



# FRIB DAY 1: Decay Spectroscopy Near $N=28$ Shell Structure

MacMillan Wheeler, Vandana Tripathi, Ryan Tang, Caleb Benneti, Soumik Bhattacharya, Samuel Tabor, Samuel Ajayi, Catur Wibisono, Sameul Tabor, Calib Benetti

Department of Physics, Florida State University

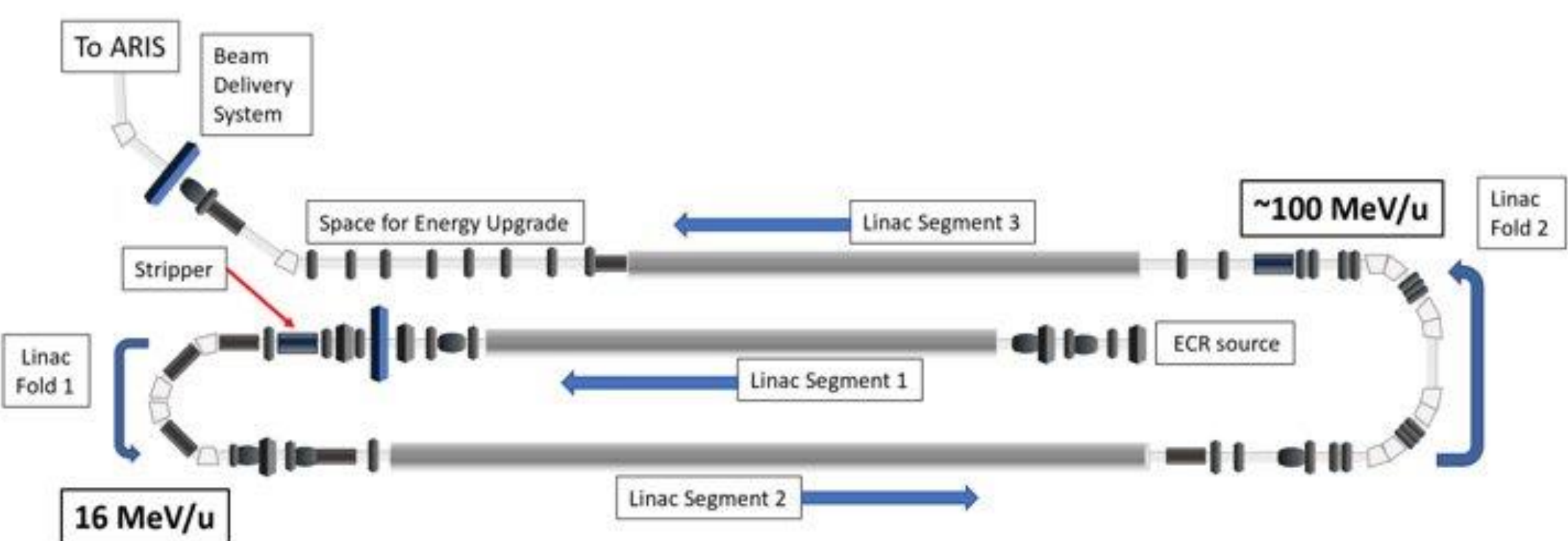
&

FDSi collaboration

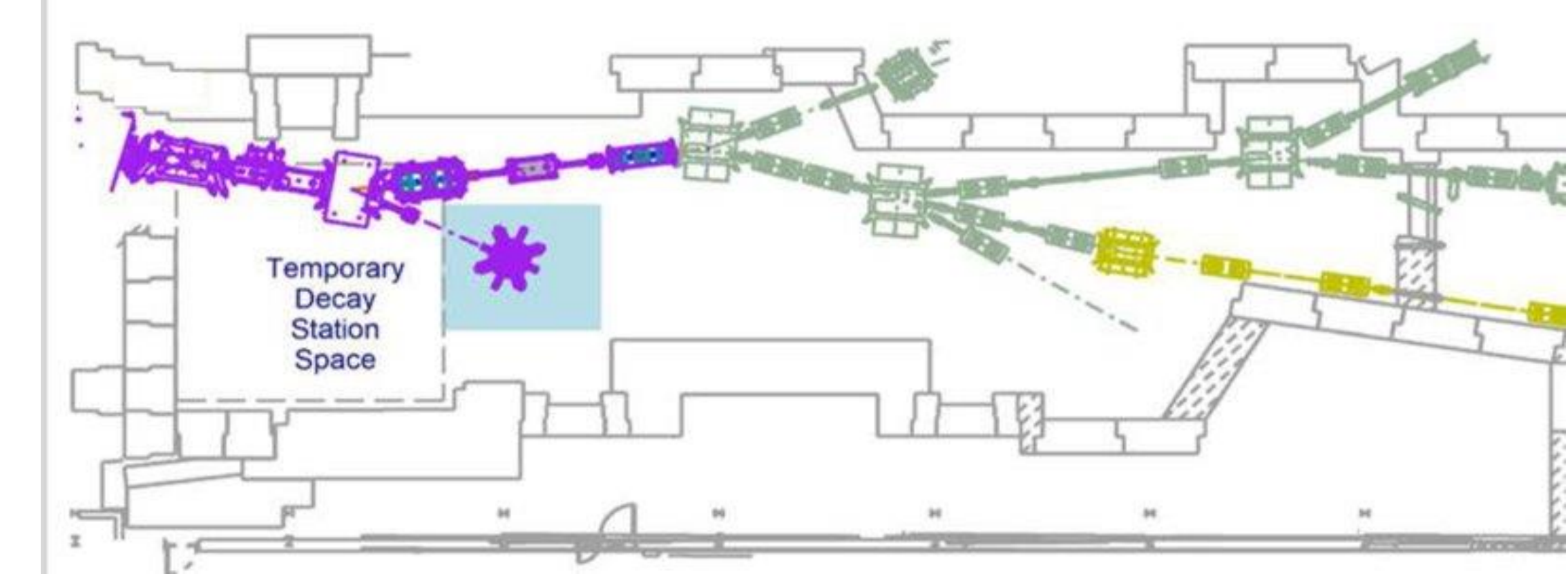


## FRIB Decay Station Initiator

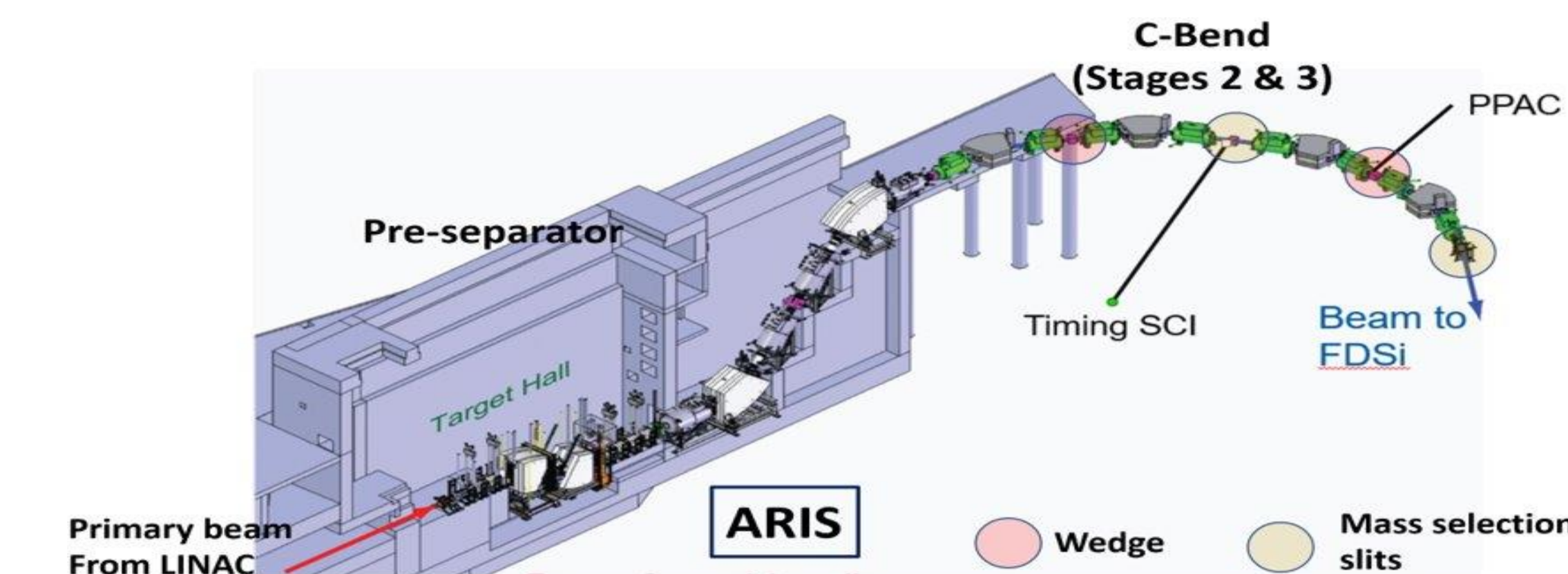
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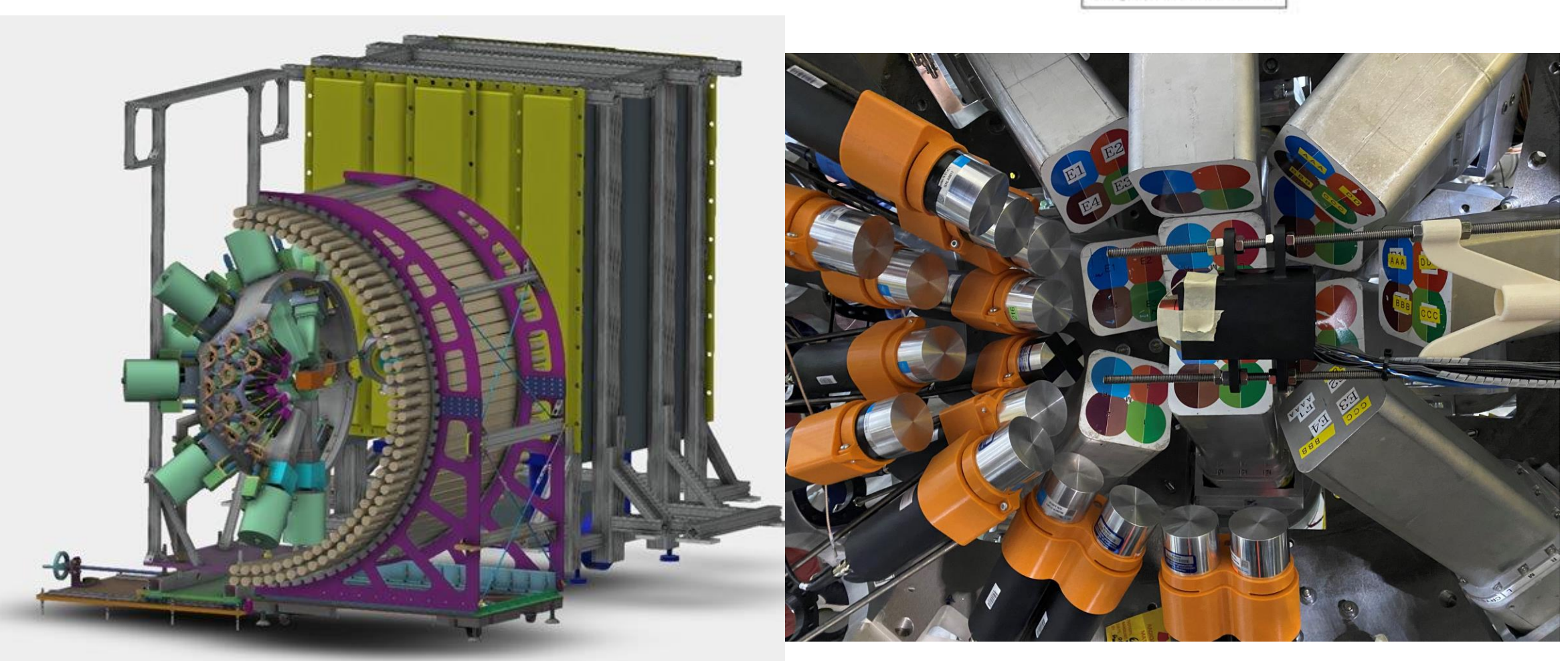
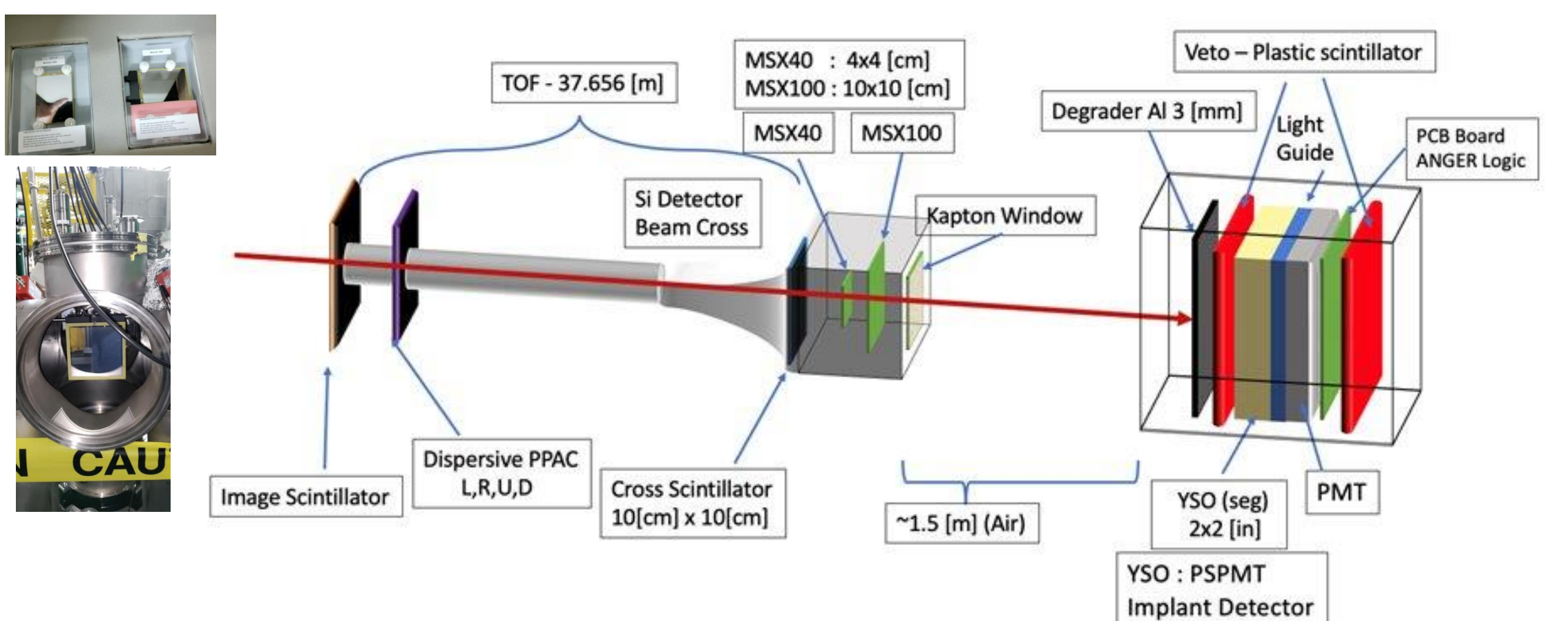
### Experimental Area at FRIB



### Fragment Selector: ARIS

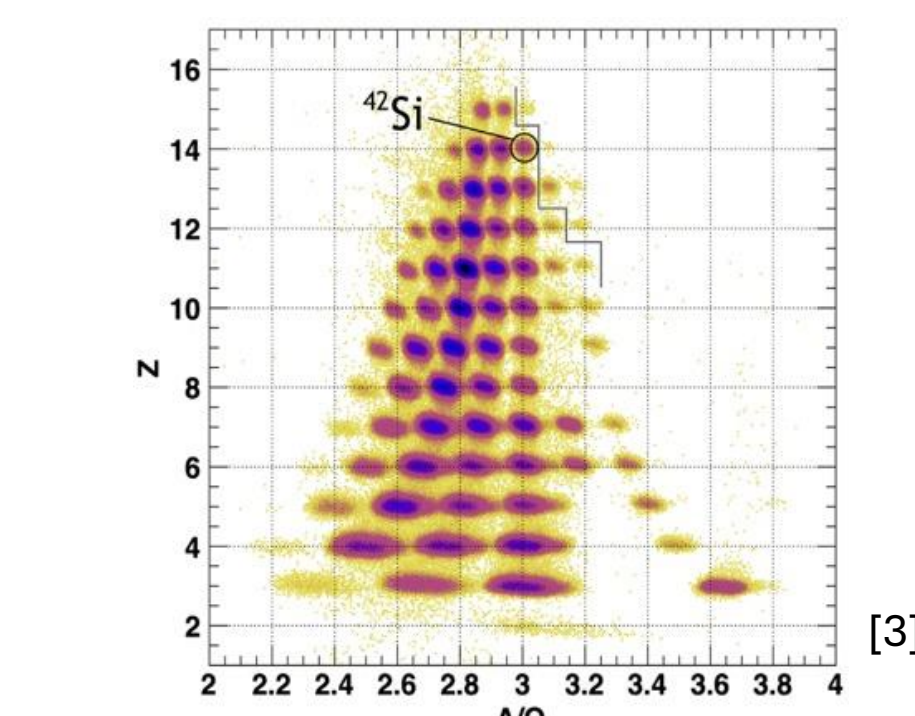


### Particle Identification (PID) & Fragment $\beta$ - $\gamma$ Correlation



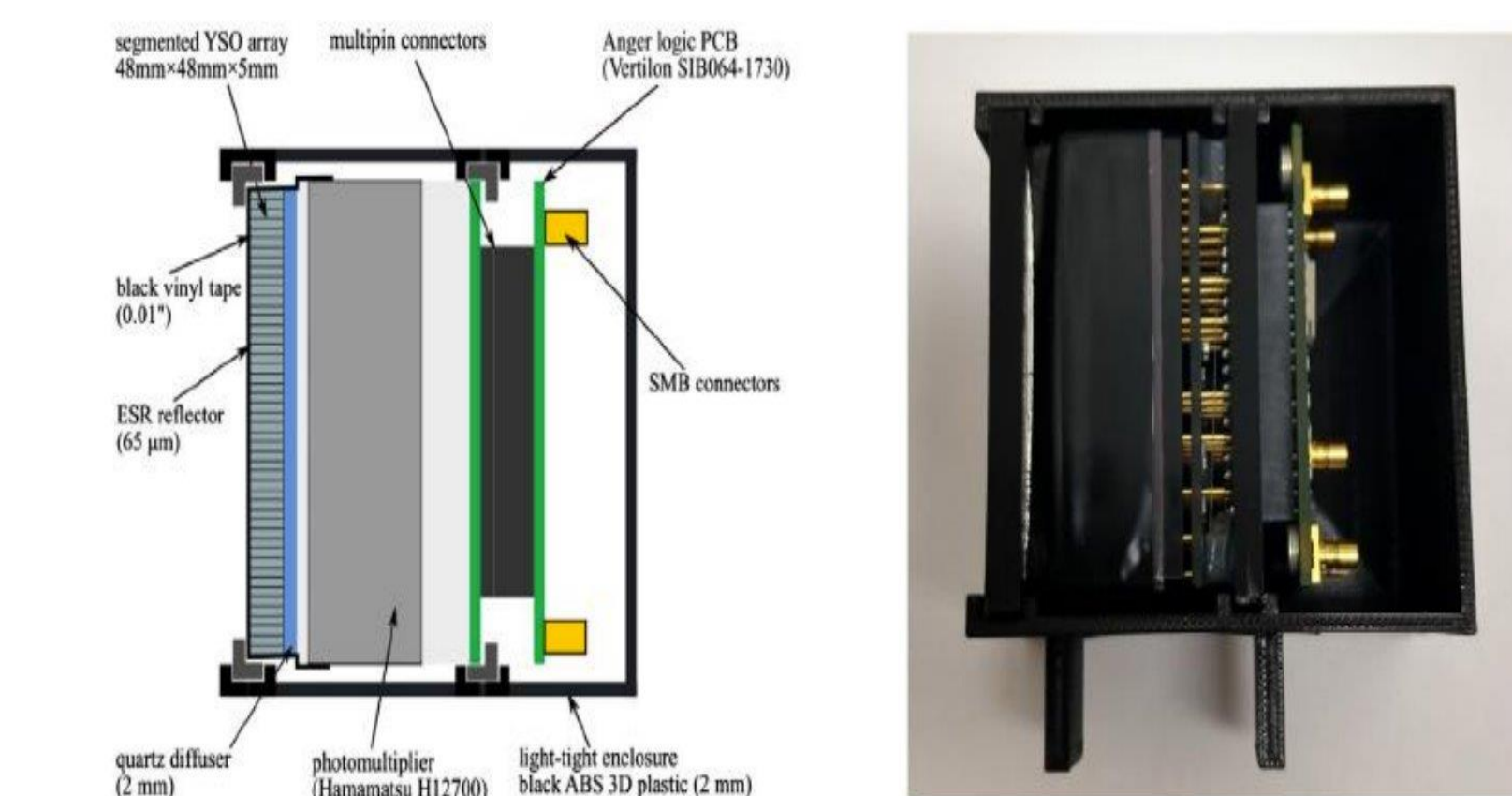
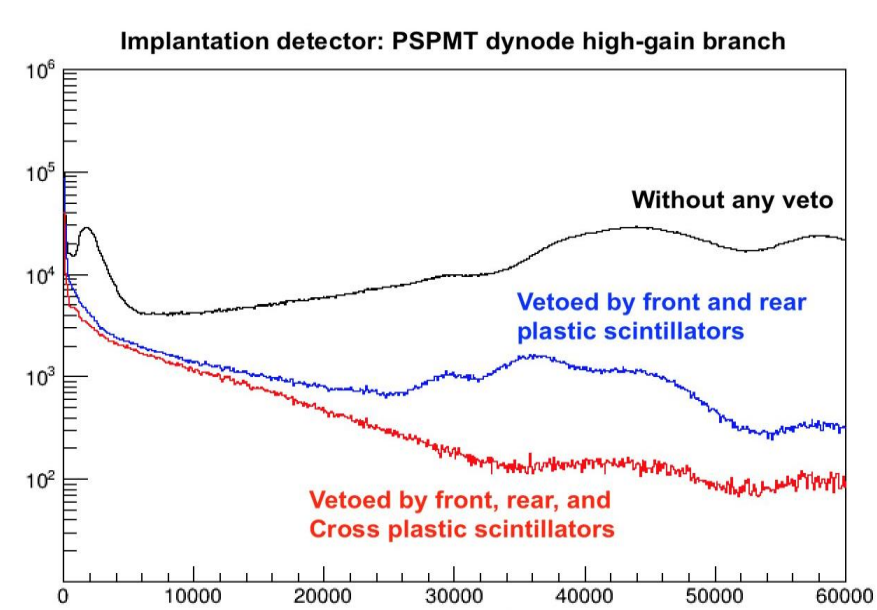
### PID

- Fragmentation of  $^{48}\text{Ca}$  on  $^9\text{Be}$
- Time of flight (A/Q); image scintillator to cross scintillator.
- $\Delta\text{Energy}$  (Z): The MX100 or MX40.



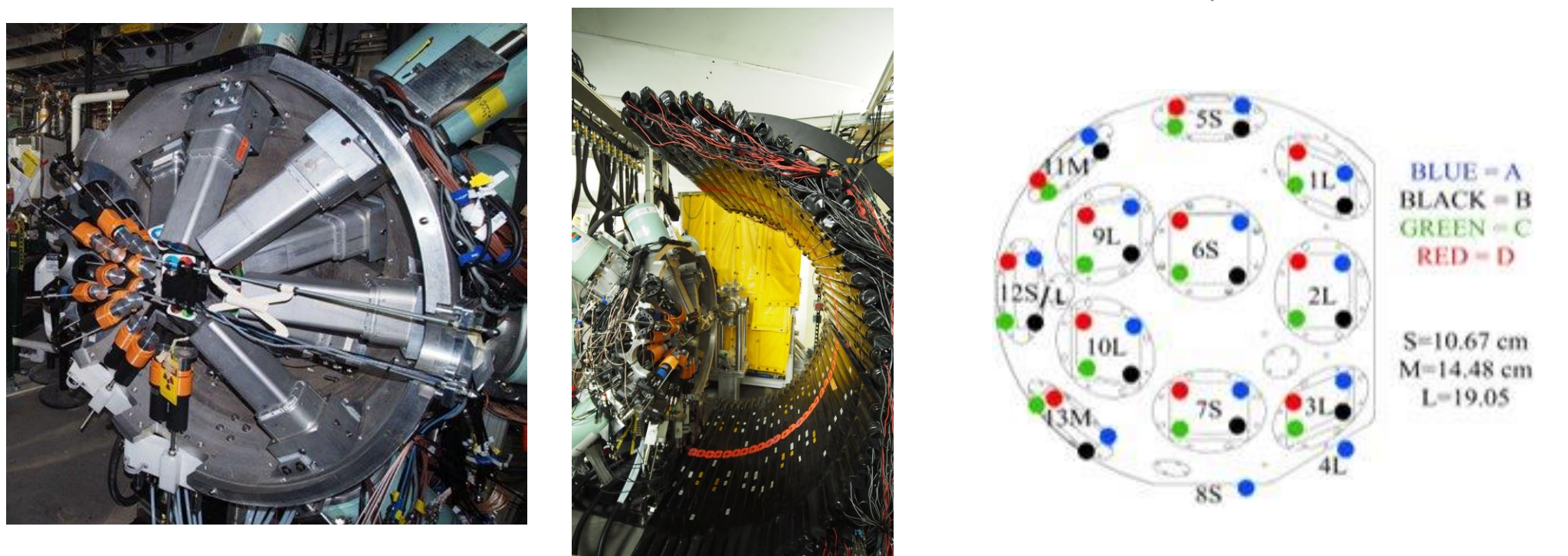
### $\text{Y}_2\text{SiO}_5\text{:Ce}$ Scintillator crystal (YSO)

- The YSO is 1mm x 1mm. The crystal is segmented into 48x 48 pixels. This is coupled with a 64 anode Position Sensitive Photomultiplier Tube (PSPMT) which allows the calculation of the x and y positions.
- Has 4 high gain anodes and 4 low gain anodes. The high gain anodes detect the betas and the low gain detect the Implants.
- High Z and therefore, high stopping power compared to Double-sided silicon-strip detectors(DSSD).
- Two veto detectors before and after the YSO for more accuracy in determining the Implants and betas.
- Greater Efficiency and timing response than the DSSD[1].



### Clover Detector Array

- The Clover has four N-type Germanium-detectors
- Used to detect  $\gamma$  rays emitted following  $\beta$  decay.
- Has high photopeak efficiency and resolution[2].
- Allows for implant gamma correlations with the YSO



## Crossing $N=28$ Toward the Neutron Drip Lin: First Measurement of Half-Lives at FRIB[3]

- The decay curves were made from the time difference of the Implant and the beta particle.
- A fit of the curve was used to find the timeline of the implant, its daughter and potential  $\beta n$  and  $\beta 2n$  decay branches.
- Elements with the same neutron excess but with a lower Z, have shorter half-lives.
- The measurements show a half-life plateau at the  $N=28$  and a sudden dip for  $^{36}\text{Mg}$ .

TABLE I. Correlation statistics and the deduced half-lives for the neutron-rich isotopes studied in the present Letter. Correlated decays include multiple generations of decays and all  $\beta$ -delayed neutron branches.

Nuclide	Parent nuclei statistics		Fit assumptions		$T_{1/2}$ (ms)	Previous
	Implants	Correlated decays	$P_{\text{beta}}$ (%)	$T_{1/2}^{\text{beta}}$ (ms)		
$^{44}\text{P}$	5116	6427	24/55/21	100/265/1013	18.8(8) <sub>stat</sub> (15) <sub>sys</sub>	18.5(2.5) <sup>a</sup> [5,6]
$^{45}\text{P}$	159	188	0/79/21 <sup>c</sup>	68/100/265	24(7) <sub>stat</sub> (9) <sub>sys</sub>	...
$^{42}\text{Si}$	11419	18495	51/48/1	48.5/101/150	15.5(4) <sub>stat</sub> (16) <sub>sys</sub>	12.5(3.5) <sup>a</sup> [6]; 20(10) [15]
$^{43}\text{Si}$	63	99	27/52/21	36.5/48.5/101	13(4) <sub>stat</sub> (2) <sub>sys</sub>	...
$^{40}\text{Al}$	53436	95511	3/94/3 <sup>b</sup>	47.5/63/90	7.22(8) <sub>stat</sub> (30) <sub>sys</sub>	7.6(1.6) <sup>a</sup> [6]; 8(2) [15]
$^{41}\text{Al}$	1632	2824	16/64/20 <sup>c</sup>	33/47.5/63	5.7(3) <sub>stat</sub> (4) <sub>sys</sub>	...
$^{37}\text{Mg}$	1027	2055	27/57/16	10.7/90/38.2	6.4(4) <sub>stat</sub> (14) <sub>sys</sub>	8(4) <sup>a</sup> [15]
$^{38}\text{Mg}$	265	556	9/81/9	9.0/10.7/90	3.1(4) <sub>stat</sub> (2) <sub>sys</sub>	1.5(5) <sup>b</sup> [17]
$^{39}\text{Na}$	377	813	14/73/10	11.3/20/92	2.4(3) <sub>stat</sub> (2) <sub>sys</sub>	3.5(9) <sup>b</sup> [18]
$^{32}\text{Ne}$	652	1449	21/75/4	13.2/17.4/48	4.5(4) <sub>stat</sub> (6) <sub>sys</sub>	2.5(3) <sup>b</sup> [13]
$^{29}\text{F}$	899	2104	40/50/10 <sup>c</sup>	14.7/18.8/30.9	3.4(4) <sub>stat</sub> (1) <sub>sys</sub>	...

<sup>a</sup>Corresponds to the adopted half-life value [13].  
<sup>b</sup> $P_{\text{beta}}$  include experimental constraints:  $P_{\text{beta}}^{\text{expt}}$  for  $^{39}\text{Na}$ ,  $^{38}\text{Mg}$ , and  $^{29}\text{F}$  are 97(22)%, 48(12)%, and 60(40)%, respectively [13].  
<sup>c</sup> $P_{\text{beta}}$  include experimental constraints from lighter isotopes:  $P_{\text{beta}}^{\text{expt}}$  for  $^{45}\text{P}$ ,  $^{40}\text{Al}$  and  $^{41}\text{Al}$  are 100% (from  $^{45}\text{P}$ ), 84(19)% (from  $^{40}\text{Al}$ ) and 97(22)% (from  $^{41}\text{Al}$ ), respectively [13].

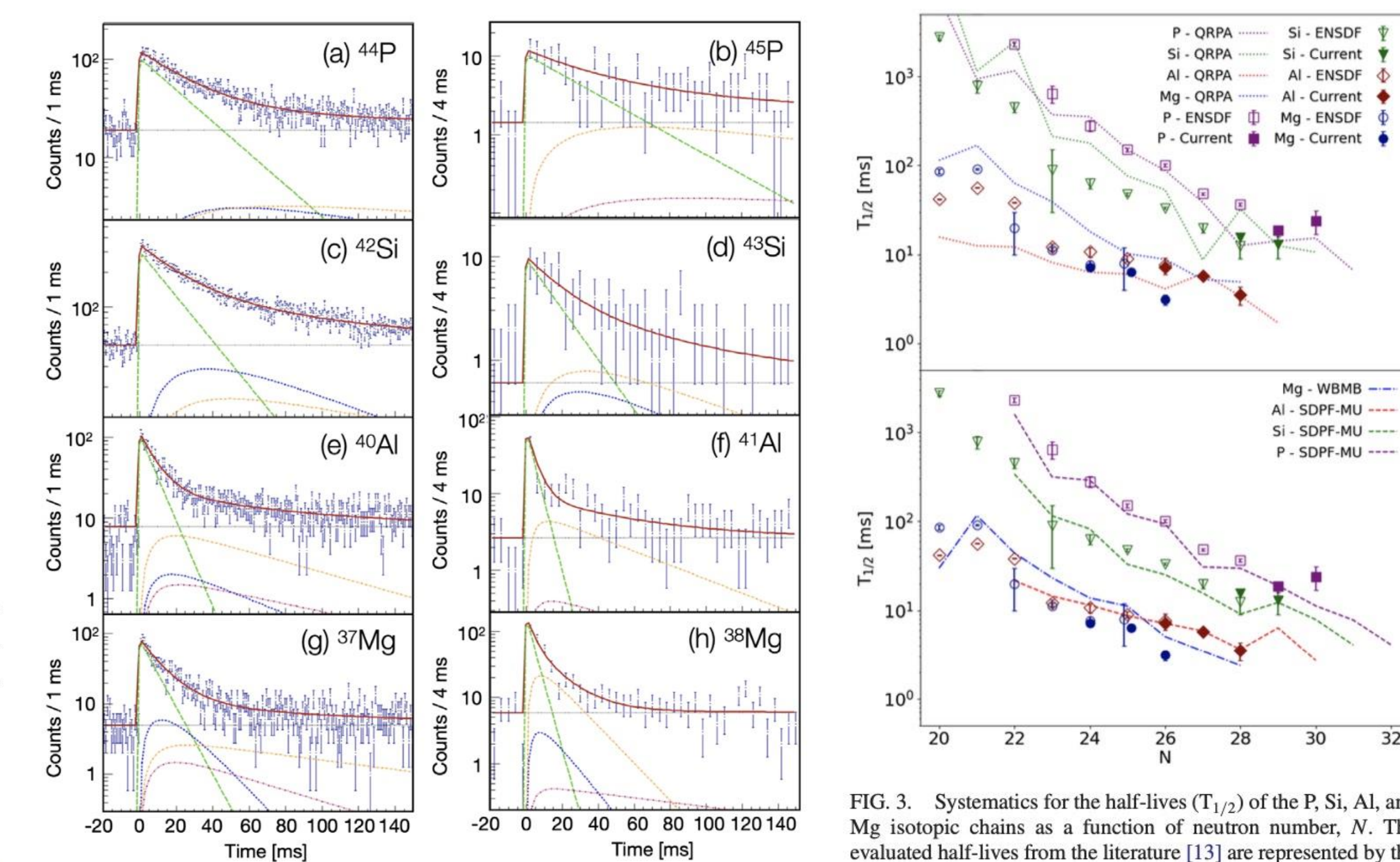
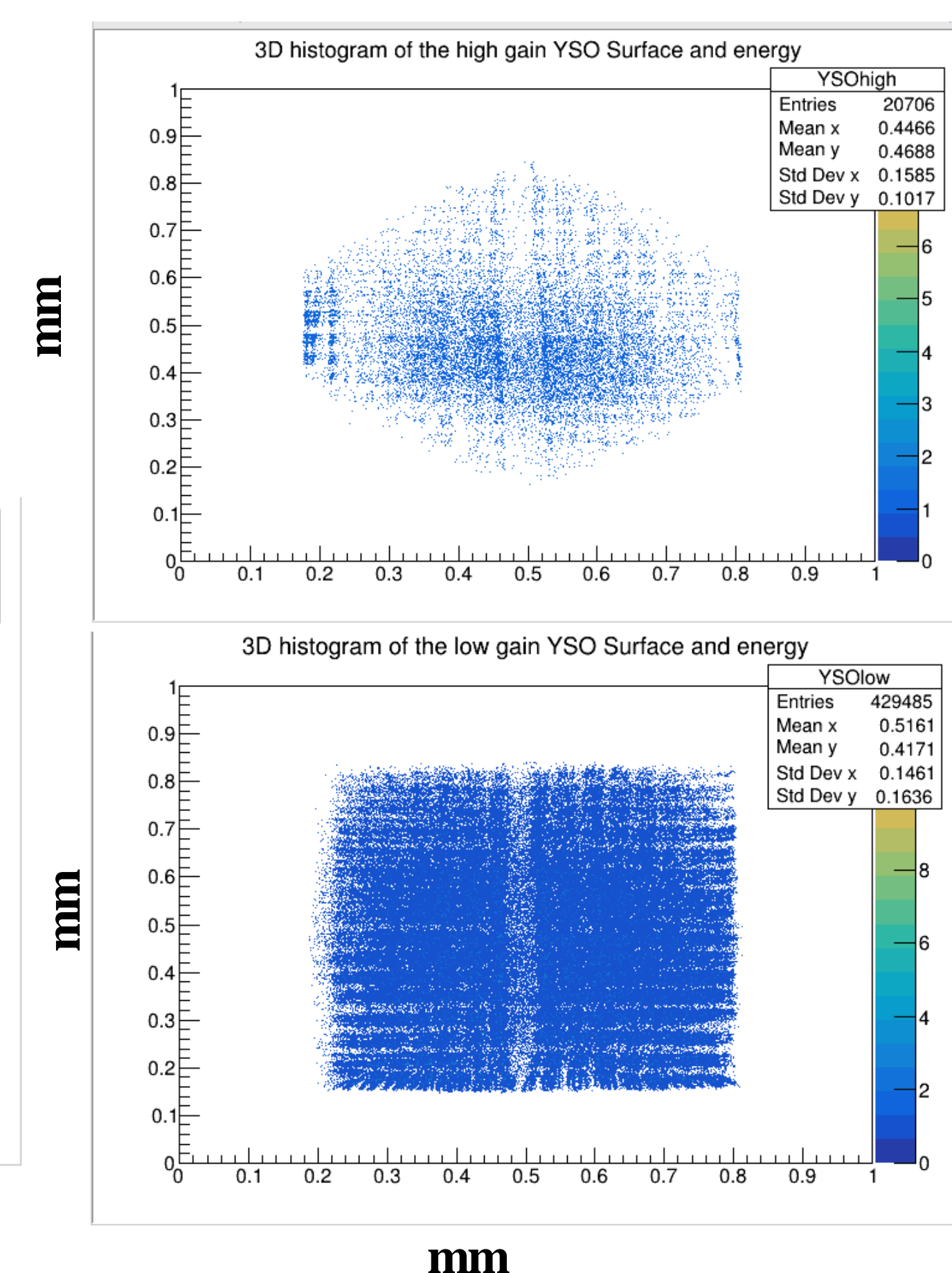
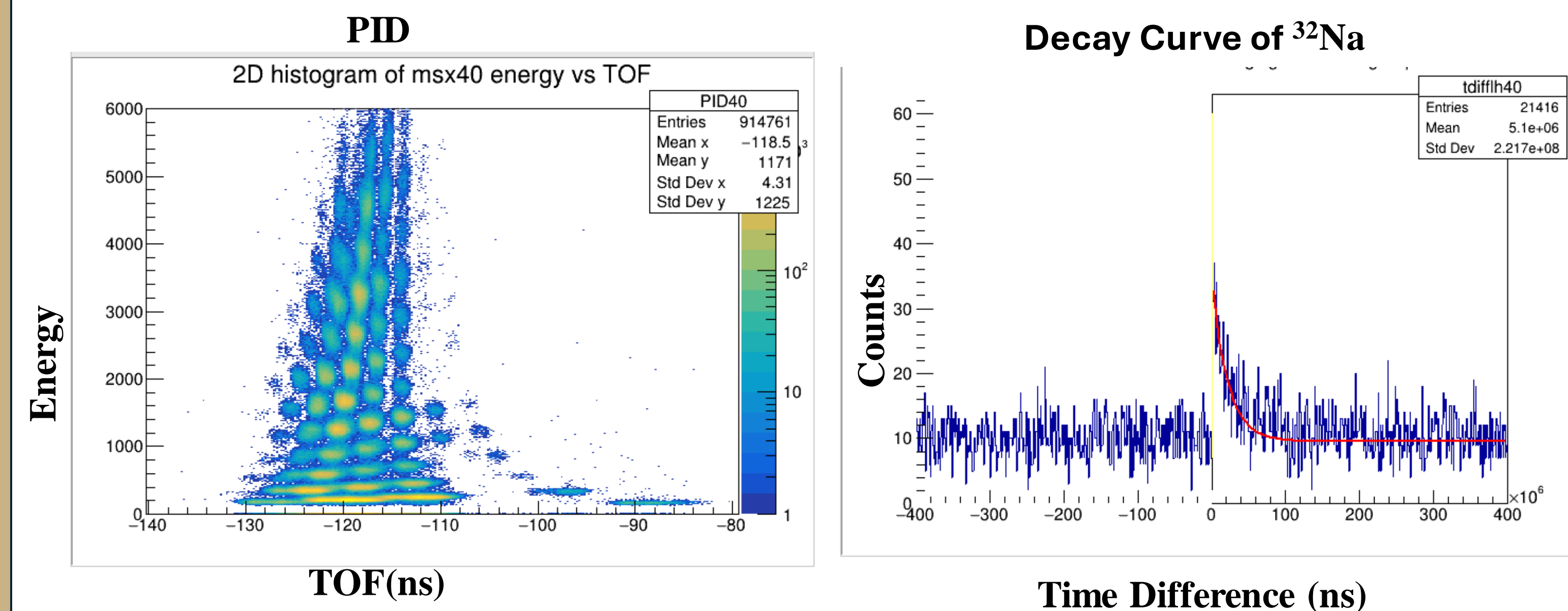


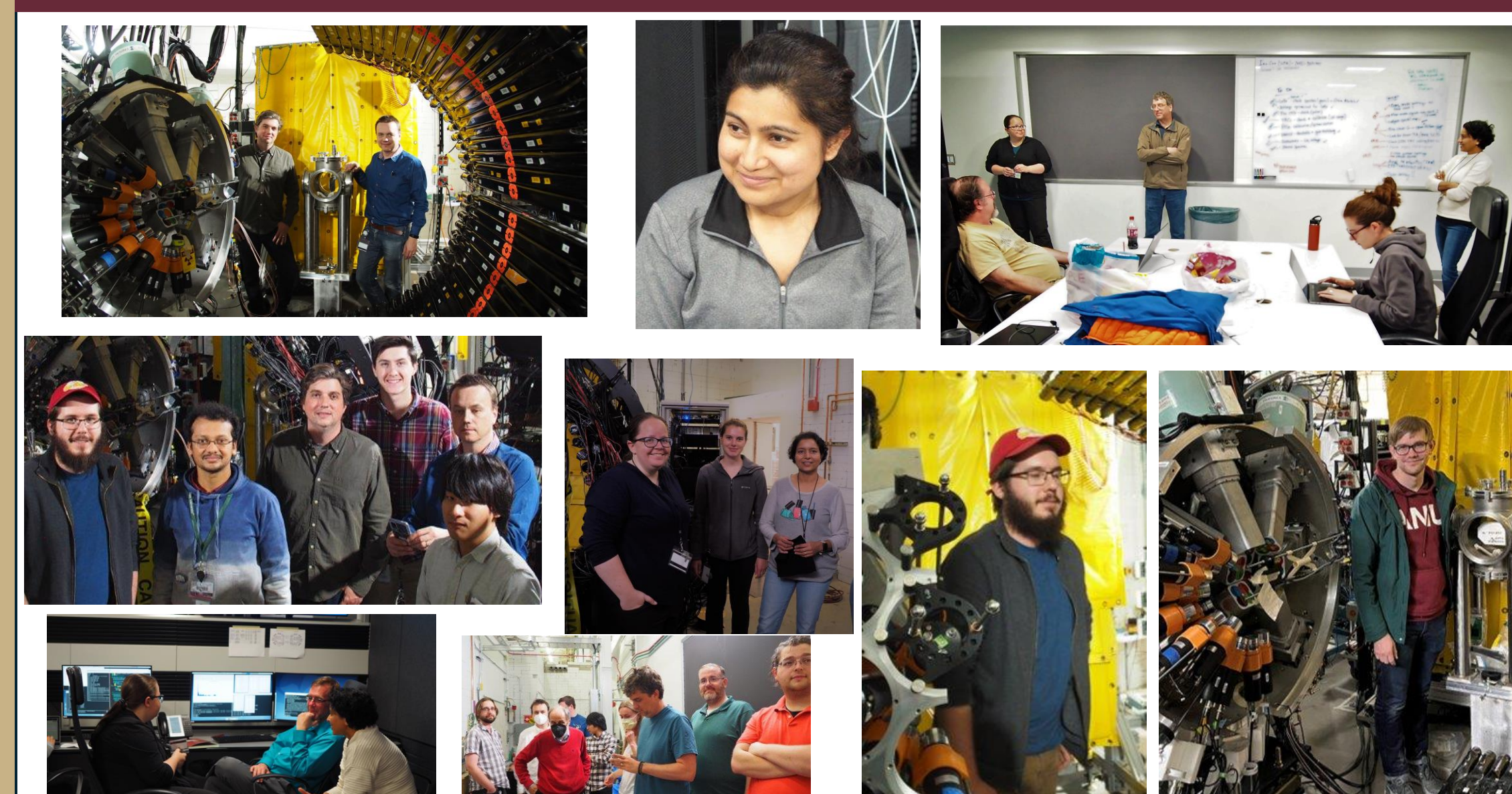
FIG. 2. Decay curves in panels (a)–(h) for  $^{44,45}\text{P}$ ,  $^{42,43}\text{Si}$ ,  $^{40,41}\text{Al}$ , and  $^{37,38}\text{Mg}$  respectively. The components of the fits are shown by the curves, where the solid red line is the total fit, the green dashed curve is the parent decay, the dot-dash blue line is the  $\beta n$  daughter contribution, the dot-dash orange line is the  $\beta 1n$  contribution, the dot-dot-dot-dash magenta line is the  $\beta 2n$  contribution, and the dotted gray line is the constant background. The derived half-lives are included in Table I.

### Work in Progress

- Exp 21062B will be run in February –March 2024 with 10KW beam power
- Fragmentation,  $^{48}\text{Ca}$  on  $^9\text{Be}$  ( $^{12}\text{C}$ ) will be used to produce the most exotic isotopes with  $N \sim 28$ .
- The FSU group will focus on the decay of exotic Si and P isotopes. Thesis project of Mac Wheeler
- Analysis examples from the data collected in May 2022



### The FDSi team!



### References

- M. Singh R. Yokoyama et al. Segmented YSO scintillation detectors as new  $\beta$ -implant detection tool for decay spectroscopy in fragmentation facilities. Nucl. Instrum. Methods Phys. Res., Sect., A 937:93, 2019.
- A.S. Medhi S. Chattopadhyay S. Bhattacharya A. Goswami P.K. Joshi, H.C. Jain. Study of the characteristics of a clover detector. Nucl. Instrum. Methods Phys. Res., Sect., A 399:51–56, 1997.
- H. L. Crawford, V. Tripathi et al. Crossing  $n=28$  Toward Neutron Drip Line: First Measurement of Half-Lives at FRIB. Physical Review Letters, 129(21):212501, 2022.

### Thank you Sponsors!

