Study of the BBN reaction D(α,γ)^{6}Li deep underground in LUNA

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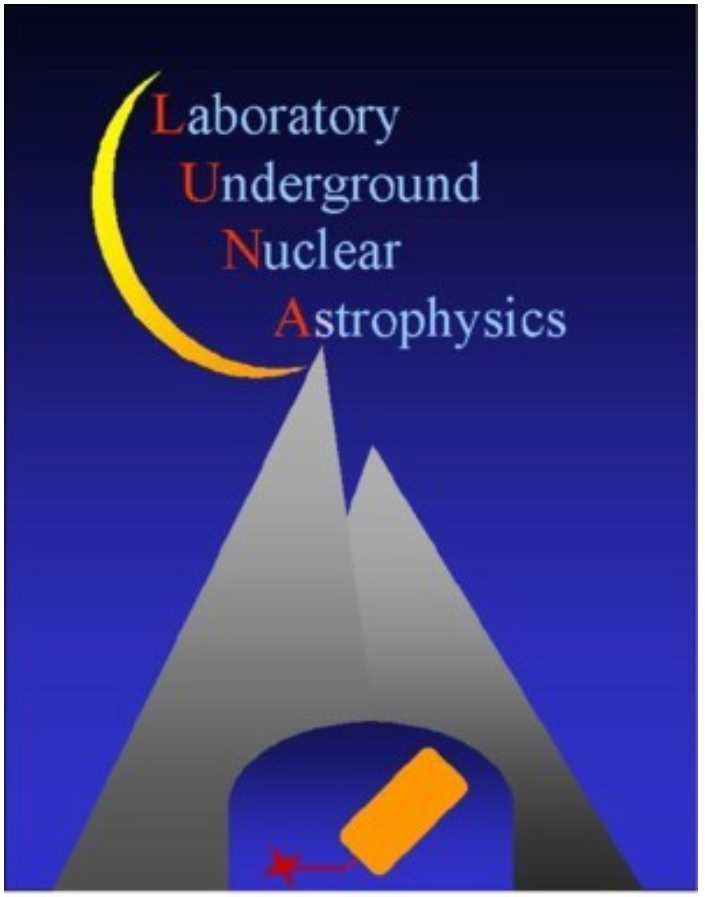
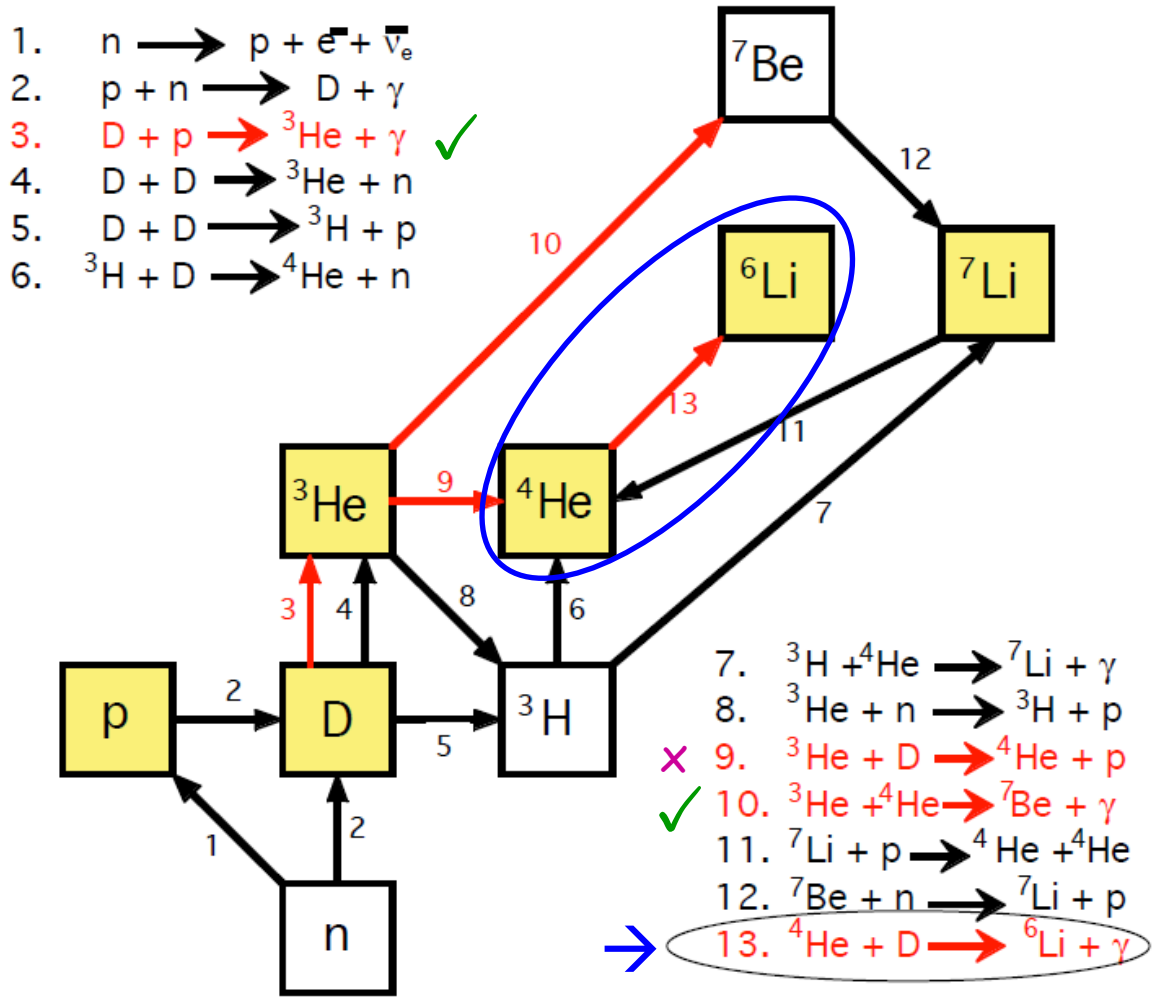
di Fisica Nucleare



The BBN reaction network

Schematic BBN network:

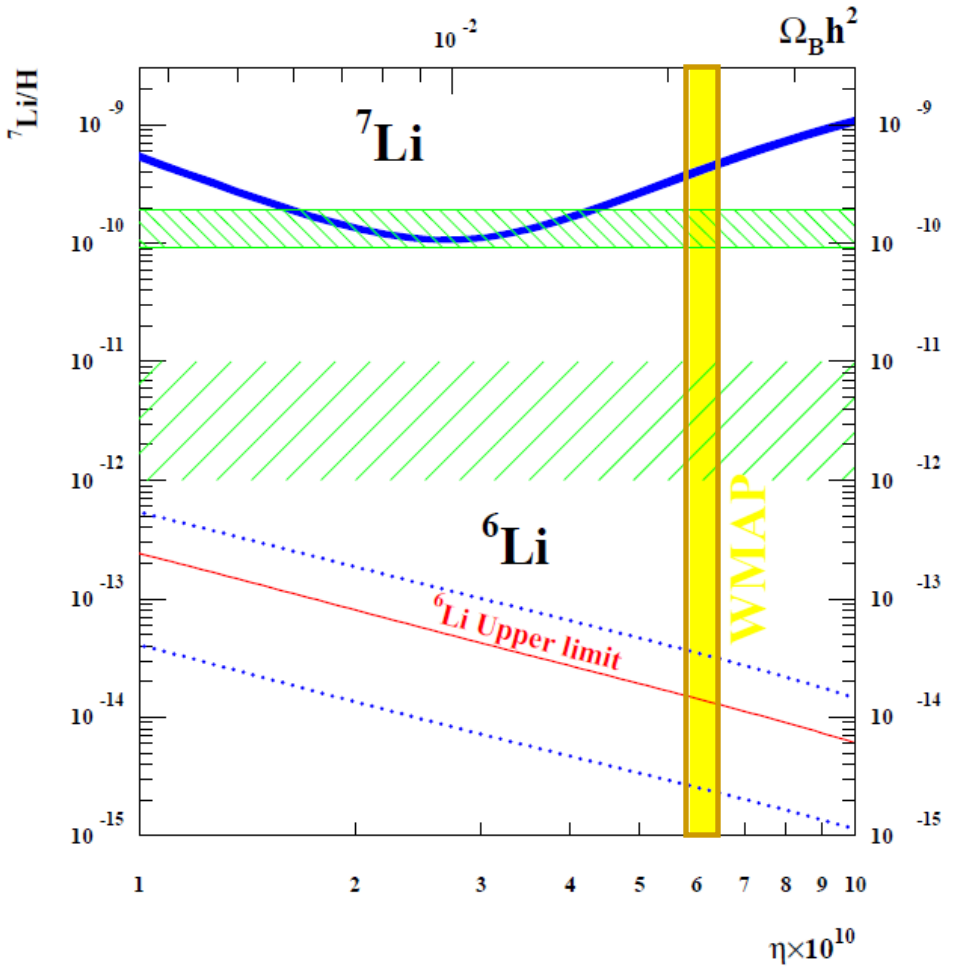


- apart for Helium, all the other nuclides are sensitive to the nuclear reaction network
- good agreement between calculations and observations for D, ^{3,4}He
- problems for ^{6,7}Li!

- Already measured by LUNA:
  → D(p,γ)^{3}He
  → ^{3}He(α,γ)^{7}Be
  (D, ^{7}Li abundance)
- Currently investigated:
  → **D(α,γ)^{6}Li**
  (^{6}Li abundance)
- Spin off:
  → D(^{3}He,p)^{4}He
  (^{3}He abundance)

BBN: $^{6/7}$Li abundance problem

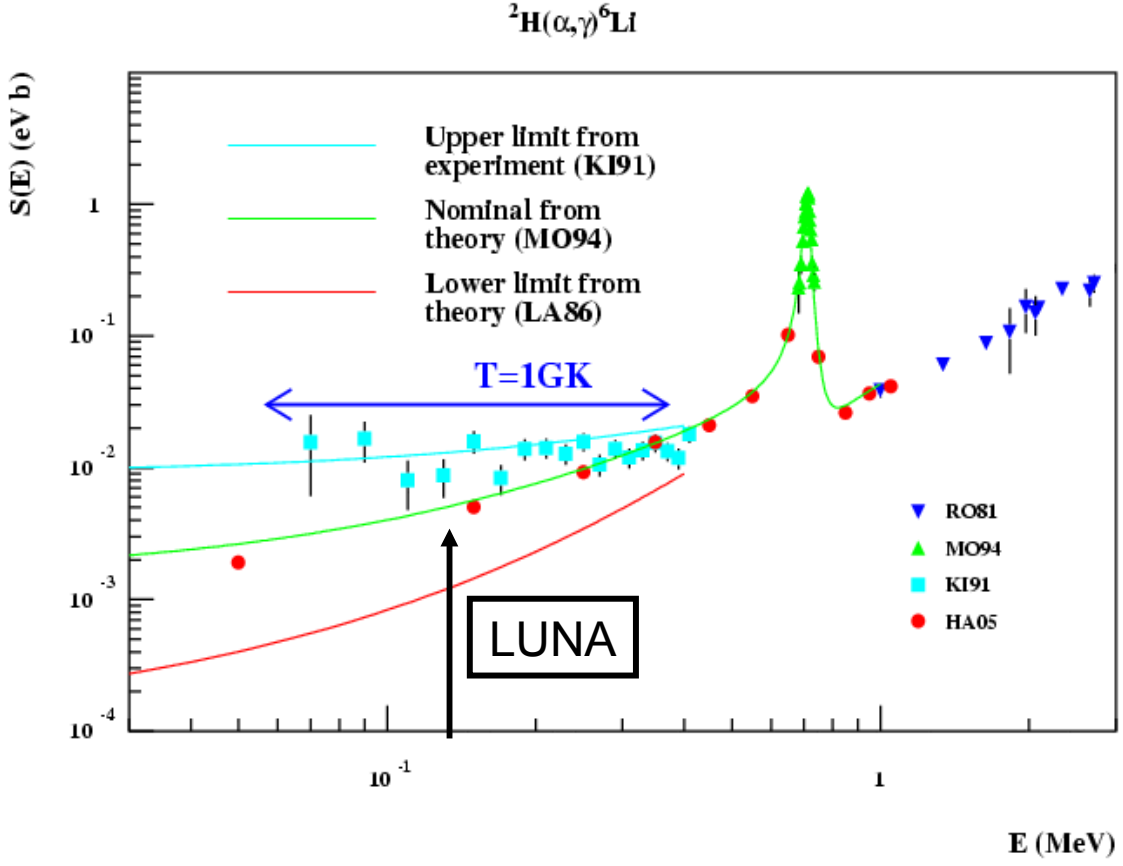
- ^{6}Li detected in metal poor stars (green bars) is unexpectedly large compared to the NACRE BBN predictions (blue dashed lines)
- upper limit from Coulomb Dissociation experiment of ^{6}Li @ GSI (indirect measurement) (red line)
- baryon-to-photon ratio η fixed by WMAP



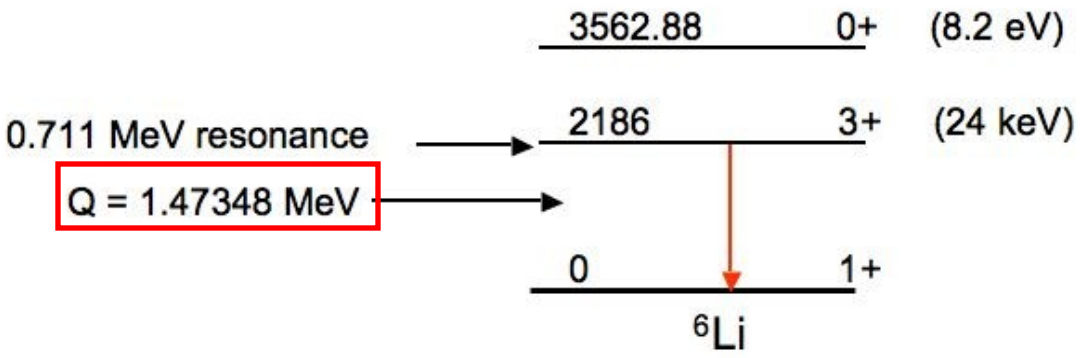
F. Hammache *et al.*, PoS (NIC-IX) 013 (2006)

Cross section of the D+α reaction

- theoretical estimates → differ by >1 order of magnitude
- no direct measurements < 650 keV (resonance: 711 keV)
- cross section very low ($\sigma(E_{c.m.}) = S(E_{c.m.}) / E_{c.m.} \cdot e^{-2\pi\eta}$)
- big uncertainty extrapolating *S*-factor (→S_0)



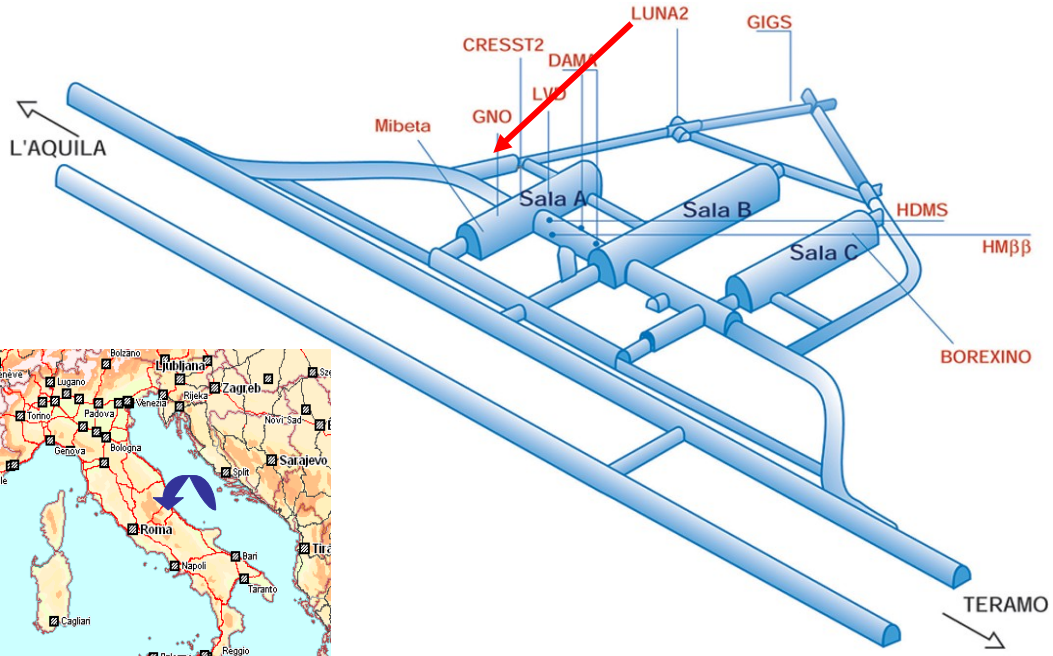
- direct measurements desirable in the ***BBN energy window*** to test models
  E_{BBN} = 50 - 300 keV
- cross section:
  $\sigma(E_{BBN})$: 10 fb – pb
- LUNA, D+α:
  $E_\alpha \leq 400$ keV →
  $E_{c.m.} \approx 130$ keV



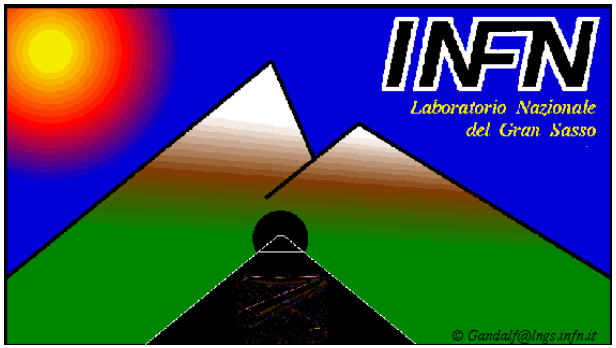
- $E_\gamma = Q + E_{cm} + \Delta E_{Dopp} - \Delta E_{rec}$ = RoI **= 1580-1630 keV**, in-beam γ-spectroscopy
- direct measurement possible @ LUNA
- LNGS: reduction of μ by 10^6, n by 10^3

→ talk **H. Costantini**
(Session 4: Stars, **Mon., 19th, 17:00 h**)

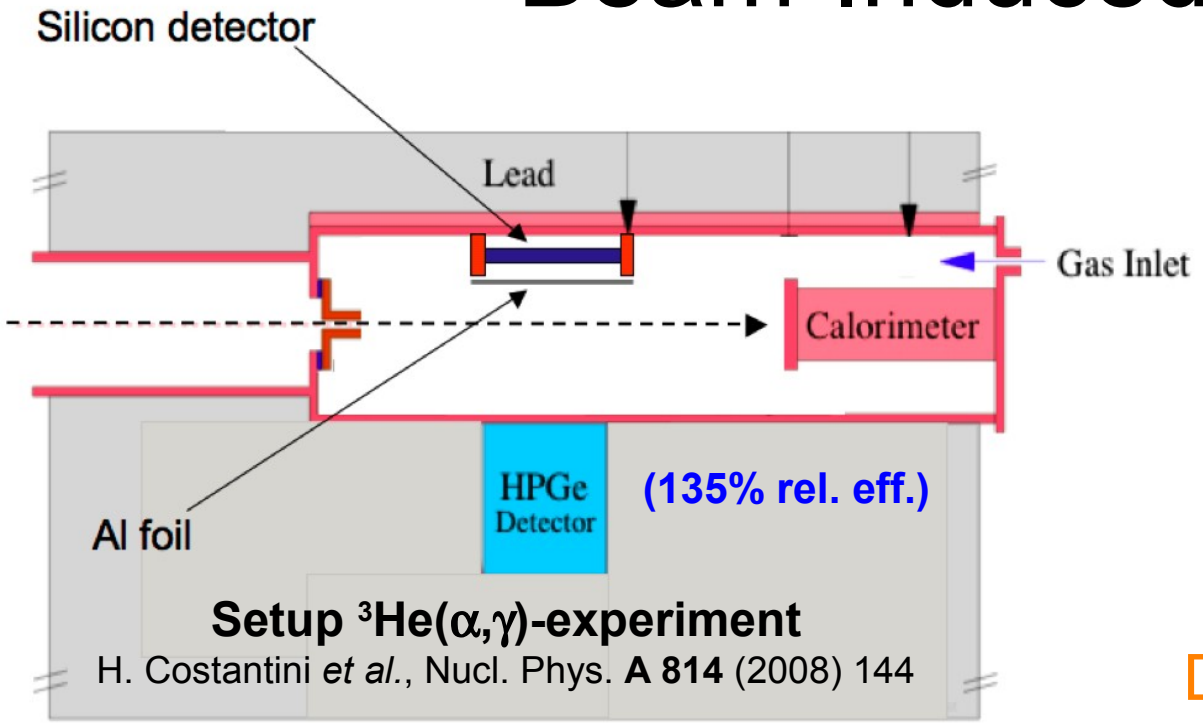
Laboratory for Underground Nuclear Astrophysics



Laboratori Nazionali del Gran Sasso (LNGS)
(shielding: 1400 m dolomite rock → 3800 m w.e.)



Beam-Induced Background (BIB)



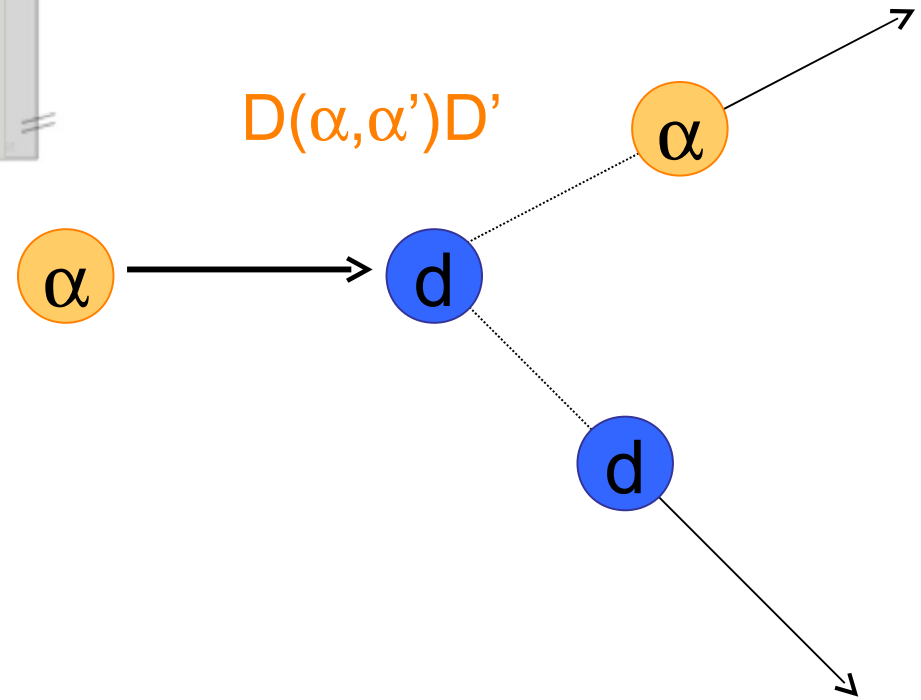
Setup ^{3}He(α,γ)-experiment

H. Costantini *et al.*, Nucl. Phys. **A 814** (2008) 144

$^{4}He^{+}$-beam

(E_{max} = 400 keV,

I_{max} ≈ 250 μA)



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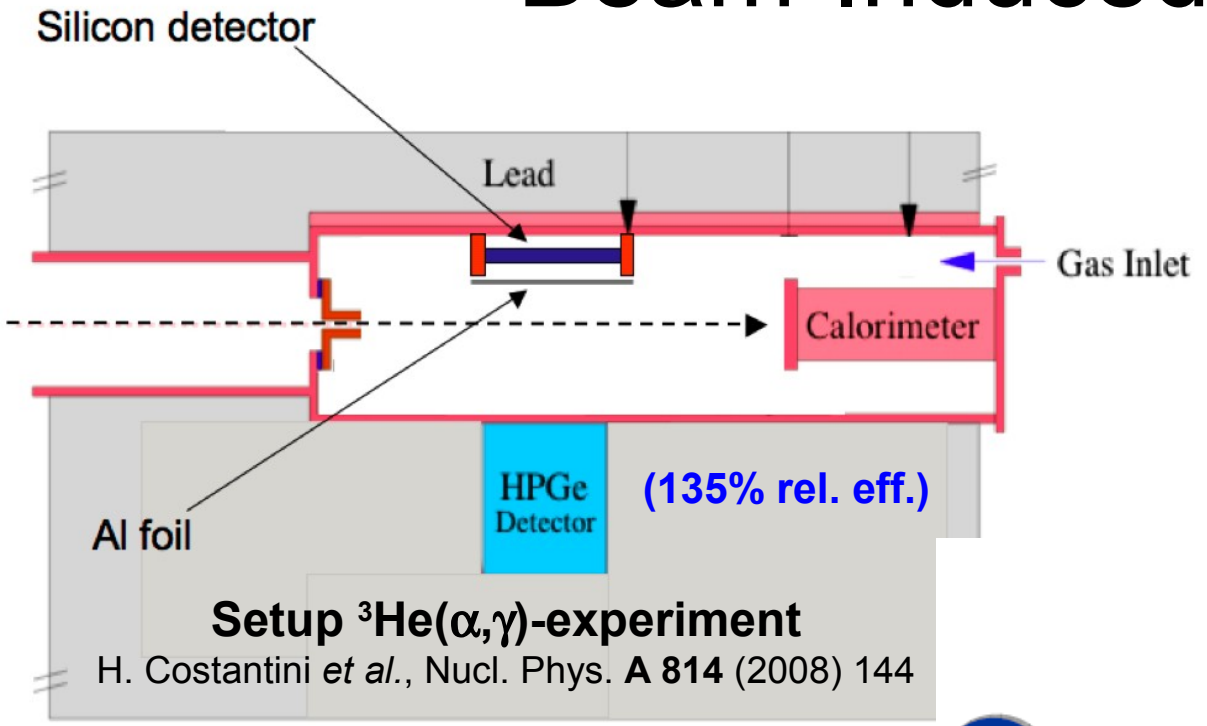

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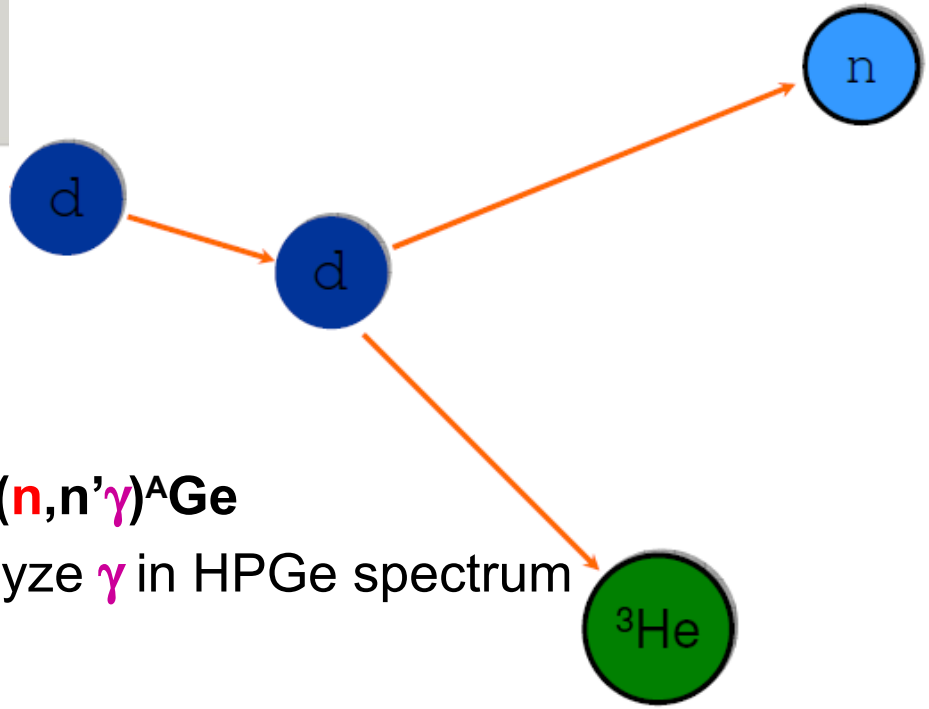


$\sigma_{D(d,n)^{3}He}$

Q = 3.269 MeV

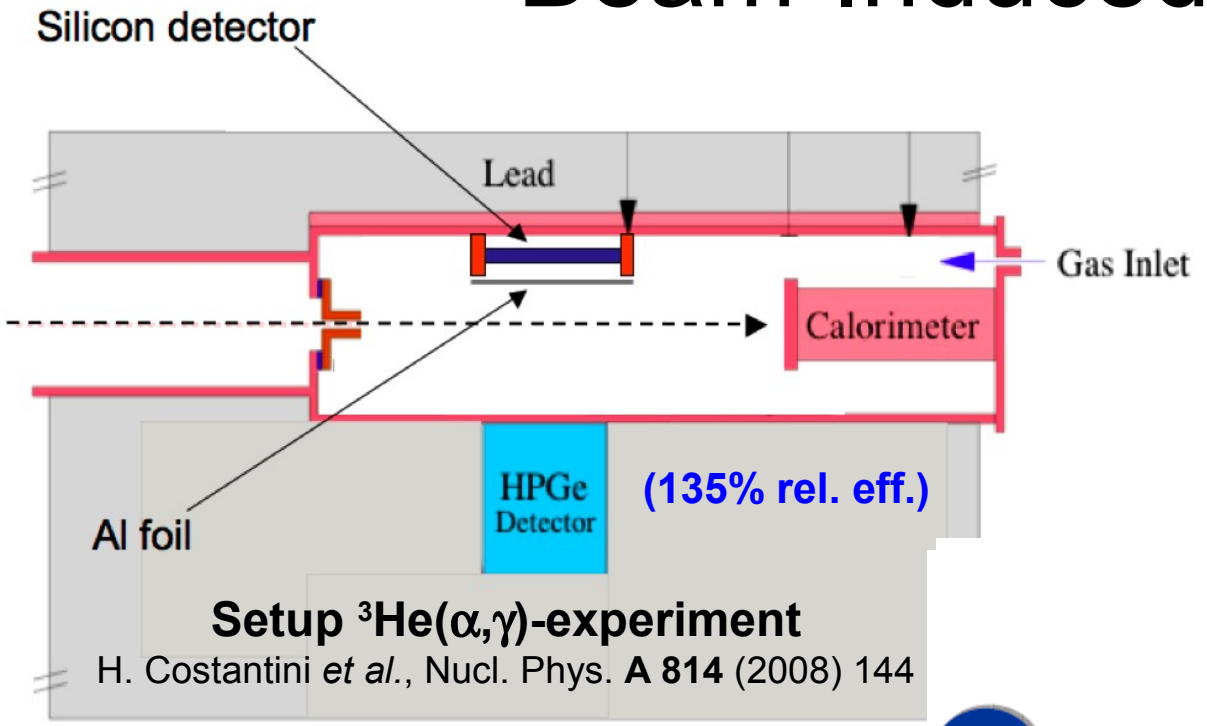
E_n = 2.450 MeV

$E_{^{3}He}$ = 0.820 MeV

^{A}Ge(n,n'γ)^{A}Ge

➔ analyze γ in HPGe spectrum

Beam-Induced Background (BIB)



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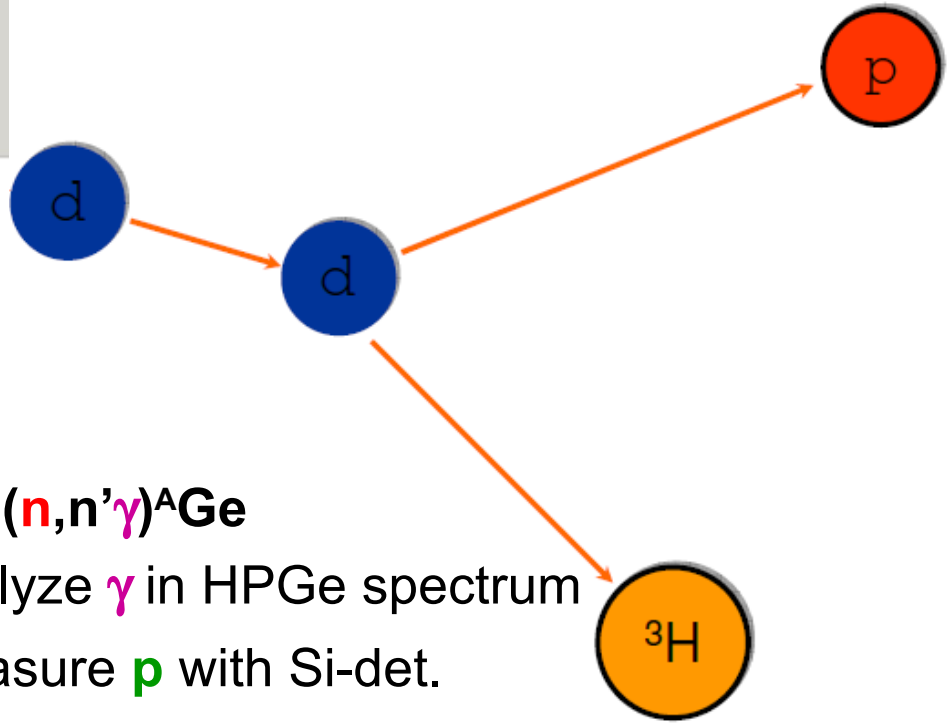


$\sigma_{D(d,n)^3He} \cong \sigma_{D(d,p)t}$

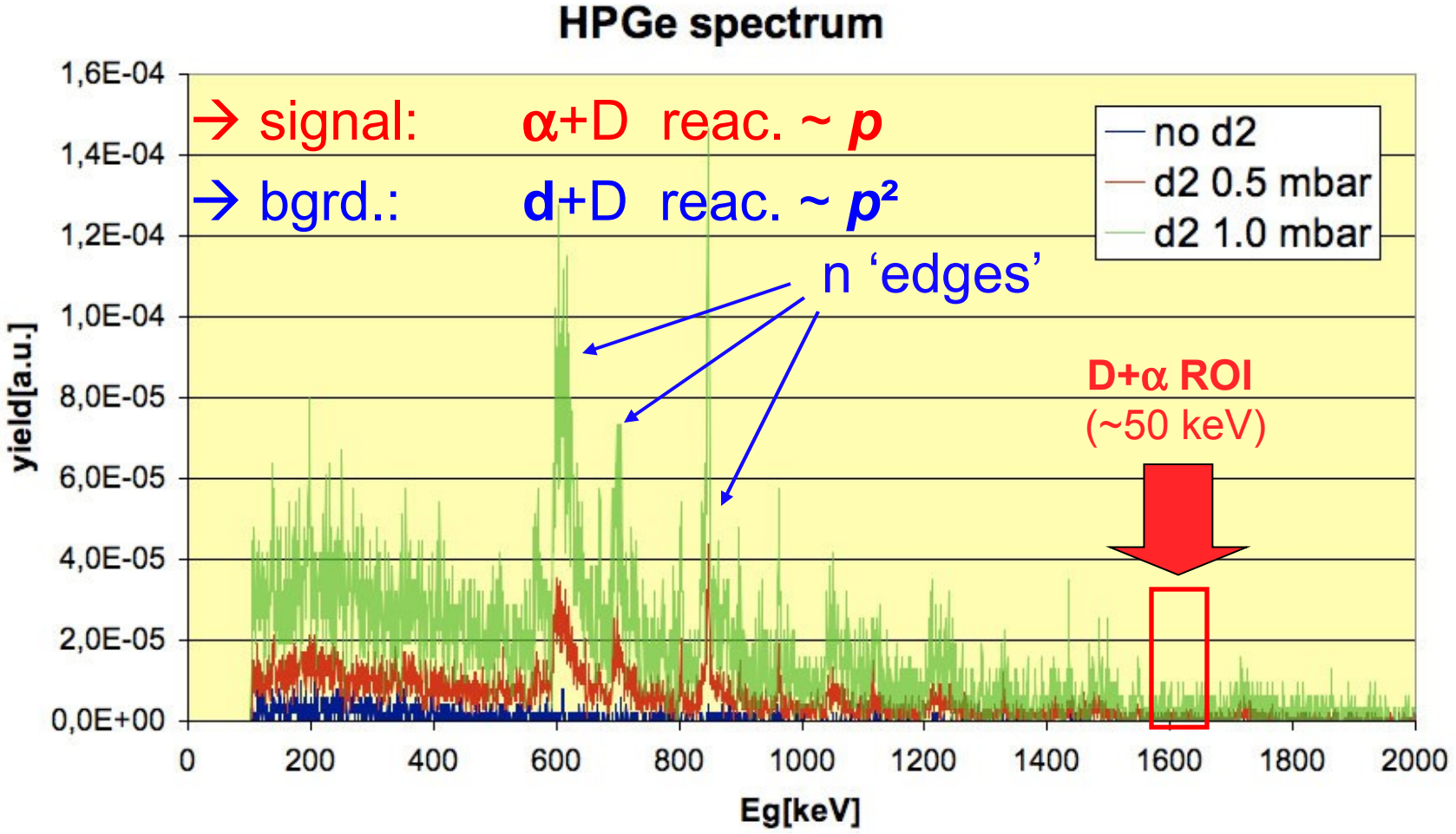
Q = 3.269 MeV	Q = 4.033 MeV
E_n = 2.450 MeV	**E_p = 3.022 MeV**
$E_{^3He}$ = 0.820 MeV	E_t = 1.011 MeV

^{A}Ge(n,n'γ)^{A}Ge

➔ analyze γ in HPGe spectrum

➔ measure **p** with Si-det.

^{A}Ge(n,n'γ) → n-fluence



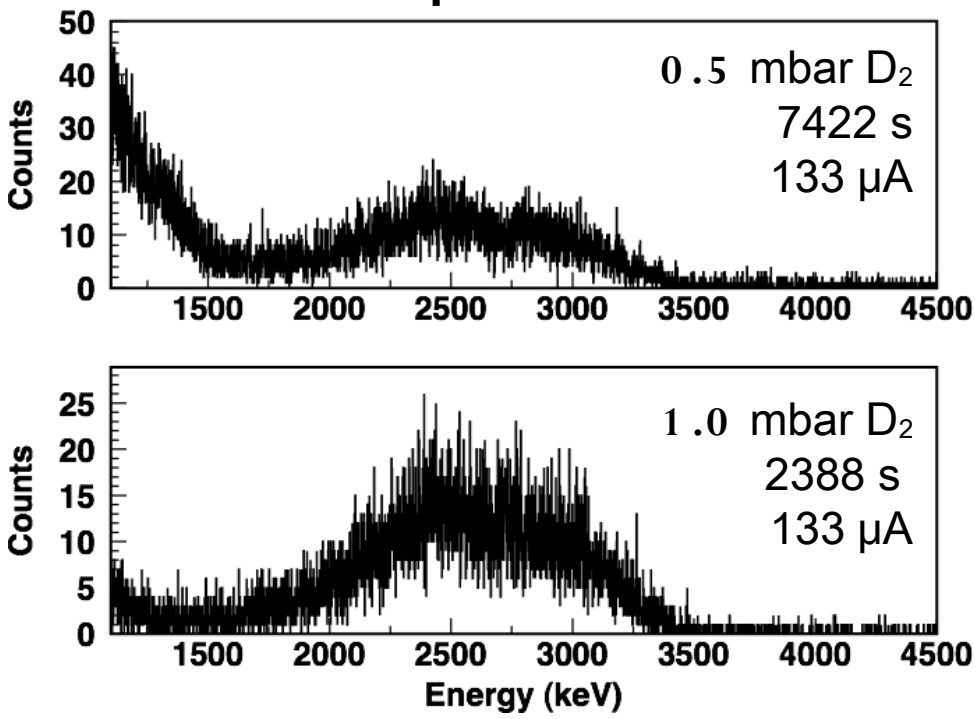
$$n / cm^2 = 300 * N_{\gamma}(693\ keV) / V_{HPGe}\ [cm^3]$$

G. F. Knoll, *"Radiation Detection and Measurement"*, Wiley, 3rd, 1999

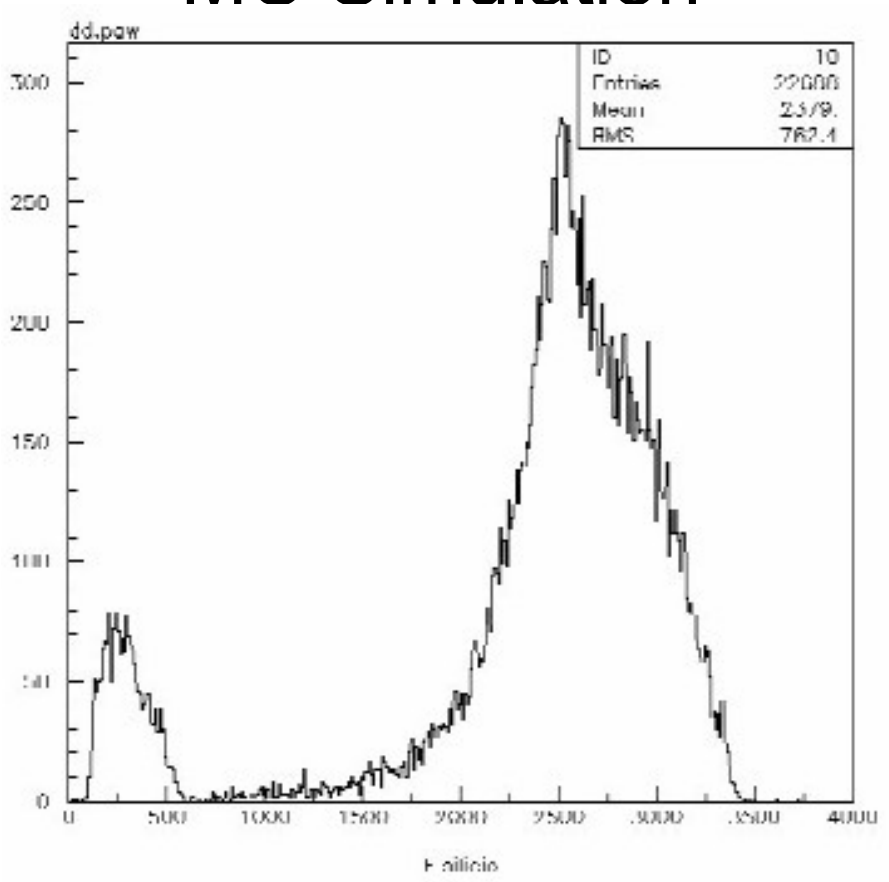
Si-detectors: D(d,p) → n-flux

→ measure p from D+d-reaction with Si-det.:

Experiment



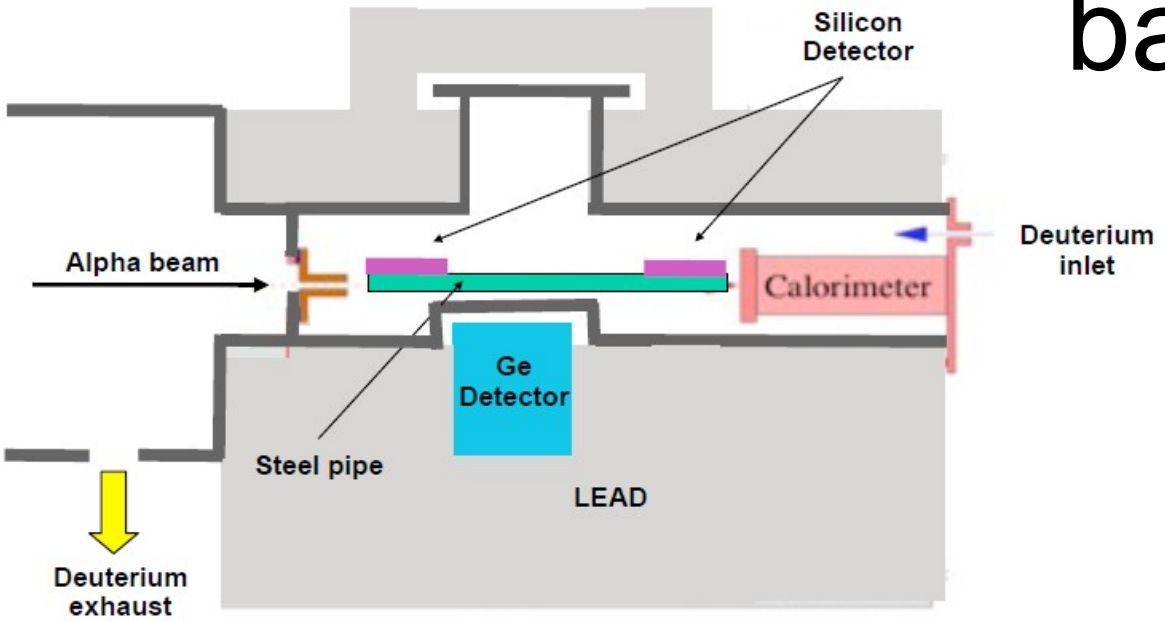
MC Simulation

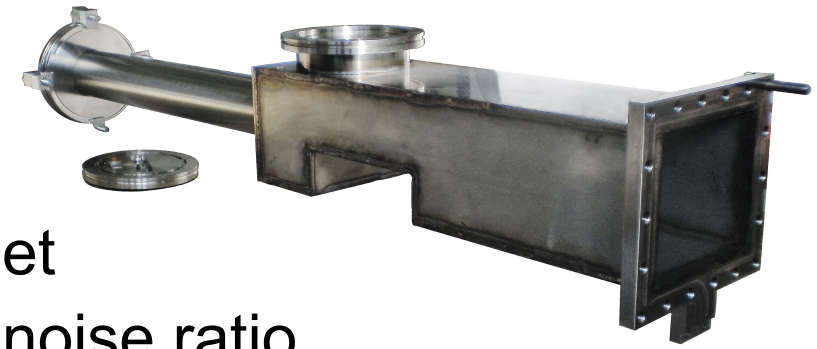


➔ Monte-Carlo simulations confirmed ✓

➔ both methods coincide ✓

Reduction of beam-induced background

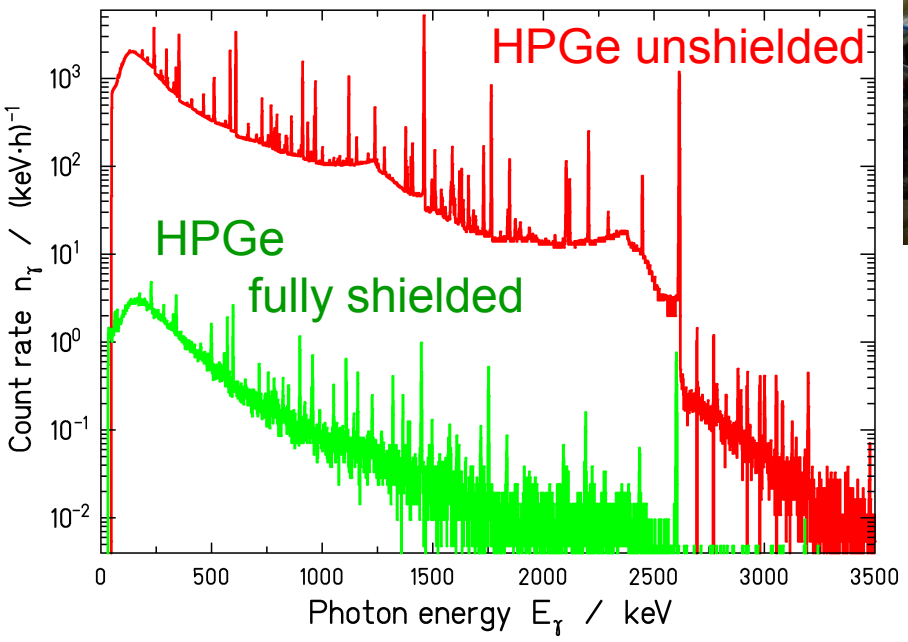




- new target chamber: steel instead of Cu to prevent (n,γ)
- recess in target chamber → HPGe det. 4 cm closer to target
- shorter target → better signal-to-noise ratio
- beam tube (18×18 mm²) inserted into gas target to limit free path of scattered D

Environmental background

- Pb-castle: to reduce ^{40}K + U-/Th-decay chain γ-lines (low *Q*-value)
- $\overline{\text{Rn}}$-box → stable + low background



- 10 cm HD-PE(5% B) shield → reduce n-background to other experiments at LNGS by a factor 5

Summary and conclusions

➔ experiment almost ready to start

- Φ_n < 10 n/s: α → D_2 @ p = 0.5 mbar, I = 130 μA, (RoI = 50 keV)
- 10 d: N_{expect} ≈ 570 cts. assuming $S(E_{cm})$ Mukhamedzhanov (PRC **52** (1995) 3483)
- signal very low → careful investigation of BIB
- D(^{3}He,p)-reaction (σ well known ≅ $\sigma_{D+\alpha}$, but no signal)
- study implantation (saturation effect → impact on BIB)
- beam heating

Acknowledgements

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