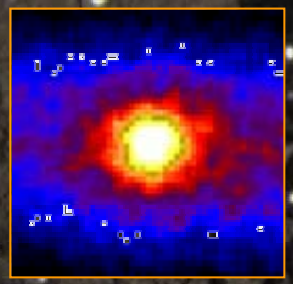
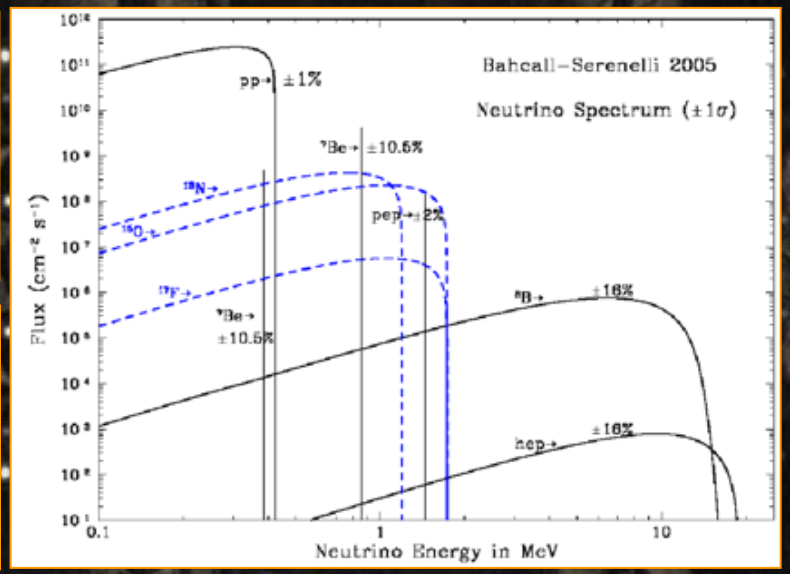
Accelerator Laboratory for Underground Nuclear Astrophysics Experiments at DUSEL

- Science
- Project
- Equipment
- Outreach
- Team (…)

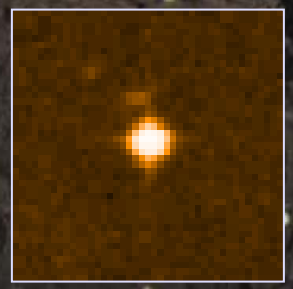
Scientific Questions

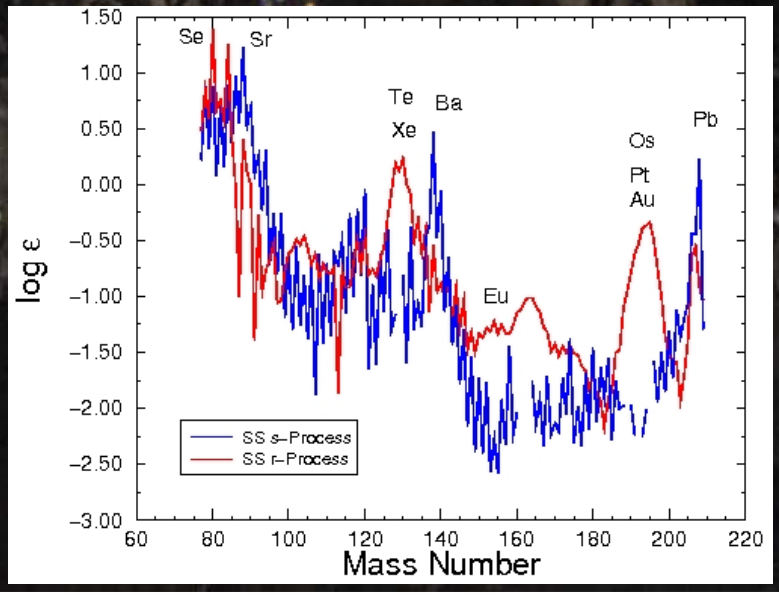




Stellar Neutrino Sources

in the sun & massive stars

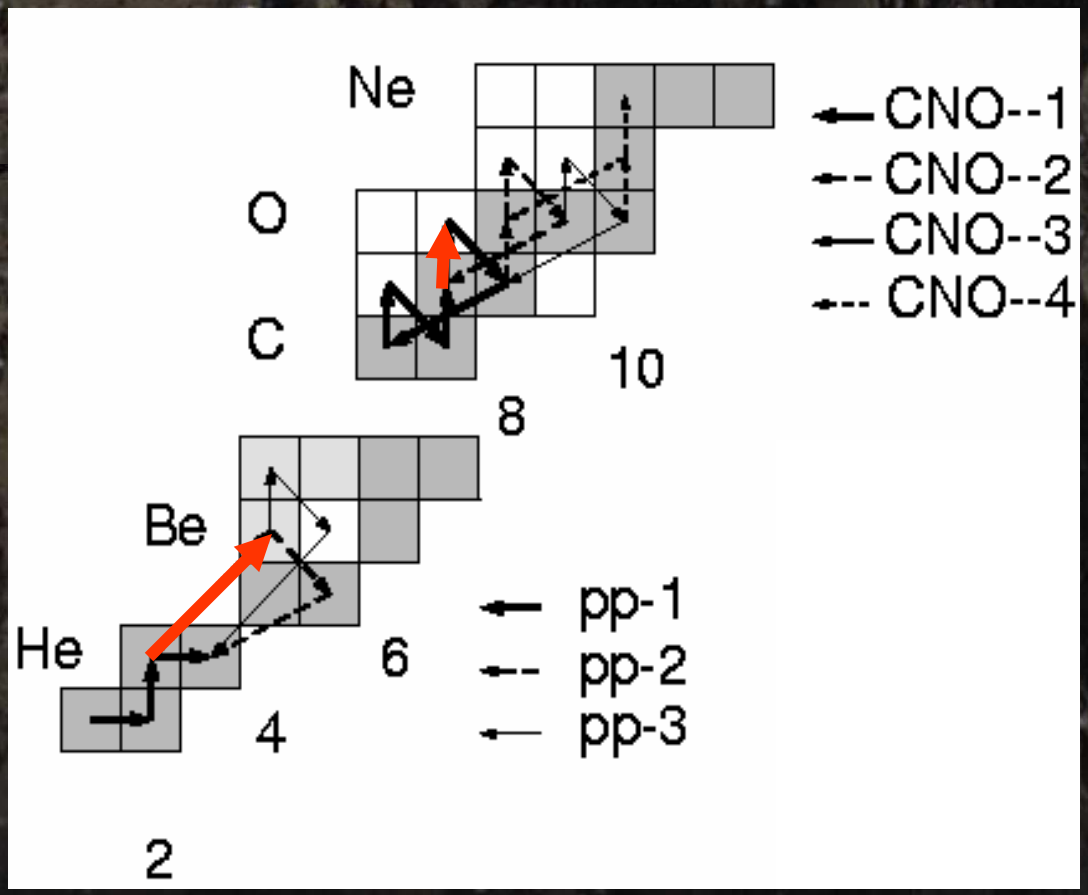




Origin of the Elements

In early & present Universe

Neutrino production & solar (stellar) metallicity



Two critical reactions

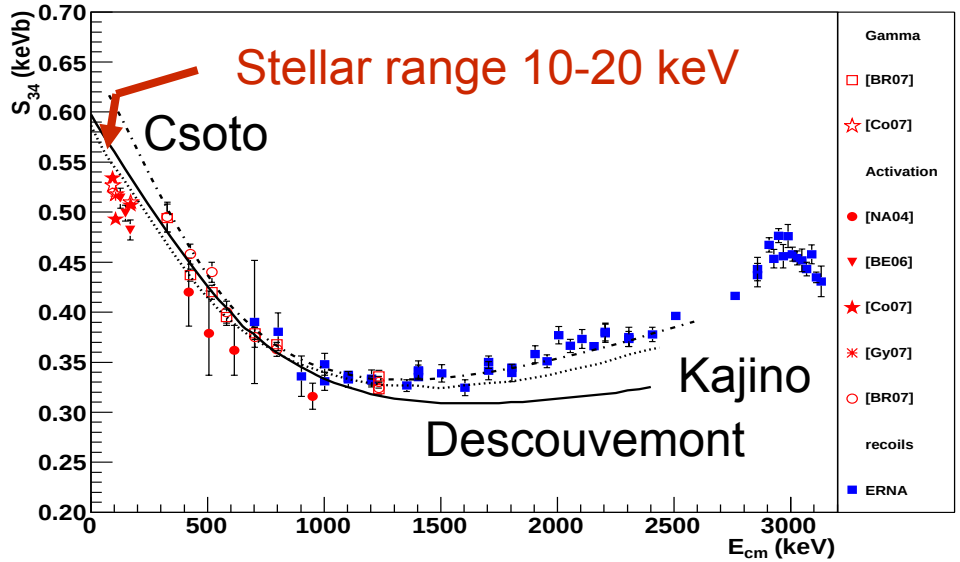
pp-chains: $^{3}He(\alpha,\gamma)^{7}Be$

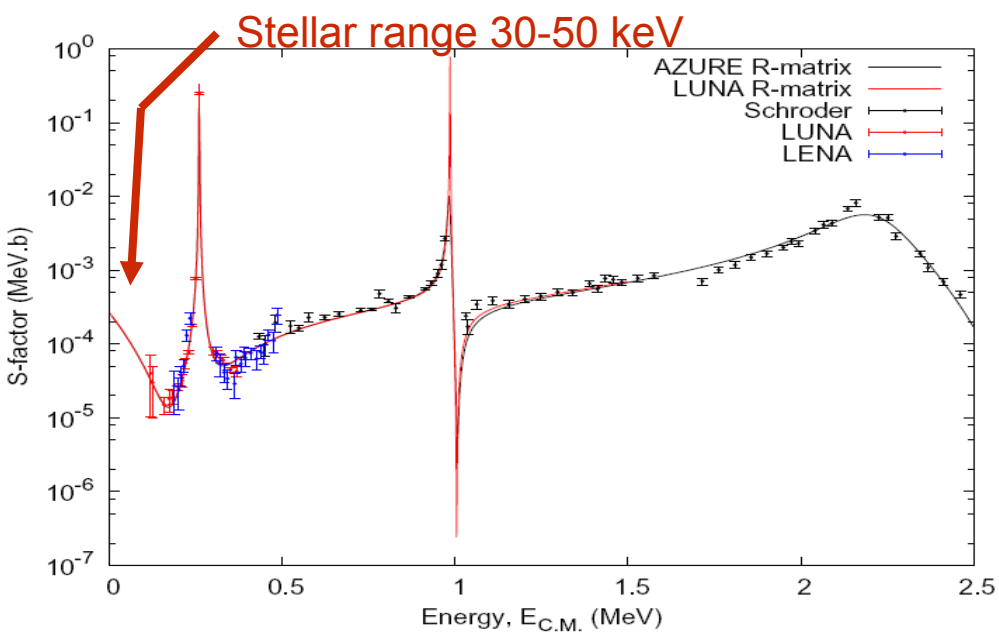
CNO-cycles: $^{14}N(p,\gamma)^{15}O$

Pioneering work at LUNA
New technology necessary for further improvement

Measurement of nuclear reactions at (near) stellar energies with 10%-20% accuracy

$^{3}He(\alpha,\gamma)^{7}Be$ and $^{14}N(p,\gamma)^{15}O$

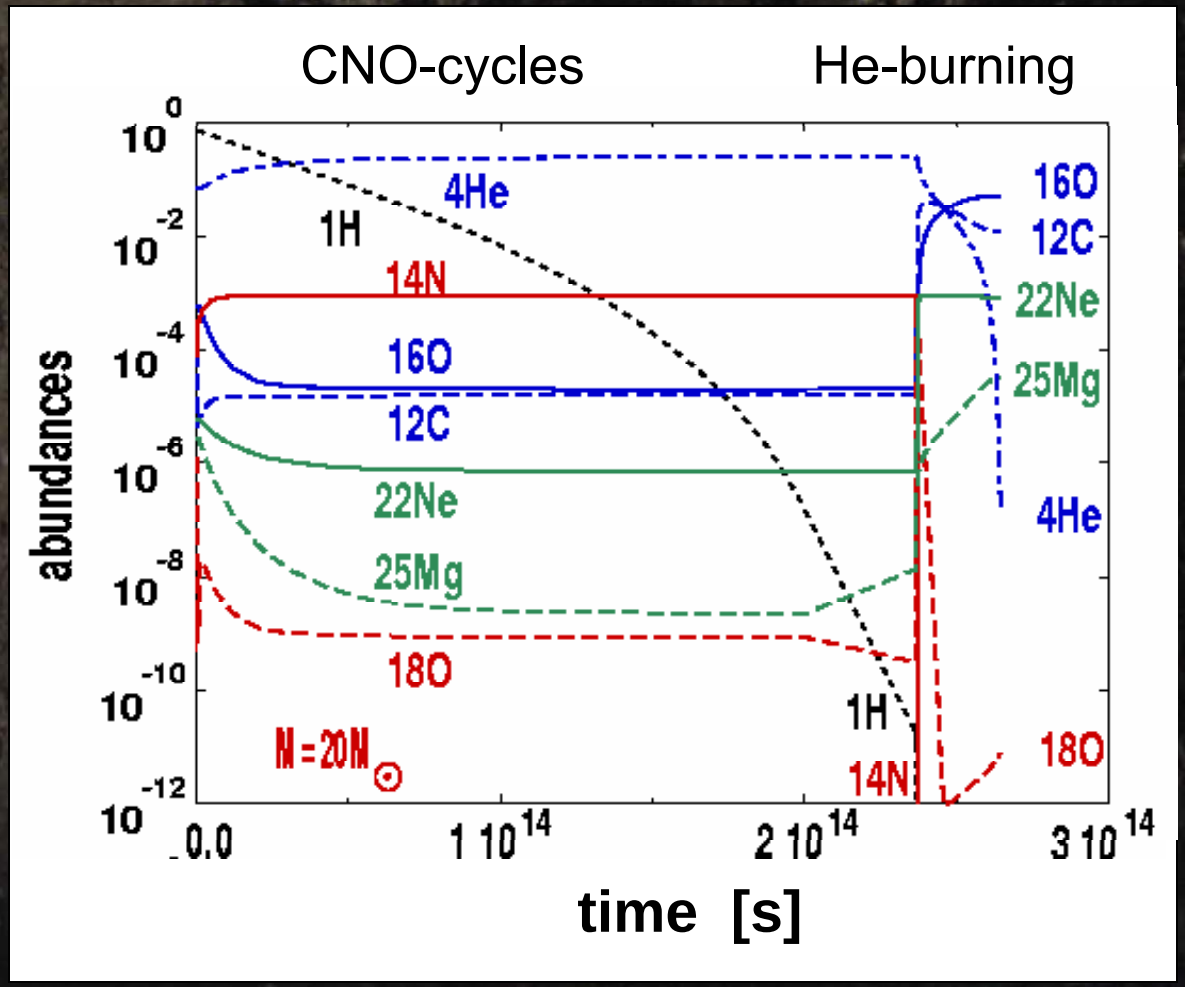




LUNA experiments are close to stellar energy range, theory based extrapolations suffer from model uncertainties.

New generation accelerators with high beam intensity in a background free environment are necessary to reach the stellar energy range.

Neutron Sources



How strong is $^{22}Ne(\alpha,n)$?

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

....

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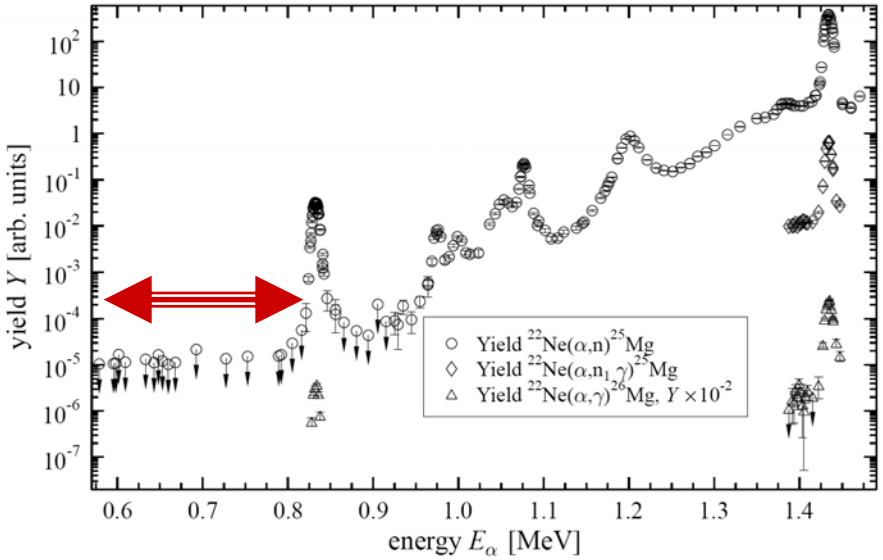
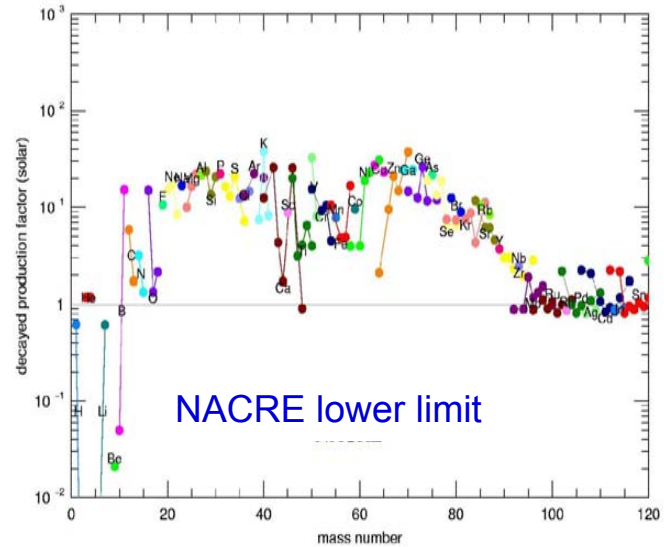
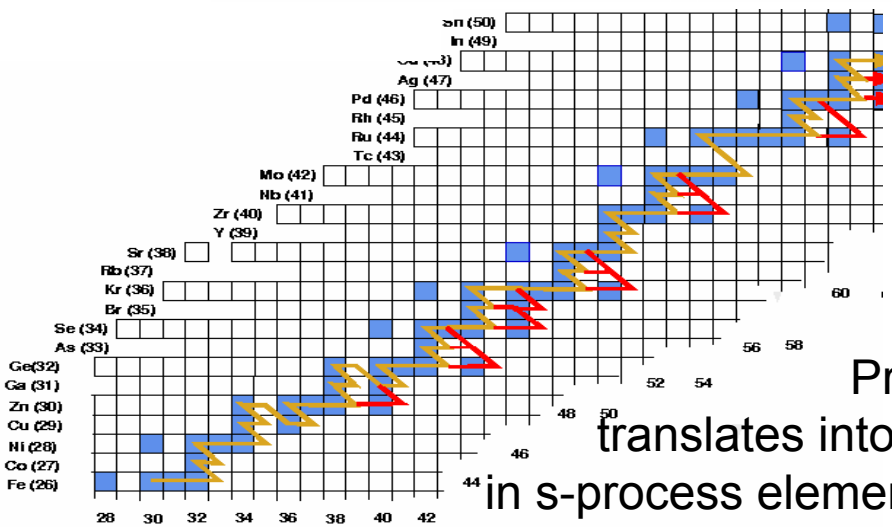
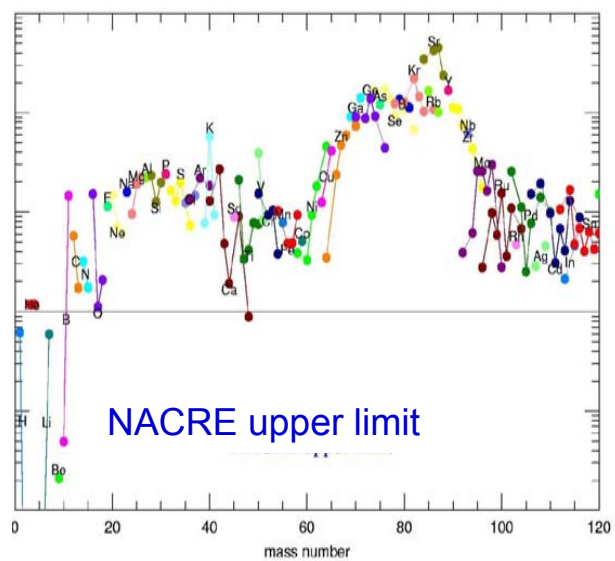
The impact of neutron production







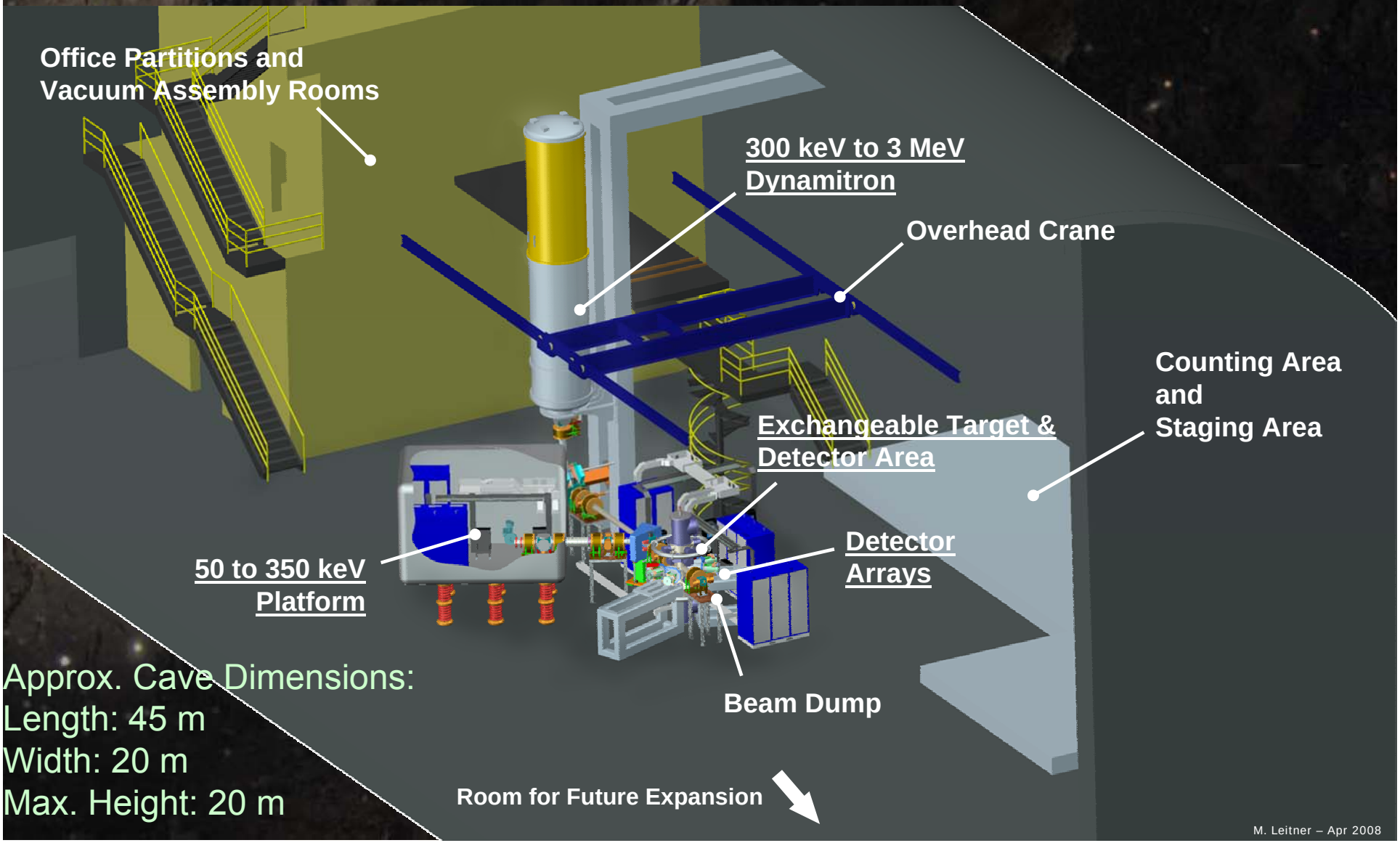


Present uncertainty translates into large uncertainty in s-process element production with broad consequences for explosive scenarios of nucleosynthesis such as p-process and r-processs

Project Design & Development

- low energy accelerator with high proton/alpha beam intensity
- medium energy accelerator for alpha and heavy ion beams
- gas target and solid target production facilities
- detector design for active background rejection
  & event identification
- passive shielding for room background rejection
  & beam induced background shielding

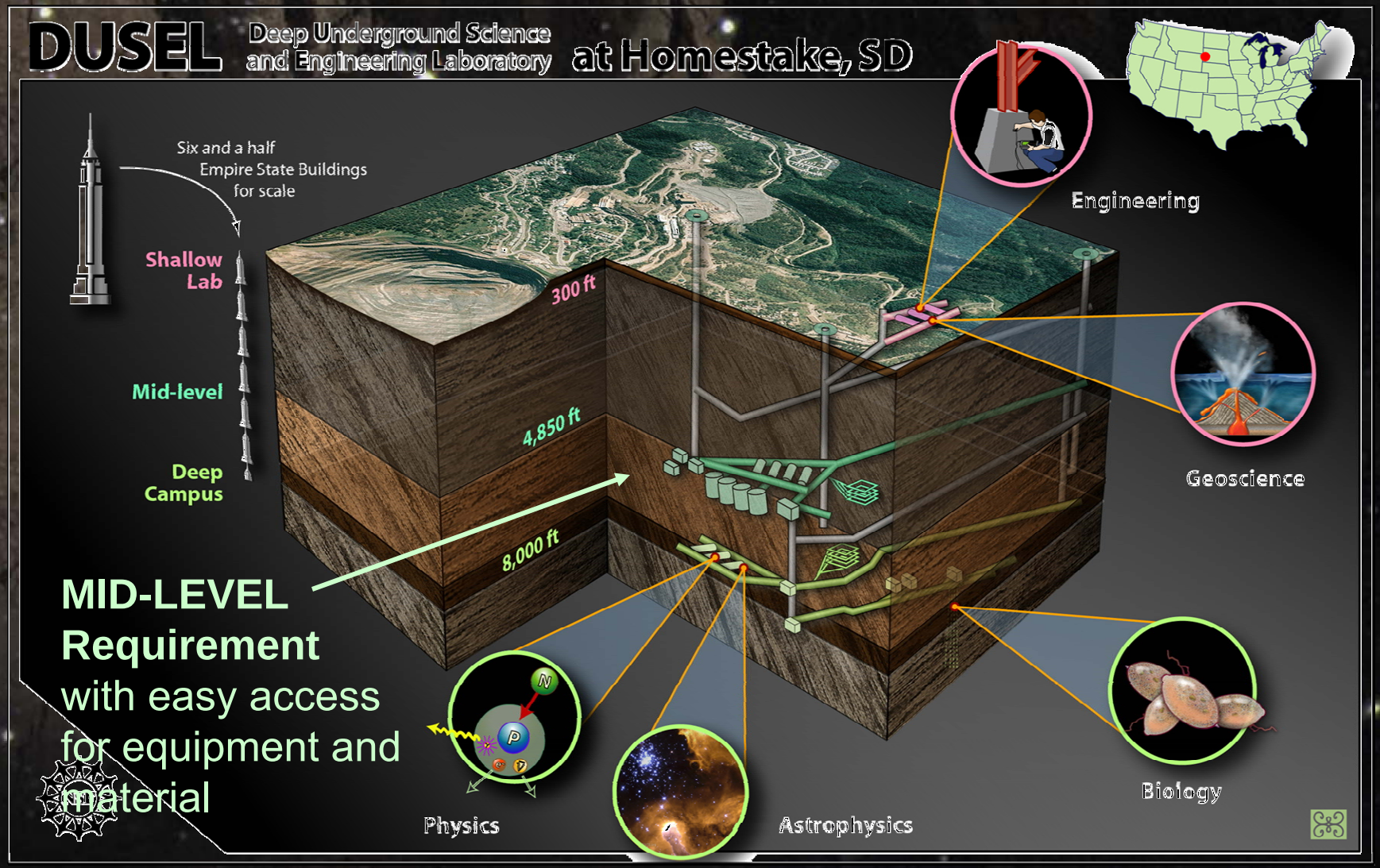
Laboratory Lay-Out



Approx. Cave Dimensions:
Length: 45 m
Width: 20 m
Max. Height: 20 m

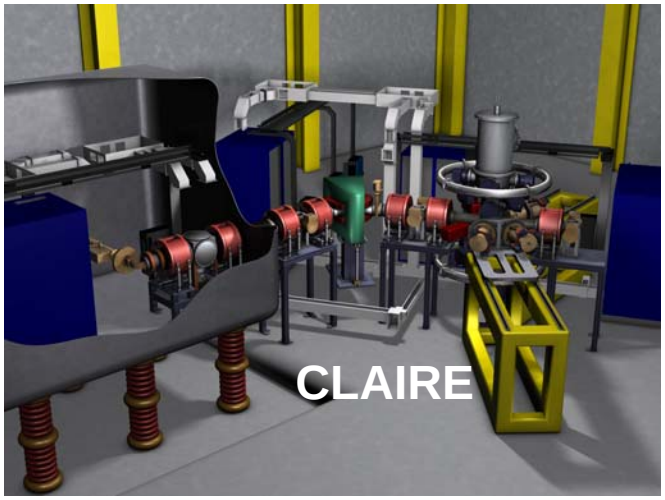
M. Leitner – Apr 2008

Location & Depth Requirements

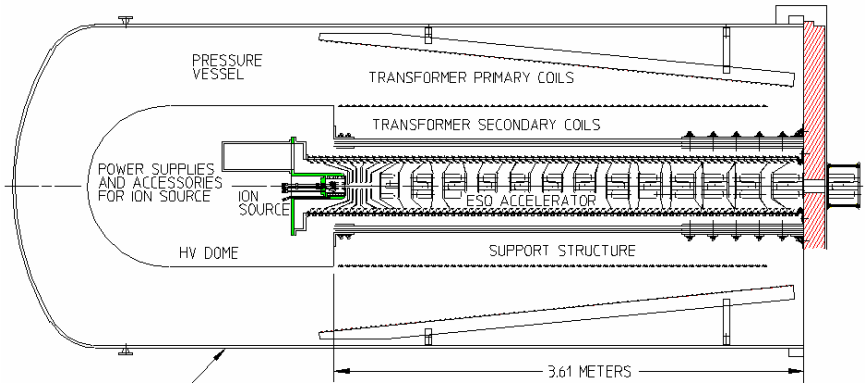


ALNA - Accelerator Laboratory for Nuclear Astrophysics Underground

1. A compact, high intensity low energy (50keV - 400keV) accelerator under development
   - CLAIRE (High current DC accelerator)



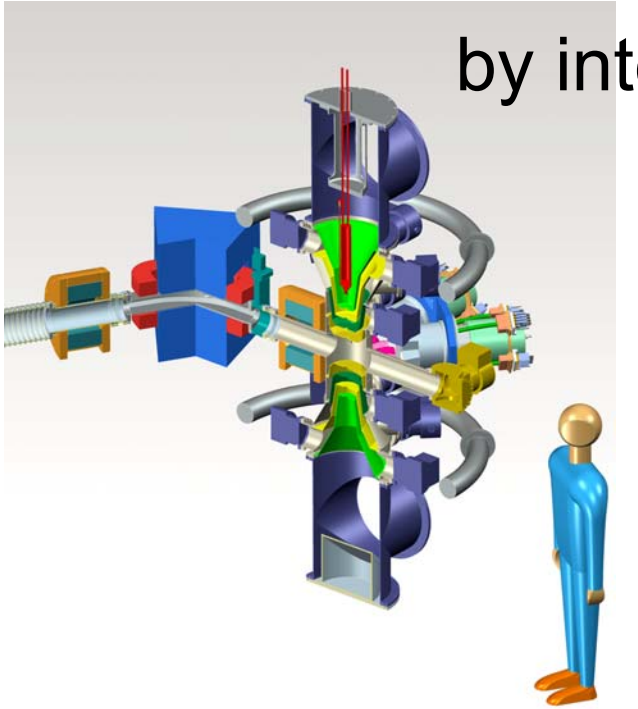
2. A versatile high intensity heavy ion accelerator for medium energies (.3 to 3MeV) in planning
   - Dynamitron type with ECR source

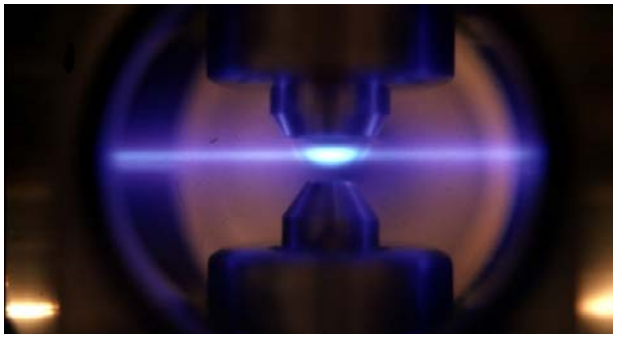


3. Ion sources for both accelerators
   - high intensity 1+ ECR (up to 100mA)
   - Medium intensity n+ ECR (.5mA)

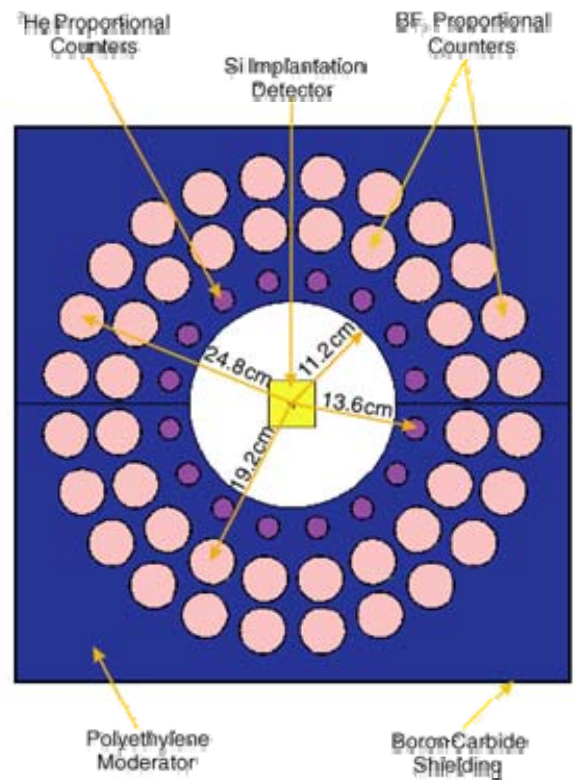
Equipment Development

by international university consortium





- Target systems
- Detector arrays
- Shielding



Project Plan

2007-2008 (Preliminary design efforts by collaboration)

Benchmark and test accelerator construction (NSF supplementary funds)
CLAIRE Design and optics simulation (LBL R&D funds)
Supersonic jet gas target prototype development (JINA & U. Naples funds)
Monte Carlo simulation of detector design & prototype construction
S4 Proposal by group

2008-2010 (development and test efforts by collaboration)

Background mapping of suitable Homestake locations (DUSEL R&D)
ECR source development (DUSEL R&D)
Site selection (background level, transport and shielding considerations)
Installation of test accelerator in WIPP
Auxiliary Equipment development (gas target, detectors)
Accelerator R&D

2010-2012 (Final Design and Preparation)

Final design of the accelerator laboratory
Final design experimental station
Infrastructure development (power, cooling water, shielding)

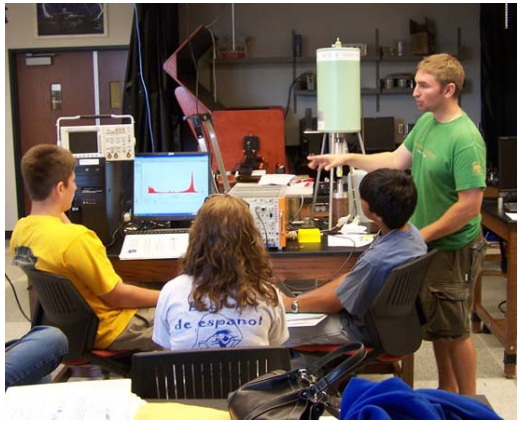
Site Oriented Outreach

Outreach opportunities in physics and geological aspects

modeled after successful outreach program at JINA (Joint Institute for Nuclear Astrophysics) and implemented and broadened by LBL

- Construction of CR Detectors (sets) and measurement of CR decline with depth level

- XRF or PIXE Analysis of local geological samples (GOLD) of Homestake Mine



Graduate student, postdoc, (local) teacher involvement

Low Energy Accelerator Community at DUSEL

Participating US groups

Lawrence Berkeley Laboratory
Colorado School of Mines
Louisiana State University
University of North Carolina
University of Notre Dame
Western Michigan University
Ohio University
University of Washington
Yale University

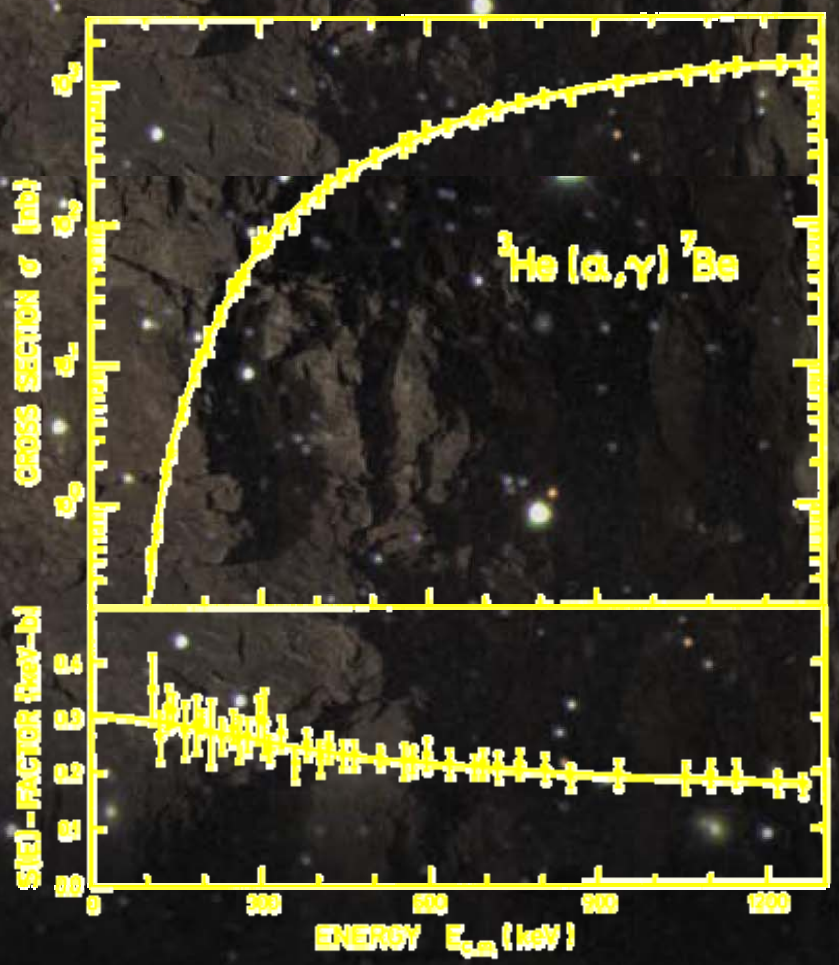
International Groups involved

Ruhruniversität Bochum, Germany
University of Edinburgh, UK
HH-NIPNE, Romania
Universita Frederico II Napoli, Italy

& additional groups with interest

Project Acronym in Preparation!

We know the problem ...

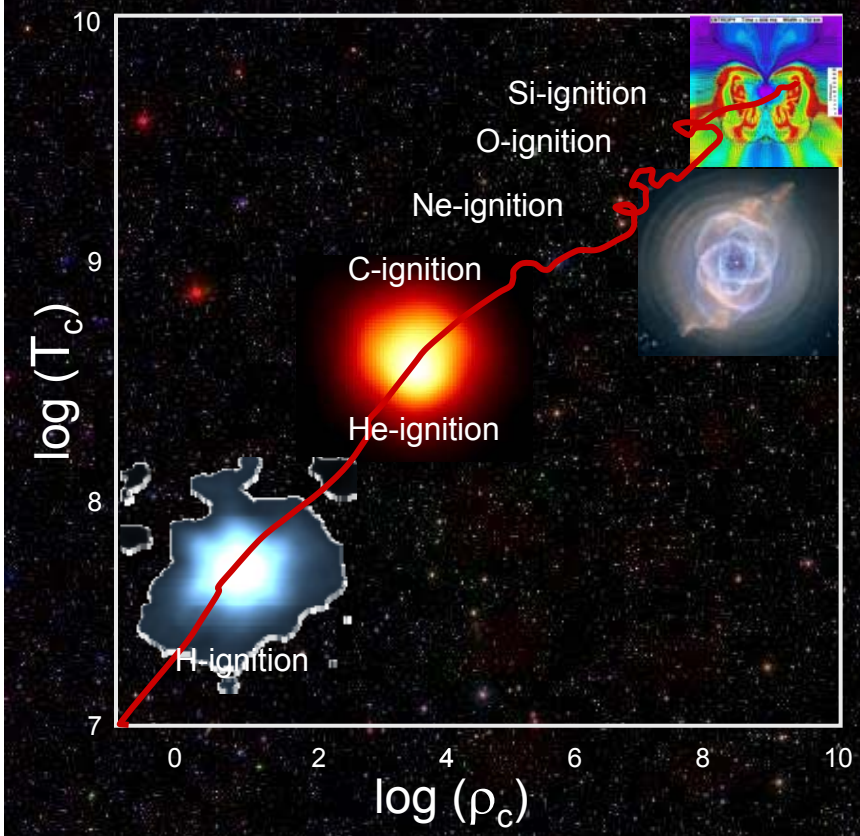


$$S(E) = \sigma(E) \cdot E \cdot e^{(E_G/E)^{1/2}}$$

Low Energy Problem:

- Reaction Yield (cross section)
- Energy Calibration (S-factor)
- Background Yield
  - Cosmic Ray Induced Background
  - Natural Background
  - Beam Induced Background

Nuclear burning & stellar evolution



Critical reactions for:

- energy generation,
- time scale
- nucleosynthesis

Hydrogen Burning

Heavy Ion Burning

$^{3}He(\alpha,\gamma)^{7}Be$

$^{12}C(\alpha,\gamma)^{16}O$

$^{3}He(^{3}He,2p)^{4}He$

$^{16}O(\alpha,\gamma)^{20}Ne$

$^{7}Be(p,\gamma)^{8}B$

$^{20}Ne(\alpha,\gamma)^{24}Mg$

$^{12}C(p,\gamma)^{13}N$

$^{18}O(\alpha,\gamma)^{22}Ne$

$^{17}O(\alpha,n)^{20}Ne$

$^{14}N(\alpha,\gamma)^{18}O$

$^{24}Ne(\alpha,\gamma)^{26}Mg$

$^{28}Si(\alpha,\gamma)^{32}S$

$^{24}Mg(\alpha,\gamma)^{28}Si$

$^{16}O,^{12}C$

...

$^{17}O(p,\gamma),(p,\alpha)^{18}F,^{14}N$

...

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

$^{19}F(p,\gamma),(p,\alpha)^{20}Ne,^{16}O$

$^{25}Mg(\alpha,n)^{28}Si$

$^{26}Mg(\alpha,n)^{29}Si$

Choice should be guided, by

- Scientific relevance
- Experimental suitability
- Alternative opportunities

Space

One Standard Experimental Cavities of 50x20x15m^3 are currently envisioned for the **4850 ft** level.

- Low energy accelerator: CLAIRE: 10x8x5m^3
- High Energy Accelerator: 30x20x5m^3, space for SF_6 (if needed)
- Experimental hall: 20x15x5 m^3 with additional space of 5x10x3 m^3 for housing the necessary power supply units for magnetic and electric beam optics systems.
- Control area, Counting area: 8x8x3 m^3
- Power supplies: 5x10x3m^3
- SF6 storage, Cooling water, Cryogenic equipment/cryogenics 10x10x5 m^3.

Above ground areas

- Machine shop area
- Above ground office space and counting areas
- Laboratory space for general use (experiment preparation, detector testing and target preparation)

Infrastructure for Accelerator and Experimental halls

- Overhead crane systems for transporting and positioning heavy equipment
- De-ionized cooling water
- Air conditioning
- Electrical power requirements 200kW (CLAIRE)
- Electrical power requirements, Medium Energy Accelerator (TBA, Engineering and R&D item)

Auxiliary Equipment

- windowless re-circulating gas target (gas jet and gas cell)
- evaporator and target laboratory (a serious shortcoming at LUNA)
- a Ge-NaI or Ge-BGO detector array
- Segmented Ge or Ge strip detectors,
- a number of Si strip detector systems
- heavy ion recoil separator