Project 8 Phase III Design Progress

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Pacific Northwest NATIONAL LABORATORY

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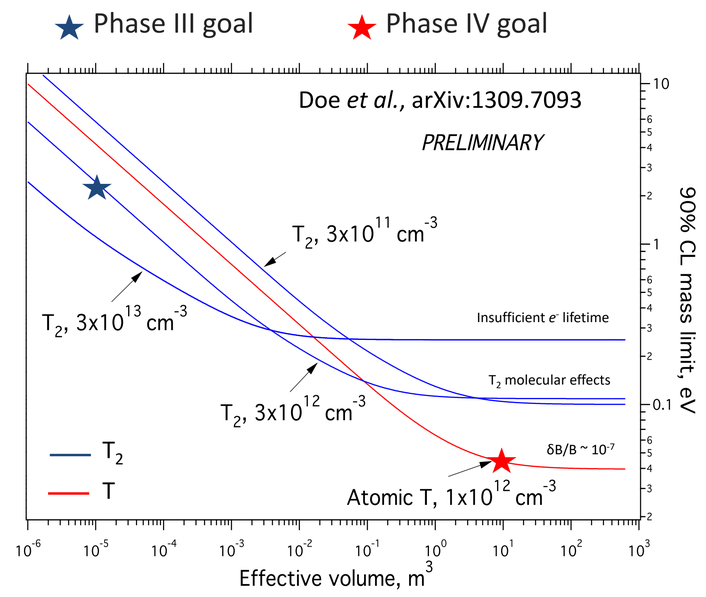
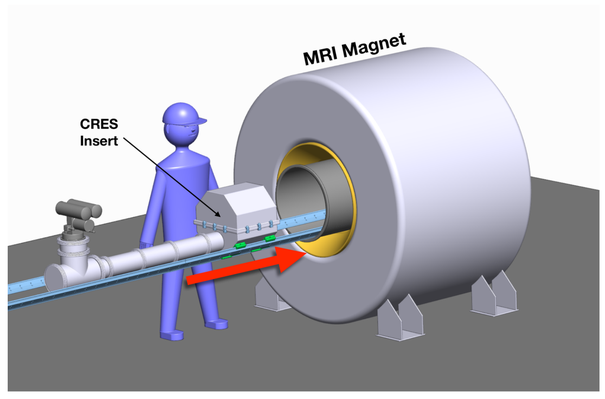
The Project 8 Collaboration

- **Project 8 is a tritium endpoint experiment to measure the absolute neutrino mass m_ν, by Cyclotron Radiation Emission Spectroscopy (CRES) [1,2,3]**
- **Phase IV targets the inverted-hierarchy scale: $m_\nu < 40$ meV (90% C.L.)**
- **Phase III is a prototype technology demonstrator for Phase IV that must prove:**
  - **A scalable receiver for CRES signals**
  - **Signal processing and data reduction by triggering**
  - **High rate capability and sensitivity to many simultaneous events**

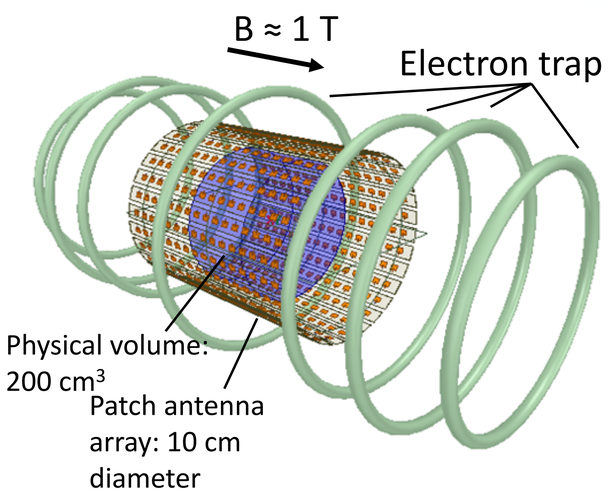


Phase-III Design targets:

- **10–20 cm³ effective volume**
- **≈200 cm³ physical volume**
- **5–10% total efficiency (trap+trigger)**
- **3×10^{12} T_2/cm³**
- **$m_\nu < 2$ eV (90% C.L.) sensitivity**

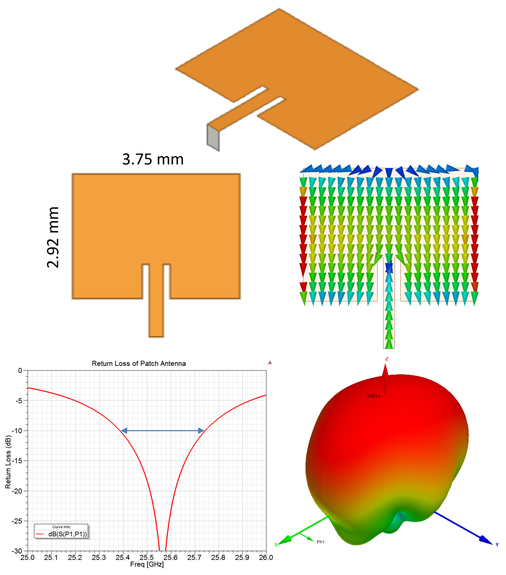


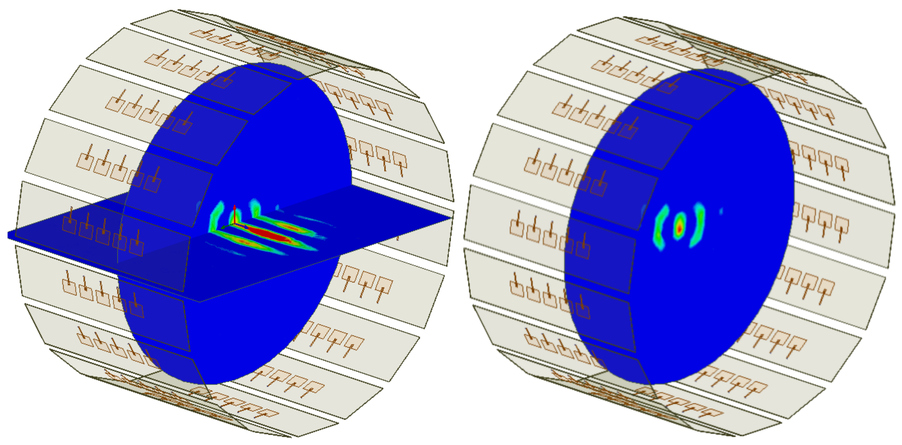
CRES Insert

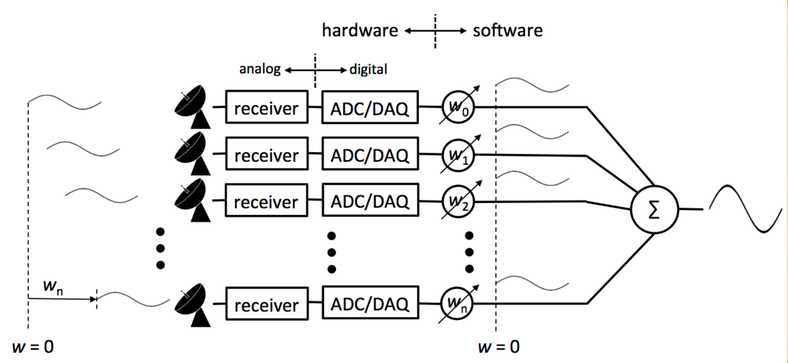


Conceptual Phase-III Design:

- **1T CRES field (MRI Magnet)**
- **10–20 cm long magnetic "bathtub" trap**
- **Cyclotron radiation detection by circular phased-array antenna**
- **Event localization by digital beam forming**







Patch Antenna Elements

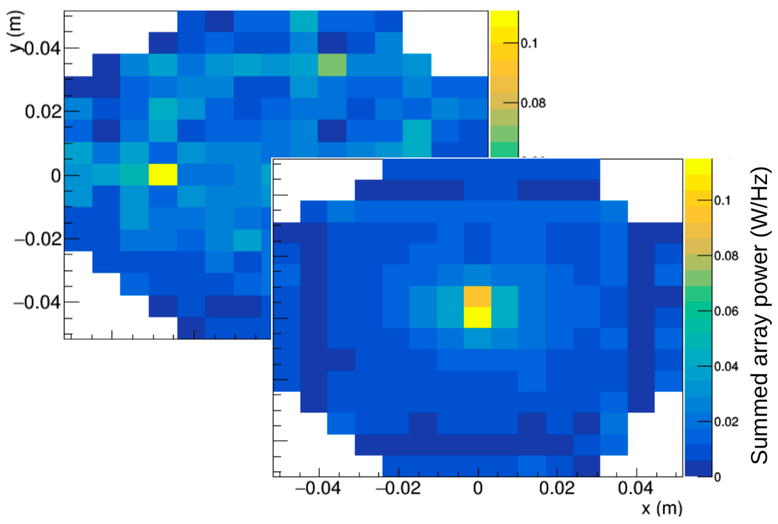
- **Resonant structures, ≈350 MHz bandwidth**
- **4.6 dBi far-field gain (lower right image)**
- **Compact → monolithic high density arrays on *e.g.*, PCB**

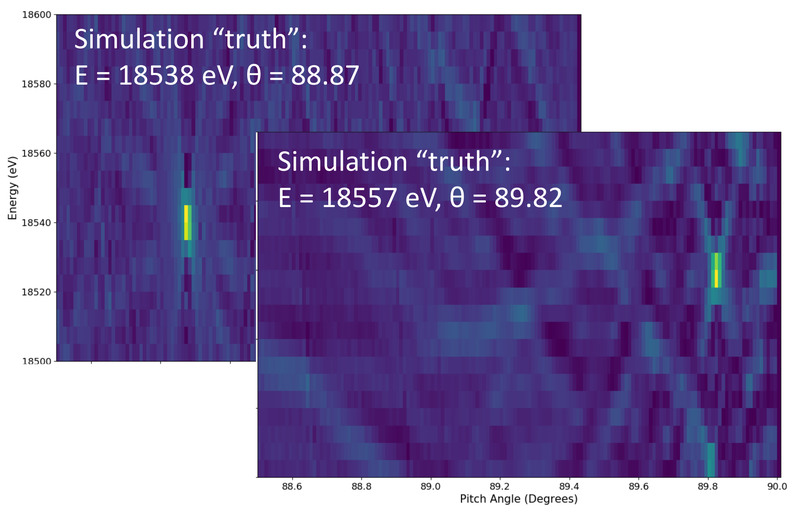
Phased Array Antenna

- **Passively combine patches along longitudinal *B*-field direction (feed network not shown) → electron signal always present in one element**
- **Instrument each of *N* longitudinal strips with one amplifier → signal increases ~N^2, noise increases only ~N**

Digital Beam Forming (DBF)

- **Focus array in software after digitization: each focal point has a unique phase-delay vectors (w_0, w_1, …, w_n)**
- **Improved signal-to-noise and reduced final data volume**
- **Potential to focus on many simultaneous electrons with sufficient digital processing power**





Simulated Array Response w/ DBF

- **Each pixel above represents the total power collected by the array when focused at the corresponding (*x, y*) coordinate**
- **Maximum power occurs when the electron location is in focus**
- **Multiple electrons can be resolved simultaneously**

Matched Filter Event Reconstruction

- **Nontrivial event reconstruction due to doppler-induced frequency modulation**
- **Signals can be simulated with high fidelity, but in data the event parameters are unknown**
- **Algorithm can extract electron kinematics from data* by comparing to a simulated template library**

(*Plots above use simulated data)

Conclusions

- **Validation of Phase III conceptual design through simulations underway**
- **Engineering design, construction and operations to follow**
- **A successful outcome of Phase III will match the neutrino-mass sensitivity of Mainz/Troitsk, and demonstrate critical technologies for the final Phase IV to follow KATRIN**

References

[1] Monreal and Formaggio, Phys. Rev. D, 80:051301 (2009)

[2] Asner *et al.*, Phys. Rev. Lett. 114:162501 (2015)

[3] Ashtari Esfahani *et al.*, J. Phys. G 44:054004 (2017)

Acknowledgments

This work is supported by the US DOE Office of Nuclear Physics, the US National Science Foundation, and internal investments at all collaborating institutions.