Fast Neutron Detection with MITPC

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DPF: August 8, 2015

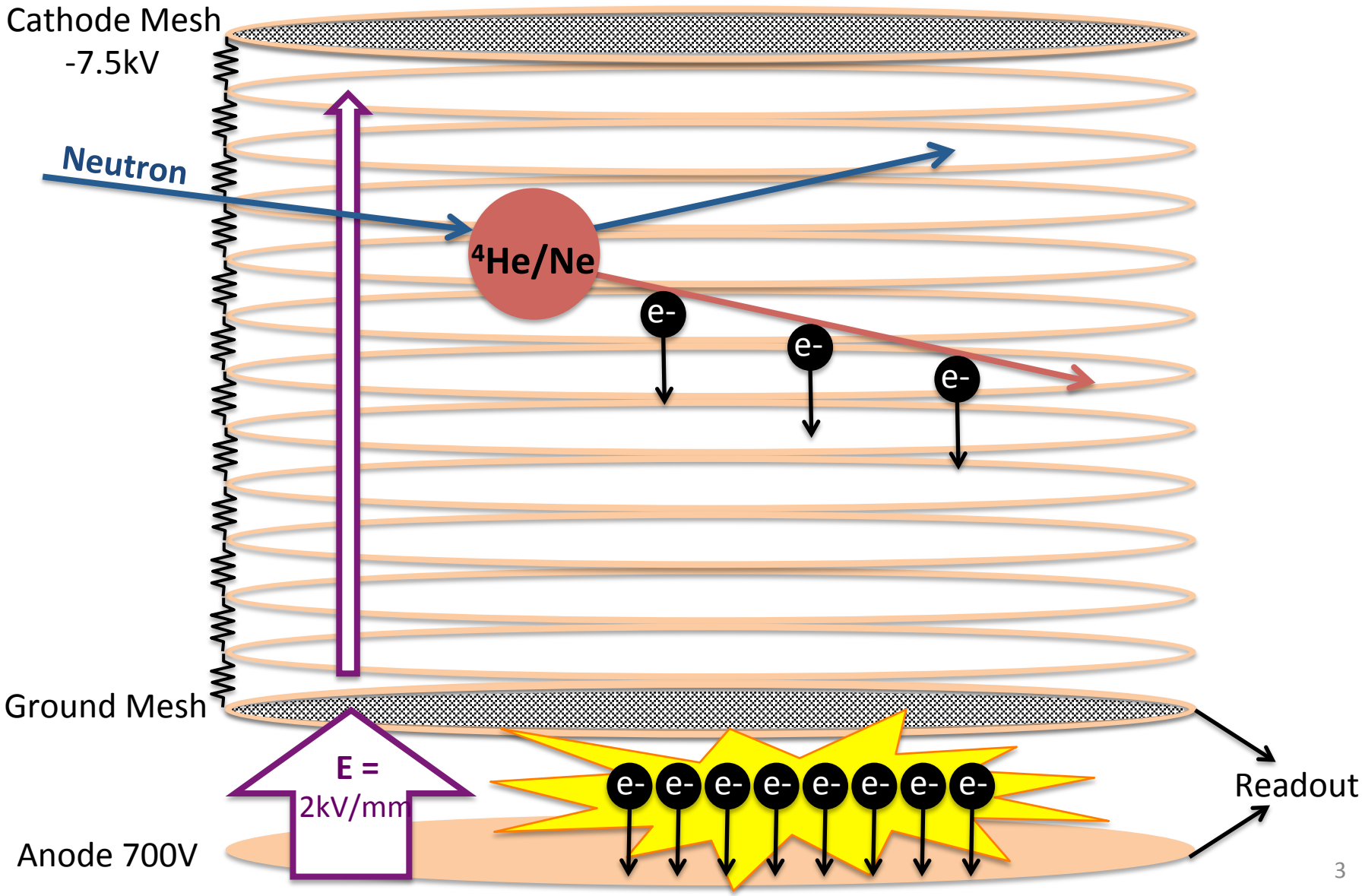
Motivation:

- Fast neutrons are a background
- Lack of measurements
- MITPC is a directional fast neutron detector

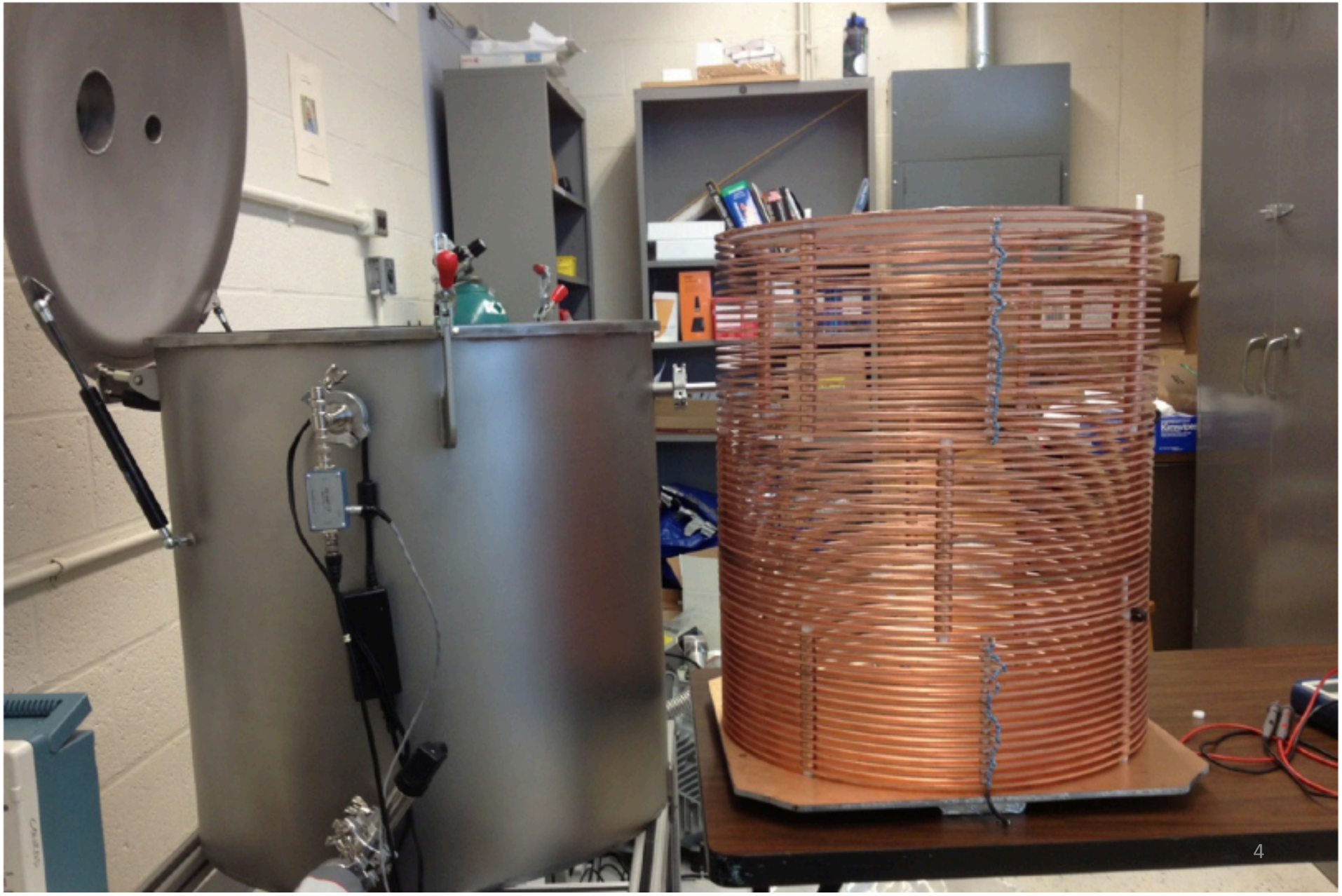
This talk:

- Detector design
- DCTPC run at Double Chooz
- MITPC run at Fermilab
- Neon studies

87.5% ^{4}He/Ne + 12.5% CF_4 @ 600 Torr



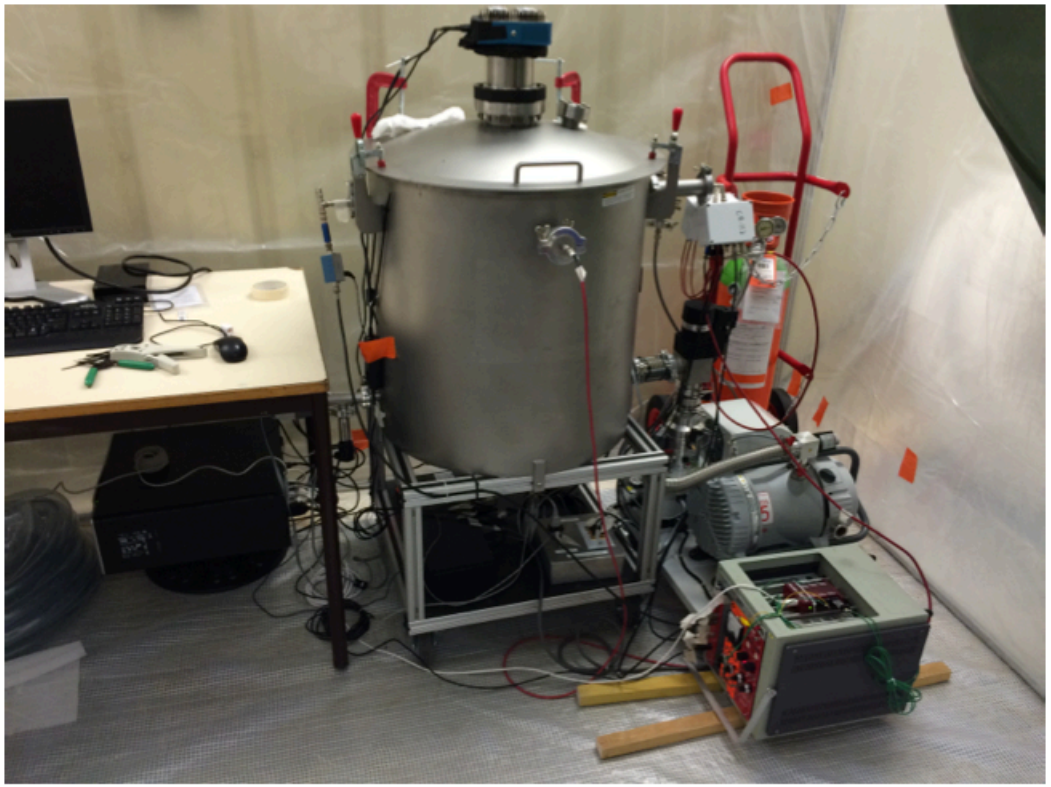
Field cage outside of chamber



Prototype and full-size detector installed at Double Chooz

Prototype

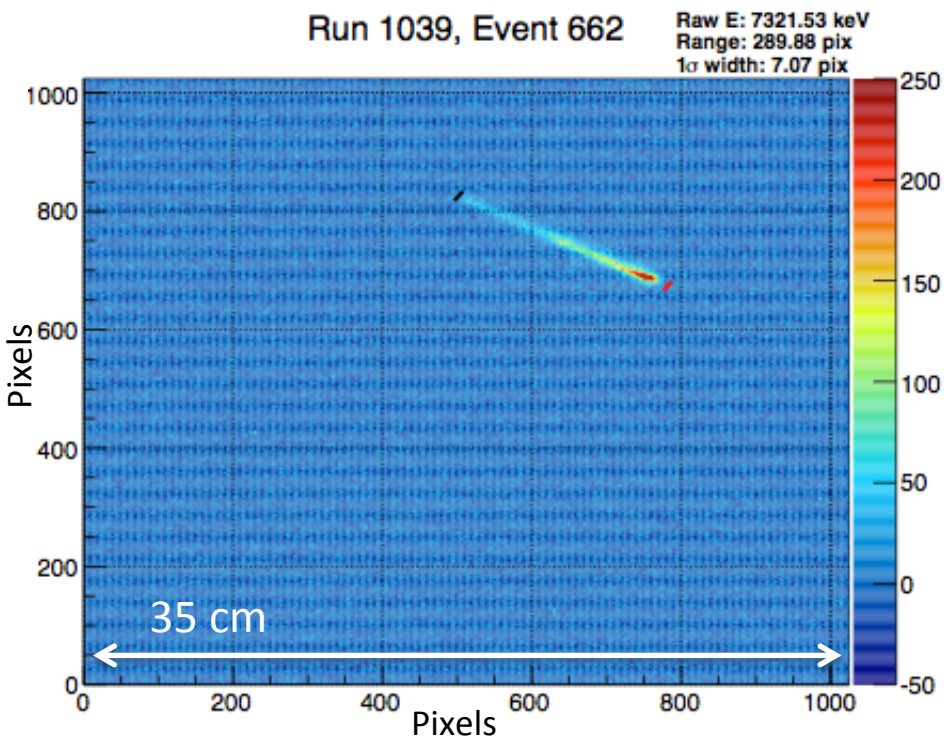
- 2.8 L
- 0.2 – 10 MeVr



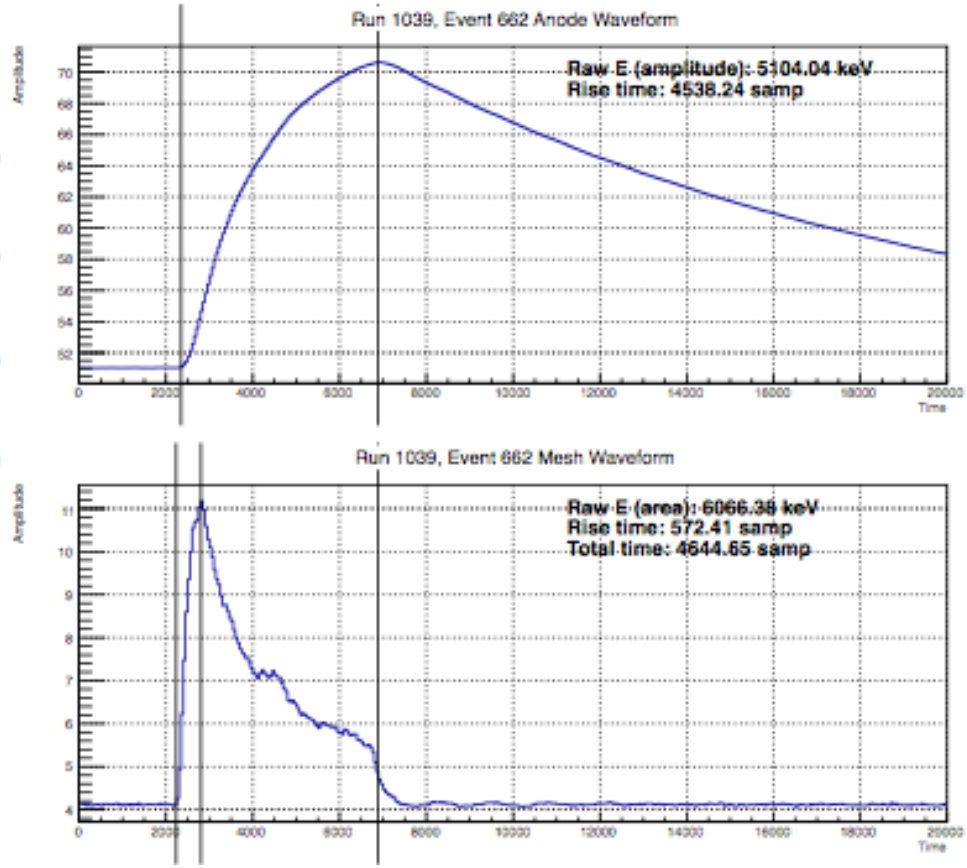
Full-sized detector

- 40/60 L
- 0.3 – 20 MeVr

Event readout of an alpha

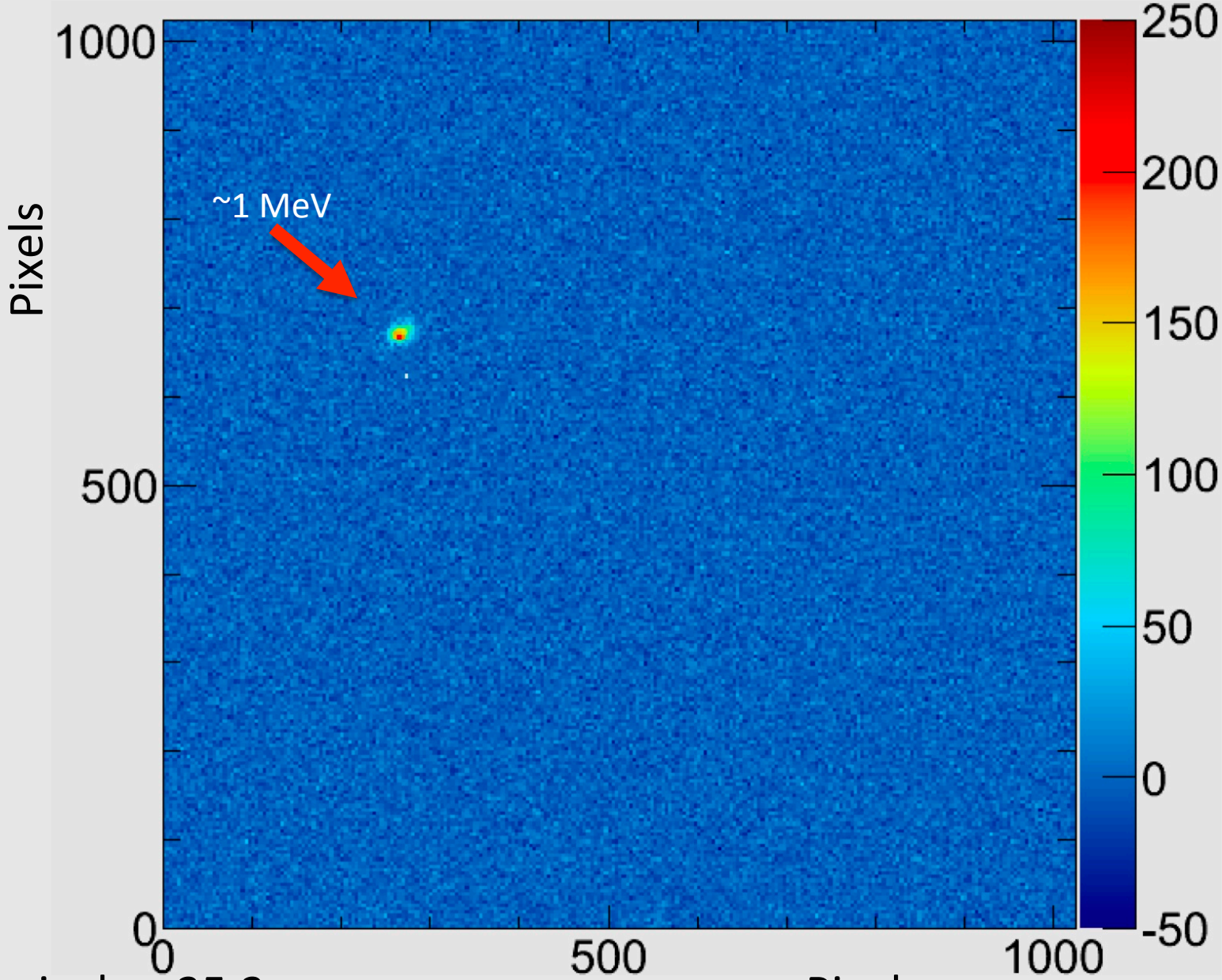


CCD readout



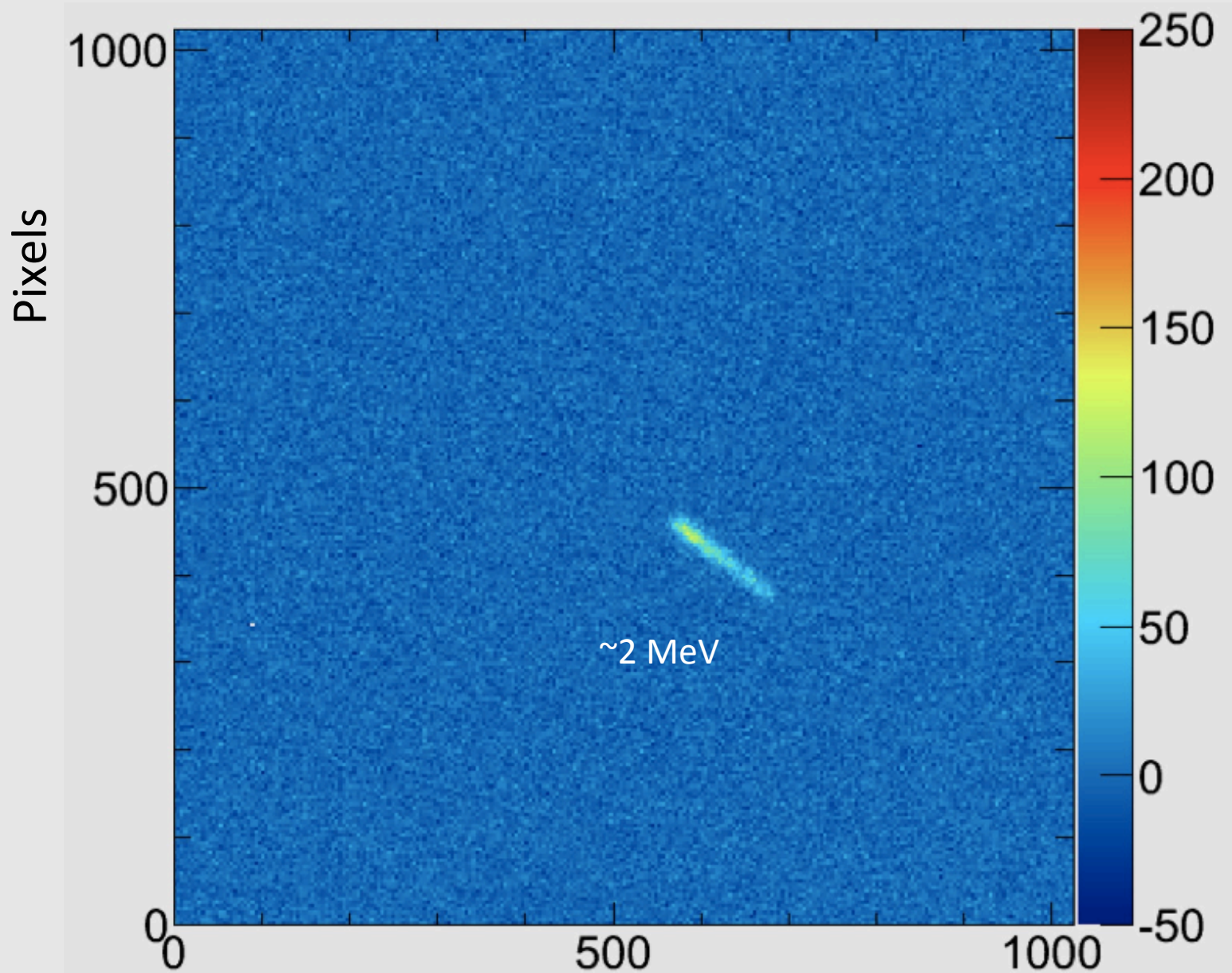
Waveform readouts: anode (top); mesh (bottom)

Neutron-Induced Nuclear Recoil, $^4He/CF_4$ gas



1024 pixels = 35.3 cm

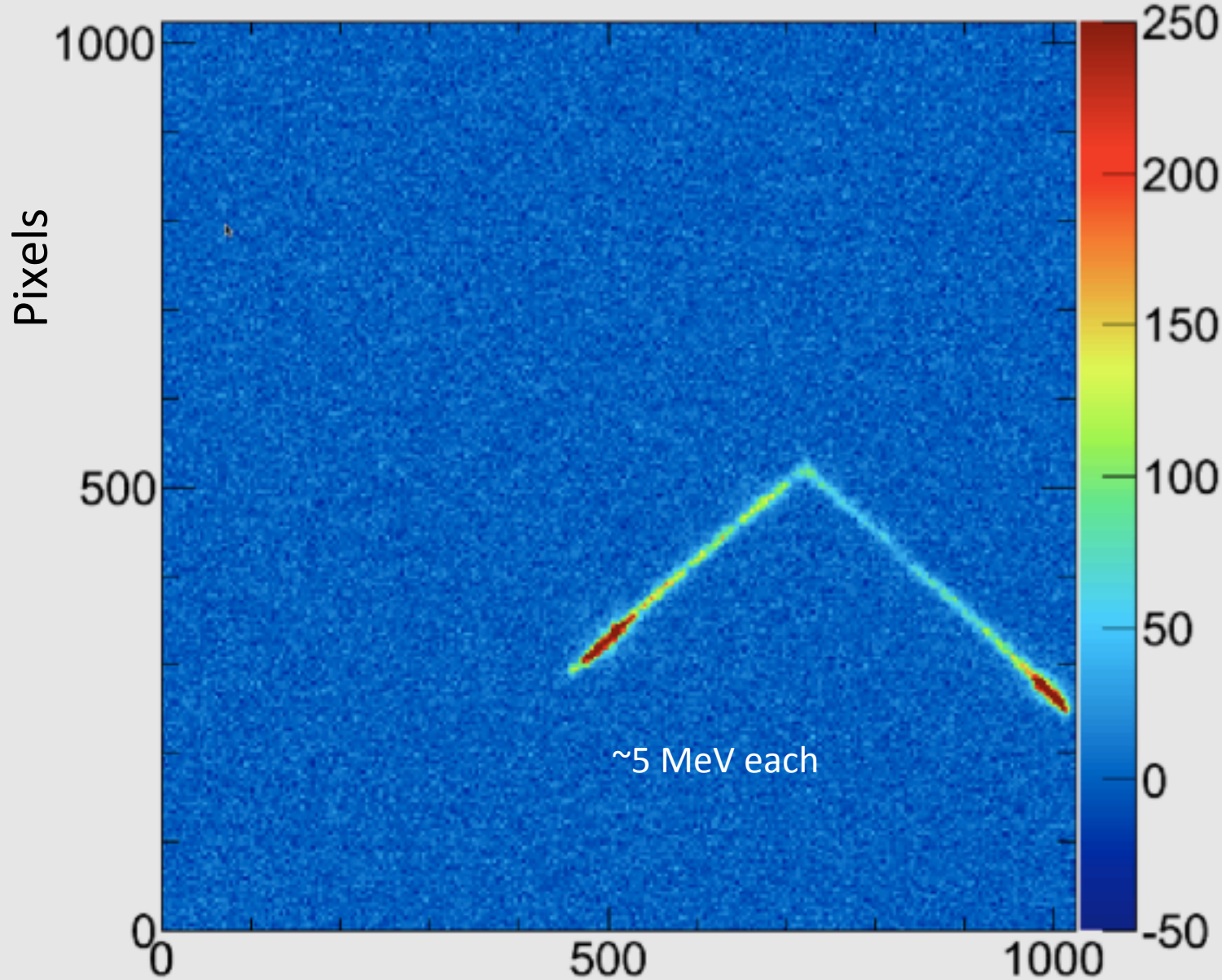
Neutron-Induced Nuclear Recoil, $^4He/CF_4$ gas



1024 pixels = 35.3 cm

Pixels

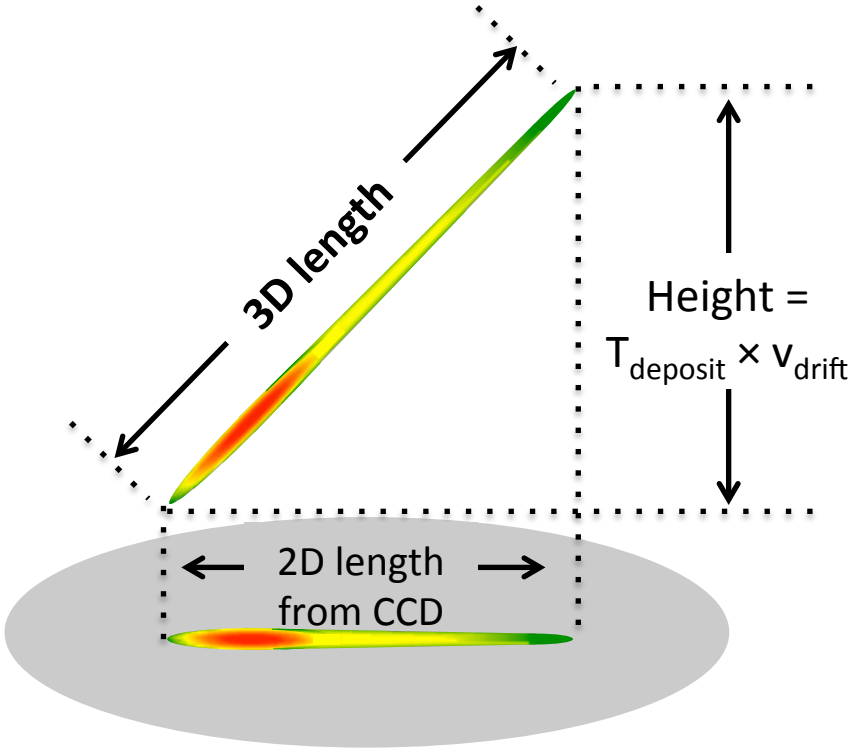
$^{220}\mathrm{Rn} \rightarrow {}^{216}\mathrm{Po} \rightarrow {}^{212}\mathrm{Pb}$

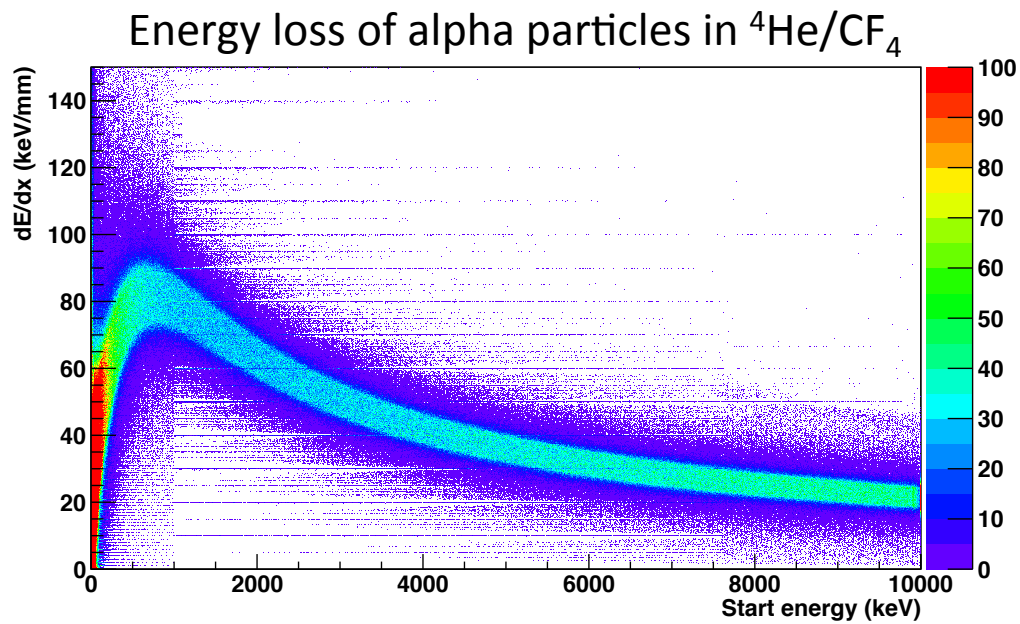


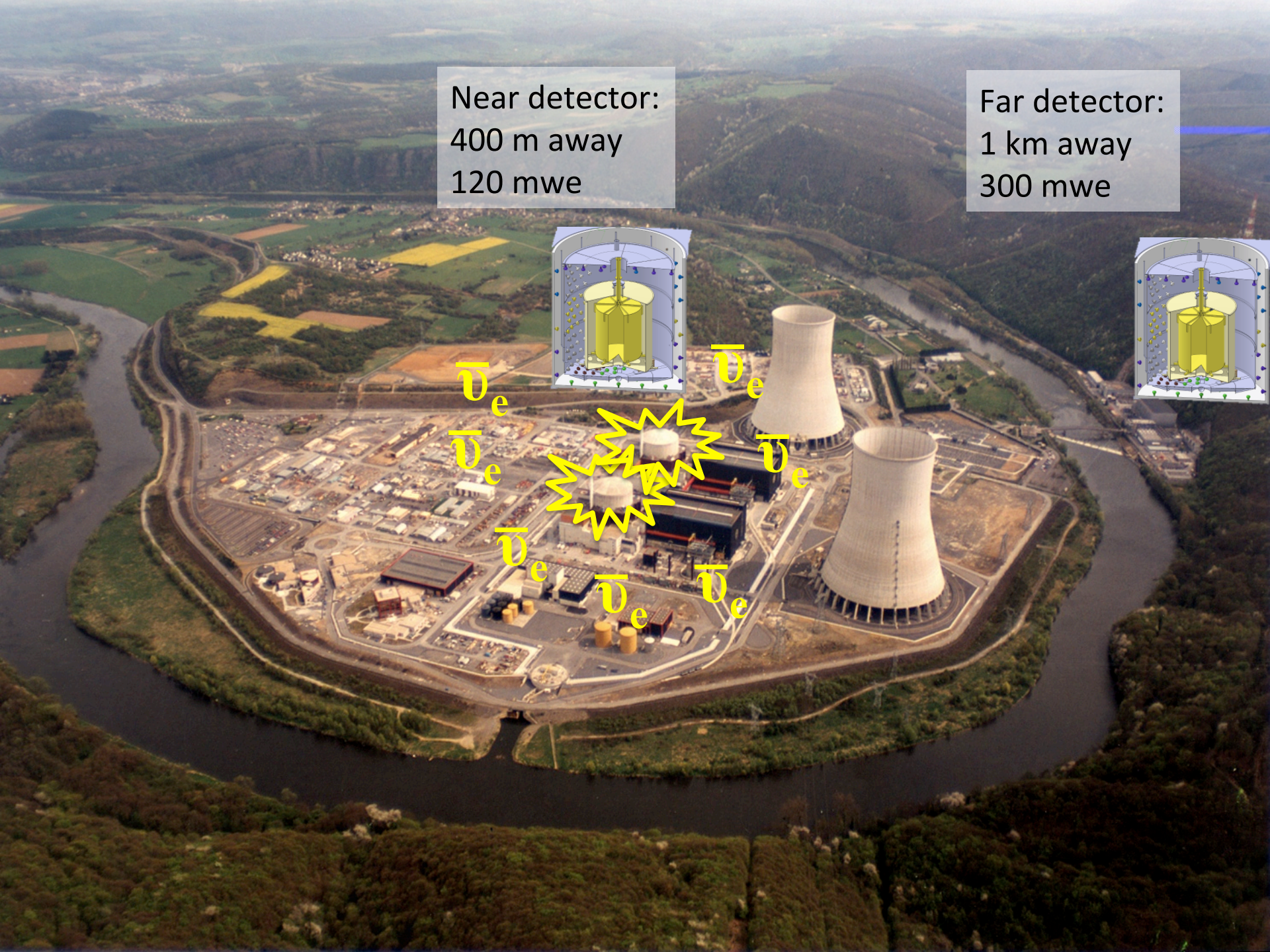
1024 pixels = 35.3 cm

Pixels

Energy reconstruction from 3D length, SRIM simulation






Near detector:
400 m away
120 mwe
Far detector:
1 km away
300 mwe
$\bar{\upsilon}_e$
$\bar{\upsilon}_e$
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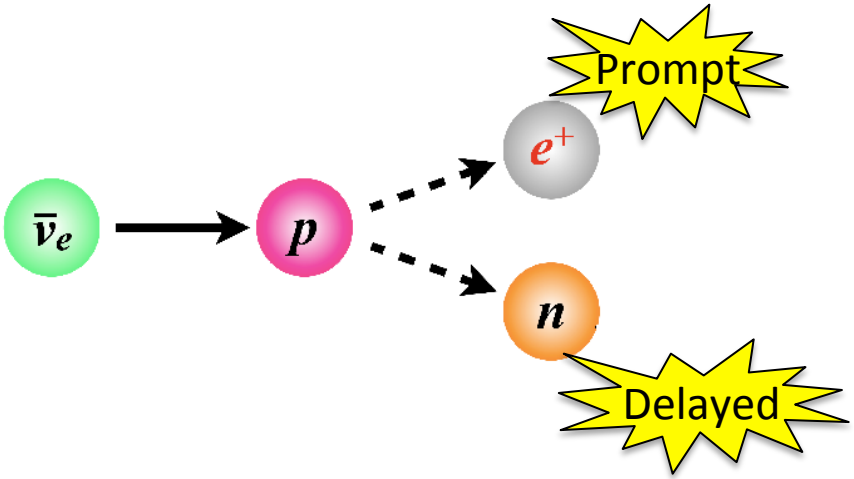
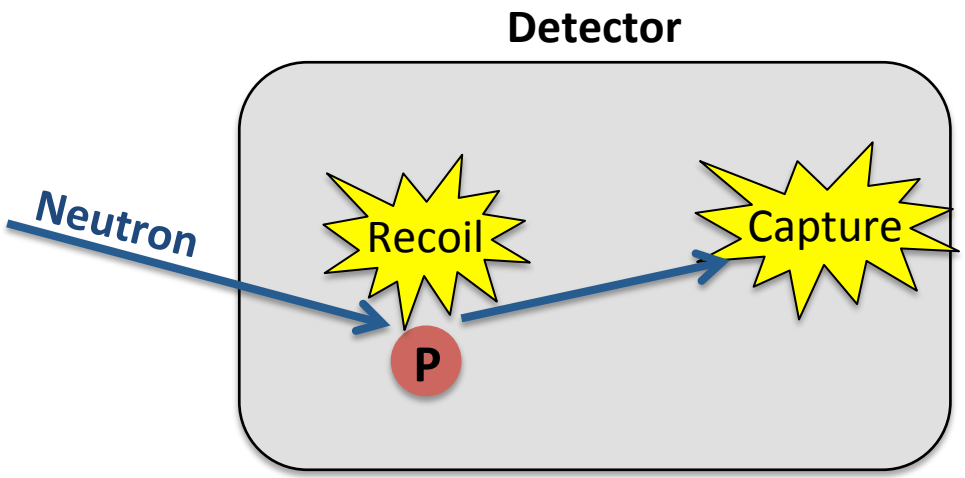
$\bar{\upsilon}_e$
$\bar{\upsilon}_e$

Neutron Background at Double Chooz

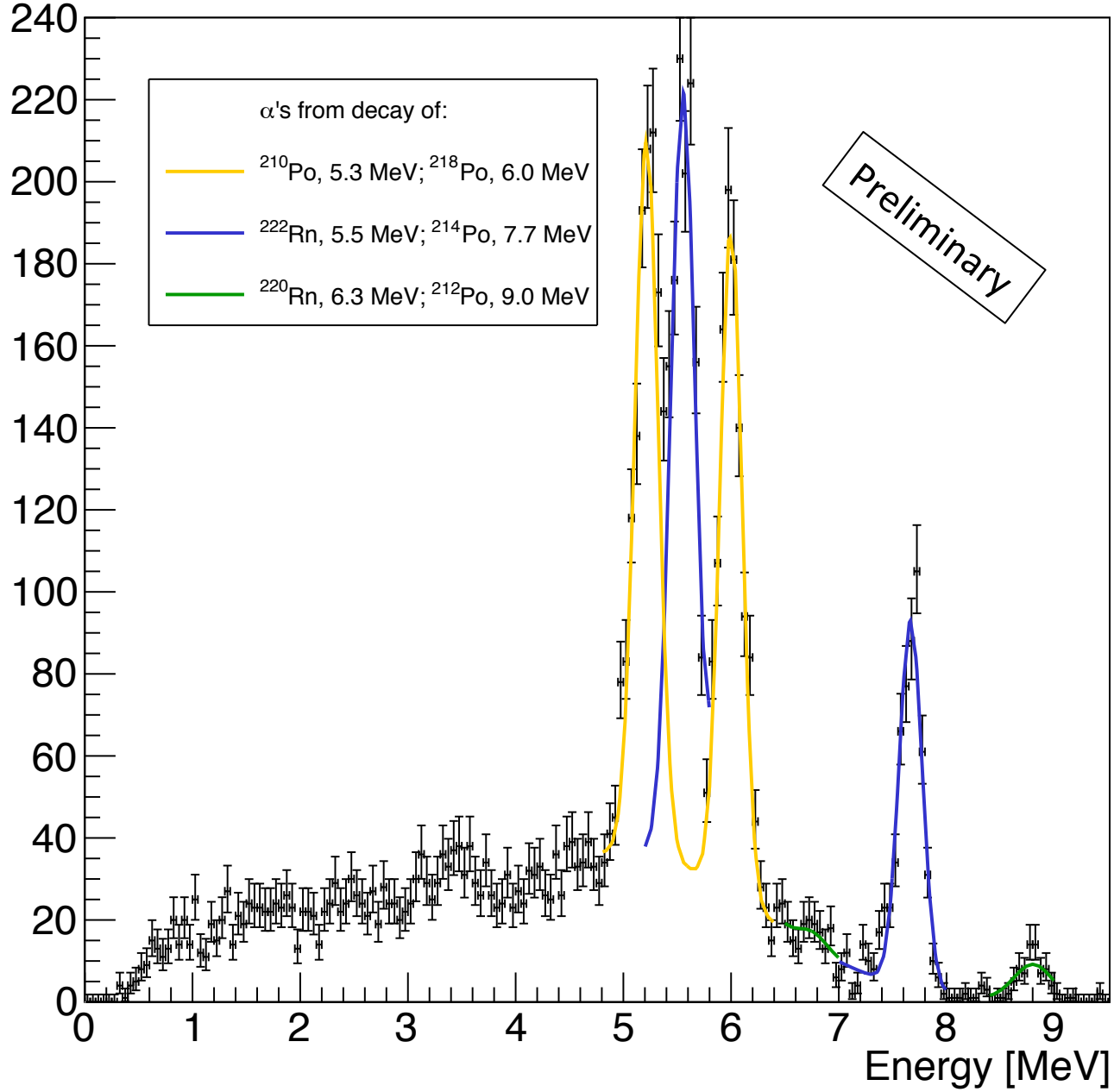


Neutrons come from:

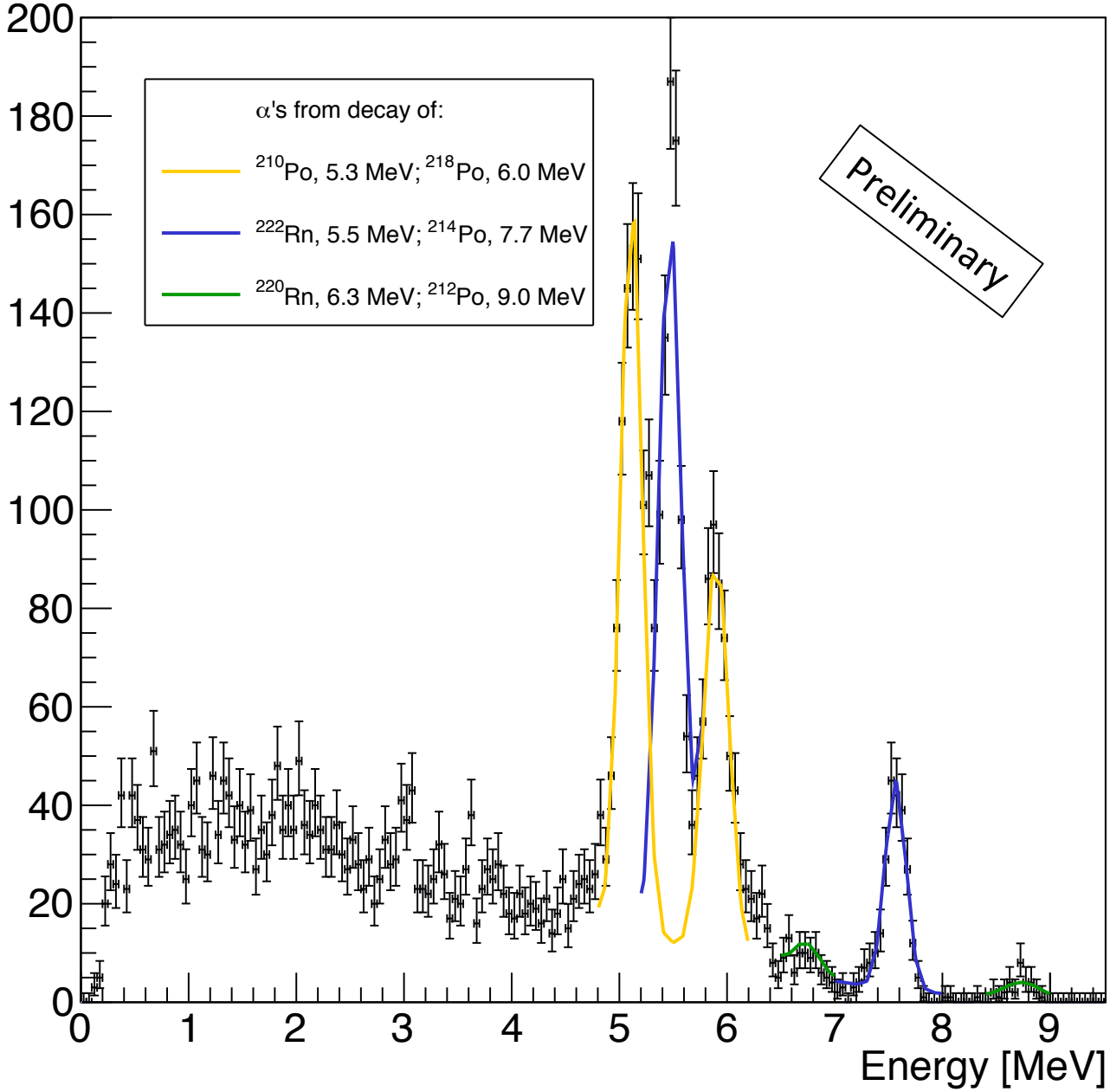
- (α,n) interactions from U/Th in rock
- Stopped muon capture
- Deep inelastic muon events



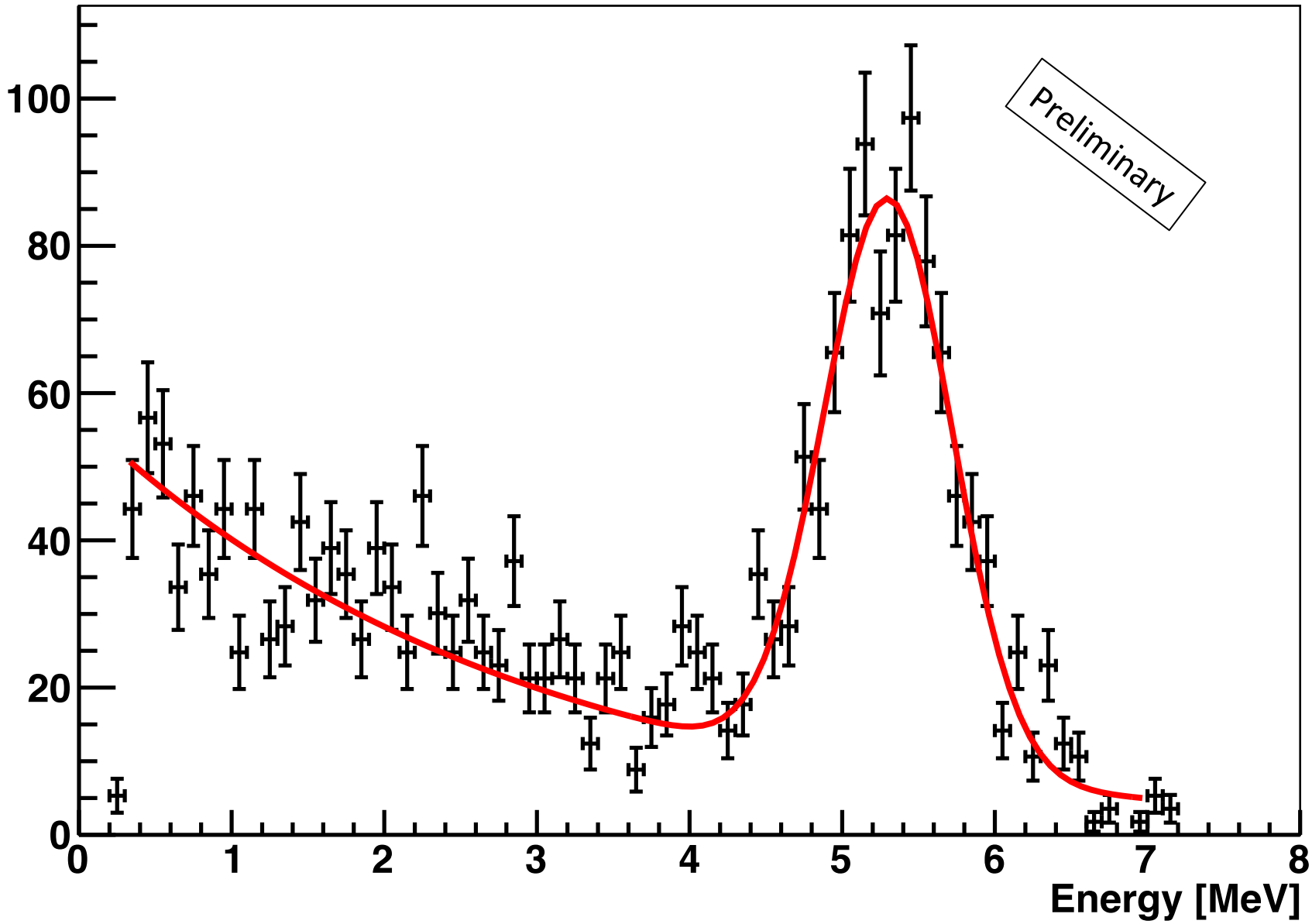
60 L detector, Double Chooz near hall, 7 months



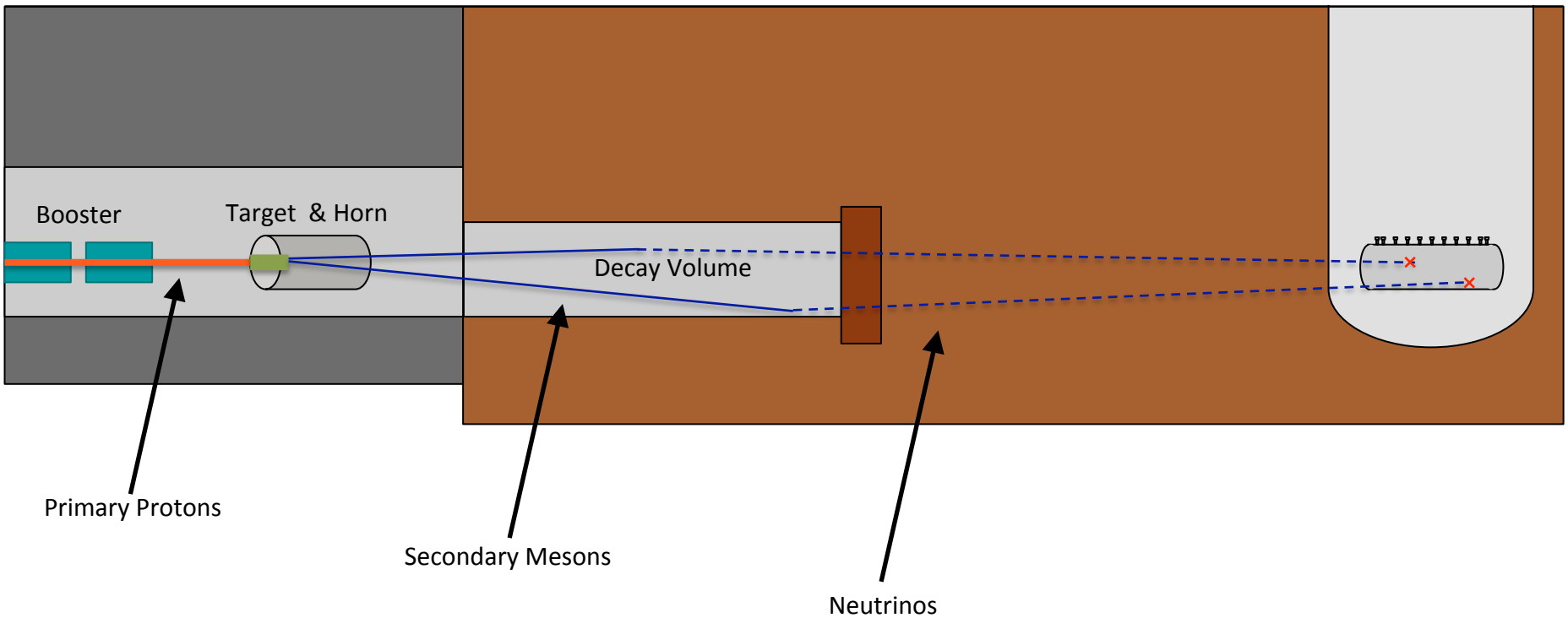
40 L detector, Double Chooz far hall, 6 months



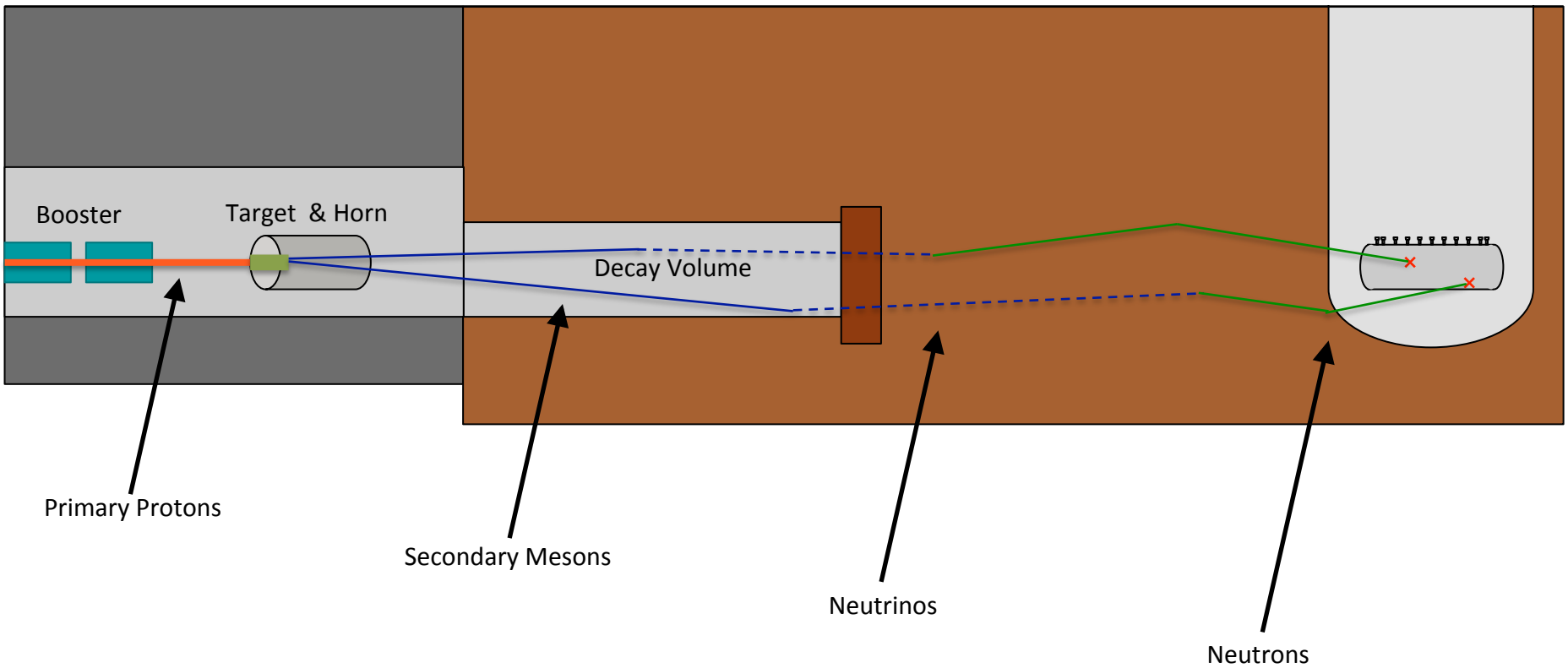
Prototype detector, Double Chooz far hall, 4 months



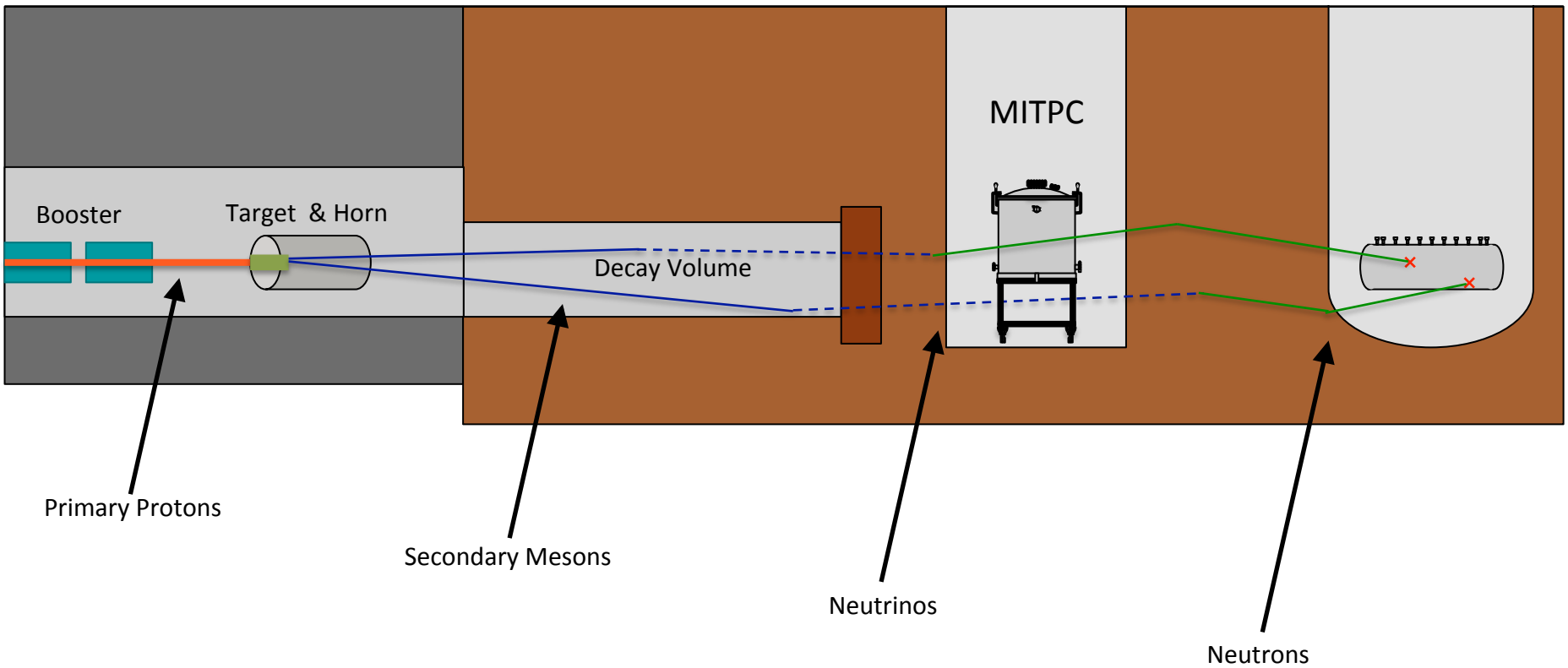
Booster Neutrino Beamline at Fermilab



Booster Neutrino Beamline at Fermilab



Booster Neutrino Beamline at Fermilab



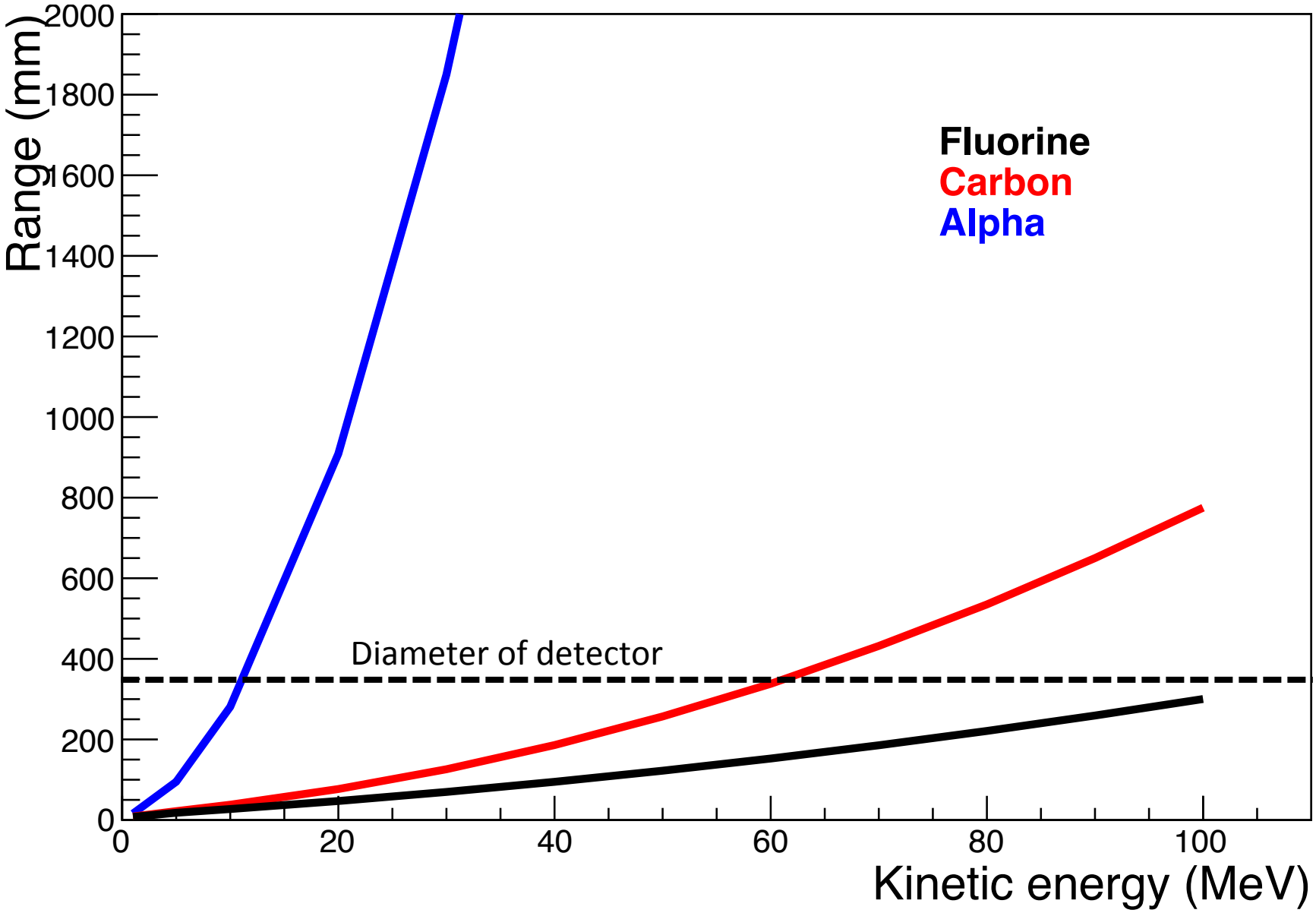
Energy Sensitity

	DCTPC at Double Chooz	**MITPC at FNAL**
Gas (600 torr)	87.5% ^{4}He, 12.5% CF_4	87.5% Ne, 12.5% CF_4
Nuclear Recoil Sensitivity	0.3-20 MeV	Over 100 MeV

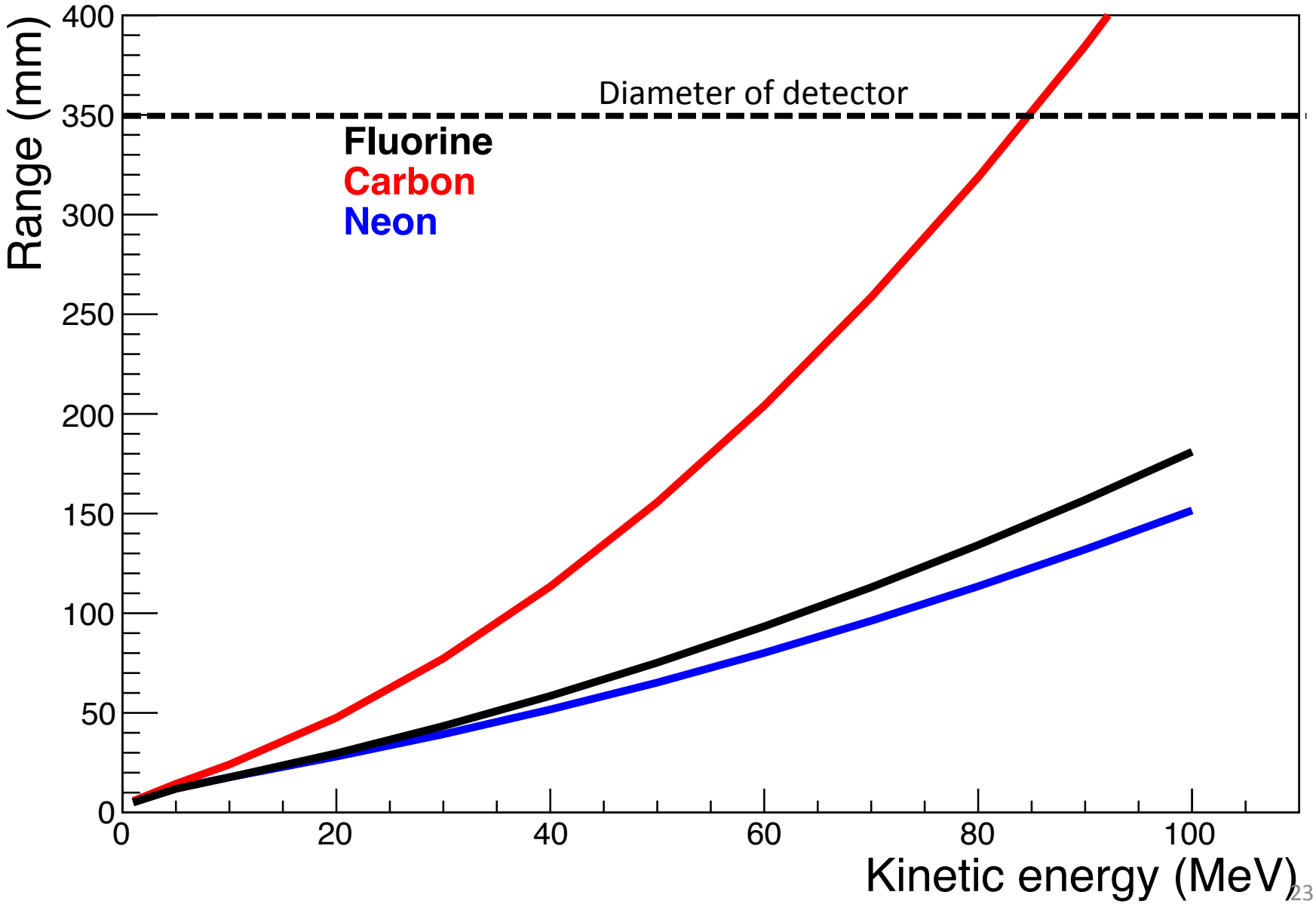
Choosing gas for MITPC at Fermilab

Need:	Test?	Calculate?
• Sufficient stopping power		✔
• Sufficient gain	✔	
• Low diffusion	✔	✔

Range of particles in (87.5% ^4He, 12.5% CF_4, 600 torr) with SRIM software



Range of particles in (87.5% Ne, 12.5% CF_4, 600 torr) with SRIM software



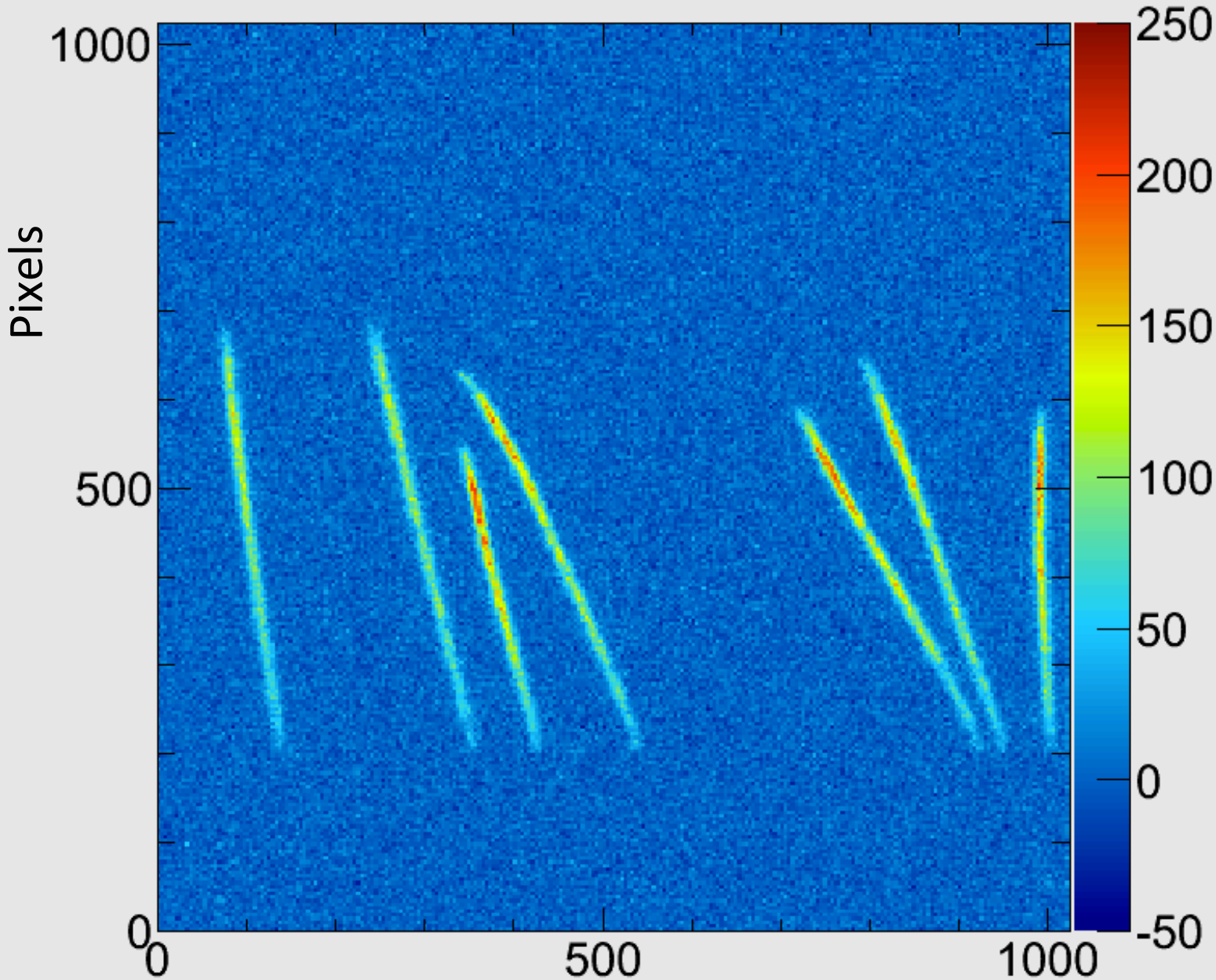
Electron diffusion in noble gases

Kinetic parameters of electrons
in noble gases in an electric field of 75 V/cm.

	V, 10^5 cm s^{-1}	eD_T/μ, eV
He	2.8	0.25
Ne	3.5	1
Ar	2.3	3.0
Kr	1.6	2.0
Xe	1.05	2.7

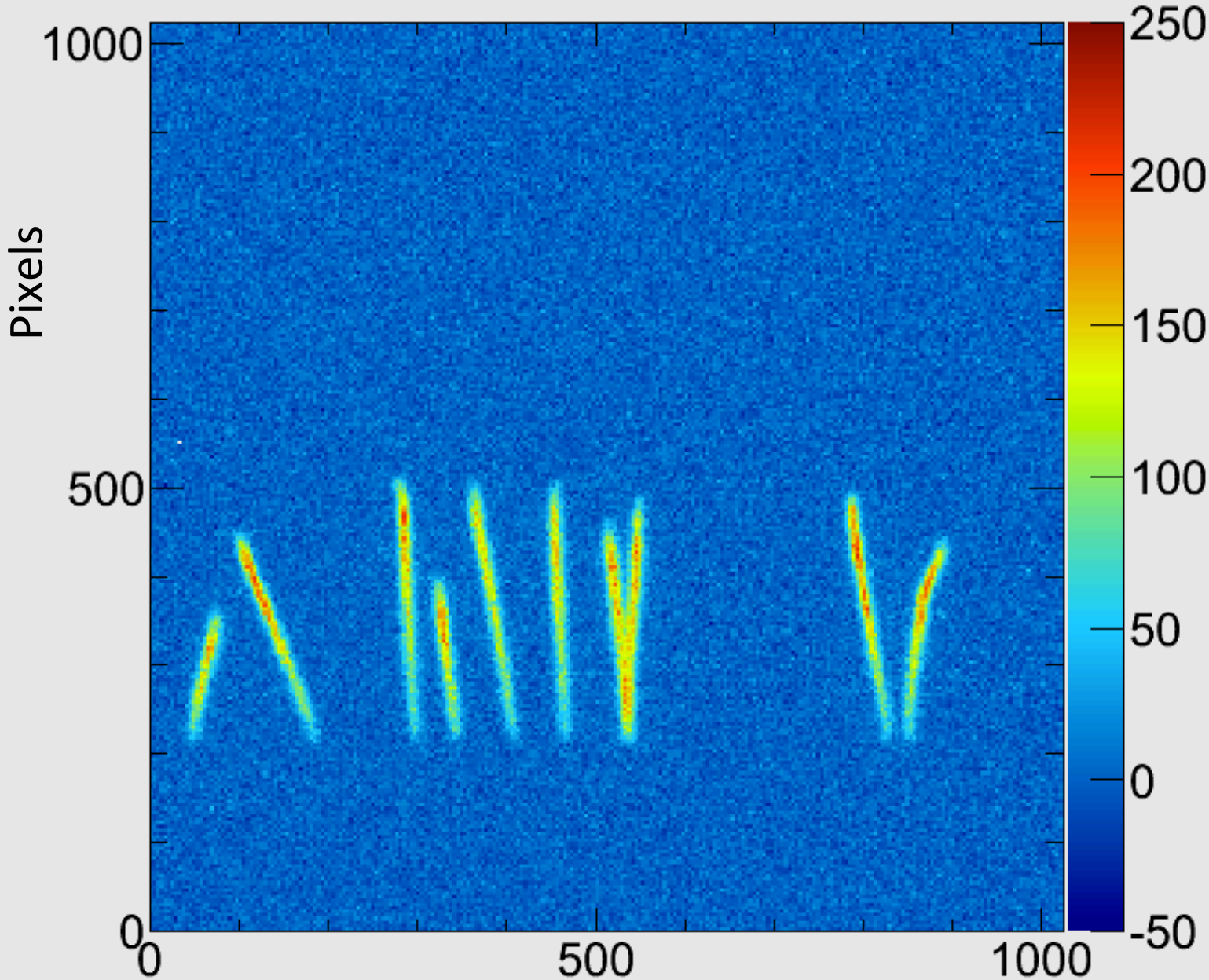
E. Aprile, et al., "Nobel Gas Detectors"

Alpha tracks in 87.5% ^{4}He, 12.5% CF_4, 600 torr (^{241}Am source)



1024 pixels = 16.7 cm

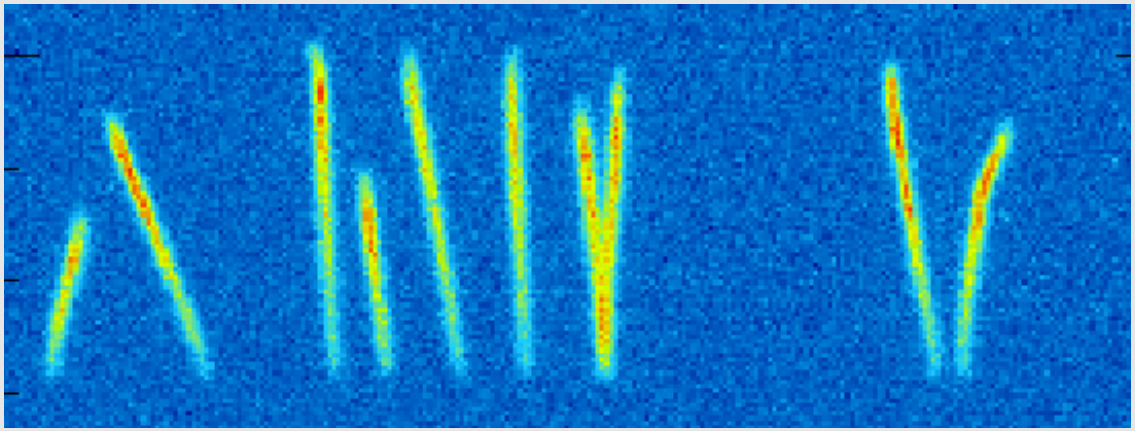
Alpha tracks in 87.5% Ne, 12.5% CF_4, 600 torr (^{241}Am source)



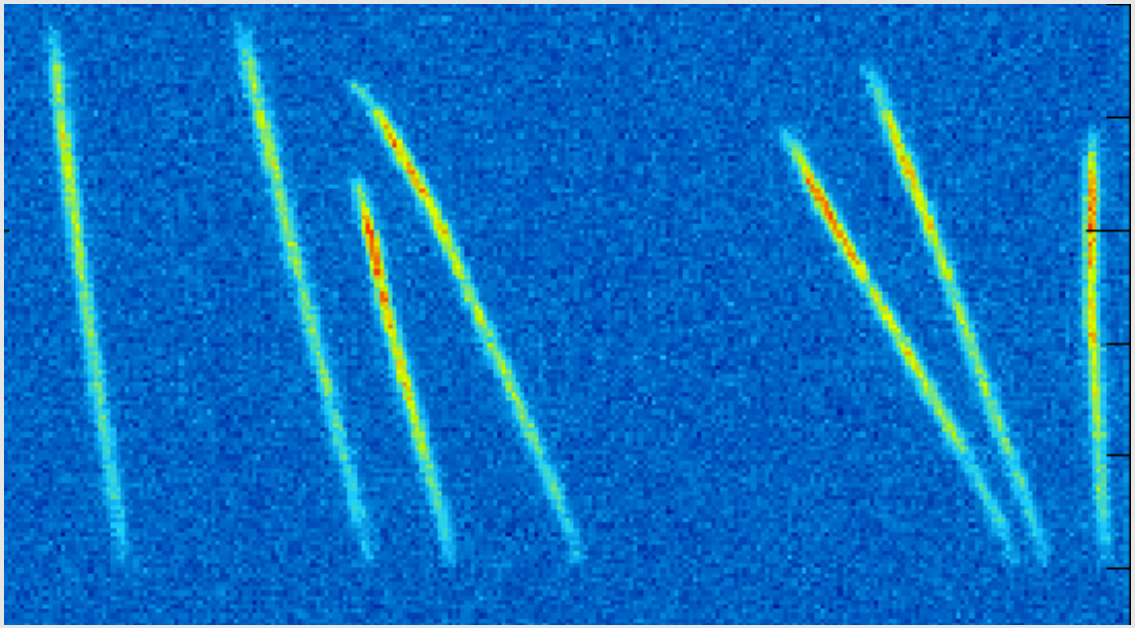
1024 pixels = 16.7 cm

Ne/CF_4

- 9% more diffuse
  - not 400%!
- 63% shorter



$^4He/CF_4$

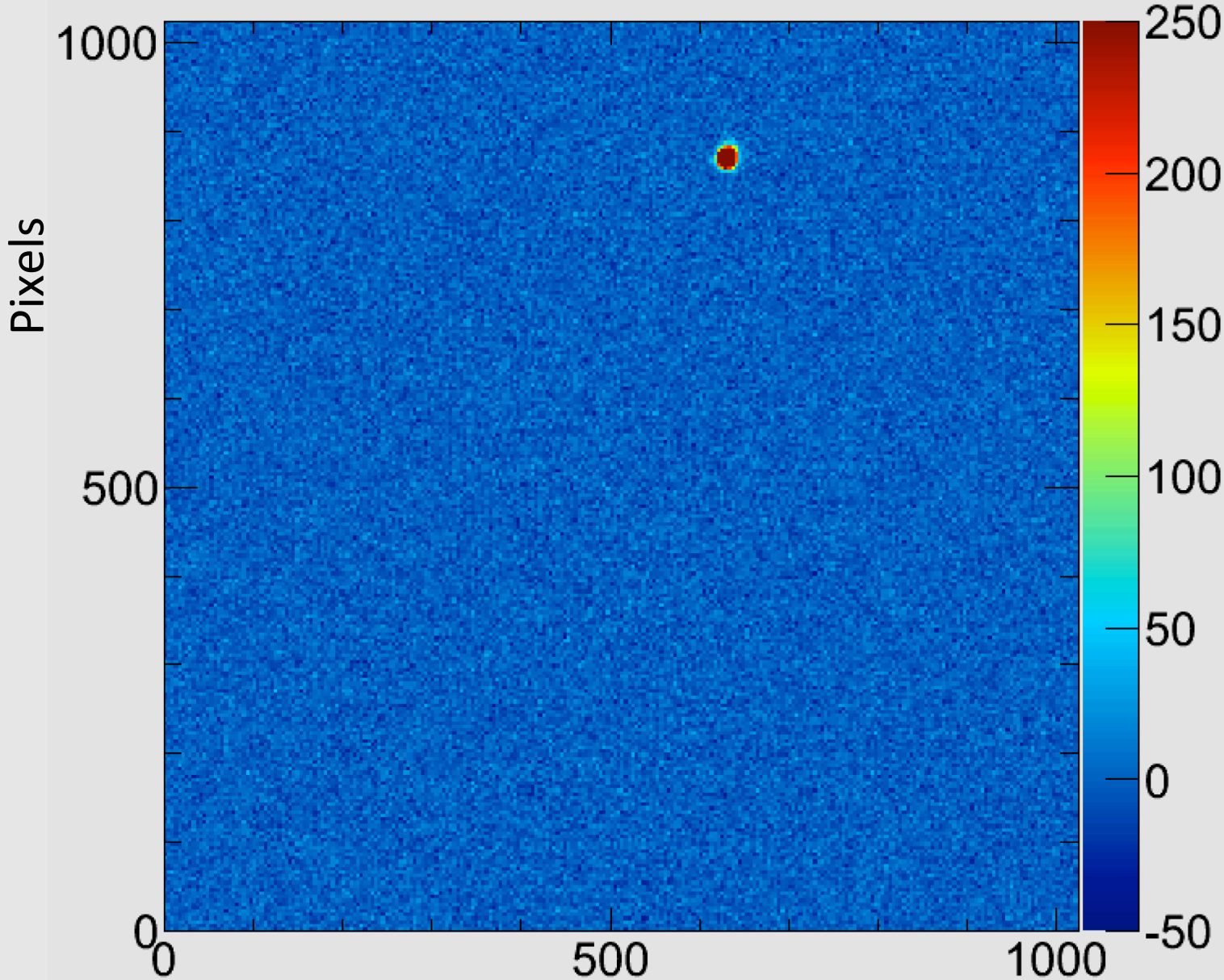


Decreased Spark Rate in Neon

- Sufficient gain with lower voltage in Ne than in ^{4}He
- Breakdown voltage of Ne is lower than that of ^{4}He
- Fewer sparks in Ne
- Higher efficiency in Ne

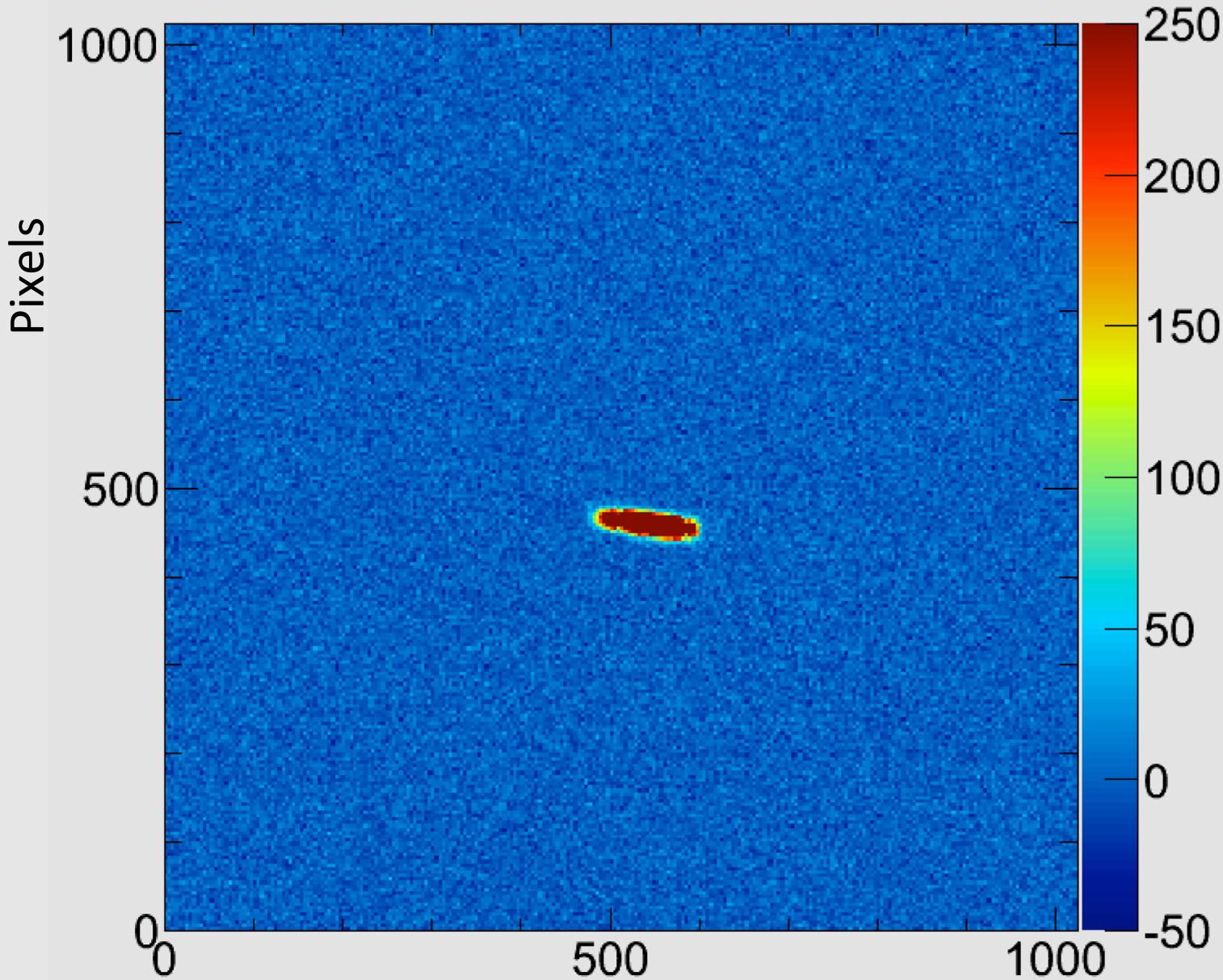
	^{4}He/CF$_4$	**Ne/CF$_4$**
Operating voltage	710 V	680 V
Approx. breakdown voltage of noble gas	690 V	710 V

Simulated 5 MeV neutron-induced nuclear recoil (87.5% Ne, 12.5% CF_4)



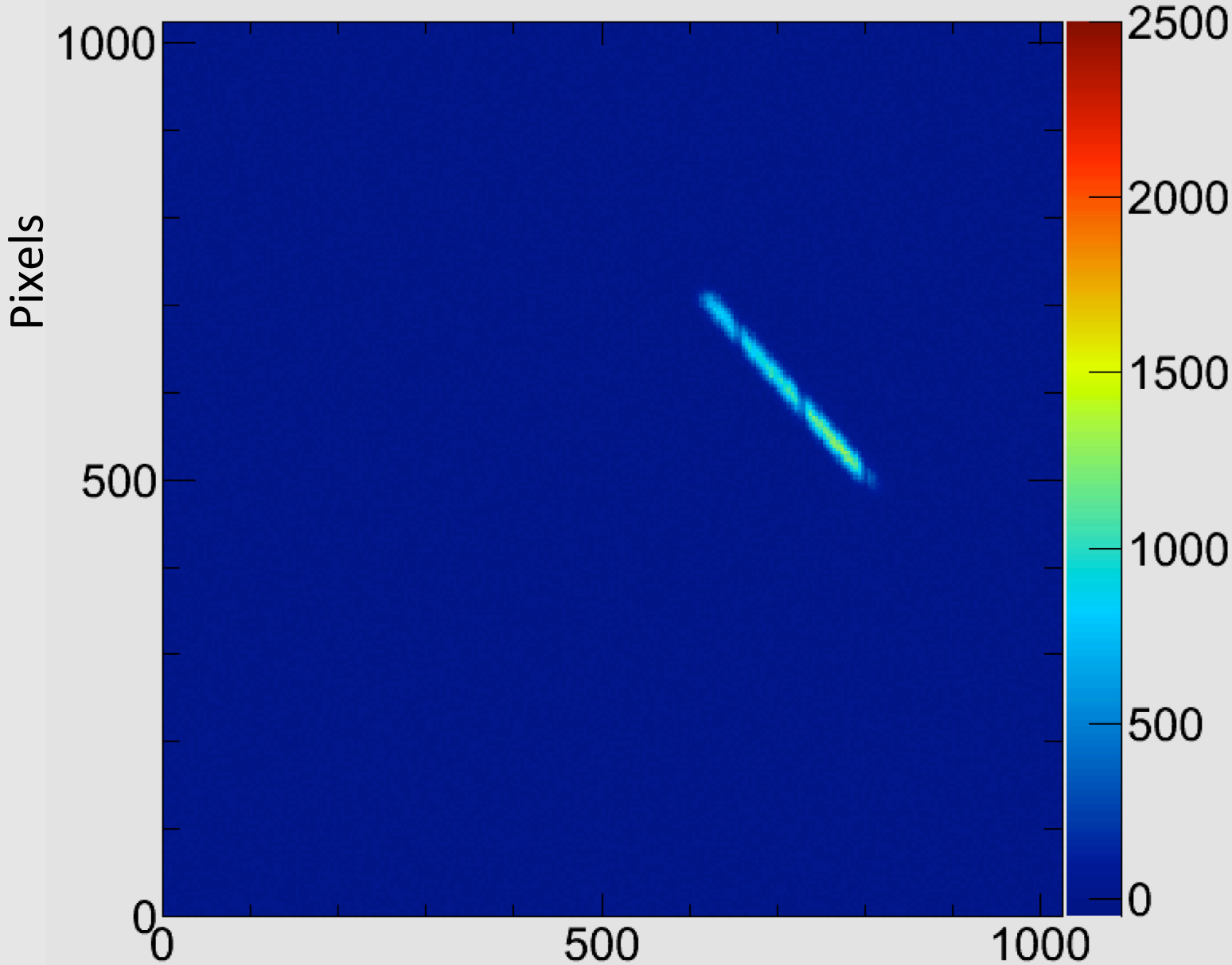
1024 pixels = 35.3 cm

Simulated 30 MeV neutron-induced nuclear recoil (87.5% Ne, 12.5% CF_4)



1024 pixels = 35.3 cm

Simulated 75 MeV neutron-induced nuclear recoil (87.5% Ne, 12.5% CF_4)



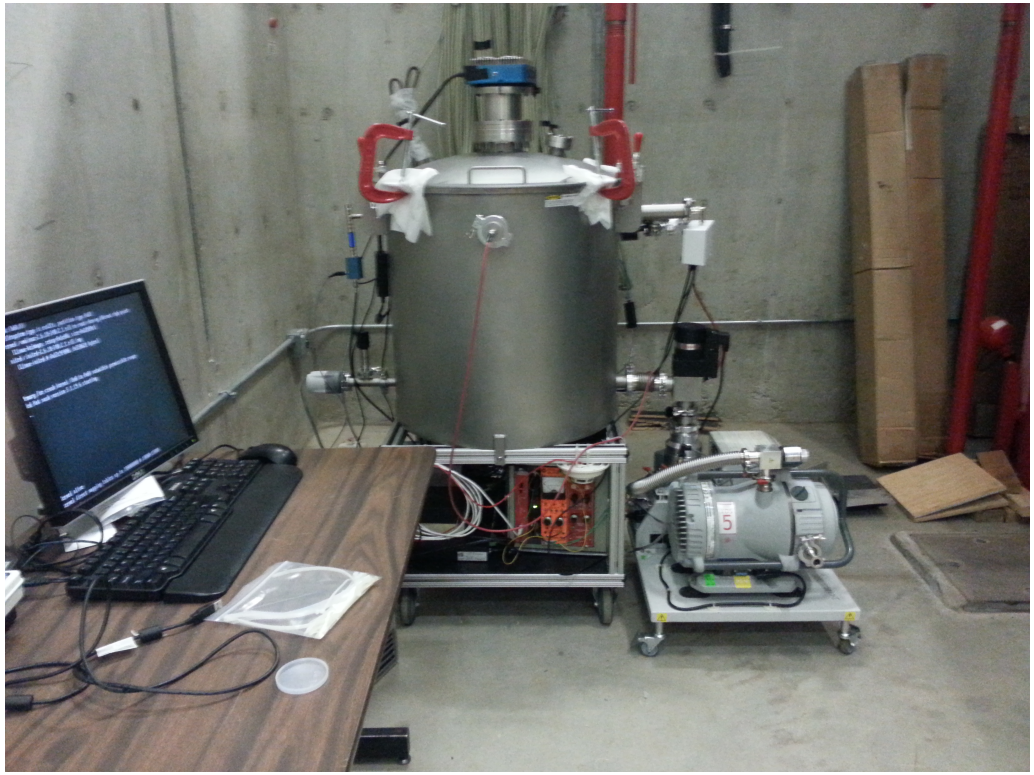
1024 pixels = 35.3 cm

MITPC at Fermilab

- Monte Carlo prediction for neutron background on Booster Neutrino Beamline (BNB)
- Neutrino experiments on BNB:
  - MicroBooNE
  - SBND
  - ANNIE

MITPC at Fermilab

- Ready for BNB turn-on
- Sensitive to over 100 MeVr
- 300-500 neutrino-induced neutrons over 6.6 x 10^{20} POT
- Also beam-induced skyshine, cosmogenic and radiogenic neutrons
- Run for 3 years
- Co-exist with ANNIE



Takeaway

- MITPC is a directional fast neutron detector
- Successful run at Double Chooz
  - Paper coming out!
- Demonstrated use of neon in a TPC
  - Paper coming out!
- Measure fast neutrons at Fermilab

Thank you!

MITPC Collaboration

Allie Hexley

Marjon Moulai

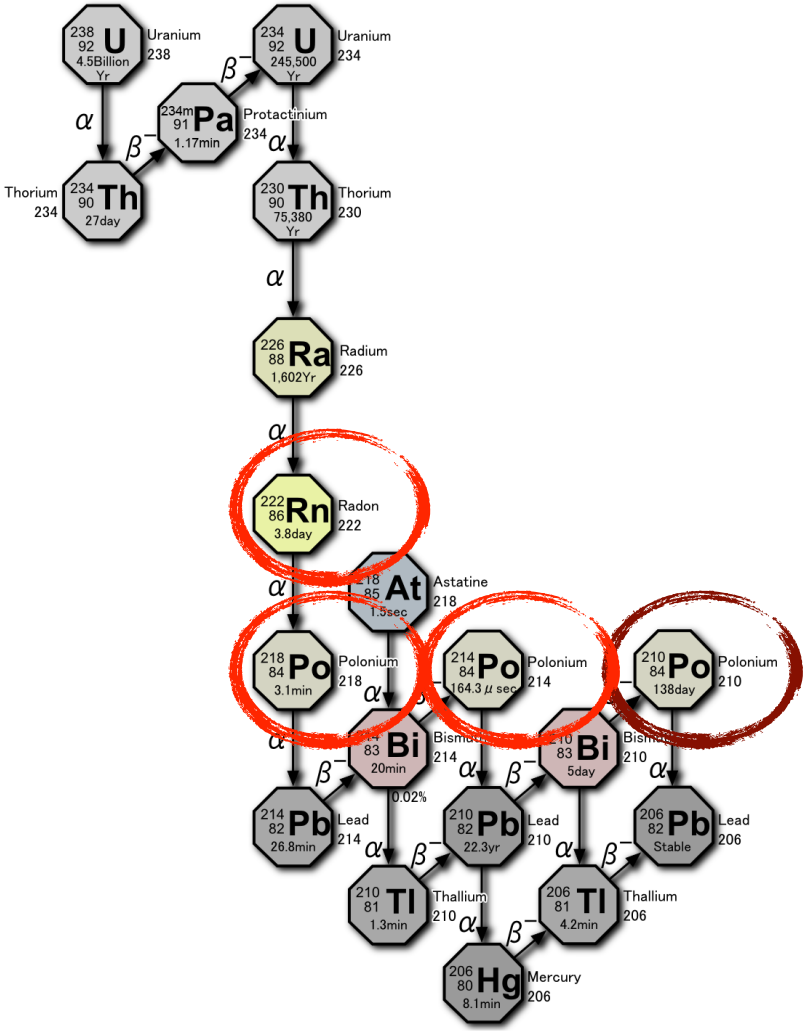
Janet Conrad

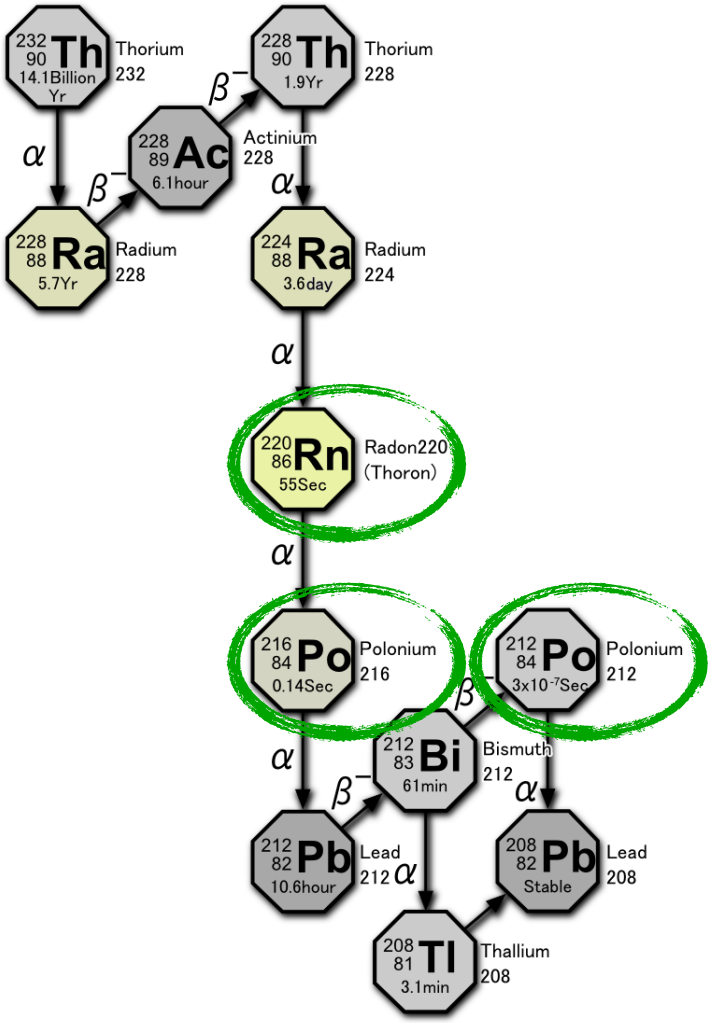
Josh Spitz

Adrien Hourlier

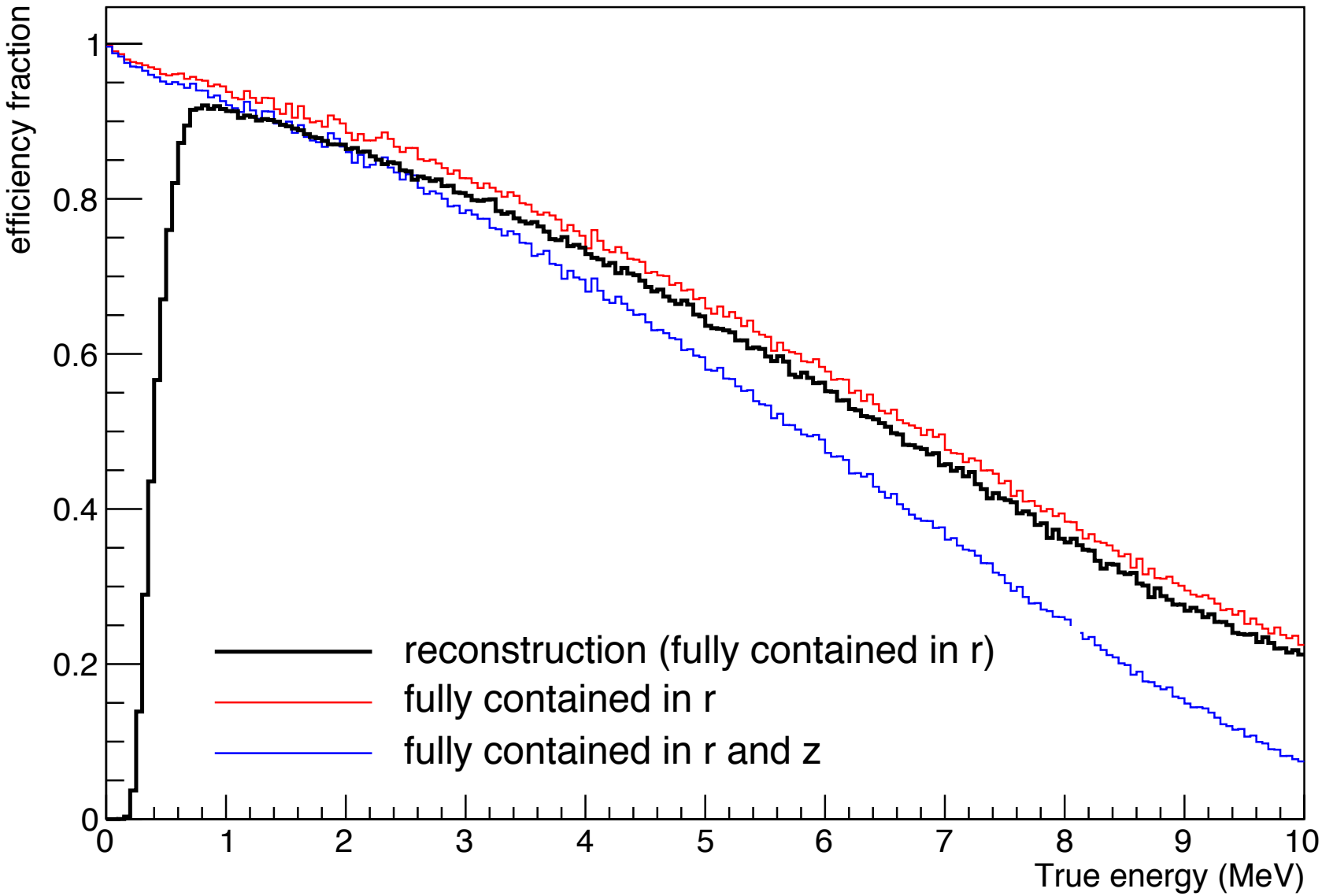
Jaime Dawson

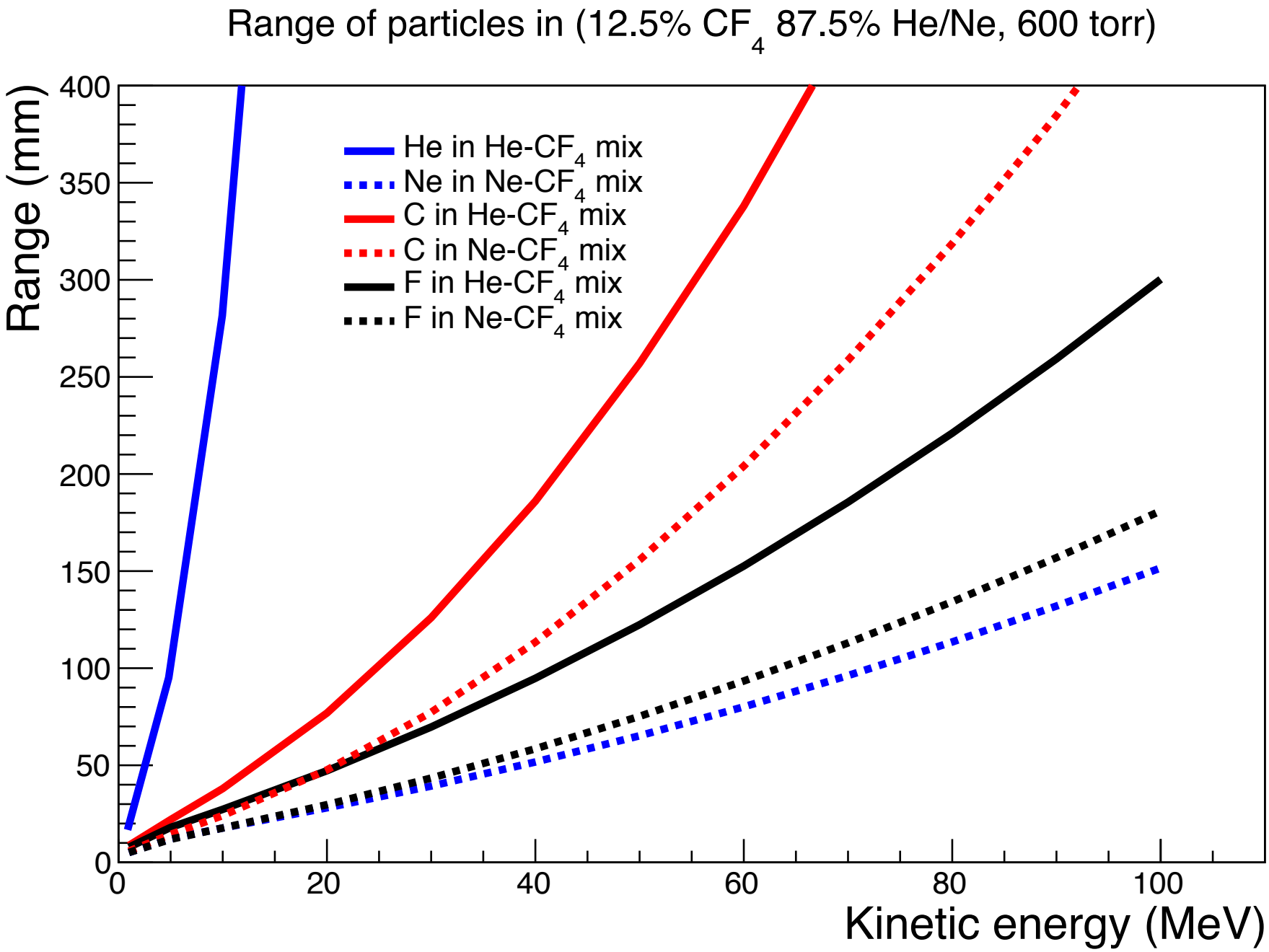
Back-up


238 92 U 4.5Billion Yr
Uranium 238
234 92 U 245,500 Yr
Uranium 234
234m 91 Pa 1.17min
Protactinium 234
234 90 Th 27day
Thorium 234
230 90 Th 75,380 Yr
Thorium 230
226 88 Ra 1,602Yr
Radium 226
222 86 Rn 3.8day
Radon 222
218 85 At 1.5sec
Astatine 218
218 84 Po 3.1min
Polonium 218
214 84 Po 164.3 μ sec
Polonium 214
210 84 Po 138day
Polonium 210
214 83 Bi 20min
Bismuth 214
210 83 Bi 5day
Bismuth 210
0.02%
214 82 Pb 26.8min
Lead 214
210 82 Pb 22.3yr
Lead 210
206 82 Pb Stable
Lead 206
210 81 Tl 1.3min
Thallium 210
206 81 Tl 4.2min
Thallium 206
206 80 Hg 8.1min
Mercury 206

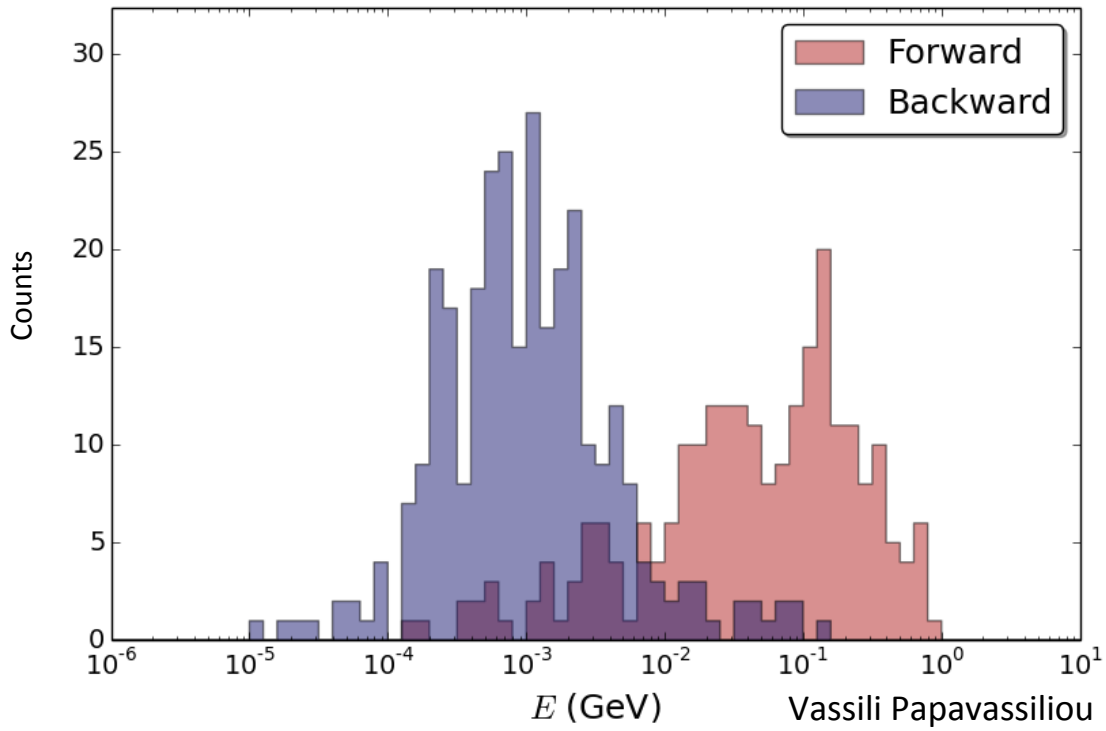

232 90 Th 14.1Billion Yr
Thorium 232
228 90 Th 1.9Yr
Thorium 228
228 89 Ac 6.1hour
Actinium 228
228 88 Ra 5.7Yr
Radium 228
224 88 Ra 3.6day
Radium 224
220 86 Rn 55Sec
Radon220 (Thoron)
216 84 Po 0.14Sec
Polonium 216
212 84 Po 3x10-7Sec
Polonium 212
212 83 Bi 61min
Bismuth 212
212 82 Pb 10.6hour
Lead 212
208 82 Pb Stable
Lead 208
208 81 Tl 3.1min
Thallium 208

Efficiency/Acceptance of 60 L detector, $^4He/CF_4$



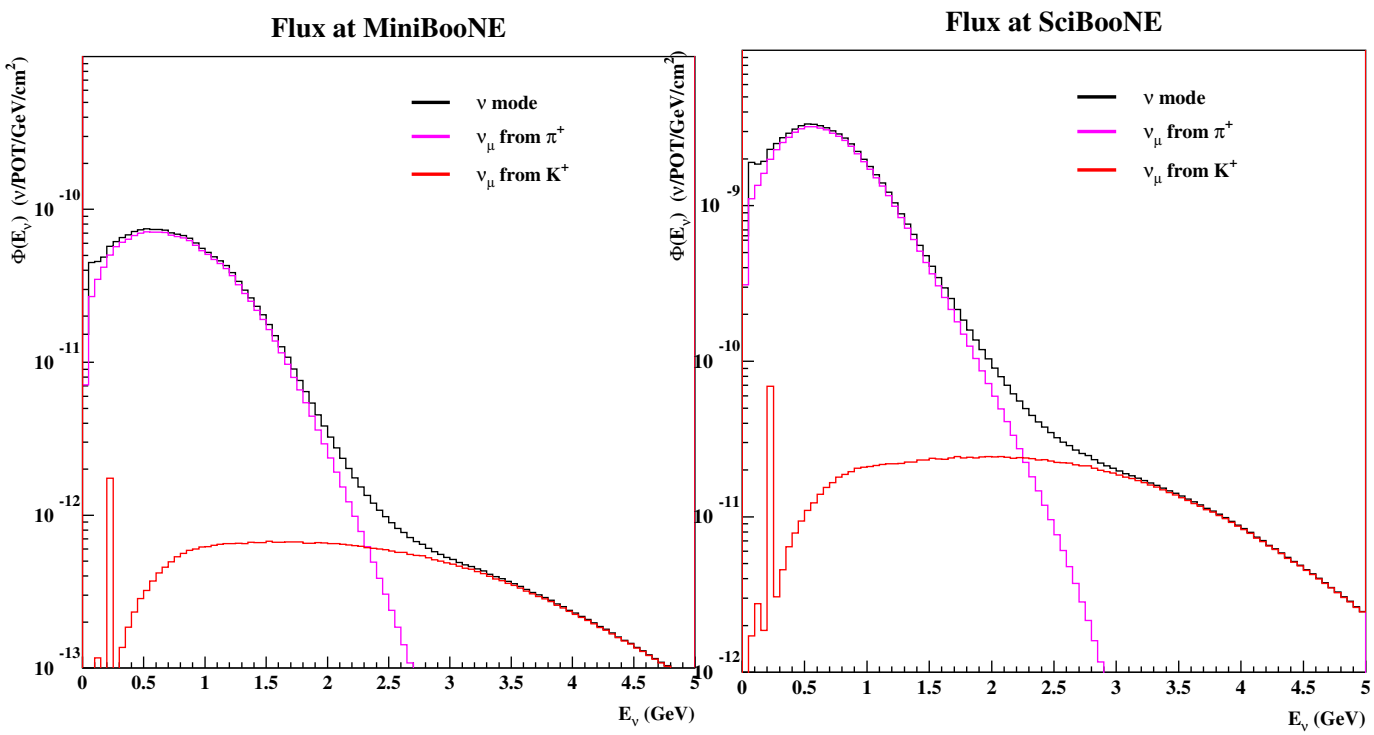

Range of particles in (12.5% CF4 87.5% He/Ne, 600 torr)
Range (mm)
Kinetic energy (MeV)
He in He-CF4 mix
Ne in Ne-CF4 mix
C in He-CF4 mix
C in Ne-CF4 mix
F in He-CF4 mix
F in Ne-CF4 mix
0
50
100
150
200
250
300
350
400
0
20
40
60
80
100

Expected neutron rate



- Neutrons through 1m x 1m area 1m upstream of MicroBooNE over 2.1-3.2 x 10^{19} POT
- MITPC would see 6-9 neutrons (on carbon) over 6.6 x 10^{20} POT (2 years)

Expected neutron rate

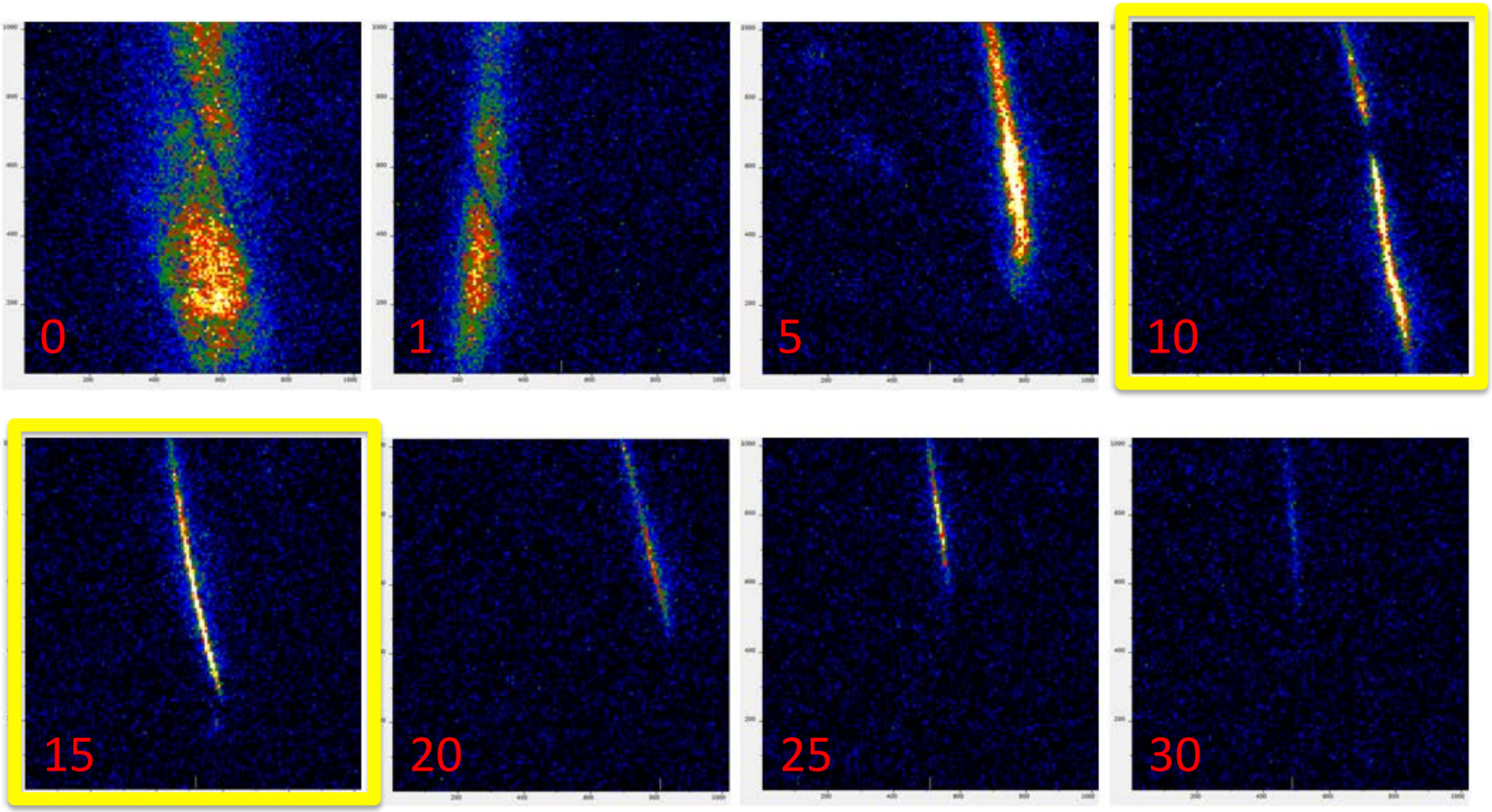


Kendall Mahn's thesis

- Neutrino flux ~60 x higher in SciBooNE Hall
- MITPC would see 300-500 neutrons over 6.6 x 10^{20} POT (2 years)

Diffusion with Xe & CF4

80 torr Xe with xyz torr CF4



Hidefumi Tomita's Thesis