The Pygmy Dipole Resonance in ^{142}Nd

R.Neveling , iThemba LABS, South Africa

The Electric Dipole Response of the Nucleus

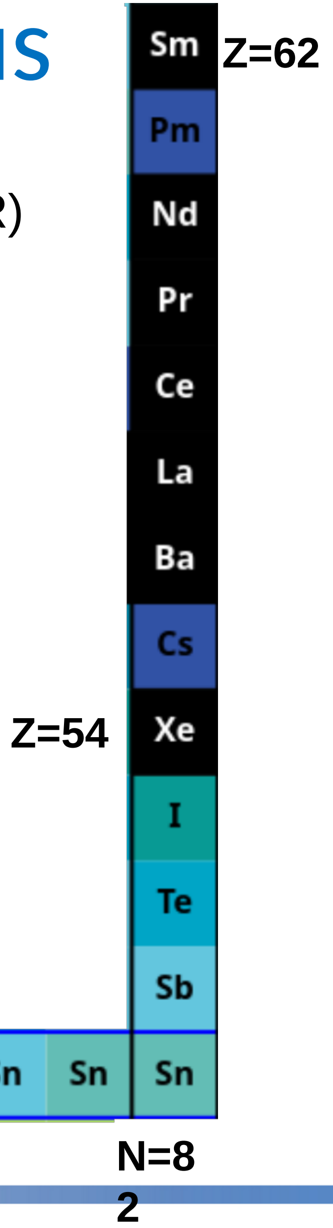
Low-lying dipole states traditionally referred to as the Pygmy Dipole Resonance (PDR)

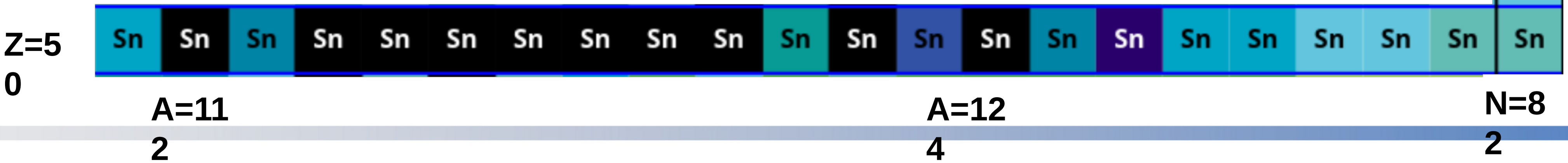
Certain aspects of the PDR well-established:

- it is present in nuclei with neutron excess (experimentally and theoretically)
- strength is a few % of EWSR
- located below the GDR, at and below neutron emission energy threshold
- the PDR has a known isospin mixed nature

For a microscopic understanding of they low-lying E1 strength
we need a clear picture of the systematics of the PDR

Need data, different probes, different nuclei





Sm
Pm
Nd
Pr
Ce
La
Ba
Cs
Xe

The stable & even N=82 isotones

144Sm	142Nd	140Ce	138Ba	136Xe	
Z=62	Z=60	Z=58	Z=56	Z=54	
N/Z=1.32	N/Z=1.37	N/Z=1.41	N/Z=1.46	N/Z=1.52	
S_n=10.519	S_n=9.829	S_n=9.200	S_n=8.612	S_n=8.087	MeV
NRF S-DALINAC	**NRF S-DALINAC**	**NRF S-DALINAC**	**NRF S-DALINAC**	**NRF S-DALINAC**	NPA 779(2006)1 PRC 84 (2011) 024326
NRF HIGS	**NRF HIGS**	**NRF HIGS**	**NRF HIGS**	-	EPJ Web of Conf 93 (2015) 01030
-	-	**(α,α'γ) KVI**	**(α,α'γ) KVI**	-	PRC 80 (2009) 34302
-	-	**(p,p'γ) KVI**	-	-	PLB 786 (2018) 6
-	-	**(^{17}O,^{17}O γ) Legnaro**	-	-	PRC 93 (2016) 044330

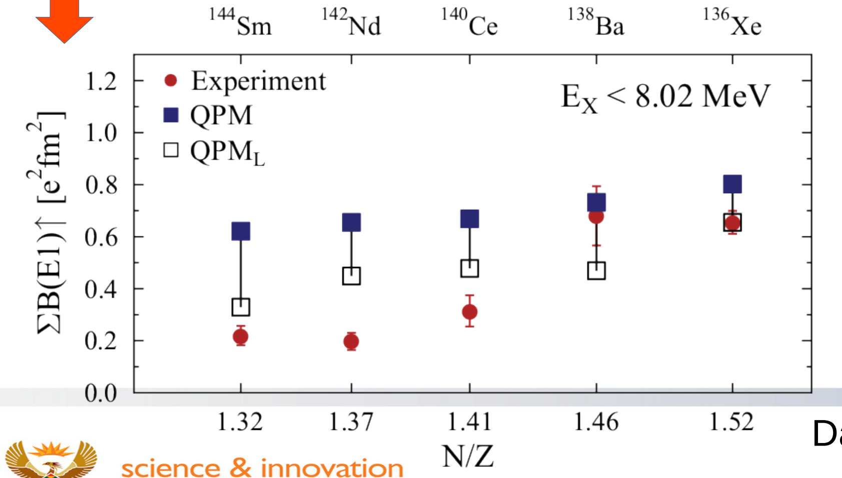
NRF @ S-DALINAC

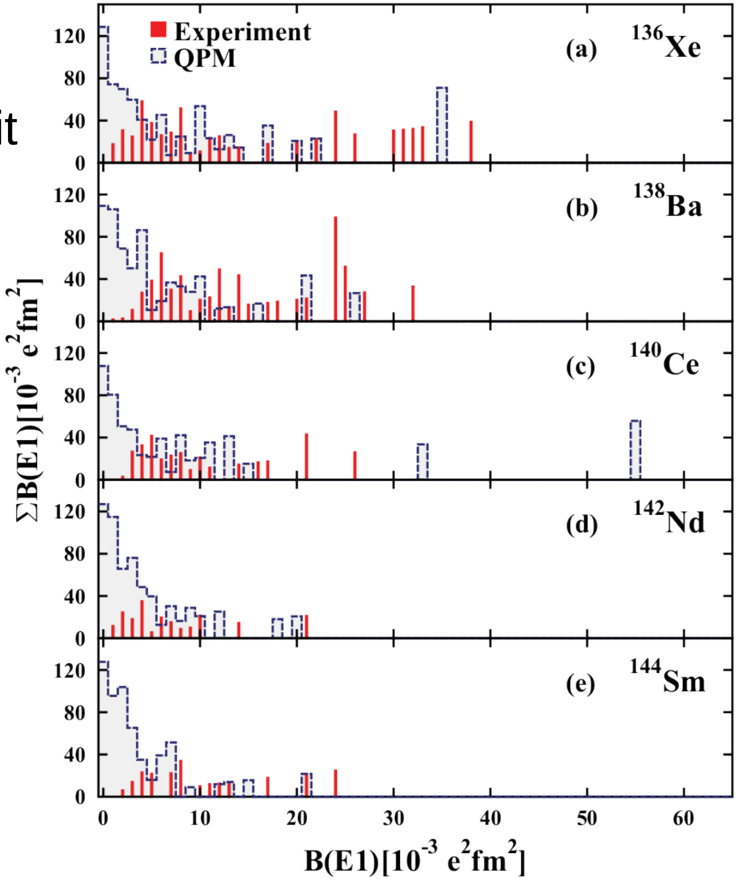
Not commenting on unresolved strength due to
limited experimental sensitivity

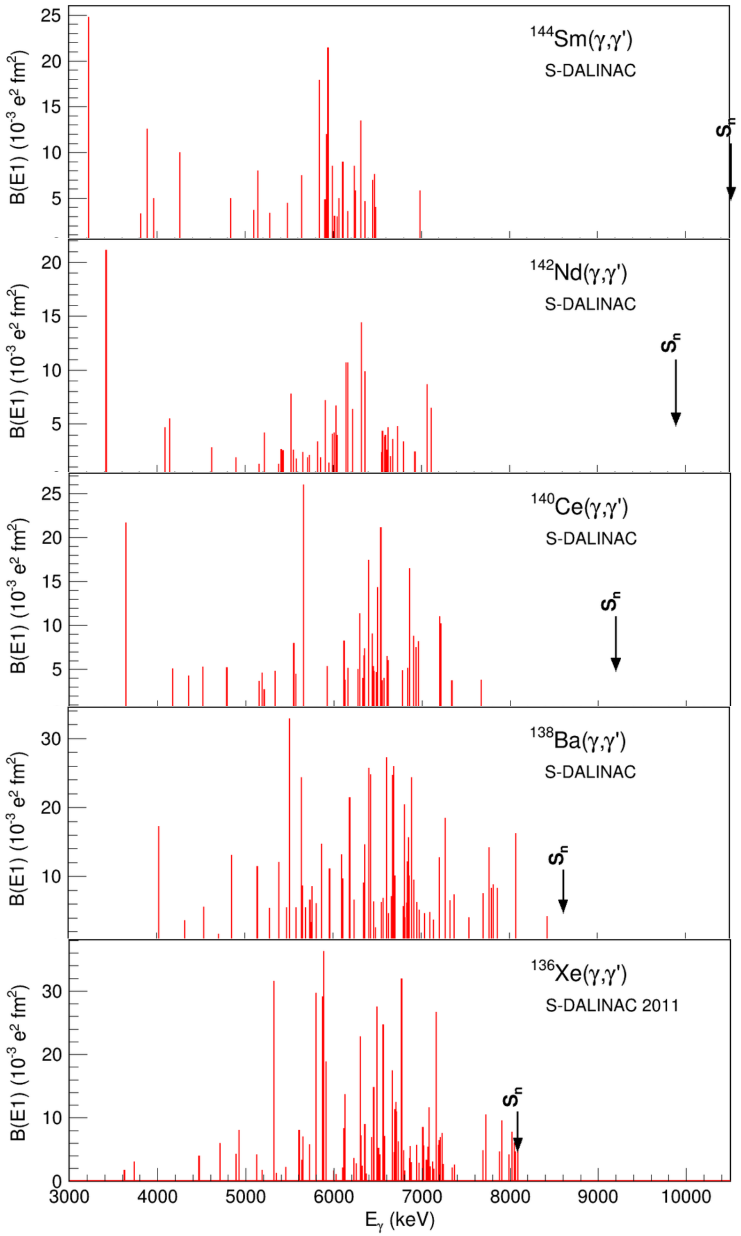
Extracted strength only represents lower limit

Fragmentation analysis
increased fragmentation as A increase
(fewer very strong excitations)

Increased fragmentation & exp sensitivity
impacts summed strength trend





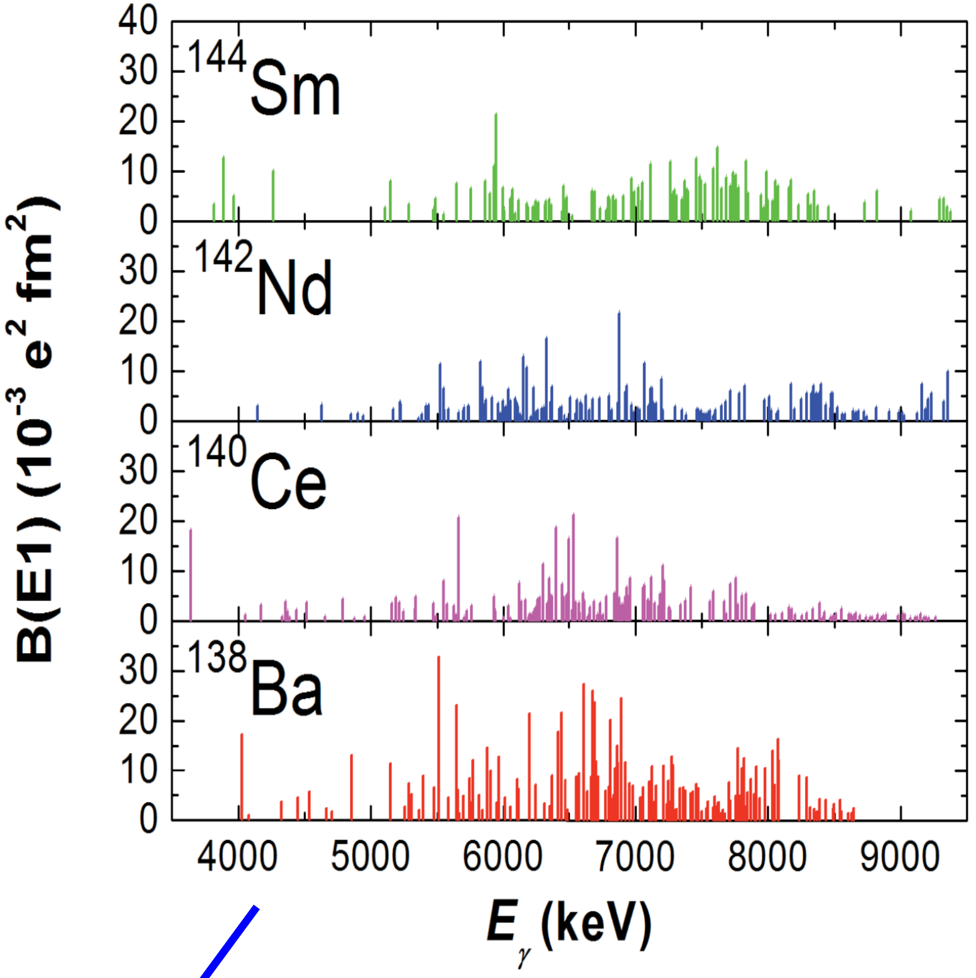


Data from NPA 779(2006)1 and PRC 84 (2011) 024326

NRF @ HIGS

Higher experimental sensitivity

"… no sizable branching transitions to low-lying excited states (greater than 2%) have been observed." → w.r.t. Ba results



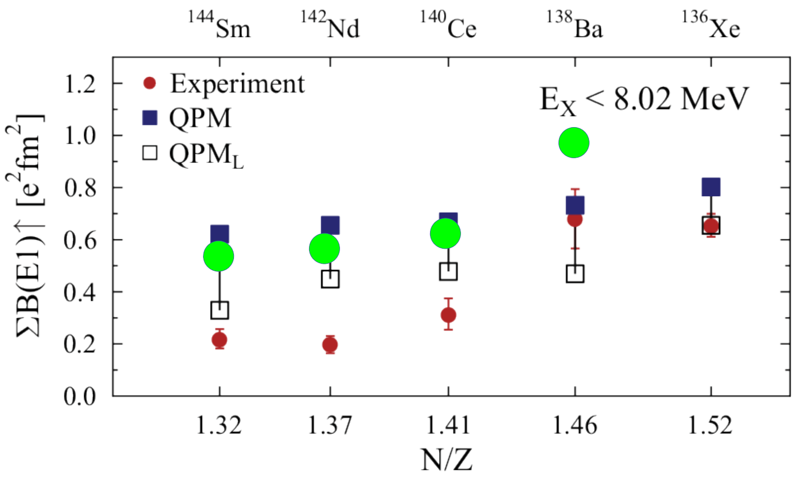
Data from PRL 104 (2010) 072501 & EPJ WoC 93 (2015) 01030

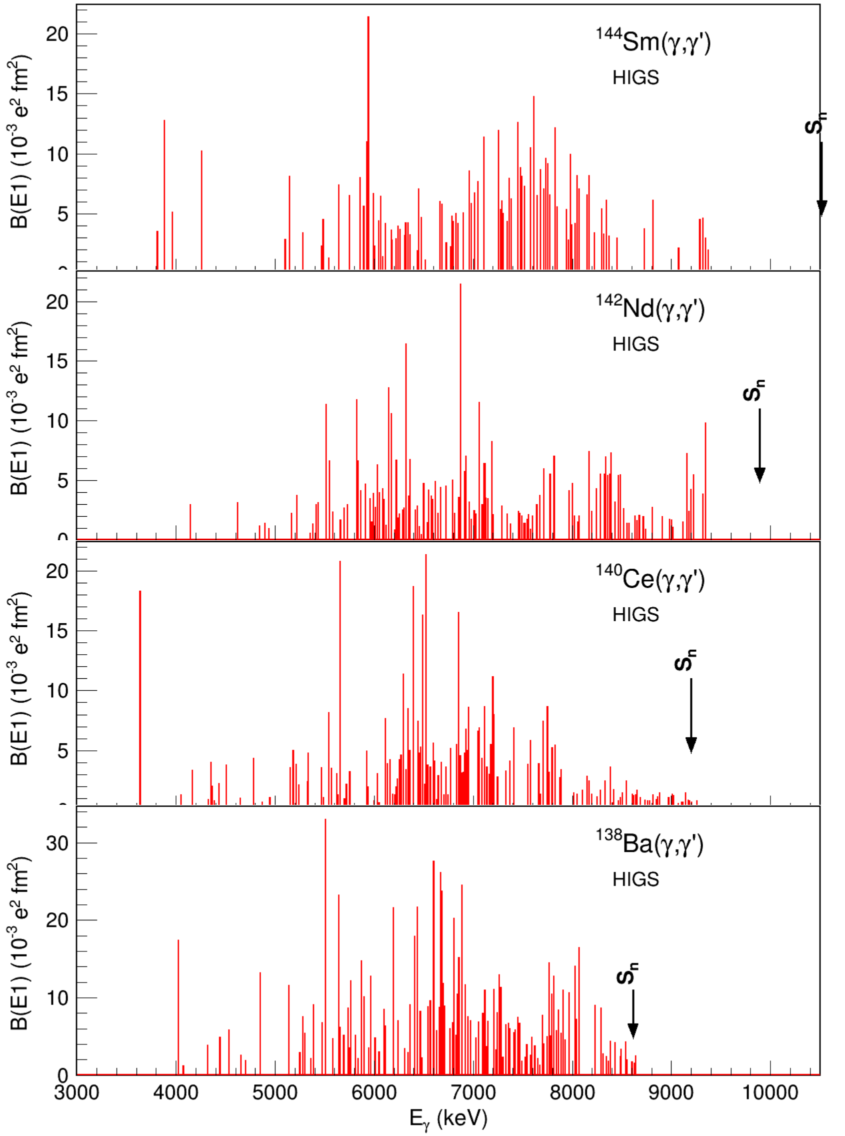
NRF @ HIGS

Higher experimental sensitivity

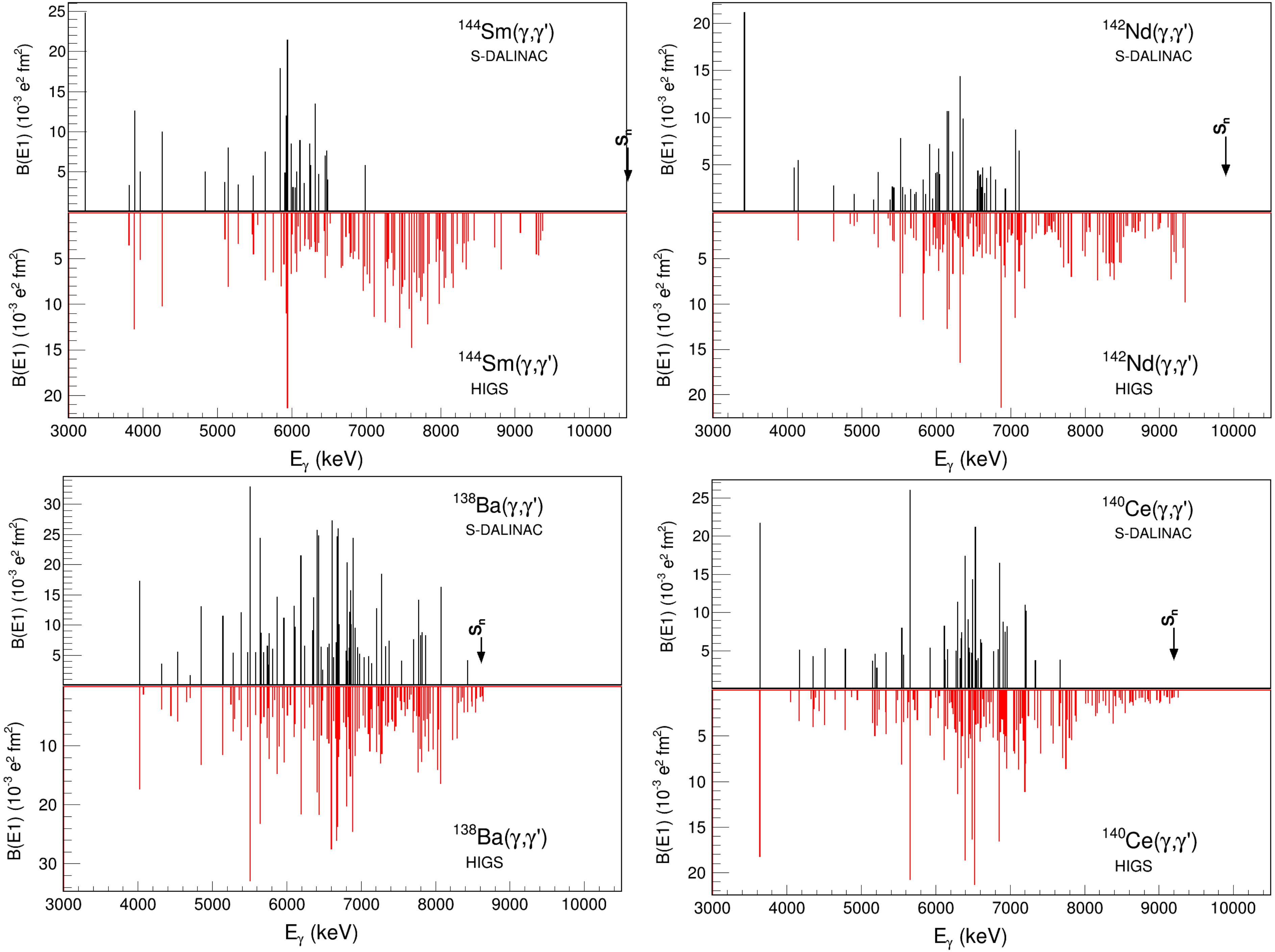
"… no sizable branching transitions to low-lying excited states (greater than 2%) have been observed." → w.r.t. Ba results

Summed B(E1):	960±153	600±119	576±98	536±96
(10^{-3} e^2 fm^2)	138Ba	140Ce	142Nd	144Sm





Data from PRL 104 (2010) 072501 & EPJ WoC 93 (2015) 01030 & PRC 84 (2011) 024326


144Sm(γ,γ')
S-DALINAC
144Sm(γ,γ')
HIGS
142Nd(γ,γ')
S-DALINAC
142Nd(γ,γ')
HIGS
138Ba(γ,γ')
S-DALINAC
138Ba(γ,γ')
HIGS
140Ce(γ,γ')
S-DALINAC
140Ce(γ,γ')
HIGS
Sn
B(E1) (10-3 e2 fm2)
Eγ (keV)
3000
4000
5000
6000
7000
8000
9000
10000

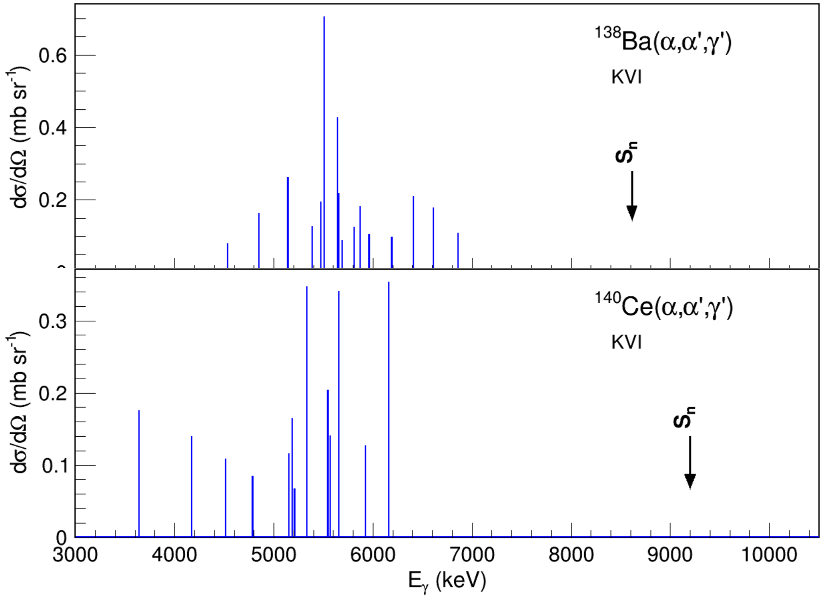
Particle probes

Suggest structural split of PDR

2 components:

- at low E (6-7 MeV) states excited with both (X,X'γ) and (γ,γ') (X= α, ^{17}O)
- at higher E states excited through (γ,γ') only

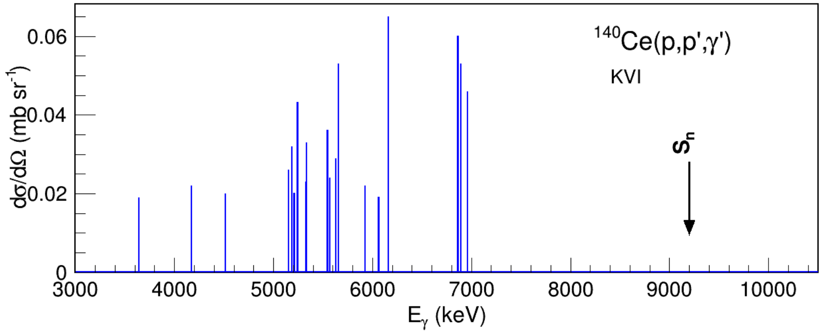
Theoretical analysis suggests low-lying part due to neutrons contribution at nuclear surface

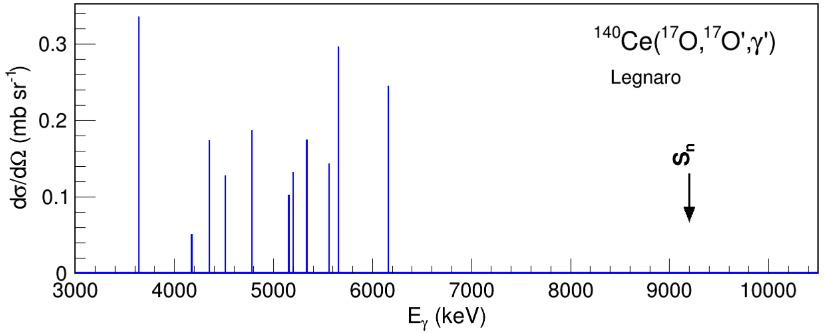


Experimental results shown represent resolved strength only

Case of ^{140}Ce investigated with three different particle probes

Question: how does low-lying part develop along N=82?





Data from NPA 779(2006)1 and PRC 84 (2011) 024326

Sm
Pm
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The stable & even N=82 isotones

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NRF HIGS	**NRF HIGS**	**NRF HIGS**	**NRF HIGS**	**-**	EPJ Web of Conf 93 (2015) 01030
		(α,α'γ) KVI	**(α,α'γ) KVI**	**-**	PRC 80 (2009) 34302
-	**-**	**(p,p'γ) KVI**	**-**	**-**	PLB 786 (2018) 6
-	**-**	**(^{17}O,^{17}O γ) Legnaro**	**-**	**-**	PRC 93 (2016) 044330

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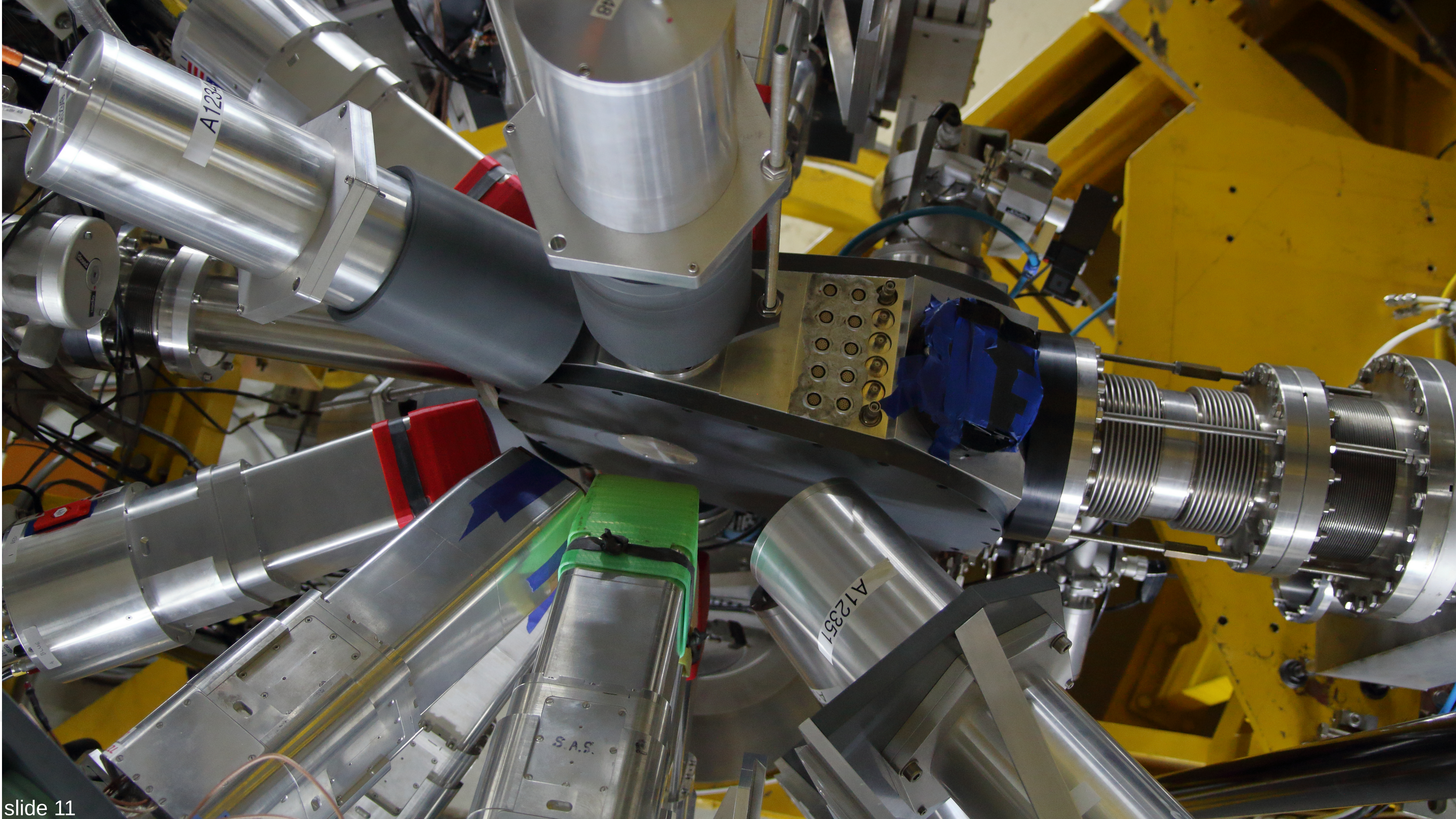
The experiment:
The K600 & BaGeL

NRF National Research Foundation

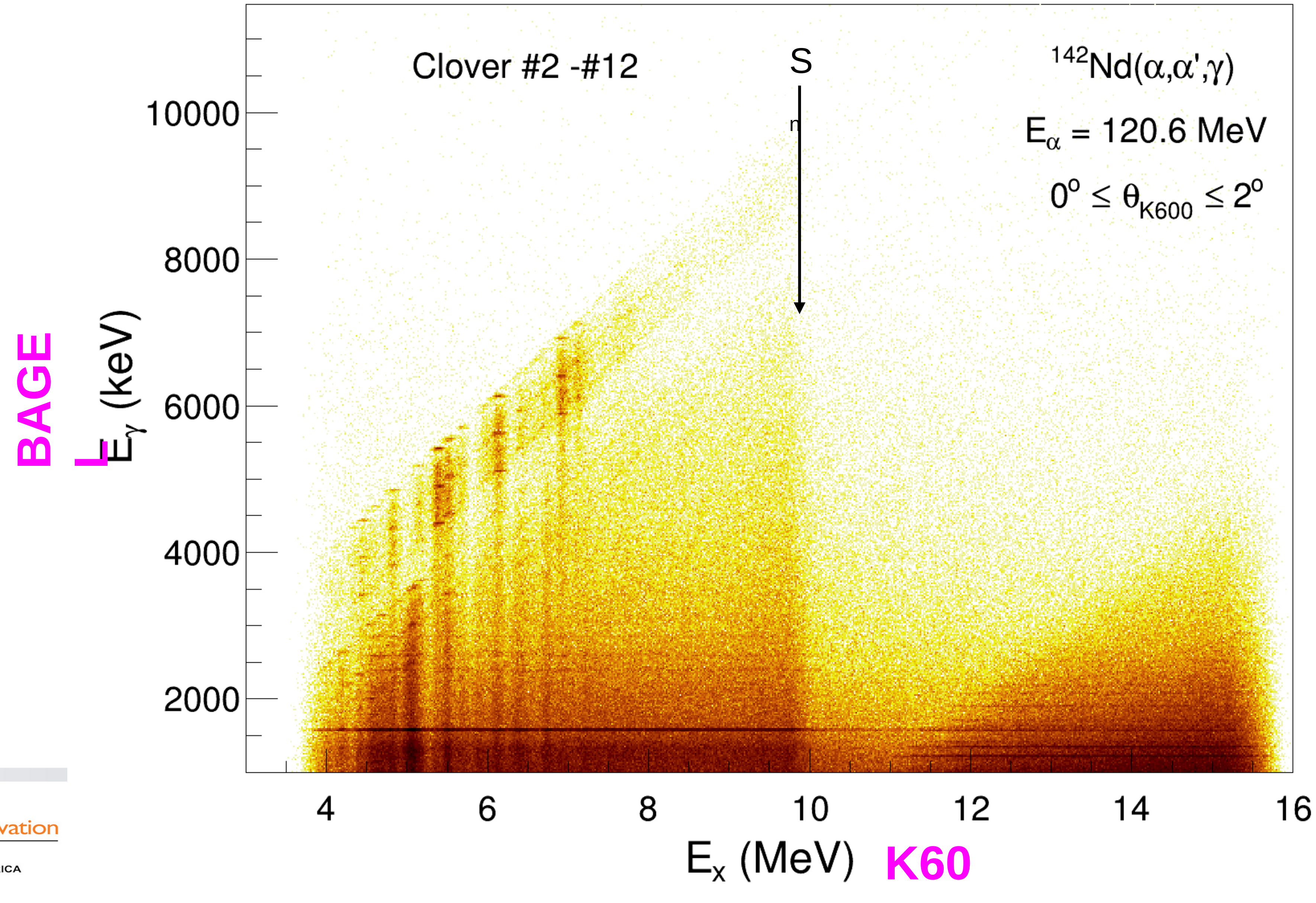
iThemba LABS Laboratory for Accelerator Based Sciences

The experiment: some numbers

Target thickness	4.63 mg/cm^2
Target isotopic enrichment	98.26 %
Beam	120.6 MeV alpha beam
Average beam intensity	0.7 pnA
SSC RF frequency	11.378 MHz
K600 central angle	**0 degrees**
K600 solid angle	3.831 msr
Average trigger rate	800 Hz
Excitation energy resolution	**87 keV (FWHM) for 3.31 mg/cm^2 ^{24}Mg target**
Excitation energy range accessed	4.3 – 15 MeV
Number of HPGe detectors	**12**
Gamma energy resolution	**20 keV (FWHM)**
Total photopeak efficiency	0.504 % @ 1.368 keV (tgt-HPGe distance = 18.5cm, no addback)
Average HPGe rates	3-5 kHz


A12351
S.A.S.

The experiment: α-γ correlated events



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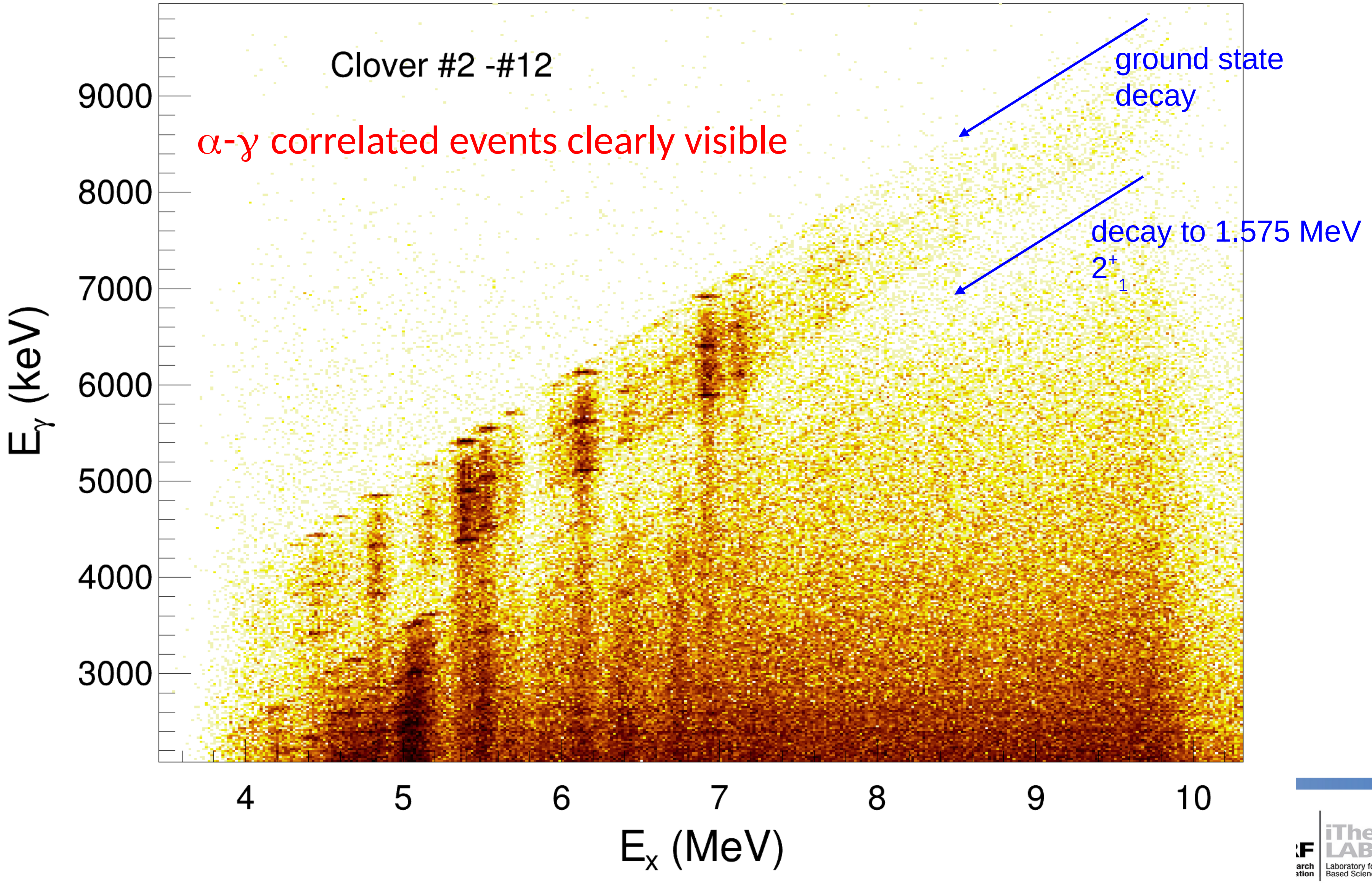
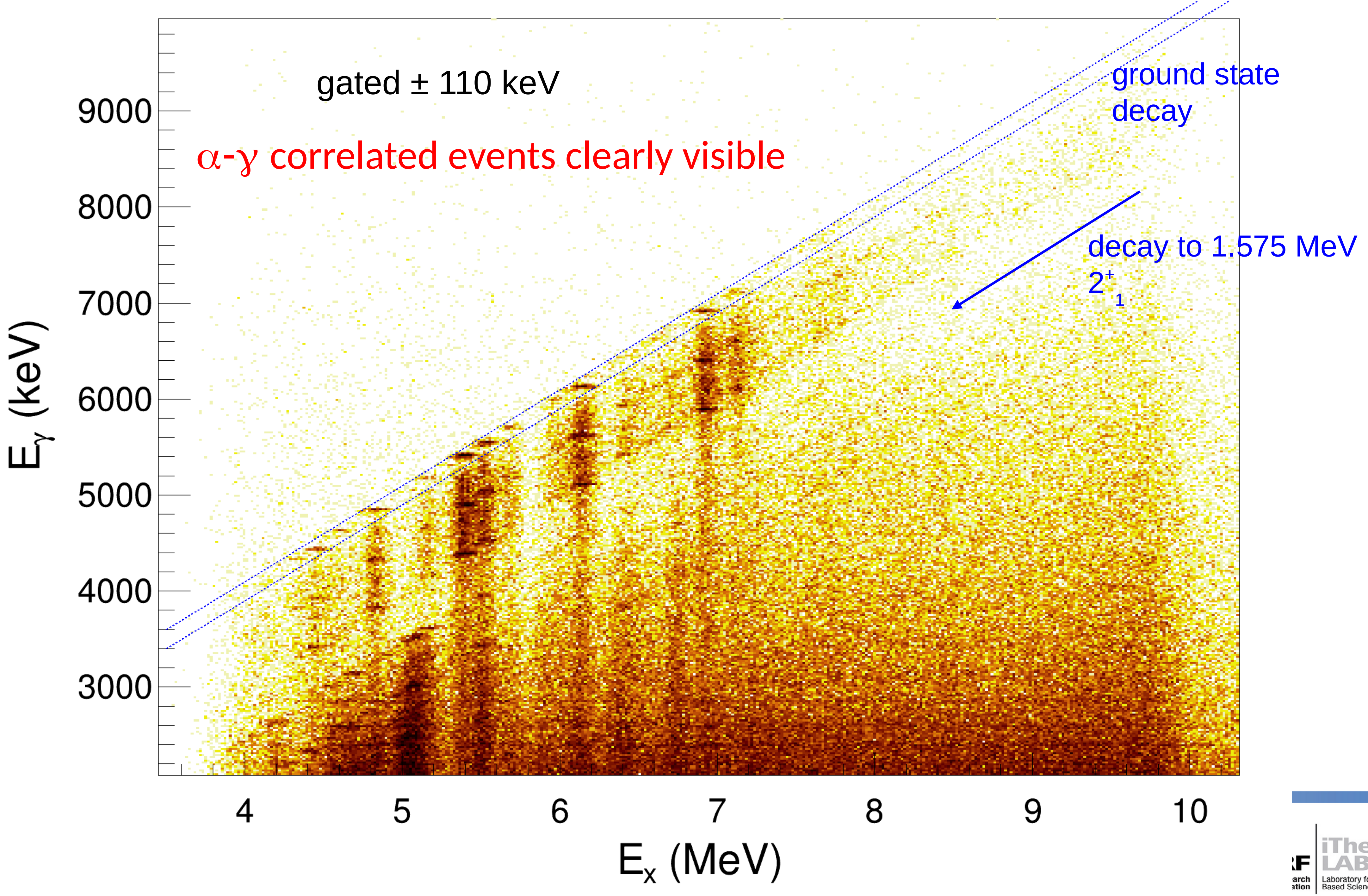
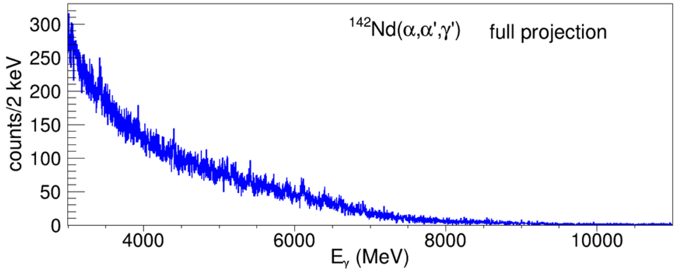
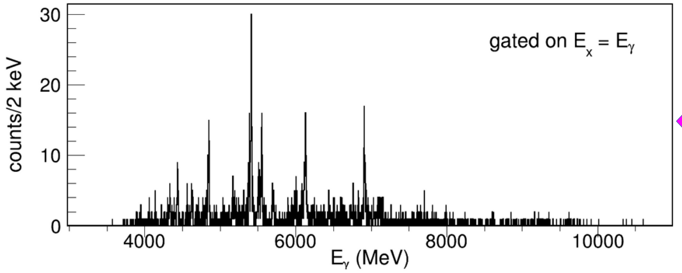


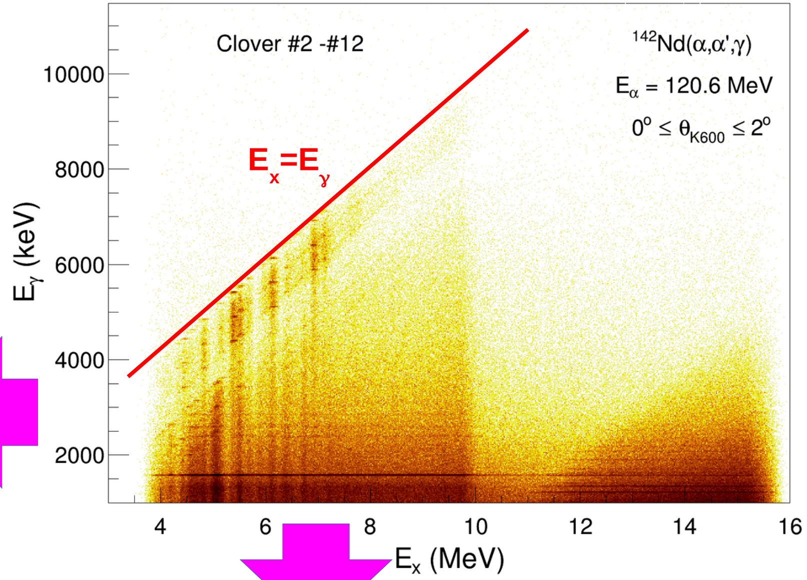
Clover #2 -#12
α-γ correlated events clearly visible
ground state decay
decay to 1.575 MeV 2^+_1
9000
8000
7000
6000
5000
4000
3000
E_γ (keV)
4
5
6
7
8
9
10
E_x (MeV)

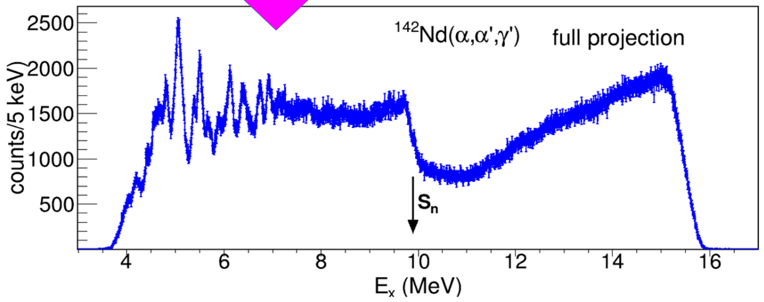

gated ± 110 keV
α-γ correlated events clearly visible
ground state decay
decay to 1.575 MeV 2^+_1
9000
8000
7000
6000
5000
4000
3000
E_γ (keV)
4
5
6
7
8
9
10
E_x (MeV)

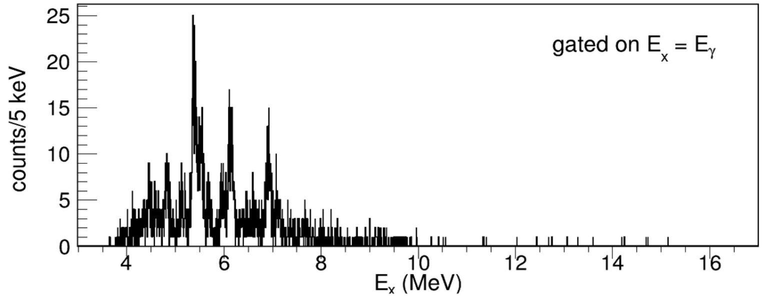
Experimental results



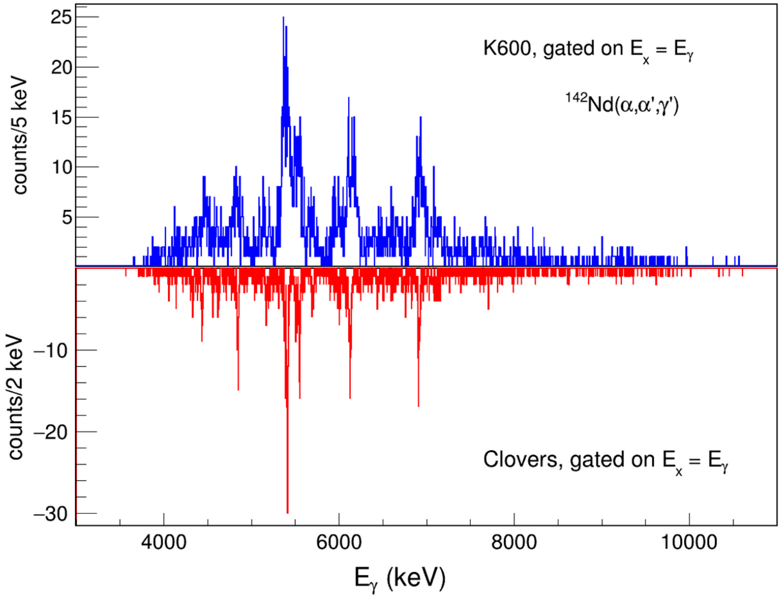








Direct transition to the g.s.:
K600 versus BAGEL



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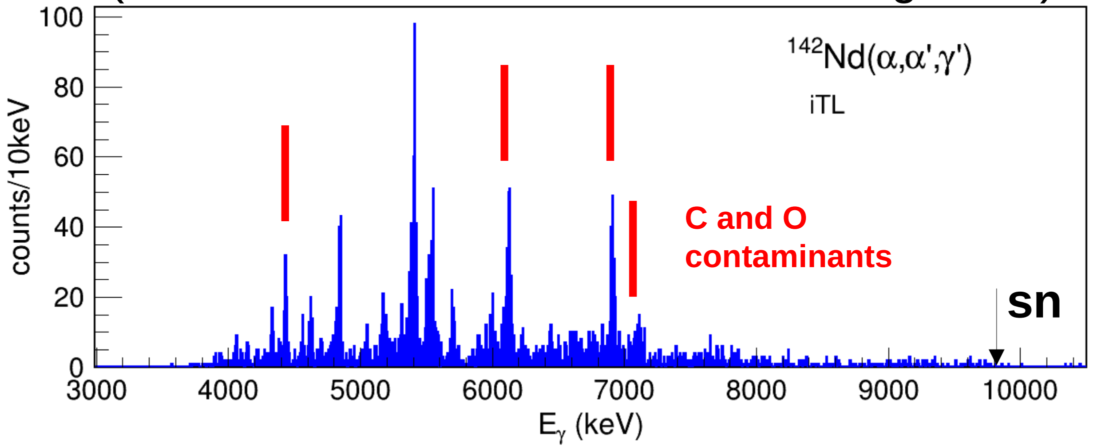
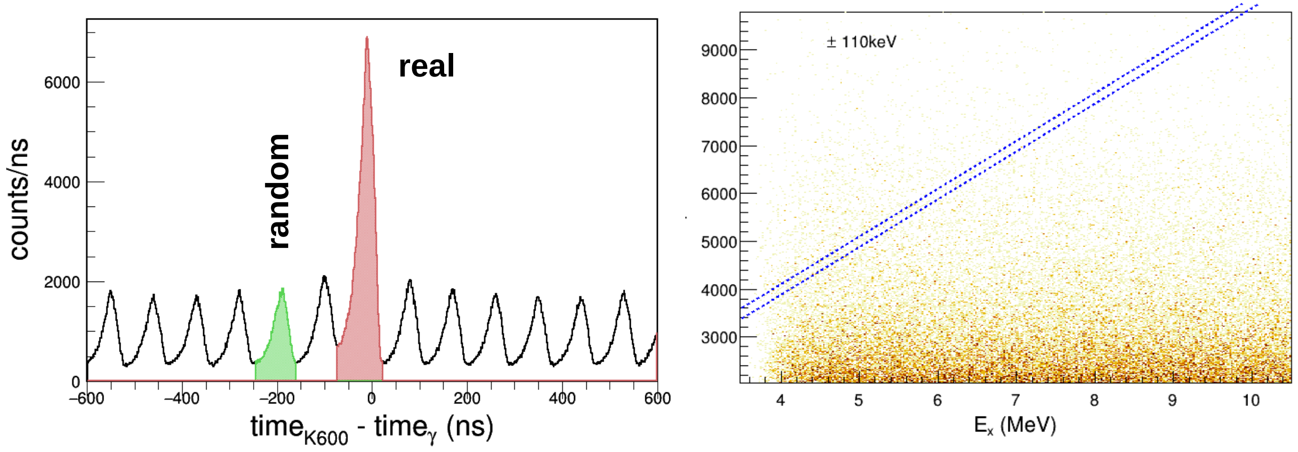
Experimental results

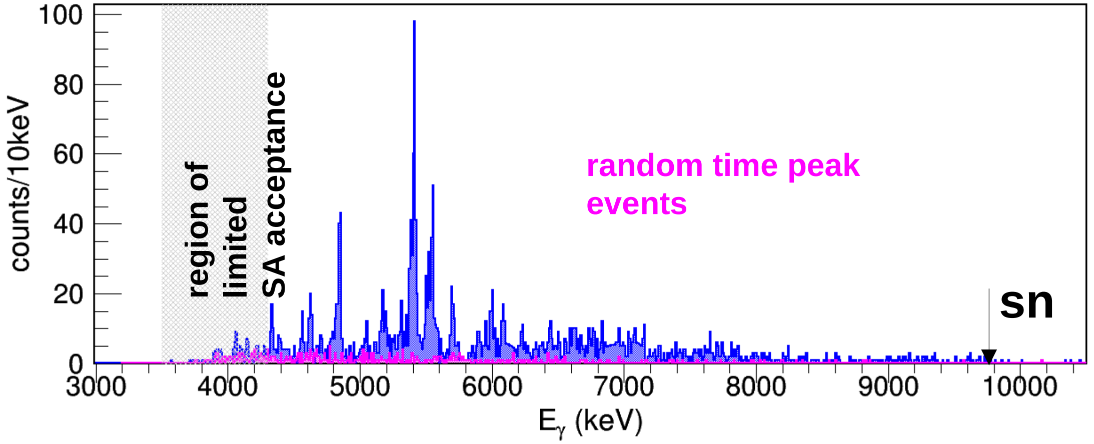
Raw counts:
(with contaminants and random background)



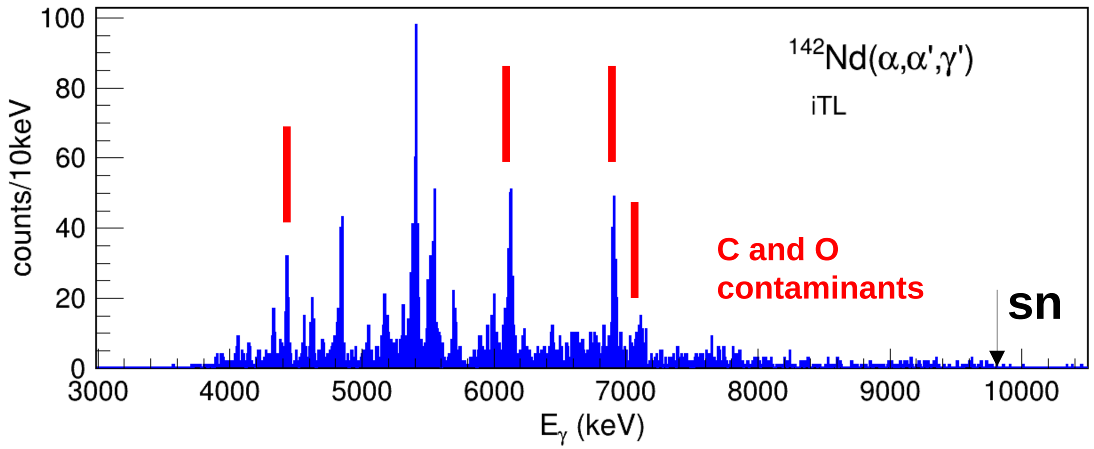
Coincidence timing: real-to-random ~ 10 to 3

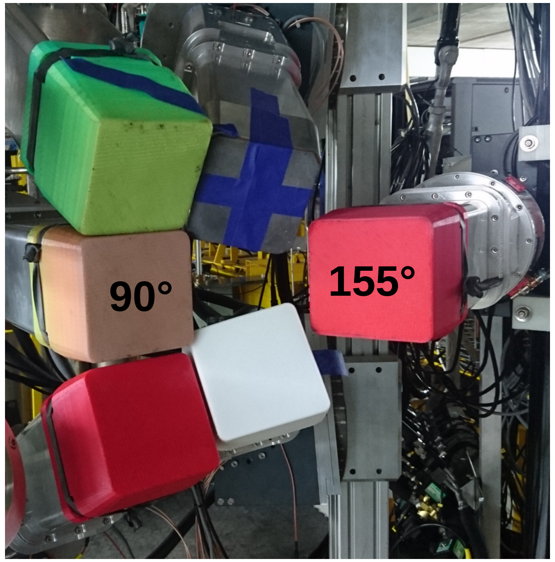


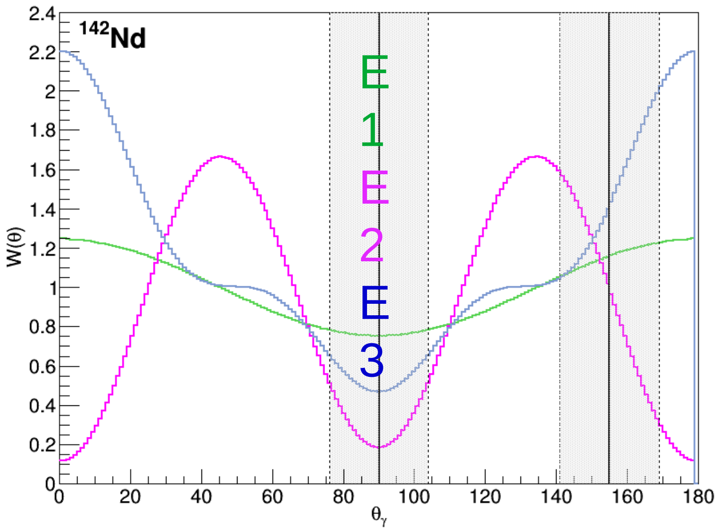
Raw counts:
(w/o contaminants, & random background indicated)

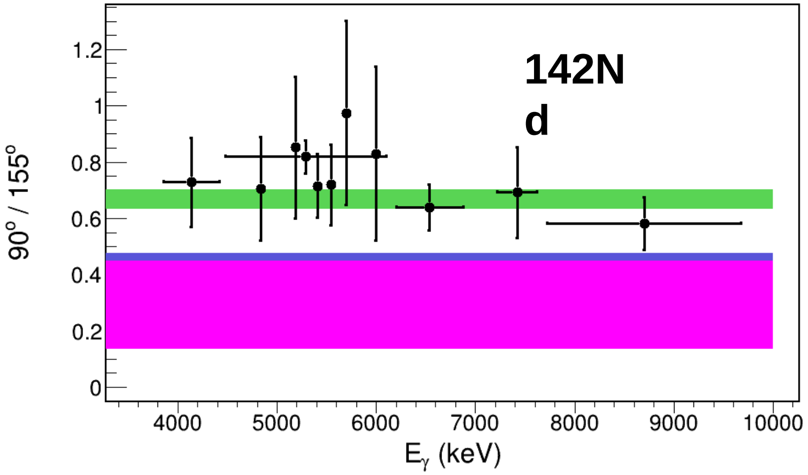


Confirming E1 character

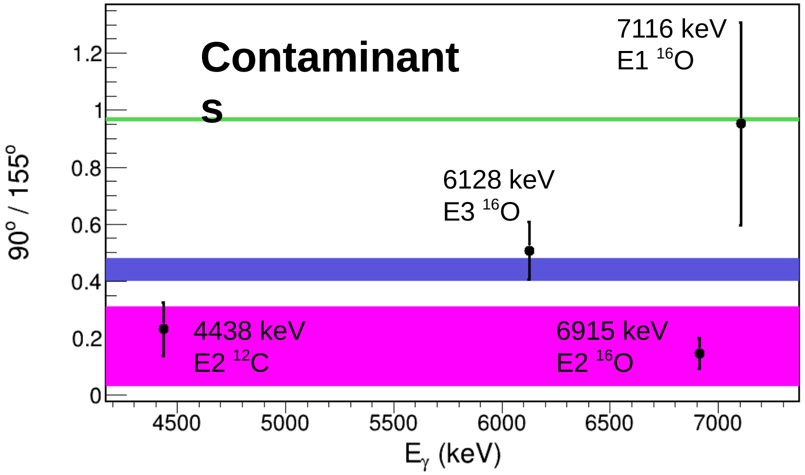






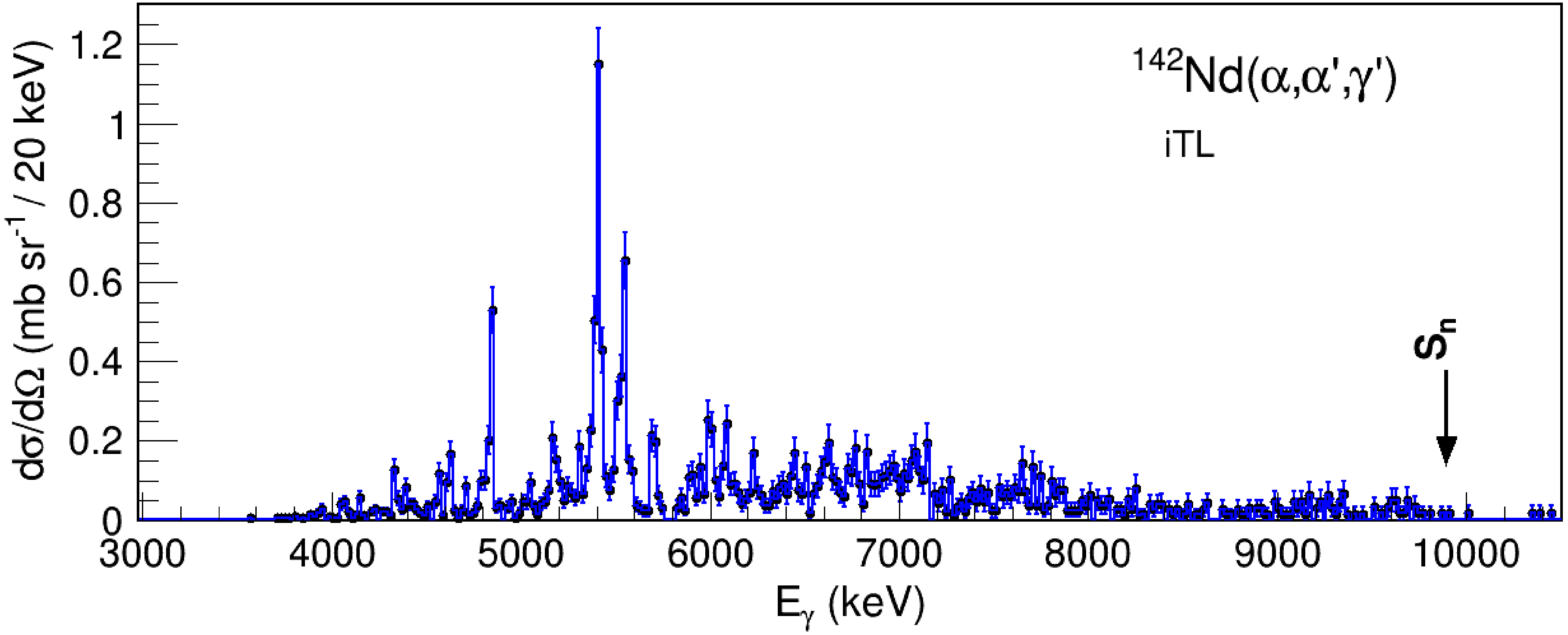


E1
E2
E3

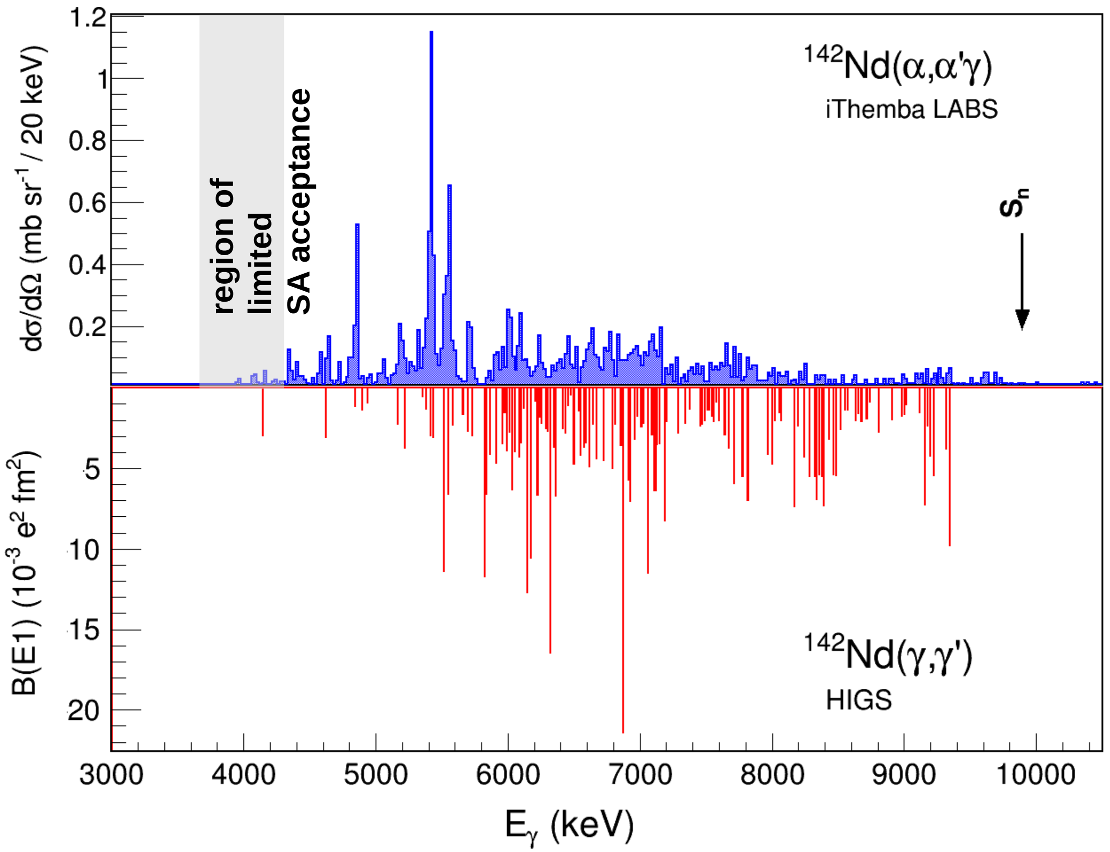


Differential cross section: g.s. decay

$$\frac{d\sigma}{d\Omega_\alpha dE} = \frac{\sum_i C_i}{N_t N_\alpha \Omega_\alpha \delta_{live} \epsilon_{k600} \Delta E \sum_i \epsilon_{abs,i}(E_\gamma) W_i}$$



^{142}Nd : comparison to (γ,γ')



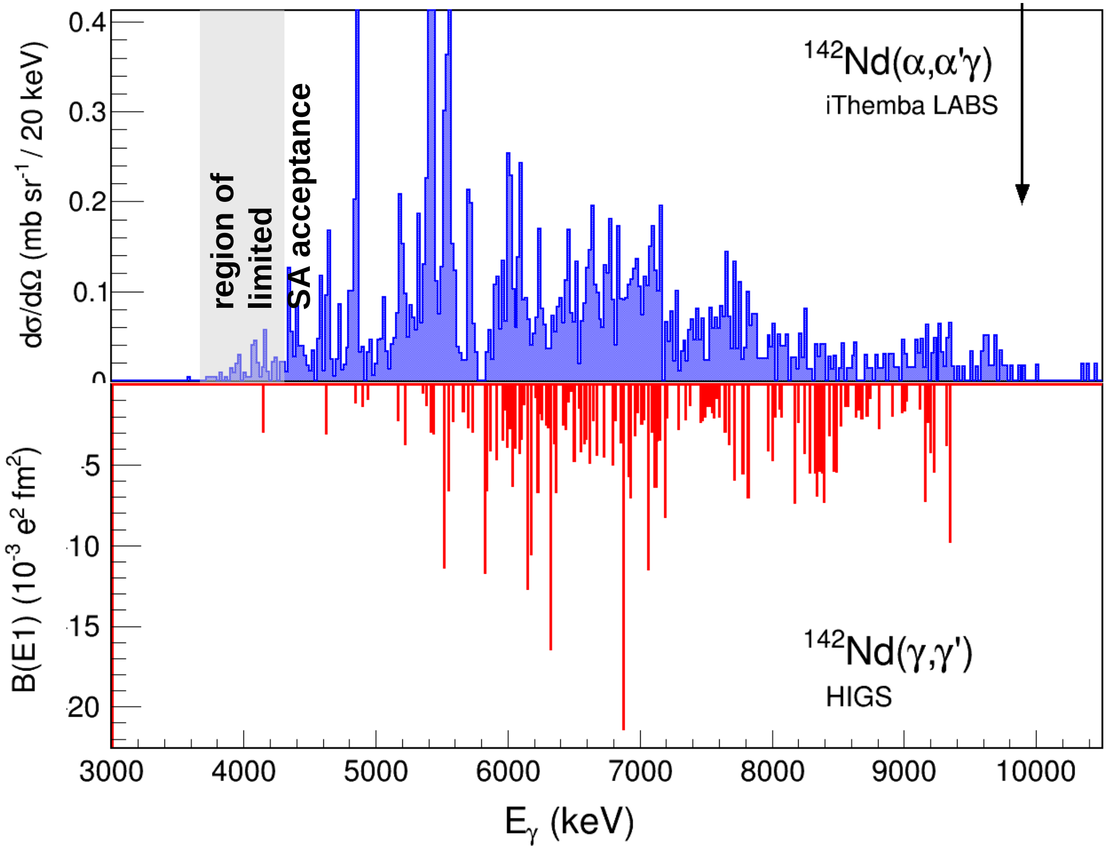
Comparison with HIGS data more instructive

Clear structural similarities

(α,α'γ) strongest below ~6 MeV, as observed for Ce/Ba

(α,α'γ) cross section up to ~6 MeV: ~50% of total
~16% for (γ,γ)

^{142}Nd : comparison to (γ,γ')



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Clear structural similarities

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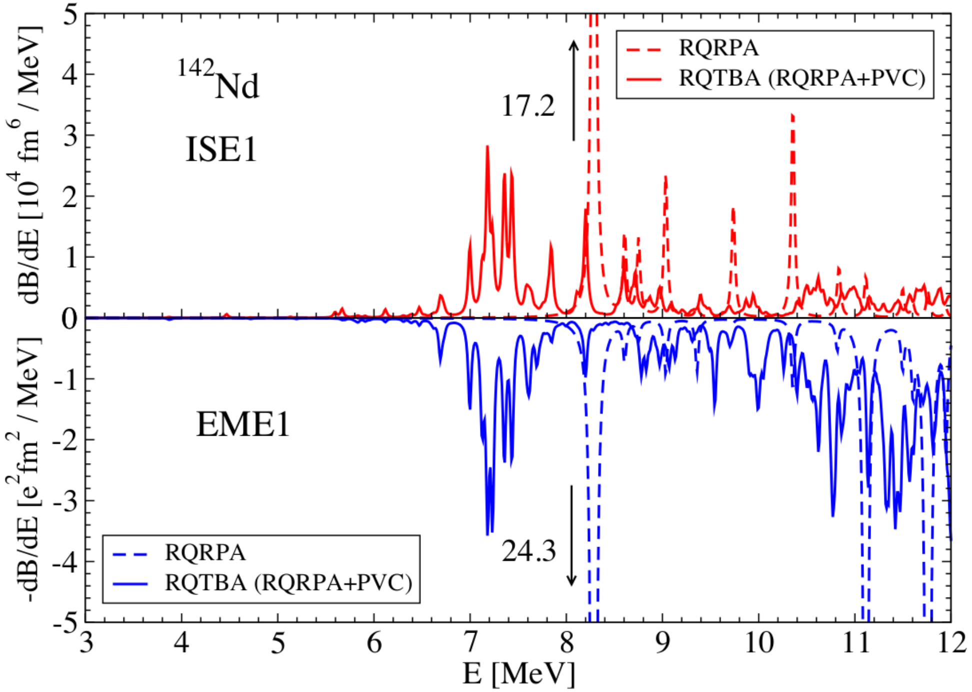
~16% for (γ,γ)

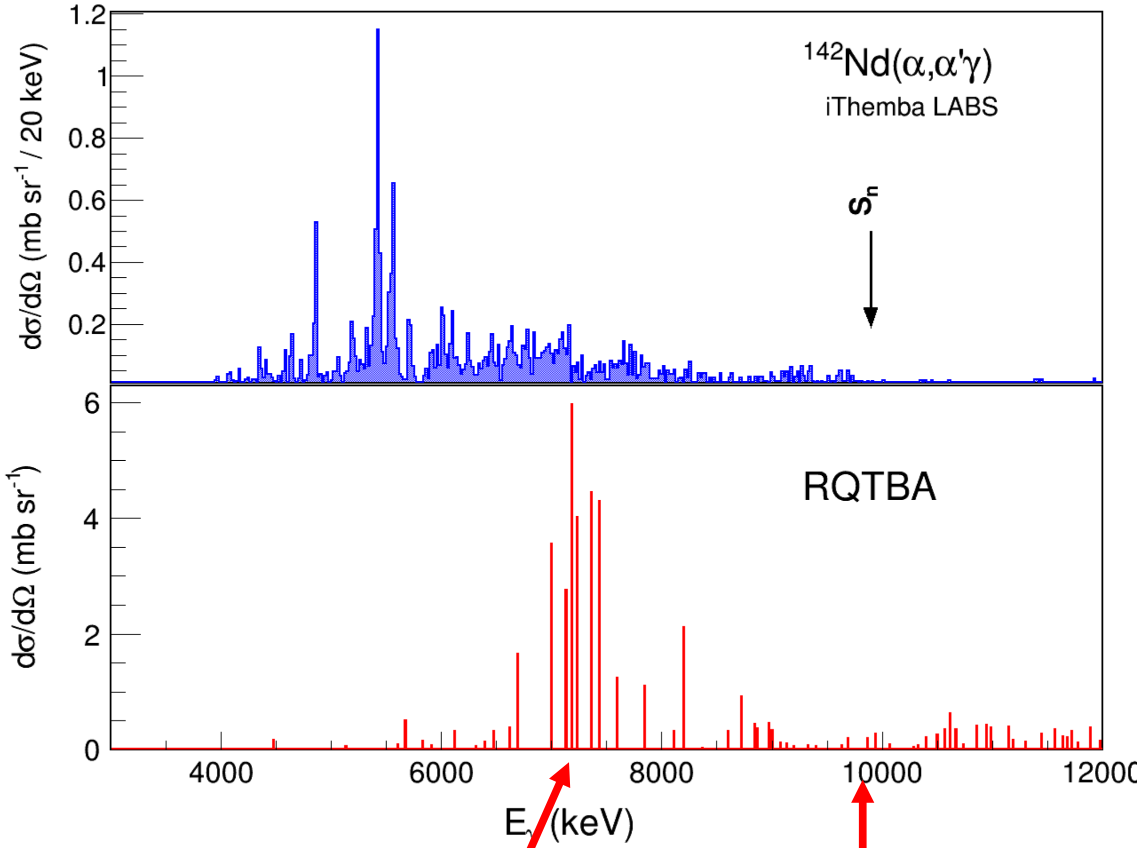
PDR structural split:
- → excitations above 6 MeV suppressed in reaction with isoscaler probe
- → see echos of NRF resolved strength structure in (α,α'γ) results

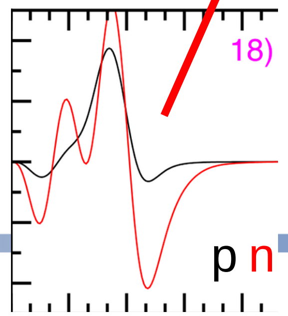
^{142}Nd: comparison to theory

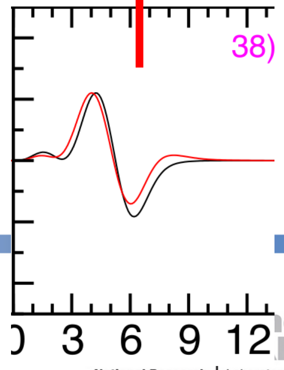
Theoretical calculations for inelastic α-scattering using semiclassical model framework
PHYSICAL REVIEW C 89, 041601(R) (2014)

Info for nucleus internal structure from RQTBA (transition densities)



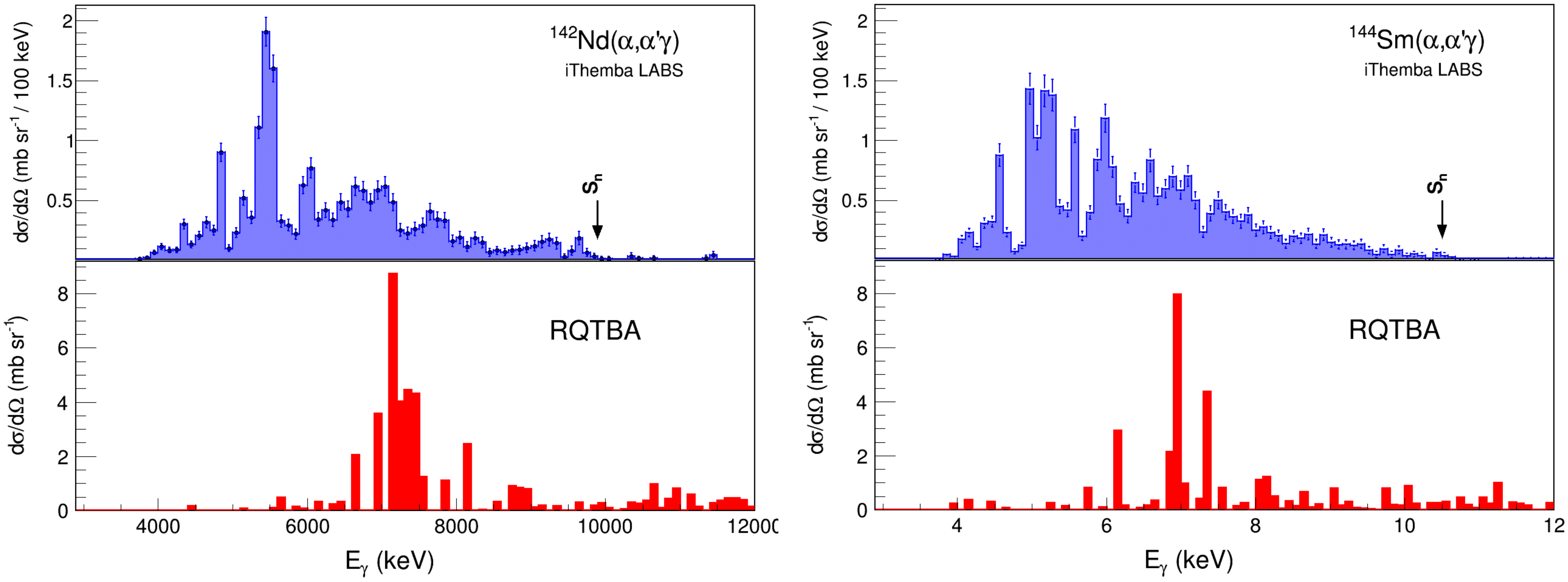






Performed by Elena Litvinova and Edoardo Lanza

^{142}Nd & ^{144}Sm: comparison to theory



^{144}Sm to ^{138}Ba : comparison to (γ,γ')

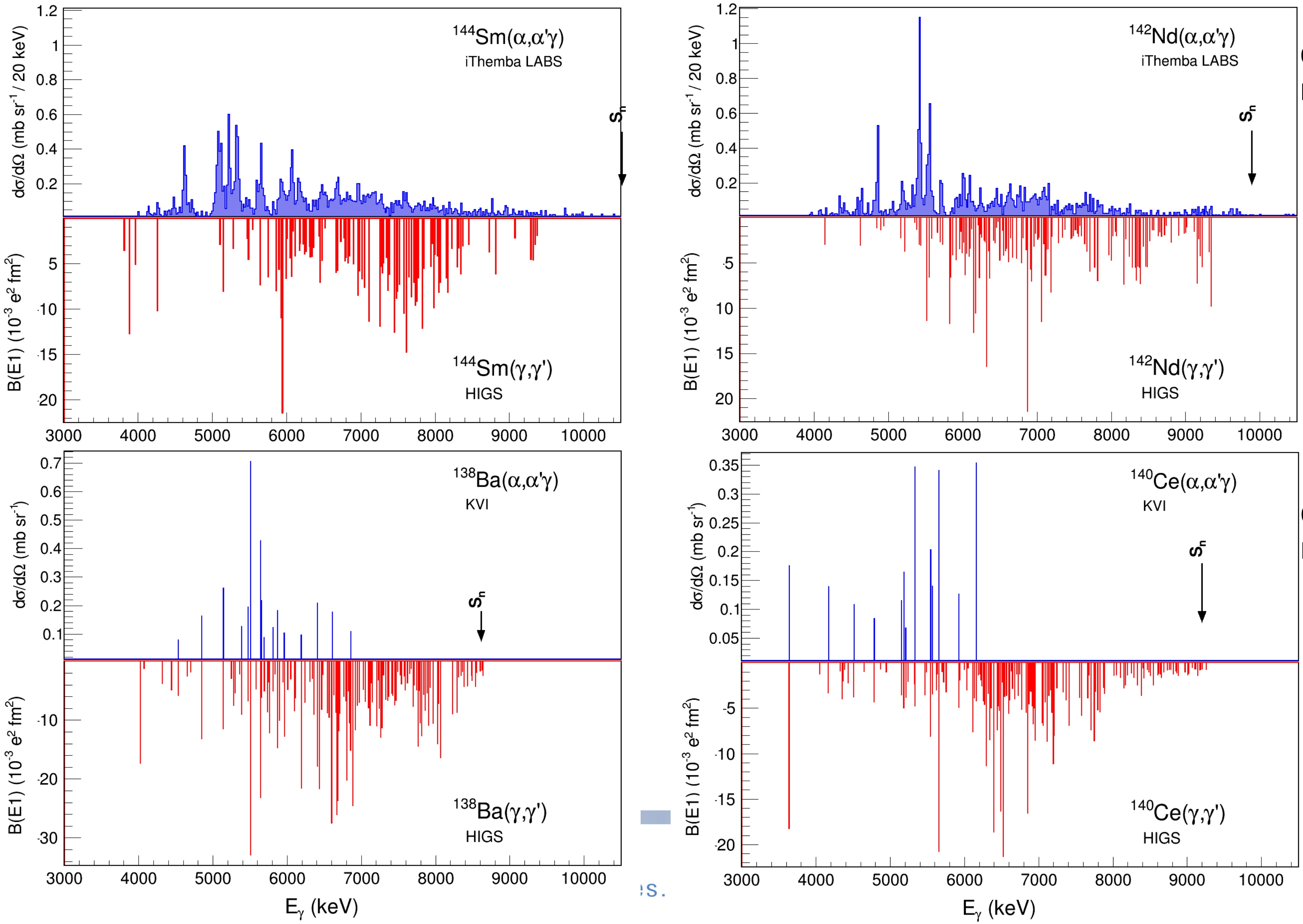
Trend in isoscalar response?

Careful with direct comparison:

1. Different inelastic scattering angles

2. Resolved versus unresolved strengths

Strongest excitations typically ~ 5 - 6 MeV



θ_{K600}=0°
E_α=120 MeV

θ_{BBS}=3.5°
E_α=136 MeV

^{144}Sm to ^{138}Ba : comparison to (γ,γ')

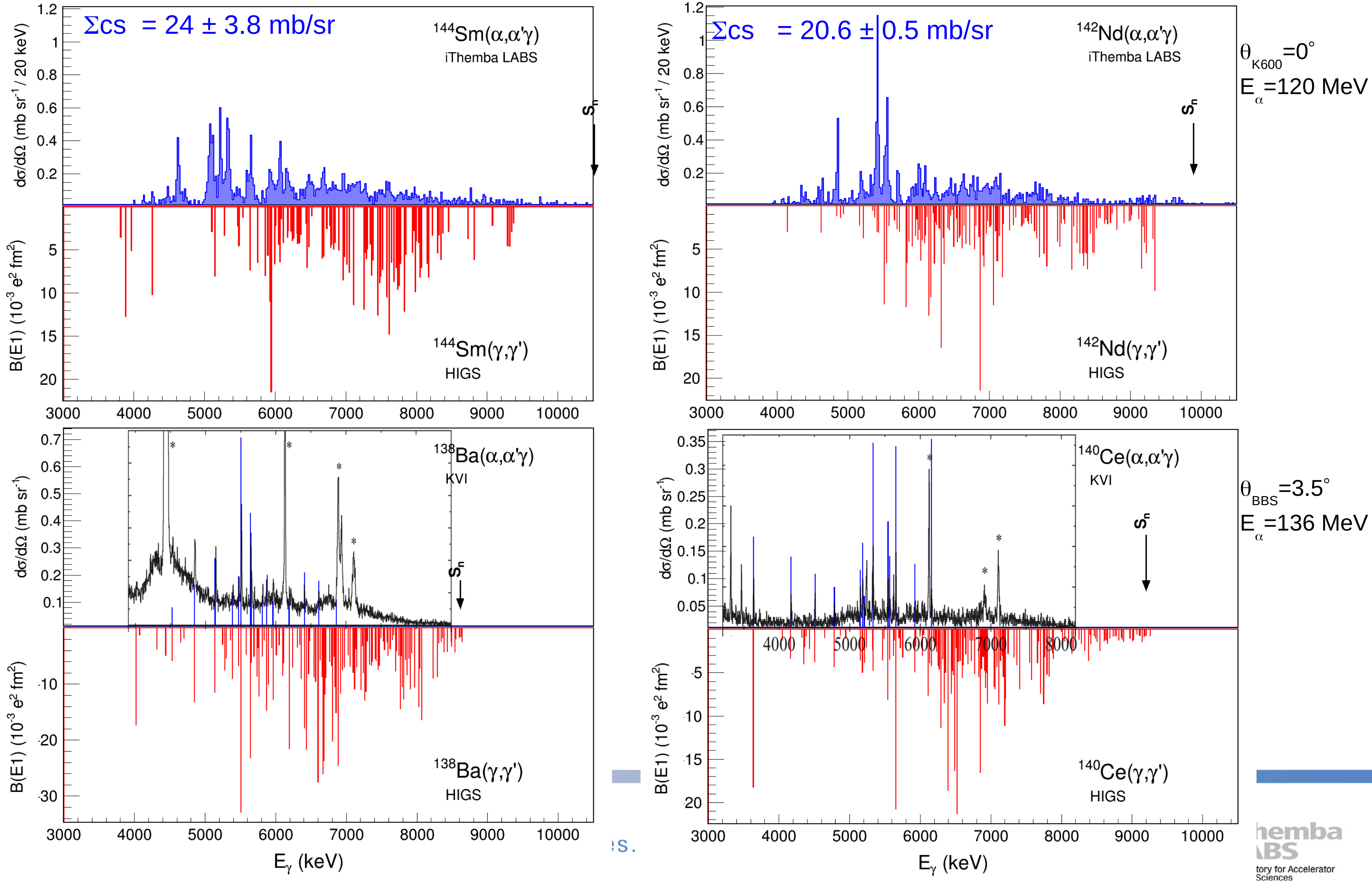
Trend in isoscalar response?

Careful with direct comparison

1. Different inelastic scattering angles

2. Resolved versus unresolved strengths

Ba, Ce: unresolved strength?



^{144}Sm to ^{138}Ba : comparison to (γ,γ’)

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Ba, Ce:
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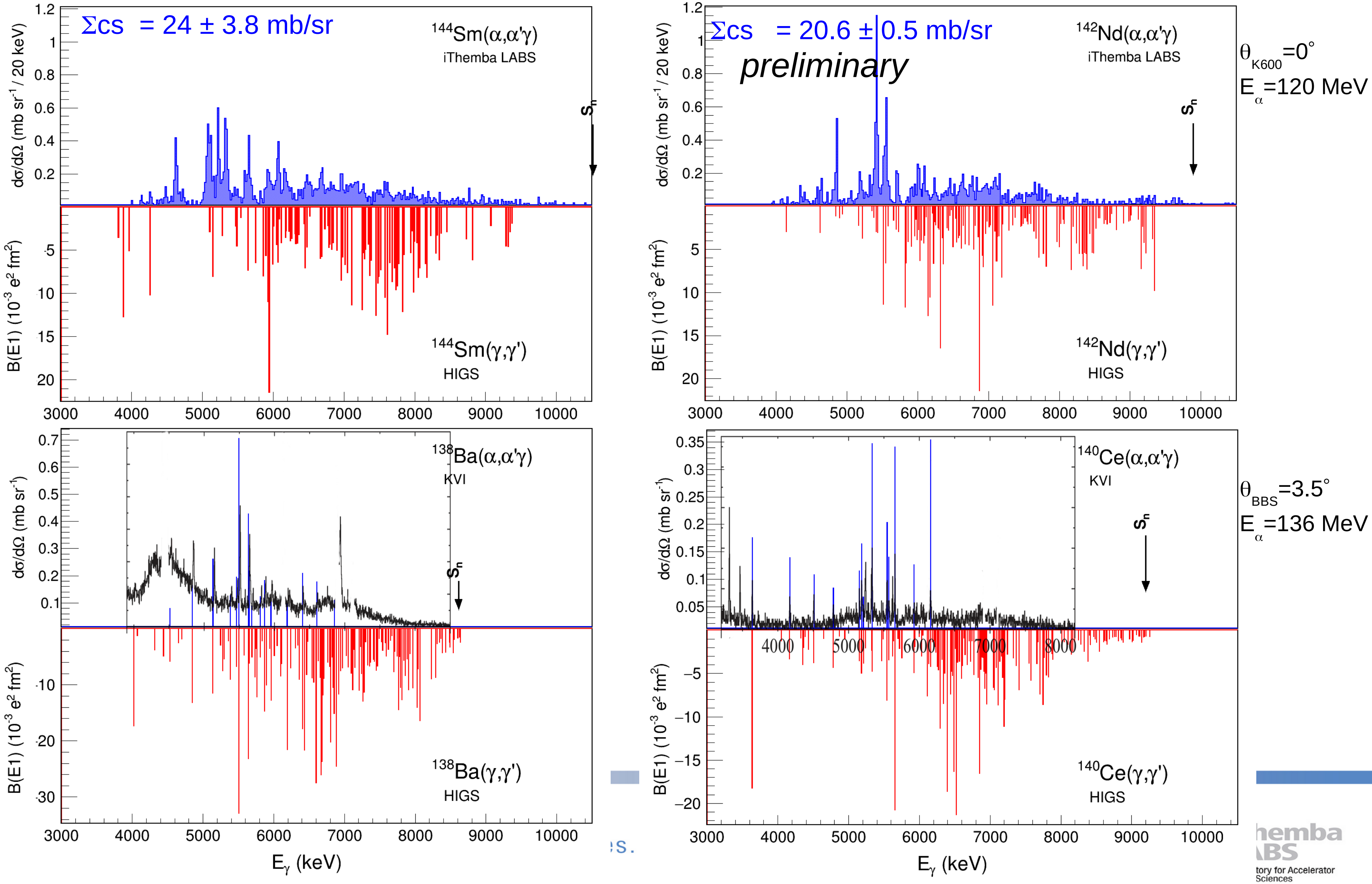

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Conclusion

There is now (α,α'γ)/isoscaler probe data for ^{138}Ba ^{140}Ce, ^{142}Nd, ^{144}Sm

Strong excitation below 6 MeV, in agreemant with established trend, & suppressed above 6 MeV

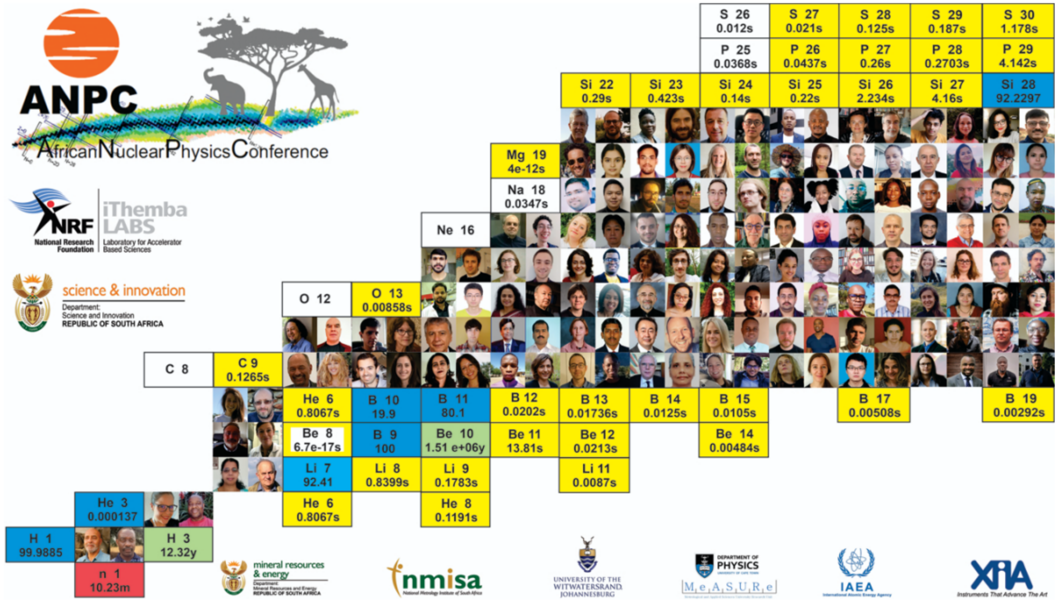
What are trends for total cross section, fragmentation along N=82?

^{144}Sm response in agreement with theoretical predictions: need to investigate closer the case for ^{142}Nd

Collaboration

P Adsley, A Bahini, JW Brummer, J. Carter, A Coman, LM Donaldson,
M. Faber, A Gorgen, H. Jivan, P. Jones, S Jongile, T. Khumalo, E.G. Lanza,
K.C.W. Li, E. Litvinova, D.J. Marin-Lambarri, C. Mihai, P.T. Molema, A Negret,
P. von Neuman-Cosel, R. Neveling, P.Papka, L. Pellegri, V. Pesudo,
D. Savran, E. Sideras-Haddad, F.D. Smit, G.F. Steyn, S. Siem, S.Triambak,
I. Usman, J.J van Zyl, M. Wiedeking and M. Wienert

Registration opens	3 July 2023
Abstract submission opens	**2 June 2023**
Abstract submission deadline	25 August 2023
Notification of acceptance of abstracts	8 September 2023
Early-bird registration closes	13 October 2023
Normal registration closes	17 November 2023



In-person registration is limited to 100 delegates so we recommend registration as soon as it opens to secure your spot!

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29 November – 3 December 2023

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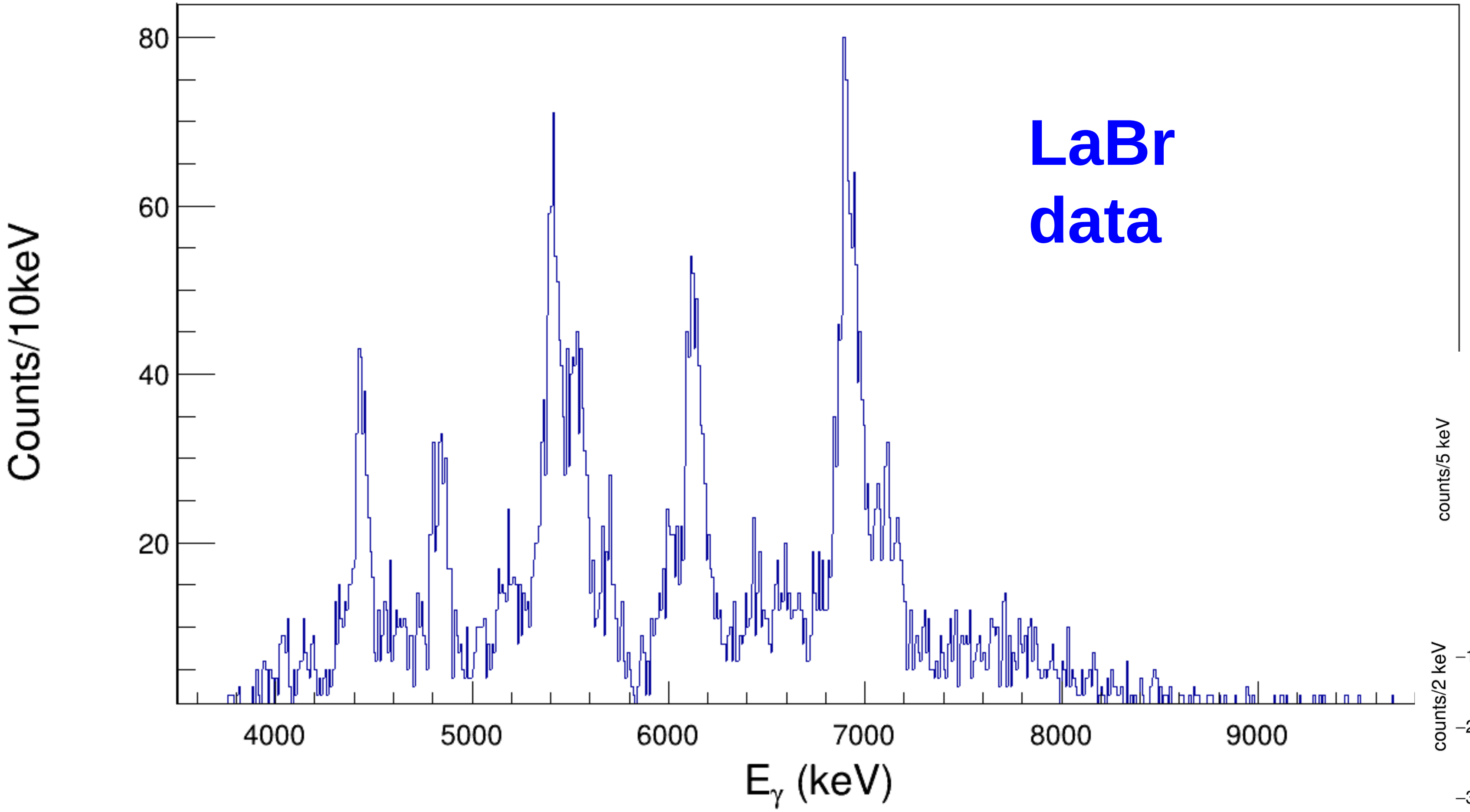
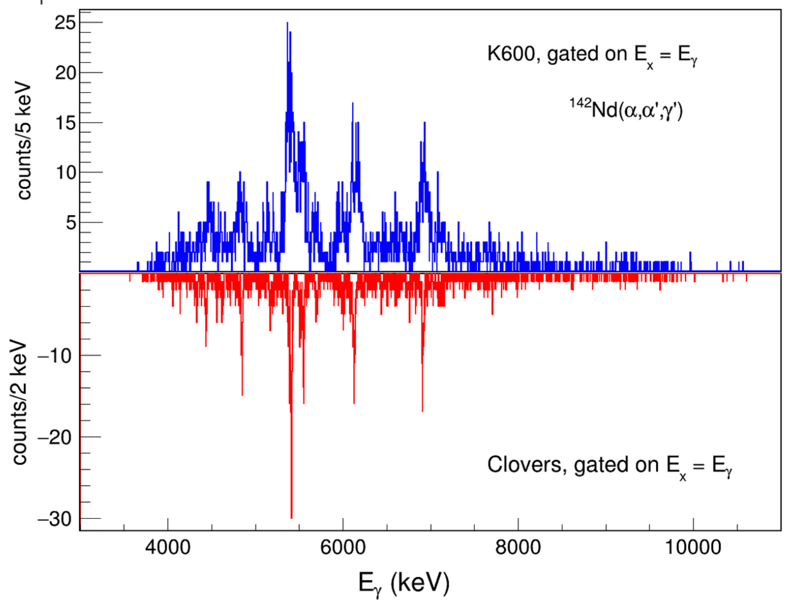
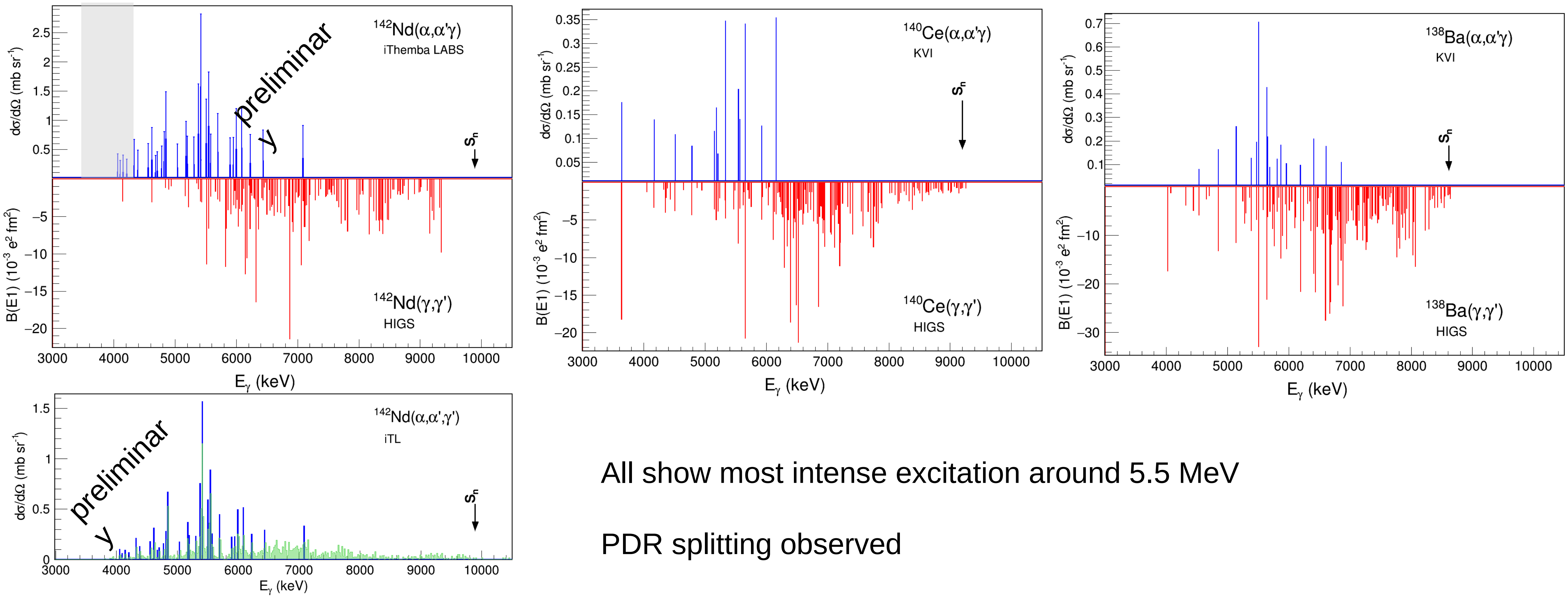
Extra slides

Still to come...





^{142}Nd to ^{138}Ba : resolved strength only



All show most intense excitation around 5.5 MeV

PDR splitting observed