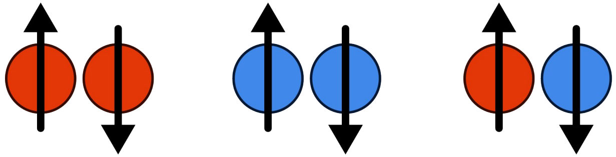
Proton-neutron pairing in the fp-shell via $^{48}Cr(p,^{3}He)^{46}V$ transfer reaction

Hugo Jacob, hjacob@ijclab.in2p3.fr
DREB conference, 28/06/2024

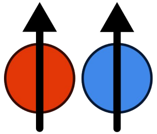
Scientific context : proton-neutron pairing

Isovector (J=0, T=1)



proton-proton   neutron-neutron   proton-neutron

Isoscalar (J=1, T=0)



proton-neutron

- Observable mostly, if not only, in N=Z nuclei
- 2 different channels available, with different strengths
- Deuteron only bound in isoscalar channel (J=1, T=0)
- Pairing effects depend on the collectivity of the shell

Scientific context : proton-neutron pairing

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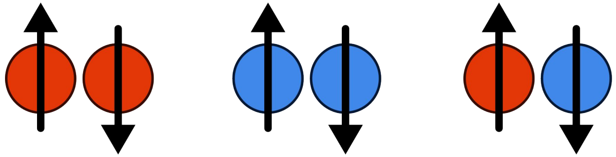
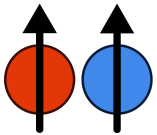


proton-proton neutron-neutron proton-neutron

Isoscalar (J=1, T=0)



proton-neutron

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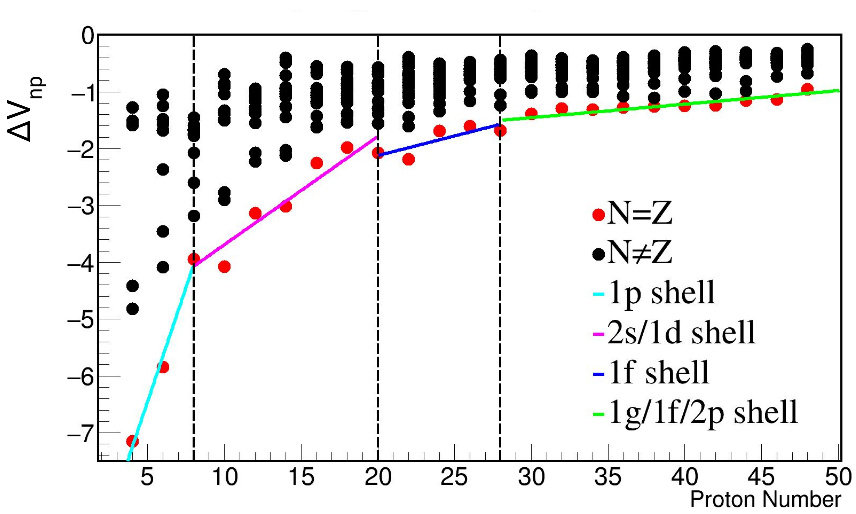
Binding energy anomaly in N=Z nuclei



Double binding energy formula:

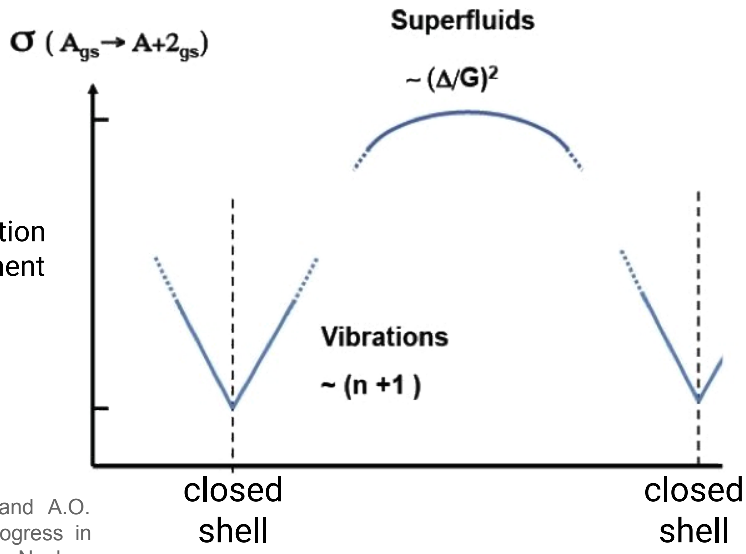
ΔV_{np} = 1/4(B(N,Z) - B(N,Z-2) - B(N-2,Z) + B(N-2,Z-2))

Data from ENSDF using TkN software

Smoking gun: two-nucleon transfer

Pairing effects on two-nucleon transfer cross-sections

Cross-section enhancement

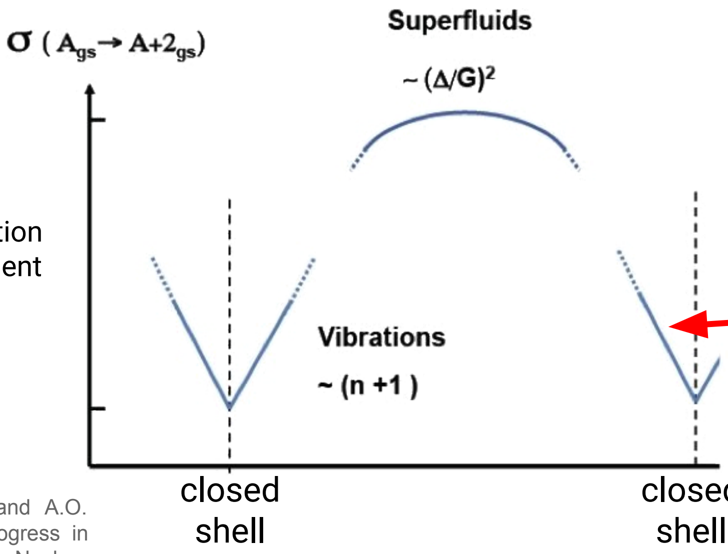


S. Frauendorf and A.O. Macchiavelli, Progress in Particle and Nuclear Physics, 24-90 **78**, 2014

- Near closed shell, cross-section increasing proportionally to the number of pairs (vibrational)
- In the middle of the shell, cross-section depends on the gap and pairing strength (rotational)

Historical example: neutron-neutron pairing

Cross-section enhancement



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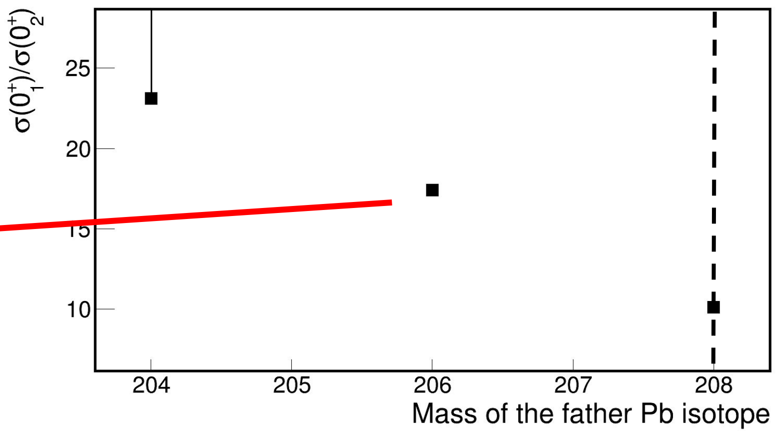
- ^{208}Pb is a double shell closure, vibrational behavior for neutron-neutron pairs in stable Pb isotopes

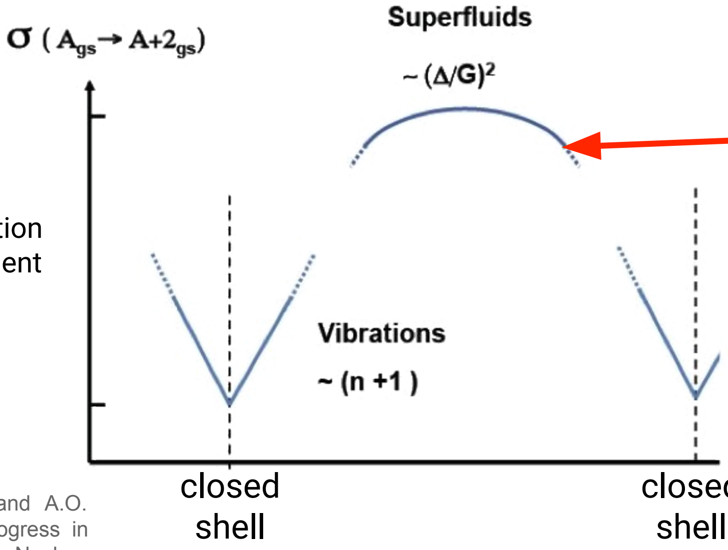
Pb isotopes (p,t) reaction cross section to the first and second 0^+ ratio



Adapted from D. M. Brink, R. A. Broglia, Nuclear Superfluidity
Data from W. A. Lanford, Phys. Rev. C **16**, 988

Historical example: neutron-neutron pairing

Cross-section enhancement



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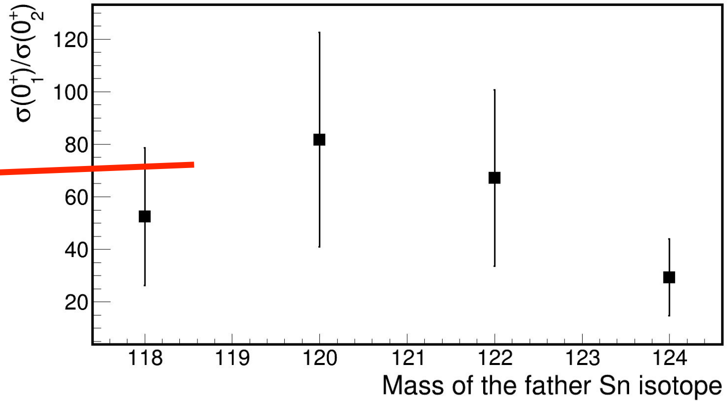
- Near closed shell, cross-section increasing proportionally to the number of pairs (vibrational)
- In the middle of the shell, cross-section depends on the gap and pairing strength (rotational)

Sn isotopes (p,t) reaction cross section to the first and second 0^+ ratio



- Sn is a proton shell closure, but stable Sn isotopes are in the middle of a neutron shell: superfluid behavior for neutron-neutron pairs

Adapted from D. M. Brink, R. A. Broglia, Nuclear Superfluidity
Data from D. G. Fleming *et al.*, Nuclear Physics A **157**, 1-31, 1970

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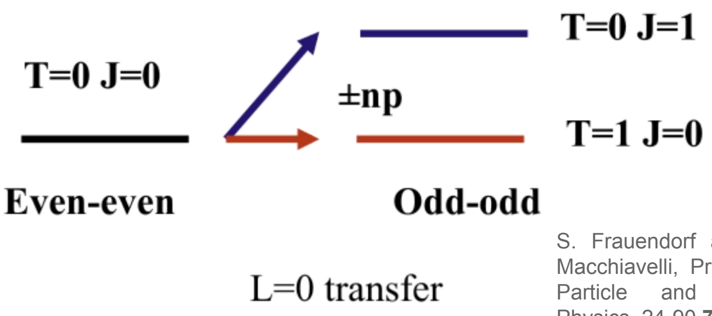
Experimental method: two-nucleon transfer

(p,^{3}He) selection rules allow to populate both low-lying states



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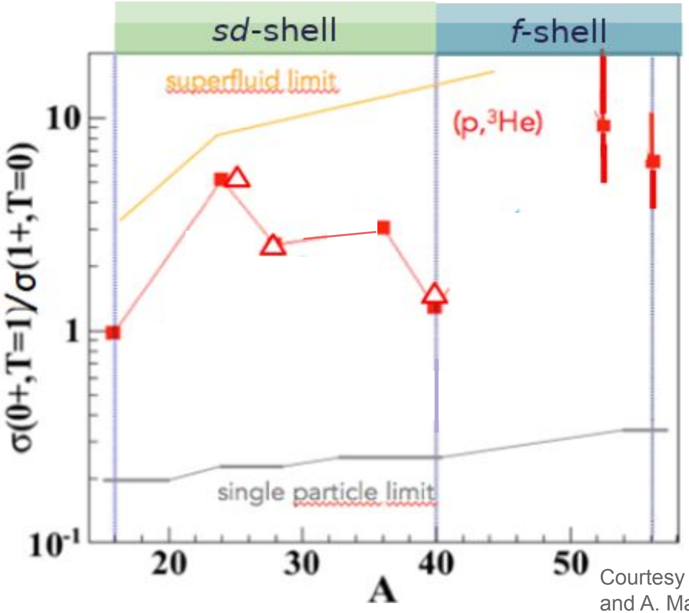

Courtesy of M. Assié and A. Macchiavelli

- Transfer to (T=0, J=1) state gives information on isoscalar pairing strength, and similarly for (T=1, J=0) and isovector pairing strength.
- Same reaction mechanism: L=0 transfer (DWBA) necessary to discriminate L=2

- Cross section ratio: useful to get rid of experimental biases
- Proton-neutron pairs: cross-section ratio shows the competition between isoscalar and isovector pairing channels

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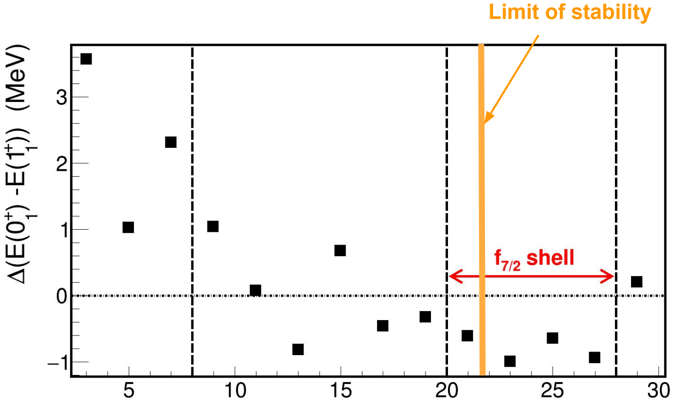
Pairing in $f_{7/2}$ shell

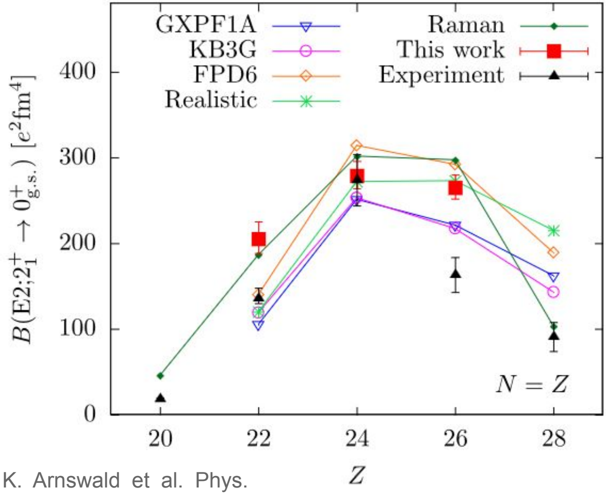
Pairing states energy difference in N=Z nuclei



Data from ENSDF using TkN software

- Pairing lowers related states energy
- 0^+ g.s. in $f_{7/2}$ could indicate stronger isovector strength in this shell

Deformation in N=Z nuclei ($f_{7/2}$ shell)

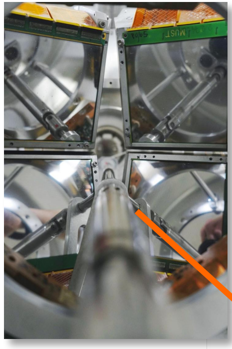


K. Arnswald et al. Phys. Lett. B 772 (2017) 599

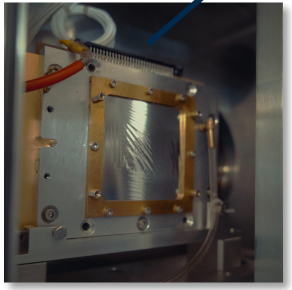
- ^{48}Cr: good candidate to study interplay between pairing and deformation

Experimental Setup

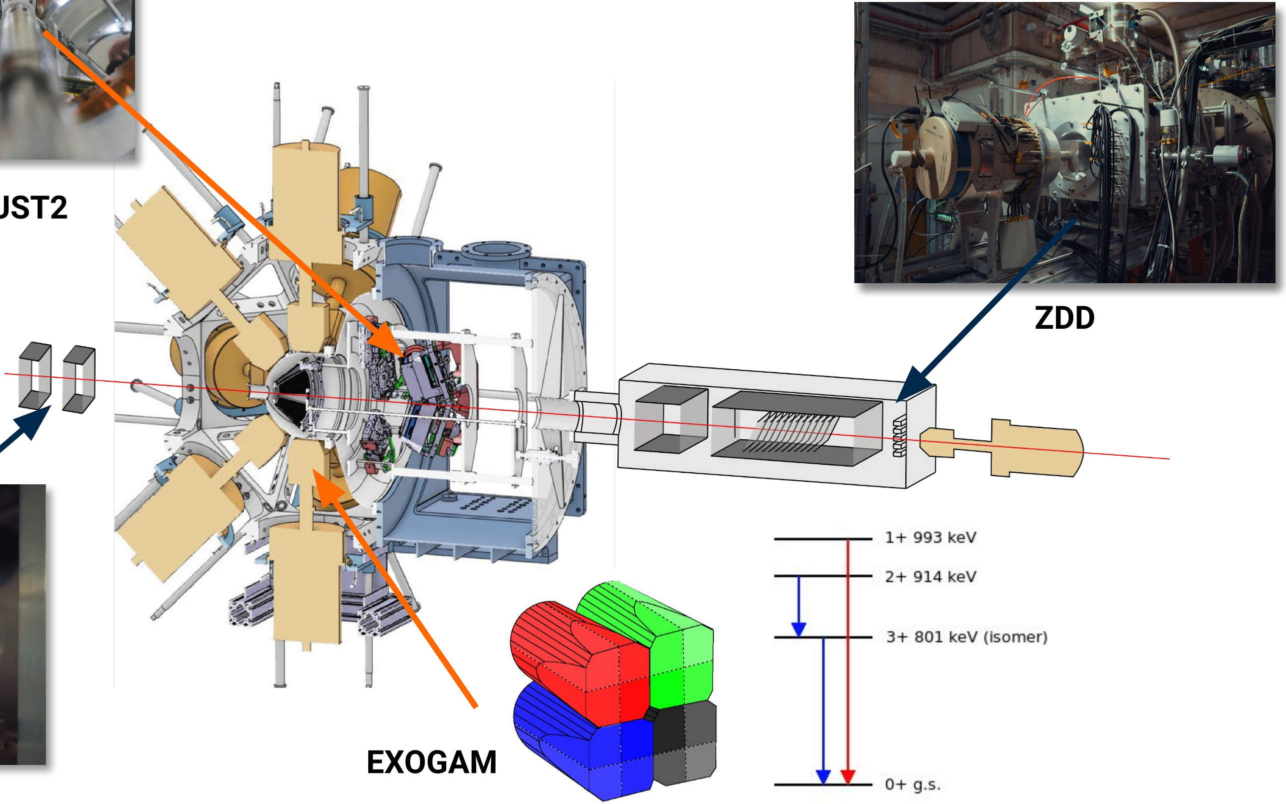
- ^{48}Cr 30MeV/u beam produced by fragmentation of ^{50}Cr and selected by LISE spectrometer at GANIL
- Impinging beam on a 5mg/cm^2 CH_2 target



MUST2

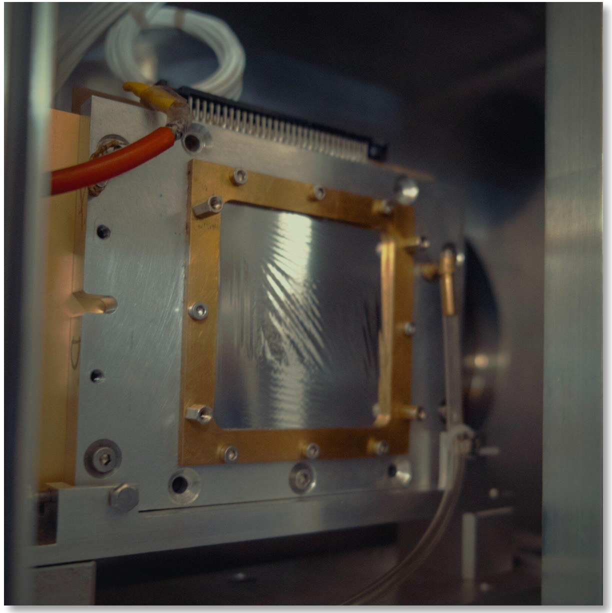


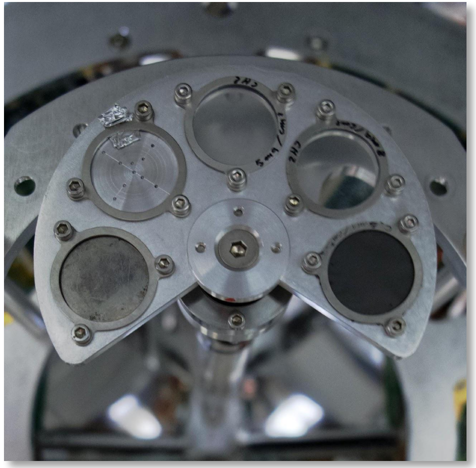
CATS (MWPC)

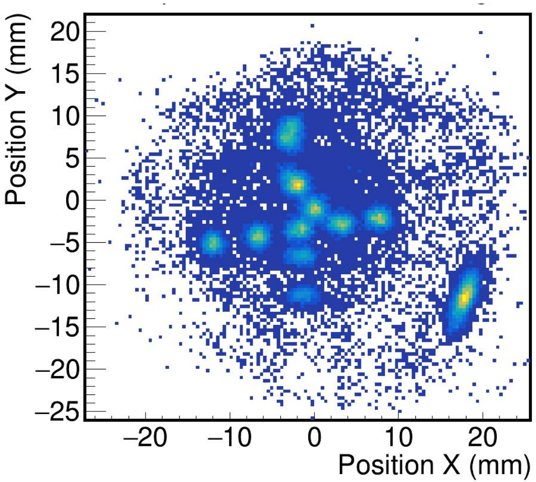


CATS

Courtesy of V. Alcindor



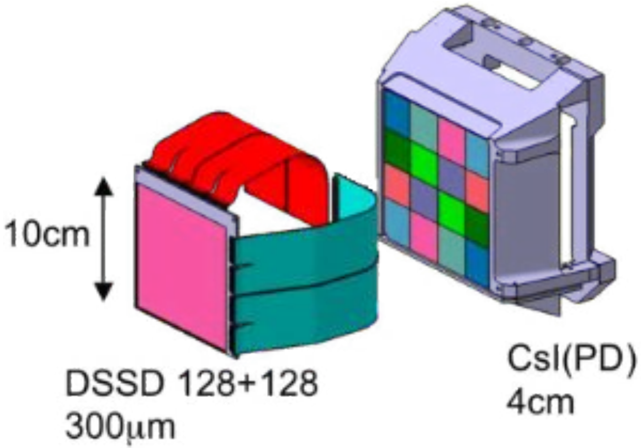


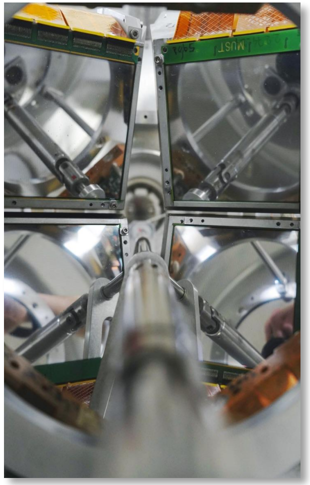


- 2 CATS trackers before the target
- Position resolution on target: 1 mm
- Necessary to improve angular resolution, and thus excitation energy reconstruction

MUST2

- MUST2 array: DSSD delta E and position, CsI Total Energy
- 4 MUST2 telescopes, angles lab between 5 and 28 degrees
- Integrated electronics





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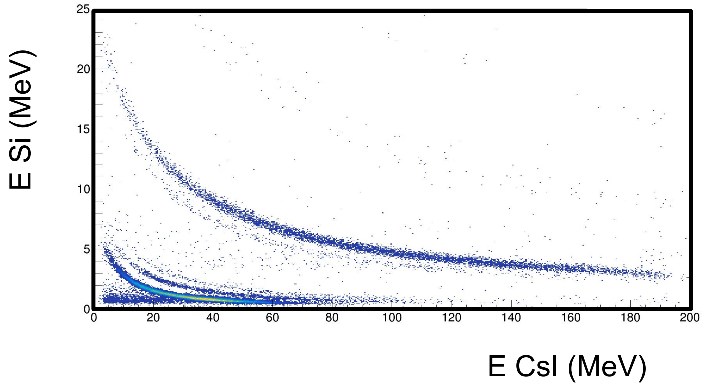
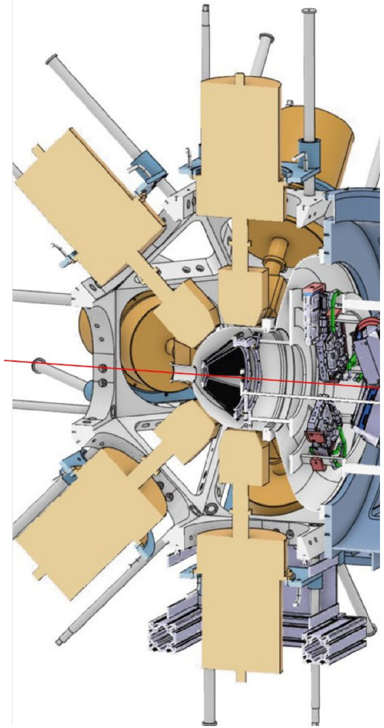
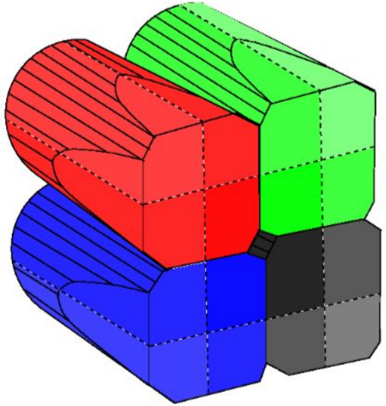
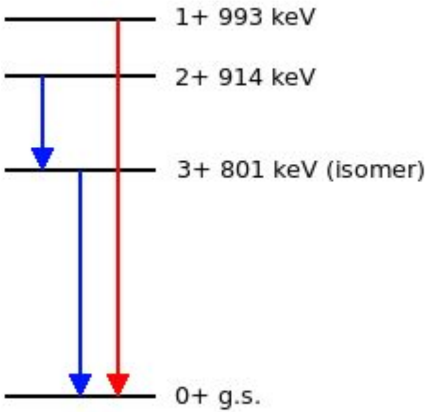


EXOGAM





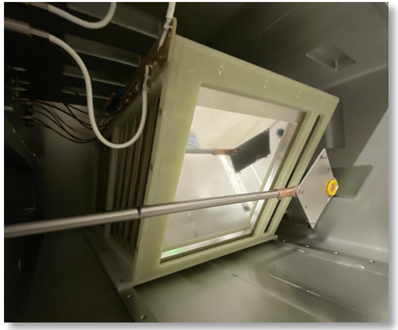
EXOGAM Clover



- 12 EXOGAM clovers around the target (~5% efficiency at 1 MeV)
- Each crystal is segmented in 4 for better Doppler correction

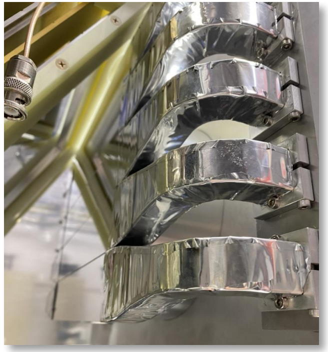
Zero Degree Detection (ZDD)

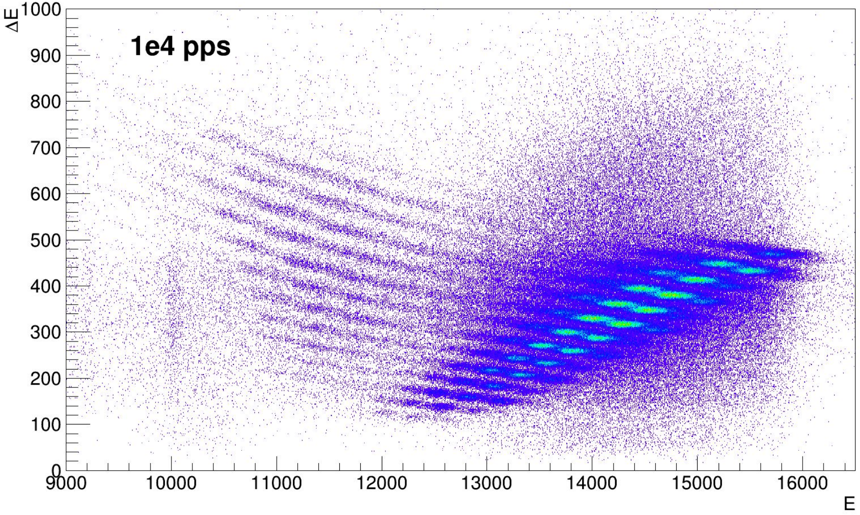
5 Ionisation chambers
(Isobutane 200 mbar)



Courtesy of V. Alcindor

5 Plastic scintillators



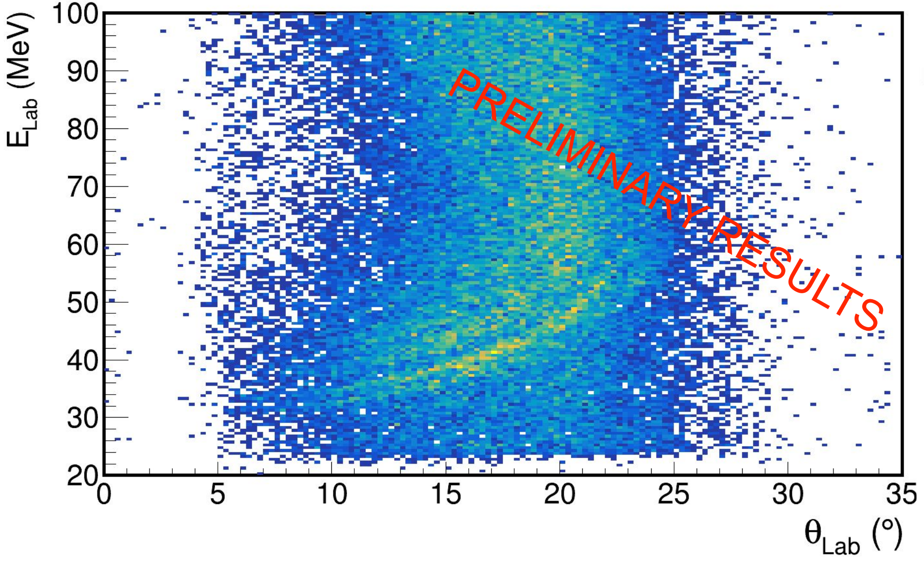


ZDD heavy recoil detection:

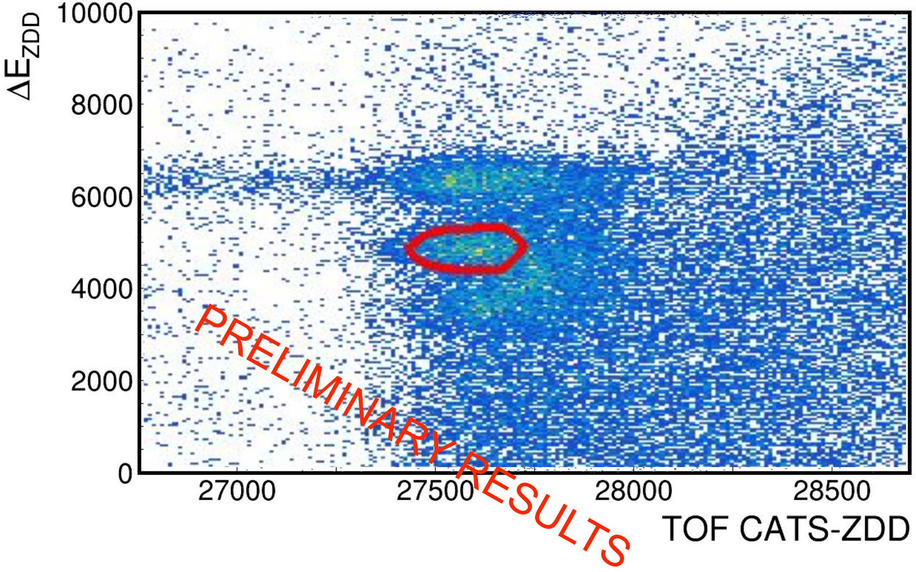
- ΔE in ionisation chambers
- Total Energy in plastics
- Time of Flight between CATS trackers and plastics

(p,^{3}He) first results

(p,^{3}He) kinematic lines (no ZDD)

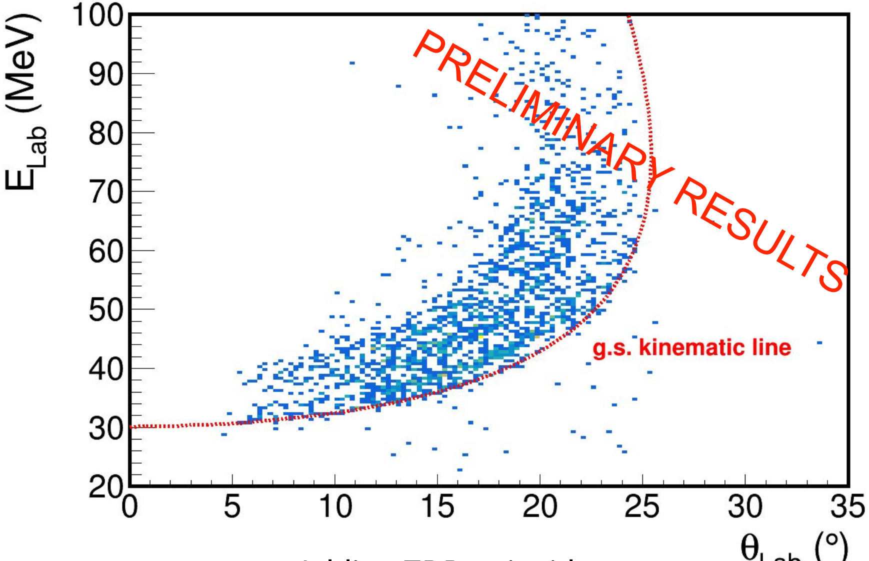


ZDD identification in coincidence with 3He

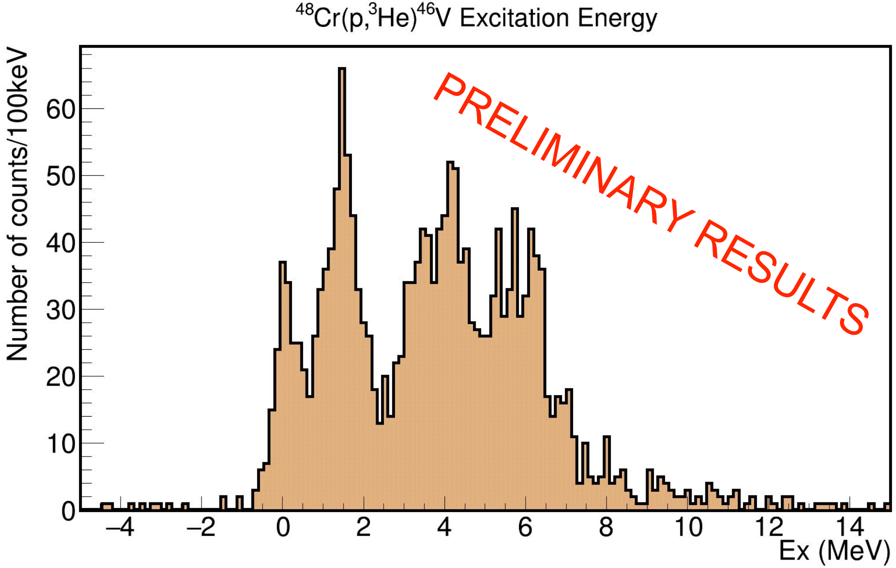


$(p,^3He)$ first results

(p,³He) kinematic lines



- Adding ZDD coincidence



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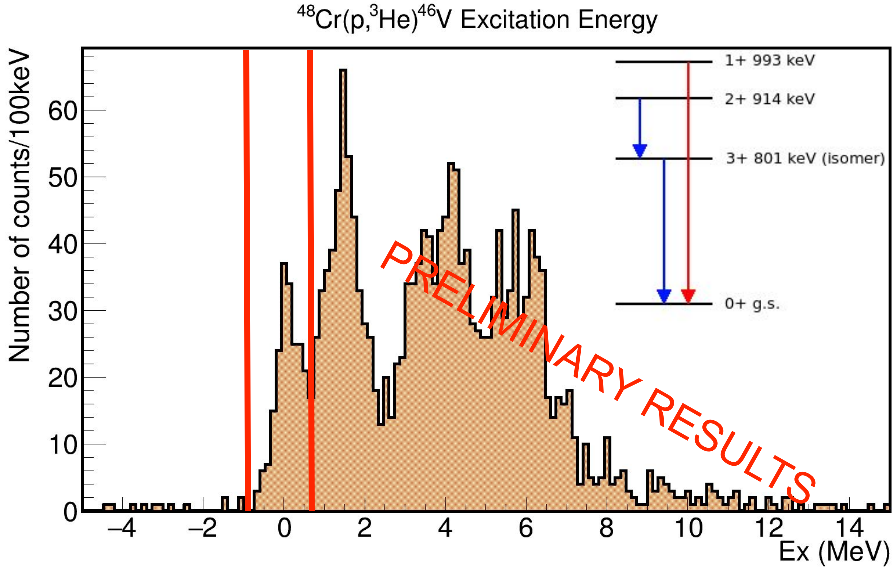
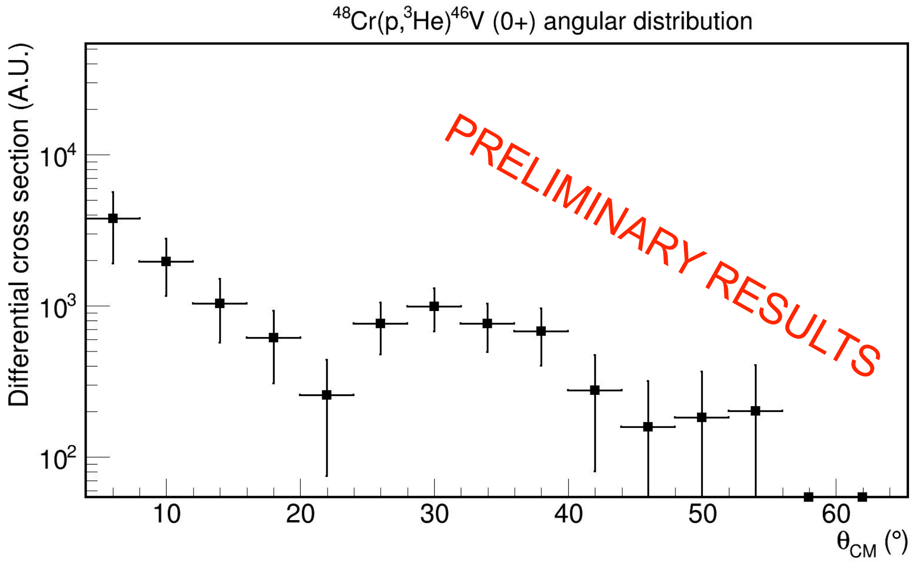
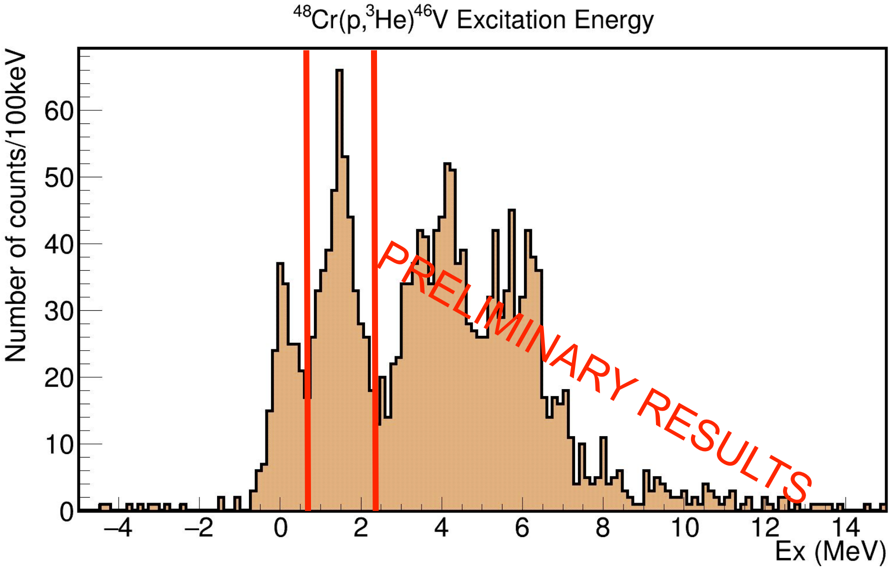
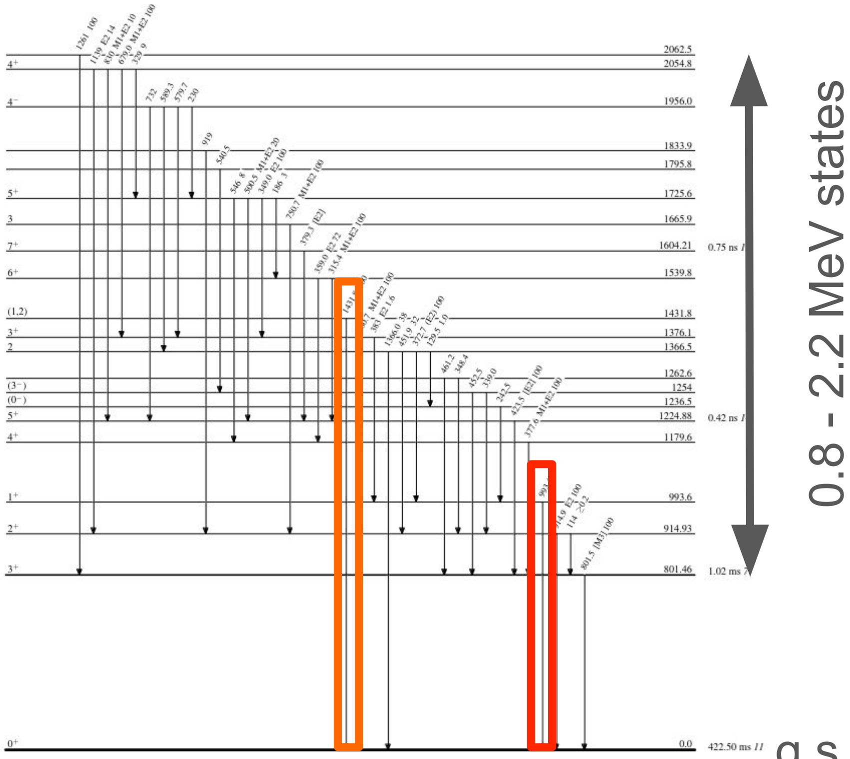
(p,^{3}He) first results





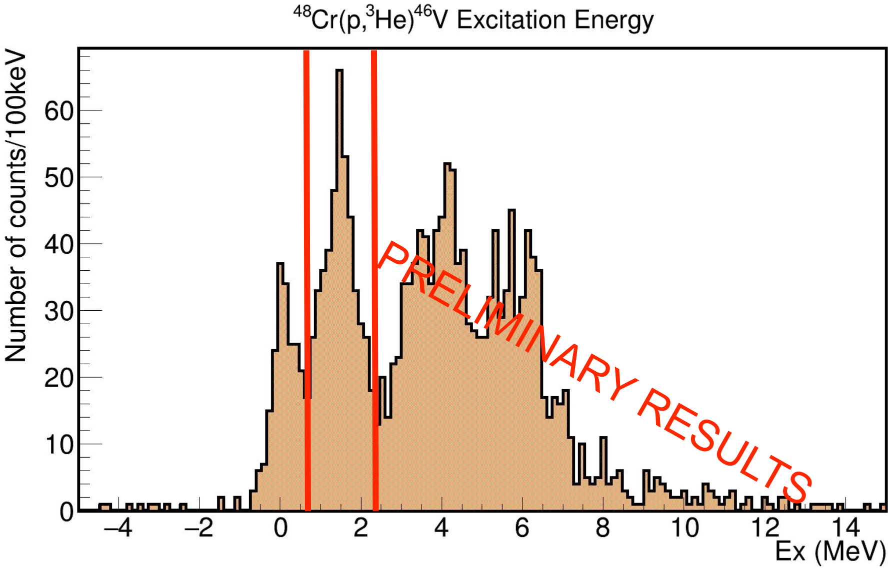
Excited states and gamma rays correlations

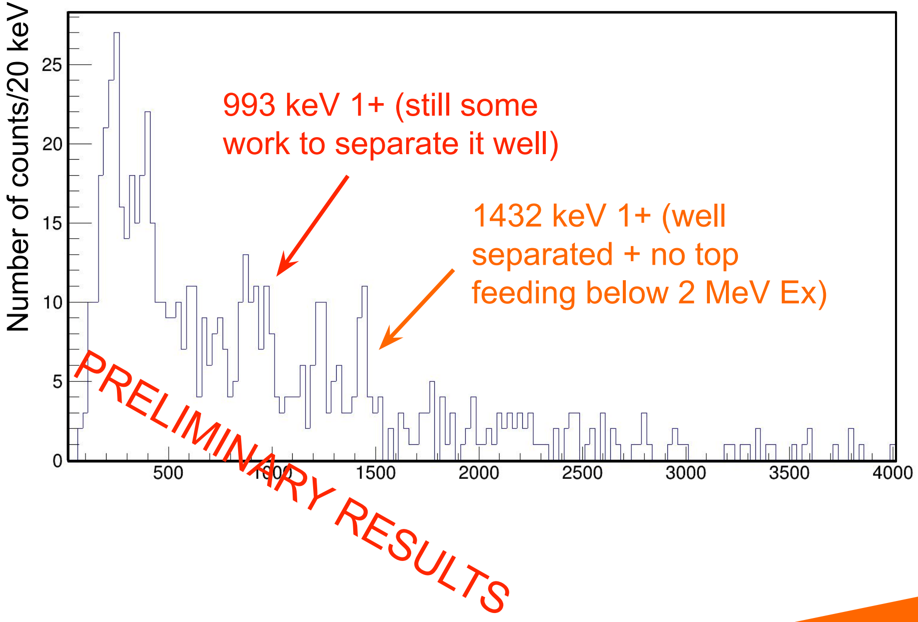




^{46}V states up to 2.2 MeV

Excited states and gamma rays correlations





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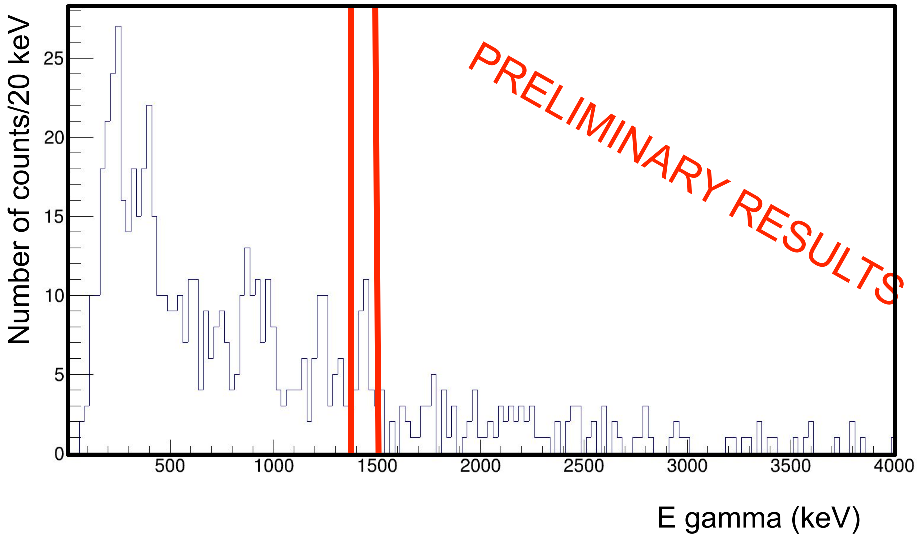
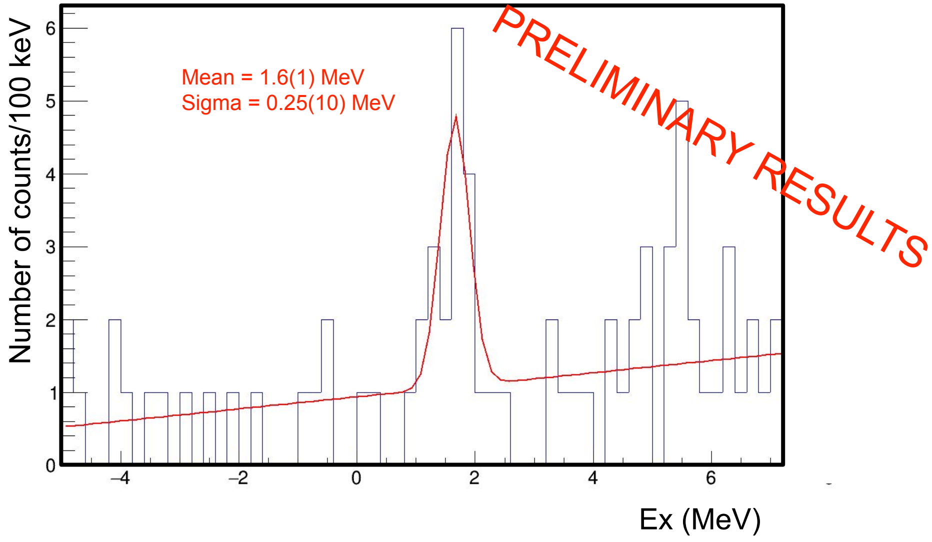
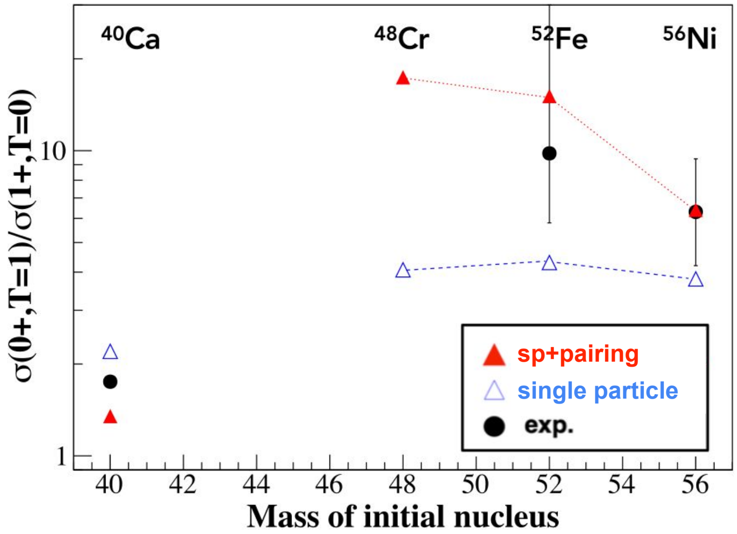




- Energy gating without ZDD coincidence

Outlook



B. Le Crom, M. Assié, *et al.*, Physics Letters B **829** (2022) 137057

- DWBA analysis of ^{46}V g.s.
- Analysis of gamma rays to determine 1^+ population
- Extraction of absolute cross sections for 0^+ and 1^+

Collaboration:

IJCLAB: H . Jacob, M. Assié, V. Alcindor, Y. Blumenfeld, D. Beaumel, J. Béquet, N. De Séréville, S. Franchoo, M. Kaci, F. Hammache, I. Matea, O. Nasr, I. Stephan

GANIL: Ö. Aktas, E. Clément, G. De France, F. De Oliveira, L. Dienis, A. Lemasson, O. Sorlin, J.C. Thomas, T. Roger, S. Koyama

INFN: S. Bottoni, F. Galtarossa, A. Gottardo, S. Pigliapoco, L. Zago

IFIN: F. Rotaru, M. Stanoiu

CENBG: Q. Delignac

University of Surrey: C. Paxman

IGFAE: M. Lozano González

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