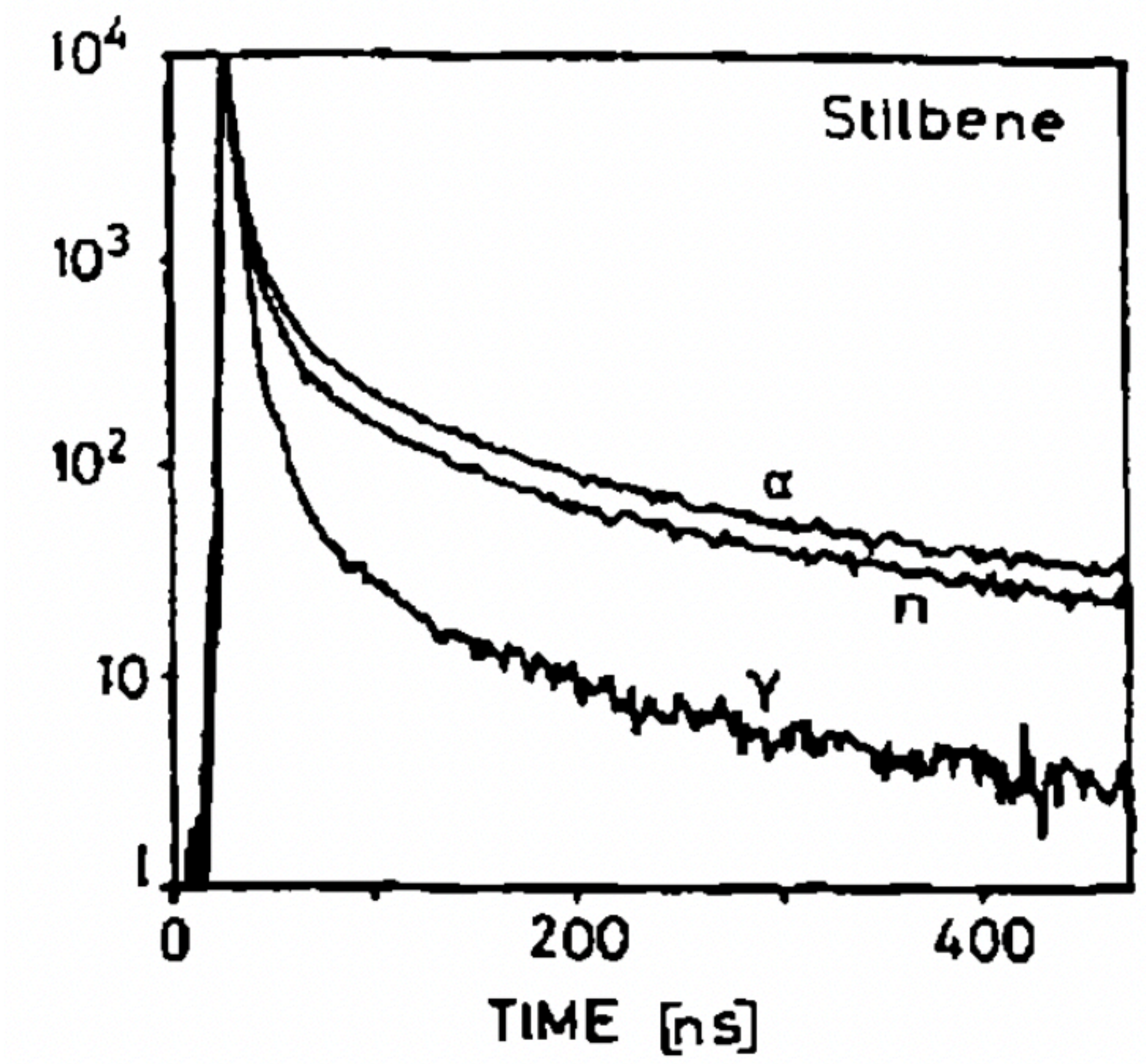
4. These scintillators are capable of distinguishing the particles on the basis of the shape of the emitted light pulse

5. Supposedly a cleaner method

6. Popular in low energy (compared to Hall C, JLab) and specially for γ - neutron separation

7. Not many article found where PSD method is tried for the higher energy regime

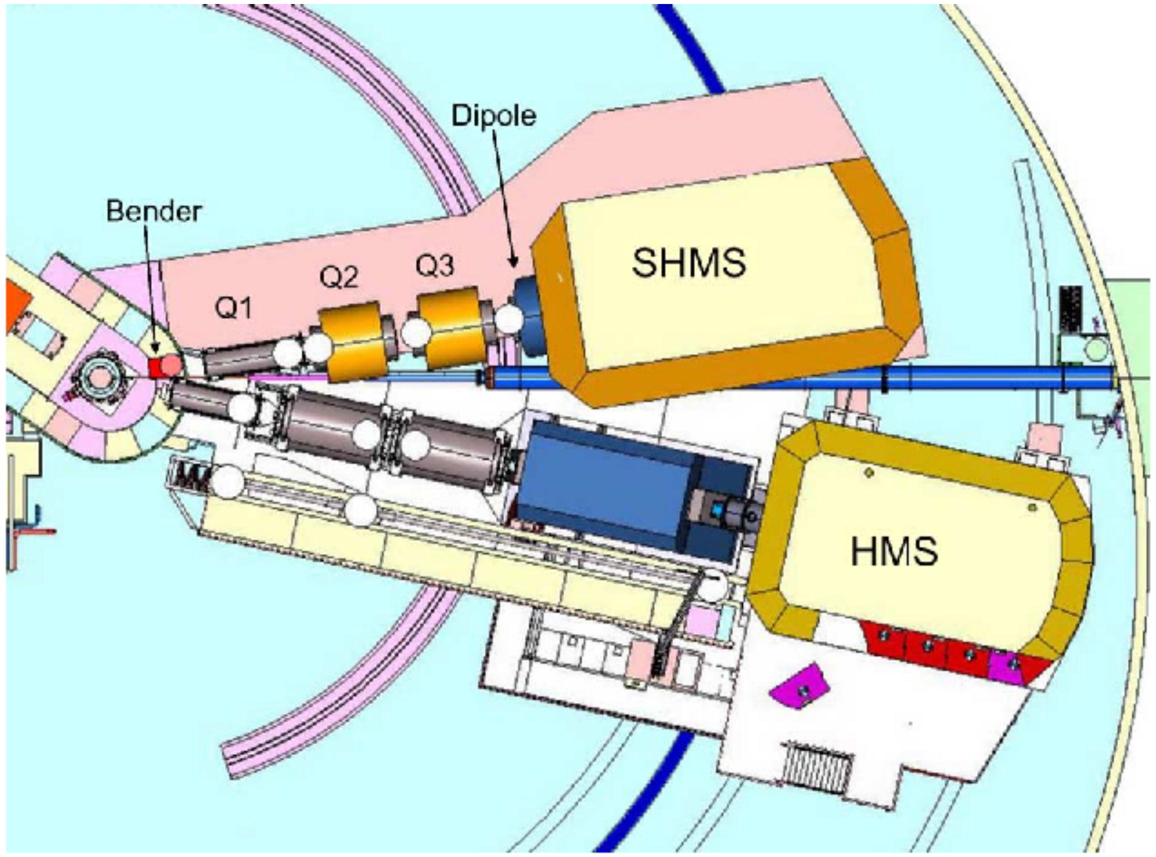
8. With better electronics and advanced technologies shouldn't we try this method for higher energies, especially where PID is challenging ? Can Preshower, shower FADC250 data can be useful ?



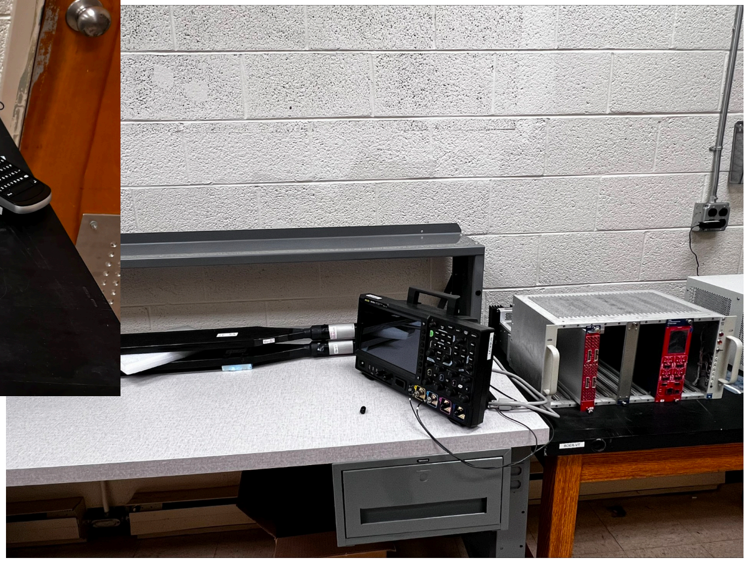
Pulse shape of Stilbene light for alpha particles, neutrons and gamma rays (From : Techniques for nuclear and particle physics Experiments by W.R. Leo)

Prototype

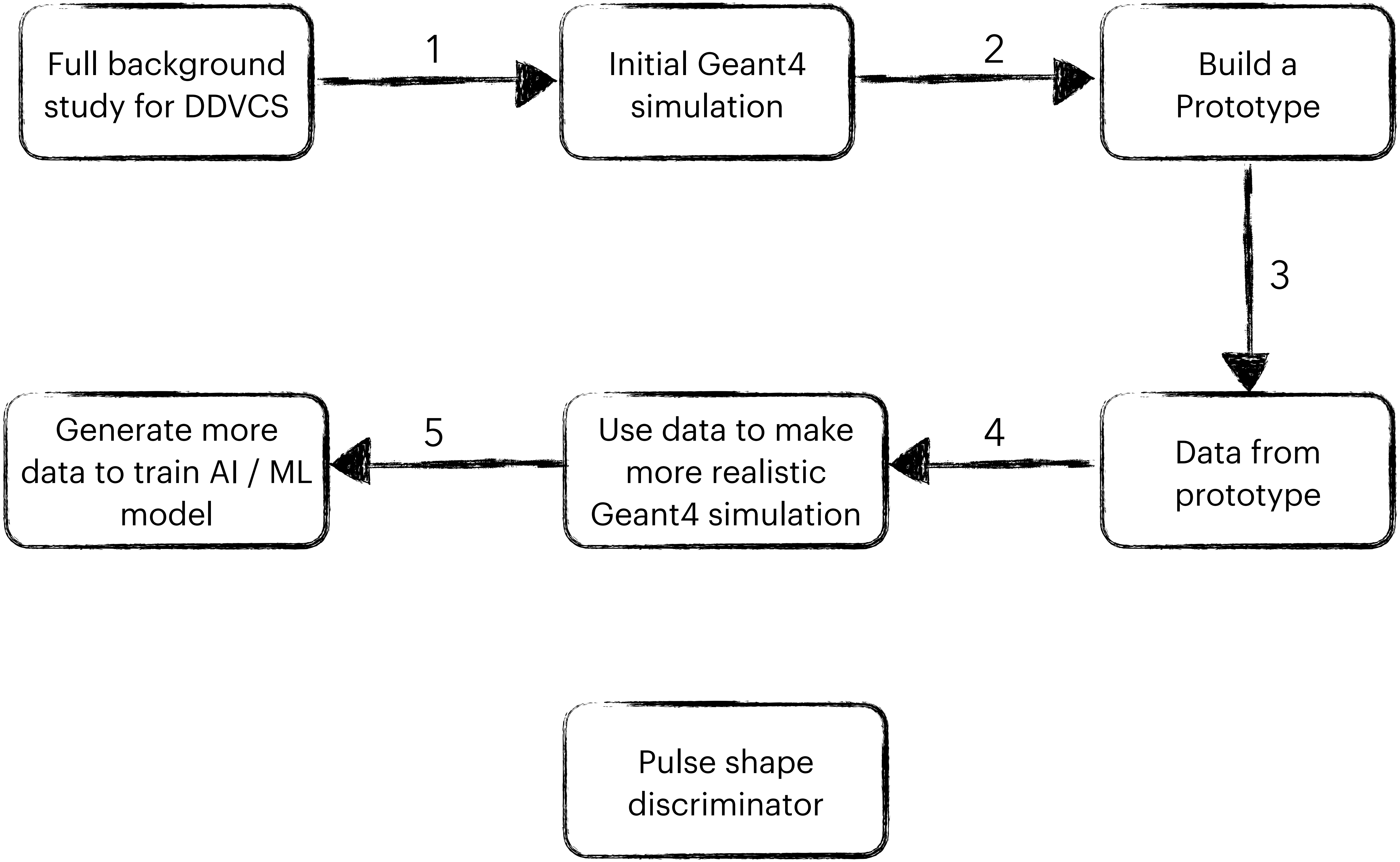
1. No Geant4 simulation can100% mimic the experimental reality
2. So, at some point we should think of making and testing a prototype in real hall environment
3. Making a prototype is comparatively easy , testing is not !
4. Data taking with the prototype need to be non invasive to current Hall setup
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



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Marie Boer

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The Jefferson Science Associates
The Jefferson Lab User Organization

This project has the potential to grow significantly and will require larger collaboration in the future, so I look forward to your continued support.