STUDY OF THE GAS TARGET DENSITY PROFILE FOR THE REACTION $^{22}Ne(\alpha, n)^{25}Mg$

Marianna Vagnoni

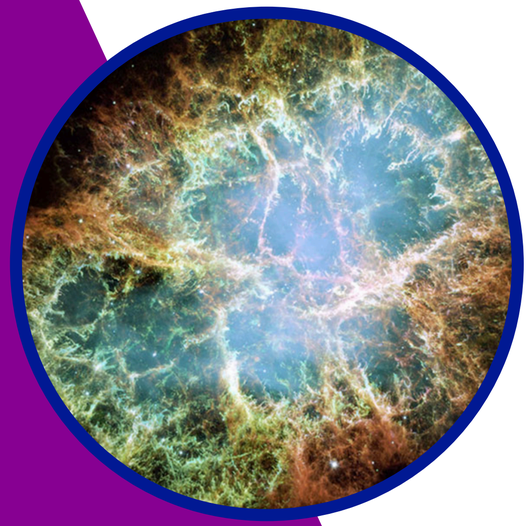
SHADES experiment

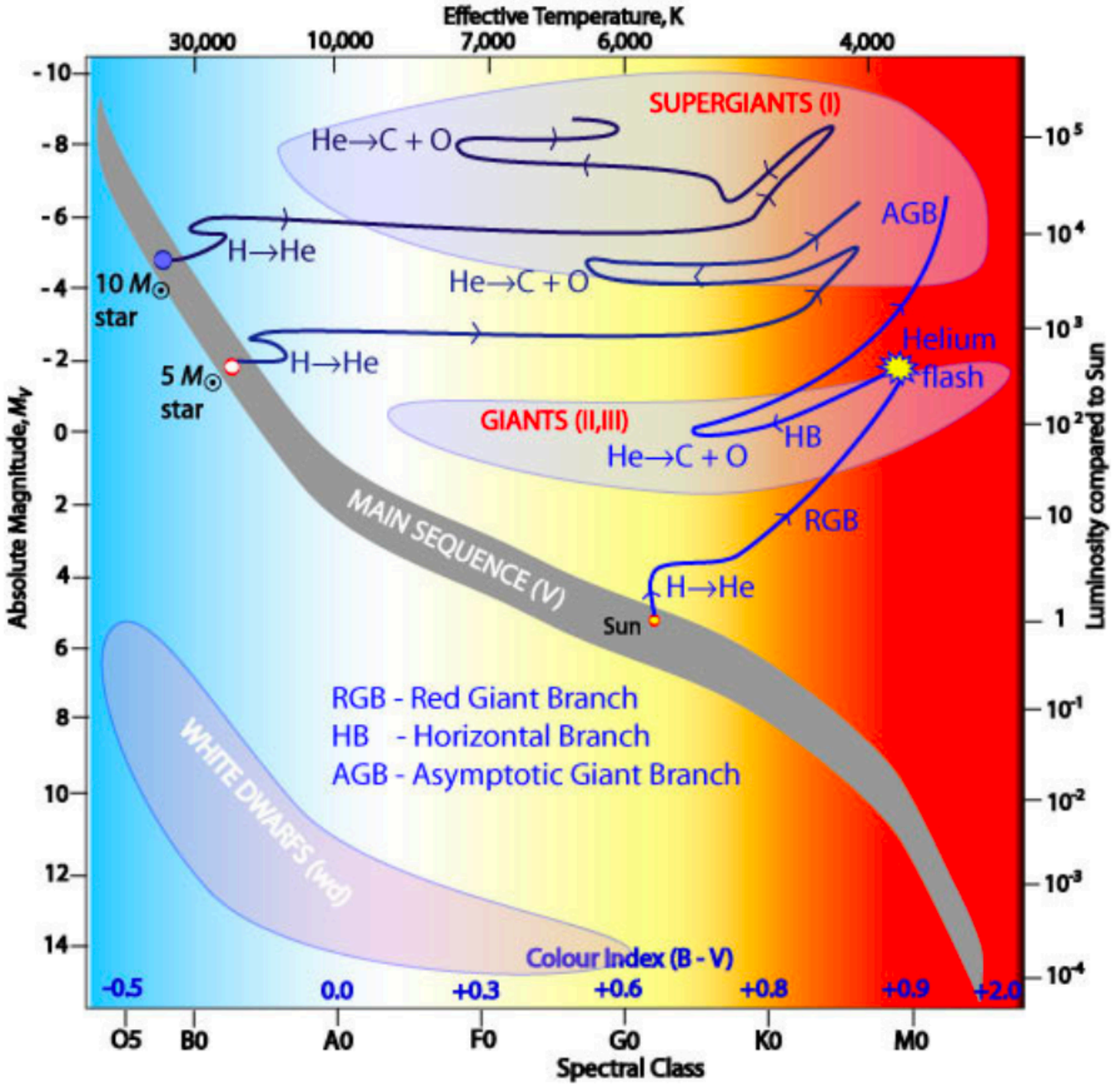
On Behalf of LUNA Collaboration

“Bruno Touschek” LNF Spring School - 13th May 2024

NUCLEAR ASTROPHYSICS

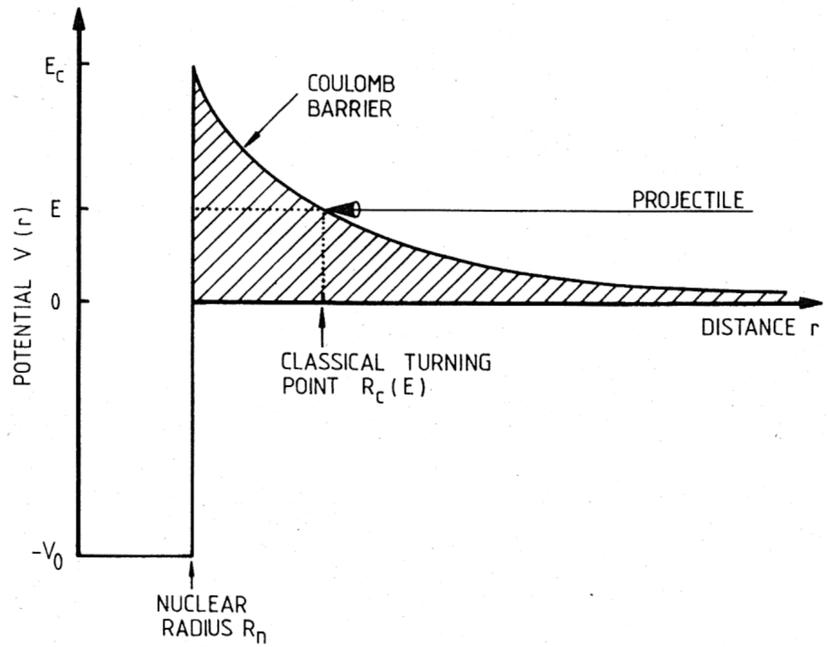
GENERAL ASPECTS

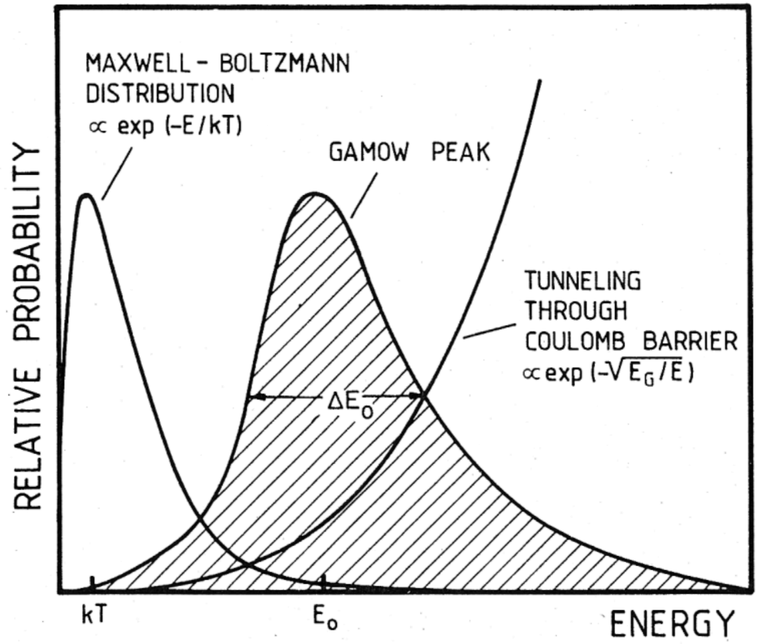




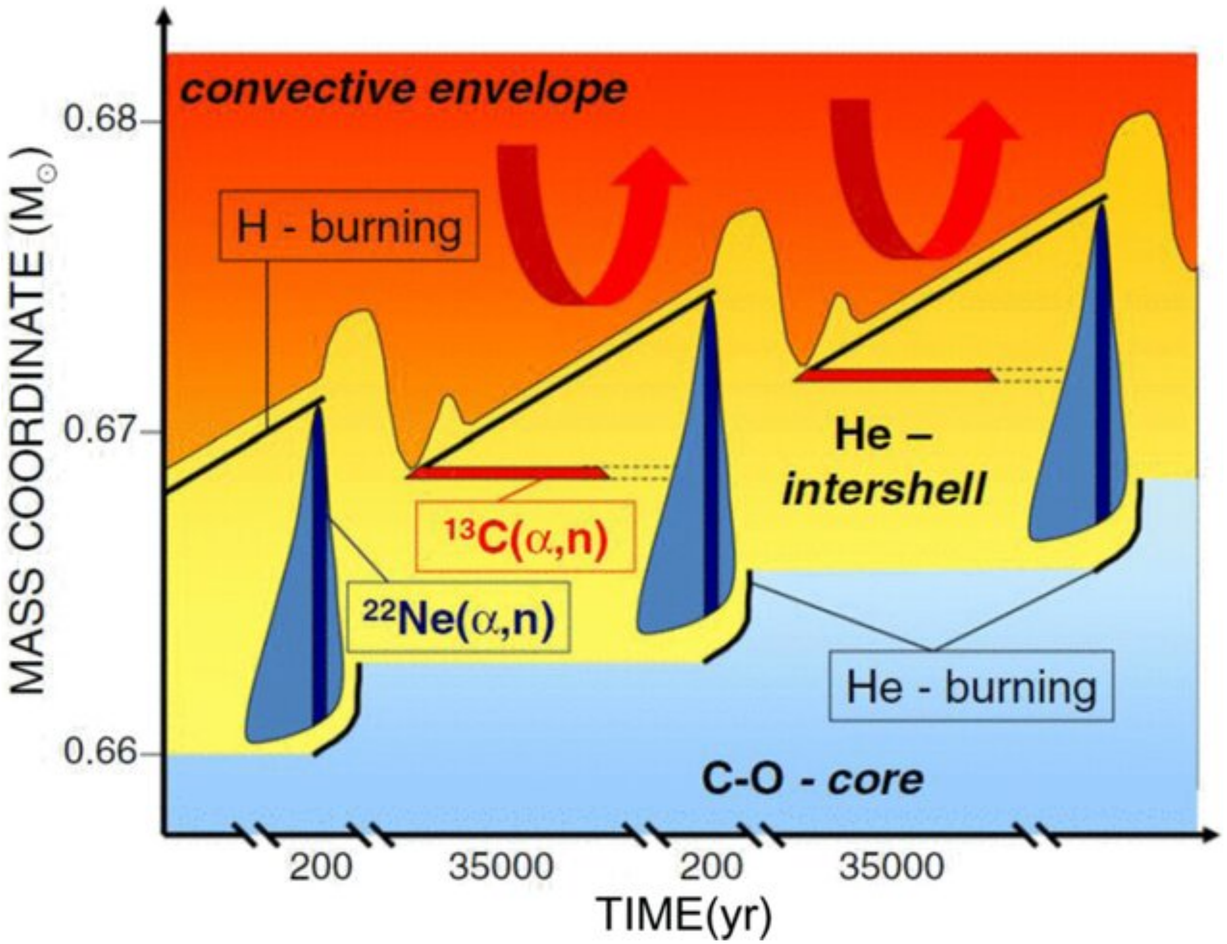
NUCLEAR ASTROPHYSICS

THEORETICAL ASPECTS





$$\sigma(E) = \frac{S(E)}{E}\exp(-2\pi\eta) \qquad \eta = \frac{Z_1 Z_2 e^2}{\pi\sqrt{E}}$$



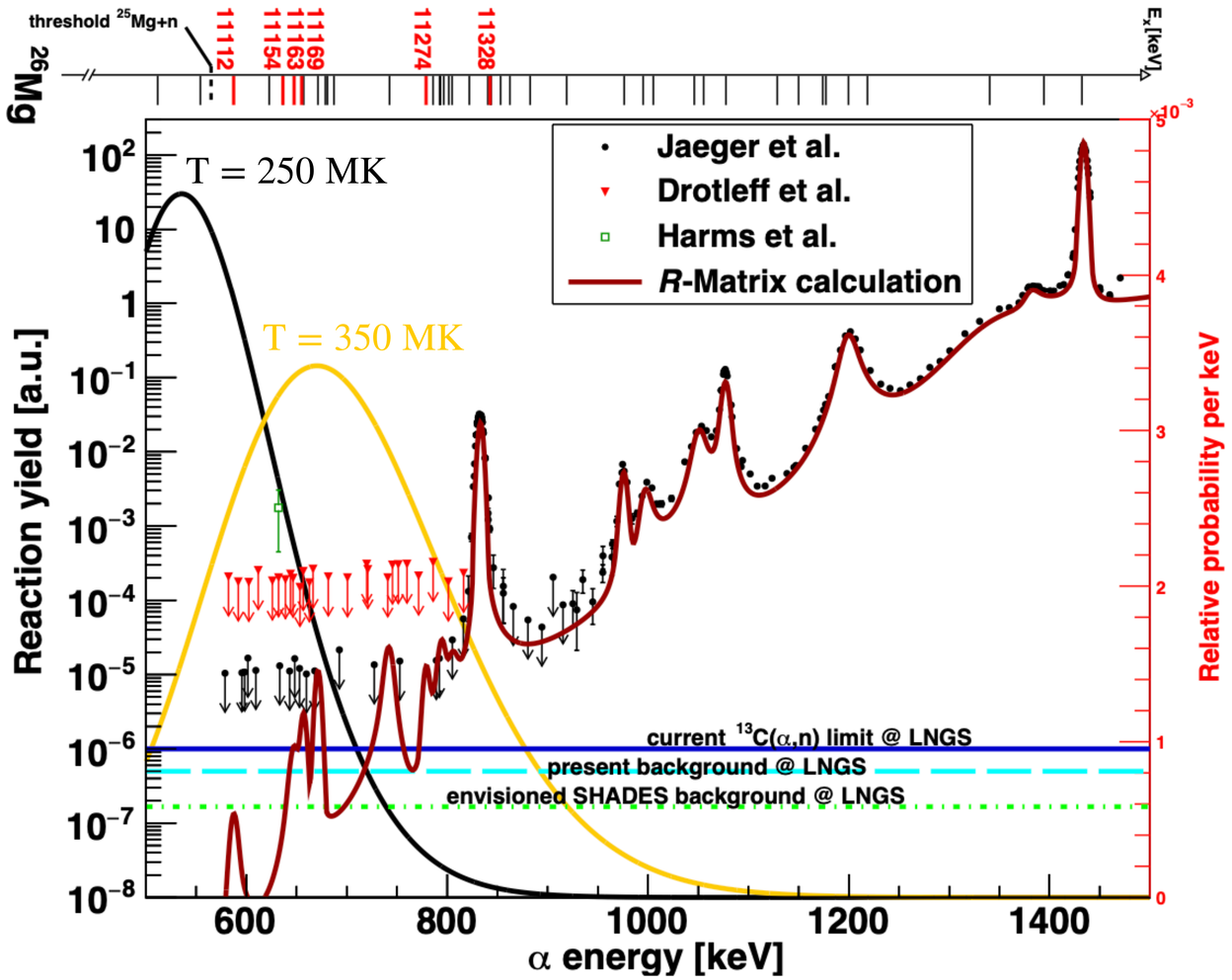
THE REACTION

$$^{22}\mathrm{Ne} + \alpha \rightarrow {}^{25}\mathrm{Mg} + \mathrm{n}$$

$Q \sim -478$ keV

- A series of α-capture produce ^{22}Ne from ^{14}Na
- Main neutron source for s-process in AGB stars
- Main neutron source for weak s-process in He-burning core of RG stars

STATE OF THE ART



R matrix courtesy of R. J. deBoer, University of Notre Dame

BACKGROUND AND LNGS

ENVIRONMENTAL BACKGROUND:

- Radioactive elements from the decay chain of Pb, U, Th

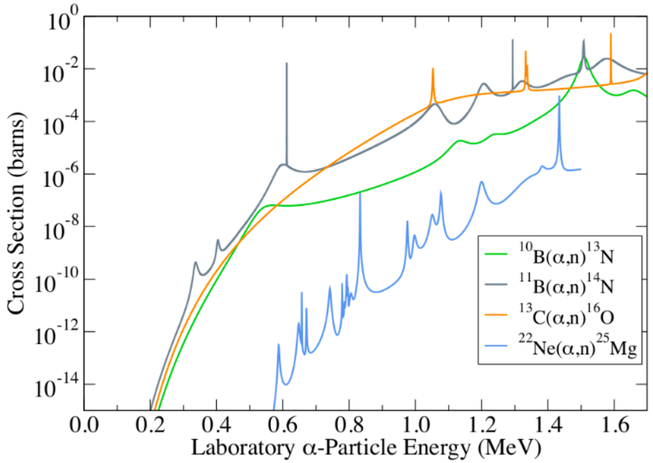
UNDERGROUND:

- Neutron flux 3 orders of magnitude less
- Cosmic flux 6 orders of magnitude less

BEAM INDUCED BACKGROUND:

- Reaction with $Q > 0$
- Discrimination with neutron energy

$$E_n = E_{beam} + Q$$



EXPERIMENTAL SETUP

$^{22}Ne(\alpha, n)^{25}Mg$

α particles → **BEAM LINE** → α particles →

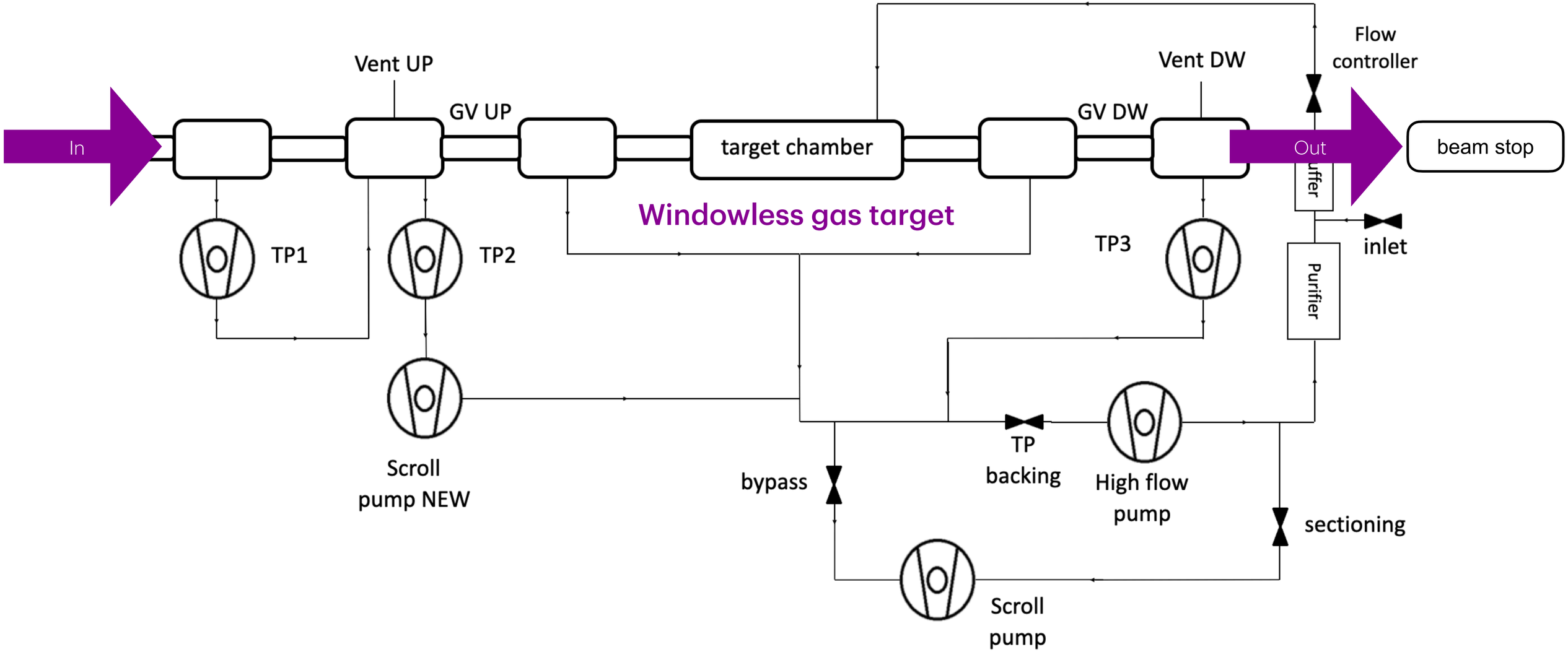
DETECTOR
neutrons counter

TARGET CHAMBER
^{22}Ne gas

DETECTOR
neutrons counter

EXPERIMENTAL SET UP

GAS TARGET & PUMPING SYSTEM



EXPERIMENTAL SETUP

CROSS SECTION MEASUREMENT

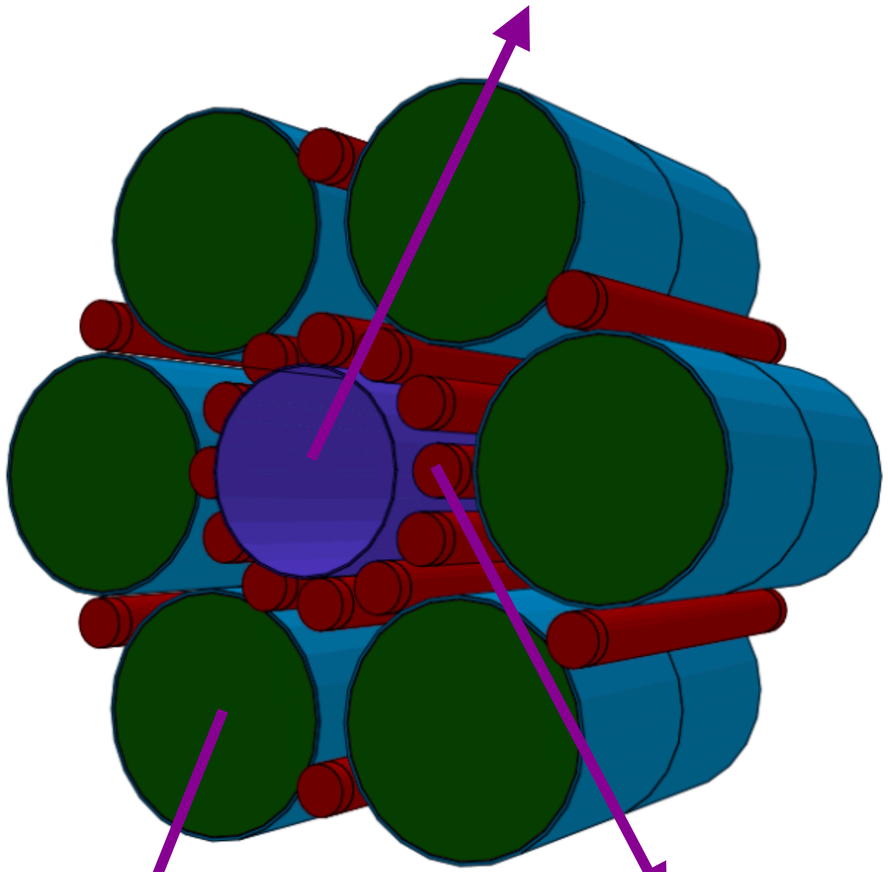
$$\sigma \propto \Phi_p N N_T \eta \, \omega(\Omega)$$

Number of events:

Measured by the SHADES detector

Number of target nuclei N_T:

Gas target characterisation



EXPERIMENTAL SETUP

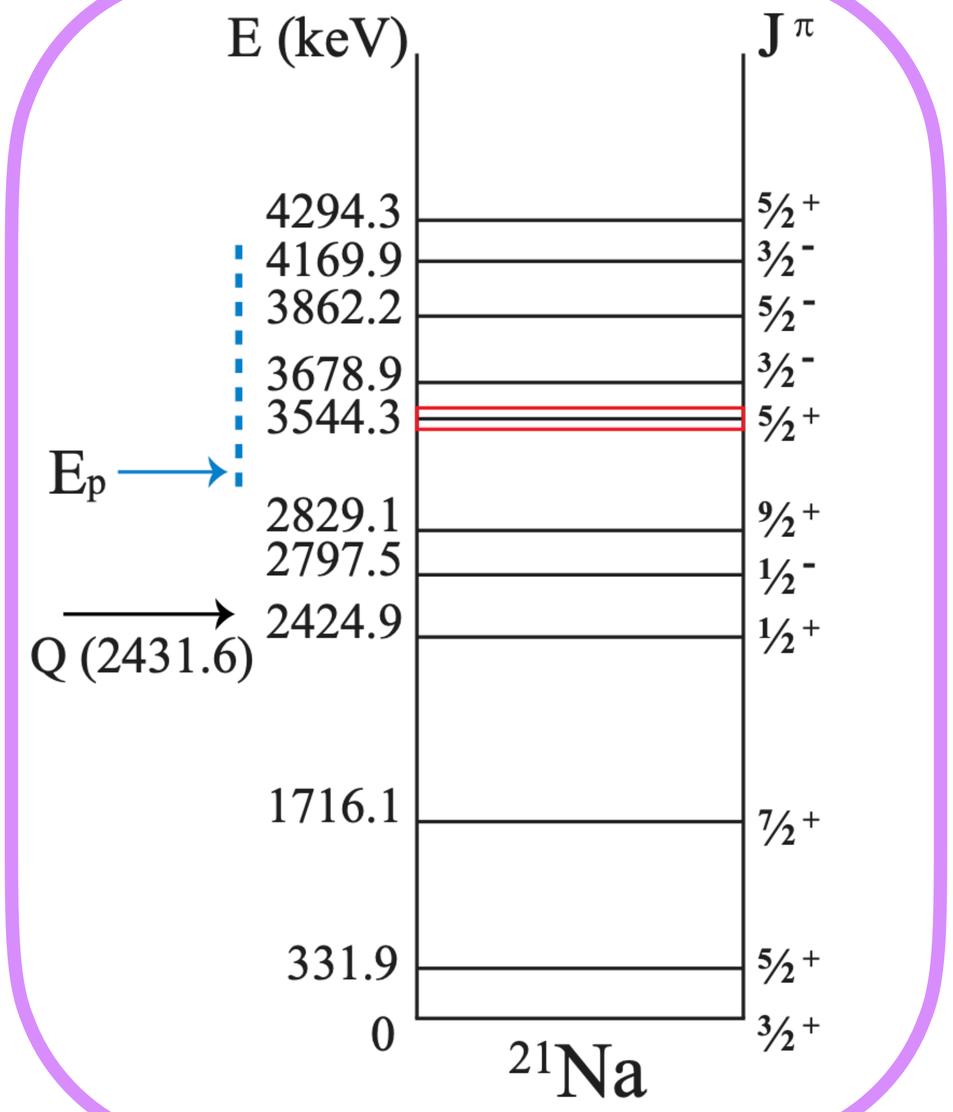
$^{20}Ne(p, \gamma)^{21}Na$

protons → **BEAM LINE** → protons → **TARGET CHAMBER** ^{20}Ne gas

DETECTOR LaBr scintillator

ANALYSIS FOR DENSITY PROFILE

THE RESONANCE



$$^{20}\mathrm{Ne} + \mathrm{p} \rightarrow {}^{21}\mathrm{Na} + \gamma$$

$Q \sim 2432$ keV

- Effect of the intense ion beam into the gas
- Narrow resonance:

$$E_R = 1113 \text{ keV} \qquad \Gamma = 0.94 \pm 0.04 \text{ eV}$$

- The position into the chamber changes as the E_{beam} is varied

ANALYSIS FOR DENSITY PROFILE

SETUP AND MEASUREMENTS

SETUP:

- Gas target chamber filled with $^{20}\mathrm{Ne}$
- Movable table with 14 steps
- LaBr scintillator collimated with Pb

MEASUREMENTS:

- Fix $\mathrm{E_{beam}}$ and $\mathrm{I_{beam}}$
- Move the table at step 1 and start a run
- Start a new run for each step until step 14

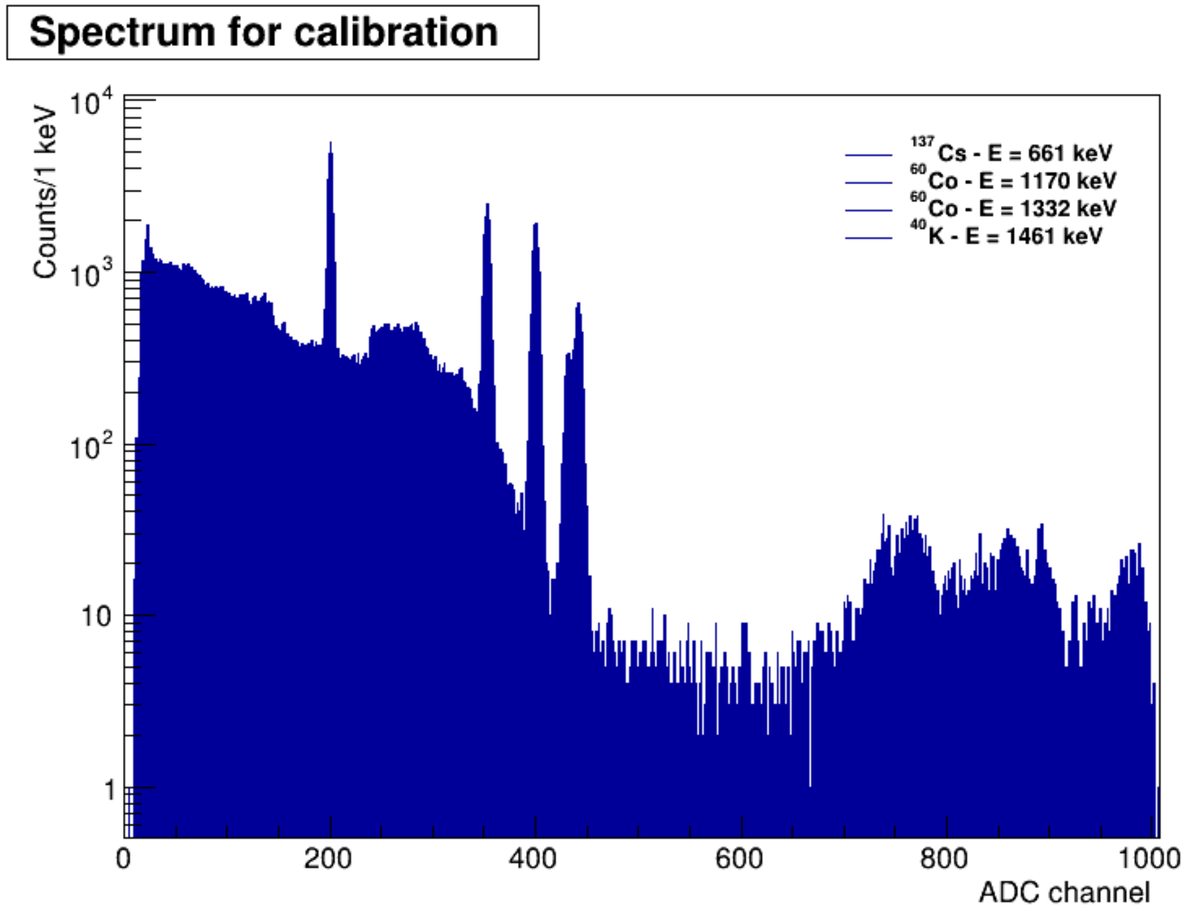
ANALYSIS FOR DENSITY PROFILE

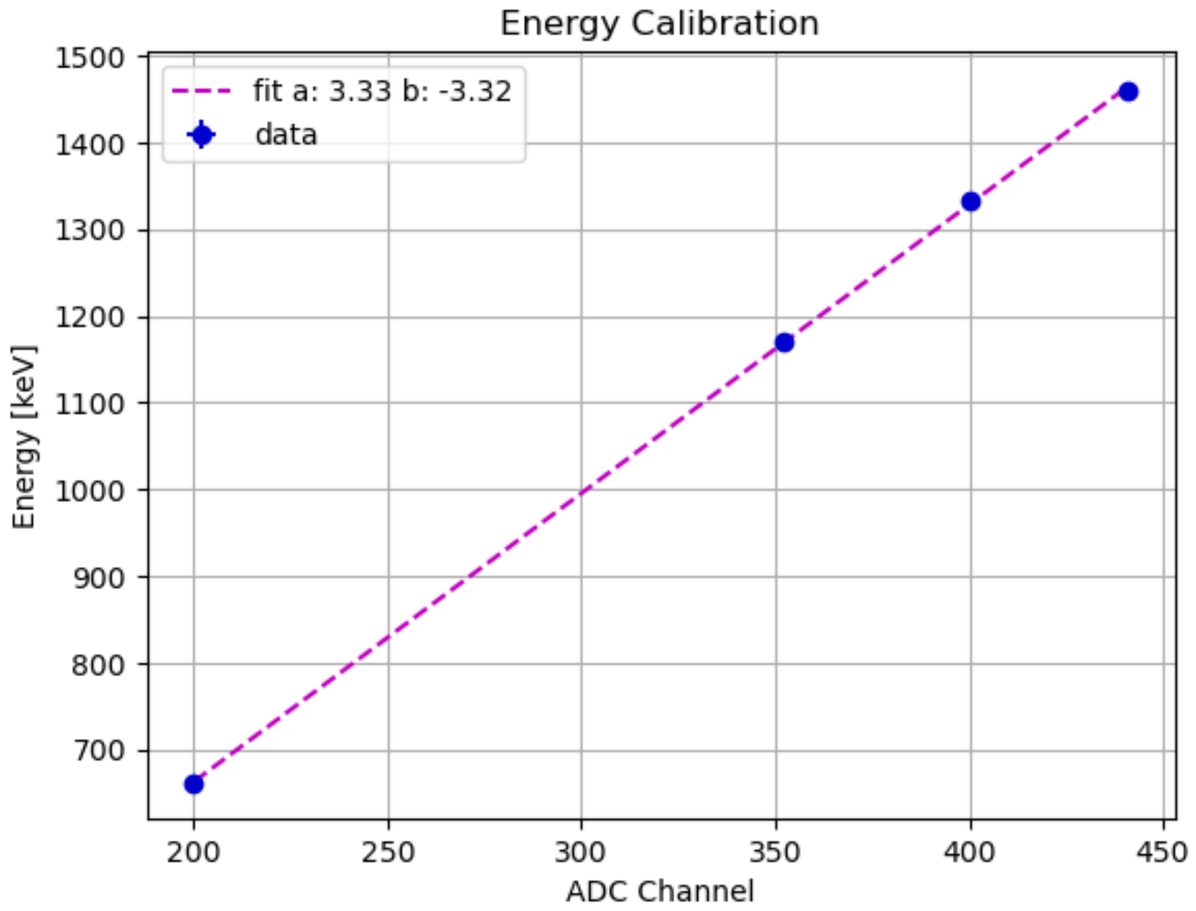
DATA AT FIXED ENERGY AND CURRENT

run_name	E_beam [keV]	E_CM [keV]	real_time [s]	I_beam [uA]	p_target [mbar]	steps [mm]	steps error [mm]
run_366	1173	1117	373.0	42	4.0	32.5	0.5
run_367	1173	1117	327.0	42	4.0	52.1	0.5
run_368	1173	1117	375.0	42	4.0	72.6	0.5
run_369	1173	1117	80.0	42	4.0	92.0	0.5
run_370	1173	1117	385.0	42	4.0	112.0	0.5
run_371	1173	1117	260.0	42	4.2	131.5	0.5
run_372	1173	1117	183.0	42	4.2	171.4	0.5
run_373	1173	1117	163.0	42	4.2	191.4	0.5
run_374	1173	1117	129.0	42	4.2	211.6	0.5
run_375	1173	1117	196.0	42	4.2	231.5	0.5
run_376	1173	1117	146.0	42	4.2	252.0	0.5
run_377	1173	1117	125.0	42	4.2	271.2	0.5
run_378	1173	1117	102.0	42	4.2	291.3	0.5
run_379	1173	1117	112.0	42	4.2	319.3	0.5

ANALYSIS FOR DENSITY PROFILE

ENERGY CALIBRATION

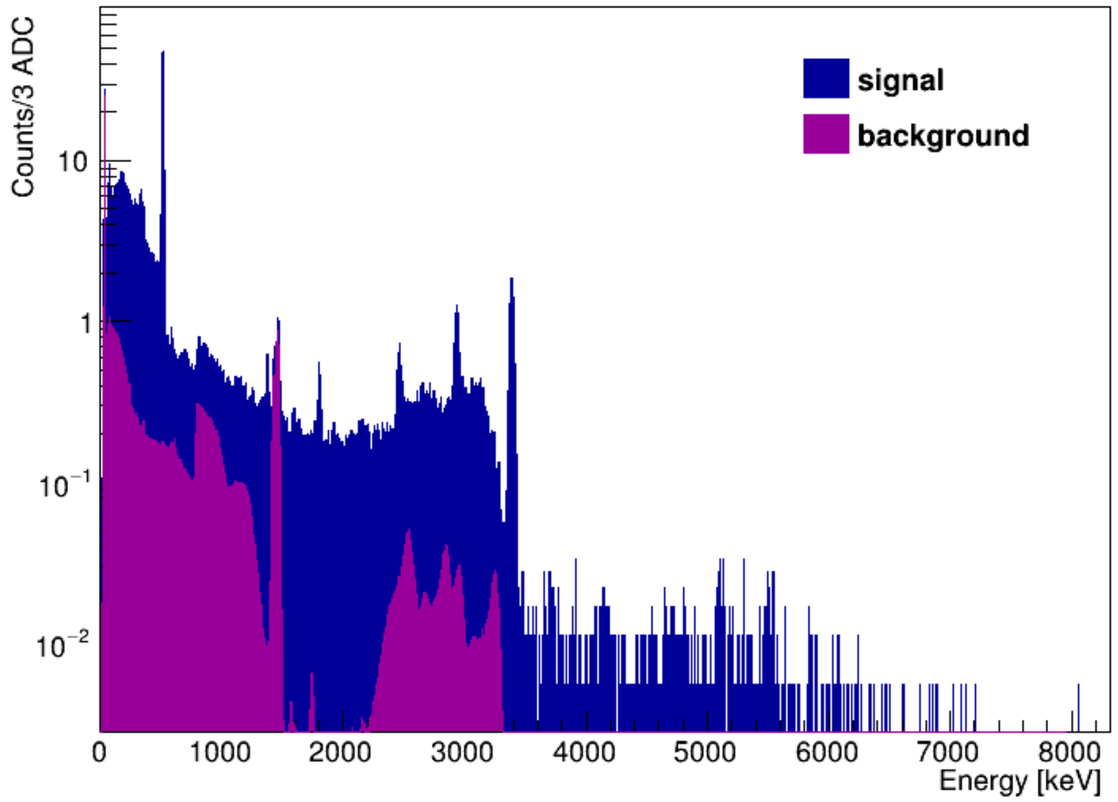




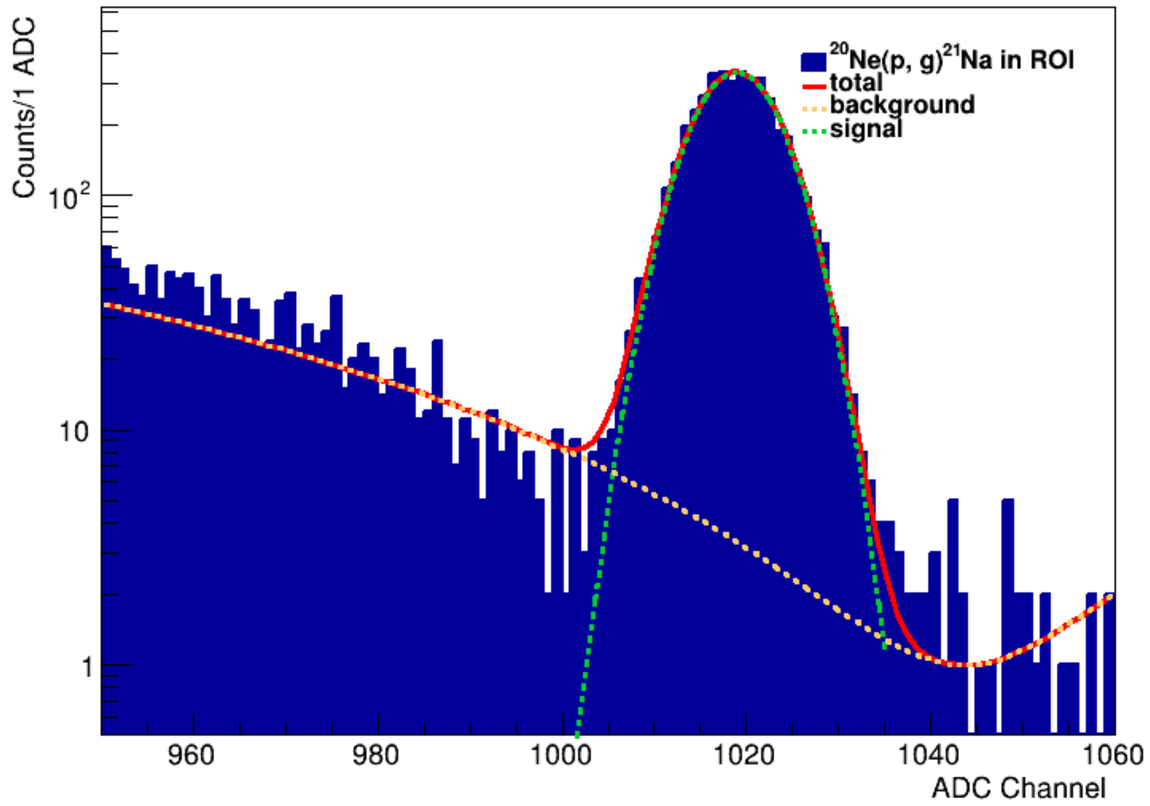
ANALYSIS FOR DENSITY PROFILE

ROI AND SIGNAL EXTRACTION

Signal and background

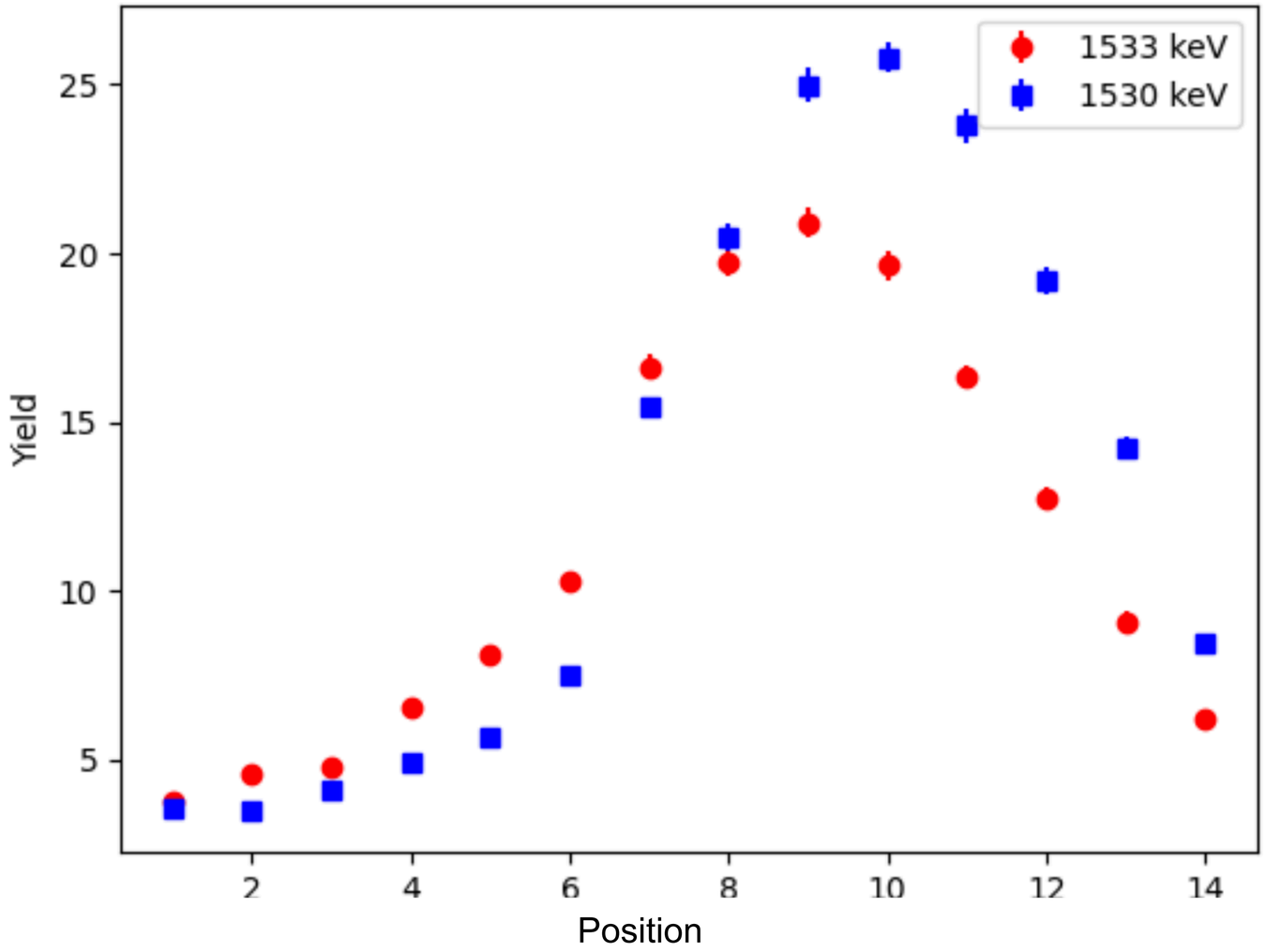


run_381



ANALYSIS FOR DENSITY PROFILE

ONLINE YIELD PROFILE



- Profile of the experimental yield versus the position into the gas target chamber

$$Y = \frac{N}{Q}$$

NEXT STEPS ANALYSIS

DENSITY PROFILE

- Definition of the yield with fixed beam energy

$$Y(E_0) = \frac{1}{\epsilon_r} \int_0^{z_{max}} dz \int_{E_0}^{0} f(E, E(z))\ \sigma_{BW}\ \eta(z)\ \rho(z)\ dE$$

$$f(E, E(z)) = \exp\left[\frac{(E - E(z))^2}{2[\sigma^2_{beam} + \sigma^2_{straggle}(E(z))]} \right]$$

- Extraction of the density $\rho(z)$ for different beam energy

- Construction of the density profile

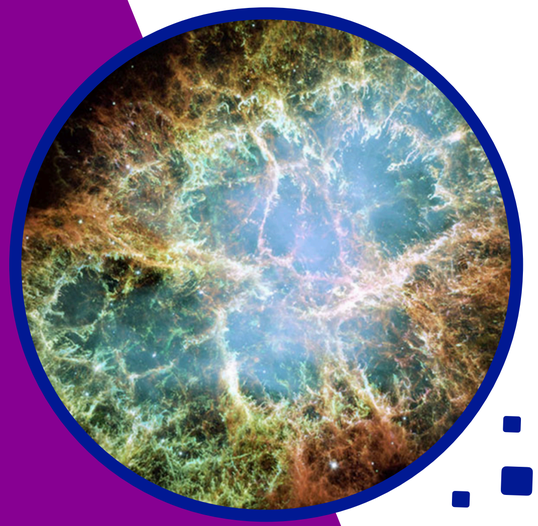
THANK YOU FOR YOUR ATTENTION

LUNA

BIBLIOGRAPHY

- Aziz, Azni Abdul, et al. "Progress in nuclear astrophysics of east and southeast Asia." *AAPPS Bulletin* 31 (2021): 1-31.
- Wiescher, M., R. J. DeBoer, and J. Görres. "The resonances in the 22 Ne+ α fusion reactions." The European Physical Journal A 59.1 (2023): 11.
- Hammer, J. W., et al. "22Ne (alpha, n) 25Mg: The Key Neutron Source in Massive Stars." Physical Review Letters 87.20 (2003).
- Görres, J., et al. "The influence of intense ion beams on gas target densities." Nuclear Instruments and Methods 177.2-3 (1980): 295-303.
- Lyons, S., et al. "Determination of Ne 20 (p, γ) Na 21 cross sections from E p= 500– 2000 keV." Physical Review C 97.6 (2018): 065802.
- Rolfs, Claus E., and William S. Rodney. *Cauldrons in the cosmos: Nuclear astrophysics*. University of Chicago press, 1988.
- Knoll, Glenn F. *Radiation detection and measurement*. John Wiley & Sons, 2010.
- Iliadis, Christian. *Nuclear physics of stars*. John Wiley & Sons, 2015.

https://luna.lngs.infn.it/



BACKUP

To satisfy your curiosity

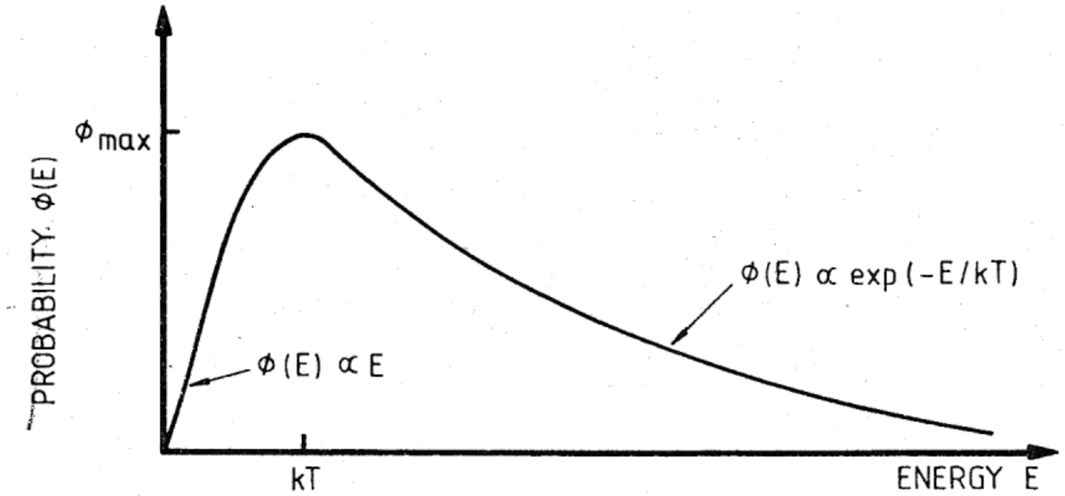
NUCLEAR ASTROPHYSICS

- Measurement of the cross section from the reaction rate

$$r = N_X \, N_Y < \sigma(\mathrm{v}) \, \mathrm{v} > (1 + \delta_{XY})$$

- Non relativistic nuclei composed the stellar gas, so velocities follow the Maxwell-Boltzmann distribution

$$< \sigma(\mathrm{v}) \, \mathrm{v} > = \left(\frac{8}{\pi \mu} \right)^{1/2} \frac{1}{(kT)^{3/2}} \int_0^\infty \sigma(E) \, E \, \exp\left(-\frac{E}{kT} \right) dE$$



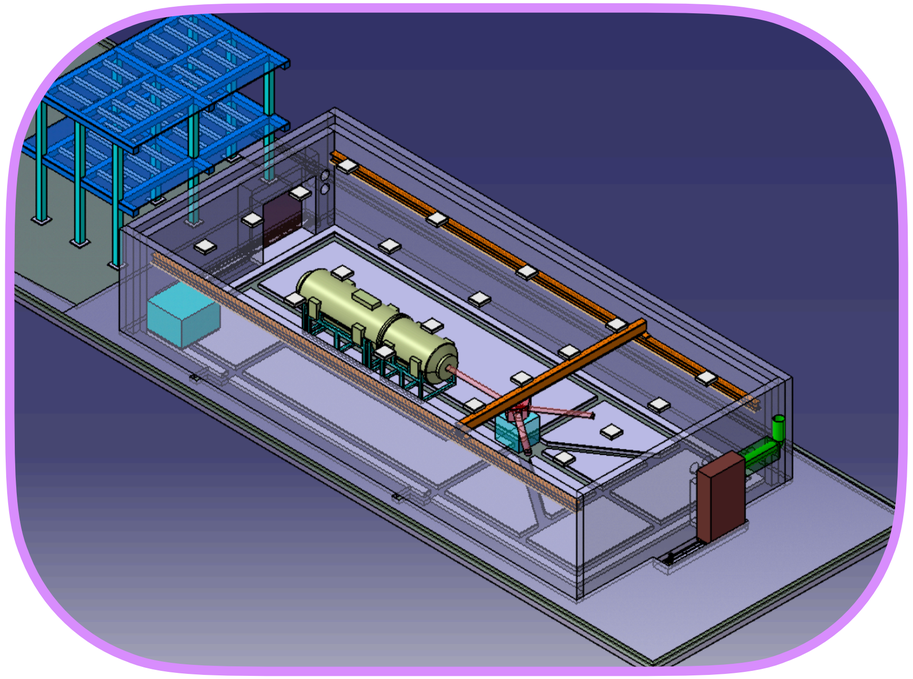
EXPERIMENTAL SETUP

BELLOTTI ION BEAM FACILITY

Electrostatic accelerator

TANK IN:

- Source with different gas to generate p-beam, α-beam and ^{12}C-beam
- Extraction tools
- Focusing lens



TANK OUT:

- Focusing lens
- Central magnet that creates 2 beam lines

ANALYSIS FOR DENSITY PROFILE

BACKGROUND SPECTRUM

Background spectrum