Preliminary measurements of the ionization loss for low-energy nuclear recoils

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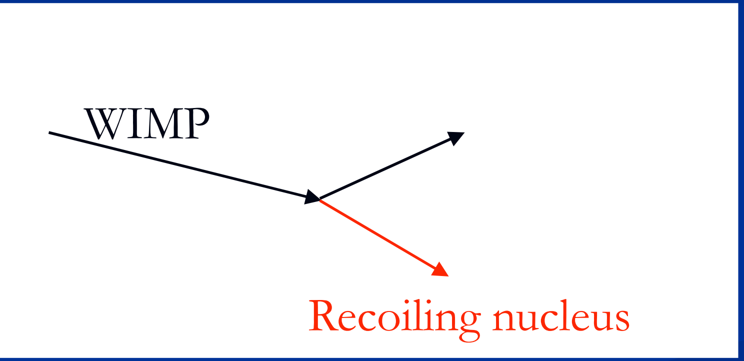
Motivation

- Want to measure fundamental track properties of low energy nuclear recoils in gas detectors
- Measure dE/dx along track and find out if full 3-D vector tracking of nuclear recoils is
  - POSSIBLE?
  - FEASIBLE?



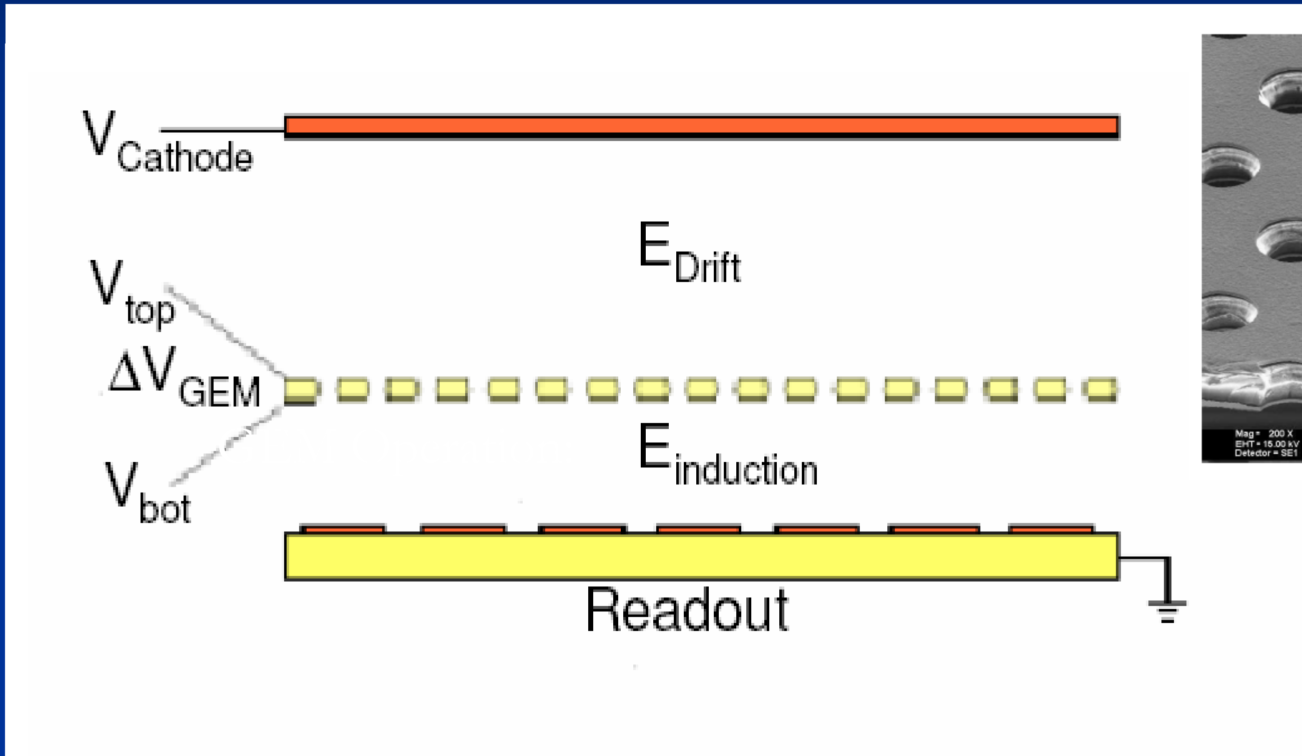
Building a small prototype detector with

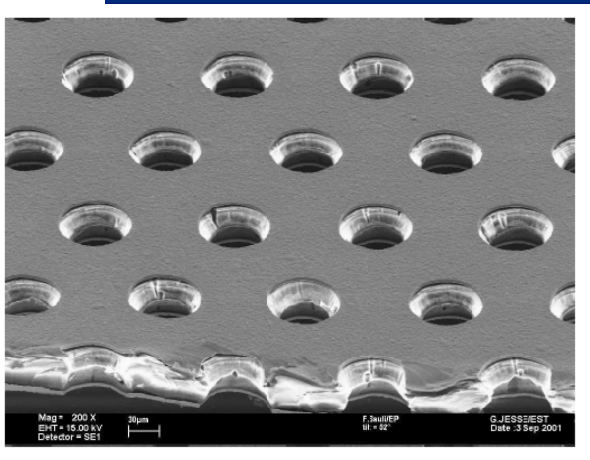
- high spatial resolution
- very high signal to noise

→ **NOT:** Feasibility study for a detector

The GEM (Gas Electron Multiplier)

GEM: 50µm thick sheet of highly insulating Kapton sandwiched between two ~5µm thick sheets of Cu (hole diameter ~50-100µm, pitch of ~140µm)





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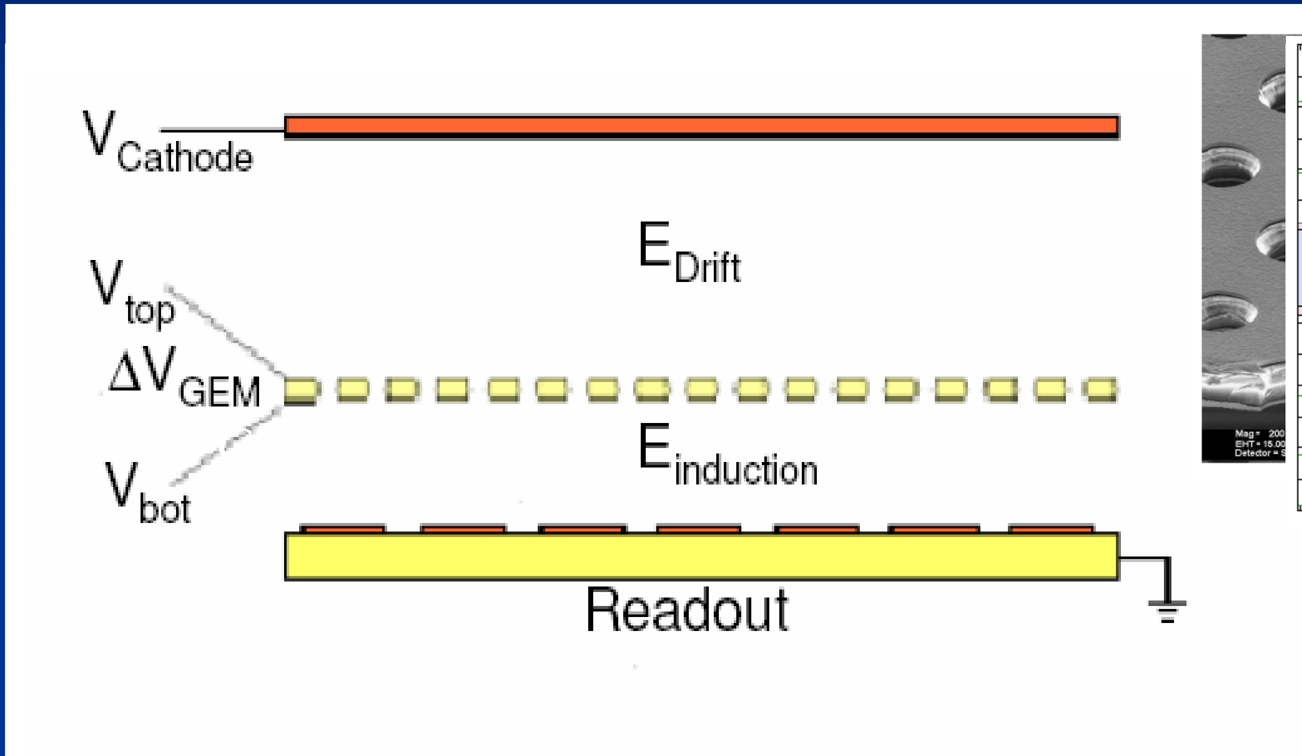
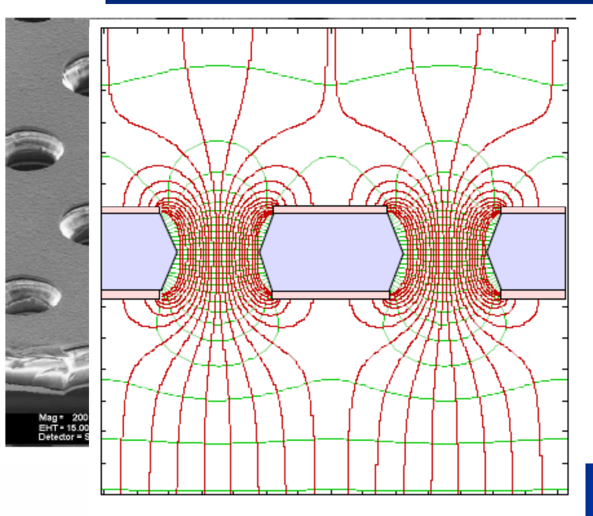
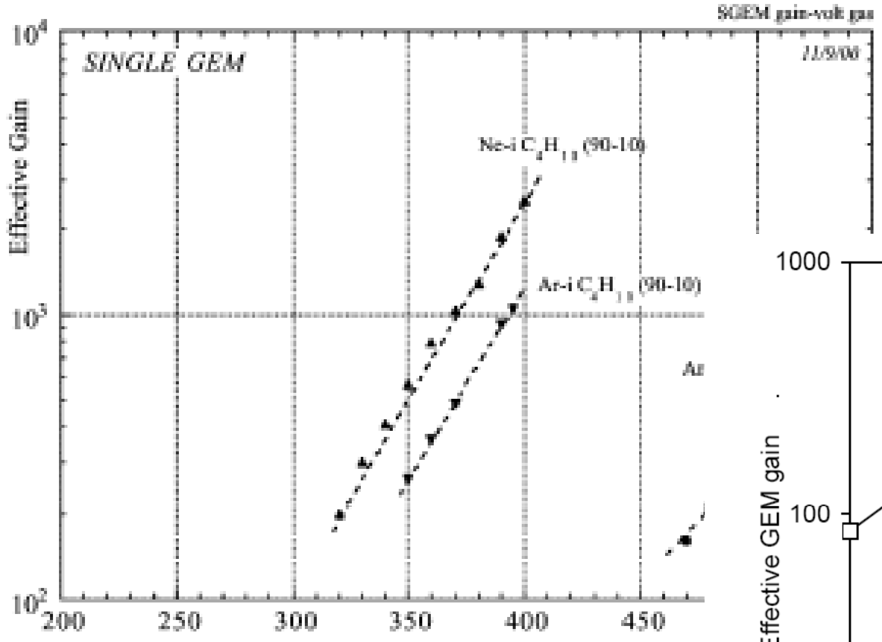


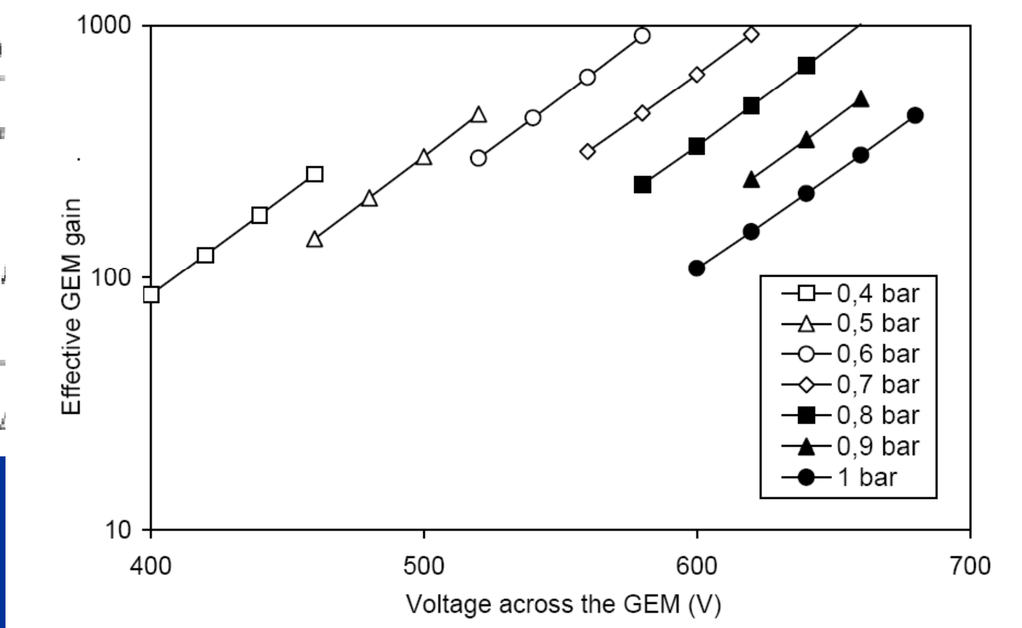


Field lines inside the GEM Holes generated with MAXWELL

GEM Gain depends on gas used and its pressure:



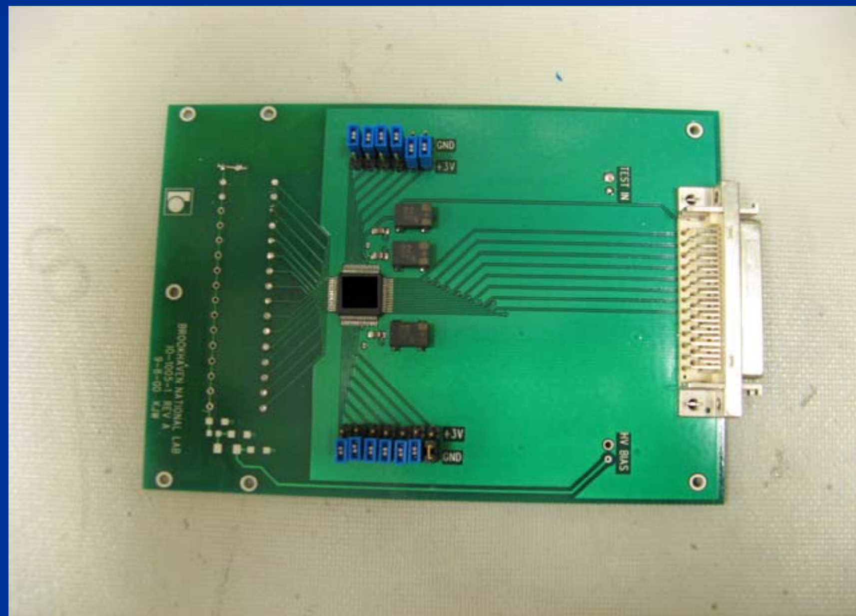
("Discharge studies and prevention in the gas electron multiplier (GEM)" S. Bachmann,et.al., NIMA 2002)



("Thermal Neutron detection based on the GEM" T.L.VanVuure, PhD Thesis)

Readout Board and PreAmplifier

1-D Readout Board: 16 strips
~ 5-10pF per strip
200μm pitch, 80μm width



Preamplifier (BNL):

- 16 (8) channels per chip
- very **low noise** (ENC ~ 88 (57) + 15(10)/pF)
- very small 2.2 x 6.12 mm
- 4.0 μs **Peaking Time** (0.6, 1.2, 2.4)
- **Gain**: 30, 50, 100, 200 mV/fC
- Test pulse input into all 16 channels

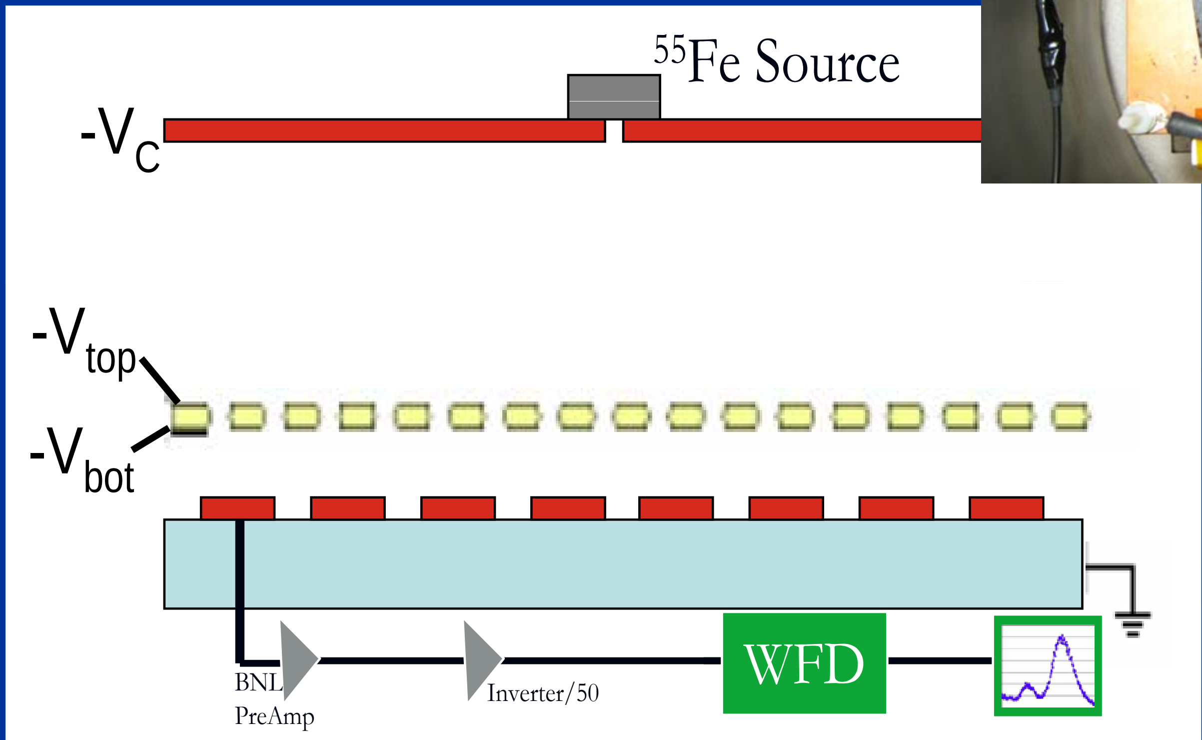
→ Due to the low noise electronics: only 1 GEM needed in the gain stage of the detector

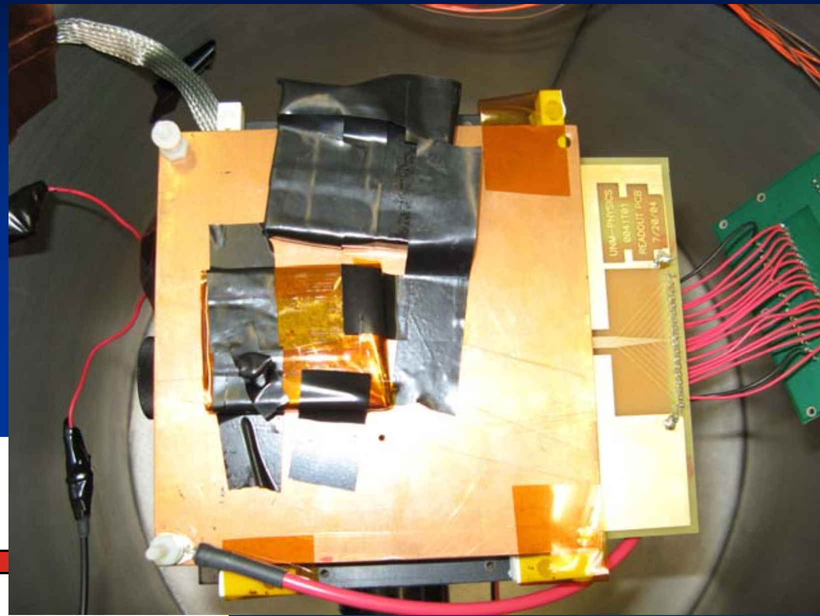
Measured Gain uniformity of electronics, < 5% discrepancy between channels

Calibration measurements

- Calibrate the detector using ^{55}Fe source (1mCi);
- Source can be turned on/off on demand
- Measurements performed before and after a neutron run to check gain stability

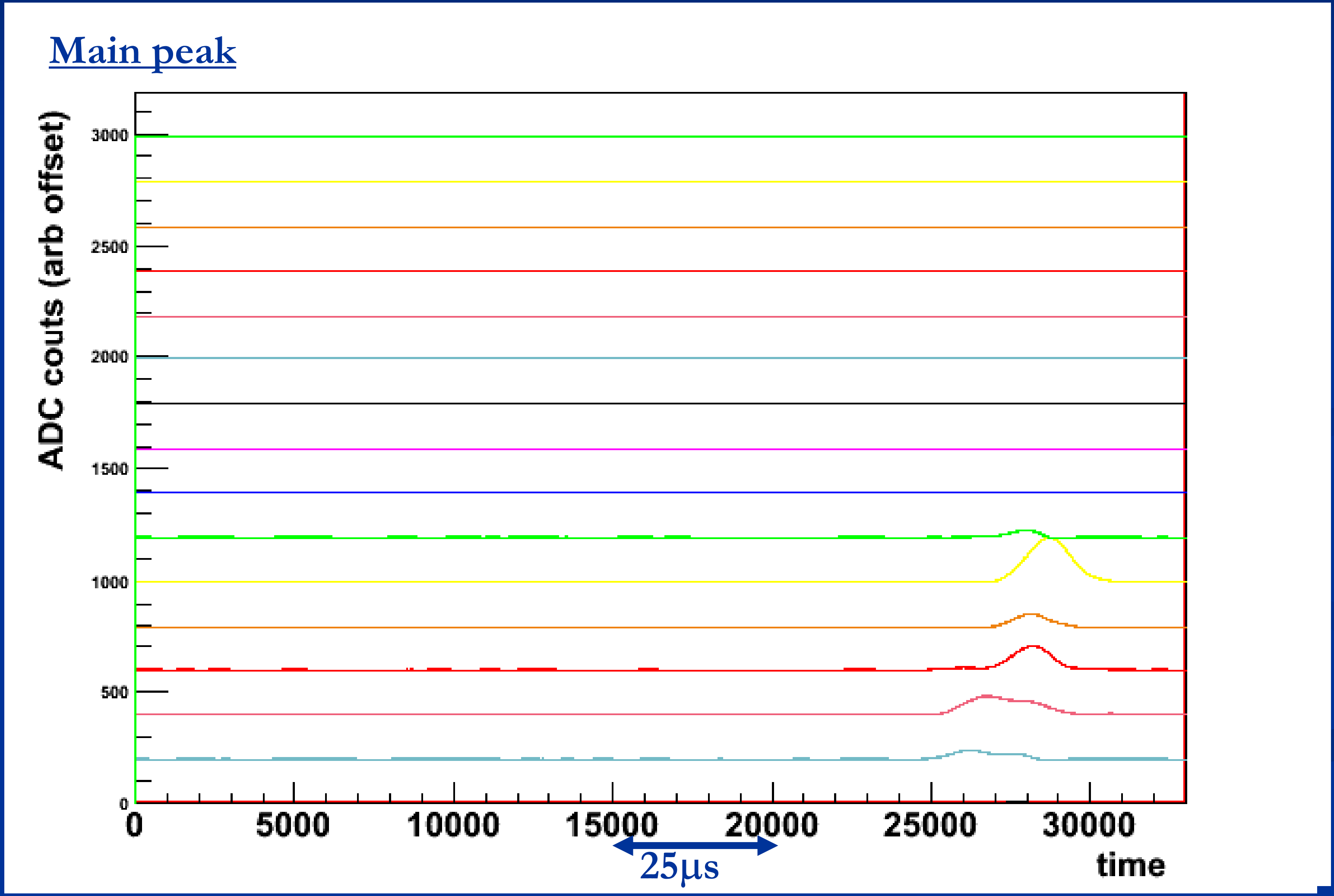
SETUP:





ΔV_{GEM} = 474V, E_D = 680V/cm, E_i = 4200V/cm; 12 channels added

Electronics Gain: 100mV/fC; 80torr CS_2, Gas Gain ~ 500,
$\Delta E_{FWHM}/E$ ~ 18% (Main peak)



Measuring low energy nuclear recoils

Neutron source: ^{252}Cf, activity of <20μCi in Jan 2007 (expected: few events per minute in active detector volume)

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Measuring low energy nuclear recoils

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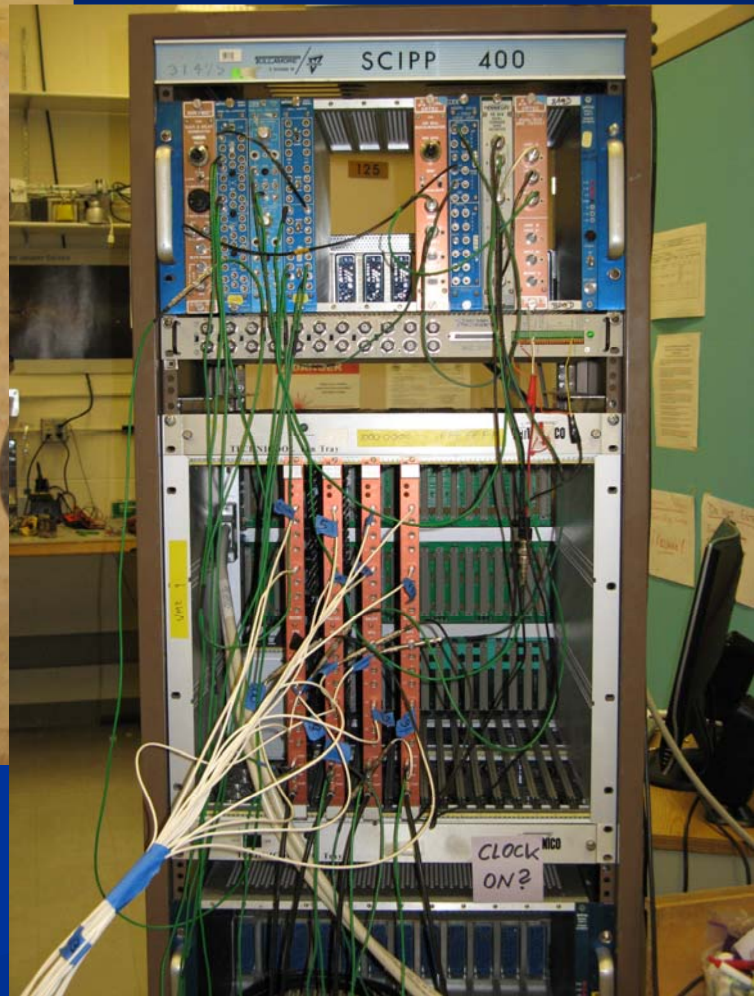
SETUP:

Paraffin to shield neutrons
→ effect on neutron backscattering from Paraffin has not been simulated

Measuring low energy nuclear recoils

Reading out 16 strips in 1D into 16 separate WFD channels giving us 200μm strip pitch



Digitizers have digitization rate of 200MHz and were designed and built for MACRO experiment;

on loan from Ed Kearns (Boston University)

Measuring low energy nuclear recoils

All our measurements are in 80torr CS_2 (higher interaction rate, shorter tracks, higher acceptance for contained tracks)

Gain Settings: electronics: 50mV/fC; GEM: ΔV_{GEM} = 453V;

E_D = 610V/cm, E_i = 4400V/cm

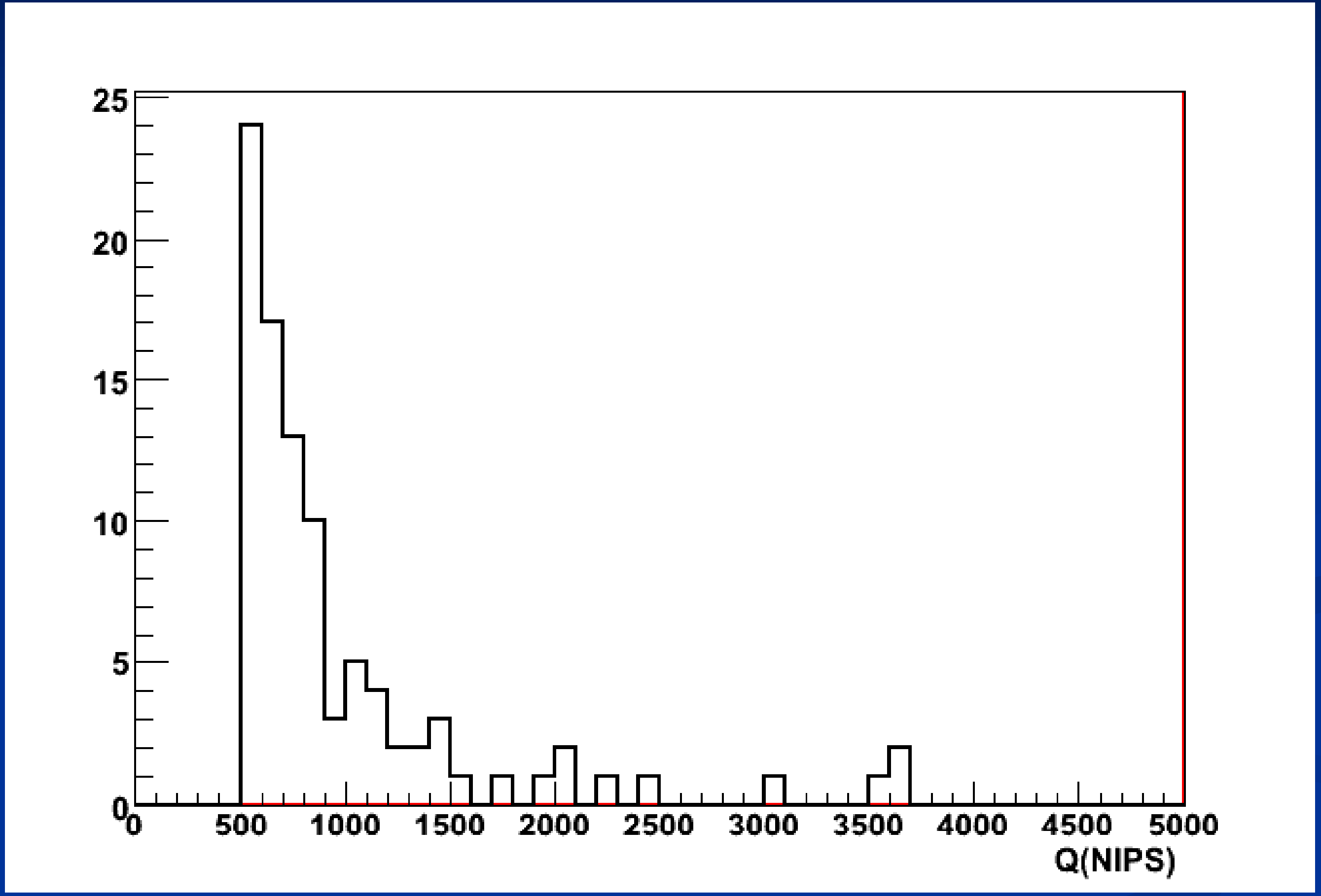
Data shown was taken over the course of 2days

- Position 1: 7.6 hours (342 events > 500NIPs)
- Position 2: 14.5 hours (692 events > 500NIPs)

- ^{55}Fe spectrum taken before, during and after the run ensured Gain stability
- Conversion factor from ADC sum to nips was found from ^{55}Fe main peak

Measuring low energy nuclear recoils

NIPs spectrum from both runs combined:

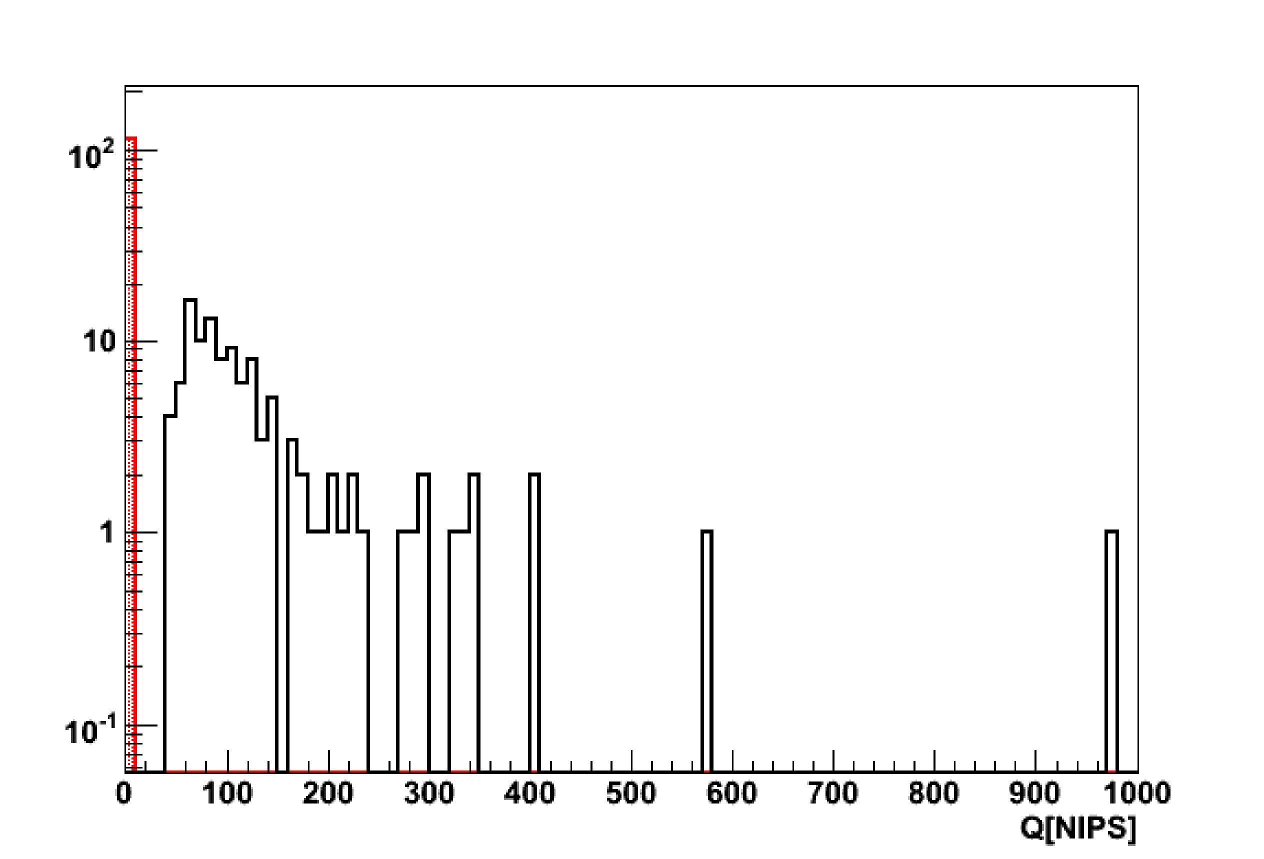


Cuts:
- NIPs > 500 (>27keV Sulfur, 17keV Carbon recoils) and
- Event needed to be contained (< 60 NIPs on strip 2 & 16)

PULSES: short pulse < 500ns; (long pulse > 50μs); pulses < 30 Nips are not hit

Measuring low energy nuclear recoils

Noise Spectrum:



Cuts:
- NIPs > 500 (>27keV Sulfur, 17keV Carbon recoils) and
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PULSES: short pulse < 500ns; (long pulse > 50µs); pulses < 30 Nips are not hit

Measuring low energy nuclear recoils

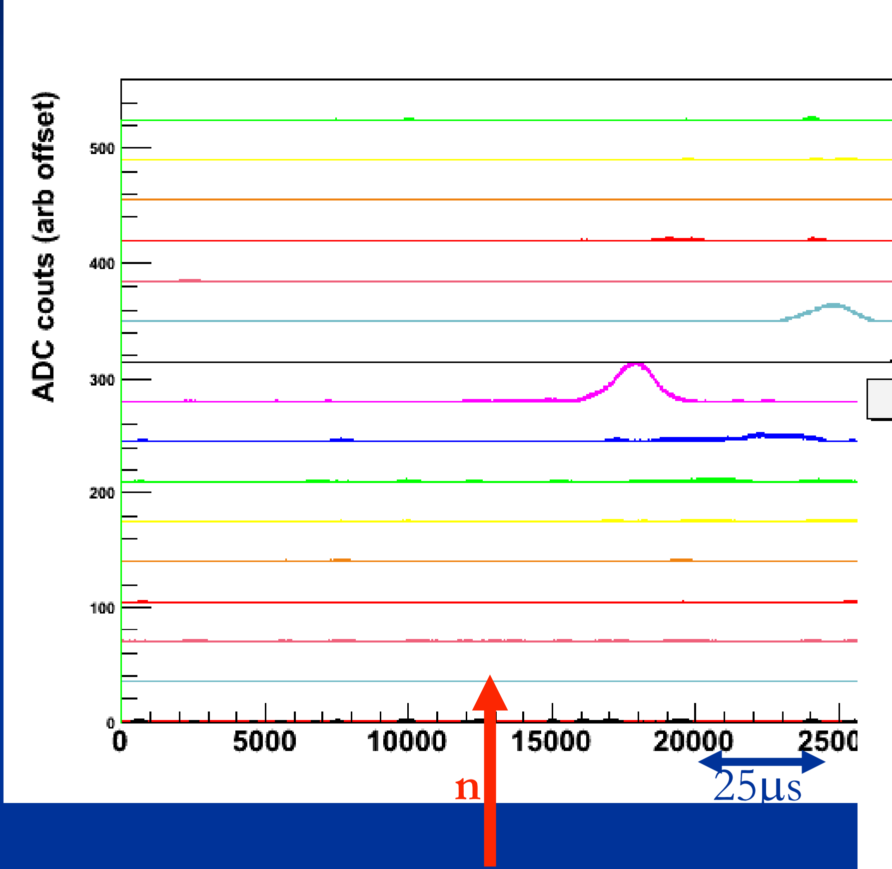
Position 2 (from strip 1), NIPs < 1000:

→ between 500 and 1000 NIPs corresponds to:

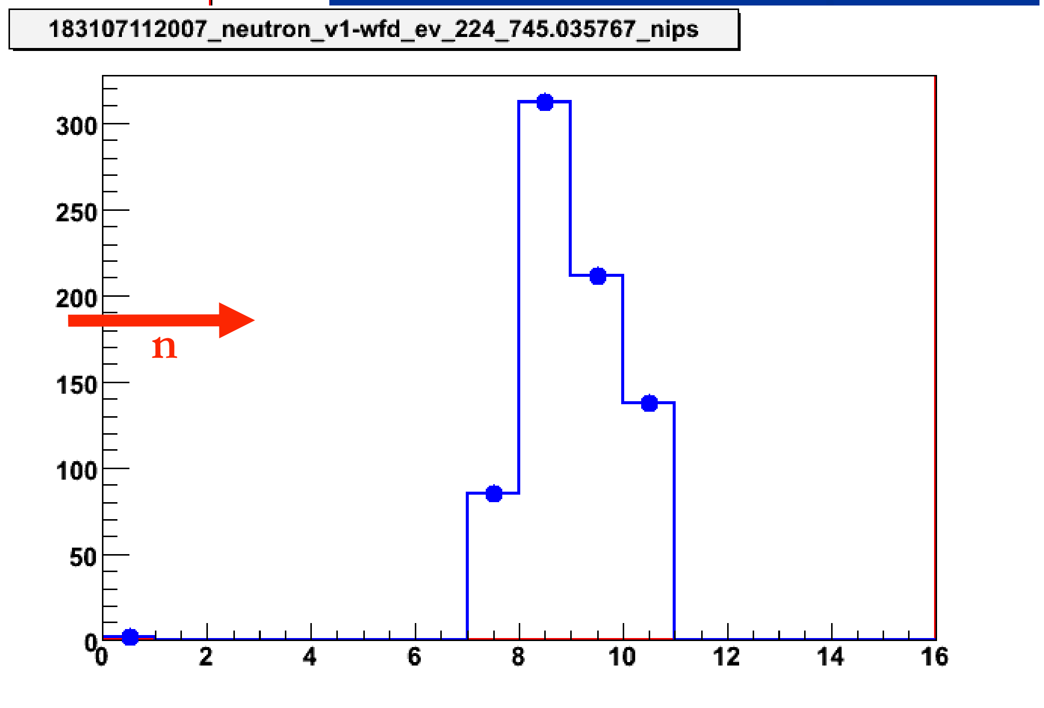
- 25 – 50keV Sulfur recoil → range: 0.25 – 0.45 mm
- 15 – 30keV Carbon recoil → range: 0.8 – 1.5 mm

Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs < 1000:

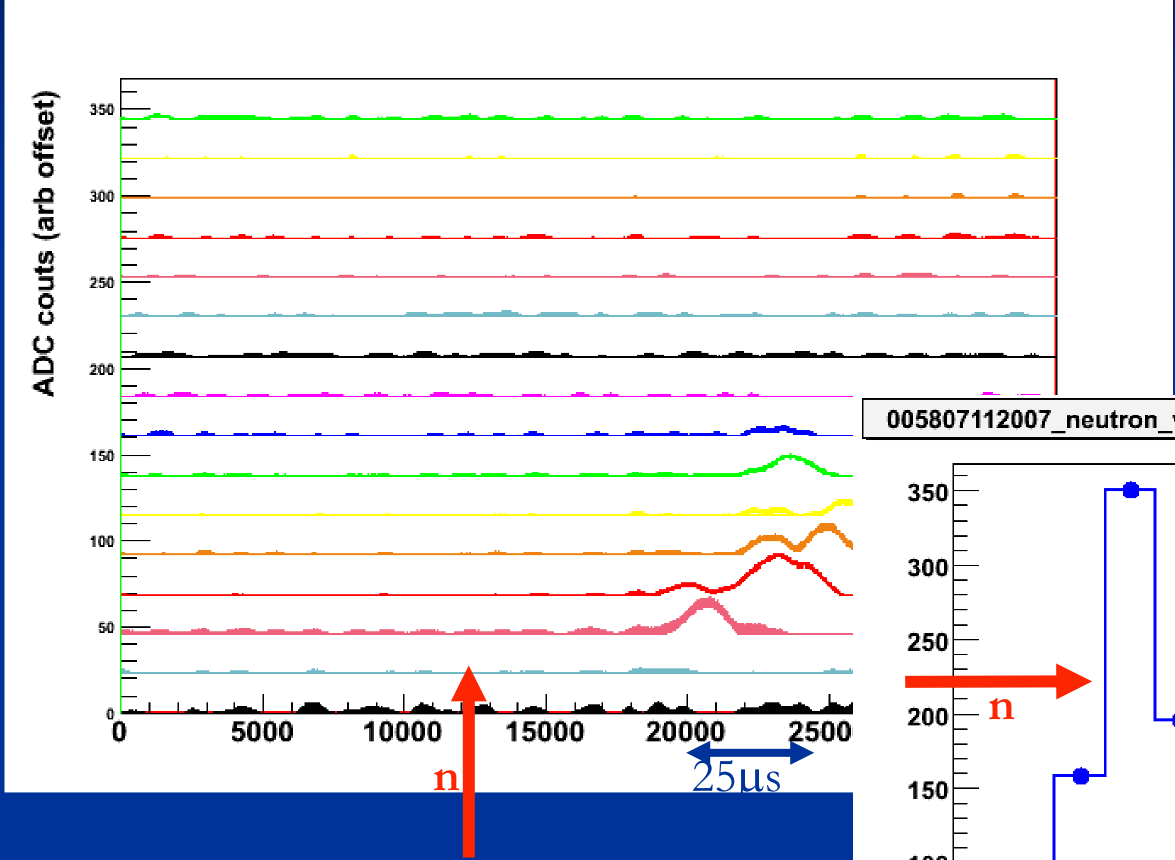


Event has ~745 NIPs
Δx ~ 0.4 mm
Δz ~ ?
[35keV Sulfur recoil]



Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs < 1000:

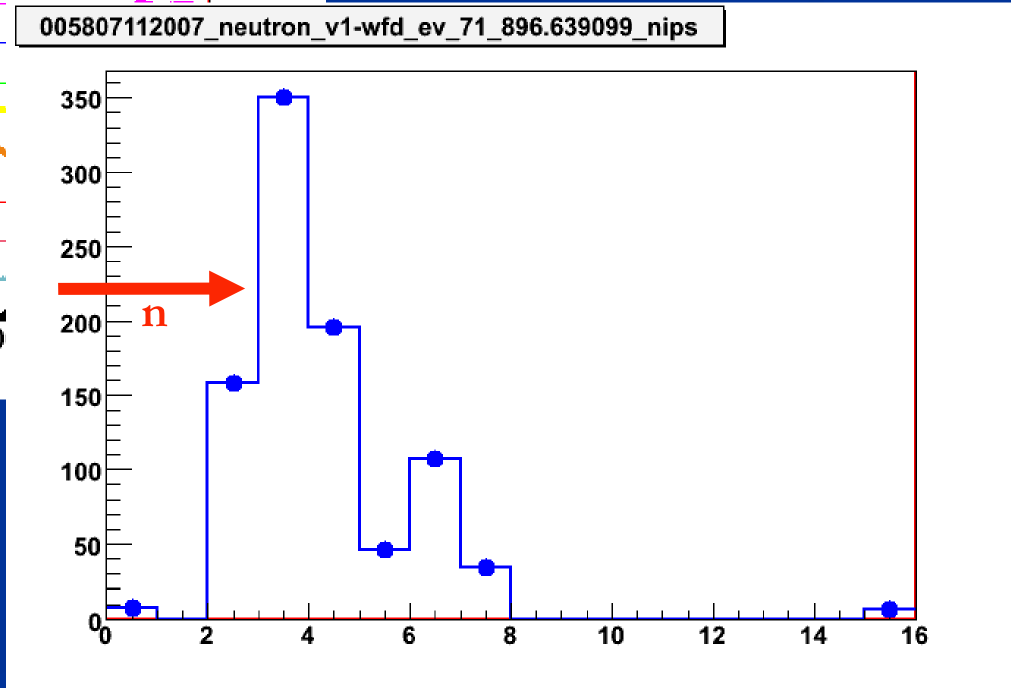


Event has ~900 NIPs

Δx ~ 1 mm

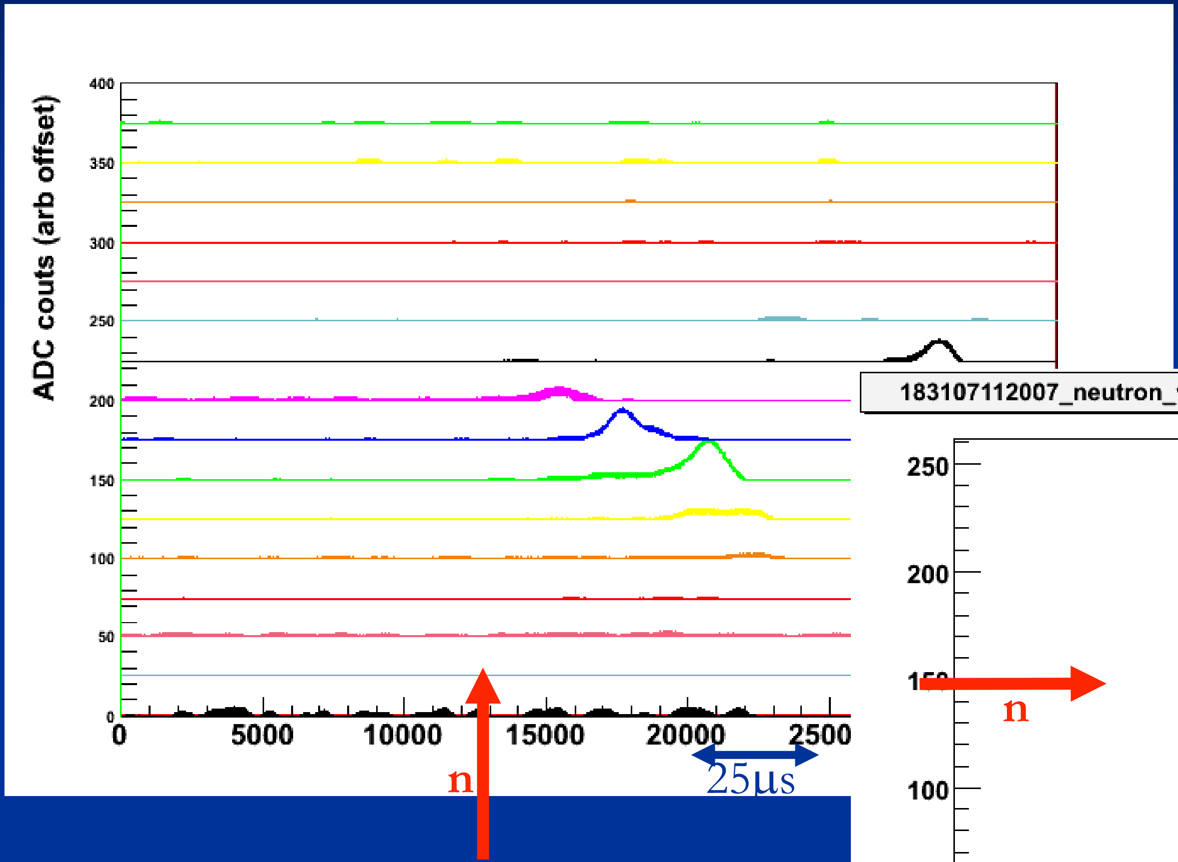
Δz ~ 0.7mm

[25 - 30keV Carbon recoil]

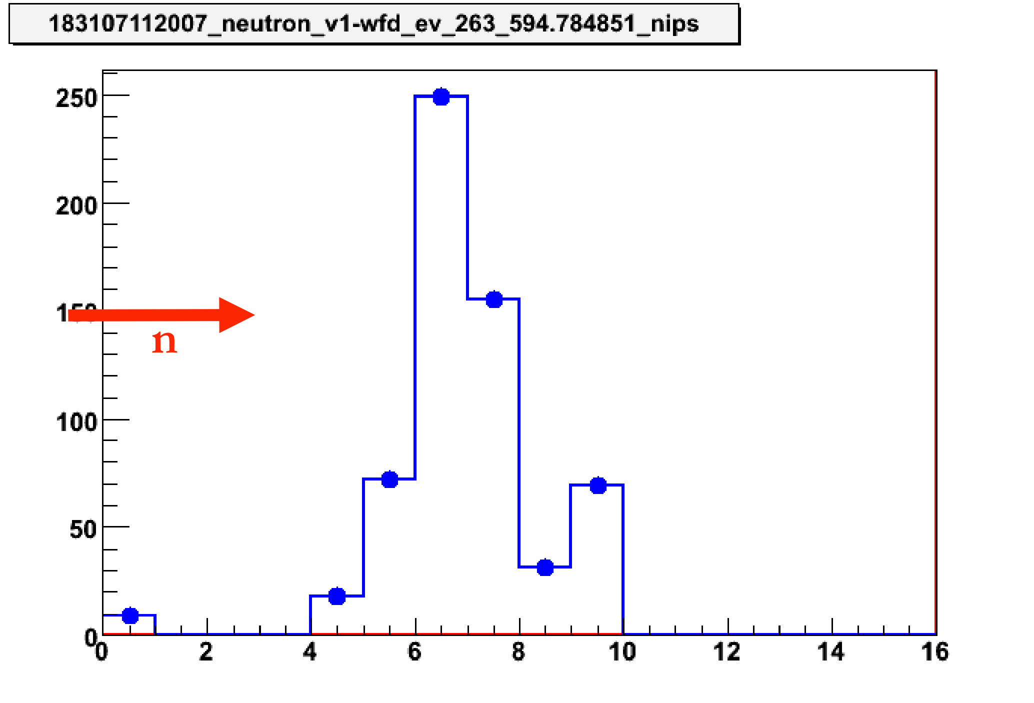


Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs < 1000:

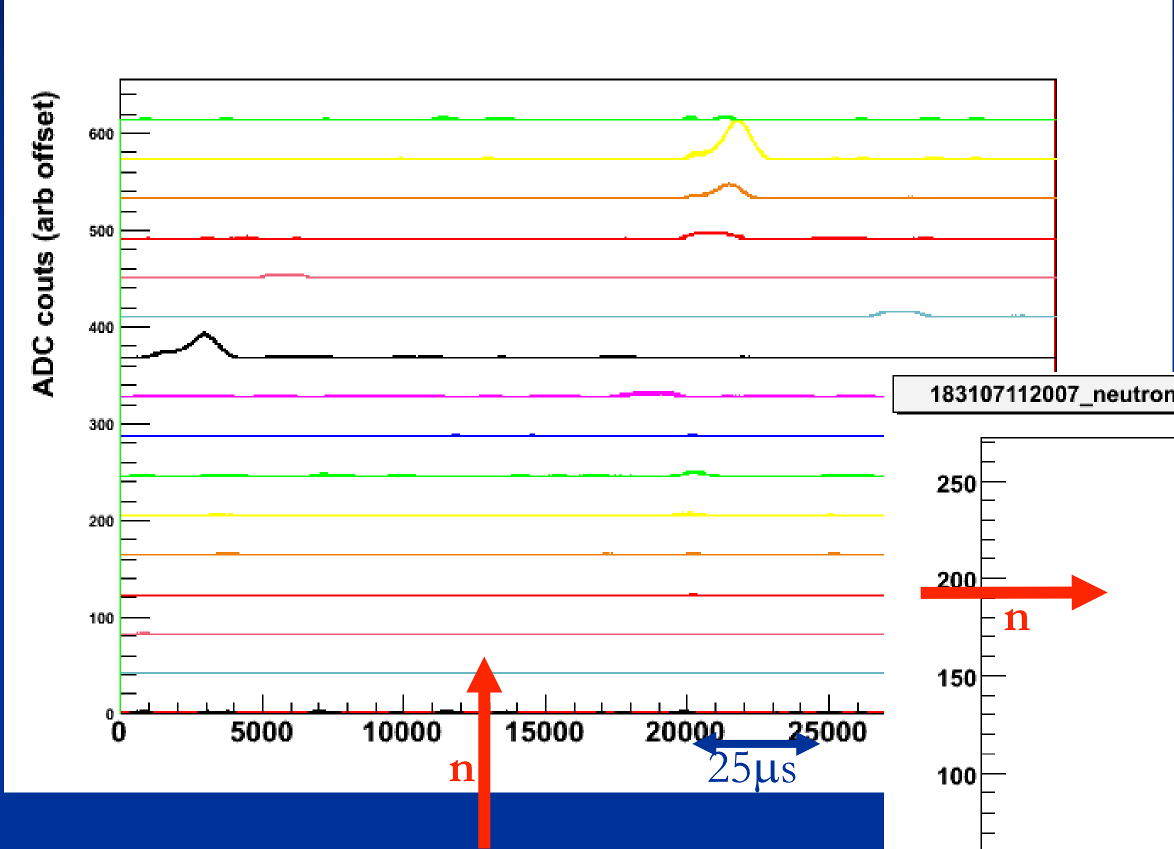


Event has ~600 NIPs
Δx ~ 1 mm
Δz ~ ?
[20keV Carbon recoil]

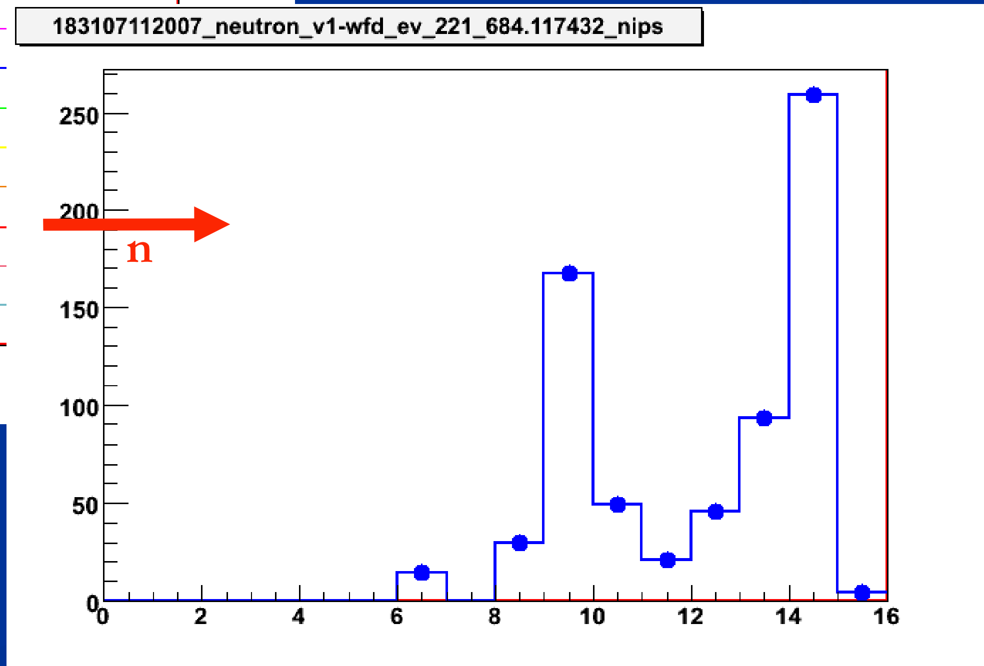


Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs < 1000:

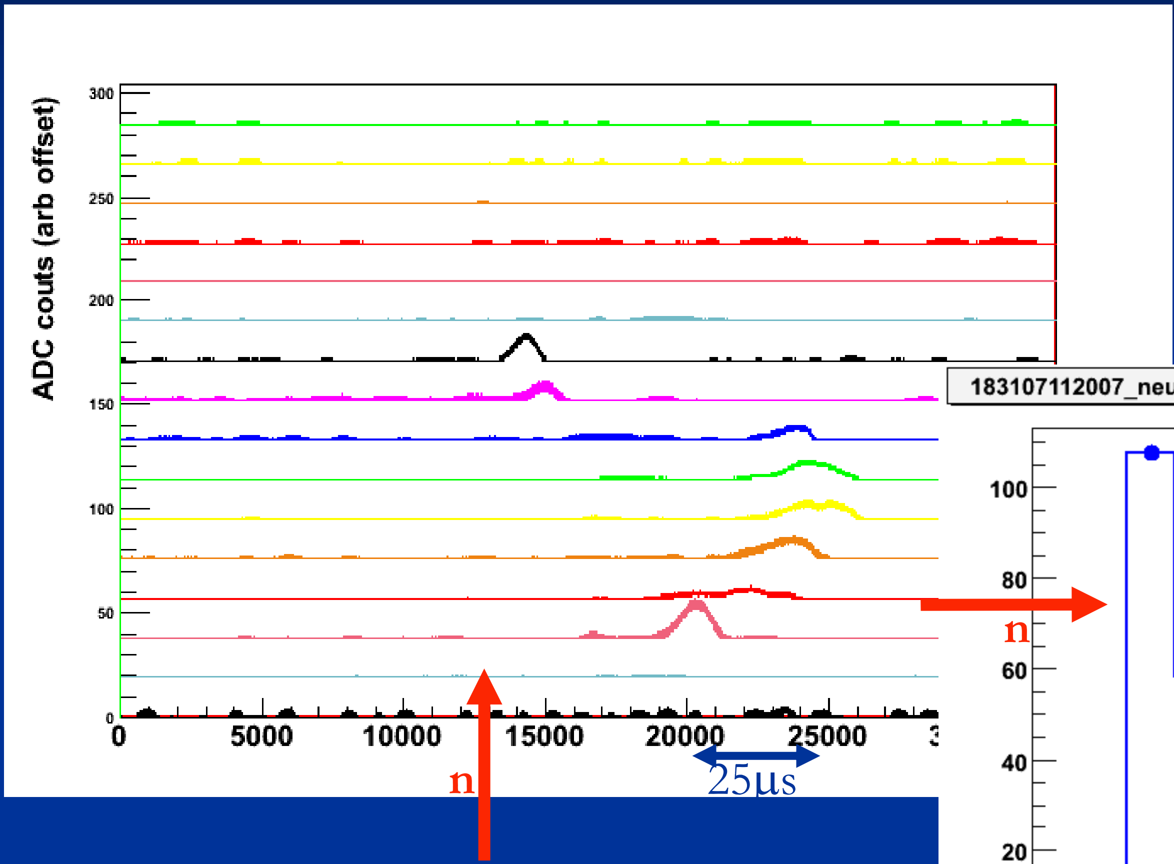


Event has ~680 NIPs
Δx ~ 1.2 mm
Δz ~ 0.2mm
[25keV Carbon recoil]

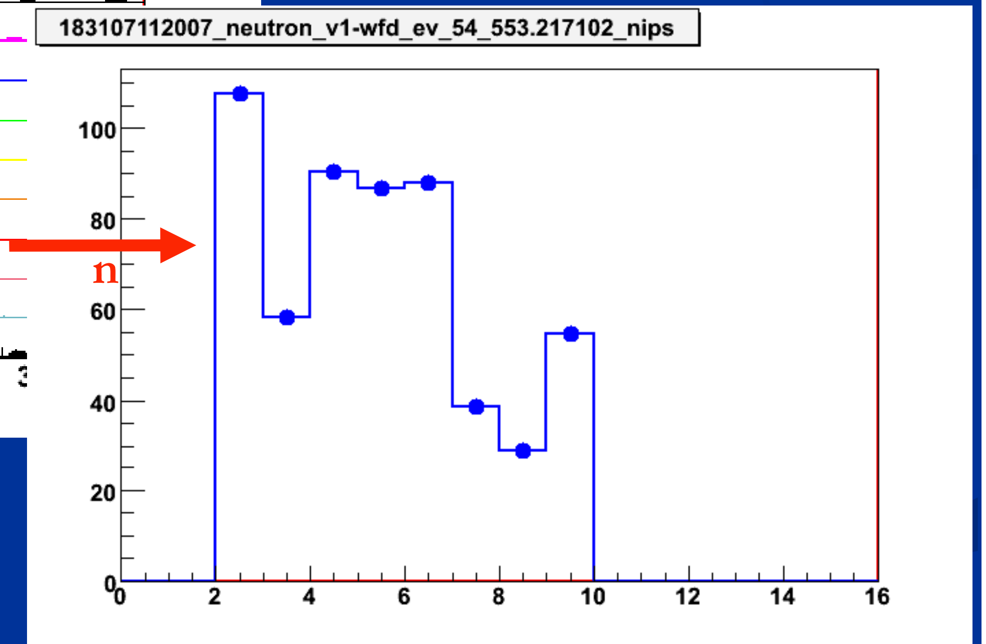


Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs < 1000:



Event has ~550 NIPs
Δx ~ 1.2 mm
Δz ~ 0.8mm
[20keV Carbon recoil]



Measuring low energy nuclear recoils

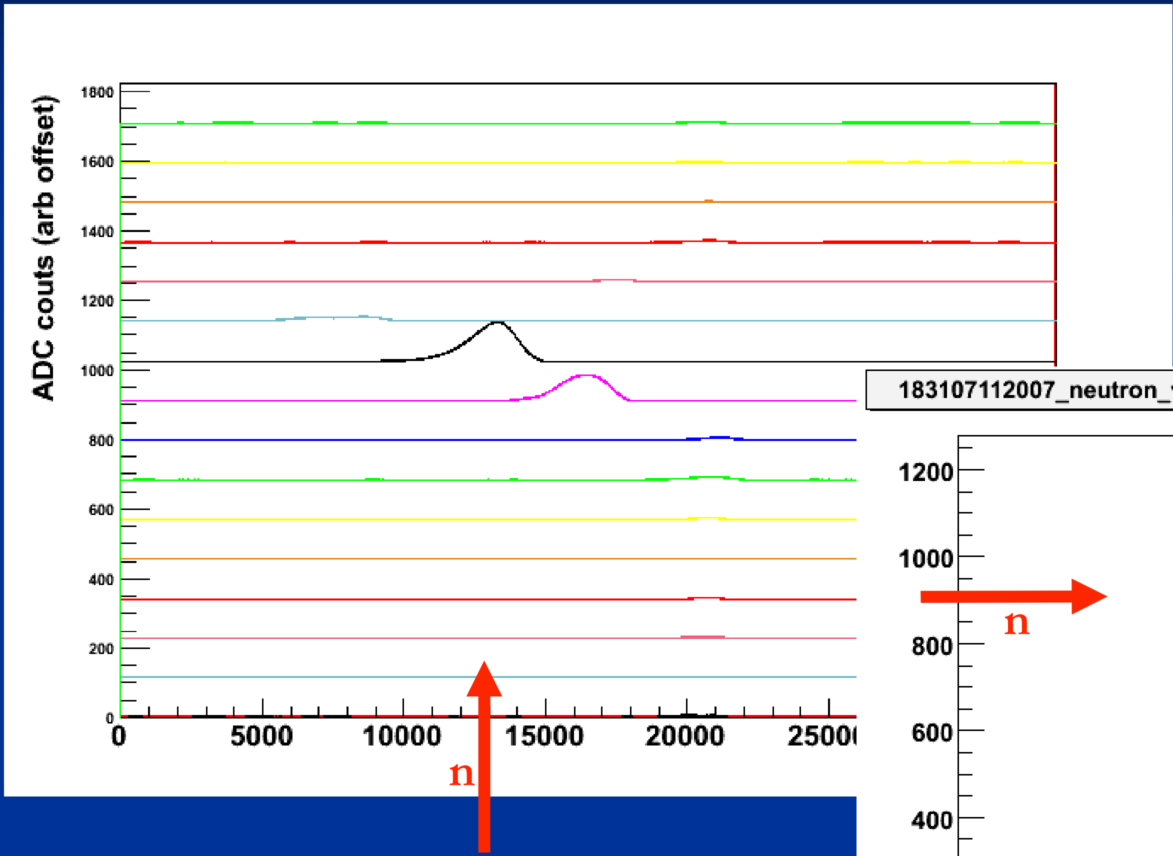
Position 2 (from strip 1), **NIPs > 1000**:

→ > 1000 NIPs corresponds to:

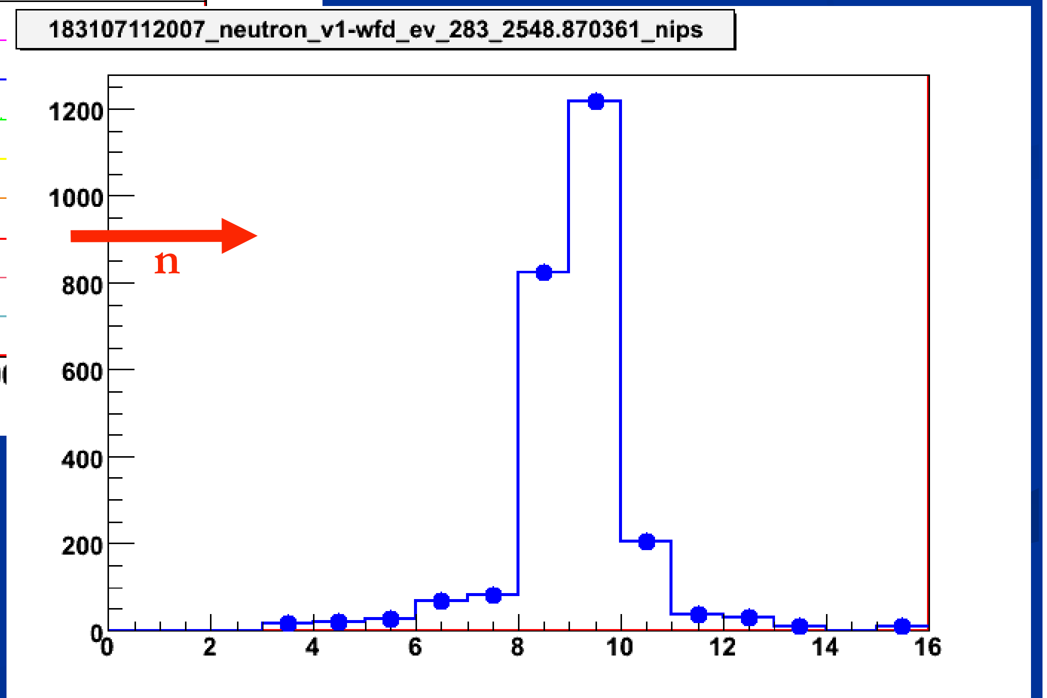
- > 50keV Sulfur recoil → range: > 0.45 mm
- > 30keV Carbon recoil → range: > 1.5 mm

Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs > 1000:

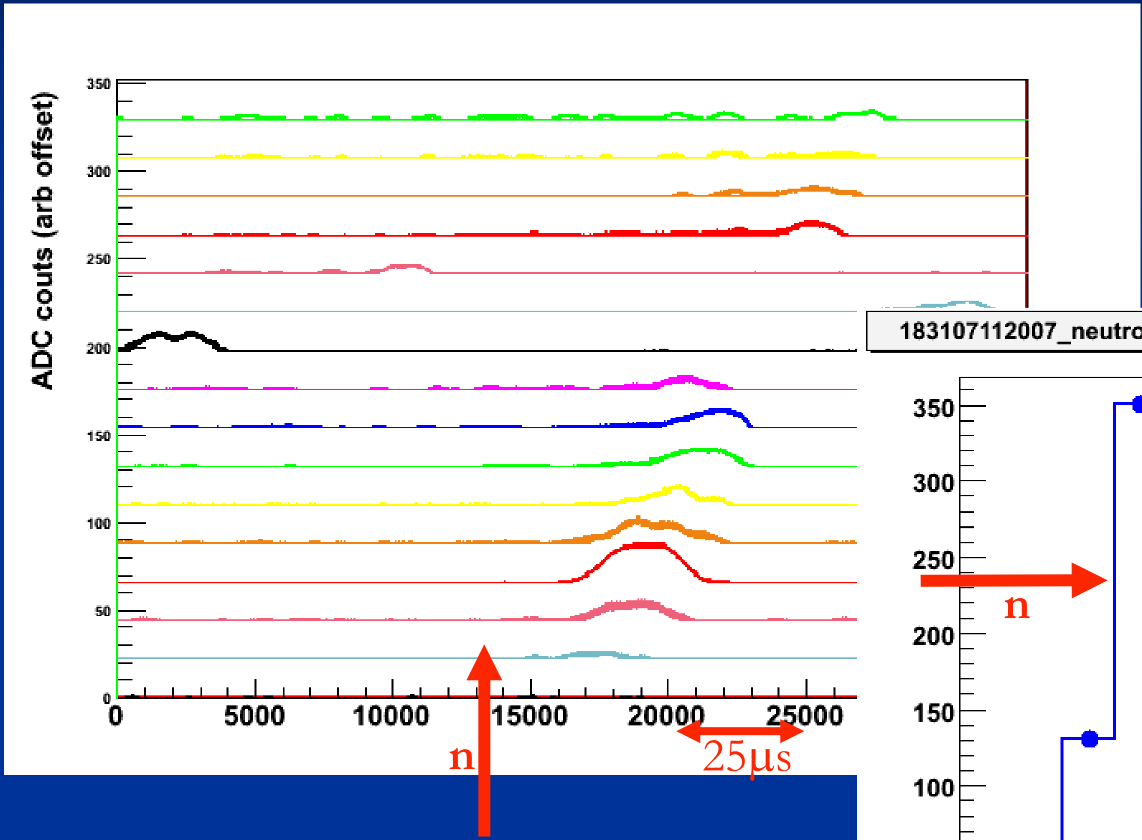


Event has ~2550 NIPs
Δx ~0.6 mm
Δz ~ ?
[95keV Sulfur recoil (?)]

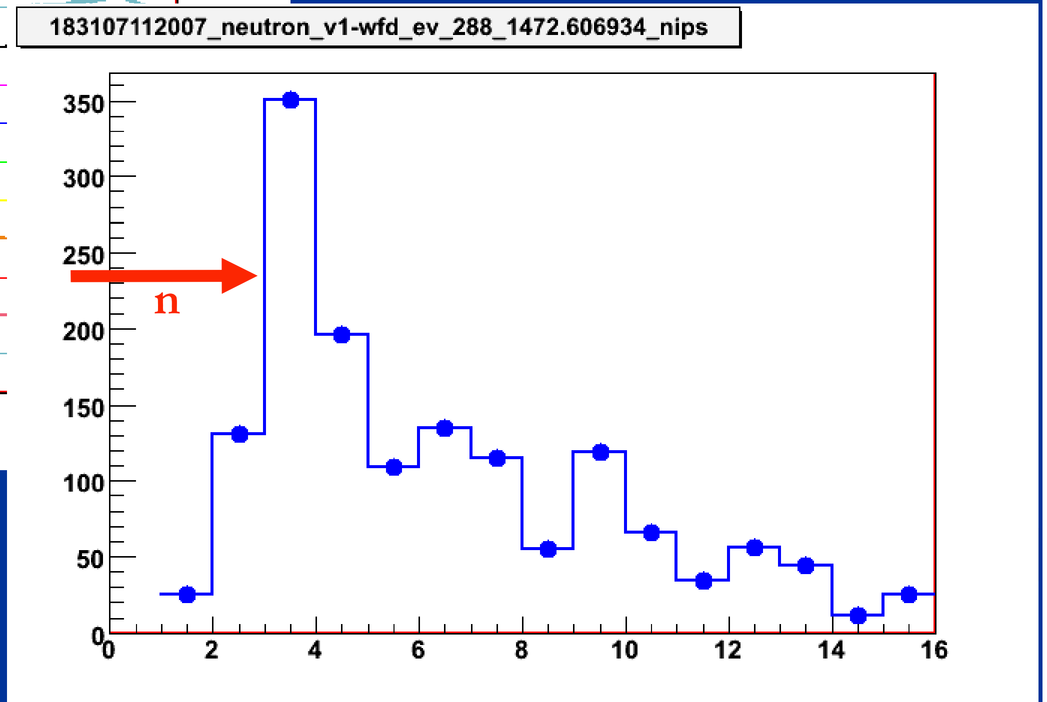


Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs > 1000:

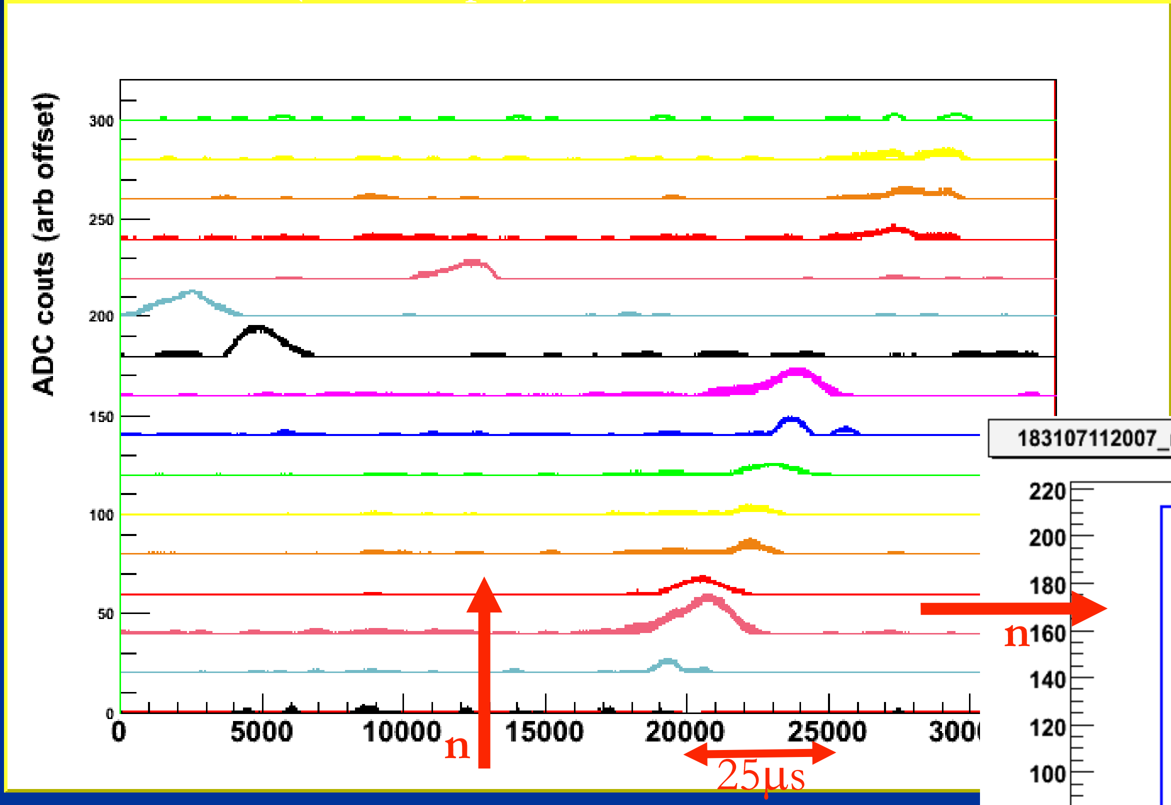


Event has ~1500 NIPs
Δx ~1.2-1.4 mm
Δz ~ 1.2mm
[40keV Carbon recoil (?)]

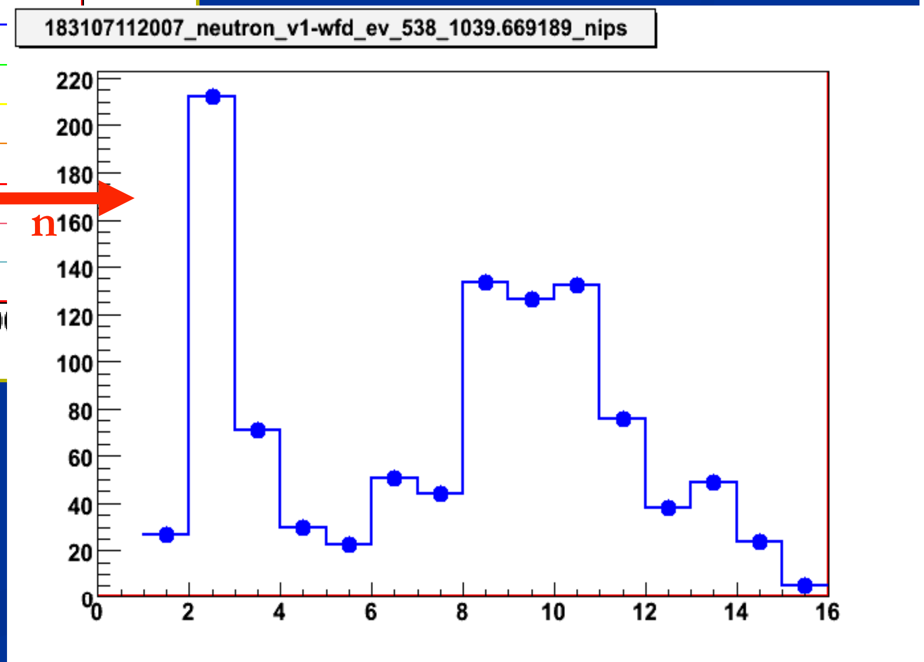


Measuring low energy nuclear recoils

Position 2 (from strip 1), NIPs > 1000:

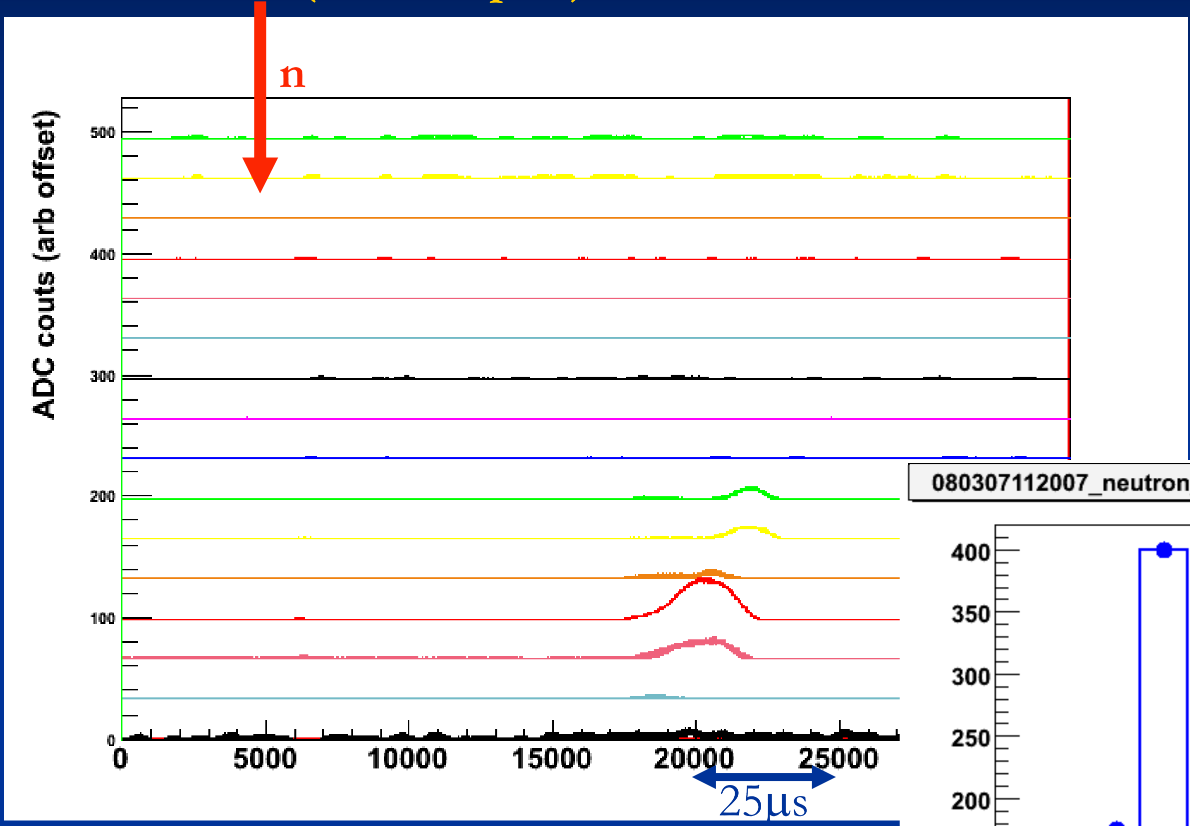


Event has ~1050 NIPs
Δx ~1.4 mm
Δz ~ 1.1mm
[31keV Carbon recoil]

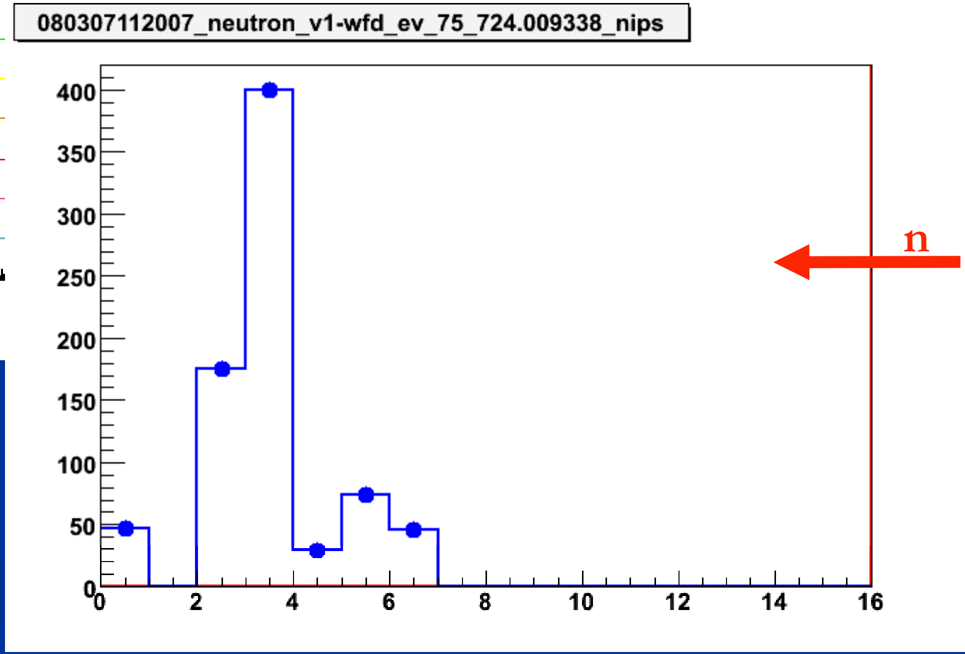


Measuring low energy nuclear recoils

Position 1 (from strip 16), NIPs < 1000:



Event has ~725 NIPs
Δx ~ 0.8 mm
Δz ~ 0.2mm
[22keV Carbon recoil]



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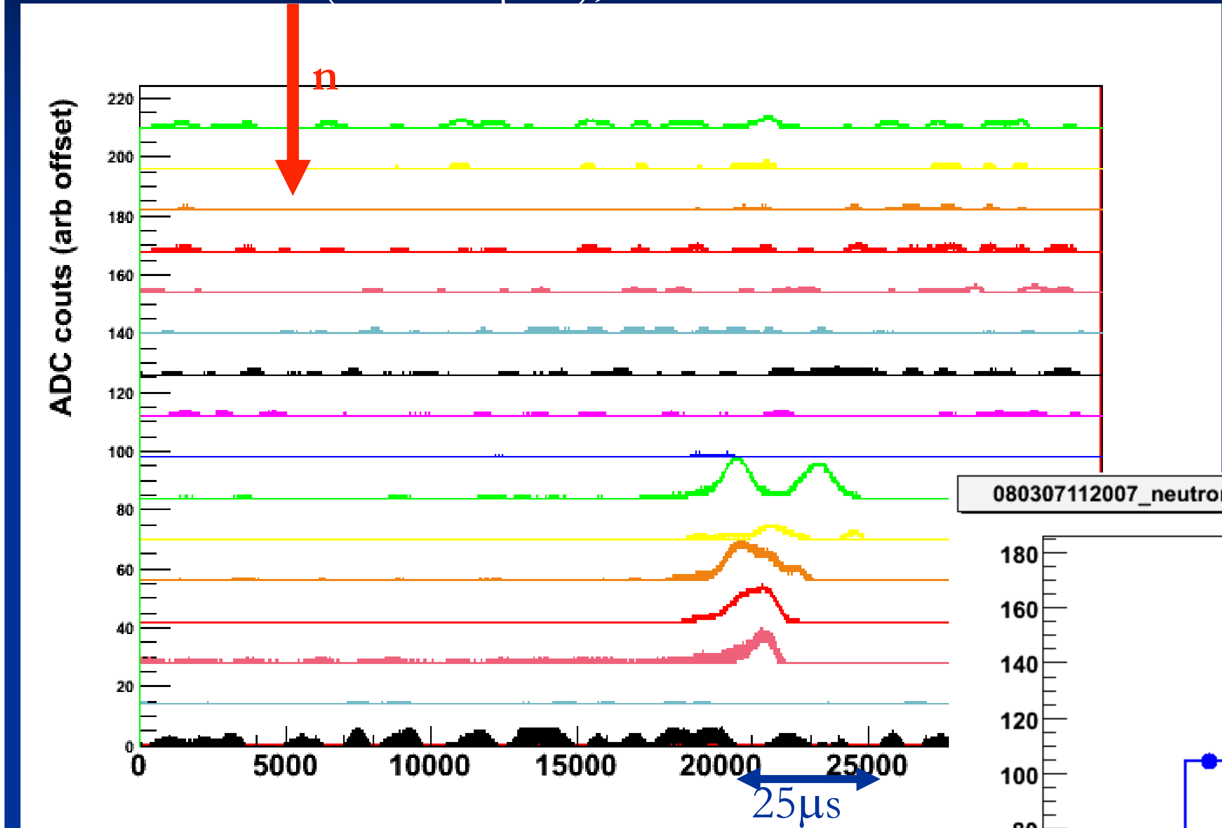

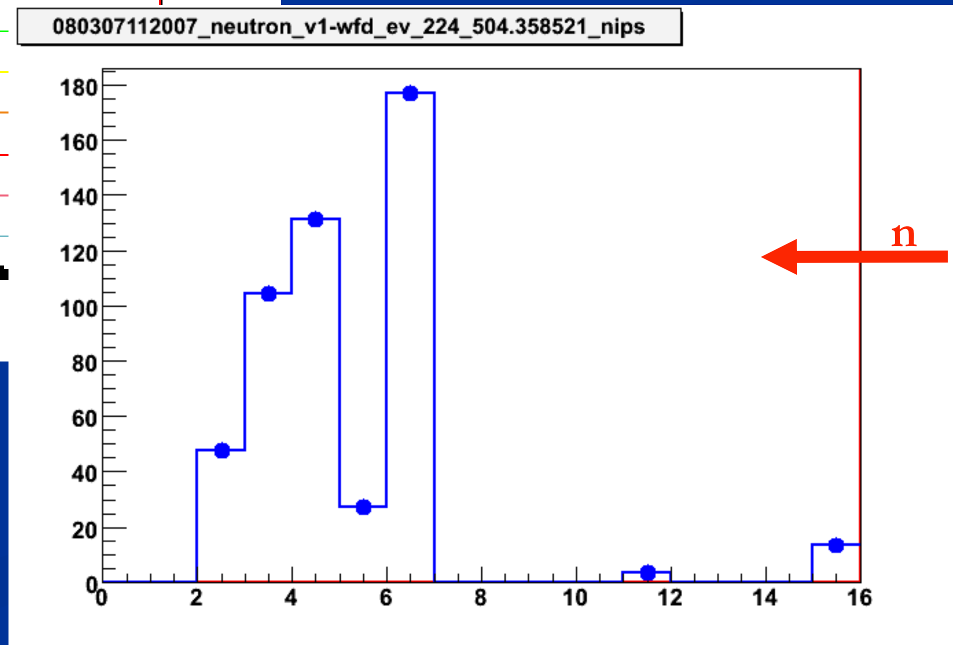

Event has ~500 NIPs
Δx ~ 0.8 mm
Δz ~ 0.5mm
[17keV Carbon recoil]

Measuring low energy nuclear recoils

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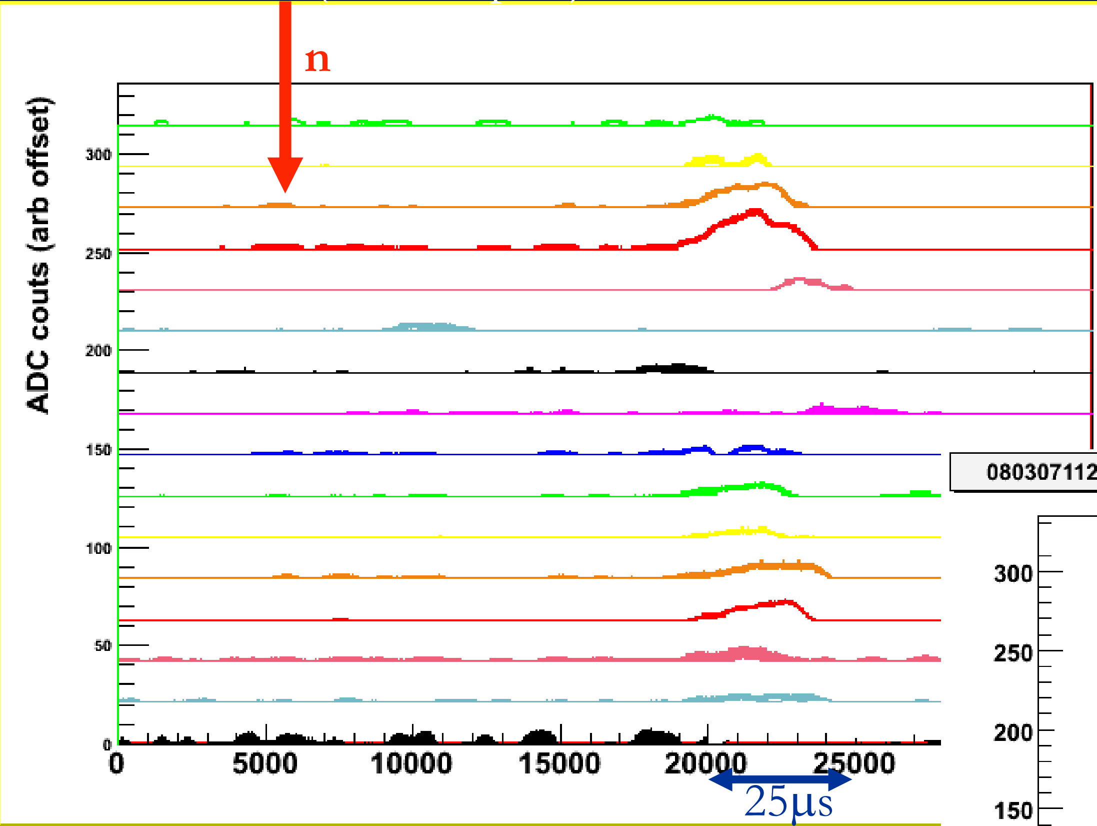
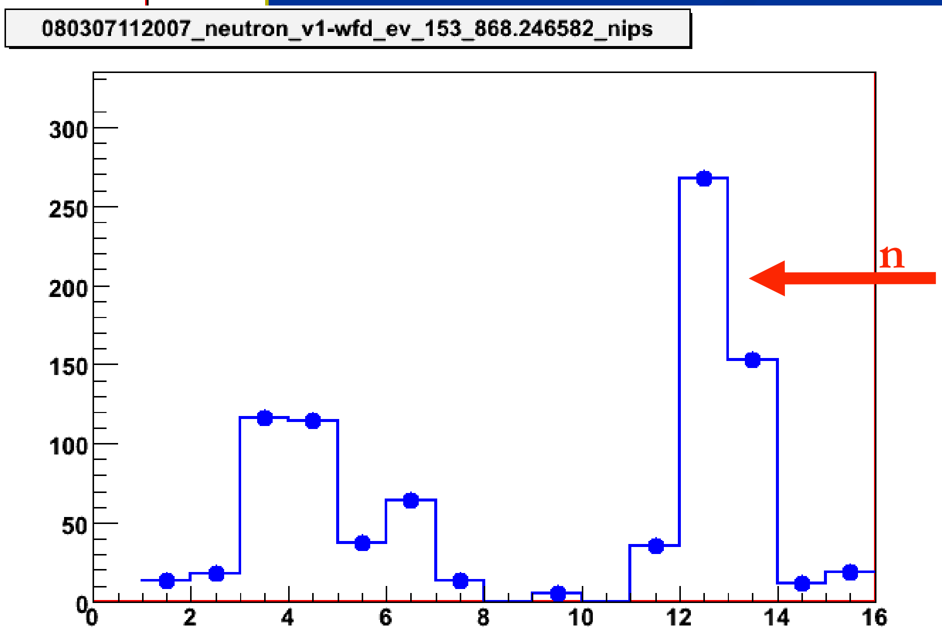
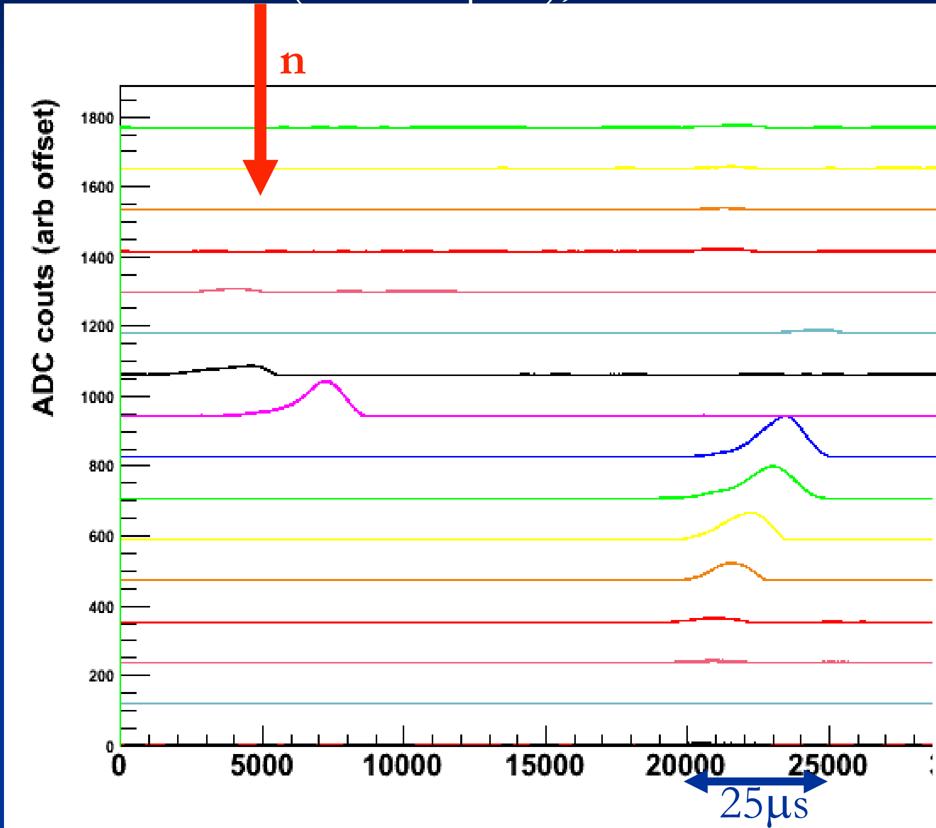


Event has ~870 NIPs
Δx ~ 1.2 – 1.4 mm
Δz ~ 0.2mm
[28keV Carbon recoil]

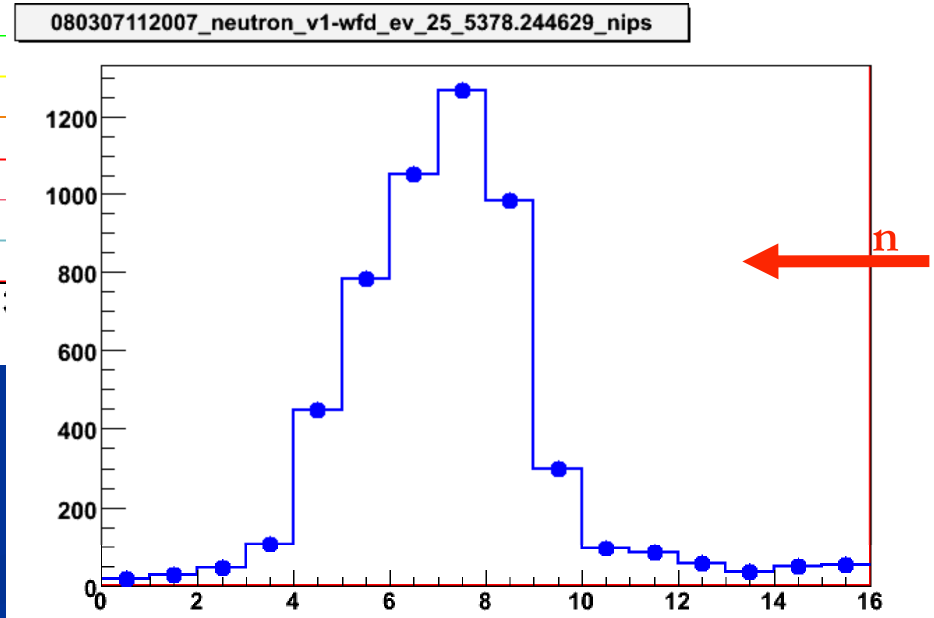


Measuring low energy nuclear recoils

Position 1 (from strip 16), NIPs > 1000:



Event has ~5400 NIPs
Δx ~ 1.2 – 1.4 mm
Δz ~ 0.2mm
[200keV Sulfur recoil]



Measuring low energy nuclear recoils

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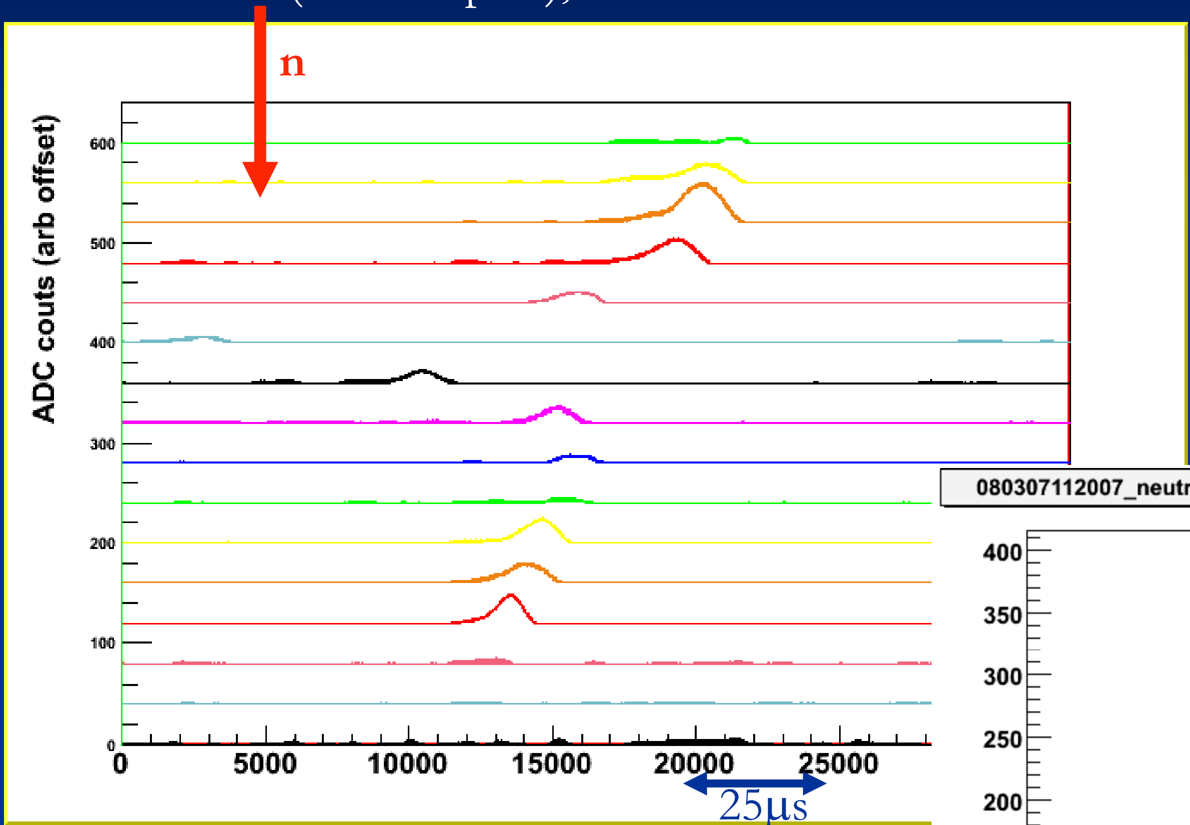
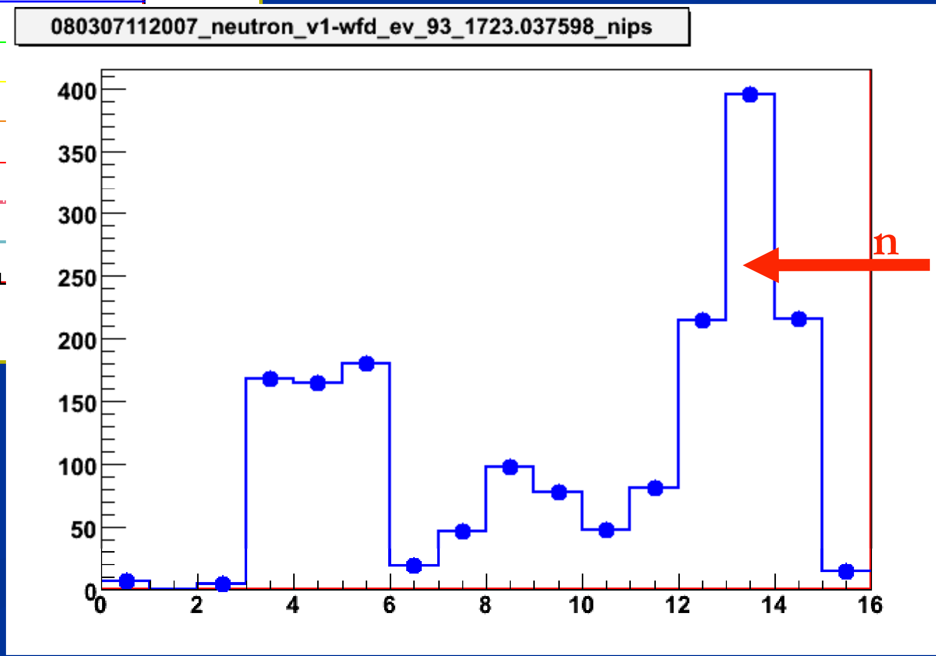
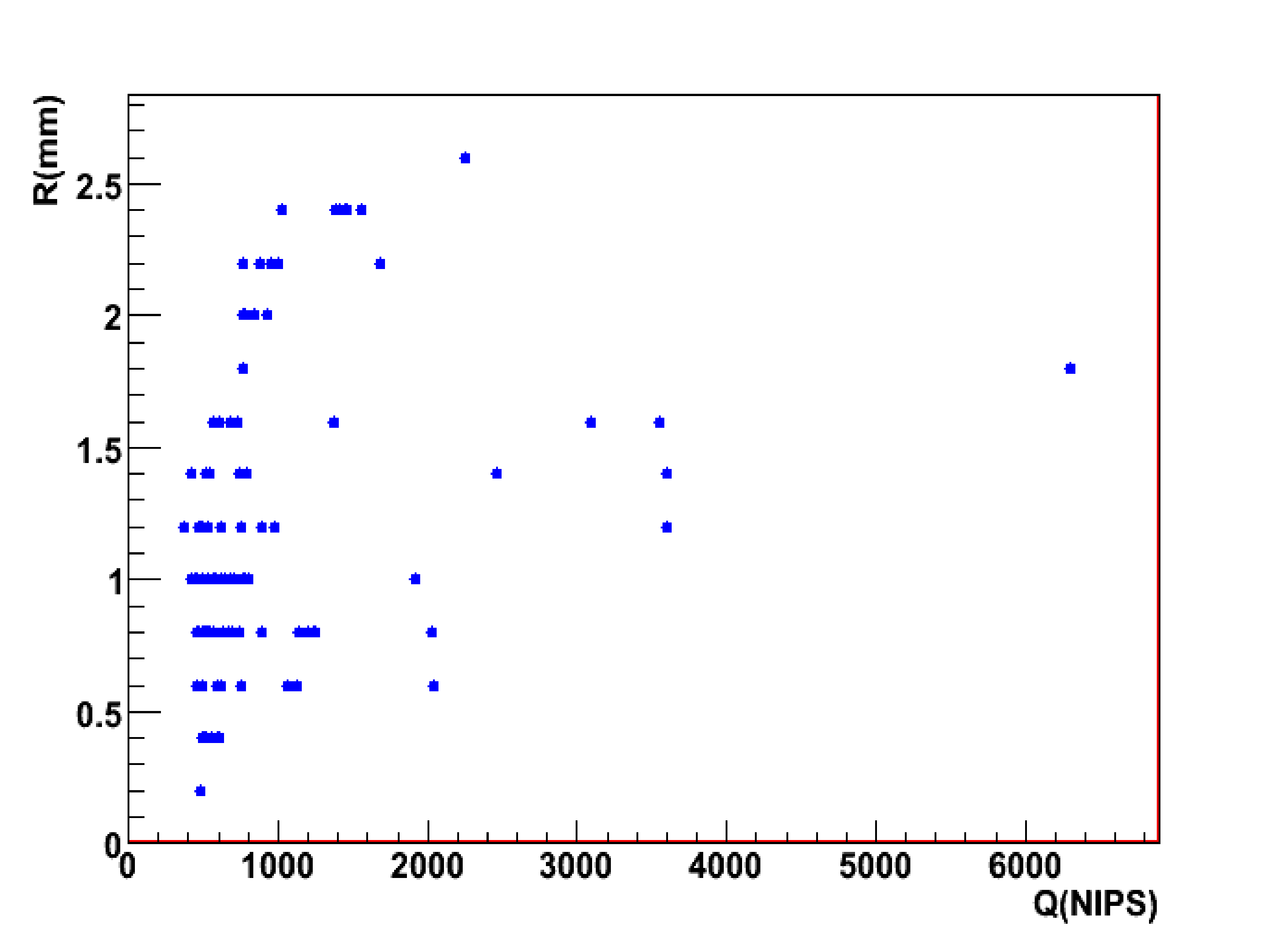


Event has ~1700 NIPs
Δx ~ 1.2 – 1.4 mm
Δz ~ 0.2mm
[48keV Carbon recoil]



Measuring low energy nuclear recoils

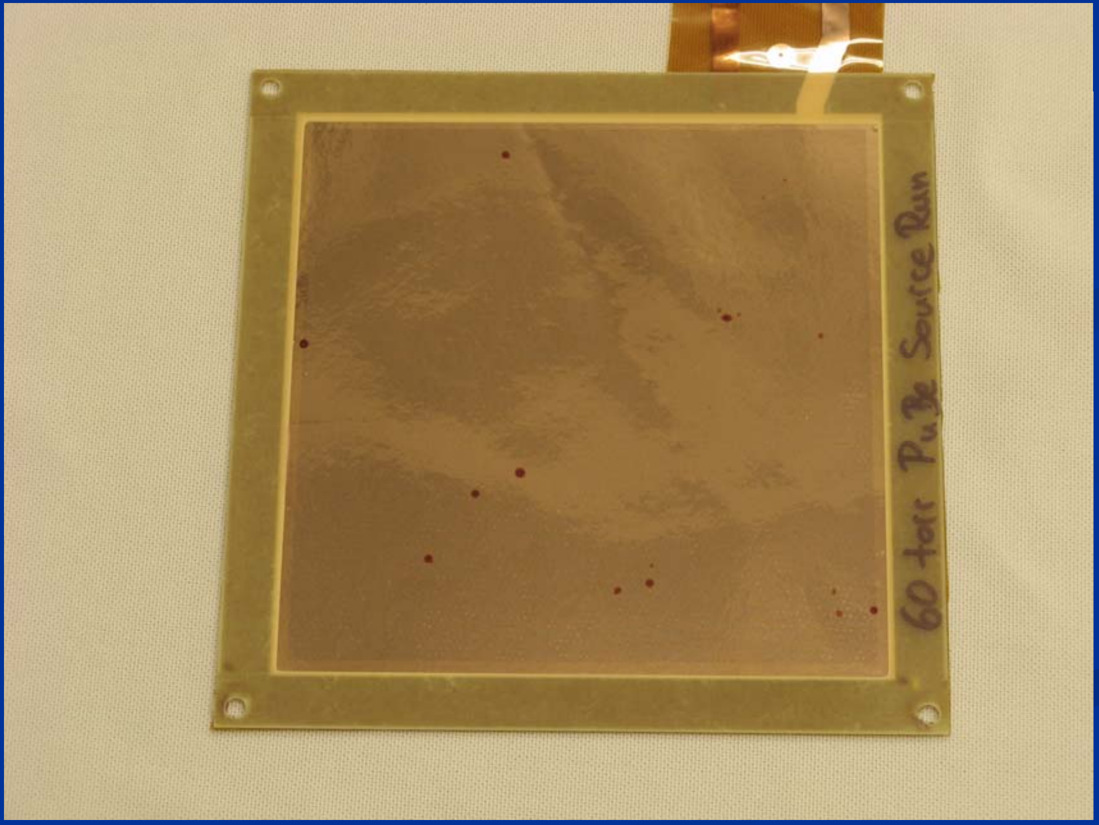
1D range vs. NIPs plot



6 hour γ run with ^{60}Co source: No event passed the cuts for the ^{252}Cf source !

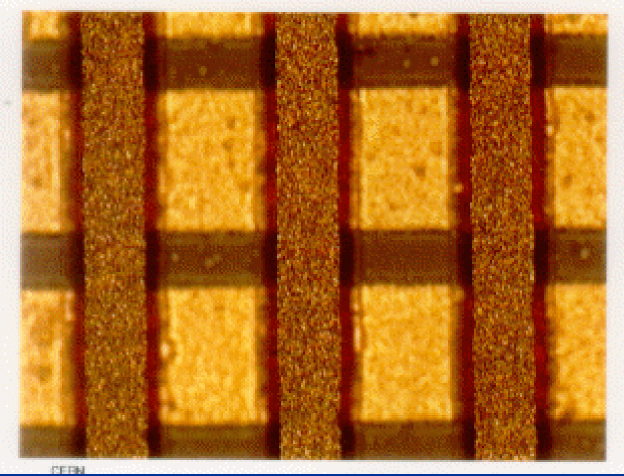
Measuring low energy nuclear recoils

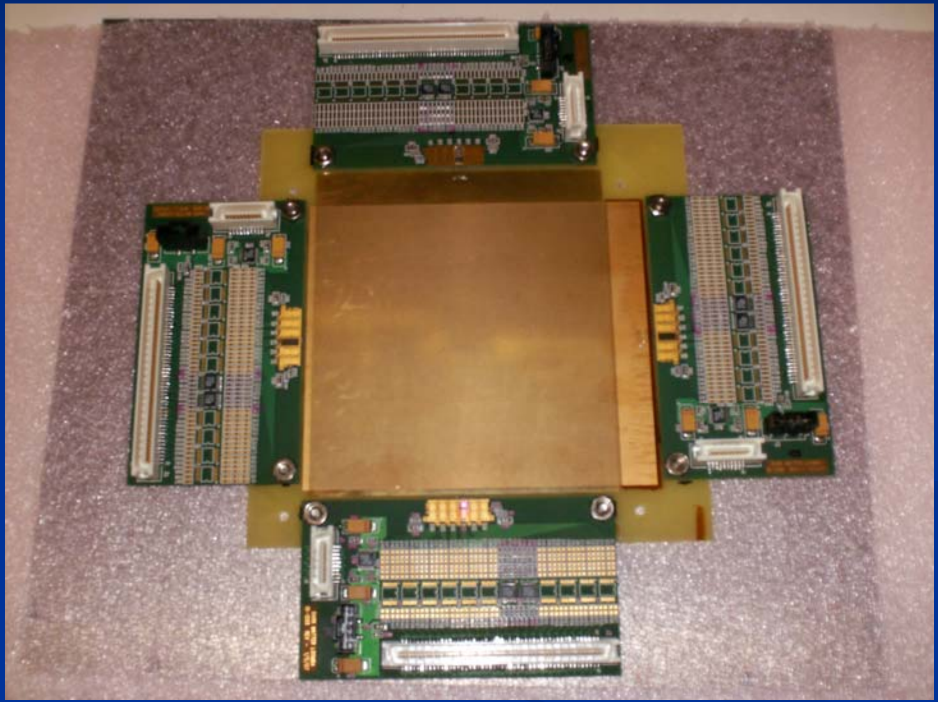
- Not the whole story because we only have 1D readout
- We ran for 10 days in CS_2 -> No problems with GEM
- Ran 2hrs with a 1Ci PuBe source -> GEM was destroyed!!!



Next Steps

- New 2 dimensional readout board designed and prototype assembled at BNL (using 2D readout board from CERN) instrumenting a 3.2 x 3.2 mm^2 region of the readout board





- 2 x 2 cm^2 is being build (extension of the smaller version)

- 300µCi ^{252}Cf source from ORNL has been ordered

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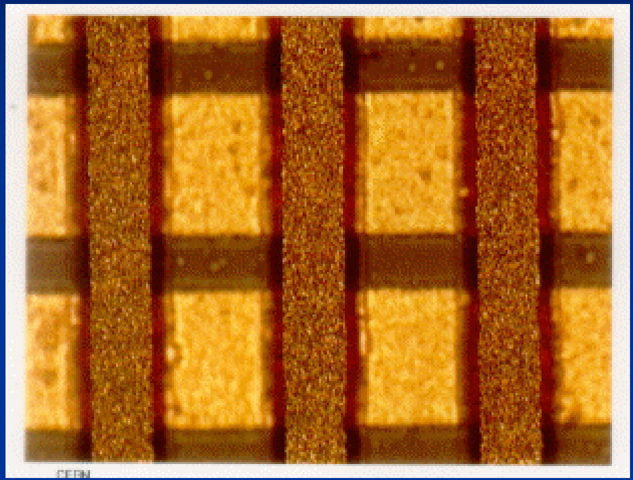
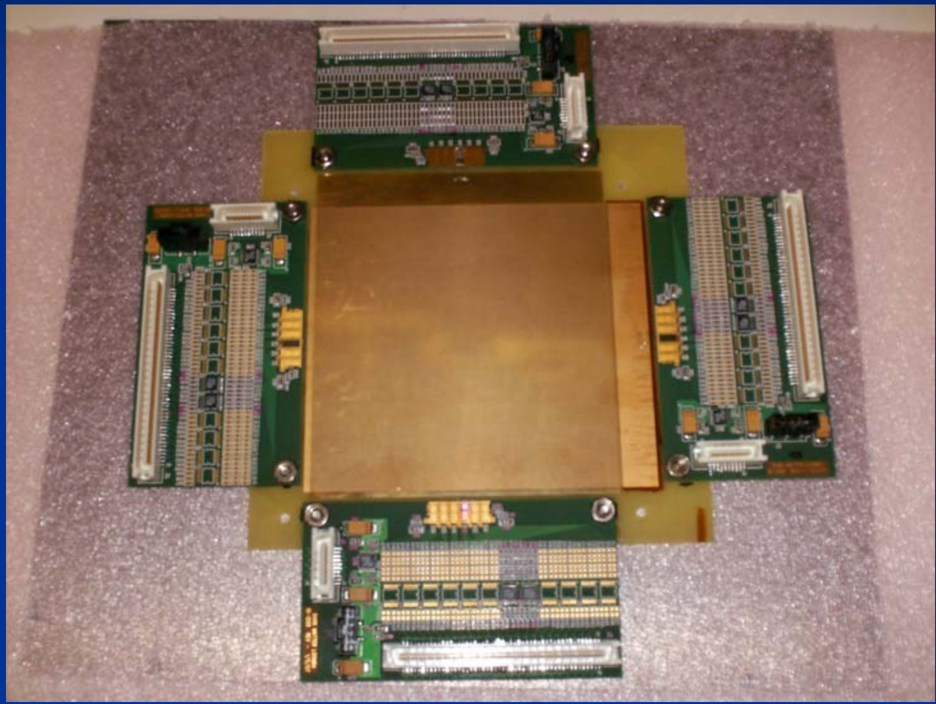




- 2 x 2 cm^2 is being build (extension of the smaller version)

- 300μCi ^{252}Cf source from ORNL has been ordered

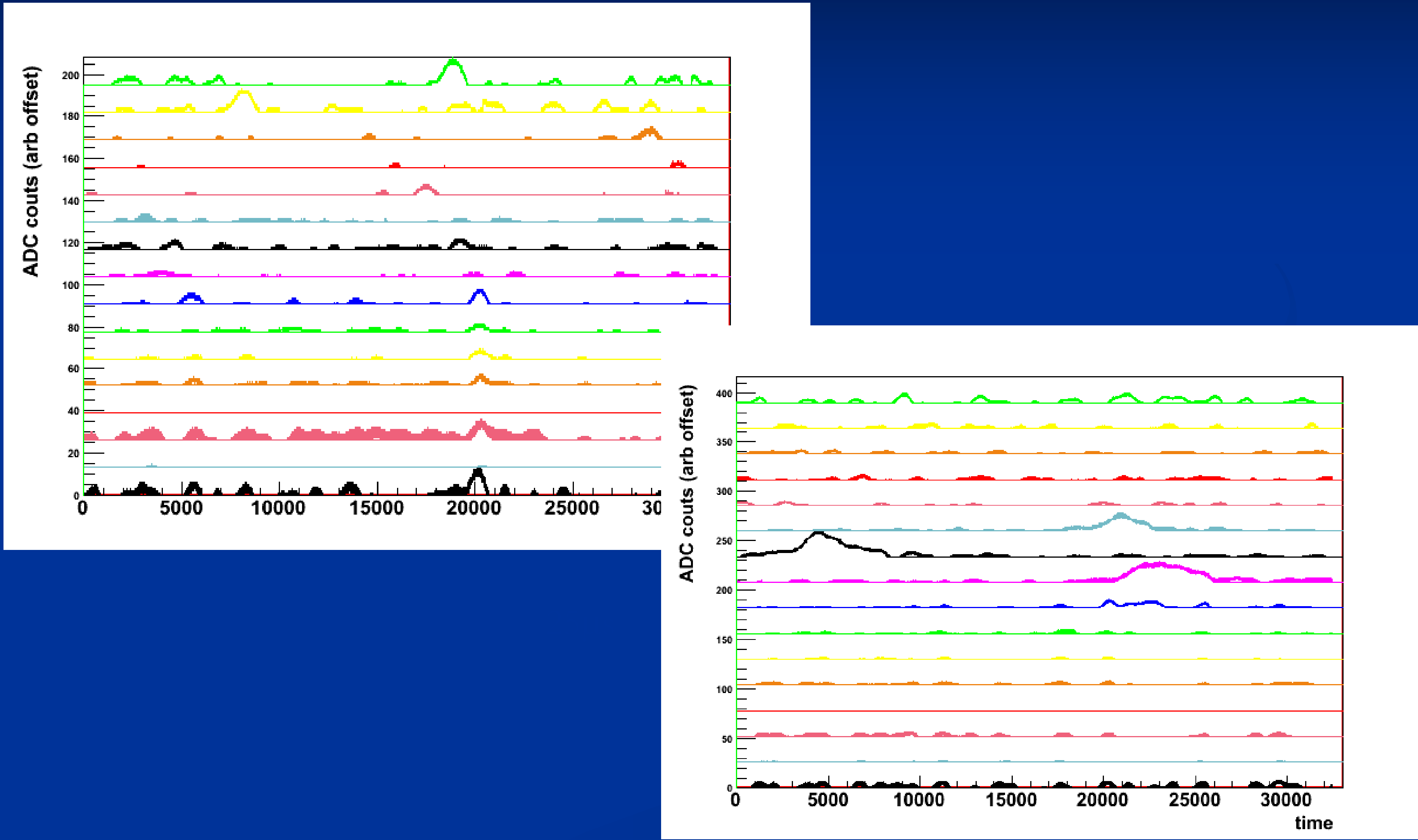
Longer Term: Build larger area detector → discussion with BNL regarding new FE electronics

Summary

- Detector has necessary resolution and signal to noise to see low energy nuclear recoils
- need to implement 2D and 3D to make recoil dE/dx measurement and characterize a head-tail asymmetry

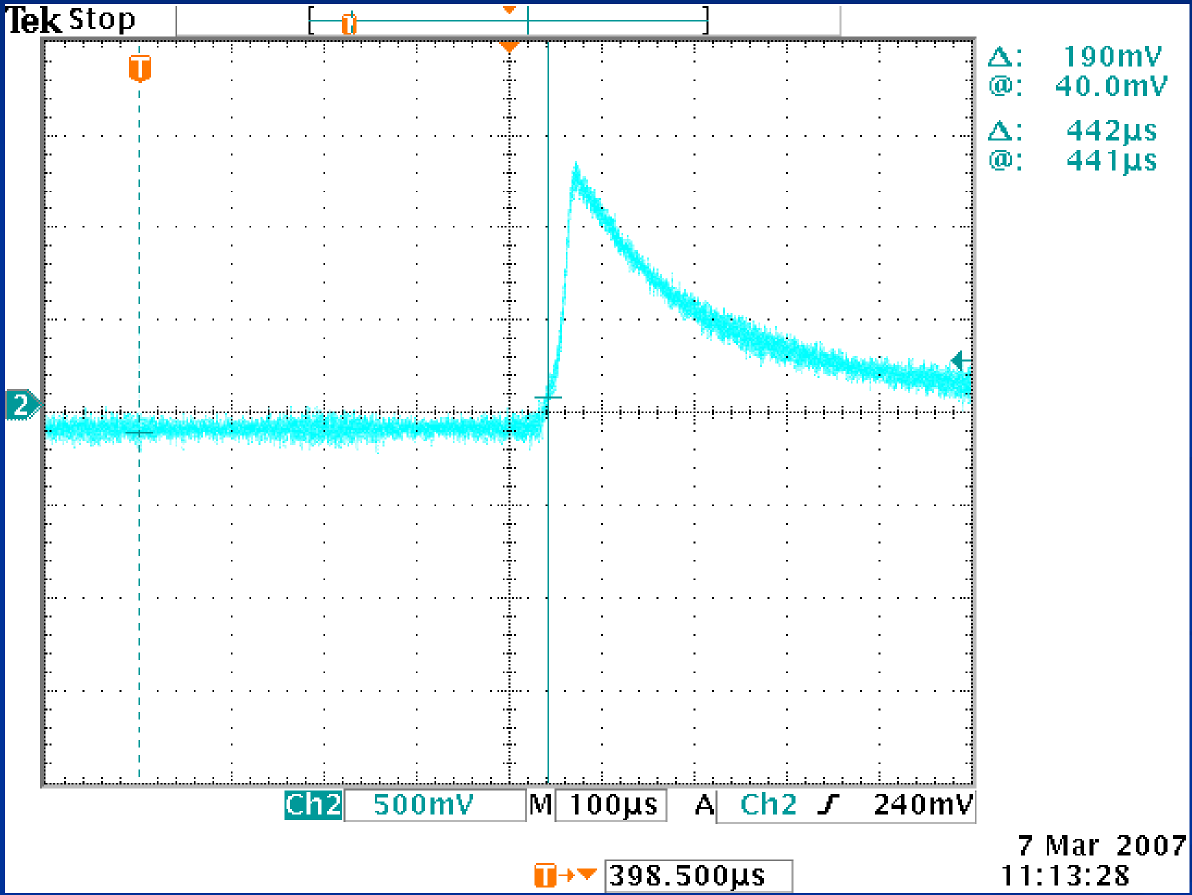
Measuring low energy nuclear recoils

^{60}Co gamma run:



CS_2 measurements

Measure the drift velocity using wire-GEM distance and time delay between laser trigger and pulse arrival (reading off the bottom of the GEM):



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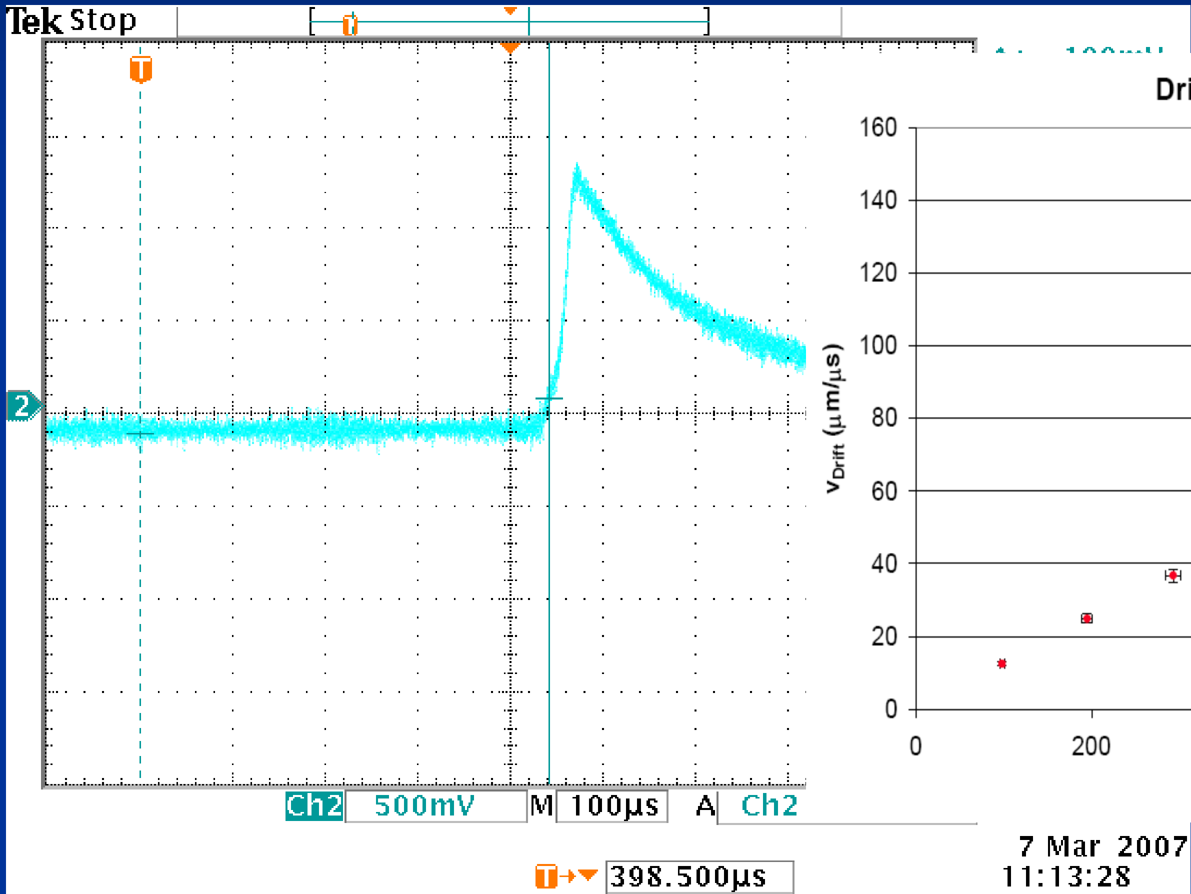
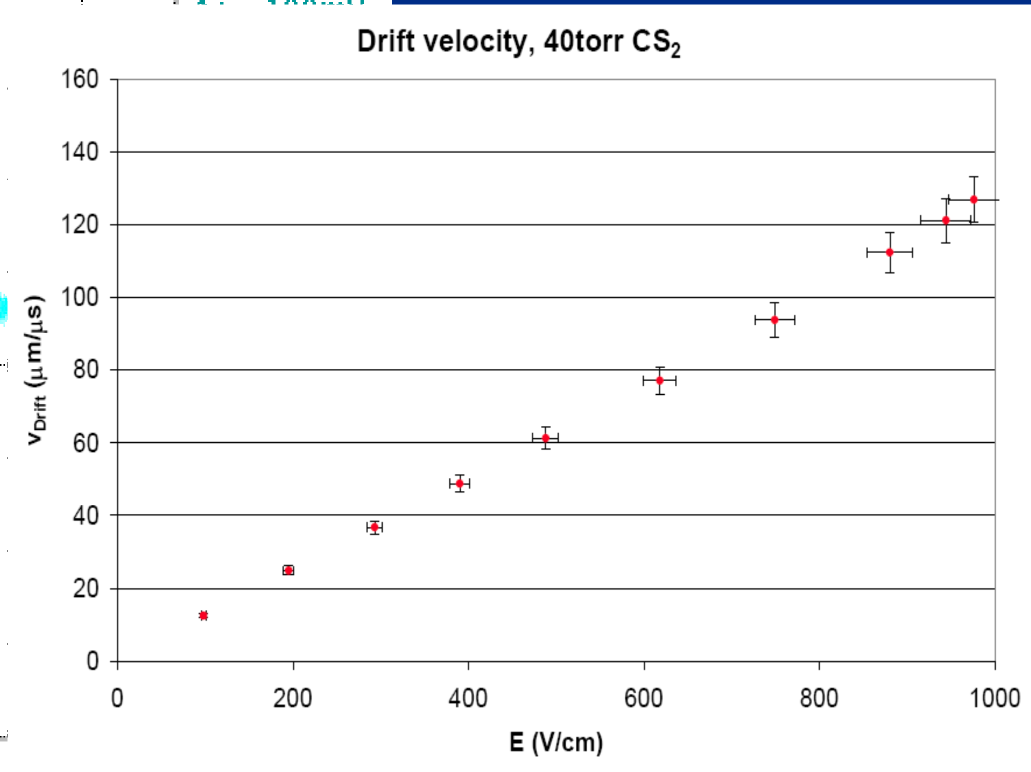
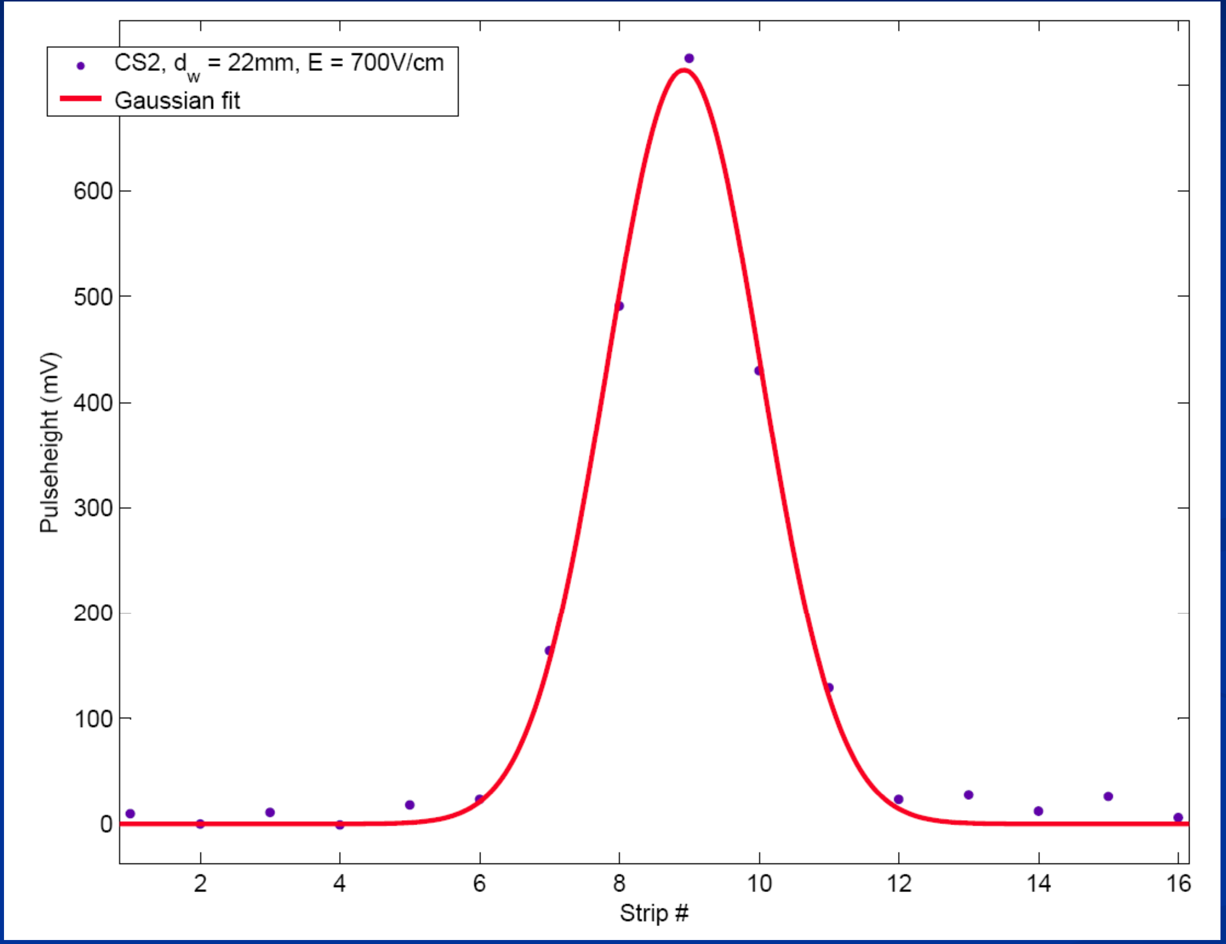




CS_2 Diffusion

Diffusion measurements at 40torr; E_i = 3000V/cm, ΔV_{GEM} = 359V, E_D = 700V/cm



→ σ_{meas} = 220μm

$\sigma_{expected}$ = 700μm x $[(d/1m)(E/kV)]^{0.5}$ = 123μm

Magboltz predicts:

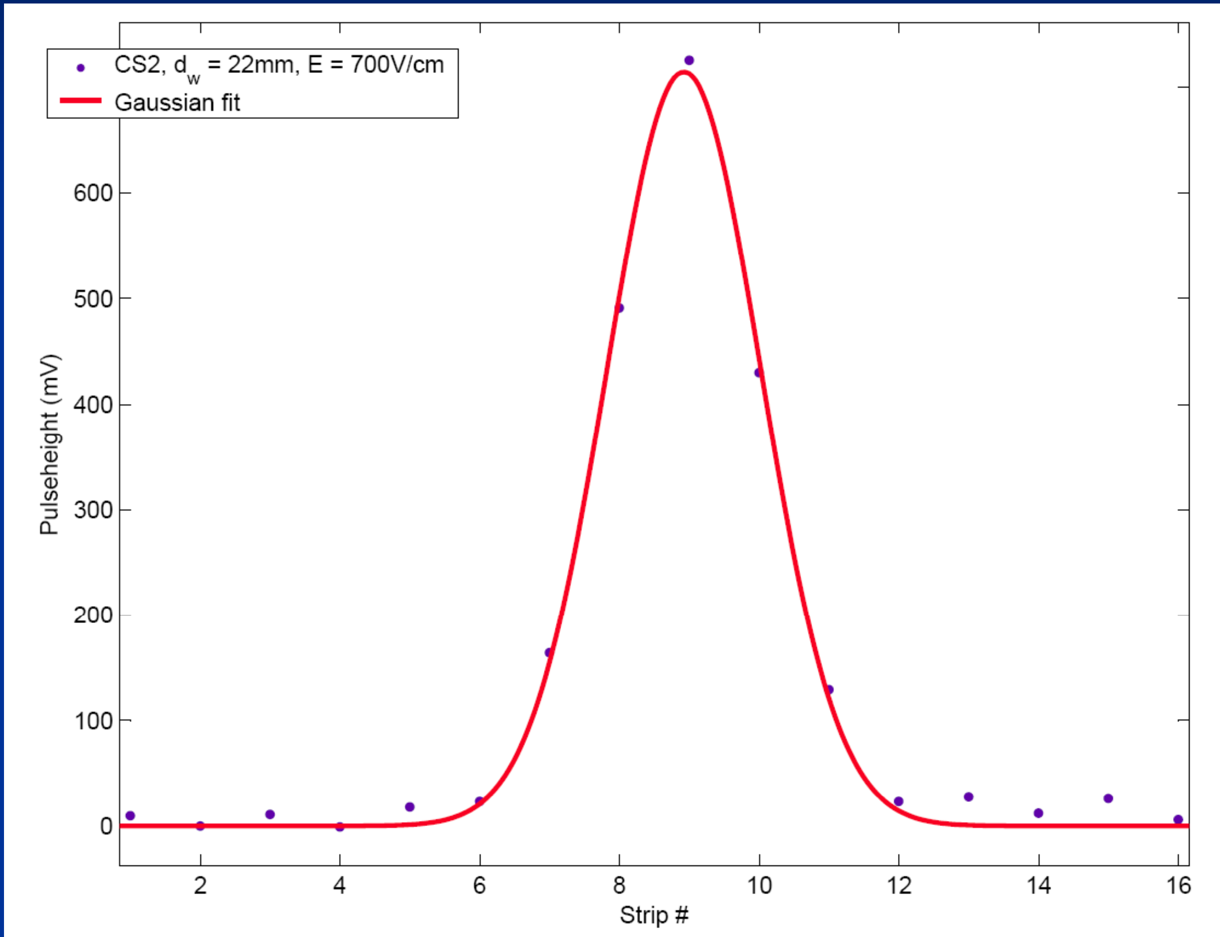
$\sigma_{induction}$ = 219μm

for (3mm, 3500V/cm)

→ σ_{total} ~ 250μm

CS_2 Diffusion

Diffusion measurements at 40torr; E_i = 3000V/cm, ΔV_{GEM} = 359V, E_D = 700V/cm



→ σ_{meas} = 220μm

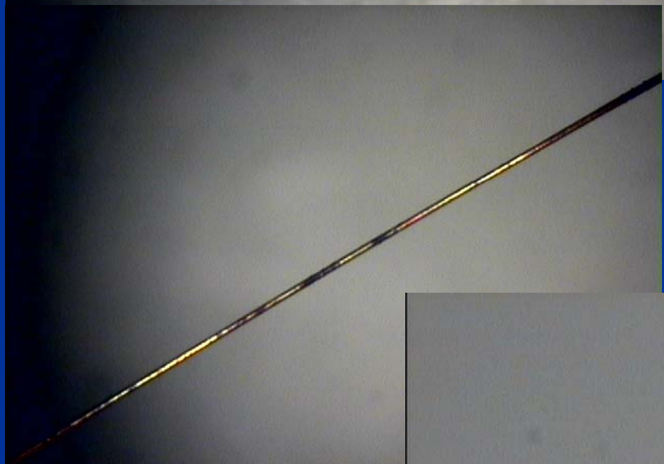
$\sigma_{expected}$ = 700μm x $[(d/1m)(E/kV)]^{0.5}$
= 123μm

Magboltz predicts:
$\sigma_{induction}$ = 219μm
for (3mm, 3500V/cm)
→ σ_{total} ~ 250μm

To decouple the effect of the diffusion in the induction region and the effect of the intrinsic charge distribution from the wire, we need to make more measurements at other drift distances and different E_i's

CS_2 Diffusion

Discharges destroying the wire & PreAmp:

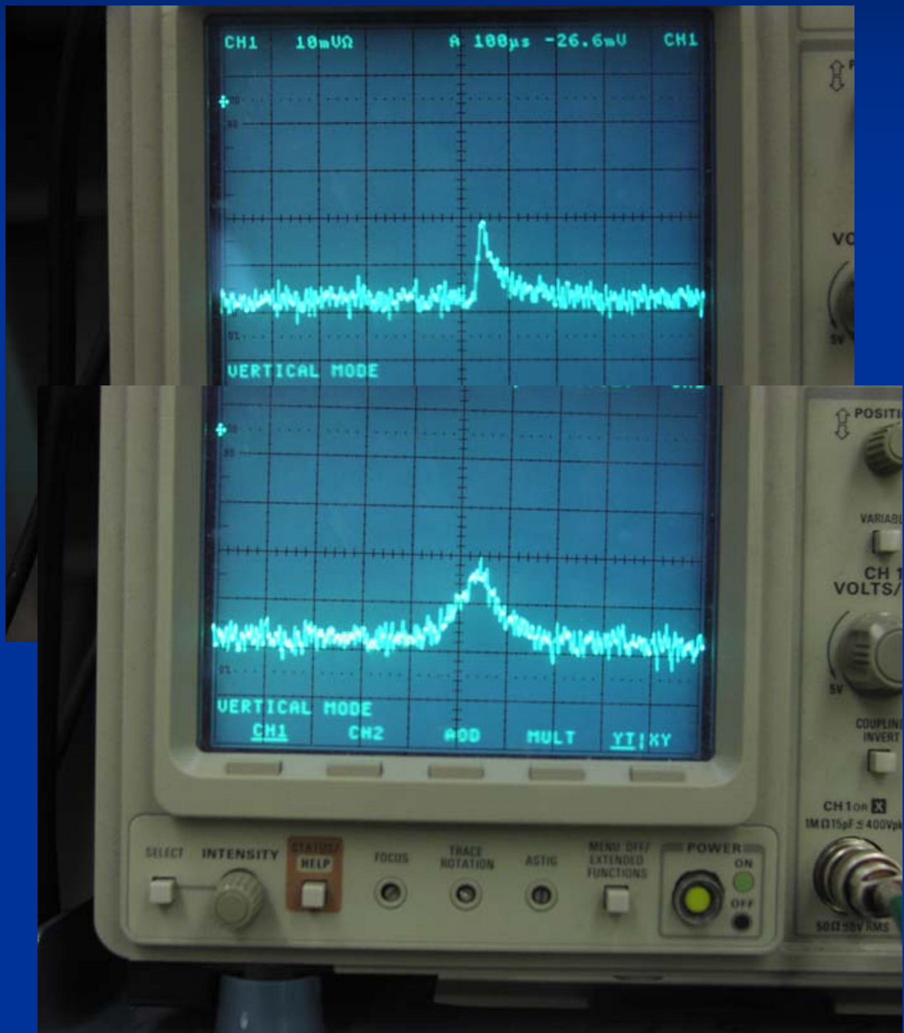


Other ideas:

- Different wavelength laser
- femto second laser
- Try CS_2 with Nitrogen Laser & without wire

CS_2 ^{55}Fe Spectrum

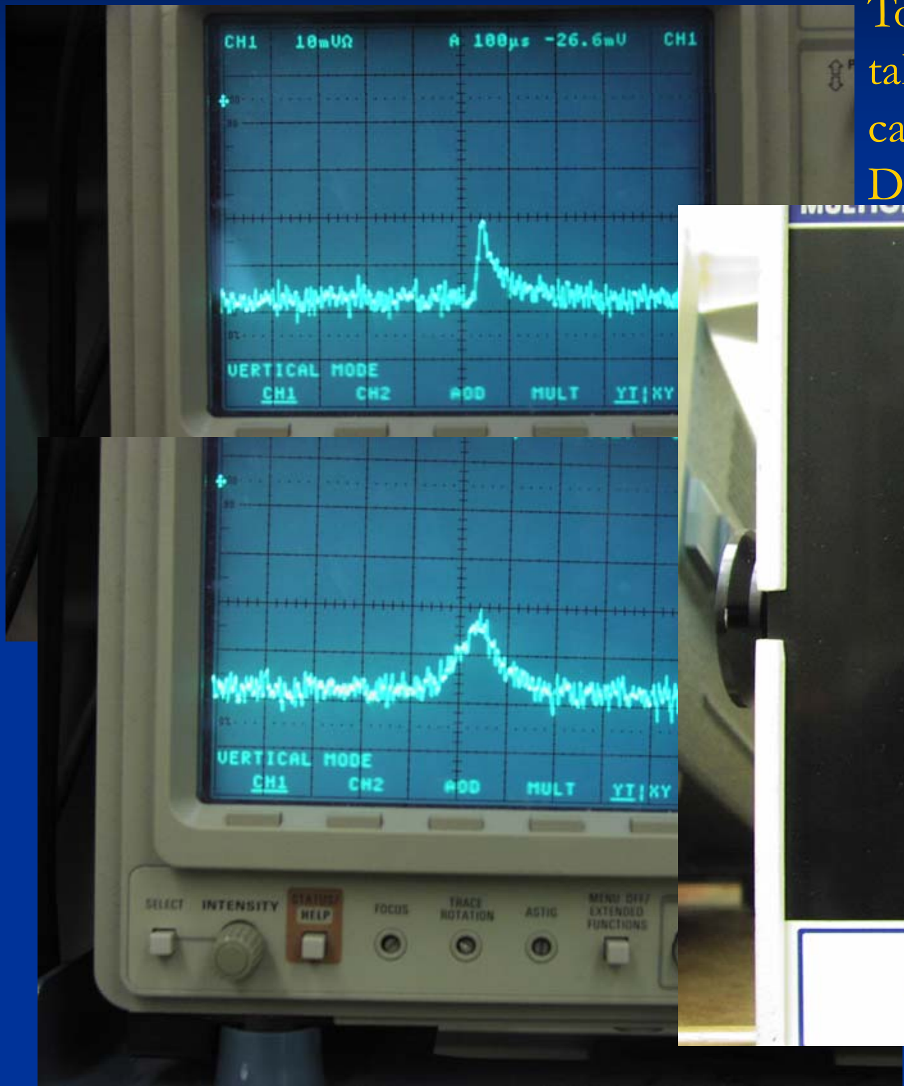
^{55}Fe signals taken from the bottom of the GEM show varying widths, some much longer than amplifier shaping time of 6μs;

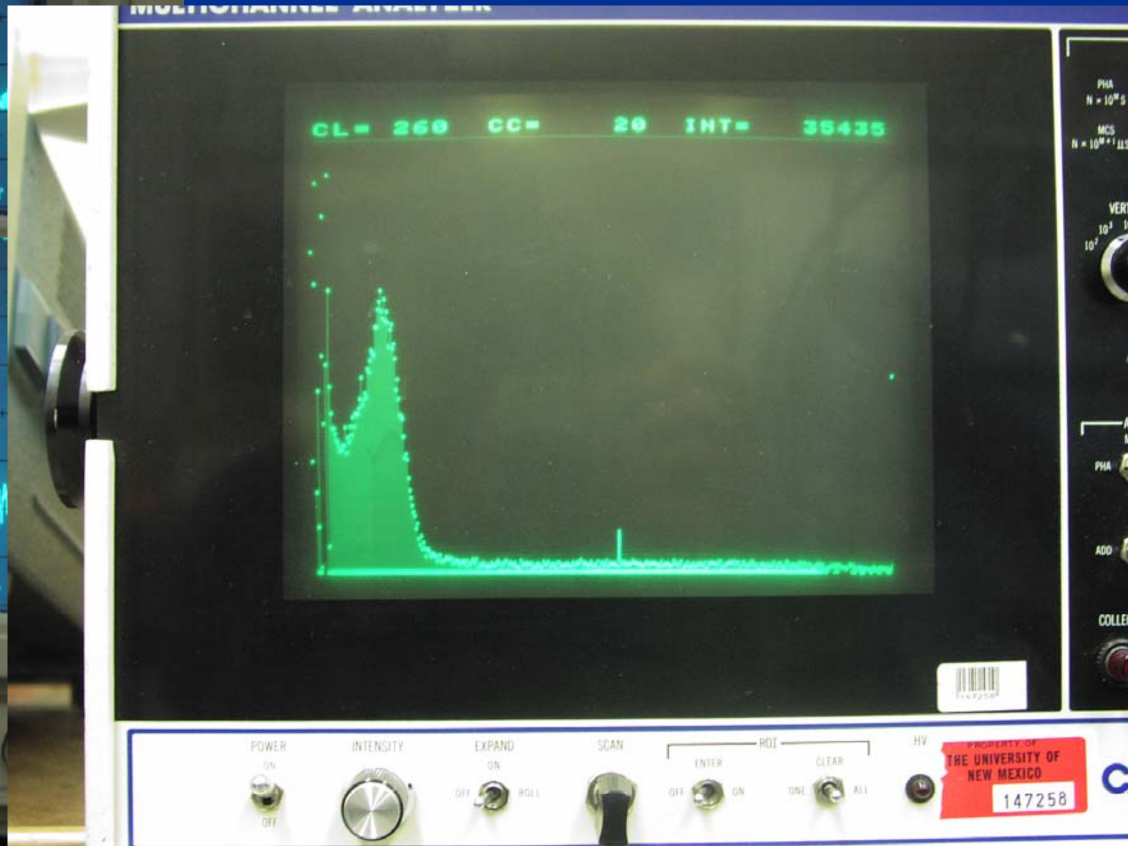


CS_2 ^{55}Fe Spectrum

^{55}Fe signals taken from the bottom of the GEM have very different widths:

To obtain spectrum, a histogram of pulse heights taken with MCA is not enough, we will need to calculate area under pulse height as is done in DRIFT





$E_d \sim 830V/cm$, $\Delta V_{GEM} = 418V$