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Studying the evolution of the nuclear structure along the zinc isotope chain, close to ^{78}Ni, via multi-step Coulomb Excitation

Dr. Andrés Illana Sisón

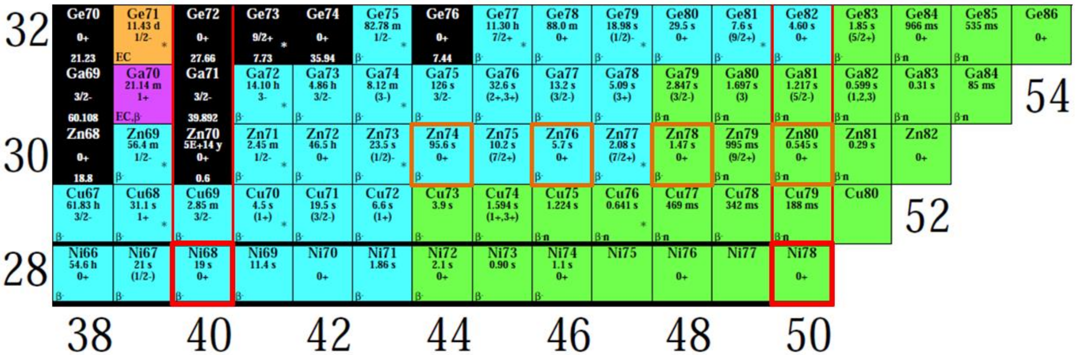
ISOLDE

MINIBALL

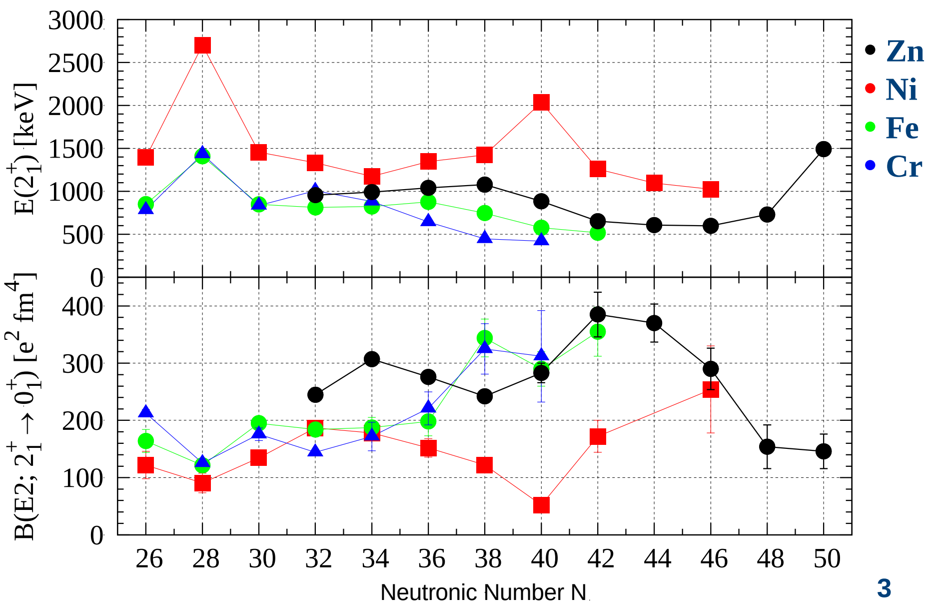
OUTLINE

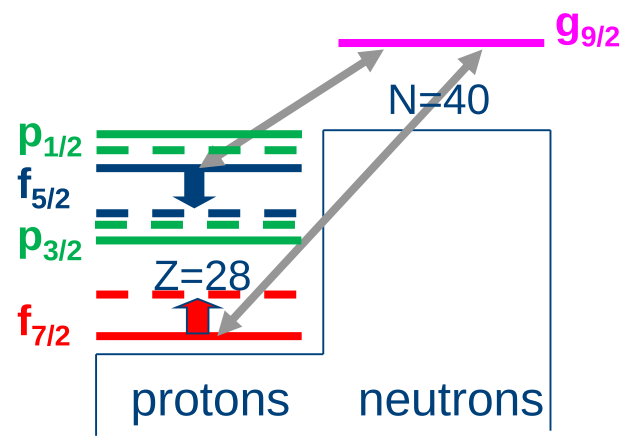
- Physics motivation
- The experiments at HIE-ISOLDE
- Preliminary results
- Outlook and future perspectives

Physics motivation



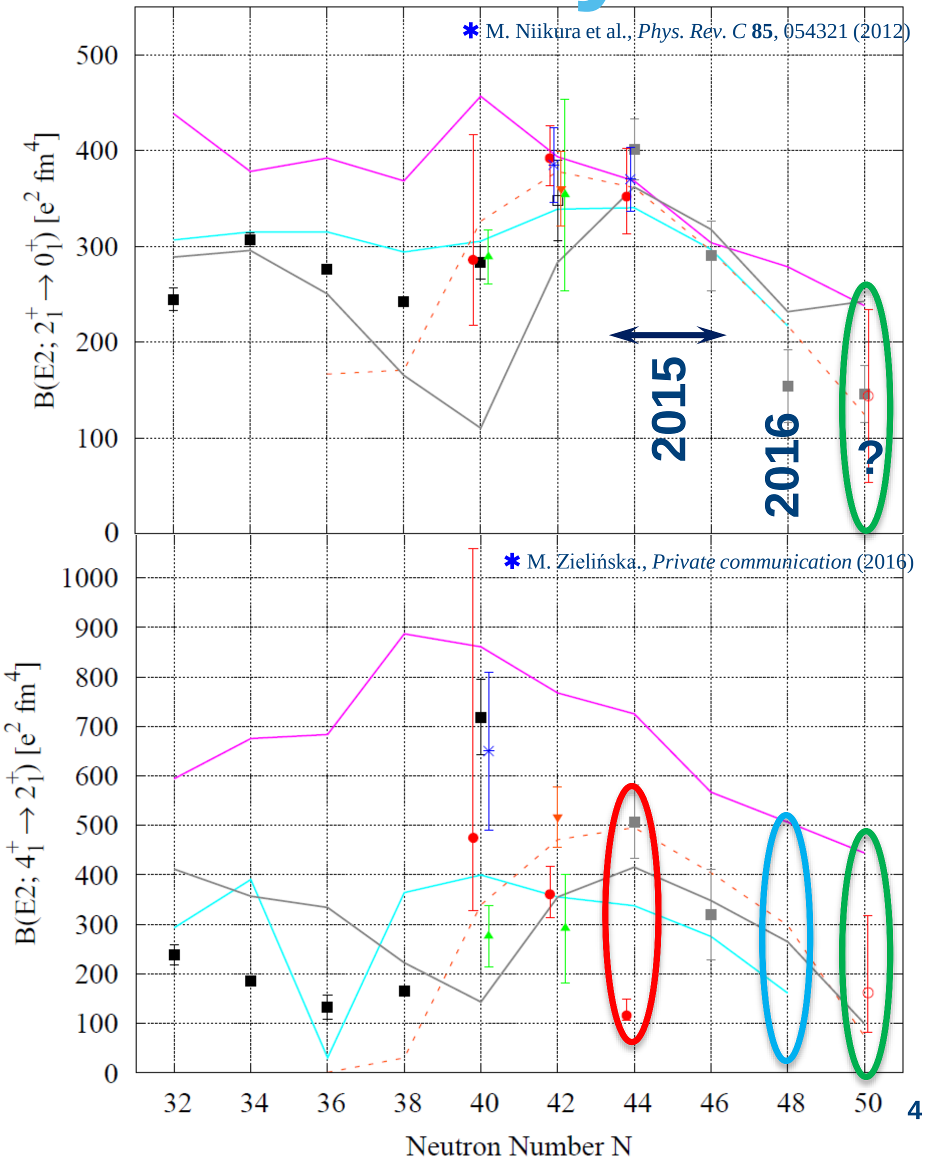
This region has been studied using different techniques: COULEX, β-decay, RDDS, laser spectroscopy,…





Reduction of the proton $f_{5/2}$ - $f_{7/2}$ gap when filling $\upsilon g_{9/2}$. *T. Otsuka, Phys. Scr. T152 (2013) 014007*

Physics motivation



Why and what?

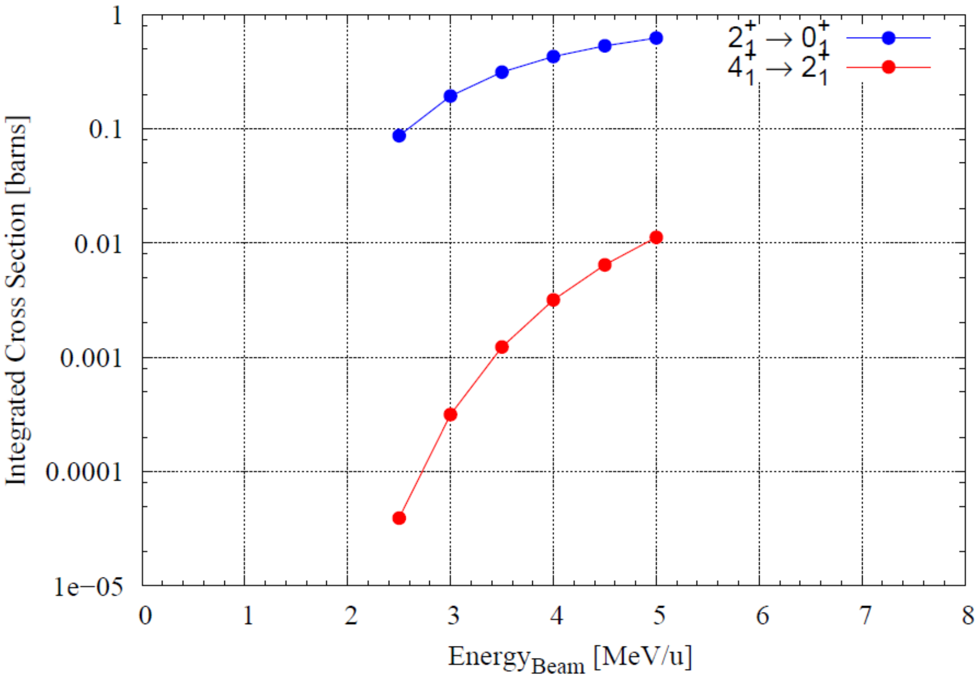
- ✓ Large disagreement for ^{74}Zn B(E2). The reduced value for ^{74}Zn is not predicted by any model.
- ✓ Clarify discrepancies with half-lifes measurements.
- ✓ Measure B(E2: $2^+ \rightarrow 0^+$) and B(E2: $4^+ \rightarrow 2^+$).
- ✓ Try to measure B(E2: $6^+ \rightarrow 4^+$).
- ✓ Measure Quadrupole moments. Observation of 4^+ in ^{80}Zn.
- ✓ Identification of low lying no-yrast states.

- ■ National Nuclear Data Center (NNDC). DSAM experiments.
- ■ J. Van de Walle et al., *Phys. Rev.* C **79**, 014309 (2009) - Coulex experiment
- ● C. Louchart et al., *Phys. Rev. C* **87**, 054302 (2013)
- ▲ I. Čeliković et al., *Act. Phys. Pol. B* **44**, 375-380 (2013)
- ▼ S. Hellgartner, PhD Thesis, TU Munich (2015)
- ○ Y. Shiga et al., *Phys. Rev. C* **93**, 024320 (2016)
- — M. Honma et al., *Phys. Rev. C* **80**, 064323 (2009)
- … S. Lenzi et al., *Phys. Rev. C* **82**, 054301 (2010)
- — J.-P. Delaroche et al., *Phys. Rev. C* **81**, 014303 (2010)
- — T. Osuka., *Private communication* (2016)

COULEX @ HIE-ISOLDE

Which is the advantage of using beams with more energy?

- ✓ High-lying states can be more efficiently populated (still in safe COULEX regime). Multi-step COULEX.
- ✓ More sensitivity in the Quadrupole moment determination.



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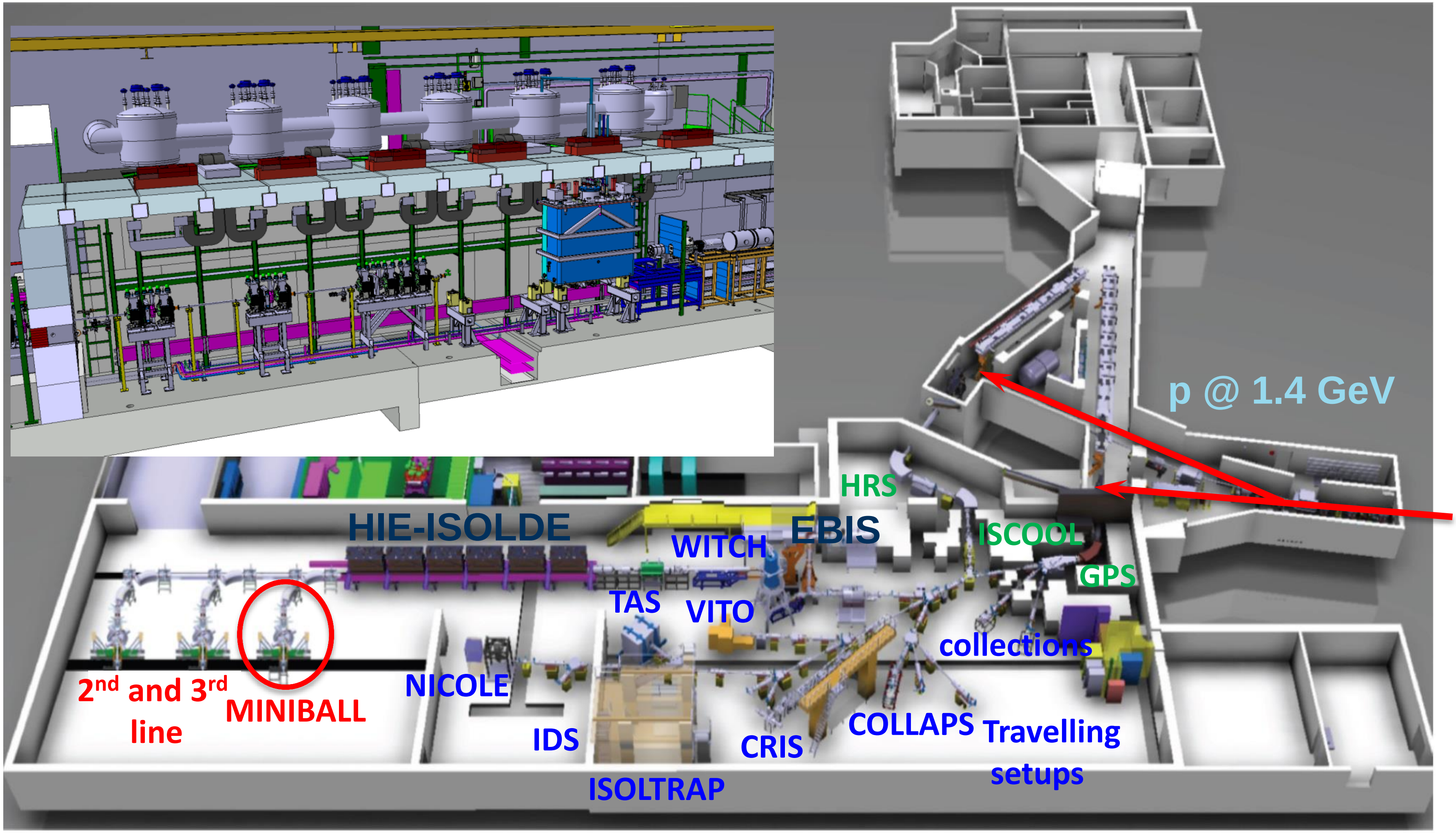
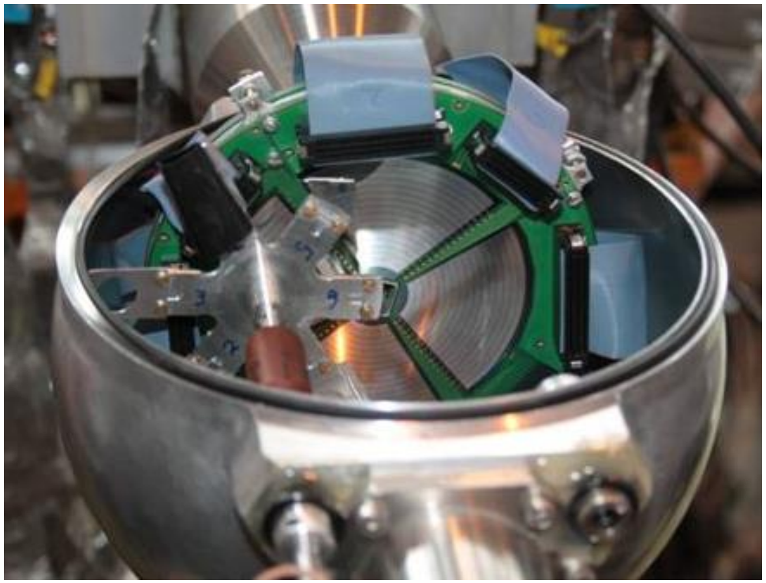
The MINIBALL array at HIE-ISOLDE

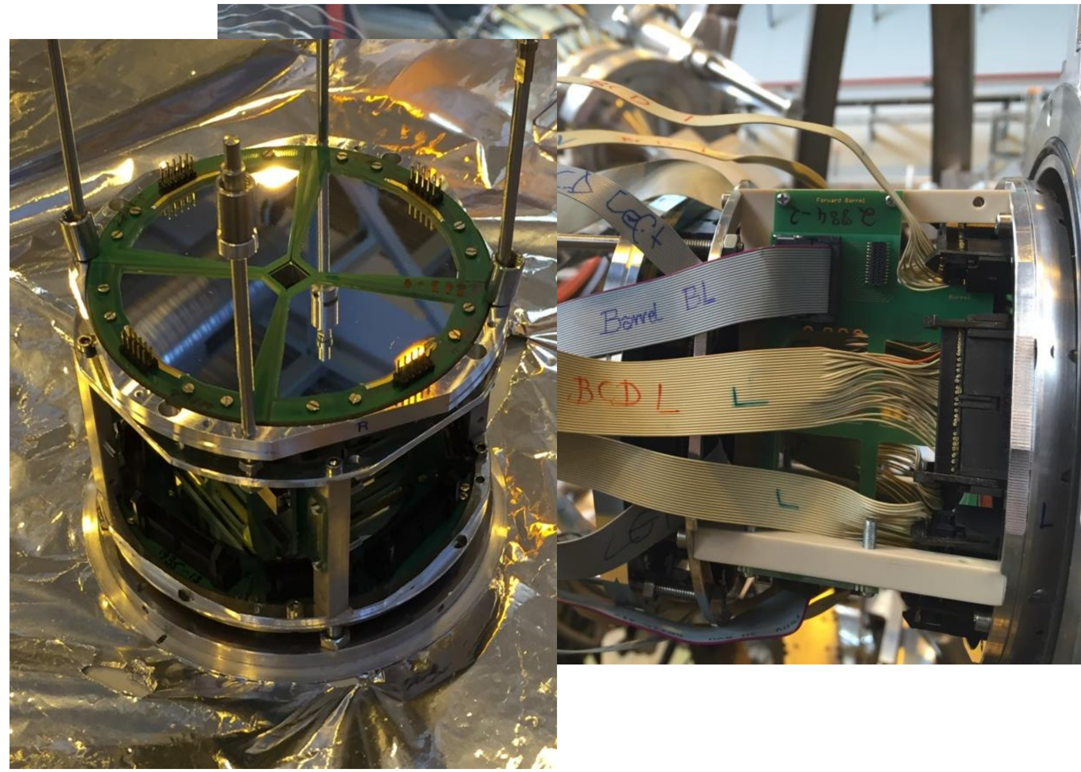


COULEX setups

Two possible setups are available: CREX and the standard COULEX chamber



Setup for 2015



Setup for 2016

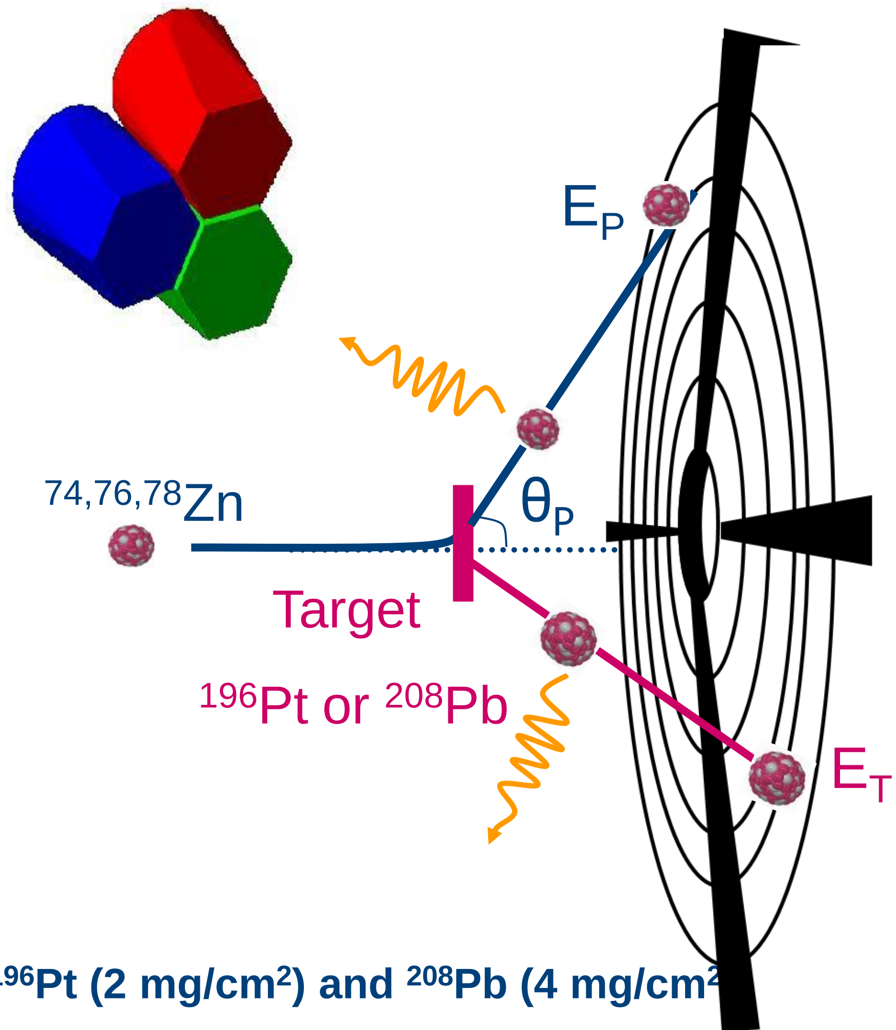
The experiments at HIE-ISOLDE

2015: Due to the problems with HIE-ISOLDE post-acceleration, we could only measure 6h/daily work and 4 nights during 3 weeks. ~ 20% time!

Isotope	Target	Energy [MeV/u]	Intensity [pps]	Total hours
^{74}Zn	^{196}Pt	2.85	~ 1.0 10^{6}	28
	^{196}Pt	4.0	~ 1.0 10^{6}	7
	^{208}Pb	4.0	~ 1.0 10^{6}	31
^{76}Zn	^{196}Pt	2.85	~ 5.0 10^{5}	20
	^{208}Pb	4.0	~ 5.0 10^{5}	14

2016: Normal conditions during 6 days.

Isotope	Target	Energy [MeV/u]	Intensity [pps]	Total hours
^{78}Zn	^{196}Pt	4.3	~ 3.0 10^{4}	~ 15
	^{208}Pb	4.3	~ 1.5 10^{3}	~ 100



2 different targets had been used: ^{196}Pt (2 mg/cm^{2}) and ^{208}Pb (4 mg/cm^{2})

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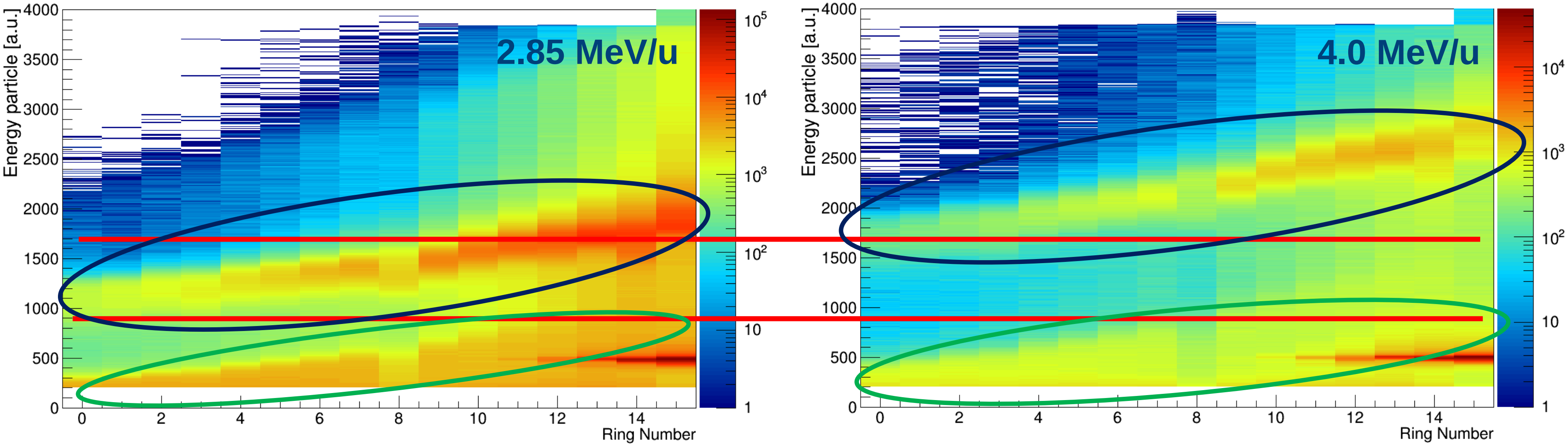
Preliminary results

Different energies different kinematics



We observe the difference between 2.85 MeV/u and 4.0 MeV/u

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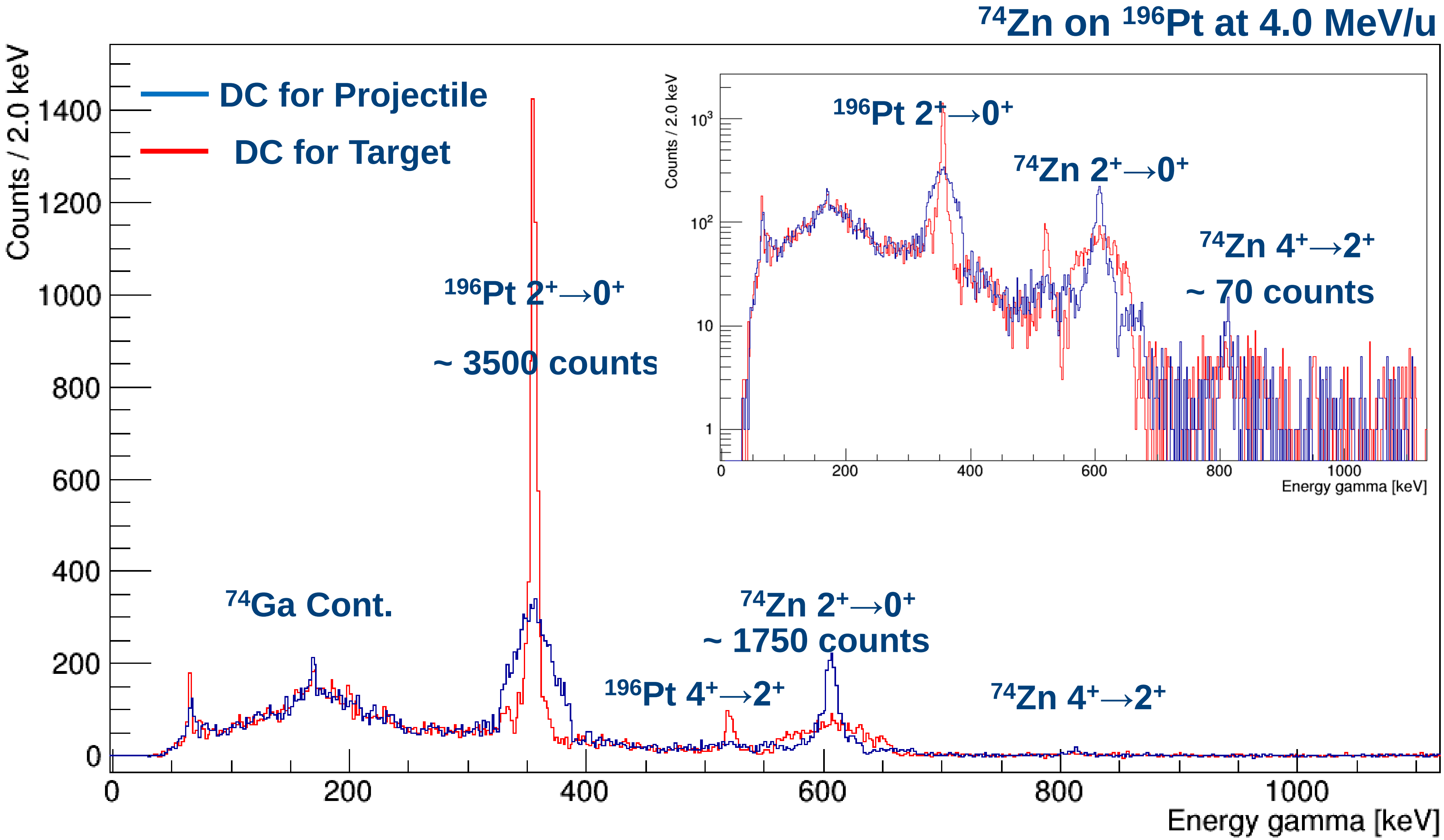
Preliminary results – Exp 2015



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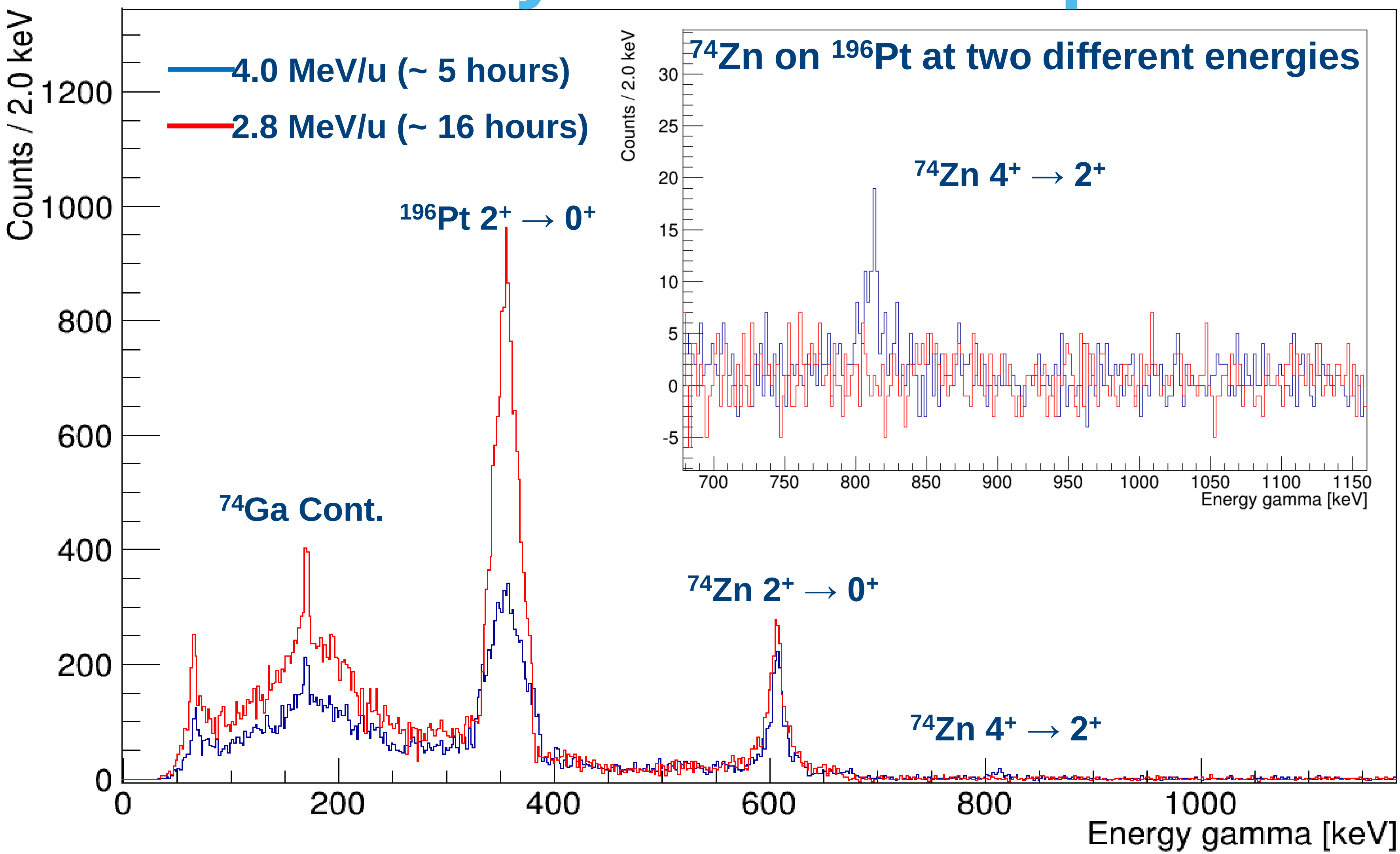

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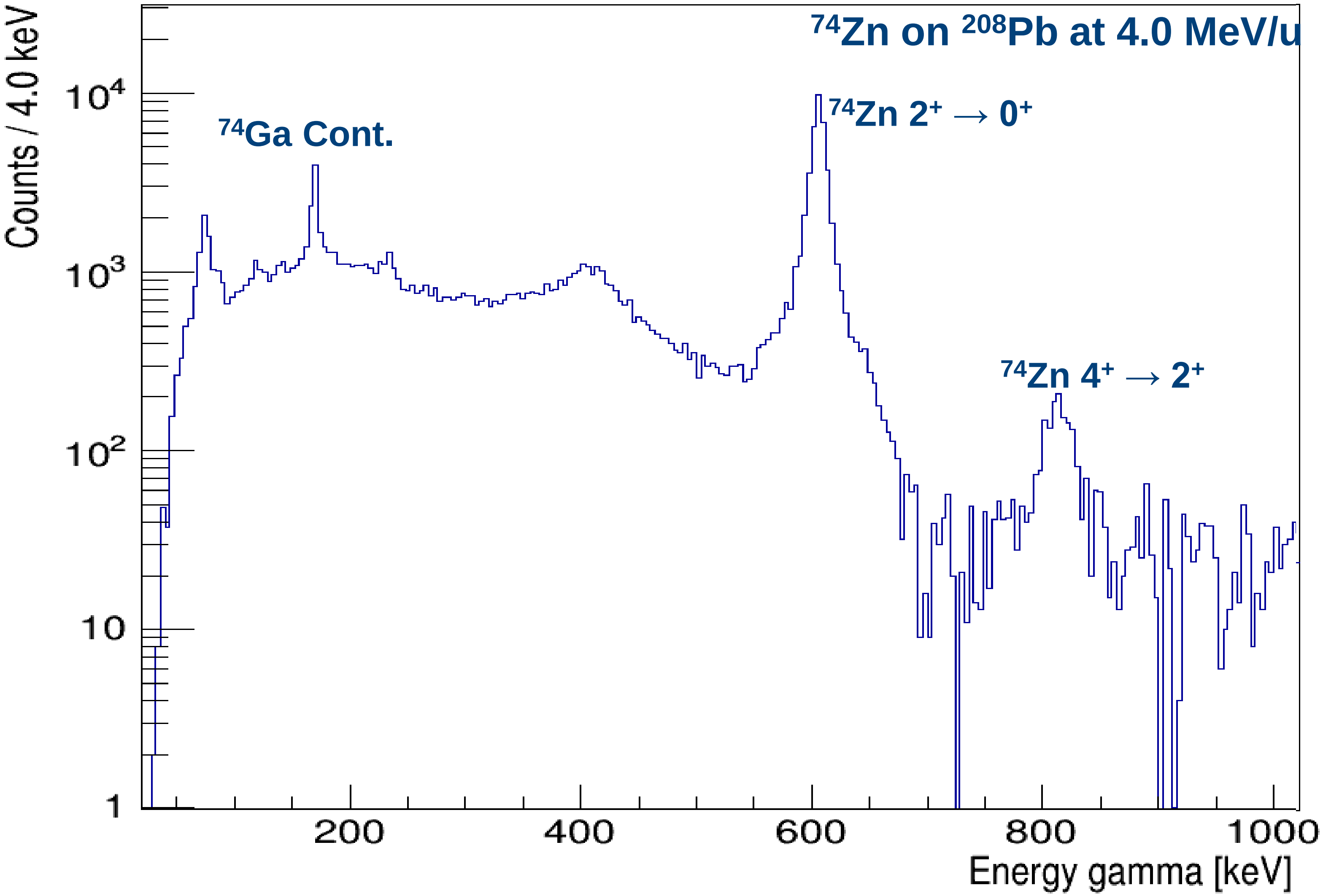
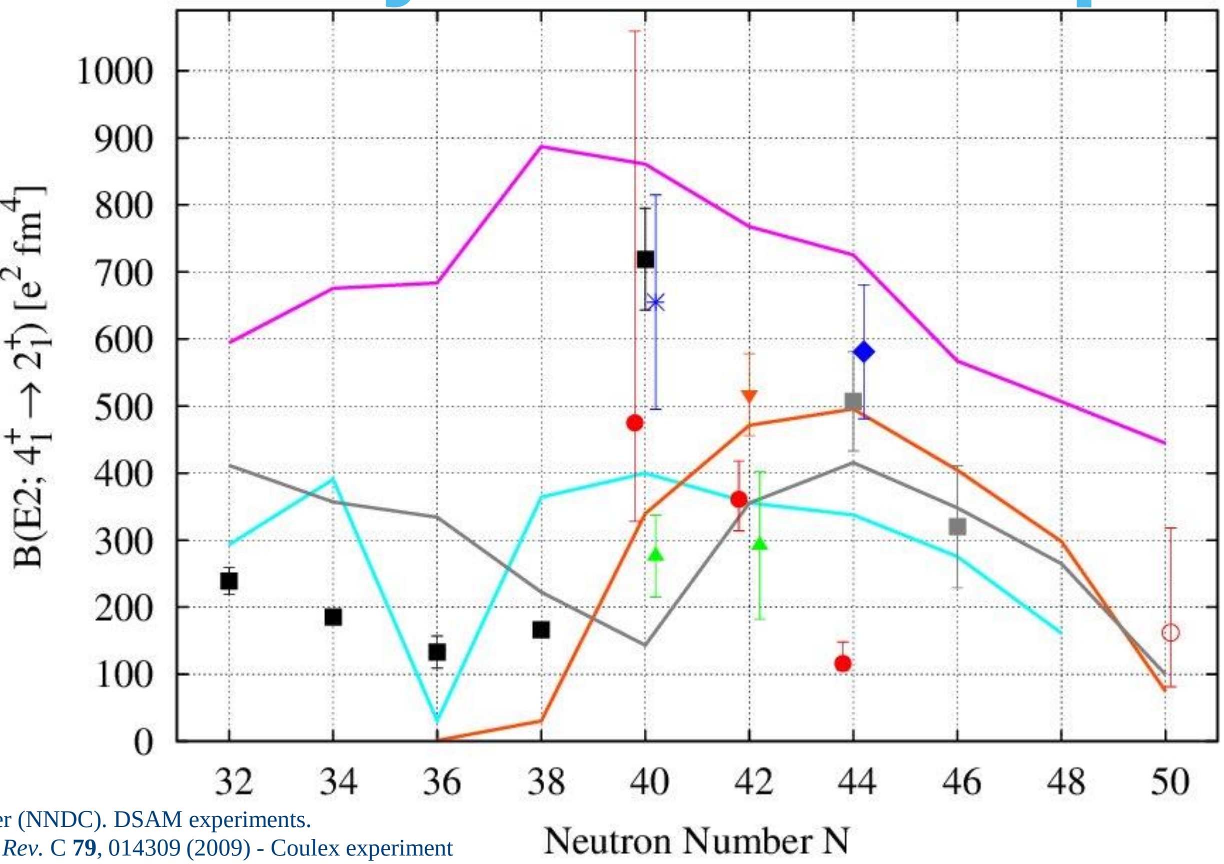


Preliminary results – Exp 2016



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✱ M. Zielińska., *Private communication* (2016)
◆ New point IS557 data
— M. Honma et al., *Phys. Rev. C* **80**, 064323 (2009)
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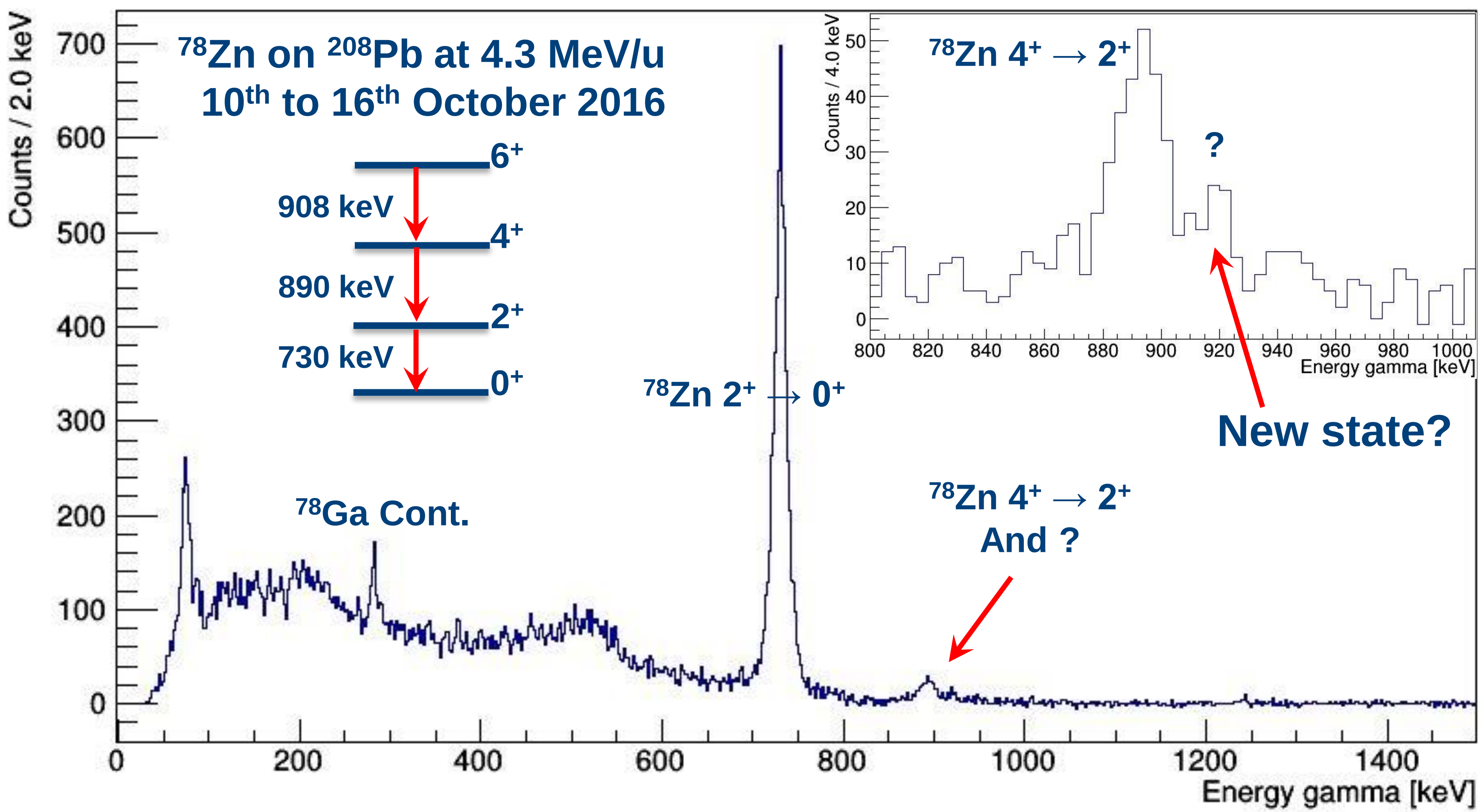
Preliminary results – Exp 2016



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Outlook and future perspectives

- Experimental campaign in 2015 was successful despite of the problems in the accelerator.
- The analysis will provide a lof of information:
  - $B(E2;2^+ \rightarrow 0^+)$ and $B(E2;4^+ \rightarrow 2^+)$ values for $^{74,76}Zn$.
  - Quadrupole moment of first 2^+ state in ^{74}Zn.
- The preliminary results from ^{78}Zn look promising, we expect to extract:
  - $B(E2;2^+ \rightarrow 0^+)$ and $B(E2;4^+ \rightarrow 2^+)$ values.
  - Quadrupole moment of first 2^+ state.
  - Identify this new state. γγ coincidence and improving the DC.

THANKS FOR YOUR ATTENTION

The IS577 COLLABORATION:
KU Leuven, CEA Saclay, HIL Warsaw, IKP Köln, T.U. Darmstadt, U. of Jyväskylä, INFN Firenze, INFN LNL, U. of West Scotland, CERN, T.U. Munich, U. Lund, U. of Surrey, U. Sofia, CSNSM, IPN Orsay, PSI and IEM-CSIC

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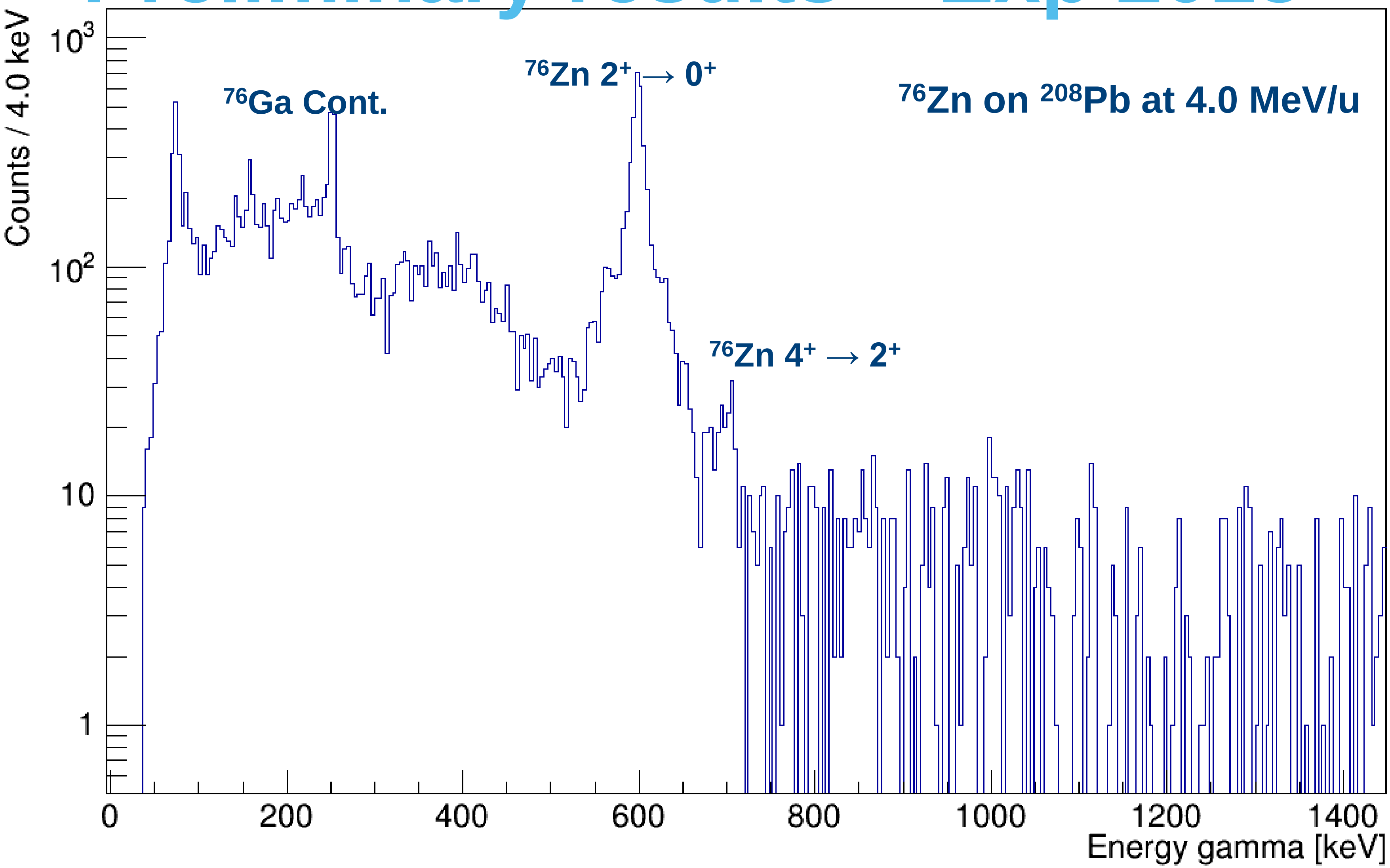
Preliminary results – Exp 2015



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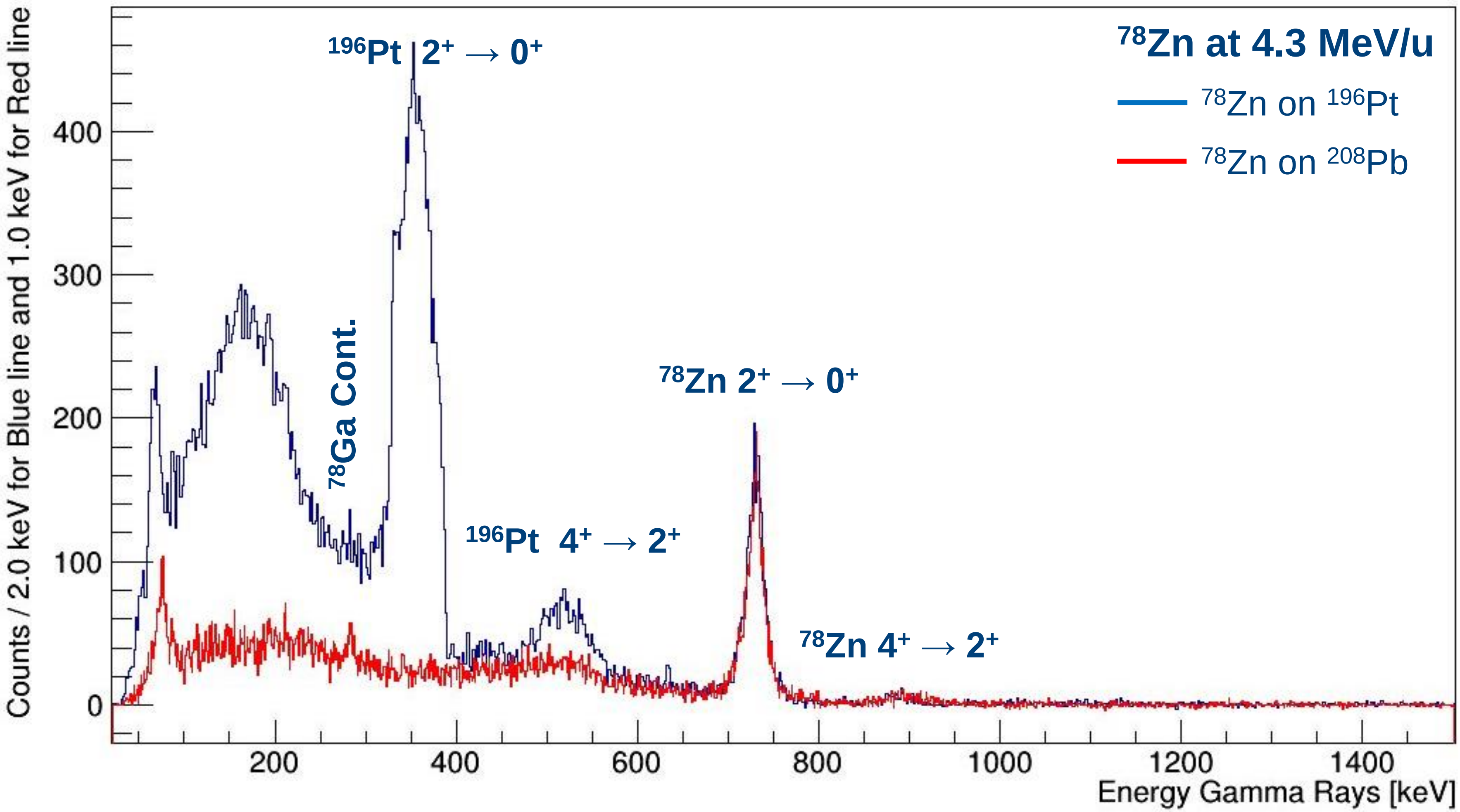
Preliminary results – Exp 2016



The COULEX technique

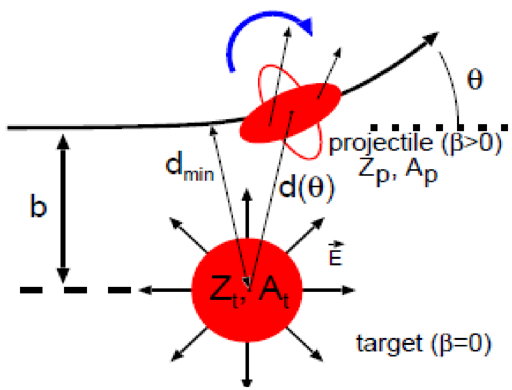
COULEX is the most powerful and direct experimental method to study nuclear collectivity and shapes.

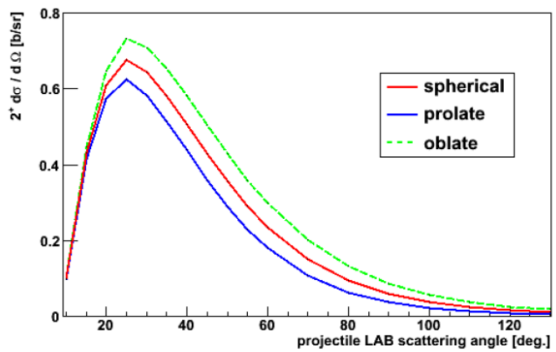
- ✓ Excitation mechanism is purely electromagnetic. The only nuclear properties involved → matrix elements of the electromagnetic multipole moments.

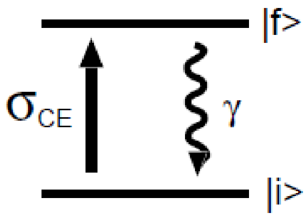
$$B(E2; 0^+ \rightarrow 2^+) = \langle 0^+ || E2 || 2^+ \rangle^2$$

- ✓ Bringing information on Qs and relative signs of matrix elements → direct distinguish between prolate and oblate shape.

$$\langle 2^+ || E2 || 2^+ \rangle = \frac{1}{0.7579} Q_2$$







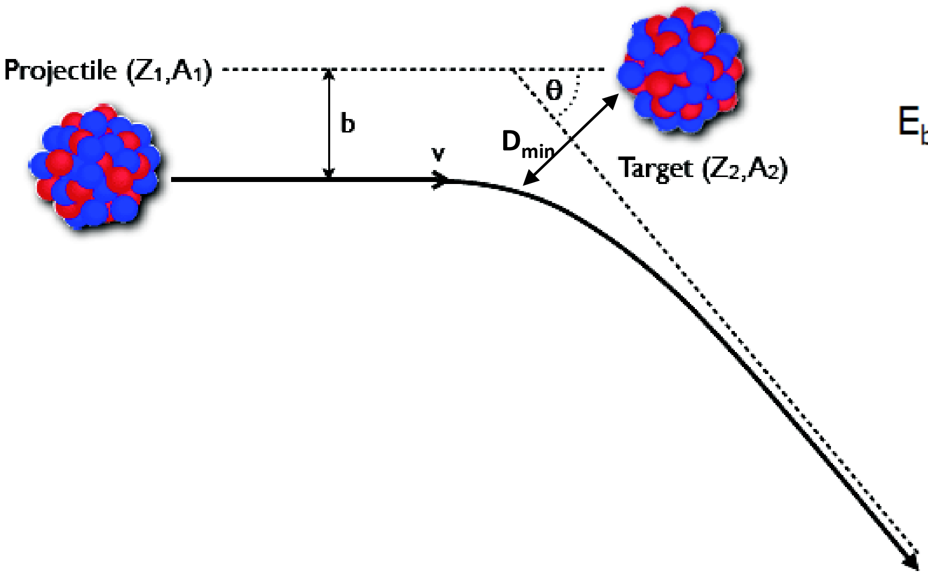
Observables: Transition energies and intensities
→ **Determine new excited levels and study deformations**

Important considerations in COULEX

Pure electromagnetic interaction if only the distance of closest approach D_{min} is at least 5 fm. Therefore, the nuclear part of the interaction can be neglected (Cline's criterion)

$$D_{min} \geq r_s = [1.25\,(A_1^{1/3} + A_2^{1/3}) + 5]\ \text{fm}$$

The excitation process depends on: $\mathbf{E_{beam}}$, **Z** of projectile and target nuclei, $\boldsymbol{\theta_{scattering}}$



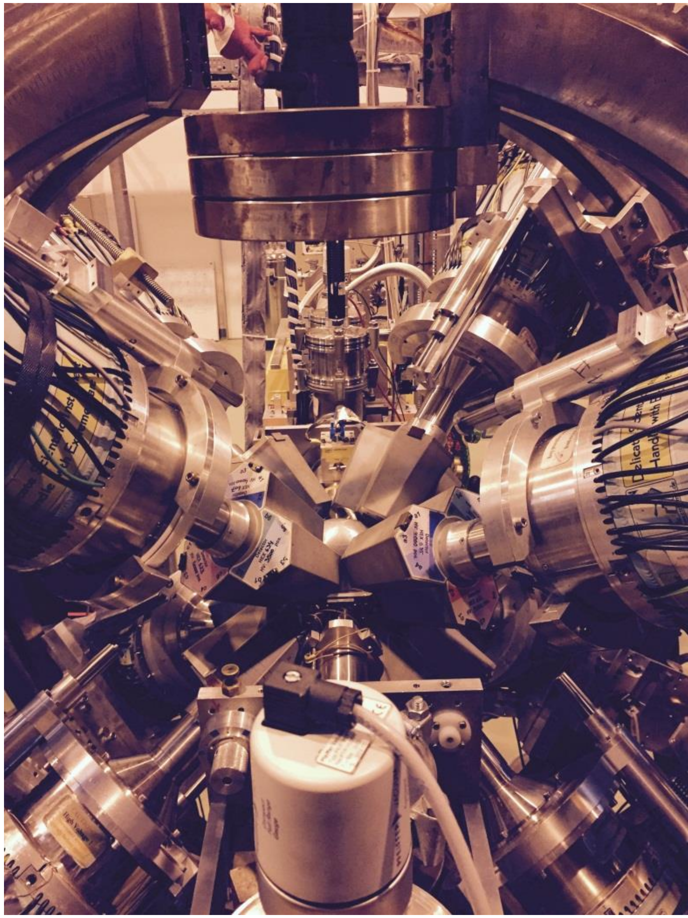
K. Alder et al., Rev. Mod. Phys. 28 (1956) 432 - 542

$$E_b(\theta_{cm}) = 0.72 \cdot \frac{Z_P Z_T}{D_{min}} \cdot \frac{A_p + A_t}{A_t} \cdot \left[1 + \frac{1}{\sin\left(\frac{\theta_{cm}}{2}\right)}\right] [\text{MeV}]$$

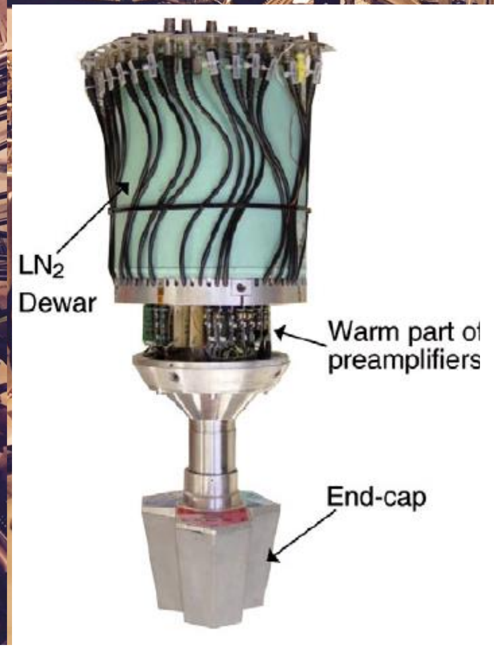
Preparing the experiment using the:

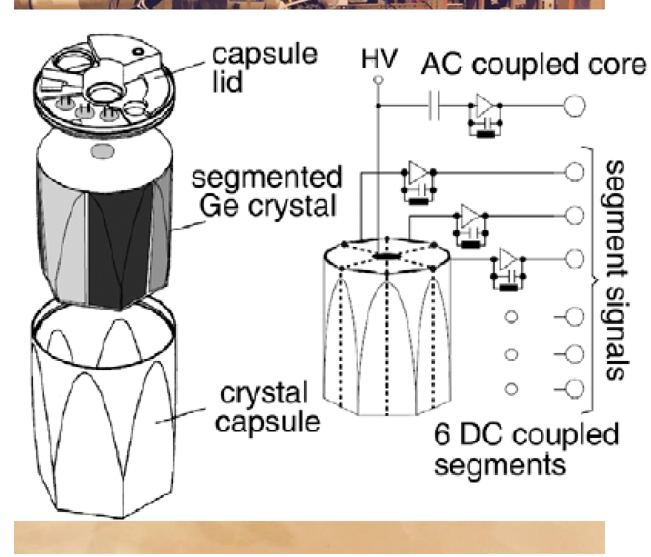
- choose adequate beam energy ($D > D_{min}$ for all θ) low-energy Coulomb excitation
- limit scattering angle, i.e. select impact parameter $b\,(E_b, \theta) > D_{min}$ high-energy Coulomb excitation

The MINIBALL array at HIE-ISOLDE



- ✓ MINIBALL has 8 clusters, each cluster is made of 3 crystals
- ✓ Each crystal is segmented in 6 parts → 144 segments in total





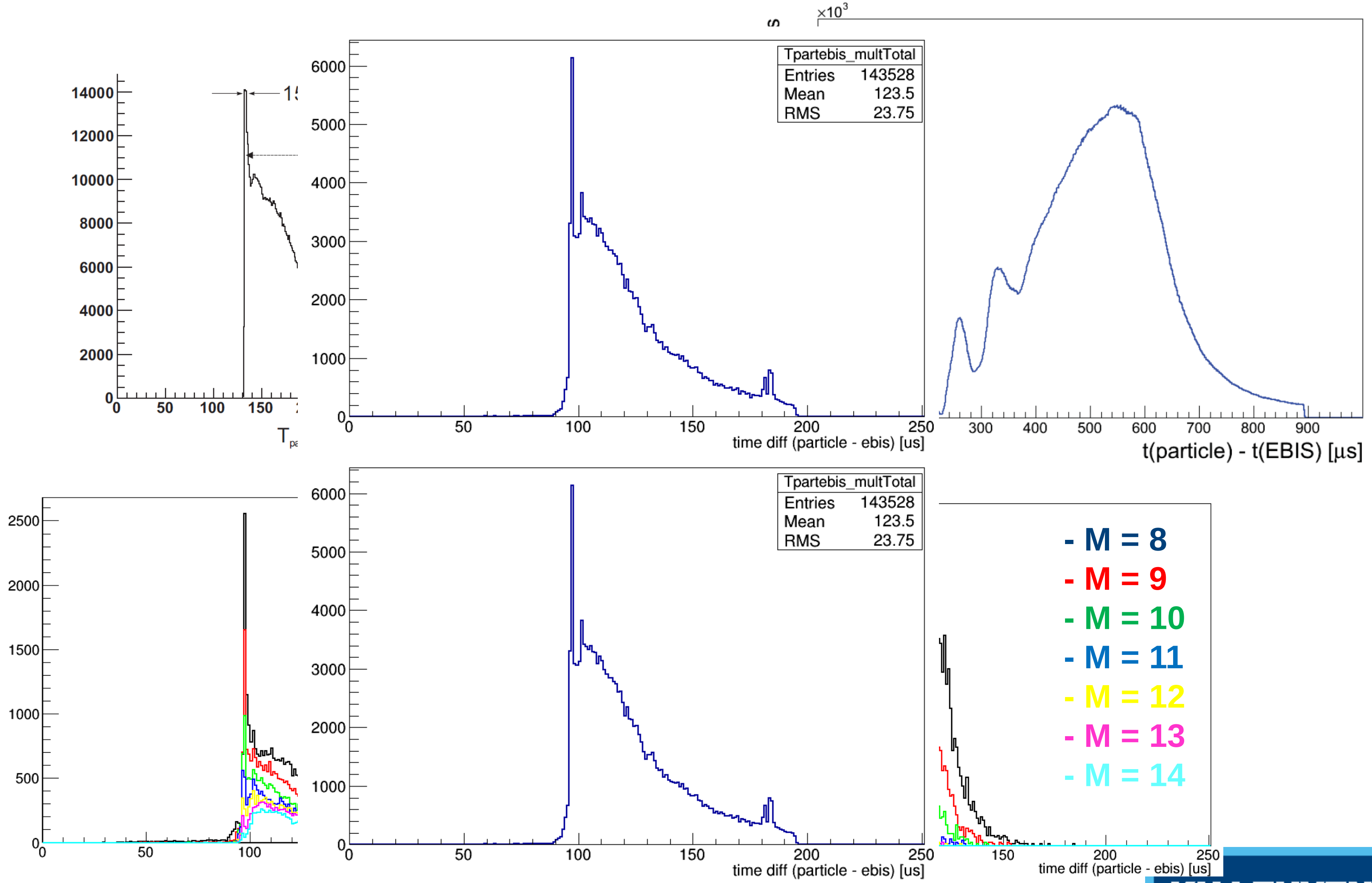
The experiments at HIE-ISOLDE

Summary about all the Zn experiments.

Year	Type Experiment	Isotope	Target	Extra information	Beam Intensity [pps]	Energy [MeV/u]	Time Laser On [h]	Time Laser On/Off [h]	EBIS pulses [Hz]	Ion Pulse size [μs]
2015	COULEX	^{74}Zn	^{196}Pt	1st week	~ 1.0 10^{6}	4.0	13.5	5.0	2.0	~ 100
			^{196}Pt	1st /3rd week	~ 1.0 10^{6}	2.85	6.5	0.5	2.0 / 10.0	~ 100
			^{208}Pb	3rd week	~ 1.0 10^{6}	4.0	25.0	8.0	10.0	~ 100
		^{76}Zn	^{196}Pt	2nd /3rd week	~ 1.0 10^{6} / <1.0 10^{5}	2.85	25.0	4.0	5.0 / 10.0	~ 100
			^{208}Pb	2nd /3rd week	~ 1.0 10^{6} / <1.0 10^{5}	4.0	9.0		5.0 / 10.0	~ 100
2012	C-REX	^{72}Zn	^{109}Ag	-	~ 3.6 10^{7}	2.87	66.0	-	12.0	~ 800
2011	T-REX	^{72}Zn	DPE	-	~ 1.0 10^{7}	2.7	72.5	-	14.0	~ 800
2004	COULEX	^{74}Zn	^{120}Sn	-	~ 1.1 10^{6}	~ 2.8	8.5	3.0	12.0	~ 300
2004	COULEX	^{76}Zn	^{120}Sn	-	~ 3.5 10^{6}	~ 2.8	11.5	2.5	12.0	~ 300

As a consequence of this anomalous beam properties, we observed high multiplicity → It reduced our statistic

Time different Particle-Ebis Vs Multiplicity



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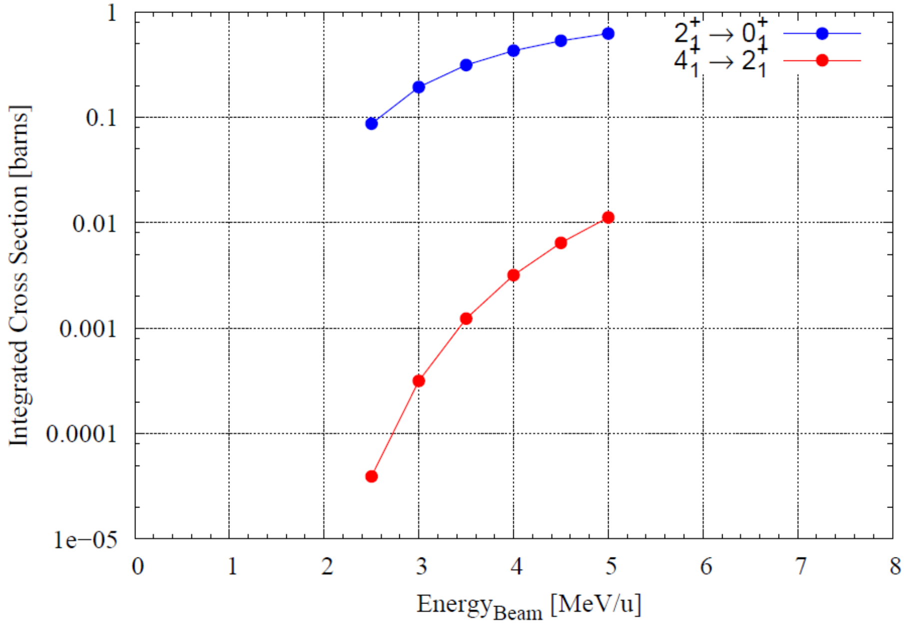

- Measure B(E2: $2^+ \rightarrow 0^+$), B(E2: $4^+ \rightarrow 2^+$) and B(E2: $6^+ \rightarrow 4^+$)
- Measure Quadrupole moments
- Clarify discrepancies with half-lifes measurements
- Observation of 4^+ in ^{80}Zn
- Identification of non-yrast states

Isotope	Energy (MeV/u)	Intensity (pps)	$2^+ \rightarrow 0^+$	$4^+ \rightarrow 2^+$	$6^+ \rightarrow 4^+$
^{74}Zn	4.3	5.10^5	$6.9.10^4$	2235	17
^{76}Zn	4.3	5.10^5	$5.4.10^4$	1470	11
^{78}Zn	4.3	10^5	5100	37	0.15
^{80}Zn	4.3	10^4	130	20	0.00012

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