



Structure of ^{13}Be and exotic decays in ^{13}O

Grigory Rogachev

*Cyclotron Institute and
Department of Physics & Astronomy*

Outline

Exotic decays of ^{13}O

Structure of ^{13}Be

Acknowledgements

Texas A&M U, College Station USA: E. Aboud (now at **LLNL**), M. Barbui, J. Bishop (now at **Birmingham**), C. Hunt (now at **FRIB**), C. Parker, E. Koshchiy, B. Roeder, M. Roosa, D. Scriven, A. Saastamoinen, S. Upadhyayula (now at **TRIUMF**)

IRFU, CEA, Saclay, France: E.C. Pollacco

EWHA Womans U, Seoul, Republic of Korea: Se Young Han

CENS, Daejeon, Republic of Korea: Insig (Kevin) Khan, S. Ahn, C.M. Cha, D. Kim,

Sungkyunkwan University, Suwon, Republic of Korea: S.H. Kim

TRIUMF, Vancouver, Canada: M. Alcorta

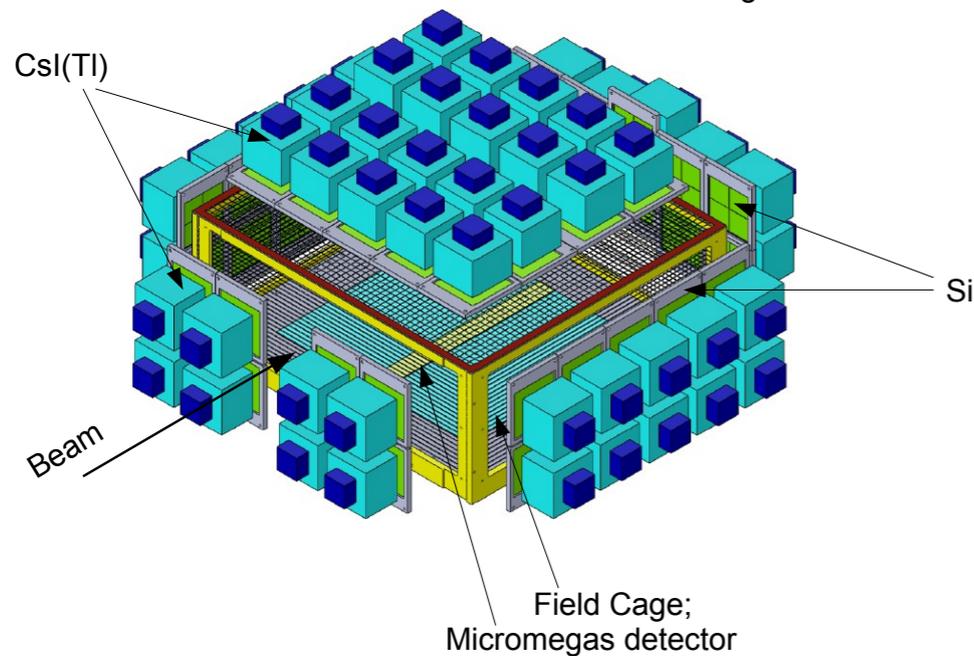
Florida State U, Tallahassee, USA: A. Volya



Texas Active Target

E. Koshchiy, et al., NIM A 957 (2020) 163398

Detectors: Si (58 total);
CsI(Tl) (58 total);
Micromegas: 1024 channels



- Resonance Elastic Scattering
 - ✓ $^8\text{B}+p$ - J. Hooker, et al., PRC (2019)
 - ✓ $^{14}\text{O}+\alpha$ - M. Barbui, et al., PRC (2022)
 - ✓ **$^{12}\text{Be}+p$ - C. Hunt, et al., PRC Lett. (sub)**
 - ✓ $^{10}\text{C}+\alpha$ - analysis
 - ✓ $^9\text{Li}+p$ - D. Scriven, analysis
- β -delayed charged particle emission
 - ✓ ^{12}N - J. Bishop, et al., PRC (2020); J. Bishop, et al., PRC Lett. (2021)
 - ✓ **^{13}O - J. Bishop, et al., PRL (2023)**
- Neutron beams
 - ✓ $^{12}\text{C}(n,n')\text{Hoyle}$ - J. Bishop, et al. Nature Comm. (2022)
 - ✓ $^{16}\text{O}(n,\alpha)^{13}\text{C}$ - analysis
- Transfer reactions
 - ✓ $^6\text{He}(p,t)$ - C. Parker, analysis
 - ✓ **$^{12}\text{Be}(d,^3\text{He})$ - M. Roosa, Poster 83**
- Charge exchange
 - ✓ $^9\text{Li}(p,n)$ - A. Alafa, analysis
- Fusion
 - ✓ $^8\text{B}+^{40}\text{Ar}$ - J. Zamora, et al., PLB (2021)
- (α,p) for astrophysics
 - ✓ $^{14}\text{O}(\alpha,p)$ - S. Ahn, analysis



C. Hunt

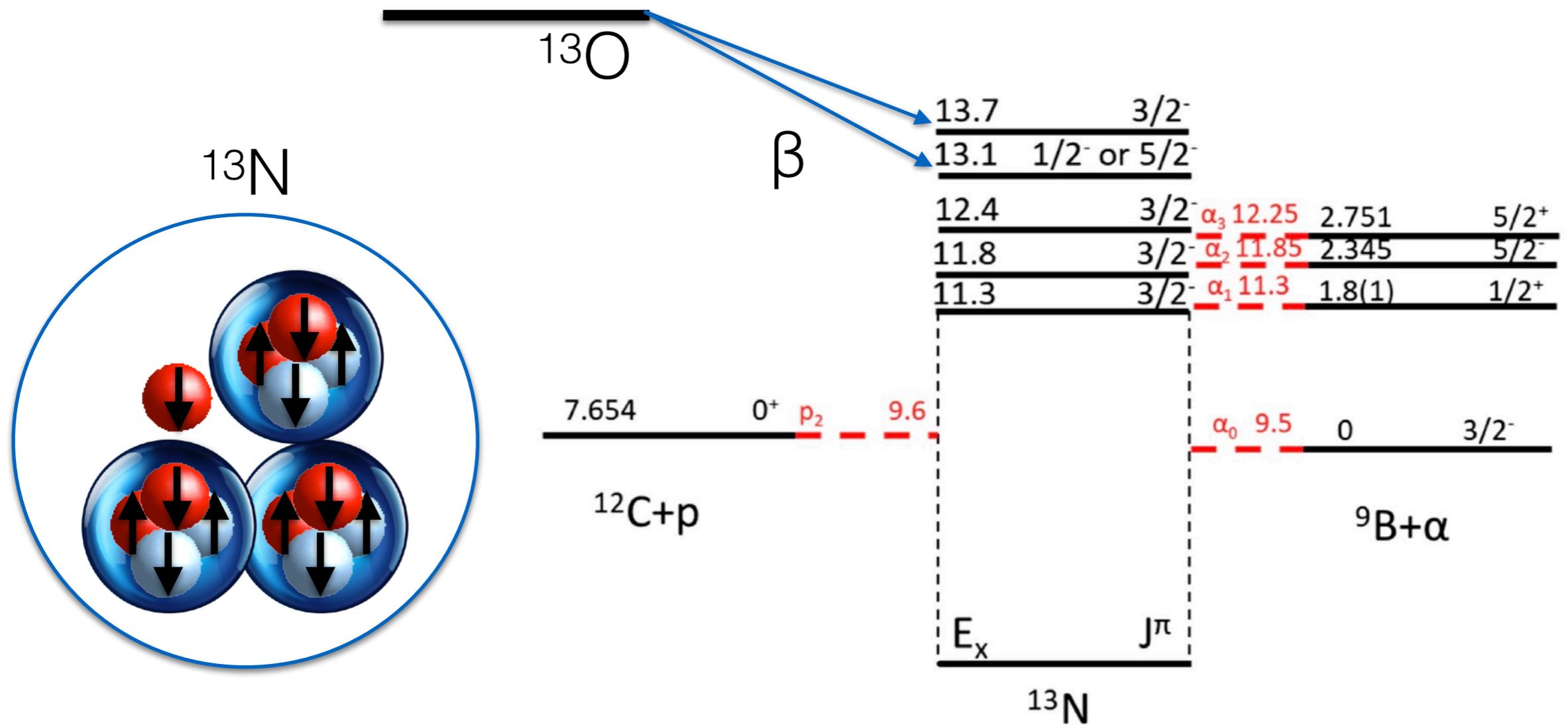


J. Bishop

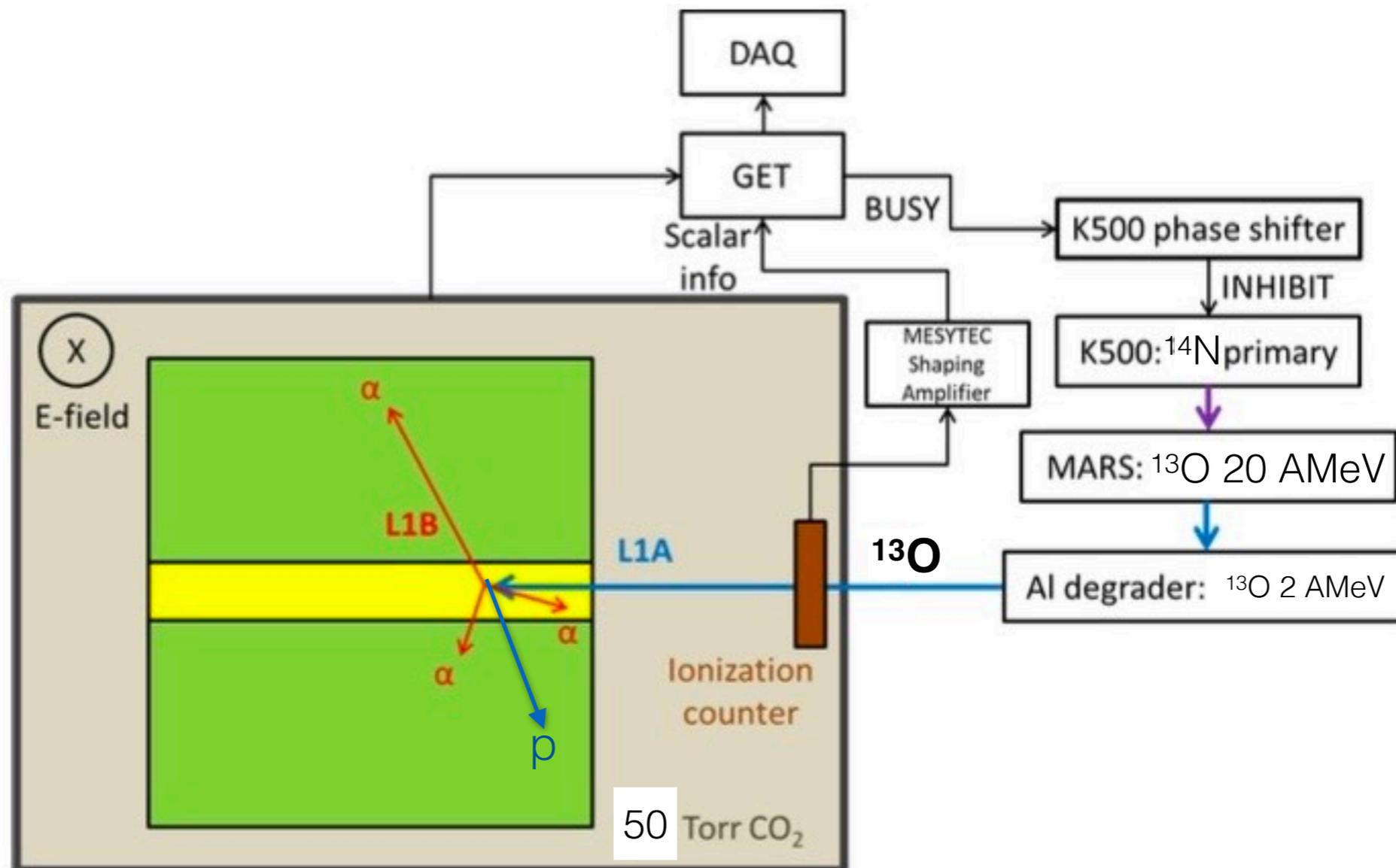


Exotic decays of ^{130}O

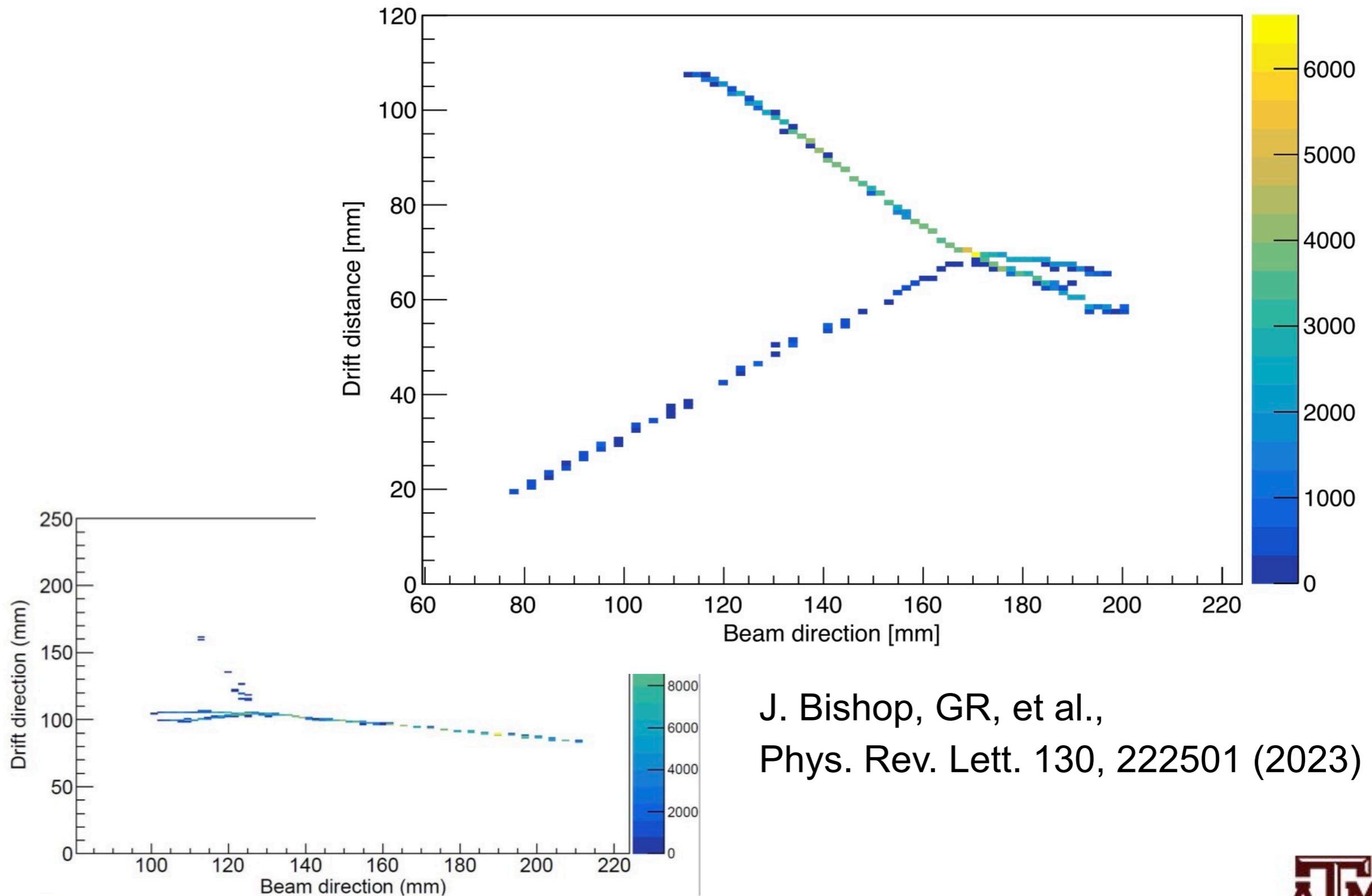
Search for exotic $\beta 3\alpha p$ decay of ^{13}O



- TAMU Cyclotron Institute
- ^{13}O from $^3\text{He}(^{14}\text{N}, ^{13}\text{O})$ reaction, MARS
- Slowed down by Al degrader to 2 MeV/u
- Stopped by 50 Torr of CO_2 in TexAT
- 2p GET mode: L1A, L1B trigger



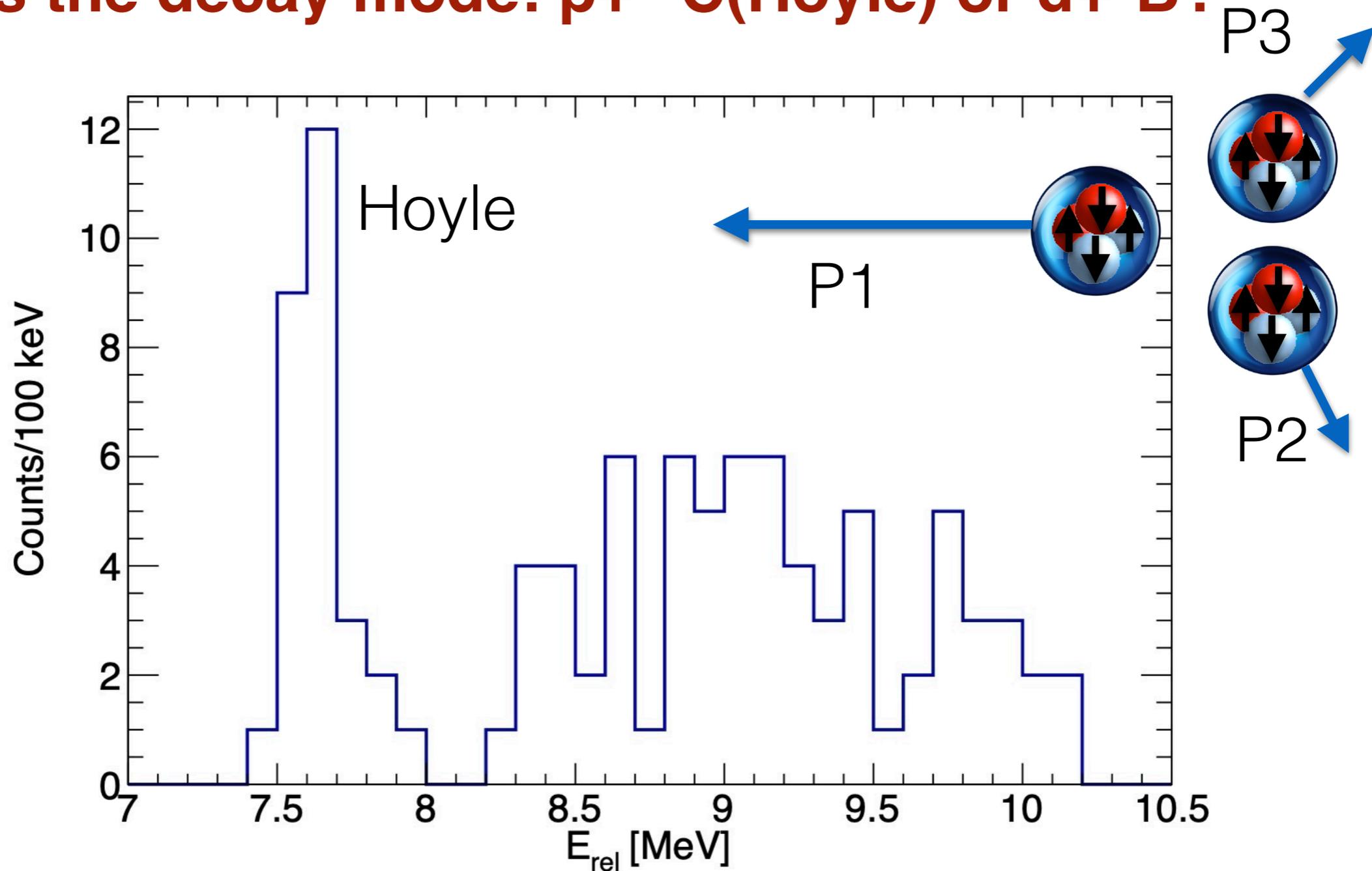
149 $\beta 3ap$ events were observed - $7.8(6) \times 10^{-4}$ BR



J. Bishop, GR, et al.,
Phys. Rev. Lett. 130, 222501 (2023)



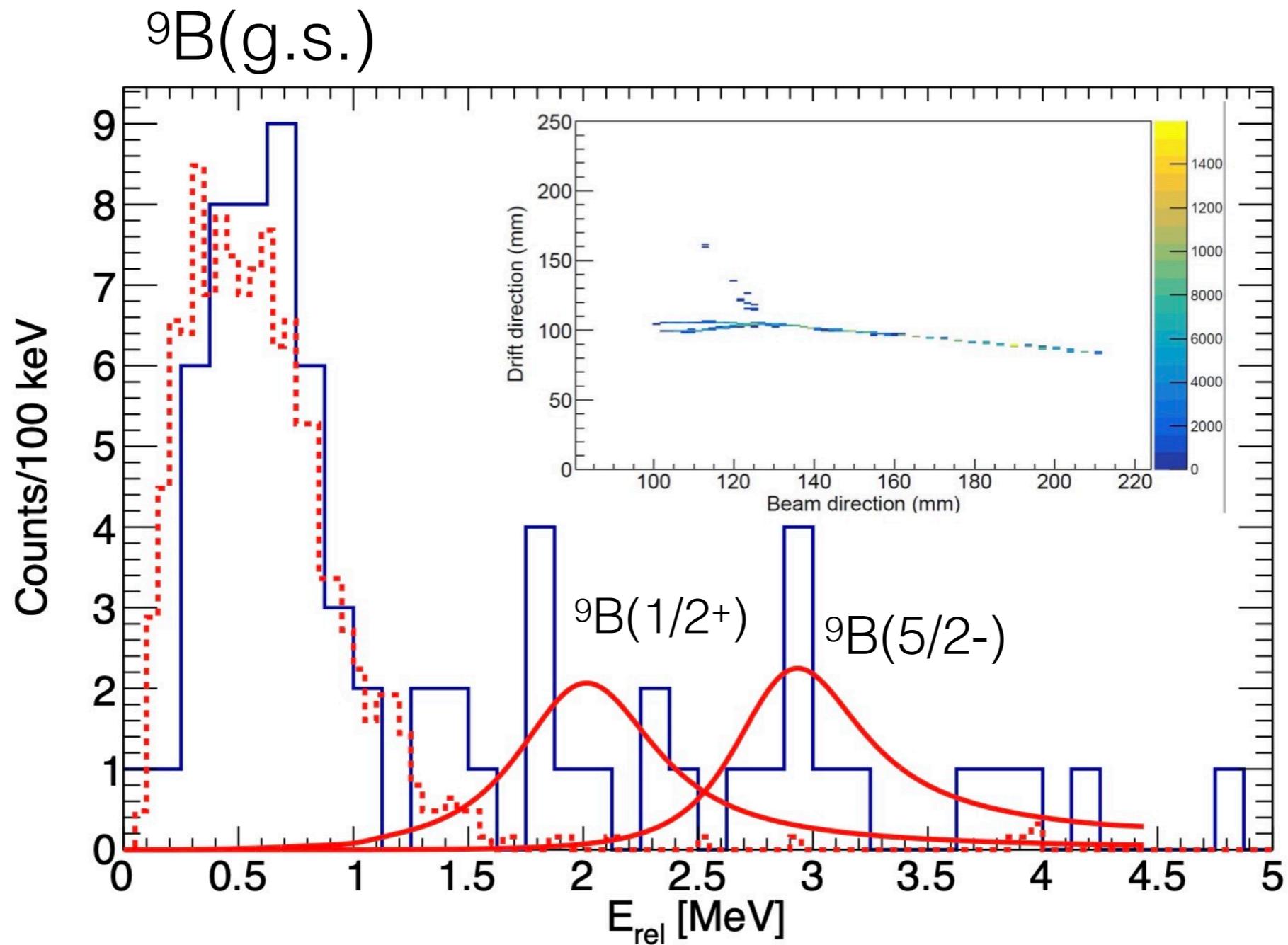
What is the decay mode: $p+^{12}\text{C}$ (Hoyle) or $\alpha+^9\text{B}$?



Invariant mass of $3\alpha + 7.276$ MeV (3α threshold in ^{12}C)

J. Bishop, GR, et al., Phys. Rev. Lett. 130, 222501 (2023)



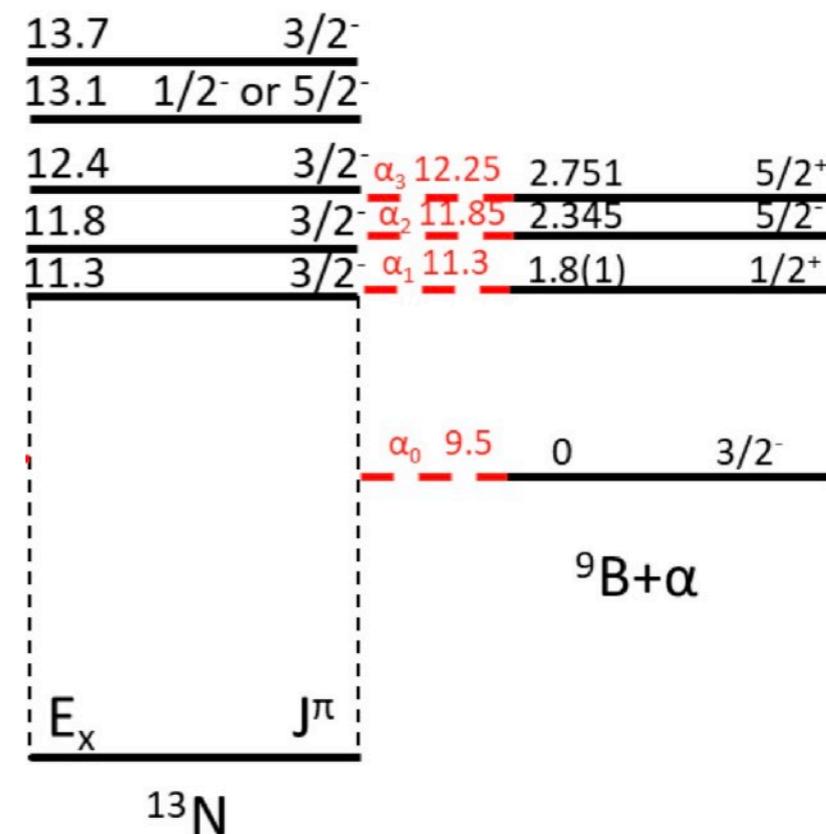
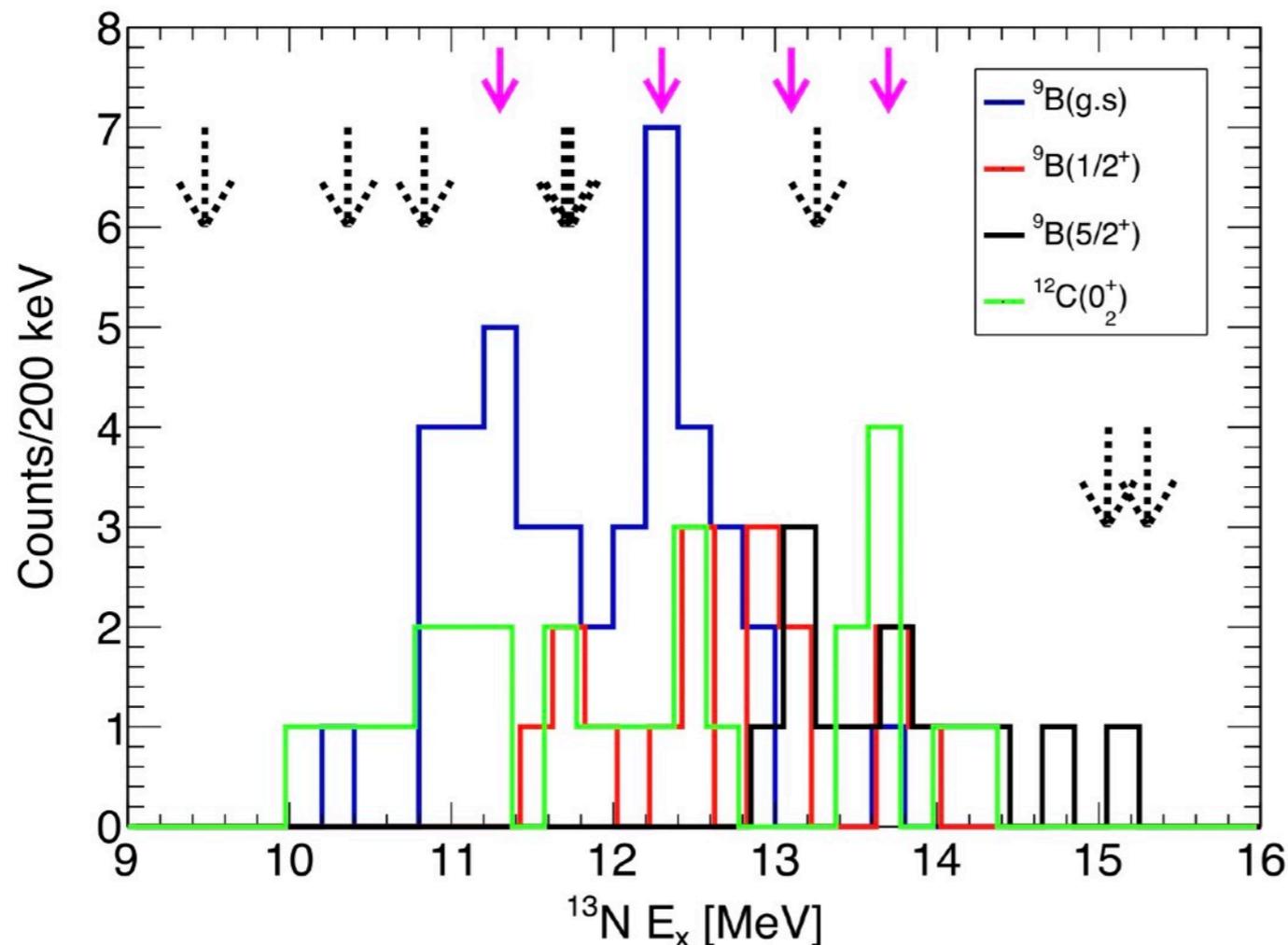


The sum of the lowest energy two $\alpha + p$
gated on non-Hoyle decays

J. Bishop, GR, et al., Phys. Rev. Lett. 130, 222501 (2023)



Spectrum of ^{13}N from $\beta^3\text{ap}$



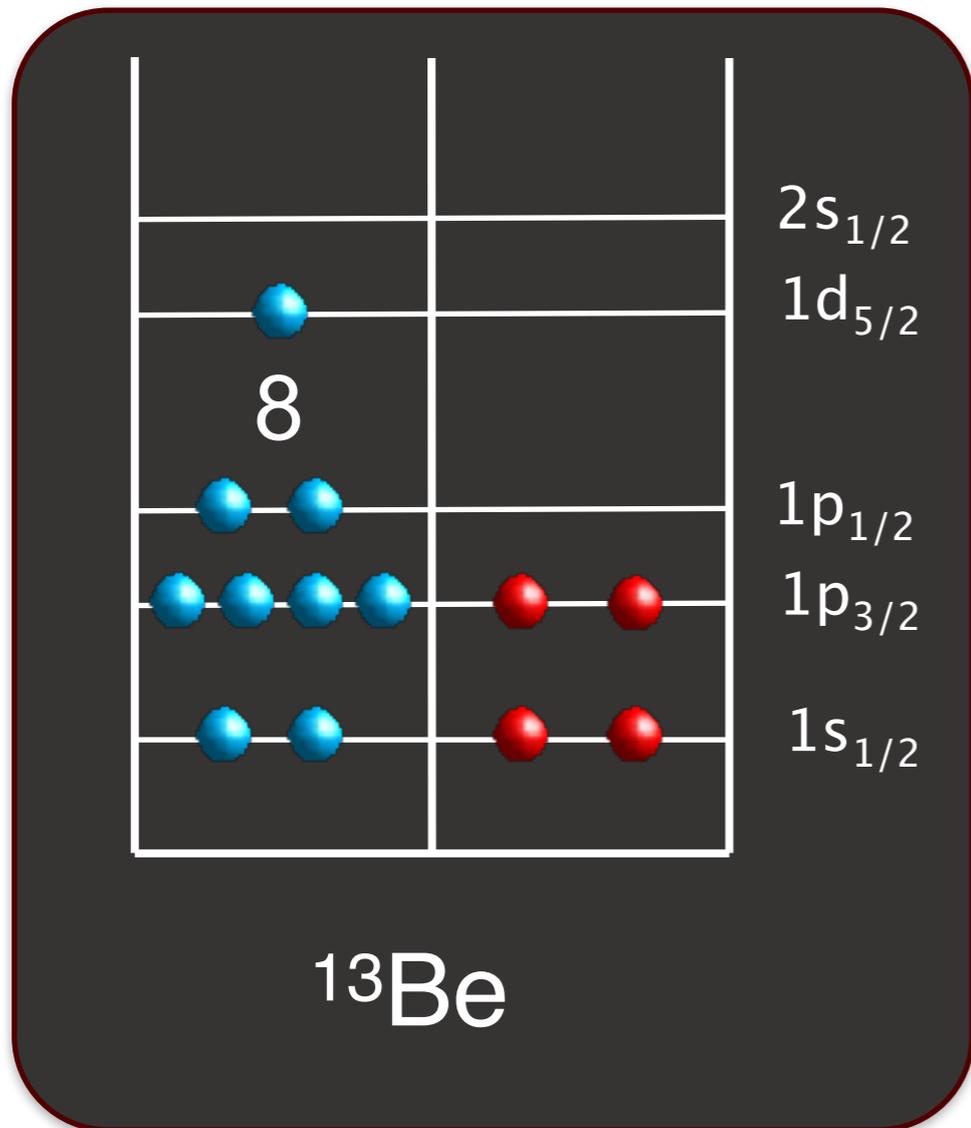
State		Counts						Efficiency-corrected $\bar{\gamma}^2$					
E_x	J^π	α_0	α_1	α_3	p_0 [11]	p_1 [11]	p_2	α_0	α_1	α_3	p_0	p_1	p_2
11.3(1)	3/2-	18(4.4)	0	0	6(2.6)	< 3	7(2.8)	67(21)%	0%	0%	4(2)%	<1%	29(13)%
11.8(1)	3/2-	< 1.8	0	0	28(14)	< 4	4(2.2)	<12%	0%	0%	50(30)%	0%	38(25)%
12.4(1)	3/2-	22(4.8)	4(2.2)	0	< 3	< 10	5(2.5)	6(2)%	88(49)%	0%	<0.1%	<2%	2(1)%
13.1	1/2-	0	3(2)	5(2.5)	21(6)	< 10	0	0%	1(1)%	98(48)% ^a	0%	<0.4%	0%
	5/2-							0%	10(10)%	89(44)%	0.7(0.2)%	<0.2%	0%
13.7(1)	3/2-	1(1.4)	3(2)	4(2.2)	< 3	< 10	6(2.7)	1(1)%	8(8)%	75(42)%	<0.5%	<7%	8(3)%

J. Bishop, GR, et al., Phys. Rev. Lett. 130, 222501 (2023)

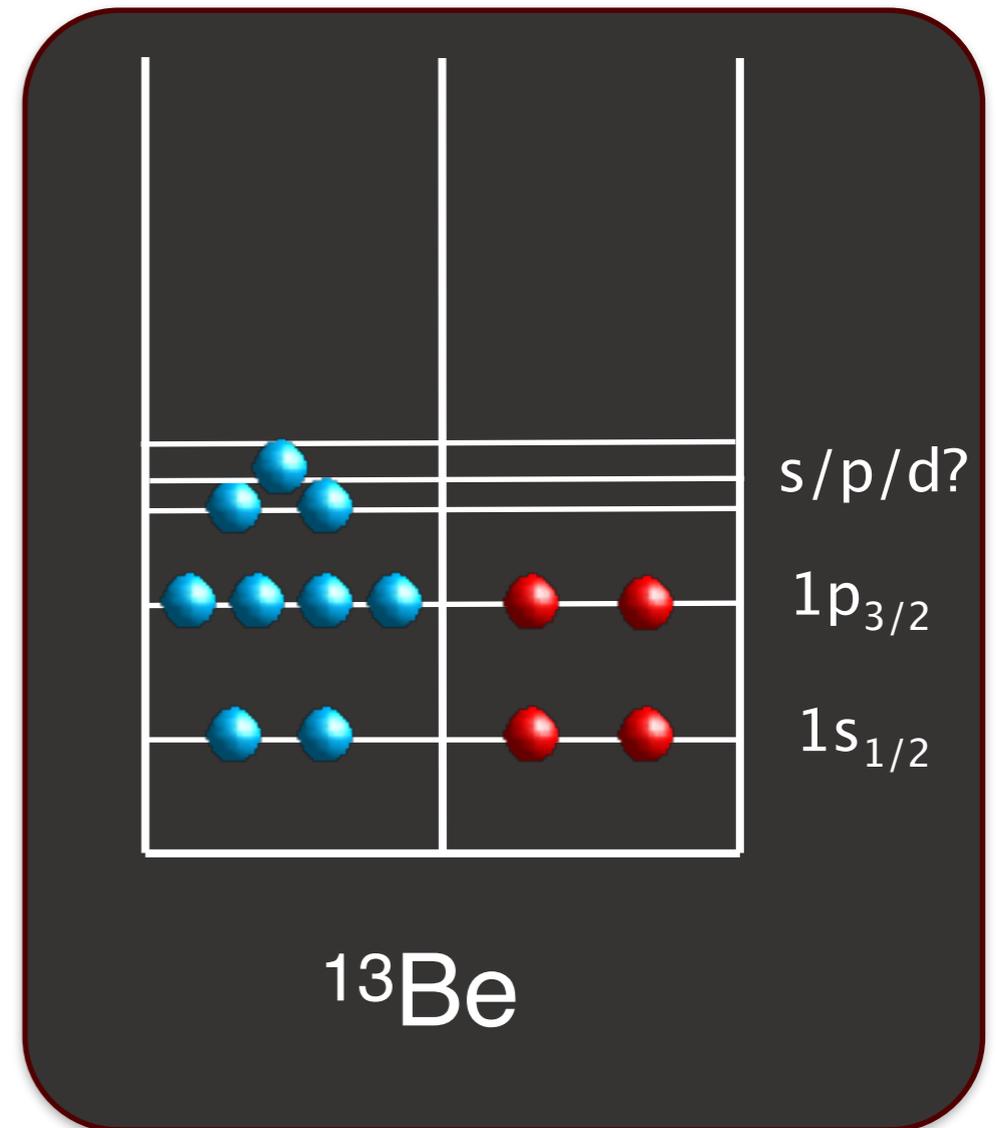


Structure of ^{13}Be

What is the ^{13}Be level structure?

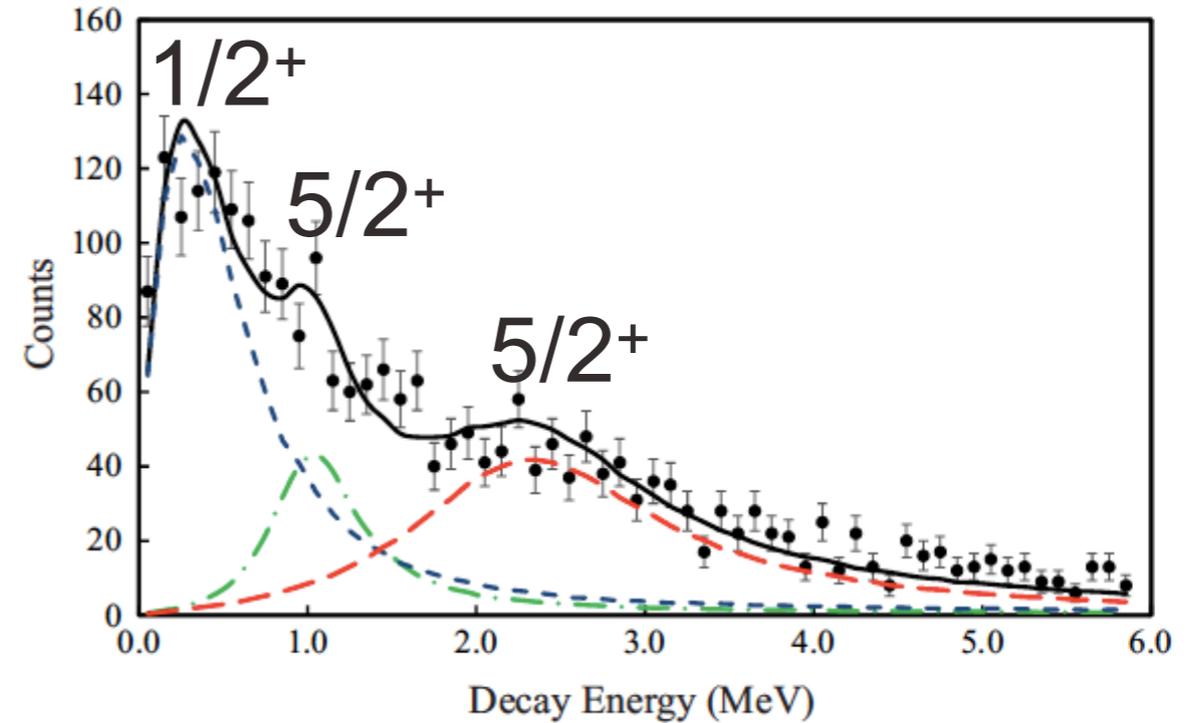


No shell evolution picture

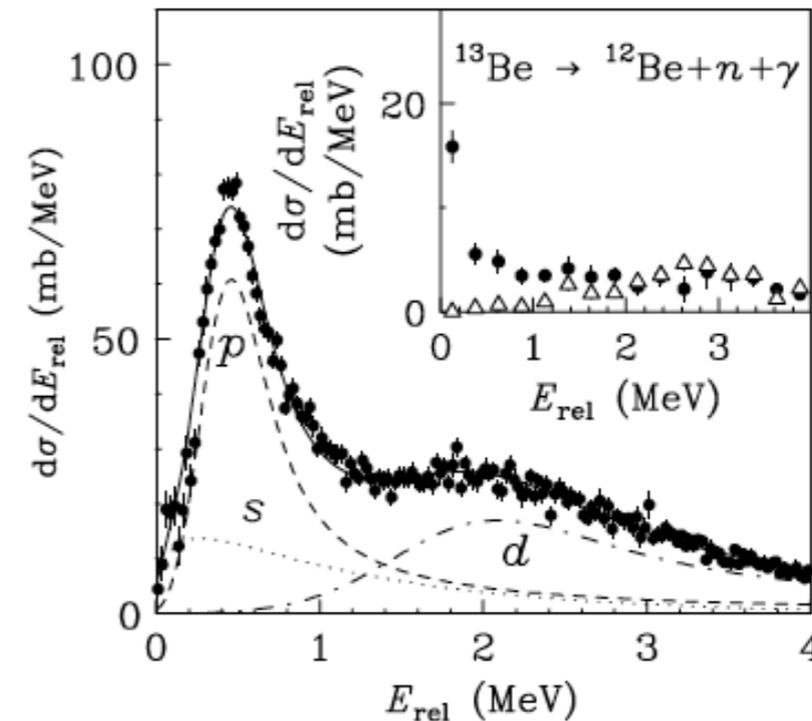


Real picture

Reference	E or a MeV or fm	Γ keV	J^π
A.N Ostrowski <i>et al.</i> [12]	2.01 3.12	300 400	$(\frac{5}{2}^+)/(\frac{1}{2}^-)$
A.V. Belozyorov <i>et al.</i> [13]	0.80 2.02 2.90 4.94 5.89 7.8		$(\frac{1}{2}^-)$
M. Thoennessen <i>et al.</i> [14]	< -10 fm		$(\frac{1}{2}^+)$
H. Simon <i>et al.</i> [15]	-3.2 fm		$(\frac{1}{2}^+)$
Y. Kondo <i>et al.</i> [16]	-3.4 fm 0.51 2.39	450 2400	$(\frac{1}{2}^+)$ $(\frac{1}{2}^-)$ $(\frac{5}{2}^+)$
Y. Aksyutina <i>et al.</i> [17]	0.81 0.46/0.44 2.07/1.95 2.98/3.02	2.1 0.11/0.39	$(\frac{1}{2}^+)$ $(\frac{1}{2}^-)$ $(\frac{5}{2}^+)$
G. Randisi <i>et al.</i> [18]	0.40 0.85 2.35	800 300 1500	$(\frac{1}{2}^+)$ $(\frac{5}{2}^+)$ $(\frac{5}{2}^+)$
B.R. Marks <i>et al.</i> [19]	0.40 1.05 2.56	800 500 2560	$(\frac{1}{2}^+)$ $(\frac{5}{2}^+)$ $(\frac{5}{2}^+)$
G. Ribeiro <i>et al.</i> [20]	0.86 2.11	1.70	$(\frac{1}{2}^+)$ $(\frac{5}{2}^+)$
A. Corsi <i>et at.</i> [21]	0.48 2.3 5.1 5.7		$(\frac{1}{2}^+)$ $(\frac{1}{2}^-)$ $(\frac{5}{2}^+)$



B.R. Marks, et al.,
Phys. Rev. C 92, 054320 (2015)

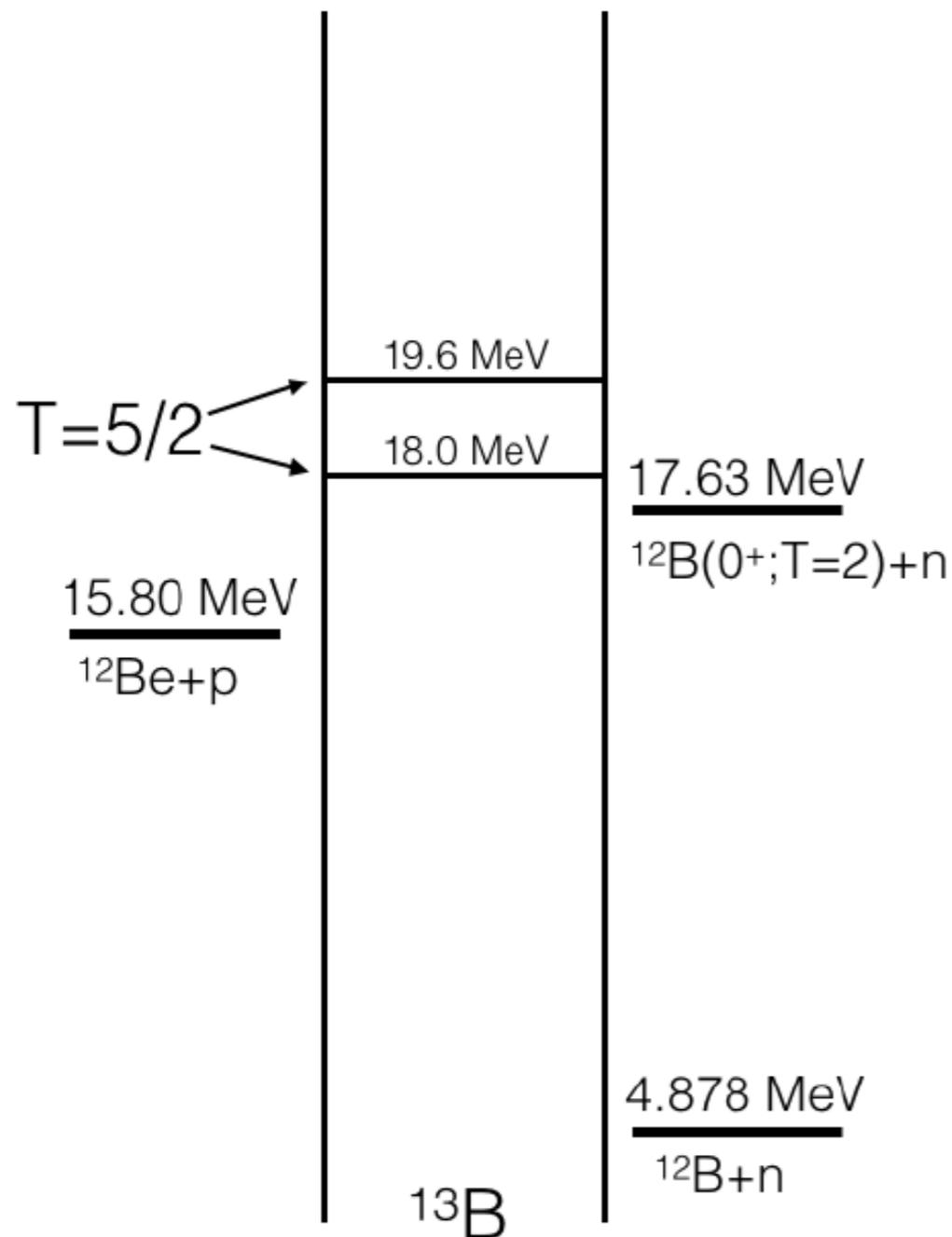


Y. Kondo et al., Phys Lett. B 690, 245 (2010)



- Interpretation is challenging
- No conclusive spin-parity

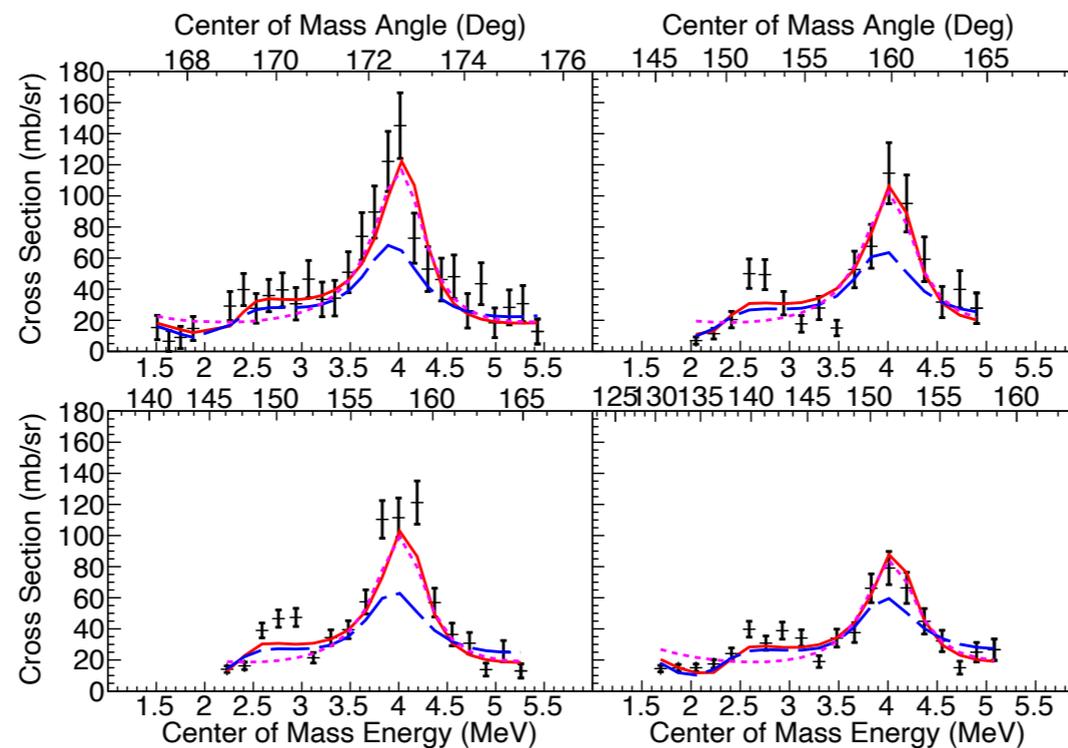
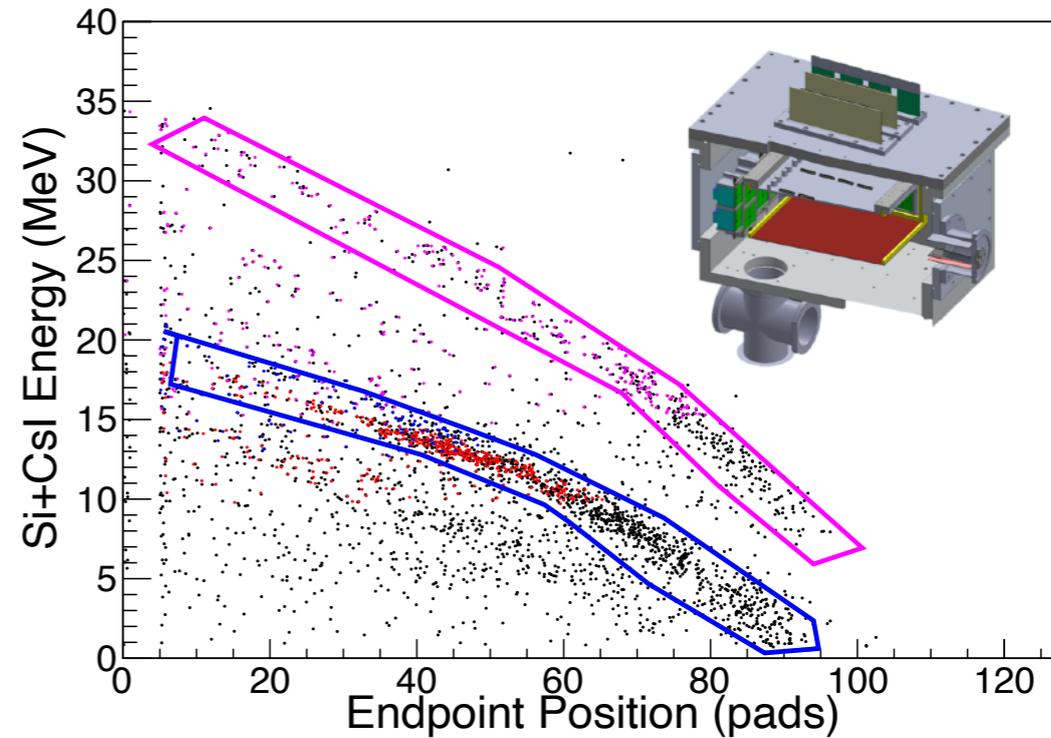
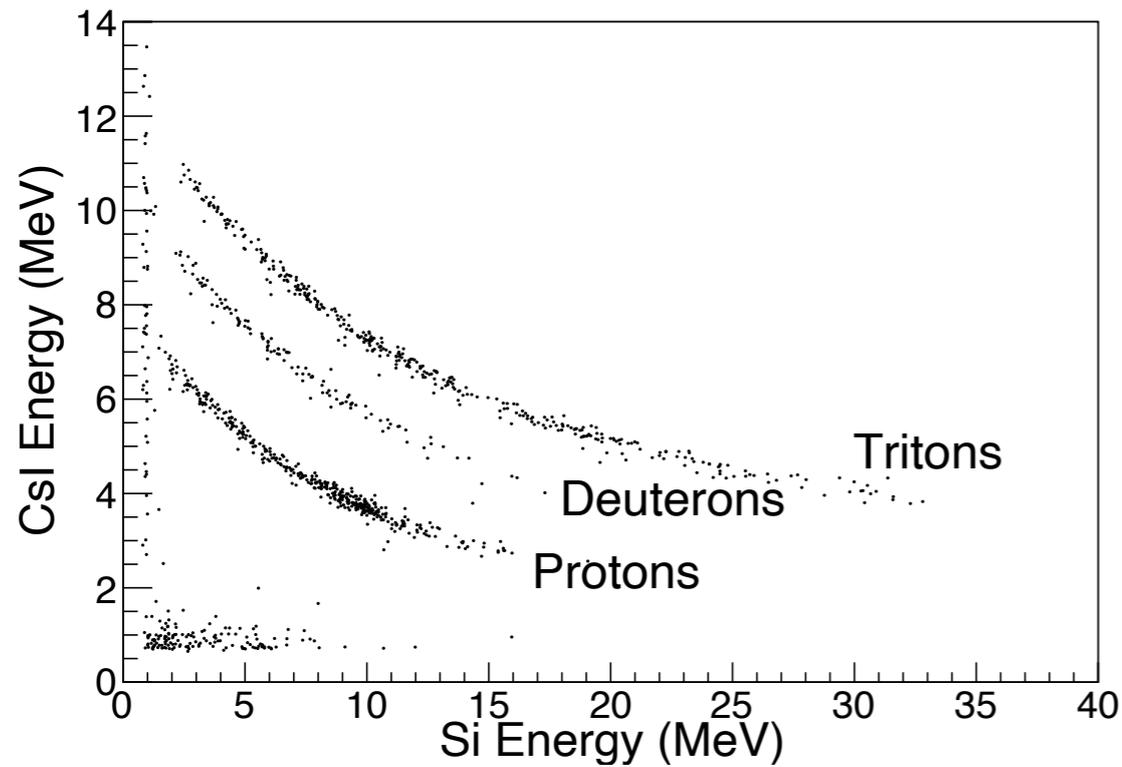
Structure of ^{13}Be through $T=5/2$ states in ^{13}B



- ✓ We propose to study ^{13}Be through the $T=5/2$ IAS in ^{13}B , populated in resonance elastic scattering $^{12}\text{Be}+p$
- ✓ $^{12}\text{Be}+p$ excitation function will be measured using thick target inverse kinetics approach
- ✓ The $T=5/2$ states would dominate the $^{12}\text{Be}+p$ excitation function

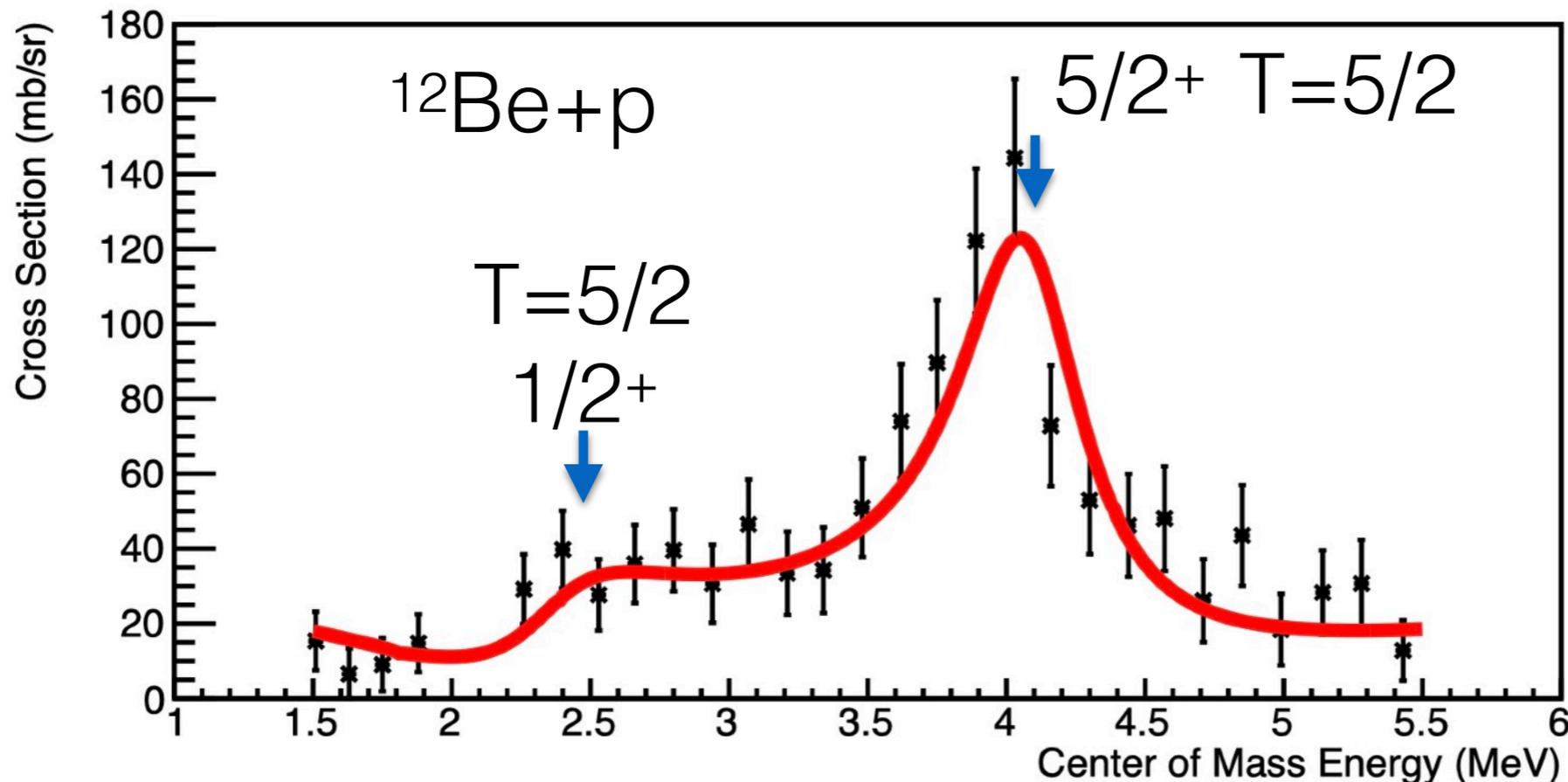
$^{12}\text{Be}+p$ resonance scattering experiment at TRIUMF

Beam: ^{12}Be at 6 MeV/u from ISAC-II. ~ 500 pps



TexAT measurements at TRIUMF

160°-180°



C. Hunt, et al.,
PRC Letter, submitted

Reduced widths:

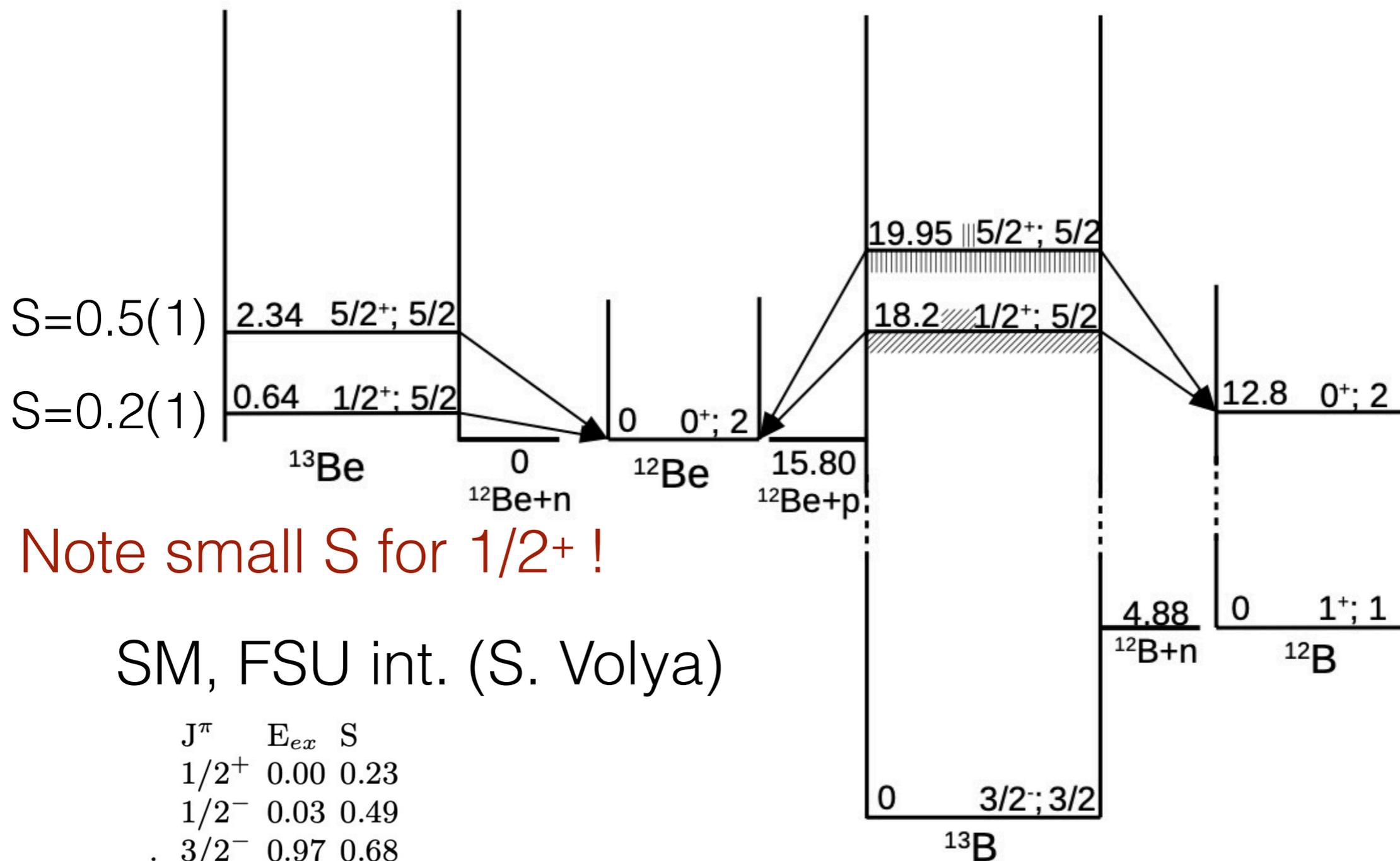
$$\gamma_{p+^{12}\text{Be}(T=2)}^2 = S(C_{\frac{1}{2}^{-\frac{1}{2}}, 2, 2}^{\frac{5}{2} \frac{3}{2}})^2 \gamma_{sp}^2 = \frac{1}{5} S \gamma_{sp}^2$$

$$\gamma_{n+^{12}\text{B}(T=2)}^2 = S(C_{\frac{1}{2}^{\frac{1}{2}}, 2, 1}^{\frac{5}{2} \frac{3}{2}})^2 \gamma_{sp}^2 = \frac{4}{5} S \gamma_{sp}^2$$

T=5/2 resonances in ¹³B:

J ^π	E _{cm} (MeV)	Γ (MeV)
1/2 ⁺	2.45(10)	0.6(3)
5/2 ⁺	4.15(6)	0.6(1)





Note small S for $1/2^+$!

SM, FSU int. (S. Volya)

J^π	E_{ex}	S
$1/2^+$	0.00	0.23
$1/2^-$	0.03	0.49
$3/2^-$	0.97	0.68
$5/2^+$	1.43	0.69
$3/2^-$	1.90	0.12
$5/2^+$	2.21	0.01



Conclusion

- 149 ^{13}O $\beta^3\alpha$ decays were observed
- Cluster states in ^{13}N decaying by α to ^9B were identified. [J. Bishop, et al., PRL 130, 222501 (2023)]
- Structure of ^{13}Be was informed by populating $T=5/2$ resonances in ^{13}B using $^{12}\text{Be}+p$ resonance scattering
- $1/2^+$ and $5/2^+$ neutron-unbound by 0.6(1) at 2.34(6) MeV can be inferred in ^{13}Be .
- SF for $1/2^+$ is small (0.2) indicating near degeneracy of $2s_{1/2}$ and $1p_{1/2}$ shells and strong configuration mixing. [C. Hunt, et al., PRC Letter, submitted]



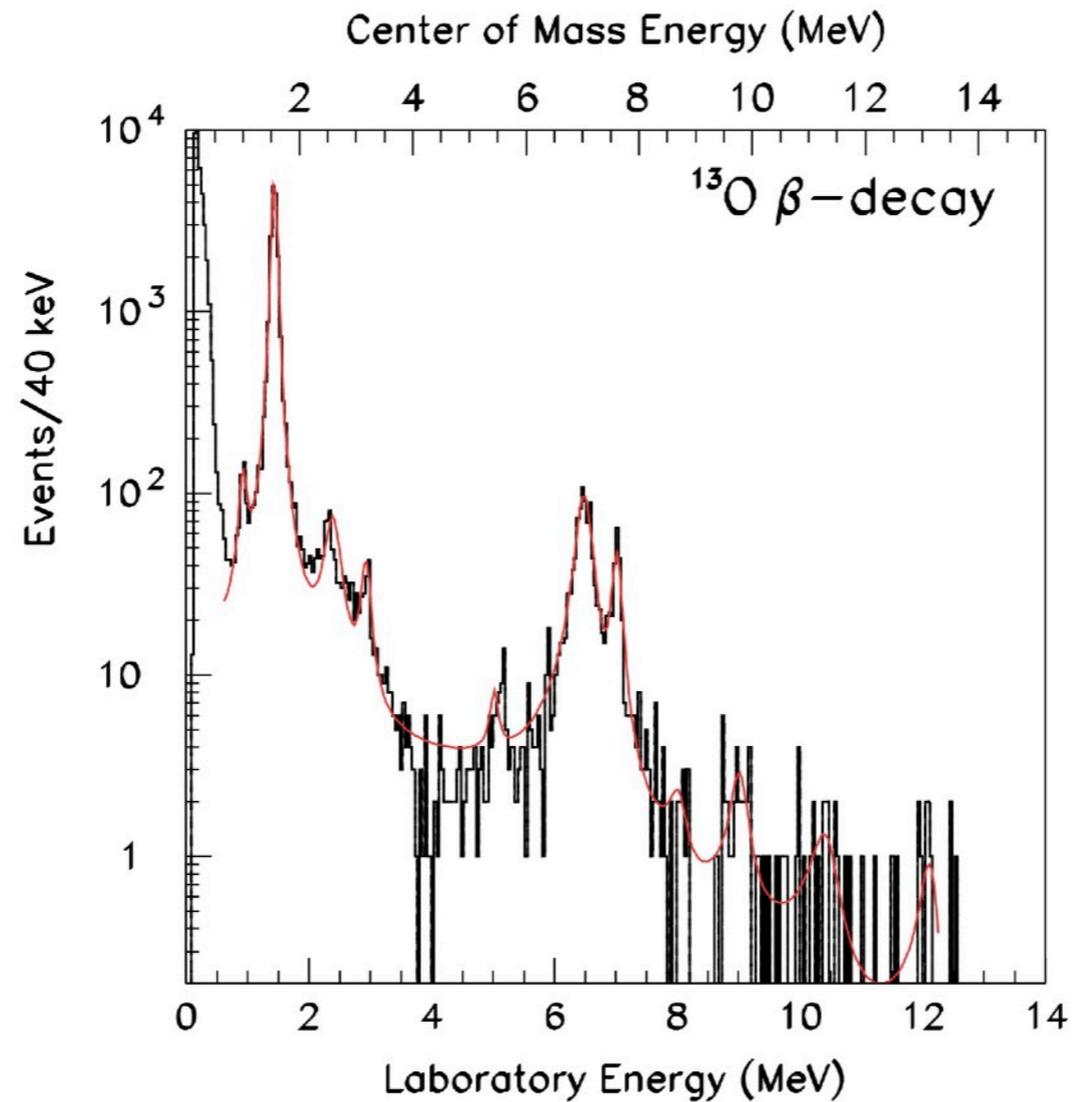
Thank you!

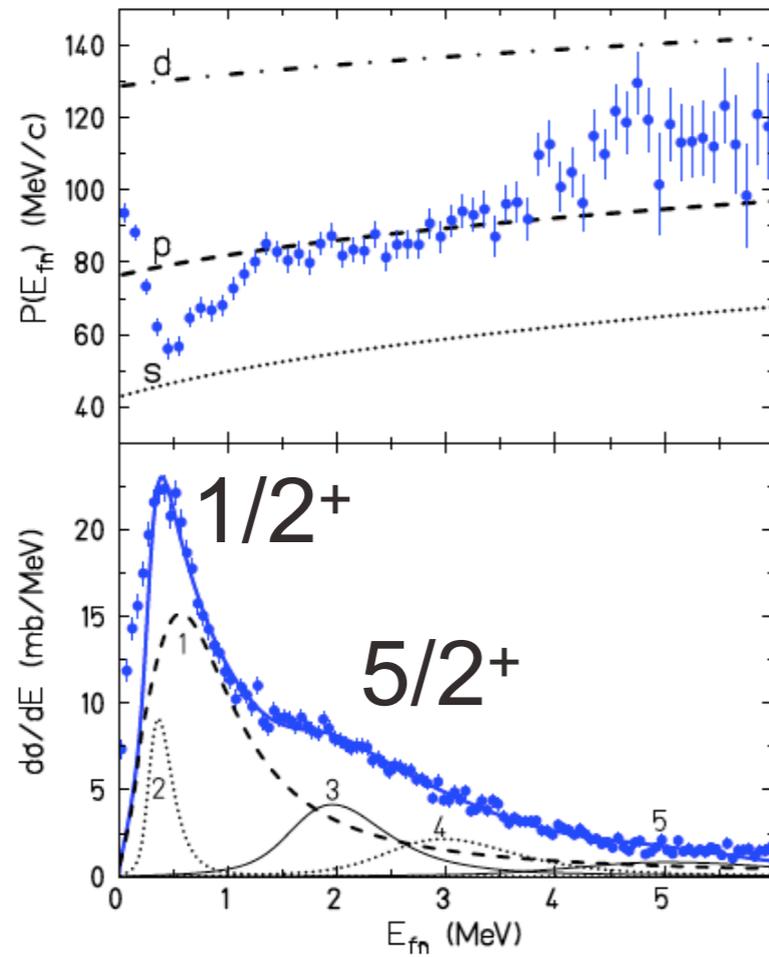




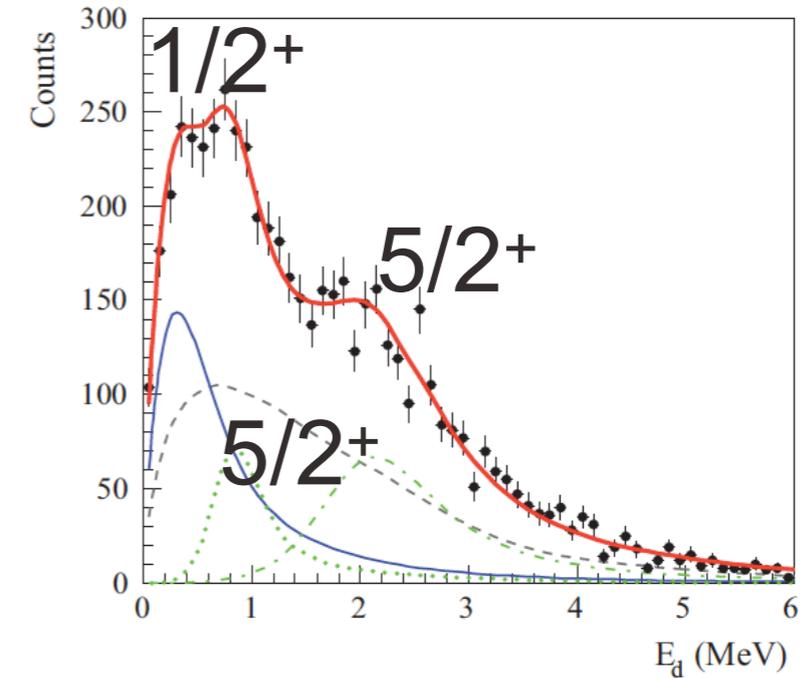
β -decay of ^{13}O

H. H. Knudsen,¹ H. O. U. Fynbo,^{1,*} M. J. G. Borge,² R. Boutami,² P. Dendooven,³ C. Aa. Diget,¹ T. Eronen,⁴ S. Fox,⁵ L. M. Fraile,^{6,†} B. Fulton,⁵ J. Huikary,⁴ H. B. Jeppesen,¹ A. S. Jokinen,⁴ B. Jonson,⁷ A. Kankainen,⁴ I. Moore,⁴ A. Nieminen,⁴ G. Nyman,⁷ H. Penttilä,⁴ K. Riisager,¹ S. Rinta-Antila,⁴ O. Tengblad,² Y. Wang,⁴ K. Wilhelmsen,⁷ and J. Äystö⁴





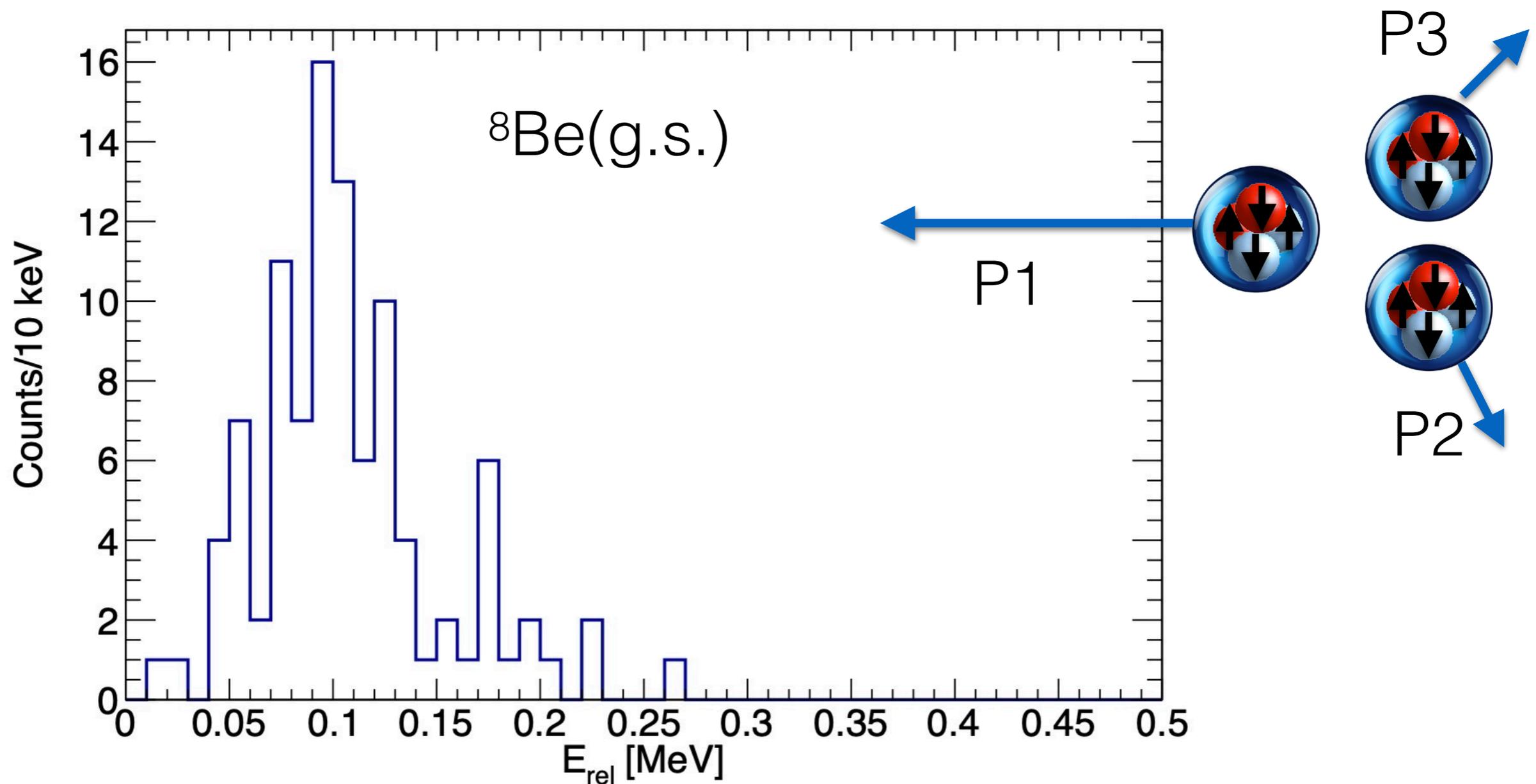
Yu. Aksyutina et al.
 Phys. Lett. B 718
 (2013) 1309



G. Randisi, et al.
 Phys. Rev. C 89,
 034320 (2014)



- 149 $\alpha+\alpha+\alpha+p$ events were identified out of 1.9×10^5 implanted ^{13}O - BR $7.8(6) \times 10^{-4}$



Invariant mass for the smallest relative energy alphas
($E_2 + E_3$)

