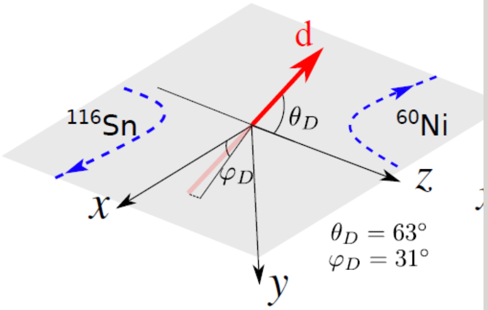
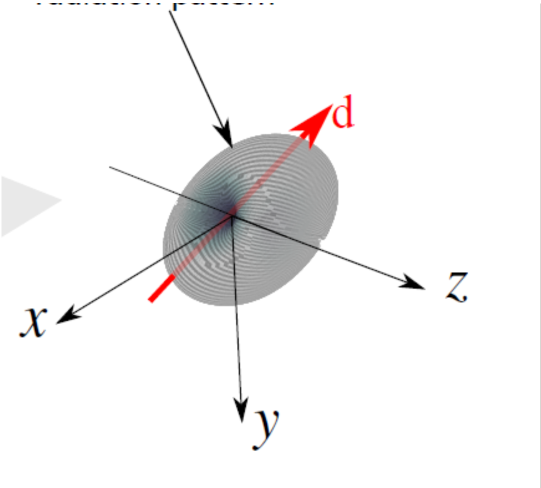
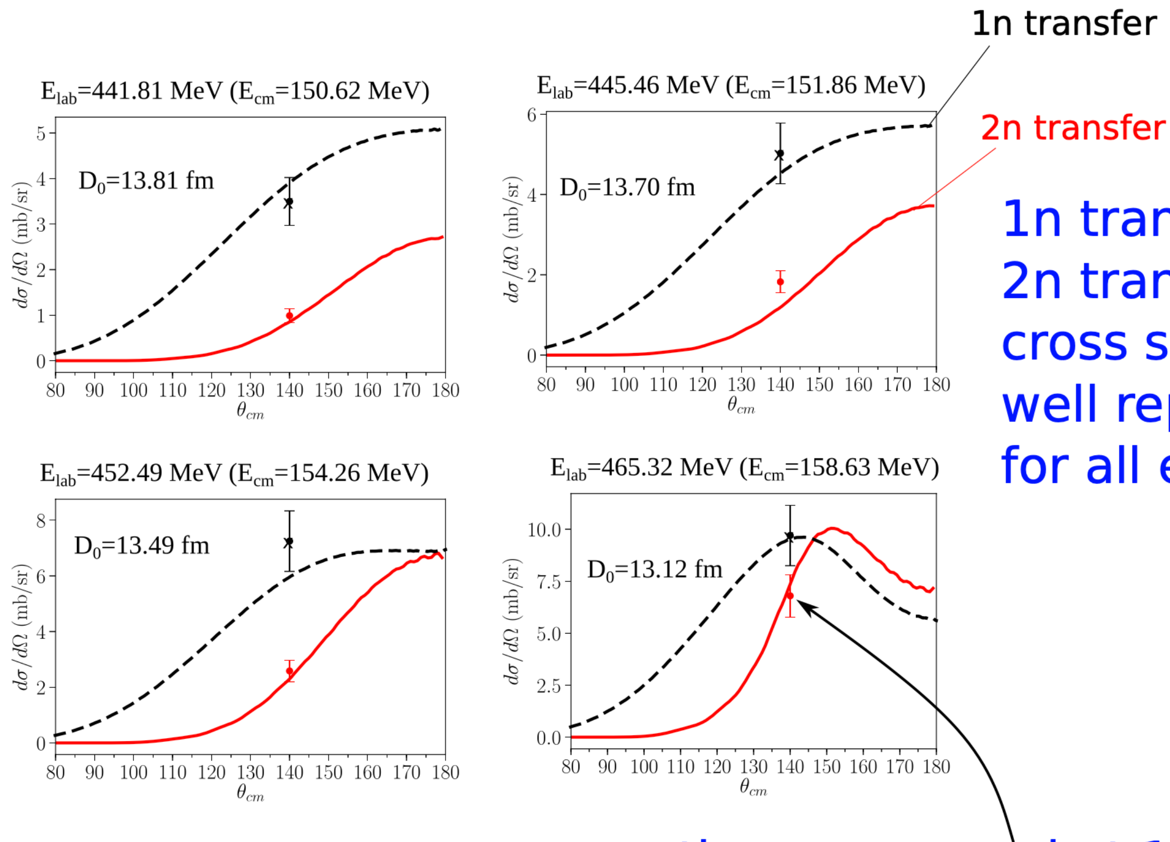




Enrico Vigezzi INFN Milano

NUCLEAR JOSEPHSON-LIKE γ-EMISSION

7th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX7)



1n transfer and 2n transfer cross sections well reproduced for all energies

cross sections measured at 140°

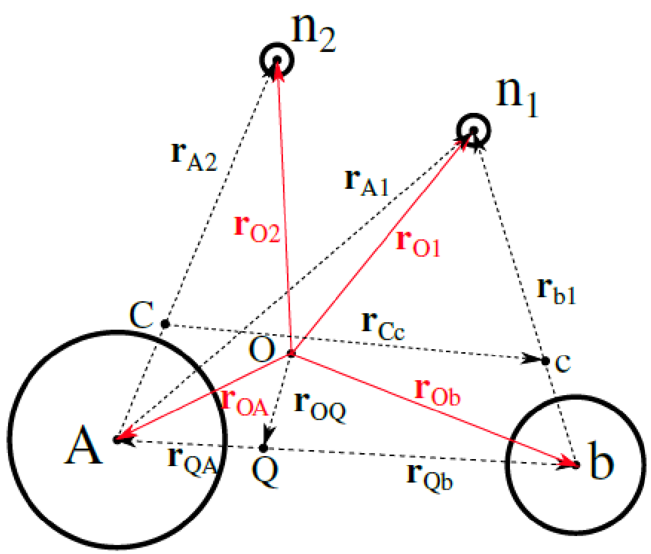
σ_{1n} and σ_{2n} are calculated for the reaction between the two superfluid nuclei ^{116}Sn and ^{60}Ni.

Second order DWBA: sequential transfer

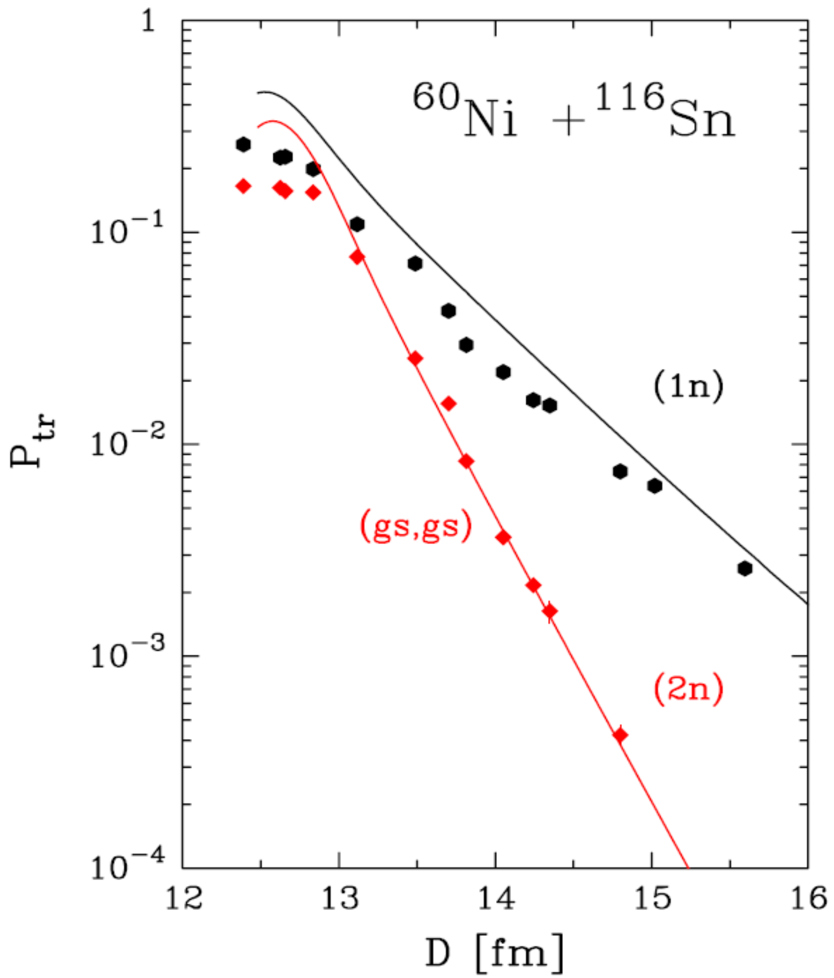
$$T(\mathbf{k}_f,\mathbf{k}_i) = 2\sum_{KM}\sum_{j_i,j_f} B_{j_f}^{(A)*}B_{j_i}^{(b)} \int \chi_f^*(\mathbf{r}_{Bb},\mathbf{k}_f)\left[\phi_{j_f}^{(A)}(\mathbf{r}_{A_2})\phi_{j_f}^{(A)}(\mathbf{r}_{A_1})\right]_0^{0*} U^{(A)}(r_{b1})\left[\phi_{j_f}^{(A)}(\mathbf{r}_{A_2})\phi_{j_i}^{(b)}(\mathbf{r}_{b_1})\right]_M^K d\mathbf{r}_{Cc}\,d\mathbf{r}_{b_1}\,d\mathbf{r}_{A_2}$$

$$\times \int G(\mathbf{r}_{Cc},\mathbf{r}'_{Cc})\left[\phi_{j_f}^{(A)}(\mathbf{r}'_{A_2})\phi_{j_i}^{(b)}(\mathbf{r}'_{b_1})\right]_M^{K*} U^{(A)}(r'_{b2})\left[\phi_{j_i}^{(b)}(\mathbf{r}'_{b_2})\phi_{j_i}^{(b)}(\mathbf{r}'_{b_1})\right]_0^0 \chi_i(\mathbf{r}'_{Aa},\mathbf{k}_i)\,d\mathbf{r}'_{Cc}\,d\mathbf{r}'_{b_1}\,d\mathbf{r}'_{A_2},$$

$$B_j = \sqrt{\frac{(2j+1)}{2}}\,U'_j V'_j,$$



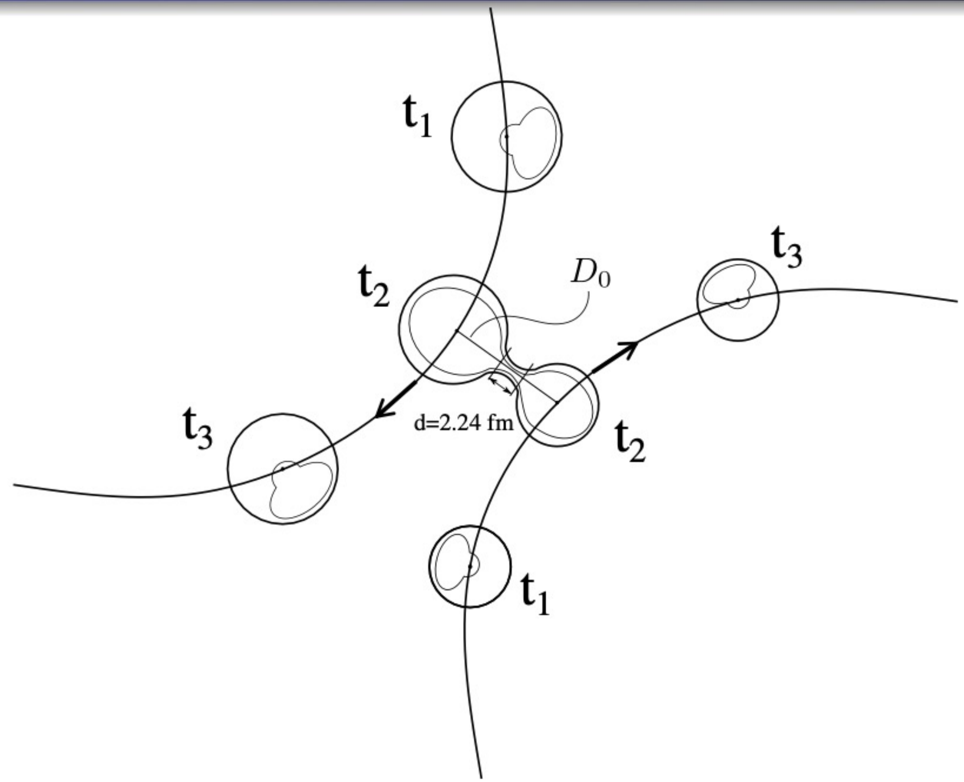
One- and two-neutron transfer probability between superfluid heavy ions as a function of the distance of closest approach



D_0(fm)	E_{cm} (MeV)	$(E_B - E_{cm})$ (MeV)	$\left(\frac{4}{\pi}\right)^2 \left(\frac{\sigma_{2n}}{\sigma_{1n}}\right)$
13.12	158.63	-1.03	1.14
13.49	154.26	3.34	0.57
13.70	151.86	5.74	0.59
13.81	150.62	6.98	0.46
14.05	148.10	9.50	0.27
14.24	146.10	11.50	0.22
14.39	145.02	12.58	0.18

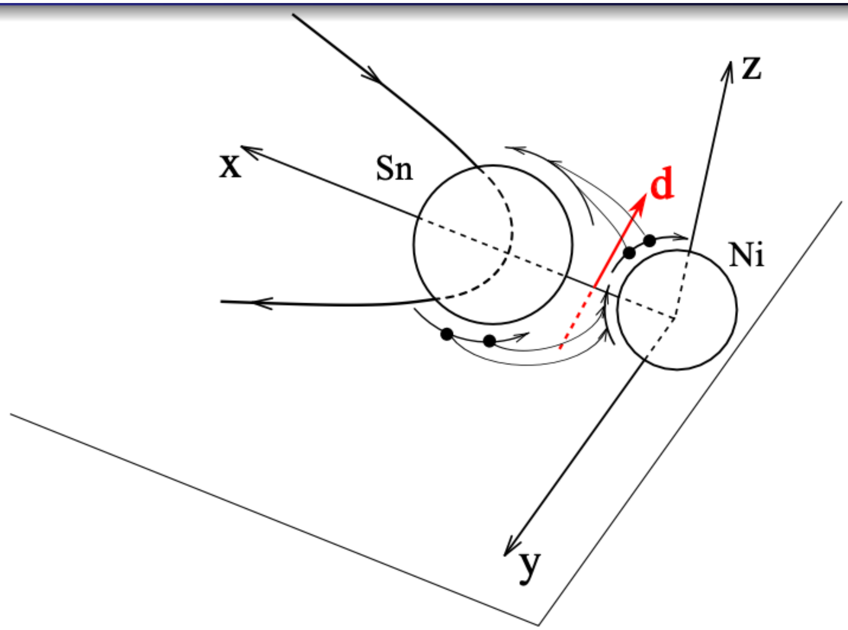
D. Montanari et al, PRL 113 052501 (2014)

Transient Josephson junction



transient Josephson junction of width D_0

A Josephson junction of width D_0 between the two superfluid nuclei is established during the very short collision time $\tau_{coll} \approx t_3 - t_1 \approx 10^{-21}$s.



- Neutrons have effective charge $e_{eff} = -e(Z_1 + Z_2)/(A_1 + A_2) = -0.44e$.
- An oscillating electric dipole $\vec{d}$ is induced during the 2n transfer process.
- The dipole emits electromagnetic radiation like an antenna during a very short time $\tau_{coll} \sim 10^{-21}$ s.

Gamma emission in 2NT channel

$$T_{m_\gamma}(\mathbf{k}_f,\mathbf{k}_i) = \sum_{j_i,j_f} B_{j_i}B_{j_f} \int \chi_f^*(\mathbf{r}_{Bb};\mathbf{k}_f)\left[\phi_{j_f}(\mathbf{r}_{A_1})\phi_{j_f}(\mathbf{r}_{A_2})\right]_0^{0*} D_{m_\gamma}\left[\phi_{j_f}(\mathbf{r}_{A_2})\phi_{j_f}(\mathbf{r}_{b_1})\right]_M^K v(r_{b1})\,d\mathbf{r}_{Cc}\,d\mathbf{r}_{b_1}\,d\mathbf{r}_{A_2}$$

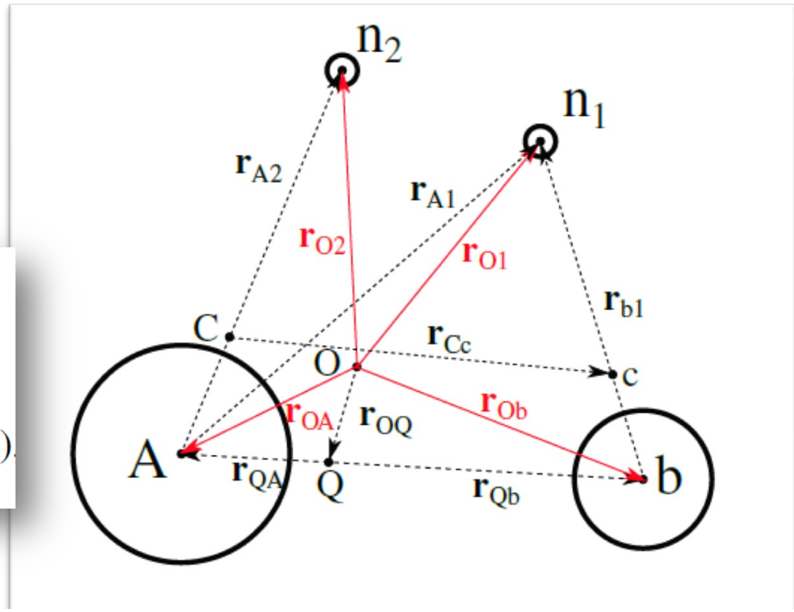
$$\times \int G(\mathbf{r}_{Cc},\mathbf{r}'_{Cc})\left[\phi_{j_f}(\mathbf{r}'_{A_2})\phi_{j_i}(\mathbf{r}'_{b_1})\right]_M^{K*} v(r'_{c2})\left[\phi_{j_i}(\mathbf{r}'_{b_2})\phi_{j_i}(\mathbf{r}'_{b_1})\right]_0^0 \chi_i(\mathbf{r}'_{Aa};\mathbf{k}_i)\,d\mathbf{r}'_{cC}\,d\mathbf{r}'_{b_1}\,d\mathbf{r}'_{A_2}.$$

$$\mathbf{D}_{m_\gamma} = e_{eff}\sqrt{\frac{4\pi}{3}}\left(r_{O1}Y^1_{m\gamma}(\hat{r}_{O1}) + r'_{O2}Y^1_{m\gamma}(\hat{r}'_{O2})\right)$$

$$\mathcal{T}^q(\mathbf{k}_\gamma,\mathbf{k}_f) = \sum_{m_\gamma} \mathcal{D}^1_{m_\gamma q}(R_\gamma)\,T_{m_\gamma}(\mathbf{k}_f,\mathbf{k}_i)$$

$$\frac{d^3\sigma^\gamma_{2n}}{d\Omega_\gamma d\Omega dE_\gamma} = \rho_f(E_f)\rho_\gamma(E_\gamma)\left(\left|\mathcal{T}^1(\mathbf{k}_\gamma,\mathbf{k}_f)\right|^2 + \left|\mathcal{T}^{-1}(\mathbf{k}_\gamma,\mathbf{k}_f)\right|^2\right)\delta(E_i - E_\gamma - E_f + Q)$$

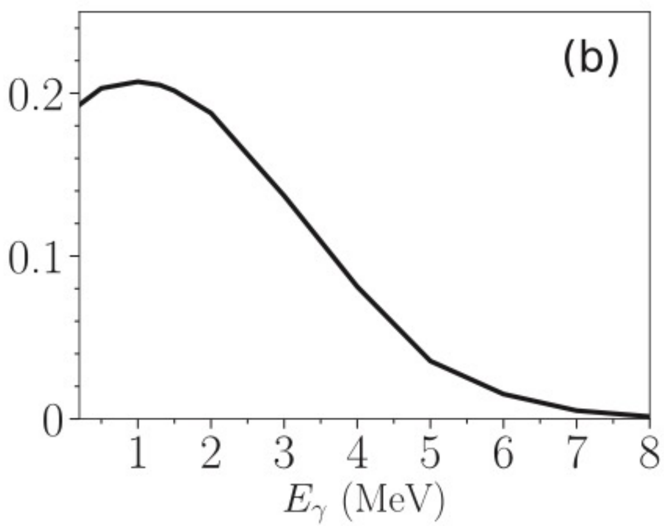
$$= \frac{\mu_i\mu_f}{(2\pi\hbar^2)^2}\frac{k_f}{k_i}\left(\frac{E_\gamma^2}{(\hbar c)^3}\right)\left(\left|\mathcal{T}^1(\mathbf{k}_\gamma,\mathbf{k}_f)\right|^2 + \left|\mathcal{T}^{-1}(\mathbf{k}_\gamma,\mathbf{k}_f)\right|^2\right)\delta(E_i - E_\gamma - E_f + Q)$$

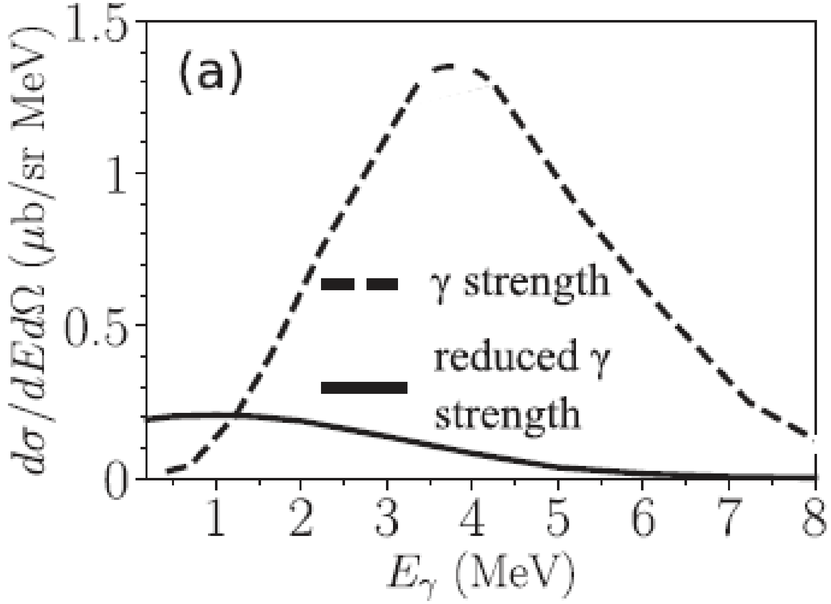


$\hbar\omega$ = Q_{2n}= 1.3 MeV

$$\frac{d^2\sigma}{d\Omega\, dE_\gamma} = \left(\frac{\mu_i\mu_f}{(2\pi\hbar^2)^2}\frac{k_f}{k_i}\right)\left(\frac{8\pi}{3}\frac{E_\gamma^2}{(\hbar c)^3}\right)|T_{m_\gamma}(\mathbf{k}_f, \mathbf{k}_i)|^2 \times\delta[E_\gamma + E_f - (E_i + Q)],$$

k_f/k_iT^2



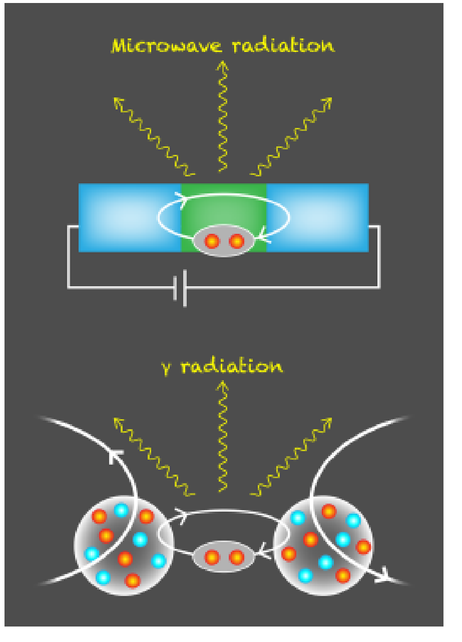


G.Potel et al, PRC 103 L021601 (2021)

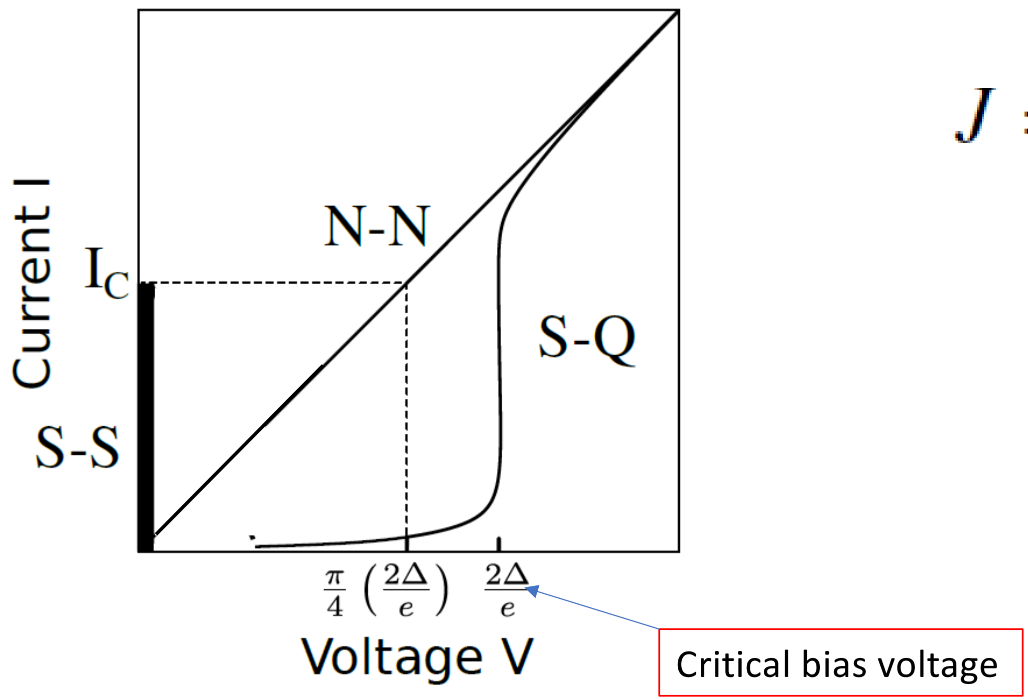
The Tiniest Superfluid Circuit in Nature

A new analysis of heavy-ion collision experiments uncovers evidence that two colliding nuclei behave like a Josephson junction—a device in which Cooper pairs tunnel through a barrier between two superfluids.

By Piotr Magierski



Josephson junctions (DC and AC)

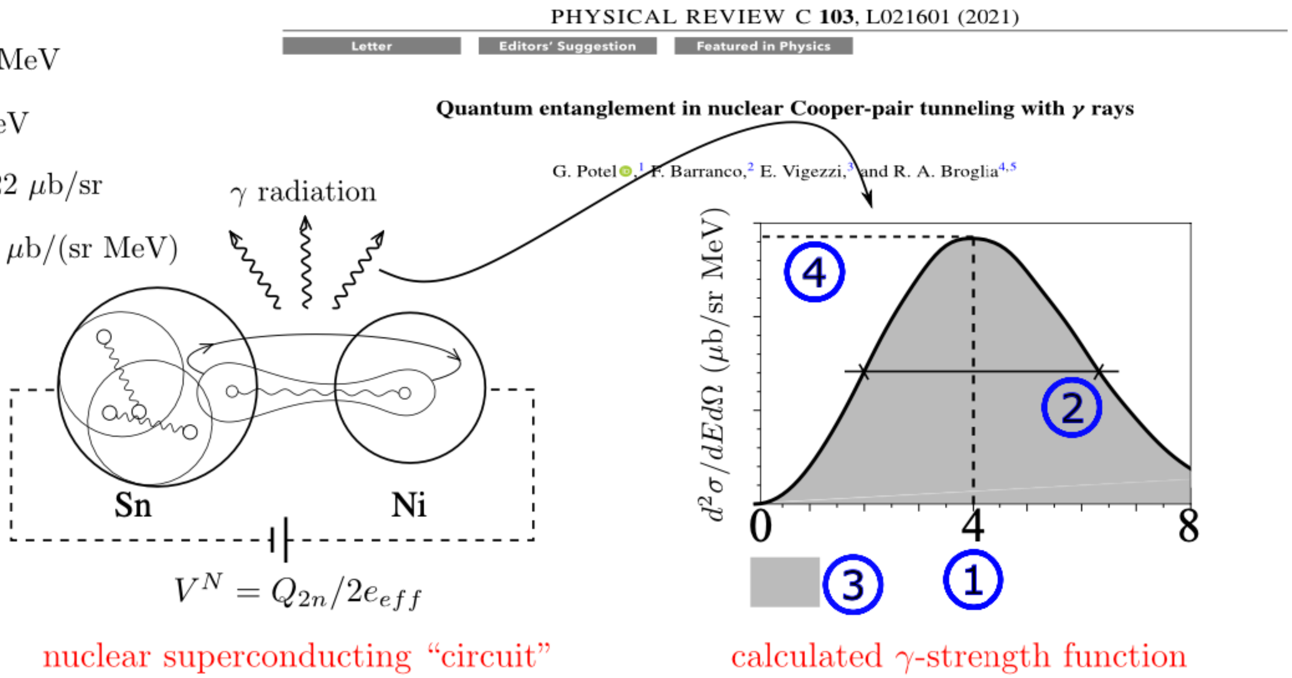


$$J = J_c \sin\left(\phi_{rel}(0) - \left(\frac{2eV}{\hbar} t\right)\right)$$

$$\omega_J = \frac{2eV}{\hbar}.$$

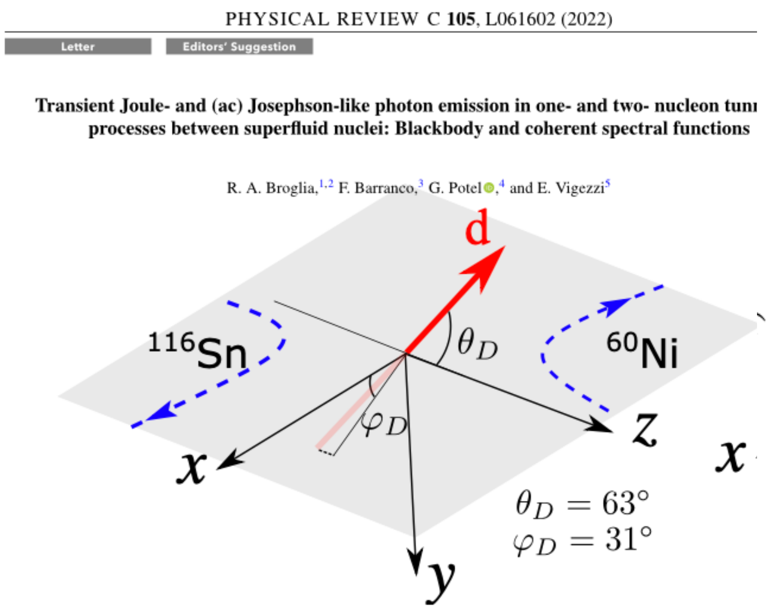
Is there a nuclear Josephson effect? A prediction

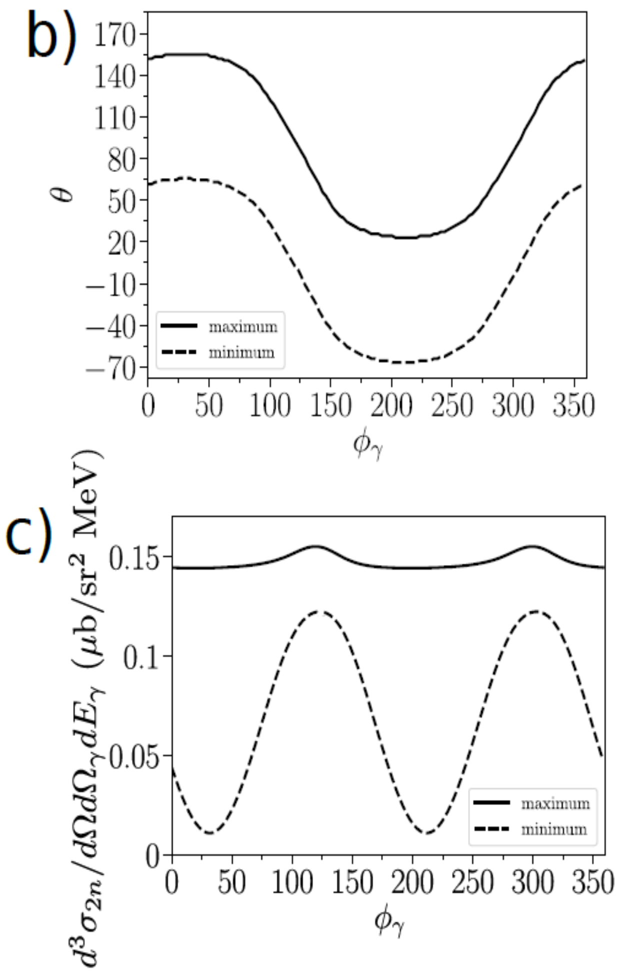
1. centroid: 4 MeV
2. width: 4 MeV
3. integral: 5.22 μb/sr
4. max. : 1.42 μb/(sr MeV)



- The *Q*-value of the reaction acts as a "battery", providing an equivalent potential V^N.
- The finite collision time, as well as recoil effects, provides a width ($\Delta E \sim \hbar/\tau_{coll}$).

Radiation pattern and dipole orientation





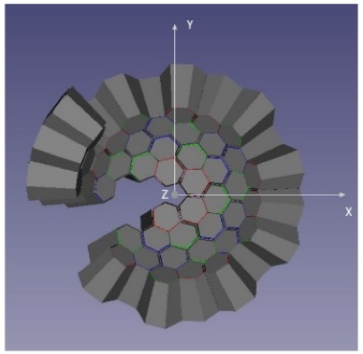
- The angular radiation pattern reflects th
  providing novel insight into the reaction
- The polarization of the emitted photons
  information.

PIAVE-ALPI ACCELERATOR

Search for a Josephson-like effect in the $^{116}Sn+^{60}Ni$ system
PRISMA + AGATA experiment

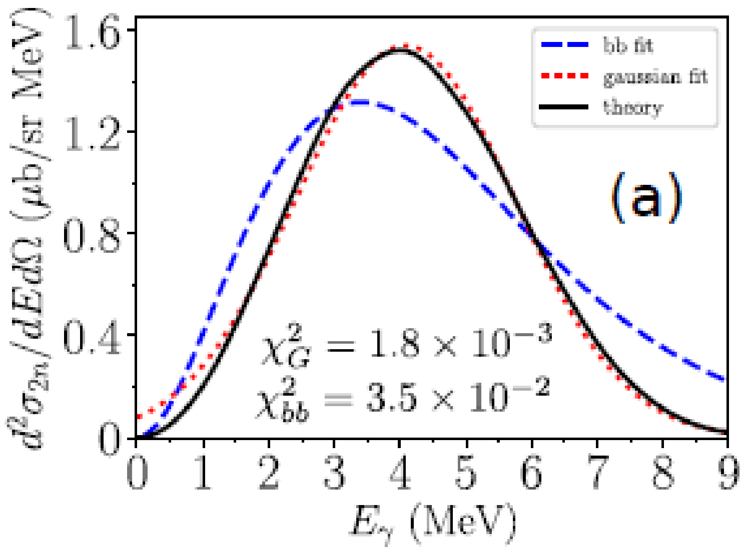
Spokesperson(s): L. Corradi, S. Szilner

116Sn beam PIAVE+ALPI
Elab = 452.5 MeV, I = 3 pnA
Target thickness 300 μg/cm2
Prisma ΔΩ = 30 msr
Prisma θlab = 20°
Agata εγ = 2.8% (at 4 MeV)
Theoretical dσ/dΩ = 30.36 μb/sr
expected rate ≈ 124 γ
coincidences with 62Ni per day



Gamma strength: 2NT versus 1NT channel

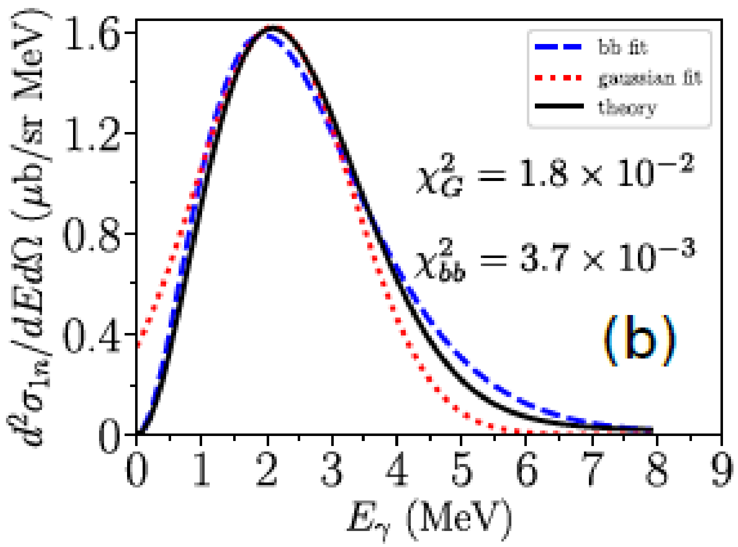
2n-transfer



Gaussian: $\sigma = 1.67$ MeV, $E_0 = 4.08$ MeV

black body: $T = 1.20$ MeV

1n-transfer



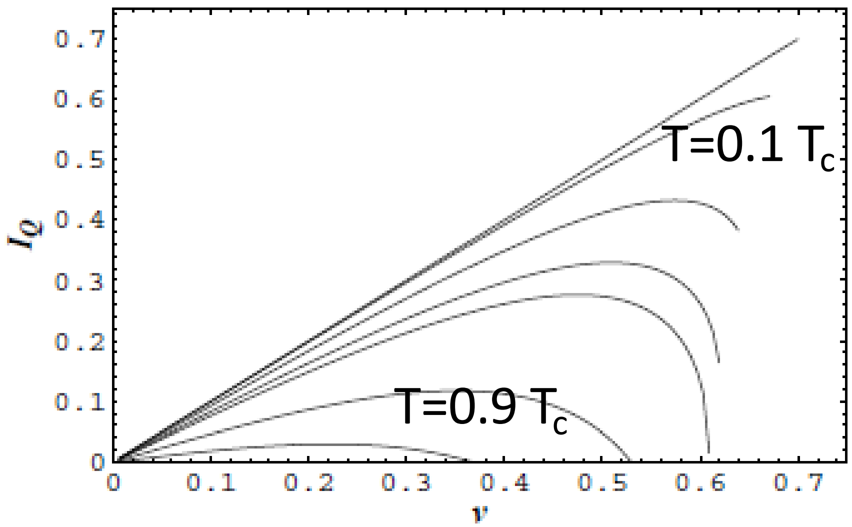
Gaussian: $\sigma = 1.2$ MeV, $E_0 = 2.1$ MeV

black body: $T = 0.69$ MeV

G.Potel et al., PRC 105 L061602 (2022)

Critical depairing velocity

$$v_c = \frac{2\Delta}{m v_F} = \frac{\hbar}{m\xi}$$

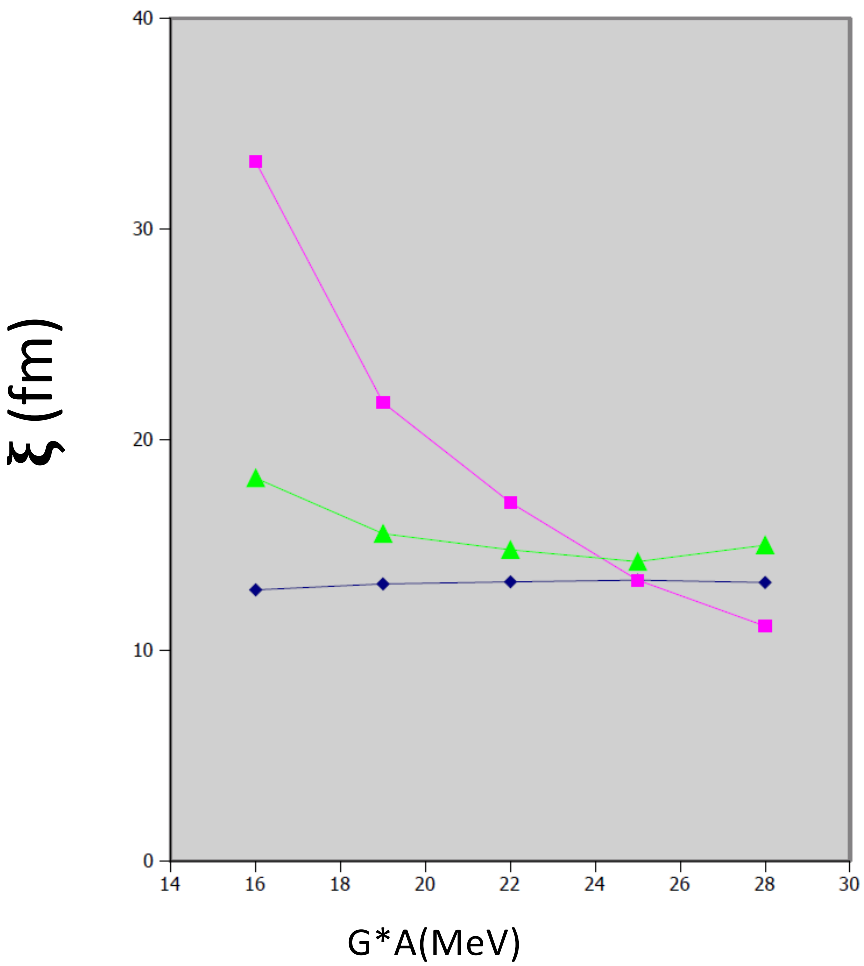


$$v = \frac{(D_0)_c - (R_A + R_b + a)}{\tau_{coll}}$$

$$v < v_c \rightarrow P_2 > P_1$$

$$v = v_c \rightarrow P_2 \sim P_1$$

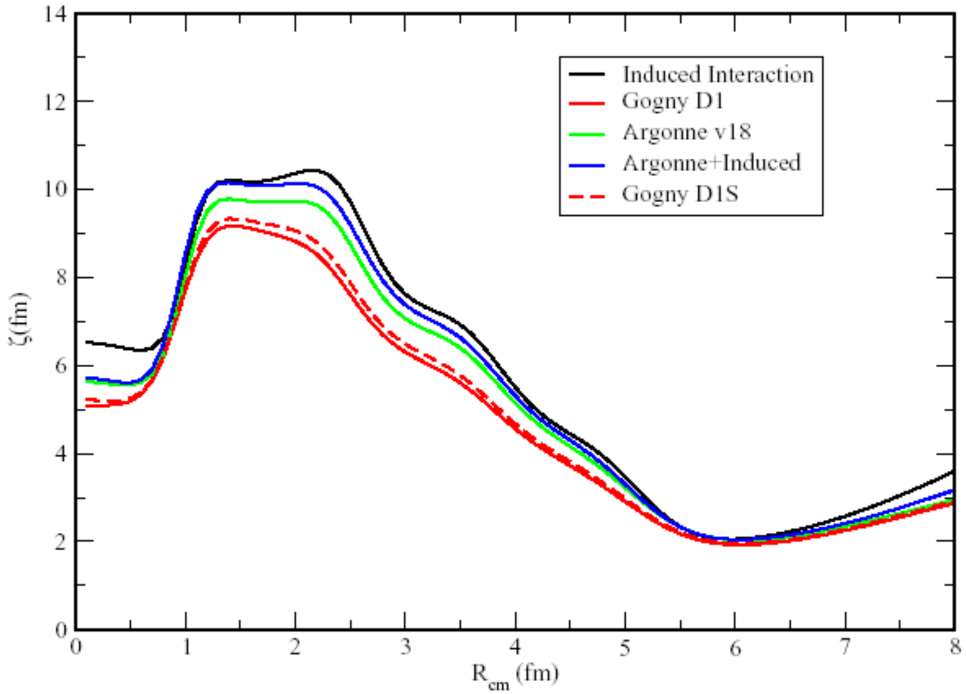
$$v > v_c \rightarrow P_2 < P_1$$



$$v = \frac{(D_0)_c - (R_A + R_b + a)}{\tau_{coll}} = \frac{1}{m}\frac{\hbar}{\xi}$$

Extension of the Cooper pair : almost the same for different forces

$$\xi(R_{CM}) = \left(\frac{\int d^3 r_{12} \, |\kappa(R_{CM}, r_{12})|^2 r_{12}{}^2}{\int d^3 r_{12} |\kappa(R_{CM}, r_{12})|^2} \right)^{1/2}$$



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Collaborators:
F. Barranco (Sevilla)
G. Potel (LBL,USA)

A legacy of Ricardo Broglia