NEW RESULTS ON PROTON CAPTURES ON NEON ISOTOPES AT LUNA

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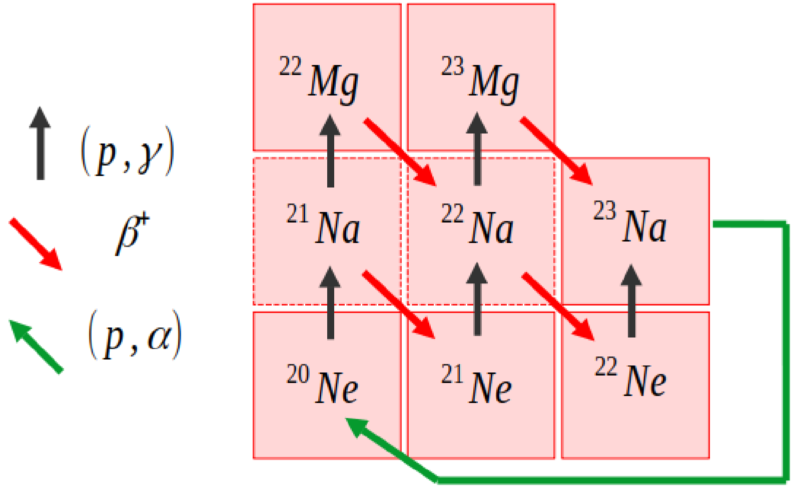
16/09/2024

THE NeNa CYCLE



NeNa cycle

Key Astrophysical sites:

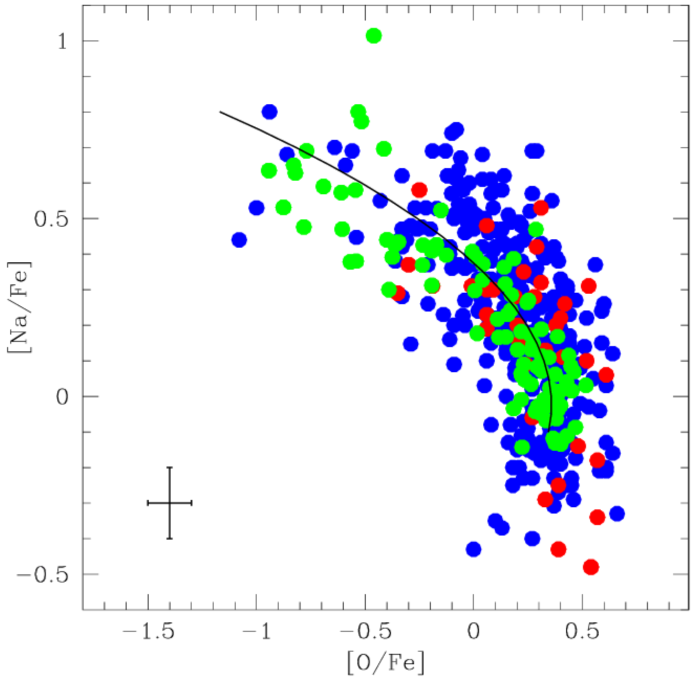
RGB stars (Red Giant Branch)

AGB stars (Asymptotic Giant Branch)

Novae

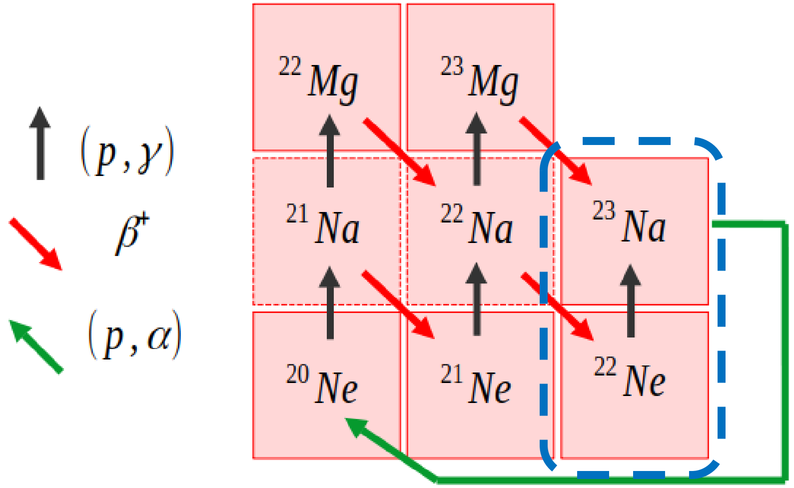
Massive stars

A better understanding of this cycle can help solving the puzzle of the Na-O anticorrelation Globular Glusters



Through the $^{23}Na(p,\gamma)^{24}Mg$ reaction, it links to MgAl cycle influencing also Mg and Al isotopes production

THE NeNa CYCLE



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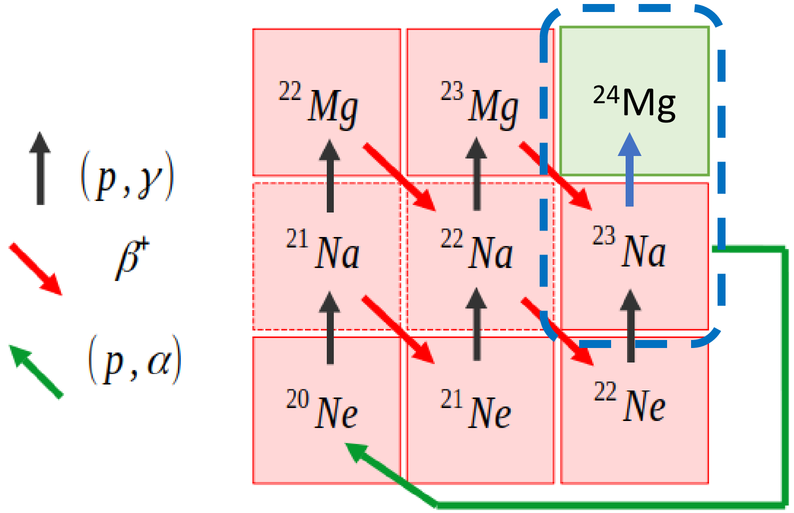
$^{22}Ne(p,\gamma)^{23}Na$ studied in two different experiments

- Three resonances measured directly and
- Direct capture cross section below 400 keV observed for the first time

Cavanna et al., PRL115(2015)252501
Ferraro et al., PRL121(2018)172701
Takacs et al., PRC109(2024)064627

THE NeNa CYCLE



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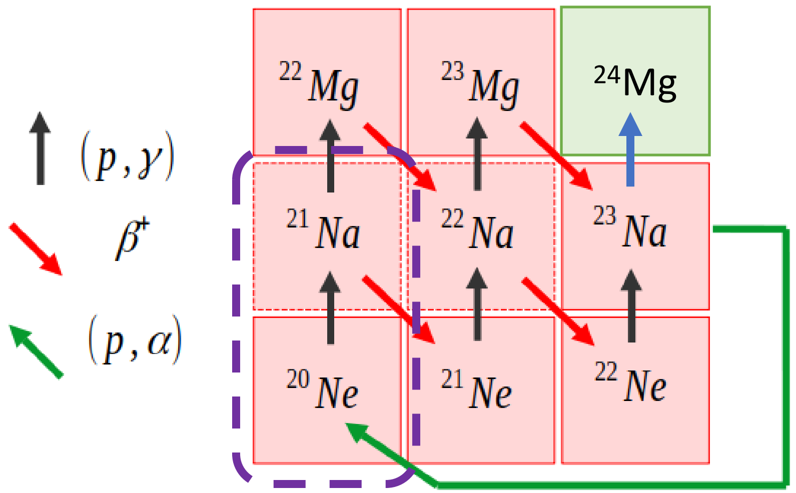
Cavanna et al., PRL115(2015)252501
Ferraro et al., PRL121(2018)172701
Takacs et al., PRC109(2024)064627
Slemer et al., MNRAS465(2017)4817

^{23}Na(p,γ)^{24}Mg → three resonances measured with improved precision wrt literature

Boeltzig et al., PLB 705(2019)122

THE $^{20}Ne(p,\gamma)^{21}Na$



NeNa cycle

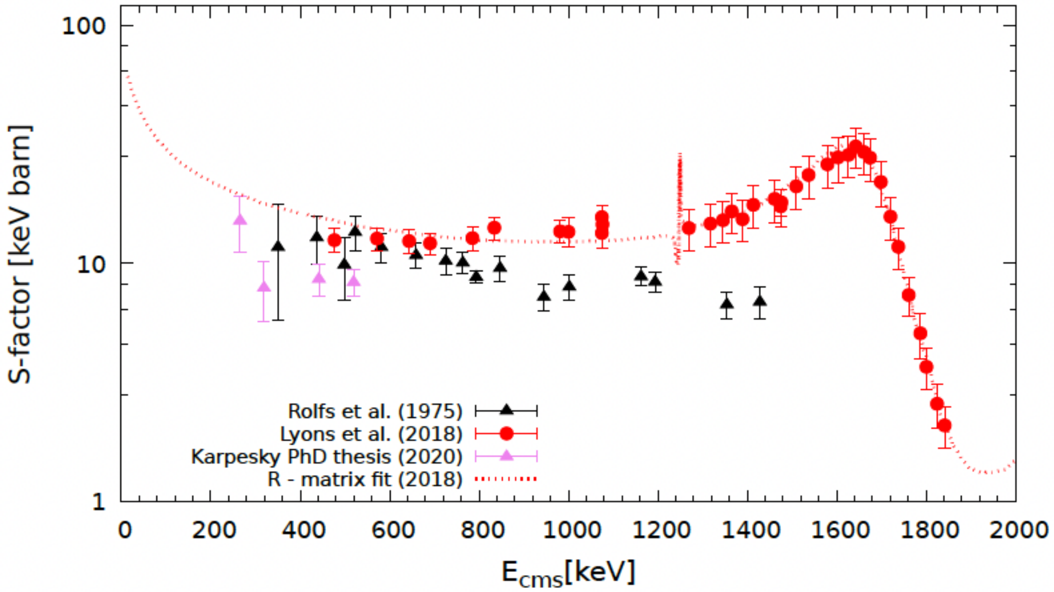
LUNA GOALS:

❖ Study of the E_{cm} = 366 keV resonance

$\omega\gamma_{Rolfs}$ = 0.11 ± 0.02 meV *(Rolfs et al. 1975)*

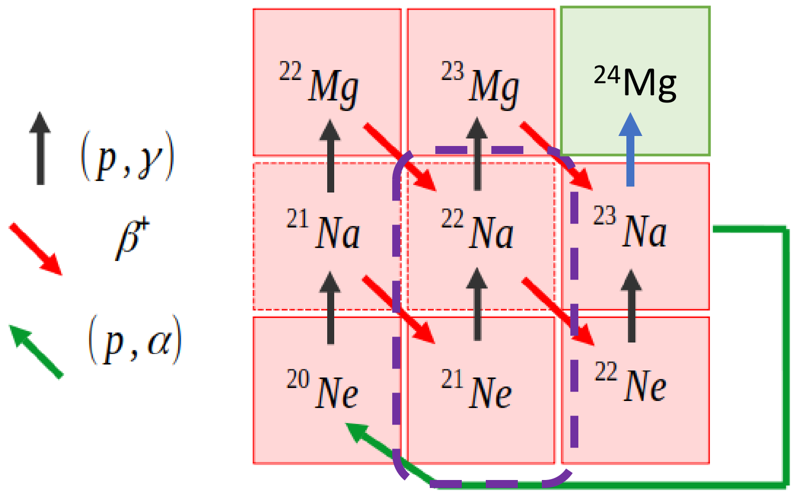
$\omega\gamma_{Cooper}$ = 0.0722 ± 0.0068 meV (*Cooper 2019, Ph.D thesis*)

❖ Direct capture below 400 keV



The $^{20}Ne(p,\gamma)^{21}Na$ (Q = 2431.6 keV) reaction is the first and slowest reaction of the NeNa cycle

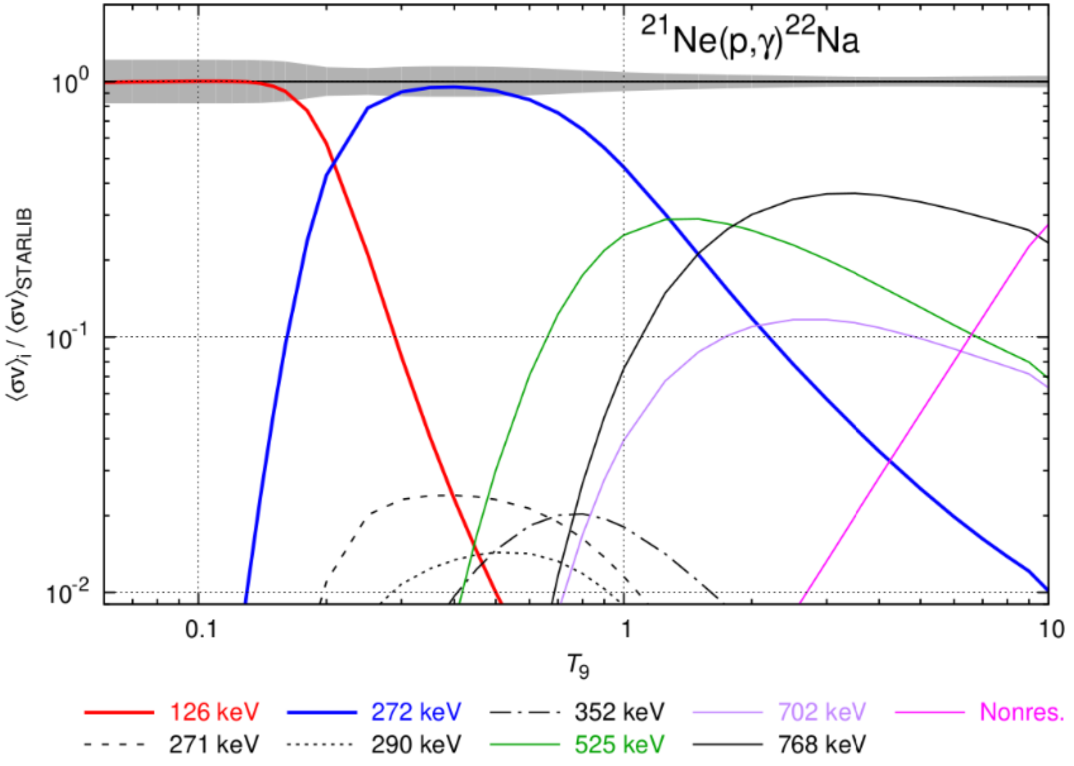
THE $^{21}Ne(p,\gamma)^{22}Na$



NeNa cycle

LUNA GOALS:

- Study 5 different resonances



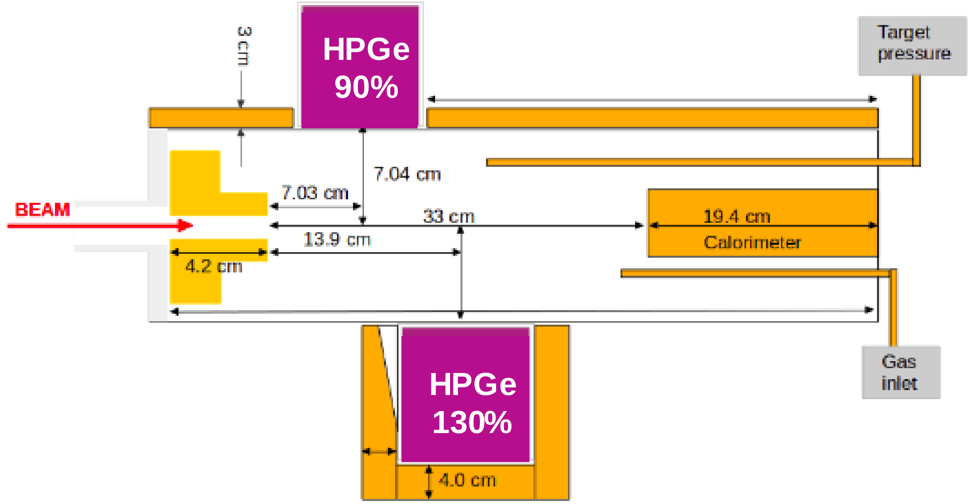
The $^{21}Ne(p,\gamma)^{22}Na$ (Q = 6738.7 keV) reaction has impact on O-Ne novae and core-collapse supernovae

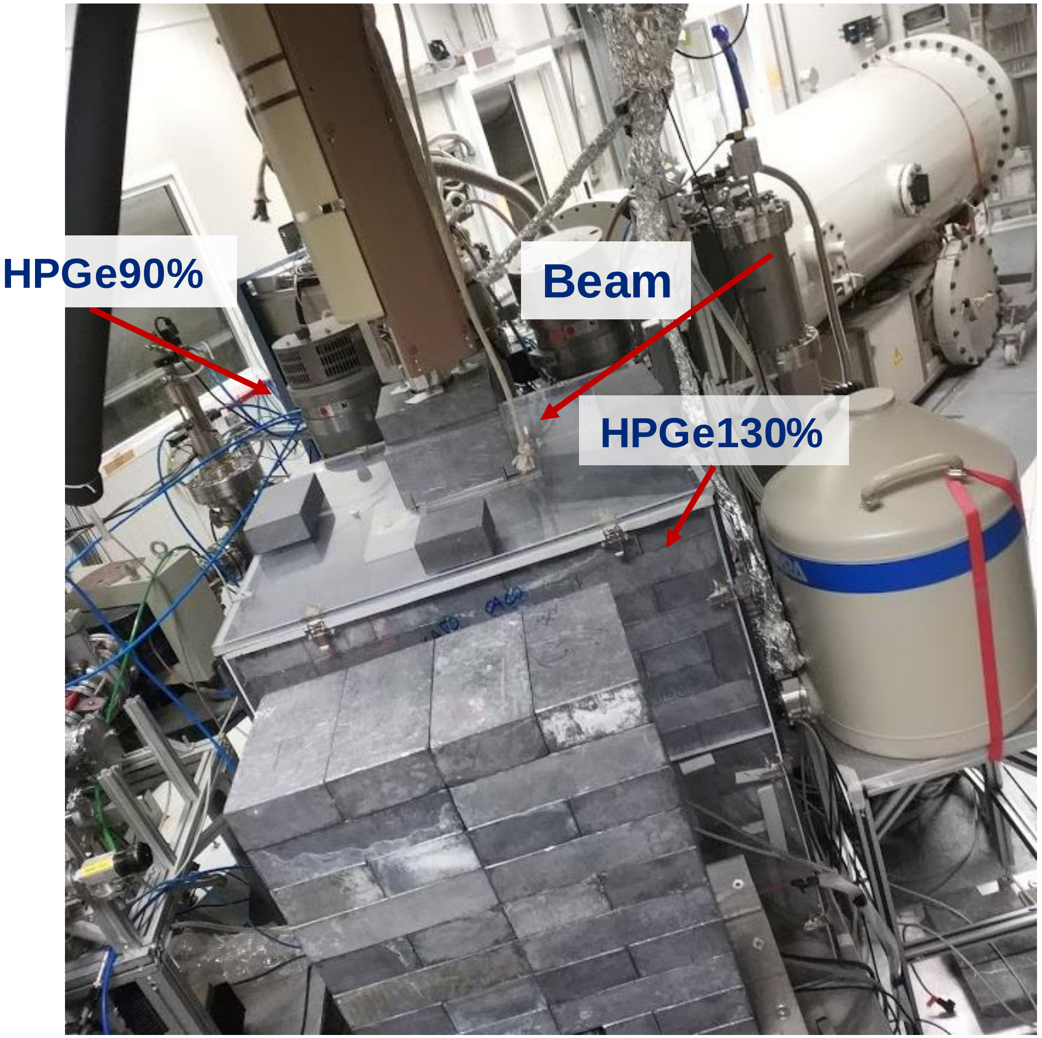
THE EXPERIMENT AT LUNA

- Natural Ne gas target (90.3% ^{20}Ne) P = 2 mbar
  or enriched ^{21}Ne (59%)
- HPGe detecors:

  Relative efficiency 130%(GePD)
  Relative efficiency 90% (GeDD)

- Lead shielding
- Radon box





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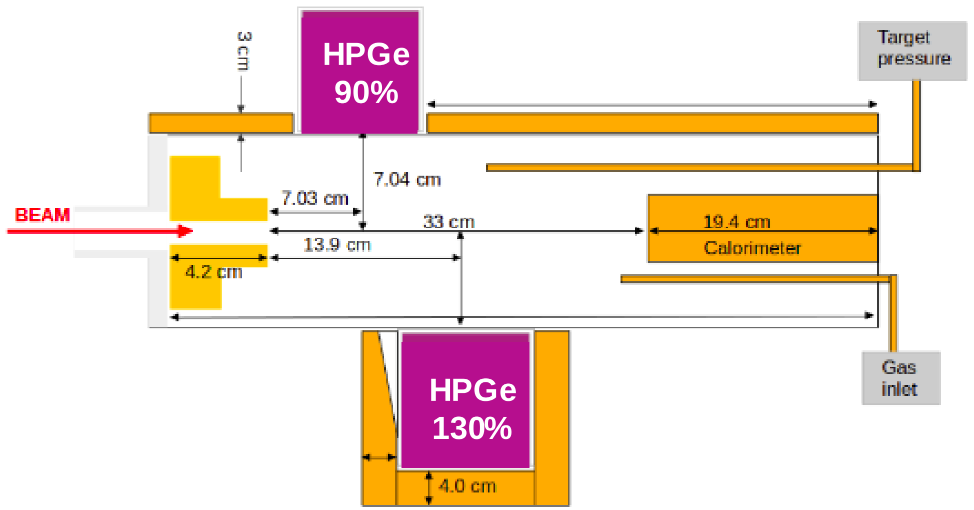
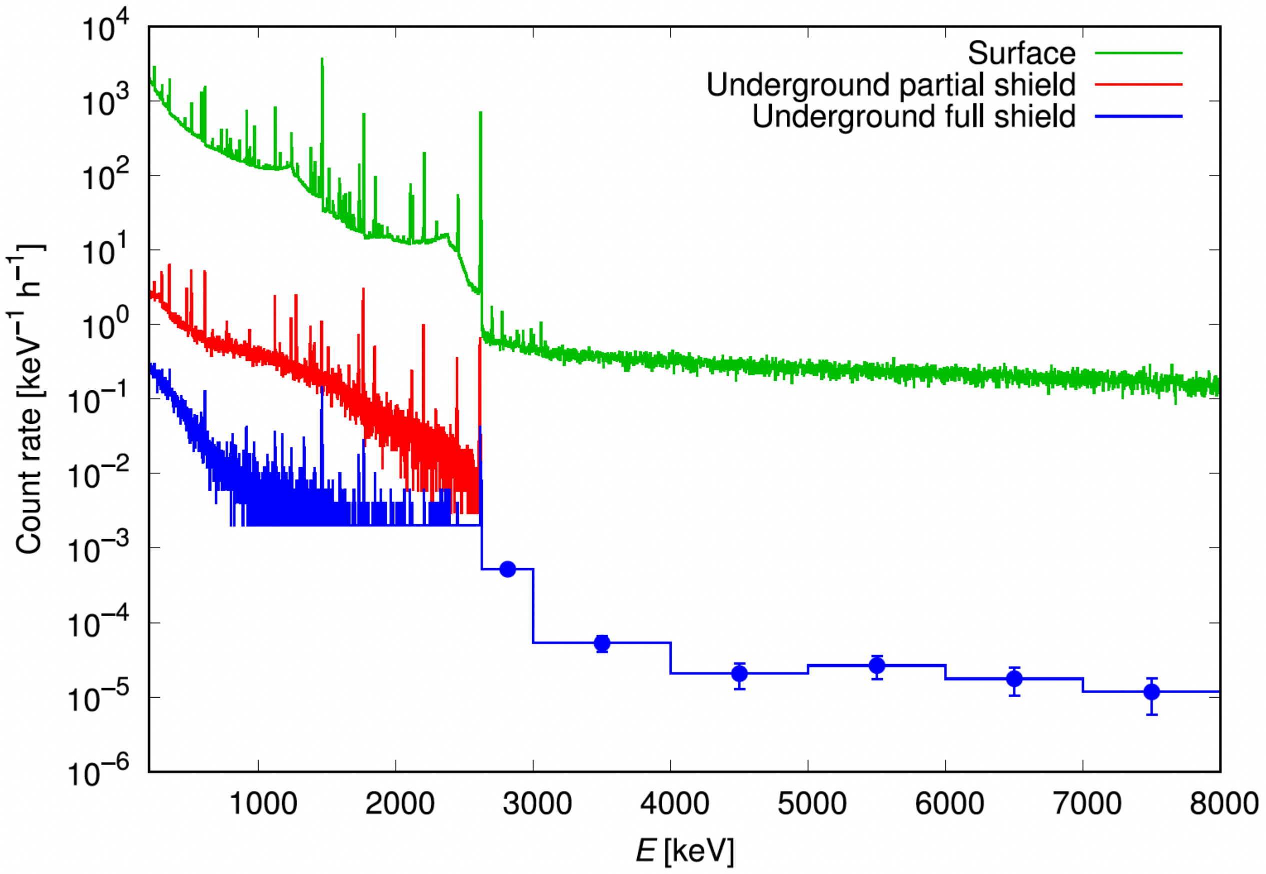
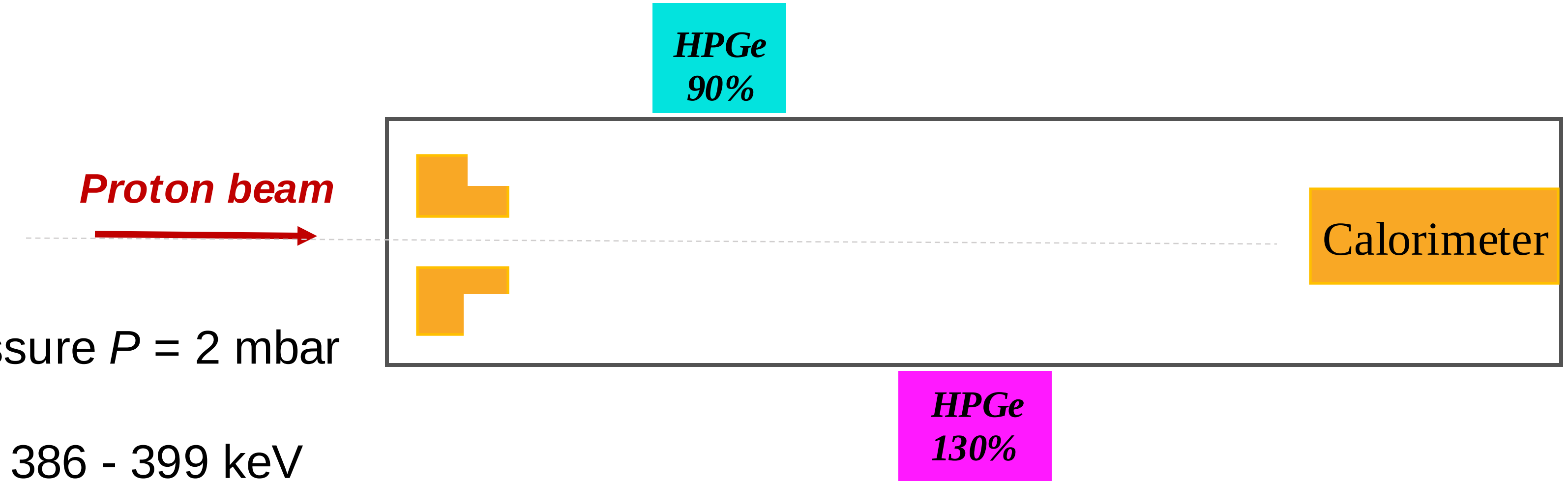




THE RESONANT MEASUREMENT



- Pressure P = 2 mbar
- E_p = 386 - 399 keV

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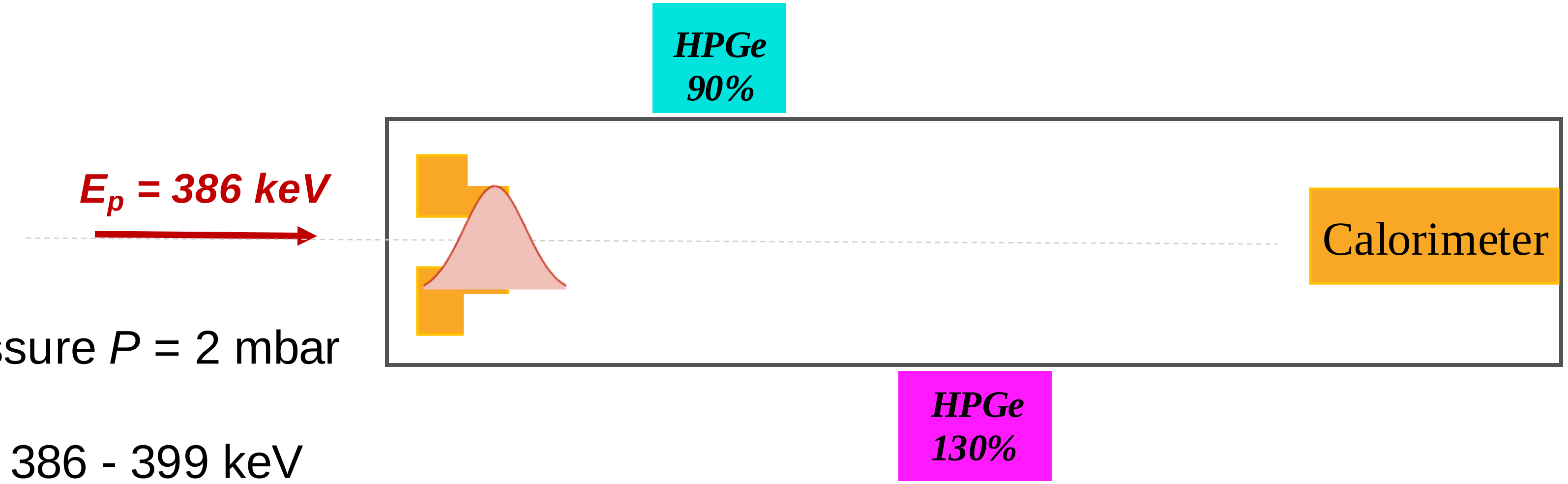

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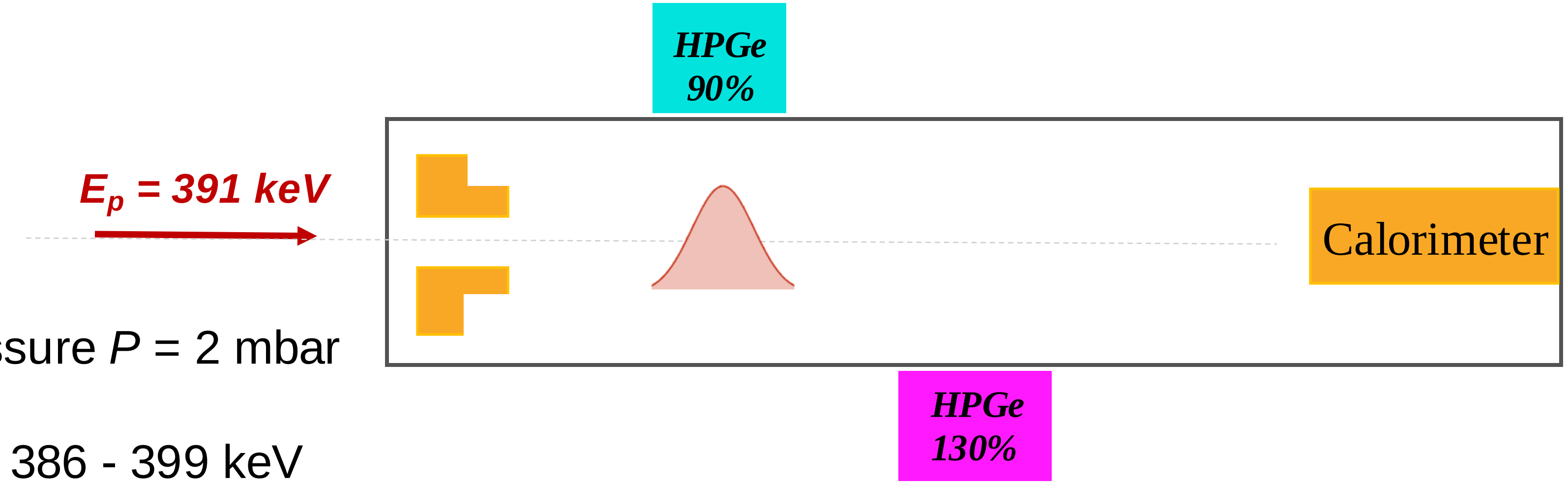

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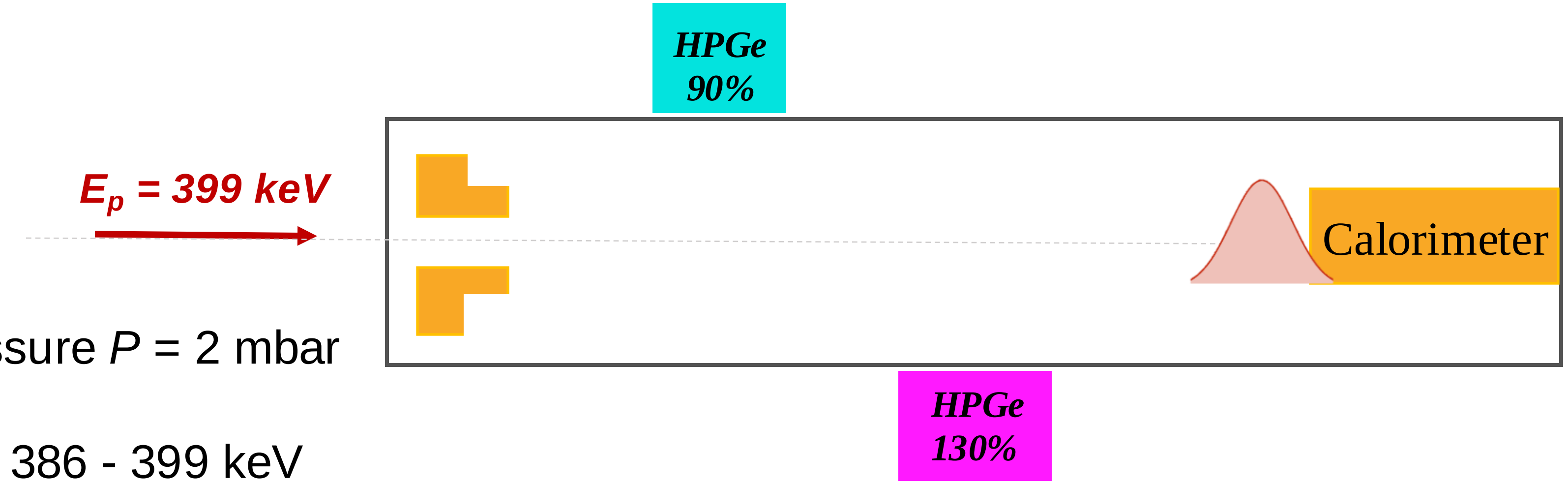

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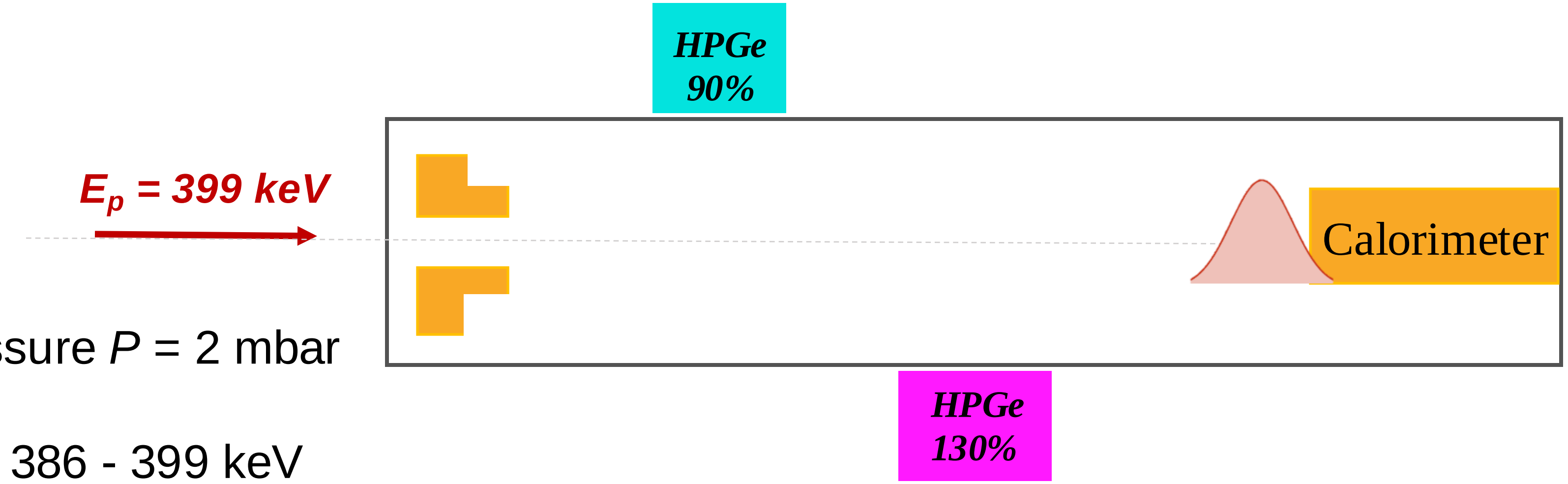

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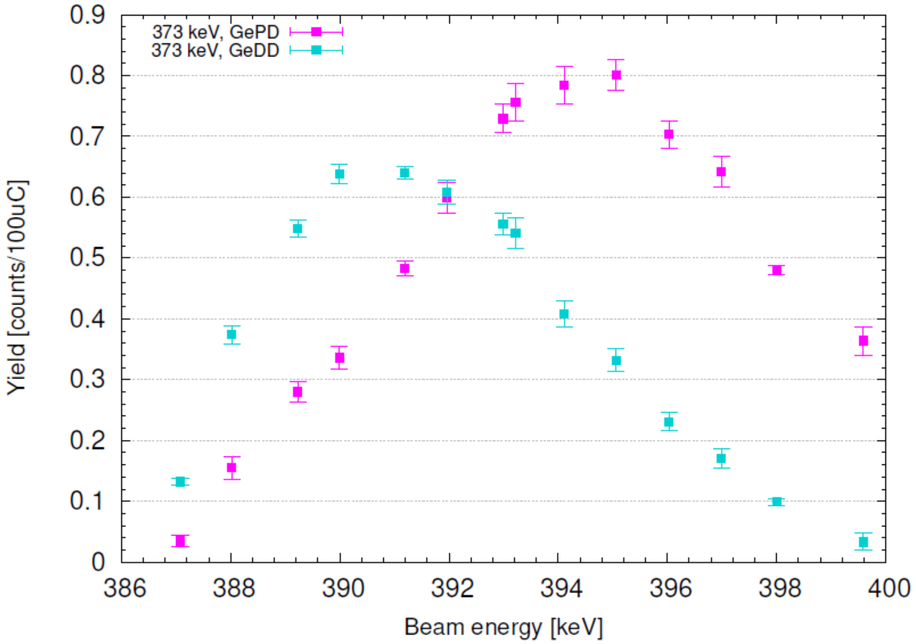
RESONANCE SCAN

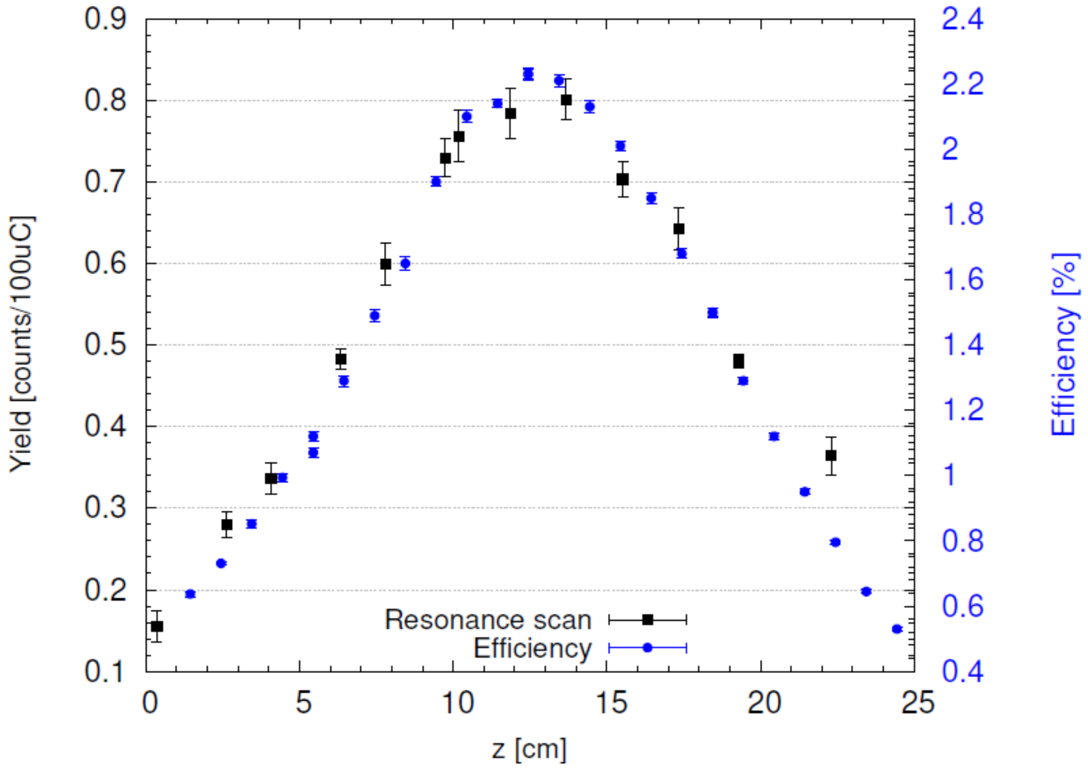
Varying the beam energy, the resonance is populated at different positions along the target chamber, where the detectors have different efficiency.



$^{20}Ne(p,\gamma)^{21}Na$ 366 keV RESONANCE ENERGY

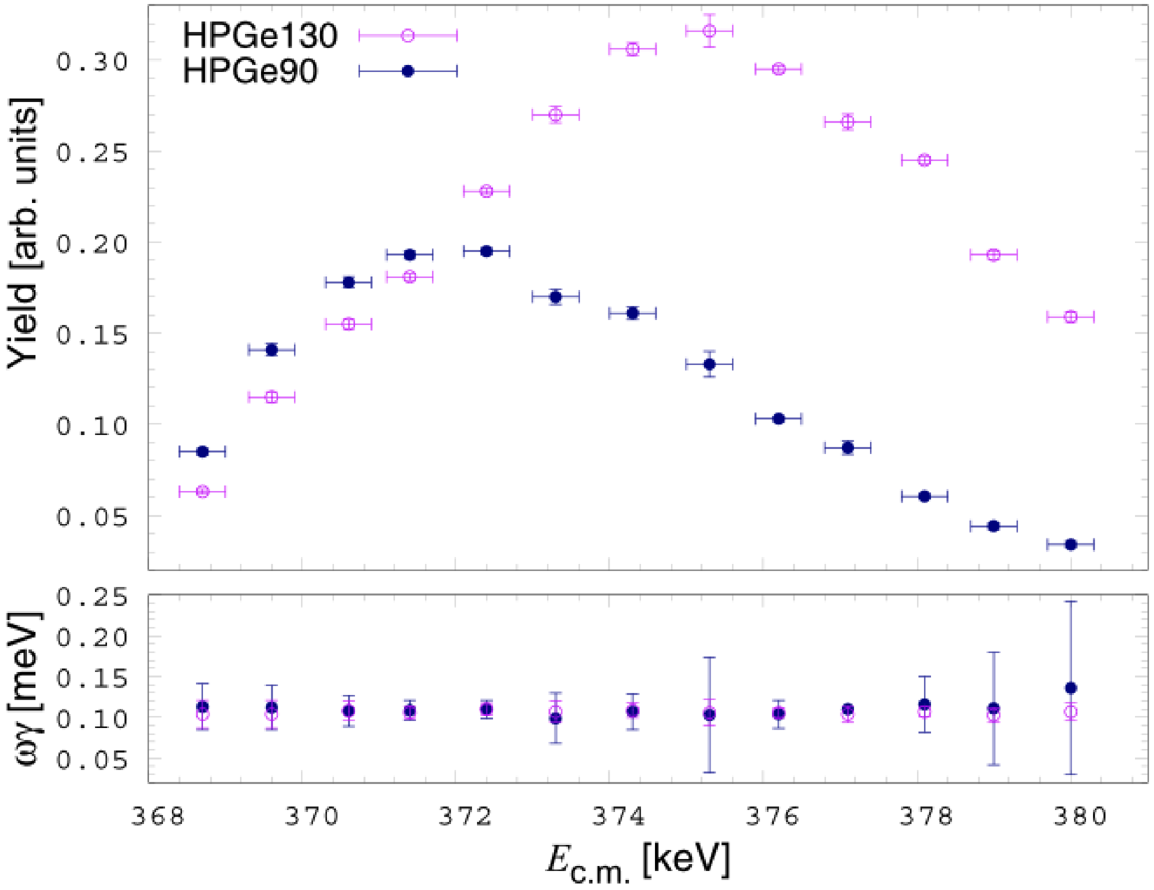
$$E_{R,lab} = E_p - z\frac{dE}{dz}$$

- E_p at the maximum yield
- Position of the maximum of the detection efficiency
- Energy loss



Rolfs et al. (1975) [keV]	LUNA (2023) [keV]
384±5	386.0±0.5

386 KEV RESONANCE STRENGTH AND BRANCHING RATIO

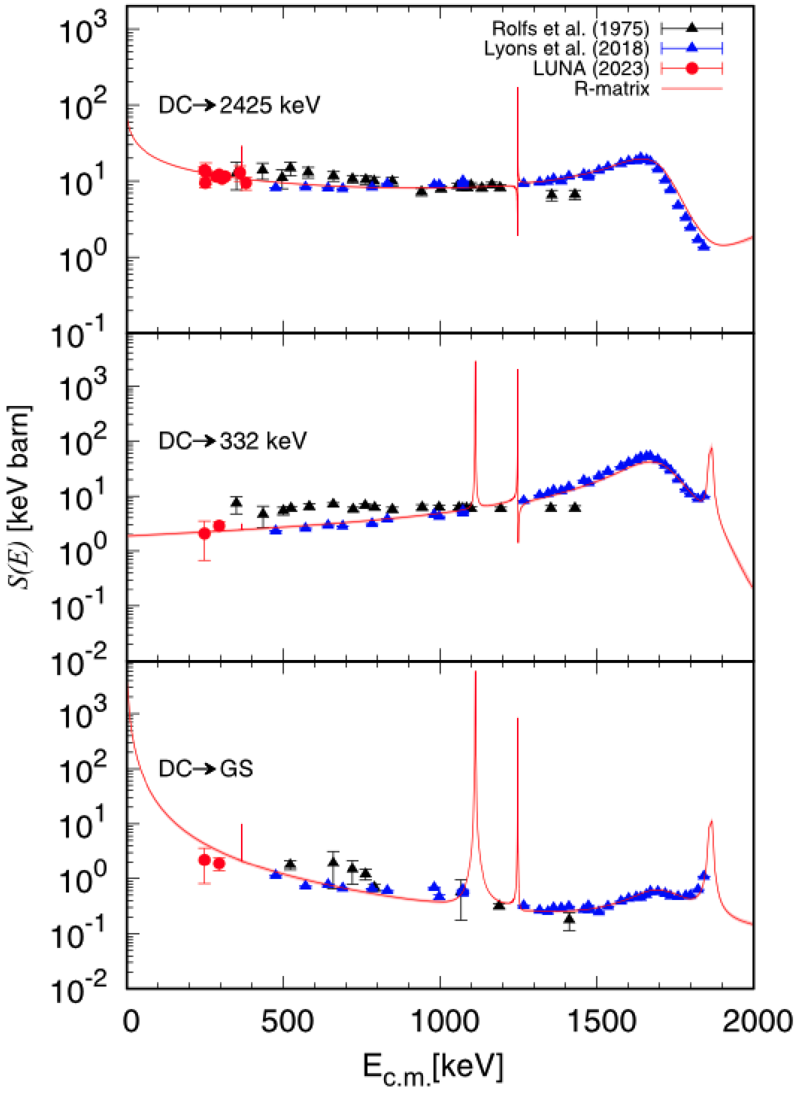


Transition [keV]	Rolfs et at. (1975) [%]	LUNA [%]
2425 →0	56±4	57.4±3.4
2798 →332	11±4	4.0±0.2
2798 →0	33±4	38.5±2.2

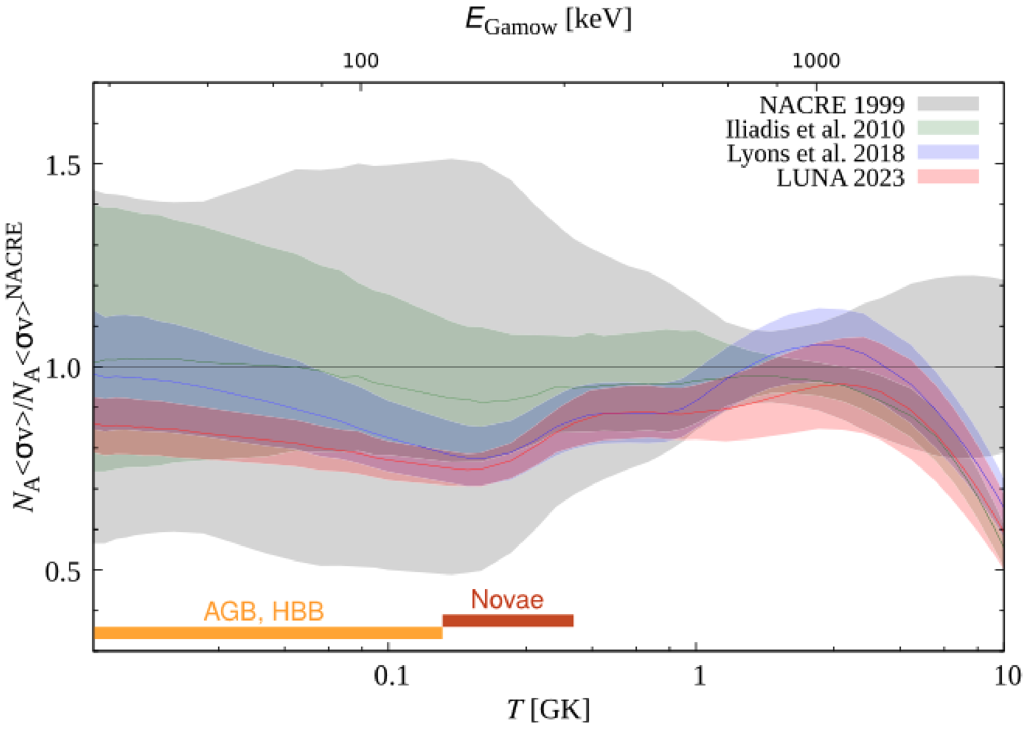
Experimental yield corrected for the combination of **efficiency** and **beam straggling** along the target chamber by using tuned **GEANT4 simulations**

Rolfs et al. (1975) [meV]	**LUNA (2023)** [meV]
0.11 ± 0.2	**0.112 ± 0.002$_{stat}$ ± 0.005$_{sys}$**

^{20}Ne(p,γ)^{21}Na S-FACTOR



Direct capture studied in the energy range : E_p = 260 keV – 400 keV

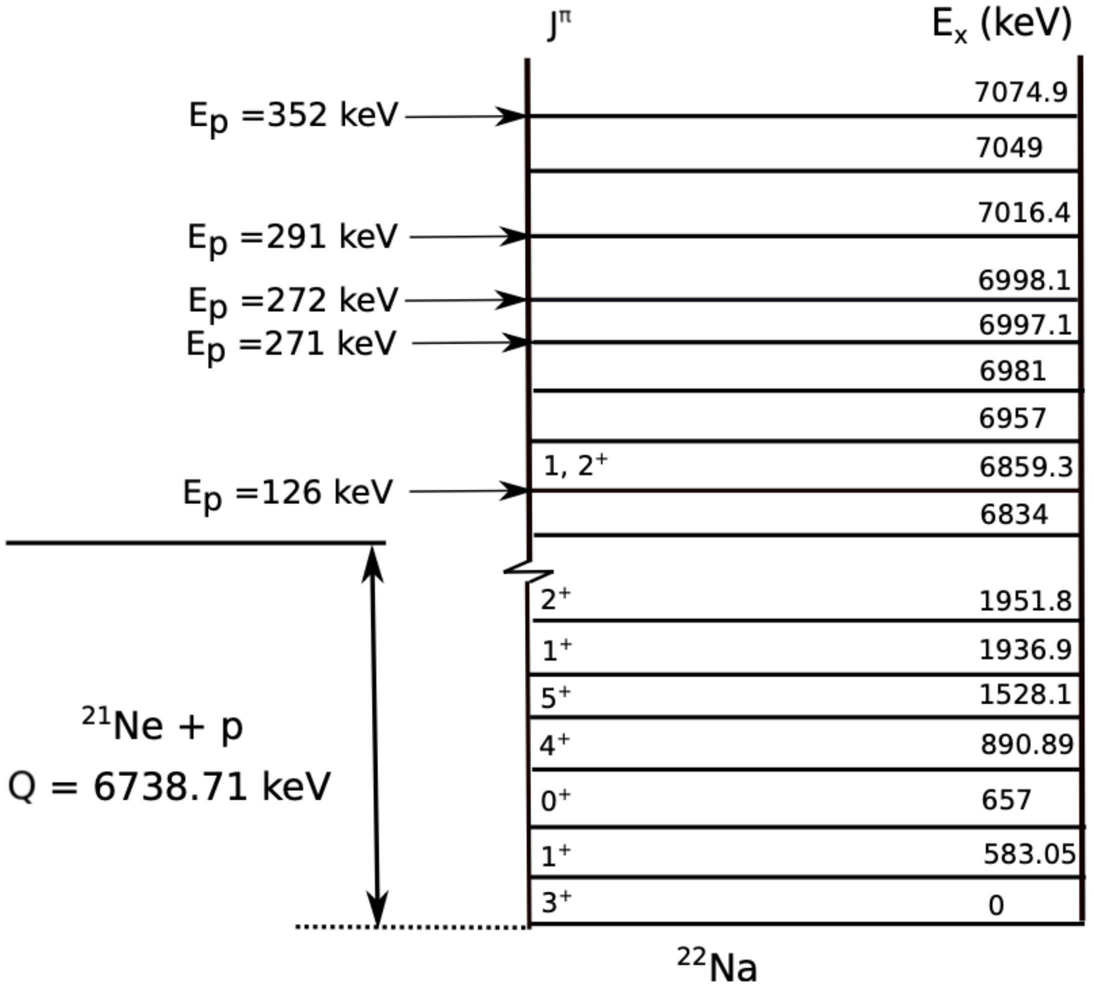


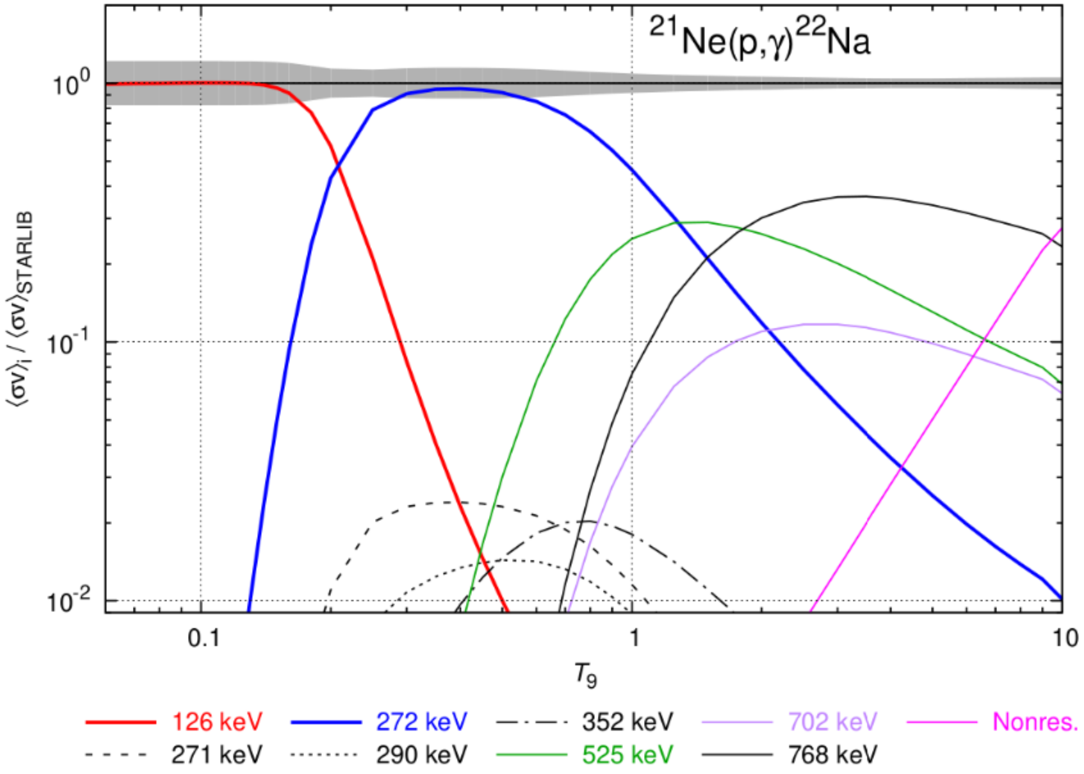
Impact

- **26%** reduction of ^{21}**Ne** surface abundance in hot bottom burning of **AGB**
- **30%** reduction of ^{21,22}**Ne** in **novae** ejecta
- **23%** reduction of ^{22}**Na** in **novae** ejecta

Masha et al.
PRC **108** (2023) L052801

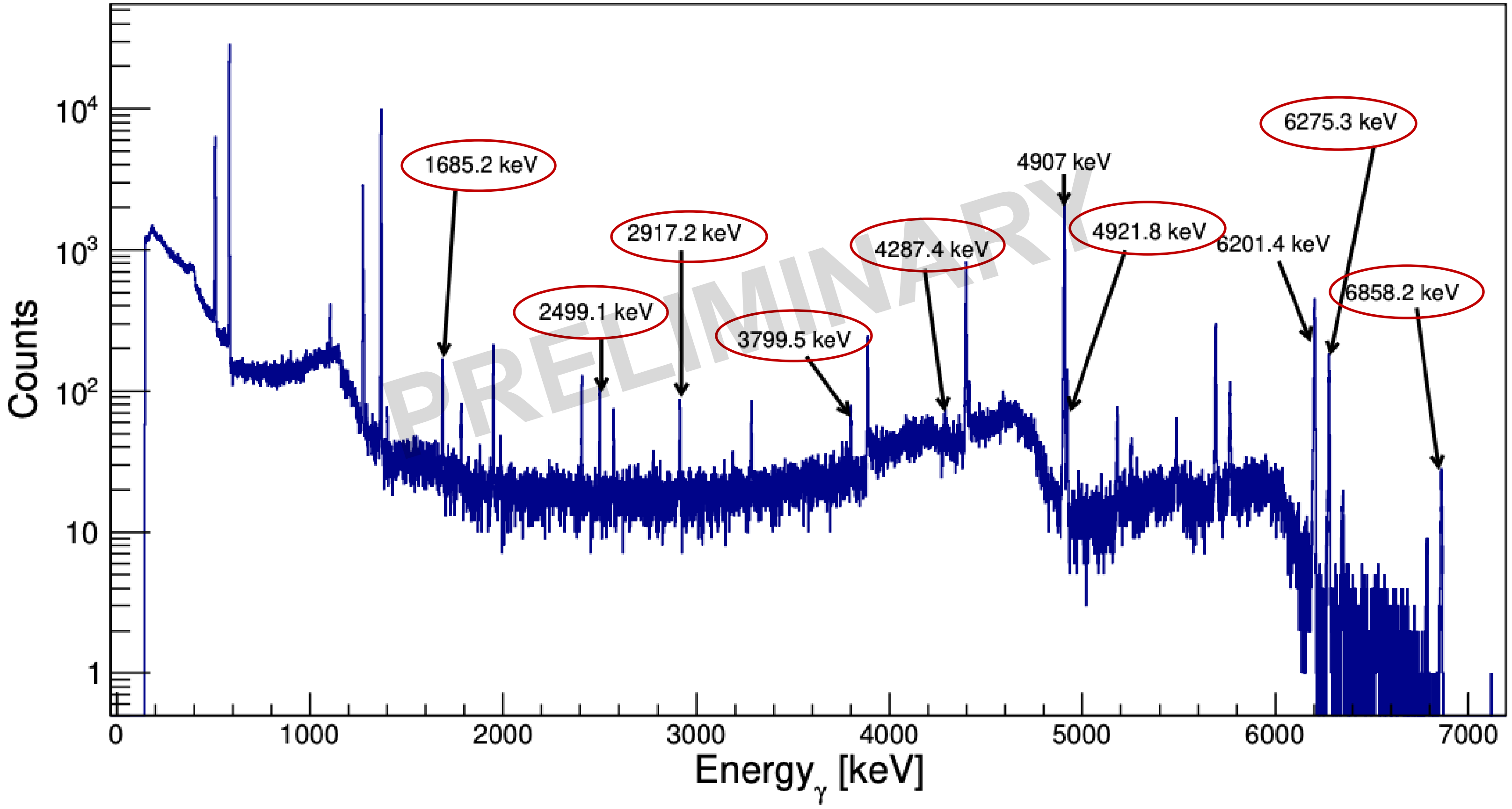
$^{21}Ne(p,\gamma)^{22}Na$ REACTION





$^{21}Ne(p,\gamma)^{22}Na$ completely **dominated** by the **resonances**

$^{21}Ne(p,\gamma)^{22}Na$ NEW TRANSITIONS



HPGe spectrum at the **126 keV** resonance

Many **new transitions** discovered for the **126 keV**, **272 keV** and **290 keV** resonances

$^{21}Ne(p,\gamma)^{22}Na$ PRELIMINARY RESULTS

E_R (lab)$_{\text{Görres[19]}}$ [keV]	E_R (lab)$_{\text{Becker[24]}}$ [keV]	E_R (lab)$_{\text{LUNA}}$ [keV]
$126.3 \pm 0.6_{\text{tot}}$	$126.69 \pm 0.04_{\text{stat}}$	$127.3 \pm 0.1_{\text{stat}} \pm 0.5_{\text{syst}}$
—	$270.67 \pm 0.04_{\text{stat}}$	$271.4 \pm 0.2_{\text{stat}} \pm 0.4_{\text{syst}}$
$271.7 \pm 0.4_{\text{syst}}$	$271.56 \pm 0.04_{\text{stat}}$	$272.31 \pm 0.01_{\text{stat}} \pm 0.44_{\text{syst}}$
$290.9 \pm 0.4_{\text{syst}}$	$290.50 \pm 0.04_{\text{stat}}$	$291.5 \pm 0.1_{\text{stat}} \pm 0.5_{\text{syst}}$
$352.2 \pm 0.4_{\text{syst}}$	—	$352.6 \pm 0.1_{\text{stat}} \pm 0.4_{\text{syst}}$

Measured **resonance energies** against literature

E_R [keV]	$\omega\gamma_{\text{literature}}$ [meV]	$\omega\gamma_{\text{LUNA}}$ [meV]
126	0.0375 ± 0.007 [19]	$0.0375 \pm 0.0002_{\text{stat}} \pm 0.0017_{\text{syst}}$
271	2.125 ± 0.375 [24]	$2.7 \pm 0.3_{\text{stat}} \pm 0.4_{\text{syst}}$
272	82.5 ± 12.5 [19]	$129.9 \pm 0.4_{\text{stat}} \pm 5.8_{\text{syst}}$
291	2.00 ± 0.37 [19]	$1.99 \pm 0.01_{\text{stat}} \pm 0.09_{\text{syst}}$
352	8.125 ± 1.375 [19]	$14.9 \pm 0.4_{\text{stat}} \pm 0.7_{\text{syst}}$

PRELIMINARY

Measured **resonance strengths** against literature

SUMMARY

- Recent efforts by **LUNA** have focused on studying all the **proton capture processes** involved in the **NeNa cycle**
- New results on the **^{20}Ne(*p*,γ)^{21}Na** reaction provide refined reaction rate that affects multiple astrophysical scenarios
- The preliminary analysis on the **^{21}Ne(*p*,γ)^{22}Na** shows new transitions in the ^{22}Na nucleus and an enhancement the reaction rate
- The last reaction of the NeNa cycle, namely the **^{23}Na(*p*,α)^{20}Ne**, is currently under study

The LUNA collaboration

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