The Project 8 Neutrino Mass Experiment

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Outline

- Introduction to Project 8
- Completed demonstrator experiment
- Current areas of R&D
- Future prospects

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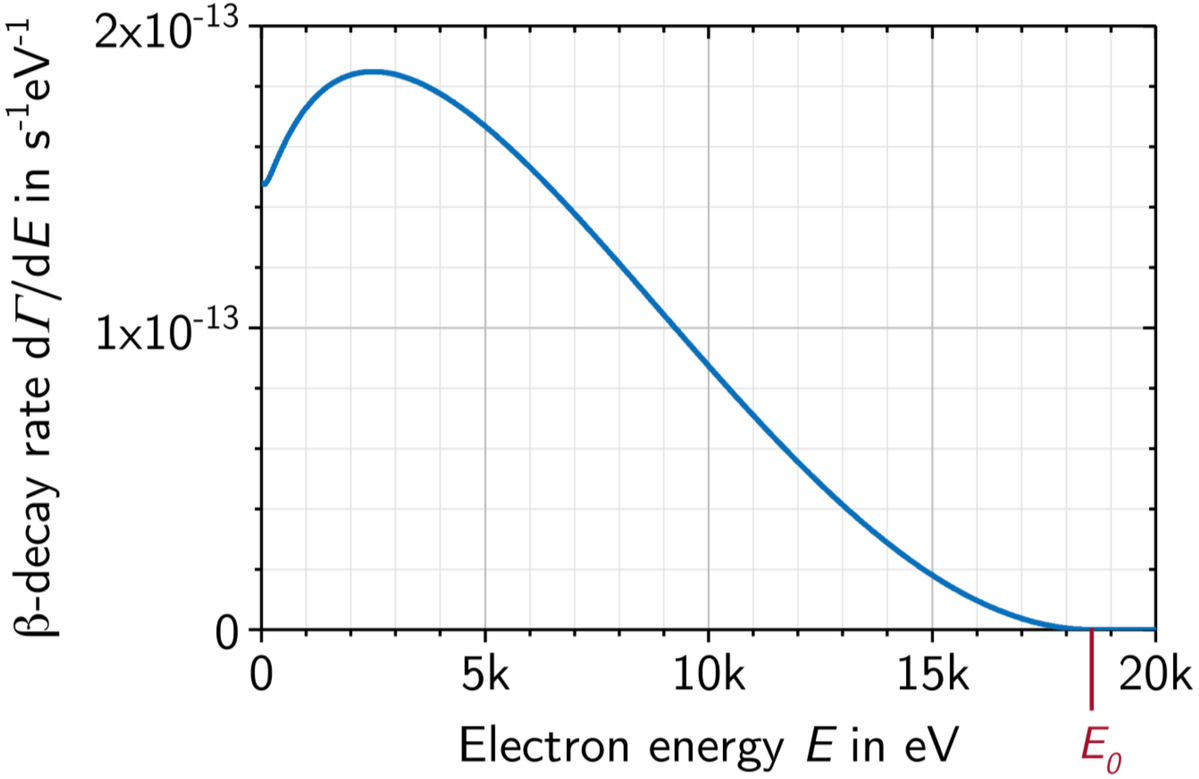
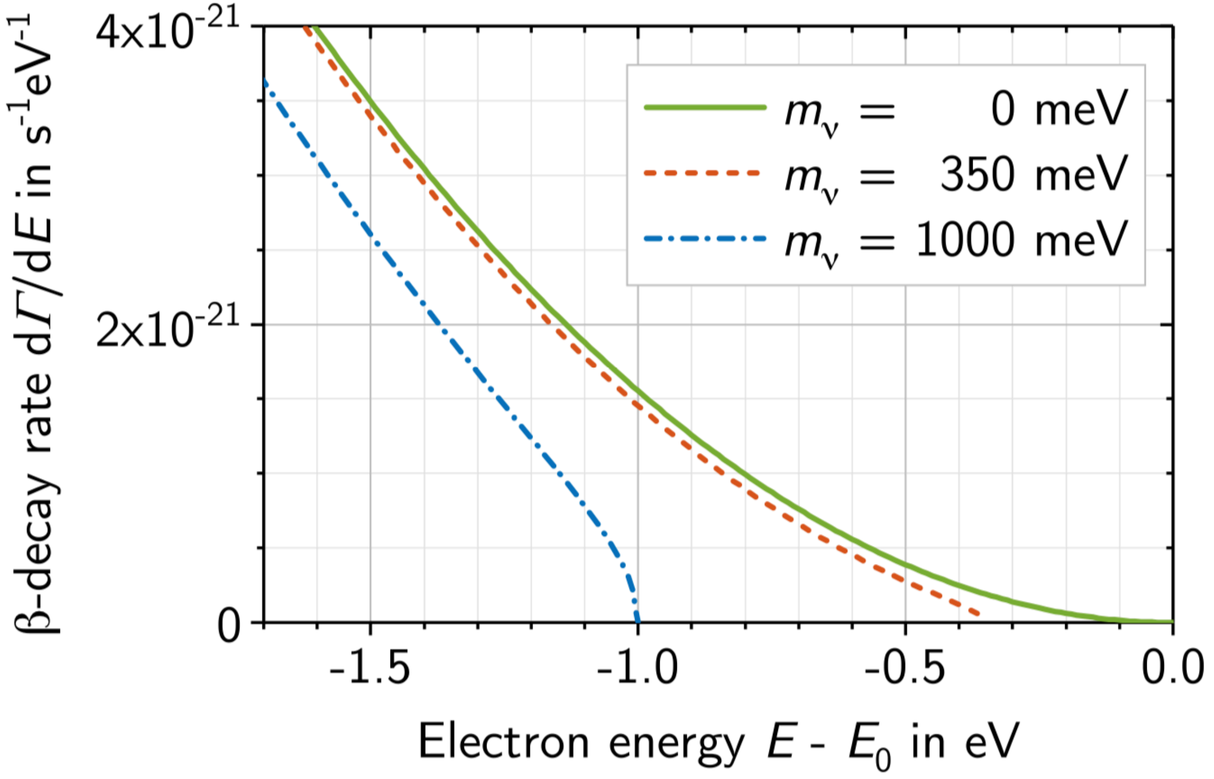
Neutrino mass

Measuring the endpoint of the tritium beta decay spectrum constrains neutrino mass

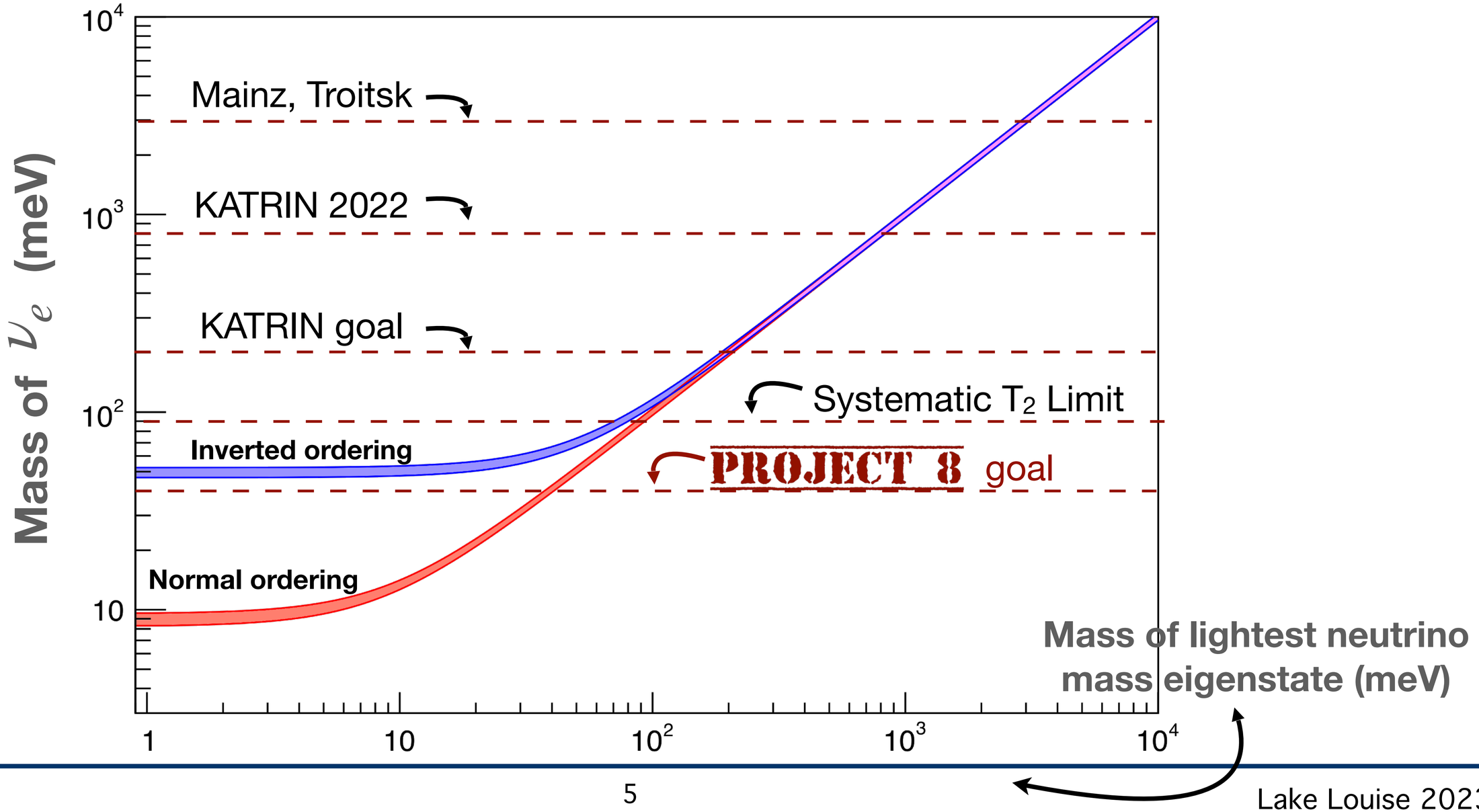
$$\mathrm{T} \longrightarrow {}^{3}\mathrm{He}^{+} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}}$$





KATRIN Experiment, *Eur.Phys.J.C* 79 (2019) 3, 204

Neutrino Mass Sensitivity Goals



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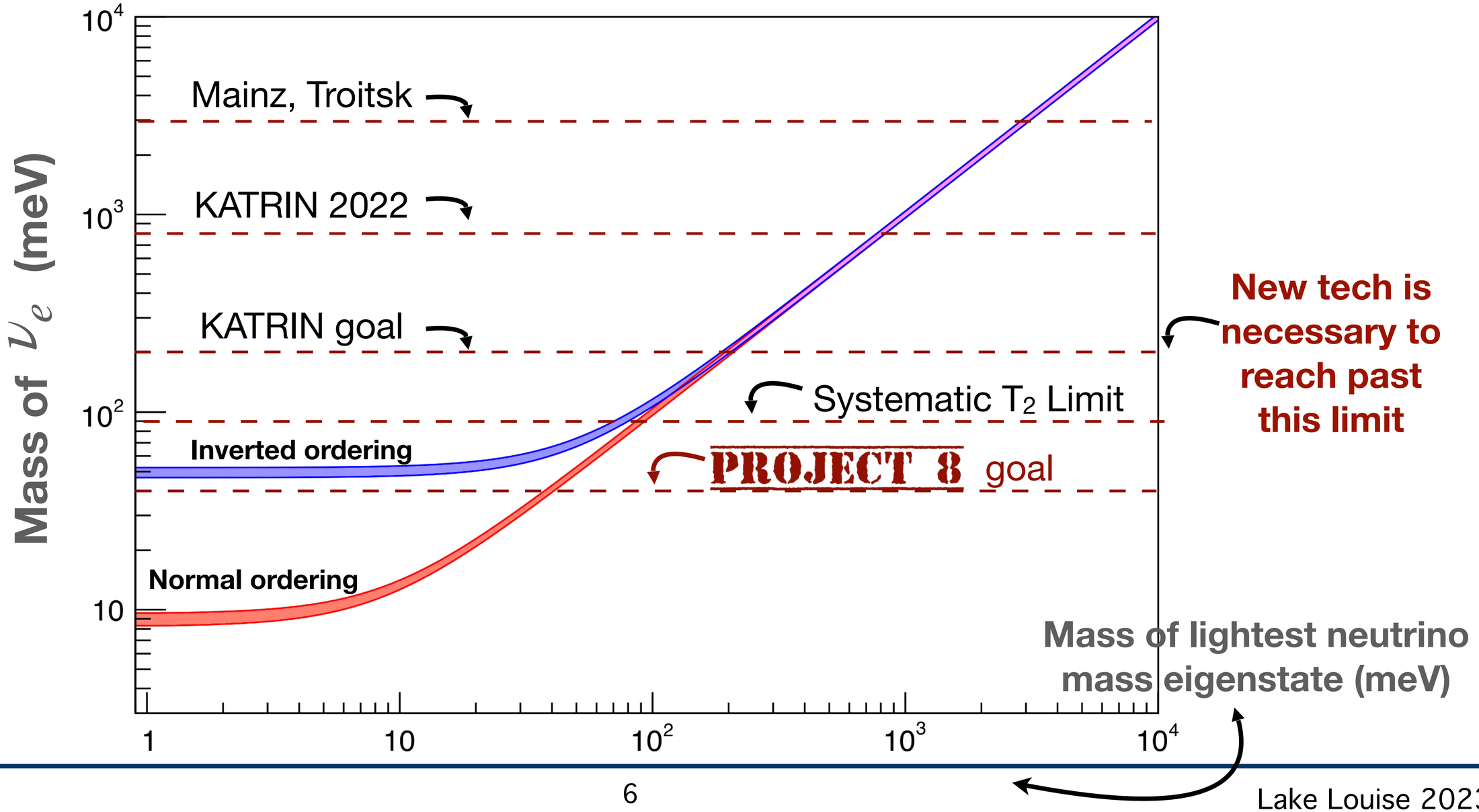
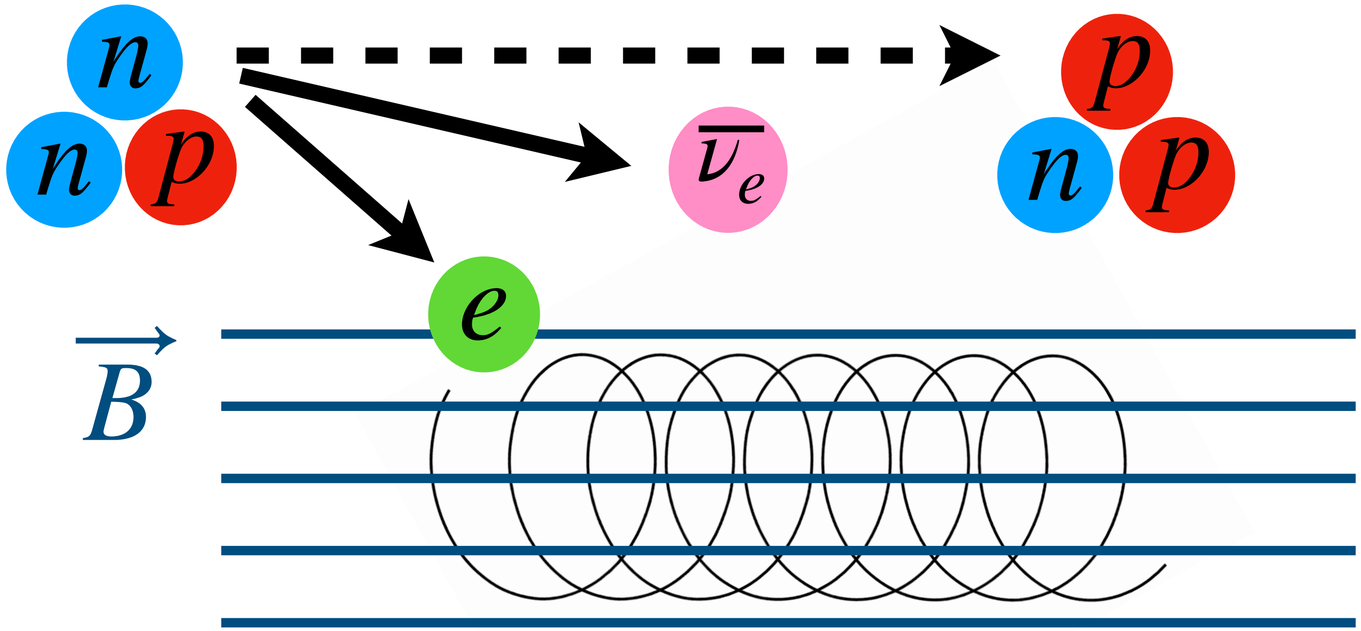


Project 8 Spectroscopy Technique

- Cyclotron Radiation Emission Spectroscopy (CRES)
- Measure cyclotron frequency -> get electron energy
- RF detector is co-located with the tritium source

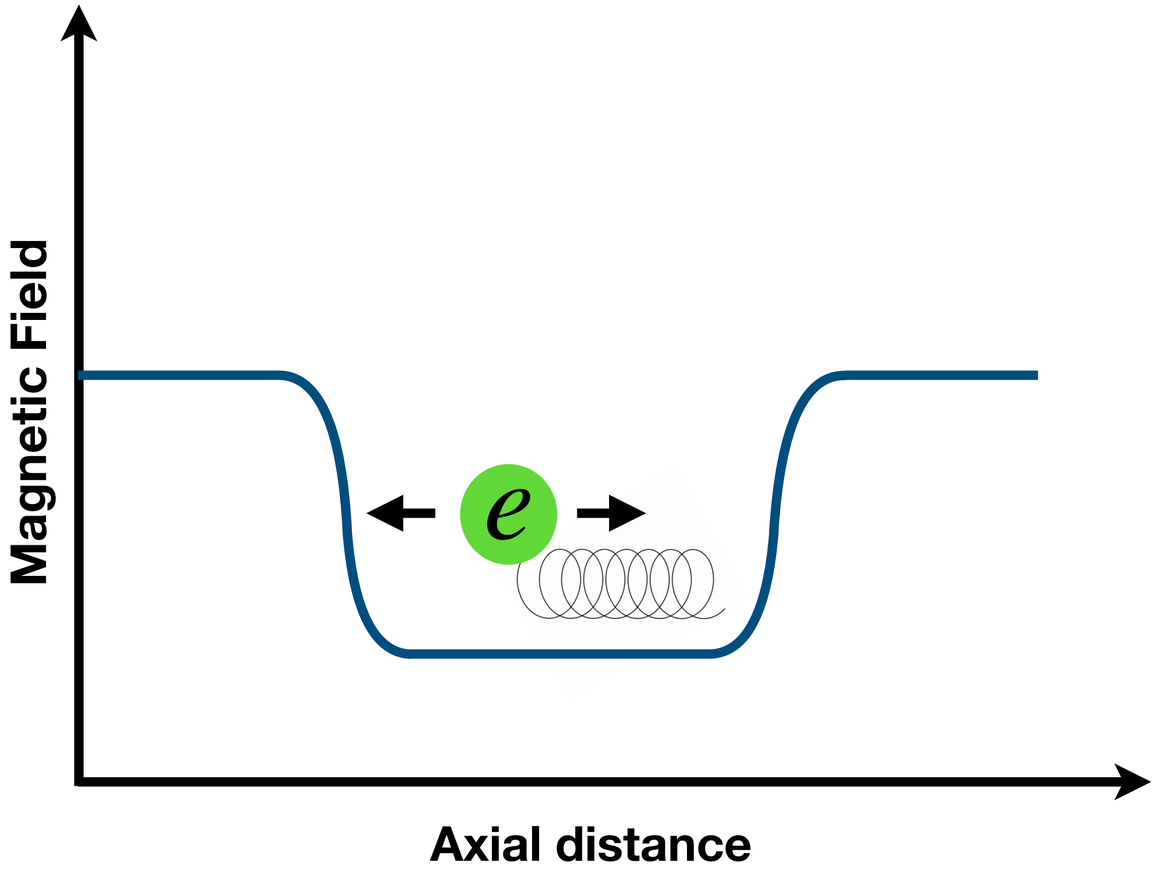


$$f = \frac{f_0}{\gamma} = \frac{1}{2\pi} \frac{eB}{m_e + E_{\text{kin}}/c^2}$$

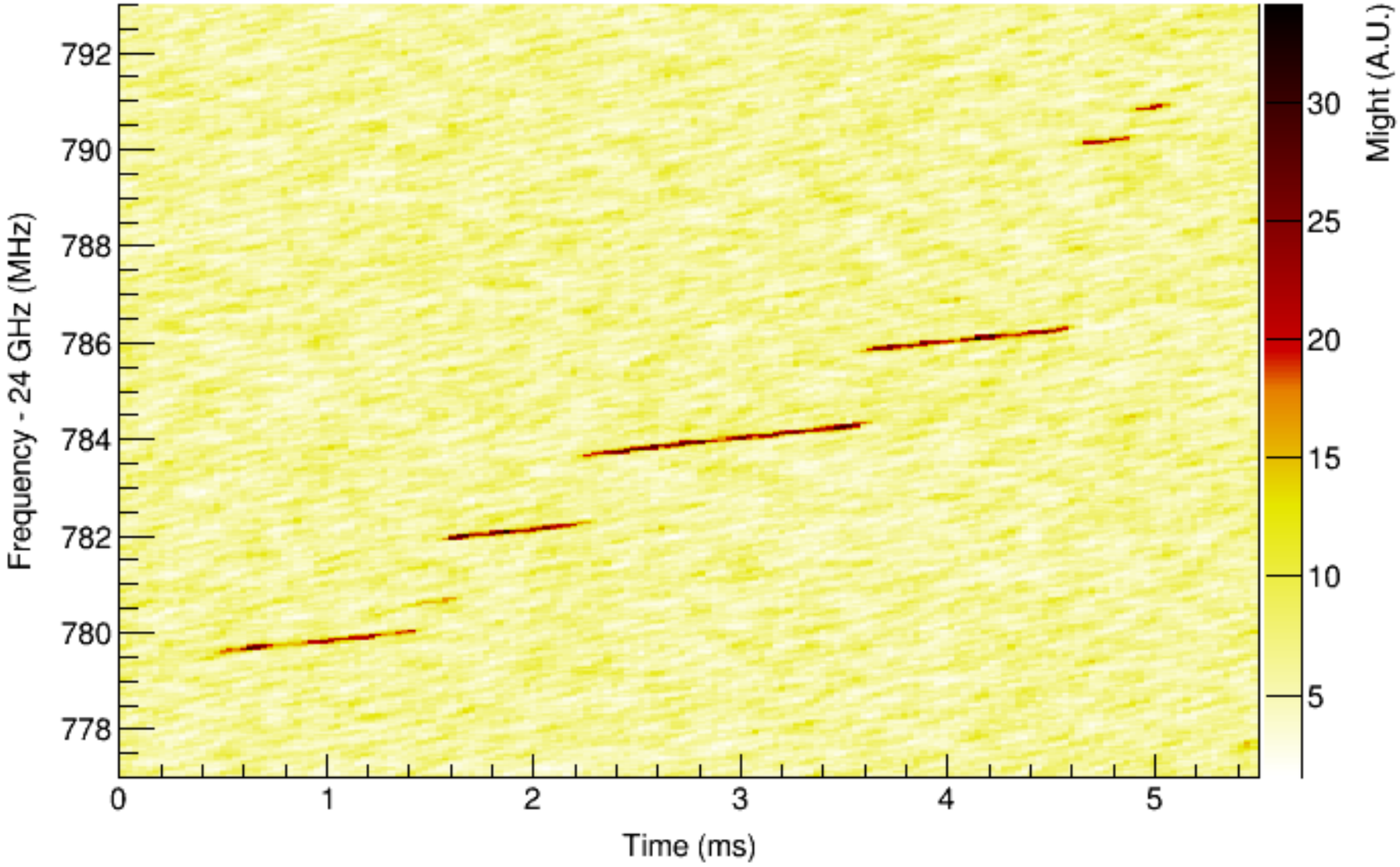
Project 8 Spectroscopy Technique

- Magnetic trap (no energy change)
- Extends observation time of electron
- Knowledge of B places limit on energy resolution

$$\triangle E = \frac{\triangle B}{B}(m_e c^2 + E_{kin})$$



A CRES signal



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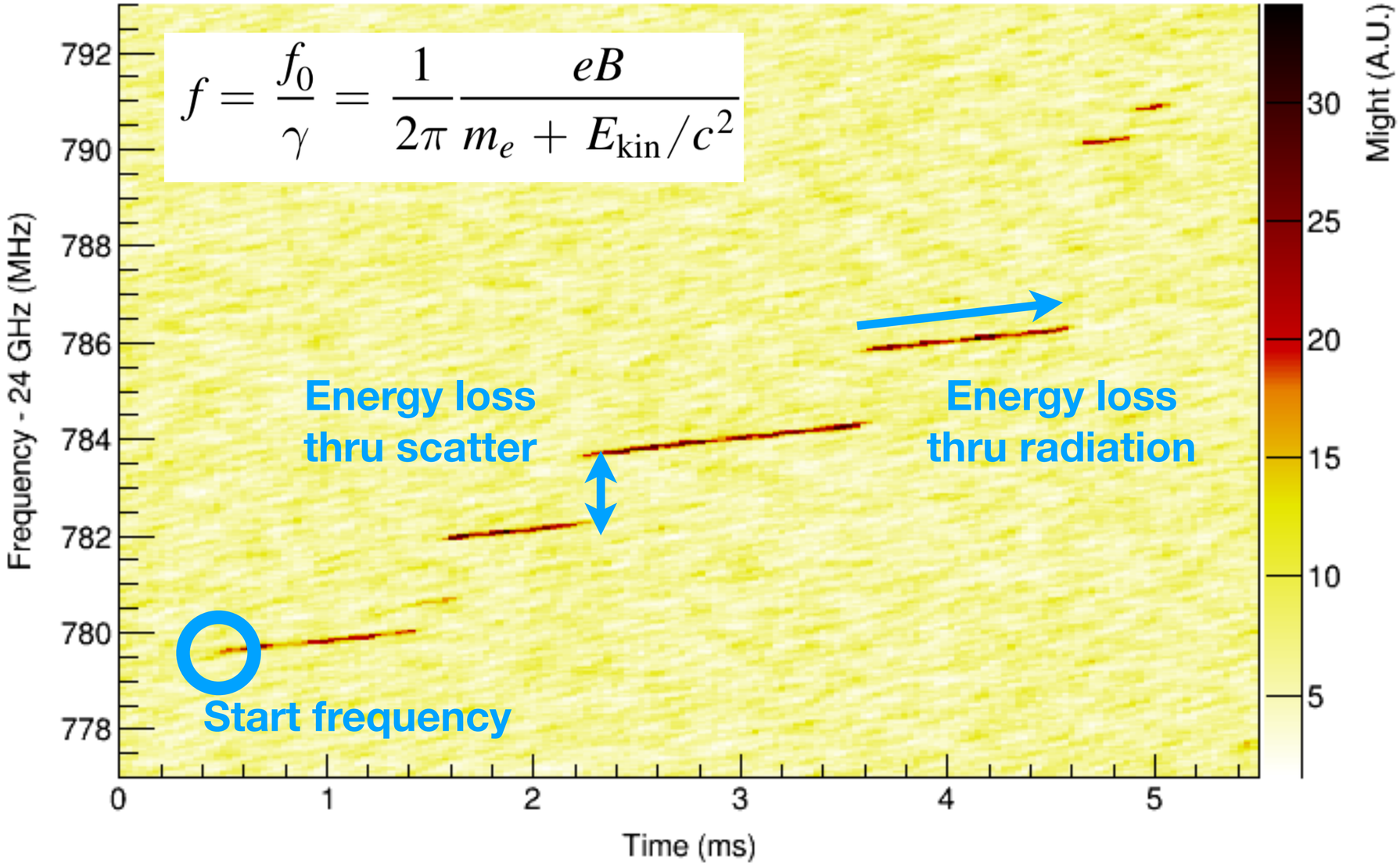

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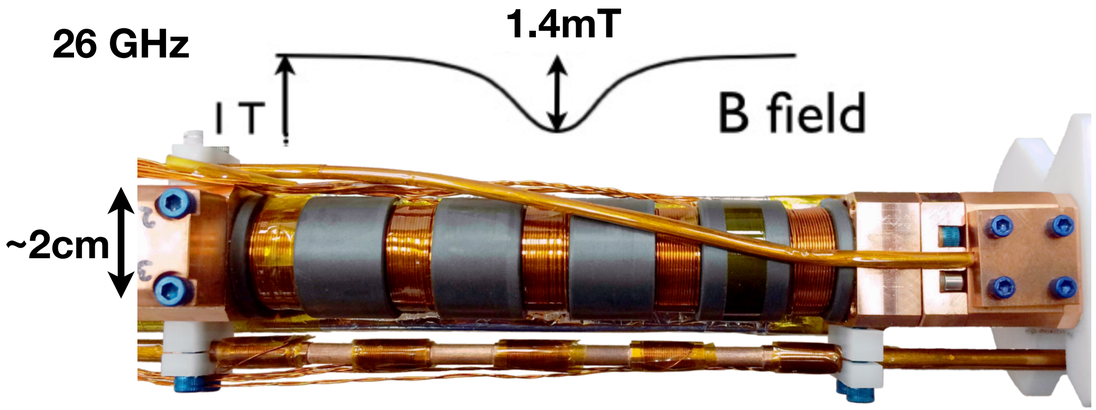
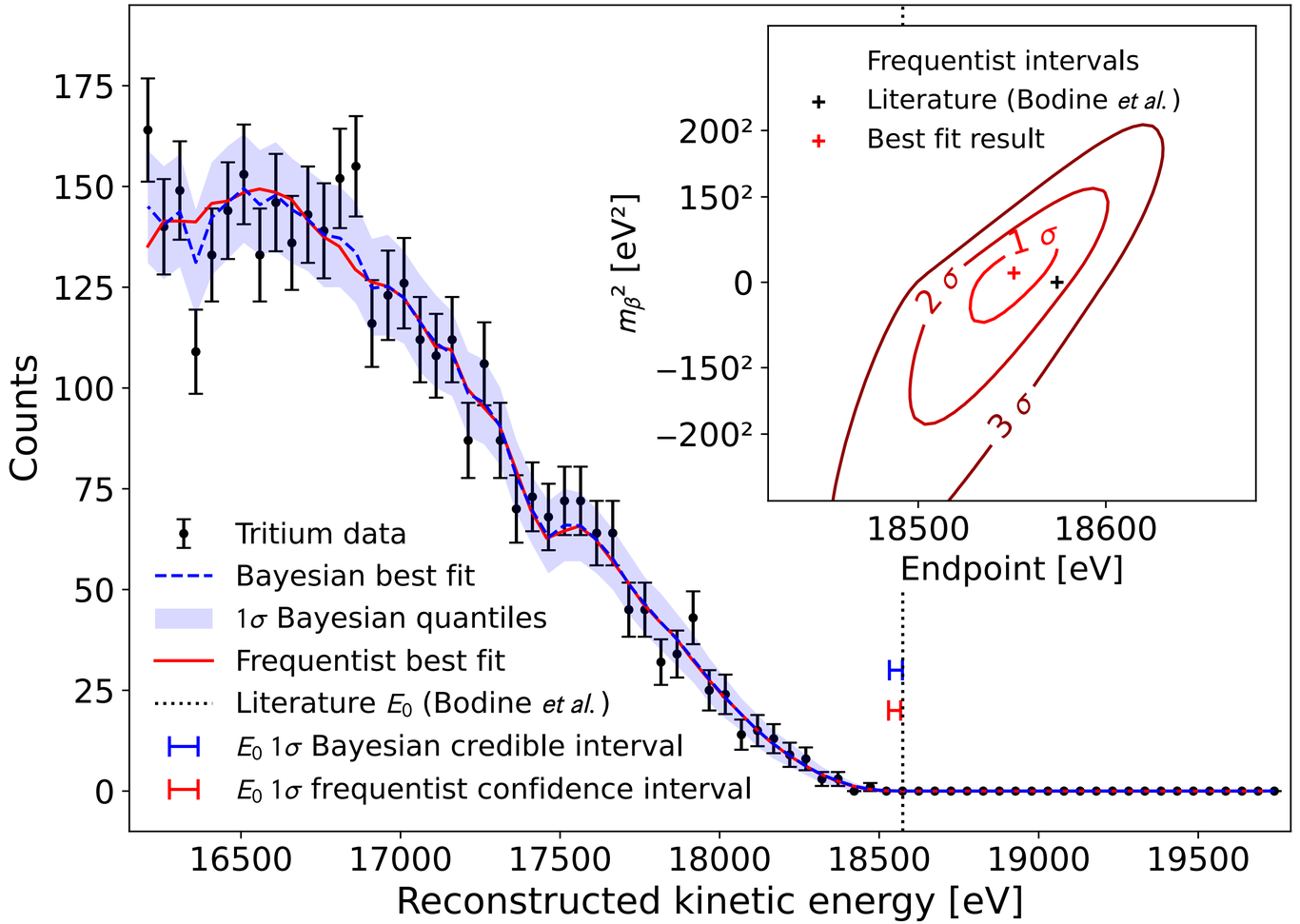
Phase II: CRES in a waveguide



- Mass limit: 170 eV (Bayesian)
  180 eV (Frequentist)
- Count rate: 3770 events over 82 days with T_2 at 10^{-6} mbar
- Resolution: 54.3 eV (FWHM)
- Effective volume: 1.20 ± 0.09 mm^3



arXiv: 2212.05048, to be submitted to PRL

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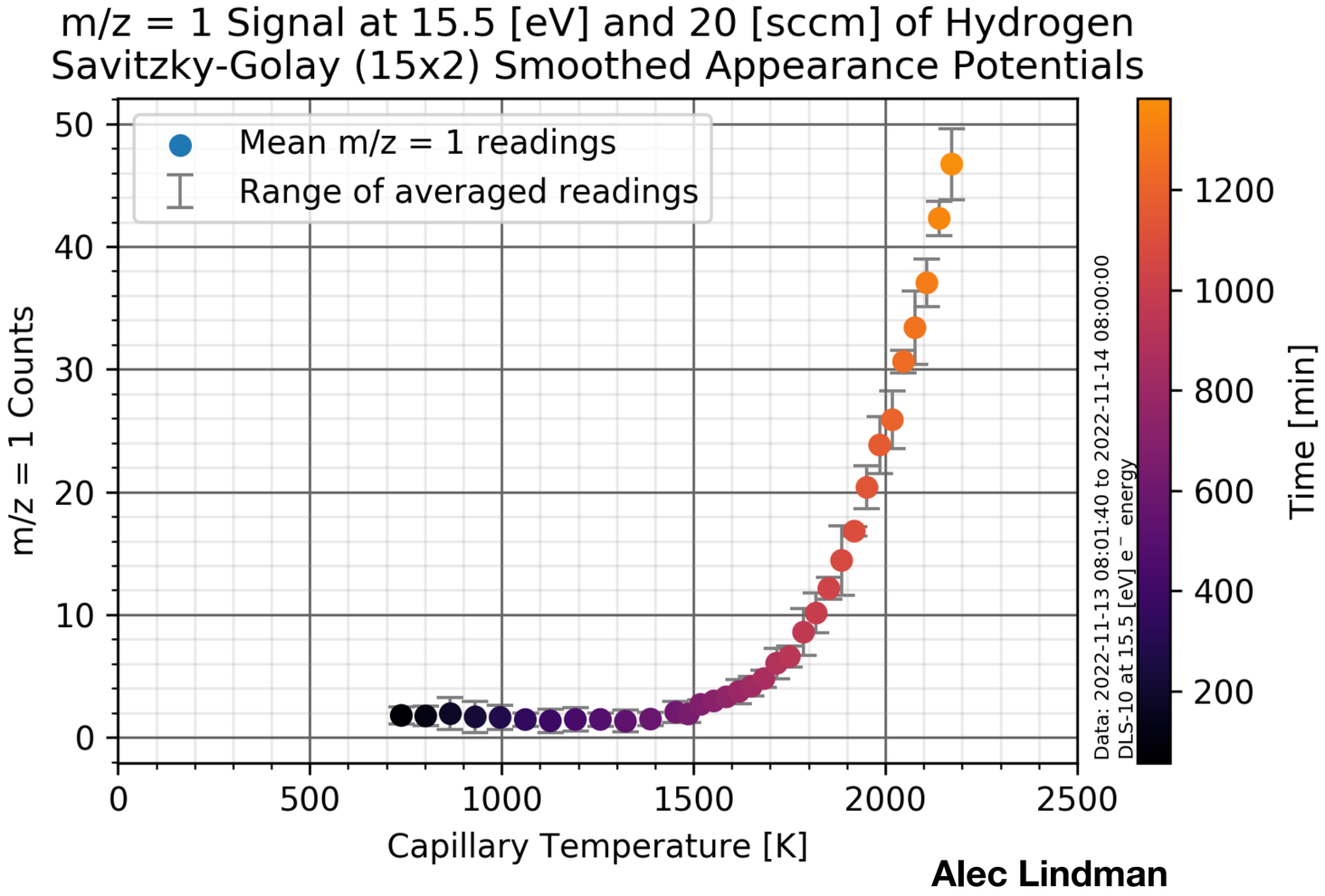
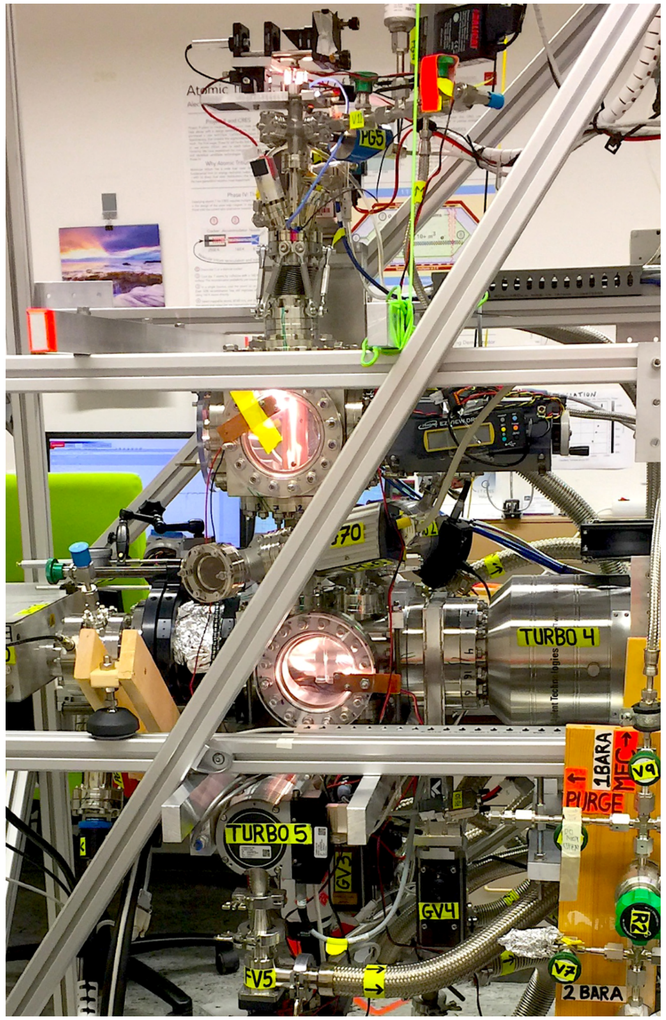
Phase III: Atomic Tritium



Johannes Gutenberg University, Mainz



Phase III: Scaling CRES

- CRES must be scaled up to work in large volumes
- Two potential technologies: antennas or resonant cavities
- Antennas currently retired, cavities under active study

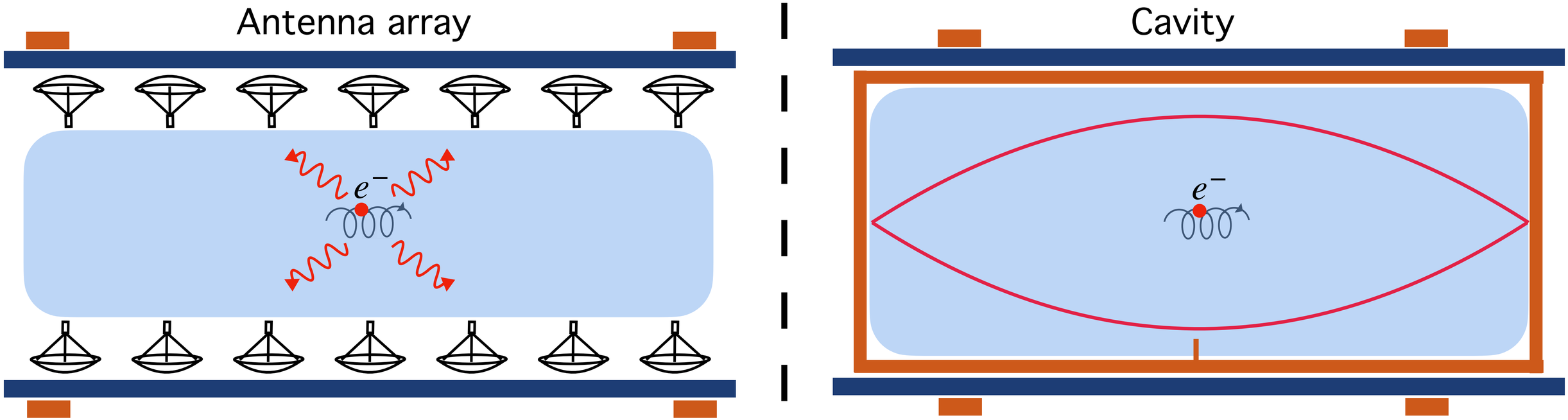
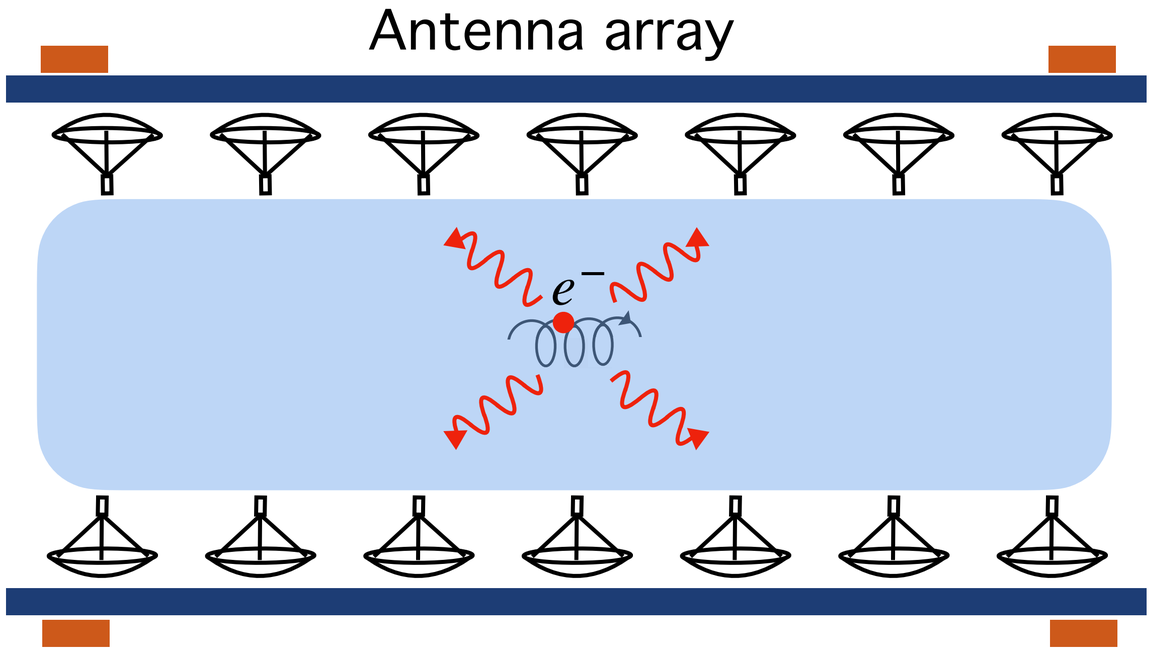


figure: Andrew Ziegler

Phase III: Scaling CRES

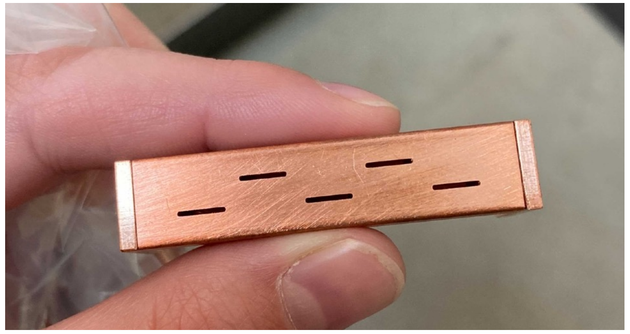


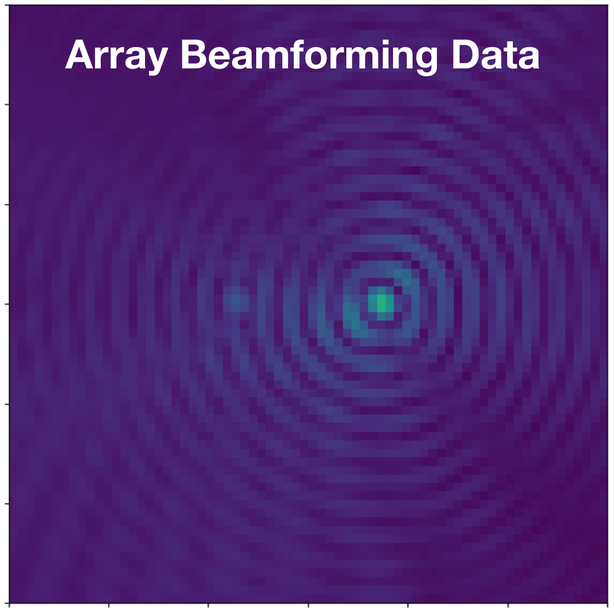
Antenna Array

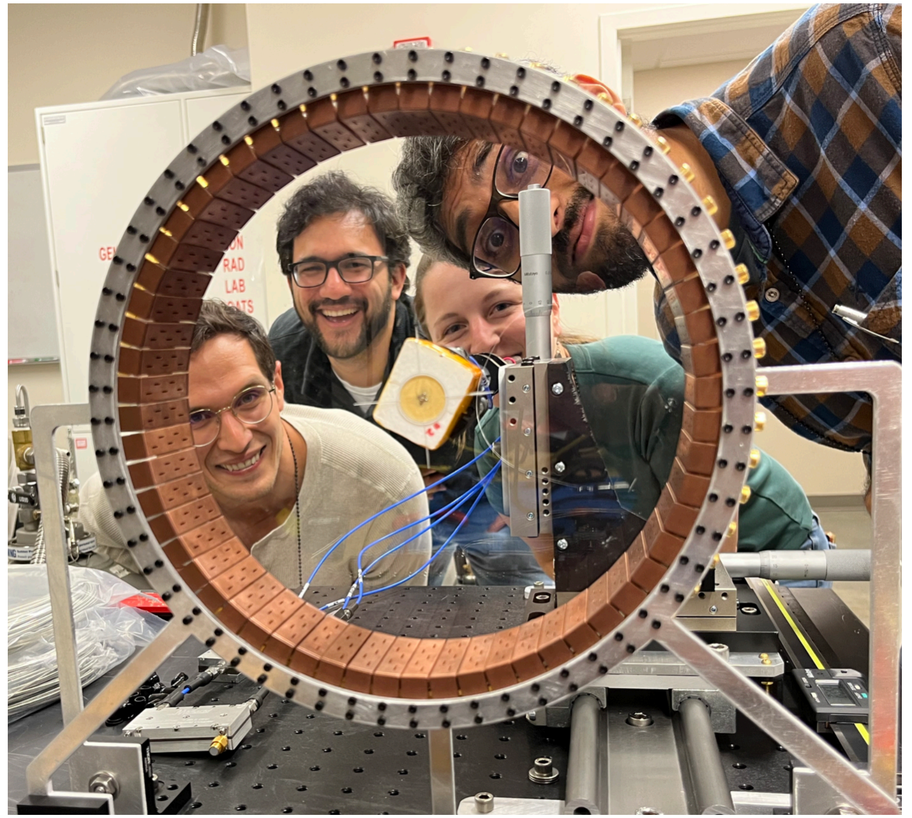
- Constructed and measured 60-antenna array in the lab with synthetic CRES antenna
- Quantifying real-world array effects such as multi-path reflections

Synthetic CRES antenna paper:
arXiv:2212.08026

Antenna array paper in progress







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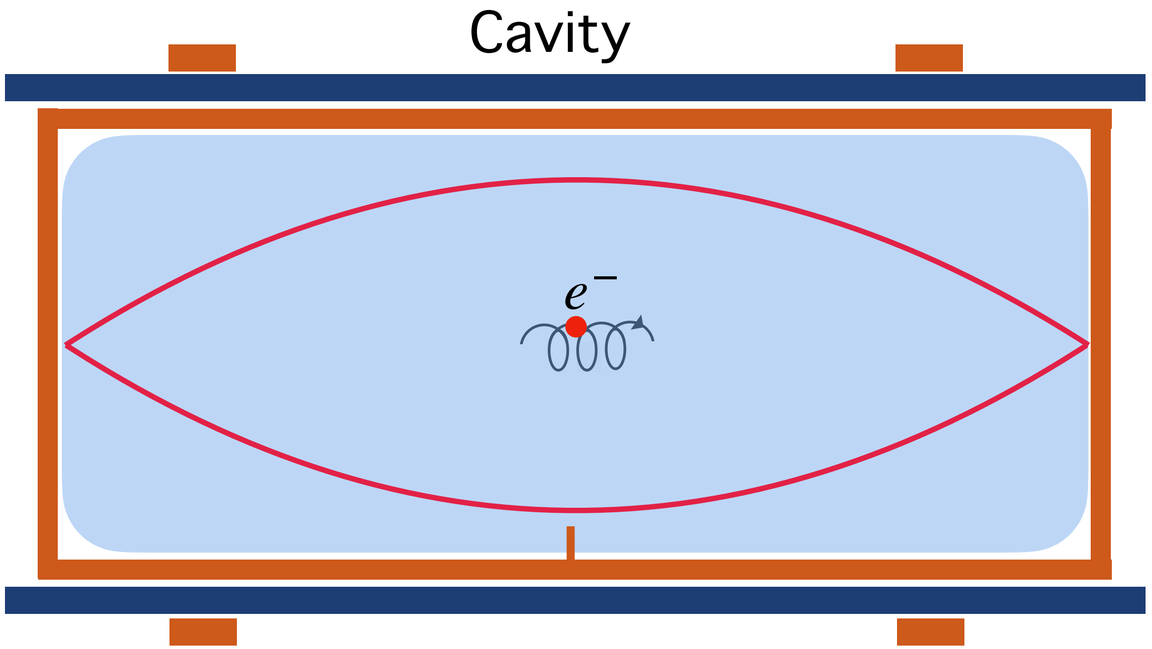
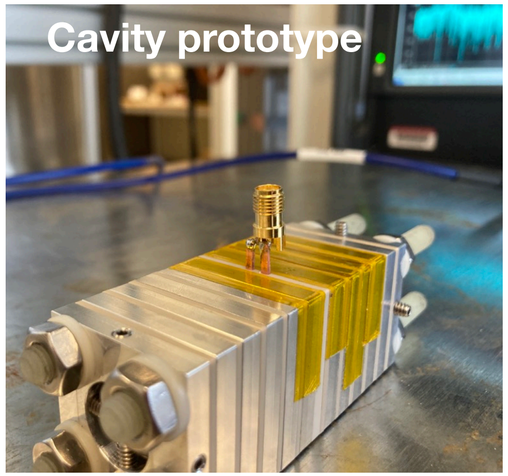
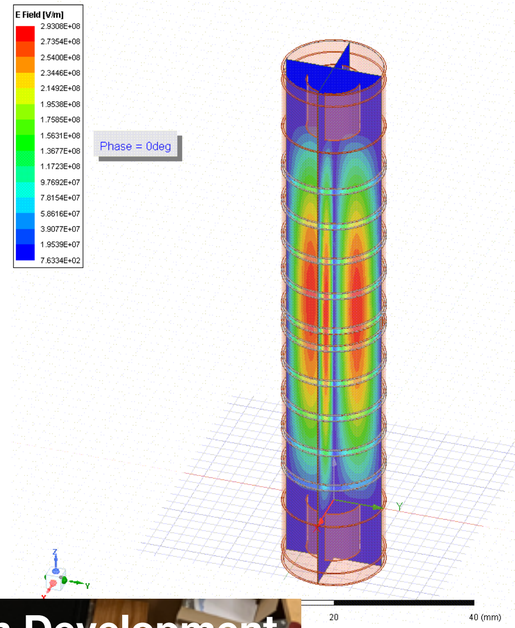
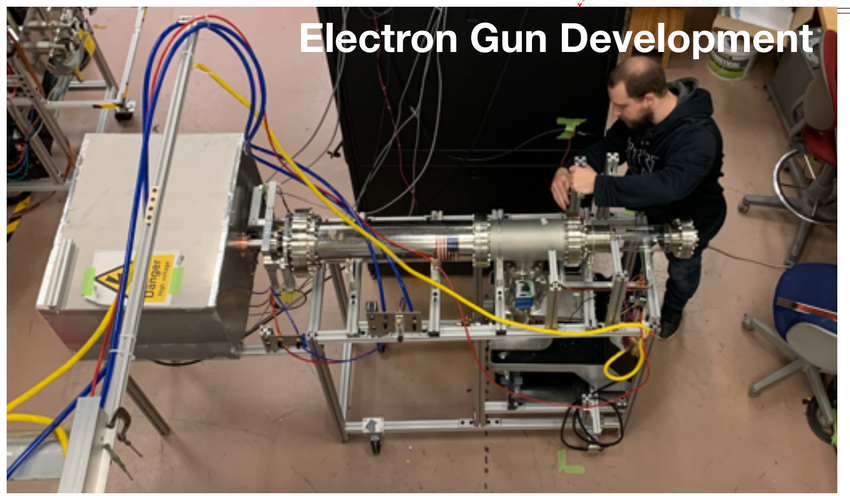


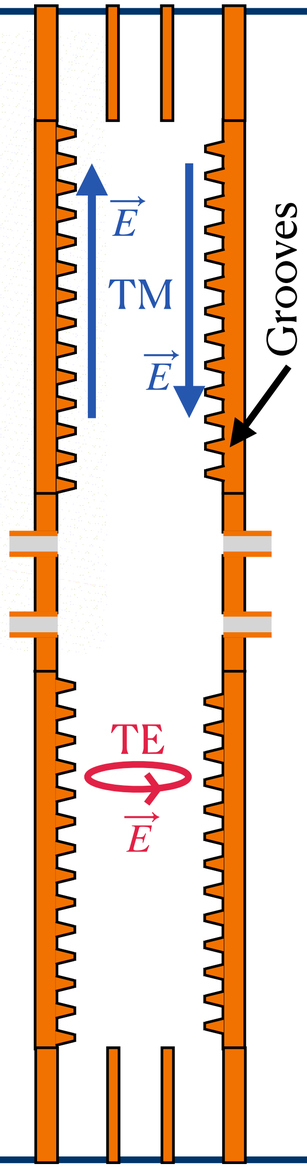
Cavity CRES at 1T / 26 GHz

- Initial cavity CRES prototype designed for MRI magnet at ~1T with electron gun source and ^{83m}Kr.
- Work ongoing for cavity prototyping, electron gun construction, magnetic trap design, system mechanical design and simulation.



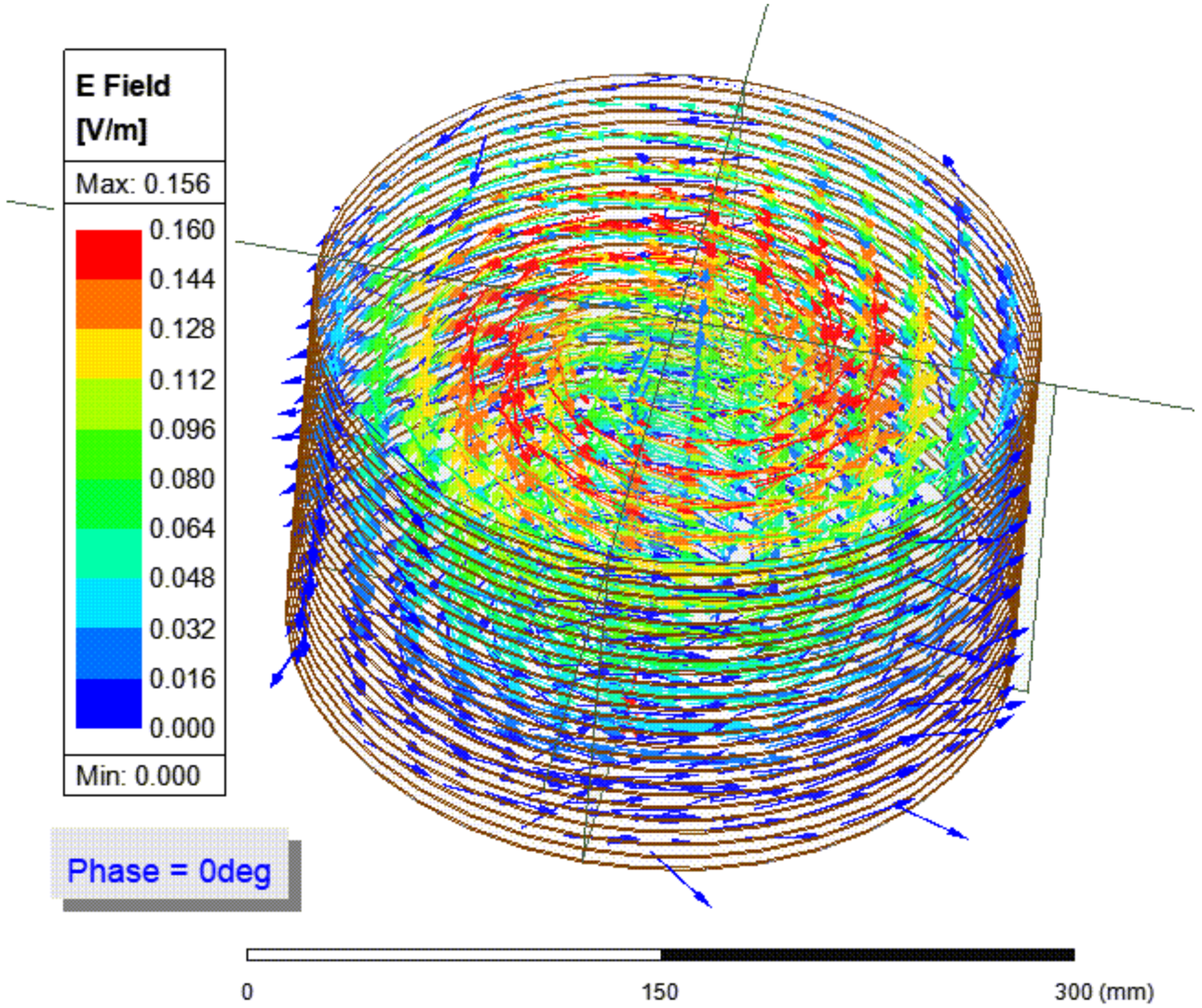






Cavity CRES at ~0.05 T, 1.5 GHz

- Lower B fields are necessary because of atomic tritium: dipolar spin flips in atom interactions cause loss of T -> effect peaks near 1 T
- Goal: demonstrate CRES at these low fields
- Main challenge: power is ~1 aW at 0.05T vs ~1 fW at 1T



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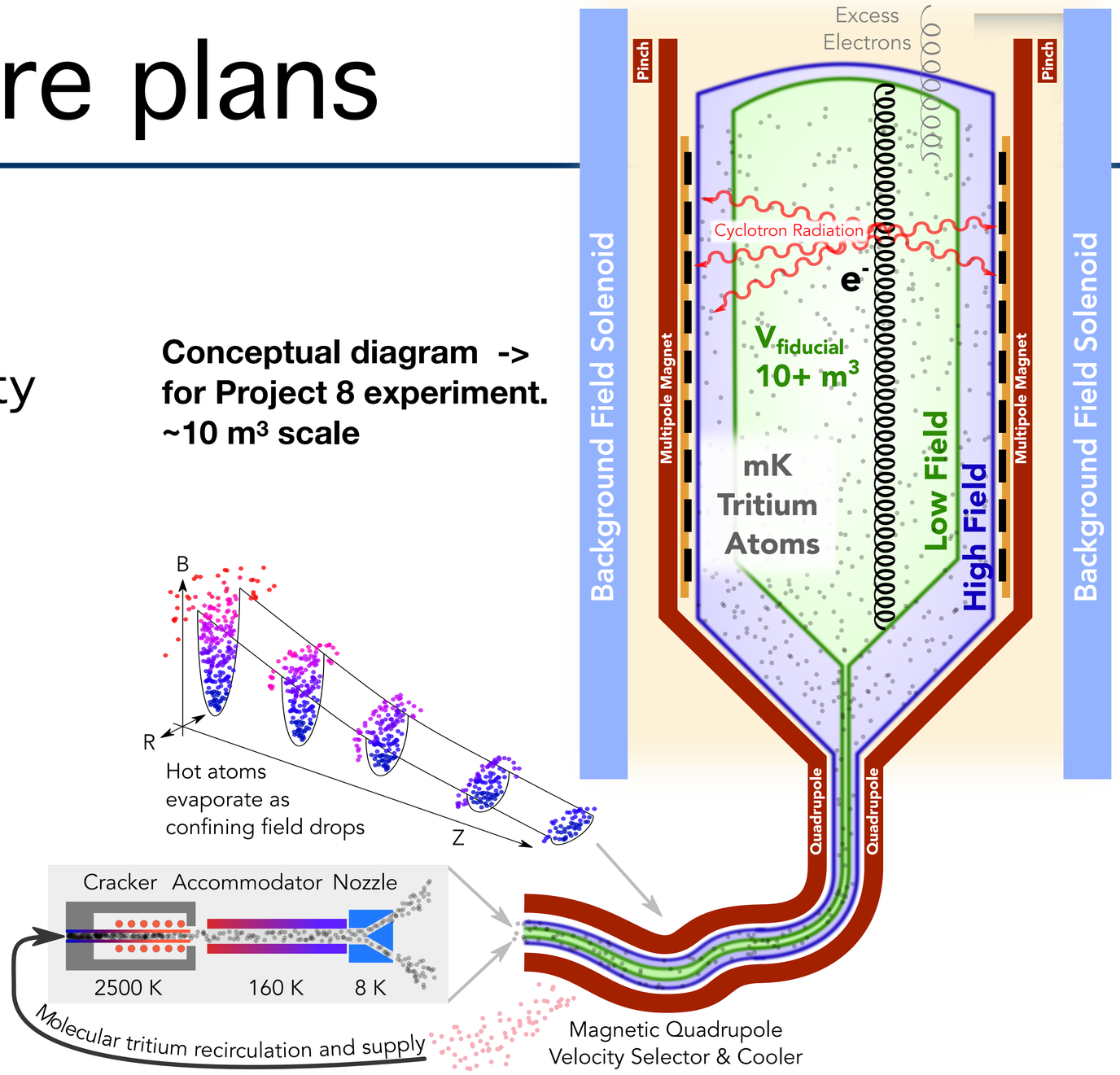
Future plans

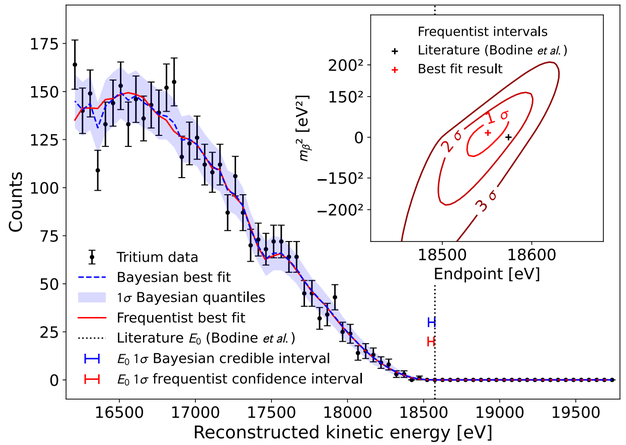
- <u>Next 2-3 years:</u>
  - Cavity CRES at 1 T
  - Prototyping and testing for cavity CRES at <0.1 T
  - Atomic subsystem development
- <u>Next 4-9 years:</u>
  - Pilot scale T_2 experiment
  - Atomic T demonstrator
- <u>Next 9-10+ years:</u>
  - Pilot scale atomic CRES
- Then final experiment designed for 40 meV sensitivity

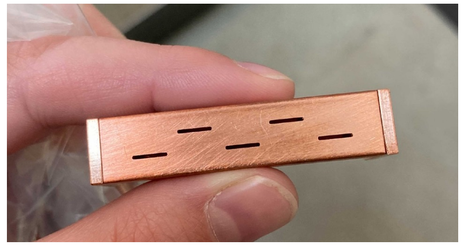
Conceptual diagram -> for Project 8 experiment. ~10 m³ scale

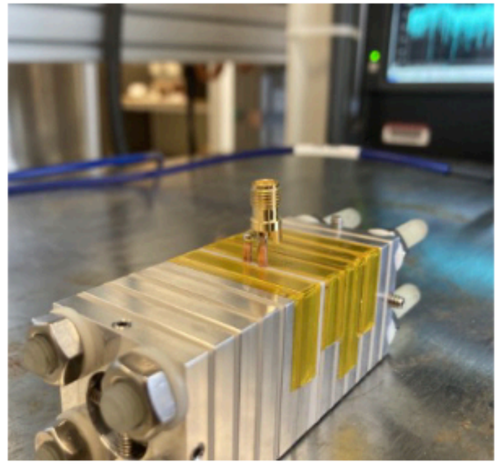


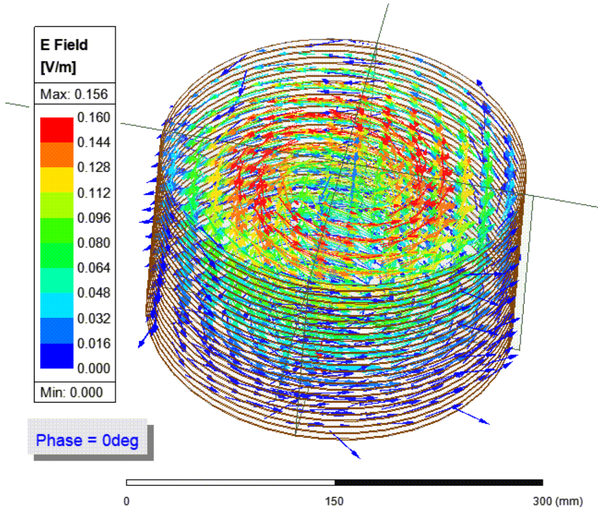
Summary

- Project 8 uses cyclotron radiation for precise tritium spectrum endpoint measurements, recently completed demonstrator phase
- Current work is focused on:
  - Demonstrating CRES in cavities, lower fields
  - Atomic tritium development
- Papers to come this year! Phase II, antennas, machine learning analysis.









PROJECT 8

Acknowledgments

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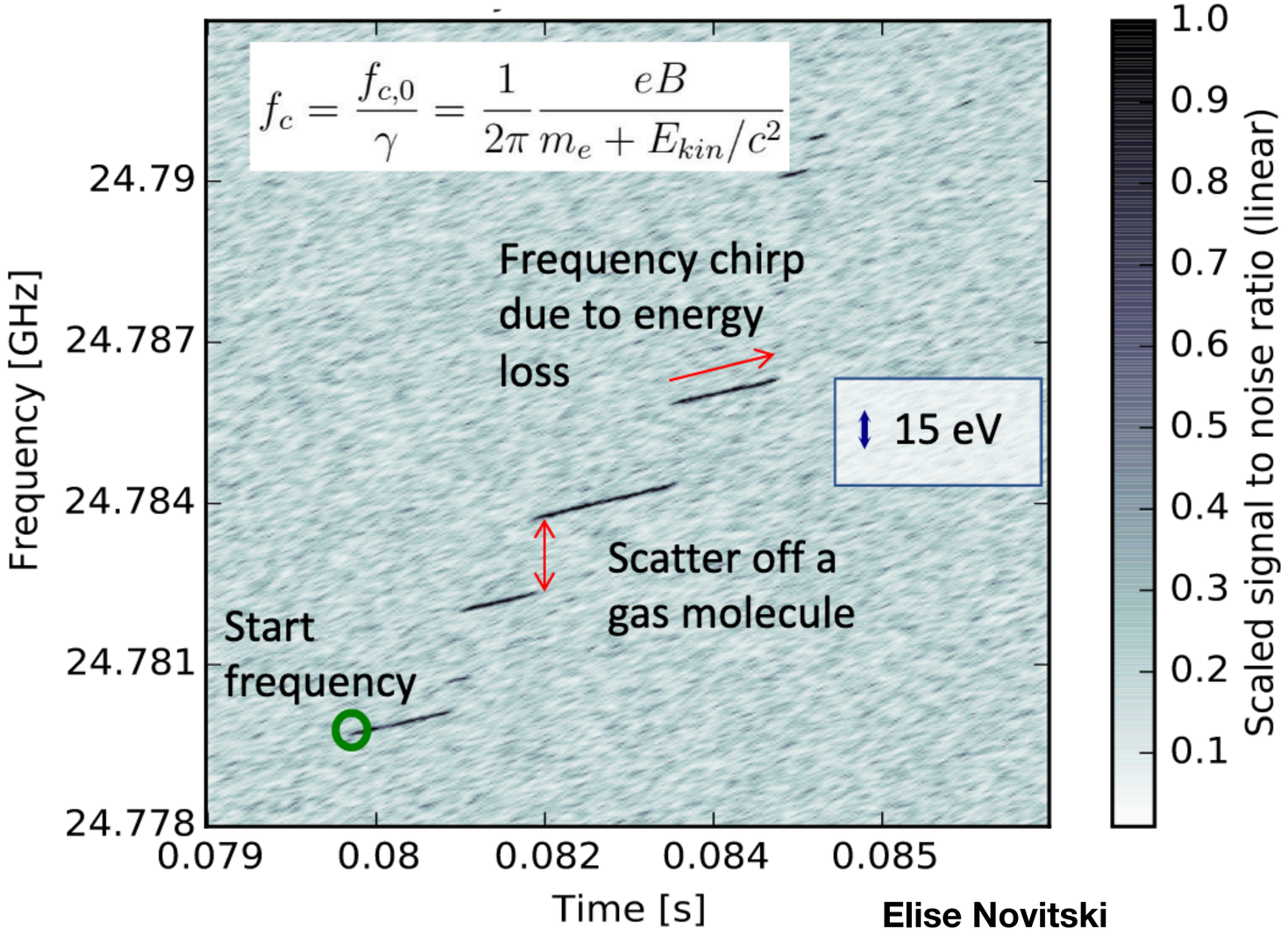
BACKUP

A CRES signal



Elise Novitski

Resolution with Krypton