Low-energy resonances in the $^{22}Ne(p,\gamma)^{23}Na$ reaction directly observed at LUNA

F. Cavanna for the LUNA collaboration

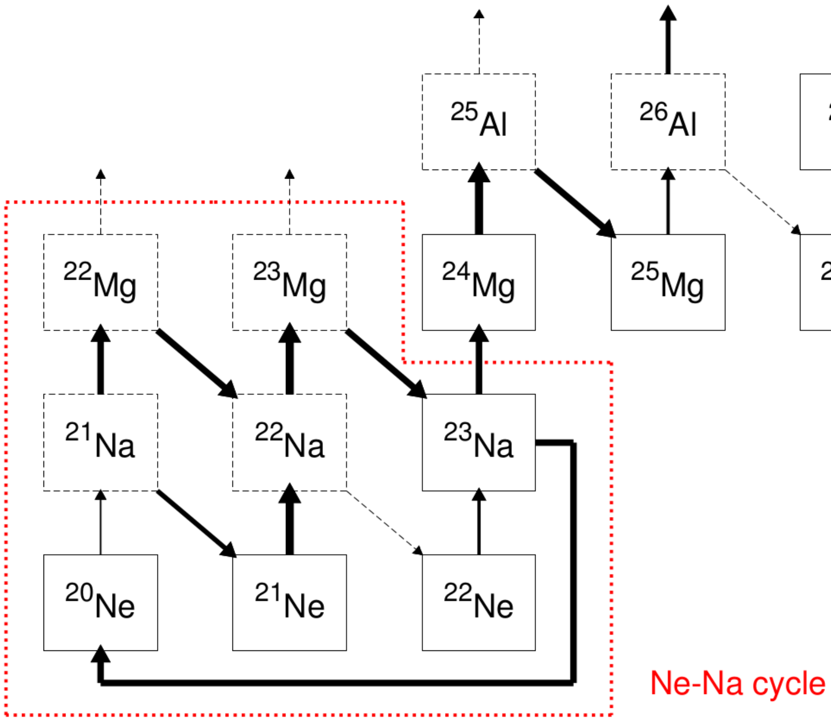
CGS15 Dresden, August 26, 2014

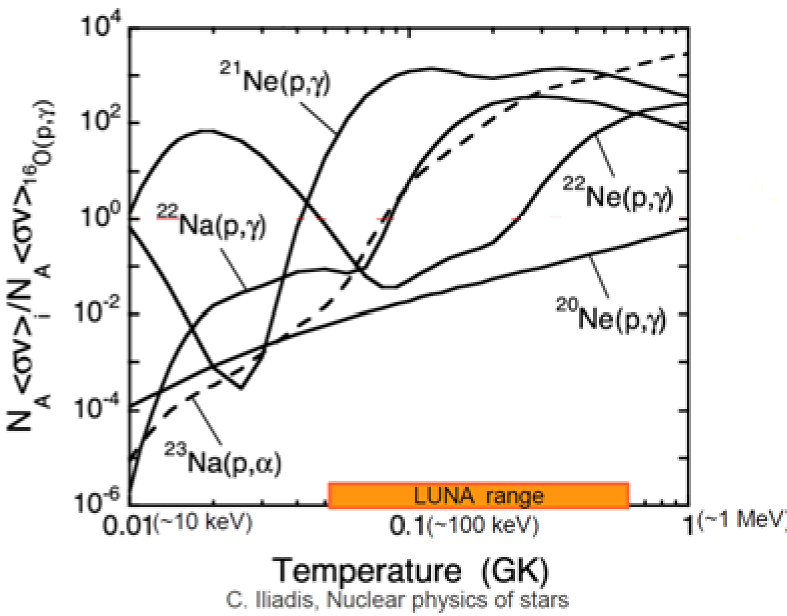
Introduction

- The $^{22}Ne(p,\gamma)^{23}Na$ reaction: astrophysical motivations
- Previous measurements
- A direct measurement at LUNA:
  - ✓ the gas target setup
  - ✓ preliminary results

Astrophysical motivation

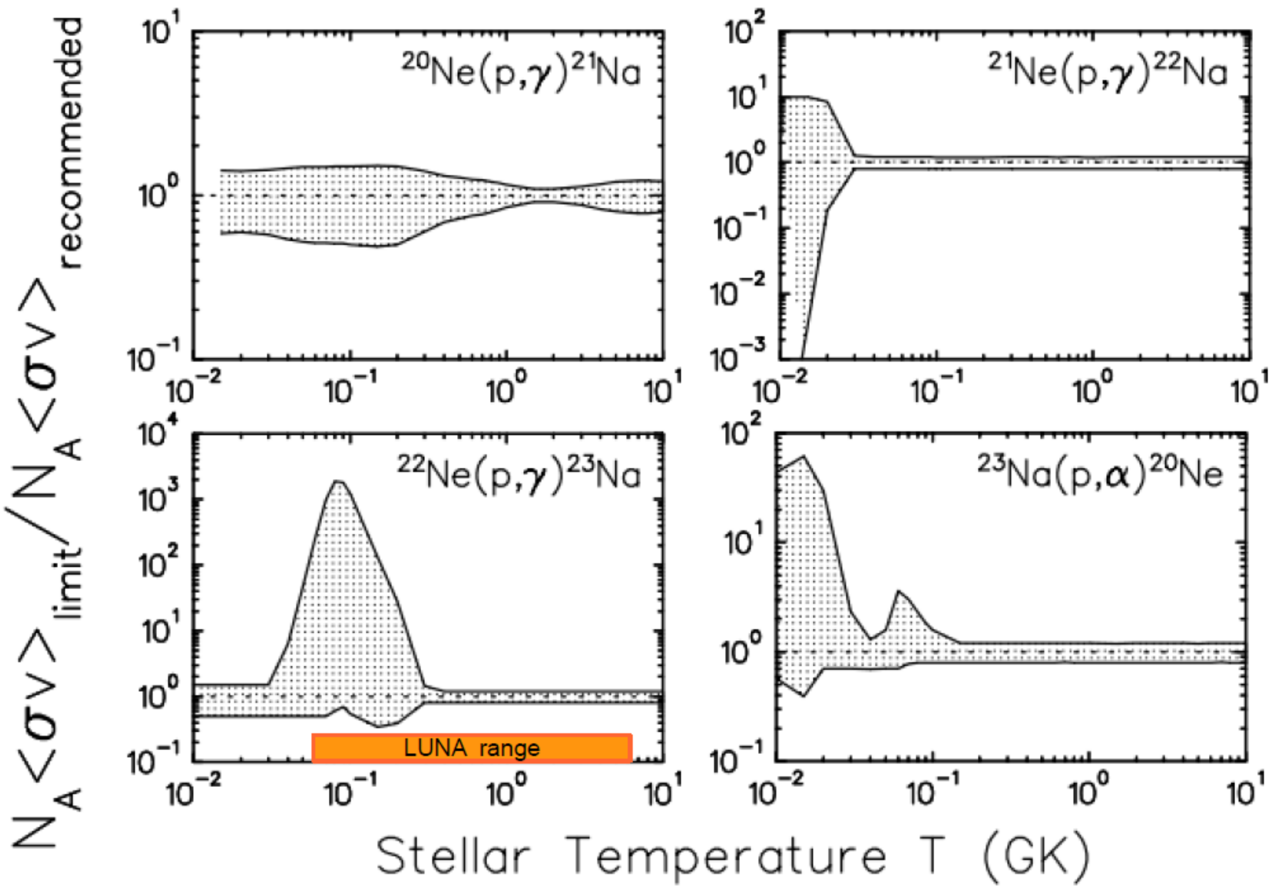
- If $A \geq 20$ seed nuclei are present in the stellar environment, they can contribute to hydrogen burning





- ^{22}Ne(p,γ)^{23}Na influences the synthesis of Ne, Na, Mg and Al isotopes

Reaction rate uncertainties



C. Iliadis et al. ApJSS 134 (2002)

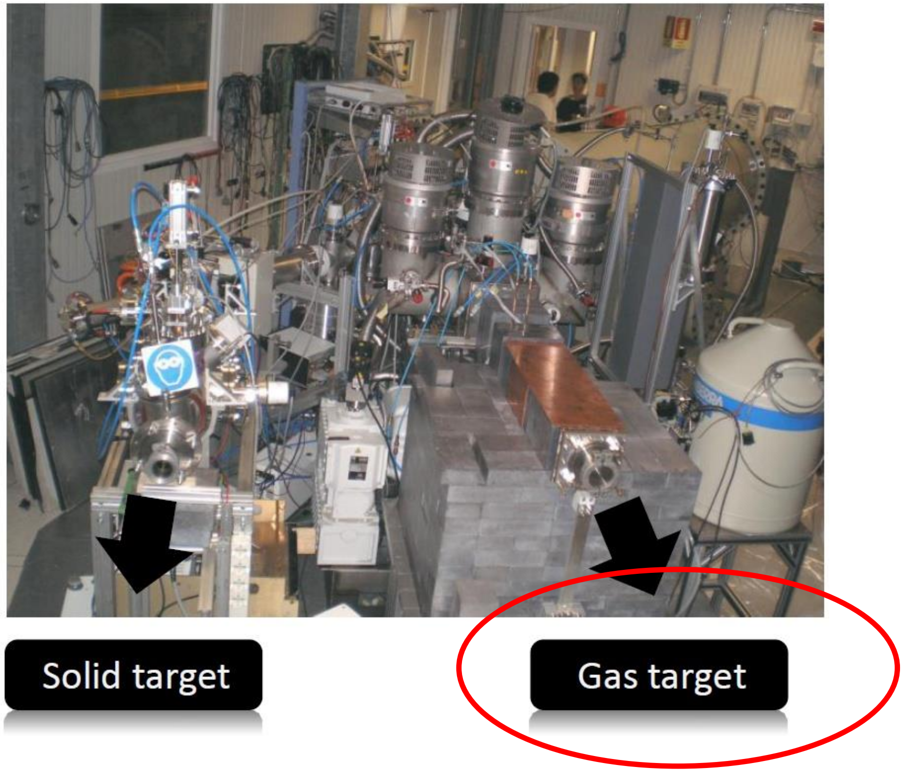
Previous scenario

E_{level} [keV]	E_{res}^{LAB} [keV]	$\omega\gamma$ [eV] Görres et al.	$\omega\gamma$ [eV] Hale et al.
8862 ?	71	≤ 4.2E-9	≤ 1.9E-10
8894 ?	104	≤ 6.0E-7	≤ 1.4E-7
8946	158	≤ 6.5E-7	≤ 9.2E-9
8972	186	≤ 2.6E-6	≤ 2.6E-6
9000 ?	215	≤ 1.4E-6	≤ 1.4E-6
9039	259	≤ 2.6E-6	≤ 1.3E-7
9072	291	≤ 2.2E-6	≤ 2.2E-6
9103	323	≤ 2.2E-6	≤ 2.2E-6
9113	333	≤ 3.0E-6	≤ 3.0E-6

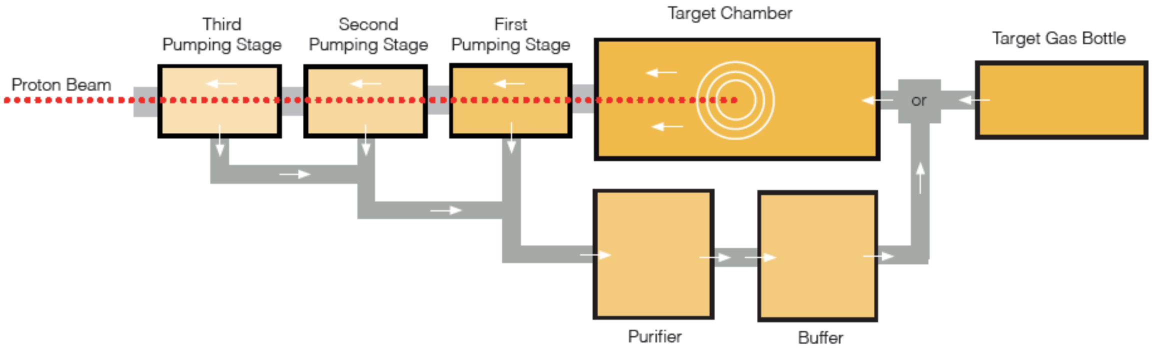
RGB (8862–9072)

AGB - Novae (9103–9113)

LUNA: gas target setup



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



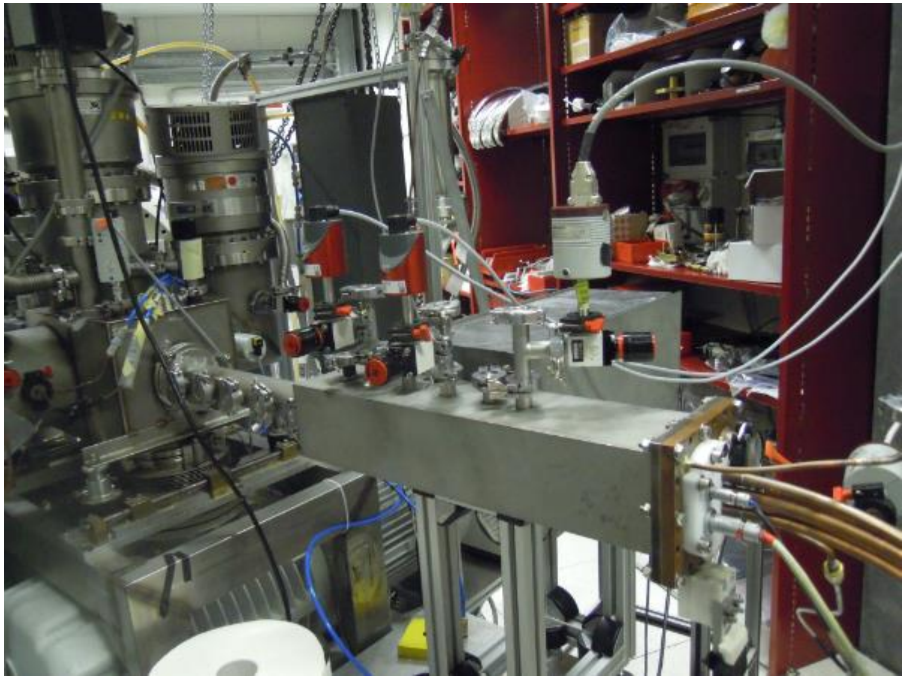
Extended target: density profile

The yield depends on the density

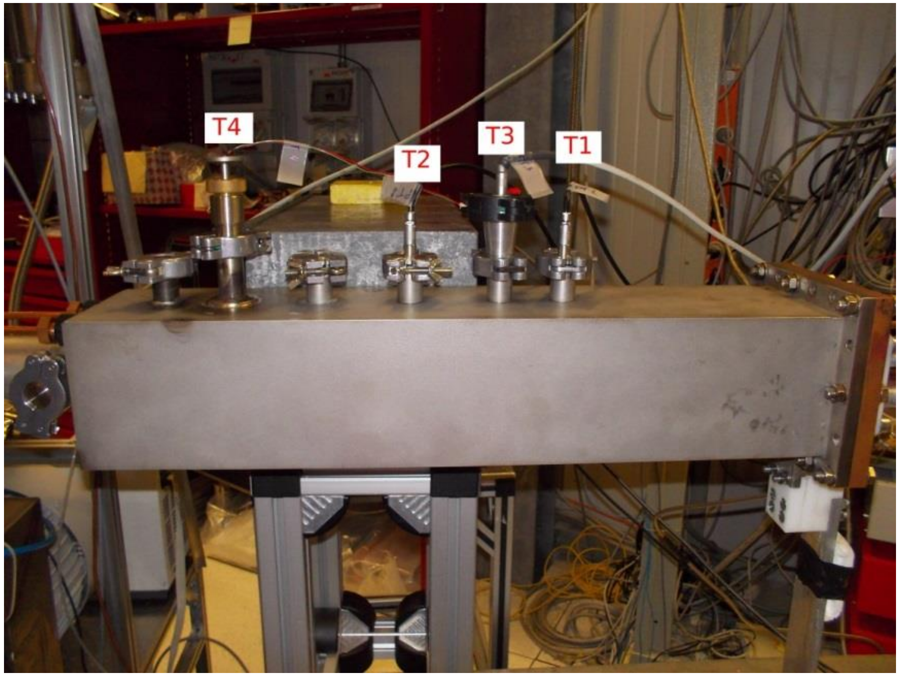
$$Y = \int_{z_1}^{z_2} \rho(z)\sigma(E(z))\eta(z)dz$$

We studied the target density without and with the beam

Pressure profile without the beam



Temperature profile without the beam



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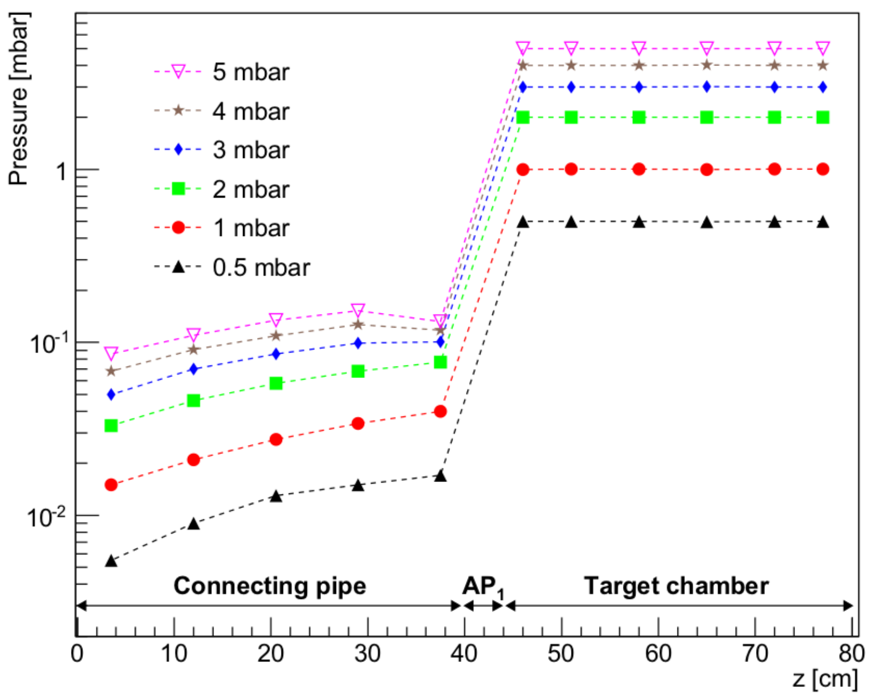
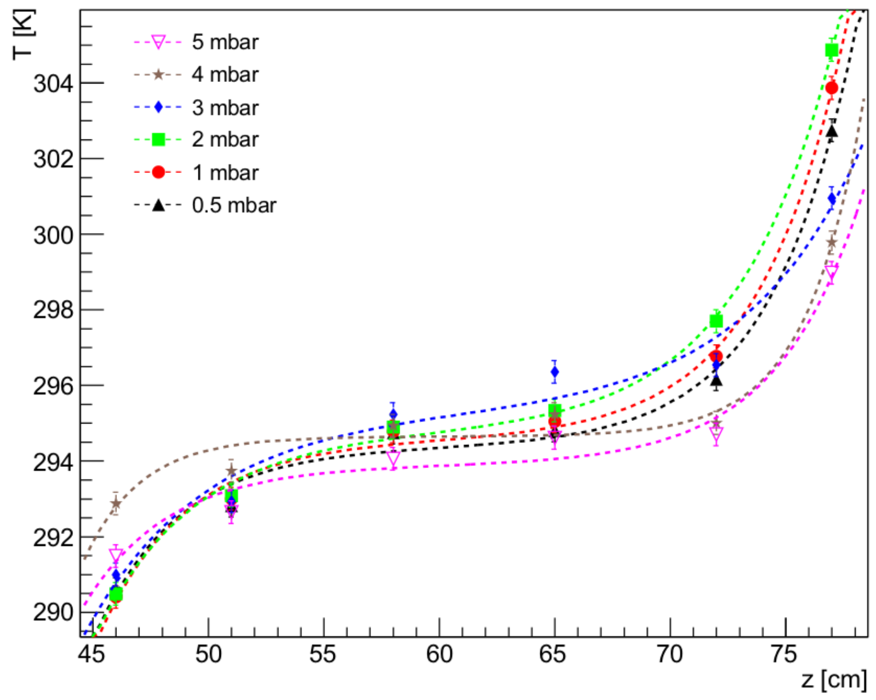
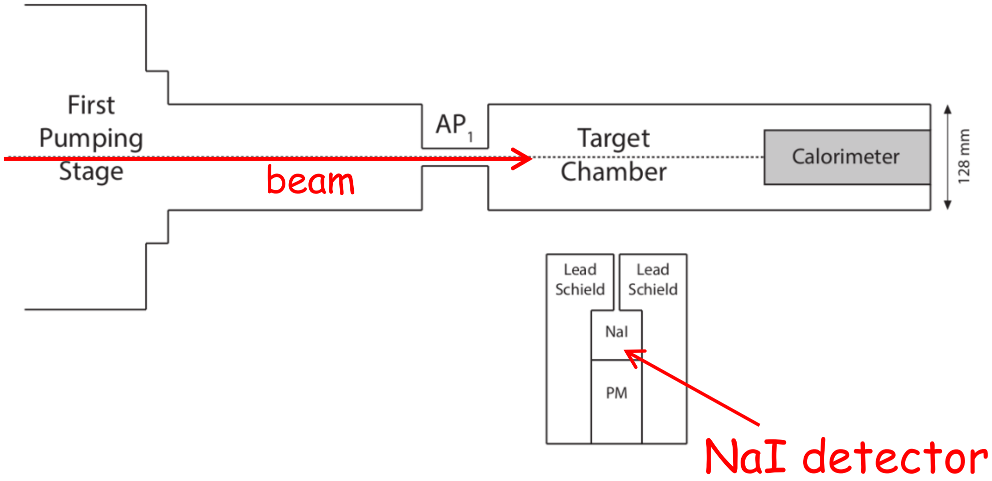


Temperature profile without the beam



Extended target: density profile

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



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

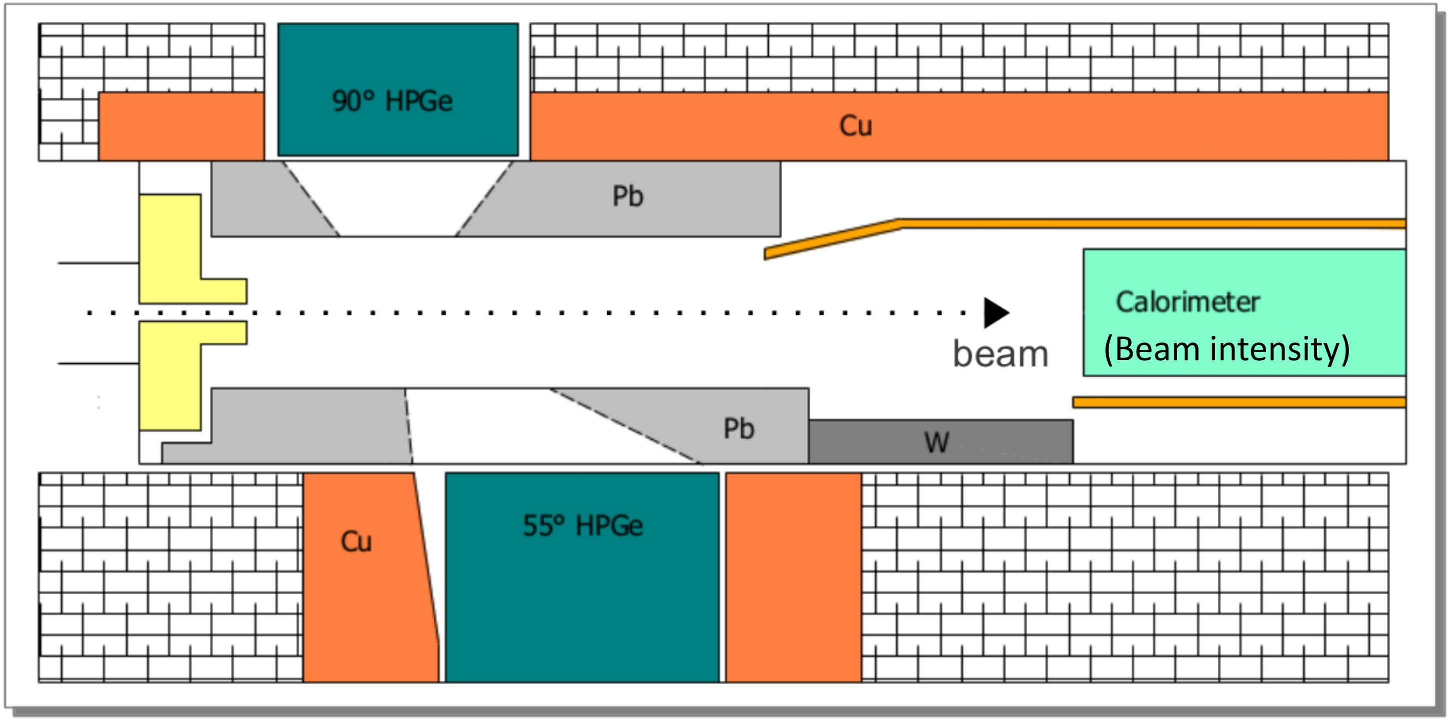
$$\frac{n}{n_0} = 1 - \alpha \frac{dW}{dx} \left[\frac{\mathrm{mW}}{\mathrm{cm}}\right]$$

- n experimental gas target density
- n_0 number density of the target gas without beam heating correction

$$\alpha = 0.36 \pm 0.06$$

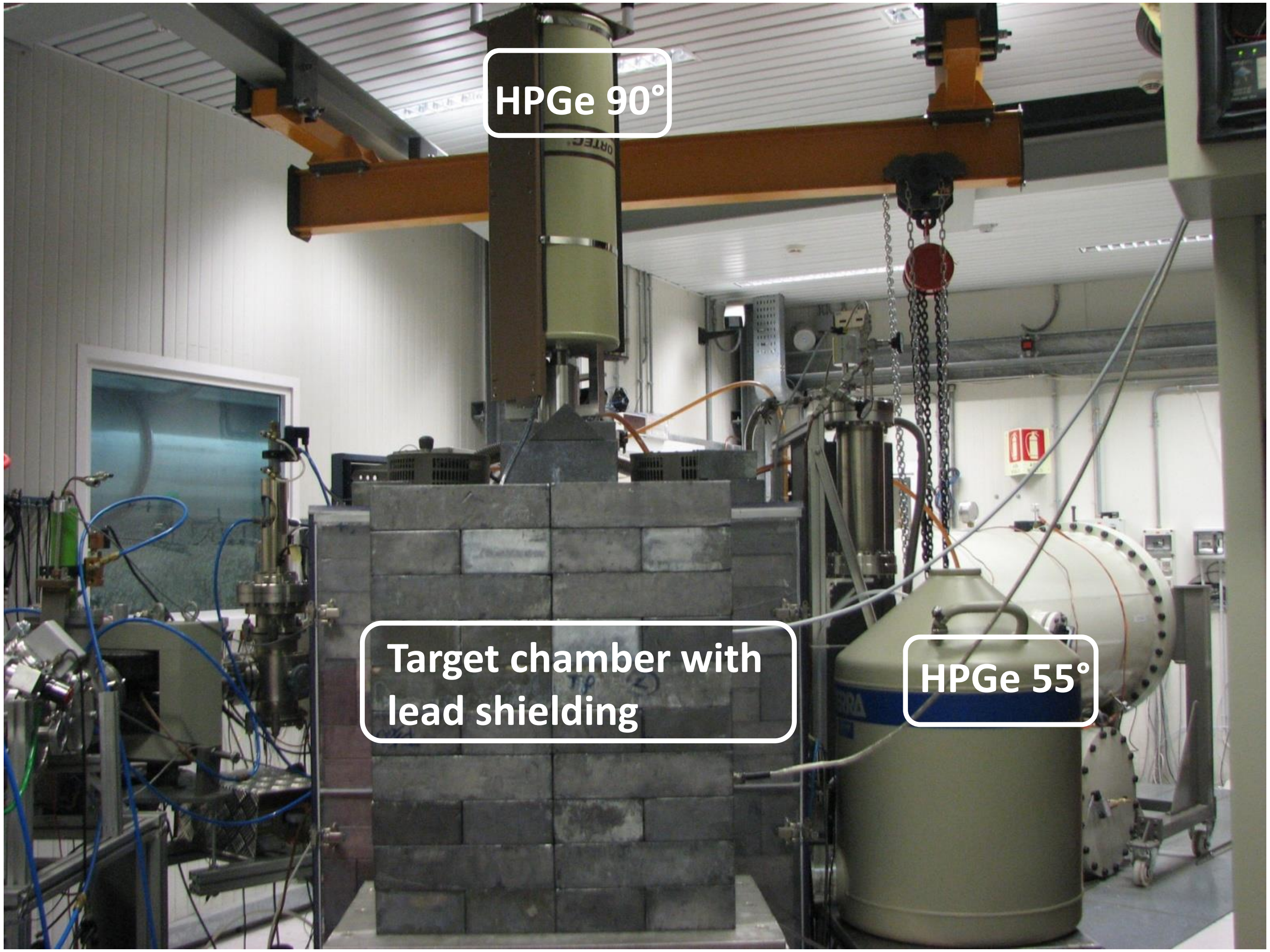
$n/n_0 \approx 0.97$ in the experimental conditions

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



~ 4 orders of magnitude background reduction compared to unshielded detectors

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



Detection efficiency

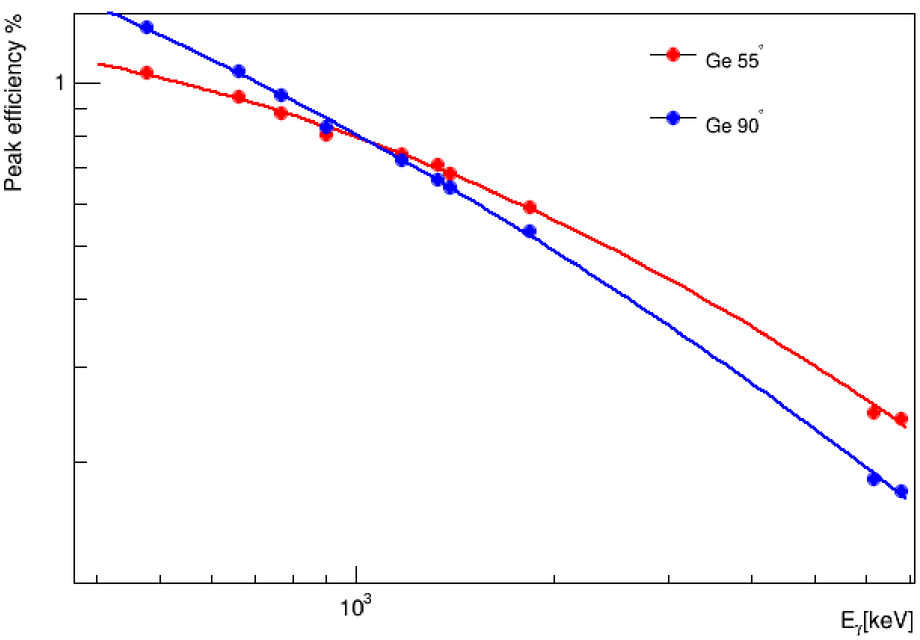
Low energies (478 keV – 1863 keV)

"High" energies (763 keV – 6791 keV)

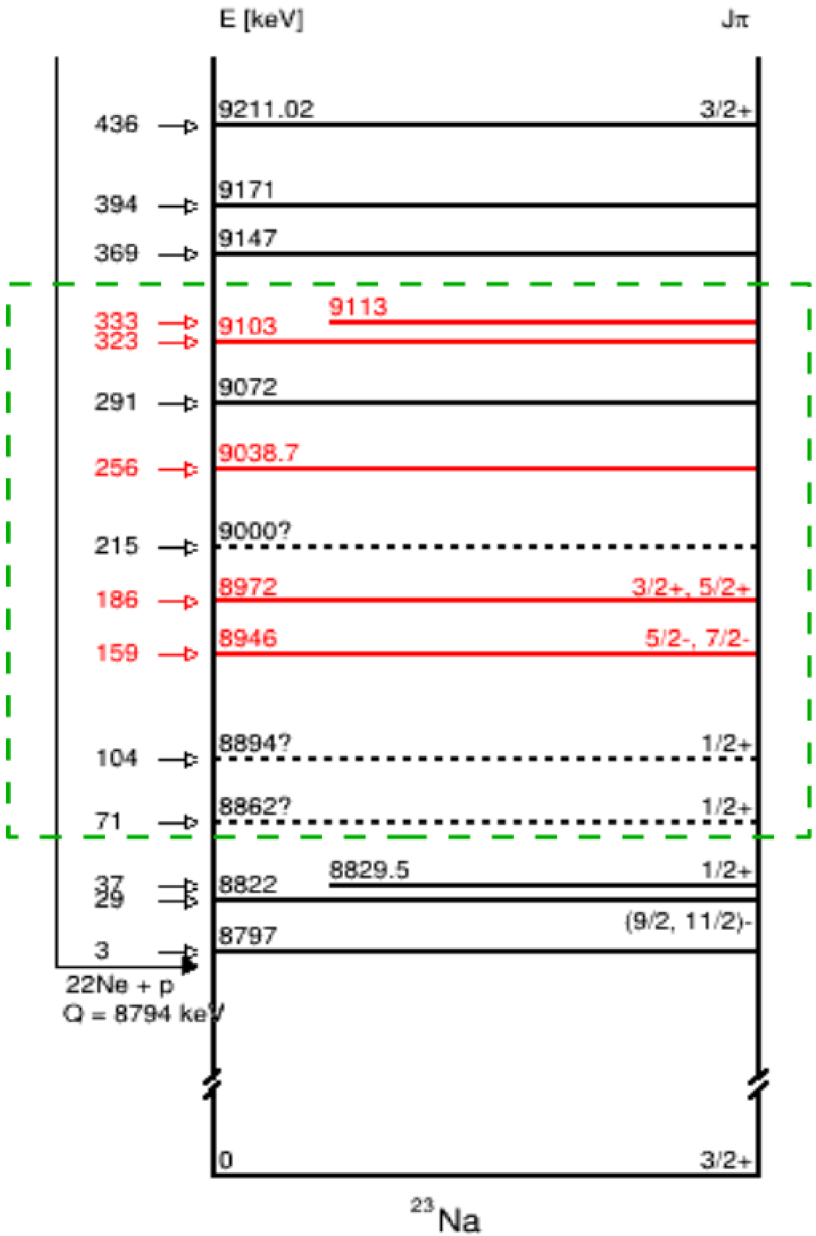
Efficiency measured with 4 point-like sources:

Source	E_γ [keV]
^{7}Be	477.60
^{137}Cs	661.66
^{60}Co	1173.23 1332.49
^{88}Y	898.04 1836.06

Efficiency curve extended up to 6791 keV with the $^{14}N(p,\gamma)^{15}O$ resonance at E_{Lab} = 278 keV



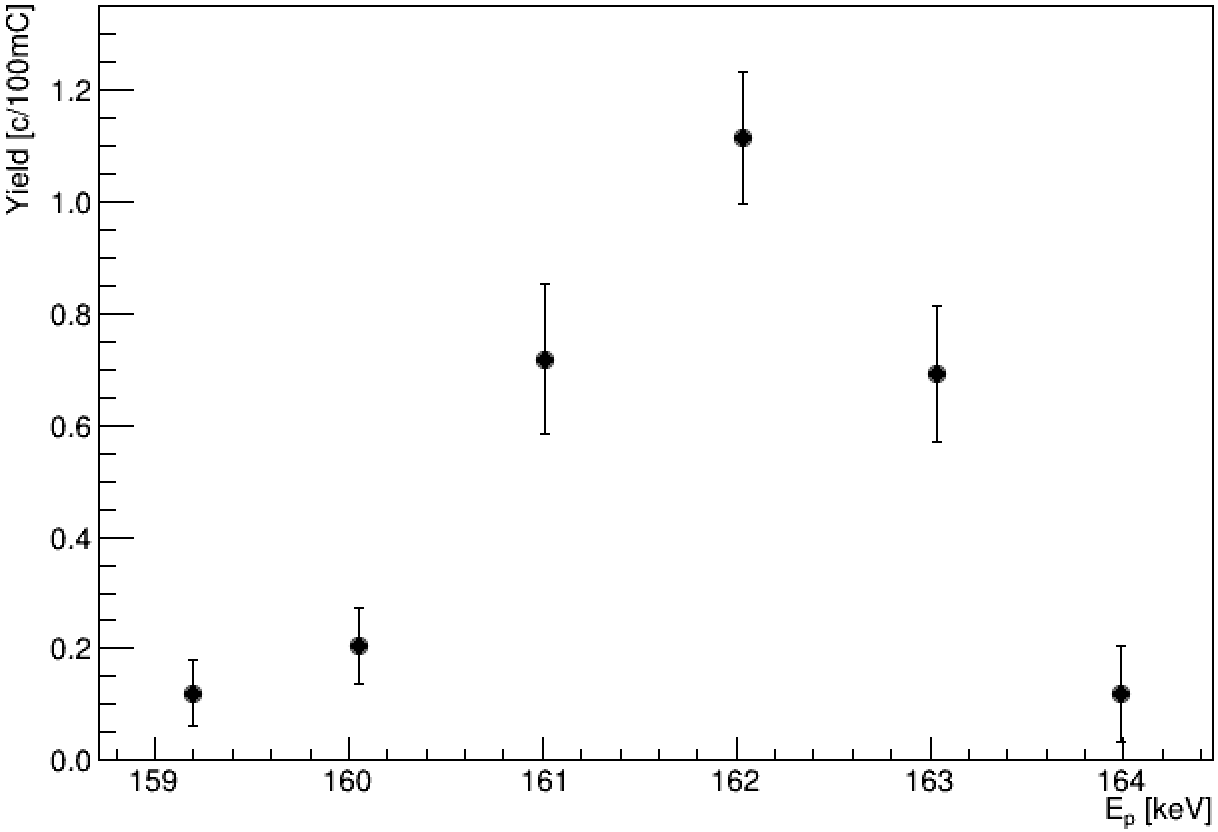
^{23}Na level scheme



- The experiment has been carried out within the "green" box
- The "red" resonances have been directly observed for the first time
- For the other "black" resonances we quoted an upper limit

$E_{res}^{LAB} = 158$ keV

The resonances energy have been determined with a resonance/yield scan technique



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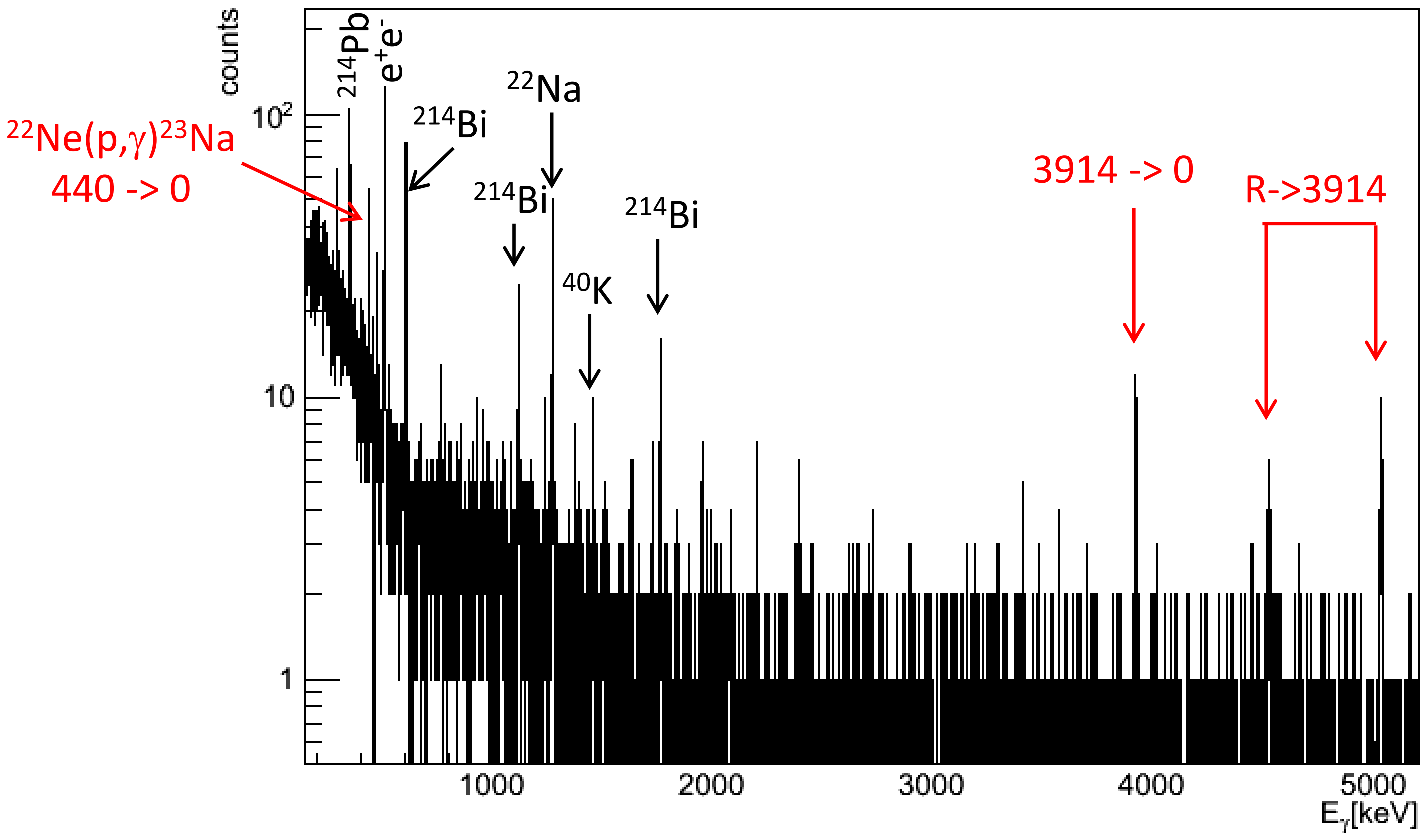
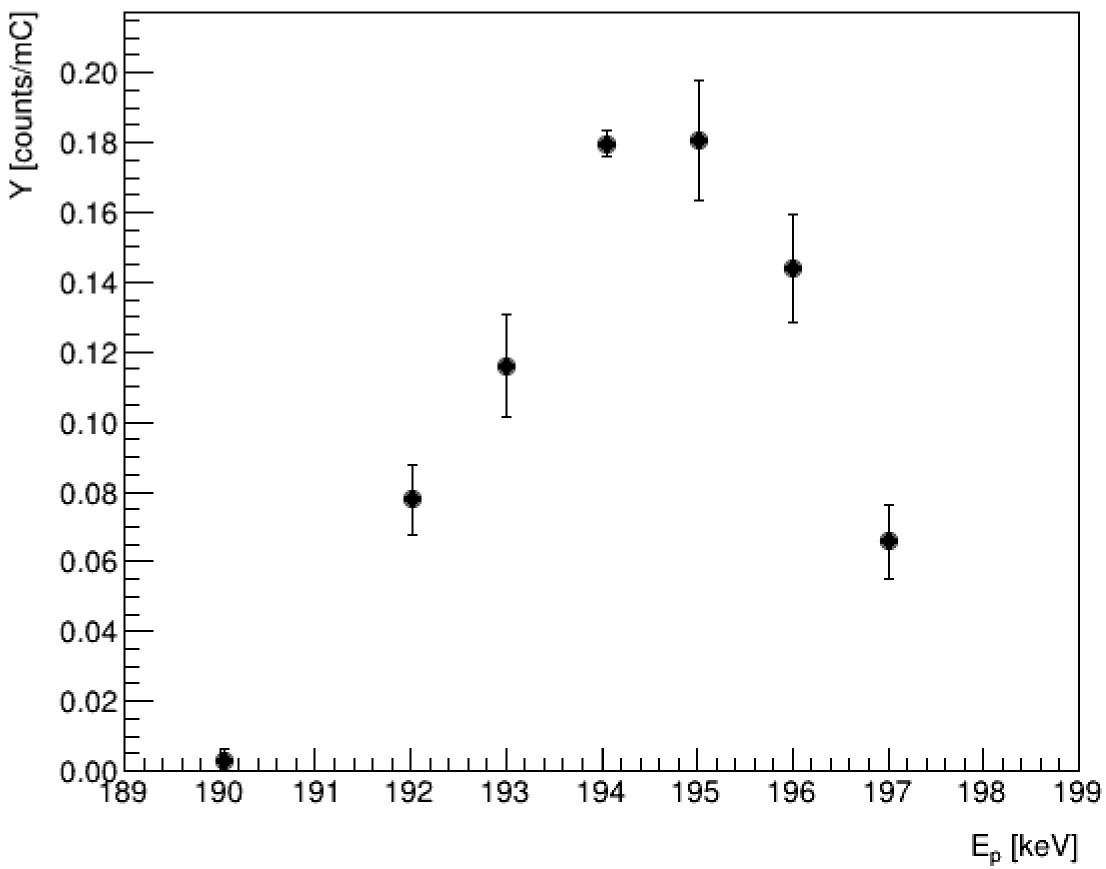


E_{res} ^{LAB} = 186 keV



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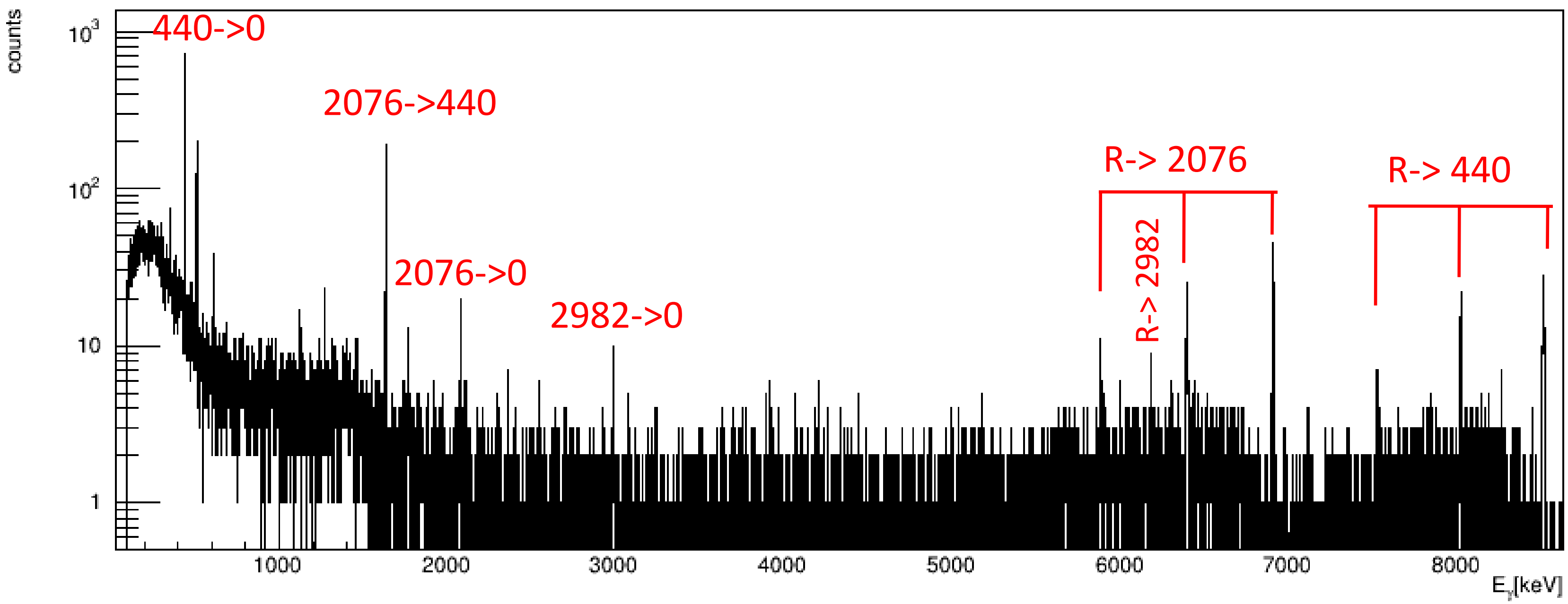
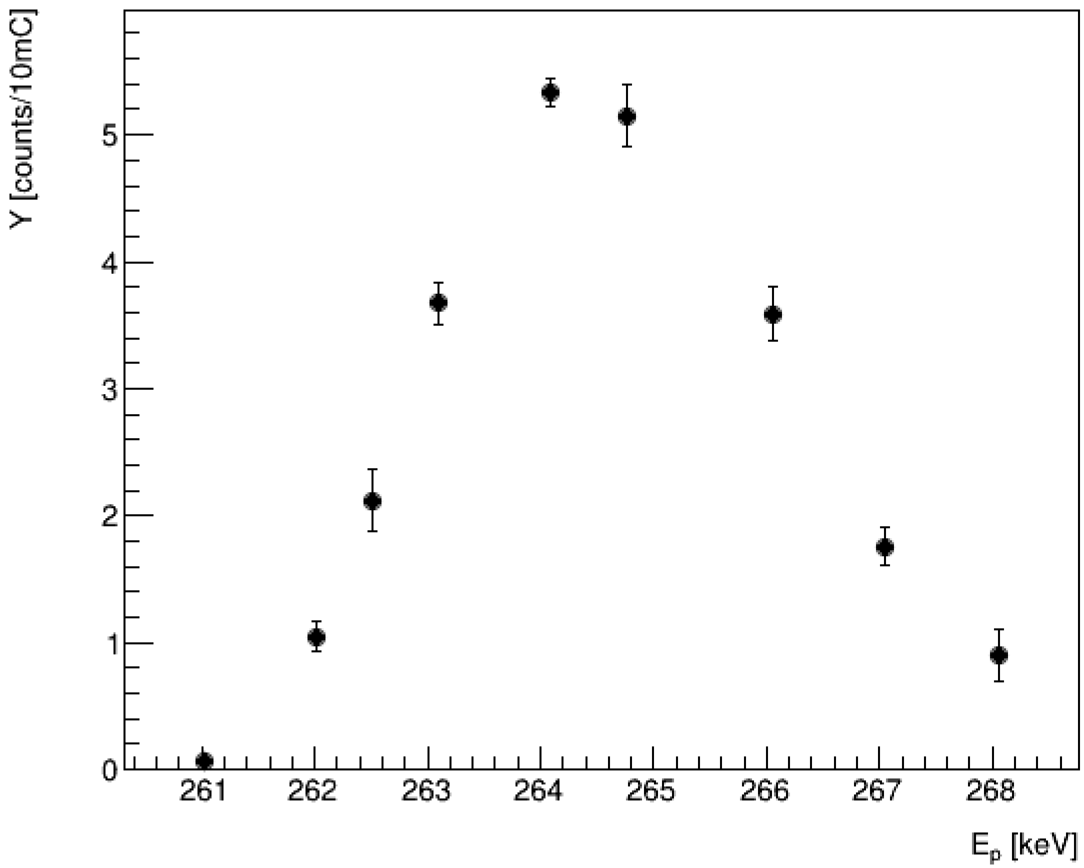
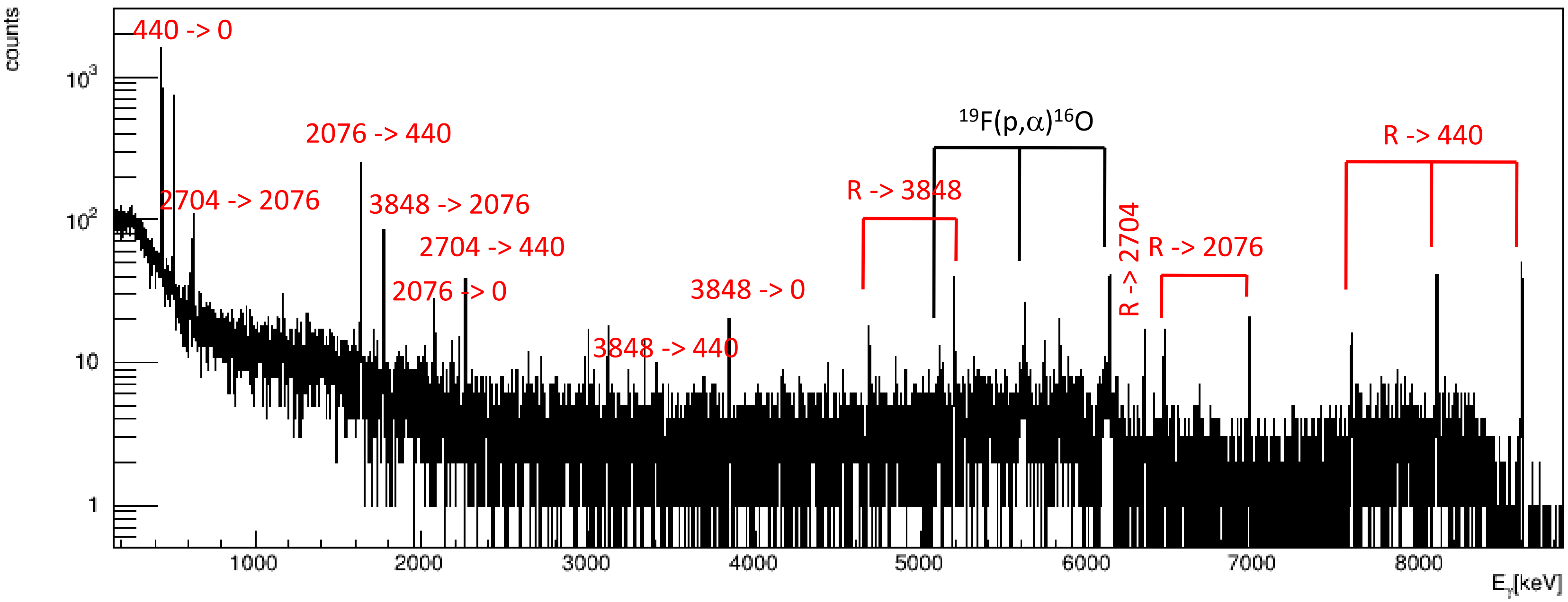


$E_{res}^{LAB} = 259$ keV

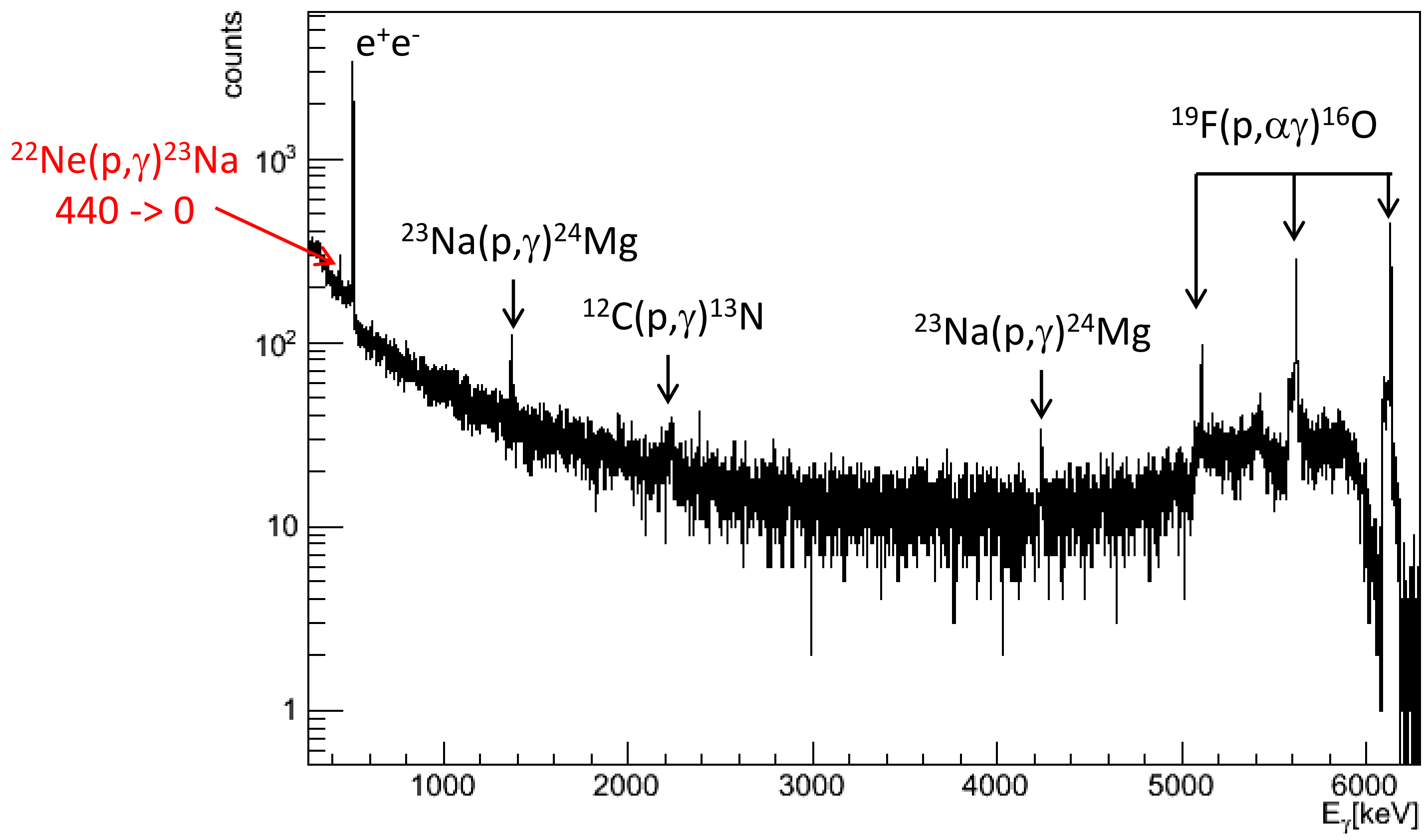


E_{res}^{LAB} = 259 keV



So much statistics that we are working on two-dimensional analysis

$E_{res}^{LAB} = 323$ keV



Conclusions

- Thanks to the extremely low background, we measured the $^{22}Ne(p,\gamma)^{23}Na$ cross section down to the energies of astrophysical interest
  - ✓ Five resonances (E = 159 keV, 186 keV, 256 keV, 323 keV and 333 keV) have been directly observed for the first time
- Resonances strength presently known as u.l. (E = 71, 104, 215, 291 keV) will be further investigated in a second phase of the experiment:
  - ✓ A new reaction chamber surrounded by a high E_γ efficiency 4π BGO will be set-up in the next months

LUNA Collaboration

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Thanks for your attention!