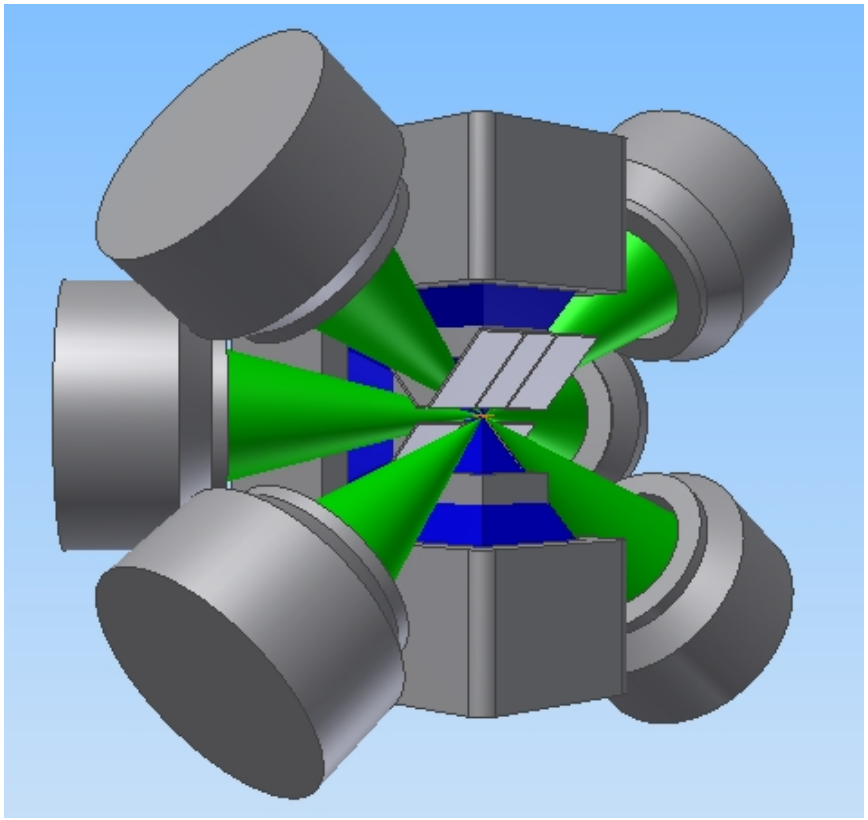
Beta-delayed neutron spectroscopy with an ion trap



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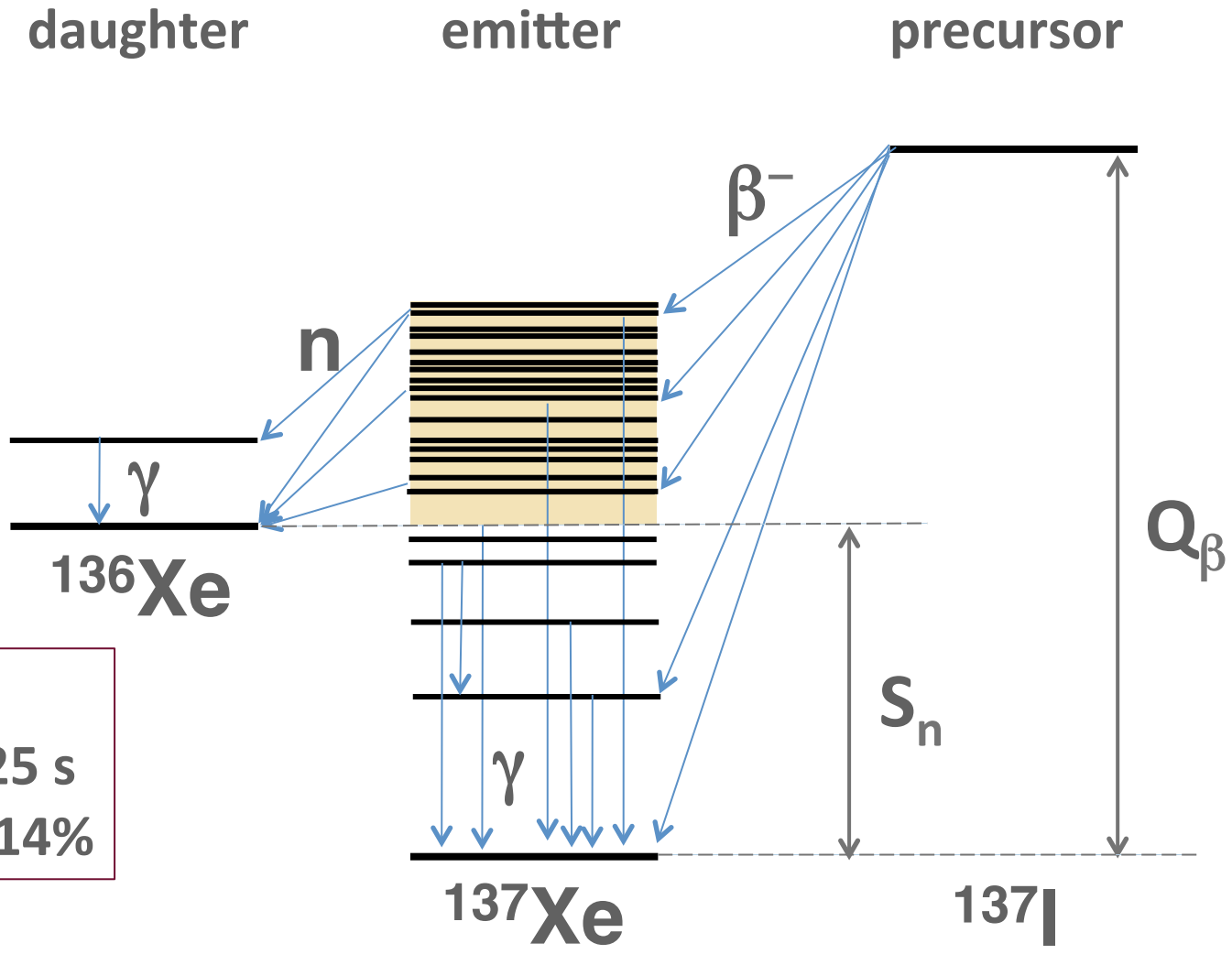
13 August 2012

Outline

1. What is beta-delayed neutron emission (BDN) and why study it?
2. New technique: Recoil-Ion Spectroscopy
3. Three generations of experiment:
   a) Proof of principle in Beta Paul Trap (BPT) – *complete*
   b) Current campaign in modified BPT – *underway*
   c) Future campaign at CARIBU with new ion trap – *in design*

Beta-delayed neutron emission (BDN):

$Q_\beta > S_n$



^{137}I:
- $T_{1/2}$ = 25 s
- P_n = 7.14%

Where is the BDN process relevant?

Need better/any data for:

Astrophysics: r-process nucleosynthesis of elements heavier than Fe

Nuclear Structure: predicting properties of neutron-rich nuclei

Nuclear Energy: reactor design, performance, and safety studies

Stockpile Stewardship: interpreting results involving production of fission fragments

New approach with ion trap: Recoil-Ion Spectroscopy

Principles

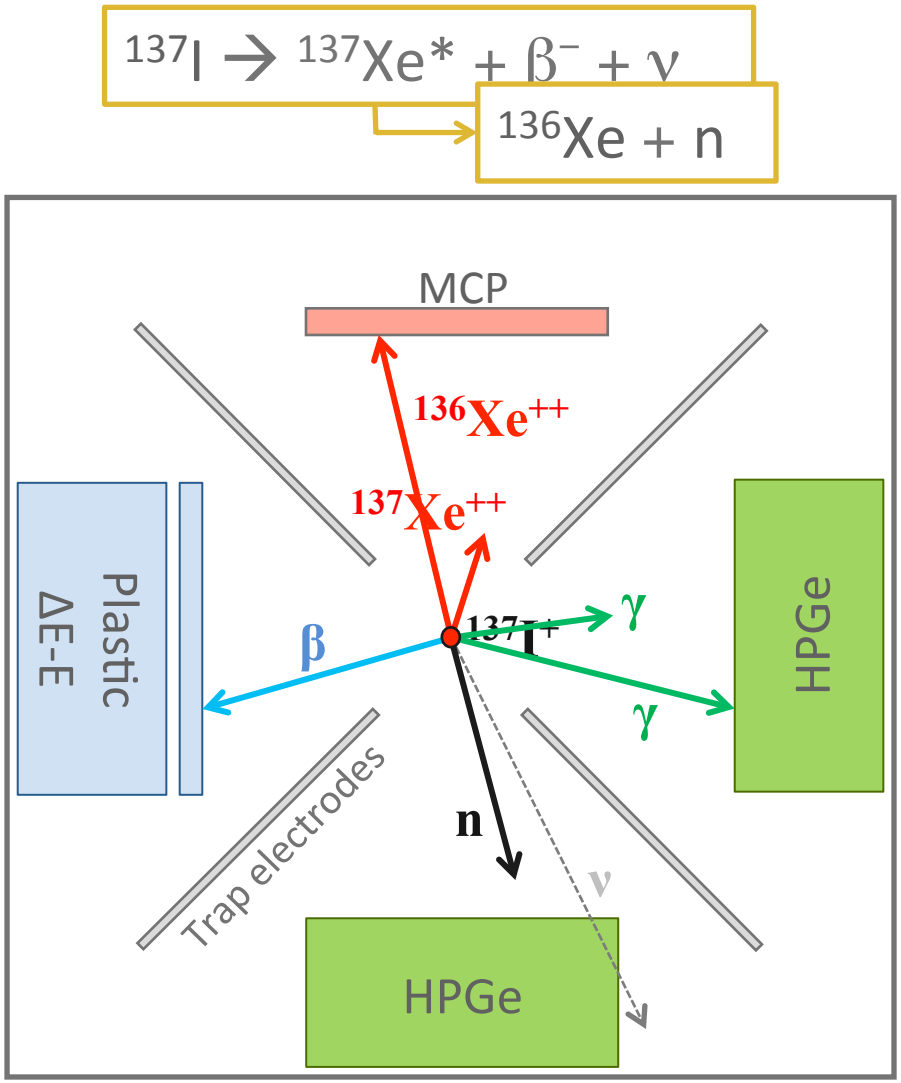
- Trap BDN precursors as ions
- Cool by He gas to ~1mm^3 volume
- Ions decay from rest at trap center
- Trigger on β's seen by plastic
- Measure recoil time of flight (TOF) to MCP
  1. β gives slow recoil (< 160 eV)
  2. β+n gives fast recoil (~10 keV)

Advantages

- No need to detect neutron
- Insensitive to background γ's & n's
- Gaussian detector response
- Works for any isotope
- Several ways to get P_n

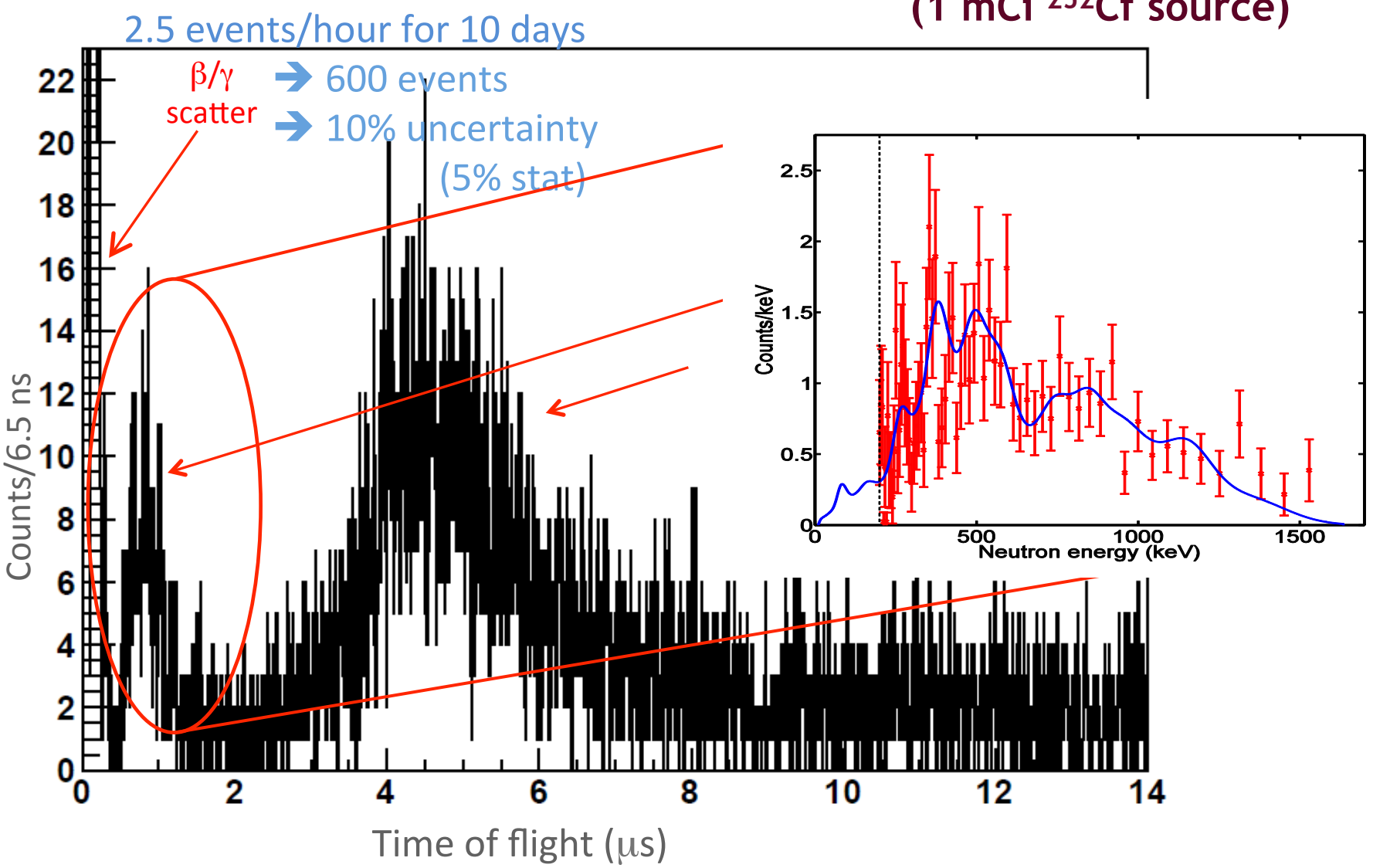
Challenges

- Trapping field can perturb ion trajectory
- Other species in trap
- Ion cloud size
- Detector thresholds

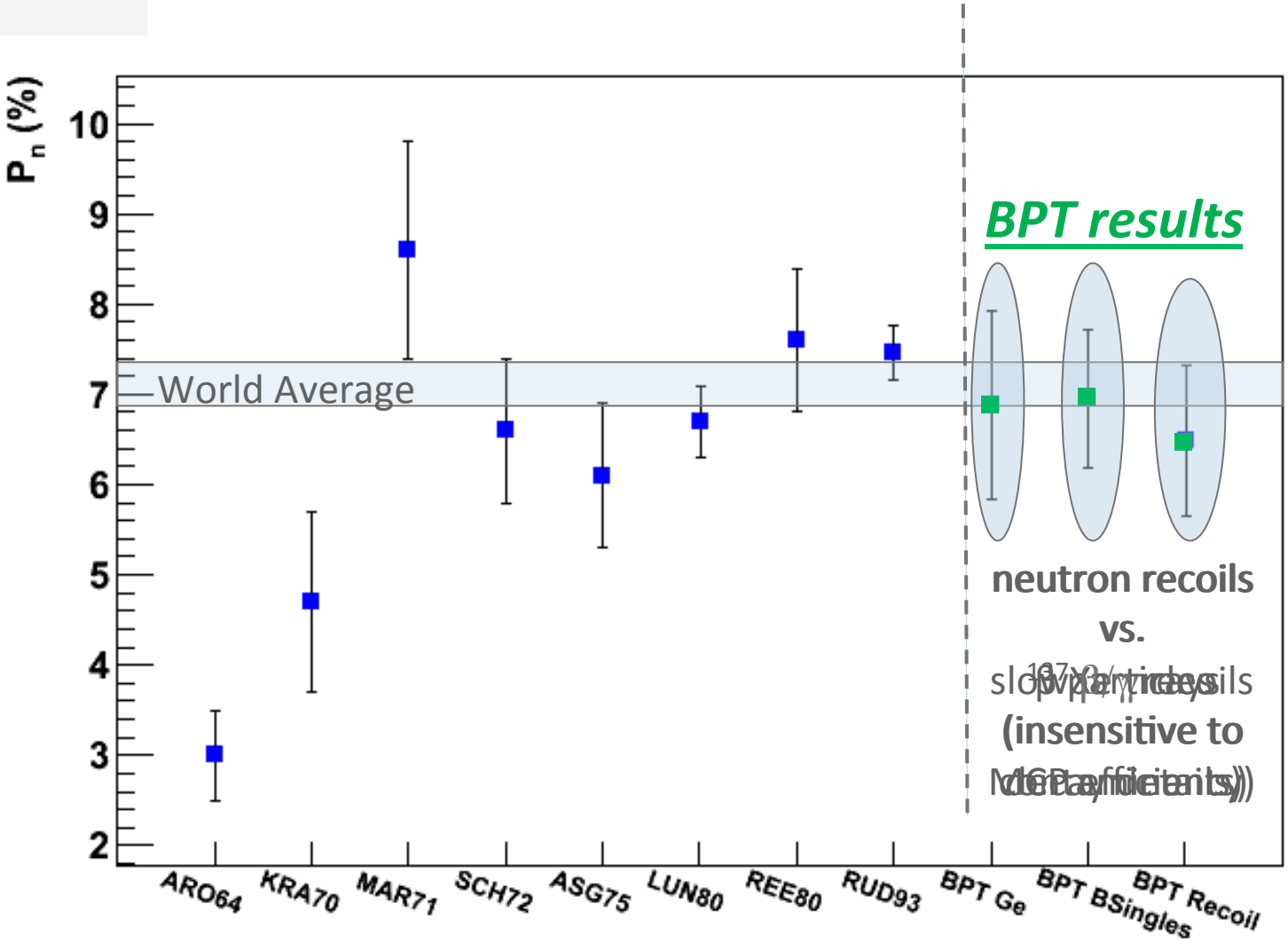


Proof of Principle with $^{137}I^{+}$ @ 30 ions/sec

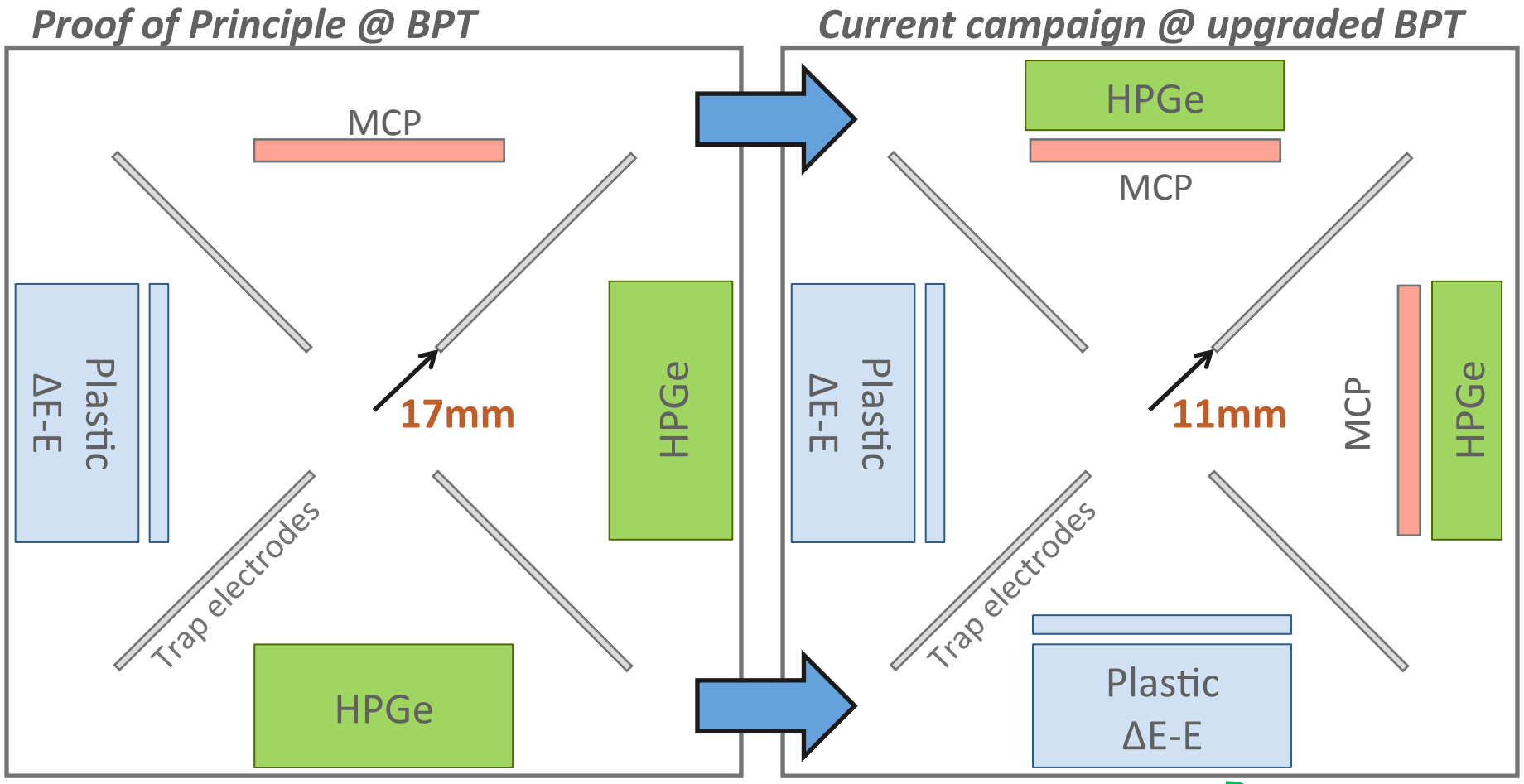
(1 mCi ^{252}Cf source)



Proof of principle: P_n



First round of upgrades (under construction)



Ω_β = 3%
Ω_r = 3%
R = 17mm ⟶ V_{rf} = 200 V

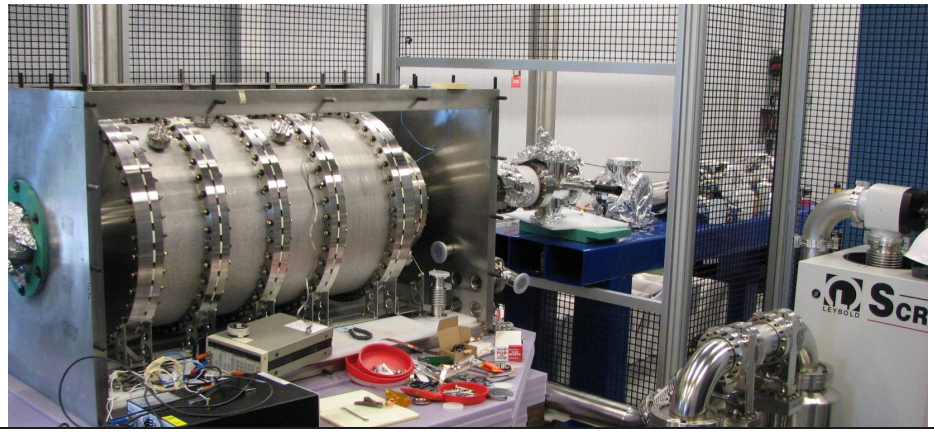
Ω_β = 10%
Ω_r = 10%
R = 11mm ⟶ V_{rf} = 85 V
+ Position sensitive MCP's

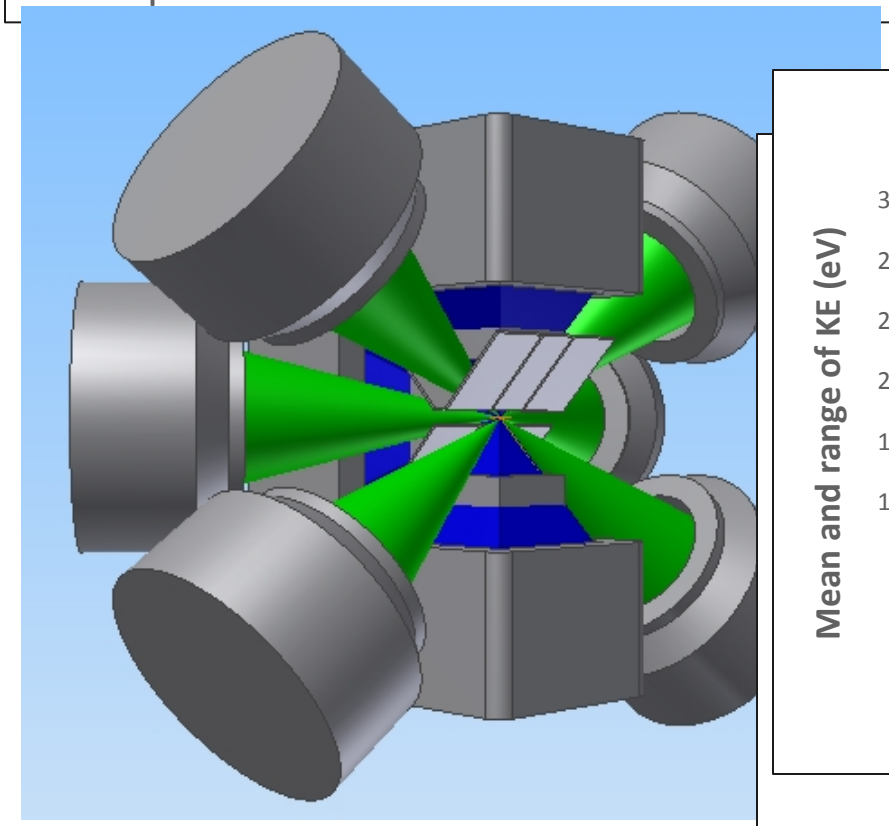
10x efficiency

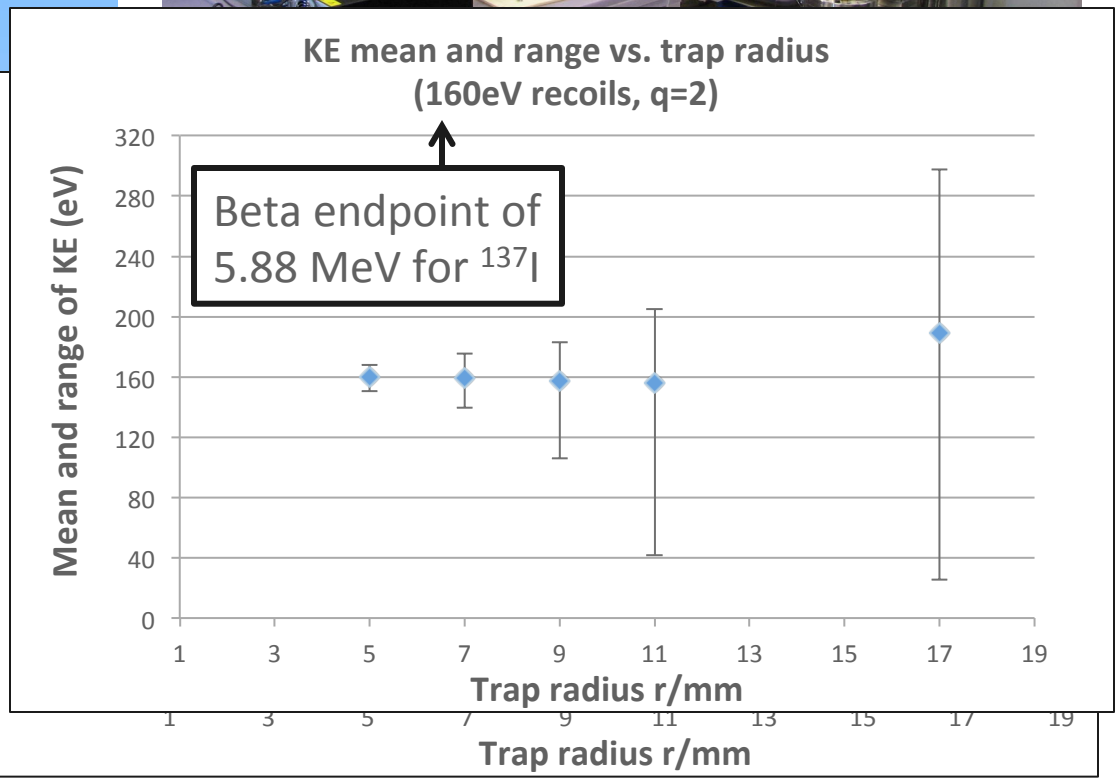
5x E_n resolution
4x E_n threshold

Next trap for CARIBU

- 500 mCi source (*2000x beam to trap*)
- More detectors! (*another 3x efficiency*)
  - $\Omega_\beta = 12\%$ ← *can improve further*
  - $\Omega_r = 26\%$
  - $\Omega_\gamma = 28\%$
- Trap radius reduced to 7mm





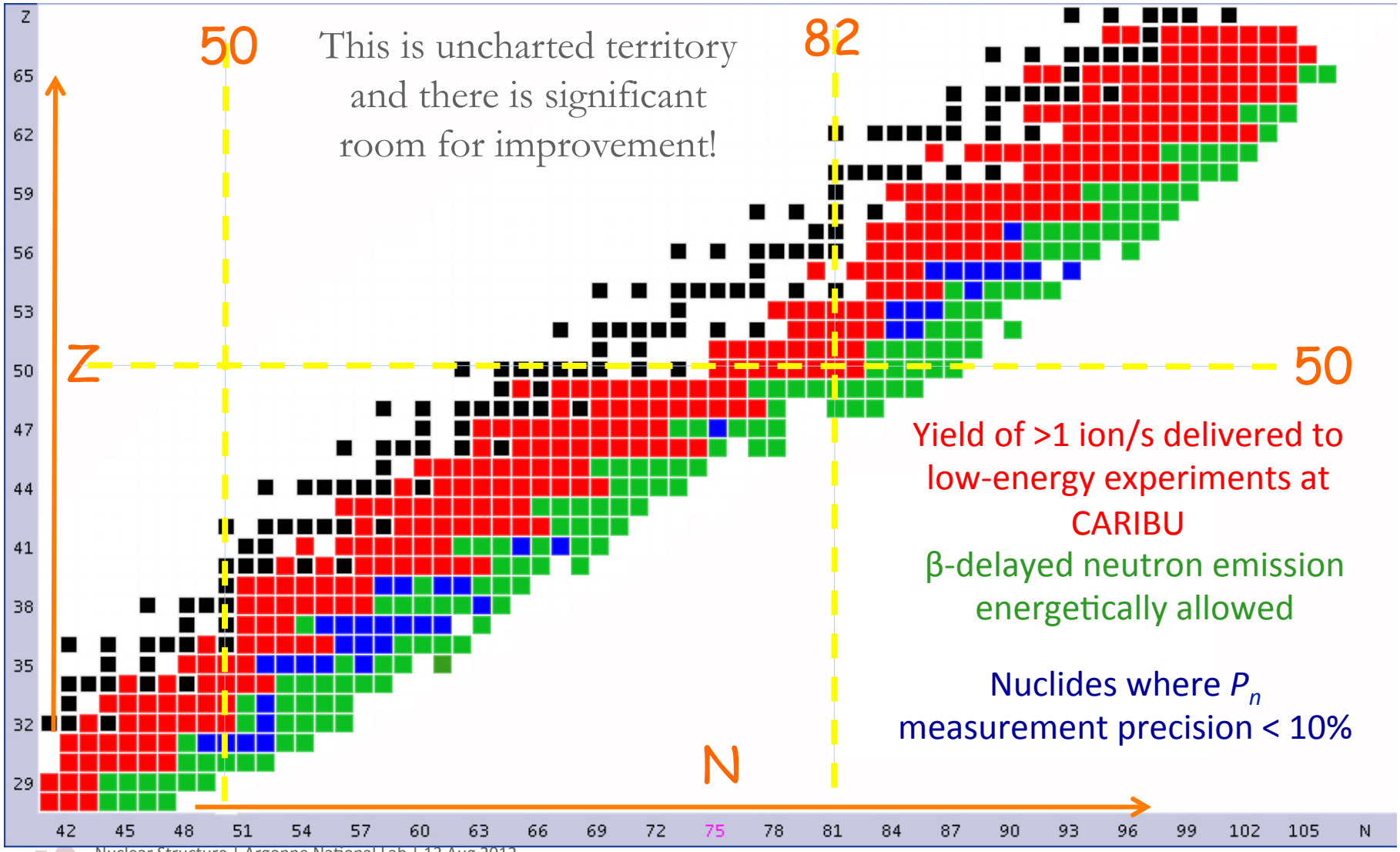


Progress:
Three generations of experiment

	Proof-of-Principle (BPT)	Current campaign (upgraded BPT)	CARIBU (new ion trap)
^{137}I rate to trap	30 Hz	30 Hz	60,000 Hz
Ω_β	3%	10%	12%
Ω_r	3%	10%	26%
Ω_γ	10%	10%	28%
$\Omega_\beta \times \Omega_r$	0.1%	1%	3%
$\Omega_\beta \times \Omega_r \times \Omega_\gamma$	0.01%	0.1%	0.9%
FOM (~Rate x Ω_β x Ω_r)	1	11	70,000
Trap radius	17 mm	11 mm	7 mm
V_{rf}	200 V	85 V	30 V
E_n resolution	10-20%	3%	3%
E_n threshold	200 keV	50 keV	30 keV
β threshold	~150 keV	25 keV	25 keV

PRELIMINARY

Existing data is limited (and often inconsistent)



Collaborators

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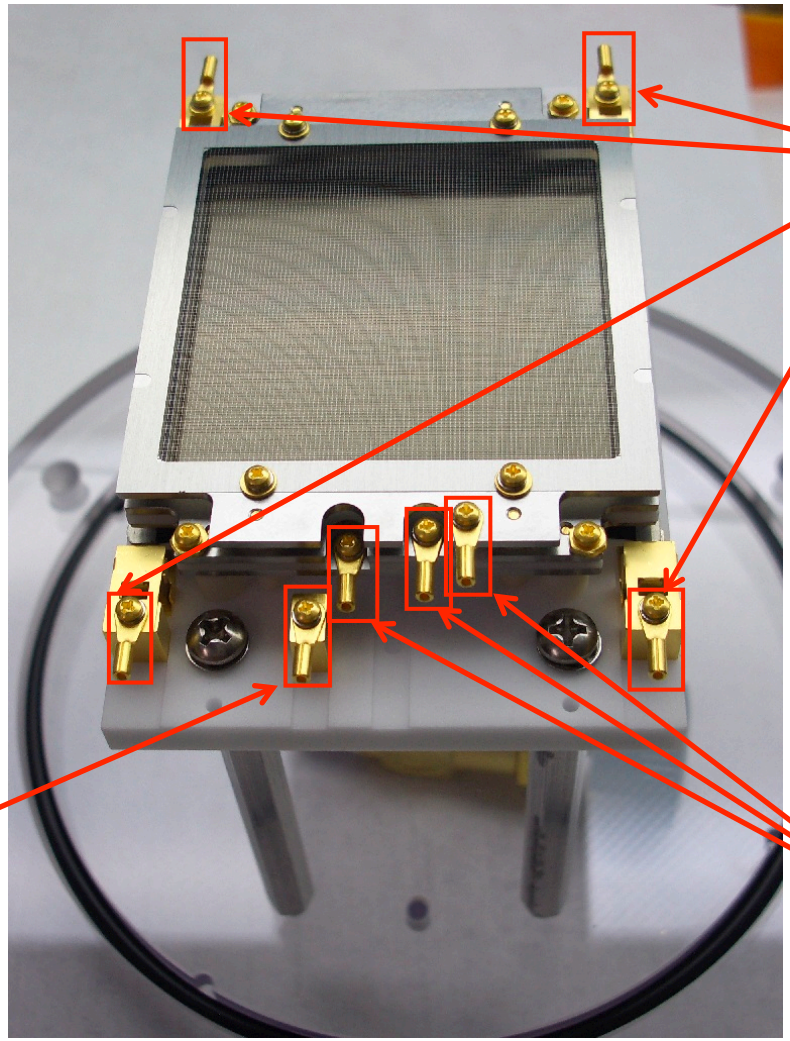
50 mm X 50 mm position-sensitive MCPs

Picture of plastic

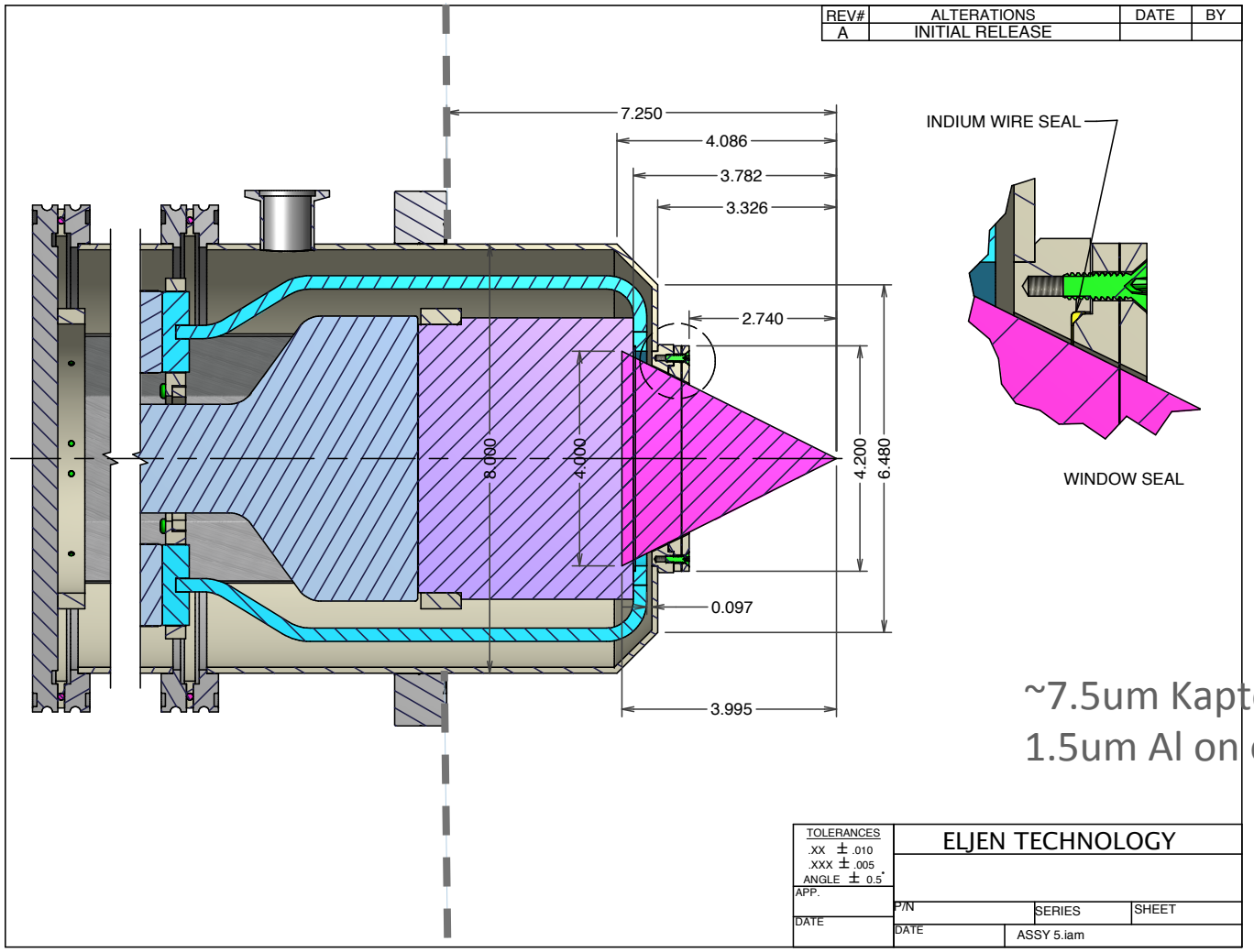


4X resistive-anode readout

Resistive-anode bias

Grid & Channel Plate bias

ΔE-E telescope with thin window re-entrant port



~7.5um Kapton foil with
1.5um Al on each side

BDN precursors relevant to r process

Nuclide	$T_{1/2}$ (sec)	Q_β (MeV)	S_n (MeV)	^{252}Cf Yield (%)	P_n (%)	FOM (^{137}I)	Rate (hr^{-1})	
(^{137}I)	25.4	5.88	4.03	1.57	7.1	1.00	25	BPT (PoP)
^{135}Sb	1.71	8.12	3.34	0.15	22.0	0.25	6.3	BPT (upgraded)
^{90}Br	1.90	10.35	6.31	0.11	25.2	0.22	5.4	
^{85}As	2.03	8.90	4.55	0.03	59.4	0.12	3.1	
^{140}I	0.86	8.72	5.42	0.12	9.3	0.07	1.8	
^{91}Br	0.54	9.80	4.42	0.04	20.0	0.05	1.2	CARIBU
^{141}I	0.45	7.60	3.40	0.03	21.2	0.03	0.8	
^{136}Sb	0.82	9.83	4.67	0.03	16.3	0.03	0.8	
^{92}Br	0.34	12.21	5.55	0.01	33.1	0.02	0.4	
^{134}Sn	1.04	7.37	3.29	0.02	17.0	0.02	0.4	

From Demonstration to CARIBU

Proof-of-principle… (existing trap)

Detector array Ω_β, Ω_{ion} each 3%

COMPLETE

Ion beam 30 ions/sec (for ^{137}I, near mass peak)

Intermediate step… (existing trap)

Increase both Ω_β, Ω_{ion} to 10% with optimized detectors

→ coinc. eff.: ×12

Data collection to begin soon

Still weak ion beams… but offline so can collect statistics for months…

Several isotopes accessible…

…at CARIBU (new trap!)

Increase both Ω_β, Ω_{ion} to 20% with optimized detector array

→ coinc. efficiency: ×40

High-quality data with ion beams of 0.1-1 ion/sec

→ reach very exotic nuclei: r-process, nuclear structure, etc.

2013

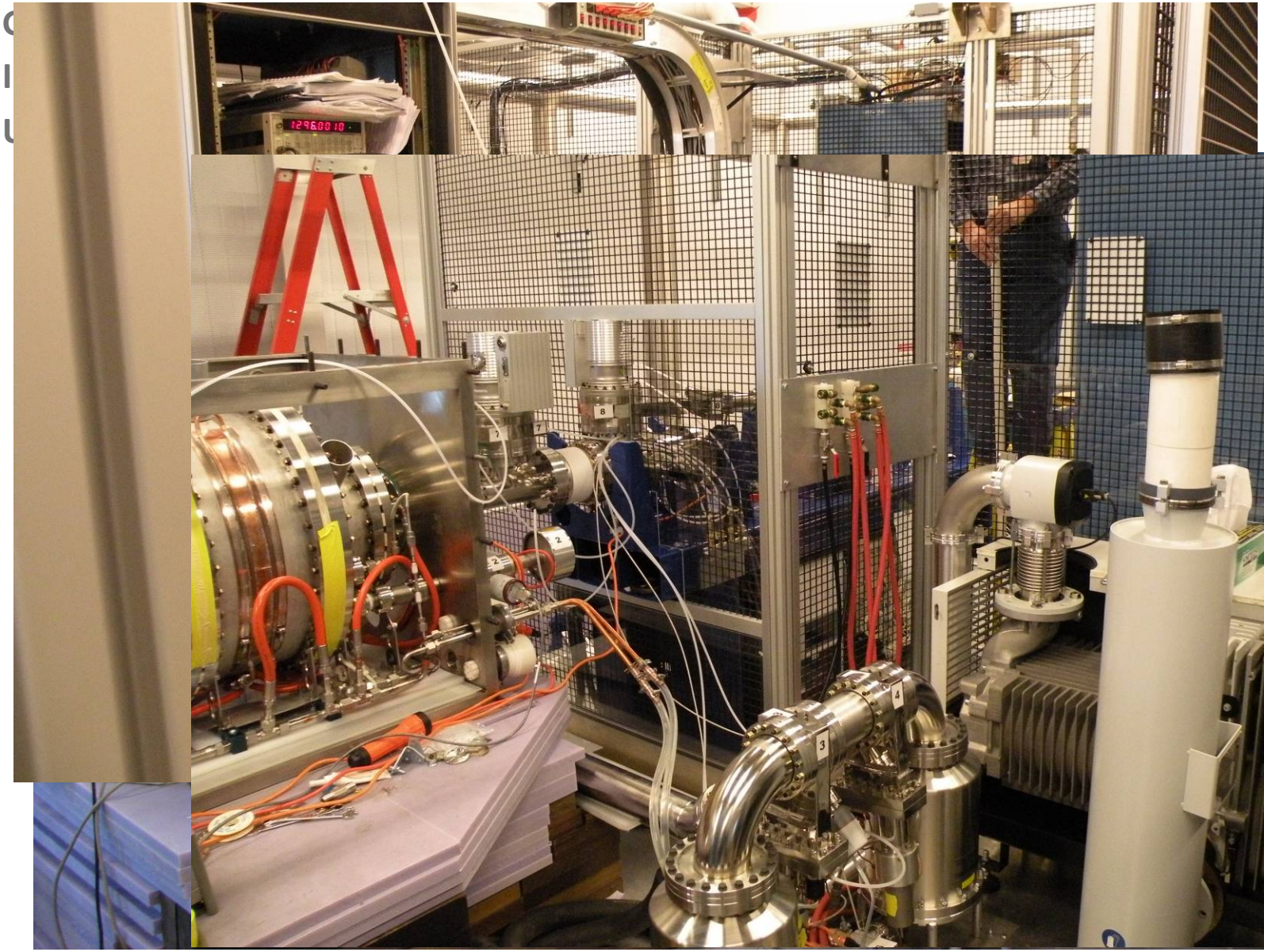
CARIBU 1-Ci source: 4×10^6 ions/sec (for ^{137}I at low-energy beamline)

High statistics for precision and systematic checks

→ nuclear energy, stockpile stewardship, etc.

From Demonstration to CARIBU

Proof-of-principle…	…at CARIBU
Detector array Ω_β, Ω_{ion} each 3%	Increase both Ω_β, Ω_{ion} to 10-20% with optimized detector array → coinc. efficiency: ×40
	High-quality data can be obtained with ion beams of ~1 ion/sec → can reach very exotic nuclei: r-process, fuel cycle, etc.
Ion beam 30 ions/sec (for ^{137}I, near mass peak)	CARIBU 1-Ci source: 4×10^6 ions/sec (for ^{137}I at low-energy beamline)
	High statistics for precision measurements and systematic checks: nuclear energy, stockpile stewardship, etc.

The very large high-intensity gas catcher for CARIBU

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