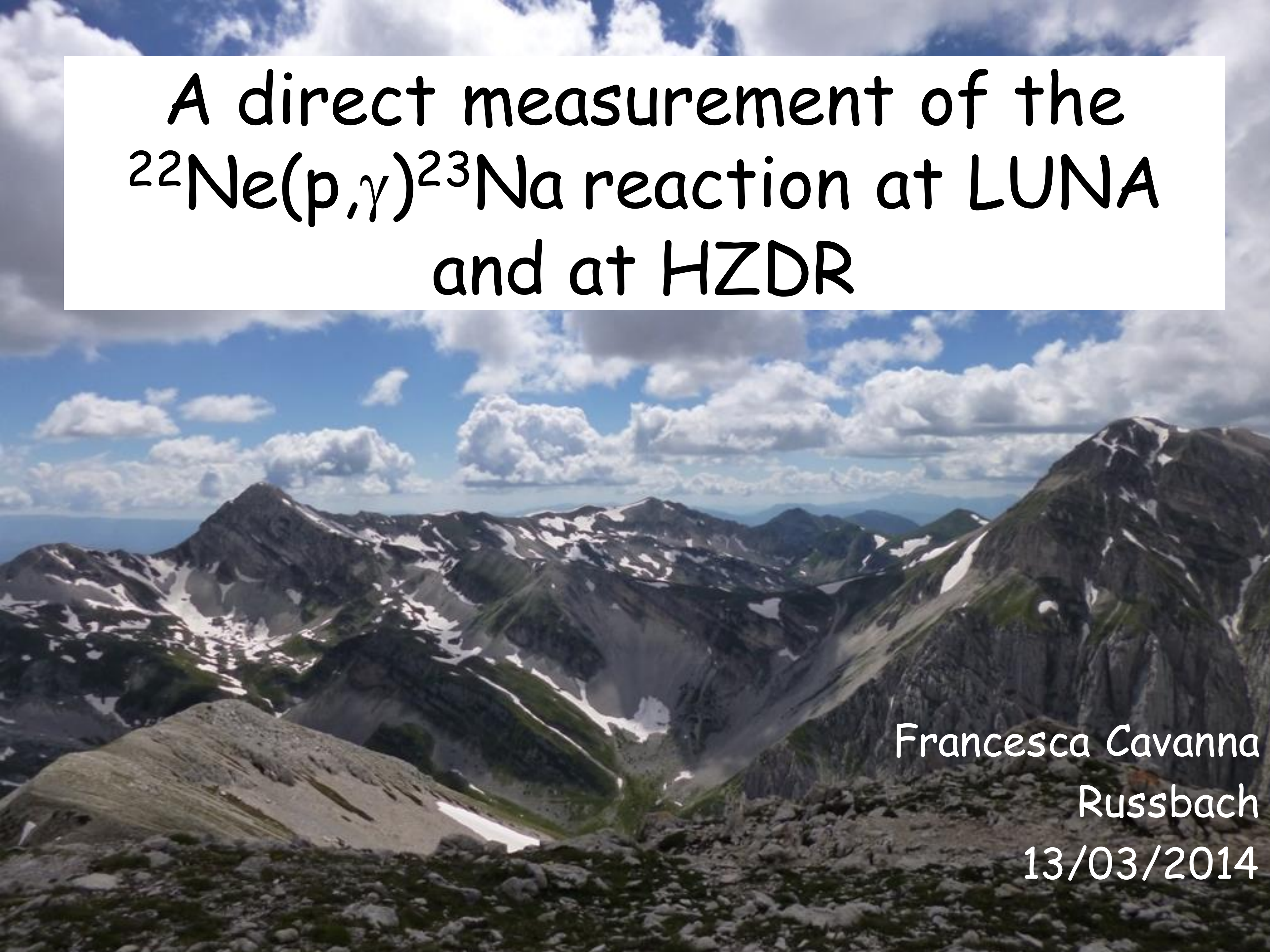
A direct measurement of the $^{22}Ne(p,\gamma)^{23}Na$ reaction at LUNA and at HZDR



Francesca Cavanna

Russbach

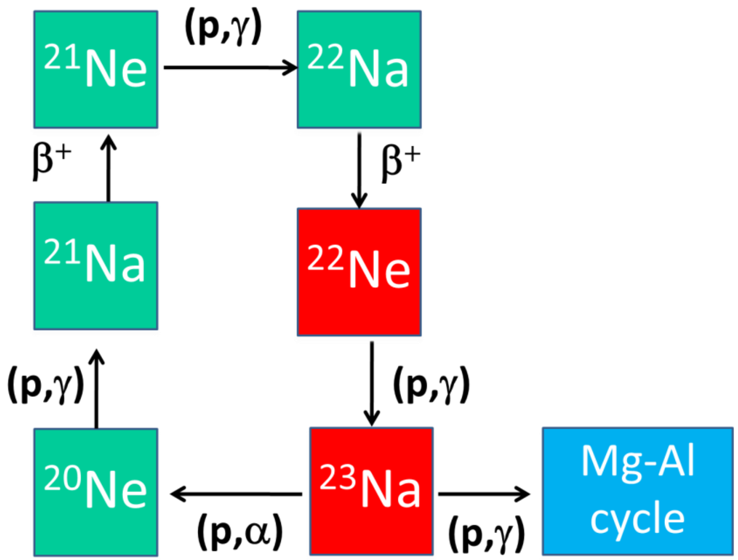
13/03/2014

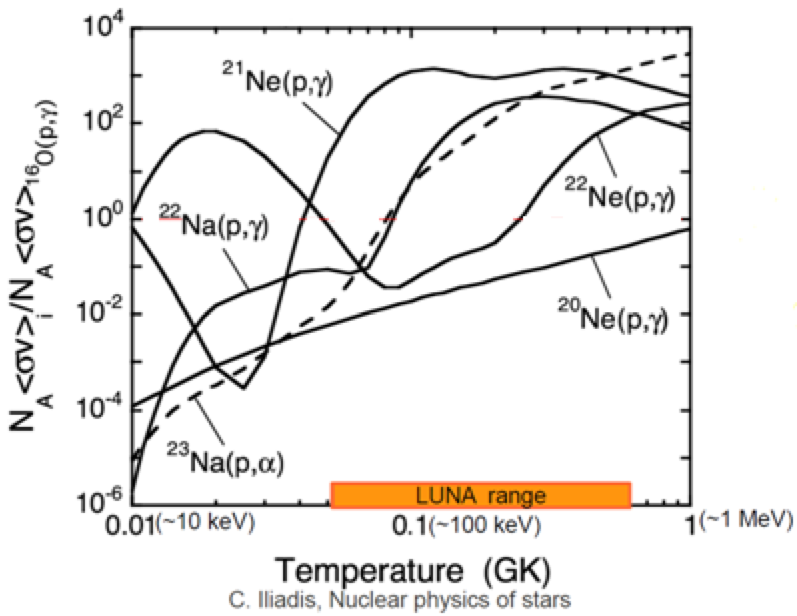
Introduction

- The $^{22}Ne(p,\gamma)^{23}Na$ reaction: astrophysical motivations
- A direct measurement at HZDR Tandetron accelerator
- An ongoing study at LUNA
  - ✓ nuclear astrophysics deep underground
  - ✓ LUNA 400 kV setup
  - ✓ status of the measurement

Astrophysical motivations

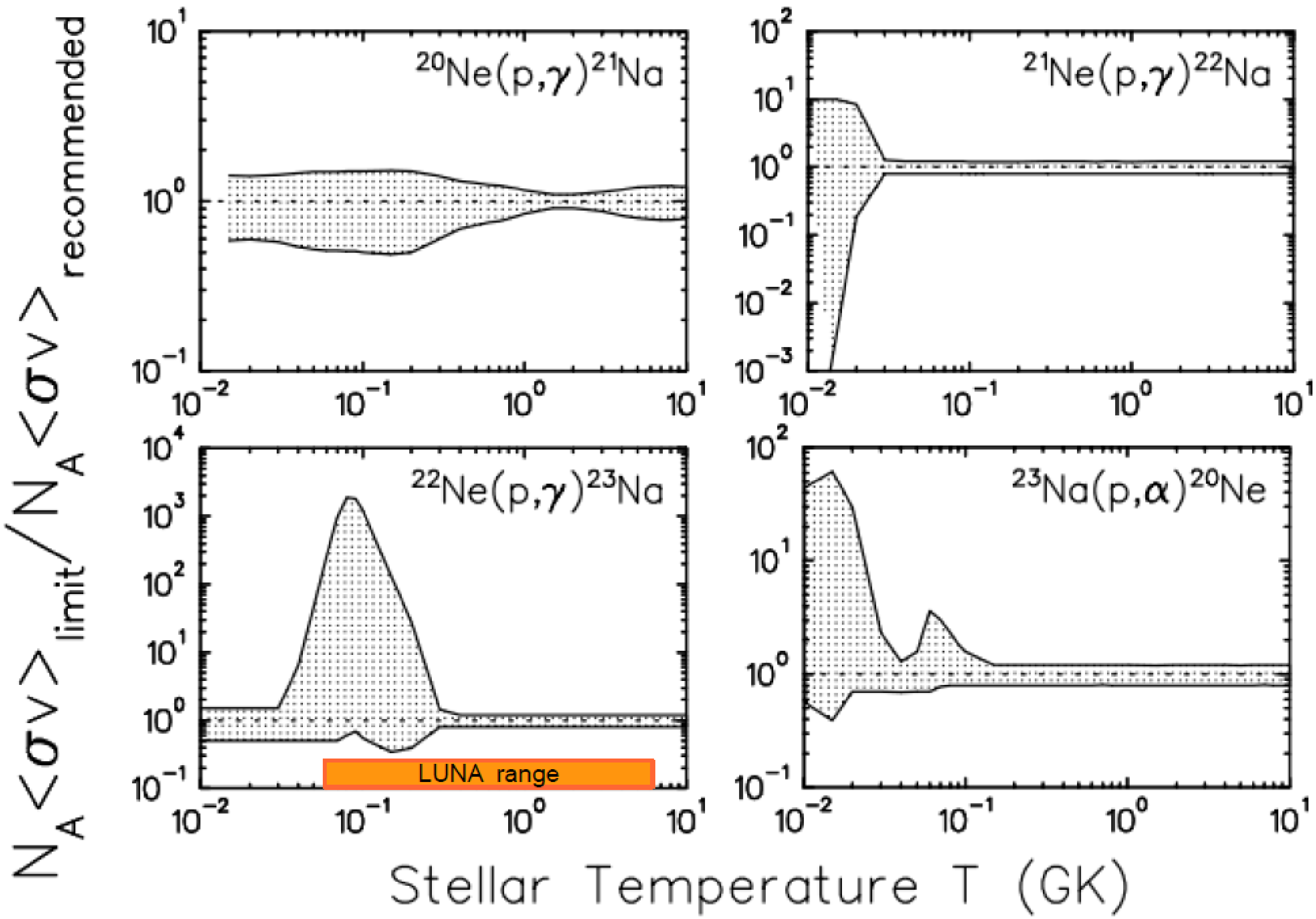
- If $A \geq 20$ seed nuclei are present in the stellar environment, they can contribute to hydrogen burning





- $^{22}Ne(p,\gamma)^{23}Na$ is important for the nucleosynthesis

Reaction rate uncertainties



C. Iliadis et al. ApJSS 134 (2002)

$^{22}Ne(p,\gamma)^{23}Na$: resonances

	E_{lev}[keV]	E_{res}^{LAB}[keV]	$\omega\gamma$[eV]
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RGB	8829.5	37.0	3.1E-15
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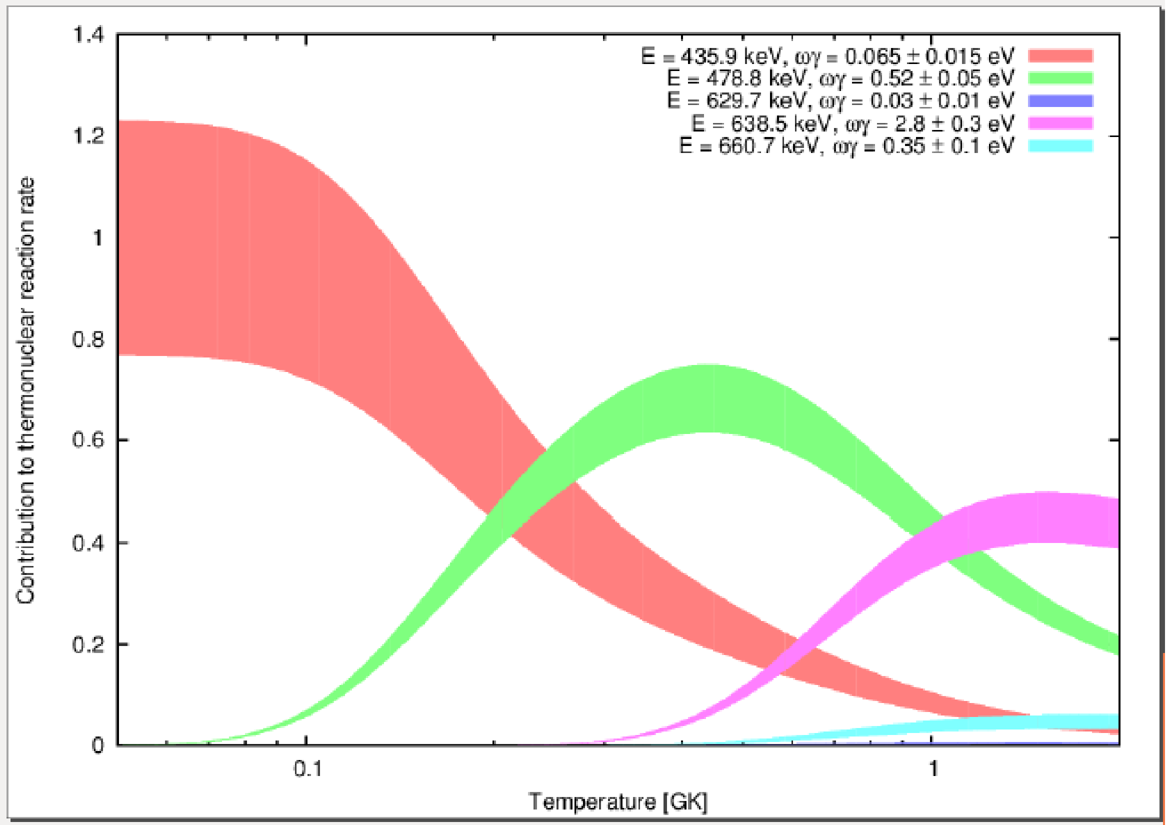

C. Iliadis et al. Nucl. Phys. A 841, 251 - 322 (2010)

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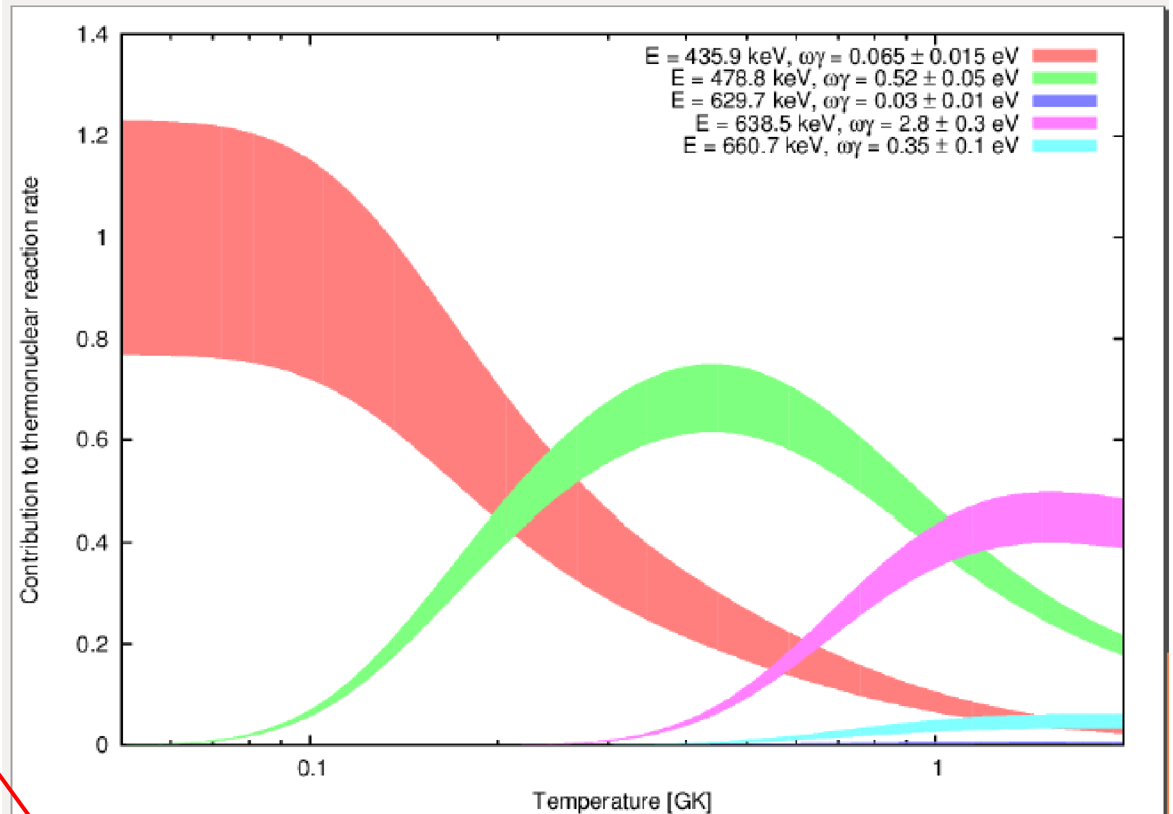

HZDR under analysis

C. Iliadis et al. Nucl. Phys. A 841, 251 - 322 (2010)

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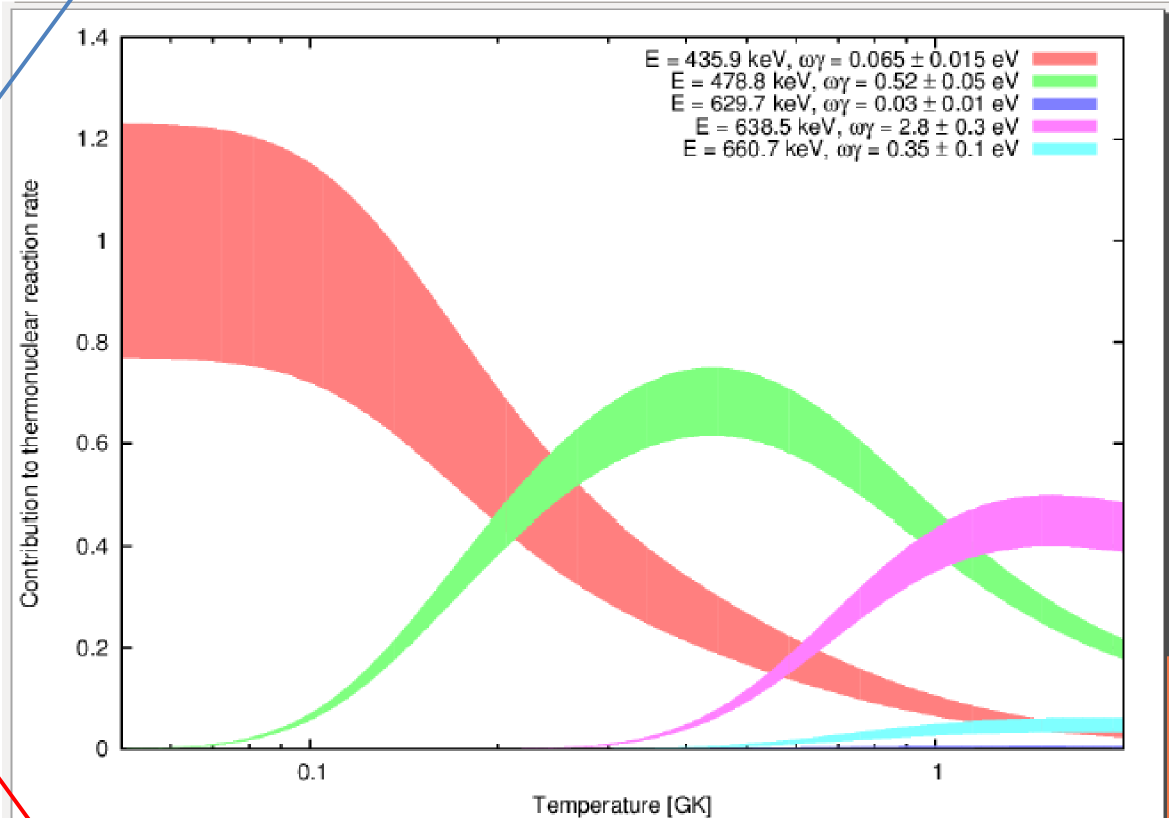
RGB

AGB - Novae

LUNA preliminary test



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C. Iliadis et al. Nucl. Phys. A 841, 251 - 322 (2010)

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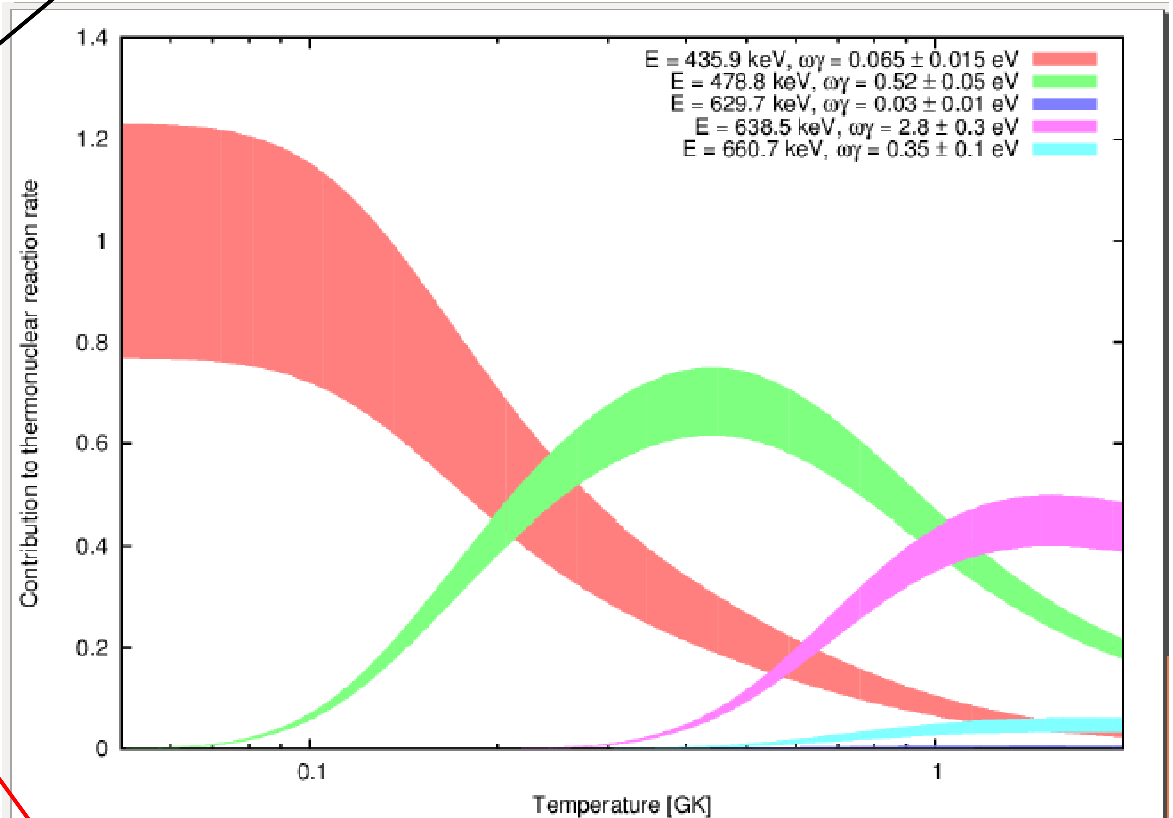
LUNA ongoing measurement



HZDR under analysis

C. Iliadis et al. Nucl. Phys. A 841, 251 - 322 (2010)

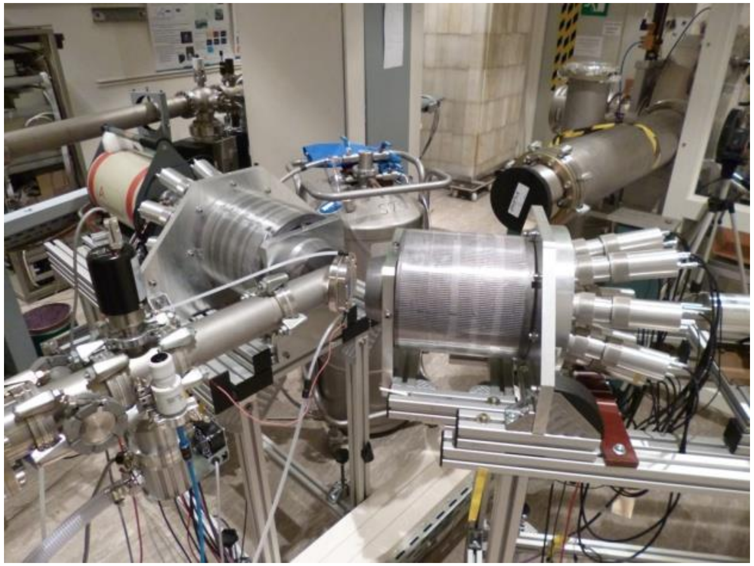
Measurement at the 3 MV Tandetron

HZDR

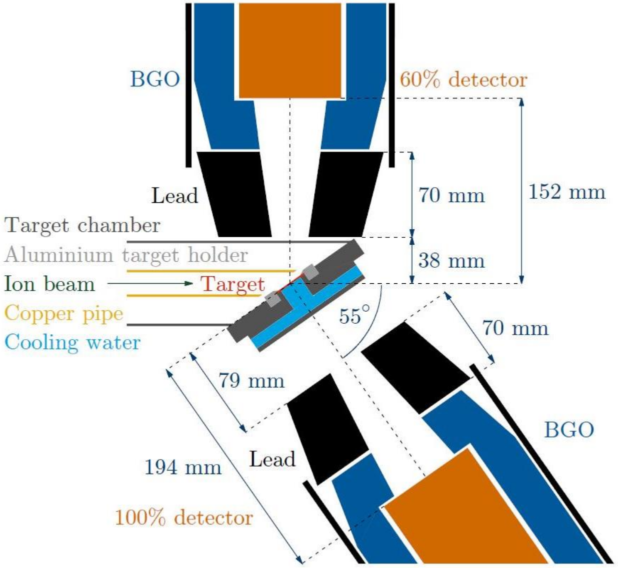
HELMHOLTZ
ZENTRUM DRESDEN
ROSSENDORF

- 5 days of beam time
- 3 MV Tandetron accelerator at HZDR
  - ✓ Ebeam: 0.1 – 3MV
  - ✓ Ibeam: 7 μA
- Supported by the SPIRIT project and INFN
- Measurement of the resonance at E_{lab}=436 keV

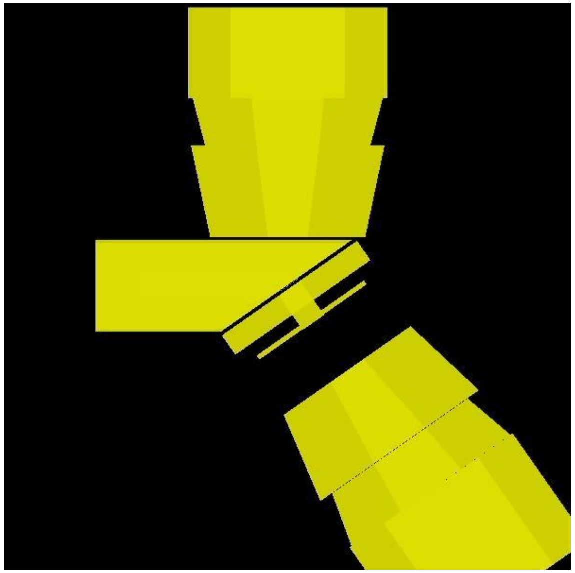
Measurement at the 3 MV Tandetron

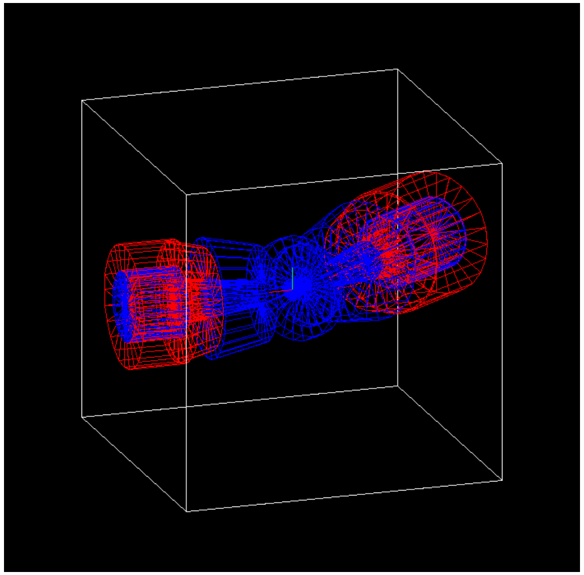


Experimental setup



Geant 4 simulations





Targets and setup

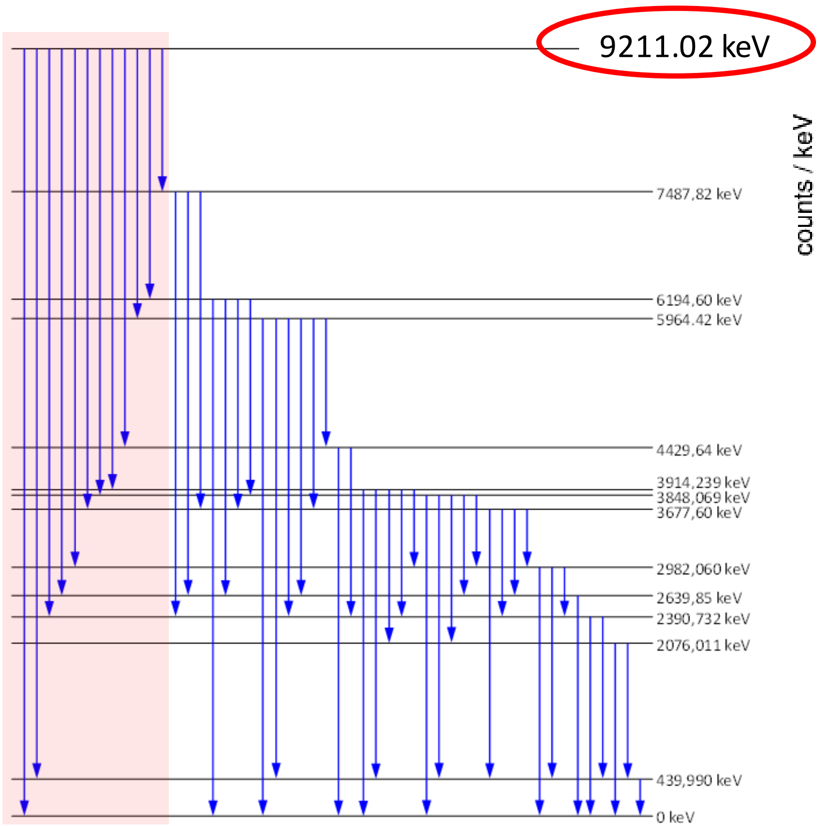
- Solid targets prepared at Legnaro National Laboratory implanter
  - ✓ ^{22}Ne implanted on Ta backing (27 mm diameter, 0.22 mm thickness)
  - ✓ Implantation energies: 150 keV (dose: 1.5 10^{17} at/cm^2) and 70 keV (dose: 0.7 10^{17} at/cm^2)
  - ✓ Stoichiometry and target stabilty checked through the well known $^{22}Ne(p,\gamma)^{23}Na$ resonance at E_{lab}= 1279 keV
  - ✓ Ne:Ta ≈ 1:8
- Setup: two HPGe detectors with BGO anticompton shielding

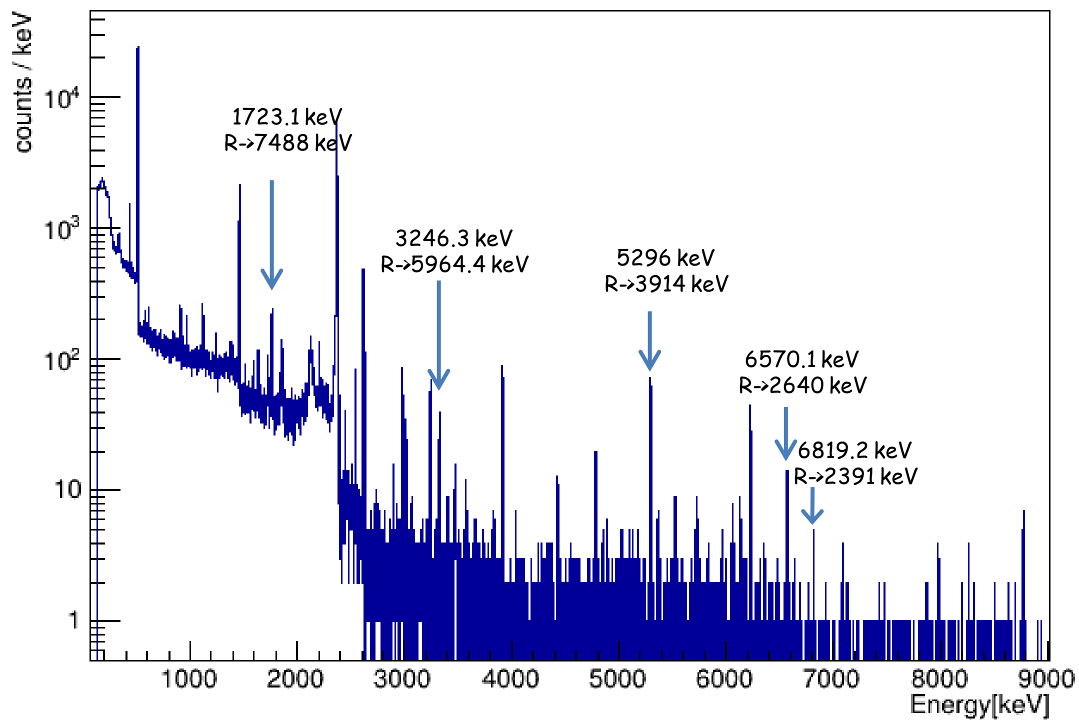
Preliminary results

Strength of the 436 keV resonance compatible with the literature but with a smaller error

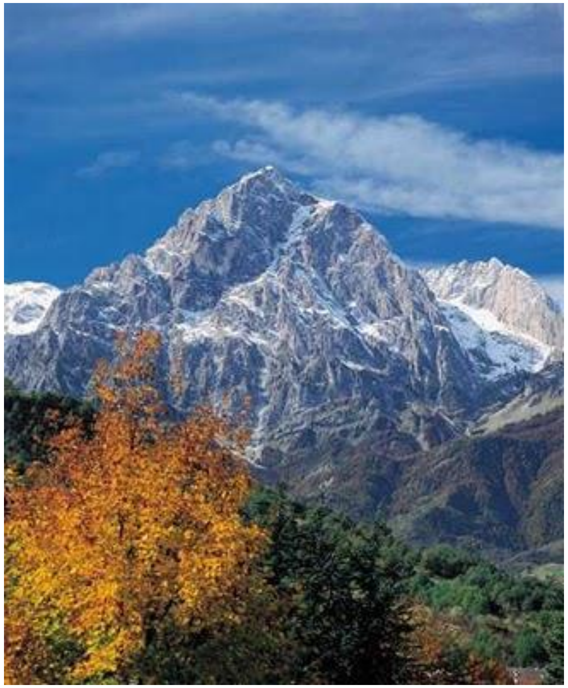
$\omega\gamma_{lit}$ = (0.065 ± 0.015) eV → $\omega\gamma$ = (0.071 ± 0.009) eV

C. Iliadis et al. Nucl. Phys. A 841, 251 - 322 (2010)





Nuclear astrophysics deep underground



- ✓ HPGe detector (η=135%) shielded by 4 cm copper and 25 cm lead
- ✓ BGO detector (4π): 7 cm radial thickness and 28 cm length

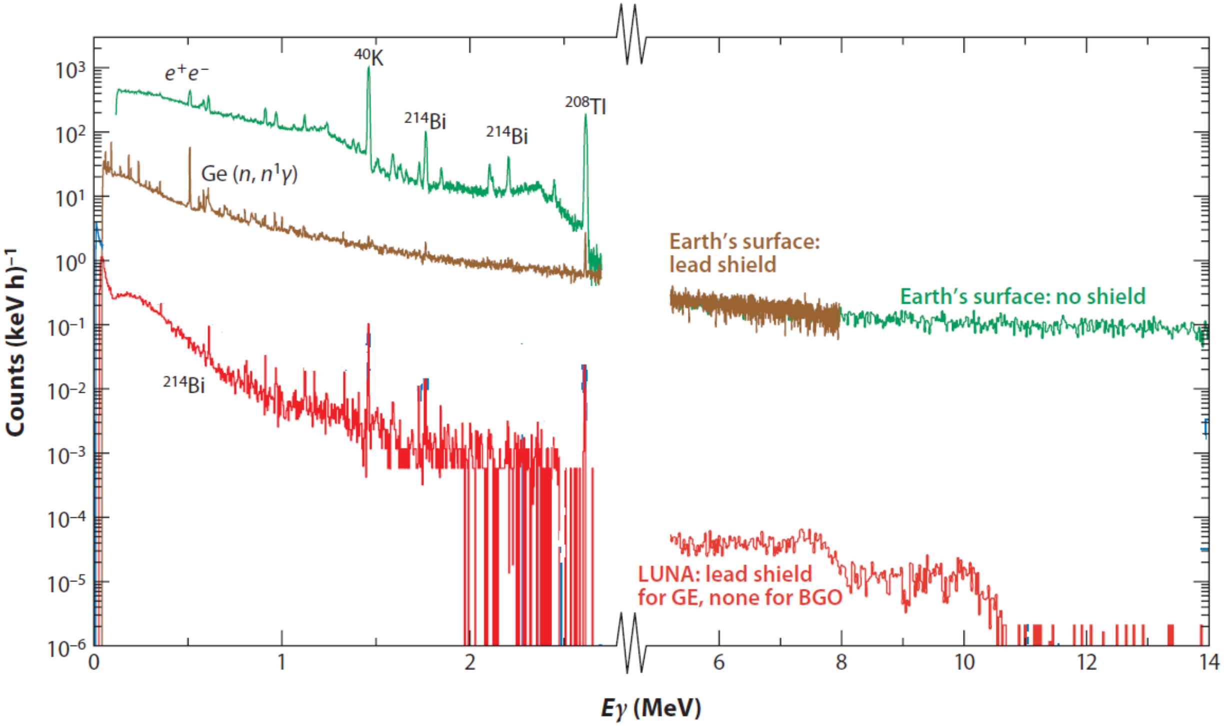
- 0.5 MeV < E_γ < 8 MeV
  - ✓ 0.5 counts/s

⬇

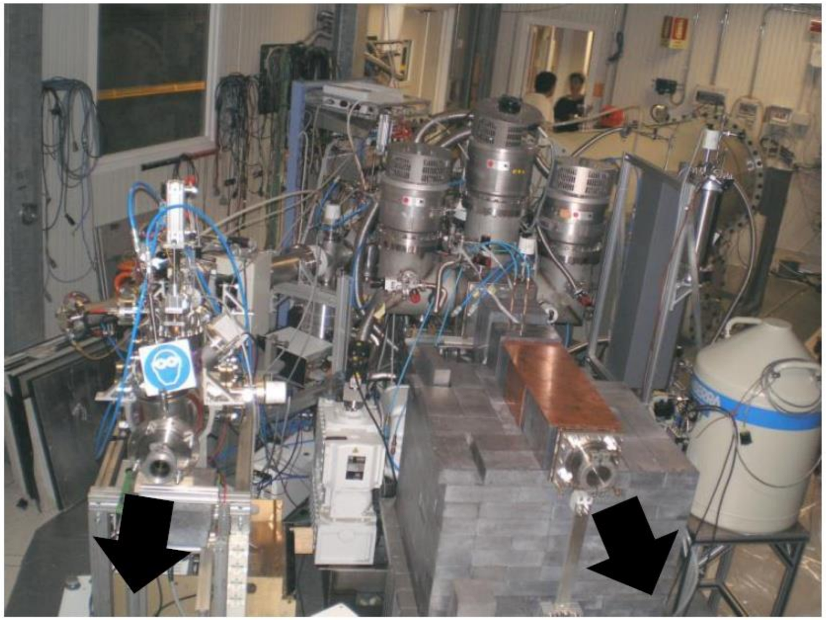
going underground

- 0.5 MeV < E_γ < 8 MeV
  - ✓ 0.0002 counts/s

Measured by HPGe detector



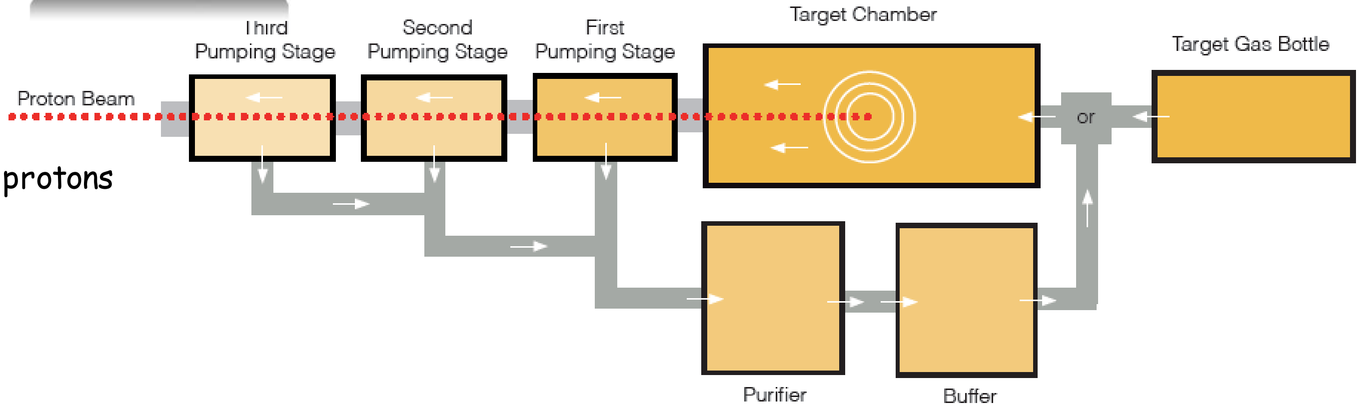
LUNA setup



Solid target

Gas target

- ✓ Beam energy: 50 – 400 keV
- ✓ Maximum current: 500 μA for protons
- ✓ Energy spread: 100 eV
- ✓ Long term stability: 5 eV/h



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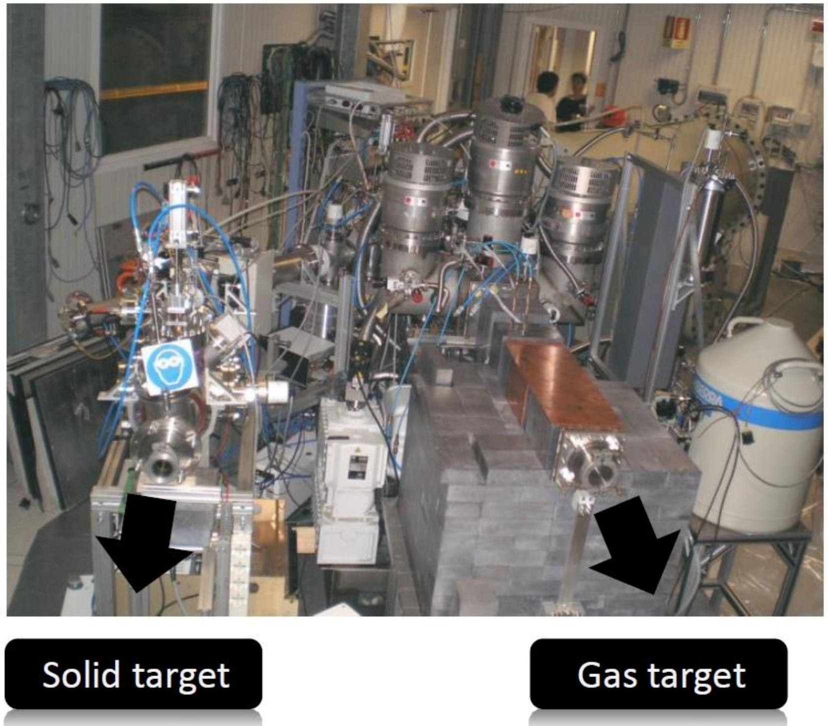

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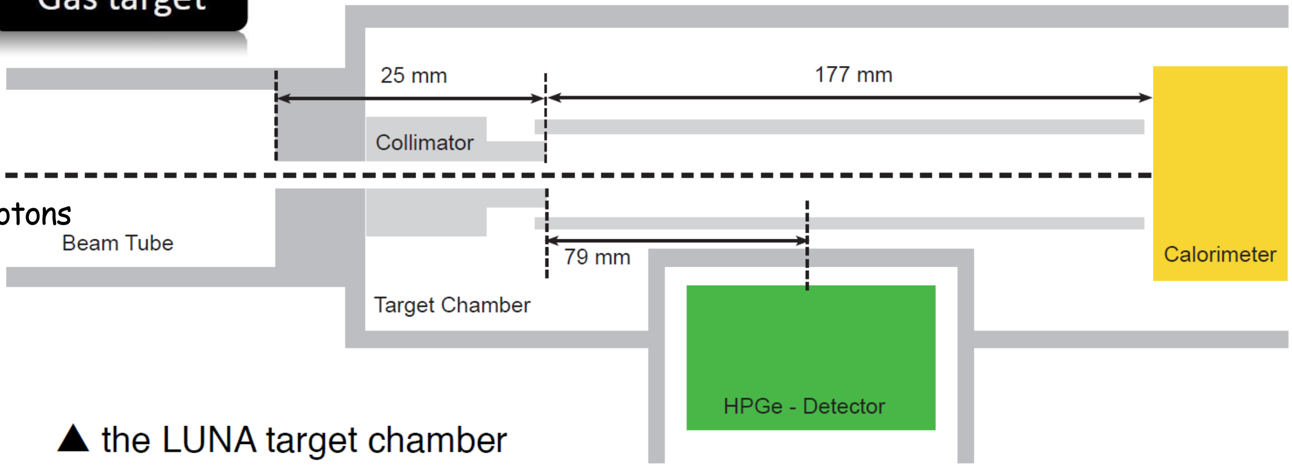


▲ the LUNA target chamber

Different phases of the experiment

Measurement of the $^{22}Ne(p,\gamma)^{23}Na$ cross section with isotopically enriched ^{22}Ne gas:

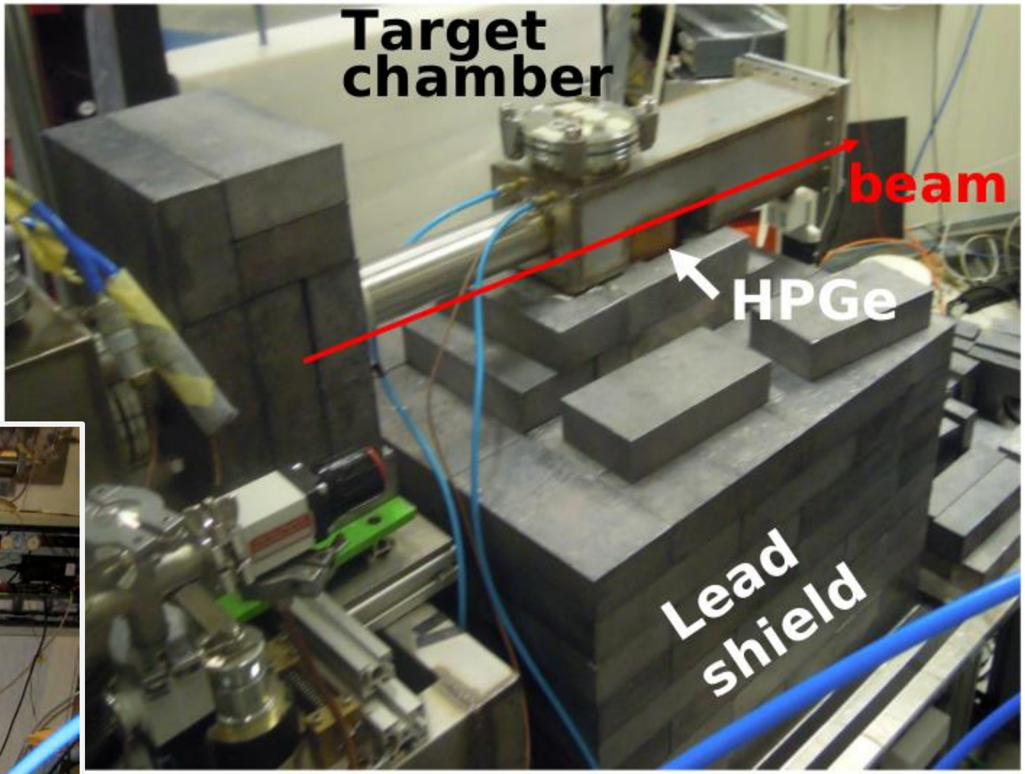
- Germanium detectors
  - ✓ Measurement of different branching ratios of the resonance decay
- 4π BGO detector:
  - ✓ high E_γ efficiency $\eta \approx 70$ %
  - ✓ Lower energies

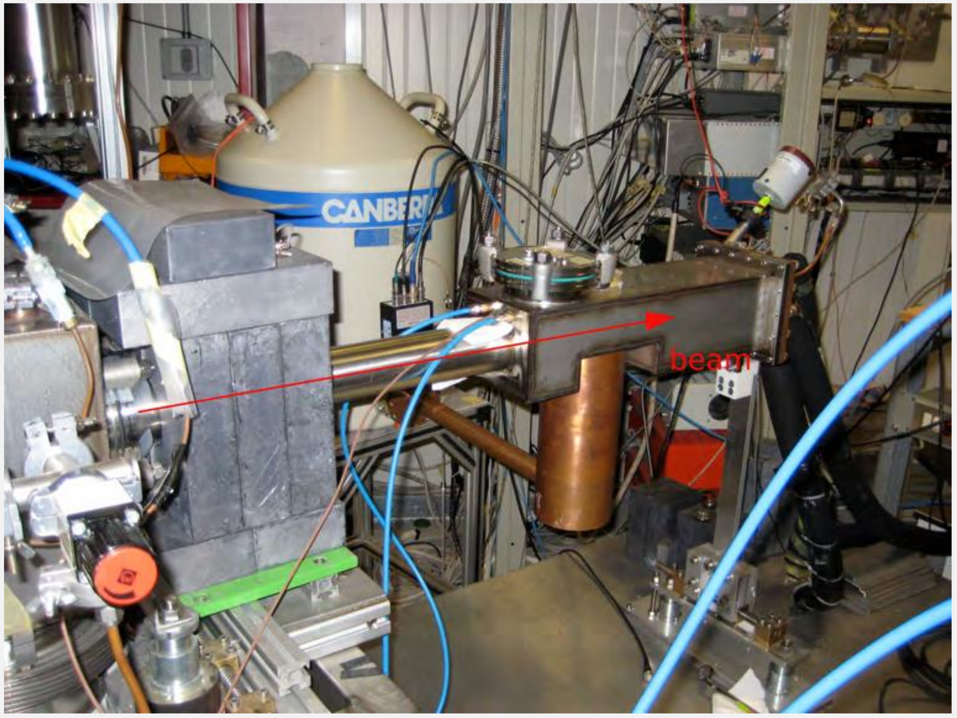
Preliminary measurements:

- test with natural neon gas:
  - ✓ Energy range: 120-400 keV
  - ✓ Germanium detector
- gas target characterization

First test with natural neon: $^{22}Ne(p,\gamma)^{23}Na$

- Use of $^{2}H(\alpha,\gamma)^{6}Li$ setup
- Beam Energy: 120 - 400 keV
- Natural neon gas:
  - ✓ 90.48 % ^{20}Ne
  - ✓ 0.27 % ^{21}Ne
  - ✓ 9.25 % ^{22}Ne





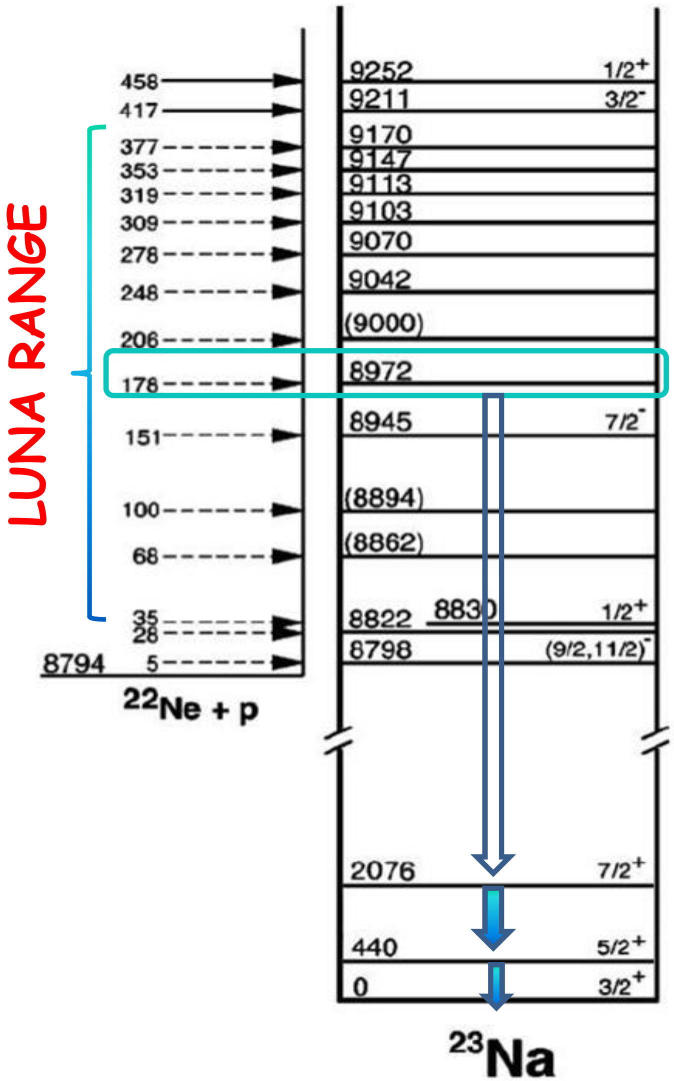
- Windowless gas target
- Pressure: 0.6 - 2.5 mbar

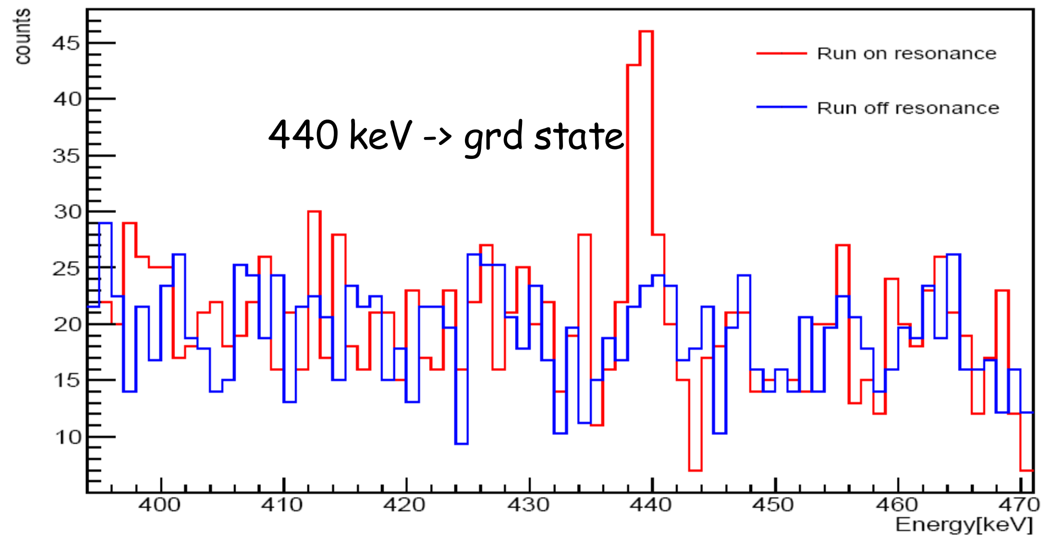
Results of the test

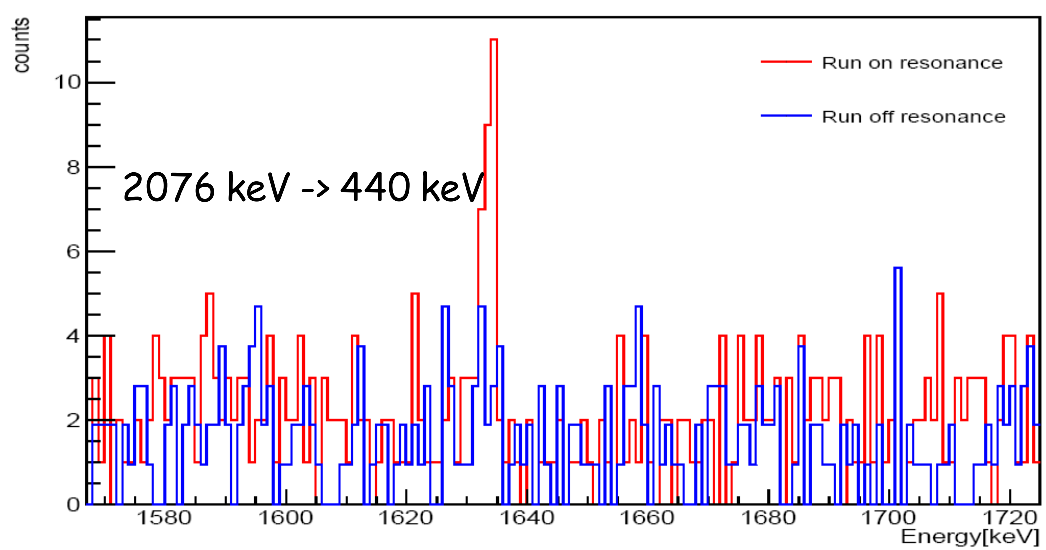
- Resonance observed for the first time
- Previously only upper limits

$\omega\gamma = (2.0^{+0.8}_{-1.2})\, eV$

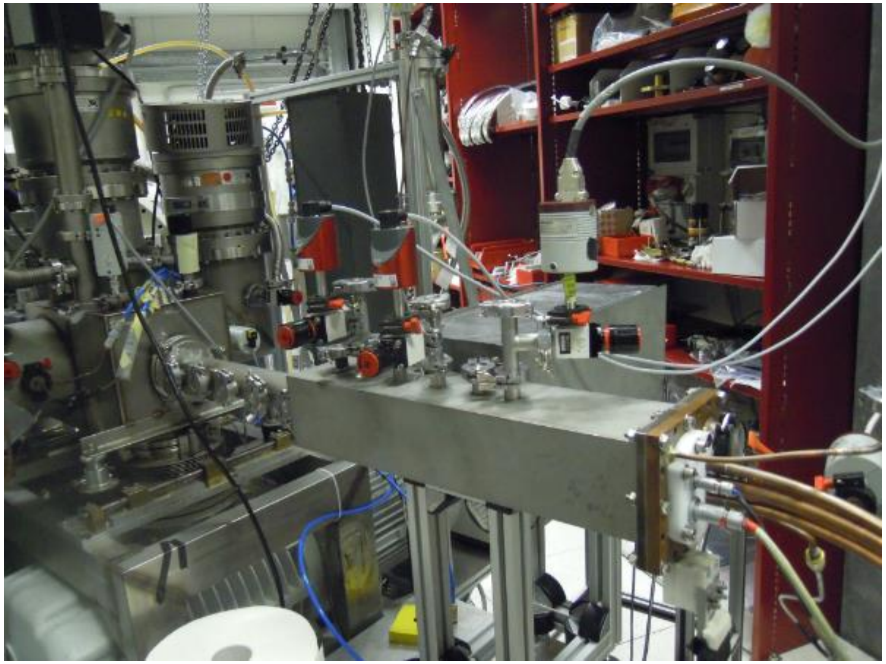
$E_{res} = (186 \pm 2)\, keV$



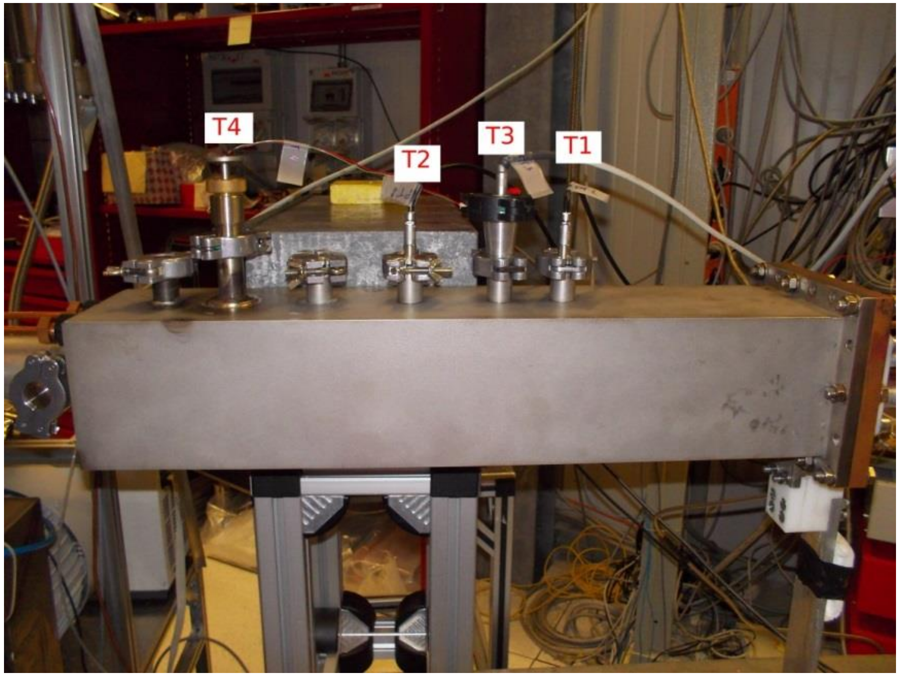




Characterization of the gas target



- Density profile studied without the beam
- Overall accurancy of 0.4%



- Yield:

$$Y = \int_{z_1}^{z_2} \rho(z)\sigma(E(z))\eta(z)dz$$

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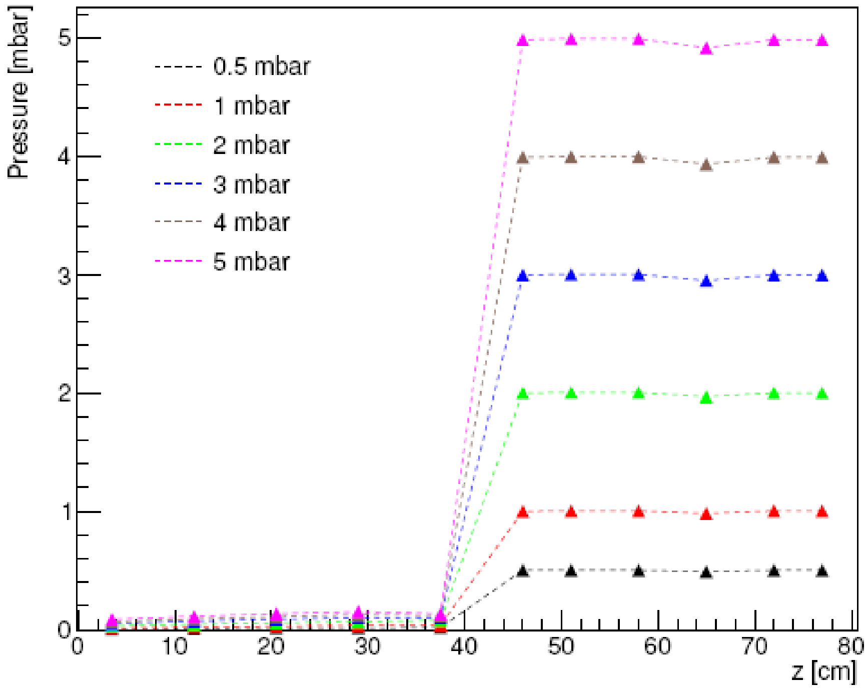

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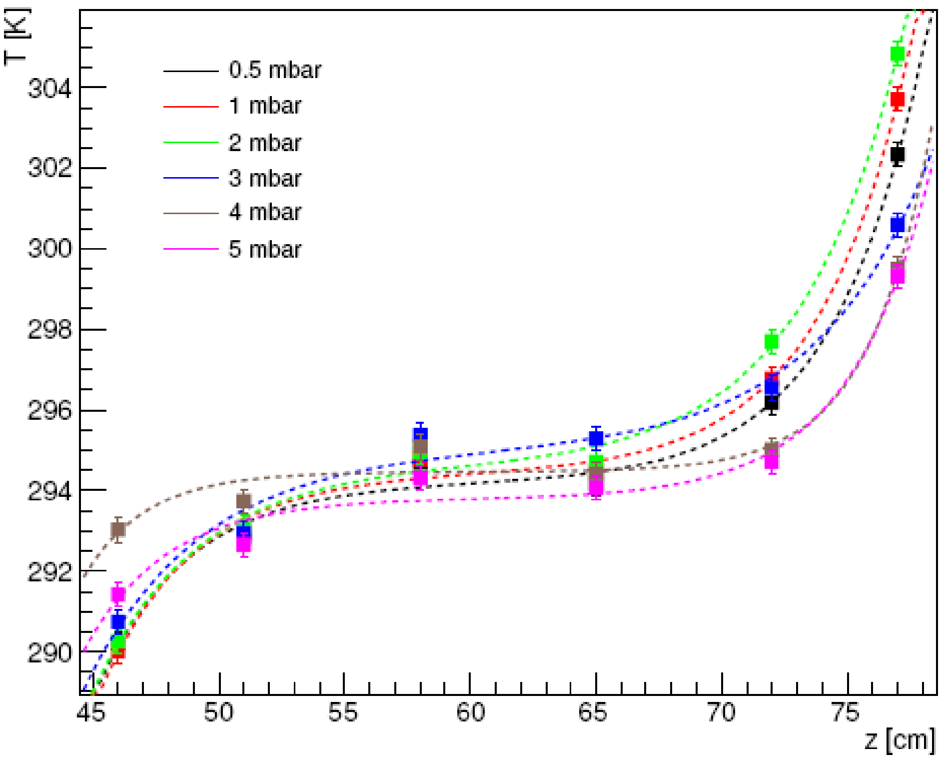

- Yield:

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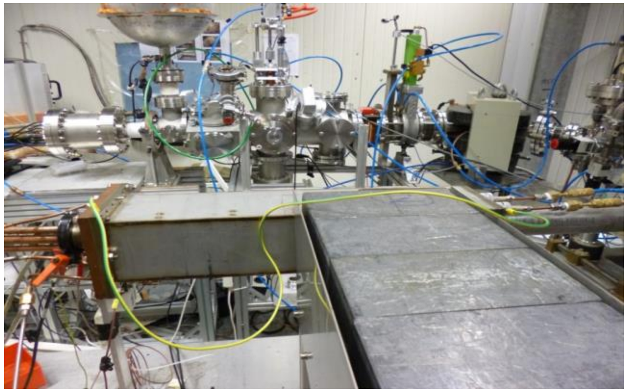
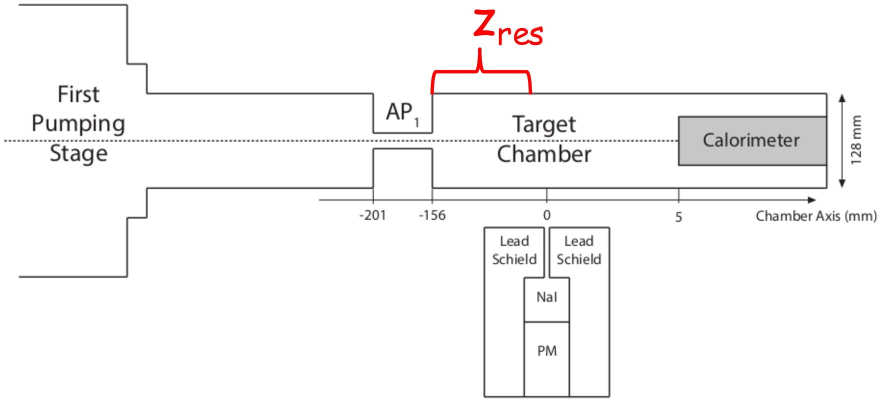
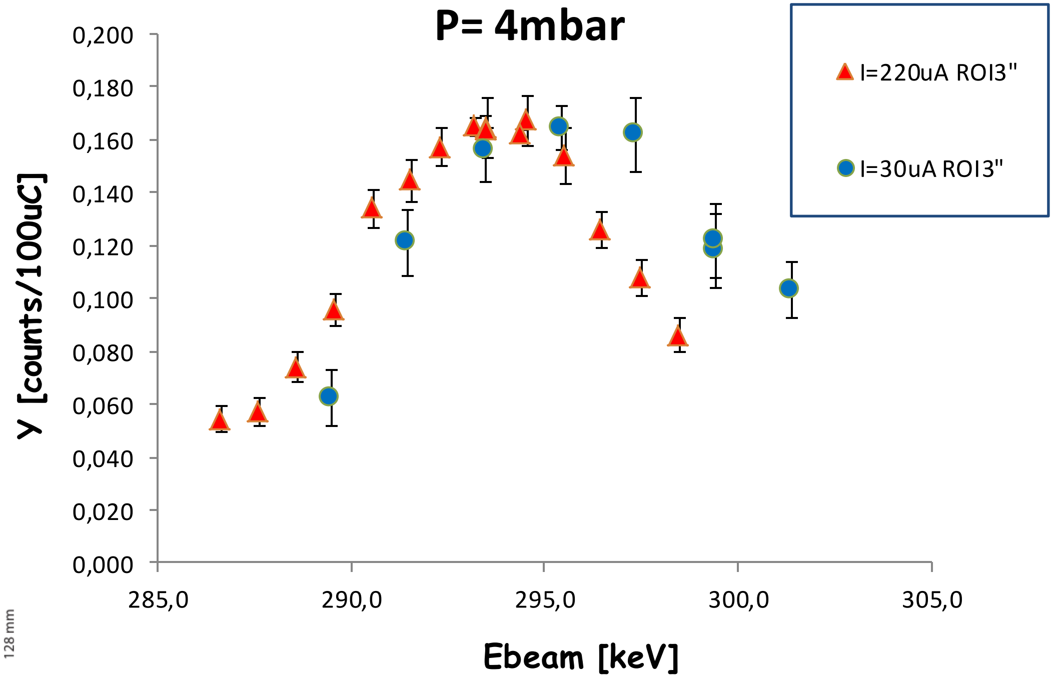
The beam heating effect

- Study of the density variation due to the beam heating
  - Natural neon gas
  - $^{21}Ne(p,\gamma)^{22}Na$ resonance at E_{lab}=274 keV
  - NaI detector (2"x2")

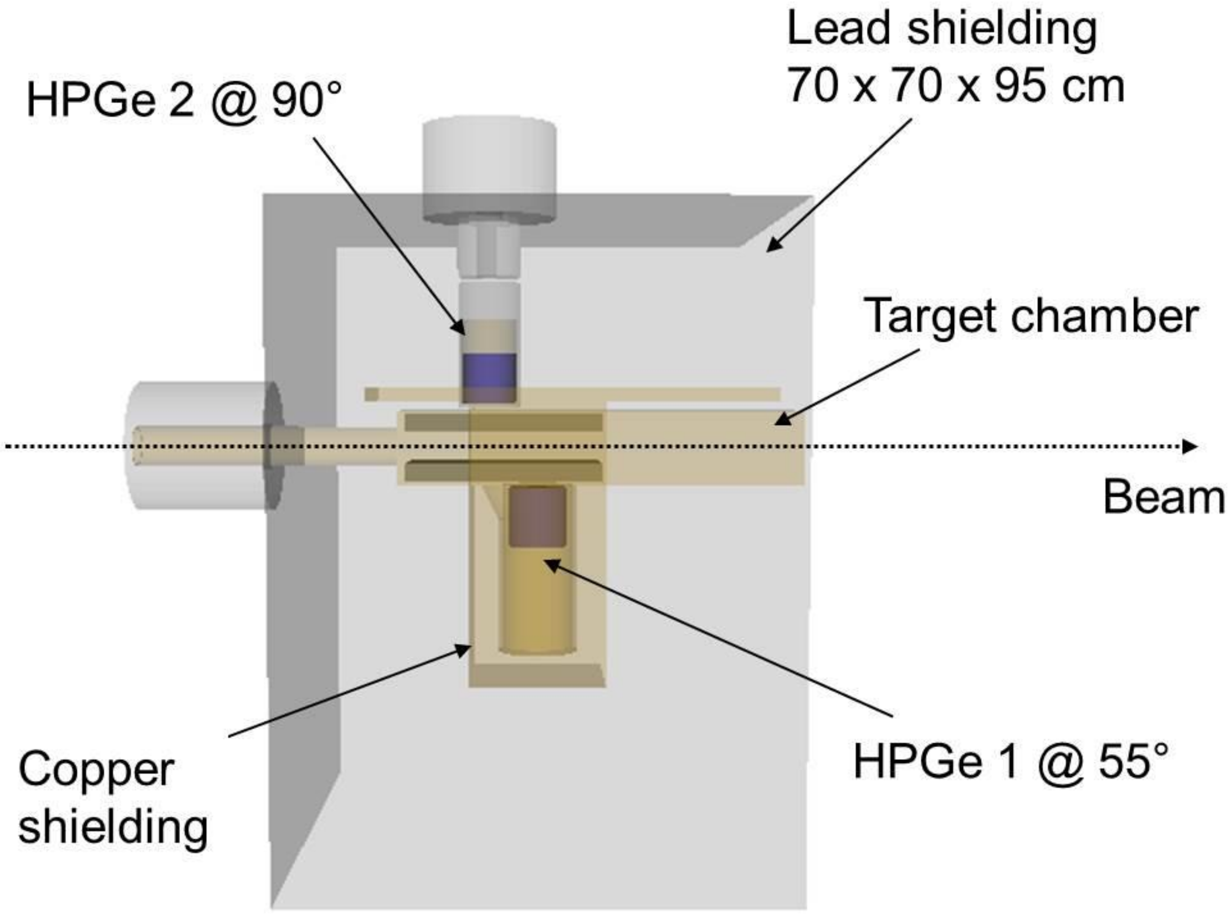






$$E_{res} = E_{beam} - \int_0^{z_{res}} \rho \frac{dE}{d(\rho z)} dz$$

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



~ 4 orders of magnitude background reduction compared to the unshielded detectors

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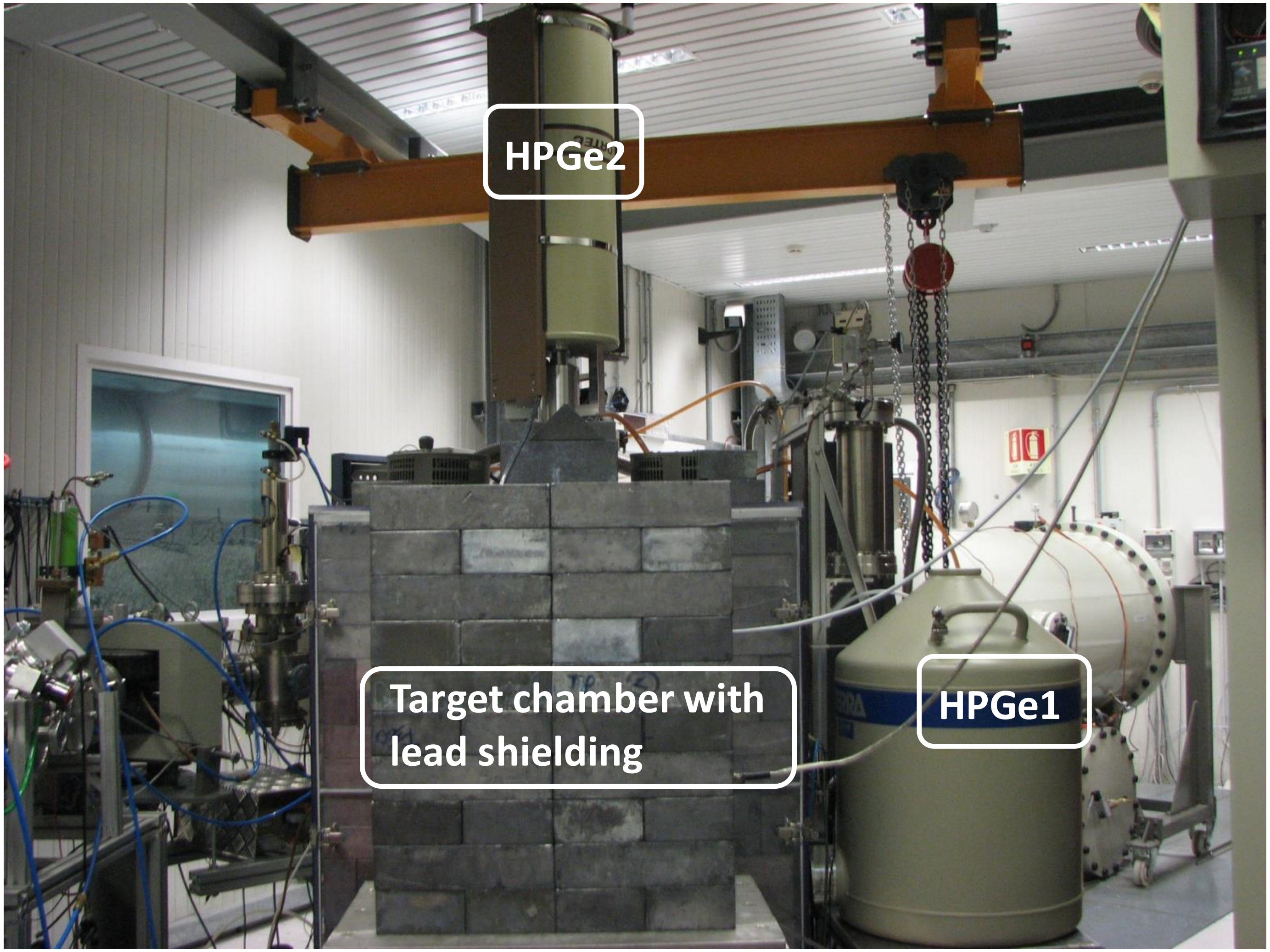

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Resonances observed so far

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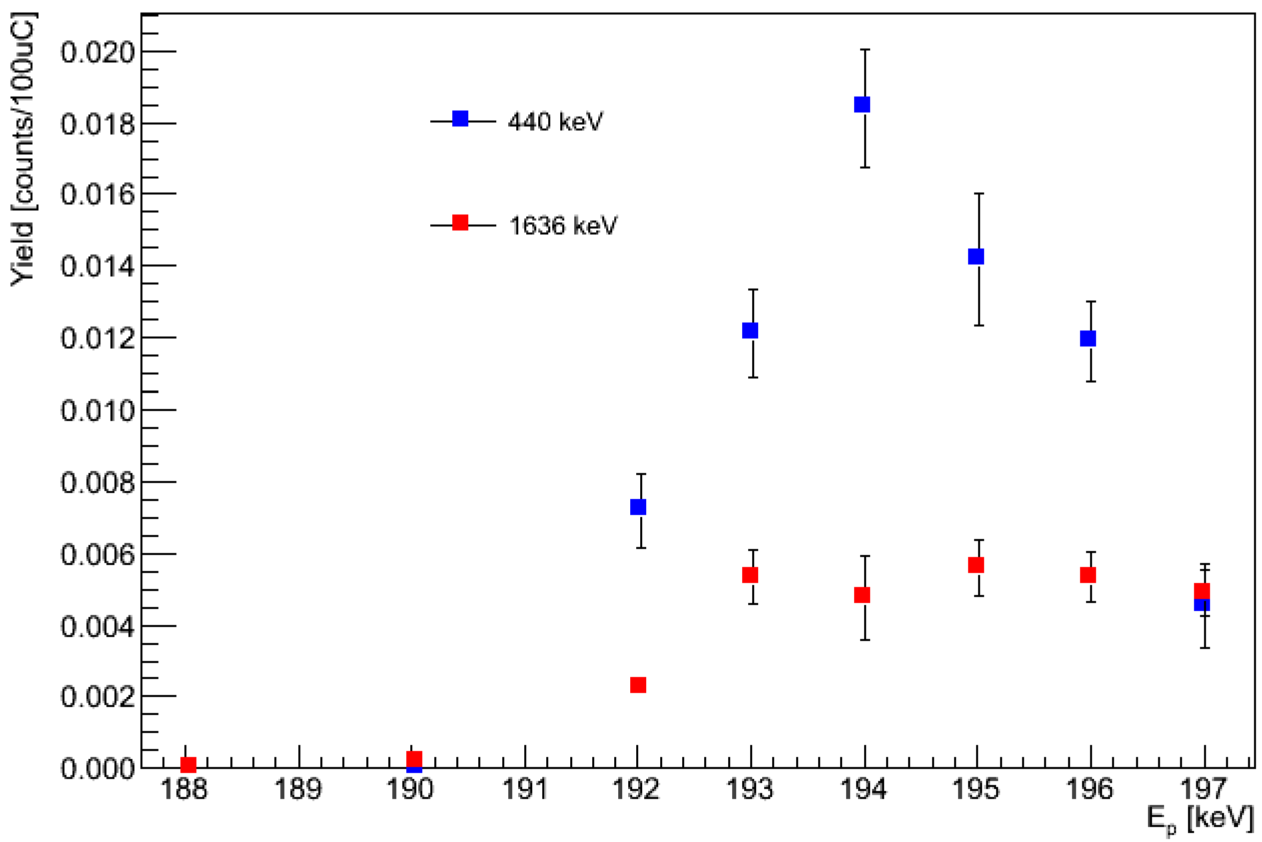
LUNA ongoing measurement

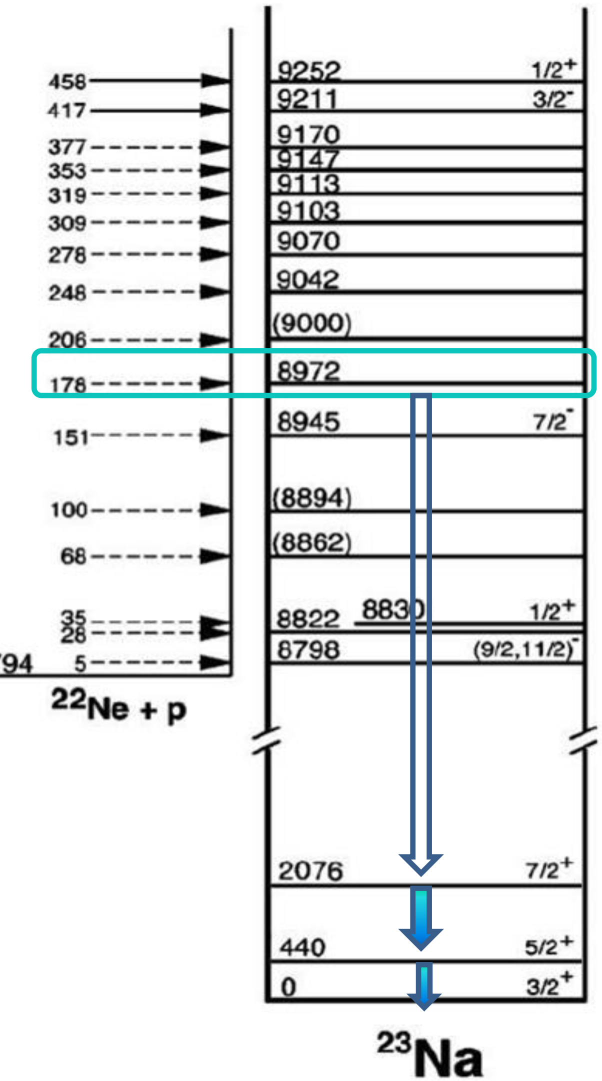
Resonance scan @ E_{res} = 186 keV

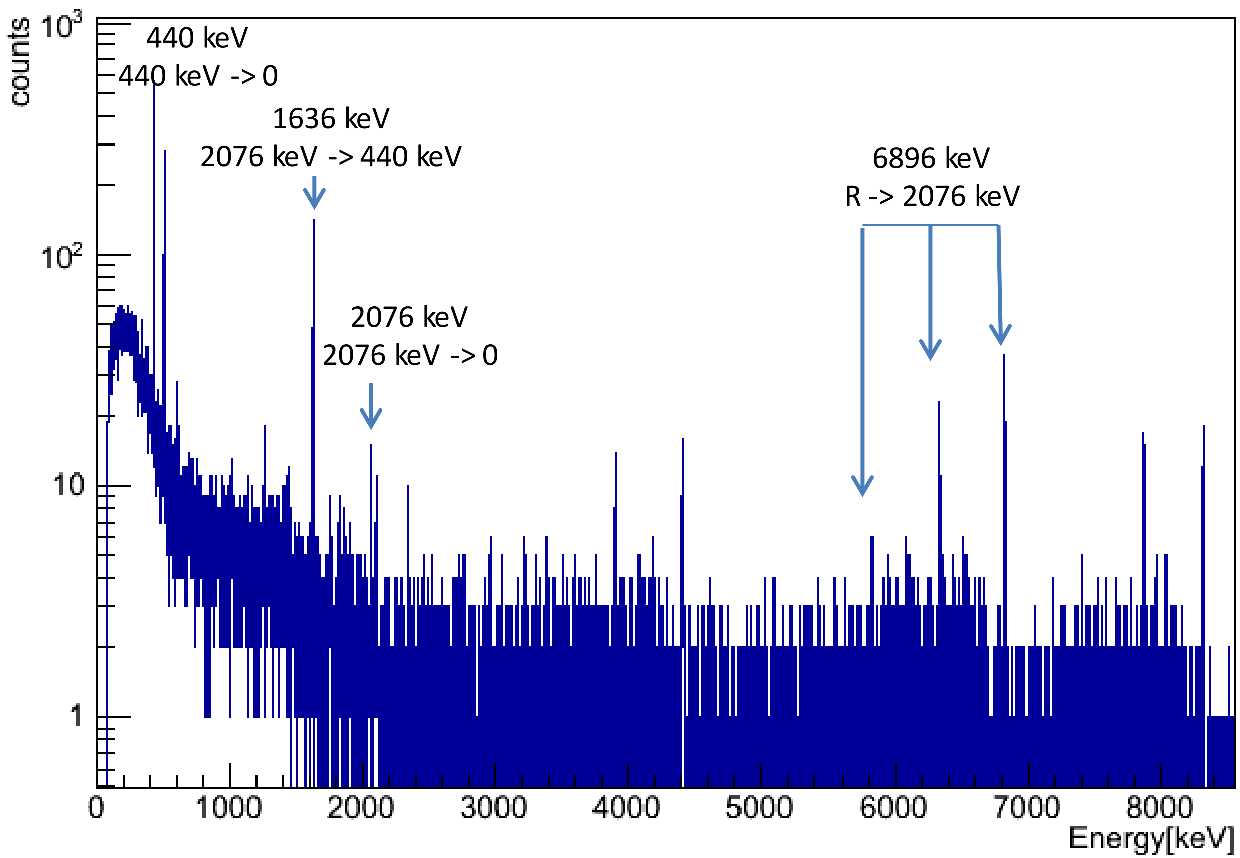
Preliminary results, data taking still ongoing



E_{res} = 186 keV - Long Night Run

Preliminary results, data taking still ongoing

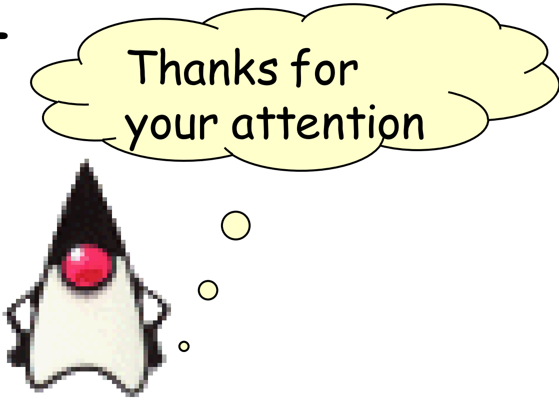




Summary

- Strength of the 436 keV resonance has been measured @ HZDR 3MV Tandetron

- @ LUNA 400 kV, with extremely low background, we are measuring the $^{22}Ne(p,\gamma)^{23}Na$ down to the energies of astrophysical interest
  - Five resonances (E = 158 keV, 186 keV, 256 keV, 323 keV and 333 keV) have been observed so far
  - Data taking will be over in June 2014



LUNA Collaboration

- Laboratori Nazionali del Gran Sasso, INFN, Assergi, Italy:
  A. Best, A. Formicola, M. Junker
- Helmholtz-Zentrum Dresden-Rossendorf, Germany
  D. Bemmerer, T. Szucs, M. Takacs
- INFN, Padova, Italy
  C. Broggini, A. Caciolli, R. Depalo, R. Menegazzo
- INFN, Roma La Sapienza, Italy
  C. Gustavino
- Institute of Nuclear Research (ATOMKI), Debrecen, Hungary
  Zs. Fülöp, Gy Gyurky, E. Somorjai
- Osservatorio Astronomico di Collurania, Teramo, and INFN, Napoli, Italy
  O. Straniero
- Ruhr-Universität Bochum, Bochum, Germany
  F. Strieder
- Seconda Università di Napoli, Caserta, and INFN, Napoli, Italy
  F. Terrasi
- The University of Edinburgh, UK
  M. Alliotta, C. Bruno, D. Scott
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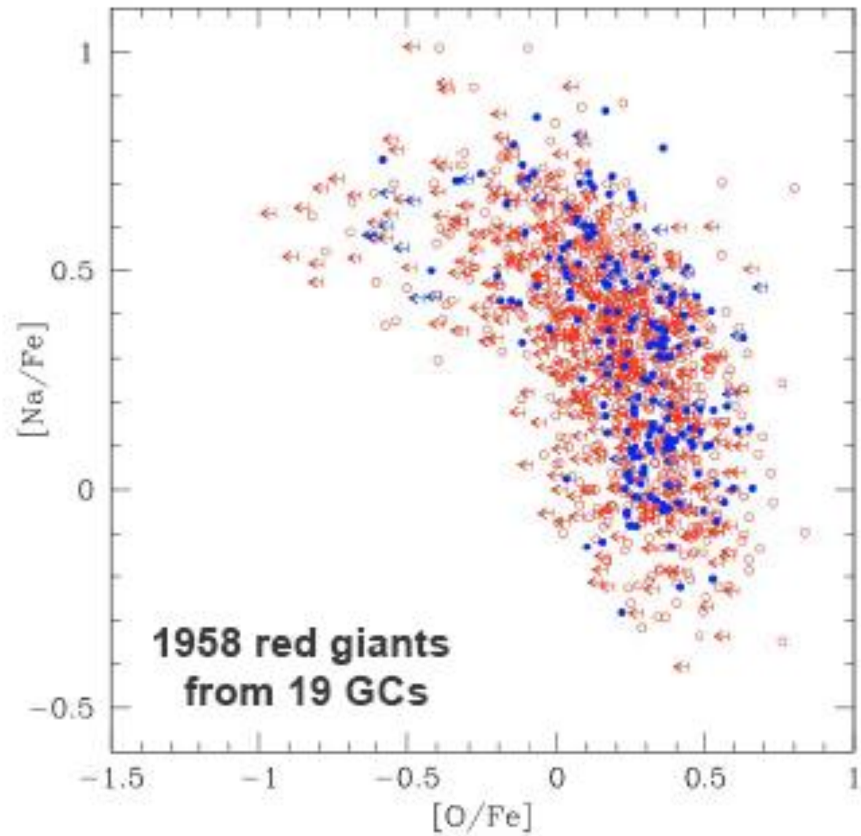
  F. Cavanna, P. Corvisiero, F. Ferraro, P. Prati
- Università di Milano, and INFN, Milano, Italy
  A. Guglielmetti, D. Trezzi
- Università di Napoli "Federico II", and INFN, Napoli, Italy
  G. Imbriani, V. Roca
- INFN, Napoli, Italy
  A. Di Leva
- Università di Torino, and INFN, Torino, Italy
  G. Gervino

Backup slides

Astrophysical motivations

- RGB stars:
  - 0.015 GK <T< 0.06 GK (30 keV <E_{cm}< 90 keV)
  - Na and O abundances are in anticorrelation, this can be explained with the action of CNO and NeNa cycle
  - Understand how the products of hydrogen burning can be brought to the surface



Carretta et al. A&A 505 (2009)

Astrophysical motivations

- AGB stars $0.1<T<0.5$ GK
  - Composition of mass loss because of the stellar wind
- Novae $0.1<T<0.5$ GK $120<E<600$ keV
  - the material accreted on the WD becomes degenerate and the H-burning is ignited in unstable conditions: outer layers are expelled
  - the NeNa cycle is important for the composition of the ejecta