Current status of the XENON100 experiment

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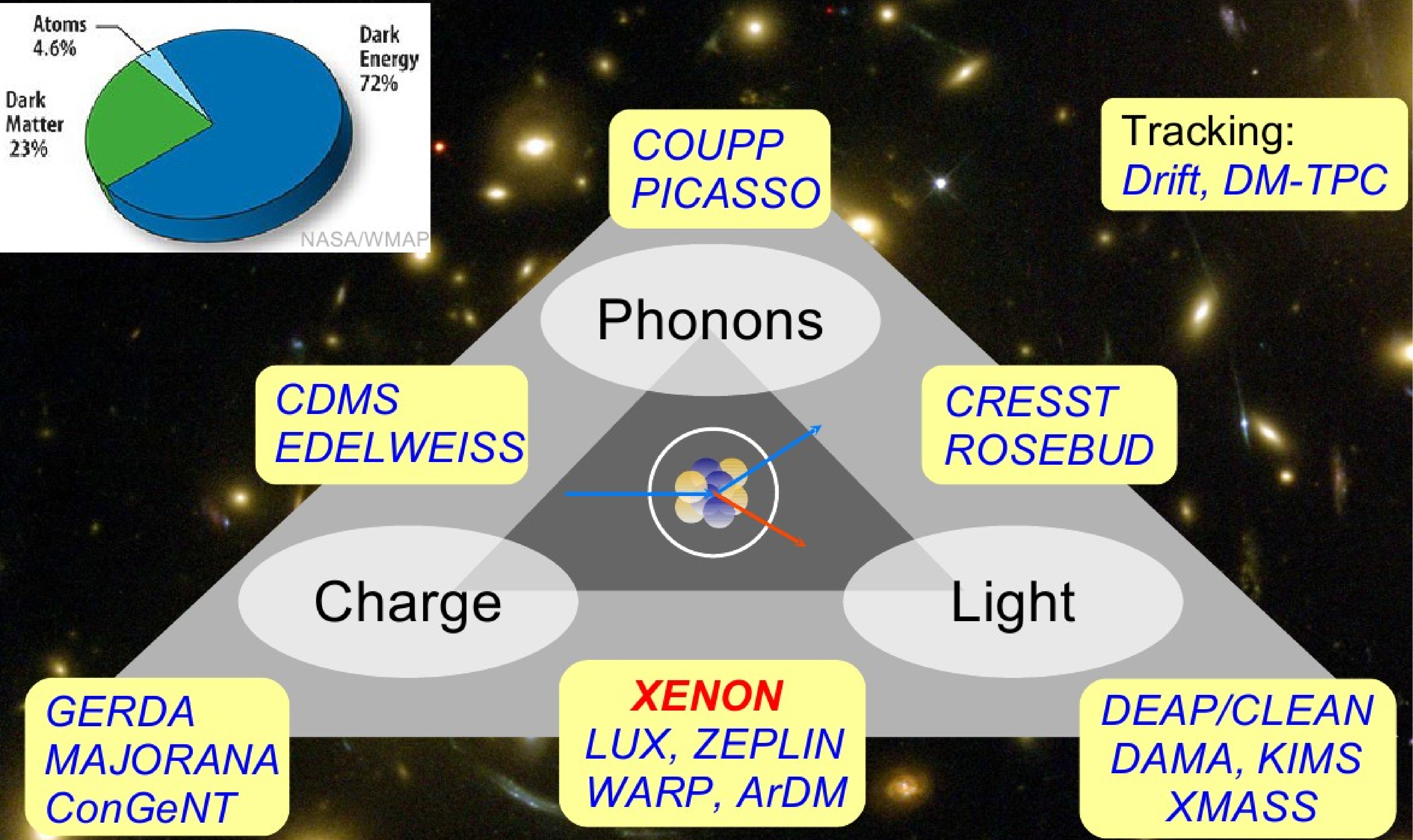
University of Zuirch

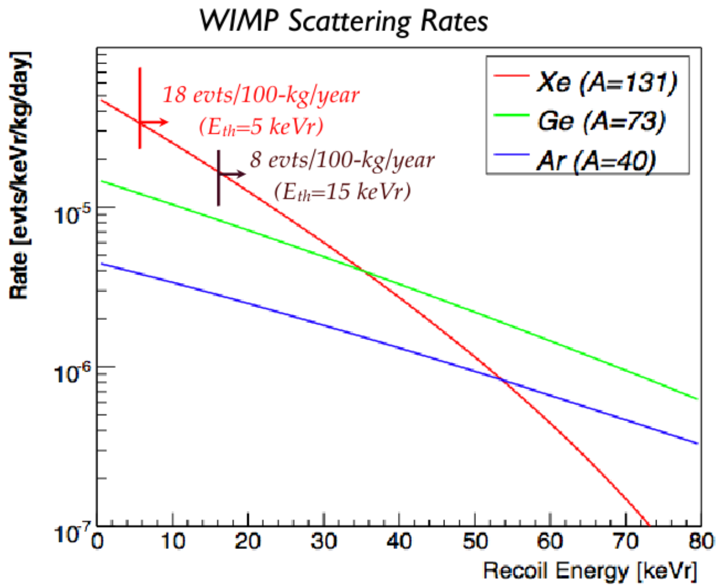
Invisible Universe - Paris, July 2009

Direct WIMP Detection



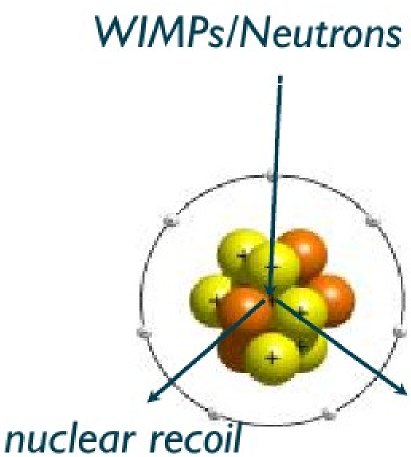
Why Xenon?

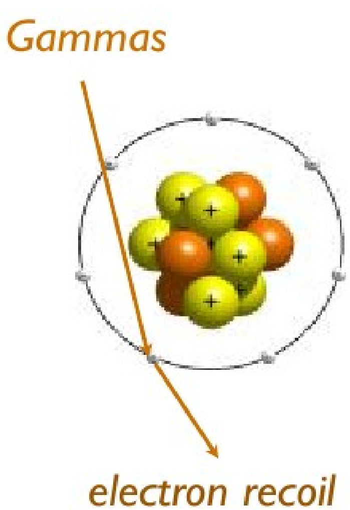
- Large A (~131) good for SI interactions
- Xe-129 (26.4%) and Xe-131 (21.2%) for SD interactions
- No radioactive isotopes (Kr-85 reduced to ppt levels)
- High stopping power (Z=54, ρ=3 g/cm3), self-shiedling geomtery
- Efficient and fast scintillator (yield~80% NaI), transparent to its own light
- Easy cryogenics at ~165 K
- BG rejection: > 99.5% by simultaneous light and charge detection

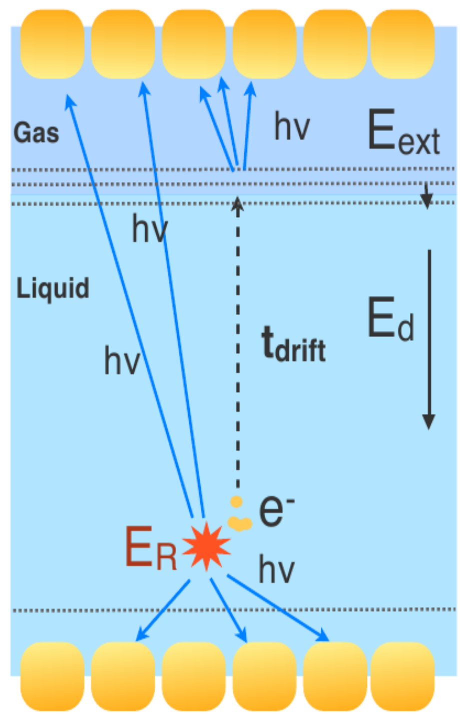


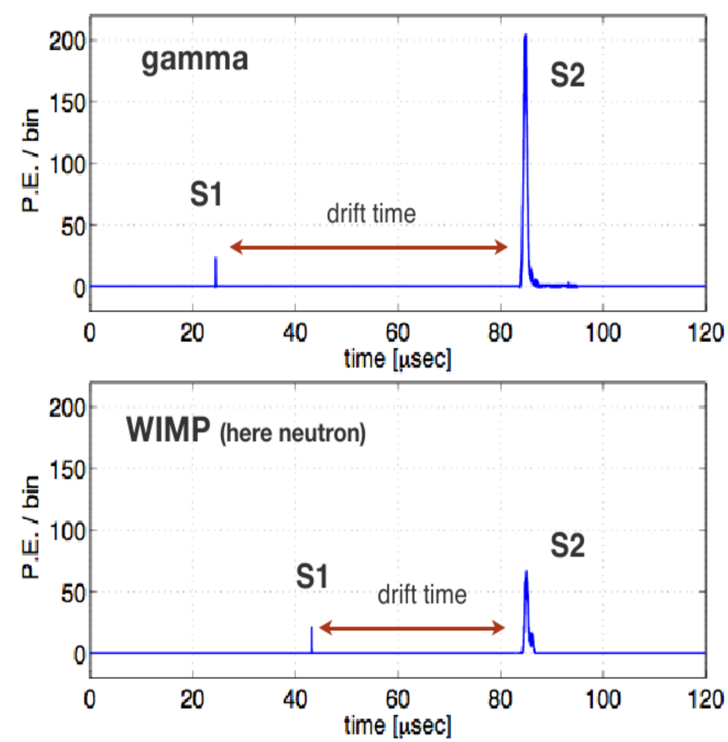
The double-phase detector concept

- Prompt (S1) light signal after interaction in active volume; charge is drifted extracted into the gas phase and detected as proportional light (S2)
- Challenge: ultra-pure liquid + high drift field; efficient extraction + detection of electrons

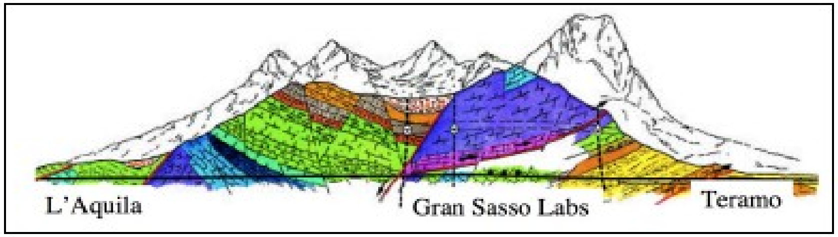








The INFN Gran Sasso National Lab (LNGS)



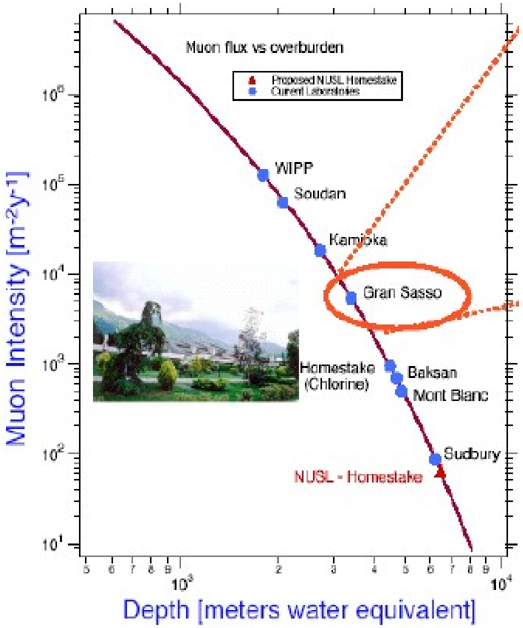
Location: Gran Sasso Tunnel (Abruzzi, Italy)

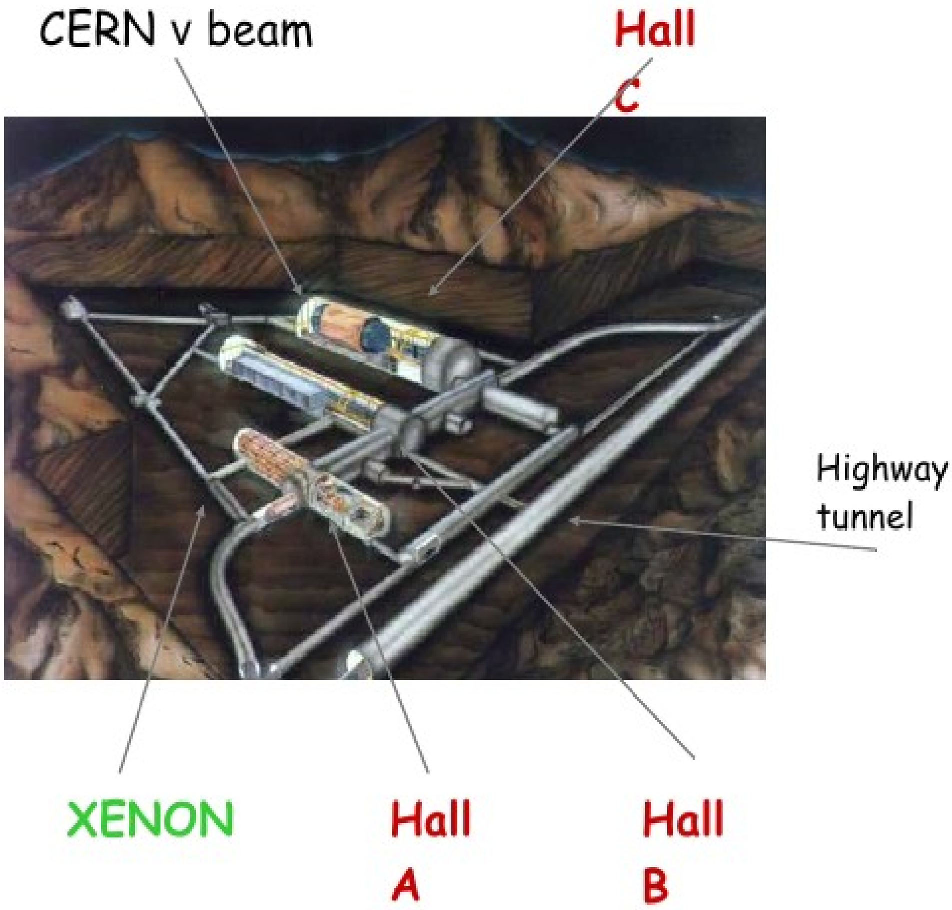
Depth: 1400 m (3800 mwe),

Underground area : 3 halls

Total volume : 180000 m^3,

Surface: > 6000 m^2

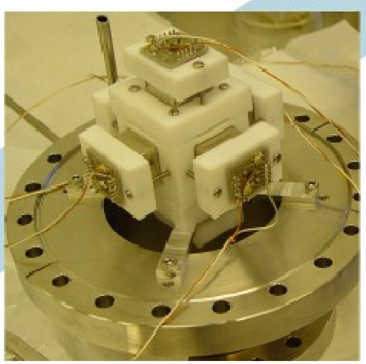




The XENON Program

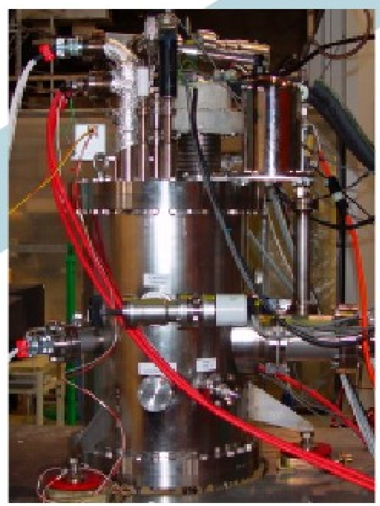
Current members:
University of Zurich
University of Coimbra
Columbia University
Rice University
UC Los Angeles
LNGS
New members:
Subatech
Muenster
Waseda

XENON R&D



ongoing

XENON10



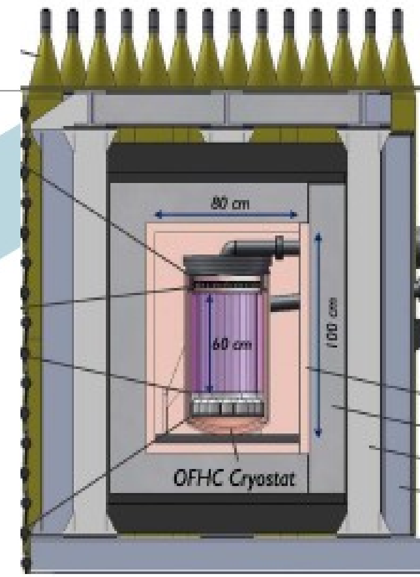
2006-2007

XENON100

in progress

XENON100 Upgrade

???

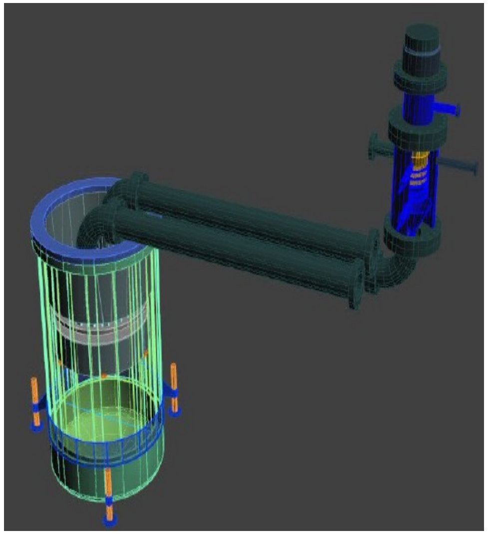


The XENON100 detector – Background Goals

Goal: to reduce gamma background by a factor of 100 comparing with XENON10 (0.6dru)

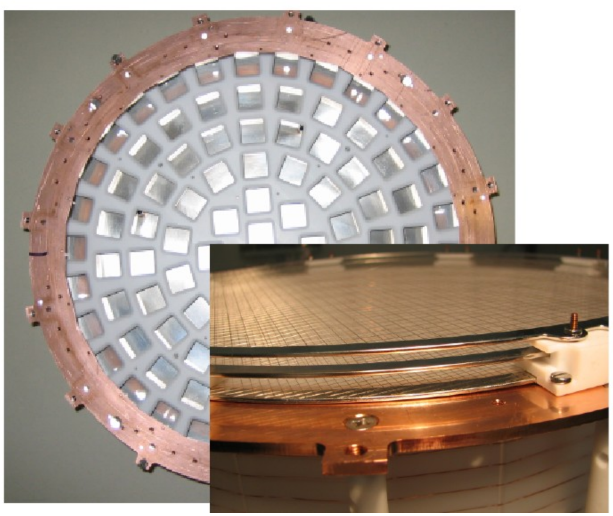
through:

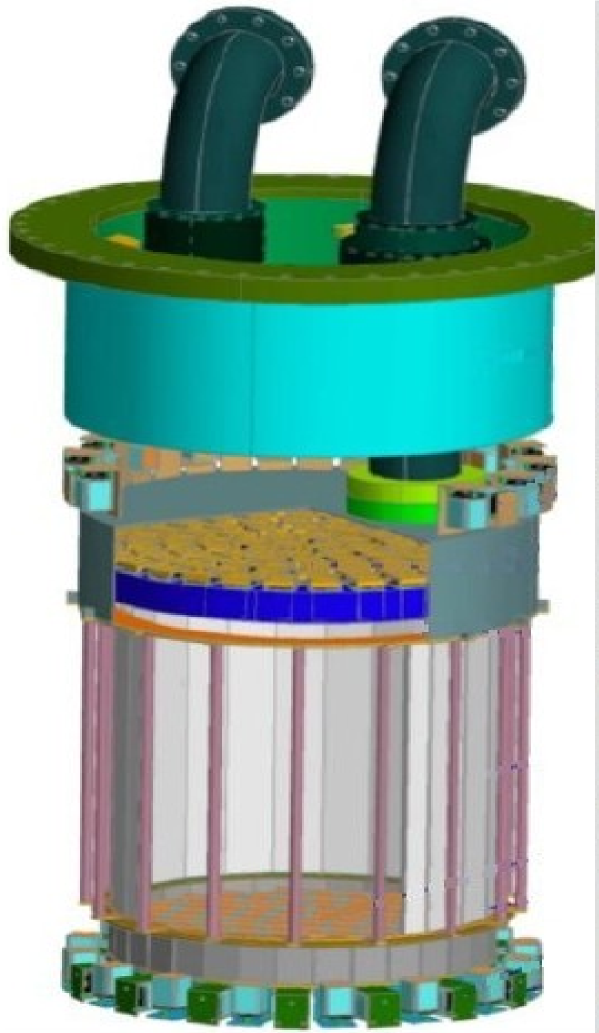
- Selection of ultra-low background materials for detector components and shields
- Active LXe veto shield (100 kg) surrounding target on all sides
- Reduce intrinsic Kr-85 contamination to the required level (50 ppt)
- Detector design: place cryogenics and feed-throughs outside the shield

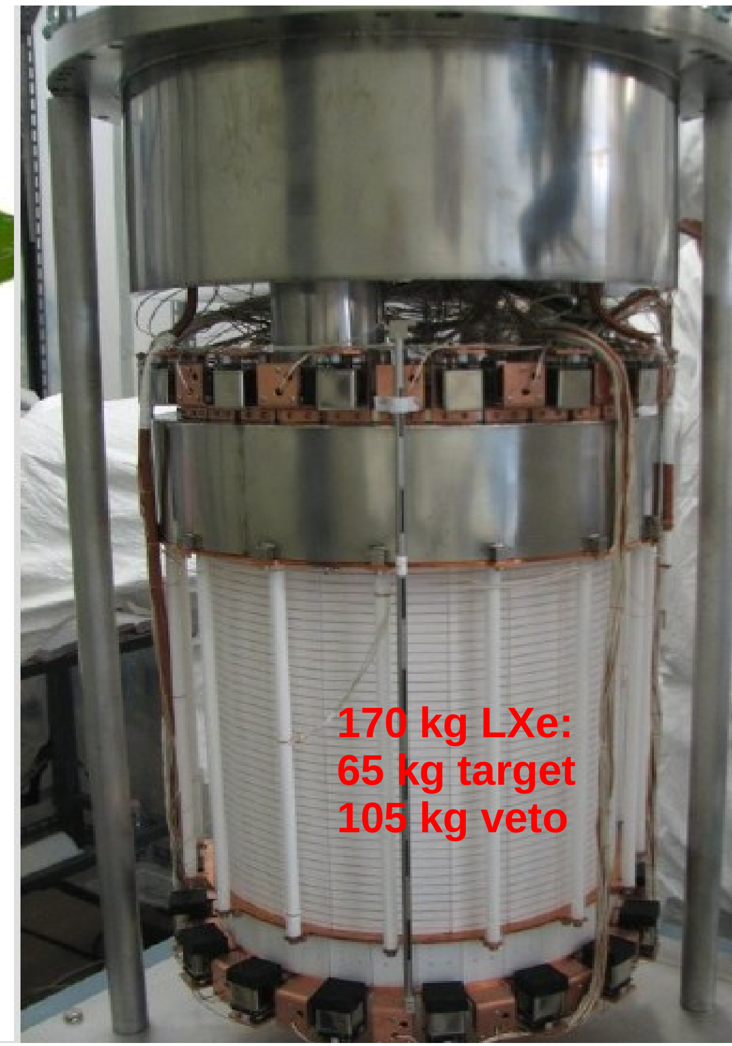


The XENON100 detector

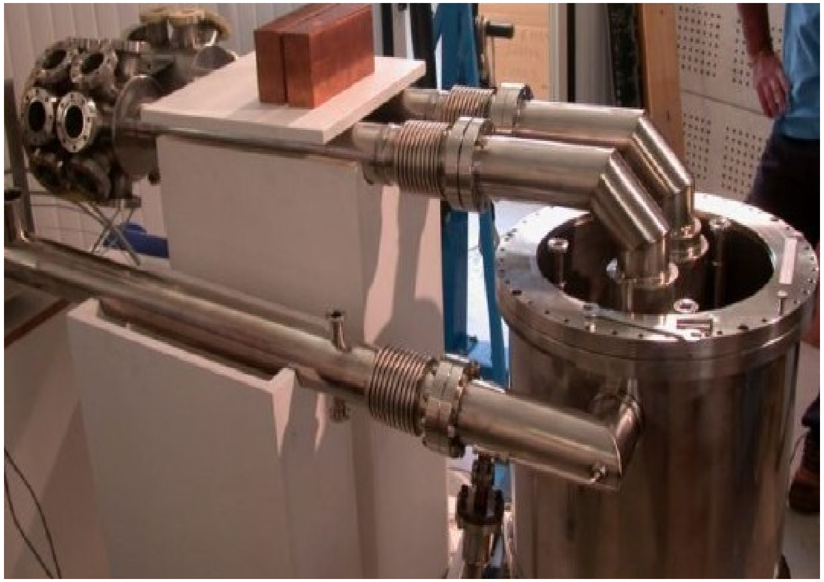
- Inner TPC: PTFE structure (total of 170 kg LXe)
- Drift length: 30 cm
- Drift field: 1kV/cm
- Extraction field: 13kV/cm

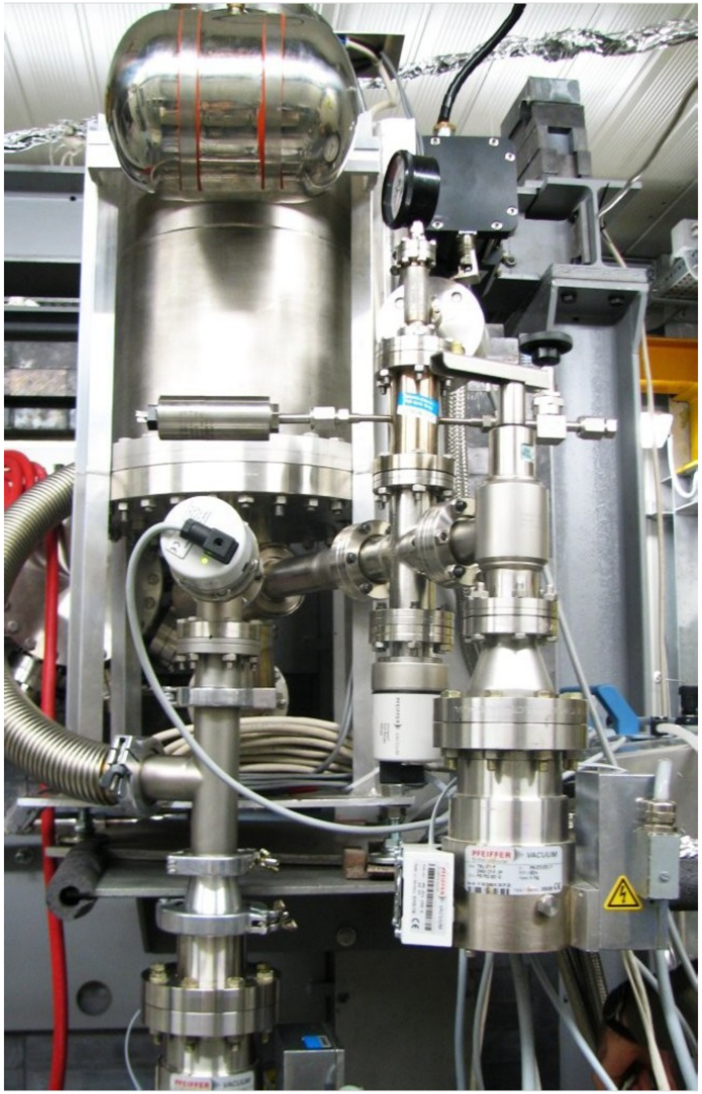






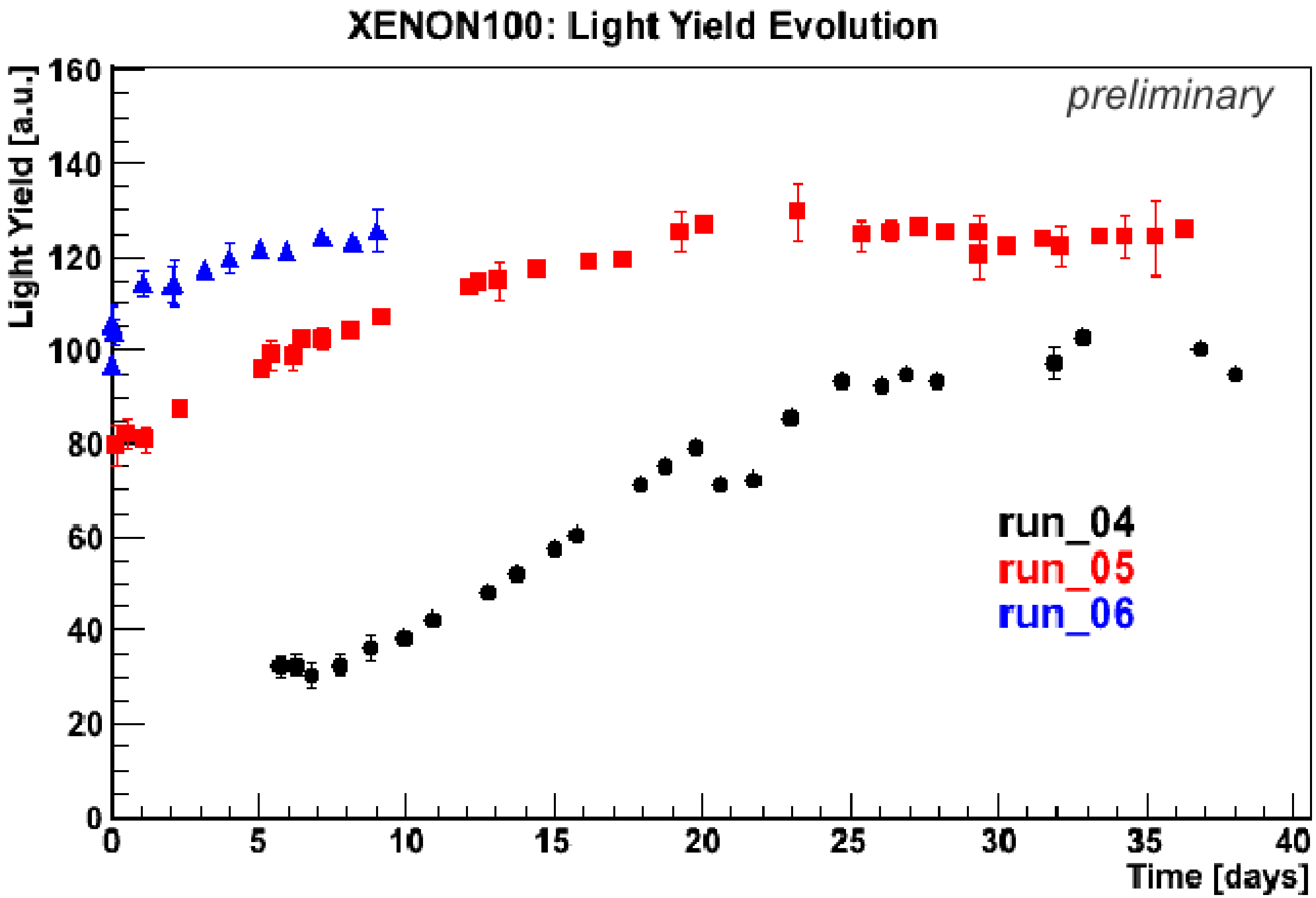
Cryostat, Cooling and Purification





- Double wall SS cryostat
- 170 W PTR cryocooler (gas gets liquified outside of the shield)
- Continuous Xe purification
- Kr distillation column

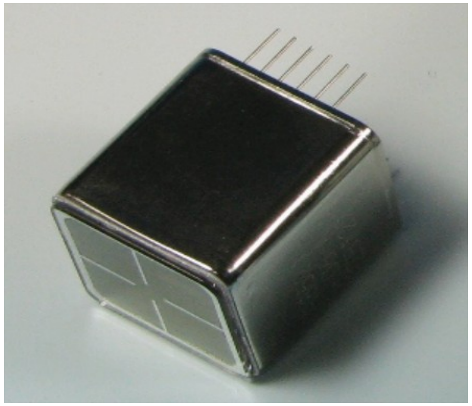
Improving the LXe purity



- Scintillation (S1) is mainly affected by water impurity
- Ionisation (S2) is mainly affected by oxygen impurity
- Electron lifetime is now more than 100 µs, continues improving

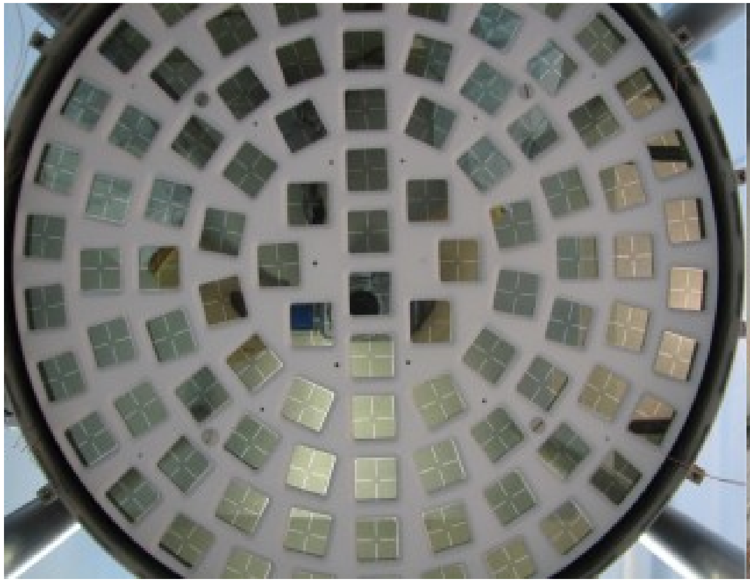
XENON100 Light Detectors

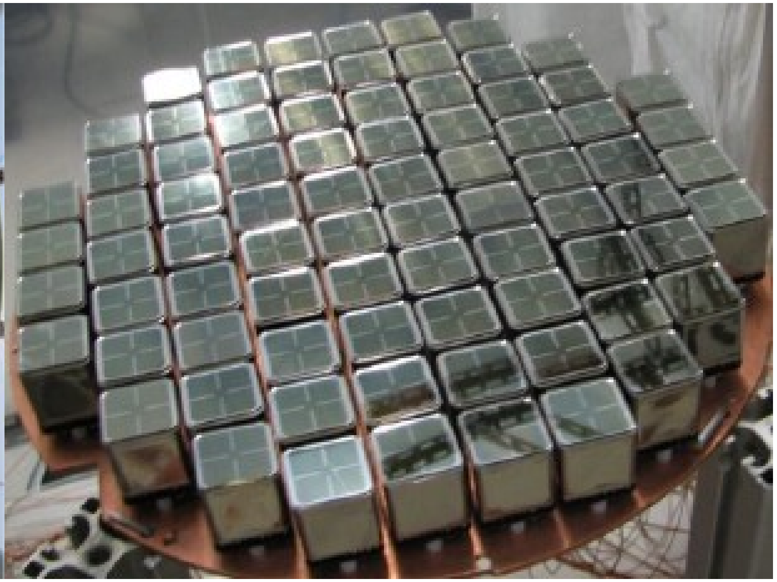
242 (Hamamatsu R8520) 1''x1''
low radioactivity PMTs



80 PMTs at bottom:
with high QE of 33% @ 175 nm
for optimal
collection efficiency
(thus low threshold)

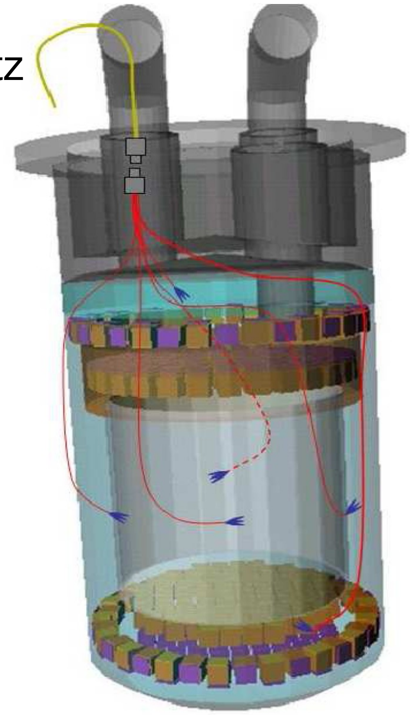
98 PMTs at top: for good fiducial
volume cut efficiency

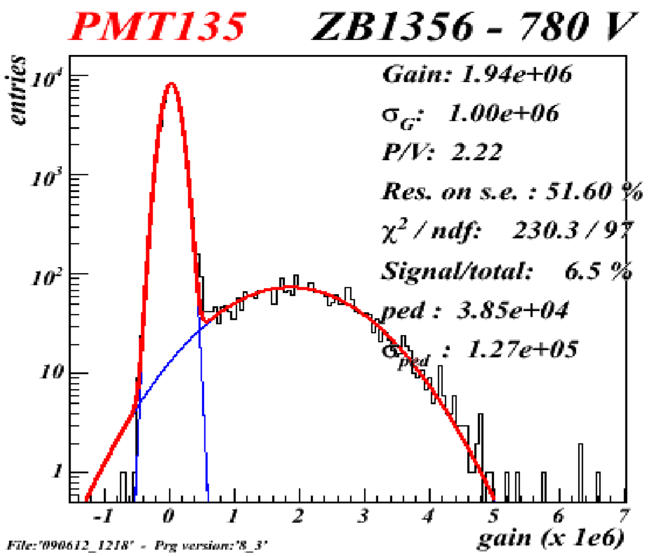




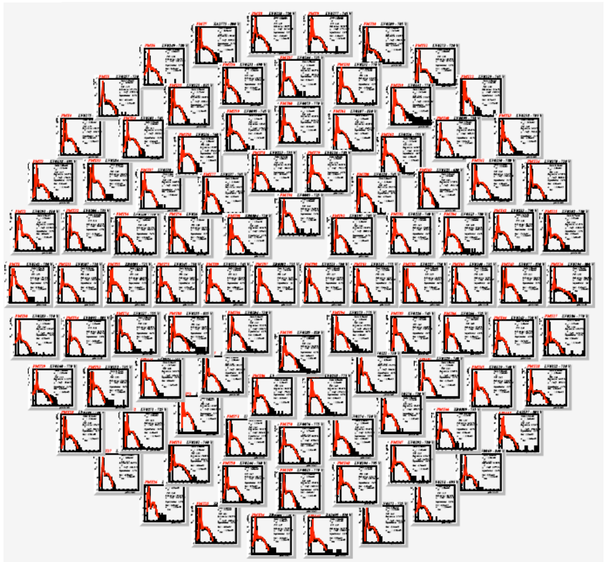
64 PMTs
in active LXe shield

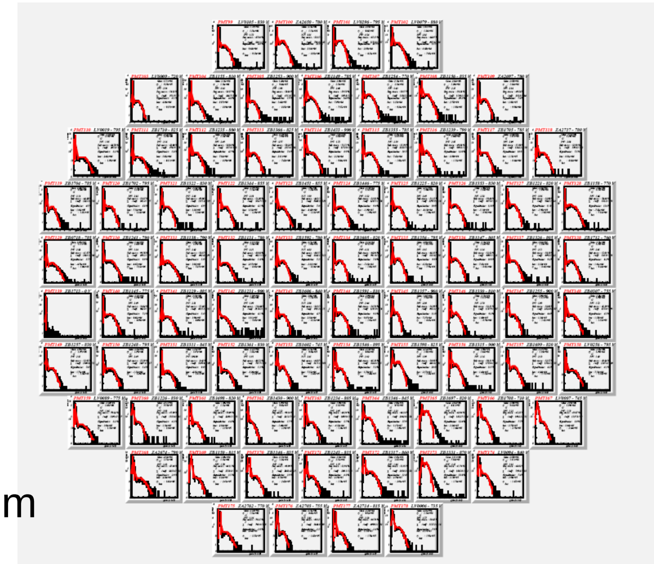
Light Calibration





Spe spectra for all the 242 PMTs

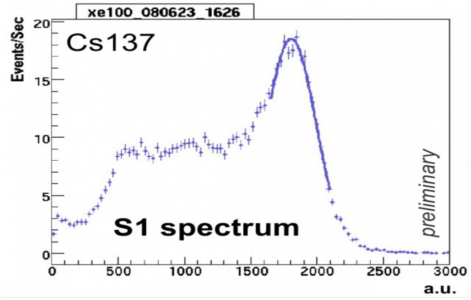


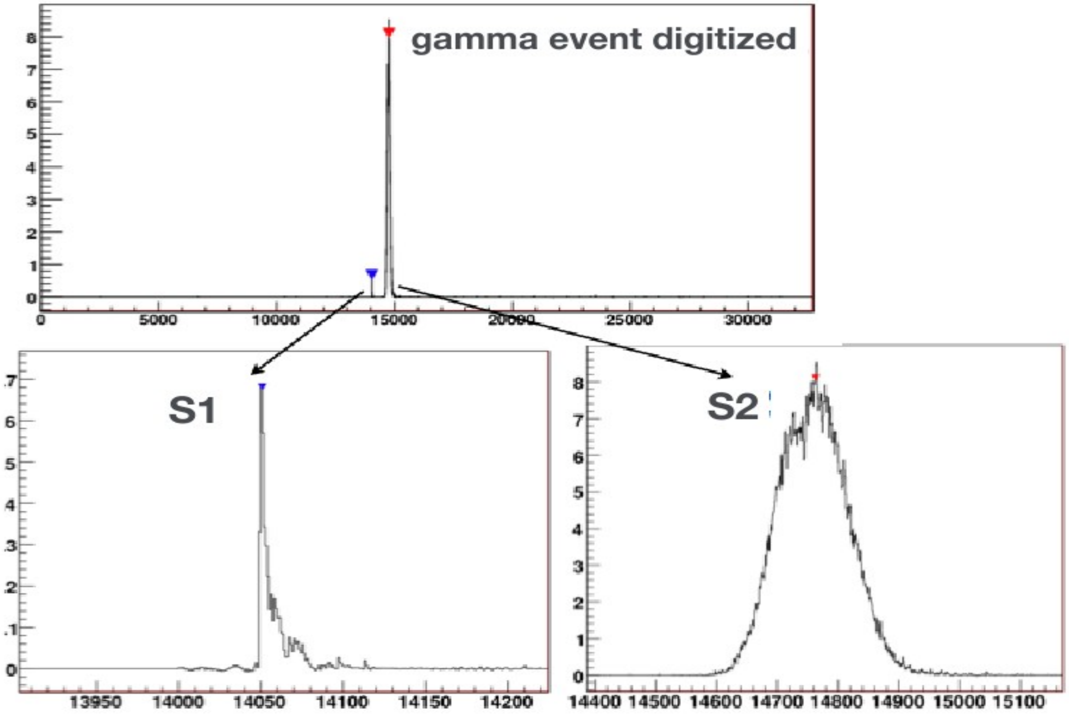


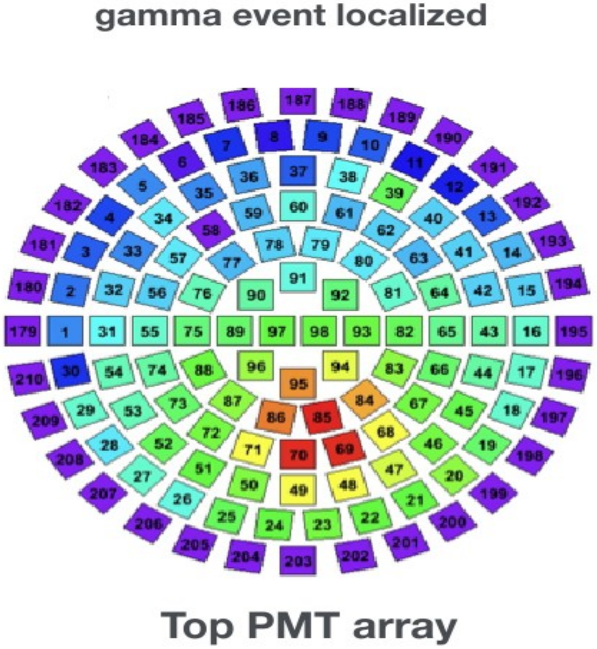
Gamma Calibration

Measurements with several gamma sources
to characterise detector performance are underway

- Cs-137 source; S1,S2: summed waveforms of all inner PMTs







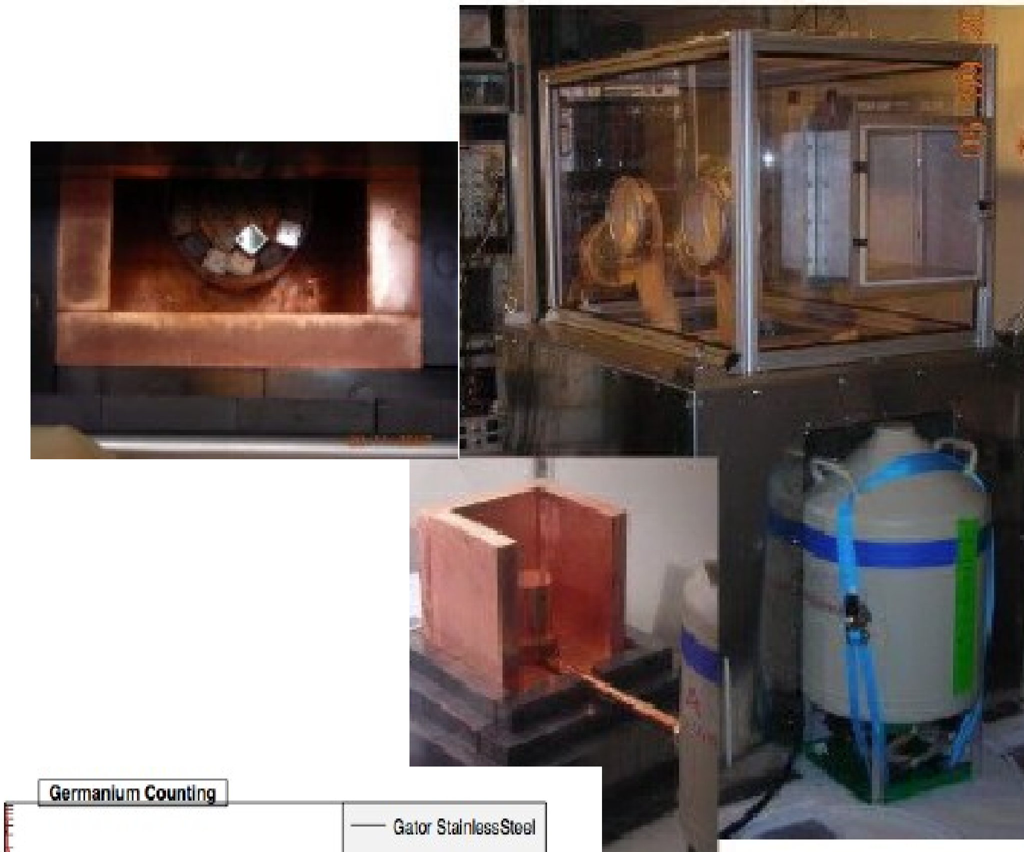
S2 x-y position reconstruction
(few mm resolution)

Material Screening at LNGS with several HP Ge detectors

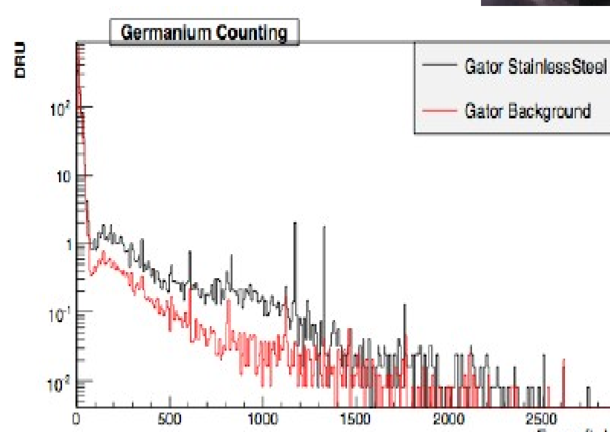
XENON100's HPGe detector

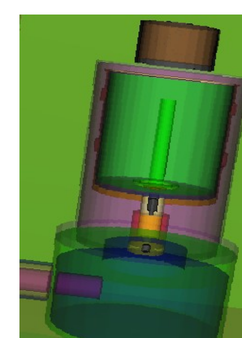
- 2.2 kg HP Ge crystal

  coaxial crystal: d=82mm, h=81.5mm
- Ultra low background Cu housing
- Low background shielding
- Low activity Pb (3Bq/kg Pb-210)
- N2 atmosphere



LNGS HPGe detectors
2 of them are the most sensitive detectors in the world





Activities of the materials* screened with the Ge detectors of LNGS

Materials	Unit	U238 [mBq/unit]	Th232 [mBq/unit]	K40 [mBq/unit]	Co60 [mBq/unit]
Stainless Steel	kg	1.7	1.9	9	5.5 +/- 0.6
PMTs	PMT	0.16 +/- 0.05	0.46 +/- 0.16	14 +/- 2.0	0.73 +/- 0.07
PMT Bases	Base	0.71 +/- 0.05	0.10 +/- 0.03	0.16	0.01
Teflon	kg	0.31	0.16	2.25	0.11
Copper	kg	0.07	0.03	0.06	0.0045
Inner Lead**	kg	0.80	0.72	1.46	0.11
Outer Lead***	kg	0.92	0.43	14 +/- 3	0.13
Polyethylene	kg	3.80	2.69	5.88	0.68
Feedthrough****		13 +/- 3	13 +/- 6	21 +/- 2	49.00
		[ppb]	[ppb]		
Concrete		1380 +/-240	1230 +/- 250	NA	NA

use results for MC simulations

* if no errors are written, then they are upper limits
** 17 +/- 5 Bq/kg Pb-210 (by "Foundaries de Gentilly")
*** 560 +/- 90 Bq/kg Pb-210
**** it was placed outside shield

Gamma and Neutron Background studies

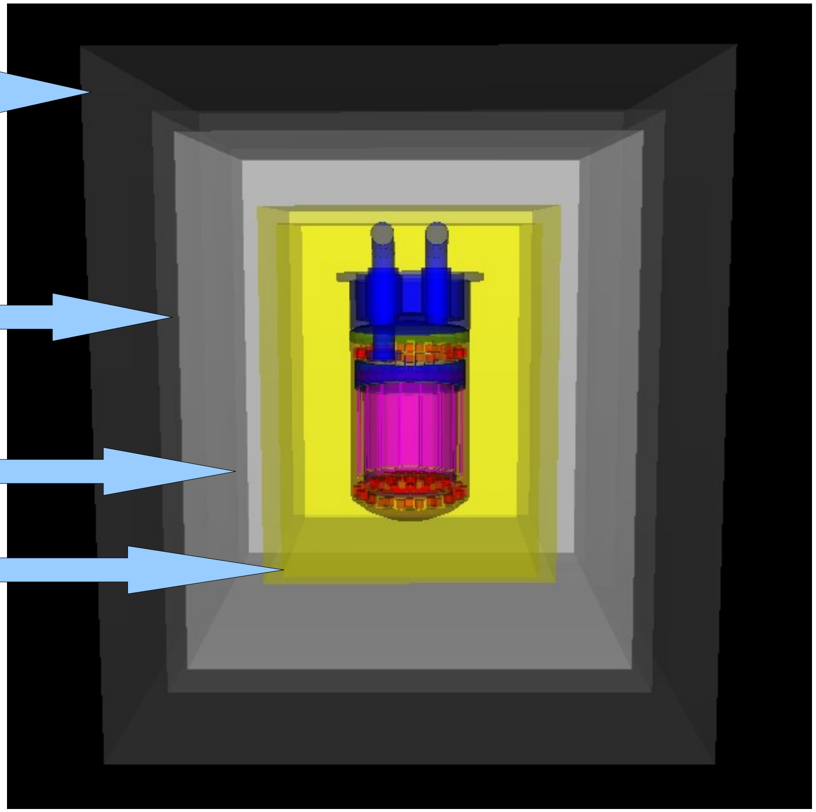
Detector geometry

Lead
15cm, 27t

Inner Lead*
5cm, 6t

Polyethylene
20cm, 2t

Copper
5cm, 2t



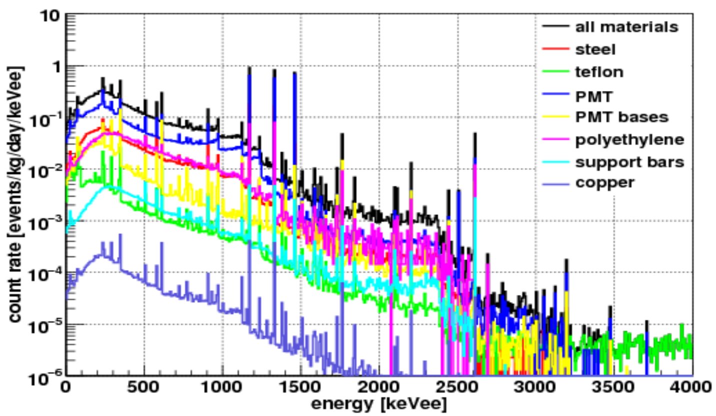
Simulated with the GEANT4 code

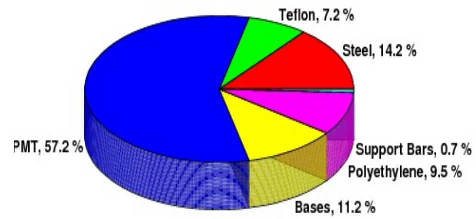
*17 +/- 5 Bq/kg Pb-210

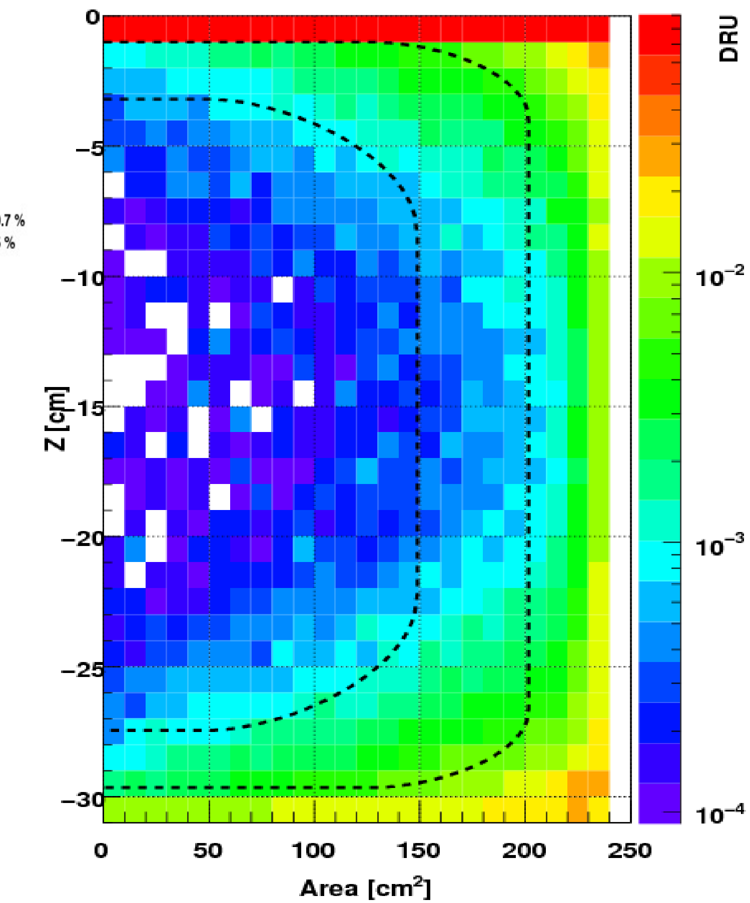
Gamma Background

Gammas from U-238, Th-232, K-40 and Co-60

Single electron recoils



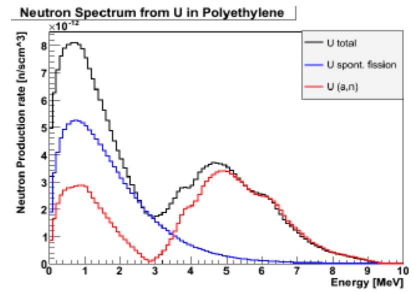




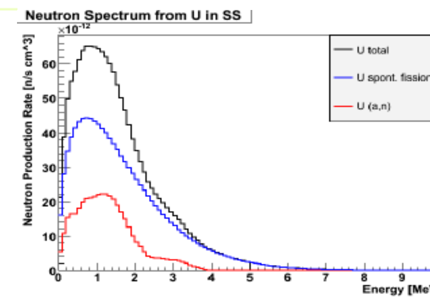
Material	Rate [mdru] 50 kg FV	Rare [mdru] 30 kg FV
Stainless Steel	3.98	1.68
Teflon	0.24	0.09
PMT	14.55	5.21
PMT Bases	1.61	0.49
Polyethylene	3.27	1.44
Support Bars	0.28	0.12
Copper (inside)	0.13	0.05
Total (passive veto)	**24.05 +/- 0.17**	**9.07 +/- 0.14**
Total (veto thresh 200keV)	**9.8**	**3.2**

Neutron Background from radioactivity in the detector and shielding materials

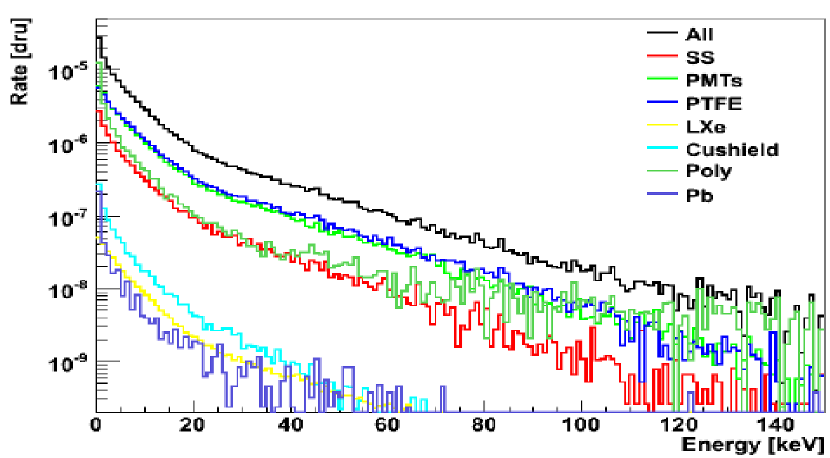
Materials	Neutron production rate per year	
Stainless Steel	12.5	
PMTs	21.8	
Teflon	14.1	
Lxe	0.1	
Copper	2.0	shield
Lead	1483.4	shield
Polyethylene	666.4	shield

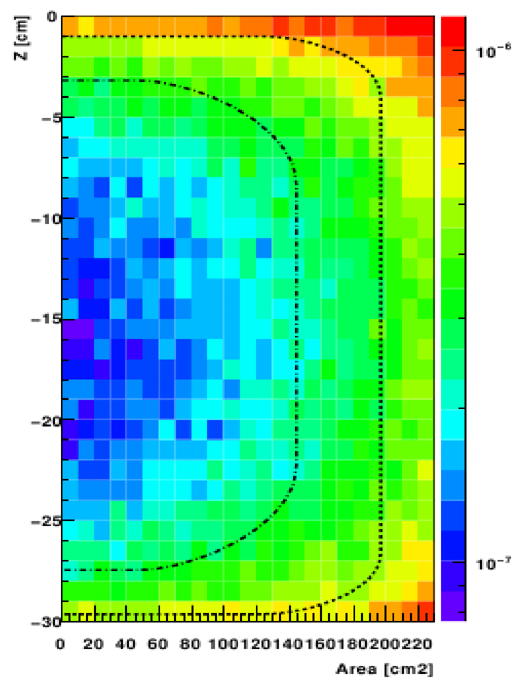


SOURCES4A code



Single nuclear recoils in the whole active volume



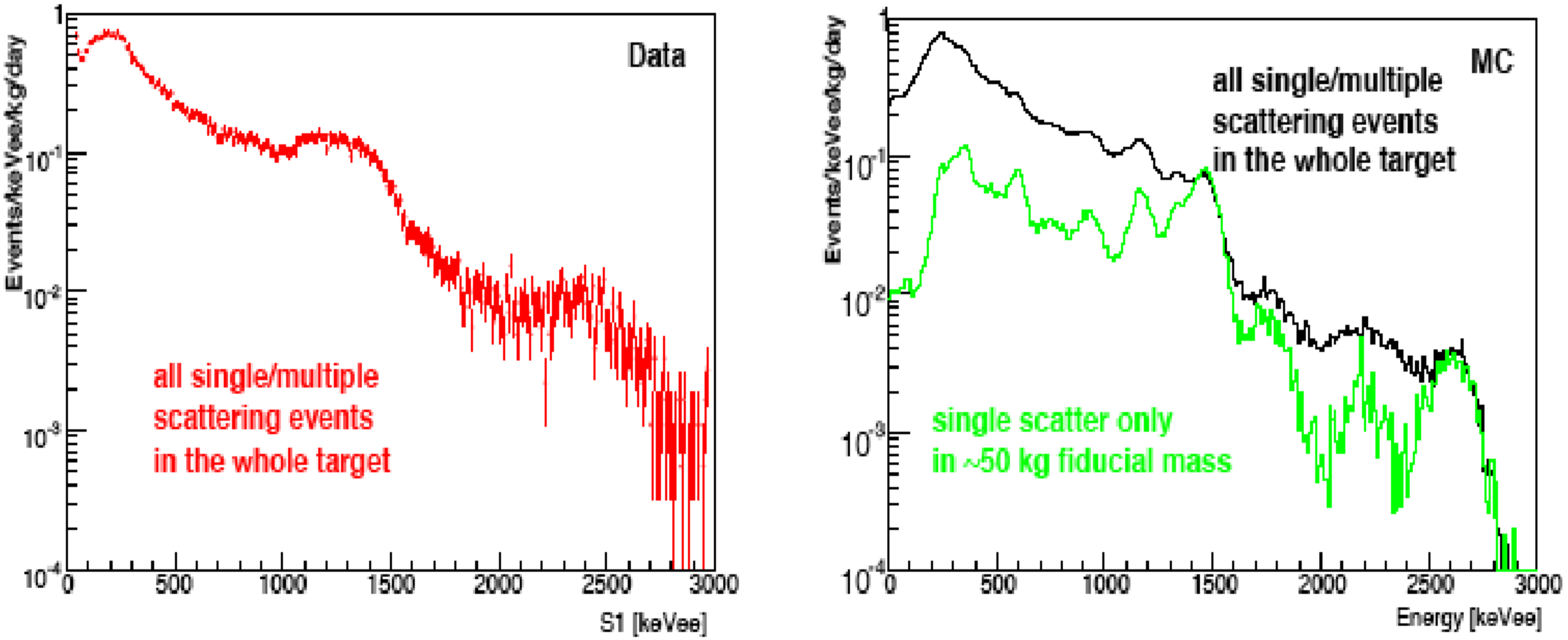


Single nuclear recoil rates in the WS region (4.5-26 keV)

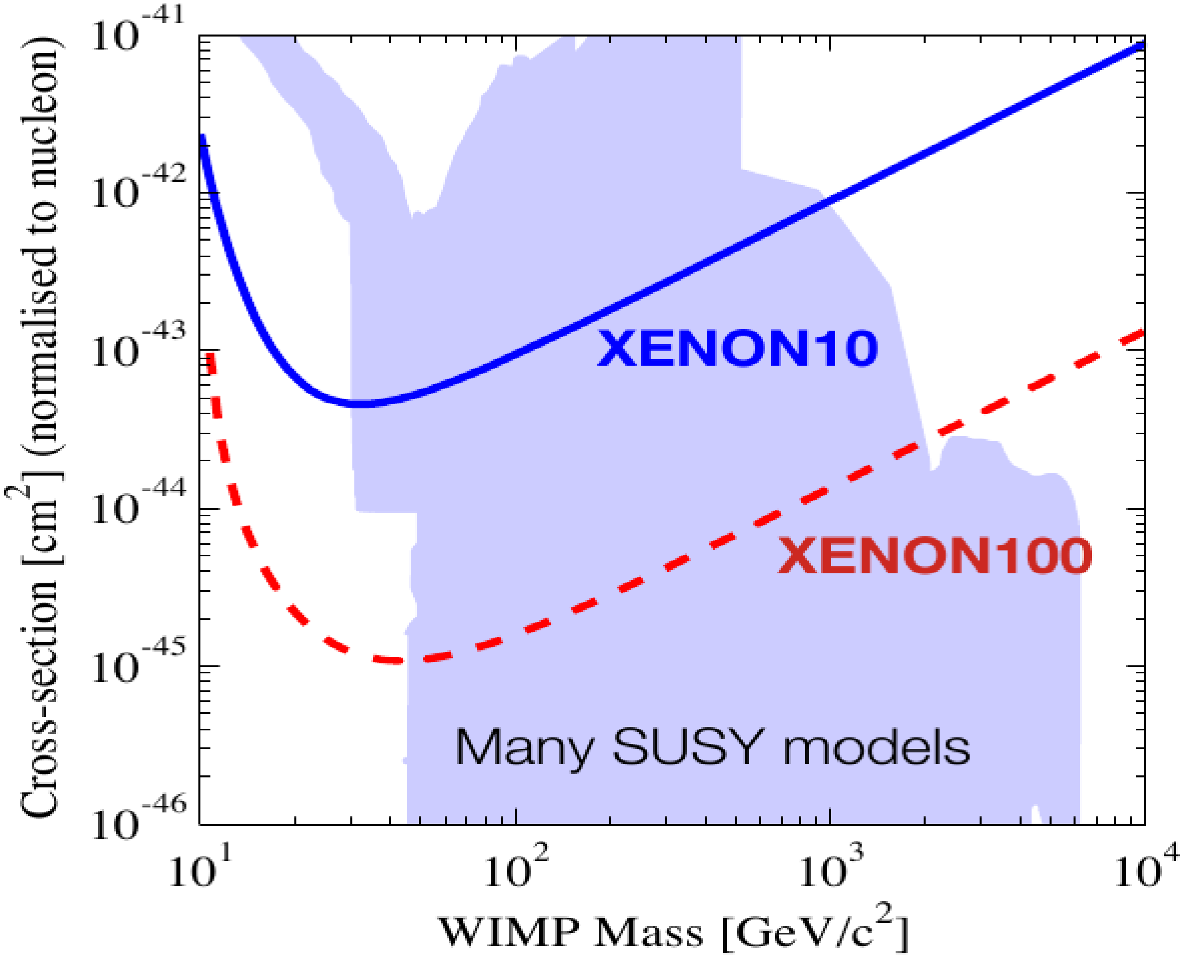
Materials	Rate [per year] in 50 kg FV mass	Rate [per year] In 30 kg FV mass
Stainless Steel	0.078	0.035
PMTs	0.255	0.108
Teflon	0.241	0.097
Lxe	0.002	0.001
Copper	0.105	0.048
Lead	0.004	0.002
Polyethylene	0.002	0.0006
Total material radioactivity	0.69	0.29
Rock-Concrete*	0.49 +/- 0.15	0.25 +/- 0.11
Muon-induced neutrons	0.54 +/- 0.24	0.10
Total neutron background	**1.72**	**0.64**

*after the addition of water shield (20cm thick, 4/6 coverage)
*** if no error is reported, then it is an upper limit

XENON100 background goal: confirmed with data



XENON100 Sensitivity

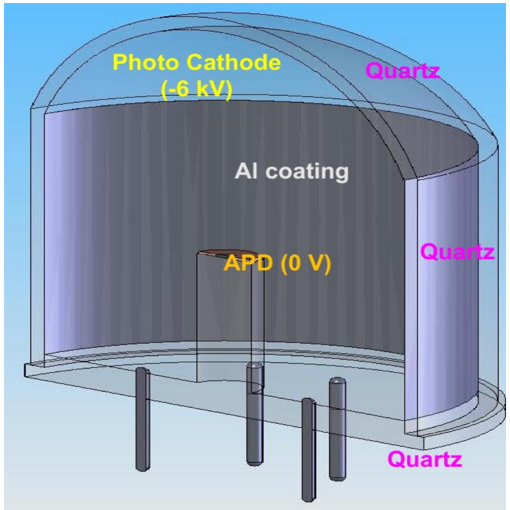


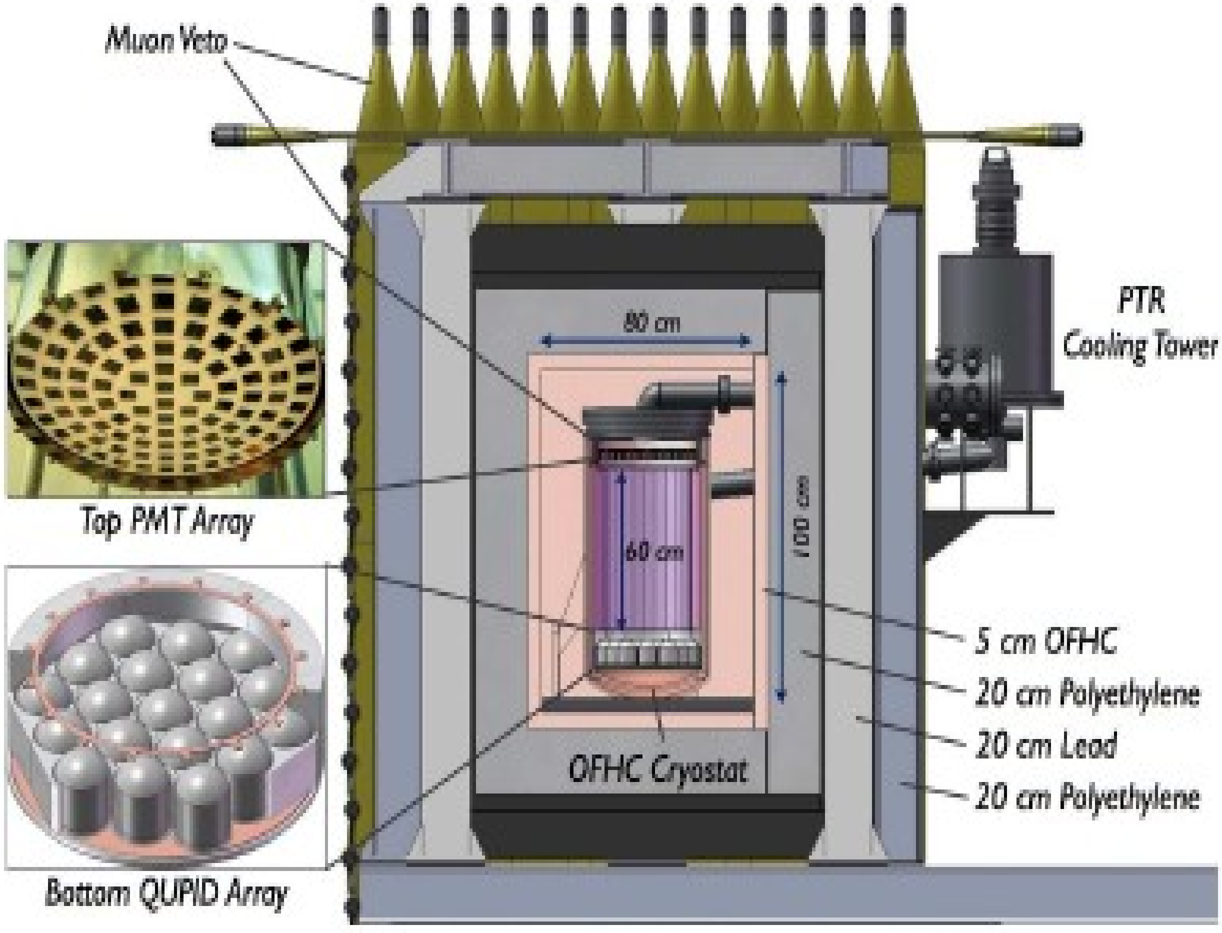
XENON10 SI limit: PRL100, 021303 (2008)

50 kg target: 40 days	$\sigma = 6\times10^{-45}$ cm^2 (at 100 GeV)
30 kg target: 200 days	$\sigma = 2\times10^{-45}$ cm^2 (at 100 GeV)

Next Step: The XENON100 Upgrade

- 100 kg fiducial mass (total of 260 kg Lxe, drift length = 60 cm)
- background $5x10^{-4}$ dru:
  new photon detectors:QUPIDs, cryostat made from OF copper,
  new shield, including muon veto
- Construction 2010
- 100kg: $\sigma=2x10^{-46}$ cm^2



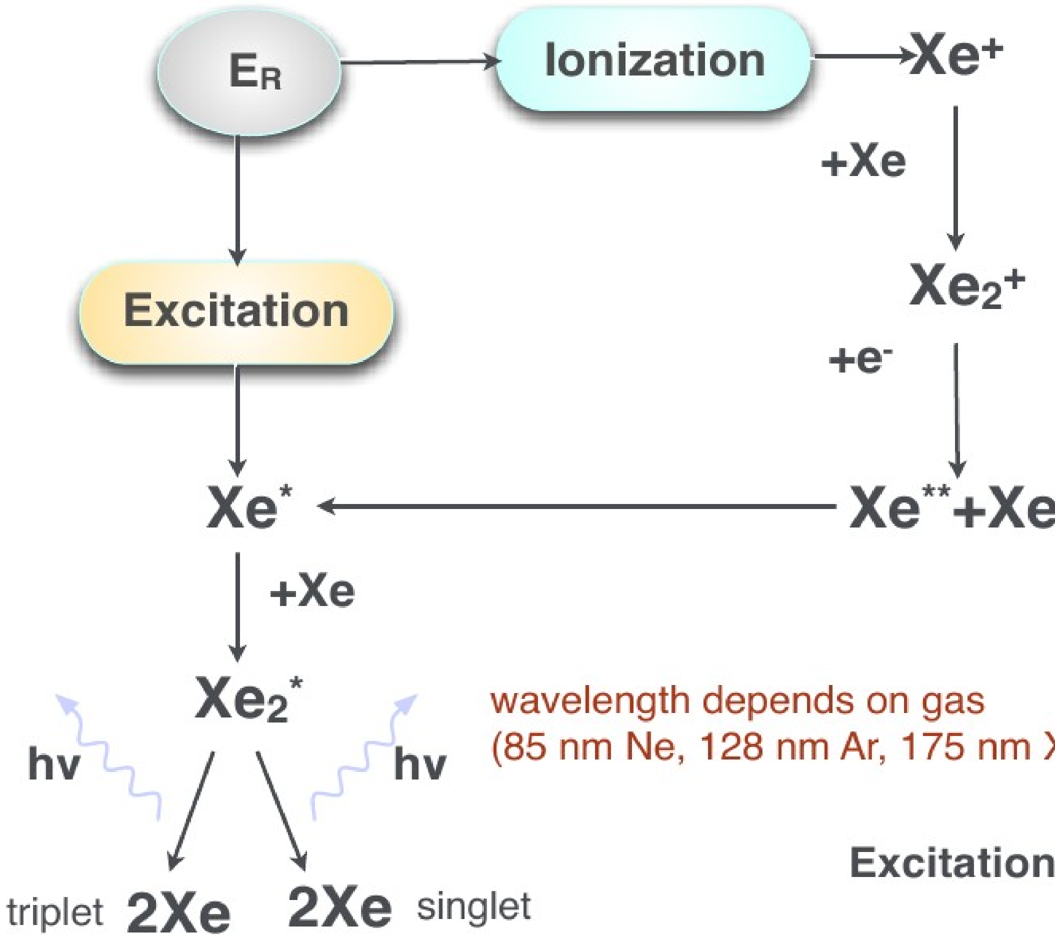


Conclusions

•XENON100 detector installed in LNGS
•Light calibration is carried out weekly to get the PMTs gains and monitor their stability
• Gamma calibration data are being taken in order to understand and characterise the detector
• XENON100 achieved its background goal, so it is expected to probe WIMP-nucleon SI cross sections down to 2×10^{-45} cm^2 for 7 months exposure

BACK UP

Charge and Light in Noble Liquids



wavelength depends on gas
(85 nm Ne, 128 nm Ar, 175 nm Xe)

time constants depend on gas
(few ns/15.4µs Ne, 10ns/1.5µs Ar, 3/27 ns Xe)

$$
\begin{aligned}
Xe^* + Xe &\rightarrow Xe_2^* \\
Xe_2^* &\rightarrow 2Xe + h\nu
\end{aligned}
$$

$$
\begin{aligned}
Xe^+ + Xe &\rightarrow Xe_2^+ \\
Xe_2^+ + e^- &\rightarrow Xe^{**} + Xe \\
Xe^{**} &\rightarrow Xe^* + heat \\
Xe^* + Xe &\rightarrow Xe_2^* \\
Xe_2^* &\rightarrow 2Xe + h\nu
\end{aligned}
$$

Excitation/Ionization depends on dE/dx!

=> discrimination of signal (**WIMPs=>NR**)
and (most of the) background (**gammas=>ER**)!

Sources of neutrons

1. Local Radioactivity: (α, n) reactions from U-238, U-235, Th-232
spontaneous fission from U-238

Neutron energy few MeV

2. Cosmic ray muons: μ- capture (important at shallow depths)

{ μ spallation
Hadronic cascades
E/M cascades } μ's in rock, shielding and detector materials

Neutron energy few GeV

Neutrons from rock and concrete surrounding the XENON Box

Materials	Neutron production [n/y/g]
Rock	7.1
Concrete	2.5

Threshold	Neutron Flux n/s/cm2
0	2.39E-6
1.0 MeV	9.70E-7

Muon induced neutrons

Threshold	Neutron Flux n/s/cm2
0	4.91E-9
1.0 MeV	1.56E-9

3 orders of magnitude lower than that from local radioactivity

Material	Multiplicity
Rock	7.3
Concrete	9.2
Polyethylene	33.5
Lead	8.9
Copper	12.1

Process	%
Hadronic	77%
E/M	18%
Muon spallation	4%
Muon capture	1%