Technical Aspects and Specifications of the LUNA Facility

Workshop on Underground Accelerators for Nuclear Astrophysics, Tucson, Arizona, 27./28.10.2003

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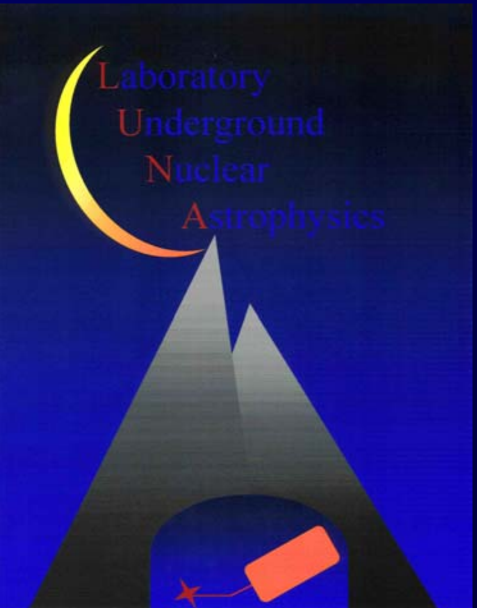
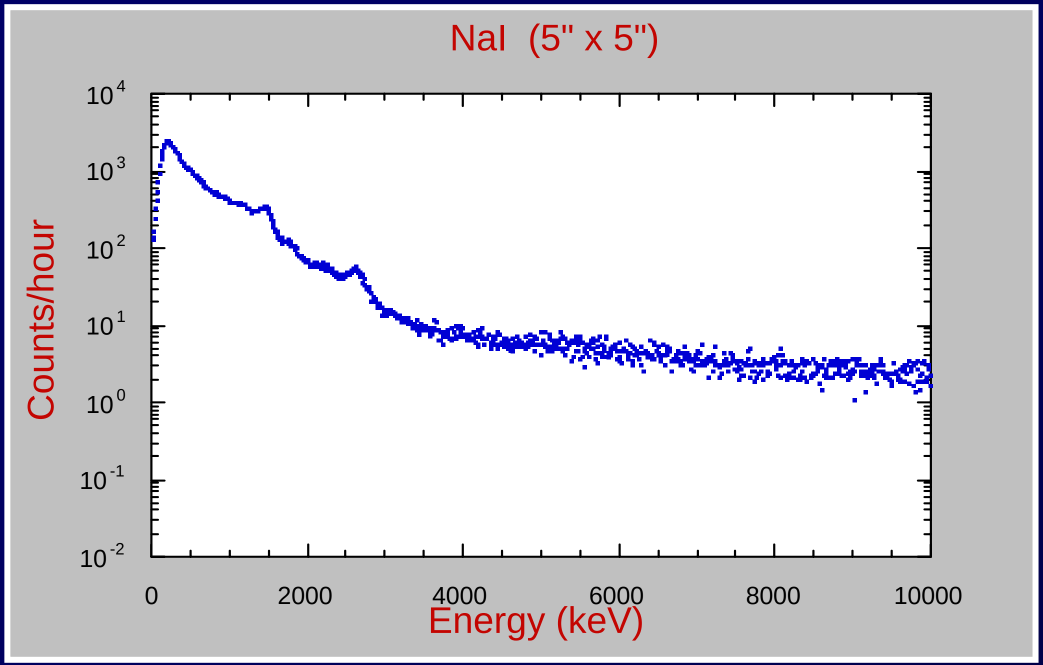
for the LUNA-Collaboration



Outline

- Background Sources
- LNGS - Laboratori Nazionali del Gran Sasso
- LUNA – Laboratory Underground for Nuclear Astrophysics
- Alternative – Recoil Mass Separator (ERNA)
- Summary and Remarks



γ ray background sources

Natural radioactivity
At earth surface

0 < E < 3.5 MeV Intrinsic and environmental radioactivity

- *radionuclides belonging to natural radioactive series (^{214}Bi, ^{226}Ra, ^{214}Pb, ^{208}Tl…)*
- *long-lived natural radionuclides (^{40}K, ^{87}Rb ..)*
- *radionuclides of cosmogenic origin (^{3}H, ^{14}C, ^{22}Na, ^{7}Be..)*
- *radionuclides of artificial origin (^{95}Nd, ^{137}Cs, ^{90}Sr, ^{144}Ce..)*

3.5 < E < 9 MeV Neutrons shoulder (max at 7 MeV) + cosmic rays

E > 9 MeV Cosmic rays (muons)

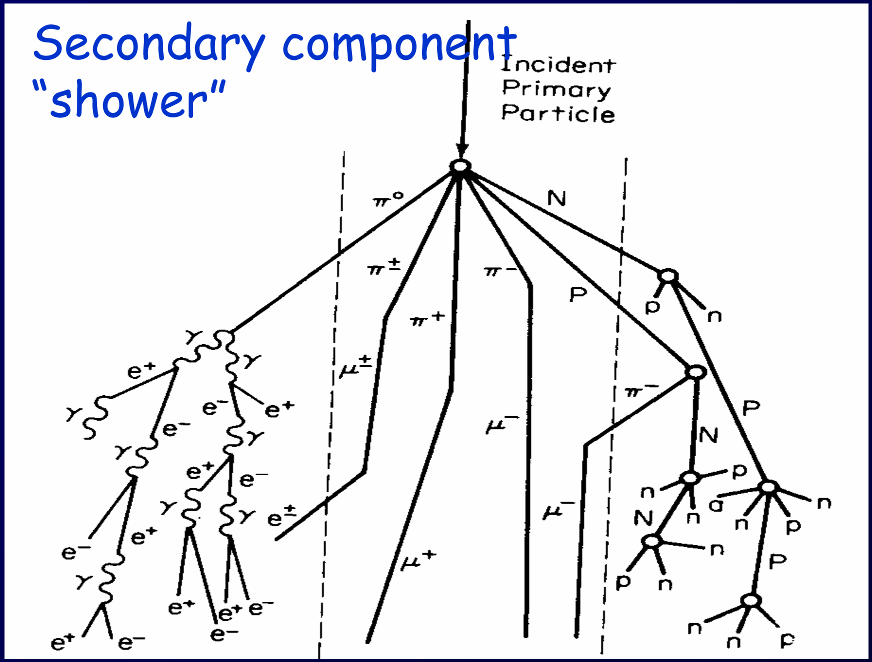
Cosmic rays

Primary component: 79% H, 20% He of very high energy

The total energy produced by cosmic rays in our galaxy is equal to 10^{52} GeV/year

$p + N \rightarrow N', p, n, \pi^{\pm}, \pi^{0}$

Secondary component
"shower"



$\pi^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}$ $T_{1/2}$=2.5 10^{-8} s

$\pi^{0} \rightarrow 2\gamma$ $T_{1/2}$=10^{-16} s

$\mu^{\pm} \rightarrow e^{\pm} + \nu_{e} + \nu_{\mu}$ $T_{1/2}$=2.2 10^{-6} s

$e^{+} + e^{-} \rightarrow 2\gamma$

$\gamma \rightarrow e^{+} + e^{-}$

$e^{\pm} + N \rightarrow e^{\pm} + N + \gamma$

At earth surface: μ, e, n

Fluxes at the sea level surface (cm^{-2} s^{-1}):

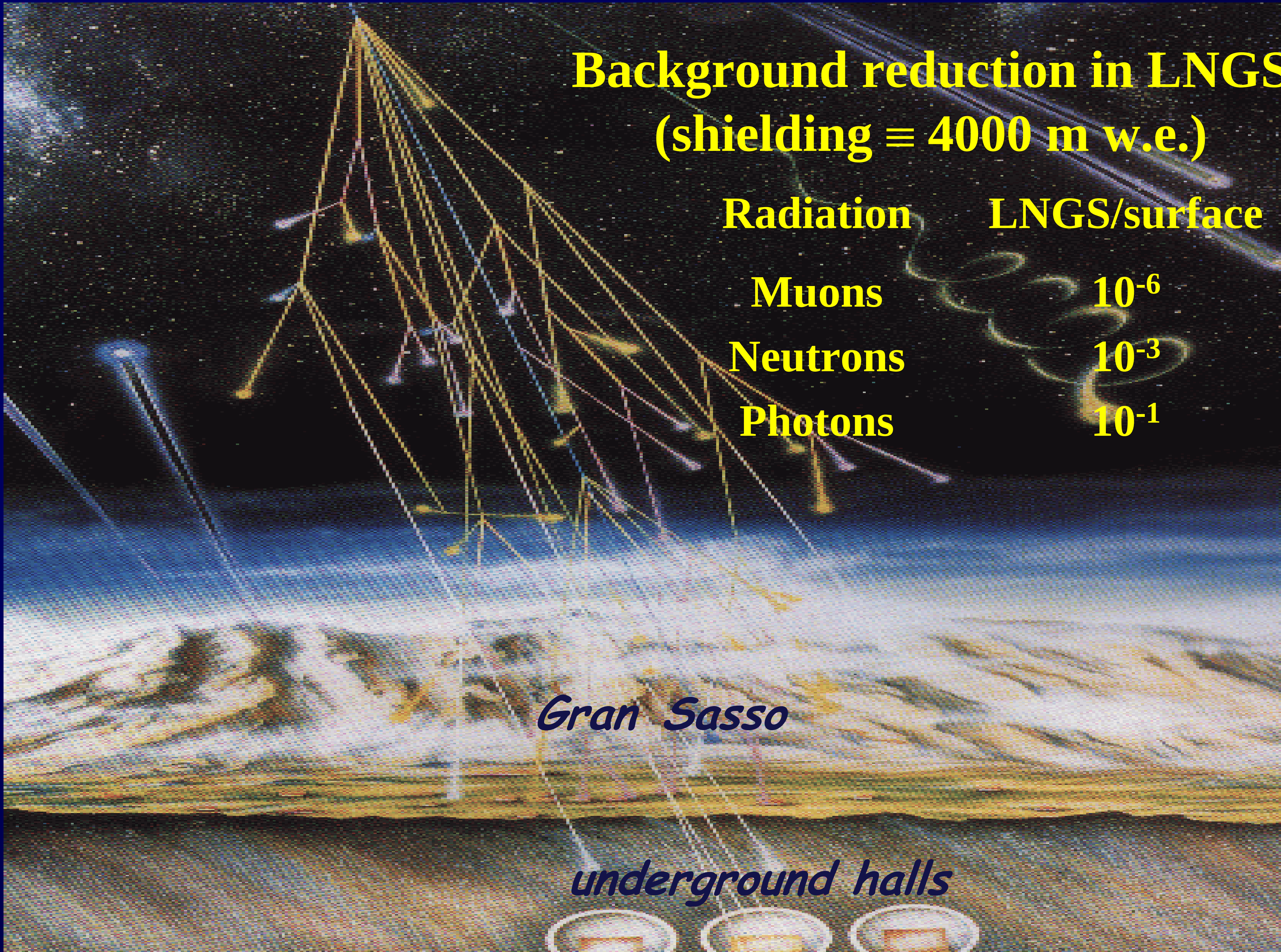
Muons	Electrons	Neutrons
1.90 10^{-2}	4.55 10^{-3}	6.46 10^{-3}

- photons: γ environmental flux $\rightarrow$ depending on local geology
- neutrons: partly (cosmic spallation) depth dependent and partly (fission) depth independent $\rightarrow$ shallow depths are sufficient
- muons: flux almost decreases exponetially with increasing depth

$\rightarrow$ relative importance of the background is strongly experiment-dependent

Background reduction in LNGS (shielding ≡ 4000 m w.e.)

Radiation	LNGS/surface
Muons	10^{-6}
Neutrons	10^{-3}
Photons	10^{-1}

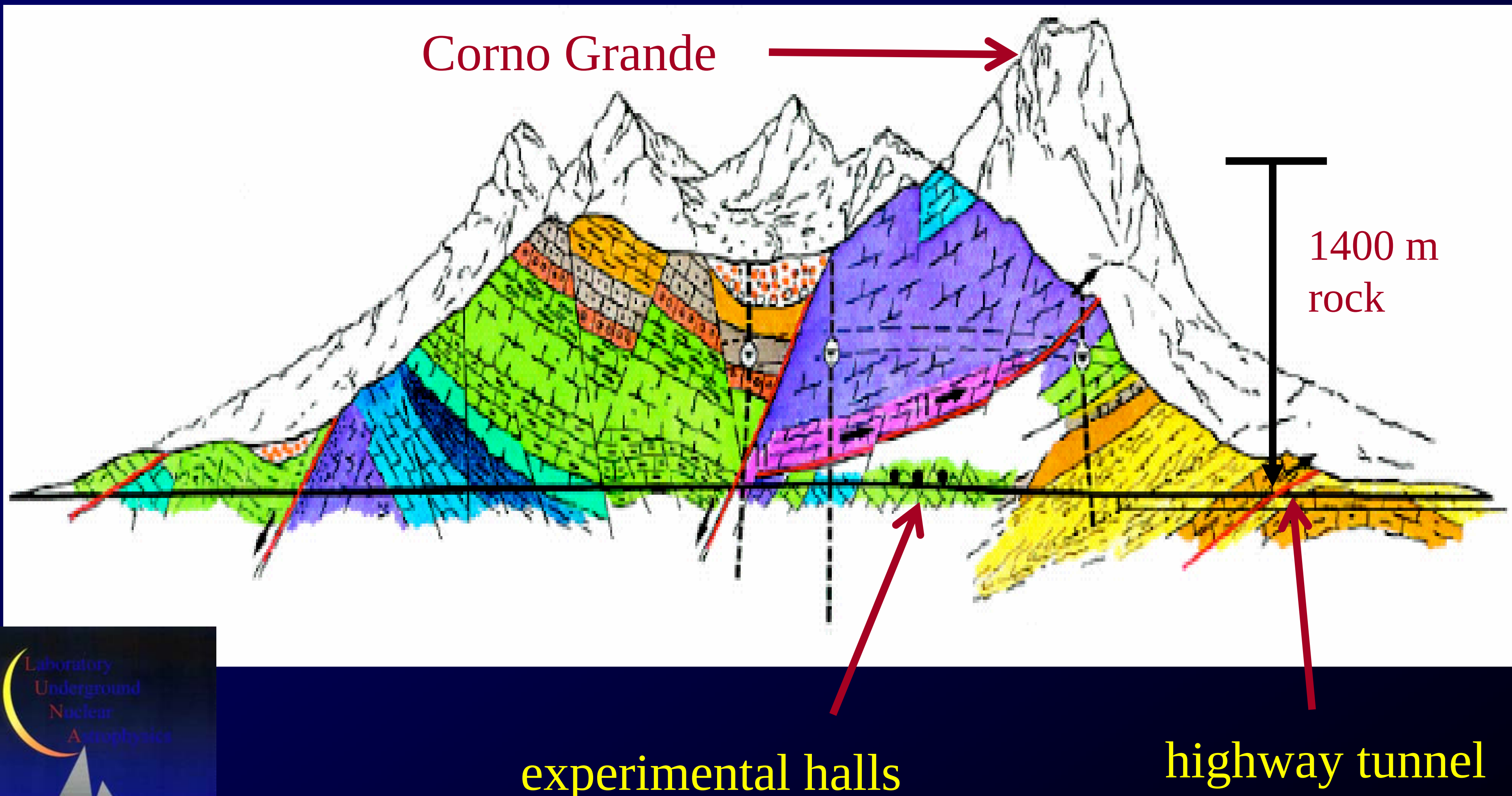


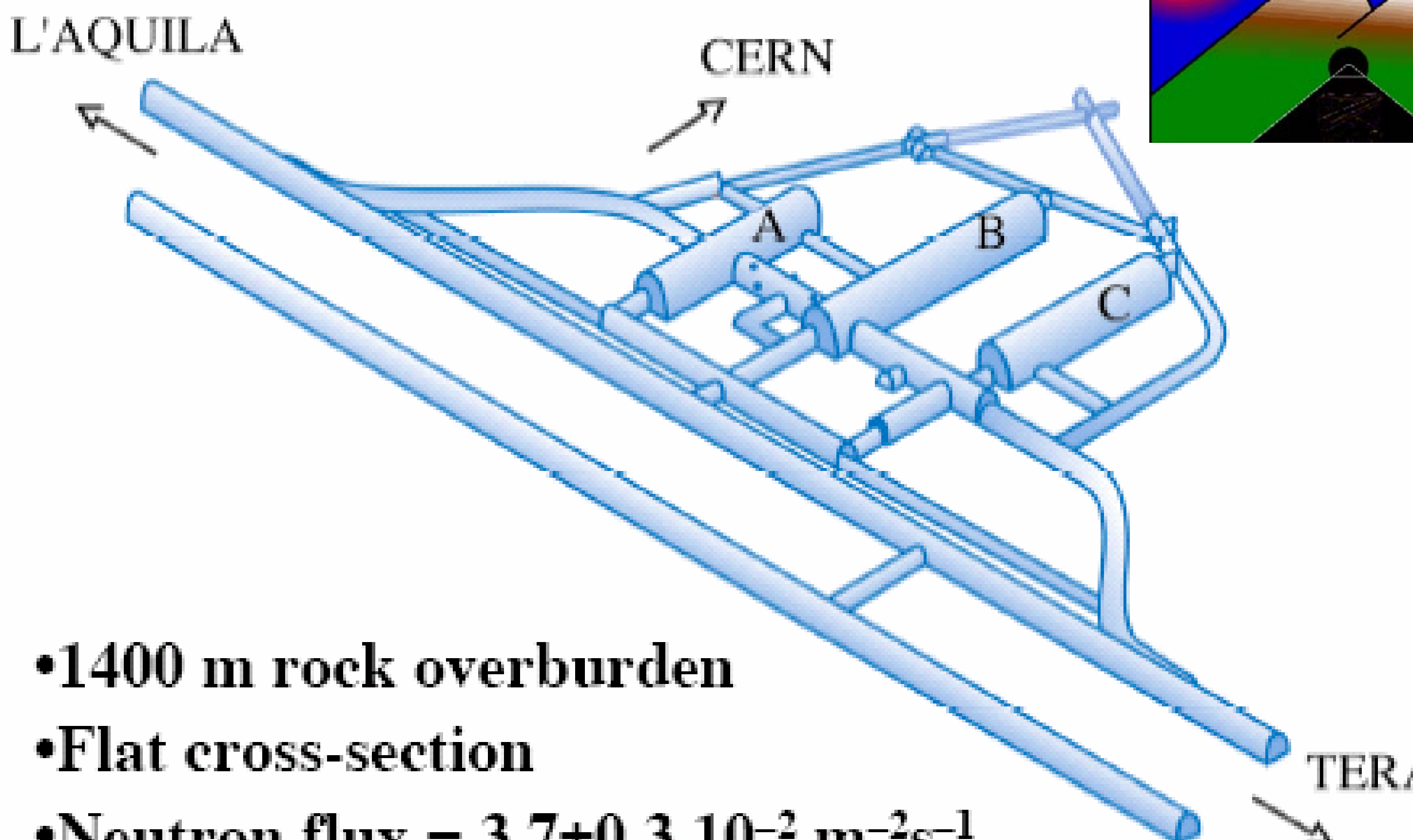
LNGS – Laboratori Nazionali del Gran Sasso

- fully equipped lab with surface support structure
- easy horizontal access through highway tunnel (10 km)
- permanent staff = 66 / scientific users ~ 750
- located in Central Italy
  (100 km east of Rome)

LNGS
surface structure

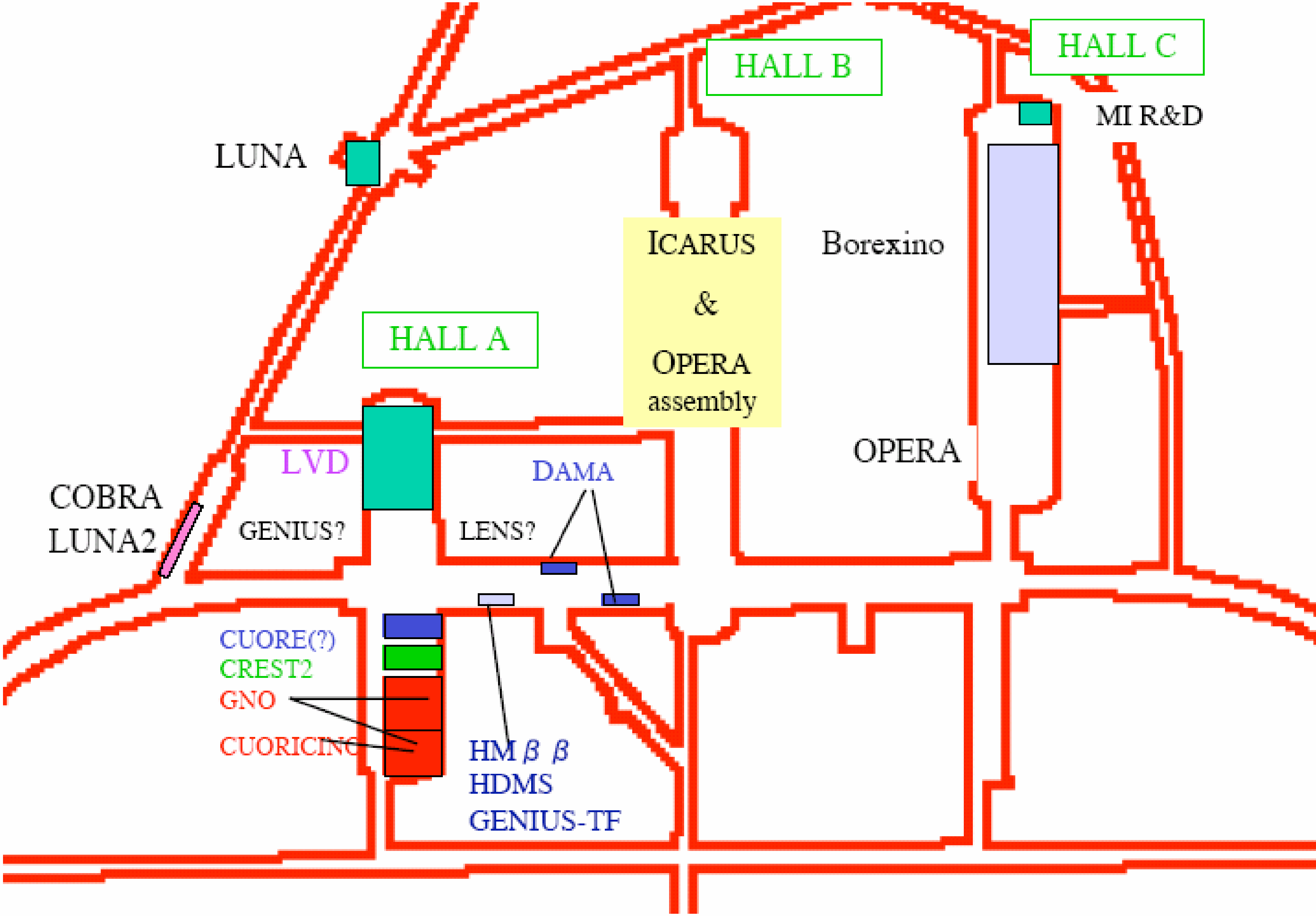
LNGS - underground structure





- 1400 m rock overburden
- Flat cross-section
- Neutron flux = $3.7 \pm 0.3 \; 10^{-2} \; m^{-2}s^{-1}$
- neutron density is of the order of one per hall. E. Bellotti
- Cosmic μ flux attenuation = 10^{-6} ($0.6 /m^2 \; h$)
- Underground area 18 000 m^2
- Support facilities on the surface
- Drive in to the experiments

Occupancy


HALL A
HALL B
HALL C
LUNA
MI R&D
ICARUS
&
OPERA
assembly
Borexino
OPERA
LVD
DAMA
COBRA
LUNA2
GENIUS?
LENS?
CUORE(?)
CREST2
GNO
CUORICINO
HM β β
HDMS
GENIUS-TF

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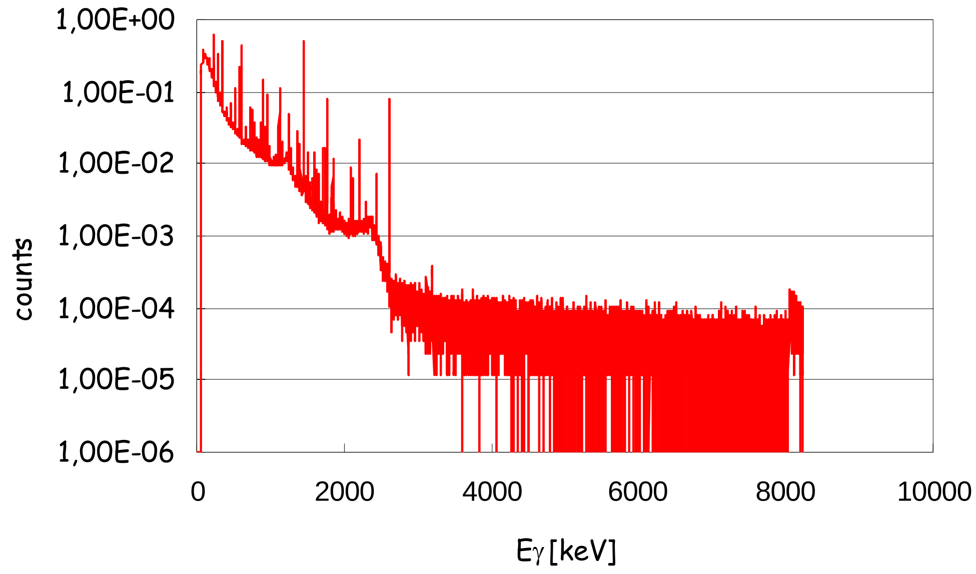
Massive shielding. Reduces

- *Cosmic muons by factor 10^6*
- *Cosmic ray induced neutrons by factor 10^3*

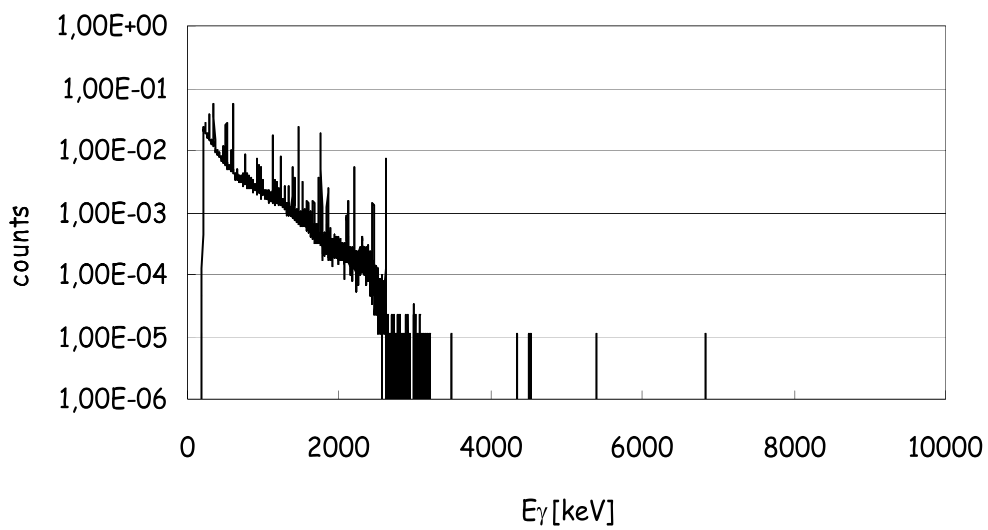
Environmental activity unaffected by rock.
Additional shielding near experiment needed

Laboratory
Underground
Nuclear
Astrophysics



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

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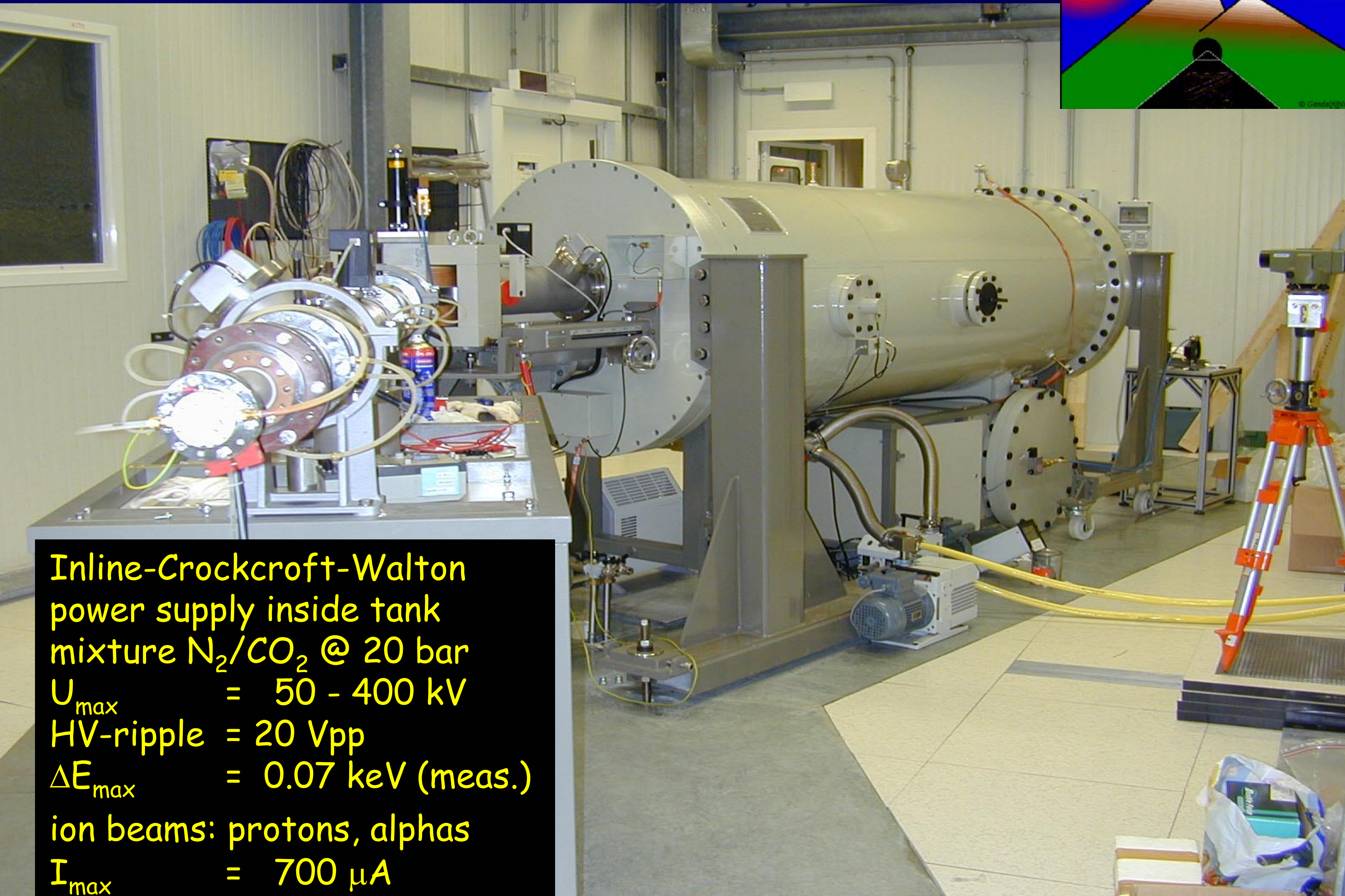
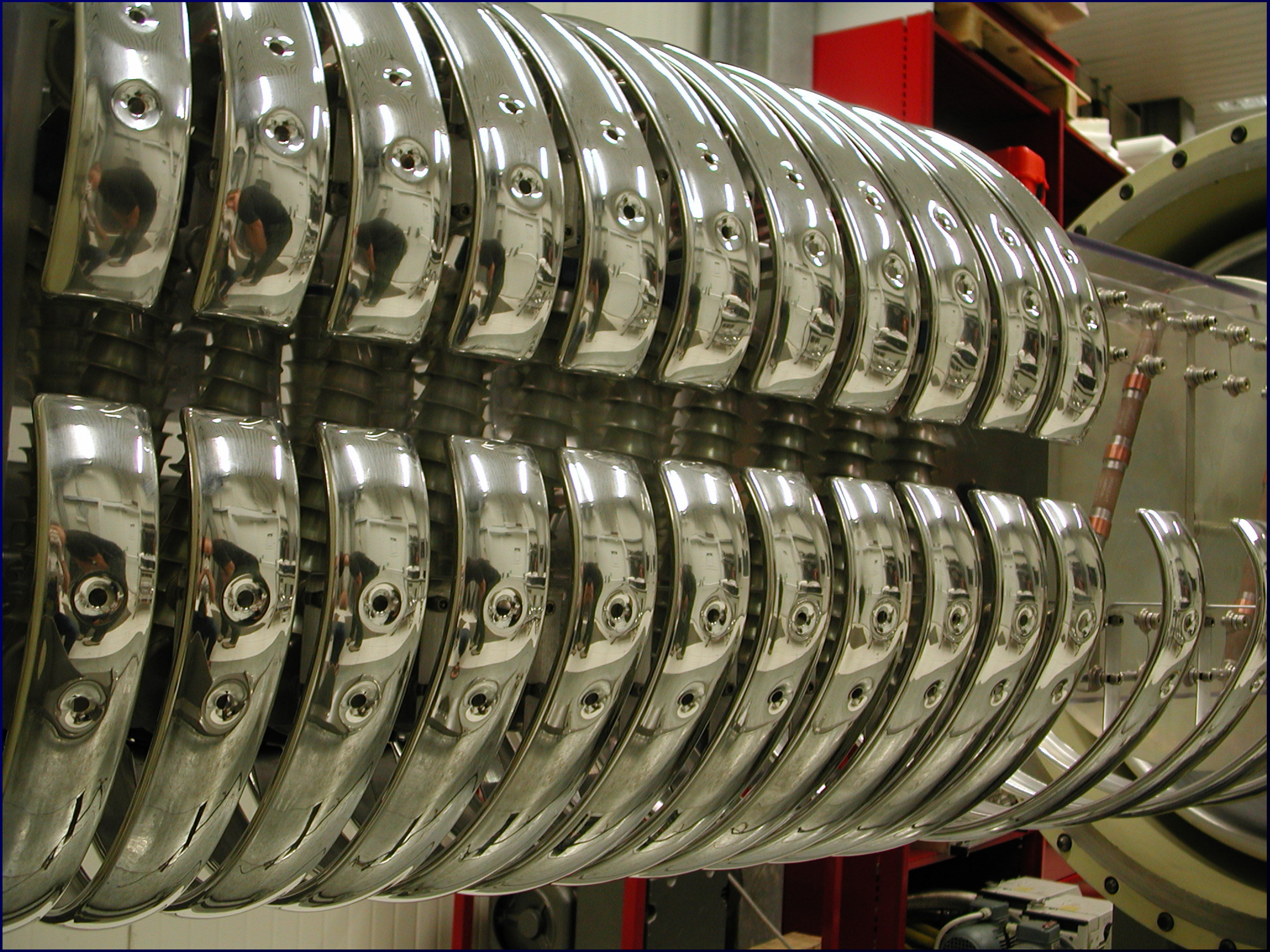
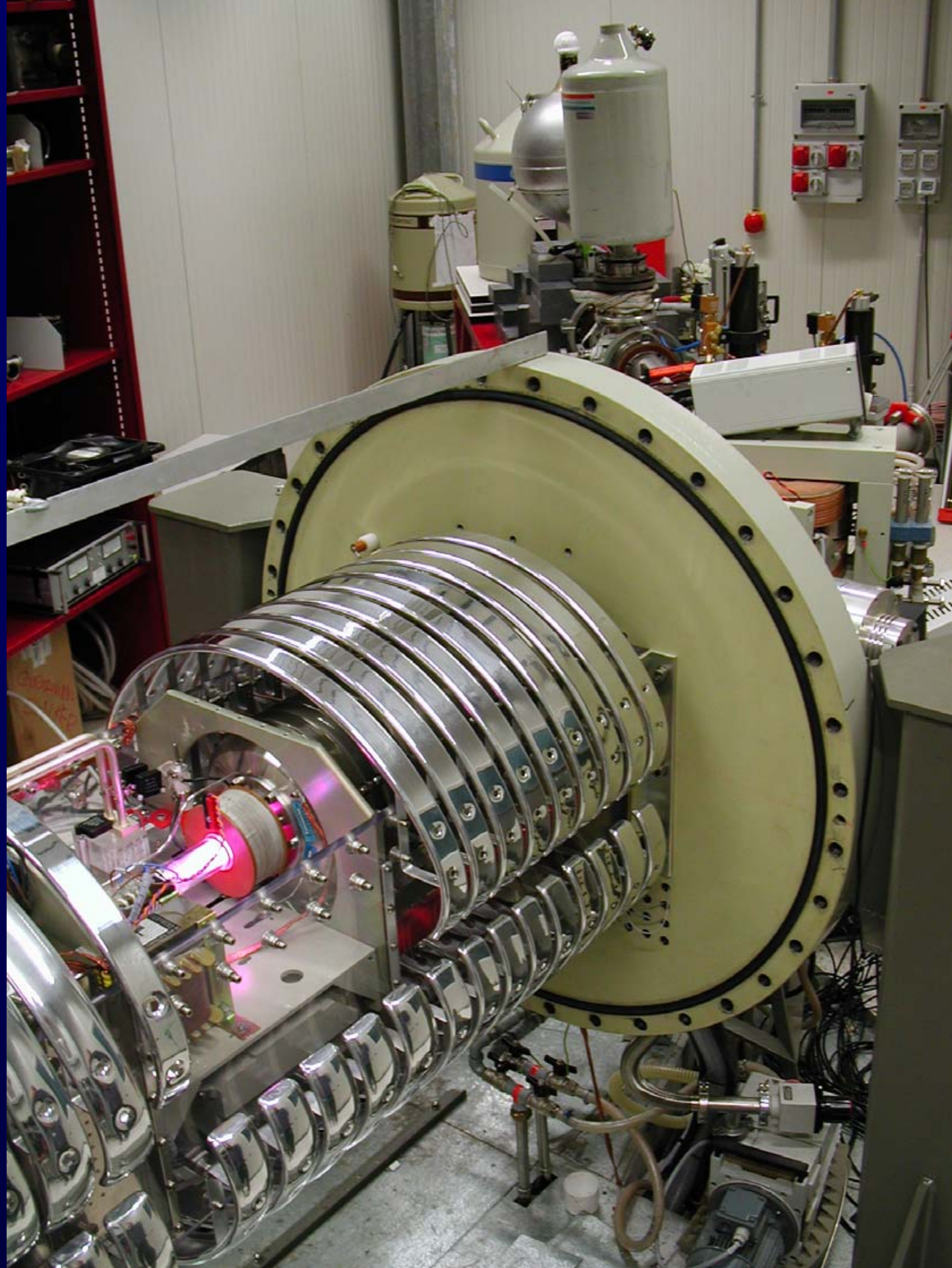
400 kV LUNA accelerator



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





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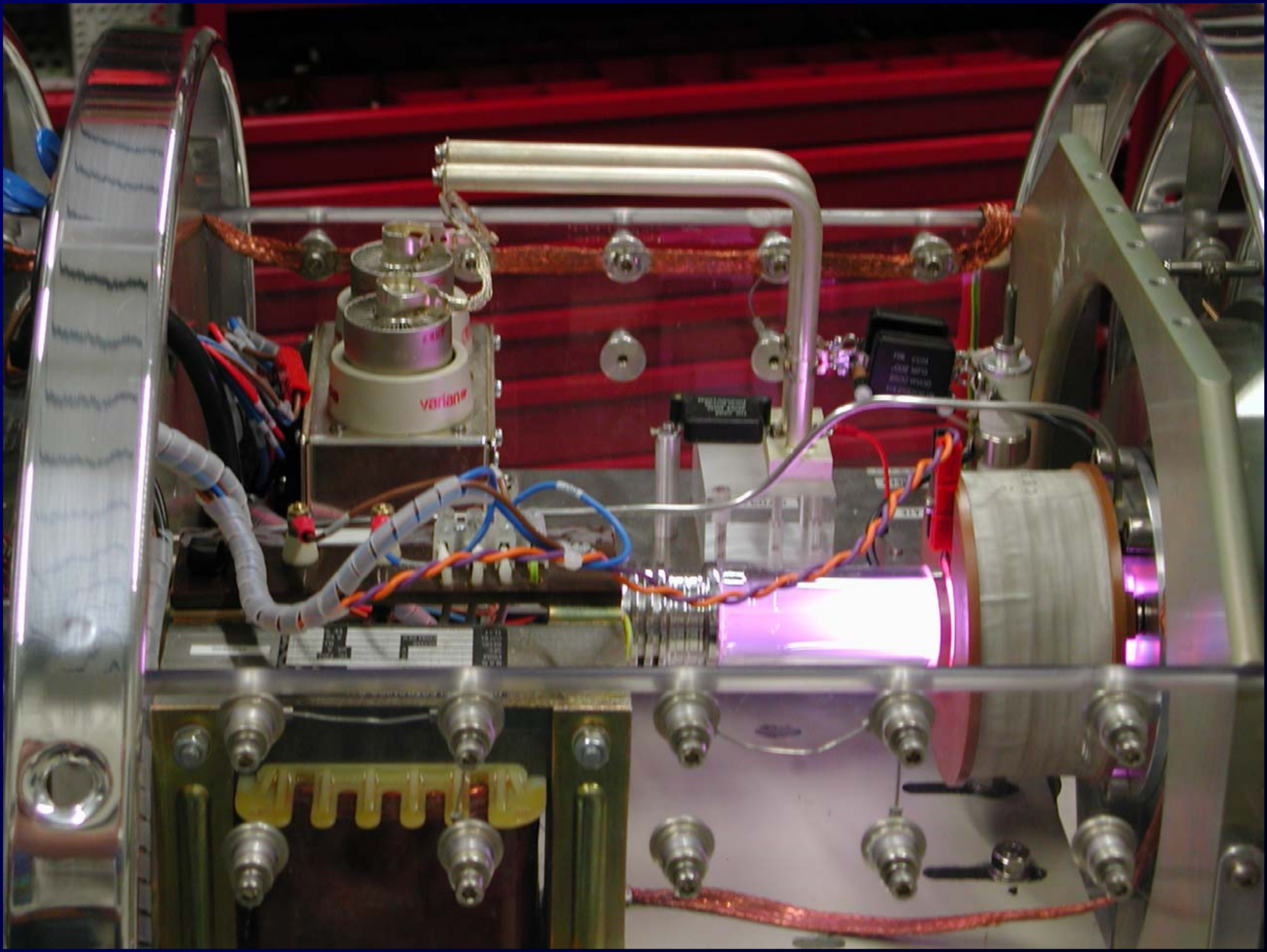
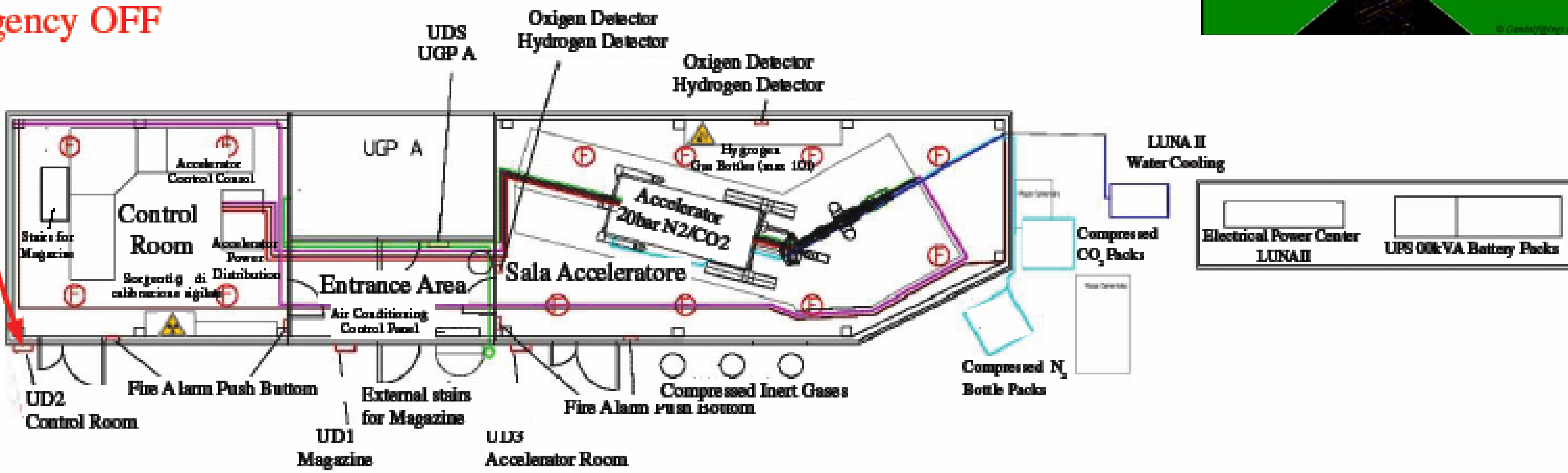

varian

Emergency OFF



Compressed Air System (7bar)

LUNA water cooling cycle (closed loop)

230/380 power cables

high current cables (max 100A) with thermal sensitive cable

control signal cables (max. 24V)

Compressed Gas System (30 bar)

Smoke Sensor

Experiment – additional shielding

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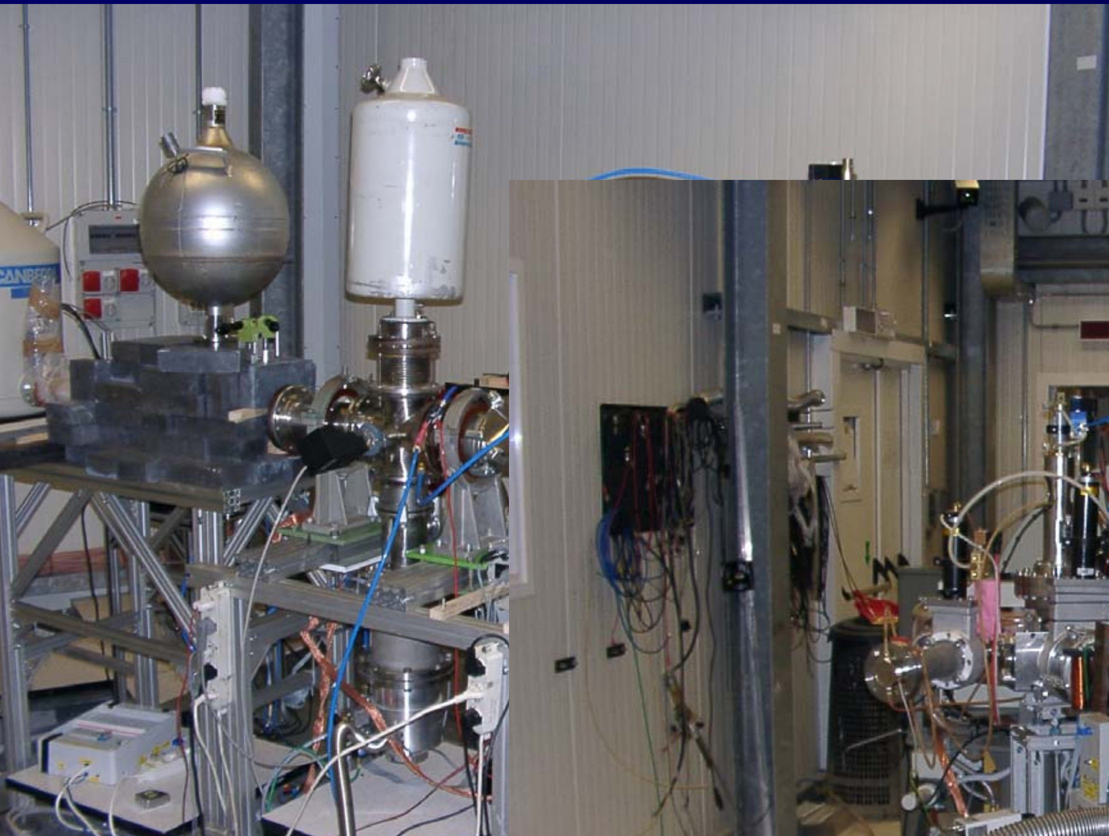

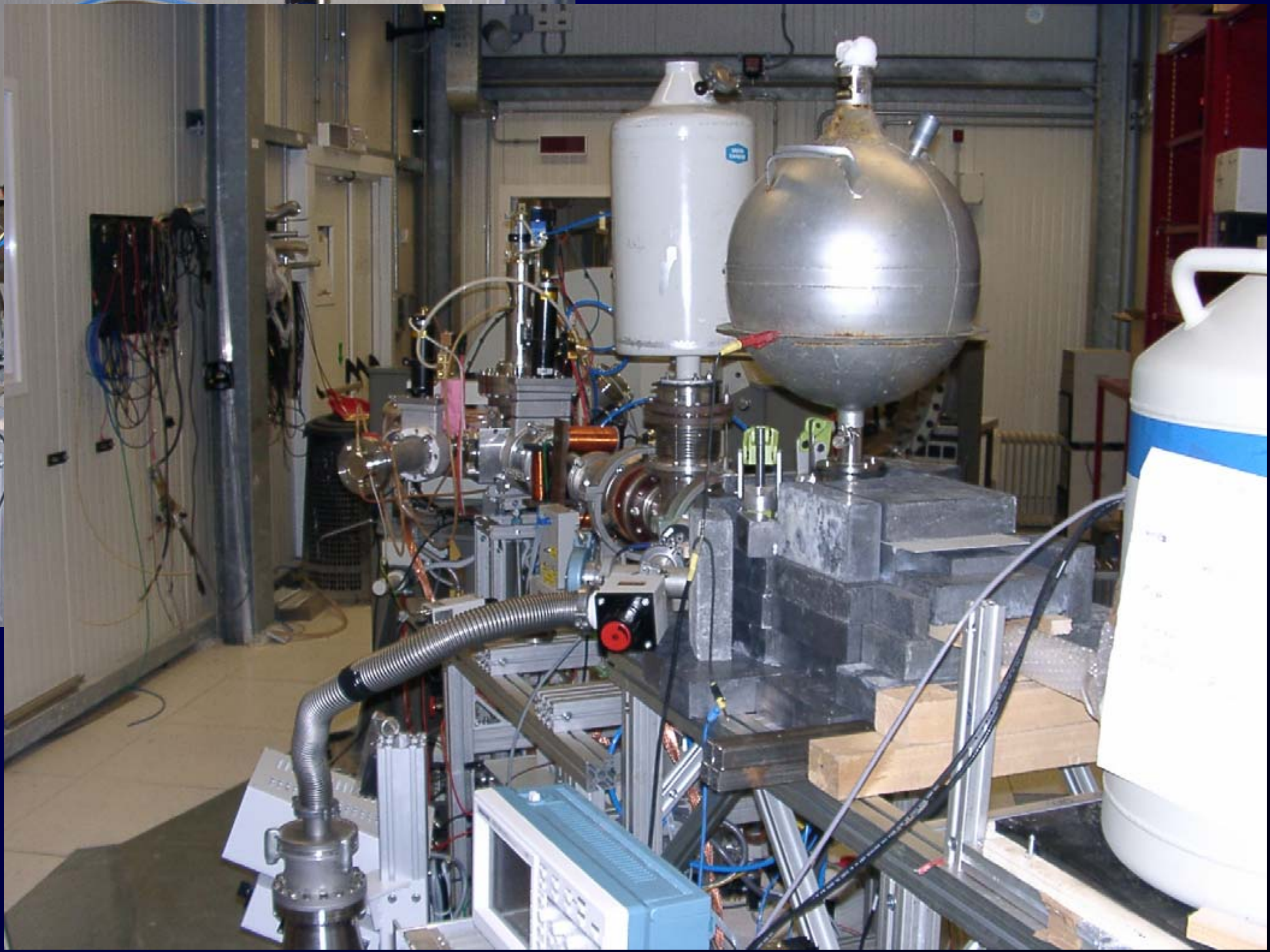

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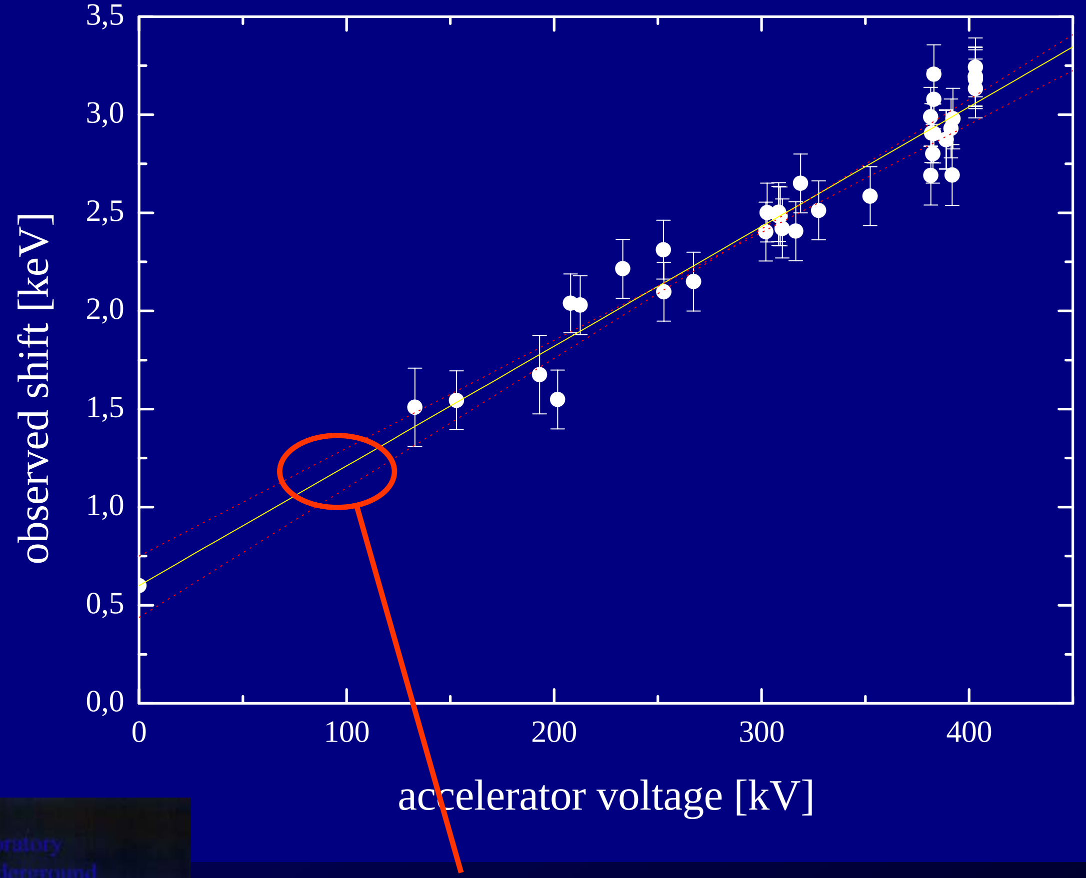
energy calibration of the accelerator

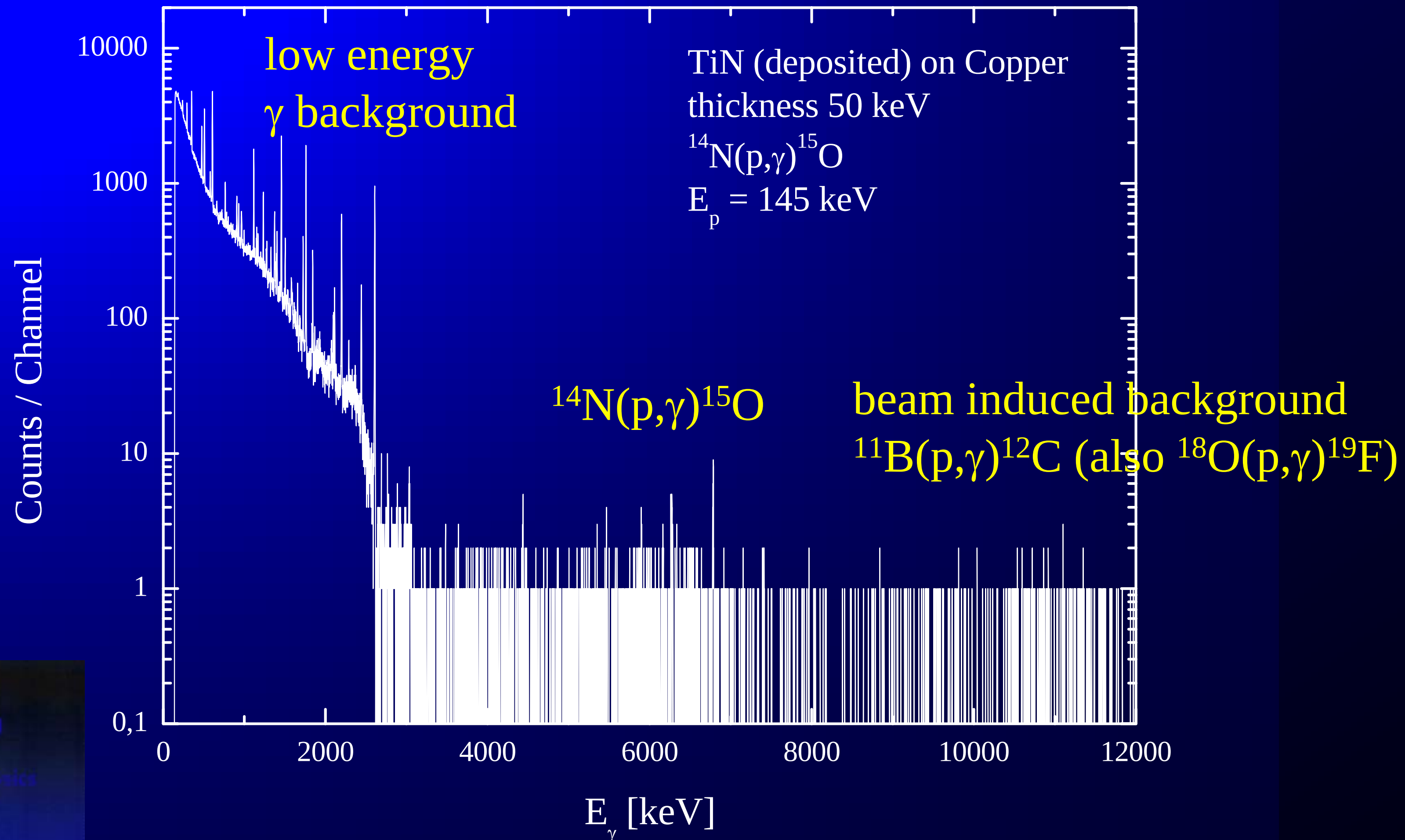


energy calibration:
E_p = 130 - 400 keV
dc reaction $^{12}C(p,\gamma)^{13}N$
and several resonances

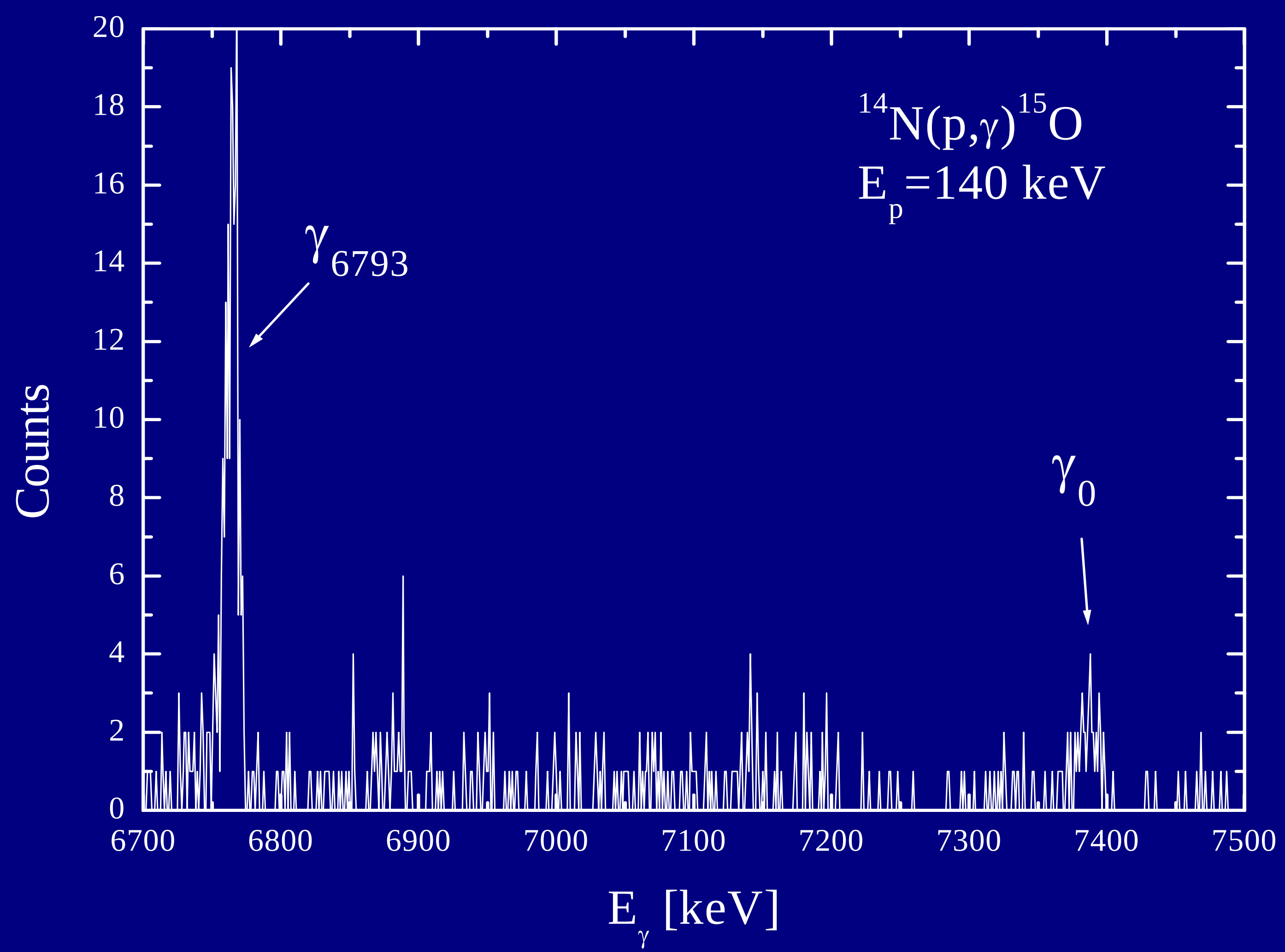
at E_p = 100 keV $\Rightarrow$ energy uncertainty $\Delta E_p \approx$ 100 eV

$\Rightarrow$ **5 % error** in cross section for $^{14}N(p,\gamma)^{15}O$

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



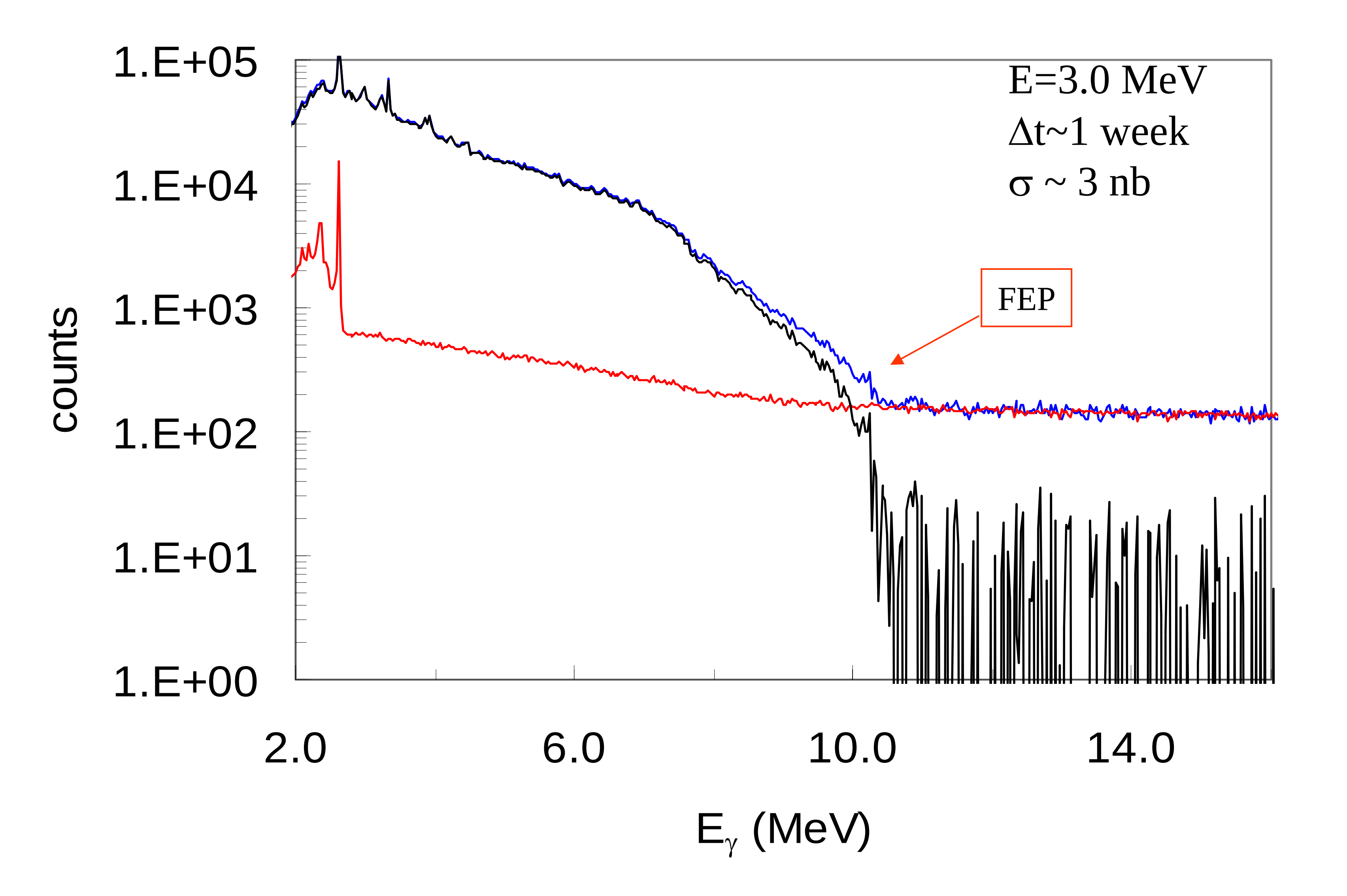
γ spectrum (HP-Ge) for $^{14}N(p,\gamma)^{15}O$



Alternative – Recoil Mass Separator

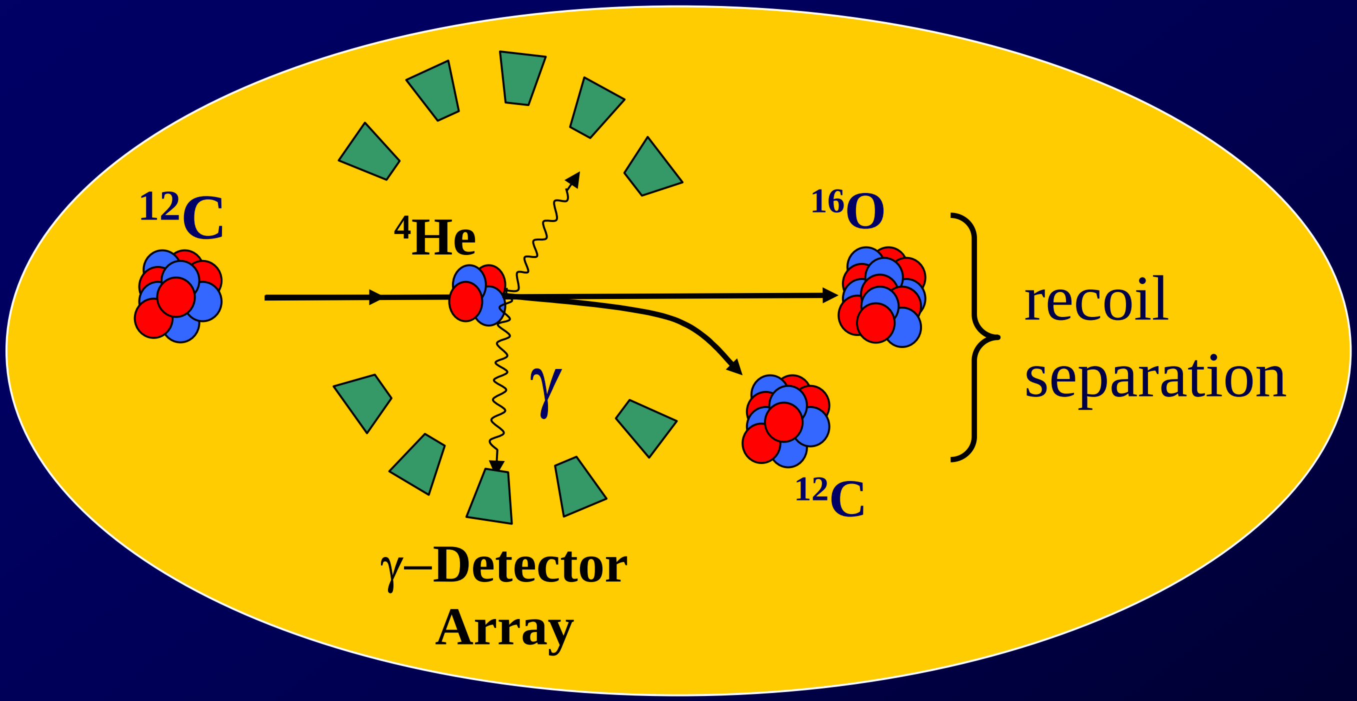
- higher energies
- specific reaction types
  - radiation capture reaction (p,γ), (α,γ)
  - heavy ion reaction $^{12}C + ^{12}C$
- radioactive ion beams

ERNA – European Recoil Separator for Nuclear Astrophysics → $^{12}C(\alpha,\gamma)^{16}O$



ERNA:

a novel approach to measure the reaction $^{12}C(\alpha,\gamma)^{16}O$



energy range

1.2 MeV

↓

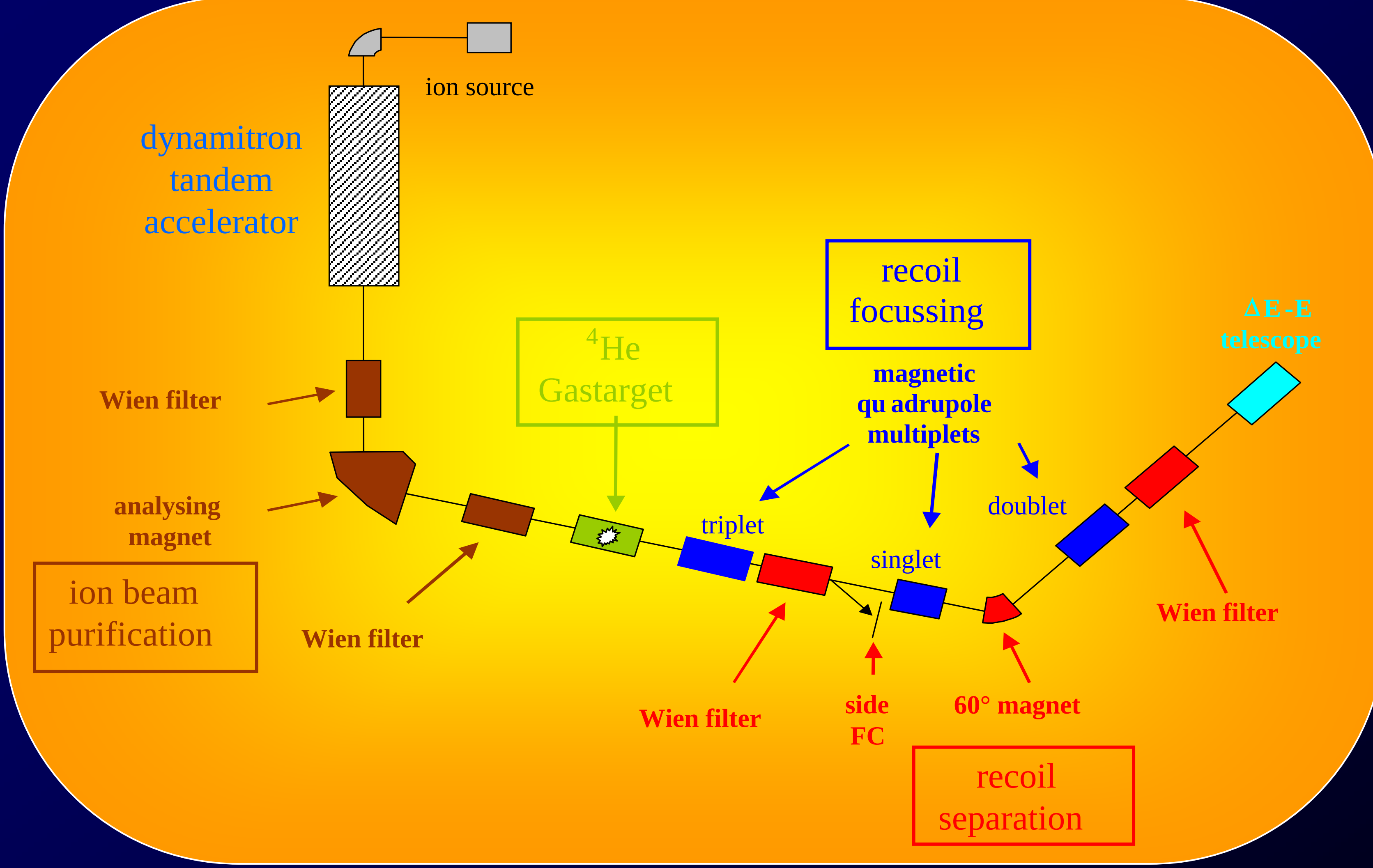
5 MeV

Requirements

- high purity of incoming ^{12}C beam
- angular / energy acceptance
- suppression of ^{12}C beam

Advantages

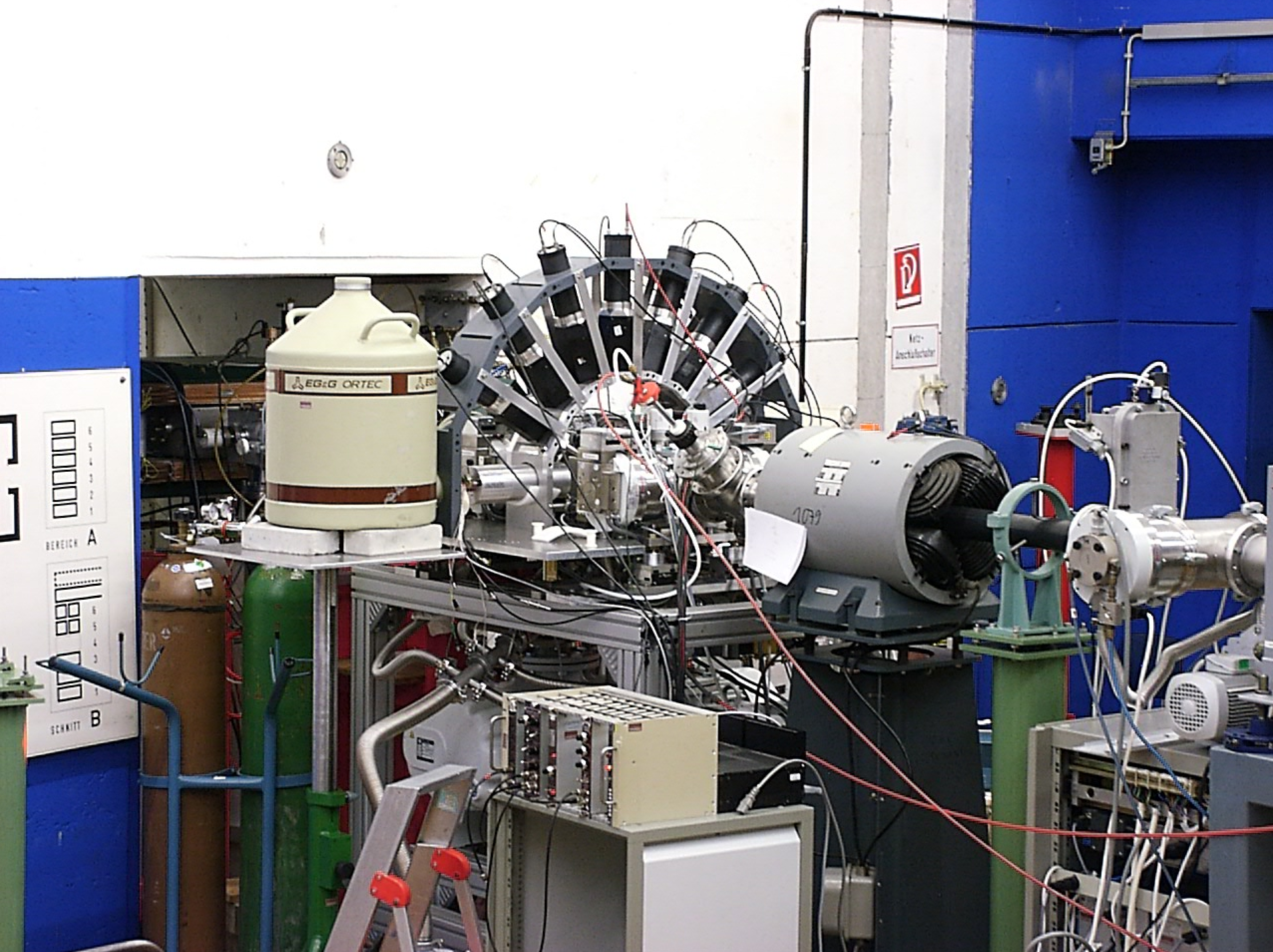
- high efficency ~p_q
- measure σ_{tot}
- independent of γ's

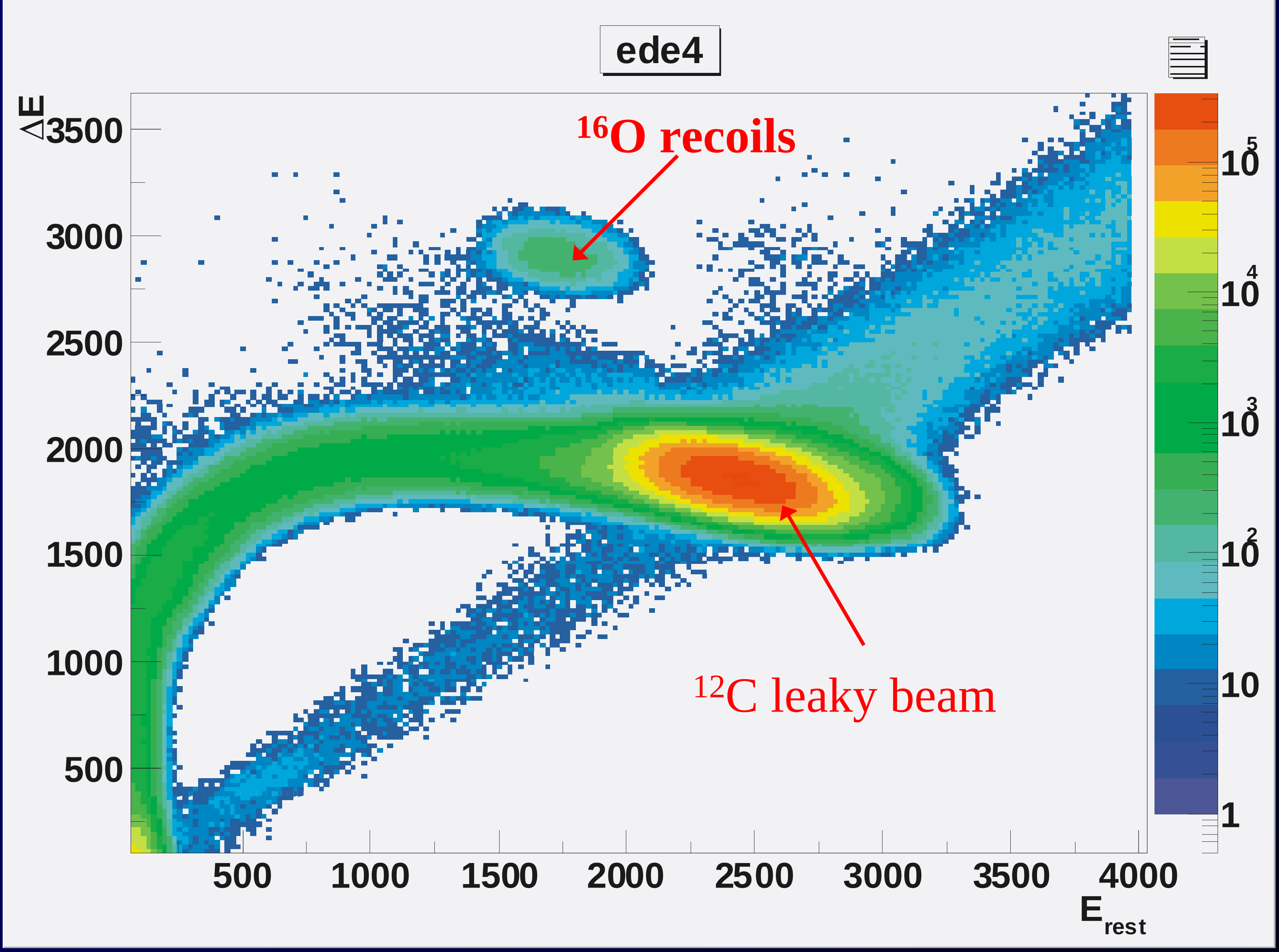


$$E_{cm} = 1.2 \text{ MeV}$$

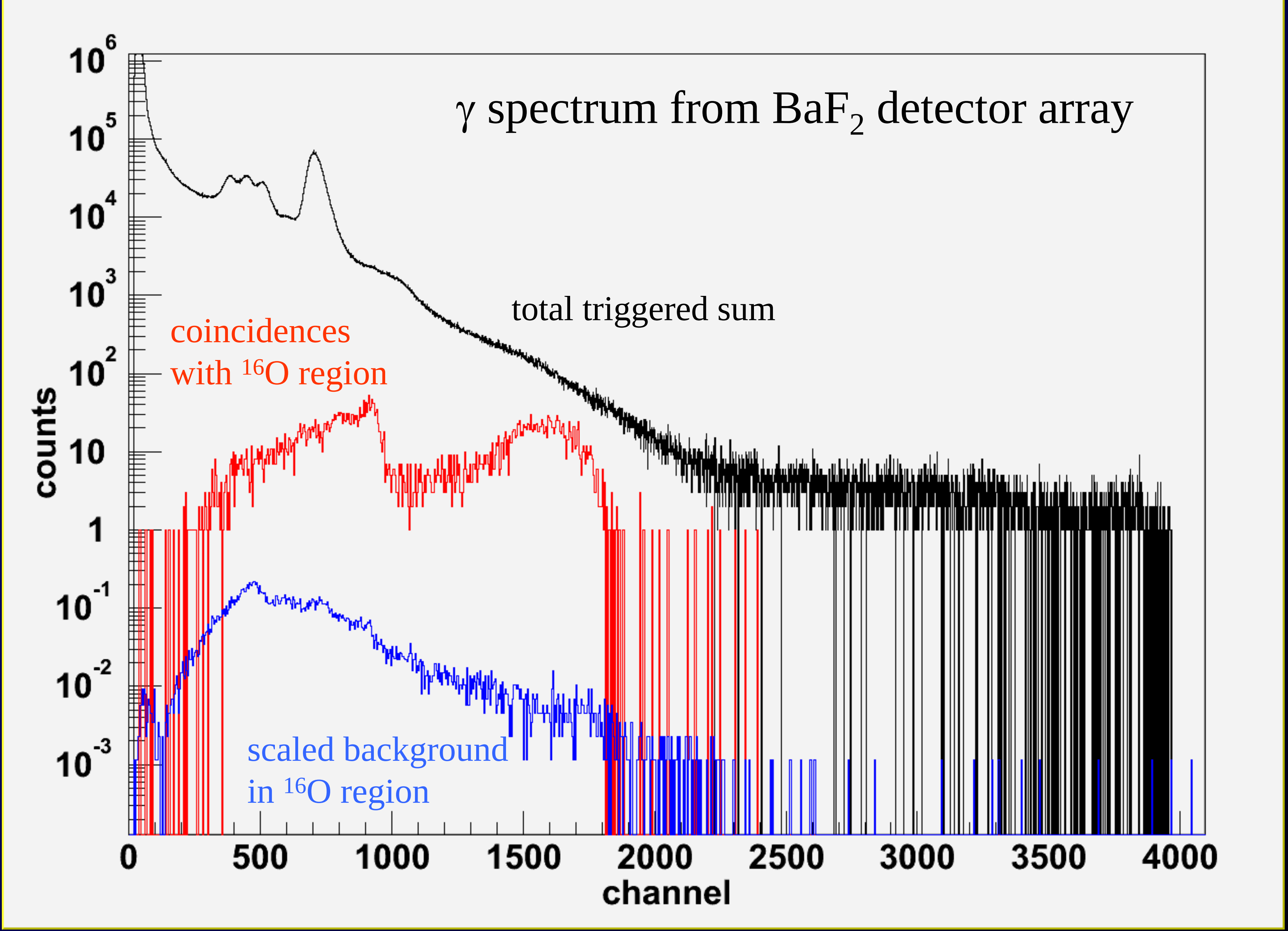
$$\vartheta_{max} = 26 \text{ mrad} \quad \Rightarrow \quad \Delta x = \pm\, 2.6 \text{ cm at } \Delta z = 1 \text{ m}$$

$$\Delta E \sim \pm\, 185 \text{ keV} \qquad \text{at } E_0 = 3.6 \text{ MeV}$$


EG&G ORTEC
BEREICH A
SCHNITT B



ΔE-E matrix of $^{12}C(\alpha,\gamma)^{16}O$ at E_{cm}=3.19MeV (4^+ Resonance)



expected: γ–γ cascade with

E_{prim}	3.4 MeV
E_{sec}	6.9 MeV

Summary and Remarks

• sufficient shielding → deep underground (expensive place)

→ costs and outcome balance

• Infrastructure of Underground Laboratory

- technical staff/operator
- people willing to stay in ugly places (Ph.D students ?)

• Infrastructure of Surface Laboratory

- closeby surface accelerator facility is highly required
- testing of expermental setup, targets, etc.

• Scientific program - type of reactions

→ underground shielding needed ?

• alternatives are possible (for example: Recoil Separators)