# UNDER: Underground Neutron Detection through nuclear Recoil

- **Neutron background**
  - Fast neutrons background to current experiments
  - Thermal neutrons: able to activate detector material, background for future large volume experiments

# Fast neutron measurements at LNGS

[1] aleksan 1989 Hall A
[2] arneodo 1999 Hall C
[3] belli 1989 Hall A
[4] bellotti 1985 Hall A
[5] cribier 1995 Hall A
[6] rindi 1988 Hall A

**NONE of this is a low radioactivity detector**

Table 1
Neutron flux measurements at the Gran Sasso laboratory reported by different authors

| E interval | Neutron Flux ($10^{-6}cm^{-2}s^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| (MeV) | Ref. [1] | Ref. [2] | Ref. [3] | Ref. [4] | Ref. [5] | Ref. [6] |
| $10^{-3}$ – 0.5 | | | | | | |
| 0.5 – 1 | | | 0.54±0.01 | | | |
| 1 – 2.5 | | 0.14±0.12 | (0.53±0.08) | | | |
| 2.5 – 3 | | 0.13±0.04 | 0.27±0.14 | | | |
| 3 – 5 | | | (0.18±0.04) | | | 2.56±0.27 |
| 5 – 10 | | 0.15±0.04 | 0.05±0.01<br>(0.04±0.01) | 3.0±0.8 | 0.09±0.06 | |
| 10 – 15 | 0.78±0.3 | $(0.4 \pm 0.4)\cdot10^{-3}$ | $(0.6 \pm 0.2)\cdot10^{-3}$<br>$((0.7 \pm 0.2)\cdot10^{-3})$ | | | |
| 15 – 25 | | | $(0.5 \pm 0.3)\cdot10^{-6}$<br>$((0.1 \pm 0.3)\cdot10^{-6})$ | | | |

In analyzing their experimental data with Monte Carlo simulations, Belli et al. [3] have used two different hypothetical spectra: flat, and flat plus a Watt fission spectrum. This leads to the upper and lower data sets shown for Ref. [3] respectively.

Ref. [1]: Li6 liquid scintillator — UL
Ref. [2]: liquid scintillator
Ref. [3]: BF3
Ref. [4]: He3
Ref. [5]: radio chemical techinque — 1 sigma
Ref. [6]: He3

# Thermal neutron measurements at LNGS

[1] bellotti 1985
[2] belli 1989
[3] debicki 2009
[4] best 2015

| E interval (eV) | Thermal Neutron Flux ($10^{-6}cm^{-2}s^{-1}$) | | | |
|---|---|---|---|---|
| | Ref. [1] (He3) | Ref. [2] (BF3) | Ref. [3] (He3) | Ref. [4] (He3) |
| 0 - 0.05 | $5.3 \pm 0.9$ | $1.08 \pm 0.02$ ($1.07 \pm 0.05$) | $0.54 \pm 0.13$ | $0.32 \pm 0.09$ |
| 0.05 - 1000 | | $1.84 \pm 0.20$ ($1.99 \pm 0.05$) | | |

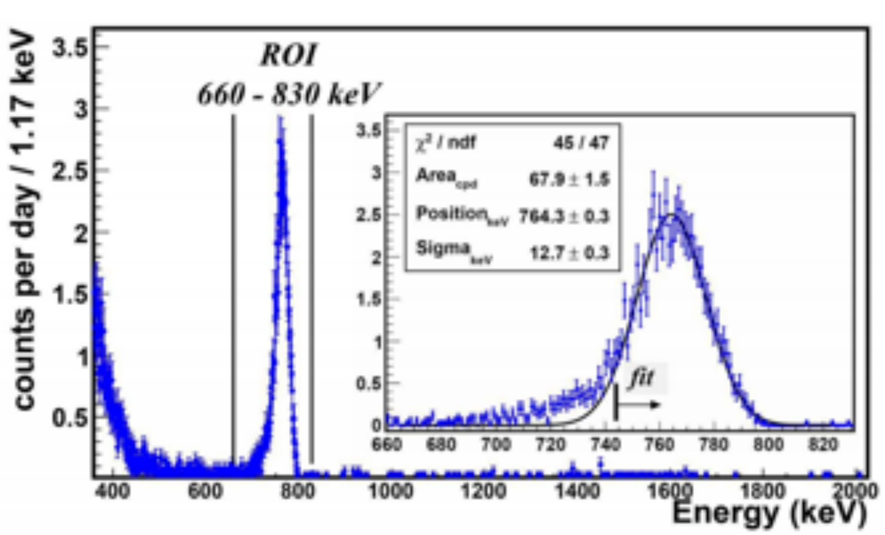
NONE of this is a low radioactivity detector

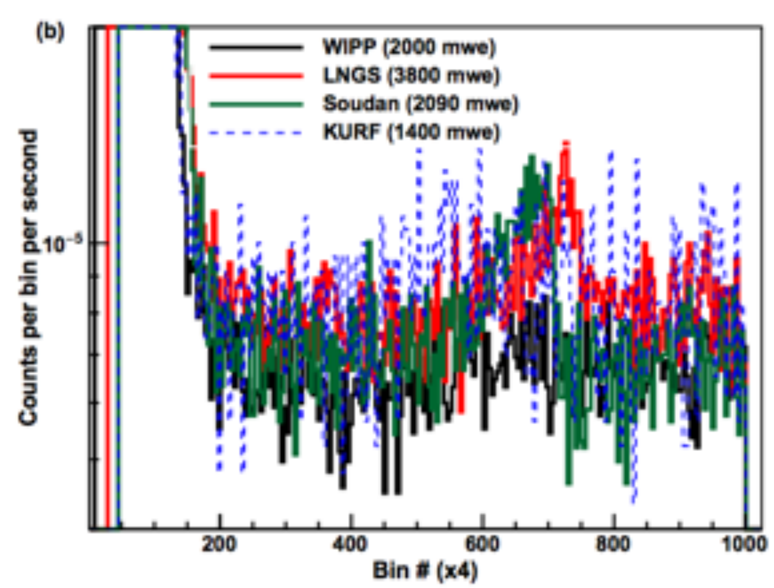
## He3 (BF3) measurements

- Thermal neutron through capture: a peak over a large background of internal radioactivity (alphas mainly), to be estimated and subtracted to obtain the final result
  - NOTE that several other laboratories felt the need to perform He3 measurements with low-radioactivity background
- Fast neutron: only through Cadmium and Polyethylene moderators, complicating detector efficiency and introducing additional uncertainty on yield and energy range

**Best He3 at LNGS (2016)**

**Edelweiss He3 at LMS (2012)**



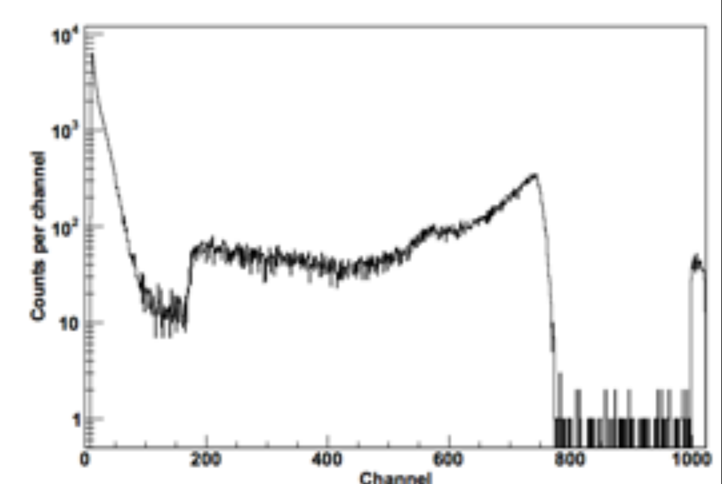
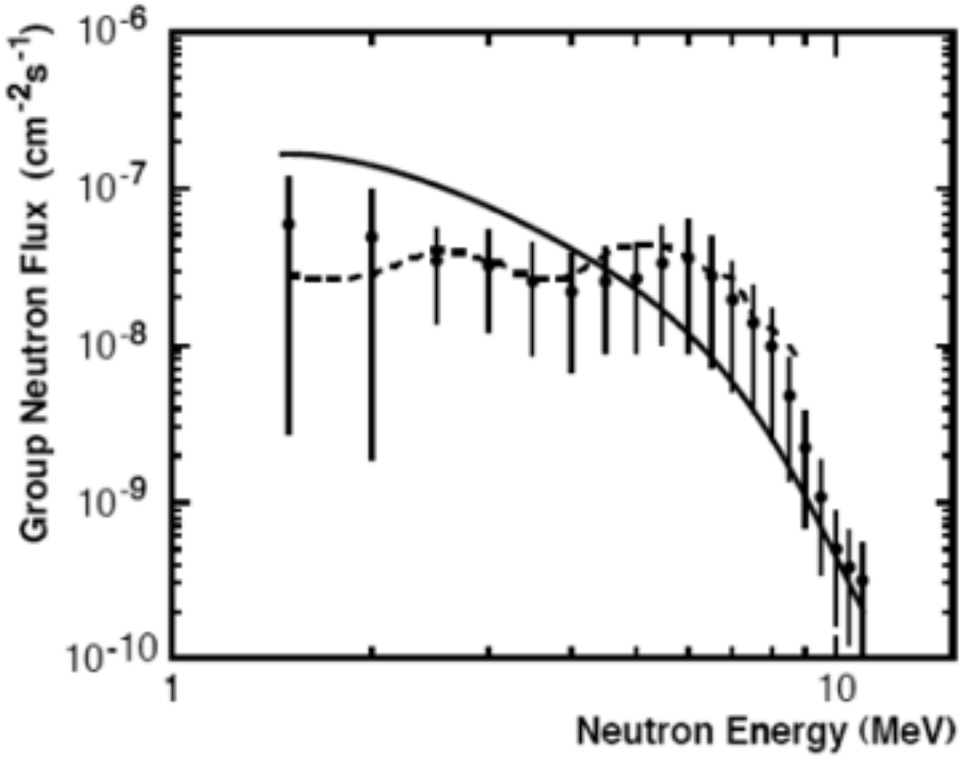




Figure 1: Typical spectrum from a $^3$He counter (1 channel ≈ 1 keV). A neutron generates a signal between channels ~200 and 800. Signals above and below this region are due to alpha particles and electronic noise, respectively.

- **Li6 scintillator measurement: upper limit**
- **Radiochemical technique (similar to chlorine solar experiments): only 1 sigma**
- **Scintillator with proton recoil technique [2] (1999)**
  - Proton recoil technique is similar to nuclear recoil
  - Authors recognize energy calibration with external gamma source was complicated and used internal alpha particles from internal radioactivity but had to estimate the contaminants from simulation (unable to resolve alpha lines)
  - Alphas were also background to proton recoils

**Neutron spectrum at Gran Sasso - Arneodo et al. Nuovo Cimento, A112 (1999) 819.**



# Hall A, Hall B and Hall C

Simulation arxiv:0312050

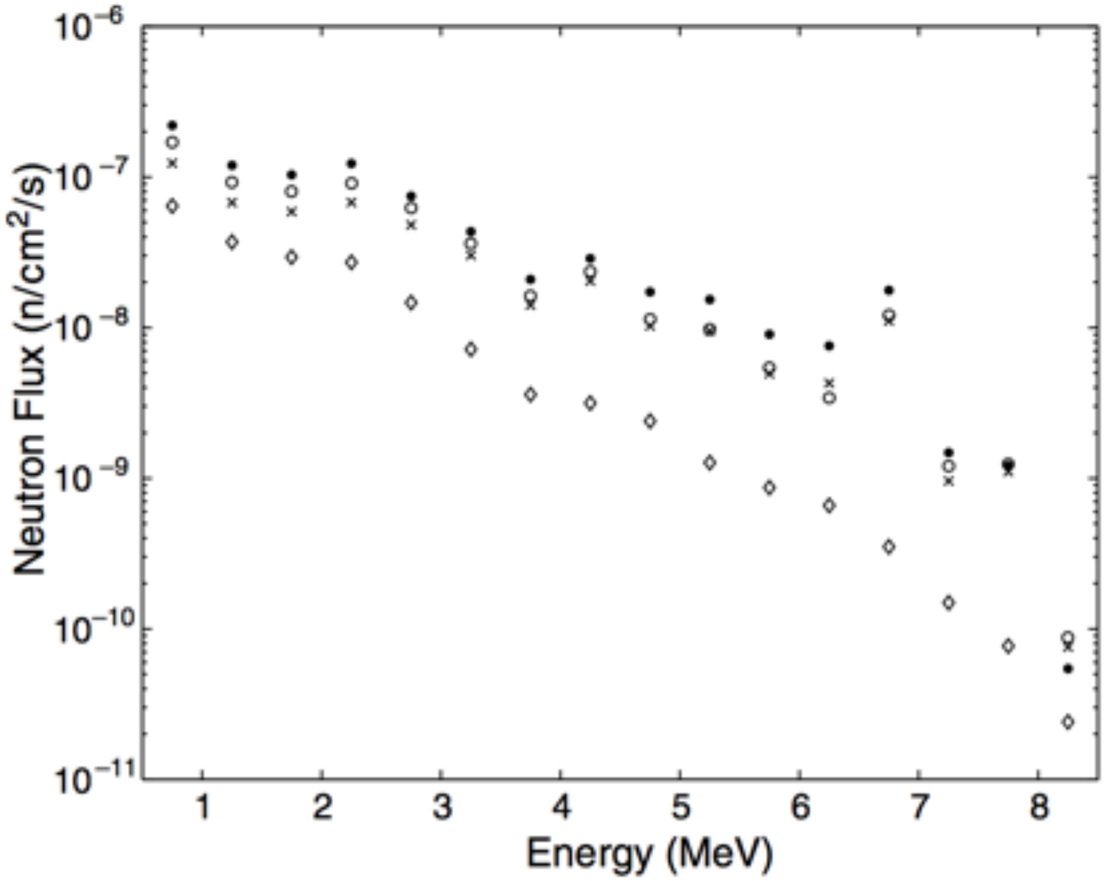



Fig. 3. Neutron flux at the Gran Sasso laboratory, ●: hall A, dry concrete, ×: hall A, wet concrete, ◇: hall A, dry concrete, fission reactions only and ○: hall C, dry concrete. Each point shows the integral flux in a 0.5 MeV energy bin.

Within the estimated uncertainties the total flux in hall C is only slightly less than in hall A for the case of dry concrete, although the neutron production rate in hall C rock is more than 10 times lower than that of hall A; above 1 MeV the fluxes in the two halls are in agreement. This is due to the concrete, which indeed reduces the neutron flux from the rock significantly so that neutrons coming into the halls are mainly those produced in the concrete layer.

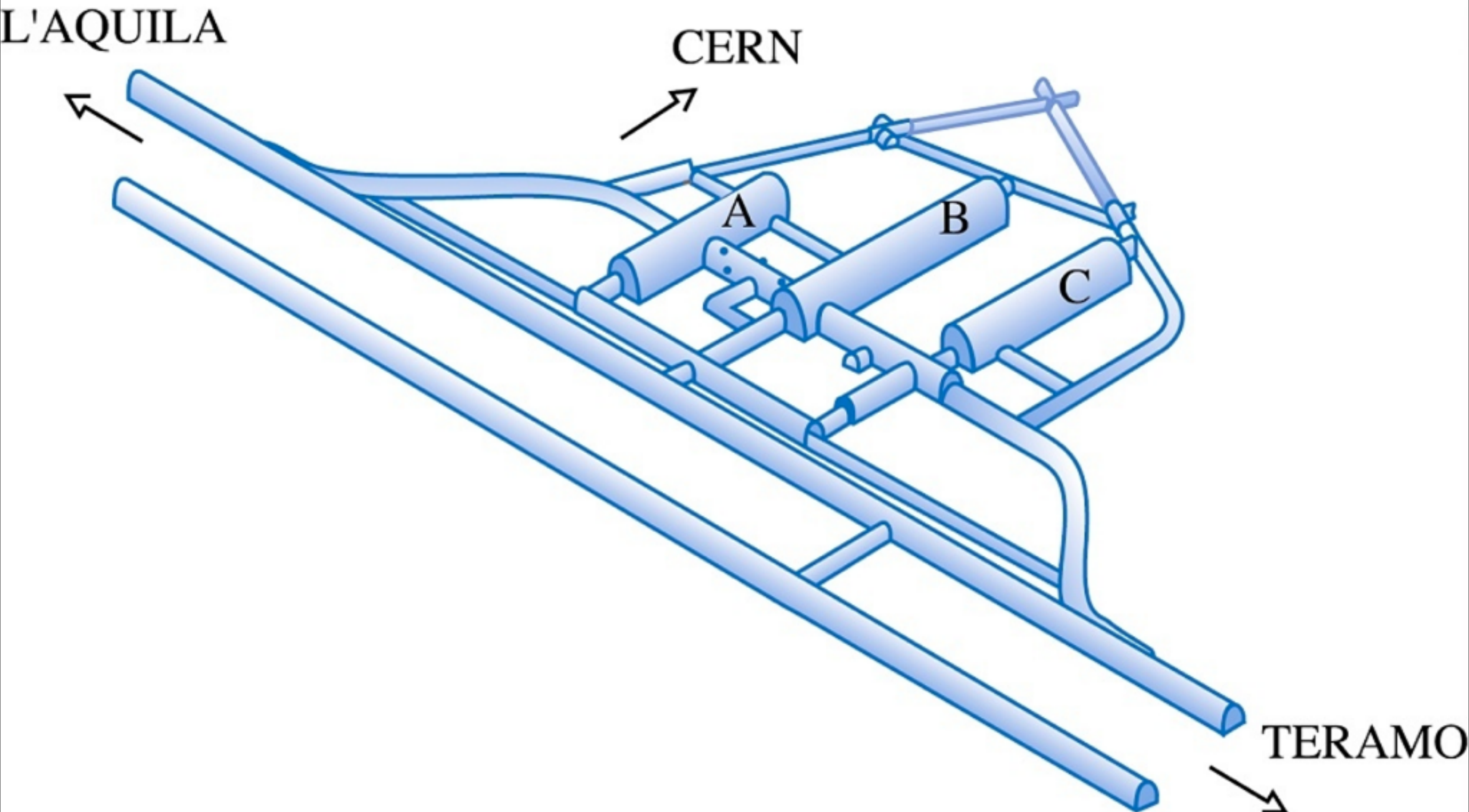
emitted per fission [11]. The total number of neutrons produced by fission and (α,n) in the rock/concrete at the Gran Sasso laboratory depends eventually on the $^{238}U$ and $^{232}Th$ contamination.

Table 3
$^{238}U$ and $^{232}Th$ activities in LNGS rock

| Hall | Activities (ppm) | |
|---|---|---|
| | $^{238}U$ | $^{232}Th$ |
| A | 6.80 ± 0.67 | 2.167 ± 0.074 |
| B | 0.42 ± 0.10 | 0.062 ± 0.020 |
| C | 0.66 ± 0.14 | 0.066 ± 0.025 |

**NEUTRON BACKGROUND HIGHLY DEPENDENT ON CONCRETE WATER CONTENT!!!** …something that can change over a year…..

| | Hall A | Hall B | Hall C | |
|---|---|---|---|---|
| rock | 3.54 | 0.22 | 0.34 | n/year/g |
| concrete | 0.55 | 0.55 | 0.55 | |

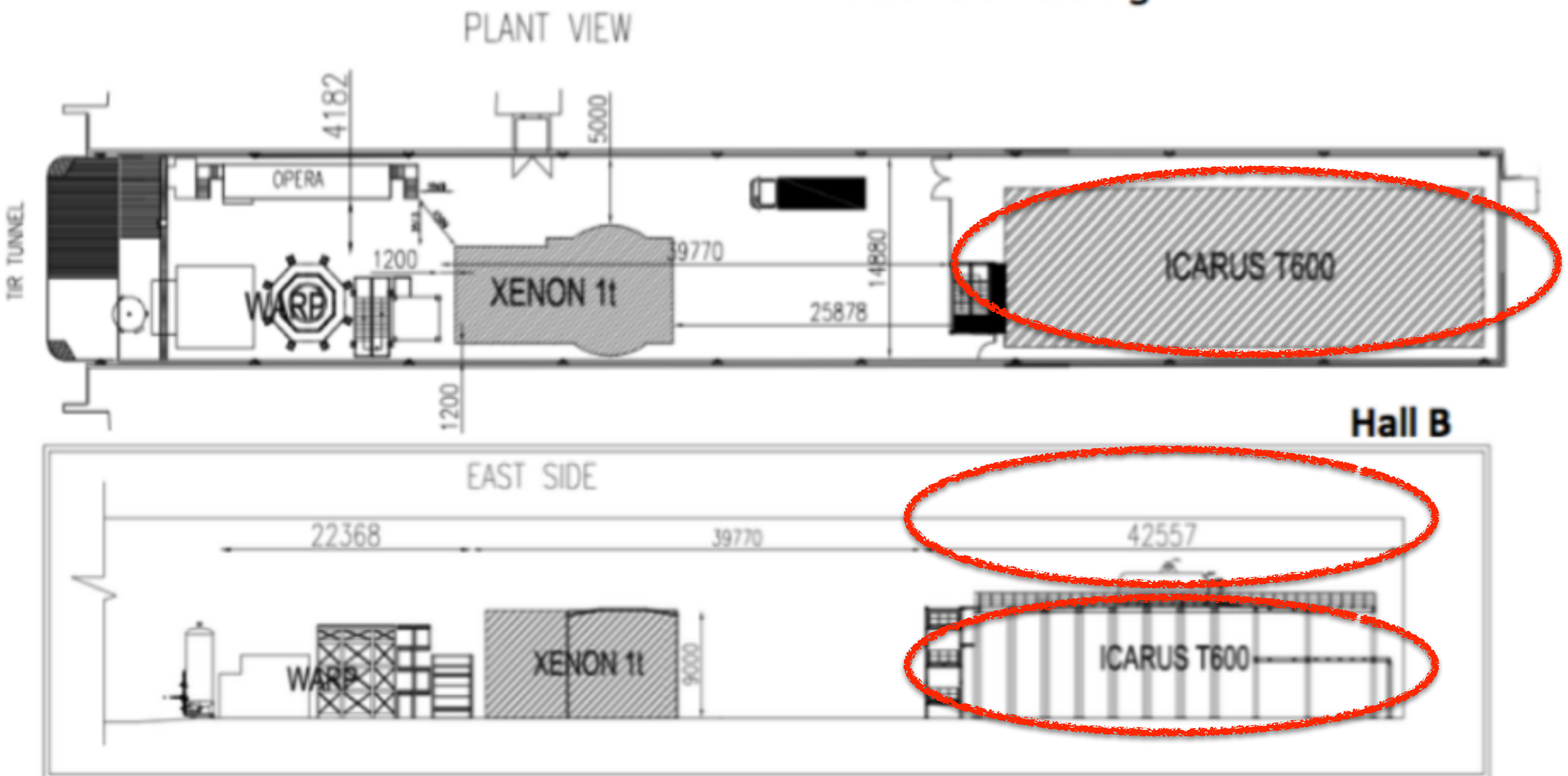

L'AQUILA
CERN
A
B
C
TERAMO

# LNGS free space and upgrades

- Icarus, Opera gone
- Free areas in Hall B:
  - "Icarus" 65 m x15 m
  - "Warp" 22 m x 10 m

Upcoming activity

- Sabre: ultra-pure NaI DM experiment
- Extension of low-background facility
- *Active shielding*




**Here there are two available levels**

# UNDER: thermal and fast neutron flux measurement in LNGS Hall B with a CYGNUS demonstrator

- **Idea based on DRIFT measurement in Boulby**
  - A 1 $m^3$ active volume with 2 back-to-back 50 cm drift NITPC with low radioactive content
- **He:He3:SF6 gas mixture**
  - Fast neutron flux through usual nuclear recoil technique
  - Thermal neutron flux through He3 capture with energy measurement plus tracking of tritium and proton recoil
- **Readout choice to come from CYGNUS-TPC studies and optimization**
- **Two-stage measurements**
  - One year directional (i.e. lower pressure) measurement in Hall B above LUNA-MV
  - Shorter non-directional (i.e. higher pressure) measurements in different location of the laboratories

# UNDER: thermal and fast neutron flux measurement in LNGS Hall B with a CYGNUS demonstrator

- **Improvements w.r.t. current measurements:**
  - First background-free measurement
  - One year measurement to see if flux change with season
  - First measurement in Hall B
  - First measurement with directionality
  - First measurement with low-pressure TPC
  - Improved spectral measurement (??? see question later on)
  - Demonstrator for CYGNUS-TPC

# Back-of-the-envelope estimation

He:$^3$He:$SF_6$ 600:1:10 Torr

**neutron capture cross section =~ 600 neutron scattering cross section**

2.14 higher density with respect to DRIFT $CS_2$:$CF_4$:$O_2$ 30:10:1 Torr

and cheaper. If we take a 30 keV energy threshold for the measurement with directionality of nuclear recoils (a 25% improvement on current DRIFT performances on F recoils [19]), and scale by the difference in density, we end up with a fast neutron energy threshold of about 500 keV ($\lesssim$ 1 MeV)$^2$. Assuming an average LNGS neutron flux of $\sim 5 \times 10^{-7}$ neutron/cm$^2$/s, 175 nuclear recoil events from fast neutron scattering are expected over a year, and at least the same number of neutron capture events from thermal neutron, allowing for a seasonal measurement. With a spectral deconvolution analysis similar to [6], UNDER can measure the fast neutron spectrum with sensitivity to neutron incoming direction. This represent only the lower limit on event statistics and the potentiality of UNDER,

**number of events based on DRIFT efficiencies & performances in the Boulby measurement (see Neil's talk)**

## VERY VERY TENTATIVE estimation of neutrons energy range

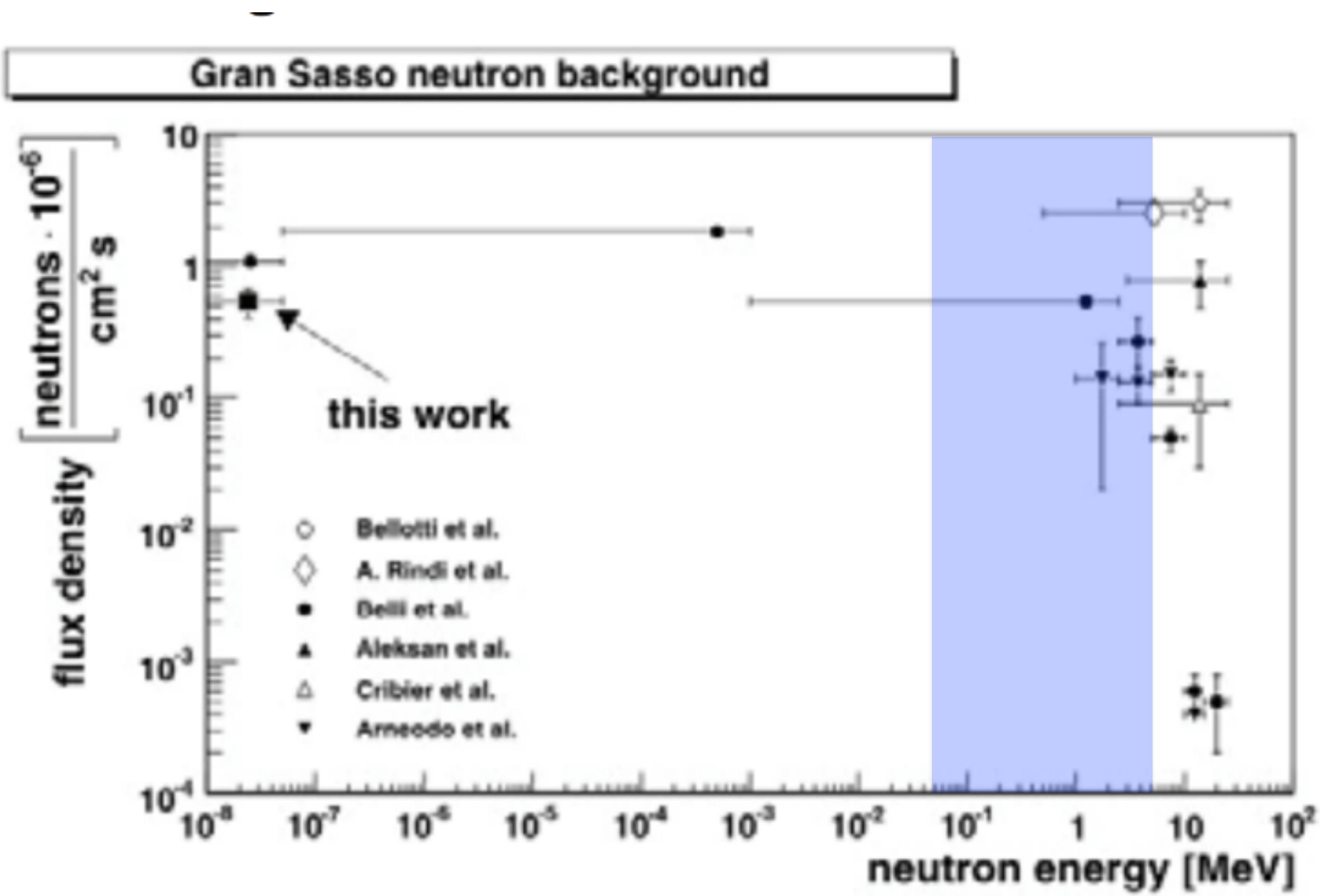



**Fig. 3** Compilation of neutron background measurements in Gran Sasso Underground Laboratory [3].

# Some (of the many) ideas for discussion

- **Lower energy threshold of DRIFT detected neutrons?**
  - What is the equivalent of 700 NIPs in terms of neutron energy that caused the recoil? I.e. which kind of neutron do we detect?
  - Can be lowered with different readout/amplification? What if we add a GEM in front of wires? What about expectations from GEM readout?
  - Can be extended above 6000 NIPs?
- **READOUT: which choice?**
  - Go safely with wires since they already did it in Boulby? But what about amplification?
  - Try one dimensional GEMs readout? Thick? Thin?
  - Go for a more sophisticated readout? Next years of R&D could see some technology emerge, maybe a staged approach

# Very very rough possible costs evaluation (probably full of mistakes)

We can have a rough estimate of the expected cost scaling from the 24 $m^3$ DRIFT III proposal presented to NSF in 2013 by the DRIFT collaboration [25] for vessel, field cage, HV and gas system and making two assumption for the readout, to represent a lower and an upper limit on costs (and performances). We take DRIFT III MWPC as low cost option and an optical + charge readout as high cost, with electronics included. The second one would be based on CMOS camera and charge readout from the GEM, to measure the time of arrival of multiple charge carriers for detector fiducialization, as in the CYGNUS-RD project [24], (please note that the CYGNUS-RD group is involved in the UNDER as well). We also assume to be able to image a 1 $m^2$ with 4 CMOS cameras. The estimate of the total cost of vessel, field cage, HV and gas system is about 60k EUROs. For the readout a low limit of about 40k EUROs for MWPC and a high limit of 100k EUROs for optical + charge with CMOS + GEM is found, giving a total range of 100-160k EUROs for the full UNDER experiment.

**Even if out of a factor 2-3, still not very expensive**

**Can exploit DRIFT and all other experiment experience, maybe reuse some parts?**