Interplay between quadrupole deformation and proton-neutron pairing through the prism of Anderson's limit

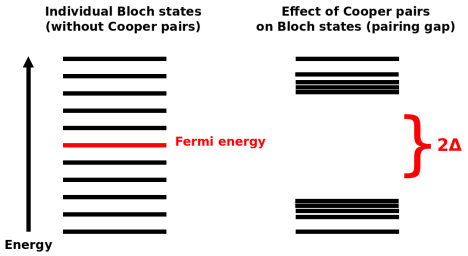
Hugo Jacob (GANIL, CNRS)

hugo.jacob@ganil.fr

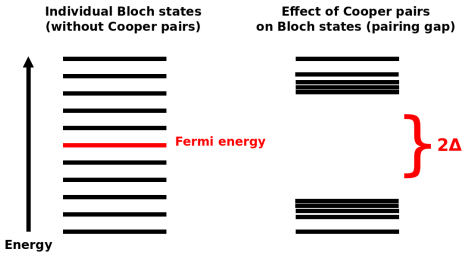
5 November 2026

Scientific Motivations

BCS scheme (in superconductors)



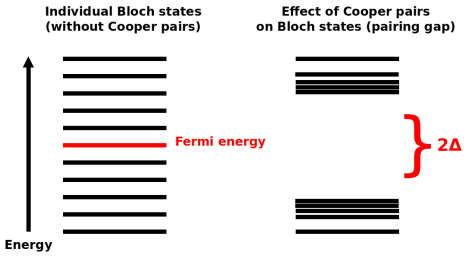
BCS scheme (in superconductors)



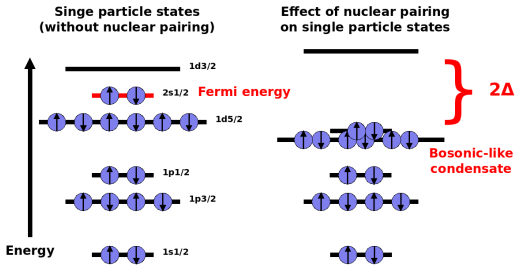
Electron pairs

- 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

BCS scheme (in superconductors)



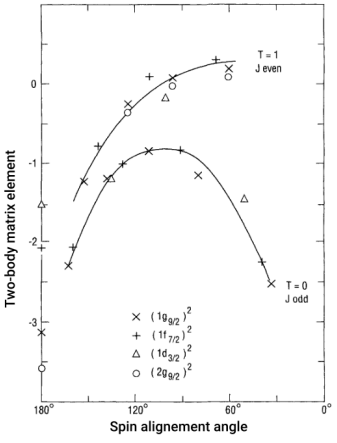
BCS scheme (in nuclei)



Electron pairs

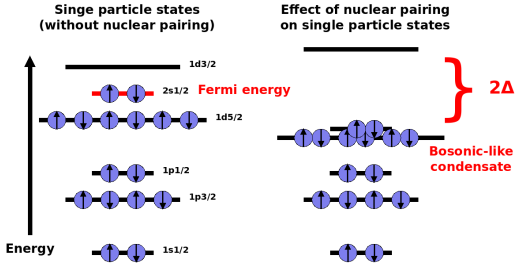
- e^--phonon interaction $\rightarrow$ e^--e^- interaction attractive
- e^- couple in time-reversed ($|\mathbf{k},\uparrow\rangle$,$|-\mathbf{k},\downarrow\rangle$) pairs
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Nucleon interaction

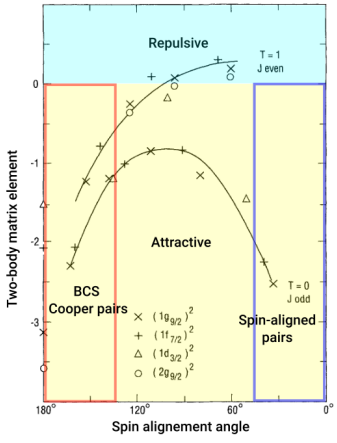


Schiffer & True, (1976)

BCS scheme (in nuclei)

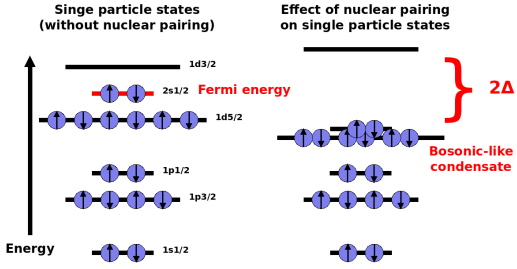


Nucleon interaction

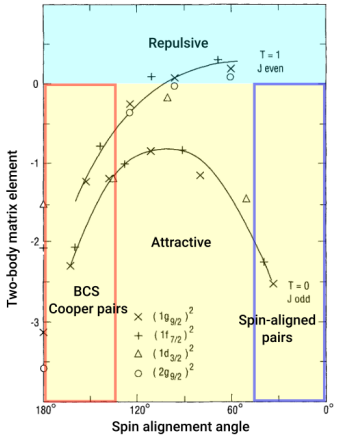


Schiffer & True, (1976)

BCS scheme (in nuclei)

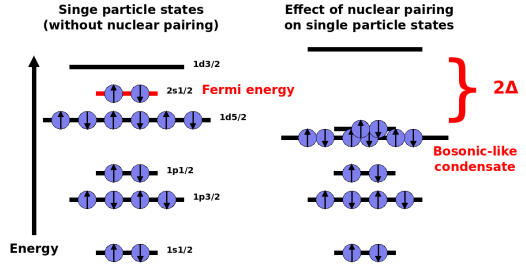


Nucleon interaction



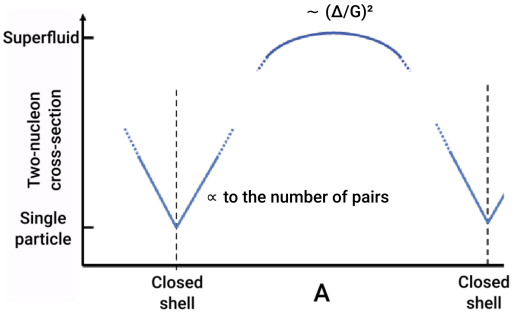
Schiffer & True, (1976)

BCS scheme (in nuclei)



Cooper nucleon pairs !

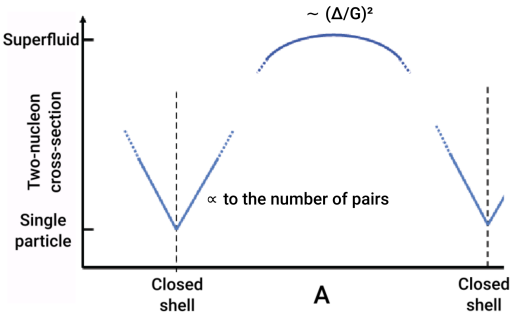
Two-nucleon transfer



Two-nucleon transfer cross section

Frauendorf & Macchiavelli, (2014)

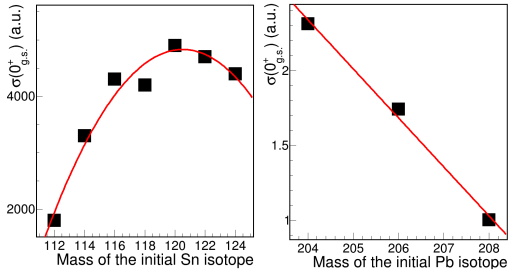
Two-nucleon transfer



Two-nucleon transfer cross section

Frauendorf & Macchiavelli, (2014)

(p, t) on Sn and Pb isotopes

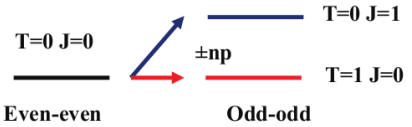


(p, t) reaction cross sections on Sn and Pb

Lanford, (1977)

Fleming *et al*, (1970)

Selection rules



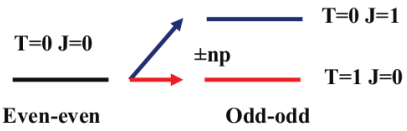
L=0 transfer

Two-nucleon transfer cross section

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

Frauendorf & Macchiavelli, (2014)

Selection rules



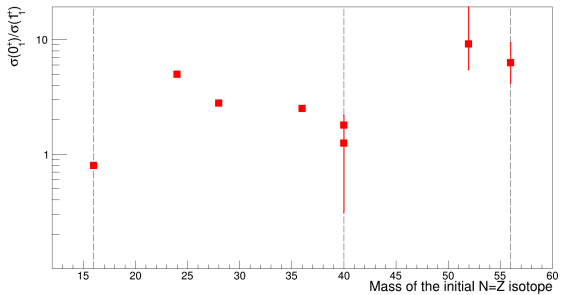
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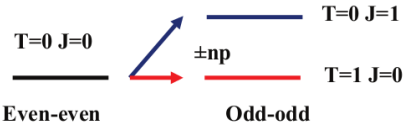
(p,^{3}He) on $N = Z$ nuclei



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)

Selection rules



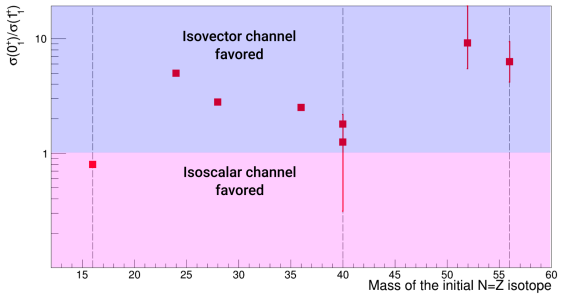
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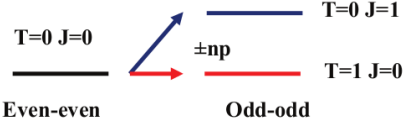


Isovector/isoscalar cross section ratio

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

Current status of pn pairing by transfer

Selection rules



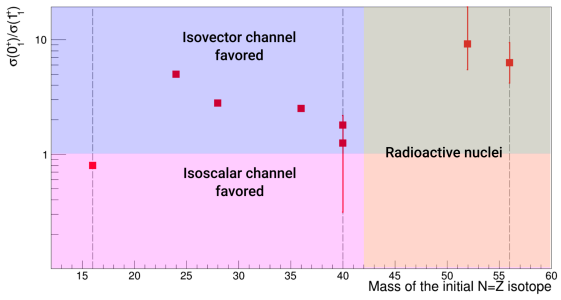
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Two-nucleon transfer cross section

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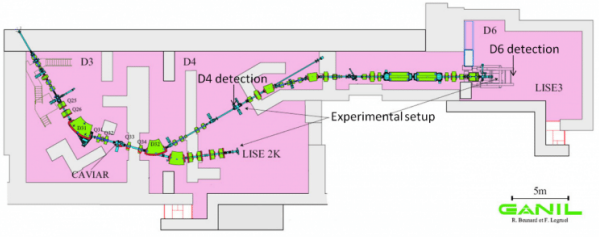


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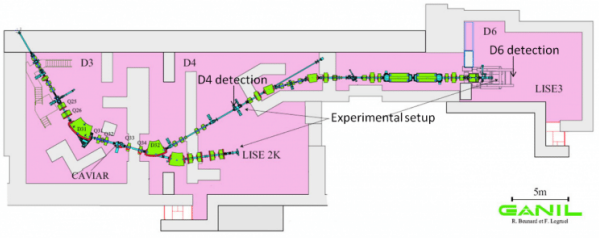
^{48}Cr(p,^{3}He)^{46}V experiment

LISE at GANIL



Scheme of the LISE spectrometer

LISE at GANIL

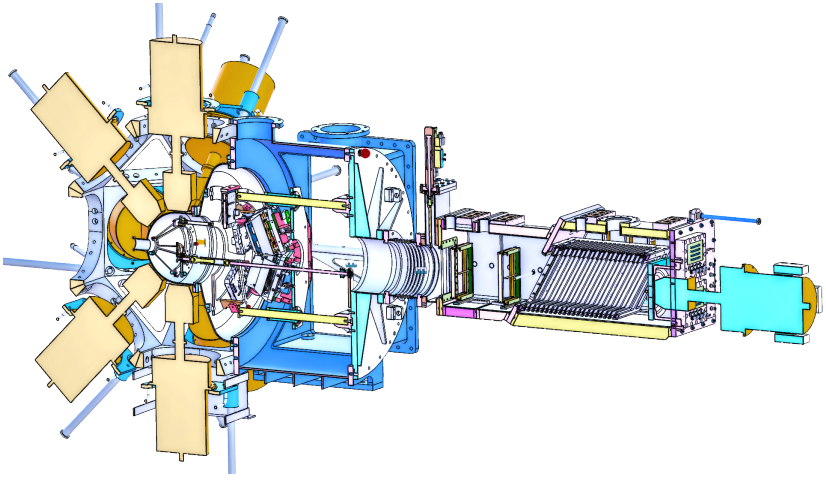


Scheme of the LISE spectrometer

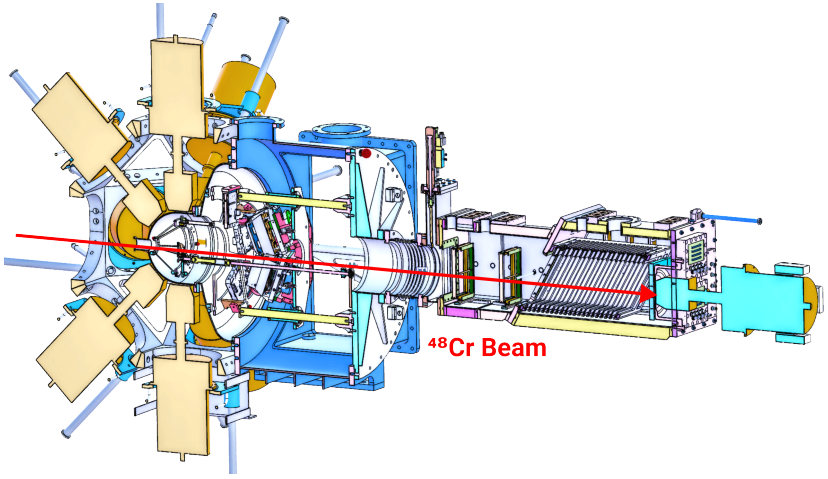
Beam characteristics

- Primary beam: ^{50}Cr at 72 MeV/u
- Secondary beam: ^{48}Cr at 30 MeV/u, 99% purity
- Secondary target: CH_2 5 mg cm^2

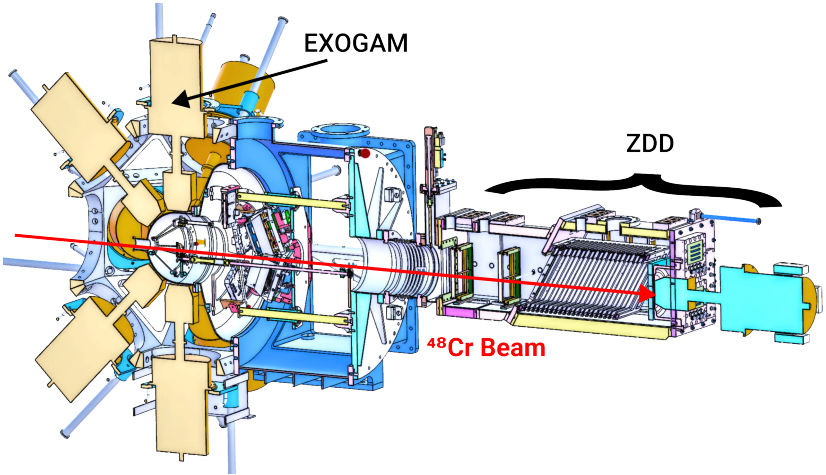
MUGAST@LISE



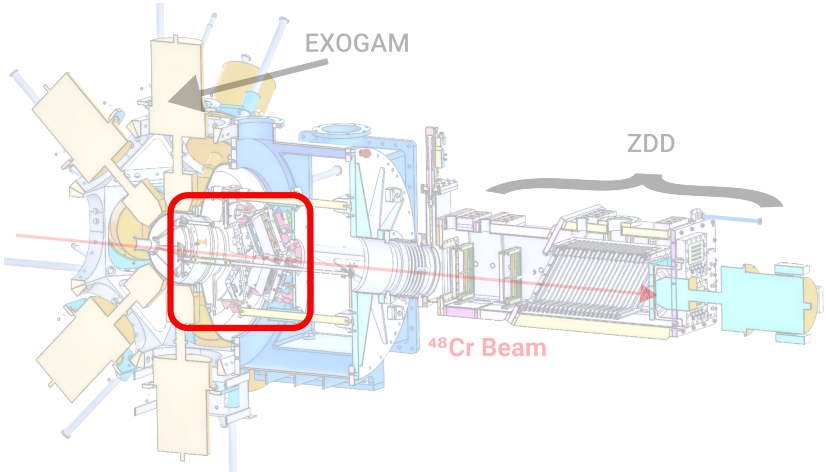
MUGAST@LISE



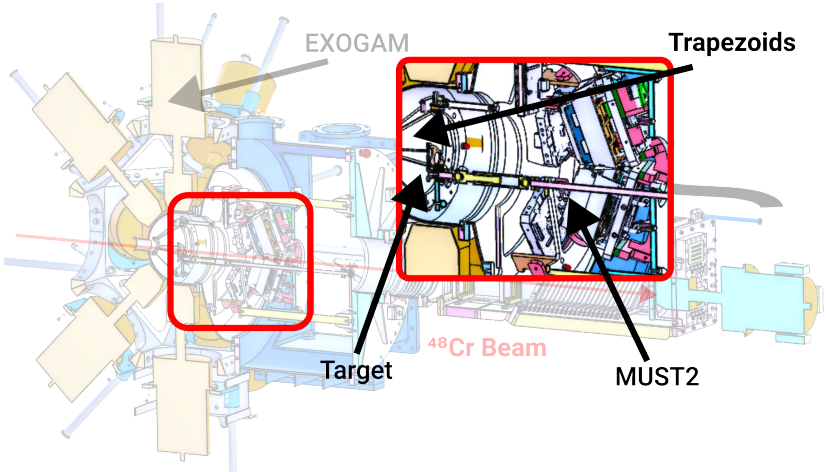
MUGAST@LISE



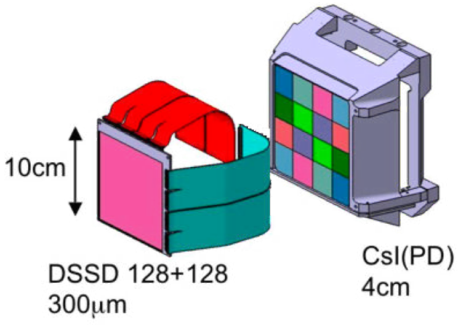
MUGAST@LISE



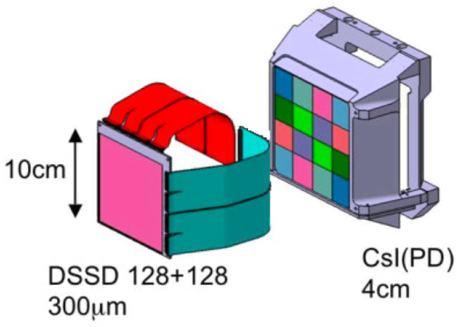
MUGAST@LISE



MUST2 (forward angles)

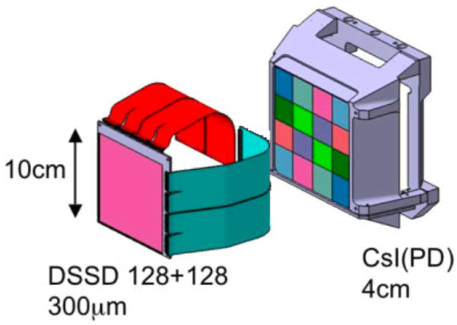


MUST2 (forward angles)



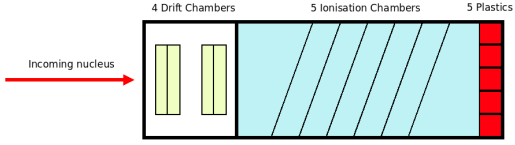
- Two layers of detection: DSSD and CsI crystals
- Particle identification by $\Delta E/E$ or $\Delta E/\mathrm{TOF}$
- Light charged particle angle and total energy

MUST2 (forward angles)



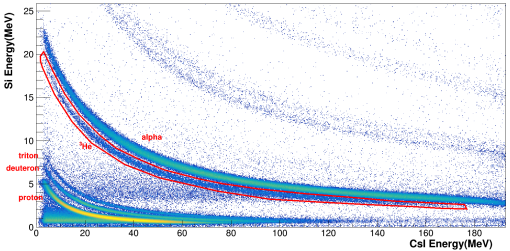
- Two layers of detection: DSSD and CsI crystals
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- Light charged particle angle and total energy

ZDD scheme



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

MUST2 identification

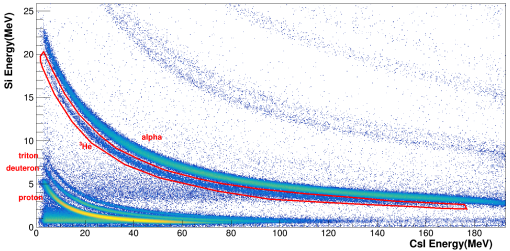


MUST2 $\Delta E / E_{CsI}$

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

Reaction channel identification

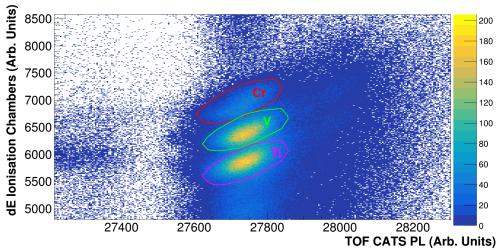
MUST2 identification



MUST2 $\Delta E / E_{CsI}$

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

ZDD identification

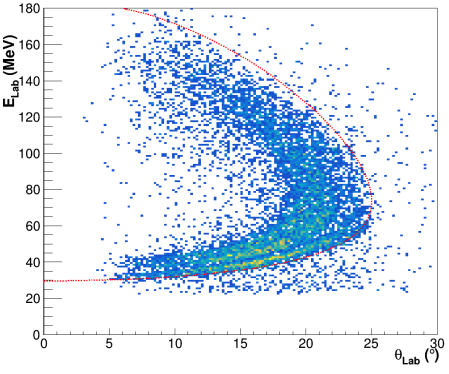


ΔE/TOF identification in the ZDD

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

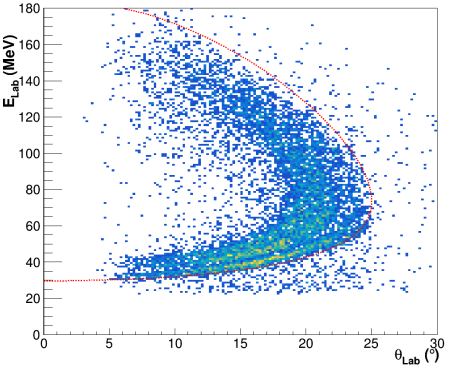
Overview and performance of the 2023 MUGAST@LISE campaign at GANIL, V. Girad-Alcindor et al. (2024)

Missing mass method



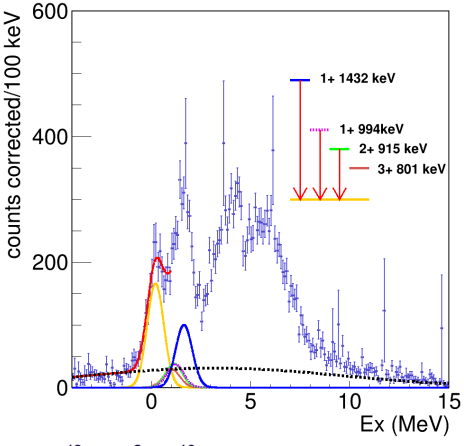
^{48}Cr(p,^{3}He)^{46}V kinematic lines

Missing mass method



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

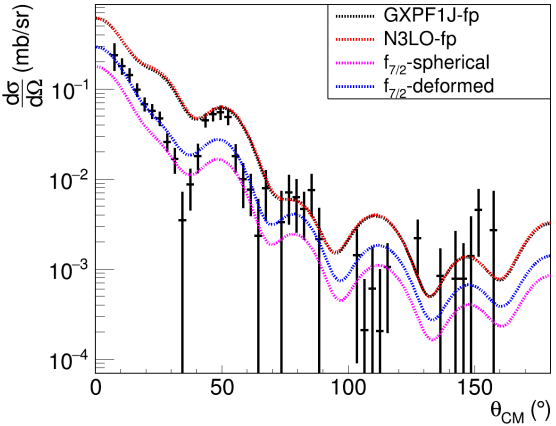
Excitation energy



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

Results

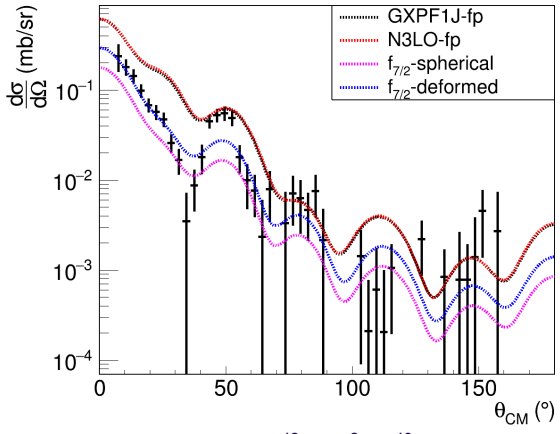
Comparison with DWBA



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

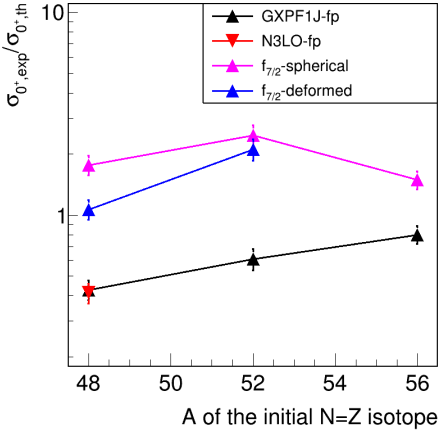
Source	σ_{0+} ub
Exp. result	$143(5)_{stat}(15)_{sys}$
GXPF1J-*fp*	334
N3LO-*fp*	347
$f_{7/2}$-spherical	81
$f_{7/2}$-deformed	134

CS between 5 and 160 degrees CM.

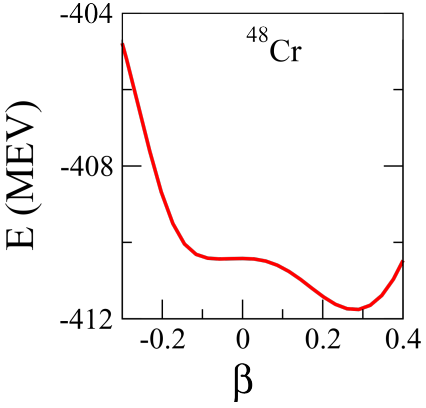
- Result compatible with $f_{7/2}$-deformed config.

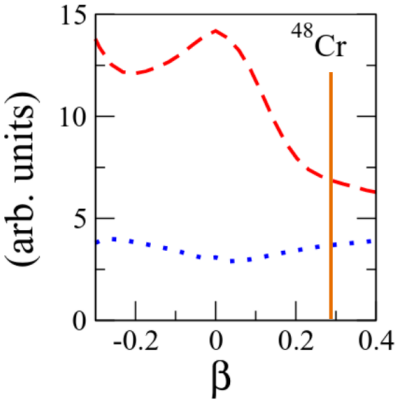
Interpretation

Ratio σ_{exp}/σ_{th}



HF + SM calculations

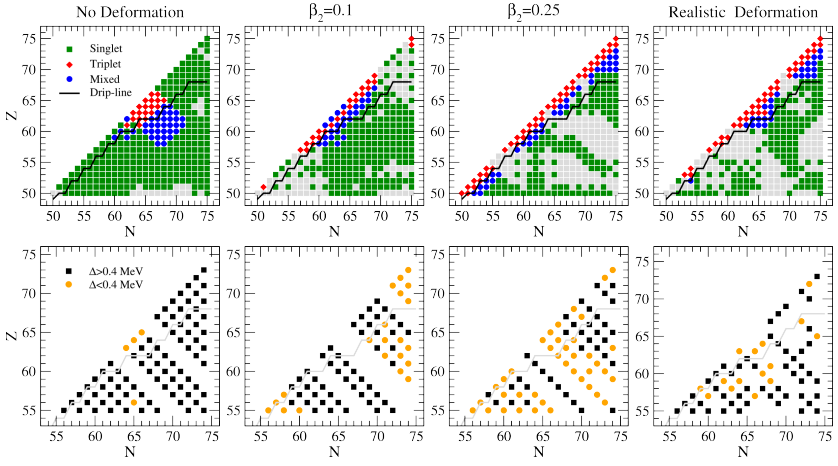




(Left) β of ^{48}Cr (Right) Pair transfer probability (blue: $T = 0$, red: $T = 1$)

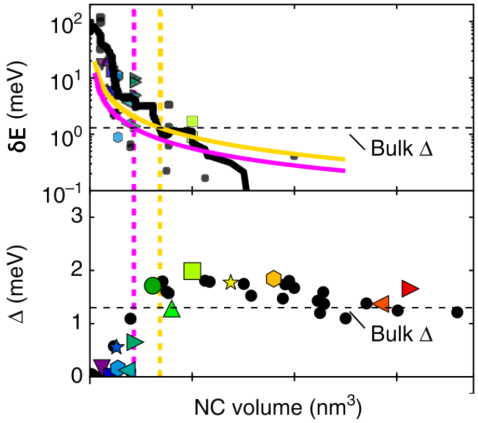
Gambacurta & Lacroix, (2015)

Deformed HFB



Palkanoglou & Stuck & Gezerlis, (2025)

Anderson Limit



Anderson (1959), Vlaic & *al*, (2017)

Deformed BCS

- Equation (5) from Simkovic *et al.* (2003) based on Civitarese *et al.* (1997)
- No isoscalar pairing, single particle energies from CEA DAM HFB (AMEDEE database)

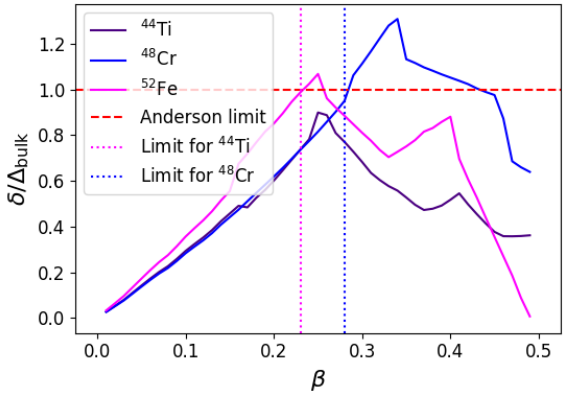
$$\begin{pmatrix} \epsilon_{ps}-\lambda_p & 0 & \Delta_{pp} & \Delta_{pn} \\ 0 & \epsilon_{ns}-\lambda_n & \Delta^*_{pn} & \Delta_{nn} \\ \Delta_{pp} & \Delta_{pn} & -(\epsilon_{ps}-\lambda_p) & 0 \\ \Delta^*_{pn} & \Delta_{nn} & 0 & -(\epsilon_{ns}-\lambda_n) \end{pmatrix} \begin{pmatrix} u_{spp} \\ u_{spn} \\ v_{spp} \\ v_{spn} \end{pmatrix} = E_{s\rho} \begin{pmatrix} u_{s\rho p} \\ u_{s\rho n} \\ v_{s\rho p} \\ v_{s\rho n} \end{pmatrix} \quad (5)$$

Deformed BCS

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$$\begin{pmatrix} \epsilon_{ps}-\lambda_p & 0 & \Delta_{pp} & \Delta_{pn} \\ 0 & \epsilon_{ns}-\lambda_n & \Delta^*_{pn} & \Delta_{nn} \\ \Delta_{pp} & \Delta_{pn} & -(\epsilon_{ps}-\lambda_p) & 0 \\ \Delta^*_{pn} & \Delta_{nn} & 0 & -(\epsilon_{ns}-\lambda_n) \end{pmatrix} \begin{pmatrix} u_{spp} \\ u_{spn} \\ v_{spp} \\ v_{spn} \end{pmatrix} = E_{s\rho} \begin{pmatrix} u_{s\rho p} \\ u_{s\rho n} \\ v_{s\rho p} \\ v_{s\rho n} \end{pmatrix} \quad (5)$$

Nuclear Anderson limit



Deformed BCS

- Equation (5) from Simkovic *et al.* (2003) based on Civitarese *et al.* (1997)
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Nuclear Anderson limit

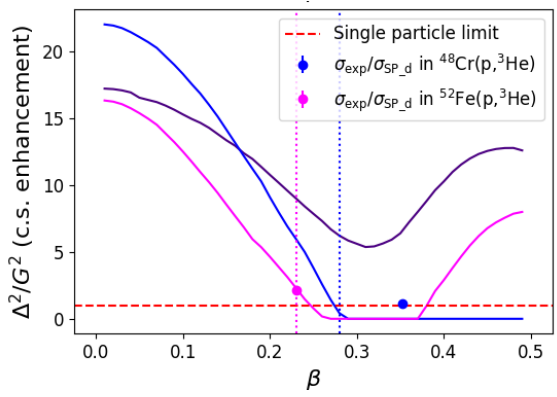


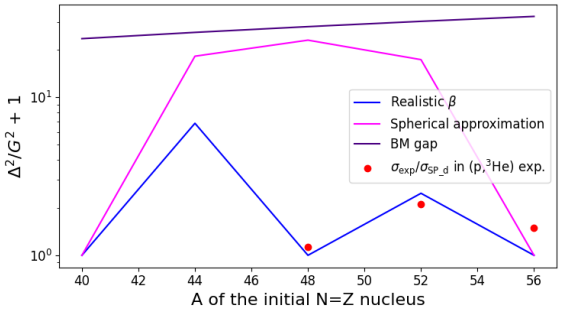
Illustration with schematic deformed BCS

Deformed BCS

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Nuclear Anderson limit

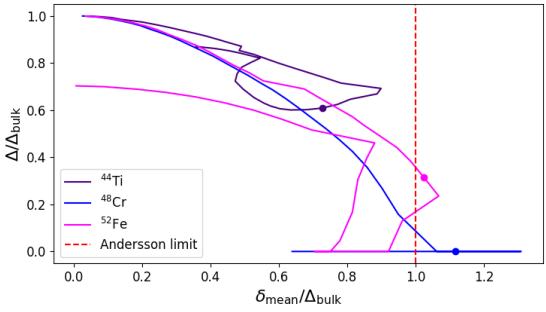


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Nuclear Anderson limit



Conclusion and perspectives

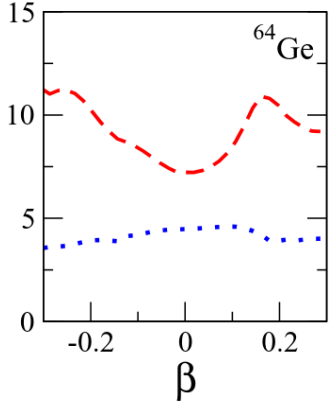
Physics conclusion

- ^{48}Cr(p,^{3}He)^{46}V @ 30 MeV/u measured at GANIL LISE
- Pairing collectivity hindered because of large β
- Analogy with Anderson limit in supercoductors suggested
- Other deformed nuclei could be favorable cases for pairing + deformation

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Transfer in ^{64}Ge



Gambacurta & Lacroix (2015)

Collaboration

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(Dated: September 14, 2026)