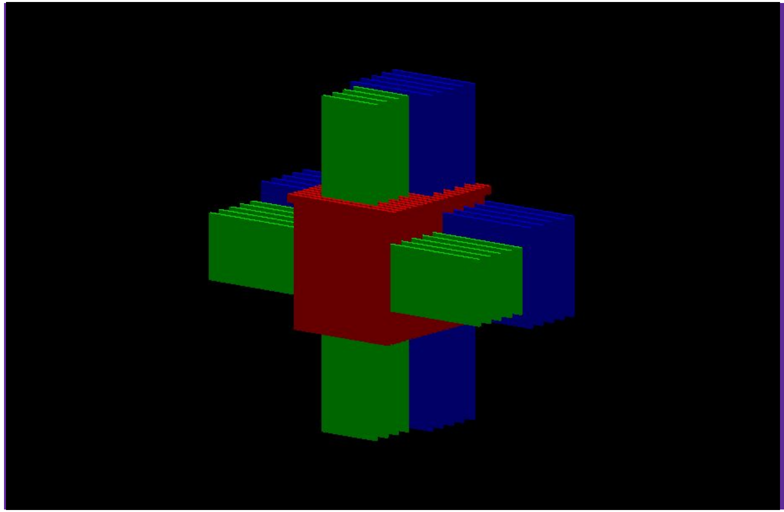
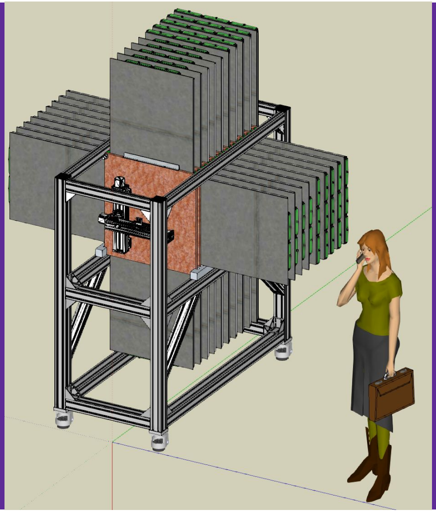
Partikeldagarna 2021

Simulation and Testing of LDMX Prototypes

by Peter Gyorgy
masters student at Lund University





The prototypes

1. smaller-scale trigger scintillator of the final LDMX
2. smaller-scale hadronic calorimeter of the final LDMX

Beamtime scheduled for Oct 18 to Oct 31, but the hcal detector parts from Caltech did not arrive on time.

Only trigger scintillator could be tested under beam

New beam expected to be scheduled for March 14 to March 28

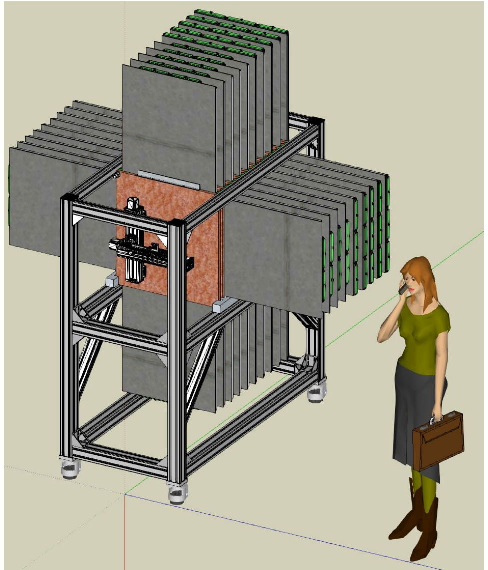


Figure by: David Hitlin

Motivation:
hadronic calorimeter prototype and test beam

Calibrate hcal

- test beam can provide specific particles
- ecal would interfere with calibration in final LDMX version

Tune the simulation to match experimental results

Verify certain predictions of the simulation

Motivation:
a trigger scintillator prototype and test beam

Try out alternate designs

Check if electronics work

Extra time to fix errors

Motivation: Prototype simulations

Provides physical predictions based on which to build the prototype

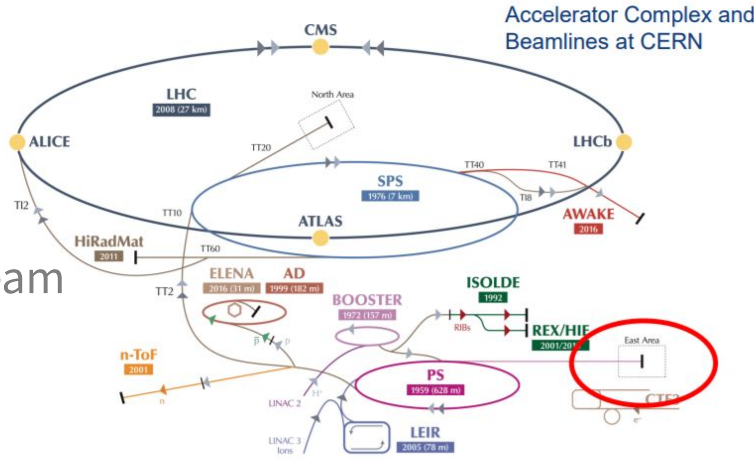
- Ex: absorber length

Helps understand physical behavior of prototype

Helps anticipate the output of the prototype

Indicates measurement limitations

The T9 beamline at CERN



Proton beam -> target -> many particles

many particles -> magnetic filtering -> charged particle beam

Can be: p+, e-, e+, μ-, μ+, K-, K+, π-, π+

0.5 GeV - 10 GeV.

T9 instrumentation:

- Scintillator telescope - serves as beam particle trigger
- Fiber tracker - identifies particle position
- 2 threshold Cherenkov detector - identify the type of particle

The hcal prototype

19 layers of plastic (Polystyrene) bars sandwiched between steel plates

8 or 12 scintillator bars per hcal layer

Bars alternate between horizontal and vertical orientation

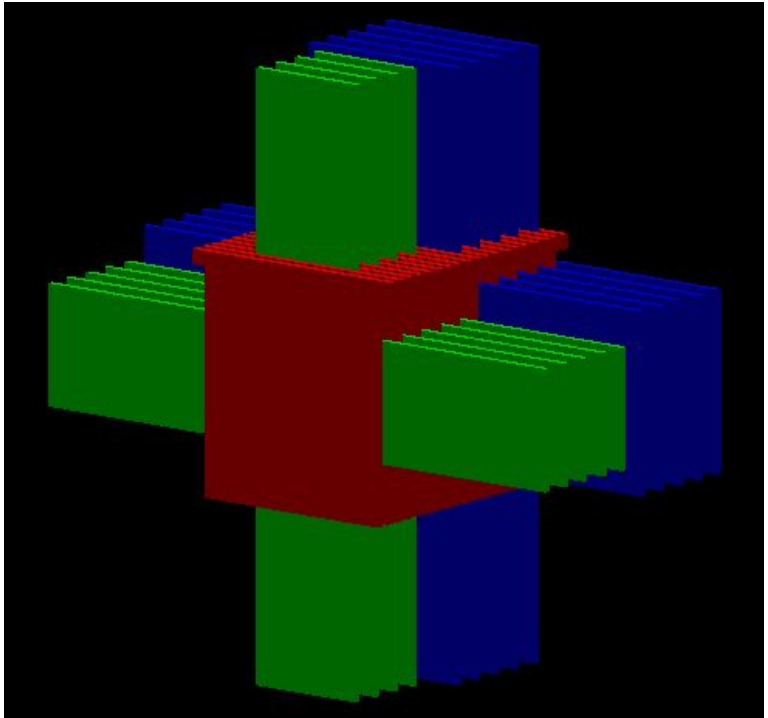


Figure by: Einar Elen

Simulations undertaken

Electrons, muons, positrons, protons, and charged pions

Various particle energies: 200 MeV - 8 GeV

Incidence angles of 0 and 30 deg

Presented here: only electrons and muons at 0.5, 2, and 4 GeV

Simulation vs Digitisation vs Reconstruction

Three types of results: "simulation", "digitisation", and "reconstruction"

"simulation": exact results of the simulation and their physical meaning

Example: exact energy deposited into detector

"digitisation": the direct, machine-language output of the prototype

Example: measured current in scintillator bar

"reconstruction": the interpretation of the output of the prototype in terms of physical properties

Example: measurable energy deposited into detector

Sim vs Reco: an Example

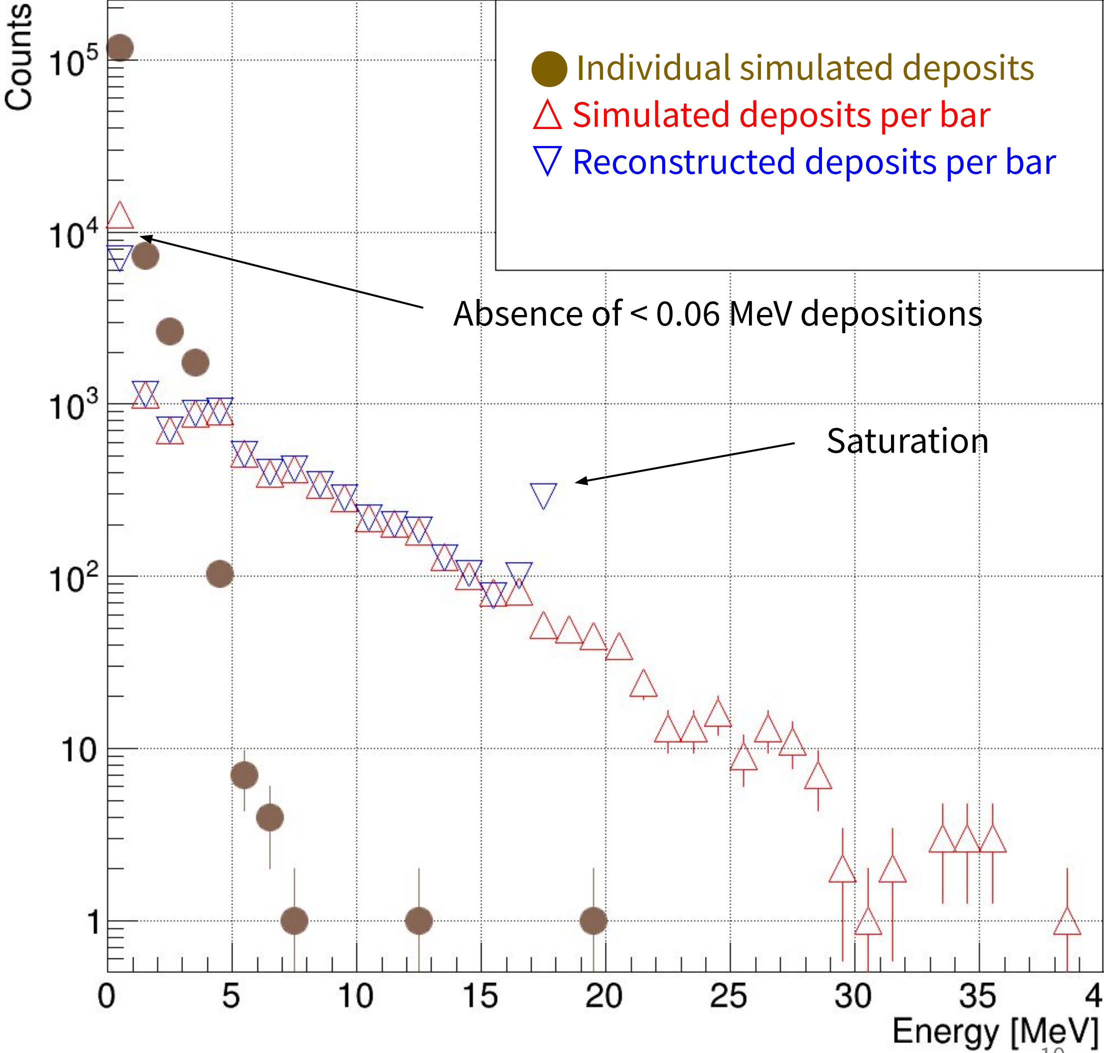
Individual simulated deposits (brown)

Simulated deposits per bar (red)

Reconstructed deposits per bar (blue)

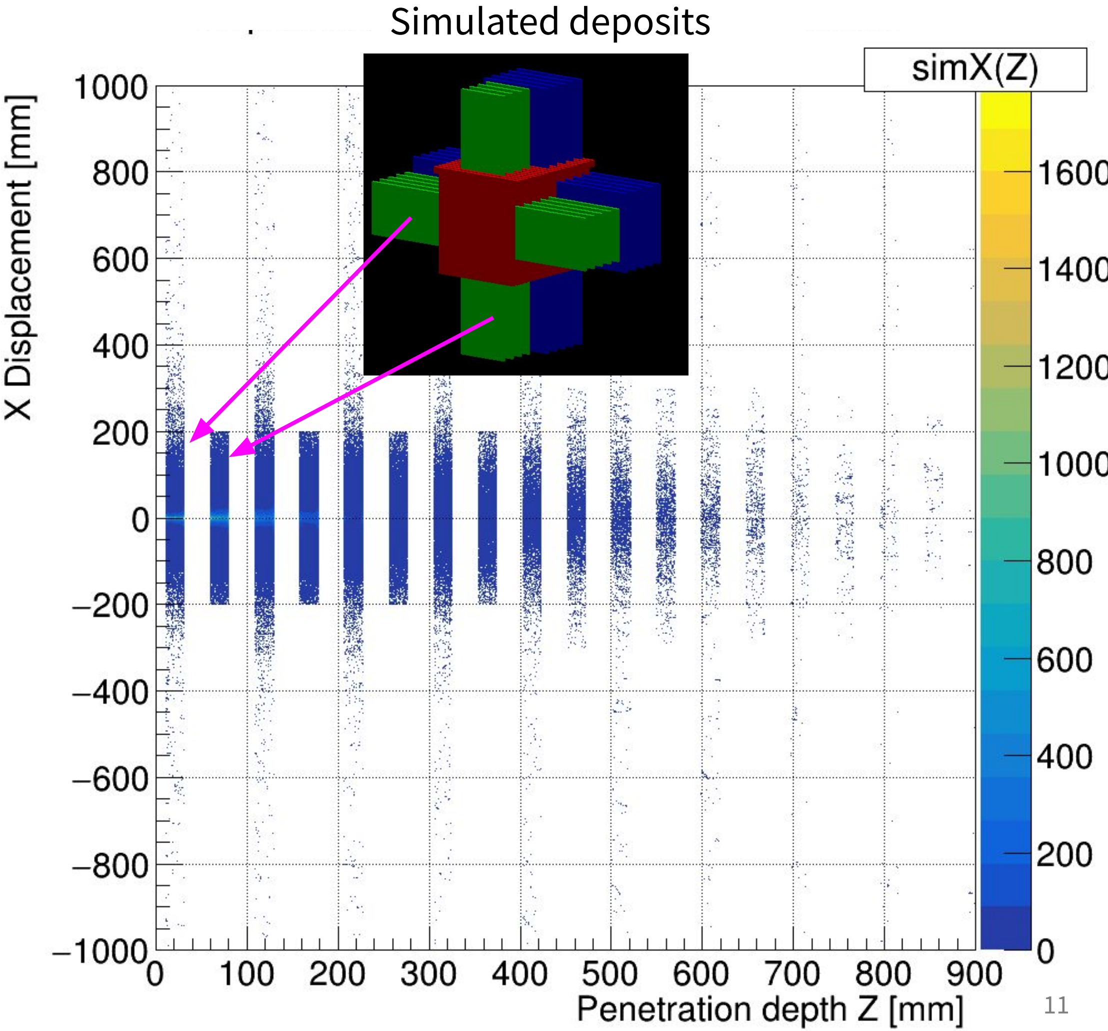
Noteworthy differences:

1. Reco has a bar readout saturation around 18 MeV
2. Reco does not detect bar depositions under 0.06 MeV



A visualisation

0.5 GeV e^-

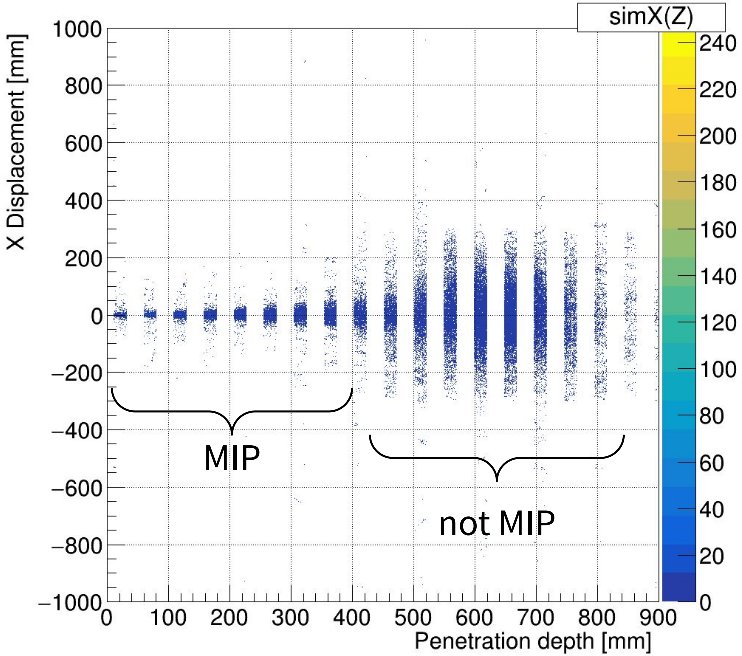


Investigating muon energy loss

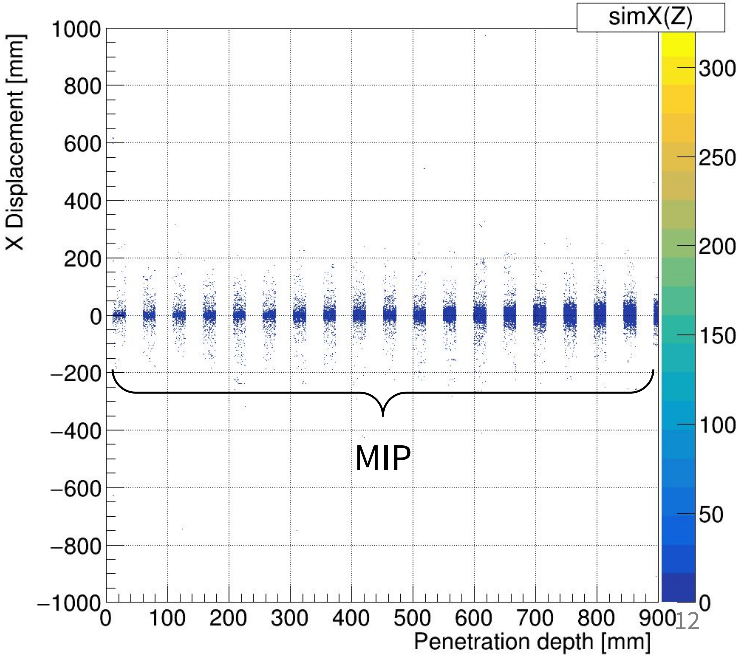
0.5 GeV muons inititall MIPs, (Minimum Ionising Particles) but become ionising.

2 GeV muons remain MIPs throughout detector

0.5 GeV muon deposit locations



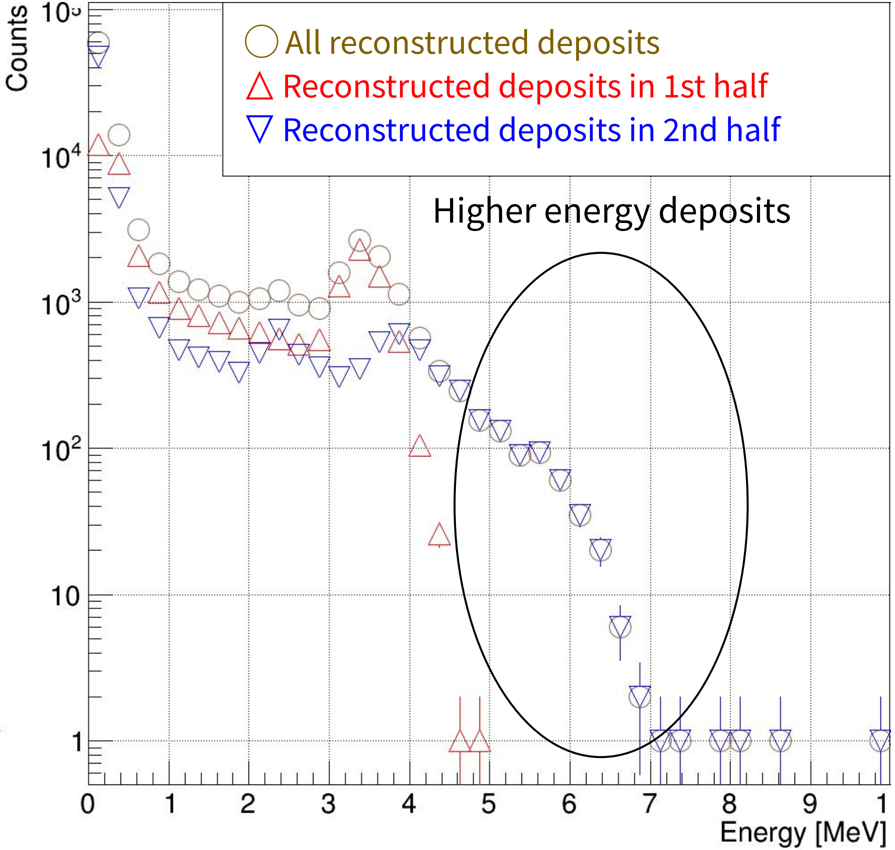
2 GeV muon deposit locations



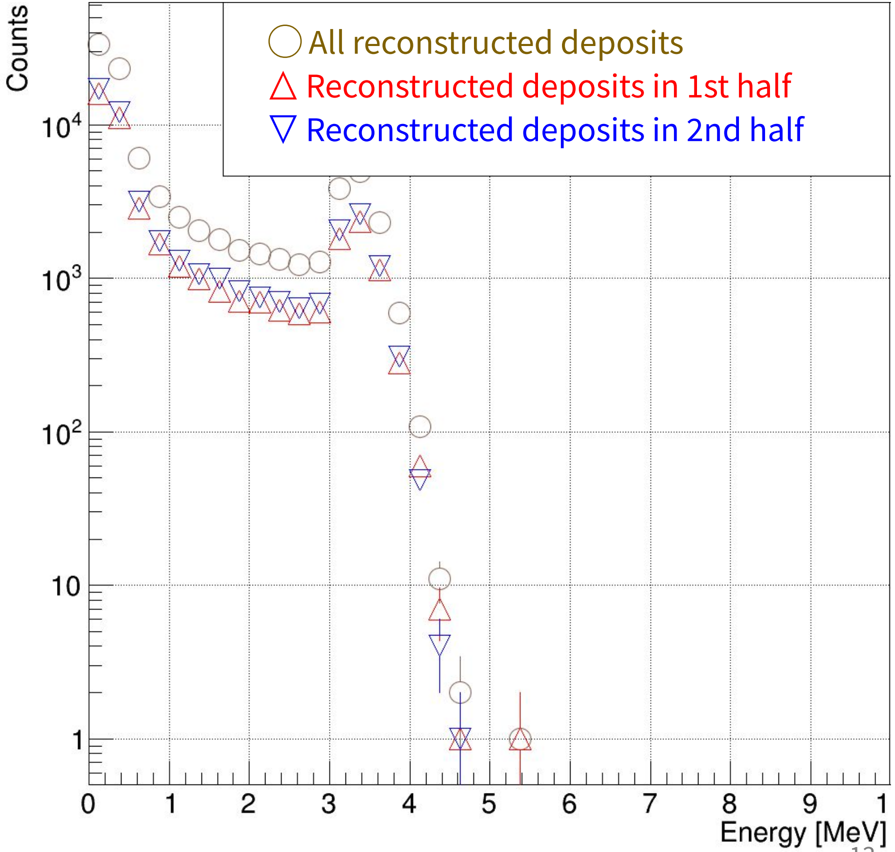
Investigating muon energy loss

Detector was split in half along the Z axis.

0.5 GeV μ^- (not MIP anymore in H2)



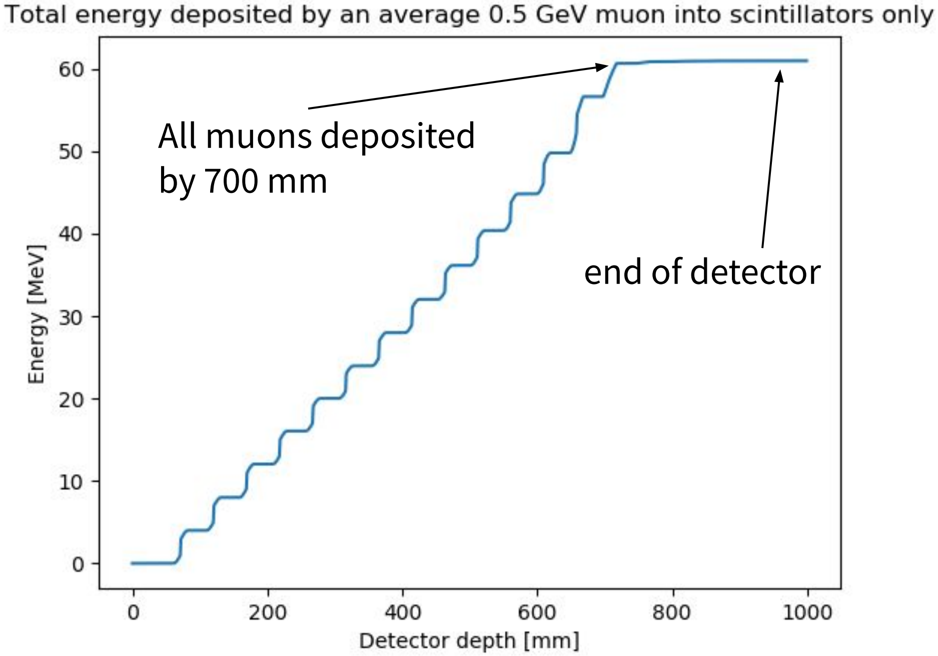
2 GeV μ^- (fully MIP)



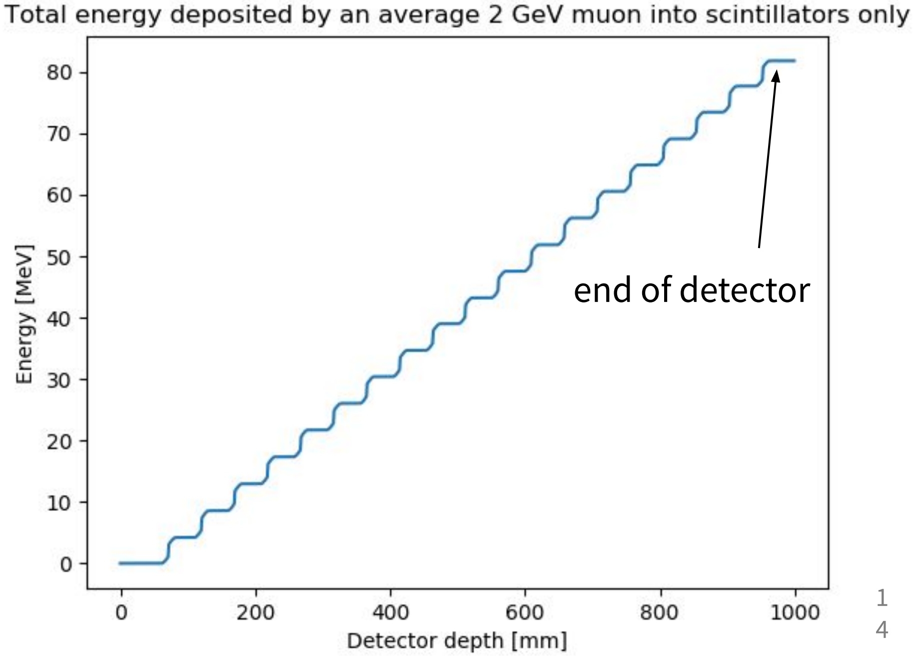
Investigating muon energy loss

Cumulative energy deposit into scintillator of a muon

0.5 GeV: loses MIP status



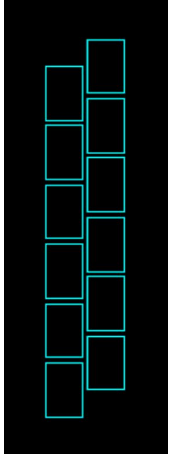
2 GeV: maintains MIP status

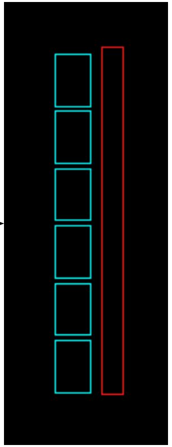


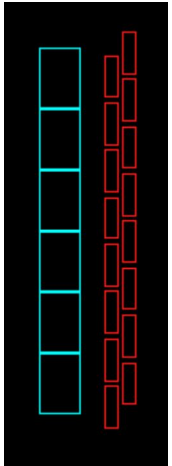
The trigger scintillator prototype

3 different designs.

1. 2 layers of 6 Plastic (Polyvinyltoluene) bars
   40 x 3 x 2 mm plastic bars
   some spatial resolution
   minimal beam interference
2. 1x6 Plastic bars, 1 LYSO plate
   30 x 20 x 1.2 mm LYSO plate
   LYSO substitutes beam target
   target interaction are directly recorded
   no spatial resolution within LYSO
3. 1x6 Plastic bars, 2x8 LYSO
   30 x 2.1 x 0.6 mm LYSO bars
   same features + spatial resolution







Digi to reco for the trigger scintillator

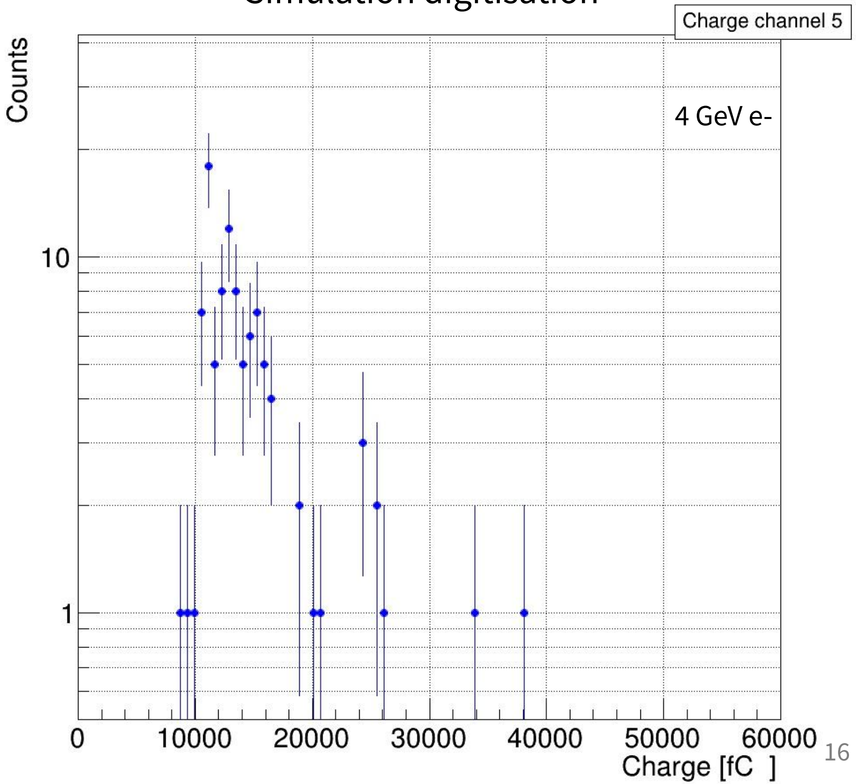
Trigger scintillator only provides:

1. ADC (amplitude to digital conversion)
2. TDC (time to digital conversion).

ADC convertible to detected charge.

Can be plotted for each scintillator bar, and used for reconstruction.

Simulation digitisation

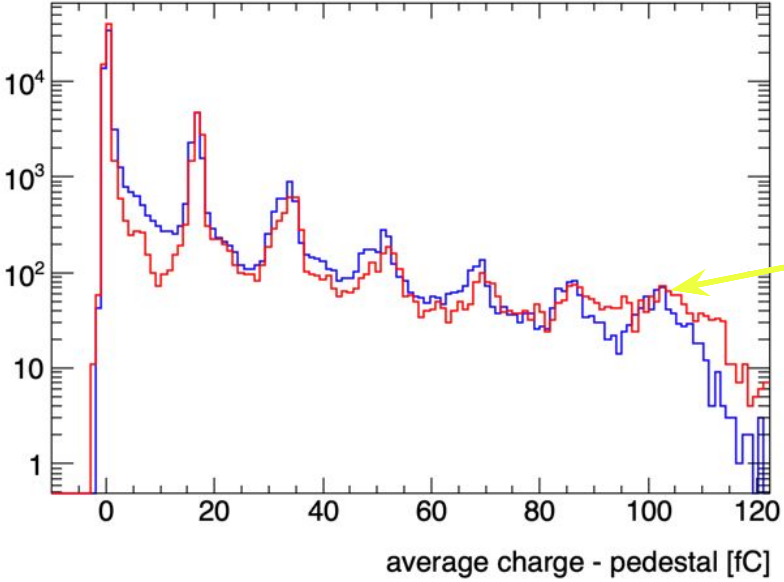


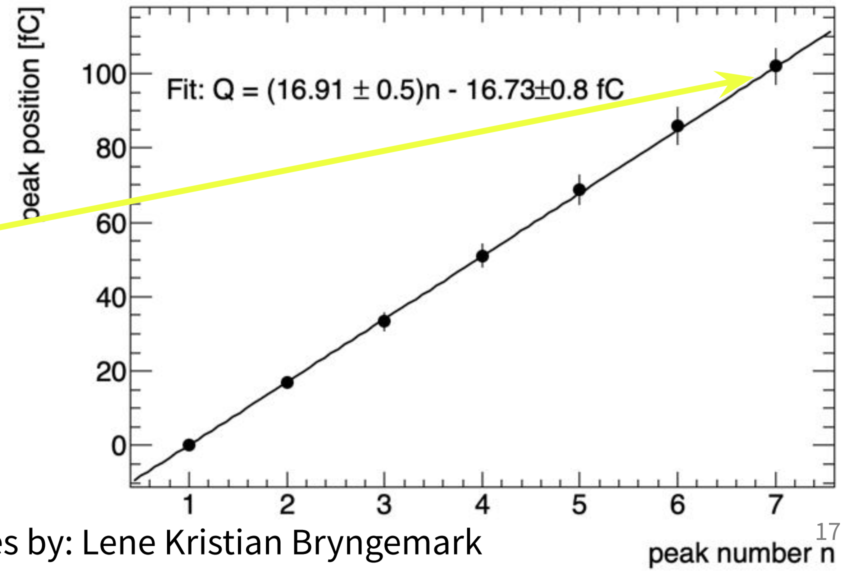
Processed preliminary trigger scintillator result

Average charge per event for LYSO and Plastic

Each *n*th peak corresponds to *n* photoelectron pulses in the electronics.

Derivable gain: demonstrates a self-calibrating system. (i.e. distance between peaks can be used to determine charge of one PE). A successful proof of concept!





Figures by: Lene Kristian Bryngemark

Measurable achievements of the test beam

Trigger scintillator results:

- PE calibration
- Channel correlation
- Particle timing information

Immeasurable achievements of the test beam

Many developments on the electronics side:

- A redesign and new implementation of the measurement timing system
- Practical testing of boards and chips
- Catalysis of further development

Software development:

- Data Acquisition program
- Translation of experimental results to format of simulation

Outlook

Second run March 14 - 28

Future hcal results:

- Successful assembly and measurement
- High statistics sample p+ and e- 1 - 2 GeV
- Muon MIP hcal response
- Measure fake rates with help of trigger
- Energy scan 0.5 - 8 GeV
- Scanning response along bars
- Measure hadronic resolution tails

More trigger scintillator results

Thank you for your attention

Any additional comments/questions?

This is the end of the presentation

All slides past this are FAQ response slides / appendix slides

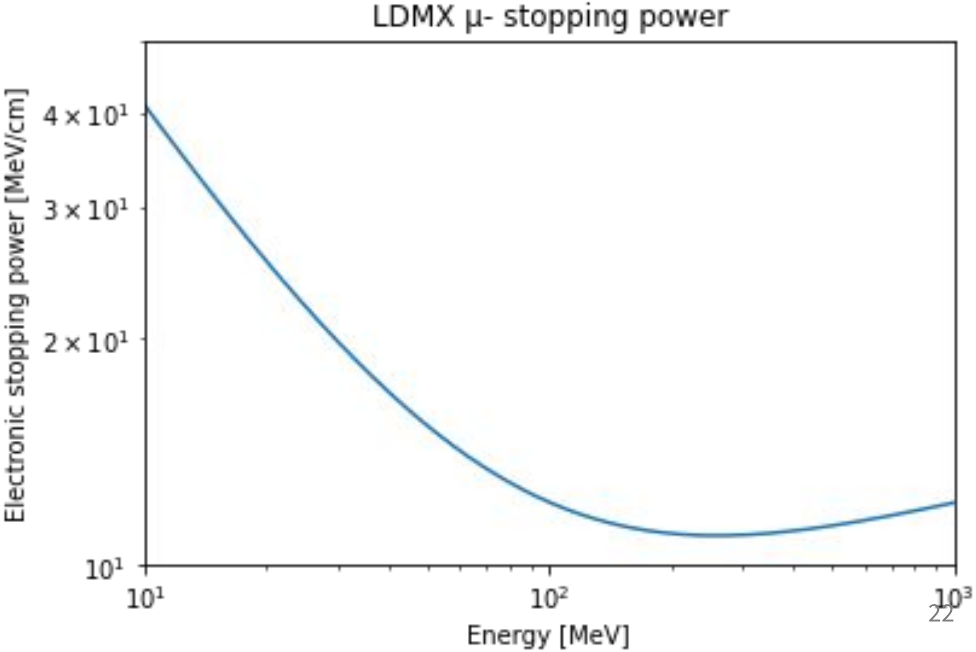
Investigating muon energy loss

Total steel absorber length: 38 cm

Bethe-Bloch formula: Energy loss at least 11 MeV / cm

Energy loss > 440 MeV throughout absorbers, muons definitely become ionising in second half.

$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0} \right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)} \right) - \beta^2 \right]$$



Overview

Structure of the presentation:

The LDMX prototypes

Motivation behind the two prototypes

The T9 beamline

The hcal prototype
- Explanation of simulation steps
- Visualisation of a run
- Investigation into muon behavior

The trigger scintillator prototype
- Explanation of 3 different designs
- Showing of preliminary results

Future of the prototype

All the motivations

1. Designing the ldmx - sim
2. Designing the prot (steel width, hcal length) - sim
3. Checking if sim predict neutrons correctly - none
4. Checking if sim predict tail ends correctly - prot&beam
5. Calibrate hcal - prot&beam
6. Tune experiment - prot&beam
7. Check if electronics work - prot&beam
8. Extra time to fix errors - prot&beam

Last rehearsal: 14 mins

Todo:

motivation for prot and test beam

What has been done

The results

People should understand why we did all this

More time added

Slowly explain the plots, let them take it in.

Less slides, presented more carefully

Show protons (like the general profile)

Talk about the beamline T9, the fibertracker and cherenkov counters, and set the scene, tal about beam composition, what energies, what the beam looks like

1 slide per minute

last resort would be adding π+-

Why are we doing this?

For example, the hcal length vs veto power plot

Calibrating the hcal (since v1 will have ecals ahead)

See if showers are modeled correctly

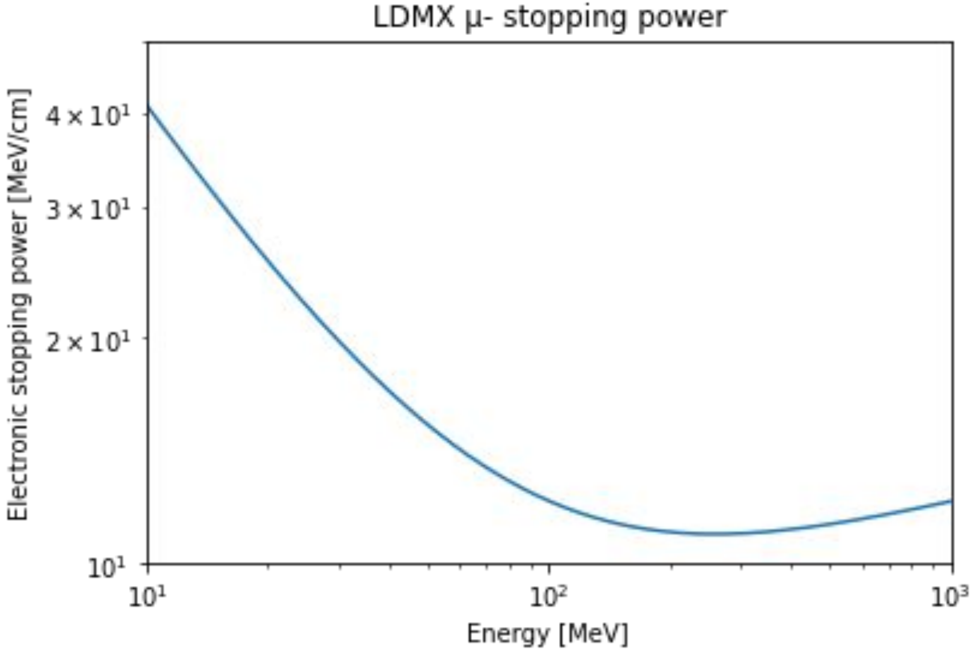
Make a reality test of our model

Neutron rejection efficiency changes with Geant4 version, so it would be good to check with reality

Already implicit: exercising system

Muons match Bethe - Bloch expectations

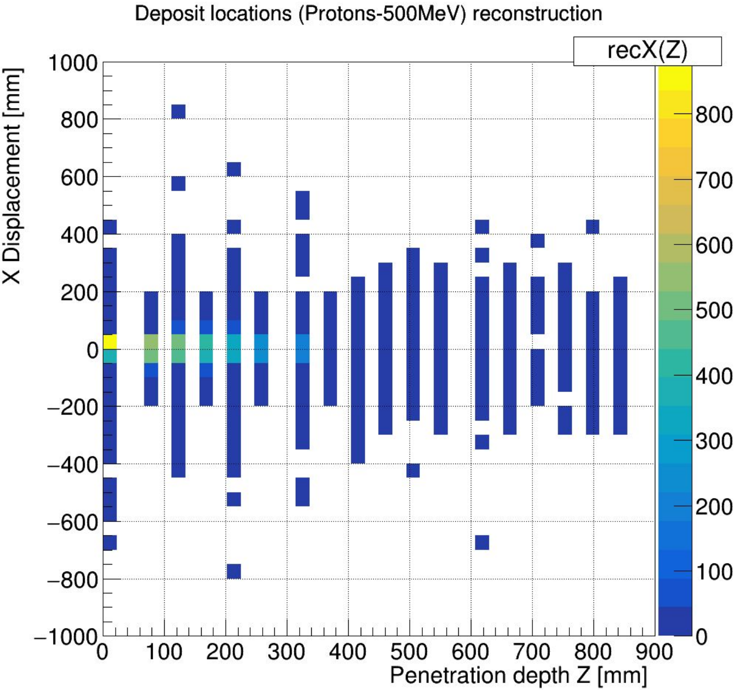
$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0} \right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)} \right) - \beta^2 \right]$$

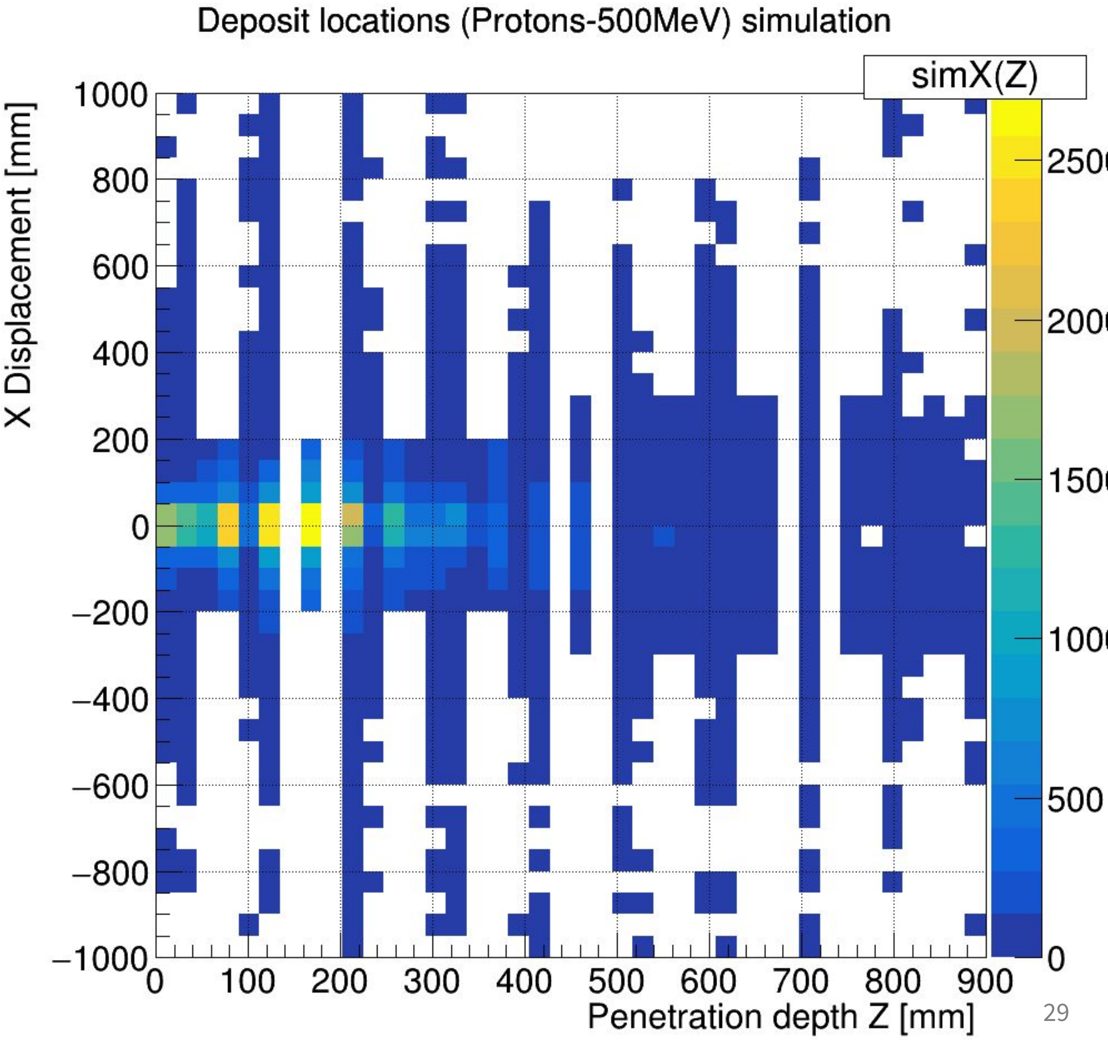


Sim and Rec: protons

Most of difference due to

small hits < 1 MeV

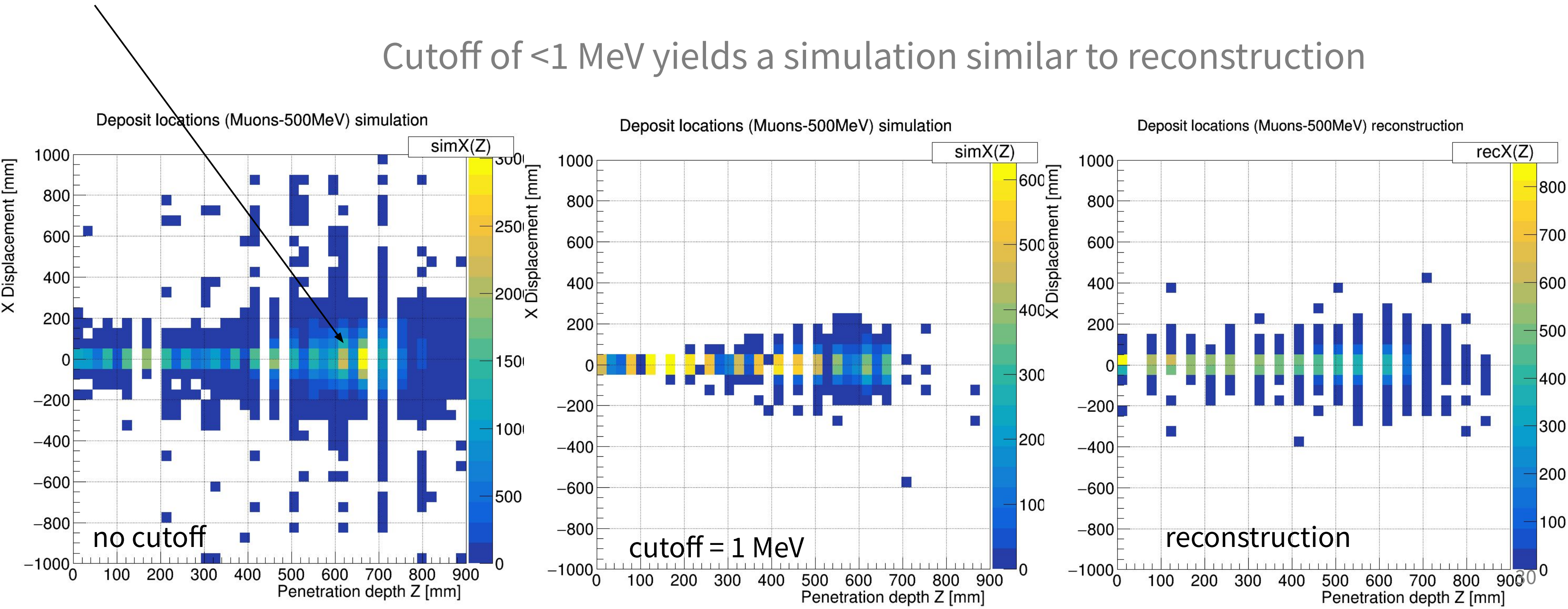




Investigating muon energy deposits

Many deposits at muon decay; most are < 1 MeV

Cutoff of <1 MeV yields a simulation similar to reconstruction



Preliminary trigger scintillator results

Average charge per event for LYSO and Polyvinyltoluene.

Some processing required:

1. Disregard pedestals over 40 fC
2. Subtract pedestals

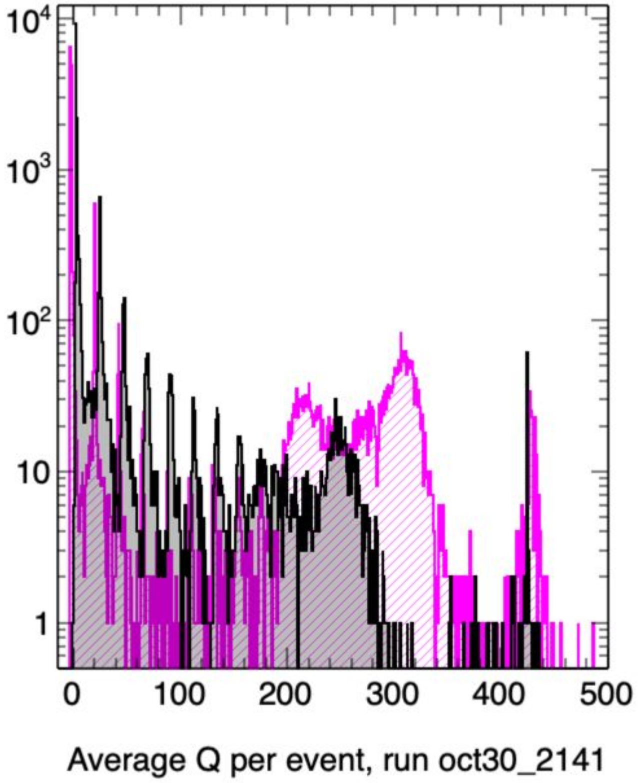


Figure by: Lene Kristian Bryngemark

Todo

Take out some slides so audience can take in plots

Go through x axis, y, units, what they should see

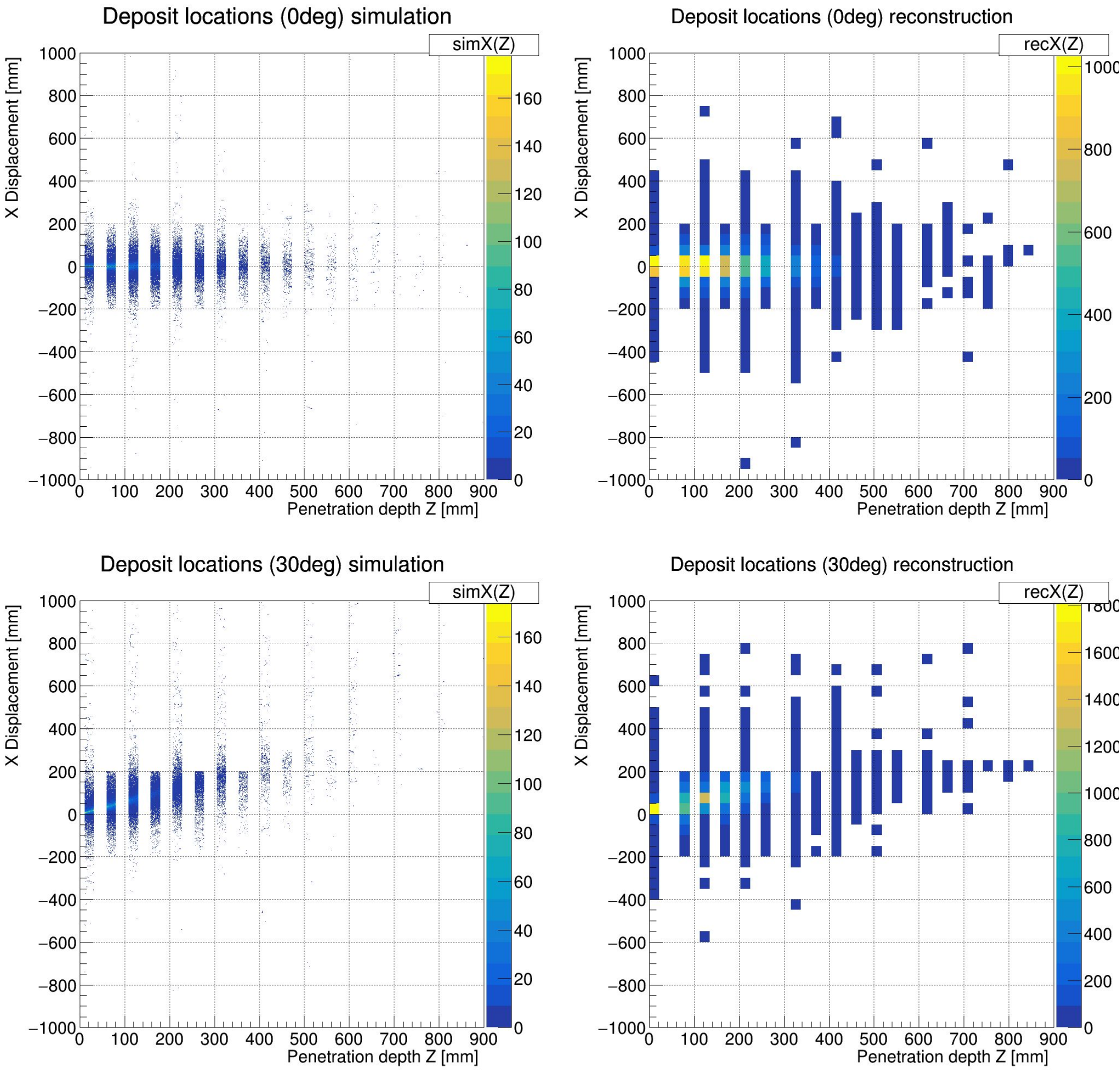
Pick a storyline to focus on, well curated examples
Suggested narrative: muons

Make plots more easy to read
Different marker shapes
Visualise how sim goes to reco

Generally: 1 min/slide
I have 30 sec/slide

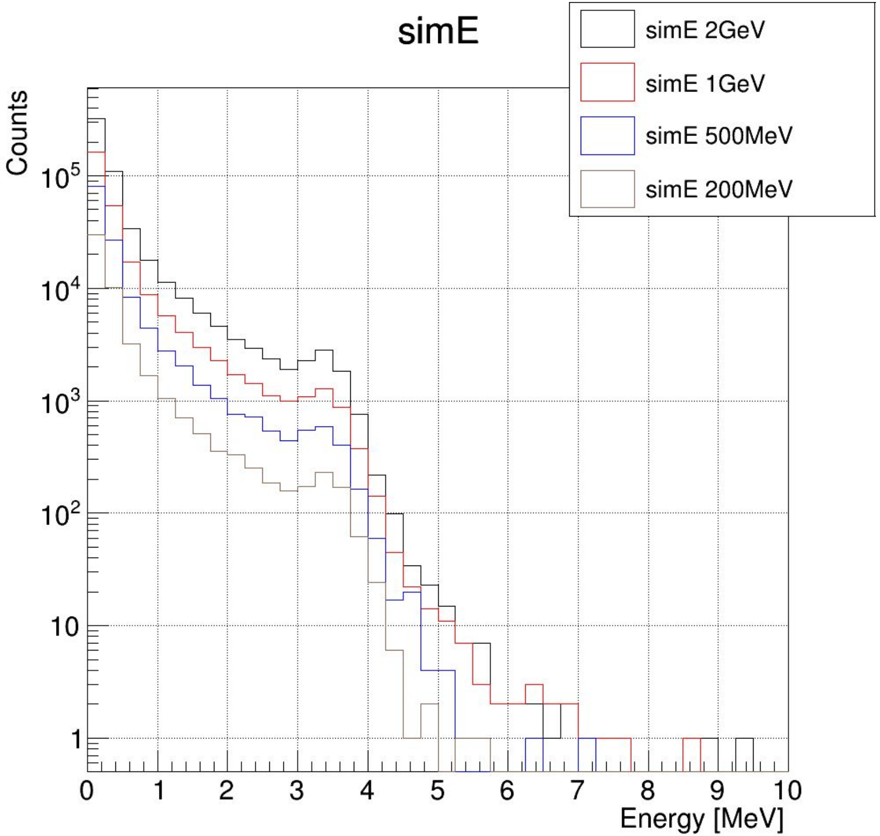
Non-zero incidence angle

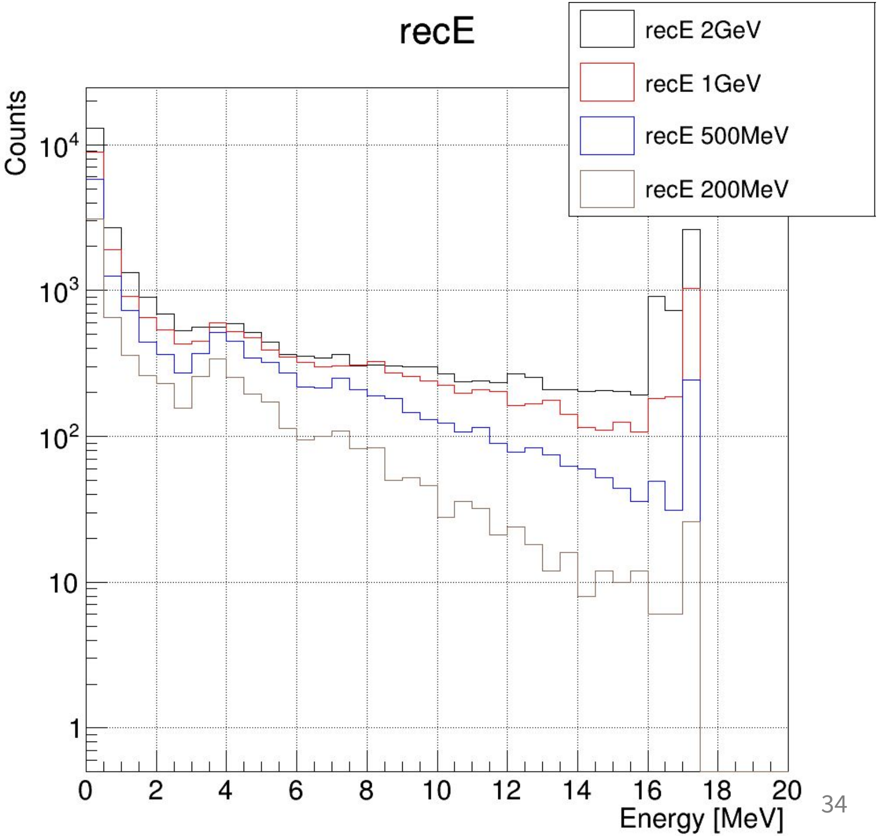
Everything seems to follow expectations



Energies 0.2-2 GeV

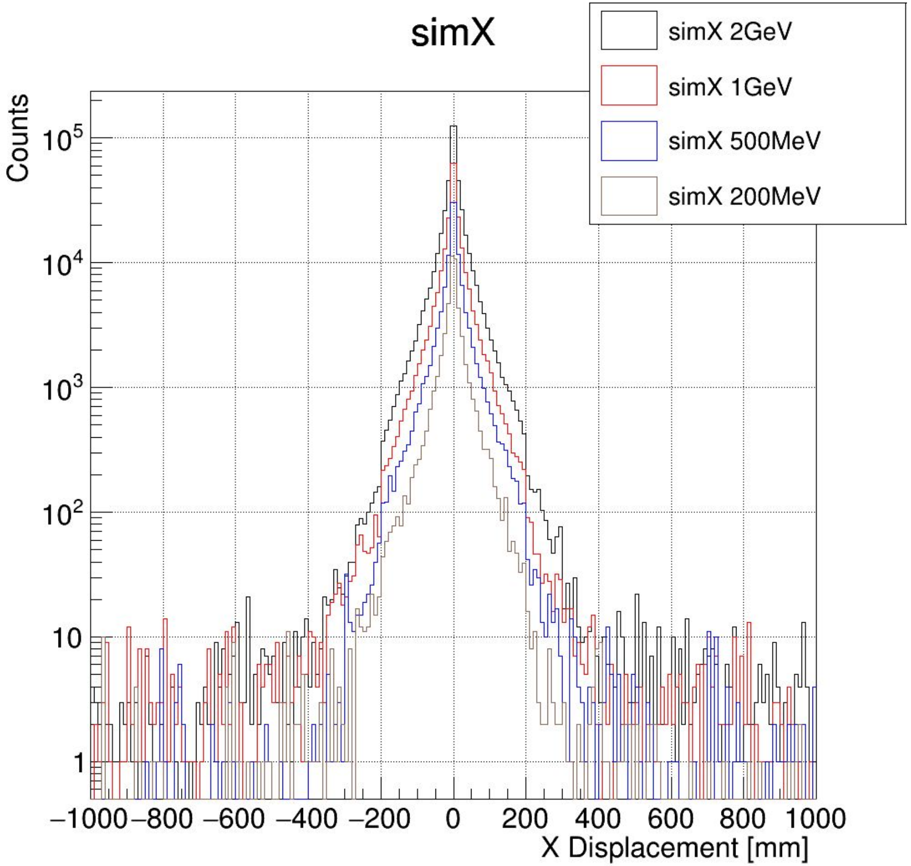
Everything seems to follow expectations

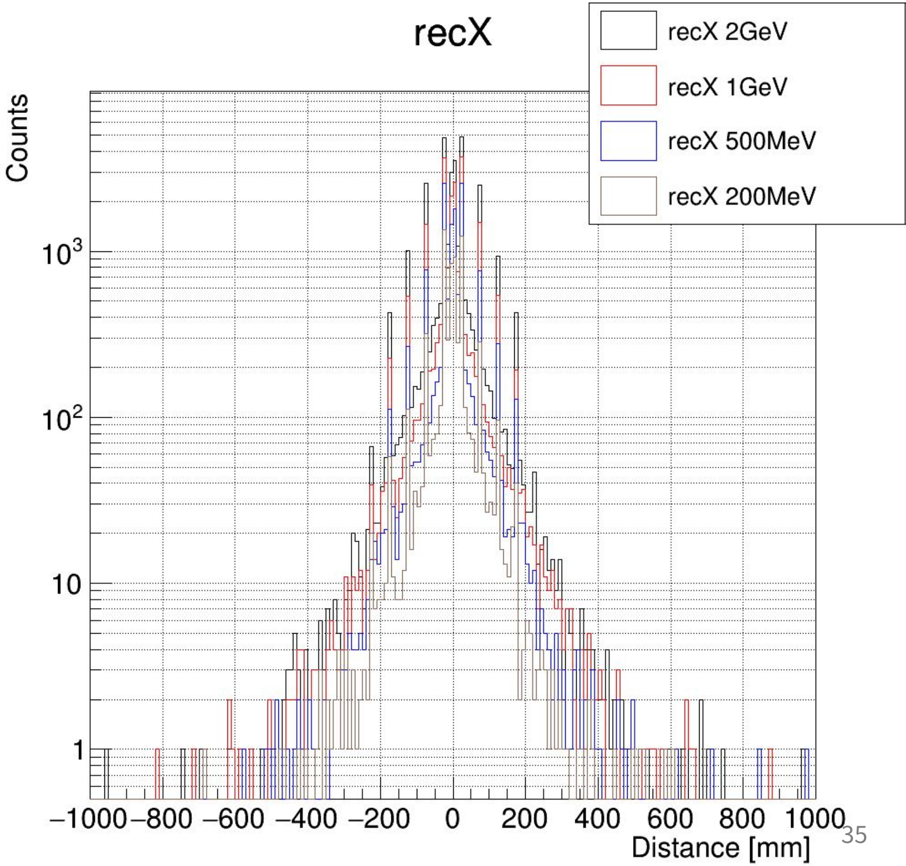




X displacement 0.2-2 GeV

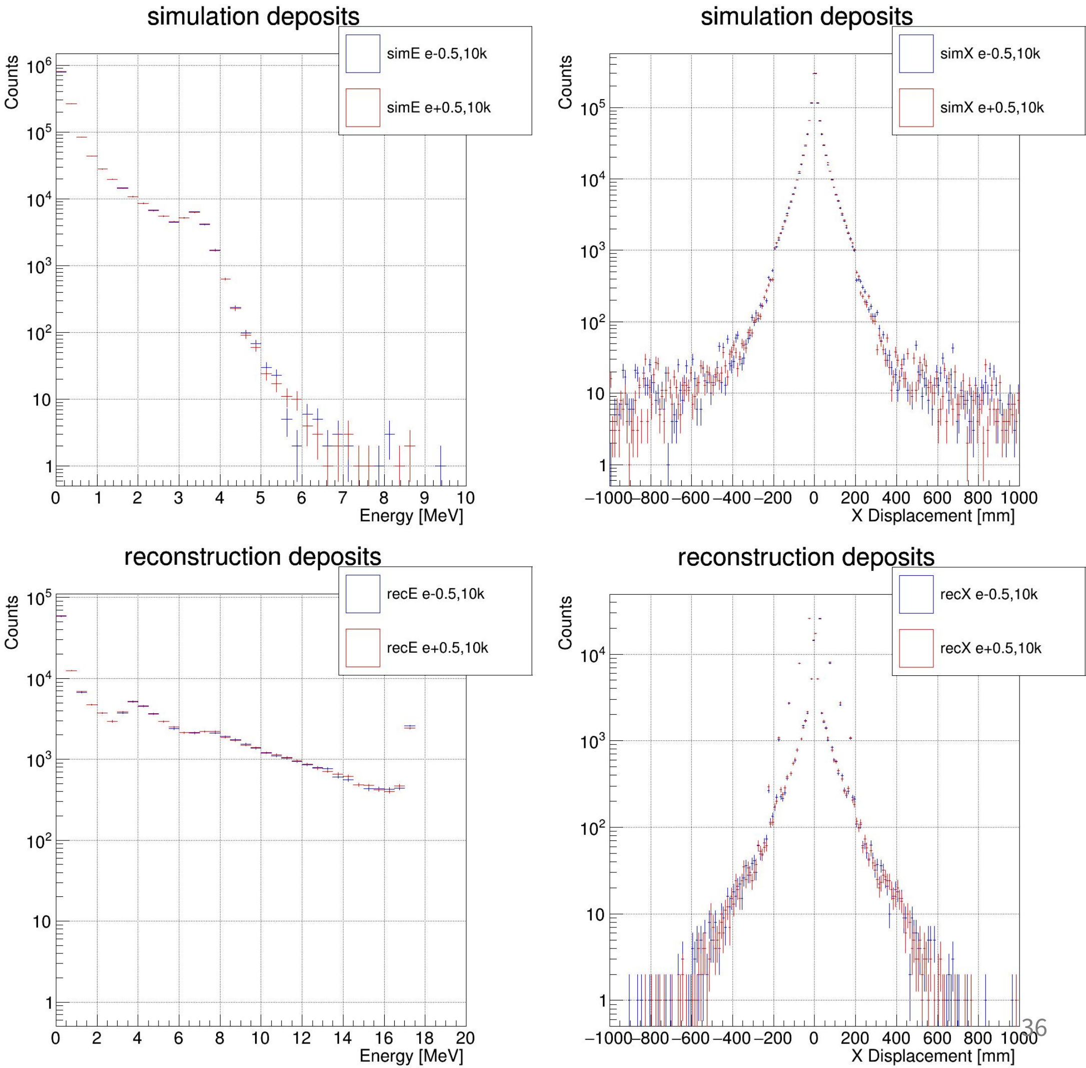
Everything seems to follow expectations





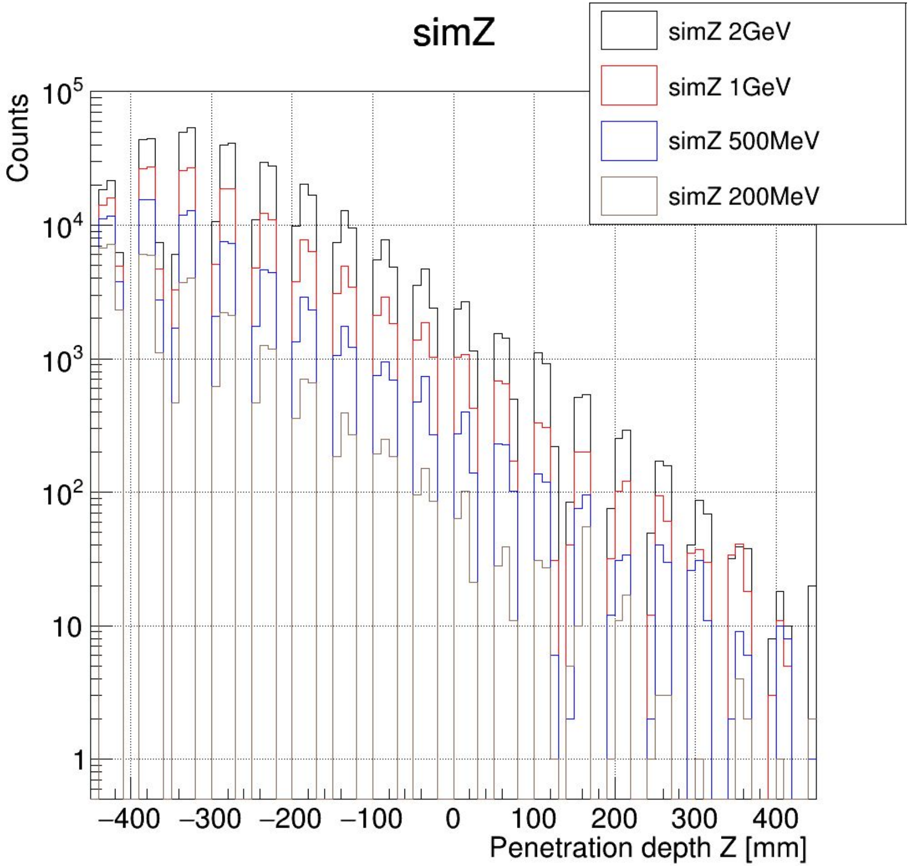
Electrons vs Positrons

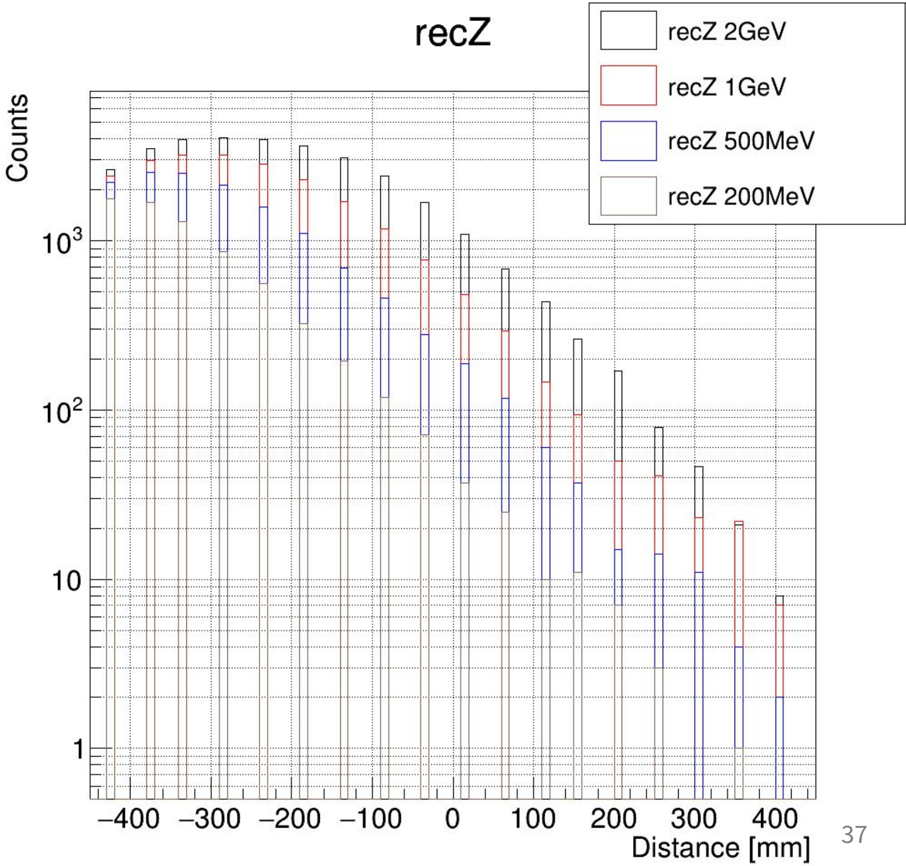
Electron events almost entirely identical to positron events



Penetration depth 0.2-2 GeV

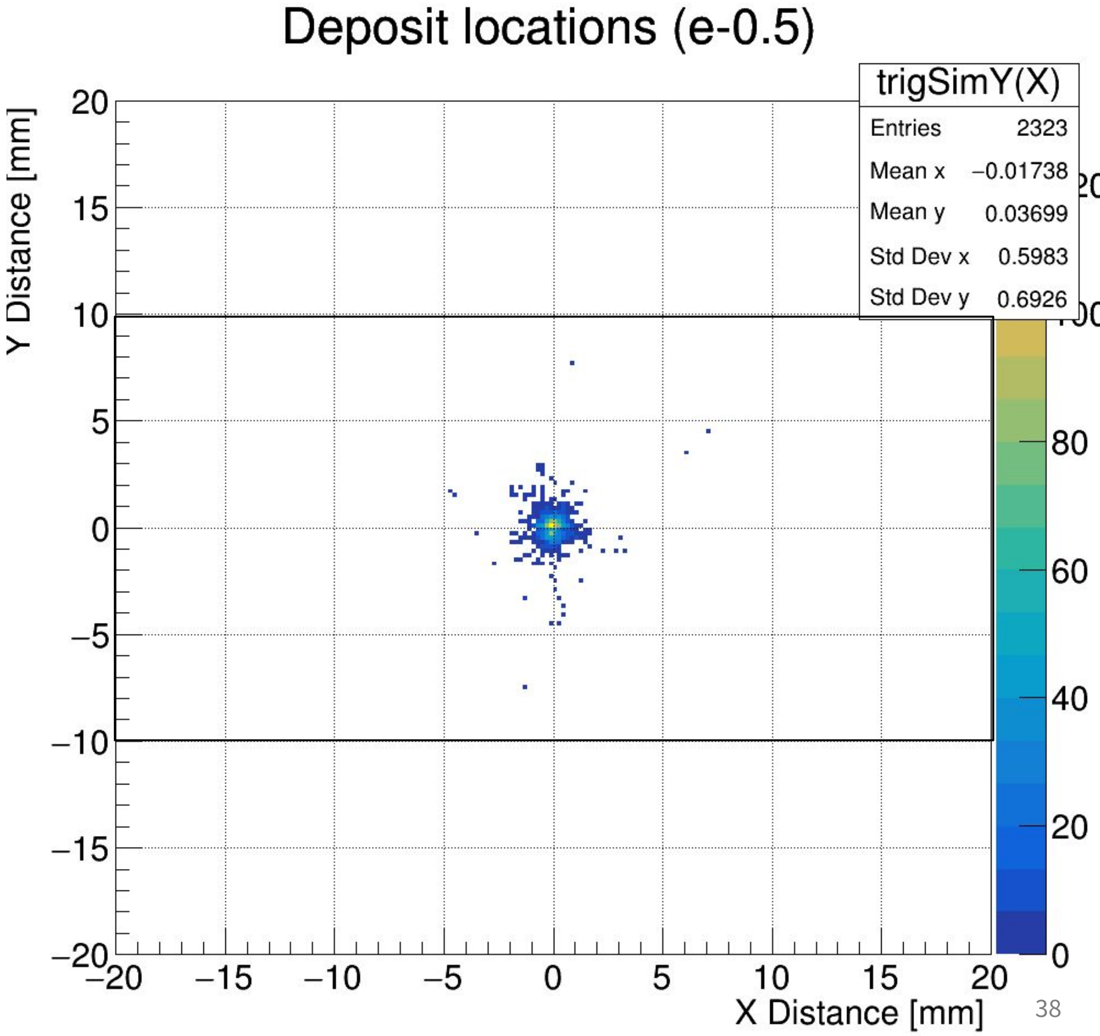
Everything seems to follow expectations





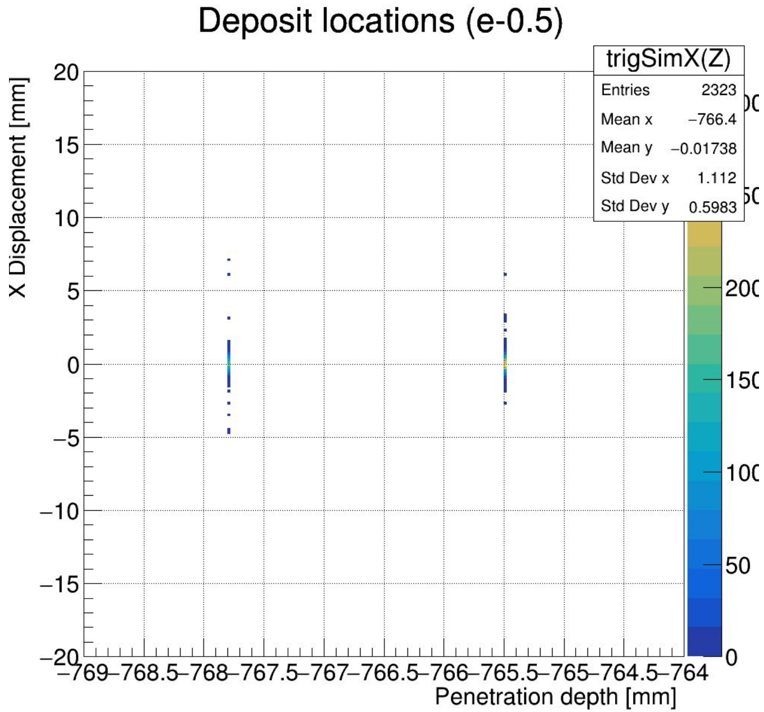
Trigger scintillators

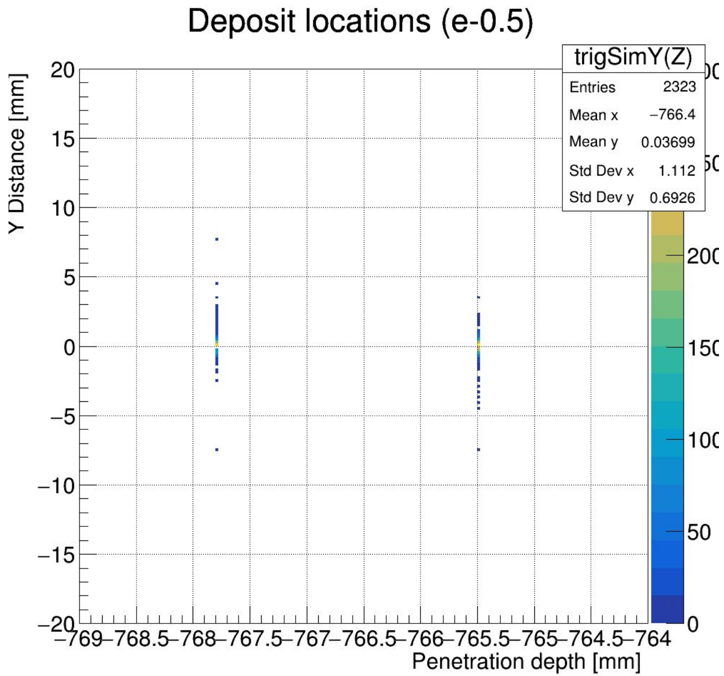
The rectangle is the approximate profile of the trigger scintillator layer



Trigger scintillator plot

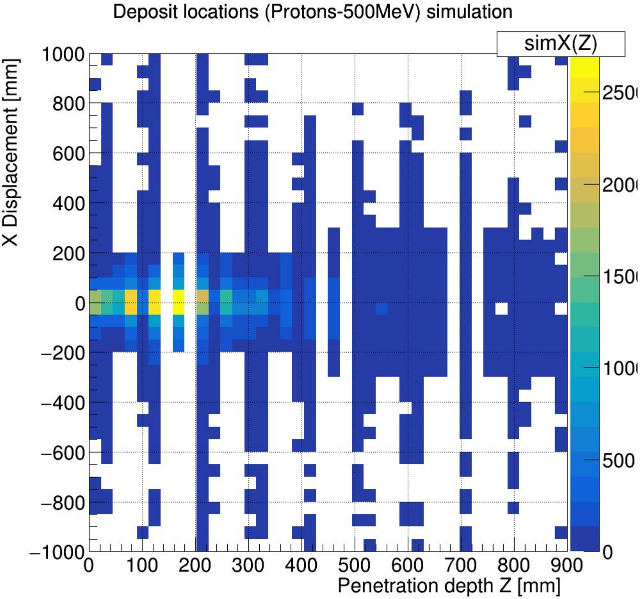
Simulated deposits in the trigger scintillator

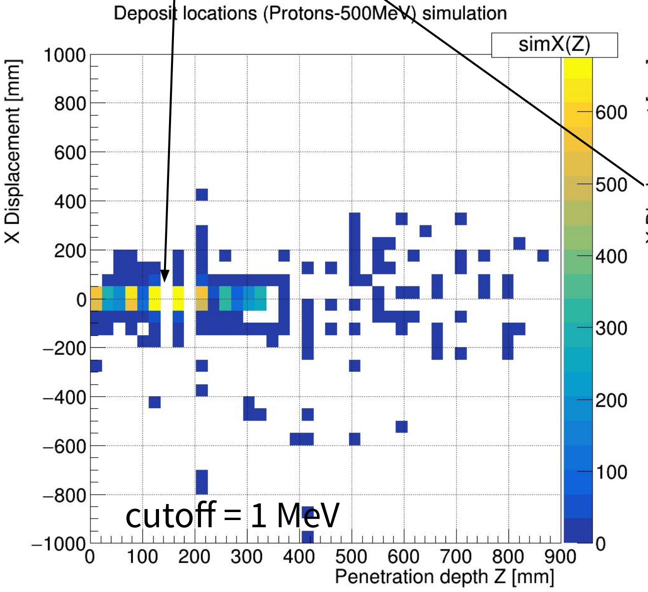


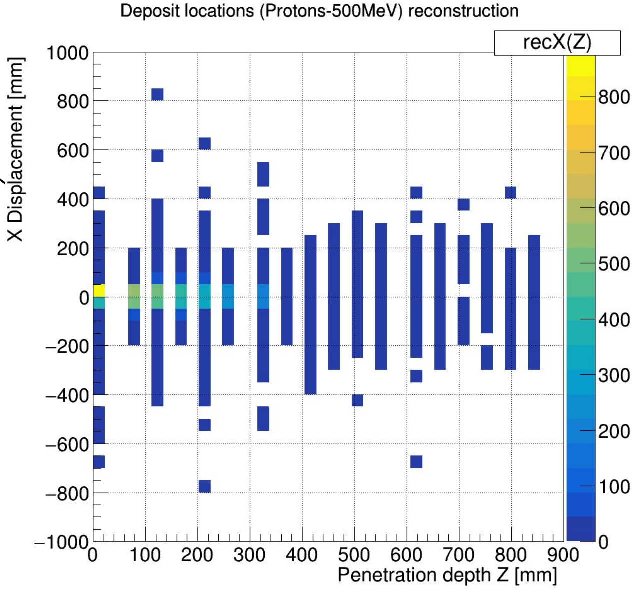


Sim vs Rec: protons

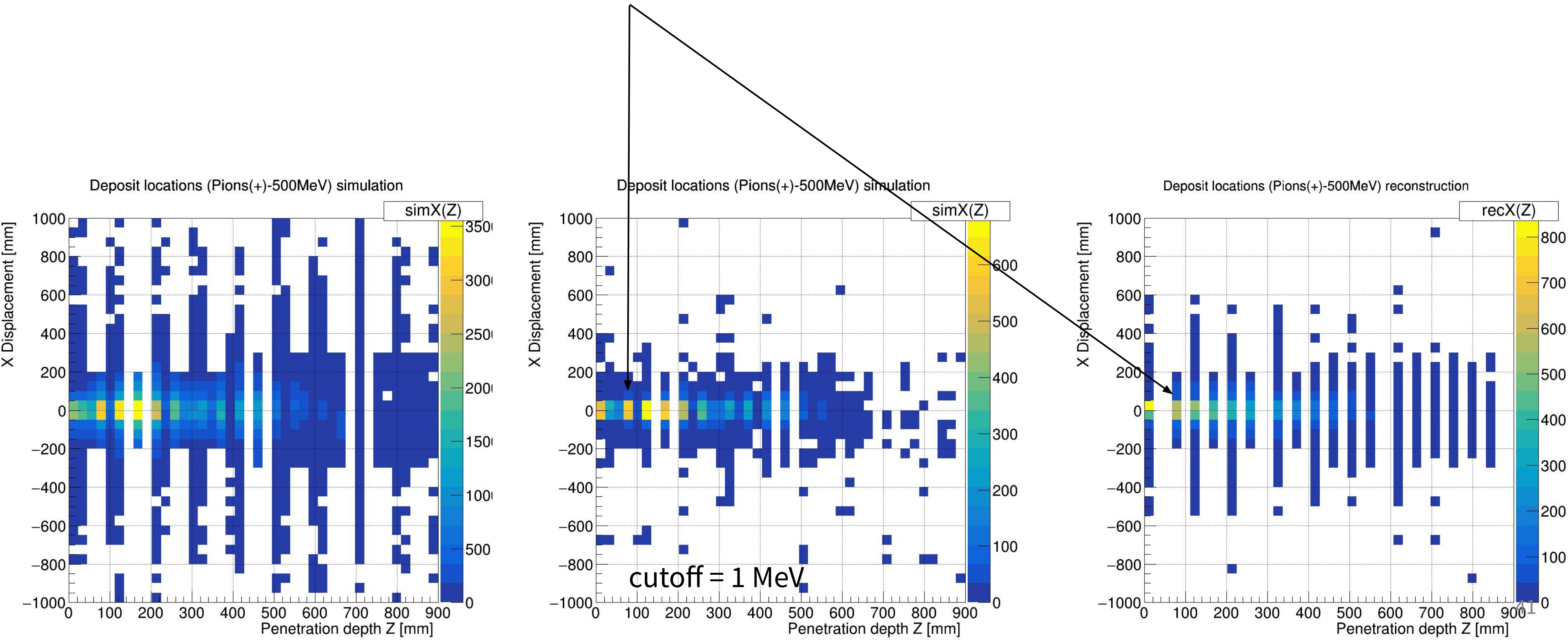
This is likely due to the reco registering many sim hits as 1 rec hit, but I have yet to verify





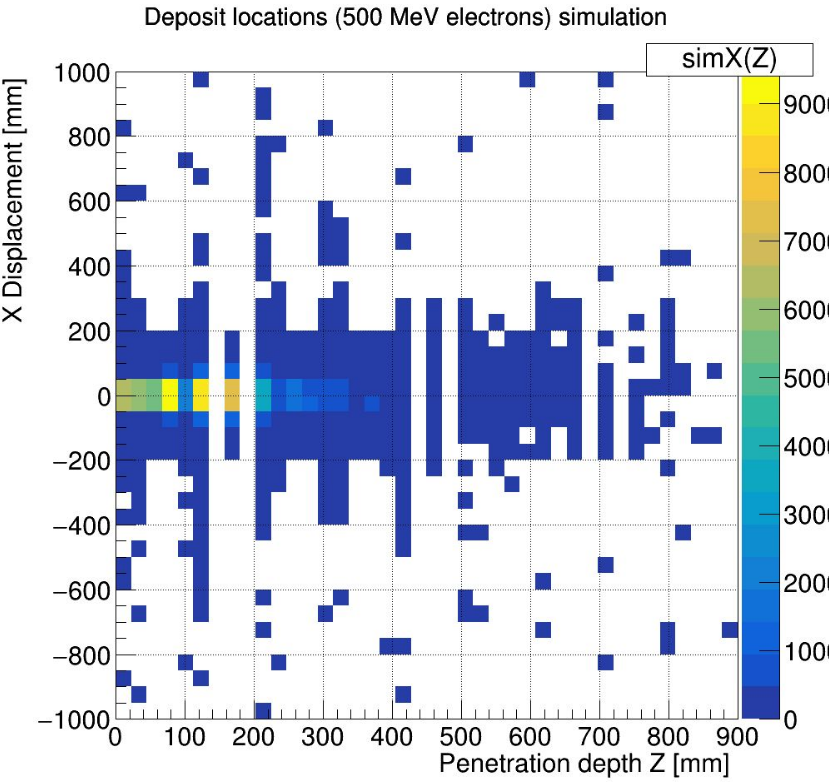


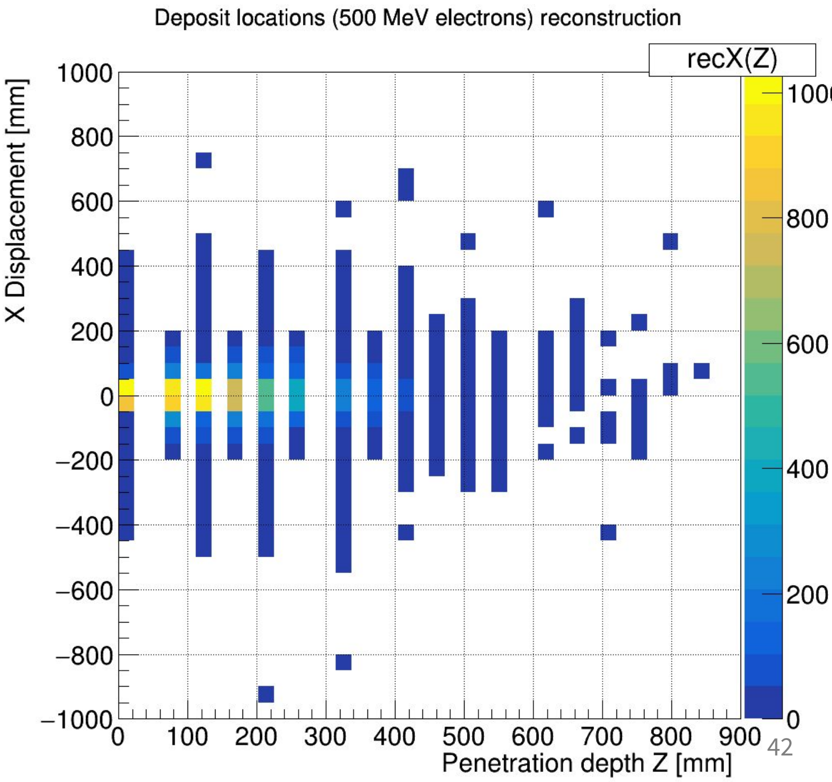
Sim vs Rec: pions+



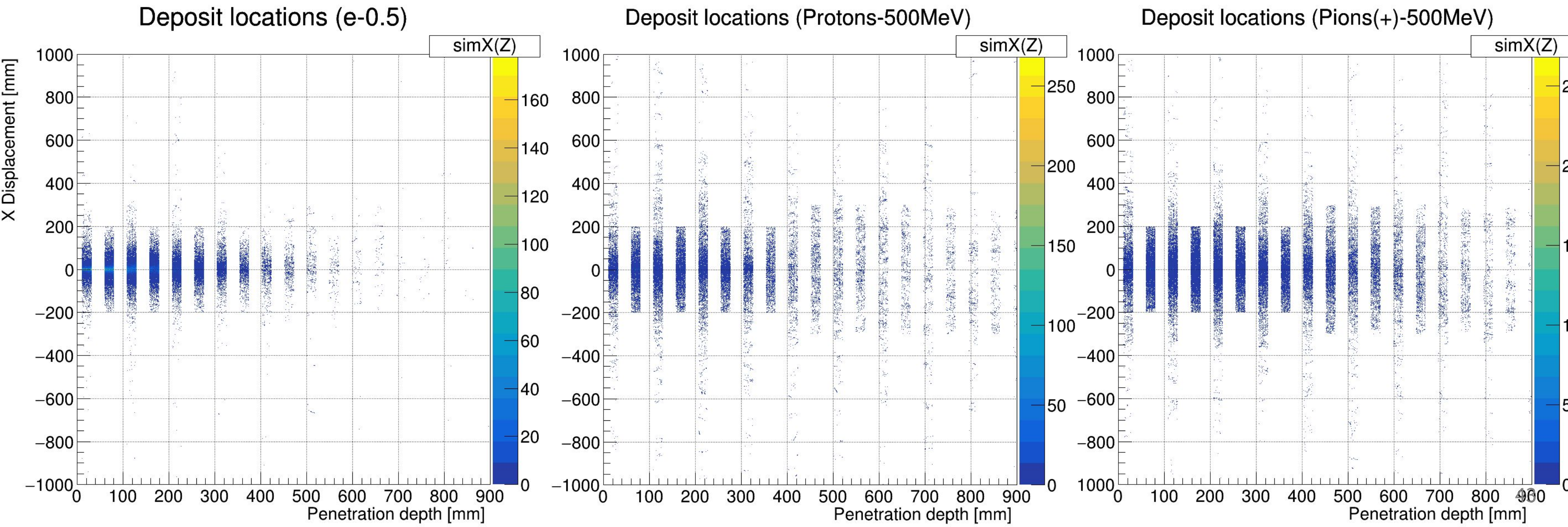
Sim vs Rec: electrons

Pretty much as expected



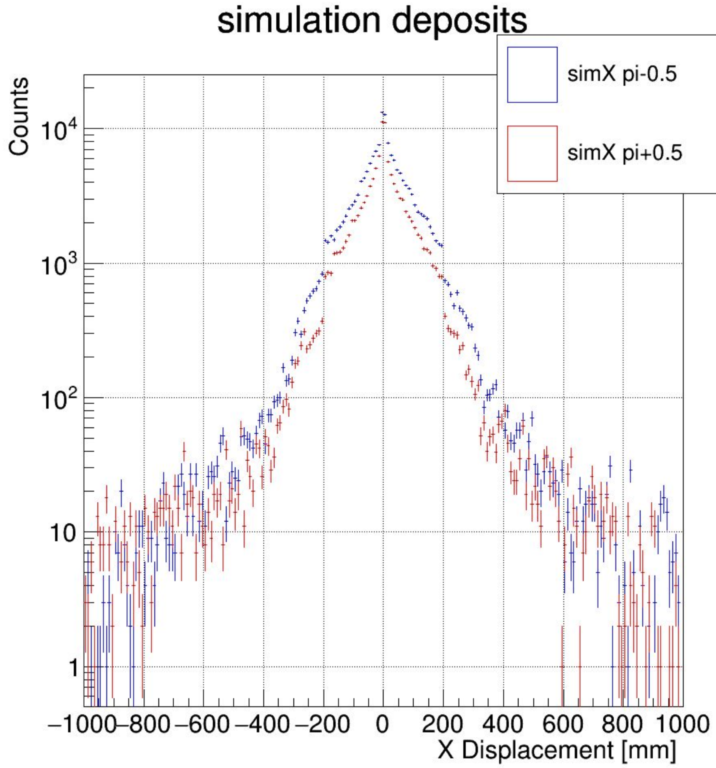


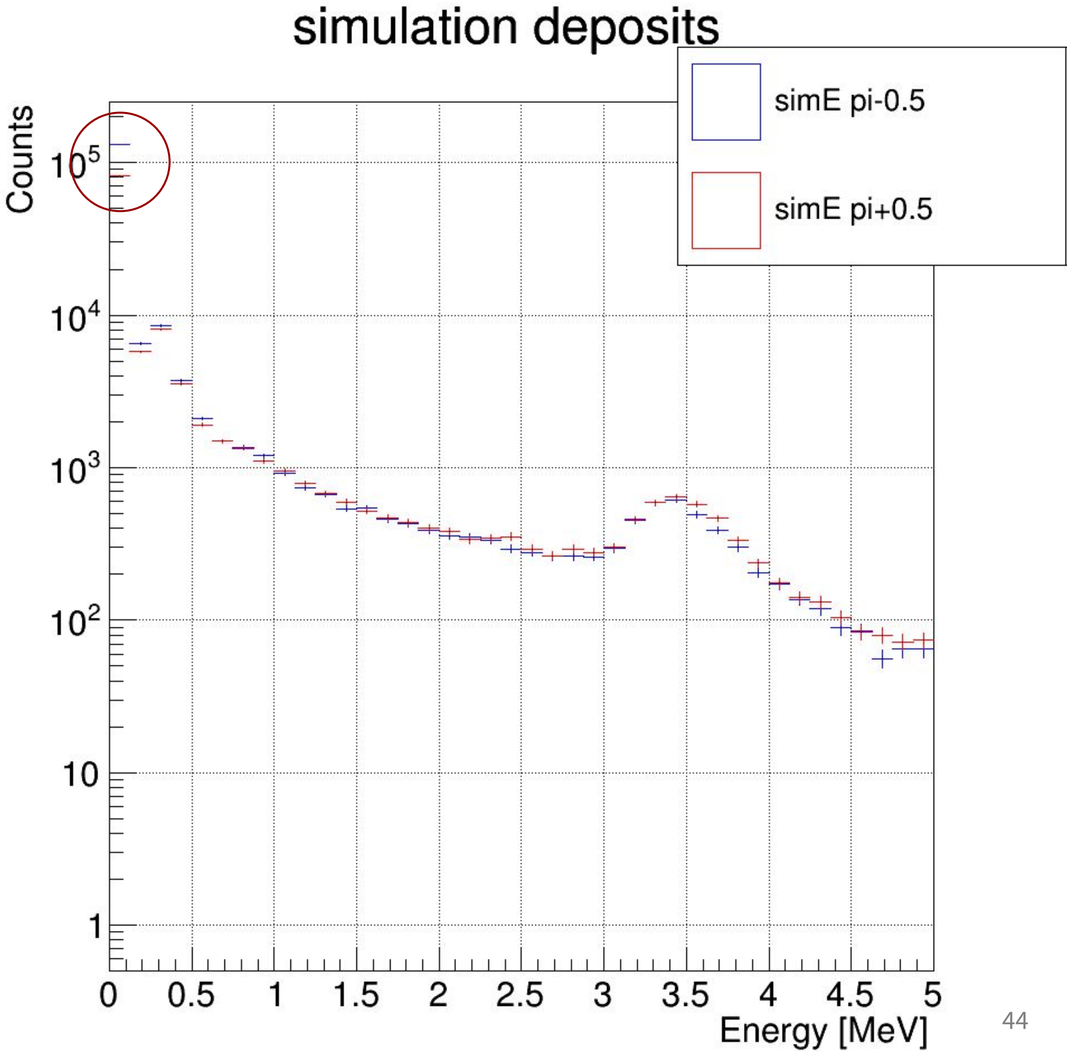
Investigating deposition shapes



π- vs π+ : a finding

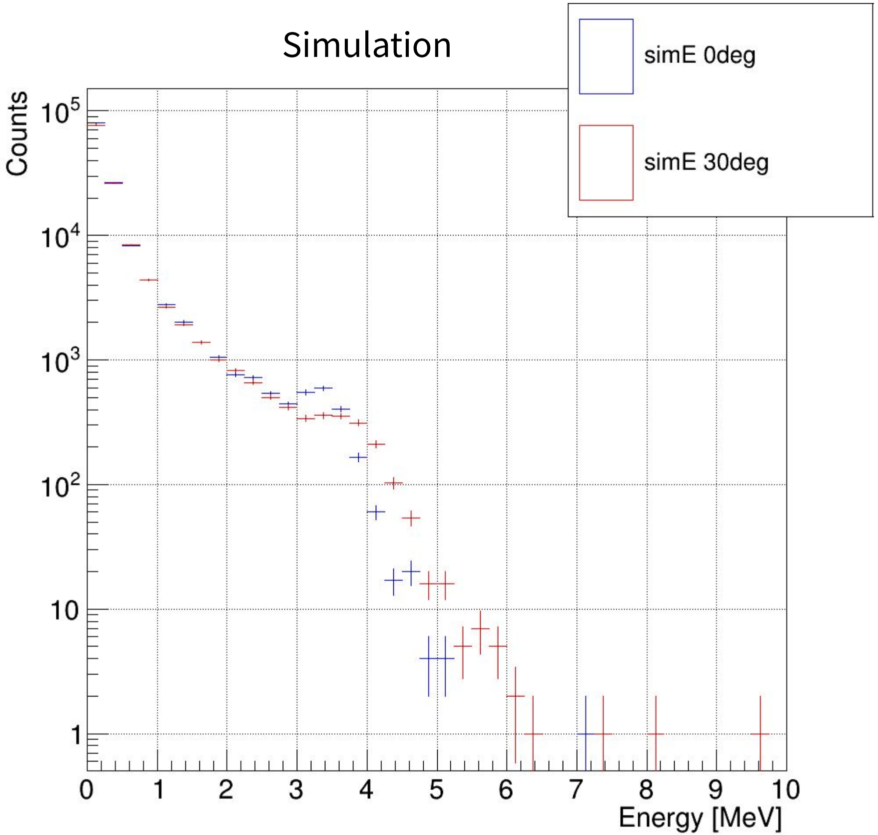
There are many more <0.3 MeV sim deposits for π-

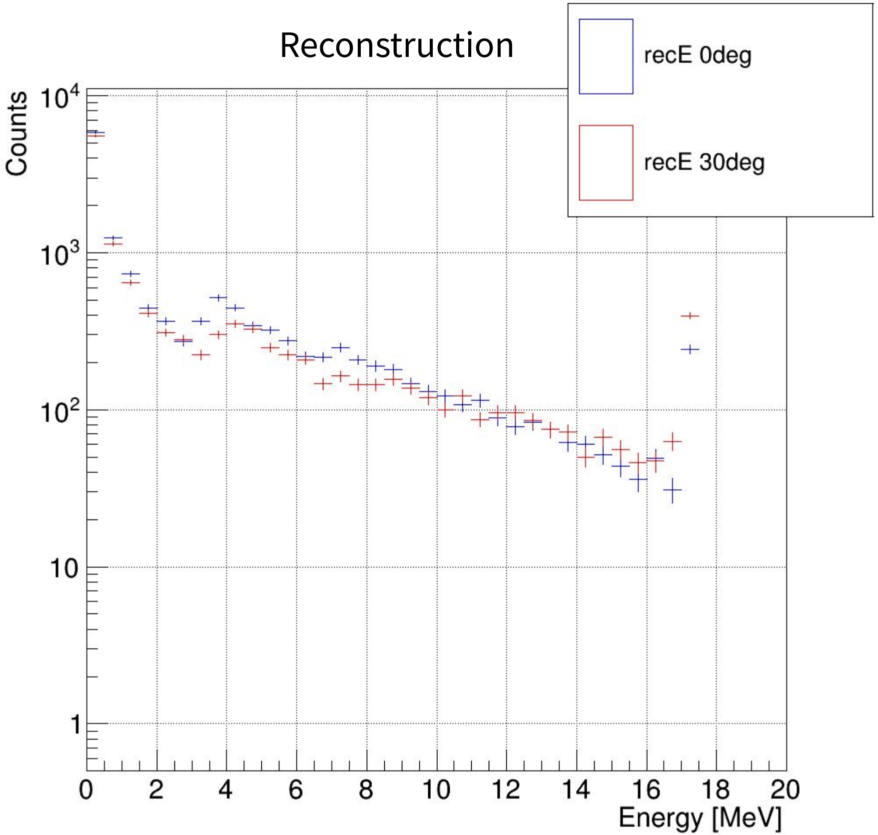




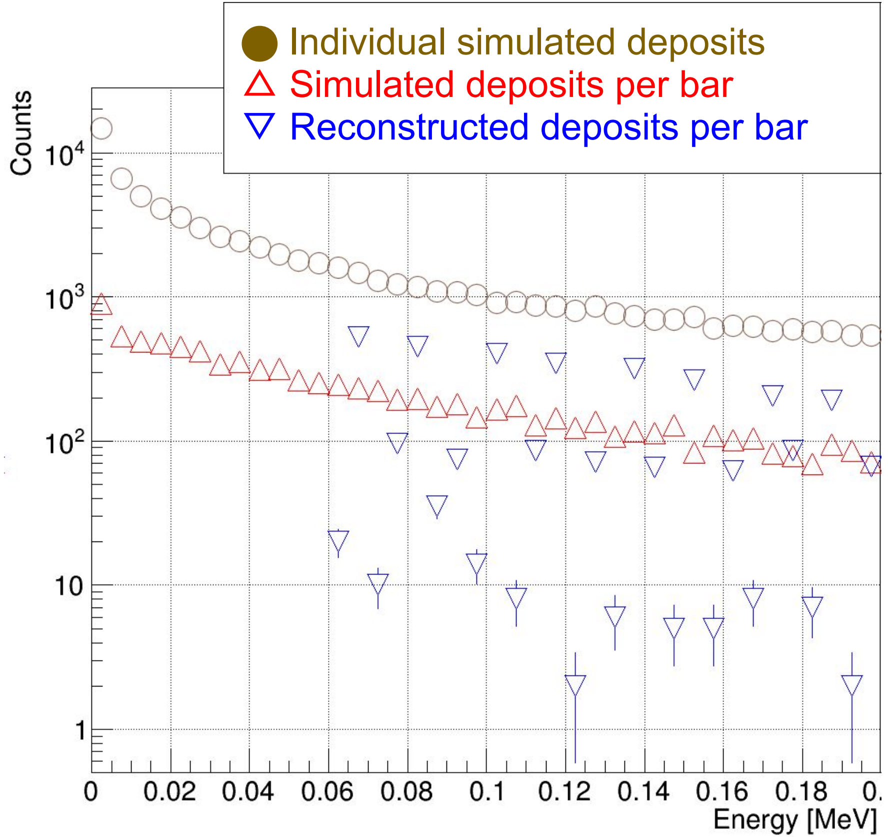
Non-zero incidence angle

Everything seems to follow expectations, but more analysis will be undertaken





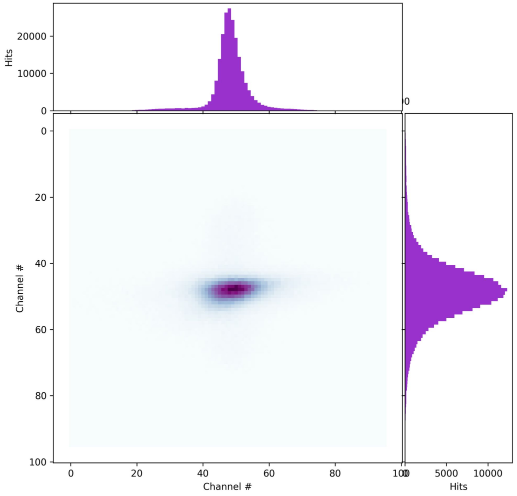
Very low energy sim vs bar vs rec



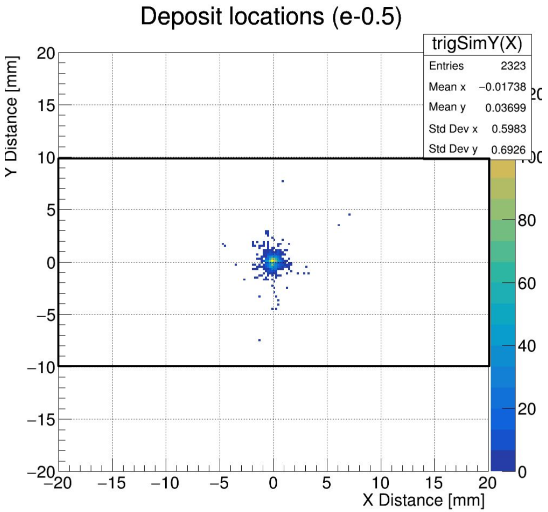
Comparing CERN's trigger to ours

The T9 beamline at CERN provided its own trigger: 2 layers of fiber trackers that allow exact spatial resolution. This result can be compared with the output from our own trigger to see how well it works

CERN trigger (real data)



LDMX trigger (concept image)

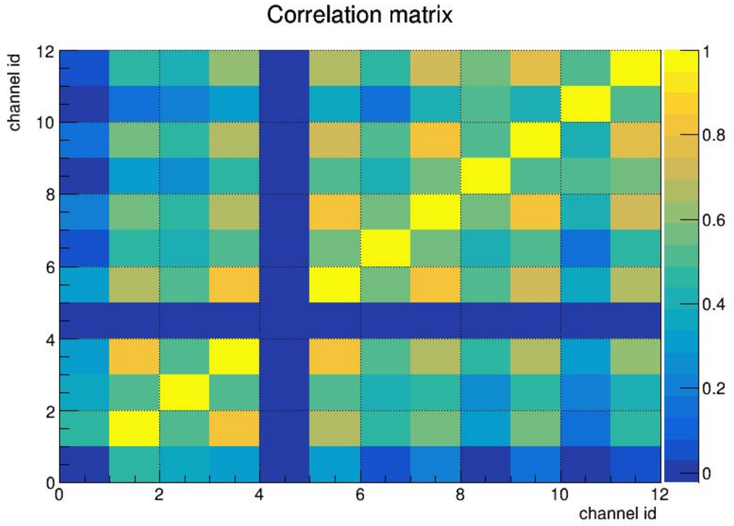


Results of the trigger scintillator test beam

Channel 5 is dead.
Plastic (even) channels not very correlated with neighboring ones - as expected

LYSO (odd) channels correlate with their neighbor - as expect

LYSO correlates with neighbor's neighbor: Not sure, we're working on it.



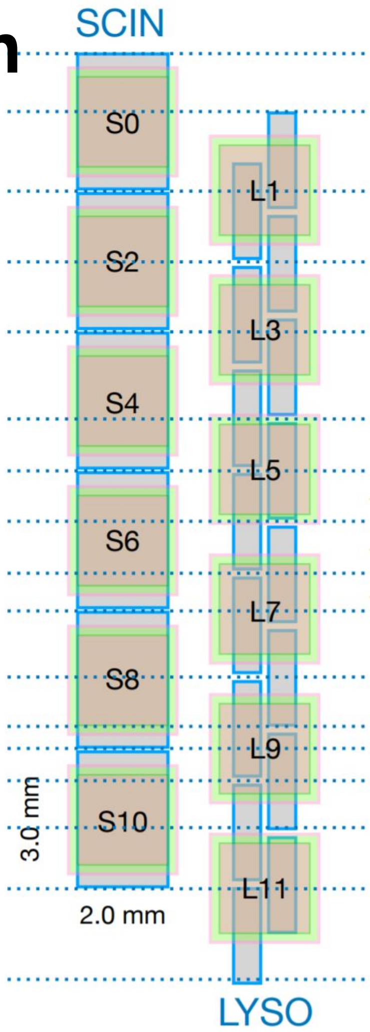


Figure by: Niramay Gogate