Overview of Project 8 and Progress Towards Tritium Operation

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on behalf of the Project 8 Collaboration

University of Washington

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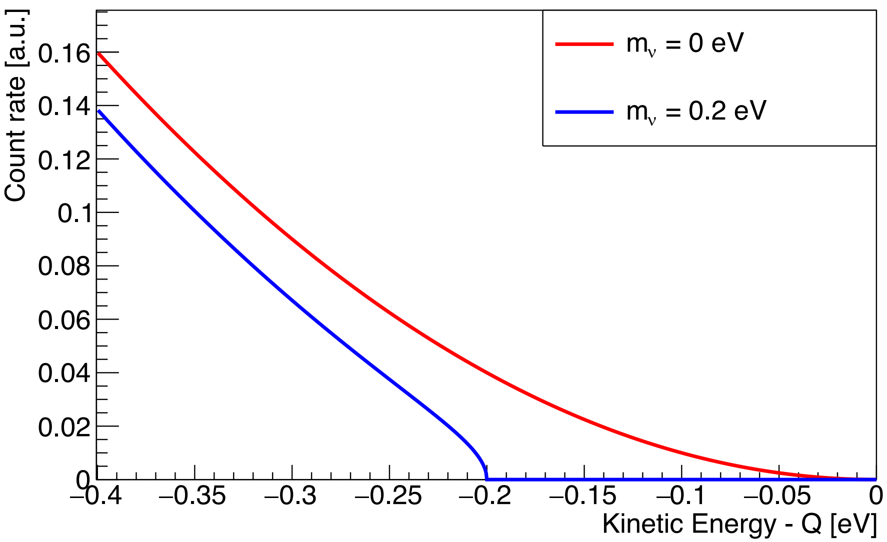
CENPA

Center for Experimental Nuclear Physics and Astrophysics

Tritium Beta Decay Endpoint

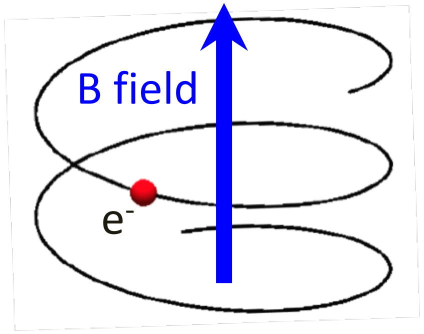
Massive neutrinos manifest in distortion of beta decay spectrum

> **Tritium has provided best direct neutrino mass limits to date**
- Q-value: 18.6 keV
- Half-life: 12.3 yr
- Superallowed decay
- But only $2 \cdot 10^{-13}$ decays in last eV of spectrum



> **Mass scale benchmarks**
- $m_{\nu e} \lesssim 2$ eV : current limit
  - Mainz and Troitsk
- $m_{\nu e} < 0.2$ eV : anticipated current-generation experimental limit
  - KATRIN
- $m_{\nu e} > 0.05$ eV (0.009 eV): allowed range under inverted (normal) hierarchy
  - From oscillation experiments

Cyclotron Radiation Emission Spectroscopy (CRES)



- **Frequency of cyclotron radiation related to energy of electrons:**

$$f_c = \frac{1}{2\pi}\frac{eB}{(m + E_{kin})}$$

  - f_c = 25 – 26.5 GHz cyclotron frequency range in Project 8
    - B = 0.9459 T magnetic field
    - E_{kin} = 0 – 30 keV for ^{83m}Kr conversion electrons
  - 1 fW of radiated power at 18 keV (tritium endpoint)

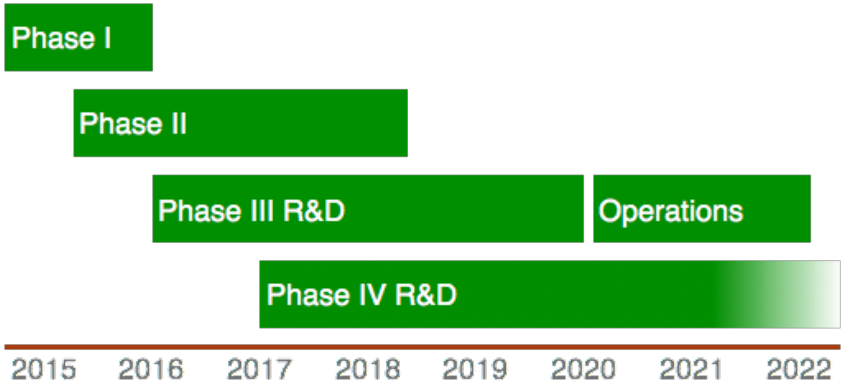
- **Advantages:**
  - Differential spectrum measurement
  - Source gas is transparent to its own cyclotron radiation
    - No limit to source size from self-attenuation
  - Excellent energy resolution from frequency measurement

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
  – *see also Mathieu Guigue, Thurs. parallel*



> **Phase III (2016-2022)**
  – CRES demonstration in 200 cm^3 free space volume
  – Neutrino mass sensitivity of ~2 eV

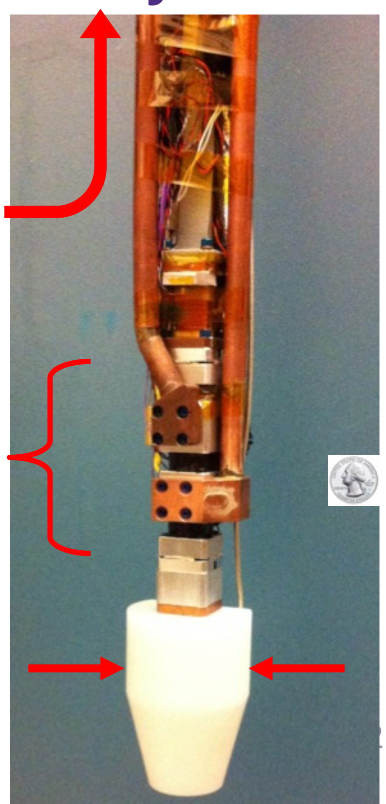
> **Phase IV (2017+)**
  – Atomic tritium endpoint measurement with m_ν ~ 40 meV projected sensitivity

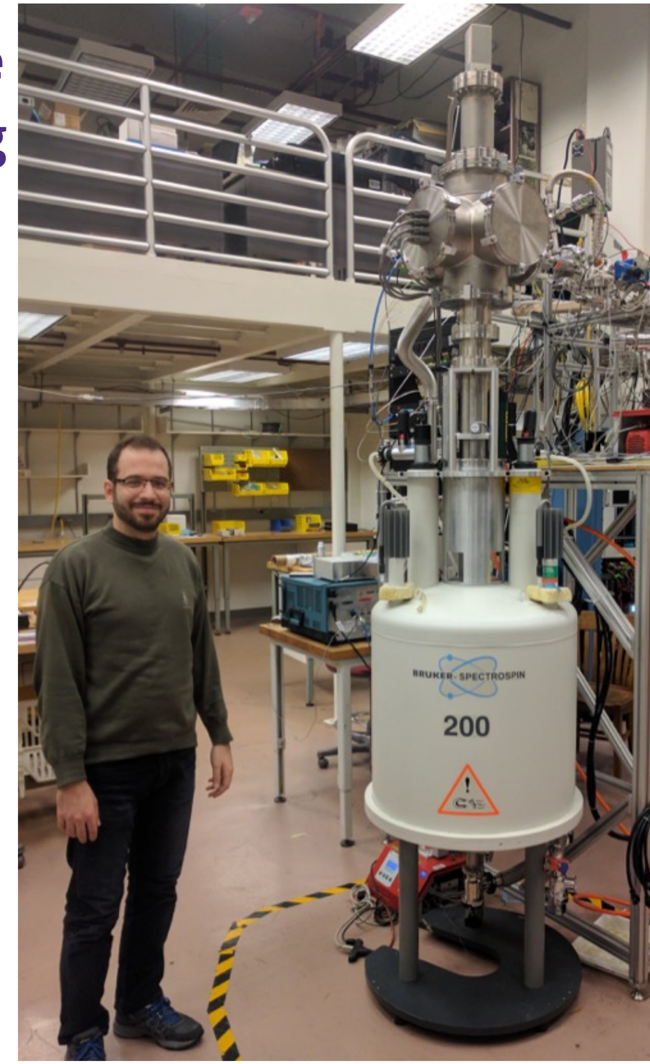
Phase I

"Tabletop" demonstrator of CRES technique

> **Commercial warm-bore superconducting NMR magnet operating at 1T**

> **WR42 rectangular waveguide to confine gas and collect cyclotron radiation**

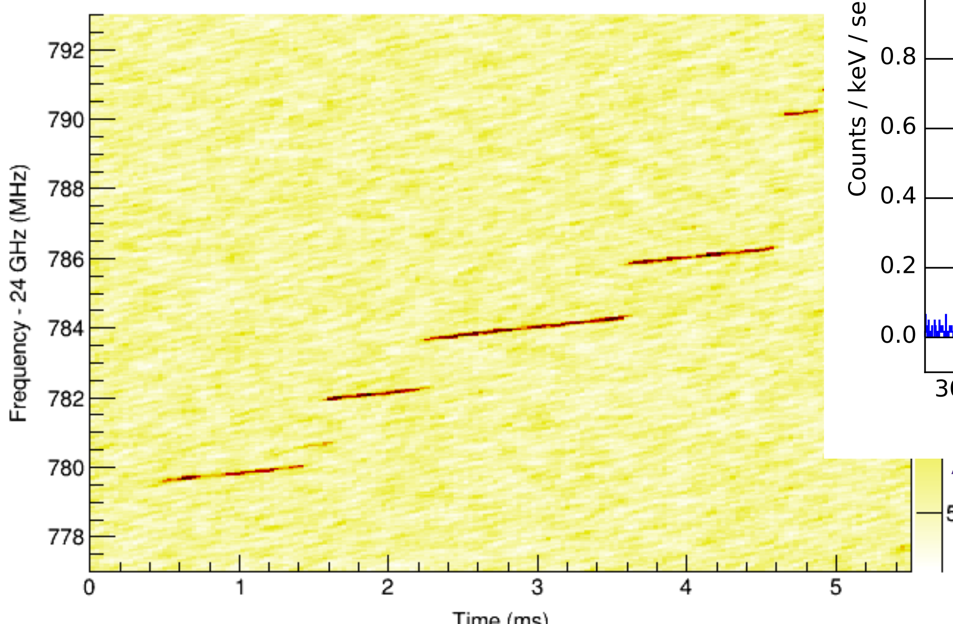




Phase I

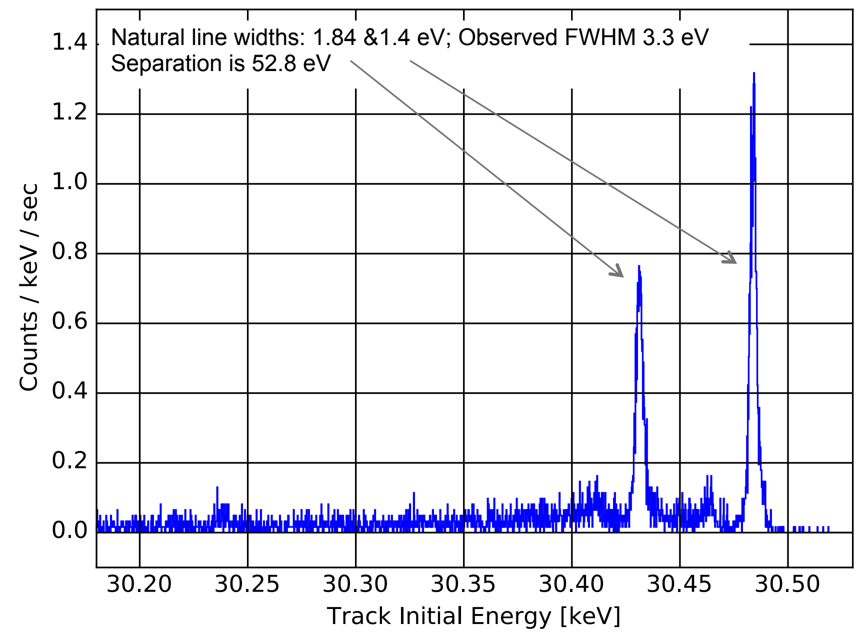
“Tabletop” demonstrator of CRES technique

> Commercial warm-bore superc 1T NMR magnet
> WR42 rectangular waveguide t gas and collect cyclotron radiat



D. Asner *et al*. Phys. Rev. Lett. 114, 162501 (2015) (reprocessed)

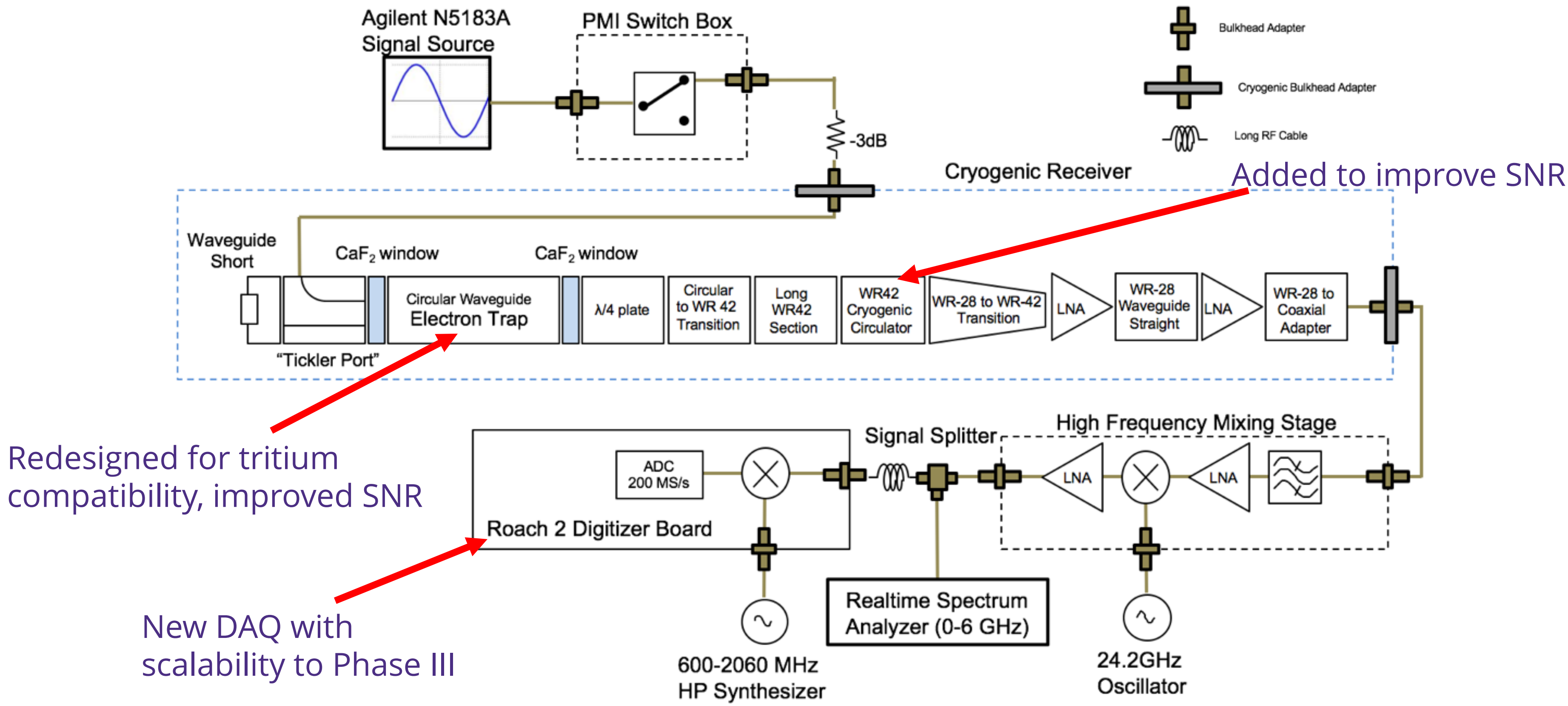
^{83m}Kr L-shell CE doublet near 30.4 keV



A. Ashtari Esfahani *et al*. J. Phys G 44, 162501 (2017) 5

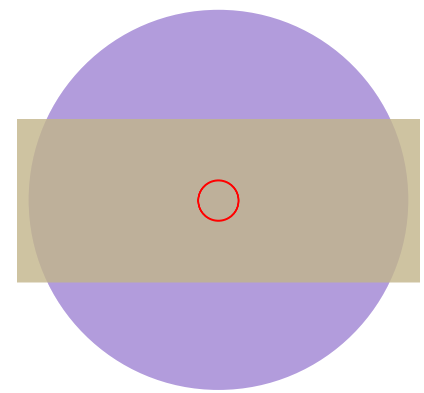
Phase II

> Upgrade gas system and cell for tritium compatibility and signal-to-noise performance



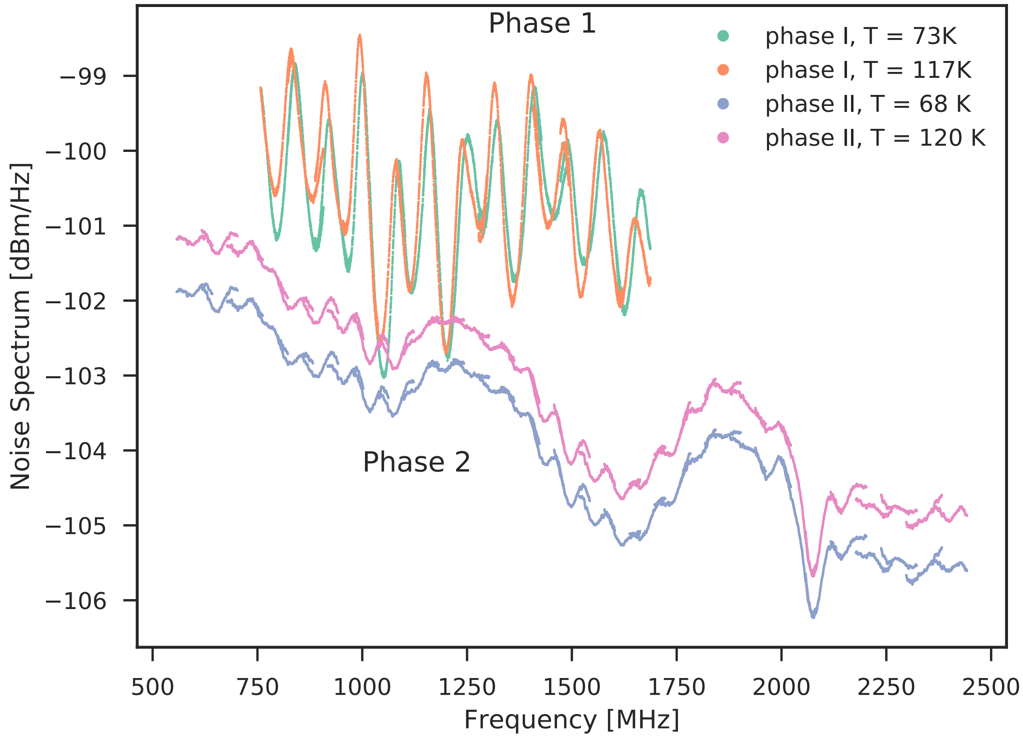
Phase II Gas Cell

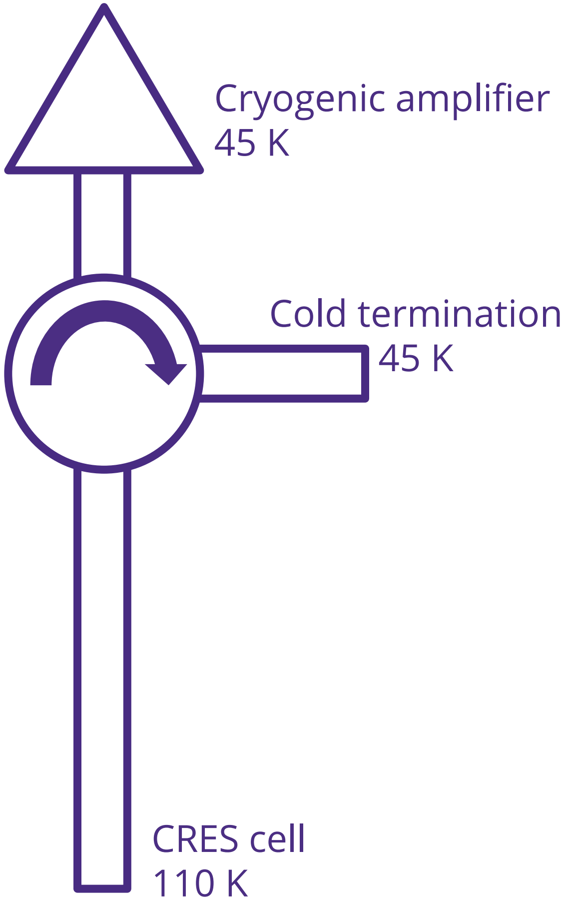
> **Circular waveguide**
  – Recover signal by matching polarization
  – Larger effective area
> **CaF_2 windows**
  – Tritium compatibility
> **5 trap coils**
  – Greater flexibility of trapping geometry
> **Off-axis ESR magnetometers**
  – Higher precision BDPA ESR agent
  – *In situ* monitoring of trapping field
> **Tickler port**
  – *In situ* RF calibration
> **Waveguide short**
  – Recover signal from reflection



Phase II Noise Reduction

> **Cryogenic circulator improves noise performance**
  - Lower absolute noise level from 45 K termination
  - Reduced frequency dependence by eliminating a standing wave

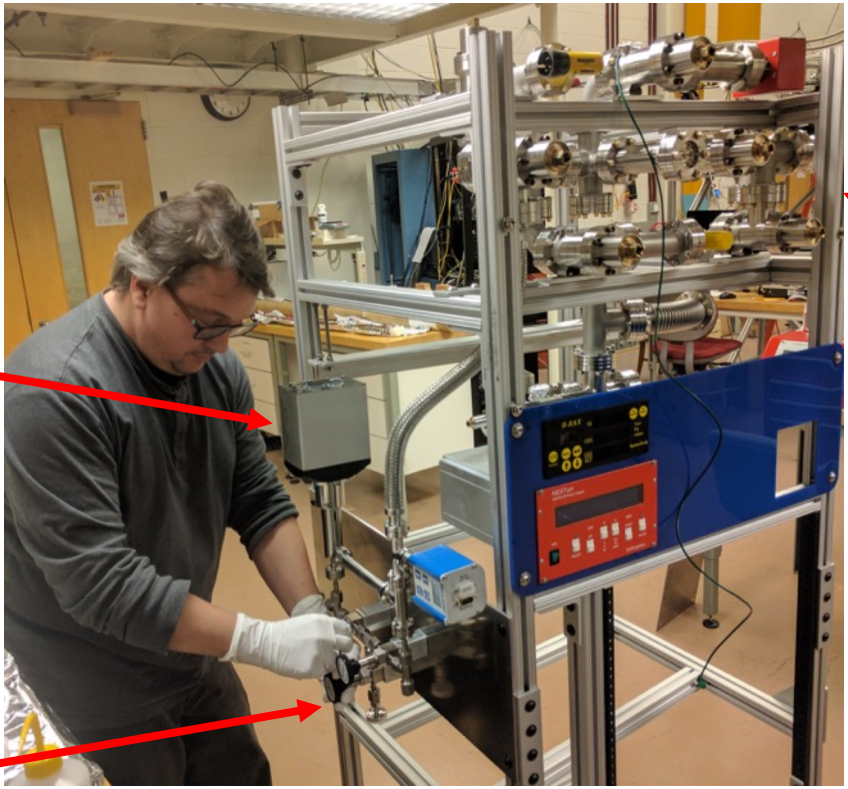




Dual $^{83m}Kr/T_2$ Gas System

All metal valves for tritium compatibility

Remote valve control and emergency automatic shutoff

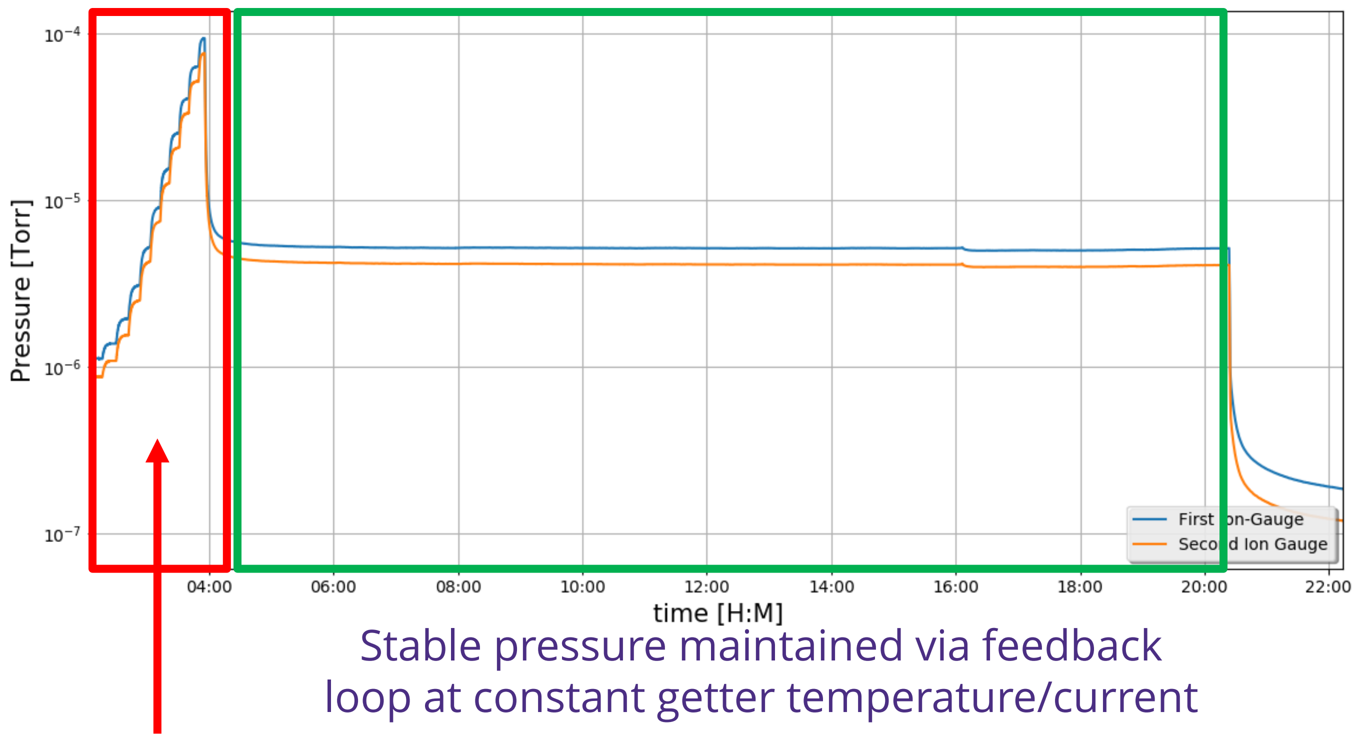


Getter for tritium pressure regulation

Simultaneous control of ^{83m}Kr and T_2 gas sources

Dual $^{83m}Kr/T_2$ Gas System

Deuterium Pressure Regulation



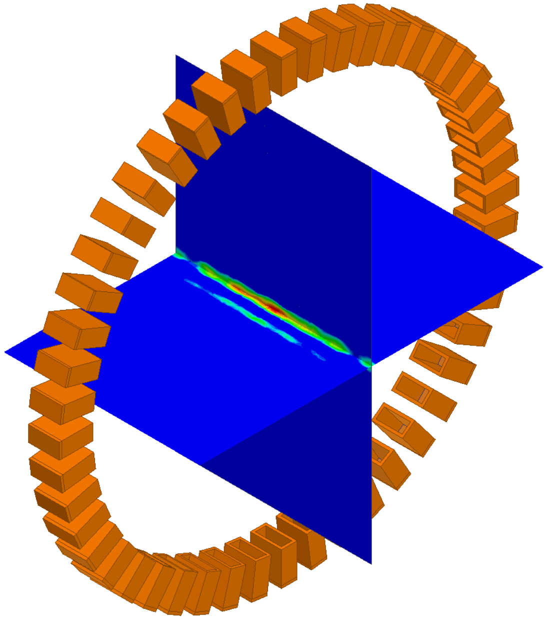
Stable pressure maintained via feedback loop at constant getter temperature/current

Pressure regulation via coarse steps of getter temperature/current

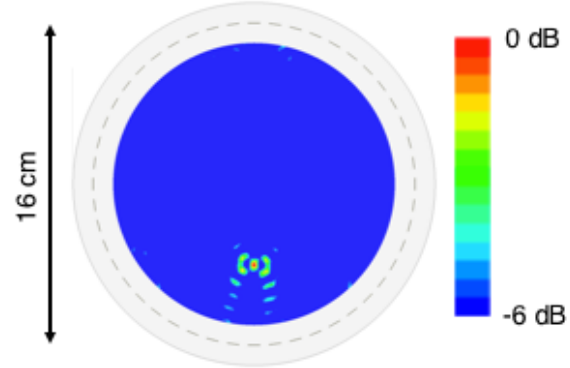
> **Safety review complete; tritium has arrived at UW**

Phase III

- Scale up to 200 cm^3 physical volume inside an MRI magnet
- Ring array of antennas detects free-space cyclotron radiation
  - Digital beam-forming used to localize signals

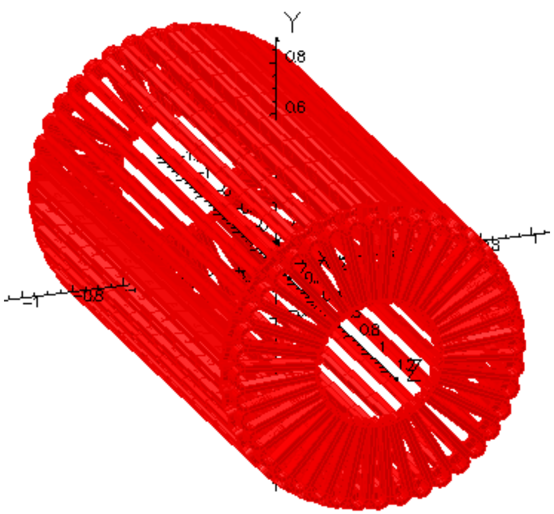


48-element array simulation

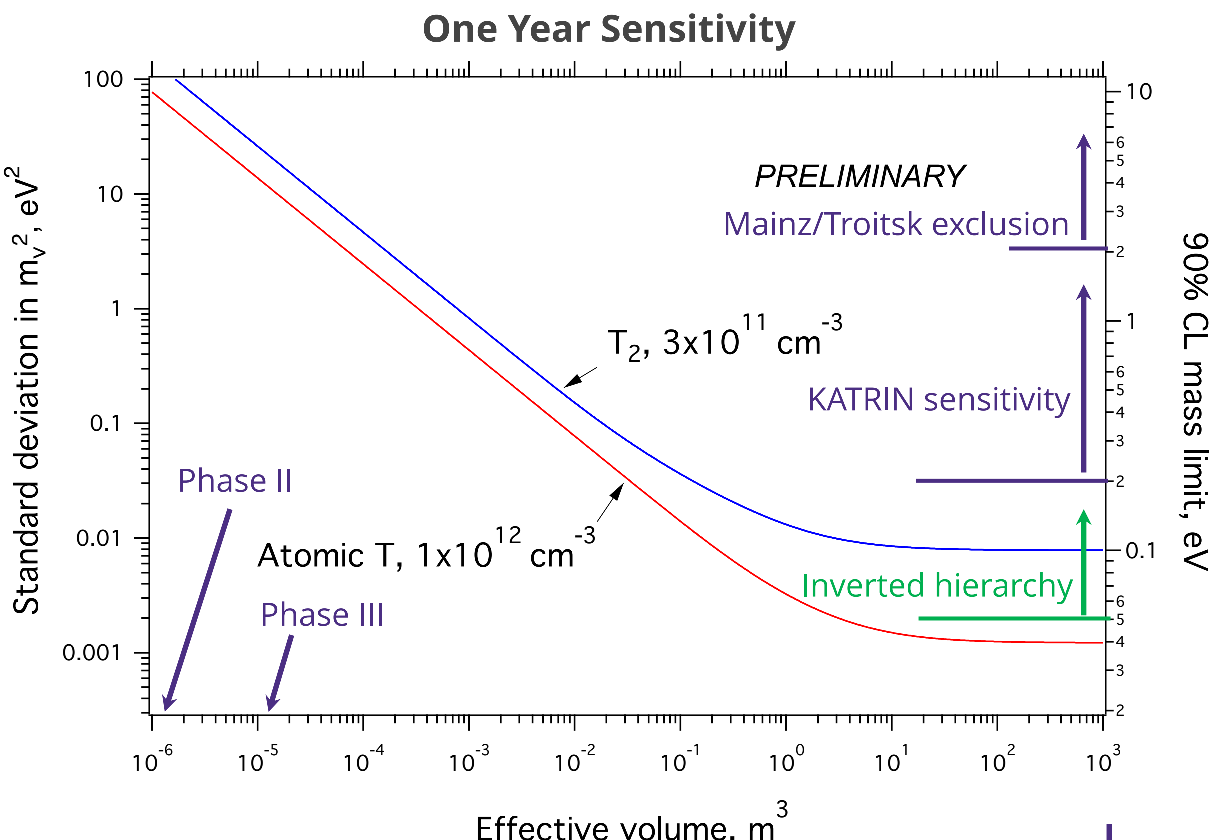


Phase IV

- Sensitivity beyond inverted hierarchy requires atomic tritium
  - Width of final state distribution an irreducible systematic for T_2
- Target design is 10^{18} atoms at 50 mK confined in a Ioffe trap



OPERA simulation of m^3-scale Ioffe trap



Conclusion

- We have demonstrated Cyclotron Radiation Emission Spectroscopy as a novel technique with a promising future in a next-generation neutrino mass experiment
  - Phase I achieved few-eV resolution of ^{83m}Kr spectrum
    - Approaching natural linewidth of ^{83m}Kr source
  - Phase II in final preparation for tritium run
    - Tritium arrived and approved for use
  - R&D underway towards Phase III and IV
- More Phase II data and analysis details from Mathieu Guigue on Thursday at 16:00 in New Technologies 4 session

Project 8 Collaboration

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