A silicon based polarimeter for pEDM searches

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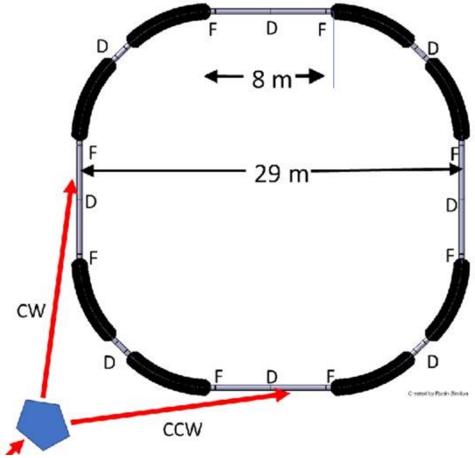
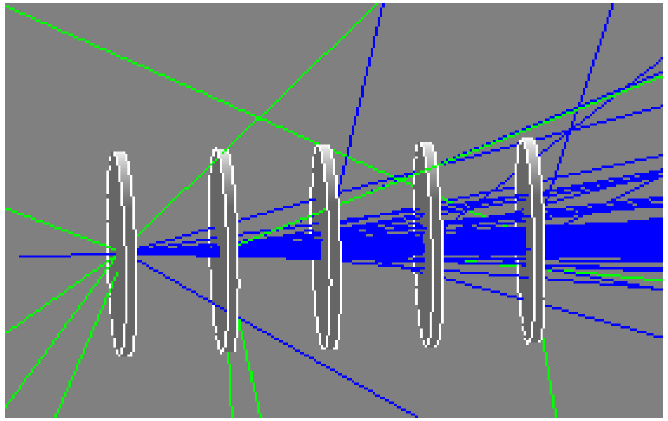
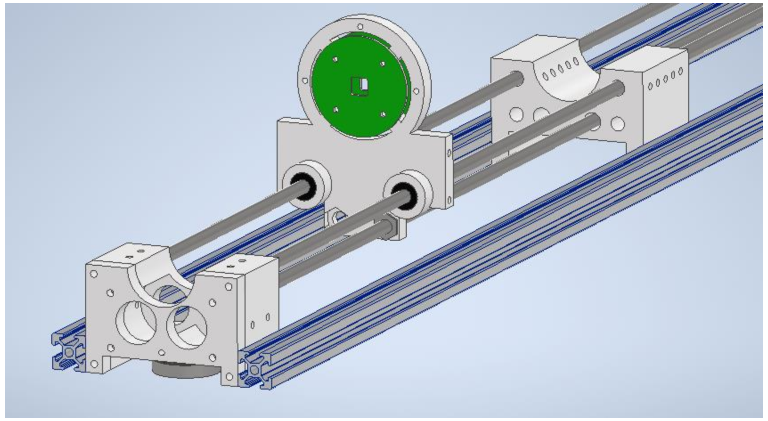
- Motivation
- Simulation
- Experimental







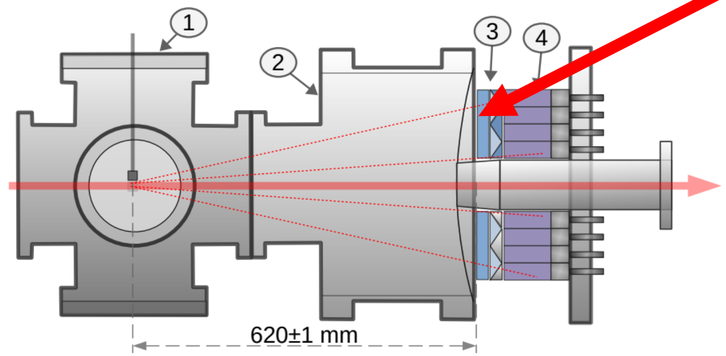
Motivation

COSY/Final ring energy = 270 MeV → Prototype ring energy = 30/45 MeV

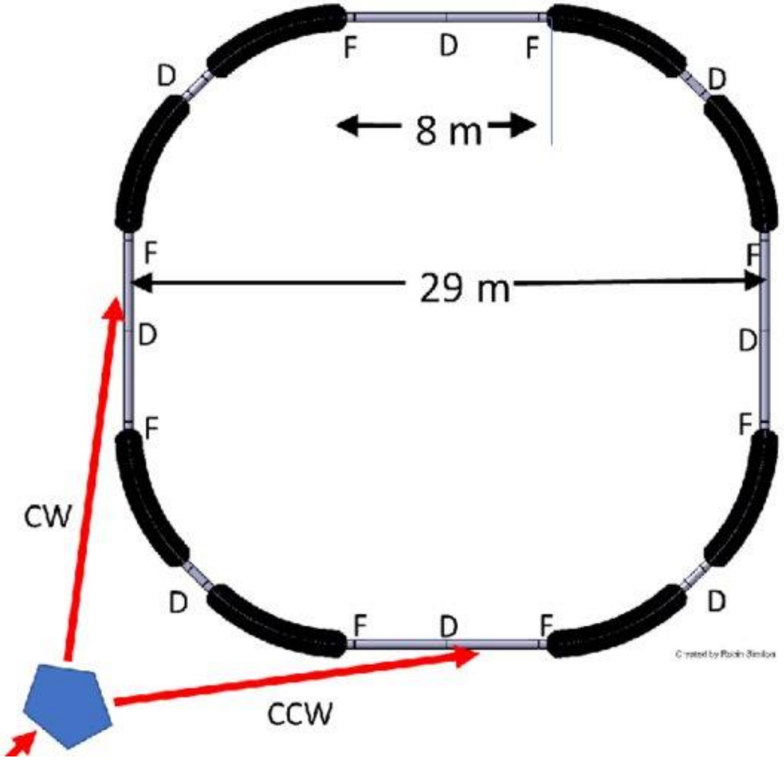
JePo incompatibility

0. Silicon detectors
1. Material budget at lower energies
2. Forward angle detector

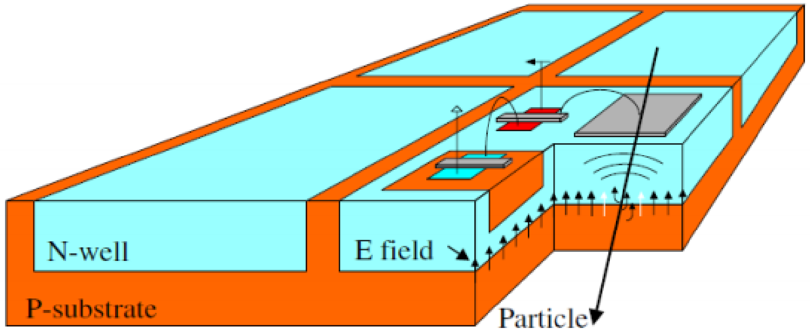
800µm Steel Beam Window



Angular acceptance of approximately 4 – 15 degrees



HVCMOS - High Voltage CMOS



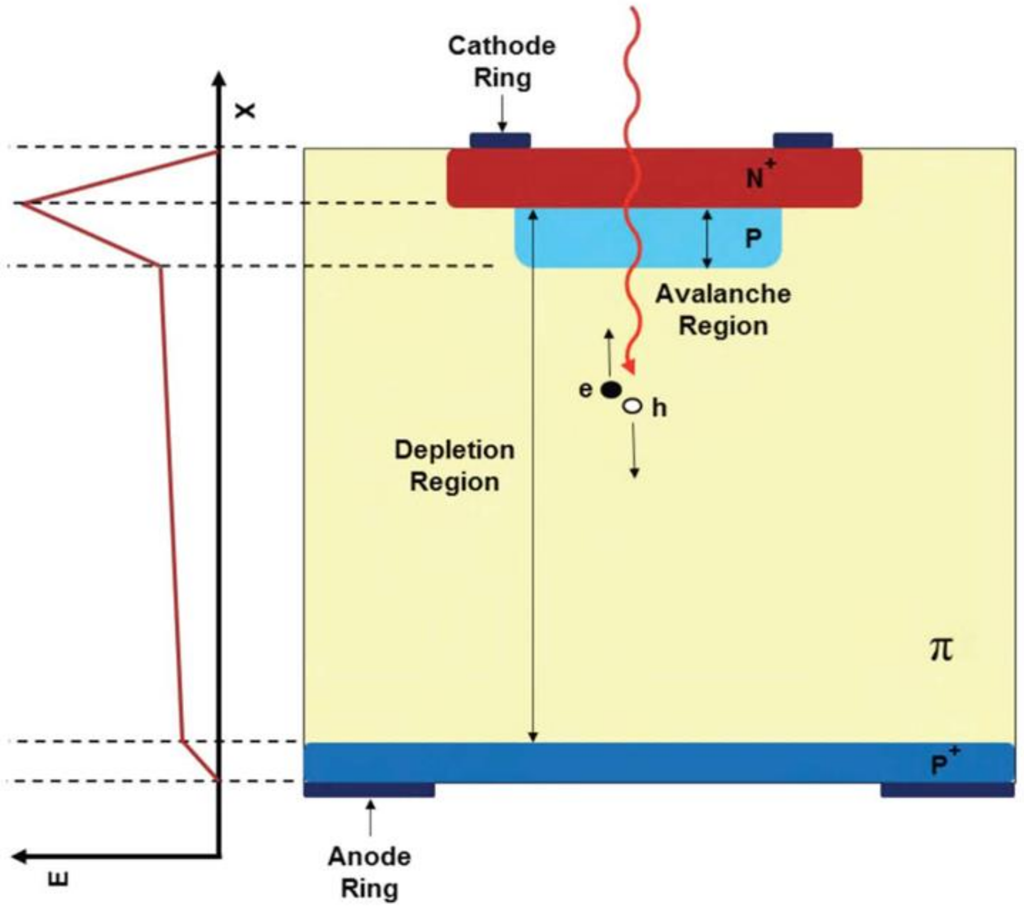
- I. Peric et al (2007)
- MuPix7 simplified cross section

CMOS structure inserted in an isolated deep N-Well.

High resistivity wafers in a standard commercial process allow large depletion to be easily achieved at a low cost compared to other detector systems such as hybrid silicon.

- Small pixel sizes (50µm×50µm)
- Thin modules (>50µm)
- High radiation tolerance (E15 n_eq/cm^2)
- Time resolution (5ns)
- Power consumption (150 mW/cm^2)

LGAD - Low Gain Avalanche Diodes

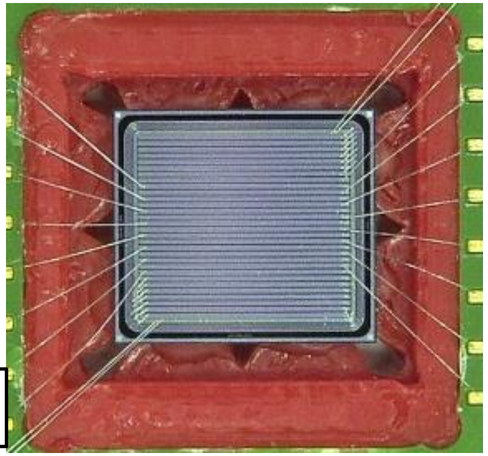


Standard n+ implant is typical for silicon diode detectors.

Heavily doped “P” avalanche/gain region producing a typical range of 10-100.

Very fast hit collection. Resolution in order of tens of ps.

Sensors can be thinned < 300 μm

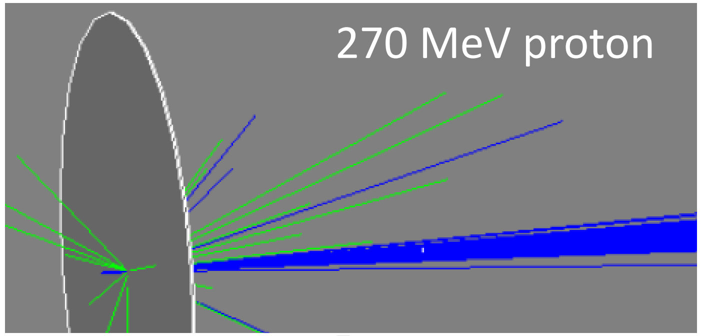


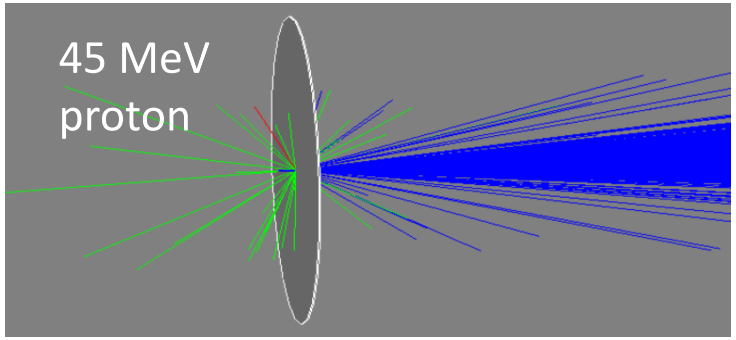
UFSD2 LGAD

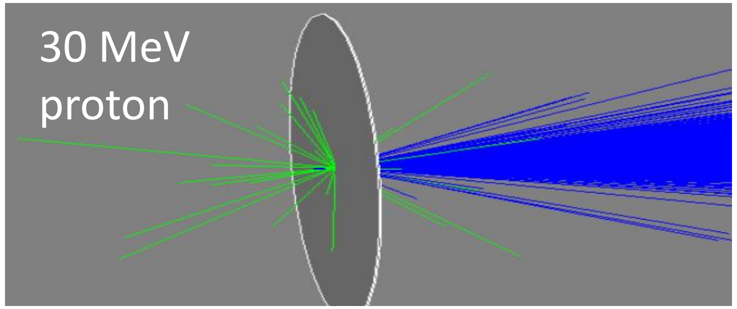
http://scipp.ucsc.edu/~schumm/talks/atlas/LGAD/SCHUMM_CPAD-2018.pptx

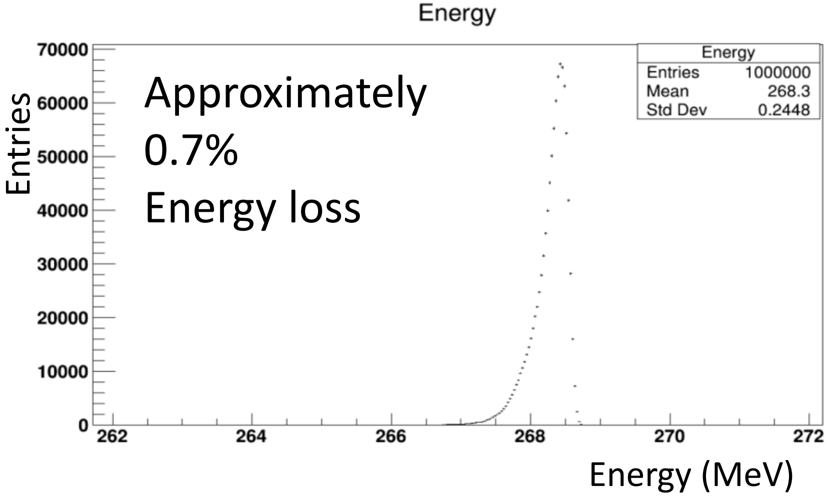
1. The necessity of low material budget

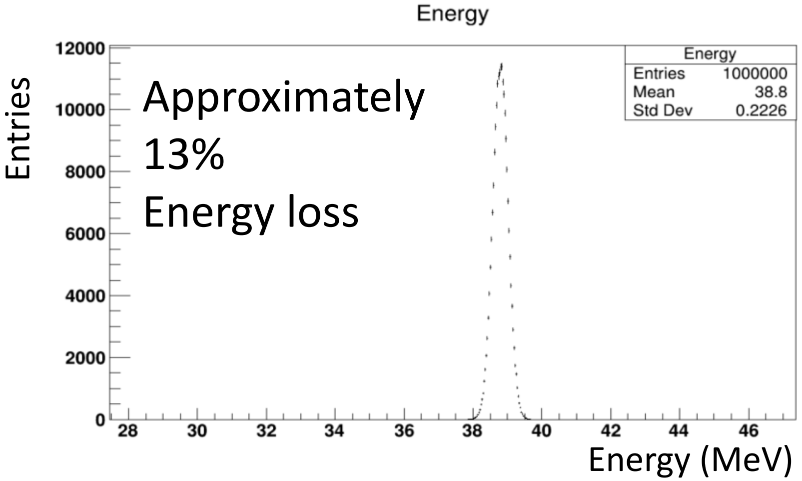
Strong effect from the current 800 um beam window at lower energies.
2cm plastic scintillator also needed for precise position resolution (1mm).
Another approach will be needed for low energy.

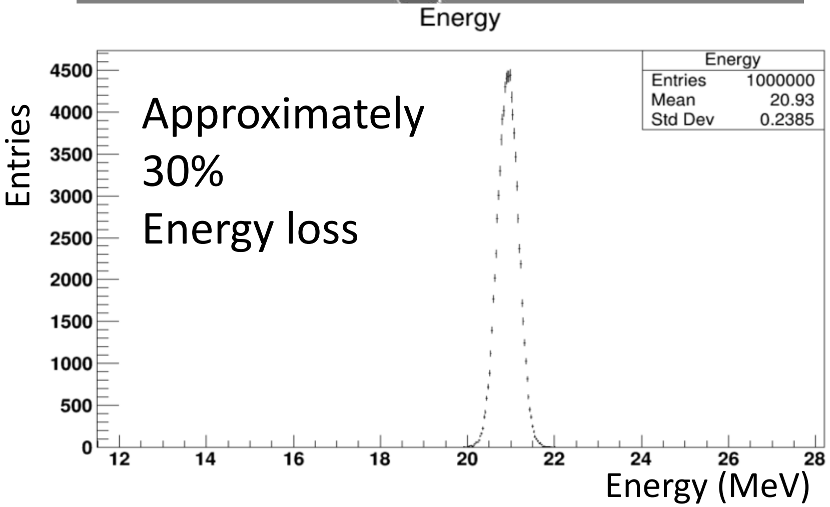










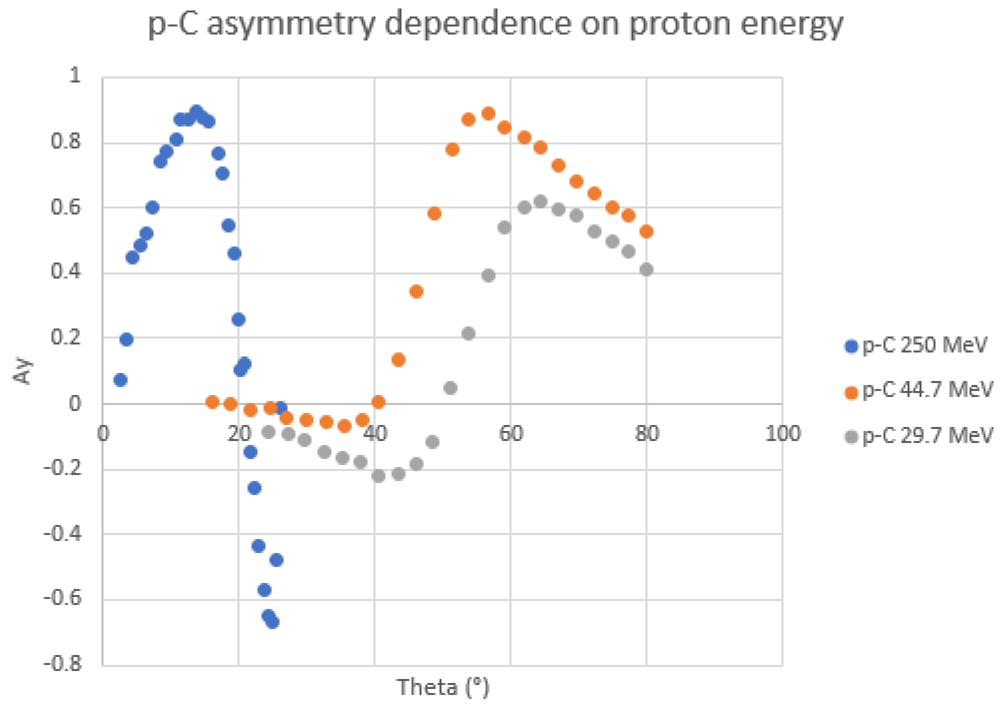


2. Energy dependence of p-C scattering

The best way to detect small changes in beam polarization caused by EDM at an energy of 200-250MeV is to deflect off a carbon target (forward-angle elastic scattering)

Spin polarization measurements at COSY are based on the asymmetry observed in these collisions.

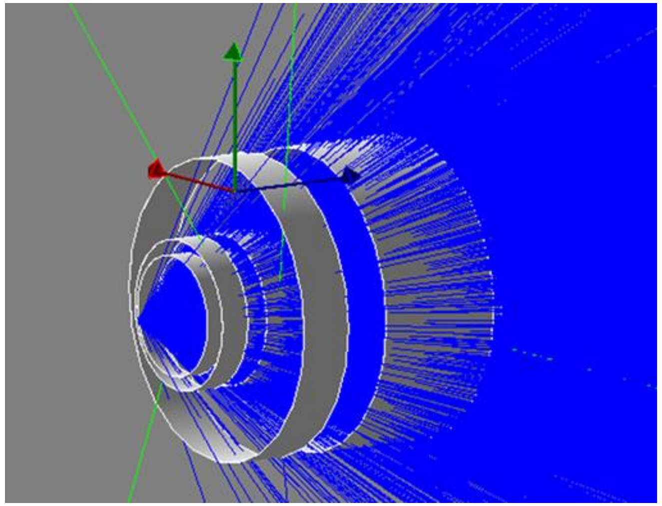
It can be seen that for lower energies used in a prototype ring, the asymmetry is seen at much larger angles and thus the current forward facing JePo polarimeter cannot be used.



Analyzing power of proton-carbon collisions at different scattering angles for different energies. 29.7 & 44.7 MeV data recovered from *, 250 MeV data provided by the JEDI collaboration

* https://doi.org/10.1016/0168-9002(87)90744-3

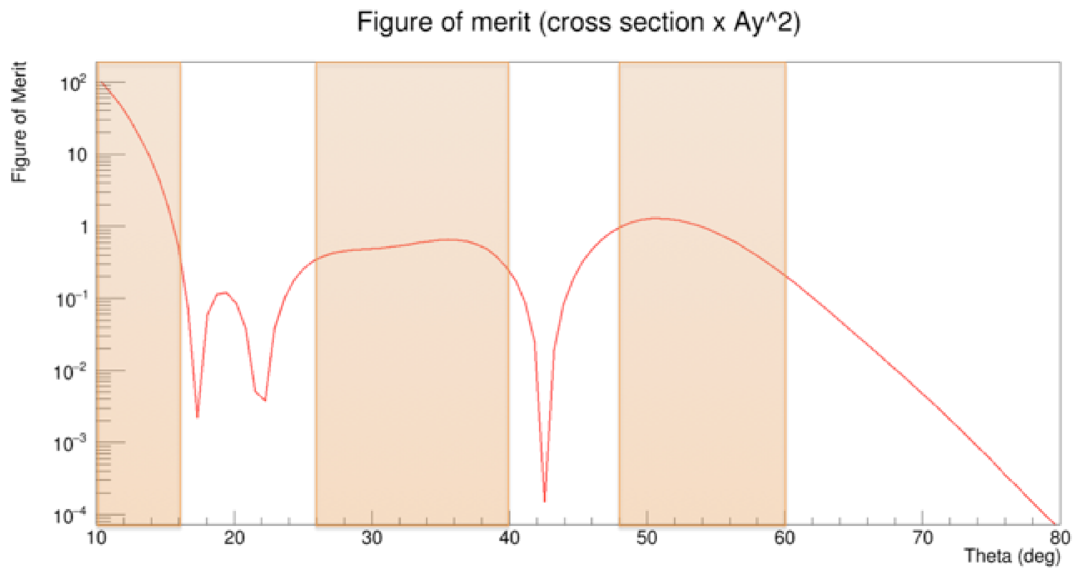
Configuration

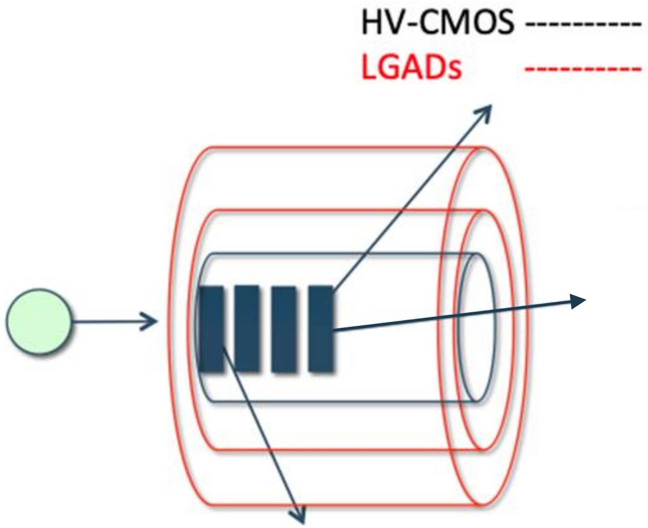


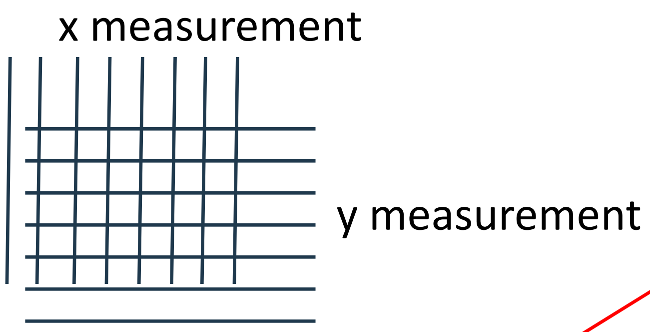
A forward configuration will target only one area of figure of merit

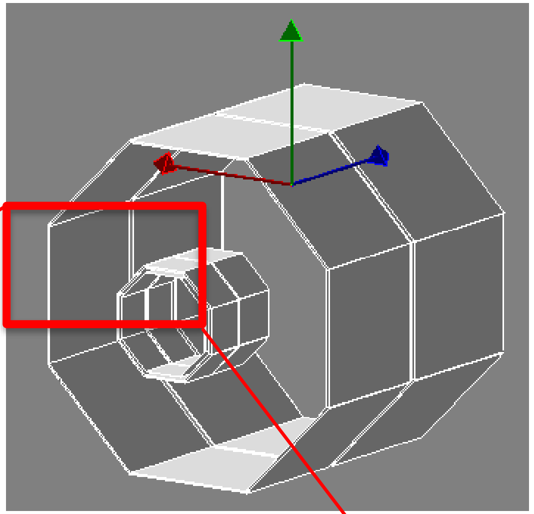
- A cylindrical design surrounding the beamline and target will be effective in two areas of high figure of merit.

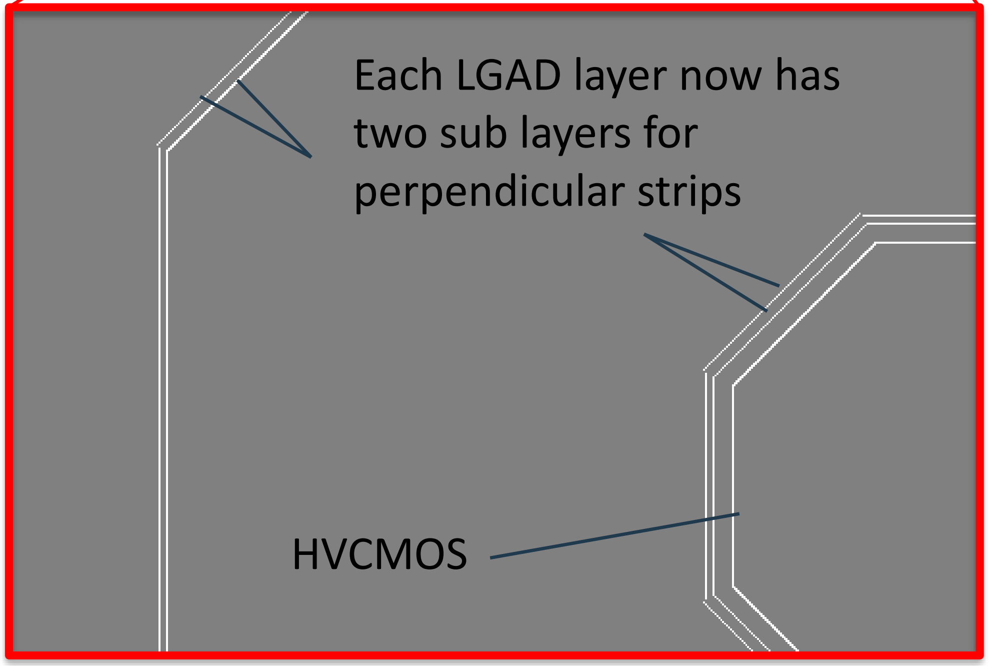
- Forward area figure of merit strongly influenced by rate, not analyzing power.

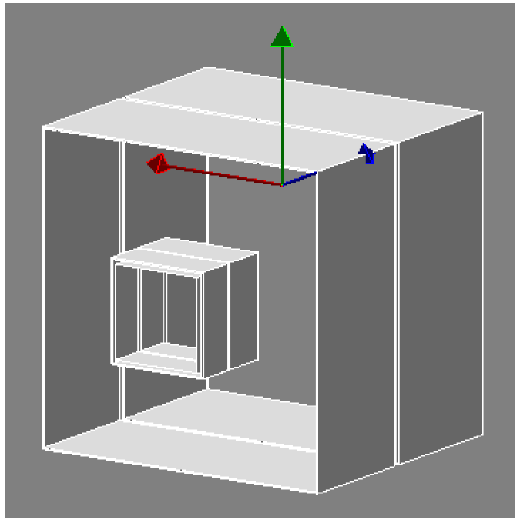


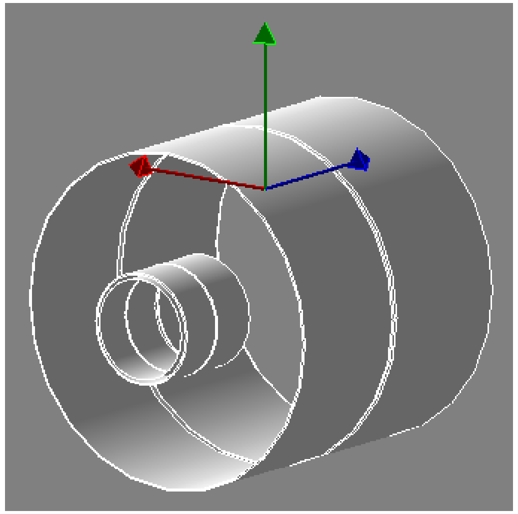



x measurement
y measurement

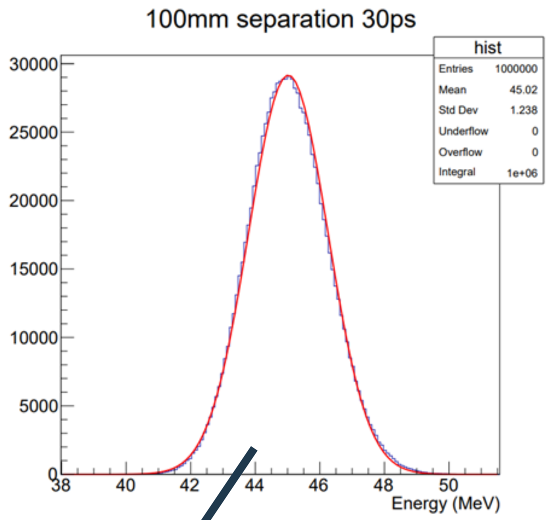



Each LGAD layer now has two sub layers for perpendicular strips
HVCMOS

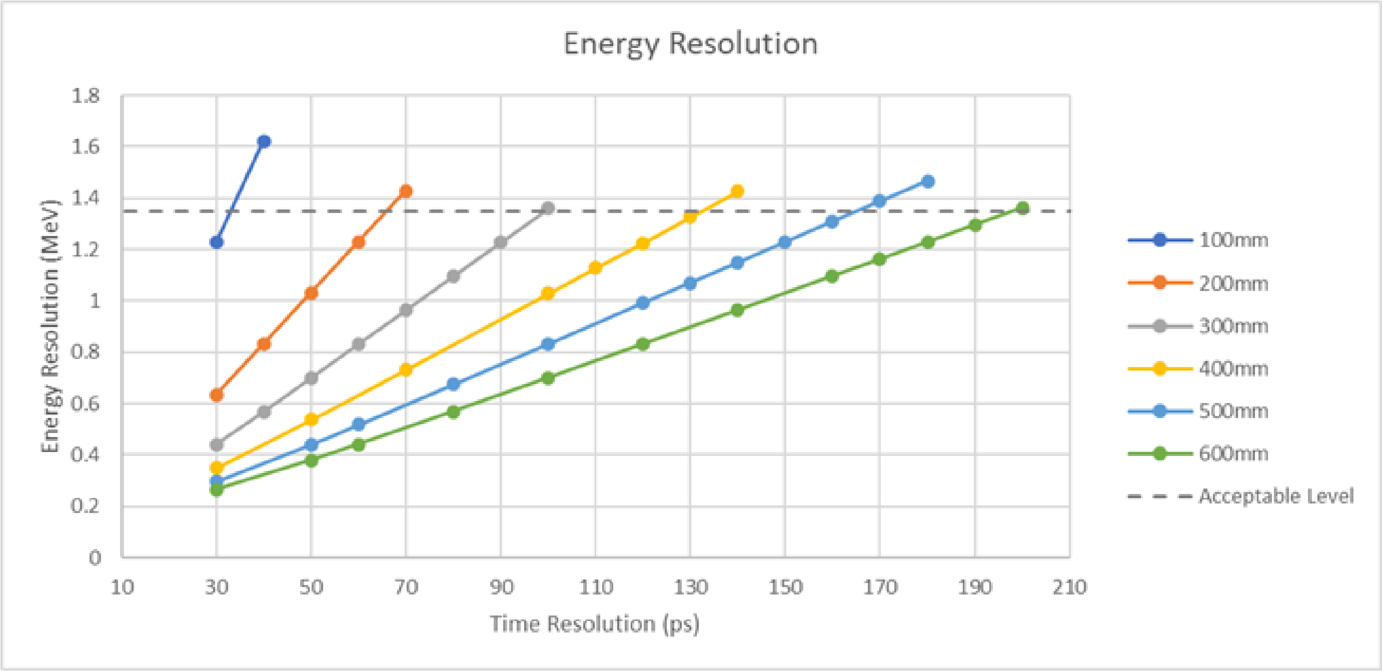


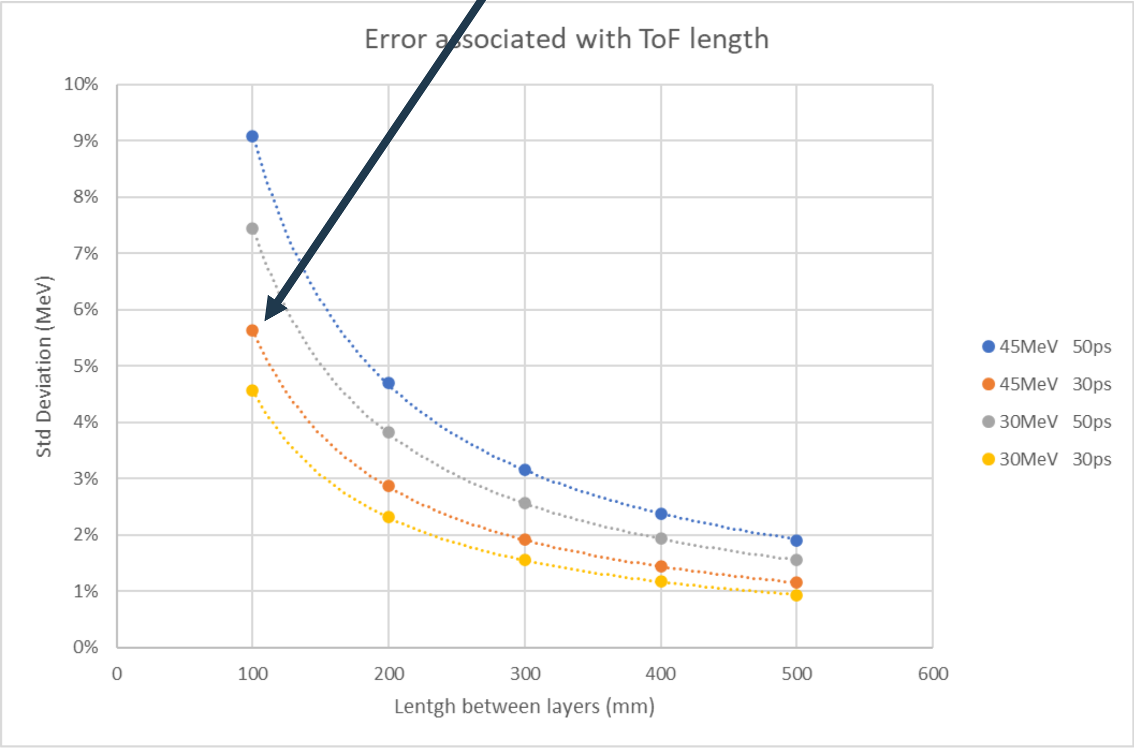


Energy Resolution
- ToF region length



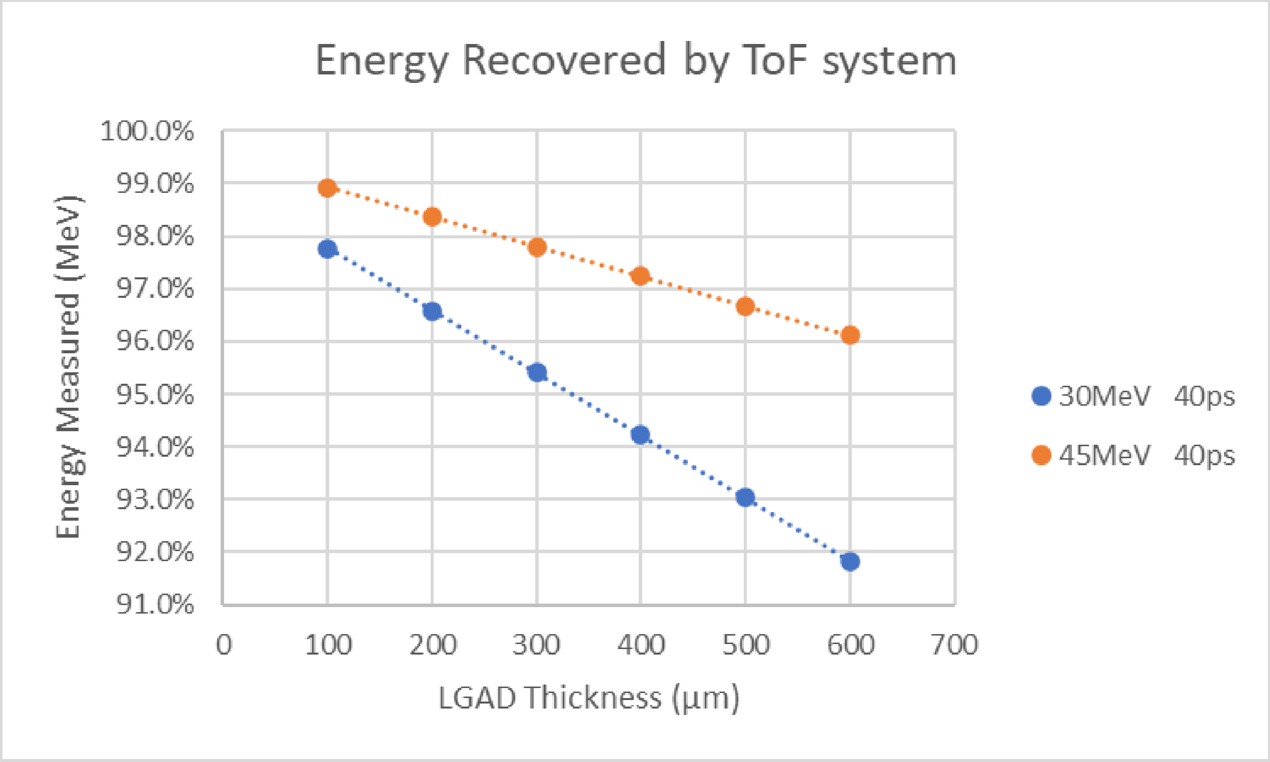
Potential LGAD time resolution 30-50 ps
What length chamber makes this suitable for this experiment?

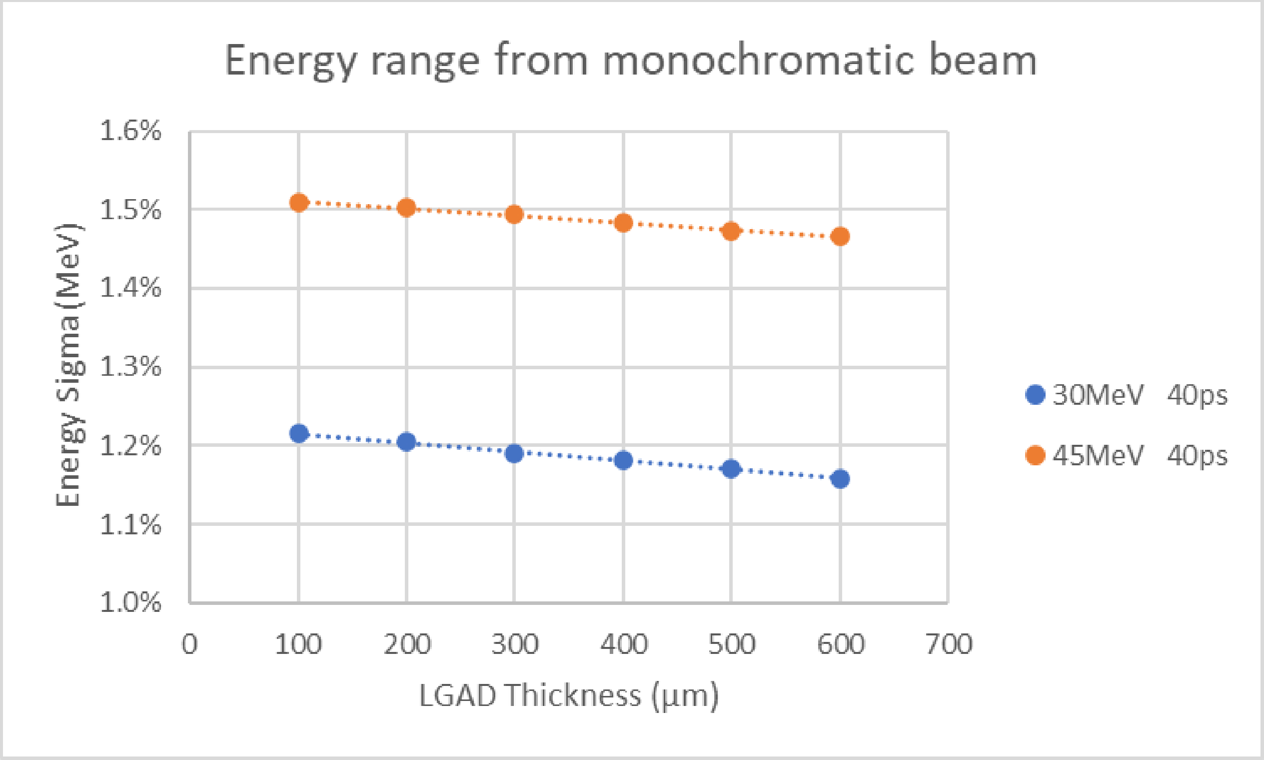




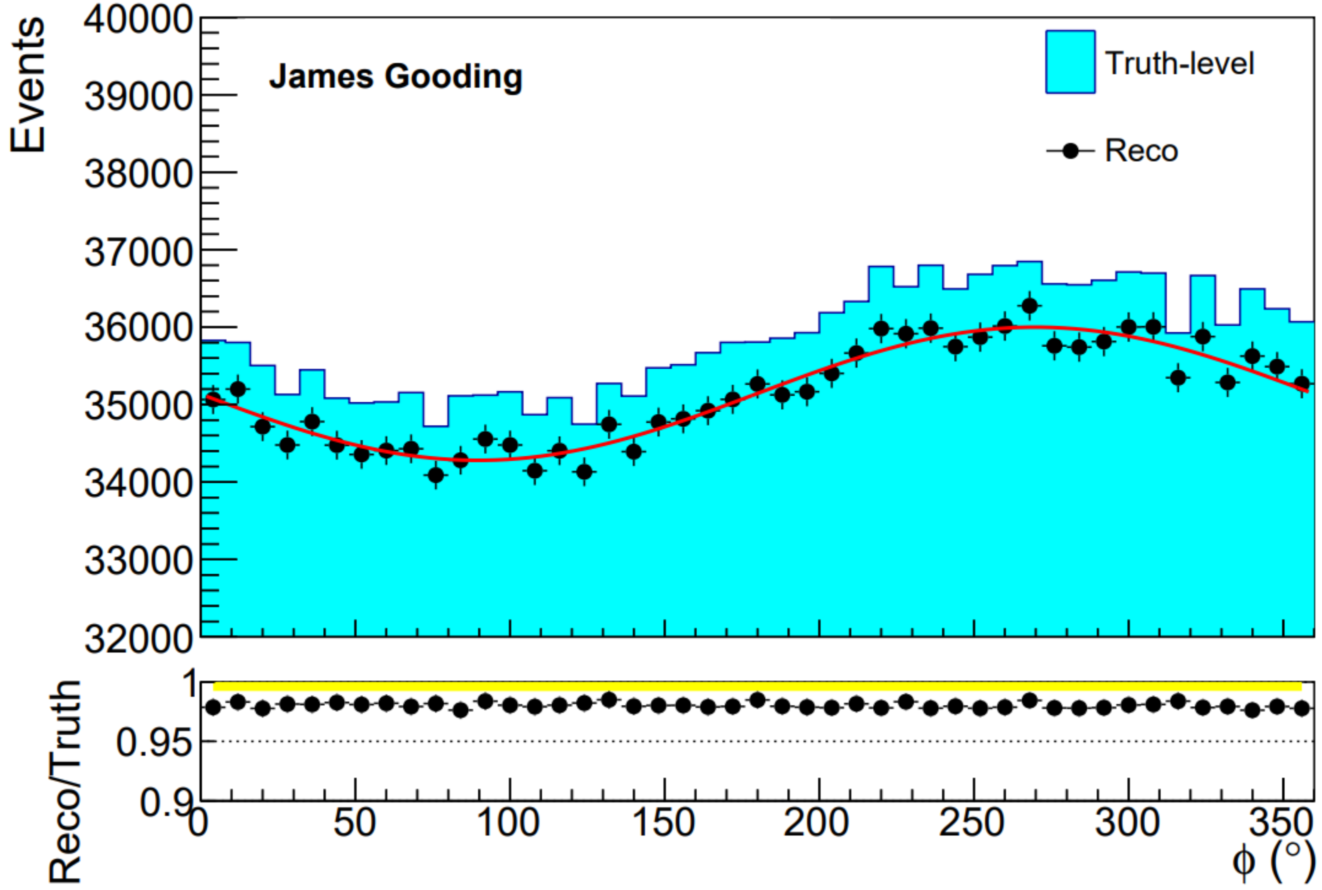
Energy Resolution
- Material budget

Simulations with 500mm between layers



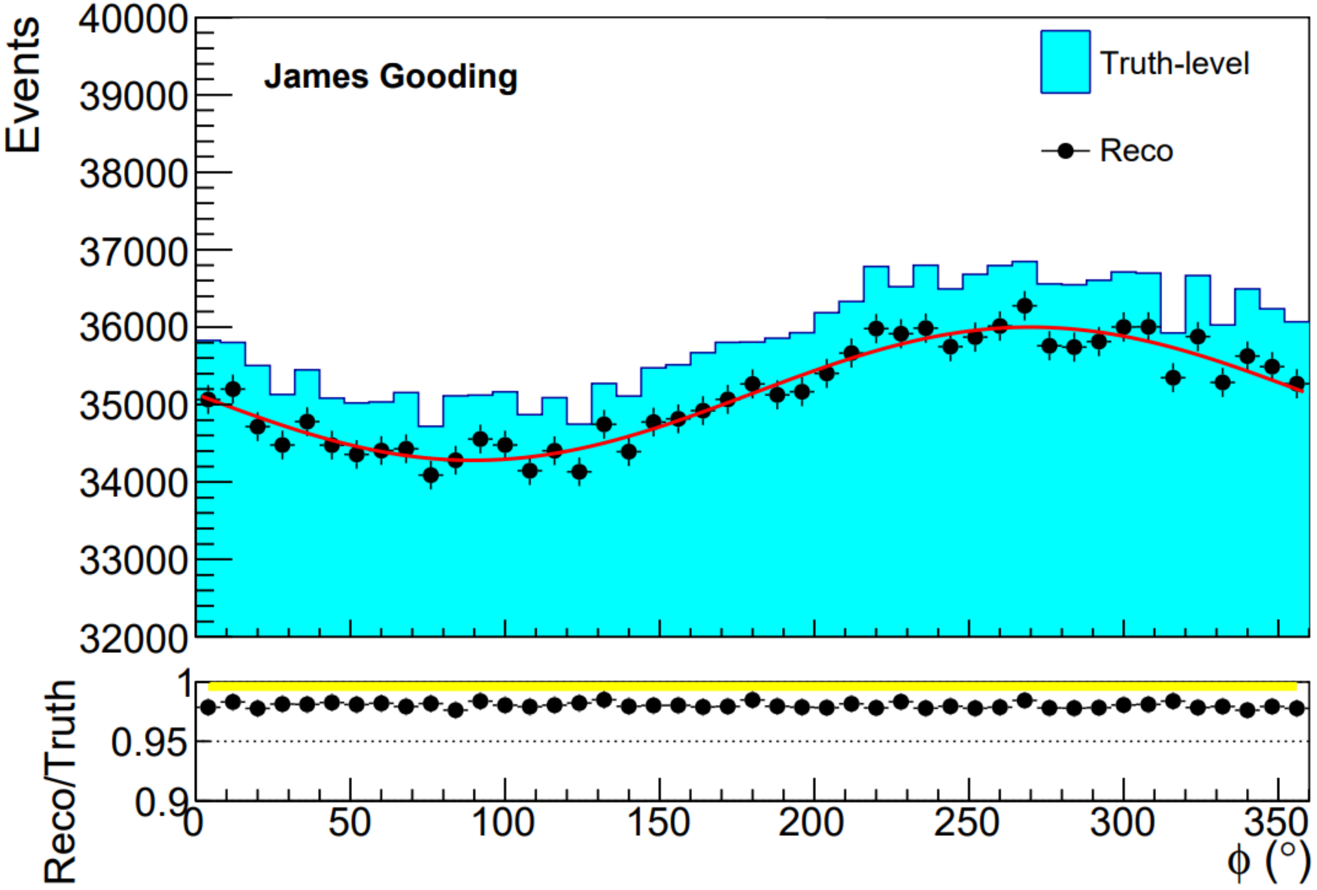


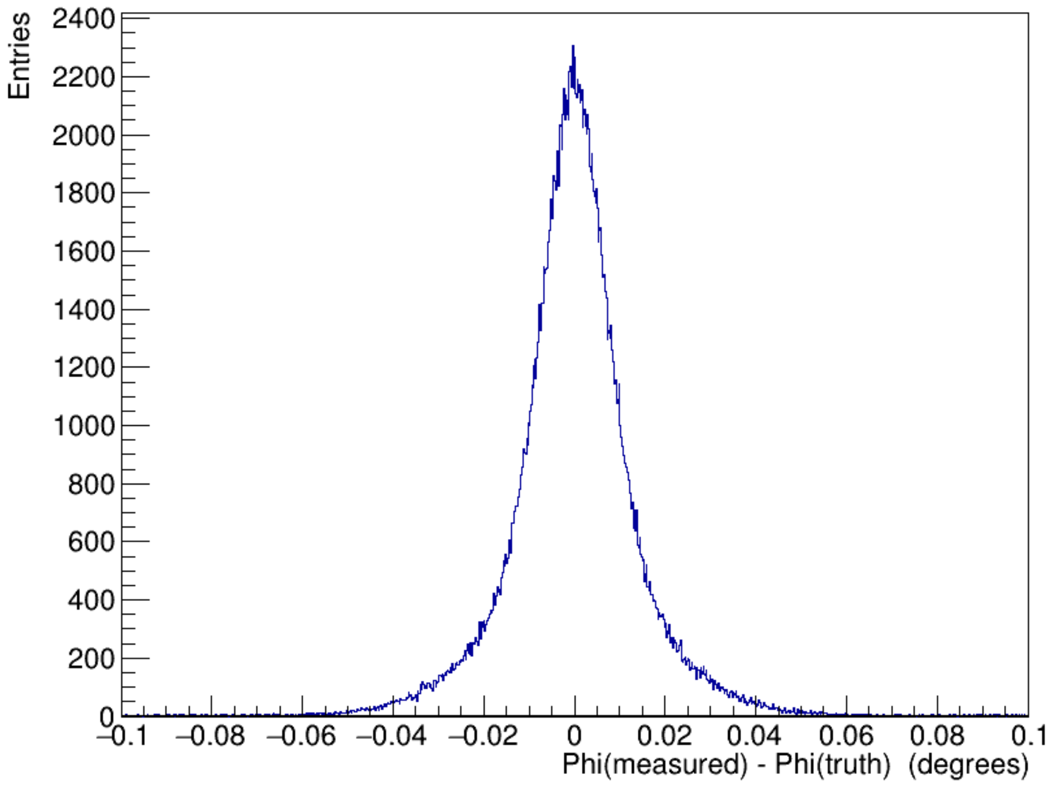
Phi measurement accuracy and efficiency



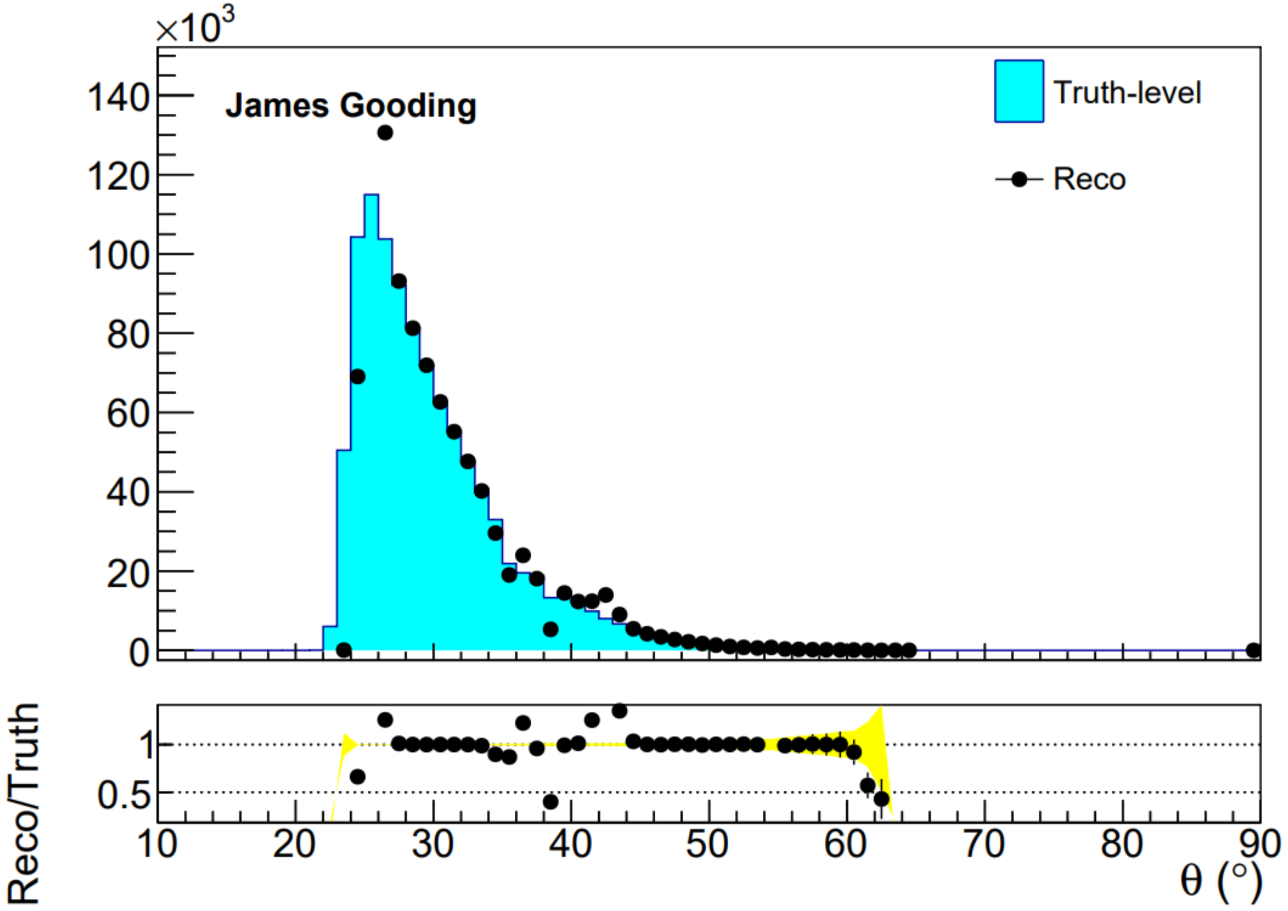
This counts only particles that have been distributed into the detector acceptance to focus on detector performance rather than target performance as target geometry still needs to be optimized.

Phi measurement accuracy and efficiency

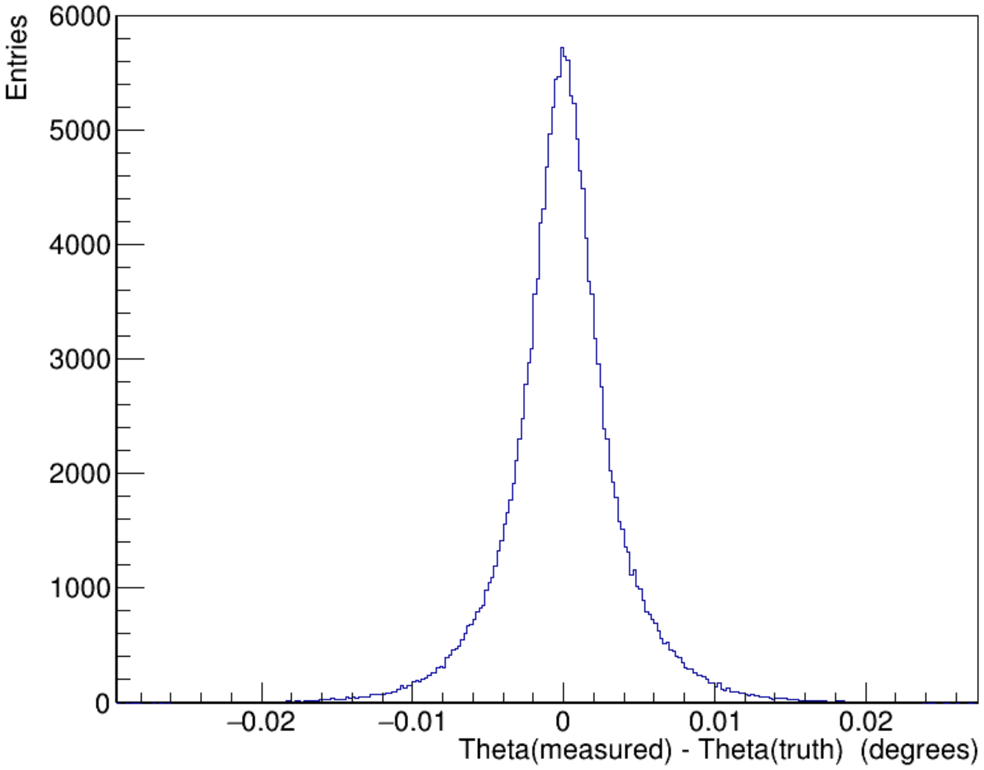




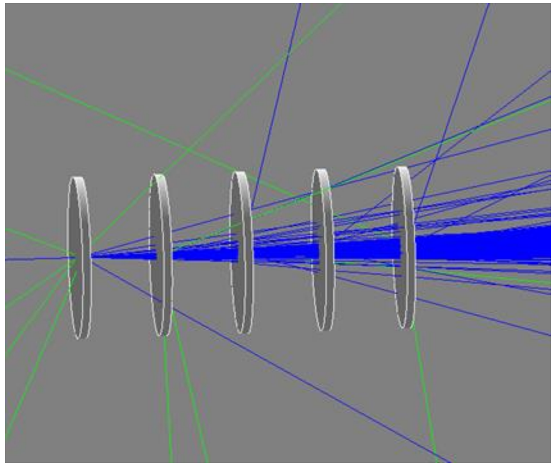
Theta accuracy and efficiency

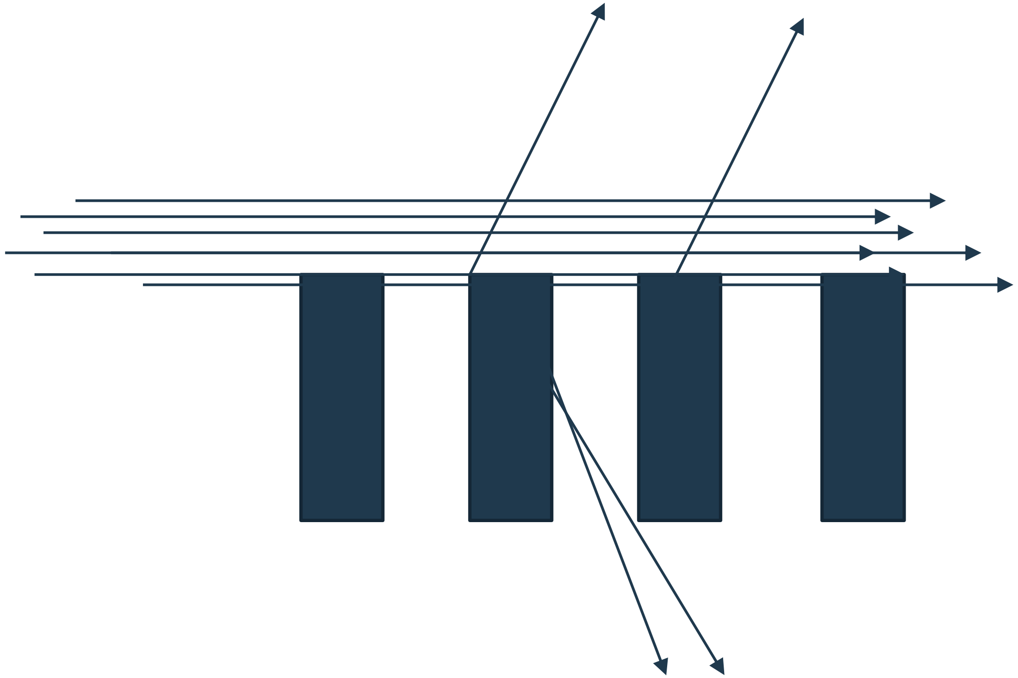


Some theta sections struggle to be reconstructed in sections where there is spacing between cylinders.



Split target

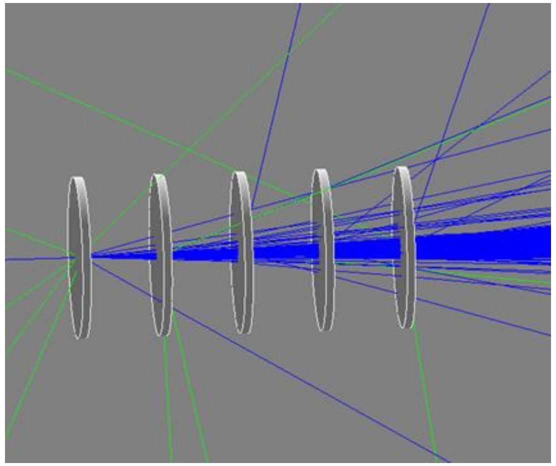


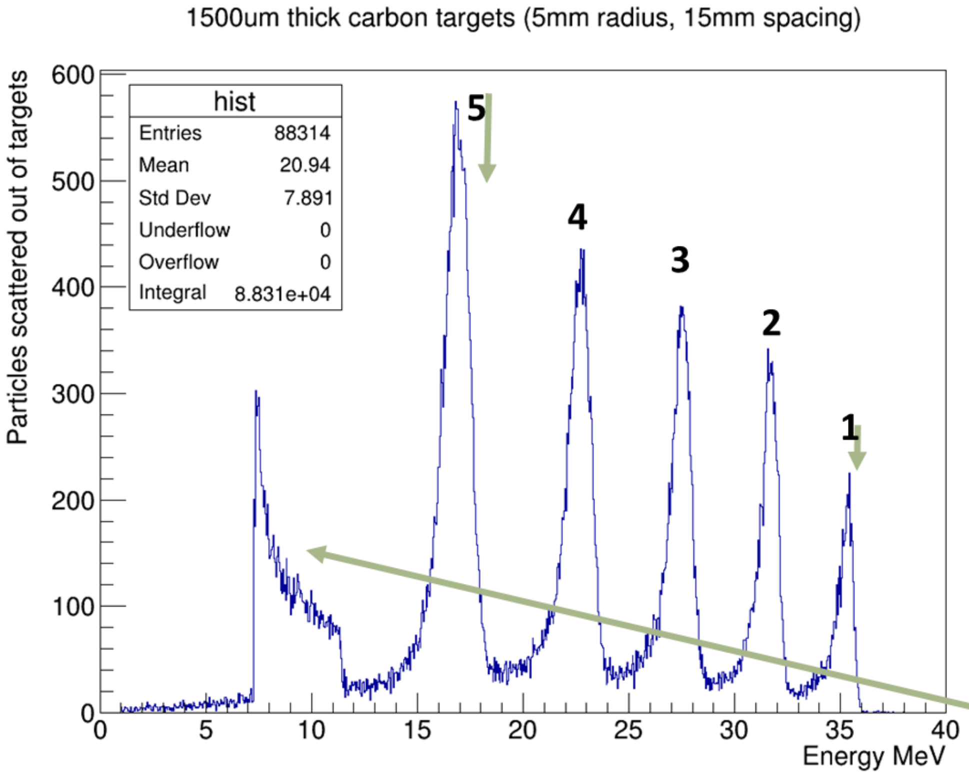


Optimize more target material:

- **Less spacing / targets**
- Increased spacing increases detector area needed.
- Increased targets -> Complexity

- **Increased target thickness**
- More losses in targets -> lower efficiency

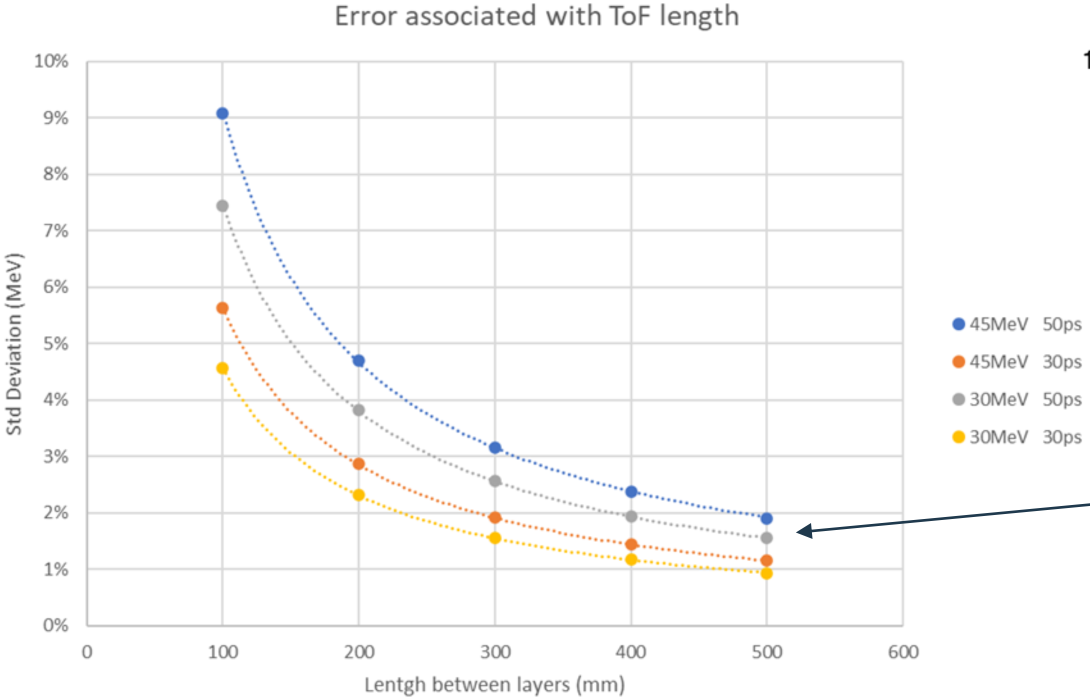




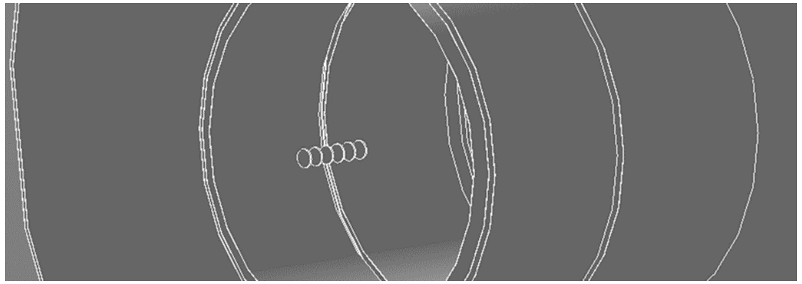
Scatter from last target

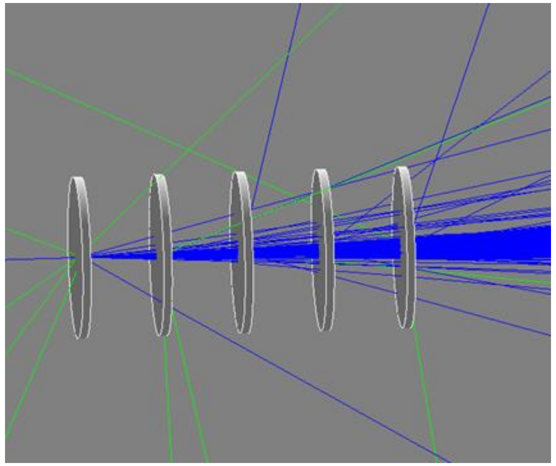
Scatter from first target

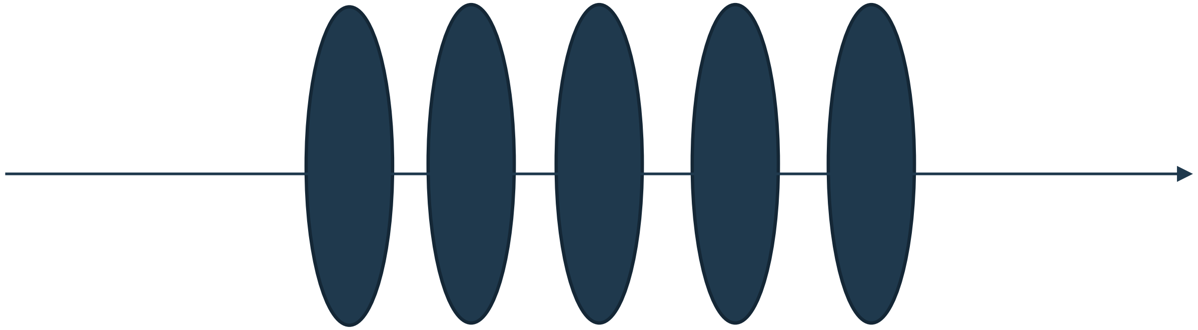
Inelastic landau region
(Proportional to thickness)
(Seems to be radius independent on first testing)

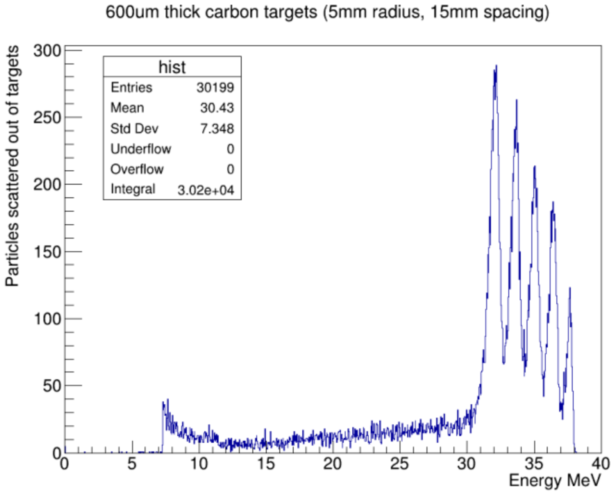


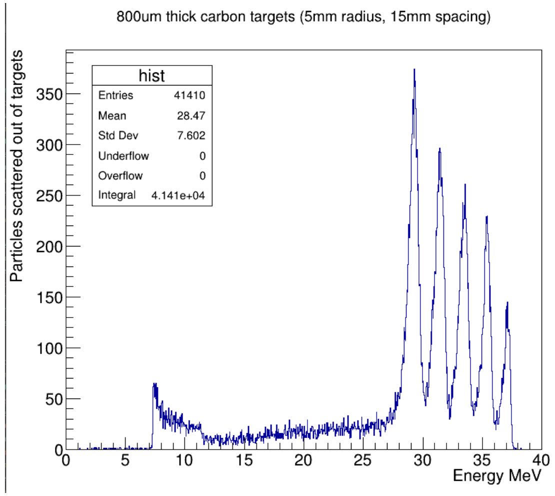
Energy resolution well under 2% possible at 30 MeV
(< 1 MeV)

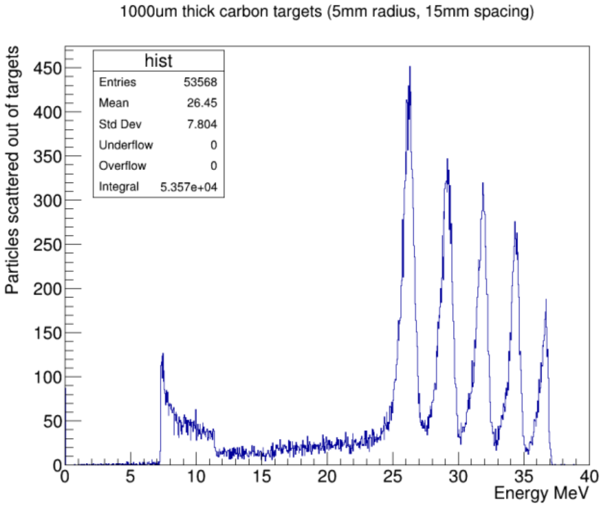


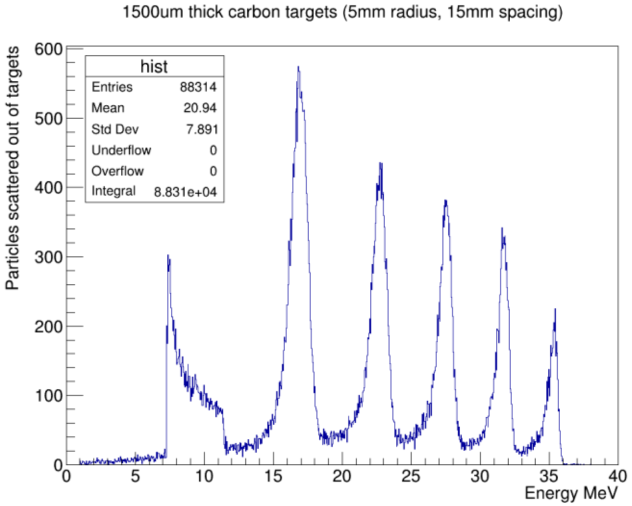





600um thick carbon targets (5mm radius, 15mm spacing)
hist
Entries 30199
Mean 30.43
Std Dev 7.348
Underflow 0
Overflow 0
Integral 3.02e+04
Particles scattered out of targets
Energy MeV


800um thick carbon targets (5mm radius, 15mm spacing)
hist
Entries 41410
Mean 28.47
Std Dev 7.602
Underflow 0
Overflow 0
Integral 4.141e+04
Particles scattered out of targets
Energy MeV


1000um thick carbon targets (5mm radius, 15mm spacing)
hist
Entries 53568
Mean 26.45
Std Dev 7.804
Underflow 0
Overflow 0
Integral 5.357e+04
Particles scattered out of targets
Energy MeV


1500um thick carbon targets (5mm radius, 15mm spacing)
hist
Entries 88314
Mean 20.94
Std Dev 7.891
Underflow 0
Overflow 0
Integral 8.831e+04
Particles scattered out of targets
Energy MeV

What efficiency can we achieve

The forward angle JePo polarimeter uses thick carbon block targets that provide a relatively high efficiency.

Polarimeter efficiency: $\epsilon = \frac{Accepted\ hits\ into\ active\ regions}{Particles\ removed\ from\ stored\ beam}$ ← Important in the case of pellet target splitting beam

Irakli's most recent paper reports an efficiency of about 1% for JePo polarimeter.

Can we do something similar by operating at the edge of a target stack with both CW and CCW beams?

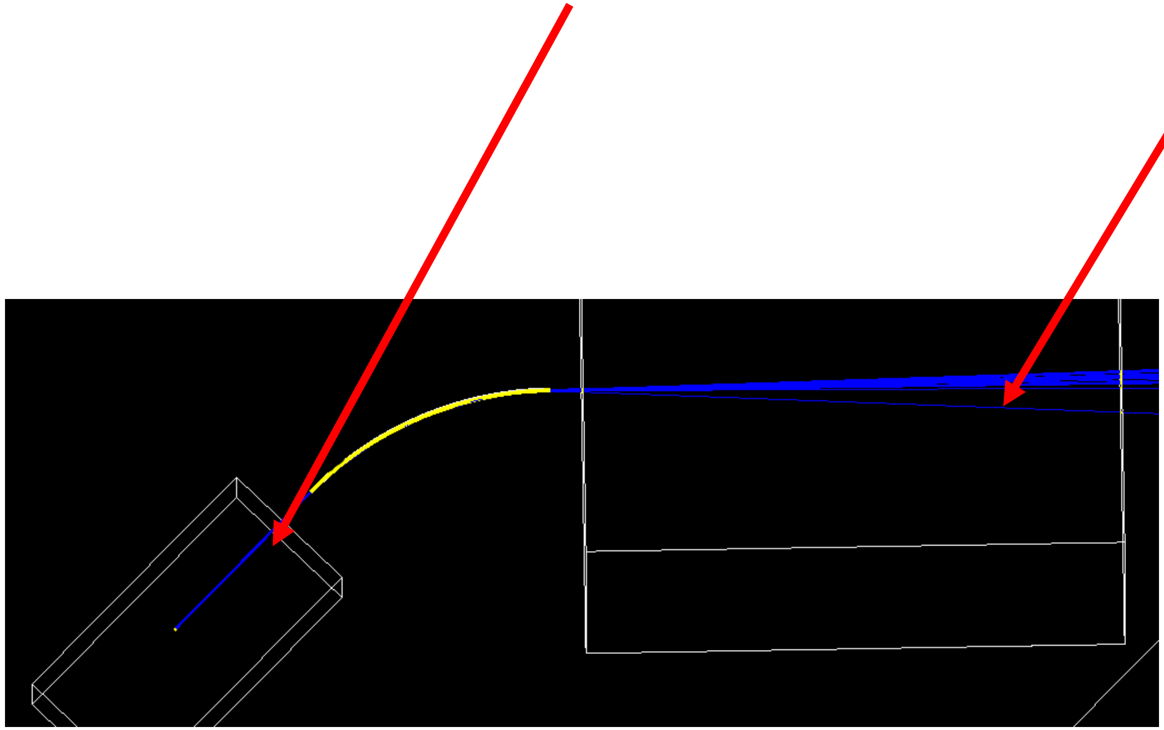
How good would be the separation of the signals from the two beams?

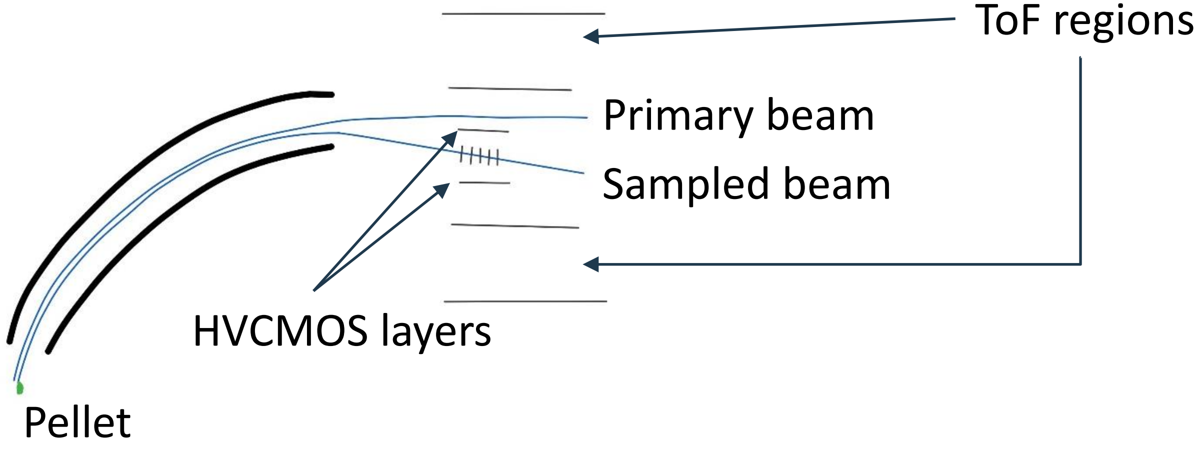
Secondary beam polarimeter via pellet target.

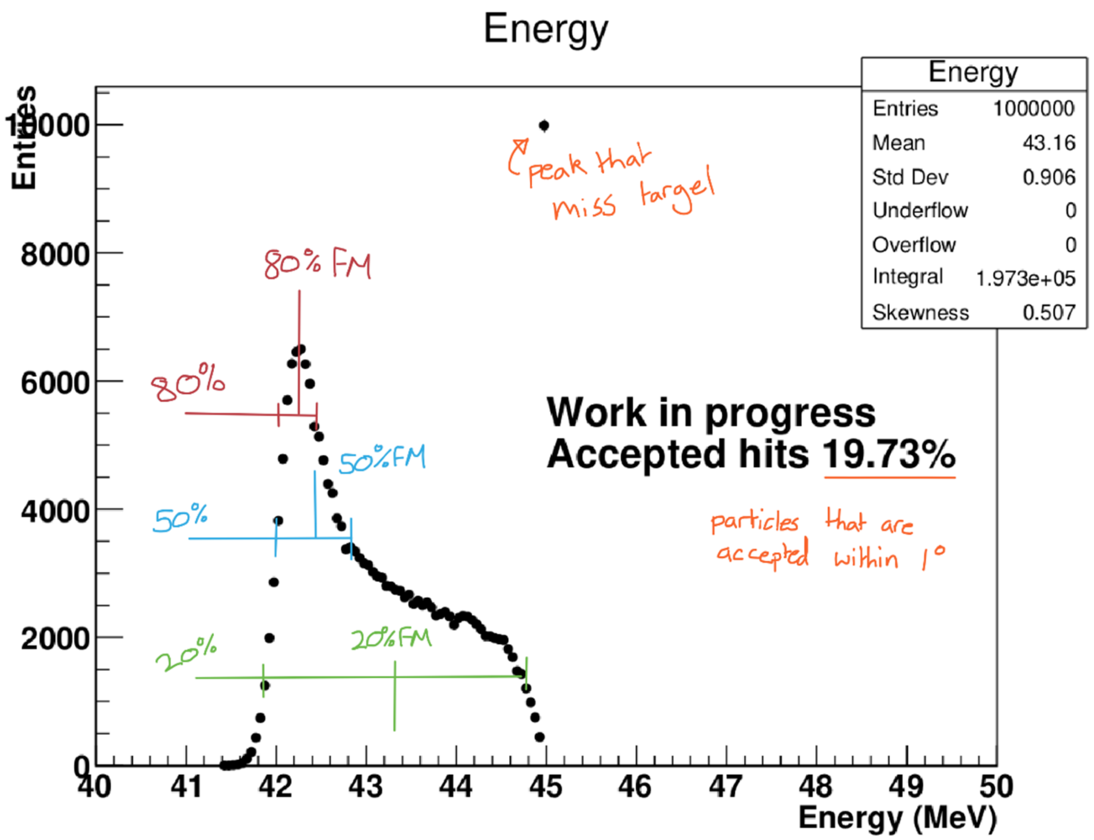
– Influence on primary beam

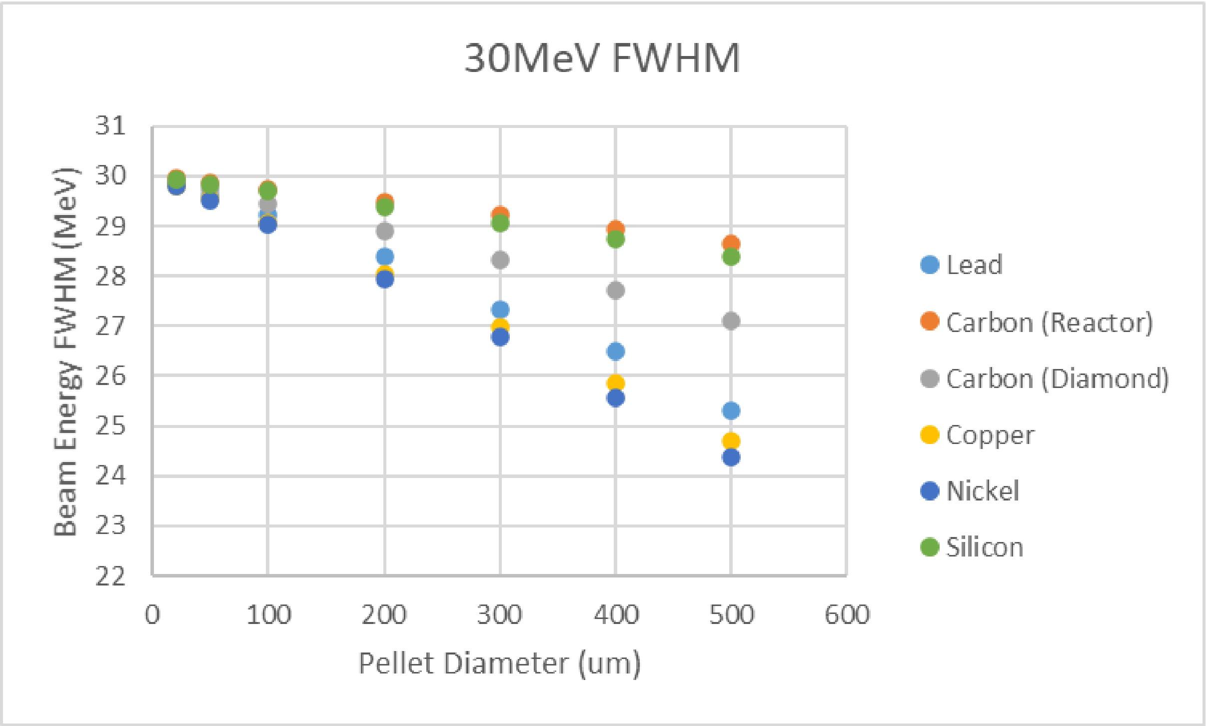
Tiny carbon pellet 20 µm

Sampled particles fall slightly out of orbit

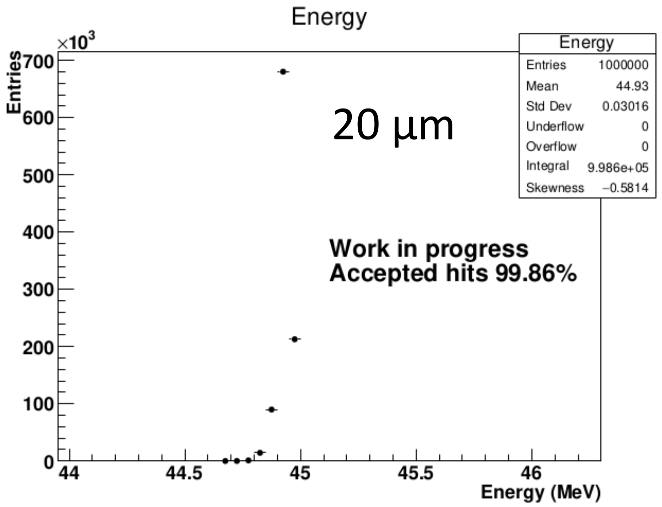


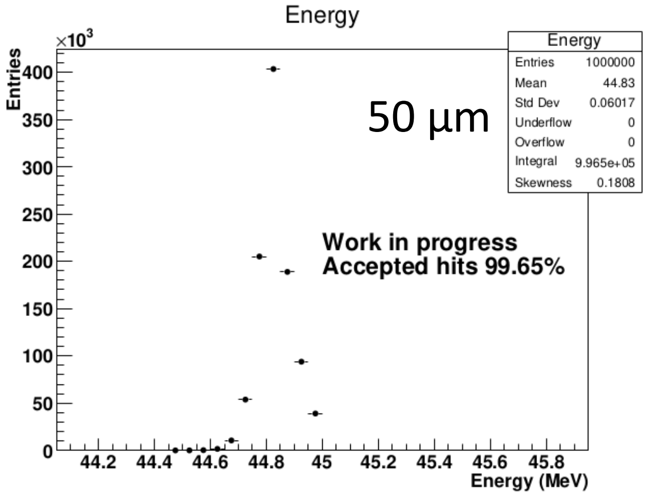


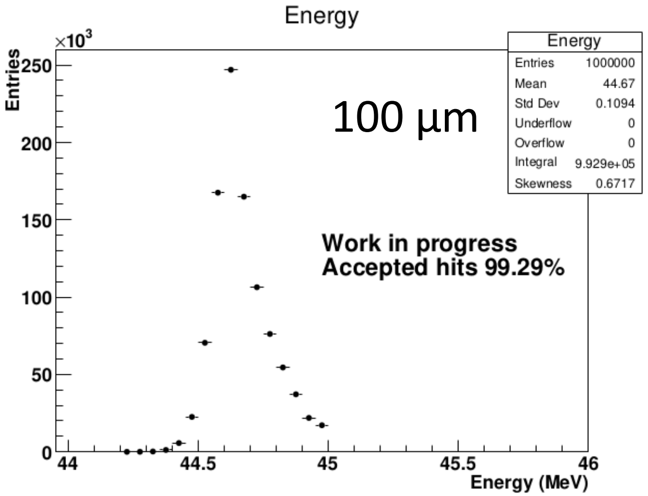

Energy
Energy
Entries 1000000
Mean 43.16
Std Dev 0.906
Underflow 0
Overflow 0
Integral 1.973e+05
Skewness 0.507
Entries
Energy (MeV)
peak that miss target
80% FM
80%
50%FM
50%
20%FM
20%
Work in progress
Accepted hits 19.73%
particles that are accepted within 1°

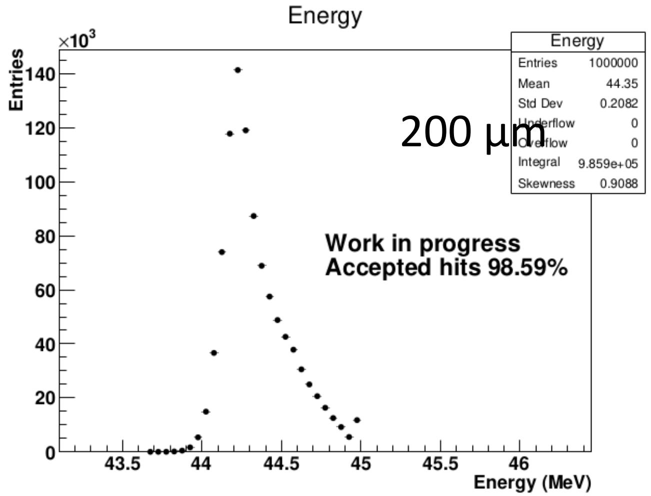

30MeV FWHM
Beam Energy FWHM (MeV)
Pellet Diameter (um)
Lead
Carbon (Reactor)
Carbon (Diamond)
Copper
Nickel
Silicon

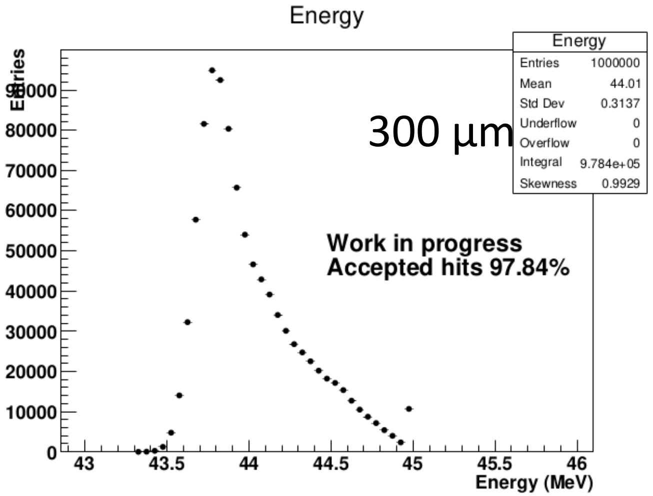
Carbon (Diamond) 45MeV

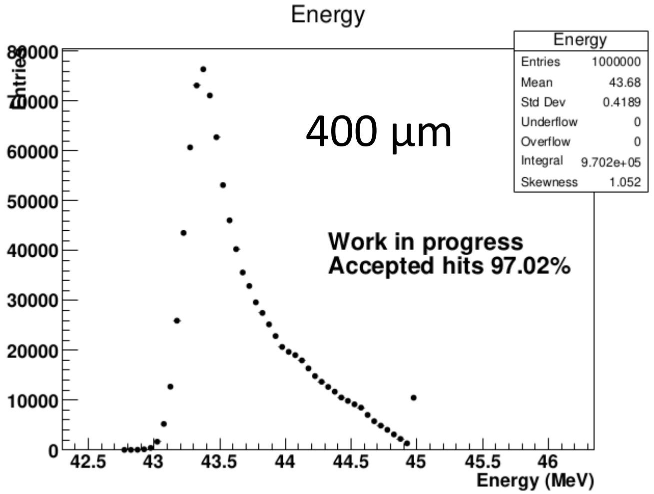




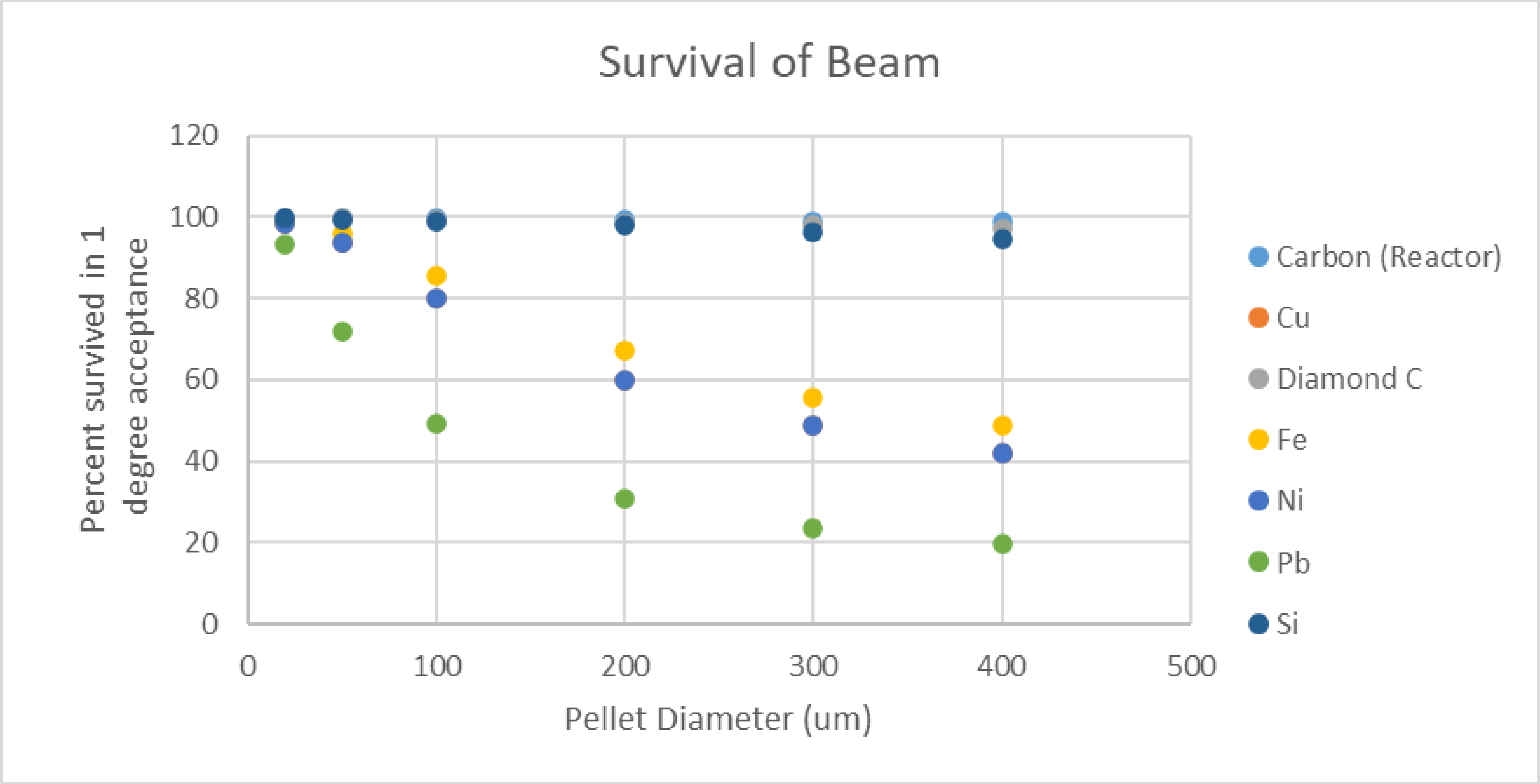








30 MeV

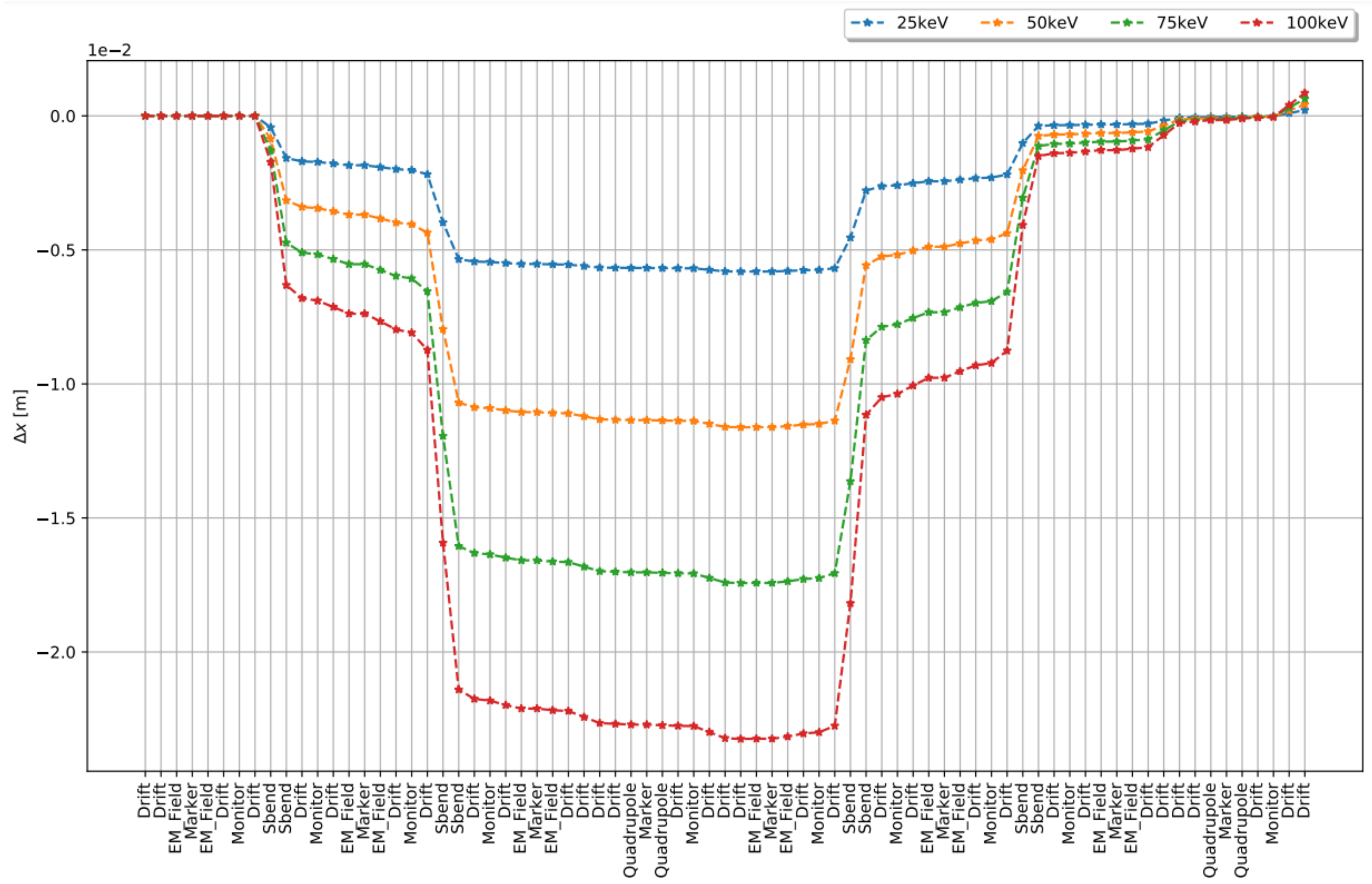


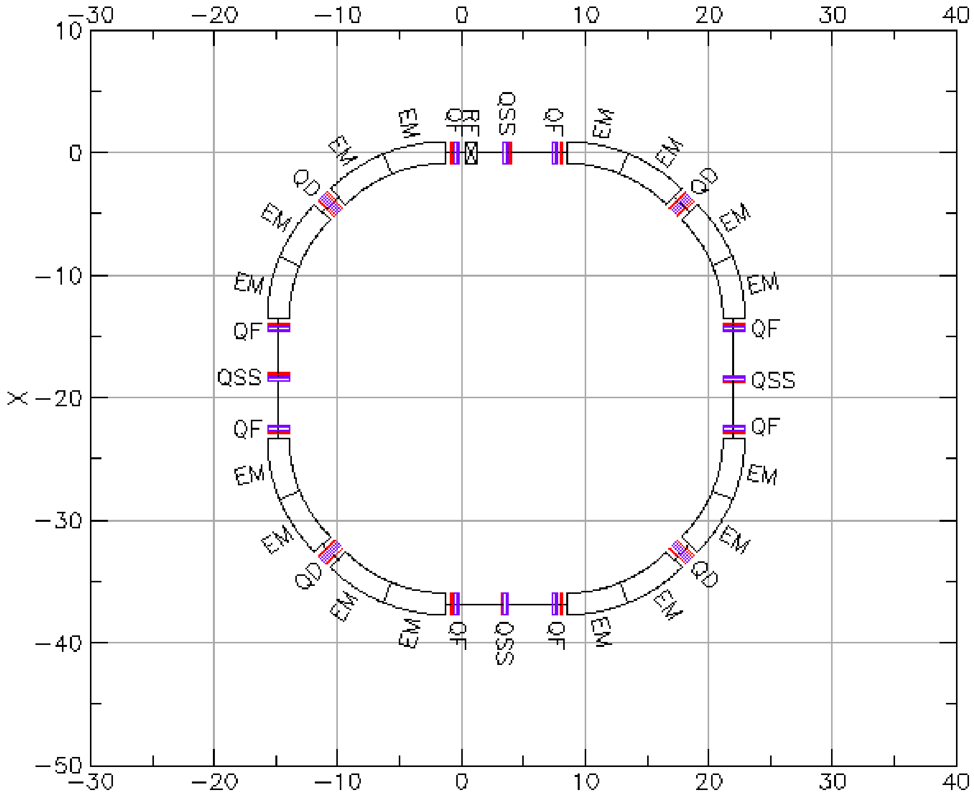
Beam defined as 1% larger diameter then pellet:
- 1.97% by definition passes pellet without interaction

Pellet target feasibility study

Dispersion range Qx 1.946, Qy 0.203

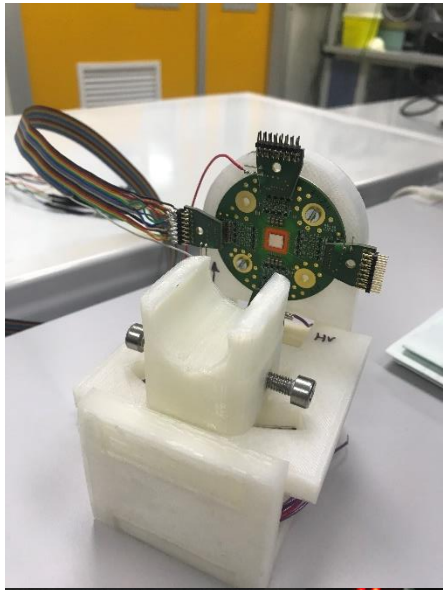
- 2 Arcs after the pellet target is simulated
- Offset from initial beam position approximately 2cm

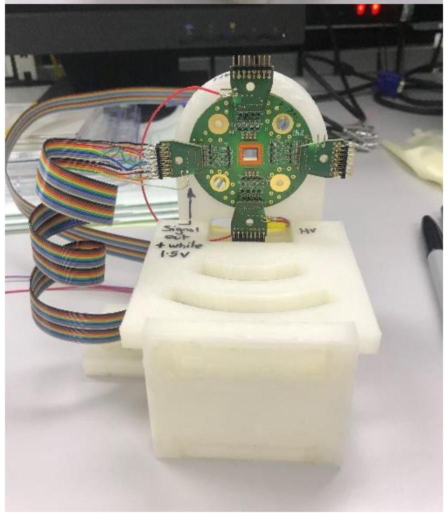


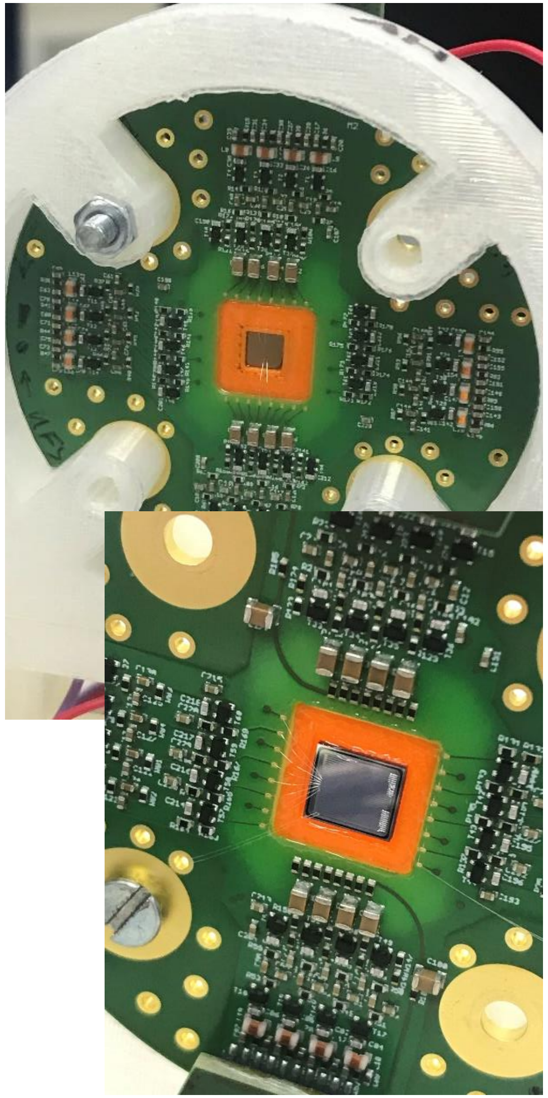


Simulations performed by Maximilian Vitz

Current LGAD / HVCMOS characterization







LGAD bonded and configured for testing at Liverpool.
Many thanks to Jerzy Pietraszko, Michael Traxler and Tetyana Galatyuk

Sensor: UFSD2
Readout PCB: GSI
Channels: 8 bonded (16 possible)
Bias: up to 300V

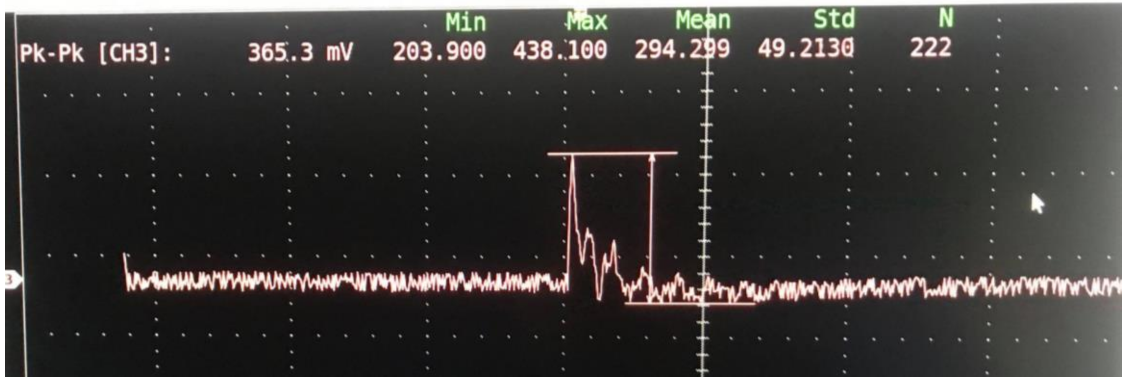
30 strip, 146 um pitch, 5 mm length

Newer models have reduced dead area

50 ps timing resolution demonstrated previously by J.Pietraszko at Jülich.

"Low Gain Avalanche Detectors for the HADES reaction time (T0) detector upgrade"
https://link.springer.com/article/10.1140%2Fepja%2Fs10050-020-00186-w

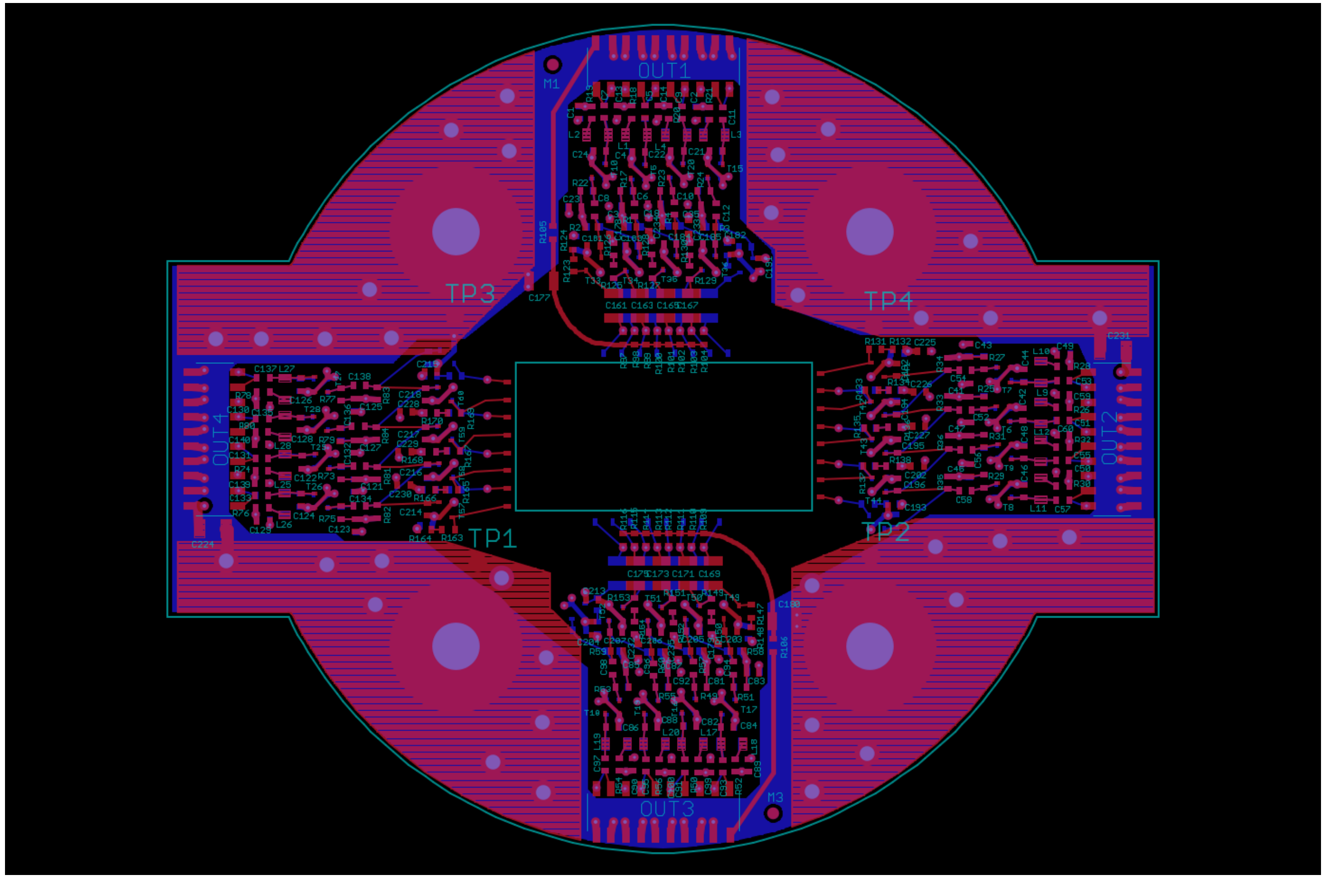
LGAD initial signals



Very first radioactive source measurements of LGAD’s at Liverpool.

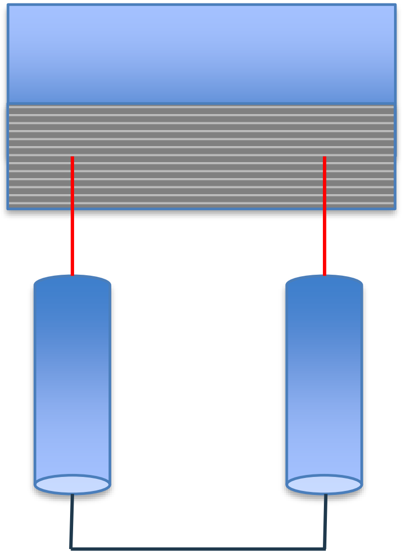
Many tests still to come to going into 2021!

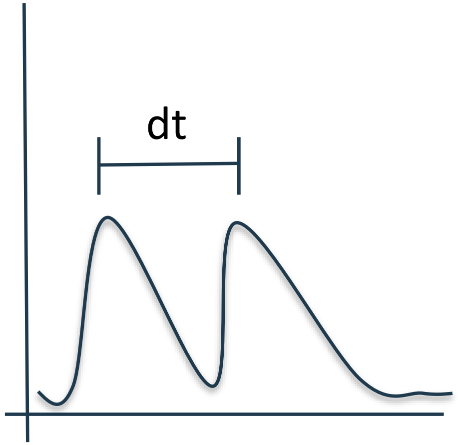
Current LGAD / HVCMOS characterization



Sensor: UFSD2
Readout PCB: GSI
Channels: 8 bonded (16 available)
Bias: up to 300V

Up to 15 mm length strips to test hit location to time resolution.

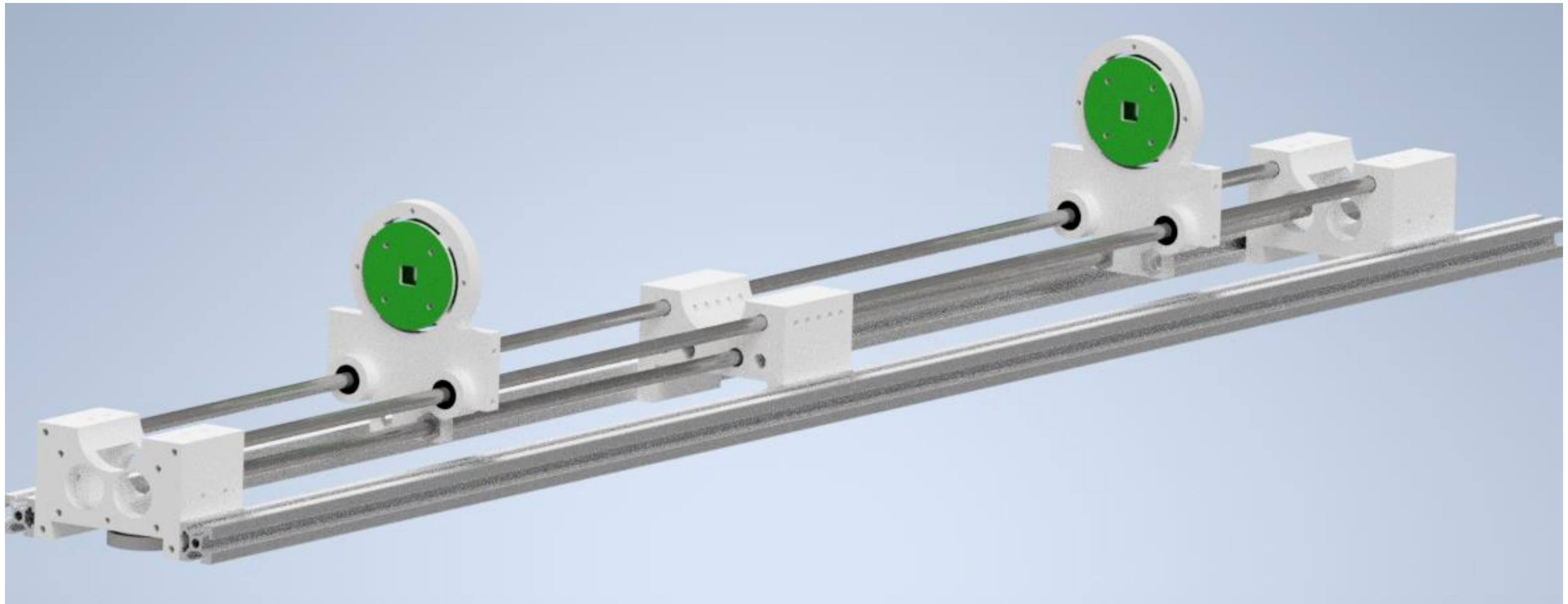


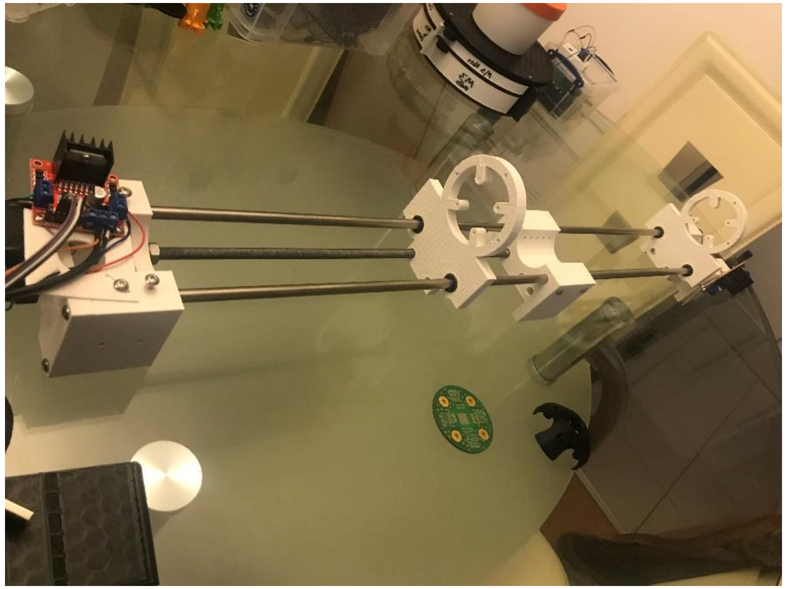


LGAD Time of Flight telescope

- Remote adjustability to below 100µm accuracy.
- Beamline planned with medical proton therapy facility.
- ToF distance range 100-900 mm

- Mechanical structure completed.
- Awaiting readout systems and PCB manufacture.
- Final assembly and wiring.
- Test beam.
- Data analysis and results.



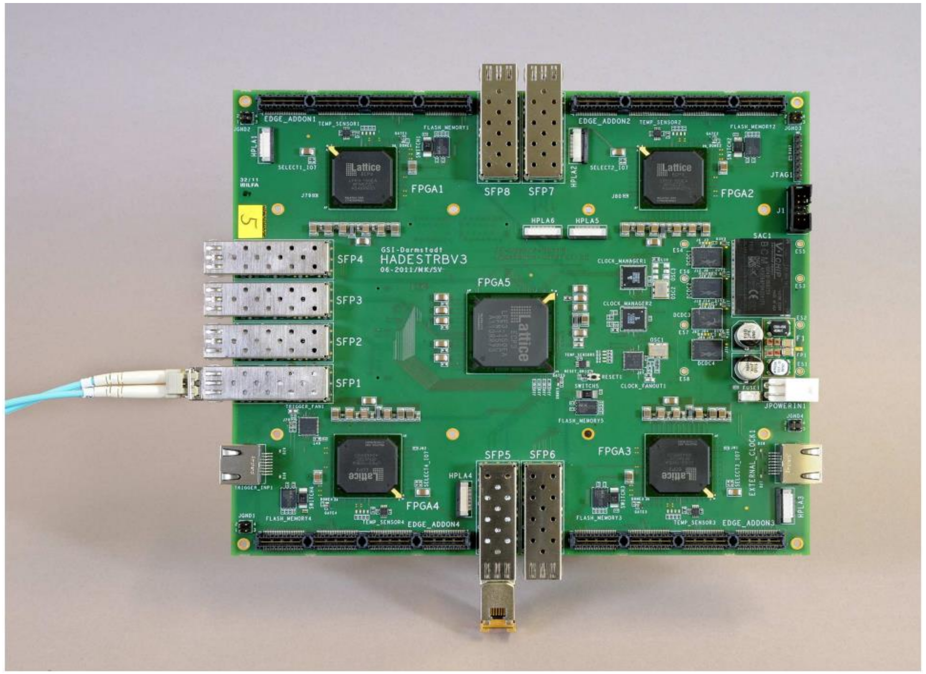


LGAD Time of Flight telescope

- Readout

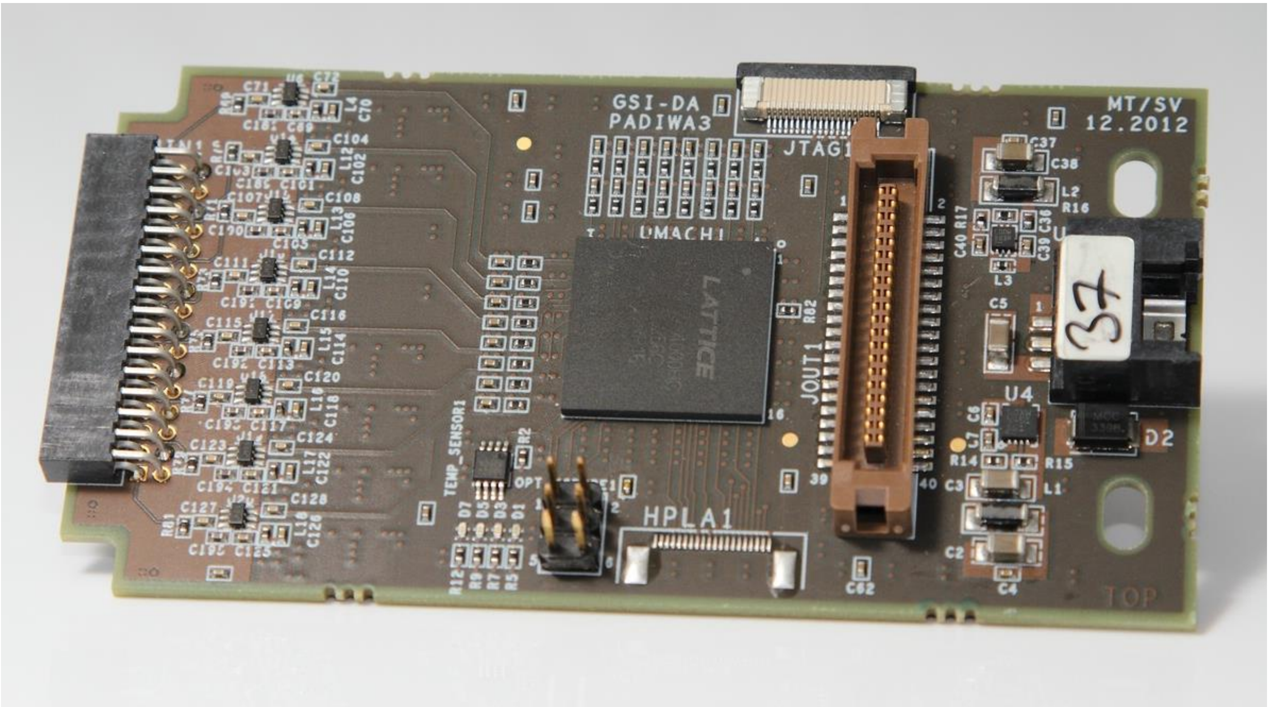
Extra information:
http://jspc29.x-matter.uni-frankfurt.de/trb/publications/201310_NoMeTDC_Ugur.pdf

TRB3 & Padiwa boards for TDC and readout

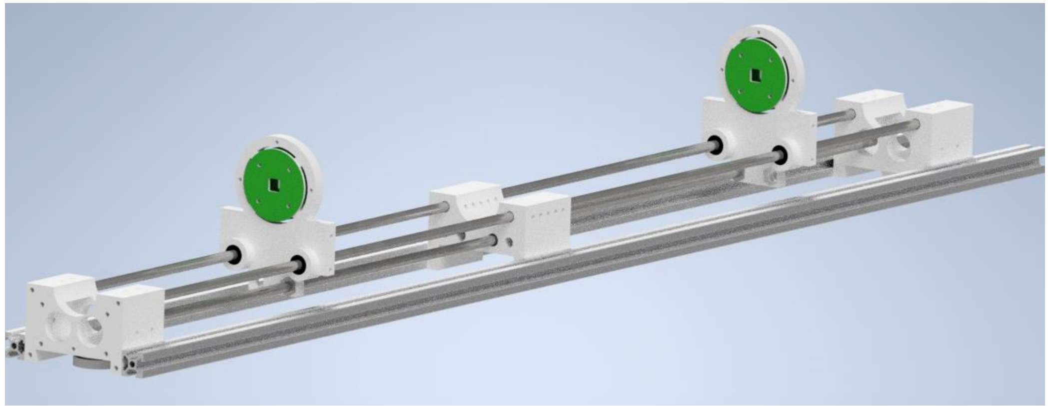


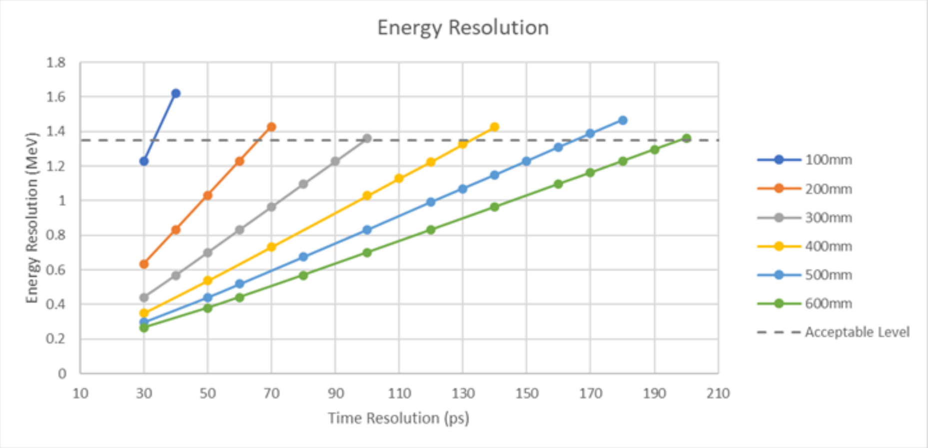
https://iopscience.iop.org/article/10.1088/1748-0221/6/12/C12004/pdf

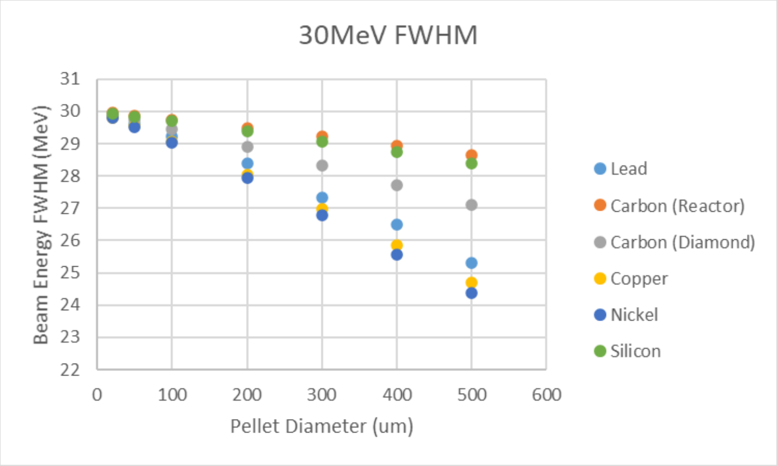
The third addition to Padiwa-family boards, optimized for direct connection to a MC-PMT - four of these 16 channel boards fit onto the 5x5 cm2 backside of a typical MC-PMT

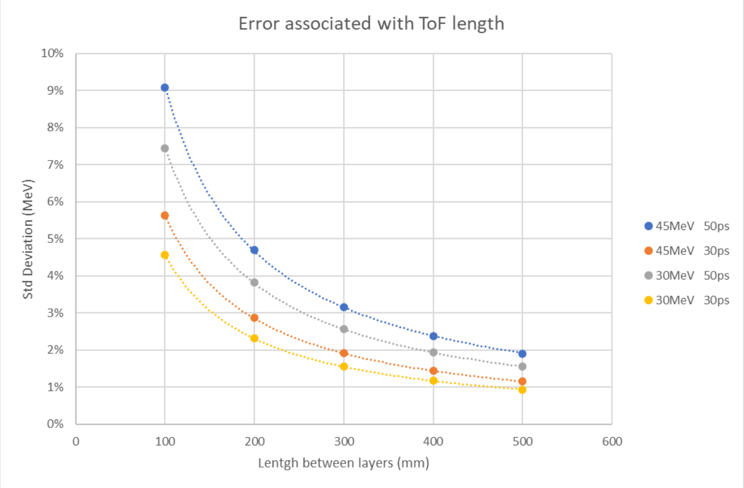


Thank you for listening!
Any Questions?



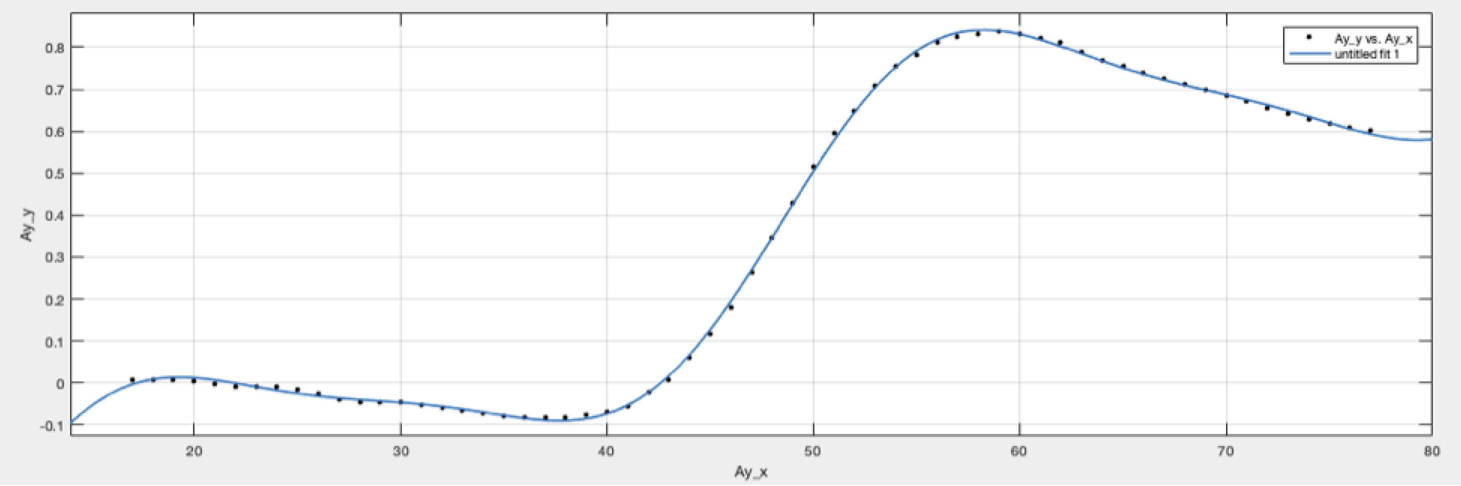






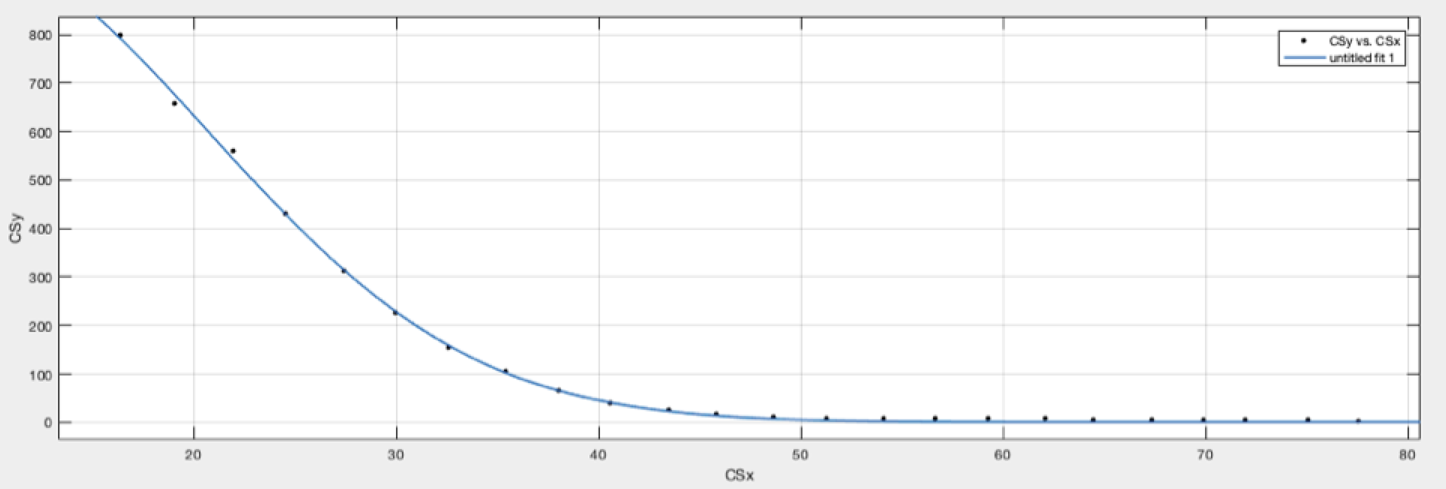
Backup Slides

A_y



Angle (°)

Cs



Angle (°)

39.6 MeV

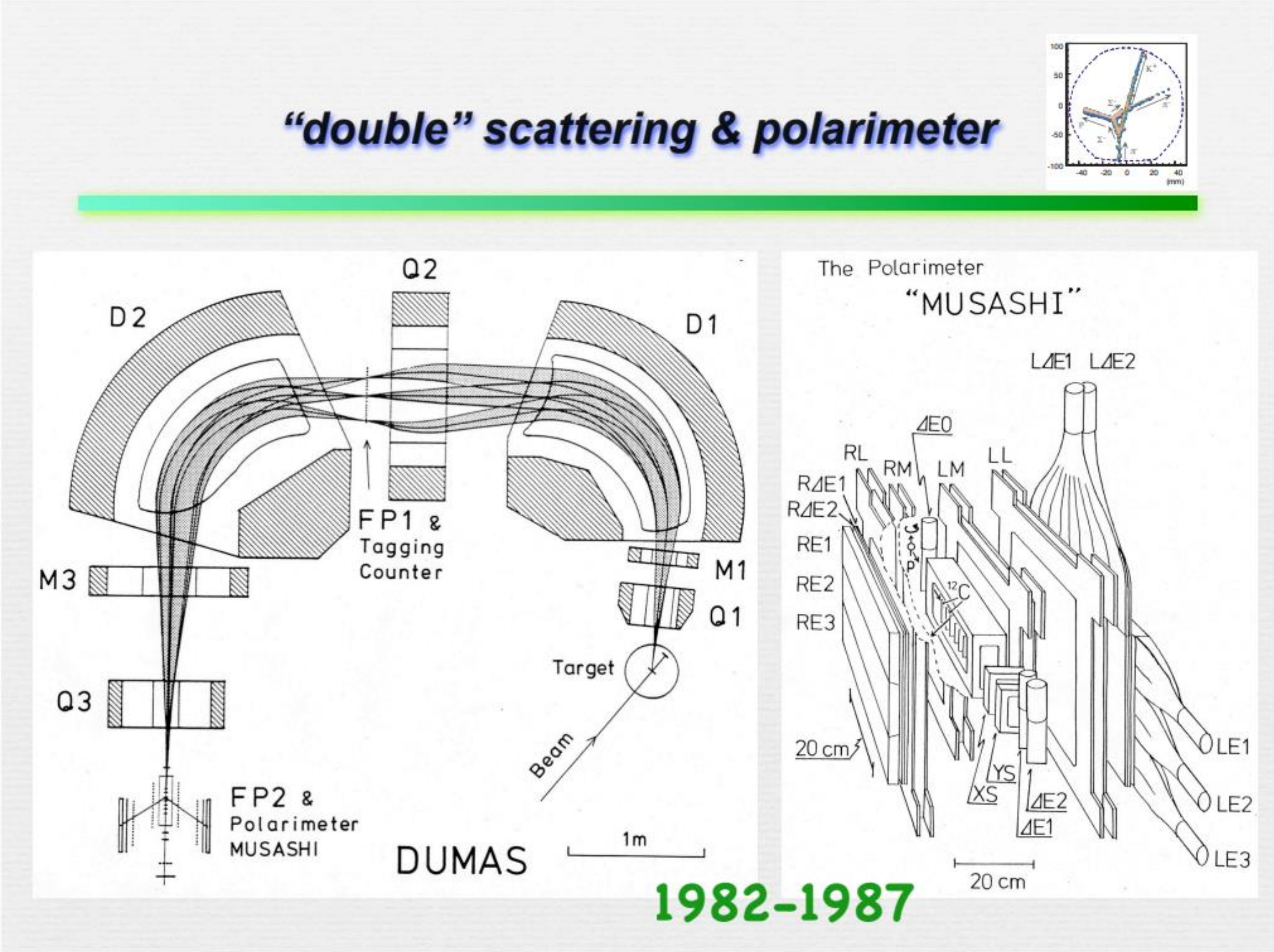
DUMAS/MUSASHI -> Low energy pEDM polarimeter

Osaka's MUSASHI polarimeter

- Can we create a system like this which preserves the stored beam with newer technologies.

- Can we use a secondary beam, using a DUMAS style spectrograph to choose a specific energy and remove to from the stored beam into a polarimeter.

- Can we produce a reasonable cost and complexity system with 2π azimuthal coverage and good acceptance.

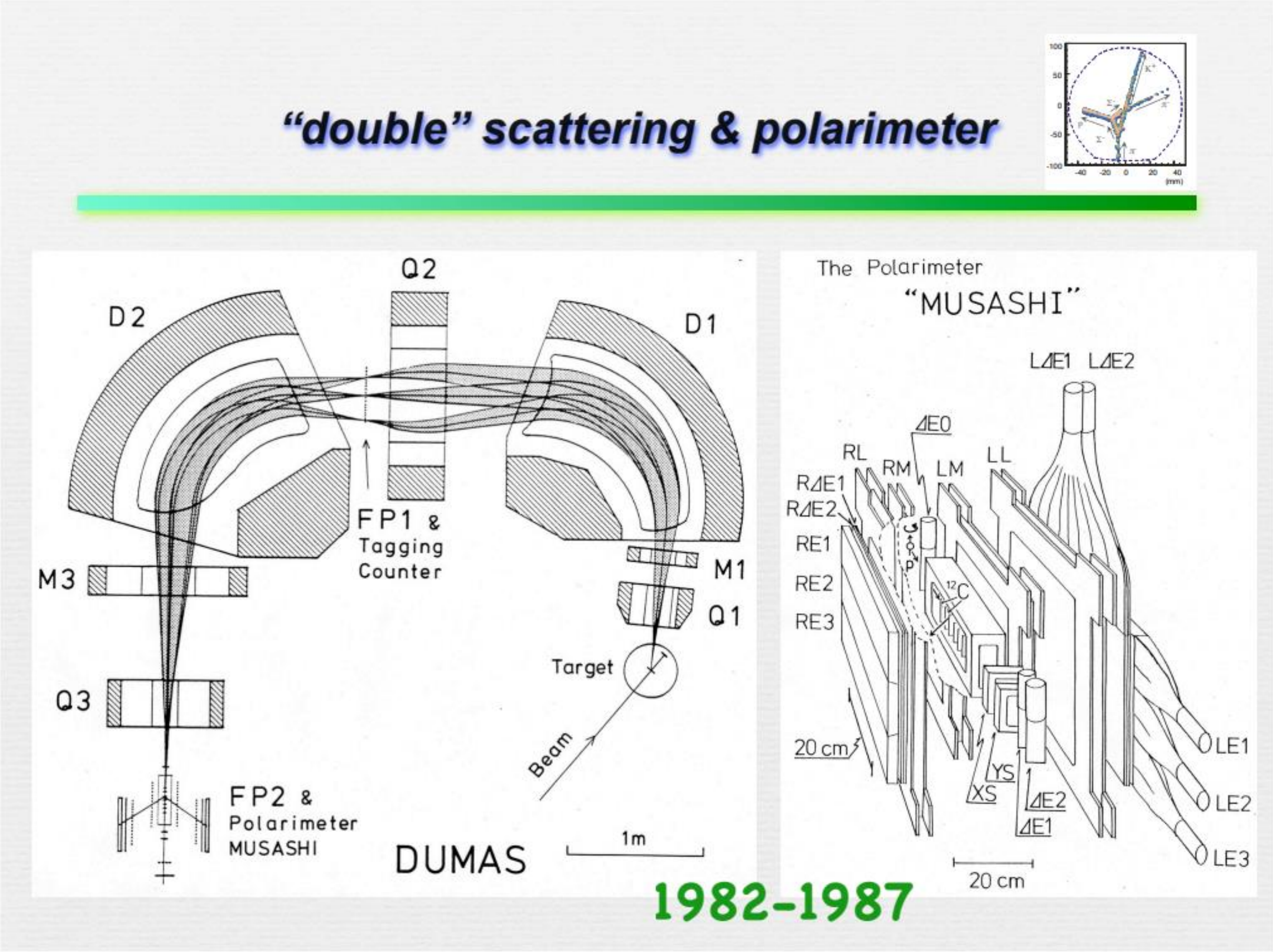


DUMAS -> Low energy pEDM polarimeter

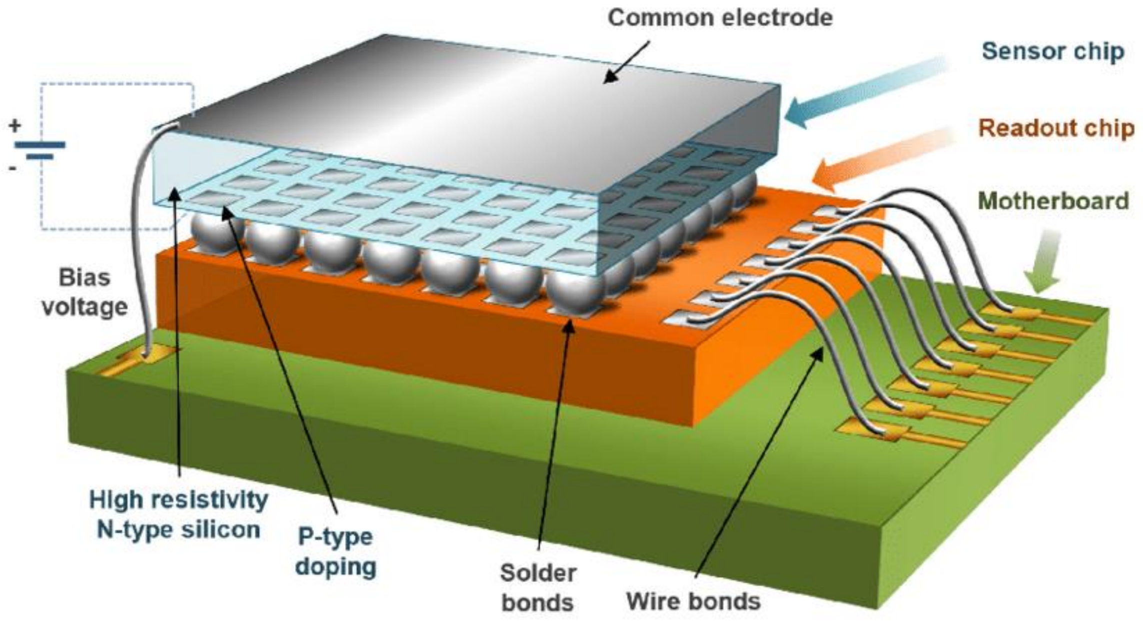
- Would a silicon based polarimeter be compatible with high vacuum, are there any stray fields that might interfere with the EDM experiment.

- Do the lower energies (30-45 MeV) involved in the prototype ring pose any other issues such as material budget/scattering.

- Do we introduce any systematic errors/ effects.



Hybrid Detectors

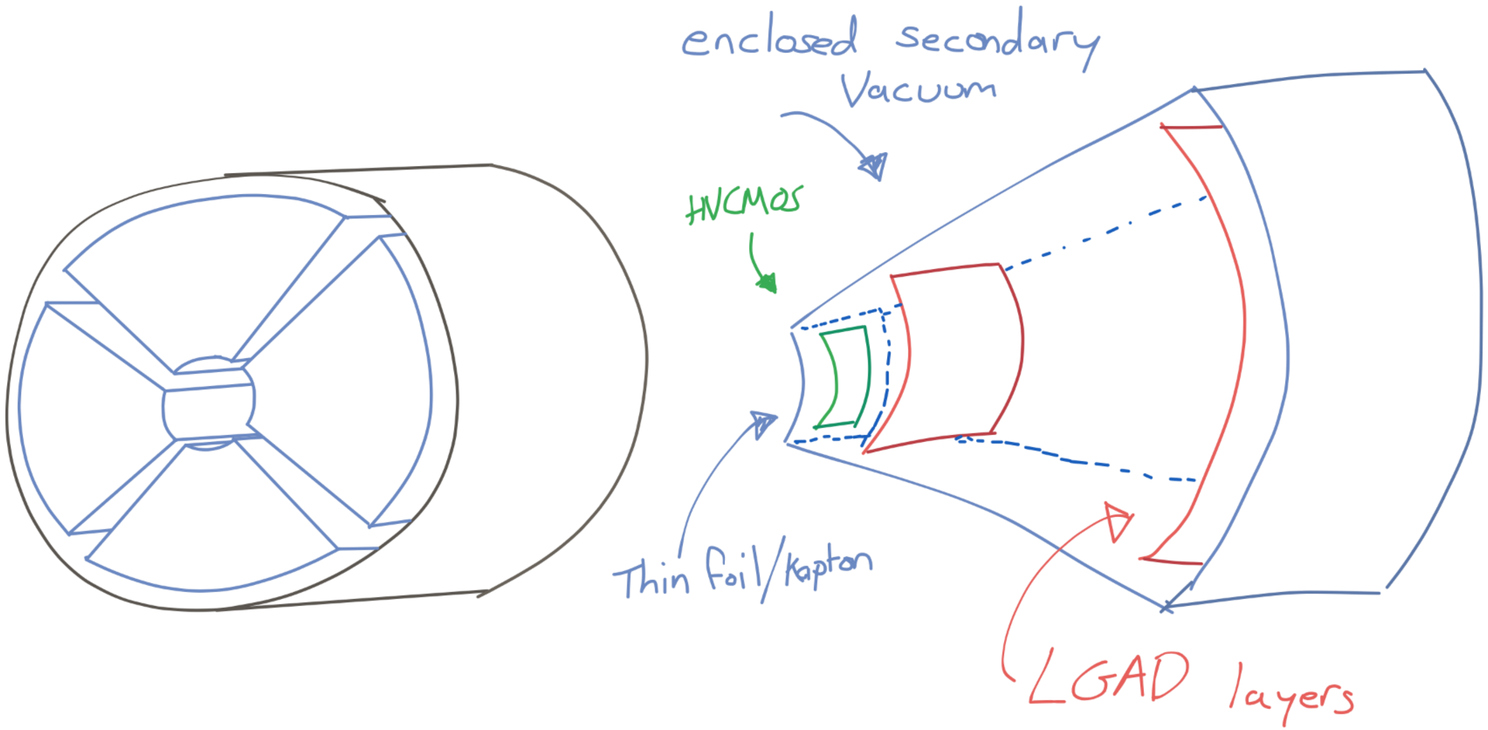


https://www.researchgate.net/figure/The-hybrid-semiconductor-device-Timepix-Platkevic-2014-Urban-et-al-2017_fig1_320267688

- Complex signal Processing
- Radiation hard ($5x10^{15}$ n_{eq}/cm^2)
- High efficiency
- Pixel pitch constrained by bump bonding size

- Large material budget
- Complex module production
    - - Bump-bonding / flip-chip
    - - Expensive and time consuming

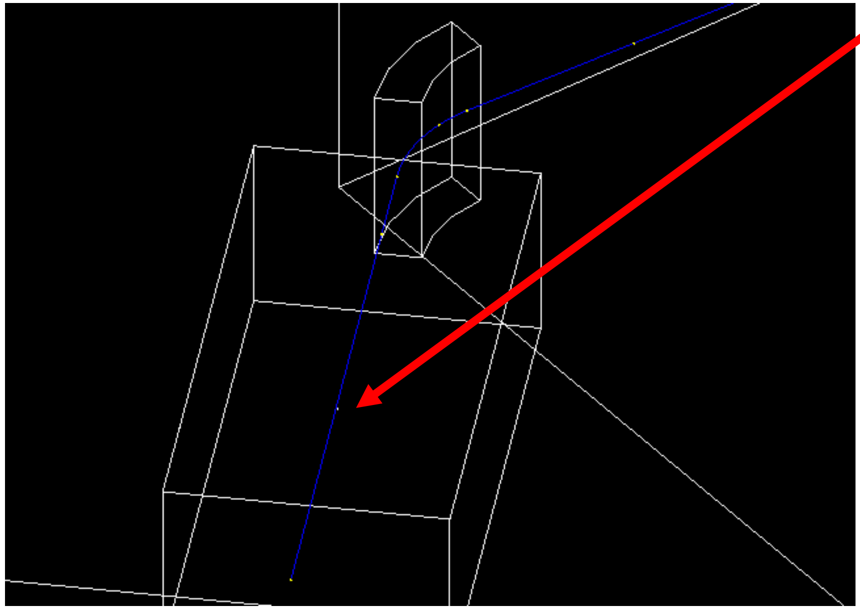
Potential modular design for strong UHV constraints

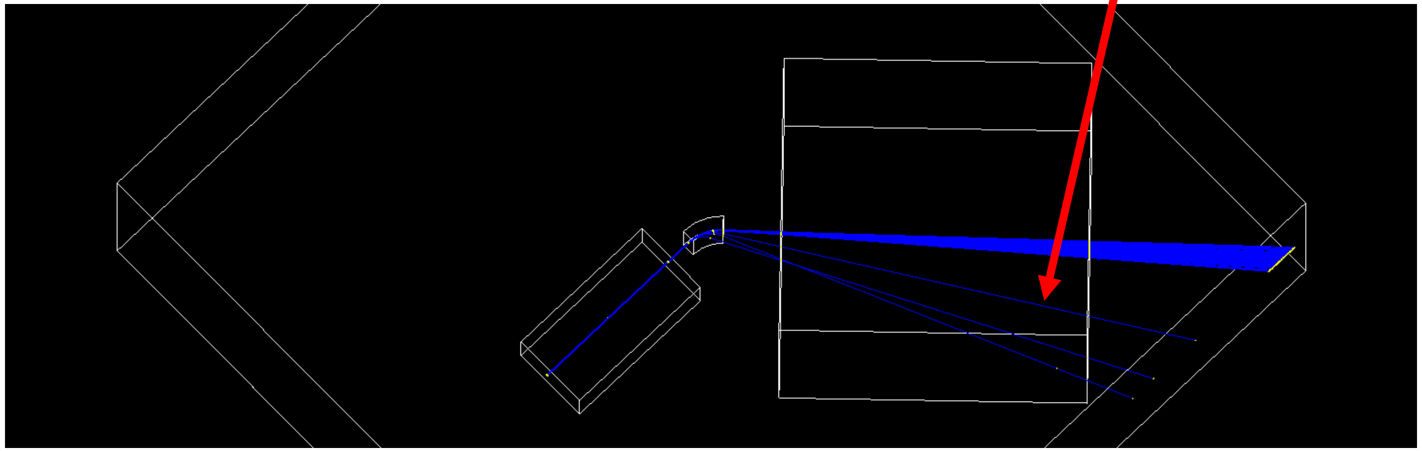


Secondary beam polarimeter via pellet target.
– Influence on primary beam

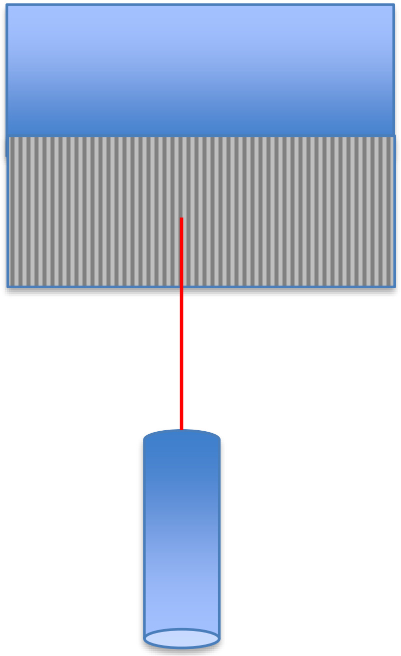
Sampled particles
- Need collimating

Tiny carbon pellet





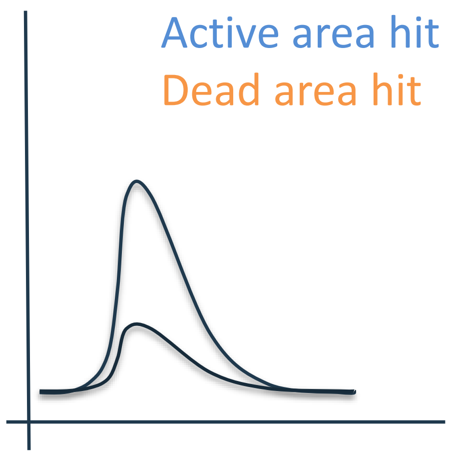
Test 0

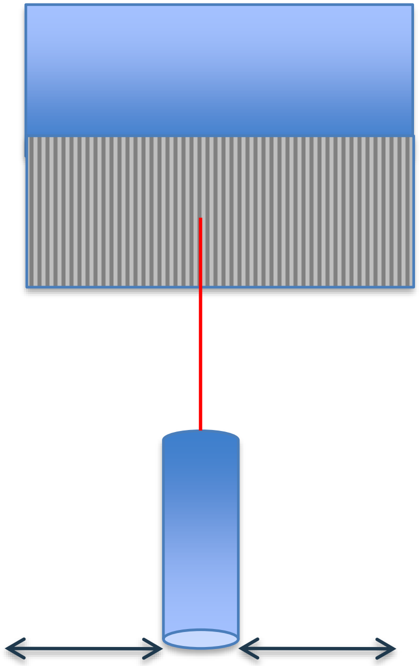


<u>Detector response:</u>

- Do silicon detectors work properly in UHV.
- Outgassing, cooling, material & structure considerations.

Test 1

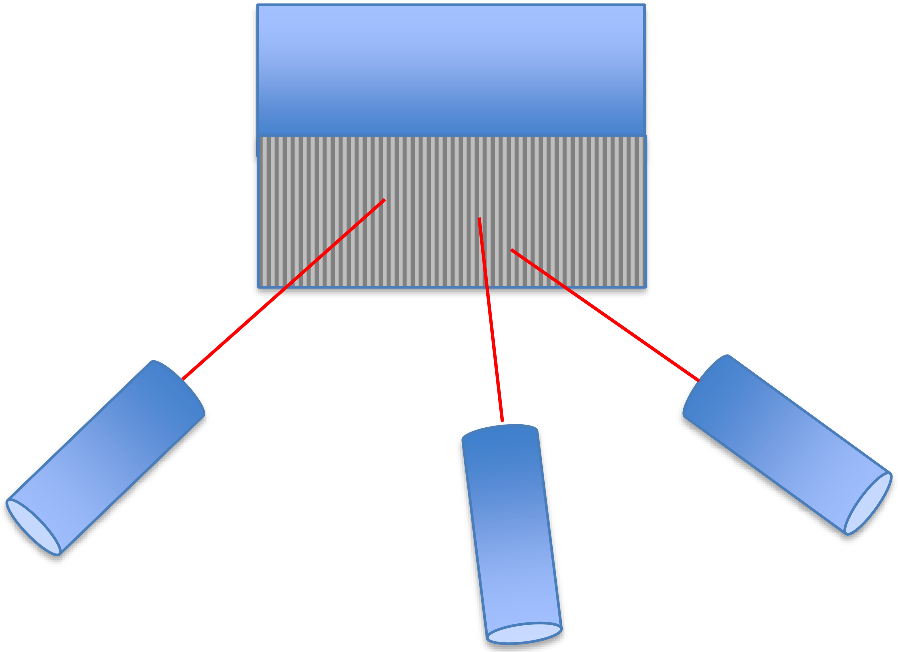




Dead area response:

- Provides information about dead area effects

Test 2

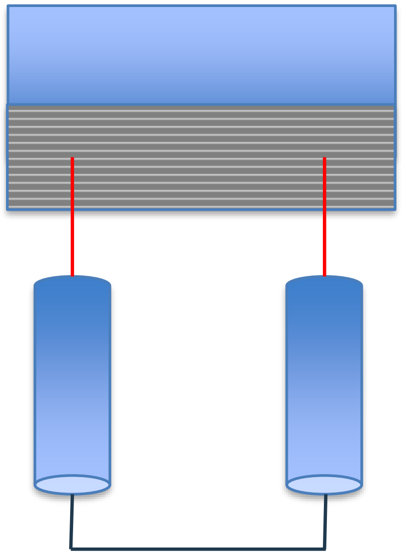


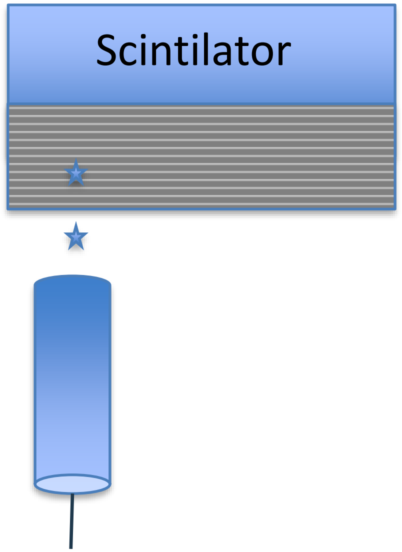
May need to remove backside metalization in a section to do this test, using laser from the rear side of the sensor

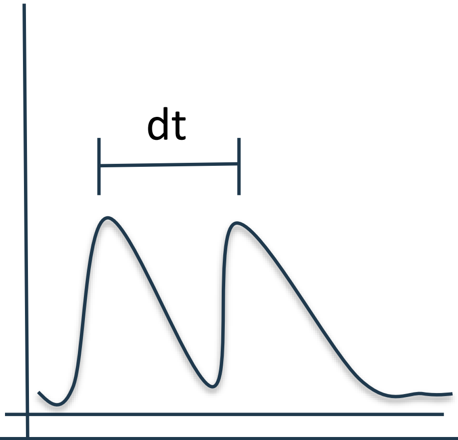
<u>Cluster size given input angle</u>

- Provides information about dead area effects.
- Does being at an angle alleviate dead area effects?

Test 3

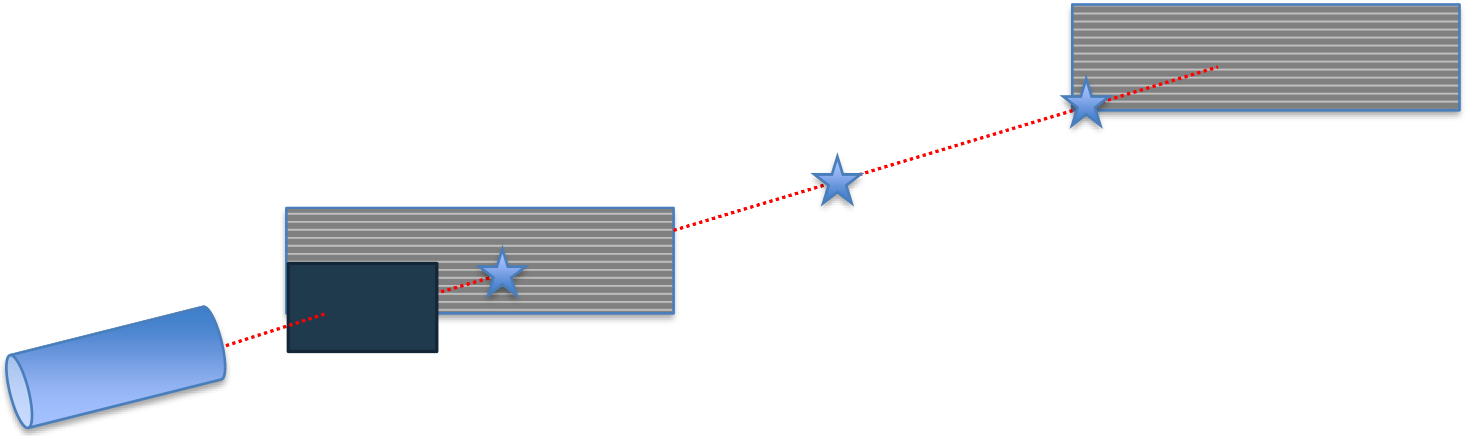






Can position along strip be measured by a delay in signal?
Could this be useful when combined with another perpendicular strip?

Test 4



Time of flight energy measurement

- HVCMOS and LGAD layers for time of flight energy measurement.
- Potential to configure system into a test beam telescope.
- Can rotate system around scattering target.