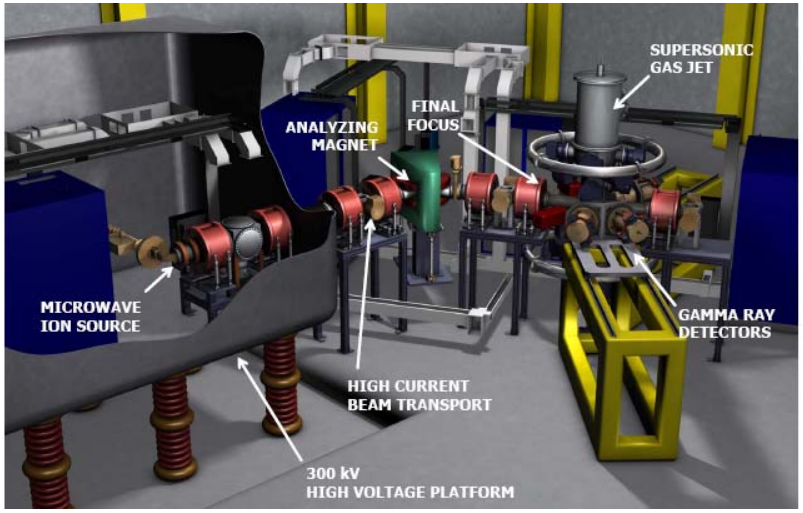
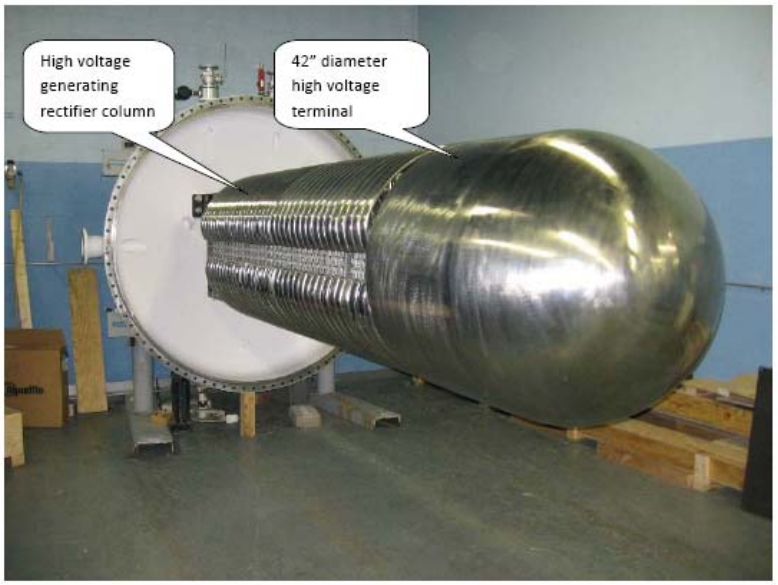
Nuclear Astrophysics
Underground Accelerator Working Group

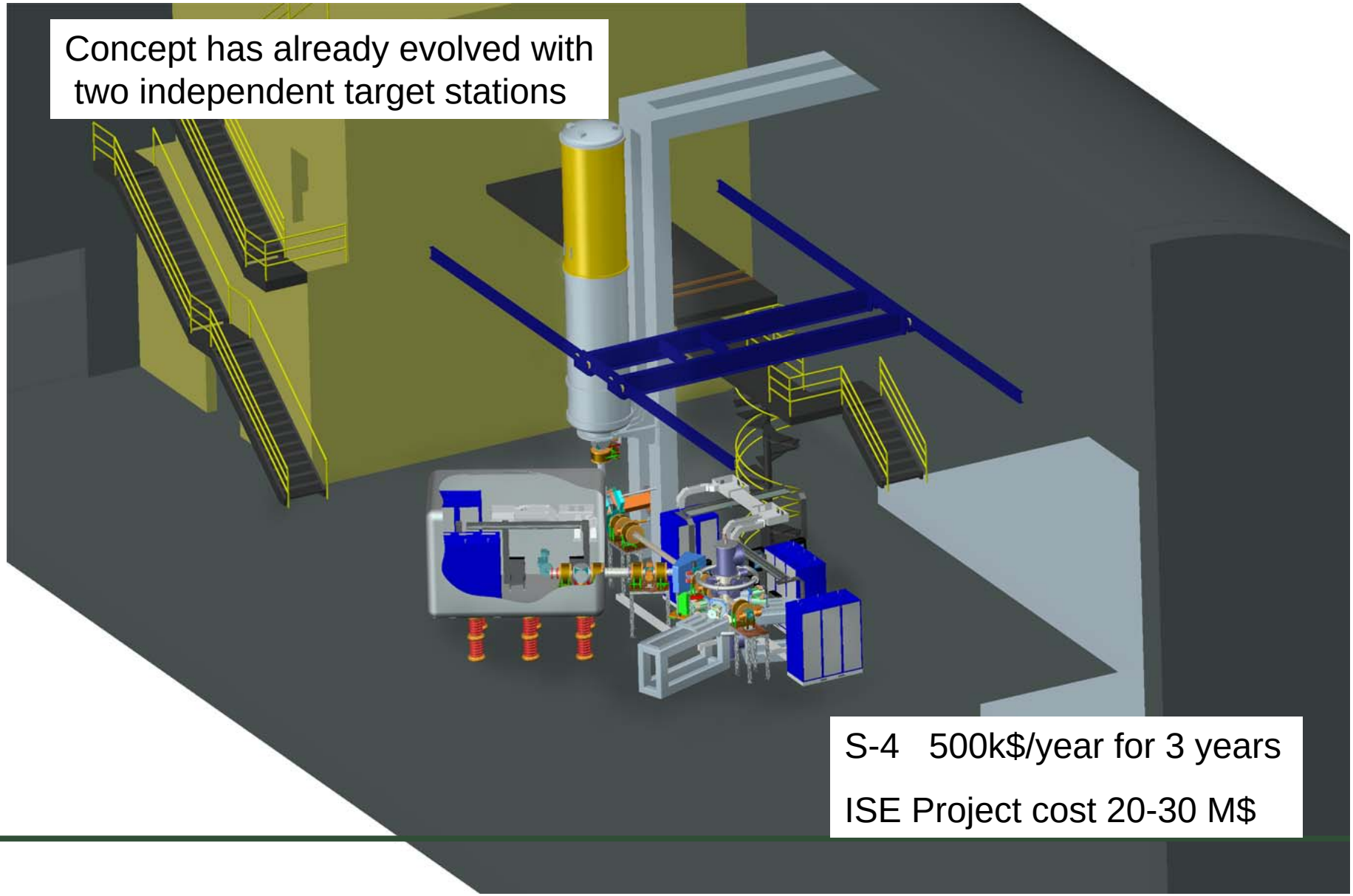
Workshop at Homestake April 2008

- Agreed on the two-accelerator concept
  - Low Energy Accelerator 'CLAIRE' 50 kV-400kV platform
    - High intensity (mA) single charged ions
    - n+ ECR ion source for extended range (low current)
  - High Energy Dynamitron
    - 350keV to 3MeV
    - High intensity (mA) single charged ions
    - n+ ECR for extended range
- Two Target Stations to enable simultaneous experiments and set-ups

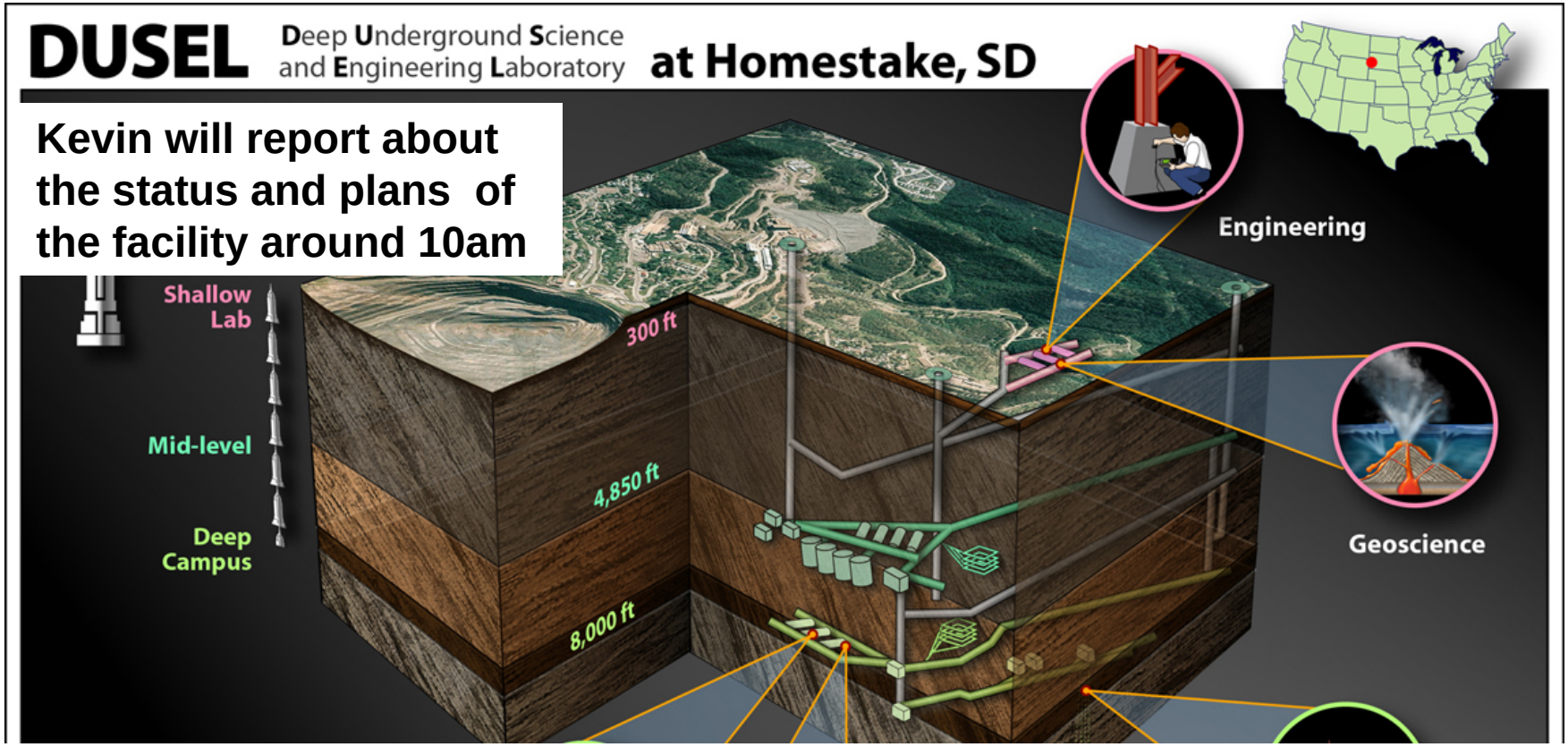




First Layout of the Laboratory, Matthaeus Leitner, LBNL



DUSEL Facility Internal Design Review
July 16-18, 2008



DUSEL Experiment Development and Coordination (DEDC) Group gave and overview on the proposed DUSEL science

Physics: S. Elliott, D. Leitner, H. Sobel
BGE: D. Elsworth, L. Murdoch, TC. Onstott

Dakota Ion Accelerators for Nuclear Astrophysics (DIANA)

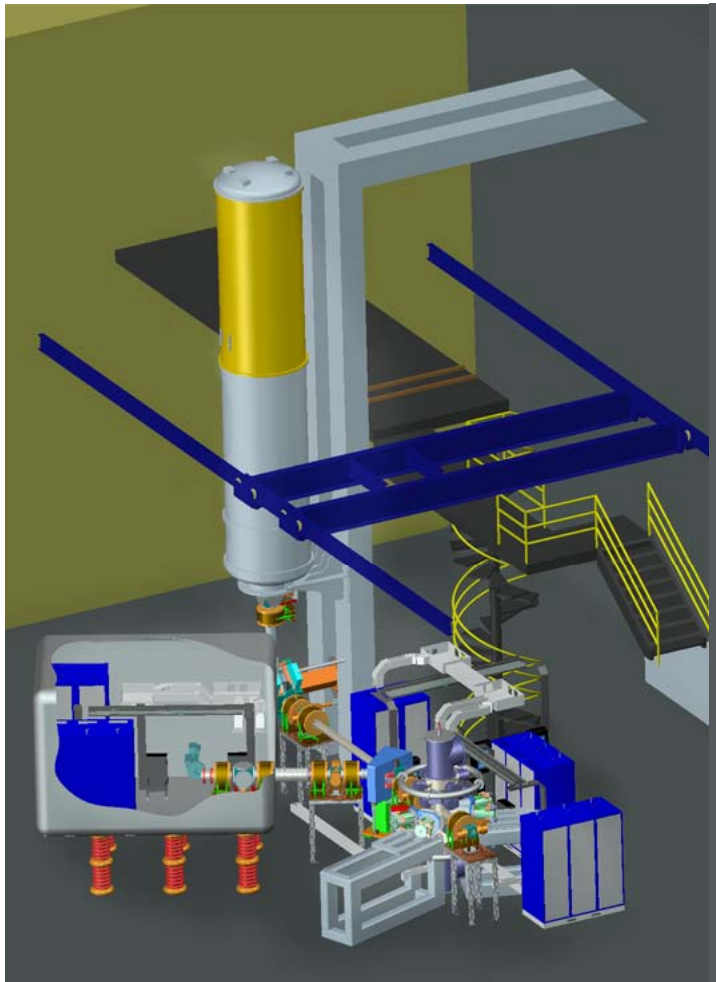
10 year + program to address the wide range of nucleosynthesis cross sections

Collaborators

Matthaeus Leitner	LBNL
Paul Vetter	LBNL
Peggy McMahan	LBNL
Daniela Leitner	LBNL
Damon Todd	LBNL
Ani Aprahamian	Notre Dame
Philippe Collon	Notre Dame
Manoel Couder	Notre Dame
Joachim Goerres	Notre Dame
Francesco Raiola	Notre Dame
Daniel Schuermann	Notre Dame
Ed Stech	Notre Dame
Michael Wiescher	Notre Dame
Xiao-Dong Tang	Notre Dame
Jose Alonso	Sanford Lab
Arthur Champagne	UNC
Claudio Ugalde	UNC
Michael Famiano	WMU
Peter Parker	Yale

International interest

Pietro Corvisiero	INFN Genova, IT
Paulo Prati	INFN Genova, IT
Heide Costantini	INFN Genova, IT
Lucio Gialanella	Naples, IT
Gianluca Imbriani	Naples, IT
Christina Bordenau	HH-NIPNE, RO



S-4 500k$/year for 3 years

ISE Project cost 20-30 M$

Two accelerators

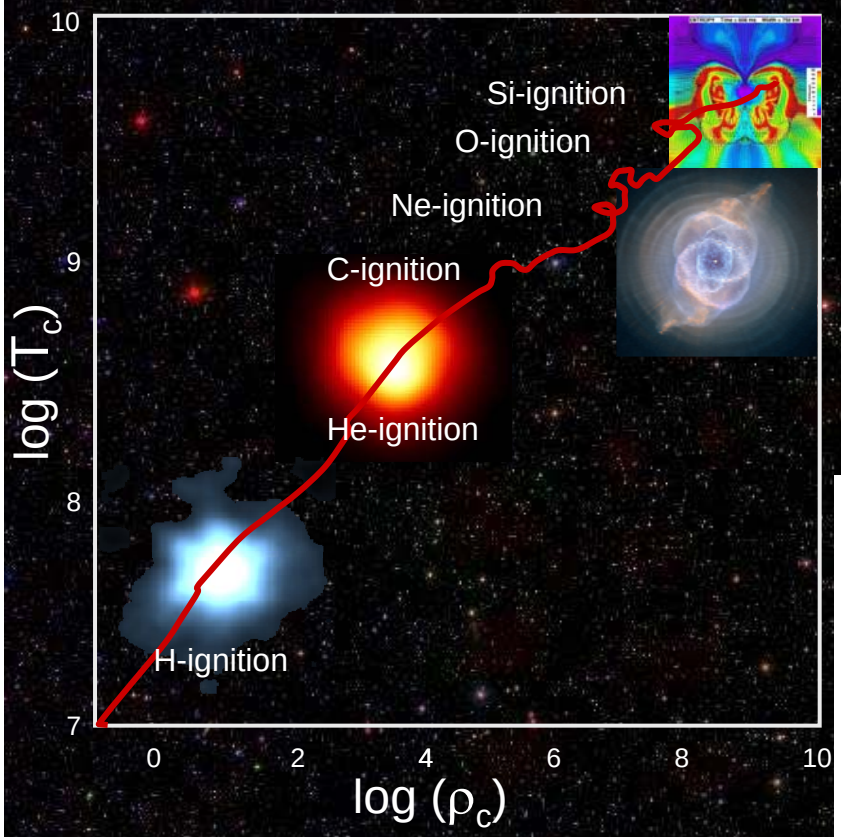
400 kV CLAIRE
350 kV-3 MV
(Dynamitron, other option being studied)

ECR ion source for extended energy range (1MeV/u)

Energy overlap allows to consistently measure cross section over a wide energy range and allow reliable extrapolations

Flexibility and wide energy range would make it a unique facility world wide

Science: **Addresses two key questions identified in the nuclear science long range plan**



- **What is the origin of the elements in the cosmos?**
- **What are the nuclear reactions that drive stars and stellar explosions?**

Critical reactions for:

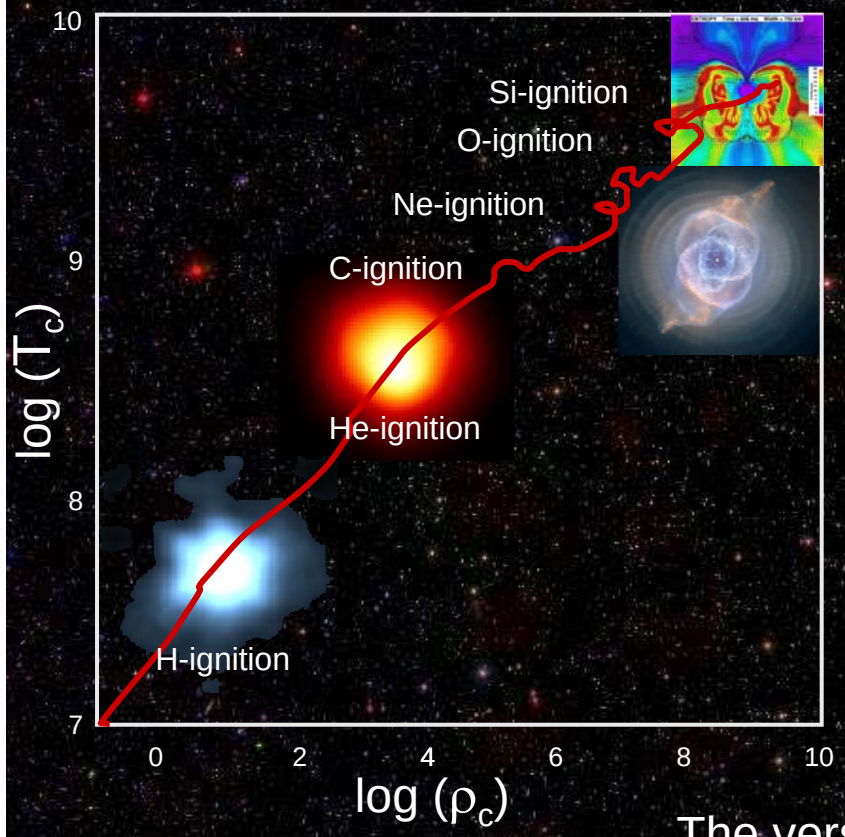
- energy generation,
- time scale
- nucleosynthesis

NP long range plan identifies a opportunity for a DIANA type facility at DUSEL:

'The **direct measurement of reaction rates on stable nuclei** that **require high-intensity beams**, and are needed to model stars and novae, also presents enormous challenges. The largest handicap is the small cross section coupled with large natural background, which prohibits the detection of the characteristic reaction signals.
The use of **underground based low-energy accelerator facilities**, as demonstrated by LUNA at the European Gran Sasso underground laboratory, **significantly reduces cosmic-ray-induced background by several orders of magnitude**. This approach is complemented by the development of active background-reduction techniques based on event identification or inverse kinematic techniques to reduce the natural radiation and beam induced background. **DUSEL will provide an opportunity for the development of such a facility in the United States.**'

Science Nuclear burning & stellar evolution

Flexibility and wide energy range would make it a unique facility world wide and enable a long experimental program (10+ years)



Hydrogen Burning

$^{3}He(\alpha,\gamma)^{7}Be$
$^{3}He(^{3}He,2p)^{4}He$
$^{7}Be(p,\gamma)^{8}B$

$^{12}C(p,\gamma)^{13}N$
$^{14}N(p,\gamma)^{15}O$
$^{15}N(p,\gamma),(p,\alpha)^{16}O,^{12}C$

$^{17}O(p,\gamma),(p,\alpha)^{18}F,^{14}N$
$^{18}O(p,\gamma),(p,\alpha)^{19}F,^{15}N$
$^{19}F(p,\gamma),(p,\alpha)^{20}Ne,^{16}O$

Helium Burning

$^{12}C(\alpha,\gamma)^{16}O$
$^{16}O(\alpha,\gamma)^{20}Ne$
$^{20}Ne(\alpha,\gamma)^{24}Mg$

$^{18}O(\alpha,\gamma)^{22}Ne$
$^{22}Ne(\alpha,\gamma)^{26}Mg$
$^{24}Mg(\alpha,\gamma)^{28}Si$

$^{13}C(\alpha,n)^{16}O$
$^{22}Ne(\alpha,n)^{25}Mg$
$^{25}Mg(\alpha,n)^{28}Si$
$^{26}Mg(\alpha,n)^{29}Si$

The versatility of the facility will also allow to address

Heavy Ion Burning

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

$^{17}O(\alpha,n)^{20}Ne$
$^{28}Si(\alpha,\gamma)^{32}S$
...
..
.

Critical reactions for:

- energy generation,
- time scale
- nucleosynthesis

S-4 Solicitation

NSF has allocated15 M$ for experiment over 3 years

invites proposals to develop project plans for specific candidate experiments that could be considered for the suite of DUSEL experiments

- Original schedule: June 2008
- Final Publication Date: October 6th 2008
- Due Date : January 9th 2009
- Peer Panel Review Period: 90 Days
- Preliminary Design Review December ~~of 2009~~, 2010 (?)
- Solicitation 5 (S-5): will call for proposals from which final selection of ISE will be made (Winter 2010 ?)

S-4 Proposal

Must not exceed 15 pages

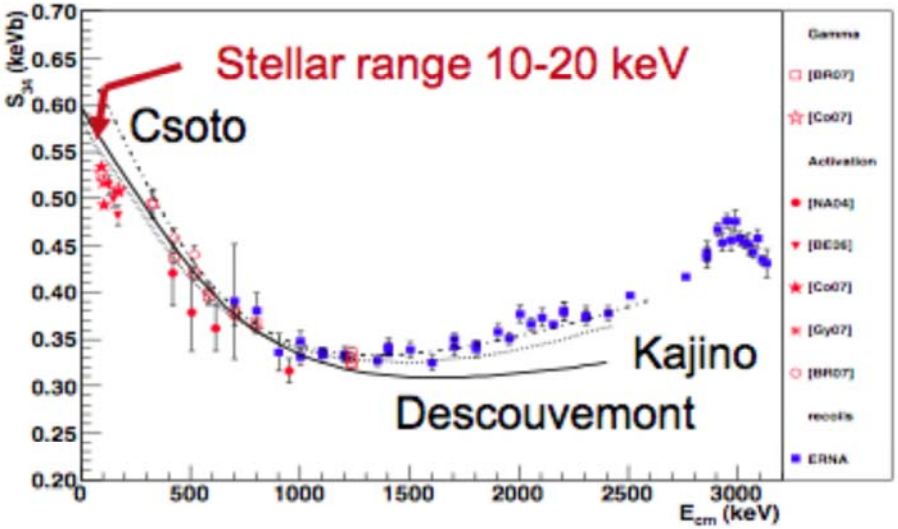
- Compelling (Transformational) Science/ Intellectual Merit
  - How important is the proposed activity to advancing knowledge and understanding within its own field or across different fields?
- Education and Outreach
  - What are the broader impacts of the proposed activity?
  - How well does the activity advance discovery and understanding while promoting teaching, training, and learning?
  - Integration of Research and Education
- Project Description
  - clear statement of the work to be undertaken and must include: objectives for the period of the proposed work
- How to arrive to project plans (Schedule, WBS)
  - S4 provides support for development of project plans for potential candidates for the suite of DUSEL experiments
- R&D money requests
  - ‘In some cases, developmental work or simulations may be needed to clarify specific technical features or approaches of the design being proposed. Accordingly, in such special cases, a limited amount of S4 funding will be considered to support targeted R&D and related activities that would complement the design work put forward..

- **INTRODUCTION**
  - Overall physics picture, why is the science compelling, program advisory committee connection, Long range plan context, international context
- **PHYSICS WITH THE NUCLEAR ASTROPHYSICS ACCELERATOR**
  - Low energy (50 to 400 keV) accelerator
  - High energy (0.3 to 3 MeV) accelerator
- **EDUCATION and OUTREACH**
- **ACCELERATOR DESIGN PERFORMANCE REQUIREMENTS**
  - The two-accelerator concept
  - Low energy accelerator
  - High energy accelerator
  - Gas jet, target area, experimental stations
  - Radiation background requirements and shielding
  - Radiation background generation and shielding
- **ACCELERATOR HARDWARE AND ENGINEERING SYSTEMS**
  - Low energy beamline
    - Ion source, High voltage platform, Beam transport
  - High energy beamline
    - Ion source, Dynamitron, Beam transport
  - Experimental stations
    - Target Areas, Detector Systems, Counting Area
- **DUSEL SITE INTEGRATION**
- **ANTICIPATED OPERATION COST**
- **SCHEDULE**
- **BUDGET**

Proposed initial experiments

$^{3}He(\alpha,\gamma)^{7}Be$ New LUNA results are close to stellar energy range, but theory extrapolations to low energy have uncertainty, will allow a very stringent benchmark of this new facility

- Determines solar neutrino flux measured by current and proposed neutrino oscillation experiments
- Constrain "invisible energy production"
- Constrain solar metallicity and temperature

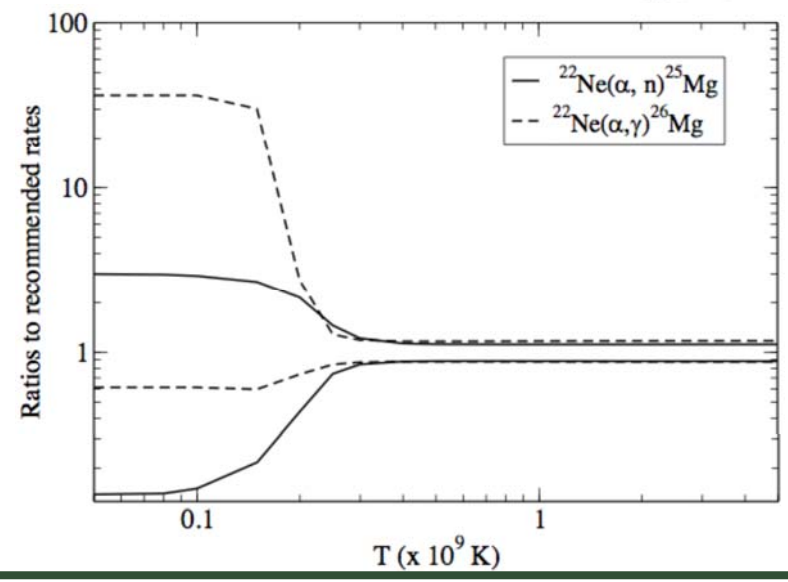


Neutron sources (important ingredient for creation of elements beyond iron)

$^{22}Ne(\alpha,n)^{25}Mg$
$^{25}Mg(\alpha,n)^{28}Si$
$^{26}Mg(\alpha,n)^{29}Si$

Large uncertainty in s-process element production and subsequent nucleosynthesis

- Large uncertainty in reaction rates at all energies. Are these reactions significant neutron sources before and during explosive nucleosynthesis?
- Cannot be addressed in the LUNA facility



Risk Identification and Management

Potential problems that could affect successful outcome or other experiments as related to the facility)

Astrophysics Underground accelerator

- **Size requirements for installation** (shaft, drift and elevator space (might be a cost driver for the construction of the underground accelerator)
- **Beam-induced neutron background**
  - Production cross sections are very low
  - Shielding issue is addressed by the collaboration, background calculation are and integrated part of the S-4 proposal effort and experimental planning
- **R&D Items**
  - Accelerator R&D
  - Movable acceleration gap (engineering and testing)
  - ECR inside the Dynamitron high voltage dome (need R&D funds to build prototype)
  - Wide dynamic range of the beam Dynamitron energy (ion optics simulations are in progress)
  - Gas jet target beam overlap, experimental configurations