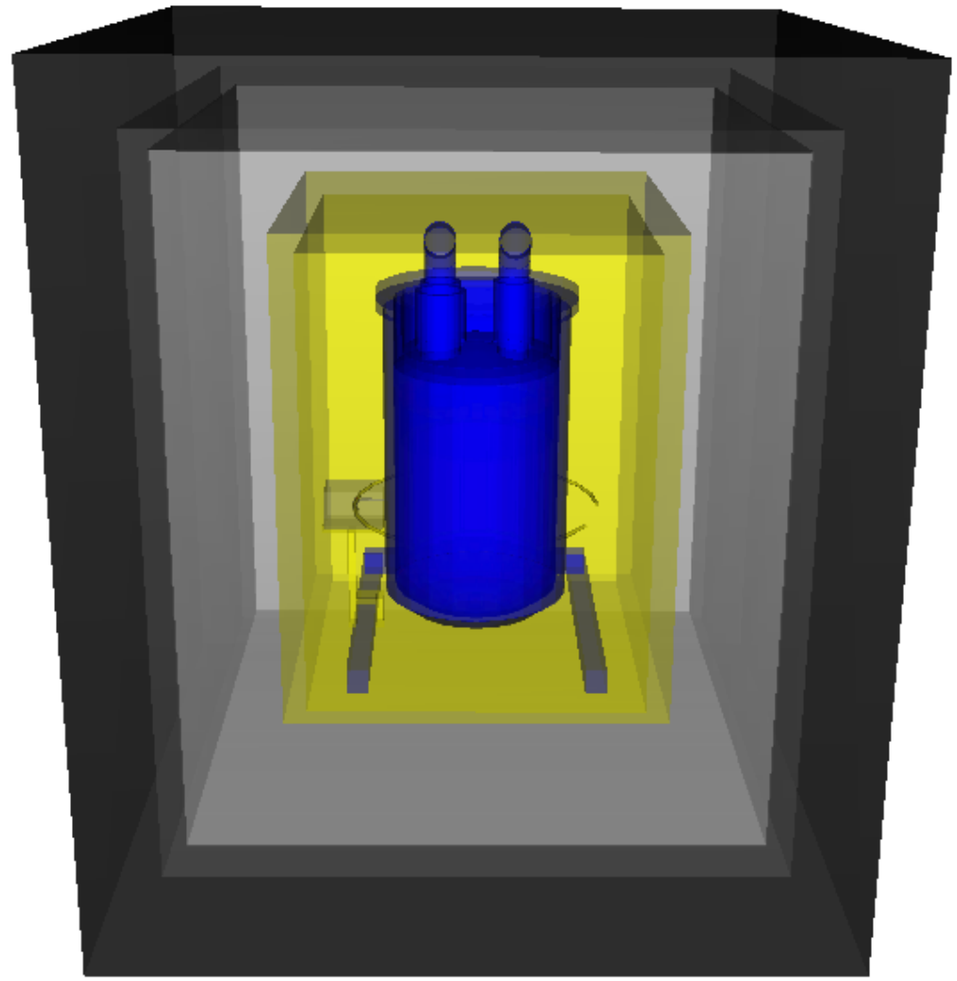
Background Studies for the XENON100 Experiment



Alexander Kish
Physics Institute, University of Zürich

Doktorandenseminar
August 30, 2010 UZH

The XENON dark matter search program

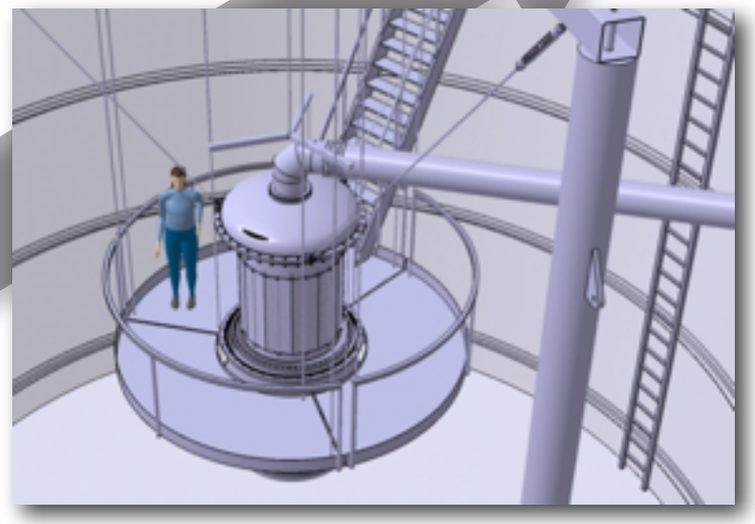
XENON 100

Target Volume 62 kg
Total 171 kg of LXe

First result
PRL arXiv:1005.0380

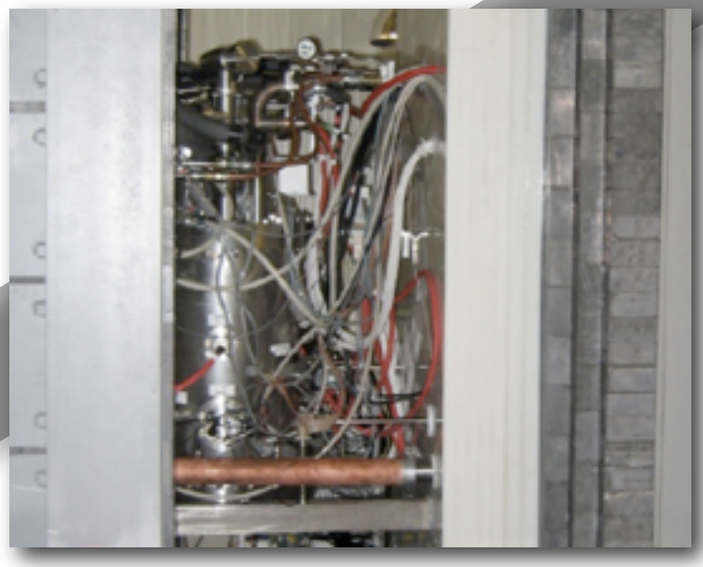
2007 - 2011

XENON 1T



2011 - 2015

XENON 10

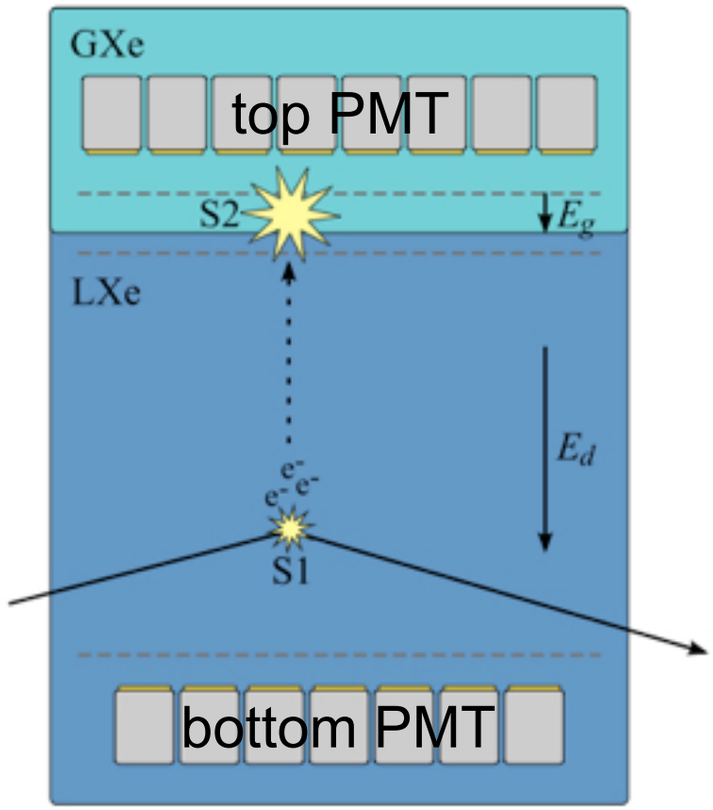


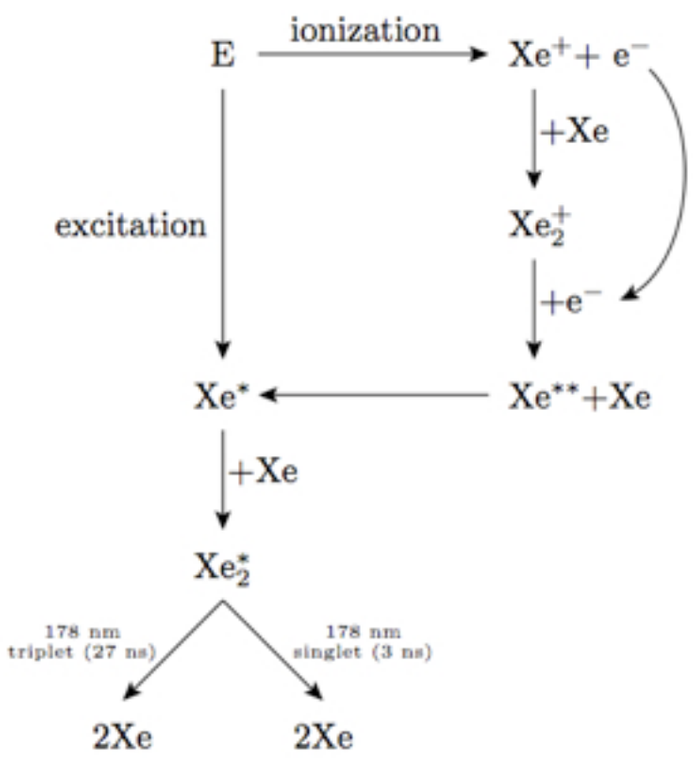
2005 - 2007

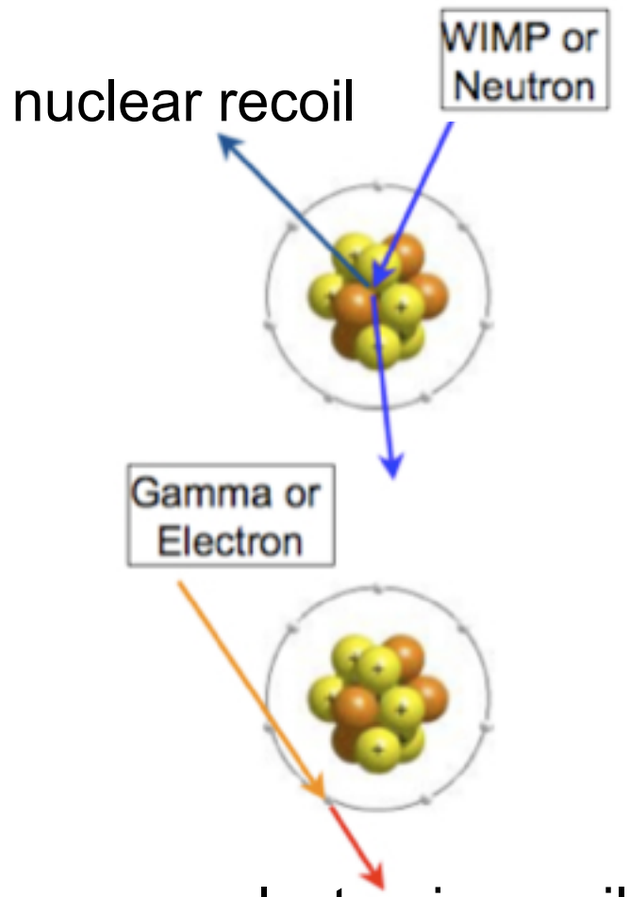
Target Volume ~10 kg
Fiducial volume 5.4 kg

Phys. Rev. Lett. **100** 021303 (2008)
Phys. Rev. Lett. **101** 091301 (2008)

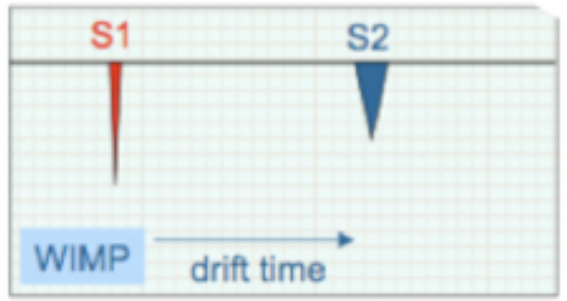
The principle of the XENON experiment

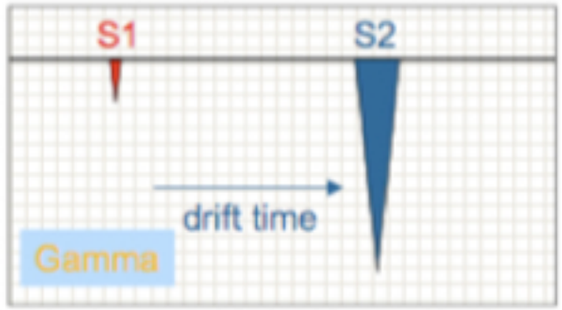




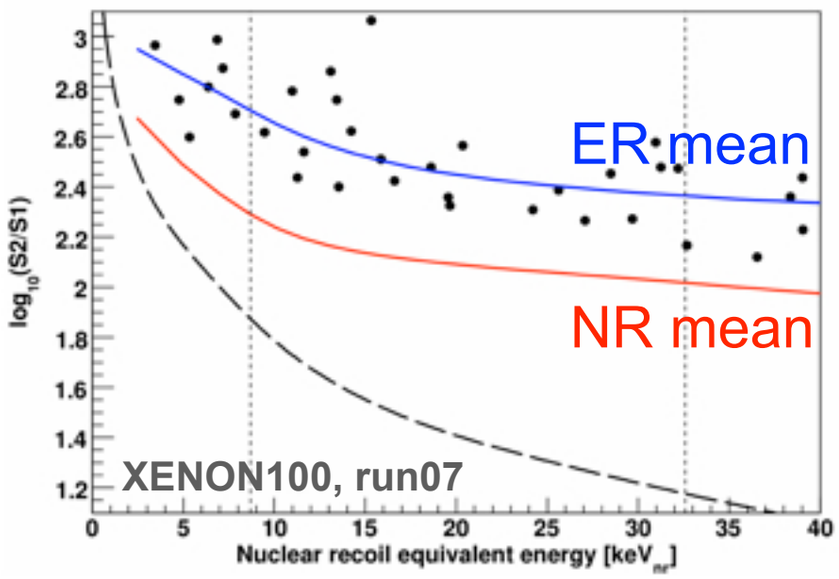


> 99% electronic/nuclear recoils discrimination based on S2/S1 ratio





$(S2/S1)_{wimp} << (S2/S1)_{gamma}$



XENON100 backgrounds

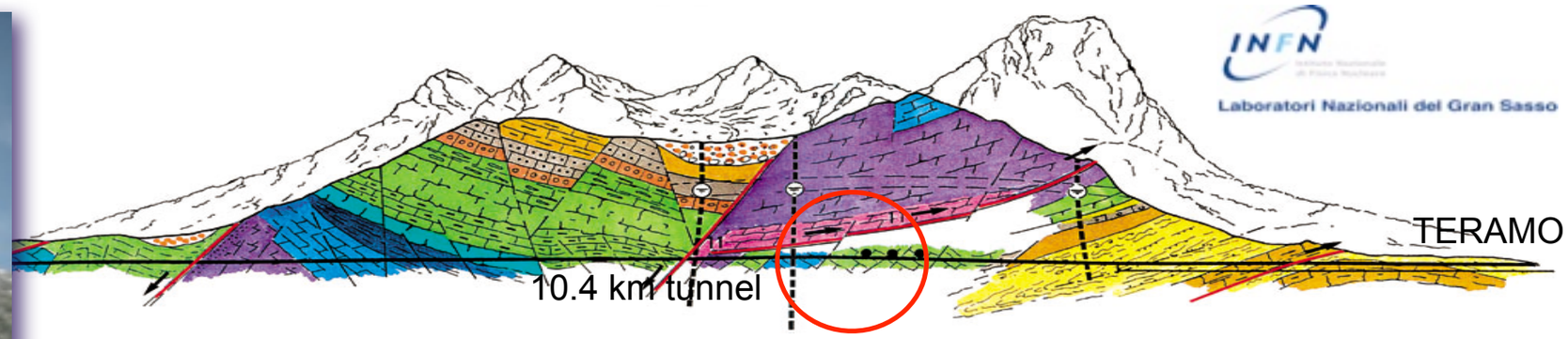
Sources of electron recoil background

- natural radioactivity in the detector and shield materials
- ^{222}Rn contamination in the air
- intrinsic contamination of ^{222}Rn, ^{85}Kr
- cosmogenic xenon activation during storage at the Earth surface

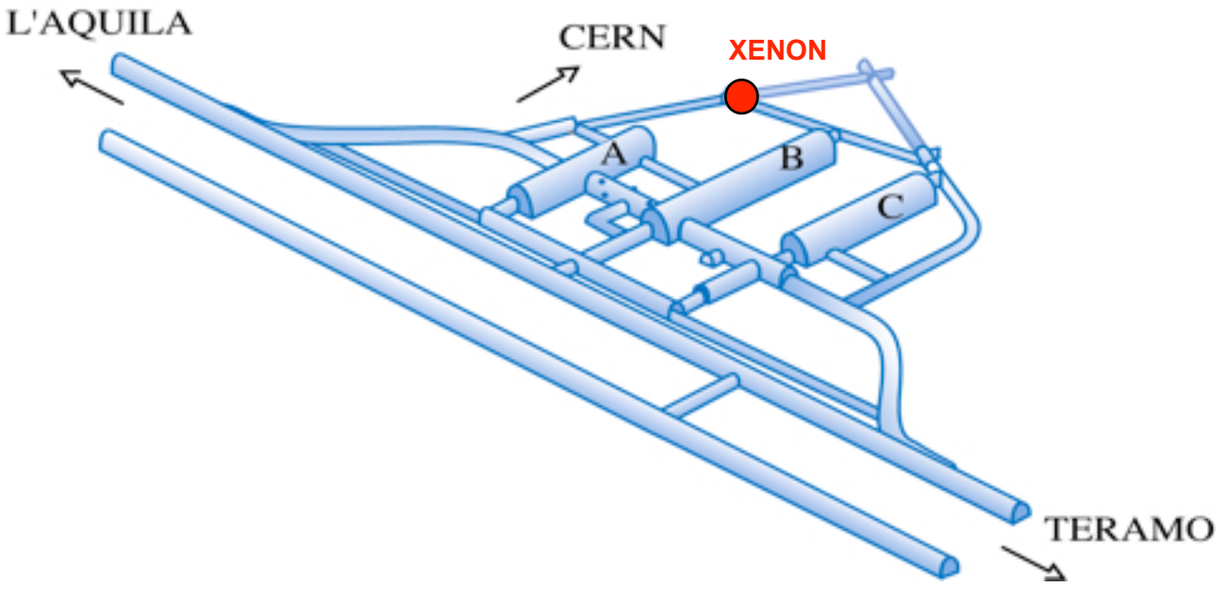
Sources of nuclear recoil background

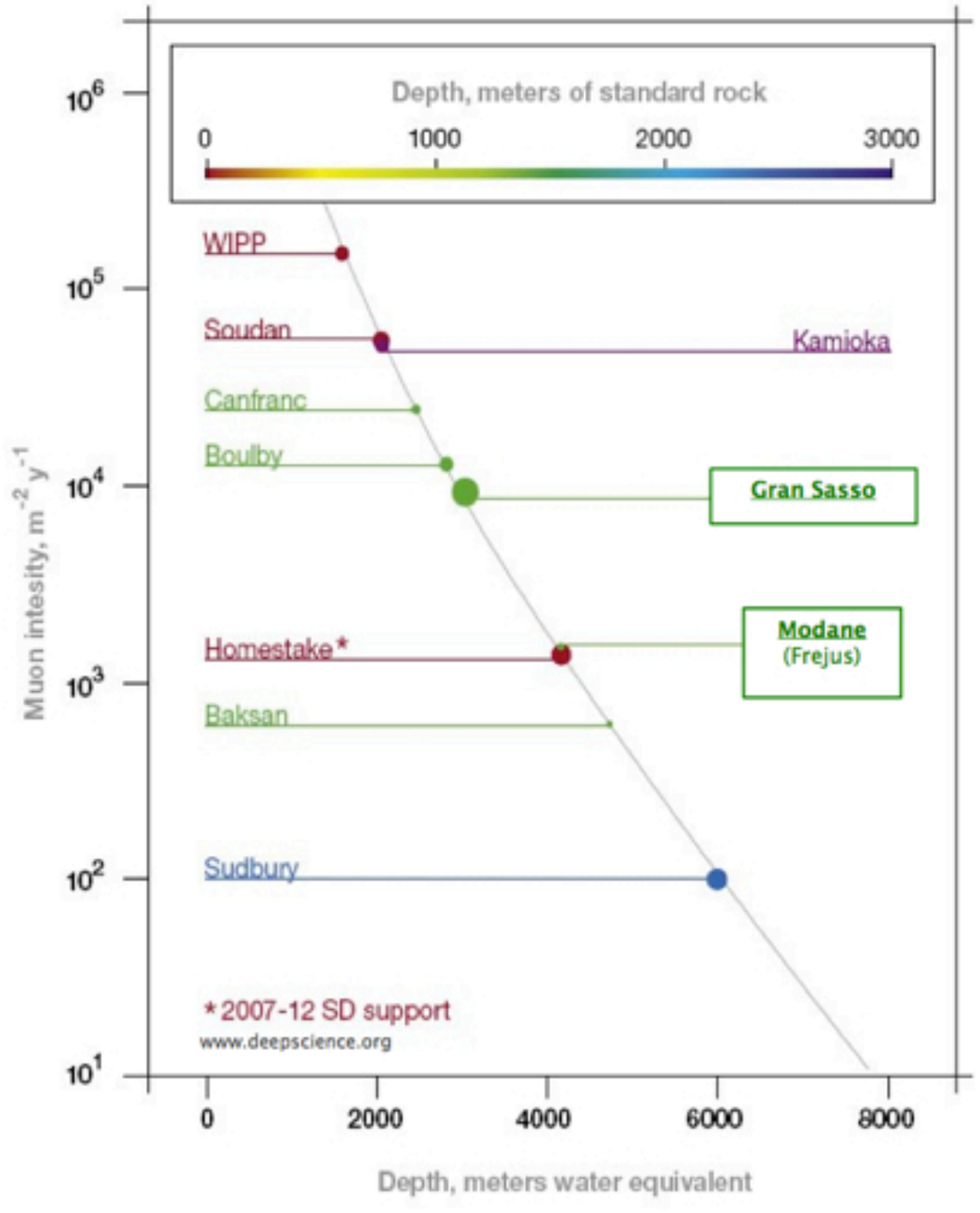
- (α,n) and spontaneous fission
- muon-induced neutrons

Location of the XENON100 experiment



1.4 km rock
=
3100 meters water equivalent
shielding from cosmic rays



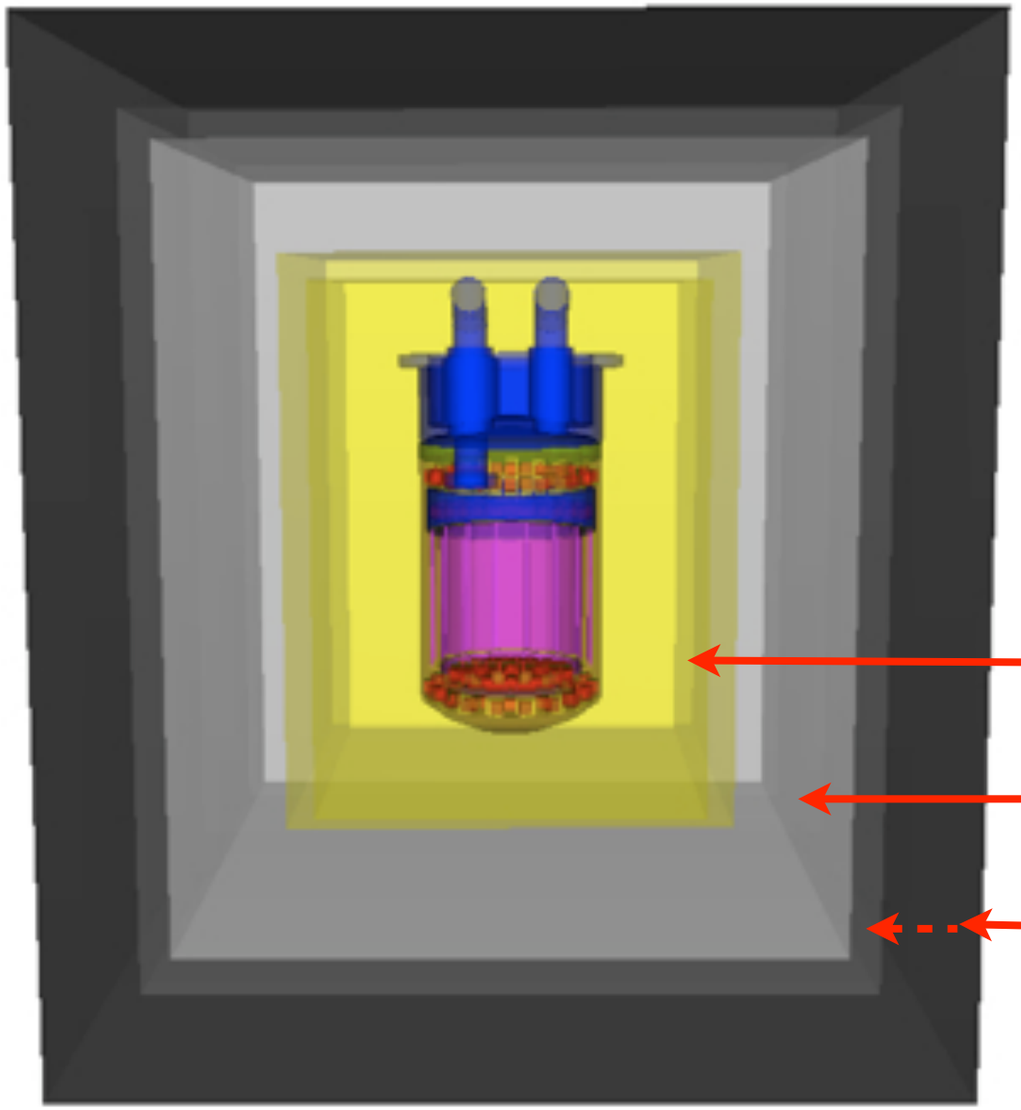


Radioactive contamination in the detector materials

- all materials screened for radioactive contamination
- screening facility at LNGS (2.2kg Ge)

} details in the talk of Ali Askin

- detailed GEANT4 model



XENON100 Shield:

copper, 5cm

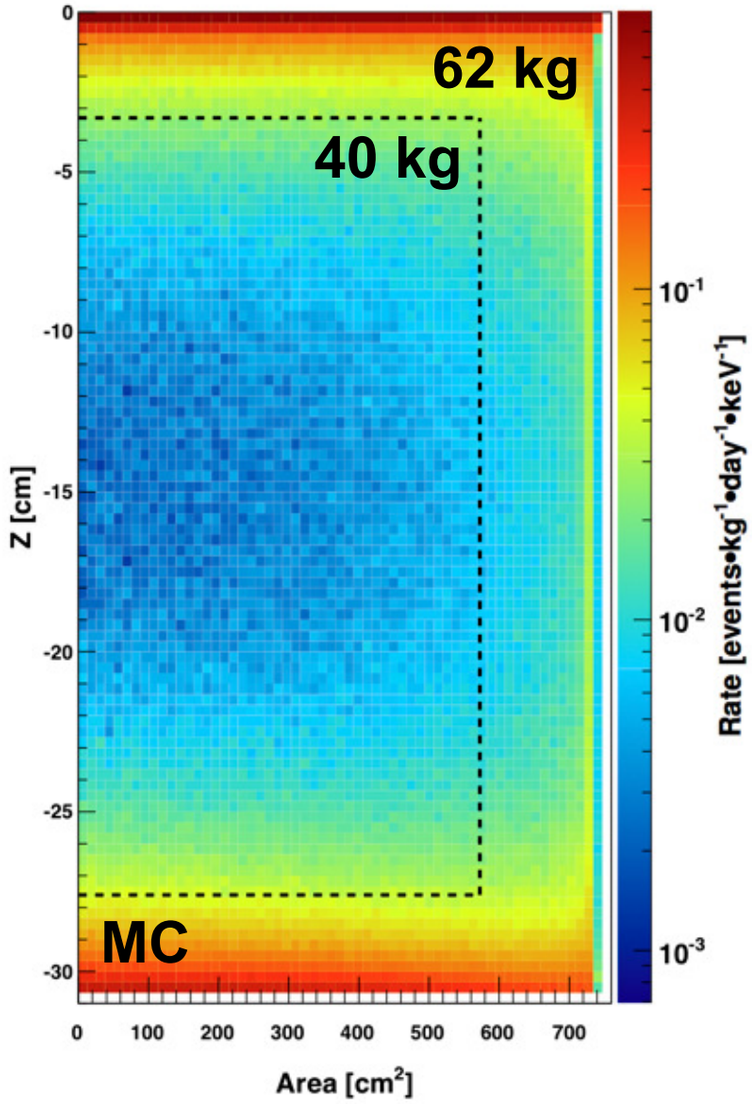
polyethylene, 20cm

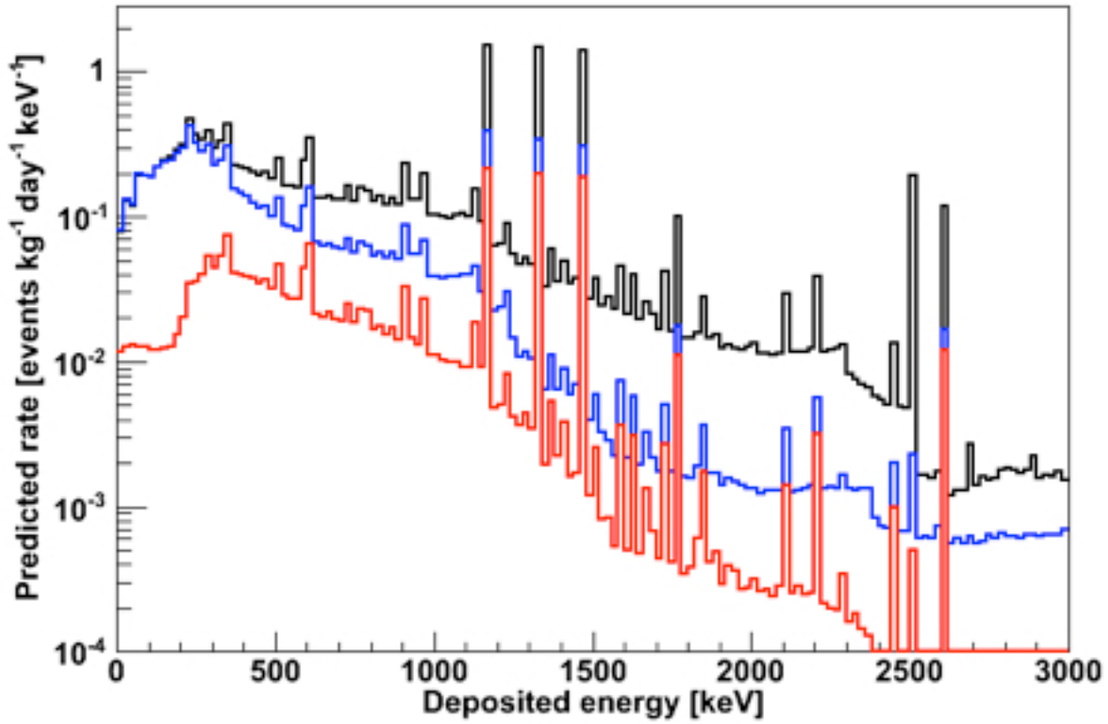
lead, 20cm

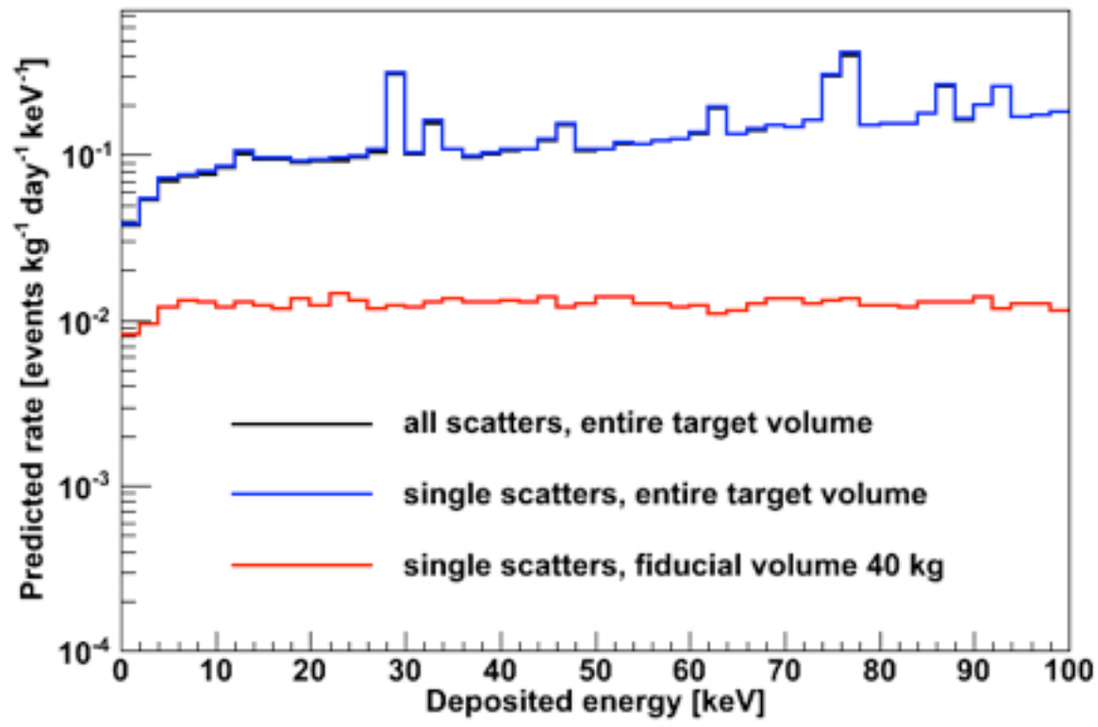
water tanks, 20cm

Radioactive contamination in the detector materials

- BG prediction with GEANT4 simulations







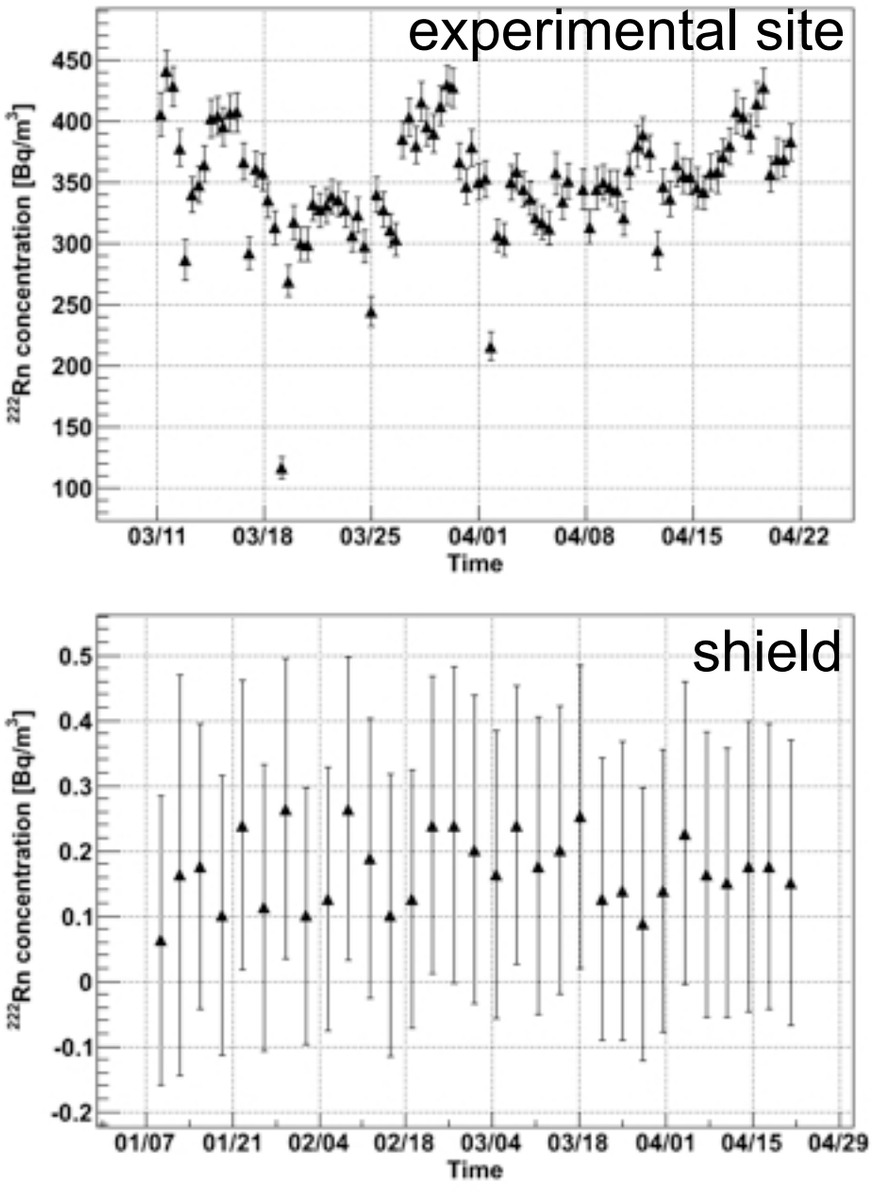
- 40 kg fiducial volume cut - 88% BG reduction
- Additional BG reduction with the veto cut

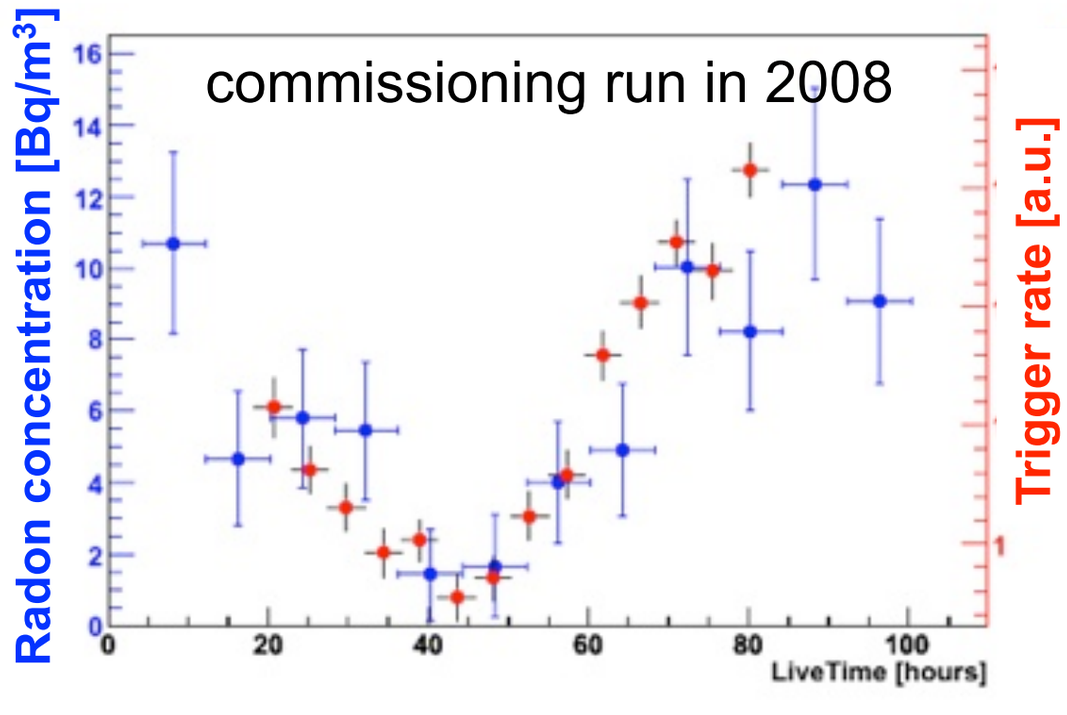
(average energy threshold 100 keV):
- entire target volume ~40%
- 40 kg fiducial volume ~70%

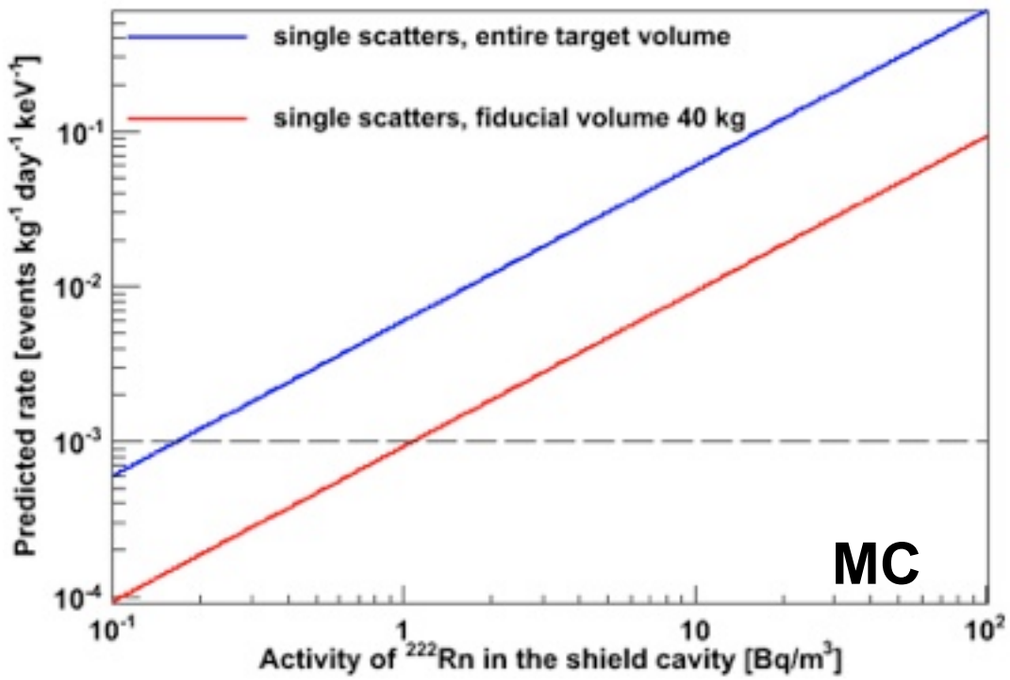
Radon in the air of the shield cavity

- **^{222}Rn in the air at the experimental site and inside the shield cavity**

- monitored with radon detectors
- at the experimental site > 300 Bq/m^3
- shield cavity purged with N_2
- inside the shield < 1 Bq/m^3
- BG rate < 10^{-3} events kg^{-1} day^{-1} keV^{-1}





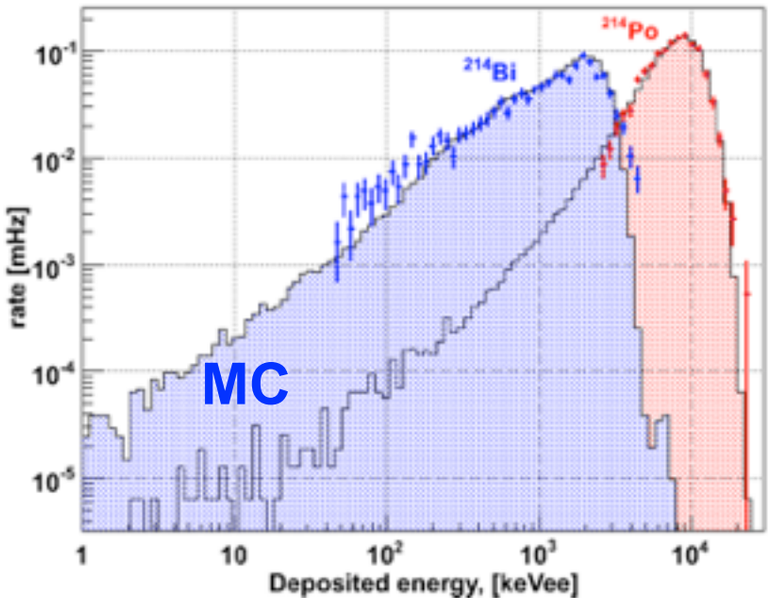


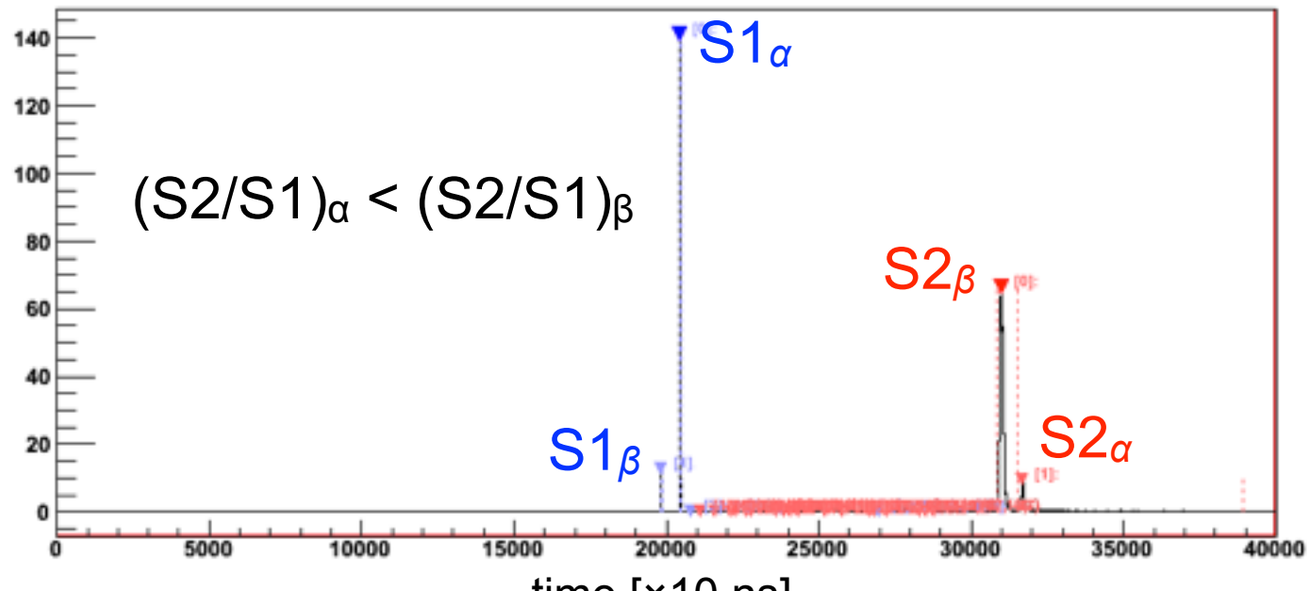
Intrinsic contamination: ^{222}Rn

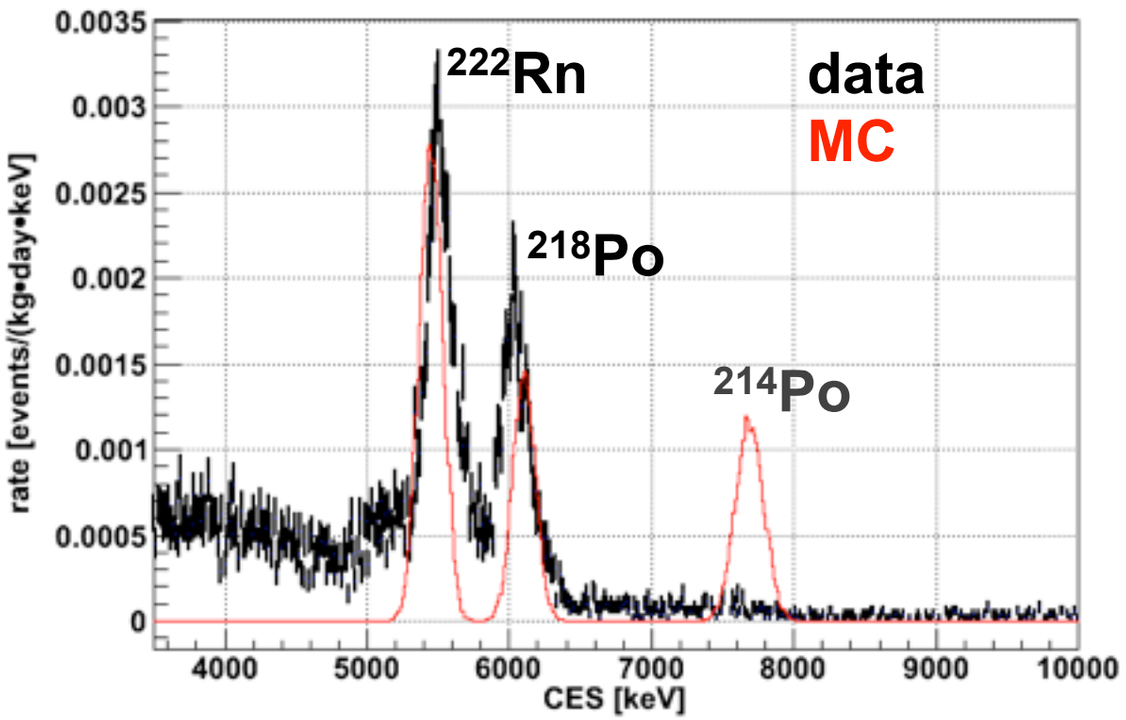
- **Intrinsic radon contamination**
- 'β-α' delayed coincidence analysis
- upper limit 21μBq/kg

$$^{238}U \ \ldots \ ^{222}Rn \ \ldots \ ^{214}Bi \xrightarrow{\beta,\ E_{max}=3.27MeV} ^{214}Po \xrightarrow{\alpha,\ E=7.69MeV} ^{210}Pb$$

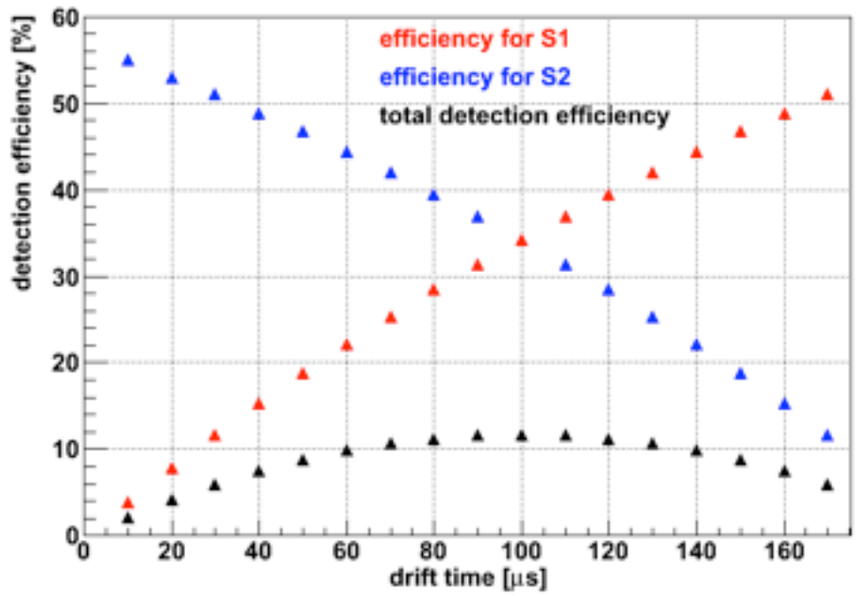
$T_{1/2}$=3.8d (for ^{222}Rn), $T_{1/2}$=19.7m (for ^{214}Bi), $T_{1/2}$=164μs (for ^{214}Po)





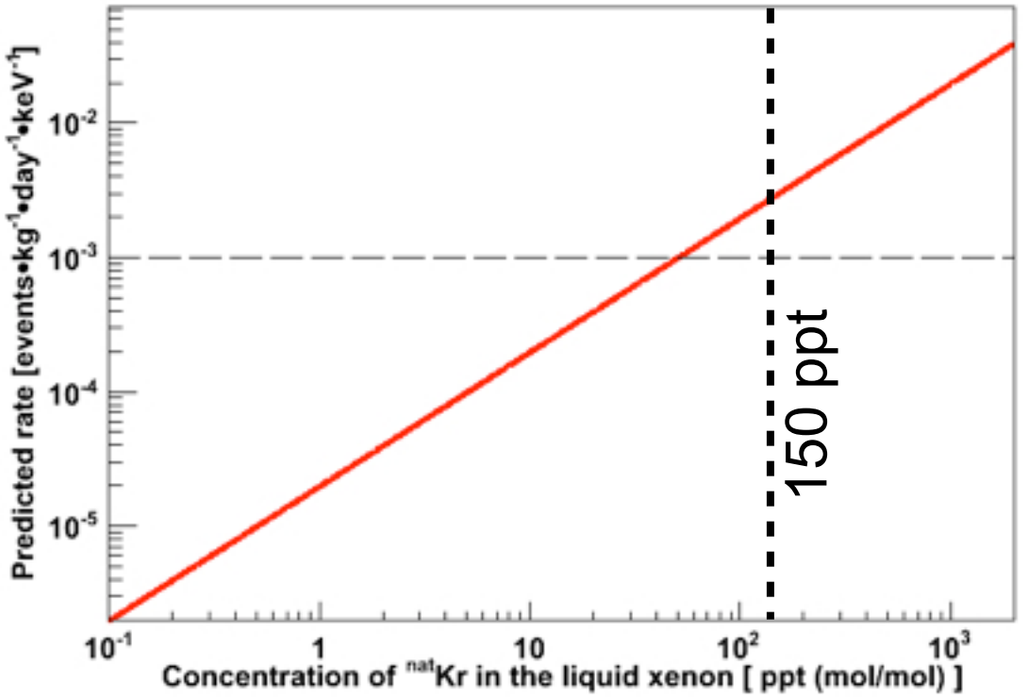


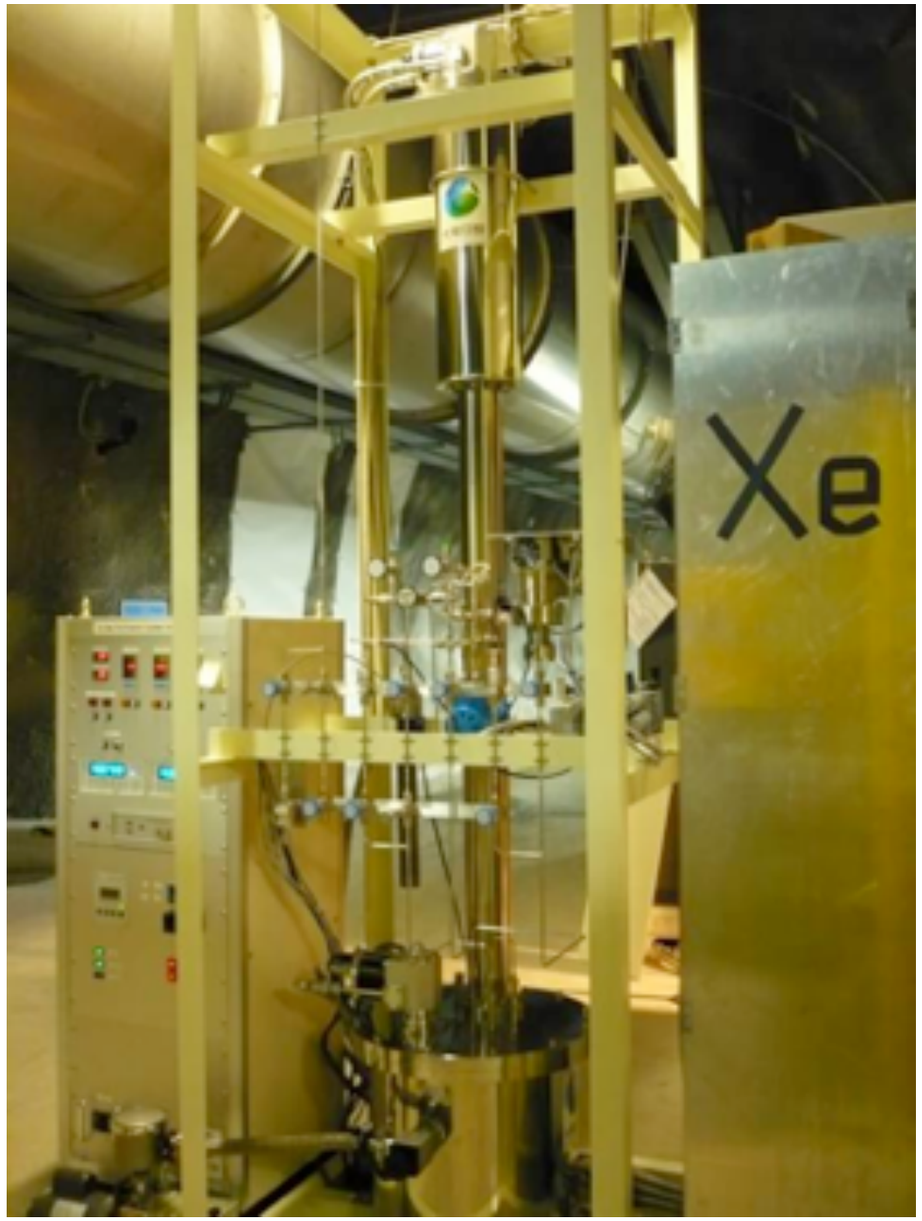
^{214}Po peak at 7.8 MeV is not visible in combined (S1+S2) energy scale



Intrinsic contamination: ^{85}Kr

- ^{85}Kr in LXe:
- natural Kr contains 10^{-11} of ^{85}Kr
- 'β-γ' delayed coincidence analysis
- ^{nat}Kr concentration (143^{+130}_{-90}) ppt (mol/mol)
- krypton contamination is reduced by cryogenic distillation





- krypton concentration 150 ppt

↓

BG rate 2.9 events kg^{-1} day^{-1} keV^{-1}

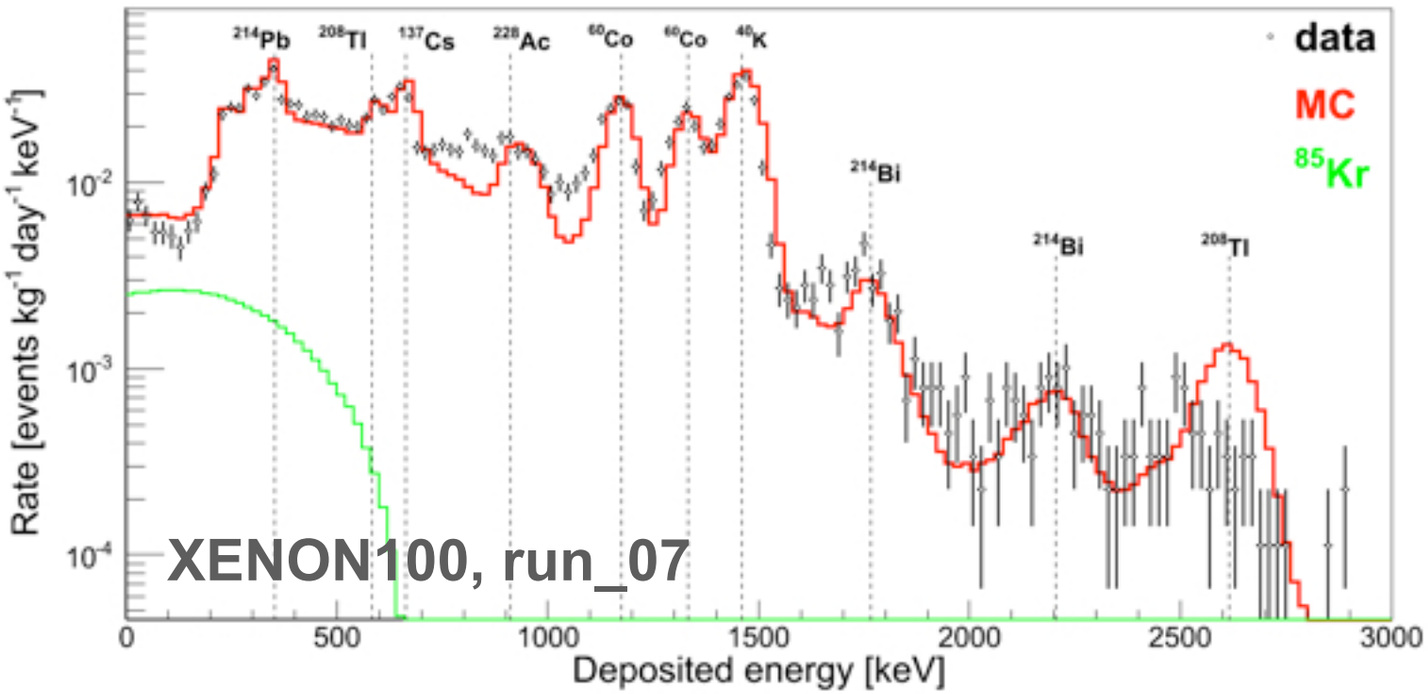
- BG level < 1 event kg^{-1} day^{-1} keV^{-1}

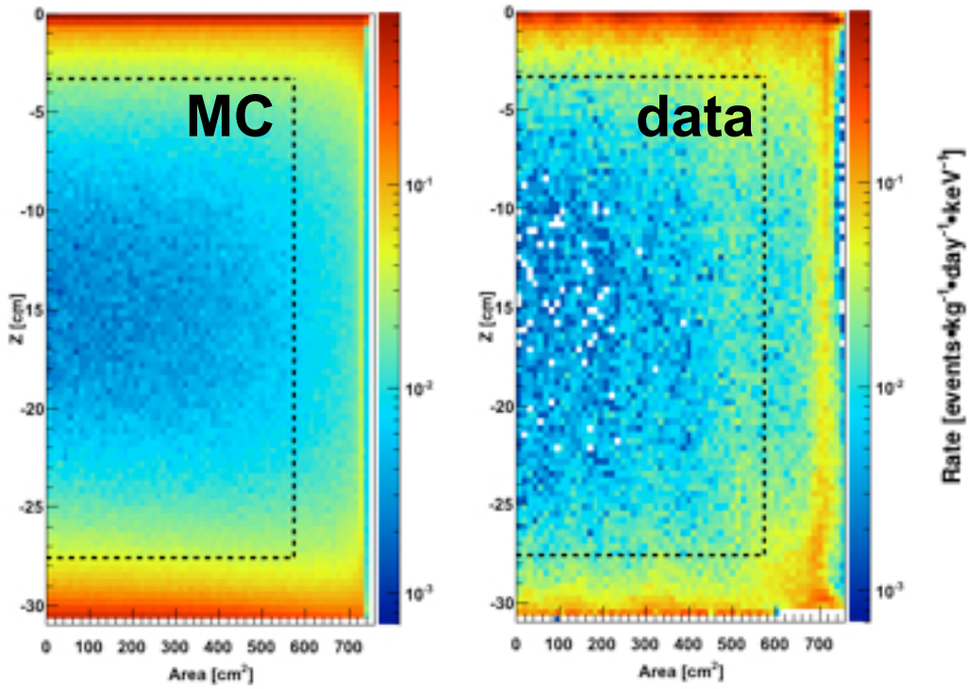
↑

krypton concentration < 50 ppt

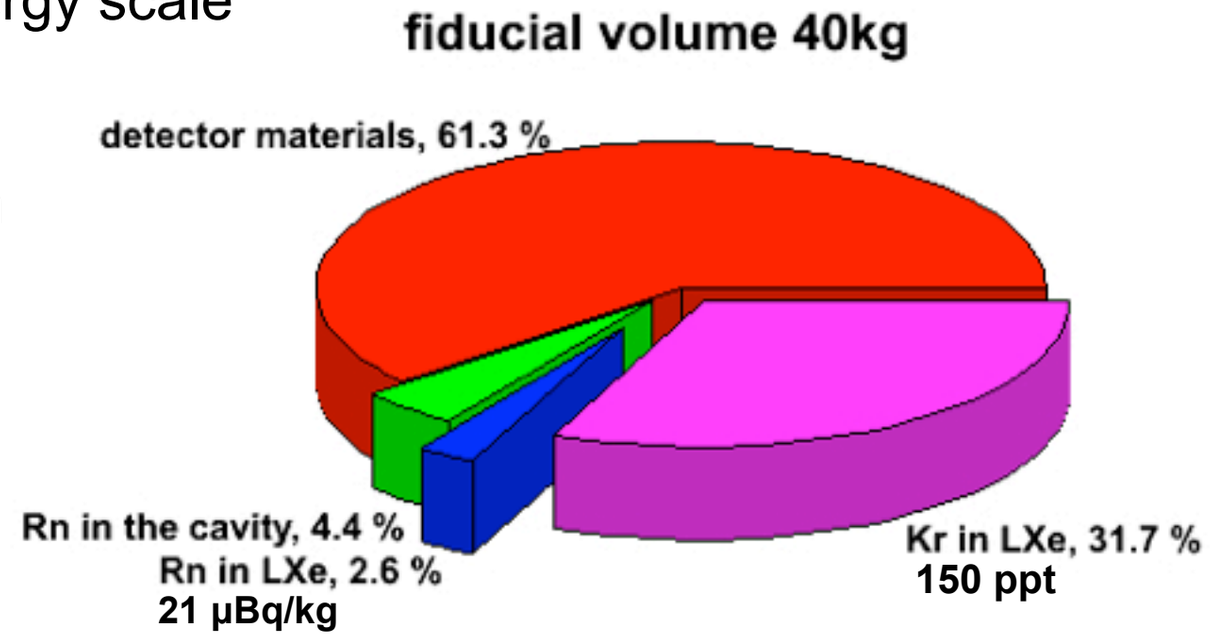
Electronic recoil background

- Material screening + delayed coincidence analysis → BG model
- Background model is in a good agreement with the measured spectrum





- measured spectrum in combined (S1+S2) energy scale
- 40 kg fiducial volume cut
- active veto cut
- MC smeared with measured energy resolution
  (2% σ/mean at 662keV)



Cosmogenic xenon activation at the Earth's surface

- simulated with the COSMO and ACTIVIA packages
- many isotopes long lived ($T_{1/2}$ > 100 days),

decay with emission of low energy gammas and electrons

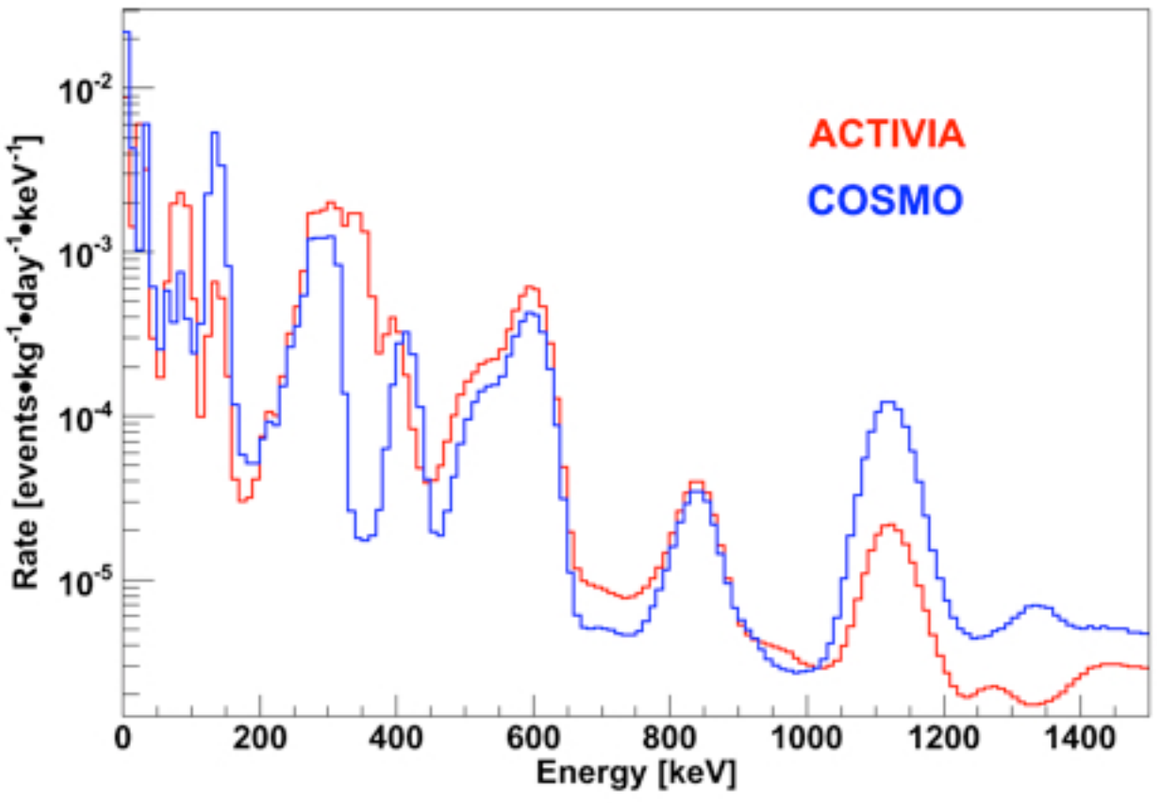
- disagreement in production rates when using

ACTIVIA and COSMO

- disagreement with a simulation with TALYS

  D.M. Mei, Z.B. Yin, S.R. Elliott, Astrop. Phys. 31, 417 (2006)

- discrepancy with the measured background spectrum

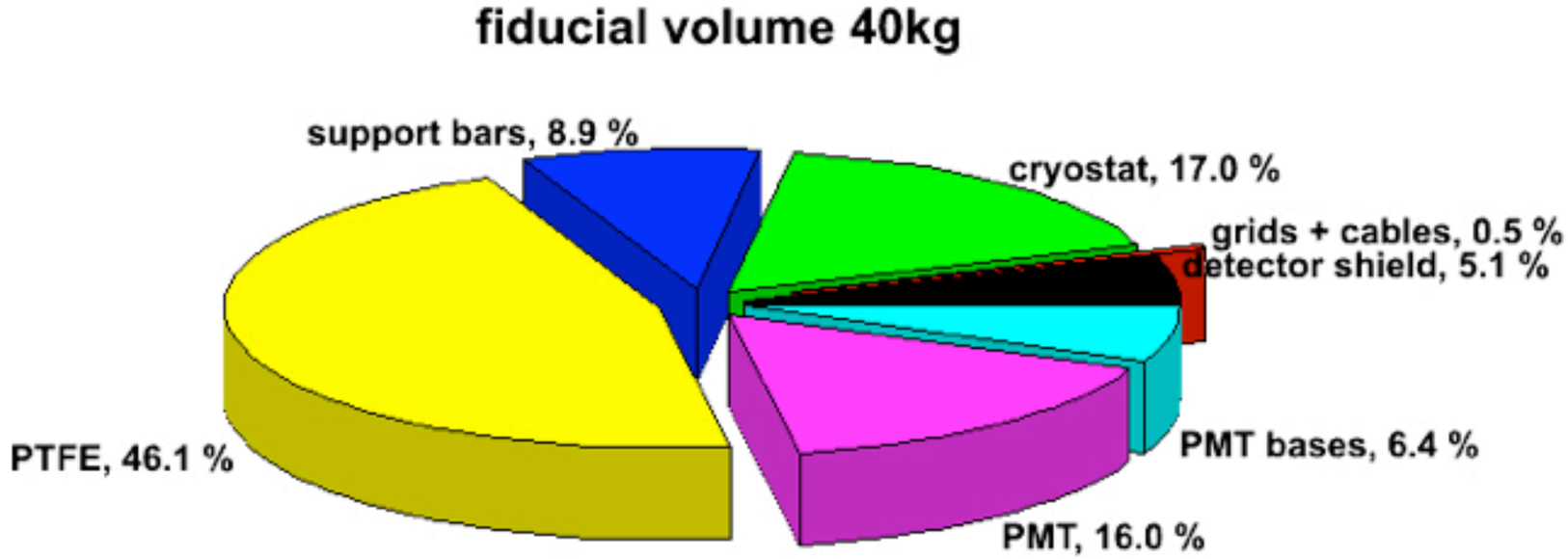


isotope	Half-life time	activation (1 year) [μBq/kg]	
		ACTIVIA	COSMO
^{3}H	12.34 years	22.762	22.165
^{22}Na	2.60 years	0.257	0.230
^{45}Ca	165 days	0.528	0.464
^{49}V	330 days	1.587	1.374
^{54}Mn	312 days	1.485	1.274
^{55}Fe	2.70 years	0.367	0.307
^{57}Co	271 days	1.030	11.840
^{60}Co	5.27 years	0.148	1.395
^{65}Zn	244.1 days	2.485	27.824
^{68}Ge	270.8 days	1.042	12.373
^{75}Se	118.5 days	3.957	42.535
^{88}Y	106.6 days	1.587	12.523
^{93m}Nb	13.61 years	0.111	0.624
^{101}Rh	3.30 years	3.493	
^{102}Rh	206 days	4.407	
^{102m}Rh	2.90 years	1.324	
^{110m}Ag	252 days	0.608	
^{109}Cd	1.24 years	16.360	
^{113}Sn	115 days	47.285	0.073
^{119m}Sn	250 days	0.478	0.663
^{121m}Te	154 days	231.996	151.157
^{123m}Te	119.7 days	12.507	11.177
^{127m}Te	109 days	11.119	11.094
^{134}Cs	2.06 years	2.705	2.738

Nuclear recoil background

- Neutron production in (α,n) and spontaneous fission reactions, due to contamination of ^{238}U, ^{235}U and ^{232}Th
  - neutron production spectra generated with SOURCES4A
  - simulation with GEANT4

Predicted BG rate in 40 kg fiducial volume (energy range 8.7-32.6 keV$_{nr}$) from the detector and shield materials < 0.29 events/year



Nuclear recoil background

- Muon-induced neutrons:

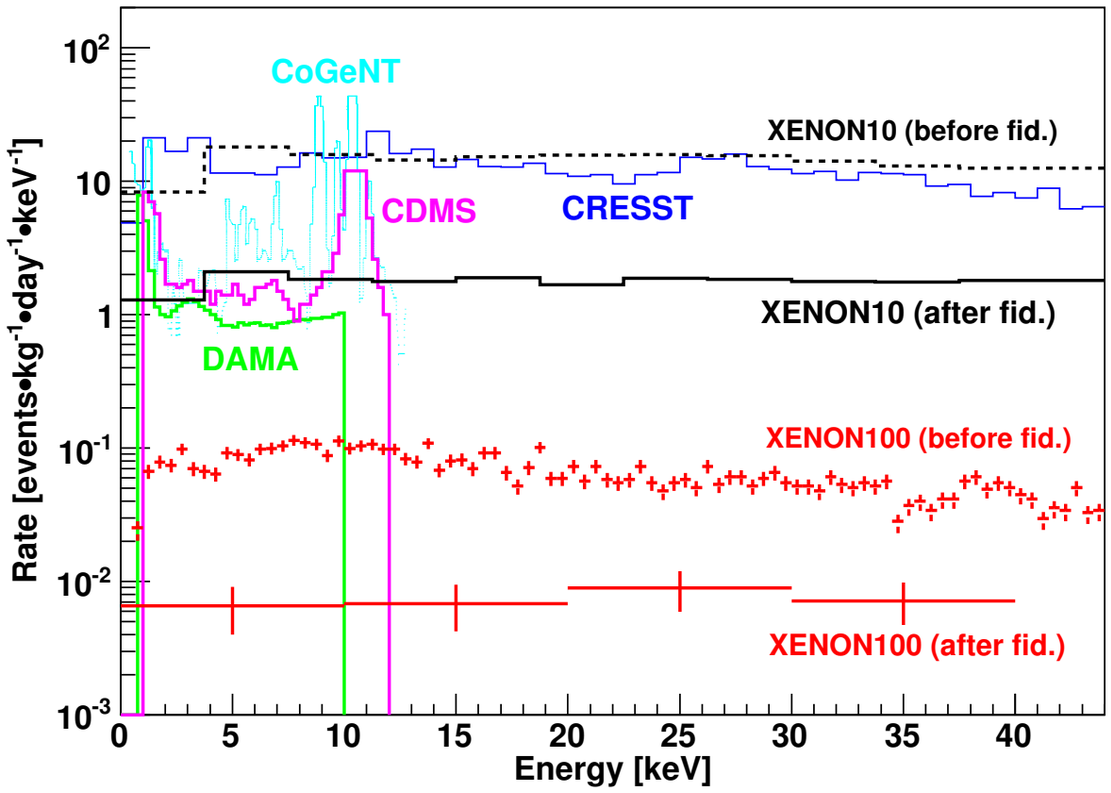
MUSIC: transport muons from the Earth's surface down to the underground laboratory
MUSUN: generate angular distribution and energy spectra at the experimental site
GEANT4: propagate muons into the detector environment

- predicted BG rate (XENON10 energy range, 4.5-26.7 keV_{nr}) in the 50 kg fiducial volume < 0.27 events/year

Material	Contribution to the total recoils rate [%]
Rock	0.04
Concrete	0.11
Polyethylene	1.8
Copper	37.6
Pb	4.6
Stainless steel	6.6
LXe	38.8
PTFE and PMTs	10.5

Summary and outlook

- Achieved background level is in the fiducial volume two orders of magnitude lower than in XENON10, and any competing Dark Matter experiment



- Further reduction of krypton contamination is expected after cryogenic distillation
- The BG model is in a good agreement with the measured spectrum
- Study of the electronic recoil background will be published soon
- Simulations of nuclear recoil background are being finalized