Overview of the MUGAST@LISE campaign: the strength of transfer reactions on exotic beams

Hugo Jacob (GANIL, CNRS)

hugo.jacob@ganil.fr

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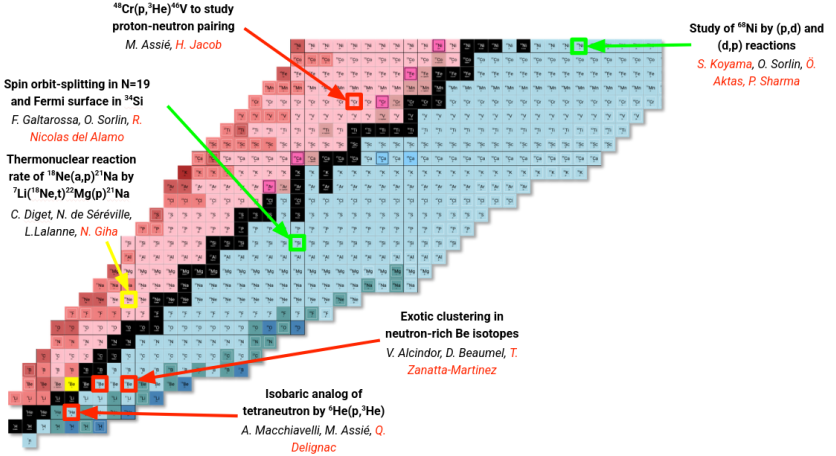
Scientific Motivations

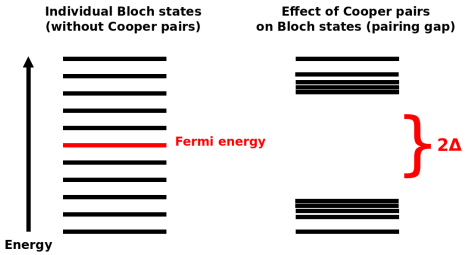
Overview of the 2023-2026 campaign

Physics cases



Nucleon pairs and pairing

BCS scheme (in superconductors)



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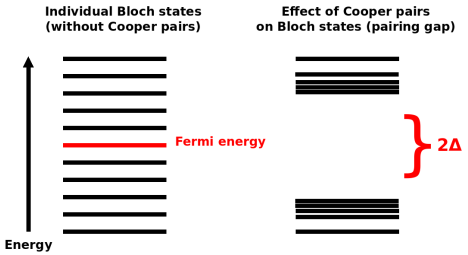

Electron pairs

- e^--phonon interaction $\rightarrow$ e^--e^- interaction attractive
- e^- couple in time-reversed ($|\mathbf{k},\uparrow\rangle$,$|-\mathbf{k},\downarrow\rangle$) pairs
- Δ: energy to break a pair

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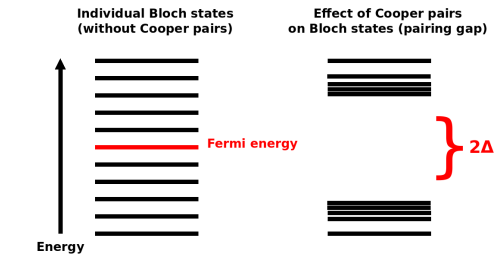

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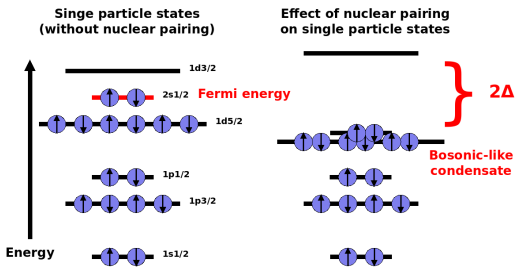

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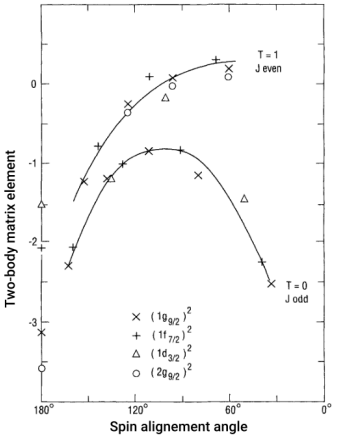

Schiffer & True, (1976)

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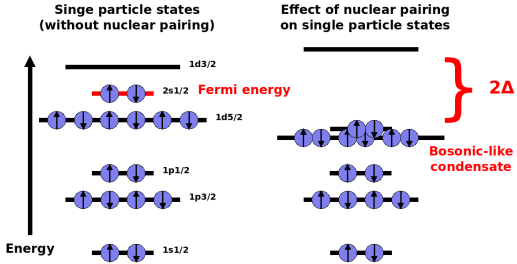

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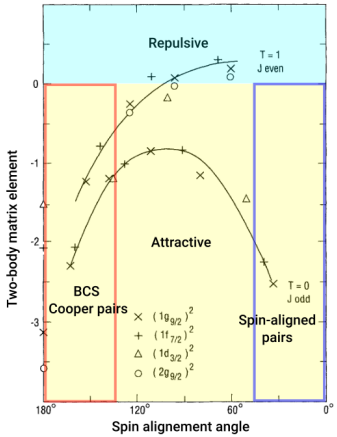

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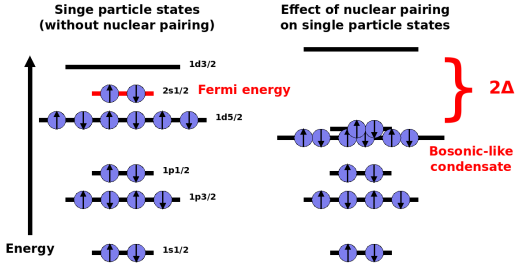

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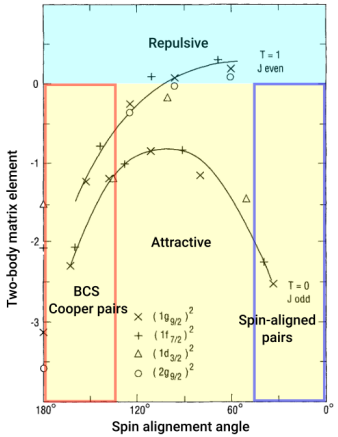

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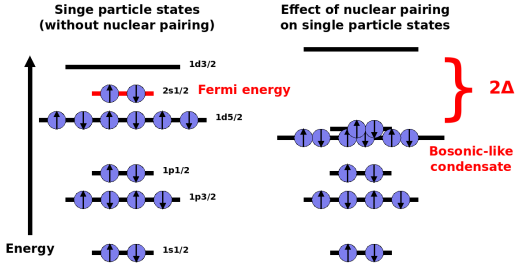
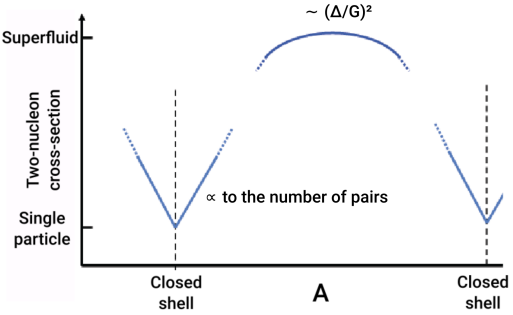


Cooper nucleon pairs !

Pairing in transfer reactions

Two-nucleon transfer



Two-nucleon transfer cross section

Frauendorf & Macchiavelli, (2014)

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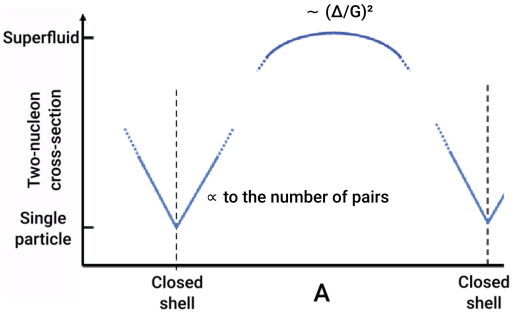

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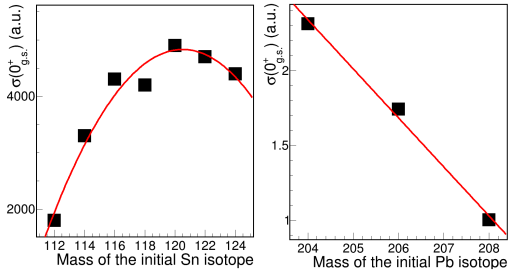
(p,t) on Sn and Pb isotopes



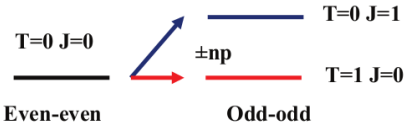
(p,t) reaction cross sections on Sn and Pb

Lanford, (1977)

Fleming *et al*, (1970)

Current status of proton-neutron pairing by transfer

Selection rules



L=0 transfer

Two-nucleon transfer cross section

- Common reactions: (p,^{3}He) and (^{3}He,p)
- Populate both $T = 0$ and $T = 1$ channels

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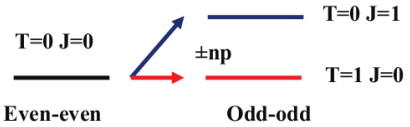

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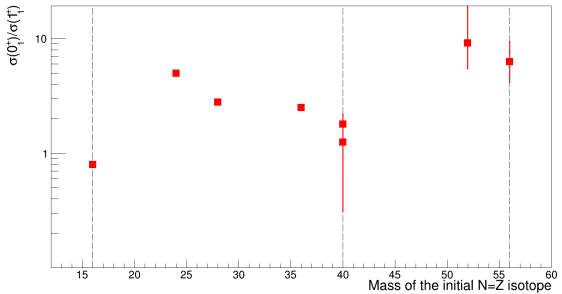

Isovector/isoscalar cross section ratio

Ayyad *et al*, (2017), Send & De Meijer, (1983), Brunnader *et al*, (1969), Fleming *et al*, (1971), Lecrom *et al*, (2022)

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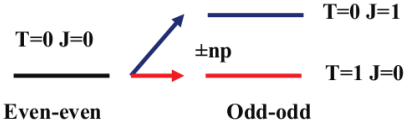

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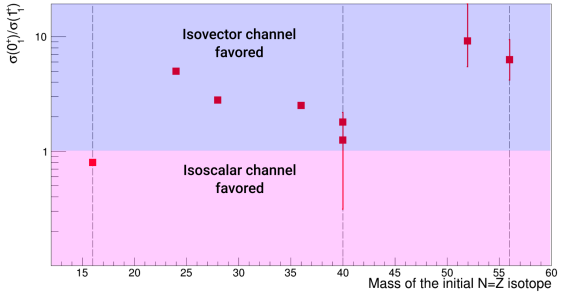

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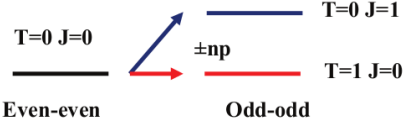

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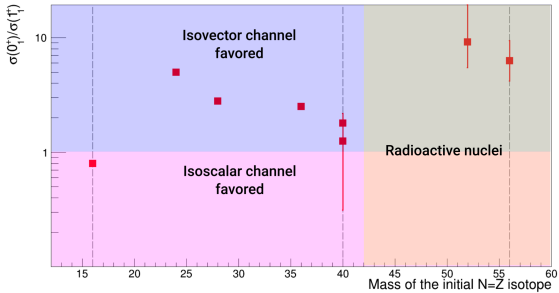

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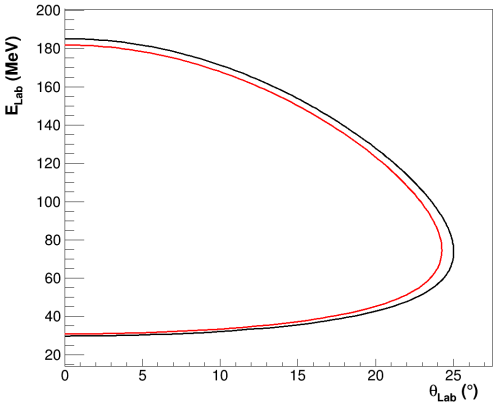
^{48}Cr(p,^{3}He)^{46}V reaction

Kinematic lines



^{48}Cr(p,^{3}He)^{46}V kinematic lines at 30 MeV/u

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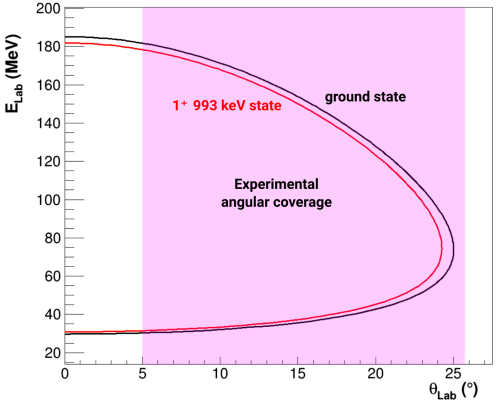

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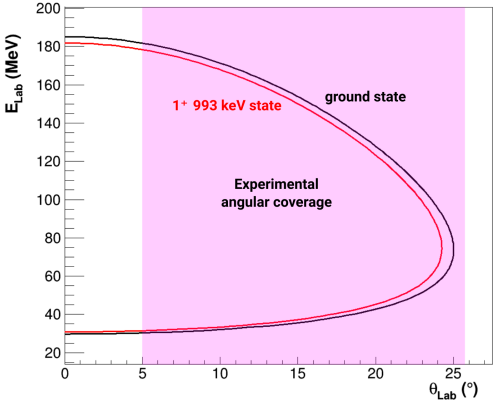

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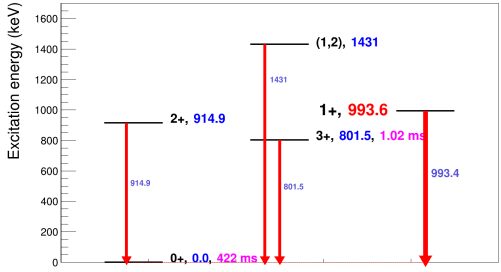
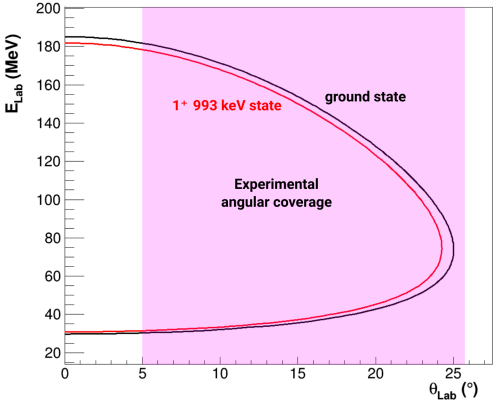
Level scheme



First excited states of ^{46}V

^{48}Cr(p,^{3}He)^{46}V reaction

Kinematic lines



^{48}Cr(p,^{3}He)^{46}V **kinematic lines at 30** MeV/u

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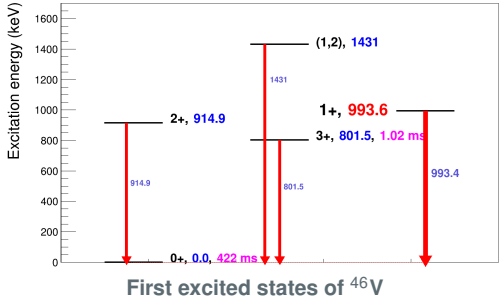
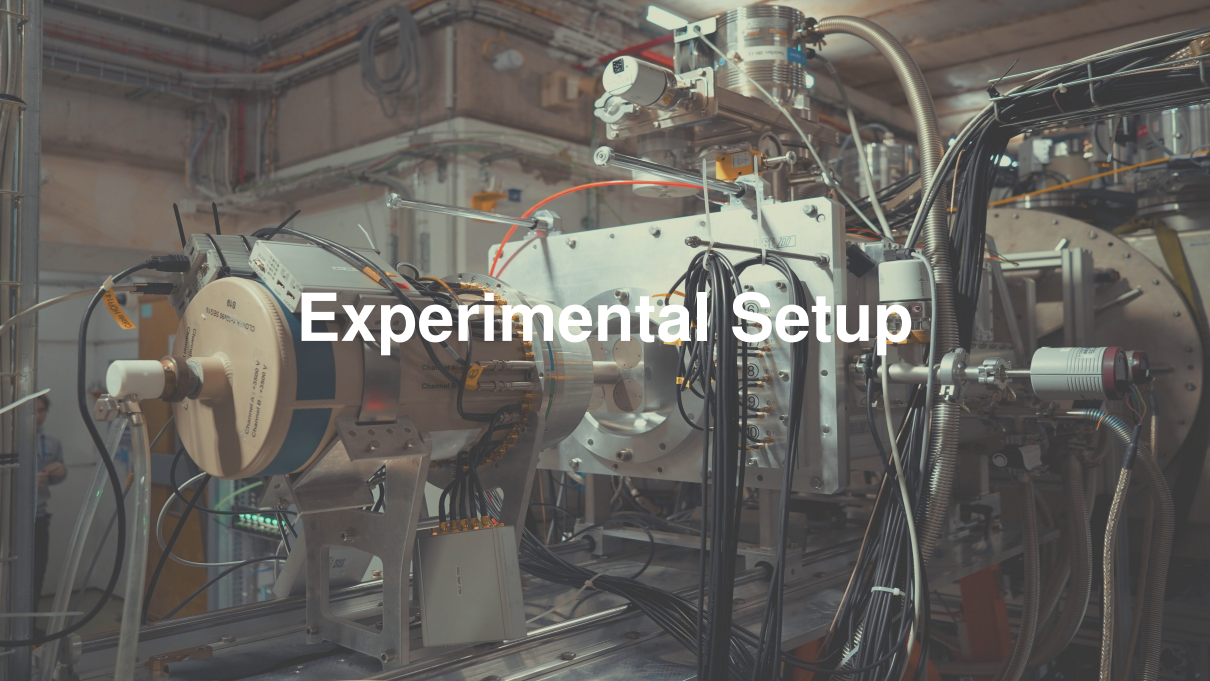


First excited states of ^{46}V

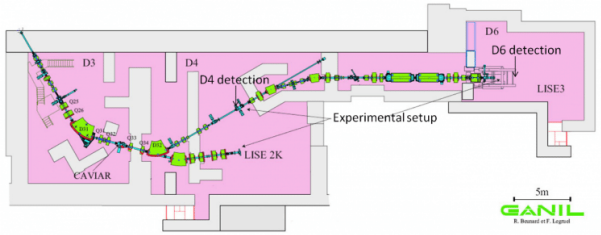
Level scheme

- Only 80 keV between $J^\pi = 2^+$ and $J^\pi = 1^+$
- Experiment requires particles and γ-rays identification


Experimental Setup

LISE Beam line at GANIL

LISE at GANIL



Scheme of the LISE spectrometer

LISE Beam line at GANIL

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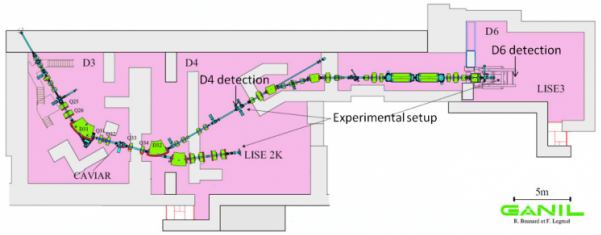


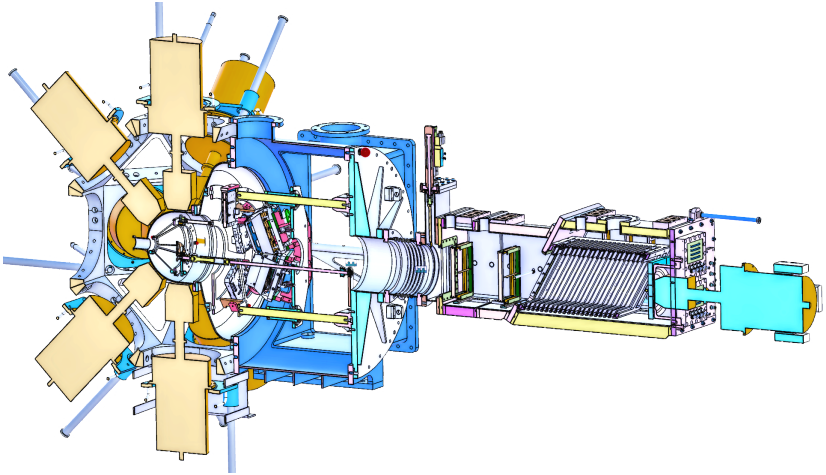
Scheme of the LISE spectrometer

Beam characteristics

- Primary beam: ^{12}C to ^{136}Xe from 50 MeV/u to 95 MeV/u
- Fragmentation target: $\sim$ 1 mm Be

Experimental setup

MUGAST@LISE



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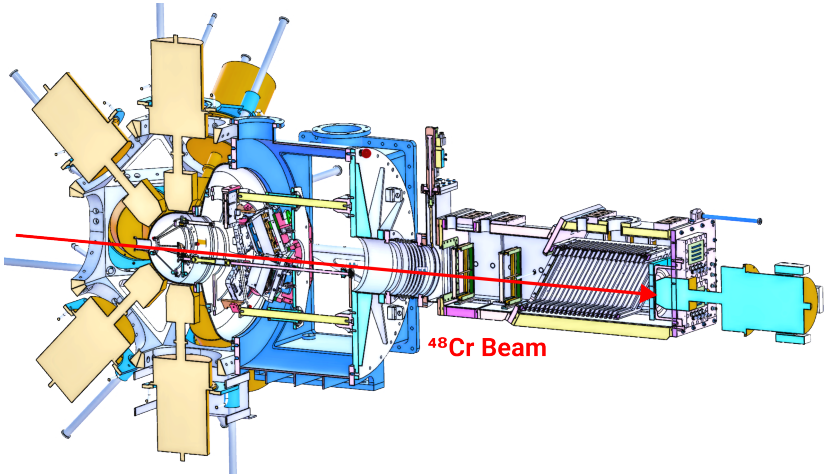

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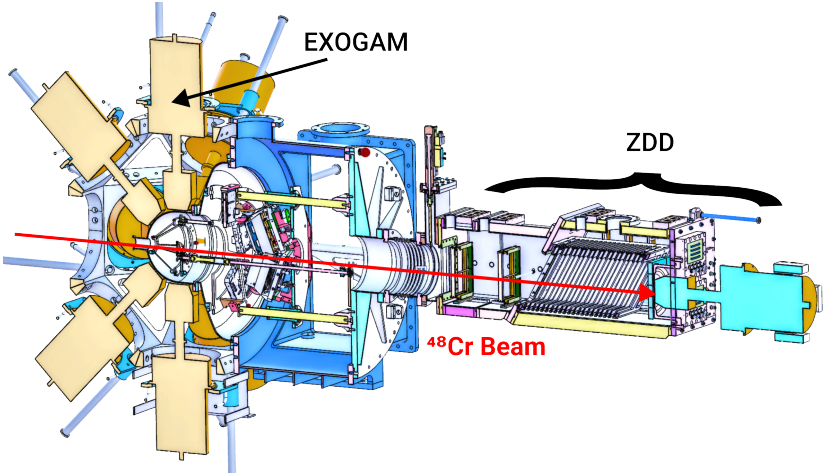

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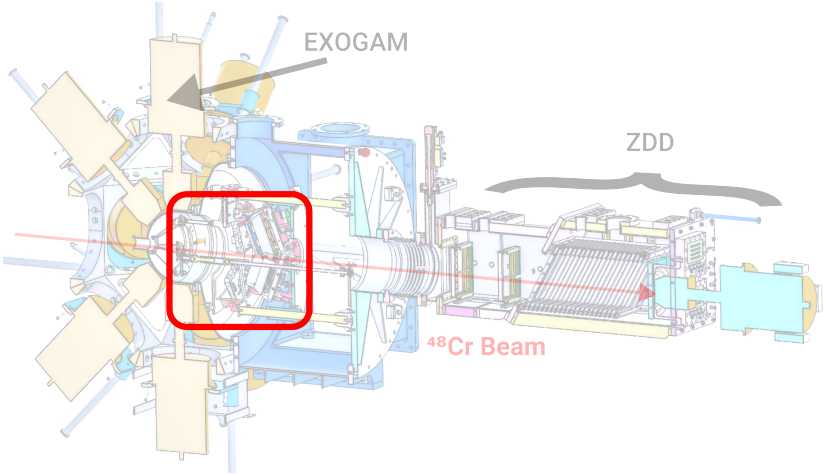

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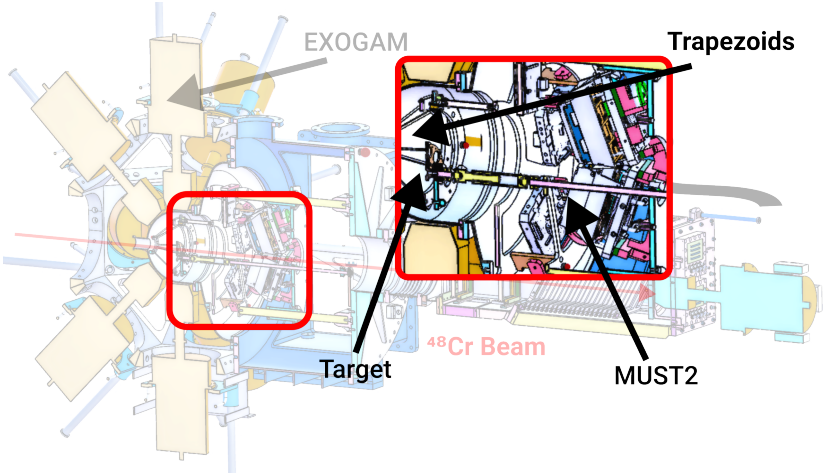
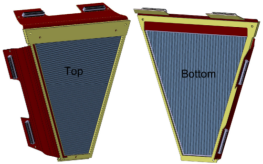


Trapezoids (backward angles)



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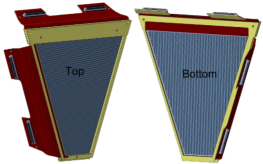

- Particle identification by $\Delta E/\mathrm{TOF}$
- Light particle angle and total energy measurement

MUGAST

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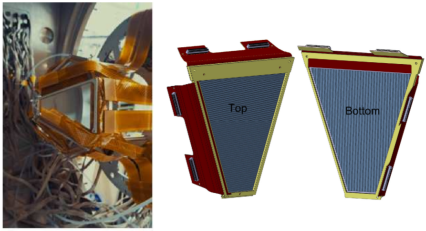

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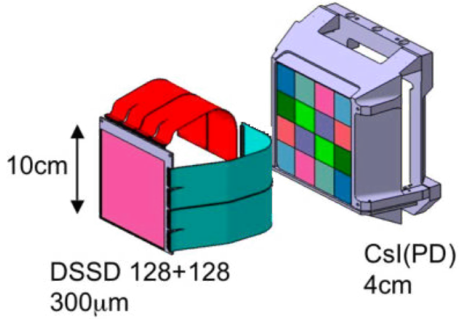
MUST2 (forward angles)



MUGAST

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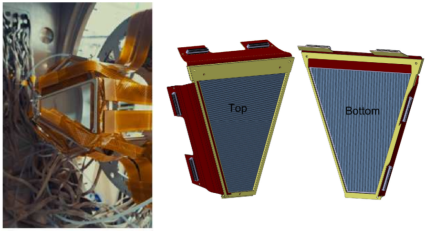

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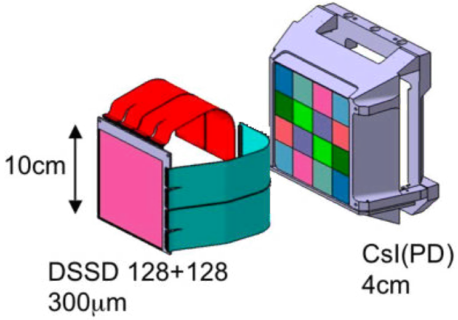
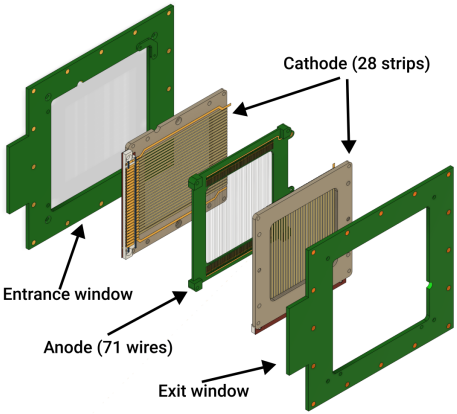


- Two layers of detection: DSSD and CsI crystals
- Particle identification by $\Delta E/E$ or $\Delta E/\mathrm{TOF}$
- Light charged particle angle and total energy

CATS Beam trackers

Scheme



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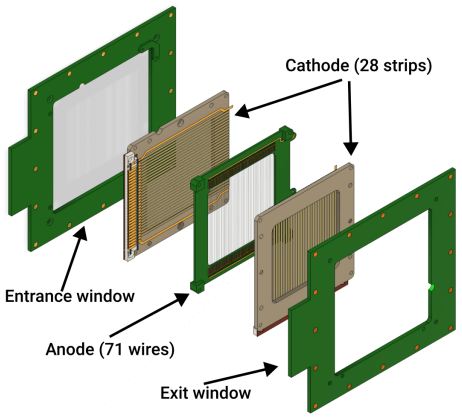

Features

- Gaseous detector filled with isobutane at 6.0 mbar
- Time signal created by the anode signal
- X and Y position from cathode charge

CATS Beam trackers

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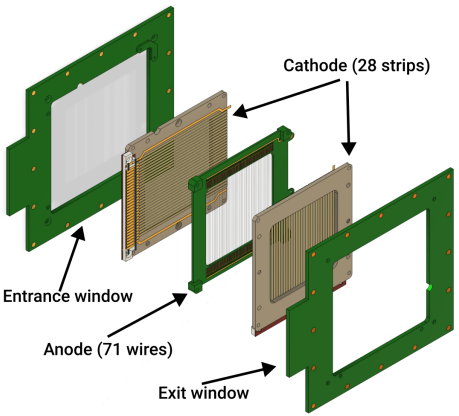

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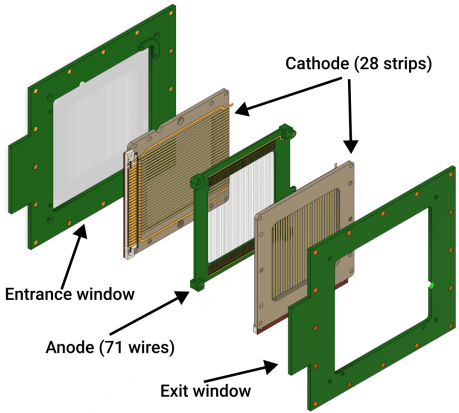

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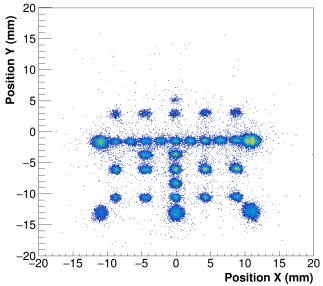
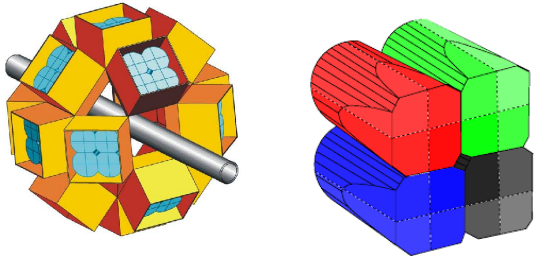


EXOGAM clovers

Scheme



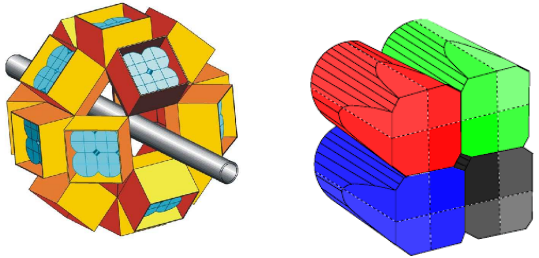
(Left) EXOGAM geometry (Right) EXOGAM clover

EXOGAM clovers

Features

- 12 clovers around the target (prompt γ-ray)
- Each clover contains 4 HPGe detectors
- Each HPGe is electrically segmented in 4

Scheme



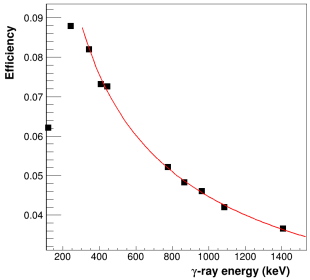
(Left) EXOGAM geometry (Right) EXOGAM clover

EXOGAM clovers

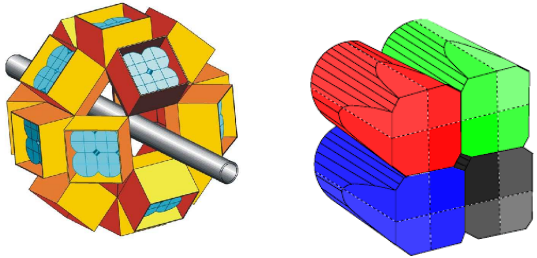
Features

- 12 clovers around the target (prompt γ-ray)
- Each clover contains 4 HPGe detectors
- Each HPGe is electrically segmented in 4

^{152}Eu calibration



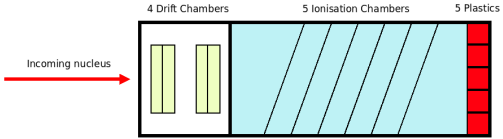
Scheme



(Left) EXOGAM geometry (Right) EXOGAM clover

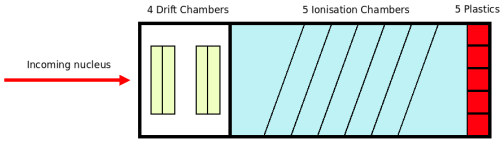
Zero Degree Detection (ZDD)

Scheme



Zero Degree Detection (ZDD)

Scheme

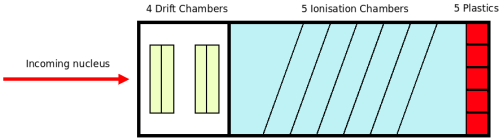


Features

- 4 drift chambers in the entrance
- Gaseous section contains 5 ionization chambers
- 5 beam stopping plastics with 2 PMTs each

Zero Degree Detection (ZDD)

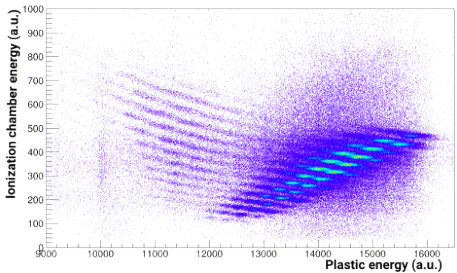
Scheme



Features

- 4 drift chambers in the entrance
- Gaseous section contains 5 ionization chambers
- 5 beam stopping plastics with 2 PMTs each

Cocktail beam identification

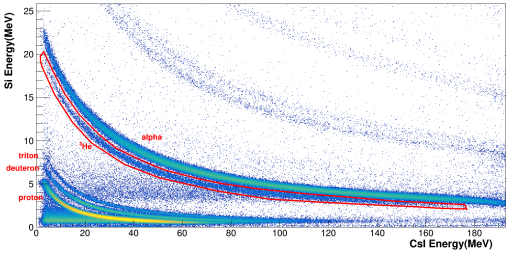


Analysis example

^{48}Cr(p,^{3}He)^{46}V @ 30 MeV/u

Reaction channel identification

MUST2 identification

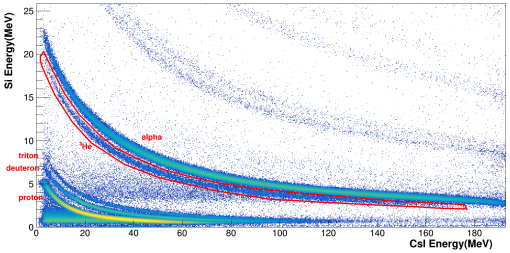


MUST2 $\Delta E / E_{CsI}$

Overview and performance of the 2023 MUGAST@LISE campaign at GANIL, V. Girad-Alcindor et al. (2024)

Reaction channel identification

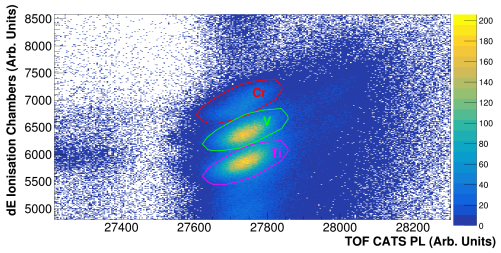
MUST2 identification



MUST2 $\Delta E / E_{CsI}$

Overview and performance of the 2023 MUGAST@LISE campaign at GANIL, V. Girad-Alcindor et al. (2024)

ZDD identification



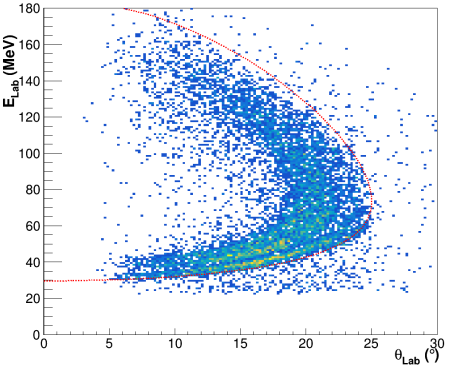
ΔE/TOF identification in the ZDD

- Spectrum in coinc. with ^{3}He
- Element identification by ΔE/TOF method

Overview and performance of the 2023 MUGAST@LISE campaign at GANIL, V. Girad-Alcindor et al. (2024)

Two-body kinematics

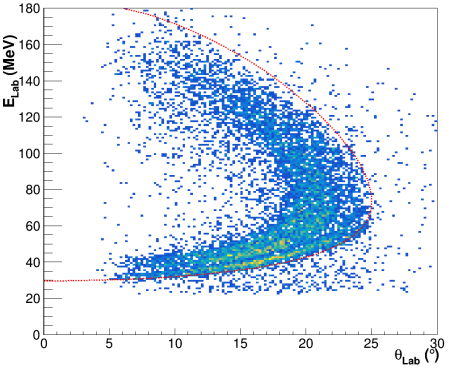
Missing mass method



^{48}Cr(p,^{3}He)^{46}V kinematic lines

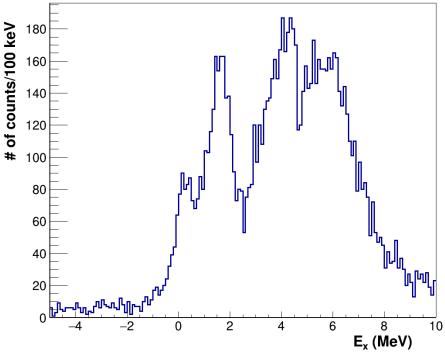
Two-body kinematics

Missing mass method



^{48}Cr(p,^{3}He)^{46}V kinematic lines

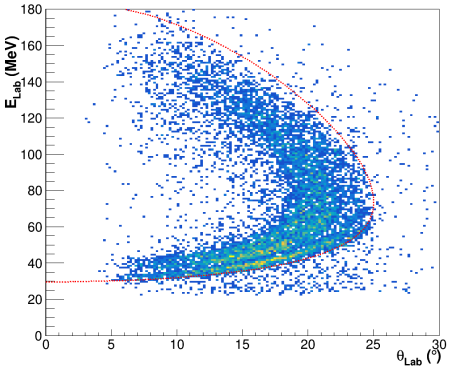
Excitation energy



^{48}Cr(p,^{3}He)^{46}V excitation energy

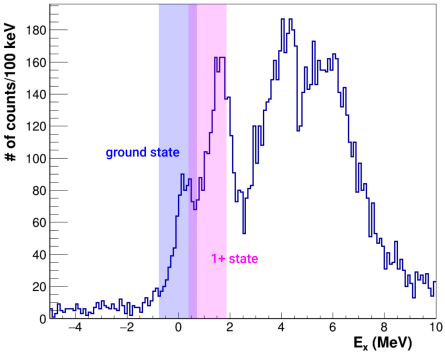
Two-body kinematics

Missing mass method



^{48}Cr(p,^{3}He)^{46}V kinematic lines

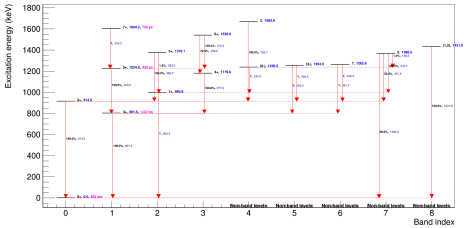
Excitation energy



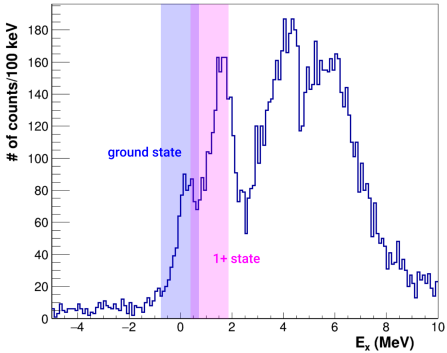
^{48}Cr(p,^{3}He)^{46}V excitation energy

Two-body kinematics

^{46}V level scheme



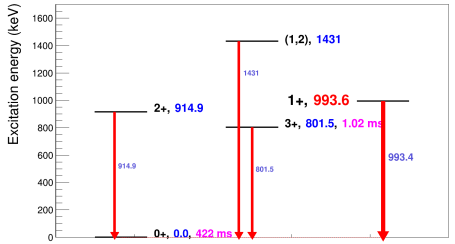
Excitation energy



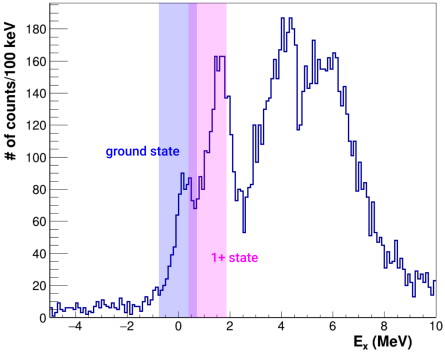
^{48}Cr(p,^{3}He)^{46}V excitation energy

Two-body kinematics

^{46}V level scheme



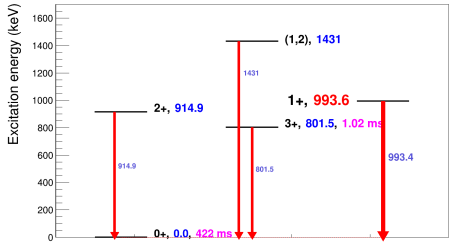
Excitation energy



^{48}Cr(p,^{3}He)^{46}V excitation energy

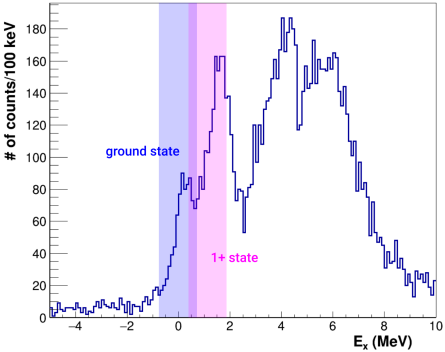
Two-body kinematics

^{46}V level scheme



- Resolution: 420 keV σ
- γ-rays needed for excited states

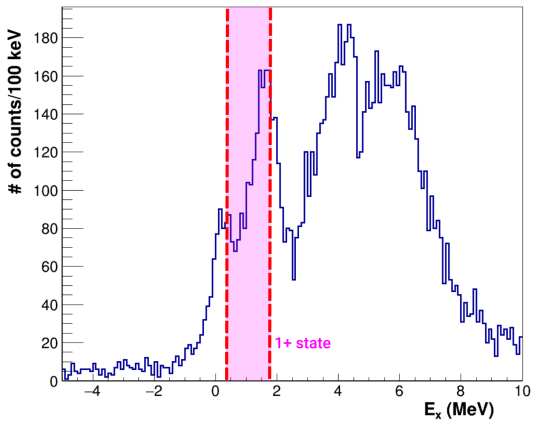
Excitation energy



^{48}Cr(p,^{3}He)^{46}V excitation energy

γ-ray identification

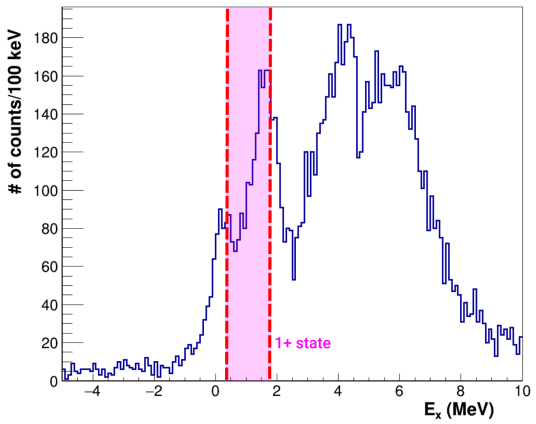
Ex gate



Excitation energy gate around 993 keV

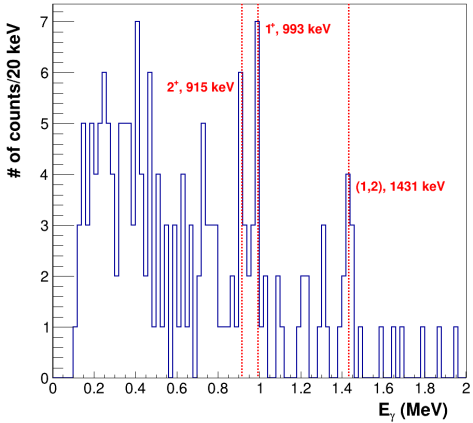
γ-ray identification

Ex gate



Excitation energy gate around 993 keV

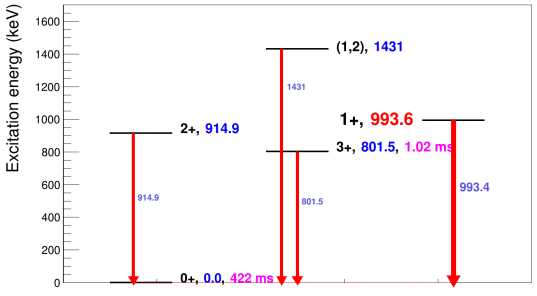
Gated γ-ray spectrum



γ-rays gated by Ex around 993 keV

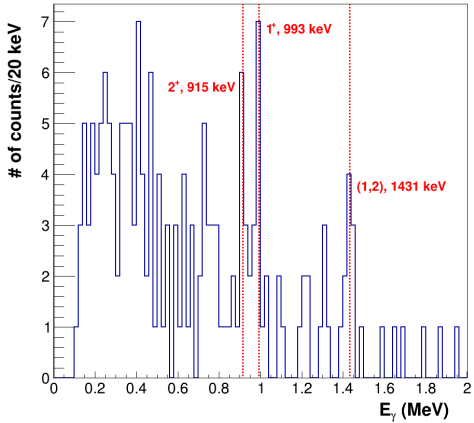
γ-ray identification

Decay scheme



Excited states close to the $J^\pi = 1^+$ state

Gated γ-ray spectrum

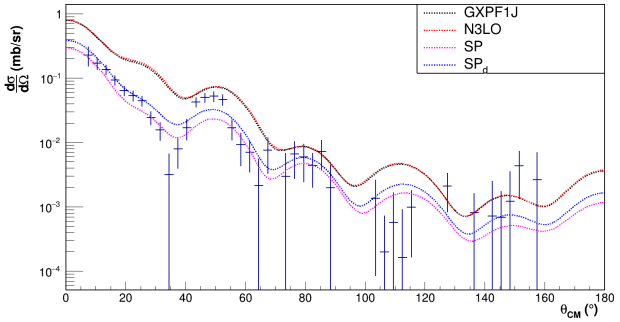


γ-rays gated by Ex around 993 keV

Results

Isovector channel angular distribution

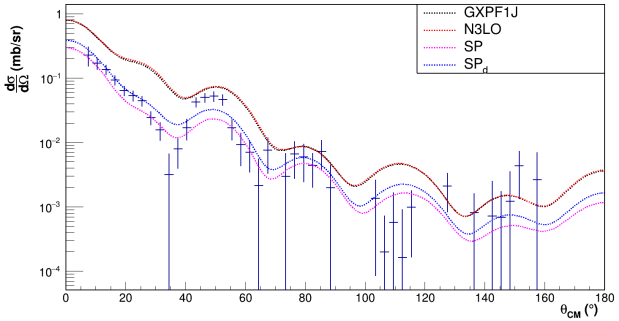
Comparison with DWBA



Angular distribution of ^{48}Cr(p,^{3}He)^{46}V $J^{\pi} = 0^{+}$

Isovector channel angular distribution

Comparison with DWBA



Angular distribution of ^{48}Cr(p,^{3}He)^{46}V $J^\pi = 0^+$

Integrated CS

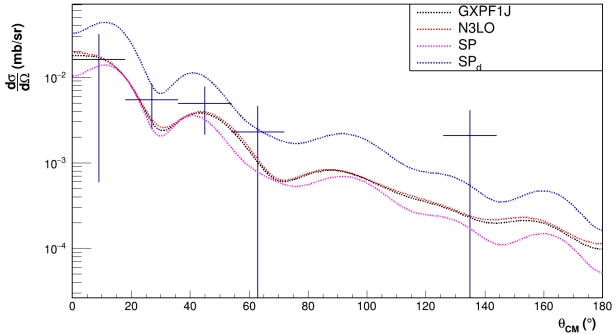
Source	σ_{0+} (μb)
Exp. result	$141(5)_{stat}(15)_{sys}$
GXPF1J CH	414
GXPF1J KD	385
N3LO CH	432
N3LO KD	398
SP CH	37
SP KD	37
SP$_d$ CH	154
SP$_d$ KD	158

CS between 5 and 160 degrees CM.

- Result compatible with SP$_d$ config.

Isoscalar channel angular distribution

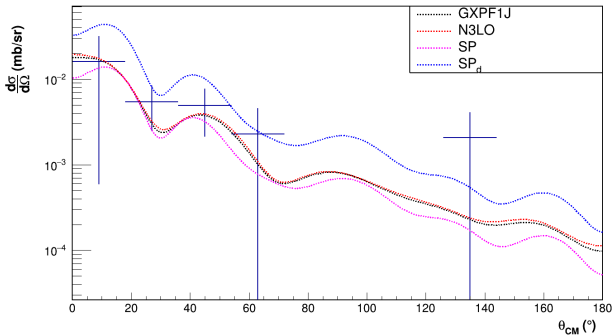
Comparison with DWBA



Angular distribution of ^{48}Cr(p,^{3}He)^{46}V $J^{\pi} = 1^{+}$

Isoscalar channel angular distribution

Comparison with DWBA



Angular distribution of ^{48}Cr(p,^{3}He)^{46}V $J^{\pi} = 1^{+}$

Integrated CS

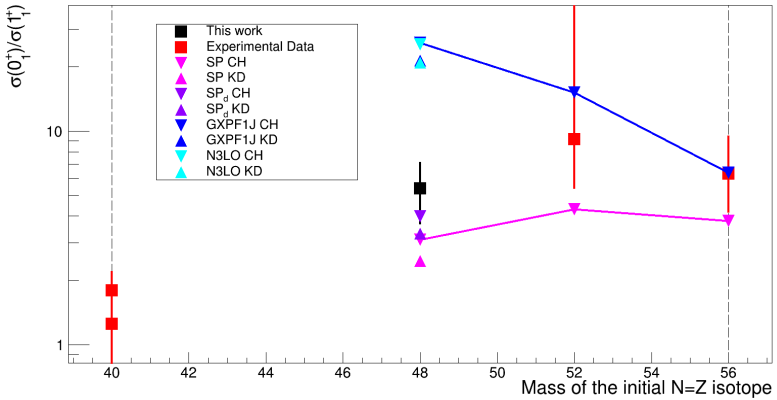
Source	σ_{1+} (μb)
Exp. result	$26(8)_{stat}(3)_{sys}$
GXPF1J CH	16
GXPF1J KD	18
N3LO CH	17
N3LO KD	19
SP CH	12
SP KD	15
SP$_d$ CH	39
SP$_d$ KD	48

CS between 5 and 160 degrees CM.

- Result compatible with SP$_d$ config.

Cross section ratio

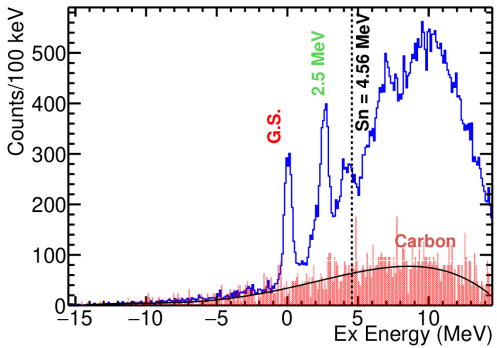
Isovector/isoscalar cross section ratio



Cross section ratio compared with calculations and experimental data

Results of other experiments: ^{68}Ni(p,d) and (d,p)

^{68}Ni(d,p) excitation energy



Courtesy: P. Sharma

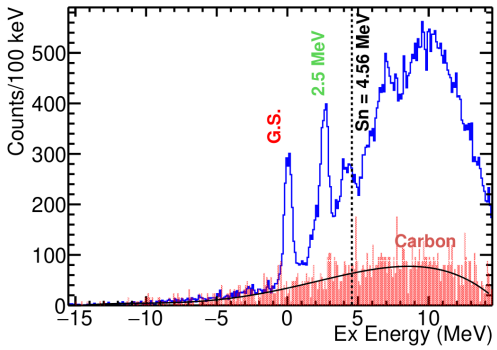
Scientific motivations

- Measuring neutron orbitals and their occupancy around N=40
- Access to orbitals from $f_{7/2}$ to $g_{7/2}$
- Spin orbit splitting in f, p and g orbitals

Courtesy: P. Sharma

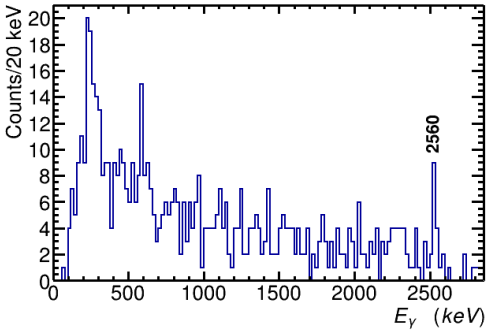
Results of other experiments: ^{68}Ni(p,d) and (d,p)

^{68}Ni(d,p) excitation energy



Courtesy: P. Sharma

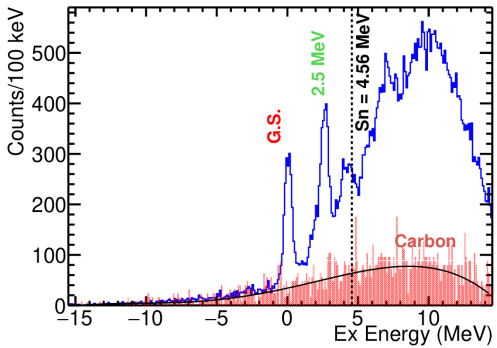
^{68}Ni(d,p) γ rays



Courtesy: P. Sharma

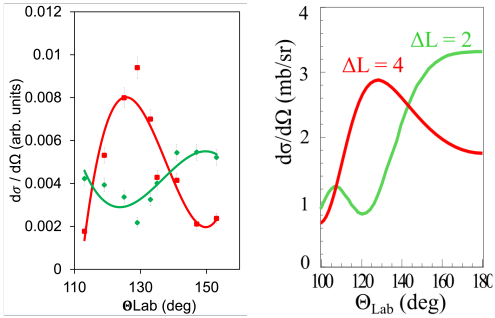
Results of other experiments: ^{68}Ni(p,d) and (d,p)

^{68}Ni(d,p) excitation energy



Courtesy: P. Sharma

^{68}Ni(d,p) angular distribution

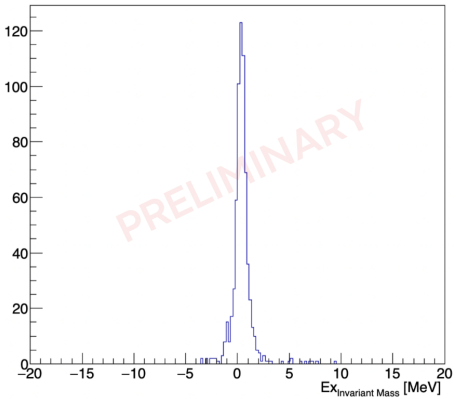


(Left) Experiment (Right) DWBA

Courtesy: P. Sharma

Results of other experiments: ^{10}Be(d,^{6}Li) and (p,α)

^{10}Be(d,^{6}Li) excitation energy



Courtesy: T. Zanatta Martinez

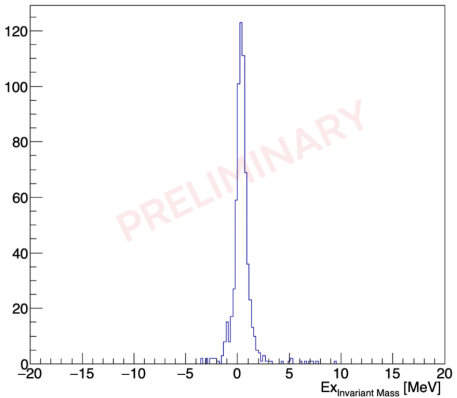
Scientific motivations

- Comparing α and triton clustering by transfer
- AMD interpretation of clustering in Be isotopes
- Comparing transfer and knockout methods for clustering

Courtesy: T. Zanatta Martinez

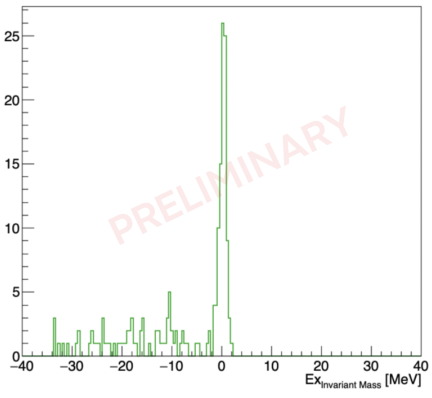
Results of other experiments: ^{10}Be(d,^{6}Li) and (p,α)

^{10}Be(d,^{6}Li) excitation energy



Courtesy: T. Zanatta Martinez

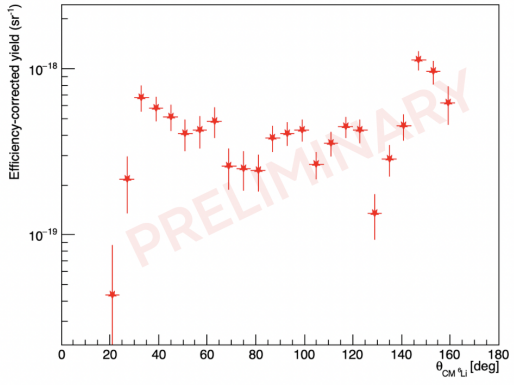
^{10}Be(p,α) excitation energy

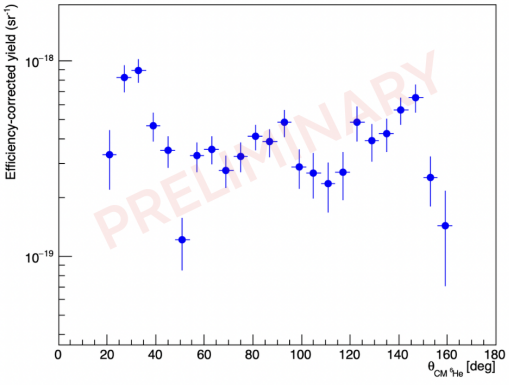


Courtesy: T. Zanatta Martinez

Results of other experiments: ^{10}Be(d,^{6}Li) and (p,α)

^{10}Be(d,^{6}Li) angular distribution

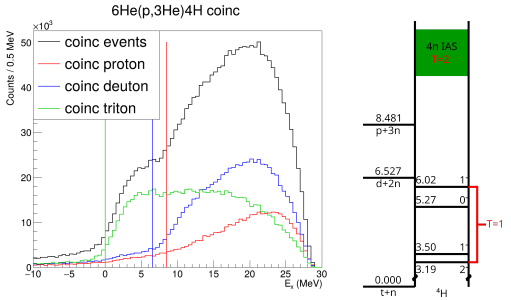




Courtesy: T. Zanatta Martinez

Results of other experiments: ^{6}He(p,^{3}He)^{4}H

^{6}He(p,^{3}He)^{4}H excitation energy



Courtesy: Q. Delignac

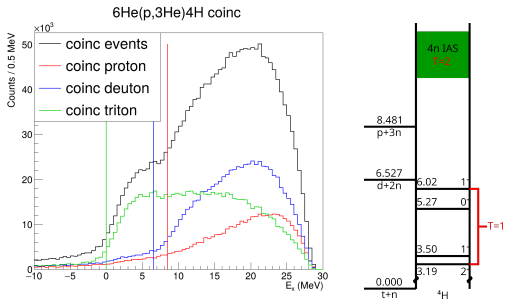
Scientific motivations

- Measuring the IAS of tetraneutron in ^{4}H
- Understand the nature of the peak found in Duer et al.

Courtesy: Q. Delignac

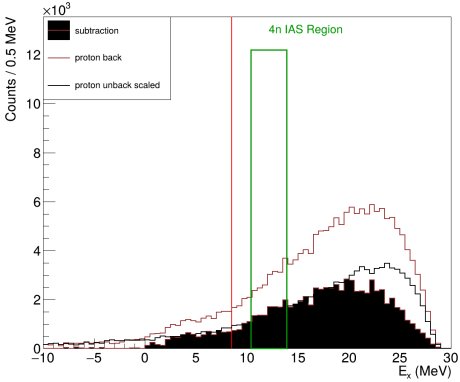
Results of other experiments: ^{6}He(p,^{3}He)^{4}H

^{6}He(p,^{3}He)^{4}H excitation energy



Courtesy: Q. Delignac

Ex with proton coinc



Courtesy: Q. Delignac

Conclusion and perspectives

Conclusion

Physics conclusion

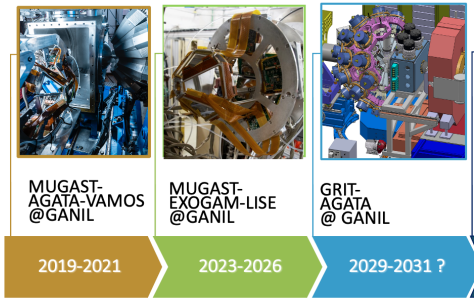
- Many different topics addressed (shell evolution, clustering, pairing)
- Triple coincidence between beam-like, target-like and γ
- Transfer reactions: high selectivity of populated levels
- Many other physics cases for the future: see C. Ciampi talk

Conclusion

Physics conclusion

- Many different topics addressed (shell evolution, clustering, pairing)
- Triple coincidence between beam-like, target-like and γ
- Transfer reactions: high selectivity of populated levels
- Many other physics cases for the future: see C. Ciampi talk

Future campaigns



Conclusion

Collaboration

- IJCLAB: H. Jacob, M. Assié, Y. Blumenfeld, V. Girard-Alcindor, D. Beaumel, F. Hammache, N. de Séréville, I. Stephan, S. Franchoo, I. Matea, O. Nasr, M. Kaci, T. Zanatta Martinez, N. Giha
- GANIL: G. de France, A. Lemasson, O. Sorlin, J.-C. Thomas, T. Roger, O. Aktas, S. Koyama, E. Clément, F. de Oliveira
- LP2IB: Q. Delignac, S. Grévy
- Surrey: C. Paxman
- Edinburgh: R. Sidhu
- INFN: D. Mengoni, A. Gottardo, S. Bottoni, L. Zago, S. Pigliapoco, F. Galtarossa, R. Nicolas del Alamo
- IFIN: F. Rotaru, M. Stanoiu
- USG: M. Lozano Gonzalez