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

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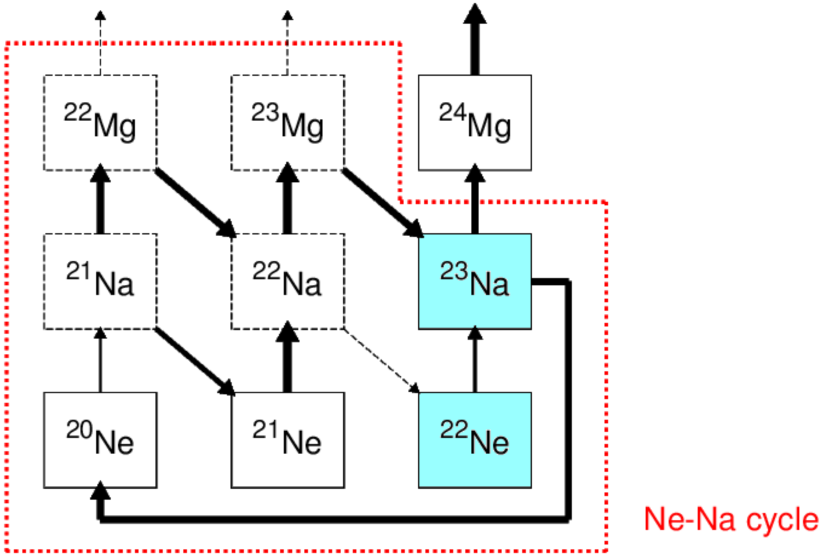
Astrophysical motivation

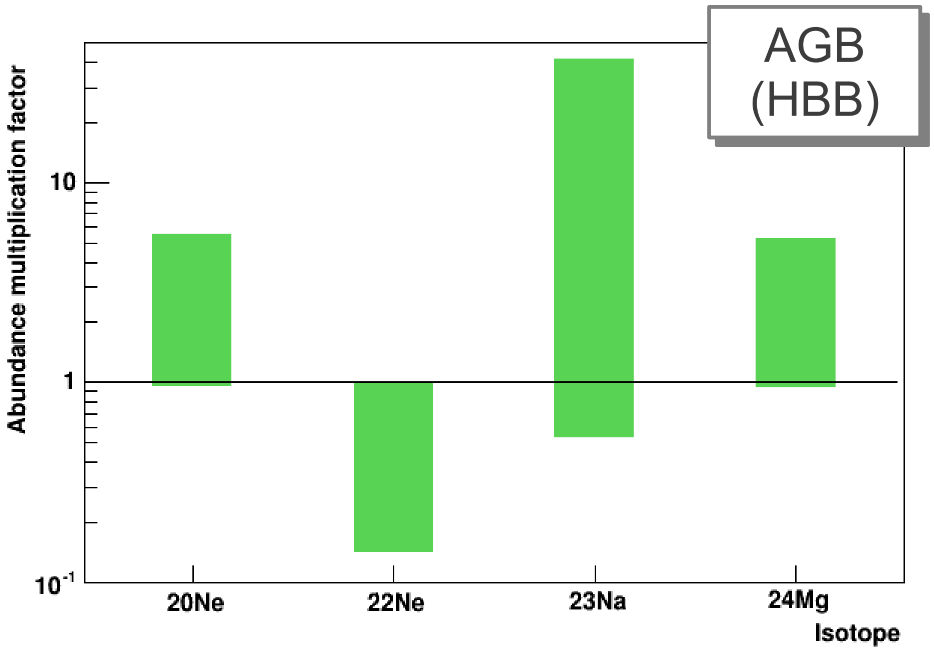
The Neon - Sodium cycle strongly influences the abundance of Ne, Na, Mg and Al isotopes in:

- Shell hydrogen burning in Red Giant Branch and Asymptotic Giant Branch stars
- Explosive H burning in classical novae

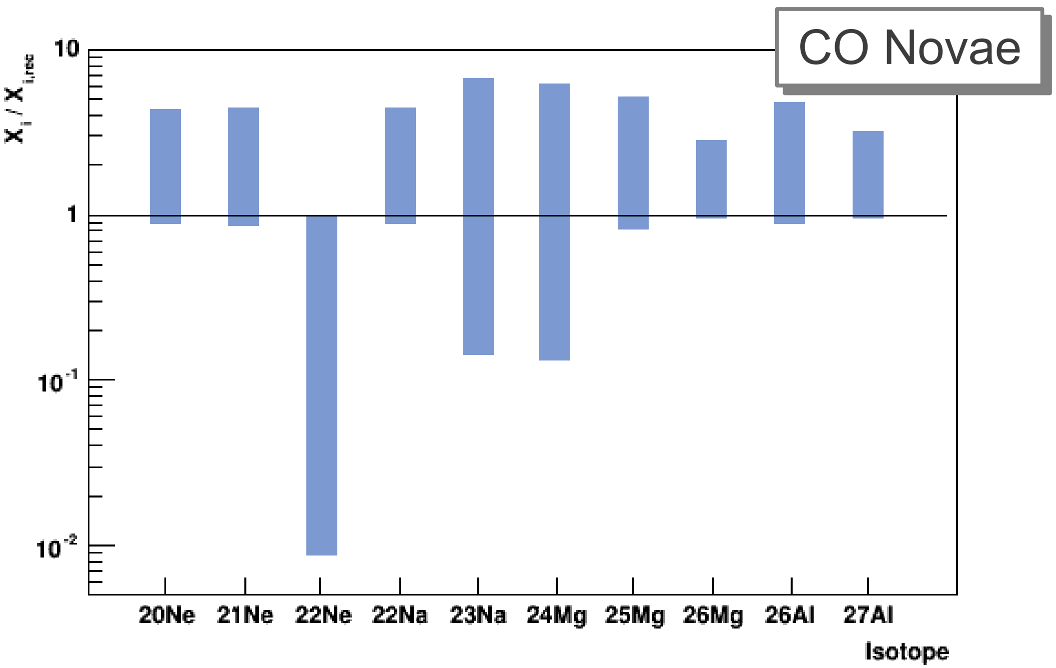


$^{22}Ne(p,\gamma)^{23}Na$ is the most uncertain reaction in the NeNa cycle

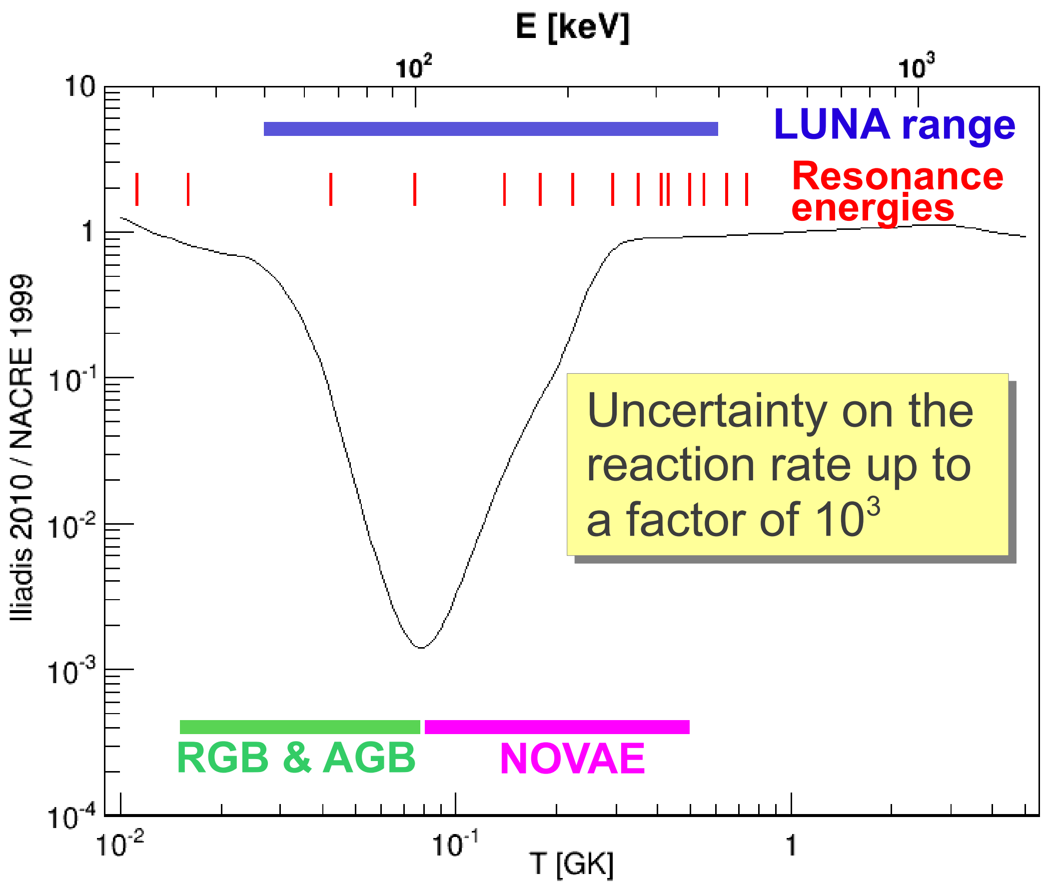
Data from R.G. Izzard et al. A&A **466**, 641 (2007)



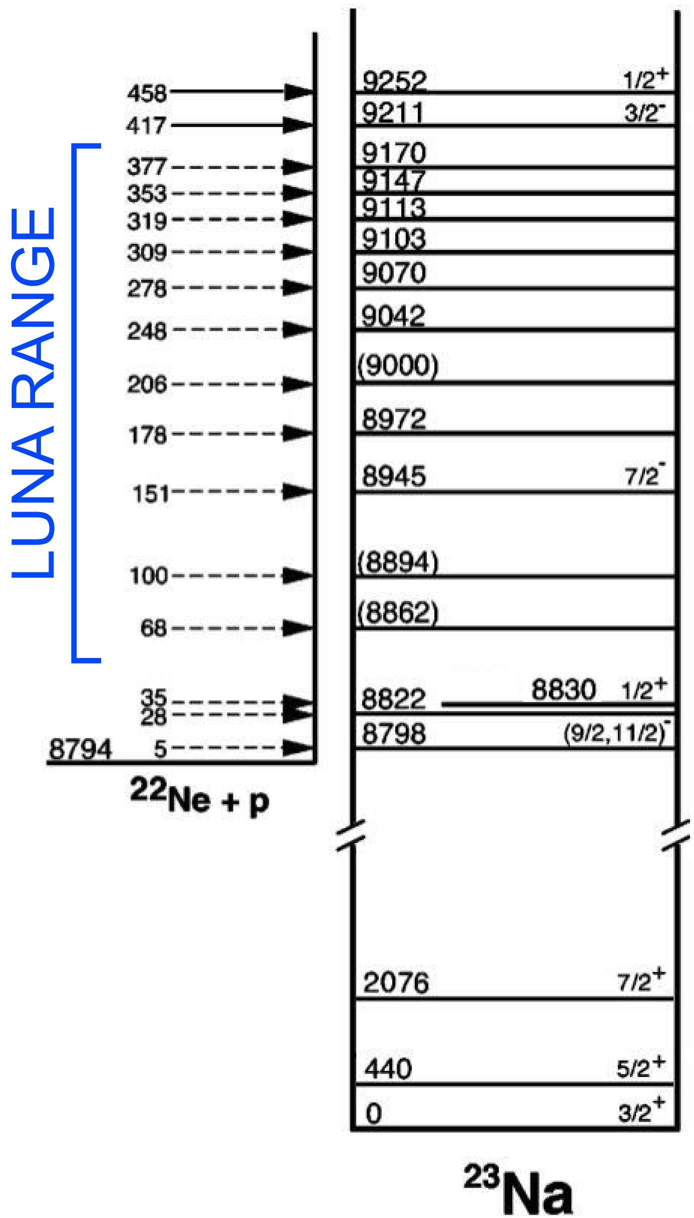
Data from C. Iliadis et al. ApJSS **142**, 105 (2002)



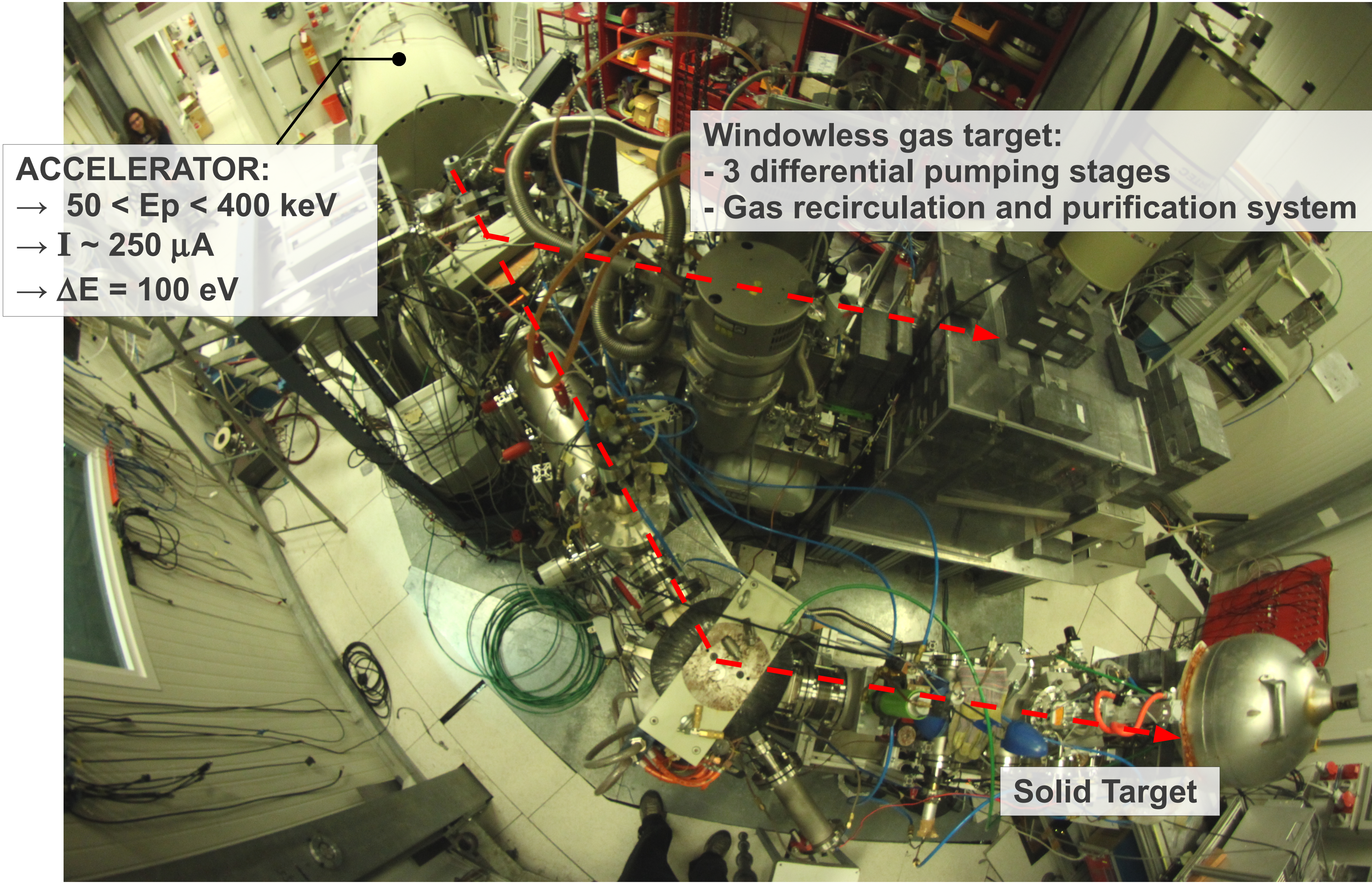
State of the art



None of the resonances in the LUNA range has been directly observed

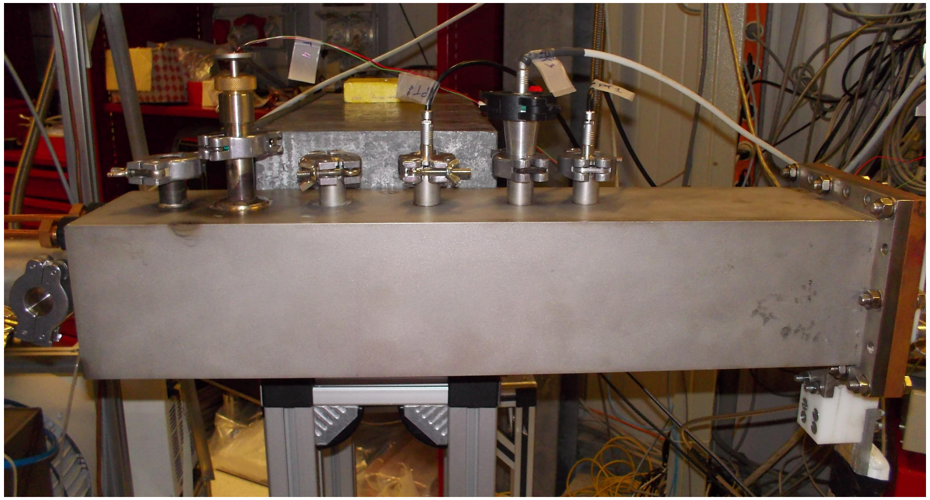


Experimental setup

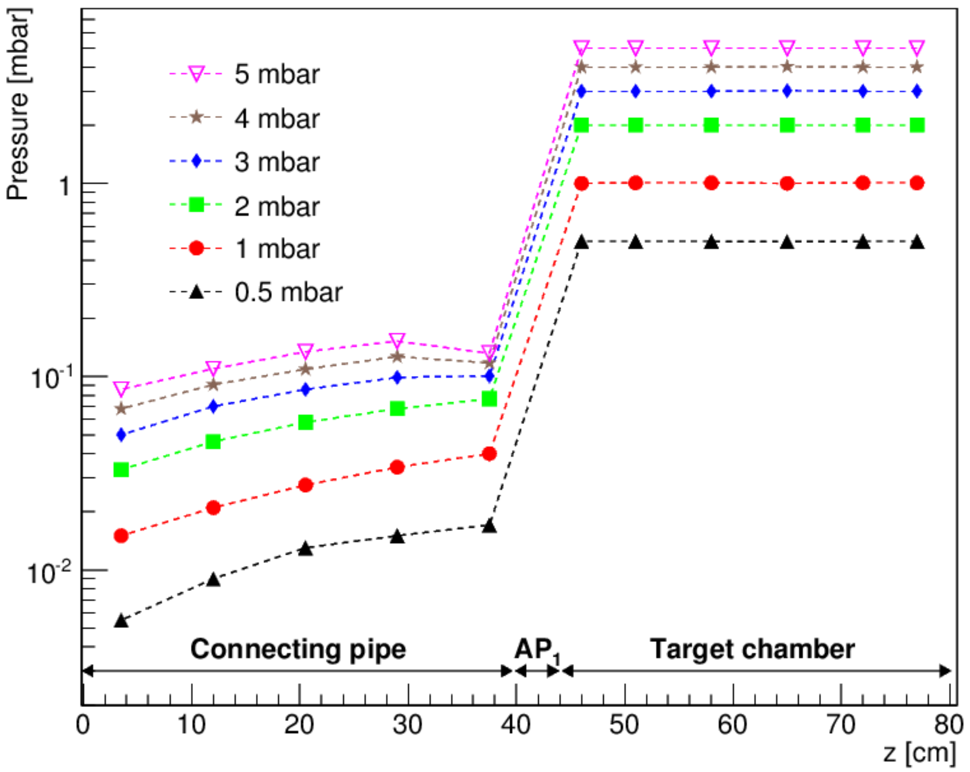


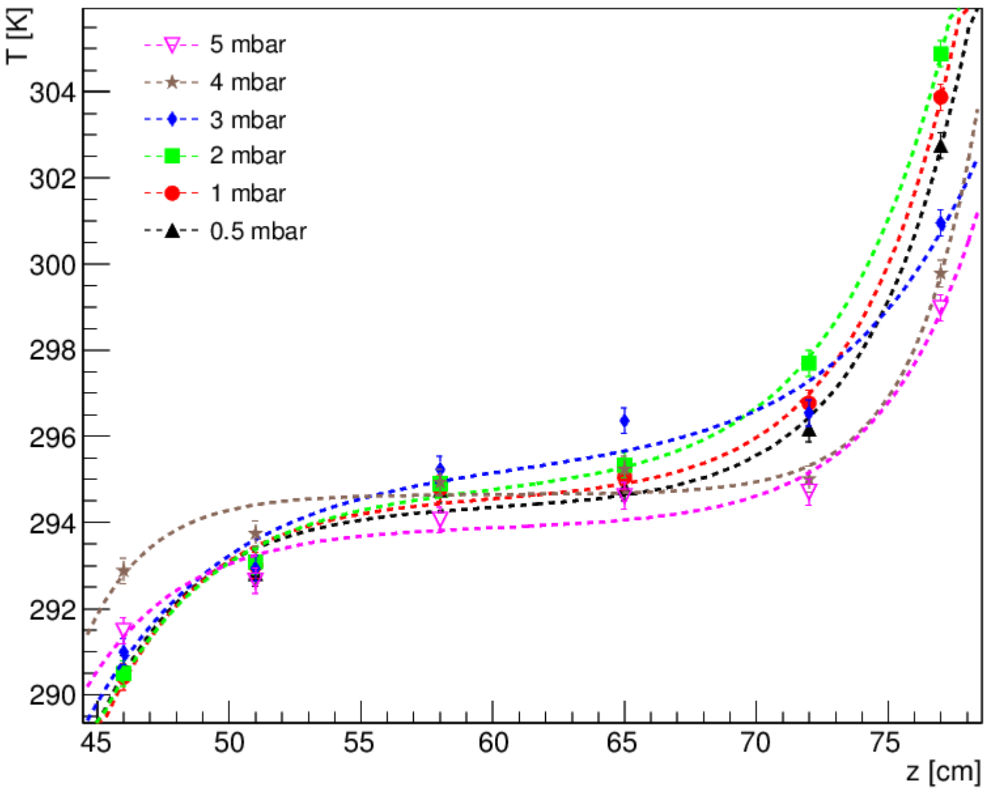
Gas target characterization

Gas density without beam: pressure and temperature profiles measurement



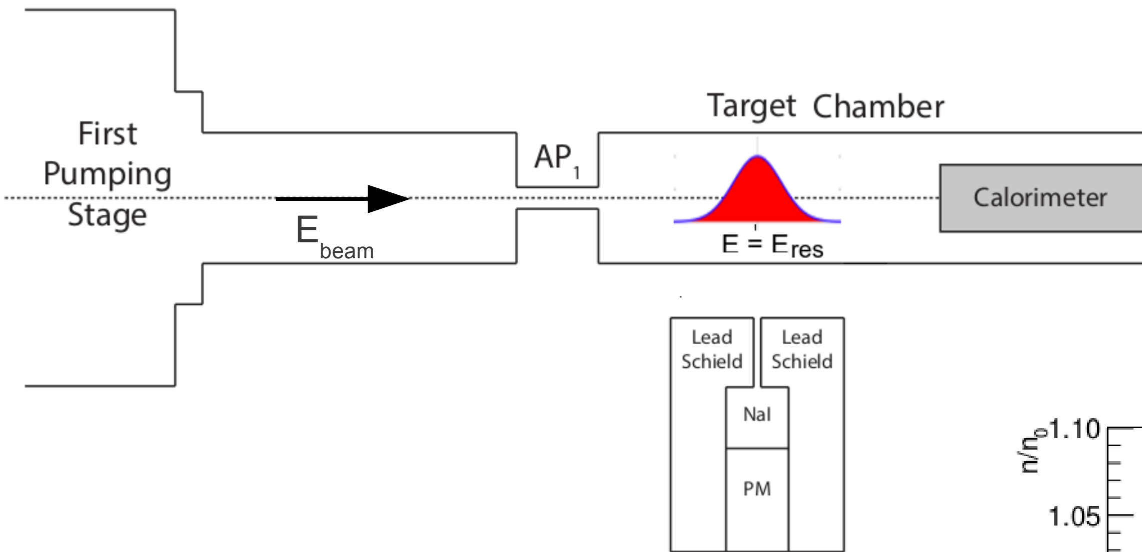
Target chamber equipped with many flanges along the beam direction





Gas target characterization

<u>Gas density reduction due to beam heating</u> measured with the resonance scan technique



→ Target chamber filled with natural Ne

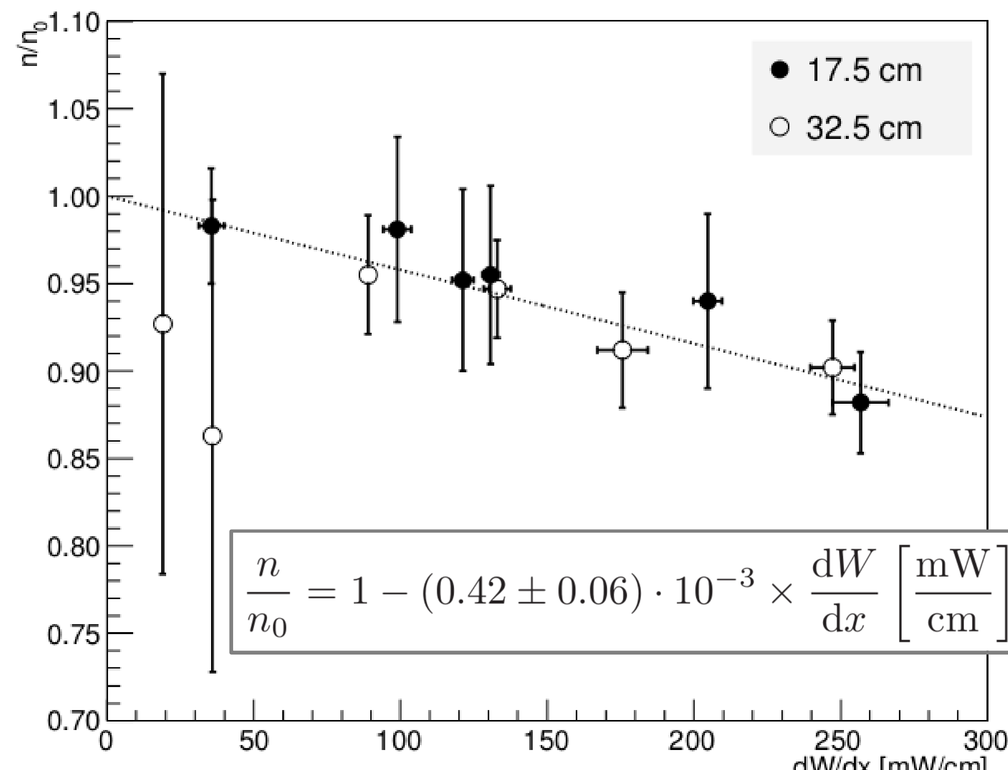
→ $^{21}Ne(p,\gamma)^{22}Na$ resonance at 272.6 keV ($\omega\gamma$ = 83 meV)

→ collimated NaI detector 2” x 2”

Density with beam

$$\frac{n}{n_0} = \frac{\Delta E_{\mathrm{p}}^{\mathrm{exp}}(p_{\mathrm{T}}, I)}{\Delta E_{\mathrm{p}}(p_{\mathrm{T}}, 0)}$$

Density without beam

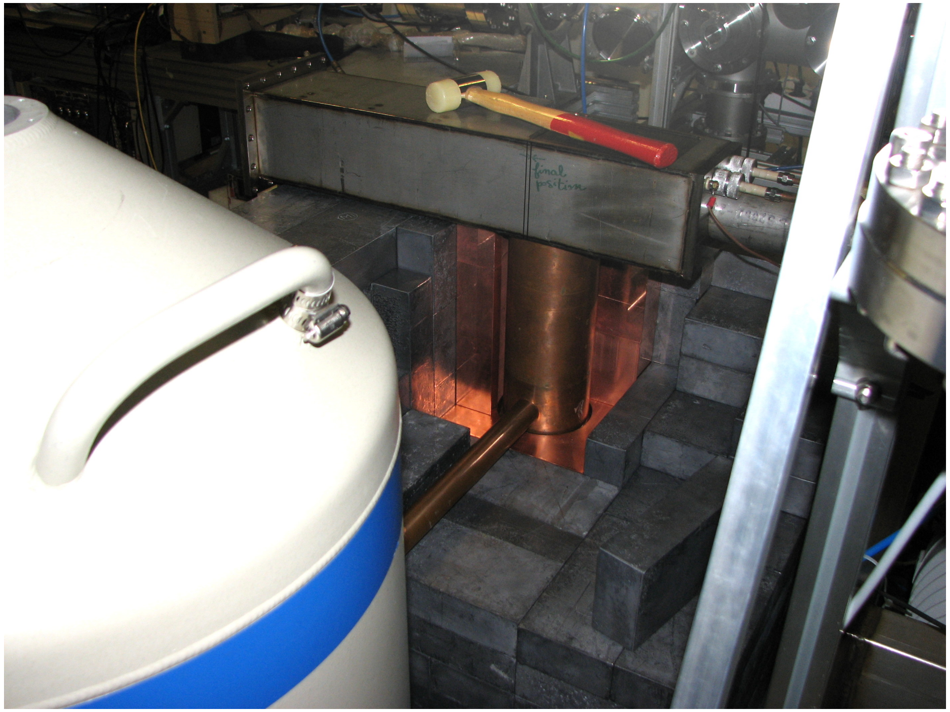


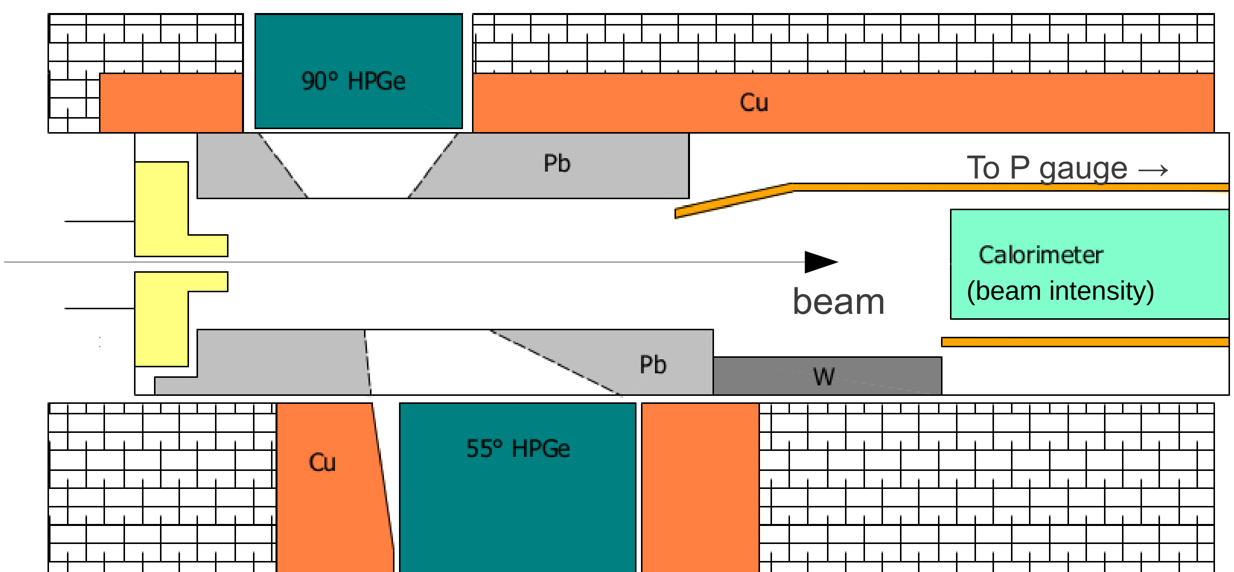
$$\frac{n}{n_0} = 1 - (0.42 \pm 0.06) \cdot 10^{-3} \times \frac{\mathrm{d}W}{\mathrm{d}x} \left[\frac{\mathrm{mW}}{\mathrm{cm}}\right]$$

The beam heating depends on the beam dissipated power:

$$\frac{\mathrm{d}W}{\mathrm{d}x} = \frac{dE}{d(nx)} nI$$

Setup for ^{22}Ne+p resonances study





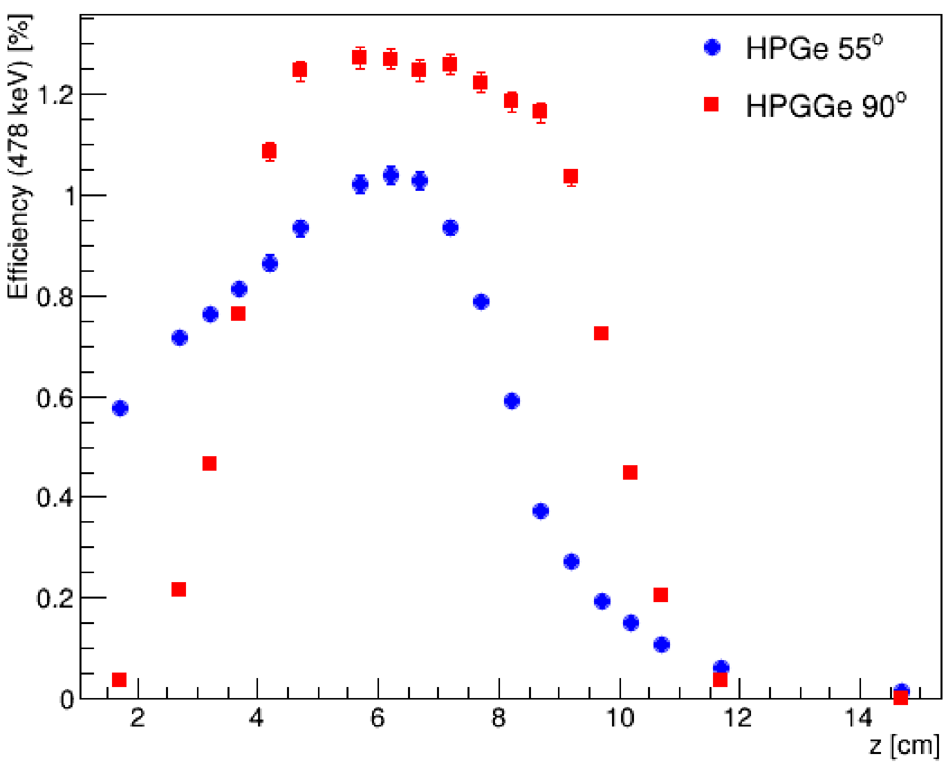
γ ray background below 3MeV suppressed by three orders of magnitude

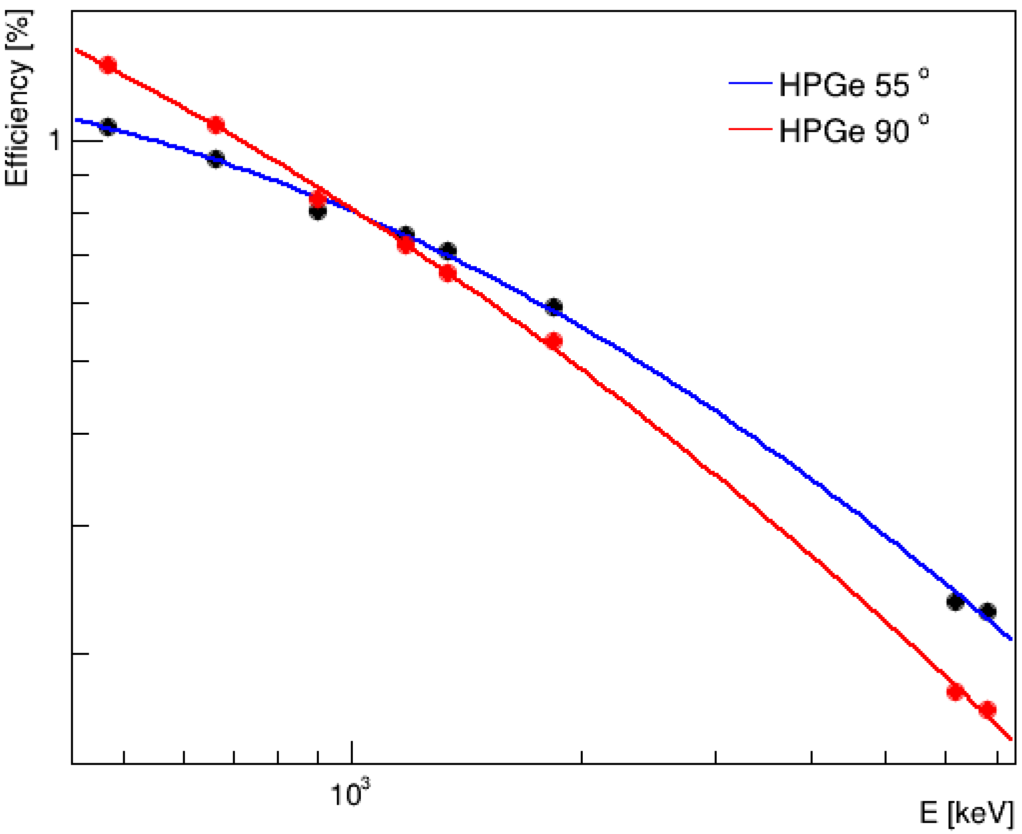
Detection efficiency

Detection efficiency measured with 4 point-like radioactive sources

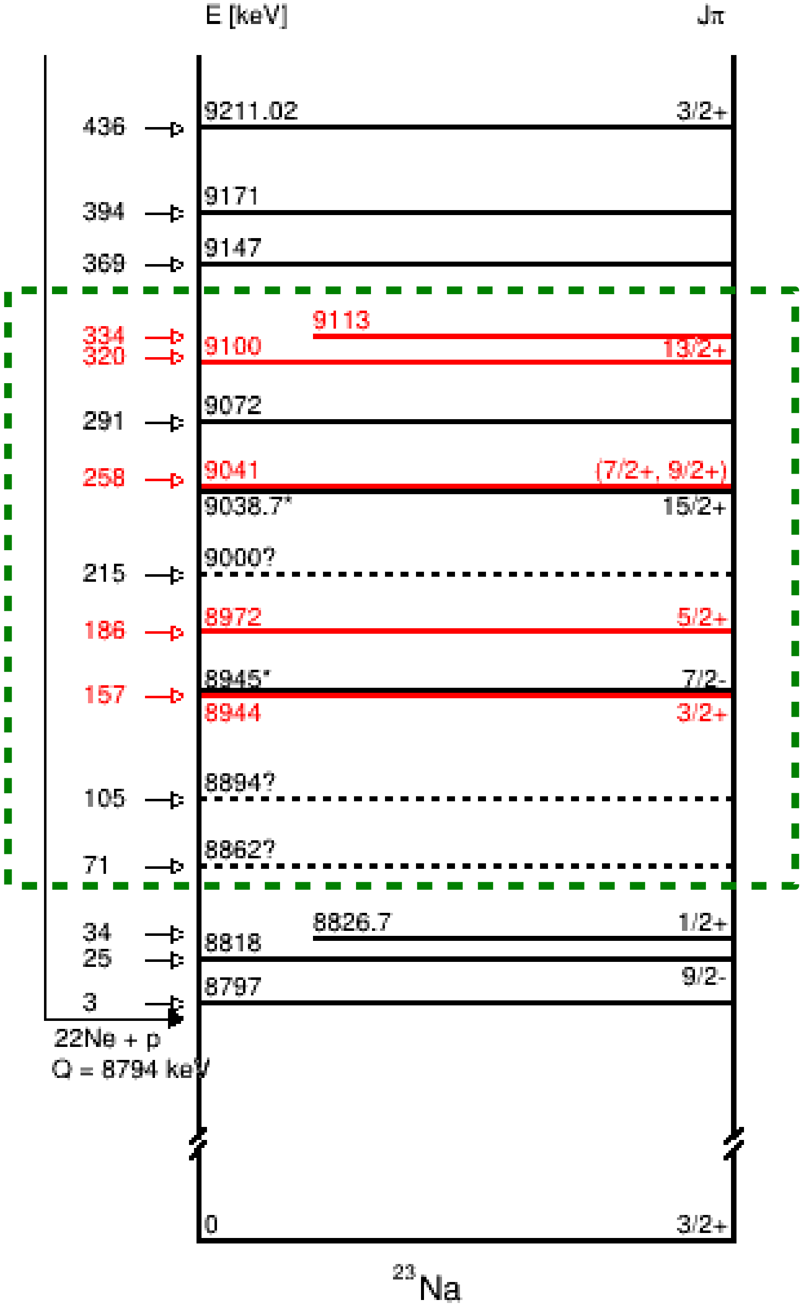
Source	Eγ [keV]
^{7}Be	477.6
^{137}Cs	661.7
^{60}Co	1173.2 1332.5
^{88}Y	898 1863.1

Efficiency curve extended up to 6.79 MeV exploiting the $^{14}N(p,\gamma)^{15}O$ resonance at 278 keV





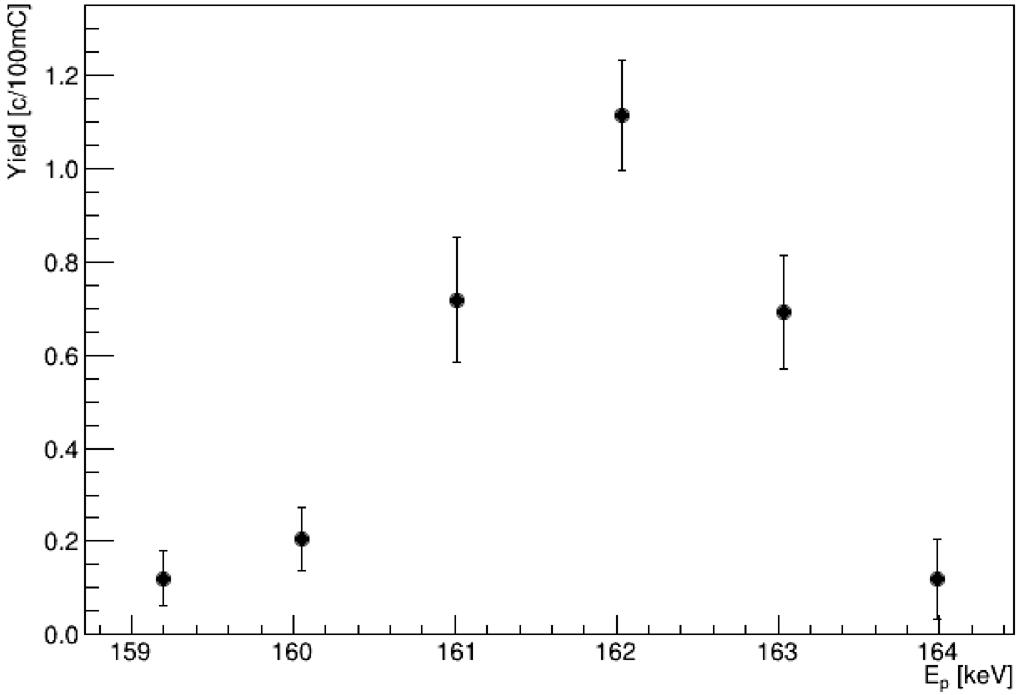
Results



- 9 resonances investigated
- 5 resonances directly observed for the first time
- New upper limits for all other resonances

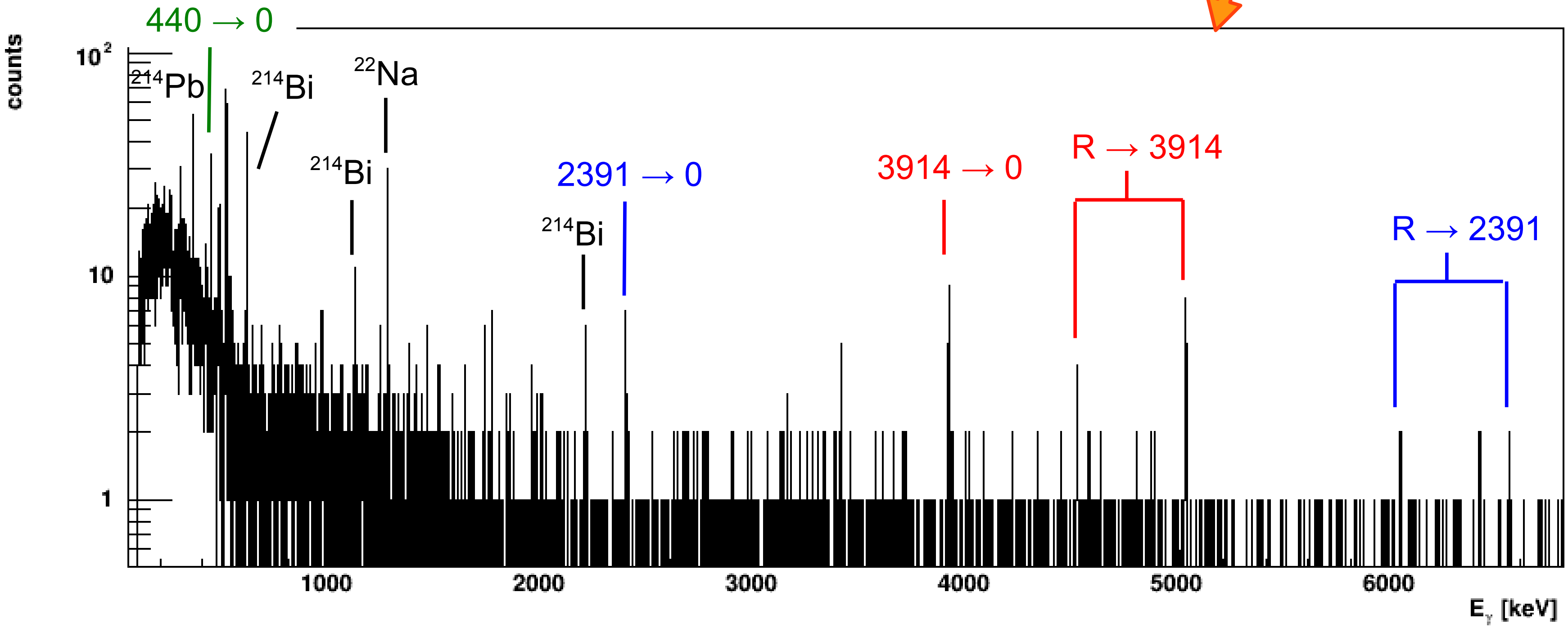
*D. G. Jenkins Phys Rev C **87**, 064301 (2013)

Results: E_{res} = 157 keV (E_{lev} = 8944 keV)

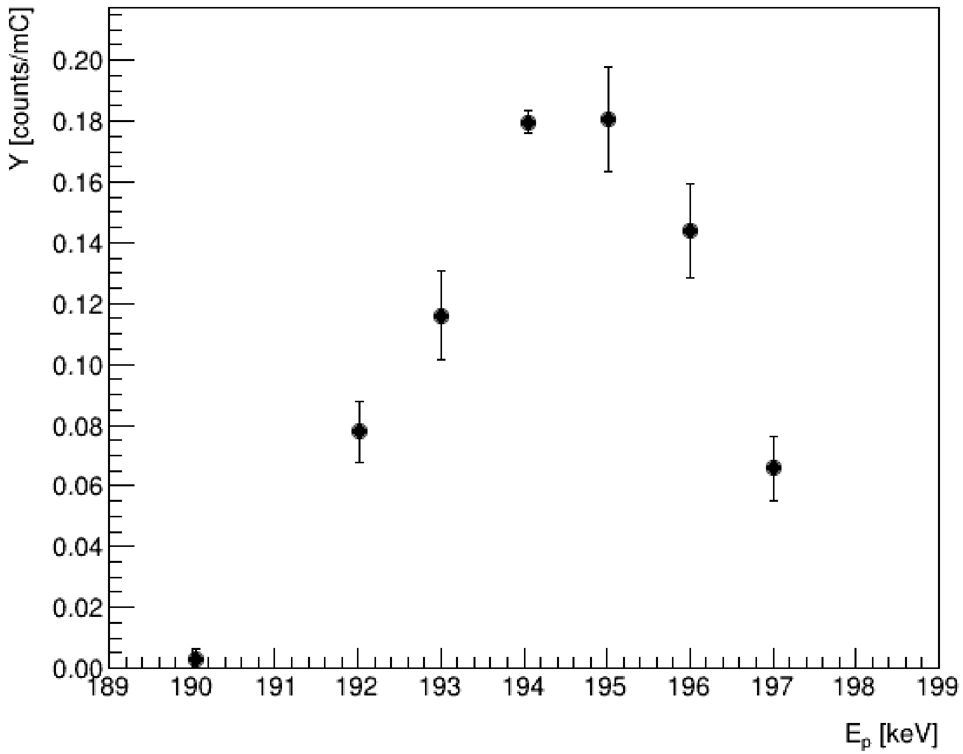


Resonance scan (sum of two detectors)

Long run spectrum (20 h)

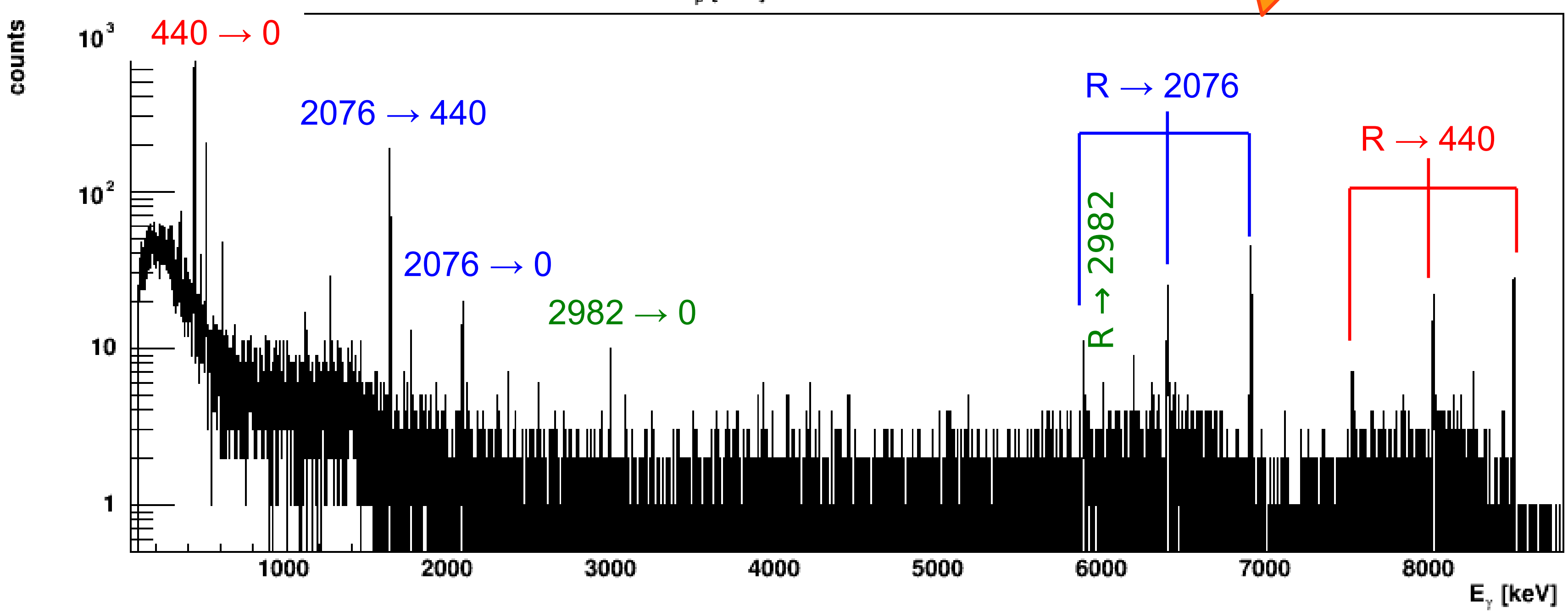


Results: E_{res} = 186 keV (E_{lev} = 8972 keV)



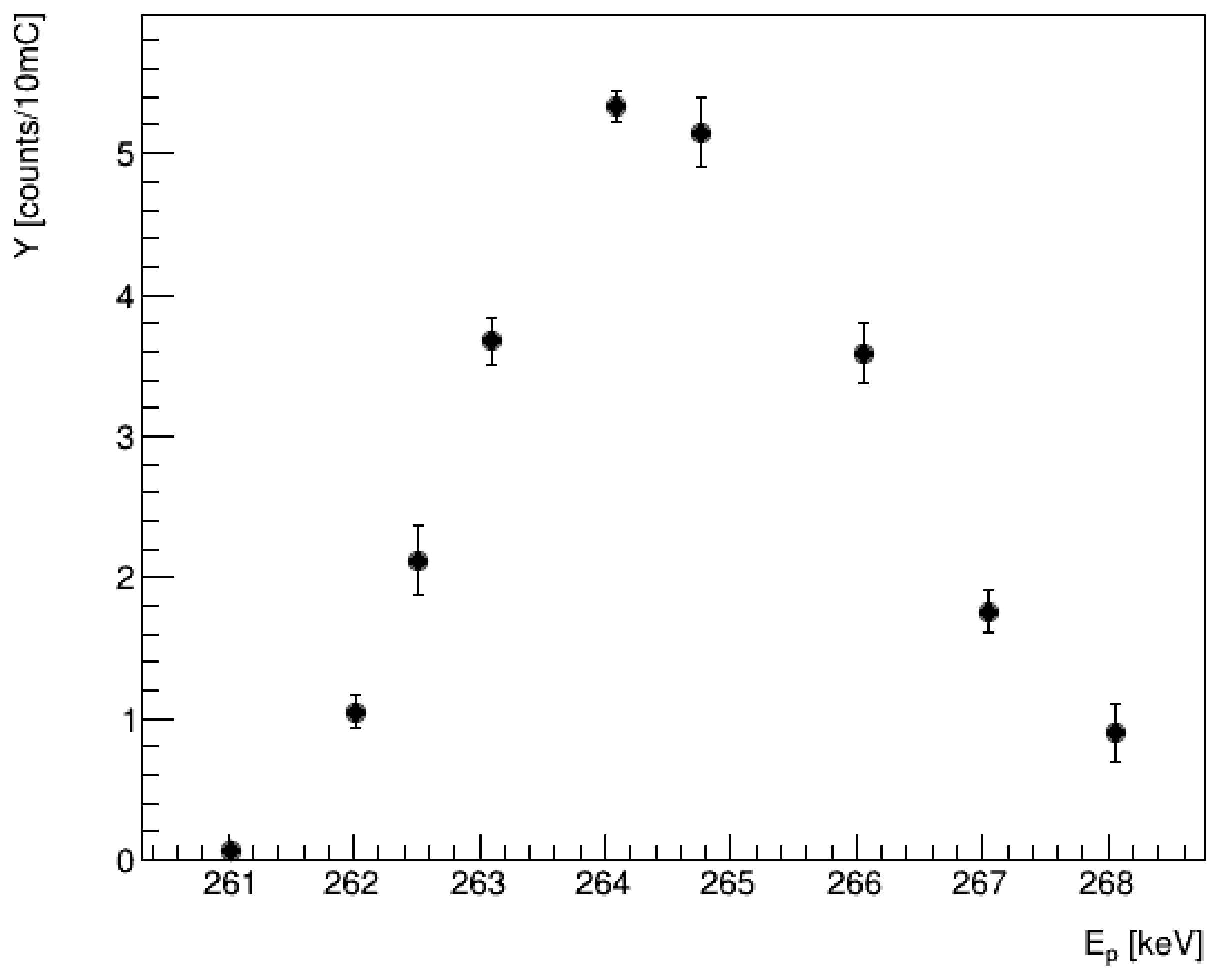
Resonance scan (55° detector)

Long run spectrum (21 h)

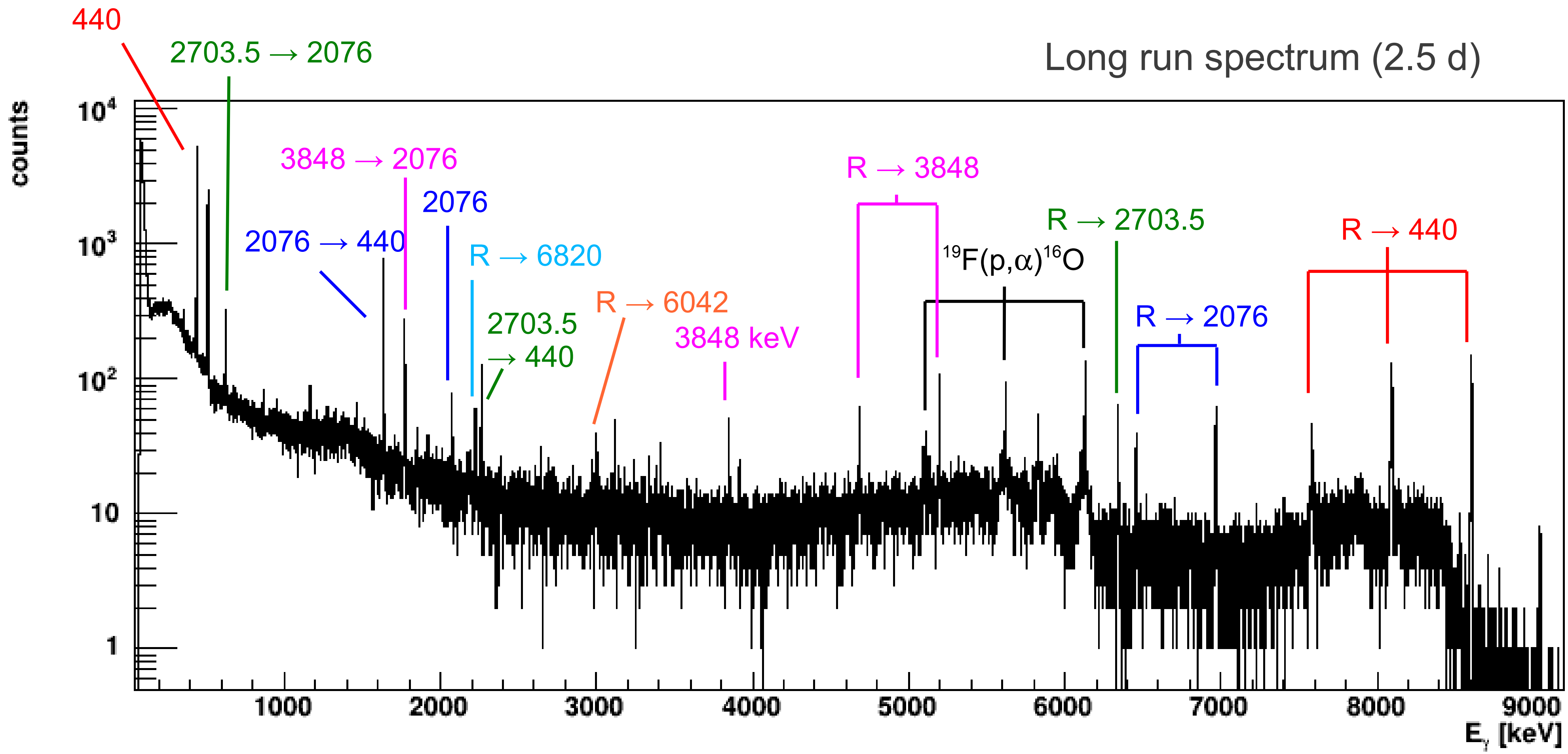


Results: E_{res} = 258 keV (E_{lev} = 9041 keV)

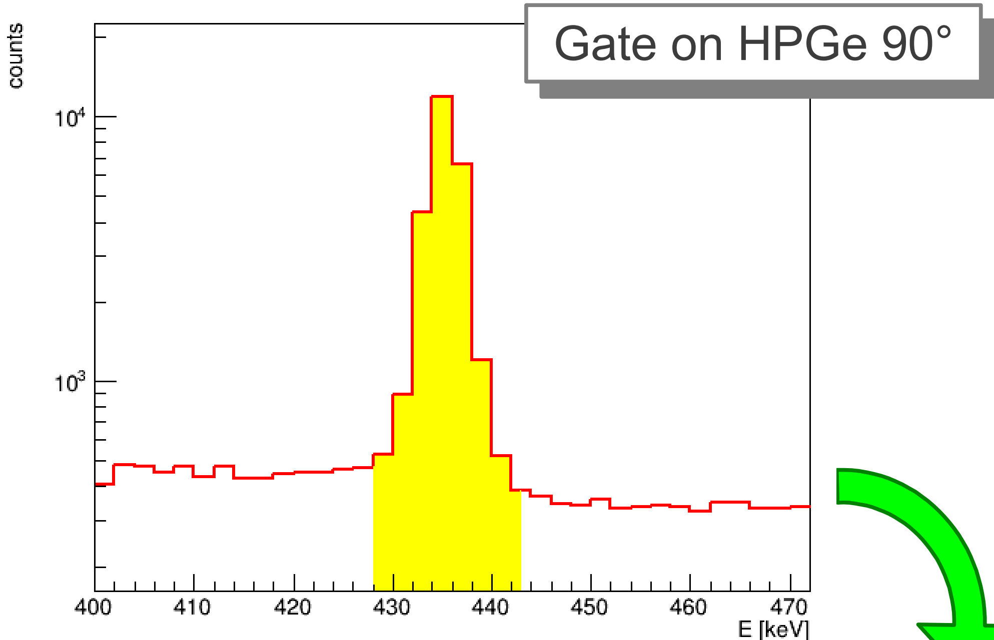
Resonance scan (55° detector)



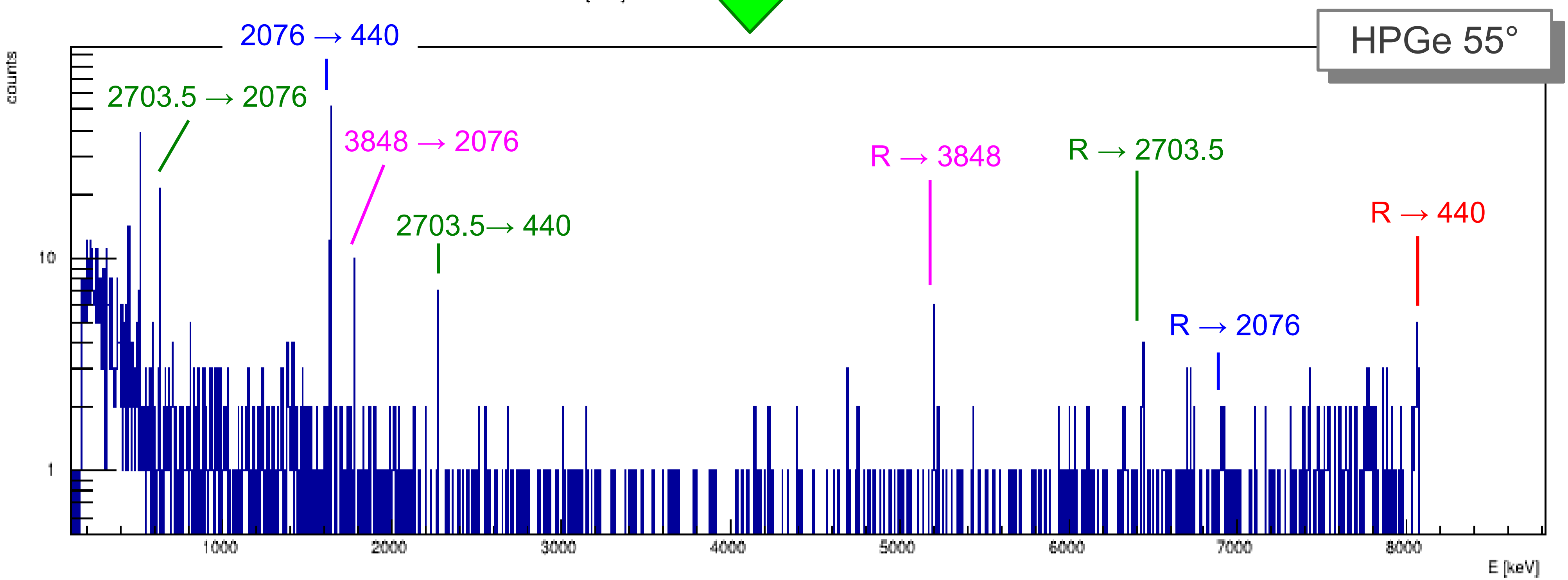
Results: E_{res} = 258 keV (E_{lev} = 9041 keV)



Results: E_{res} = 258 keV (E_{lev} = 9041 keV)

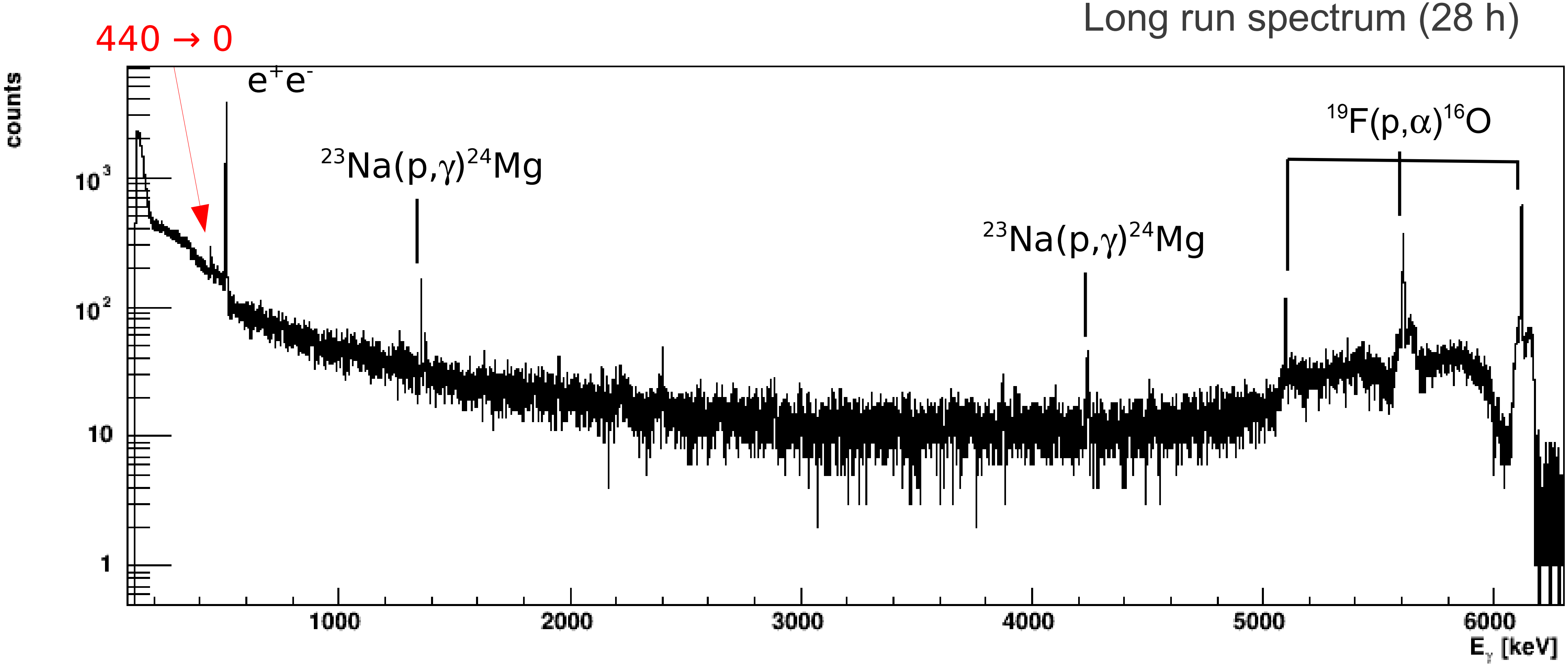


Analysis of γ - γ coincidences in progress



Results: 320 + 334 keV resonances

Long run spectrum (28 h)



Summary

E_{level} [keV]	E_{res}^{LAB} [keV]	ωγ [eV] NACRE [1,2]	ωγ [eV] Hale et al. [3]	ωγ [eV] LUNA
8862?	71	≤ 4.2E-9	≤ 1.9E-10	≤ 4.5E-9
8894?	105	≤ 6.0E-7	≤ 1.4E-7	≤ 3.6E-9
8944	**157**	**6.5E-7**	**≤ 9.2E-9**	**3.8 E-8**
8972	**186**	**≤ 2.6E-6**	**≤ 2.6E-6**	**1.4 E-6**
9000?	215	≤ 1.4E-6	≤ 1.4E-6	≤ 2.4E-8
9041	**258**	**≤ 2.6E-6**	**≤ 1.3E-7**	**6.2 E-6**
9072	291	≤ 2.2E-6	≤ 2.2E-6	≤ 8.1E-8
9100	**320**	**≤ 2.2E-6**	**≤ 2.2E-6**	**2.8 E-7**
9113	**334**	**≤ 3.0E-6**	**≤ 3.0E-6**	**7.7 E-7**

[1] C. Angulo et al. Nucl. Phys. A **656**, 3 - 183 (1999)
[2] J. Görres et al. Nucl. Phys. A **385**, 57 (1982)
[3] S. E. Hale et al.Phys. Rev. C **65**, 015801 (2001)

Summary

- Thanks to the extremely low background at Gran Sasso Laboratories, the $^{22}Ne(p,\gamma)^{23}Na$ cross section has been measured directly at astrophysical energies:
  - 5 resonances have been observed for the first time
  - New upper limits will be available for unobserved resonances

- Resonances strength presently known as upper limits will be further investigated in the next phase of the experiment:
  - A new reaction chamber surrounded by a 4π BGO detector with high detection efficiency will be set-up in the next months

LUNA Collaboration

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