Project 8:
First Results & More

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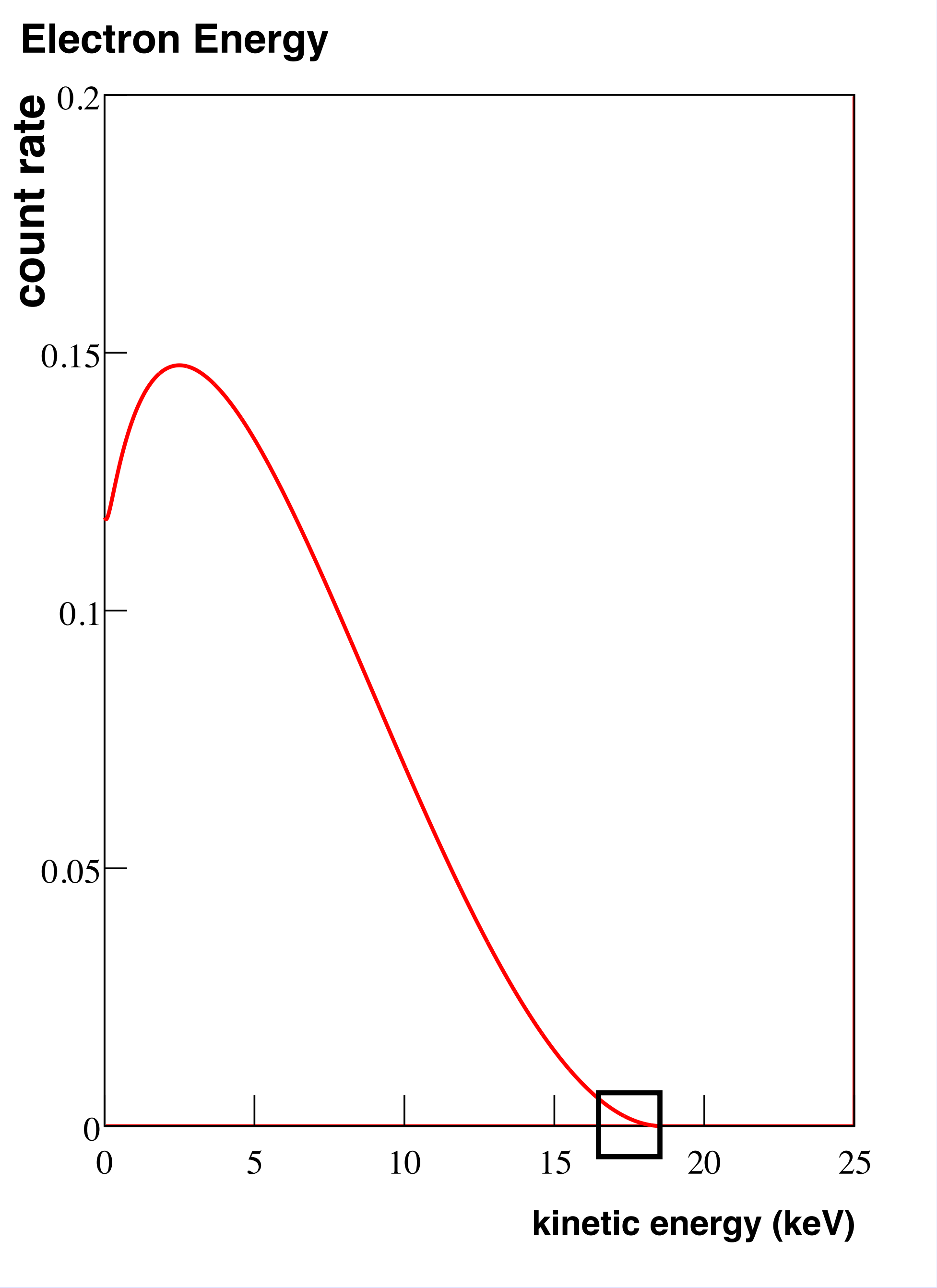
XVI International Workshop on Neutrino Telescopes
Venice, Italy
March 5, 2015

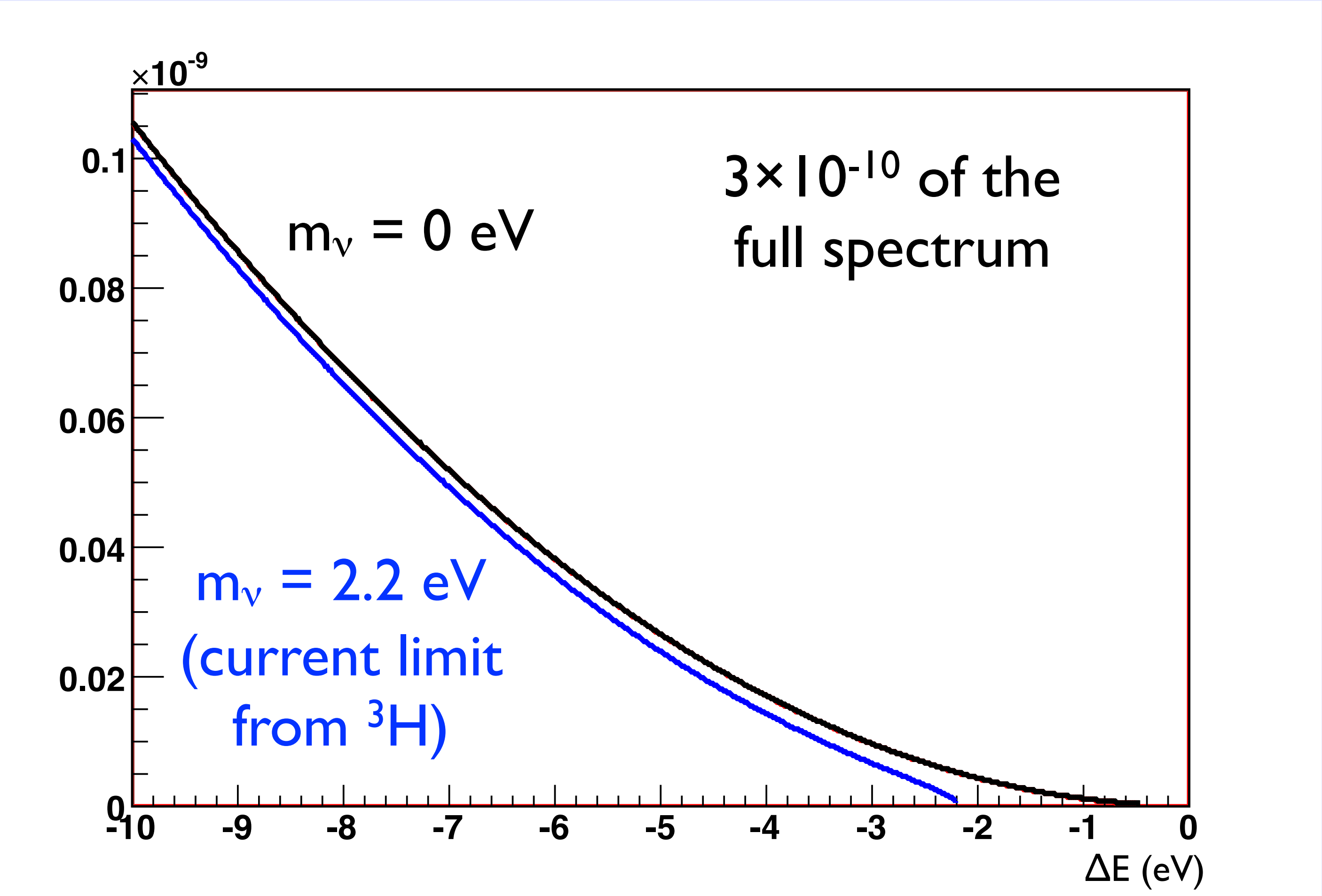
Laboratory for Nuclear Science

PROJECT 8

Using Tritium β Decay



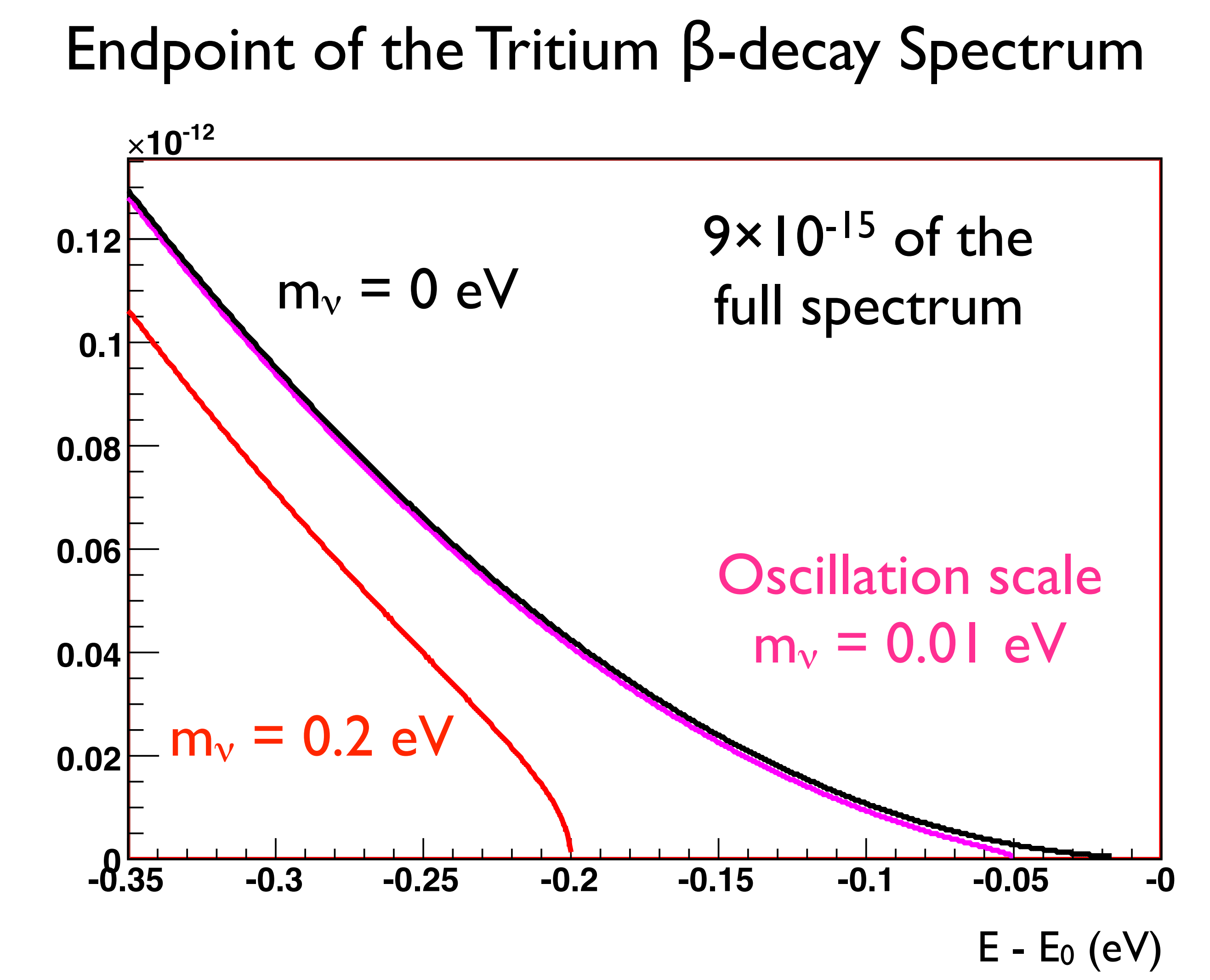
Zoom in on the endpoint . . .



$$\frac{dN}{dE} \approx KF(Z,E)p(E+m_e c^2)\left((E-E_0)^2 - \frac{1}{2}m_\beta^2\right)$$

$$m_\beta = \sqrt{\sum_i |U_{ei}^2| m_i^2}$$

Beyond KATRIN



Overview

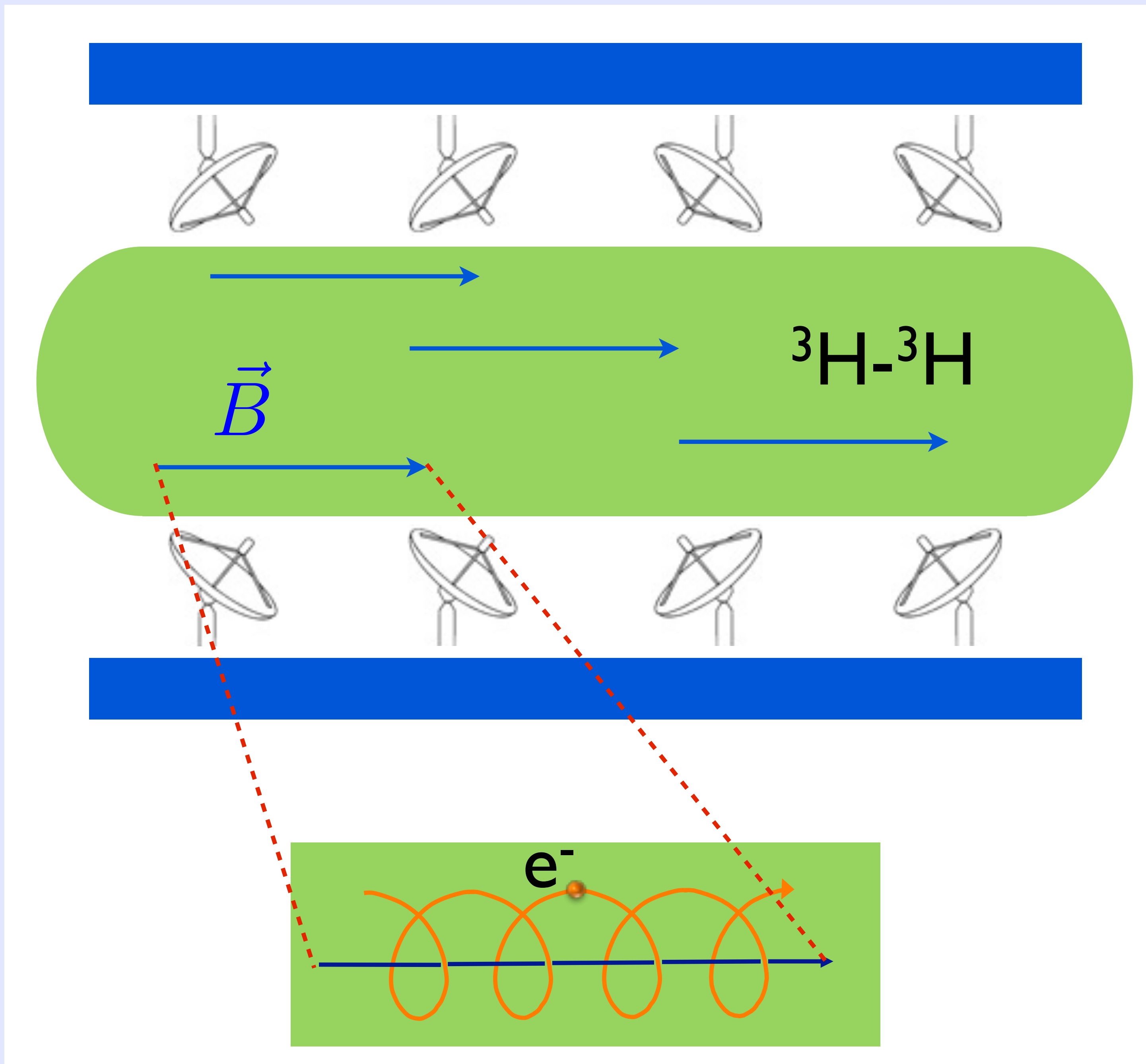
PROJECT 8

- Goal: use a novel technique to be more sensitive to the neutrino mass
- New technique: Cyclotron Radiation Emission Spectroscopy (CRES)
- First direct measurement of single-electron cyclotron radiation made in June, 2014
- Currently seeking improvements in energy resolution and statistics
- First tritium measurement in late 2015

Novel Technique: CRES

Cyclotron Radiation Emission Spectroscopy

- Enclosed volume
- Fill with tritium gas
- Add a magnetic field

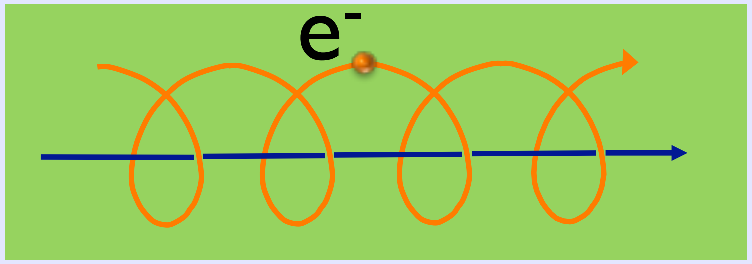


- Decay electrons spiral around field lines
- Add antennas to detect the cyclotron radiation

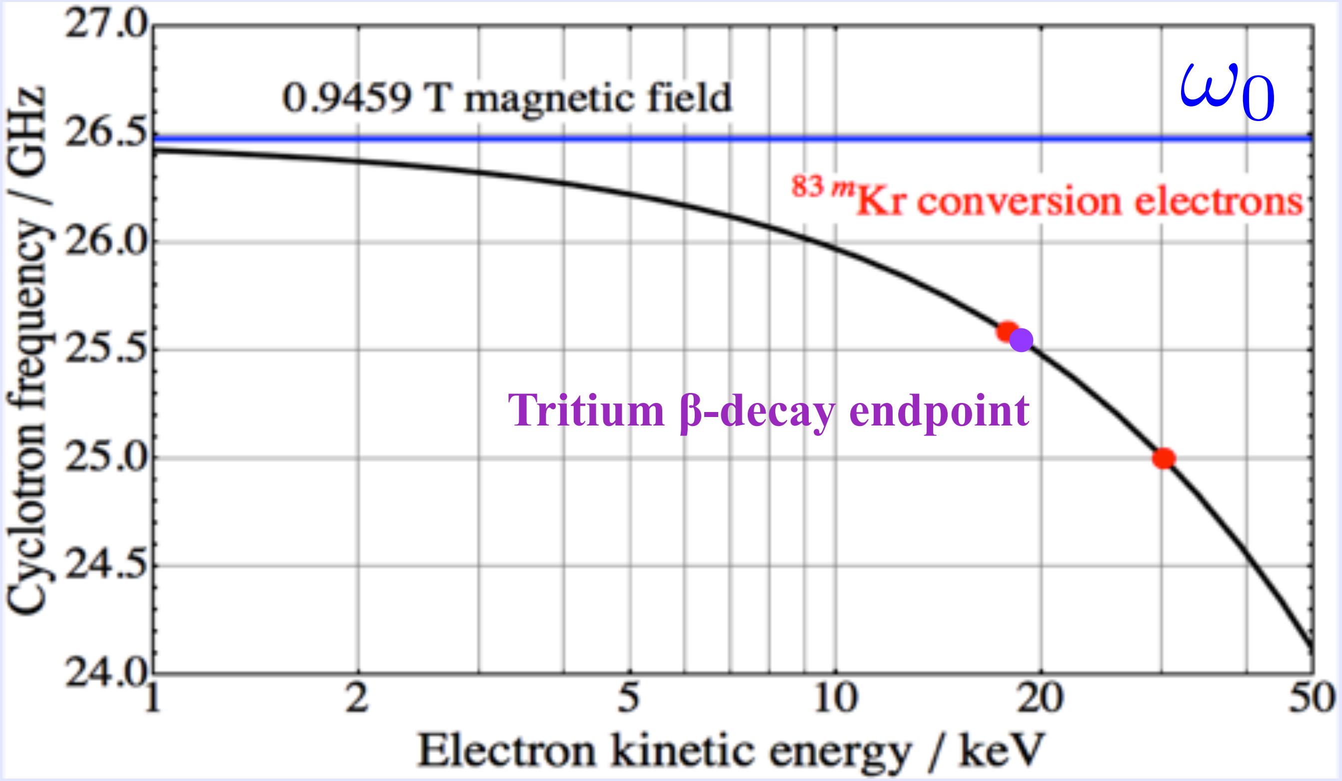
B. Monreal and J. Formaggio, Phys. Rev. D80 051301 (2009)

Cyclotron Radiation

- An electron traveling in a magnetic field emits cyclotron radiation
- The frequency of the emitted radiation depends on the relativistic boost

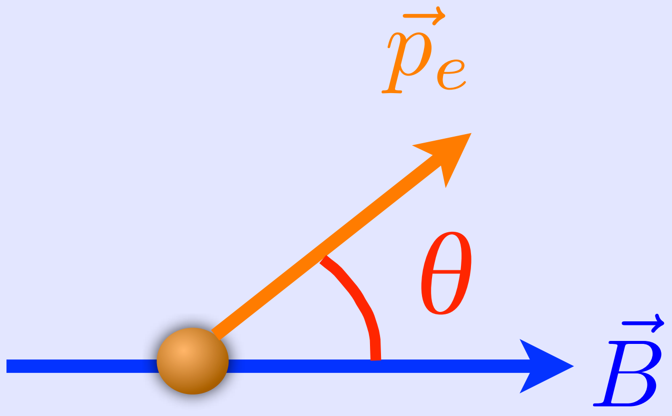


$$\omega_\gamma = \frac{\omega_0}{\gamma} = \frac{eB}{K + m_e}$$



Pitch Angle

The angle between
the electron momentum
and the magnetic field



- Correction term for the cyclotron frequency

$$\omega_\gamma = \frac{\omega_0}{\gamma} = \frac{eB}{K + m_e}\left(1 + \frac{\cot^2\theta}{2}\right)$$

- Power emitted

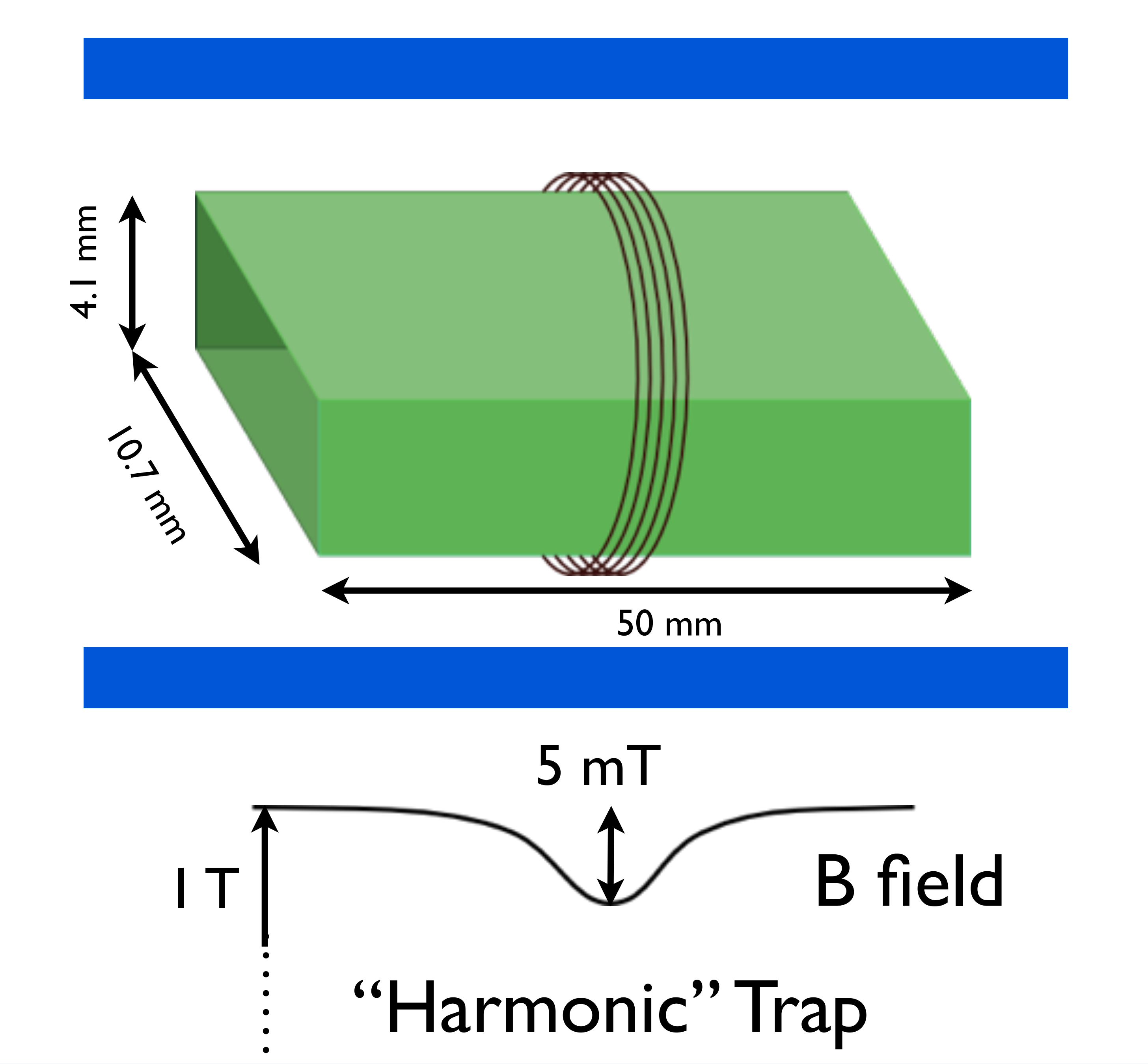
$$P_{\text{tot}} = \frac{1}{4\pi\epsilon_0}\frac{2q^2\omega_c^2}{3c}\frac{\beta^2\sin^2\theta}{1-\beta^2}$$

Novel Technique: CRES

PROJECT 8

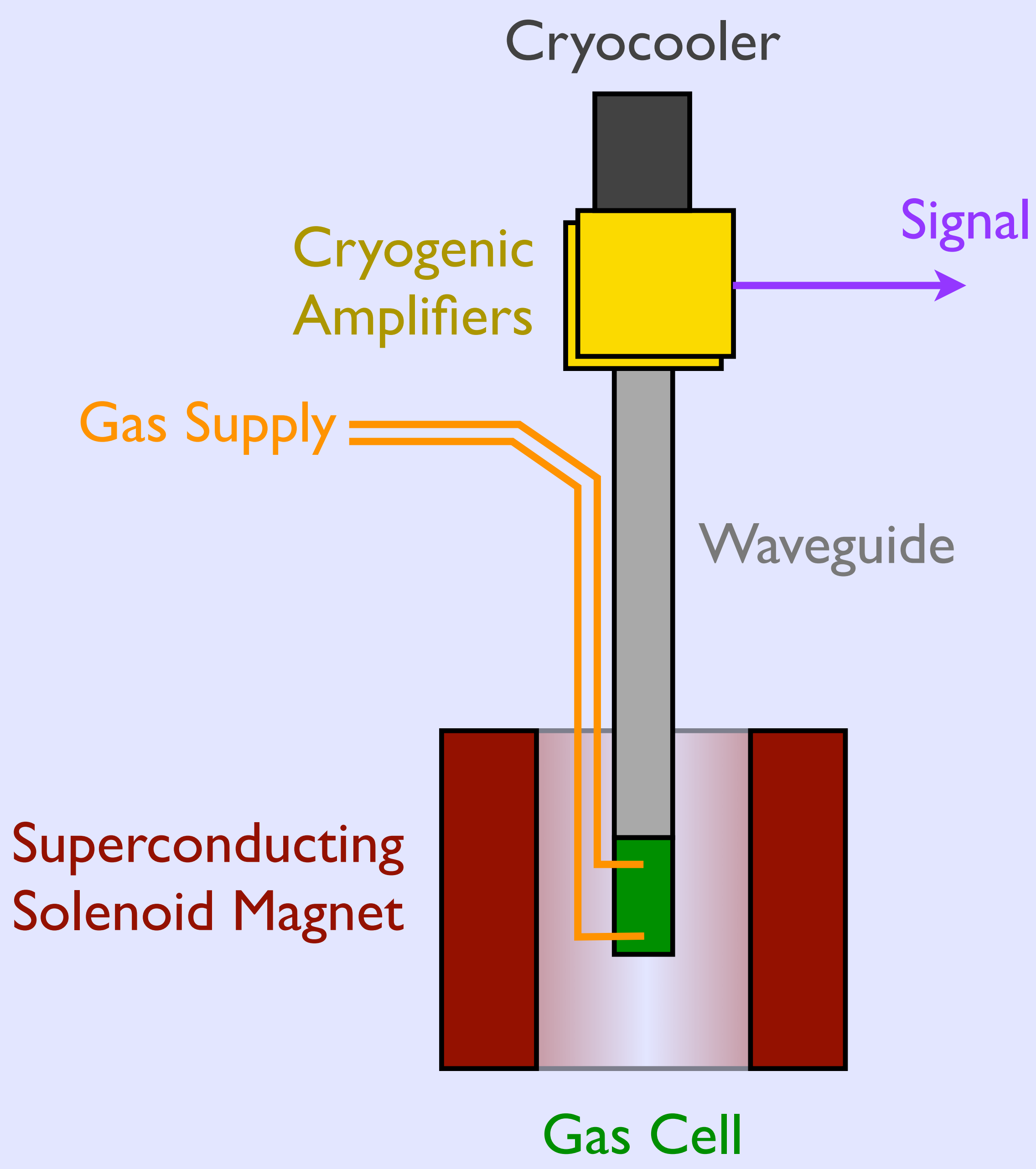
Cyclotron Radiation Emission Spectroscopy

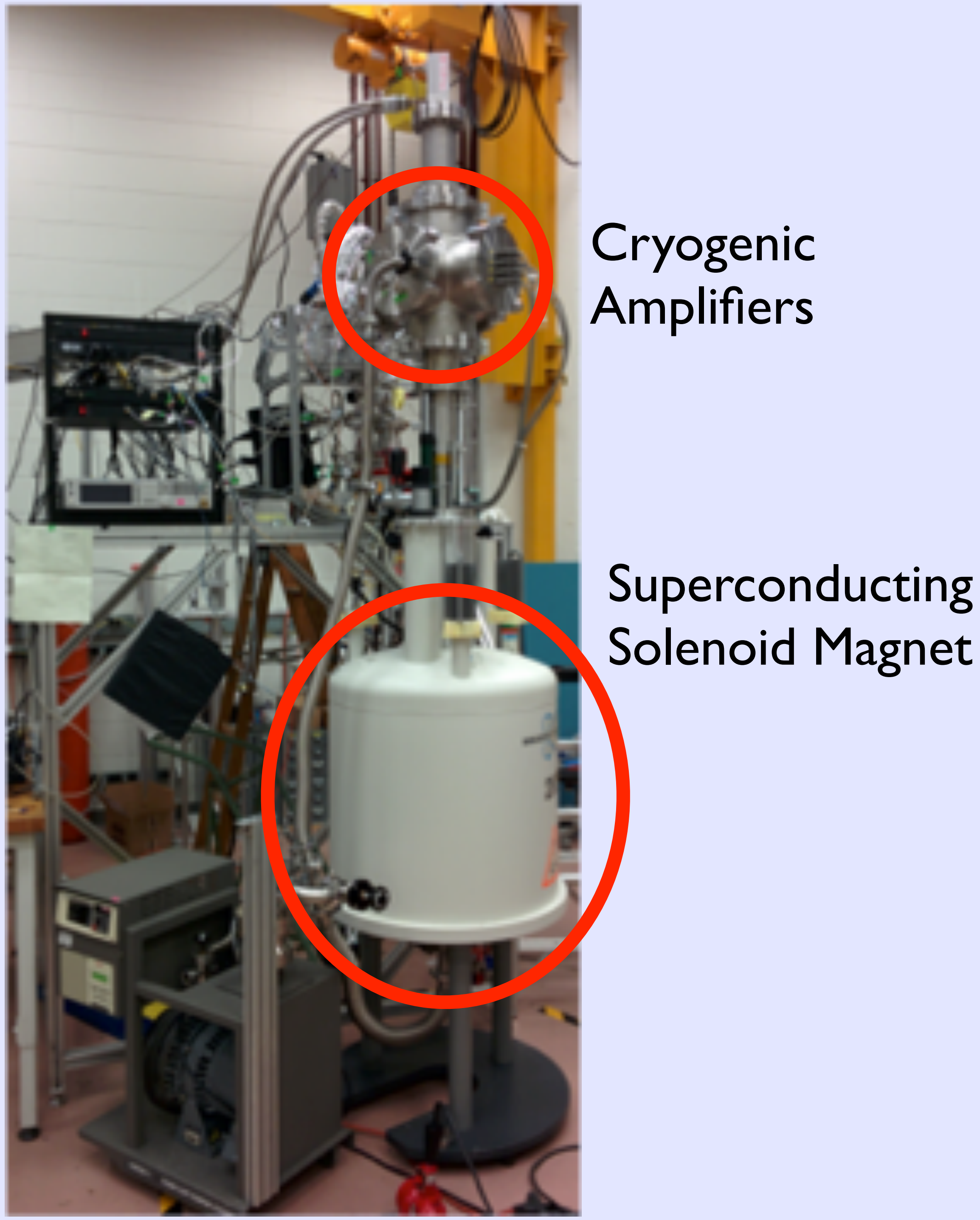
- Enclosed volume
- Fill with ^{83m}Kr gas
- Add a magnetic field



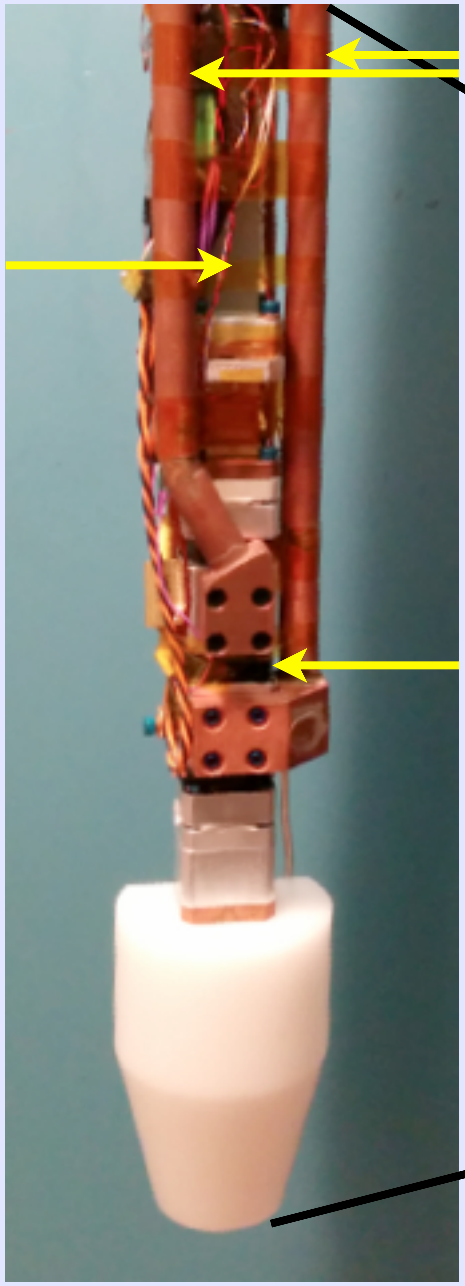
- Decay electrons spiral around field lines
- Waveguide & cryogenic amplifiers to detect the cyclotron radiation

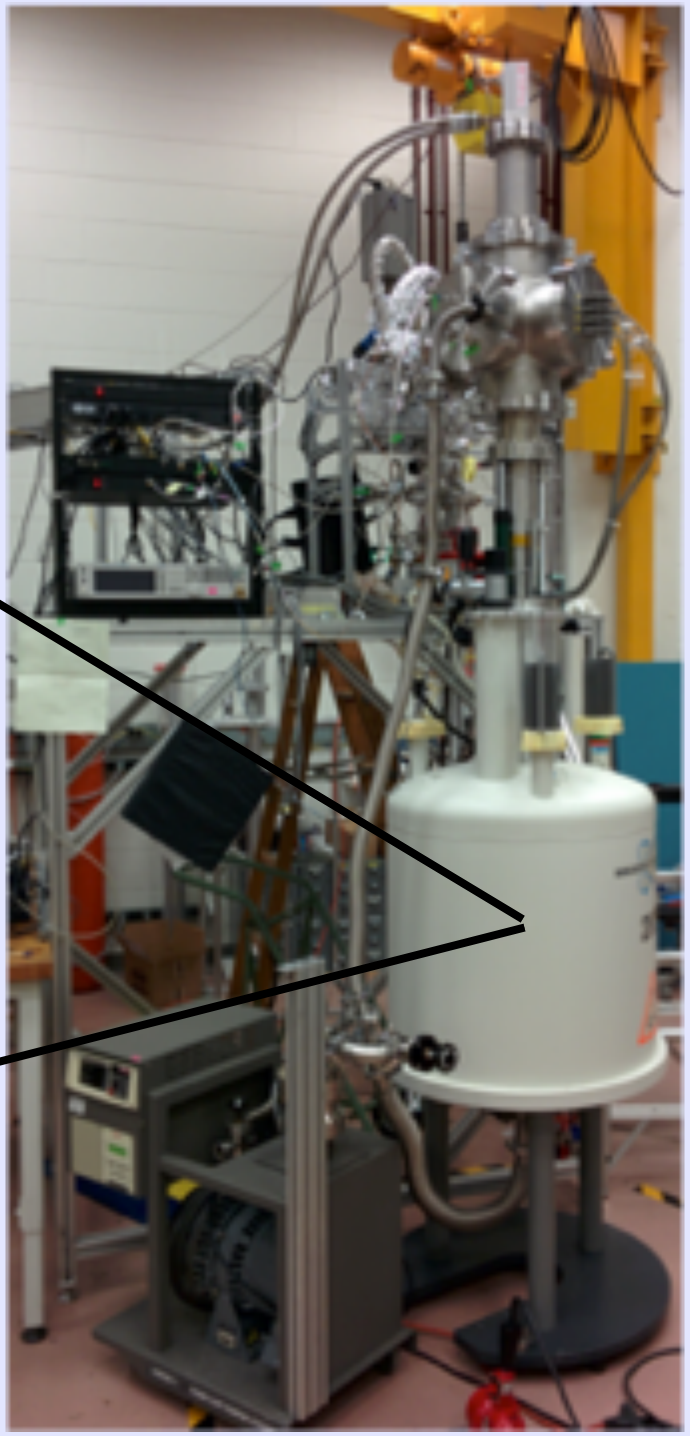
Project 8 Prototype



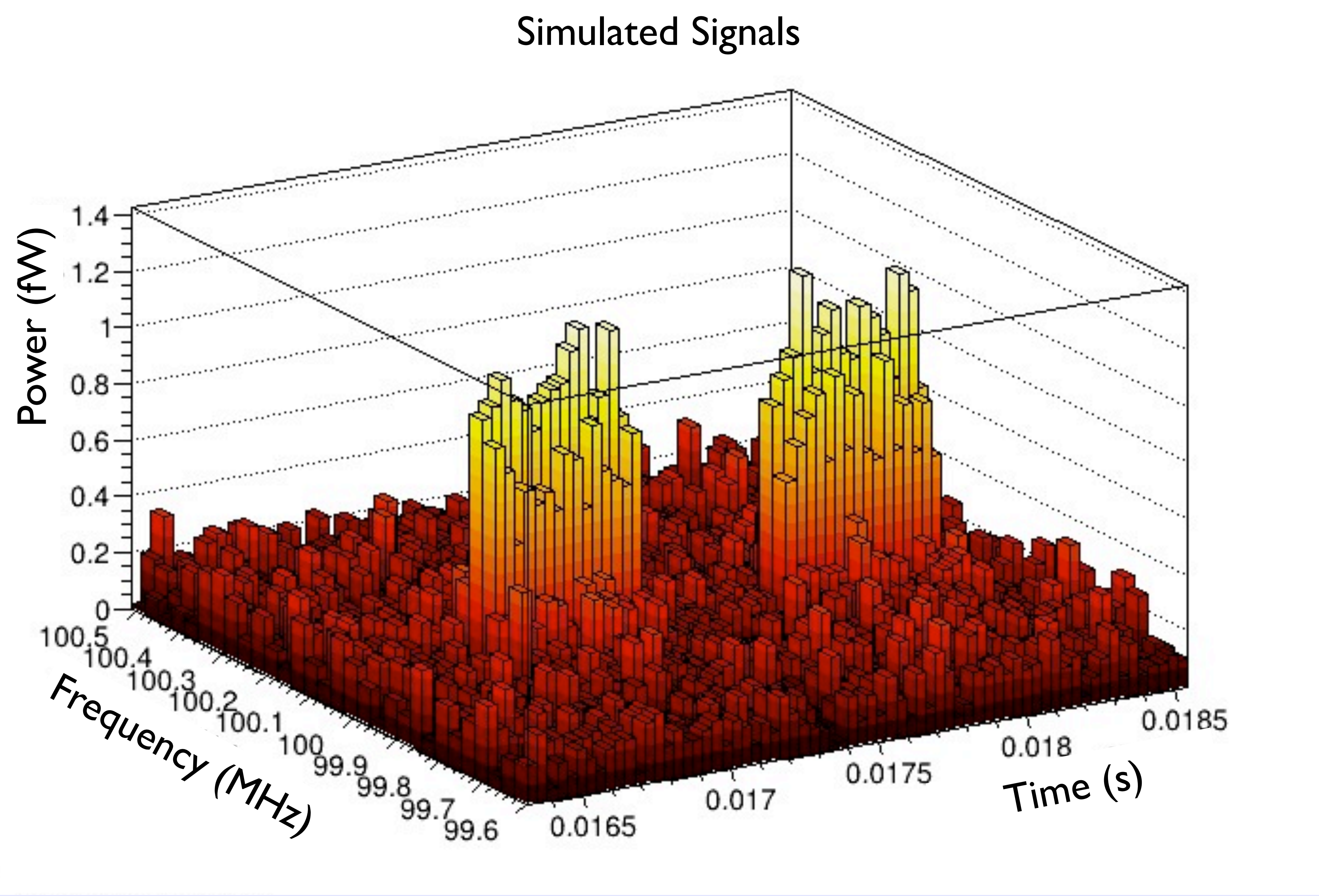


Prototype - Gas Cell



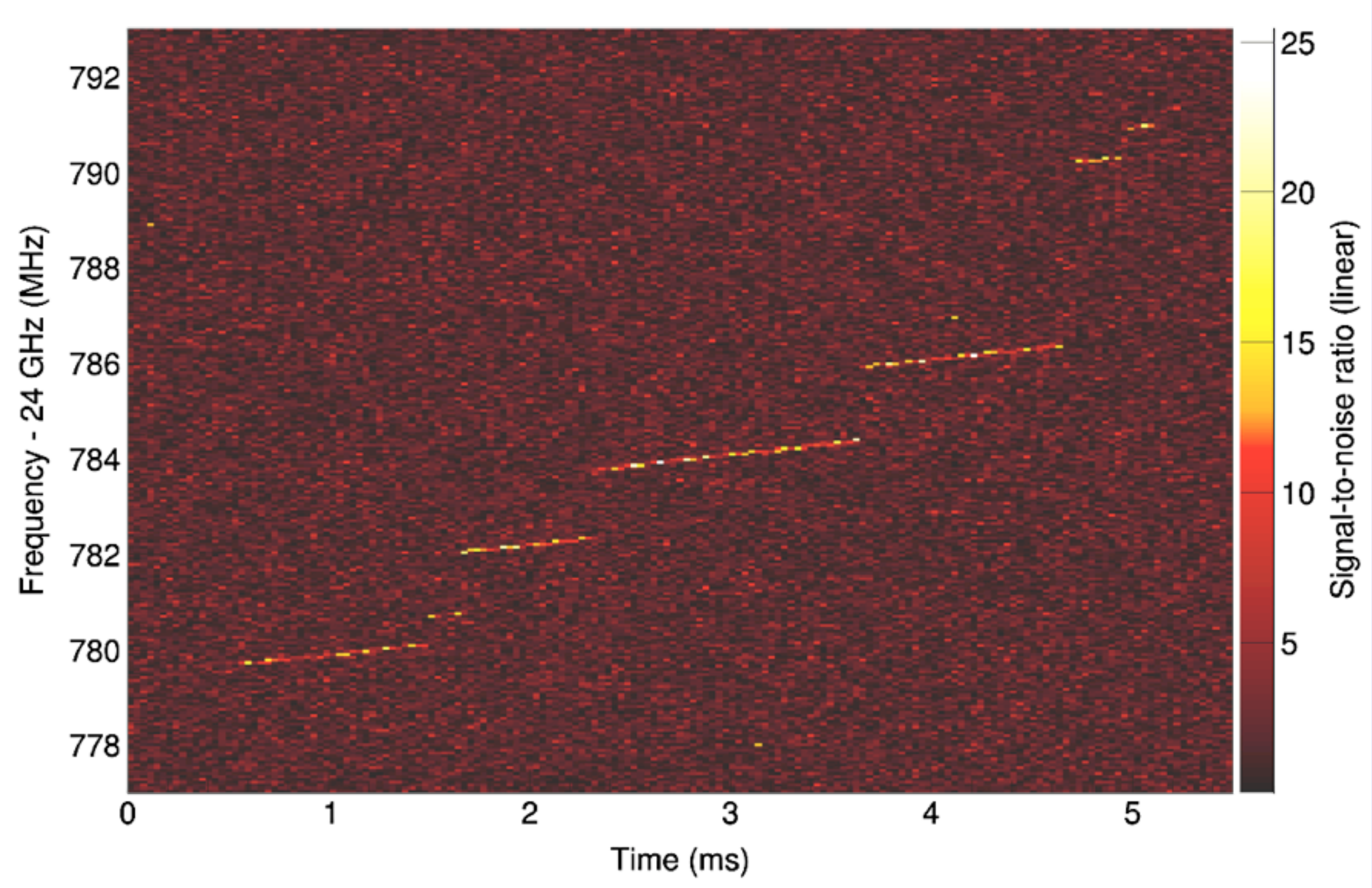


Frequency vs Time

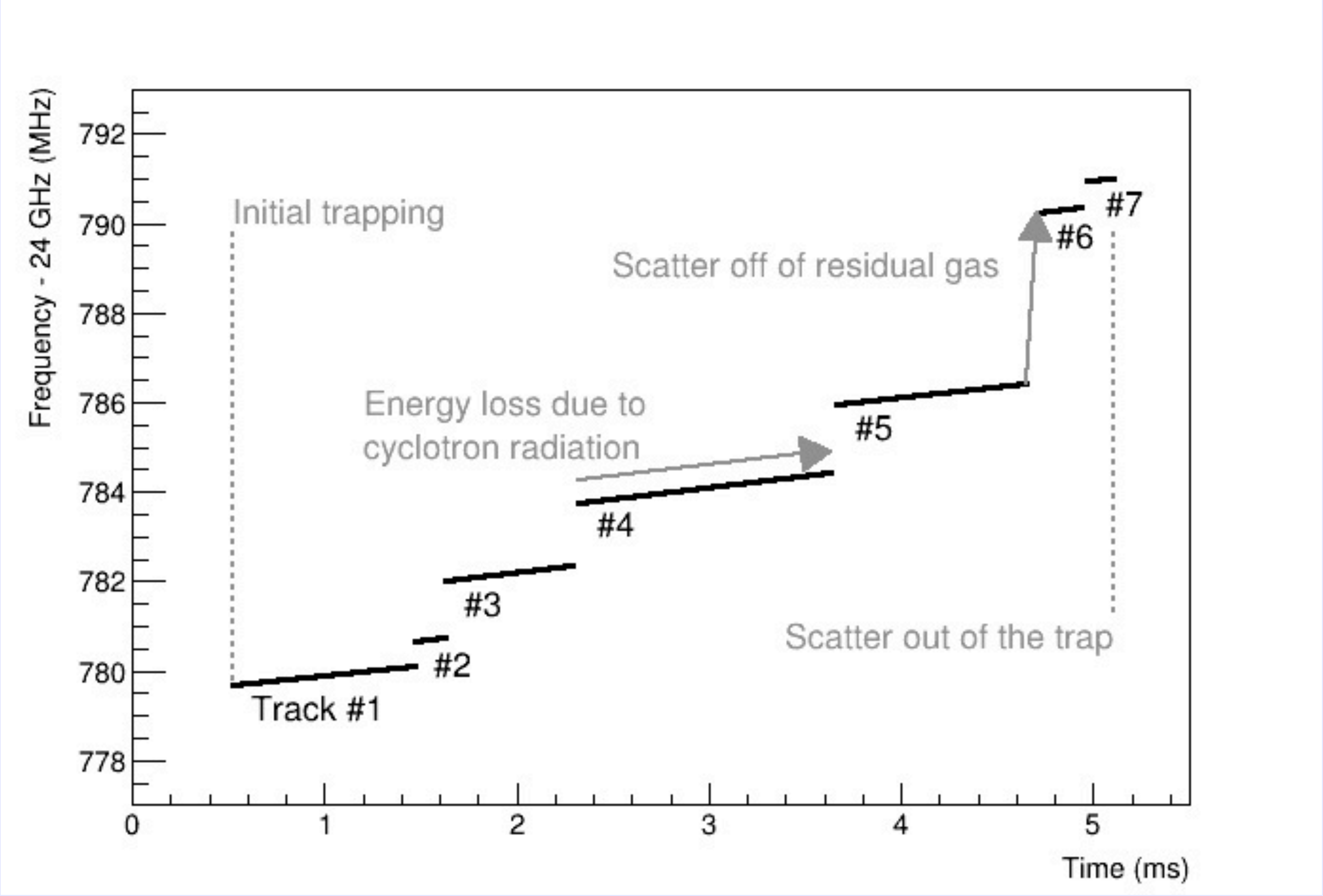


Event 0 - June 6, 2014

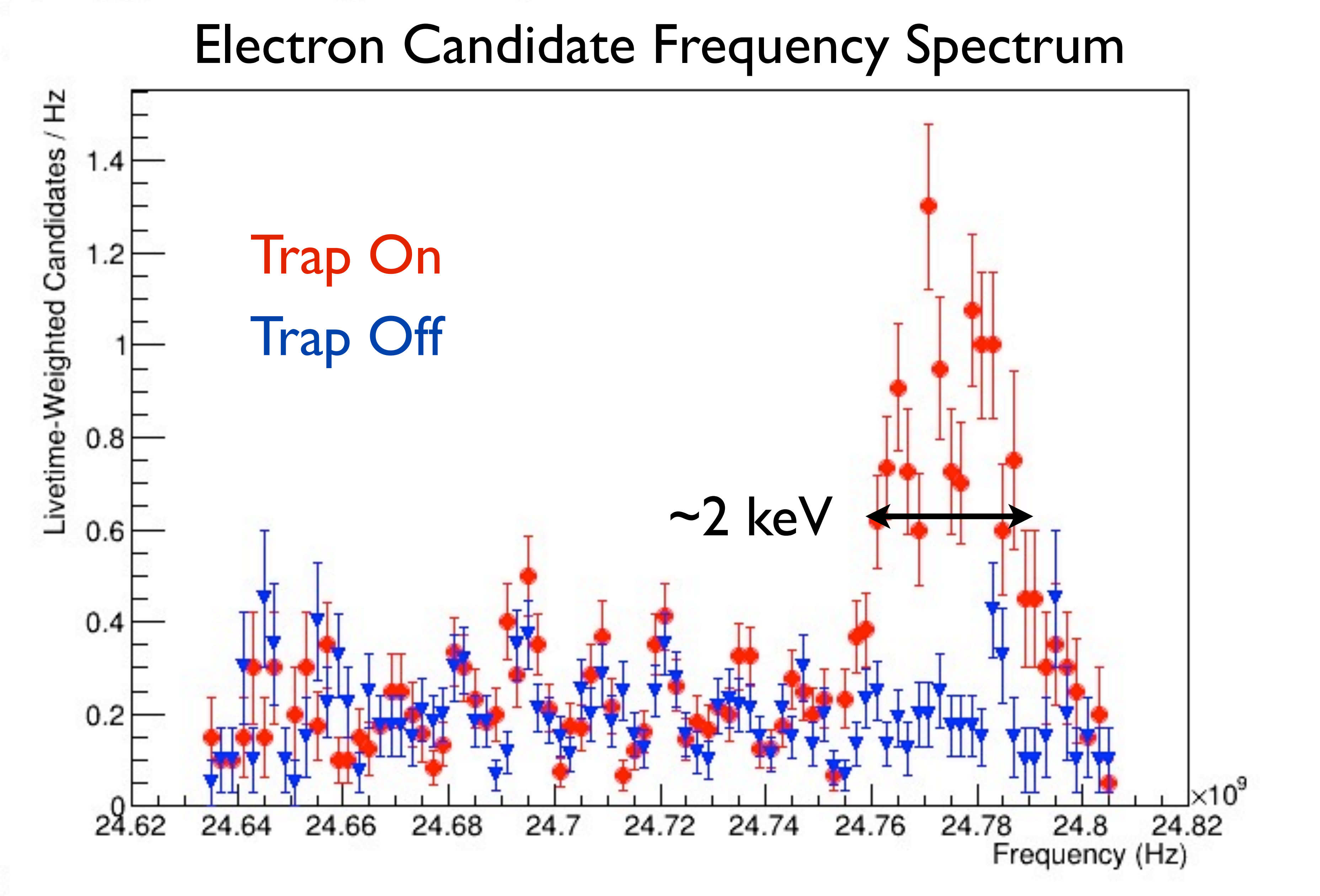
Project 8



Event 0 - Features

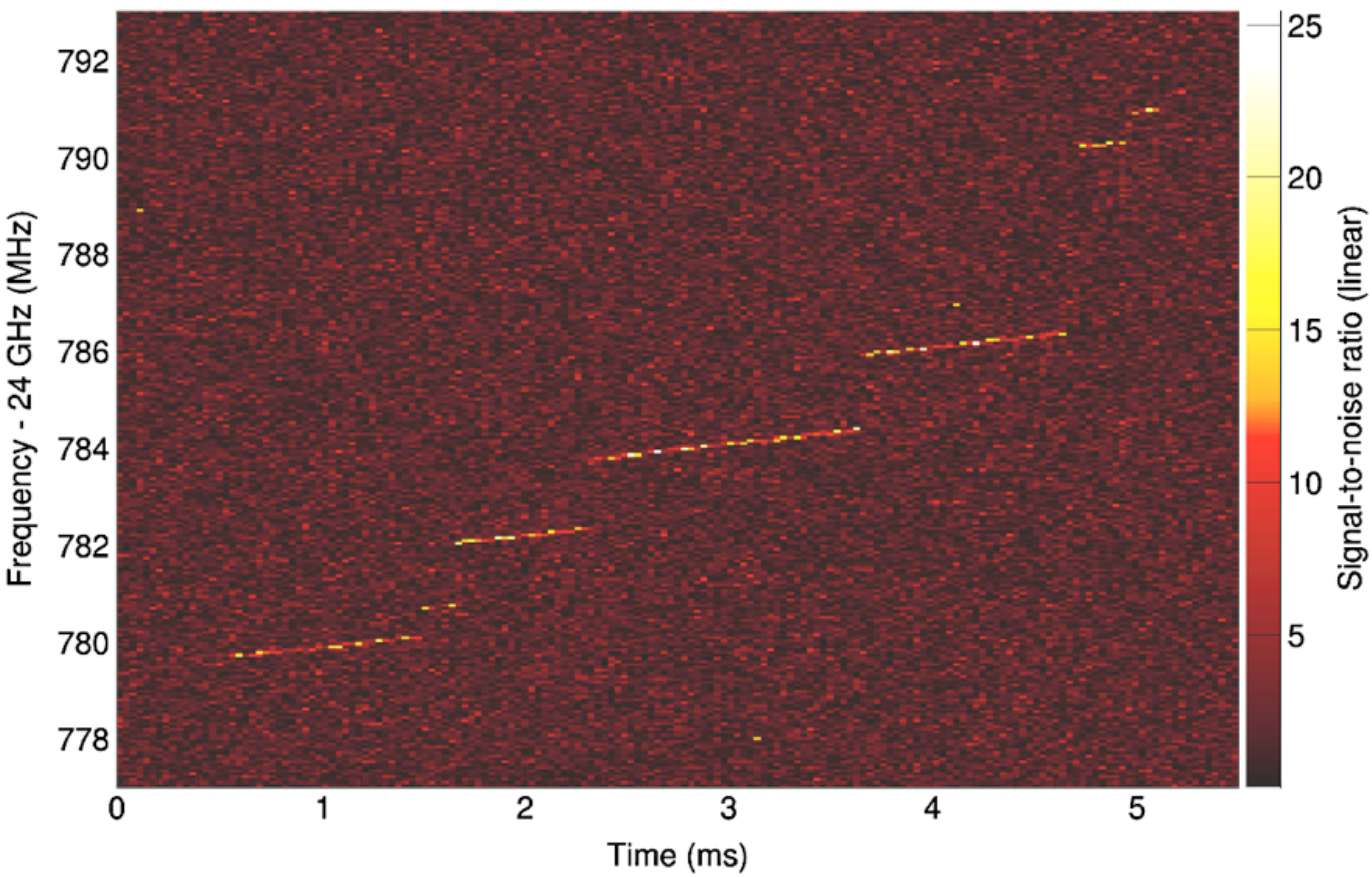


First Spectrum

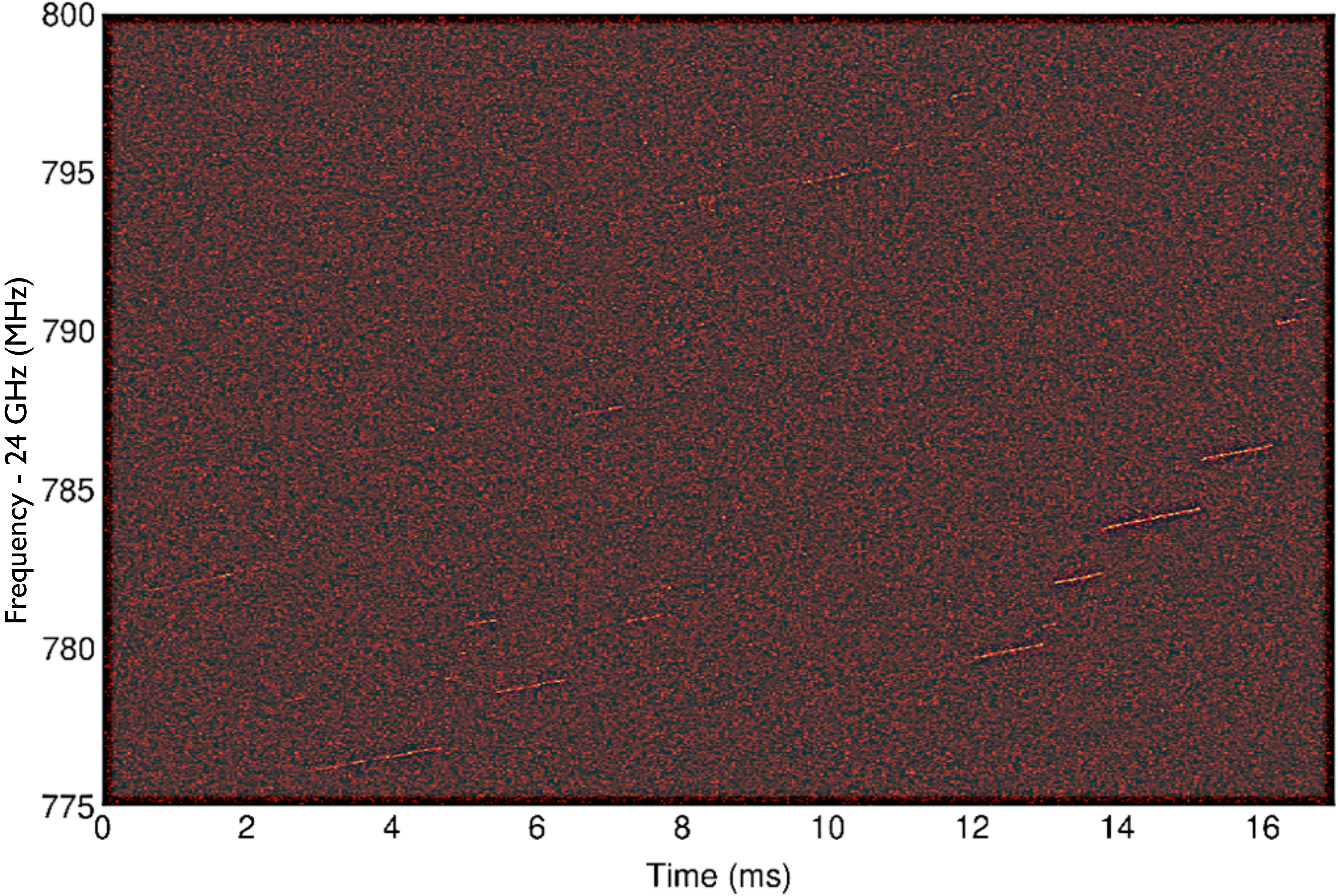


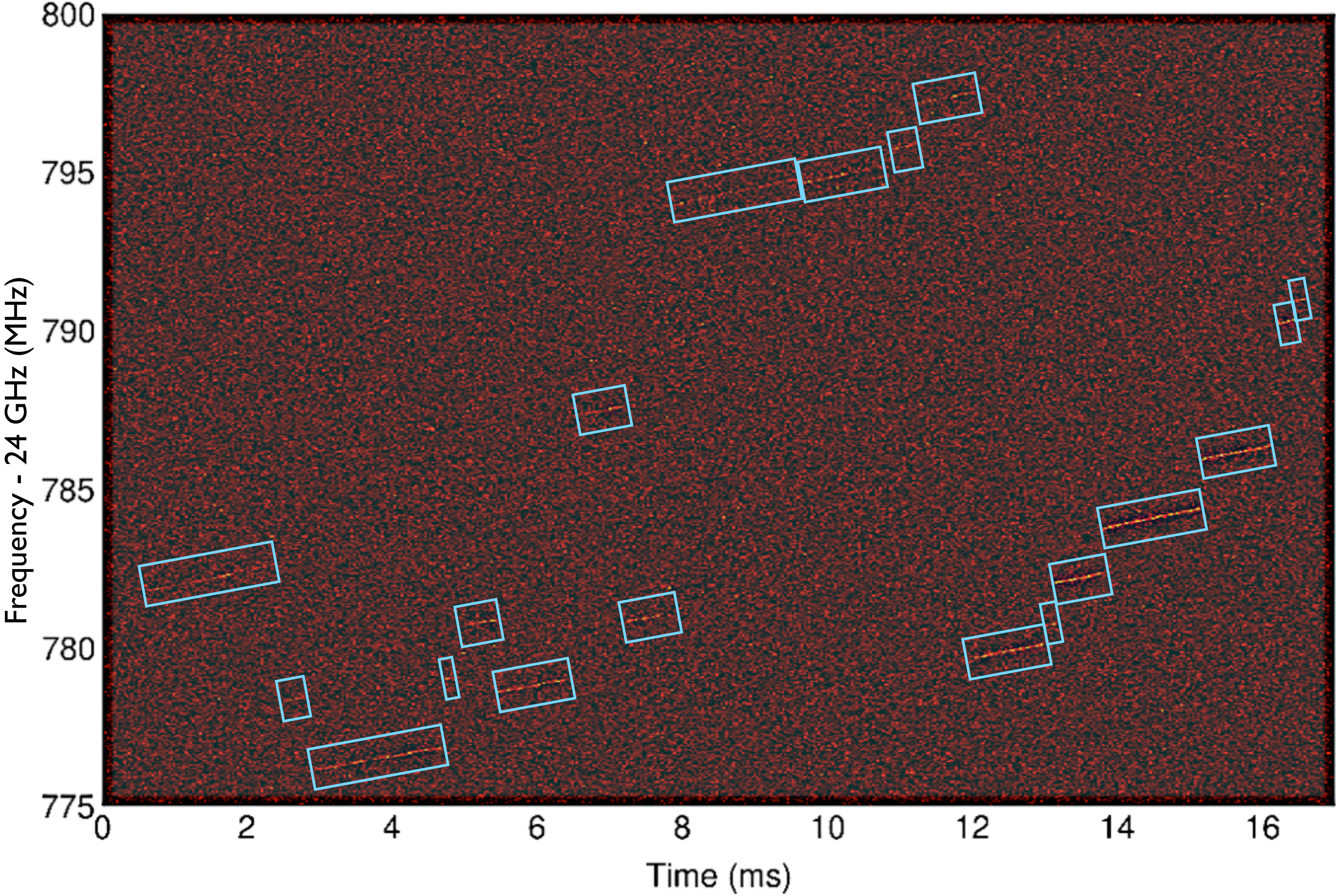
30 keV

Event 0



Frequency - 24 GHz (MHz)
792
790
788
786
784
782
780
778
0
1
2
3
4
5
Time (ms)
25
20
15
10
5
Signal-to-noise ratio (linear)


800
795
790
785
780
775
0
2
4
6
8
10
12
14
16
Frequency - 24 GHz (MHz)
Time (ms)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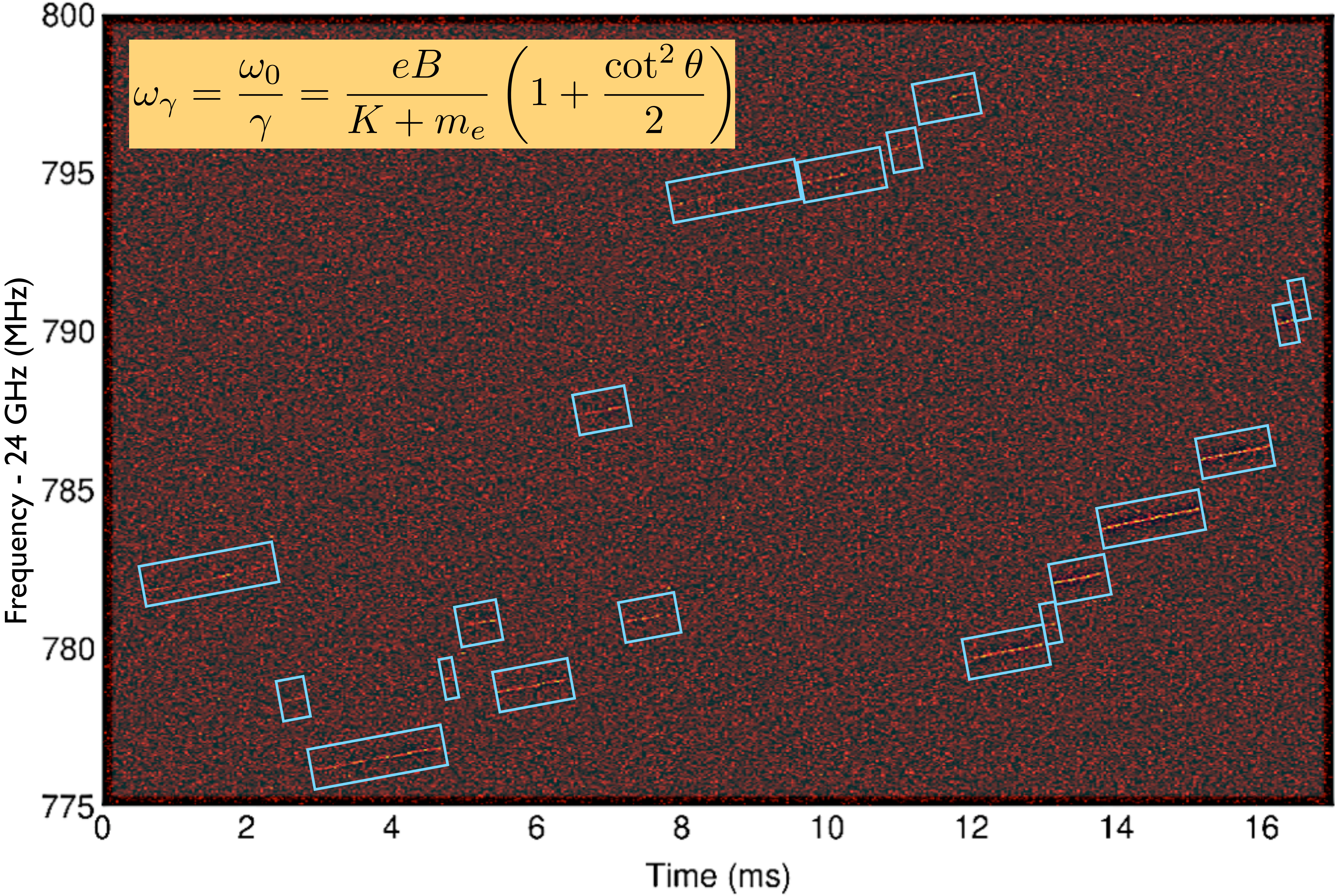

$$\omega_\gamma = \frac{\omega_0}{\gamma} = \frac{eB}{K + m_e}\left(1 + \frac{\cot^2\theta}{2}\right)$$
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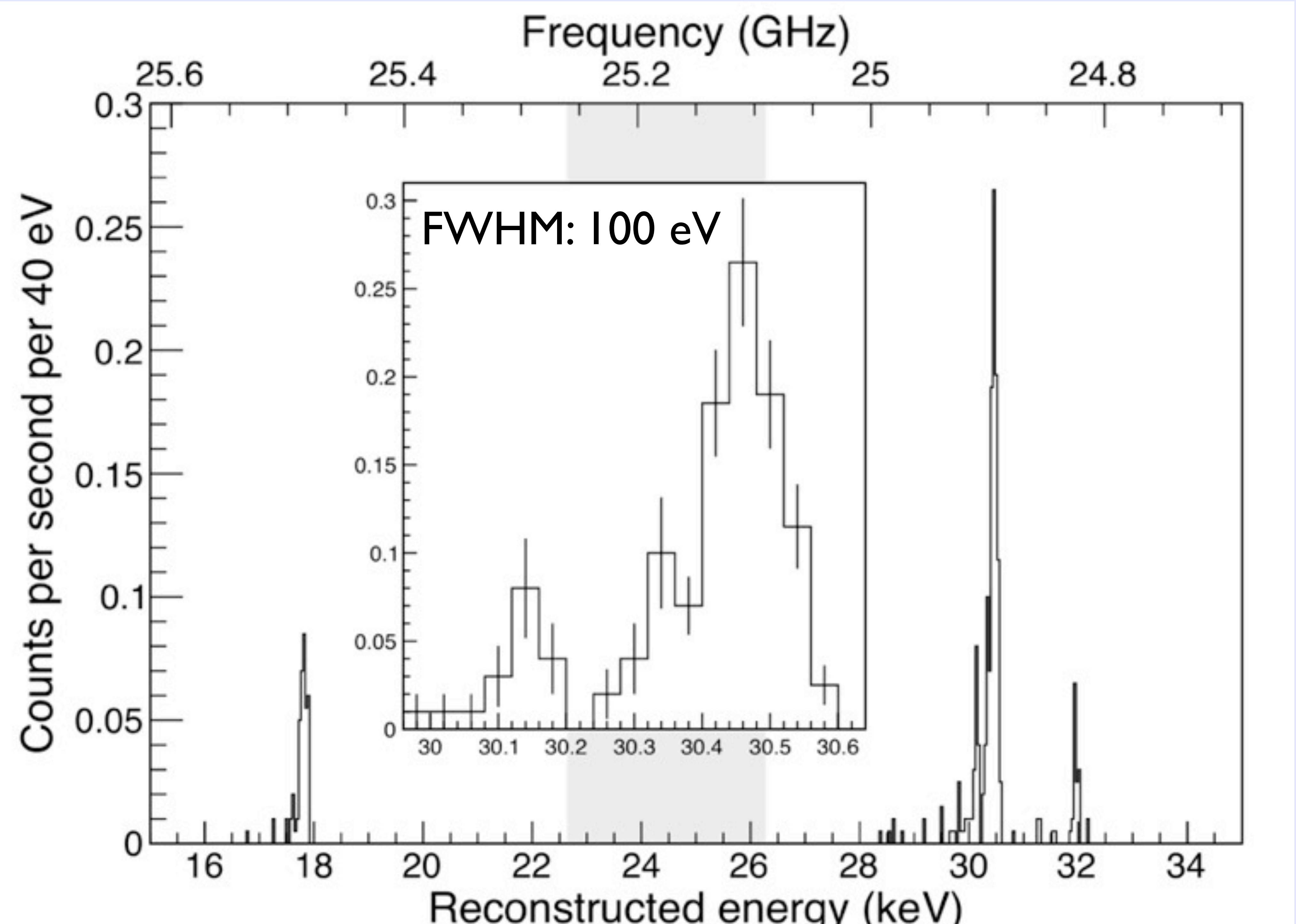
16
Frequency - 24 GHz (MHz)
Time (ms)

June 2014 Spectrum

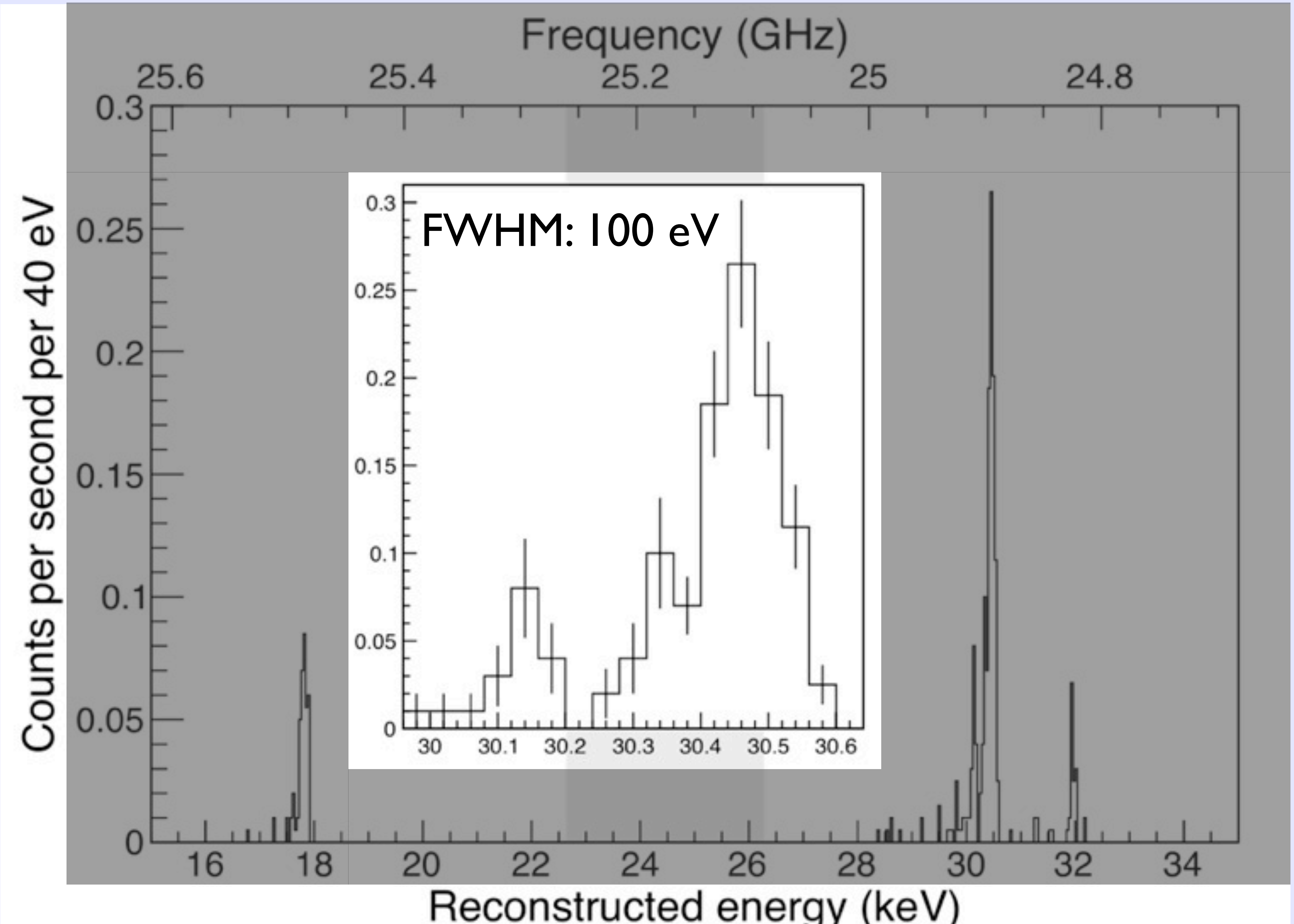
PROJECT 8

Harmonic Trap @ 800 mA



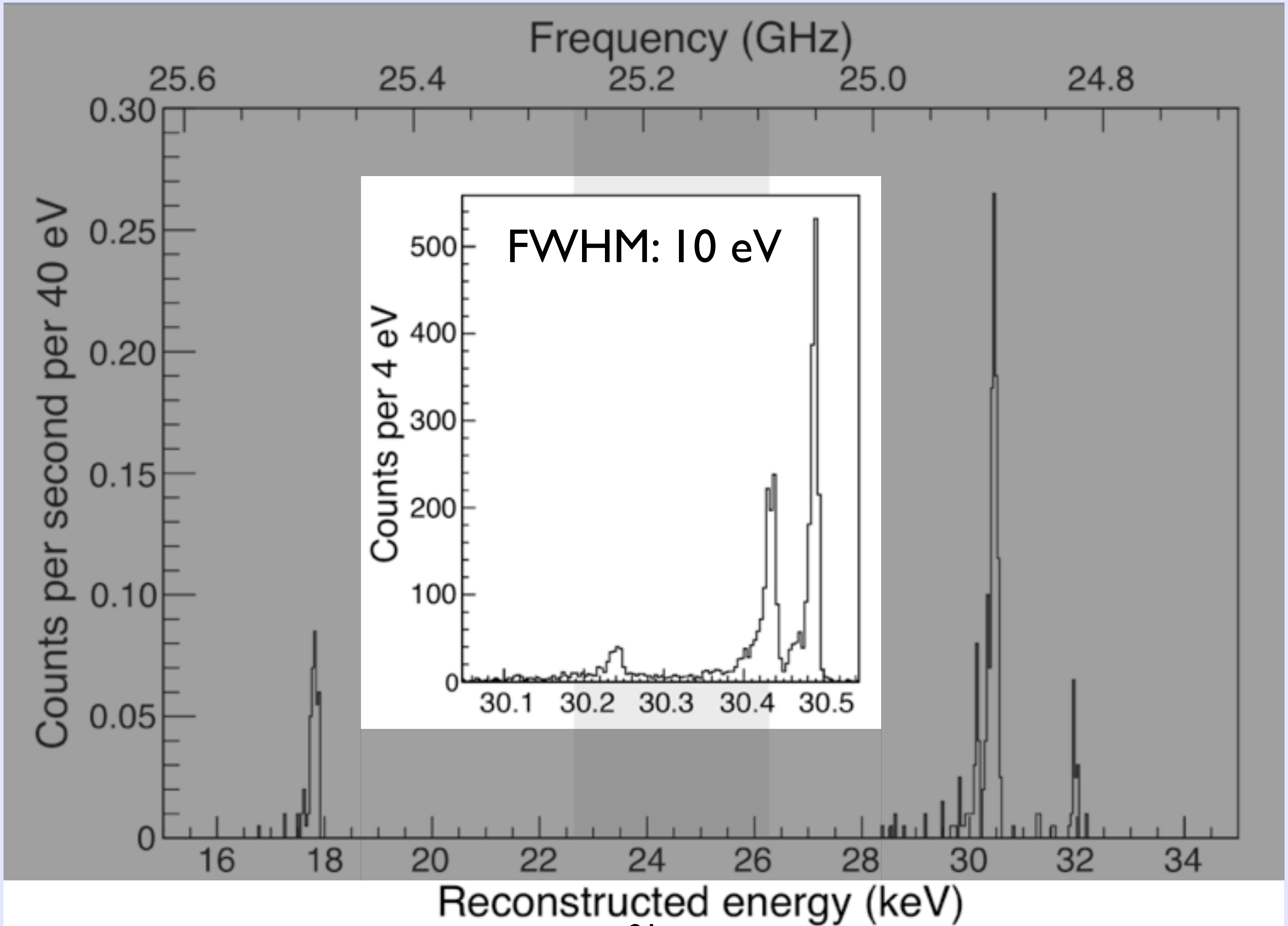
June 2014 Spectrum

Harmonic Trap @ 800 mA



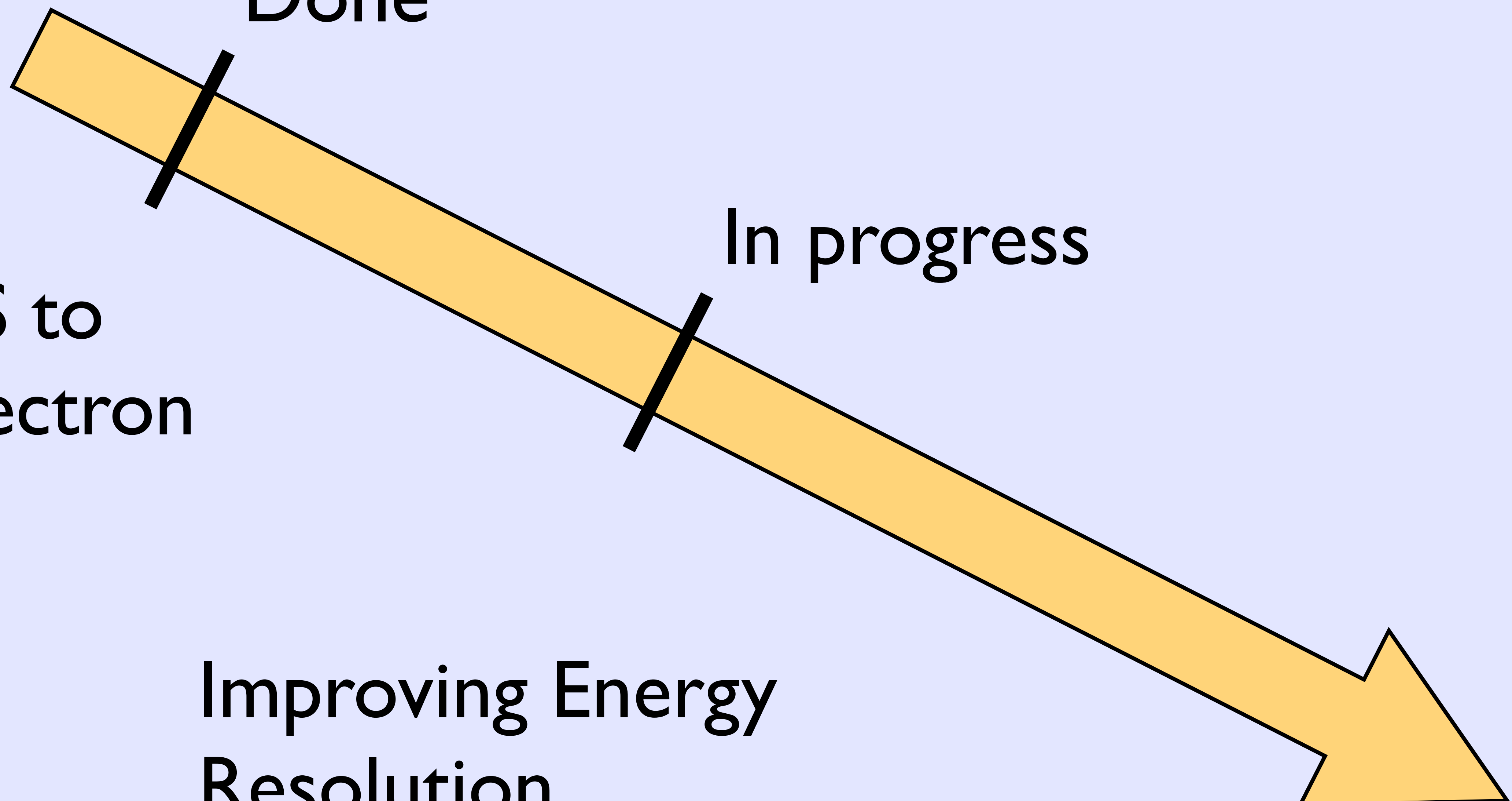
Sept. 2014 Spectrum

Harmonic Trap @ 400 mA



Moving Forward

PROJECT 8



Done

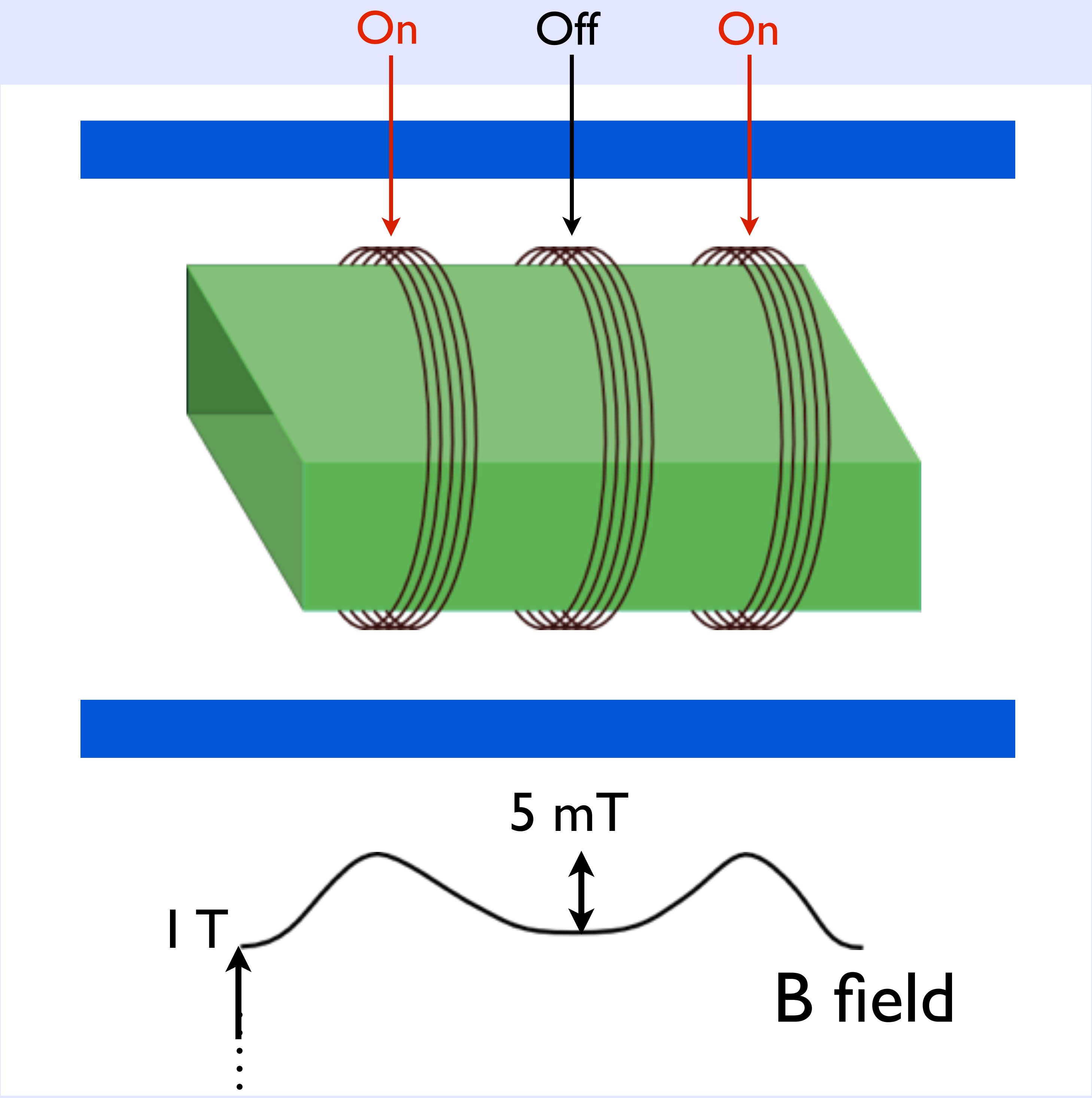
In progress

Using CRES to measure electron energies

Improving Energy Resolution

Measuring the tritium spectrum

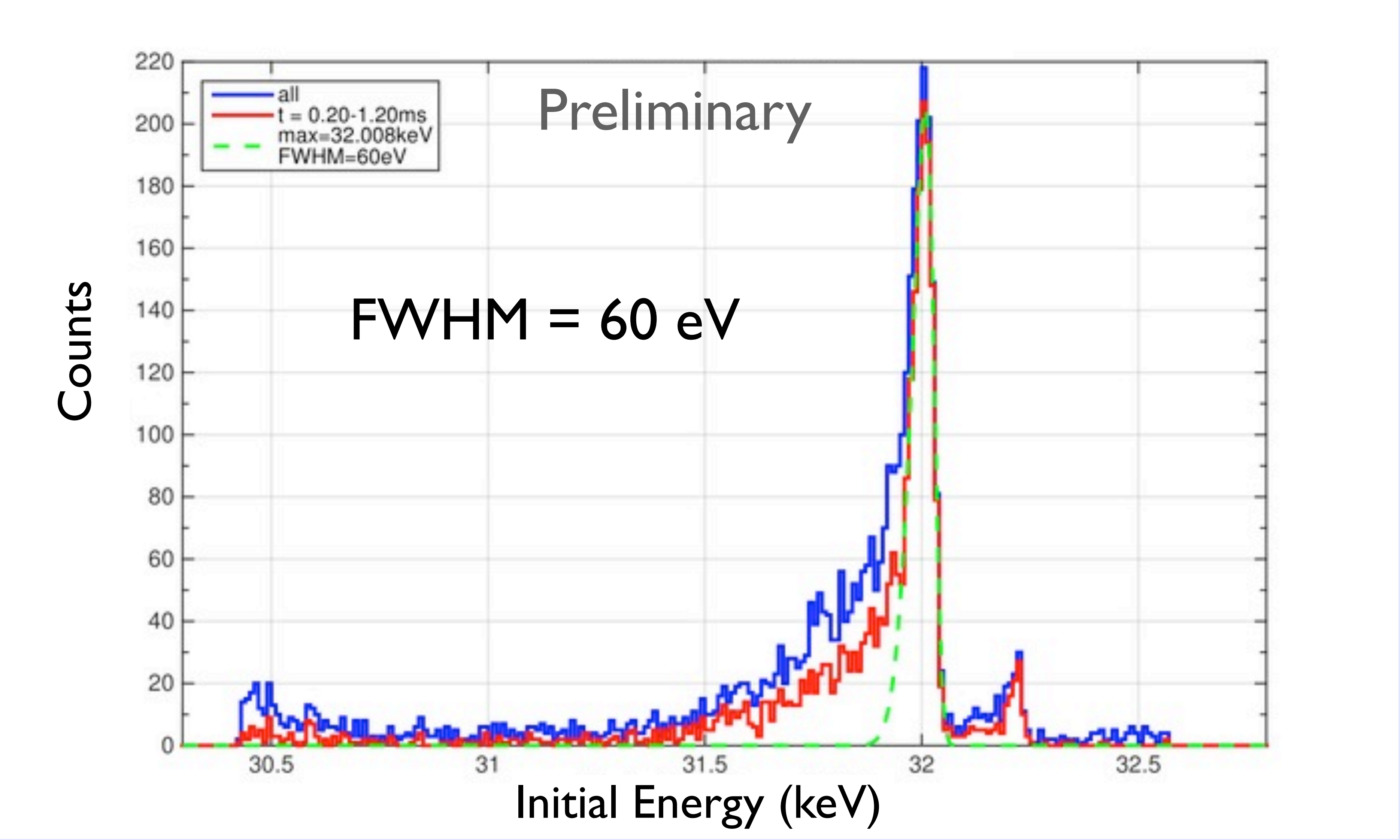
“Bathtub” Trap



- Improved field homogeneity
- Larger trapping volume

Half-Bathtub Trap

32 keV electrons -- ½ bathtub trap @ 1A



Compare to FWHM ≈ 140 eV for a 1A harmonic trap

Disentangling Energy and θ

PROJECT 8

$$\omega_\gamma = \frac{\omega_0}{\gamma} = \frac{eB}{K + m_e}\left(1 + \frac{\cot^2\theta}{2}\right)$$

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Use the axial frequency: modulation of the cyclotron radiation signal

$$\omega_a \propto v\left(\frac{a}{\sin\theta} + \frac{4\sin\theta}{m\cos^2\theta}\right)^{-1}$$

For an approximation of a bathtub trap

Disentangling Energy and θ

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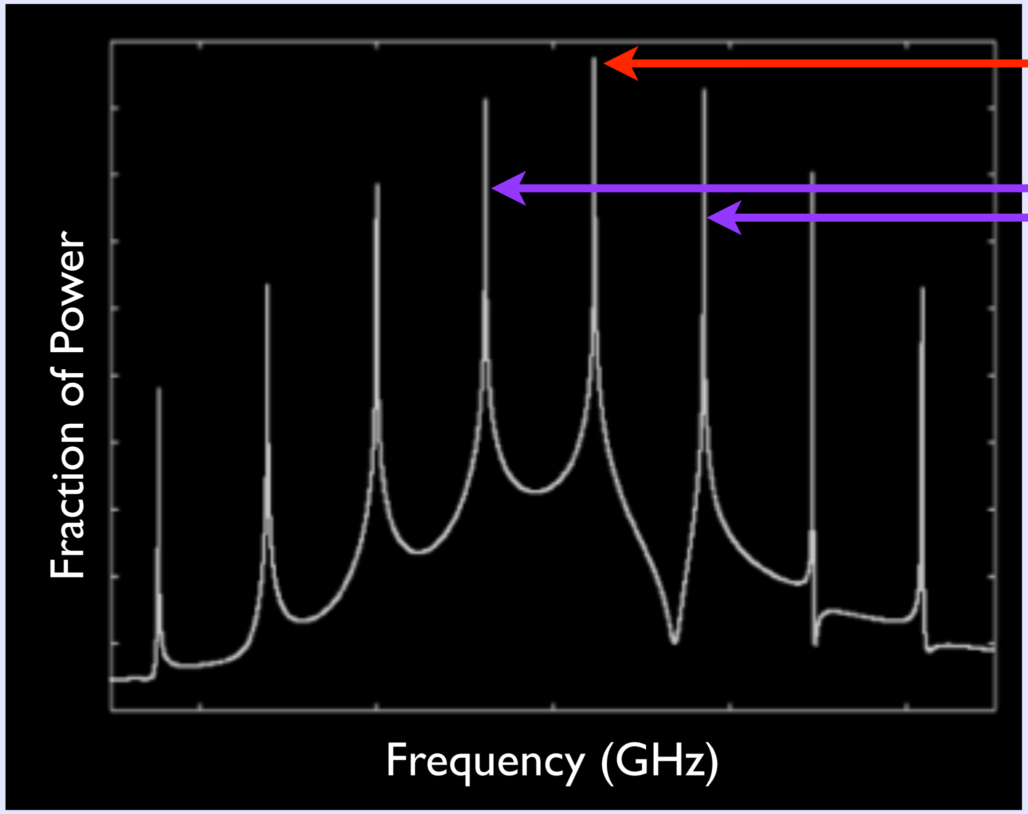
For an approximation of a bathtub trap

Expected frequencies: 50-200 MHz

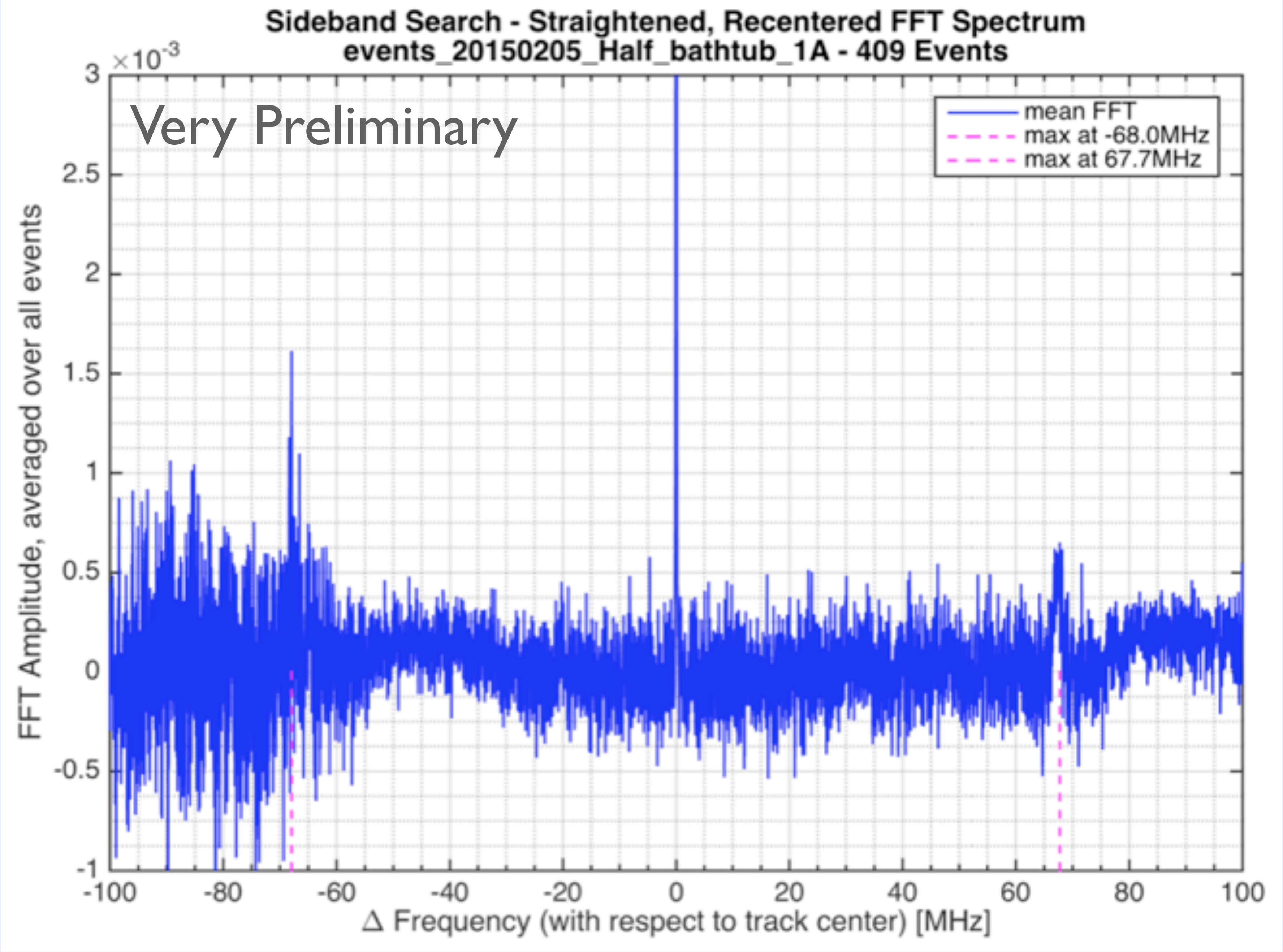


Main Peak

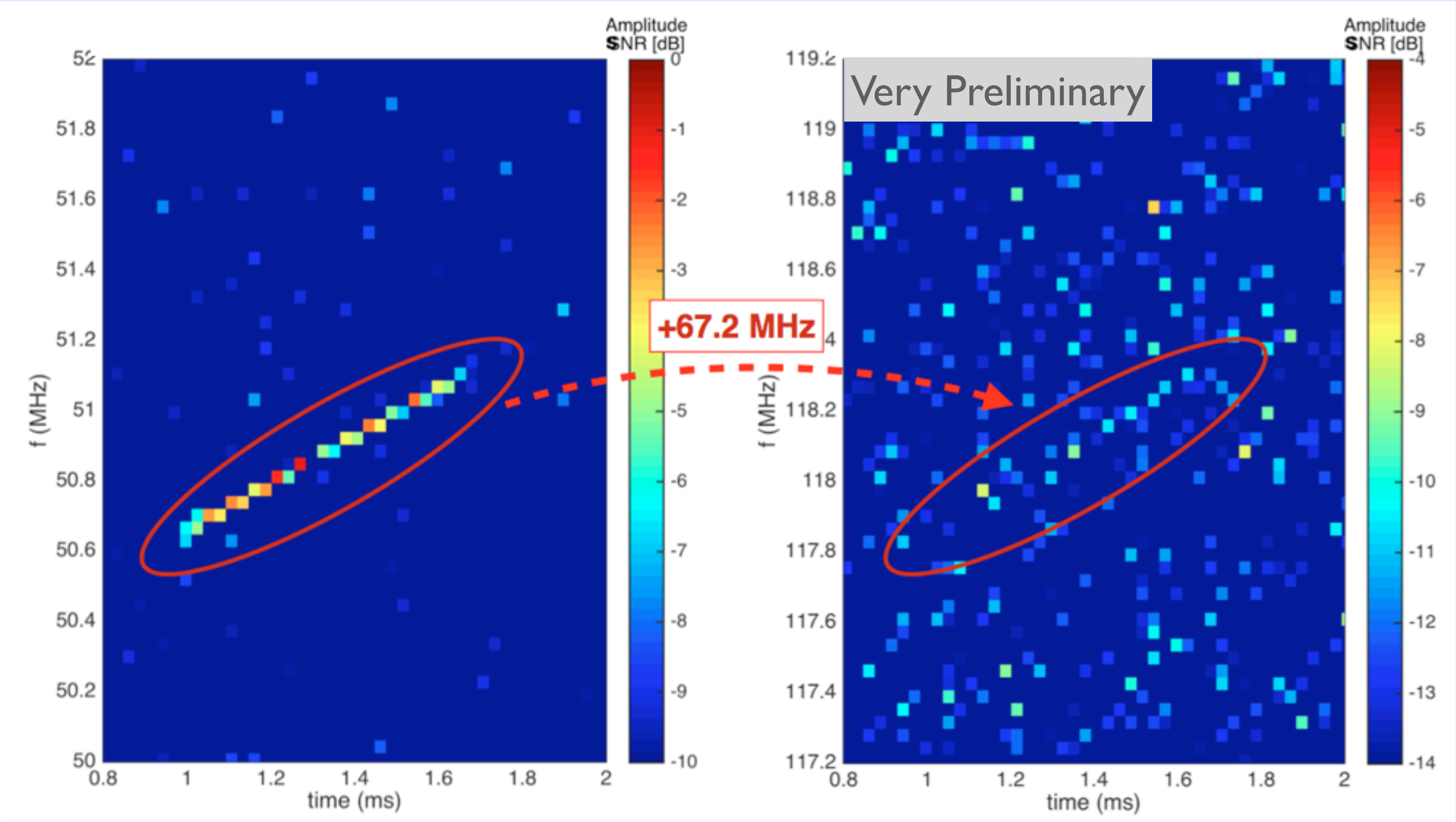
First Sidebands

Sidebands Found!

Rotate spectrogram, and average along track



Sideband Spectrogram

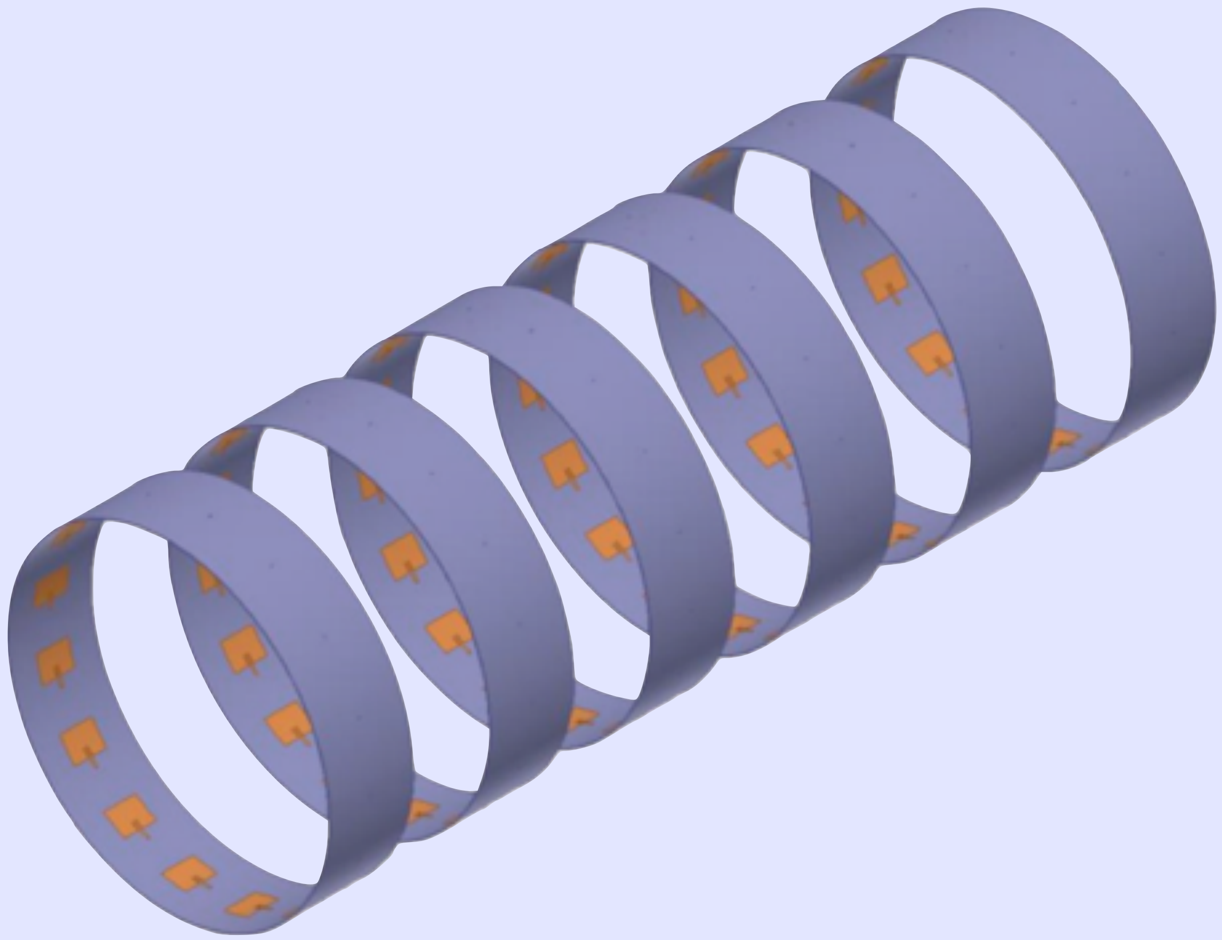


Using Tritium

PROJECT 8

1. Sealed waveguide cell
   - Avoid contamination
   - Late 2015?

2. Larger source
   - Improved endpoint statistics
   - Up to the 2-inch bore diameter
   - Phased patch-antenna array



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Project 8 Collaboration

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