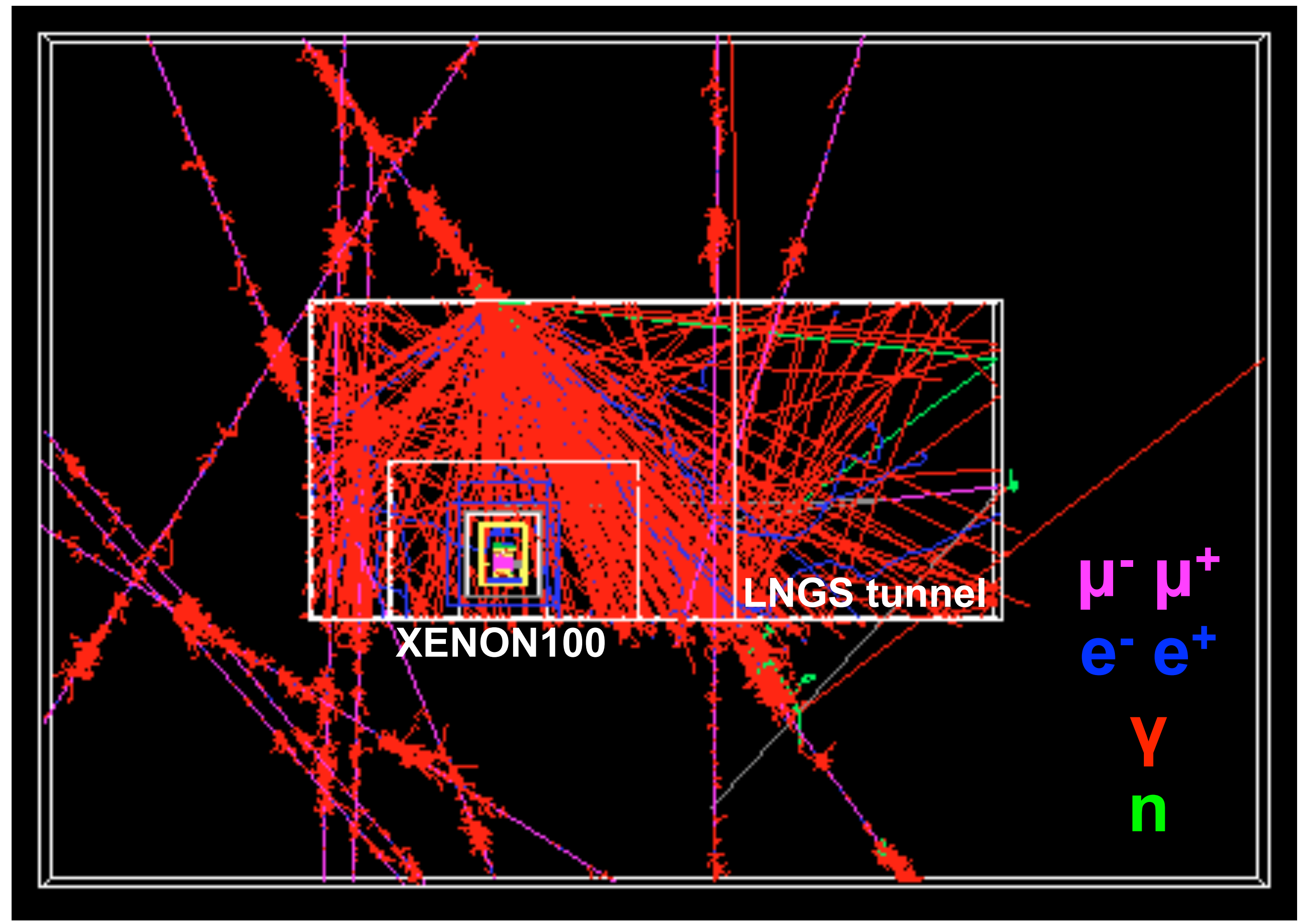
Cosmogenic backgrounds in the XENON100 experiment



Alexander Kish
Physics Institute, University of Zürich

Cosmogenic Activity and Backgrounds Workshop by DUSEL
LNBL April 15, 2011

XENON collaboration

- ~50 scientists, 14 institutions, 9 countries:
USA, Switzerland, Germany, Italy, France, China, Israel, Portugal, Netherlands

Zürich

Columbia

Gran Sasso

Mainz

Münster

Rice

UCLA

Max-Planck

Subatech

Weizmann

Coimbra

Bologna

SJTU

NIKHEF

The XENON dark matter search program

XENON 10

2005 - 2007

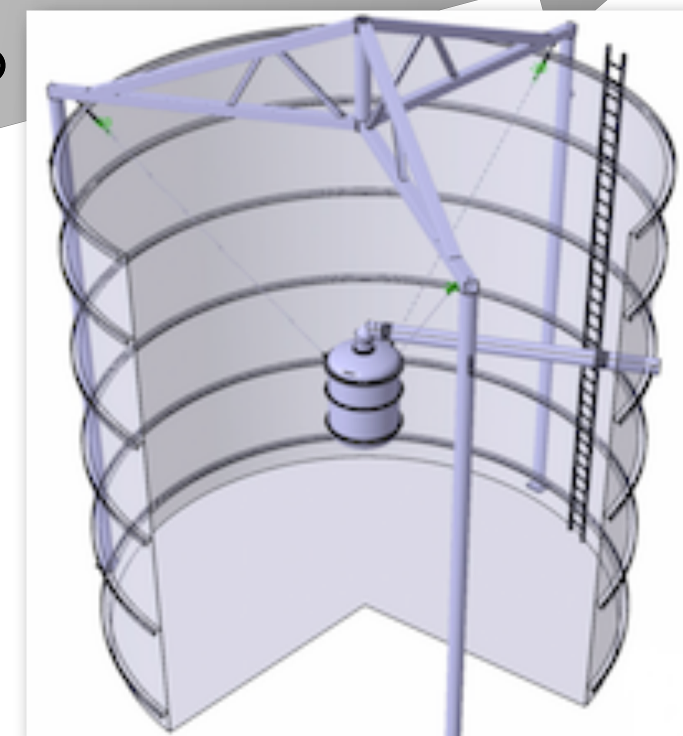
Target mass ~10 kg

XENON 100

2007 - ongoing

Target mass 62 kg
(161 kg of LXe in total)

XENON1T

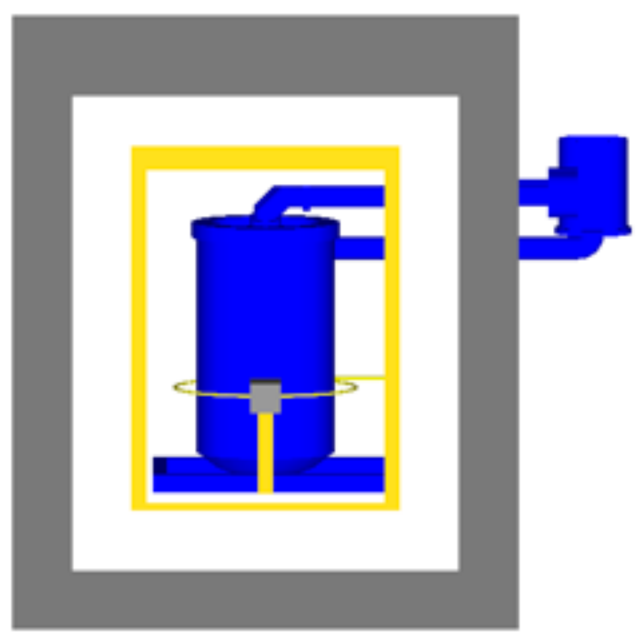


2013 - 2015

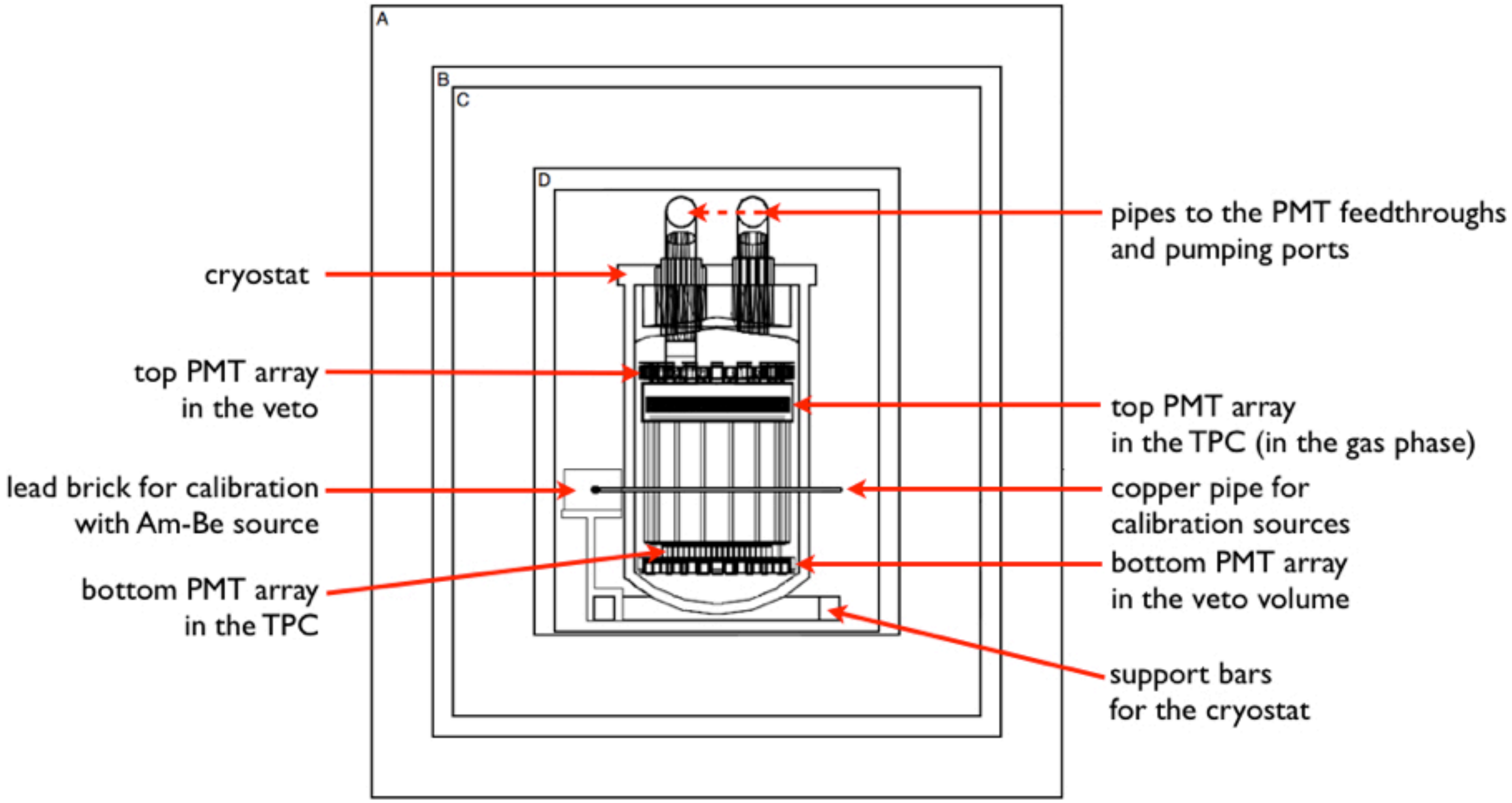
Target mass 2t
Water shield / muon veto
(D=10m, h=10m; ~26t)

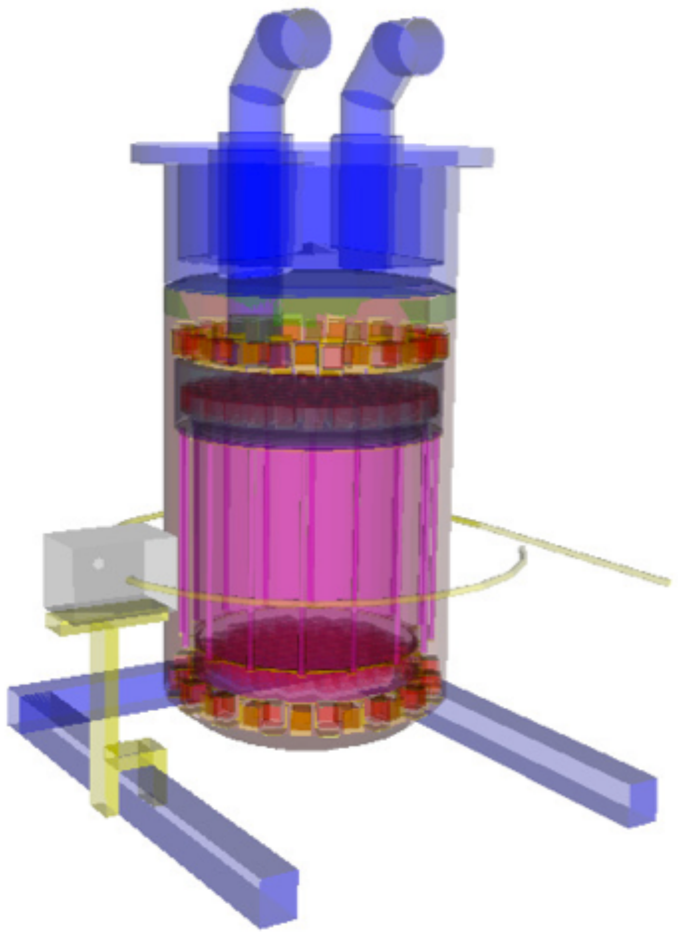
Xe10/Xe100 shield:

- copper, 2.2T
(5cm innermost shield layer)
- polyethylene, 1.6T
(+ 25cm layer on the bottom)
- lead, 33.8T in two layers
- water tanks, 20x20x40cm



XENON100 detector





- active LXe veto, 99kg (~4cm on all sides around the target)
- 242 1”-square Hamamatsu PMTs: 98+80 in the TPC (top/bottom), 64 in the veto

Backgrounds in XENON100

Sources of nuclear recoil background

- (α,n) reactions and spontaneous fission in the detector and shield materials due to natural radioactivity

- muon-induced neutrons

Sources of electron recoil background

- natural radioactivity in the detector and shield materials

- ^{222}Rn contamination in the shield cavity

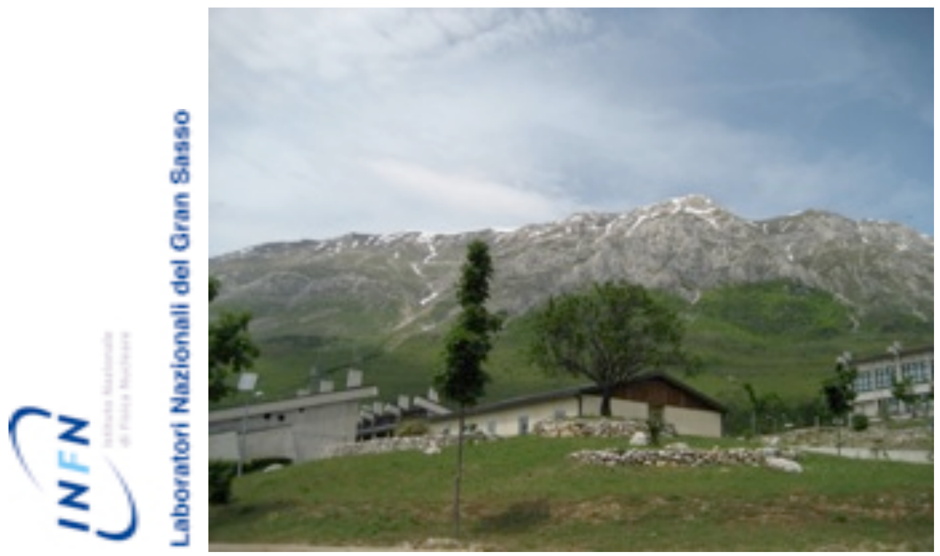
- intrinsic contamination of ^{222}Rn, ^{85}Kr

- cosmogenic activation of the detector components during construction and storage at the Earth surface

- cosmogenic activation of the xenon during production and storage at the Earth surface

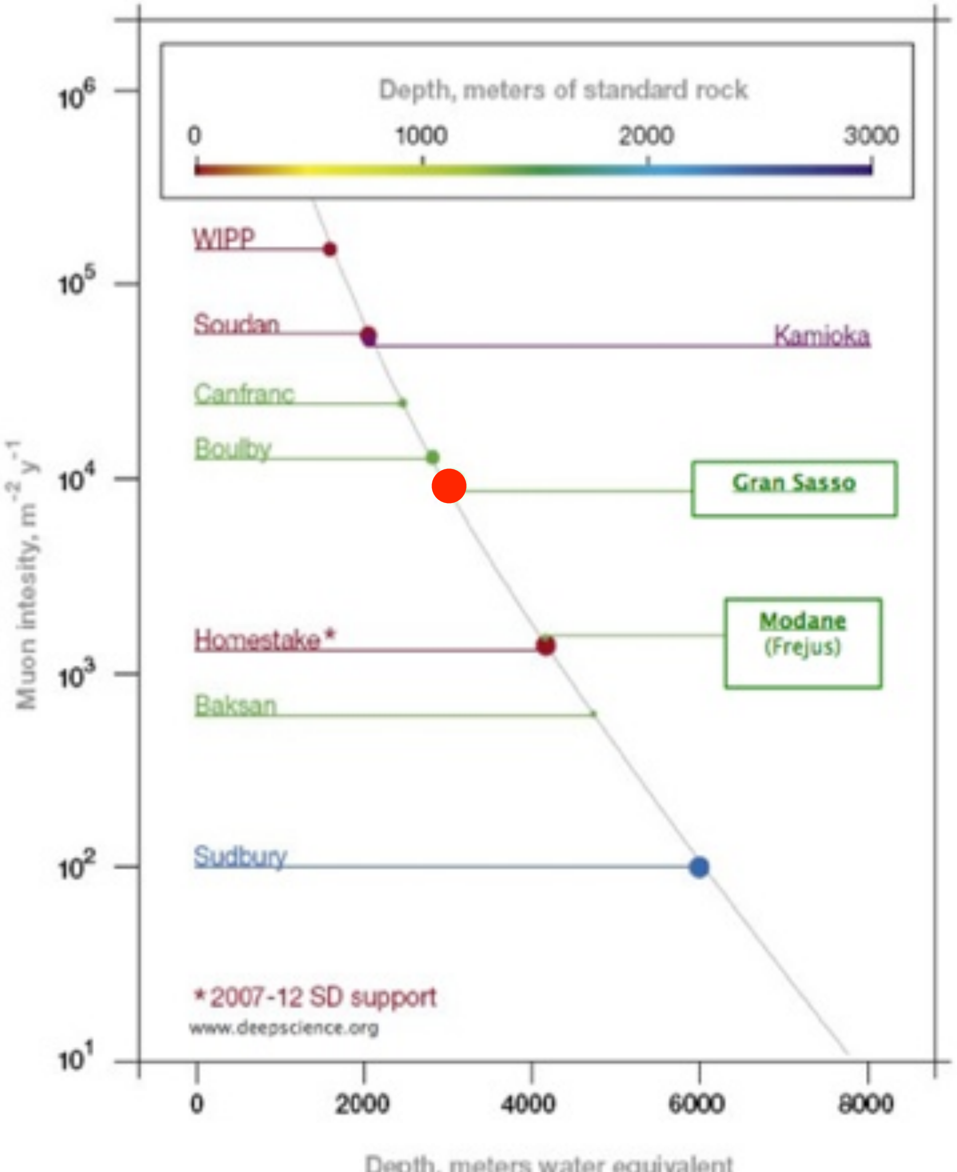
Muon-induced neutron background

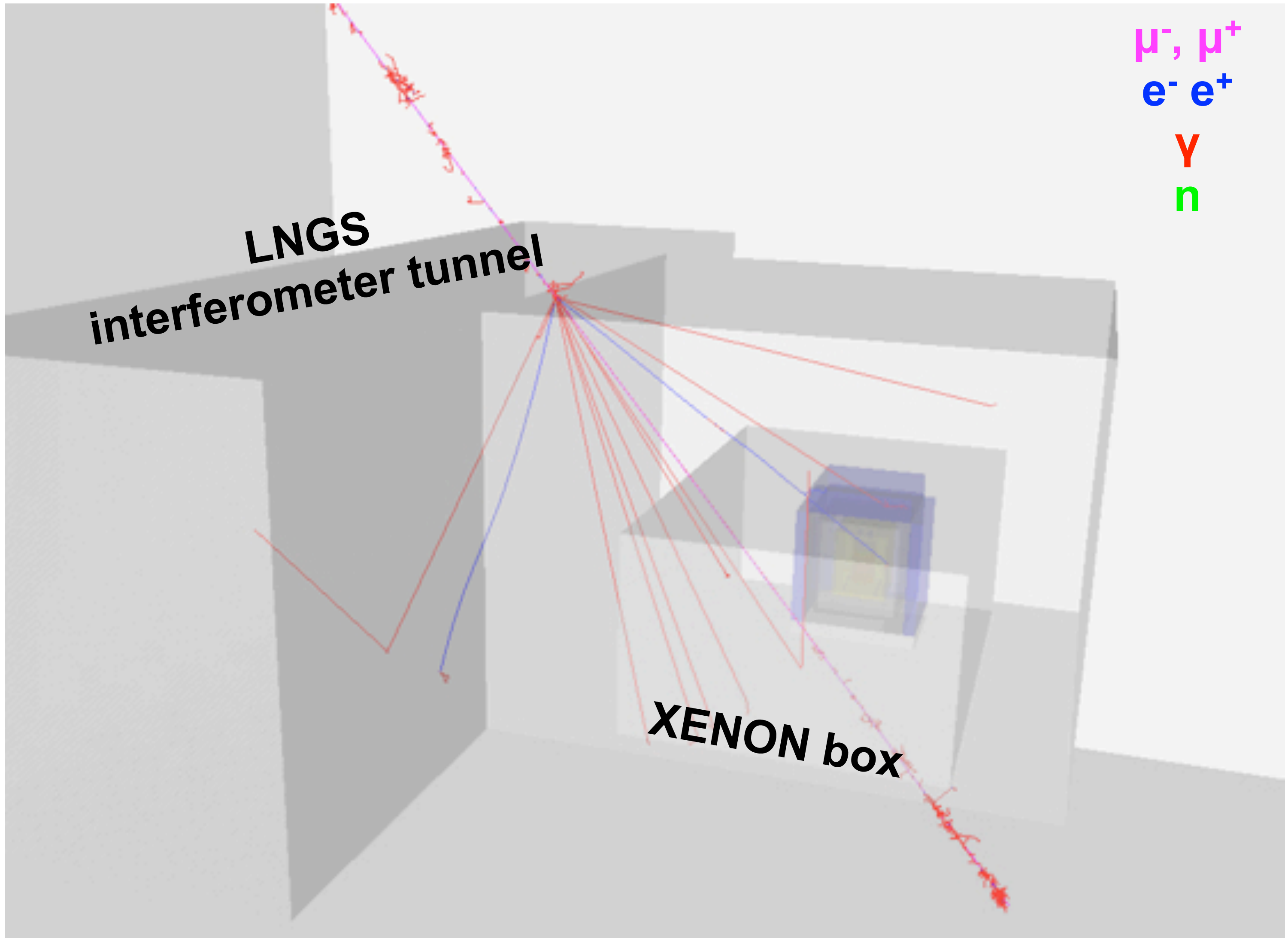
Muon-induced neutrons



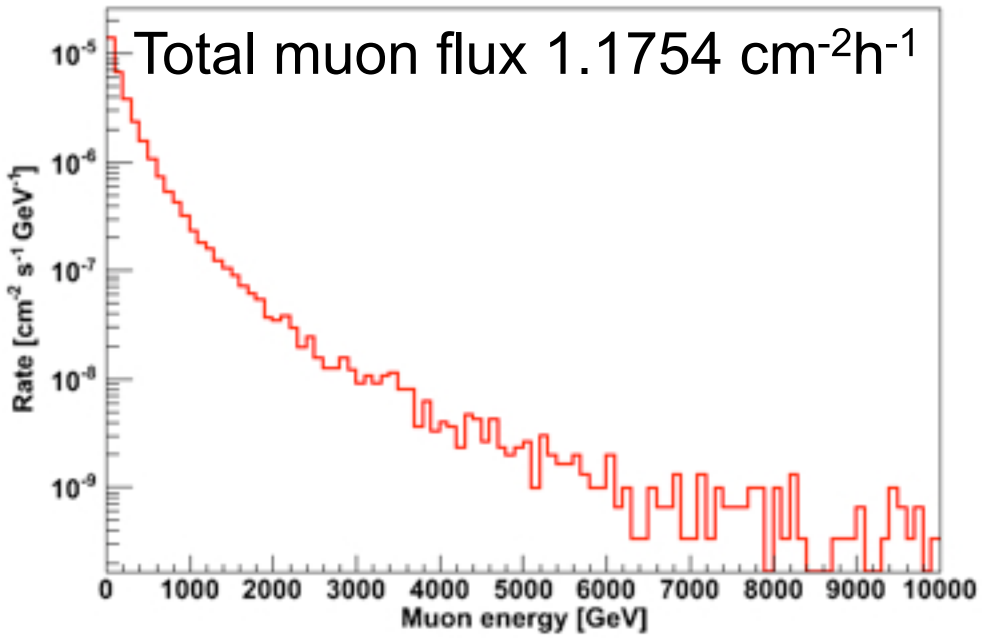
1.4km rock = 3.1km water equivalent shielding from cosmic rays; reduction of muon flux by a factor ~10^6

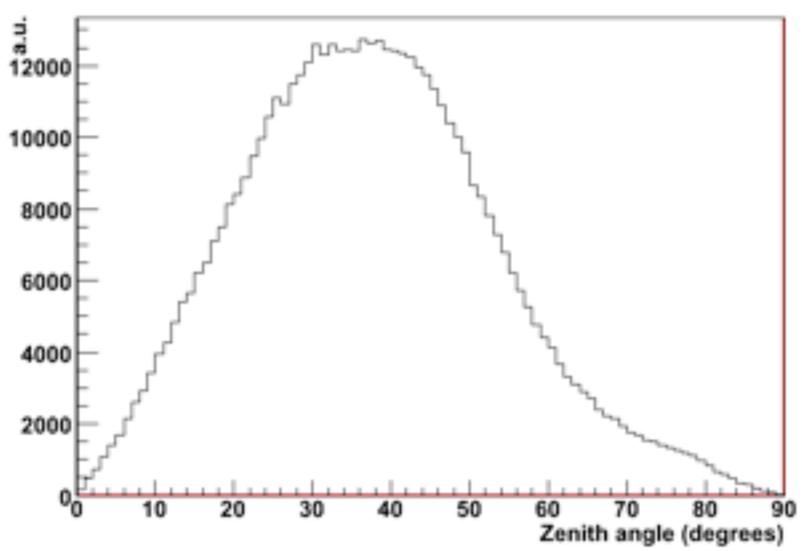
Neutrons can be produced in the following reactions:
• photonuclear reactions in EM showers triggered by an incident muon
• secondary neutron production (π-n, π-absorption, p-n, etc.)
• deep inelastic muon-nucleus interaction via virtual photon

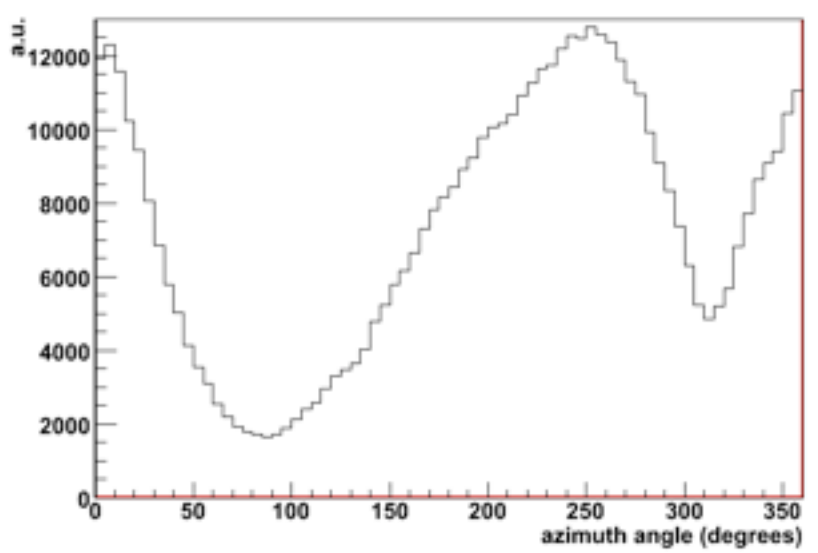




Muon-induced neutrons

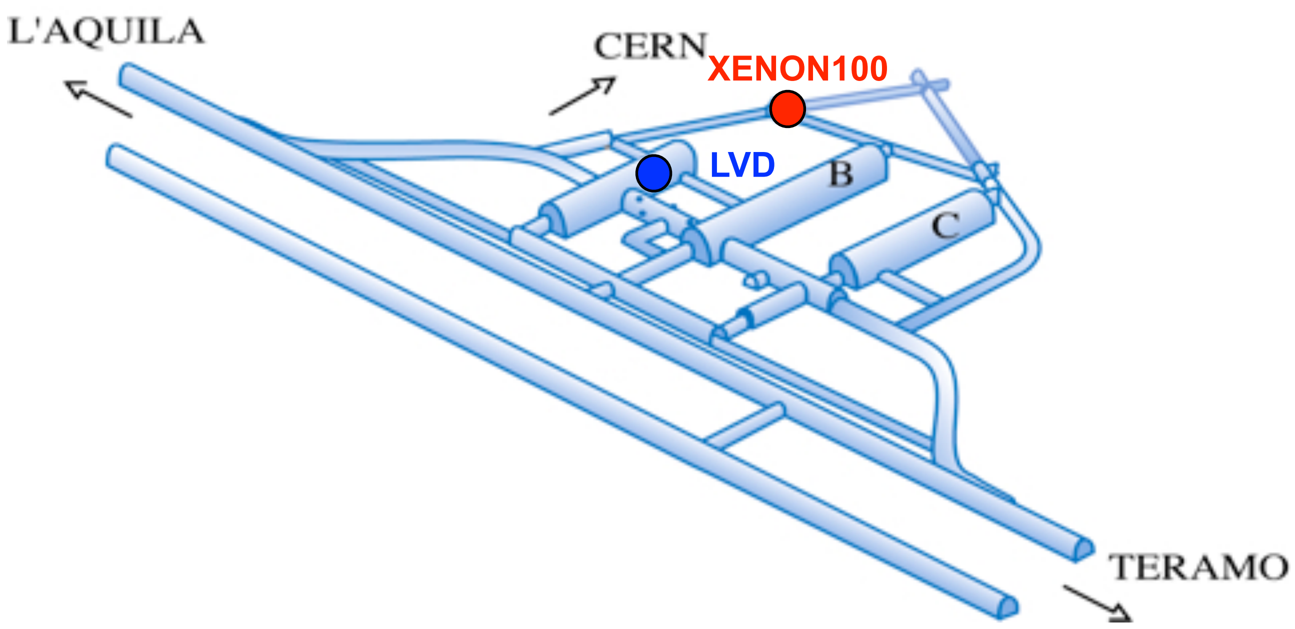






- muon energy and angular distribution spectra calculated with MUSUN and MUSIC (for LVD by M.Selvi, for XENON100 by E.Tziaferi)

- muon intensity measured by LVD



- the physics list used in the simulations is QGSP BIC HP

- Geant4.9.3.p01 and neutron data files with thermal cross sections G4NDL 3.13

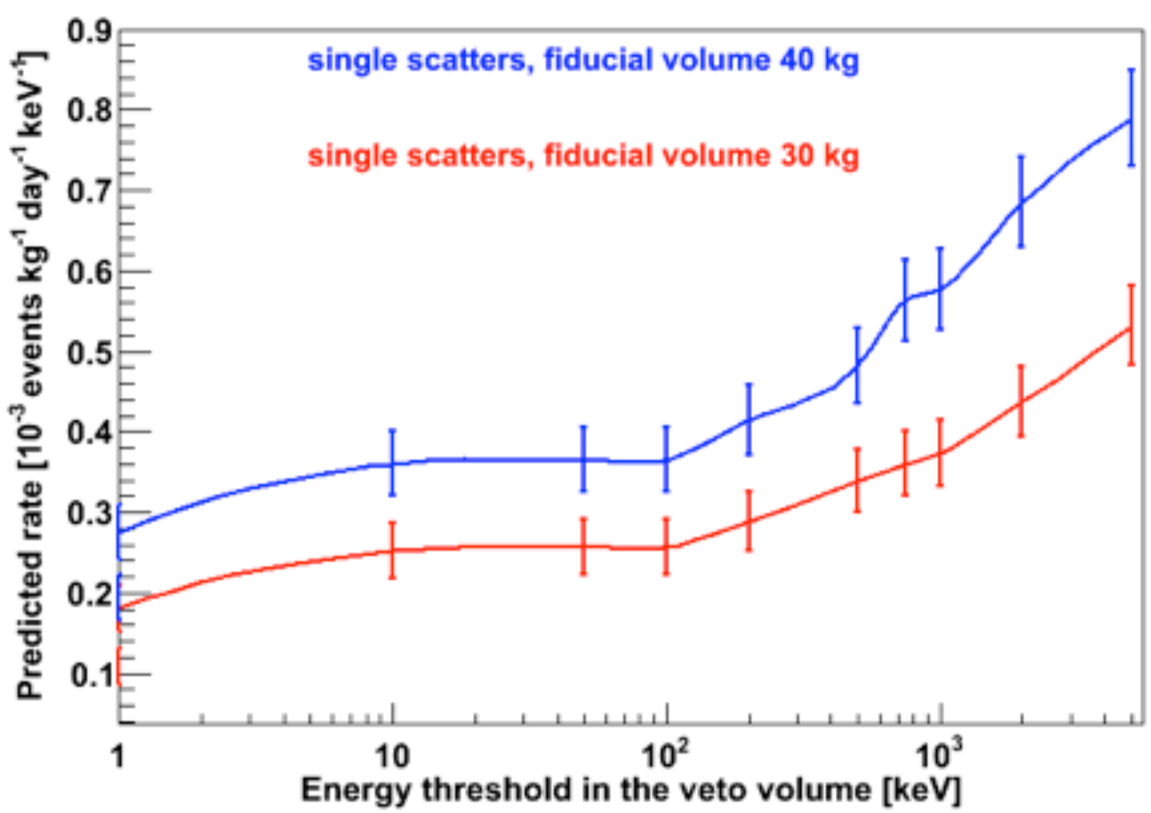
Muon-induced neutrons

- muons are propagated through 5 m of rock

- Xe100 background consists of only single scatter elastic nuclear recoils, electronic recoils and NR/ER coincident events are rejected

- neutron production
all neutrons that scatter in LXe
neutrons that contribute to NR BG

rock	0.18%	5%
water shield	0.02%	5%
lead shield	5.88%	15%
polyethylene shield	1.51%	5%
copper shield	32.64%	55%
cryostat (stainless steel)	3.18%	
teflon	5.13%	10%
LXe	46.30%	5%
other materials/components	5.16%	



- muons induce EM and hadronic showers → ~50% background reduction with a LXe veto coincidence cut

- measured average energy threshold is the LXe veto volume is ~100keV$_{ee}$

Prediction of the NR background. Uncertainties

● from the validation of the muon-induced muon production via comparison with experimental data:

- GEANT4 underproduces neutrons by a factor of ~2
  NA55 ‘*M.G.Marino et al., NIM A582, 611-620, 2007*’

- GEANT4 overproduces neutrons by a factor of ~2
  ZEPLIN-II ‘*A.Lindote et al., Astrop. Phys. 31, 2009*’

➡ systematic uncertainty factor of 2

● 185.5 years have been simulated for muon-induced BG

➡ statistical uncertainty ~10%

● the prediction of the total NR background includes contribution from (α,n) and SF neutrons. The study is based on the measured radioactive contamination in the detector and shield components (arXiv:1103.5831), calculations of the neutron production spectra with SOURCES4A and simulations with GEANT4

➡ systematic uncertainty 17% (standard error of SOURCES)
➡ statistical uncertainty 1%

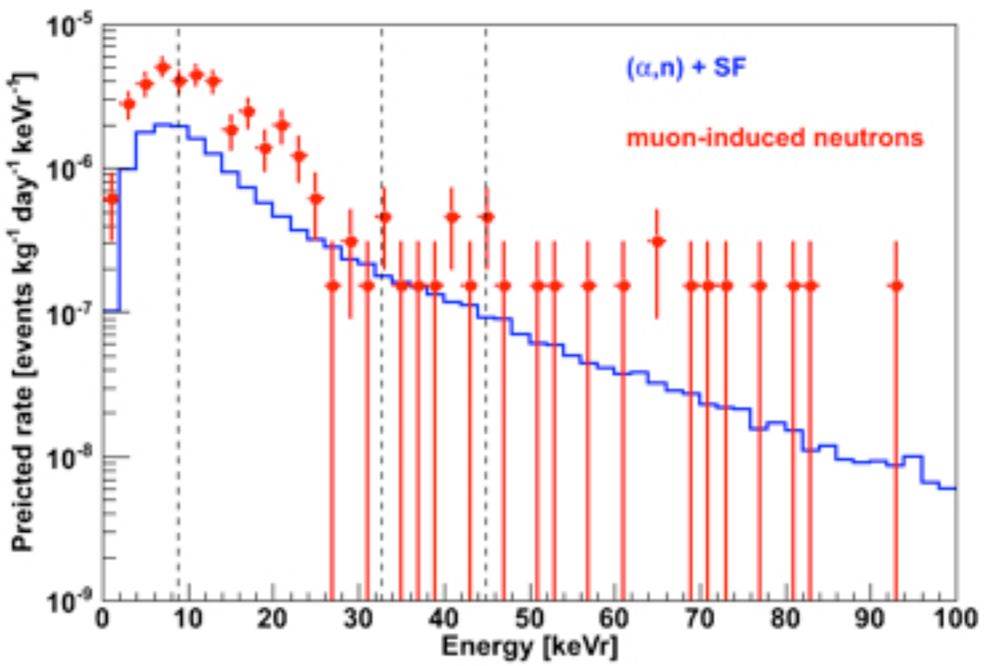
Prediction of the NR background

- the final prediction includes the measured trigger efficiency and energy threshold in the active LXe volume, and position/time resolution

- energy range 4-30phe (8.4-44.6keVr)

- fiducial volume 48kg

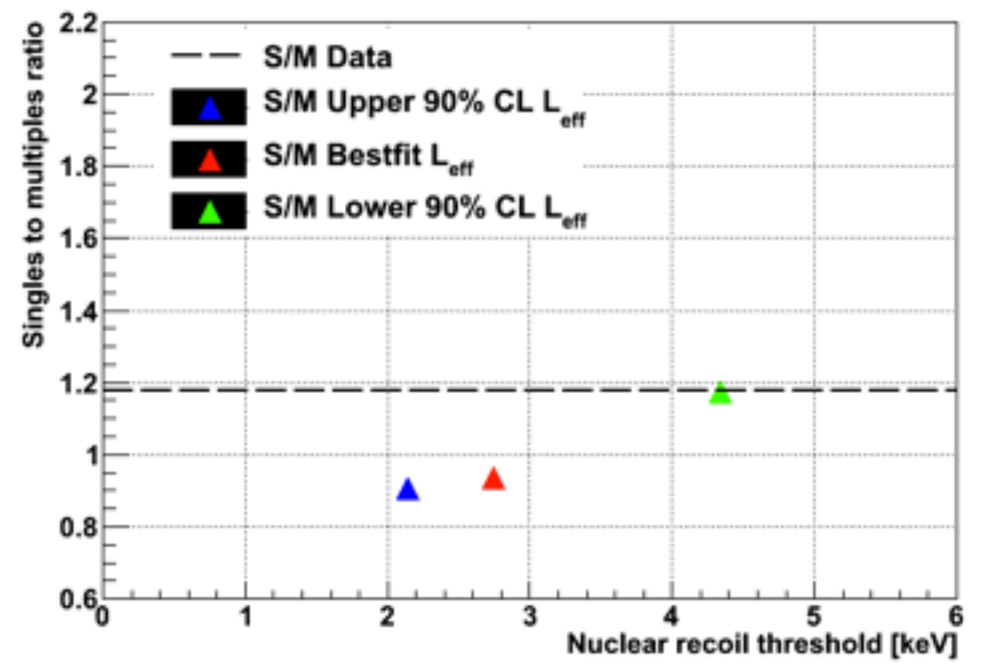
- run08 (2010): 100.9 days, NR acceptance 36%



		run 08
(α,n) and SF	0.32±0.05 events/year	0.032±0.005 events
muon-induced neutrons	0.80 +0.80 -0.40 events/year	0.08 +0.08 - 0.04 events
Total NR background	1.12 +0.80 -0.41 events/year	0.11 +0.08 - 0.04 events

- muon veto (plastic scintillator) would give up to 85% BG reduction, but is not relevant at this stage

- single-to-multiple ratio has been validated on ^{241}Am-Be data/MC

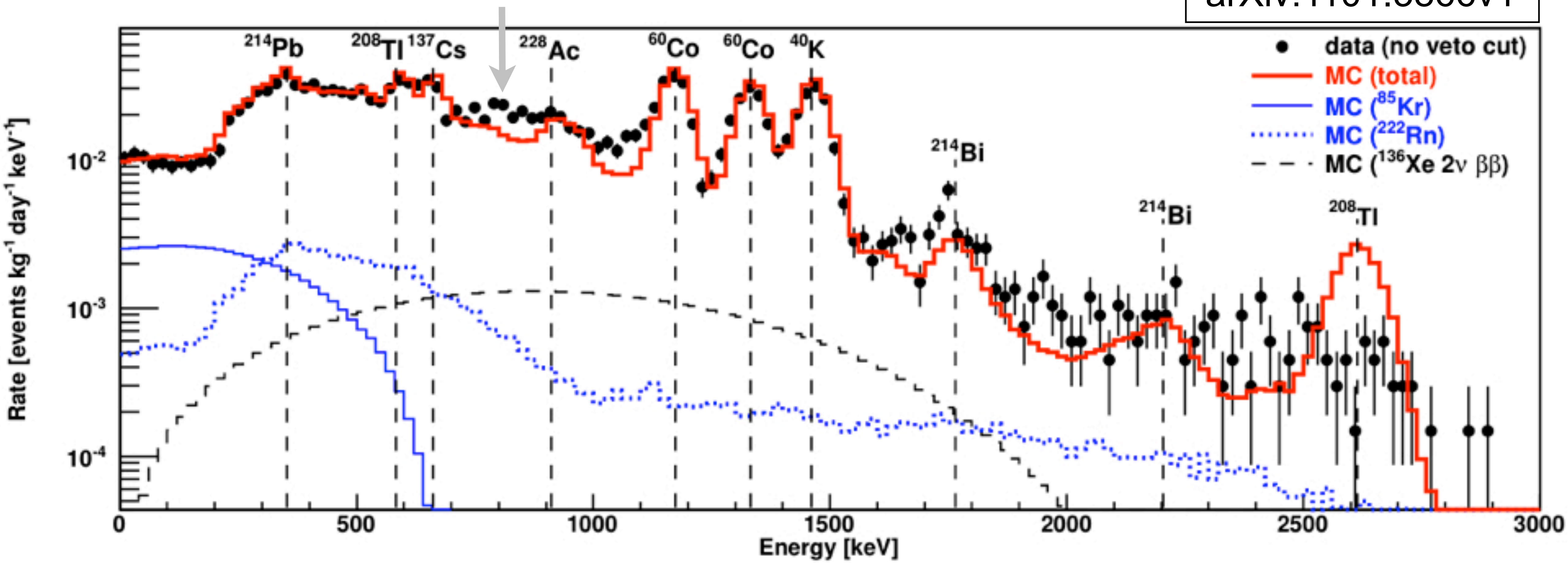


Cosmogenic activation in stainless steel

Electronic recoil background in XENON100

● the discrepancy in high energies is due to non-linearity in the PMTs (affects position reconstruction and spatial corrections)

arXiv:1101.3866v1



● using only measured radioactive contamination in the detector and shield components and in in LXe, simulated background spectrum shows a deficit in the 700-1100 keV range

Cosmogenic activation of the stainless steel

● the XENON100 cryostat, 'diving bell', support rings for the electrode meshes are made from 1.4571 / 316Ti stainless steel (total amount 73.6kg). Chemical composition:

Fe	Cr	Ni	Mo	Mn	Si	Ti	C	P	N	S
69.12%	16.62%	10.55%	2.03%	0.83%	0.47%	0.32%	0.03%	0.025%	0.012%	0.003%

^{54}Mn	^{56}Fe(n,p2n), ^{56}Fe(μ^-,ν2n)
^{58}Co	^{60}Ni(n,p2n), ^{60}Ni(μ^-,ν2n), ^{58}Ni(n,p)
^{56}Co	^{58}Ni(n,p2n), ^{58}Ni(μ^-,ν2n)
^{46}Sc	^{48}Ti(n,p2n), ^{48}Ti(μ^-,ν2n), Spallation on Fe
^{48}V	^{52}Cr(n,p4n), ^{50}Cr(n,p2n), ^{50}Cr(μ^-,ν2n),

● radioactive screening does not provide information about the cosmogenic radionuclides due to the different activation history of the screened samples and actual detector components:
- the cryostat and the TPC have been assembled at the surface
- a few parts (support rings for the electrode meshes) have been manufactured in the US at Rice University, and shipped overseas by air

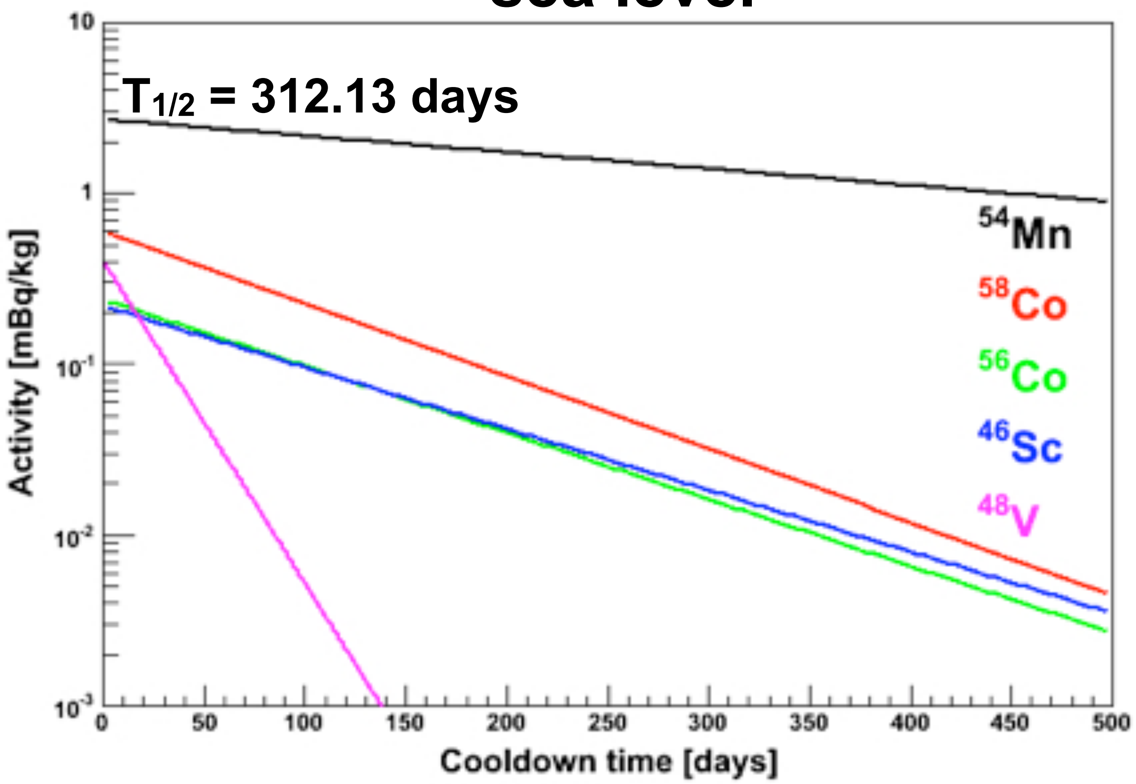
● stainless steel of the same type, from the same producer has been used for the construction of the GERDA cryostat.
The cosmogenic activation has been studied with Ge spectroscopy. The production rates at the sea level and LNGS altitude: '*M.Laubenstein, G.Heusser, Appl. Radiat. Isotopes 67, 5, 2009*'

Cosmogenic activation of the stainless steel

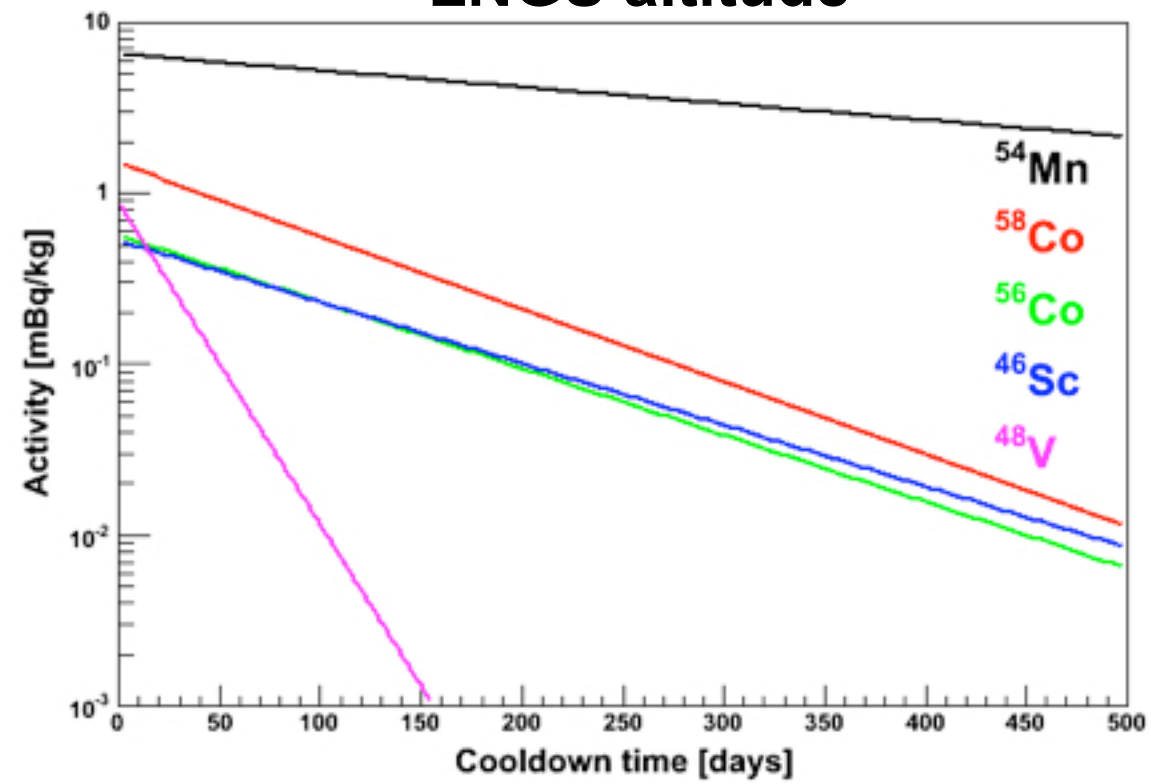
- at the time of run07 (Fall 2009) the detector has been underground for ~500 days

- the upper limits on the cosmogenic contamination assuming measured saturation activities (*M.Laubenstein, G.Heusser, Appl. Radiat. Isotopes 67, 5, 2009*)

sea level



LNGS altitude



- the only isotope imposing potential danger is ^{54}Mn

2.7mBq/kg → 0.89mBq/kg

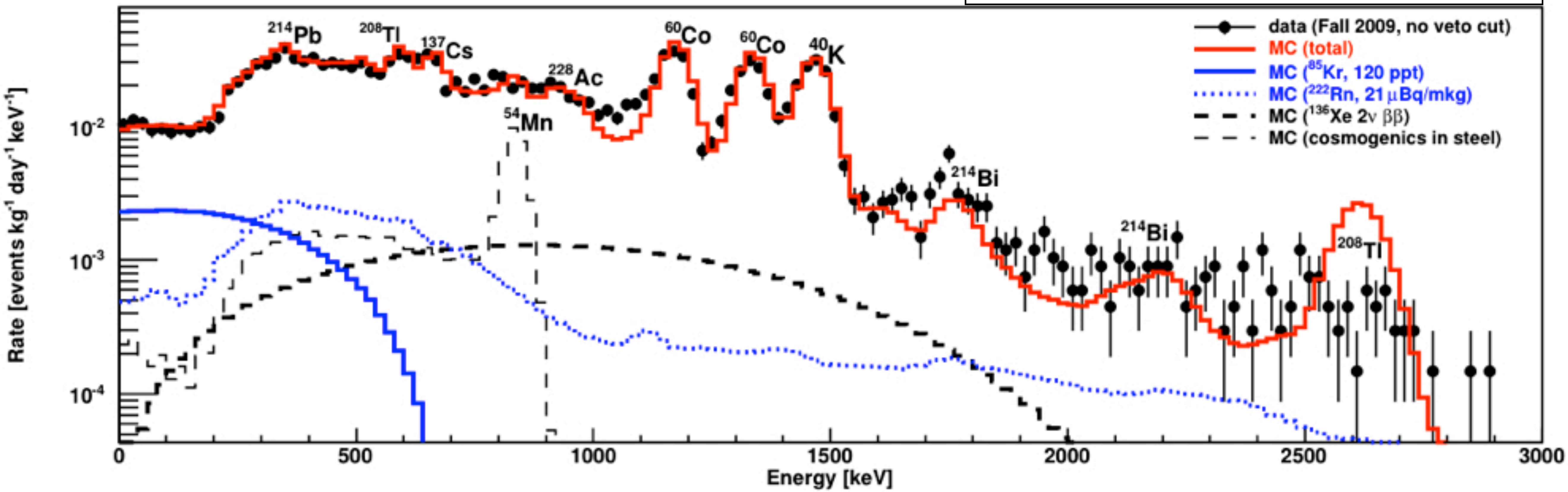
6.5mBq/kg → 2.14mBq/kg

Electronic recoil background in XENON100

● including 1.55mBq/kg of ^{54}Mn in the background model improves data/MC agreement at ~800keV

● background from this source in the WIMP-search energy range (below 100keV) is at the level of
10^{-4} events·kg^{-1}·day^{-1}·keV^{-1}, which is ~5% of that from natural radioactivity in the same components

arXiv:1101.3866v2, Phys. Rev. D



● some discrepancy is still present at ~1100keV

● it cannot be explained by the cosmogenic activation of copper → this would result in high contamination of ^{60}Co

Cosmogenic activation in xenon

Cosmogenic activation in xenon

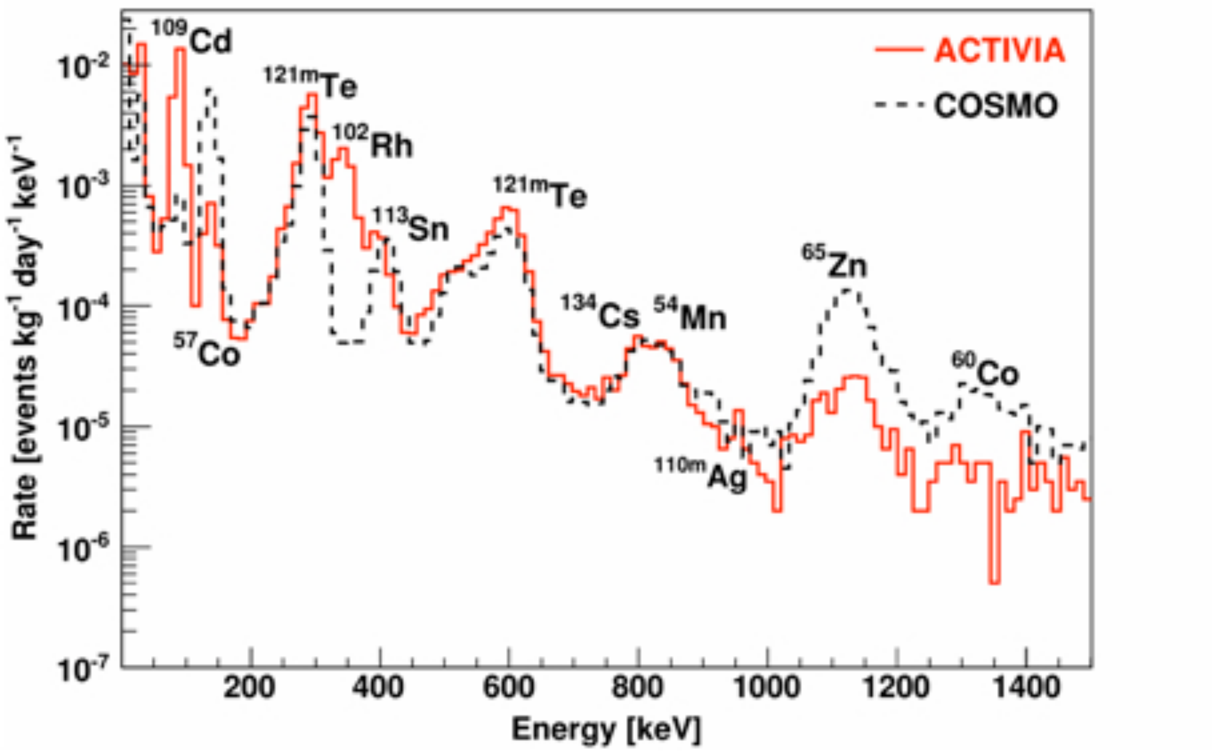
- cosmogenic production in natural xenon has been calculated with ACTIVIA and COSMO, and compared to the results of the calculation with TALYS (*D.M.Mei, Z.B.Yin, and S.R.Elliott, Astropart. Phys. 31, 417, 2009*) → no agreement

isotope	$T_{1/2}$	PR (saturation activities) [$kg^{-1}day^{-1}$]		
		ACTIVIA	COSMO	TALYS
^{3}H	12.3 y	36.0	35.1	16.0
^{22}Na	2.6 y	0.09	0.09	N/A
^{45}Ca	165 d	0.06	0.05	N/A
^{49}V	330 d	0.26	0.22	N/A
^{54}Mn	312 d	0.23	0.20	N/A
^{55}Fe	2.7 y	0.14	0.12	N/A
^{57}Co	271 d	0.15	1.69	N/A
^{60}Co	5.27 y	0.10	0.98	N/A
^{65}Zn	244.1 d	0.33	3.73	N/A
^{68}Ge	270.8 d	0.15	0.18	N/A
^{75}Se	118.5 d	0.39	4.17	N/A
^{88}Y	106.6 d	0.15	1.19	N/A
^{93m}Nb	13.6 y	0.19	1.09	N/A

isotope	$T_{1/2}$	PR (saturation activities) [$kg^{-1}day^{-1}$]		
		ACTIVIA	COSMO	TALYS
^{101}Rh	3.3 y	1.59	0	N/A
^{102}Rh	206 d	0.54	0	N/A
^{102m}Rh	2.9 y	0.54	0	N/A
^{110m}Ag	252 d	0.08	0	N/A
^{109}Cd	1.3 y	3.30	0	3.2
^{113m}Cd	14.0 y	0.07	0	0.02
^{113}Sn	115 d	4.59	0.01	N/A
^{119m}Sn	250 d	0.06	0.09	0.02
^{125}Sb	2.7 y	0.02	1.14	0.04
^{121m}Te	154 d	24.85	16.19	11.7
^{123m}Te	119.7 d	1.23	1.10	12.1
^{127m}Te	109 d	1.07	1.06	5.0
^{134}Cs	2.1 y	0.82	0.83	N/A

Cosmogenic activation in xenon

● radioactive decays simulated with GEANT4, assuming 1 year activation and 2 years cooldown time



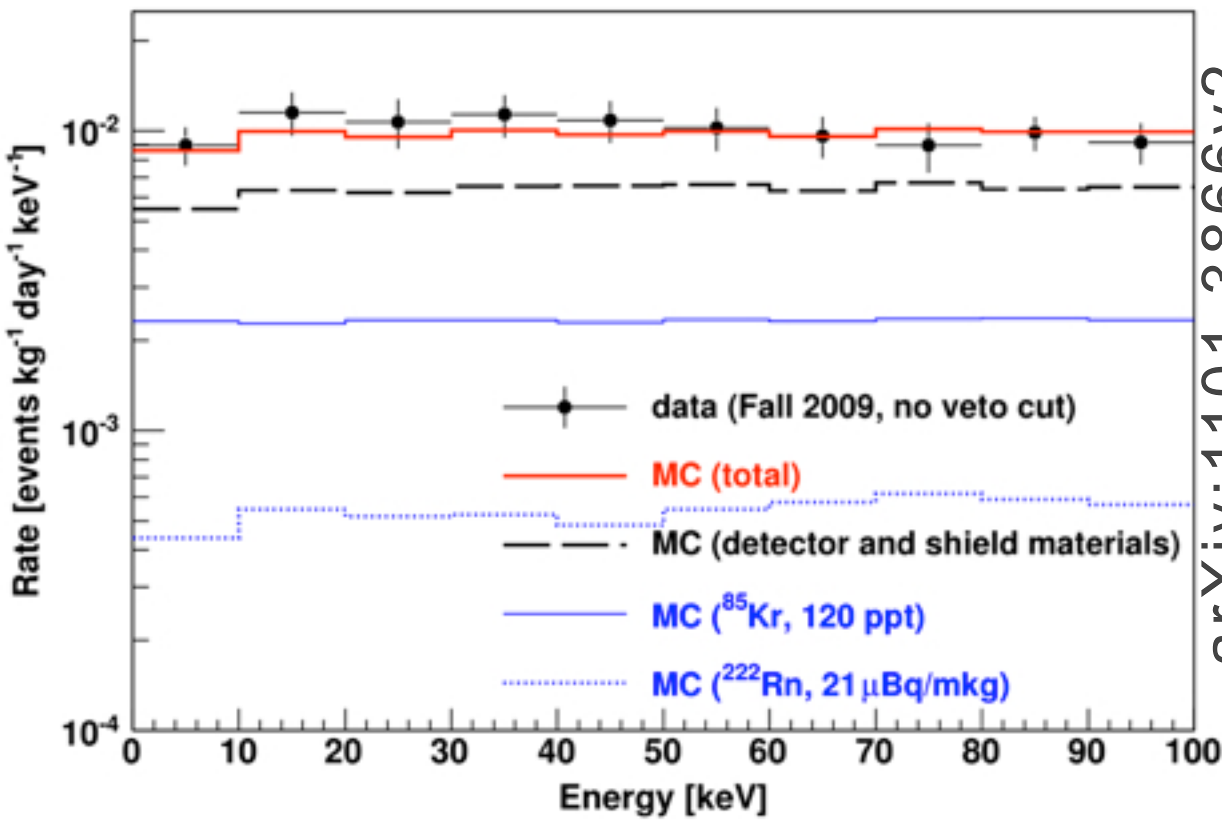
● resulting background rate is too high to be realistic

● an attempt to explain the remaining discrepancy destroys the agreement between the measured and simulated background spectra

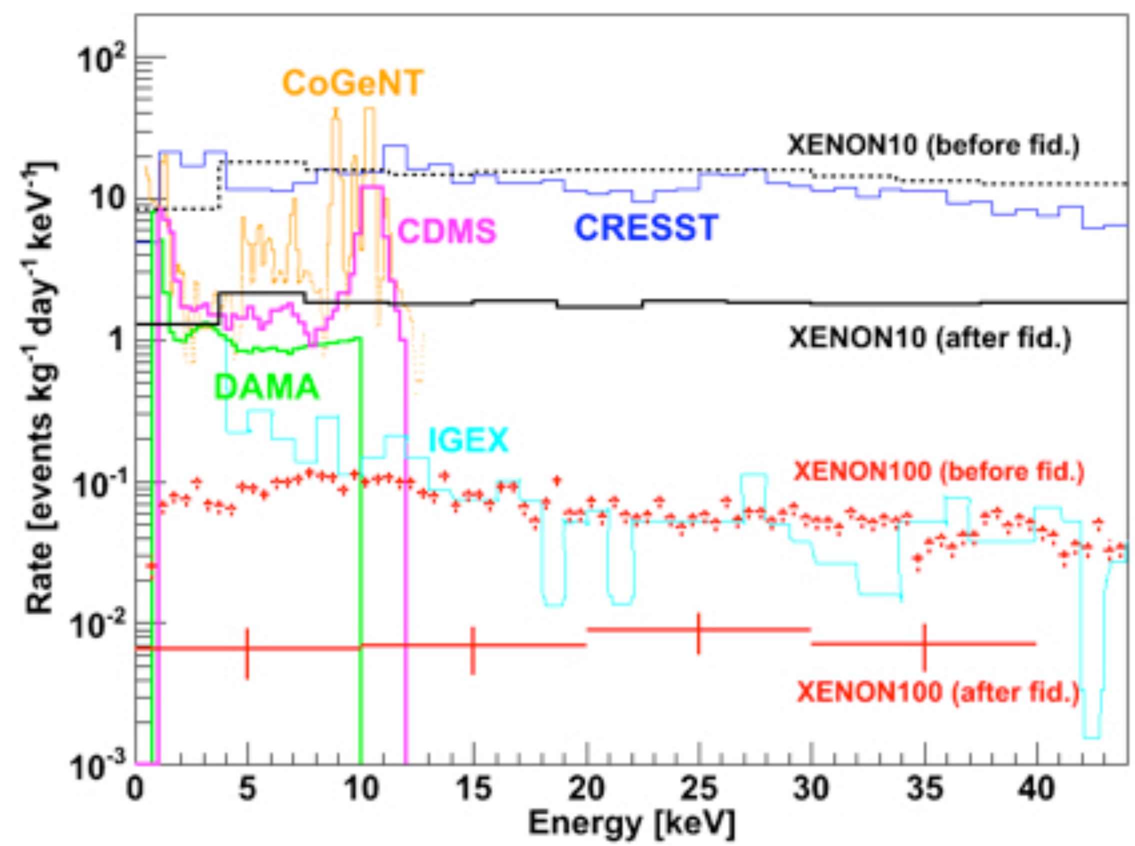
● additional problem - GEANT4 does not handle properly some beta decays and metastable states

Summary

● a very low background has been achieved, and the full energy spectrum explained



arXiv:1101.3866v2
upcoming PRD issue



preliminary/indicative

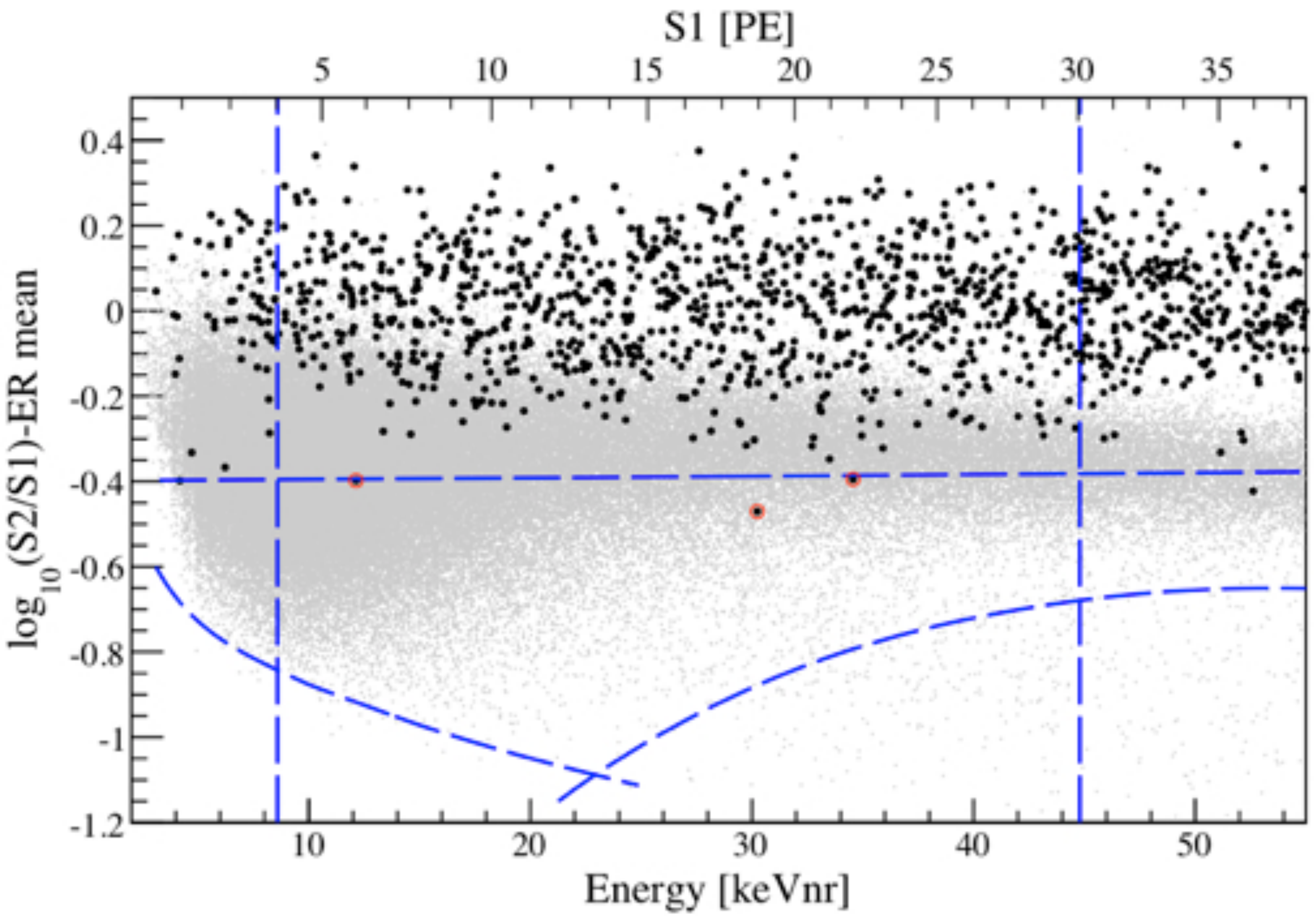
● NR background has been predicted with conservative assumptions, and is negligible in comparison to the expected leakage from ER band

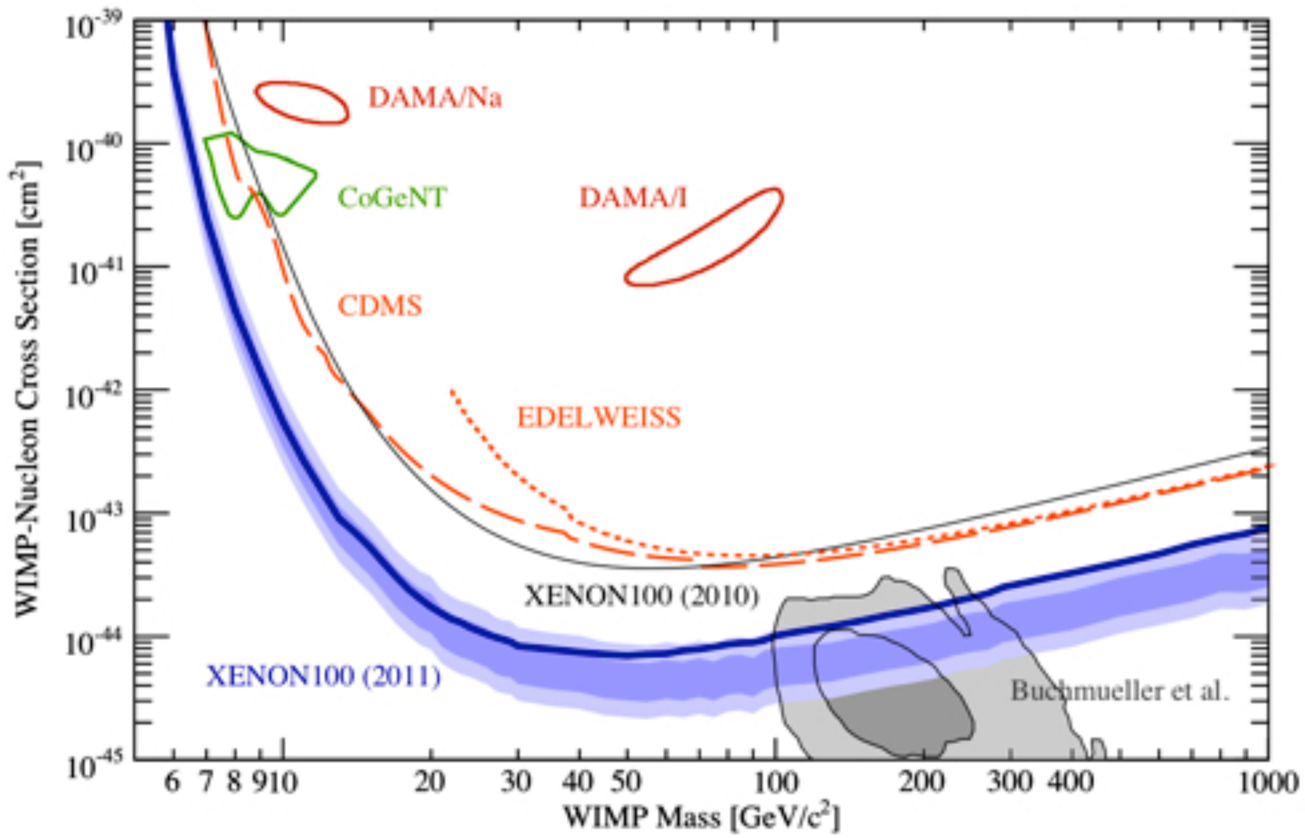
● cosmogenic activation in the stainless steel of the detector cryostat has been identified; the contribution in the energy region of interest is negligible

● cosmogenic activation in LXe requires more work

Conclusions

● the best limits on the cross-section of the spin-independent WIMP-nucleon elastic scattering have been set
E.Aprile et al. (XENON100), PRL 105, 131302 (2010)
E.Aprile et al. (XENON100), Submitted to PRL, arXiv:1104.2549 (2011)





● 3 events observed in the signal region (below 99.75% ER rejection line, in 100.9days and 48kg)
➡ in agreement with the total background expectation of 1.8±0.6 events, dominated by the leakage from ER band

● cosmogenic backgrounds do not limit the sensitivity of the XENON100 experiment, but are challenging for the next generations of dark matter detectors (XENON1T, DARWIN)