A Radio-Frequency Fragment Separator (RFFS) for FRIB

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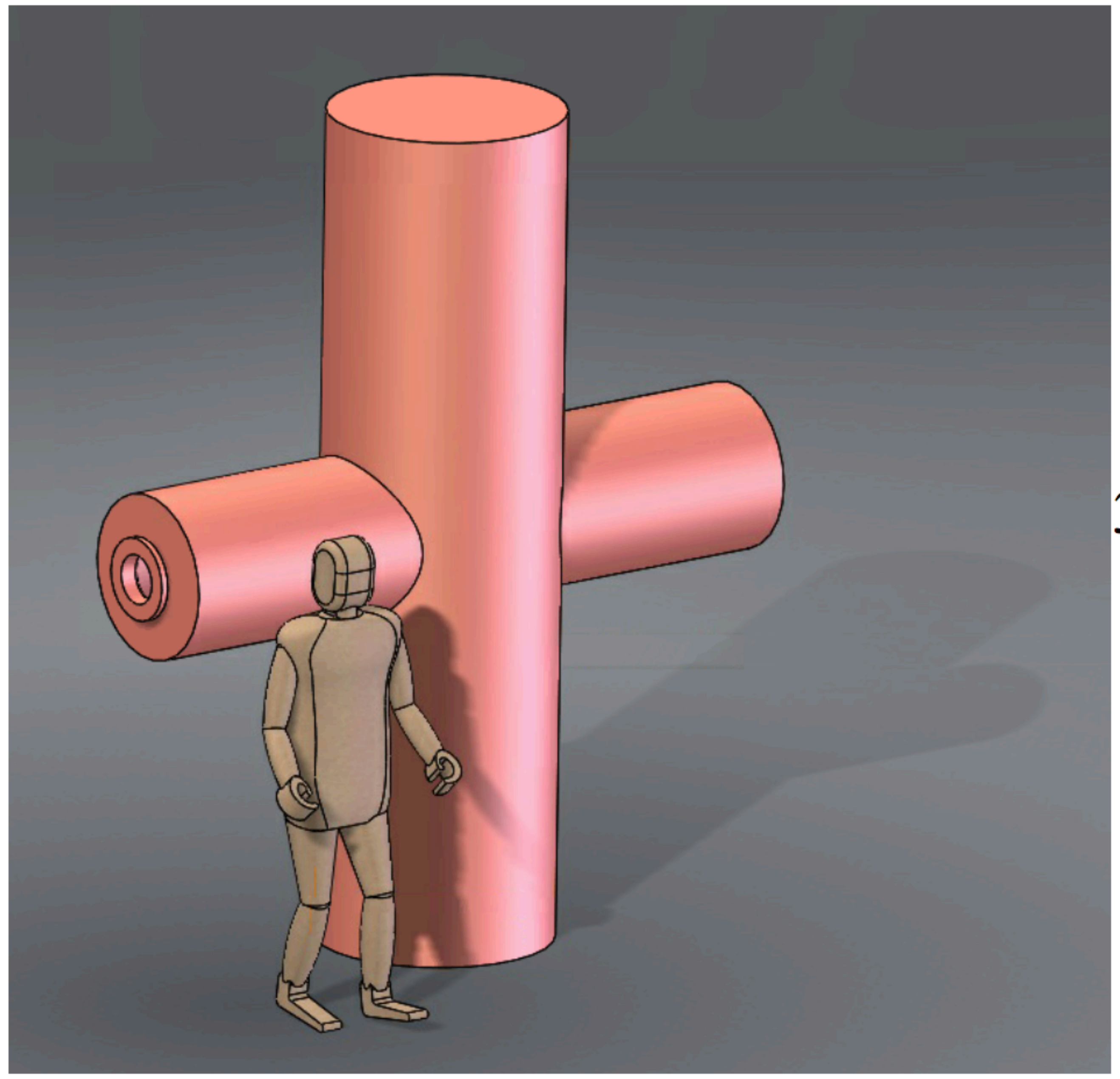
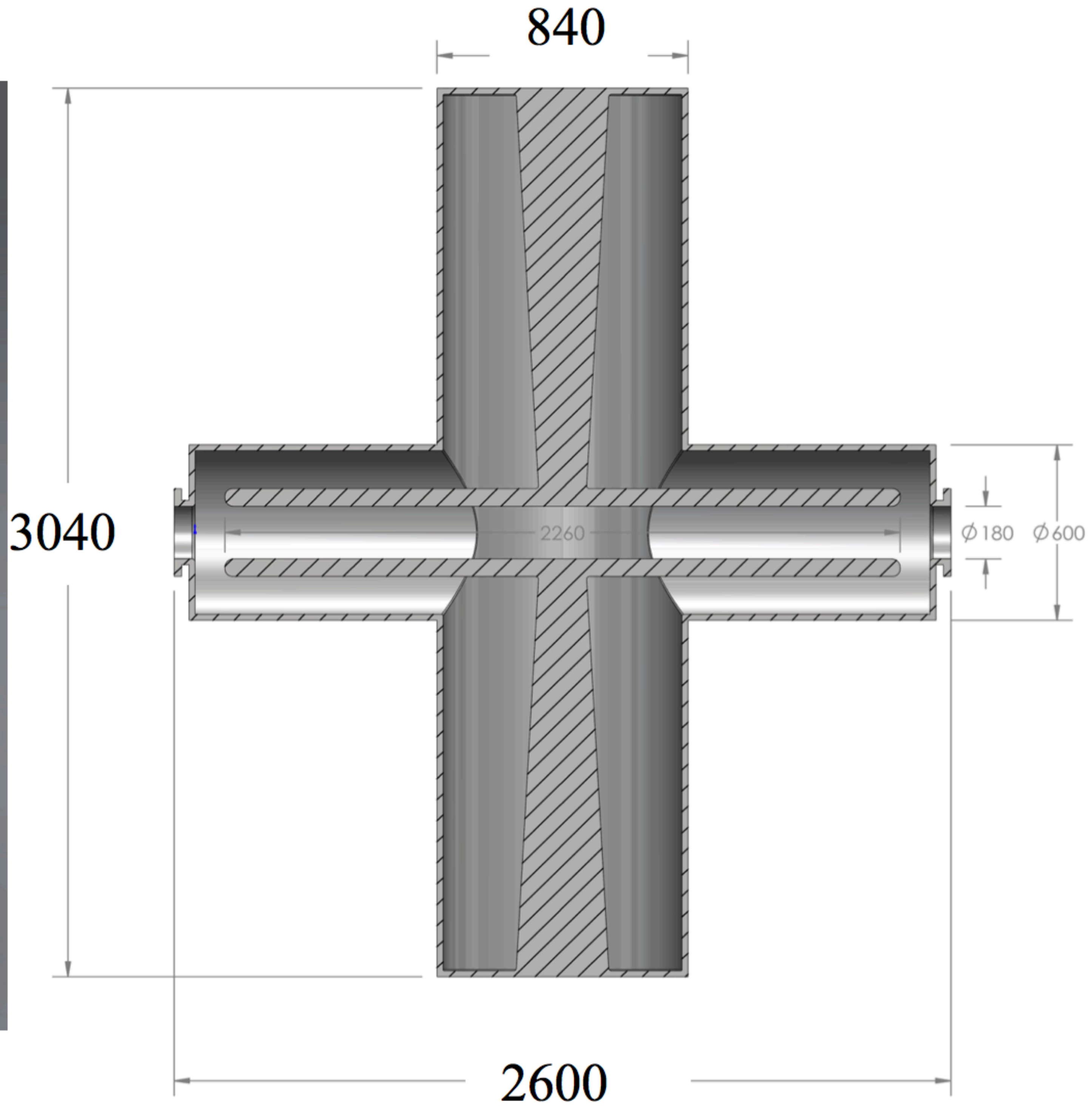
Outline

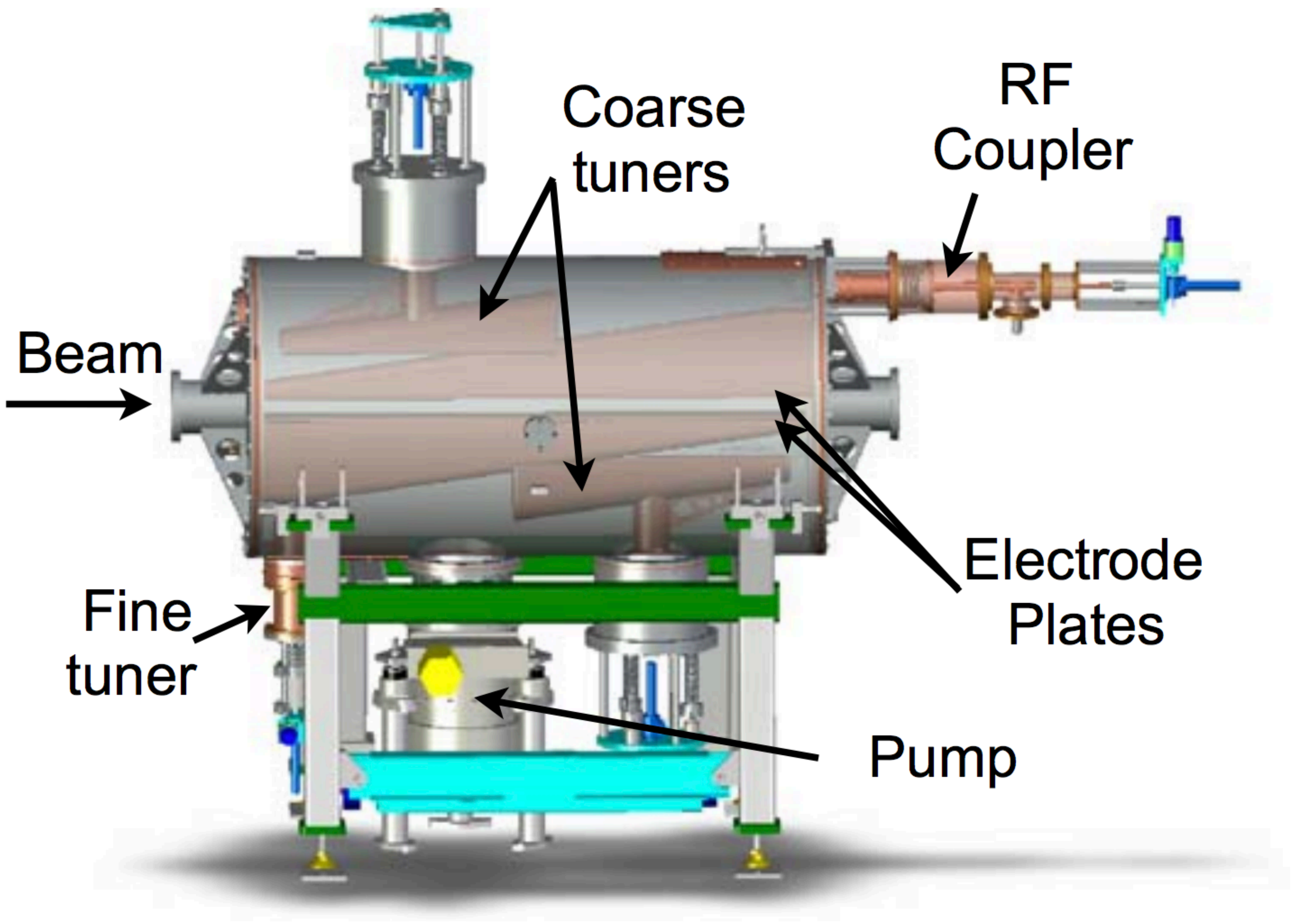
- Capabilities of current RFFS at NSCL
- Experiments enabled by current RFFS
  - First observation of ^{11}O
  - ^{73}Sr β-delayed proton emission
- Capabilities of proposed RFFS at FRIB
- Day 1 experiments at FRIB with new RFFS
  - ^{34}Ca 2p decay
  - ^{72}Rb decay studies
  - ^{100}Sn decay studies





Length(m)	Gap(cm)	Peak Voltage(kV)	Frequency(MHz)	Q
2.26	18	150	20.125	12,900

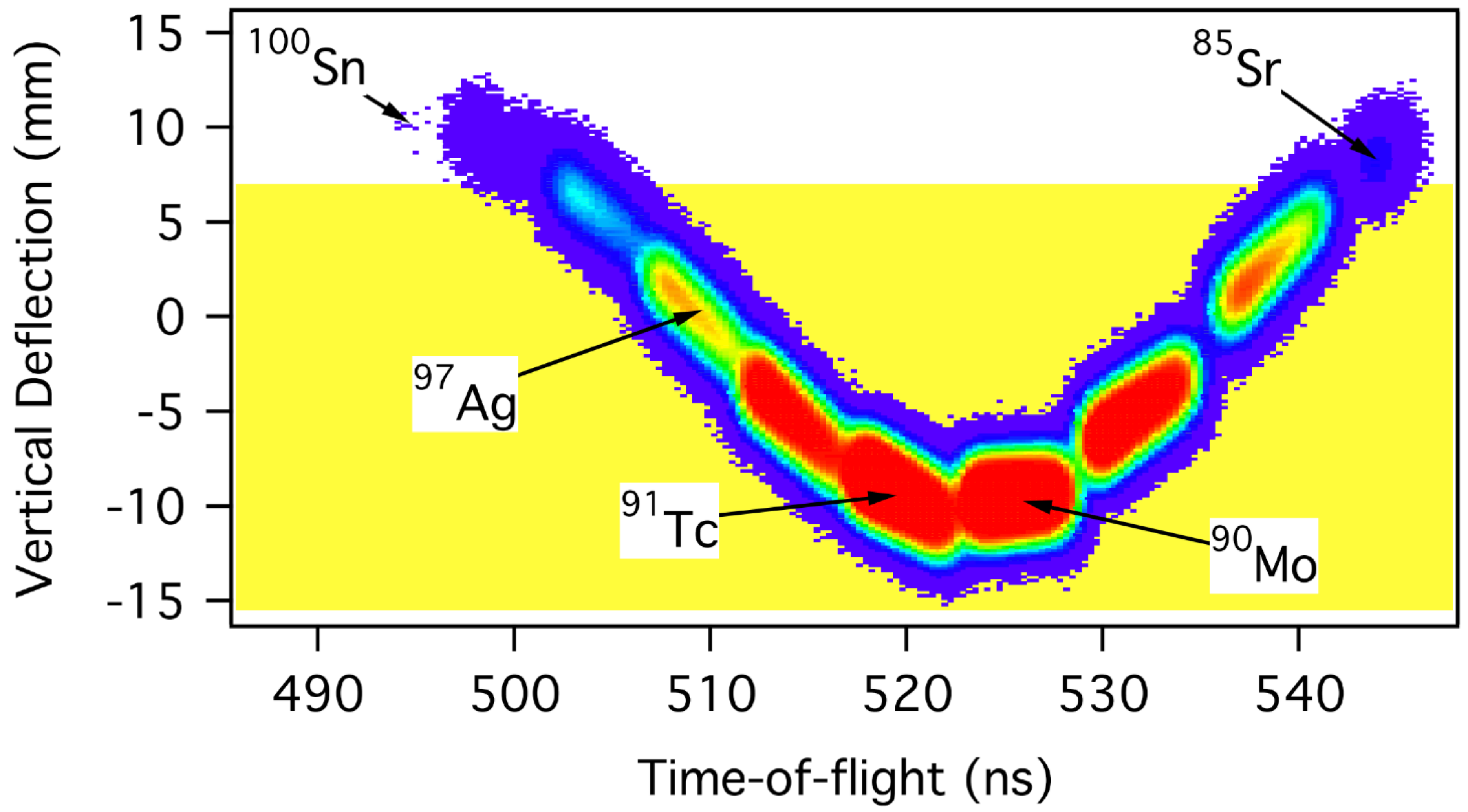
RFFS at NSCL



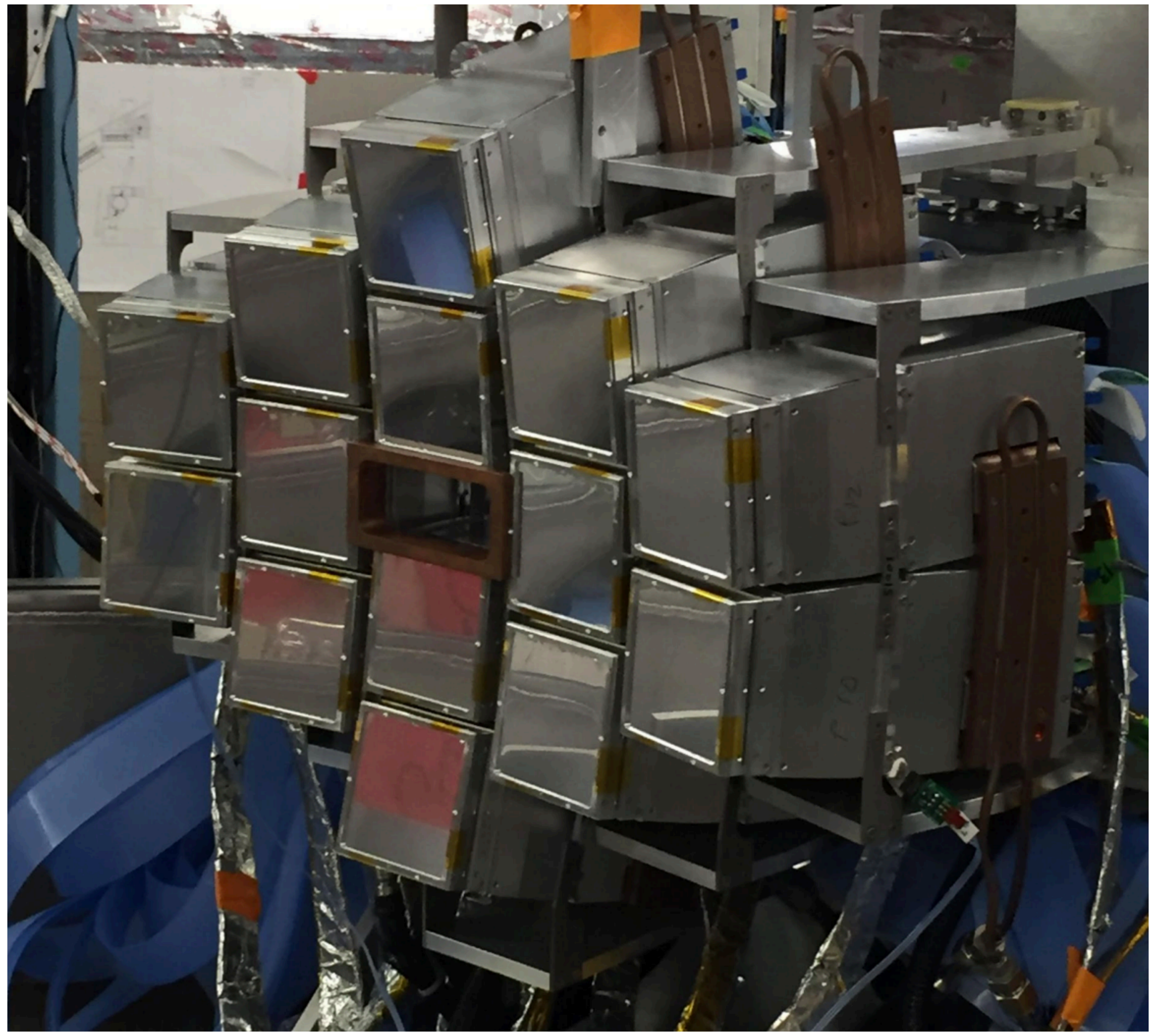
Length (m)	Gap (cm)	Peak voltage (kV)	Frequency (MHz)	Q
1.5	5	100	19–27	7500–10,000

D. Bazin et al., NIM A **606** (2009)

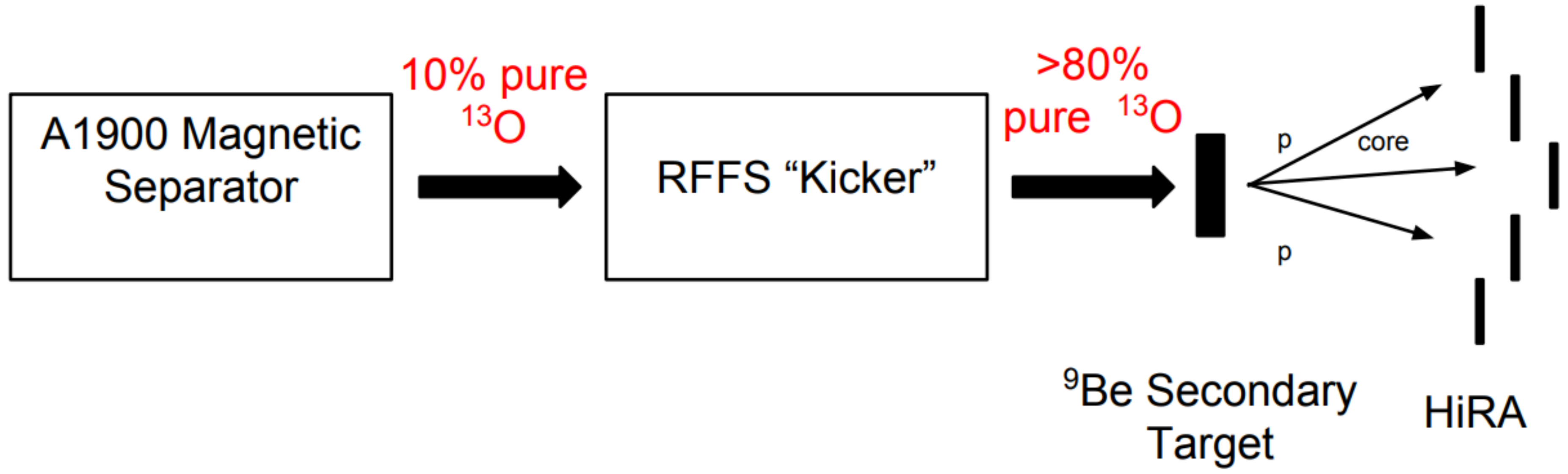
- RF Cavity tuned to around 20 MHz.
- Phase of RF is optimized to deflect ion of interest maximally.
- Other ions are blocked by slits, resulting in purification of beam.
- Greatly purifies proton-rich beam cocktails, enabling experiments along the proton dripline.



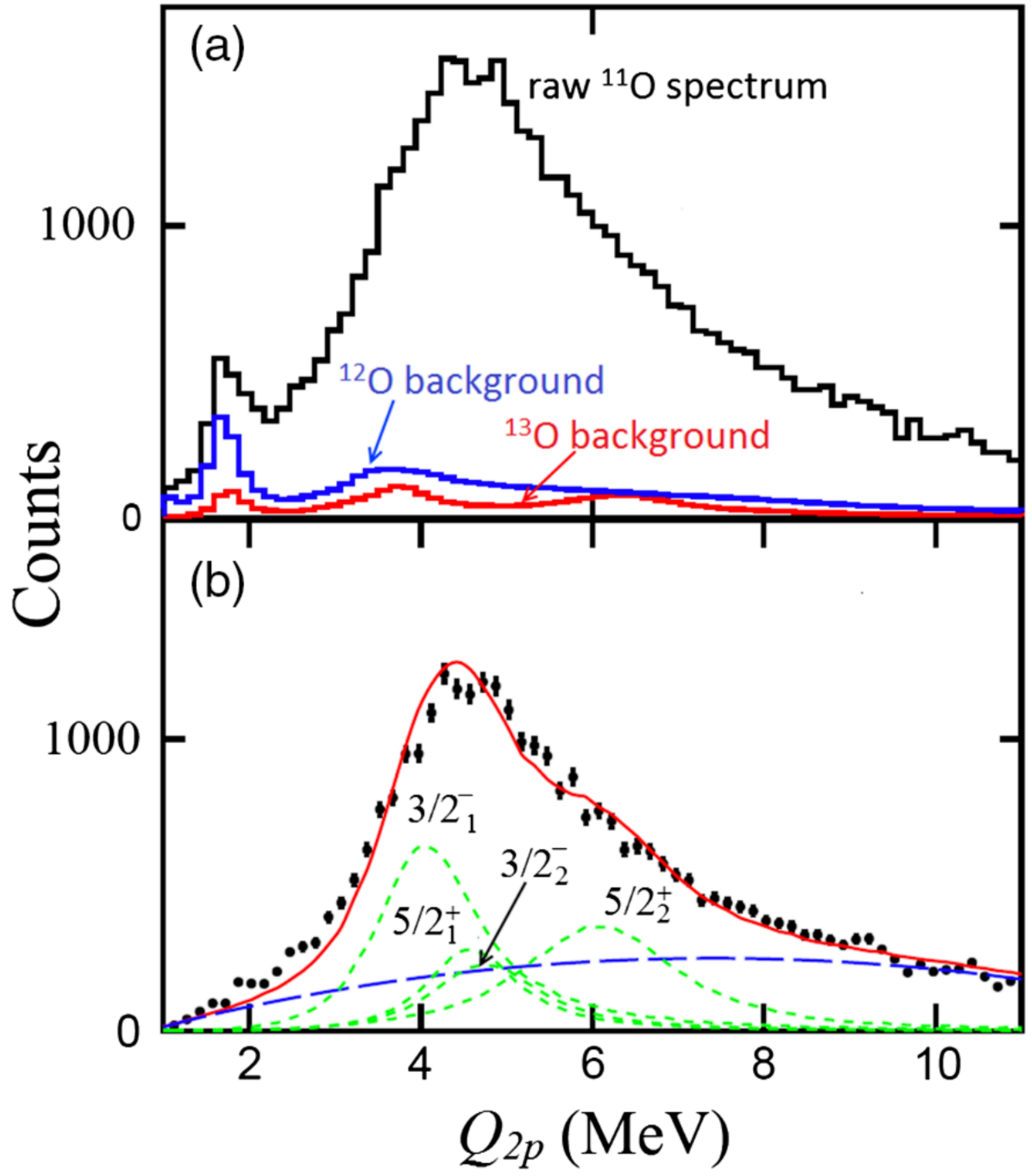
First Observation of ^{11}O



High Resolution Array (HiRA)

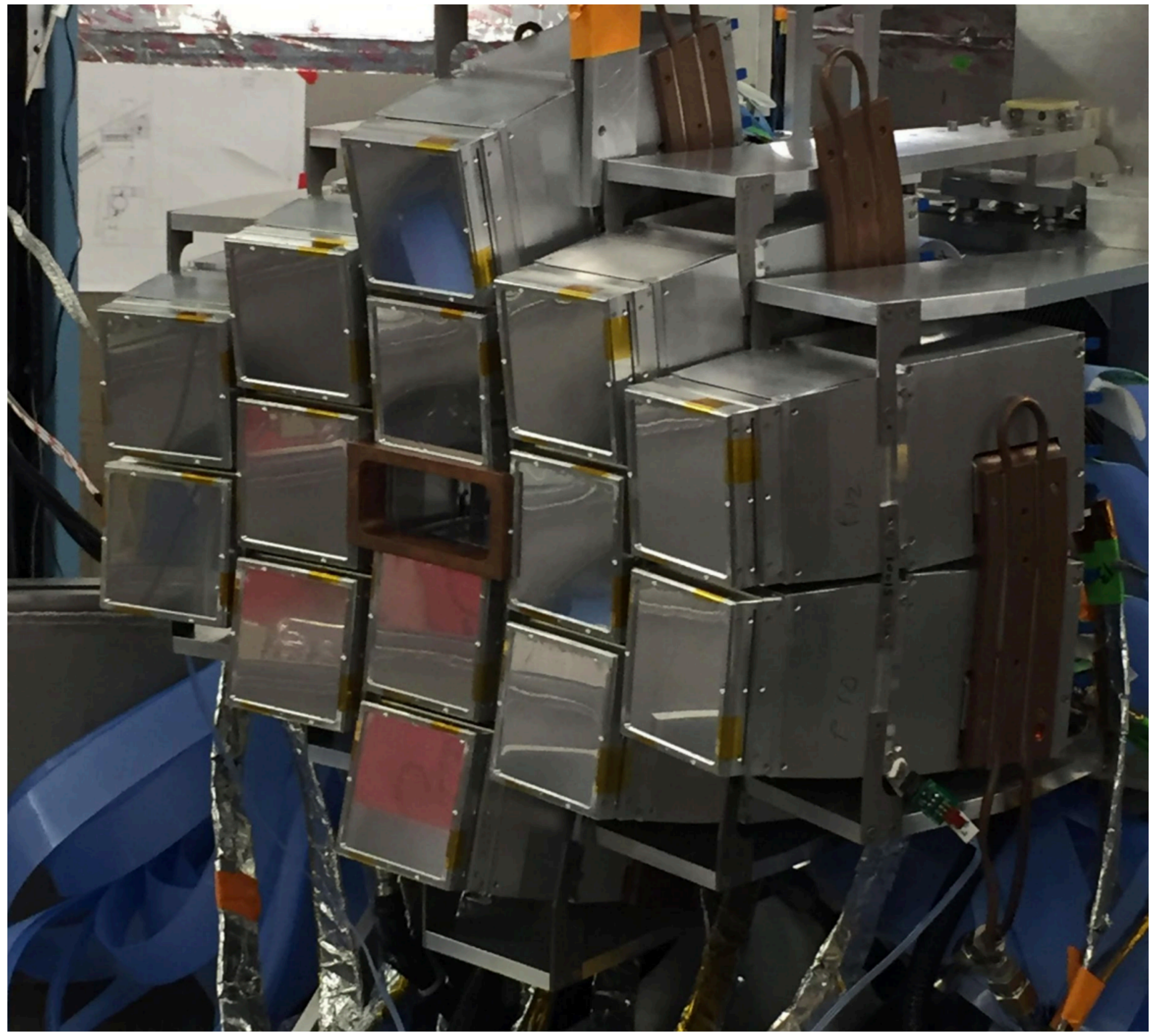


- ^{11}O was first observed by fragmenting a ^{13}O secondary beam on a Be target, looking for ^{9}C+2p events in HiRA.
- After A1900 secondary beam only had 10% of ^{13}O.
- **After passing through RFFS 80% of beam consisted of ^{13}O!**



T.B. Webb et al., Phys. Rev. Lett. **122** (2019)

First Observation of ^{11}O



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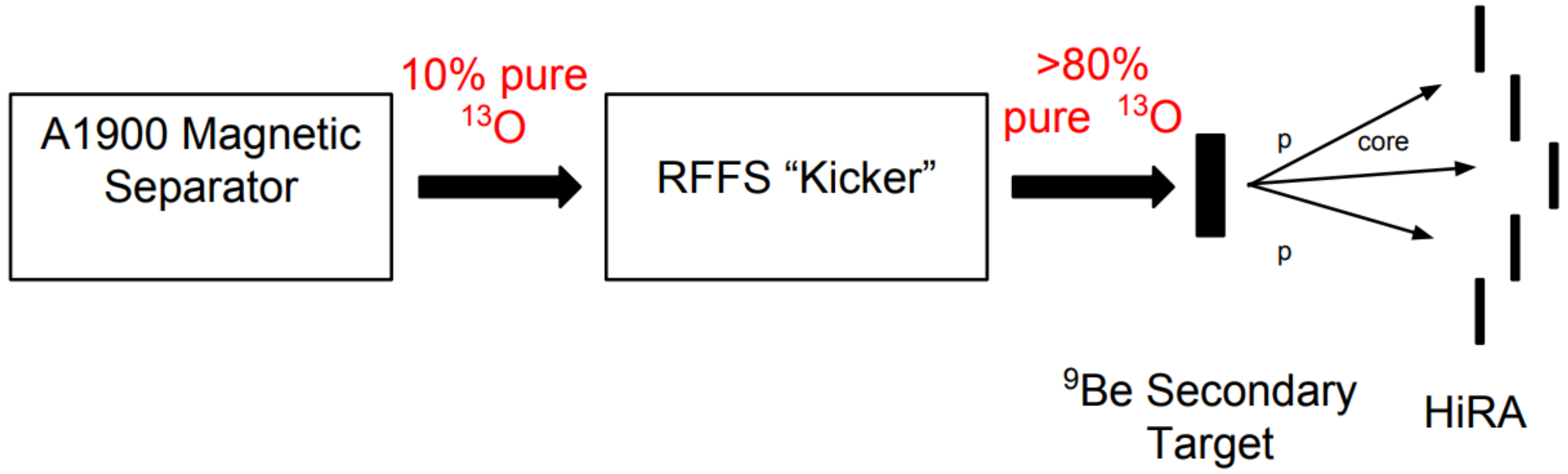
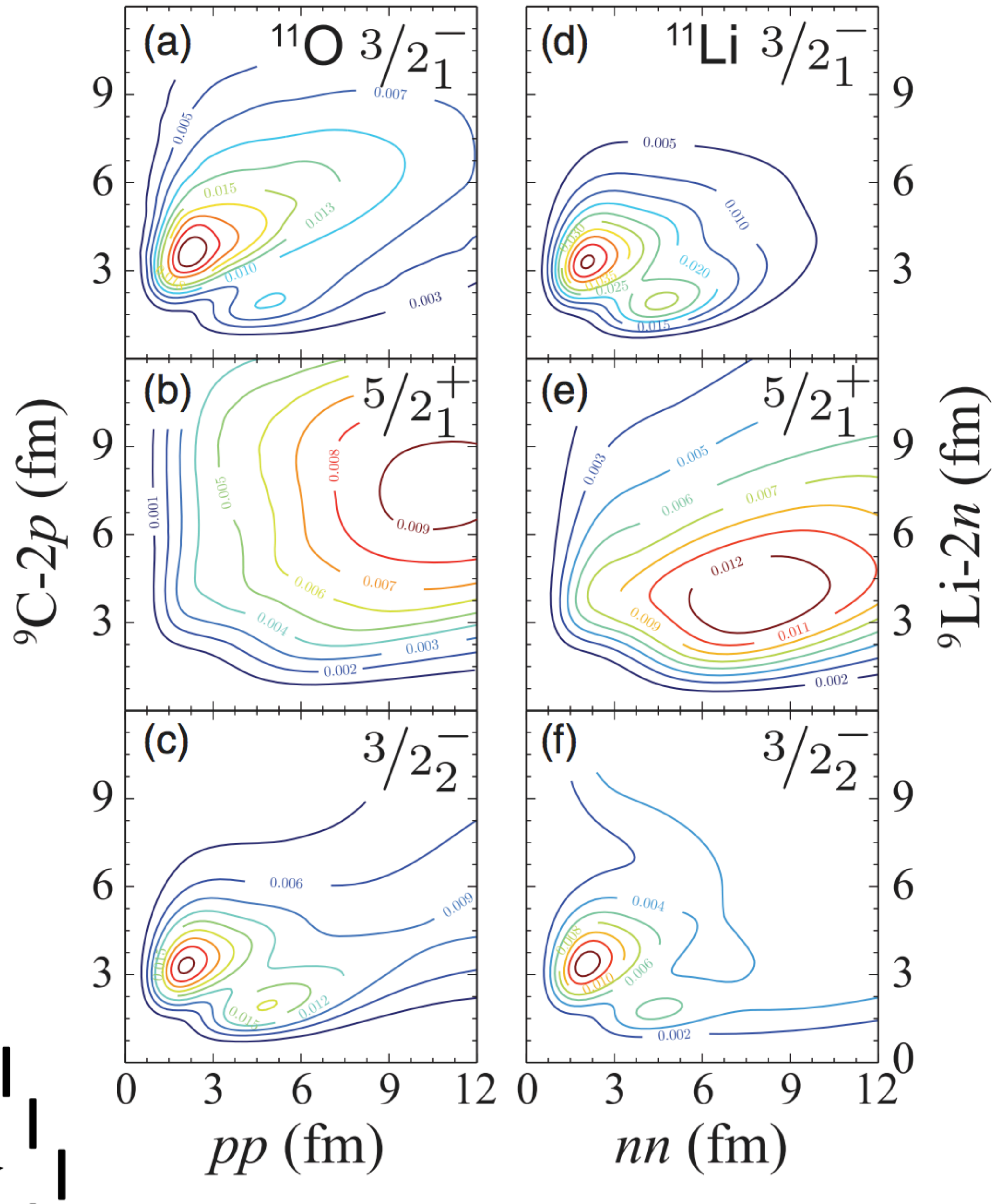
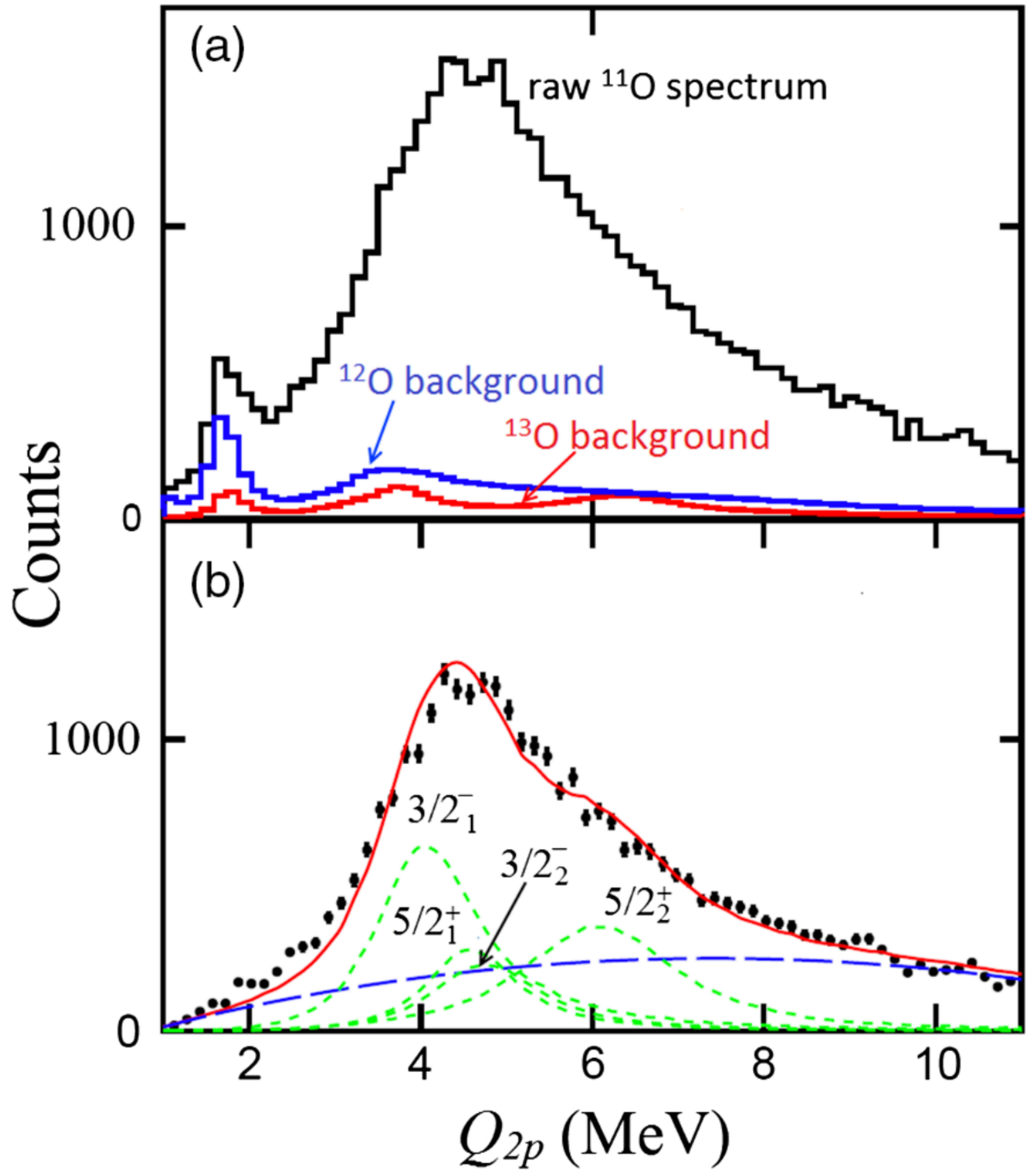




Thomas-Ehrman Shift Visualized!

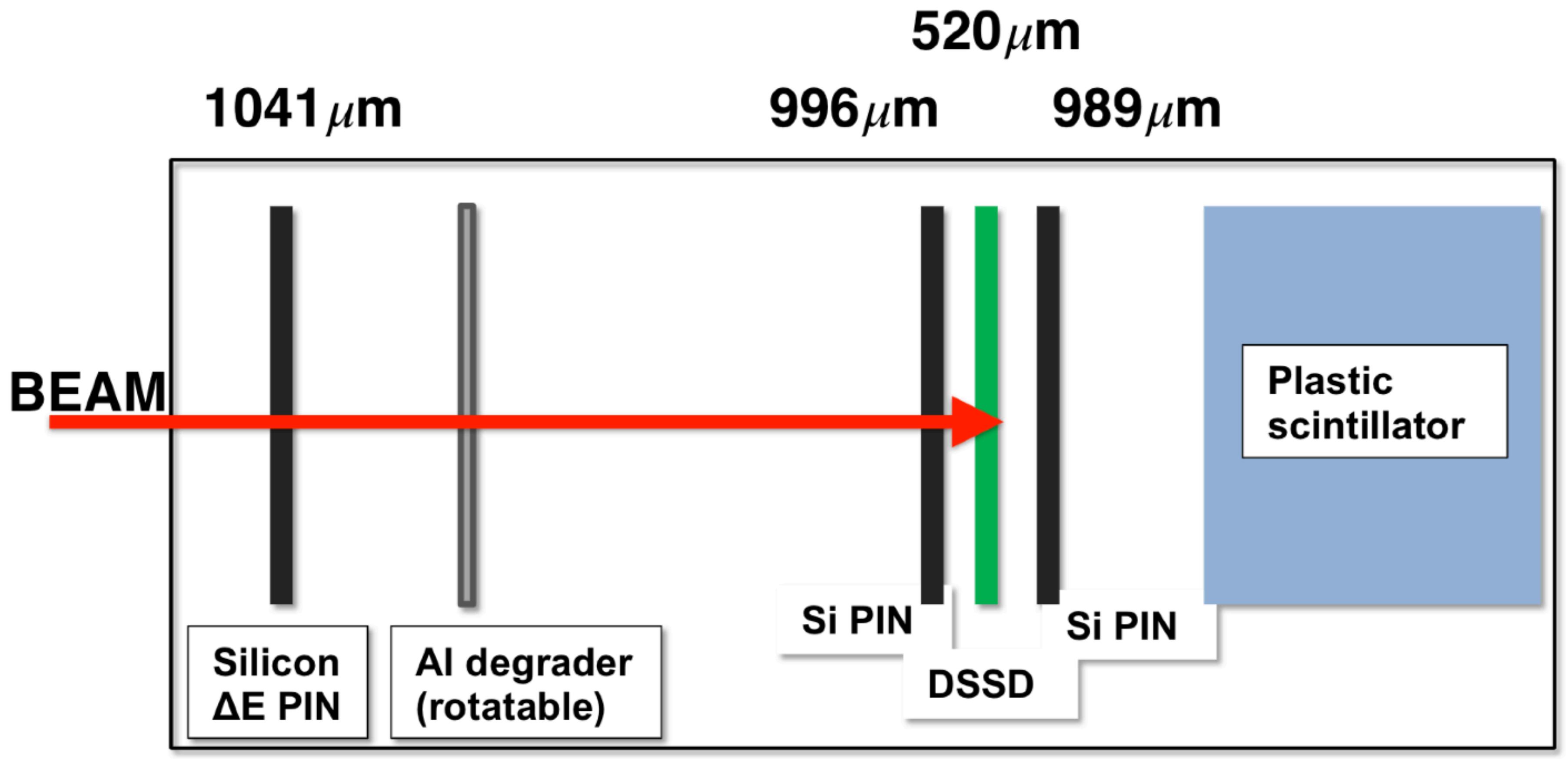


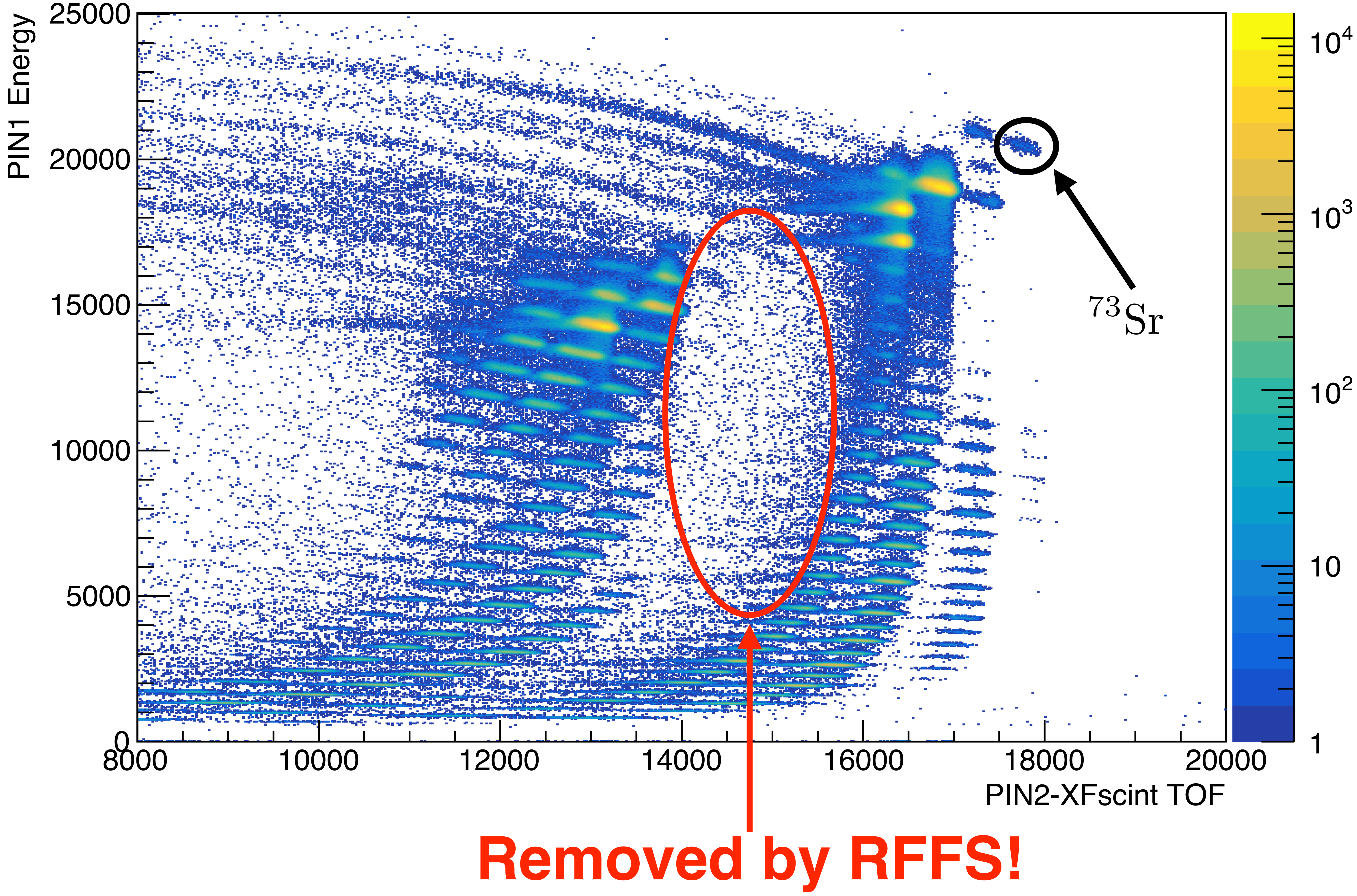
T.B. Webb et al., Phys. Rev. Lett. **122** (2019)

^{73}Sr β-delayed proton emission

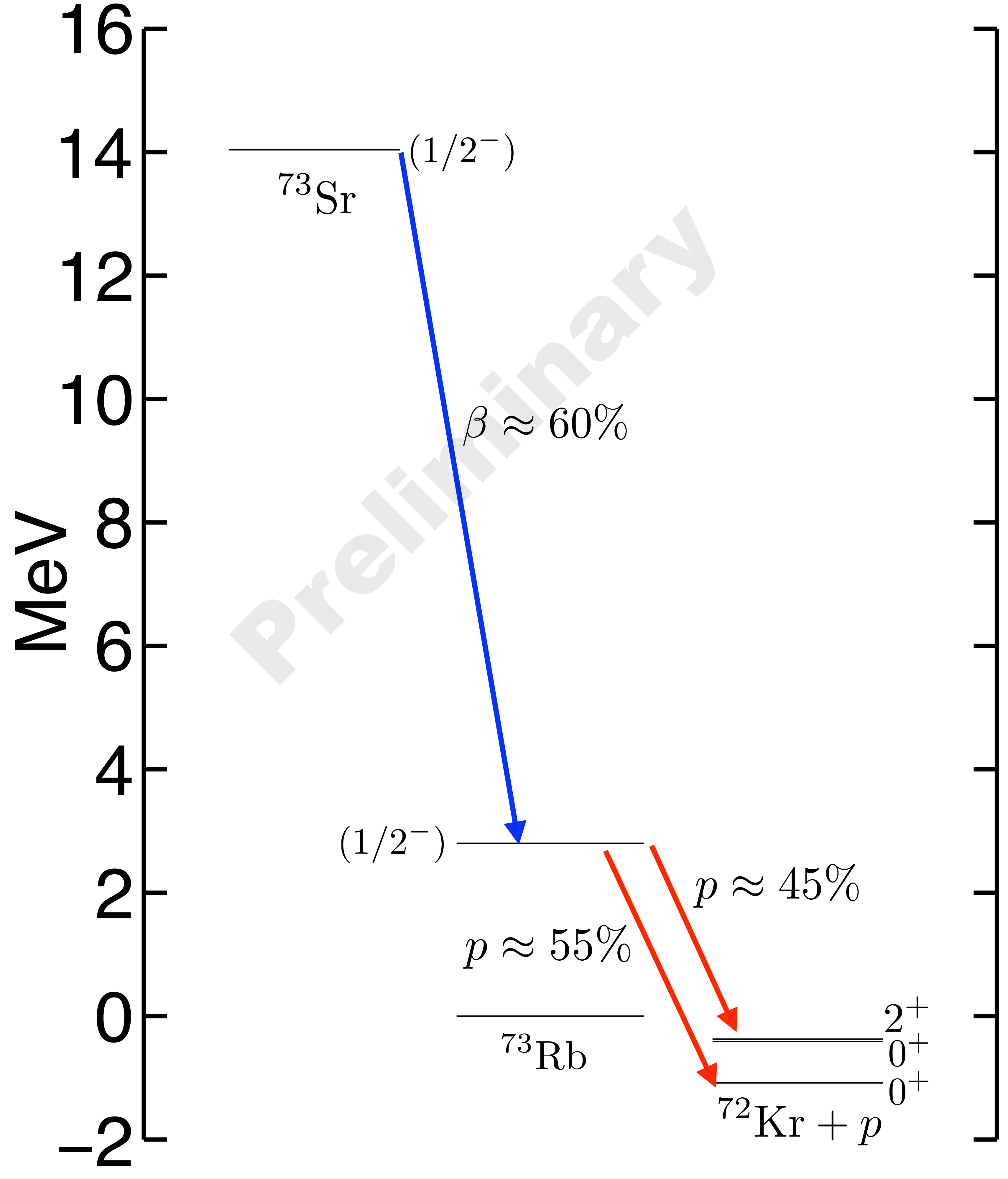
- Current RFFS has already been used to study nuclei that would have been unfeasible due to beam contaminates.

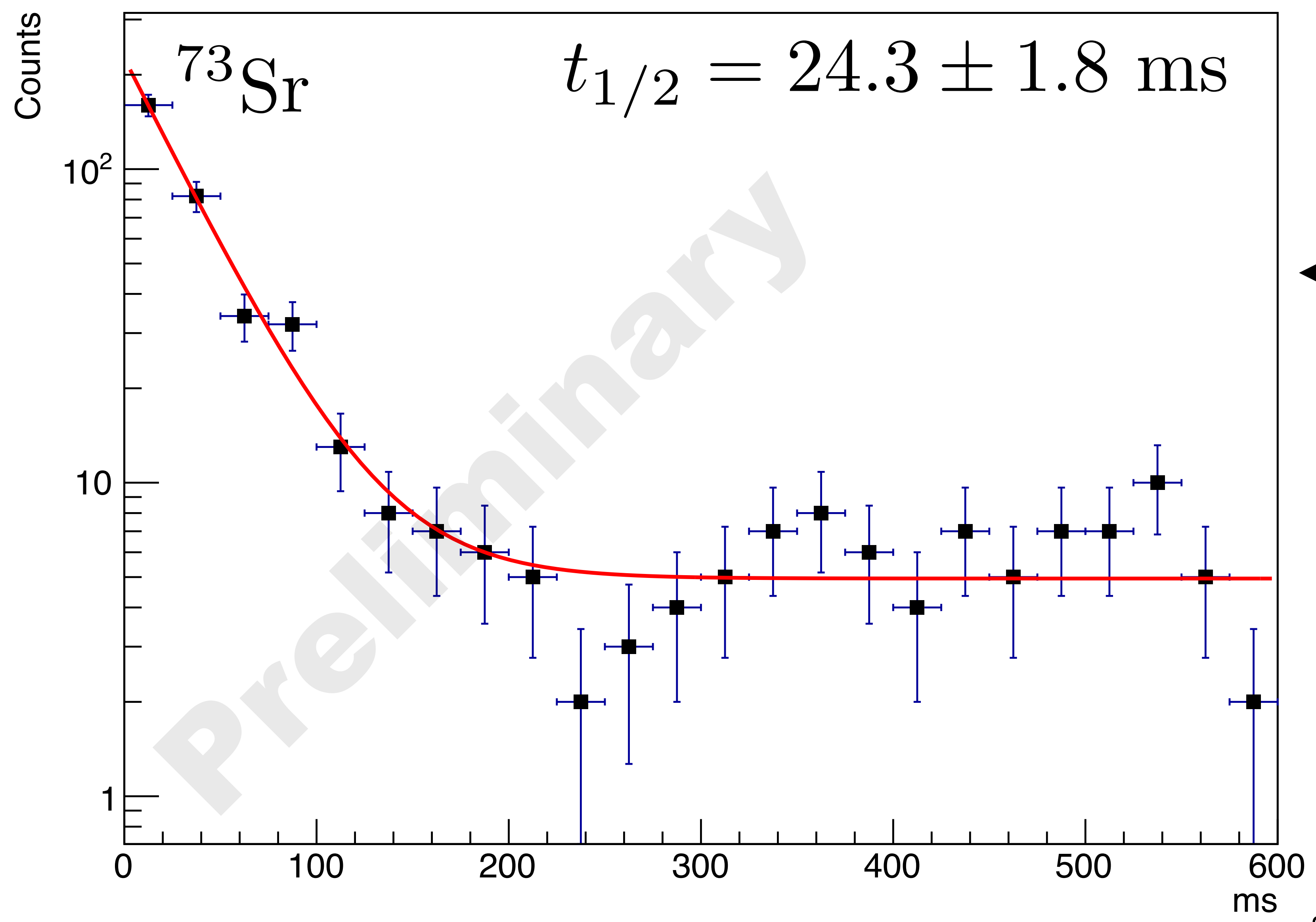
- Measured properties of ^{73}Rb, by watching beta-decay of ^{73}Sr secondary beam implanted into a DSSD. **Beam was purified by a factor of 4500 down to 10 pps!**





^{73}Sr β-delayed proton emission

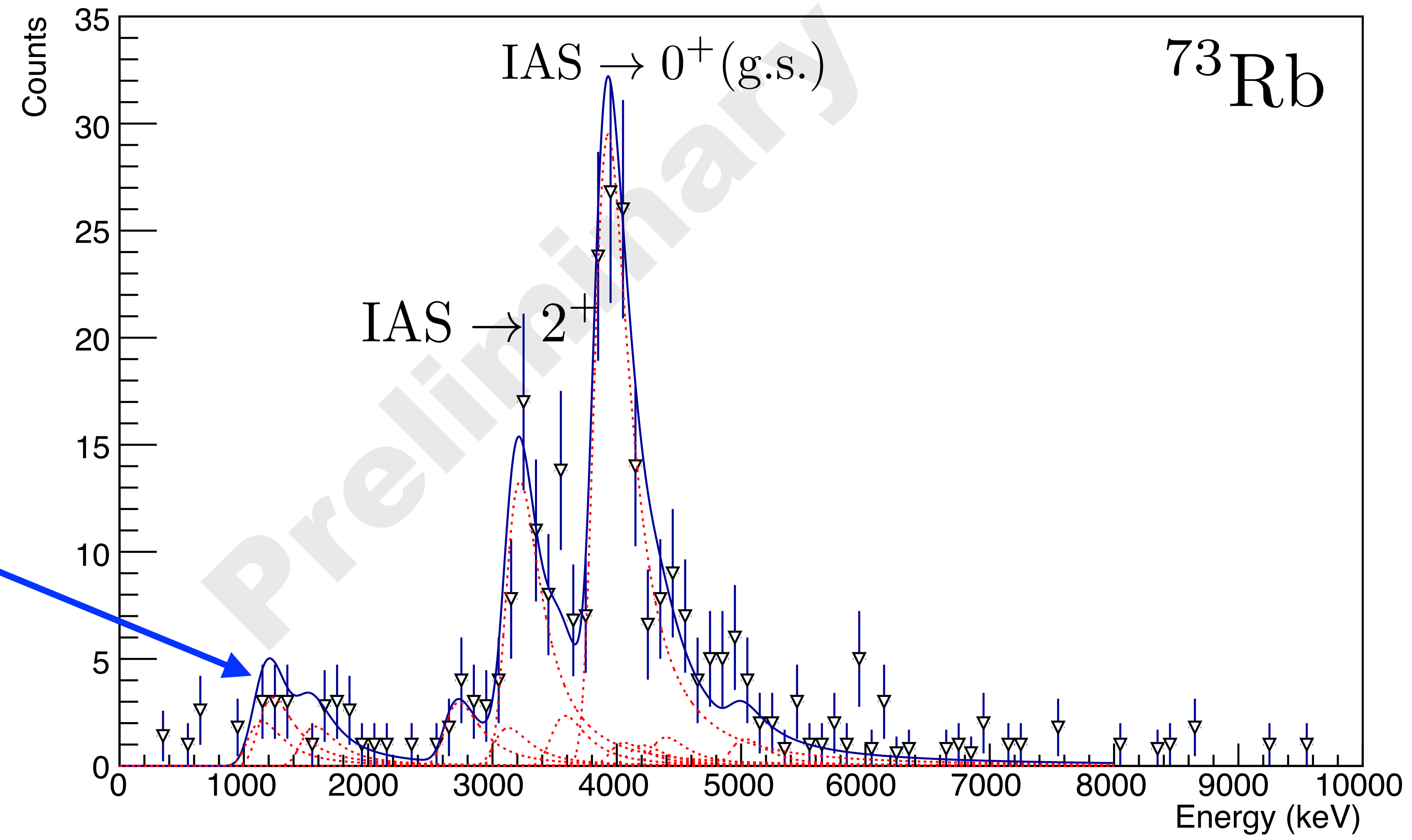




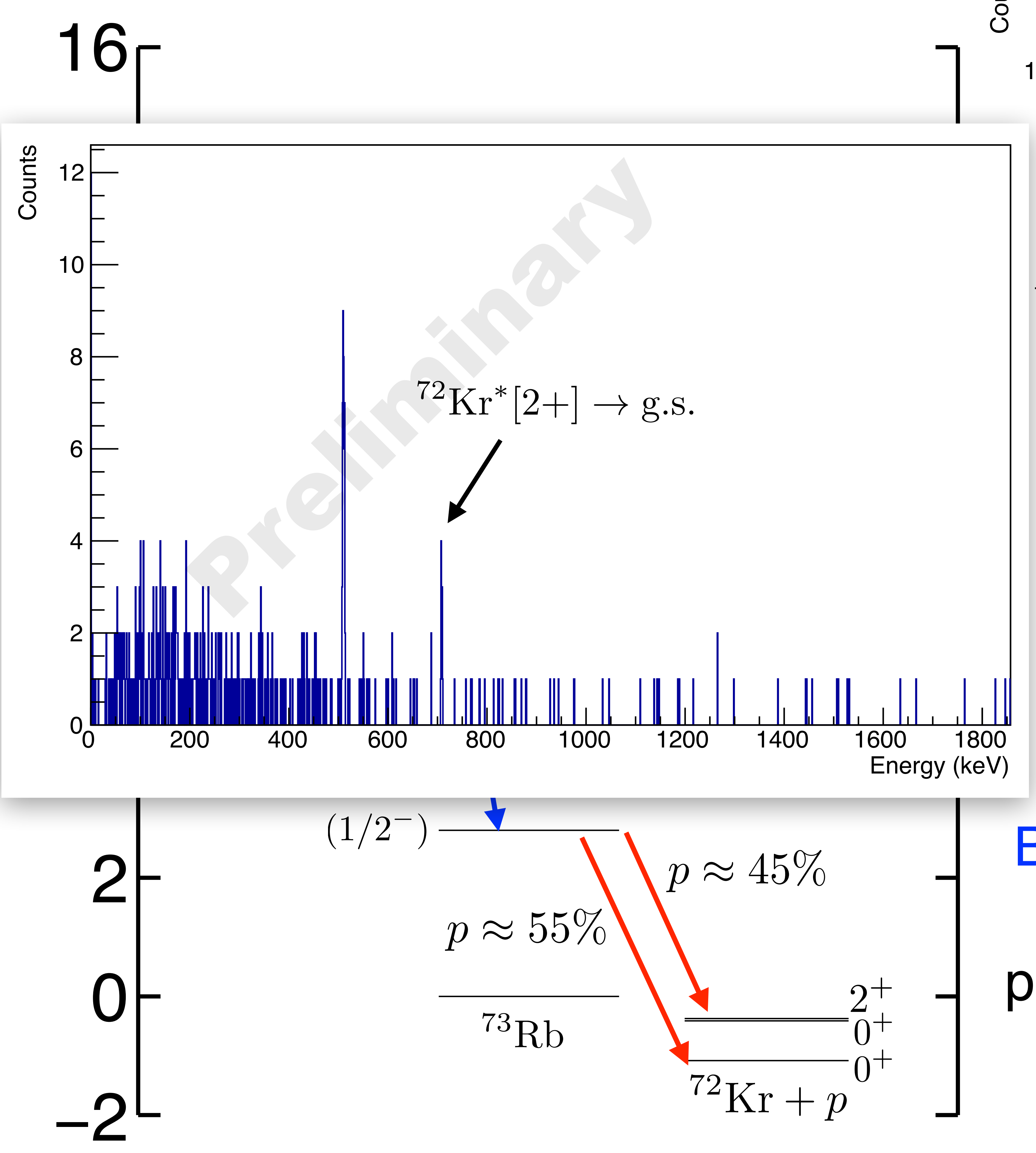
First direct measurement of ^{73}Sr β-decay half-life.

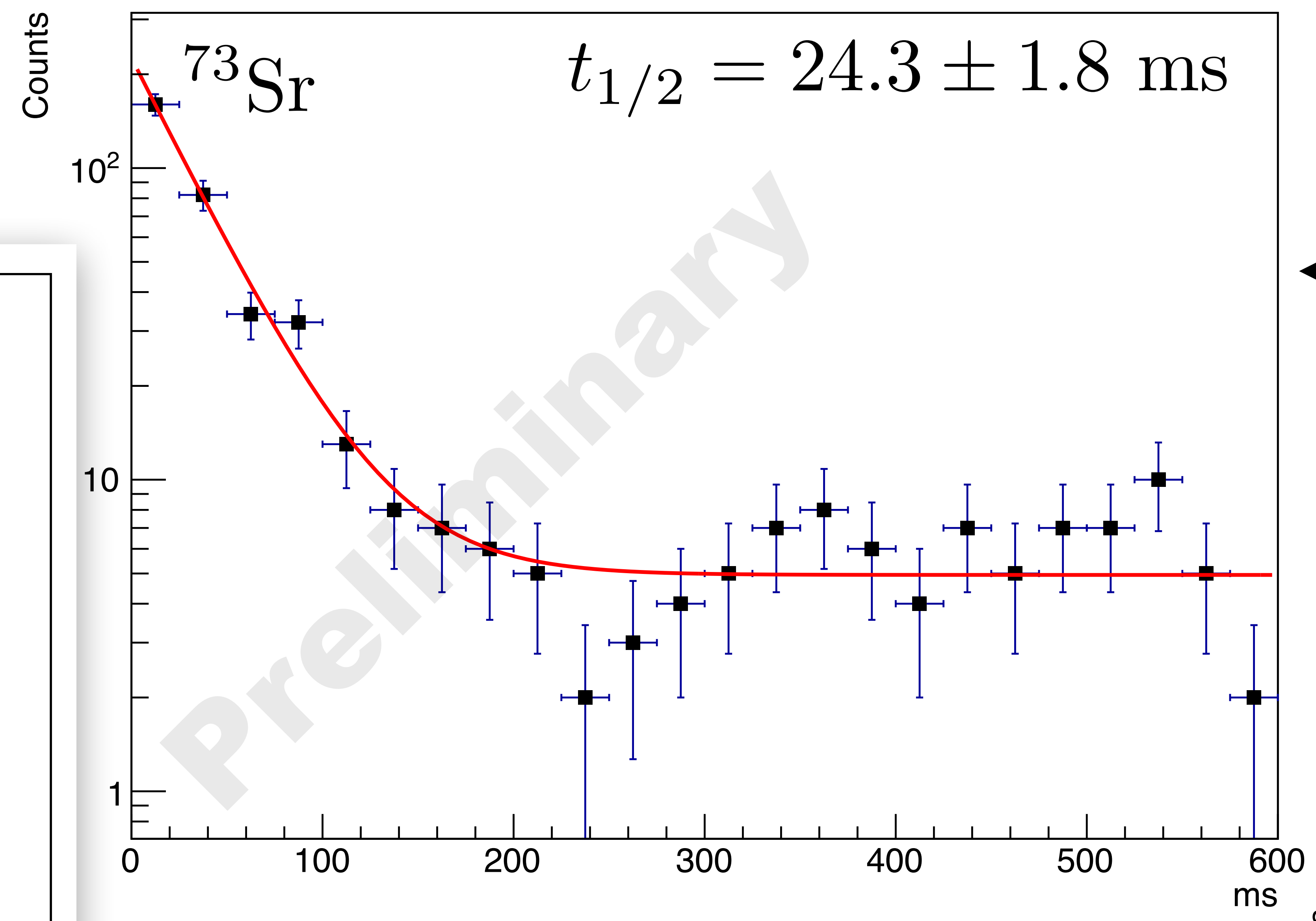
^{73}Rb proton separation energy impacts rp-process reaction flow.

Blue curve is expected experimental spectrum from *fp* shell-model predictions for ^{73}Sr β-feeding of ^{73}Rb.



^{73}Sr β-delayed proton emission





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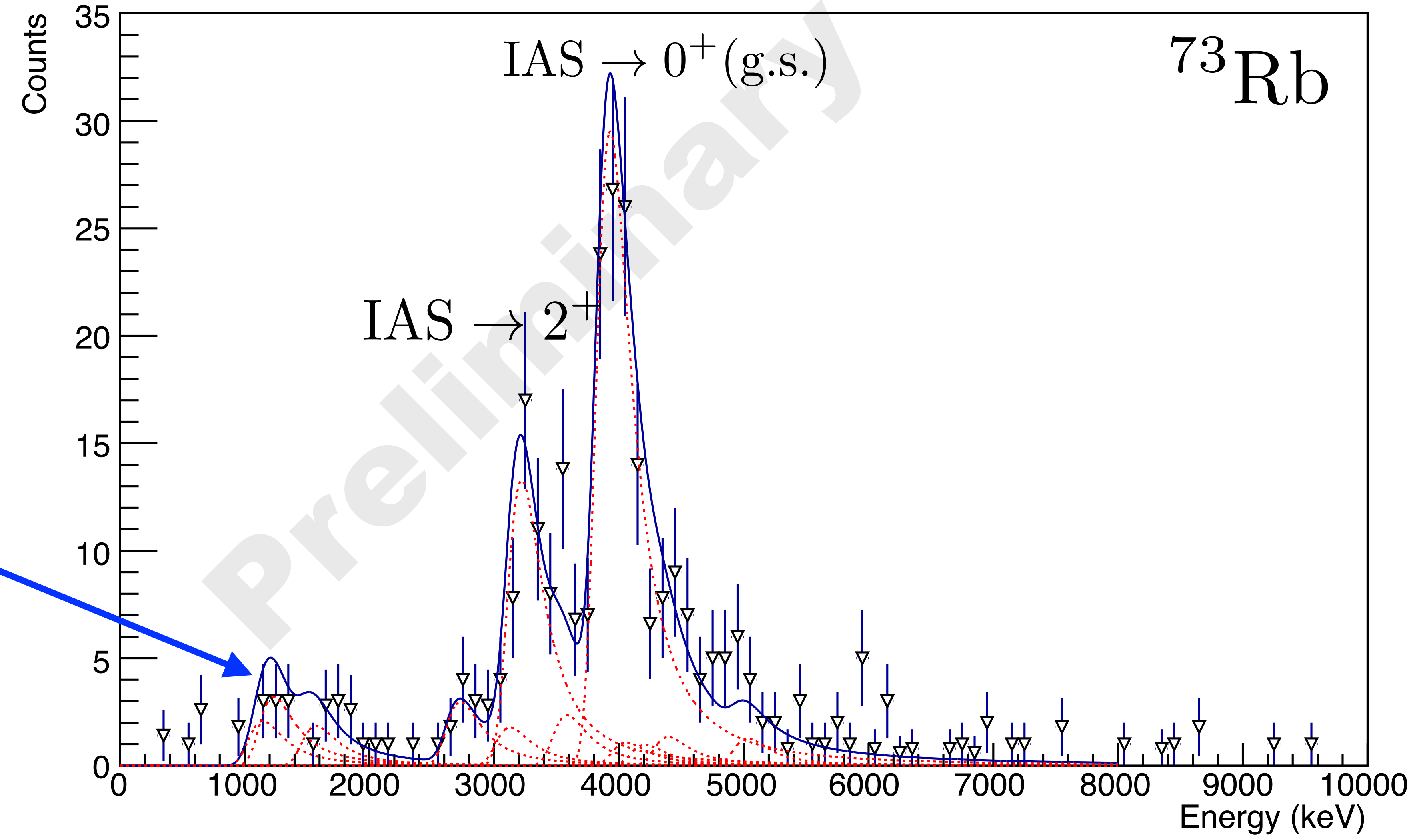
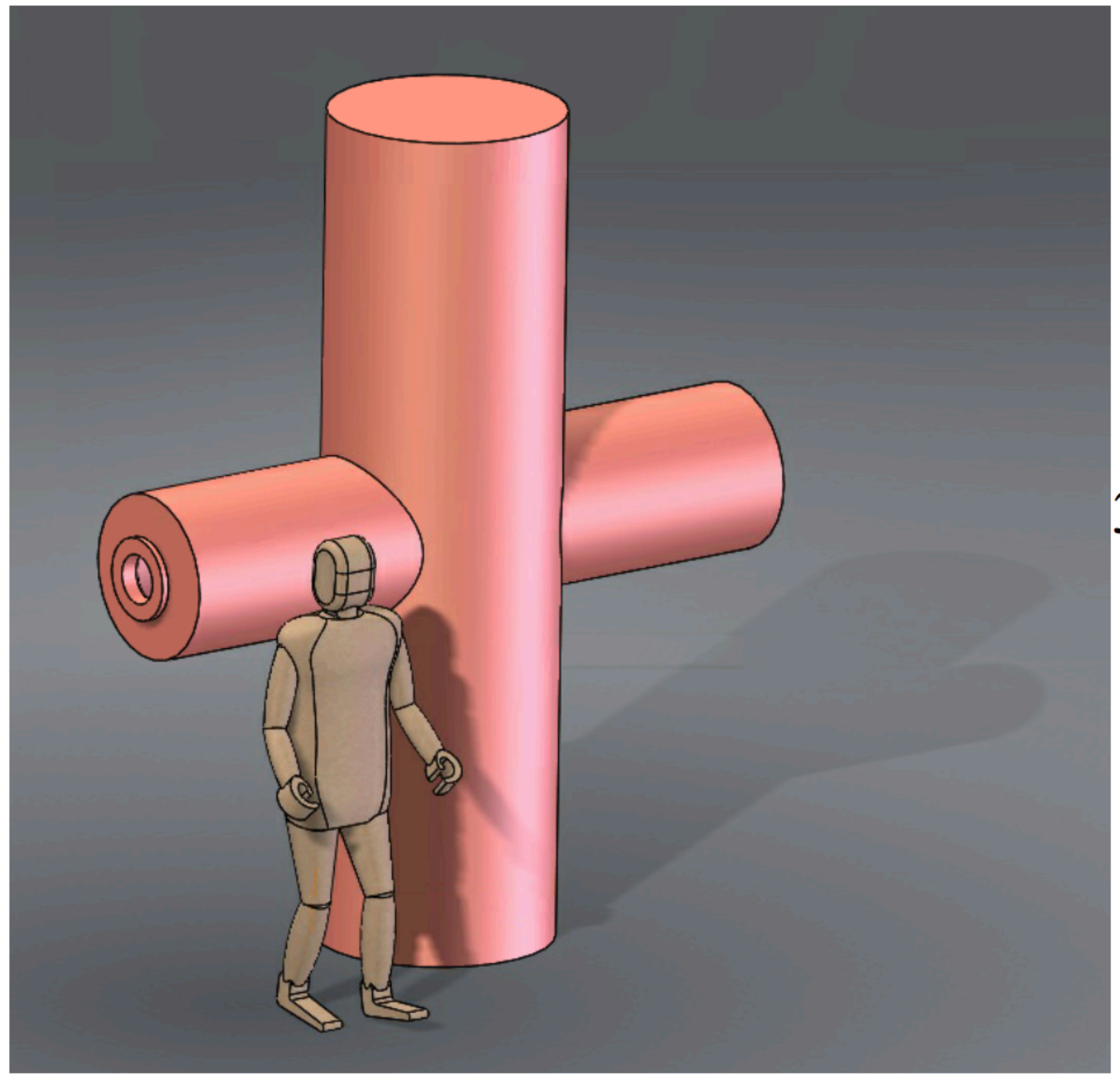
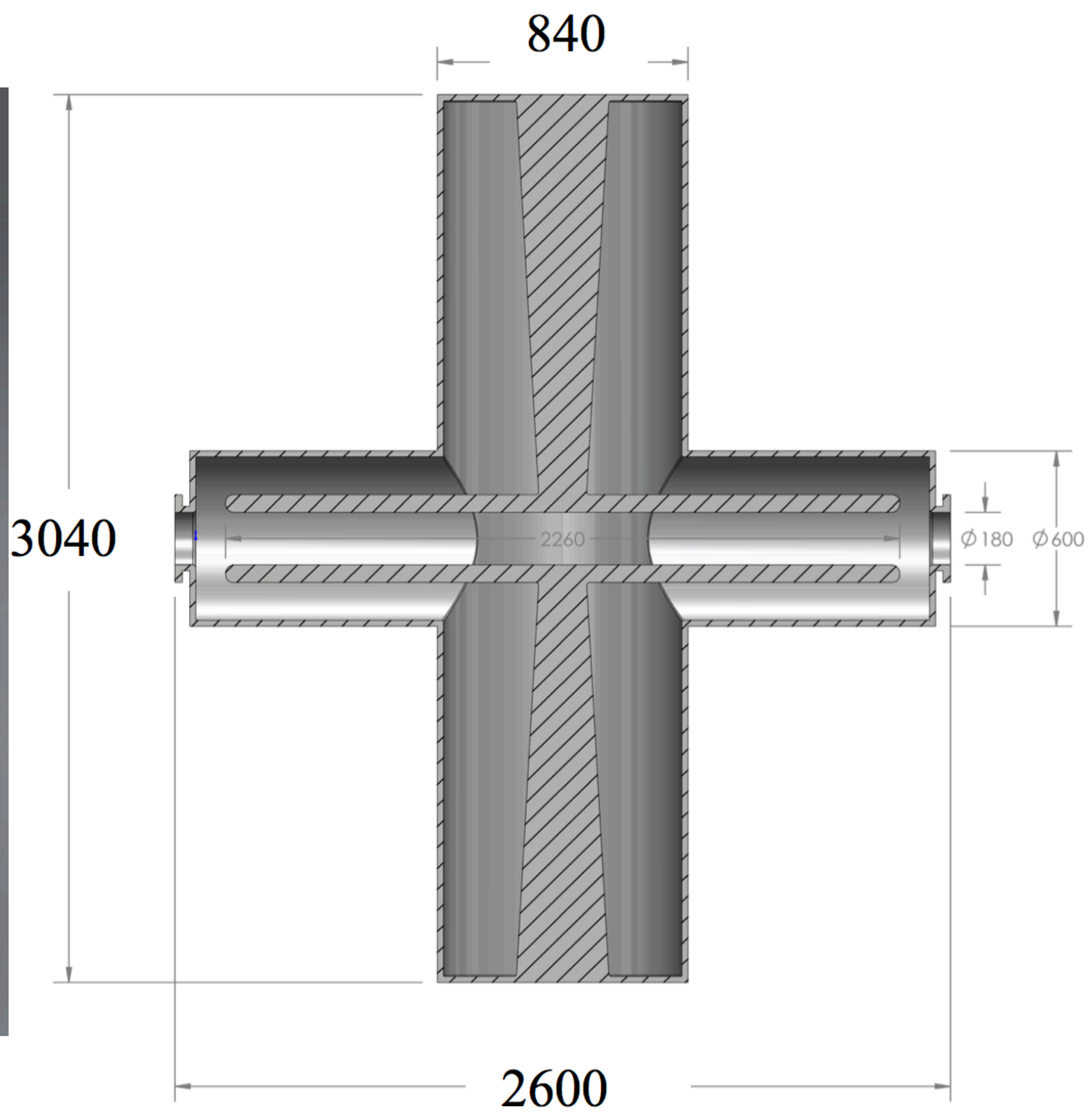


RFSS at FRIB





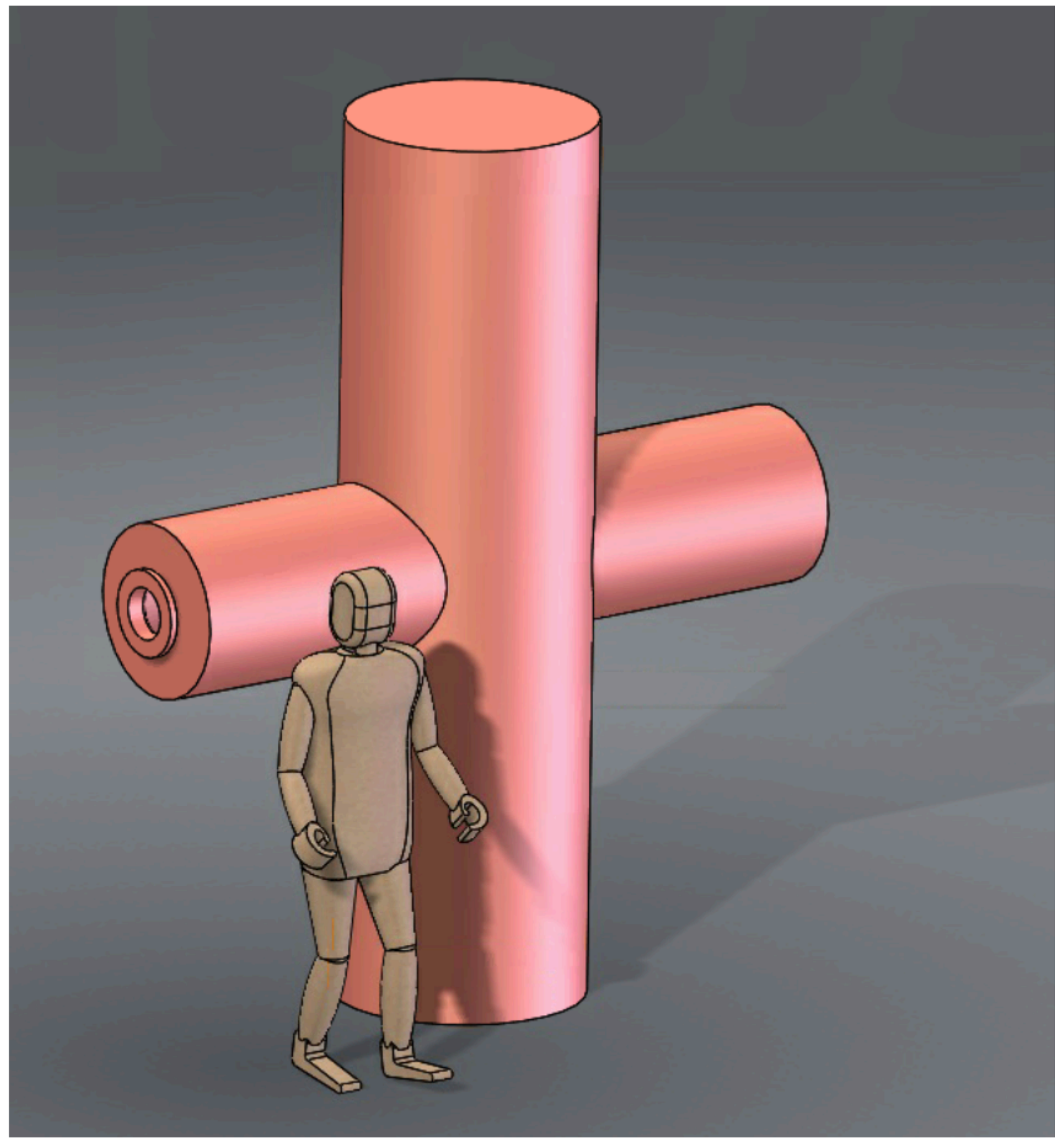
- Operating at 80 MHz of FRIB would result in “wrap around” of certain isotopes.
- Subharmonic bunching of 20.125 MHz will be implemented at FRIB upon funded construction of RFFS.

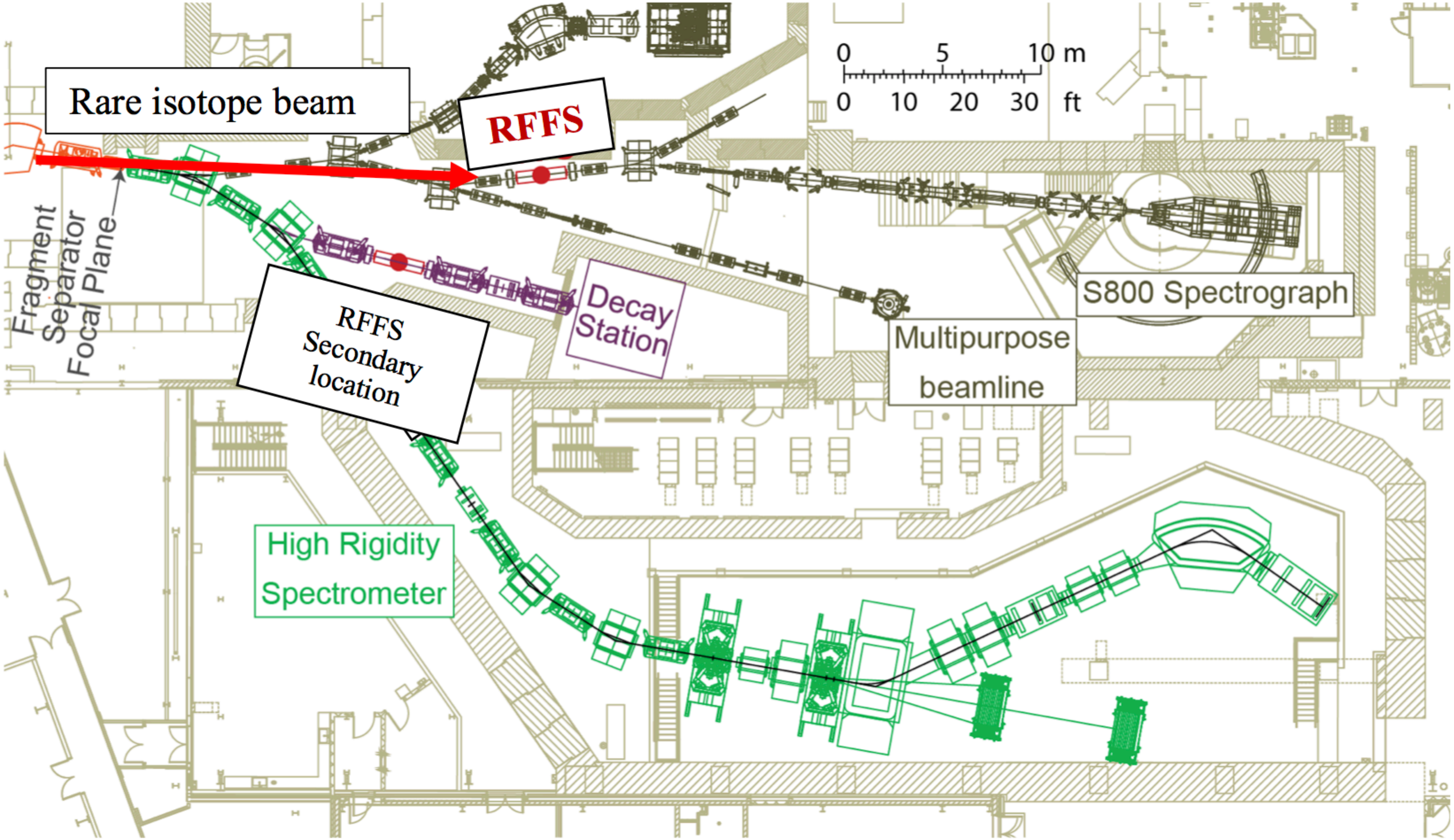
Cavity design has been investigated with E&M simulations performed by Alexander Plastun

Electrodes (plates)	Width	26	cm
	Length	226	cm
	Gap	18	cm
	Field gradient	17	kV/cm
	Voltage	± 153	kV
	Peak surface field	46	kV/cm
	$\int_{-\infty}^{\infty} \boldsymbol{E_y(z)dz}$	4	MV
Coaxial line of QWR	Inner diameter of the tank	80	cm
	Outer diameter of the stem	16..31	cm
	Height	138	cm
Chamber inner dimensions	Length	246	cm
	Diameter	56	cm
RF parameters	Frequency	20.125	MHz
	RF power consumption	2 × 21	kW
	Quality factor	12,900	
Beam kick at the exit	Positional	±1.3	Cm
	Angular	±8.6	mrad

- Larger gap to have large momentum acceptance of RIB’s.
- Large gap requires larger resonators.

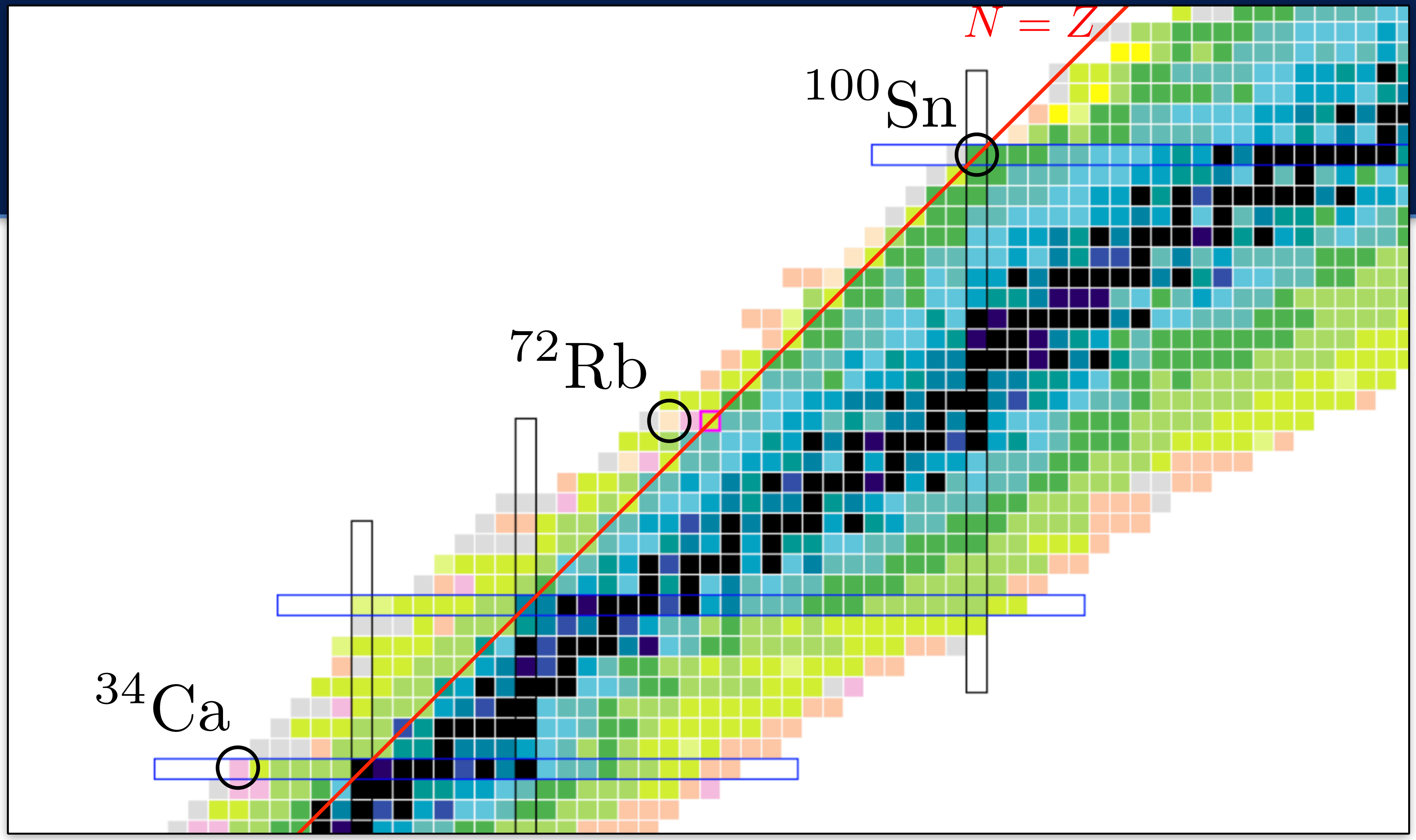
RFSS at FRIB





Rare isotope beam
RFFS
0 5 10 m
0 10 20 30 ft
Fragment Separator Focal Plane
RFFS Secondary location
Decay Station
Multipurpose beamline
S800 Spectrograph
High Rigidity Spectrometer

Day 1 Experiments at FRIB

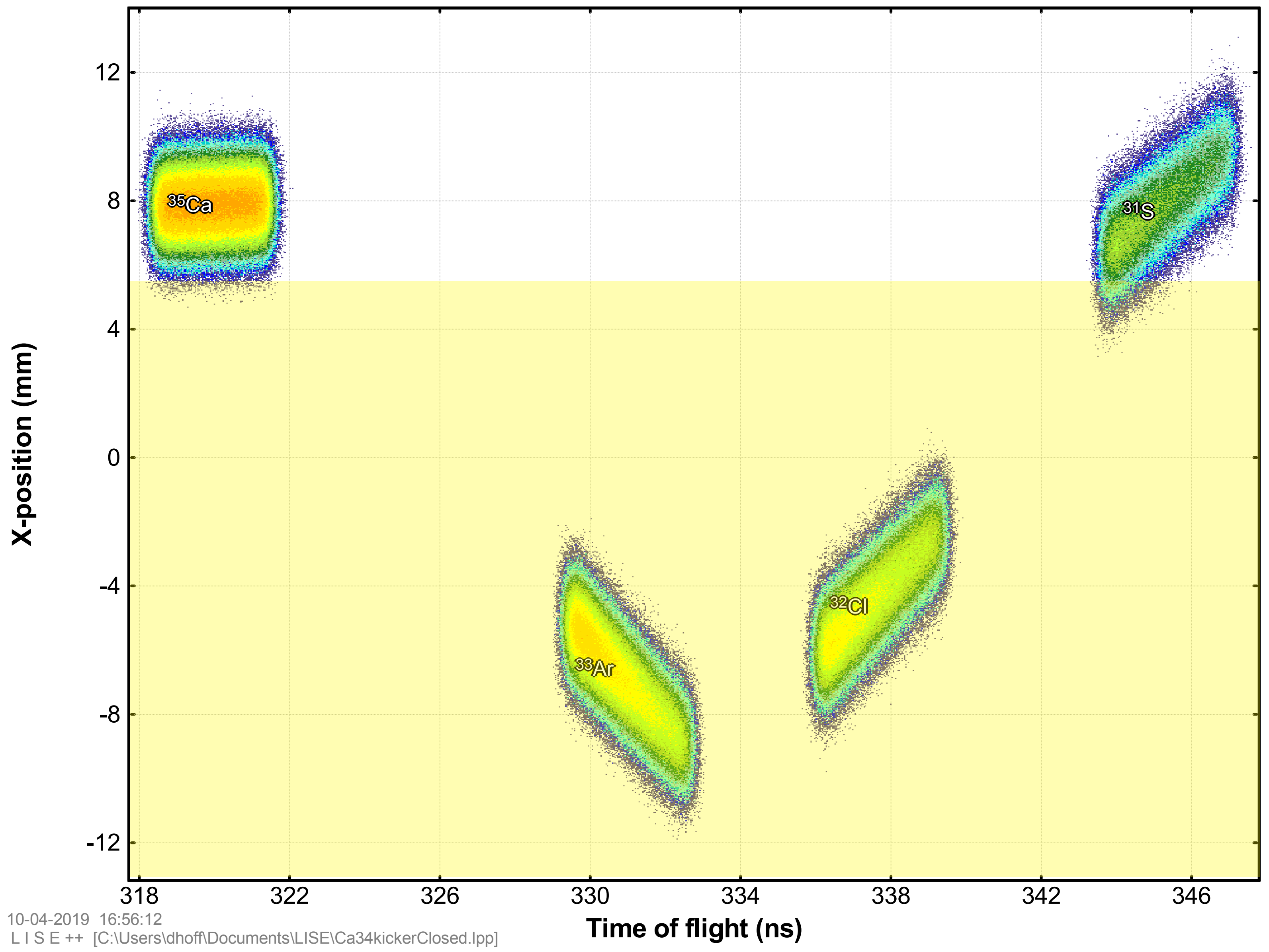


Invariant Mass Spectroscopy of ^{34}Ca

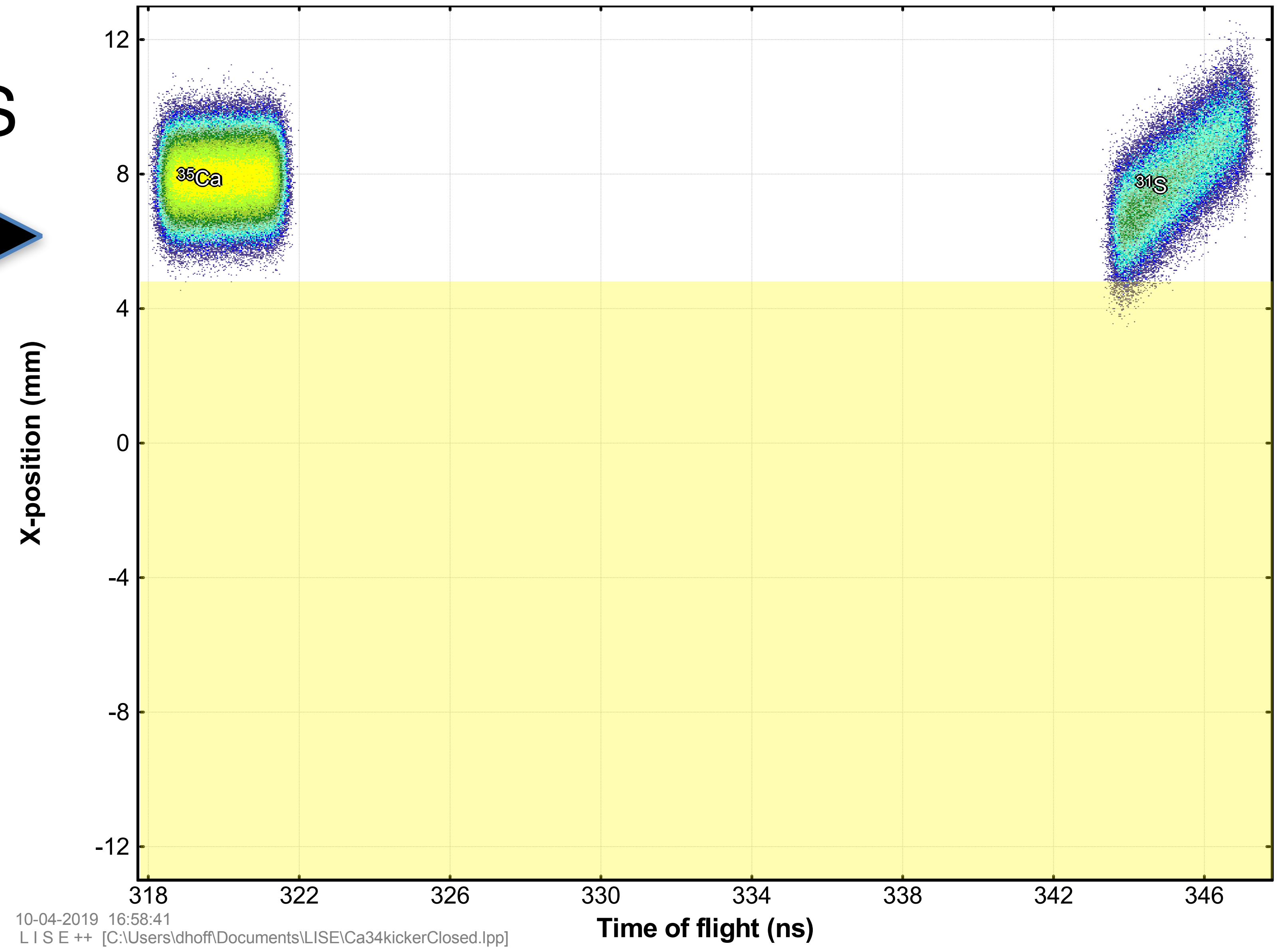
LISE++ FRIB setup
provided by Daniel Bazin

- One nucleon knockout of secondary ^{35}Ca beam, from 40Ca primary beam.
- ~1.5% of beam would be ^{35}Ca without kicker
- ~95% of secondary beam would be ^{35}Ca after RFFS
- ^{34}Ca $\rightarrow$ ^{32}Ar + 2p channel can be measured with upgraded HiRA (10 cm long CsI(Tl)'s) + S800

10 kW 140 MeV/u ^{40}Ca primary beam

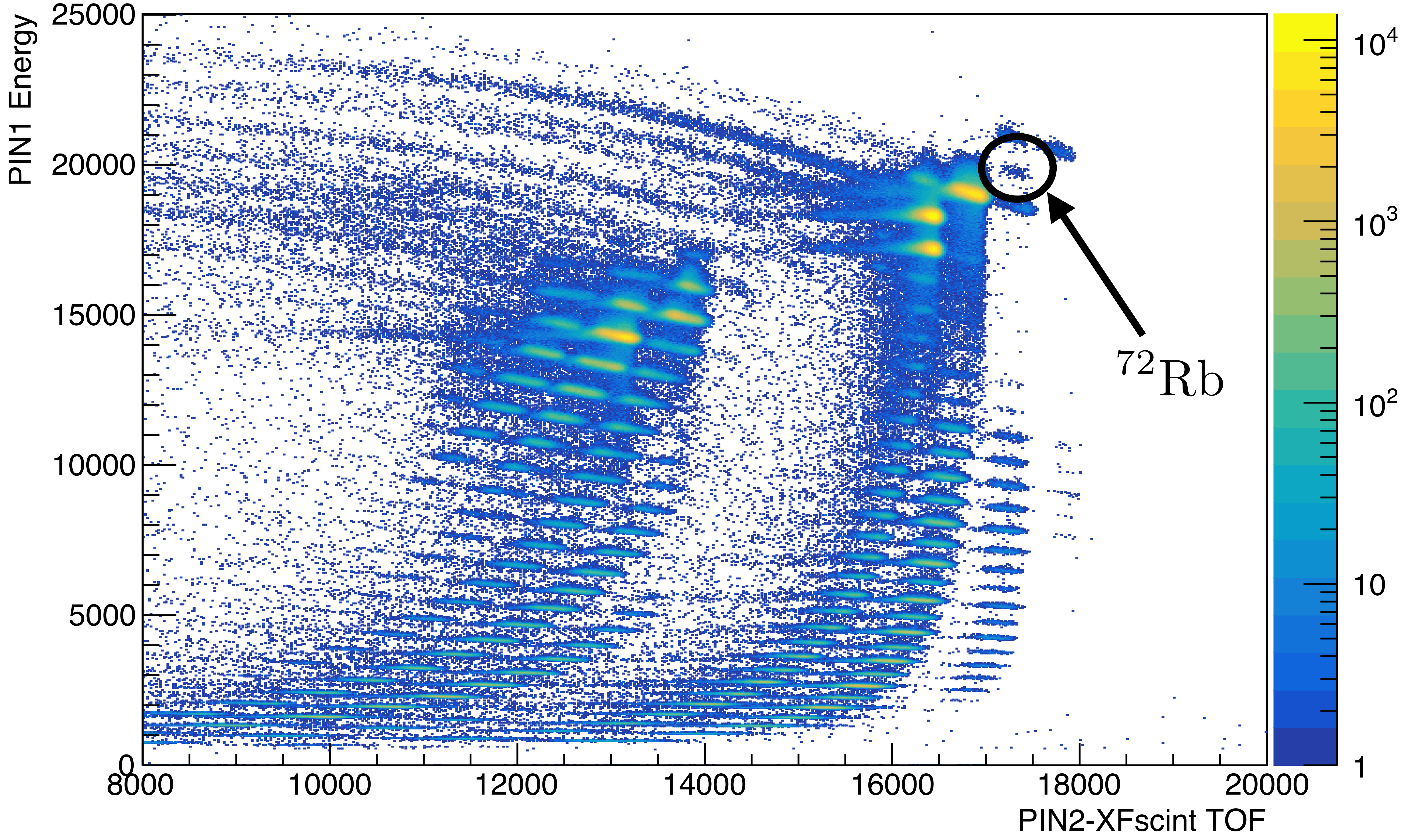


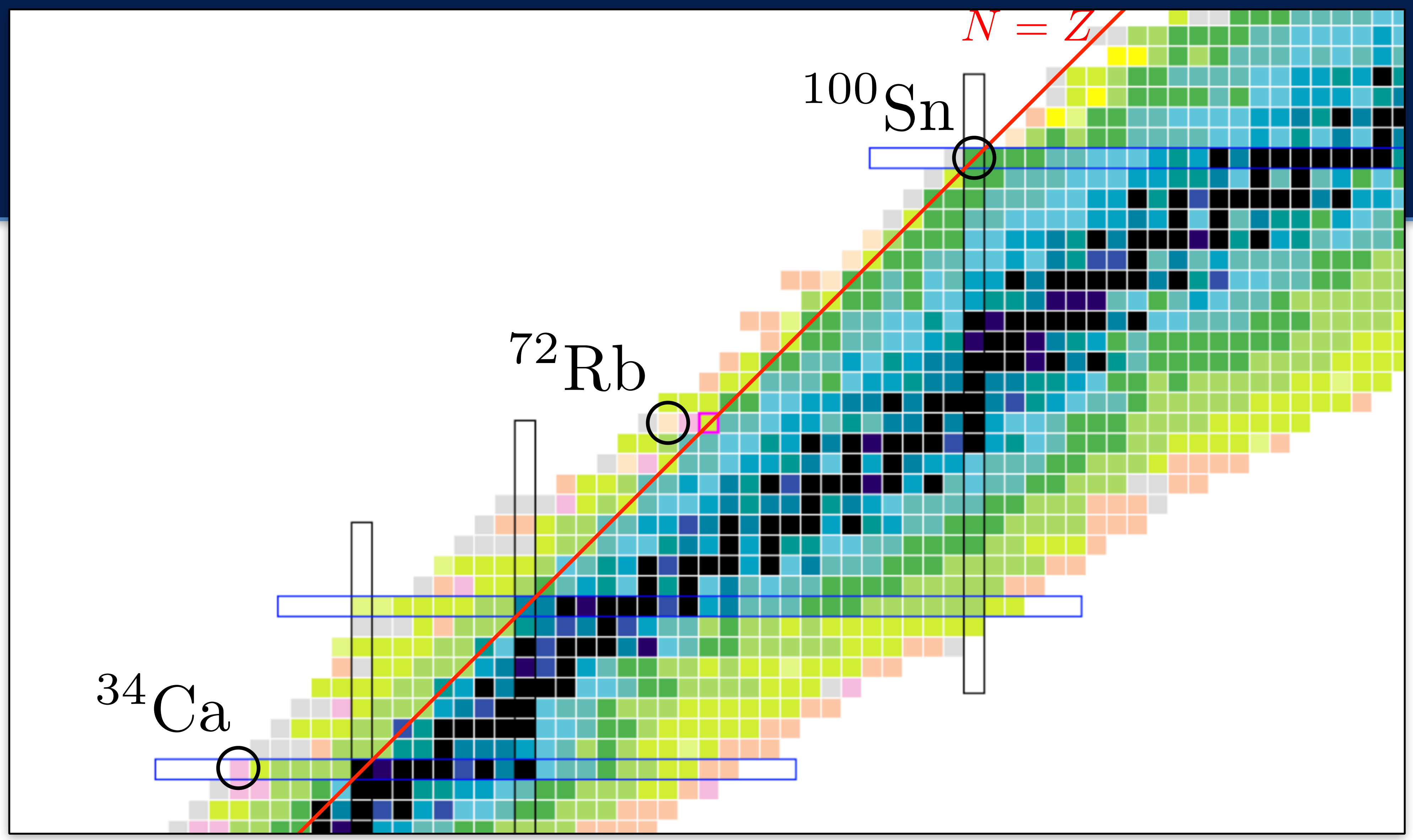
RFFS



Day 1 Experiments at FRIB

Decay studies of ^{72}Rb



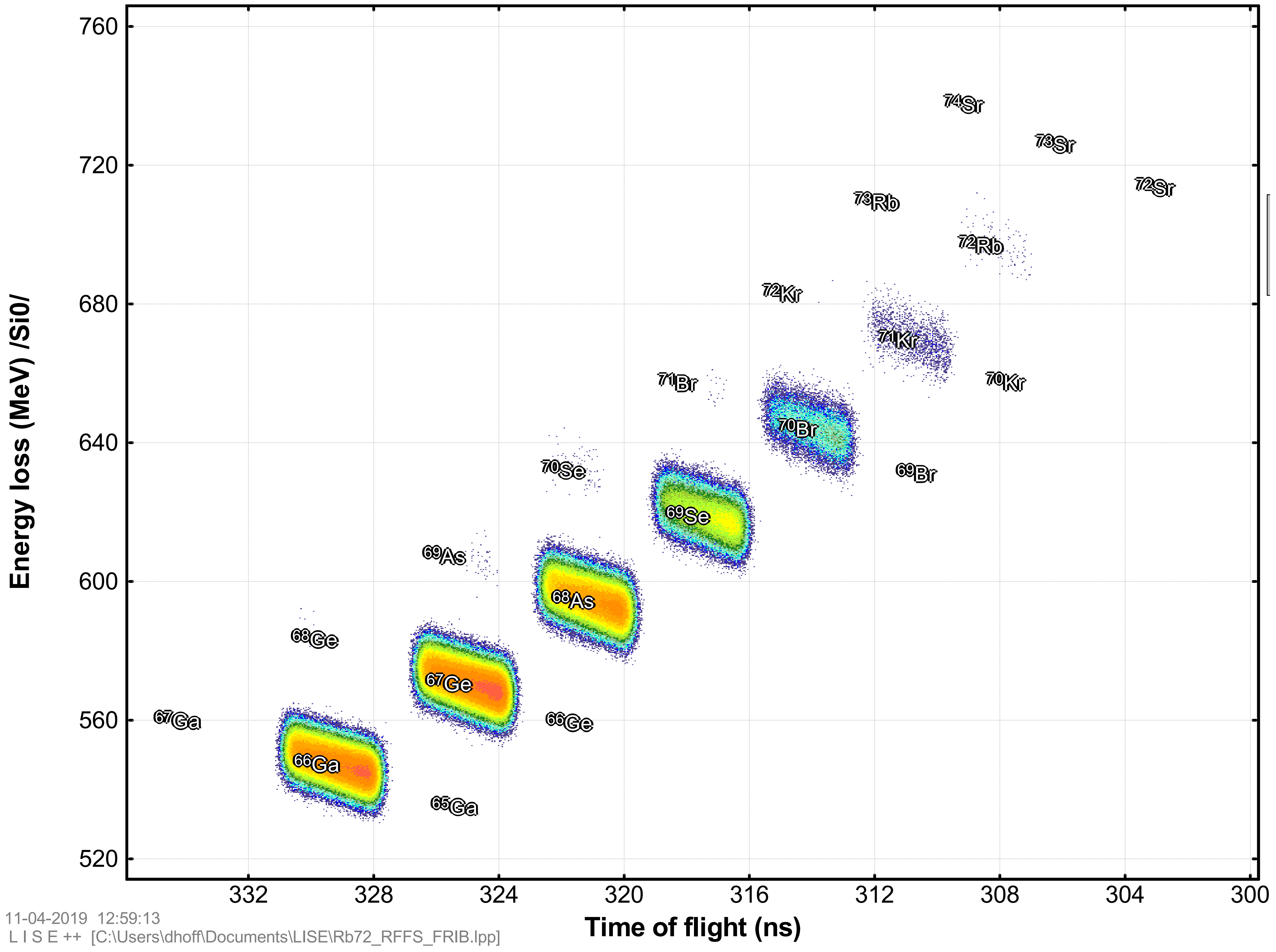


- Observed ^{72}Rb in ^{73}Sr run… but too few statistics to extract observables.
- One could run same similar experiment with A1900 focused on ^{72}Rb.
- With FRIB beam rates, would obtain same number of statistics from week-long ^{73}Sr run in a matter of hours!

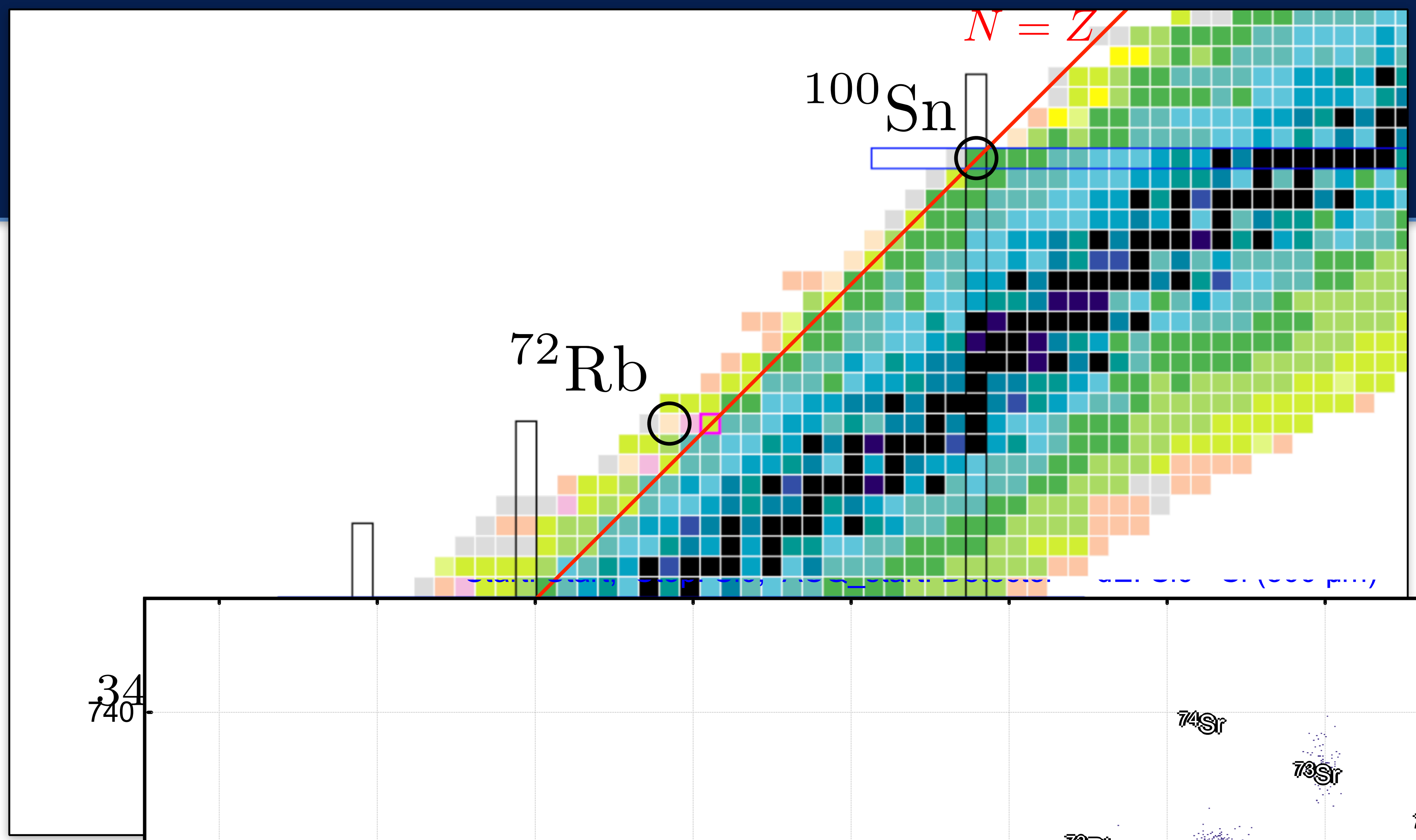
Day 1 Experiments at FRIB

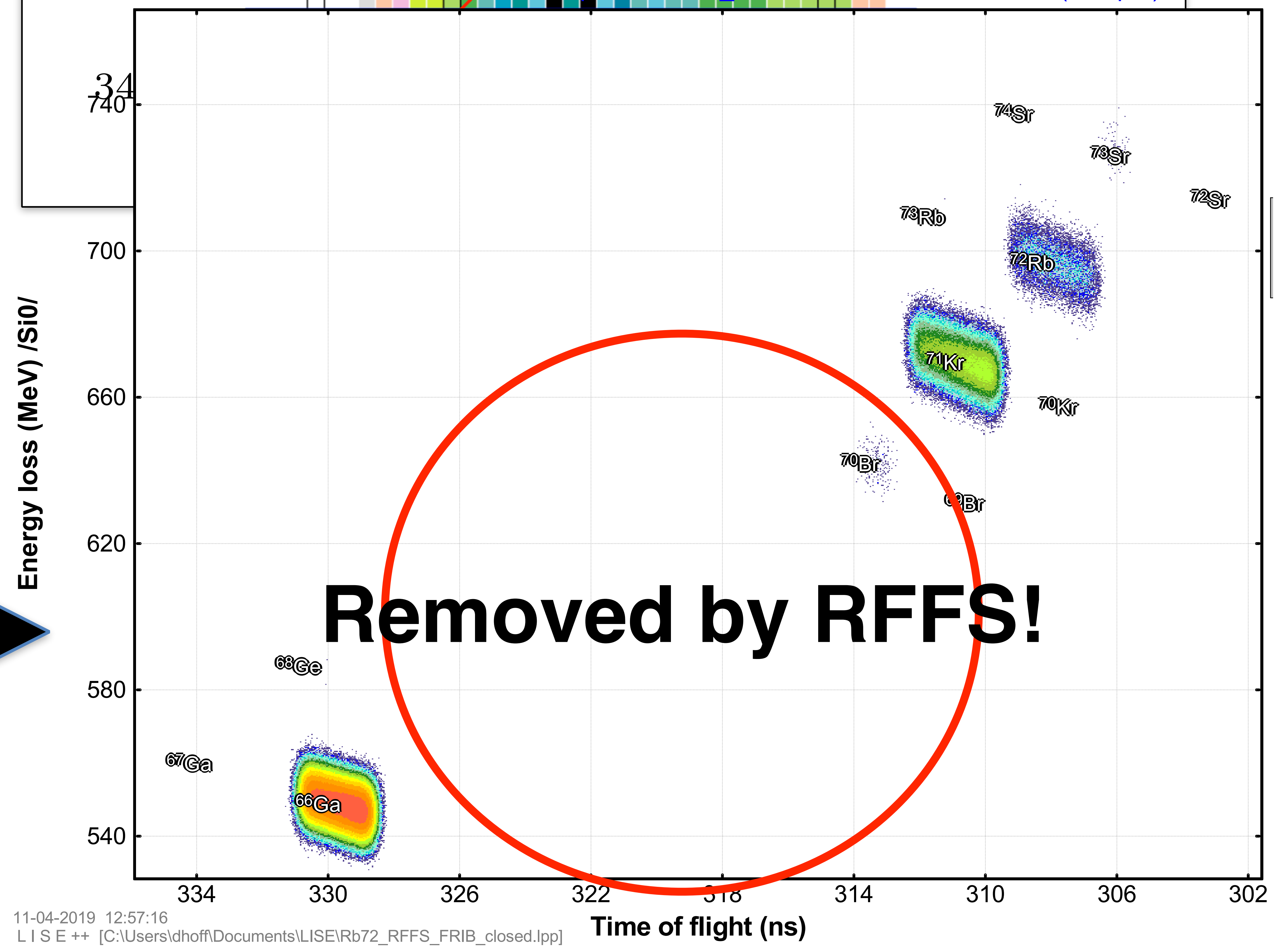
Decay studies of ^{72}Rb

200 MeV/u 92Mo primary beam fragmented on thick Be target with thick Al wedge



RFFS

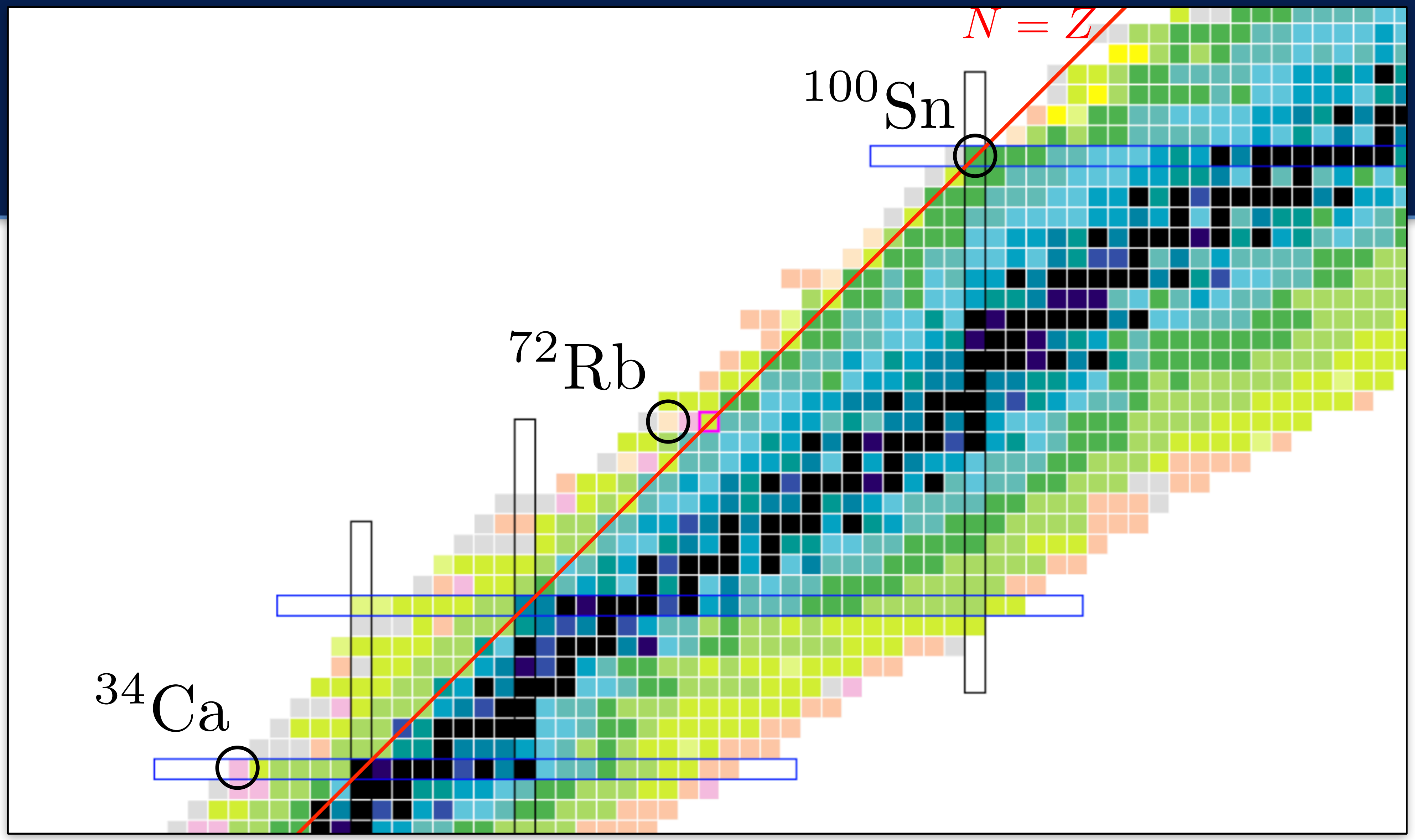




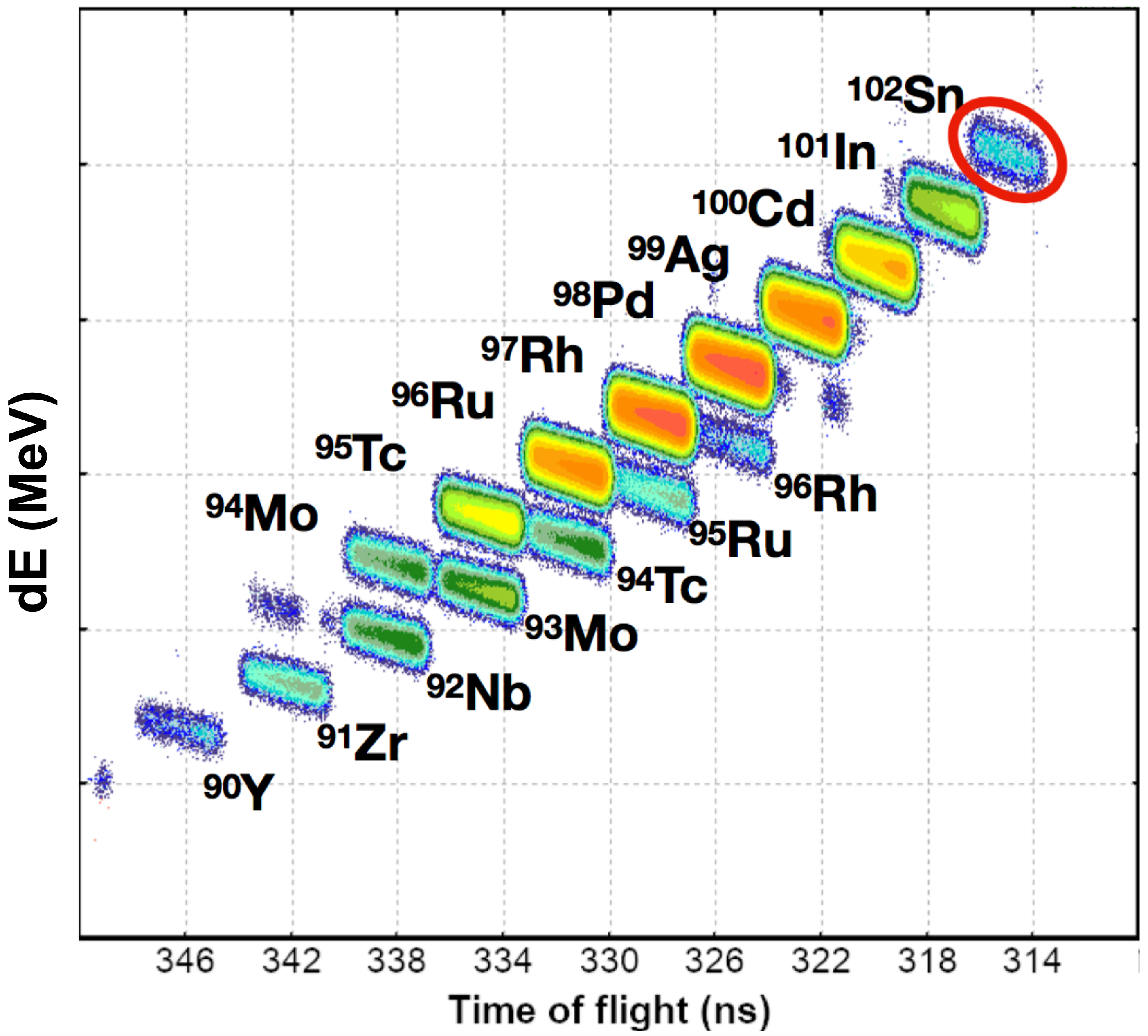
Day 1 Experiments at FRIB

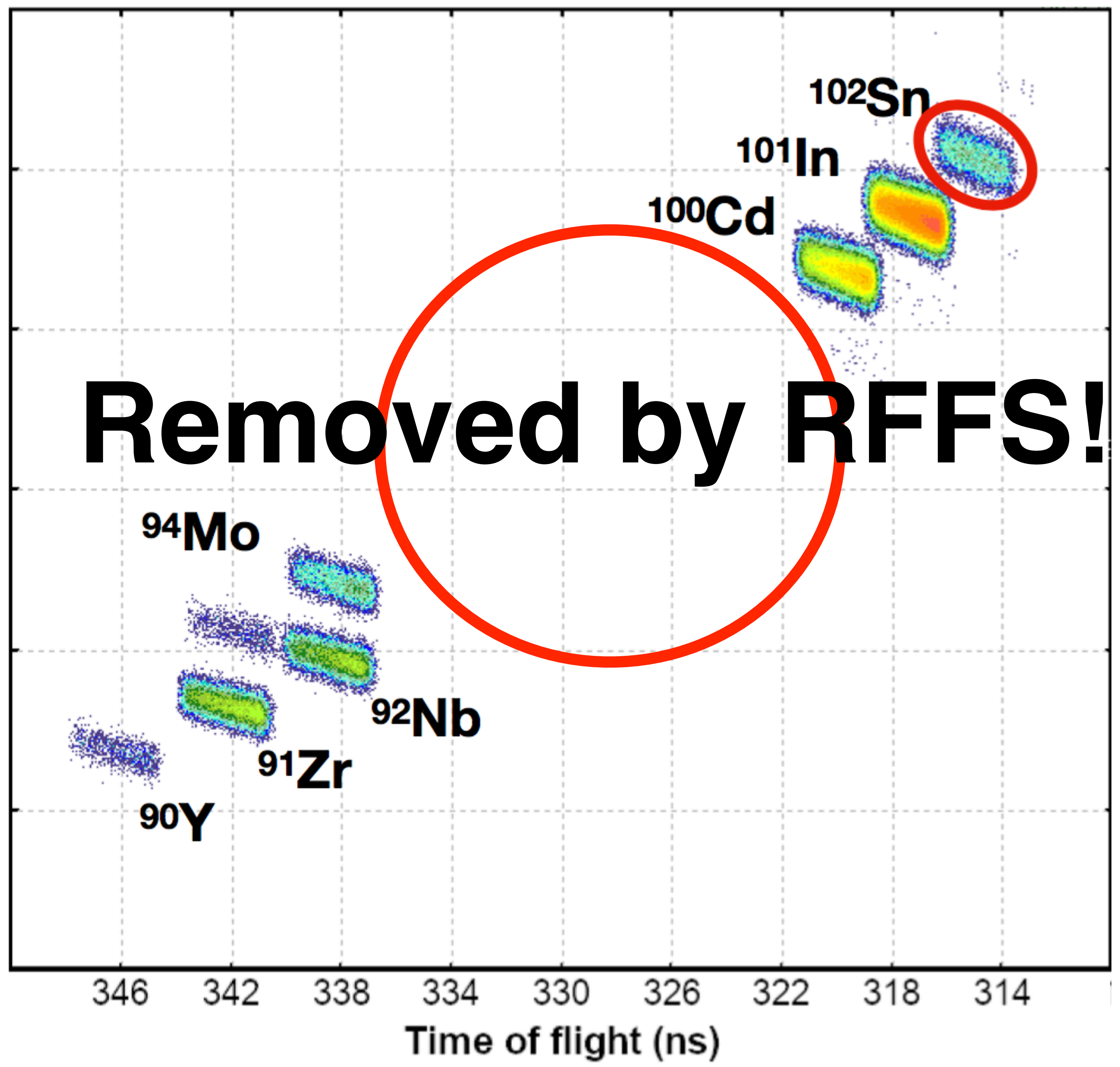
Decay studies of ^{100}Sn

- Previous experiments only measured β-decay properties.
- To understand shell structure, need to populate higher lying states.
- Higher lying states can be populated by nucleon knockout reactions → **Use ^{102}Sn secondary beam!**
- Could even do experiments at the endpoint region of the rp-process.

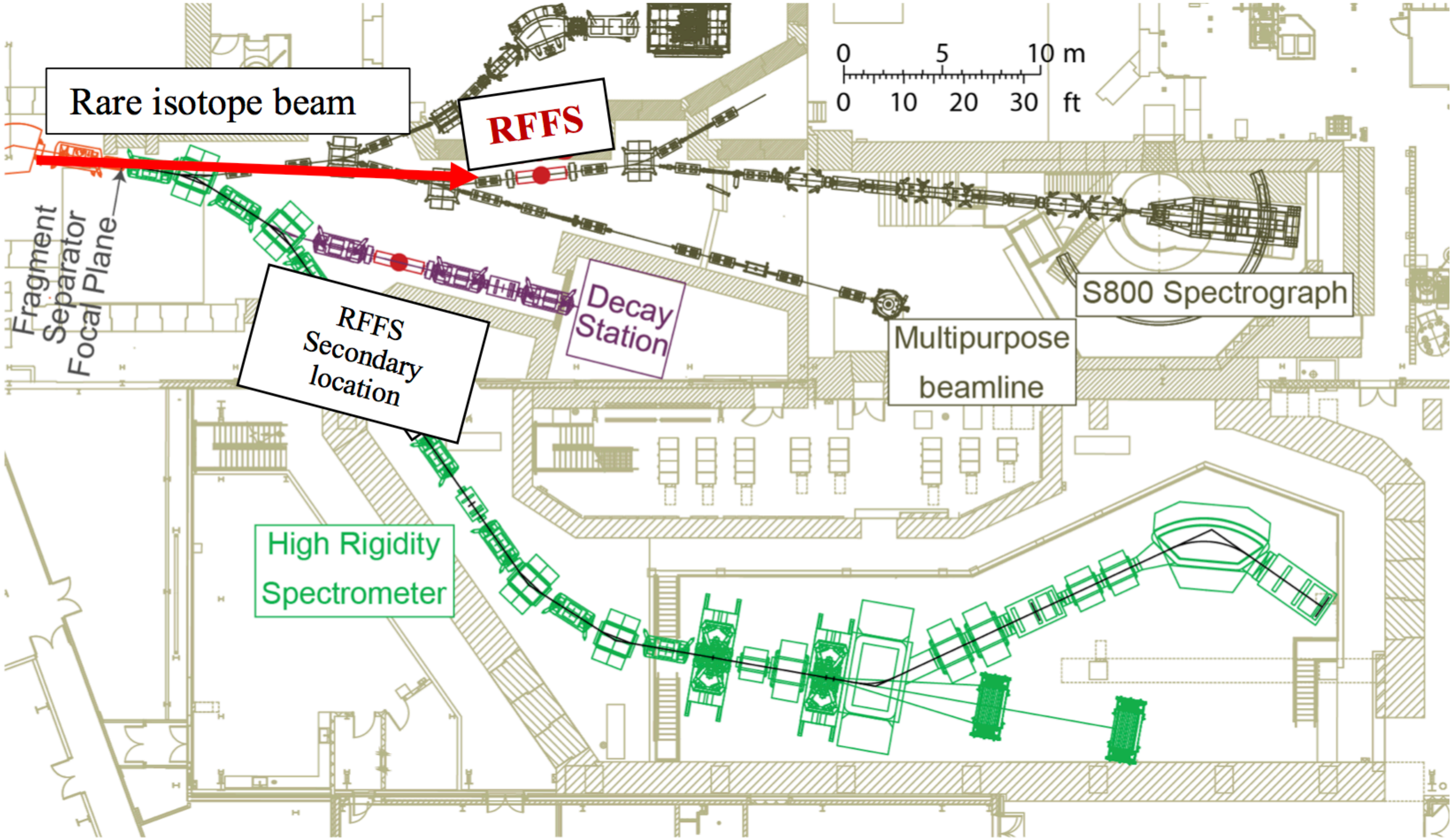


10-kW 242-MeV/u primary beam of ^{124}Xe





Outlook



- Preliminary designs for new RFFS already done.
- Many Day 1 FRIB experiments could use new proposed RFSS.
- Outlook looks good!