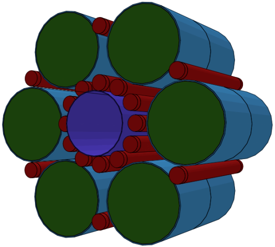
Scintillator-^{3}He Array for Deep-underground Experiments on the S-process

SHADES



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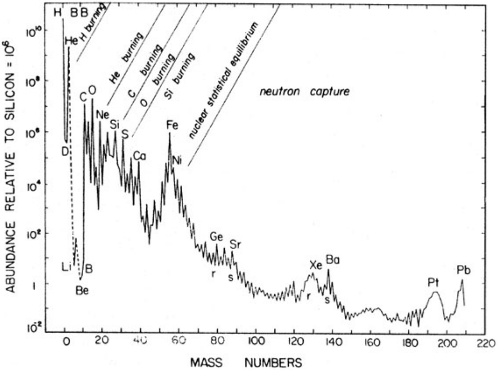
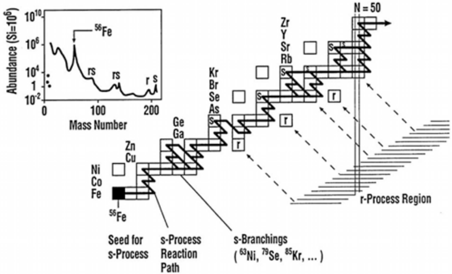
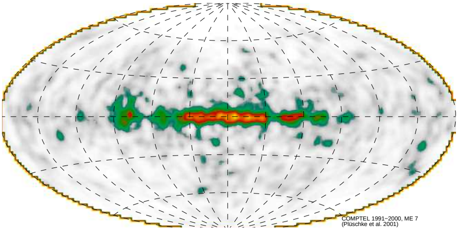
Synthesis of the elements



- Almost all elements $>$ Li produced in stars
- A $<$ Fe: charged-particle capture
- A $>$ Fe: neutron capture (r-, **s-process**, p-process)
- ^{22}Ne$(\alpha, n)^{25}$Mg one of the two main neutron sources for s process

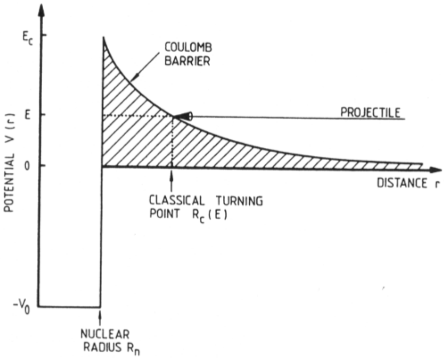
$^{22}Ne(\alpha, n)^{25}Mg$ physics case: production of the heavy elements, and more

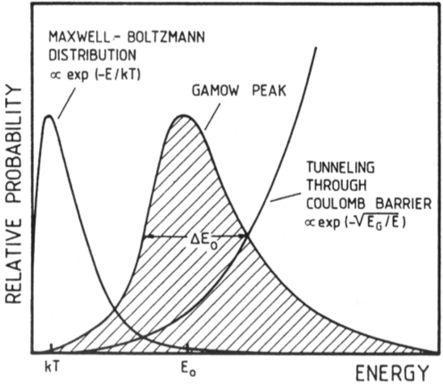




- Residual elemental abundances attributed to other n-processes
  $N_r = N_\odot - N_s$
- Formation of early solar system - cosmic grains in meteorites
- Astronomical observation of gamma-rays (COMPTEL, INTEGRAL)
- Mg isotope observations in stellar atmospheres

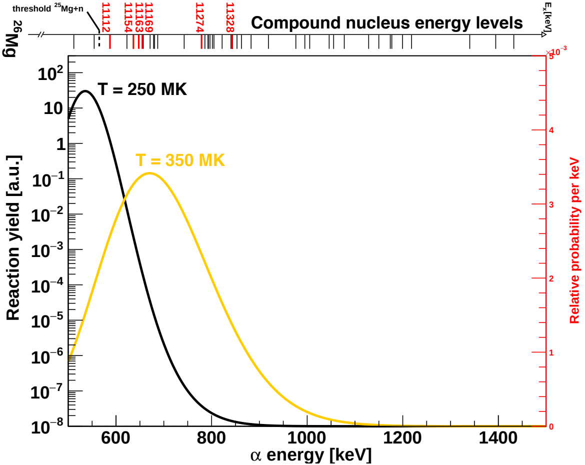
Reaction rate and effective energy





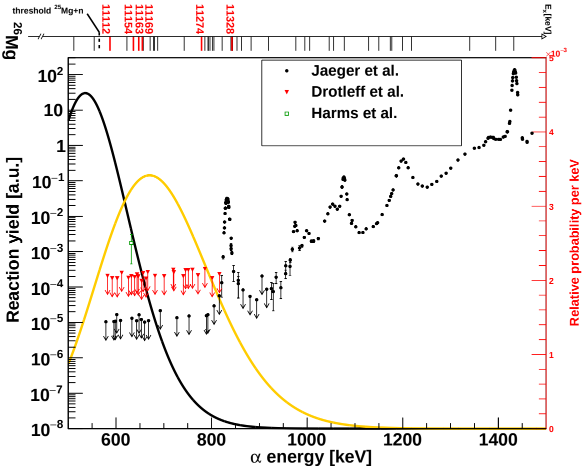
- How quickly does reaction proceed:
  $\langle \sigma v \rangle_{j,k} = \sqrt{\frac{8}{\pi \mu_{jk}}} (kT)^{-3/2} \int_0^\infty E \sigma(E) e^{-E/kT} dE$
- Thermal energies in stars in keV range, far below Coulomb energy
- Tunneling combined with Maxwell-Boltzmann: Gamow-peak
- ^{22}Ne$(\alpha, n)^{25}$Mg: kT $\approx$ 30 keV (T $=$ 0.3 GK), E$_G$ $\approx$ 600 keV

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



- Capabilities on surface exhausted (20 years since last data)
- Current lowest data 2 reactions/minute
- Covers one resonance close to Gamow
- 300 keV of upper limits. . .
- Many states that can contribute
- Need improvement by more than 2 orders of magnitude

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



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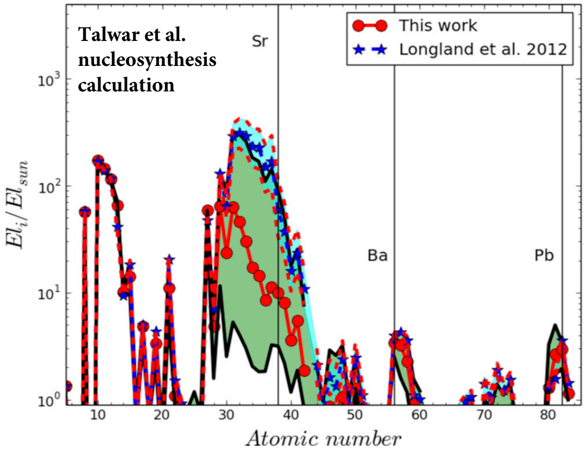
Low-energy states

Table 1. Properties of states in ^{26}Mg between the neutron threshold and the 832 keV resonance. Values taken from [15], except for the last row, which is from [14].

E_n [keV]	E_x [keV]	E_α [keV]	Jπ	Neutron width [eV]
19.92	11112	589	2+	2095
72.82	11163	649	2+	5310
79.23	11169	656	3-	1940
187.95	11274	779	2+	410
194.01	11280	786	3-	1810
243.98	11328	843 ?	?	171
235 [14]	11319	832	2+	Total width = 250 eV

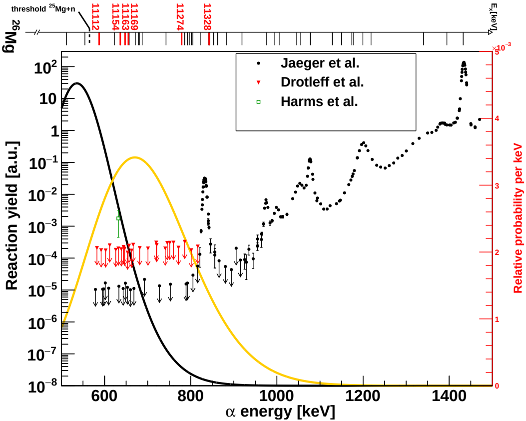
- Recent nTOF study of energies and neutron widths (Massimi et al. 2017)
- 832 keV state still a bit unclear w.r.t. n/α channel
- No α widths are known

Uncertainties



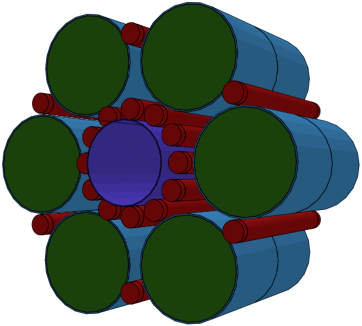
- Cross section at critical energies extremely low, unmeasured
- Little information on low energy states → large uncertainty
- Two orders of magnitude variation in nucleosynthesis output

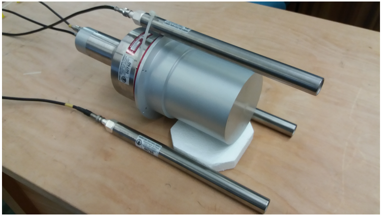
What to do?



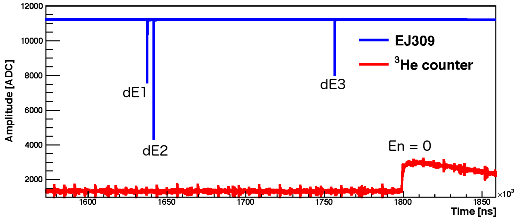
- Drastic background reduction
- Drastic beam current increase
- Suppression/identification of beam-induced background

Detector array

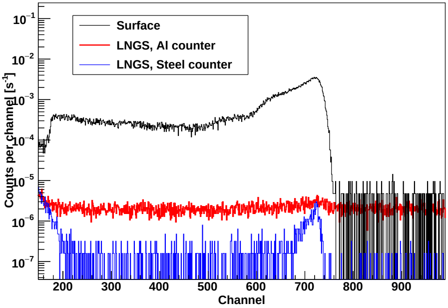


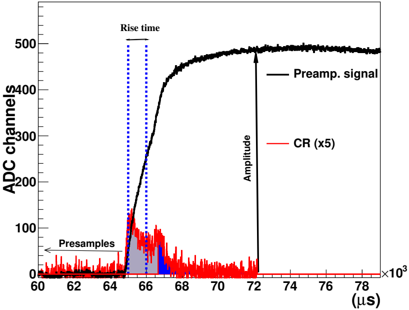


- Need to measure very low event rates
- Require some sort of energy sensitivity
- Hybrid detector array: ^{3}He counters & liquid scintillator
- High efficiency + energy sensitive
- Prototype built & tested



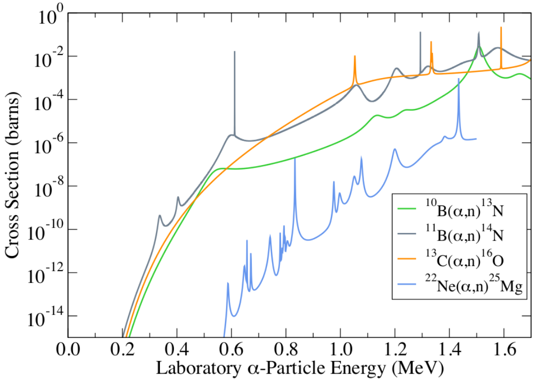
Background reduction





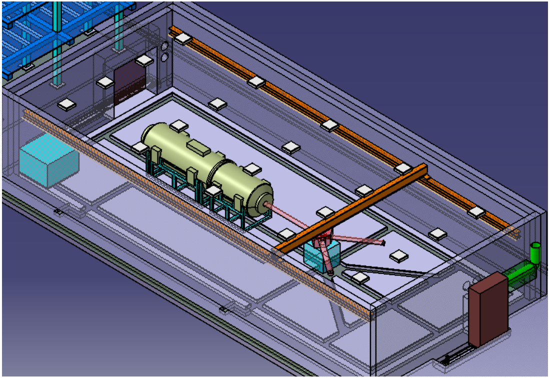
- Deep underground @ LNGS: Suppression of (thermal) neutron background by > 1000
- Additional clean detector material & PSD
- Extended gas target with enriched ^{22}Ne
- Total background ≈ 1 count/hour

Beam-induced backgrounds



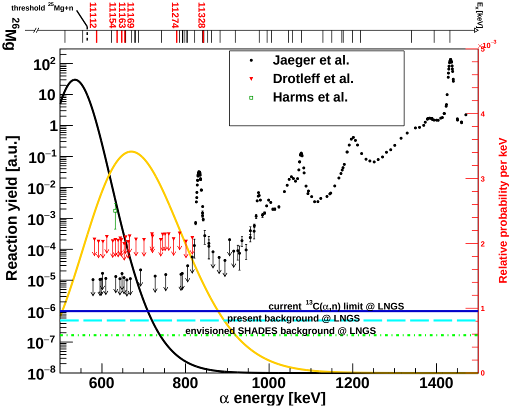
- Q-values:
  - ^{22}Ne = - 478 keV
  - ^{10}B = 1059 keV
  - ^{11}B = 158 keV
  - ^{13}C = 2216 keV

Top-of-the-line accelerator



- Specifically designed to fit nuclear astrophysics needs
- Reaction rates of $< 1/\text{hour}$:
  - Beam current ($\approx 5\times$ Jaeger et al.): push signal-noise ratio
  - Current stability: measurements of the order of weeks
  - Energy stability: must not drift over long periods
- 300 - 3500 kV: cover entire astrophysical energy range

Goals



- Cover from threshold to 3.5 MeV
- $>$ two orders of magnitude improvement
- Comprehensive R matrix analysis
- Perform nucleosynthesis calculations with new data

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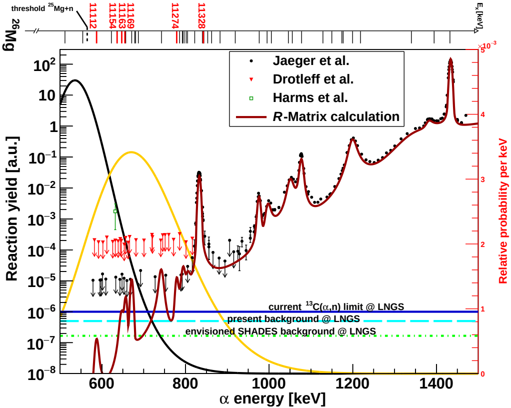

R matrix courtesy of R. J. deBoer, University of Notre Dame

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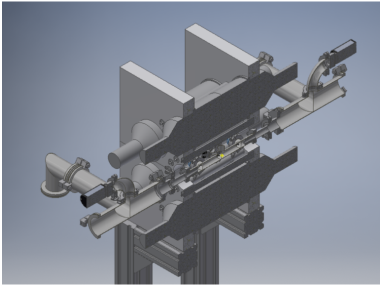
Timeline



- 5-year project, started February 2020
- Currently procuring detectors, target components
- First $\sim$ 2 years
  - Target+detector assembly
  - Target characterisation
  - Detector background
  - DAQ development
  - Detector characterisation
- Then transport and assembly at LNGS
- Underground campaign at LUNA MV
- Data evaluation and astrophysical impact - collaboration with M. Pignatari/Univ. Hull

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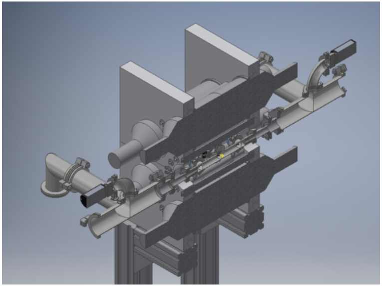

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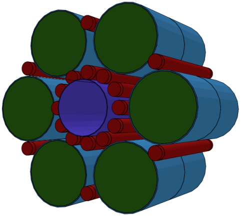
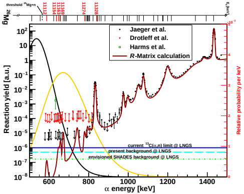
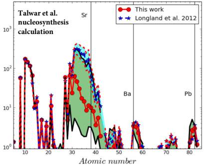
- Vacation

Summary







- $^{22}Ne(\alpha, n)^{25}Mg$ critically important in astrophysics
- Measurement very challenging, impossible up to now (20 years since last data set)
- All the ingredients are here
  - Deep underground lab
  - New detection and DAQ techniques
  - Custom-made accelerator

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