Extracting CryoMPET

Rio Weil
TITAN Collaboration

TRIUMF Summer Student Symposium 2019
August , 2019

Discovery, accelerated

Precision Mass Measurements - Motivation

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$$E = mc^2$$

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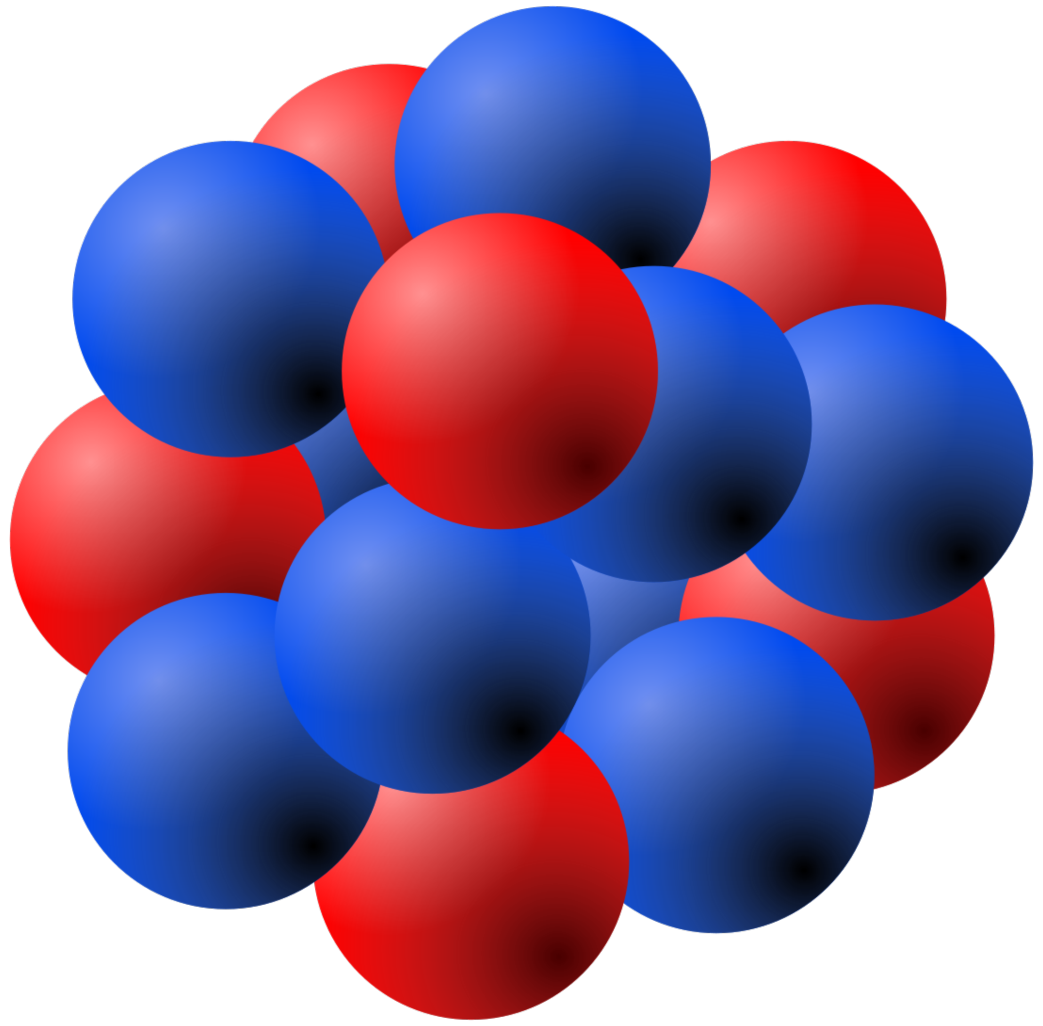
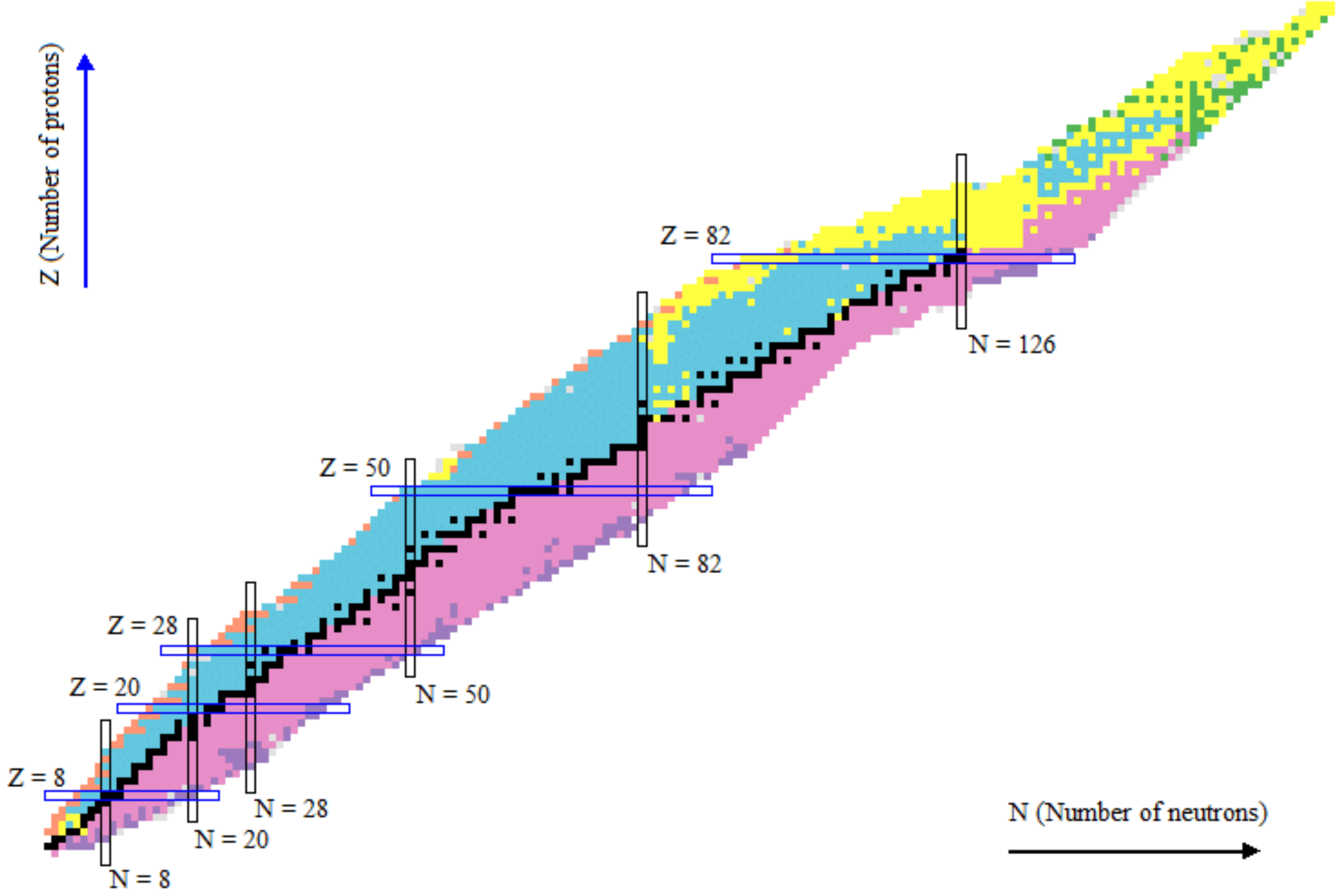
$$E = mc^2$$

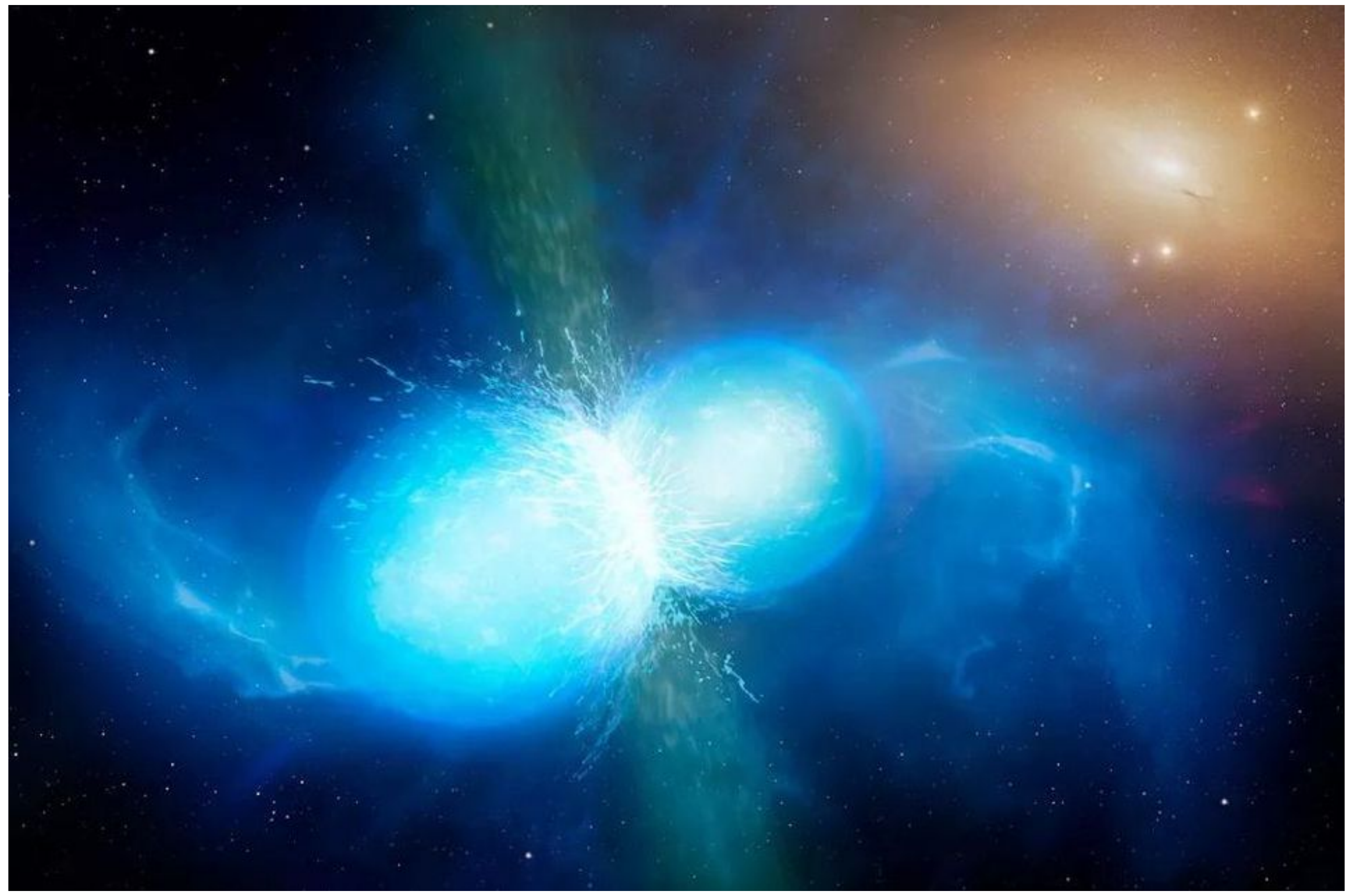
Obtain the binding energies of nucleons



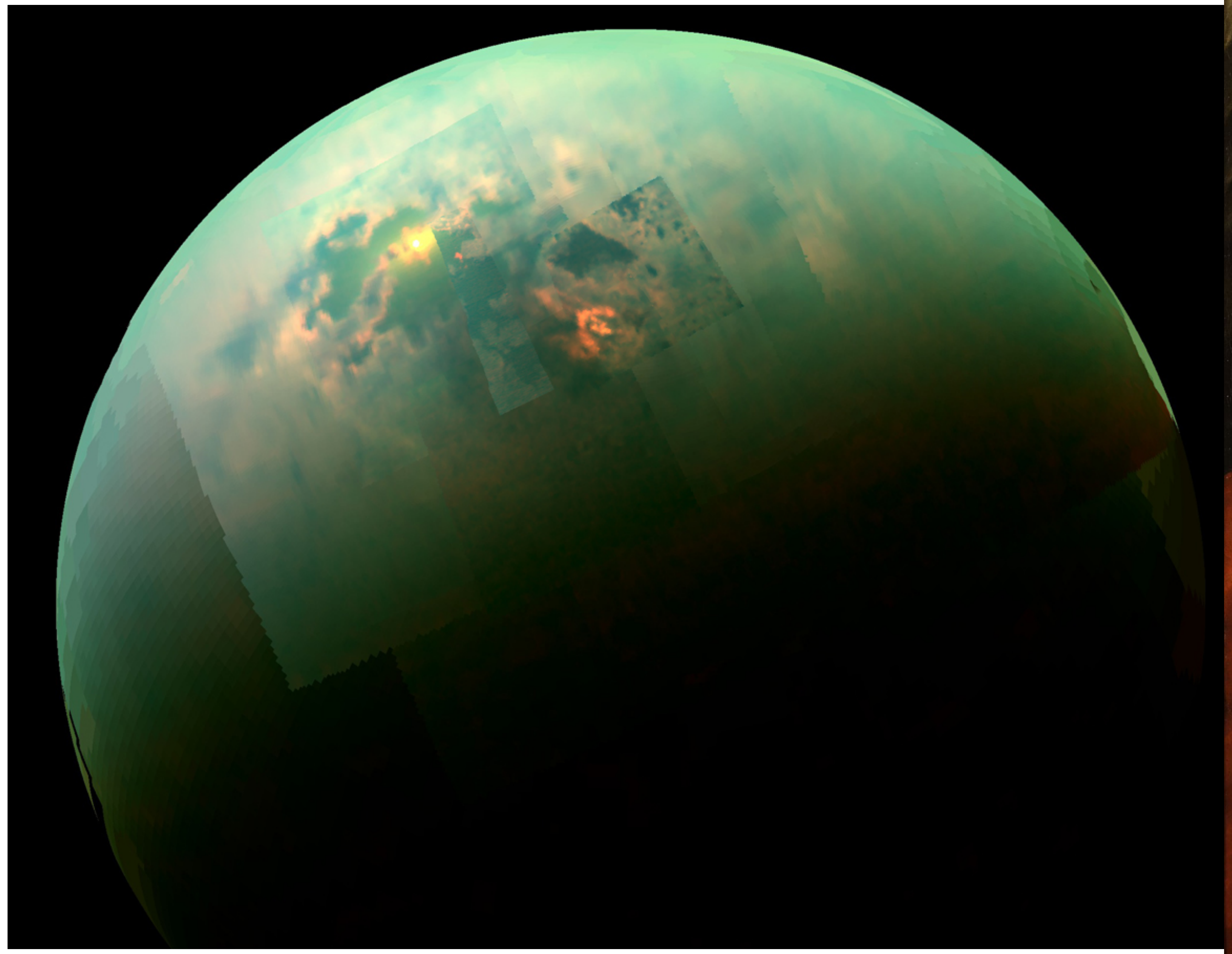
Precision Mass Measurements - Motivation

Area of scientific interest	Required mass precision
Nuclear structure	$\frac{\delta m}{m} \approx 10^{-6} - 10^{-8}$
Nuclear astrophysics	$\frac{\delta m}{m} \approx 10^{-7}$
Tests of fundamental physics	$\frac{\delta m}{m} \approx 10^{-8} - 10^{-9}$





What is TITAN?



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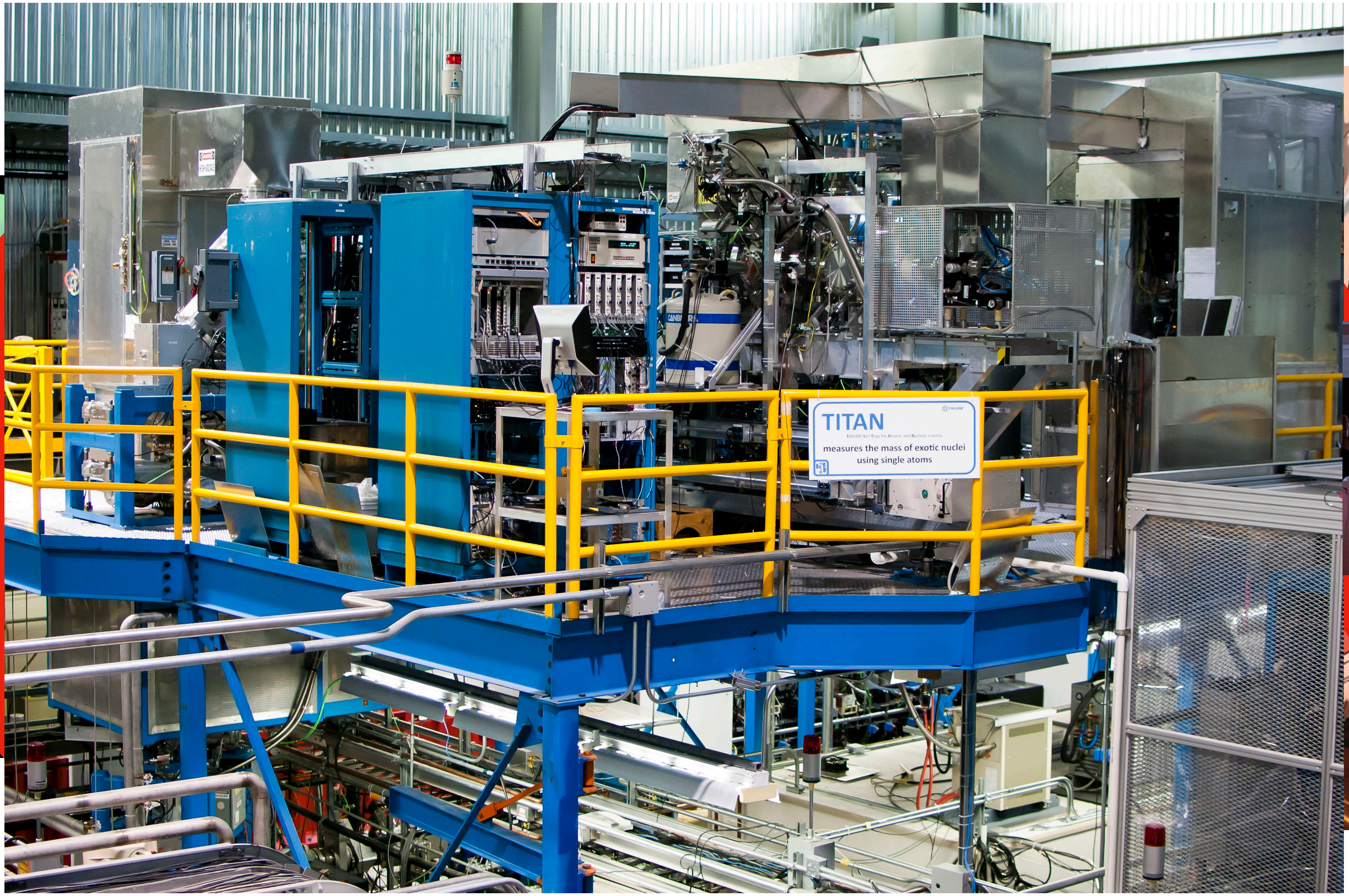
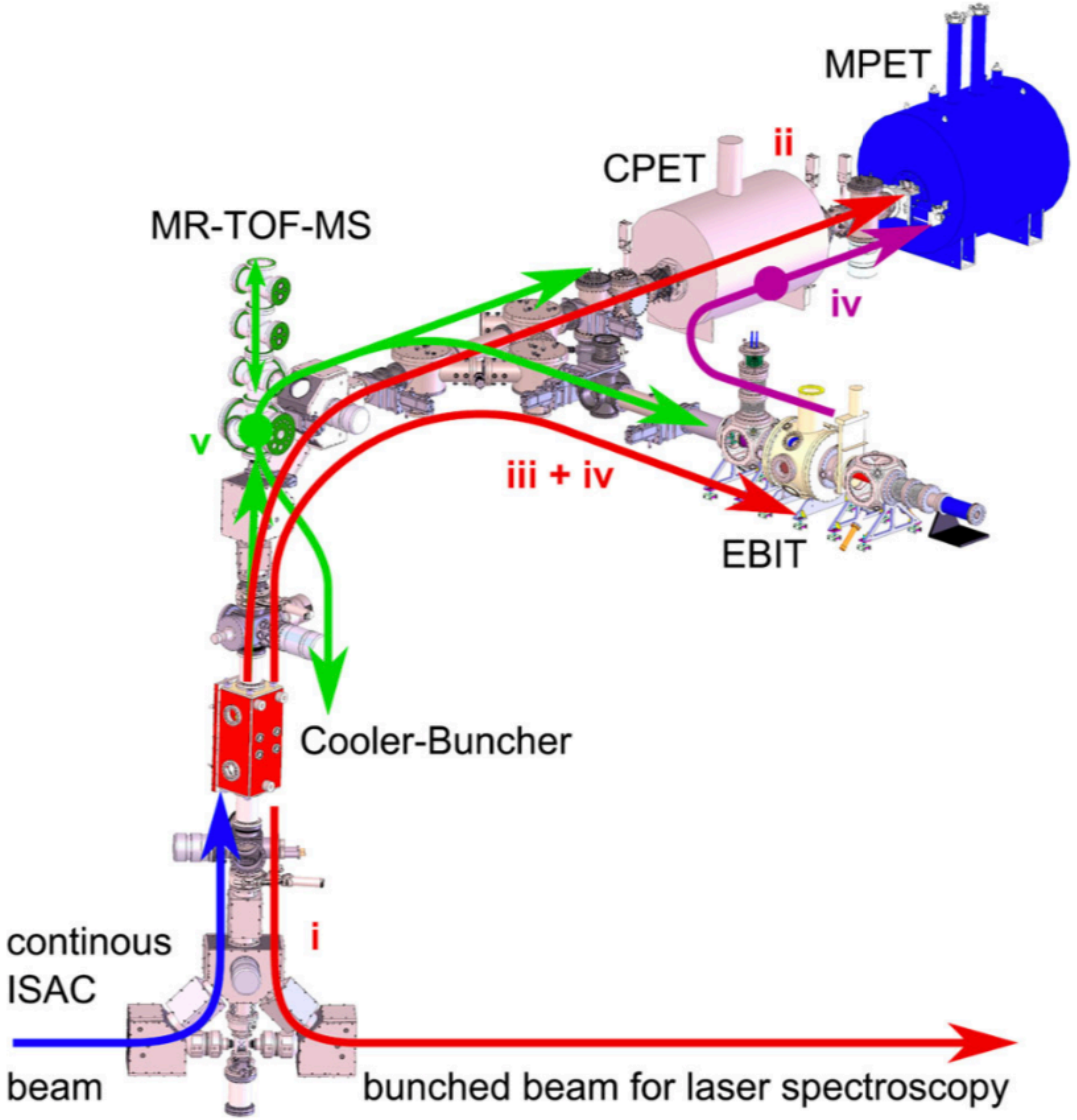


TRIUMF's Ion Trap for Atomic and Nuclear Science

Overview of TITAN

- TITAN RFQ: Cooler-Buncher
- MR-TOF-MS: Multiple Reflection Time-Of-Flight Mass Spectrometer
- EBIT: Electron Beam Ion Trap
- CPET: Cooler Penning Trap
- MPET: Measurement Penning Trap



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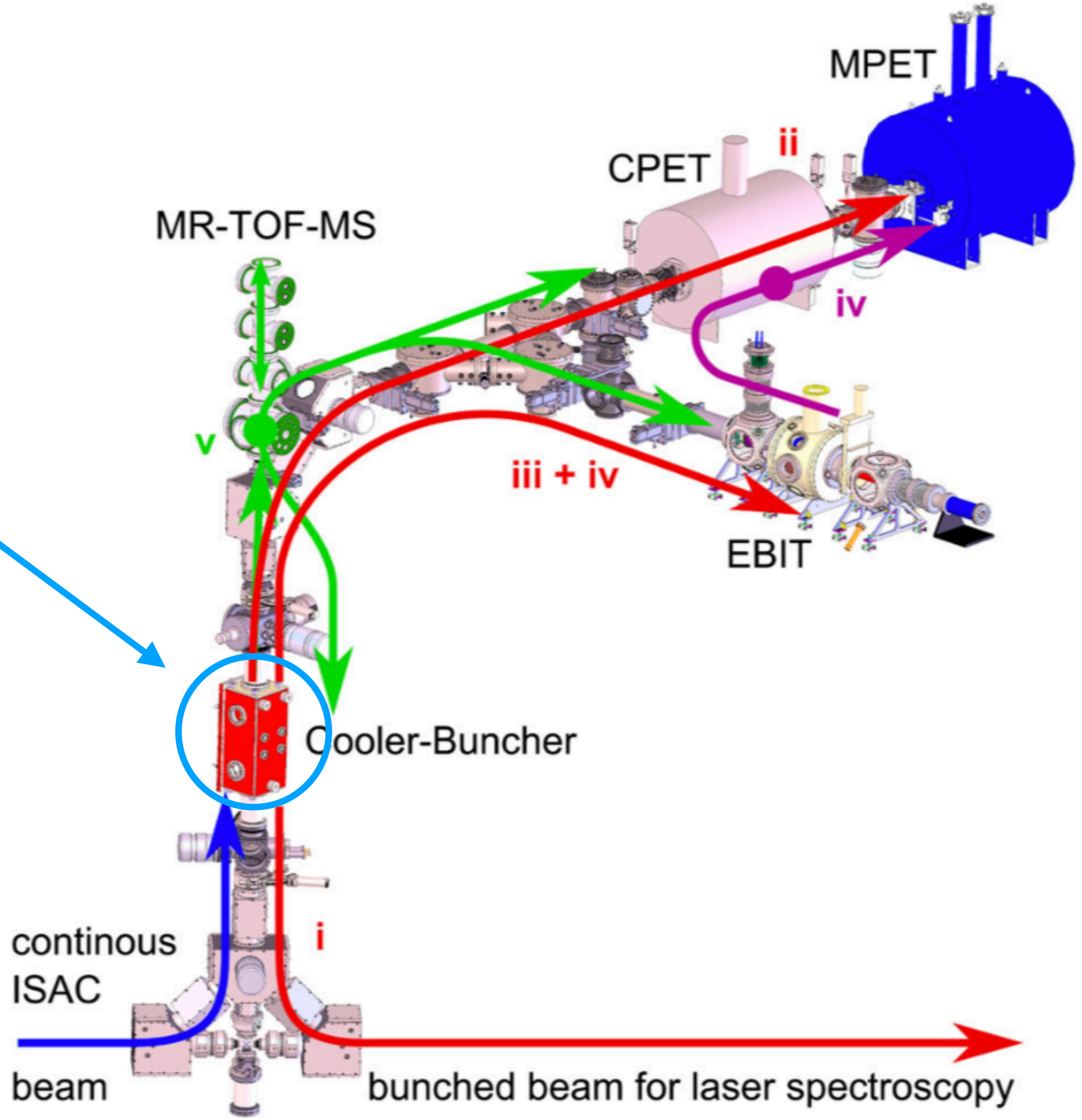

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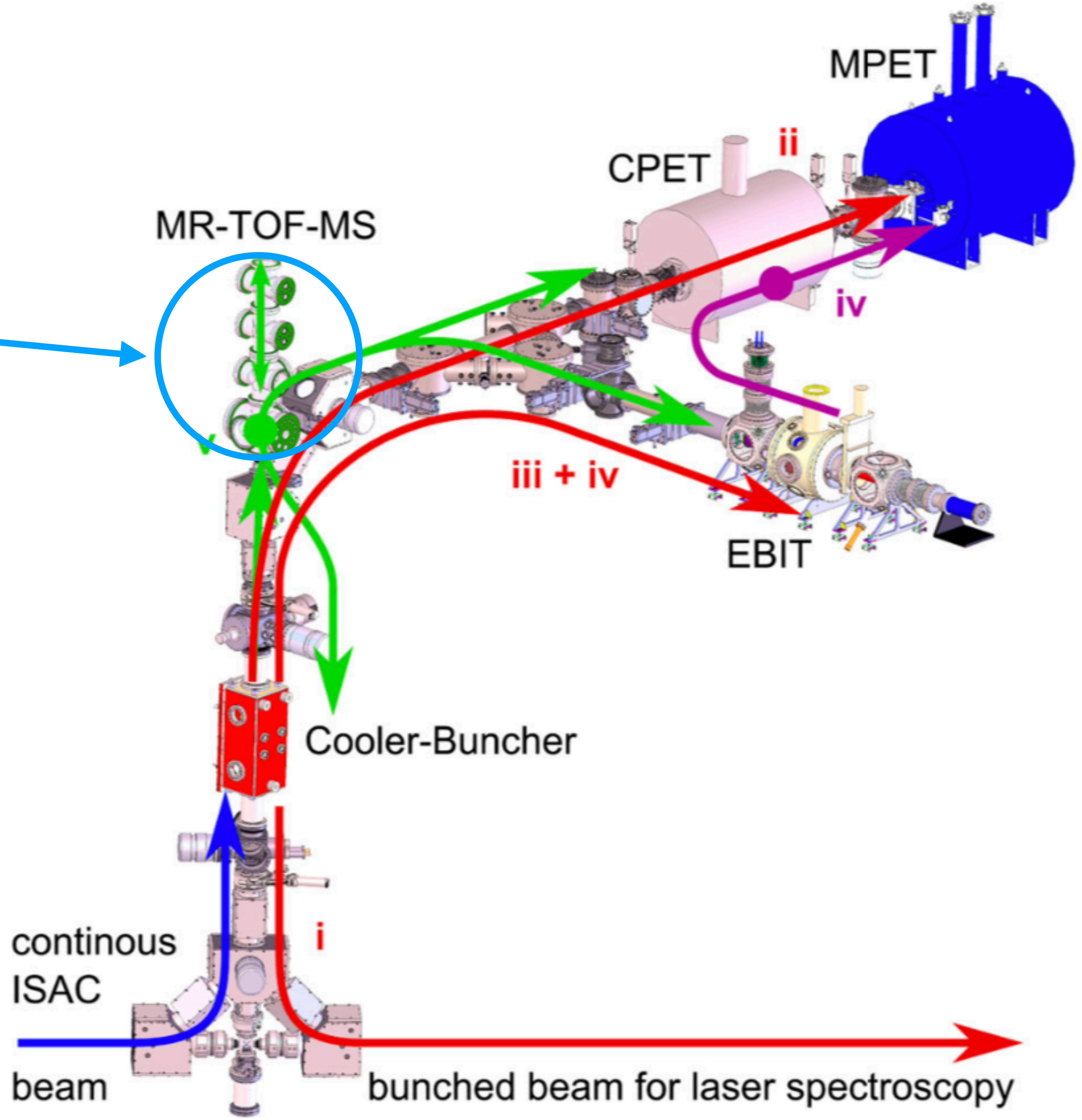

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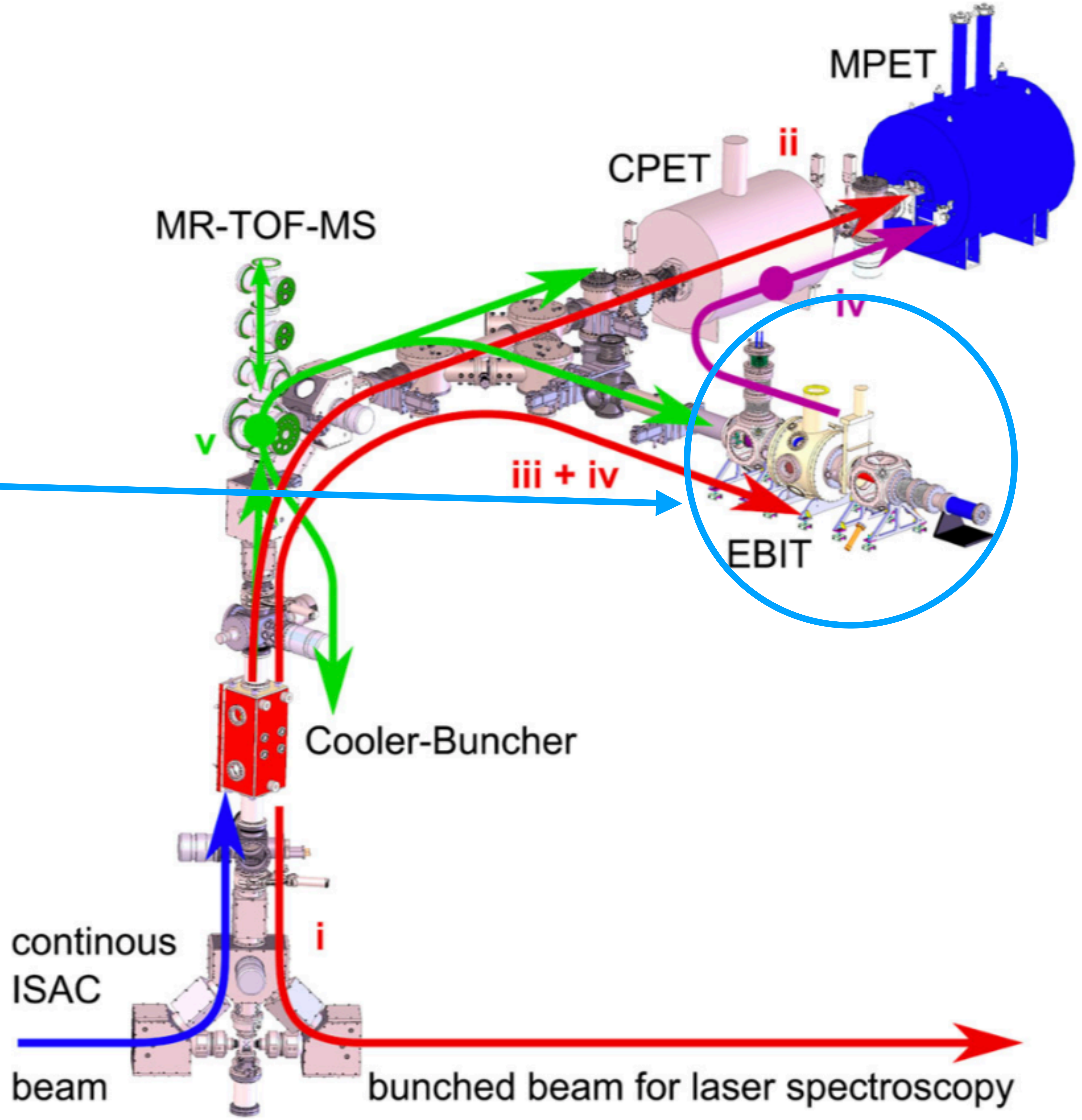

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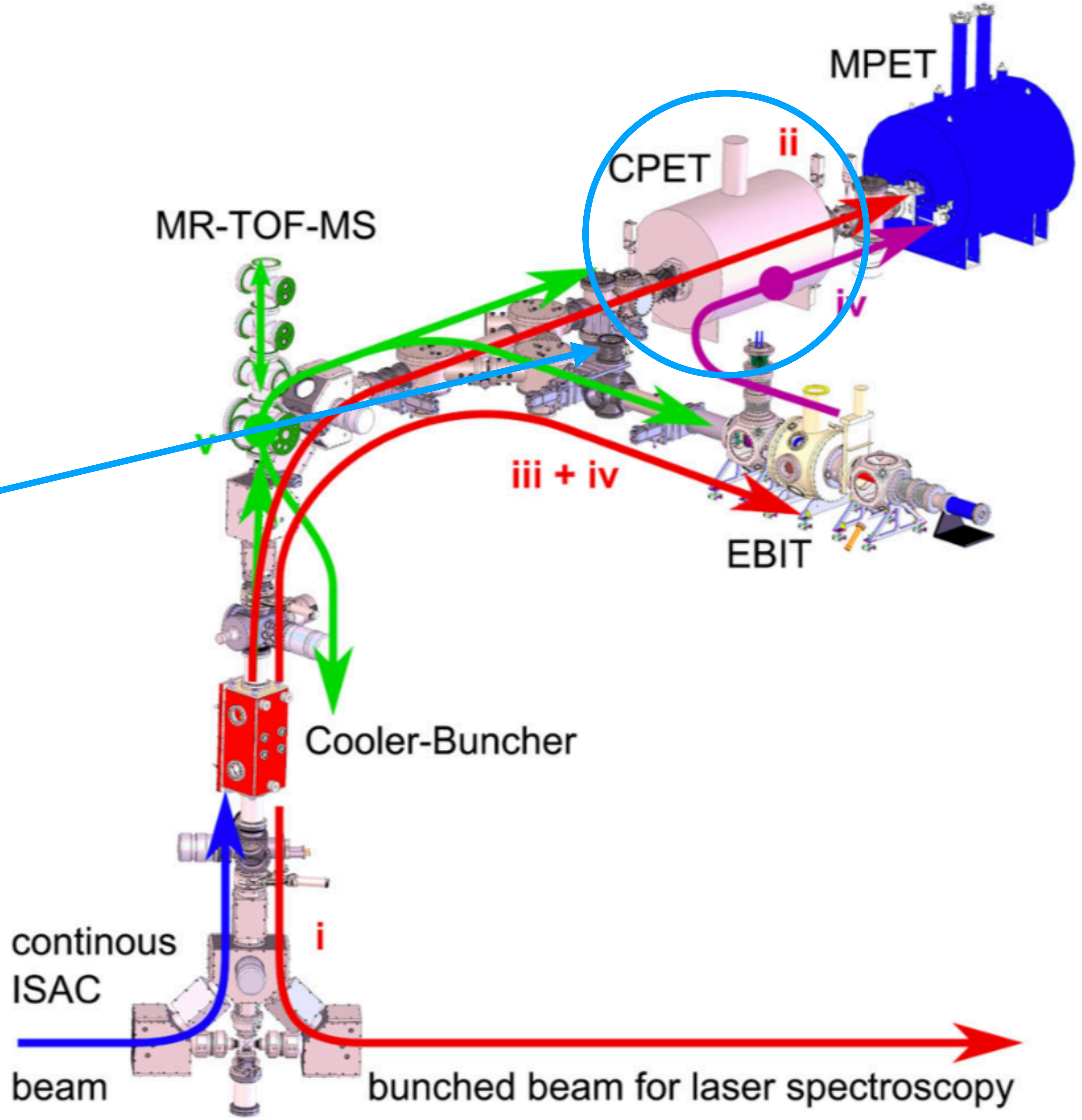

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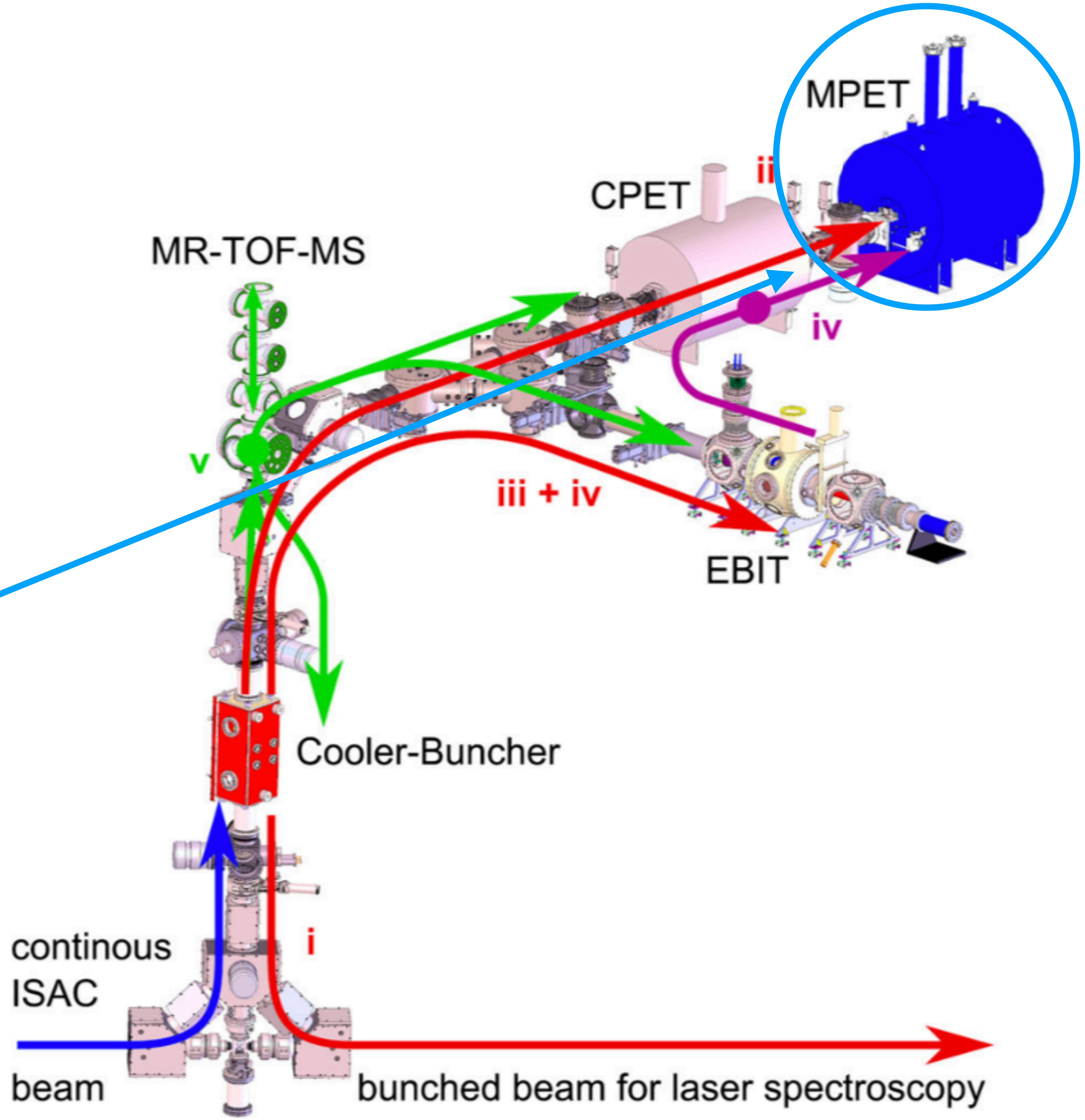
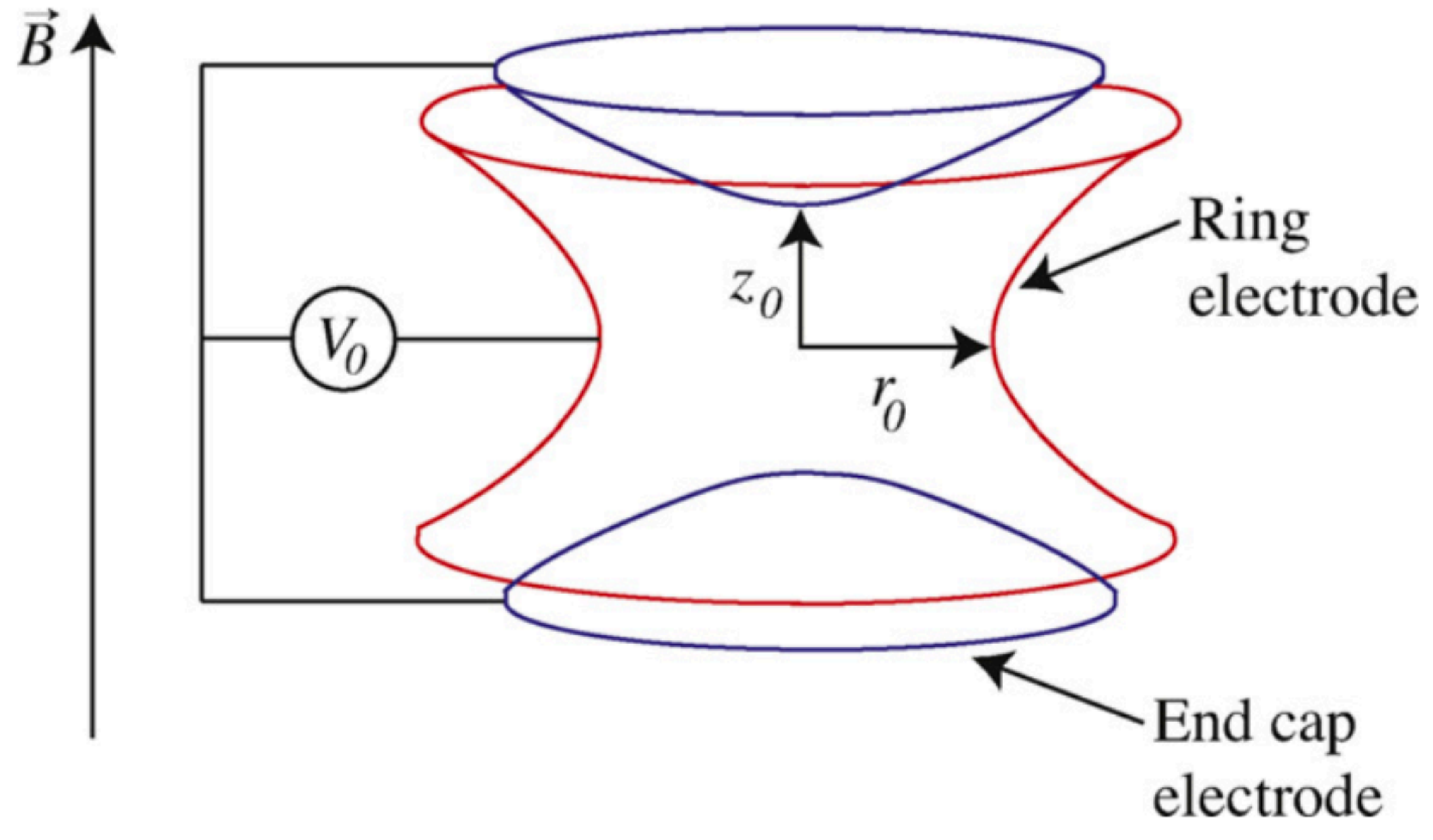
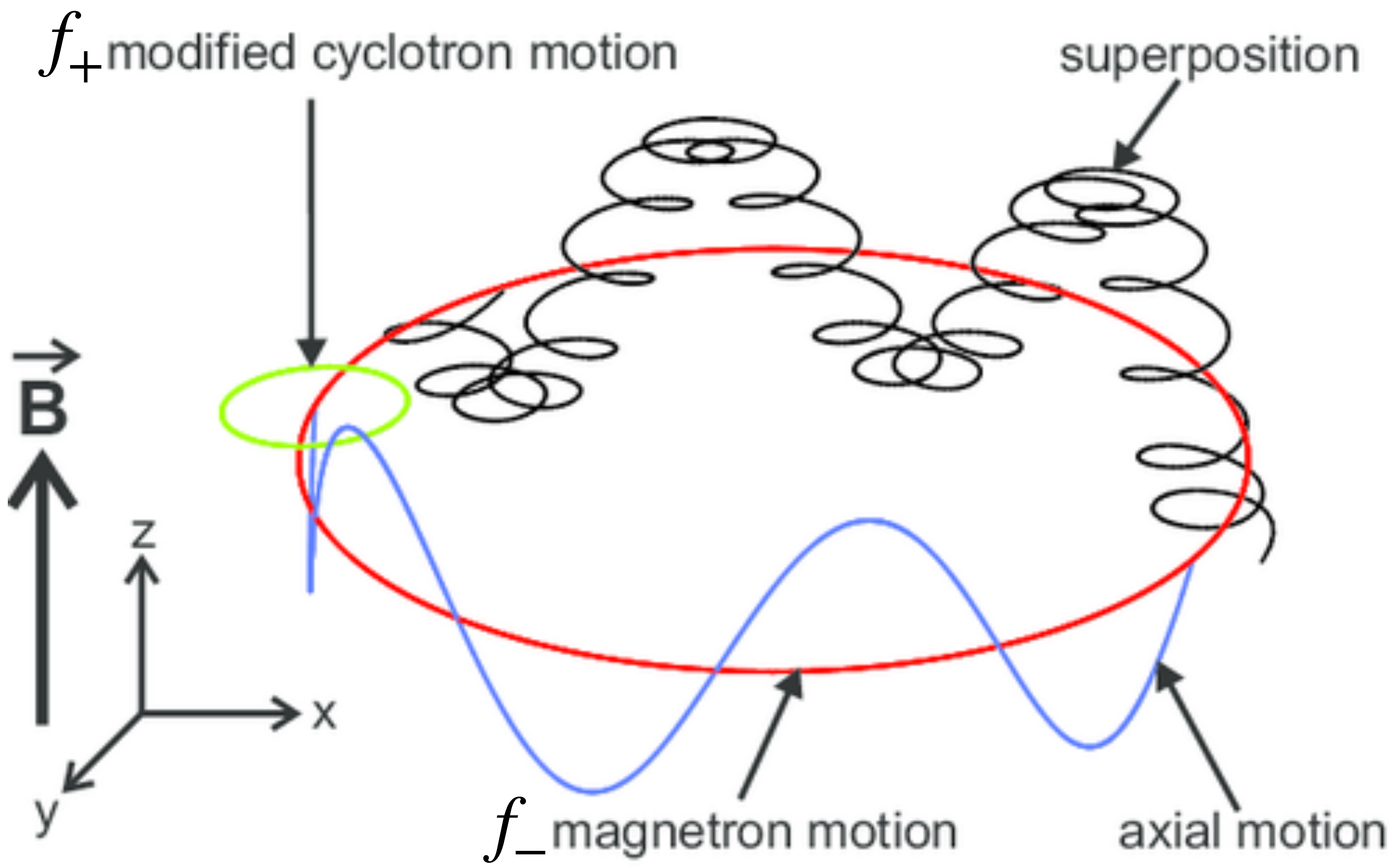


Penning Traps 101 - Ion confinement

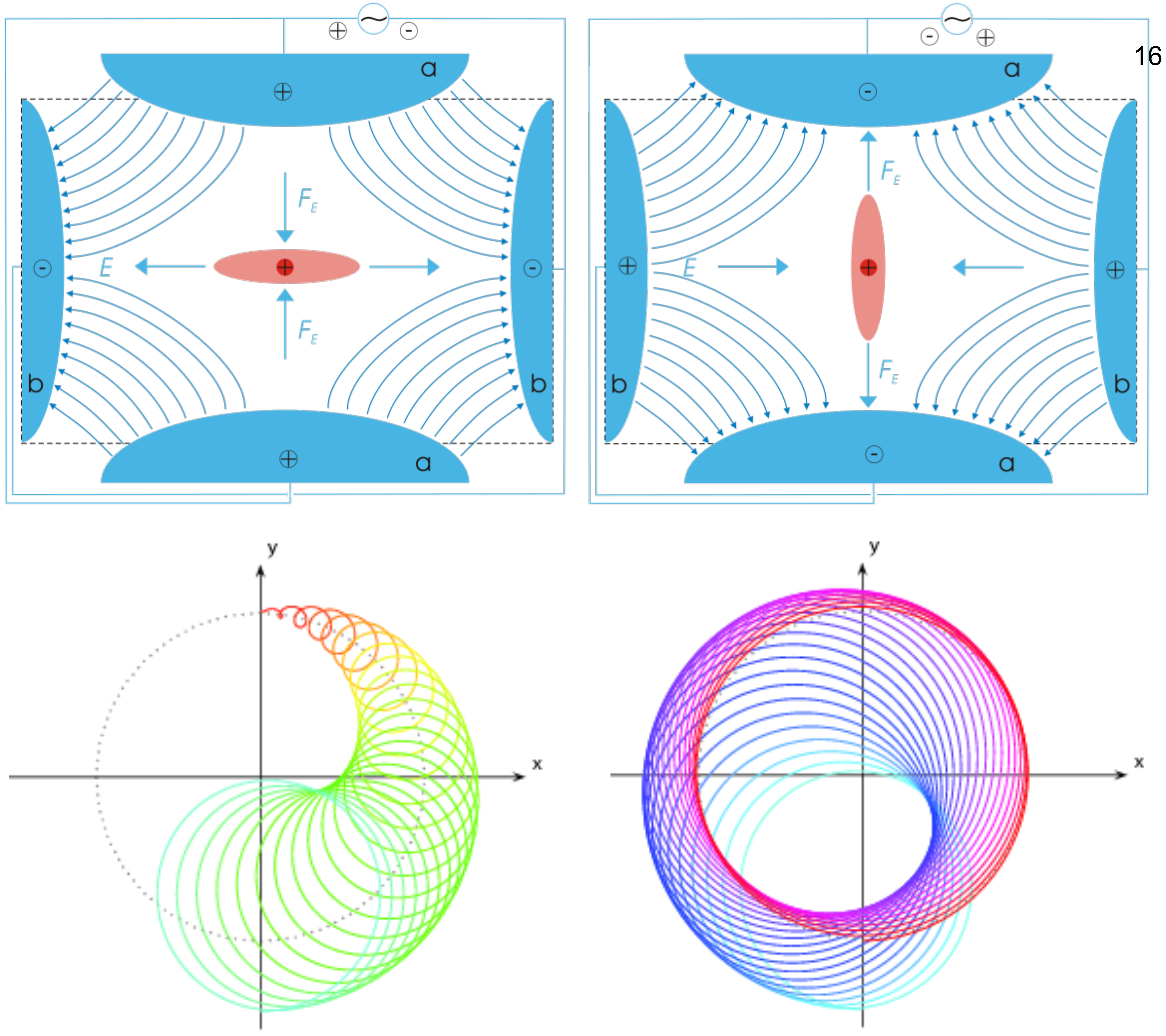
- Lorentz force $\overrightarrow{F} = q\overrightarrow{v} \times \overrightarrow{B}$ directs ions in B-field into circular motion with cyclotron frequency $f_c = \frac{qB}{2\pi m}$
- Magnetic + Electrostatic field to confine ions
- Magnetron motion f_- on order of kHz
- Modified cyclotron motion f_+ on order of MHz
- $f_c = f_+ + f_-$





Penning Traps 101 - Mass Measurement

1. Scan over f_{RF}
2. $f_{-} \leftrightarrow f_{+}$ occurs when $f_{RF} = f_c$
3. Increase in E_{radial} of ions
4. Decrease in Time-of-Flight to Detector



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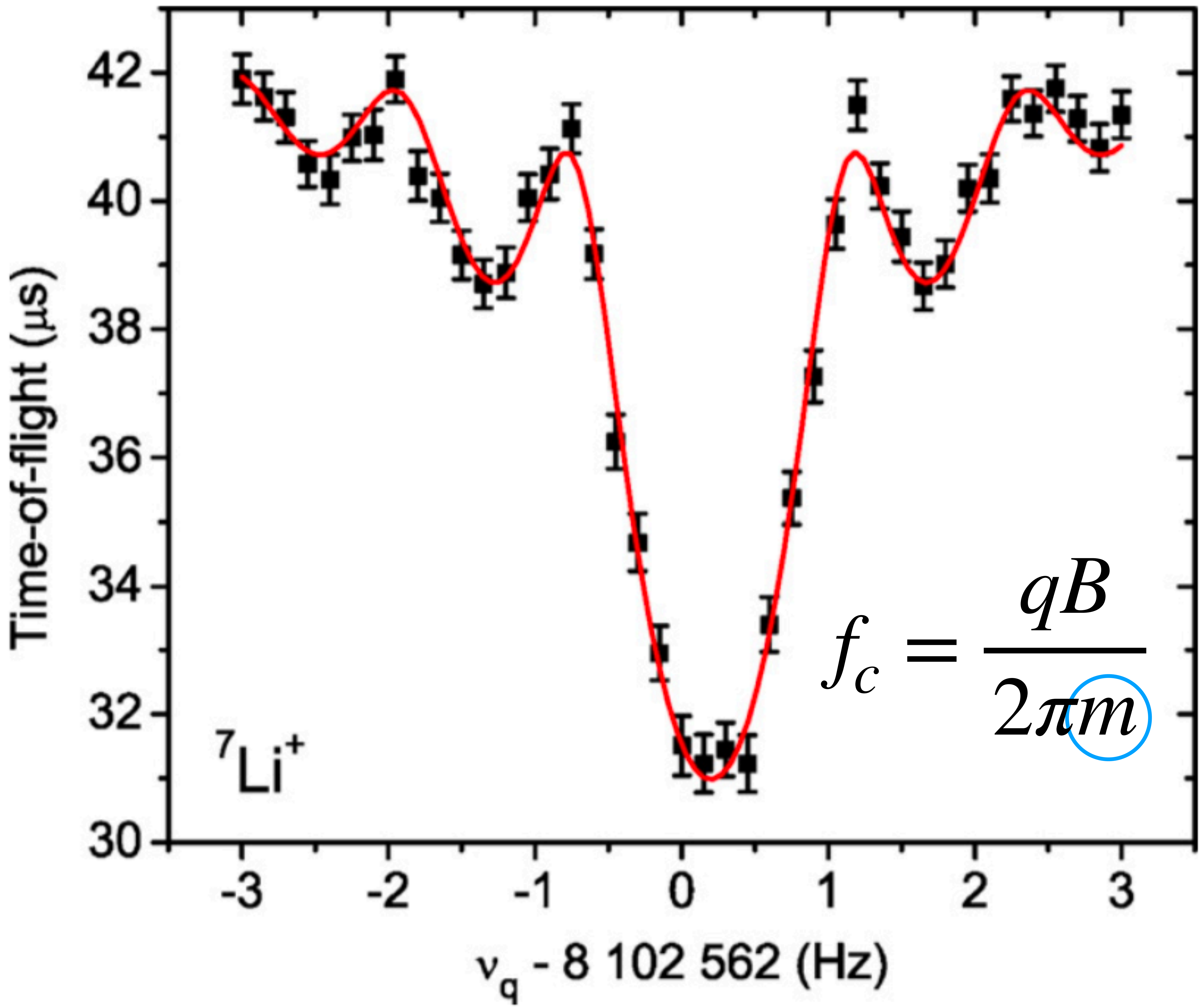
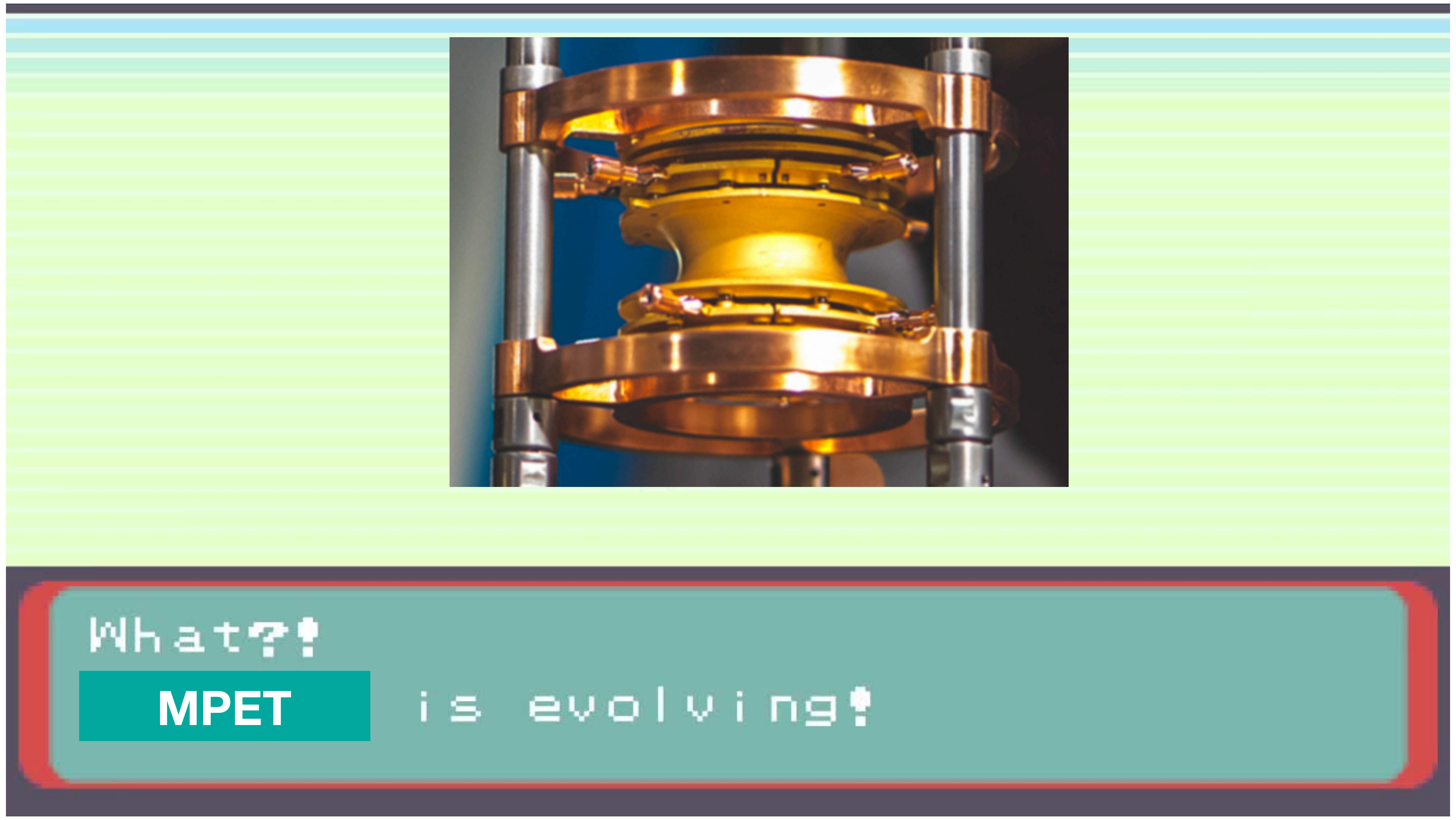


$$f_c = \frac{qB}{2\pi m}$$

MPET to CryoMPET

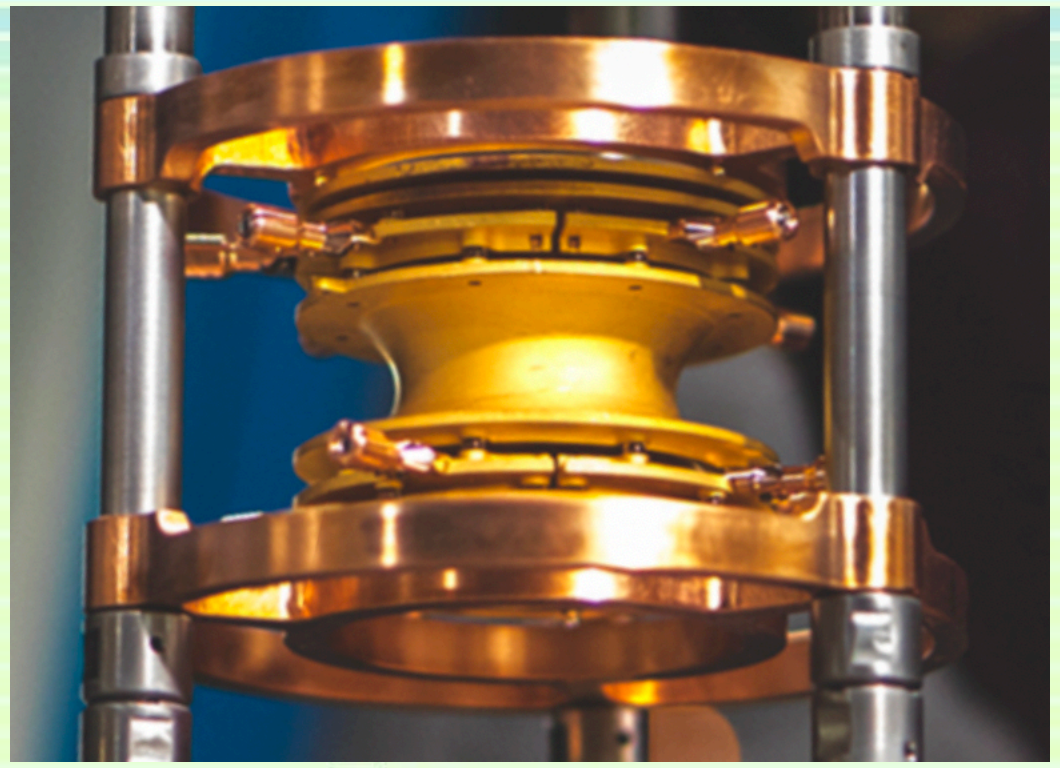
MPET



Room Temperature Penning Trap, online 2007-2017

MPET to CryoMPET

MPET



What?!
MPET is evolving!

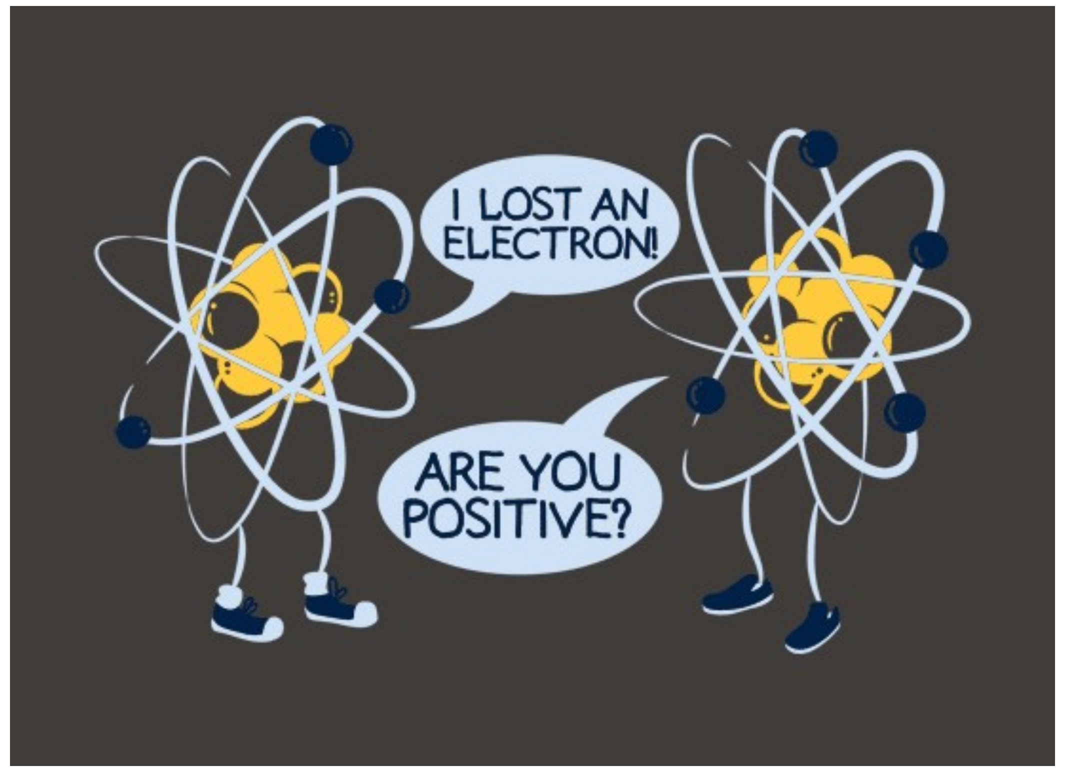
Room Temperature Penning Trap, online 2007-2017

CryoMPET

CONGRATULATIONS! Your MPET evolved into CryoMPET!

Cryogenic Penning Trap, in development 2017-present

Motivation for CryoMPET



TITAN EBIT increases the charge state of ions

$$X^{+} \rightarrow X^{2+} \rightarrow X^{3+} \rightarrow \cdots$$

↓

This decreases the relative uncertainty of measurement

$$\frac{\delta m}{m} \approx \frac{m}{qBT_{RF}\sqrt{N_{ions}}}$$

↓

However, increased charge state leads to increased chance of interaction with background gas

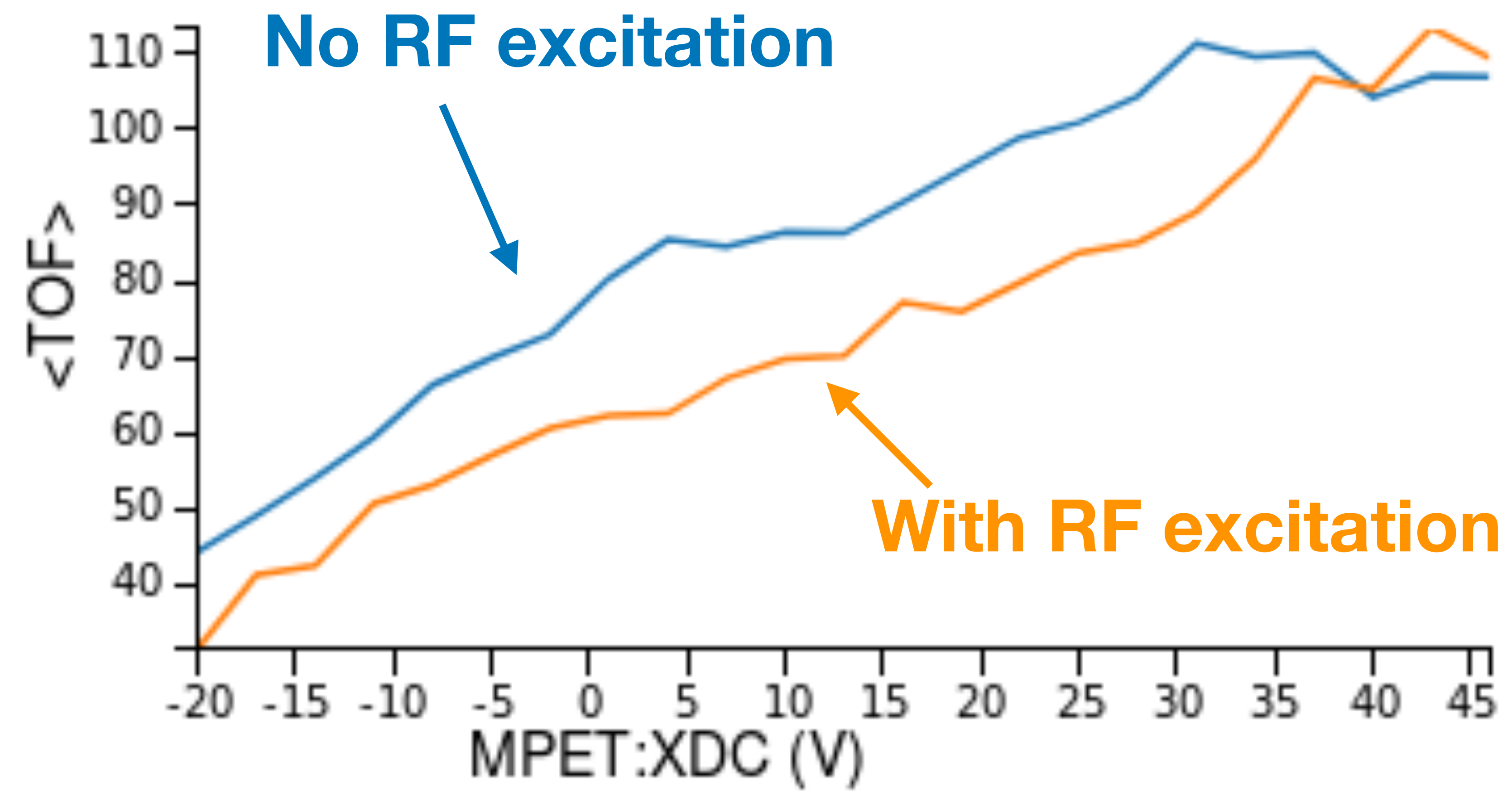
↓

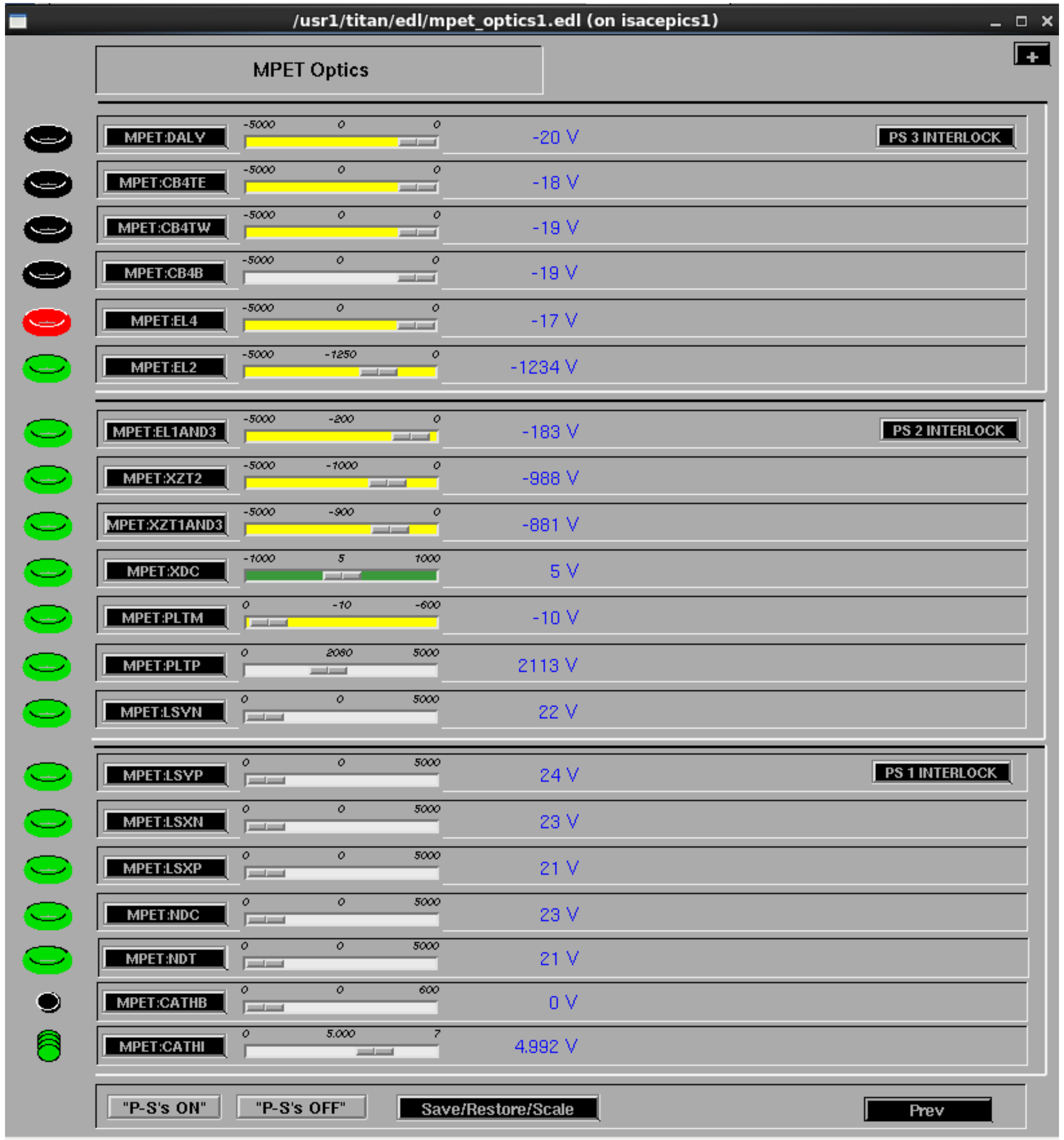
Cryopumps for better trap vacuum!

Extraction Scans: Real-Life Resonance Hunt

- CryoMPET installed spring 2019 -> Tuning+Resonance search in progress
- Resonance dependent on extraction electrode voltages
- Scans over electrodes to find and improve Time-of-Flight (TOF) resonance effect.

Avg TOF vs. XDC Voltage (Scanned Value)





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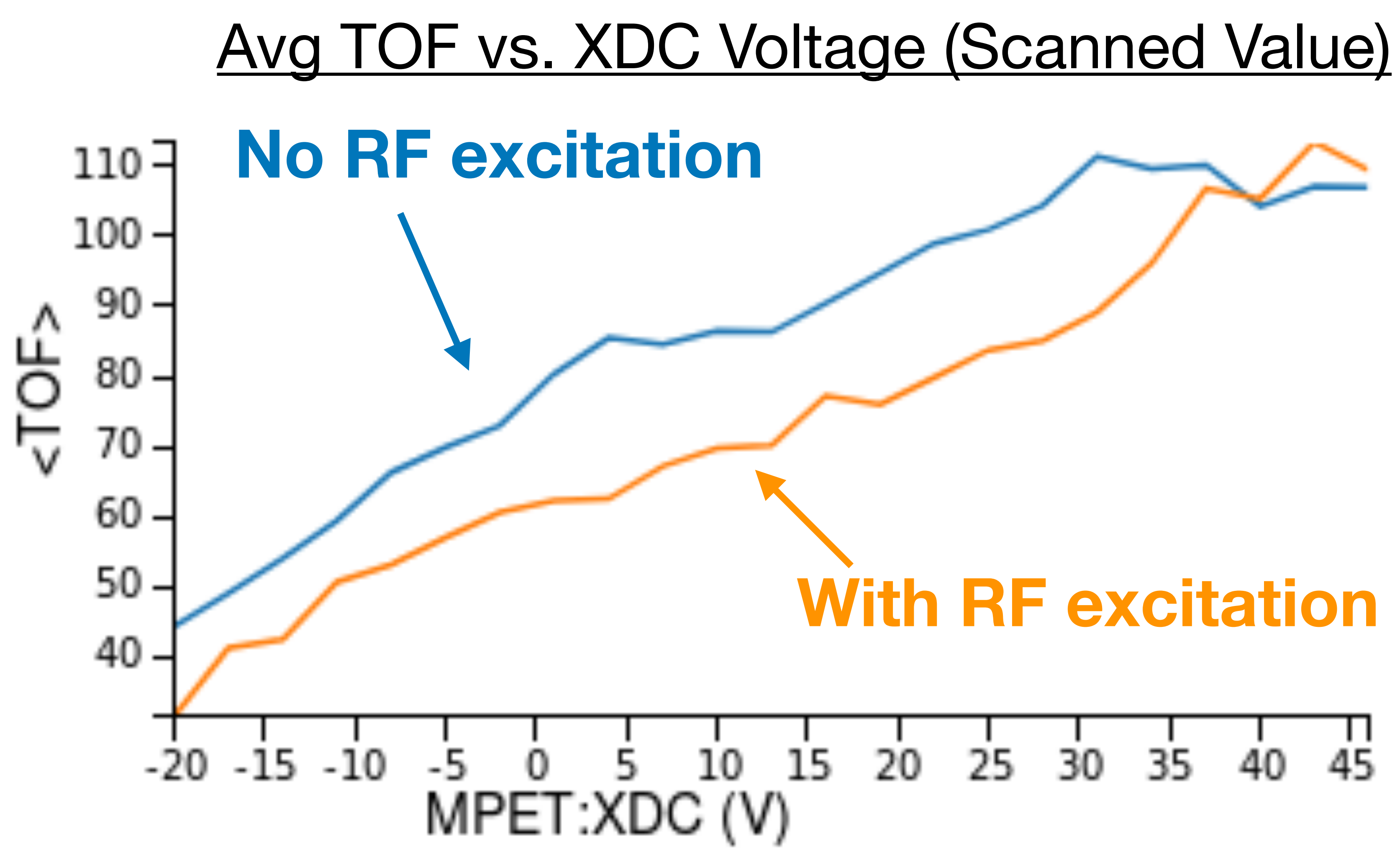
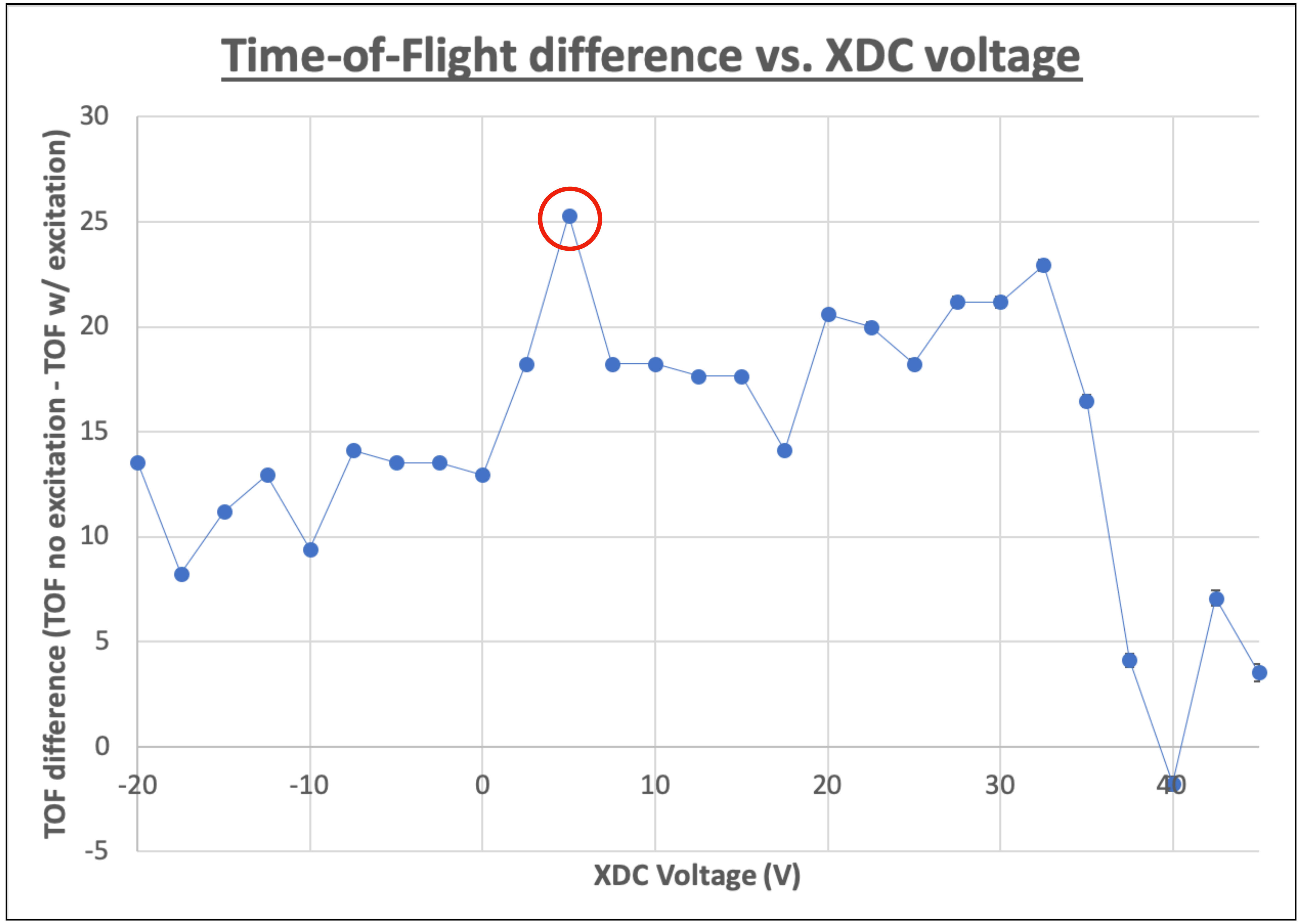
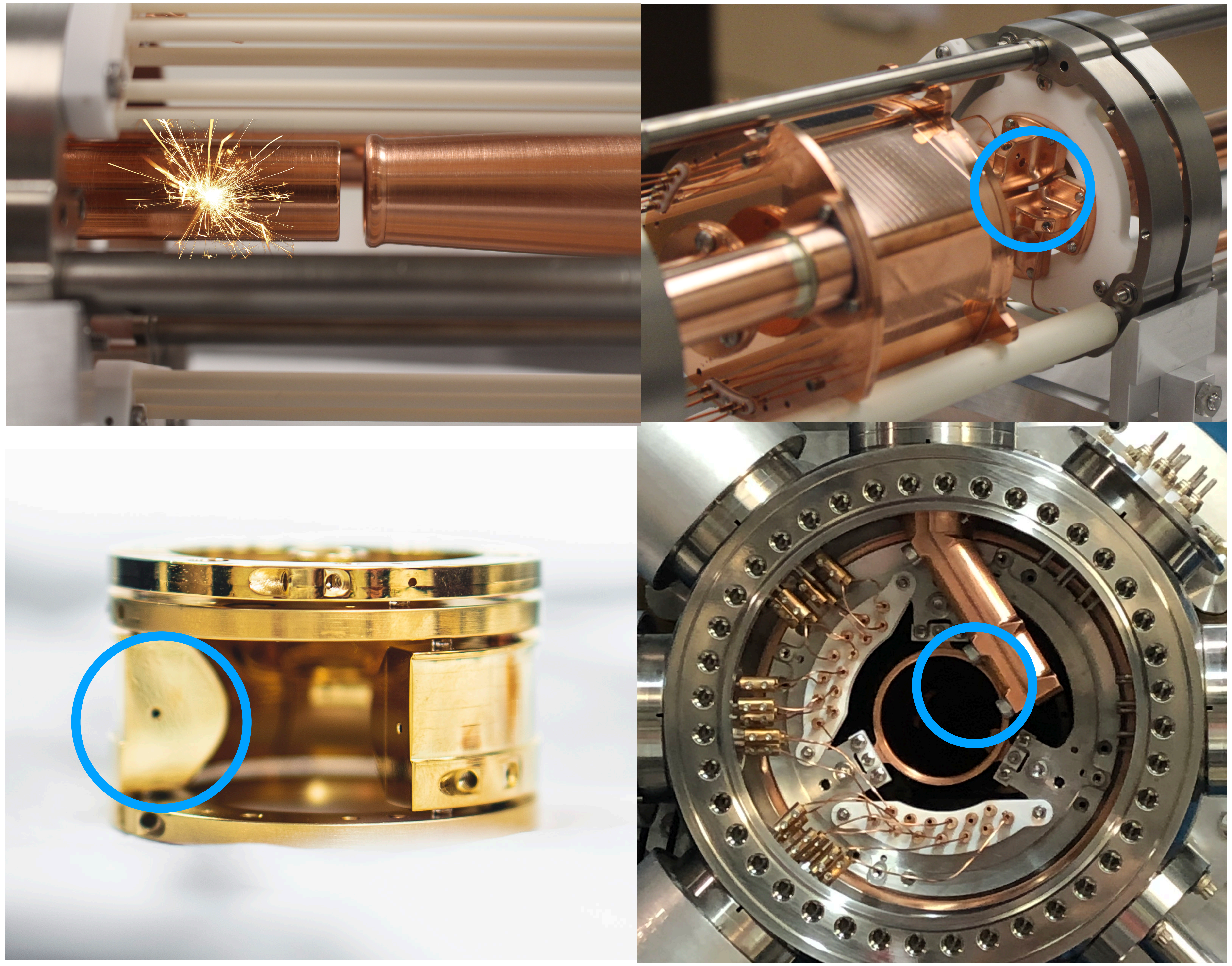




Setbacks

- Sparking
- Shorts at 3 components.
- Temperature threshold not met



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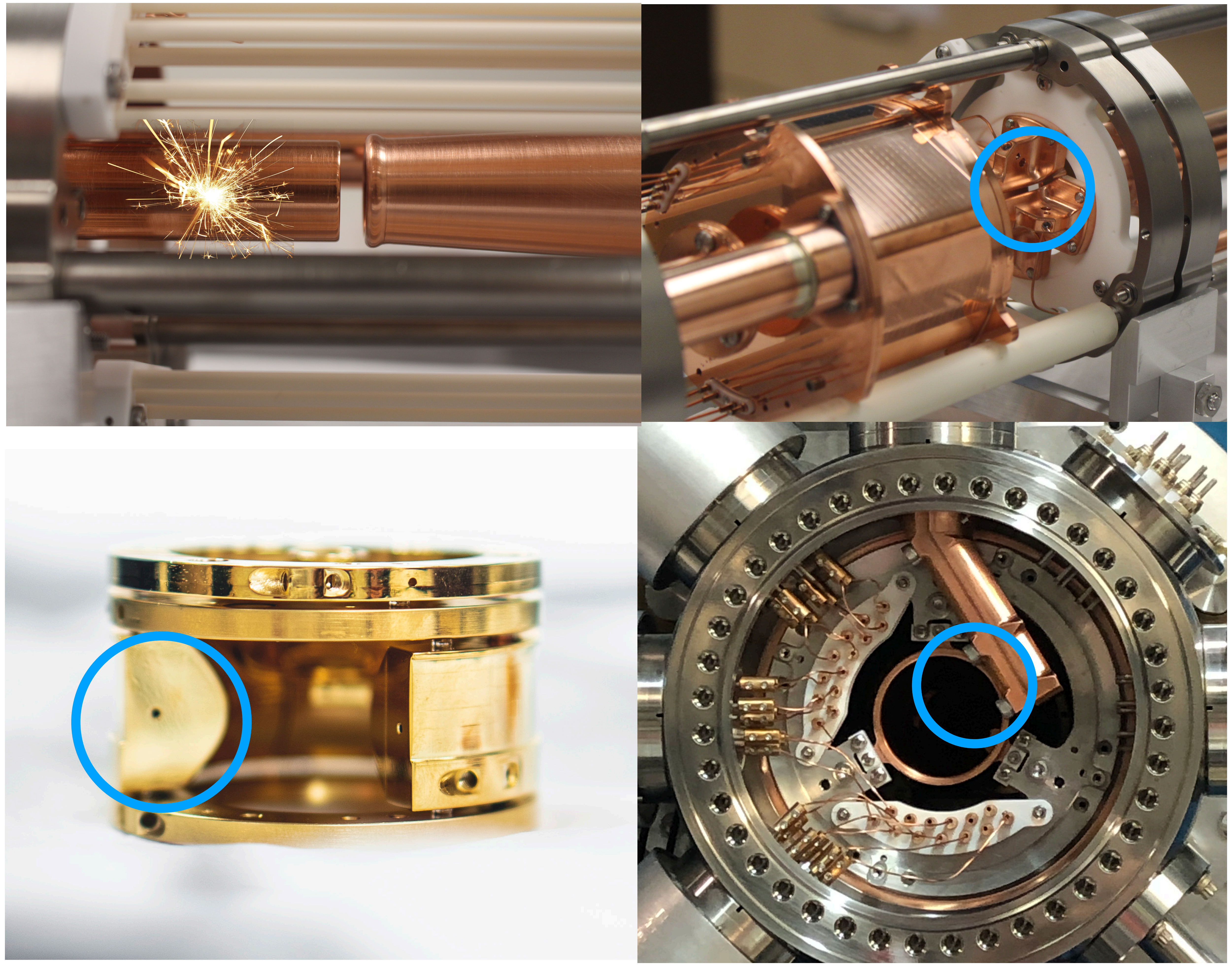
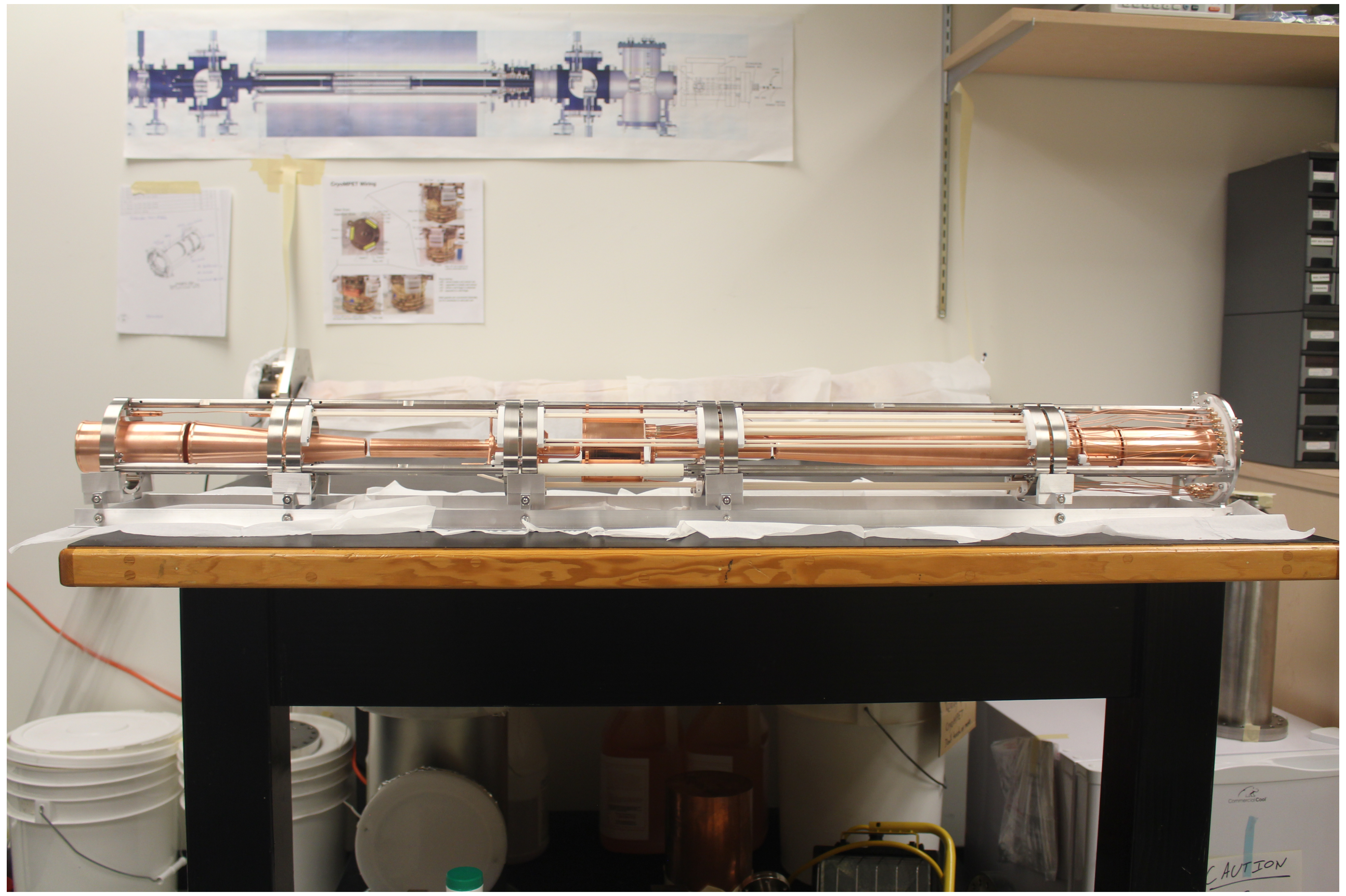
↓

- Trap has to be pulled from magnet



Meanwhile, with extractions…



Difficult to tune a disconnected trap…

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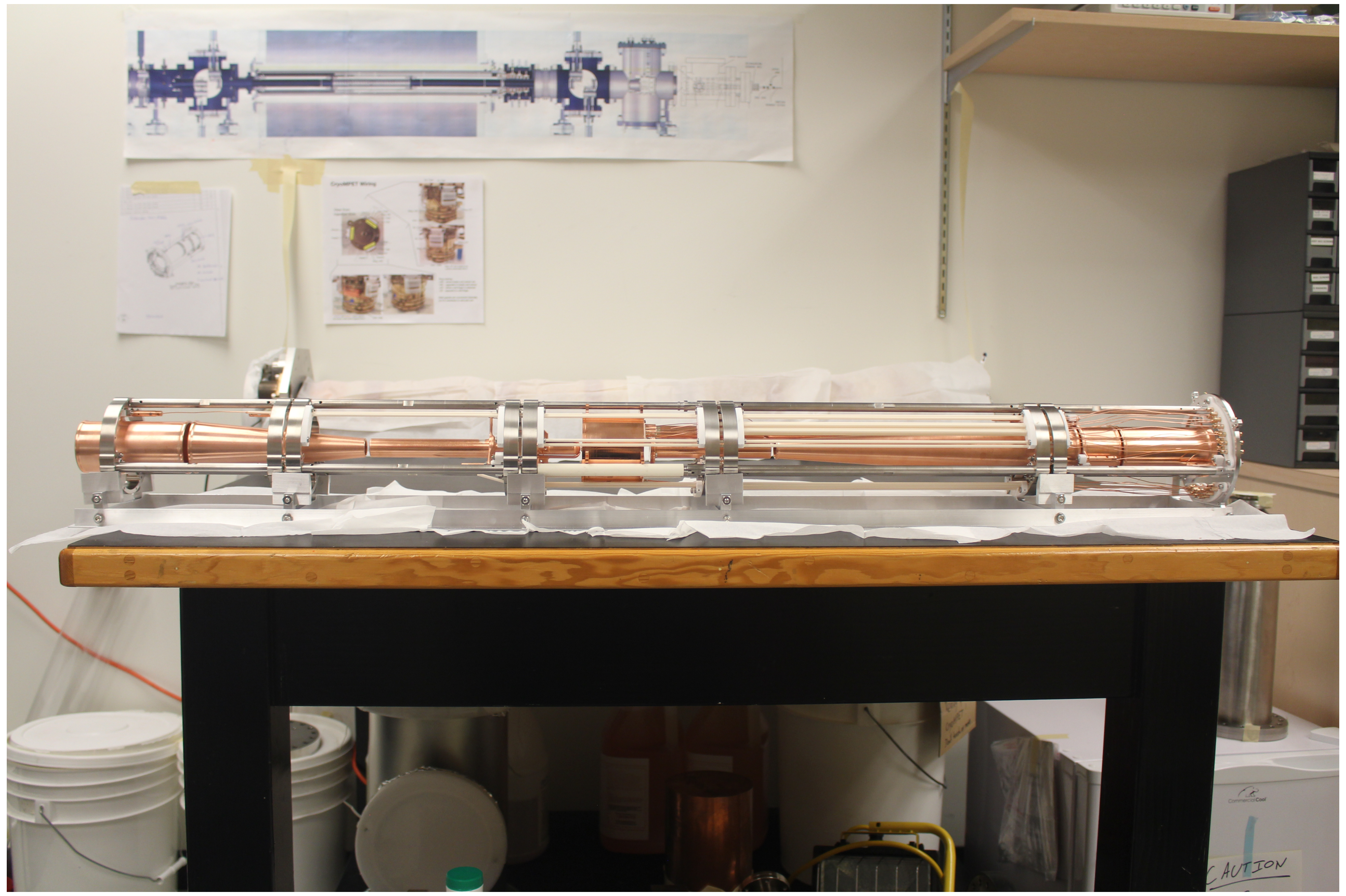

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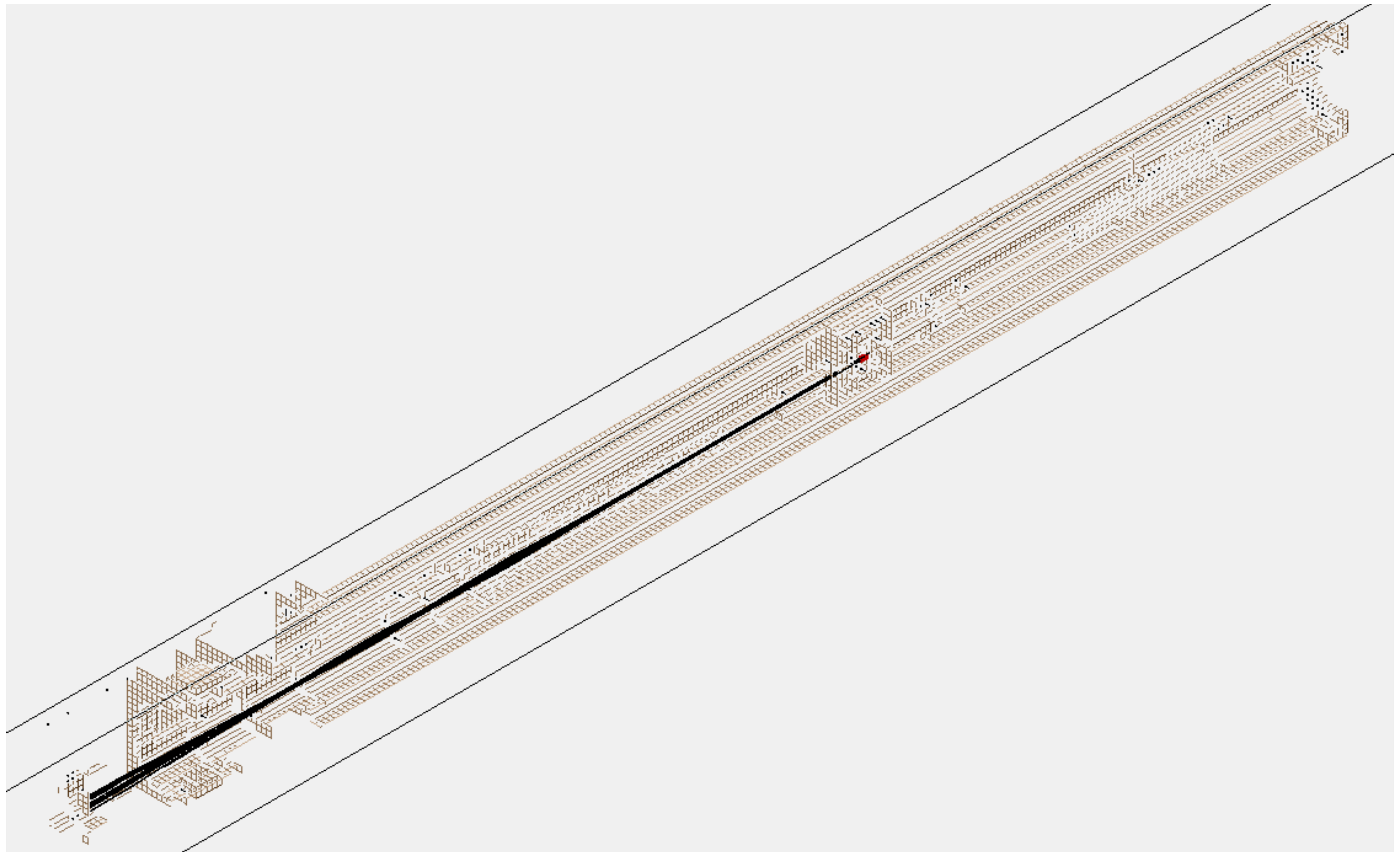
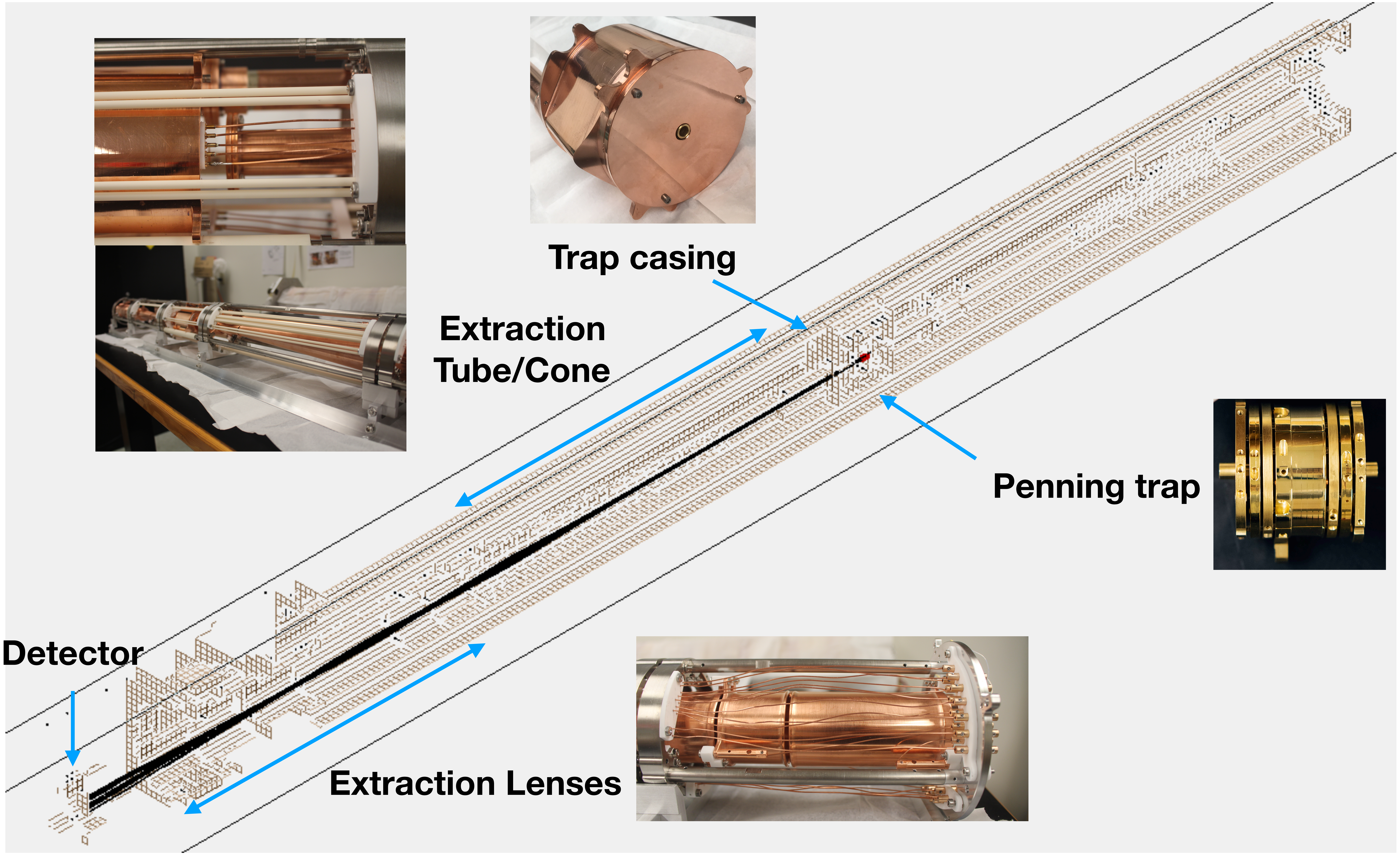


Simulations with SIMION!

Extraction Scans: Virtual (with SIMION)



Physicists hate him: The 5-step plan to obtain clean virtual resonances

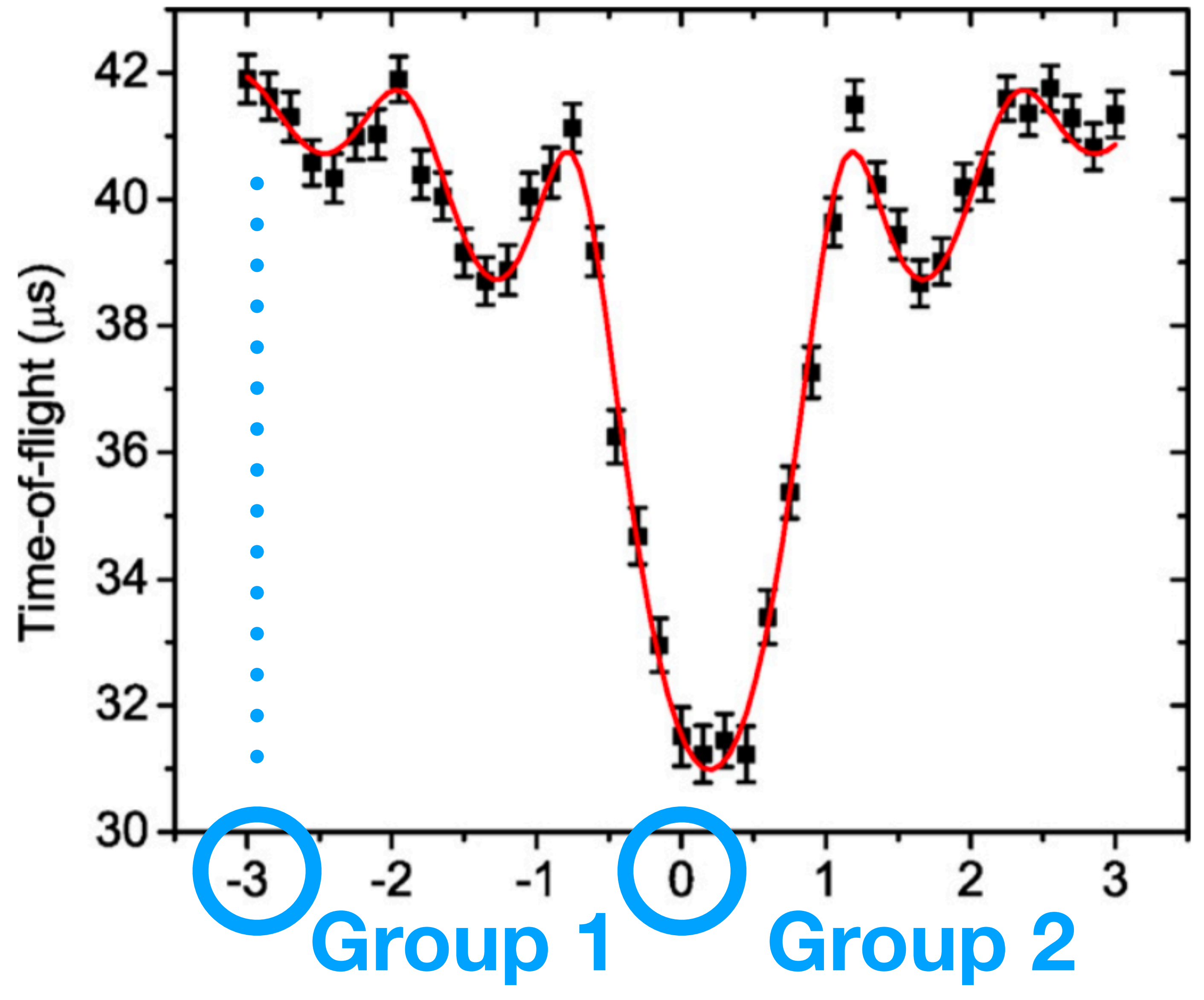
1. Generate 2 groups of ions with differing initial conditions (on/off resonance)

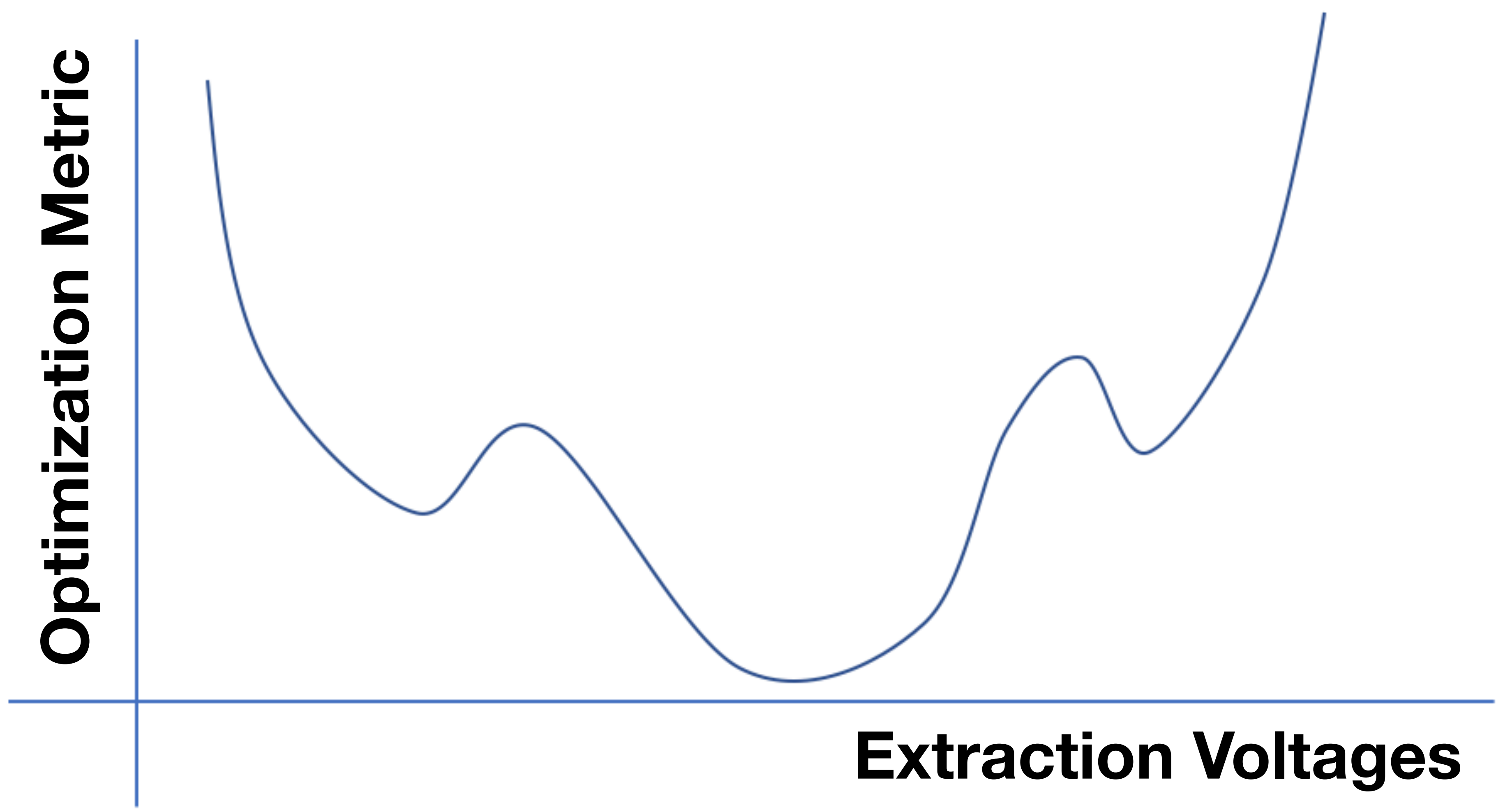
2. Select a random initial voltage for each extraction electrode

3. Test run of ions to ensure reasonable transmission

4. Run for hundreds of iterations with optimizer algorithm until extrema is reached

5. Record the extrema, and repeat process as long as time permits.





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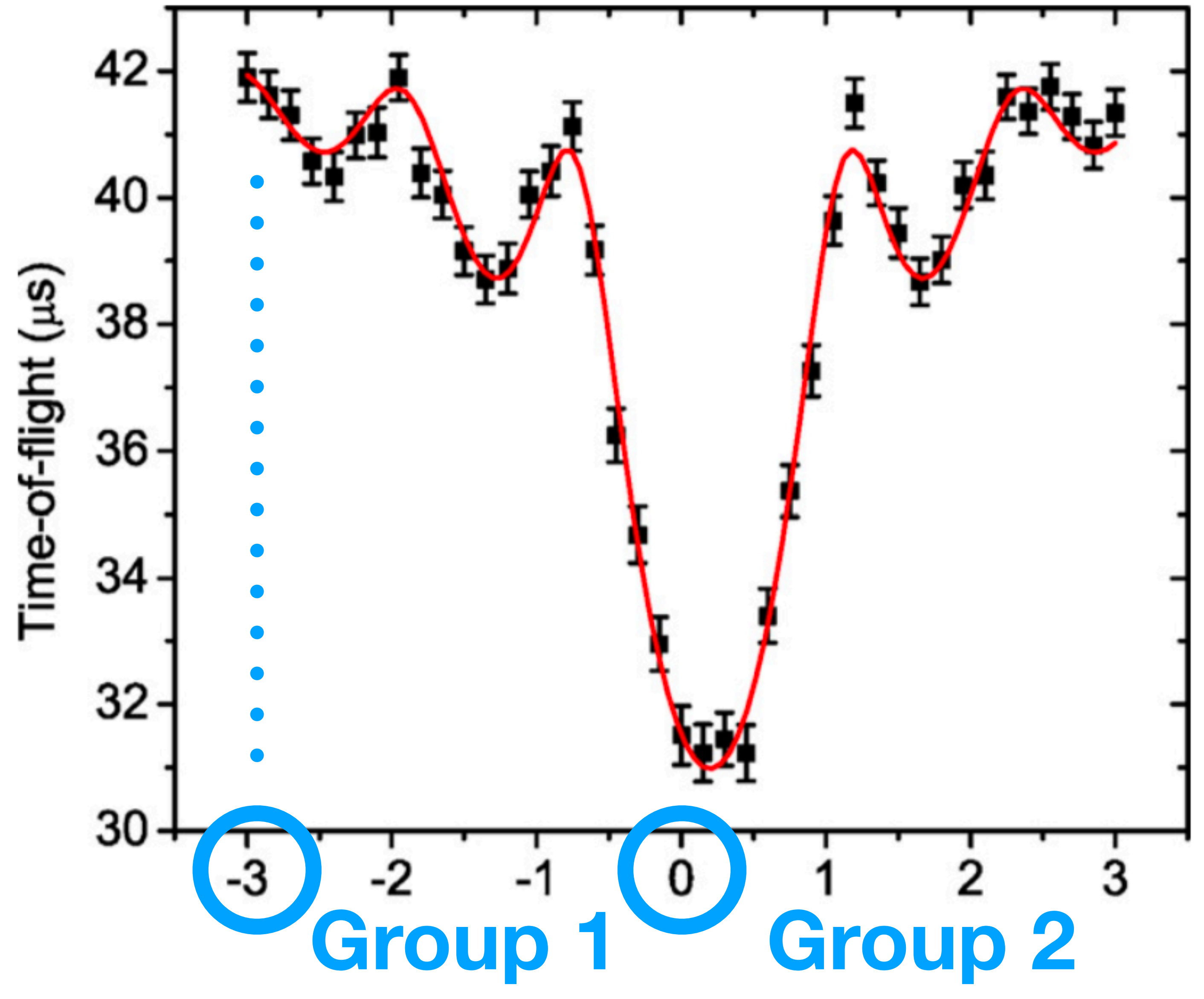

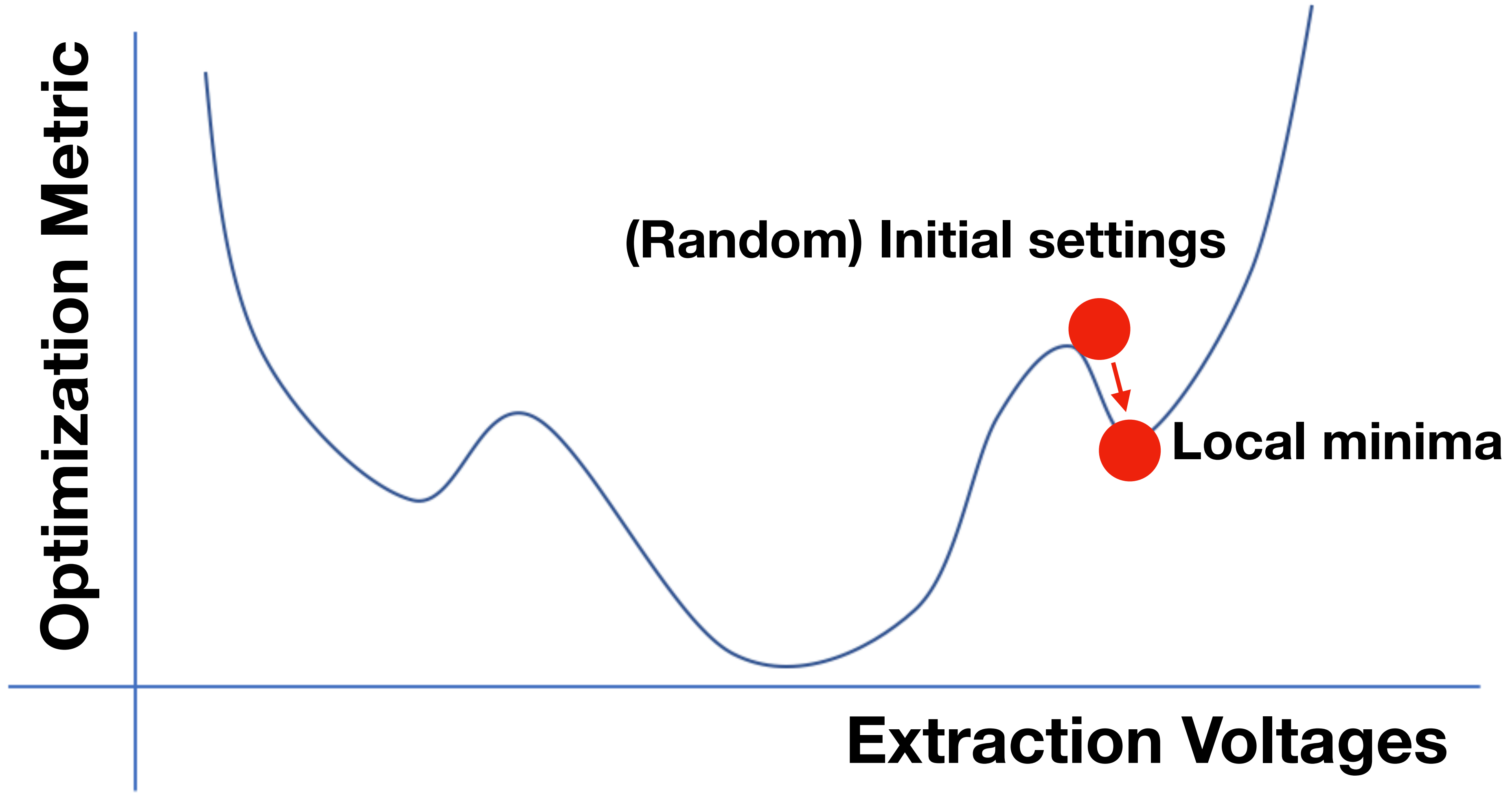

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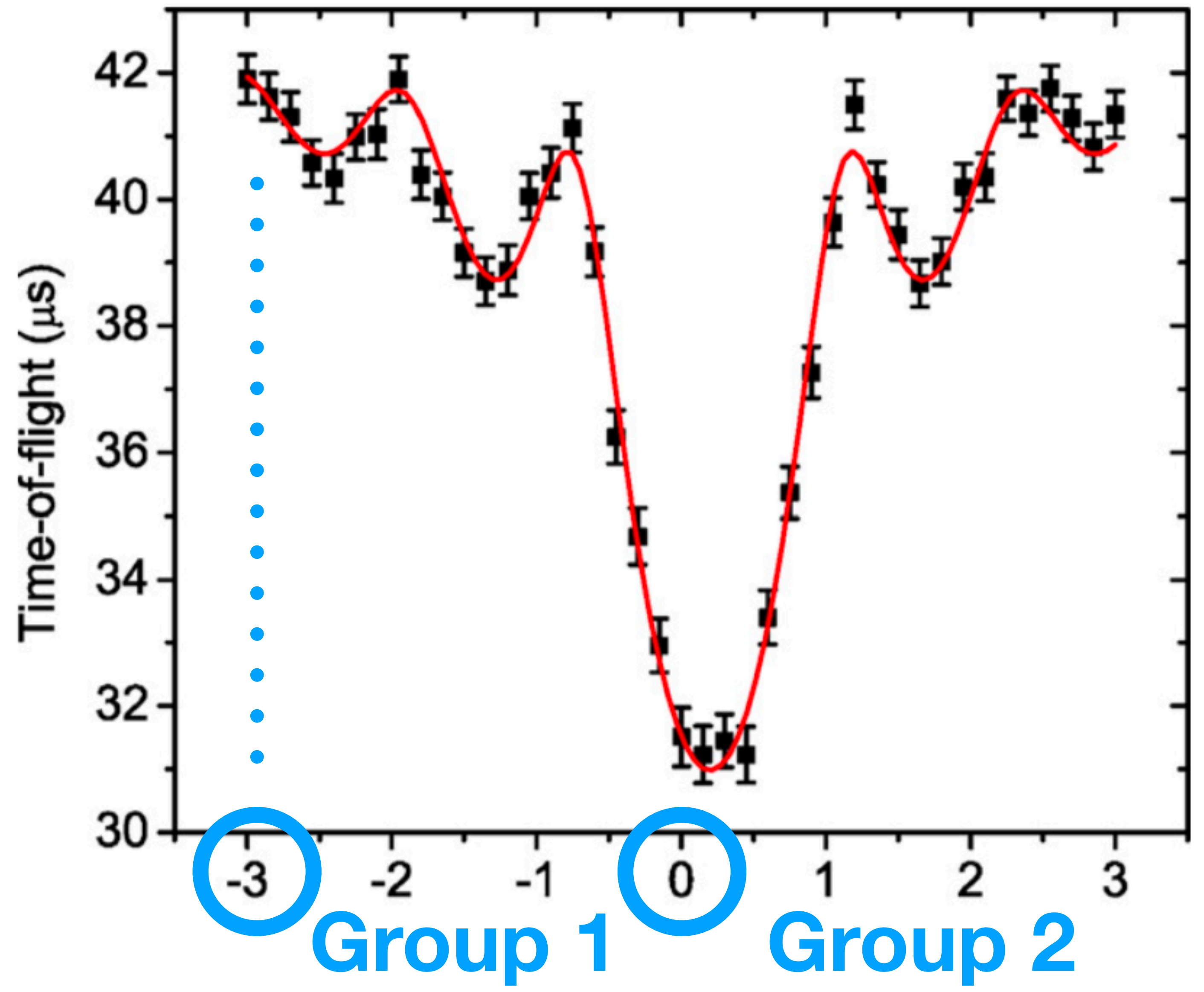
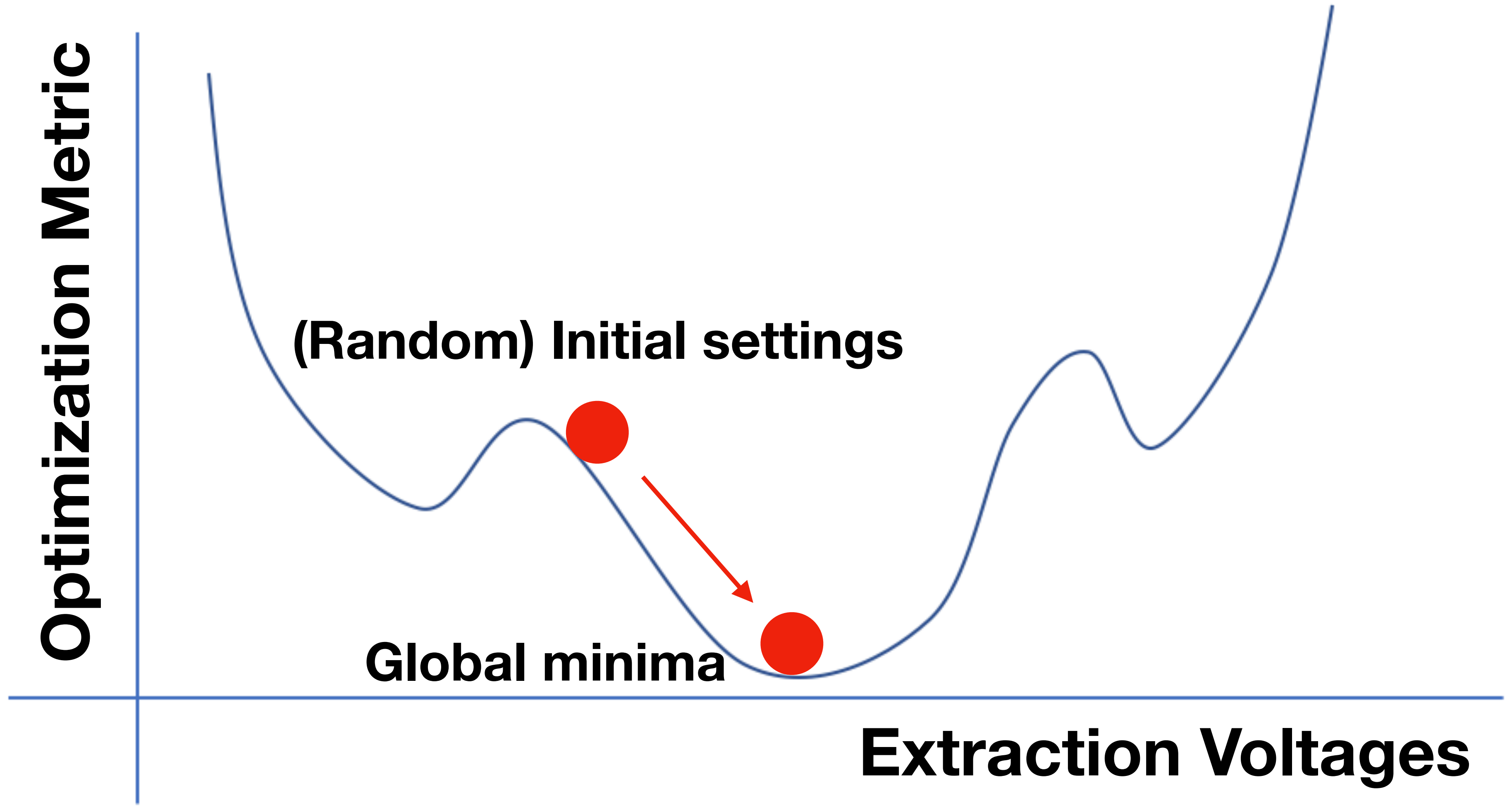
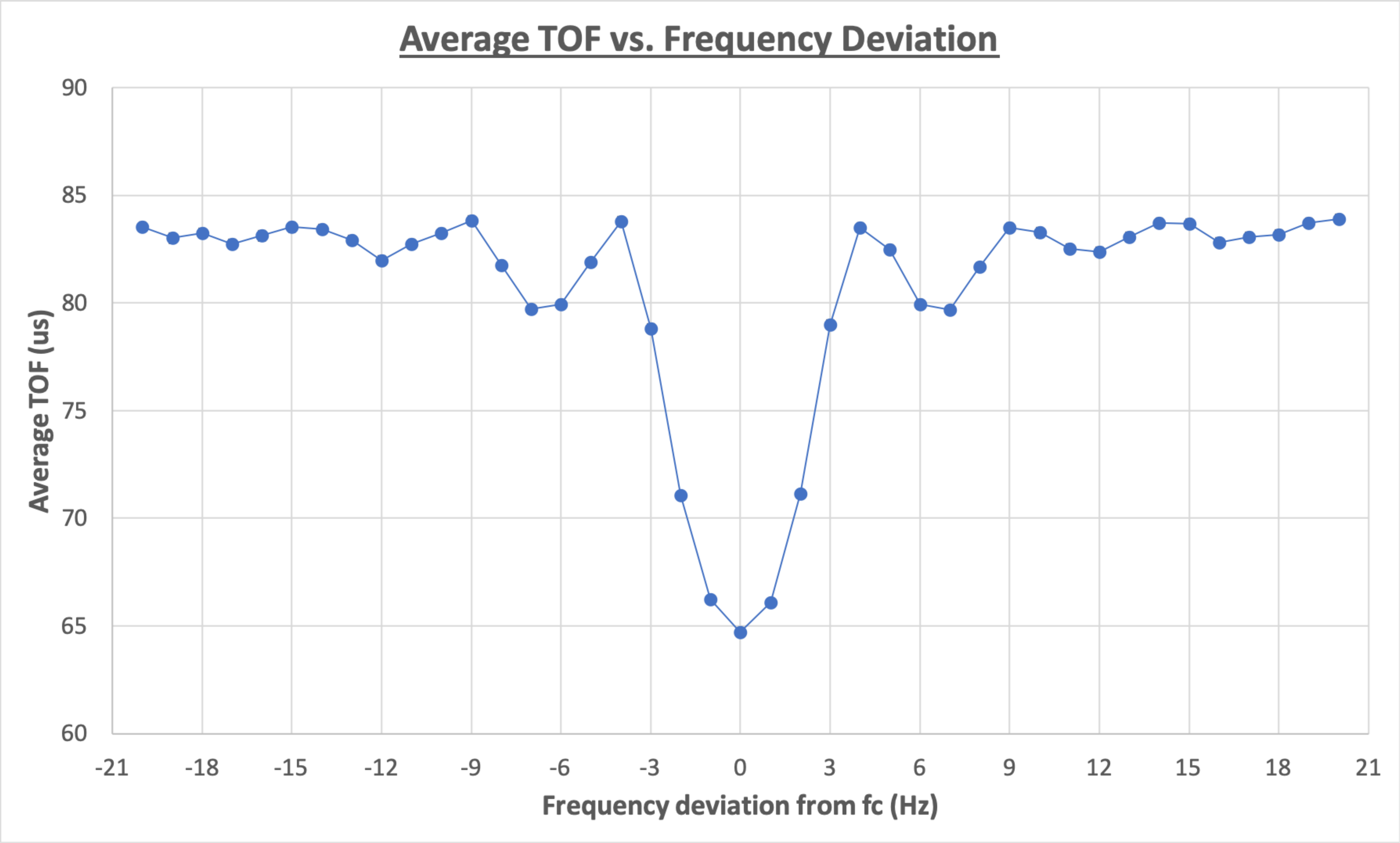


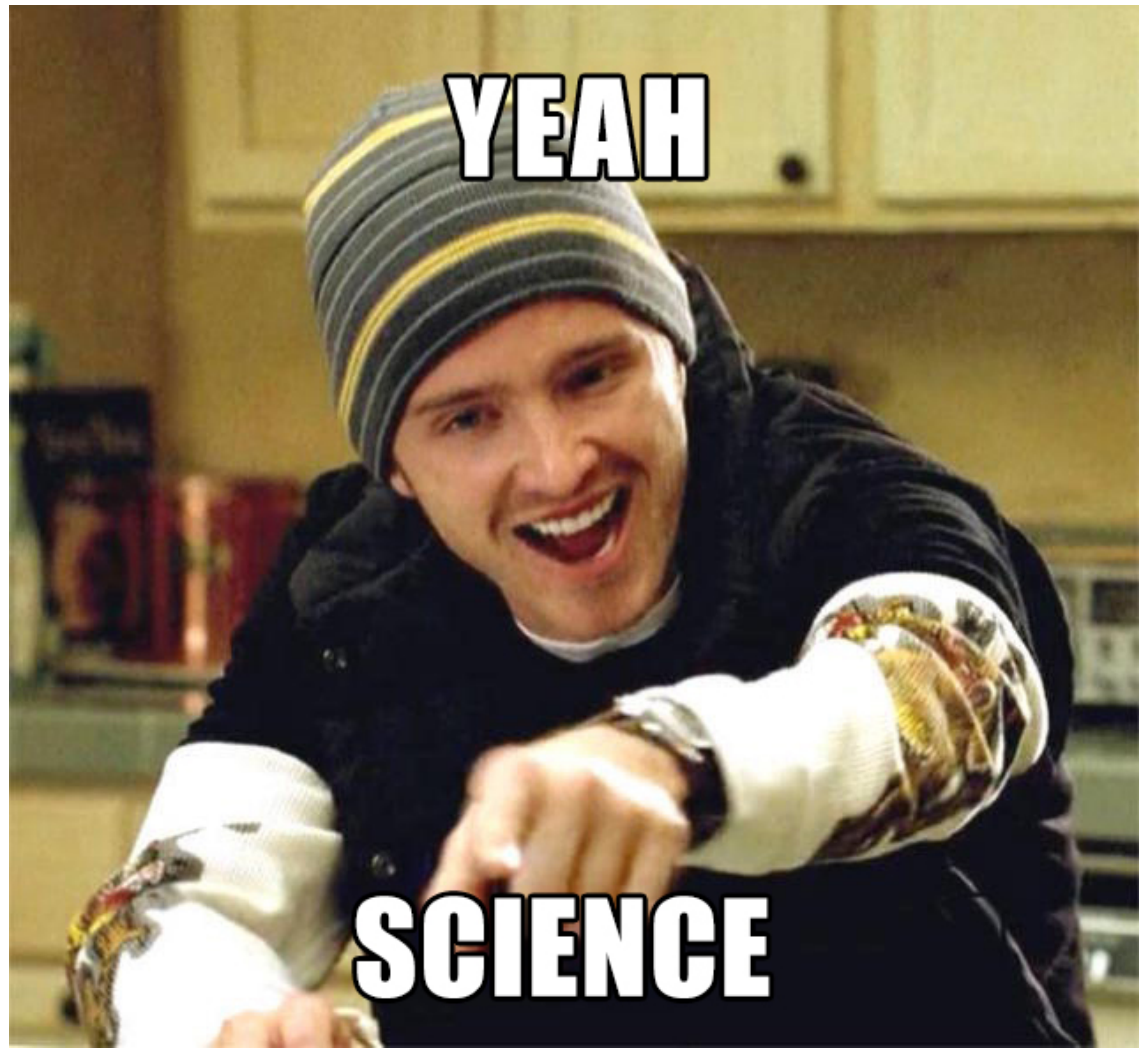


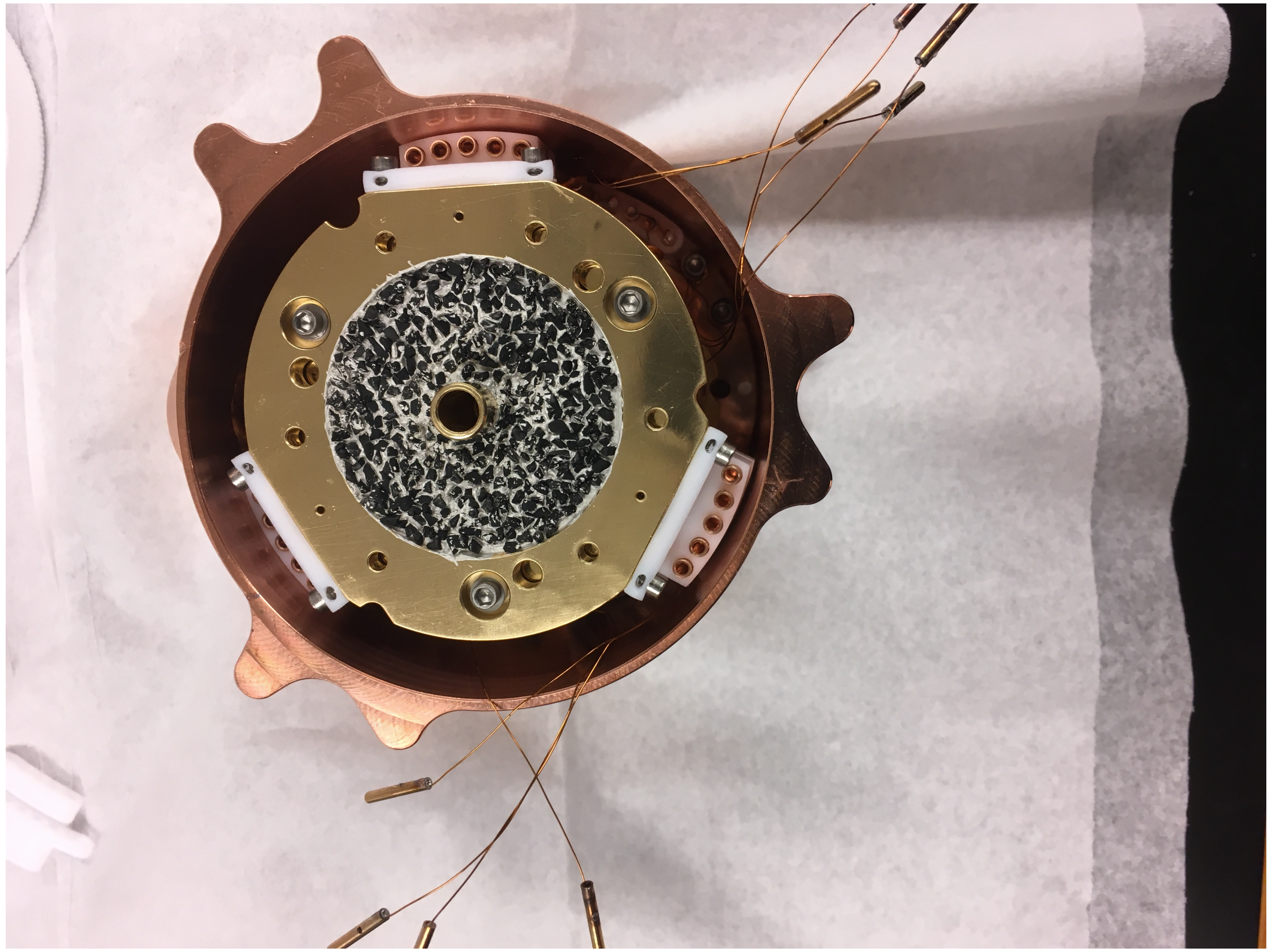
Results


Average TOF vs. Frequency Deviation
90
85
80
75
70
65
60
Average TOF (us)
-21
-18
-15
-12
-9
-6
-3
0
3
6
9
12
15
18
21
Frequency deviation from fc (Hz)

The future of CryoMPET

- Return of trap to magnet
- Voltage tuning for maximization of resonance - assisted by simulation results!
- Usage in future experiments to explore various science cases in nuclear and fundamental physics!





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university of groningen

kvi - center for advanced radiation technology

NRC-CNRC

NSERC CRSNG

DFG Deutsche Forschungsgemeinschaft

TRIUMF

www.triumf.ca

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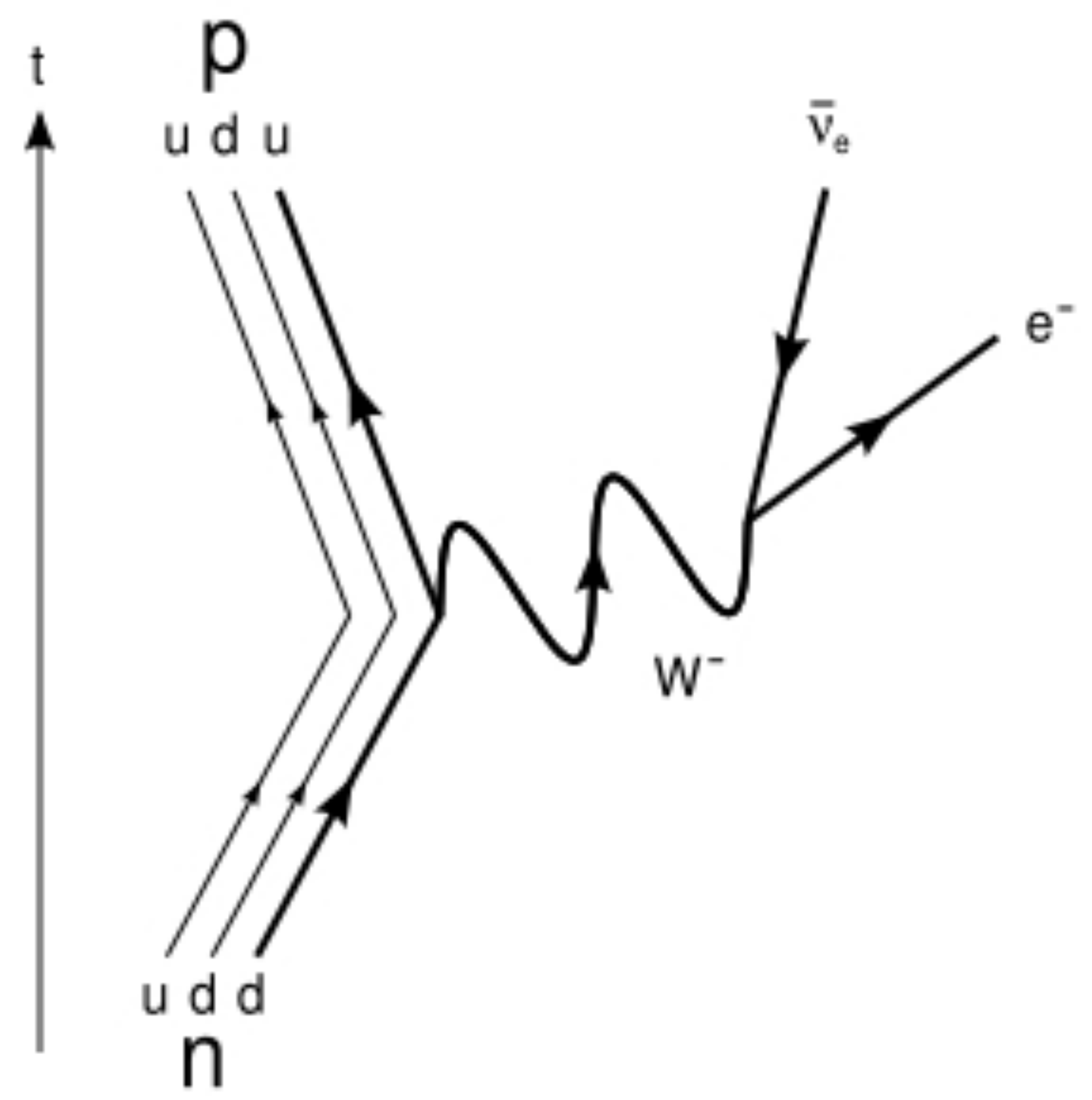
@TRIUMFLab

Discovery, accelerated

Standard Model Testing with Mass Measurements

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1$$



A *slightly* more detailed look at Penning Trap mass spectrometry

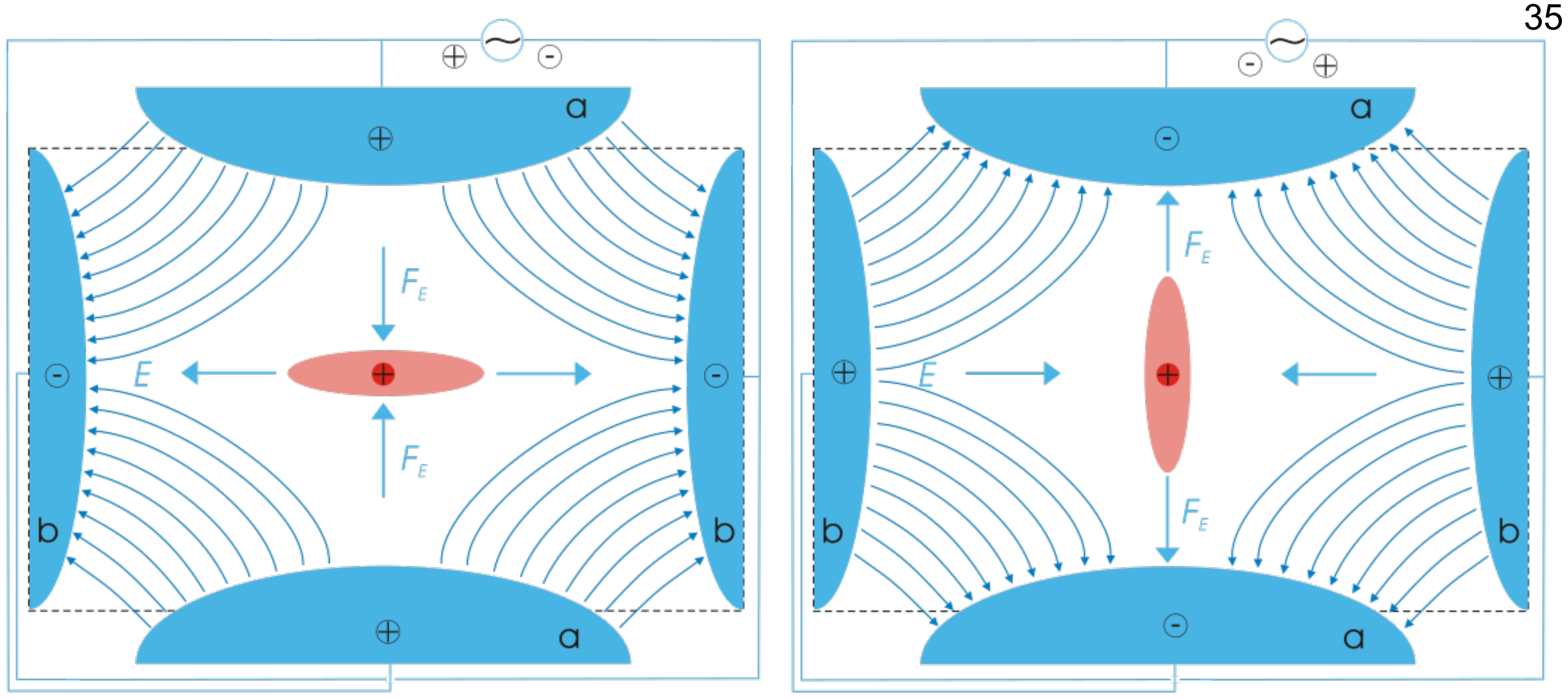
1. Scan over f_{RF}

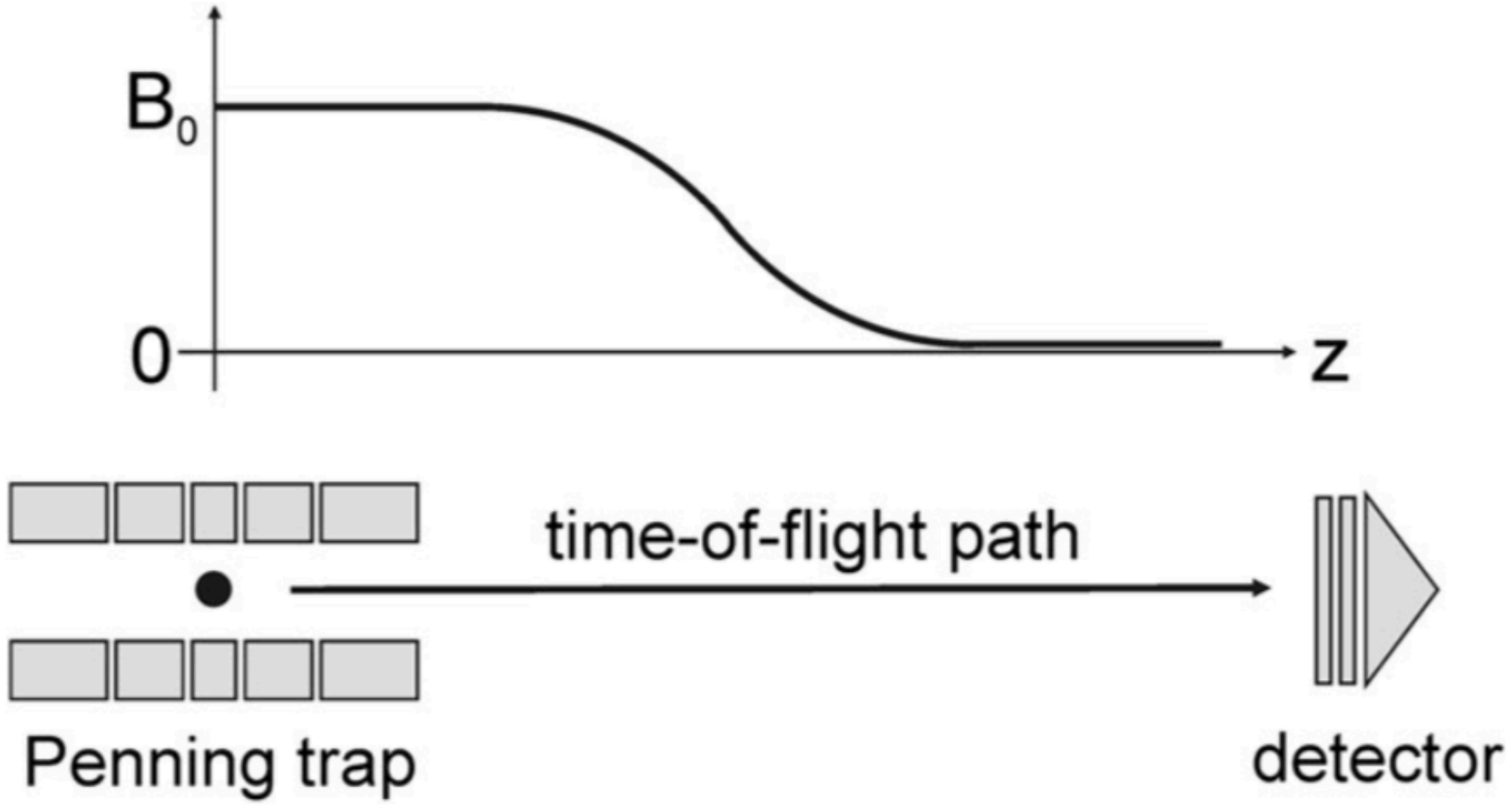
2. $f_- \leftrightarrow f_+$ occurs when $f_{RF} = f_c$

3. Increase in E_{radial} $\rightarrow$ Increase in μ

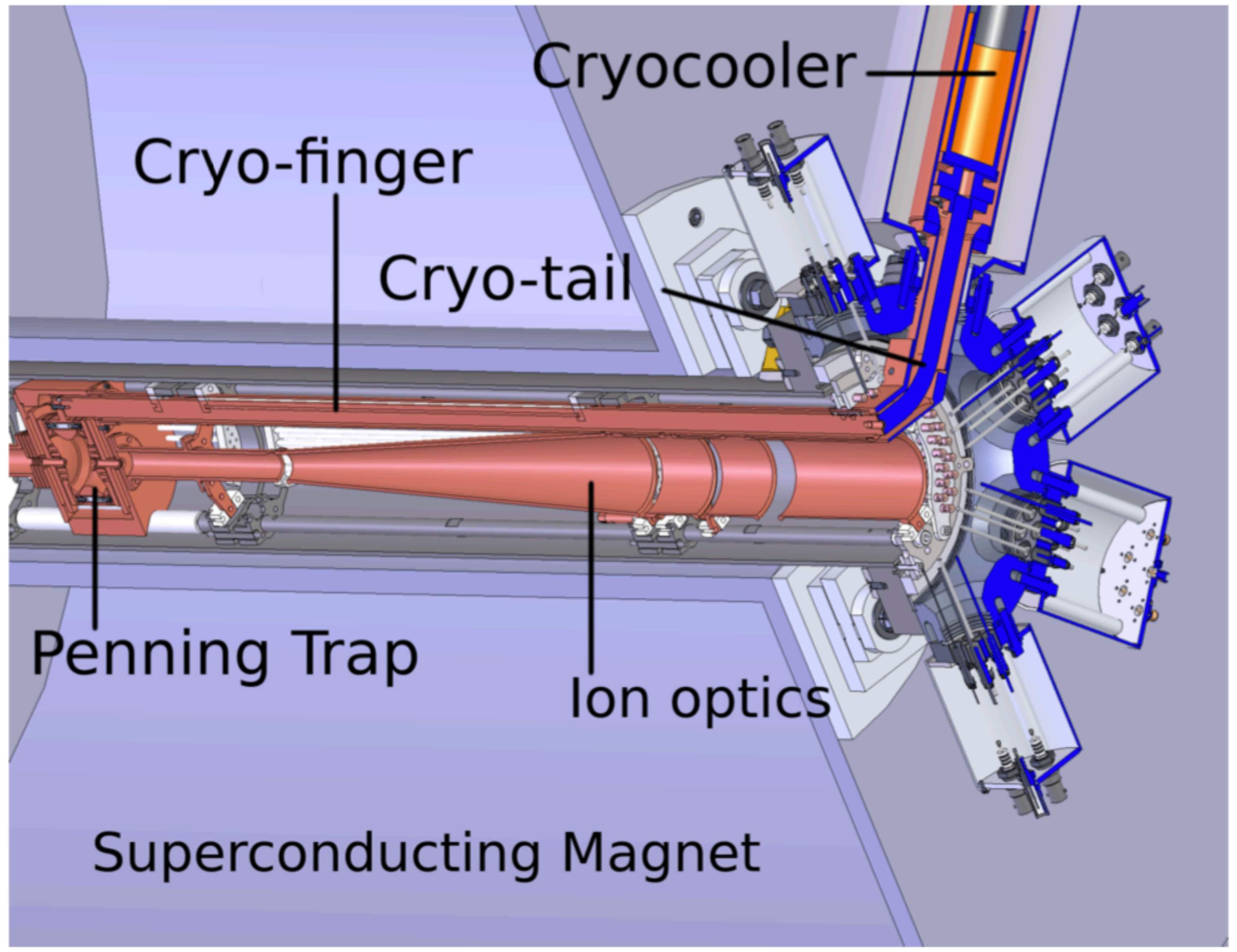
4. Ions get harder "kick" from B-field, decreasing time-of-flight to detector.

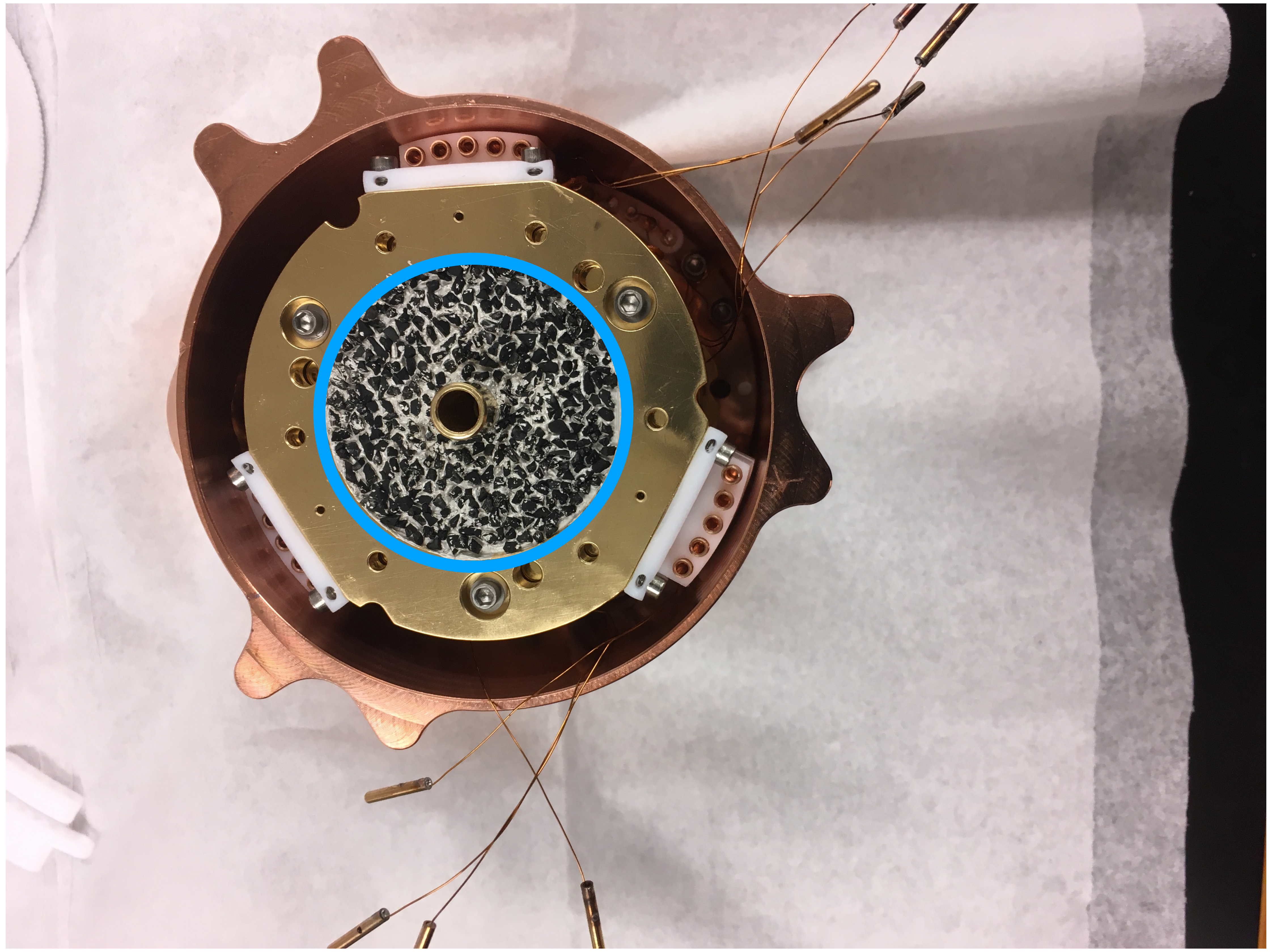
$$|F_B| = \left|\mu \cdot \frac{\partial B}{\partial z}\right| = \left|\frac{E_r}{B_0} \cdot \frac{\partial B}{\partial z}\right|$$





Background Gas Removal



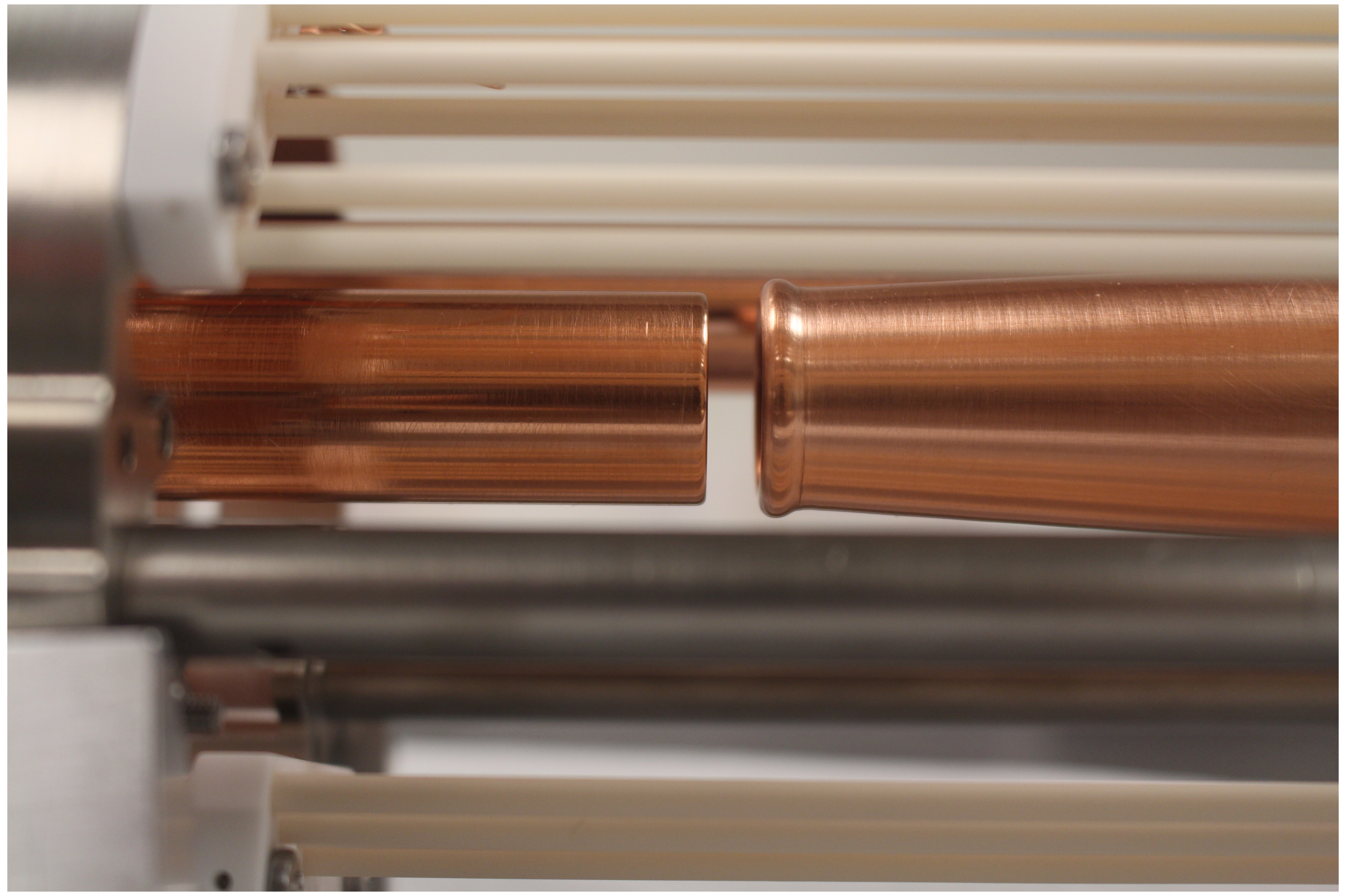


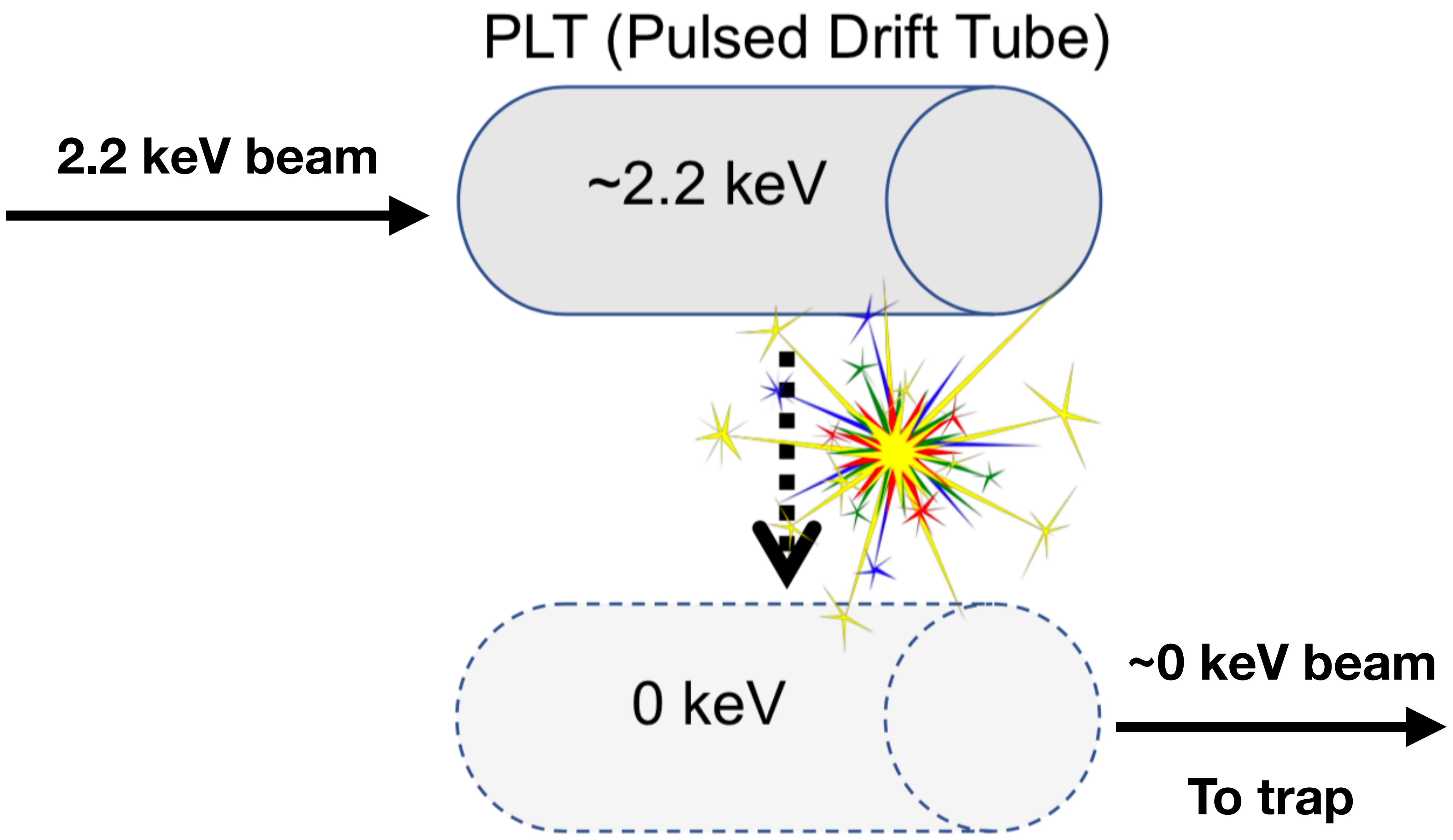
Cryogenic Pumping (Condensation)

Getter Material (lighter gases)

Sparking in the PLT

- **Sparking** in Pulsed Drift Tube (PLT) when pulsing down ion beam energy





Setback Solutions

- **Shorts:**
  -Addition of spacers
  -Kapton at insulation breaks
  -Replacing wires

- **Sparks:**
  -Decreasing beam energy resolved sparking

- **Temperature threshold:**
  -Machining of parts to decrease conduction
  -Plating components to decrease thermal radiation effects

Nelder-Mead Optimization Method

- SIMION's optimization algorithm.
- Manipulation of simplex through stretching, reflection, and shrinking to find extrema.
- Search area dependent on the initial simplex shape size.
- Heuristic search, so global extremum is not guaranteed.