PROJECT 8

PROJECT 8

*An Update

Catania, Italy

Oct 20th 2017

Joseph A. Formaggio

MIT

Discovery!

After decades of searching, Atlas and CMS groups report discovery of the Higgs, completing the architecture of the Standard Model.

NEW YORK, THURSDAY, JULY 5, 2012 $2.50

Physicists Find Elusive Particle Seen as Key to Universe

POOL PHOTO BY DENIS BALIBOUSE

Scientists in Geneva on Wednesday applauded the discovery of a subatomic particle that looks like the Higgs boson.

Date Night at the Zoo, if Rare Species Play Along

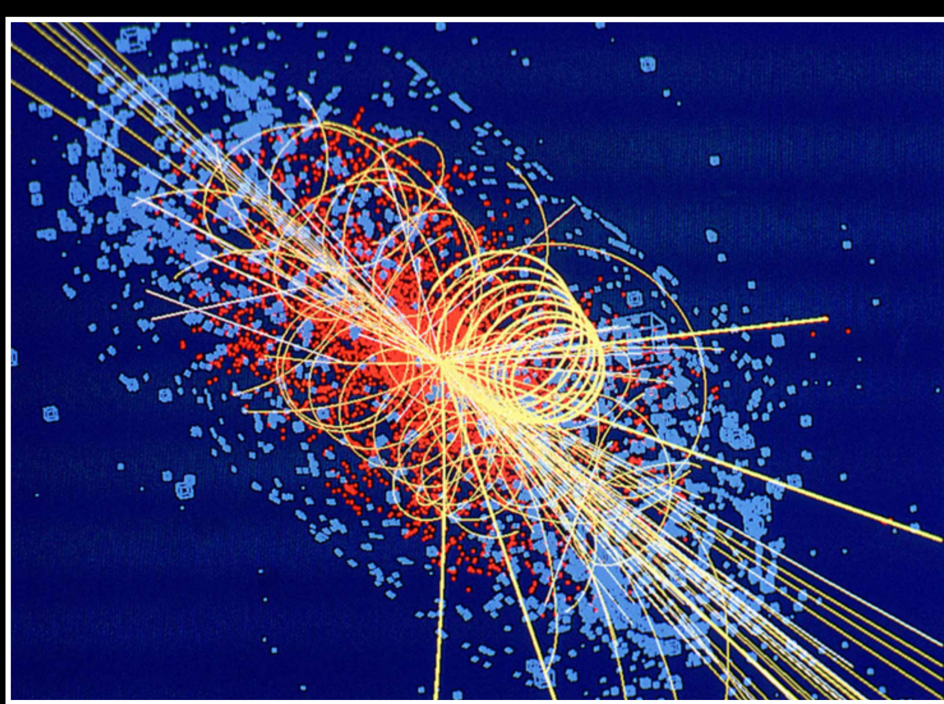
By LESLIE KAUFMAN

FRONT ROYAL, Va. — After cautiously sniffing the grass,

THE ANIMAL LIFEBOAT
Barriers to Breeding

thing but.
Eighty-three percent of those species in North American zoos are not meeting the targets set for maintaining their genetic di-

'I Think We Have It' Is Cheer of Day at Home of Search



Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

CMS Collaboration *

CERN, Switzerland

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away. In recognition of their many contributions to the achievement of this observation.

ARTICLE INFO

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Received 31 July 2012
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Editor: W.-D. Schlatter

Keywords:
CMS
Physics
Higgs

ABSTRACT

Results are presented from searches for the standard model Higgs boson in proton–proton collisions at $\sqrt{s} = 7$ and 8 TeV in the Compact Muon Solenoid experiment at the LHC, using data samples corresponding to integrated luminosities of up to 5.1 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$, and $b\bar{b}$. An excess of events is observed above the expected background, with a local significance of 5.0 standard deviations, at a mass near 125 GeV, signalling the production of a new particle. The expected significance for a standard model Higgs boson of that mass is 5.8 standard deviations. The excess is most significant in the two decay modes with the best mass resolution, $\gamma\gamma$ and ZZ; a fit to these signals gives a mass of $125.3 \pm 0.4(\text{stat.}) \pm 0.5(\text{syst.})$ GeV. The decay to two photons indicates that the new particle is a boson with spin different from one.

Almost immediately, we know *a lot* about this new particle...

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

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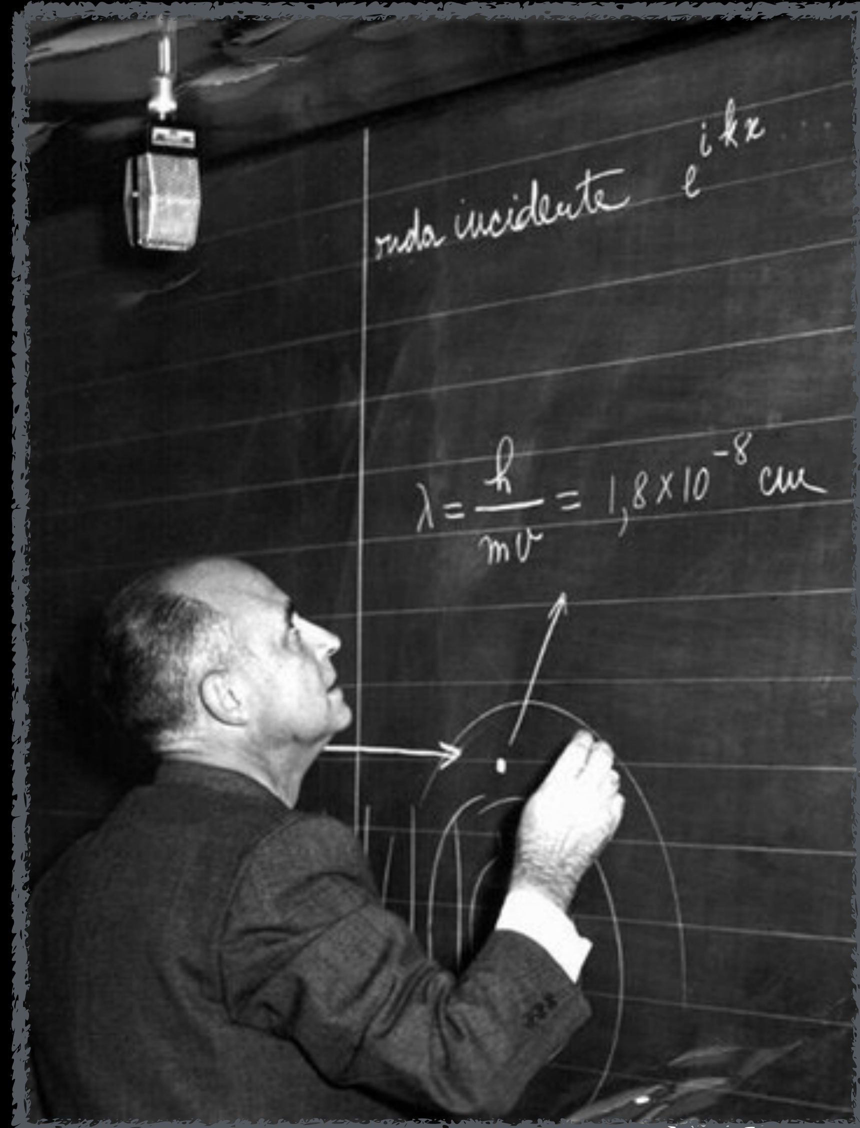
of $125.3 \pm 0.4(\mathrm{stat.}) \pm 0.5(\mathrm{syst.})$ GeV.
with spin different from one

... including its mass.

Wolfgang Pauli
1930
(proposal)



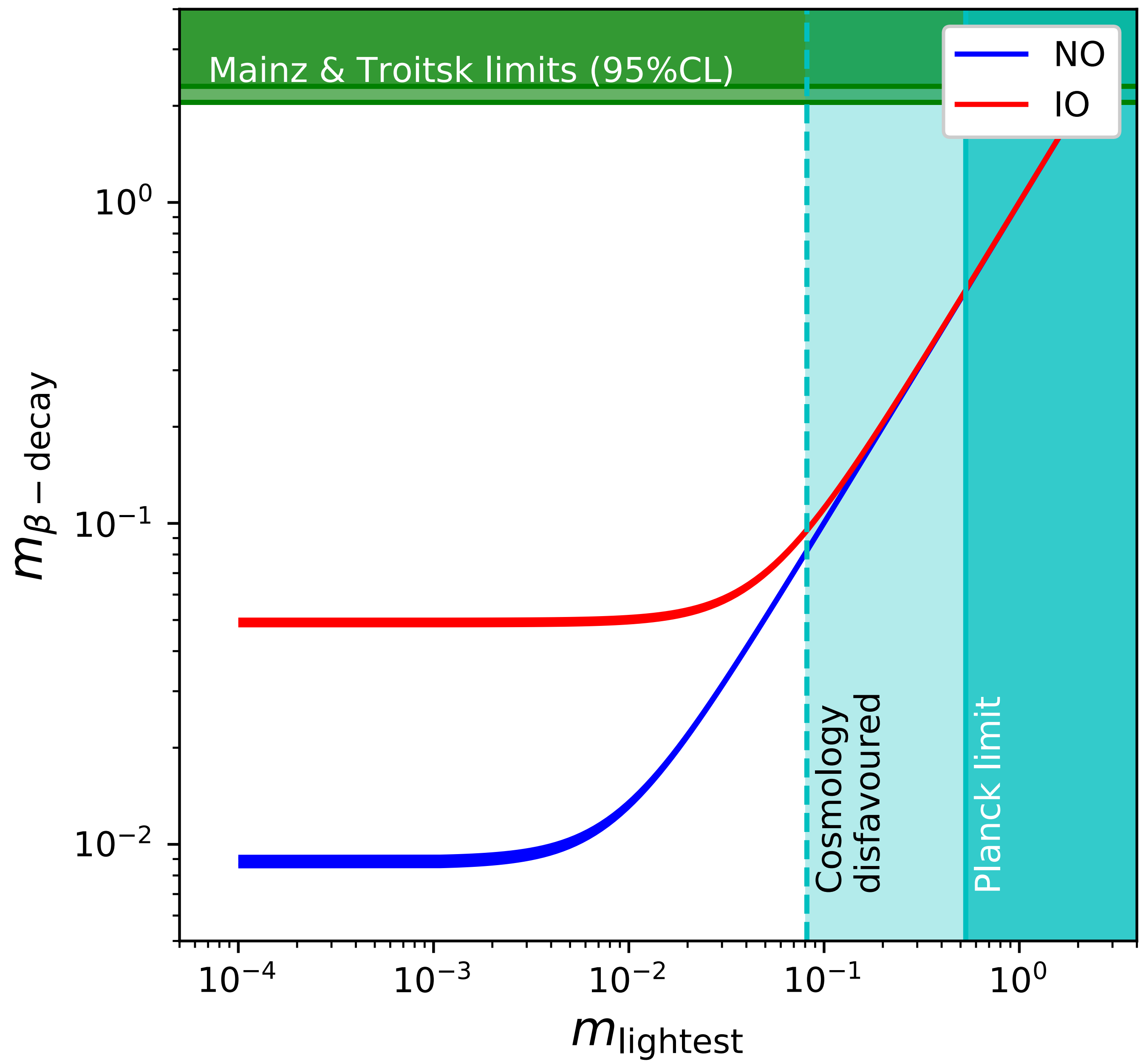
Enrico Fermi
1934
(theory)

Reines & Cowan
1956
(discovery)

26 years

One would imagine as similar pattern would unfold for all particle discoveries.

Landscape Outlook

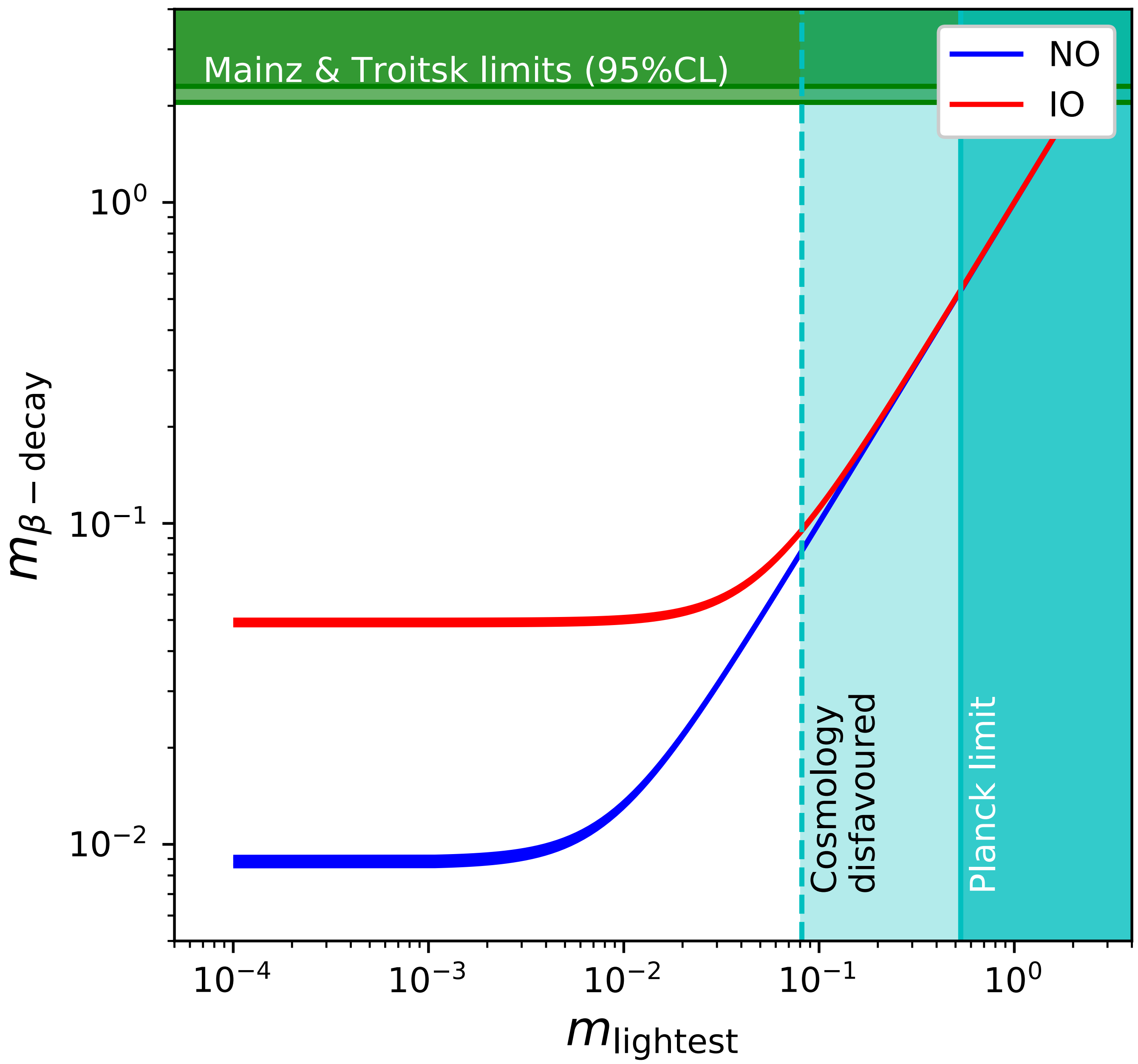


Created using www.nu-fit.org

With oscillations established, the scale of neutrino masses can be probed with several techniques.

Oscillation confirmation predicts we could see signals from cosmology, 0νbb, and direct kinematic searches.

Landscape Outlook



Created using www.nu-fit.org

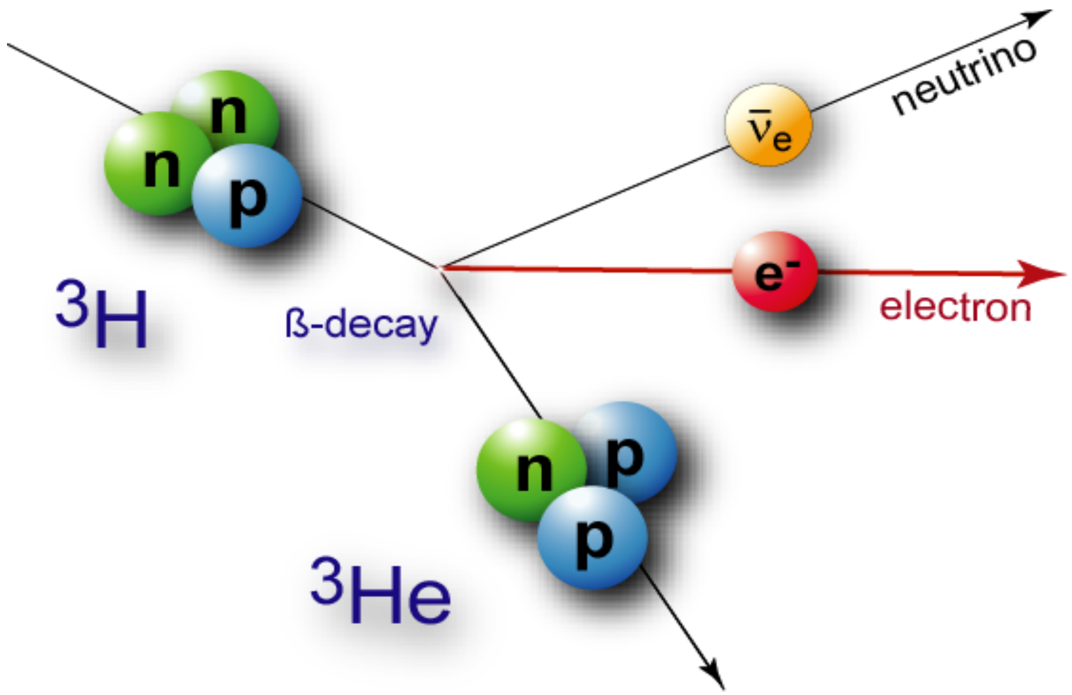
With oscillations established, the scale of neutrino masses can be probed with several techniques.

CMB Only:
Σm_ν < 140-590 meV

CMB + LSS:
Σm_ν < 120 meV

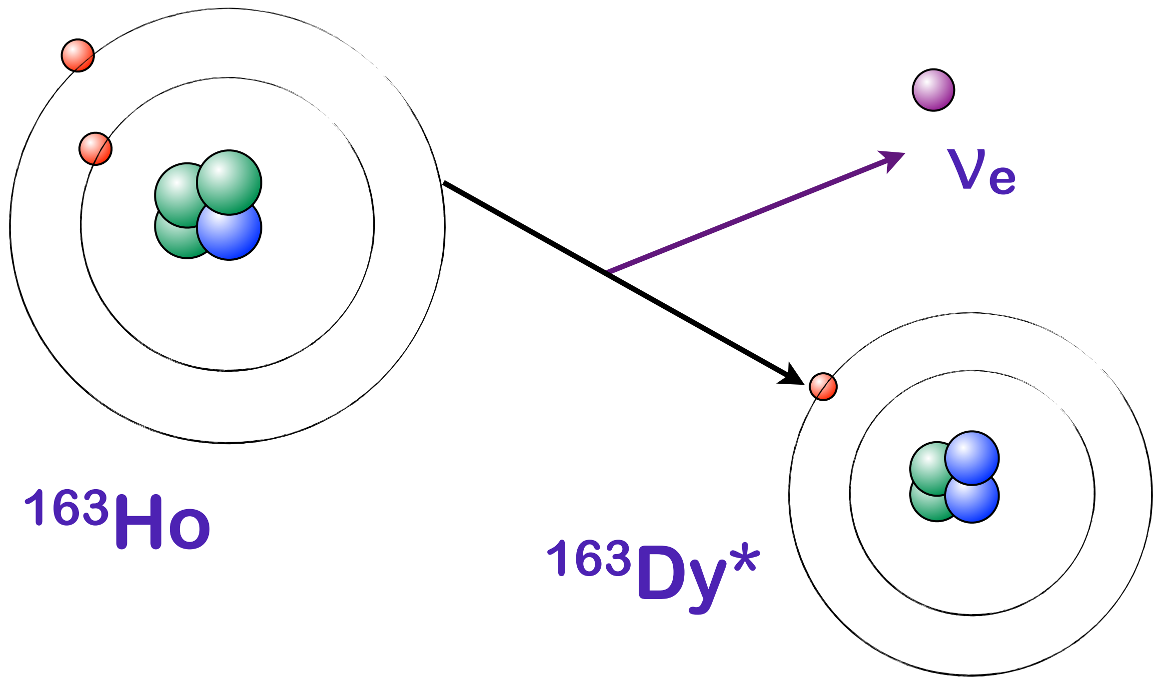
Future:
Σm_ν < 40-60 meV

Tritium beta decay



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

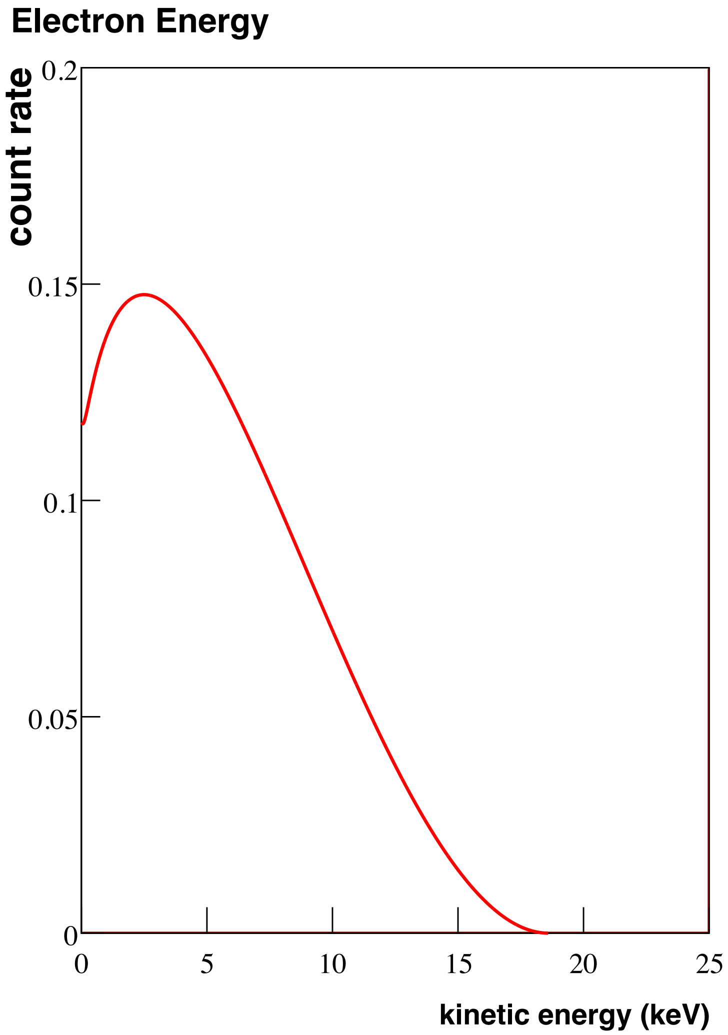
Holmium electron capture



$$^{163}\mathrm{Ho} + e^- \rightarrow {}^{163}\mathrm{Dy}^* + \nu_e$$

Kinematic spectra from beta decay or electron capture embed the neutrino mass near the endpoint.

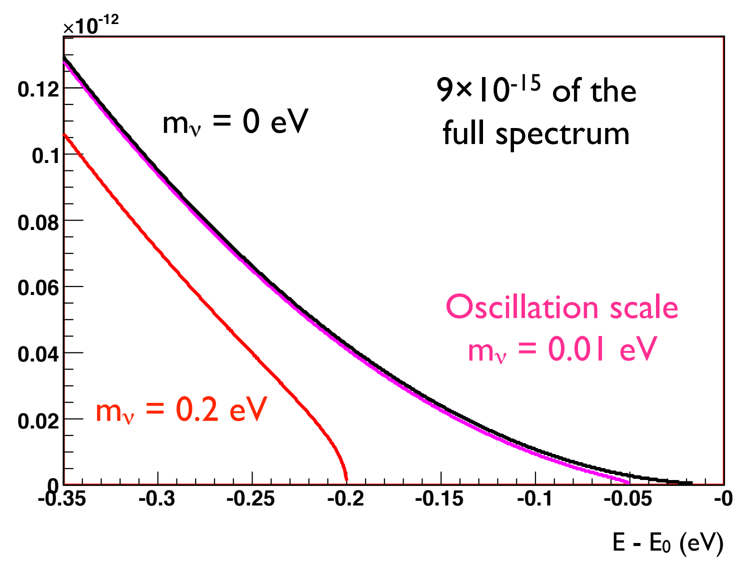
Kinematic determination of neutrino mass (dispersion relation).

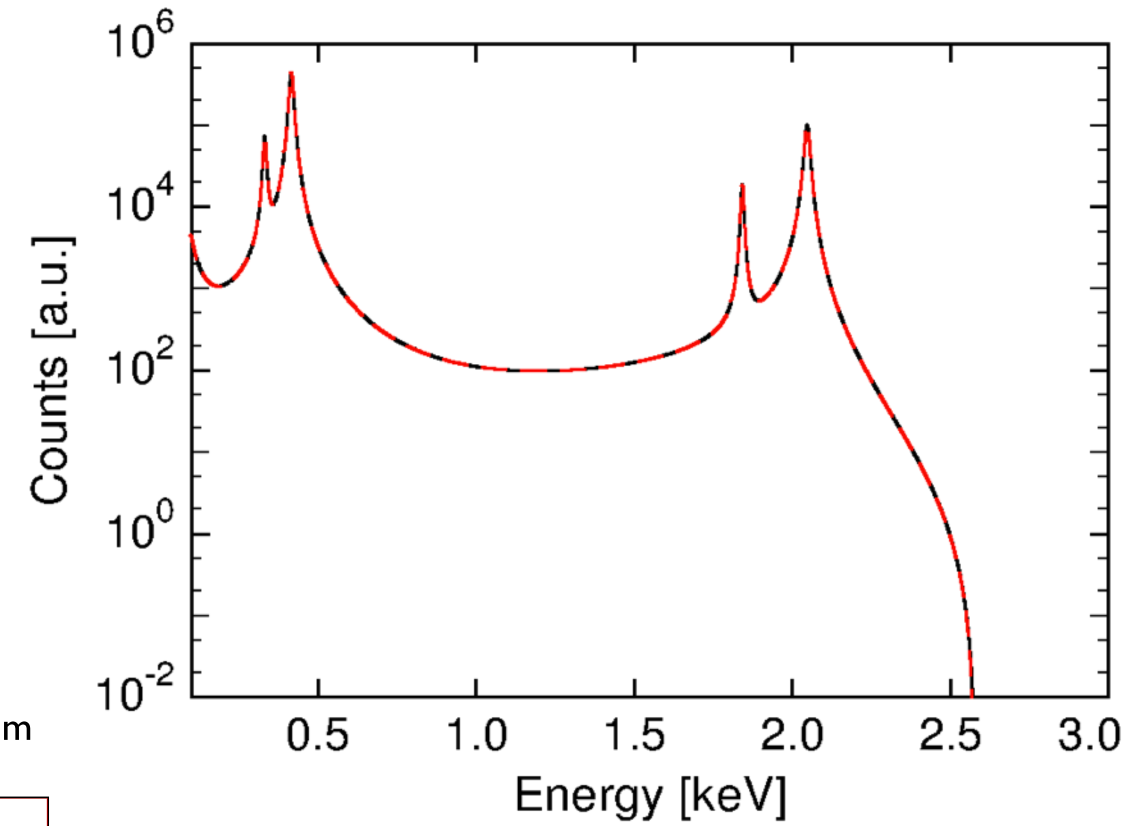


$$\dot{N} \propto p_\nu E_\nu$$

In both cases, differential spectrum depends on the neutrino momentum.

Endpoint of the Tritium β-decay Spectrum





$$m_\beta^2 = \sum_i |U_{ei}|^2 m_{\nu i}^2$$

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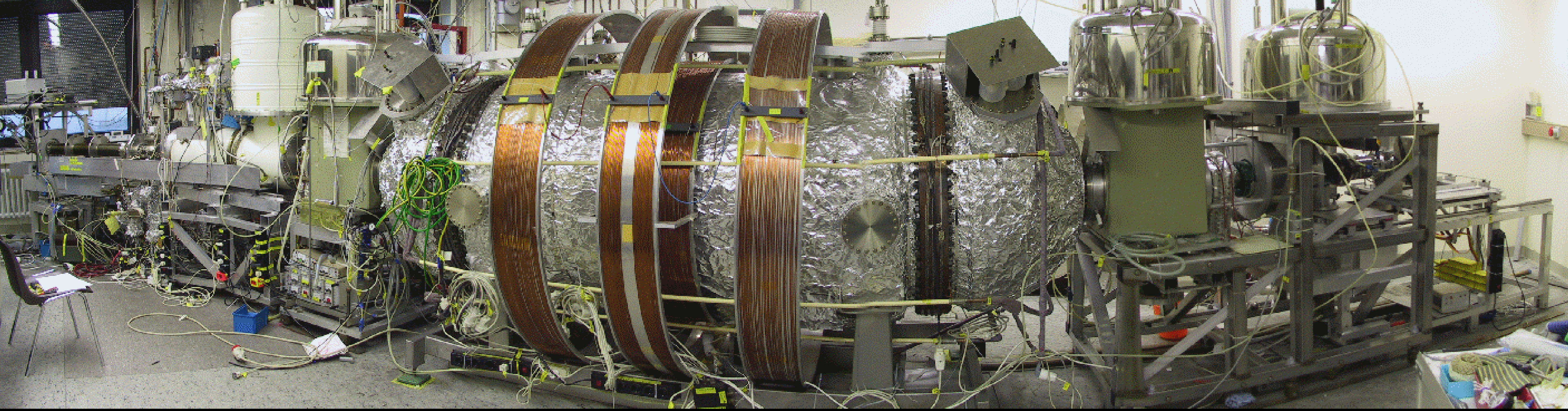
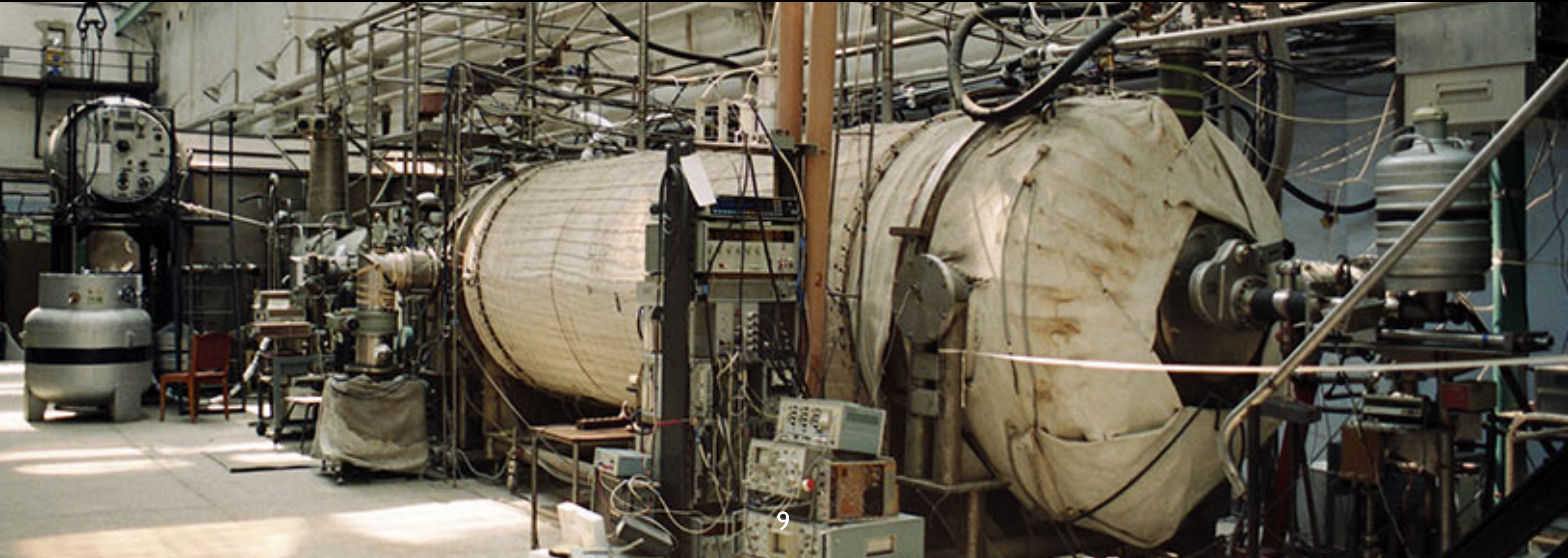


Predecessors: Mainz & Troitsk (Limit m_β < 2 eV 90% C.L.)



Modern-day Techniques

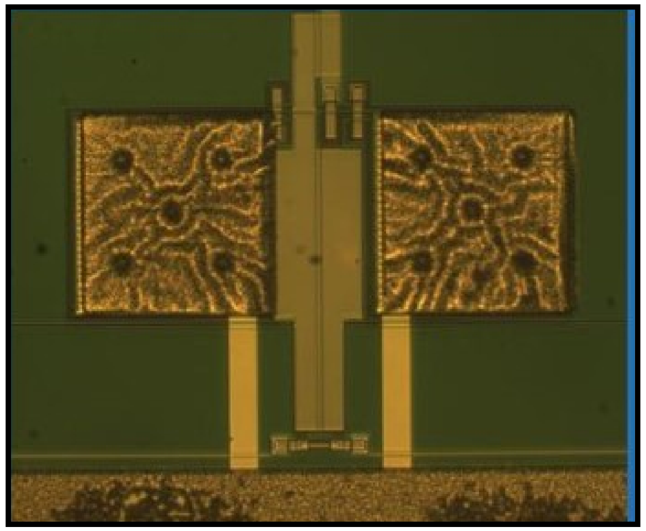
MAC-E Technique

Magnetic Adiabatic Collimation with Electrostatic Filtering

(KATRIN)

Calorimetry

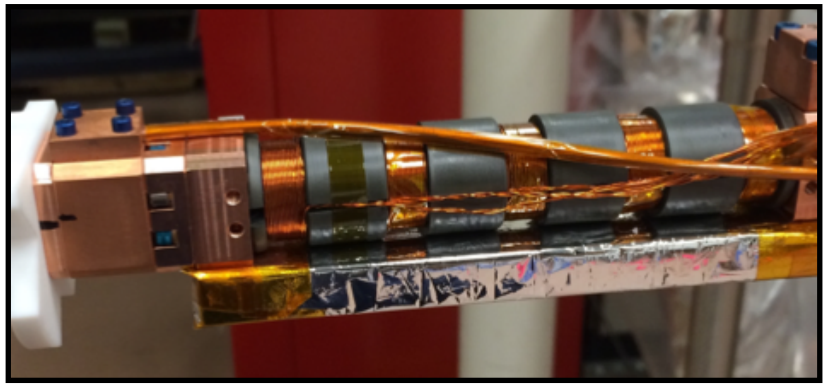
Bolometric measurement of ^{163}Ho



(ECHO & HOLMES)

Frequency

Cyclotron Resonance Emission Spectroscopy



(Project 8)

Frequency

(Project 8)

PROJECT 8

Frequency Approach

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

Frequency

(Project 8)

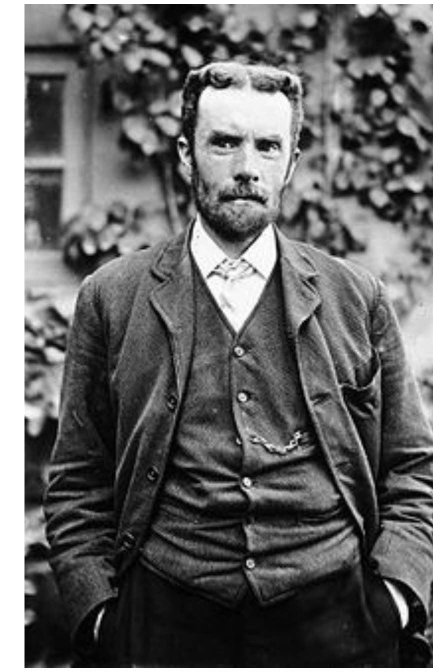
PROJECT 8

Frequency Approach

$$^3\text{H} \rightarrow \, ^3\text{He}^+ + e^- + \bar{\nu}_e$$

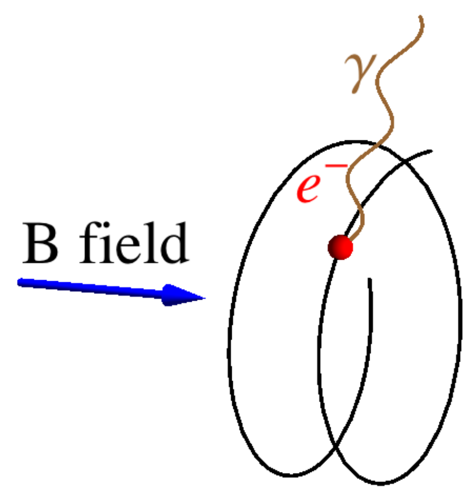
A. L. Schawlow

"Never measure anything but frequency."



O. Heaviside

Use frequency measurement of cyclotron radiation from single electrons:



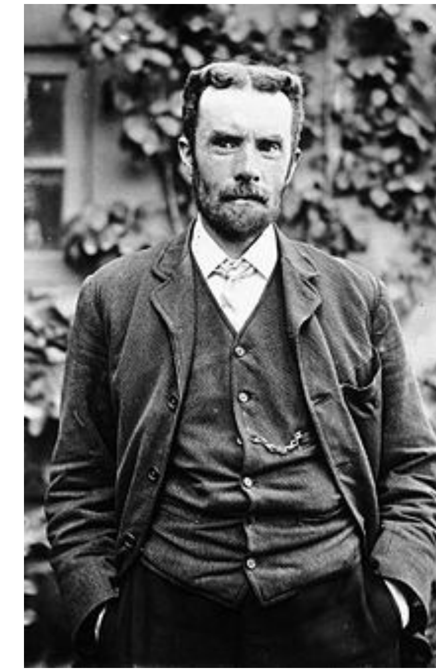
- Source transparent to microwave radiation
- No e- transport from source to detector
- Highly precise frequency measurement

B. Monreal and JAF, Phys. Rev D80:051301

Frequency

(Project 8)

"Never measure anything but frequency."



A. L. Schawlow

O. Heaviside

Use frequency measurement of cyclotron radiation from single electrons:

$$f_c = \frac{f_{c,0}}{\gamma} = \frac{1}{2\pi}\frac{eB}{m_e c^2 + E_{\rm kin}}$$

- Highly precise frequency measurement (~26 GHz).
- Small, but detectable power emitted.

$$P\,(17.8\,\mathrm{keV}, 90^\circ, 1\,\mathrm{T}) = 1\,\mathrm{fW}$$
$$P\,(30.2\,\mathrm{keV}, 90^\circ, 1\,\mathrm{T}) = 1.7\,\mathrm{fW}$$

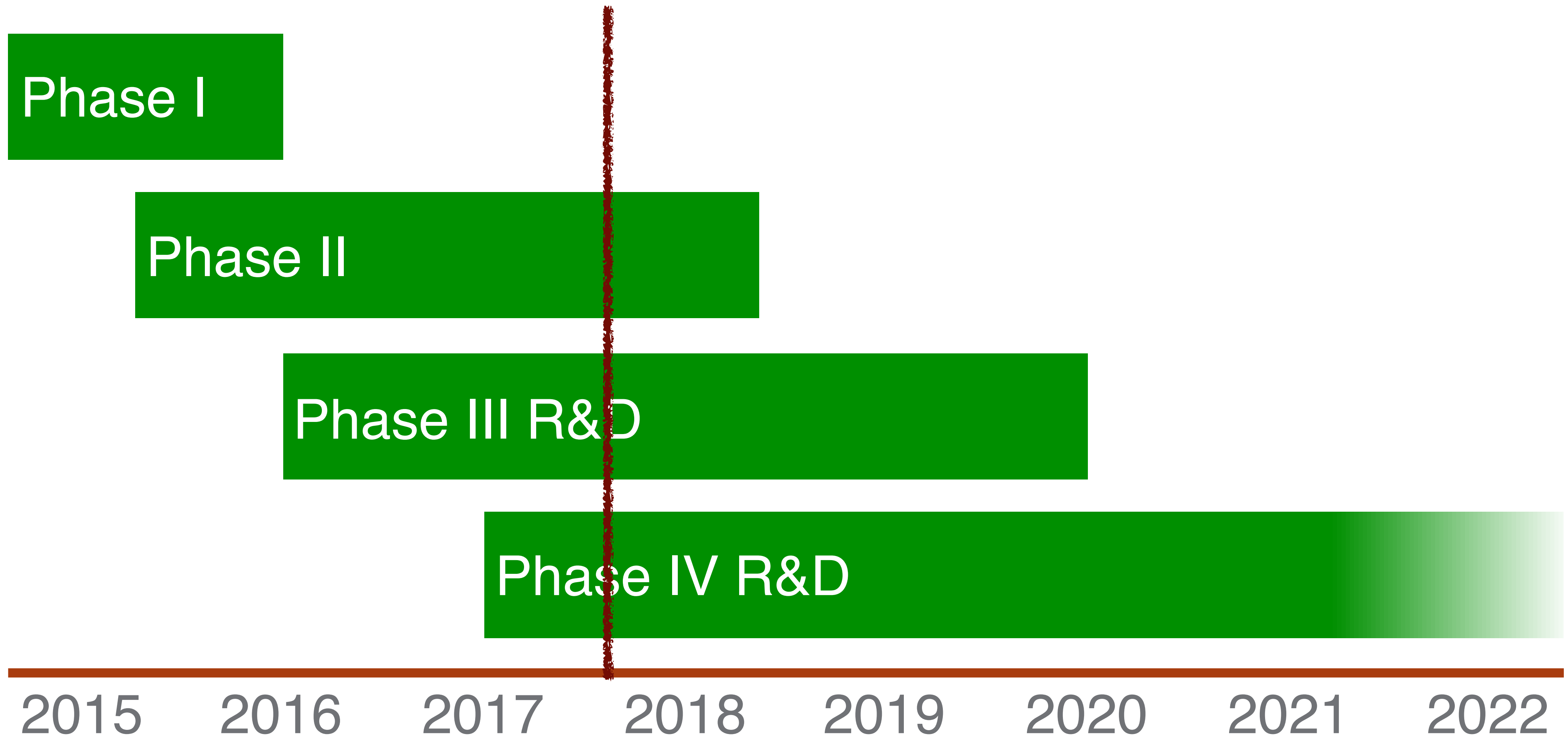
B. Monreal and JAF, Phys. Rev D80:051301

PROJECT 8

Frequency Approach

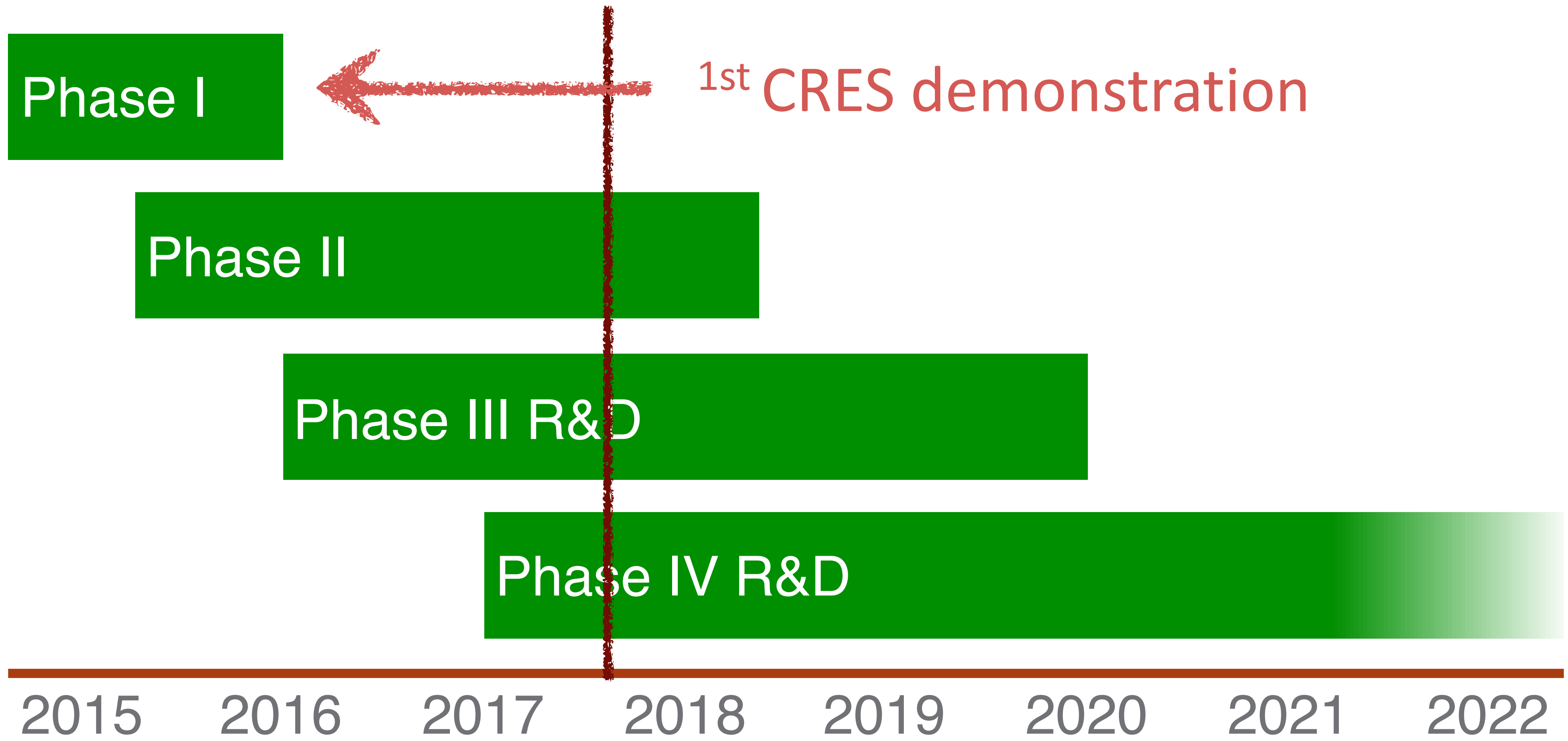
$$^3\mathrm{H} \rightarrow {}^3\mathrm{He}^+ + e^- + \bar{\nu}_e$$

Project 8: A Phased Approach



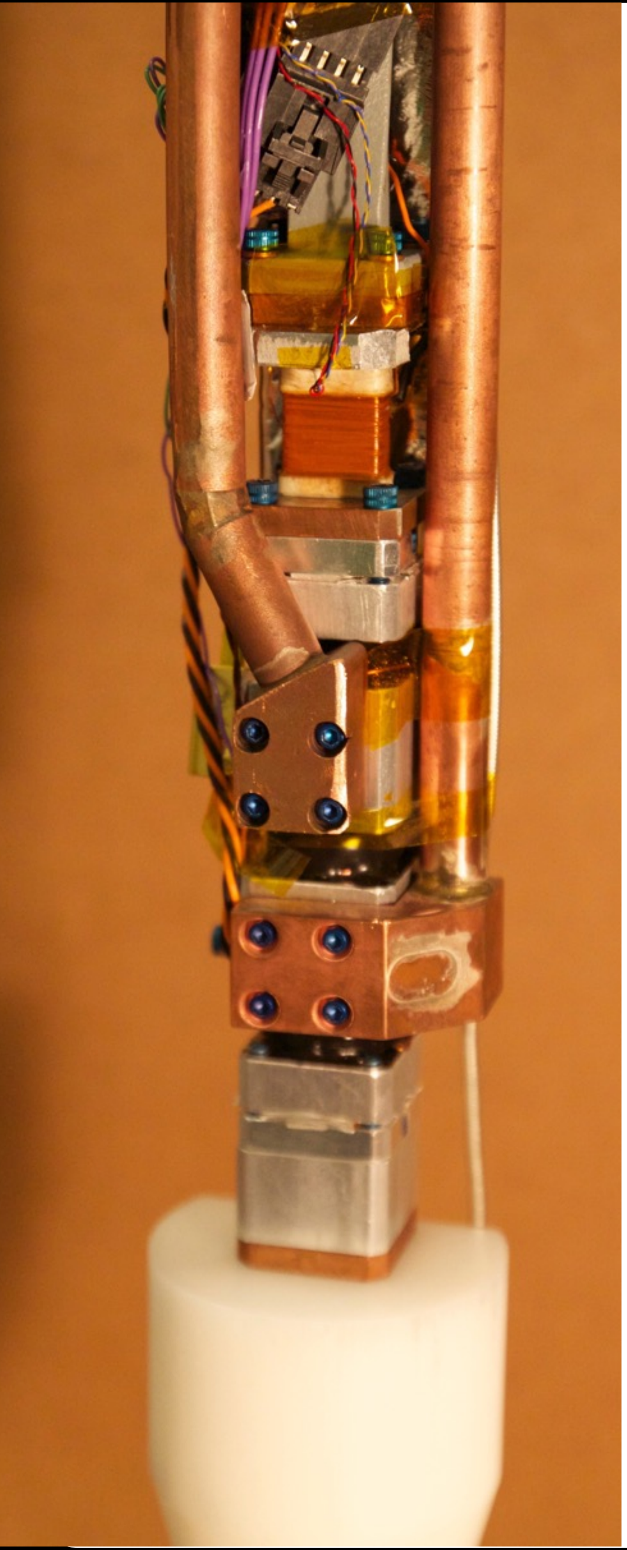
A phased R&D approached is used to advance the sensitivity and understand scaling & systematics.

Project 8: A Phased Approach



A phased R&D approached is used to advance the sensitivity and understand scaling & systematics.

Phase I Demonstration: ^{83m}Kr



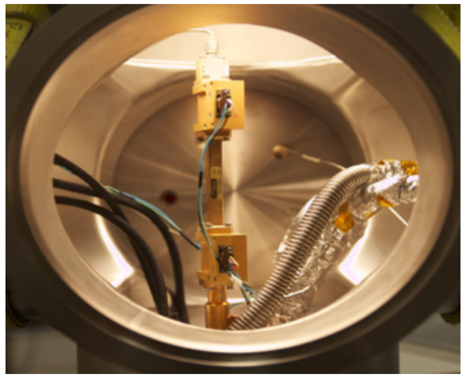
Copper waveguide

Kr gas lines

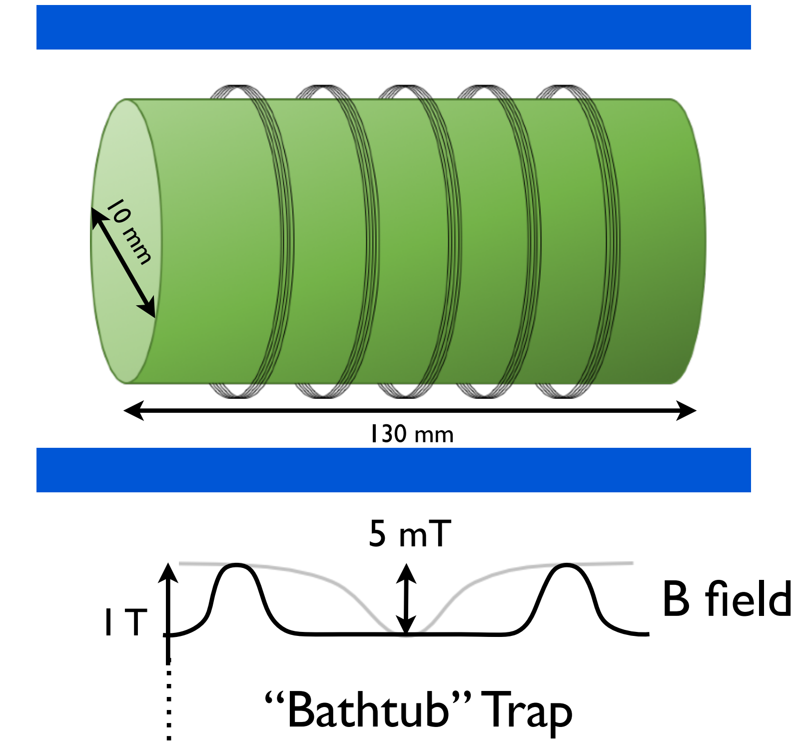
Magnetic bottle coil

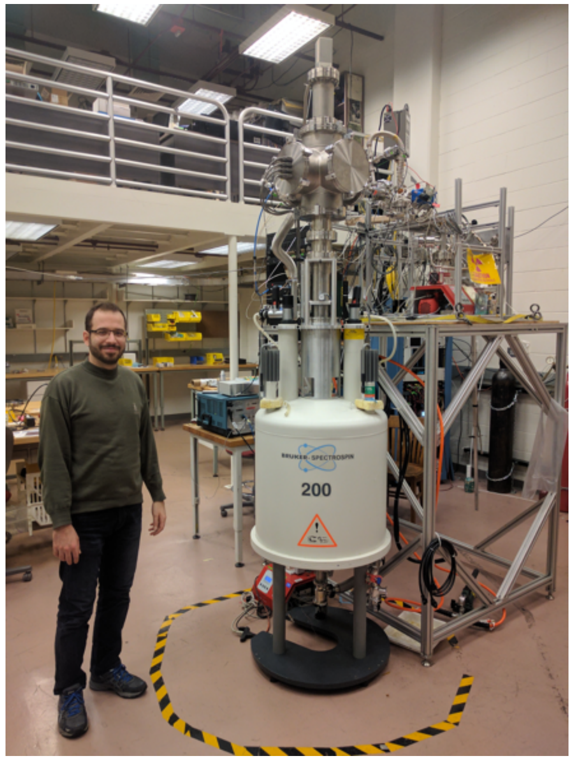
Gas cell

Test signal injection port



- Waveguide insert with small magnetic trapping coil.
- Use ^{83m}Kr gas as calibration source; mono-energetic lines at 17 keV and 30 keV.



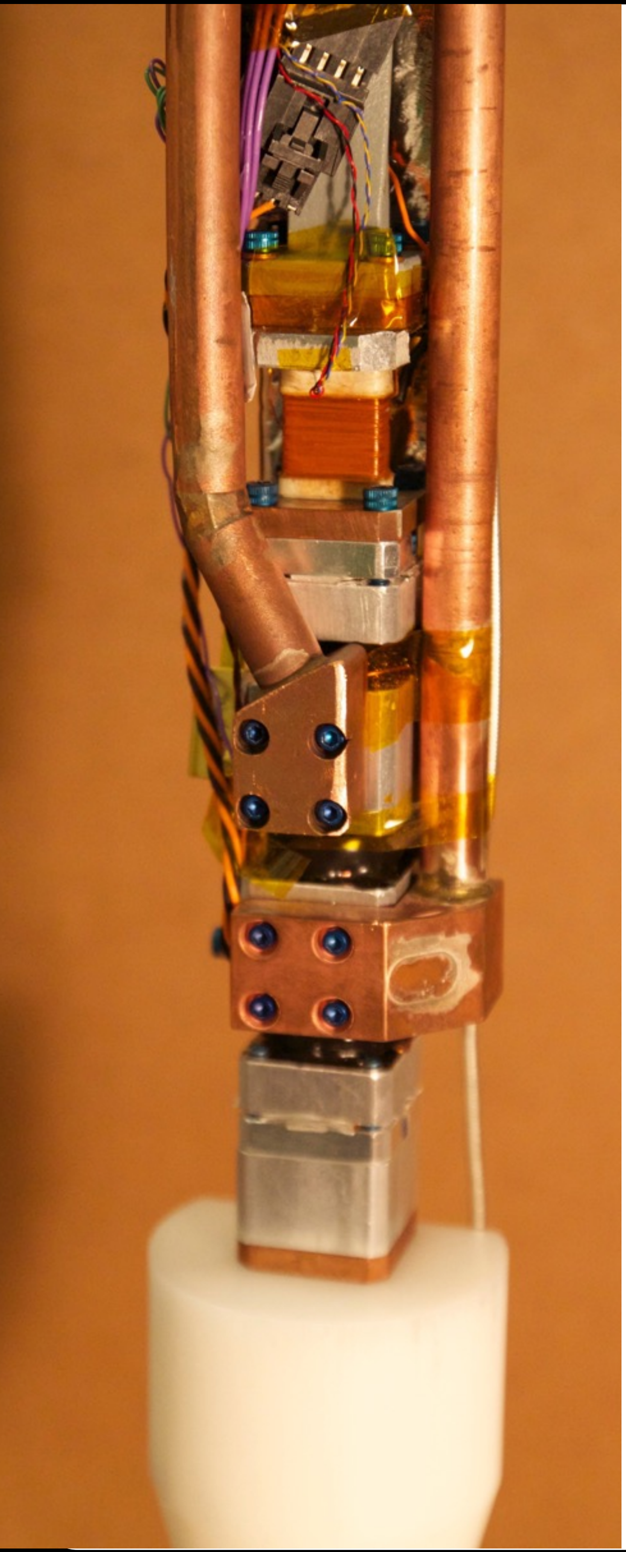


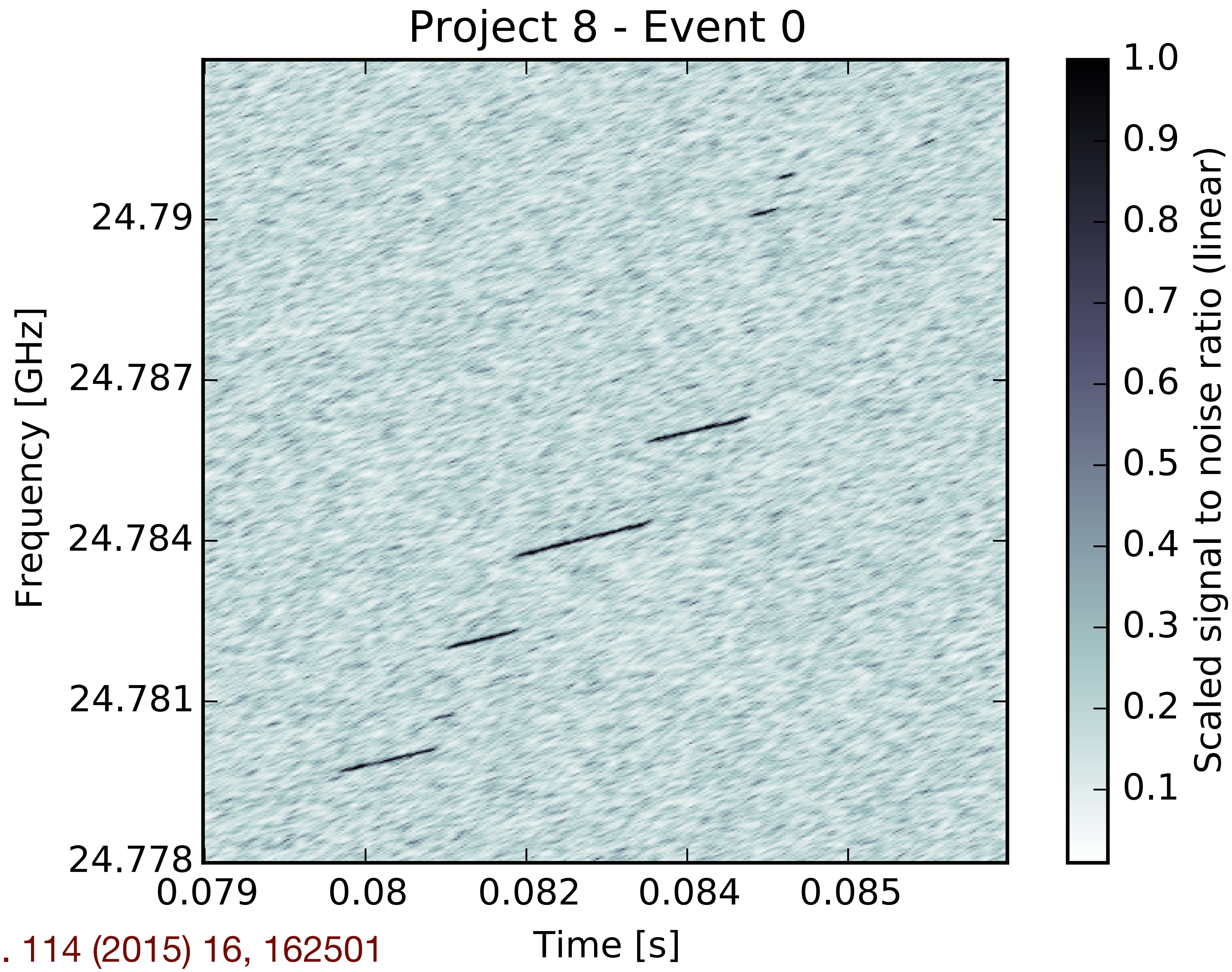
Cyclotron frequency coupled directly to standard waveguide at 26 GHz, located inside bore of NMR 1 Tesla magnet.

Magnetic bottle allows for trapping of electron within cell for measurement.

Phase I

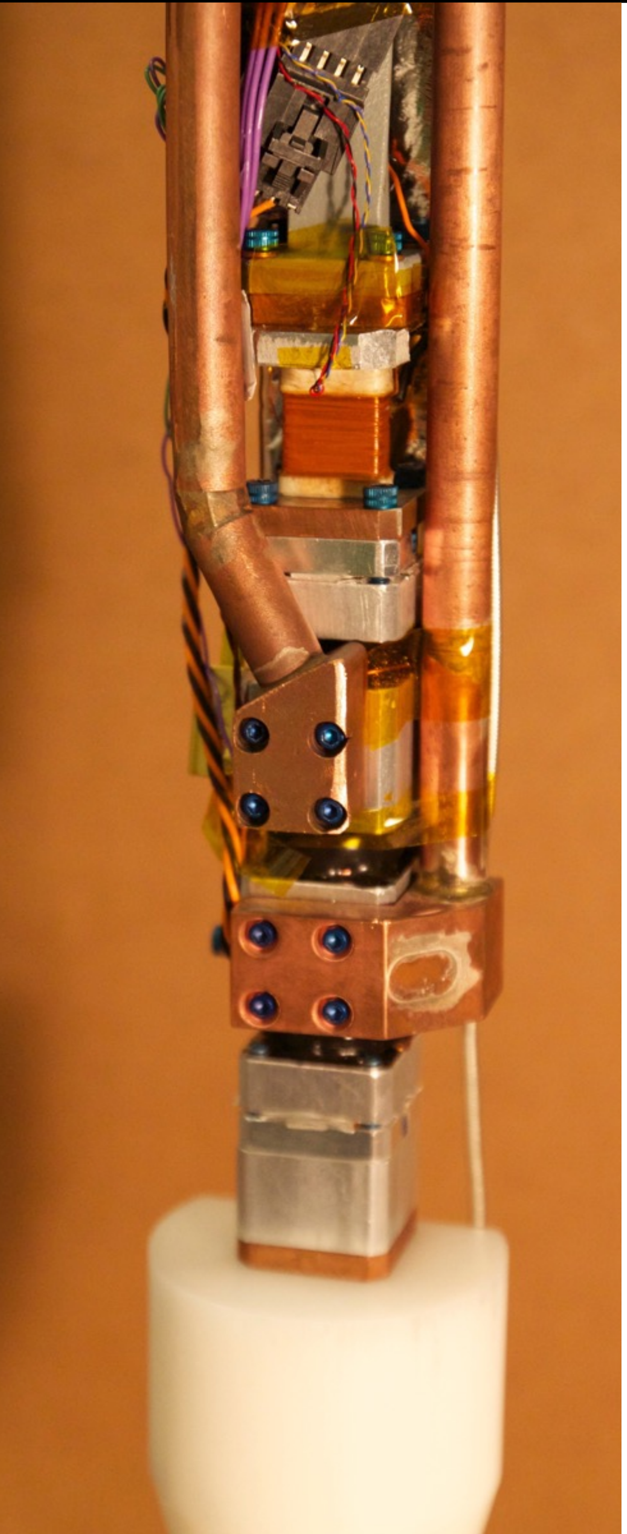
Demonstration: ^{83m}Kr





Phys. Rev. Lett. 114 (2015) 16, 162501

Characteristics of electron cyclotron frequency signature readily detected.



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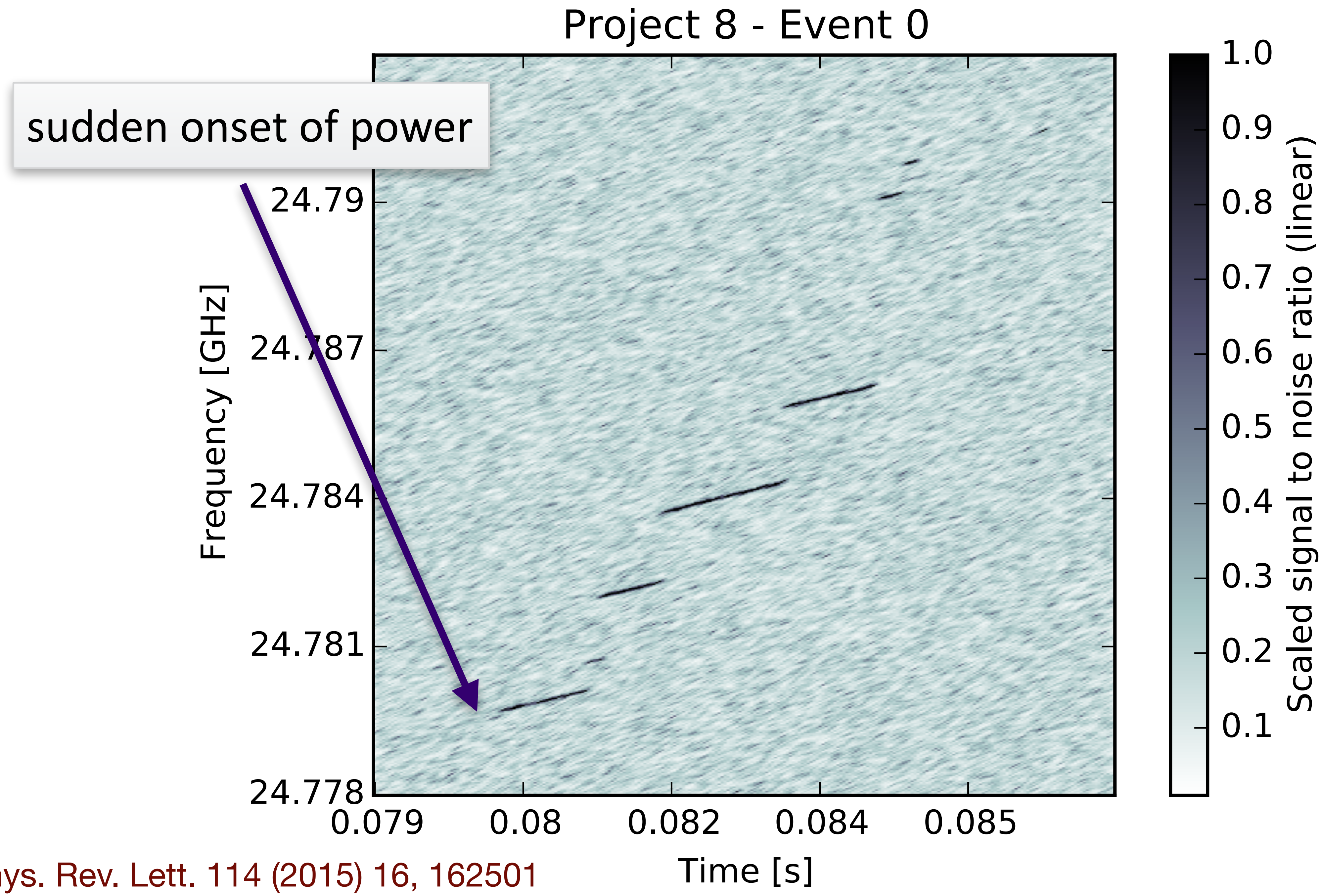

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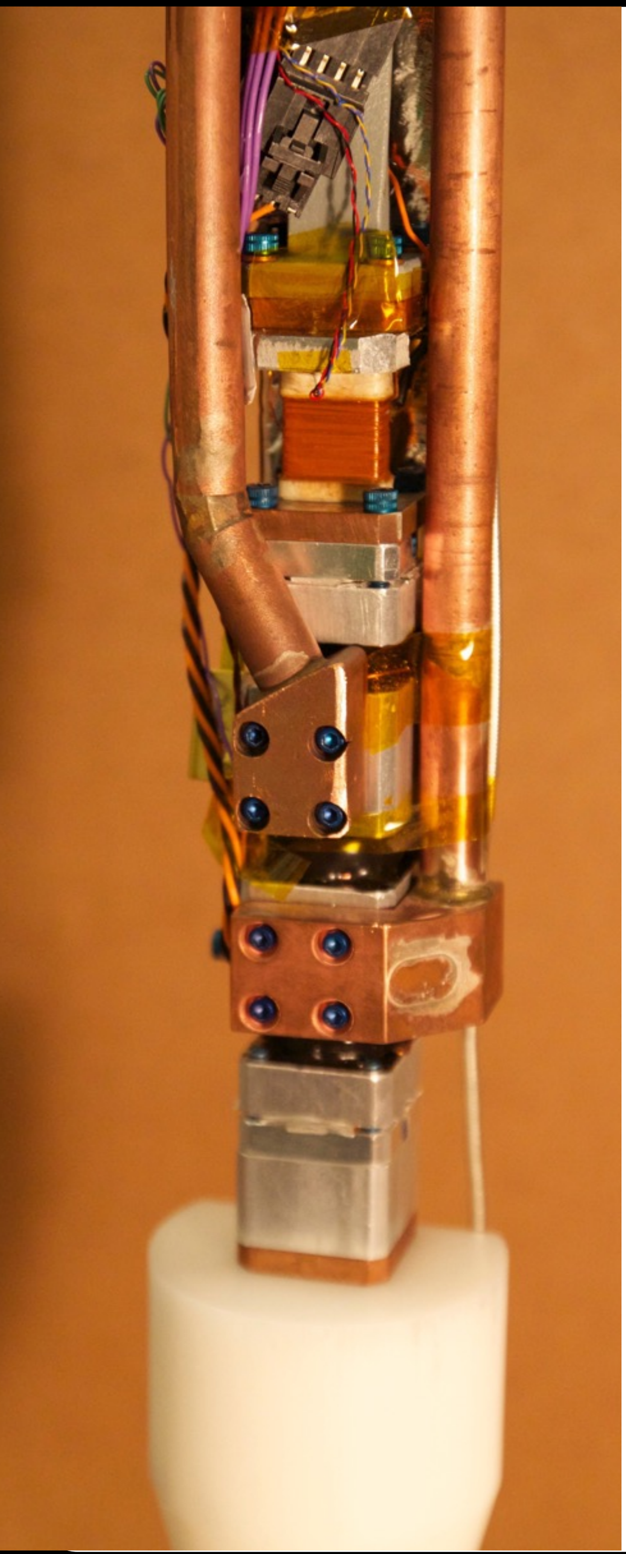

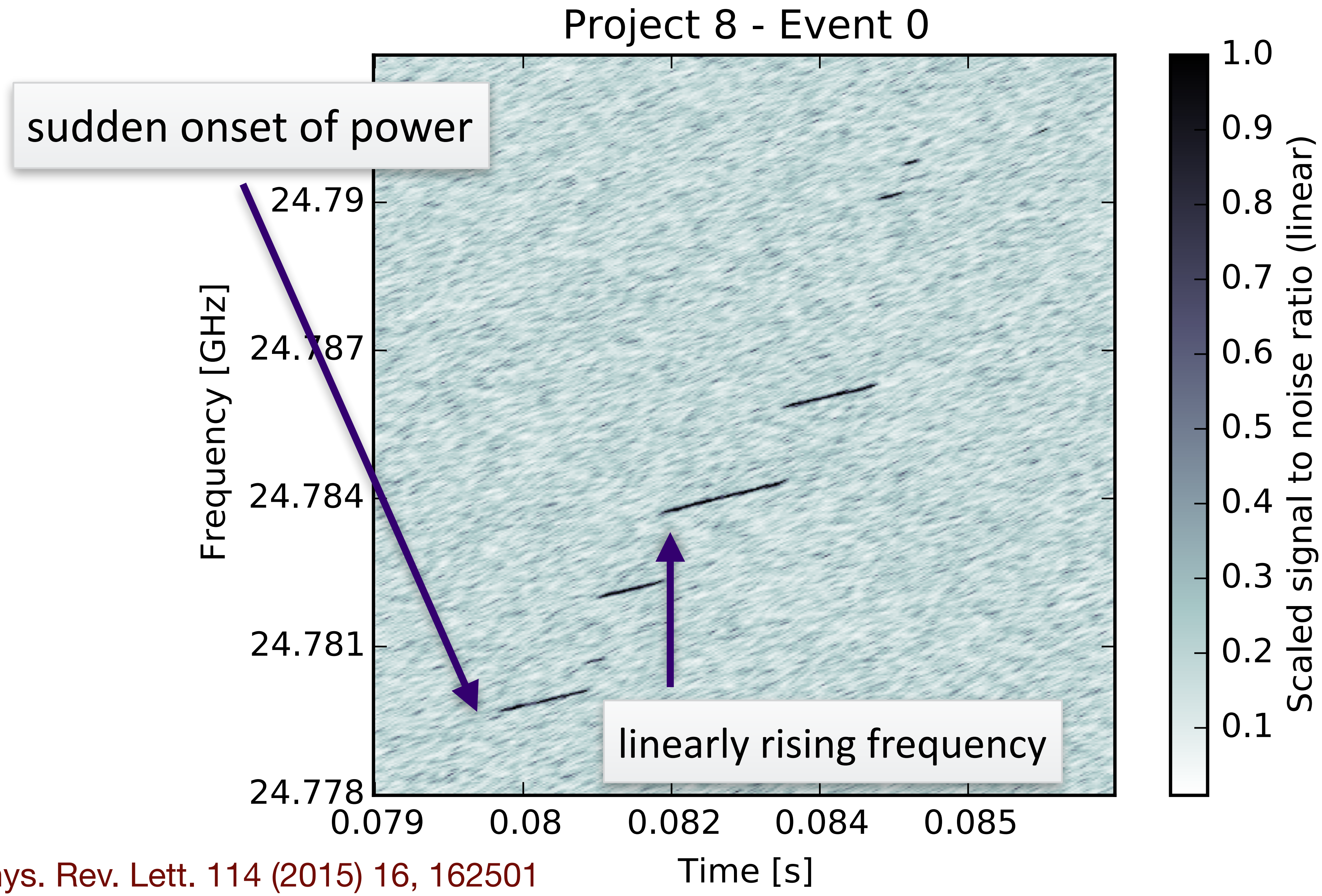

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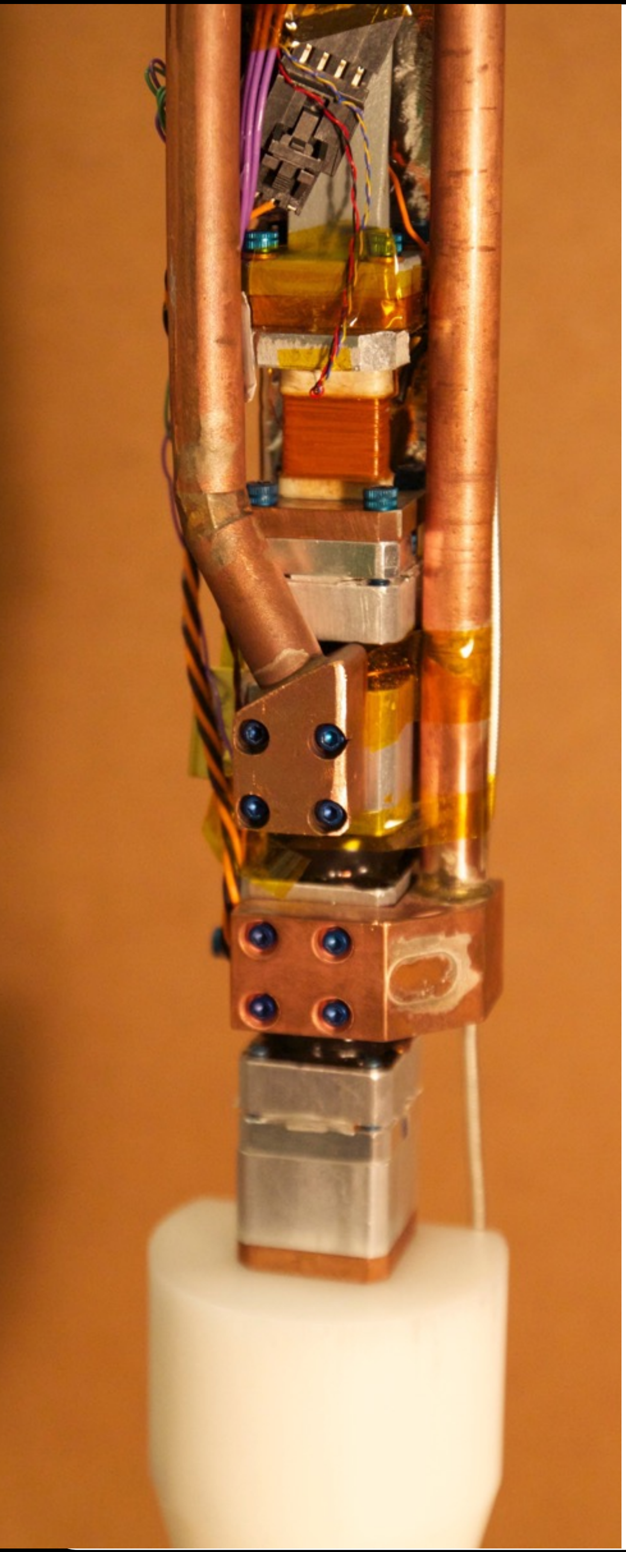

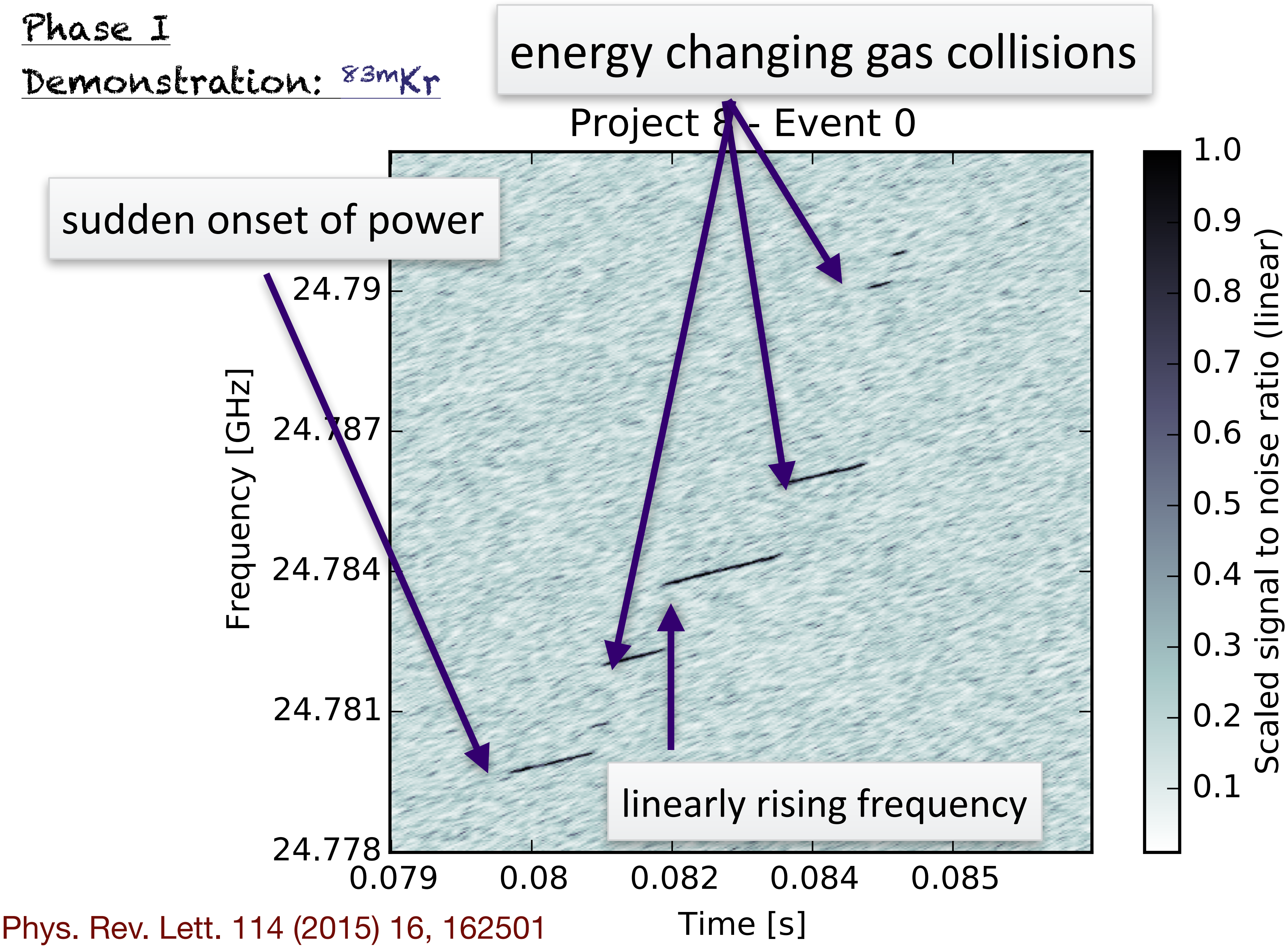

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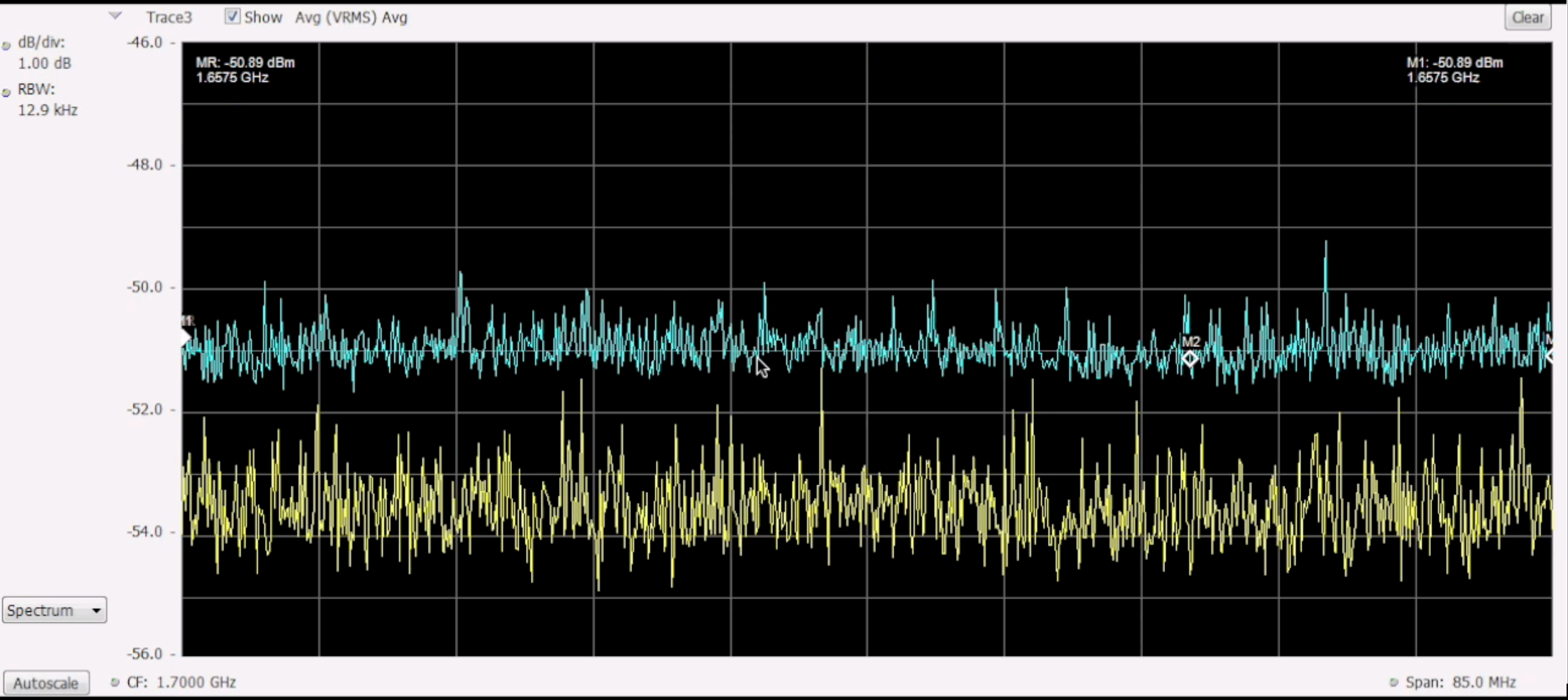
Characteristics of electron cyclotron frequency signature readily detected.

Collecting events now routine...



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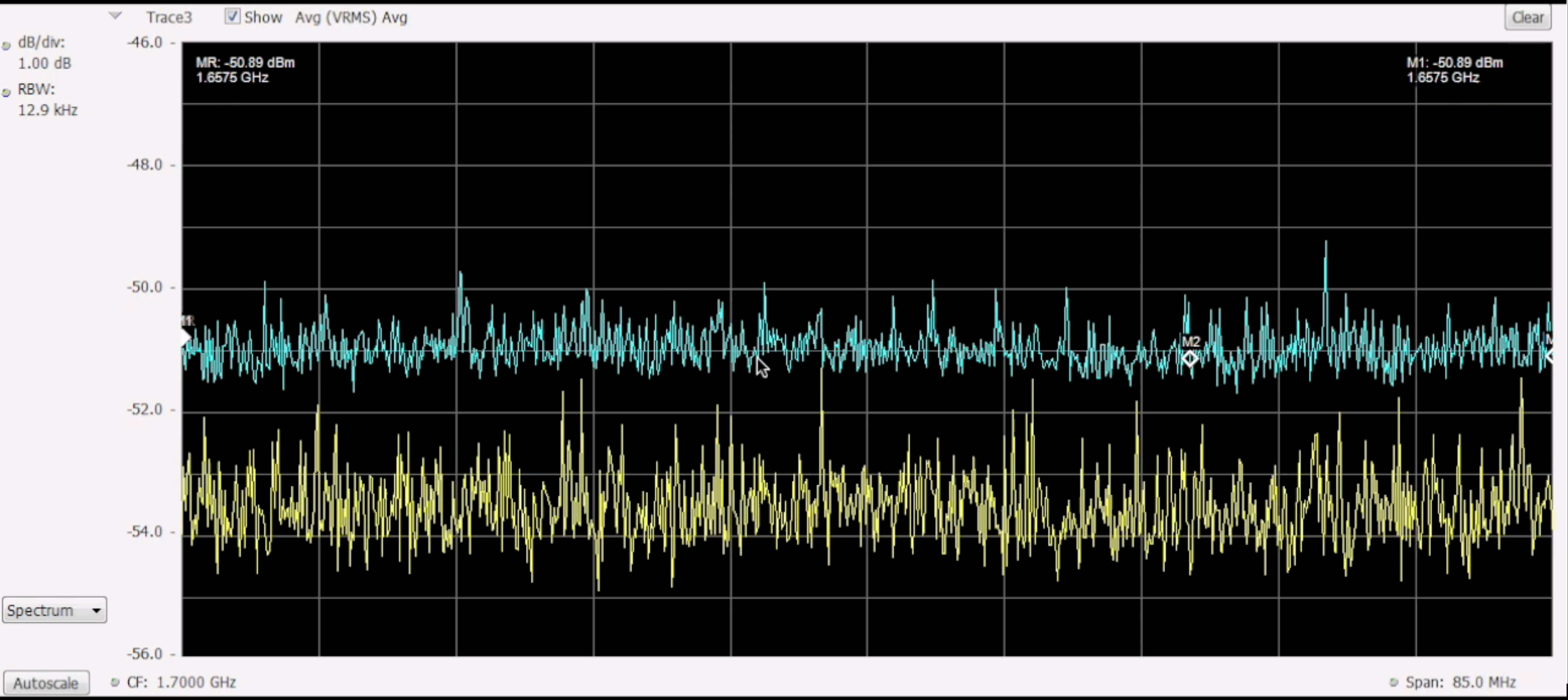
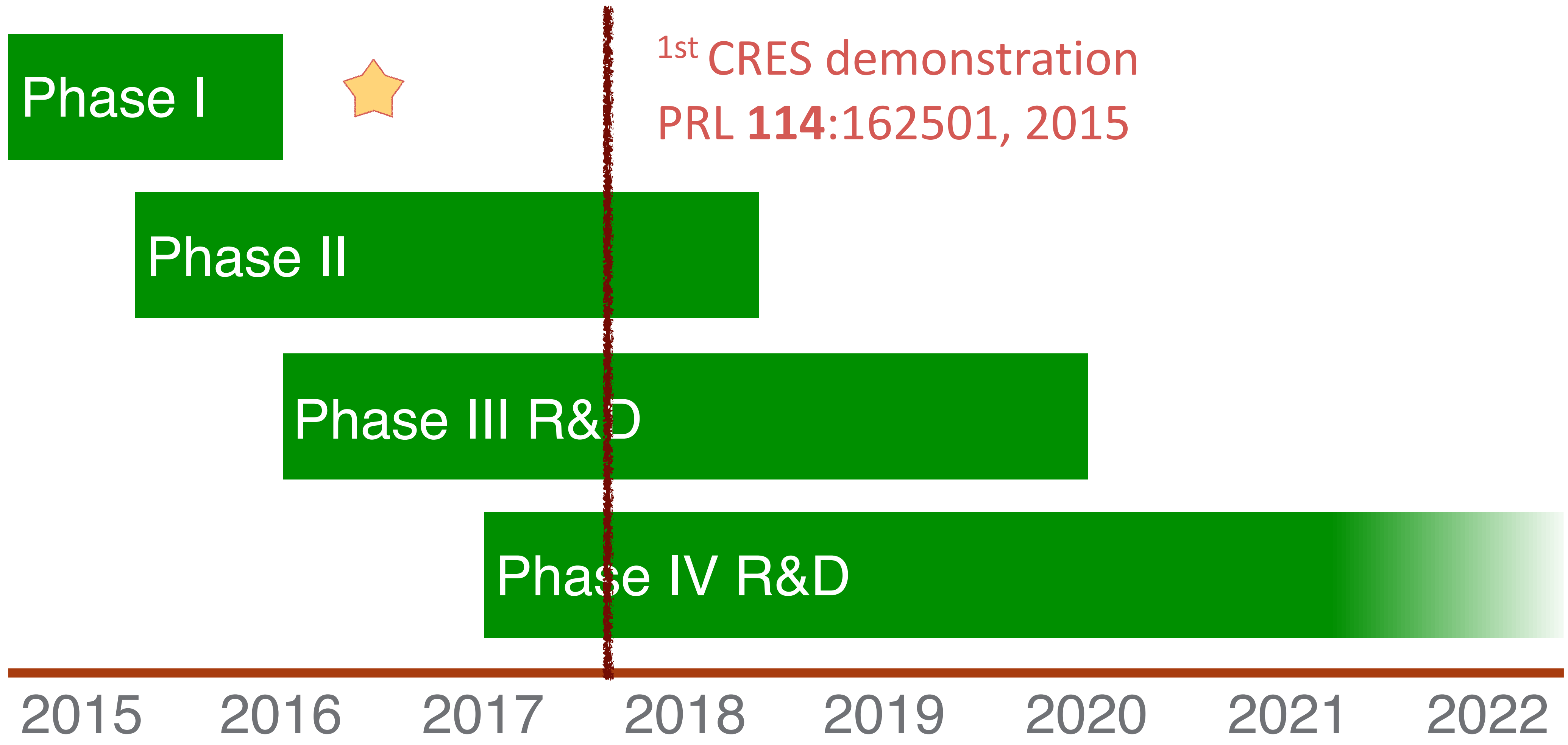


Project 8: A Phased Approach



A phased R&D approached is used to advance the sensitivity and understand scaling & systematics.

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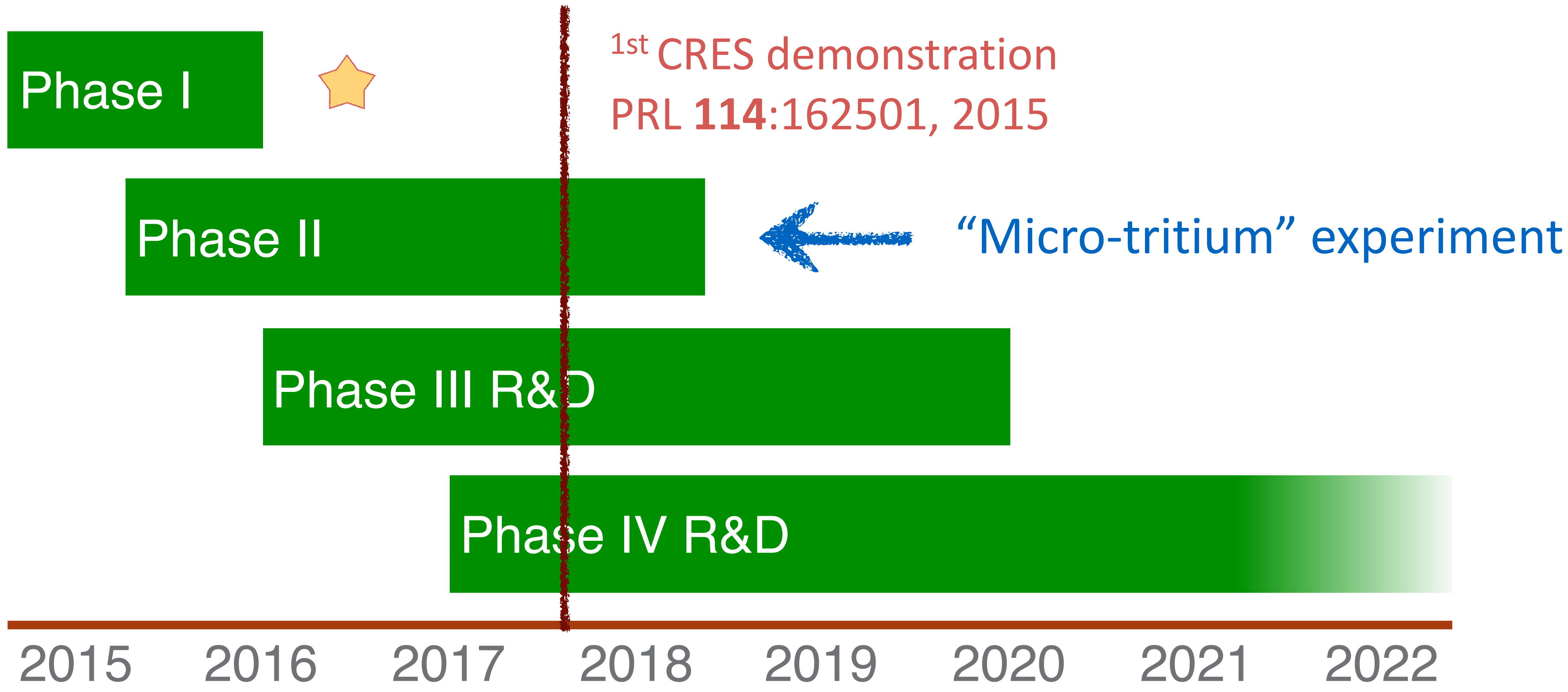
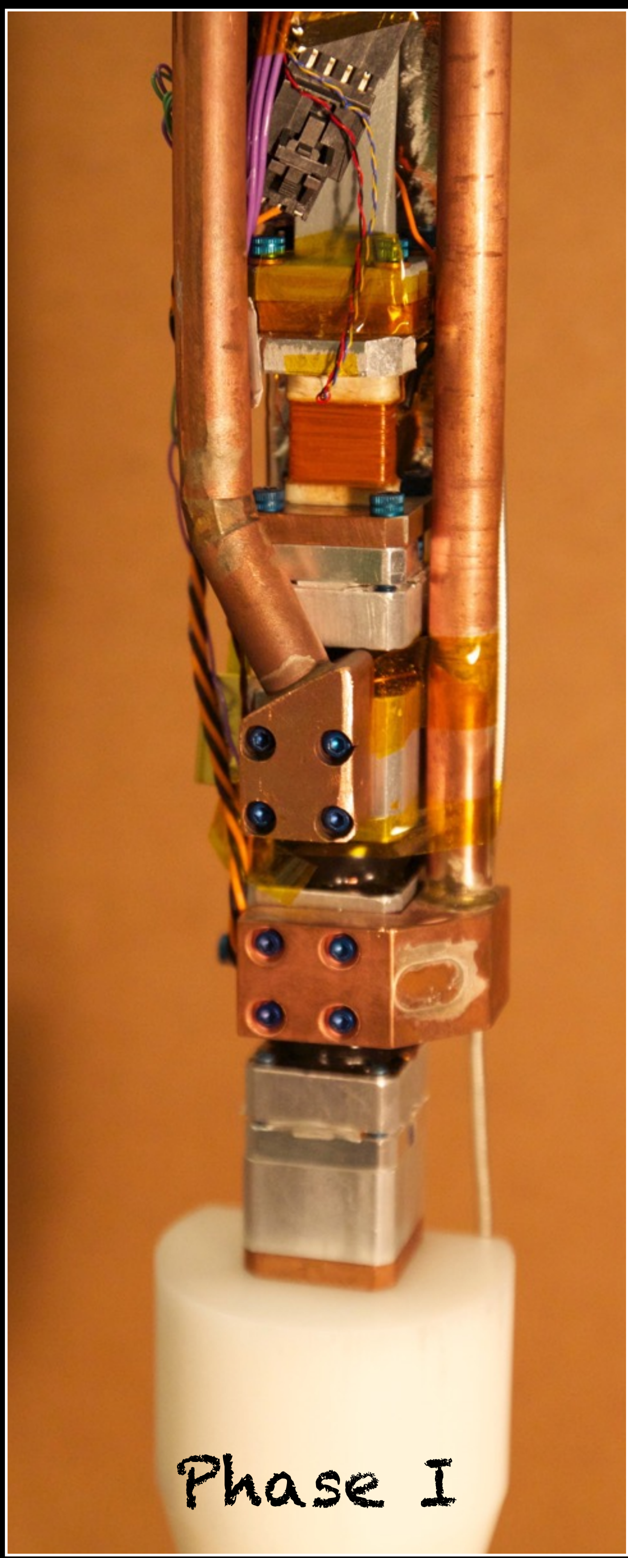


A phased R&D approached is used to advance the sensitivity and understand scaling & systematics.

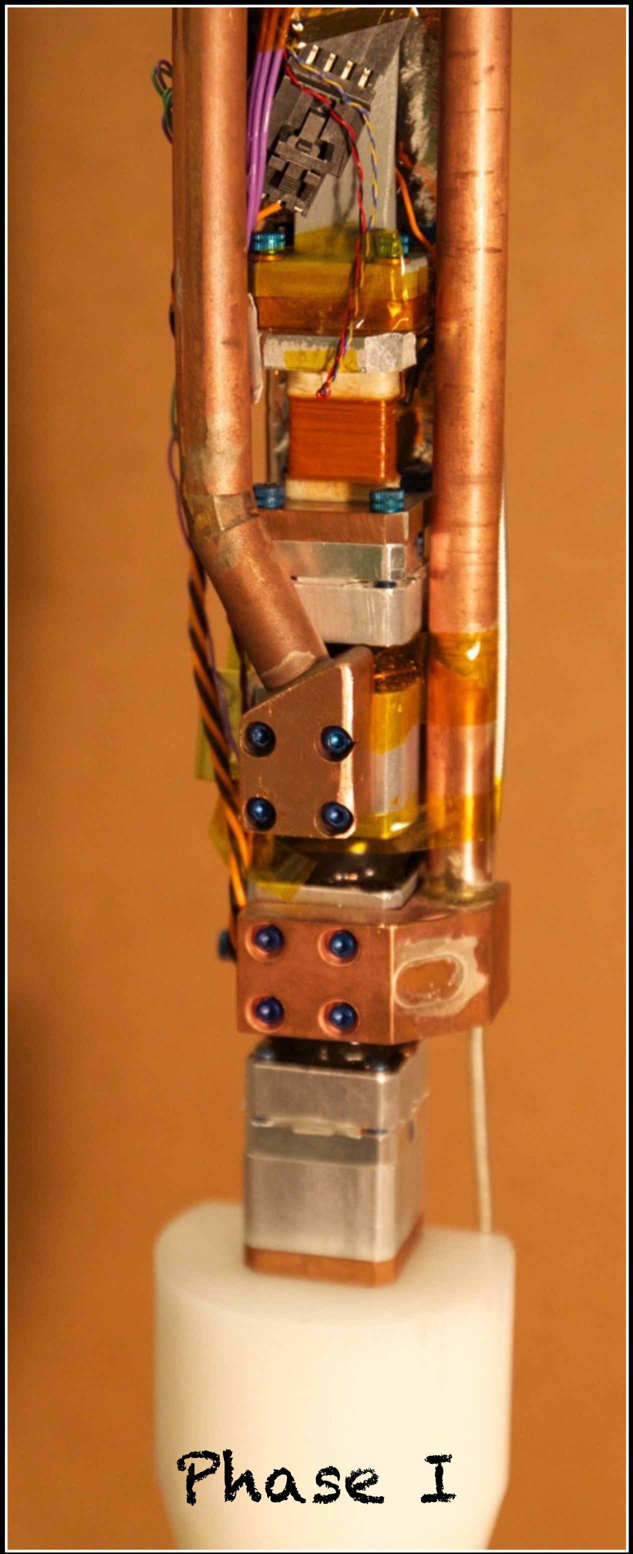
Phase II: Micro-Tritium (with Kr co-magnetometer)



We want a first demonstration of using CRES technique using tritium.

Apply the Kr as a co-magnetometer to the tritium spectrum

Phase II: Micro-Tritium (with Kr co-magnetometer)



Waveguide

Rectangular

Circular (greater volume!)

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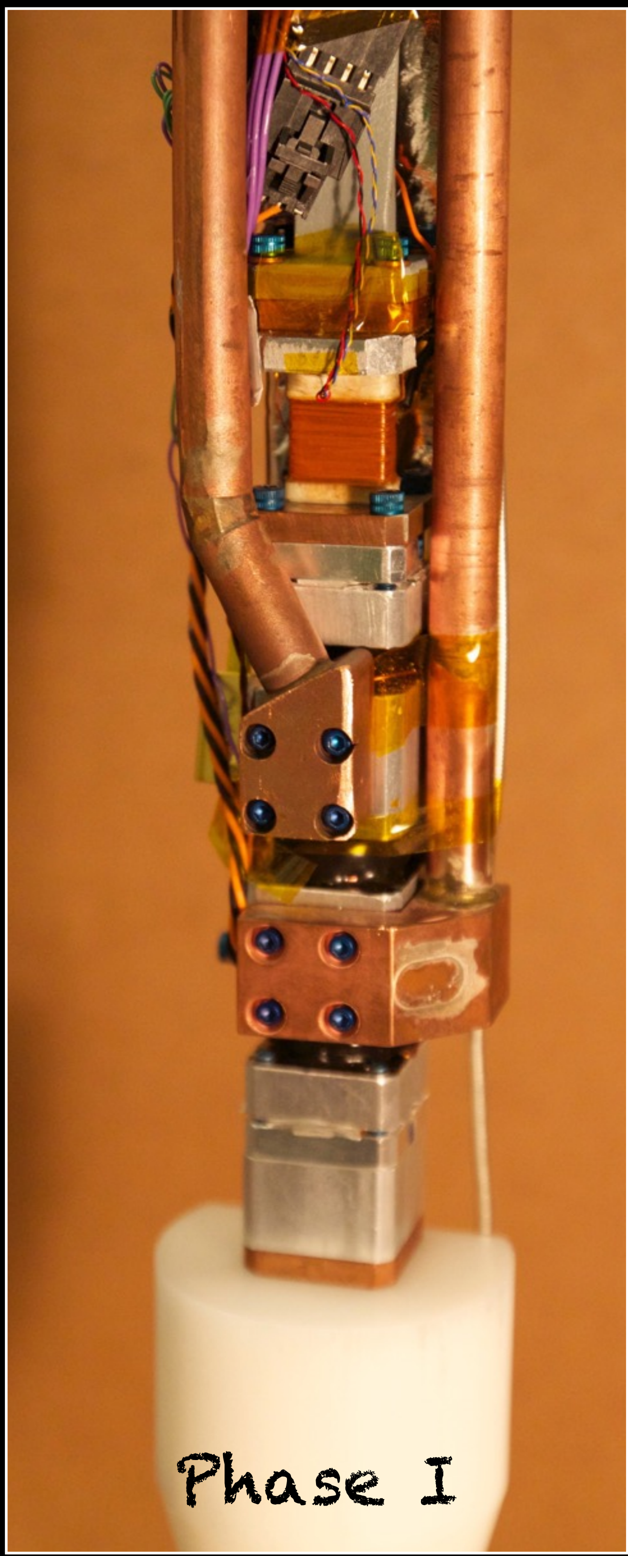

Waveguide

Rectangular	Circular (greater volume!)

Trapping Coils

One (Harmonic)	Five (Harmonic & Bathtub)

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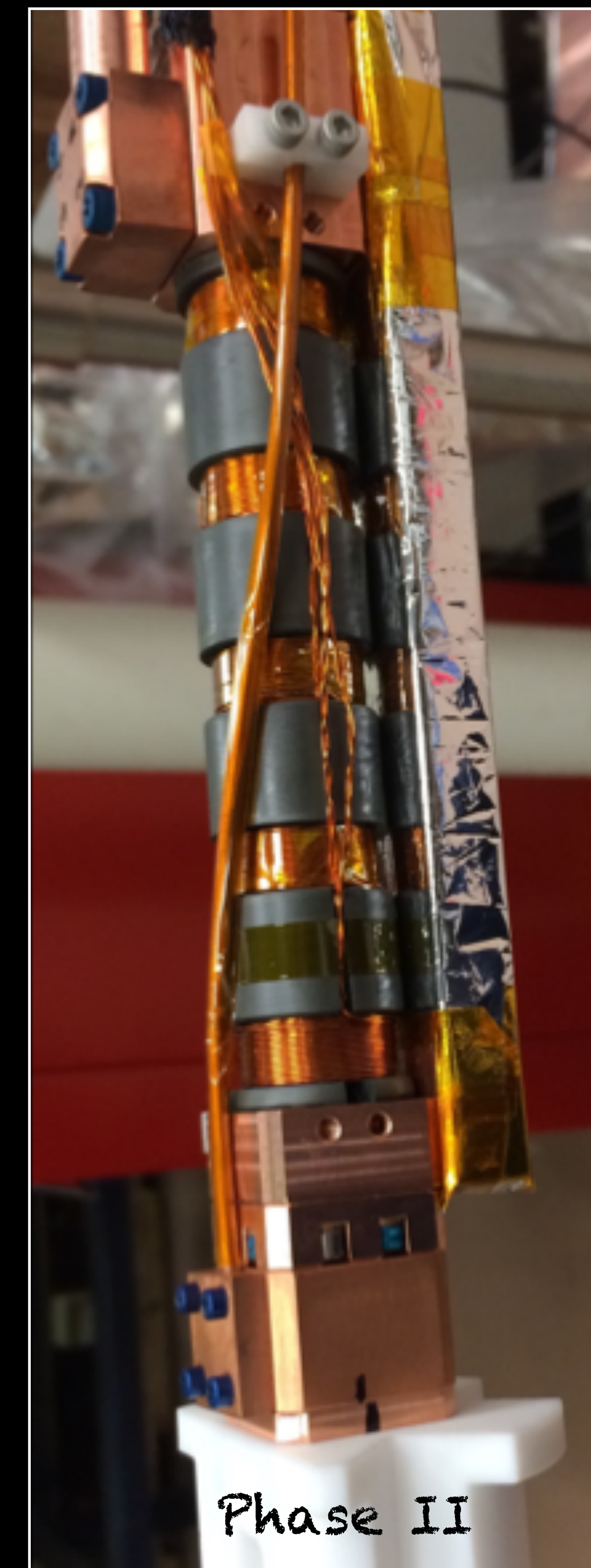

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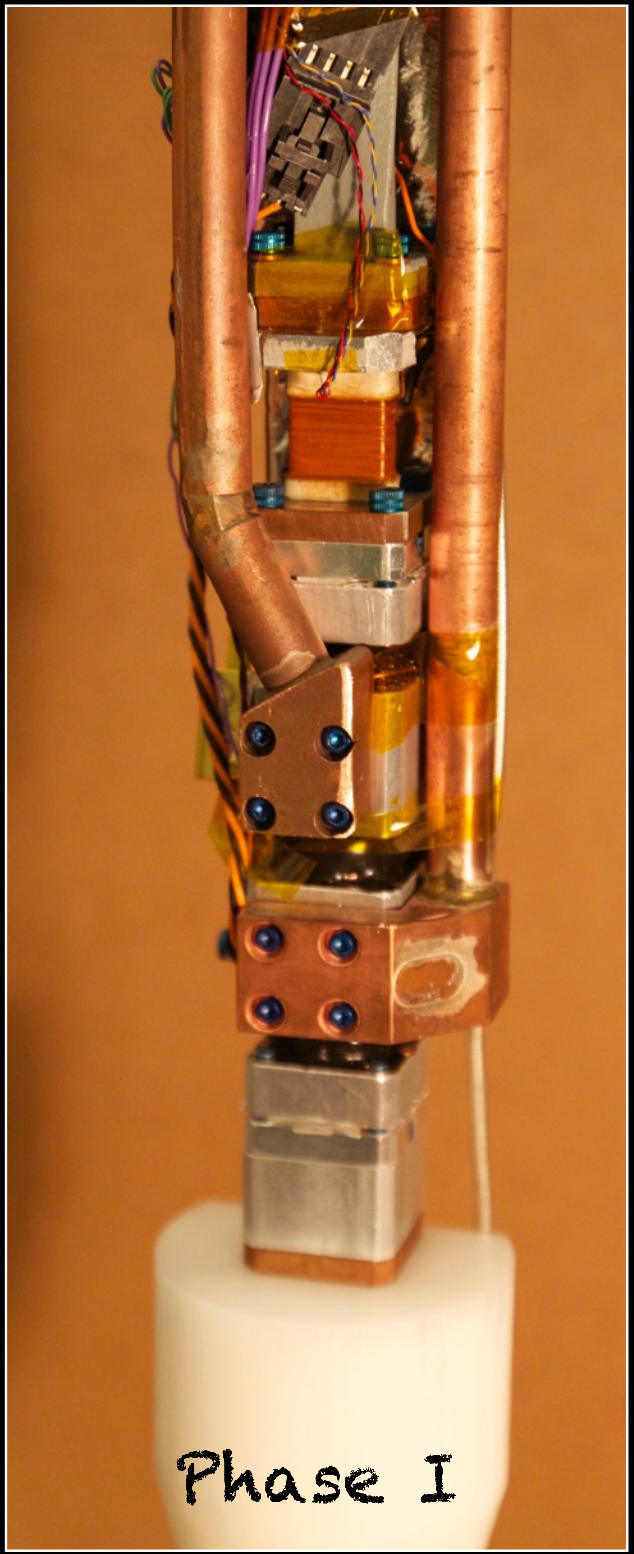

Waveguide

Rectangular	Circular (greater volume!)

Trapping Coils

One (Harmonic)	Five (Harmonic & Bathtub)

Gas Load

^{83m}Kr Only	^{83m}Kr Only & Tritium

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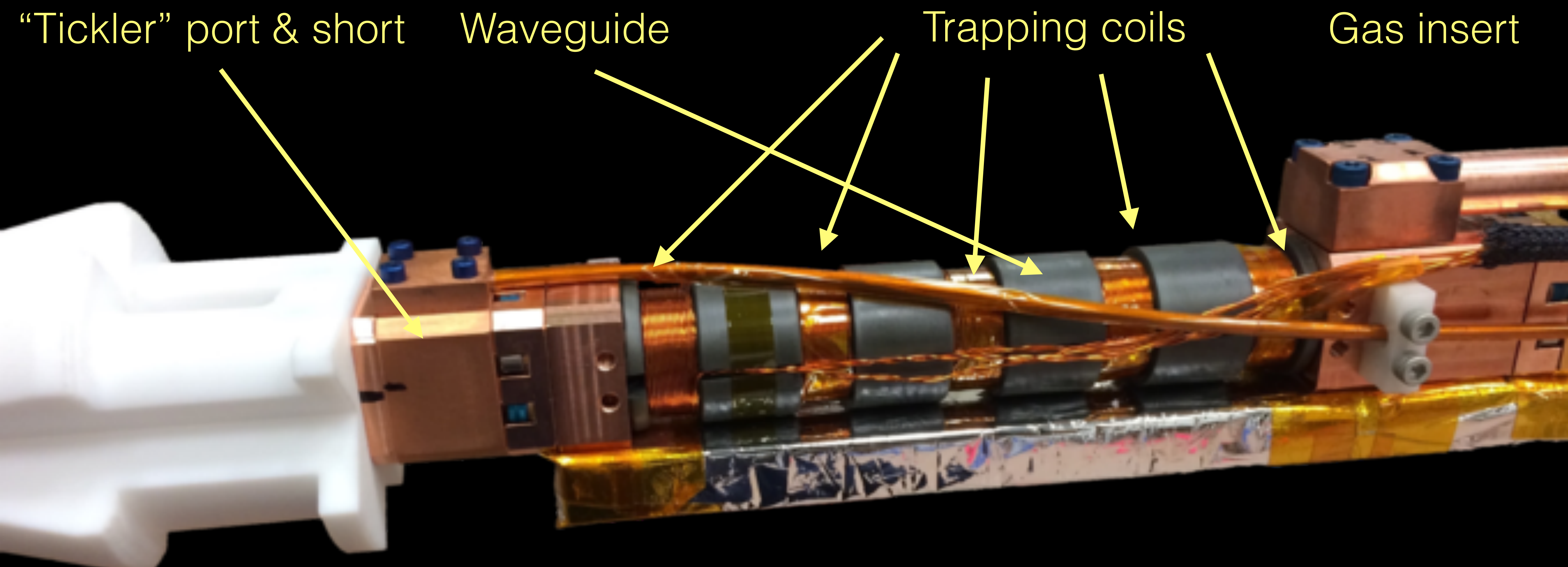
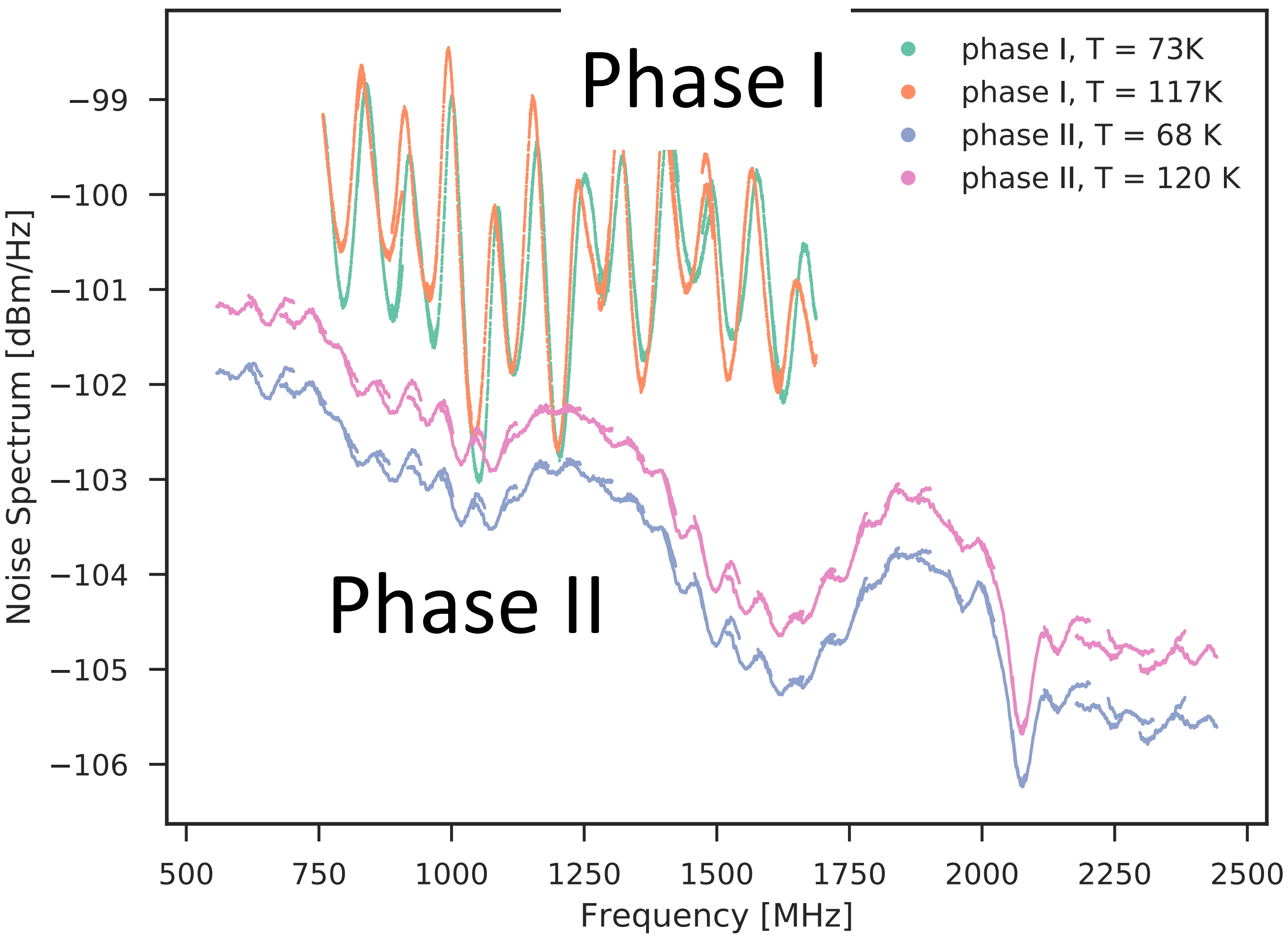
Apply the Kr as a co-magnetometer to the tritium spectrum

Phase II: Tritium & Kr Cell

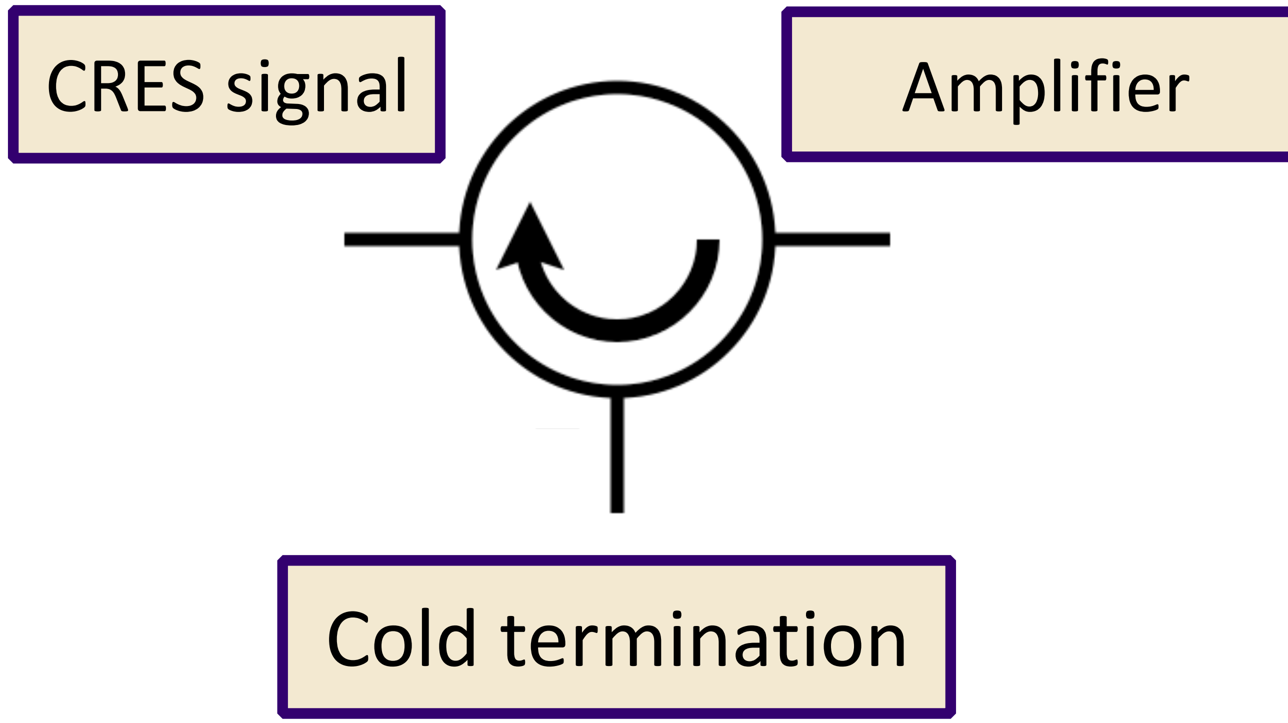


- Next stage will incorporate tritium with Kr as co-magnetometer.
- New 5-coil circular waveguide constructed, already in operation.
- Inject tritium through getter heating.
- Improved microwave cavity with better noise performance.

Phase II: Tritium & Kr Cell



Cryogenic circulator suppresses black body radiation interference



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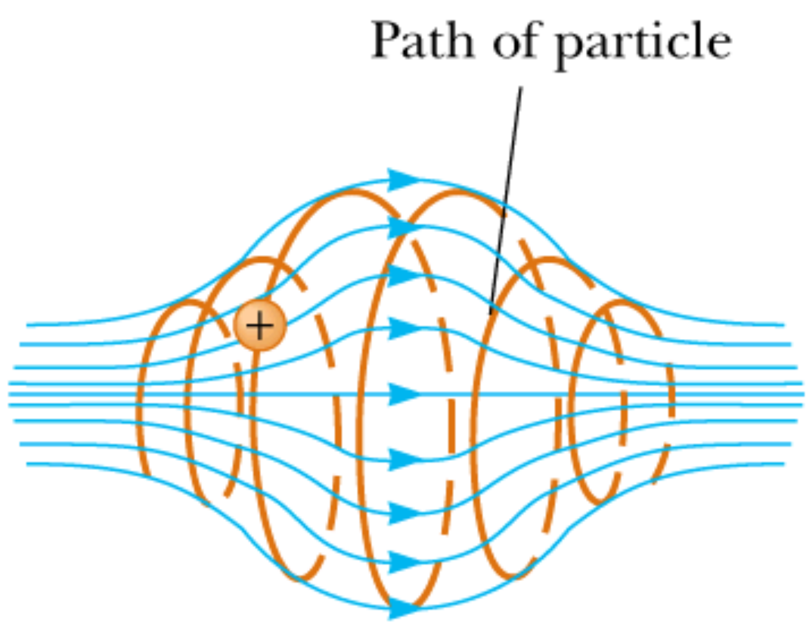
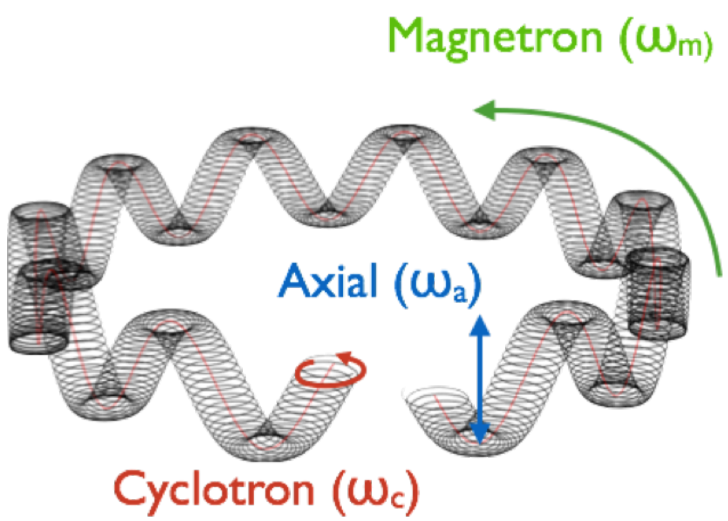
Wide Range of Motion



Motion in magnetic bottle

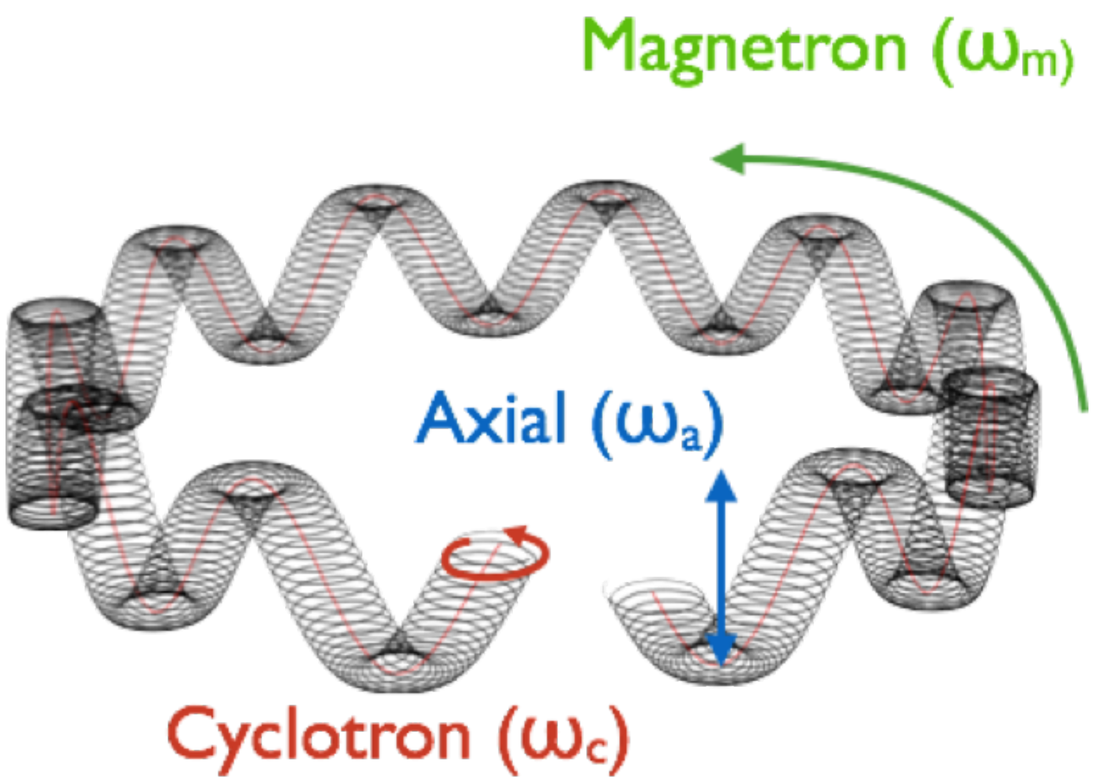


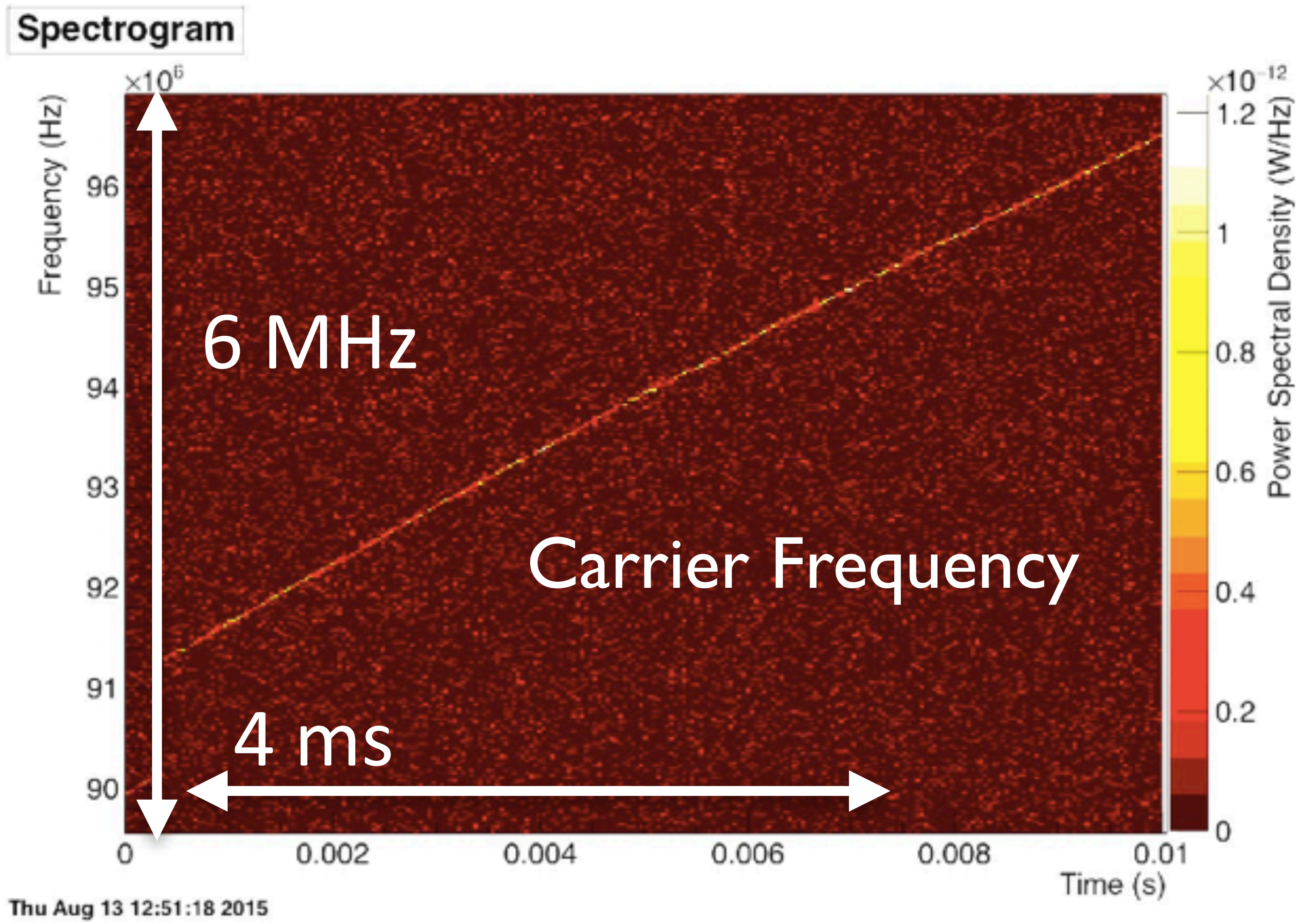
Motion in Penning trap

- Complex motion of a magnetically trapped electron, akin to motion in a Penning trap's eigenmotions.
- Variation due to magnetic field gradients and Doppler shift effects.

Frequency spectrum in principle has access to all motion eigenstates of trapped electrons.

Wide Range of Motion

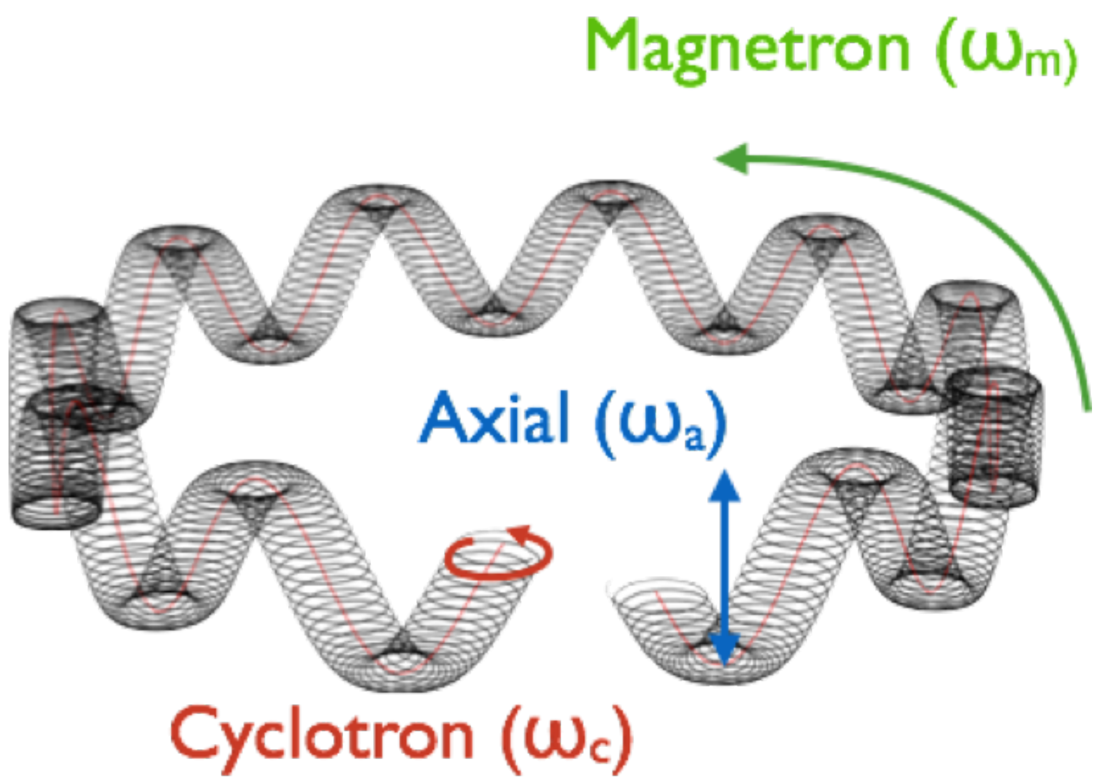


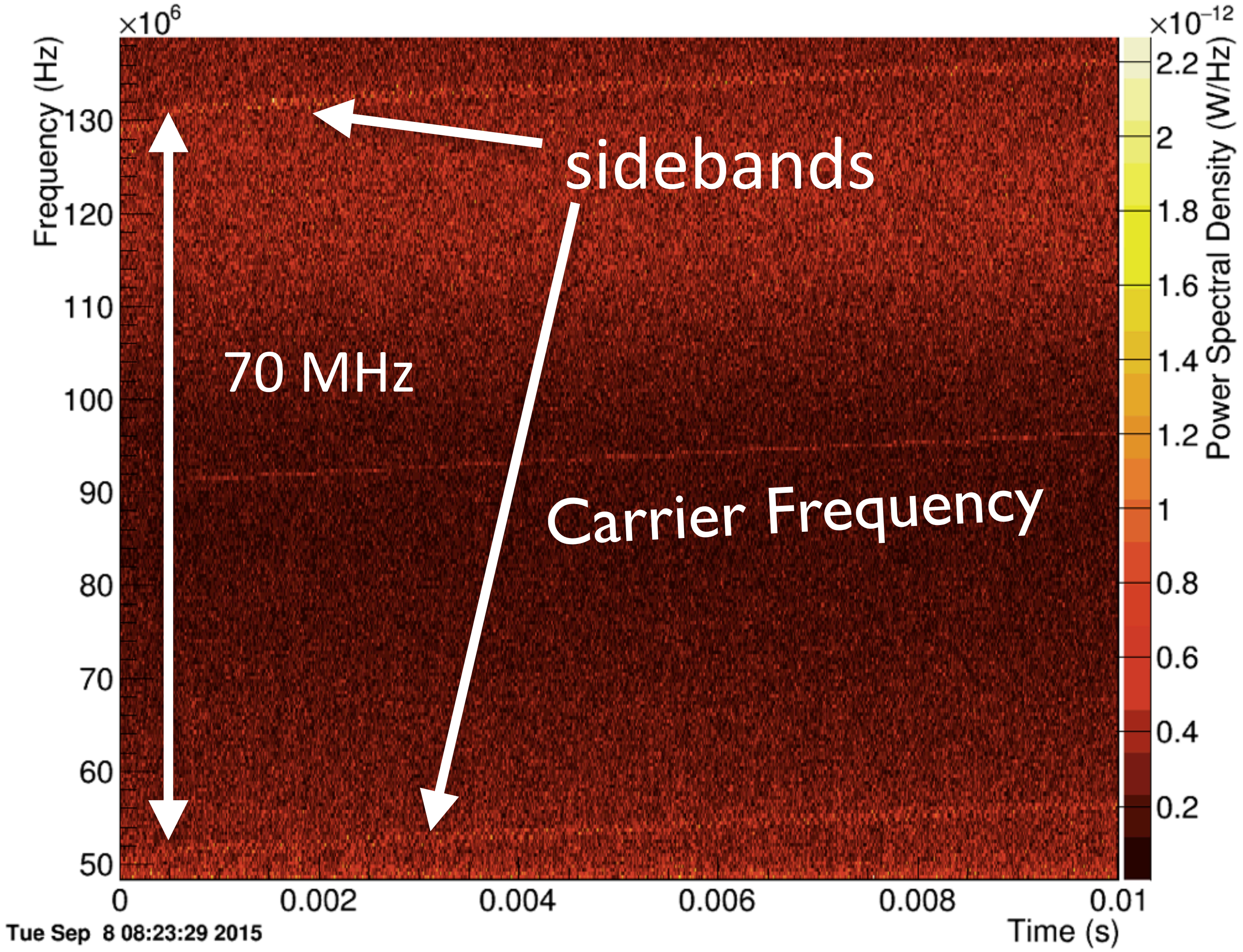


Motion under trapping magnetic fields

Frequency spectrum in principle has access to all motion eigenstates of trapped electrons.

Wide Range of Motion

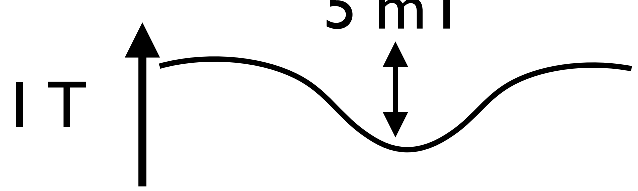


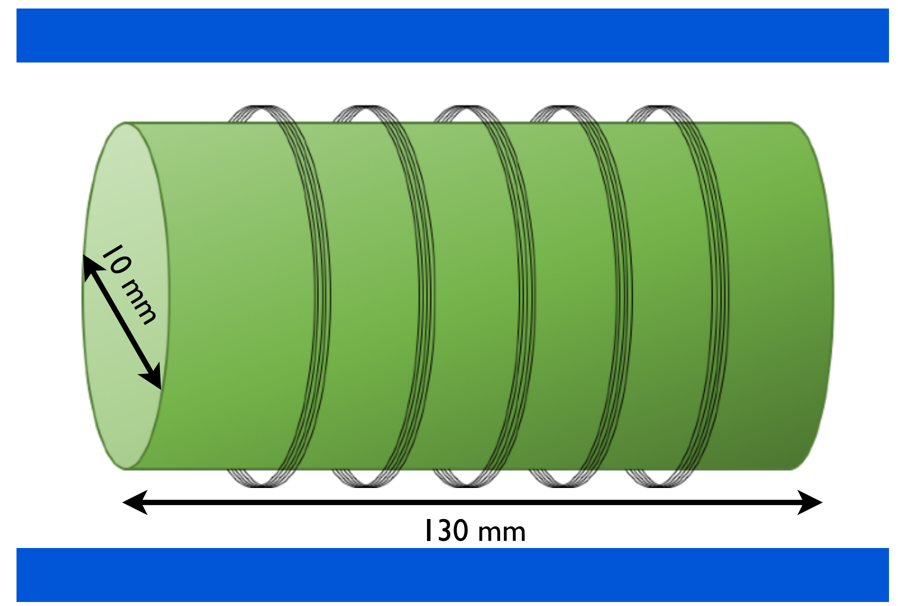


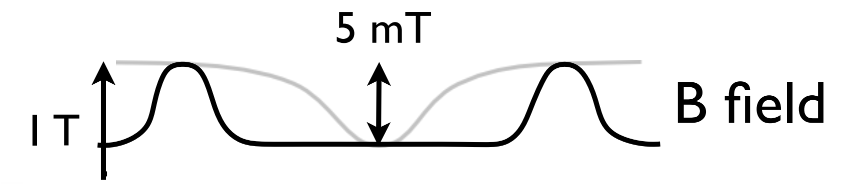
Motion under trapping magnetic fields

Frequency spectrum in principle has access to all motion eigenstates of trapped electrons.

Two Types of Traps

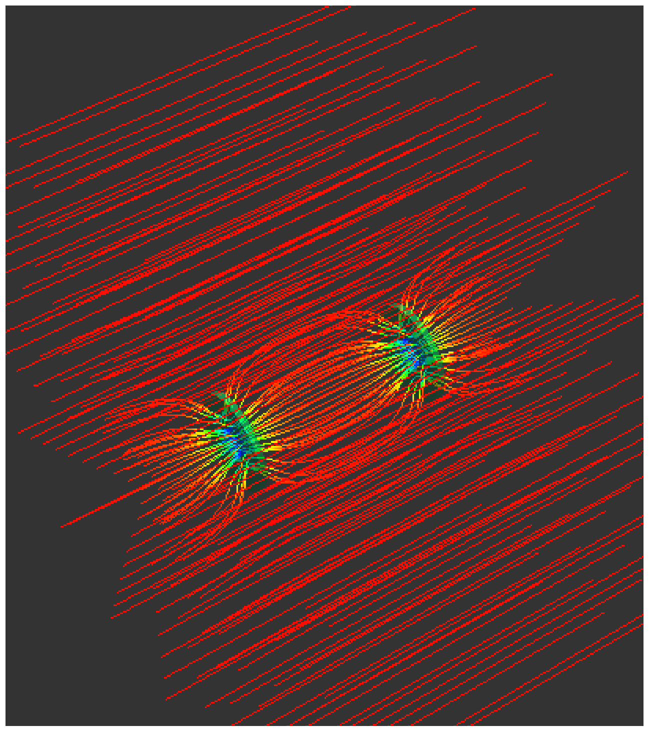






"Harmonic" Trap

$$\omega_\gamma = \frac{eB}{m + E_{\mathrm{kin}}}\left(1 + \frac{\cot^2\theta}{2}\right)$$

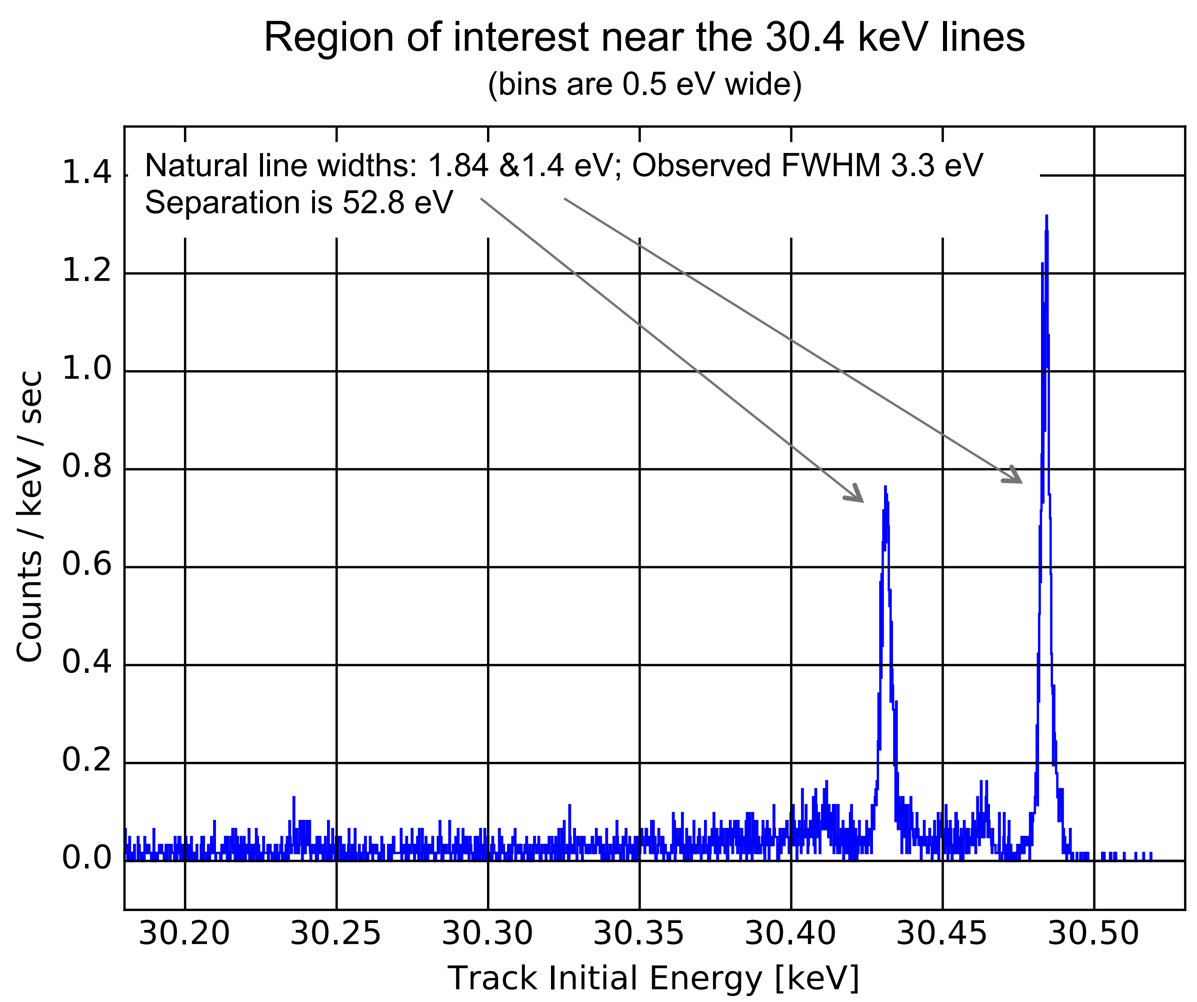


"Bathtub" Trap

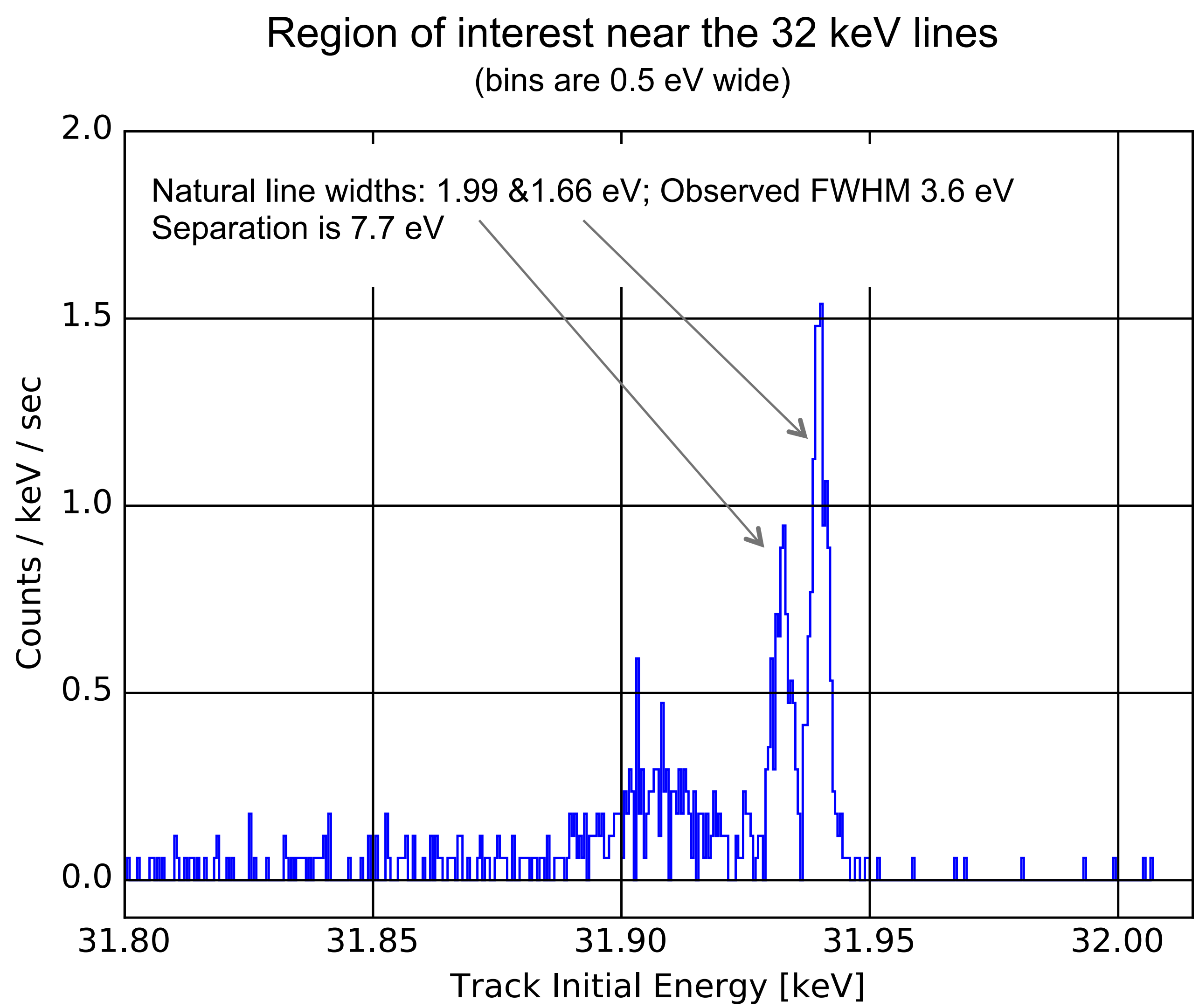
$$\omega_{\mathrm{a}} \propto v\left(\frac{a}{\sin\theta} + \frac{4\sin\theta}{m\cos^2\theta}\right)^{-1}$$

We utilize two types of magnetic configurations for electron traps.

Energy Lines at 30.4 keV



...and at 32 keV

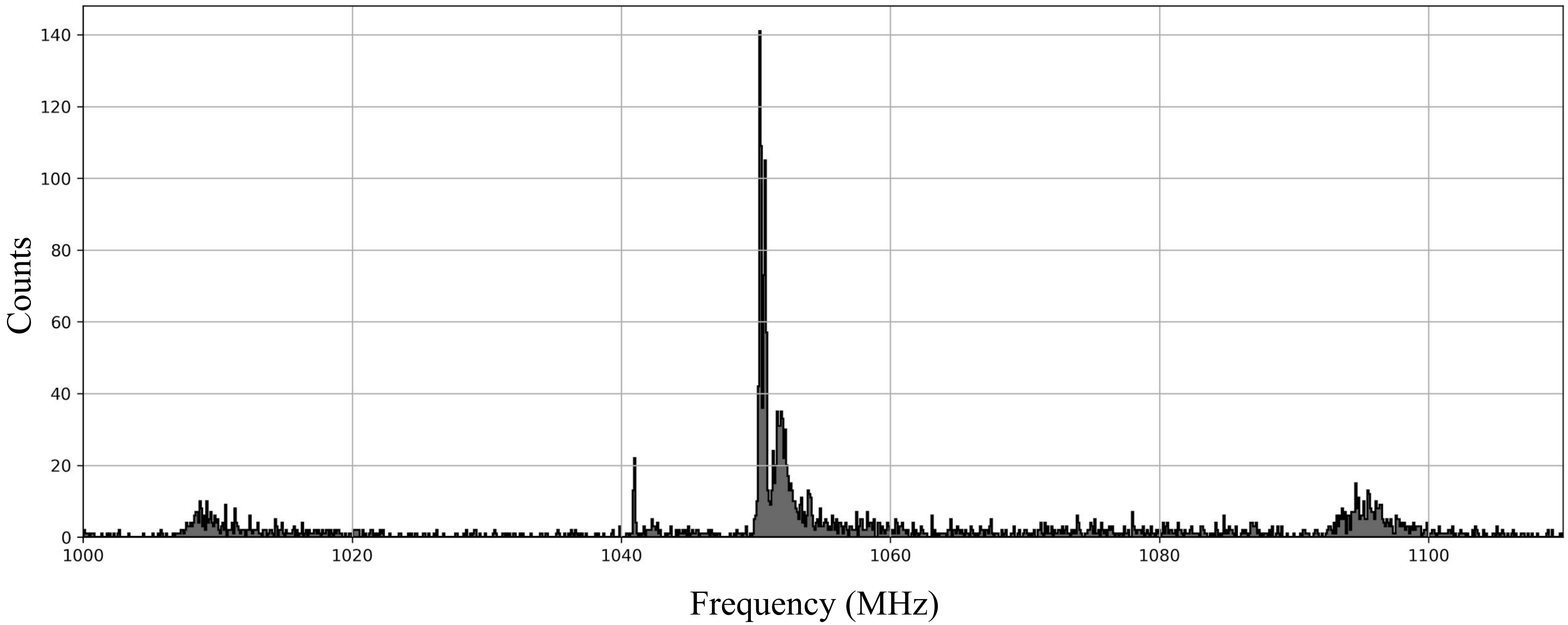


Energy resolution of krypton lines has been steadily improving.

Currently at 3.3 eV energy resolution @ 30 keV

Event Reconstruction

preliminary, L. Saldana & A. Ashtari



We are starting to utilize both carrier frequency & sideband frequencies to deconvolve event dynamics using Support Vector Machine (SVM) techniques. (preliminary)

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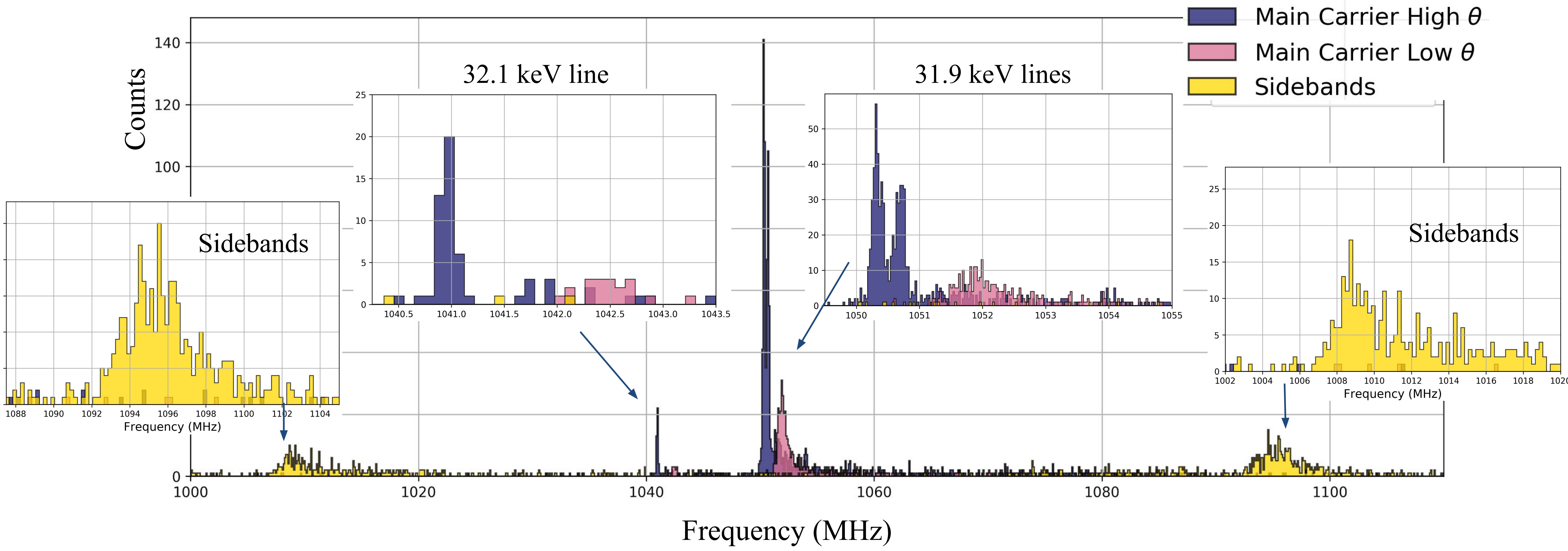

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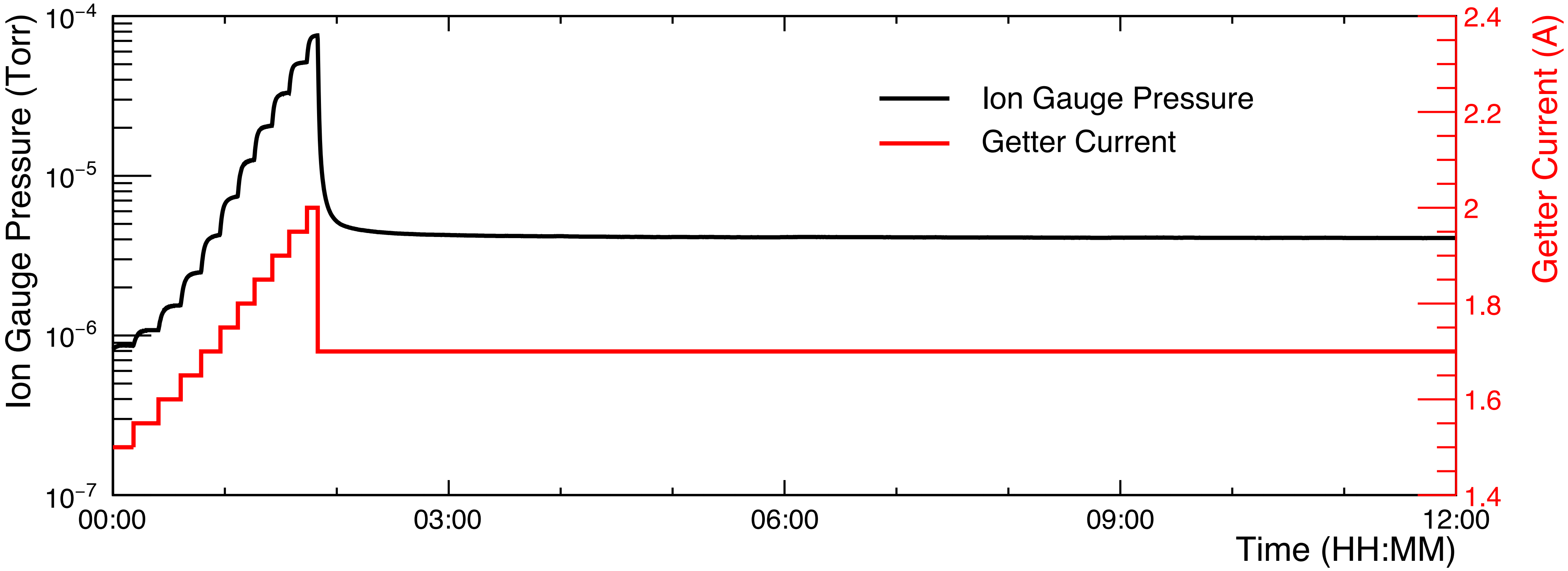
Phase II: Tritium & Kr Cell

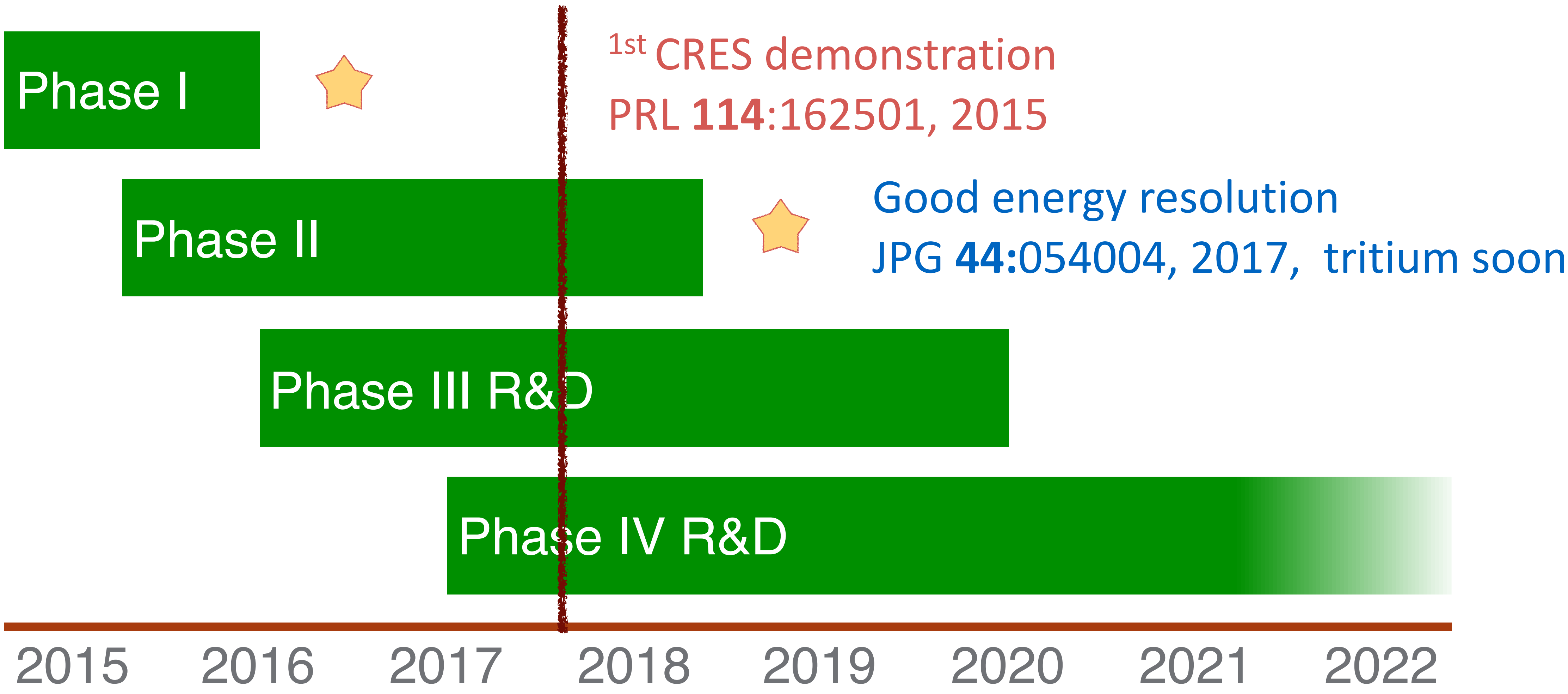
preliminary, A. Ashtari (UW)



Pressure test with deuterium load.

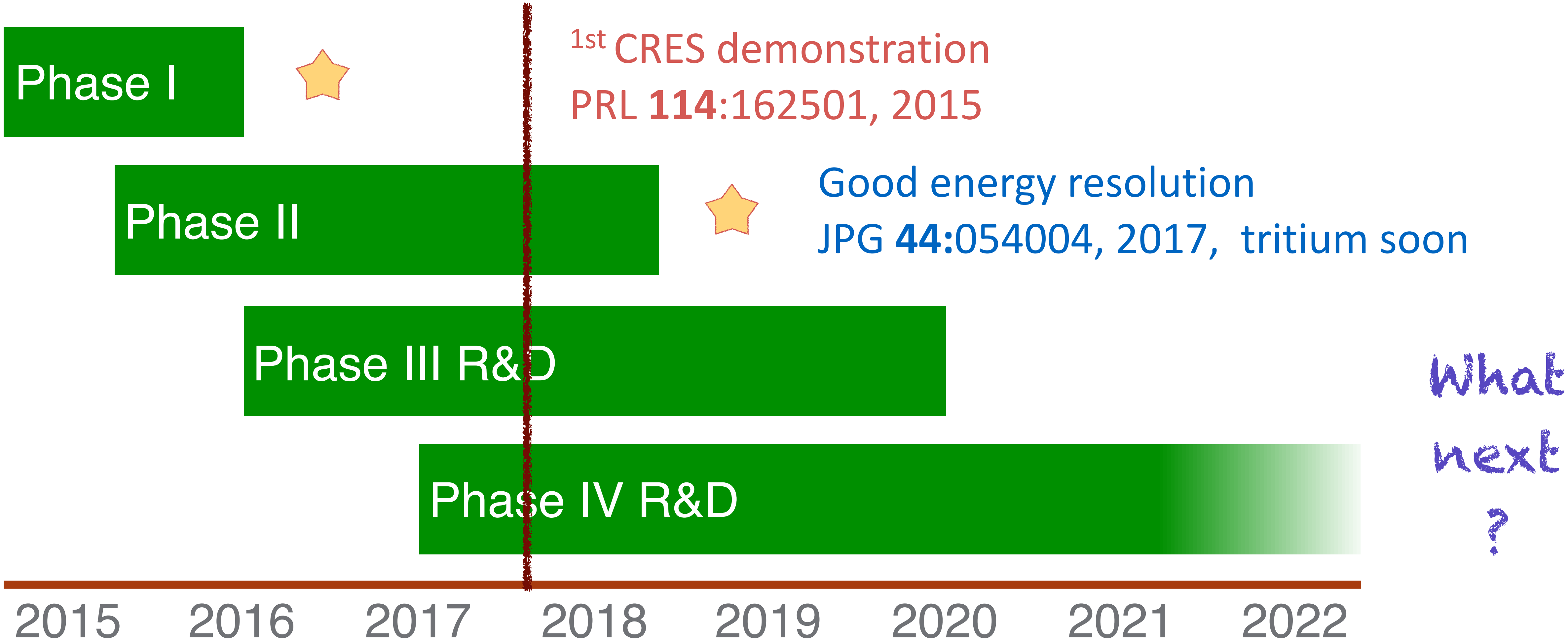
- Inject tritium through getter heating. Initial tests with deuterium show good control of partial pressures.
- System is near-ready for tritium injection.

Project 8: A Phased Approach



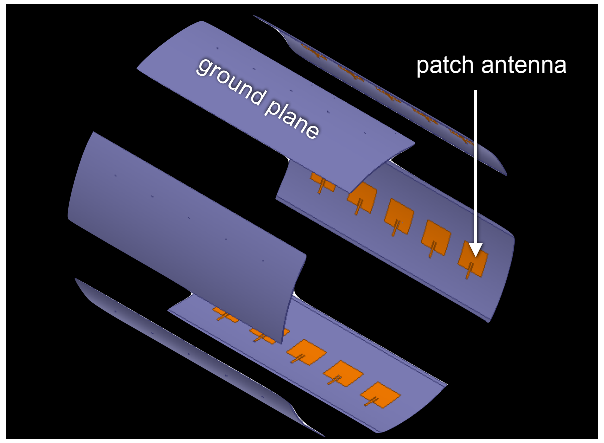
A phased R&D approached is used to advance the sensitivity and understand scaling & systematics.

Project 8: A Phased Approach

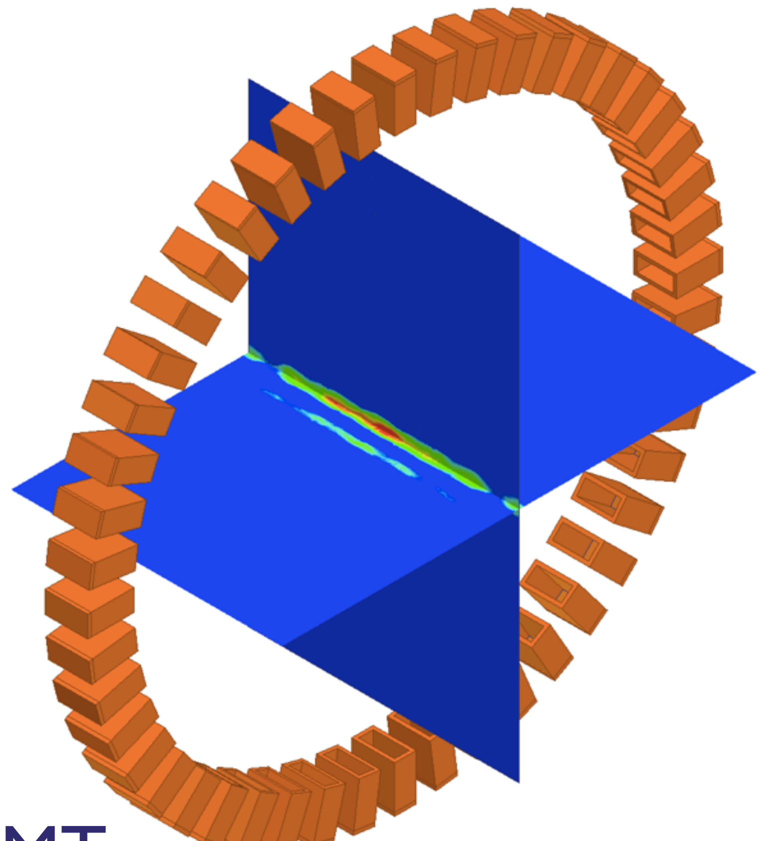


A phased R&D approached is used to advance the sensitivity and understand scaling & systematics.

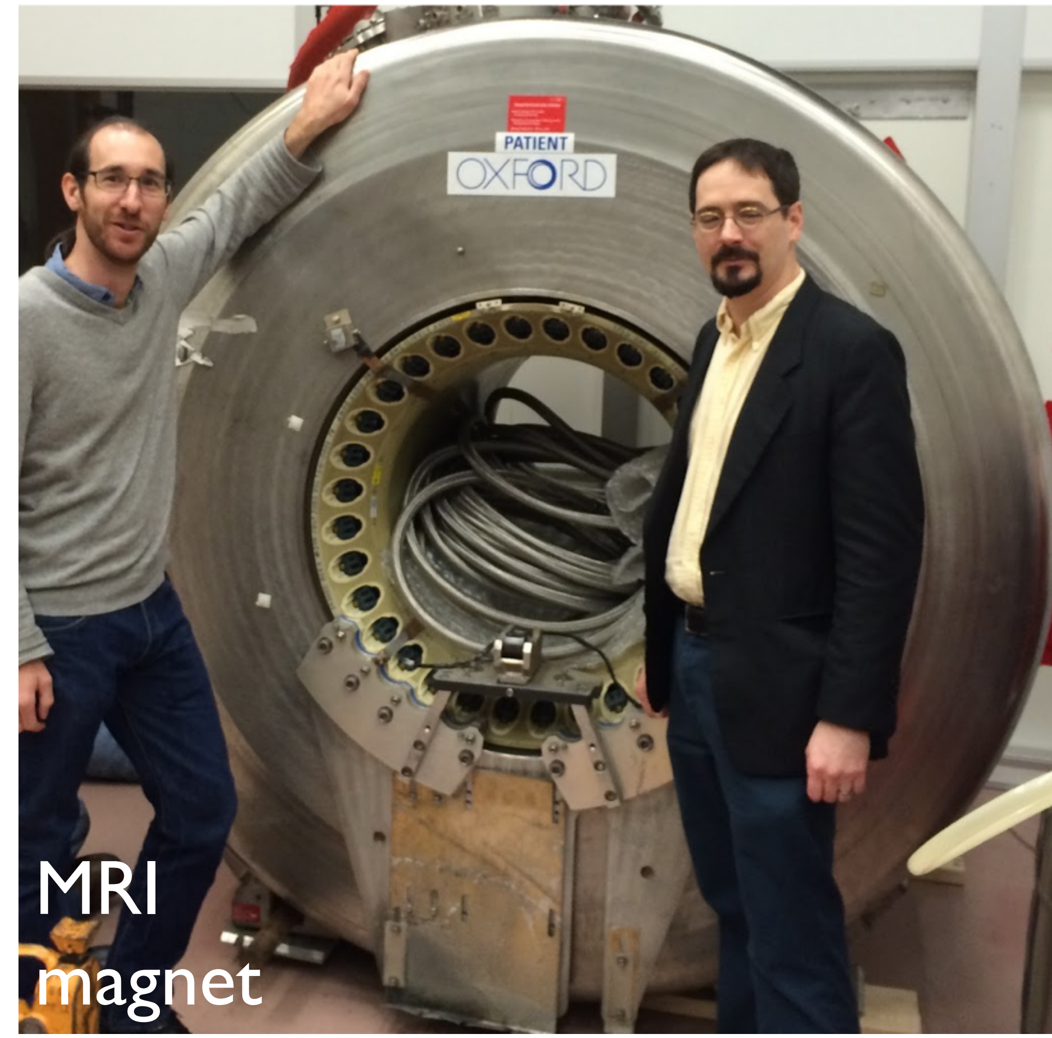
Phase III



Patch antenna array



HEMT array

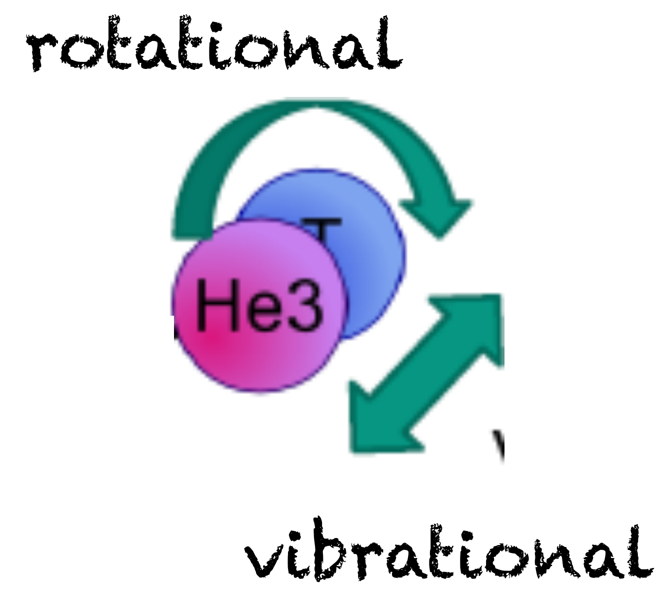


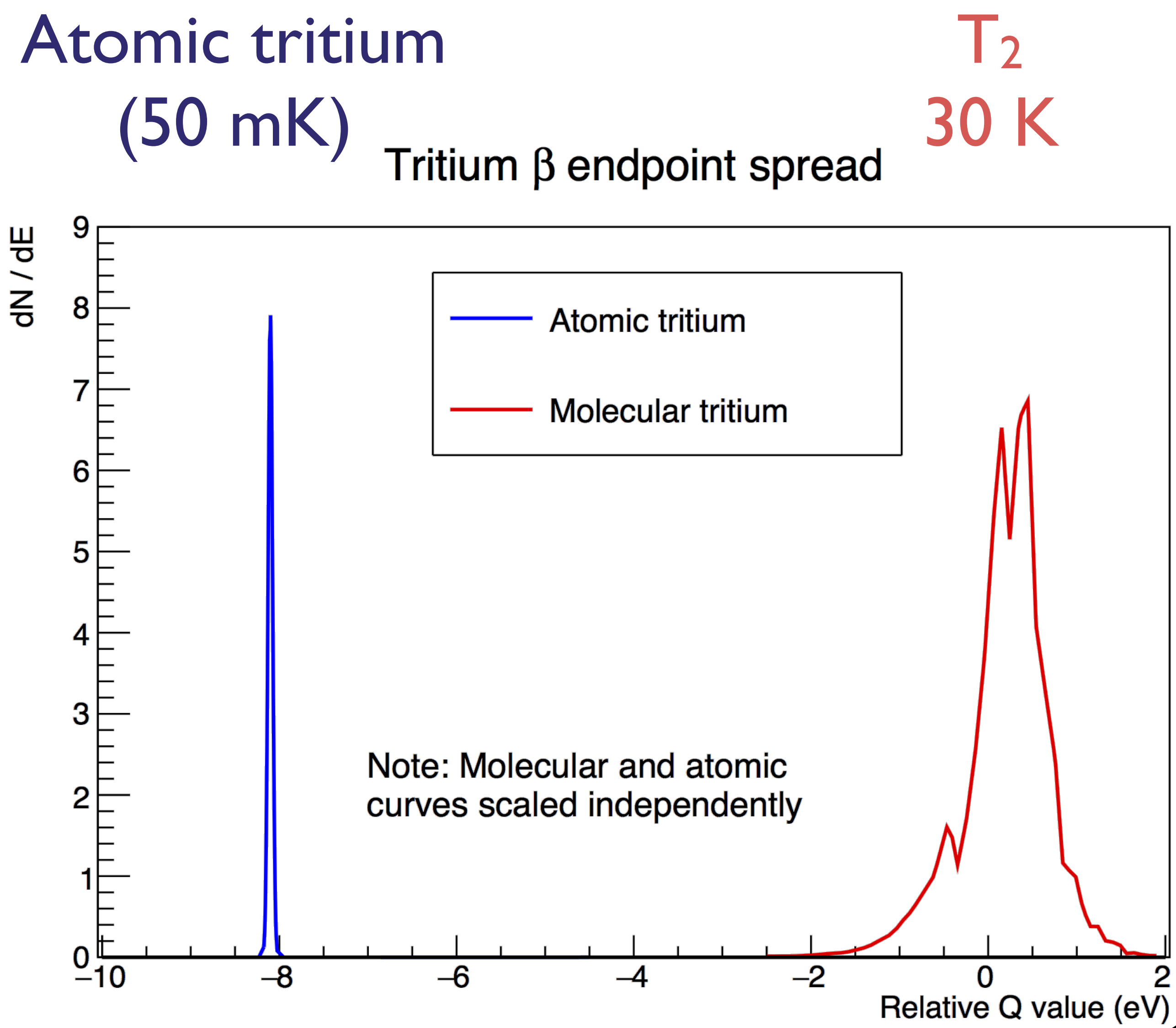
MRI magnet

- Engineering work on Phase III is going in parallel.
- Aim to measure CRES tritium spectrum in large volume system.
- Would also aim at making Mainz-level mass measurement.

Moving Beyond the Degeneracy Scale

- Most effective tritium source achieved so far involves the use of gaseous molecular tritium.
- Method will eventually hit a resolution "wall" which is dictated by the rotational-vibrational states of T_2.
- The trapping conditions necessary for electrons also lends itself for atomic trapping of atomic tritium





Looking forward

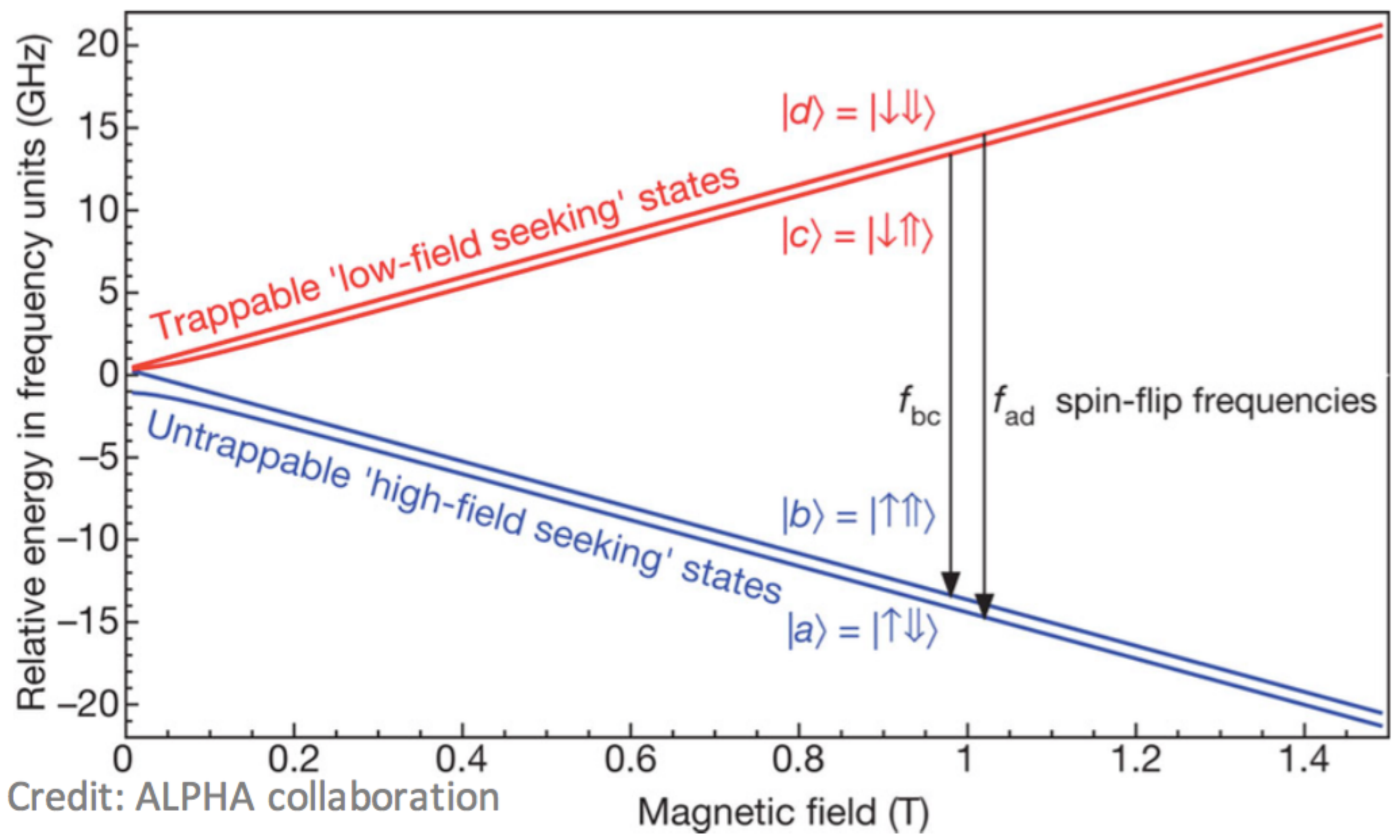
Phase IV: Atomic Tritium

- Take advantage of spin states of atomic tritium to magnetically confine low field seeking states.

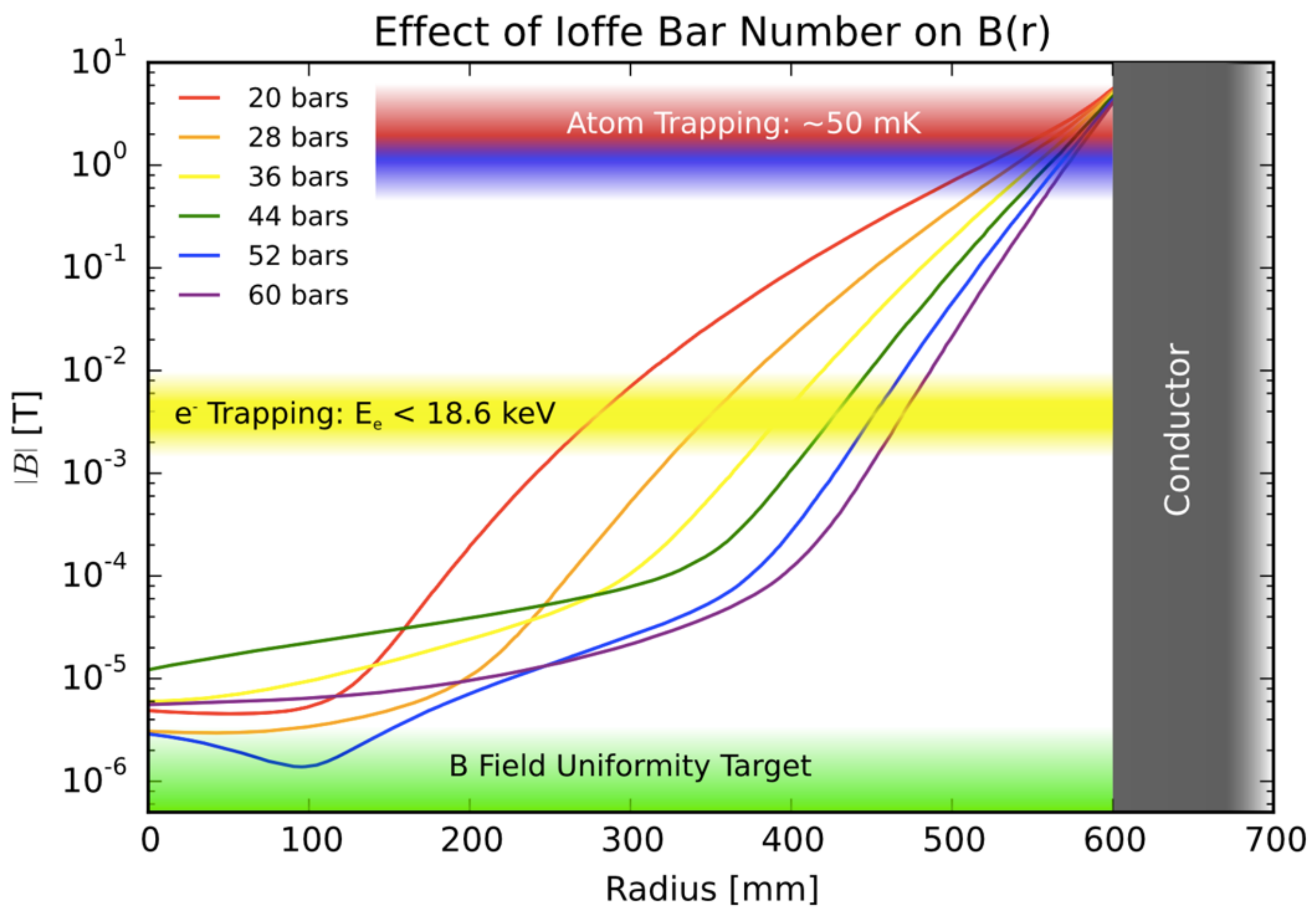
- Requires high magnetic field gradients and low temperatures.

$$\Delta E = -\mu \cdot B$$

- Naturally filters molecular tritium.



Credit: ALPHA collaboration



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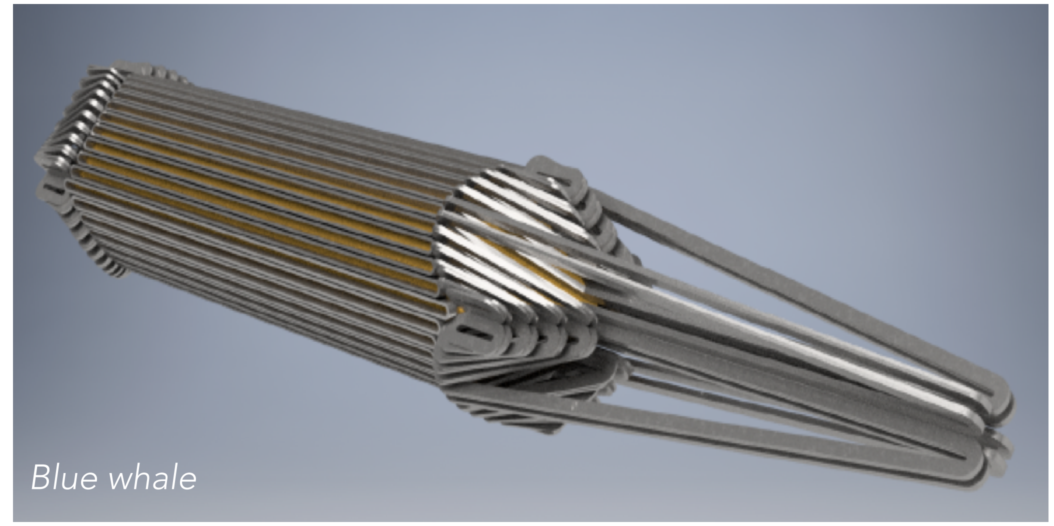
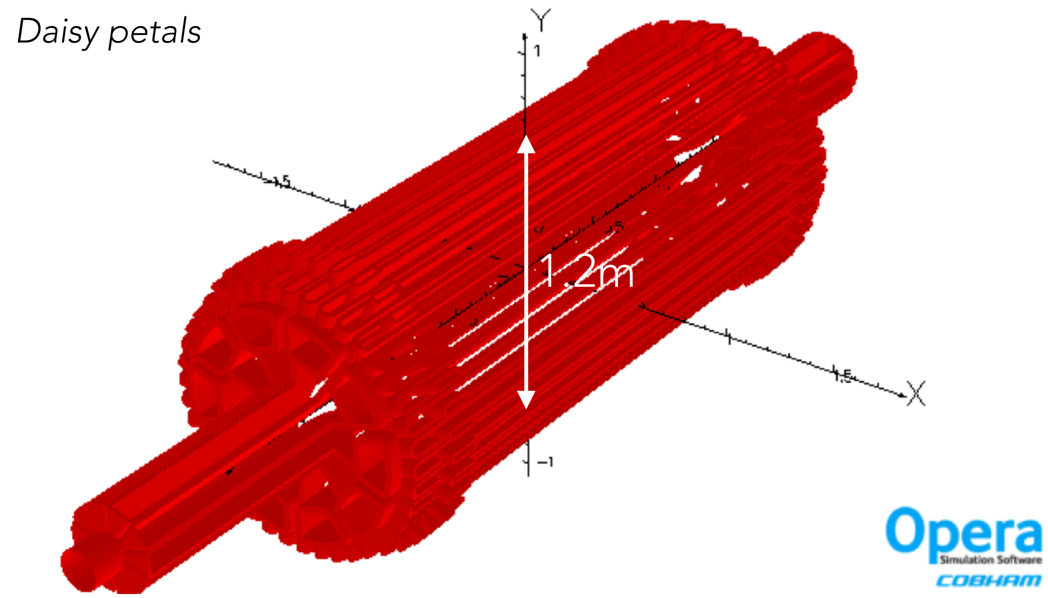
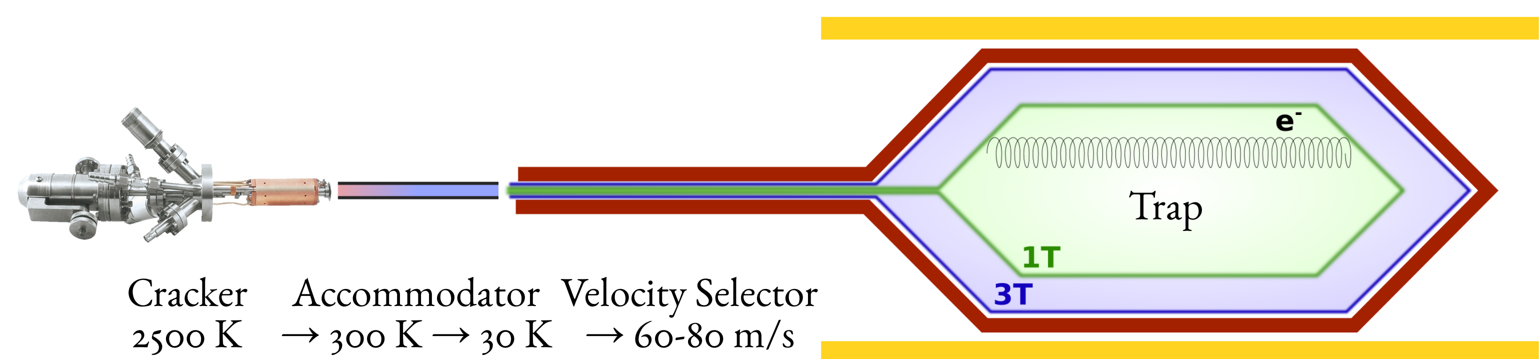


Blue whale design



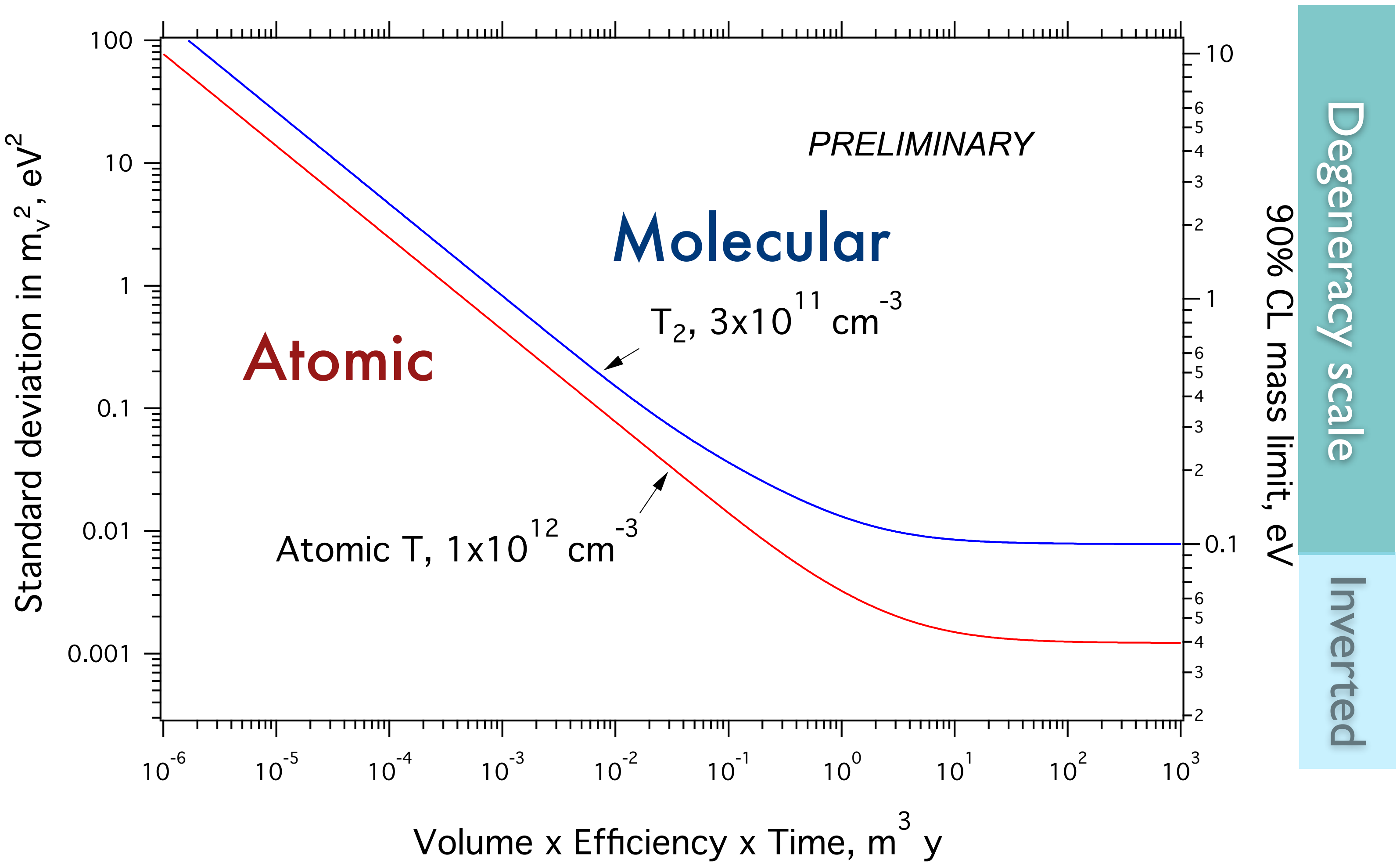
Ioffe petal design



Phase IV Conceptual design

Looking forward

Phase IV: Atomic Tritium



Systematics included:

Magnetic field homogeneity

Scattering cross-section

Backgrounds (cosmic)

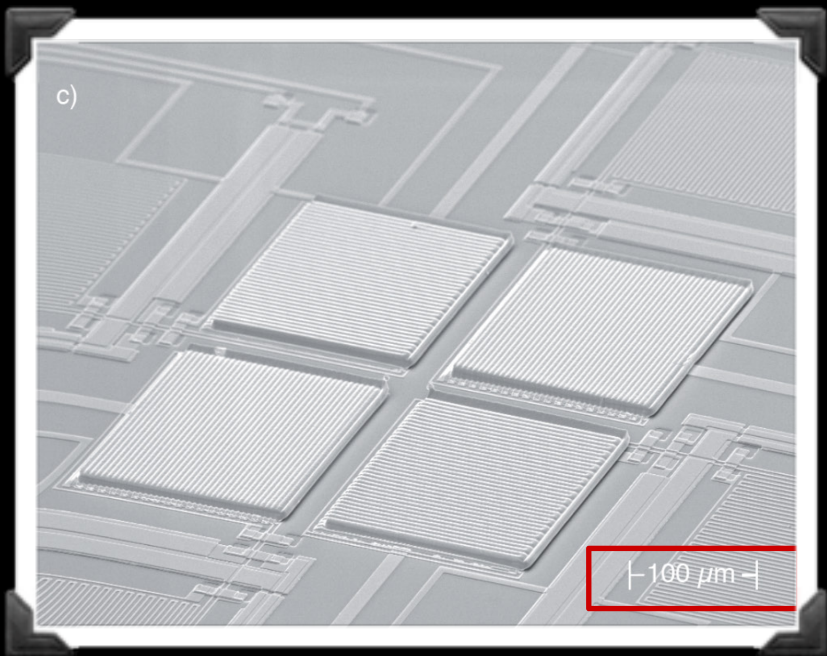
Final states

(more need to be evaluated)

- Scaling to inverted scale possible, provided the system can scale to m^3 level.
- Intensive part of the Project 8 R&D program.

Fermi's original challenge seems to emerge on the horizon...

KATRIN is poised to commence tritium data taking. Improved limits (or discovery!) coming soon .



ECHO and HOLMES currently aim at the eV scale are being constructed, with sub-eV in their sights.

Project 8 advances forward, with cross-hairs focuses at the inverted scale.

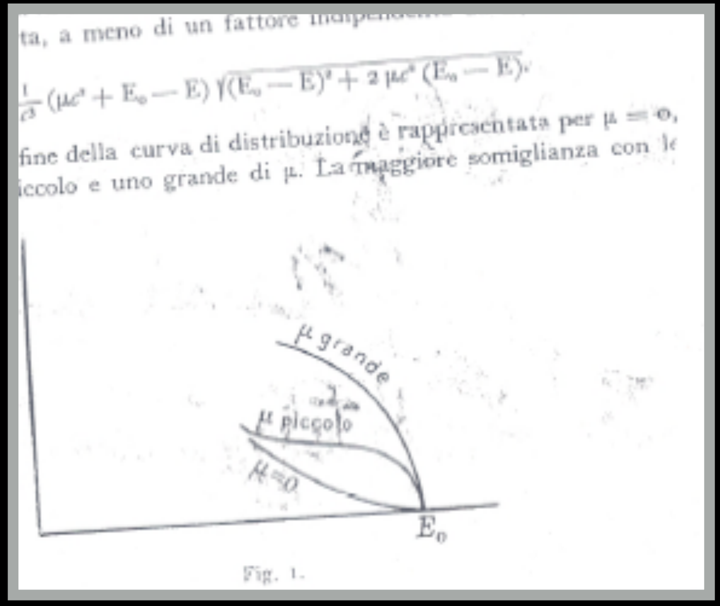

ta, a meno di un fattore
$\frac{1}{c^3}(\mu c^2 + E_0 - E)\sqrt{(E_0 - E)^2 + 2\mu c^2 (E_0 - E)}$.
fine della curva di distribuzione è rappresentata per μ = 0,
iccolo e uno grande di μ. La maggiore somiglianza con le

Fig. 1.

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vostra
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