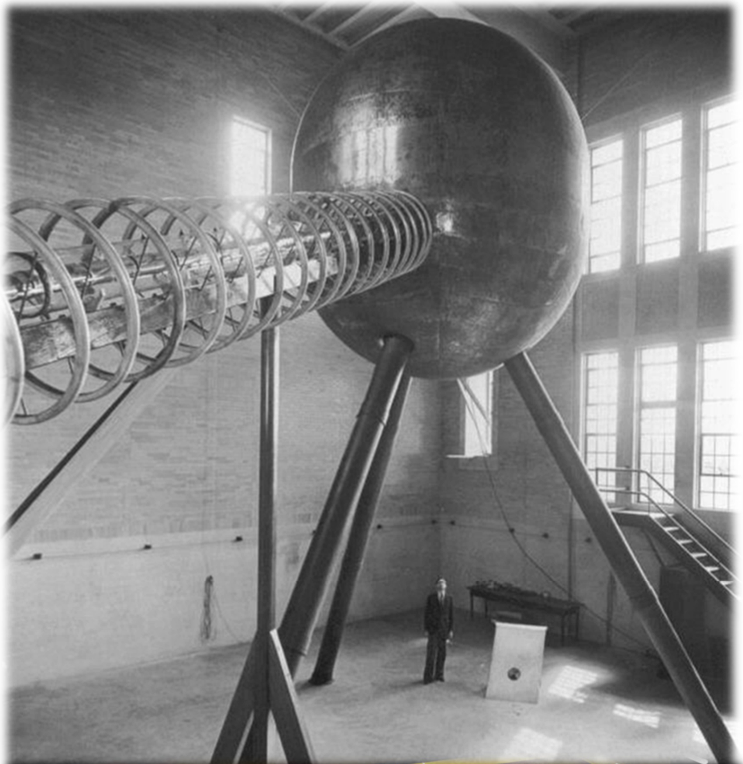
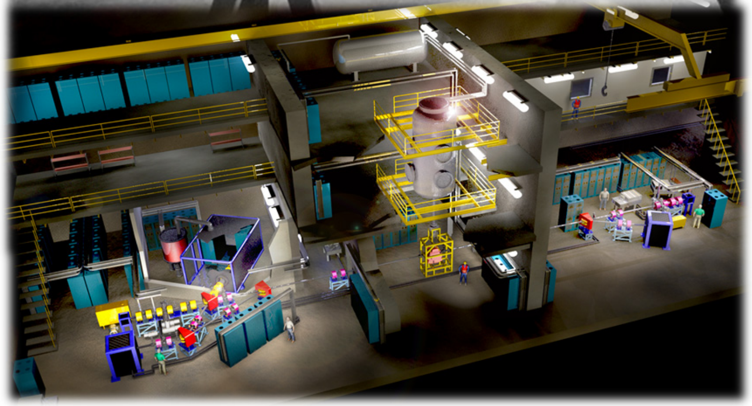
Low Energy Underground Accelerators





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CASPAR

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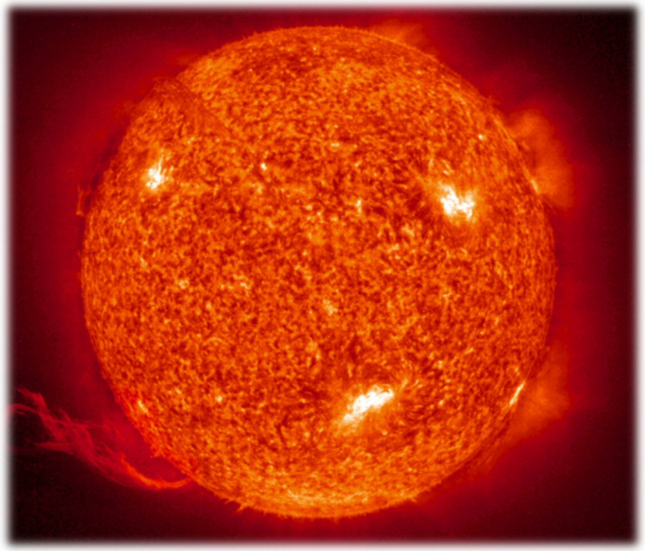
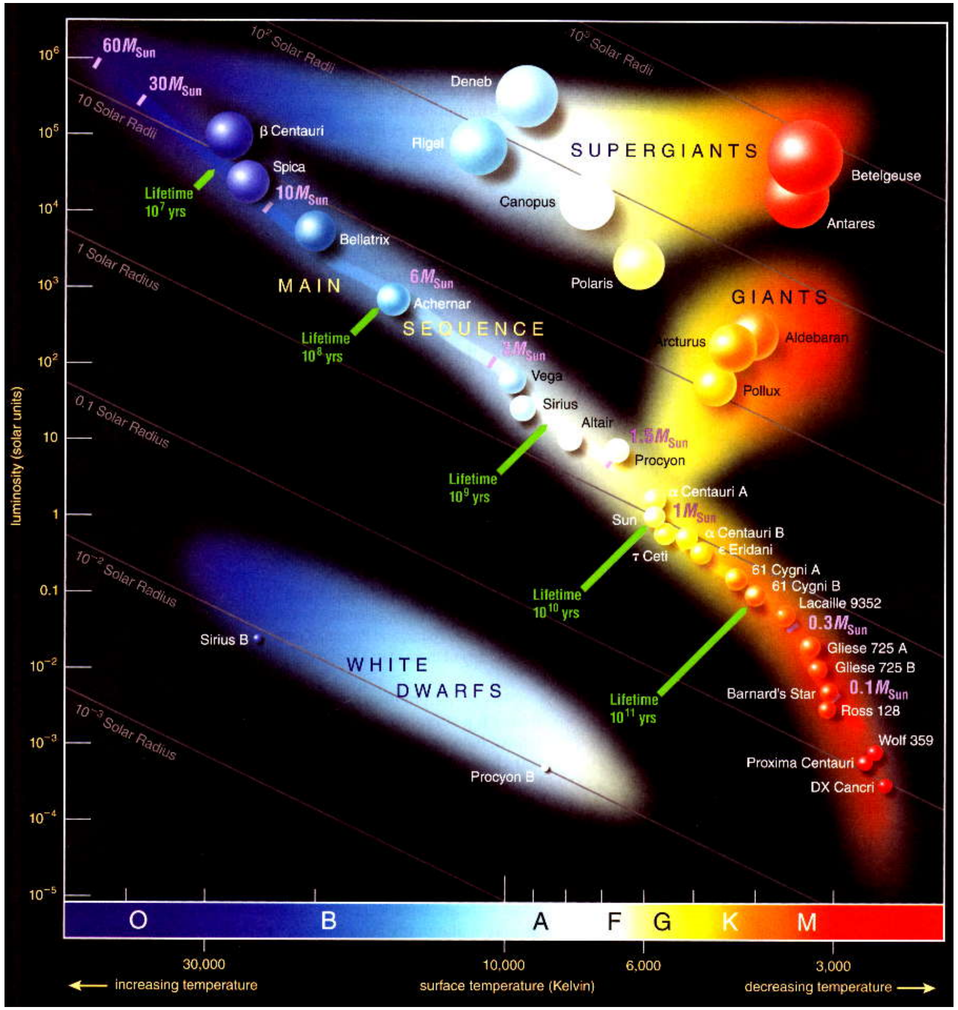
Outline

- Stellar nuclear burning: What we are measuring and why.
- Challenges and possible solutions
- Why go underground, merits of the underground solution
- Facilities: Current and proposed
- Where next?

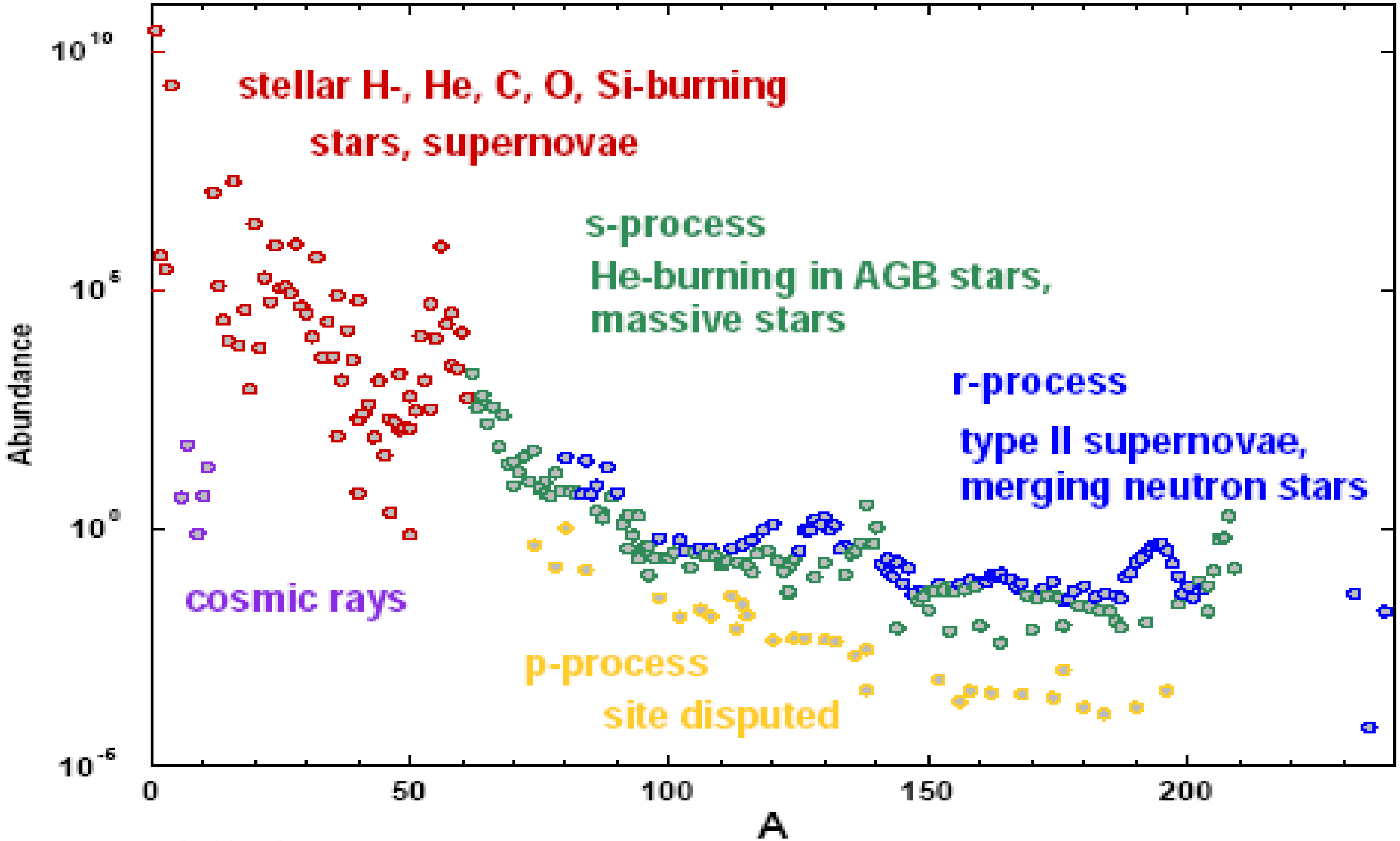


Stellar Nucleosynthesis

- Determines the lifetime of stellar burning sequences and stars
- Defines the stage and age of stars
- Provides and defines observable signatures, color, luminosity, neutrinos
- Determines interior thermo- and hydrodynamic conditions of stars
- Defines the conditions for subsequent explosive evolution
- Provides the nucleosynthesis fuel for stellar explosions as white dwarfs or massive giant stars.

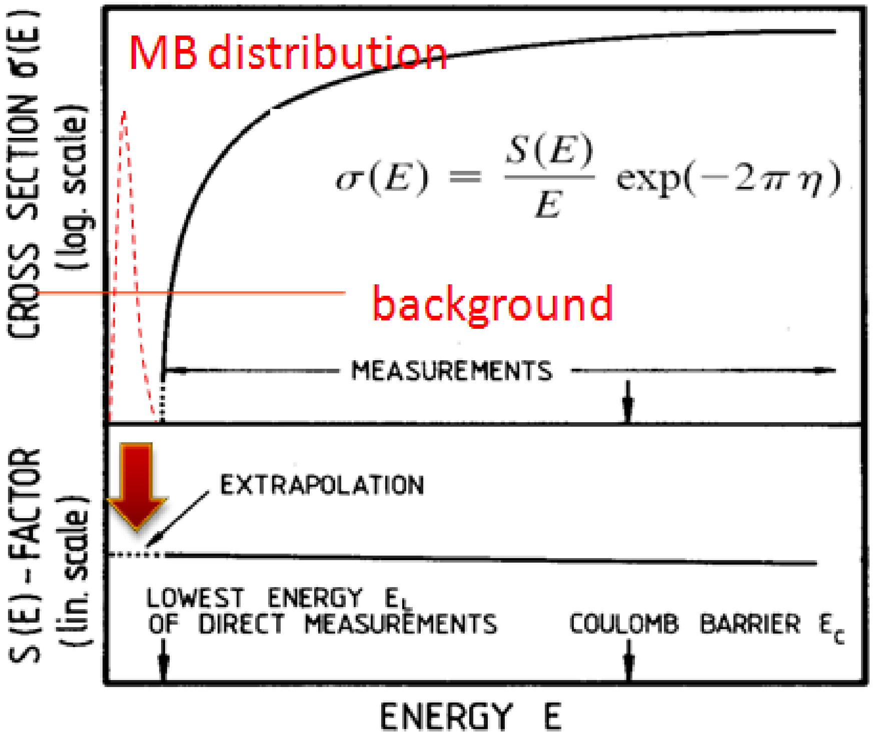


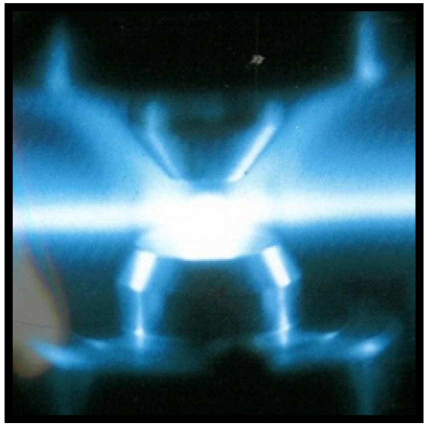
Elemental Stellar Production



Reaction Rate Complications

$$N_A\langle\sigma v\rangle = \sqrt{\frac{8}{\pi\cdot\mu}}\cdot(kT)^{-3/2}\cdot\int_0^\infty E\cdot\sigma(E)\cdot\exp\left(-\frac{E}{kT}\right)dE$$





Laboratory Experiments

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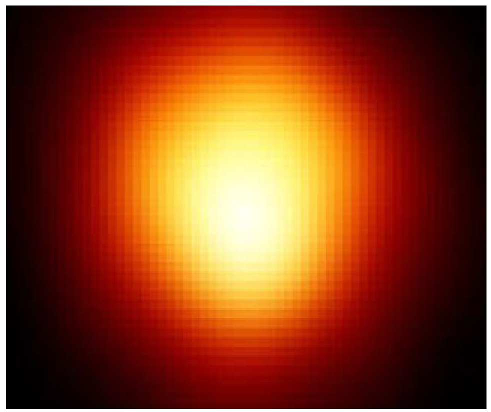
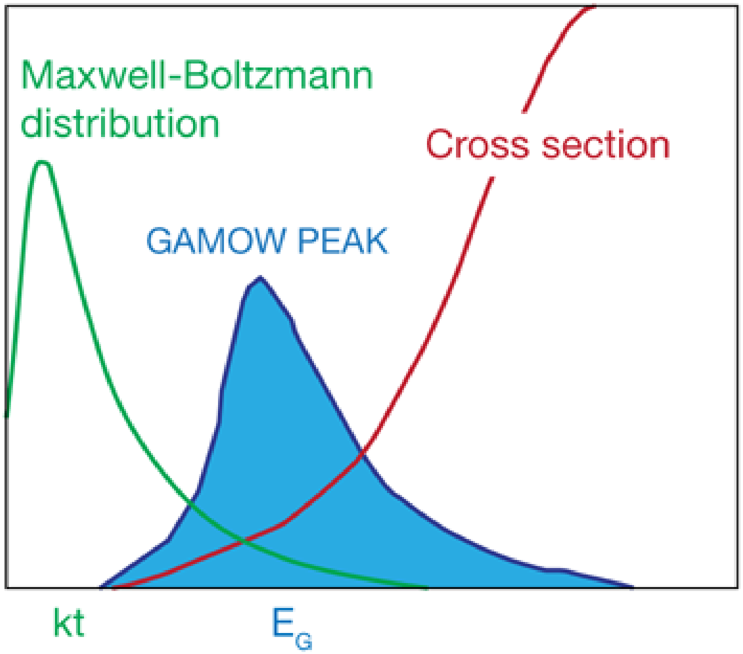
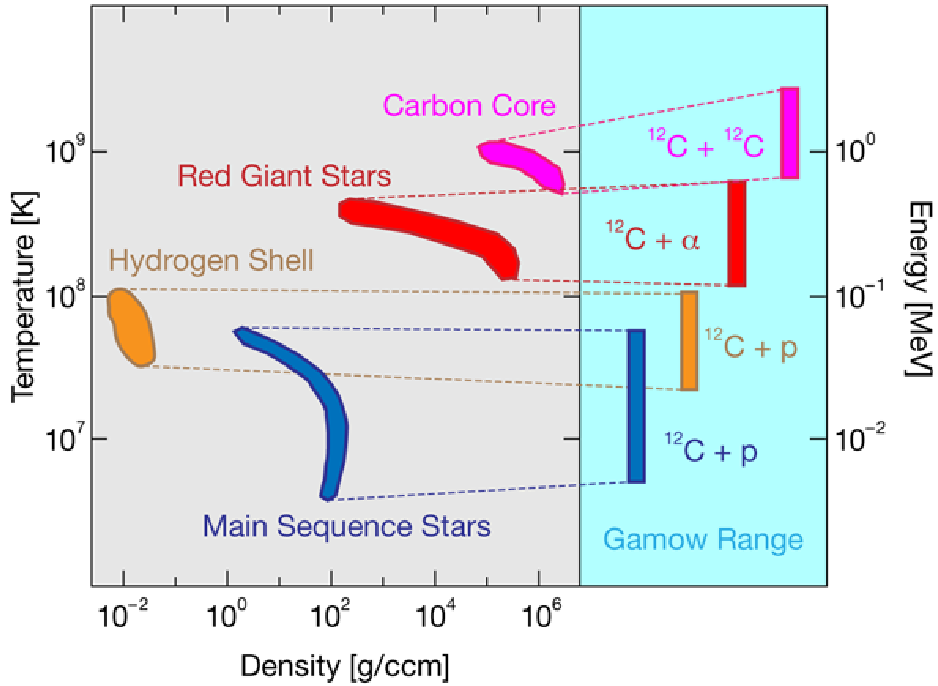
Stellar Environments



Low Energy Cross Sections

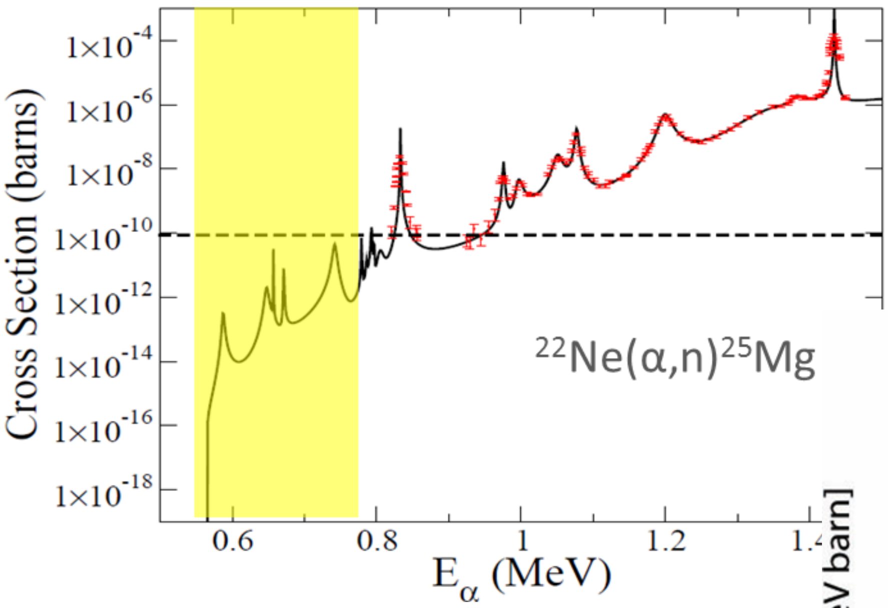
Nuclear energy range for reactions in stars: $E_g \equiv 2m_r c^2 (\pi\alpha Z_a Z_b)^2$



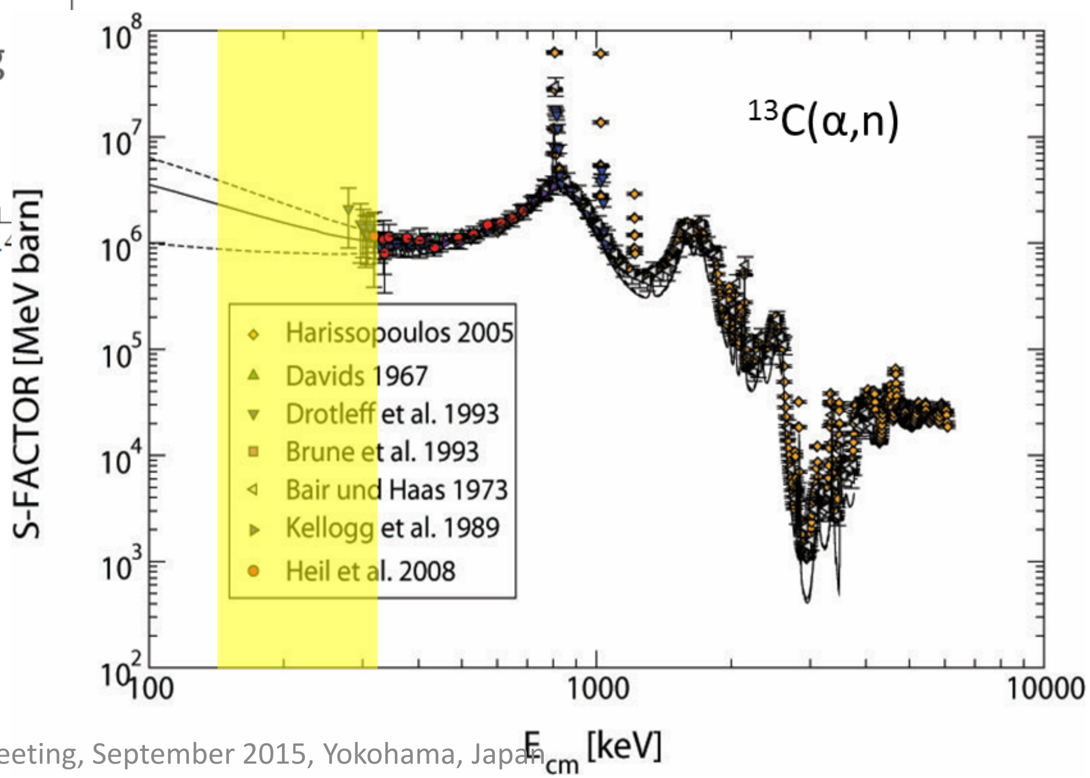


Depending on the charge of the interacting particles and the stellar density and temperature conditions the energy range between 10 keV and 1 MeV! The reaction cross sections are well in the sub-pico-barn range; experiments are seriously handicapped by natural as well as beam-induced background!

S-process seeds example



Since the present technical possibilities appear to be exhausted, a reduction of the remaining uncertainty can probably only be achieved in an underground laboratory, where the cosmic-ray induced γ background can be avoided.
M. Heil et al., Phys. Rev. C **78**, 025803 (2008)



- ^{22}Ne(α,n) and ^{13}C(α,n)
- Neutron sources for the s-process
- Not s-process elements
- Currently not viable at LUNA

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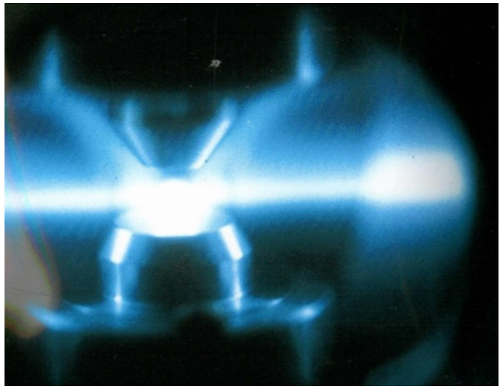
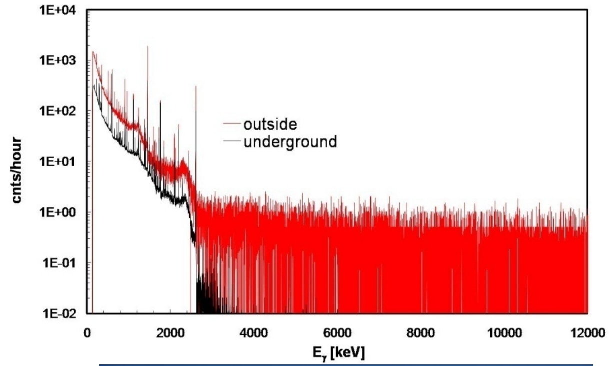
What is needed?

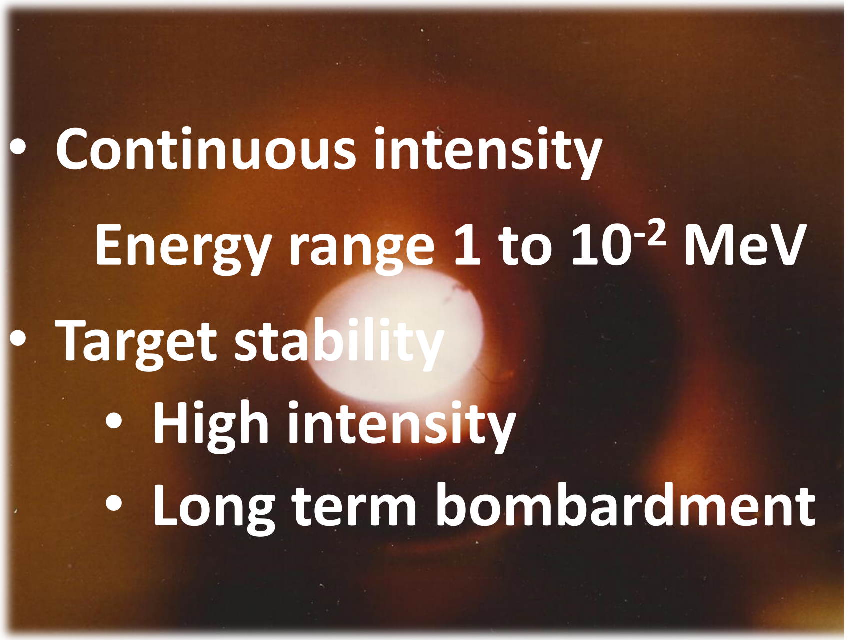
- **Increase of reaction yield**
  - Increasing beam intensity
  - Improving target stoichiometry
  - Improving target stability
- **Background reduction in detector devices**
  - Cosmic radiation background
  - Environmental decay background
  - Beam induced background
- **Long term measurements**
  - Long term operation support
  - Long term accessibility of facility
  - Broad community





Specs: Yield Increase

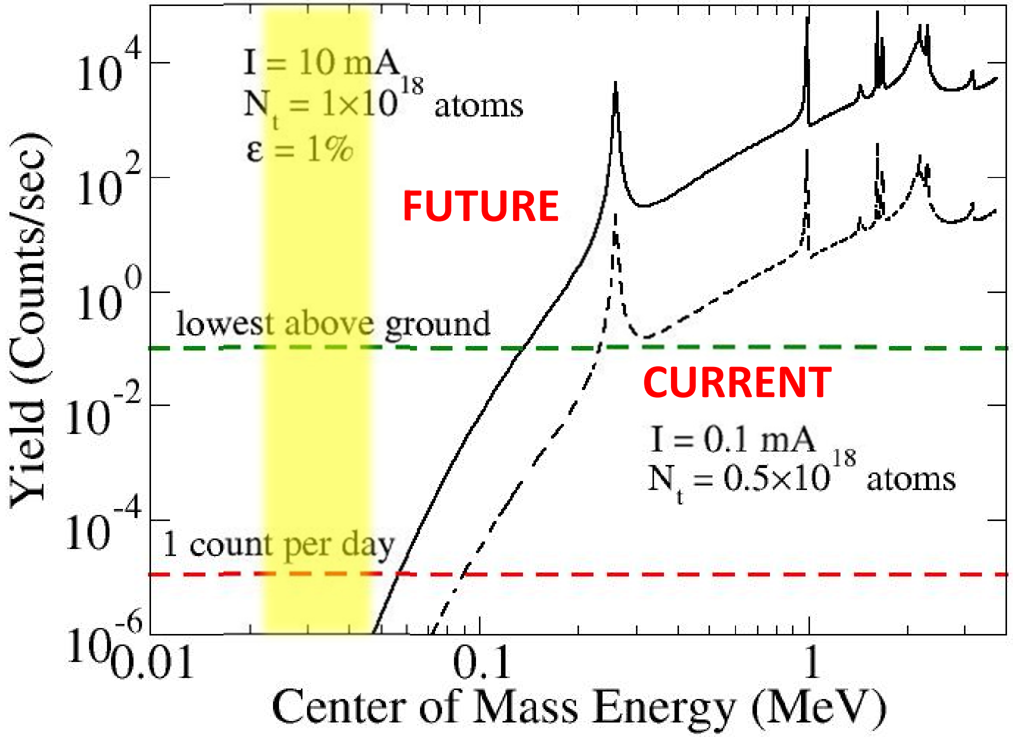
- H burning example:
  - ➢ Solar reactions ~ 10^{38} s^{-1}
  - ➢ With current range 0.1 mA ~ 0.015 events/day
  - ➢ With expanded range 10 mA ~ 15 events/day



- Continuous intensity

  Energy range 1 to 10^{-2} MeV
- Target stability
  - High intensity
  - Long term bombardment

$^{14}N(p,\gamma)^{15}O$



Specs: Background

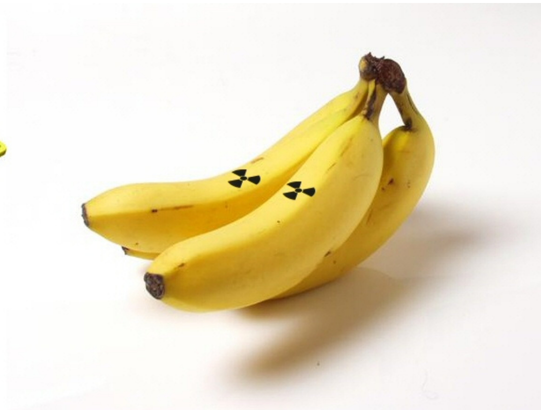
Total Background = Beam Induced + Environmental + Cosmic

Beam induced – Everything that touches the beam

Environmental – Natural decay chains

Cosmic – Mainly muons

Passive shielding increase



Specs: Community

- Community continues to grow, necessary for difficult experiments

- 3rd priority in US Nuclear Physics Long Range Plan

- Low background

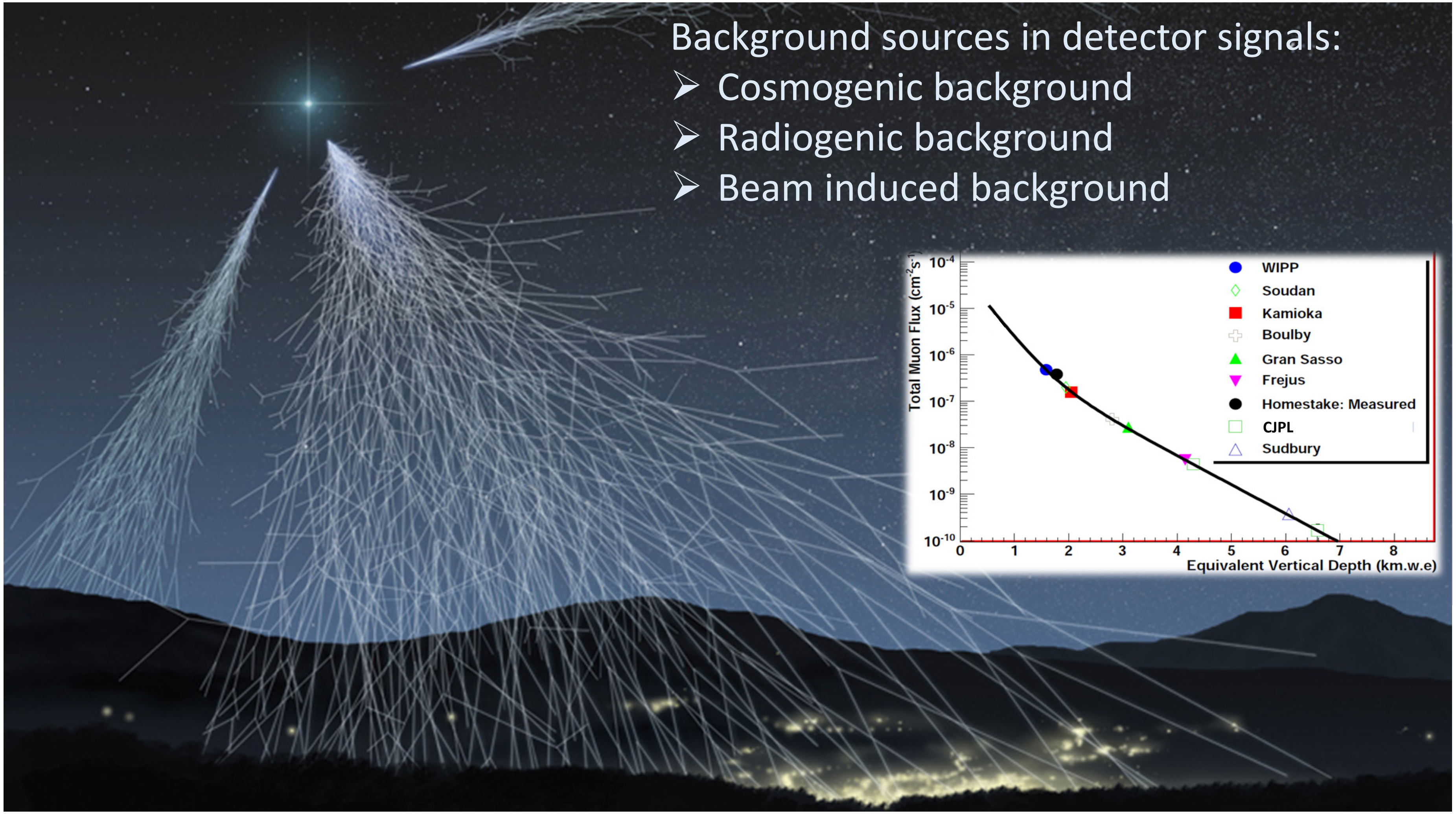
requirements in many fields

Possible Solutions

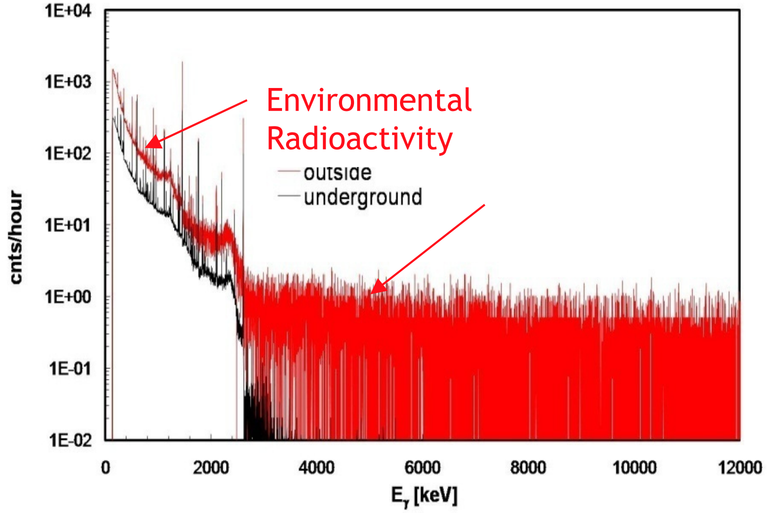
1. Higher energy measurements and extrapolation
2. R-matrix theory application using current data
3. ^{26}Mg(γ,γ) at HIGS, given ^{26}Mg information
4. High neutron flux experiments
5. Background suppression by underground measurement

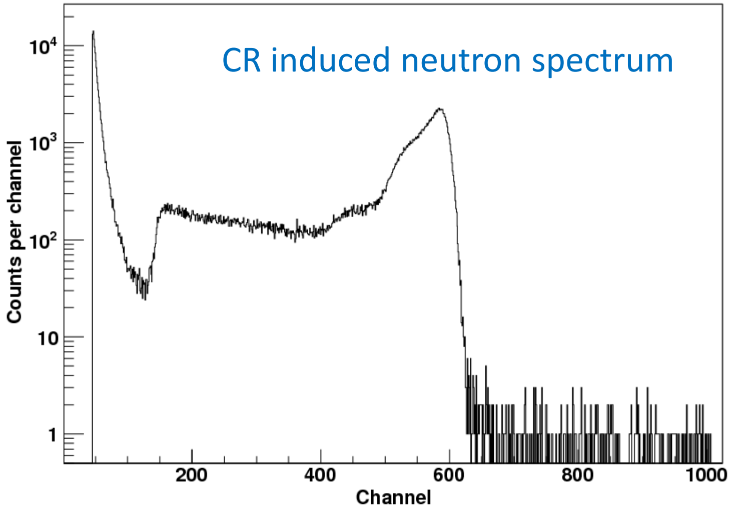
Moving Underground

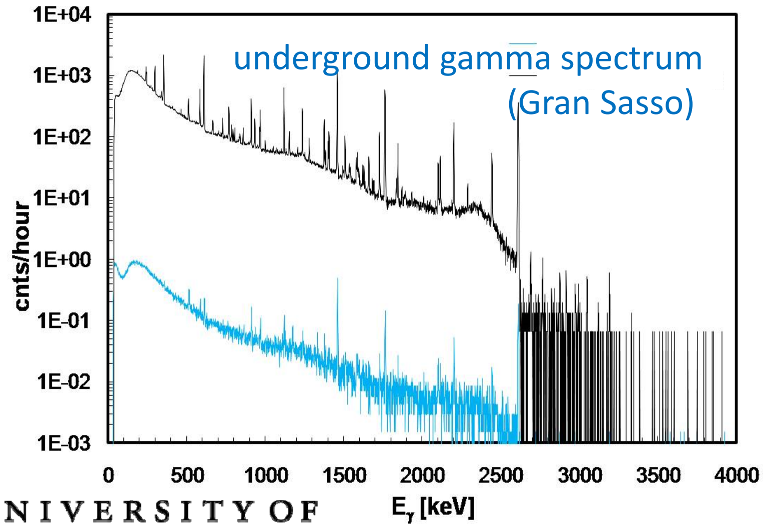
Background sources in detector signals:
- Cosmogenic background
- Radiogenic background
- Beam induced background

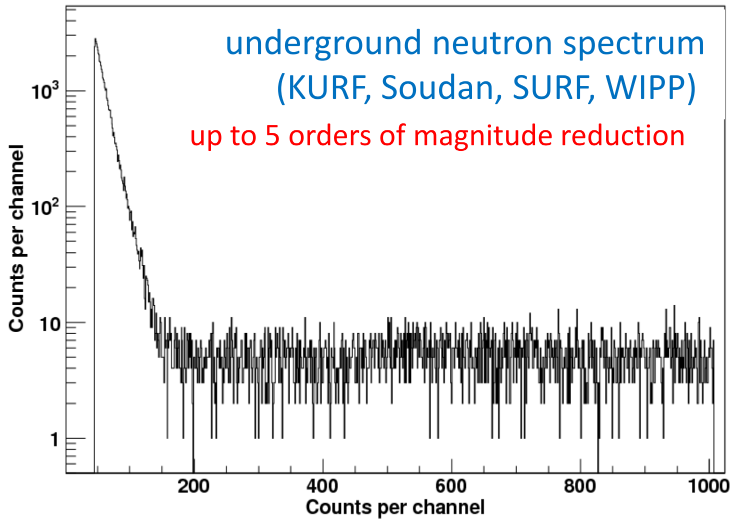


Underground Detection Benefit

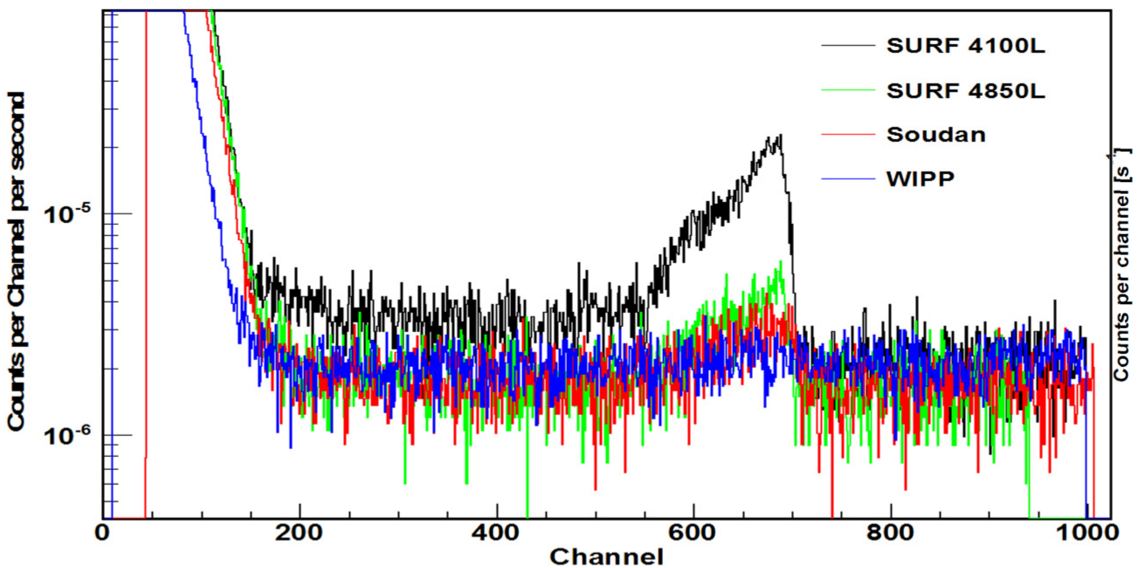


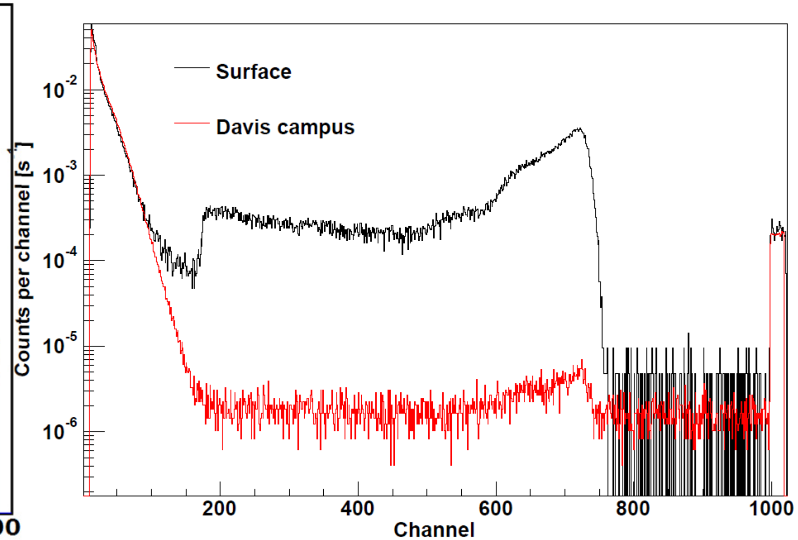




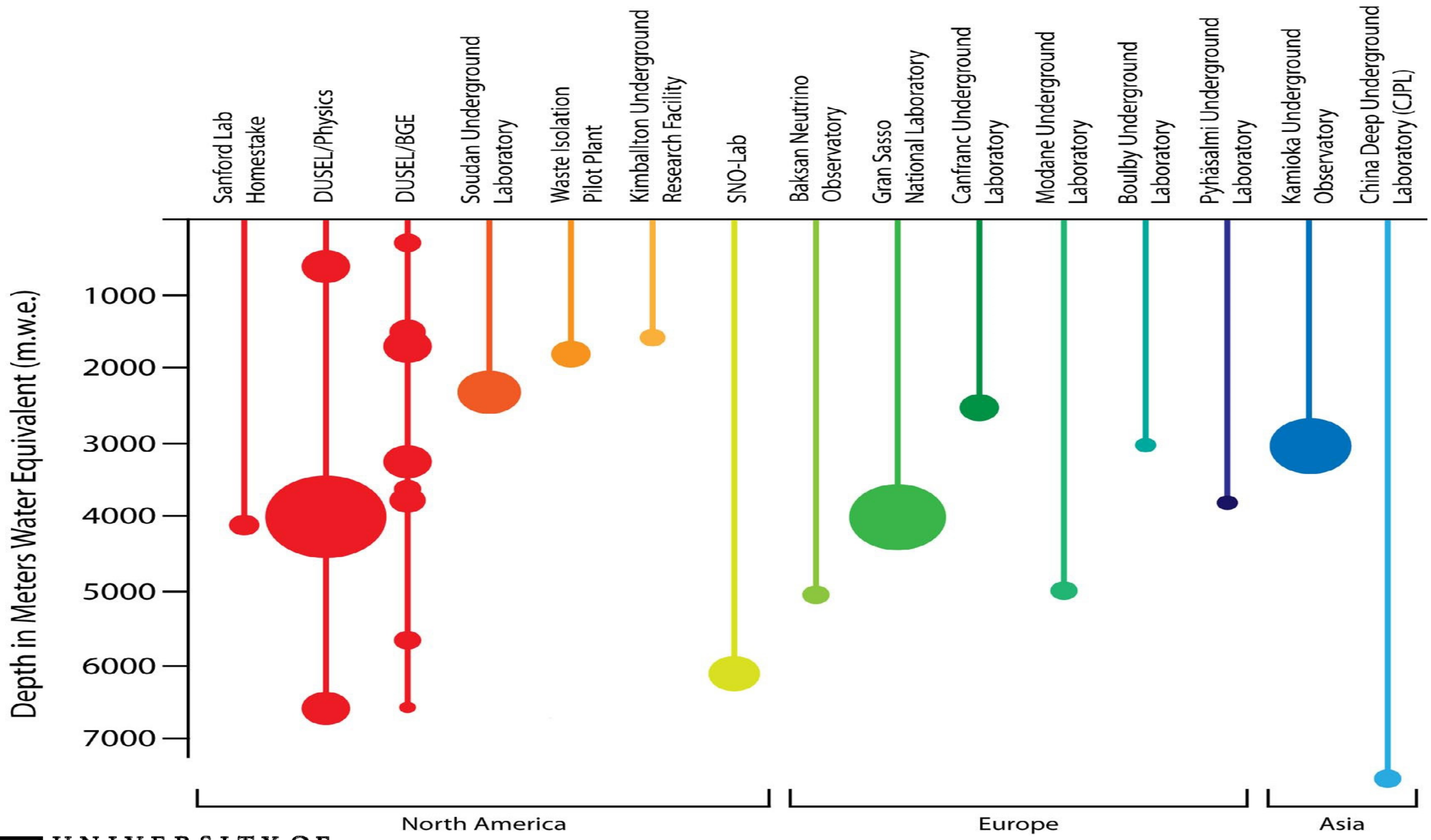


But Where To Go?

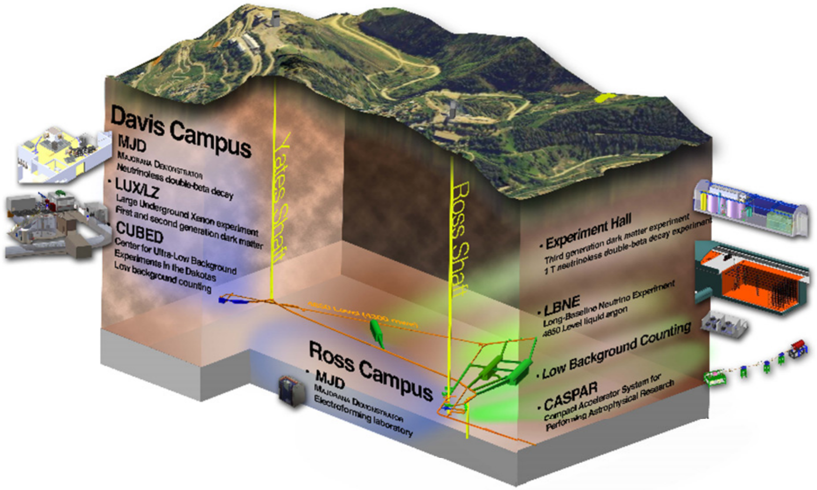




Hijacking Other Fields

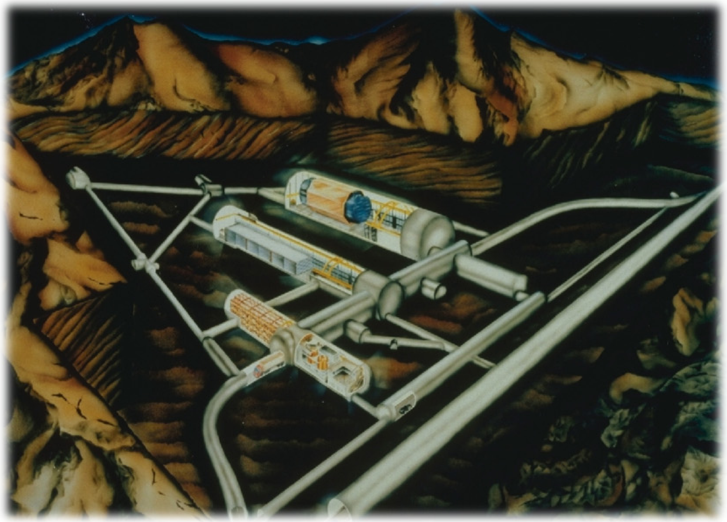


What Are The Options?



Gran Sasso (Italy) - LUNA
SURF (USA) – CASPAR
Dresden (Germany) – Felsenkeller
Jinping (China) – JUNA
South America
India

Proposed



Facilities: LUNA

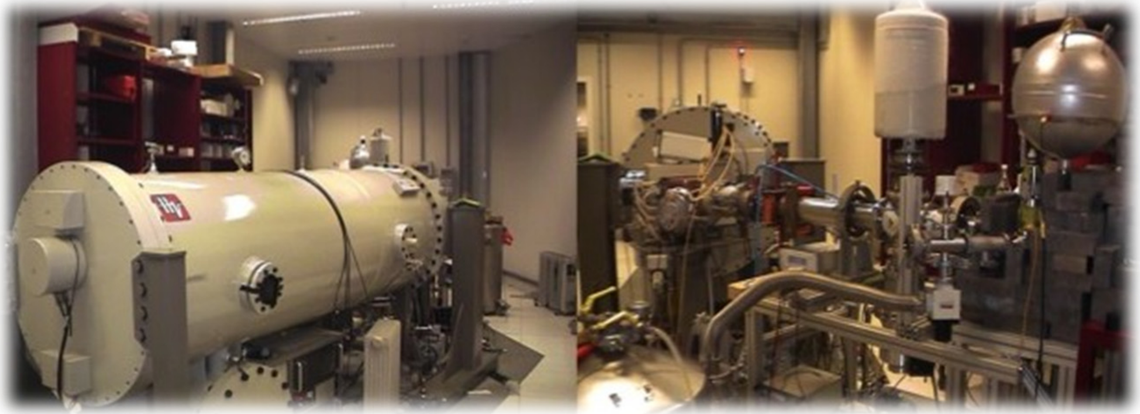
Location: Gran Sasso Mountain, Italy

Timeline: Operational since 2000 (1992 50 kV)

Depth: 1400 m → 4000 m.w.e

Equipment: 400 kV HVE accelerator

Windowless gas-target and solid target



Facilities: LUNA-MV

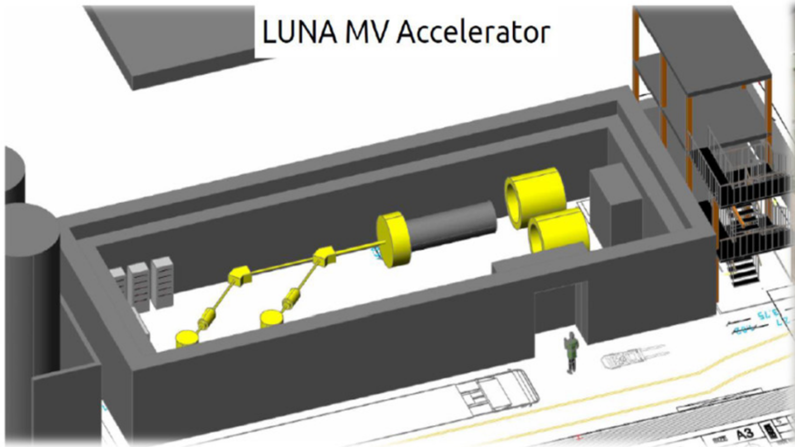
Location: Gran Sasso Mountain, Italy

Timeline: Commisioning ~ 2018

Depth: 1400 m → 4000 m.w.e

Equipment: 3.5 MV accelerator (NEC or HVE)

Targets under consideration



Facilities: CASPAR

Location: SURF-Homestake Mine, USA

Timeline: Commisioning ~ 2016

Depth: 1500 m → 4300 m.w.e

Equipment: 1 MV HVE accelerator

Windowless gas-target and solid target

Facilities: Felsenkeller

Location: Beer cellar outside Dresden, Germany

Timeline: Commisioning ~ 2016

Depth: 47 m → 130 m.w.e

Equipment: 5 MV HVE accelerator

Solid target

Facilities: JUNA

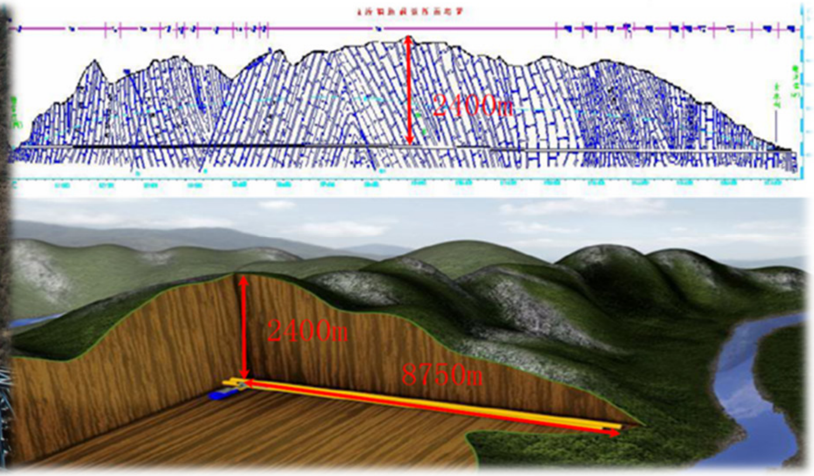
Location: Jinping Mountain, China

Timeline: Commisioning ~ 2018 (JUNA II ~2020)

Depth: 2400 m → 7200 m.w.e

Equipment: 400 kV accelerator

Solid target



Underground accelerator project DIANA for low energy studies

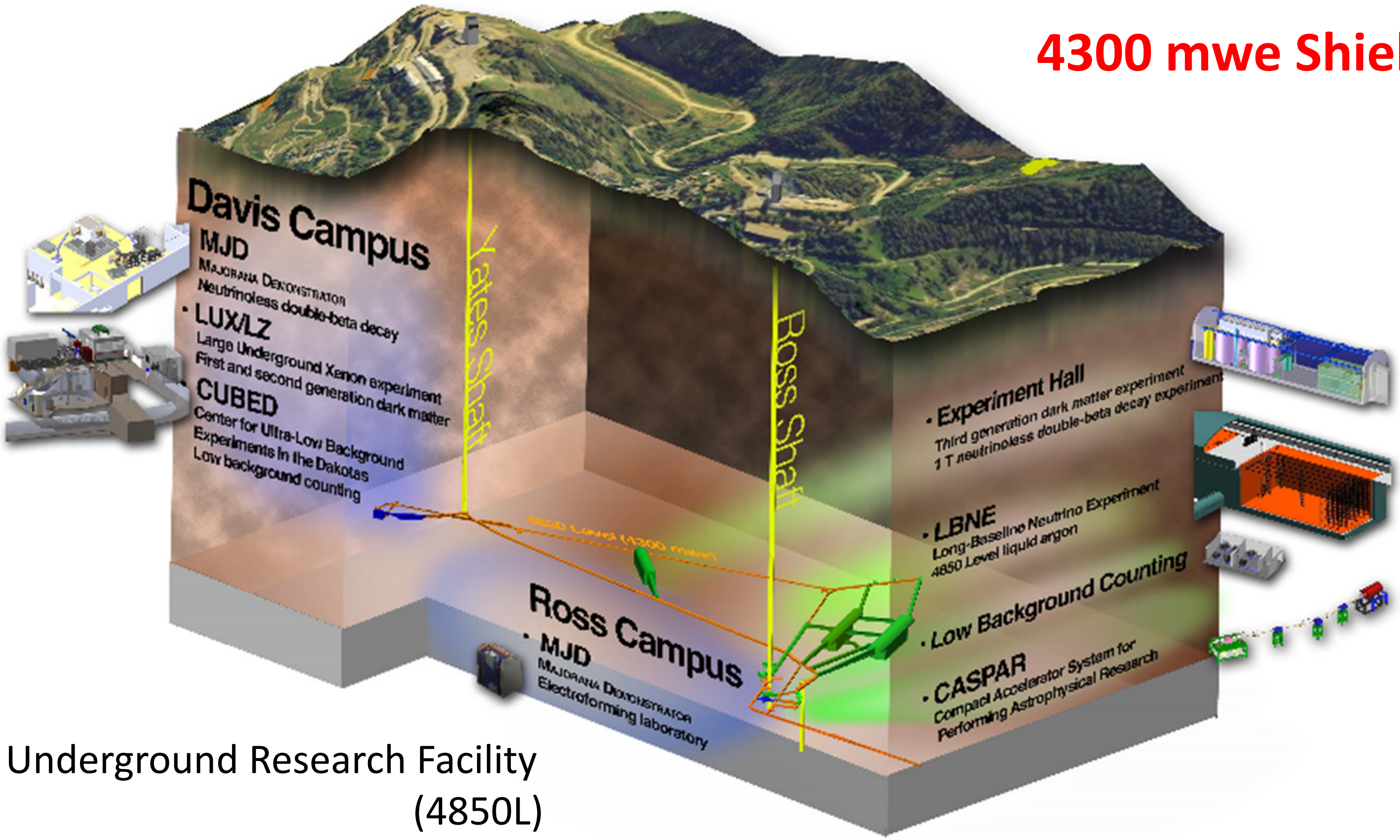
p, α, HI beams
100 x LUNA luminosity

High luminosity, low background experiments

CASPAR Concept

Underground Accelerator 3rd LRP priority of Nuclear Astrophysics community

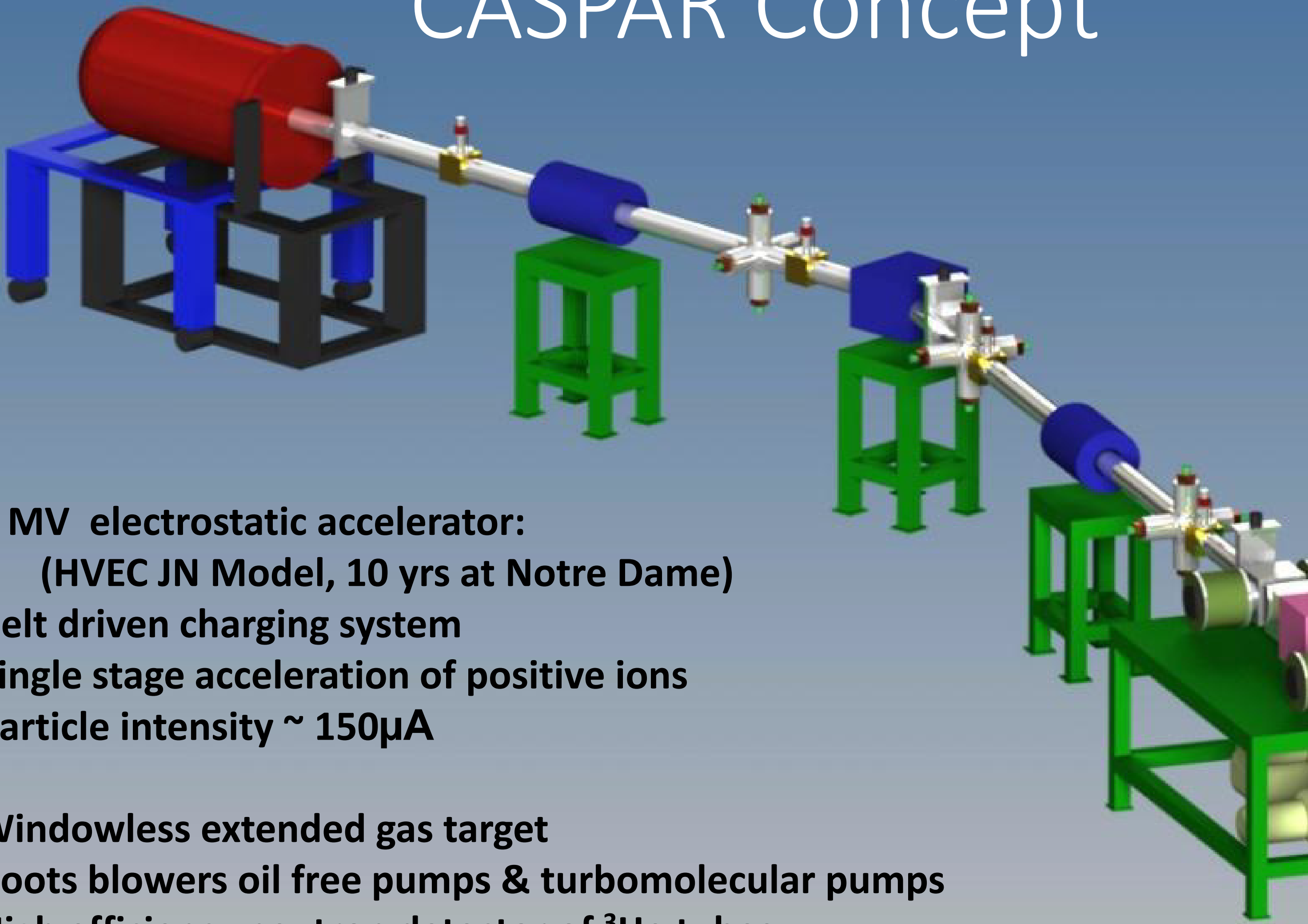
4300 mwe Shielding

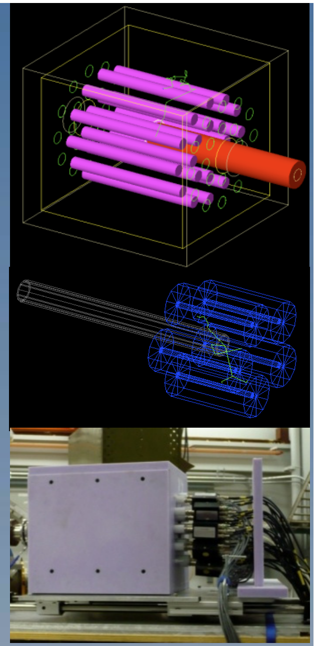


Sanford Underground Research Facility
(4850L)

CASPAR Concept

CASPAR Concept





1 MV electrostatic accelerator:
(HVEC JN Model, 10 yrs at Notre Dame)
Belt driven charging system
Single stage acceleration of positive ions
Particle intensity ~ 150μA

Windowless extended gas target
Roots blowers oil free pumps & turbomolecular pumps
High efficiency neutron detector of ^{3}He tubes


KNAACK


Pallet
#19

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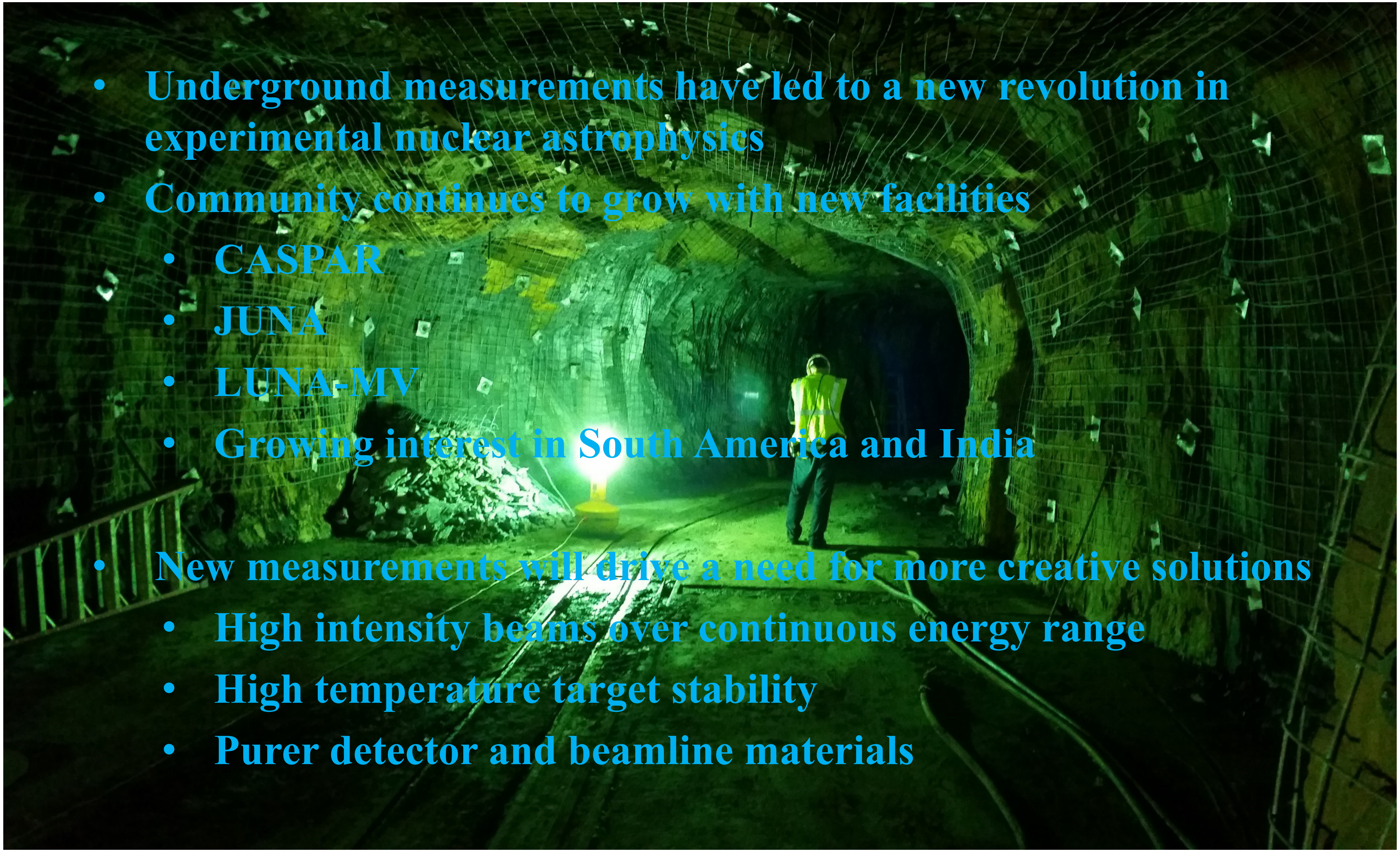

- Underground measurements have led to a new revolution in experimental nuclear astrophysics
- Community continues to grow with new facilities
  - CASPAR
  - JUNA
  - LUNA-MV
  - Growing interest in South America and India
- New measurements will drive a need for more creative solutions
  - High intensity beams over continuous energy range
  - High temperature target stability
  - Purer detector and beamline materials