Study of the performances of the shield and muon veto of XENON1T

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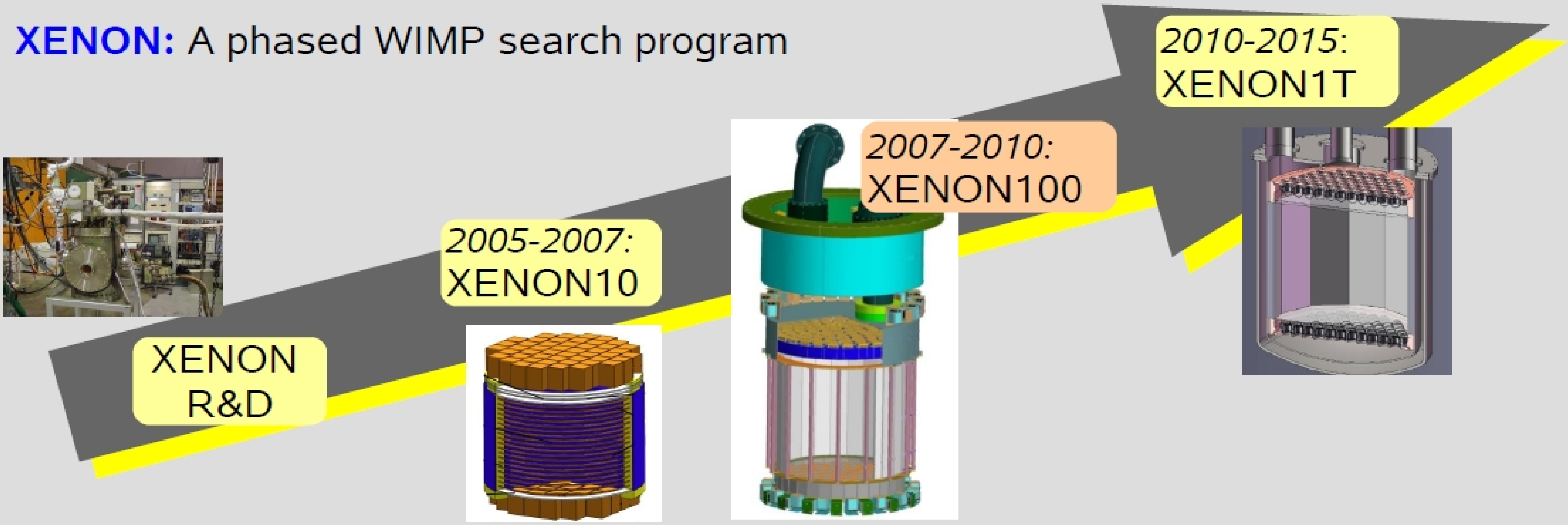
on behalf of the XENON1T collaboration

IDM2010, Montpellier, 27th July 2010

The XENON program

XENON Dark Matter Project

XENON: A phased WIMP search program



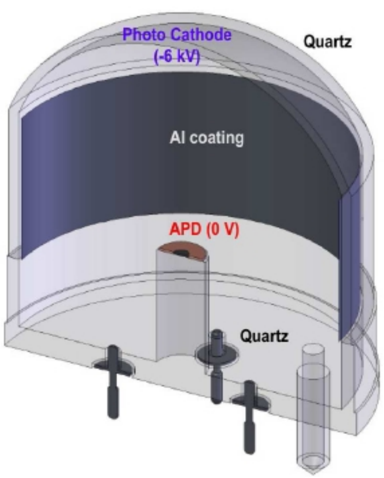
Columbia · Rice · UCLA · U Zürich · Coimbra · LNGS · SJTU

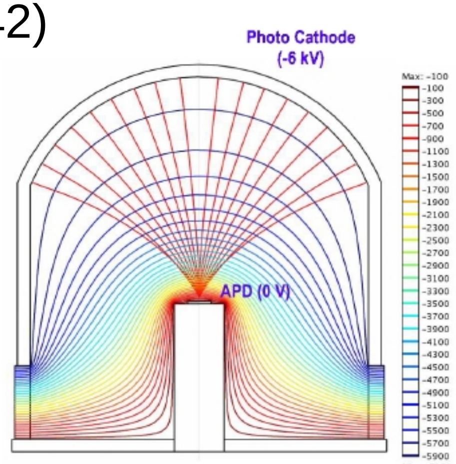
Bologna · MPIK · NIKHEF · Mainz · Subatech · Münster · WIS

The next step: XENON1T

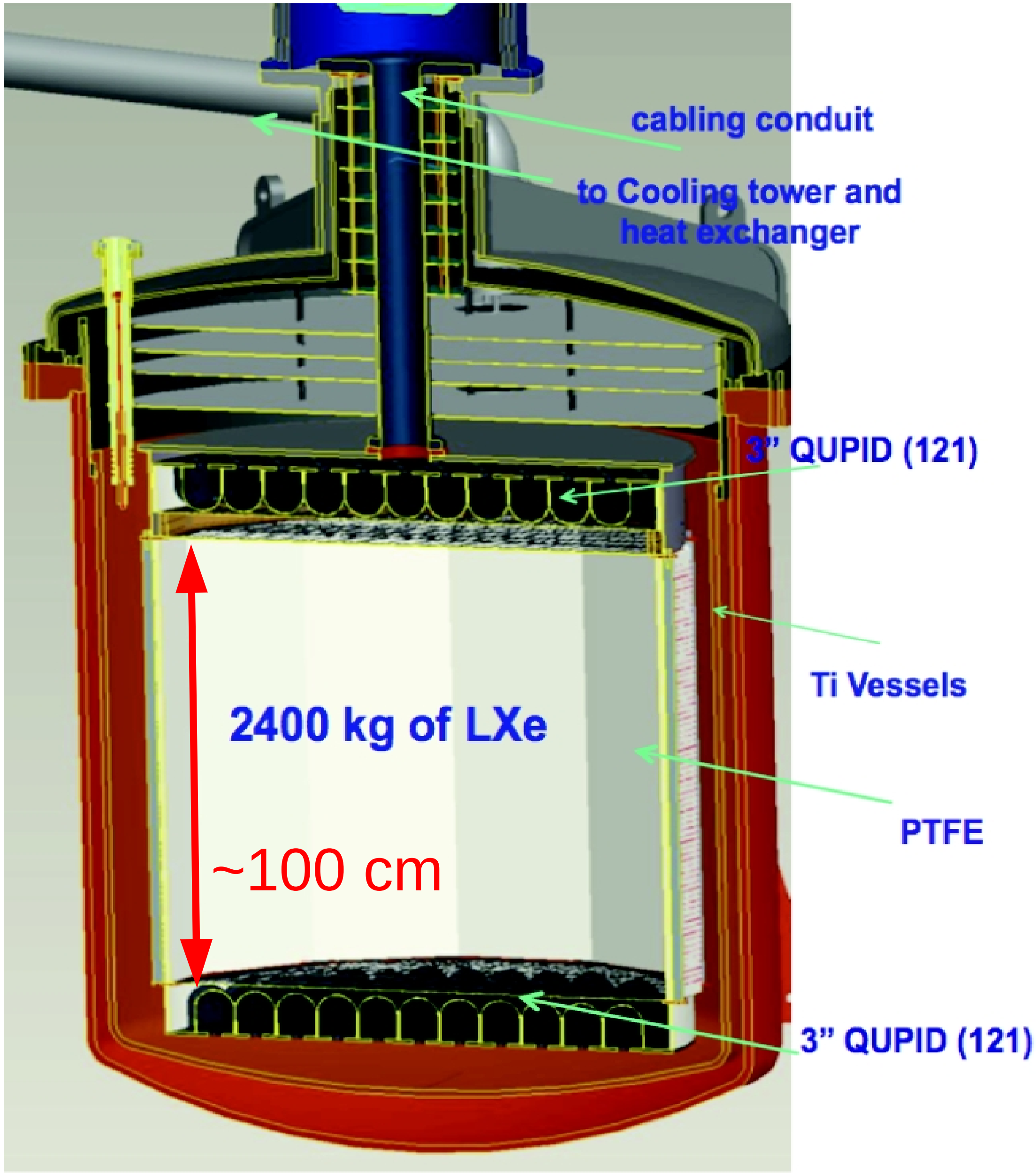
Baseline design similar to XENON100 with improvements in different areas:

- 2.4 t of LXe, 10 cm fiducial cut (1.2 t)
- Kr contamination in Xe at sub ppt level
- Lower radioactivity cryostat (Titanium)
- Lower radioactivity Photon Detector (3” QUPID, Total 242)

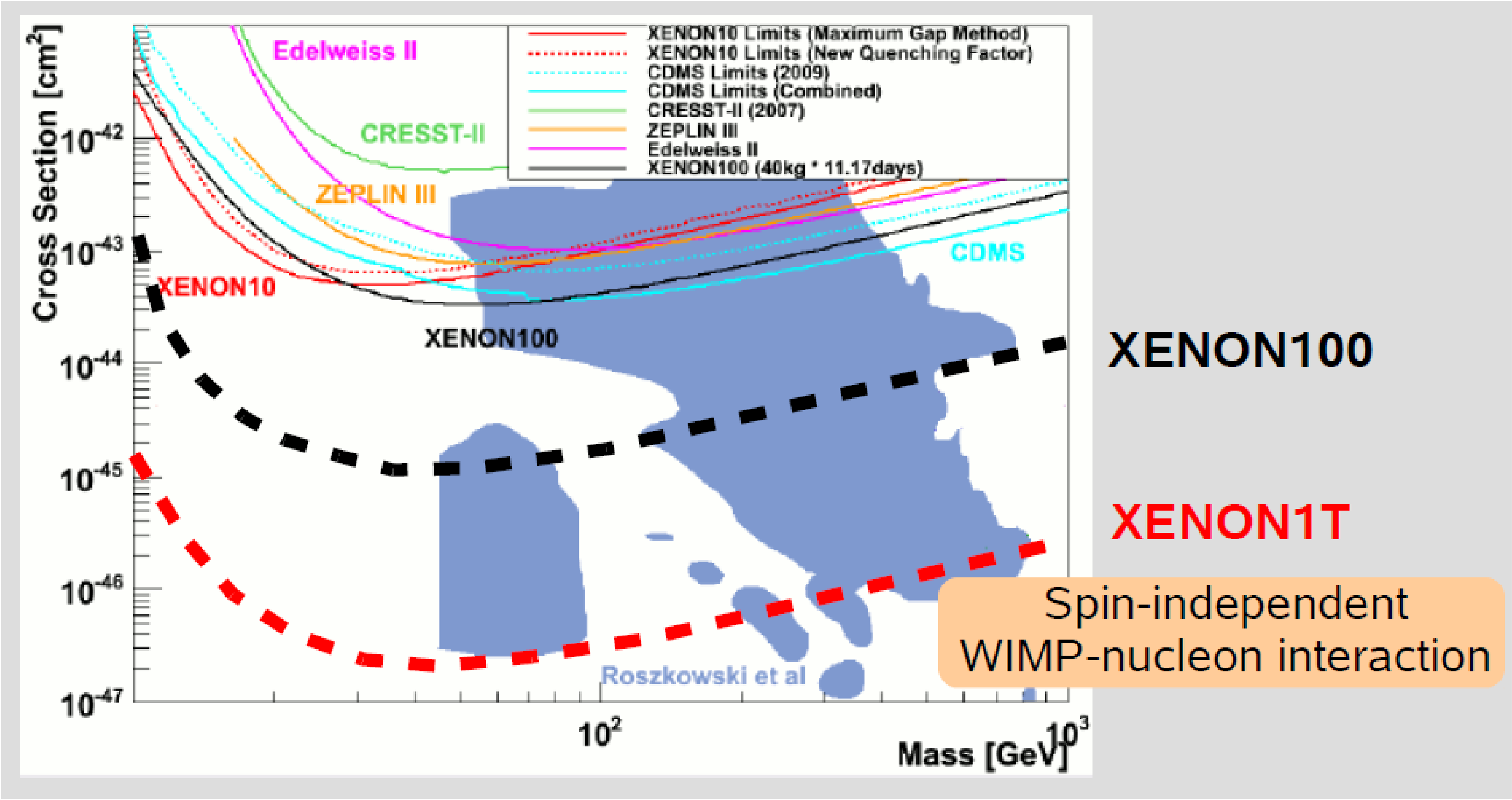




With respect to XENON100:
- ~ x20 fiducial mass
- ~ x100 lower background



The next step: XENON1T

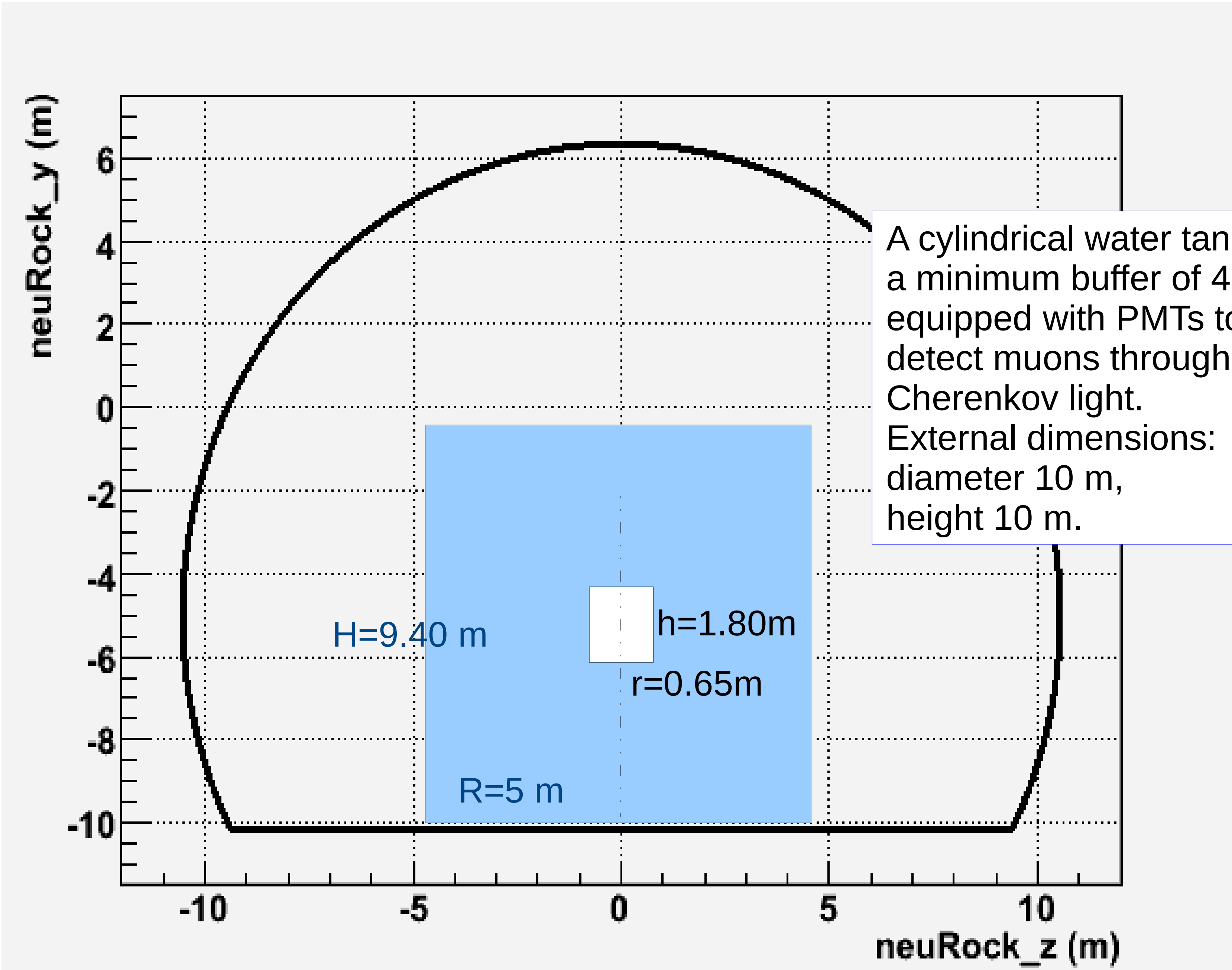


Where and how? 2 options

- LNGS, with a water tank acting as a muon veto and shield.
- LSM, with a polyethylene/lead shield and plastic scintillators for the muon veto.

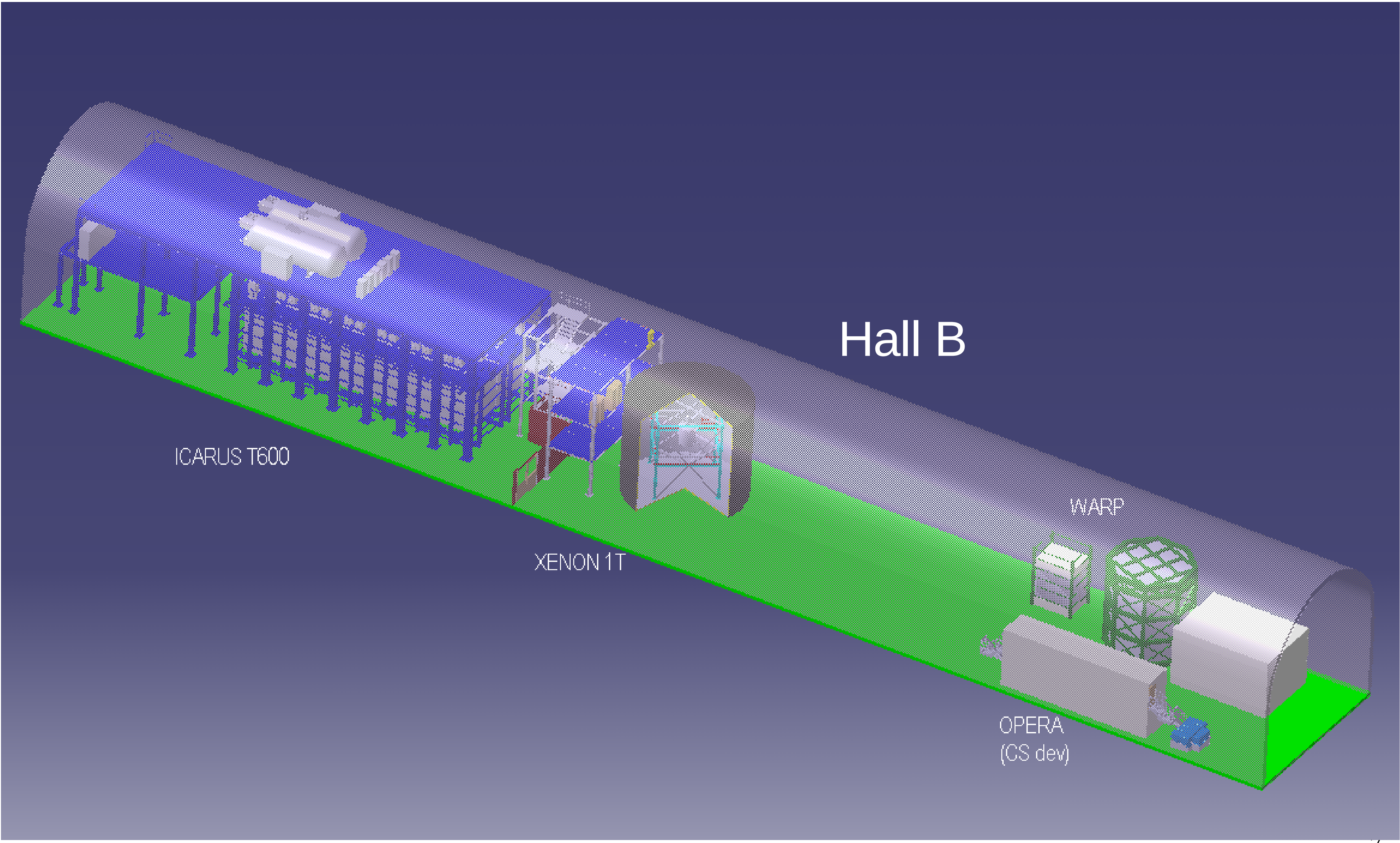
See Cecilia Levy poster for more details on the simulations of the shield at LSM

Water shield @ LNGS



A cylindrical water tank with a minimum buffer of 4-5 m, equipped with PMTs to detect muons through Cherenkov light.
External dimensions:
diameter 10 m,
height 10 m.

Water shield @ LNGS



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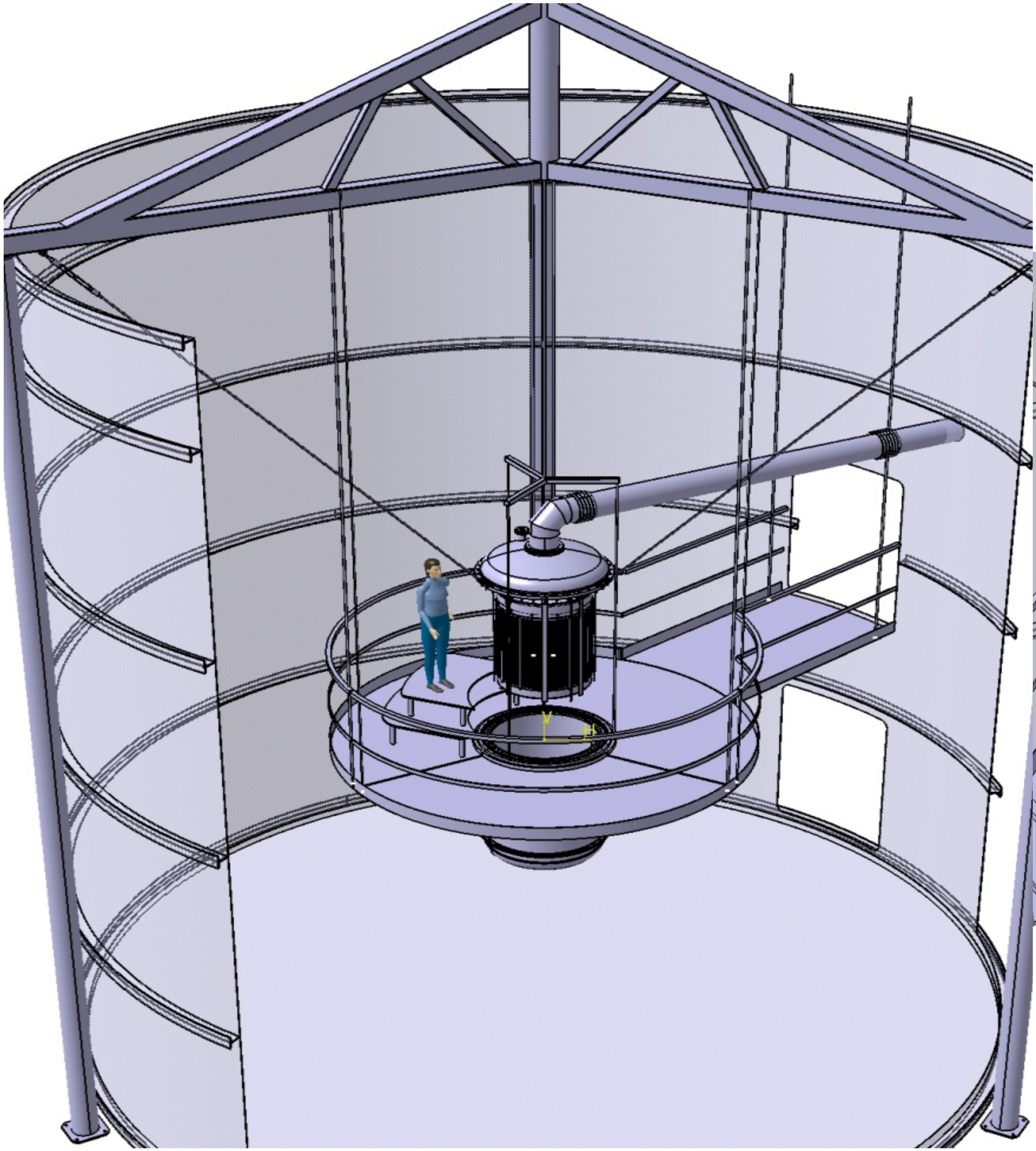
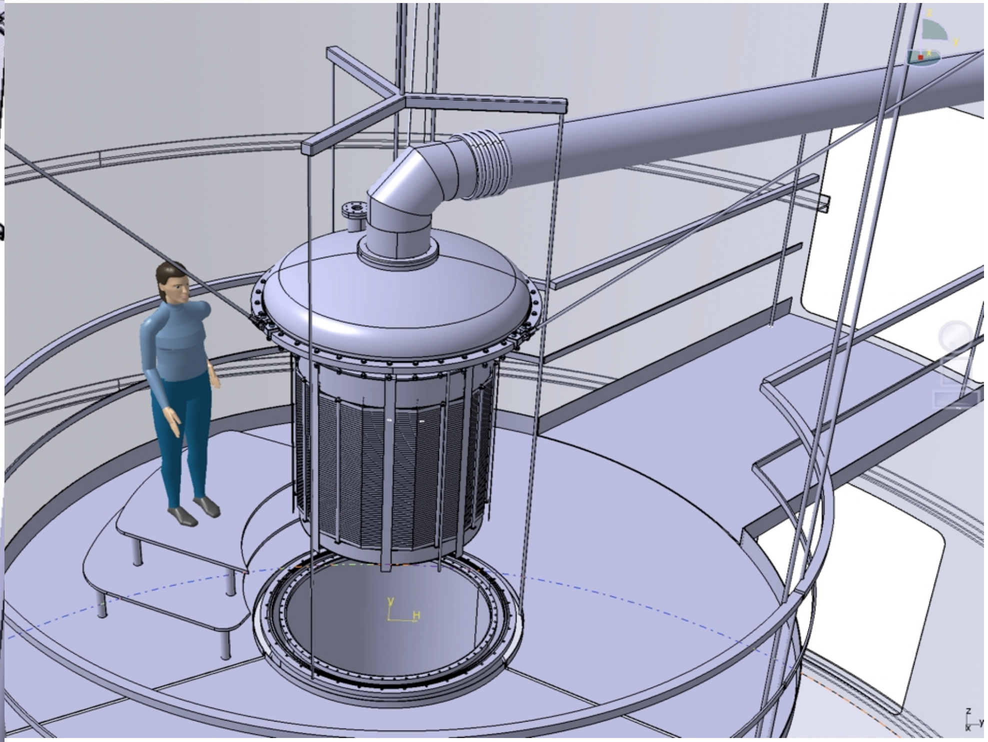
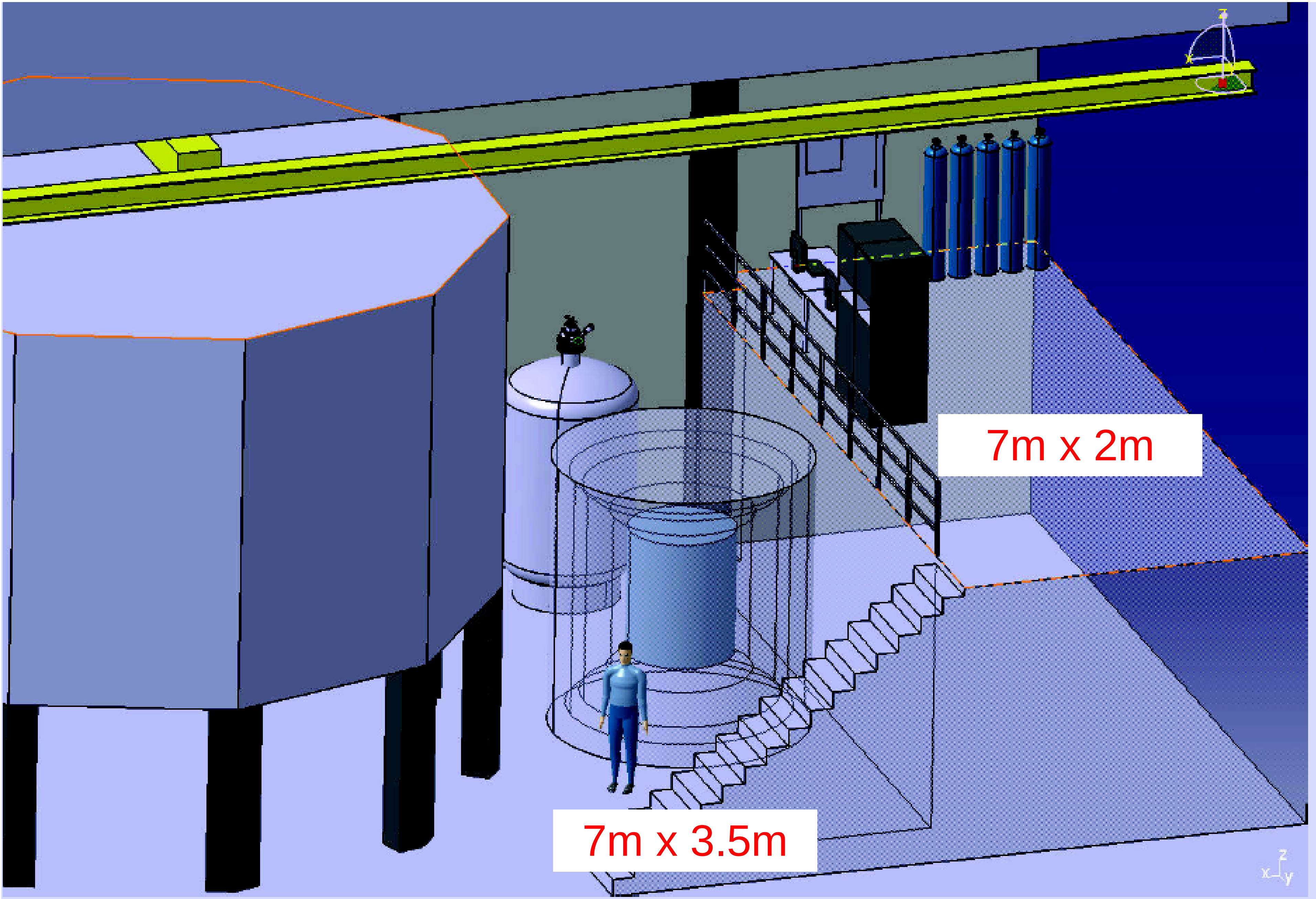
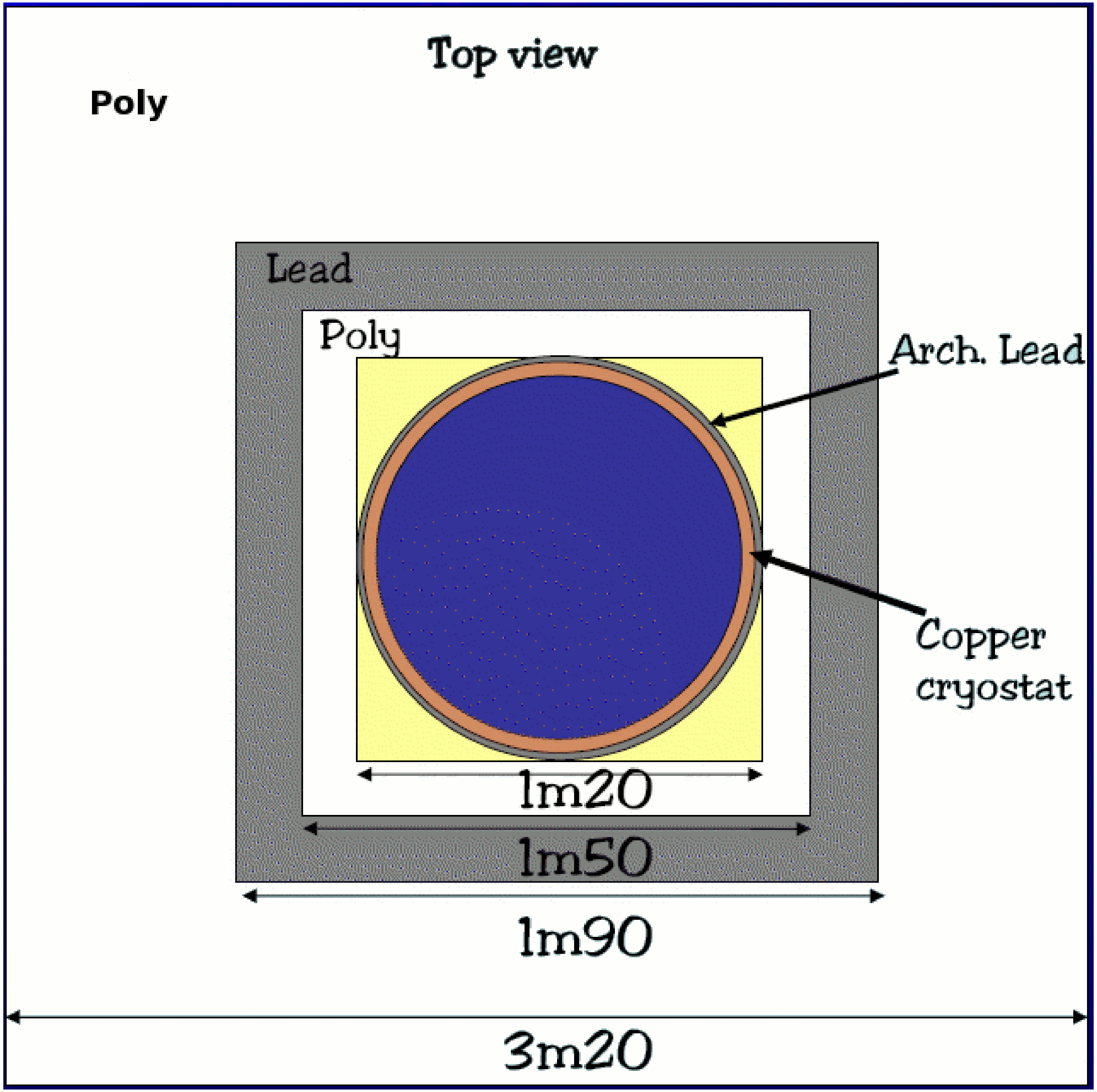




Pb/poly shield @ LSM



Pb/poly shield @ LSM



From external to internal
the shield is made of:
- Poly 55 cm,
- Pb 20 cm,
- Poly 15 cm,
- Arch. Pb 2 cm.

A muon veto is foreseen all
around the external Poly box.

Sources of ext. background

- Gammas from the environment
- Neutrons from rock radioactivity
- Muon-induced neutrons in the rock
- Muon-induced neutrons and gammas in the shield itself

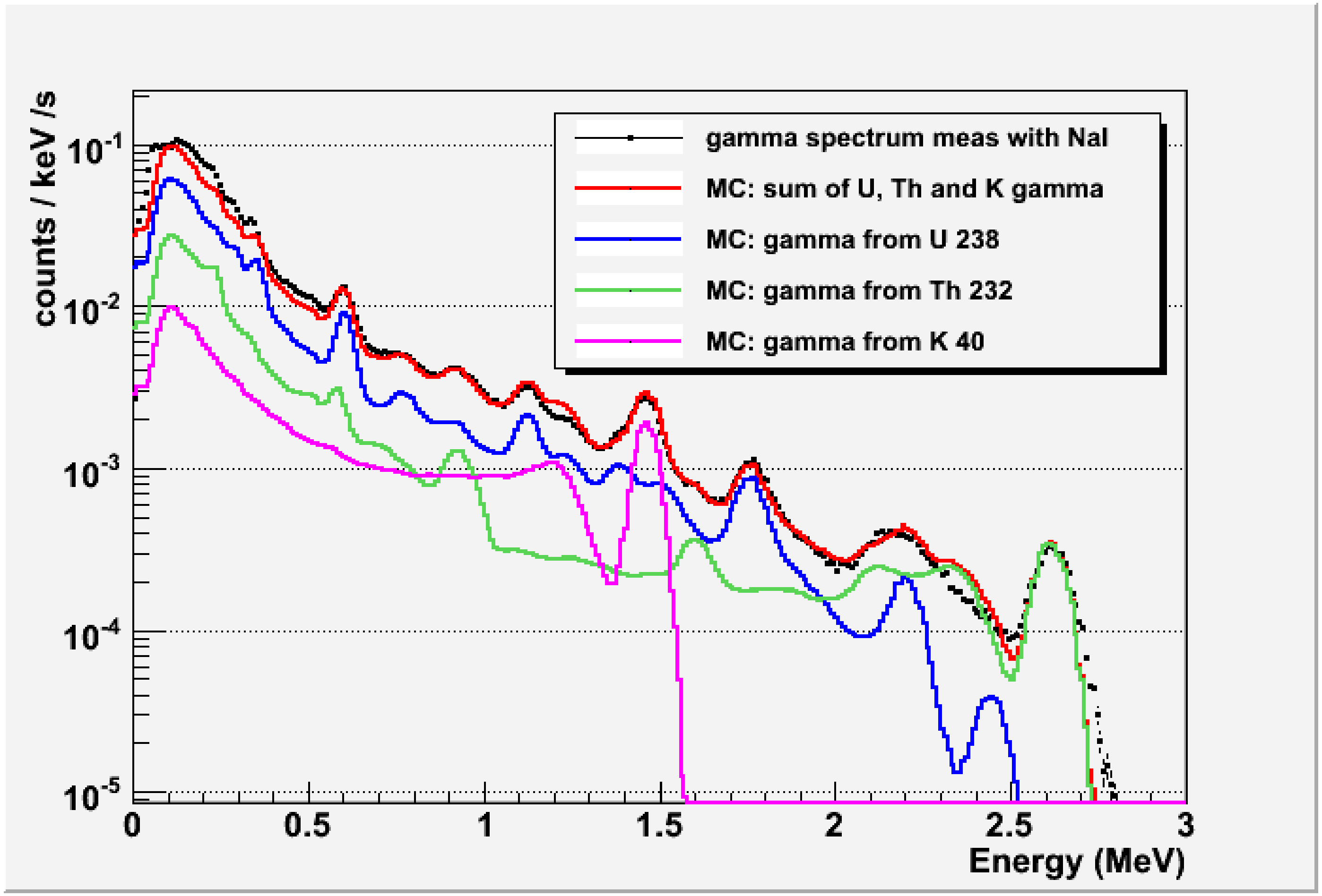
Gamma background

Gamma spectrum @ LNGS

Gamma background at LNGS measured in hall B with a 2” NaI detector.

The MC is done generating U, Th and K gammas isotropically inside the LNGS concrete (30 cm thick), and simulating the response of a 2” NaI detector, smeared with its energy resolution.

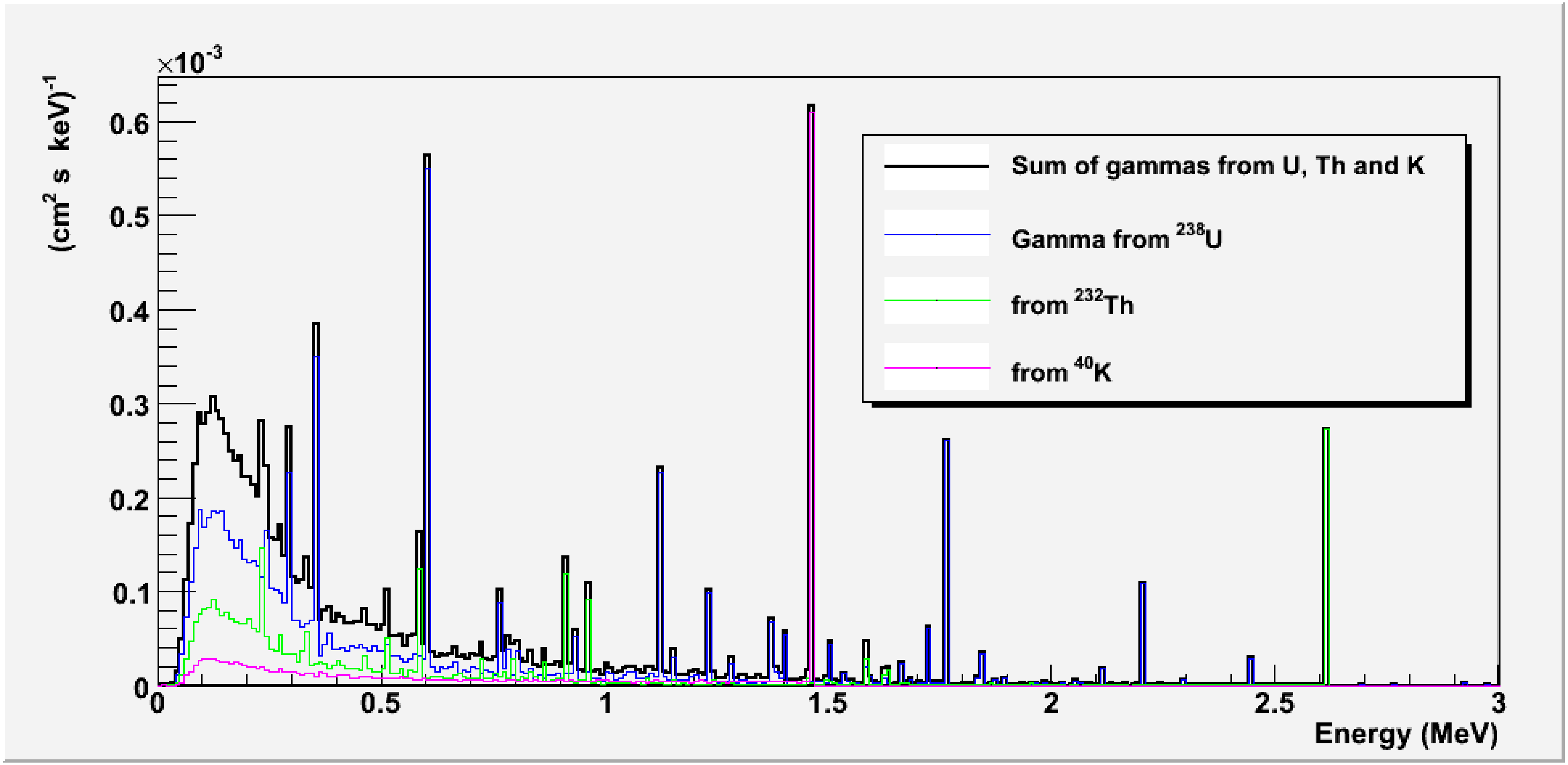
Then the weight of the 3 contributions are chosen to match best their sum (red histo) with the measured spectrum (black dots).



The agreement between data and MC simulation is very good, especially for E> 500 keV

Gamma spectrum @ LNGS

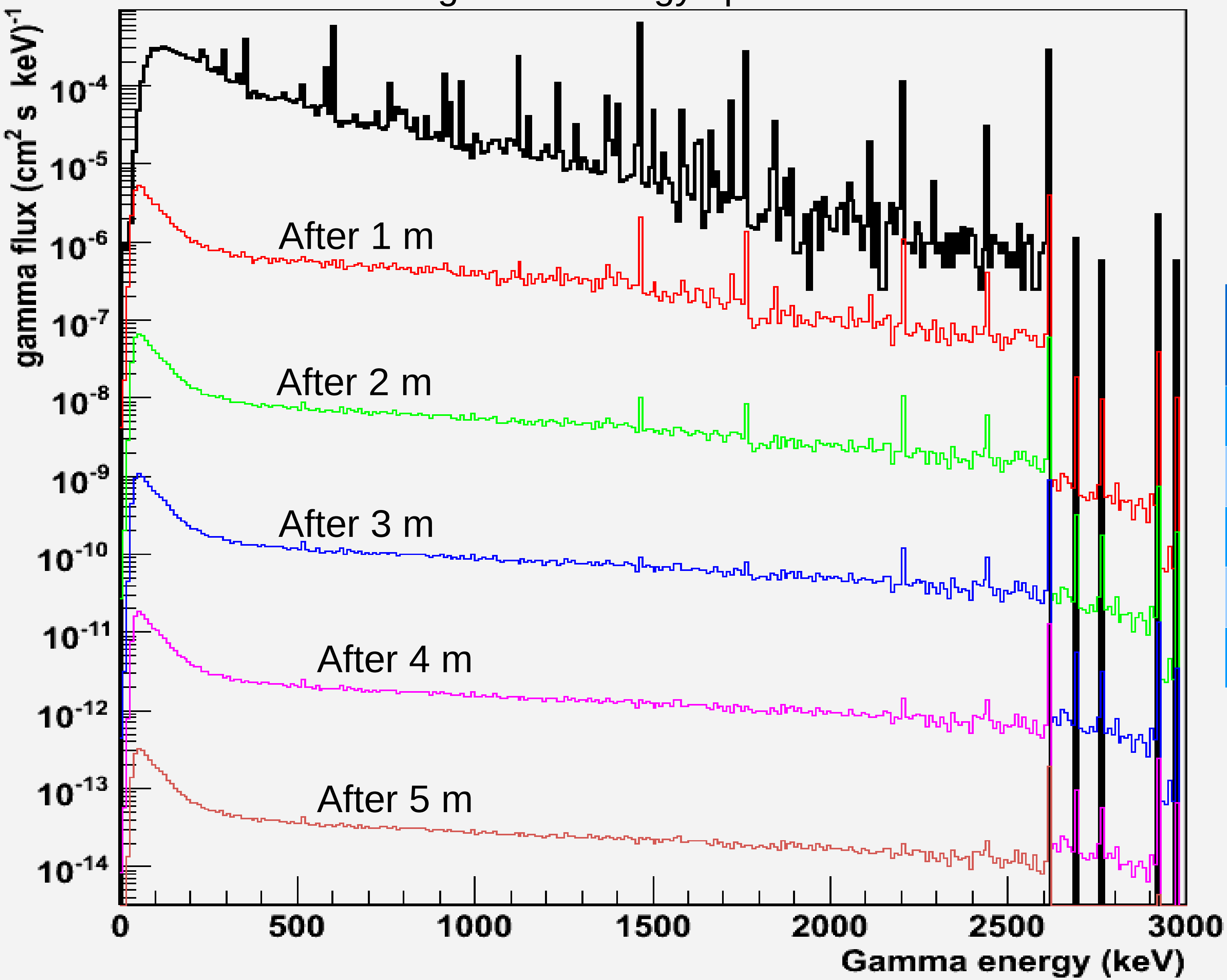
With the relative weights obtained in the previous picture we get the gamma spectrum in the Hall (black histo). This is the input spectrum for our shield.



The total flux is 0.13 gamma / (cm^2 s) i.e. 1.13 10^8 gamma / (m^2 day)

Water shield for gammas

The thick line is the gamma energy spectrum before the shield.
The thin lines are the gamma energy spectrum after each meter of water.



Total gamma flux outside the shield:
$1.3\ 10^{-1}$ $(cm^2\ s)^{-1}$

Water buffer (m)	Flux reduction
1	$1.0\ 10^{-2}$
2	$1.2\ 10^{-4}$
3	$1.9\ 10^{-6}$
4	$6.2\ 10^{-8}$
5	$3.0\ 10^{-10}$

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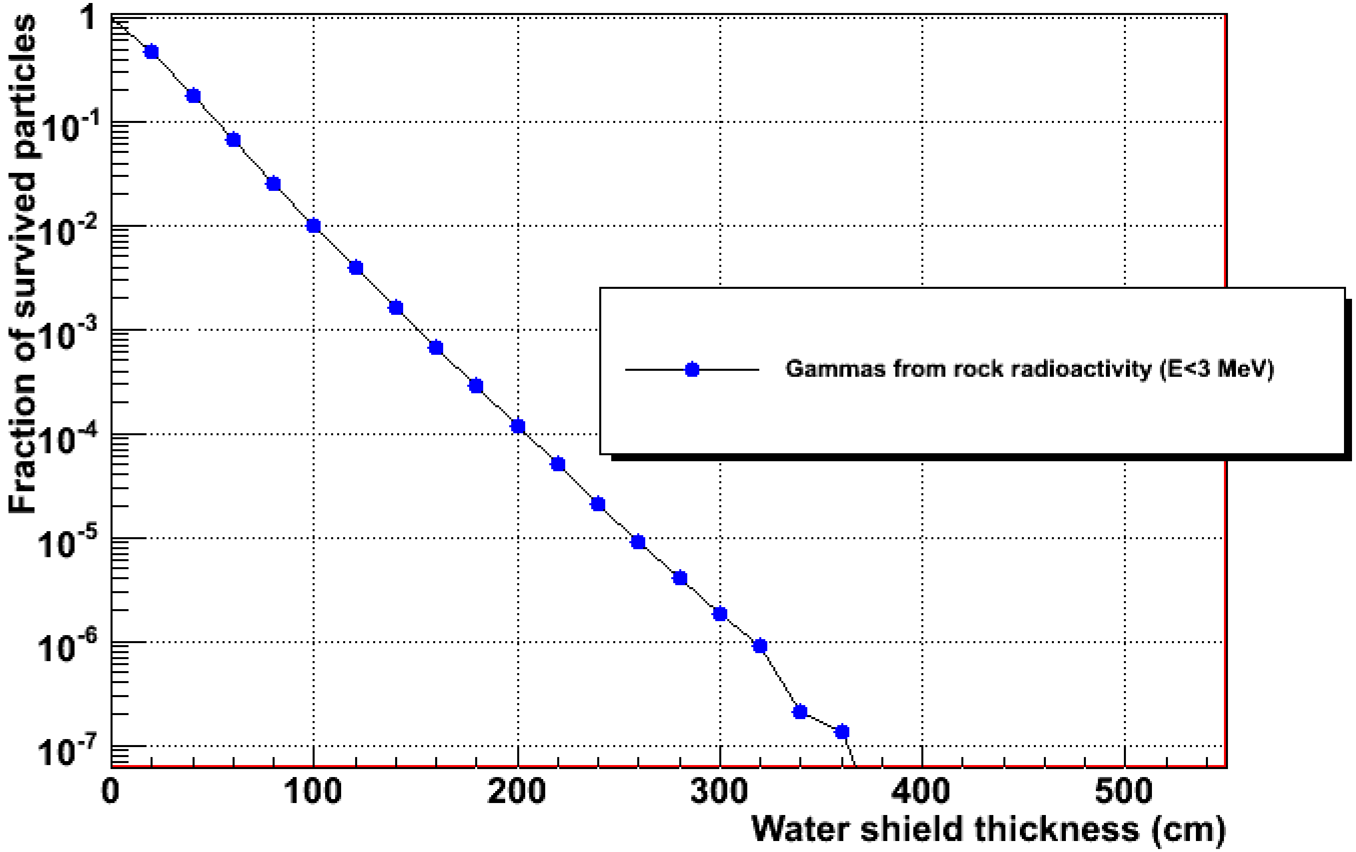

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Water shield 3m: γ in LXe

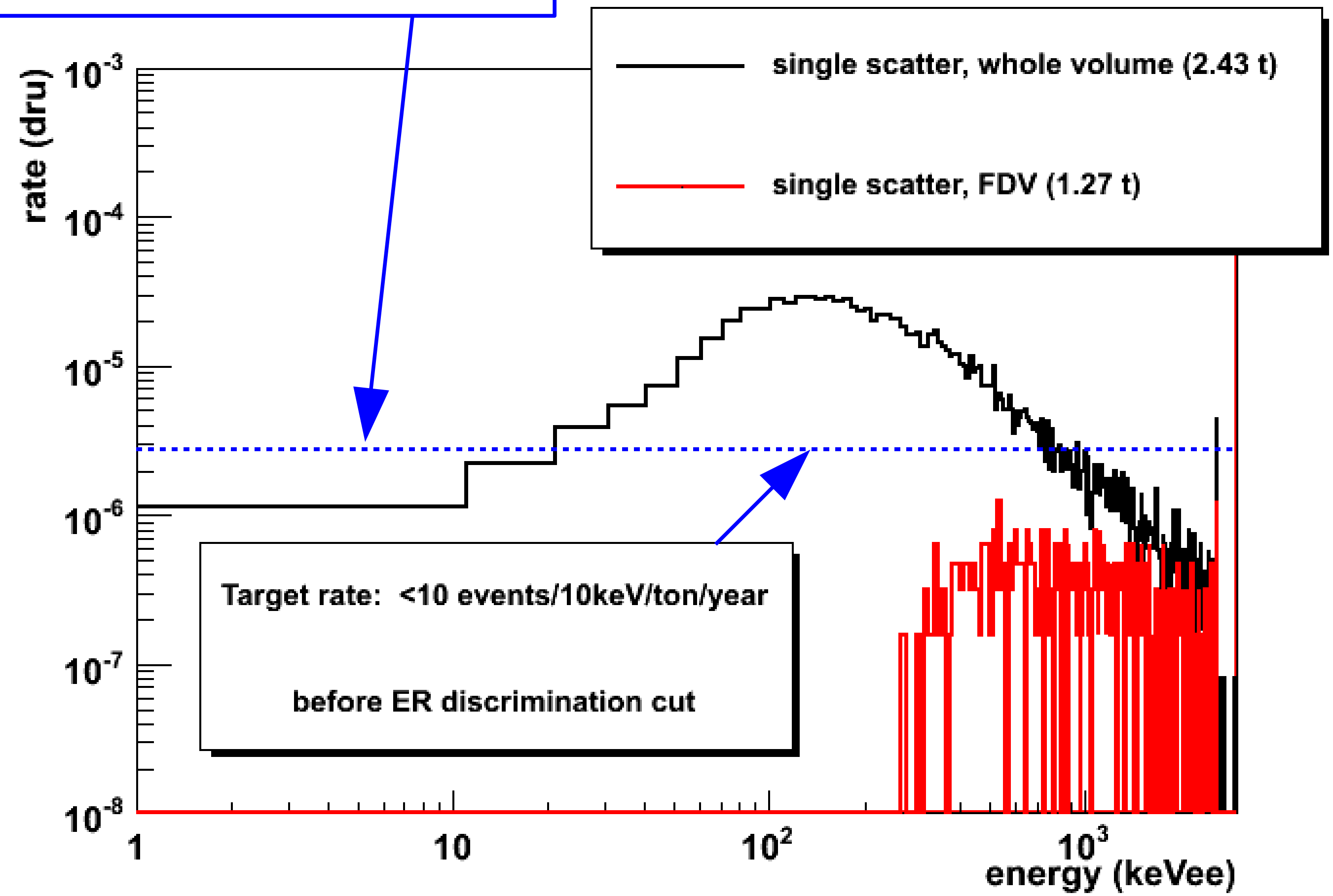
Background rate allowed to detect WIMPs with $\sigma \sim 10^{-47}$ cm^2.

Selection criteria:

- Single scatter
(segmentation: 3mm along Z)

- Fiducial volume:
remove the most external 10 cm of LXe

- NR-ER discrimination cut
(through the ratio S1/S2): we assume 1% contamination of ER



Conclusion: 3 m of water is well enough to shield external gammas.

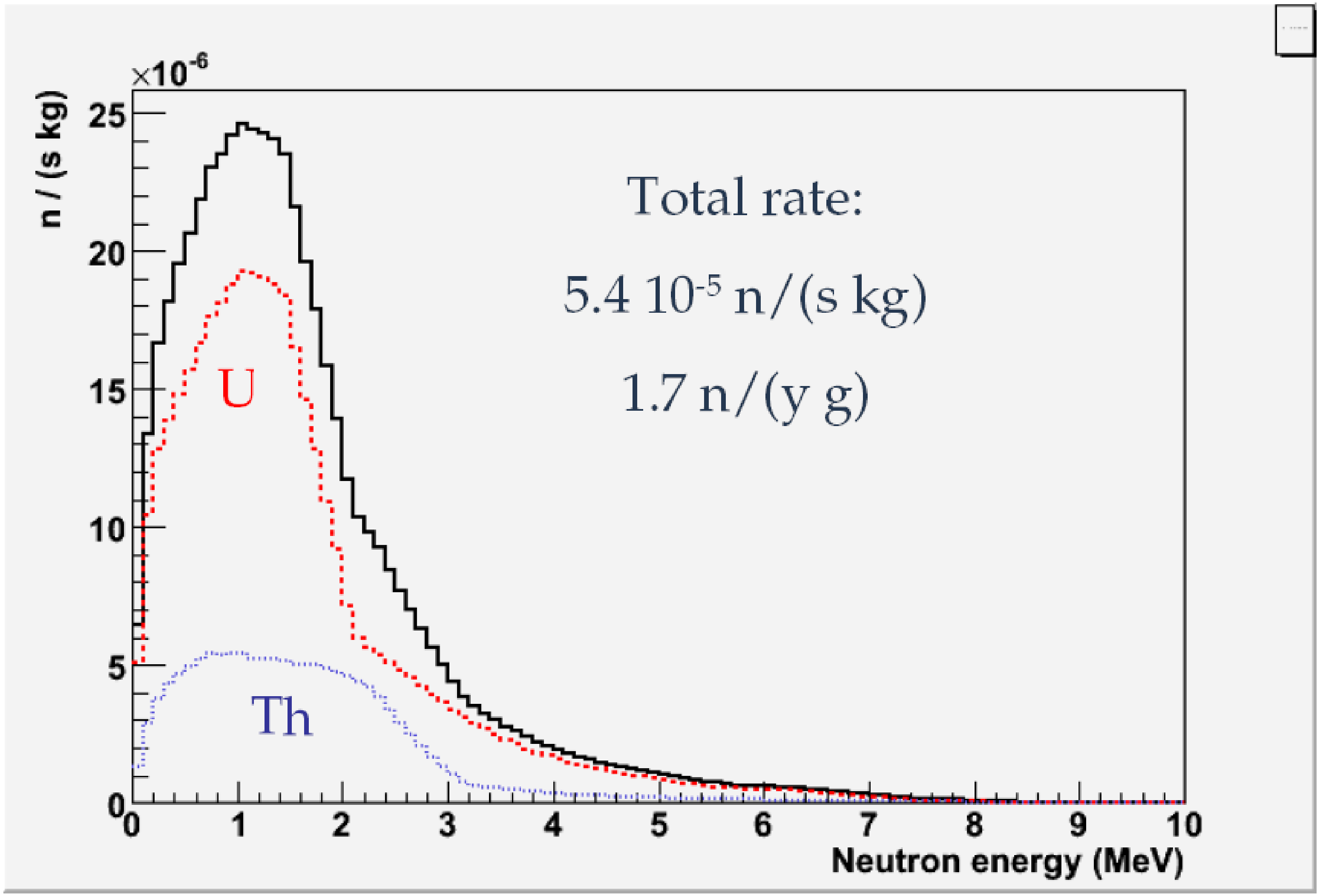
We'll have less than 0.001 evts/10keVee/ton/year in the 1.2 ton FDV after ER discrimination cut.

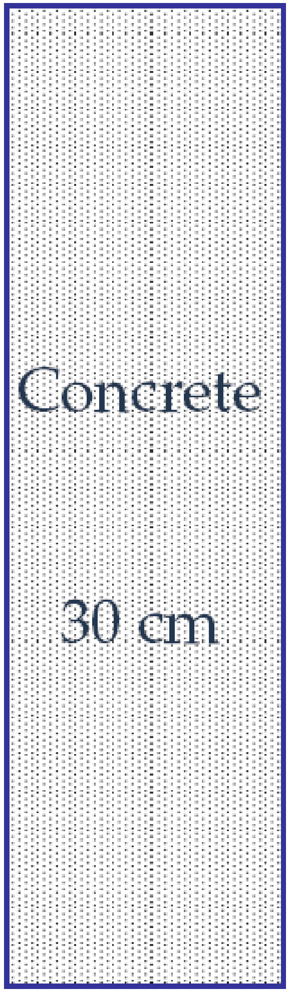
Neutrons from rock and concrete radioactivity

Neutrons from fission and (α, n) in LNGS concrete

Neutrons from ^{238}U fission and (α,n) and ^{232}Th (α,n), generated with the modified SOURCES code in concrete

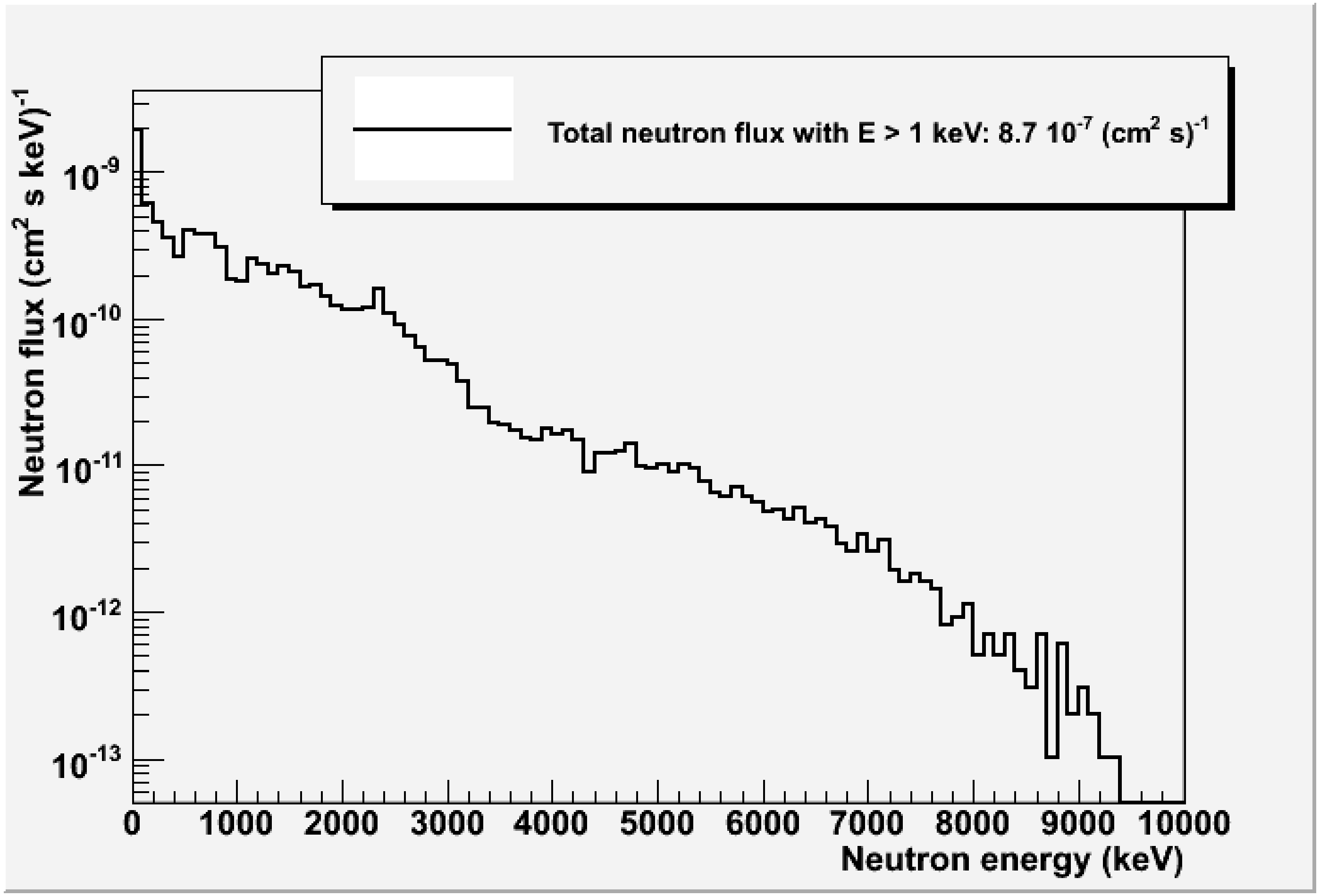
[U]=1.05 ppm, [Th]=0.656   from Wulandari et al., hep-ex/0312050 v2



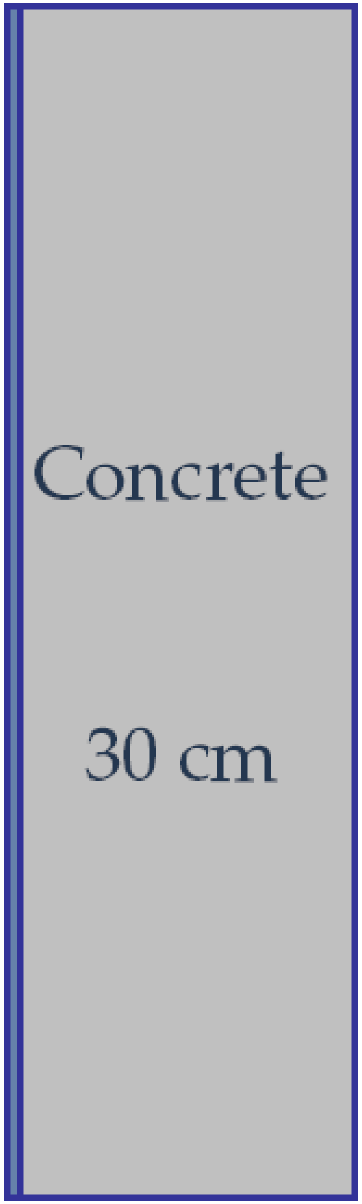


Neutrons from fission and (α, n) in LNGS concrete

Neutron flux at the surface of LNGS concrete

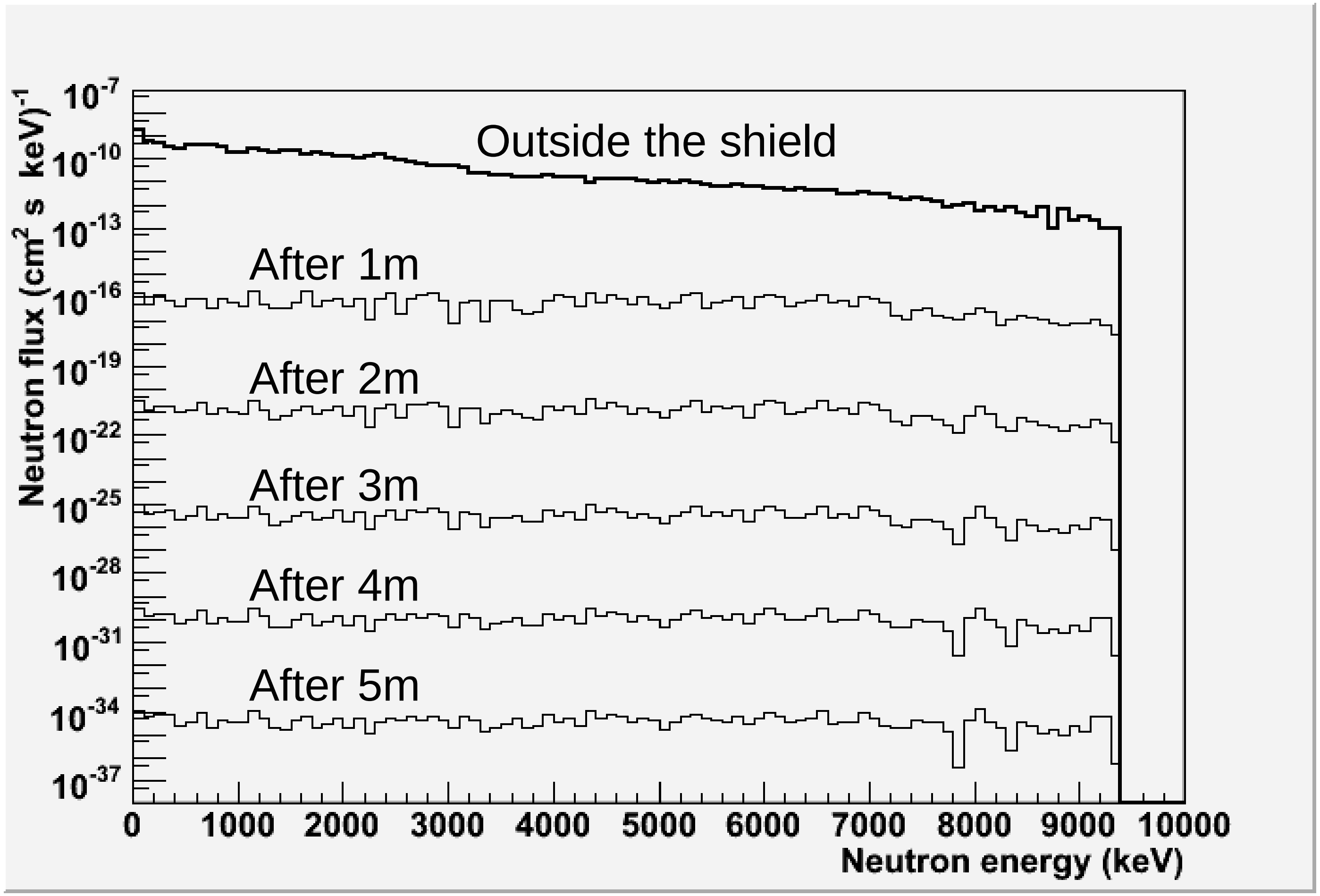


Consistent with the measurements and simulations listed in Wulandari et al., hep-ex/0312050v2 , table 8.



Water shield for neutrons

The thick line is the neutron energy spectrum before the shield.
The thin lines are the n energy after each meter of water.

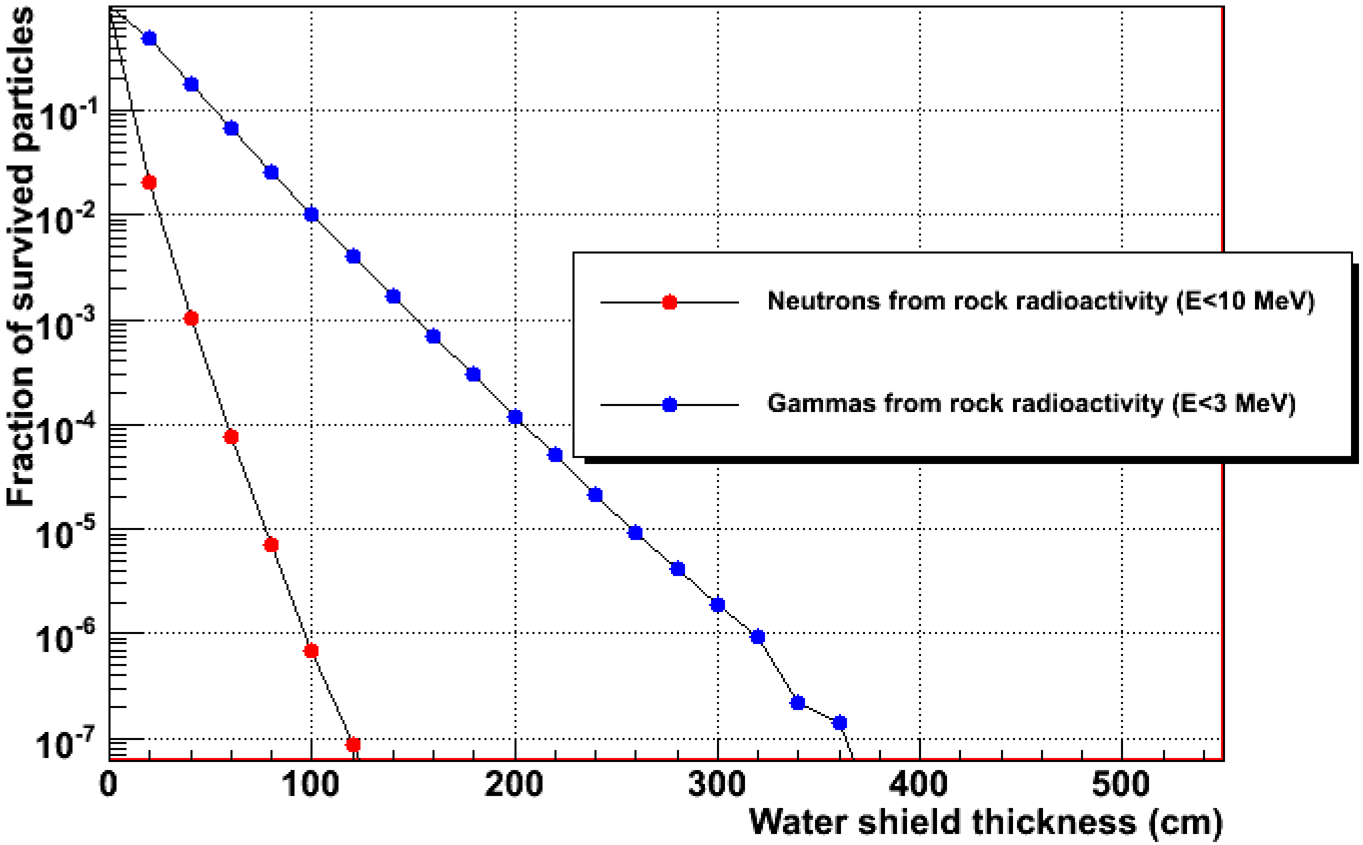


Total neutron flux outside the shield:
$8.7\ 10^{-7}$ n / (cm^2 s)

Water buffer (m)	Flux reduction
1	$7.\ 10^{-7}$
2	$1.4\ 10^{-11}$
3	$4.\ 10^{-16}$
4	$1.3\ 10^{-20}$
5	$5.0\ 10^{-25}$

After 3 m of water the neutrons coming from rock and concrete radioactivity are completely negligible.

Water shield for neutrons



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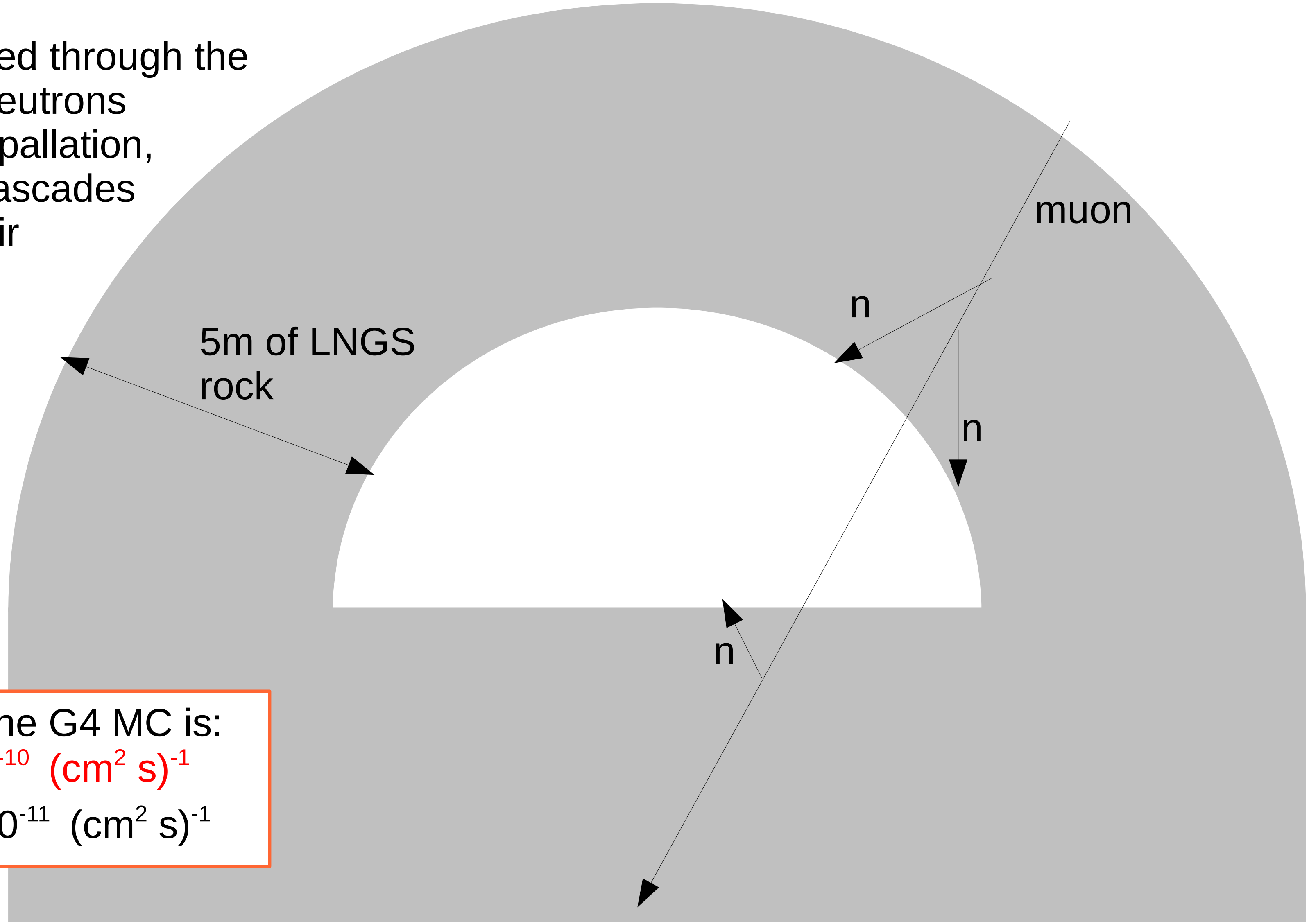
Muon-induced neutrons

MC simulation

10M muons were generated with Geant4 (physics list QGSP-BIC-HP) with the proper energy and angular distribution.
They were sampled over a large area: a circle with 15m radius, corresponding to about 500 days at Gran Sasso.
Muons are propagated through the LNGS rock, all the neutrons produced by direct spallation, e.m. and hadronic cascades are followed and their entrance point and momentum at the hall surface is recorded.



The total flux from the G4 MC is:
E_n> 10 MeV: 1.3 10^{-10} $(cm^2\ s)^{-1}$
E_n> 100 MeV: 3.7 10^{-11} $(cm^2\ s)^{-1}$

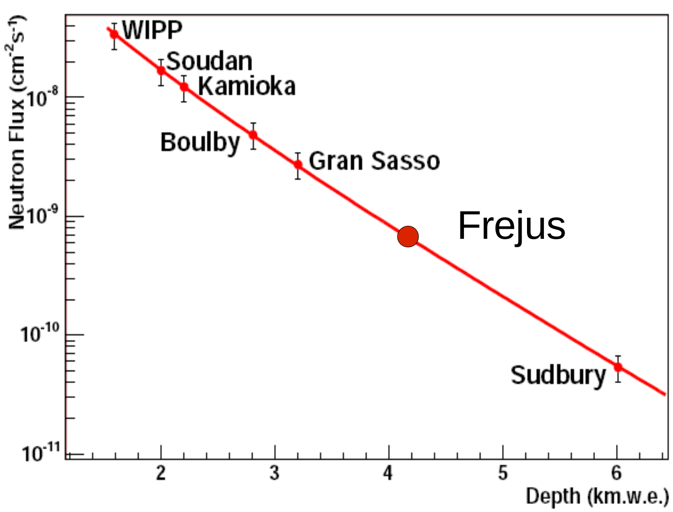
Neutron flux & energy

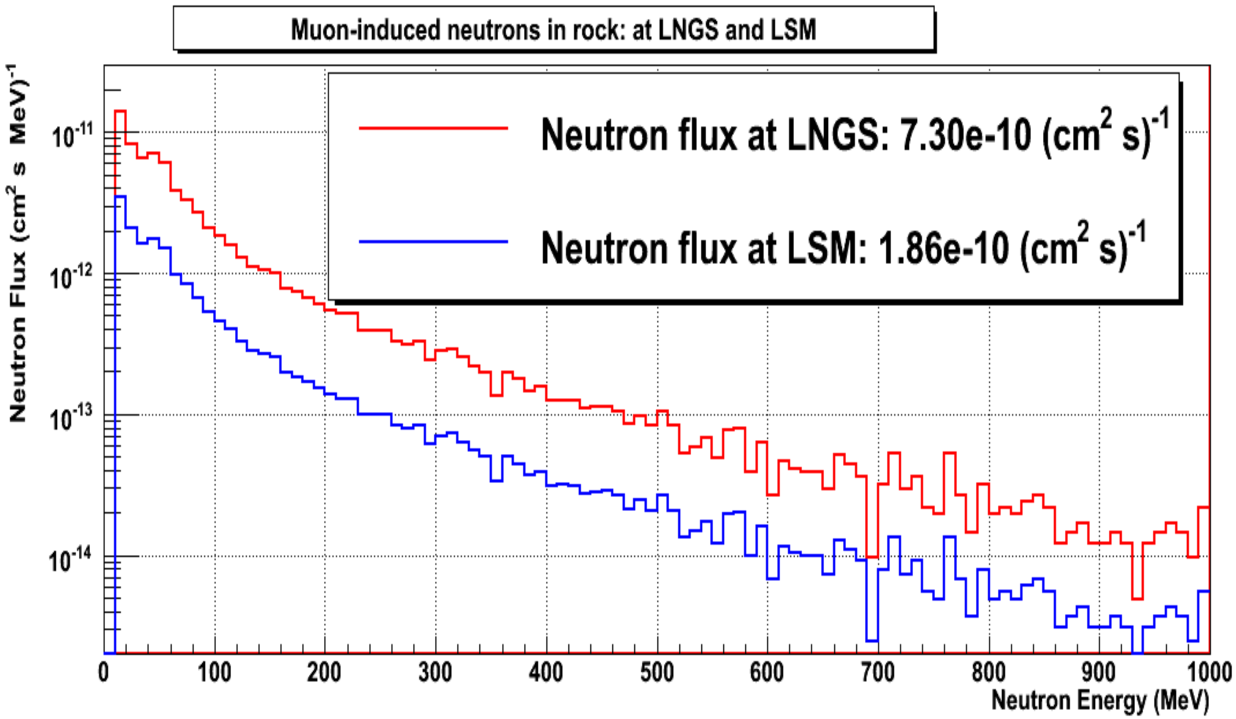
To be conservative, we scale the total neutron flux to the results obtained with FLUKA by Mei and Hime, Phys. Rev. D 73, 053004 (2006): $E_n > 10$ MeV: $7.3\ 10^{-10}\ (cm^2\ s)^{-1}$

The neutron flux (ϕ_n) as a function of depth is shown in Fig. 14 where we have included a fit function of the following form:

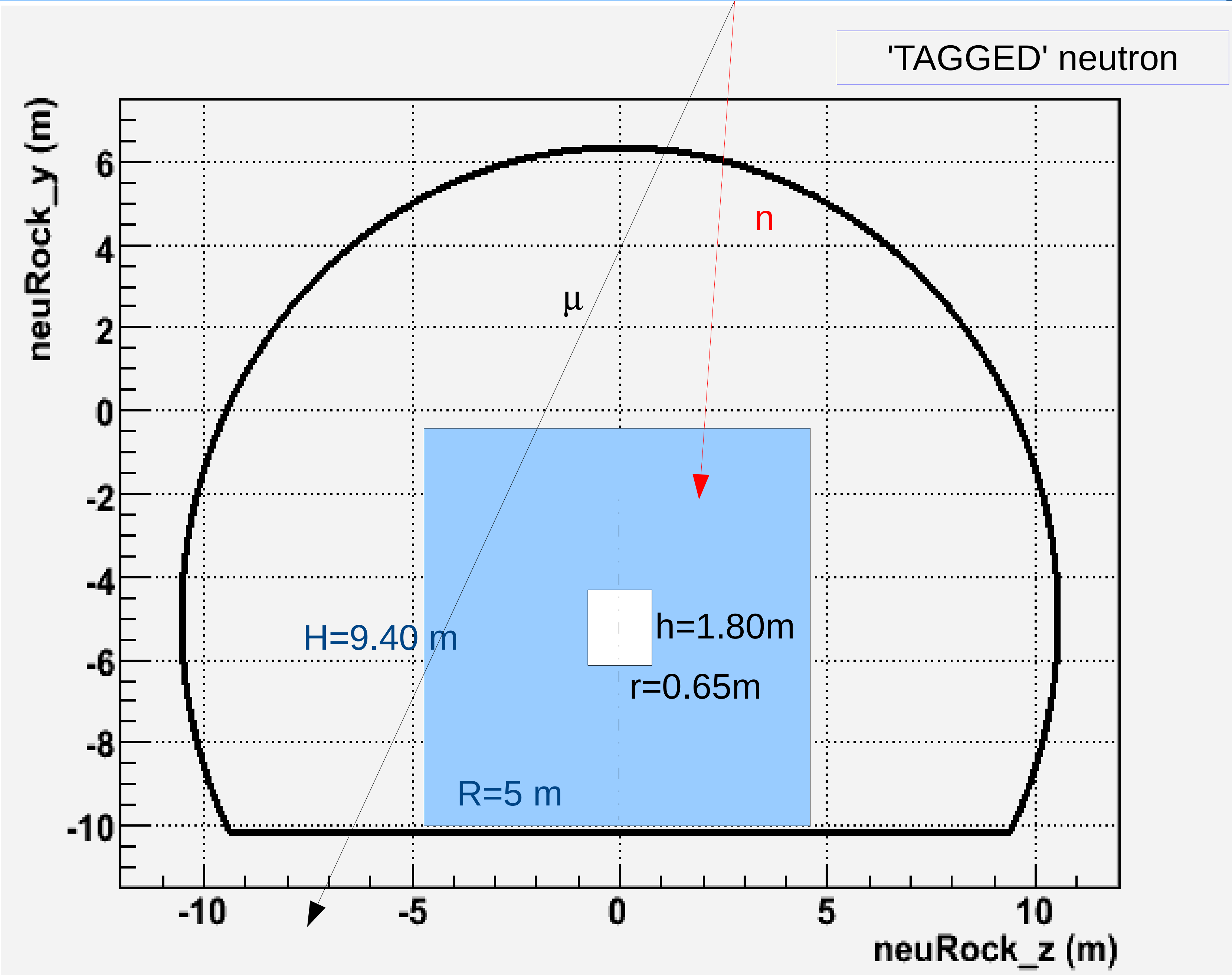
$$\phi_n = P_0(\frac{P_1}{h_0})e^{-h_0/P_1}, \qquad (13)$$

where h_0 is the equivalent vertical depth (in km.w.e.) relative to a flat overburden. The fit parameters are $P_0 = (4.0 \pm 1.1)\times 10^{-7}$ cm^{-2}s^{-1} and $P_1 = 0.86 \pm 0.05$ km.w.e..

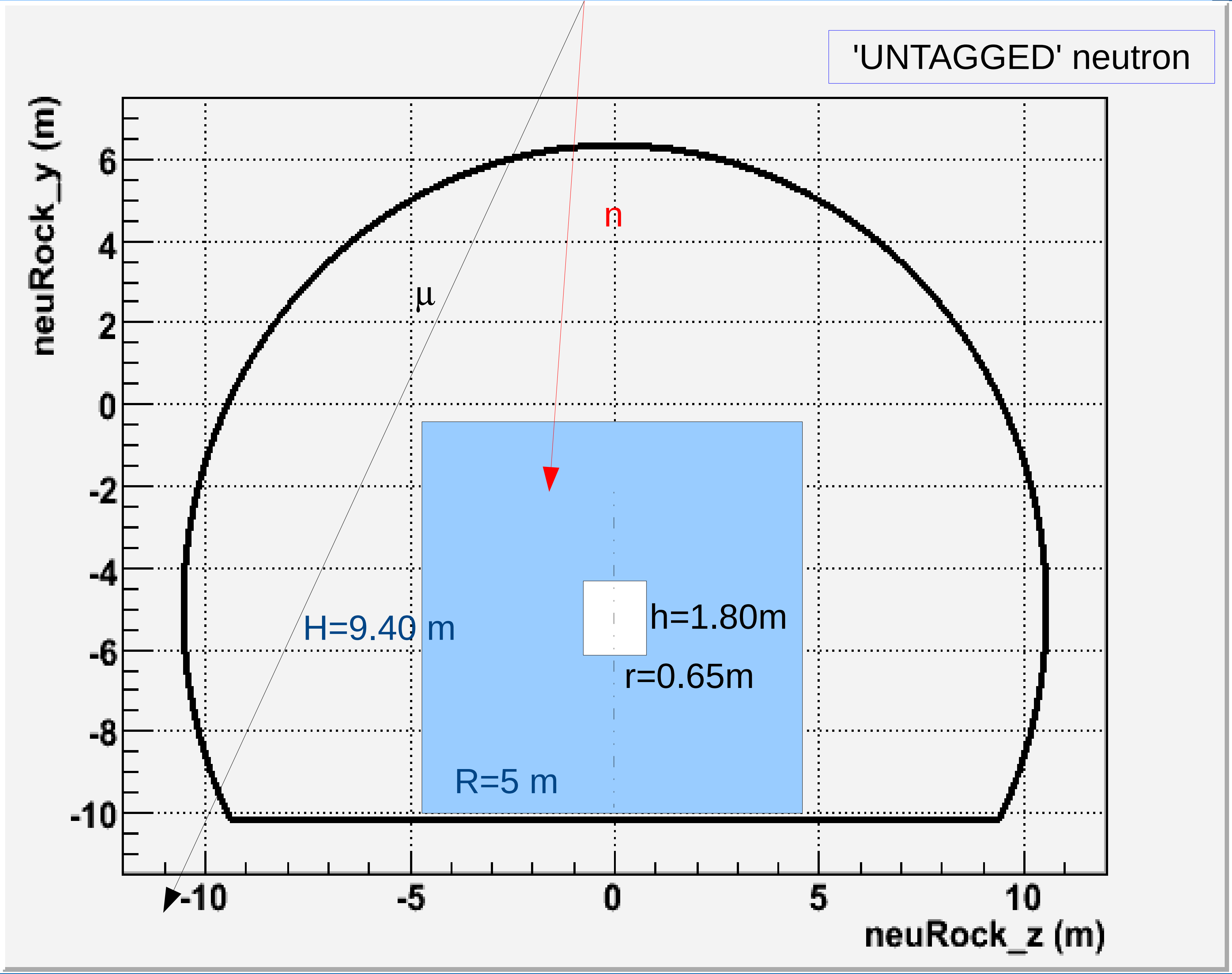




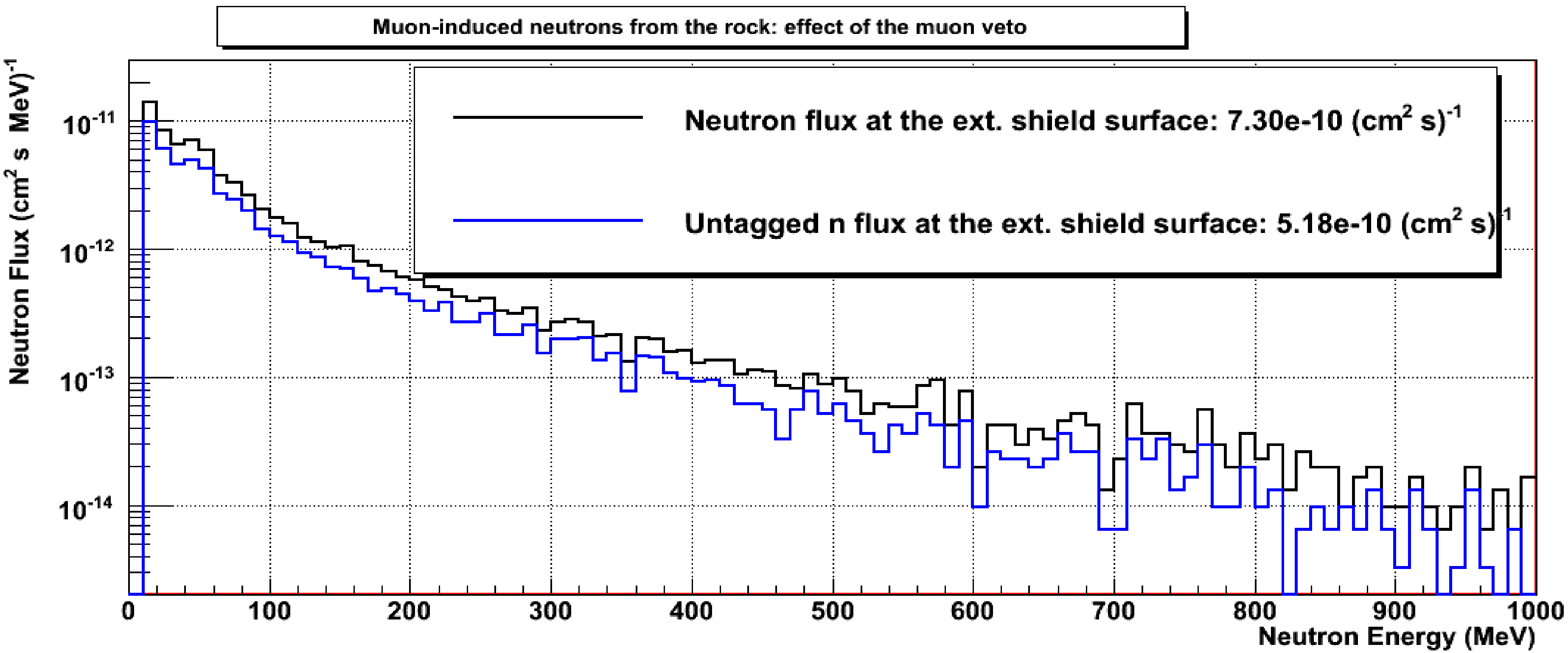
Veto and shield @ LNGS



Veto and shield @ LNGS



Effect of the muon veto

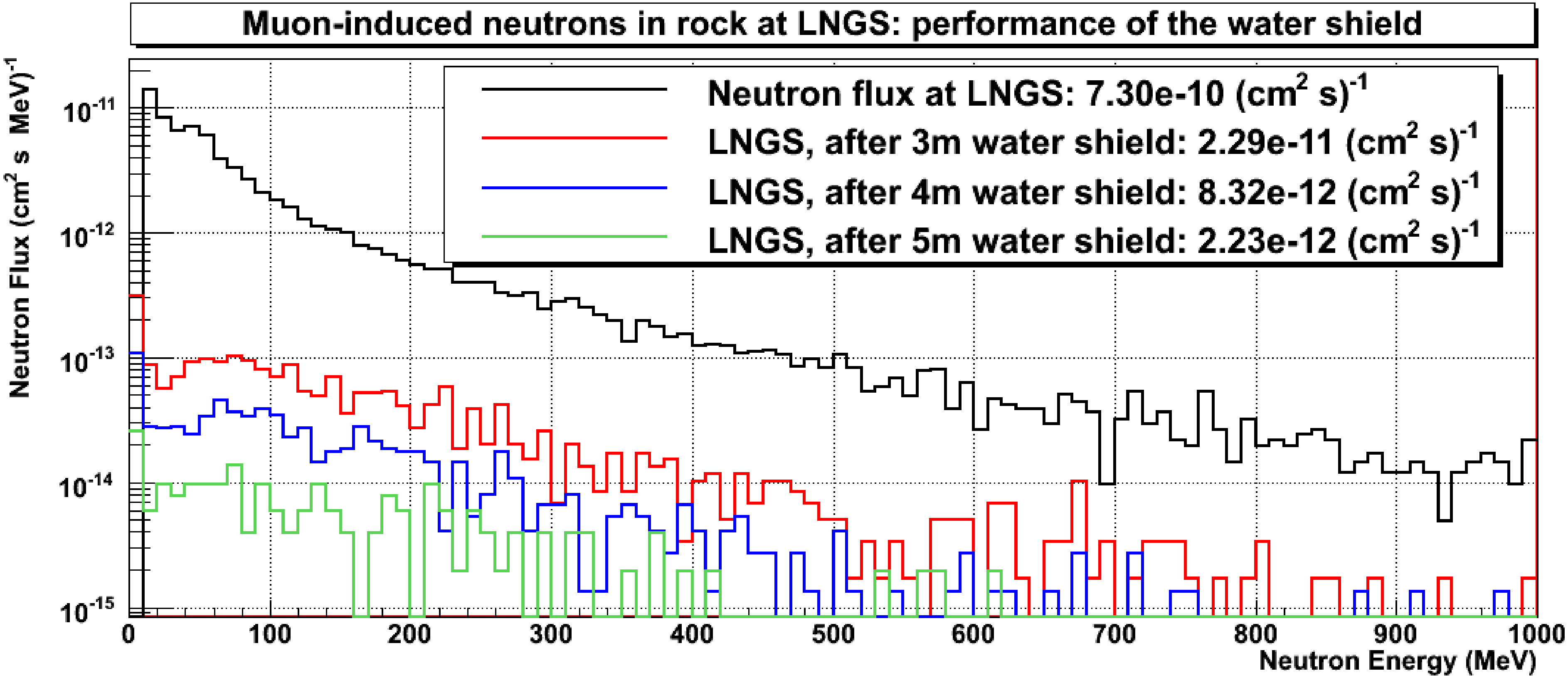


30% of the muon-induced neutrons
are removed by tagging the corresponding muon with the water Cerenkov muon veto.

+ effect of the water shield

Tagging muons with the active veto (water cerenkov) with a water buffer of 3, 4, 5 m allows to remove respectively about 20, 30, 40% of the neutrons produced in rock.

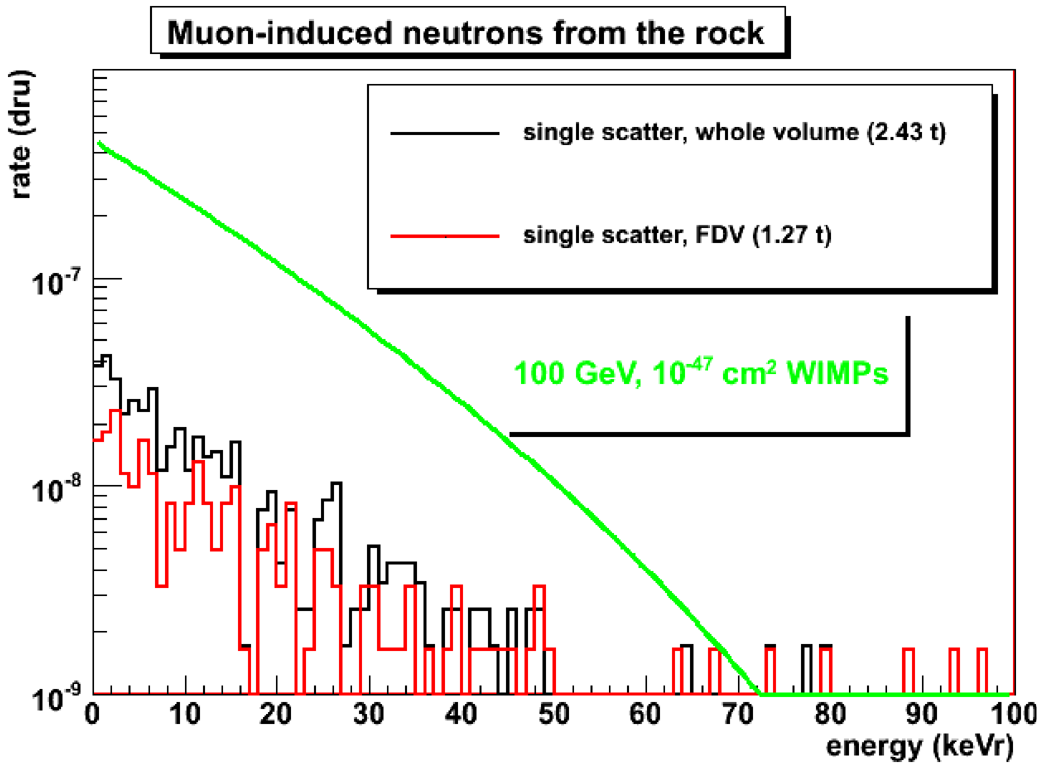
A further reduction of 96, 98, 99.5% of the neutrons is given by the moderation in the water shield itself.

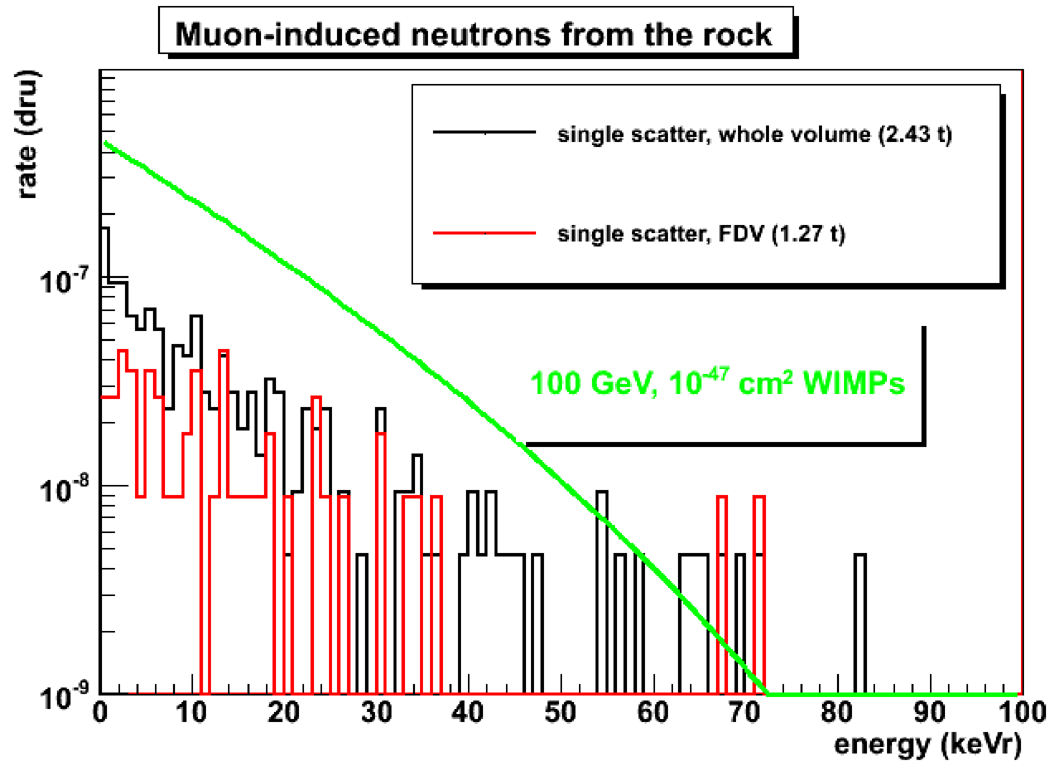


μ-induced neutron in LXe

XENON Dark Matter Project

LNGS Water shield	LSM Poly-Pb shield



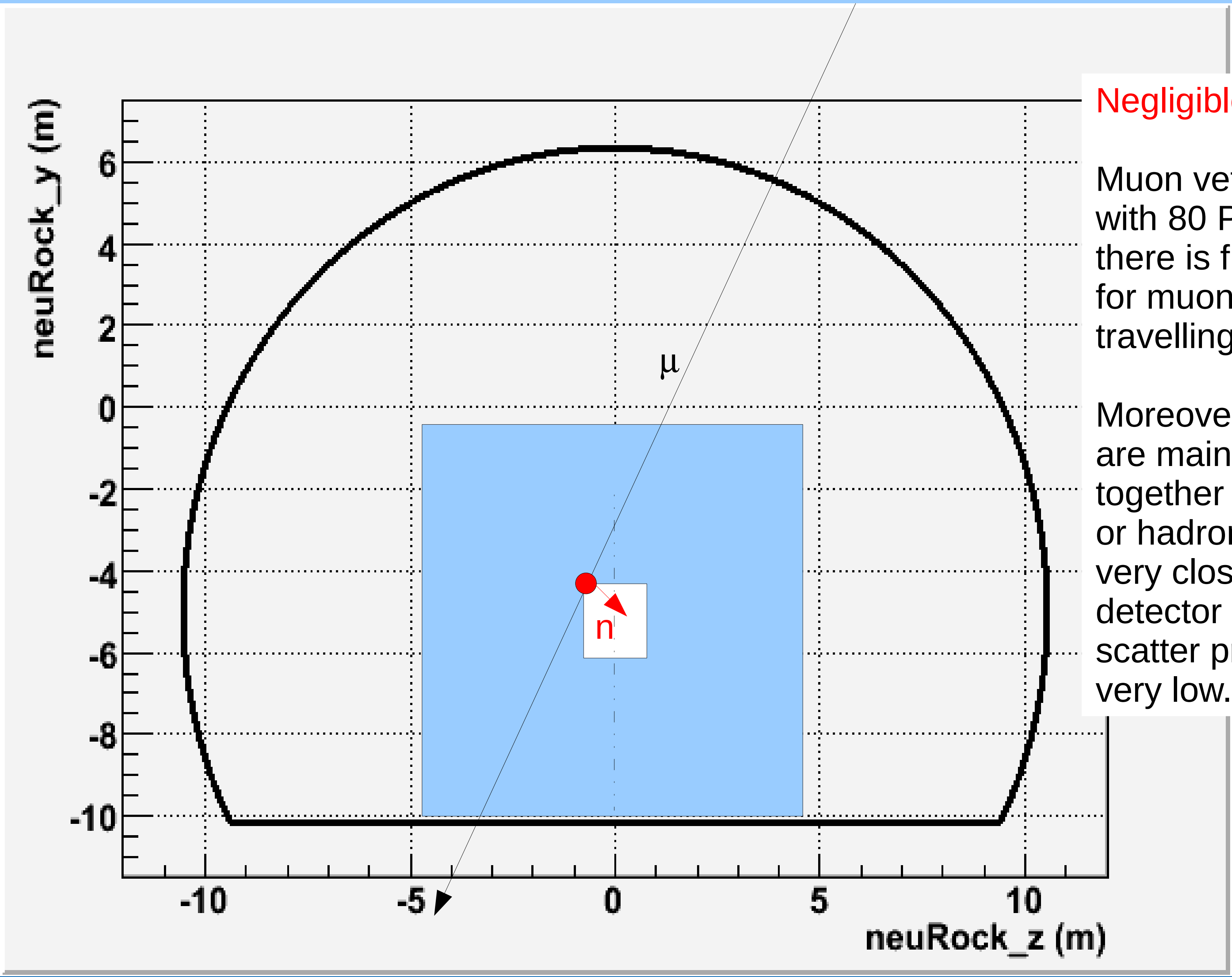


Single nuclear recoil rate in the fiducial volume in [7,45] keV

0.07 per year

0.14 per year

μ-induced n in the shield

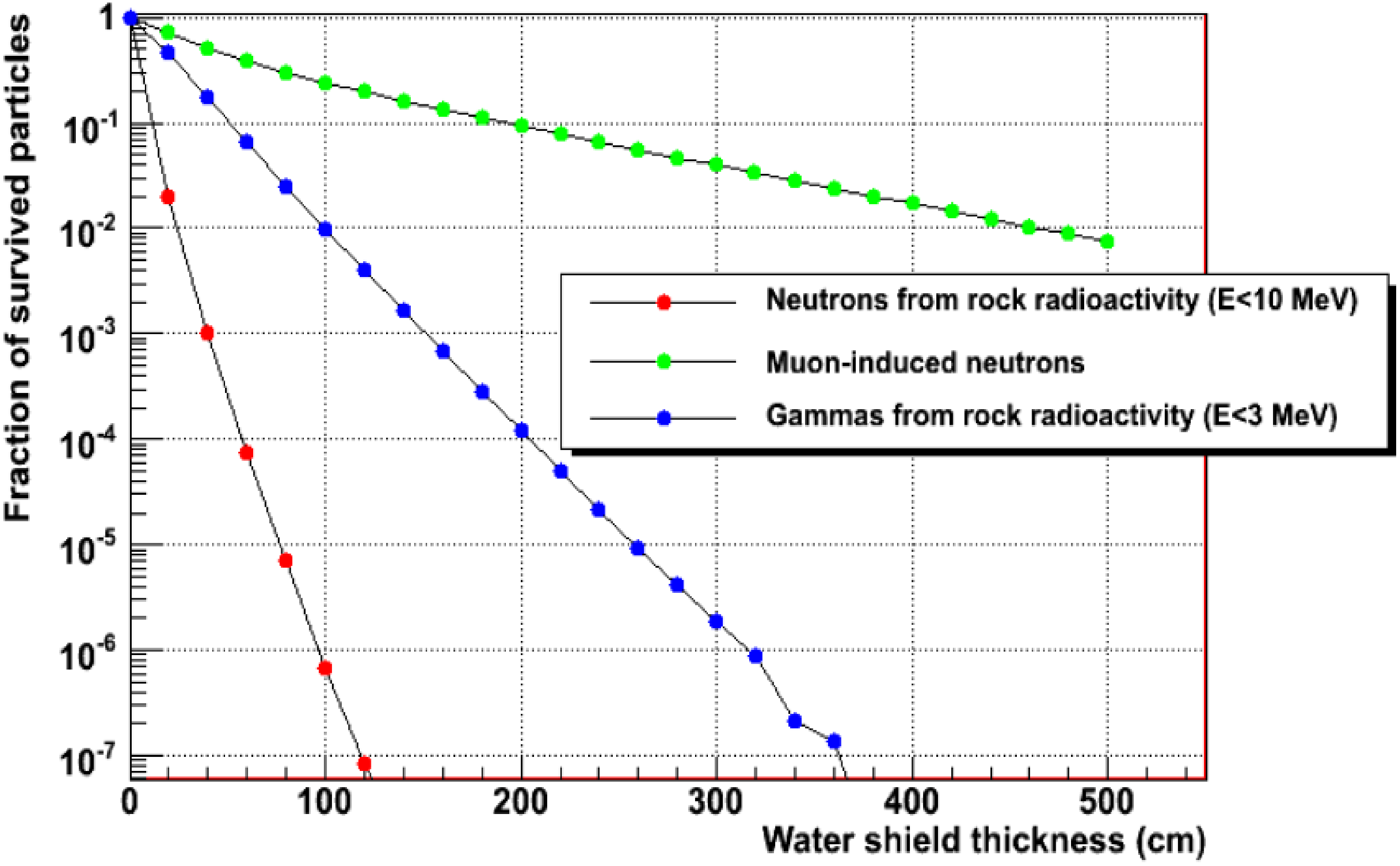


Negligible contribution.

Muon veto:
with 80 PMTs
there is full efficiency
for muons
travelling > 1m.

Moreover, neutrons are mainly produced together with an e.m. or hadronic cascade very close to the detector --> the single scatter probability is very low.

Water shield summary



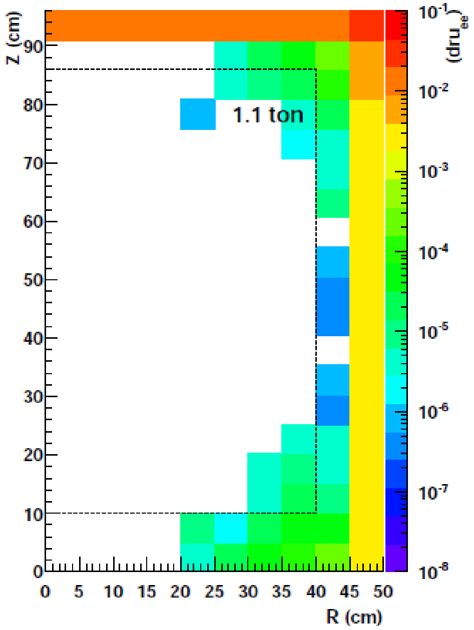
Conclusions

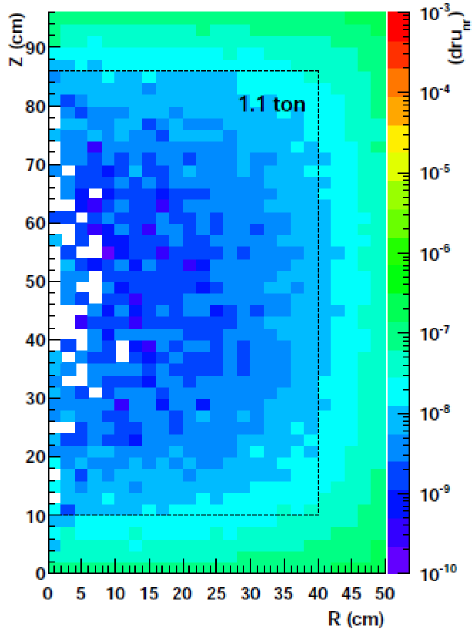
- Gammas from the environment
  well shielded by 3m of water or 20 cm of lead
- Neutrons from rock radioactivity
  negligible
- Muon-induced neutrons in the rock
  ~ of the order of 0.1 single scatter, NR per year in the DM energy region both for the LNGS and the LSM sites

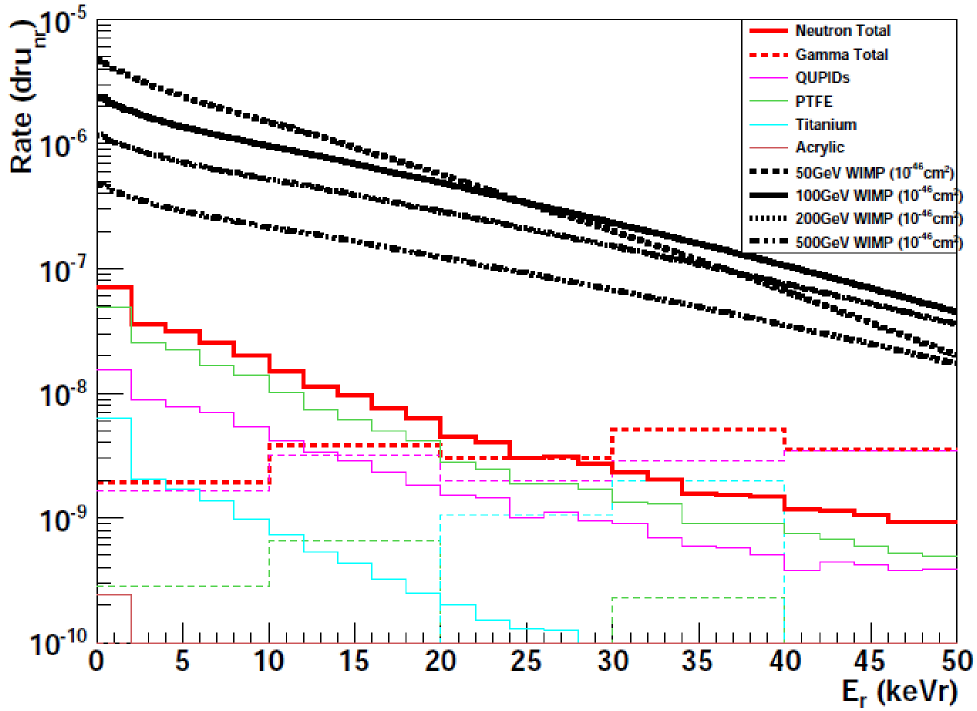
The external backgrounds are thus reduced to a level compatible with the sensitivity goal of better than 10^{-46} cm^2.

Spares

Internal Background

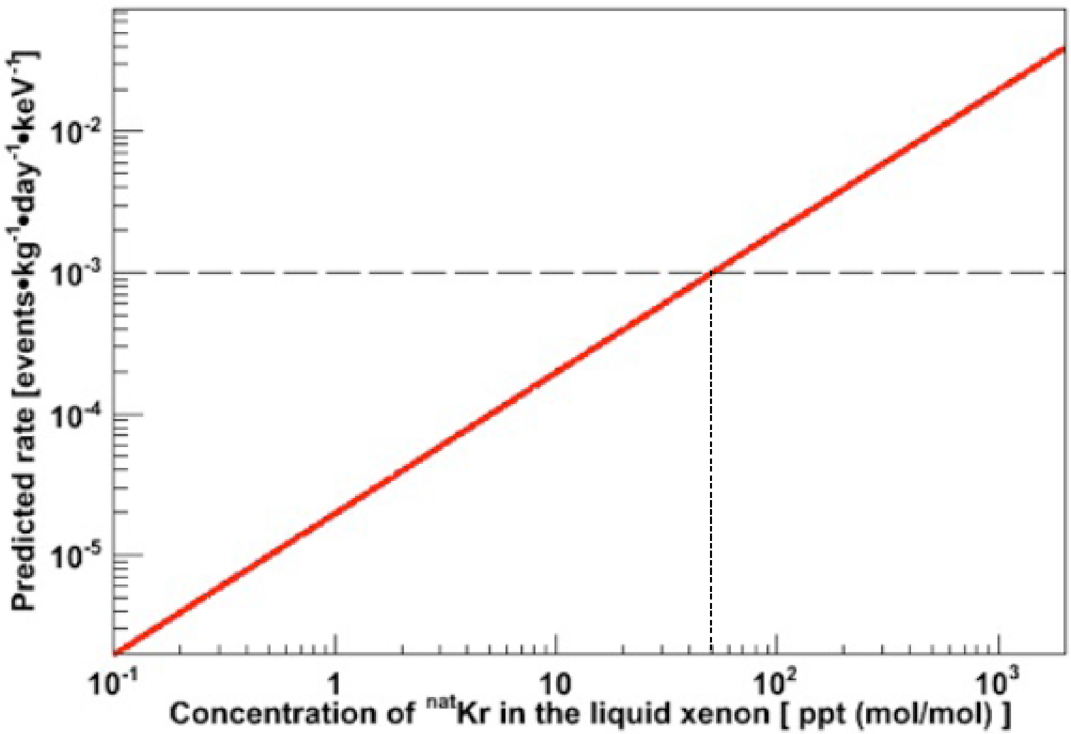






Background	ER	NR
Unit	$[10^{-7}\ \mathrm{dru}_{ee}]$	$[10^{-9}\ \mathrm{dru}_{nr}]$
QUPID	<8.50	<2.18
PTFE	<0.84	<4.84
Titanium	<2.13	<0.34
Total BG	<11.5	<7.4
# of BG events $[(\text{ton year})^{-1}]$	<0.07	<0.10
# of WIMP events $[(\text{ton year})^{-1}]$ $(M_\chi = 100\ \mathrm{GeV/c^2},\ \sigma_{\chi-p} = 10^{-47}\ \mathrm{cm}^2)$	0.56	

Intrinsic Background

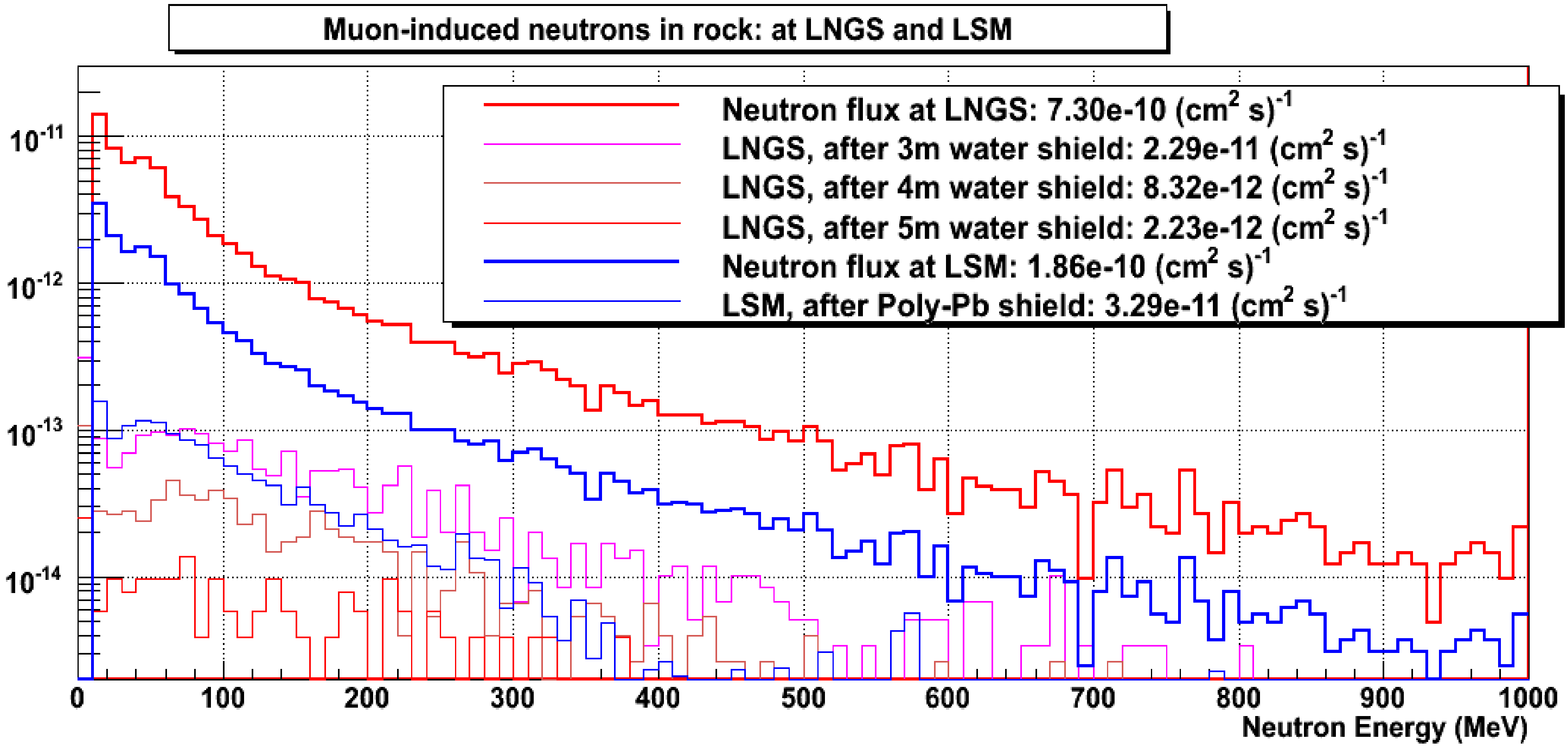


- natural krypton contains 10^{-11} of ^{85}Kr
- beta^{-} decay with endpoint energy 687keV and branching ratio 99.563%
- fiducial volume cuts do not provide the reduction of this background

- in order to have the BG rate from ^{85}Kr of < 1mDRU, the concentration of natural krypton has to be < 50 ppt
- commercially available gas - ppm/ppb level of natural Kr
- XENON100: purification with the cryogenic distillation ⟶ ~150 ppt ⟶ ~3 mDRU

Muon-induced neutrons in rock

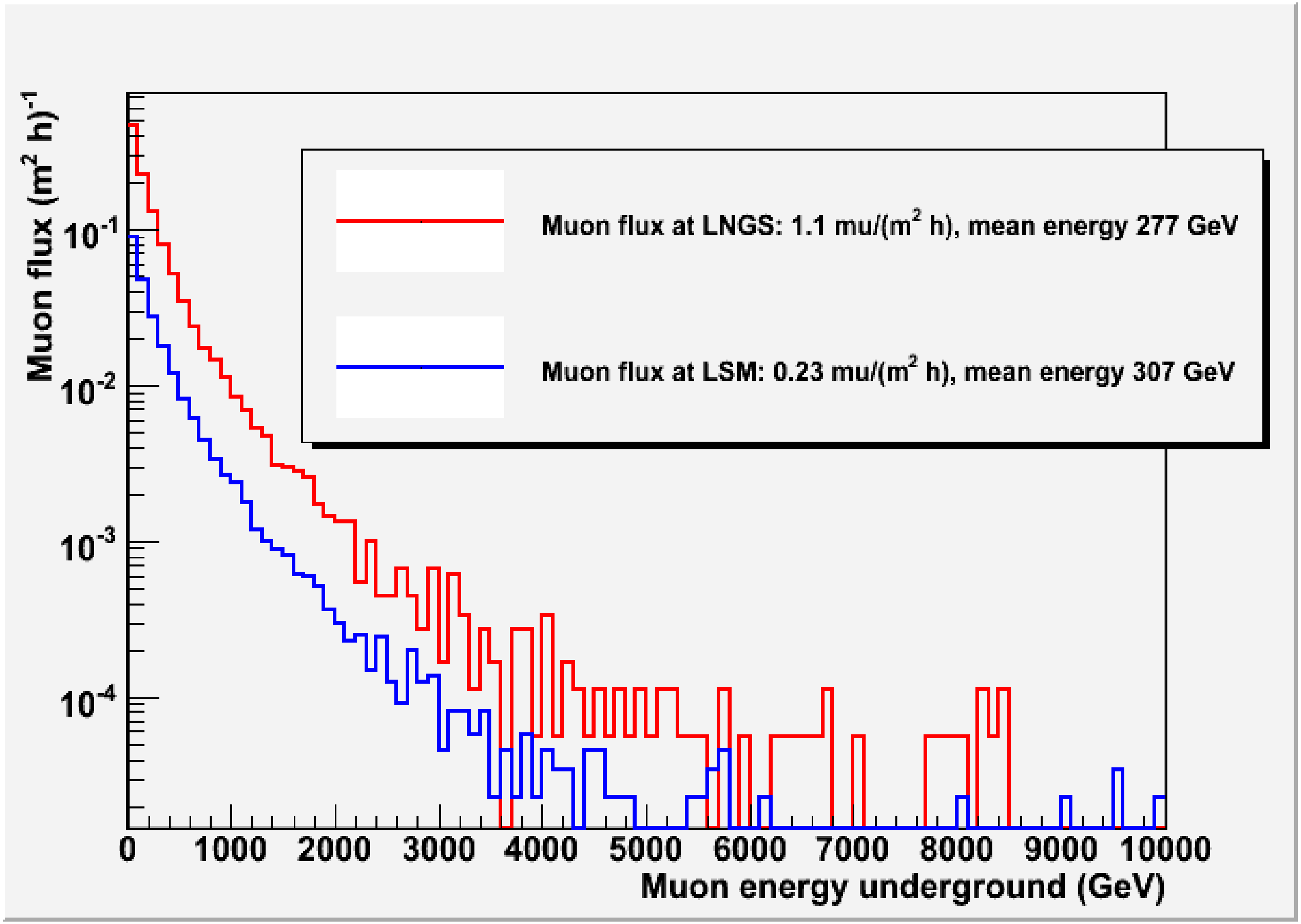
Comparison LNGS - LSM



The neutron flux inside the Poly-Pb shield @ LSM is of the same order of magnitude of the one inside 3m of water @ LNGS.

Muon-induced neutrons: detailed simulation for LSM

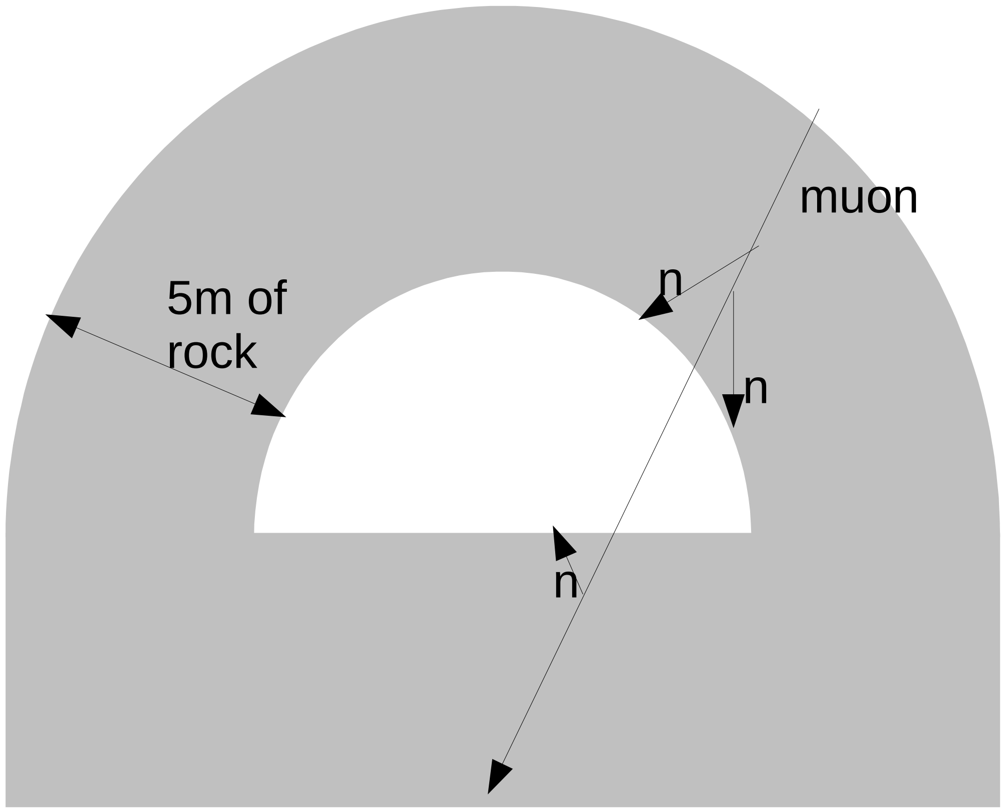
Muon flux and spectrum



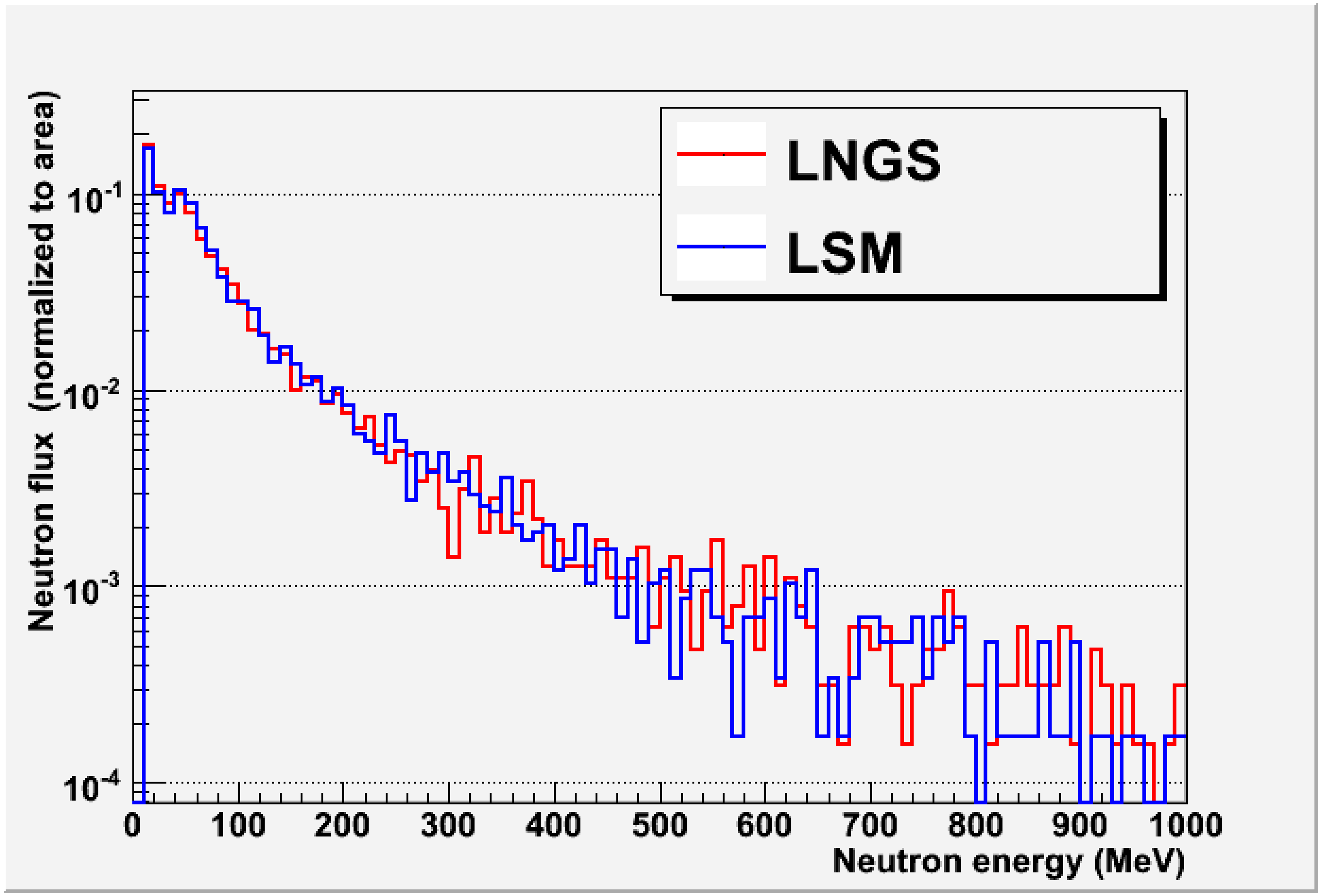
Rock composition and shape

	Percentage in weight	
Element	**LNGS**	**LSM**
H	0	1
C	12	5.94
O	51	49.4
Na	0	0.44
Mg	8.4	0.84
Al	0.6	2.58
Si	1	6.93
P	0	0.06
K	0	0.21
Ca	27	30.6
Ti	0	0.07
Mn	0	0.03
Fe	0	1.9

Up to now the shape of the rock and the hall is the same for the two sites: i.e. the LNGS one.



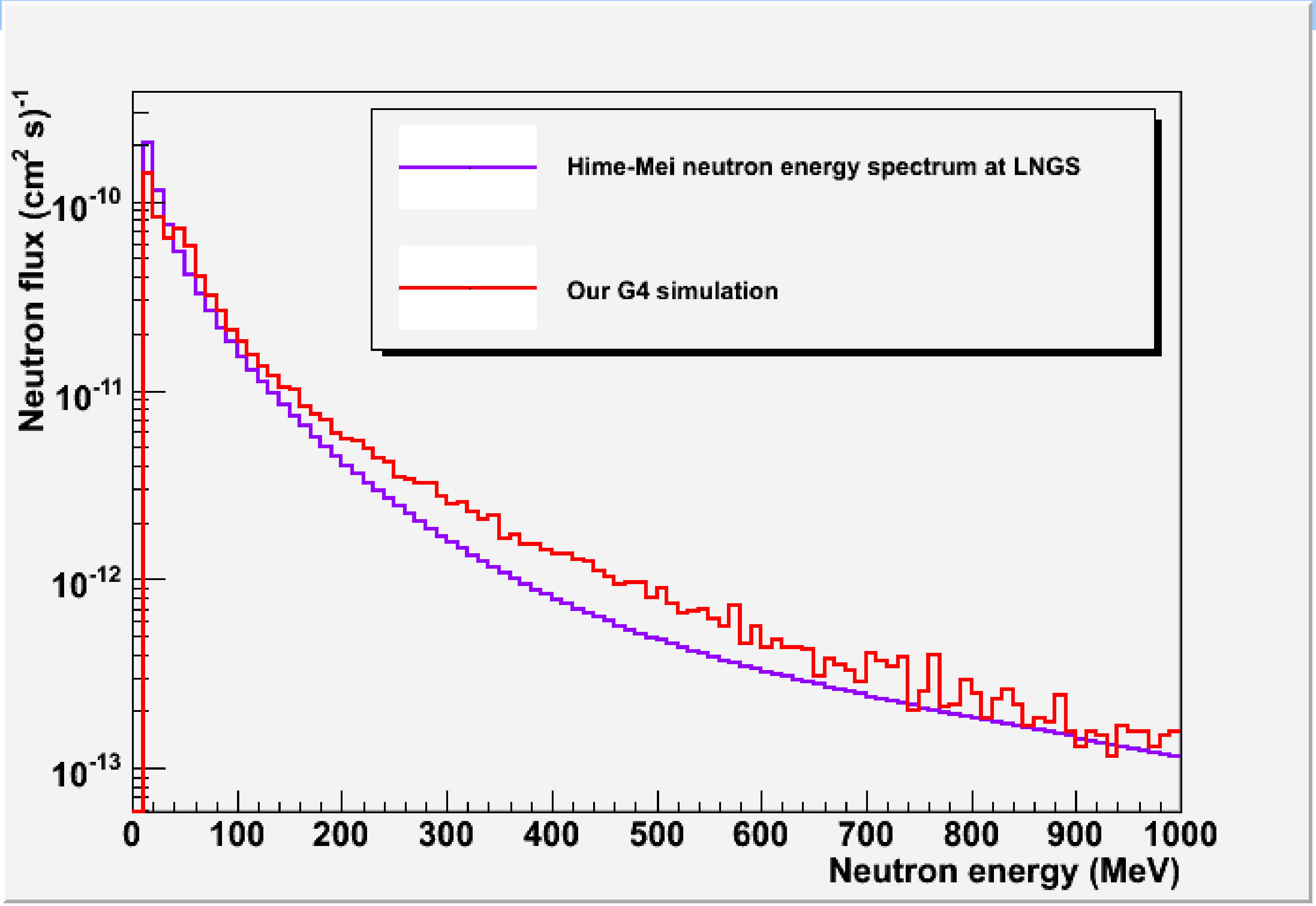
Results: neutron spectra



This is the neutron spectrum at the rock-hall surface, normalized to the same number of neutrons ... just to compare the shape of the two energy spectra.
They are very similar for En>10 MeV.

Thus, this proves that the previous simulations (that were done with the energy spectrum at LNGS just rescaled for the neutron intensity at LSM) are a good approximation.

Results: neutron spectra



Another cross-check: we compared the shape of the neutron energy spectrum at the rock-hall boundary of our G4 simulation and the one obtained by Mei&Hime with Fluka.

Water shield @ LNGS