Physics cases addressed at HIE-ISOLDE

ISRS meeting 2022

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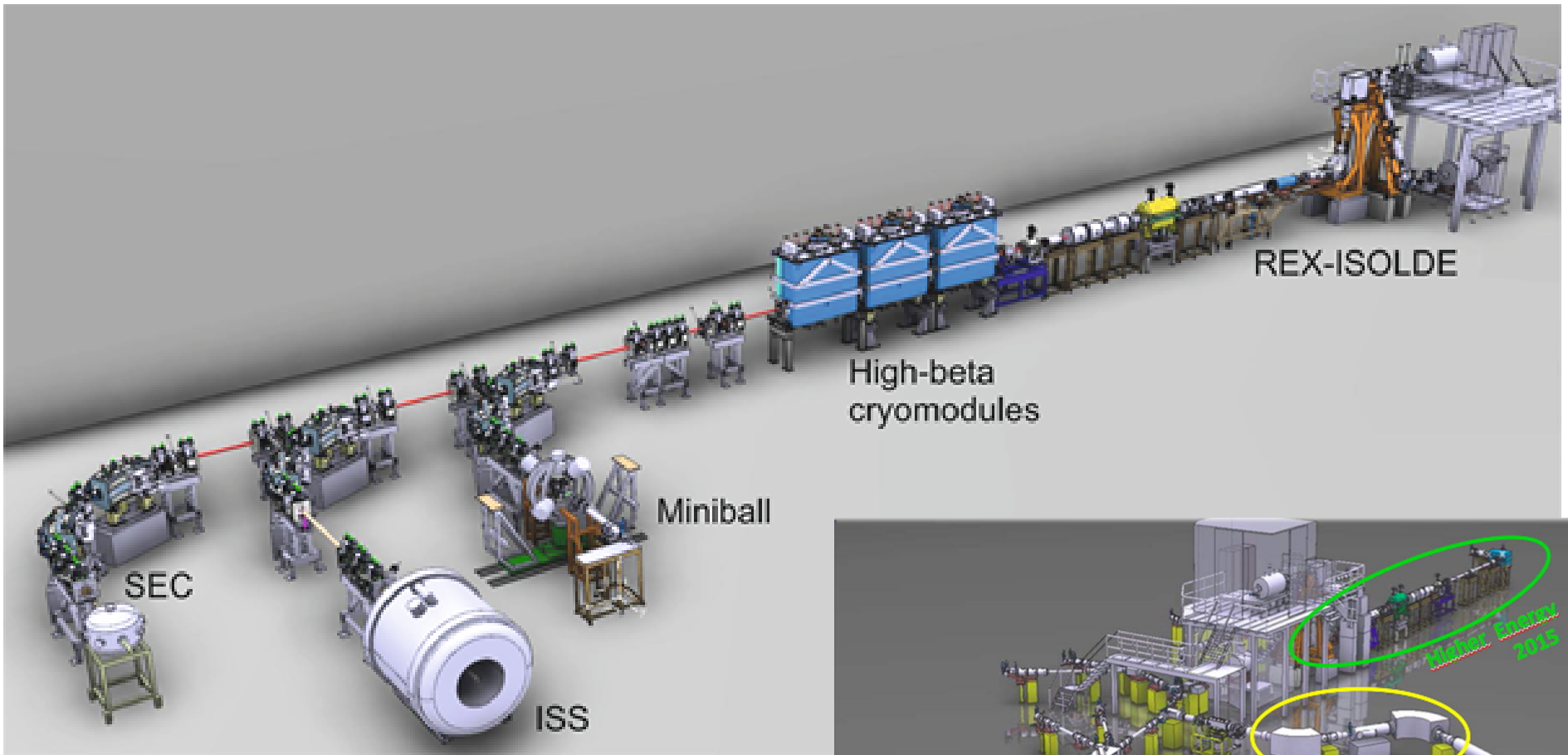
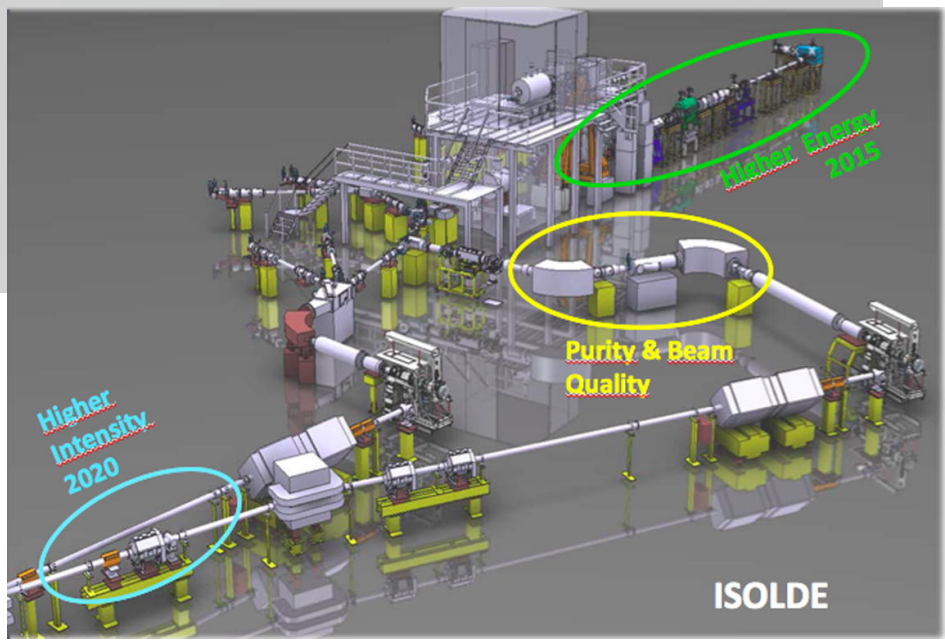
CERN, CH-1211 Geneva 23, Switzerland

Tuesday 29th November, 2022

HIE-ISOLDE overview

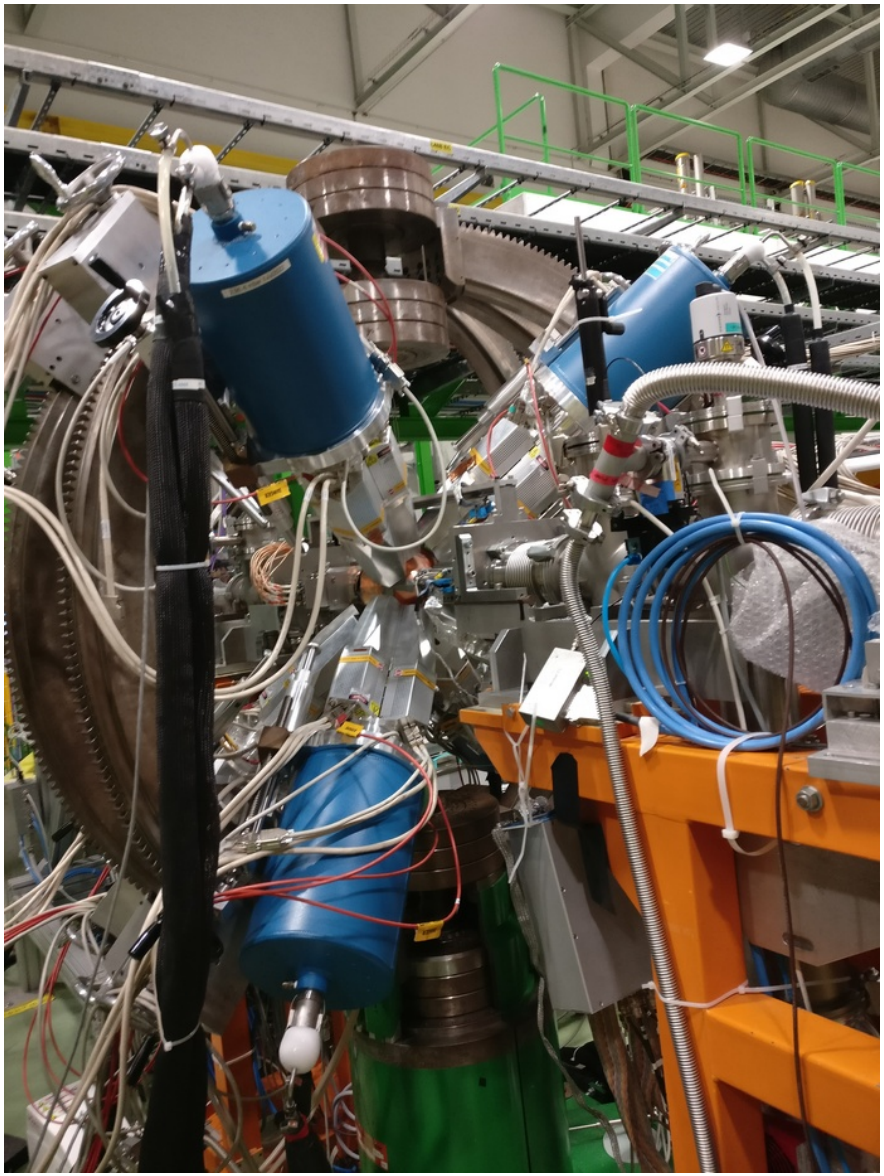


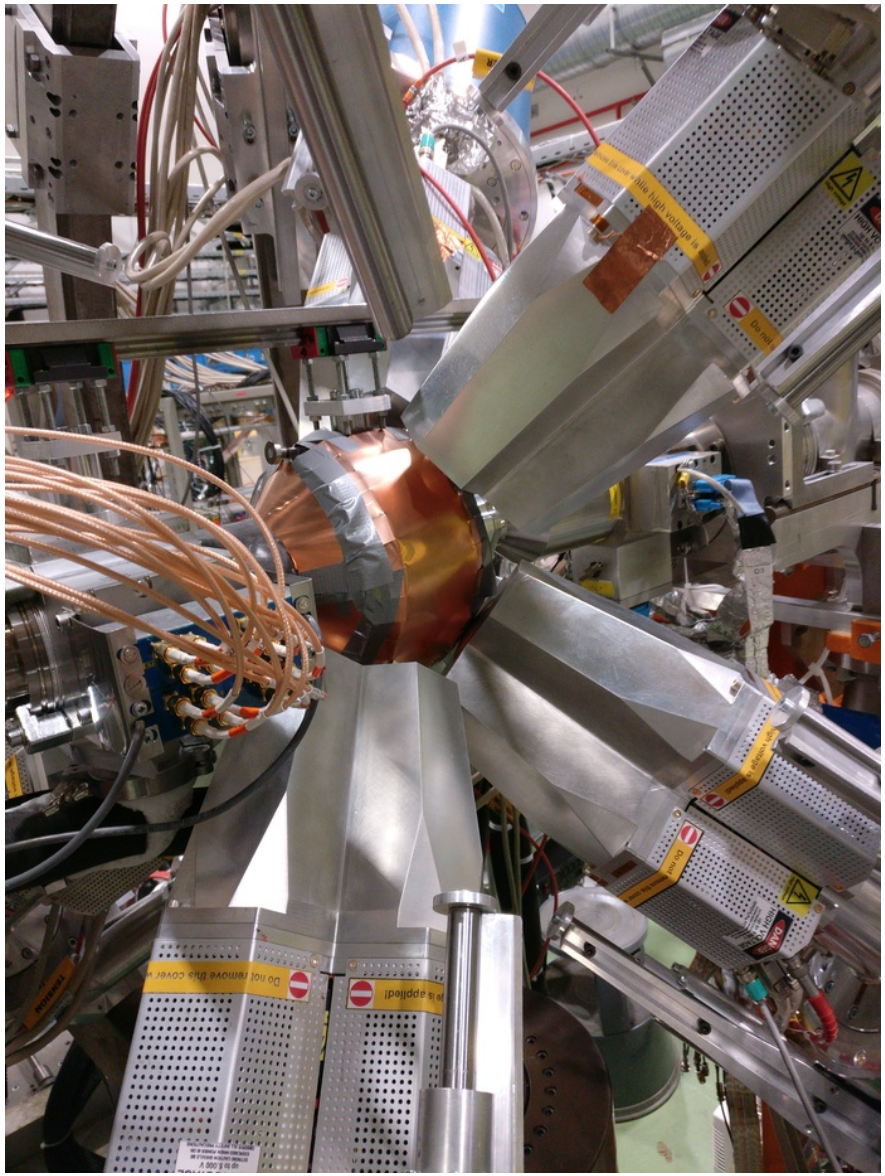


- High Intensity Energy
  - $\rightarrow E_{\text{beam}} \leq 10$ MeV
- Located after "REX"
  - $\rightarrow E_{\text{beam}} \leq 2$ MeV

M. J. G. Borge, Nucl. Instr. Meth. Phys. Res. B **376** 408 (2016).

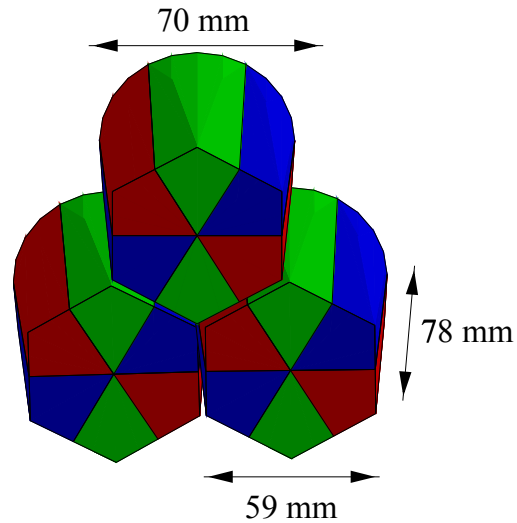
The Miniball array



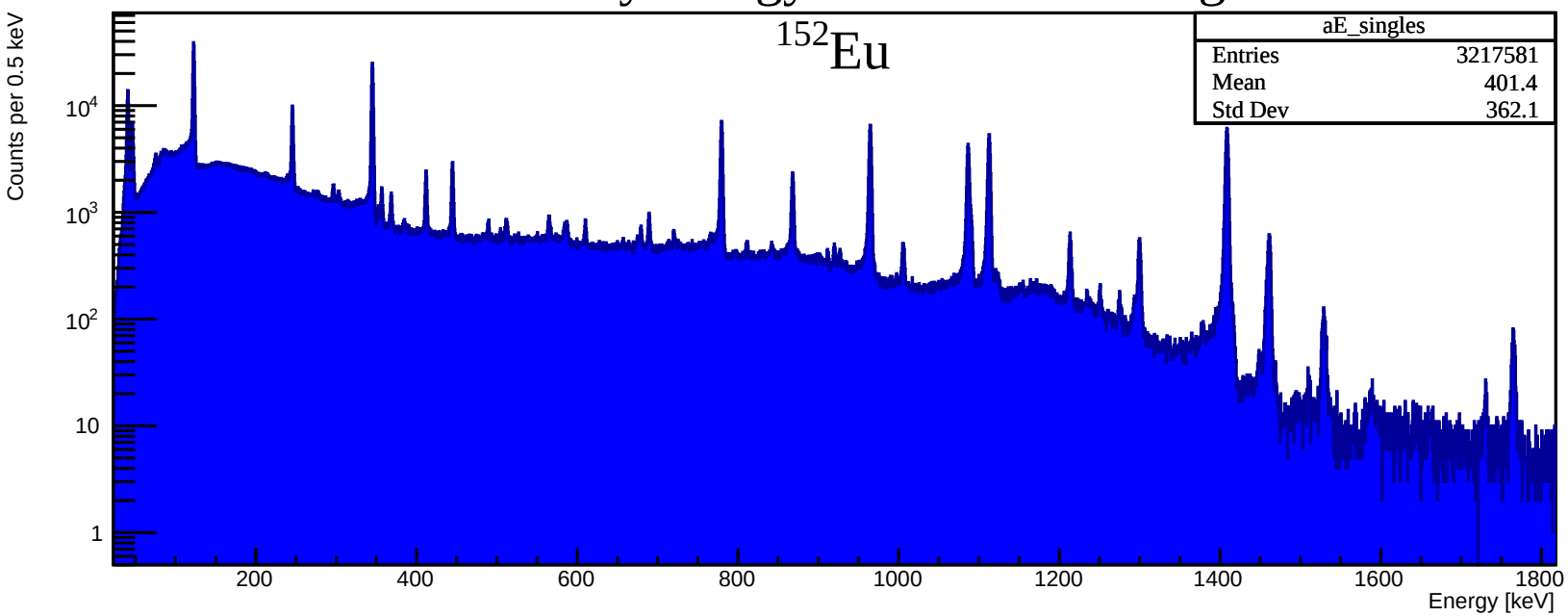


The Miniball array

- Miniball: KU Leuven/U. of K oln
  - →6-fold segmentation
  - →Triplet crystal arrangement
  - →8×in the array
  - →FWHM(1 MeV)≈3 keV
  - →Eff.(1 MeV)≈9%

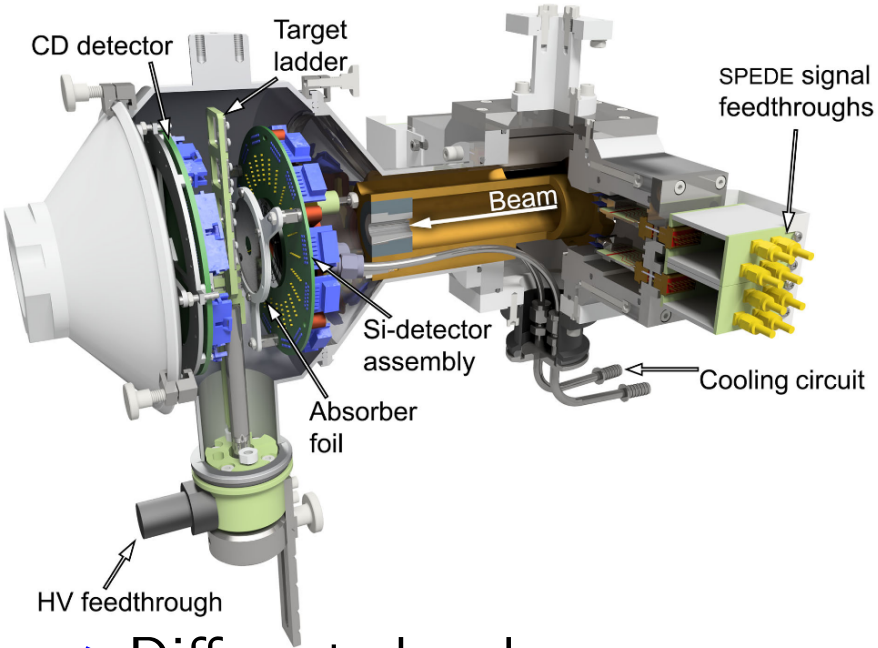


Gamma-ray energy with addback singles

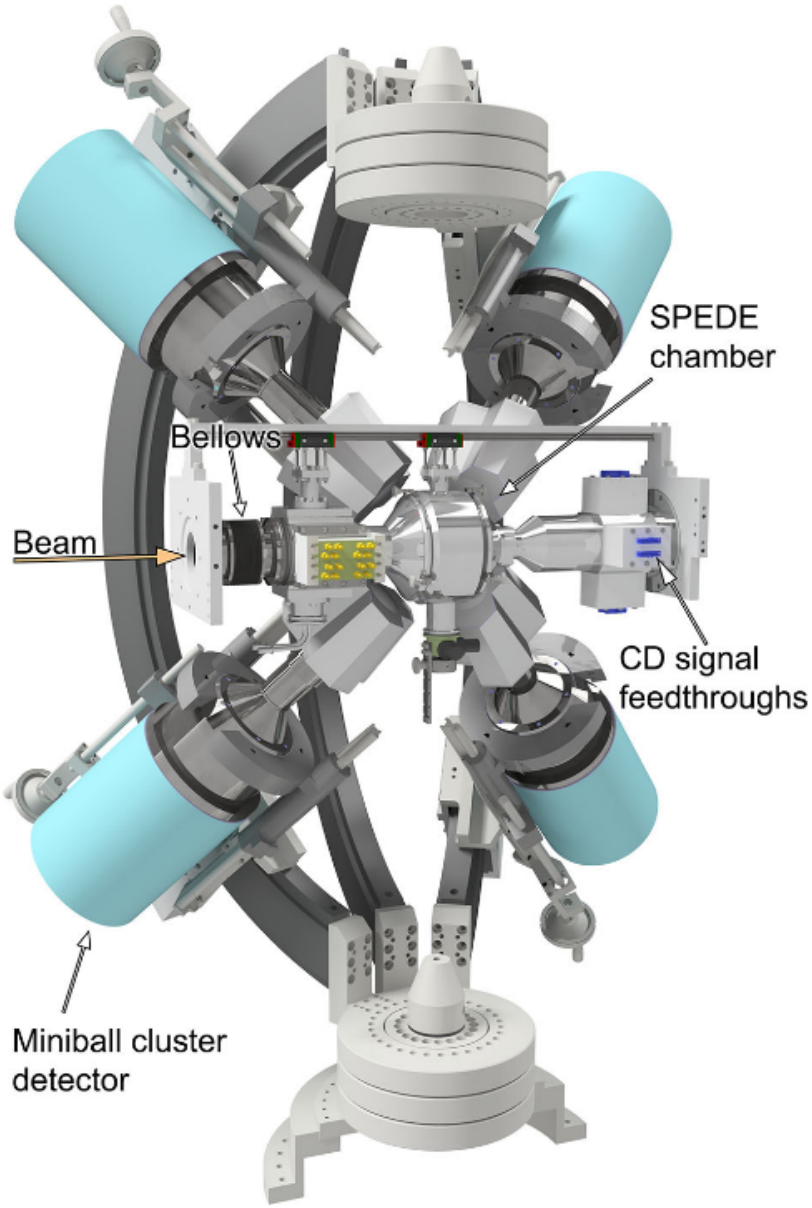


P. Doornenbal, PhD Thesis (2007).

Target chamber

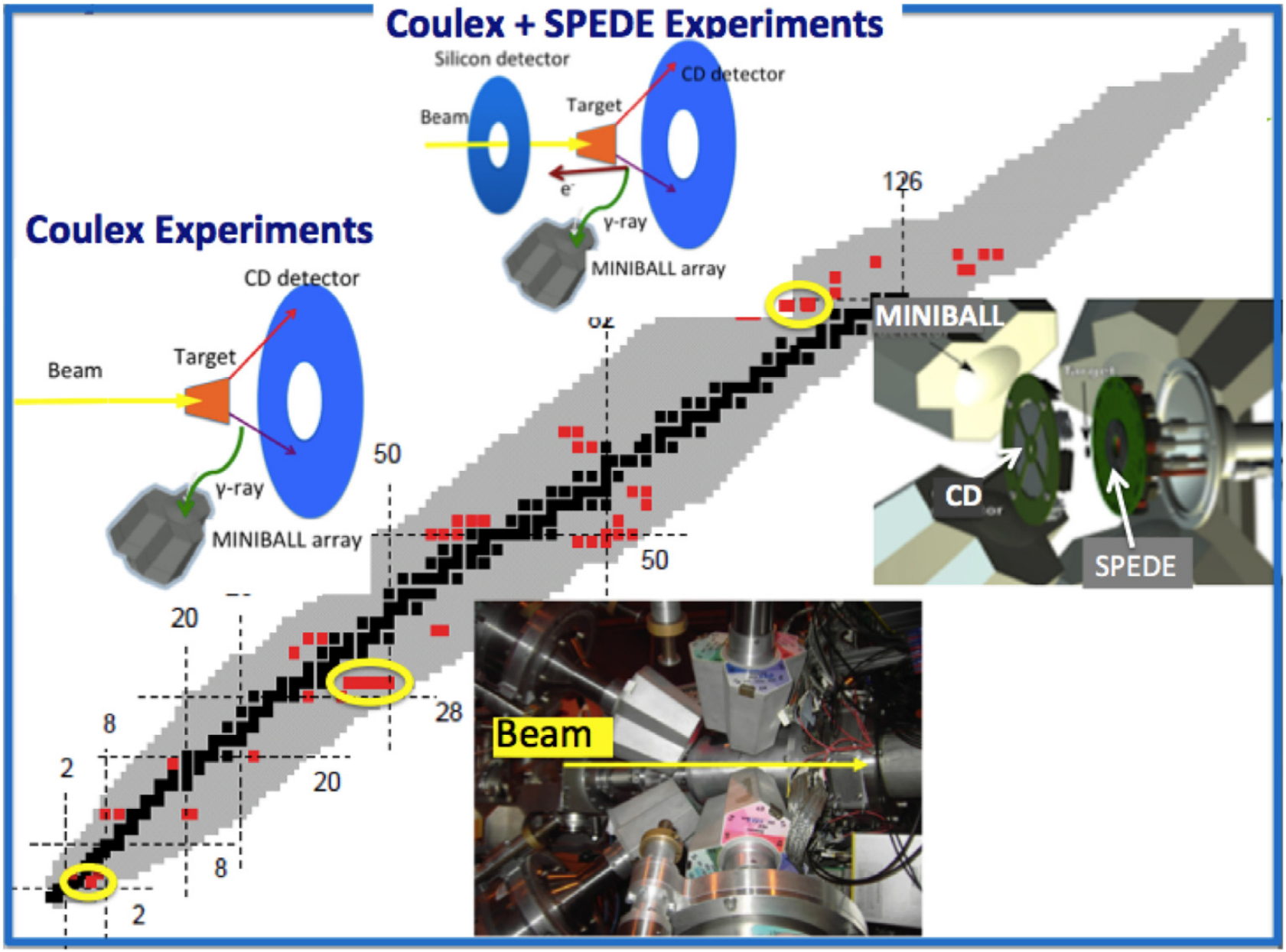


- Different chambers
  - →Coulex/Transfer
- Downstream "CD" common to all
  - →Annular DSSSD
  - →Detects scattered particles
- SPEDE (**NEW!!!**)
  - →Annular DSSSD
  - →conversion electron detector



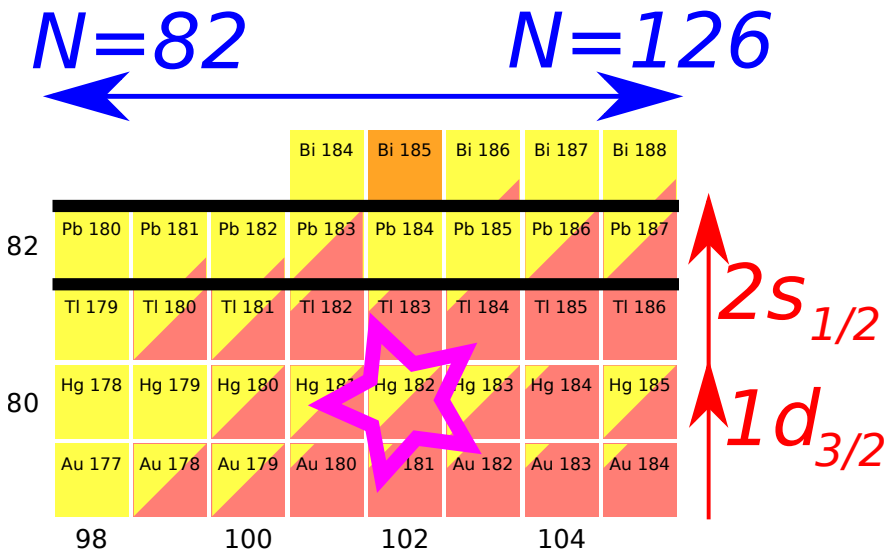
P. Papadakis *et al*, Eur. Phys. J. A **54** 42 (2018).

Coulex at Miniball

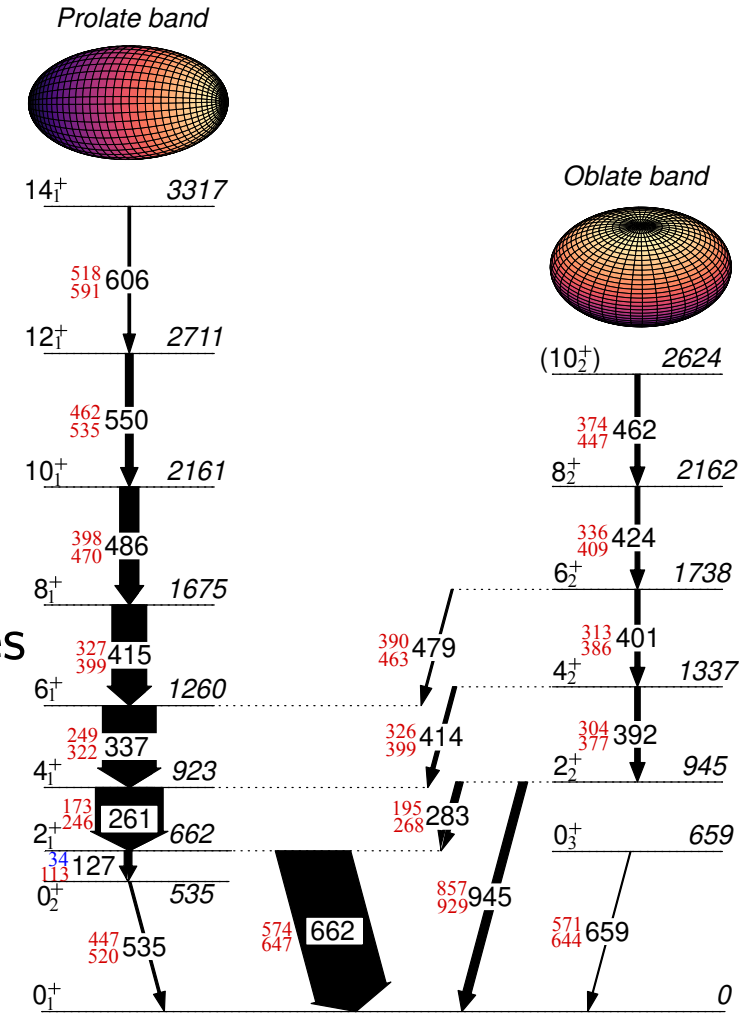


M. J. G. Borge, Nucl. Instr. Meth. Phys. Res. B **376** 408 (2016).

Example physics: Shape coexistence in ^{182}Hg



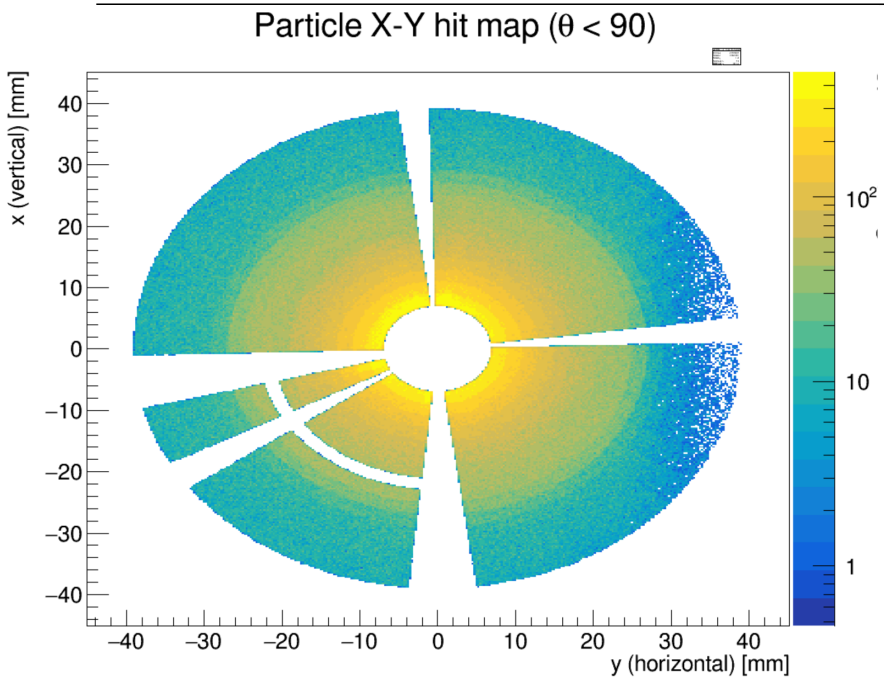
- Region known for co-existing shapes
- Coulex well-suited to investigation
- γ-decaying states
  - $\rightarrow B(E2)$
  - $\rightarrow$Miniball
- C.E.-decaying transitions
  - $\rightarrow B(E0)$
  - $\rightarrow$SPEDE

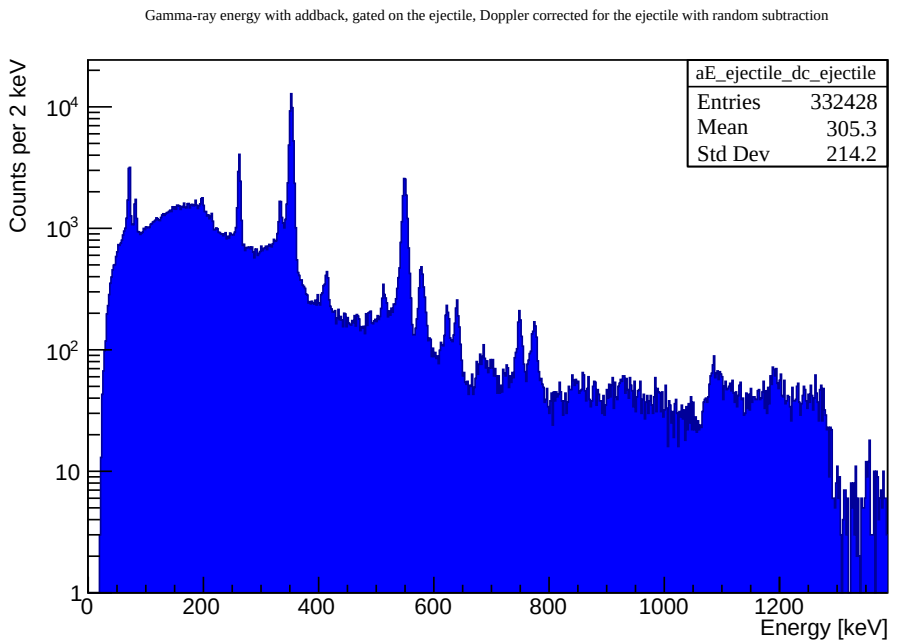


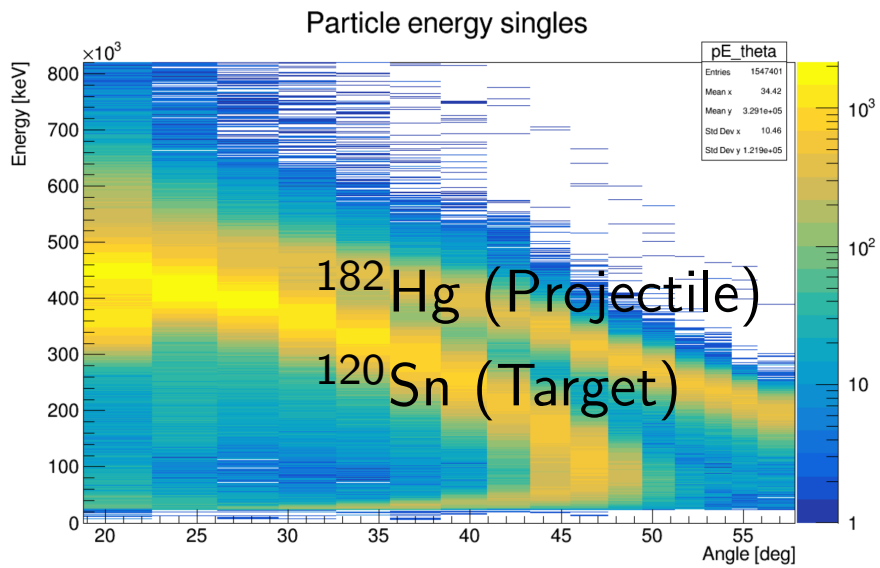
^{186}Pb

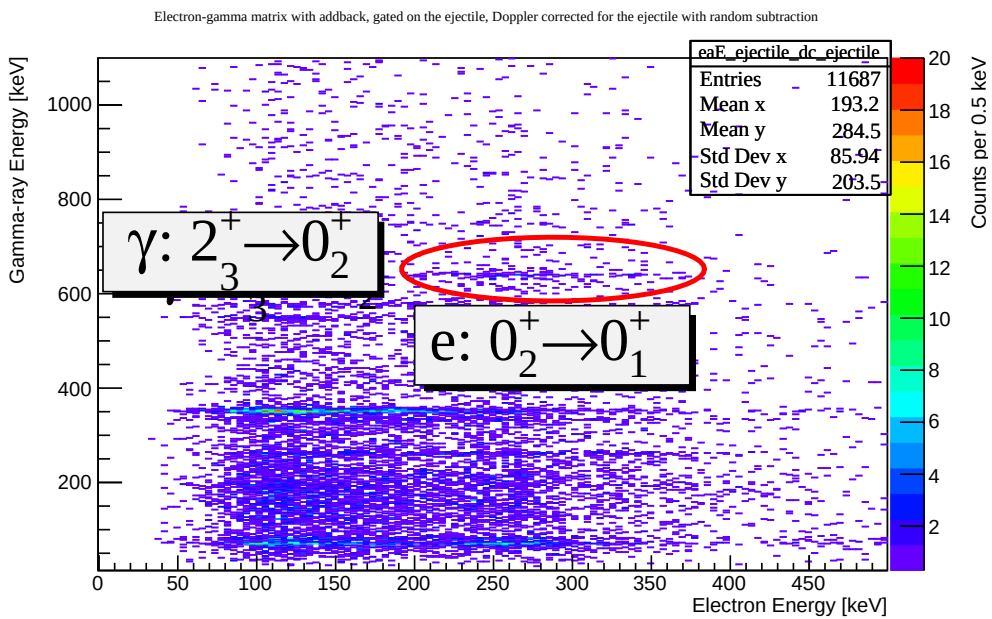
J. Ojala *et al*, Comm. Phys. **5** 213 (2022).

Very preliminary results of ^{182}Hg Coulex



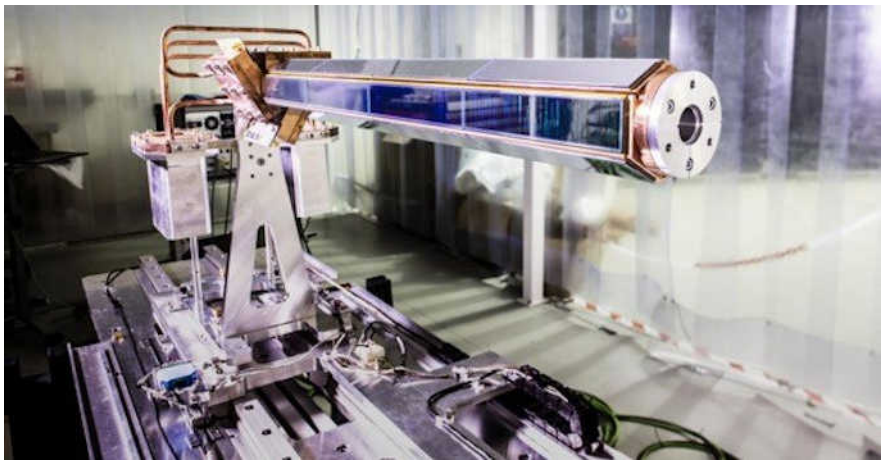


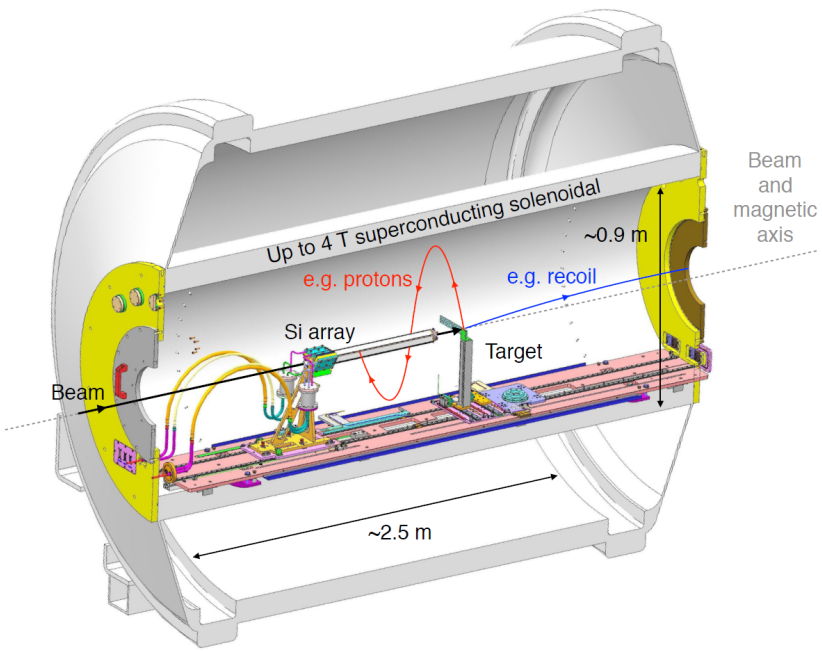




Courtesy of IS563 collaboration.

ISS setup & principle



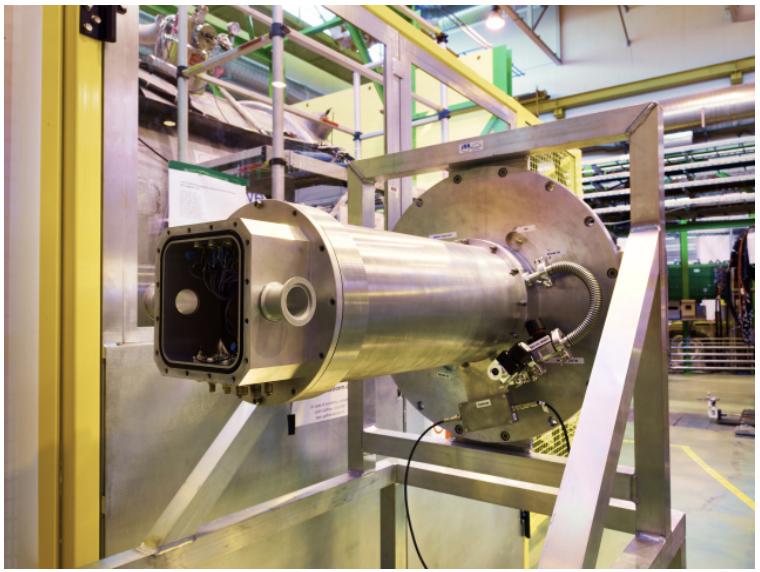


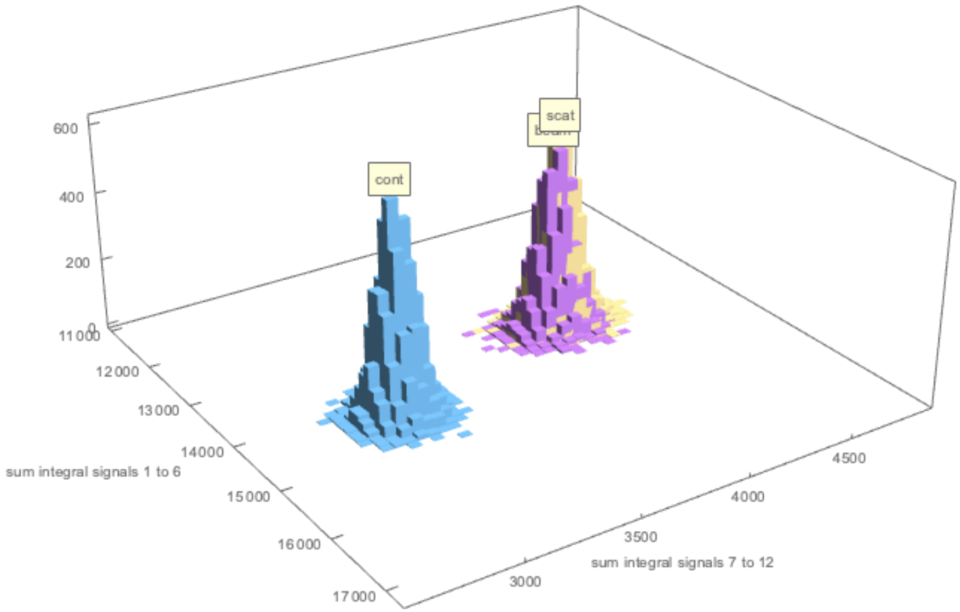
- Advanced Liverpool Array
  - → 6 "sides" of 4 DSSSDs
  - → Each DSSSD 128x11 mm
  - → 1688 channels
    - – ASIC readout

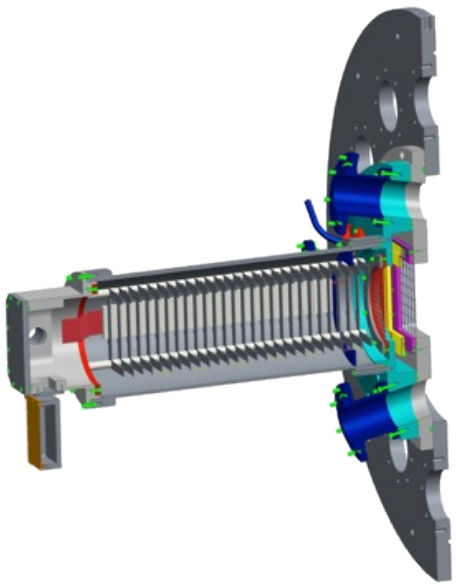
$$E_{\mathrm{CM}} = E_{\mathrm{lab}} + \frac{mV_{\mathrm{CM}}^2}{2} - \frac{mzV_{CM}}{T_{\mathrm{cyc}}}$$

- No kinematic compression
- Linear in z position
- High efficiency at high E

Gas ionisation chamber



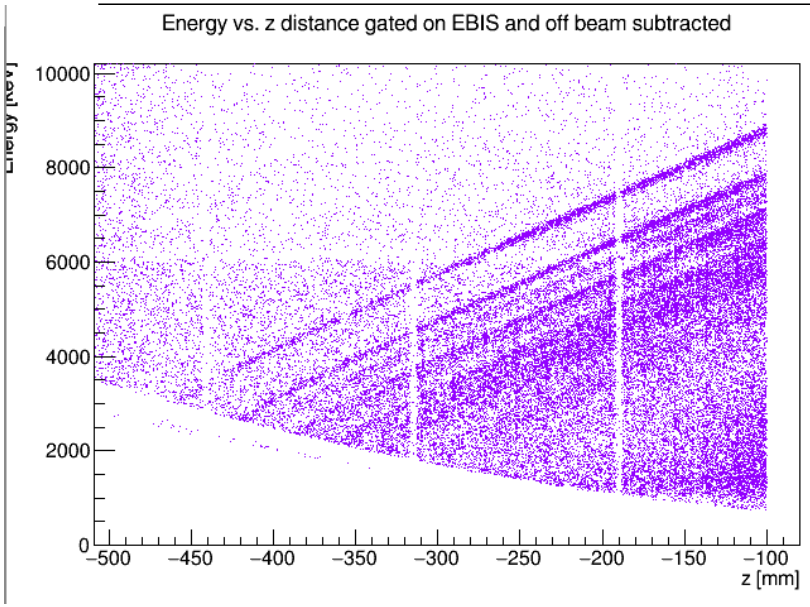


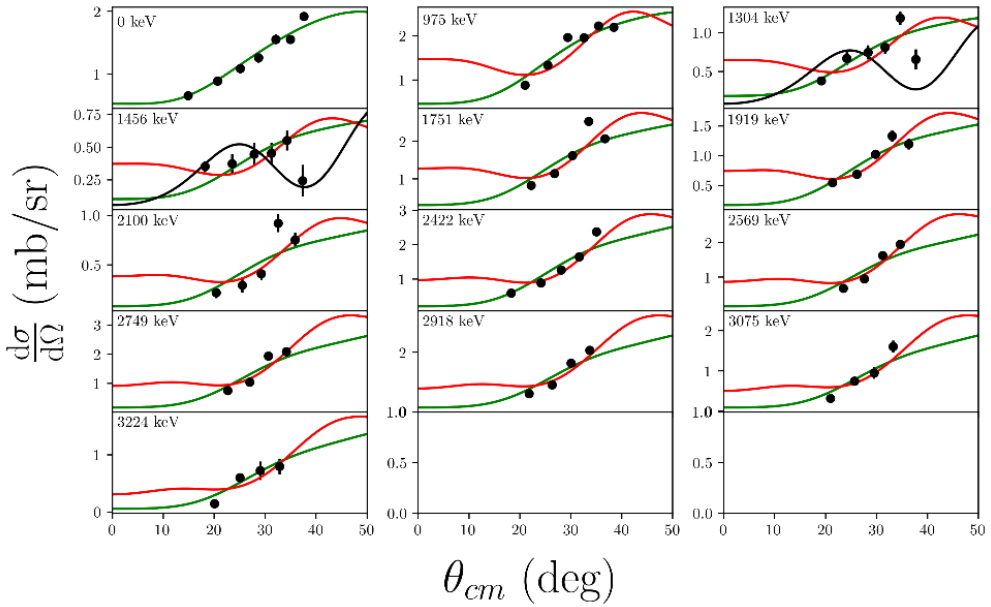


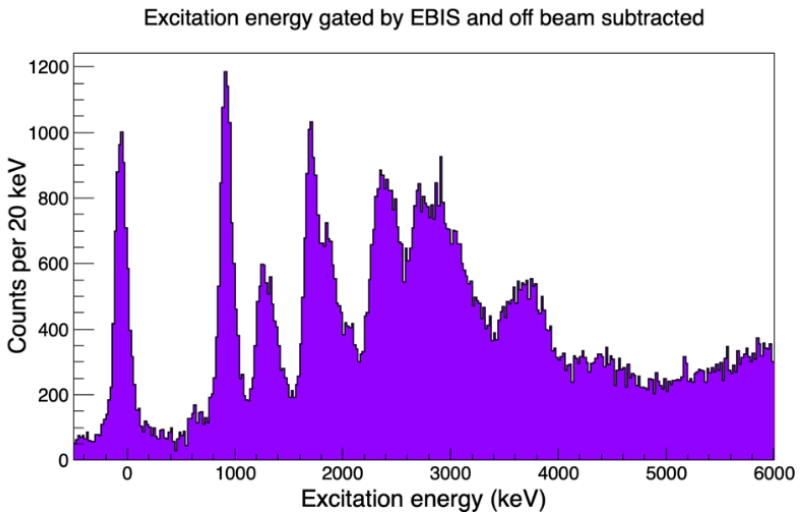
- Up to 100 kHz rate
- Segmented with digital readout
- Sample dE/dx along recoil tracks
- Beam composition identification
- MWPC for position and timing

Courtesy of B. Olaizola.

Preliminary results of ^{212}Rn$(d,p)^{213}$Rn





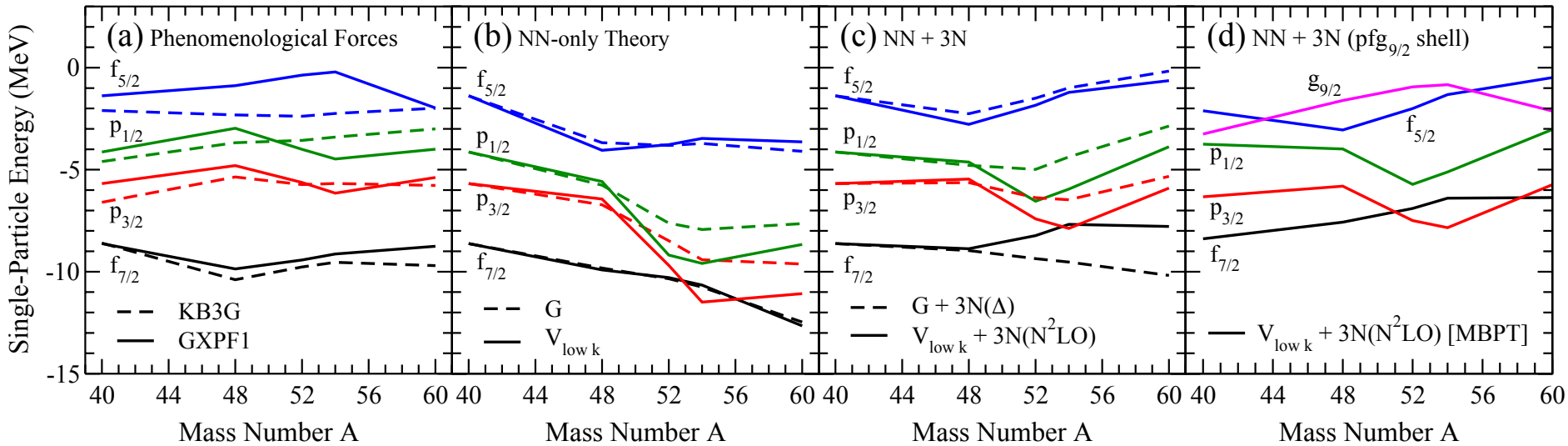


PRELIMINARY!

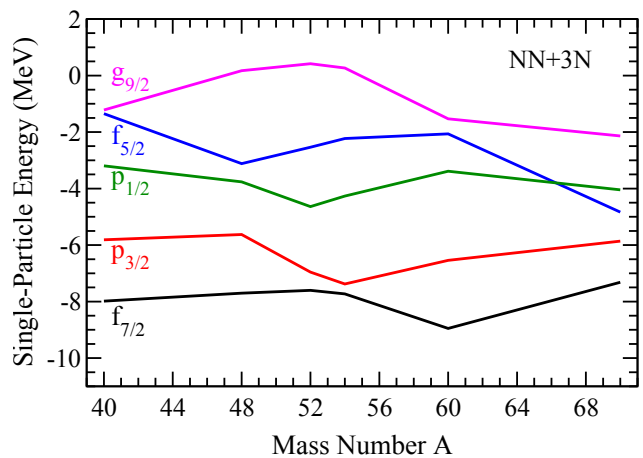
- Single-particle levels at $N \sim 126$
- Best resolution ~ 100 keV
- Backgrounds:
  - $\rightarrow$Beam α decay
  - $\rightarrow$Fusion evaporation
- 24 states seen mostly $\ell = 2$ &4

Courtesy of D. Sharp via B. Olaizola.

Shell evolution in N-rich Ca isotopes



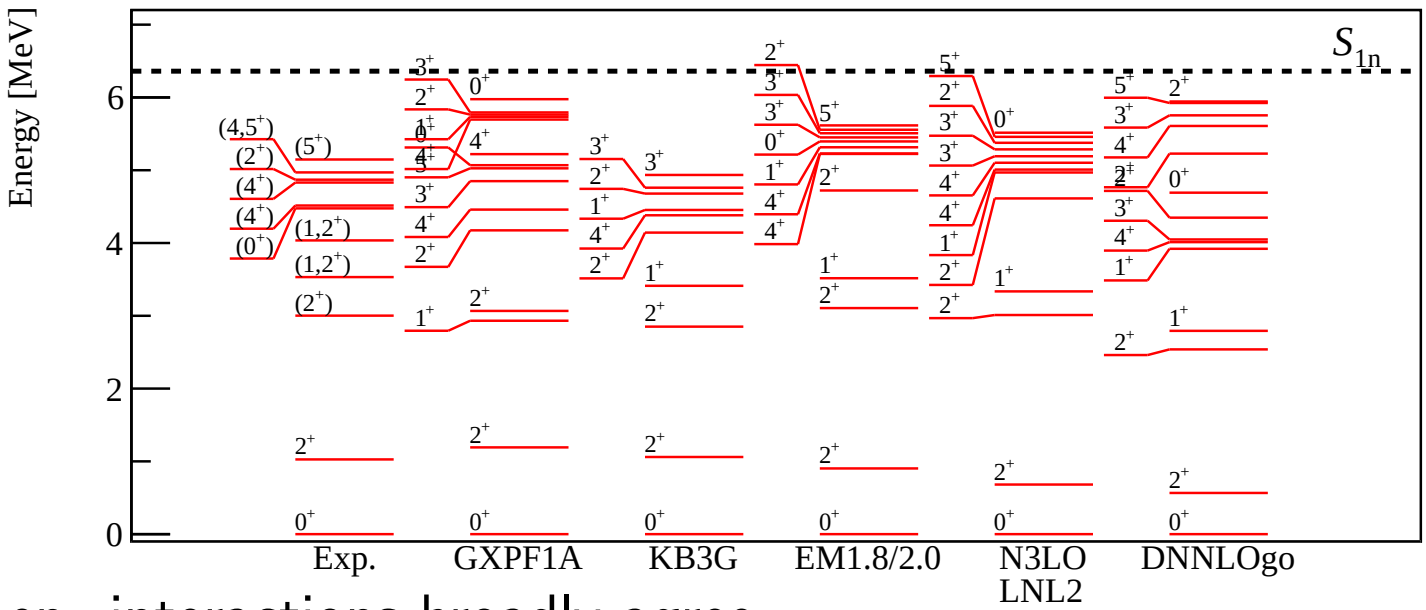
- Region of drastic shell evolution
  - → New $N = 32, 34$ shell closures
- A frontline of *ab initio* capabilities
  - → Recently: VS-IMSRG
- Conflicting theory
  - → Some approaches⇒ weak closures
- and experiment
  - → For: $E(2^+)$, S_{2n}, K.O.; Against: R_{ch}



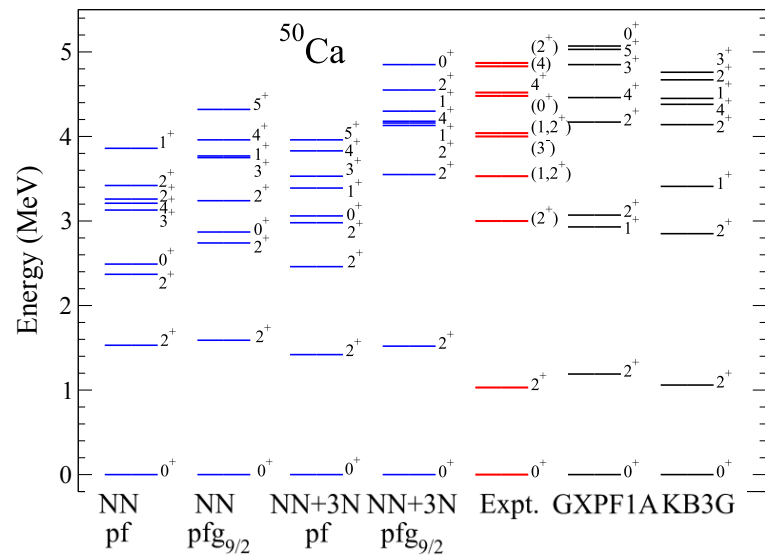
- $0g_{9/2}$ influence?

J. D. Holt *et al*, J. Phys. G **39** 085111 (2012).
J. D. Holt *et al*, Phys. Rev. C **90** 024312 (2014).

Recent predictions of ^{50}Ca levels



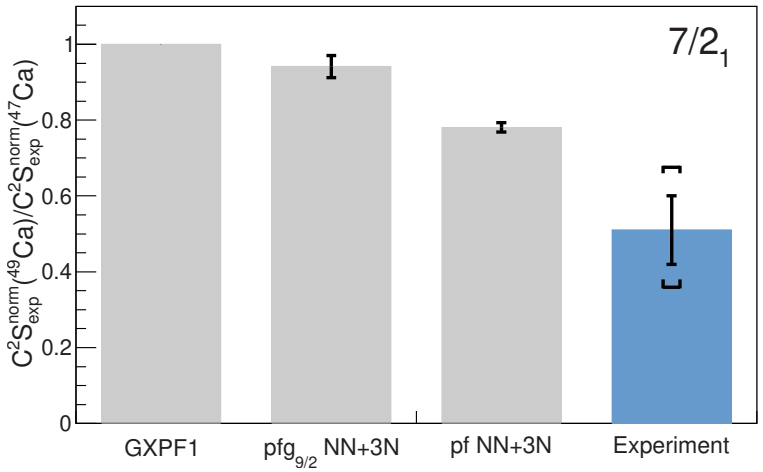
- Phen. interactions broadly agree
- Many-body perturbation theory (right):
  - → dependent on $3N$ forces and $g_{9/2}$
  - → **3.5 MeV state properties needed**
- VS-IMSRG (above) similar to phen. at low E
- All but 2_1^+ state tentative
  - → ^{48}Ca(t,p), (p,p'), ^{50}K(β^-), ^{51}K($\beta^- n$), ^{238}U/^{208}Pb(^{48}Ca,xγ)



J. D. Holt *et al*, Phys. Rev. C **90** 024312 (2014).
J. D. Holt & B.-S. Hu, Private comm. (2022).

Neutron removal from ^{50}Ca

- ^{50}Ca neutron-stripping
  - → Depleted $\nu f_{7/2}$ strength
  - → Some evidence of enhanced $\ell = 1$
    - – Similar to Sc(-1n)
- MBPT and phen. predictions agree
  - → But not with experiment!



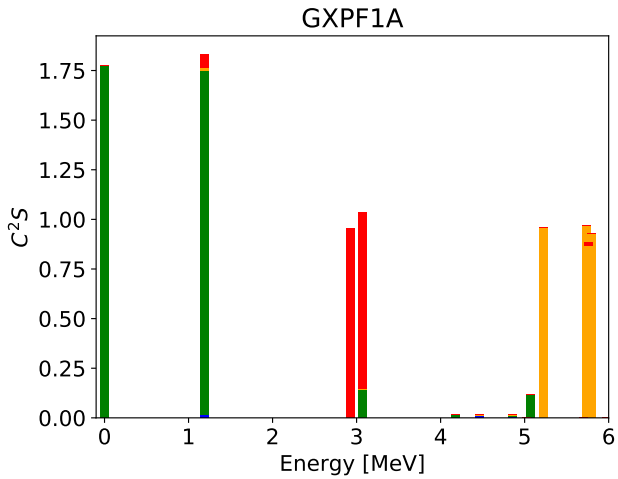
Level energy (keV)	J^π	σ_{-1n} (mb)	σ_{sp} (mb)	C^2S_{exp}	R_S	$C^2S^{norm}_{exp}$	Theoretical C^2S		
							GXPF1	*pf* NN+3N	*pf* $g_{9/2}$ NN+3N
0	$3/2^-$	$41.8^{+5.2}_{-5.9}$	18.63	2.1(3)	0.77	$2.7(^{+0.3}_{-0.4})_{stat}(\pm 0.5)_{sys}$	1.73	1.70–1.72	1.50–1.56
2023	$1/2^-$	$4.4^{+0.8}_{-0.5}$	15.04	$0.28^{+0.05}_{-0.03}$	0.74	$0.37(^{+0.07}_{-0.05})_{stat}(\pm 0.1)_{sys}$	0.17	0.12–0.14	0.12–0.14
3357	$7/2^-$	$38.9^{+5.1}_{-3.9}$	10.87	$3.4^{+0.4}_{-0.3}$	0.72	$4.7(^{+0.6}_{-0.5})_{stat}(\pm 0.9)_{sys}$	7.7	5.6–5.7	6.3–6.7
3750–3900[a]	$7/2^-$							1.5–1.8	0.4–0.5
4017	$9/2^+$	0.8	11.39	0.07	0.71	0.09			0.15–0.20
Direct inclusive: 98(10) [*Total inclusive:* 116(10)]									

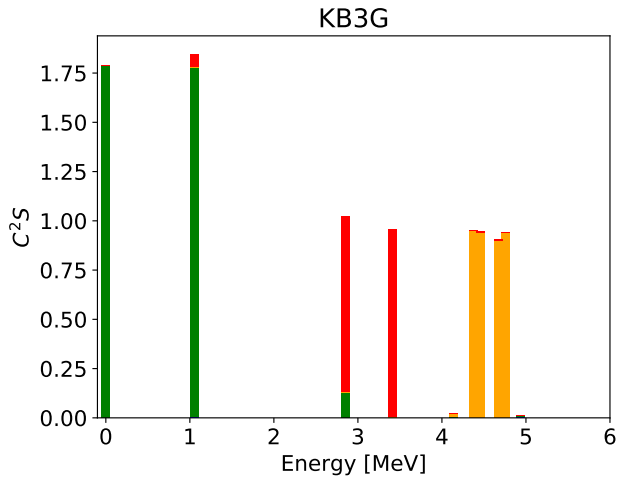
[a]Prediction for $7/2^-_2$ state in NN+3N calculations; the range captures the prediction for calculations in the *pf* model space (400 keV above $7/2^-_1$) and *pf* $g_{9/2}$ model space (550 keV above $7/2^-_1$).

H. L. Crawford *et al*, Phys. Rev. C **95** 064317 (2017).

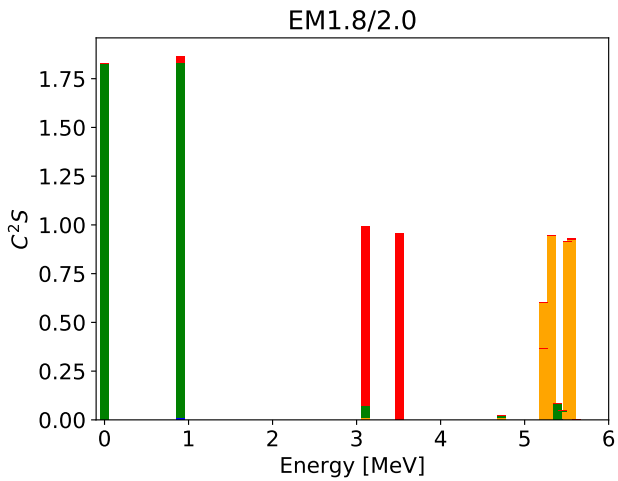
Spectroscopic factor predictions

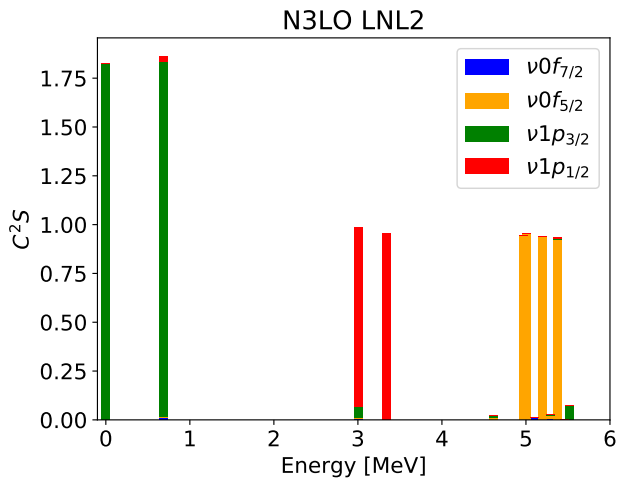
Phenomenological

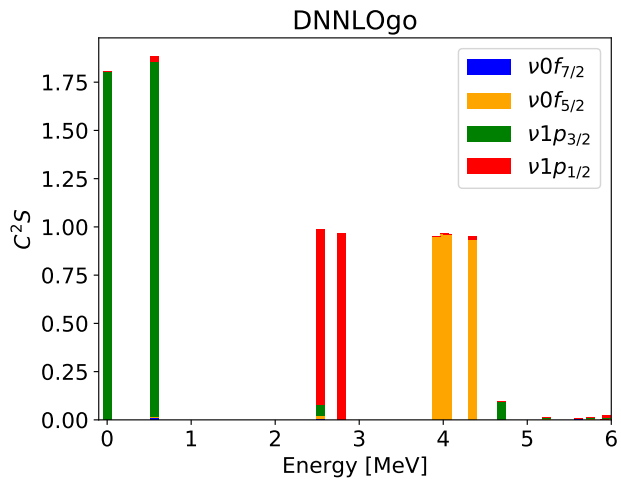




ab initio (VS-IMSRG)

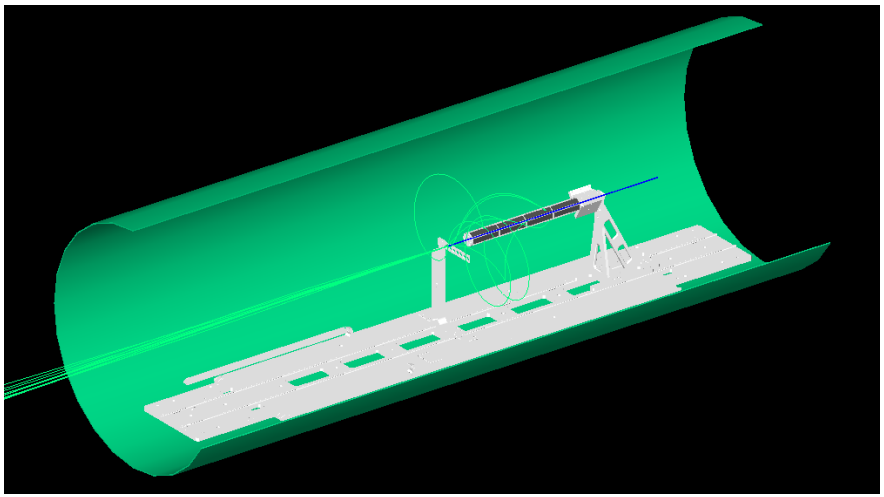


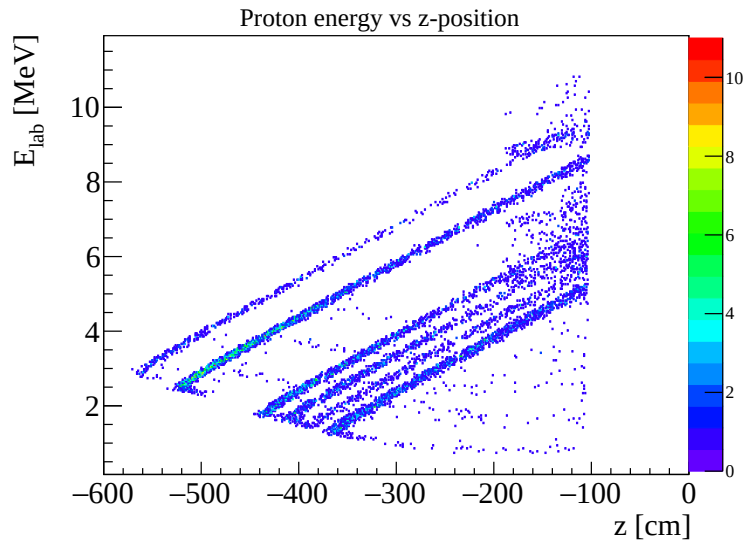


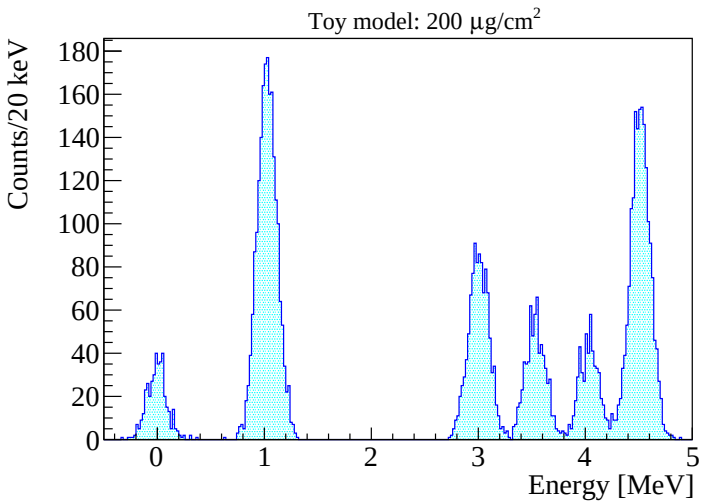


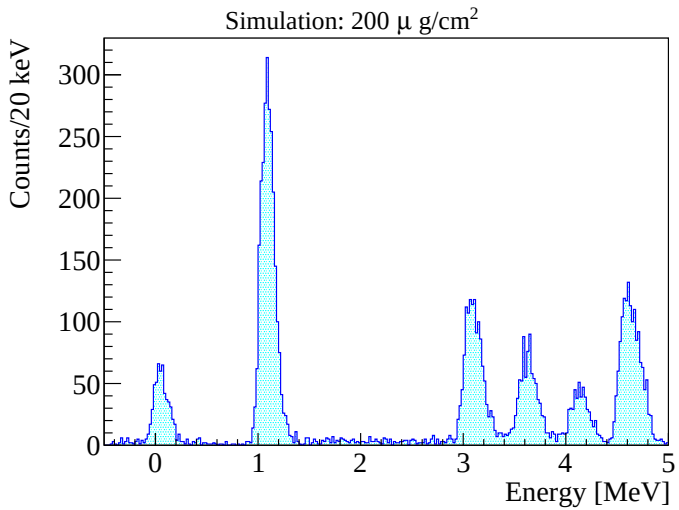
J. D. Holt & B.-S. Hu, Private comm. (2022).

Experiment: ISS simulations





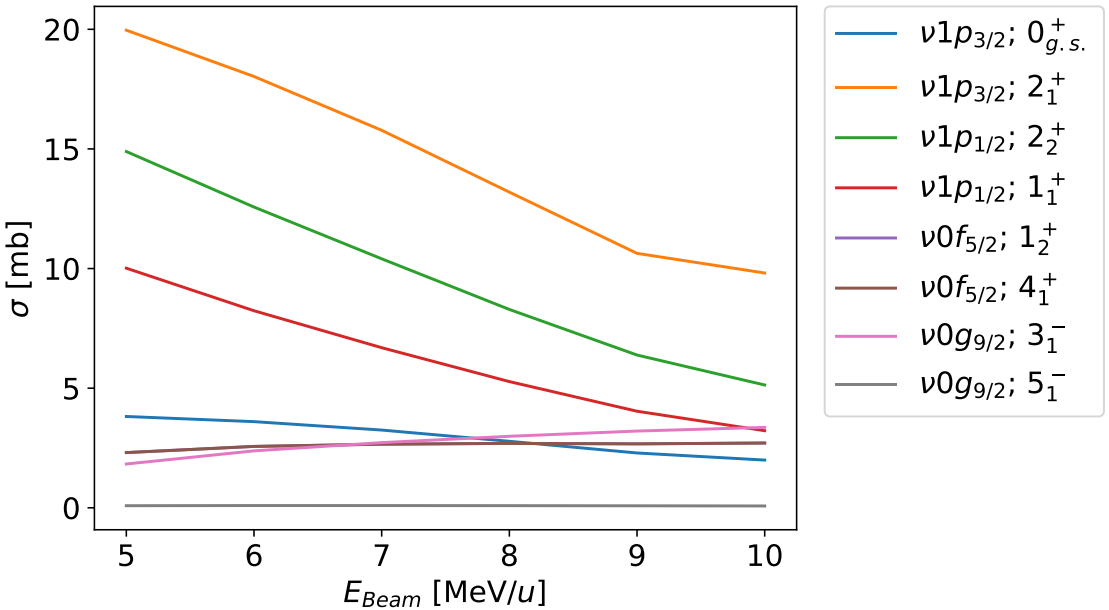




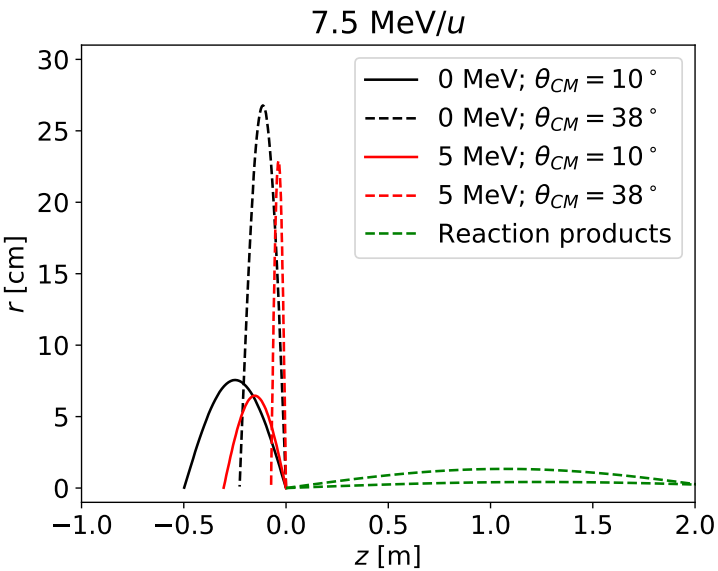
- FWHM $= 210$ keV $\forall E$
- Not a bad approximation
- 7.5 MeV/u, same rates as proposal

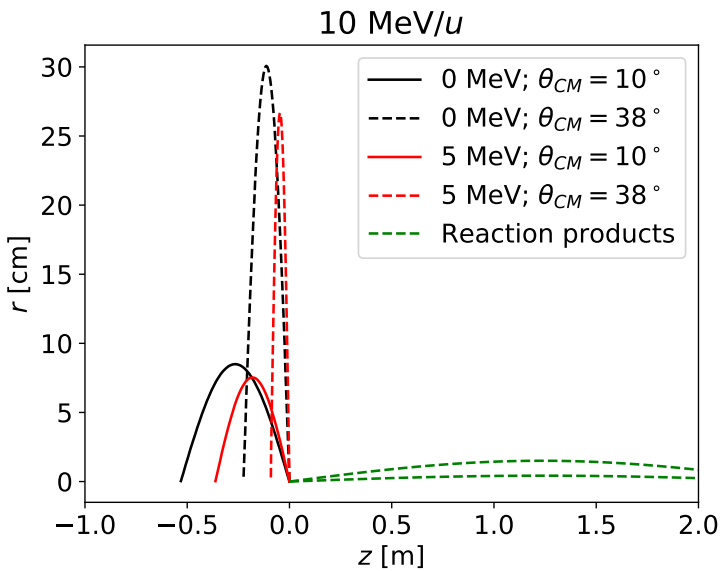
- $150 \lesssim$ FWHM $\lesssim 230$ keV

Experimental overview: reaction



- Lower E_{beam} beneficial
- 7.5 MeV/u: possible $\ell = 4$ detection E-ΔE measurement
- Kinematics fine at lower E

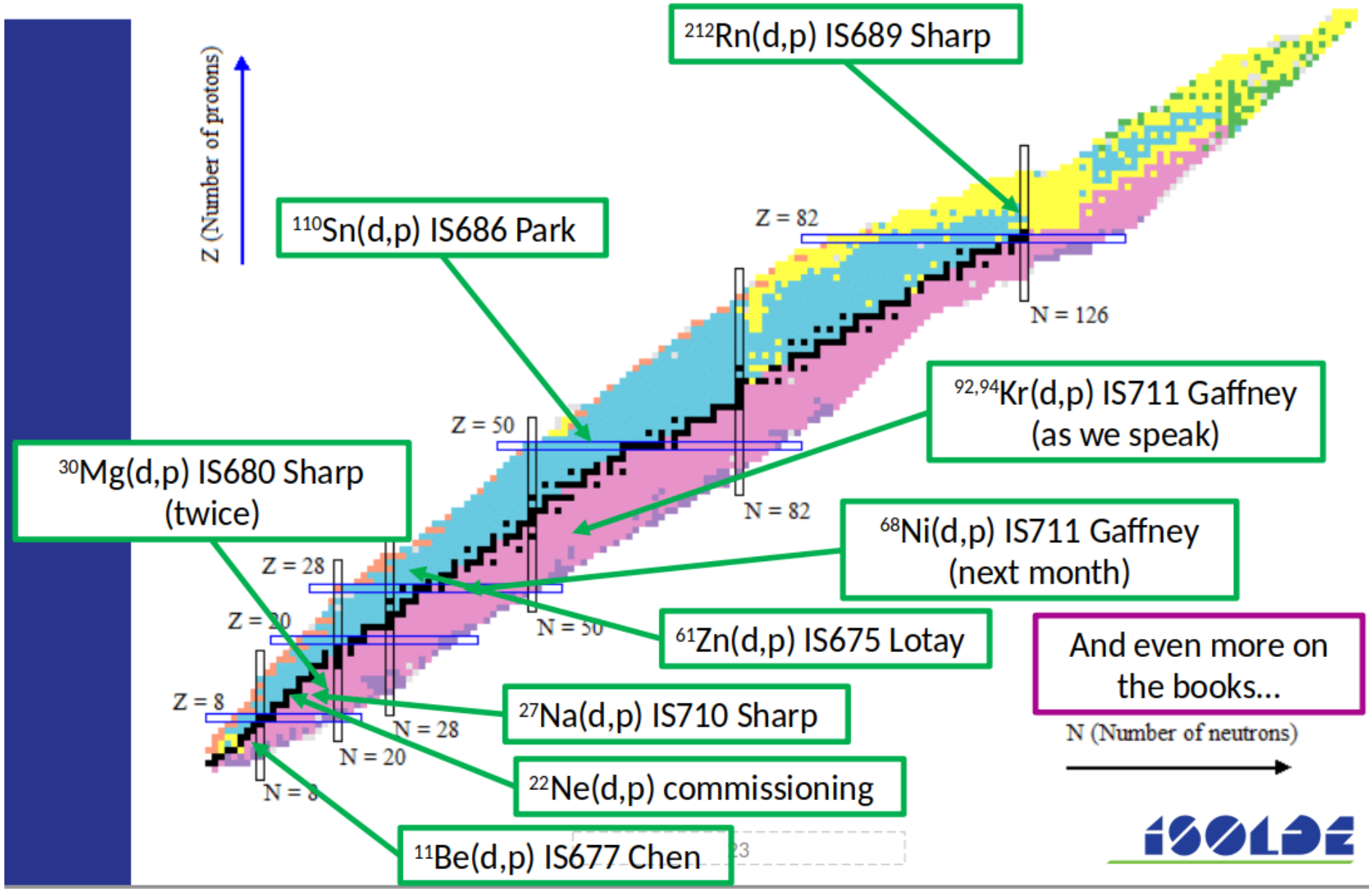




Measurement objectives

- Perform first nucleon-adding reaction to n-rich Ca
  - → Populated states will likely be of single-particle nature
- Inform on the nature of observed states in ^{50}Ca
  - → Almost all states are tentative
  - → Necessary for testing of predictions
- Benefits of ^{49}Ca(d,p)
  - → S.p. orbits fragment into many states
    - – Potential observation of new states
    - – Location of s.p. energies
  - → Mitigates possible sequential transfers of ^{48}Ca(t,p)
- Search for inconsistencies in *ab initio* and phenomenological interactions
  - → Enhancements of $\ell = 3$ and depletion of $\ell = 1$ in ^{50}Ca(-n)
    - – Not correctly predicted by either theory
- Any evidence of $\ell = 4$ transfer?

ISS experiments 2021–2022



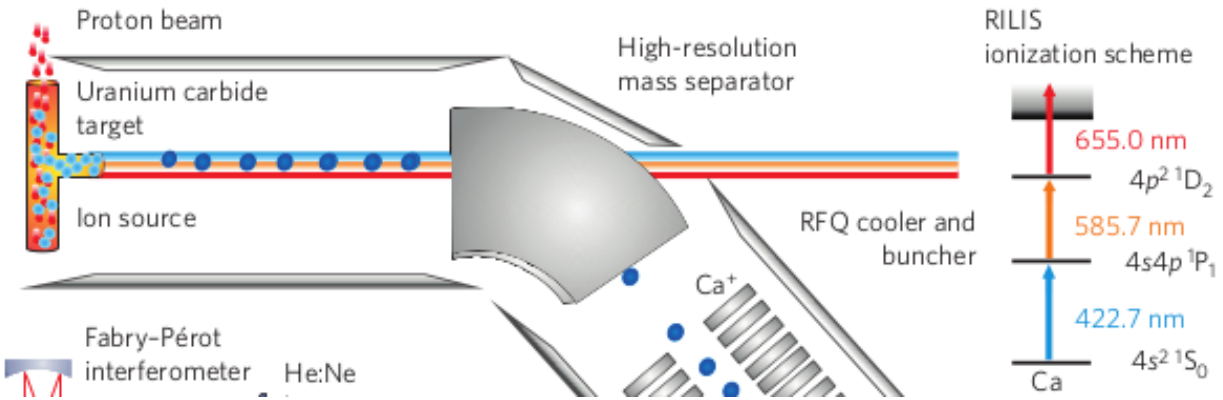
Courtesy of B. Olaizola.

Summary

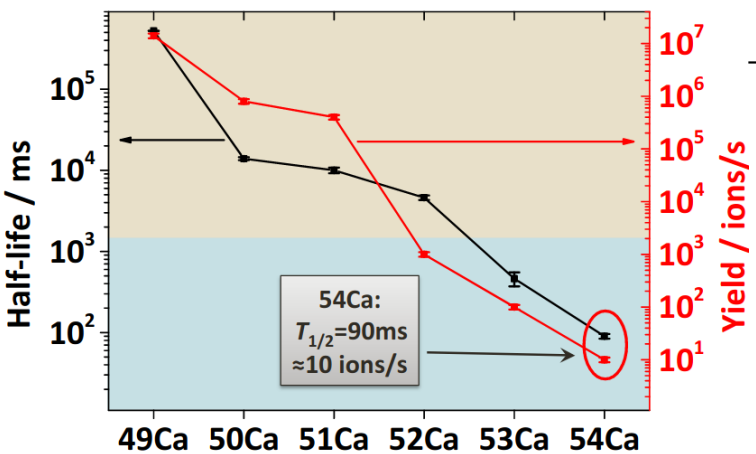
- HIE-ISOLDE
  - → Beams up to 10 MeV/u with FWHM$\leq$ 1%
    - – New physics opportunities!
- Miniball
  - → High resolution γ-ray spectroscopy
    - – Measures *Transitions*
  - → Can probe collective behaviours through Coulex
- Isolde Solenoidal Spectrometer
  - → Measures states directly
  - → Ideal for single-particle studies
  - → High efficiency at high energies

Merci beaucoup

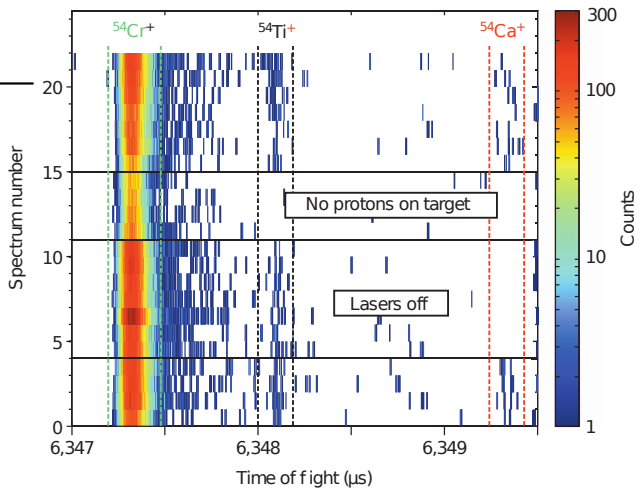
Beam production & yields



- 1.4 GeV protons
- 3-step ionisation scheme
- 30 keV continuous beam
- HRS
- 60 ns bunches



A	Yield [ions/s]
49	1.37×10^7
50	8.05×10^5
51	3.97×10^5
52	1.00×10^3
53	9.81×10^1
54	1.00×10^1



R. F. Garcia Ruiz *et al*, Nat. Phys. **12** 594 (2016).
F. Wienholtz *et al*, Nature **498** 346 (2013).
F. Wienholtz, Presented at: Hirschegg 2015.

Angular cross section dependence