Underground Nuclear Astrophysics at Gran Sasso Laboratories, Italy

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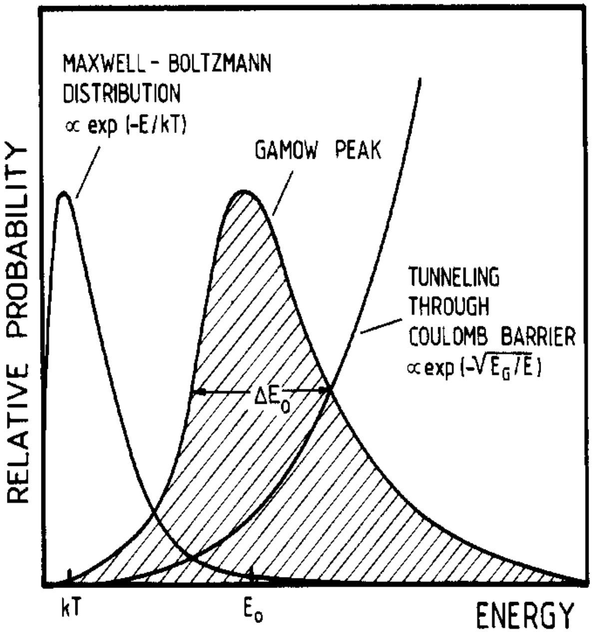
Laboratory
Underground
Nuclear
Astrophysics

The importance of performing cross sections measurement underground



Sun:
kT = 1 keV
$E_C \approx$ 0.5-2 MeV
$E_0 \approx$ 5-30 keV
for reactions of hydrogen burning in the Sun

kT but also $E_0 \ll E_C$!!

$$\sigma(E) = \frac{1}{E} \exp(-31.29\, Z_1 Z_2 \sqrt{\mu/E})\, S(E)$$

Cross sections in the range of pb-fb at stellar energies

with typical laboratory conditions, counting rate R can be as low as few events per month

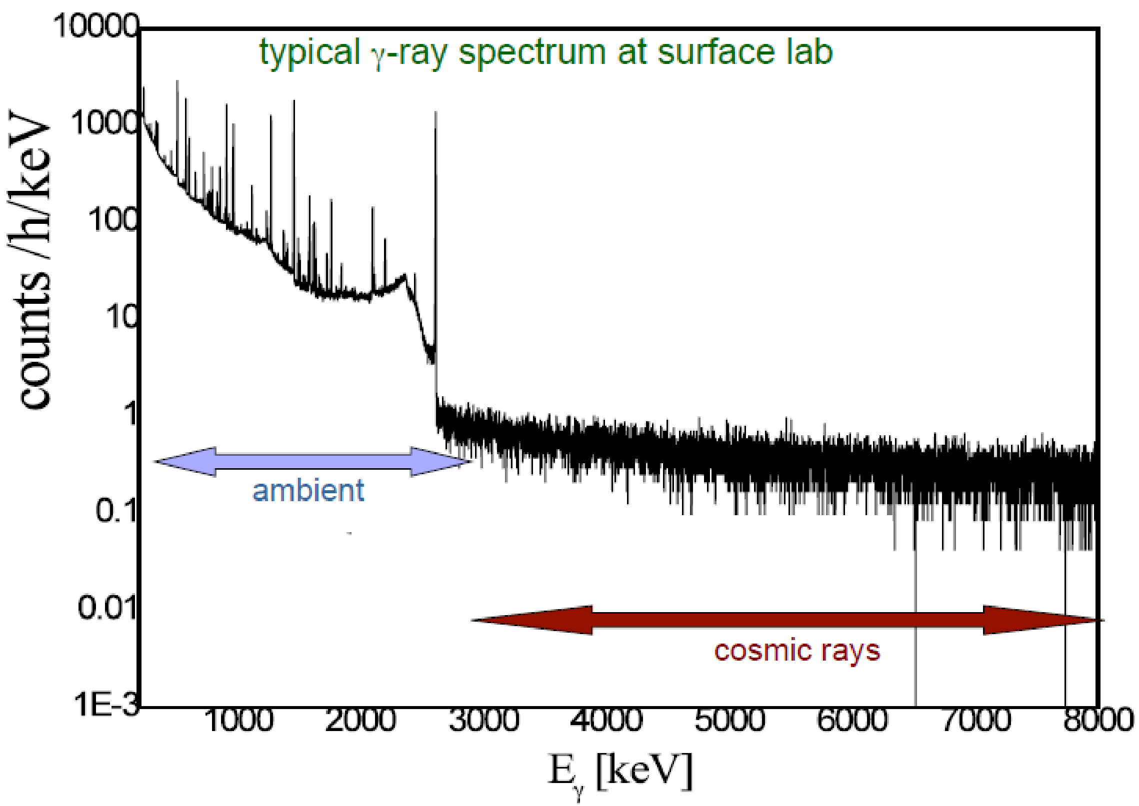
Rate and background

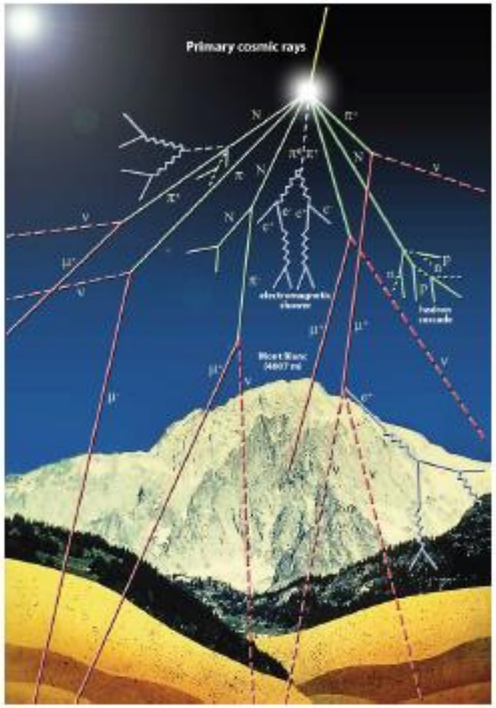
Rate has to be compared with background B

$B_{beam\ induced}$: reactions with impurities in the target, collimators,… secondary processes

B_{env} : natural radioactivity mainly from U and Th chains

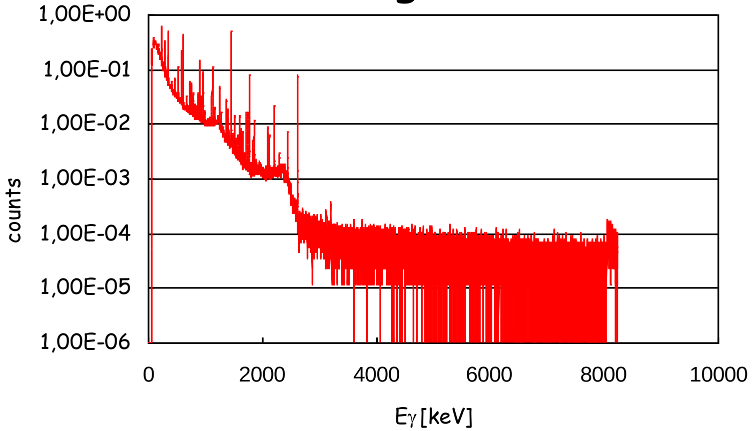
B_{cosmic} : mainly muons





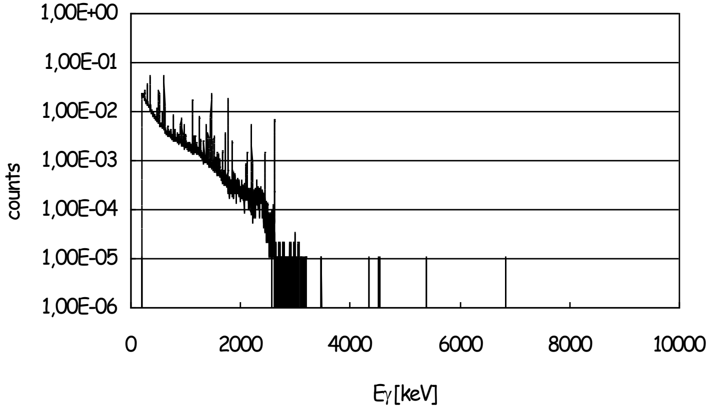
Background reduction - HPGe detectors - gamma

Overground



3MeV < Eγ < 8MeV
0.5 Counts/s

Underground

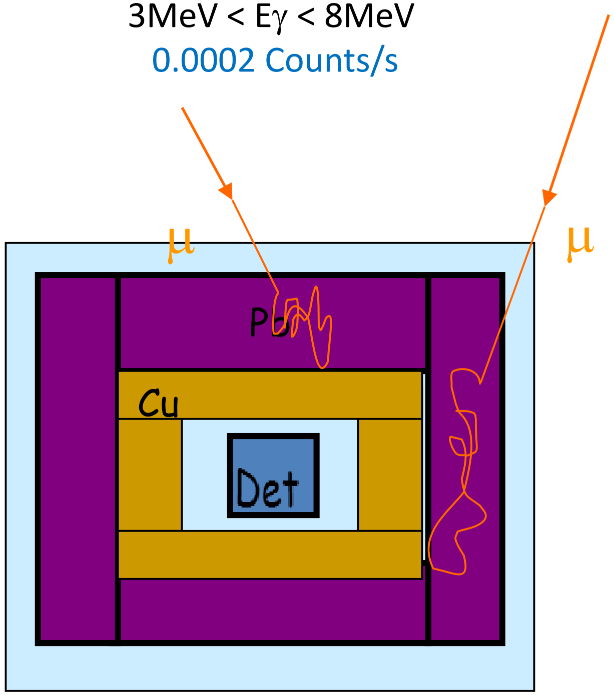


3MeV < Eγ < 8MeV
0.0002 Counts/s

E_γ<3MeV→passive shielding for environmental bck

Secondary gammas created by μ interactions are reduced

underground passive shielding is more effective!



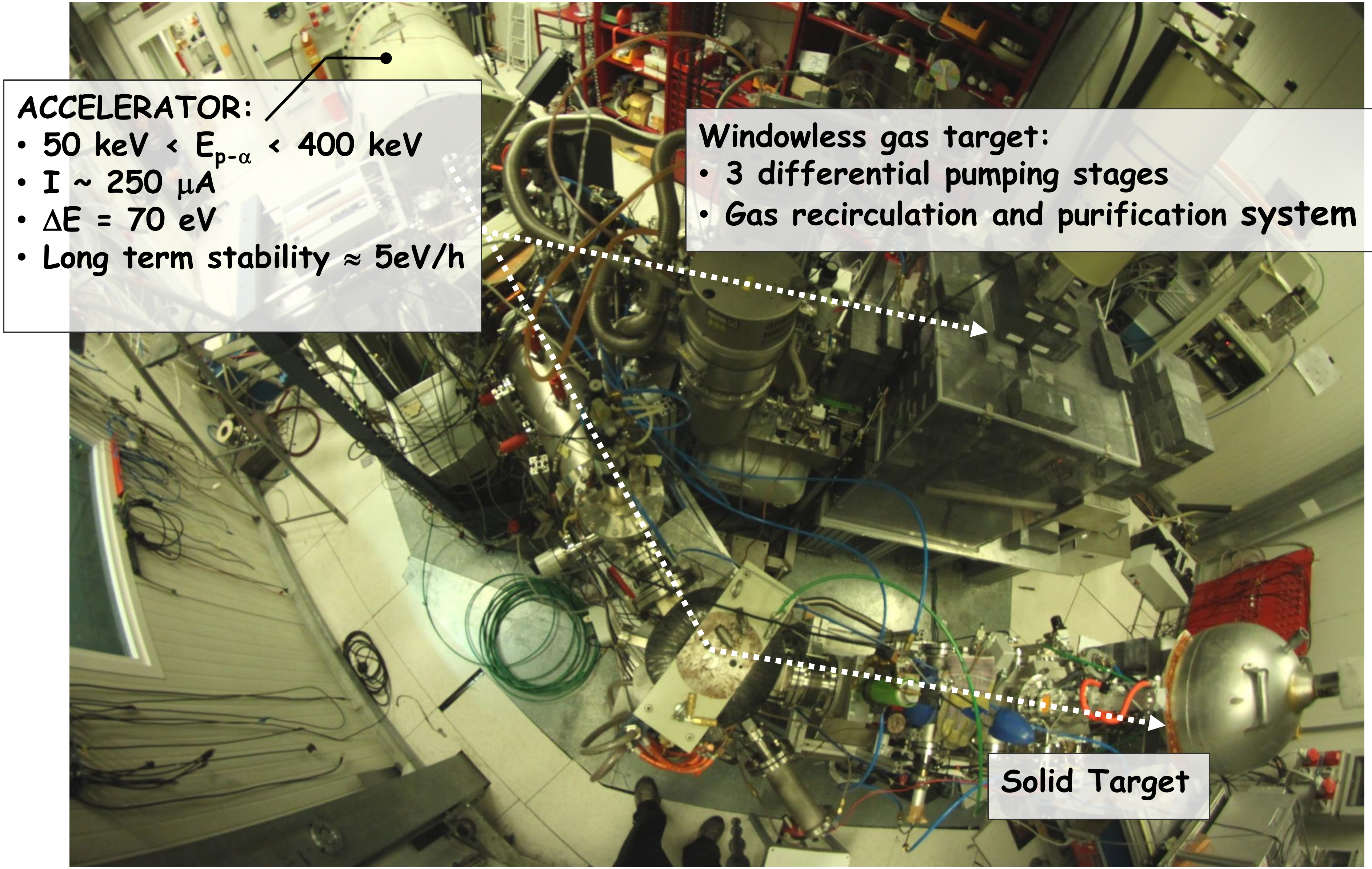
Laboratory for Underground Nuclear Astrophysics

From an idea of ***E. Bellotti, G. Fiorentini & C. Rolfs***

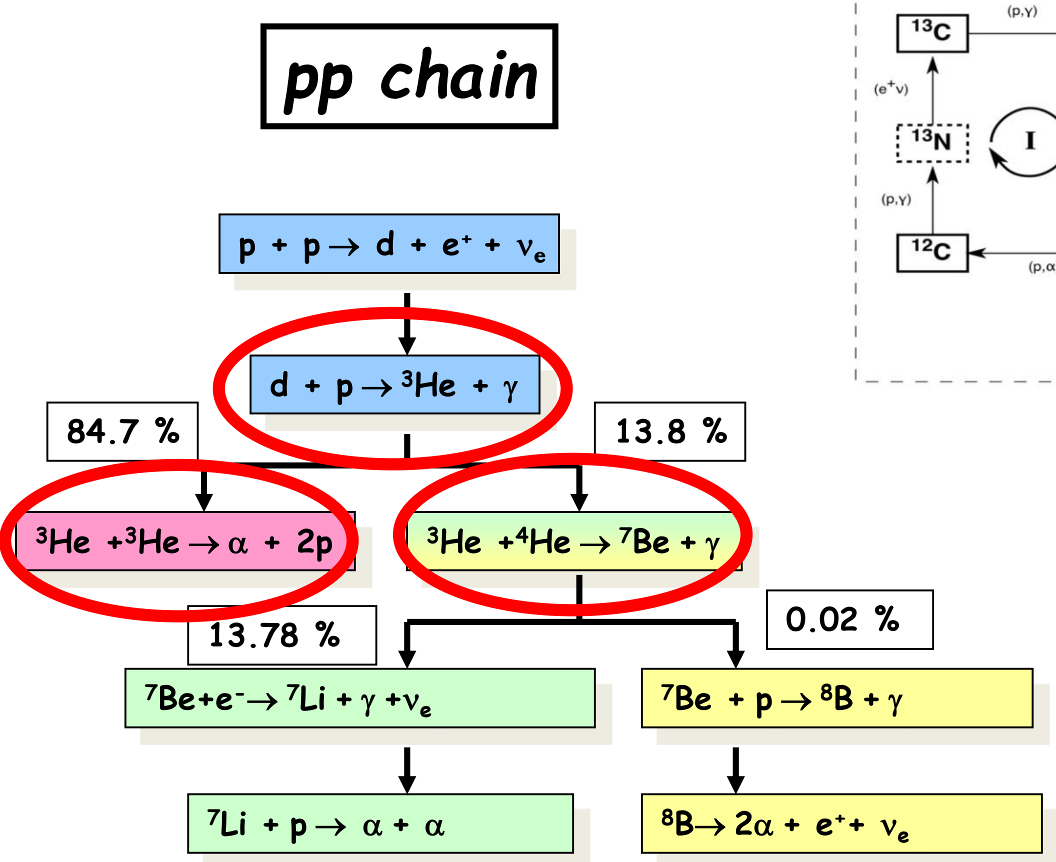
Radiation	LNGS/surface
Muons	10^{-6}
Neutrons	10^{-3}

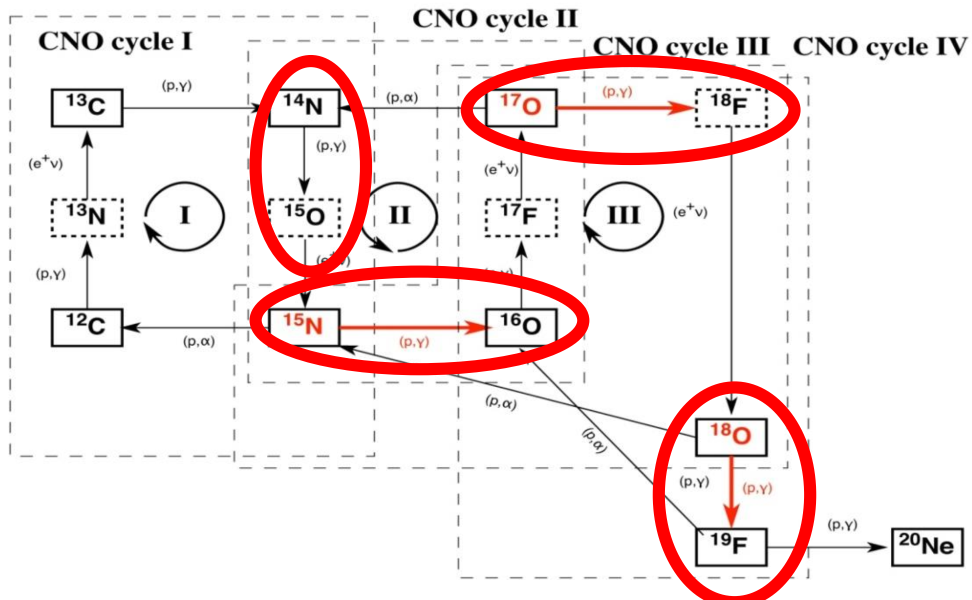
LNGS (1400 m rock shielding ≡ 4000 m w.e.)

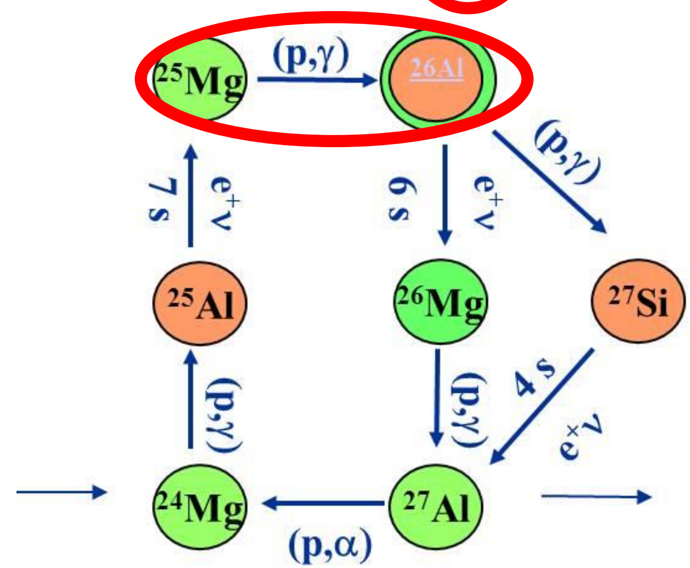
LUNA experimental setup



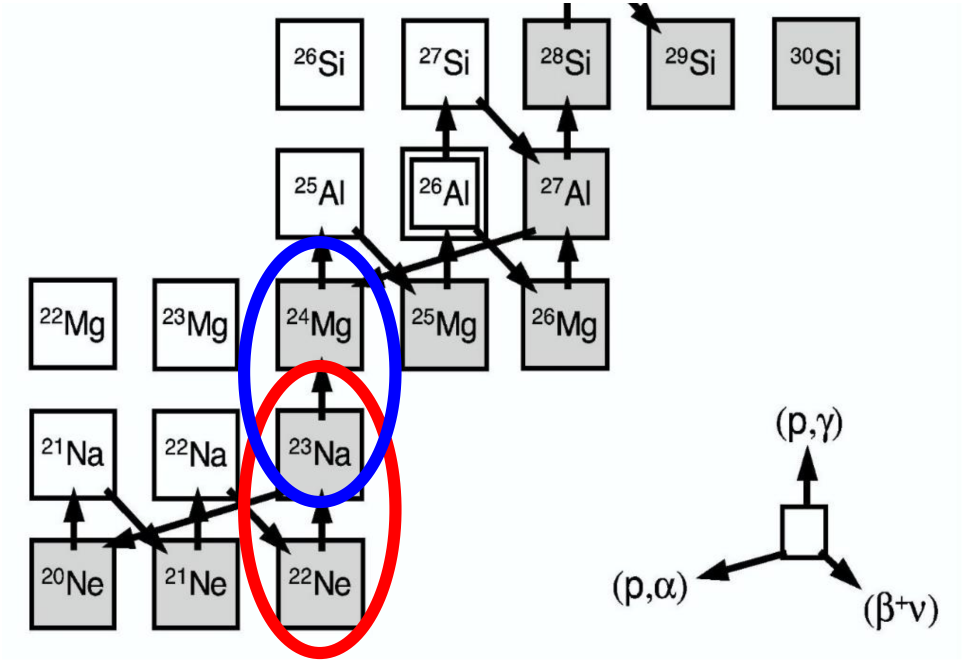
Completed LUNA measurements







Ongoing LUNA measurements

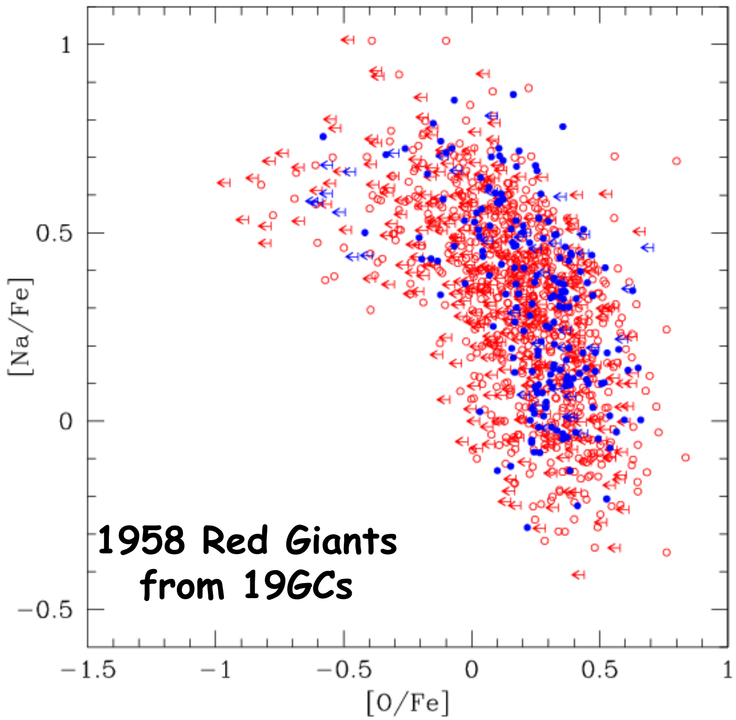


- $^{22}Ne(p,\gamma)^{23}Na$
- $^{23}Na(p,\gamma)^{24}Mg$ (see Axel Boeltzig talk)

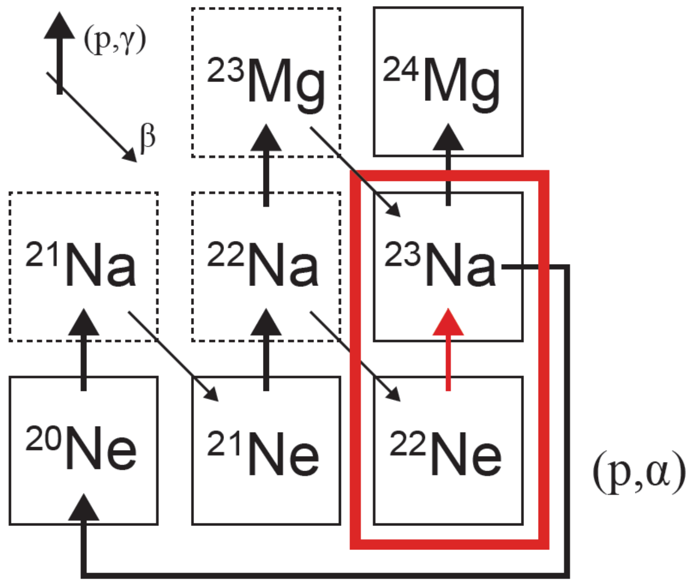
Astrophysical motivation

The Neon - Sodium cycle strongly influences the abundance of Ne, Na, Mg and Al isotopes in:

- Hydrostatic hydrogen burning in massive stars
- Shell hydrogen burning in Red Giant Branch and Asymptotic Giant Branch stars (Na-O anticorrelation problem)



Carretta Astron. Astrophys. 505 (2009)



$^{22}Ne(p,\gamma)^{23}Na$ is the most uncertain reaction in the NeNa cycle

Astrophysical motivations

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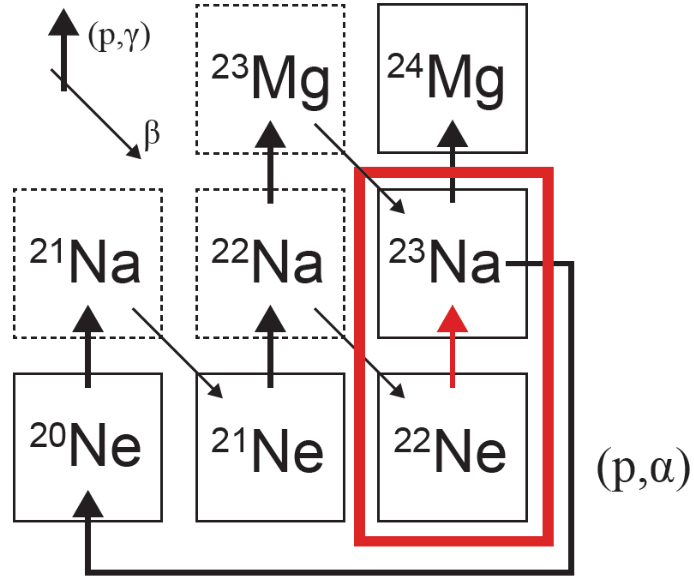
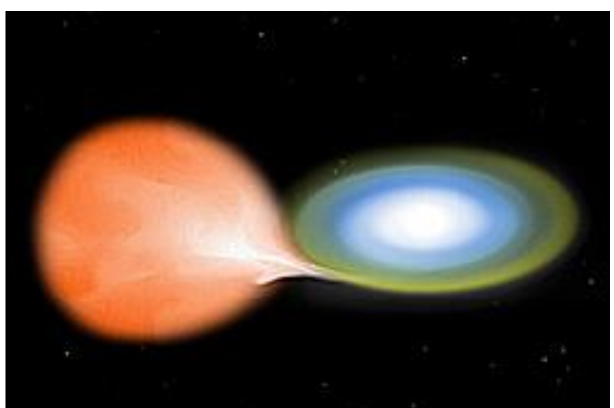


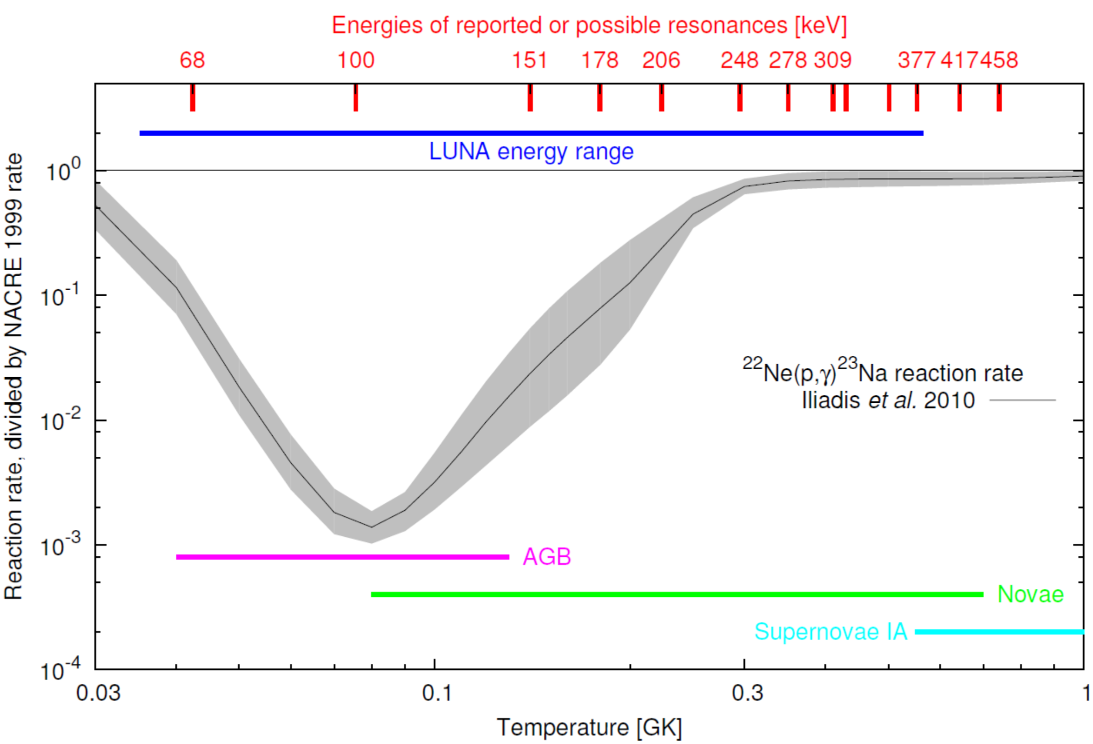
- Explosive H burning in classical novae and supernovae IA

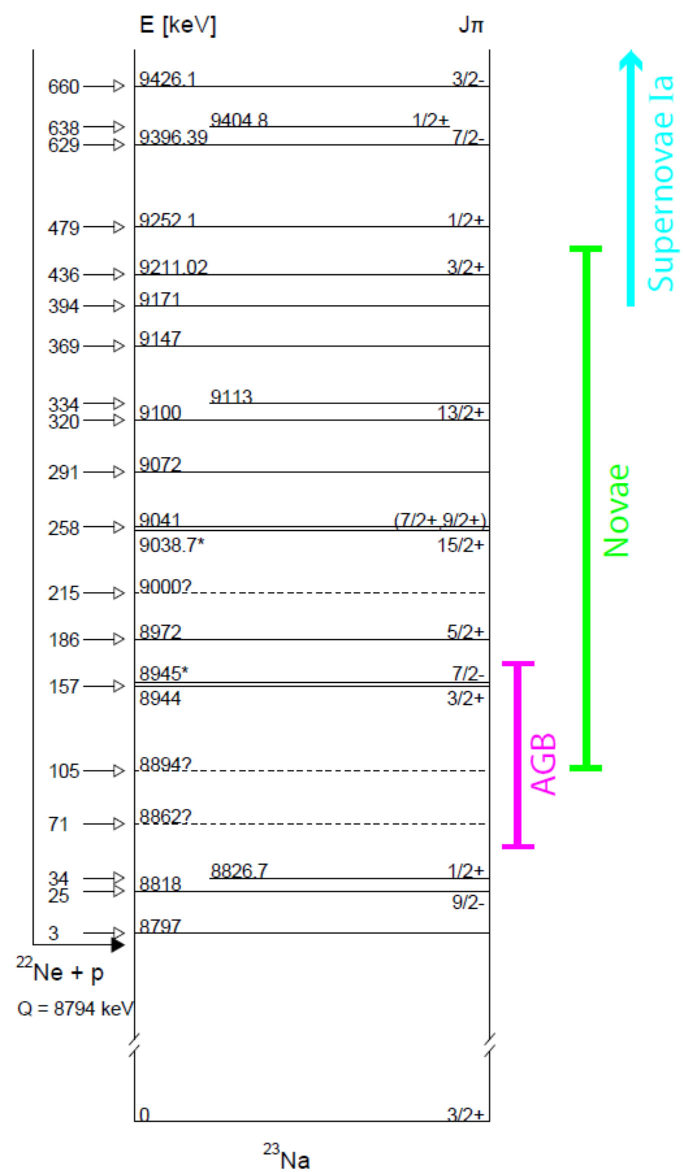


State of the art

Two recent compilations:

- NACRE reaction rate compilation 1999
- Iliadis et al. compilation 2010
- Strong differences!





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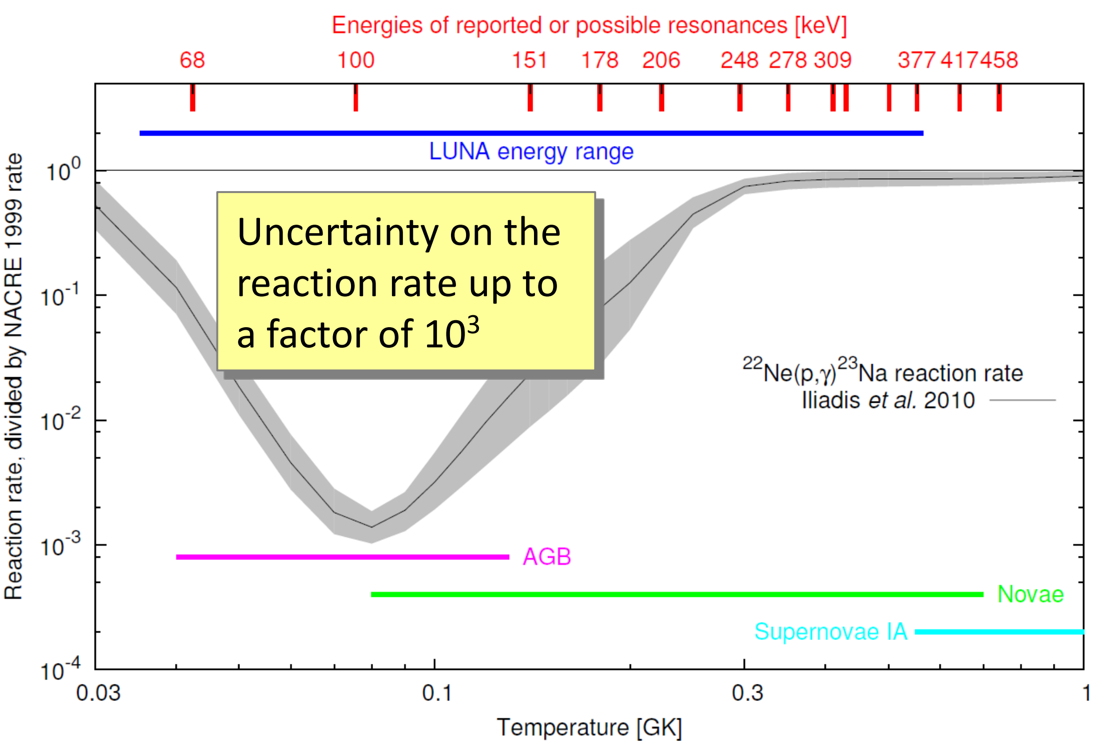

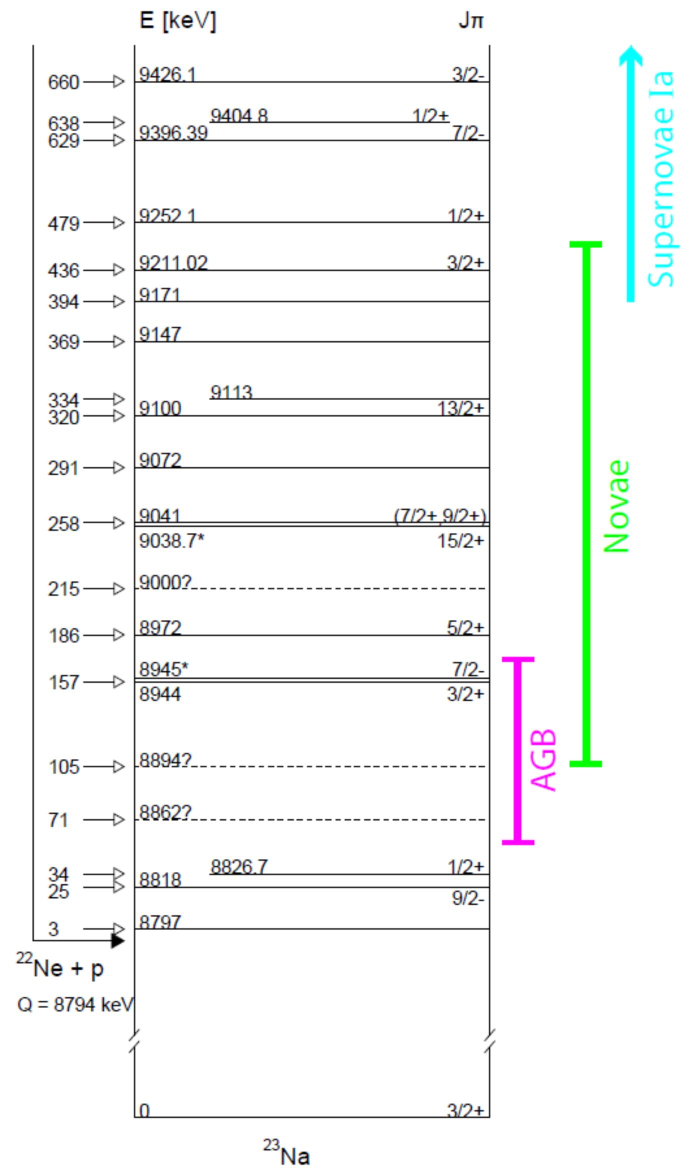

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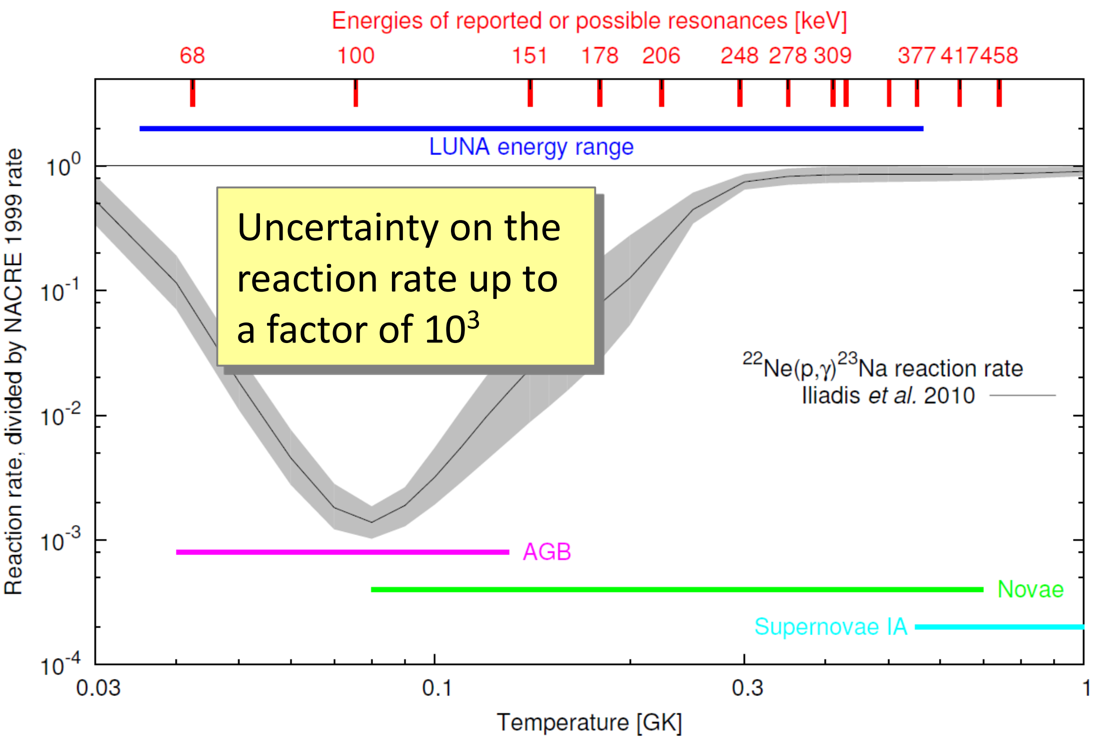
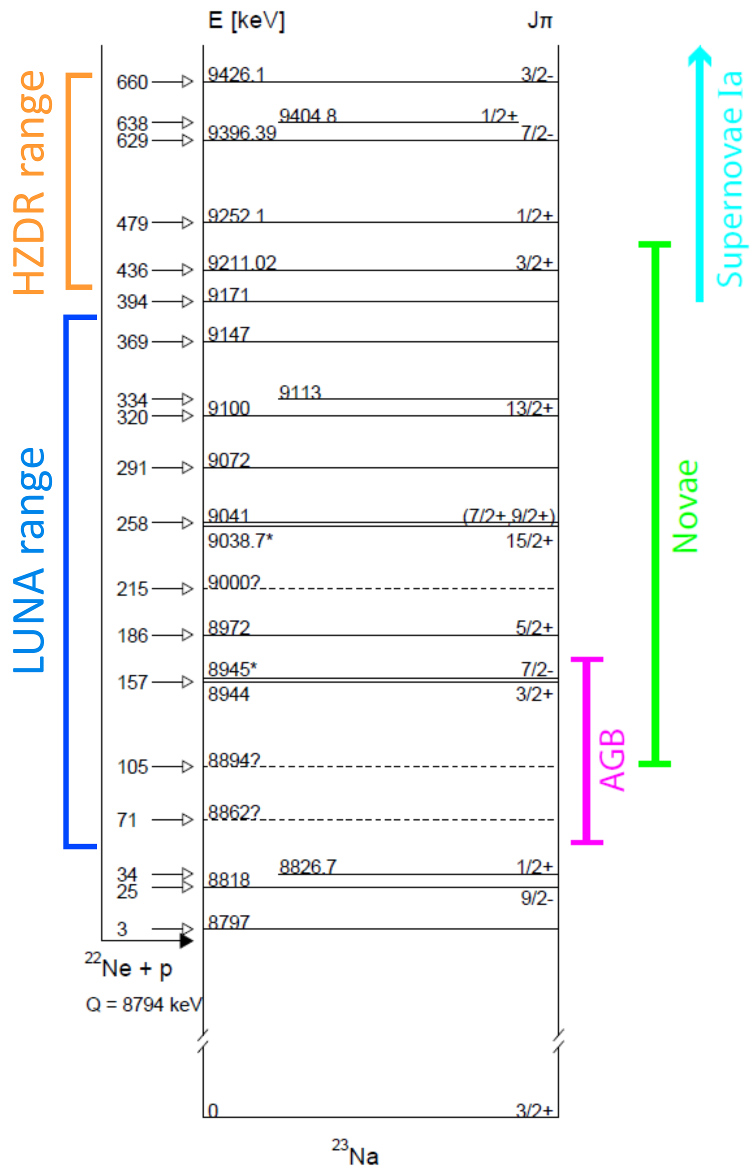
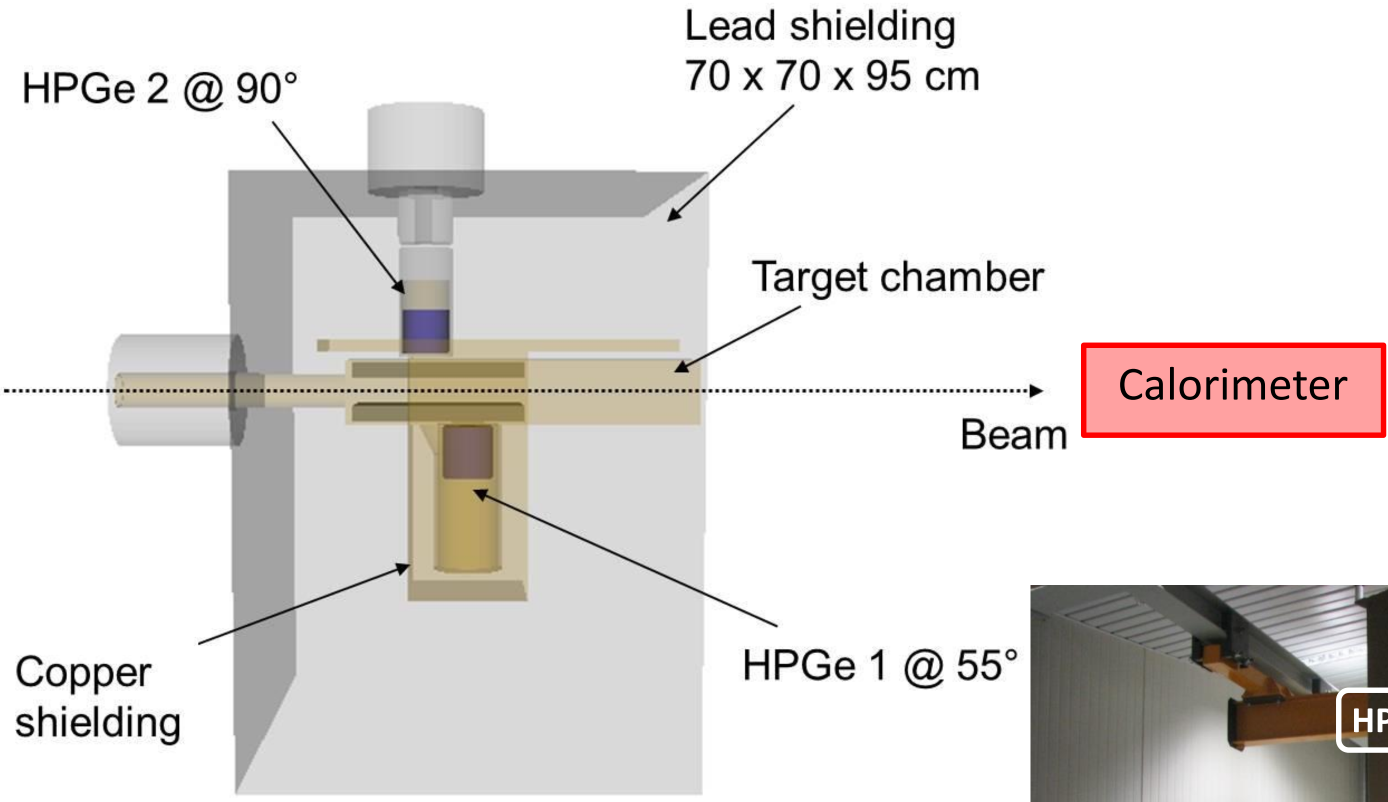
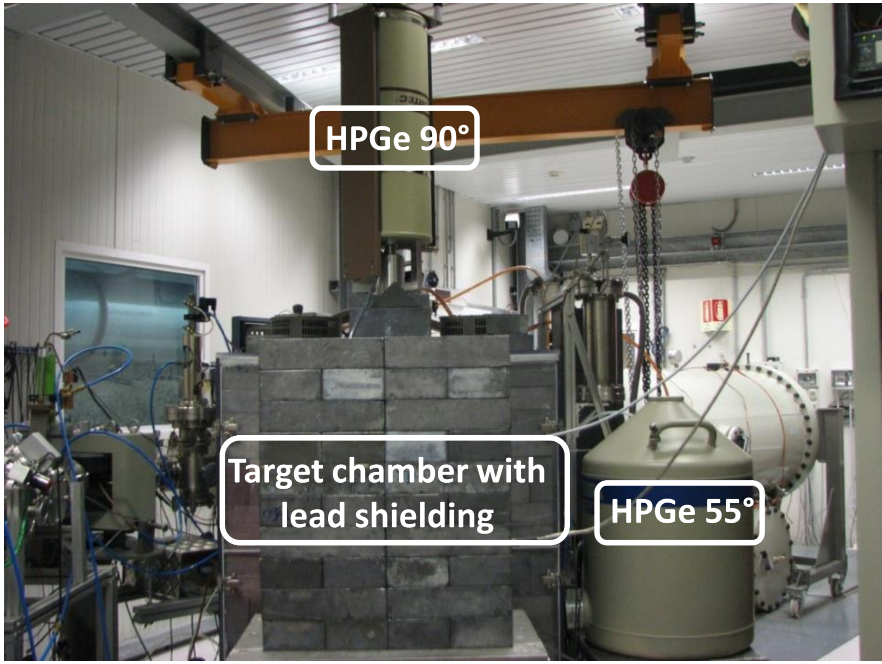




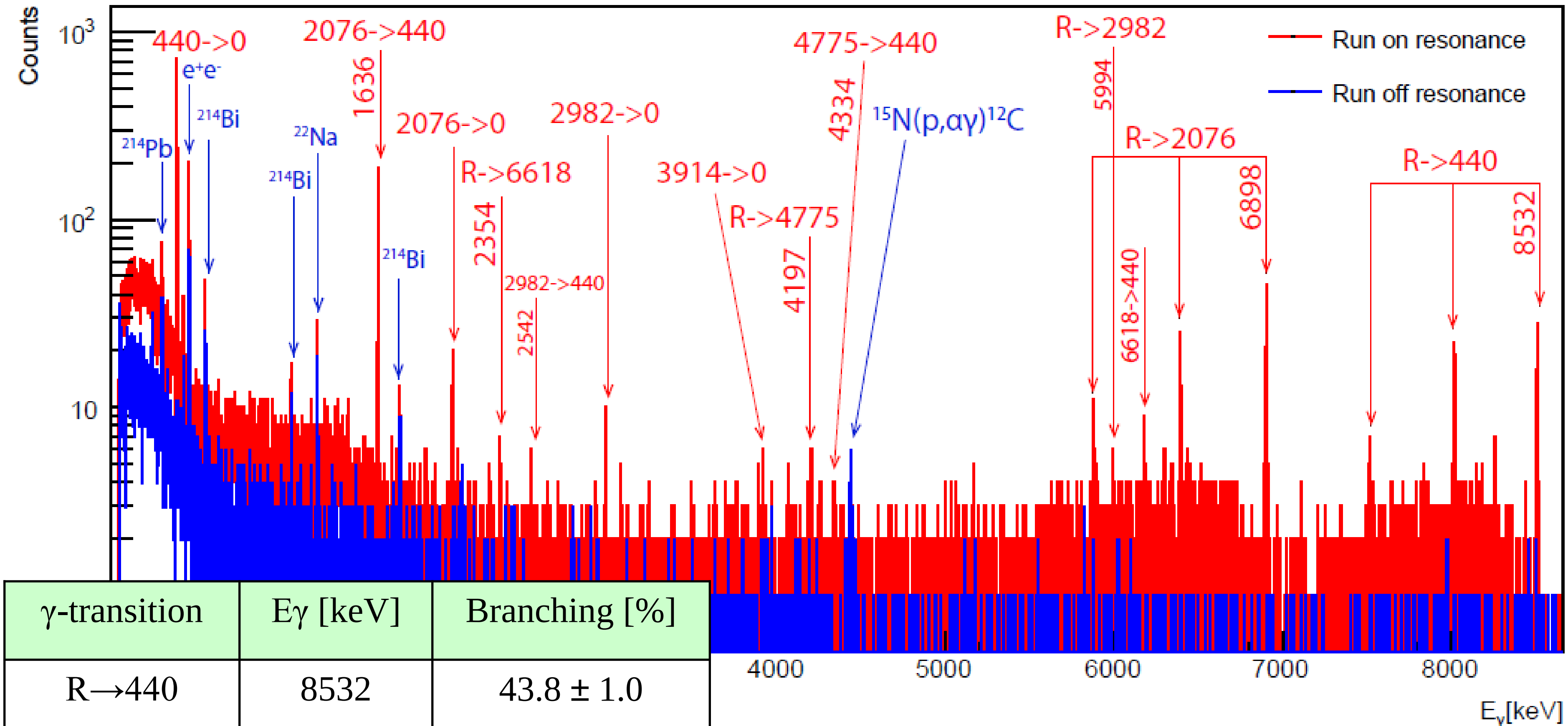
Setup for $^{22}Ne(p,\gamma)^{23}Na$ resonances study



- Two large HPGe detectors (135% and 90% relative efficiency)
- 15-20 cm thick lead shielding
- 5 cm additional copper shield for 55° detector



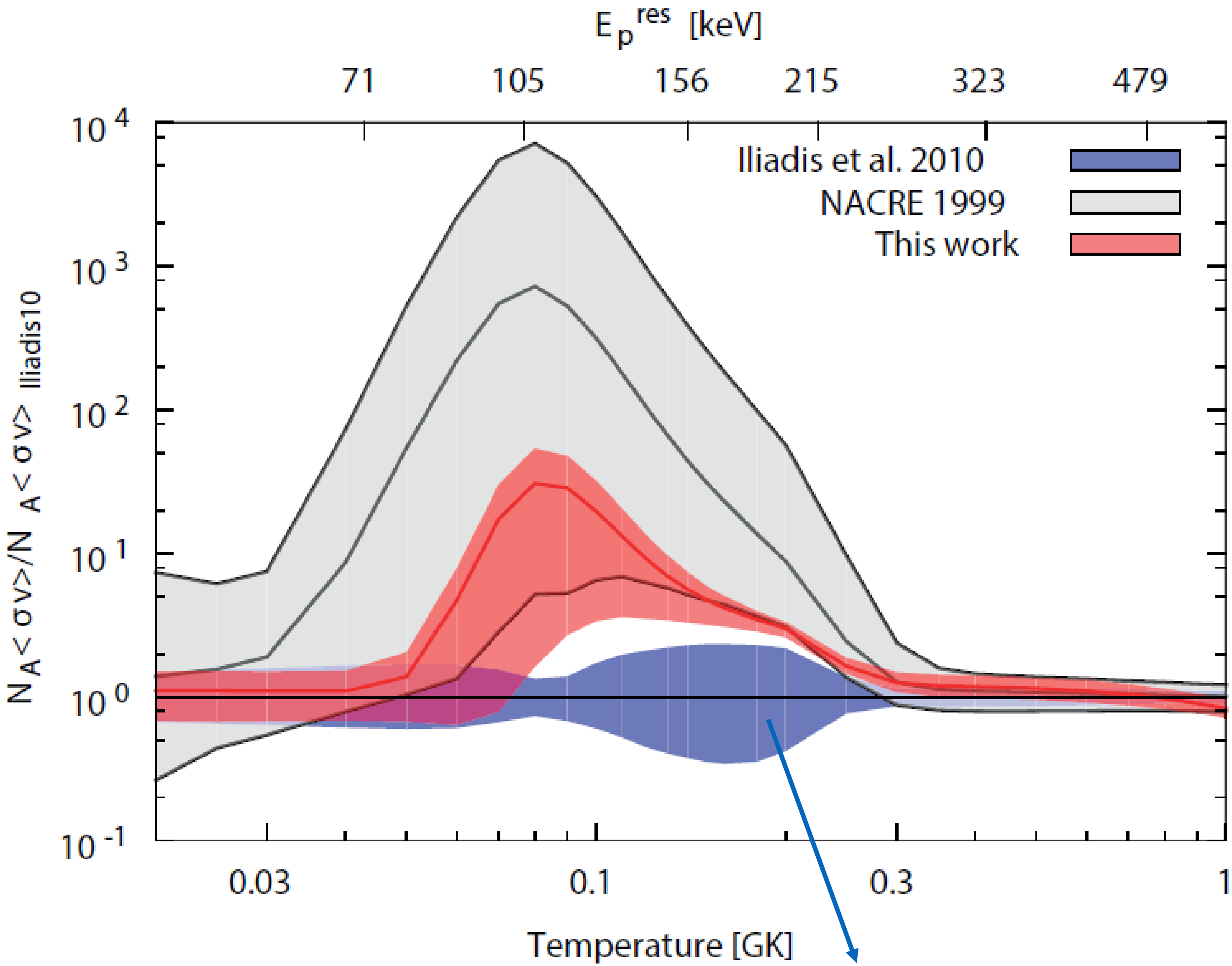
E_R^{lab}=189.5 keV



γ-transition	Eγ [keV]	Branching [%]
R→440	8532	43.8 ± 1.0
R→2076	6896	47.7 ± 0.9
R→2982	5990	3.8 ± 0.5
R→3914	5058	1.0 ± 0.2
R→4775	4197	1.9 ± 0.3
R→6618	2354	2.8 ± 0.2

	ωγ [eV]
Ge55	[1.84 ± 0.04 (stat) ± 0.04 (syst)] 10^{-6}
Ge90	[1.88 ± 0.04 (stat) ± 0.04 (syst)] 10^{-6}
Average	[1.86 ± 0.03 (stat) ± 0.05 (syst)] 10^{-6}

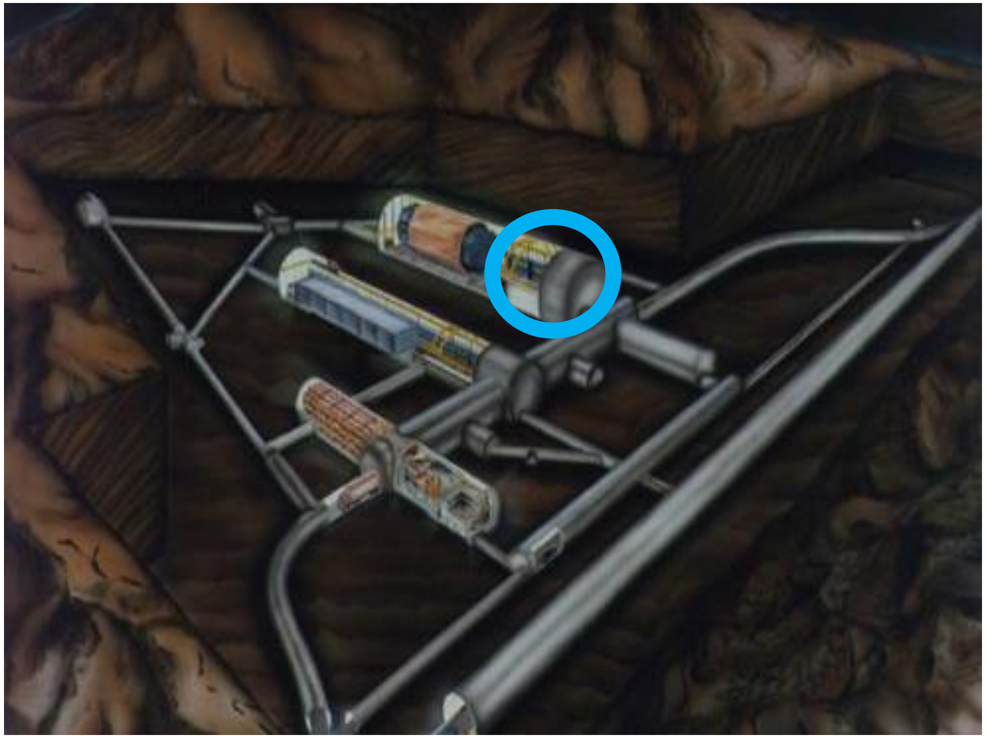
Thermonuclear reaction rate

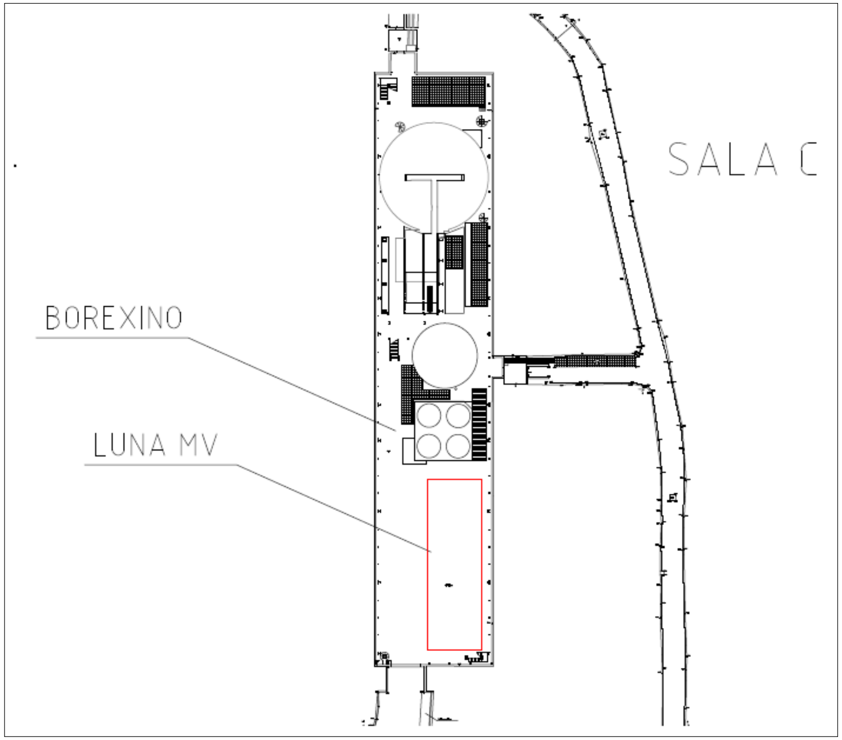


Iliadis rate obtained neglecting the contribution of the resonances at 71, 105 and 215 keV

LUNA MV project

LUNA MV accelerator will be installed in Hall C of LNGS laboratory (next to Borexino/Sox location)





Provisionary dimensions of the hall: 27x11x5 m^3

Site cleaning started in Jan 2015. Should be finished by October 2016

LUNA MV- scientific program (2019 →)

$^{13}C(\alpha,n)^{16}O$: enriched ^{13}C solid target. Neutron detector
Data taking at LUNA 400 kV in 2018.

$^{22}Ne(\alpha,n)^{25}Mg$: enriched ^{22}Ne gas target. Neutron detector.

$^{12}C(\alpha,\gamma)^{16}O$: ^{12}C solid target depleted in ^{13}C and alpha beam or α jet gas target and ^{12}C beam.

Conclusions

- Thanks to the extremely low background and the high luminosity of the LUNA experiment, many important reactions have been measured in recent years

- Very recently the $^{22}Ne(p,\gamma)^{23}Na$ cross section has been studied down to the energies of astrophysical interest:

  - ✓ **Three resonances (E = 156.2 keV, 189.5 keV and 259.7 keV) have been directly observed for the first time**

  - ✓ The uncertainty on the total thermonuclear reaction rate is strongly reduced compared to previous works

  - ✓ Resonances strength presently known as u.l. (E = 71 keV and 105 keV) will be further investigated in a second ongoing phase of the experiment to finalize the reaction rate calculation

- The LUNA-MV project is started: The aim is to measure key reactions of Helium-burning and important reactions for the s-process neutron source

The LUNA collaboration

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Thanks for your attention!