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

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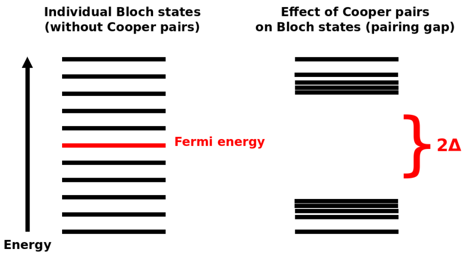
21/09/2026

Scientific Motivations

BCS scheme (in superconductors)



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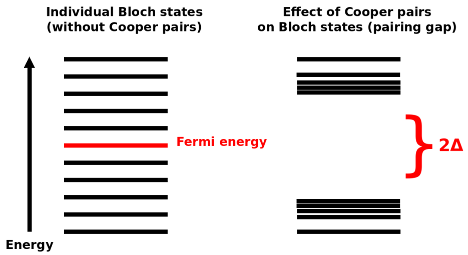

Electron pairs

- 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

Nucleon pairs and pairing

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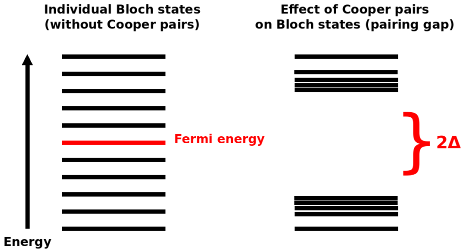

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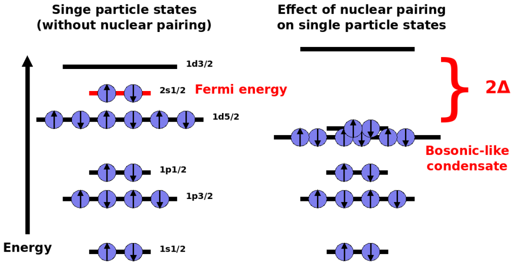

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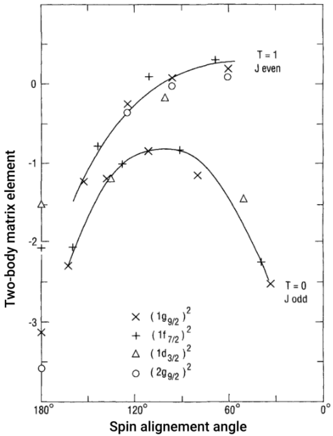
Nucleon interaction



Schiffer & True, (1976)

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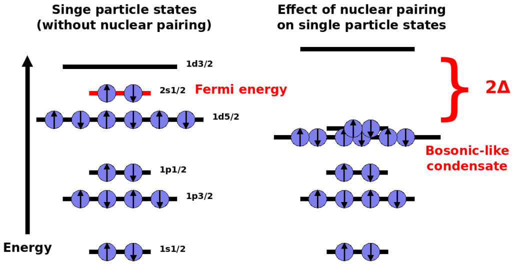
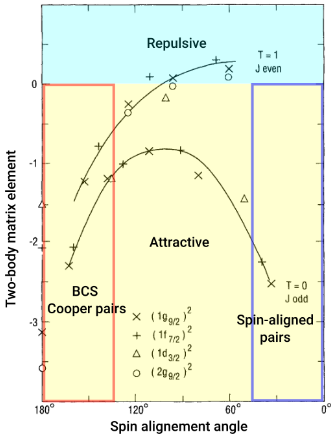


GANIL

Nucleon interaction



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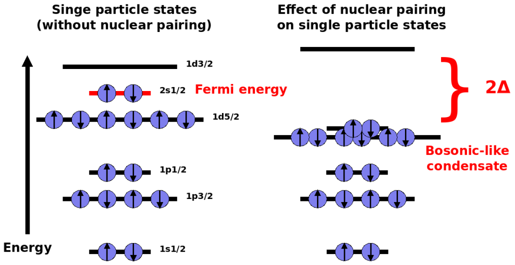

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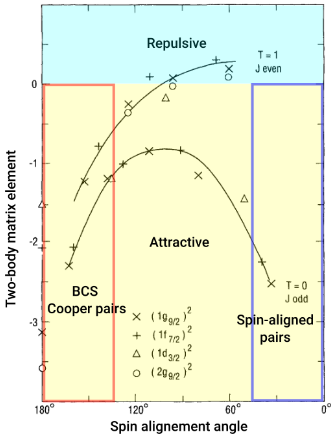

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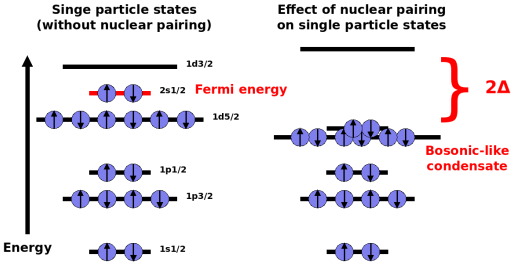
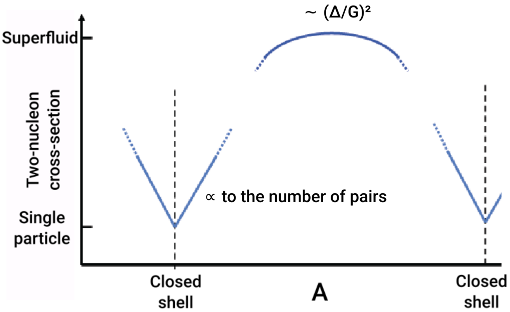


Cooper nucleon pairs !

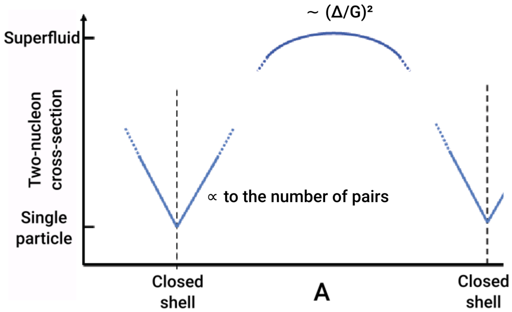
Two-nucleon transfer



Two-nucleon transfer cross section

Frauendorf & Macchiavelli, (2014)

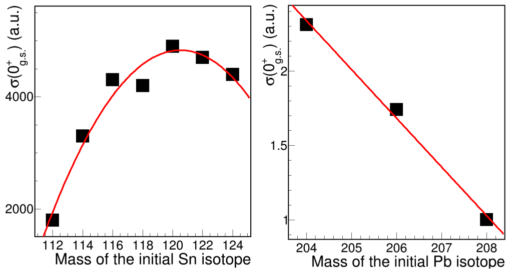
Two-nucleon transfer



Two-nucleon transfer cross section

Frauendorf & Macchiavelli, (2014)

(p, t) on Sn and Pb isotopes

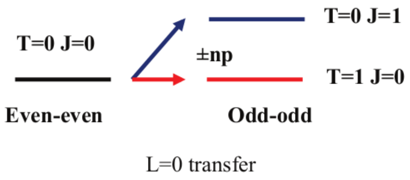


(p, t) reaction cross sections on Sn and Pb

Lanford, (1977)

Fleming *et al*, (1970)

Selection rules



Two-nucleon transfer cross section

- Common reactions: (p,^{3}He) and (^{3}He,p)
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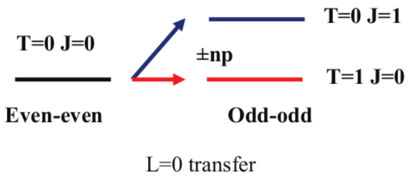

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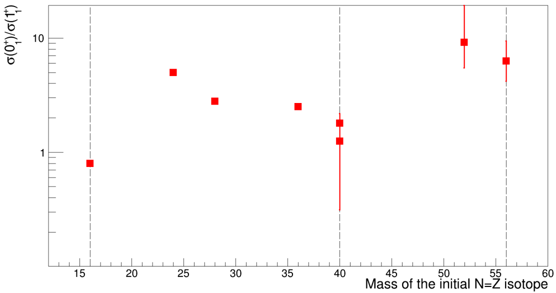
(p,^{3}He) on $N = Z$ nuclei



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)

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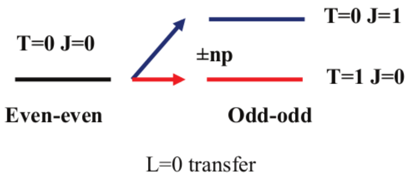

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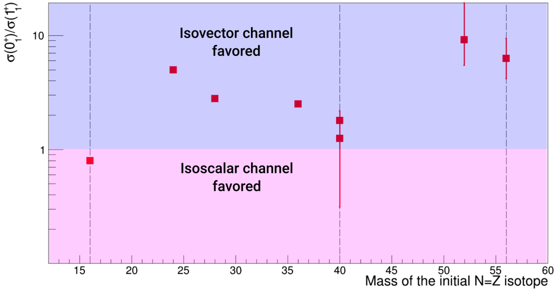

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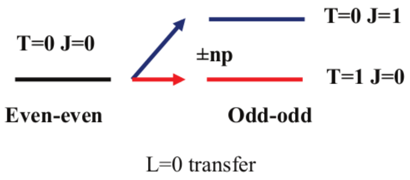

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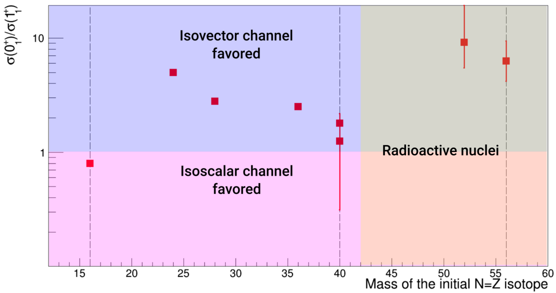

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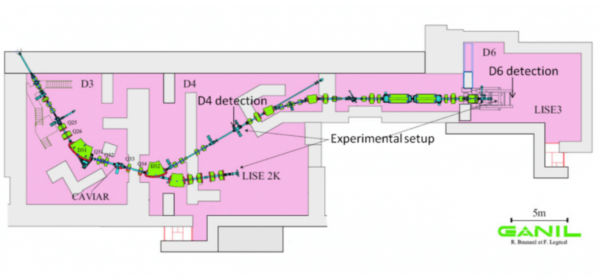
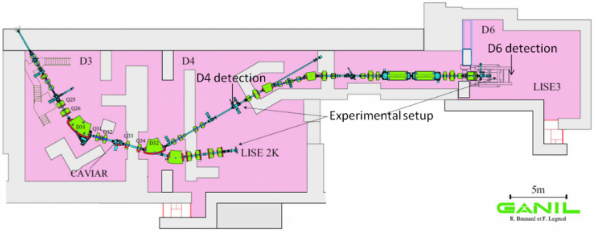
$^{48}Cr(p,^{3}He)^{46}V$ experiment

LISE at GANIL



Scheme of the LISE spectrometer

LISE at GANIL

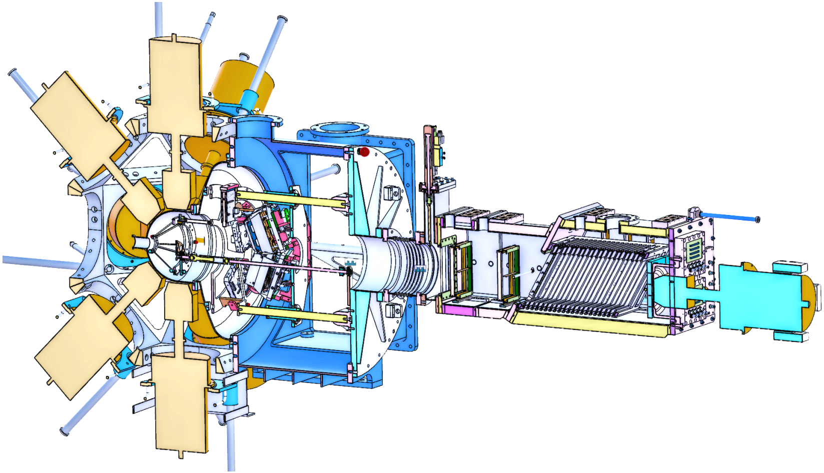


Scheme of the LISE spectrometer

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



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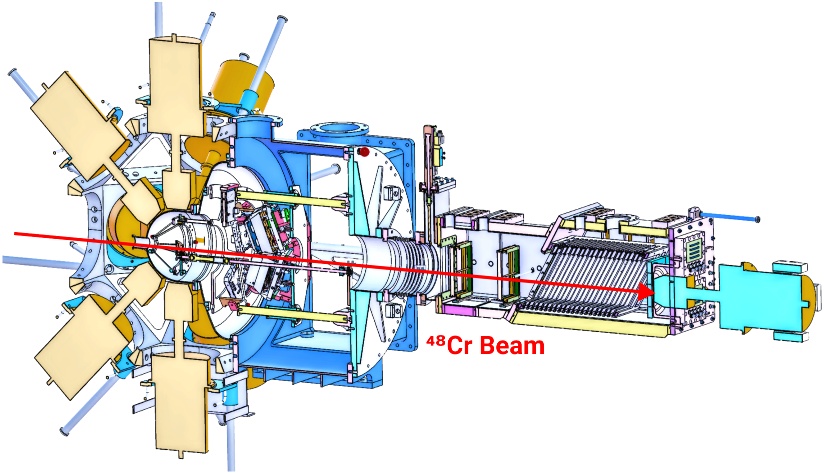

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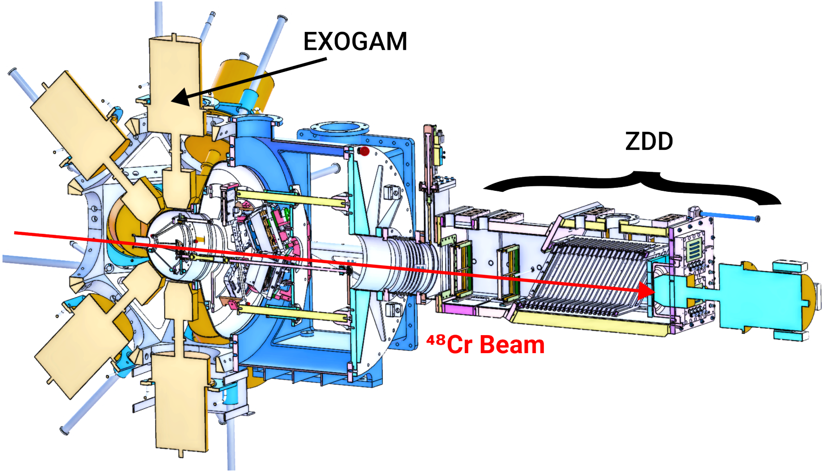

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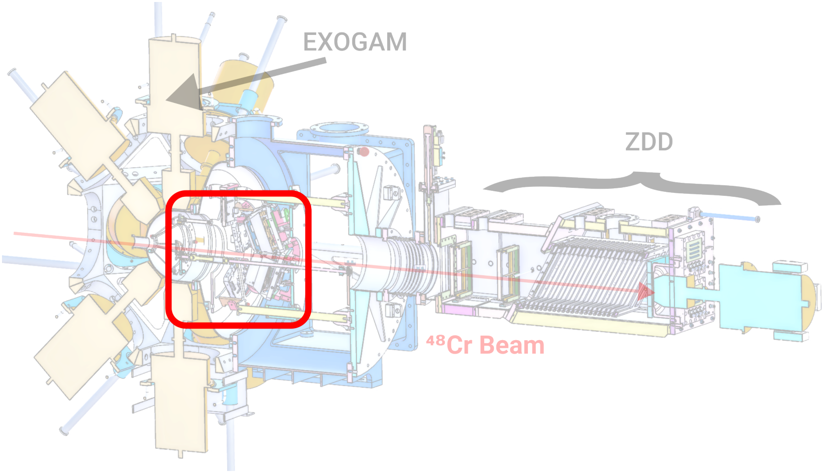

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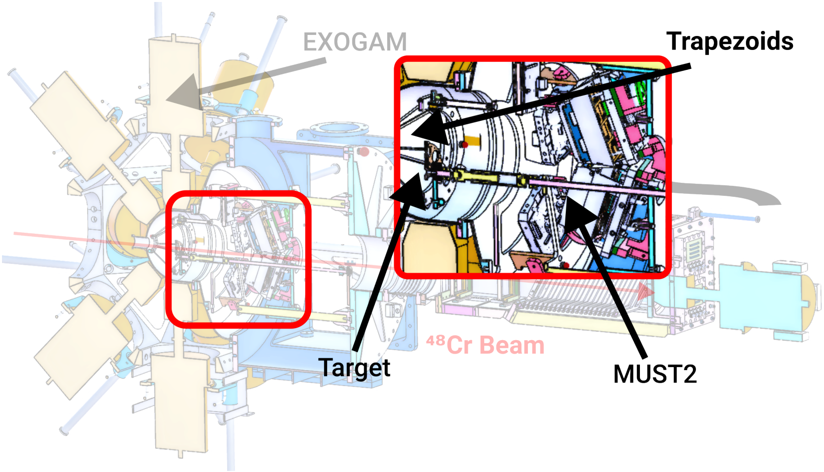
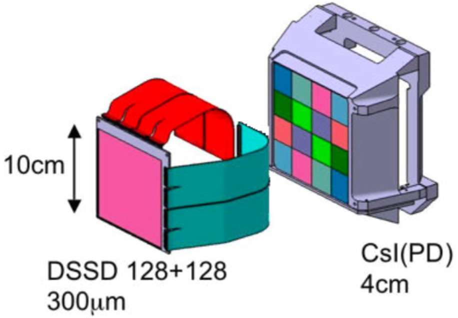


MUST2 (forward angles)



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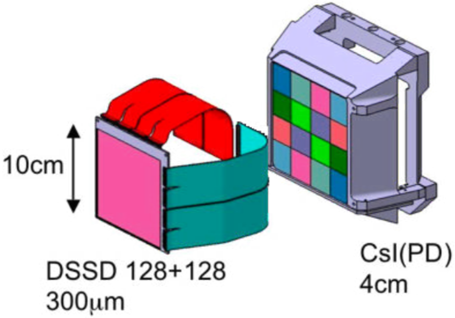

- Two layers of detection: DSSD and CsI crystals
- Particle identification by $\Delta E/E$ or $\Delta E/$TOF
- Light charged particle angle and total energy

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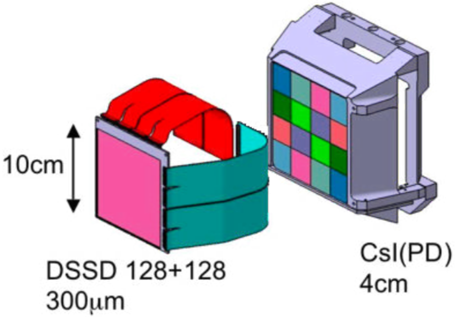

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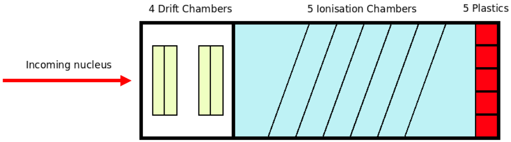
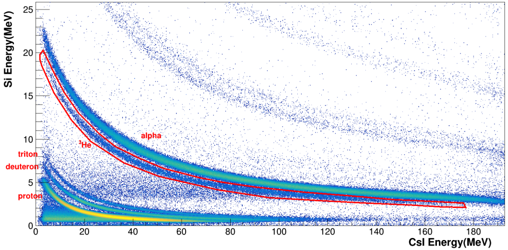
ZDD scheme



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

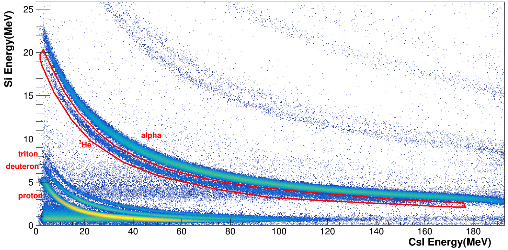
MUST2 identification



MUST2 $\Delta E / E_{CsI}$

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

MUST2 identification



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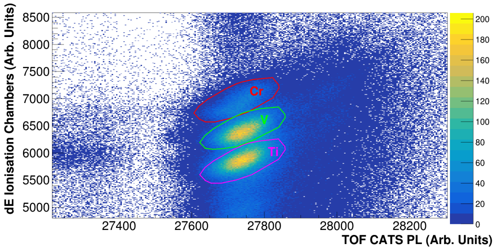
ZDD identification

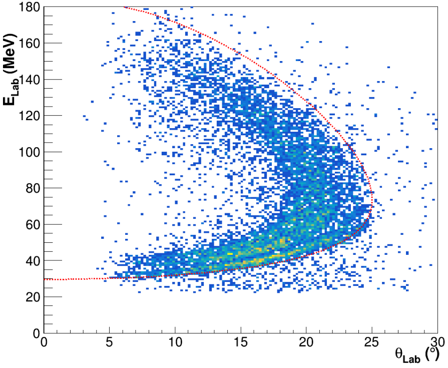


ΔE/TOF identification in the ZDD

- 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

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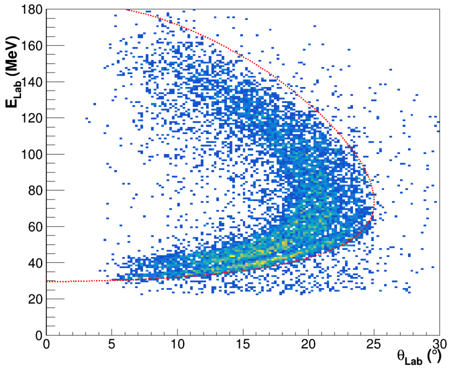

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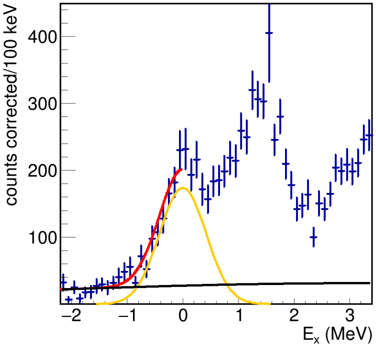
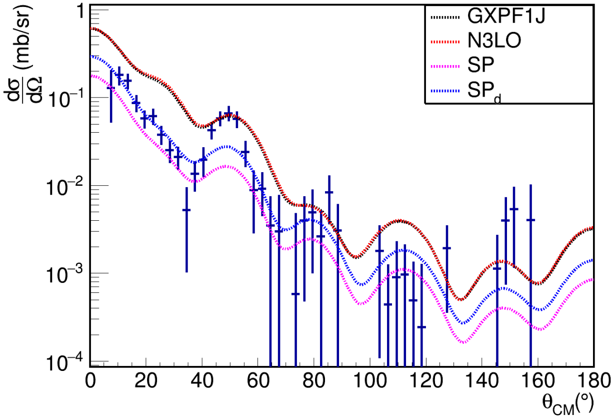
Excitation energy



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

Results

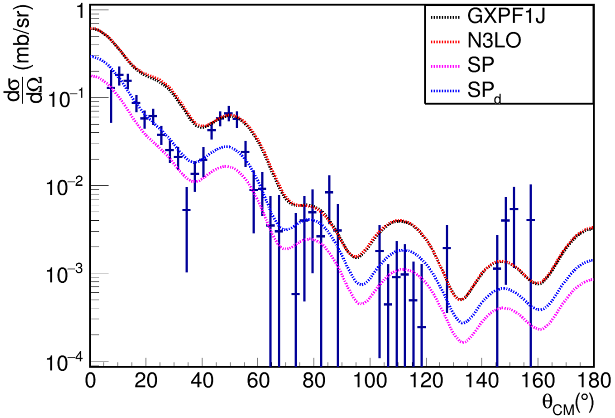
Comparison with DWBA



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	$151(7)_{stat}(15)_{sys}$
GXPF1J KD	331
N3LO KD	347
SP KD	81
SP_d KD	134

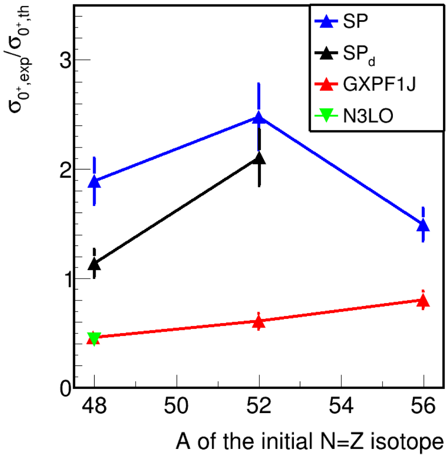
CS between 5 **and** 160 **degrees CM.**

- Result compatible with SP_d config.

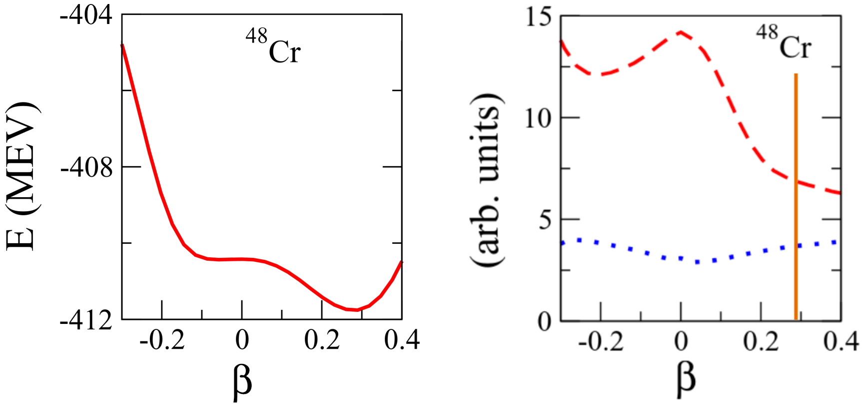
Interpretation

Comparison of integrated CS with theory

Ratio σ_{exp}/σ_{th}



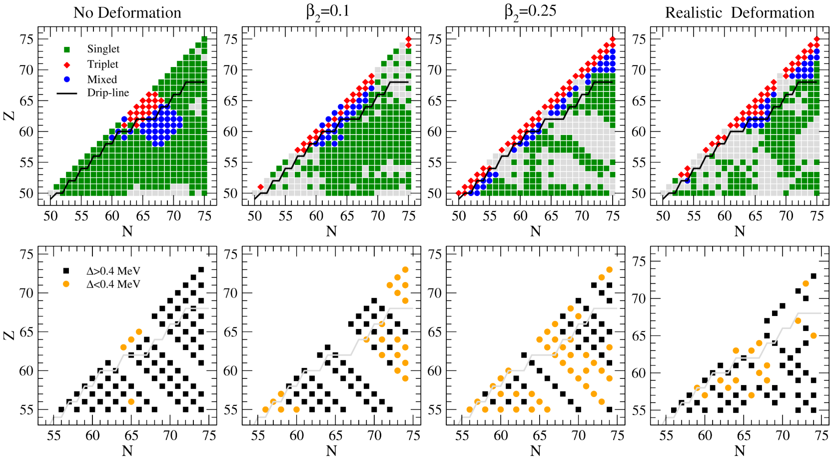
HF + SM calculations



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

Gambacurta & Lacroix, (2015)

Deformed HFB



Palkanoglou & Stuck & Gezerlis, (2025)

How to break superconductivity ?

Anderson Limit

ing. On the other hand, on reducing the particle size, we will begin to get to the point at which the scattered wave functions ψ_n have energies E_n which are separated by discrete energy gaps. That is, their energies must extend over something like the total Fermi energy, which is about 10 eV; and if there were only about a thousand electrons, that would mean that the energy differences between the states would be of the order of 0·01 eV. With such energy differences among the E_n, supercon-ductivity would no longer be possible; in fact, it is fairly easily seen that the energy differences must be less than the energy gap. That means that

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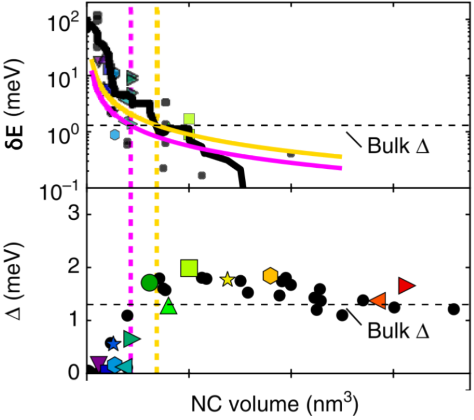

Anderson (1959), Vlaic & *al*, (2017)

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_{sp} \begin{pmatrix} u_{spp} \\ u_{spn} \\ v_{spp} \\ v_{spn} \end{pmatrix} \qquad (5)
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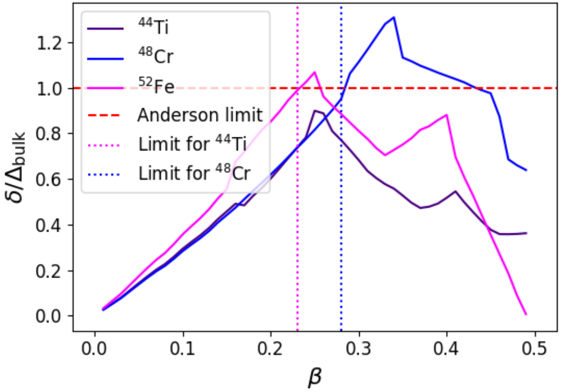
Nuclear Anderson limit



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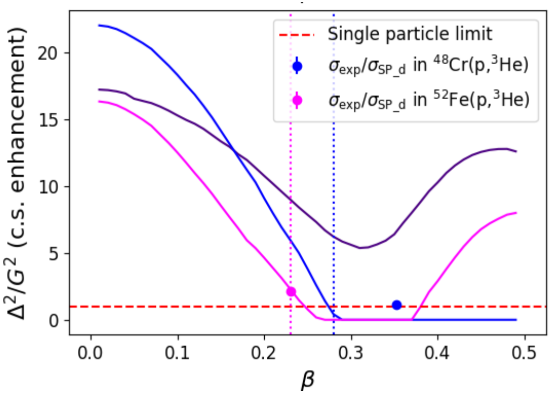

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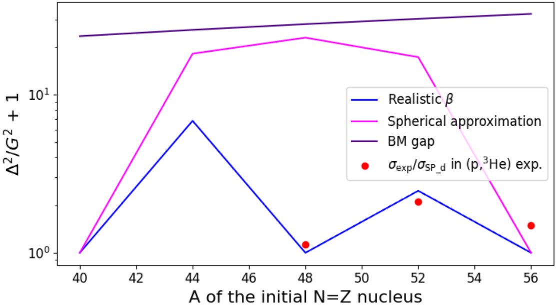

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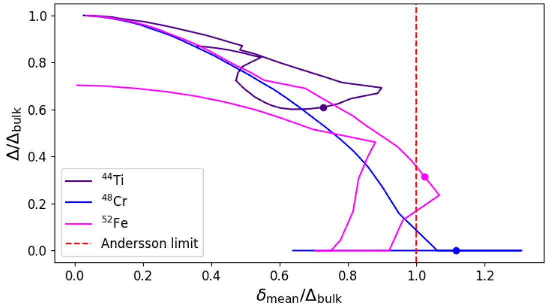
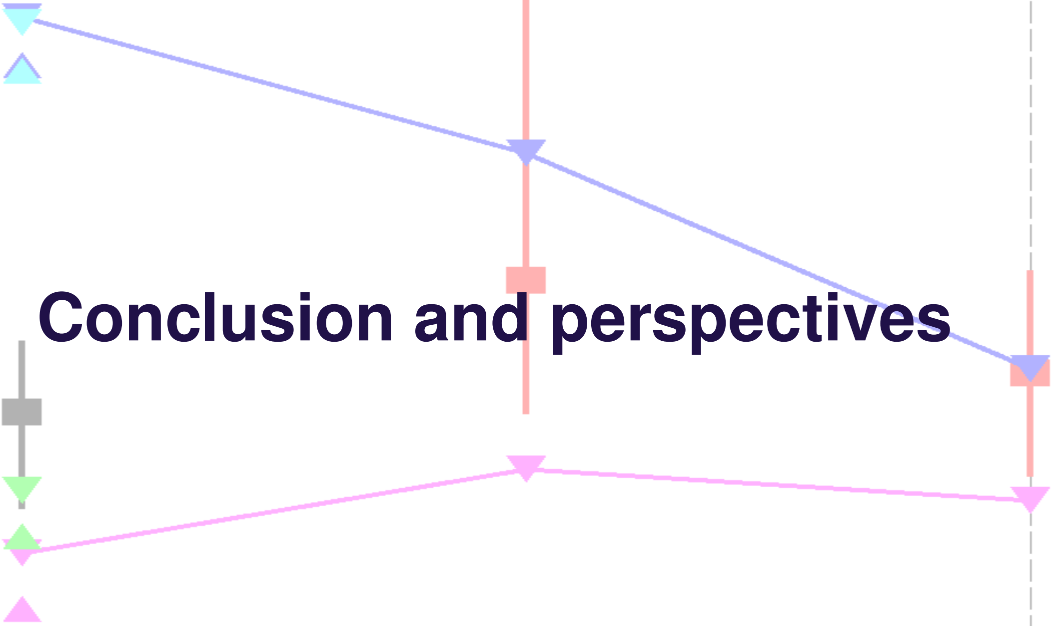
$$\begin{pmatrix} \epsilon_{ps}-\lambda_p & 0 & \Delta_{pp} & \Delta_{pn} \\ 0 & \epsilon_{ns}-\lambda_n & \Delta^*_{pn} & \Delta_{nn} \\ \Delta_{pp} & \Delta_{pn} & -(\epsilon_{ps}-\lambda_p) & 0 \\ \Delta^*_{pn} & \Delta_{nn} & 0 & -(\epsilon_{ns}-\lambda_n) \end{pmatrix} \begin{pmatrix} u_{spp} \\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

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 supraconductors suggested
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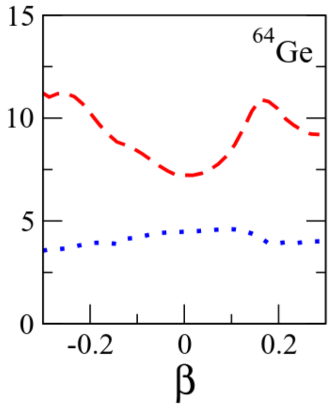
Transfer in ^{64}Ge



Gambacurta & Lacroix (2015)

Collaboration

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(Dated: September 14, 2026)