XENON1T R&D:
Water Cherenkov Muon Veto

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XENON
Dark Matter Project

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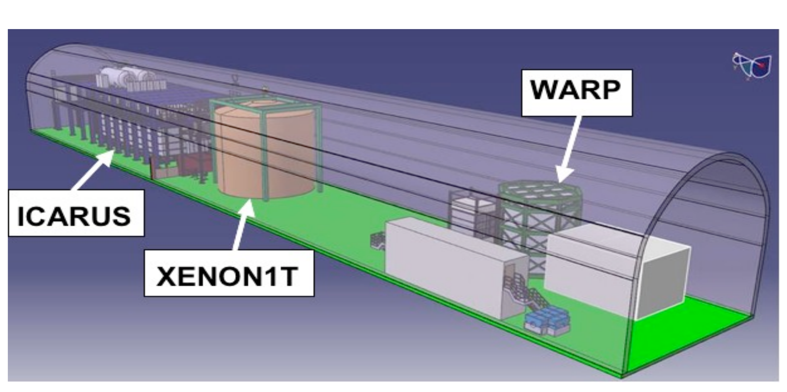
XENON Project

❑ **XENON10** (of 10 kg scale mass), operated in 2006-2007 at the Gran Sasso National Laboratory (LNGS) - Italy, publishing, the world's best limits, in 2008, on elastic WIMP-nucleon interactions ([1] [2]): in particular **$4.5 \cdot 10^{-44}$ cm²** for SI case and WIMP mass of 30 GeV/c² at 90% C.L..

❑ **XENON100** (of 100 kg scale mass) is currently taking dark matter data at LNGS, with the duty to explore the SI elastic WIMP-nucleon scattering cross section at the sensitivity in the order of ~10^{-45} cm², and has recently completed a dark matter run with 100.9 live-days of data, setting the best published limit for the above mentioned cross section, of **$7.0 \cdot 10^{-45}$ cm²** for a WIMP mass of 50 GeV/c² at 90% C.L.([3]), and ruling out the explanation for the observed DAMA/LIBRA modulation as being due to inelastic dark matter ([4]).

❑ During the operation of XENON100, an extensive R&D program for its successor of ton scale mass, **XENON1T**, is taking place. This new generation detector aims to reach the sensitivity on the scale of **10^{-47} cm²**. To achieve this goal a background reduction of two orders of magnitude, comparing to XENON100, is required. This background reduction must act on the selection of the materials to assemble the detector, on the shielding from external radioactivity (mainly coming from rock and concrete constituting the underground environment where the detector is located), and on muon vetoing. This last point is strongly correlated to the site where the experiment is going to be installed. In the current vision, XENON1T could be located in Hall B of LNGS, as shown in the picture below. This choice would required the employment of an active muon veto; in fact the muons reaching the LNGS underground halls have a residual flux of **$(3.31\pm0.03)\cdot10^{-8}\mu/\mathrm{cm}^2\mathrm{s}$** ([5]) and an average energy of **320 GeV** ([6]). These high energy muons can produce neutrons through electro-magnetic and hadronic cascades; these neutrons are a dangerous background for the dark matter search since they can scatter elastically off the xenon nuclei leaving a WIMP-like signal. Neutrons can be produced in the rock surrounding the experimental hall and in the materials the detector itself is made of. By detecting the passage of a muon, events of the μ-correlated neutron flux can be rejected from the acquired data.

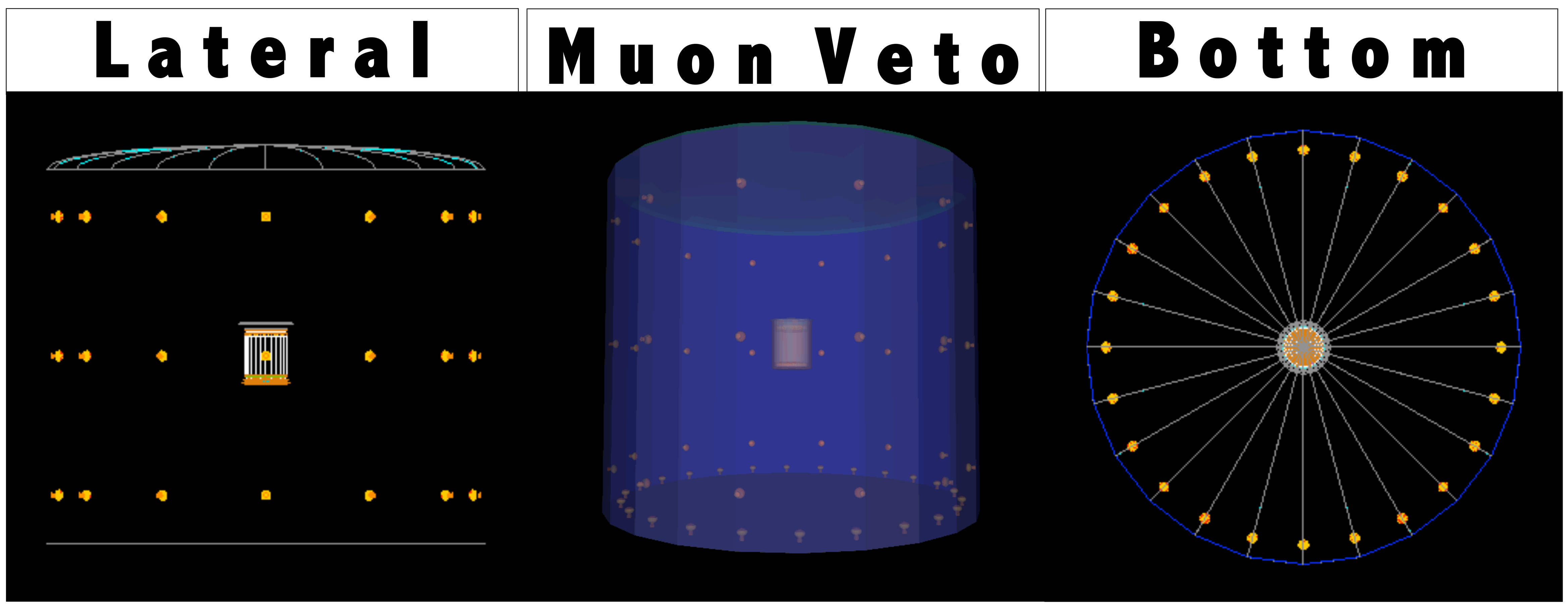


References

[1] Phys.Rev.Lett. 100:021303, 2008.
[2] Phys.Rev.Lett. 101:091301, 2008.
[3] arXiv:1104.2549.
[4] arXiv:1104.3121.
[5] M.Selvi et al, Proceedings of the 31st ICRC 2009.
[6] Astropart.Phys.10:11-20,1999.

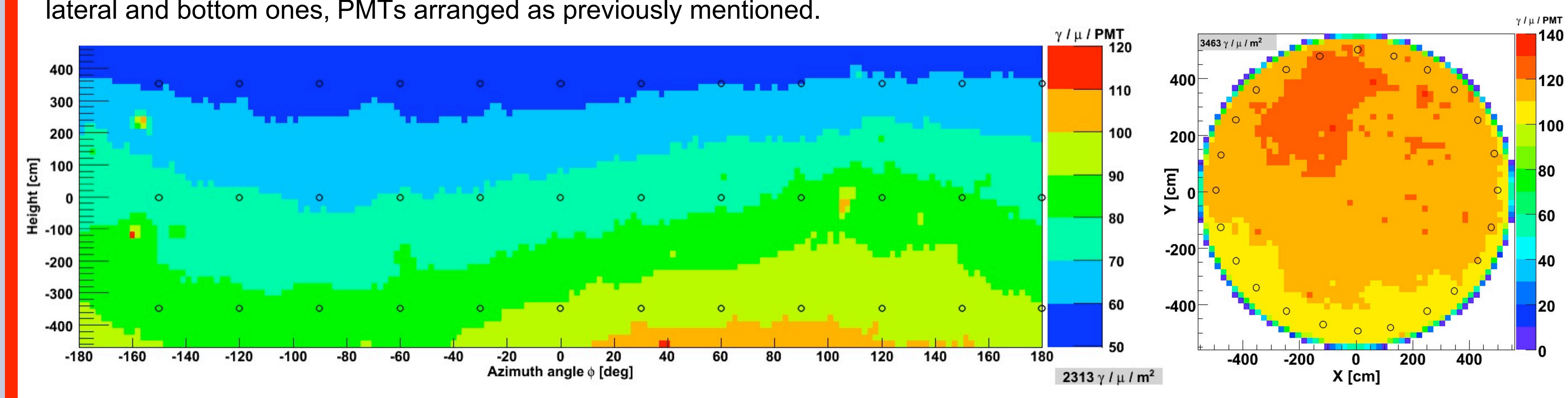
MUON Veto Study

Here we present the study of a muon veto system. In this proposed idea the liquid xenon detector is placed in the center of a large water tank 5.5m in radius and about 10m height. In such a way the XENON1T detector is surrounded on all sides with a layer of pure water, which constitutes a shielding system against external radioactivity.
Moreover by equipping the water tank with an array of photomultipliers, fixed onto the inner tank walls, the water could be exploited as a Cherenkov medium to detect the optical photons produced by cosmic muons inside the water tank.
The photomultiplier model selected for this study is 8" Hamamatsu R5912ASSY, already provided with a water-proof enclosure.
The proposed number of PMTs is 60 and for their positioning different geometries were considered leading to the choice of: 36 PMTs placed in 3 rings of 12 each in the lateral surface and 24 PMTs placed in a ring of 5.0m radius on the bottom surface.
For the internal surfaces of the water tank we suggest to use a reflector film (VM2000) which provides a very good reflectivity; it allows also to shift the wavelength of the UV Cherenkov photons towards the blue region, to have a better match with the PMTs window and the photocathode.
All these proposed ``ingredients'' of the muon veto were tested though a series of GEANT4 Monte Carlo simulations.
The below figures show graphical outputs of the MC study for the selected PMTs geometry.



MC Results & Conclusions

Hit-patterns of the photons on the internal surfaces of the water tank were generated in the different configurations of the Cherenkov detector, leading to some important conclusions for its design:
-- the number and placement of PMTs were validated;
-- the need to use the reflector film also on the ceiling of the water tank was pointed out;
-- efficiency did not show dramatic decrease for slight decreases (some percent) of the reflectivity;
-- the higher effectiveness of the specular reflector comparing to the diffusive one was shown.
The below pictures show the light distributions for one case, lets call it ``the selected case'', chosen as the most performant between the feasible ones: specular reflector with 90% reflectivity on the top internal surface of the water tank and 95% on the lateral and bottom ones, PMTs arranged as previously mentioned.



The efficiency of our muon veto system was evaluated as a function of different parameters such as:
-- the path in water of the muon;
-- the energy deposited in water by all the particle of the shower (including the muon);
-- the triggering conditions: photelectrons to trigger a PMT (from 1 to 20) and PMTs to trigger an event (from 2 to 4).
This last case is proposed in two versions: the first one including all the muons crossing the tank and the second one cutting away from the calculations the muons that travelled less than 2 m in water.
Results for the ``selected case'' are presented in the below pictures.
In conclusion we can say that, with triggering at 10 photoelectrons for PMT and 3 PMTs for event, with just 60 PMTs (which is equal to a coverage of the water tank surface of less than 0.5%), a detection efficiency of ~99% can be achieved if we consider the muons travelling at least 2.0m in water; 100% efficiency is obtained if the muonic cascade releases above 1 GeV energy in the water tank. All these results rapidly improves if we have less strong requirements from the electronic side (i.e. smaller number than 10 photoelectrons to trigger a PMT).