Project 8
A Radio Frequency Measurement of the Neutrino Mass Scale

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PROJECT 8

LNS
Laboratory for Nuclear Science

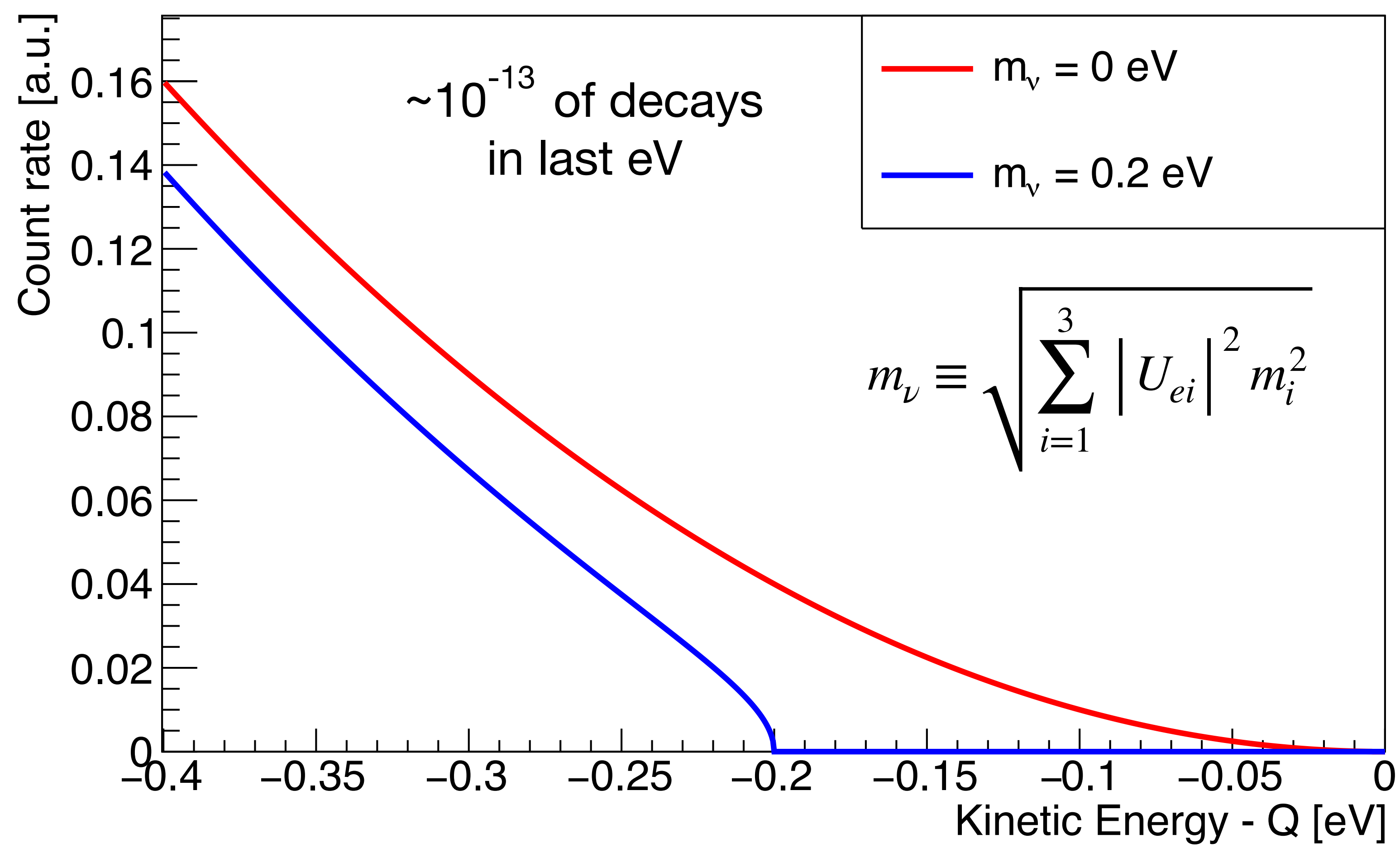
Tritium β Decay

- Non-zero neutrino mass modifies the energy spectrum of beta decays, near the endpoint

- Spectral shape is fitted with m_ν as a free parameter

- Good energy resolution and event rate needed to perform measurement

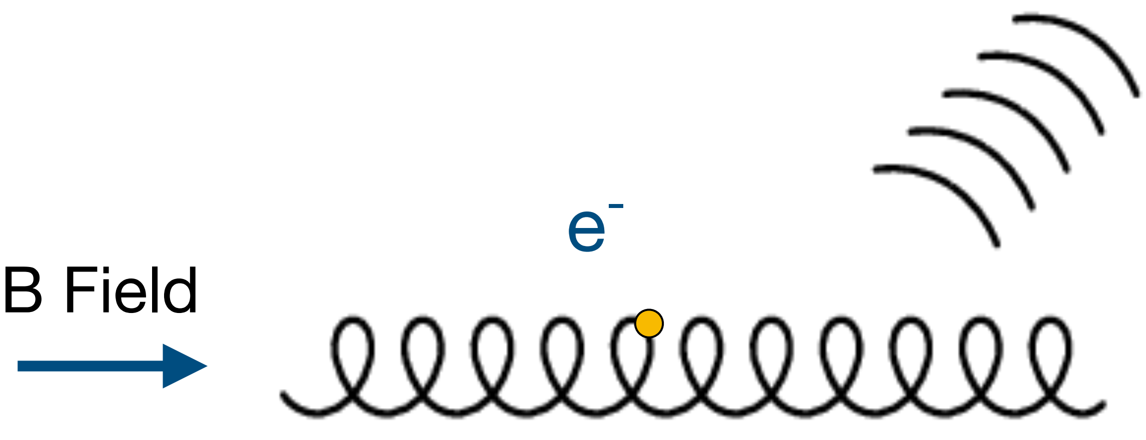
$$^3\mathrm{H} \rightarrow {}^3\mathrm{He}^+ + \mathrm{e}^- + \overline{\nu}_e$$



$$m_\nu \equiv \sqrt{\sum_{i=1}^{3} \left|U_{ei}\right|^2 m_i^2}$$

Cyclotron Radiation Emission Spectroscopy (CRES)

- In a uniform magnetic field, a charged particle will have a helical trajectory



- The accelerating electron will radiate EM waves at frequency:

$$f_{\text{cyc}} = \frac{1}{2\pi}\frac{qB}{m\gamma} = \frac{1}{2\pi}\frac{qB}{m_e + E_e}$$

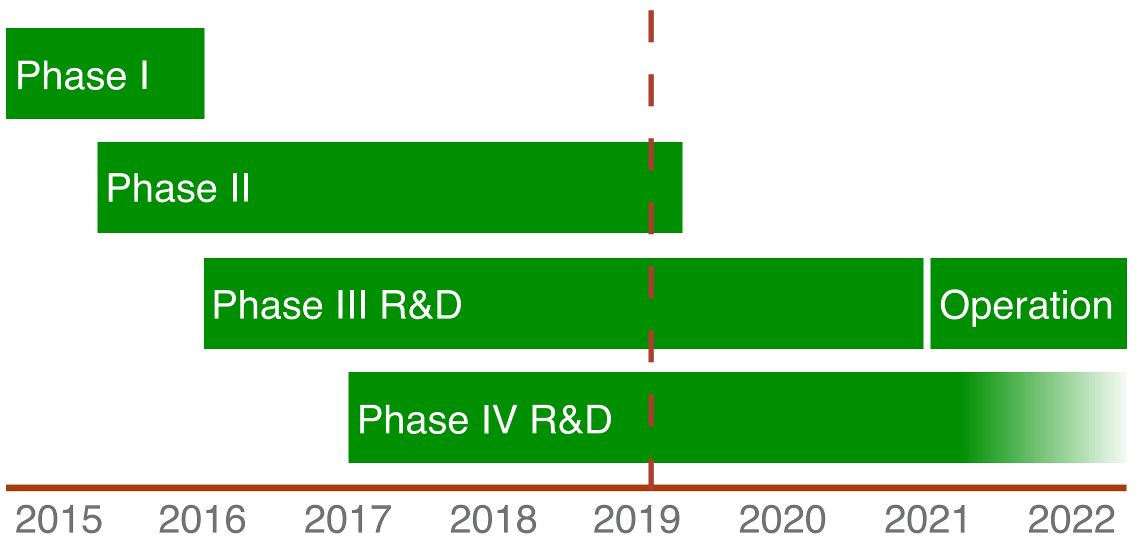
$E_e = 18.6$ keV
B = 1 T
$\Rightarrow P \approx 1$ fW

- Advantages:
  - Excellent energy resolution from frequency measurement
  - Source gas is transparent to cyclotron radiation
  - Differential spectrum measurement
  - Low background

Project 8 Experiment

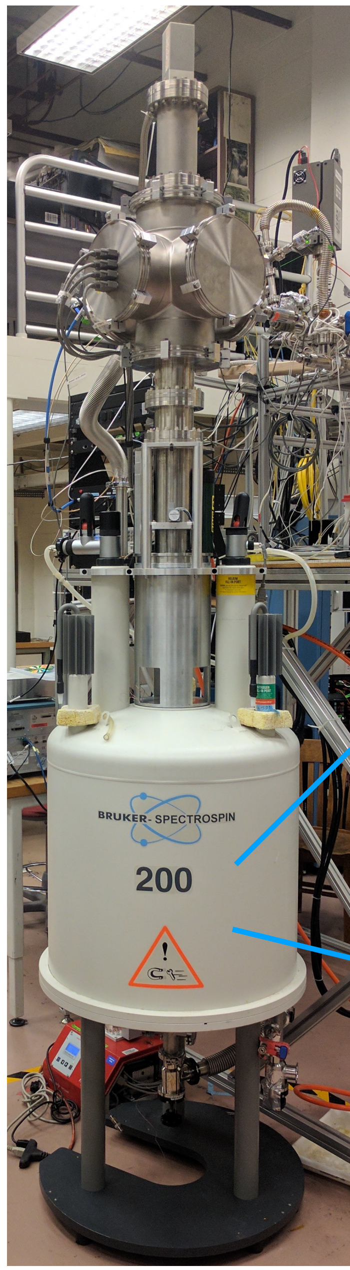
A phased tritium beta endpoint experiment to measure the electron neutrino mass

- **Phase I (Complete)**
  - First demonstration of CRES technique with ^{83m}Kr
- **Phase II (2015-2018)**
  - First tritium measurement with CRES
  - Endpoint determination to ~30 eV
- **Phase III (2016-2022)**
  - CRES demonstration in 100-200 cm^3 free space volume
  - Neutrino mass sensitivity of ~2 eV
- **Phase IV (2017+)**
  - Atomic tritium endpoint measurement with m_ν ~40 meV sensitivity

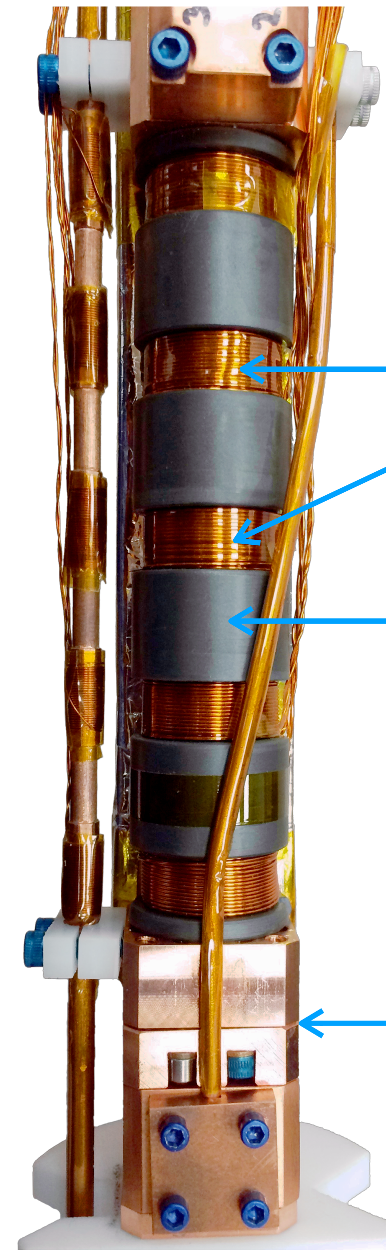


Phase II Design

Superconducting
Magnet
(1 T)



B



To Amplifier Chain

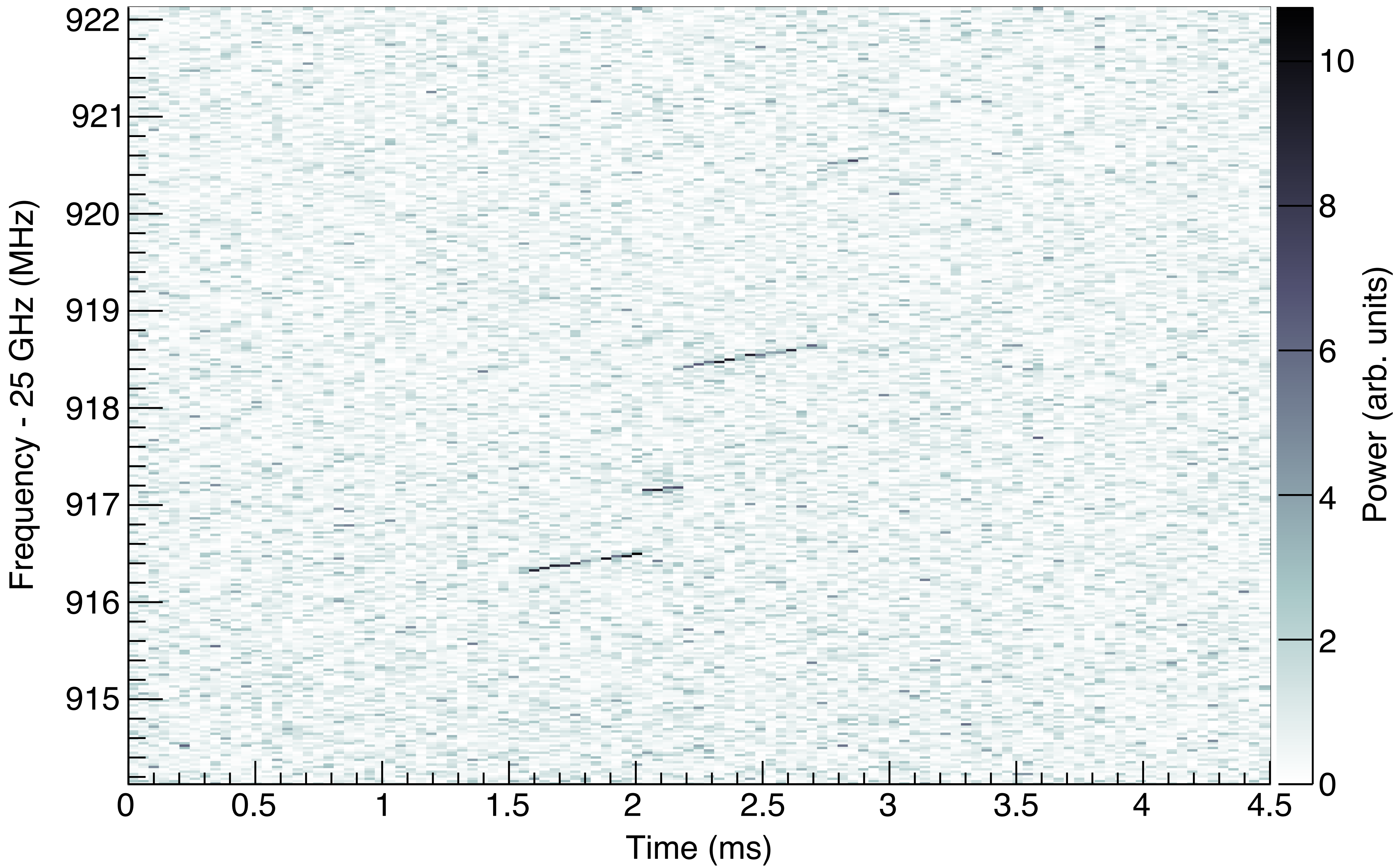
Trap Coils

Circular
Waveguide
(inside)

CaF_2 Window

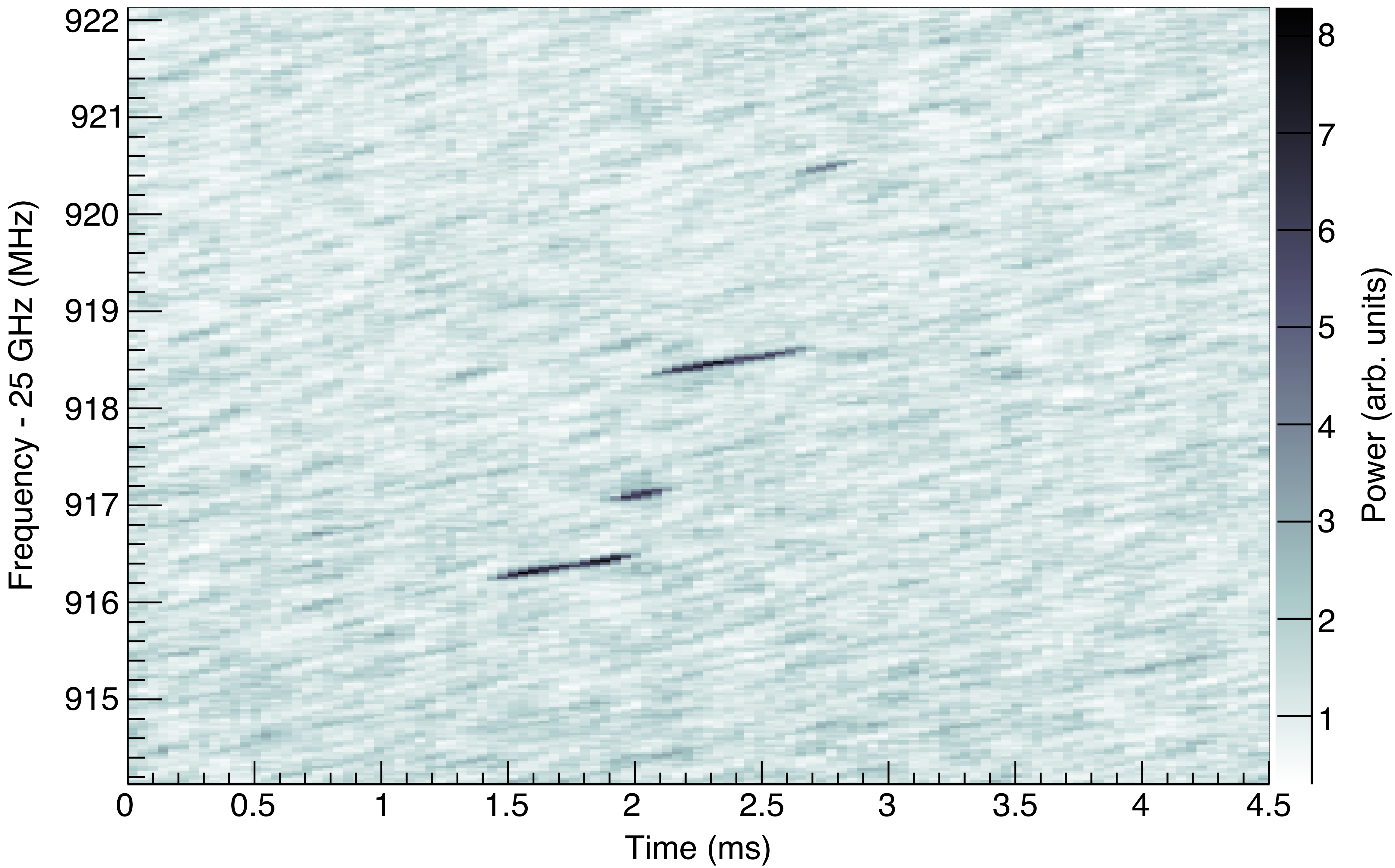
To Terminator

Event 0



922
921
920
919
918
917
916
915
Frequency - 25 GHz (MHz)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Time (ms)
10
8
6
4
2
0
Power (arb. units)

Event 0



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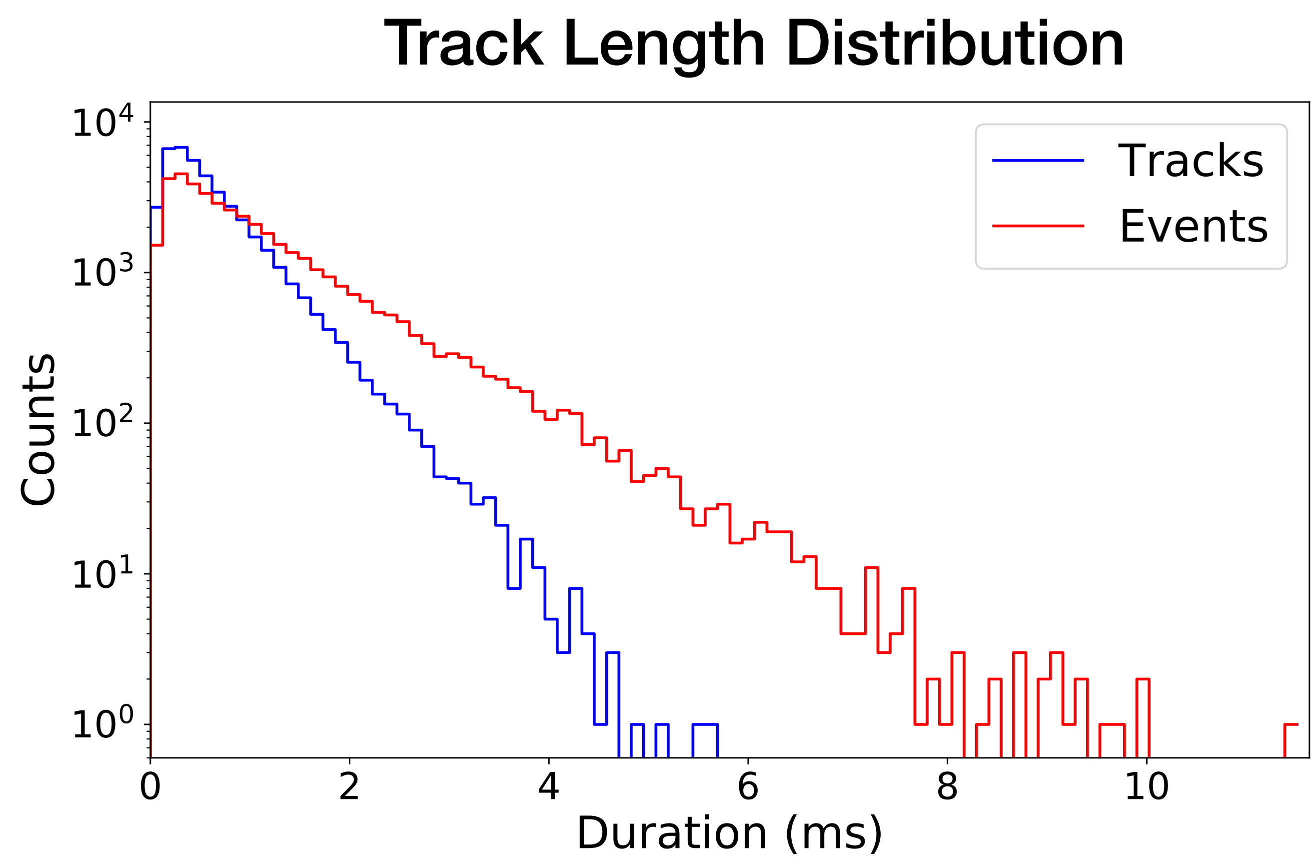
2.5
3
3.5
4
4.5
Time (ms)
8
7
6
5
4
3
2
1
Power (arb. units)

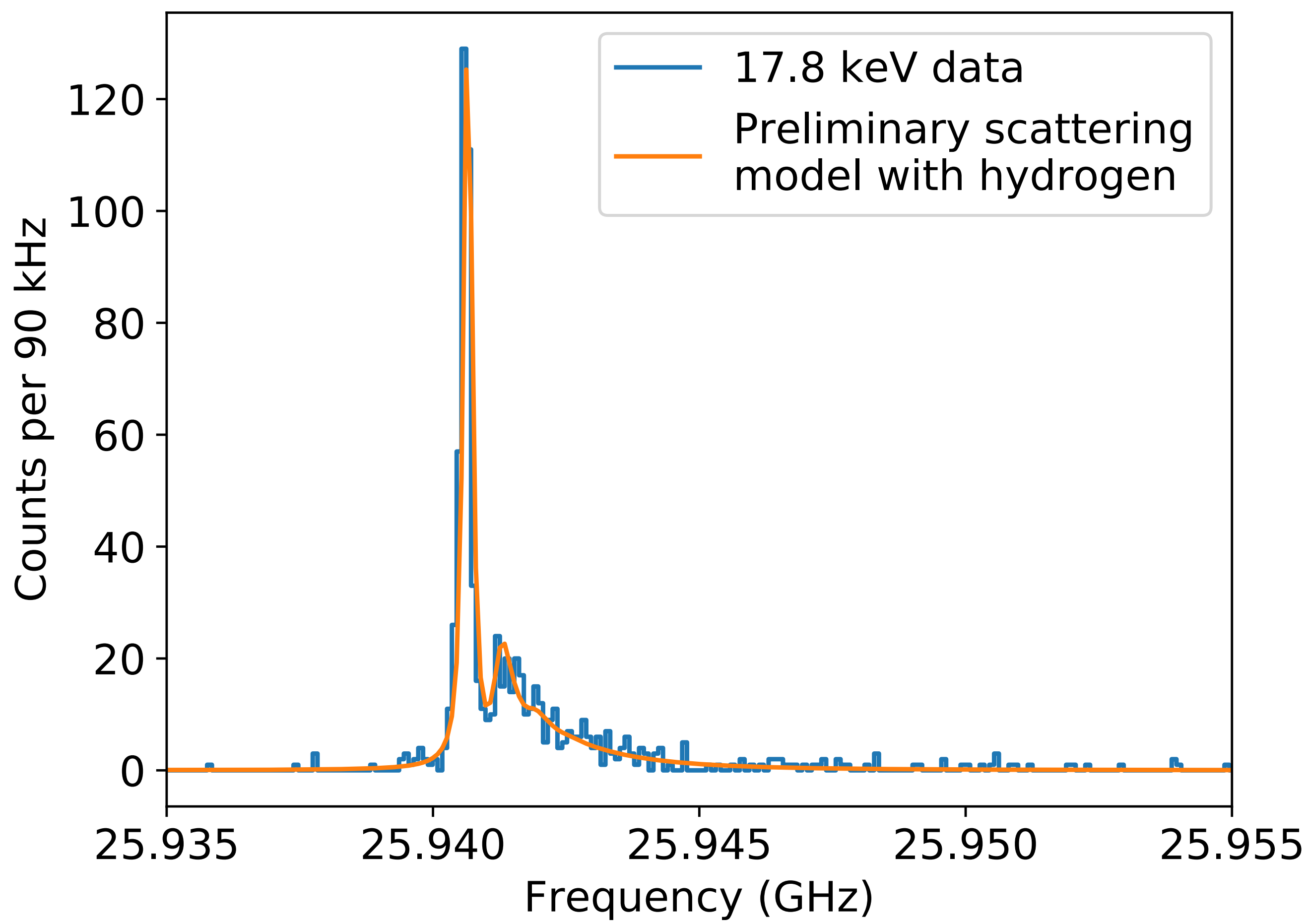
Track Reconstruction & Data Quality

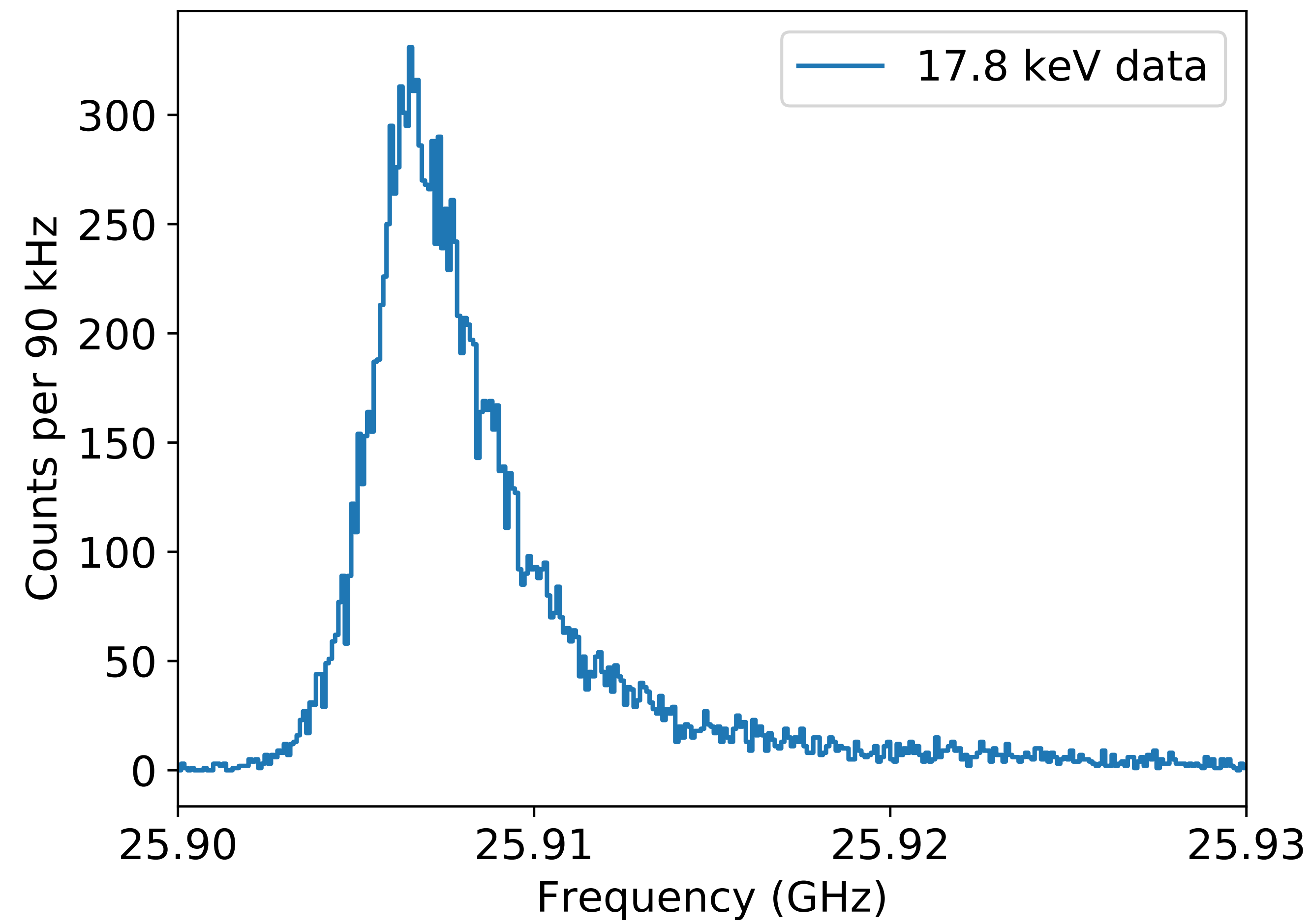
* Spectrograms are very information rich
* Inelastic scattering from residual gas limits temporal extent of tracks
* Short tracks are more difficult to distinguish from thermal noise
  - Sets limit on maximum gas pressure in cell



Excellent reconstruction demonstrated down to 250 μs track lengths

Energy Resolution

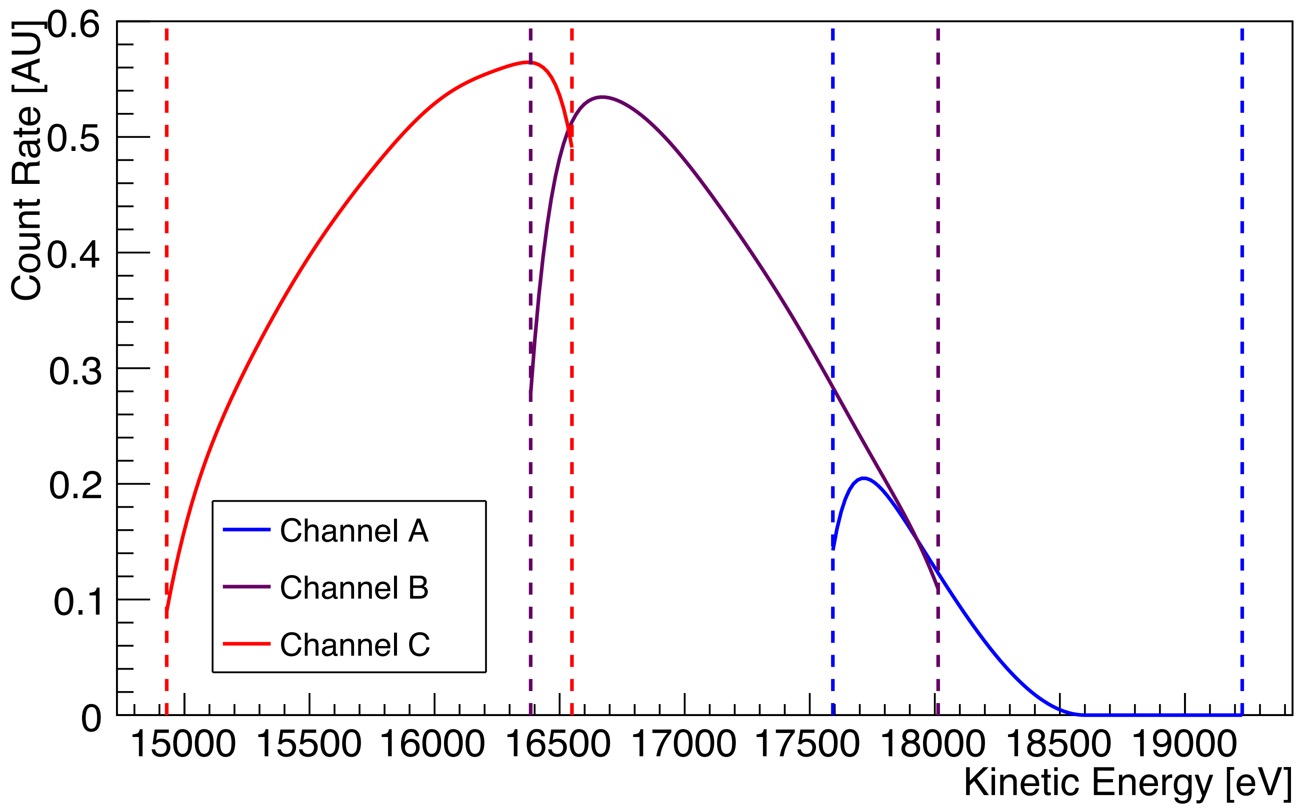




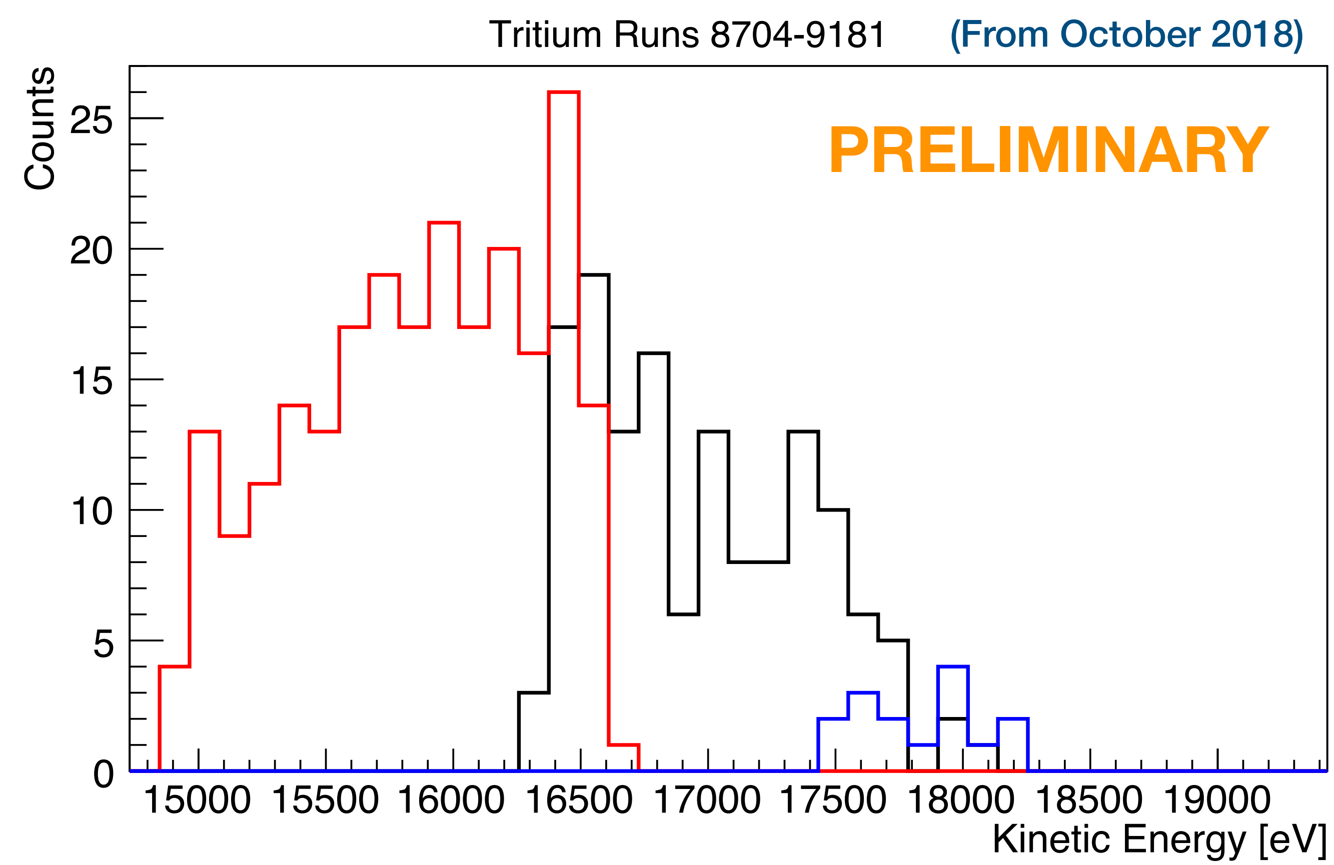
- Using ^{83m}Kr calibration (IC), energy resolution in shallow traps found to be ~4 eV
- Deeper magnetic traps yield more statistics, though lower energy resolution
  - Better predicted sensitivity to neutrino mass for ~100 day run

Preliminary Tritium Spectrum

Predicted Energy Spectrum

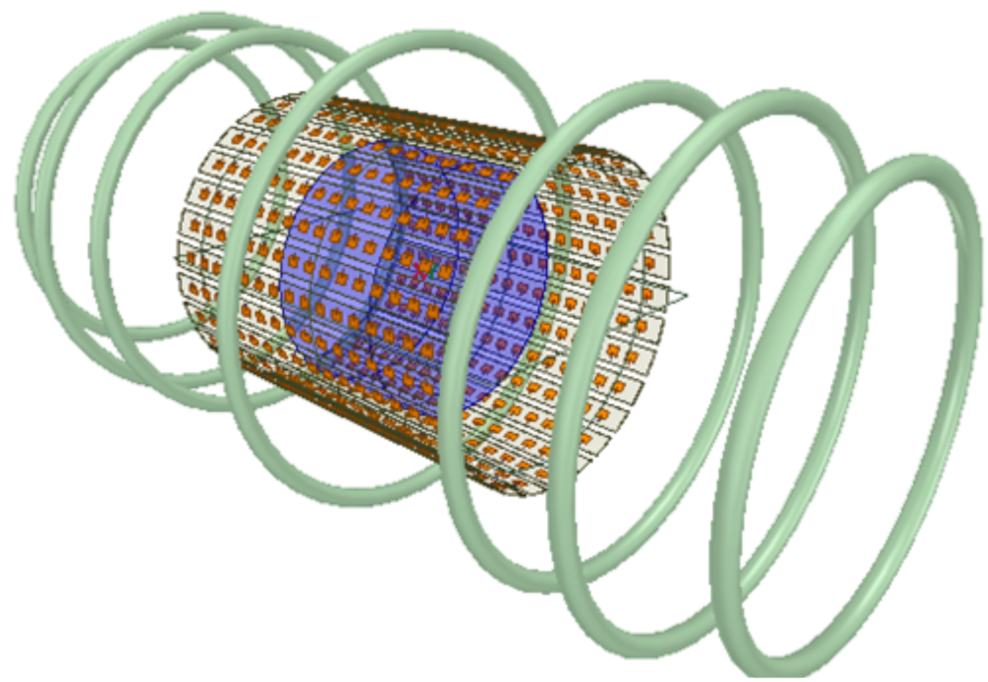


Observed Energy Spectrum

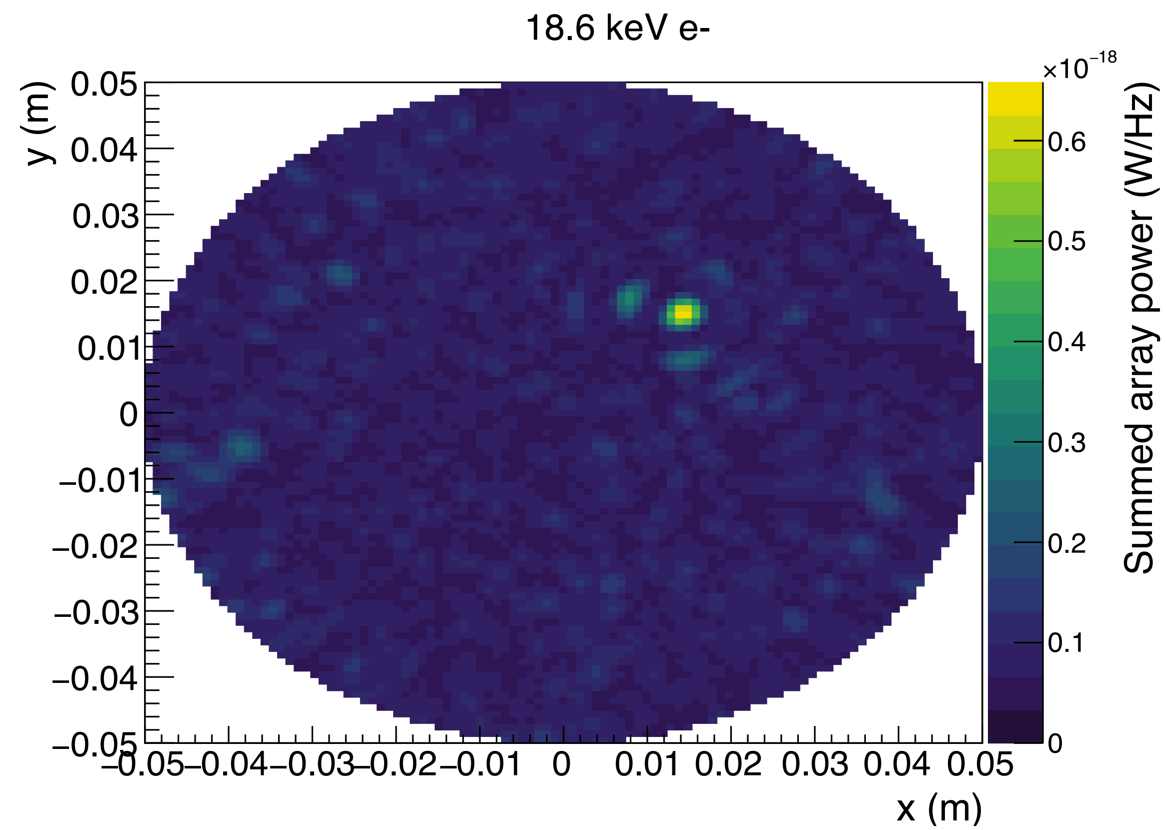


- 417 events
- Agrees with expected spectrum
- No background above endpoint

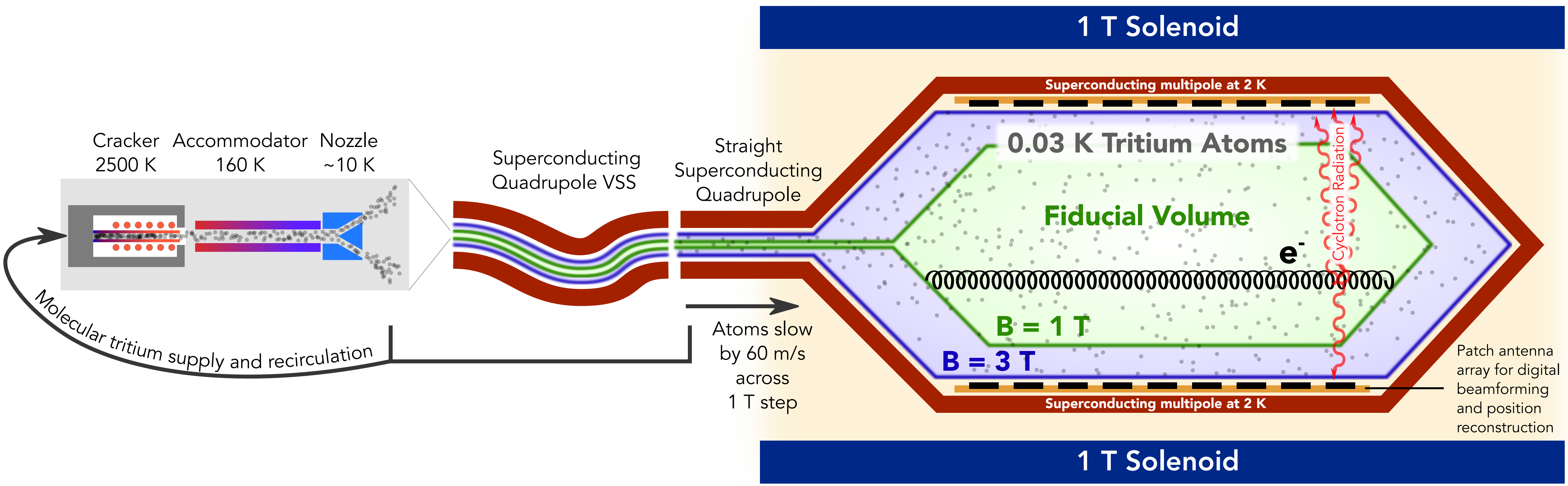
Next Steps: Phase III R&D



- Higher statistics are needed for a competitive measurement
  - Waveguide does not scale to larger volumes. Go to free-space!
- Simulations of realistic electron radiation patterns are underway
  - Detailed E&M simulations of patch antennas + feed networks
  - Digital beamforming between channels



Next Steps: Phase IV R&D



- Phase IV requires ~10 m^3 at a tritium number density of 10^{12} cm^{-3} for sufficient statistics for 40 meV mass resolution
- Early research has focused on:
  - Cracking sufficient molecular tritium
  - Conceptual design for velocity selection/ magnetic trap

Project 8 Collaboration

Case Western Reserve University
- Laura Gladstone, Benjamin Monreal, Yu-Hao Sun

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Pacific Northwest National Laboratory
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