The UMD/NIST Fast Neutron Spectrometer at KURF

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June 7, 2013

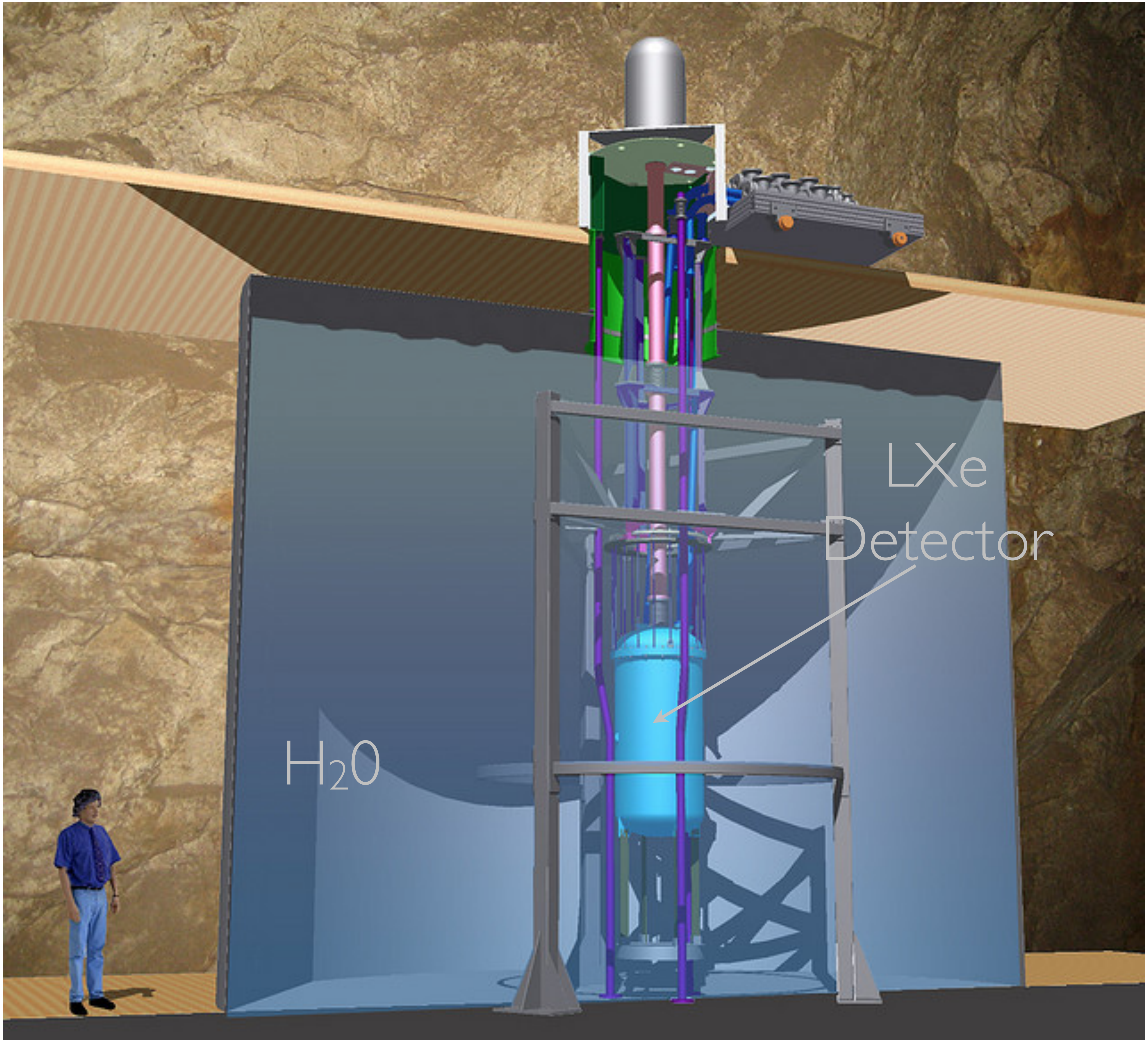
Outline

- Fast Neutrons as backgrounds
- FN Detection Techniques
  - Capture-gated spectroscopy
  - ^{3}He rise-time discrimination
- *FaNS-1 at the surface and KURF*
- FaNS-2: Design and Testing

Fast Neutron Backgrounds for Underground Science

- Fast neutrons play a particularly problematic role in low background experiments
  - Deeply penetrating
  - Create long lived isotopes (Co60, Xe137,...)
  - FNs are indistinguishable from WIMP dark matter interactions
- *Important to know the surface fast neutron spectrum for shielding and transport of materials*

LUX Dark Matter Search



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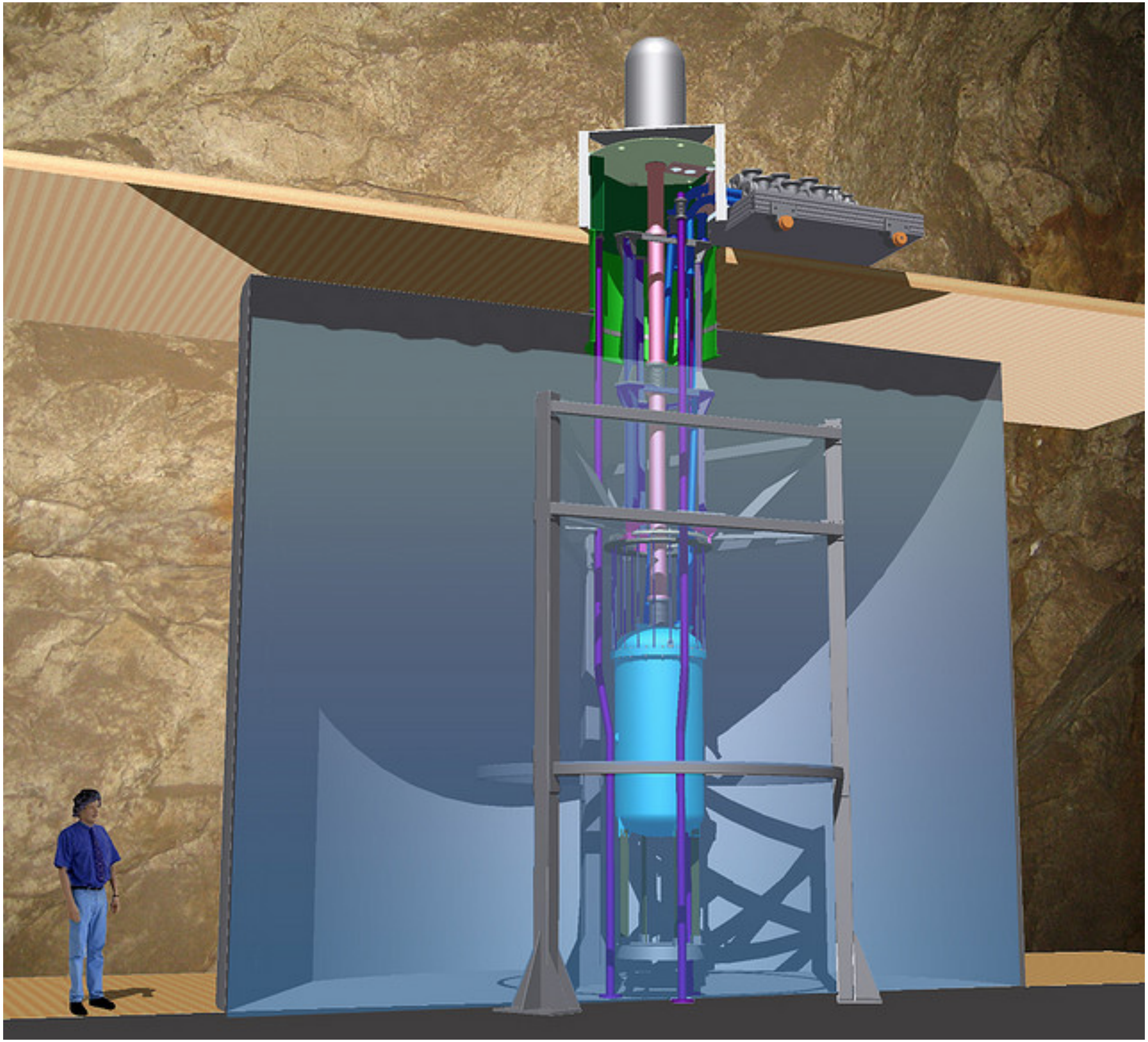

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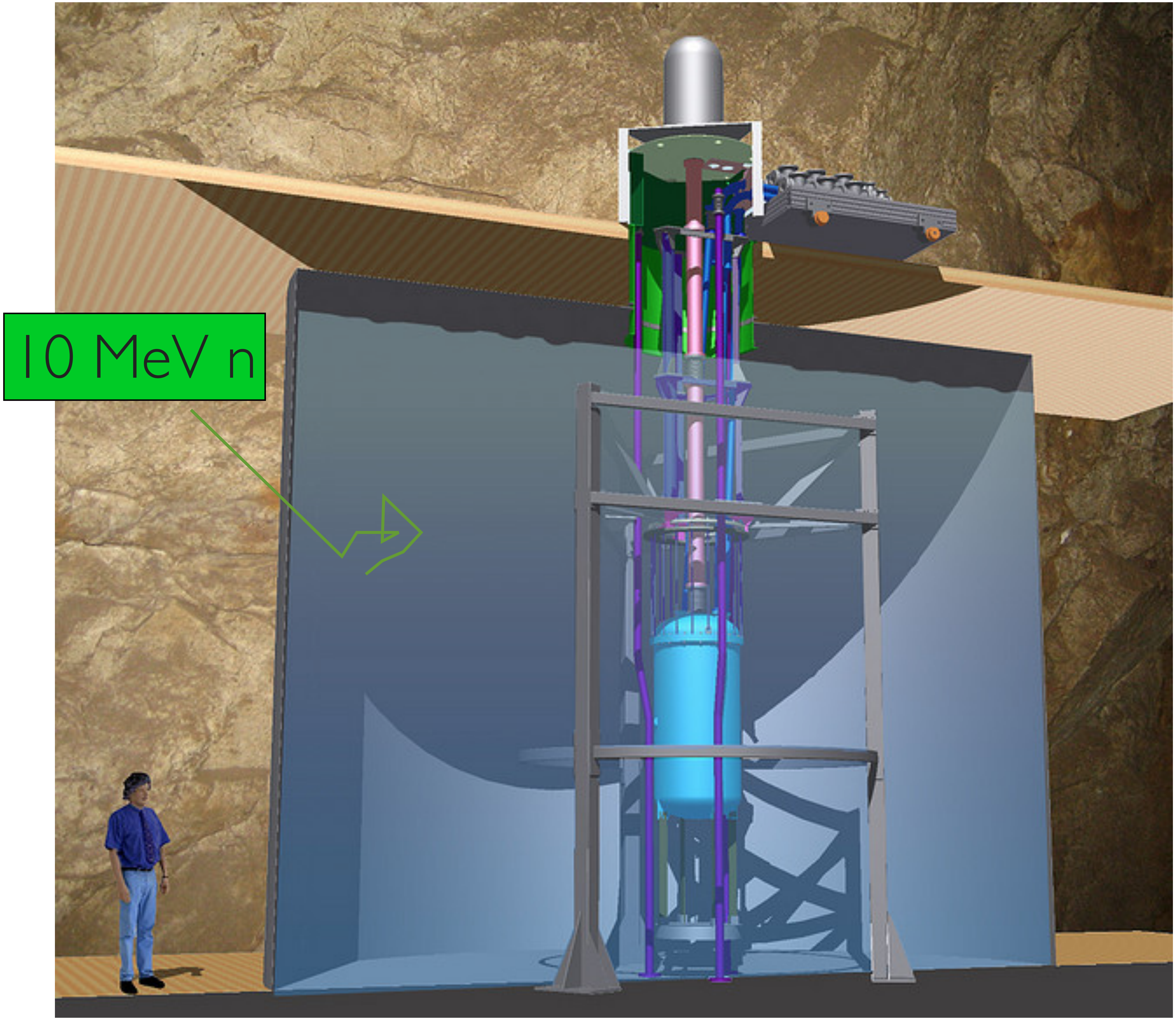

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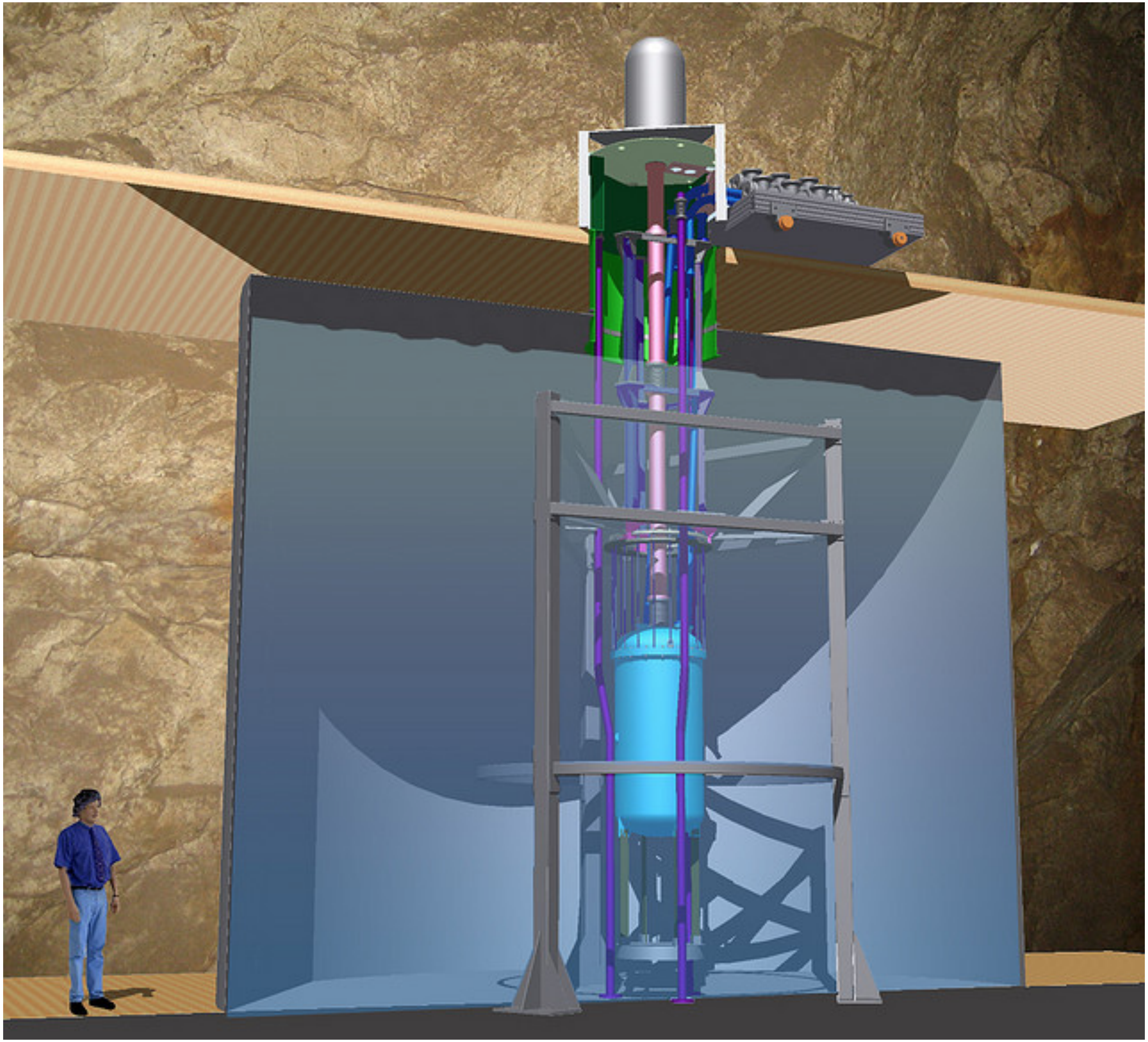

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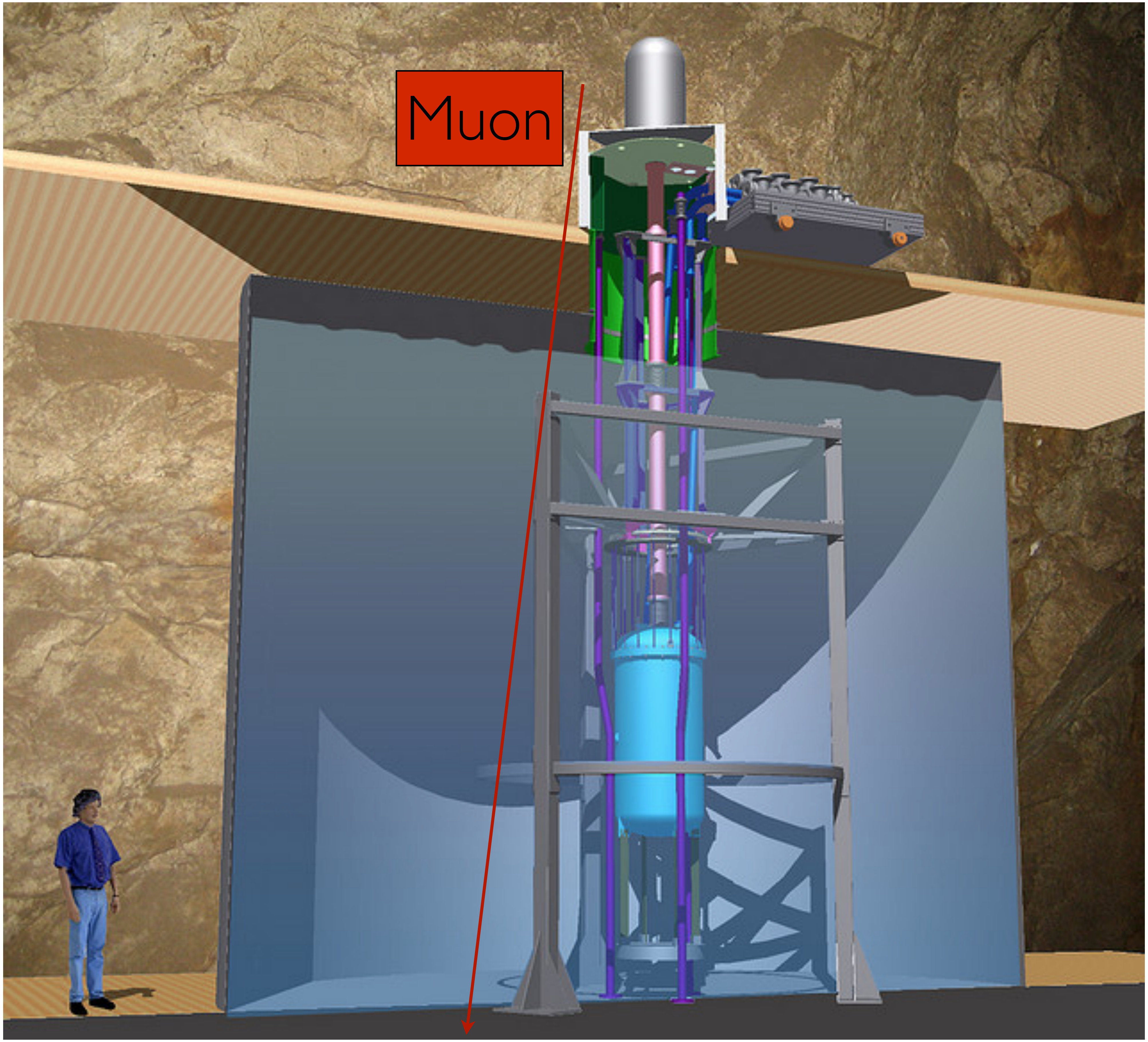

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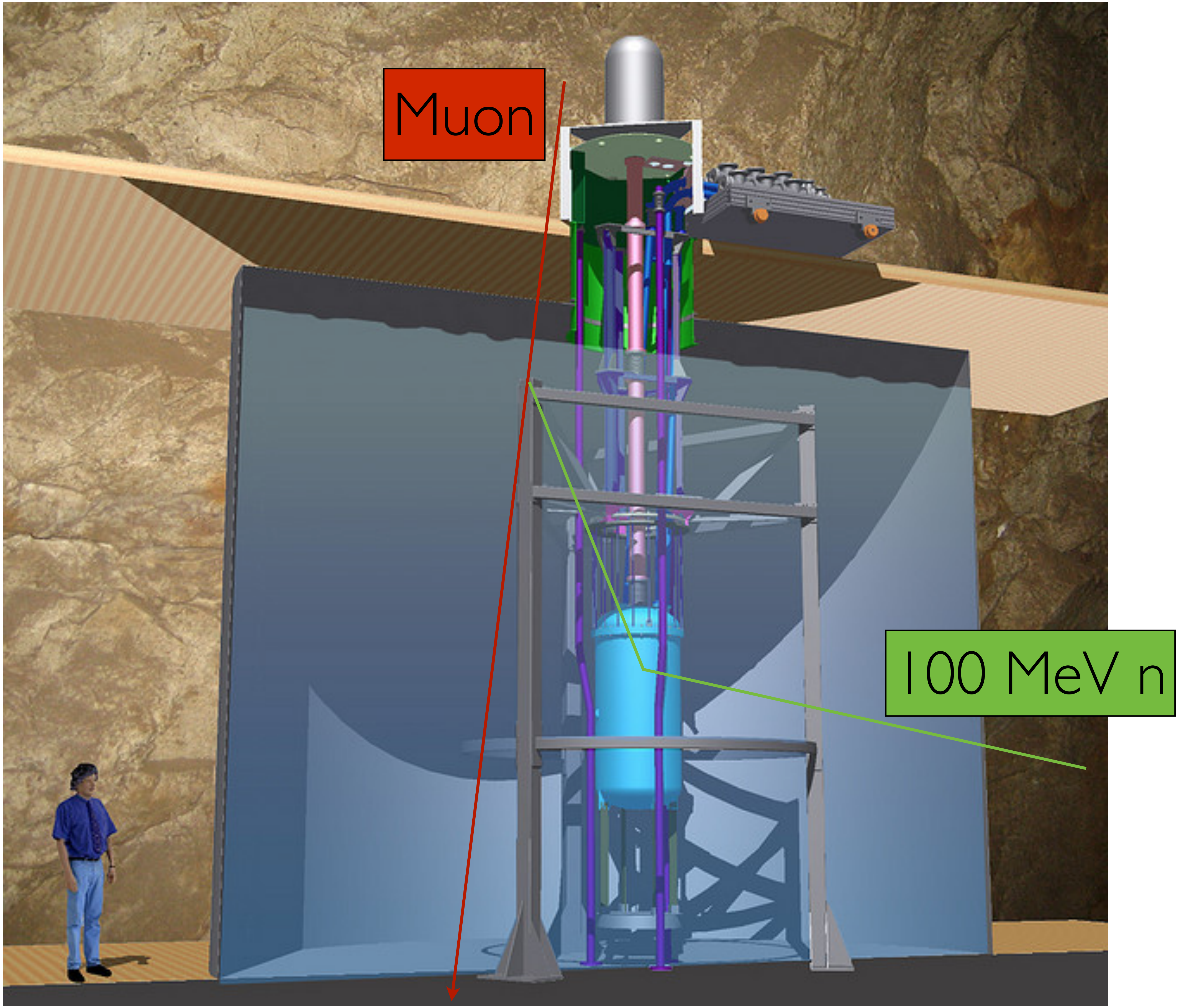


Neutron Production
Simulation vs Data

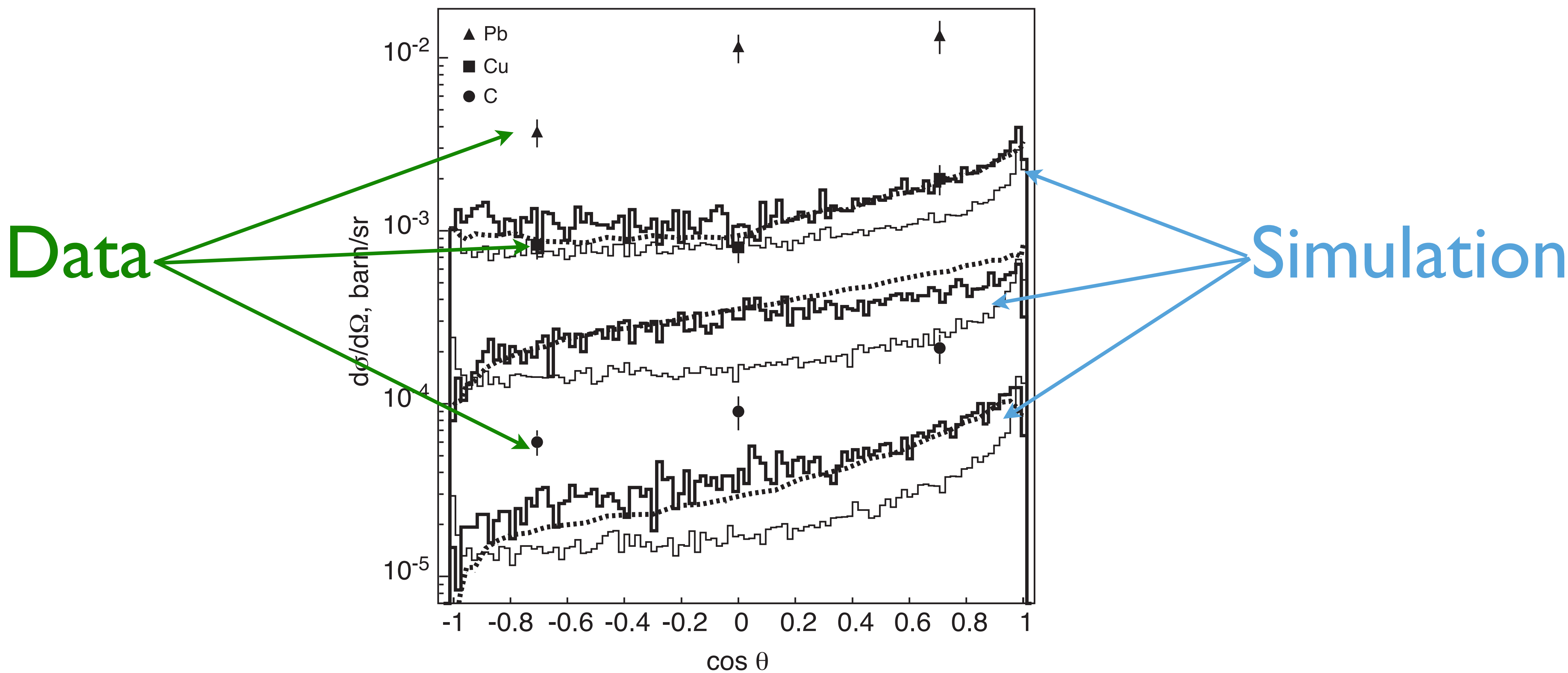


Fig. 7. Differential cross-section of neutron production by 190 GeV muons for a 10 MeV threshold in neutron energy. The data points represent the results of the NA55 experiment. The thin-line histogram shows the GEANT4 simulation considering muon–nucleus interaction only; the thick histogram includes all physics processes. The dashed line represents the FLUKA results for the latter case.

Araújo, et. al. NIM A, 2005

Neutron Production

Simulation vs Data

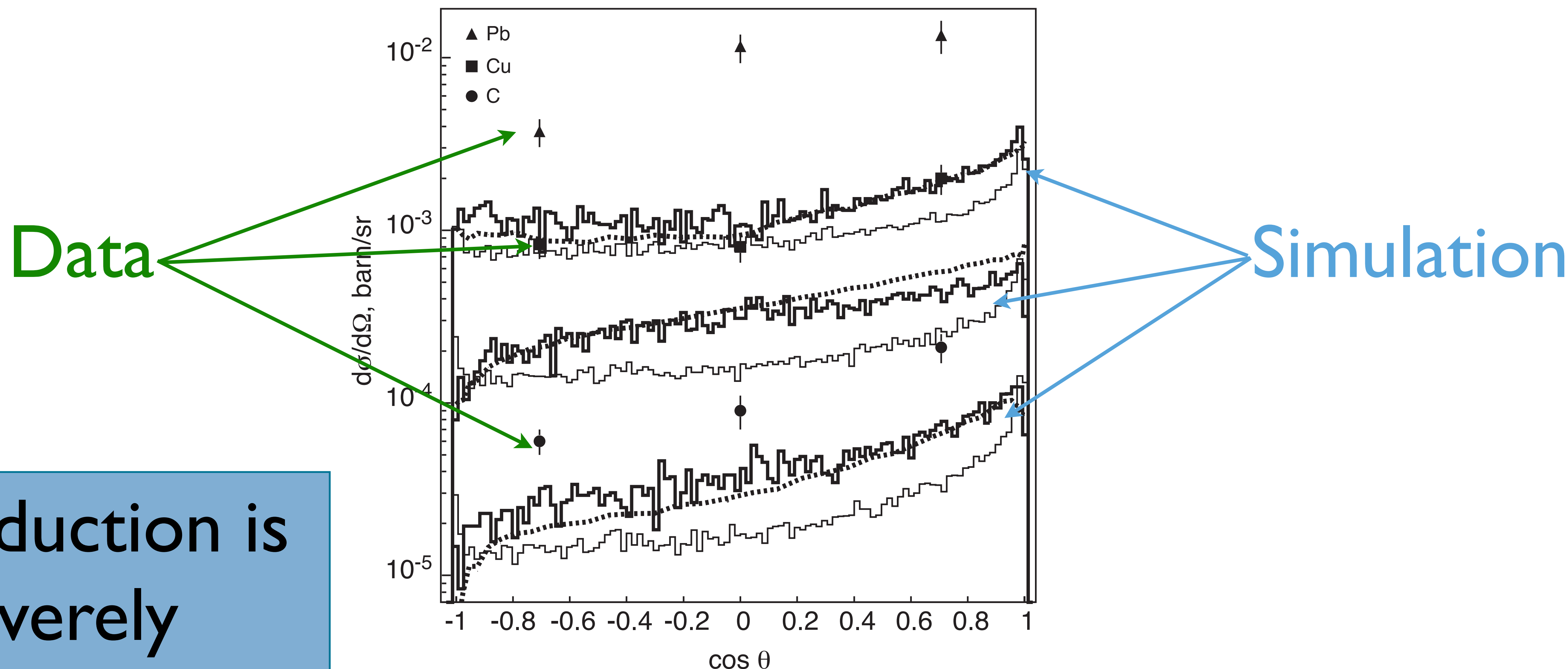
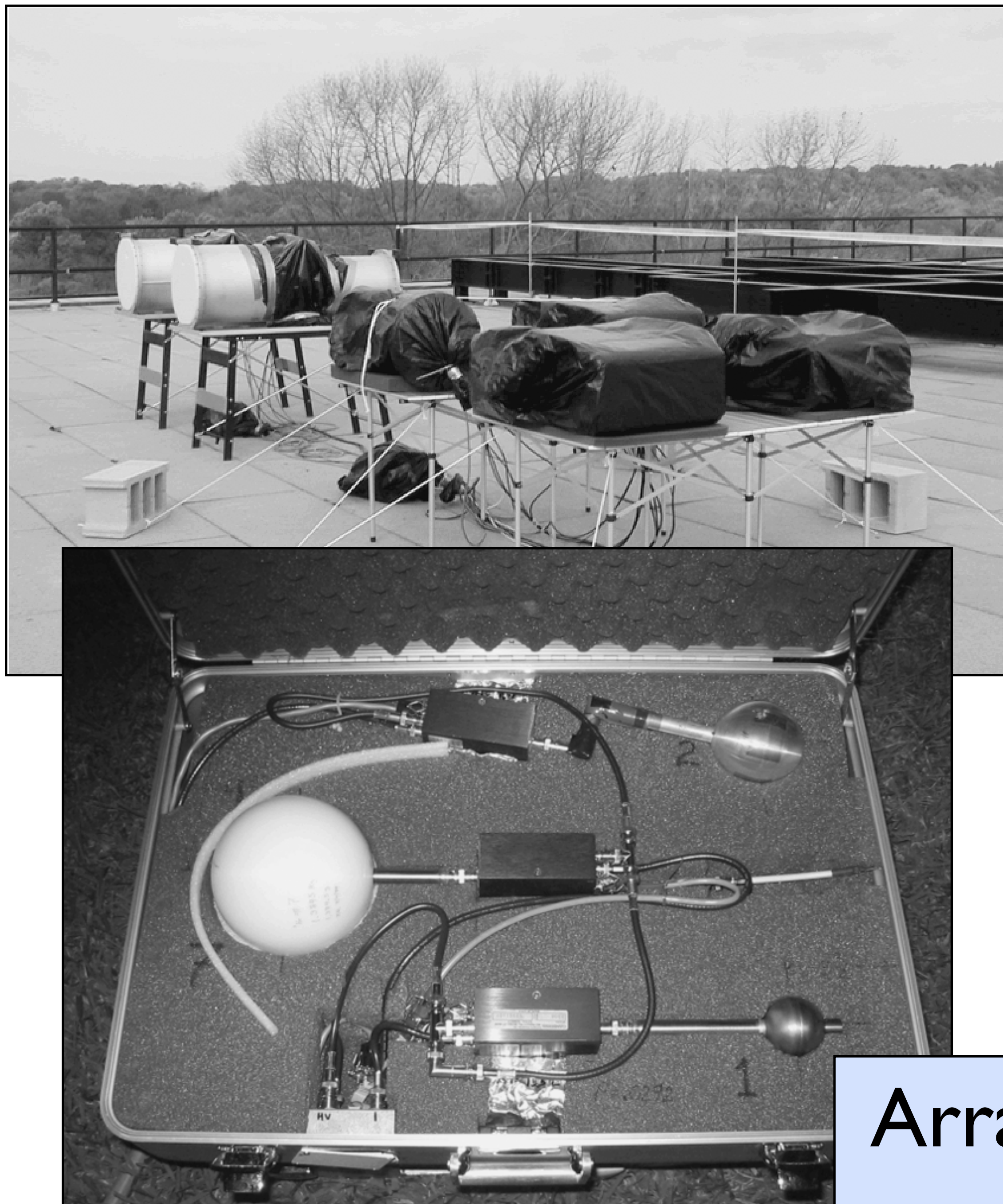


Fig. 7. Differential cross-section of neutron production by 190 GeV muons for a 10 MeV threshold in neutron energy. The data points represent the results of the NA55 experiment. The thin-line histogram shows the GEANT4 simulation considering muon–nucleus interaction only; the thick histogram includes all physics processes. The dashed line represents the FLUKA results for the latter case.

Araújo, et. al. NIM A, 2005

n-production is severely underestimated

Surface Fast Neutron Spectrum



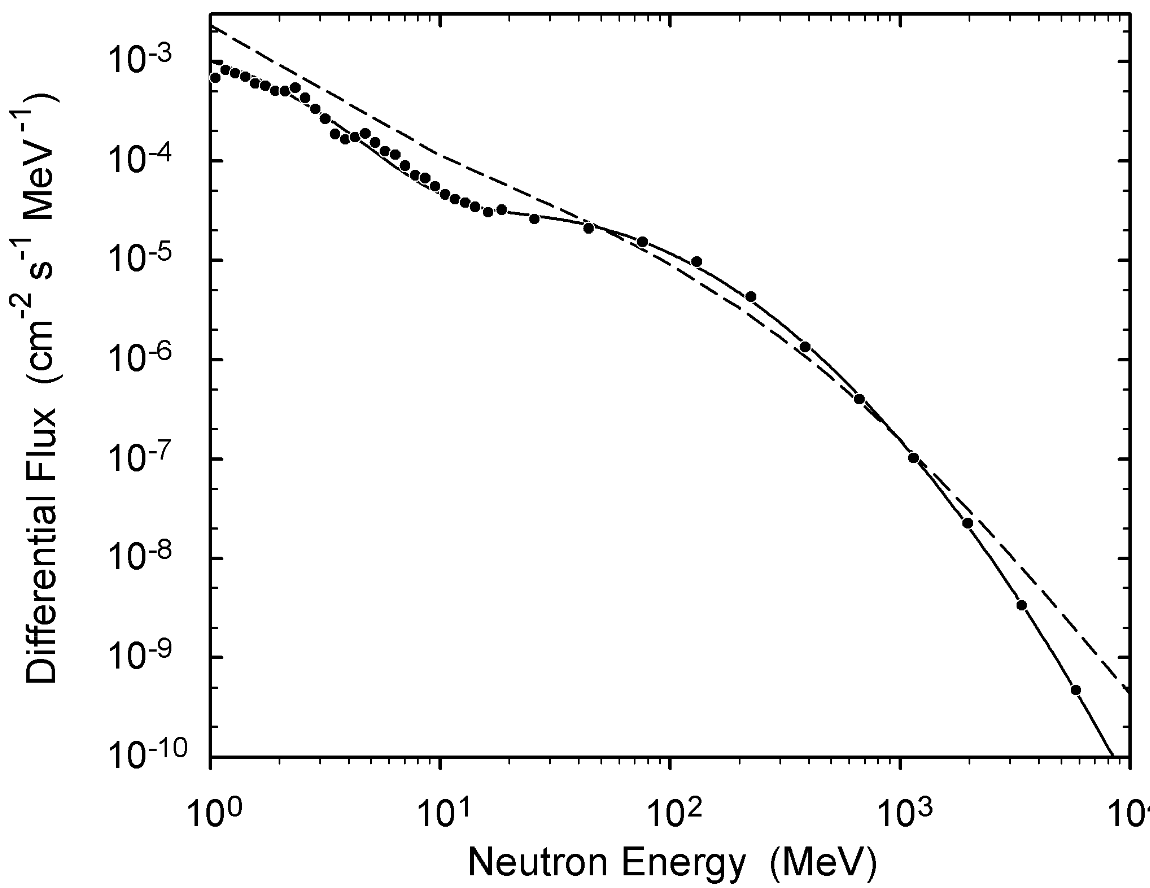


Fig. 8. Differential flux, $d\phi/dE$, $(\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{MeV}^{-1})$ of cosmic-ray induced neutrons as a function of neutron energy. The data points are our reference spectrum from the measurements, the solid curve is our analytic model, and the dashed curve is the JEDEC model [38].

Array of 14 Bonner spheres, count rates are unfolded to make a spectrum

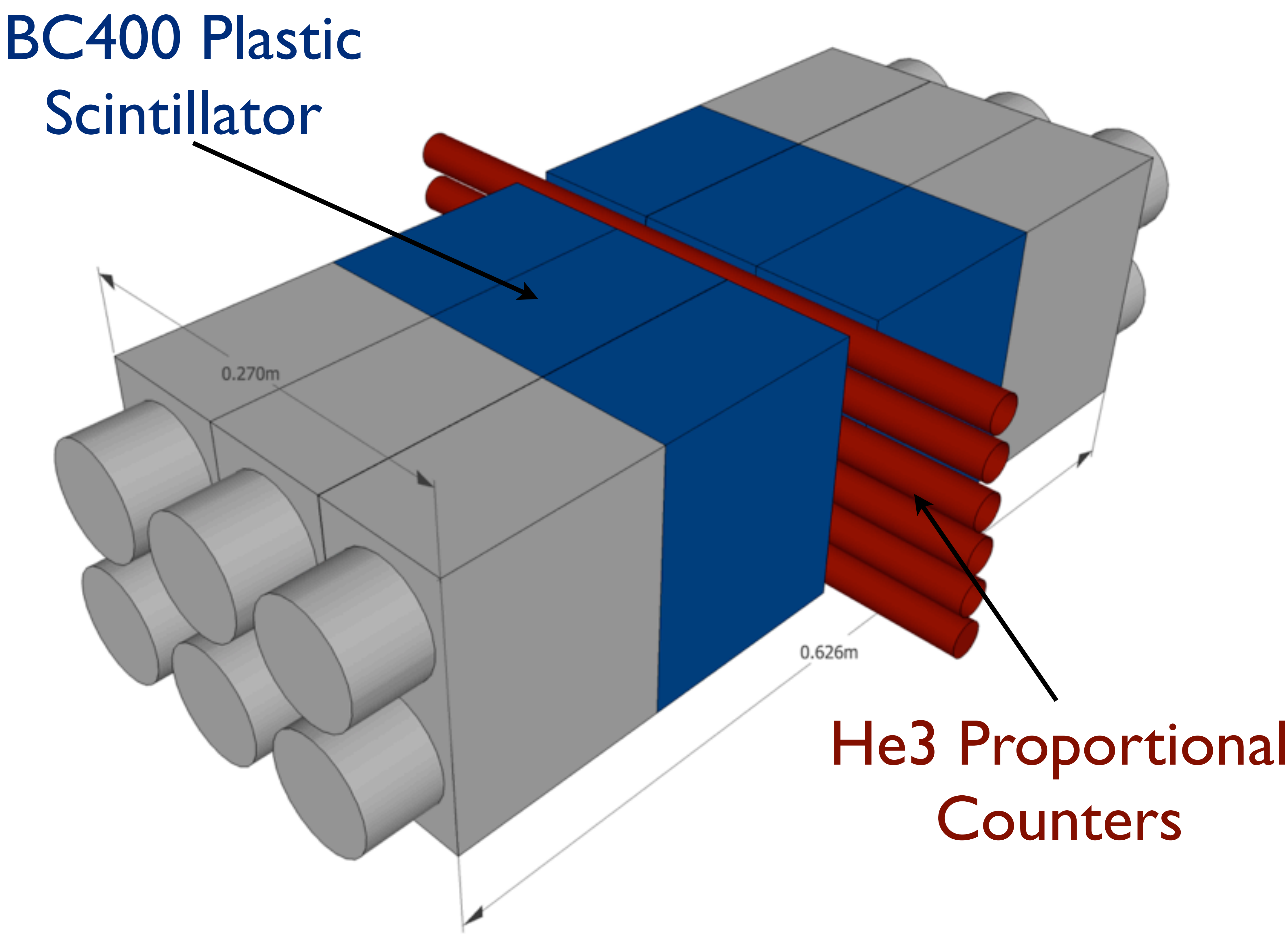
Gordon, et al., IEEE Trans 51, (2004)

The UMD/NIST
Fast Neutron Spectrometers

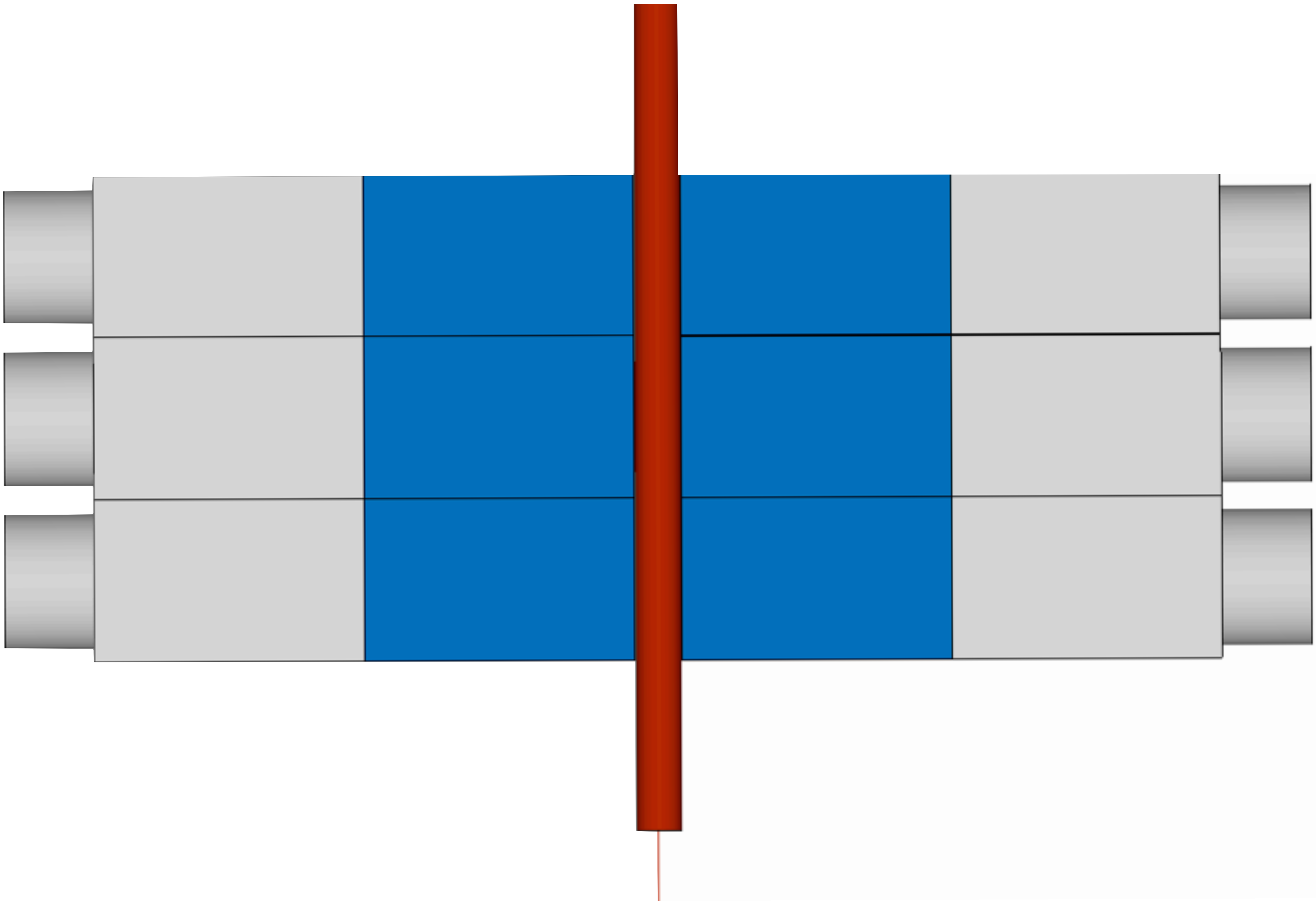
The FaNS Detectors

- Arrays of plastic scintillator segments and helium-3 proportional counters
  - Segmentation improved energy reconstruction
- *Use Capture-gated Spectroscopy for particle identification and energy information*
- Calibrated at NIST with Cf-252, DD, and DT neutrons
- Measure the surface and underground neutron spectra
  - FaNS-1: operated at Kimballton Underground Research Facility
  - FaNS-2: to be operated at shallow location at NIST

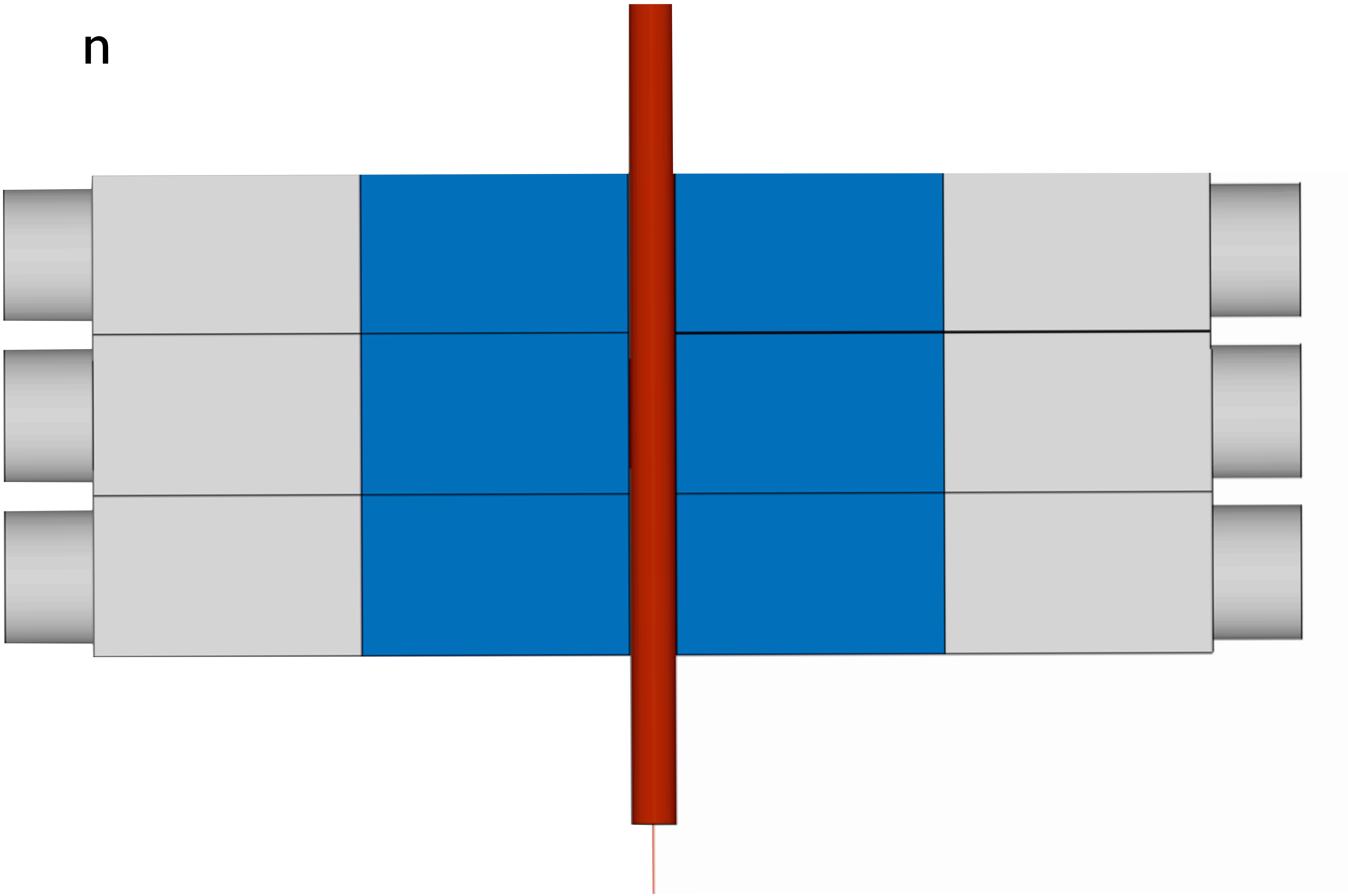
FaNS-1


BC400 Plastic
Scintillator
0.270m
0.626m
He3 Proportional
Counters

FaNS-1



FaNS-1



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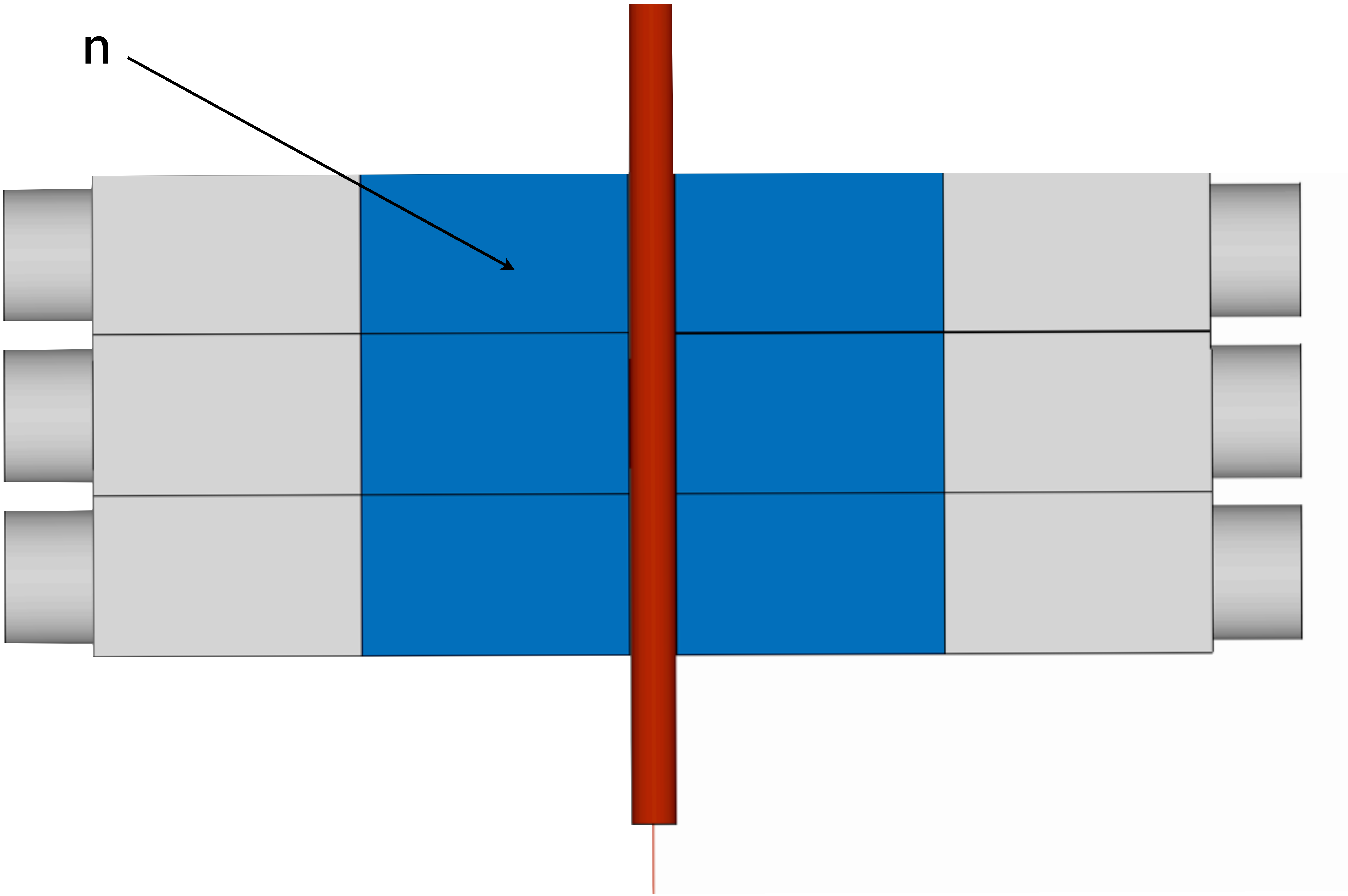
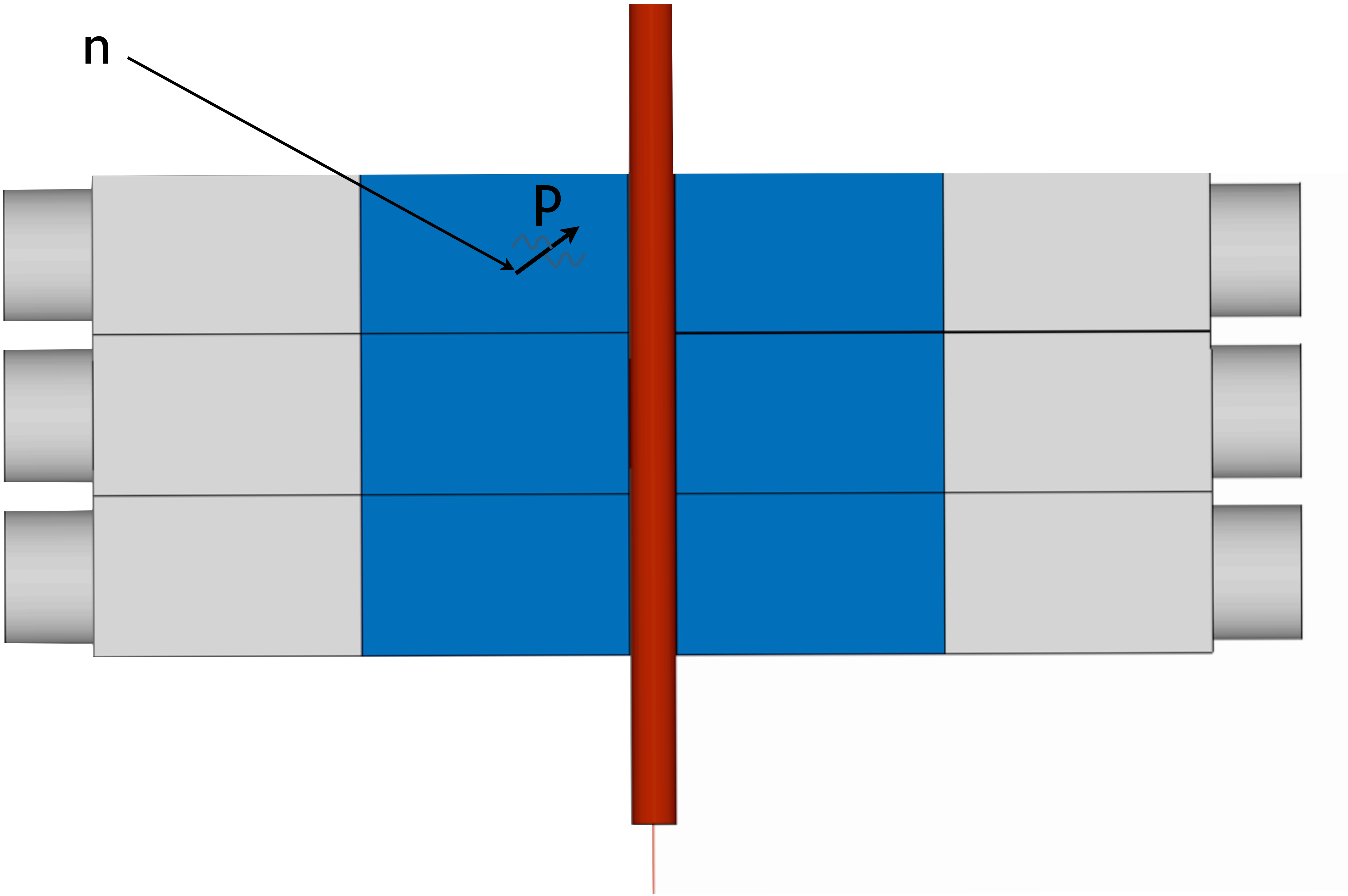


FaNS-1



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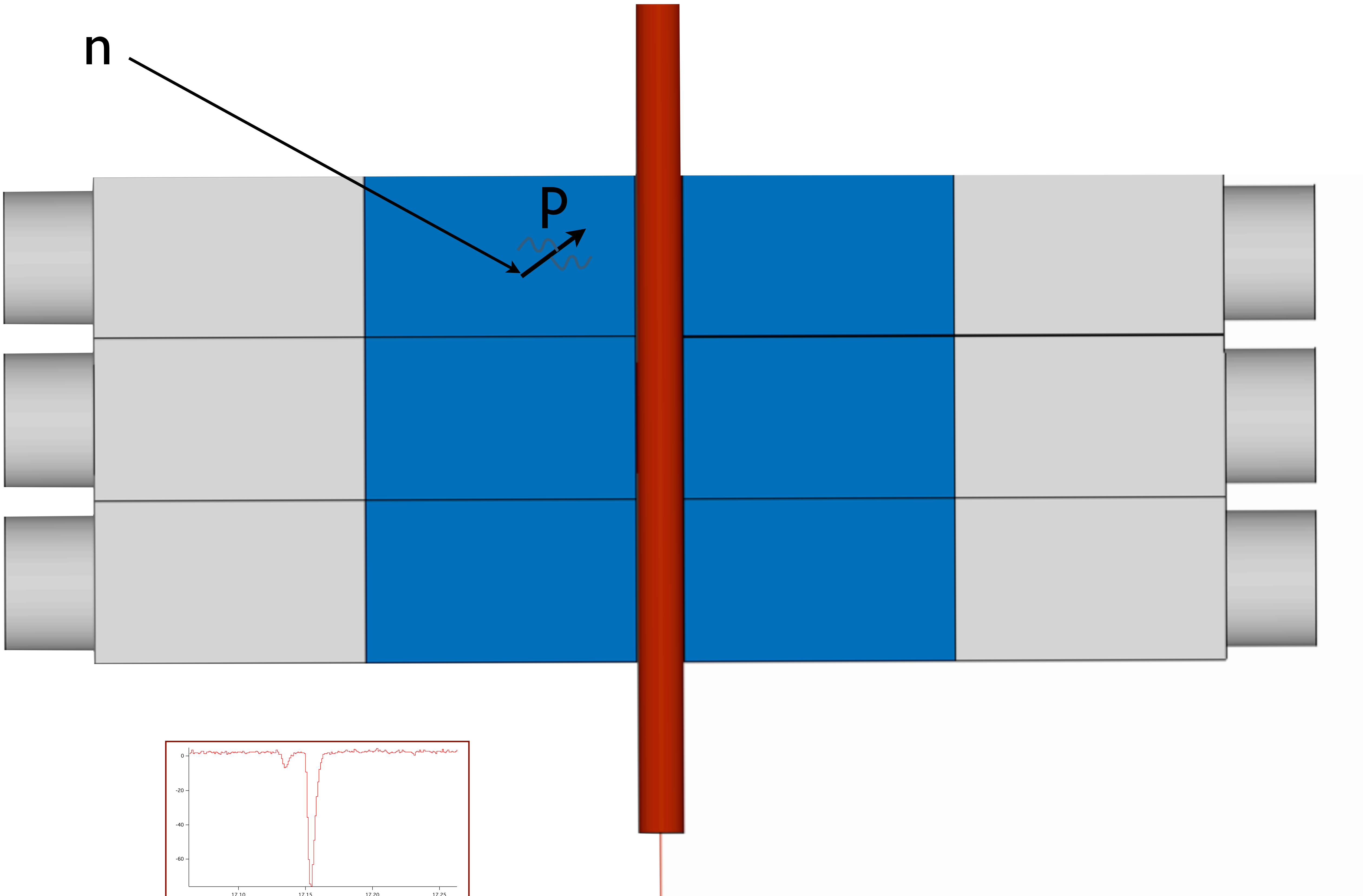

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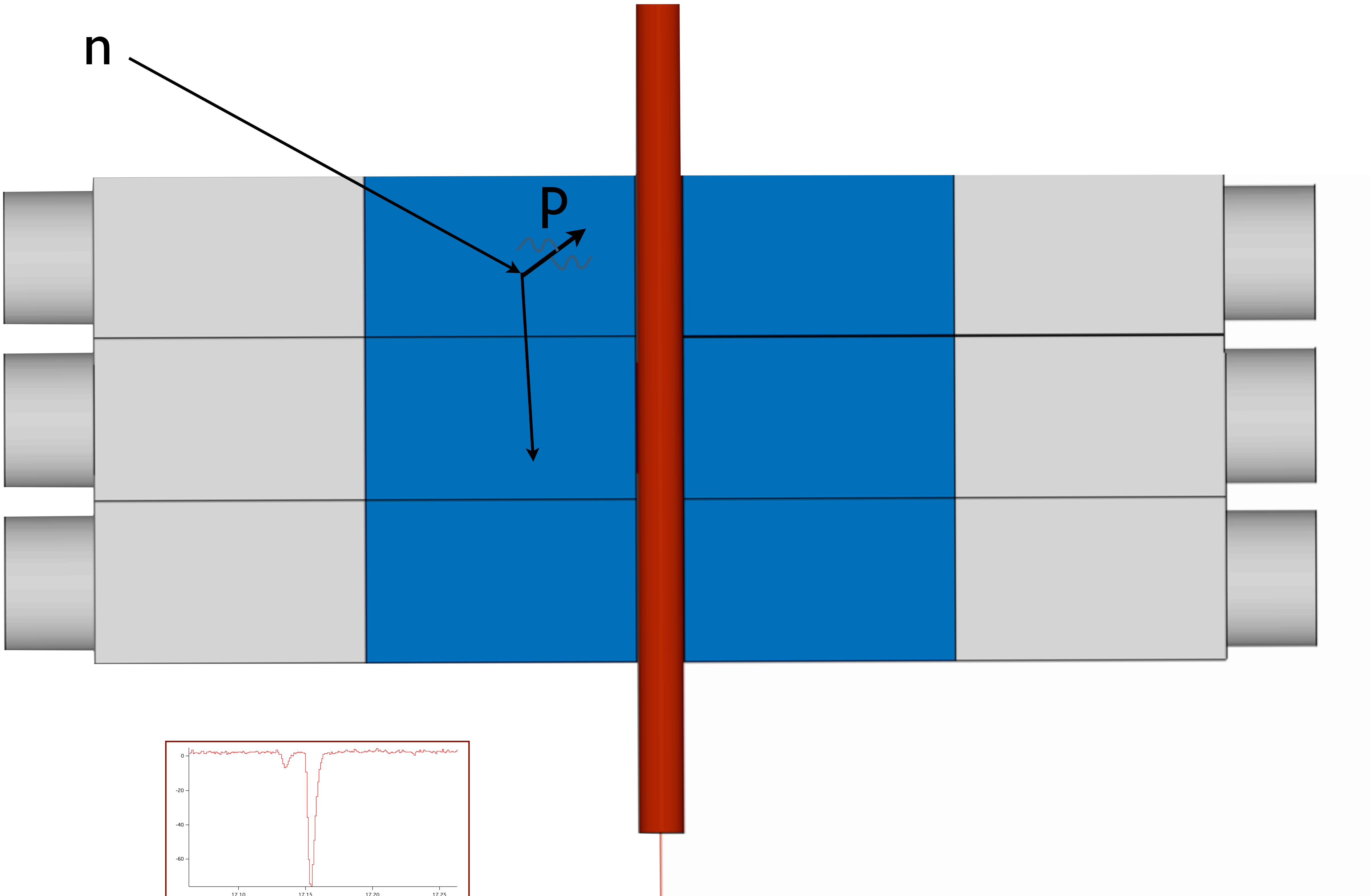

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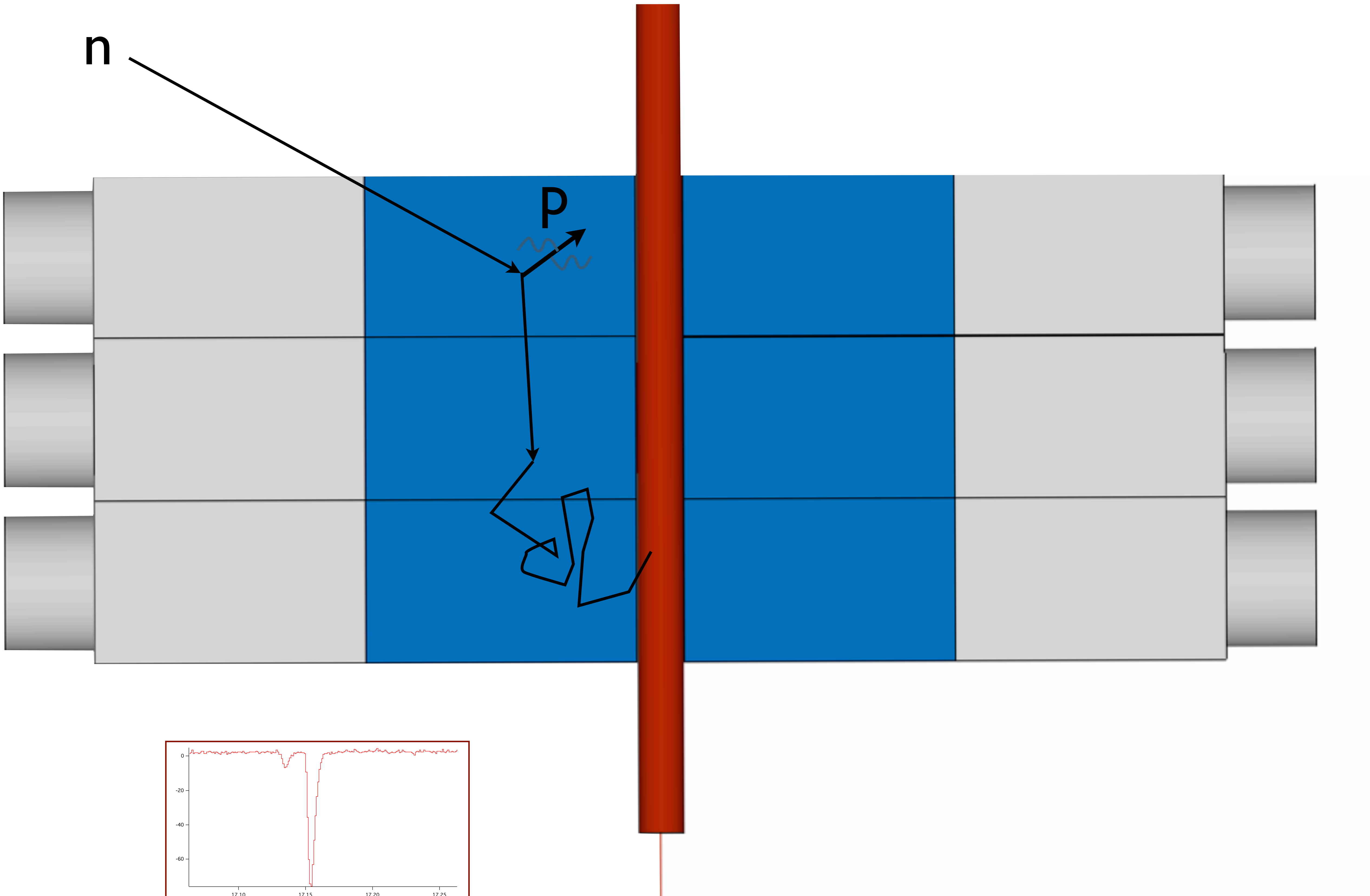

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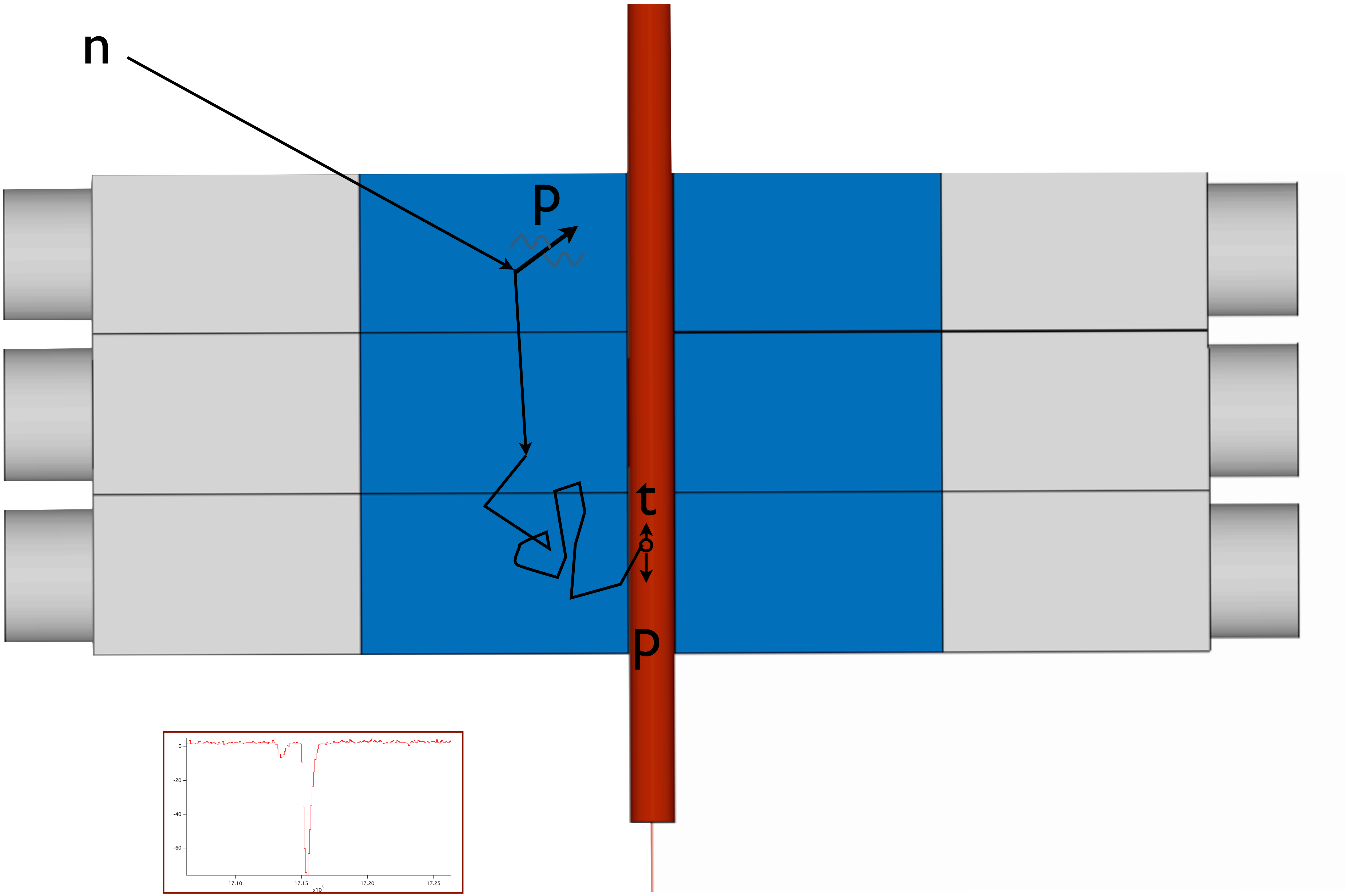

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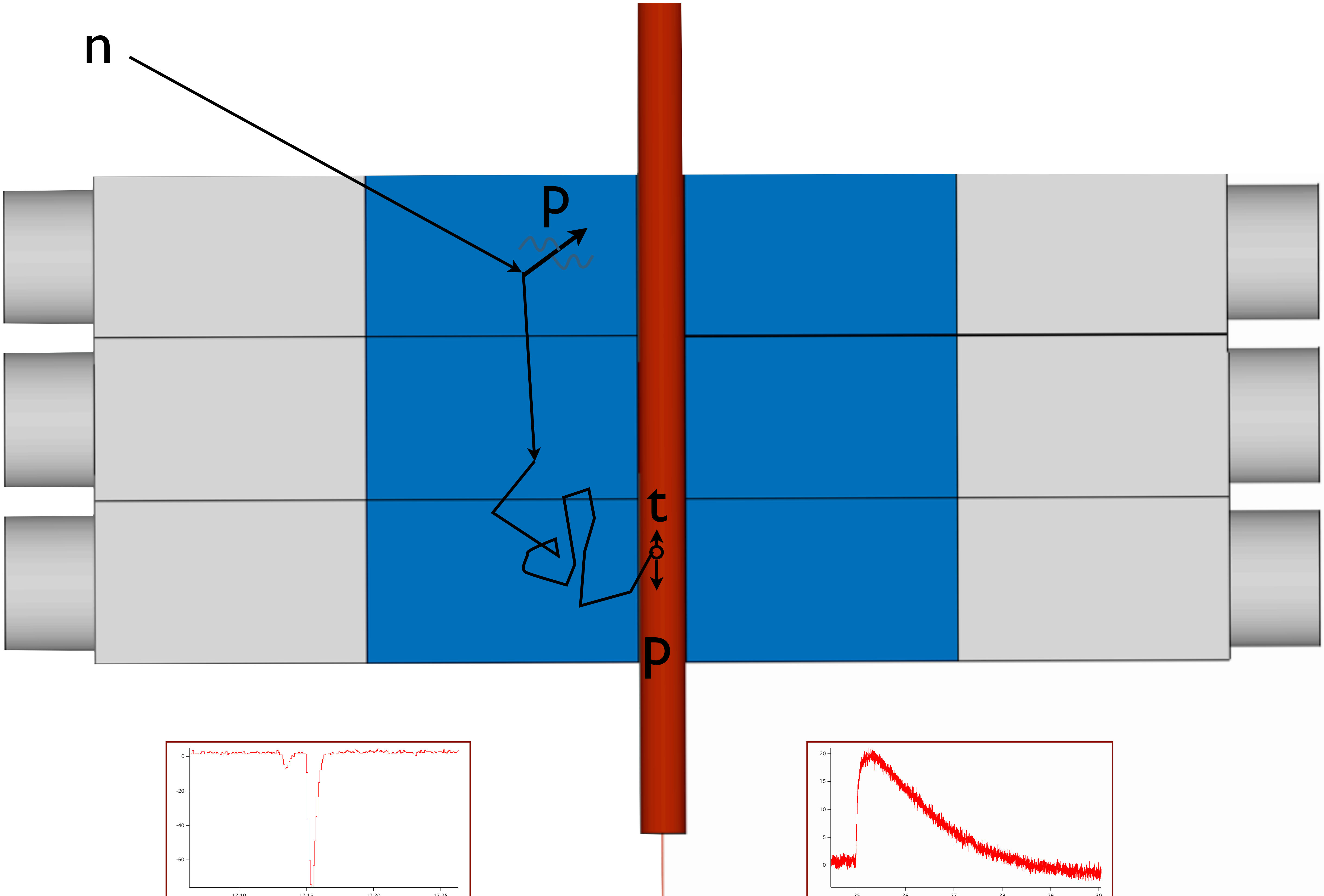
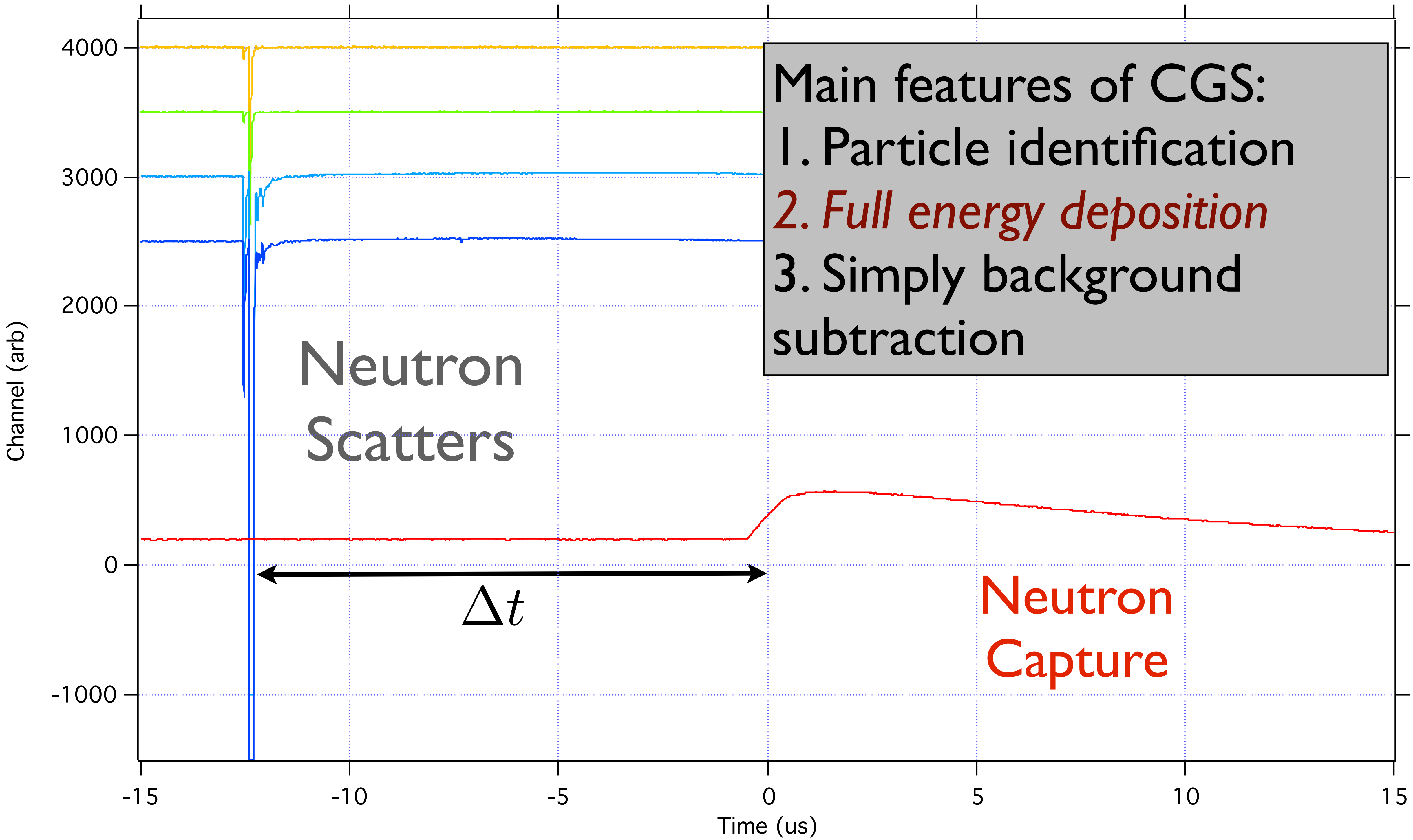
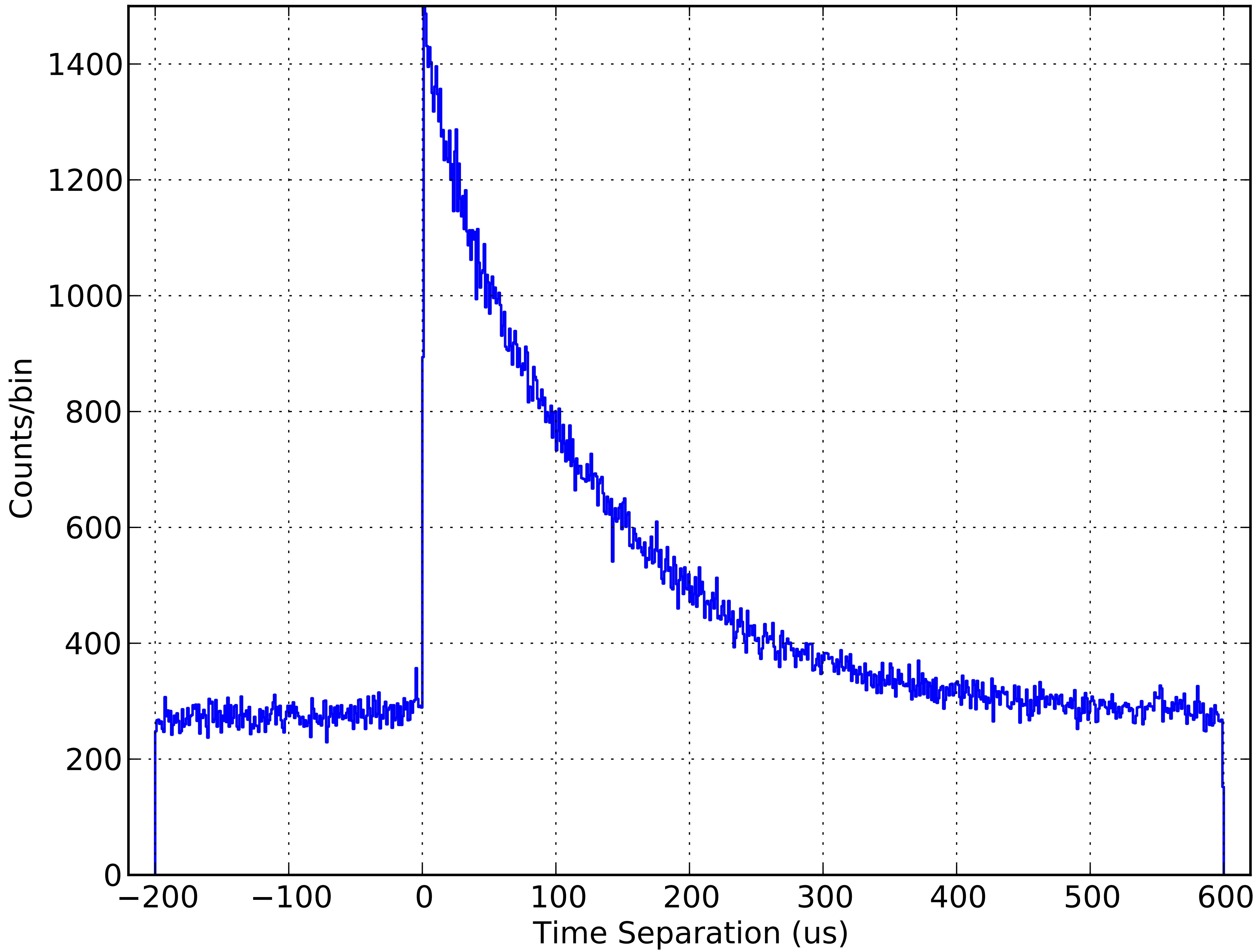


Capture Gated Spectroscopy



Timing Spectrum



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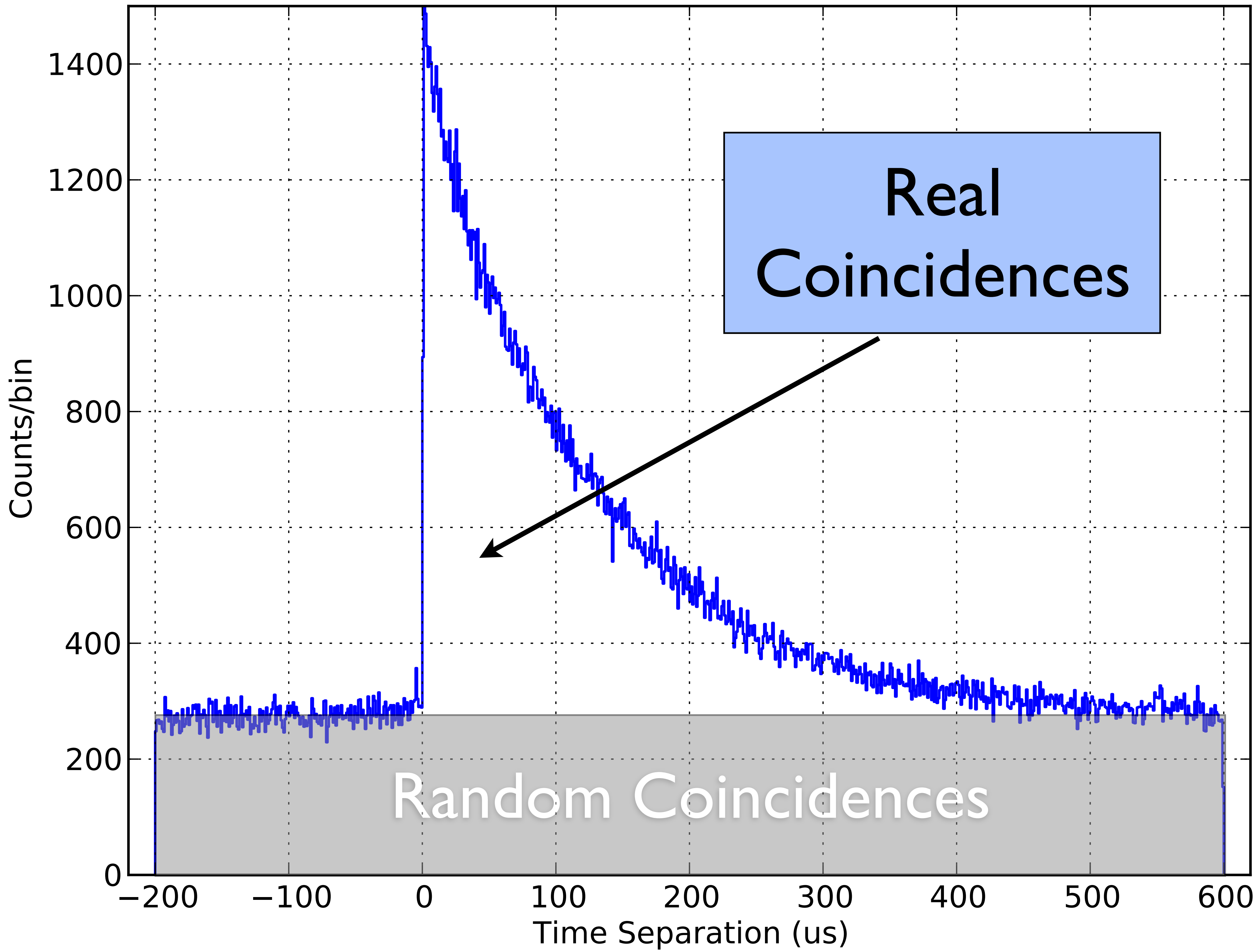
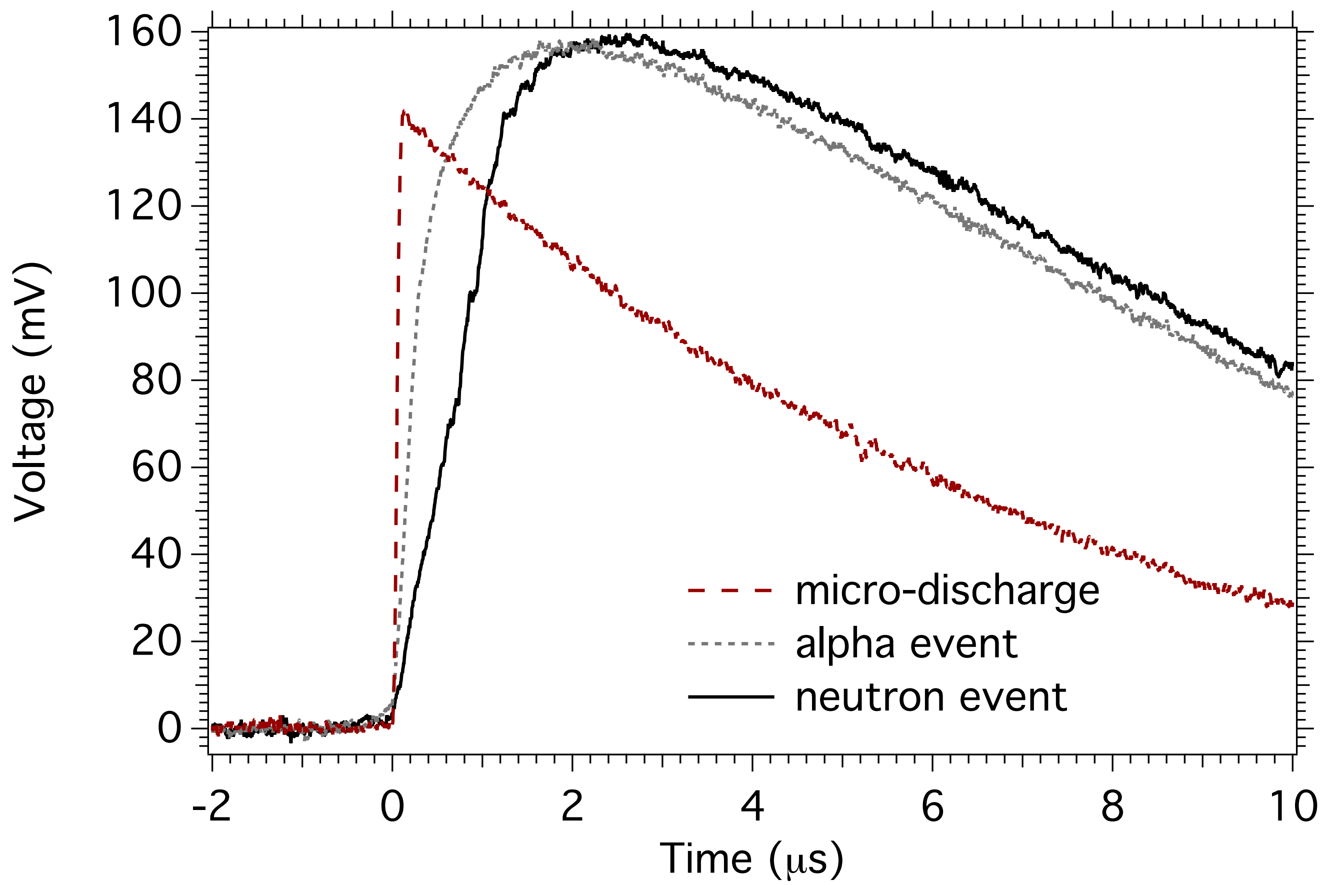
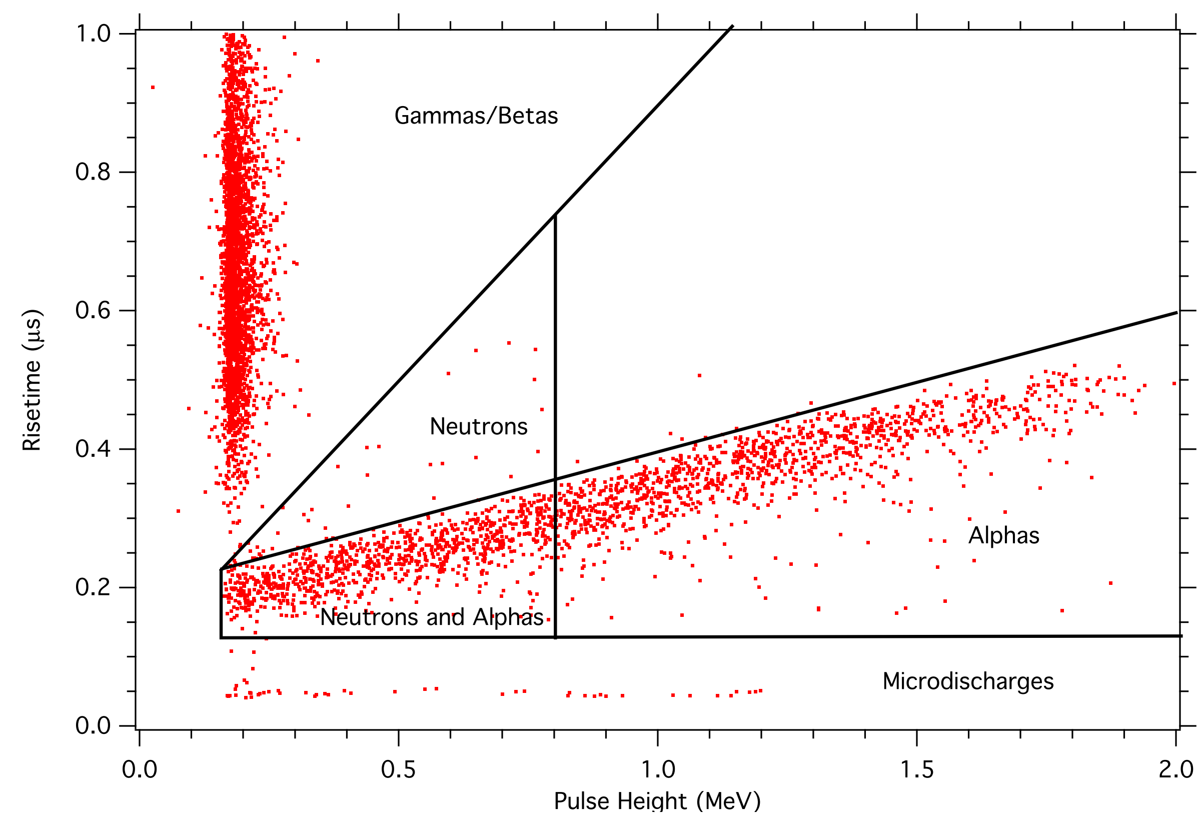


Risetime of Helium Signals



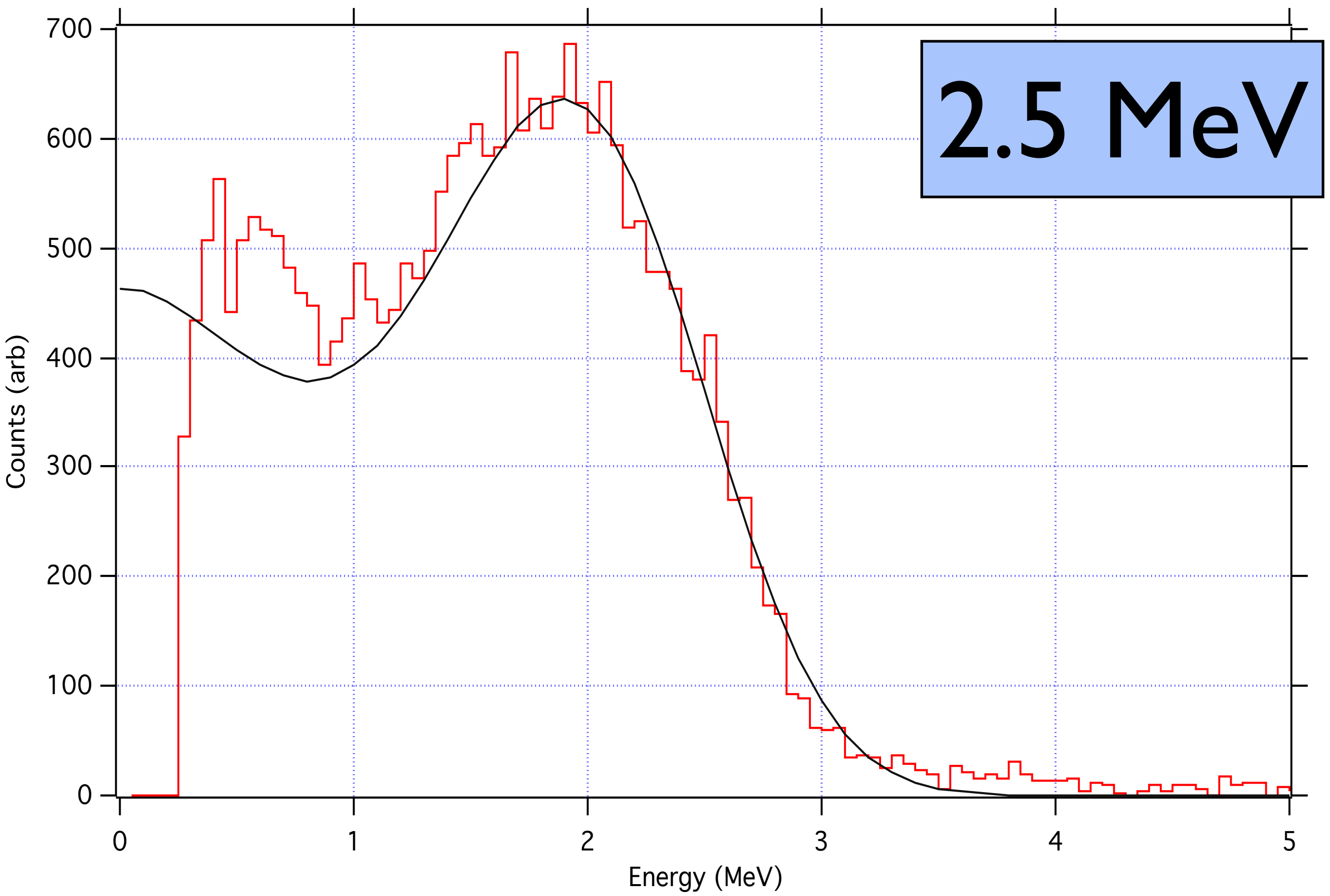
1. Use preamp signals directly
2. Digitize signals
3. Risetime =50% - 10%

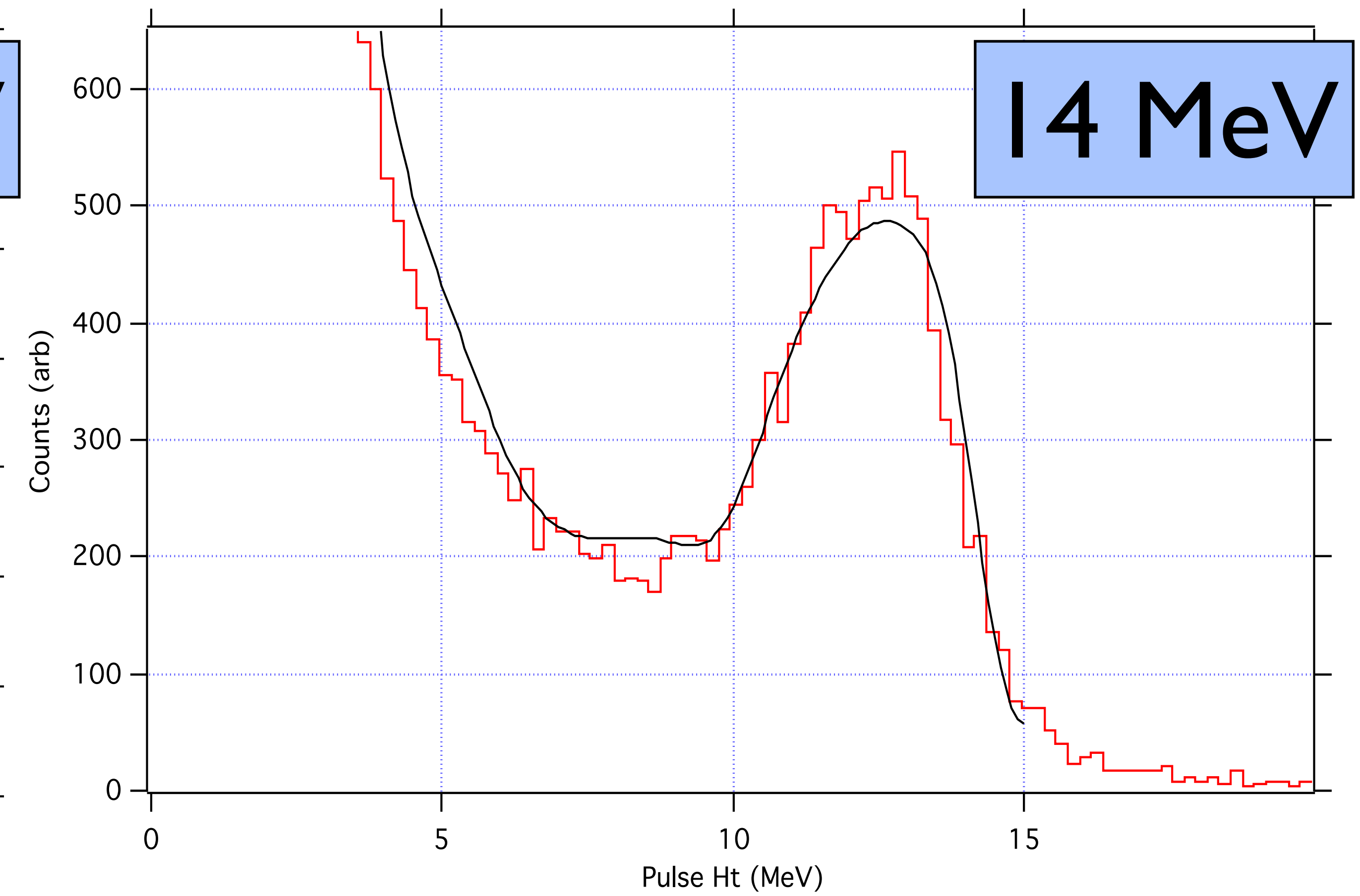


Allows for suppression of alpha, gamma, and microdischarge noise signals

Langford et al. http://arxiv.org/abs/1212.4724

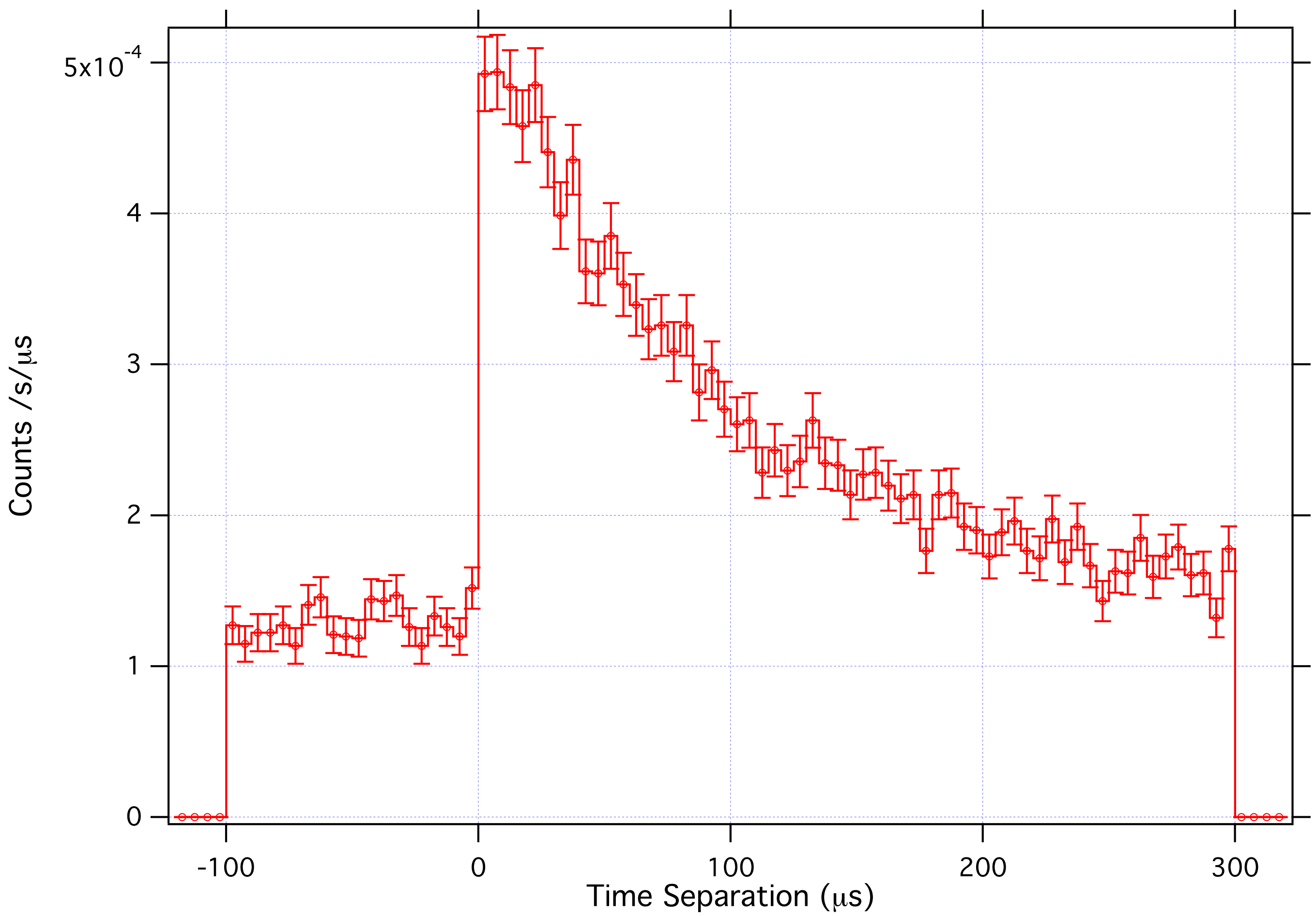
Calibrations as NIST



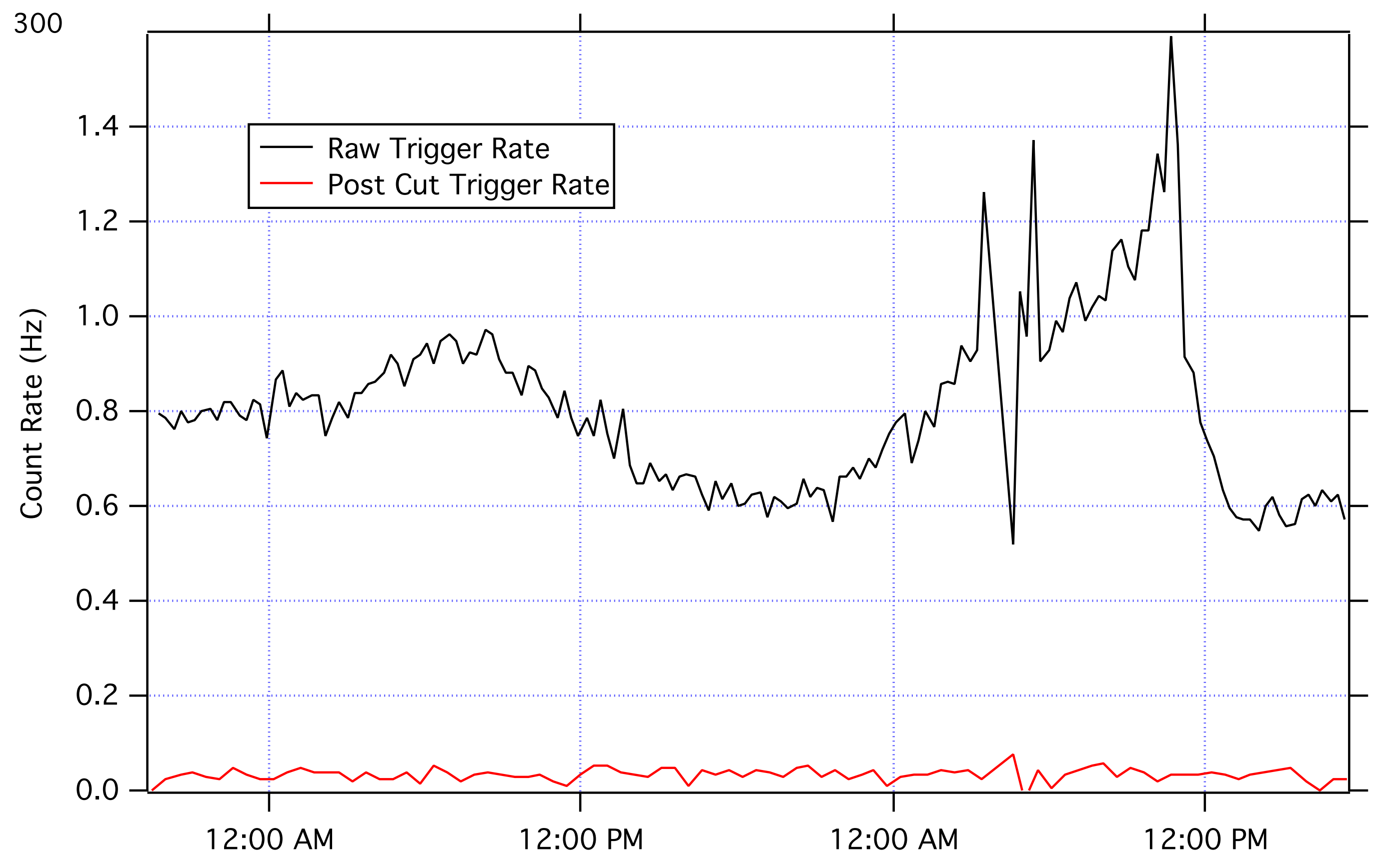


- Used two mono-energetic neutron generators to measure FaNS-1 energy reconstruction
- Both show good agreement with MCNP
- *Shows that we have full energy deposition*

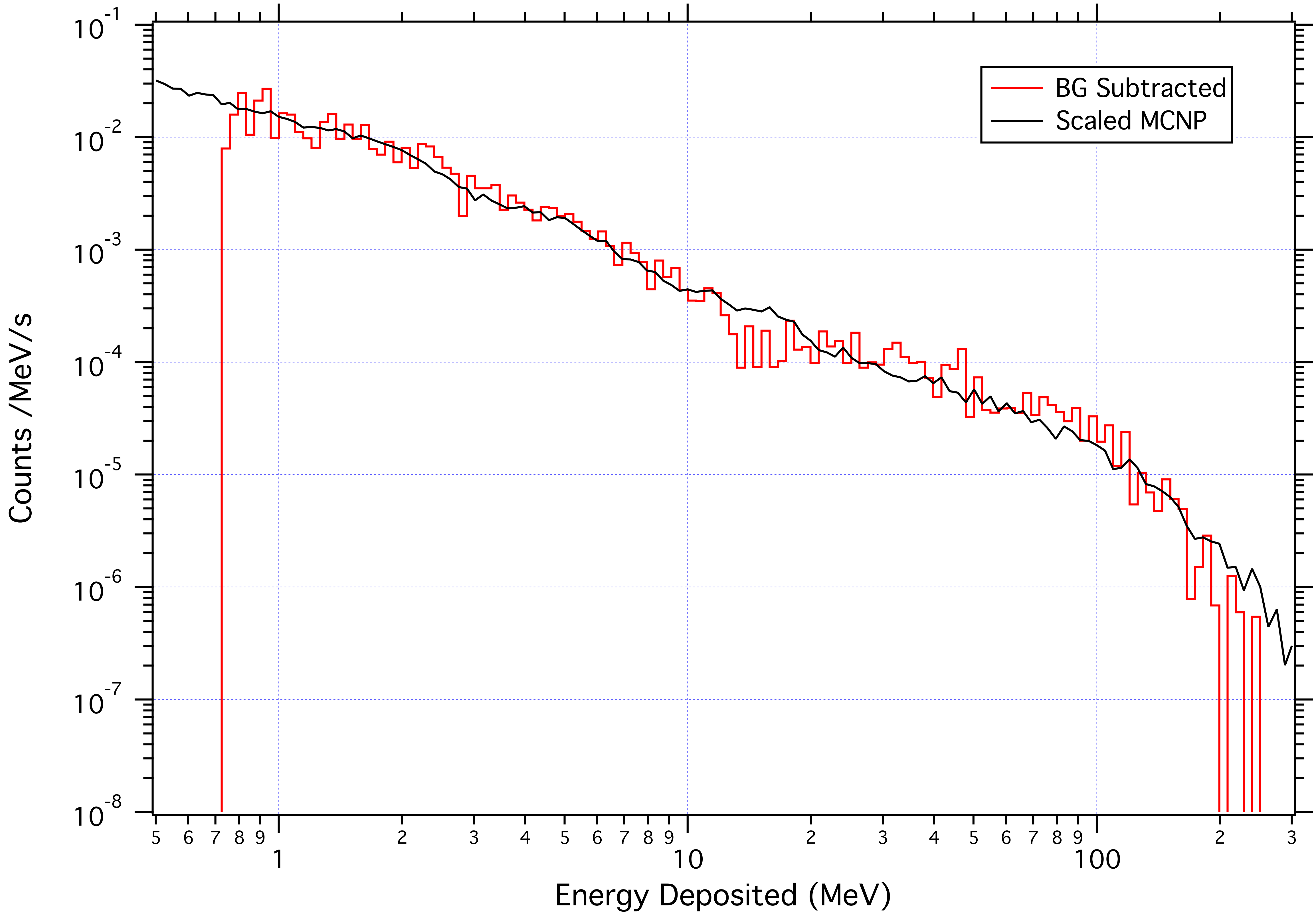
FaNS-1 at the Surface



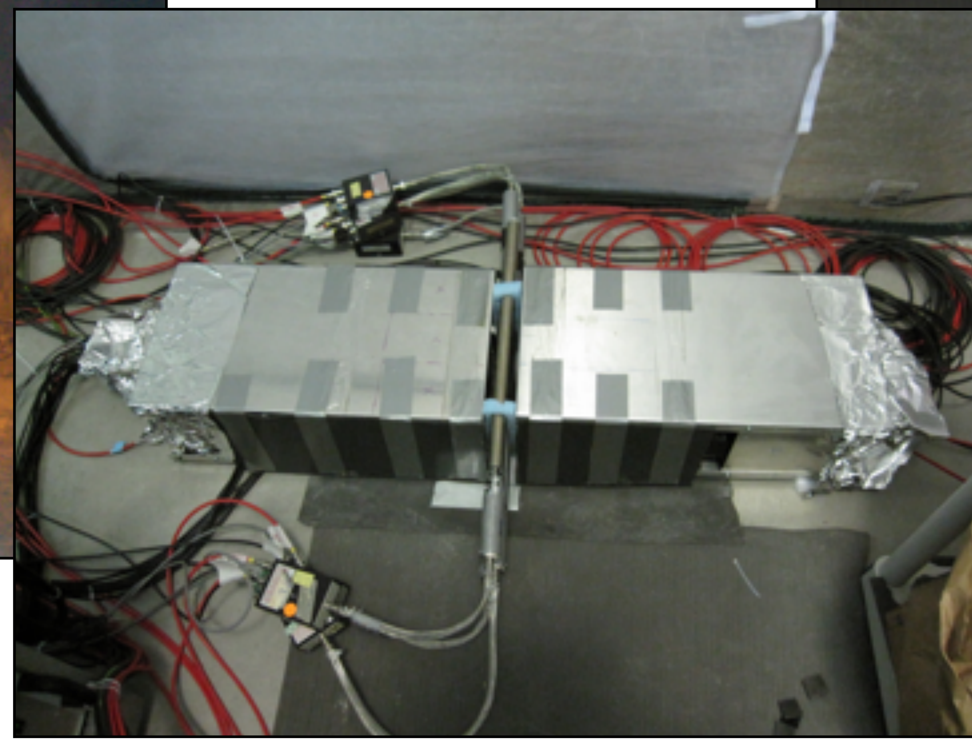
- Operated FaNS-1 for 1.6×10^5 seconds
- Recorded 1.3×10^5 events (0.8 Hz)
- After cuts, ~6000 neutron events (0.04Hz)
- *Recorded neutron energies up to 300 MeV*



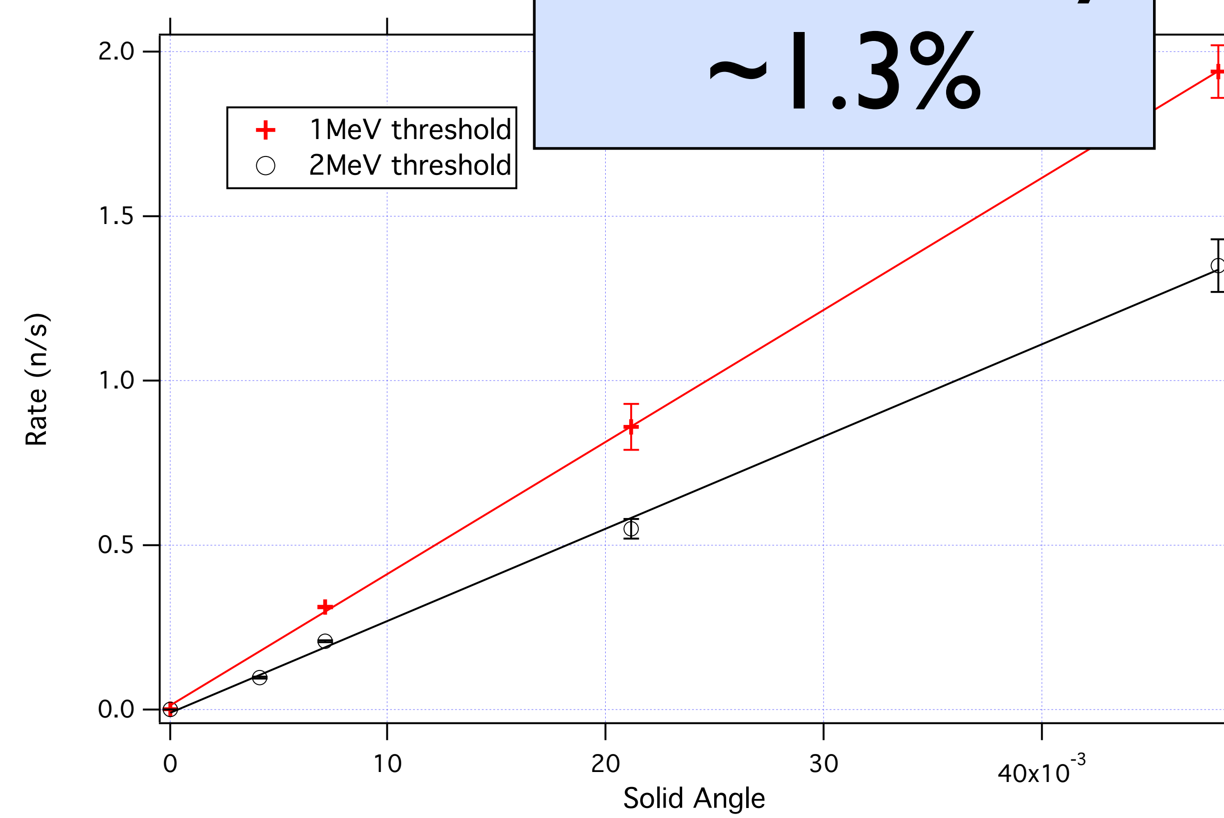
FaNS-1 at the Surface



FaNS-1 at KURF

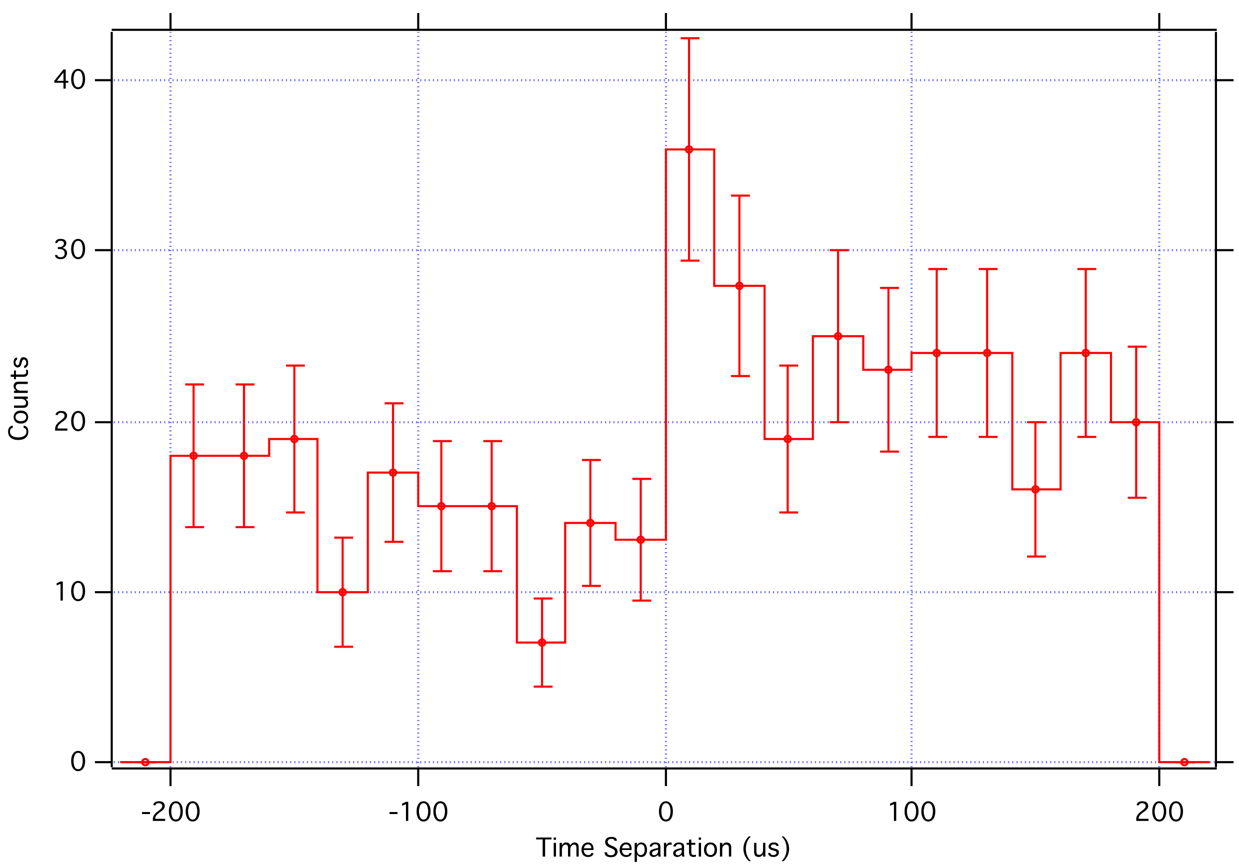


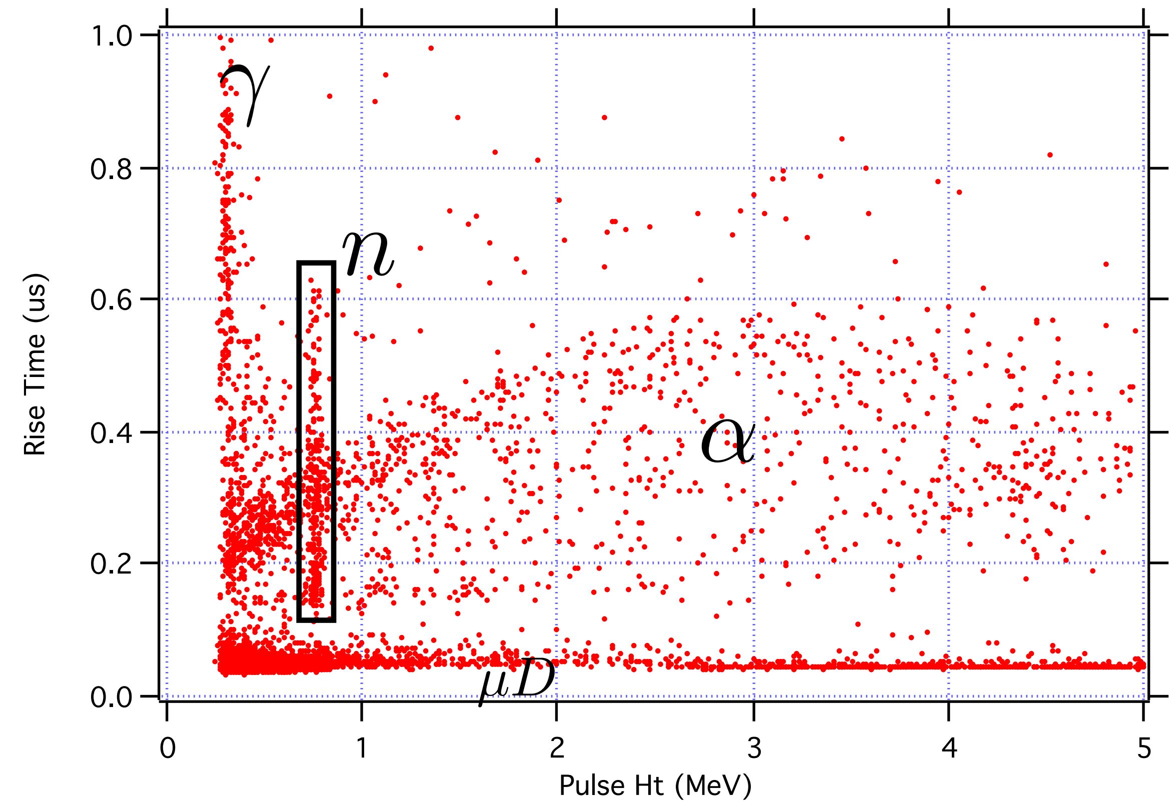
Cf Efficiency ~1.3%

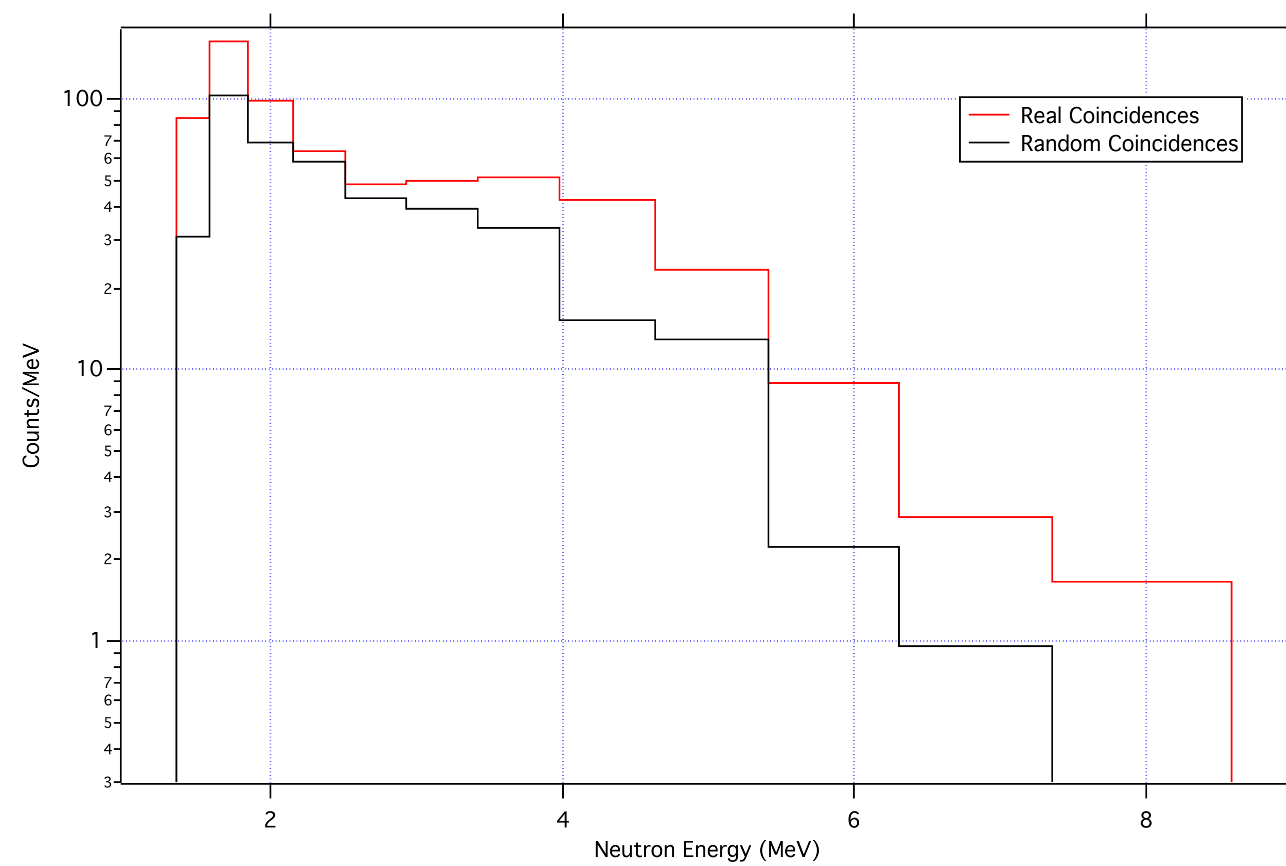


- Multiple upgrades to electrons to reduce backgrounds and noise
- *Measured efficiency with Cf-252 source (1.3+-0.1)%*
- Final dataset included 100 days of operation

FaNS-1 at KURF - 1450mwe

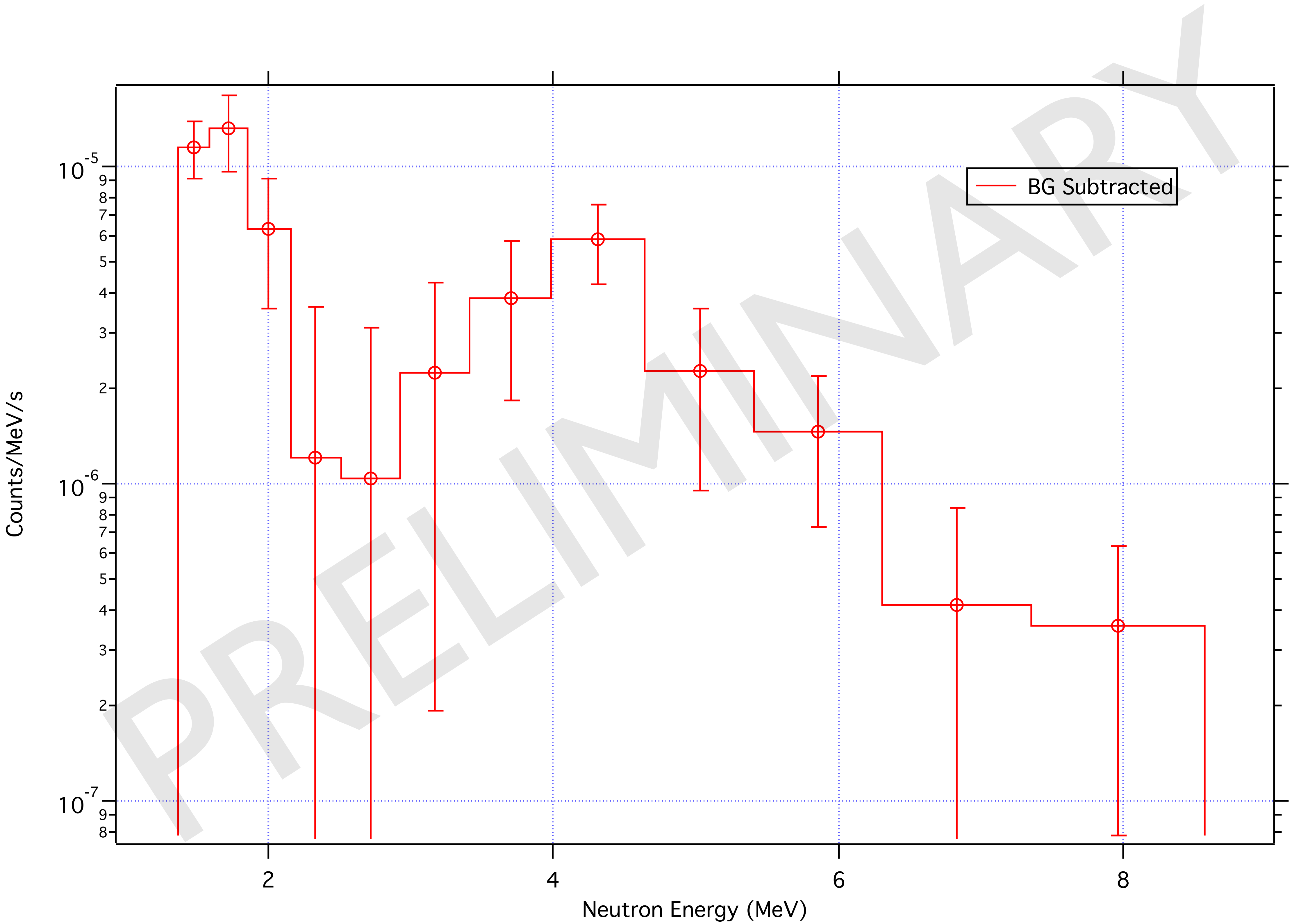






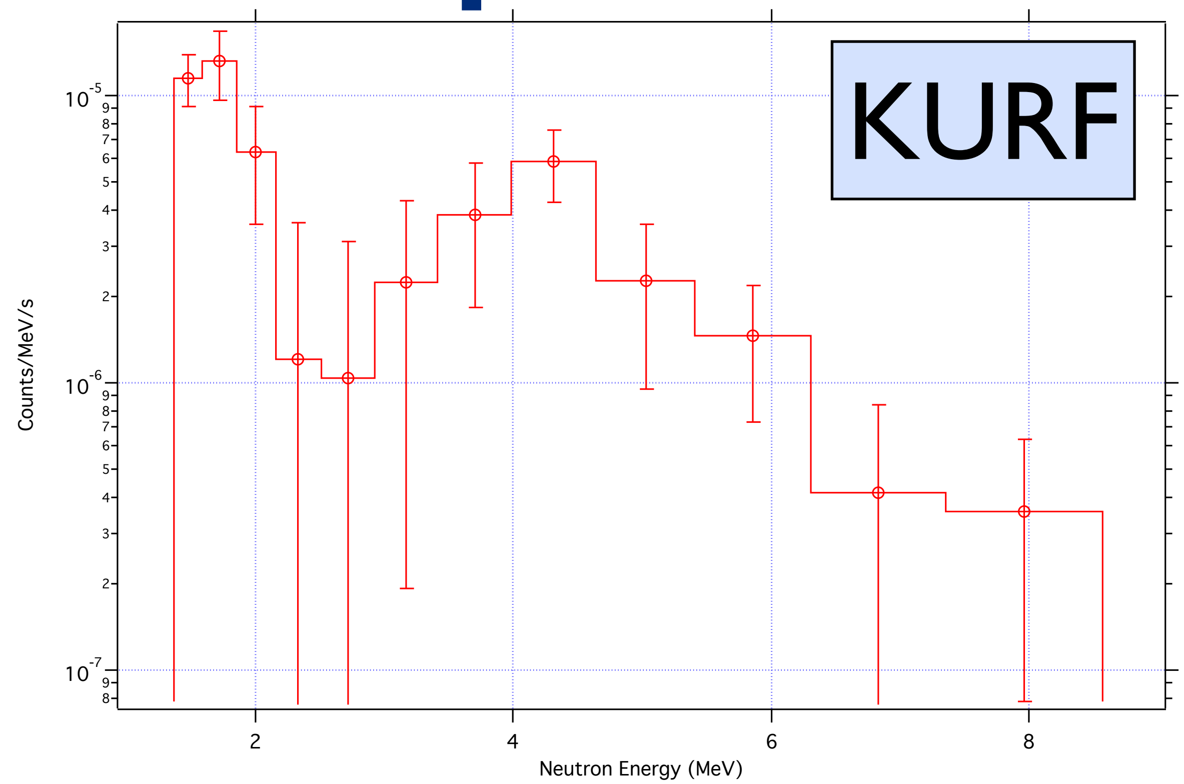
- 62 day dataset
- 1.67×10^5 events
- 250 counts pass all cuts
- *92 remain after BG sub.*

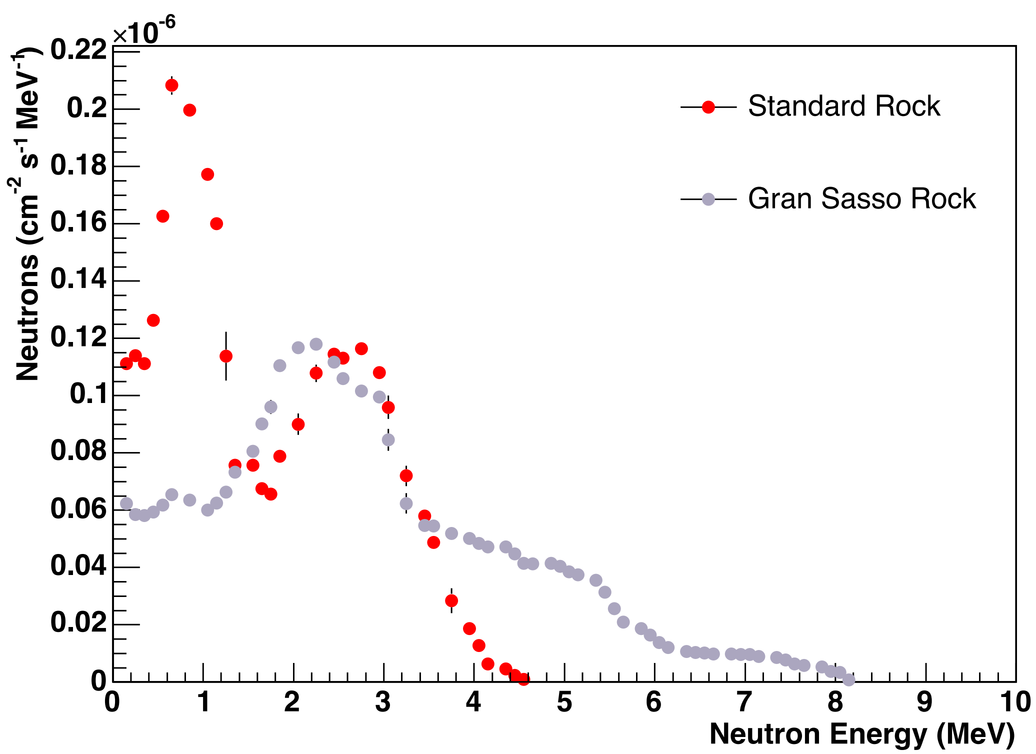
FaNS-1 at KURF - 1450mwe



(alpha,n) vs Fission Spectrum

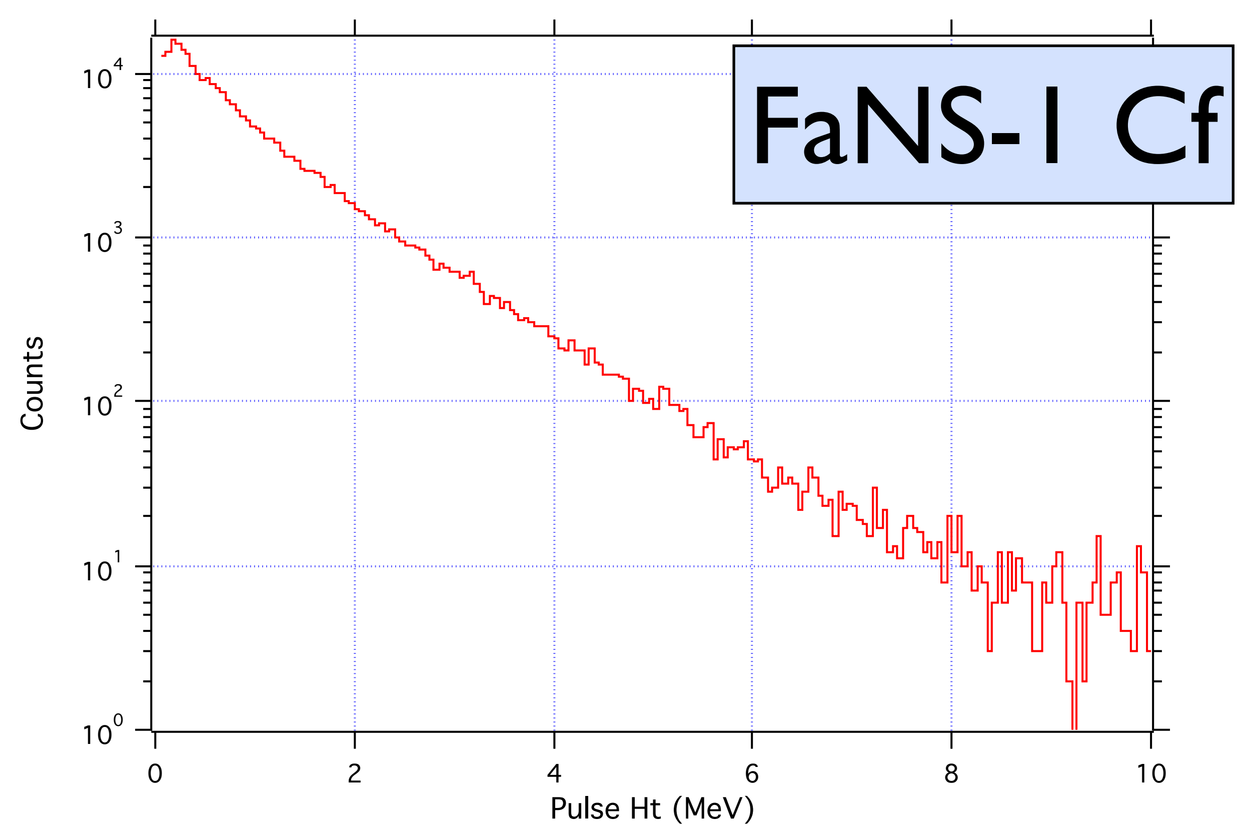
- The measured spectrum at KURF is more (alpha,n)-like
- We are working on simulating the expected spectrum based on BG measurements of U,Th



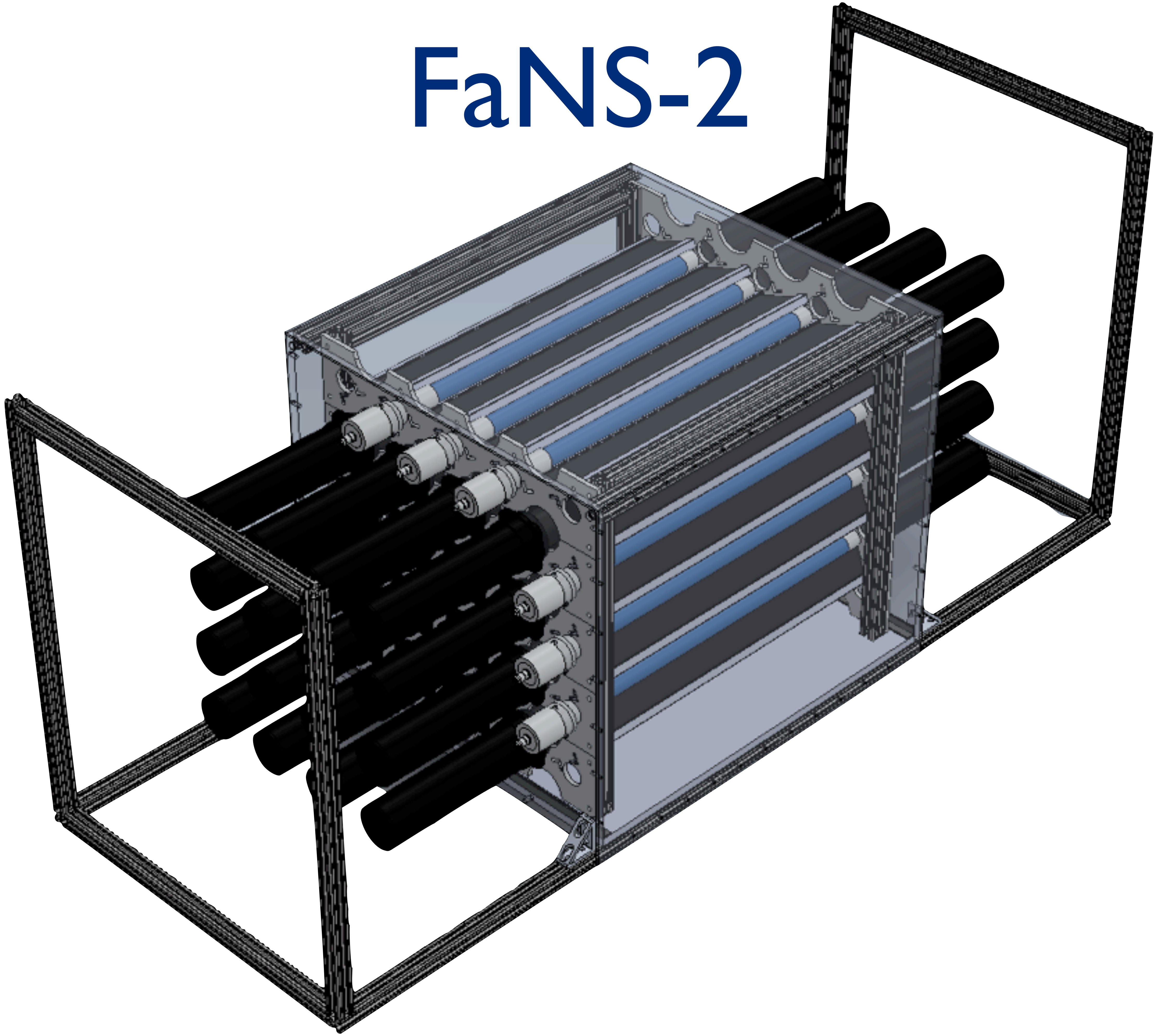


Mei Hime 2005

FIG. 26: The neutron energy spectrum arising from (α,n) reactions due to radioactivity in the rock. We predict a harder energy spectrum in Gran Sasso rock relative to standard rock owing to the presence of carbon and magnesium.



FaNS-2



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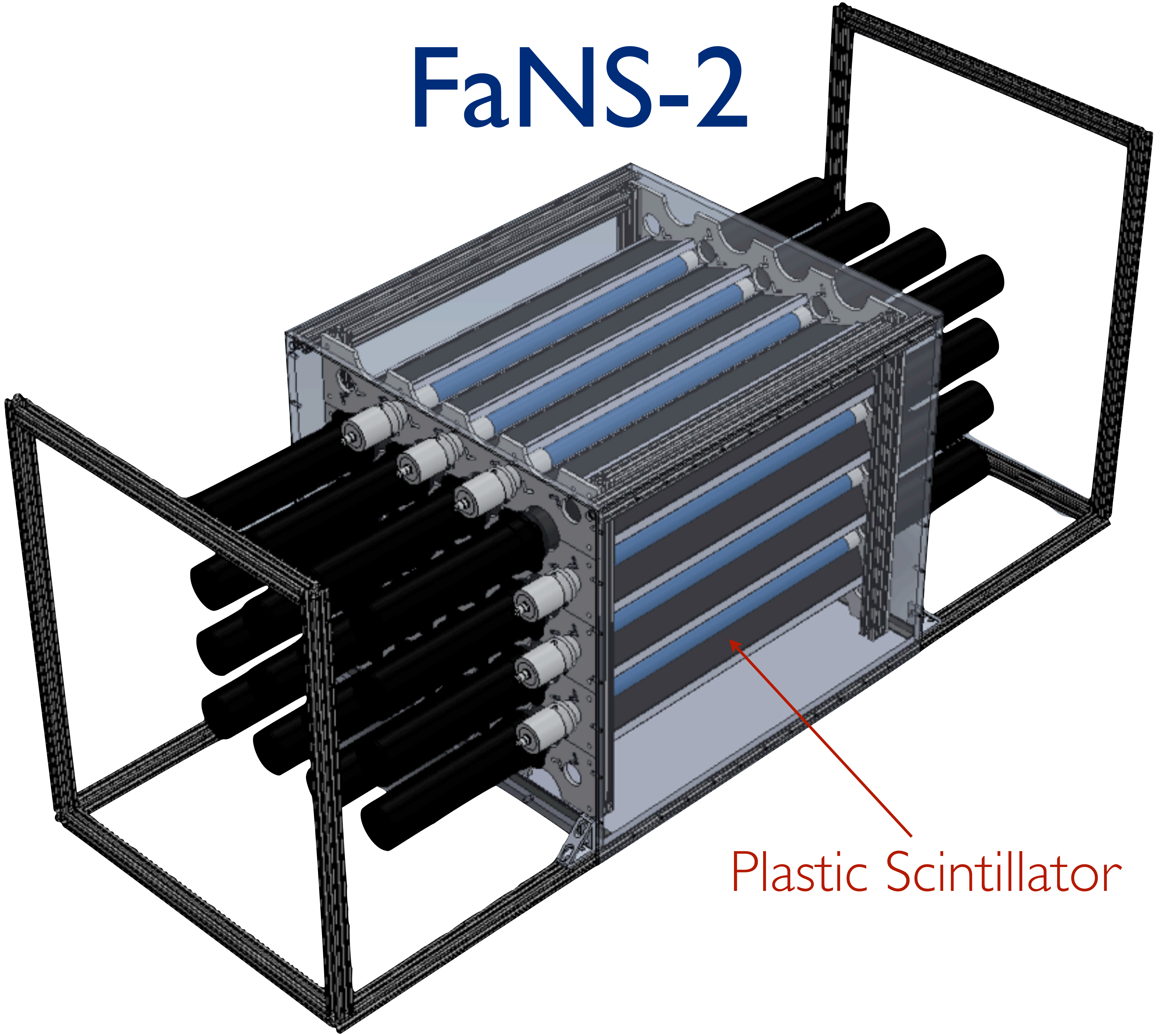

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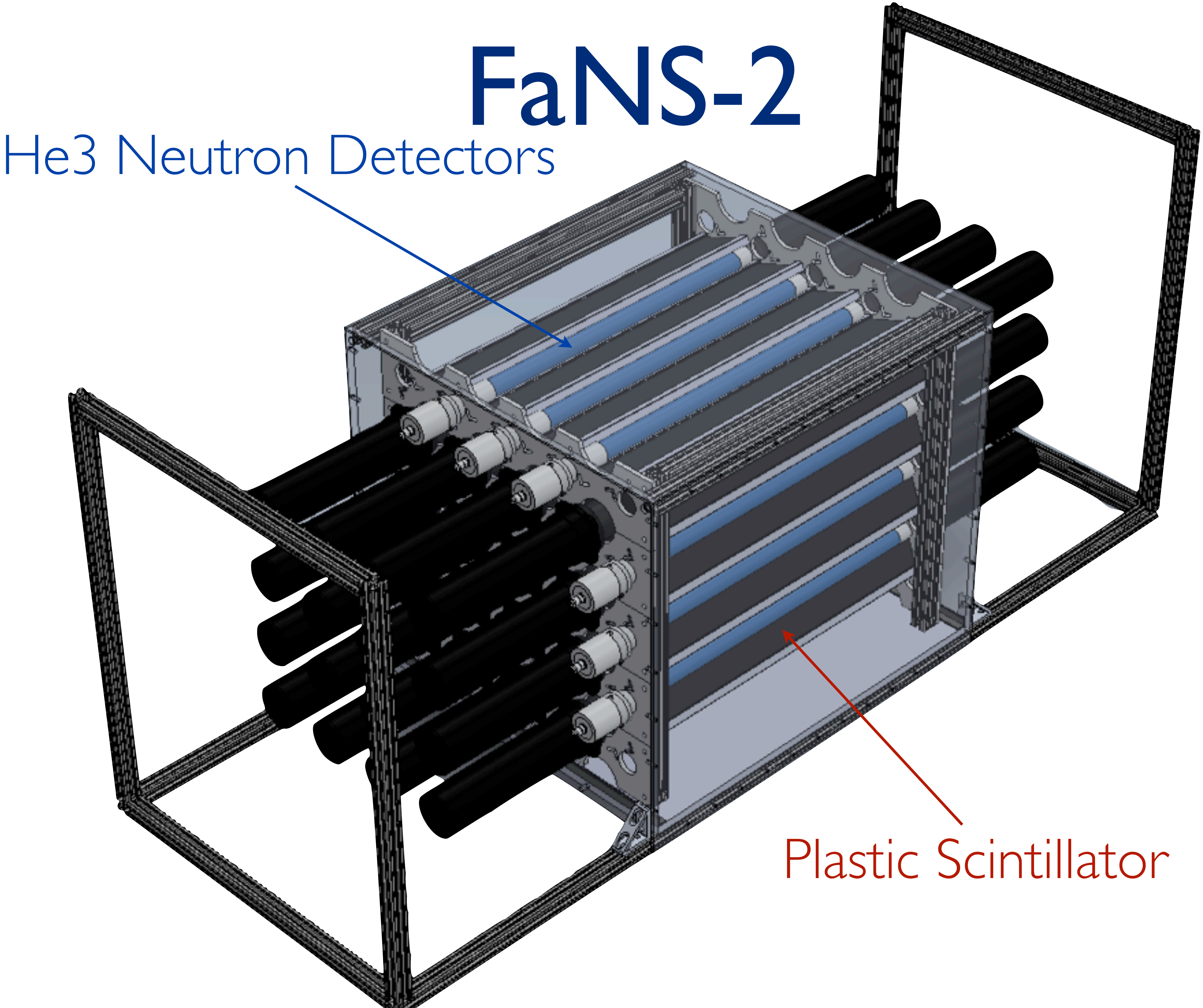
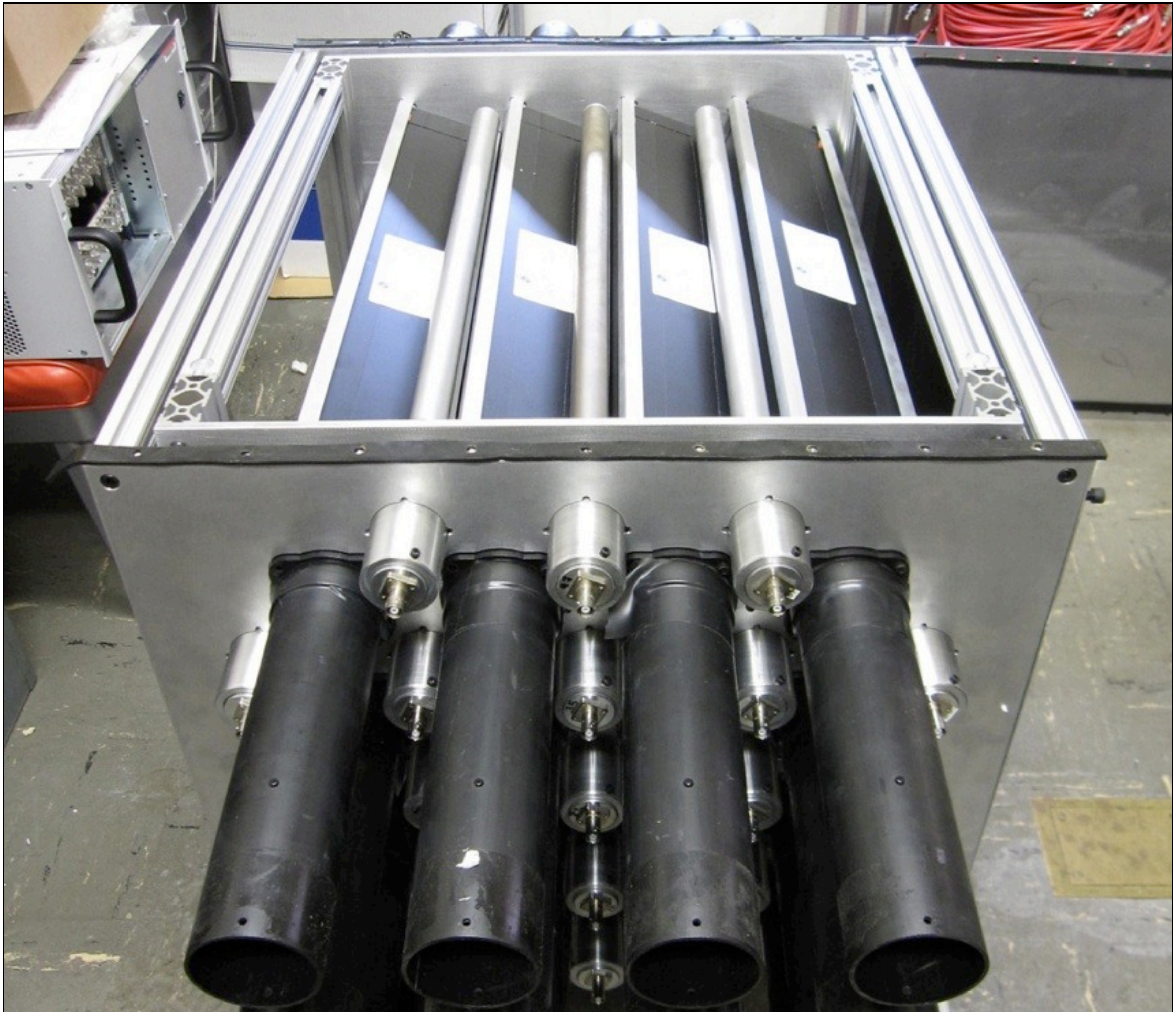
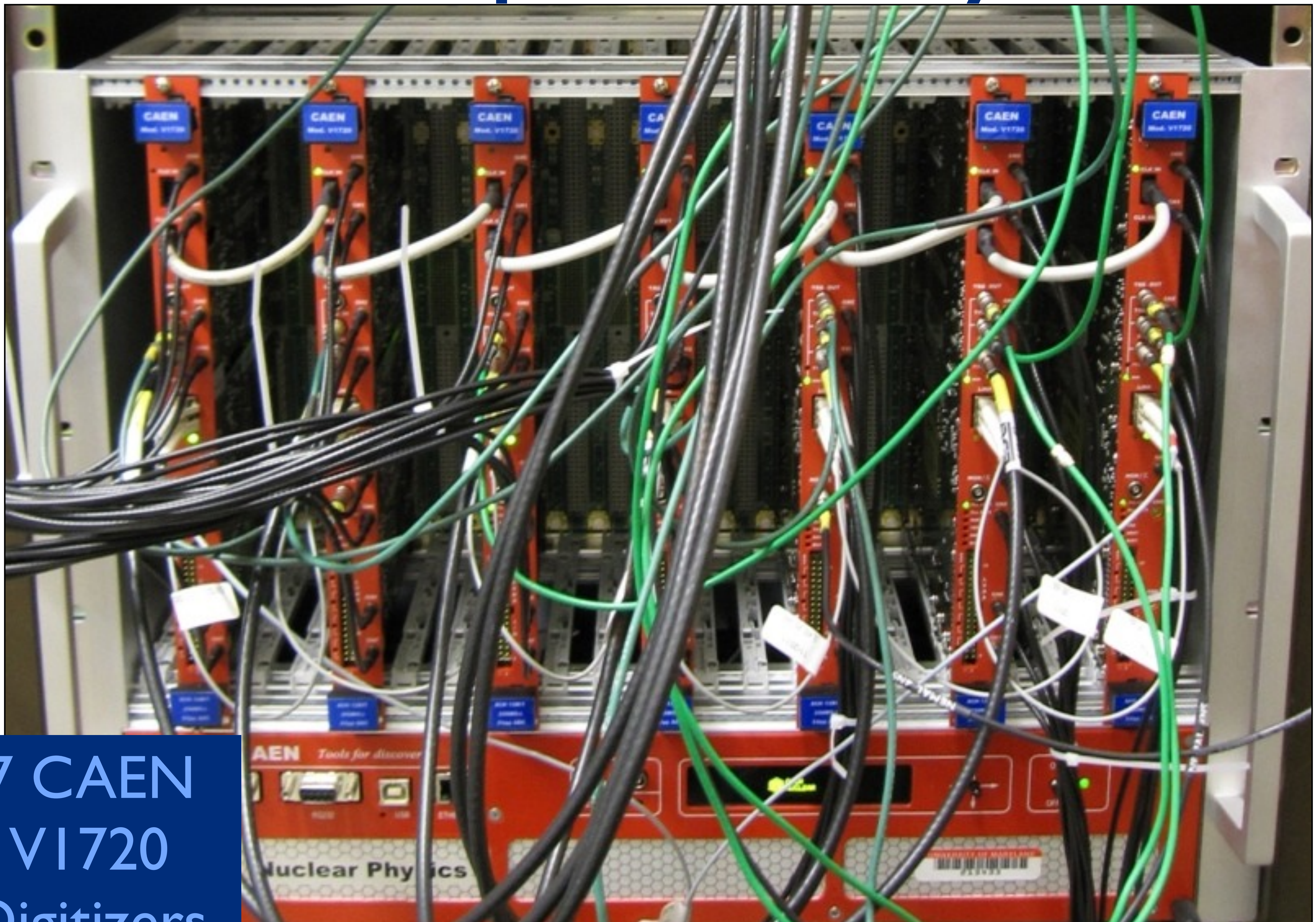



KIMTECH



Data Acquisition System

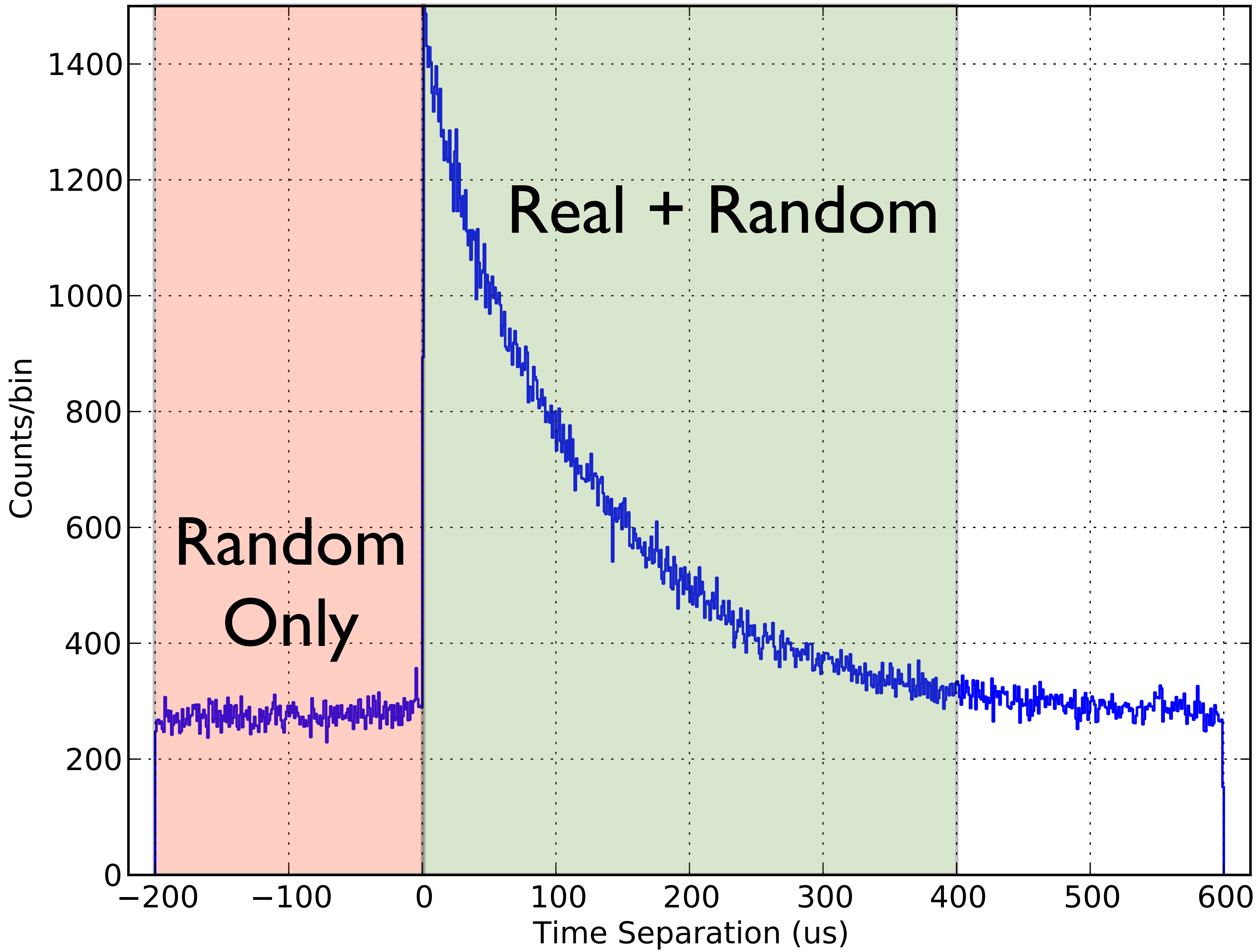


7 CAEN V1720 Digitizers

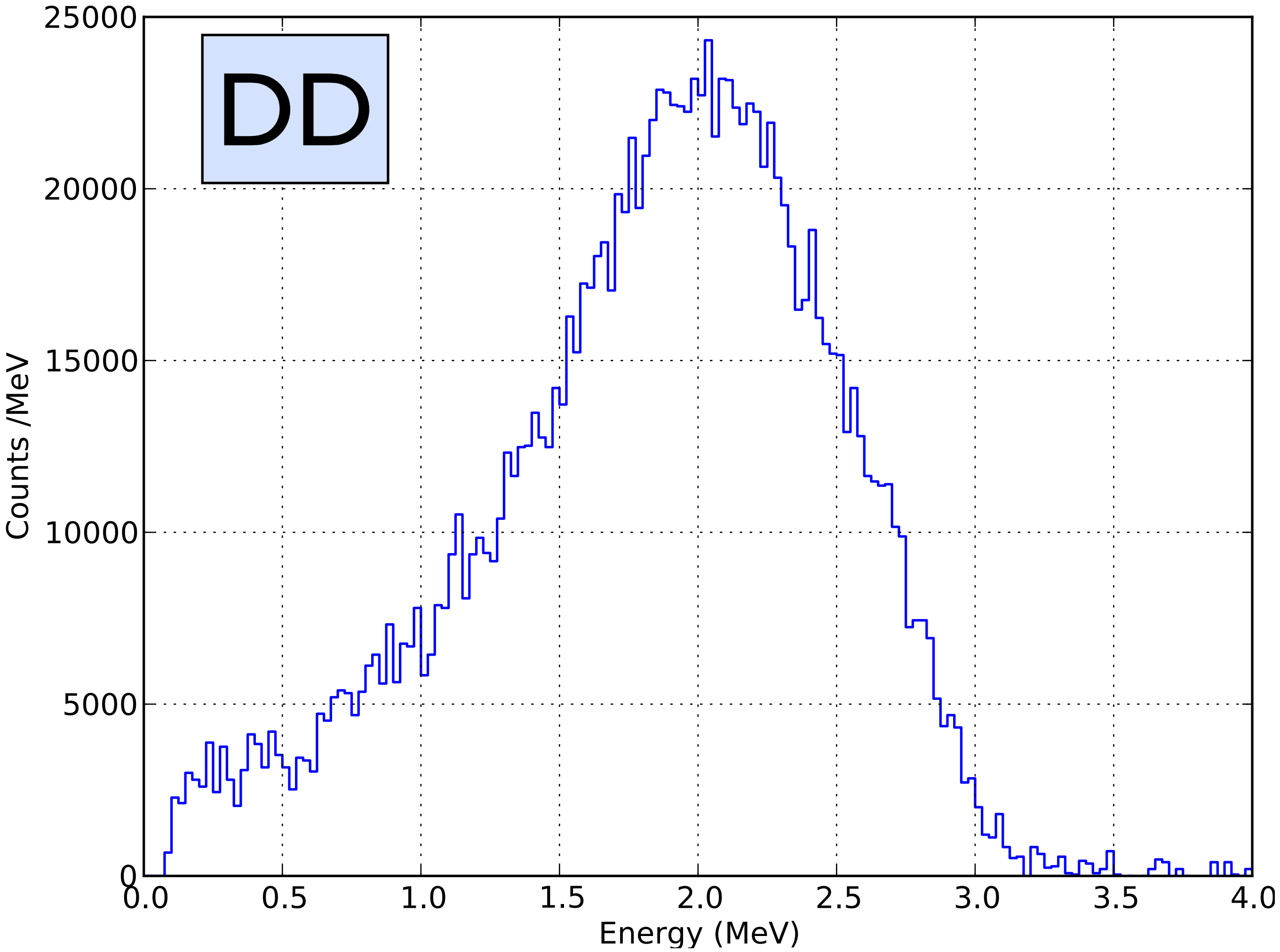
FaNS-2 Operation at NIST

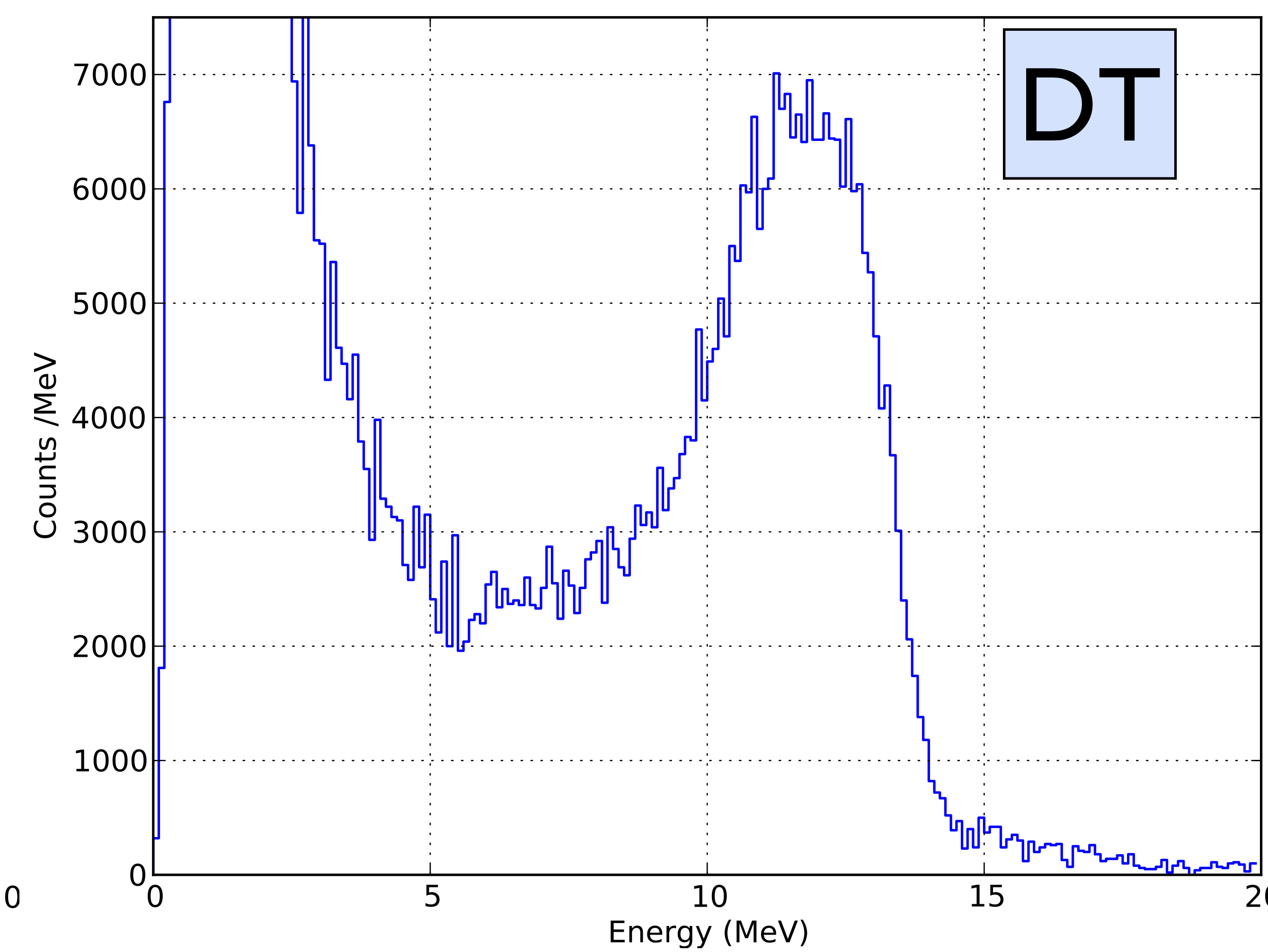
- NIST provides an array of neutron sources for calibrations
  - Californium-252 (known activity at 1%)
  - DD and DT mono-energetic generators
  - AmBe
- FaNS-2 is operating in a low scatter room measuring source and ambient neutrons
  - Low number of backscattering neutrons
  - *Effectively no shielding of ambient neutrons from cosmic rays*
- *FaNS-2 will move to a 20mwe lab at NIST soon*

Timing Spectrum



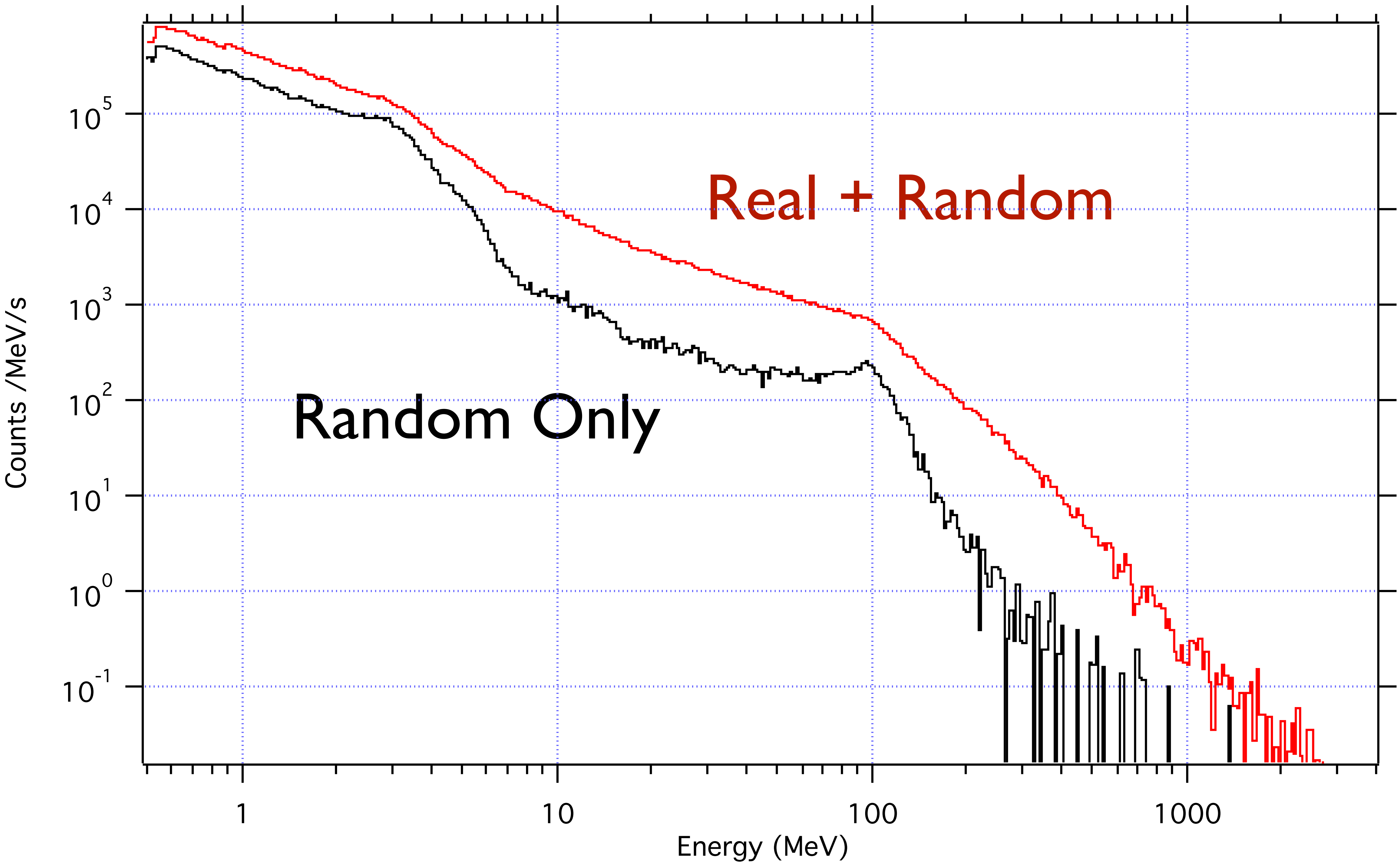
Neutron Source Calibration



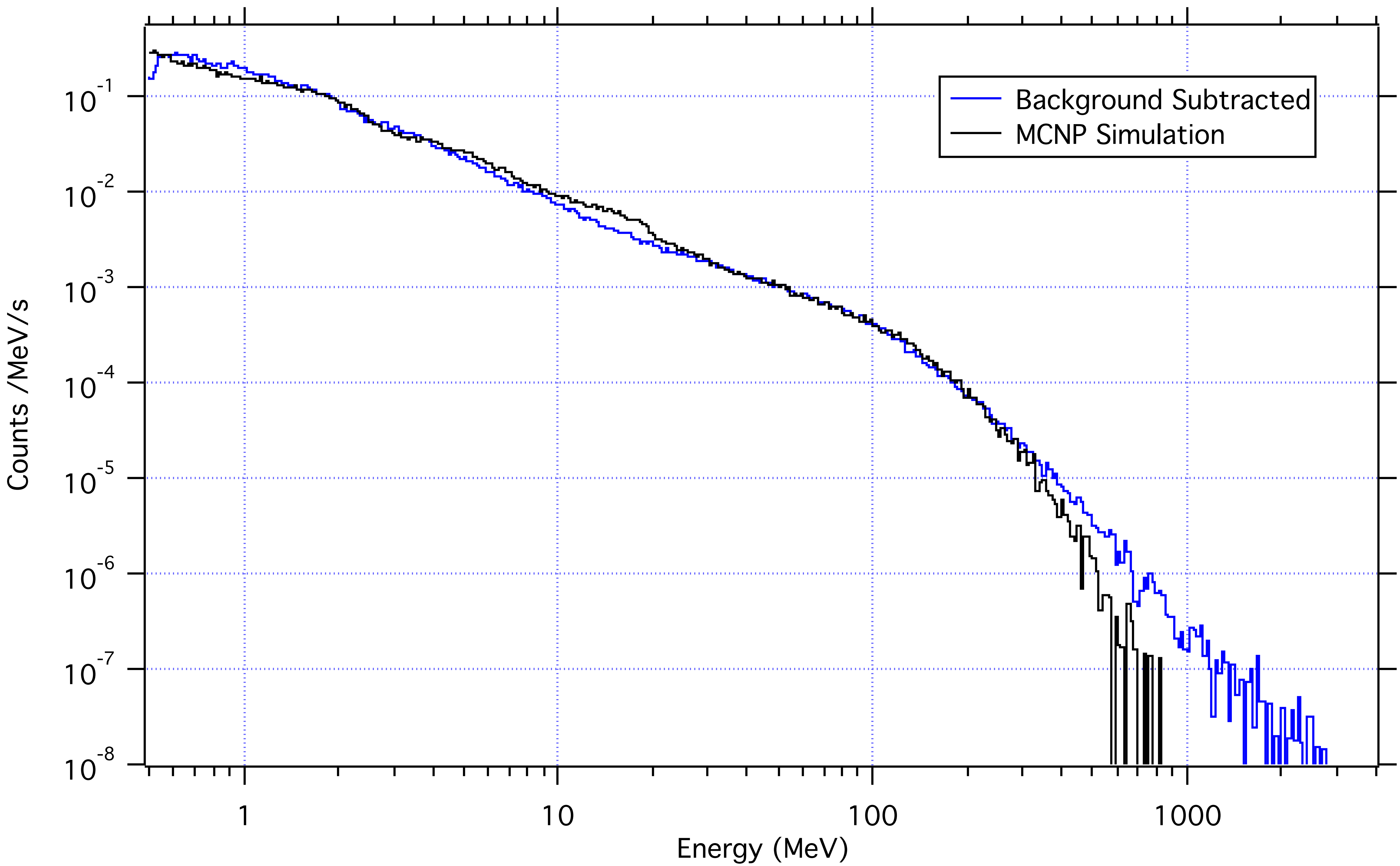


Have measured the absolute efficiency with calibrated Cf source, ~9% above 1MeV

Cosmogenic Neutrons at NIST



Cosmogenic Neutrons at NIST

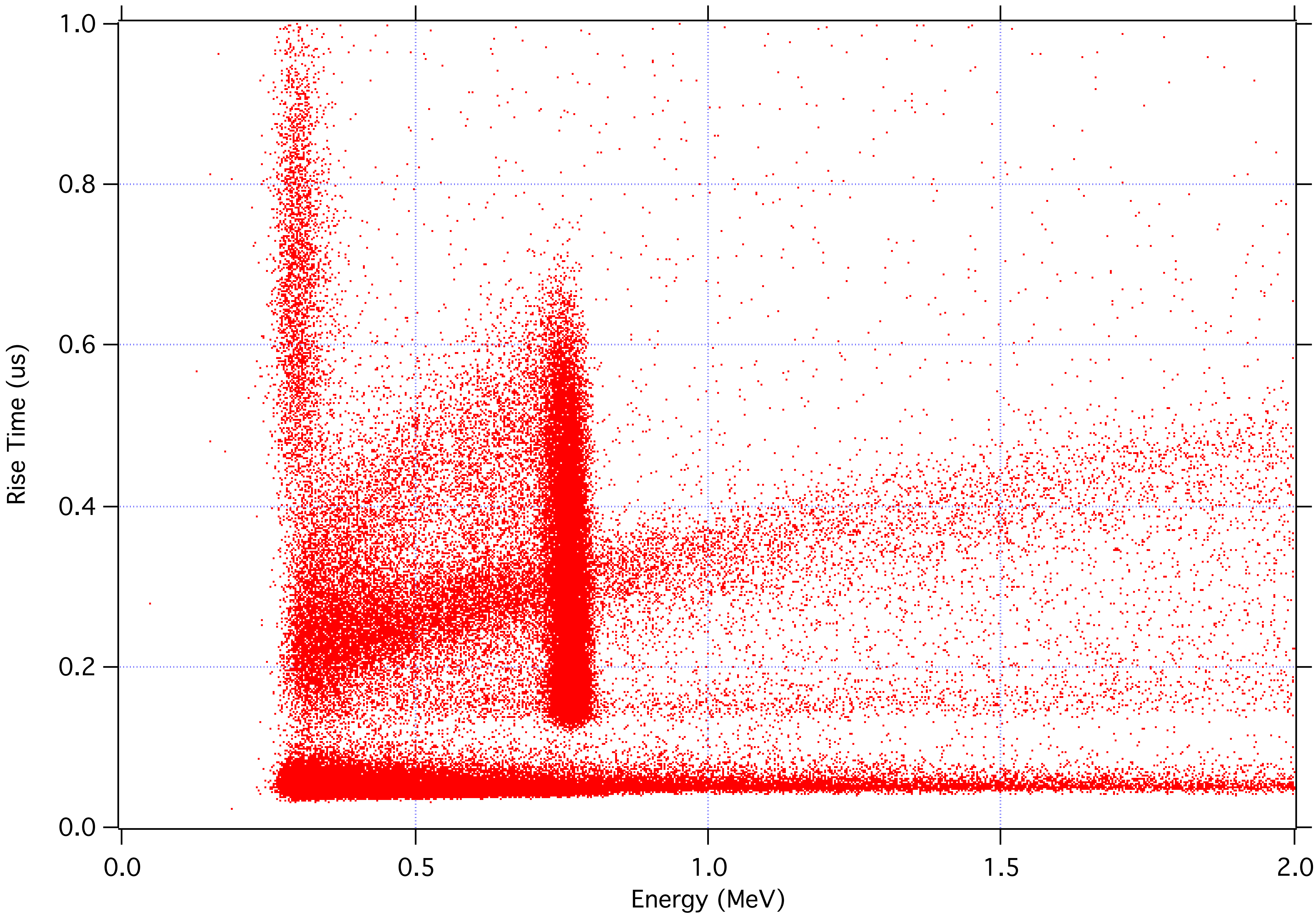


Conclusions

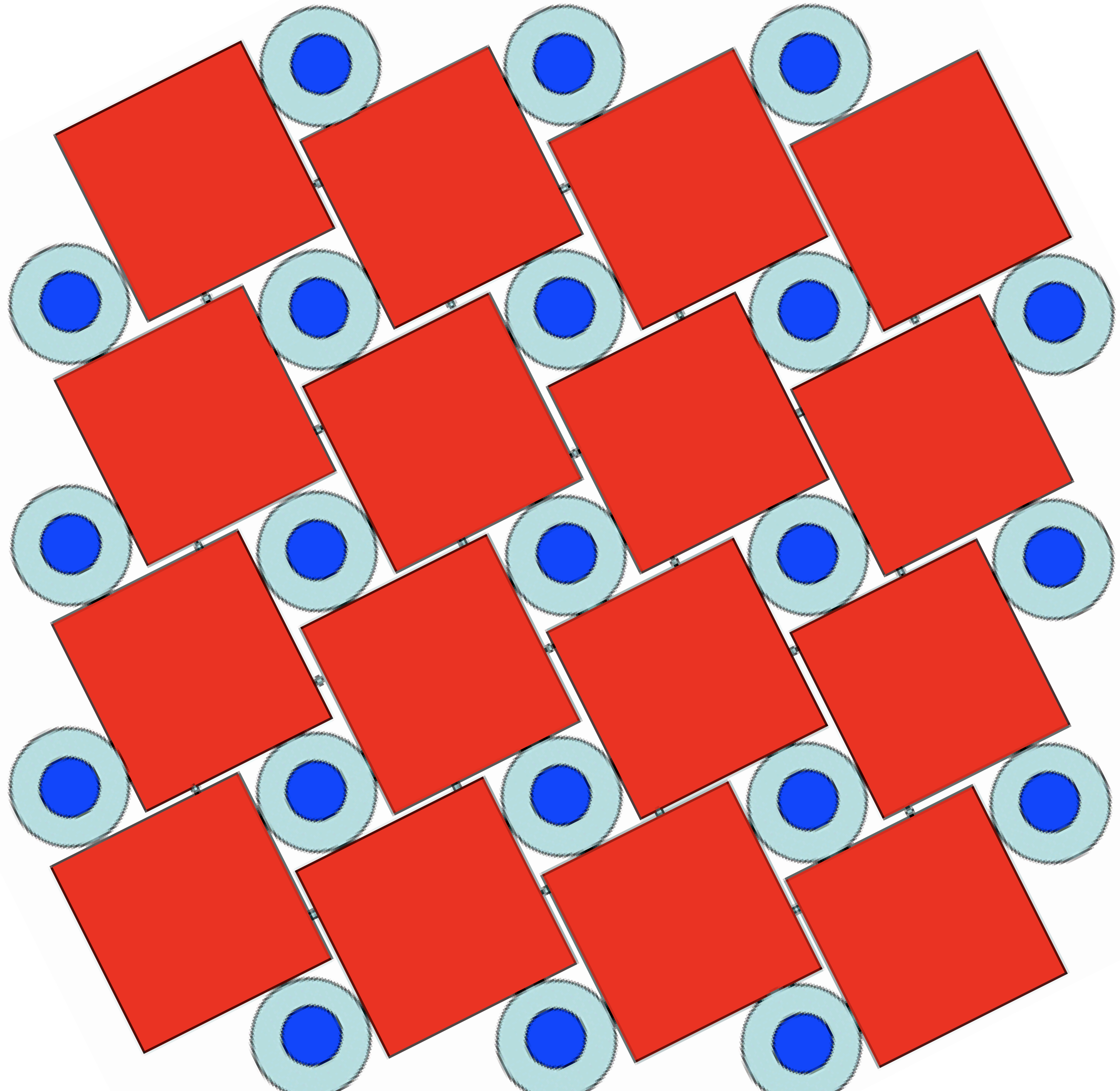
- We have shown that FaNS-1 has sensitivity up to 300 MeV
- FaNS-1 has been calibrated with Cf, DD, and DT neutron sources
- MCNP simulations have been done that match the response of the detector
- A measurement of the neutron spectrum at KURF has been made
- *FaNS-2 is now operating, and moving underground soon*

Backup Slides

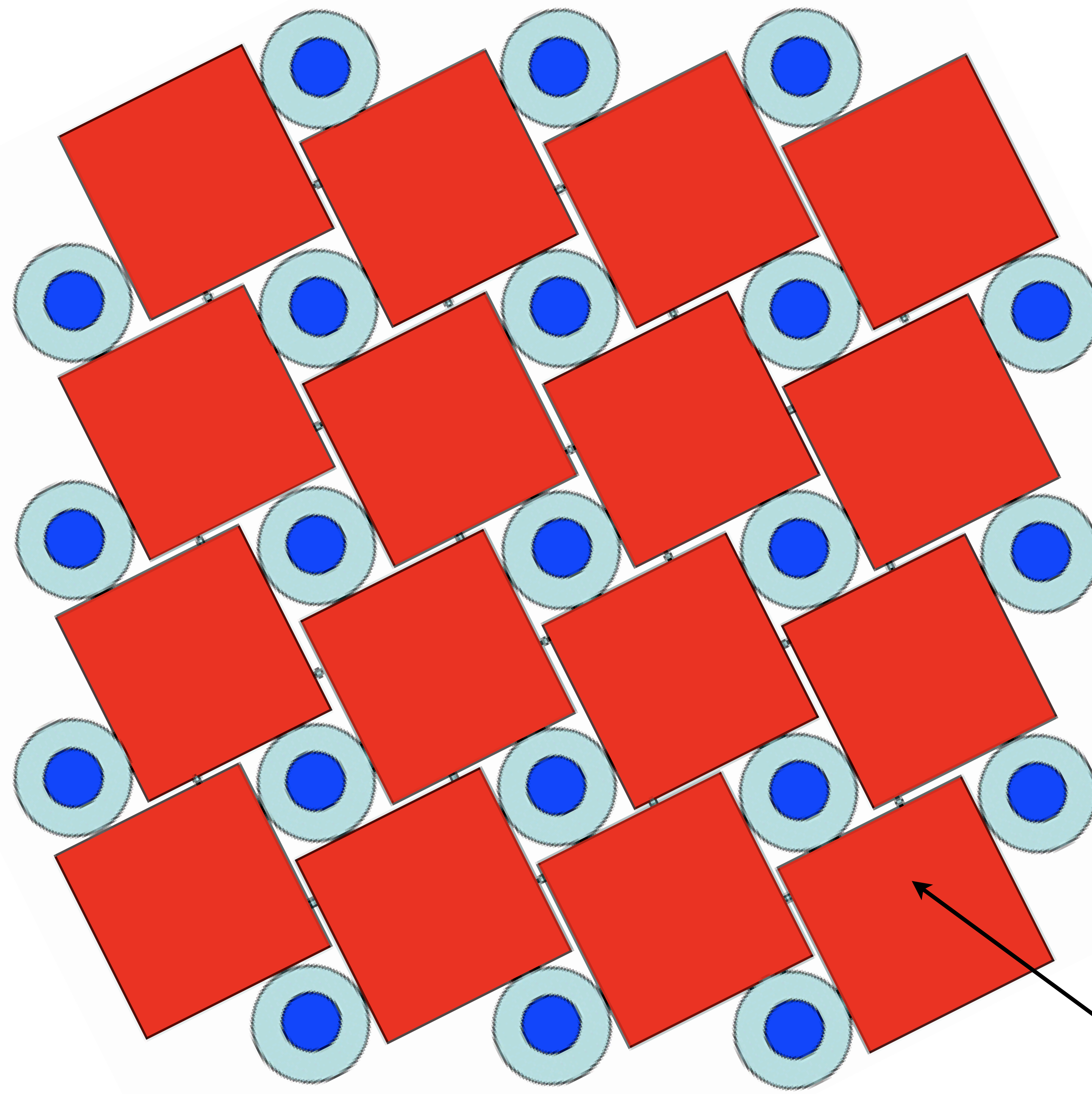
FaNS-1 at KURF - 1450mwe



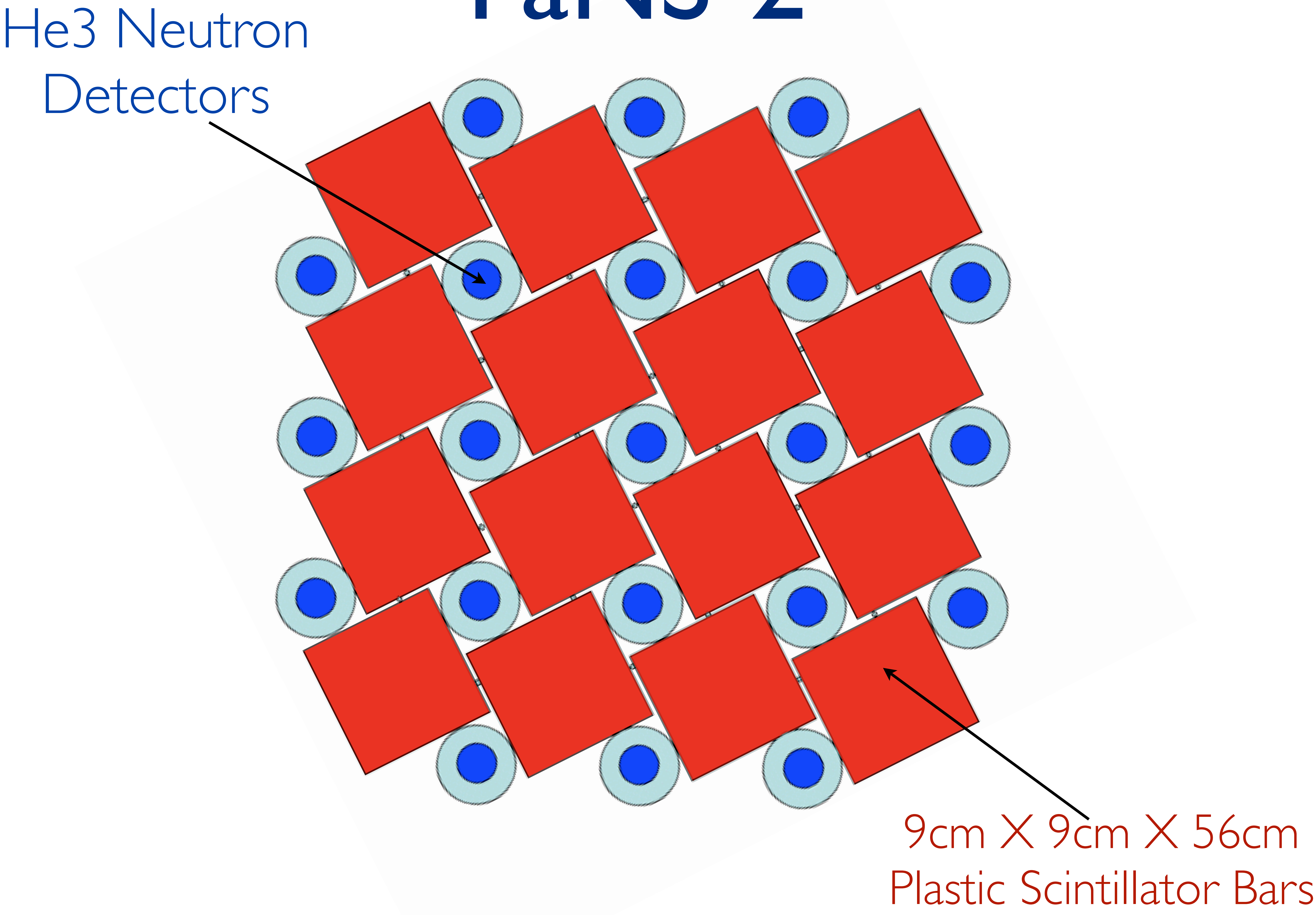
FaNS-2



FaNS-2



FaNS-2

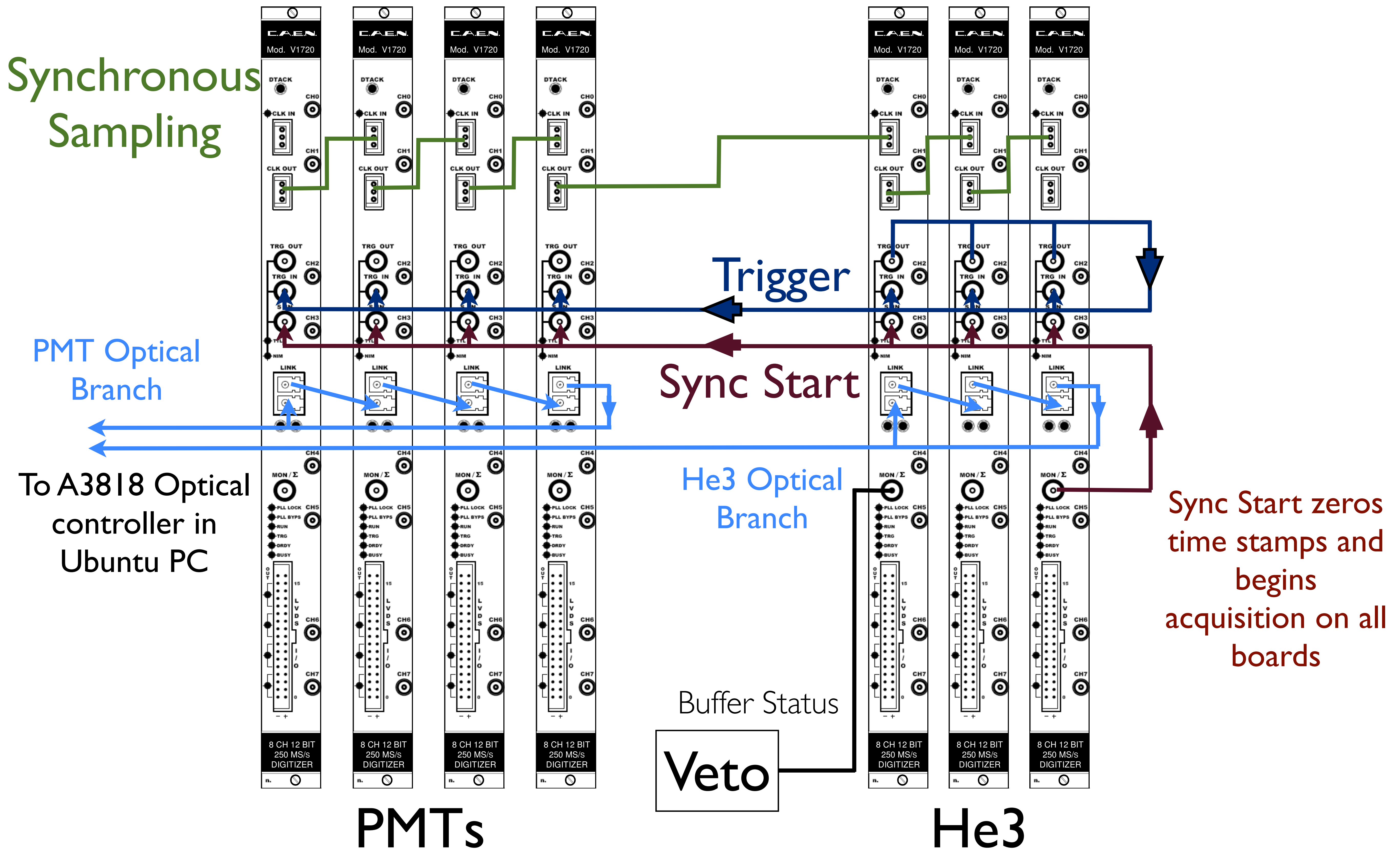

He3 Neutron
Detectors
9cm X 9cm X 56cm
Plastic Scintillator Bars


BANKERS BOX

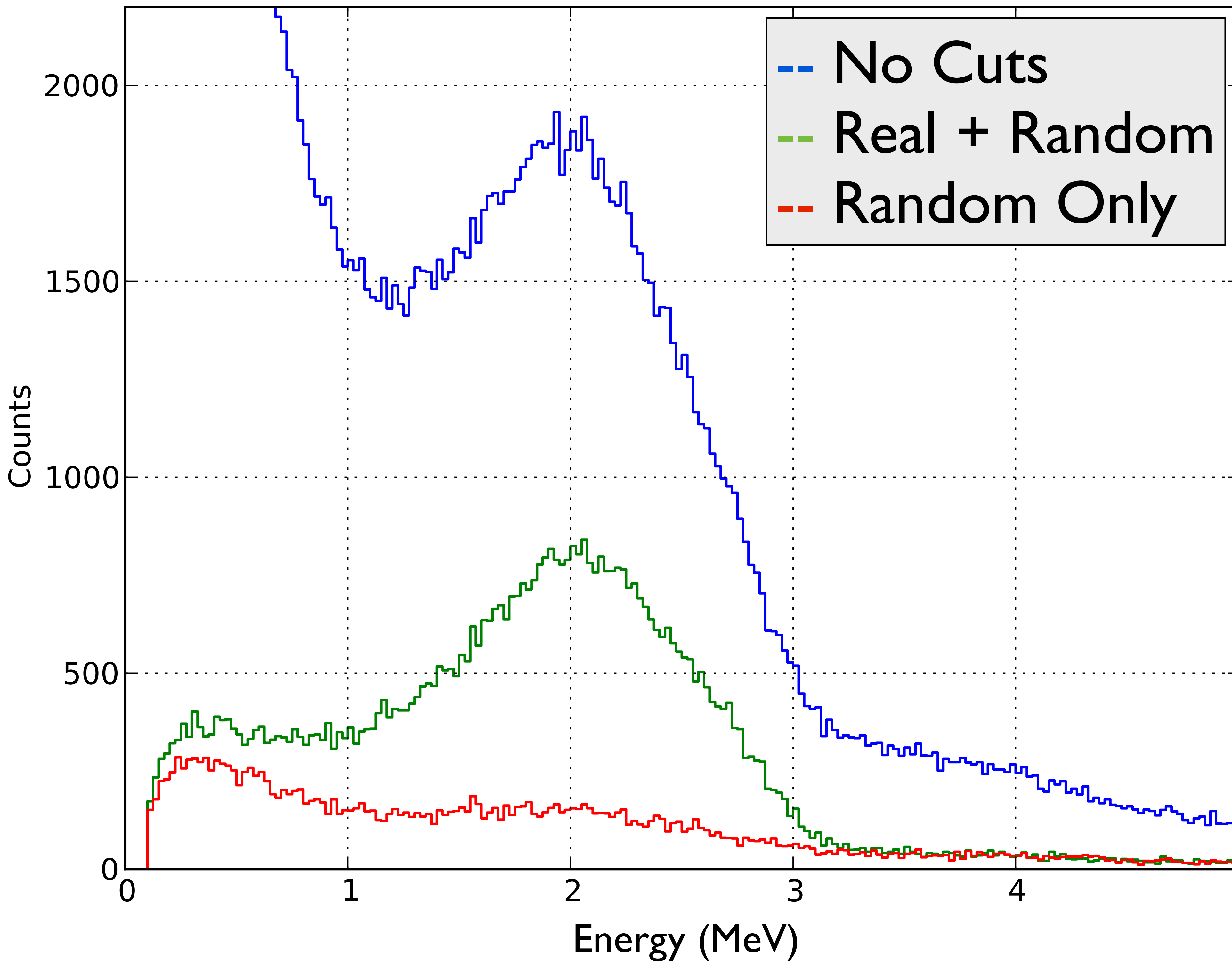
Data Acquisition Requirements

- *Synchronous sampling and triggering of 56 channels*
- Operate in three trigger modes:
  - Gamma calibration: Any PMT triggers all PMTs
  - Muon calibration: Trigger on high multiplicity PMT events
  - Neutron data: Any helium signal triggers all channels
    - ~1ms long traces with ZLE to reduce data size
    - Large dynamic range (30 keV:200 MeV per channel)
- Need to automatically switch between different modes

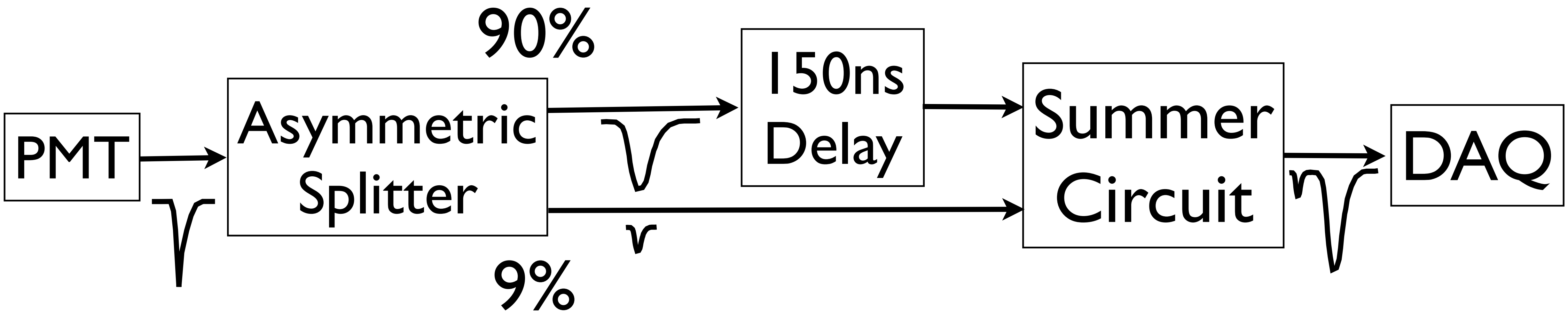
Neutron Trigger



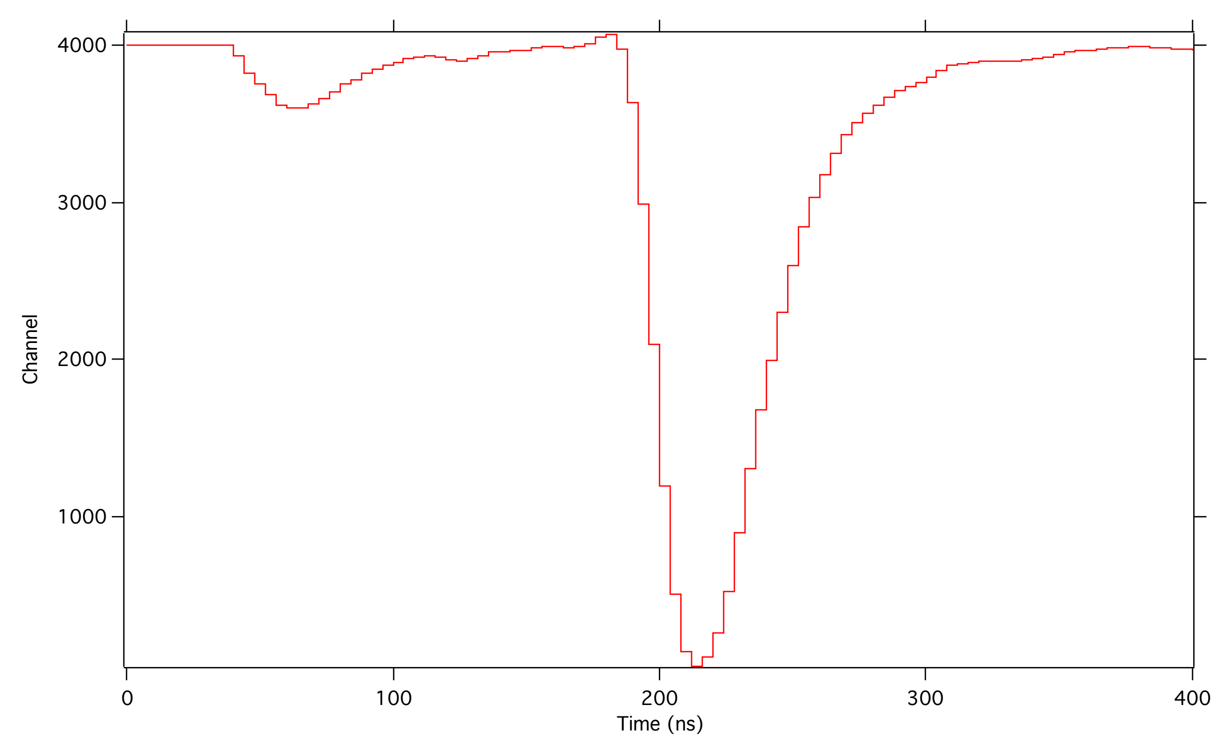
DD Neutron generator



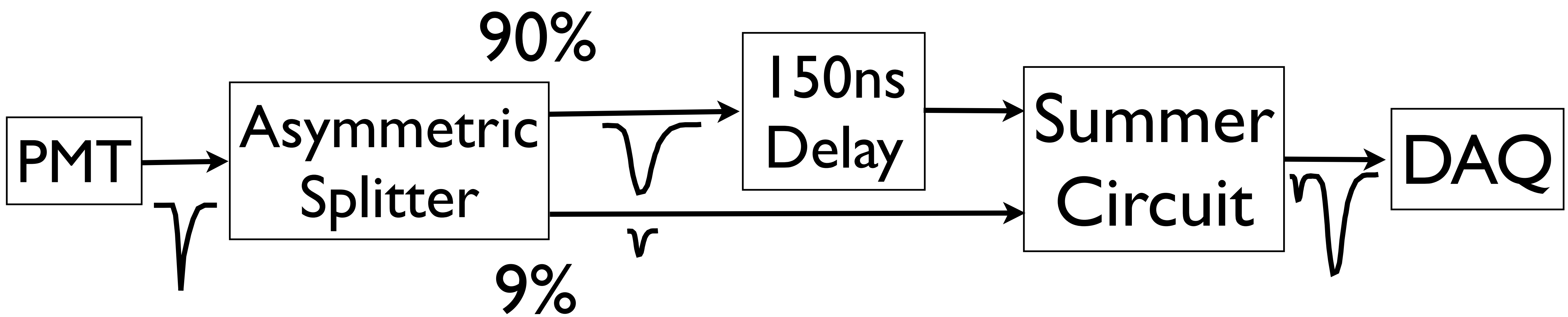
PMT Signal Conditioning



- Custom circuit board
- 8ch, NIM form factor
- *Factor of 10 increase in dynamic range*
- Increase of signal width from 10ns to 50ns
  - ➡Reduces digitization error



PMT Signal Conditioning



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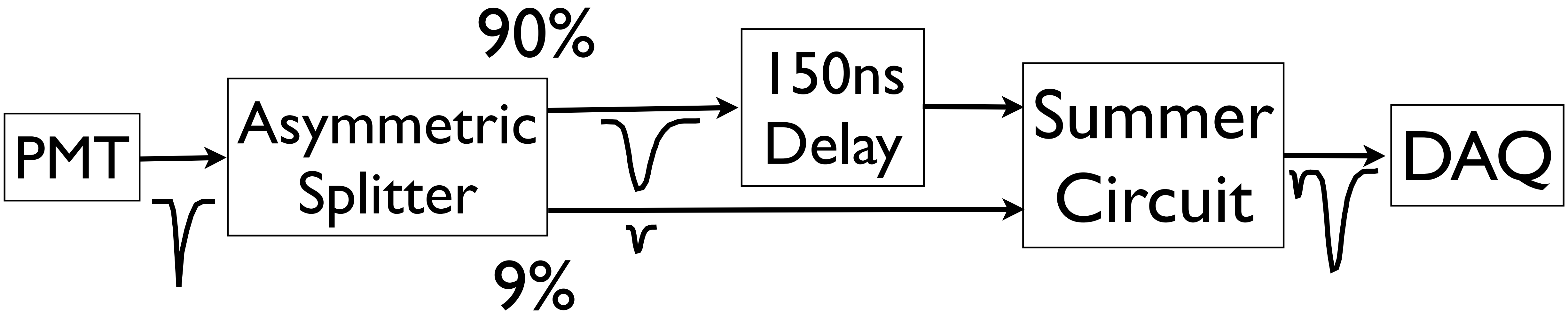

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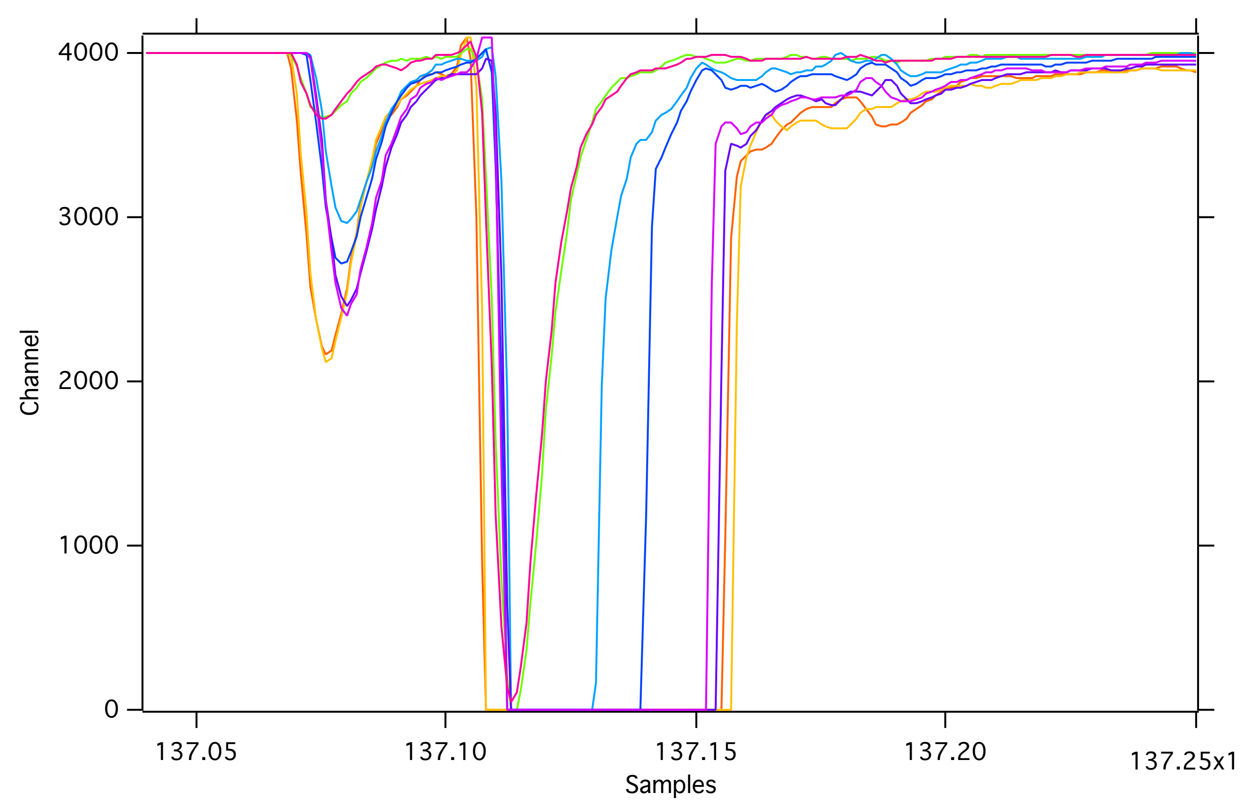
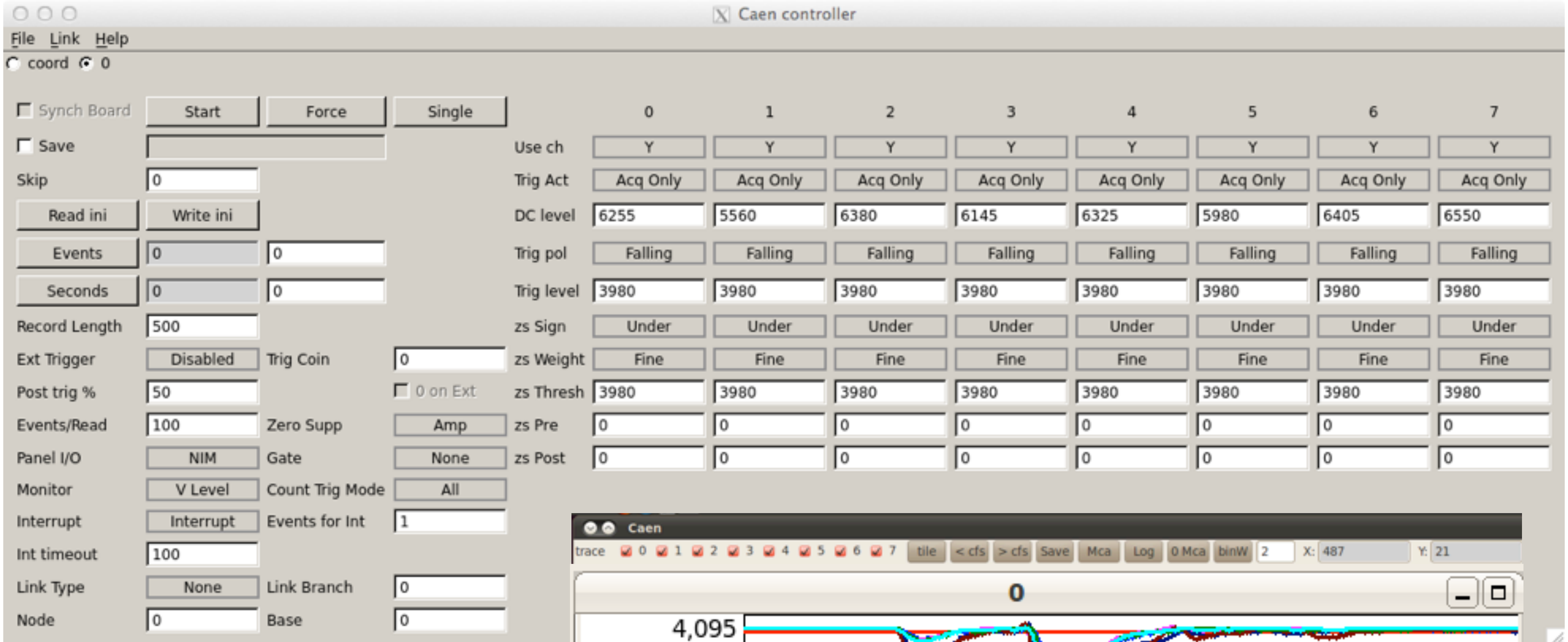
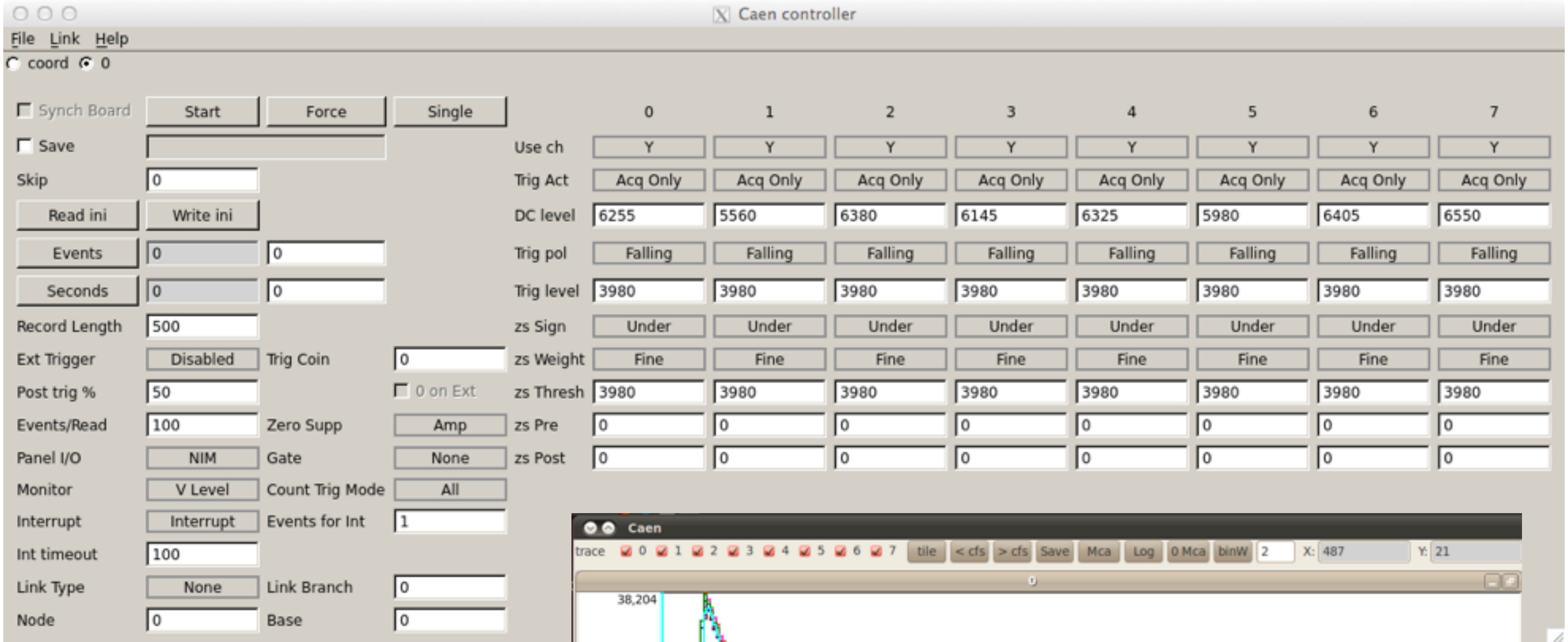
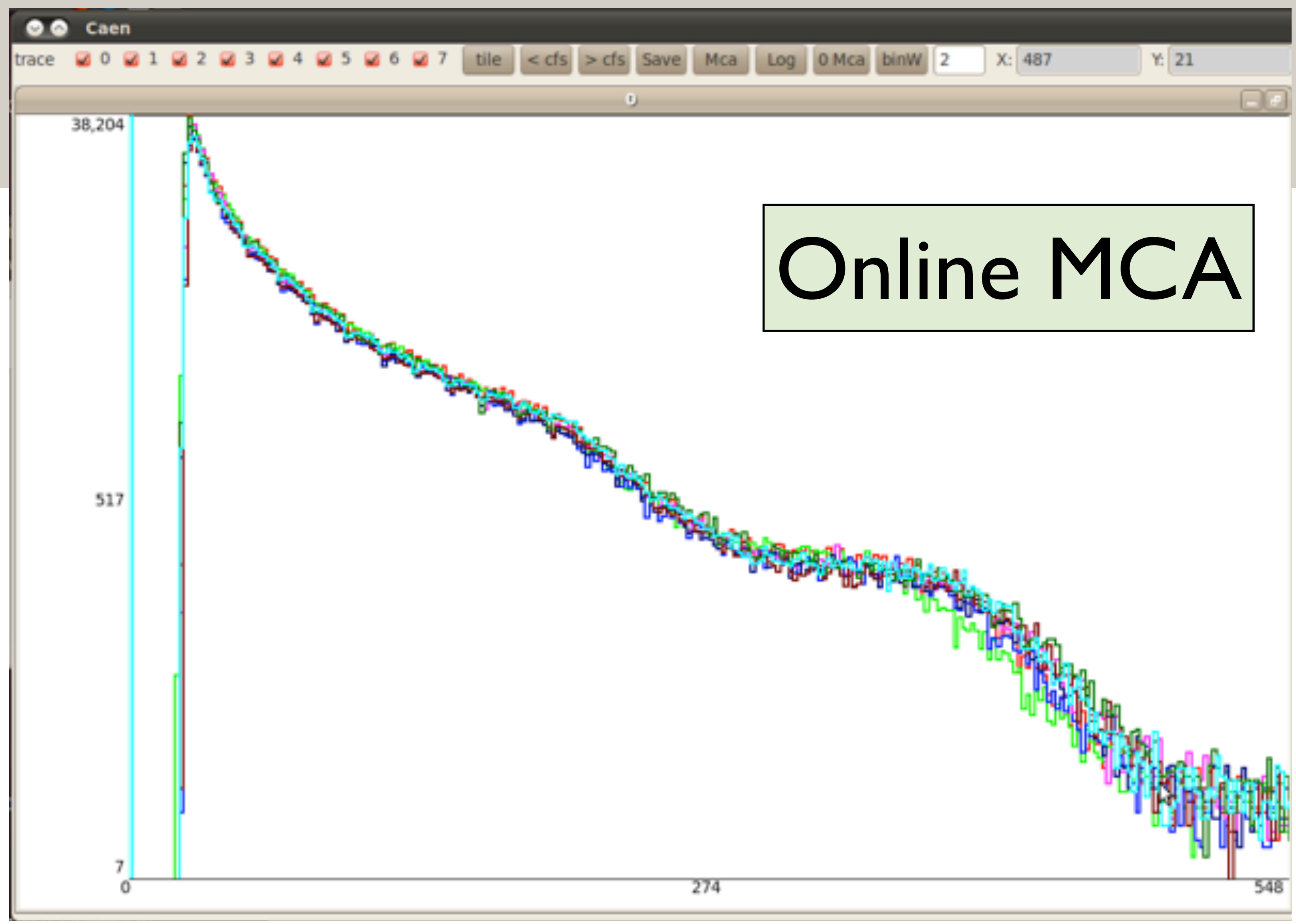




- Homebuilt code with C++
- GUI uses QT for cross platform
- Controls an arbitrary number of cards, set at compile time
- Each card can operate separately or any combination can be coordinated
- Settings can be loaded from a file
- *Controlled by an external Python function over TCP/IP*





- Homebuilt code with C++
- GUI uses QT for cross platform
- Controls an arbitrary number of cards, set at compile time
- Each card can operate separately or any combination can be coordinated
- Settings can be loaded from a file
- *Controlled by an external Python function over TCP/IP*

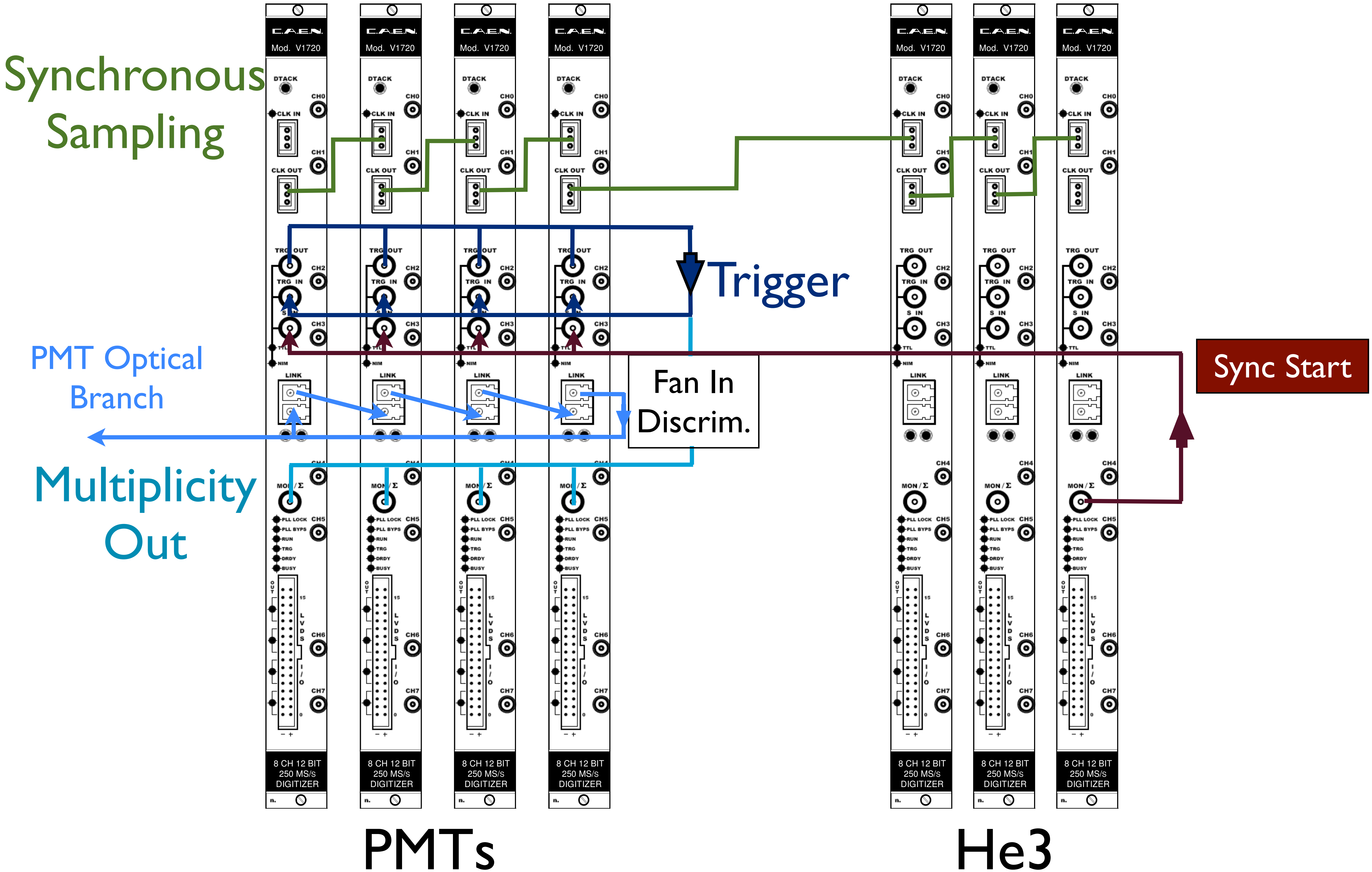
Python Control Program

- Platform independent development
- Simple to program, *easy to debug*!
- Commands sent over TCP/IP to DAQ program
- Script controls card settings, start, stop, saving data, writing MCAs, etc.
- Can be controlled locally or remotely
- Easy interoperation with HV control, logging, email notifications, environmental monitoring, and data transfer

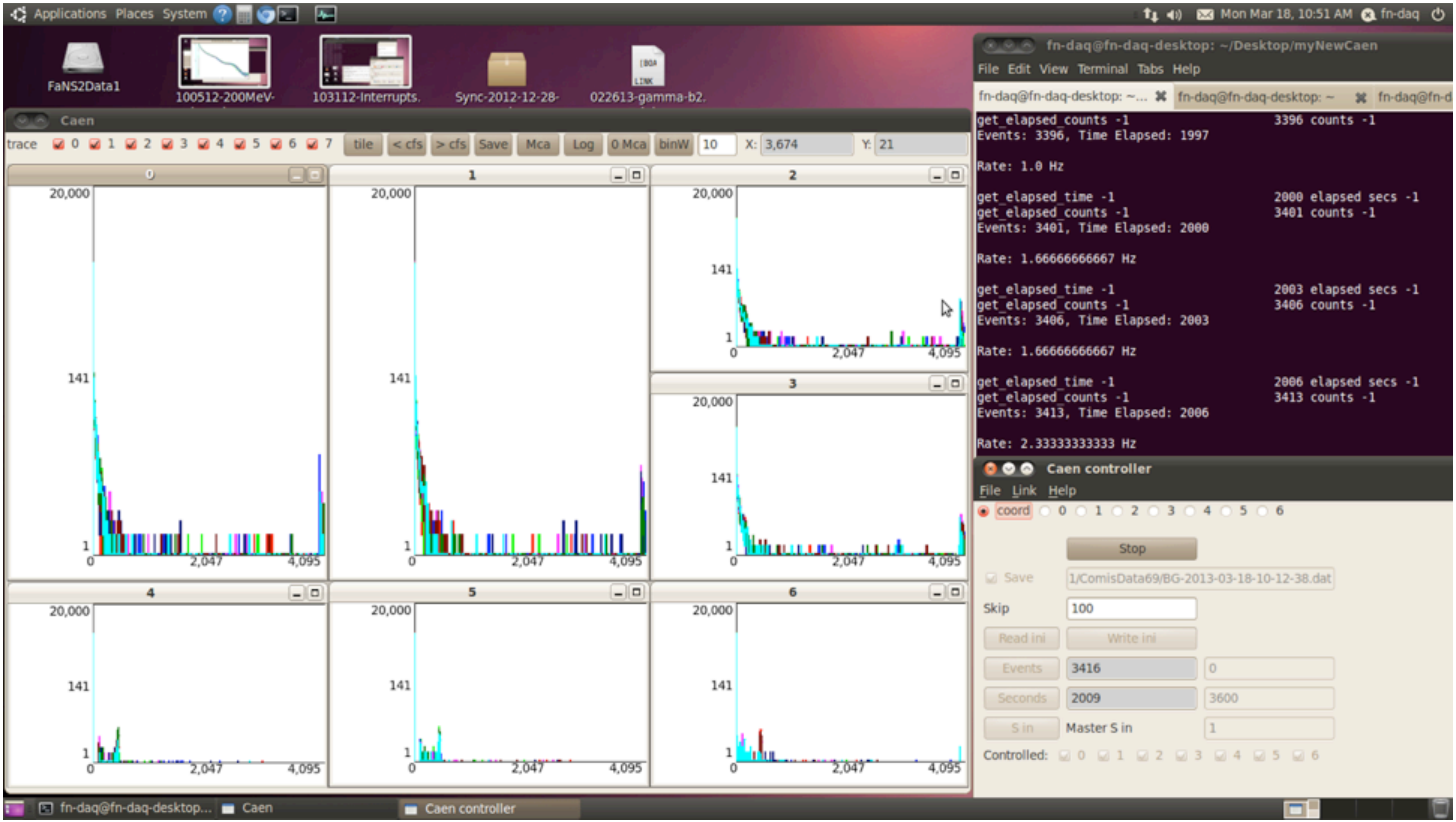
newLowScatterRun.py (no symbol selected)

```python
for iters in xrange(nIters):
    date = time.strftime("%Y-%m-%d-%H-%M-%S")
    if emailSent:
        fileList = []
        mcaList = []

    # PMT Calibration (Gamma)
    if calRun == 1:
        calIniFile = calIniLocation + "022013-gammaCoord.ini"
        s.send("set_preset_time " + str(board) + " " + str(secsPerCal))
        s.send("set_preset_counts " + str(board) + " 0")

        s.send("set_skip " + str(board) + " 10000")
        s.send("zero_time " + str(board))
        s.send("zero_counts " + str(board))
        s.send("read_ini " + str(board) + ' ' + calIniFile)
        if useDate:
            dataName = dataLocation + "GammaSync-" + date + ".dat"
        else:
            dataName = dataLocation + baseName + "-" + str(iters) + "_GammaSync.d
        fileList.append(dataName)
        s.send("write_data " + str(board) + " " + dataName)
        print "\nStarting gamma run ", str(iters), "at ", time.strftime("%Y-%m-%d
        sys.stdout.flush()
        logFile.write("\nStarting gamma run ", str(iters), "at ", time.strftime("
        logFile.flush()
        s.send("start " + str(board))
        time.sleep(secsPerCal+5)
        s.send("stop " + str(board))
        s.send("write_data " + str(board) + " ")
        elapsed = s.send("get_elapsed_time " + str(board))
        numEvents = s.send("get_elapsed_counts " + str(board))
        for i in range(4):
            mcaName = dataName[0:-4] + "-b" + str(i) + ".mca"
            s.send("write_hist " + str(i) + " " + mcaName)
            mcaList.append(mcaName)
            s.send("zero_hist " + str(i))
        s.send("zero_time " + str(board))
        s.send("zero_counts " + str(board))
        print numEvents, " Events in ", elapsed, " seconds \n"
        sys.stdout.flush()
        logFile.write(print numEvents, " Events in ", elapsed, " seconds \n")
        logFile.flush()
```

Gamma/Muon Trigger

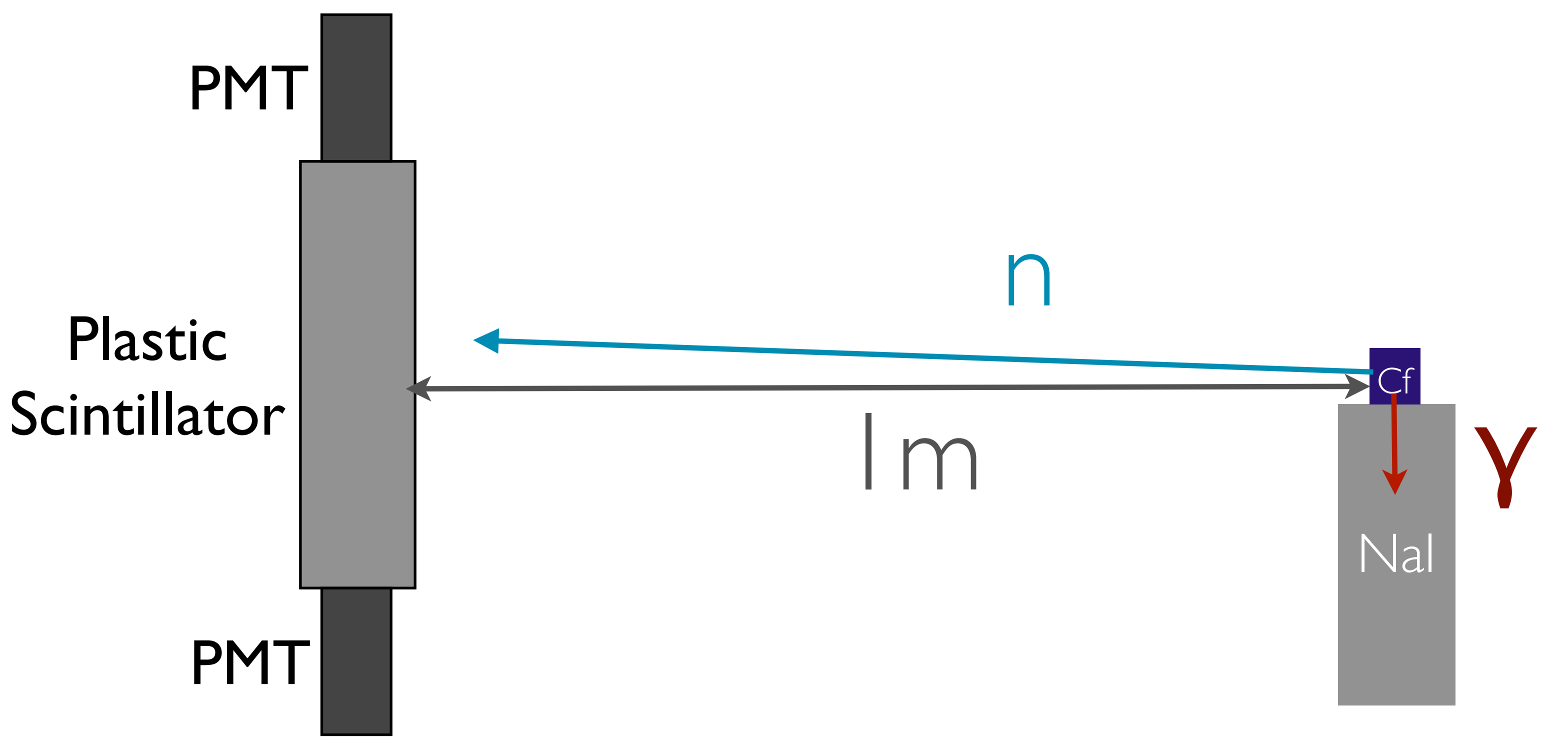


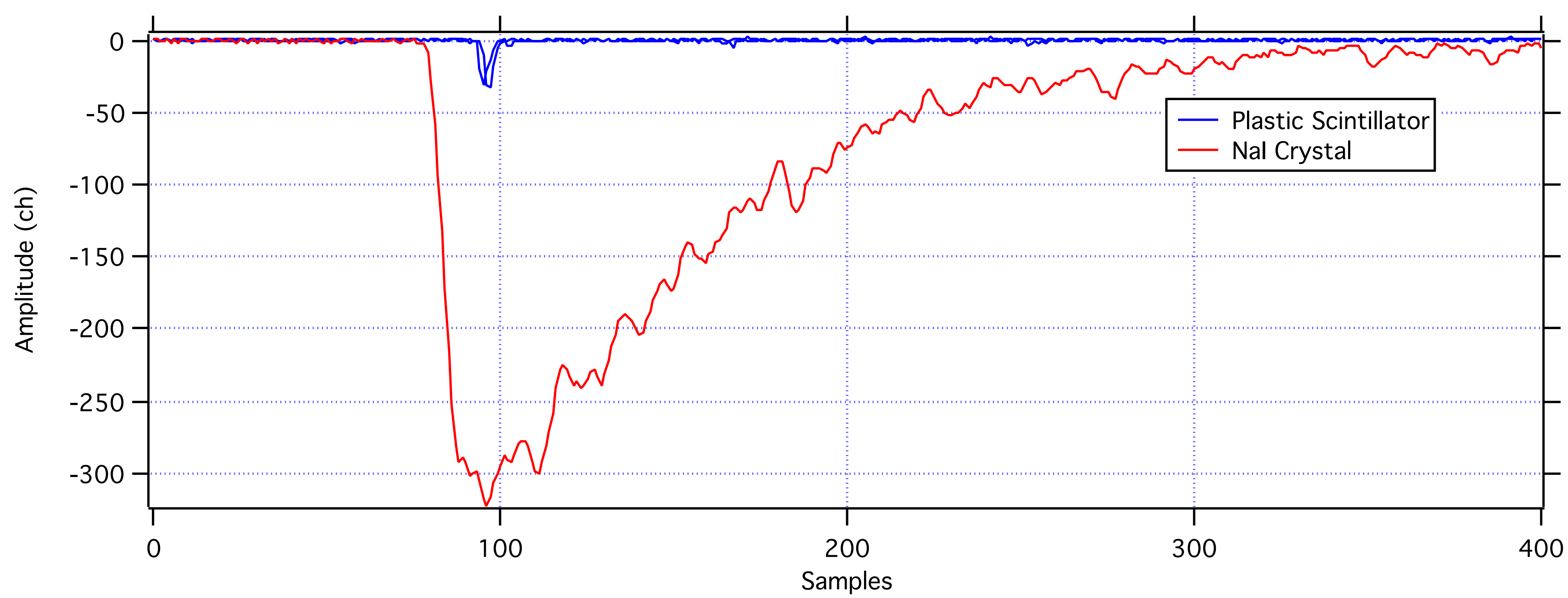
DAQ at Work!



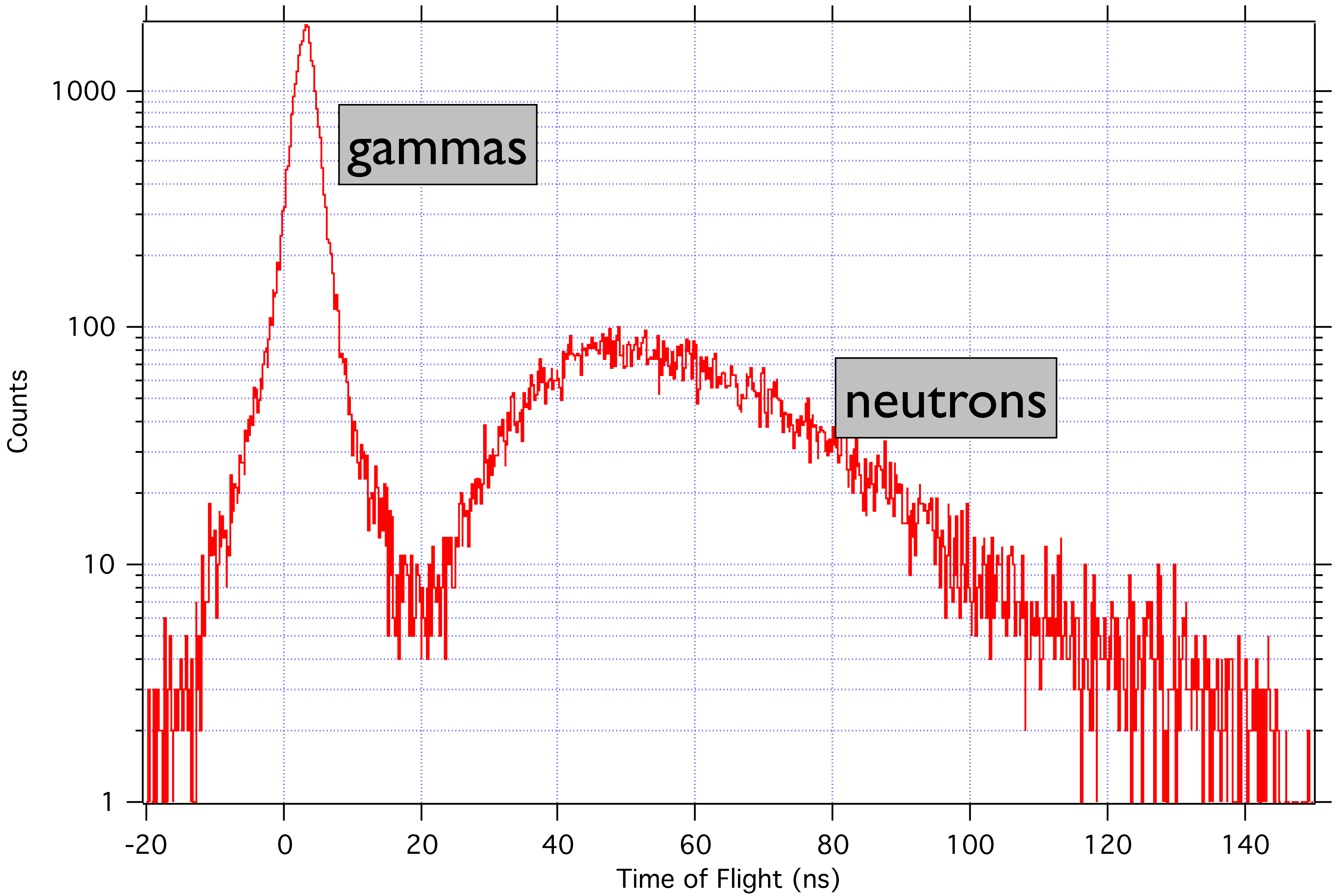
Applications Places System
Mon Mar 18, 10:51 AM fn-daq
FaNS2Data1
100512-200MeV-
103112-Interrupts.
Sync-2012-12-28-
022613-gamma-b2.
Caen
trace 0 1 2 3 4 5 6 7 tile < cfs > cfs Save Mca Log 0 Mca binW 10 X: 3,674 Y: 21
fn-daq@fn-daq-desktop: ~/Desktop/myNewCaen
File Edit View Terminal Tabs Help
get_elapsed_counts -1 3396 counts -1
Events: 3396, Time Elapsed: 1997
Rate: 1.0 Hz
get_elapsed_time -1 2000 elapsed secs -1
get_elapsed_counts -1 3401 counts -1
Events: 3401, Time Elapsed: 2000
Rate: 1.66666666667 Hz
get_elapsed_time -1 2003 elapsed secs -1
get_elapsed_counts -1 3406 counts -1
Events: 3406, Time Elapsed: 2003
Rate: 1.66666666667 Hz
get_elapsed_time -1 2006 elapsed secs -1
get_elapsed_counts -1 3413 counts -1
Events: 3413, Time Elapsed: 2006
Rate: 2.33333333333 Hz
Caen controller
File Link Help
coord 0 1 2 3 4 5 6
Stop
Save 1/ComisData69/BG-2013-03-18-10-12-38.dat
Skip 100
Read ini Write ini
Events 3416 0
Seconds 2009 3600
S in Master S in 1
Controlled: 0 1 2 3 4 5 6

NIST nTOF Apparatus

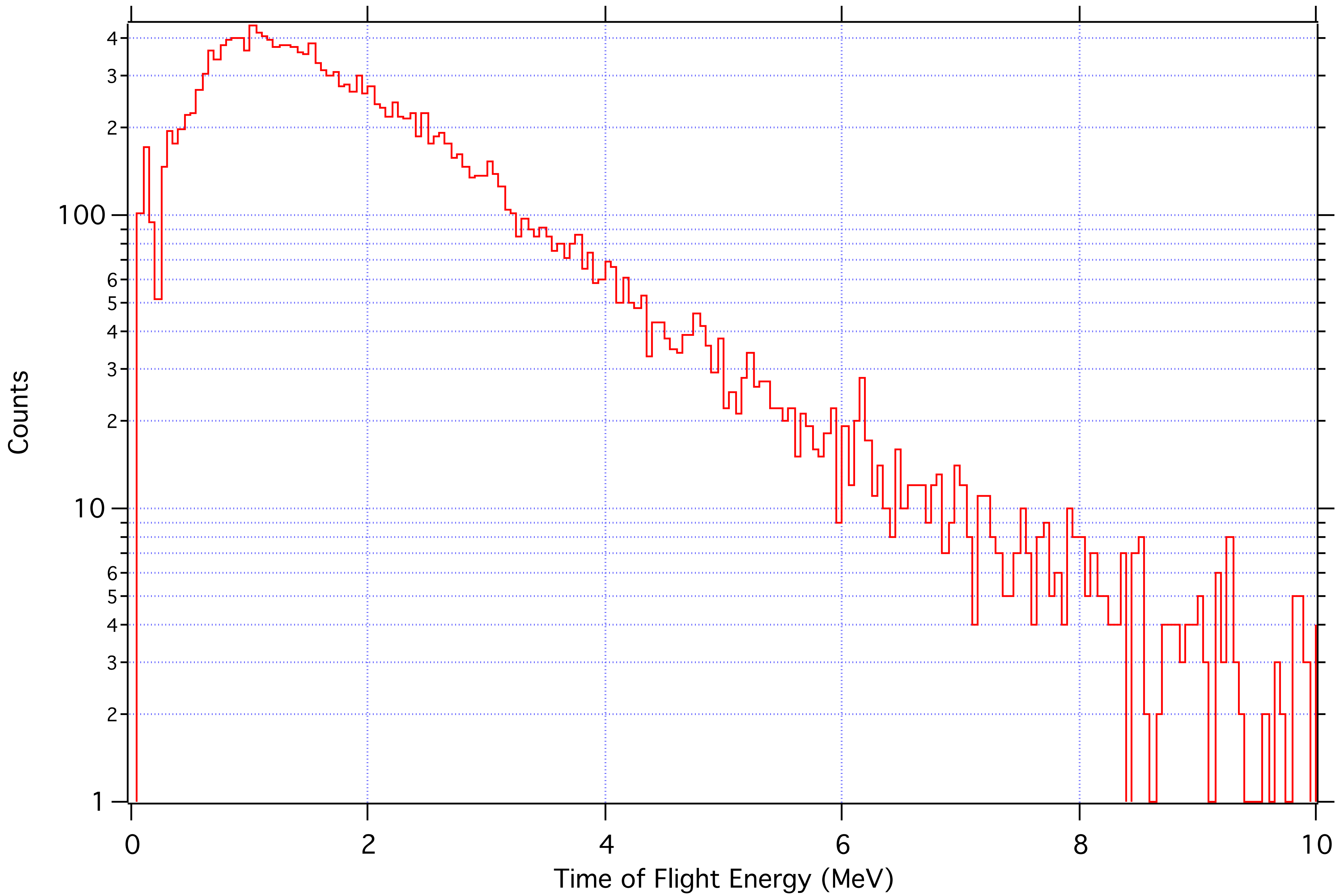




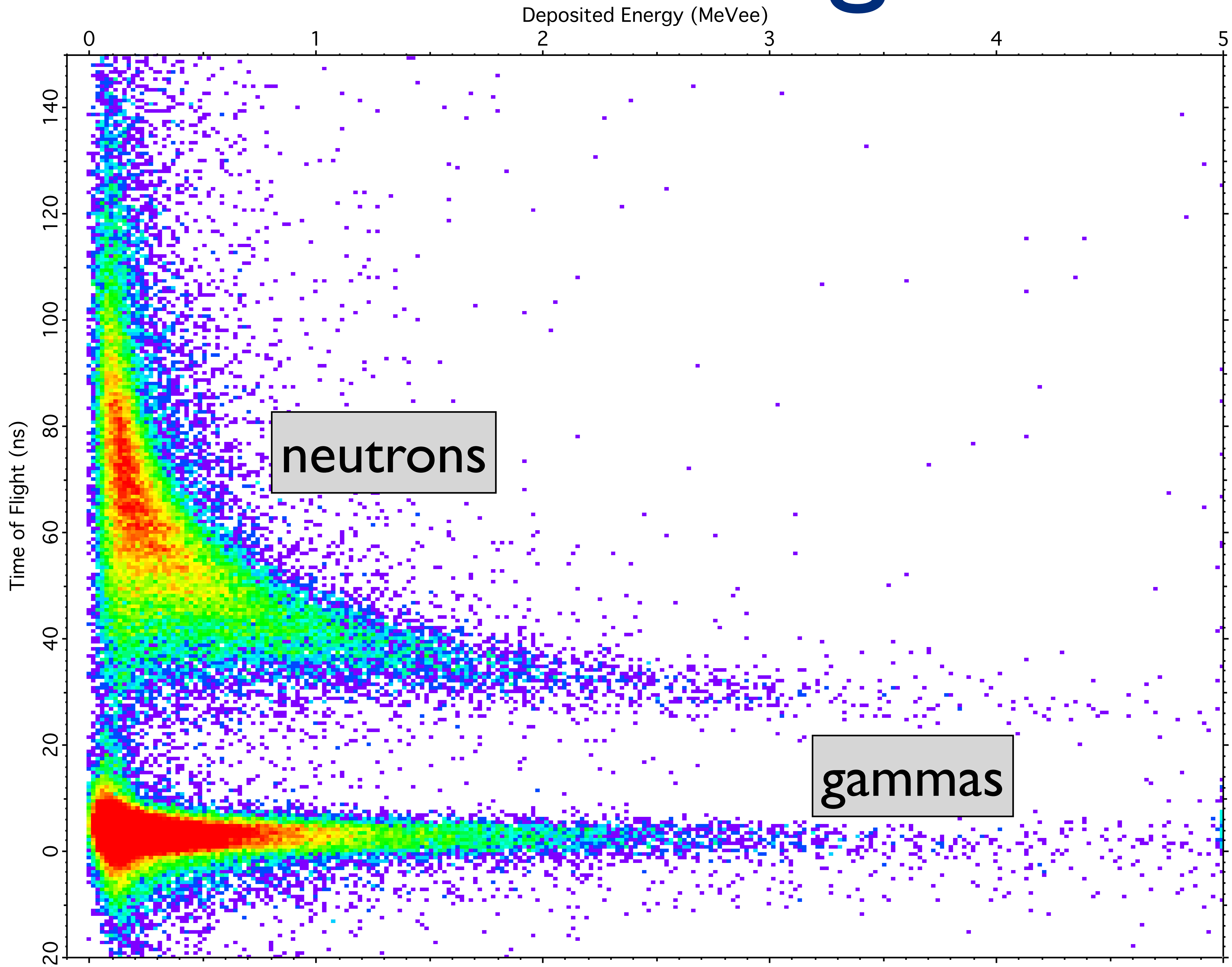
Time of Flight



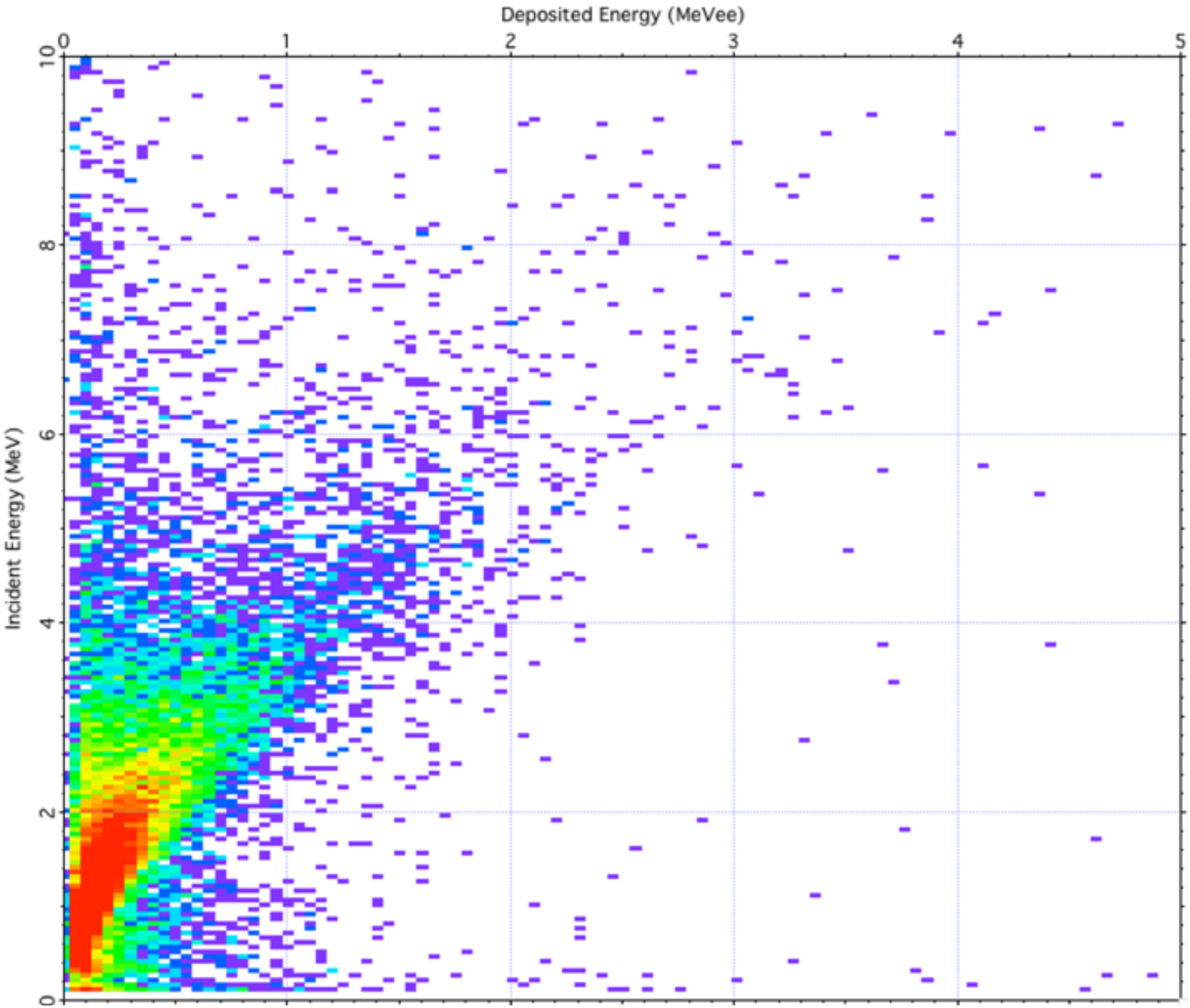
Time of Flight Energy



Time of Flight

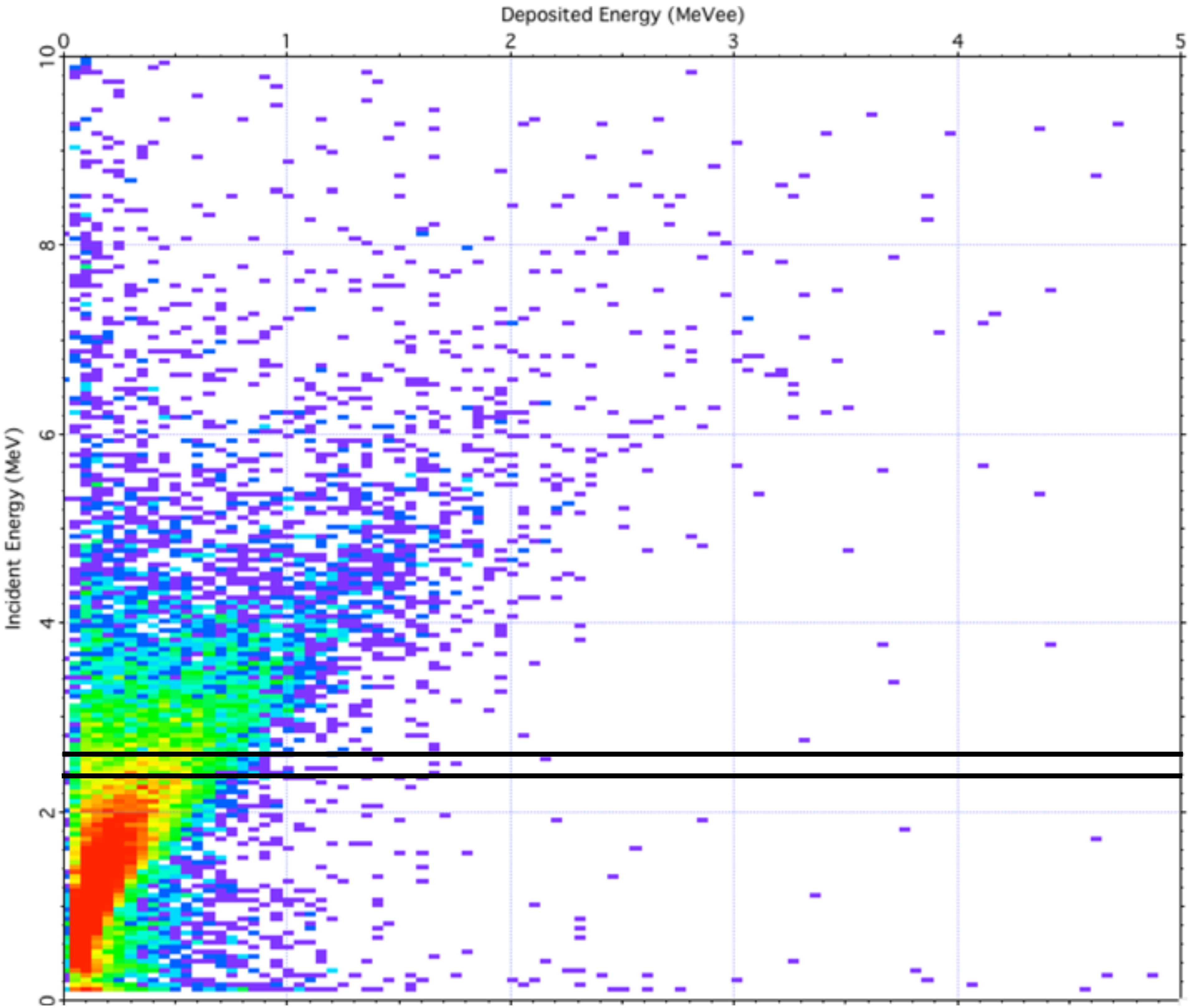


MeV vs MeVee



Deposited Energy (MeVee)
0
1
2
3
4
5
Incident Energy (MeV)
0
2
4
6
8
10

MeV vs MeVee



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0
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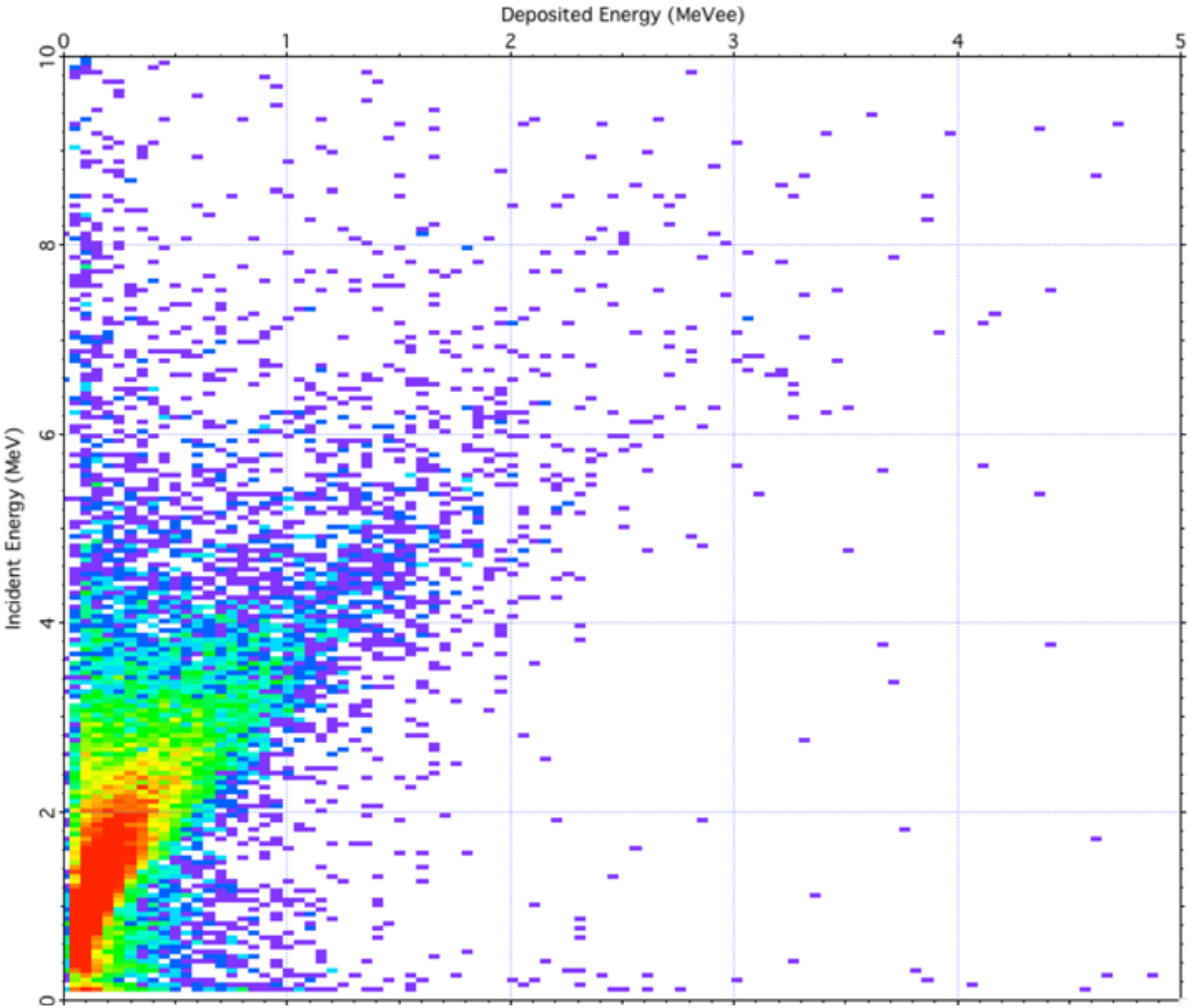
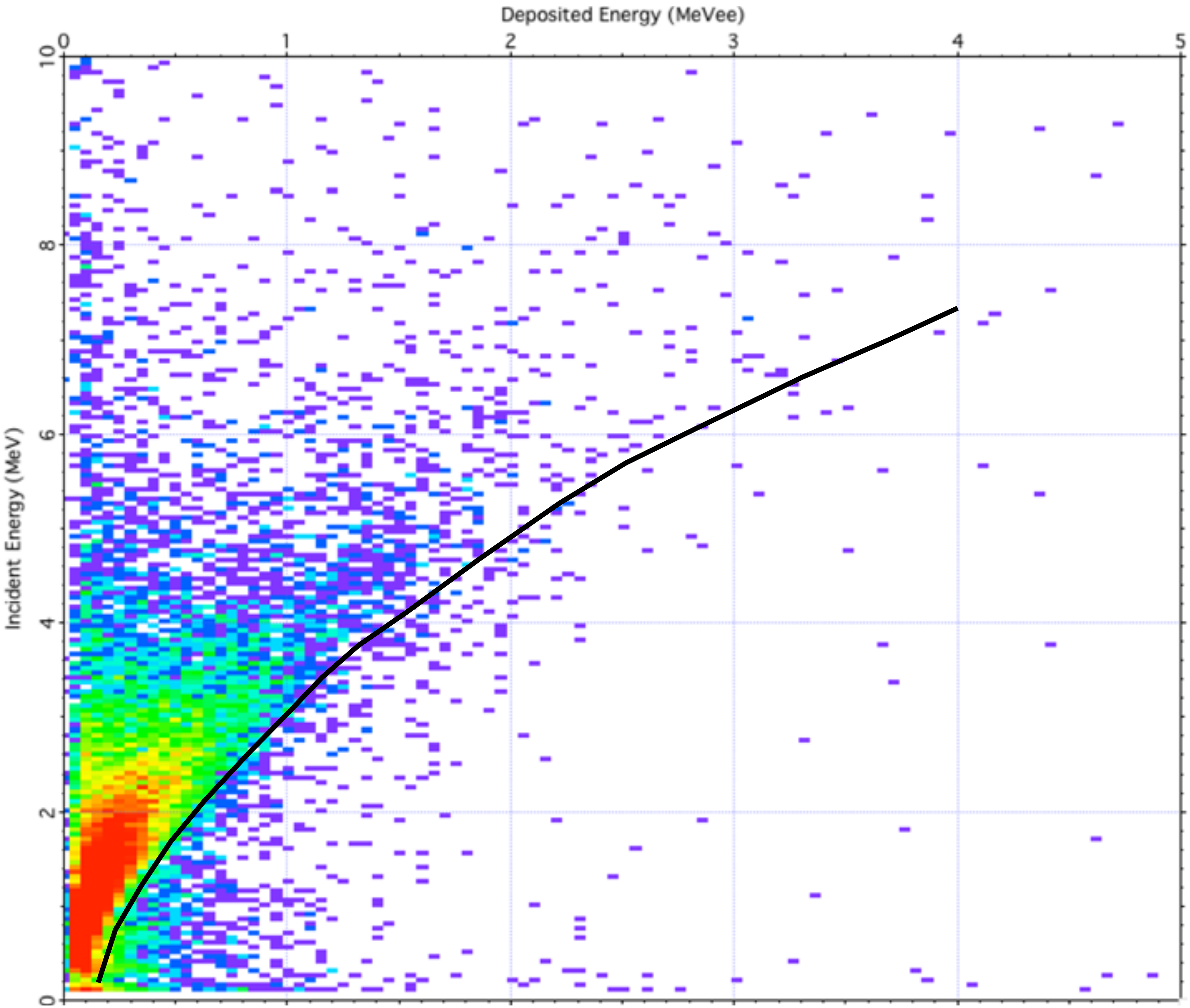
MeV vs MeVee



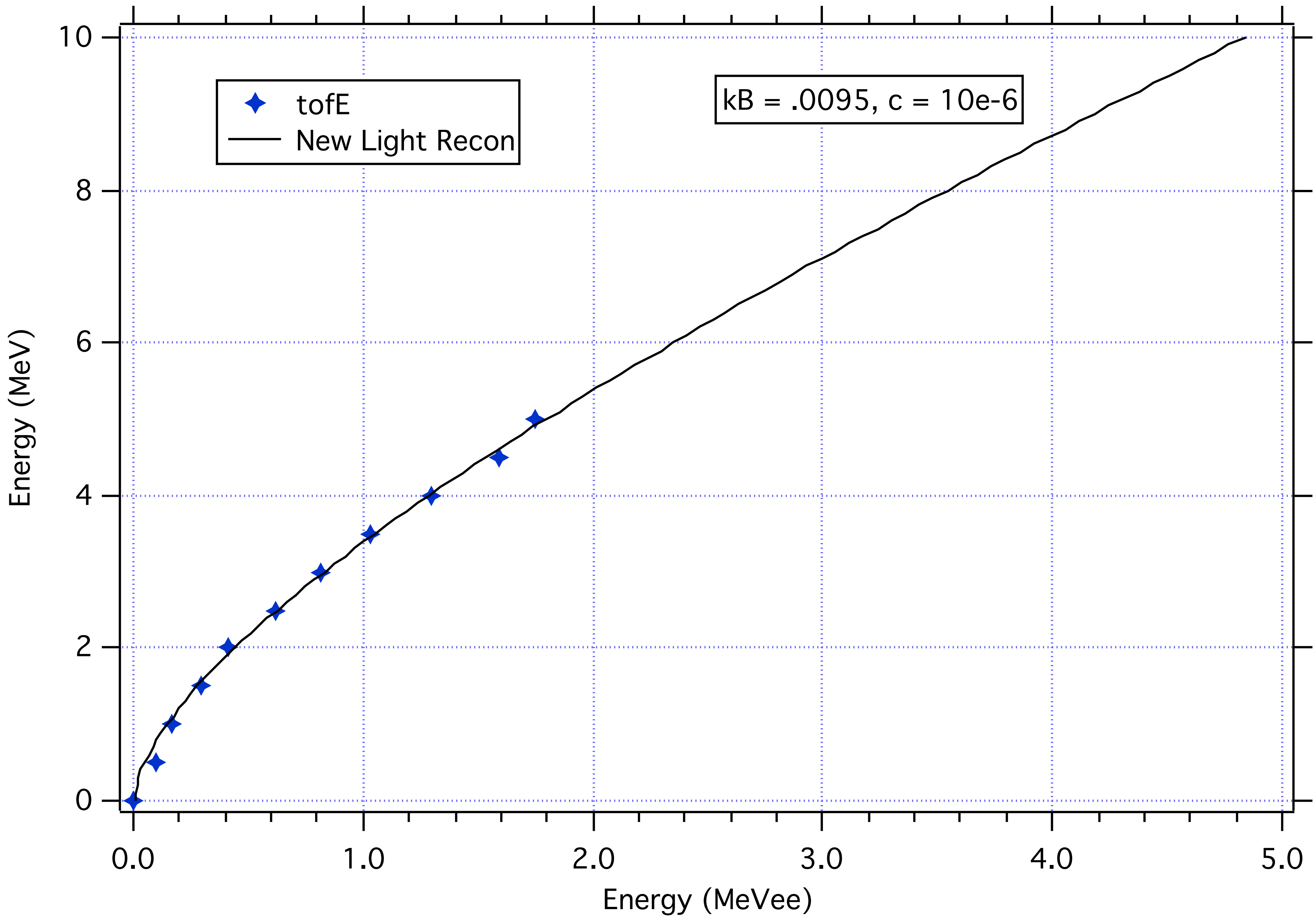
Deposited Energy (MeVee)
0
1
2
3
4
5
Incident Energy (MeV)
10
8
6
4
2
0

MeV vs MeVee



Deposited Energy (MeVee)
Incident Energy (MeV)
0
1
2
3
4
5
10
8
6
4
2
0

Measured Light Response



FaNS-2 Outlook

- Efficiency calibration up to 10 MeV with Cf neutron sources
- Measure response to 14 MeV neutrons with DT generator
- Continue collecting ambient neutron data at the surface, measure from 500 keV to >1 GeV
- Install in a shallow underground facility at NIST to measure the muon induced neutron spectrum
- Simulate the spectrum with Geant4/Fluka/MCNP to compare with data