Search for E1 strength below the Giant Dipole Resonance from zero to finite temperature in Ni isotops at IFIN-HH and NLC-CCB facilities

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Italy

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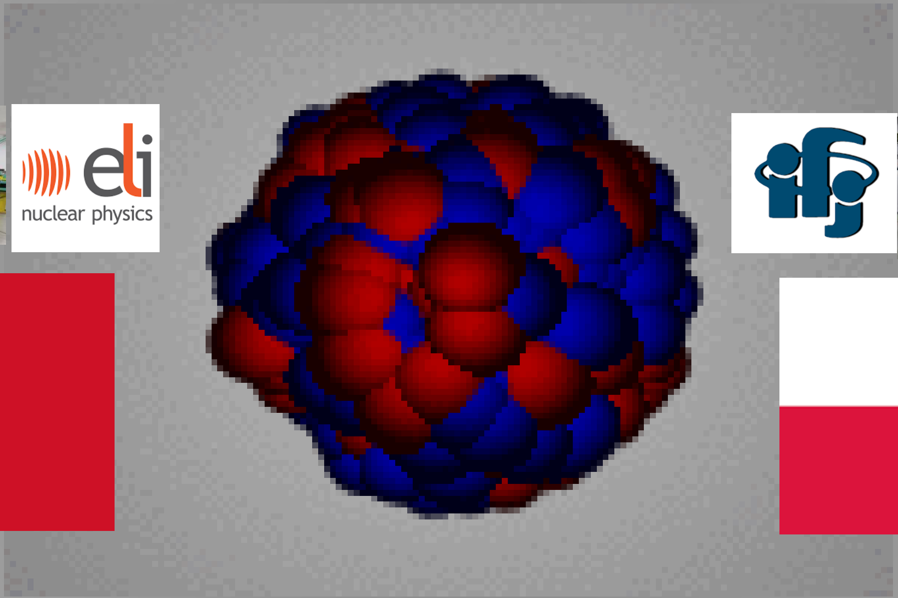
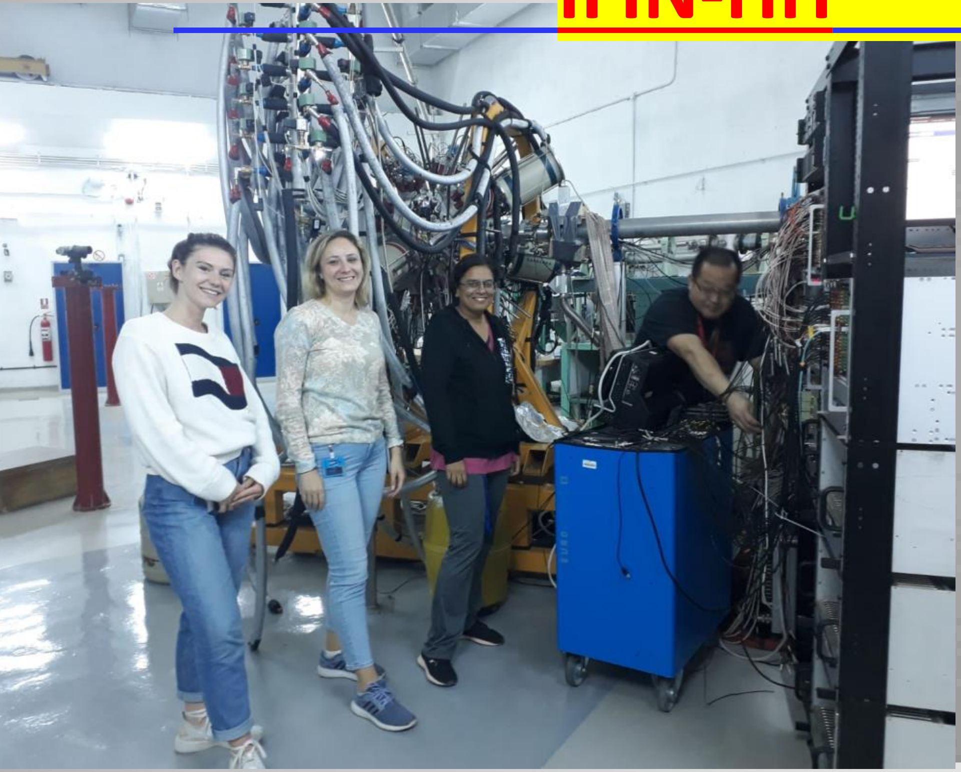
Oliver Wieland



One scientific Question studied in 2 different experimental facilities for a complementary research project

Search for E1 strength below the Giant Dipole Resonance from zero to finite temperature in Ni isotops at IFIN-HH and NLC-CCB facilities

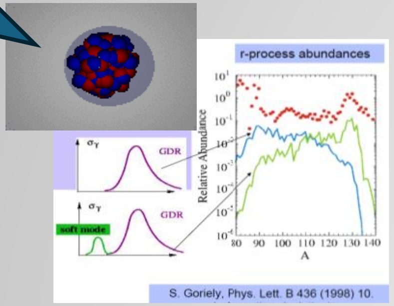


In total 120 overall project partecipants

80 Persons @ IFIN HH+ ELI NP
11 Persons took Eurolabs support

40 Persons @ CCB + IFJ
6 Persons took Eurolabs support.

Why to study resonances in nuclei around the particle separation energy **below the Gian Dipole Resonance** in **Neutron rich Nuclei** ?



Roca-Maza and Paar,
Prog. Part. Nucl. Phys. 101, 96 (2018)

❑ has an impact on the r-**process** nucleosynthesis

E1 and M1 excitations

⬇

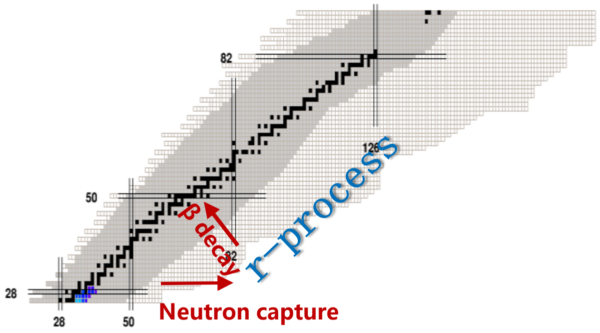
γ-ray strength function

⬇

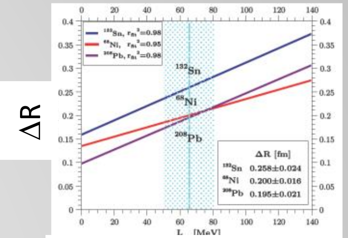
Neutron capture cross section and rates

⬇

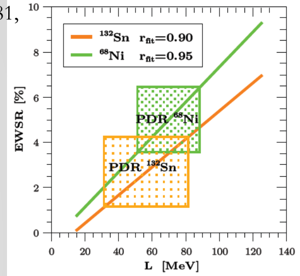
« Astro» Physics



➡ «Pure» Nuclear Physics



*Carbone et al. Phys. Rev. C 81, 041301(R) (2010)



❑can be used for **Neutron skin thickness** determination

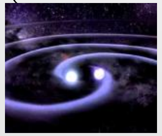
❑ can be used for determination of **Nuclear symmetry energy***

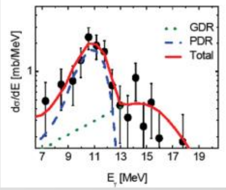
(*Data on n-rms radius constrain the isospin-asymmetric part of the EOS of nuclear matter)

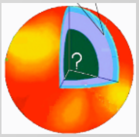
Please note

Relation between neutron skin and neutron stars (both built on n-rich nuclear matter so that one-to-one correlations can be drawn)

Relation between EOS and neutron star mergers







Stellar environment → unstable n-rich nuclei where it is

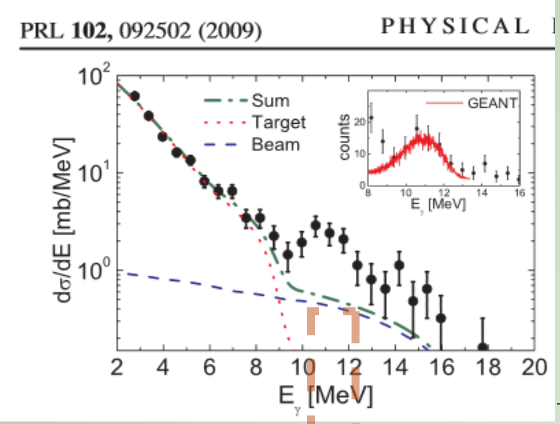
difficult to extrapolate from stable to unstable nuclei with theory

We need Experimental DATA !!!

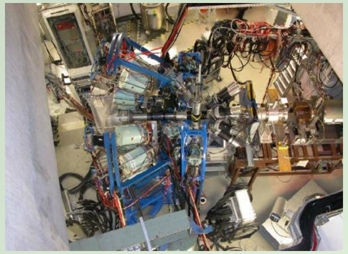
History:

It was shown in 2004 (2009) at GSI and confirmed in 2018 at RIKEN-RIBF that with RVPS at 600*A*MeV
one can measure successfully **Pygmy-strength** around (also above) the threshold **in EXOTIC n-rich Ni NUCLEI !**

O. Wieland et al. PRL 102, 092502 (2009)



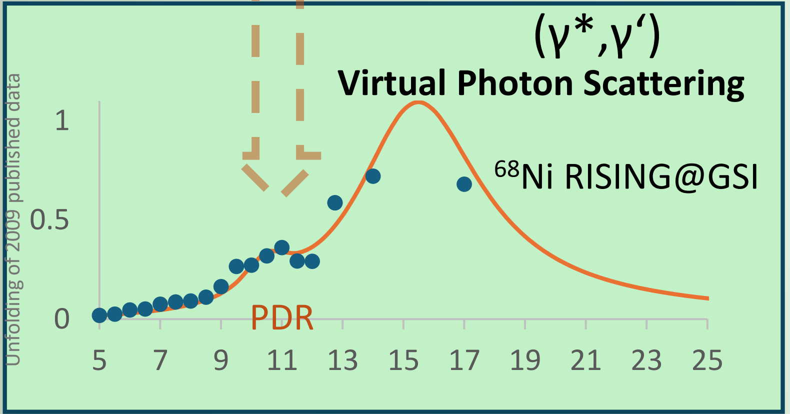
^{68}Ni



EuroBall-HECTOR

$$\frac{d\sigma_{C\gamma}}{dE_\gamma} = RF\left\{\frac{1}{E_\gamma} N_\gamma(E_\gamma)\cdot\sigma_\gamma(E_\gamma)\cdot R_\gamma(E_\gamma)\right\}$$

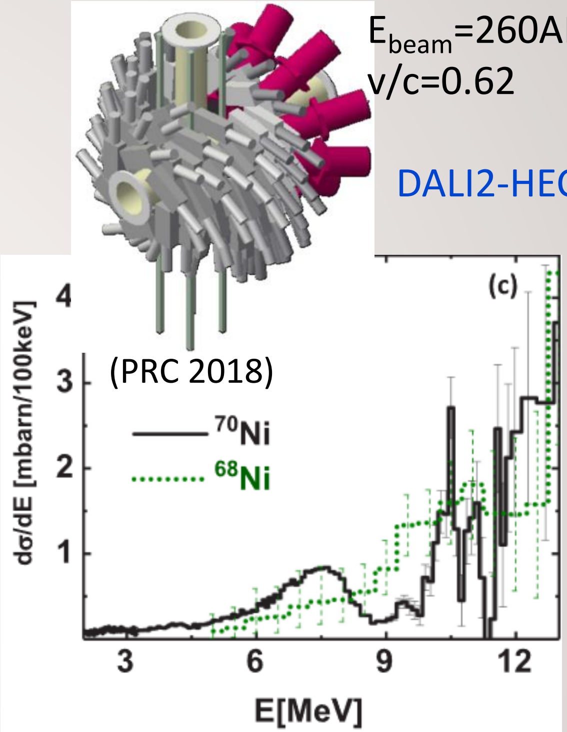
E_{beam} =600AMeV



^{70}Ni

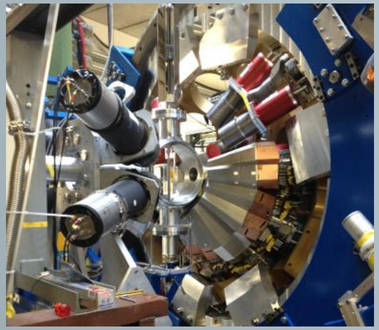
RIKEN-RIBF
E_{beam}=260AMeV
v/c=0.62

DALI2-HECTOR+

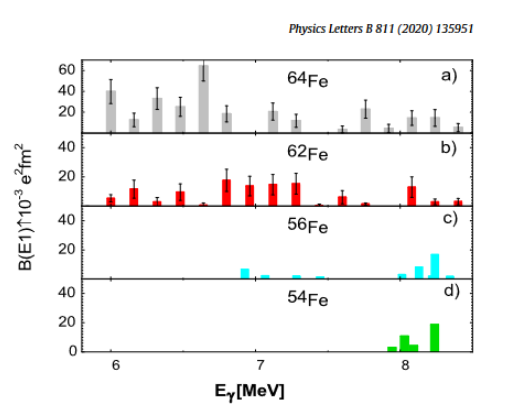


O. Wieland et al. PRC 98, 064313 (2018)

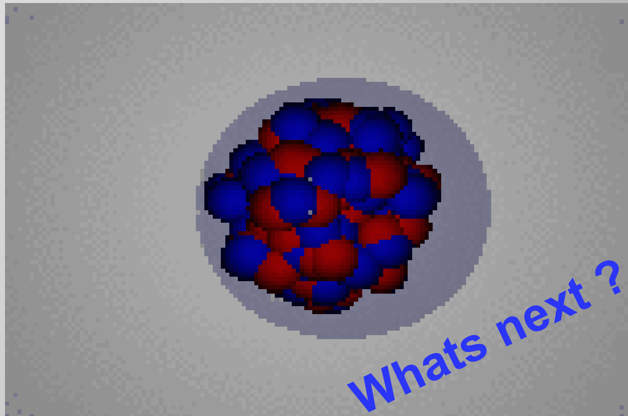
R. Avigo, O. Wieland et al. Physics Letters B Volume 811, 2020, 135951



AGATA-HECTOR+
@GSI (PLB 2020)
E_{beam} =400AMeV
Only
3 phonon model
can explain



^{64,62}Fe

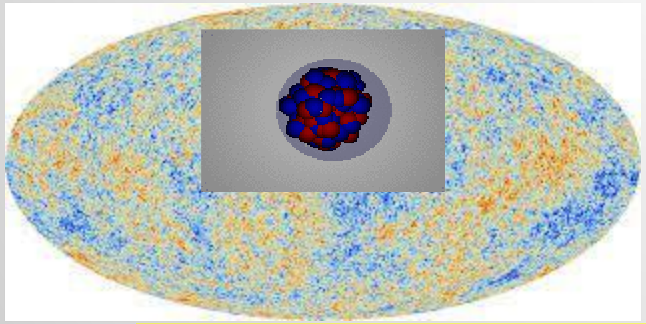


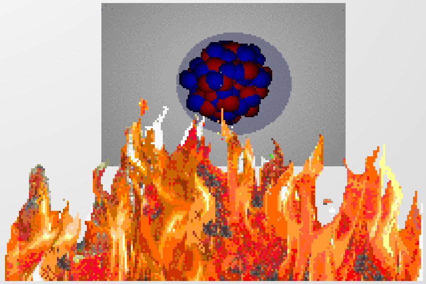
Question

- → What happens to the Pygmy Resonance when going from GS to **E*** (Temperature) and **Rotation** ?
- → The Pygmy Resonance will **form** and **survive** inside a rotating **CN** ?
- → Adding **deformation**, with increas of **radius**, **thermal fluctuations** ?
- → Change of proton distribution/radius & neutron distribution/radius ?
- → Change in **skin thickness** ??
- → Emissing of LCP, neutrons and γ ?

- **The Idea:** **Measure From « 0 to *HOT* *PYGMY* »**

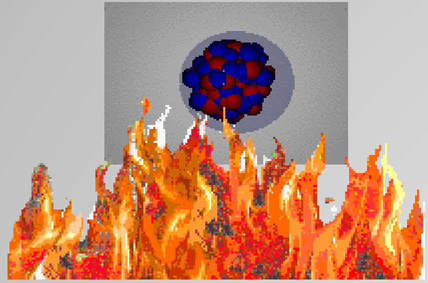
photo absorption for long isotopic chain from ground state to finite temperature



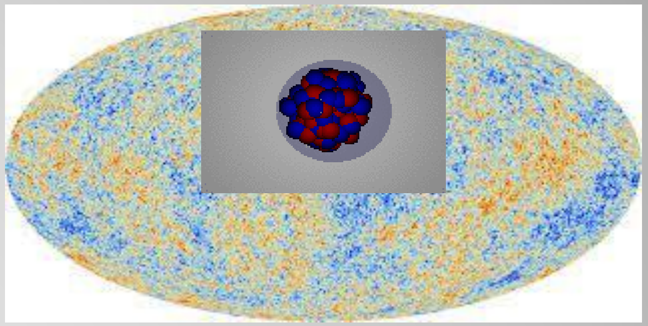


One scientific Question to be answered in two different laboratories with 2 different Methods !

ADDITIONAL THEORY:



Predictions 1



The global **temperature** (mass) dependence of the proton R_p , neutron R_n radius and skin thickness of the Ni isotopes

PHYSICAL REVIEW C 95, 024314 (2017) A. N. Antonov et al.

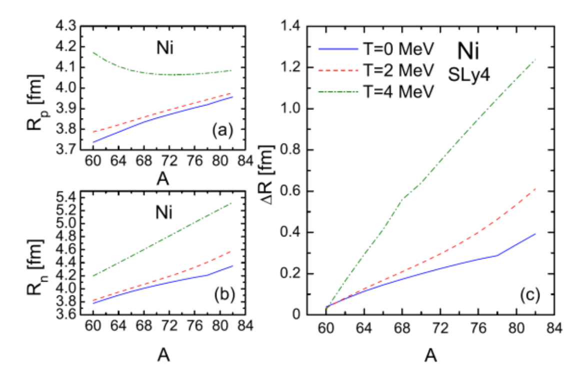


FIG. 4. Mass dependence of the proton R_p (a) and neutron R_n (b) radius of the Ni isotopes ($A = 60$–82) calculated with the SLy4 interaction at $T = 0$ MeV (solid line), $T = 2$ MeV (dashed line), and $T = 4$ MeV (dash-dotted line). Neutron skin thickness ΔR as a function of A (c) for the Ni isotopes.

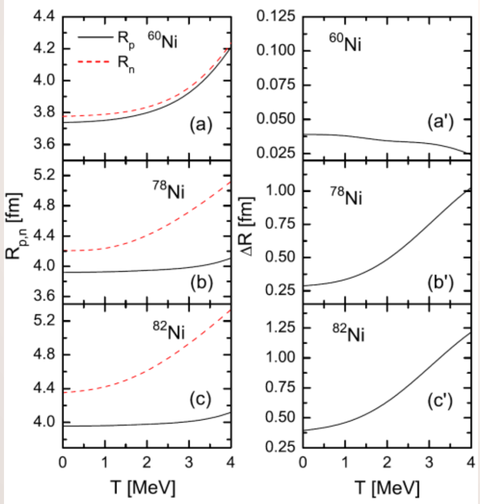
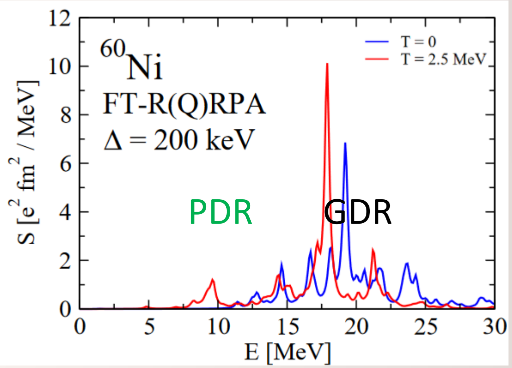


FIG. 7. Left: Proton R_p (solid line) and neutron R_n (dashed line) radius of ^{60}Ni, ^{78}Ni, and ^{82}Ni isotopes with respect to the temperature T calculated with SLy4 interaction. Right: Neutron skin thickness ΔR for the same Ni isotopes as a function of T.

QUESTION : Skin thickness and r_n grows faster with Temperaturet than r_p , can this grow survive fluctuations and deformation ?)

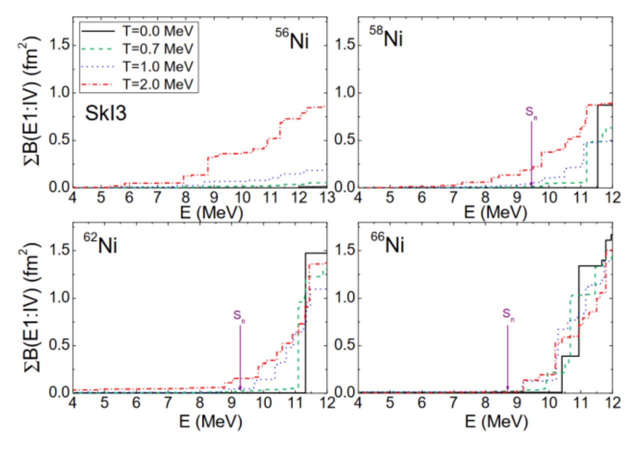
Elena Litvinova



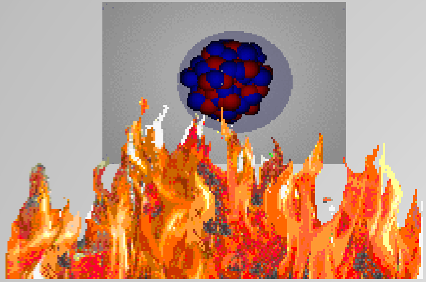
At ZERO temperature only little PDR Strength is present !

It grows with Increasing Temperature and with Neutron excess

Esra Yüksel



ADDITIONAL THEORY:



Predictions 2

The cumulative sum of the isovector dipole strength (in units of fm^2) in nickel isotopes below 12.0 MeV.

SLy5	$T = 0.0$ MeV	$T = 0.7$ MeV	$T = 1.0$ MeV	$T = 2.0$ MeV
^{56}Ni	0.013	0.0742		
^{58}Ni	0.301	0.230	0.310	0.778
^{62}Ni	0.628	0.570	0.538	0.828
^{66}Ni	0.670	0.641	0.626	0.935

INCREASE between T = 1 and 2 MeV

E. Yüksel[1], G. Colò[2,3], E. Khan[4,a], and Y.F. Niu[5,6]
Eur. Phys. J. A (2019) 55: 230
DOI 10.1140/epja/i2019-12918-8

«thermal unblocking, threshold effect»

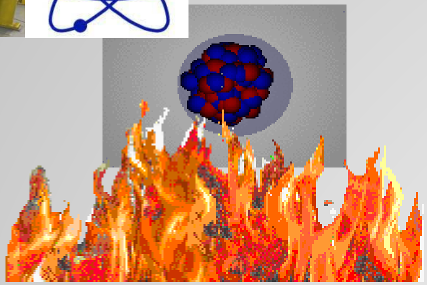
Eur. Phys. J. A (2019) **55**: 230

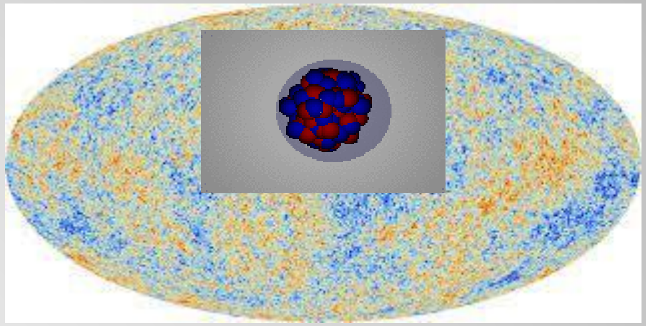
Table 2. The critical temperature (T_c) values (in MeV) for the selected nickel isotopes using SkI3 and SLy5 interactions.

	SkI3	SLy5
^{58}Ni	0.84	0.69
^{62}Ni	1.01	0.93
^{66}Ni	0.82	1.0

Critical Temperature where
properties are changed and differ measurably from Ground State properties ,
pairing correlations vanish and
occupation probabilities change strongly

ADDITIONAL EXPERIMENT:





COLD nucleous→ stable target !

How we want to **built** a nucleus with **ZERO** and

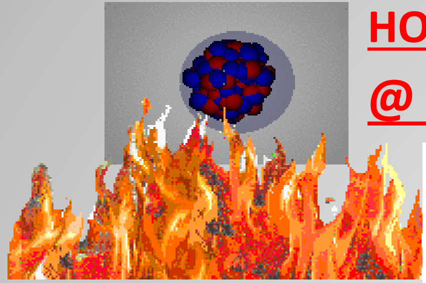
Finite temperature and spin ?

With **fusion evaporation reactions** and the measurement of the γ **decay** from the **Compound nucleus (CN)** system (Measure and calculate Statistical decay cascade γ and of particles (mainly n, p, alpha)). **T>0**

With Stable Targets in the ground state and as pure as possible virtual photon excitation

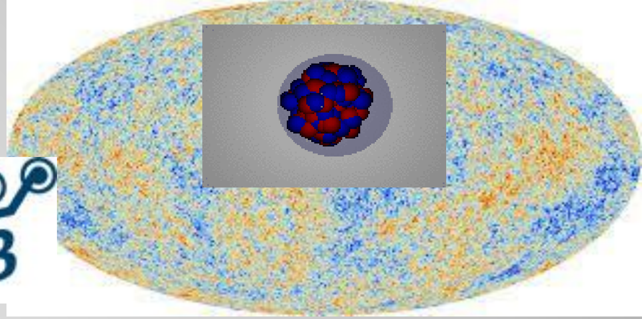
with proton high energy beam. Direct Virtual Photon excitation. T=0

ADDITIONAL EXPERIMENT:



HOT PDR in $^{56,60,62,64,66}Ni$ CN @ IFIN

GROUND STATE (zero T) PDR in $^{58,62,64}Ni$ Target @ CCB



Z = 28

^{56}Ni	^{57}Ni	^{58}Ni	^{59}Ni	^{60}Ni	^{61}Ni	^{62}Ni	^{63}Ni	^{64}Ni	^{65}Ni	^{66}Ni	^{67}Ni	^{68}Ni
6.1 d	36.0 h	68.08	$8\cdot10^4$ y	26.22	1.14	3.63	100.8 y	0.93	2.52 h	54.6 h	21 s	29 s

N = 28

N/Z: 1, 1.07, 1.14, 1.21, 1.29, 1.36

N/Z	1	1.07	1.14	1.21	1.29	1.36
Reaction	$^{32}S + ^{24}Mg$		$^{34}S + ^{26}Mg$	$^{36}S + ^{26}Mg$	$^{16}O + ^{48}Ca$	$^{18}O + ^{48}Ca$
	N=Z		N=Z+4n	N=Z+6n	N=Z+8n	N=Z+10n

Neutron excess

T1 T=0 T=0 T=0,T1,T2 T1,T2

Ebeam 60-90 MeV

E* 30-60 MeV

T≈1 - 2 MeV,

similar formation and angular momentums, no preequilibrium (LCP measurement)

@IFIN Magurele Bucharest

complementary measurements (p,p',γ) at T=0, polarisation and go also above threshold @CCB Krakow

ADDITIONAL EXPERIMENT:

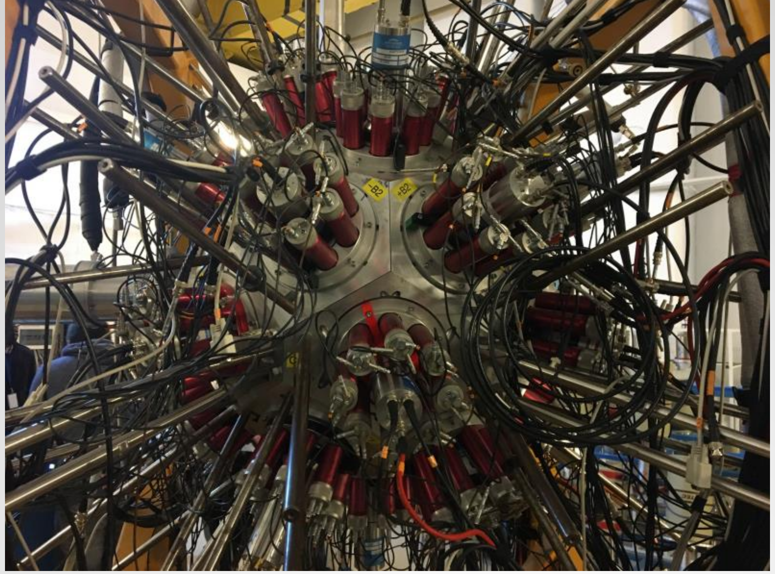
Experimental SETUP1 (**IFIN**)

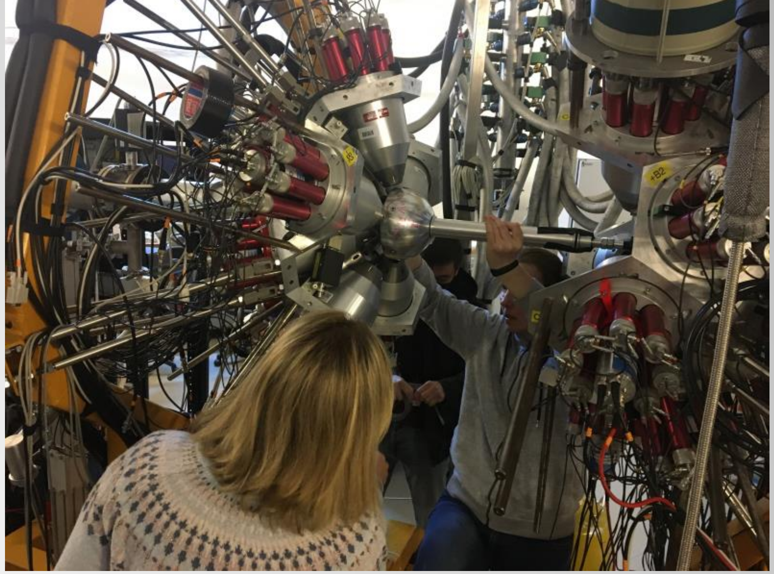
for T>0

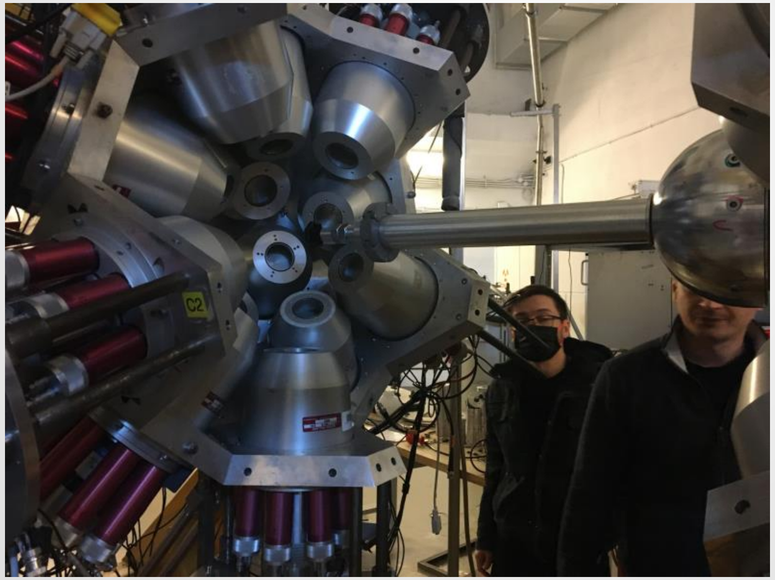
ELIFANT-GG@IFIN 2022
And recently 2024

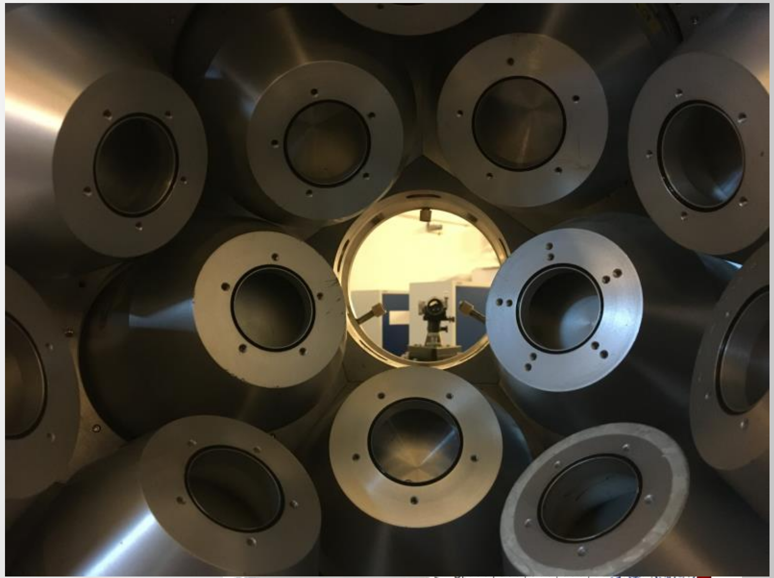
21 Bromide* scintillator Detector-array with AC-shield and 4 HPGe

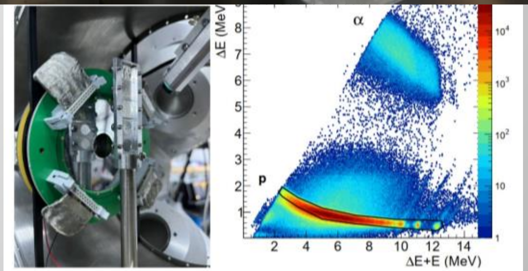
*
11 3x3 inch $LaBr_3:Ce$
10 3x3 inch $CeBr_3$









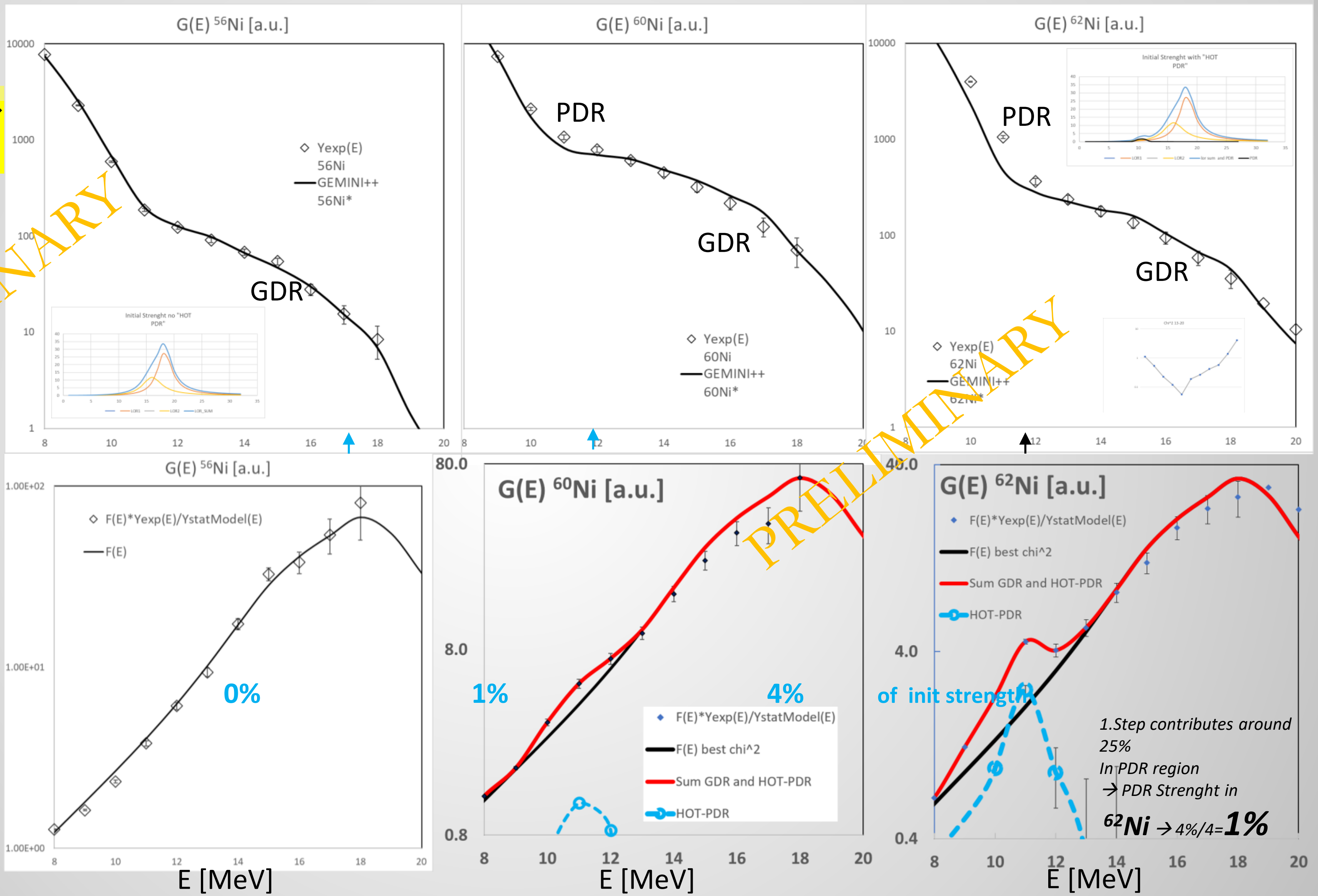


A setup for high-energy γ-ray spectroscopy with the ELI-NP large-volume $LaBr_3:Ce$ and $CeBr_3$ detectors at the 9 MV Tandem, S.Aogaki et. al., Nucl. Instrum. Methods Phys. Res. A, 1056, 168628 (2023)

ADDITIONAL RESULTS:

- **Analysis 2022**

Time gated γ-spectra → and stat. model

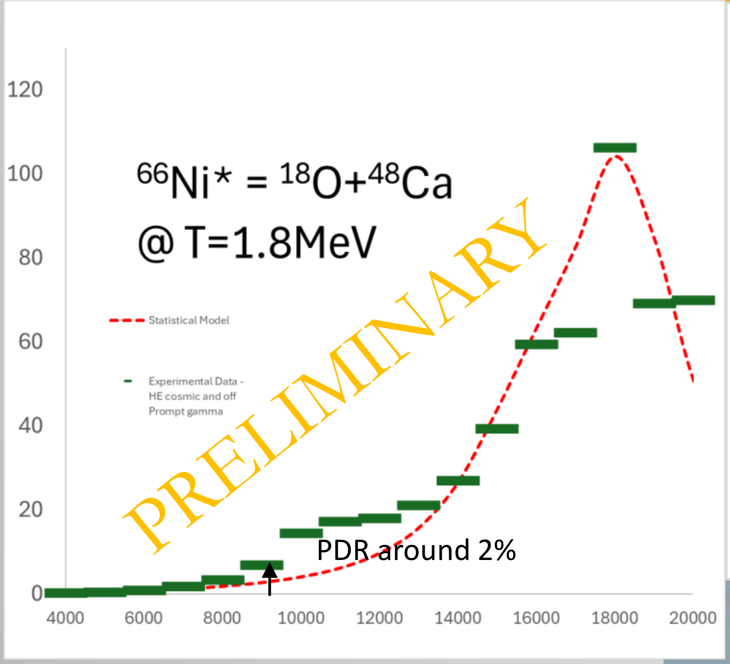


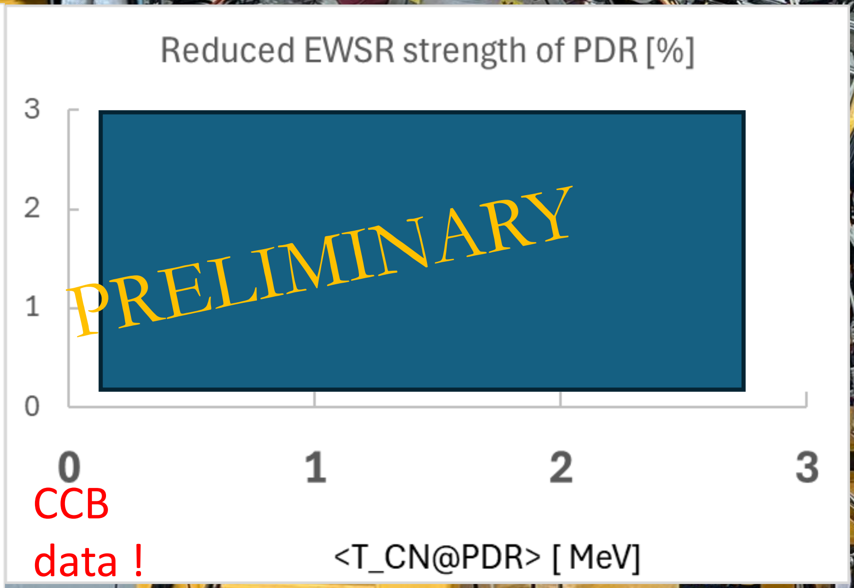
"Extra yield in hot Ni isotopes below the Giant Dipole Resonance",
O. Wieland, et al. Il Nuovo Cimento C, 47, 24 (2024)

REMARK: To reproduce the lower extra yield effect by deformation (angular momentum) an unphysical one is needed and additionally the GDR part will not be reproduced anymore

Preliminary Result from 2024 exp.

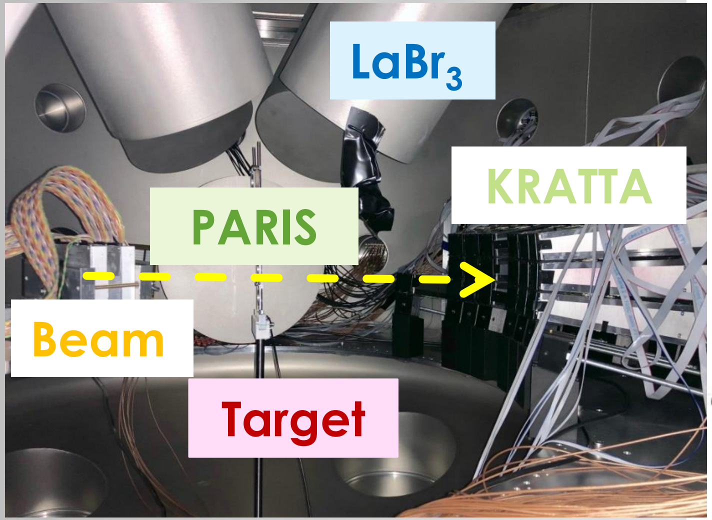
Hot extra Yield bellow GDR in neutron rich (exotic) ^{66,64}**Ni at different T**

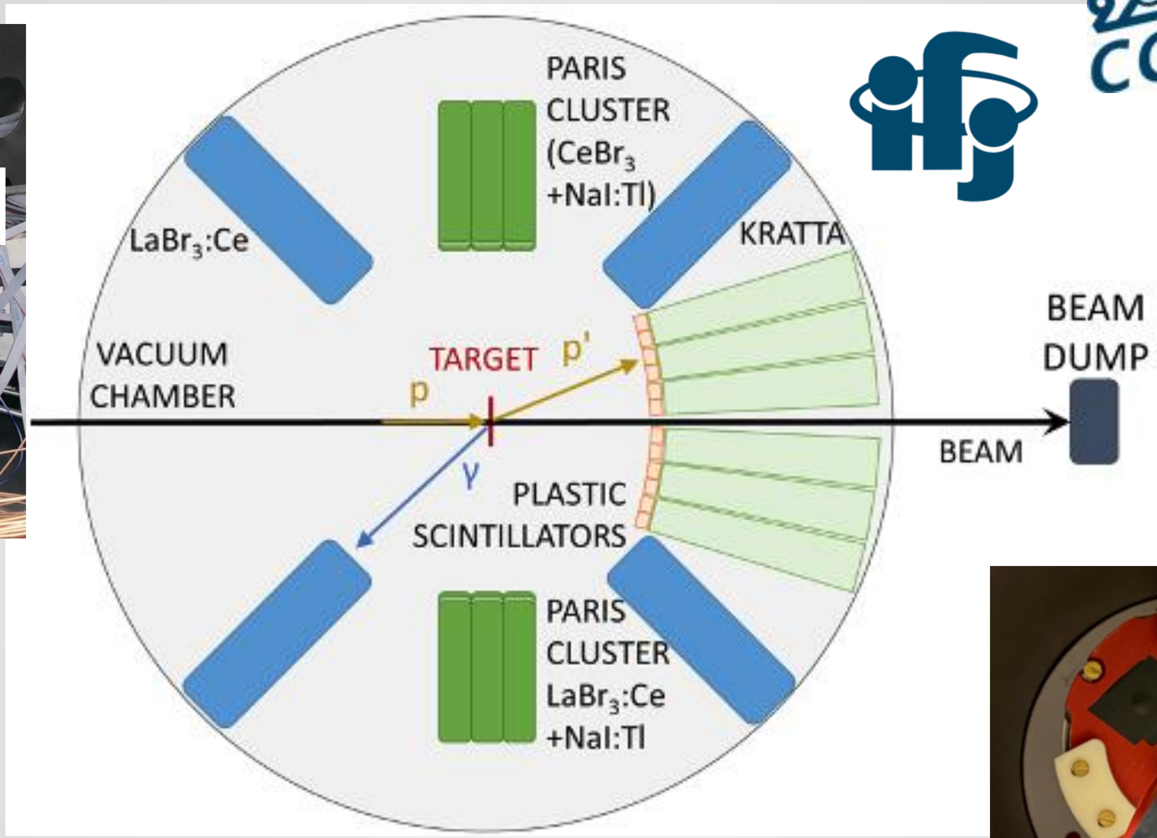


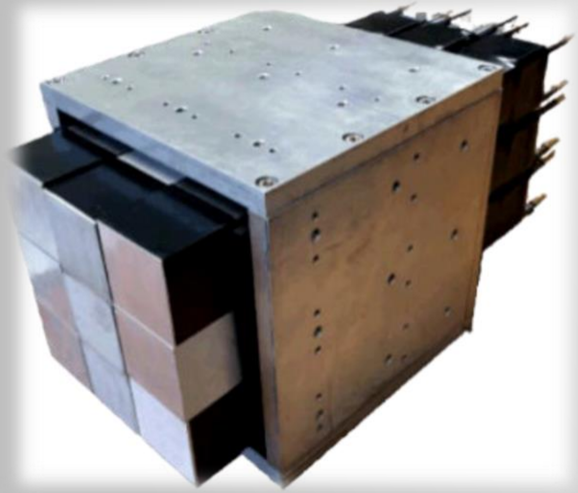


Temperature (&A) dependance

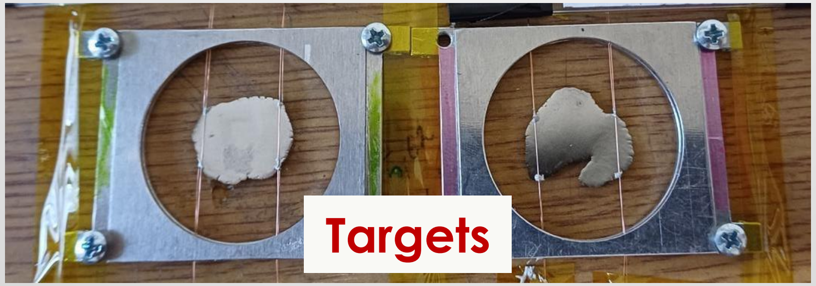
Experimental SETUP2 **(CCB) for T=0**

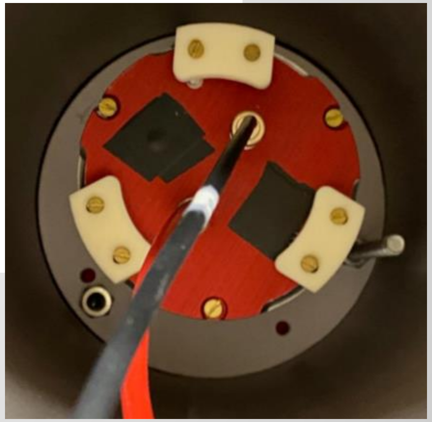






PARIS DETECTOR

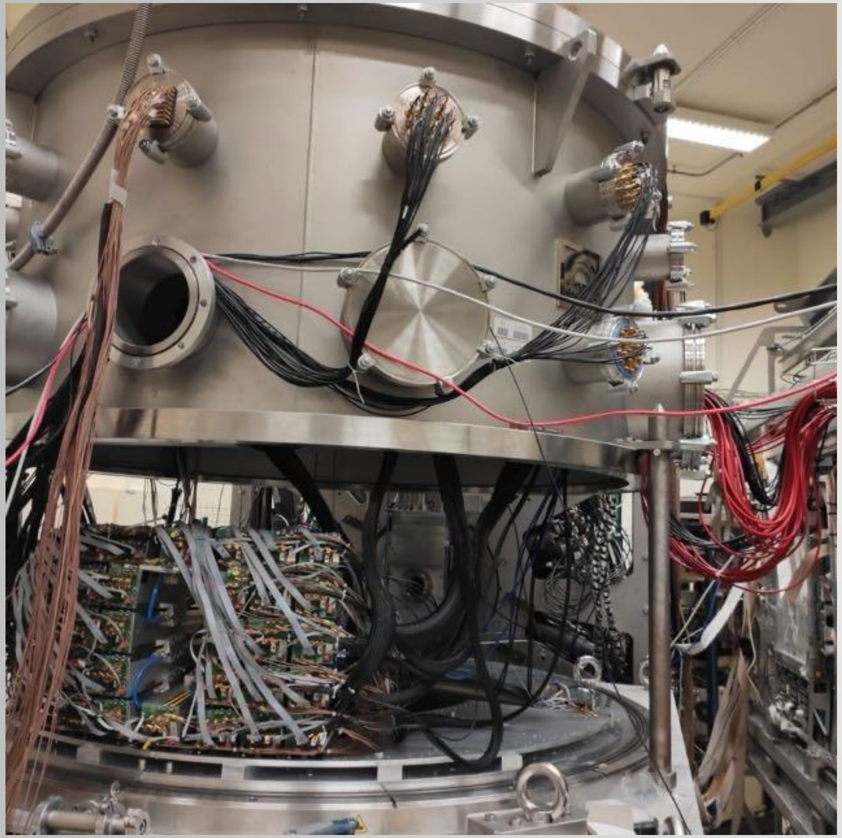


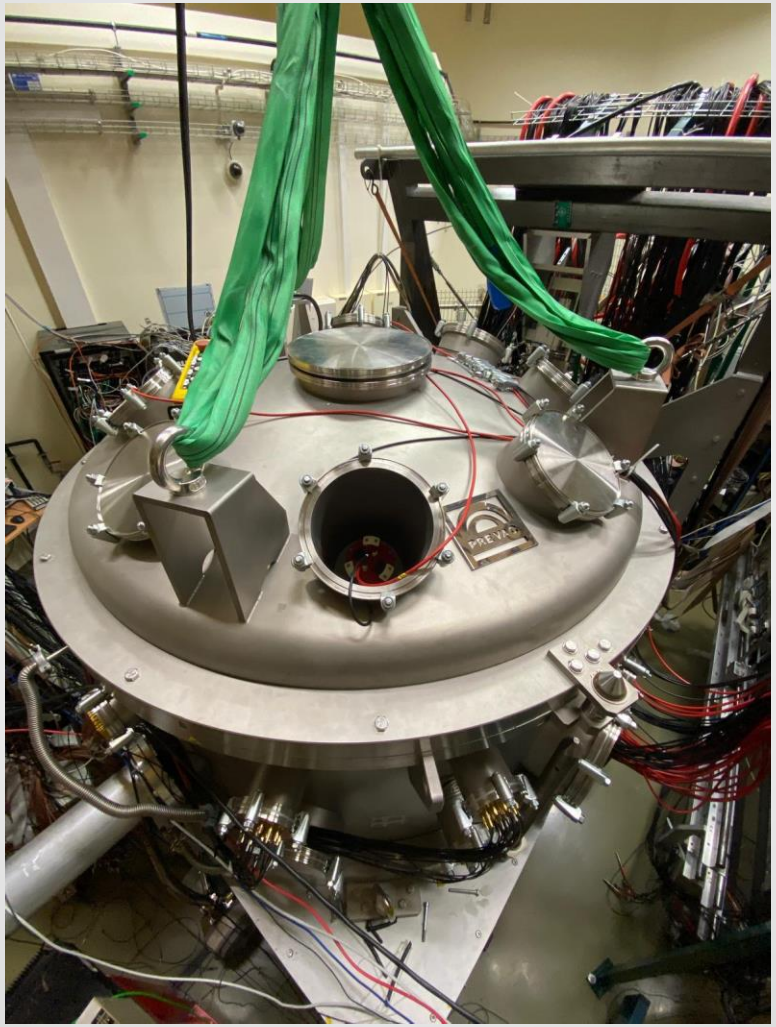


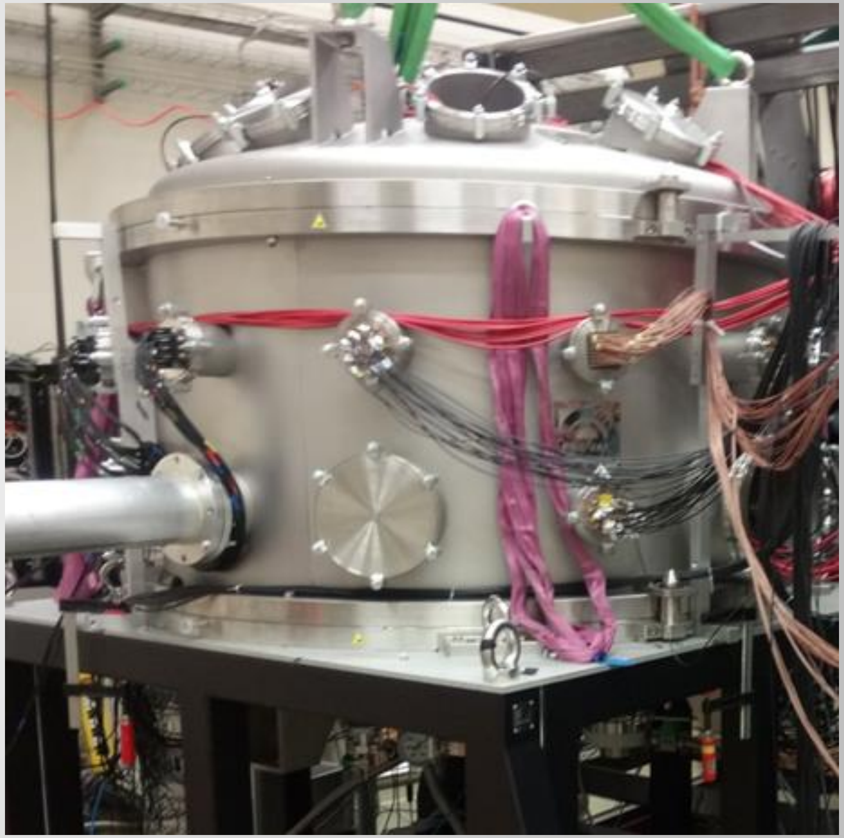
4 $LaBr_3$:Ce

Gamma decay to the ground state from the excitations above the neutron threshold in the 208Pb(p,p' gamma) reaction at 85 MeV
B Wasilewska, et al. Physical Review C 105 (1), 014310 2022

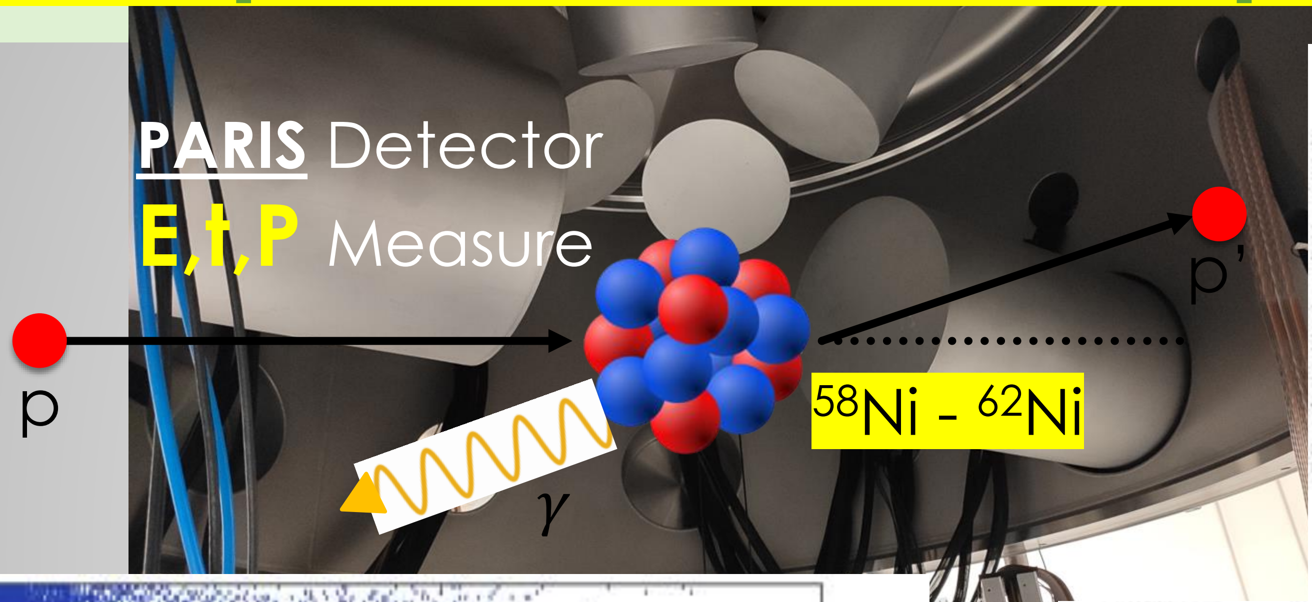
Experimental SETUP **(CCB) for T=0**

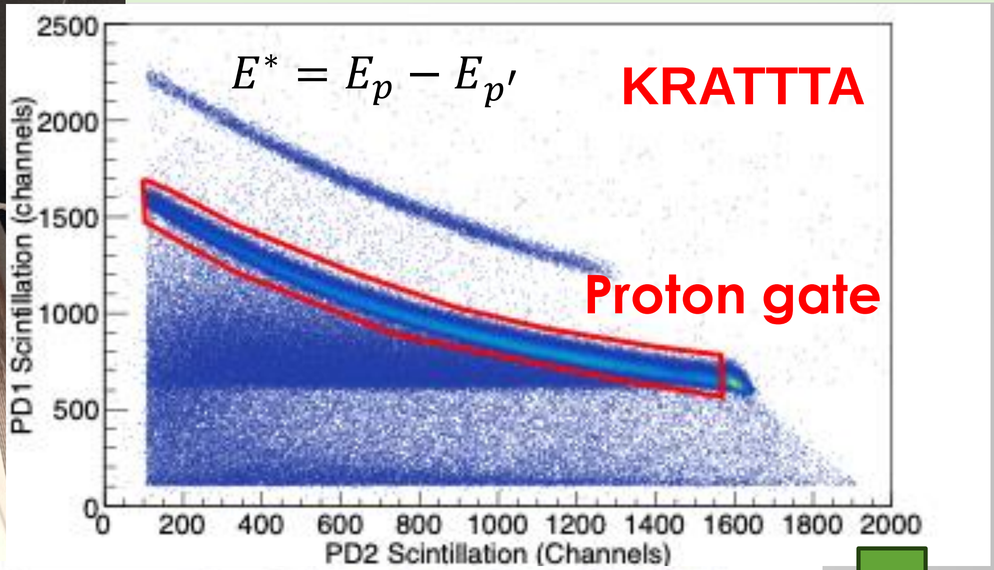


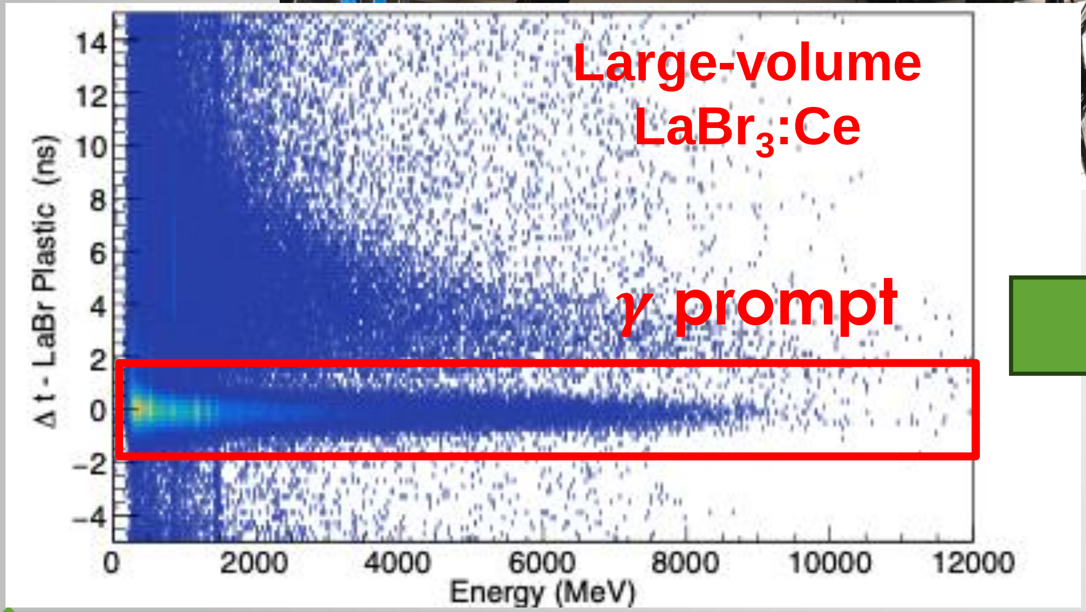


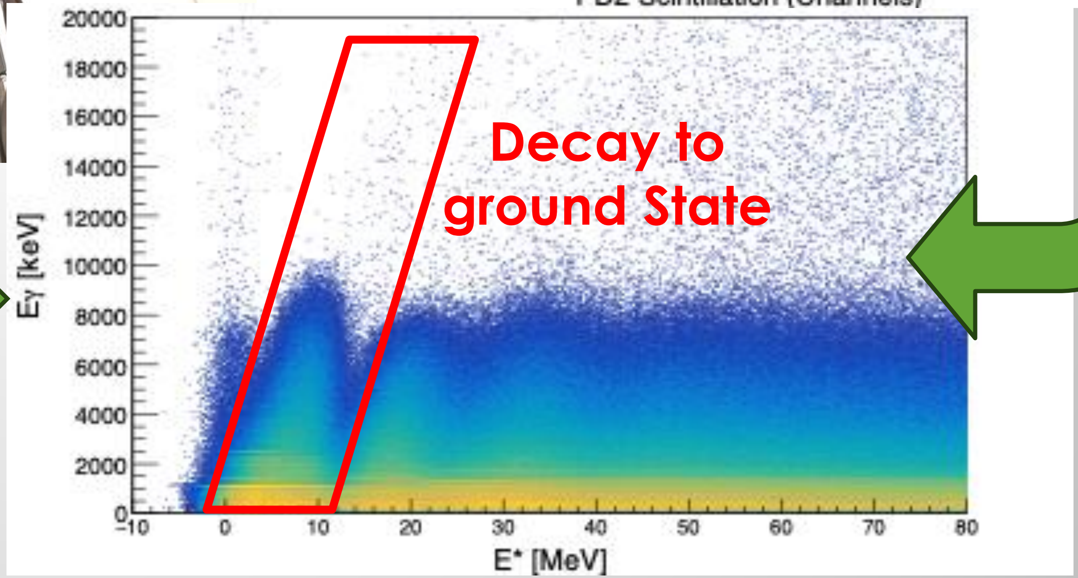


The experimental technique

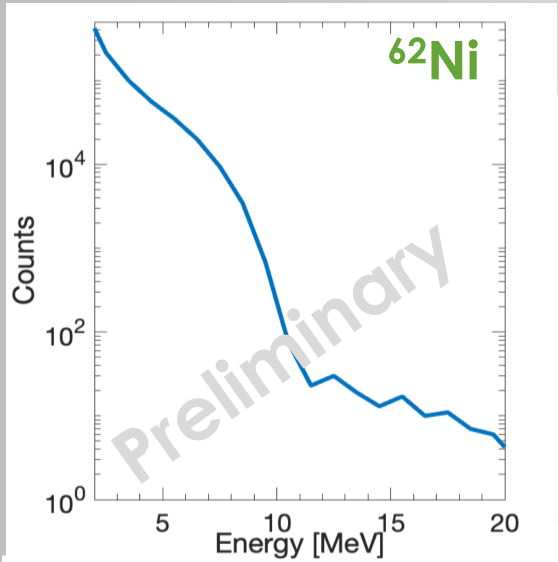


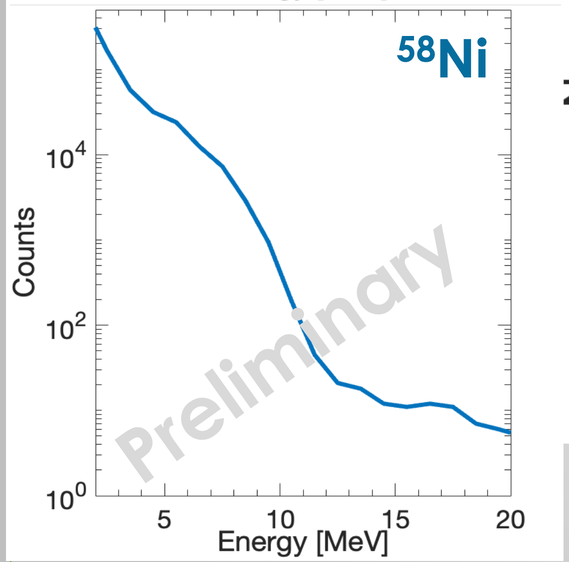


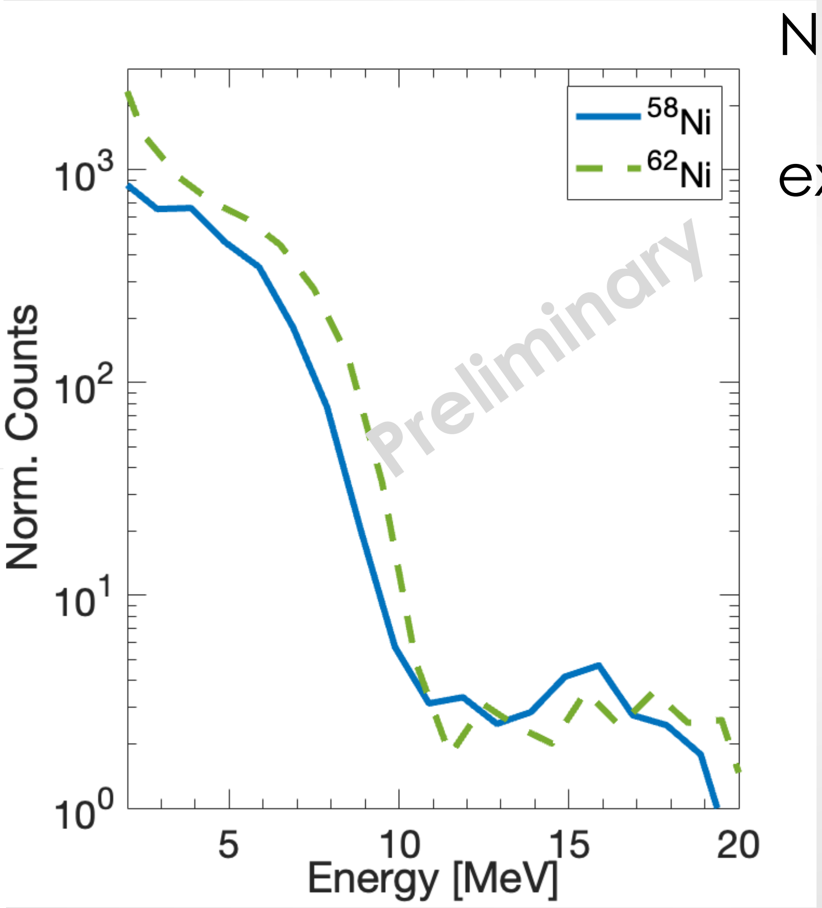




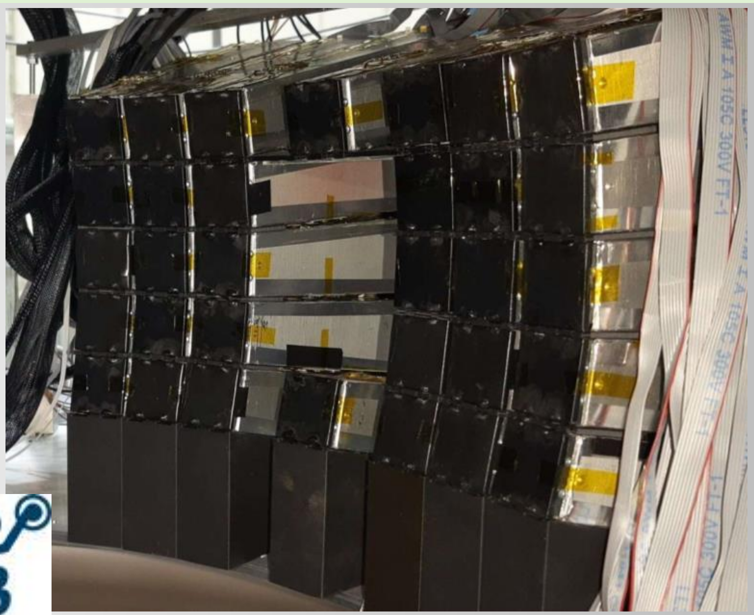
Results of the $^{58,62}Ni$ Experiement (CCB) for T=0







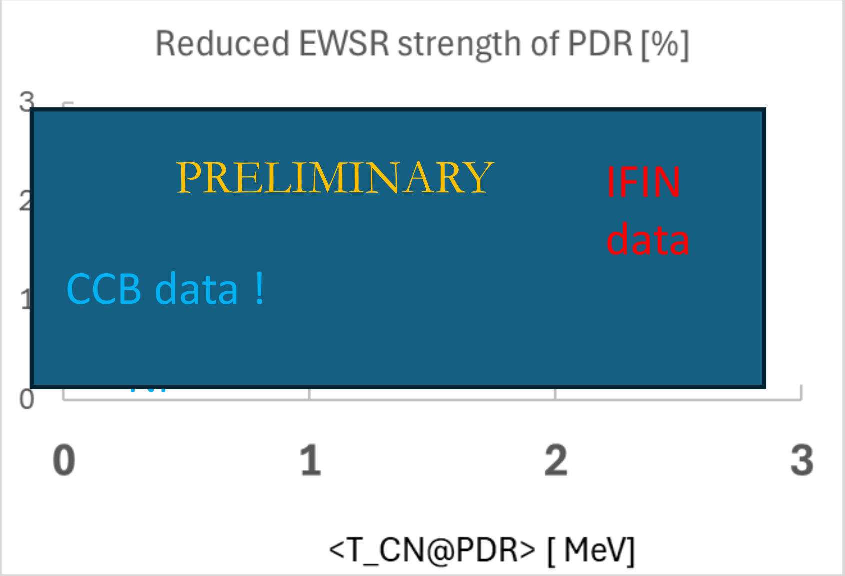
^{62}Ni
N/Z = 1.21
Pygmy expected

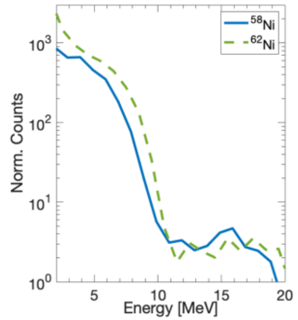


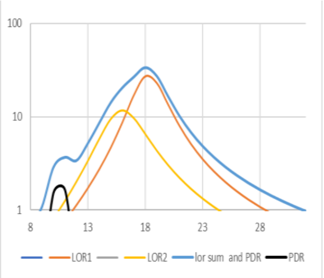
^{58}Ni
N/Z = 1.07
No Pygmy or negligible Pygmy expected

- **Results**

- evidence of a possible **extra** (initial) strength at **T=0 and T>0**
- does not arise from deformation (angular momentum) effects or n
- located bellow GDR and with Strength around 1-8 % of total GDR-EWSR
- appears **not strong in N=Z nucleus,** but (only) in N=Z+xn nucleus in ground state and growing with excitation energy (CN Temperature up to 2 MeV) in rotating nucleus formed in fusion evaporation reaction







Temperature (&A) dependance

Theory: Must include rotation and angular momentum in predictions

Cold PDR has STRONG impact on stellar processes, neutron star collisions, mergers,… :

What is the total ASTROPHYSICAL impact of

HOT +COLD PDR ?

→ WHATS NEXT IN 2026,27,28,..:

→ Go further, different isotopic CHAIN and do things better
Better Resolution, Better Residues detection,
to enter in astrophysical region and benchmark Theory

Go further…
proton rich side …? Proton skin ??

WORK IN PROGRESS

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