Towards a Low Background CYGNUS-10

Neil Spooner (University of Sheffield)

- Quick update on DRIFT
- Electron-NR discrimination simulations at low energy
- Intrinsic backgrounds and passive shielding
- Simplified low background readout (GEM-wire hybrid)

Reporting work mainly by:
Warren Lynch, Anthony Ezeribe (Sheffield)
Tiziano Baroncelli (Melbourne)

DRIFT Update

- Long process to transfer to new Boulby lab now done

  HV feed damaged and replaced

  New water n-shield and source delivery

Operational with CF_4:CS_2:O_2

New BDT analysis underway to increase efficiency and lower energy threshold to 12.5 keV_{ee}

Simulation of Low Energy e^- background rejection

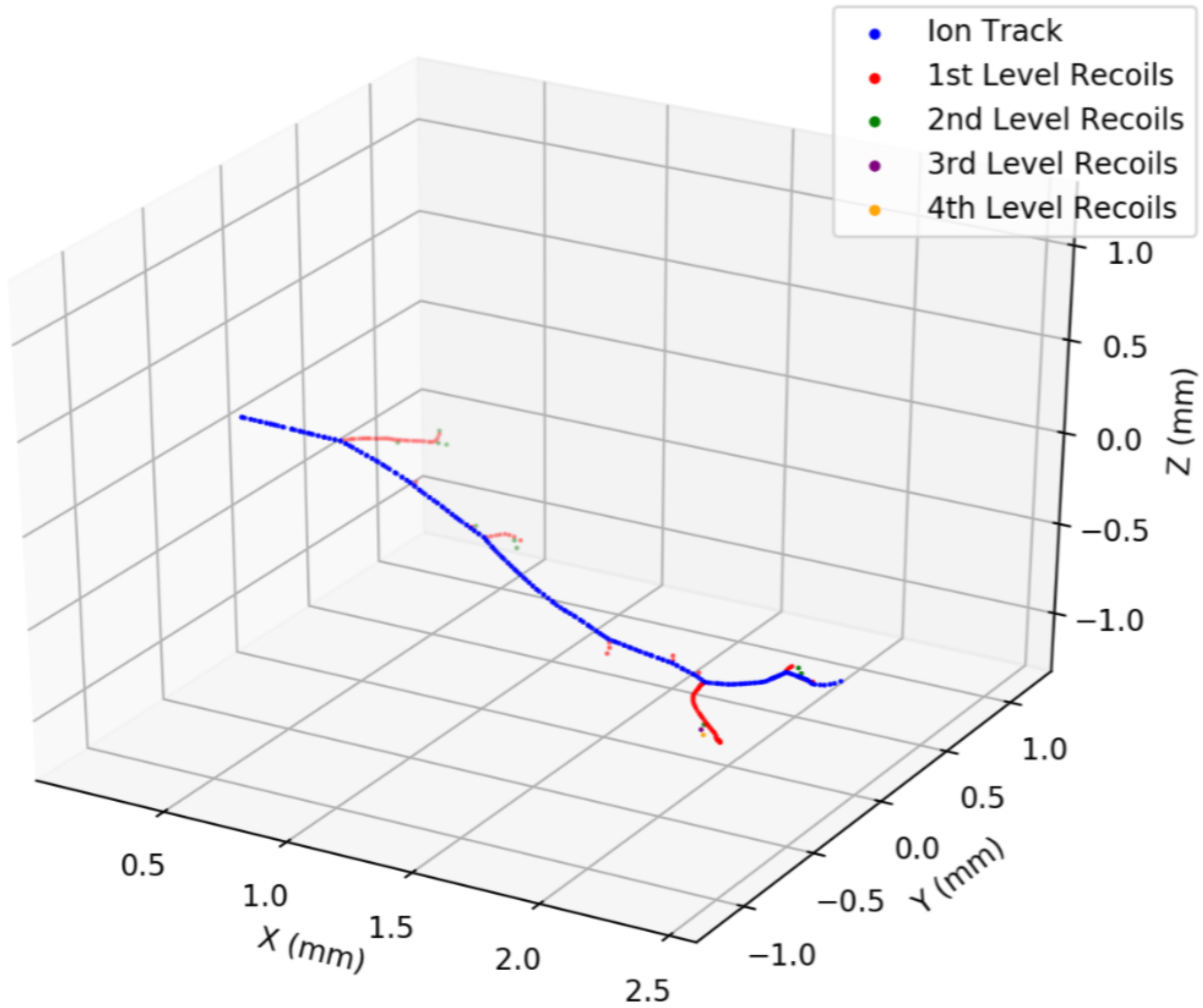
- Aim is CYGNUS-10 design with low WIMP mass capability
- Intrinsic gamma background is a severe challenge below 10 keV_{ee}
- Supplement work by Hawaii and elsewhere
- TRIM for nuclear recoils, GEANT4+PAI for e^- recoils
- Use of realistic position resolutions and drift distances
- Focus on 20 Torr SF_6
- Examine position resolution 600 μm

Track Generation

Nuclear recoils created using TRIM

Up to 4 levels of secondary recoils included

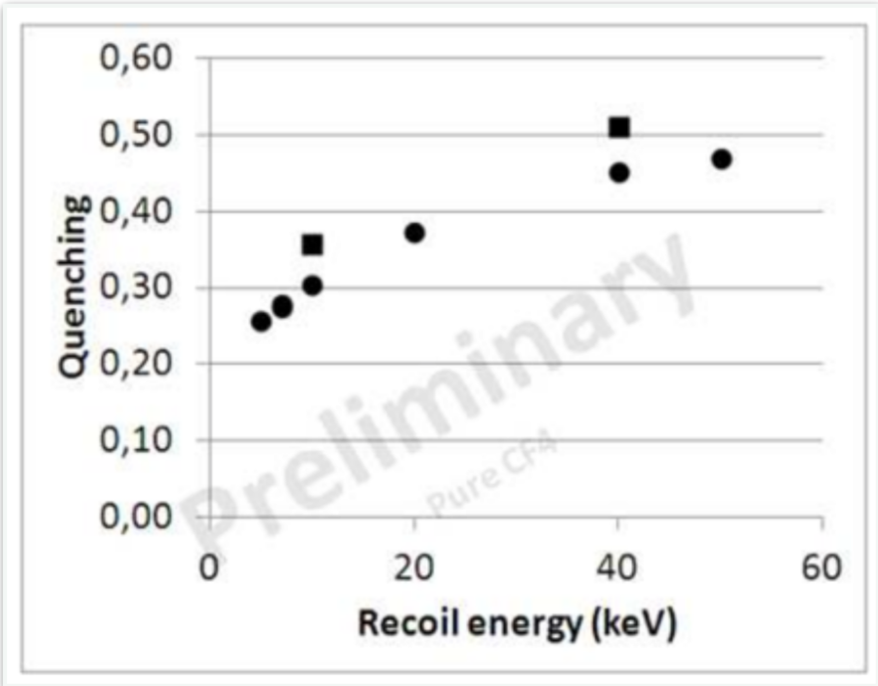
Electron recoils created with GEANT4 PAI Model



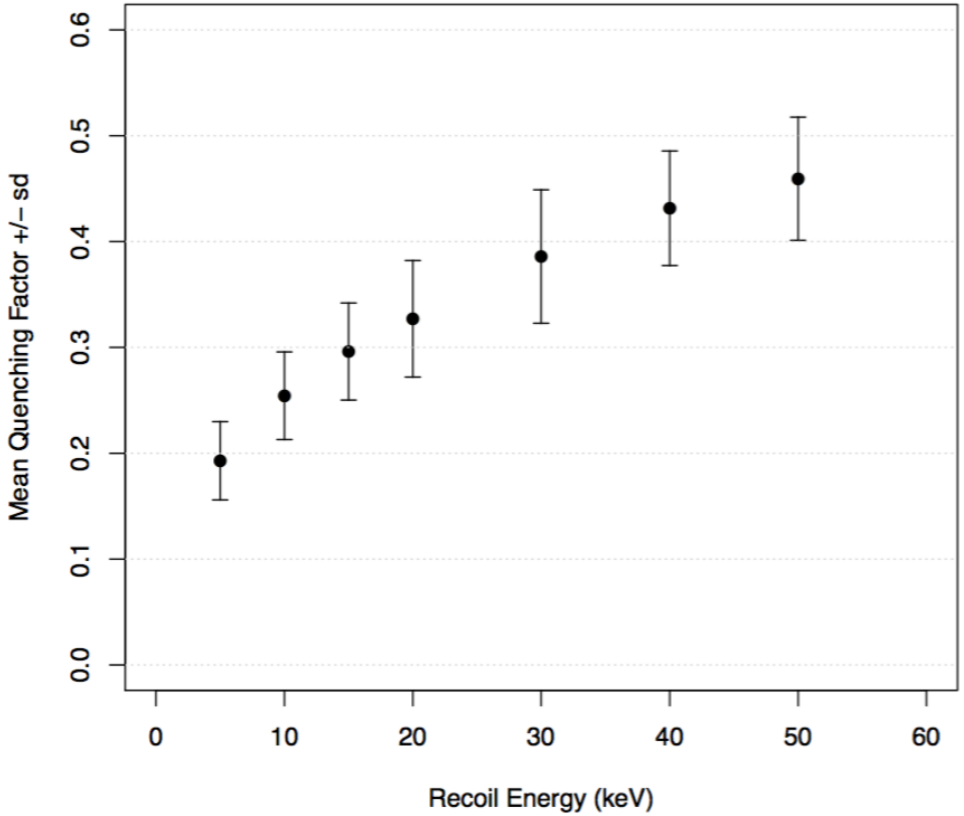
50 KeV_r fluorine track
20 Torr SF_6

Simulated Quenching

Fluorine recoils in 50 mbar CF_4



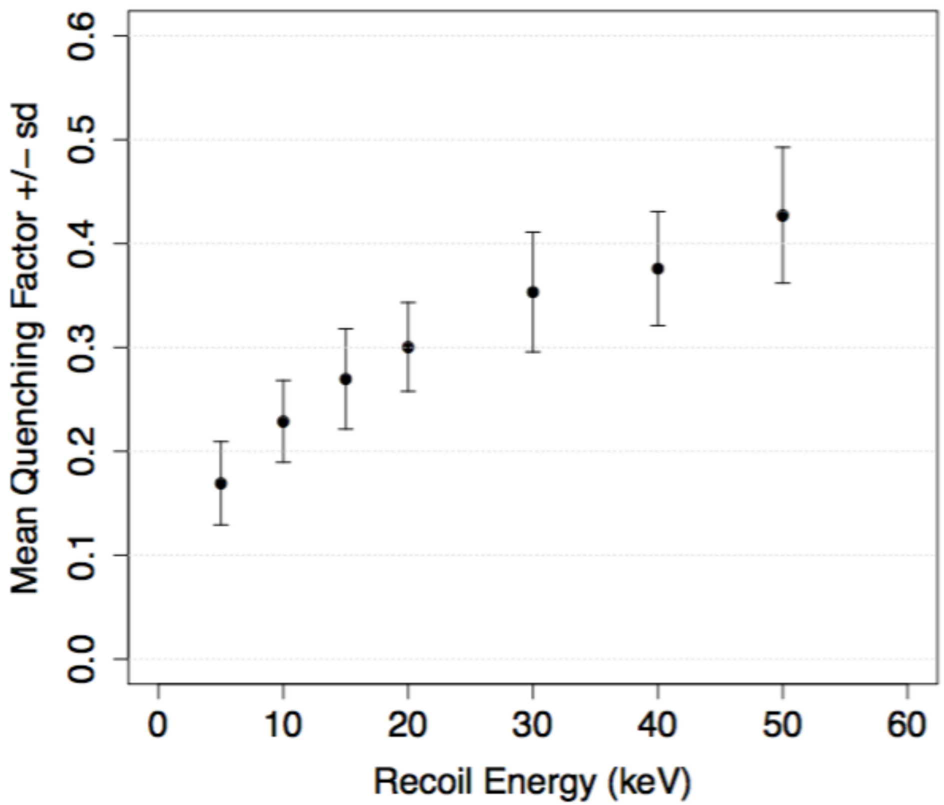
MIMAC Measurement
Circles = Fluorine



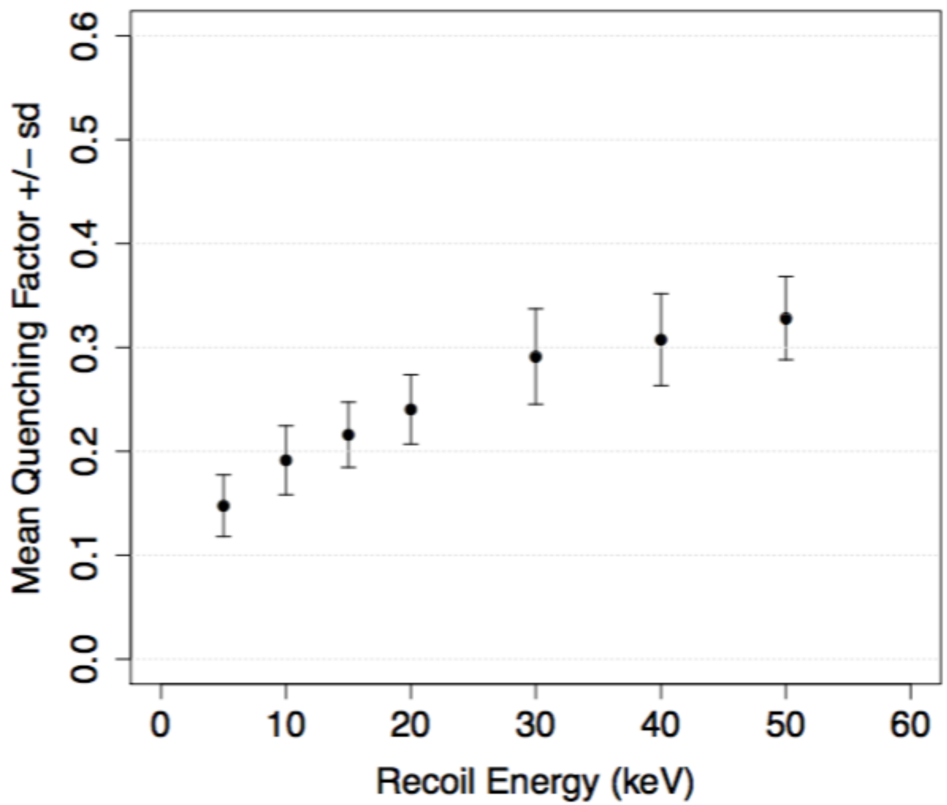
Simulation result

Simulated Quenching

Recoils in 20 Torr SF_6



Fluorine



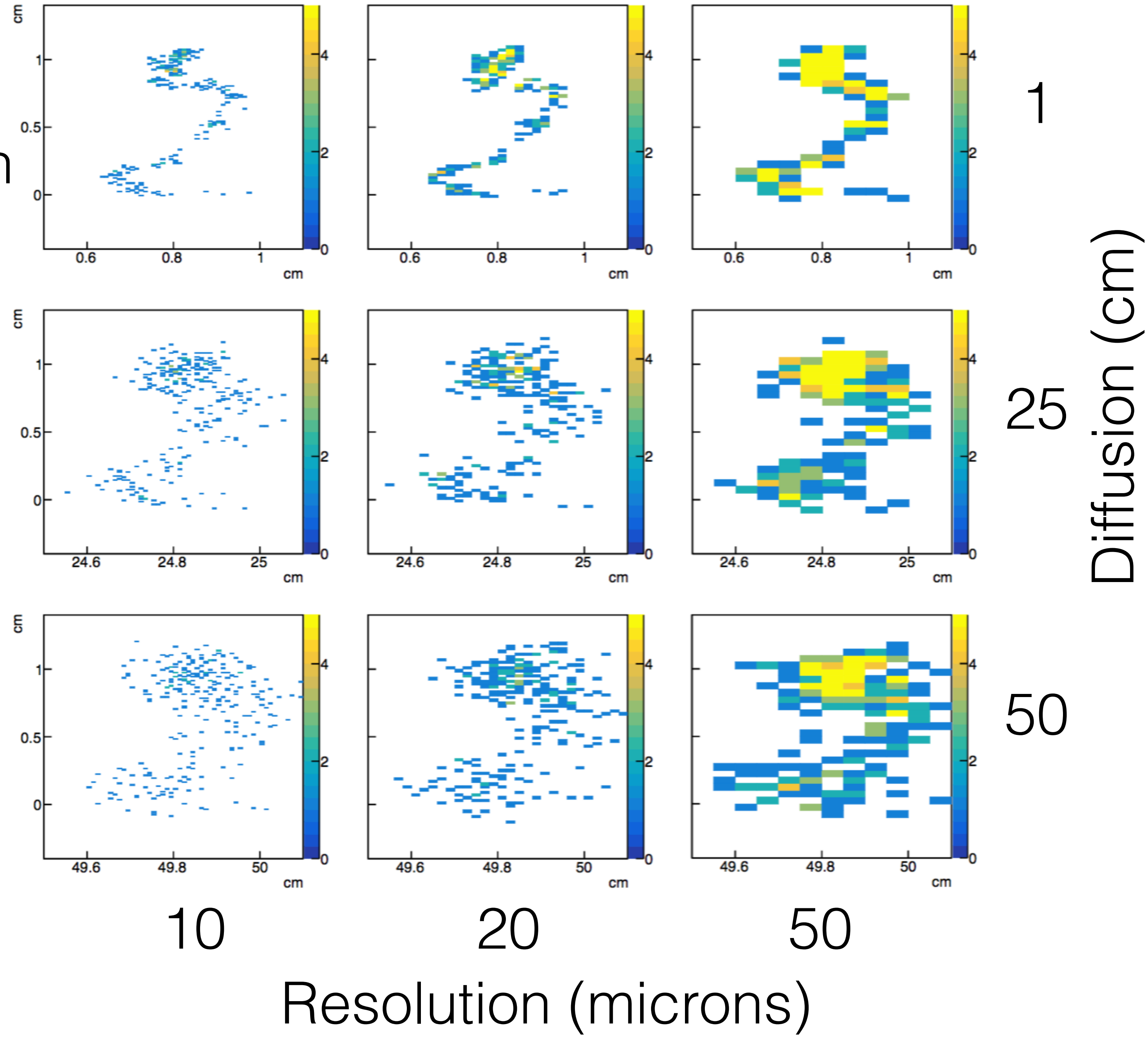
Sulfur

Diffusion and Resolution

10 keV electron in 20 Torr SF_6

Diffusion using Garfield++

Resolution using 3d binning



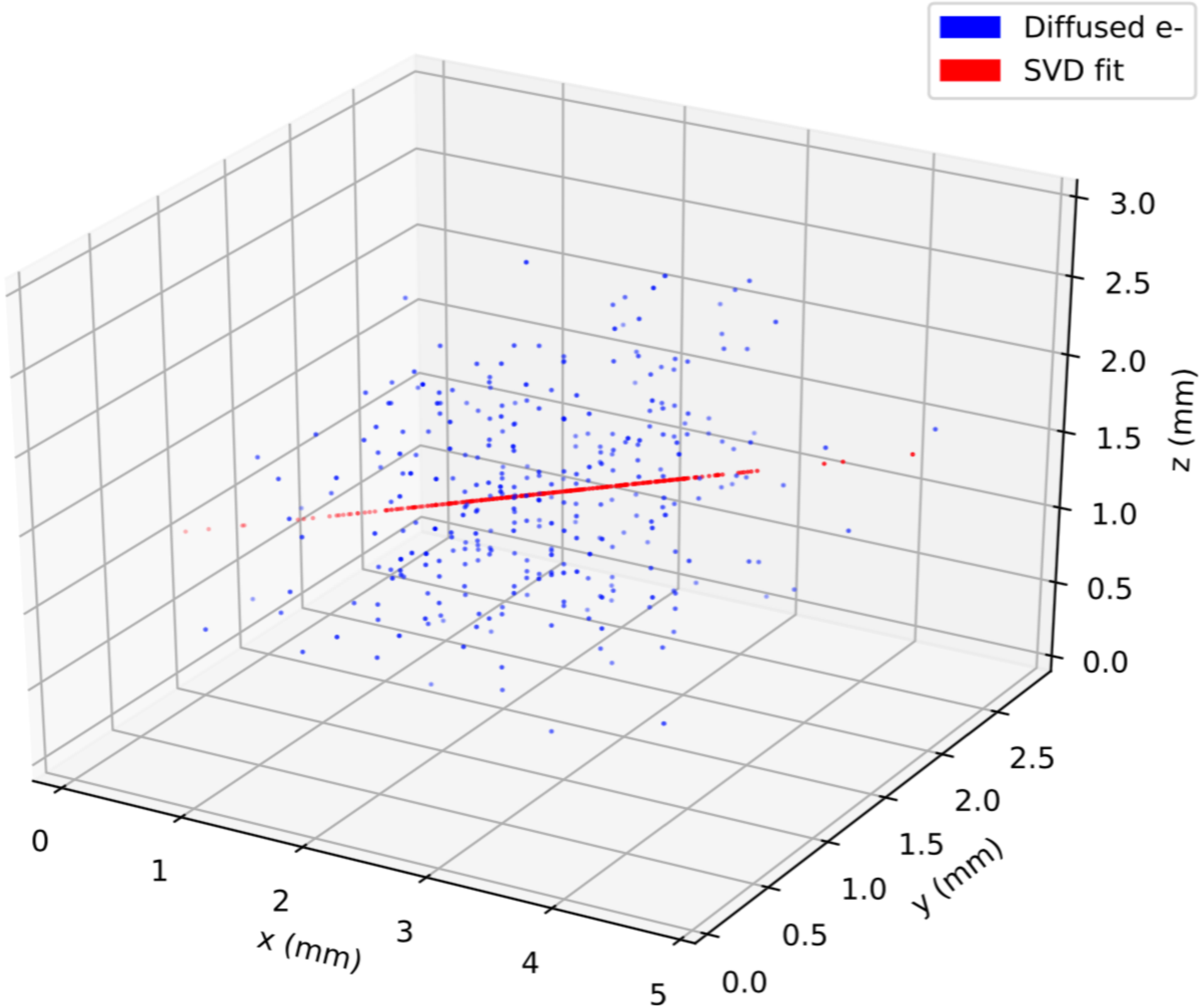
Line Fit to Data

10 keV_{ee} fluorine, in 20 Torr SF_6

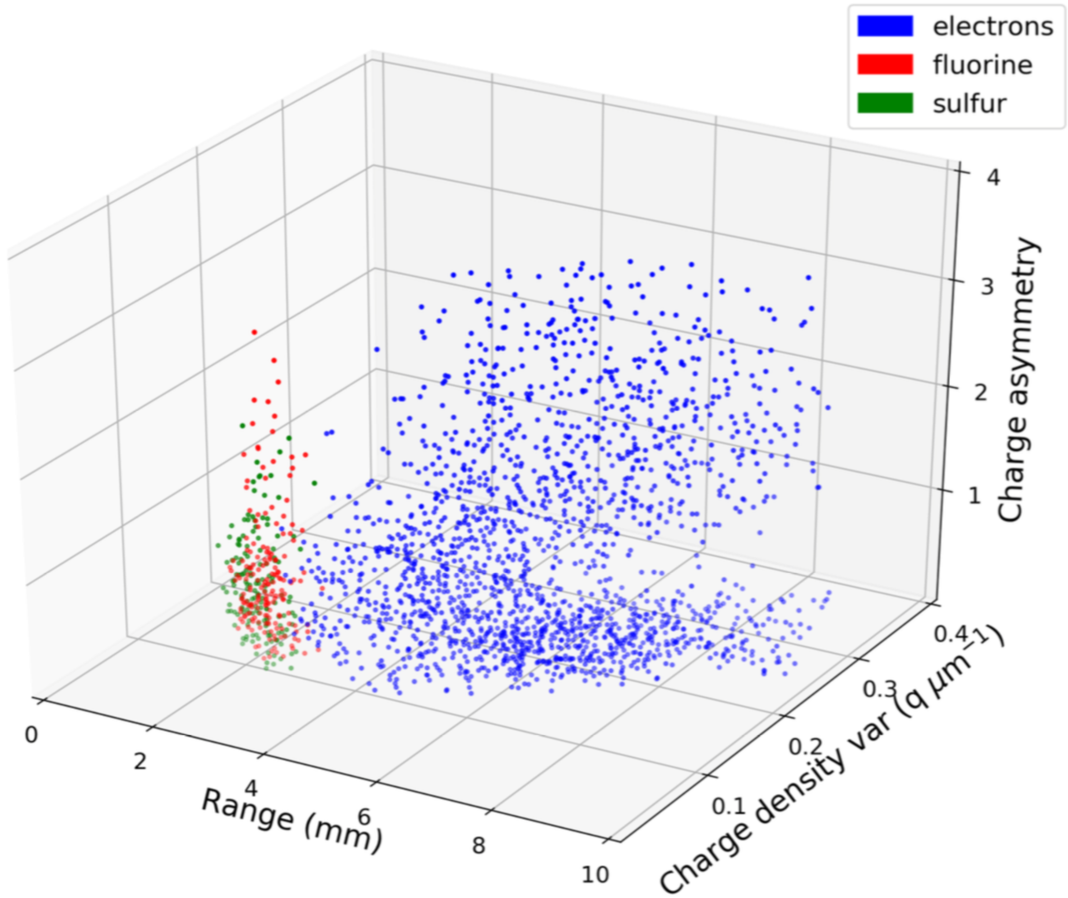
25 cm diffusion

100 μm resolution

Singular Value Decomposition (SVD) used to fit line in 3d.



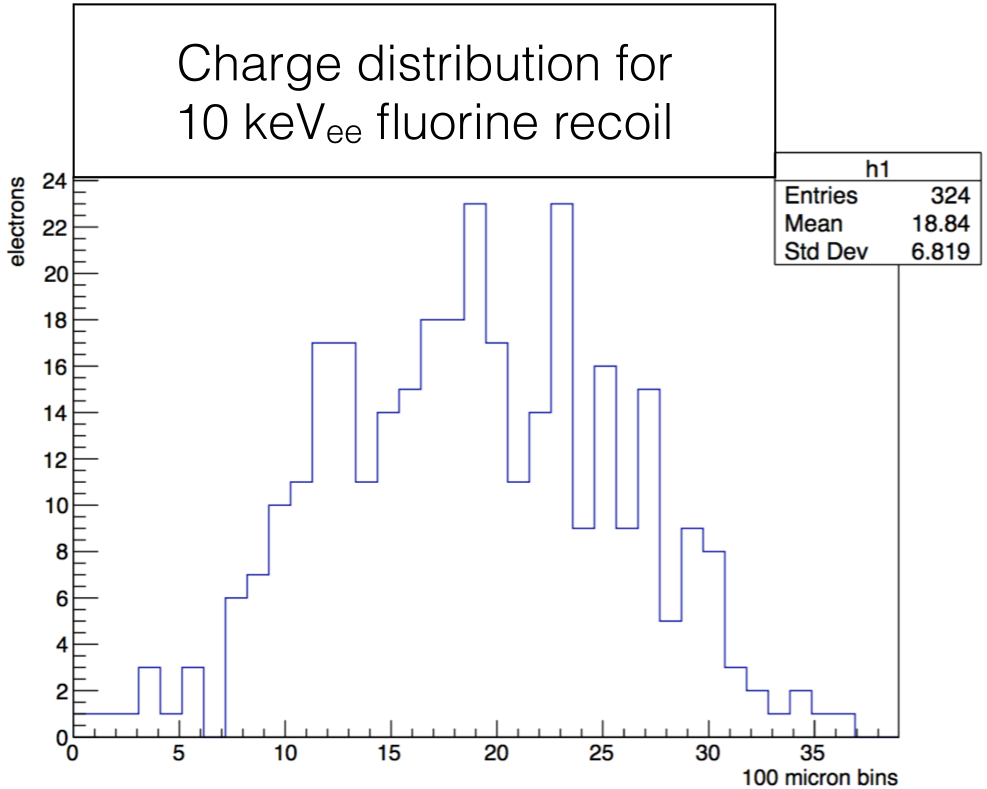
Recoil Parameters



100 μm spatial resolution

3 fit parameters:

- Range of fitted line
- Charge distribution
- Charge asymmetry



Results

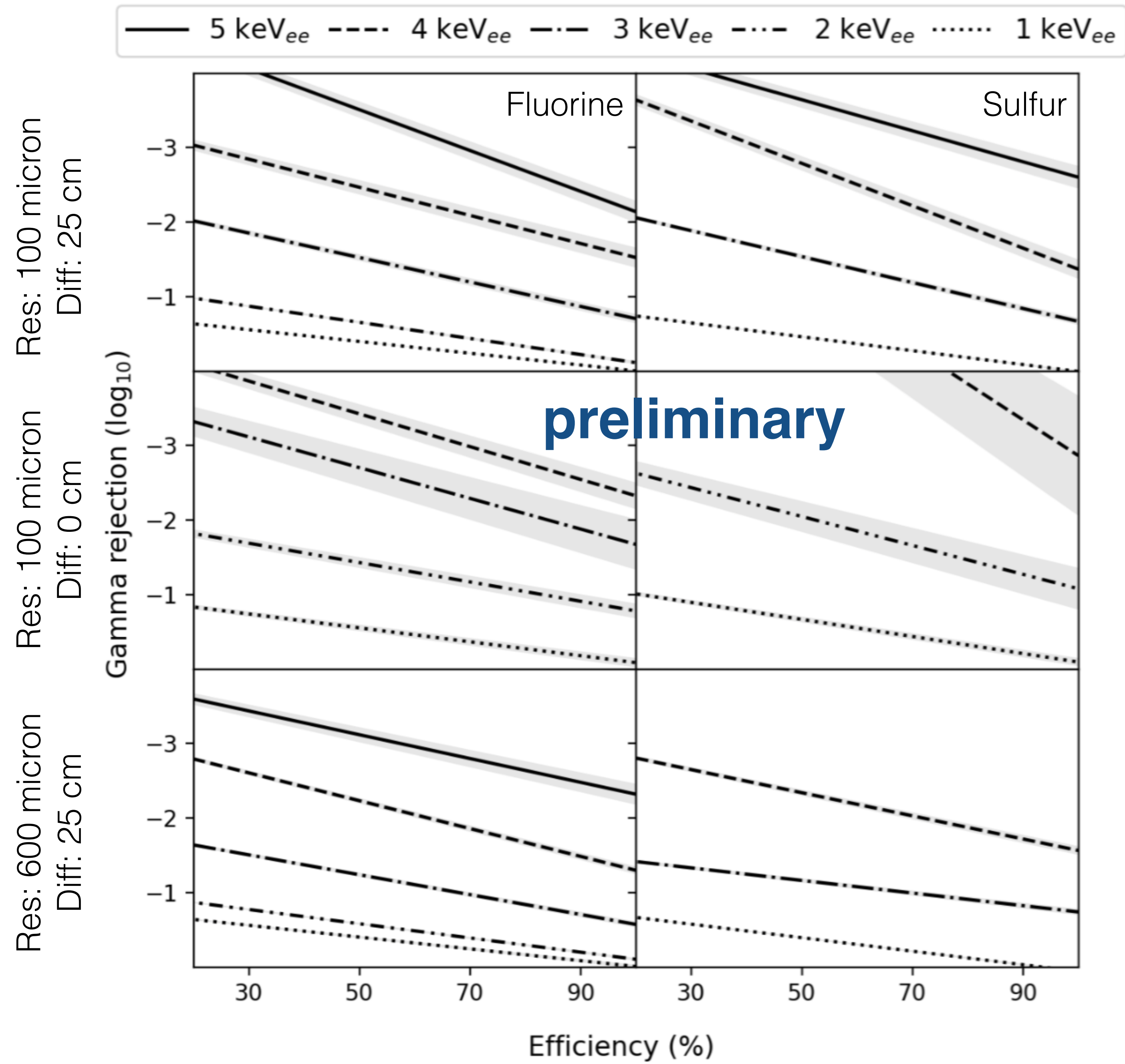
Rejection vs Efficiency

Recoils per energy bin:

~10^5 electrons,
~200 fluorine,
~200 sulfur,

Table : Efficiency at which all background was rejected for 100 micron resolution 25 cm diffusion

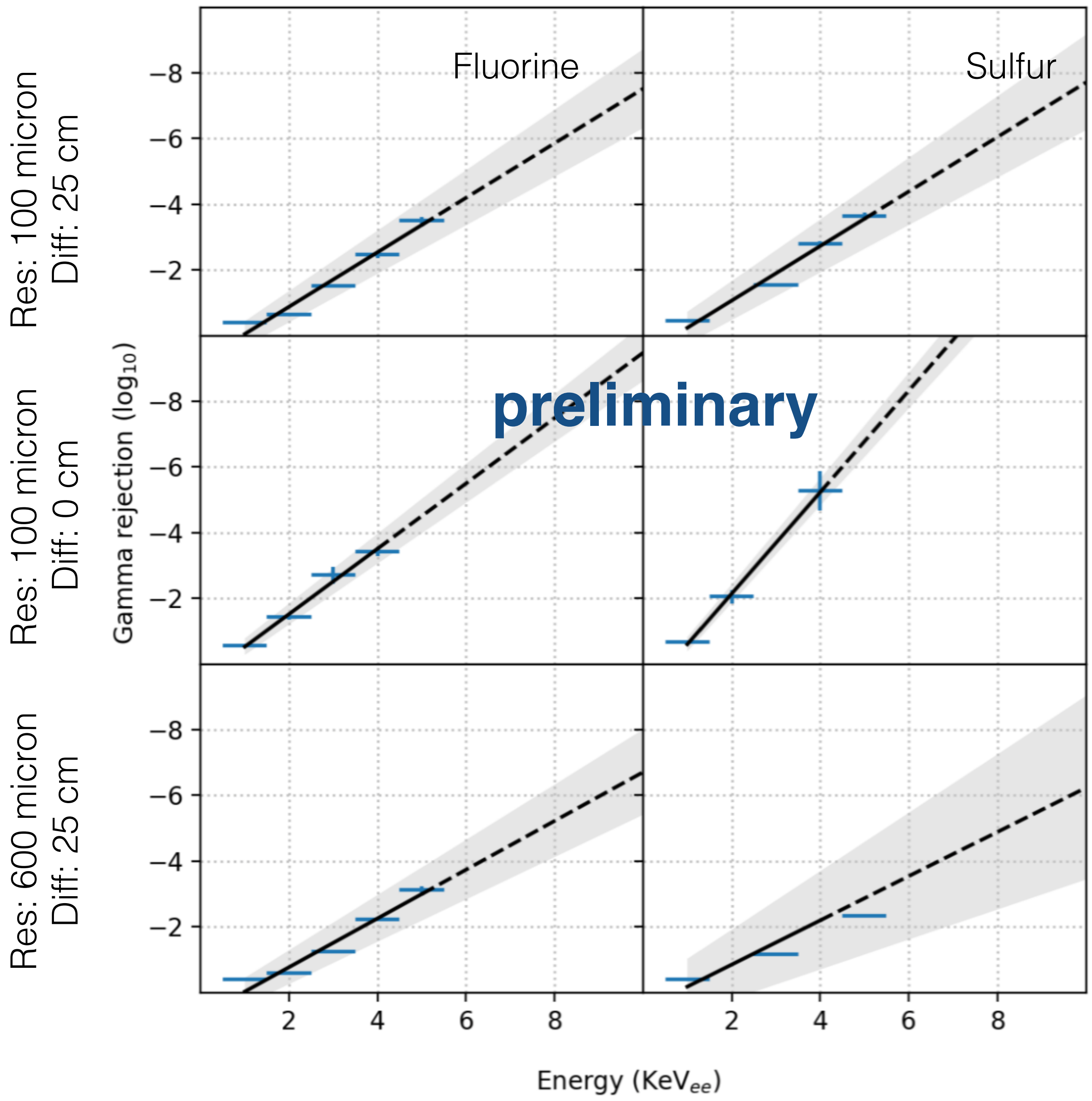
Energy (keV_{ee})		7	8	9	10
Efficiency (%)	F	69	75	75	100
	S	93	99	100	100



Results

Rejection vs Energy at 50 % efficiency

Solid line = fit to data
Dashed = prediction
Blue = data and error



Conclusions on Rejection

preliminary

- ~95% rejection at 2 keV, 50% eff., zero diff., 100 μm
- ~99% rejection at 4 keV, 50% eff., 25 cm diff., 100 μm
- ~99% rejection at 4 keV, 50% eff., 25 cm diff., 600 μm

Demonstrates no need for better than ~600 μm for 25 cm drift
i.e. diffusion dominated

- ~10^4 at 6 keV_{ee} - provides benchmark for e^- background
- This is with 3 parameters + BDT. Expect to do better….

CYGNUS-10 Background

- $\sim 10^4$ at 6 keV_{ee} - provides benchmark for e^- background
- Goal is < 1 neutron induced recoil per year in 1-10 keV_{ee}
- Goal is < 1 e^- background per year in 1-10 keV_{ee}

↓

- Design must achieve intrinsic electron background rate of $\sim < 10^4$ per year in 1-10 keV_{ee}
- Assume 10 m^3 fiducial volume, -ve ion for fiducilisation
- Assume Boulby Rock

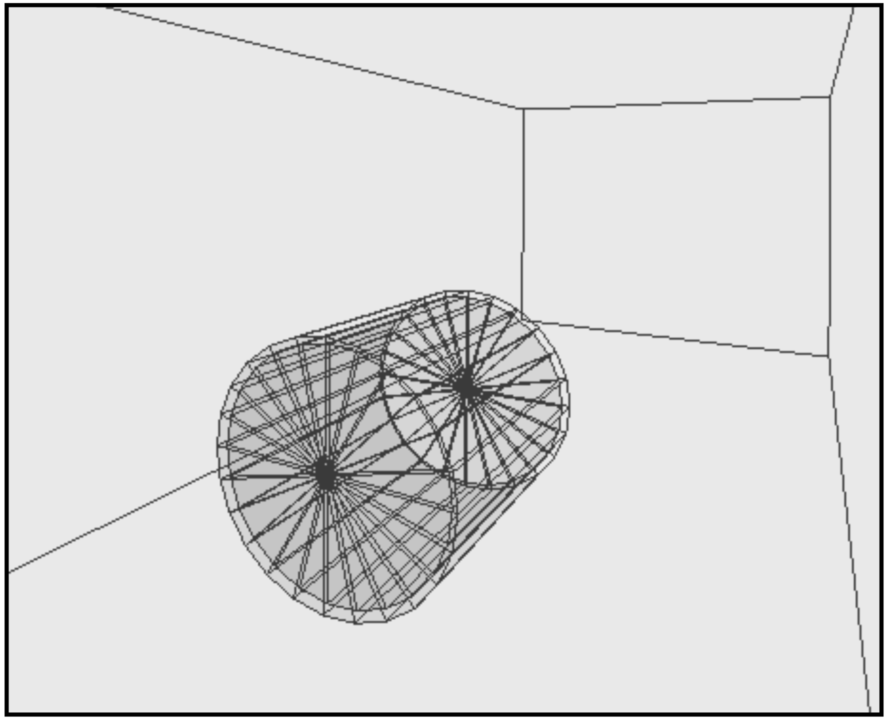
Vessel Geometry

Example engineered design (Tiziano):

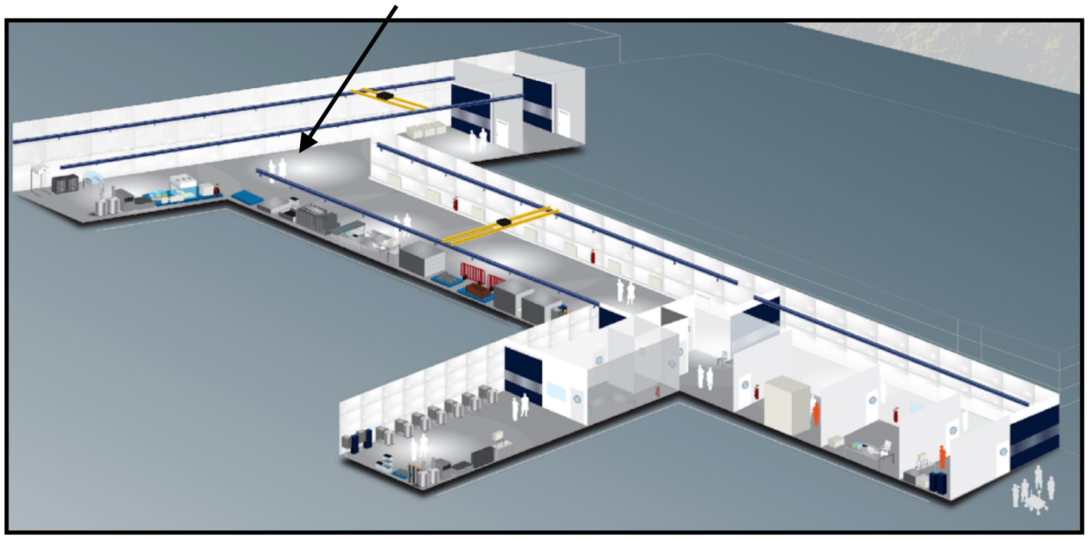
Cylindrical vessel made of 13 mm thick steel, 1.1 m radius, length (depends on internal shield thickness) ~ 2.5-3 m

Similar results for cubic design

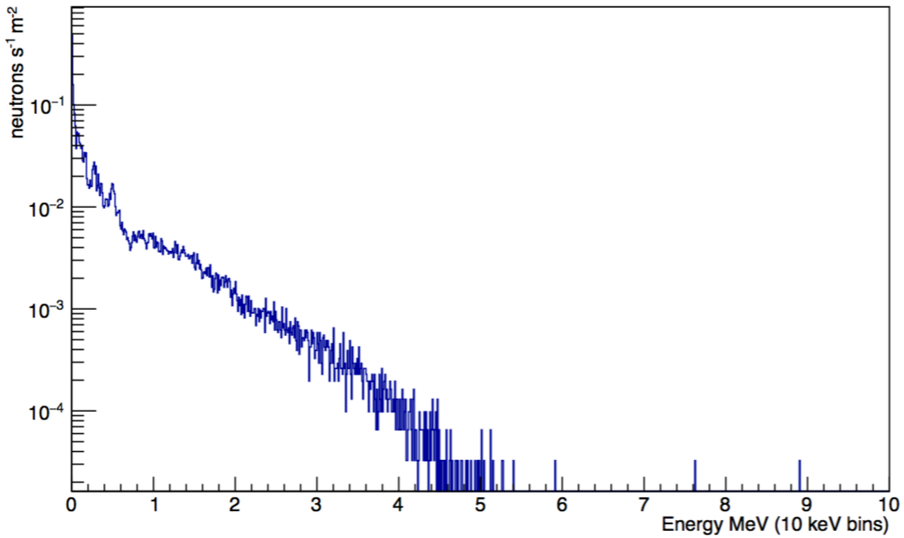
Assume best known steel background (LZ data)



Designed to fit Boulby LEC



Rock Neutron Background

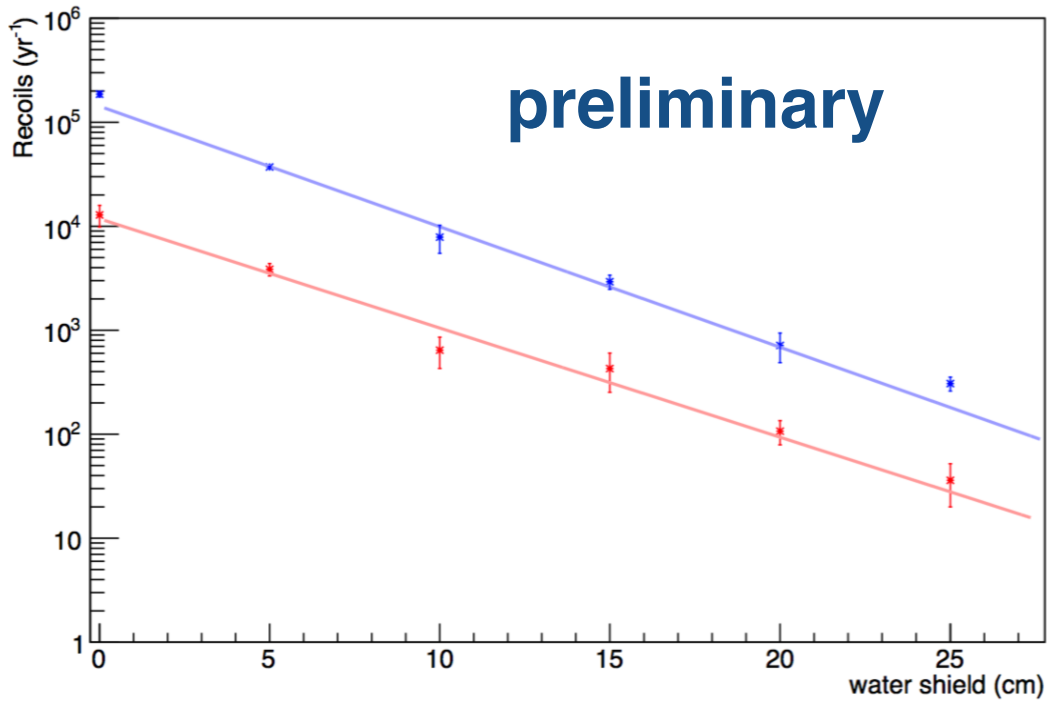


Salt rock surface energy spectrum from Sources4C

Gas (Torr)	Recoil Rate (yr^{-1})	Water Shield (cm)
SF_6 (20)	< 0.1	50
	< 1	40
+ He (740)	< 0.1	55
	< 1	45

Extrapolated results from line fits

Recoils yr^{-1} as a function of water shield thickness.
Red : 20 Torr SF_6
Blue : 20 Torr SF_6, 740 Torr He



Conclusion: ~55 cm passive water shield required

Vessel Internal Shielding

- Steel is too active, so install internal Cu shield

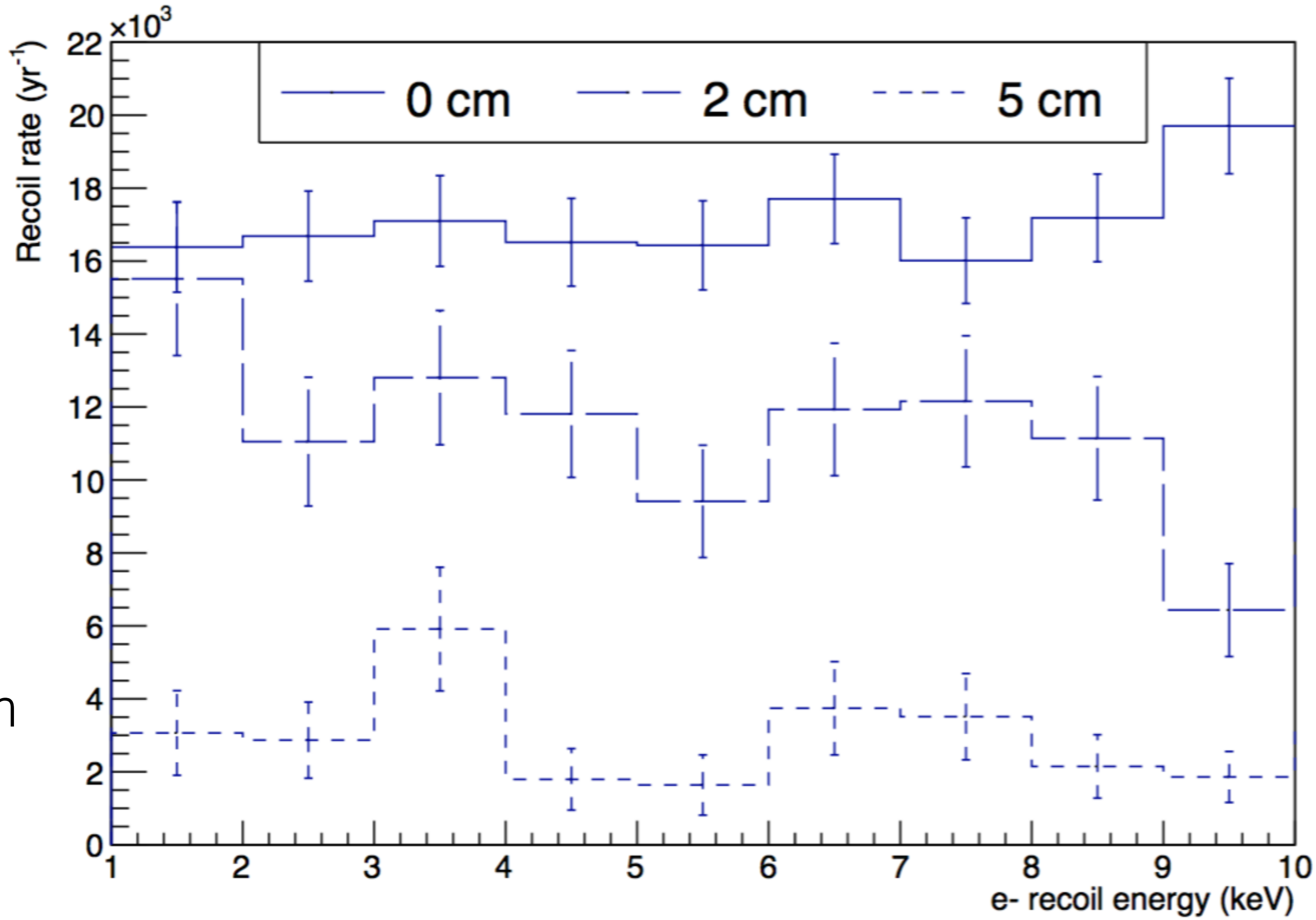
Gamma recoil in 20 Torr SF_6 for:

0 cm internal shield

2 cm internal shield

5 cm internal shield.

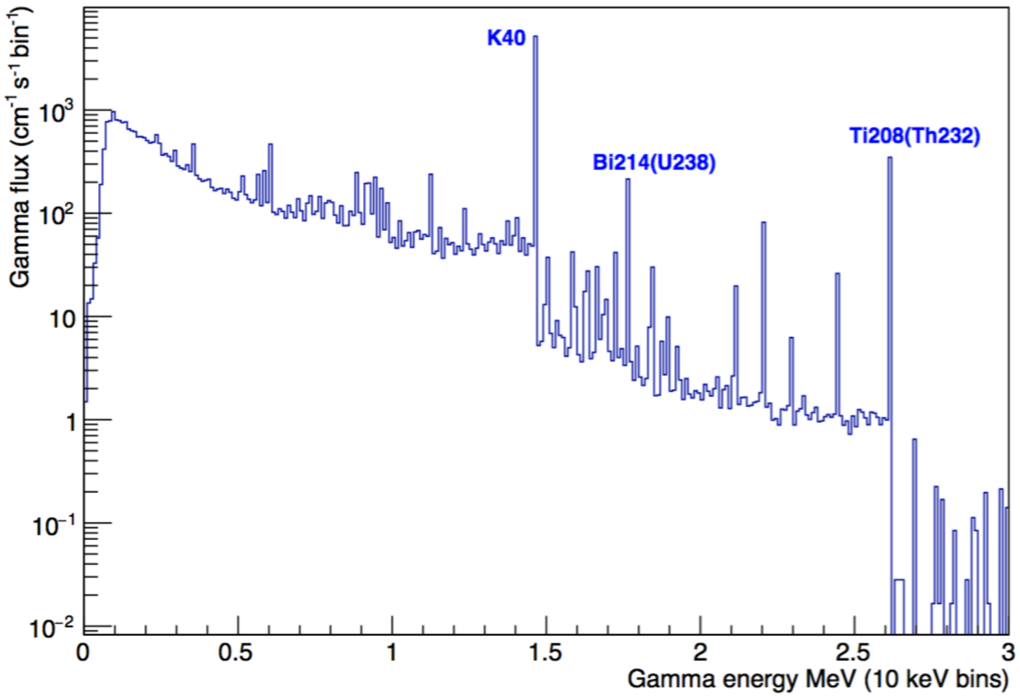
used U, Th, K from LZ collaboration (best seen)



Conclusion: ~5 cm passive internal Cu shield required

Vessel External Shielding

Rock gamma spectrum



External Shield added to vessel and internal shield until rock gamma background <10^4

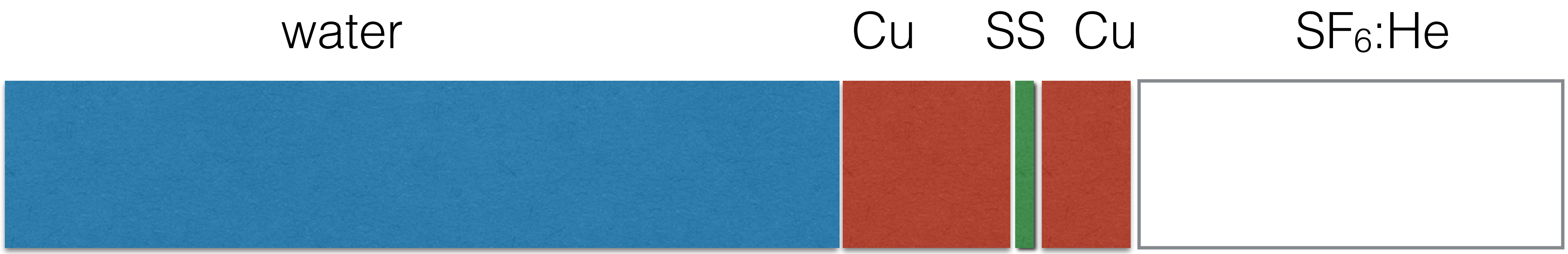
Total rate from rock, vessel and internal and external shielding

Gas	Pressure (Torr)	Internal shield (cm)	External shield (cm)	Water shield (cm)	Recoil rate (keV^{-1} yr^{-1})
SF_6	20	5	10	50	$4.3 \pm 1.0 \times 10^3$
SF_6+He	20+740	5	10	55	$7.1 \pm 0.4 \times 10^3$

Conclusion: ~10 cm passive external Cu shield required

Conclusions on Shield for CYGNUS-10

preliminary



Alternatives:

- All Copper vessel (has to be structural), no SS
- ?

This get's us to $<10^4$ per year neutron and e^- events from external sources…

Internal Detector Background

preliminary conclusion

- All current readout technology for CYGNUS-1000 except simple GEM+wire using known U, Th, K levels can not achieve $<10^4$ e^- per yr

(see CYGNUS paper)

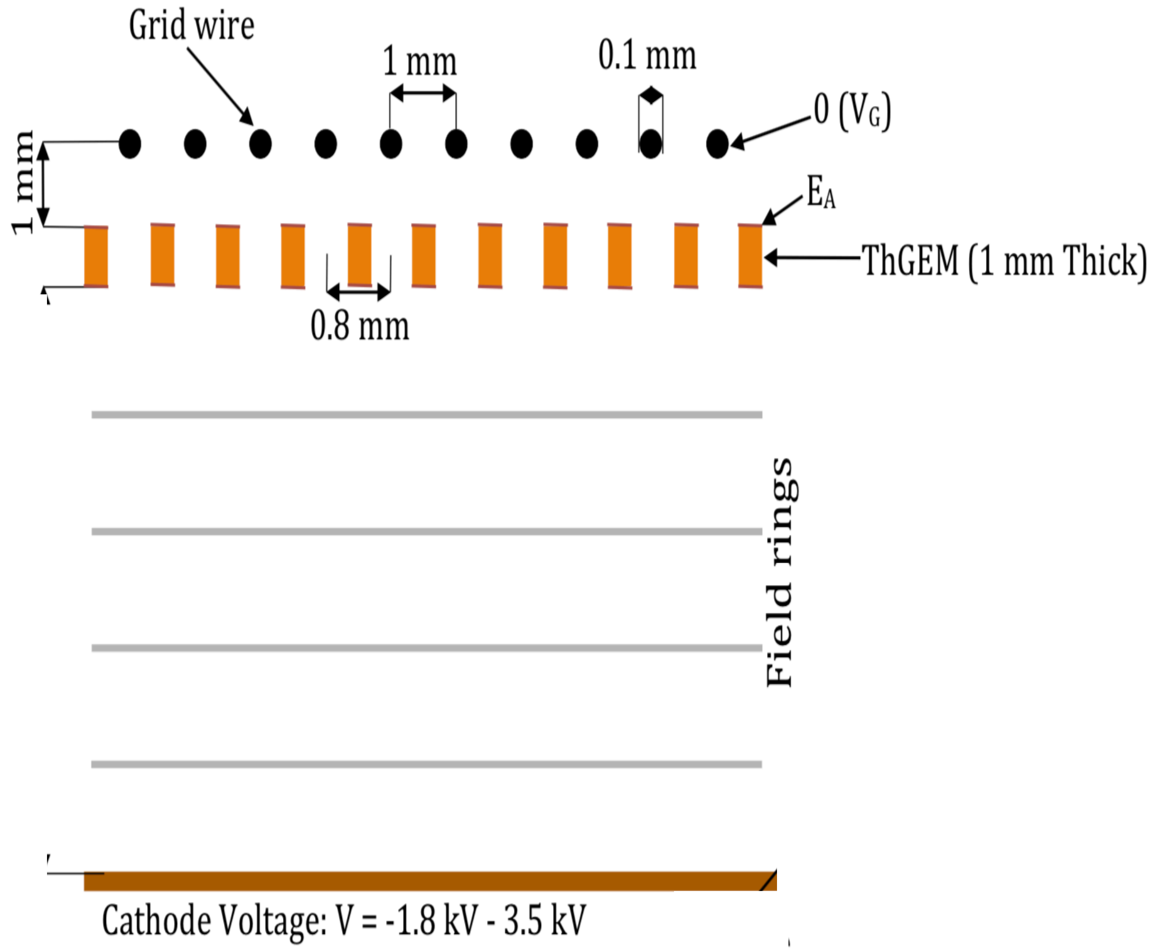
Internal TPC background from :

- THGEM+wire hybrid readout
- Acrylic support frame
- Field cage

THGEM-wire Hybrid Readout

Concept:

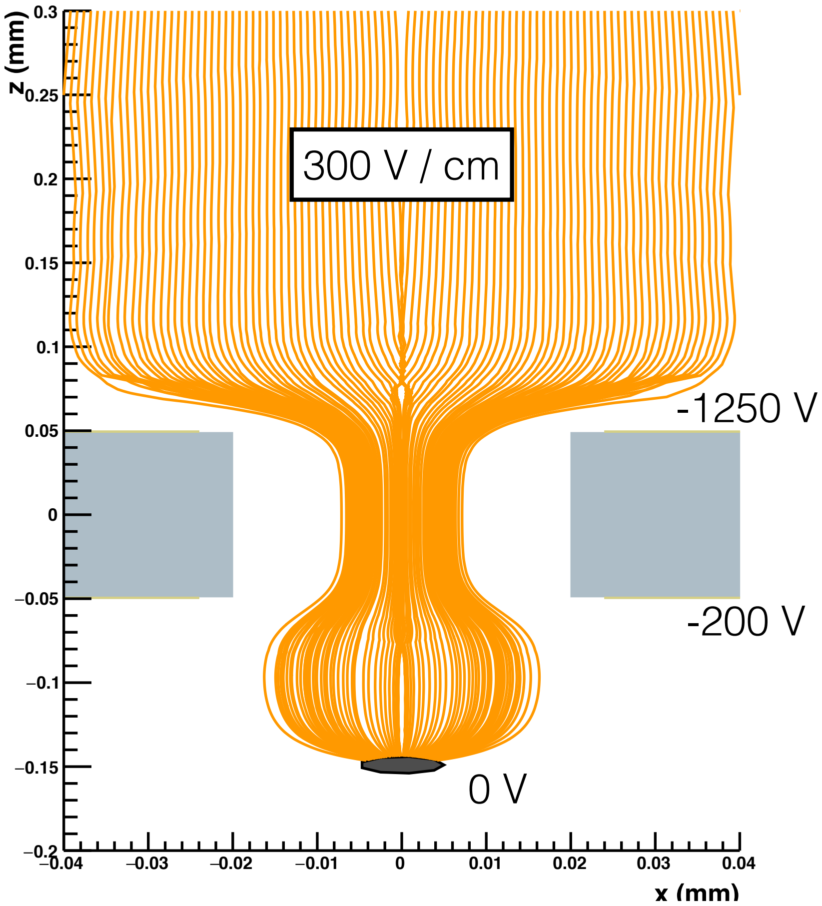
- Use simple low background (acrylic) CERN THGEM as gain stage for SF_6 (x~4000)
- Use simple low capacitance, low background wire readout (no or minimal gain)
- 600 μm XY resolution
- We believe this can achieve required intrinsic background



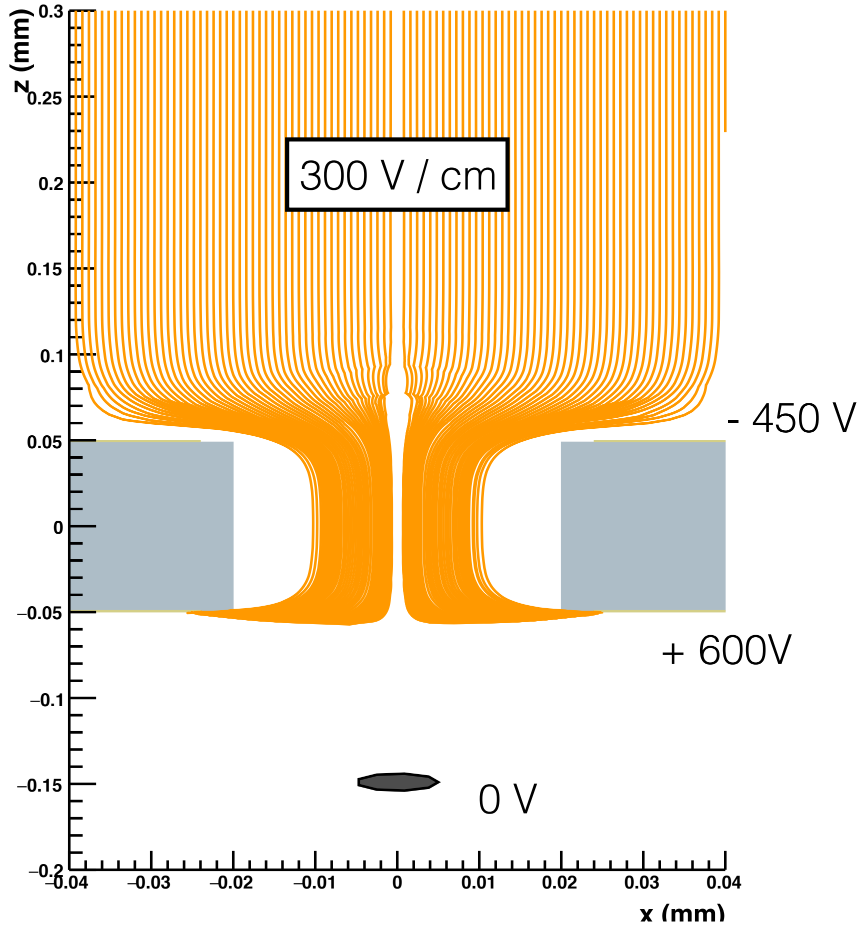
Garfield Simulations

For 1 mm THGEM and 1 mm wire pitch

Collecting electrons

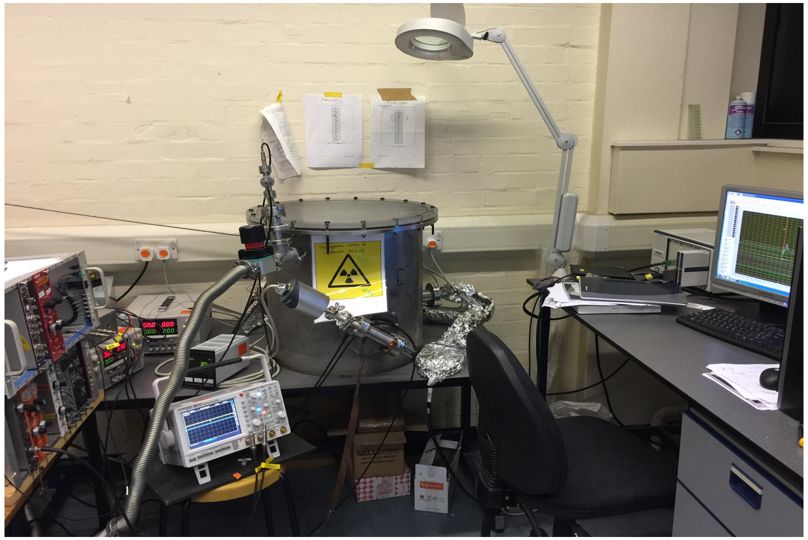


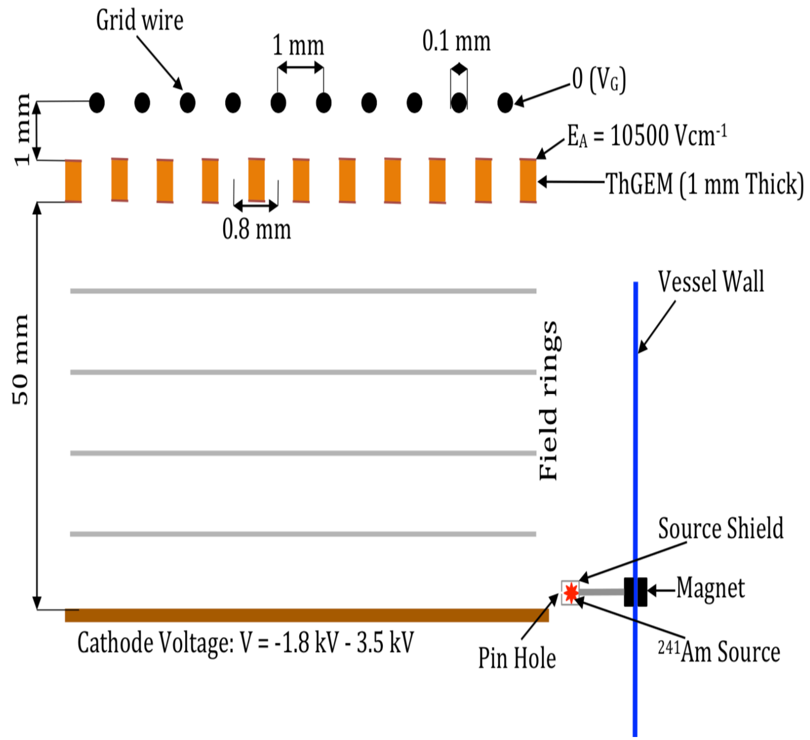
Induced Signal

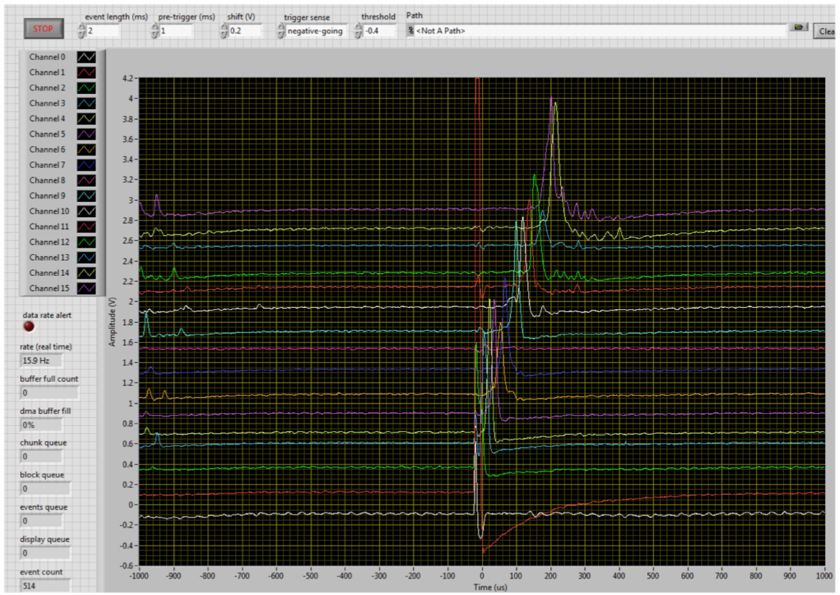


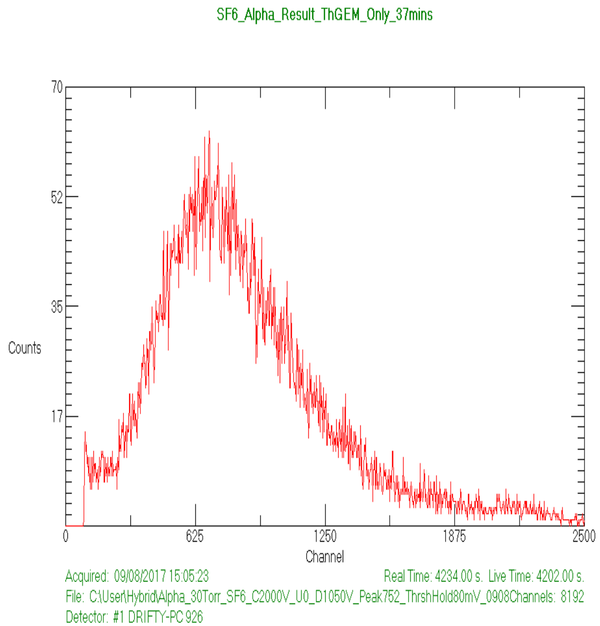
1st Prototype (2 x 2 x 5cm FV)

- alpha tracks seen
- gain in 30 Torr SF_6 ~ x1270





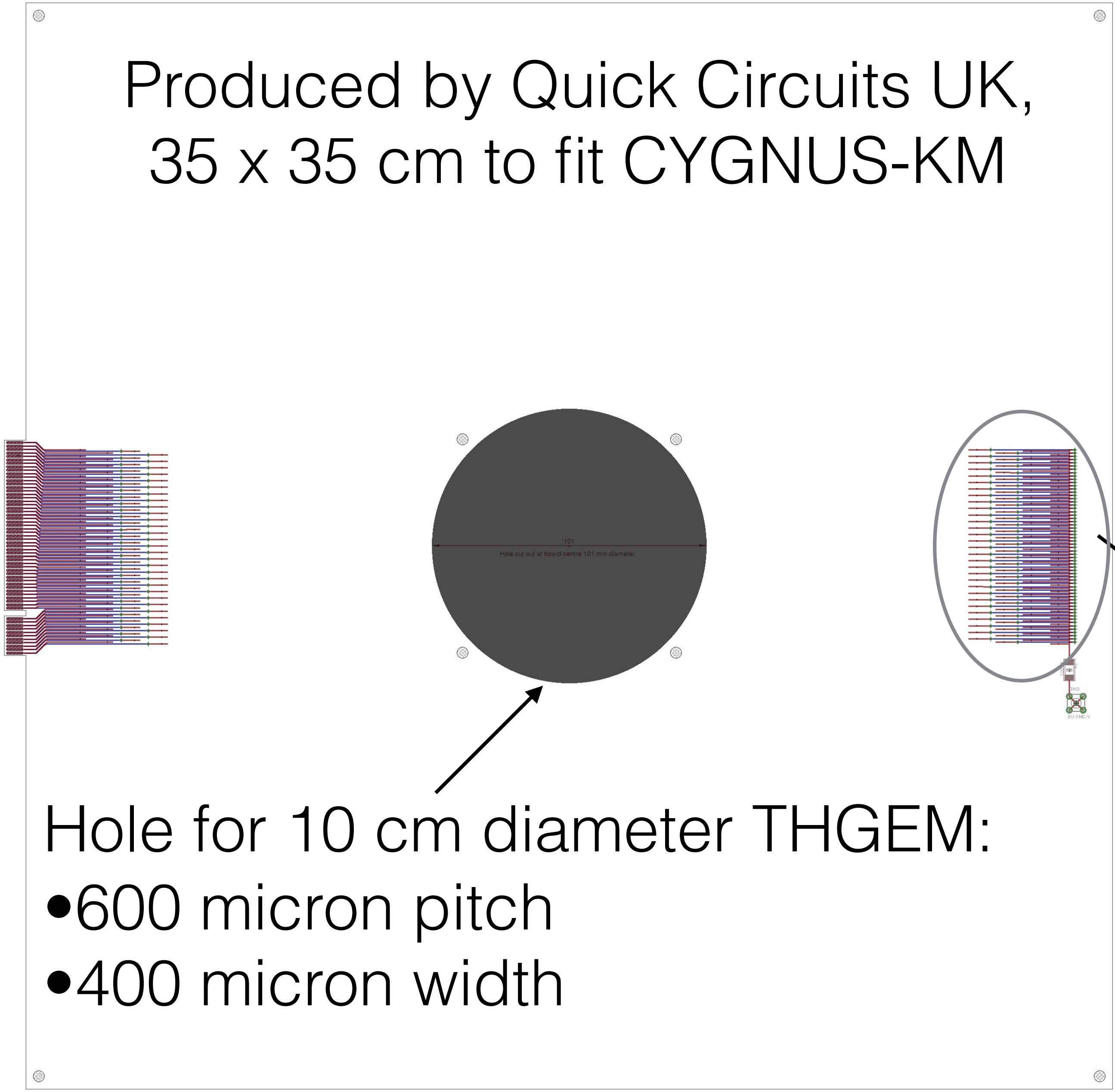




^{241}Am alpha

2nd Prototype - scale up

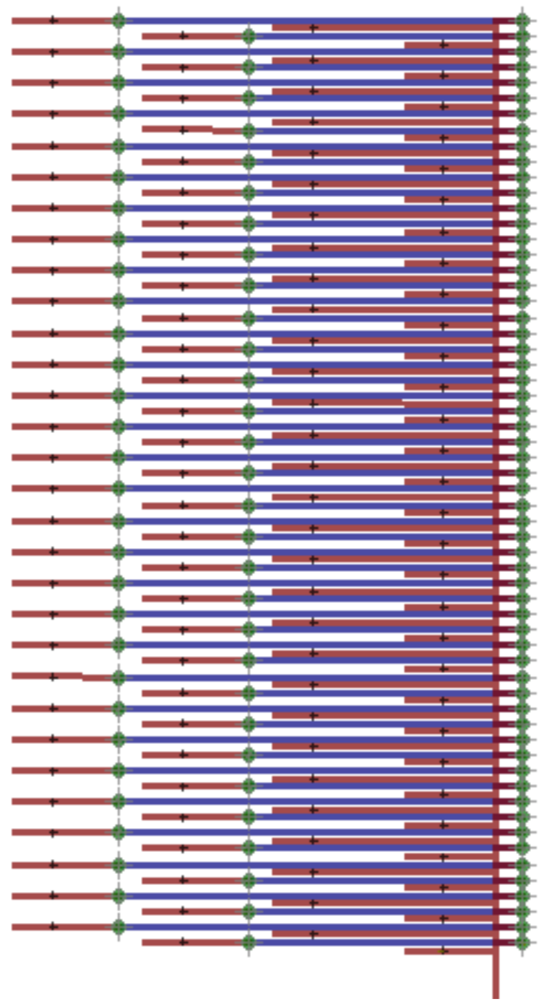
Produced by Quick Circuits UK,
35 x 35 cm to fit CYGNUS-KM



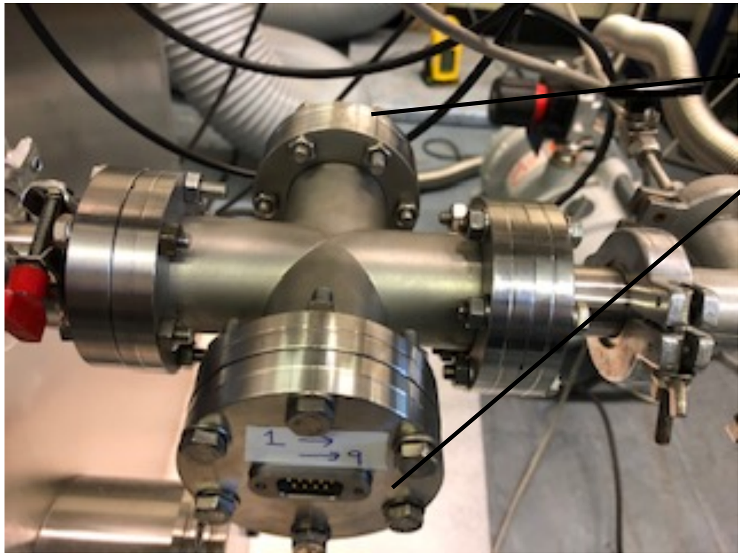
Hole for 10 cm diameter THGEM:

- 600 micron pitch
- 400 micron width

Solder pads vertically separated by 600 microns and staggered to help with soldering the wires in place

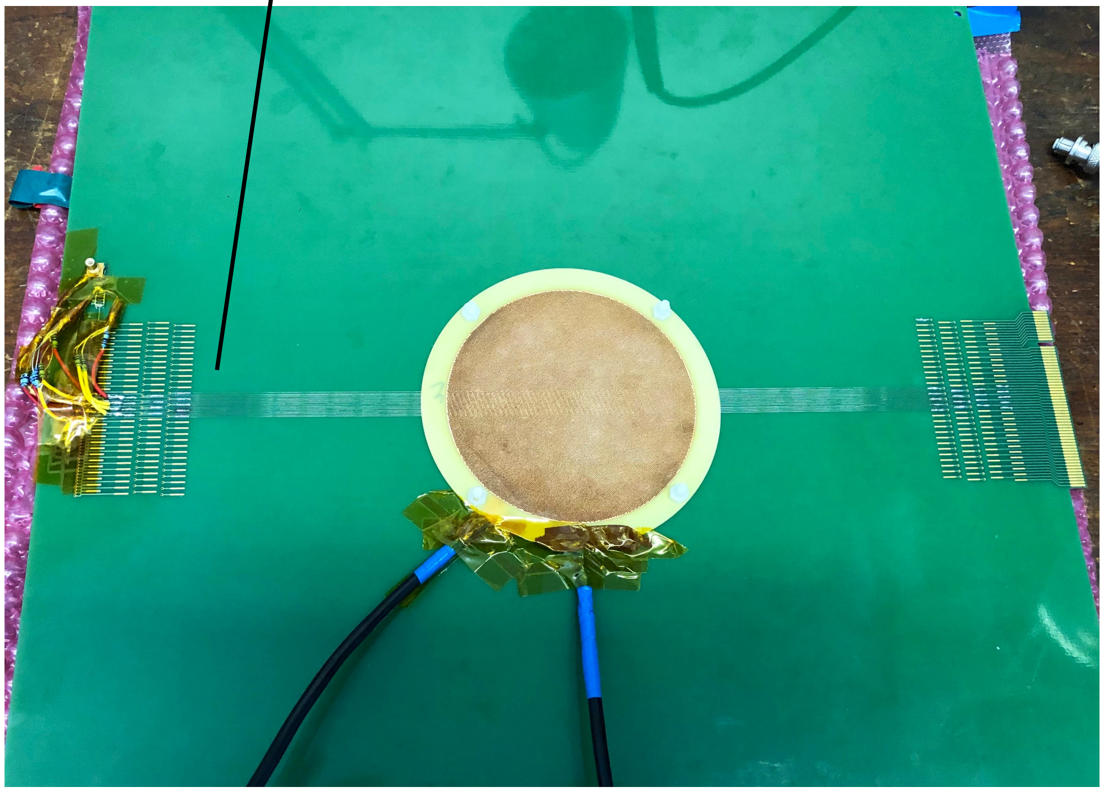


Setup



x2 9-pin D-sub feedthroughs for unto 18 channels

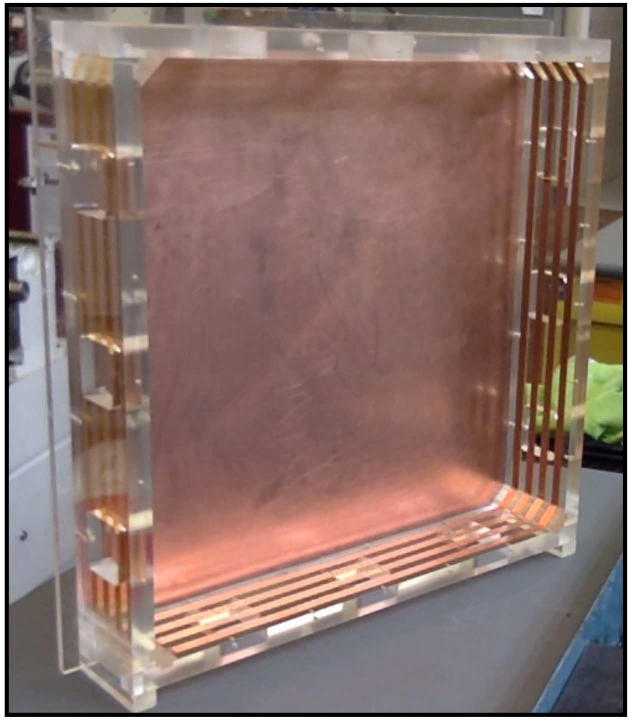
18 wires each grounded via 1 Mohm resistor.

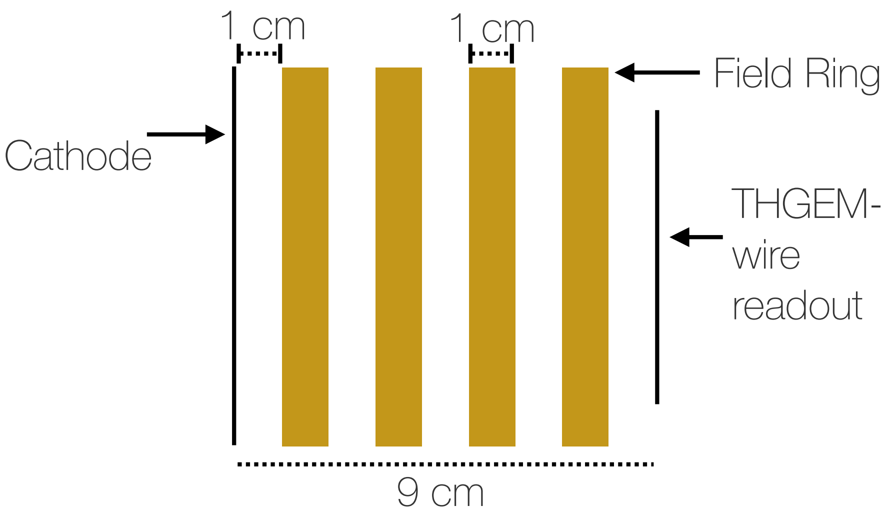


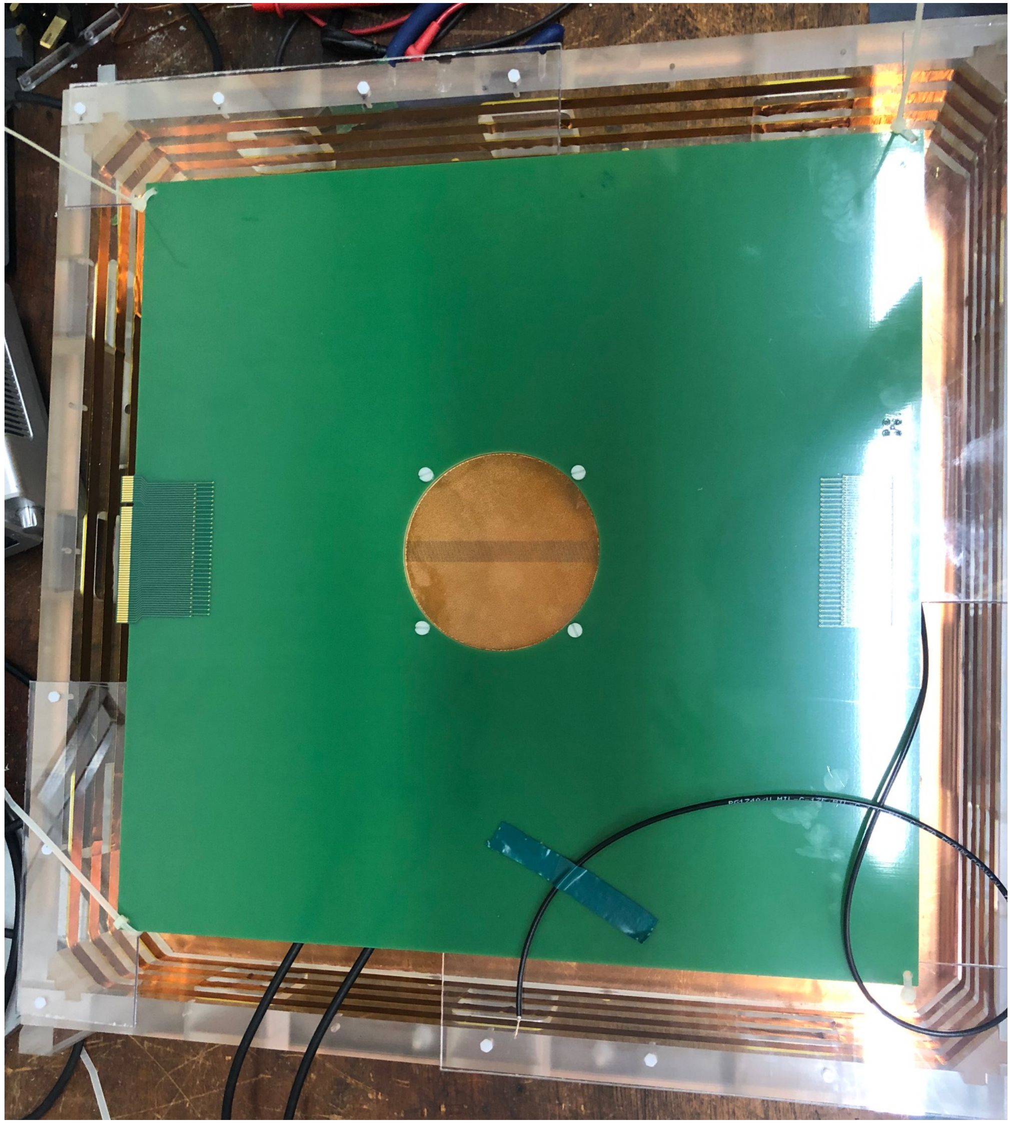
1 mm between THGEM and wires.

0.6 mm between each wire.

Field Cage

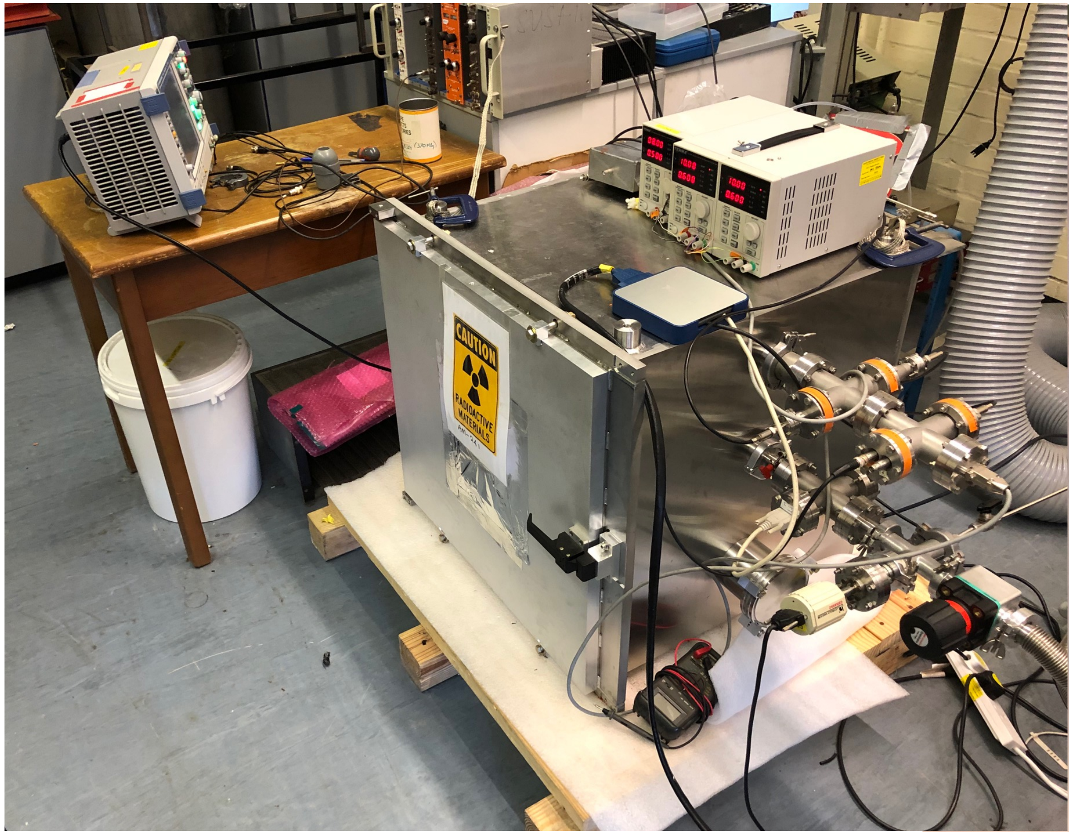


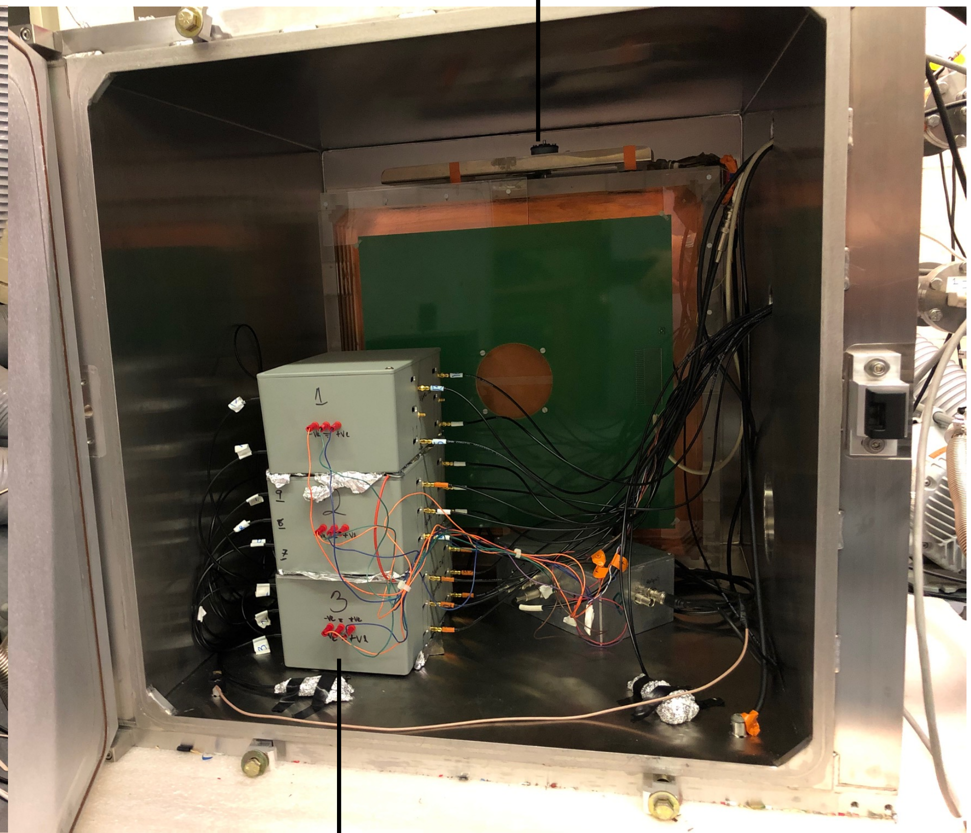




Lab Setup and Electronics

Source Shutter, used for alpha source



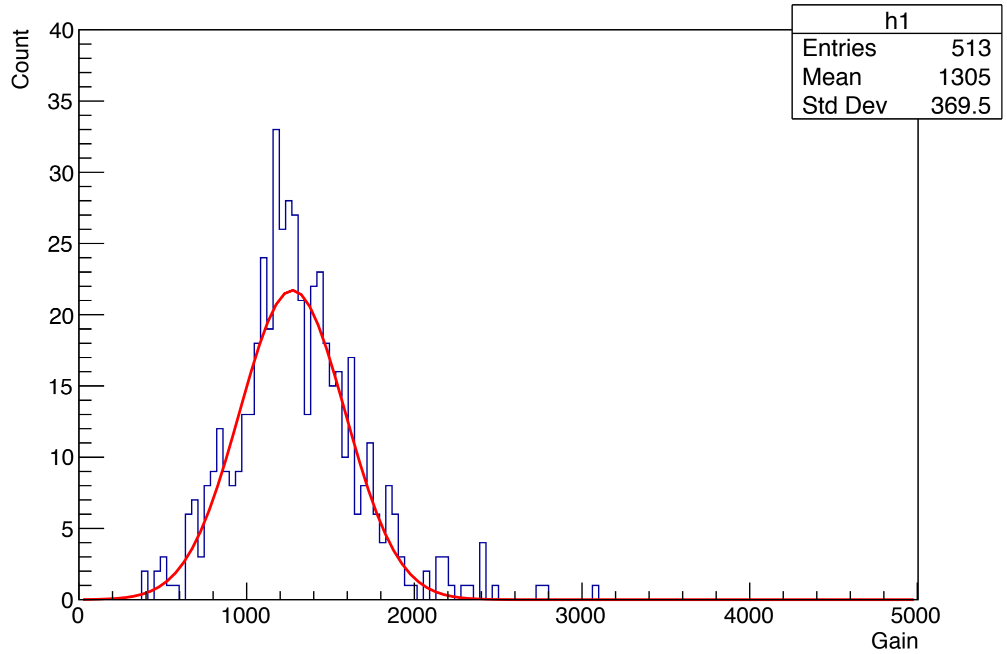


Cremat pre-amps and shapers (16 in total)

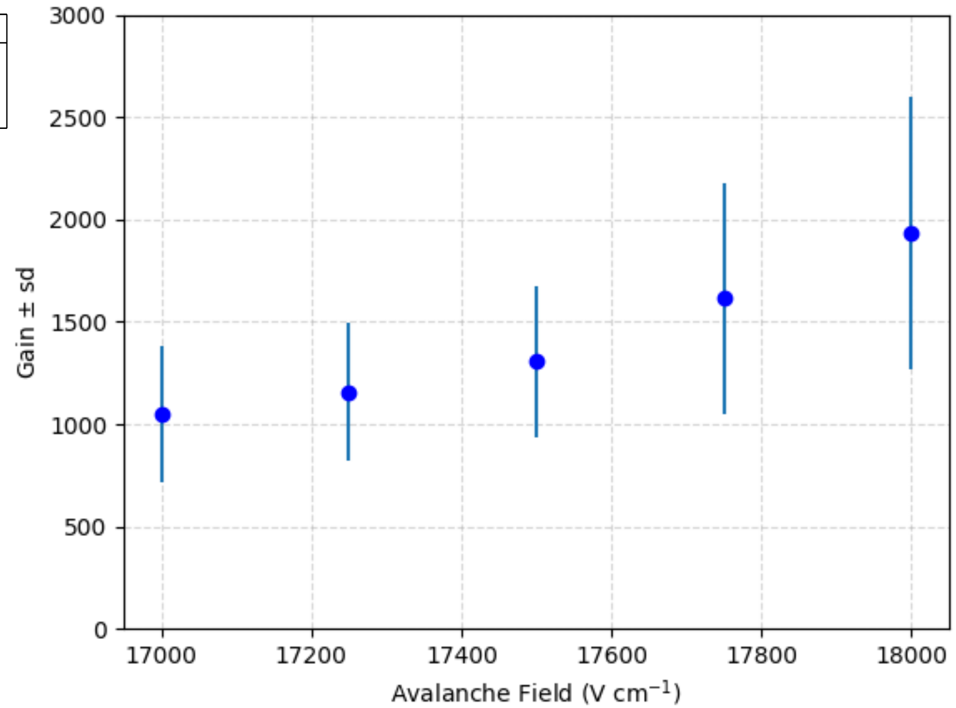
Fe55 in 50 Torr CF_4

Fields: Drift 400 V cm^{-1}, Between wires and THGEM 2000 V cm^{-1}

Spectra at 17500 V cm^{-1}

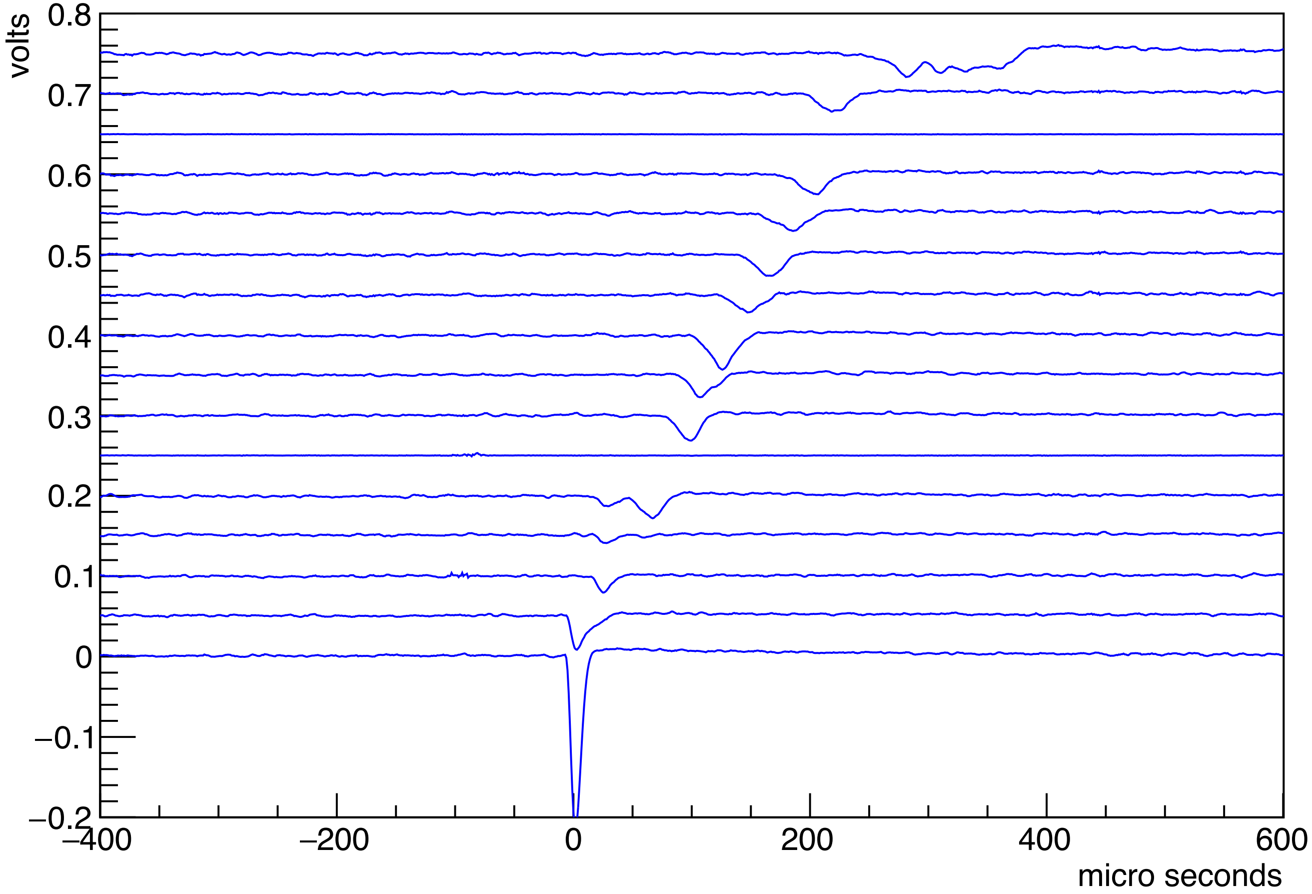


Gain curve (wires)



Alphas (Am^{241})15 Torr SF_6

Fields: Drift 500 V cm^{-1}, Avalanche 12500 V cm^{-1}, Between wires and THGEM 3000 V cm^{-1}



Delay, showing presence of negative Ion drift.

Conclusion: Promising, but much optimisation needed…

Conclusions

- A design for a CYGNUS-10 that has (on paper) the required “zero” background at ~5 keV_{ee} has been explored
- e^-/NR discrimination at 10^4 in the ROI may be feasible
- Even with this an all steel vessel is not acceptable unless internal Cu shielding is used
- A simplified GEM+wire readout may achieve sufficiently low internal background
- First results from this concept with 600 μm look promising