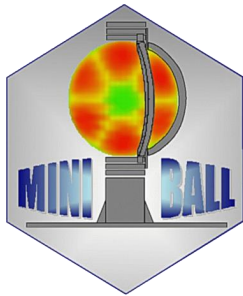


Exploiting post-accelerated RIBs at HIE-ISOLDE

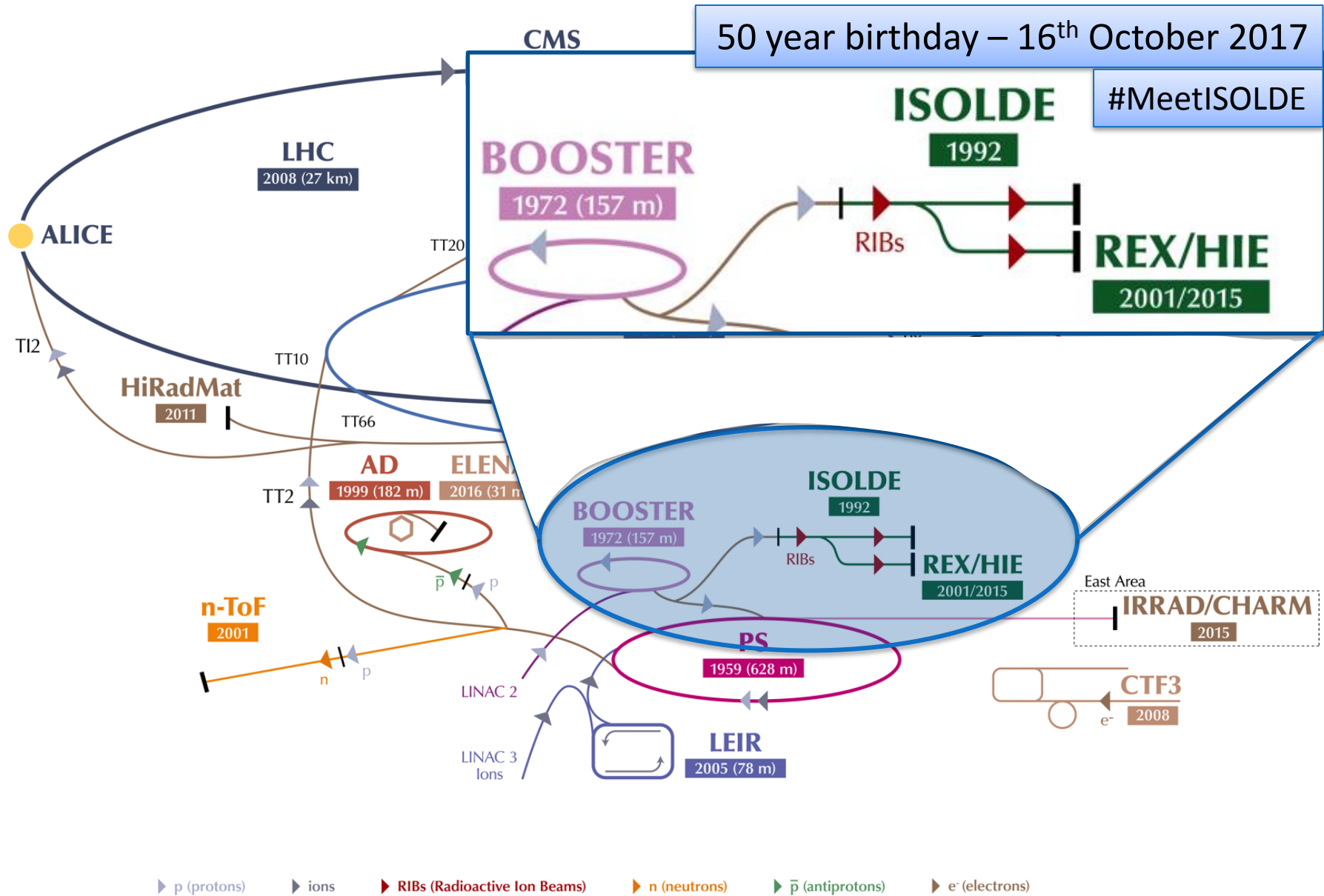
Liam Gaffney (CERN)



CERN accelerator complex

50 year birthday – 16th October 2017

#MeetISOLDE

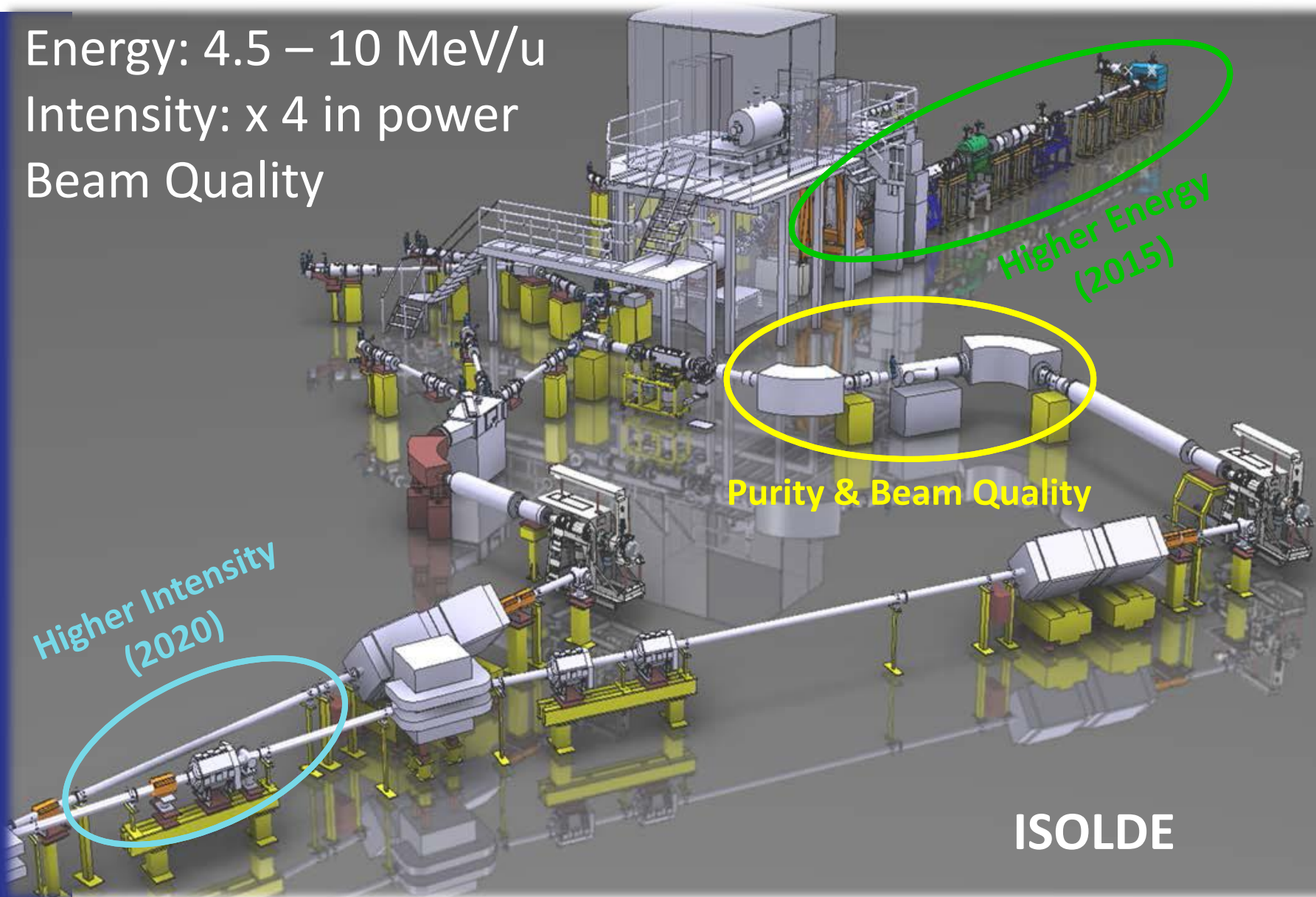


The HIE-ISOLDE project (2010 -)

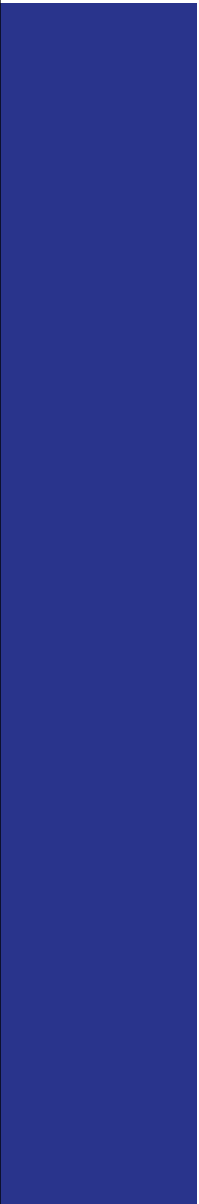
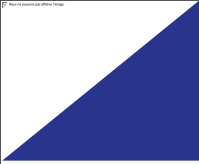
Energy: 4.5 – 10 MeV/u

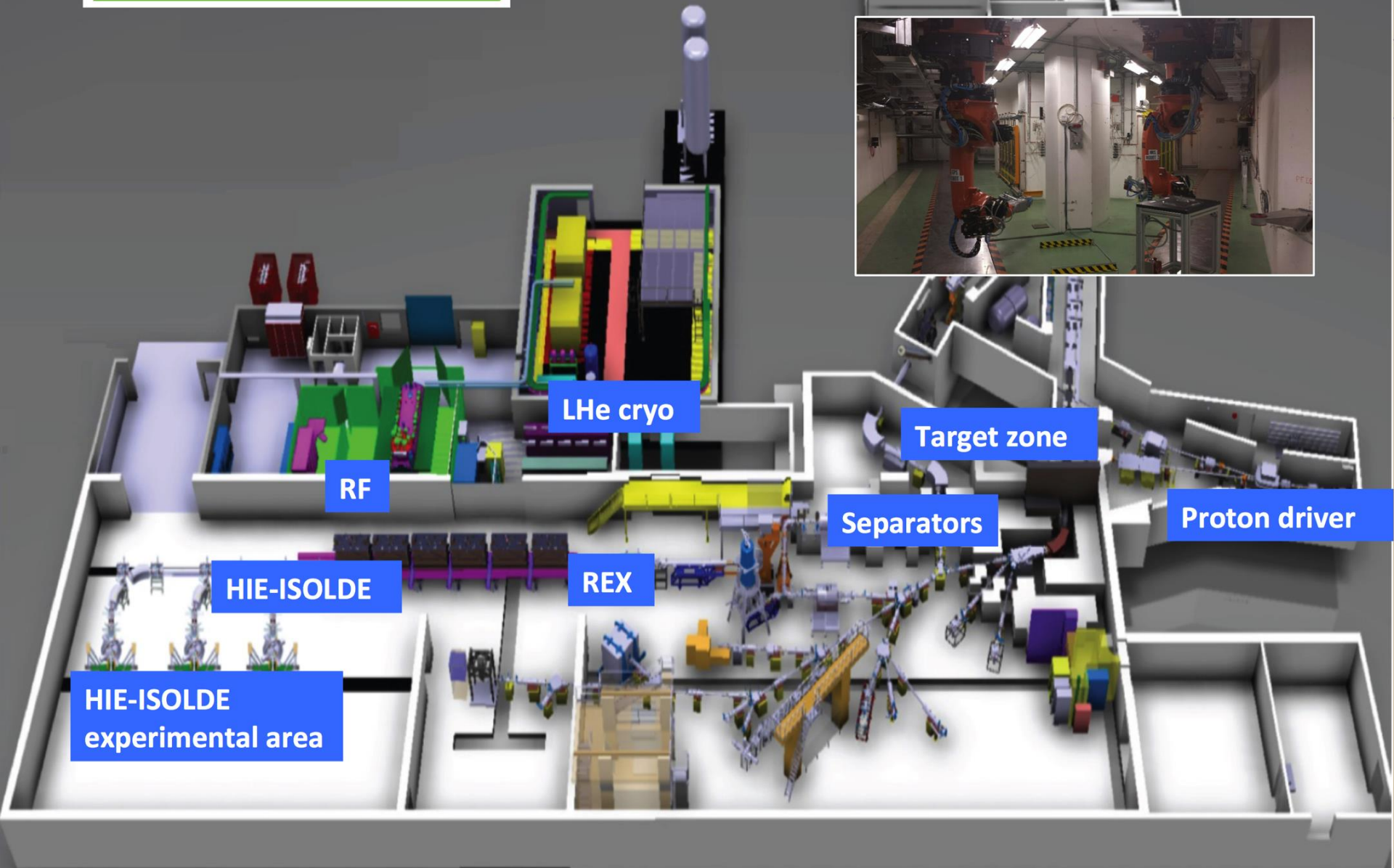
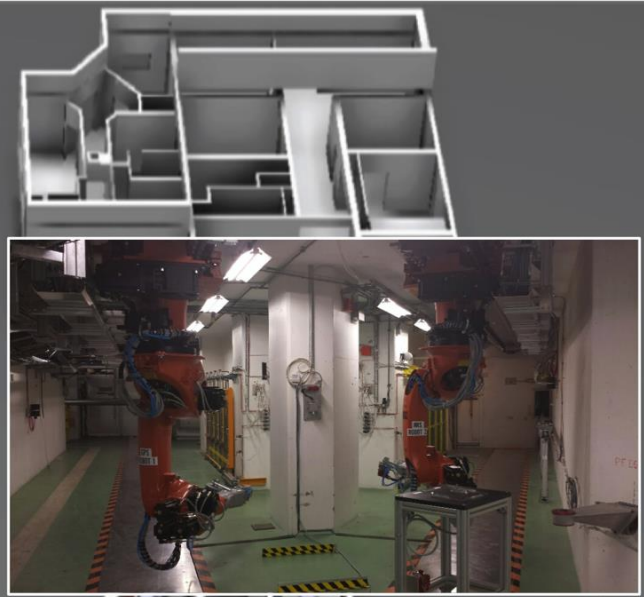
Intensity: x 4 in power

Beam Quality



ISOLDE





RF

LHe cryo

HIE-ISOLDE

REX

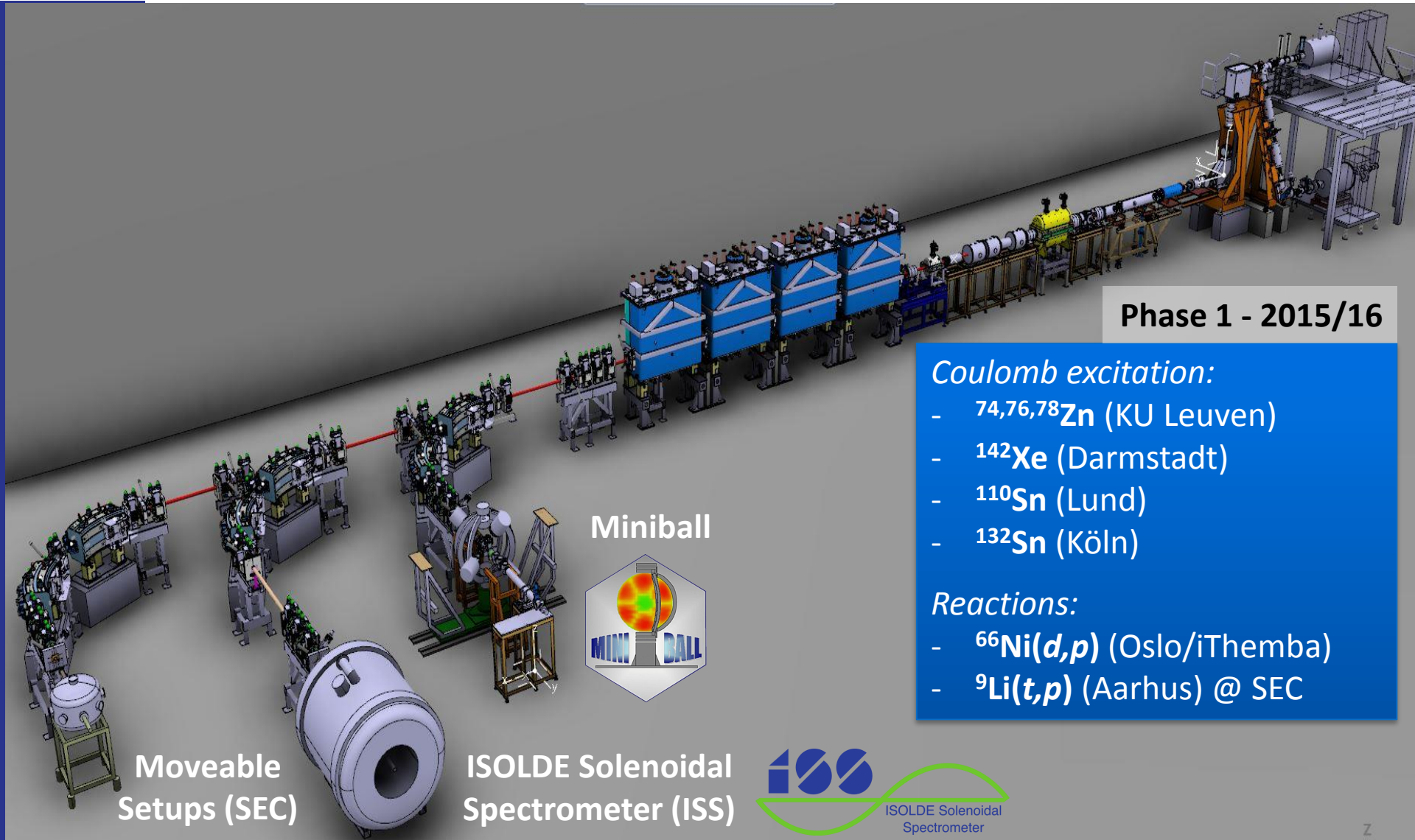
Separators

Target zone

Proton driver

HIE-ISOLDE
experimental area

HIE-ISOLDE Phase 2 (2016-2018)



Phase 1 - 2015/16

Coulomb excitation:

- $^{74,76,78}\text{Zn}$ (KU Leuven)
- ^{142}Xe (Darmstadt)
- ^{110}Sn (Lund)
- ^{132}Sn (Köln)

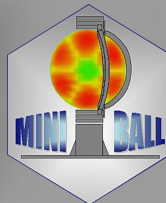
Reactions:

- $^{66}\text{Ni}(d,p)$ (Oslo/iThemba)
- $^9\text{Li}(t,p)$ (Aarhus) @ SEC

Moveable
Setups (SEC)

ISOLDE Solenoidal
Spectrometer (ISS)

Miniball



HIE-ISOLDE Phase 2 (2017-2018)

Reactions:

- $^{94}\text{Rb}(^{208}\text{Pb})$ MNT (Legnaro/Zagreb)
- $^{15}\text{C}(^{208}\text{Pb})$ Elastic (Huelva)
- $^9\text{Li}(t,p)$ (Aarhus)
- $^{59}\text{Cu}(p,\alpha)$ (Edinburgh)

Commissioning:

- ^{22}Ne to ISS

Phase 2a – 2017

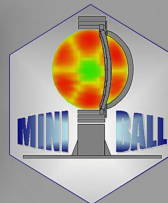
Coulomb excitation:

- ^{72}Se (Surrey)
- $^{70}\text{Se}/^{66}\text{Ge}$ (Western Cape)
- $^{142,144}\text{Ba}$ (Paisley/Liverpool)
- ^{140}Sm (Oslo)
- ^{140}Nd (Darmstadt/Sofia)
- ^{108}Sn (Lund)
- ^{206}Hg (Surrey)

Moments:

- ^{28}Mg g-factor (Orsay)

Miniball



Moveable
Setups (SEC)

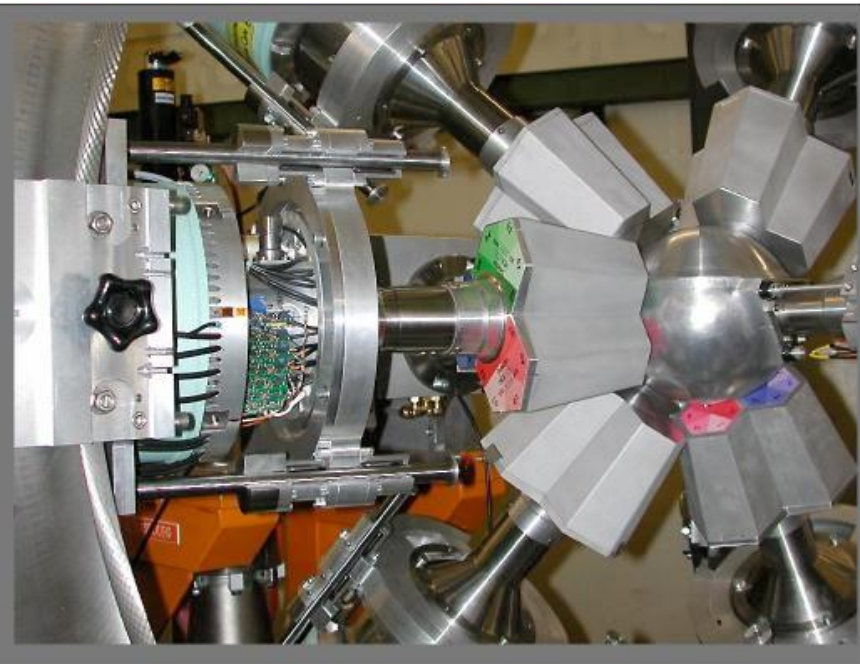


Miniball @ HIE-ISOLDE



$A/Q \sim < 4$
 $< 7.5 \text{ MeV/u}$
(2017)

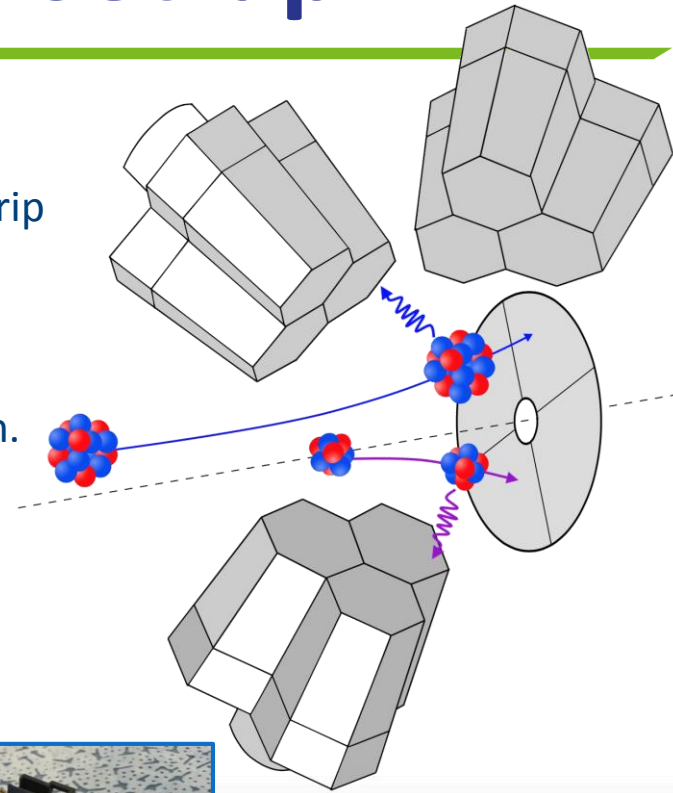
Miniball: Coulex set-up



Particle ID in a
Double-Sided Si Strip
Detector (DSSSD).

Event-by-event
Doppler correction.

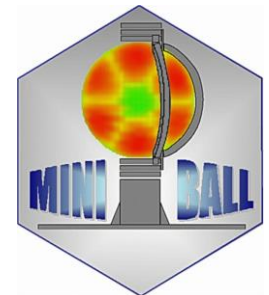
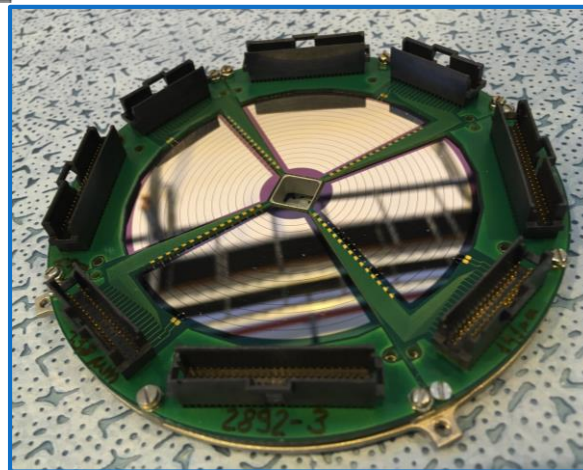
$$17^\circ < \theta_{\text{lab}} < 54^\circ$$



Array of HPGe of 8 triple clusters

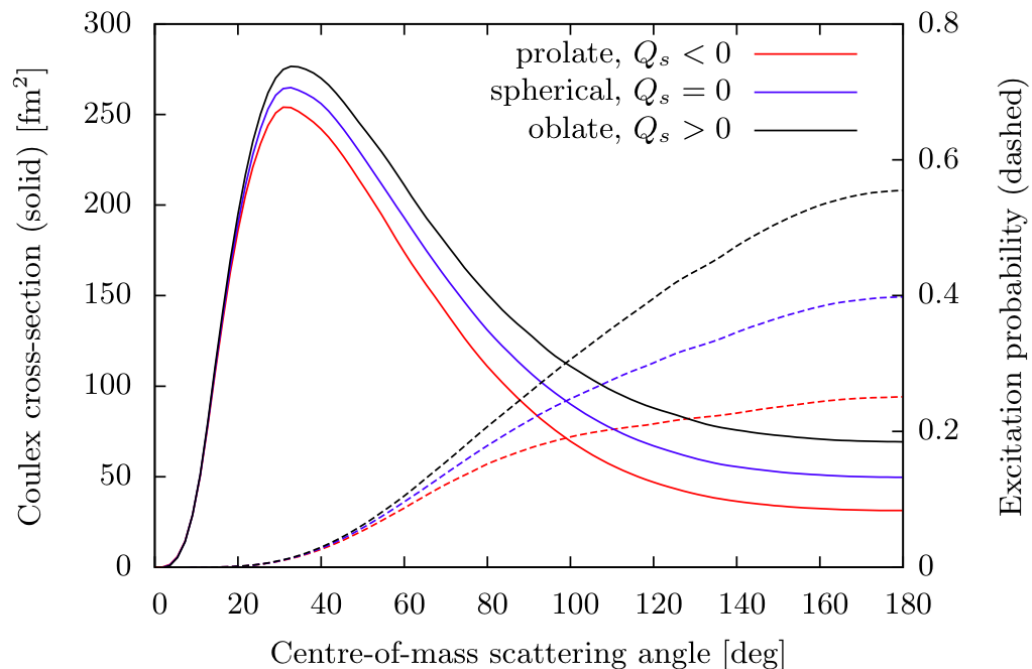
6-fold electronic segmentation

$\epsilon > 7\%$ for 1.3MeV γ -rays



Why use Coulomb excitation?

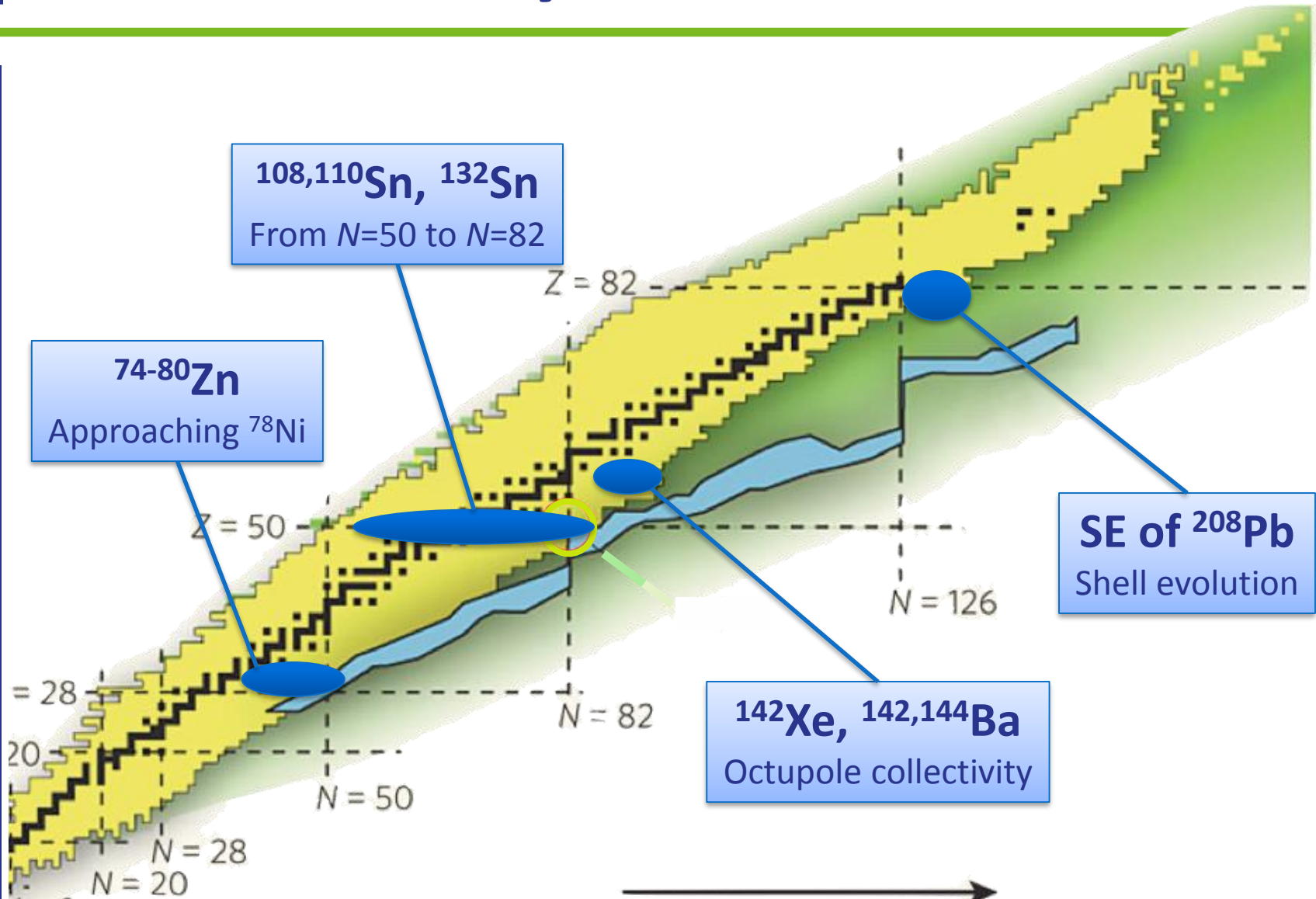
- Renaissance of “old” technique at new state-of-the-art RIB facilities.
- High cross sections (\sim barns)
- Ideal beam energies at ISOL facilities with post-acceleration – HIE-ISOLDE!
- Access to non-yrast states
- Complete sets of matrix elements accessible
- Sensitivity to spectroscopic quadrupole moments, Q_s .



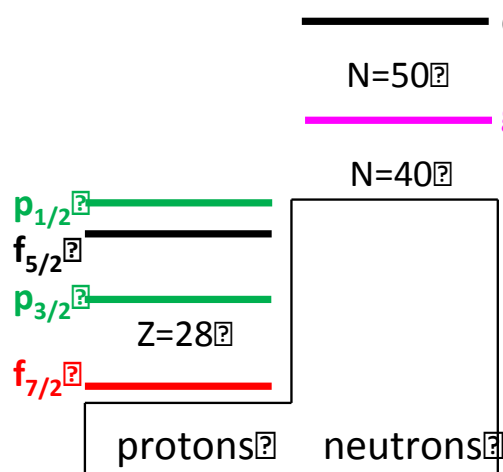
Additionally:

- useful in the search for new states
- sensitive to **sign** combinations

Physics cases

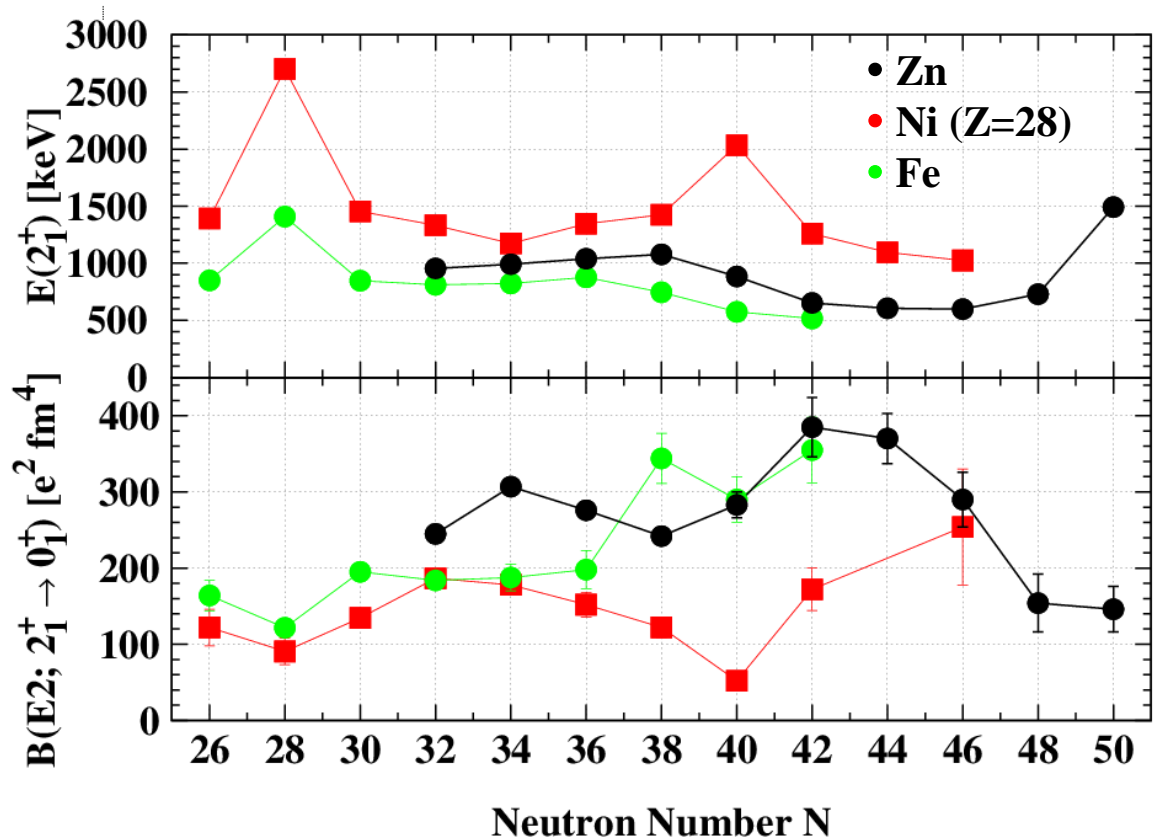


74,76,78Zn – IS557

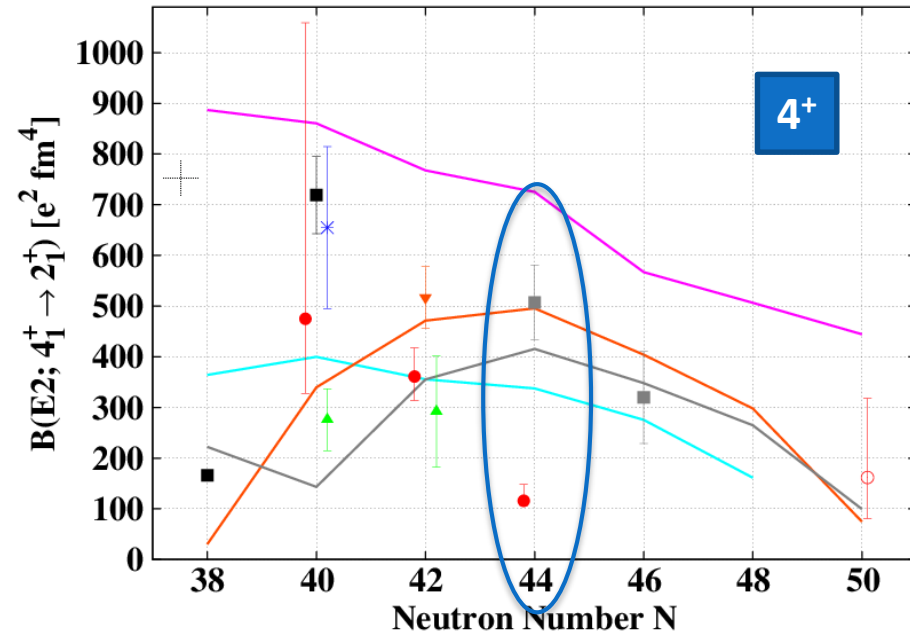
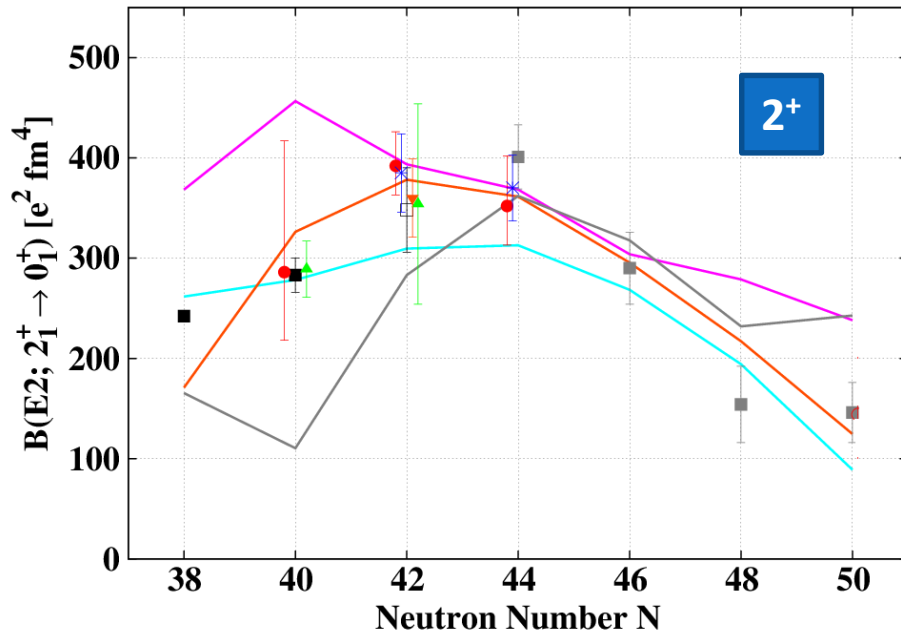


What happens when going towards $N=50$?

74-80Zn: Coulomb excitation at REX-ISOLDE
(Van de Walle PRC (2009))



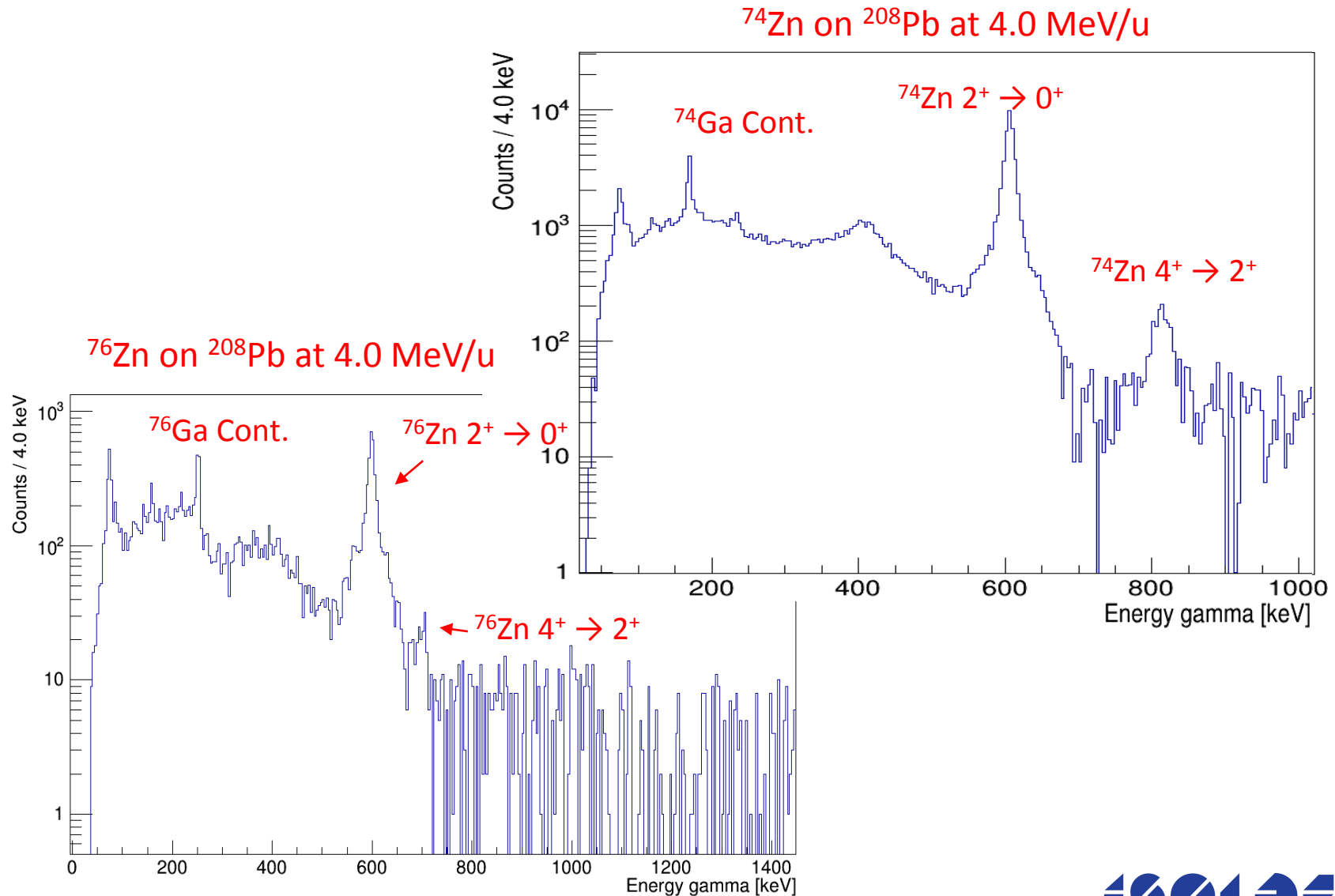
Transition strengths in Zn



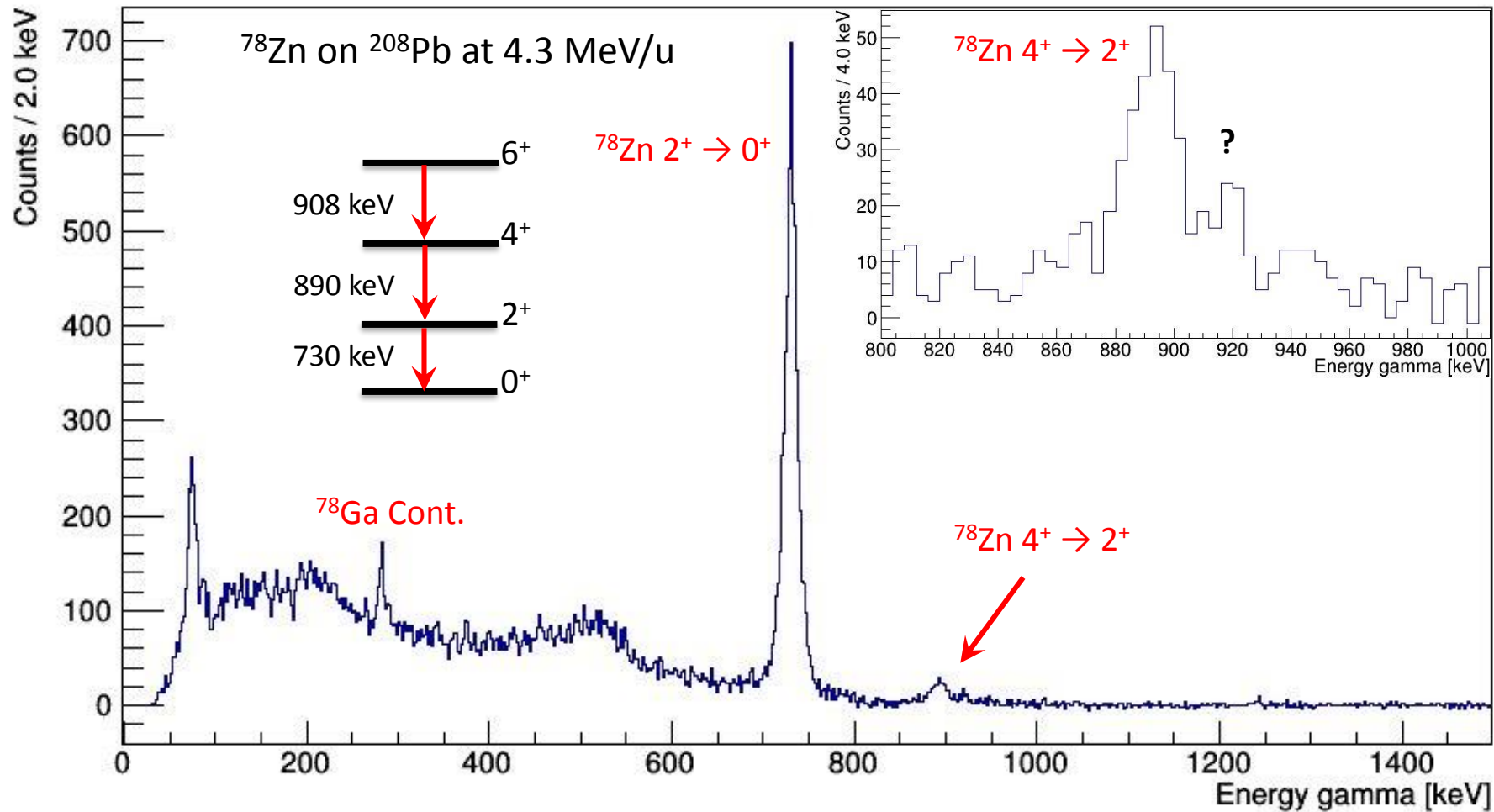
- Data:
 - Coulomb excitation
 - Van de Walle PRC (2009)
 - ▼ Hellgartner, TU Munich (2015)
 - Doppler shift
 - Louchart PRC (2013)
 - ▲ Čeliković Act. Phys. Pol. (2013)
 - National Nuclear Data Center (NNDC)
 - Shiga PRC (2016)

- Theory:
 - Shell model calculations
 - JUN45 (⁵⁶Ni core: pf_{5/2}g_{9/2}) Honma PRC (2009)
 - ... LNPS (48Ca: pfg_{9/2}d_{5/2}) Lenzi PRC (2010)
 - MCSM Otsuka *Priv. comm.* (2016), Shimizu Phys. Scr. (2017)
 - HFB – Gogny D1S force
 - Delaroche PRC (2010)

γ -ray spectra $^{74,76}\text{Zn}$



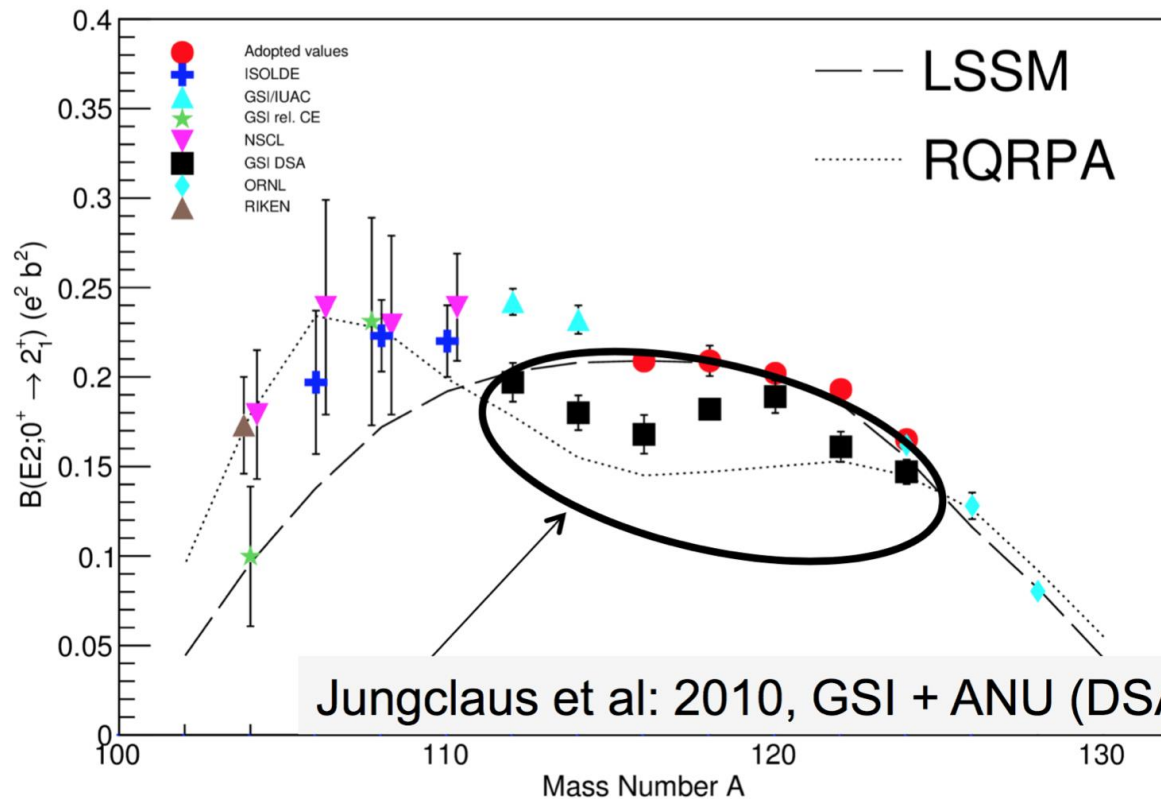
γ -ray spectra ^{78}Zn (2016)



108,110...132Sn – Extreme isotopes

99Sn 5 ME	100Sn 1.0 f	101Sn 1.7 f	102Sn 4.5 f	103Sn 7.0 f	104Sn 20.8 f	105Sn 34 f	106Sn 115 f	107Sn 2.90 M	108Sn 10.90 M	109Sn 18.0 M	110Sn 4.11 H	111Sn 35.3 M	112Sn STABLE	113Sn 115.09 D	114Sn STABLE	115Sn STABLE	116Sn STABLE	117Sn STABLE	118Sn STABLE	119Sn STABLE	120Sn STABLE	121Sn 27.03 H	122Sn STABLE	123Sn 129.2 D	124Sn STABLE	125Sn 9.64 D	126Sn 2.30E+5 Y	127Sn 2.10 H	128Sn 59.07 M	129Sn 2.23 M	130Sn 3.72 M	131Sn 56.0 f	132Sn 39.7 f	133Sn 1.45 f	134Sn 1.050 f	135Sn 530 ME	136Sn 0.25 f	137Sn 190 ME					
ε	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%

- Both ends of the Sn isotopic chain, towards N=50 and N=82.
- Discrepancies exist even in the middle of the chain...
- Large uncertainties on the neutron-deficient side



Doubly magic ^{132}Sn – IS551

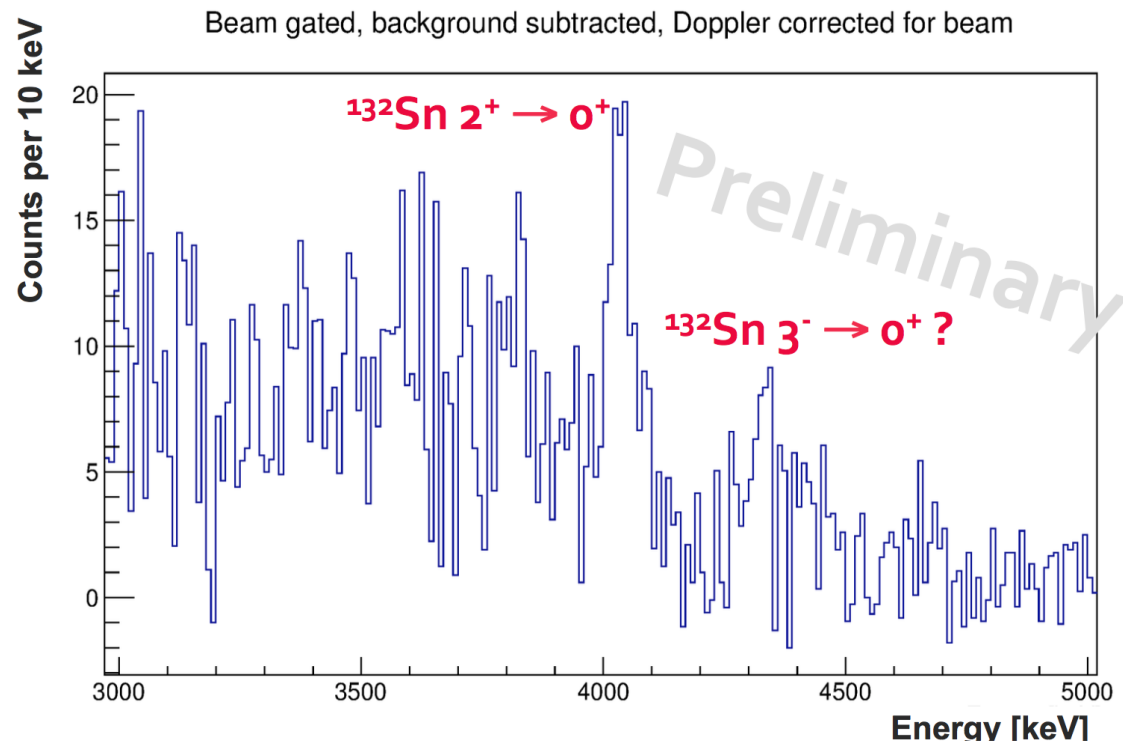
99Sn 5 ME	100Sn 1.0 f	101Sn 1.7 f	102Sn 4.5 f	103Sn 7.0 f	104Sn 20.8 f	105Sn 34 f	106Sn 115 f	107Sn 2.90 M	108Sn 10.90 M	109Sn 18.0 M	110Sn 4.11 H	111Sn 35.3 M	112Sn STABLE 0.2%	113Sn 115.09 D	114Sn STABLE 0.6%	115Sn STABLE 0.3%	116Sn STABLE 14.5%	117Sn STABLE 7.6%	118Sn STABLE 24.2%	119Sn STABLE 8.9%	120Sn STABLE 32.9%	121Sn 27.03 H	122Sn STABLE 4.6%	123Sn 129.2 D	124Sn STABLE 5.7%	125Sn 9.64 D	126Sn 2.30E+5 Y	127Sn 2.10 H	128Sn 59.07 M	129Sn 2.23 M	130Sn 3.72 M	131Sn 56.0 f	132Sn 397 f	133Sn 1.45 f	134Sn 1.050 f	135Sn 530 ME	136Sn 0.25 f	137Sn 190 ME					
ε	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%	ε-100.00%

- First 2^+ at 4.041 MeV; coupled with low $B(E2) \rightarrow$ Very low cross-section!
- Preliminary result, analysis of single- and double-escape peaks.
- Hints of 3^- excitation also observed.

Previous measurements:

$B(E2; 0^+ \rightarrow 2^+) = 0.14(6) e^2b^2$
D.C. Radford et al., Nucl. Phys. A746, 83c (2004)

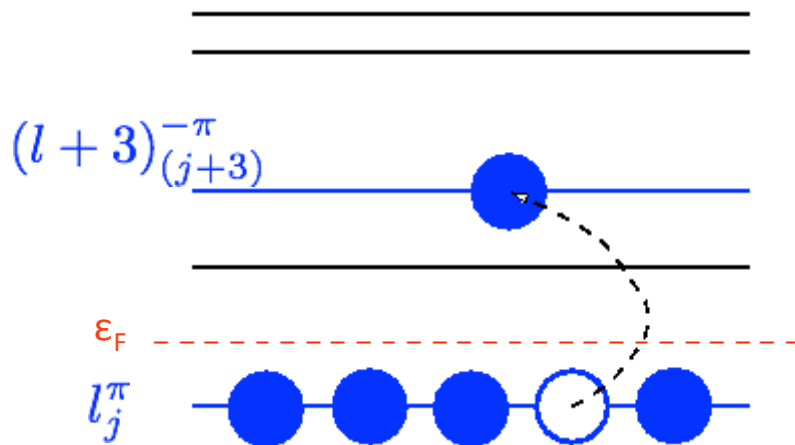
$B(E2; 0^+ \rightarrow 2^+) = 0.11(3) e^2b^2$
R.L. Varner et al., Eur. Phys. J. A 25, s01, 391 (2005)



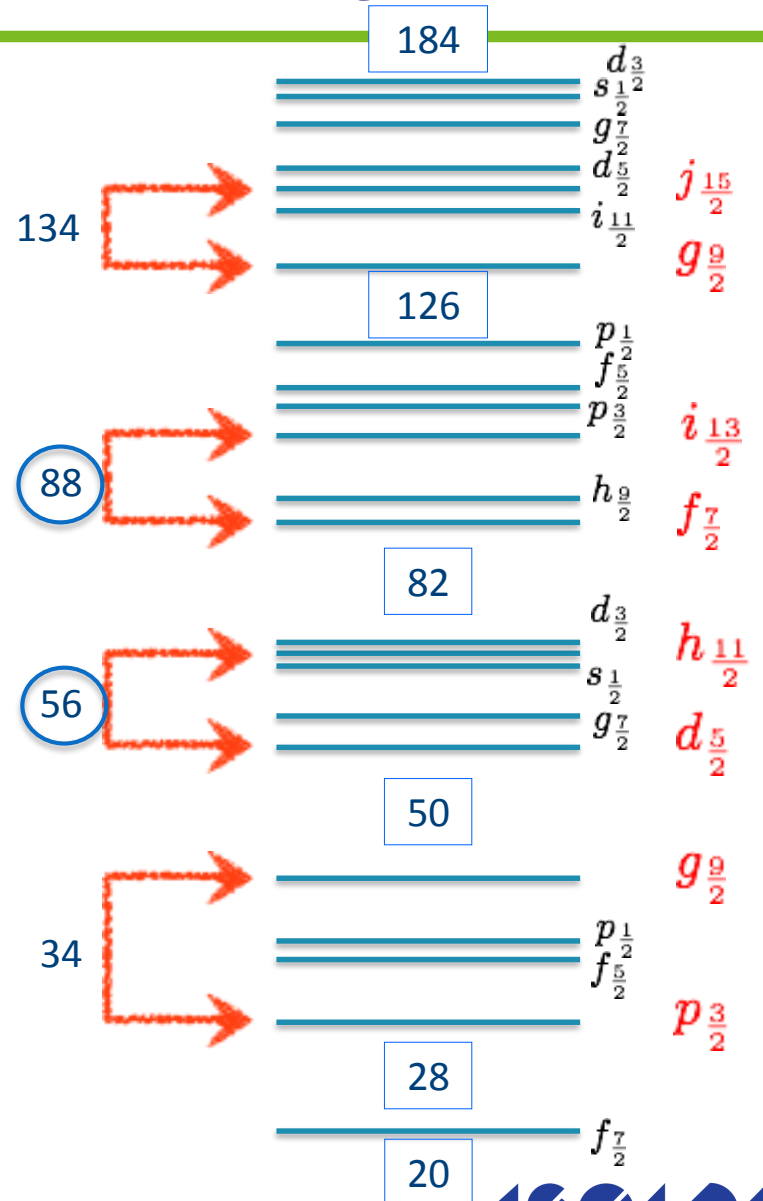
Octupole Collectivity

Microscopically driven...

Intruder orbitals of opposite parity and ΔJ ,
 $\Delta L = 3$ close to the Fermi level

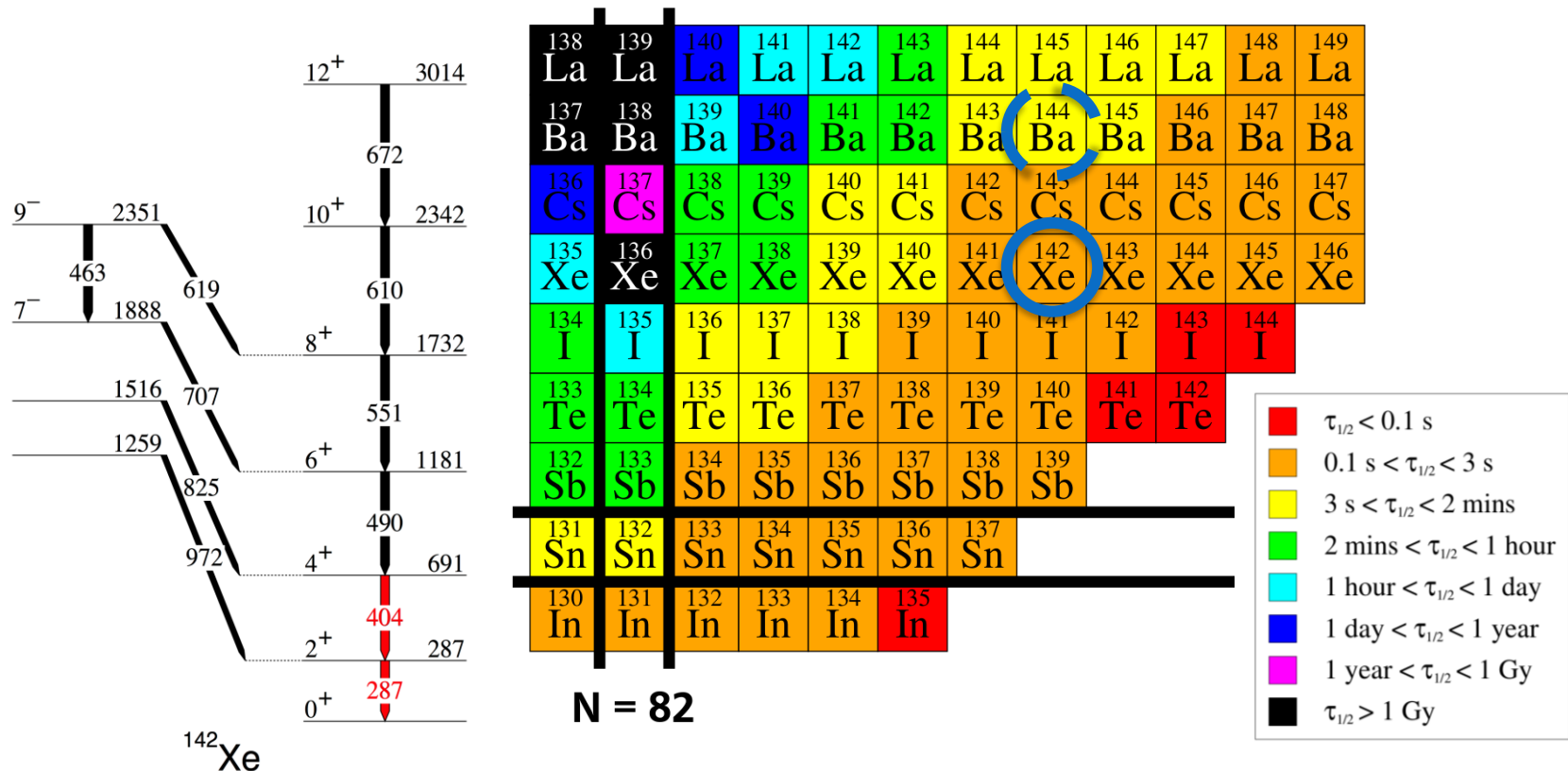


^{144}Ba is centre of the
 $Z = 56, N = 88$ region



North-east of ^{132}Sn : ^{142}Xe & ^{144}Ba

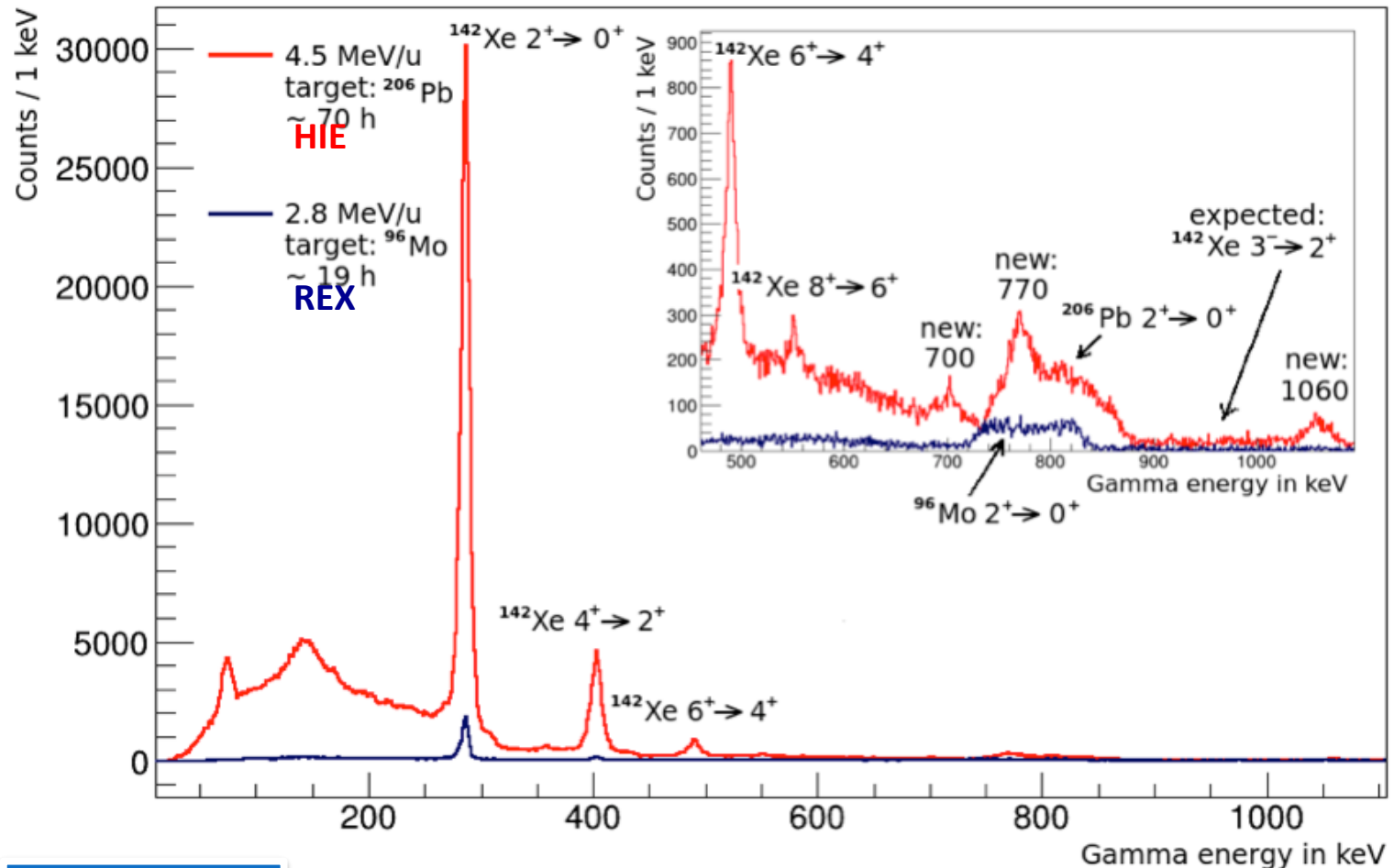
- Regions to the north-east of doubly-magic shell closures, good candidates for octupole deformation.
- B(E3) known to be good measure; CARIBU@ANL^[1] – $^{144}\text{Ba} = 48^{+25}_{-34}$ W.u.



[1] B. Bucher et al. Phys. Rev. Lett. 116, 112503 (2016)

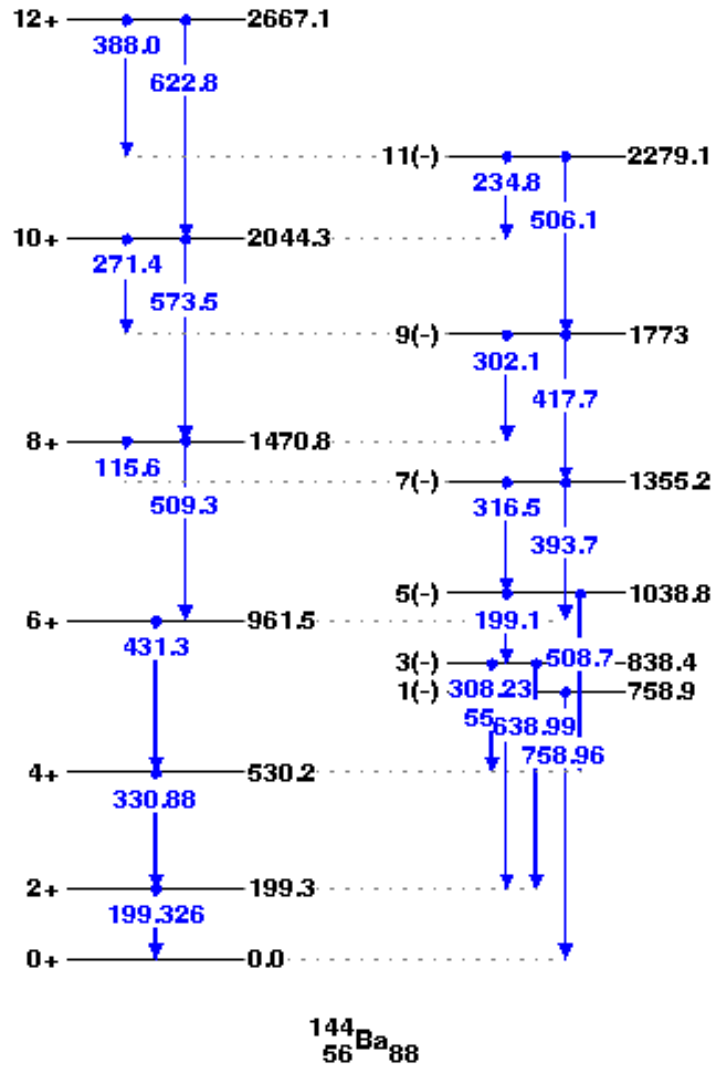
Comparison of REX/HIE – ^{142}Xe

Doppler corrected with respect to Xe



2016 data

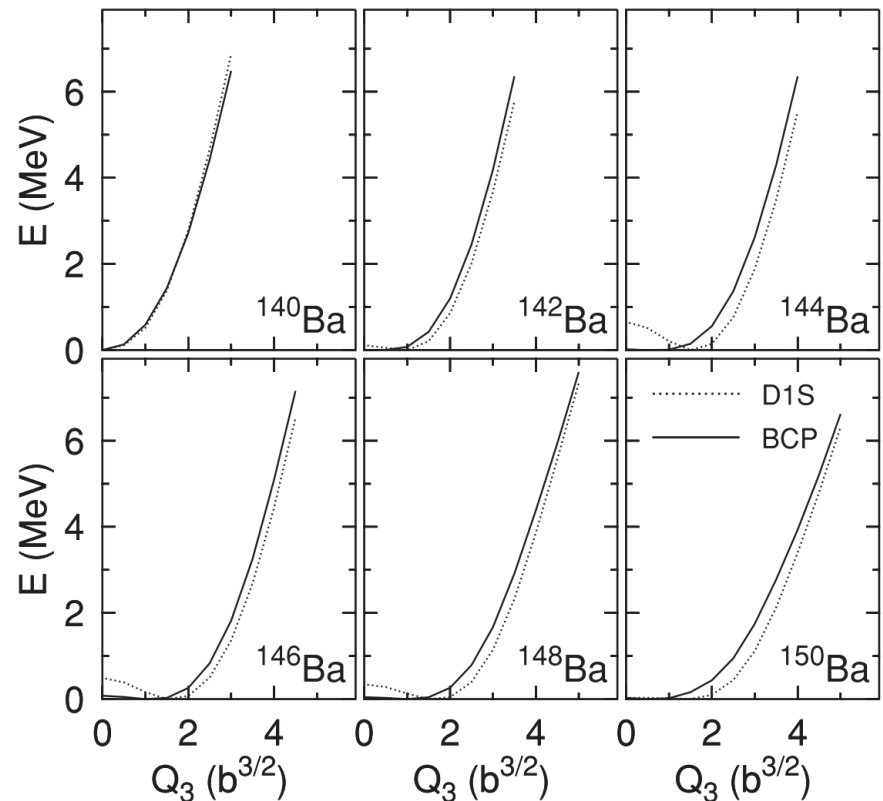
Lanthanides: $^{142,144}\text{Ba}$ – IS553



Marcus Scheck (UWS Paisley)

● Predicted by mean-field approaches to be most likely candidate for β_3 deformation in lanthanide region.

*L. M. Robledo, M. Baldo, P. Schuck, and X. Viñas, Phys. Rev. C **81**, 34315 (2010).*

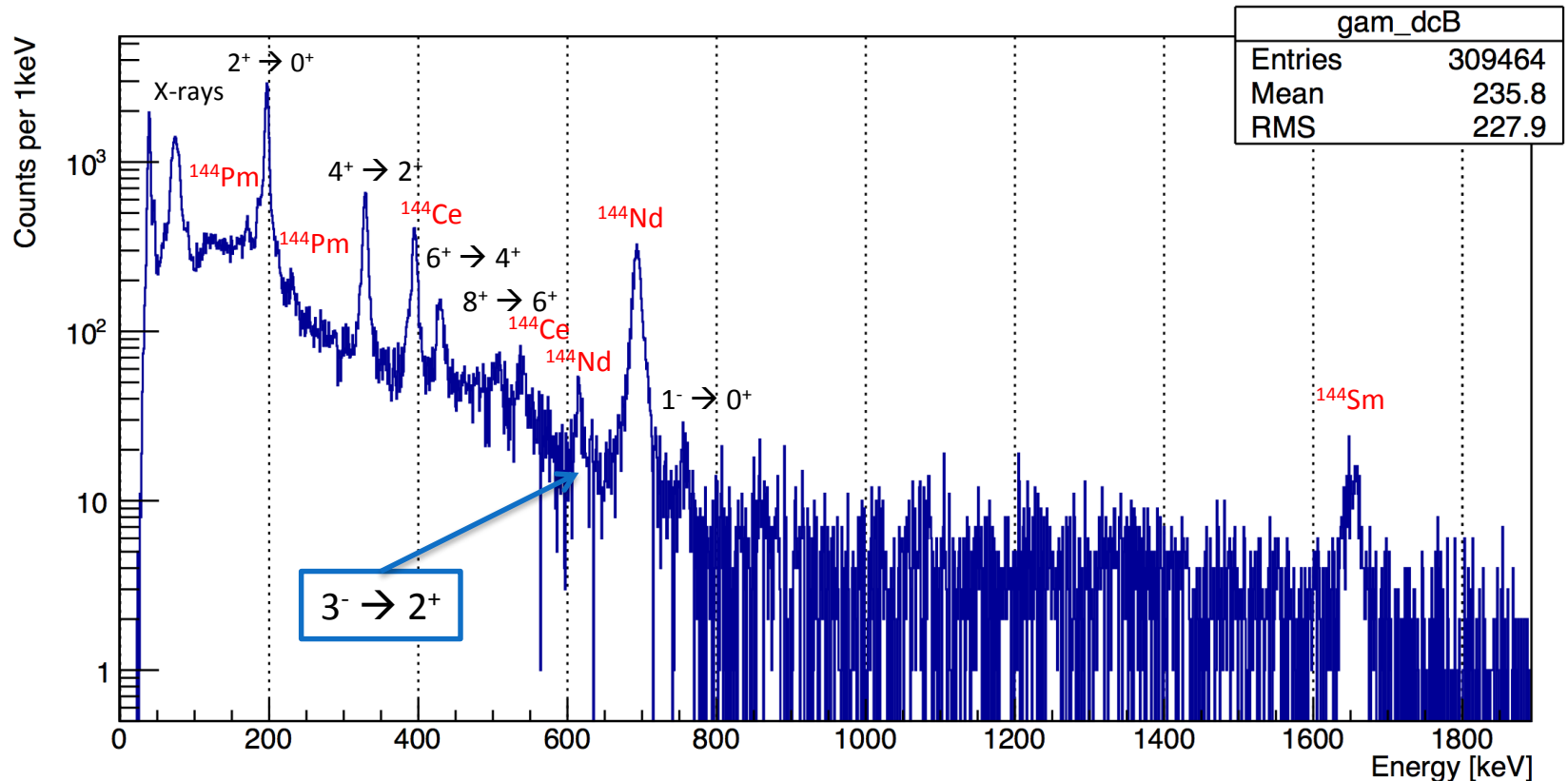


^{144}Ba on ^{208}Pb

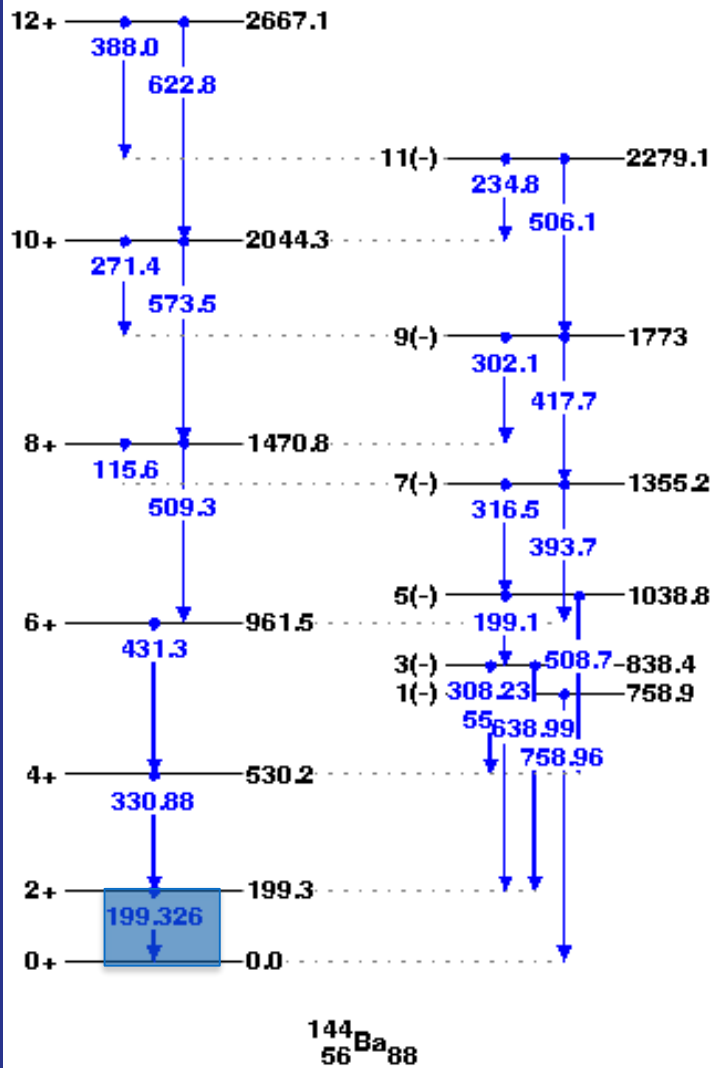
2017 data

- ~50% of the total statistics shown.
- Doppler correction/gating/background subtraction to be improved

Total statistics for gamma rays, background subtracted, Doppler corrected for scattered projectile

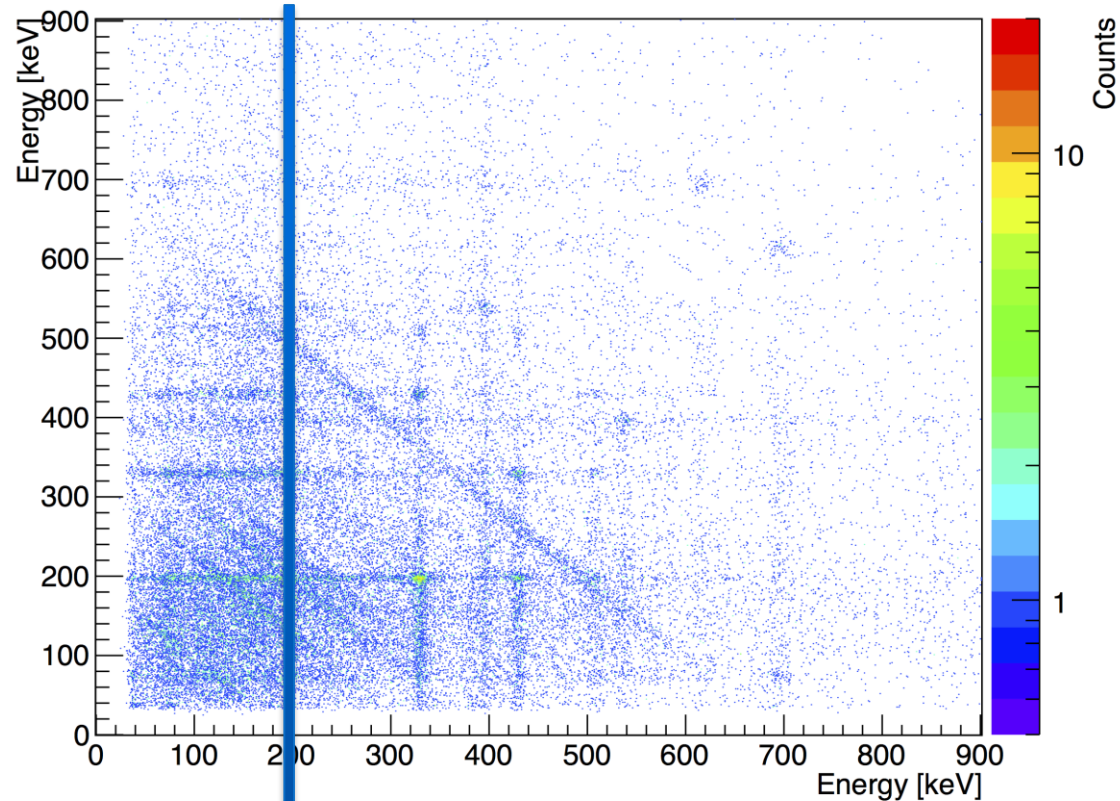


$\gamma\gamma$ matrix: ^{144}Ba on ^{208}Pb

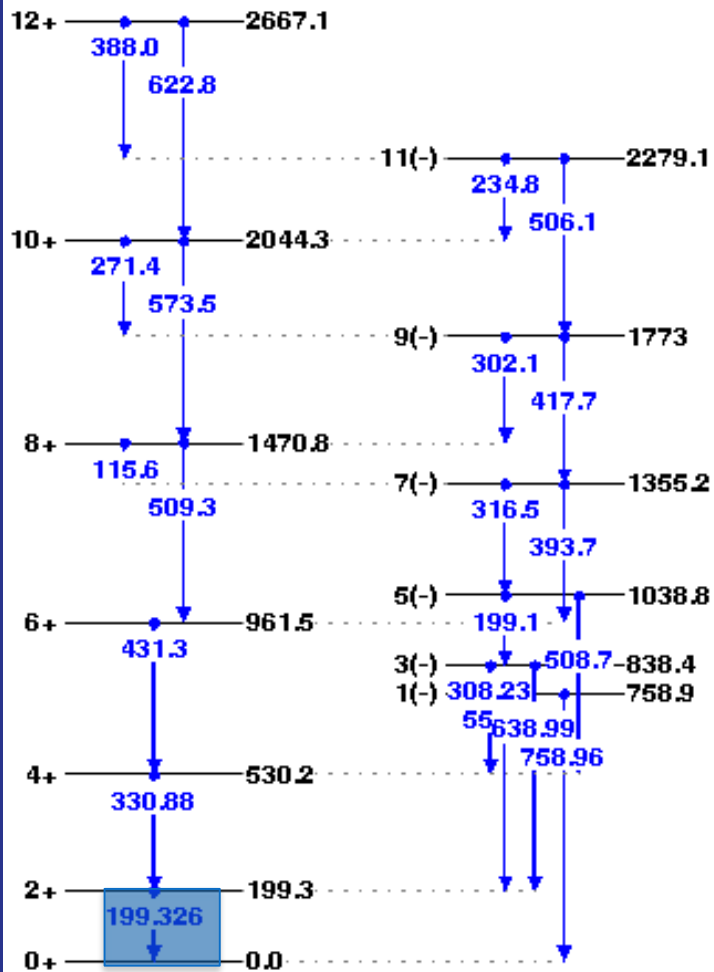


- Particle-gamma-gamma spectrum.
- Doppler-corrected for ^{144}Ba (to be improved)

Gamma-gamma matrix, DC for beam



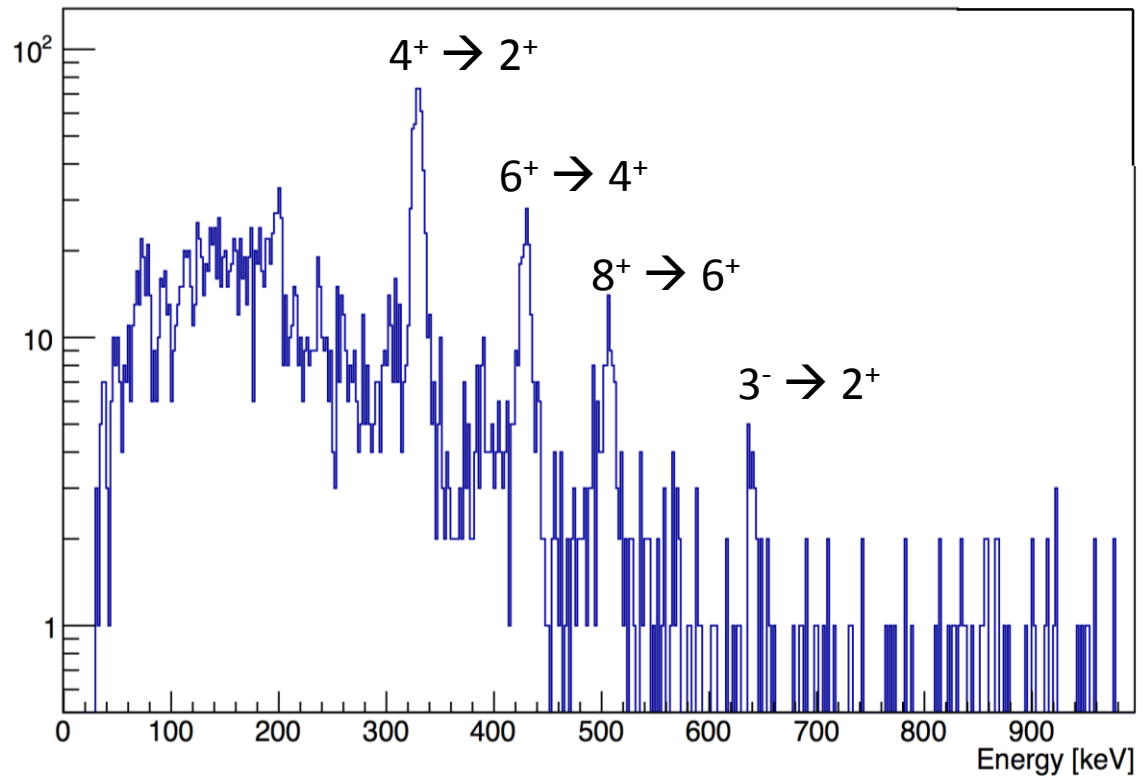
$\gamma\gamma$ matrix: ^{144}Ba on ^{208}Pb



$^{144}_{56}\text{Ba}_{88}$

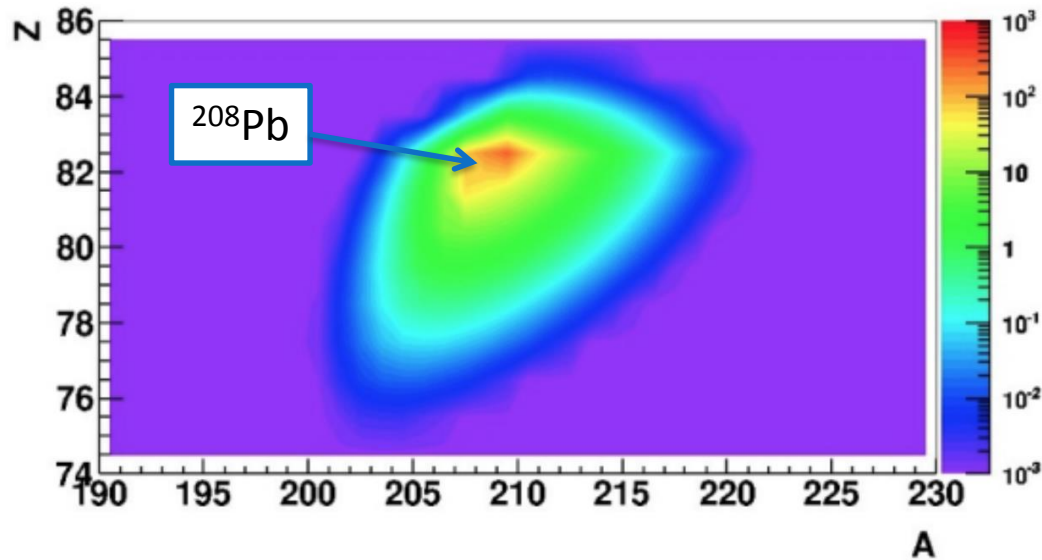
- Particle-gamma-gamma spectrum.
- Doppler-corrected for ^{144}Ba (to be improved)
- 17 counts in $3^- \rightarrow 2^+$ peak.

Counts 1/keV

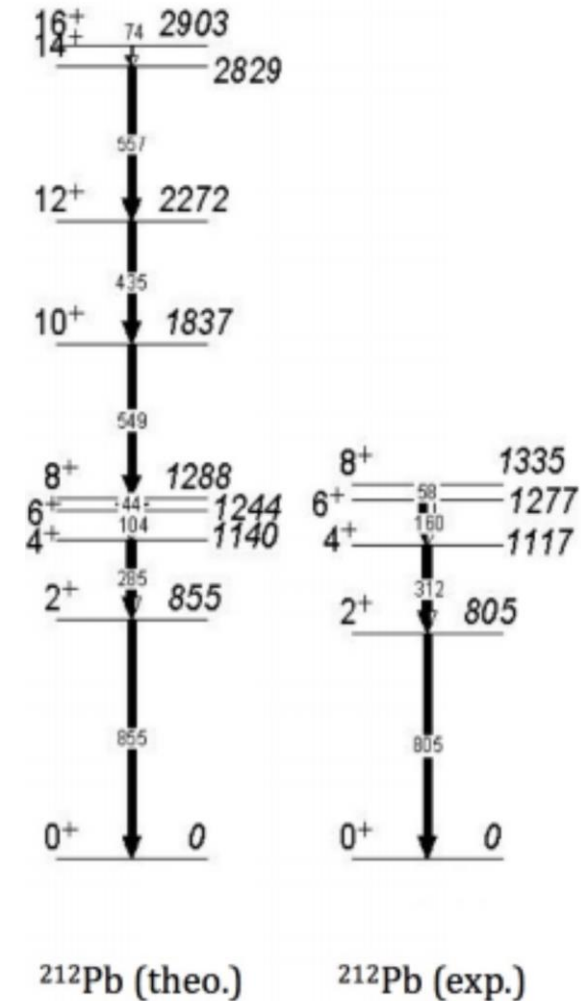


Multi-nucleon transfer – IS572

- Neutron-rich ^{94}Rb beam above Coulomb barrier.
- Populate nuclei south-east of ^{208}Pb .

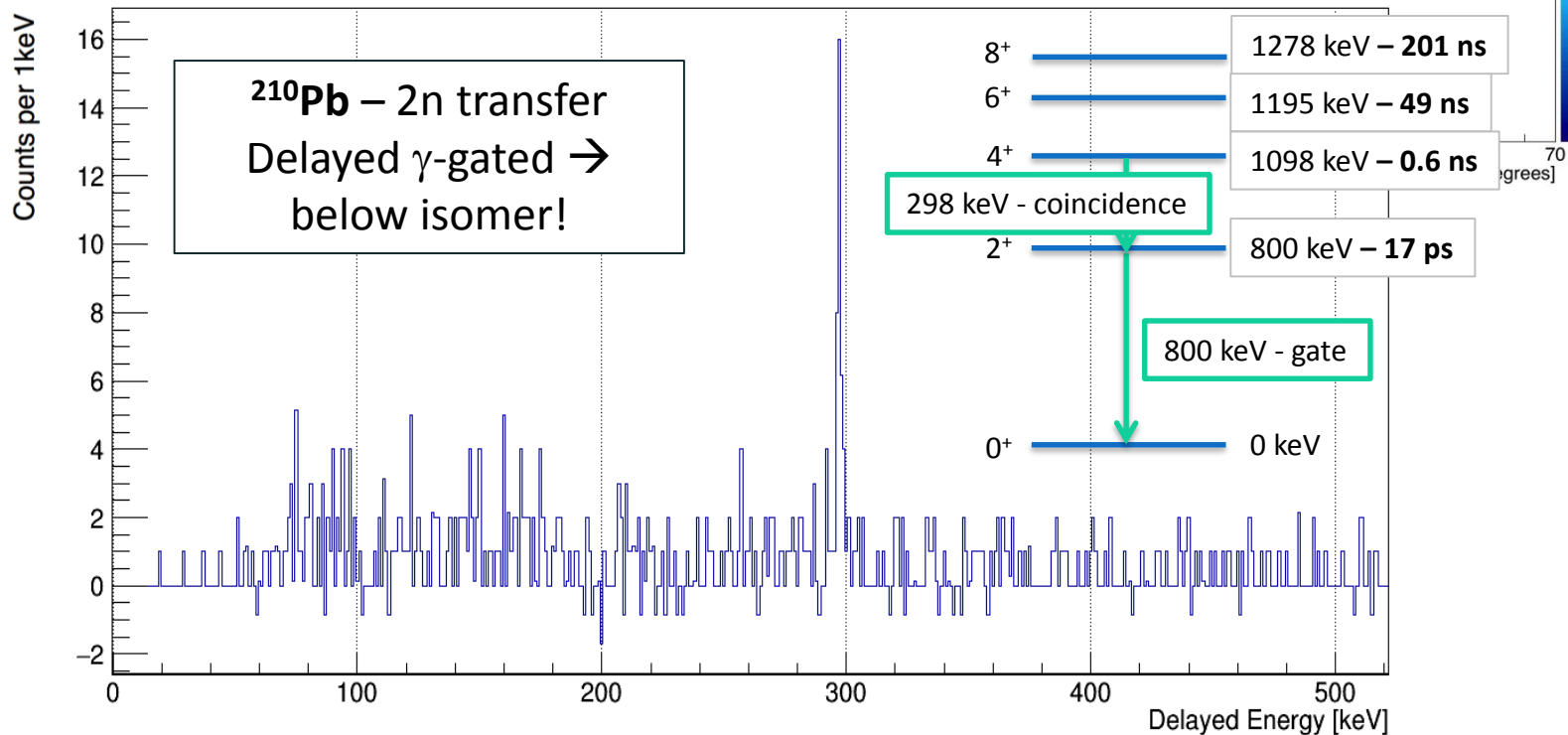
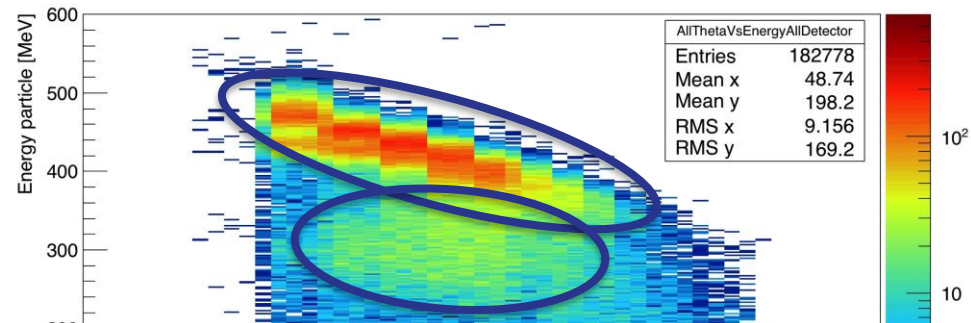


- Technical challenges of high-rates:
 - Slow extraction of EBIS \rightarrow 1.6 ms.
 - Trigger selection of Miniball implemented.



Preliminary γ -ray spectra

- Particle-gated
- Prompt coincidence
- Doppler-corrected
- Background-subtracted

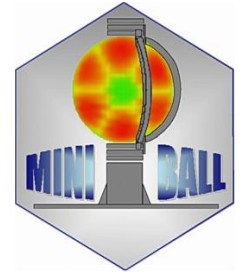


Thanks to Jose Javier Valiente-Dobon, Susana Sziler, Petra Colovic, Andrés Illana Sison.

Few hours of data

New developments: Plunger

- New plunger chamber installed for 2017.
- Developed at IKP Köln.
- Excited-state lifetime measurements, g-factors, etc.



Coulex target wheel

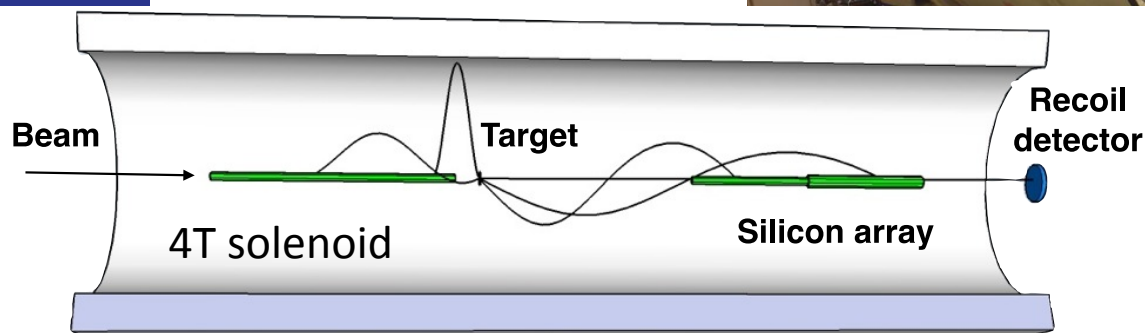
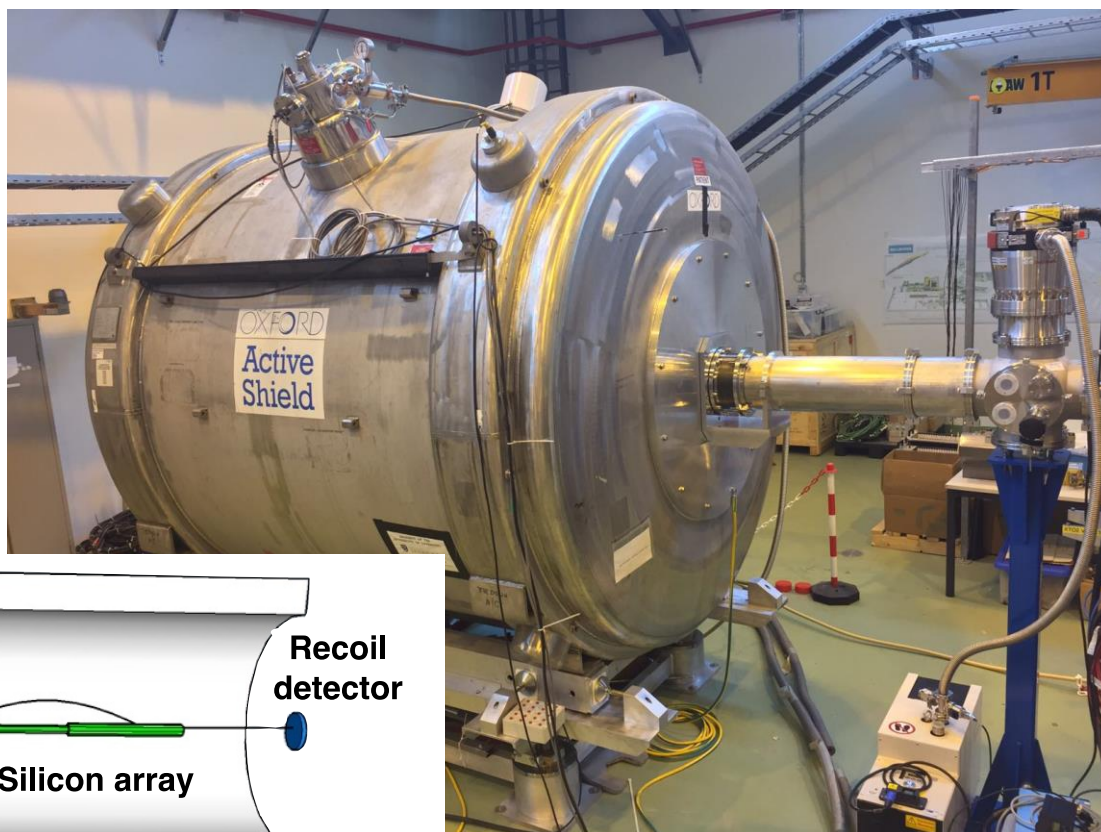


Plunger



ISOLDE Solenoidal Spectrometer

- Cold and tested up to 2.75 T.
- Connected to beam line and bore holds vacuum.
- Stable beam next month
- **RIB in 2018!!**
 - $^{206}\text{Hg}(d,p)$
 - $^{28}\text{Mg}(d,p)$



Helical orbit spectrometer principle 30

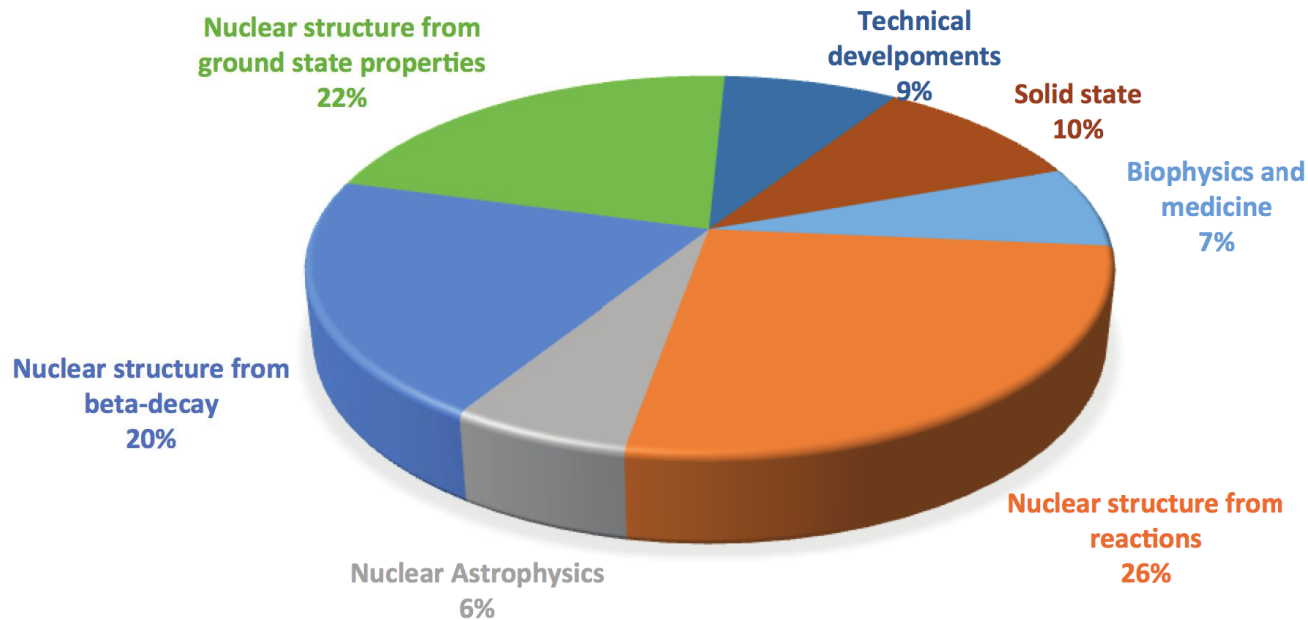
Conclusions

The HIE-ISOLDE facility

- HIE-ISOLDE is operating as a reliable and exciting new facility.
 - Three beam lines are now in use, Miniball, ISS and SEC.
- Last year (2016) saw 6 RIB experiments, 5 of them at Miniball
- This year (2017) we've seen a full campaign of 12 RIB experiments.



SUM OF SHIFTS DELIVERED



Thank you – Merci

