Stable beam experiments: charged particle induced reactions

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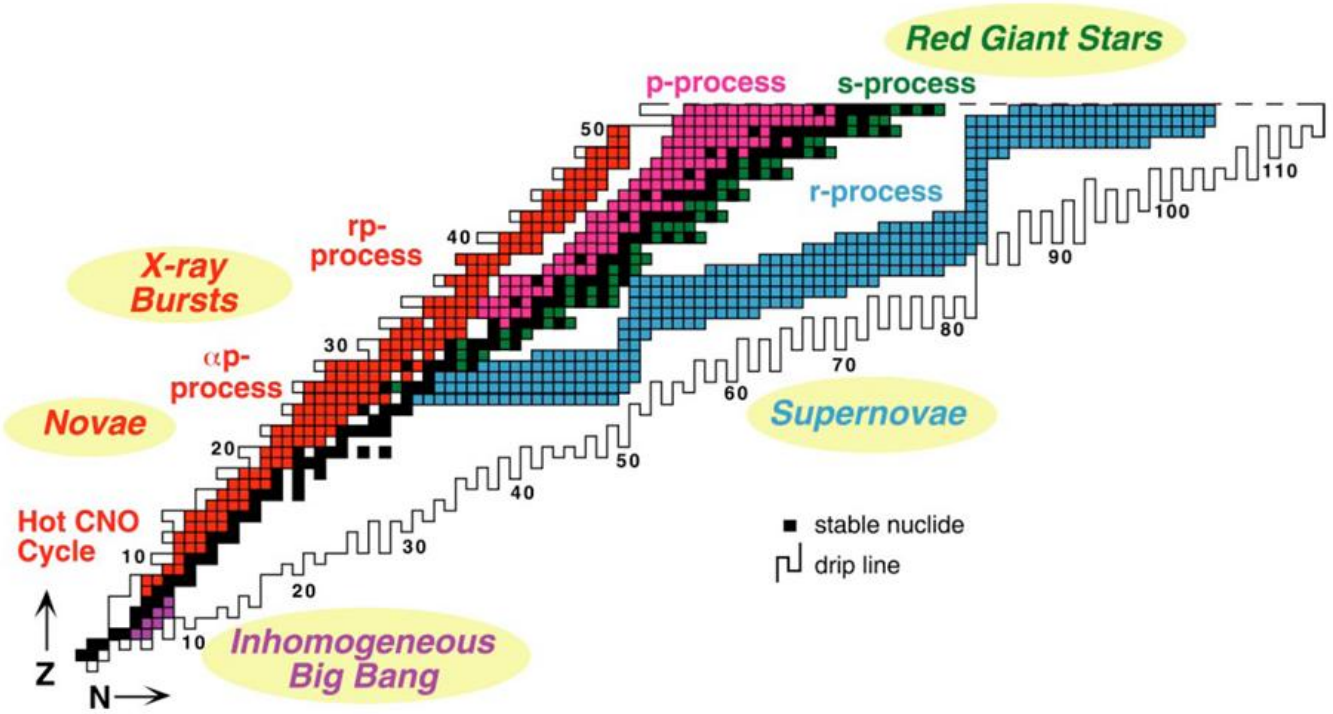
Why stable beams?

- Quiescent burning: H and He induced reactions on stable isotopes (almost always). We are far from a the full understanding.
- Other processes (like e.g. p-process): useful complementary information from stable beam experiments



… and indeed!

- large fraction of nuclear astrophysics results come from H and He induced reaction studies
- and from small scale facilities

The Joint Institute for Nuclear Astrophysics

Virtual Journal of Nuclear Astrophysics

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- Atomki, Debrecen (HU)
- Lisbon (PT)
- Bucharest-Magurele (RO)
- Soreq, Yavne (IL)
- Dresden-Rossendorf (DE)
- Cologne (DE)
- Frankfurt (DE)
- Darmstadt (DE)
- Legnaro (IT)
- Naples/Caserta (IT)
- Catania (IT)
- Canfranc (ES)
- York (UK)
- Demokritos, Athens (GR)
- GANIL (FR)
- CSNSM, IPNO, Orsay (FR)
- IPHC, Strasbourg (FR)
- Gran Sasso (IT)
- Munich (DE)
- Zagreb (HR)

Requirements

Always emphasized

- Low energy (small accelerators)
- High beam intensity (new technology ion sources, accelerators)
- Low background (underground labs)

Needs to be stressed

- High precision
- Wide energy range
- Complementary experiments (indirect methods, nuclear data)

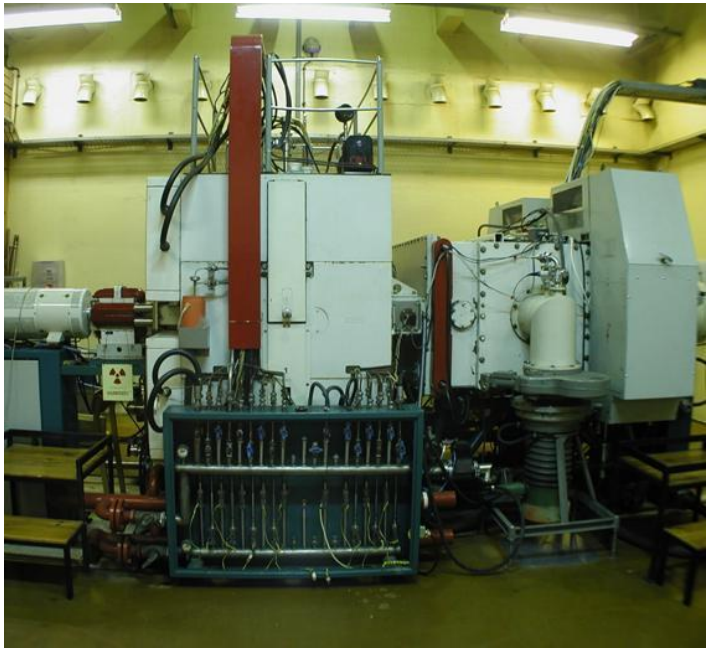
Atomki, Debrecen, Hungary

New 2MV tandetron

- $^{17}O(p,\gamma)^{18}F$
- $^{14}N(p,\gamma)^{15}O$

20 MeV cyclotron

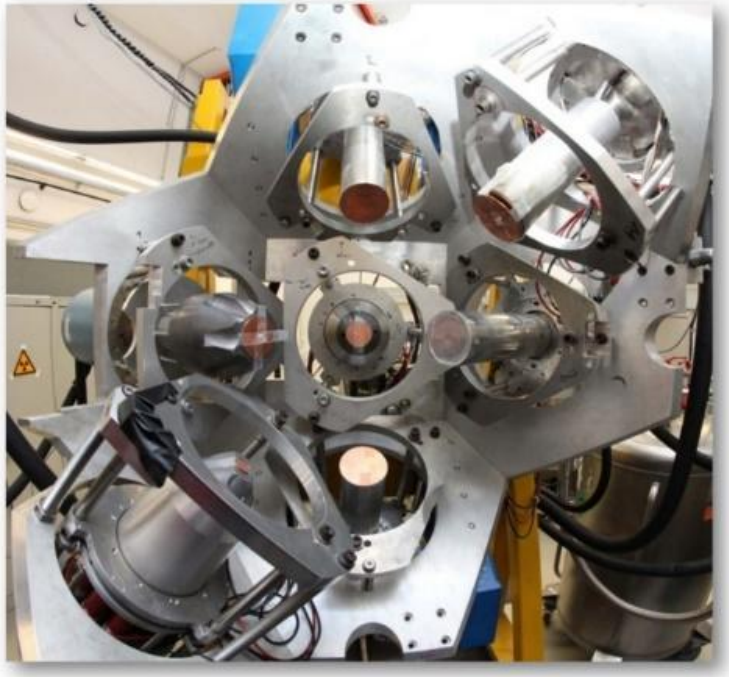
- p-process (proton and alpha capture, alpha elastic scattering)
- $^{3}He(\alpha,\gamma)^{7}Be$ at high energies

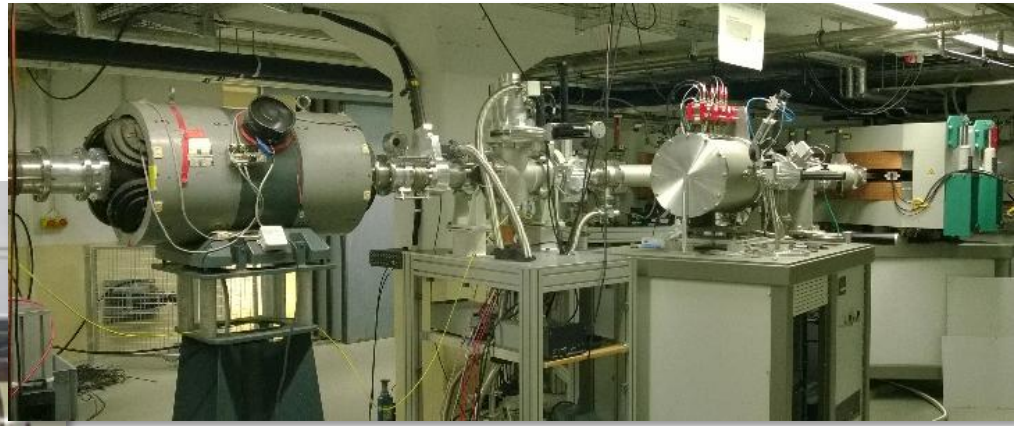


Cologne, Germany

Heavy element nucleosynthesis

- proton and alpha induced reactions
- cross section, γ-strength measurements
- HORUS spectrometer (in-beam)
- activation
- AMS





Info provided by L. Netterdon

Lisbon, Portugal

p-process

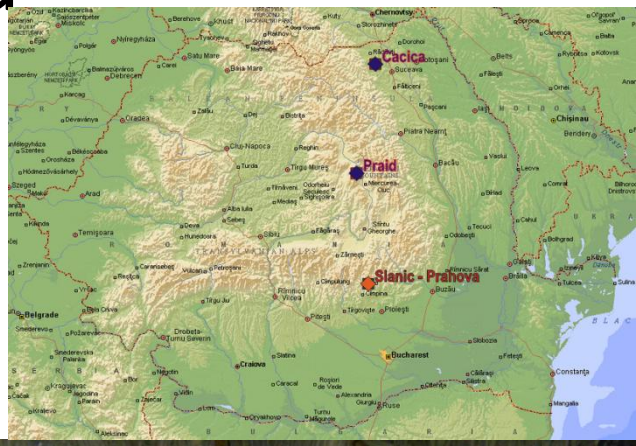
- (p,n) reactions near threshold
- validation of proton potentials

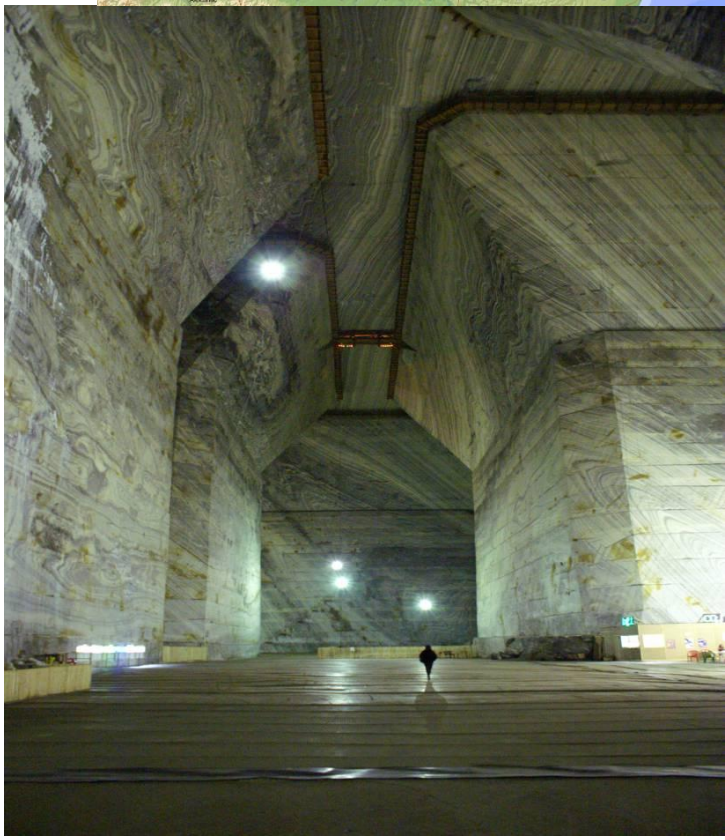
- CTN/IST Tandem
- activation method with short lived reaction products

Info provided by D. Galavíz

IFIN-HH, Bucharest, Romania

- 3 MV tandetron
- low background counting facility (salt mine)
- $^{12}C + {}^{13}C$

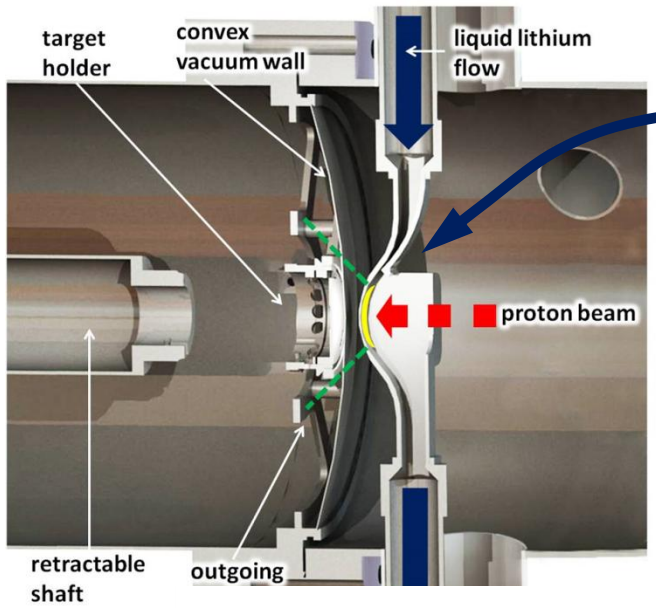




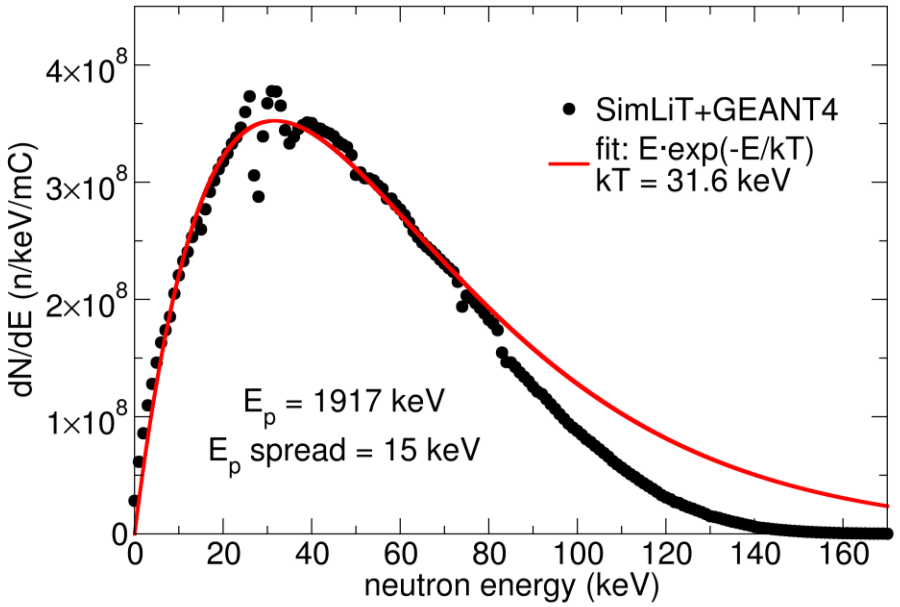
Info provided by
L. Trache

SARAF, Soreq, Israel

- LiLiT: Liquid Lithium Target
- high intensity neutron beam
- MACS measurement for s-process, but not only



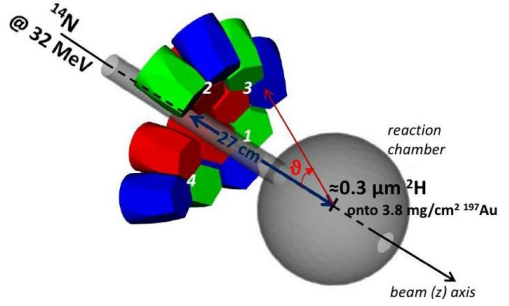
free-surface liquid lithium target
I_p = 1-2 mA, 1.92 MeV

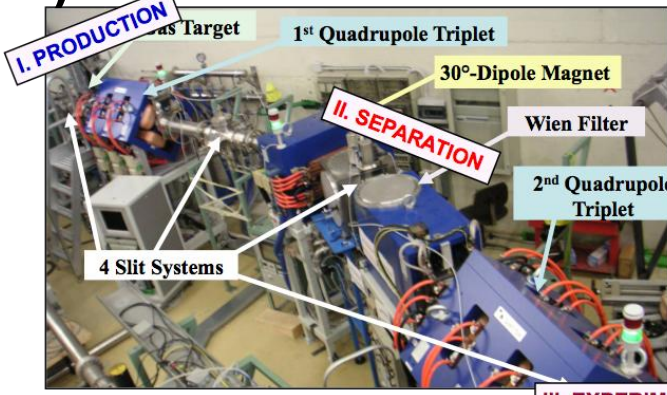


Info provided by M. Paul

Legnaro

- Low energy accelerators
- IBA (target characterization)
- $^{10}B(p,\alpha_{0,1})^{7}Be$, $^{19}F(p,\alpha)^{16}O$ $^{25}Mg(\alpha,n)^{28}Si$
- Indirect methods
- AGATA (^{15}O lifetime)
- Legnaro Neutron Source (LENOS)





Info provided by A. Caciolli

Caserta, Italy

- ERNA collaboration at CIRCE
- Recoil separator on the 3MV pelletron
- Program: $^{7}Be+p$, $^{7}Be+^{4}He$, $^{14}N+^{4}He$, $^{15}N+^{4}He$, $^{12}C+^{4}He$, $^{12}C+^{12}C$

Dresden - Rossendorf, Germany

- HZDR ELBE 40 MeV superconducting electron linac:
  * bremsstrahlung for nuclear resonance fluorescence and photoactivation
  * neutron time-of-flight (0.1 - 10 MeV)
  recently, e.g. 15N levels (2015)

- TU Dresden DD / DT neutron generator:
  high flux of 2 / 14 MeV neutrons for activation analysis

- HZDR 6 MV accelerator mass spectrometry system:
  recently, e.g. 60Fe analyses (2016)

- HZDR ion beam center:
  3 MV, 2 MV, 0.5 MV, 0.2 MV, 0.04 MV accelerators for various applications

Underground Nuclear Astrophysics

- Presently only LUNA
- Europe, in preparation: Canfranc, Felsenkeller (shallow underground)
- Outside Europe, in preparation: Jinping (China), Homestake (USA)

LUNA: present

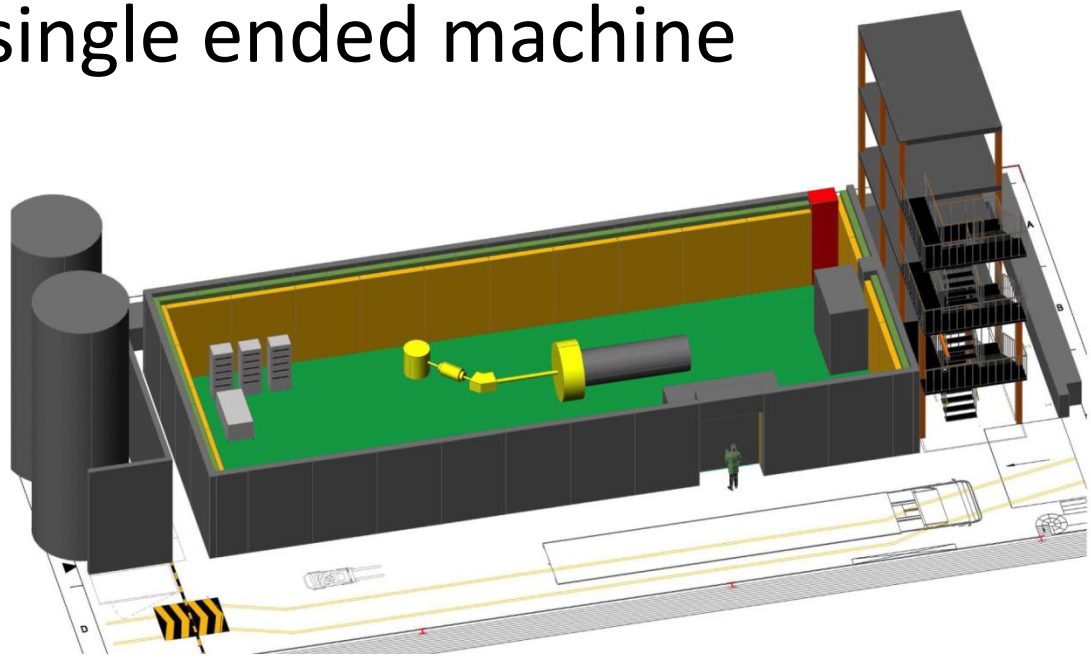
400 keV accelerator

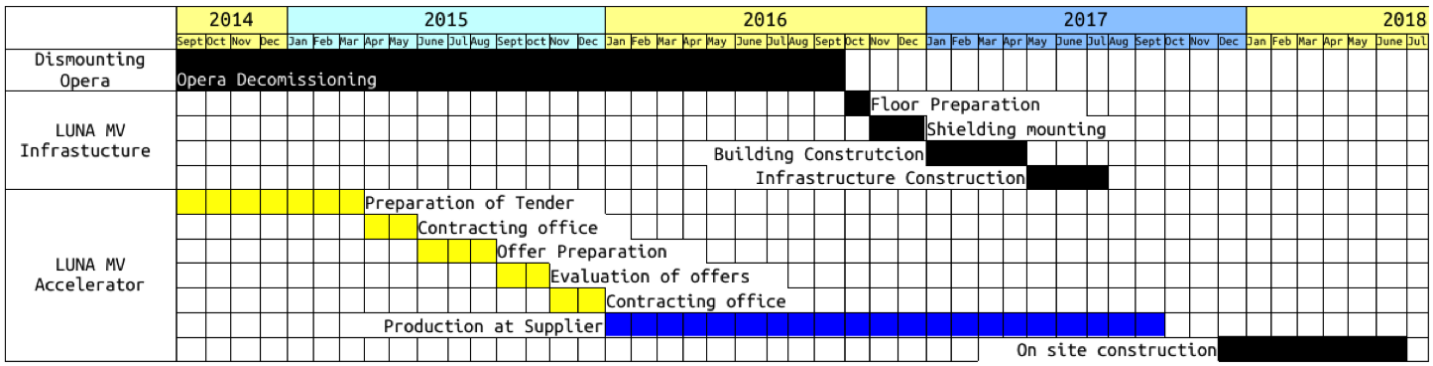
- $^{23}Na(p,\gamma)^{24}Mg$
- $^{22}Ne(p,\gamma)^{23}Na$
- $^{18}O(p,\gamma/\alpha)$
- $d(p,\gamma)^{3}He$
- $^{6}Li(p,\gamma)^{7}Be$
- ... further plans

LUNA: future

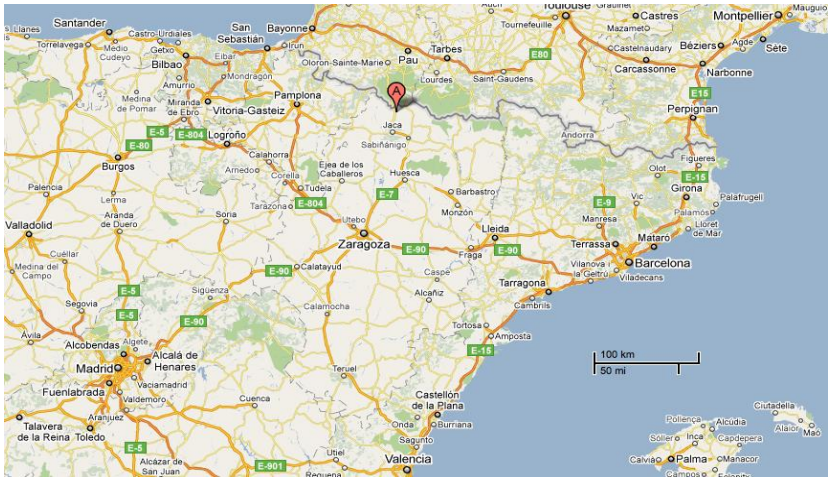
LUNA MV: 3.5 MV single ended machine

- $^{12}C(\alpha,\gamma)^{16}O$
- $^{13}C(\alpha,n)^{16}O$
- $^{22}Ne(\alpha,n)^{15}Mg$
- $^{12}C + ^{12}C$
- $^{14}N(p,\gamma)^{15}O$

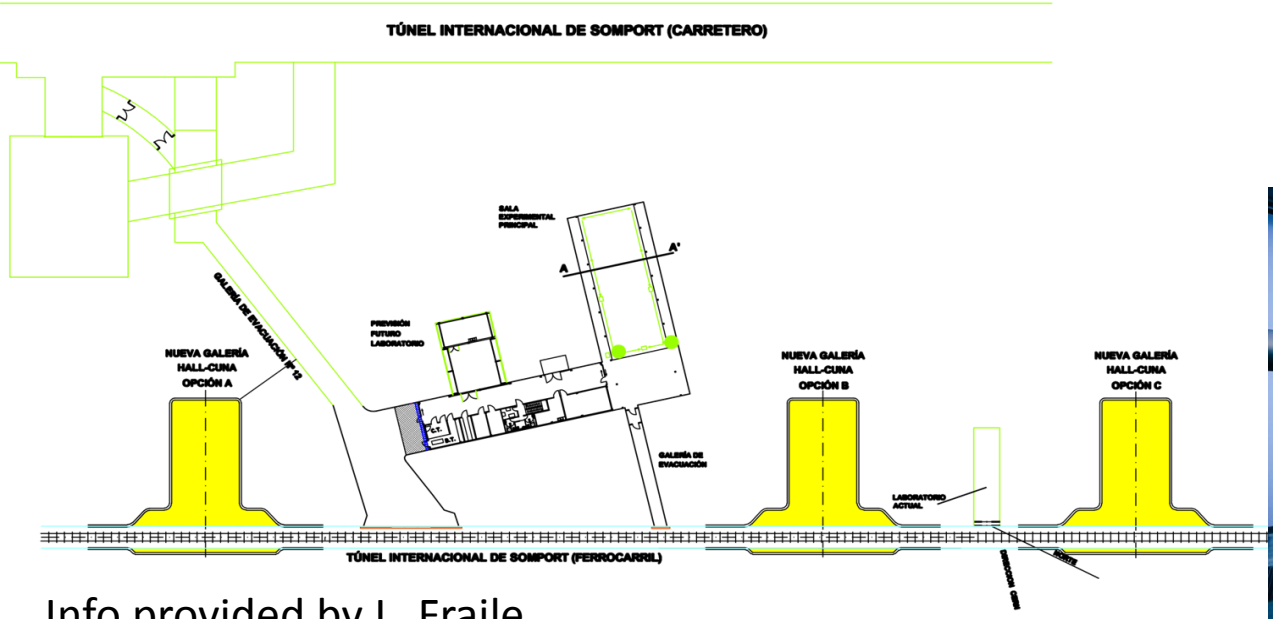




Canfranc



- LoI 2009
- Science case: neutron sources, etc.
- 2nd workshop in two week



Info provided by L. Fraile

Felsenkeller, Dresden, Germany

- 5 MeV pelletron shallow underground + low background counting facility
- Program: stellar H, He, C burning reactions
- Fully funded, open in 2017, external users welcome