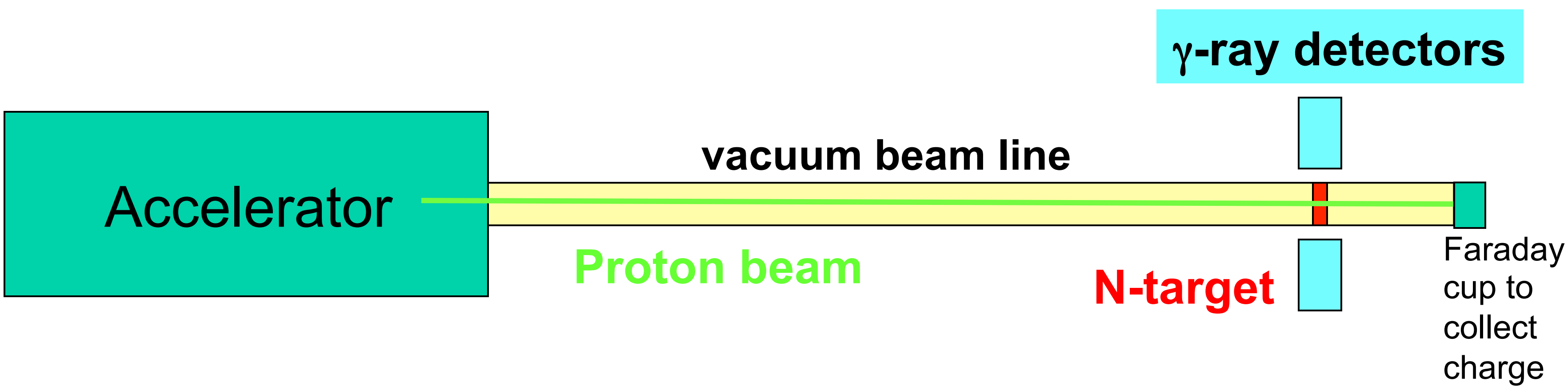
Reaction rates in the Laboratory

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

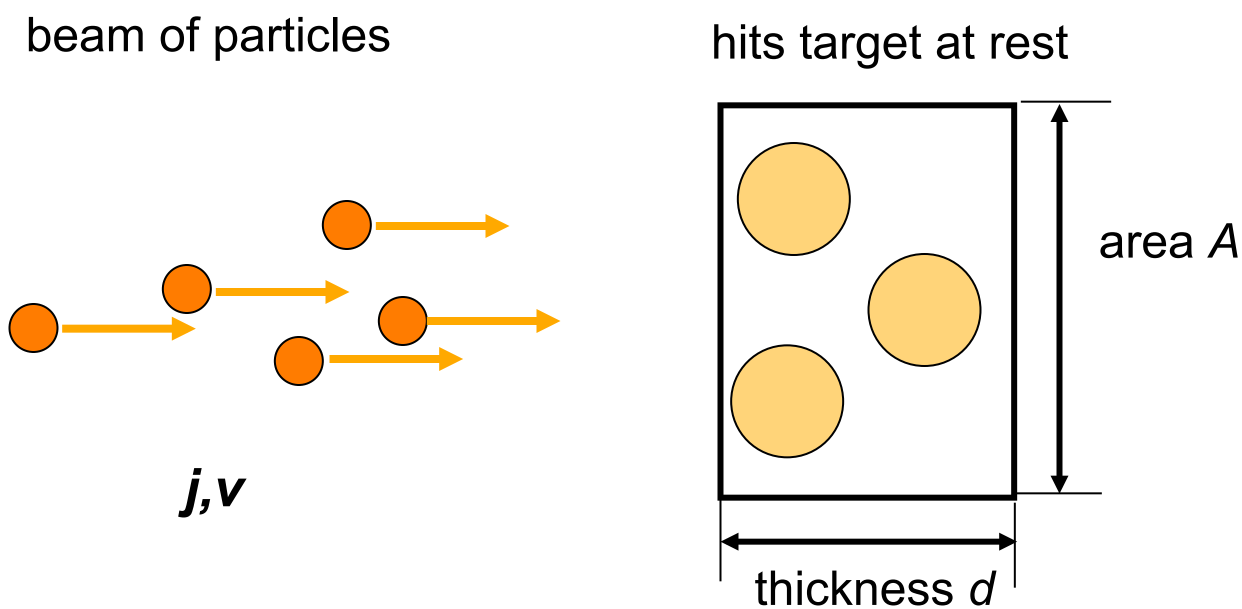
- slowest reaction in the CNO cycle
  - → Controls duration of hydrogen burning
  - → Determines main sequence turnoff – glob. cluster ages

- stable target → can be measured directly:



- but cross sections are extremely low:
  → Measure as low an energy as possible
  – then extrapolate to Gamow window

Calculating experimental event rates and yields



assume thin target (unattenuated beam intensity throughout target)

Reaction rate (per target nucleus): $\lambda = \sigma j$

Total reaction rate (reactions per second) $R = \lambda A d n_T = \sigma I d n_T$

with n_T : number density of target nuclei

$I = jA$: beam number current (number of particles per second hitting the target)

note: dn_T is number of target nuclei per cm^2. Often the target thickness is specified in these terms.

Events detected in experiment per second R_{det}

$$R_{\mathrm{det}} = R\varepsilon$$

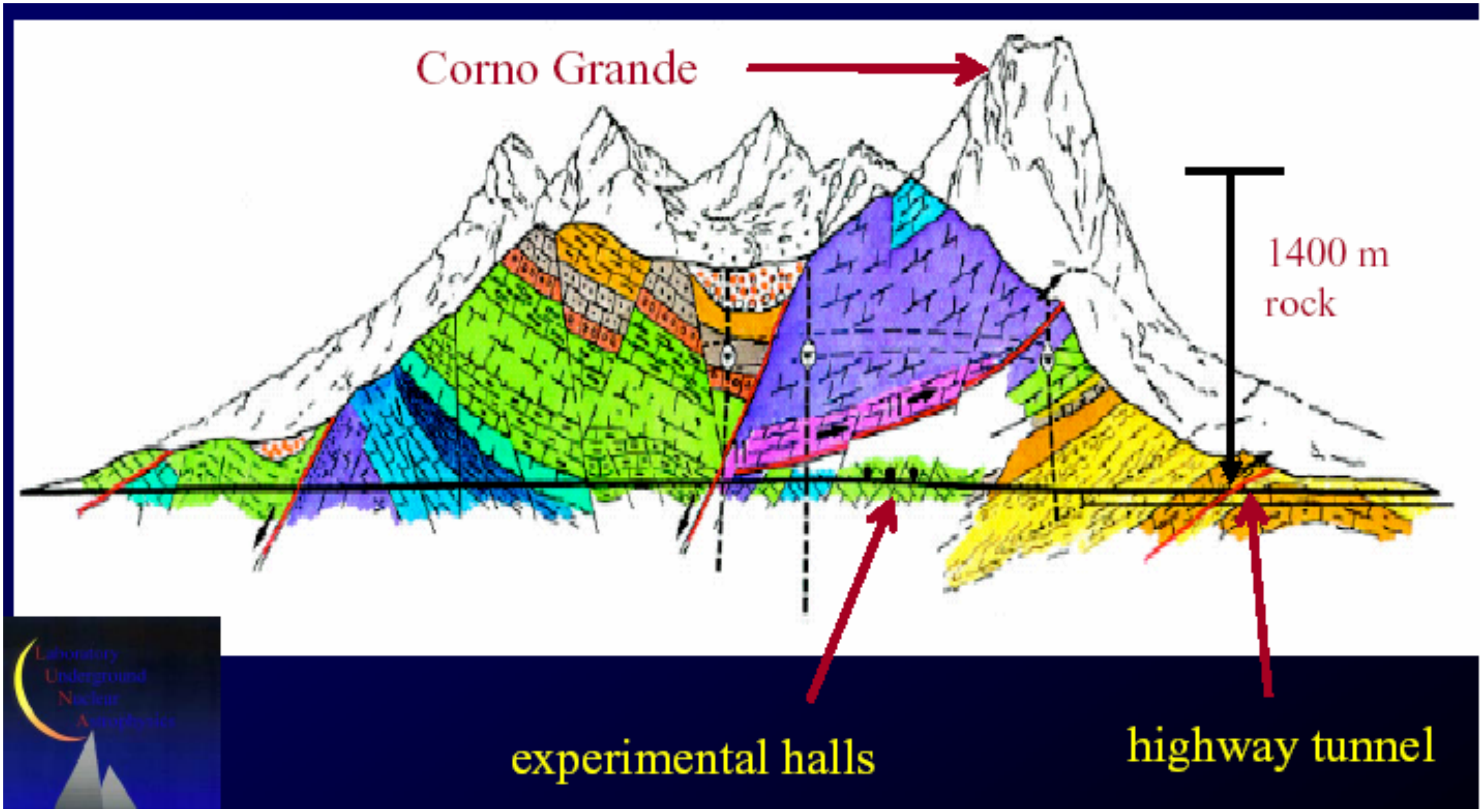
ε is the detection efficiency and can accounts for:

- detector efficiency
  (fraction of particles hitting a detector
  that produce a signal that is registered)
- solid angle limitations
- absorption losses in materials
- energy losses that cause particles energies to slide
  below a detection threshold
- …

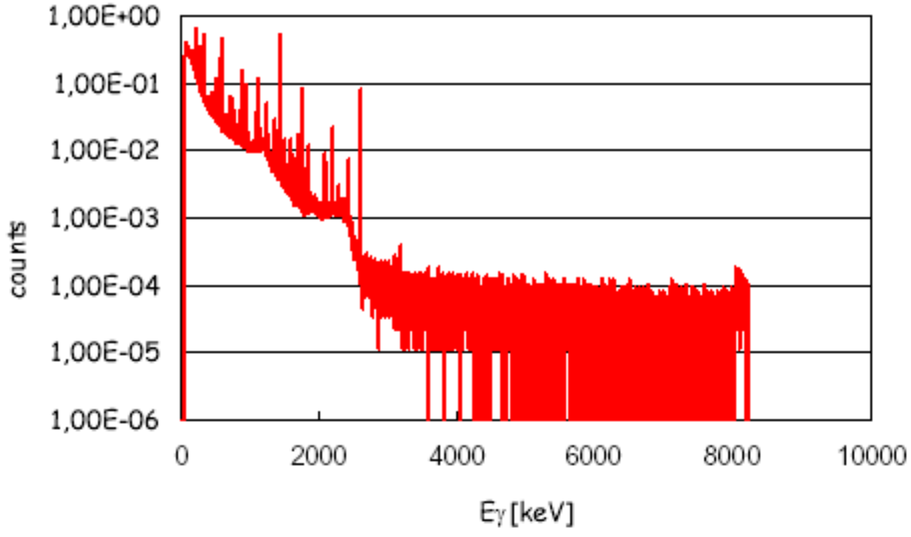
LUNA

Laboratory Underground for Nuclear Astrophysics

(Transparencies: F. Strieder http://www.jinaweb.org/events/tucson/Talk_Strieder.pdf)

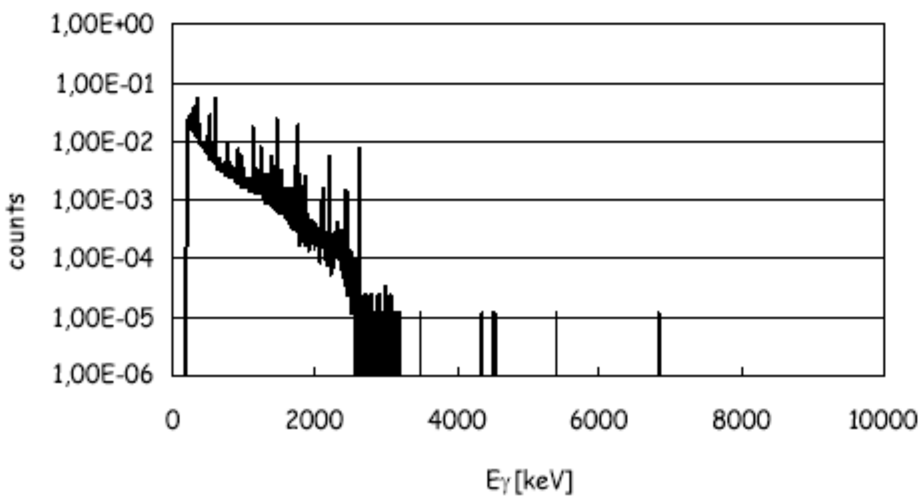


1:1 Mio cosmic ray suppression



HP Ge-Detector
earth surface
detector without any shielding

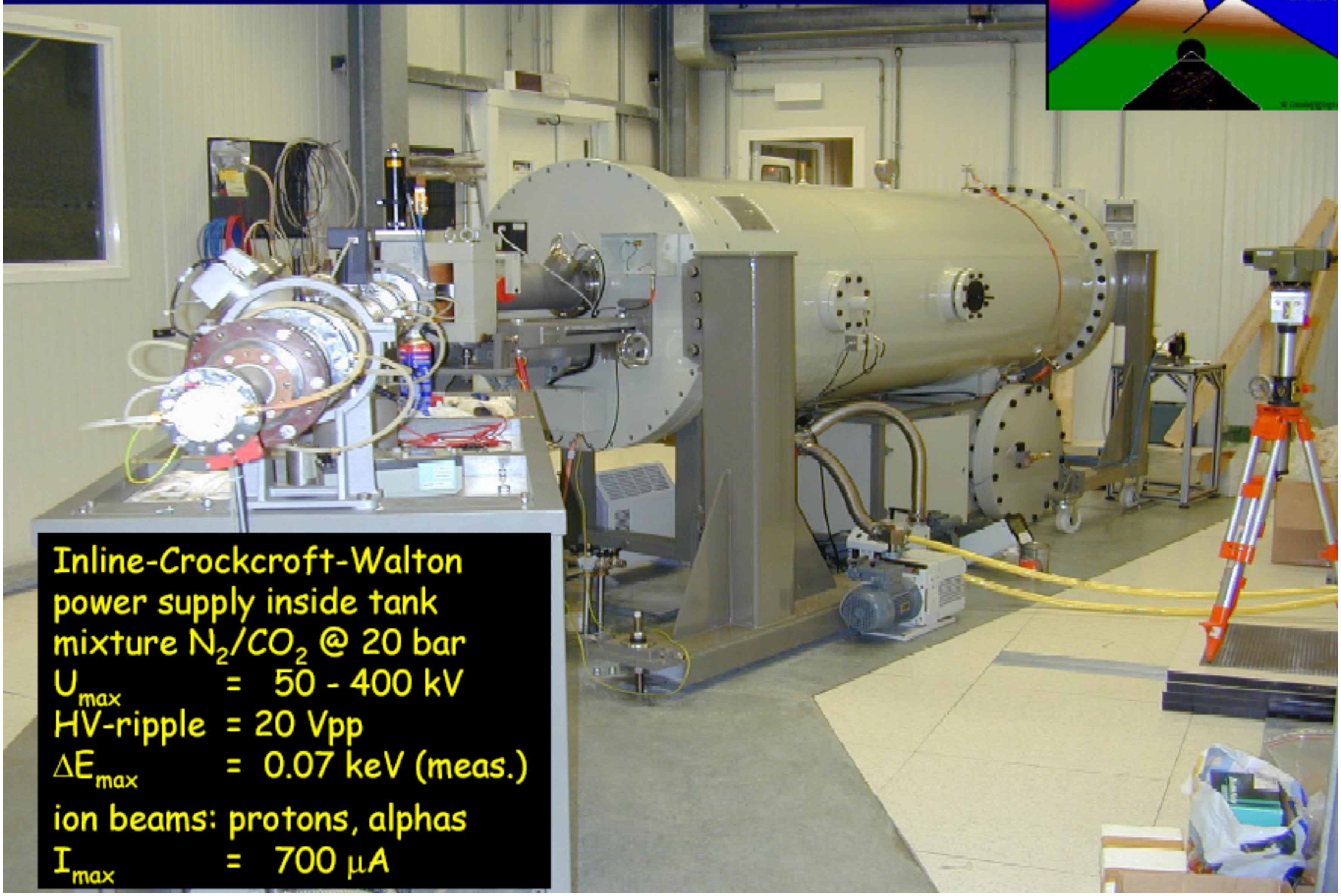
3 MeV < E_γ < 8 MeV
⇒ 0.5 counts/s



HP Ge-Detector
LNGS underground
detector with Pb shielding

3 MeV < E_γ < 8 MeV
⇒ 0.0002 counts/s

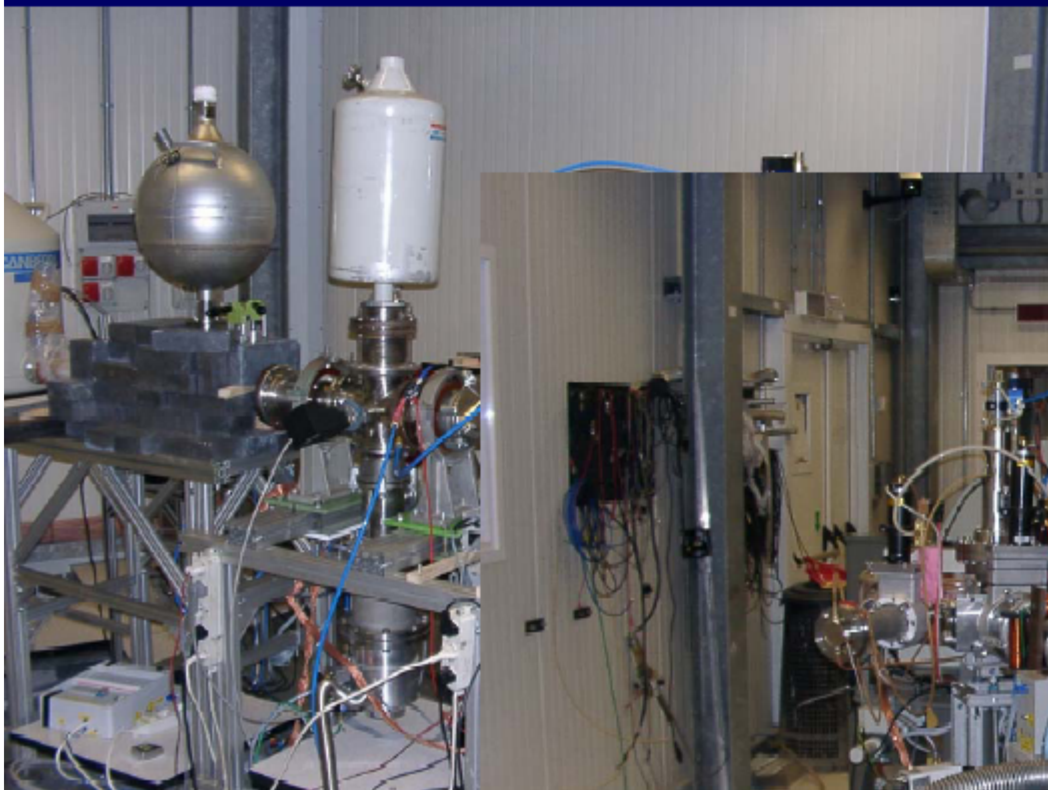
400 kV LUNA accelerator

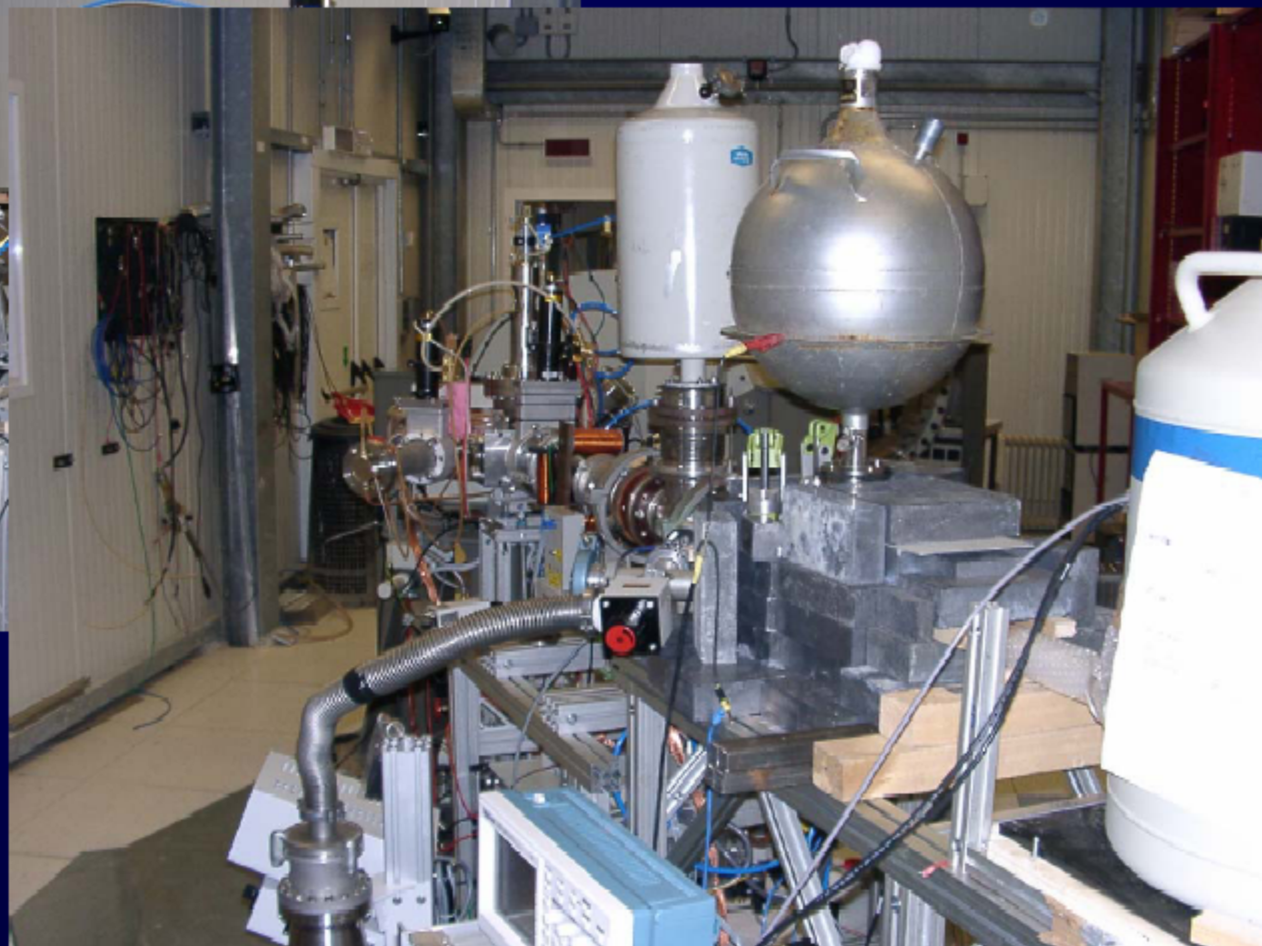


Inline-Crockcroft-Walton
power supply inside tank
mixture N_2/CO_2 @ 20 bar

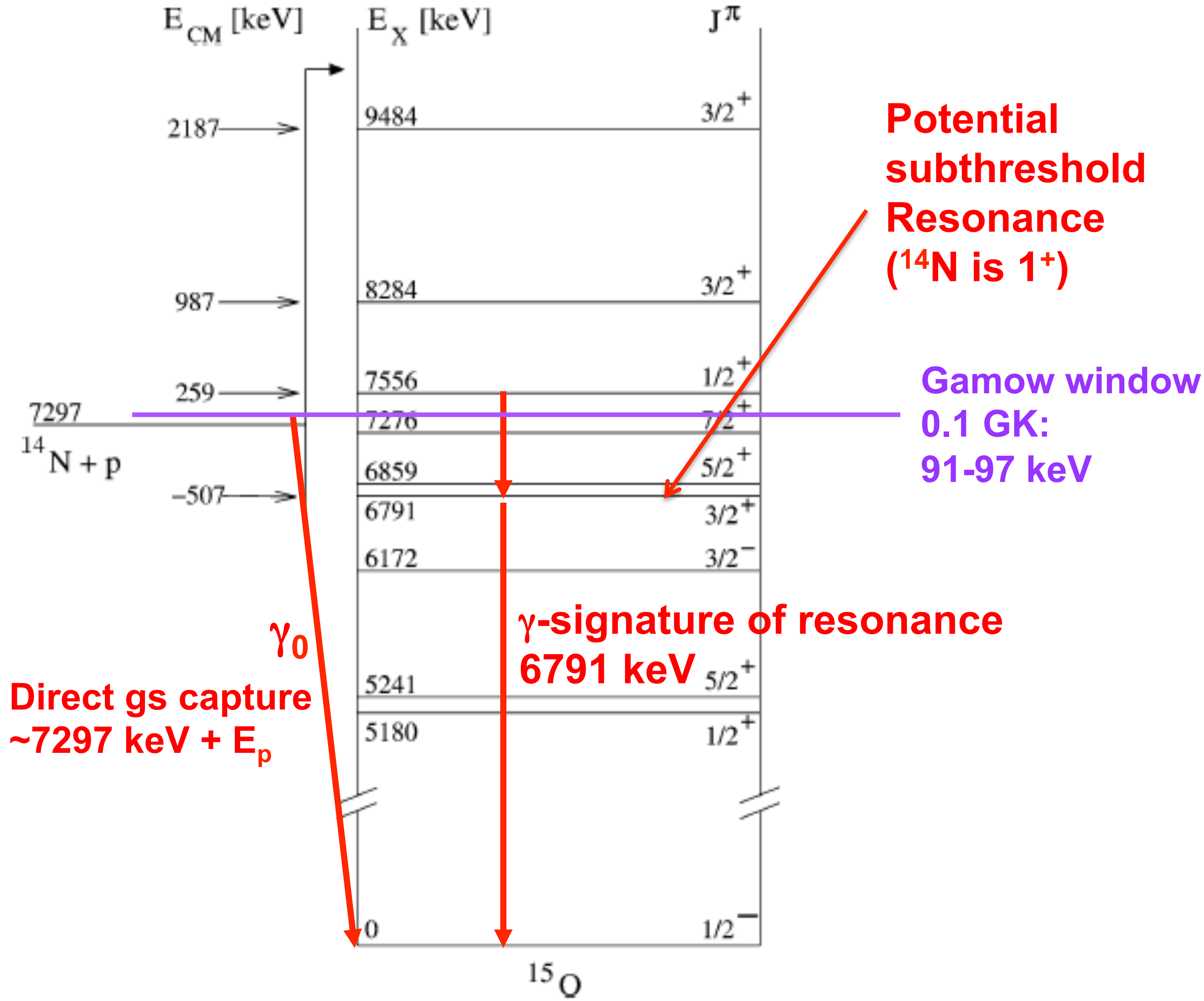
U_{max} = 50 - 400 kV
HV-ripple = 20 Vpp
ΔE_{max} = 0.07 keV (meas.)
ion beams: protons, alphas
I_{max} = 700 μA

Experiment – additional shielding

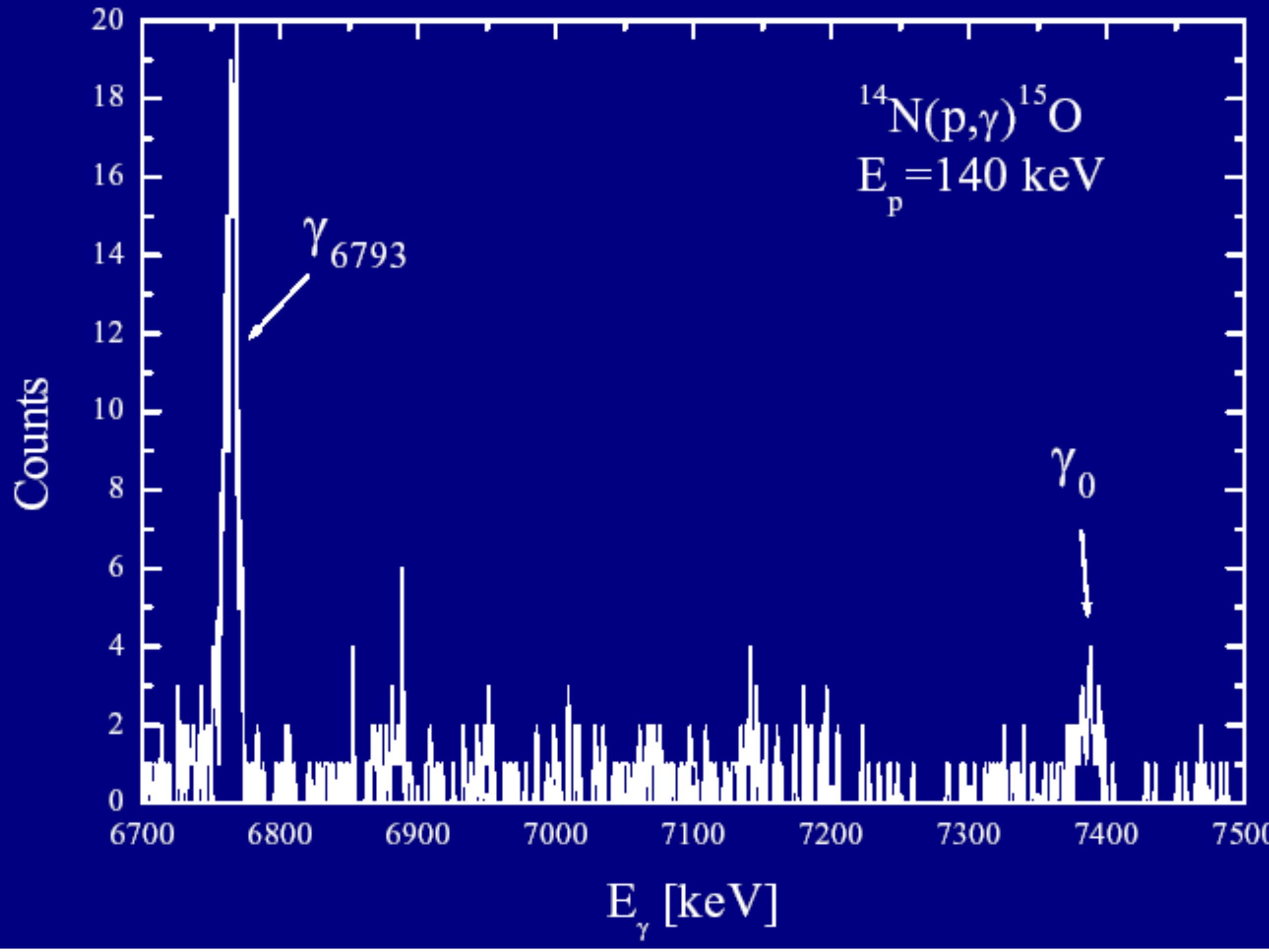




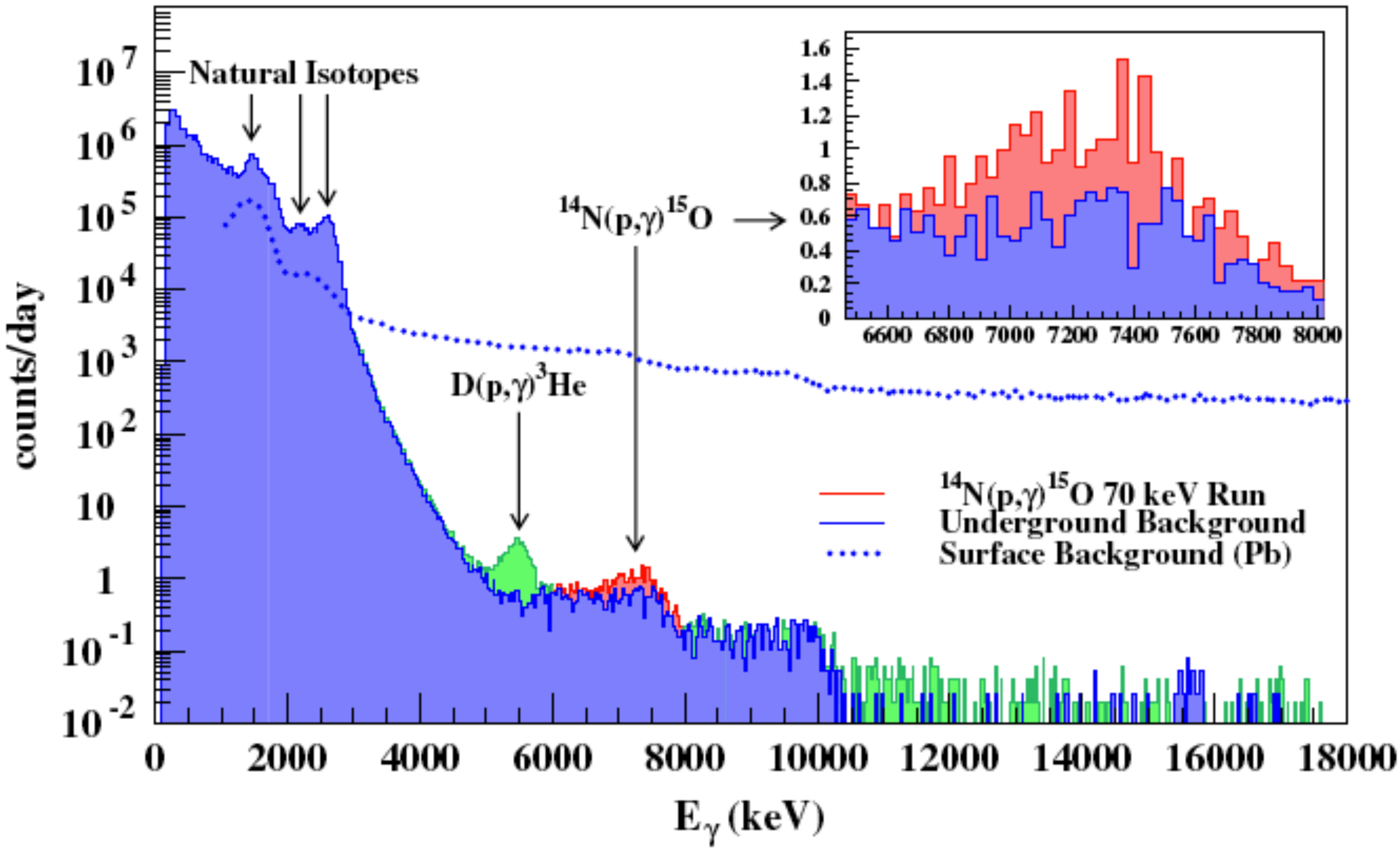
$^{14}N(p,\gamma)$ level scheme

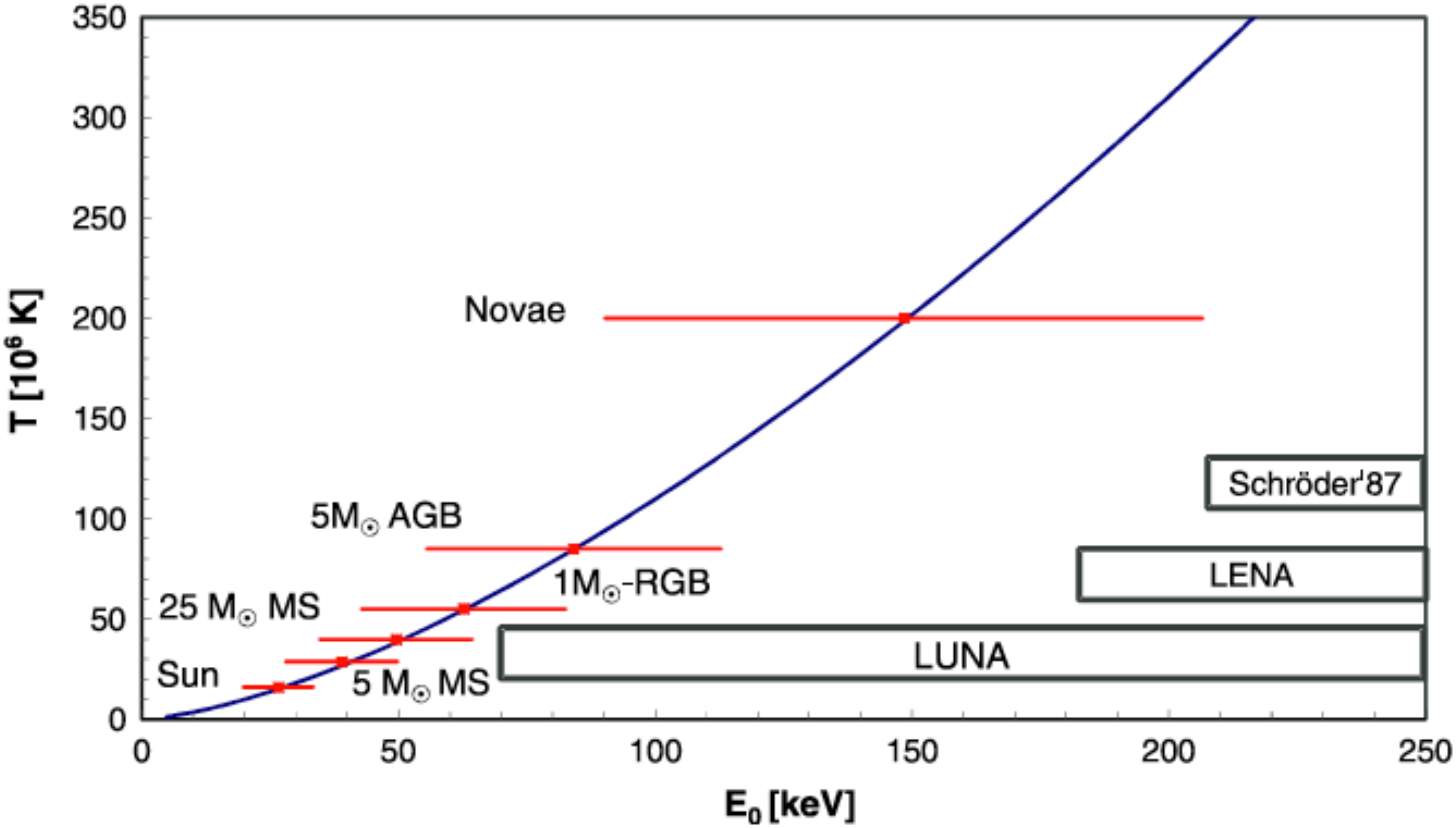


γ spectrum (HP-Ge) for $^{14}N(p,\gamma)^{15}O$

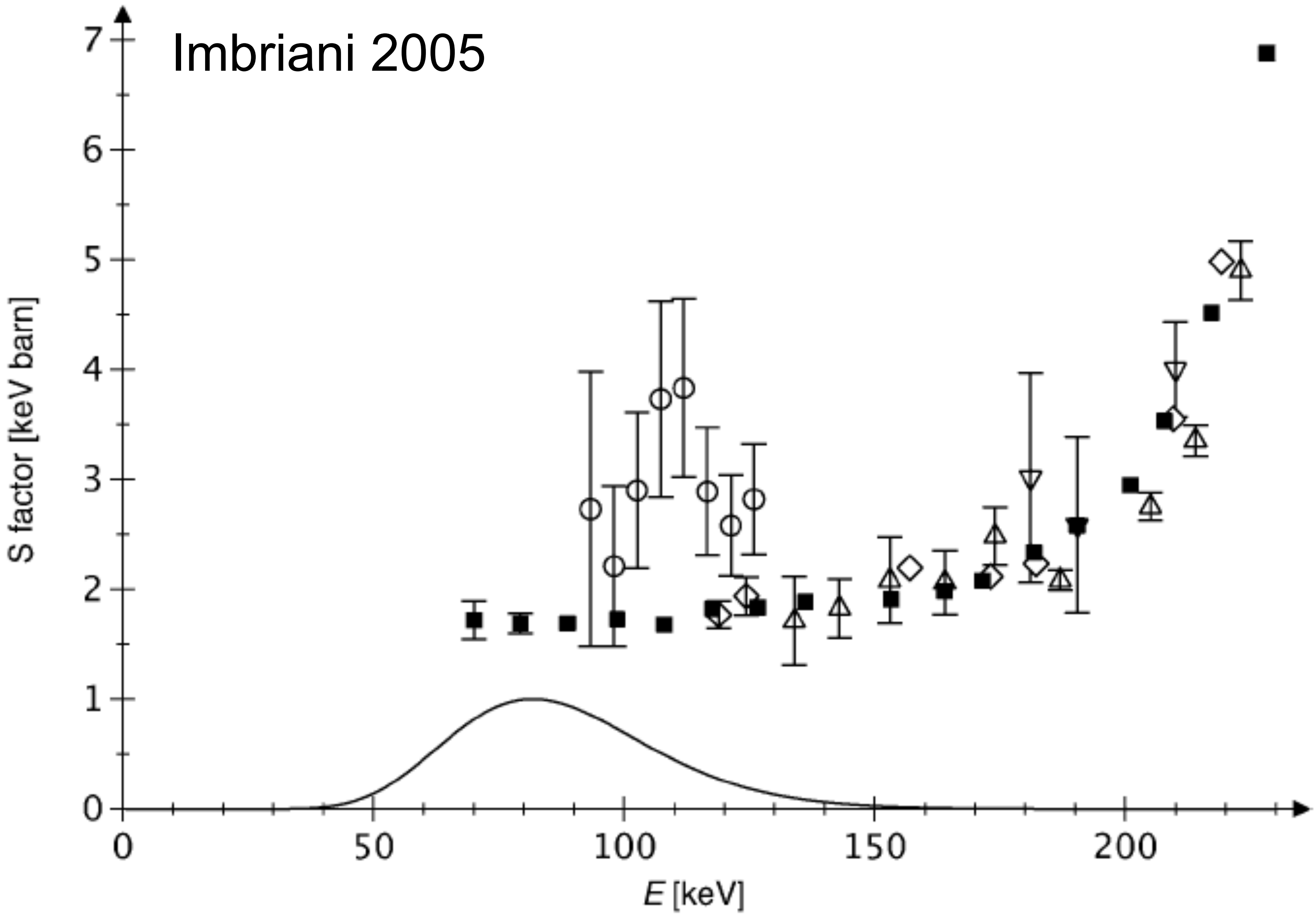


γ-ray spectrum at E_p=70 keV after 49 days





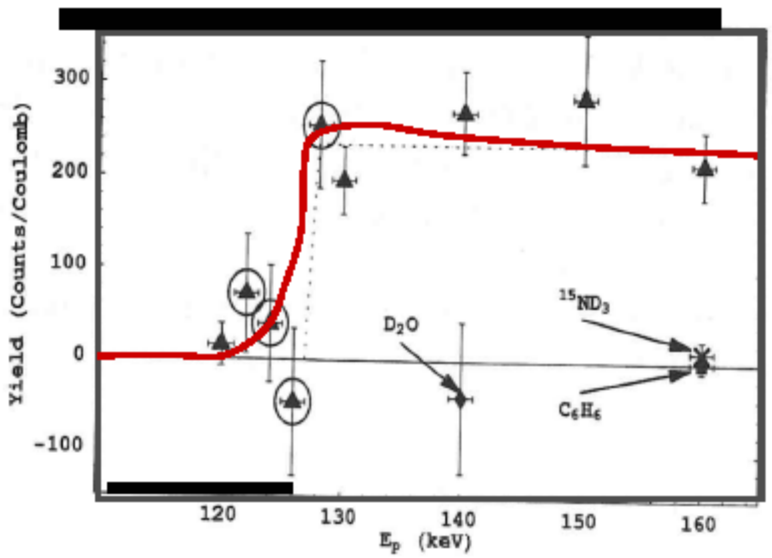
T [10^6 K]
E_0 [keV]
Novae
$5M_\odot$ AGB
$1M_\odot$-RGB
25 $M_\odot$ MS
Sun
5 $M_\odot$ MS
Schröder'87
LENA
LUNA

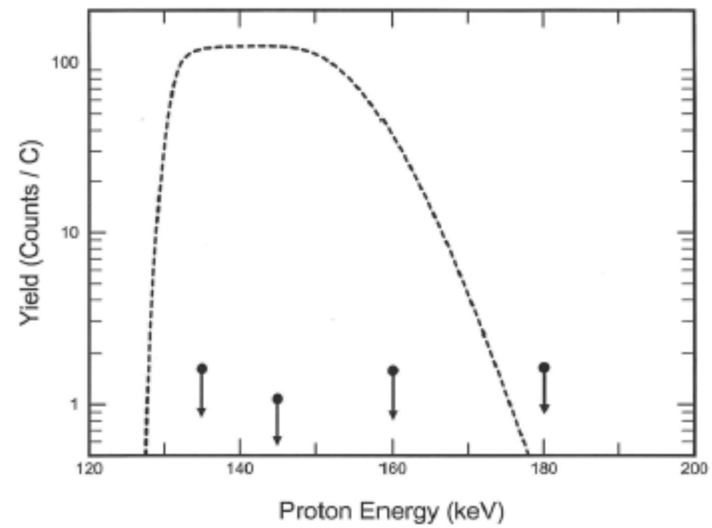


New S(0)=1.7 +- 0.2 keVb (NACRE: 3.2 +- 0.8)

New Resonance ?

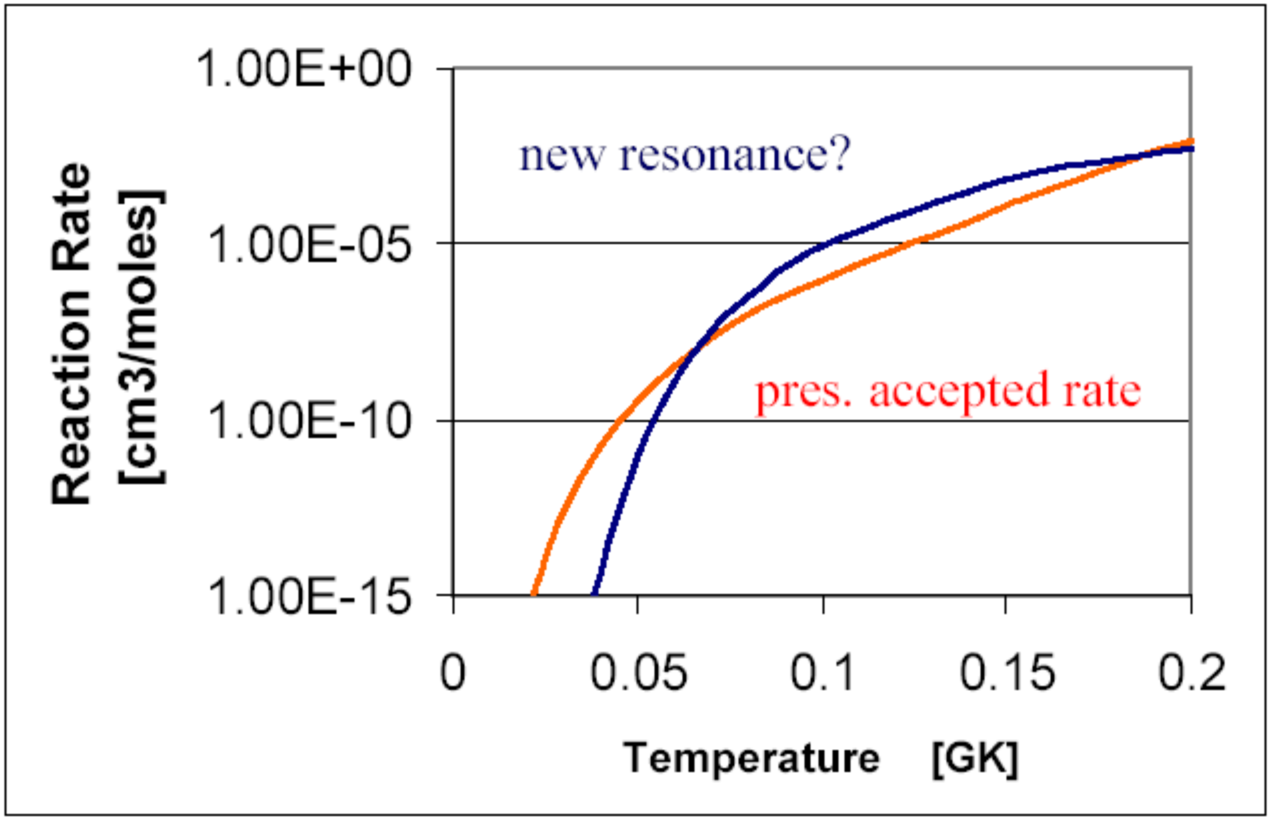
Infinite thick target measurement TUNL 2001





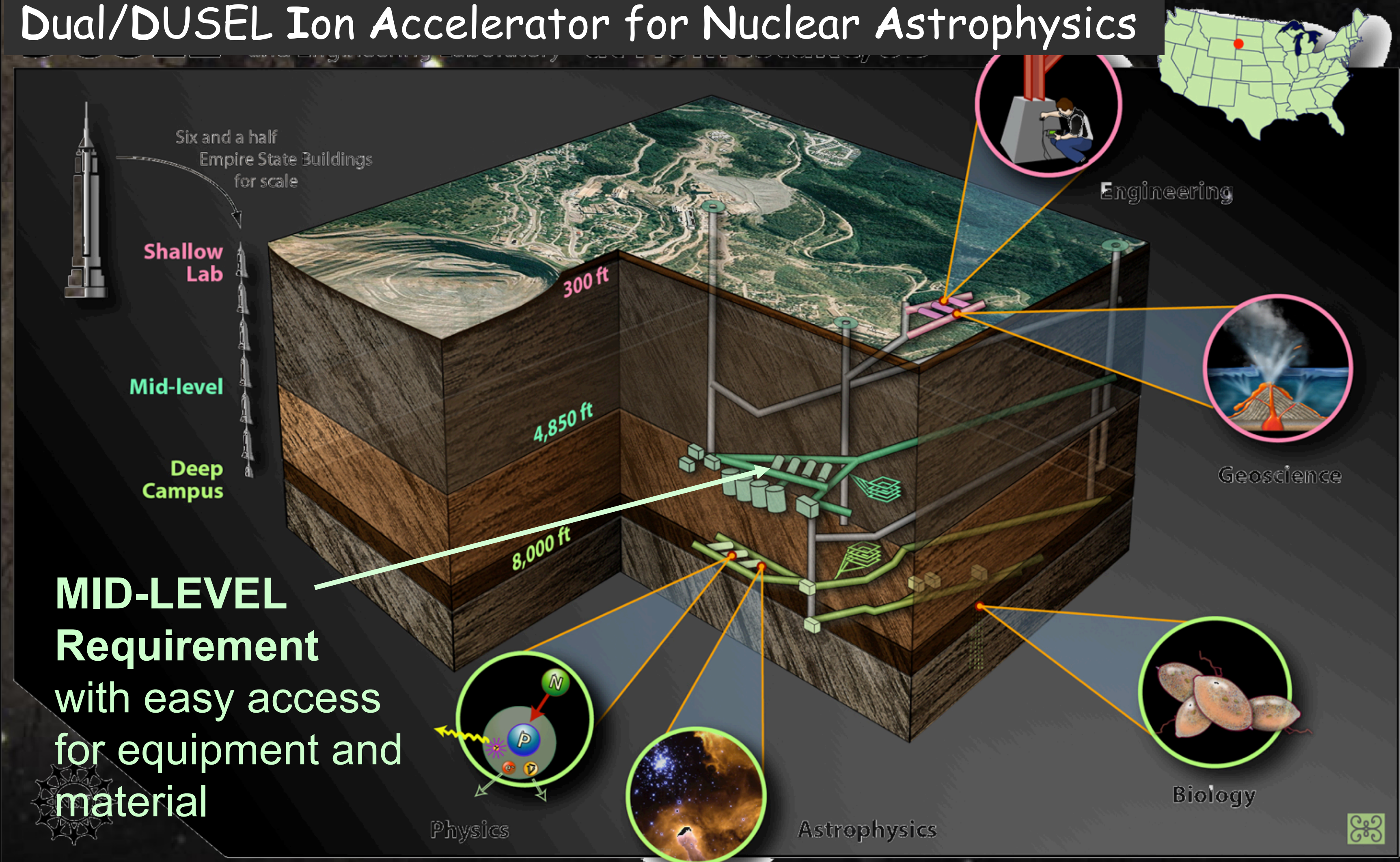
No confirming evidence in UNC data 2002

Effect that speculative resonance would have had



US proposal of DIANA

Dual/DUSEL Ion Accelerator for Nuclear Astrophysics

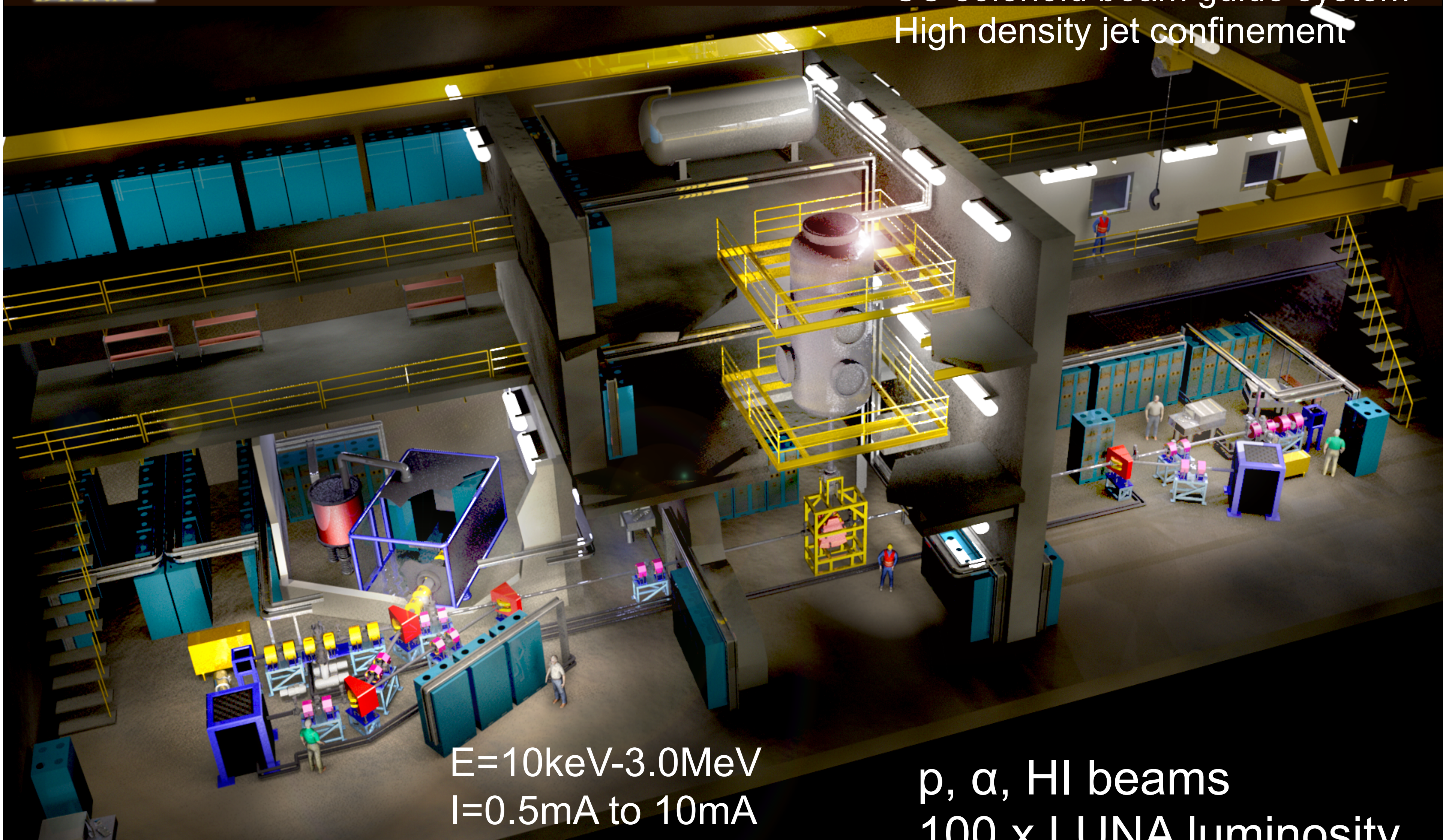


MID-LEVEL Requirement with easy access for equipment and material

DIANA design

Technical achievements:

New acceleration tube design
SC solenoid beam guide system
High density jet confinement



E=10keV-3.0MeV
I=0.5mA to 10mA
ρ=10^{19}prt/cm^2

p, α, HI beams
100 x LUNA luminosity