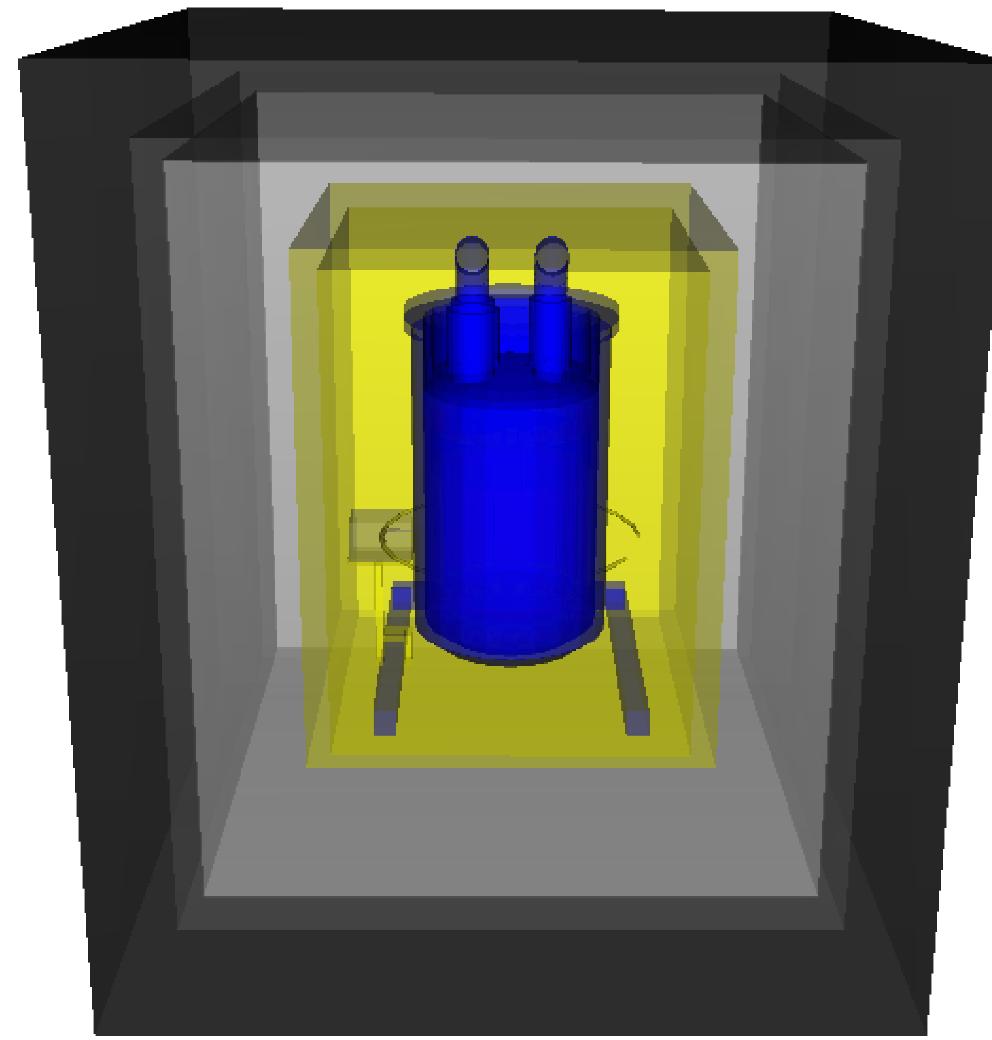
The XENON100 Detector for Dark Matter Searches



Alexander Kish
Physics Institute, University of Zürich

CHIPP Plenary Meeting | Gersau, Switzerland | August 23, 2010

Outline

- light detection in the XENON100 detector
- reconstruction of the event vertex
- energy calibration
- electronic recoil background

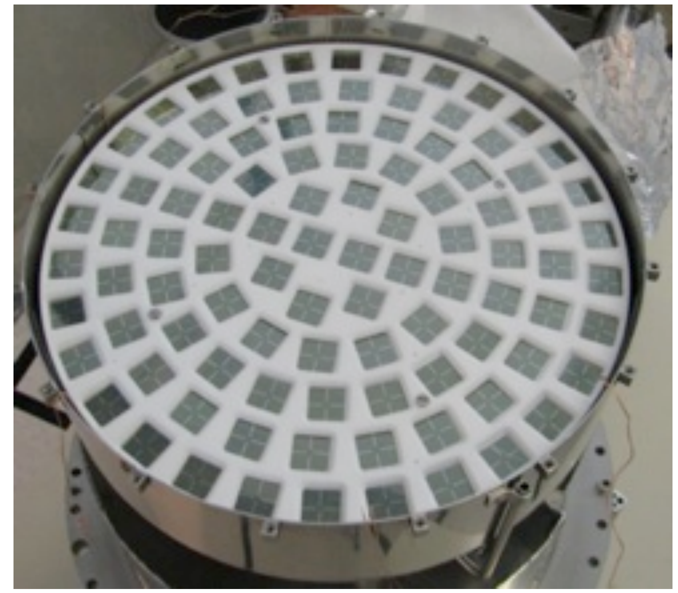
Light detection in XENON100

Hamamatsu R8520

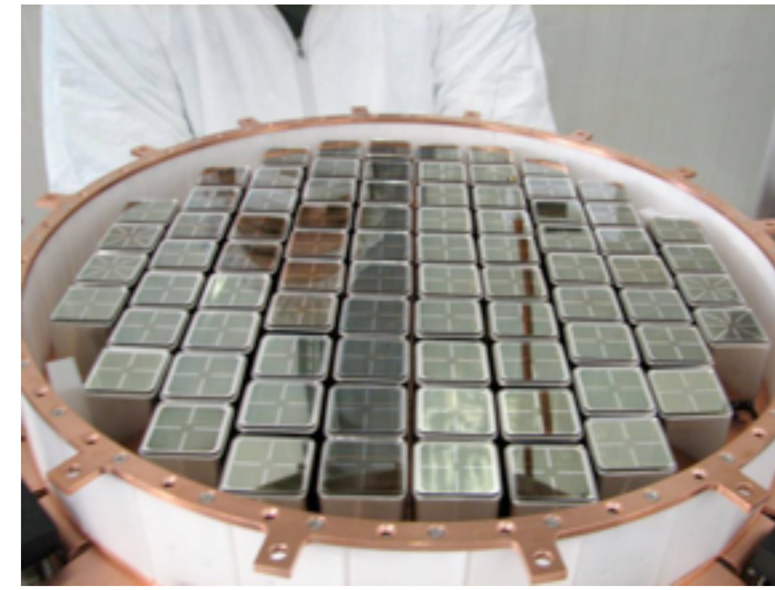
- 2.5 x 2.5 mm window
- low radioactivity (~10mBq/PMT)

- Top array - concentric circles to optimize fiducial cut efficiency
- Bottom PMTs - rectangular grid to maximize photocathode coverage
- Average QE: top 23%, bottom ~33%

Target Volume

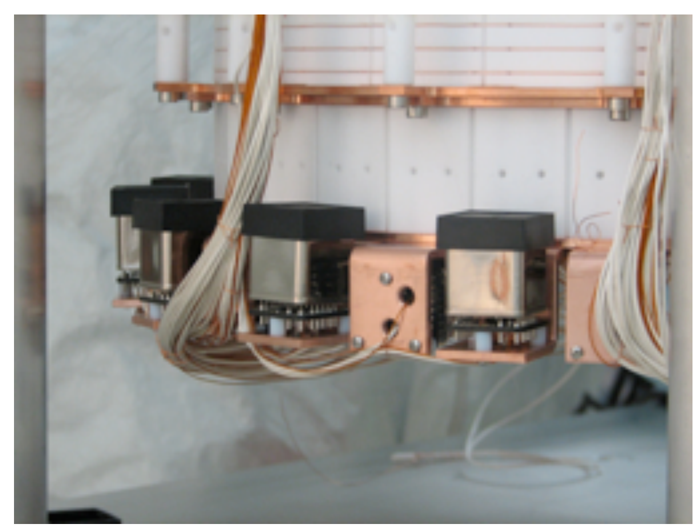


Top PMT array
(98 PMTs)

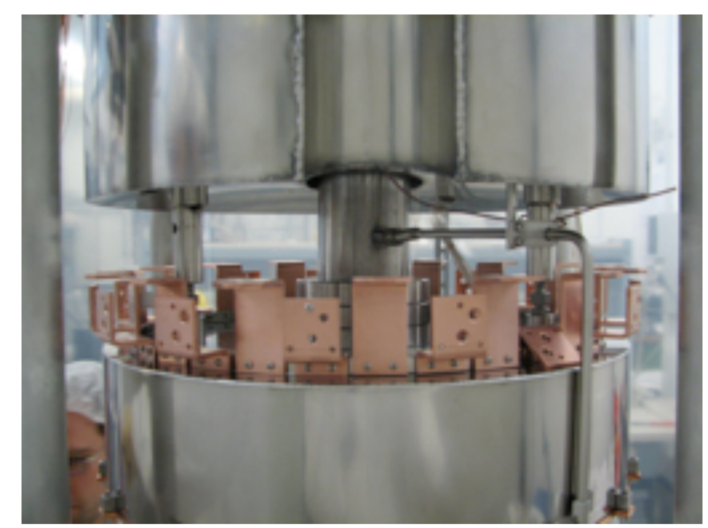


Bottom PMT array
(80 PMTs)

Veto Volume



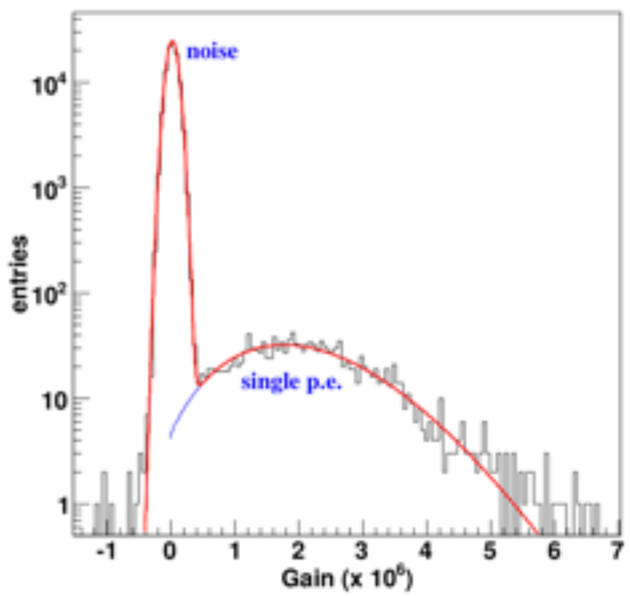
Top/Side Top arrays
(32 PMTs)

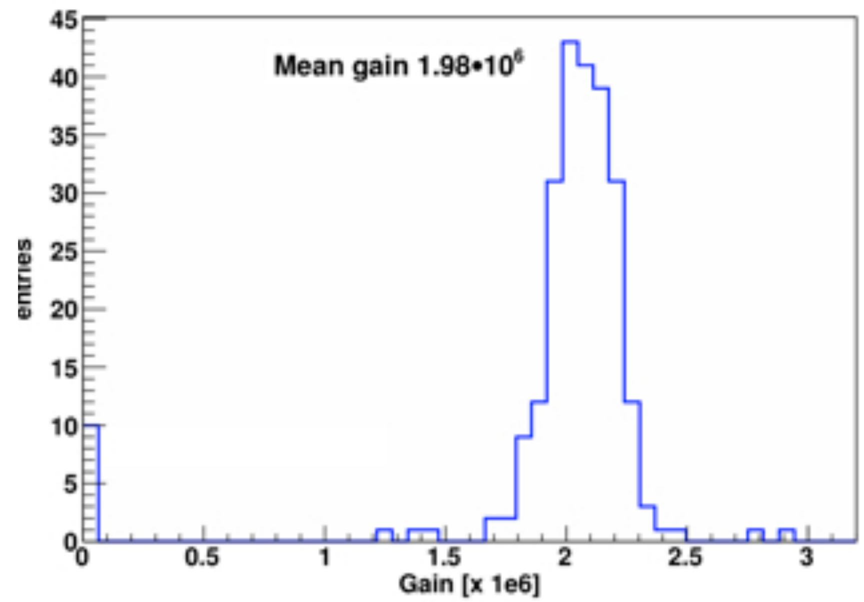


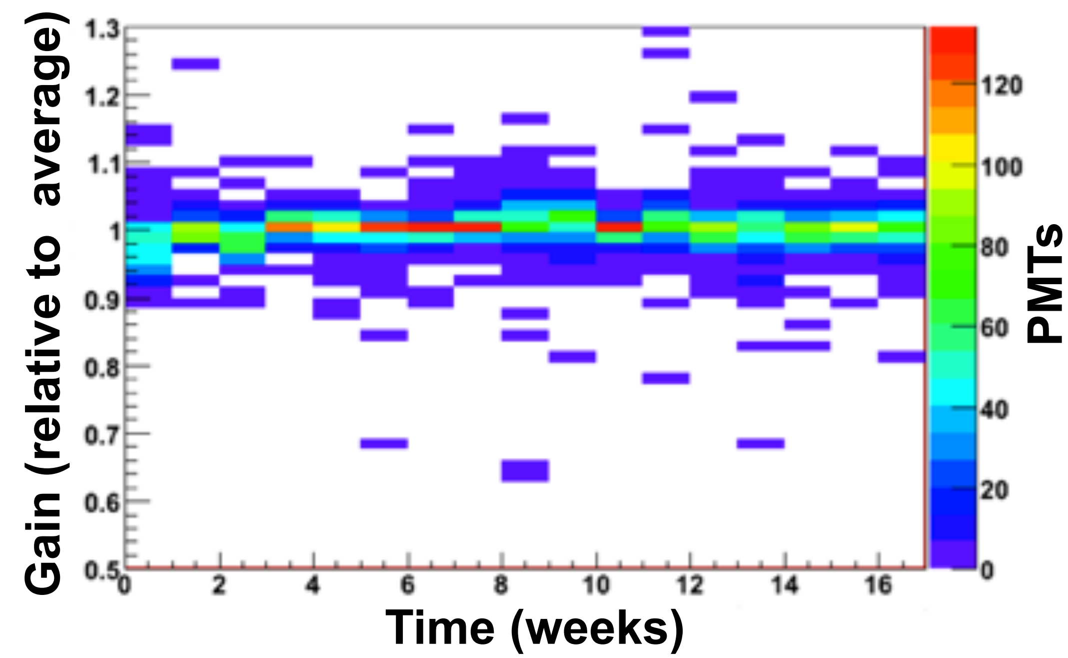
Bottom/Side Bottom arrays
(32 PMTs)

PMT gain calibration

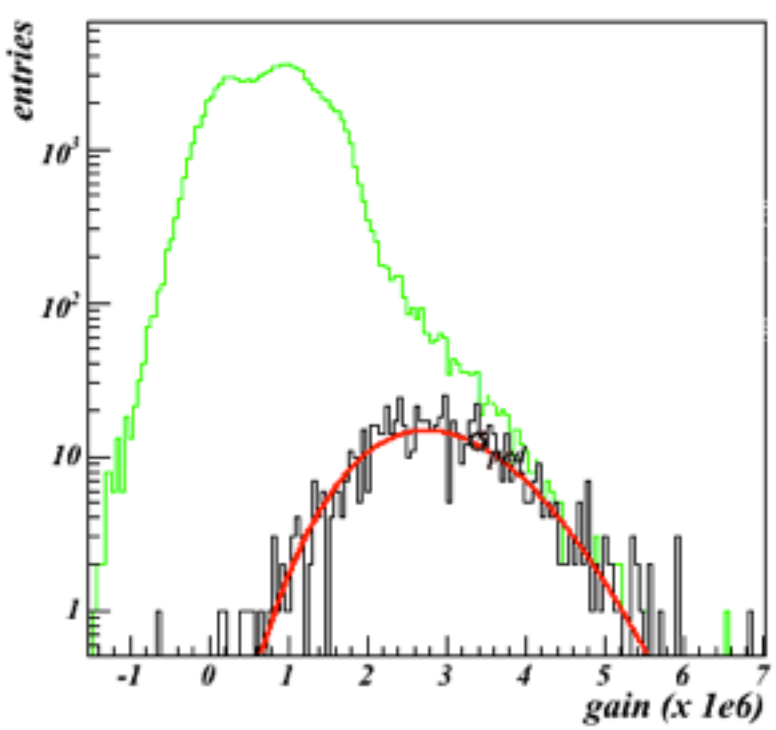
- weekly calibration external with blue LED + optical fibers setup
- PMT gains are equalized



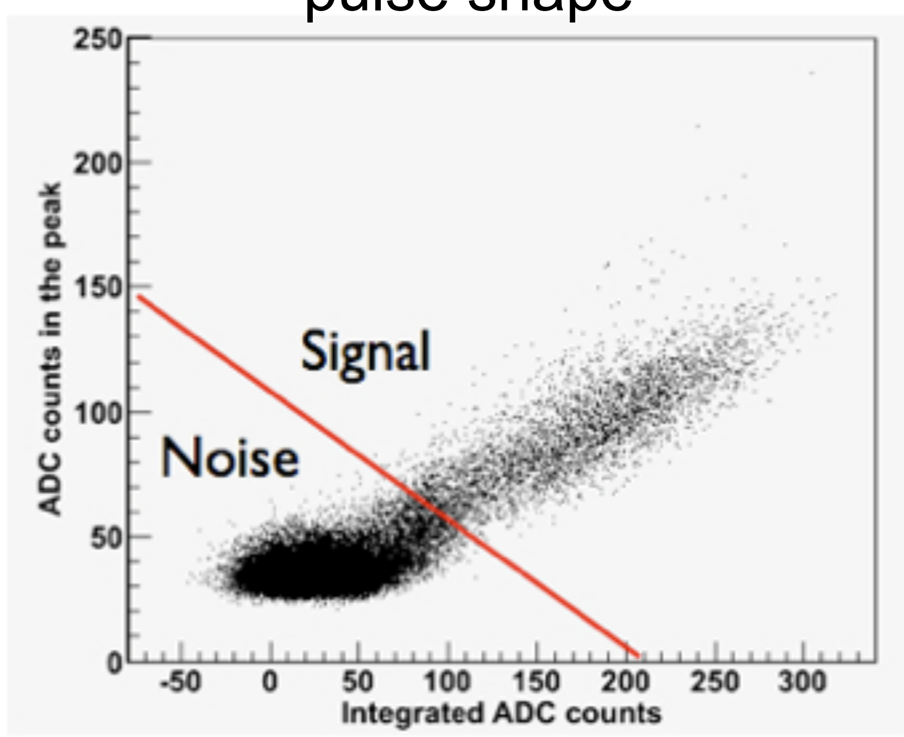




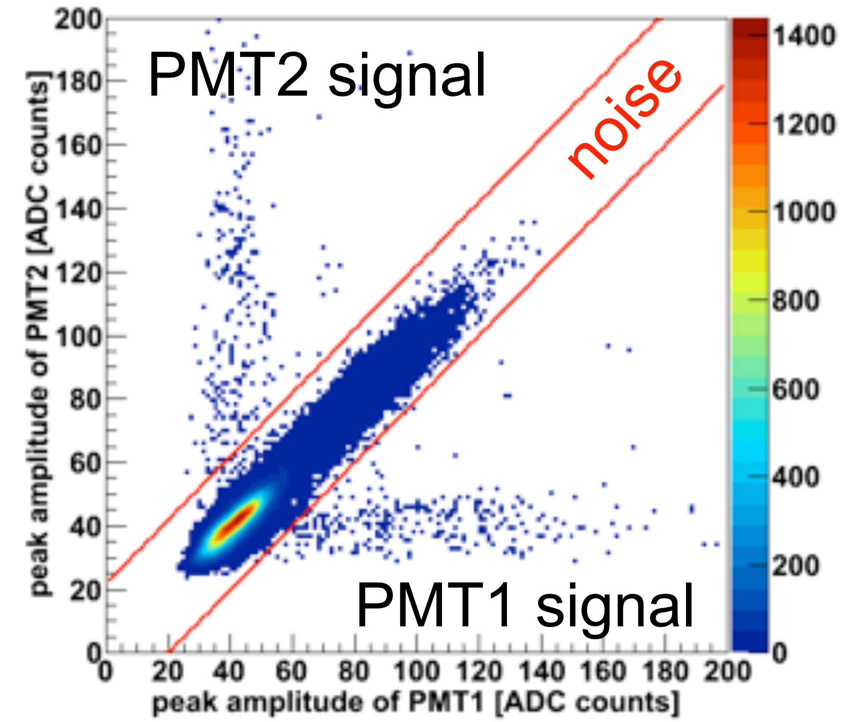
- cuts for noise reduction



pulse shape

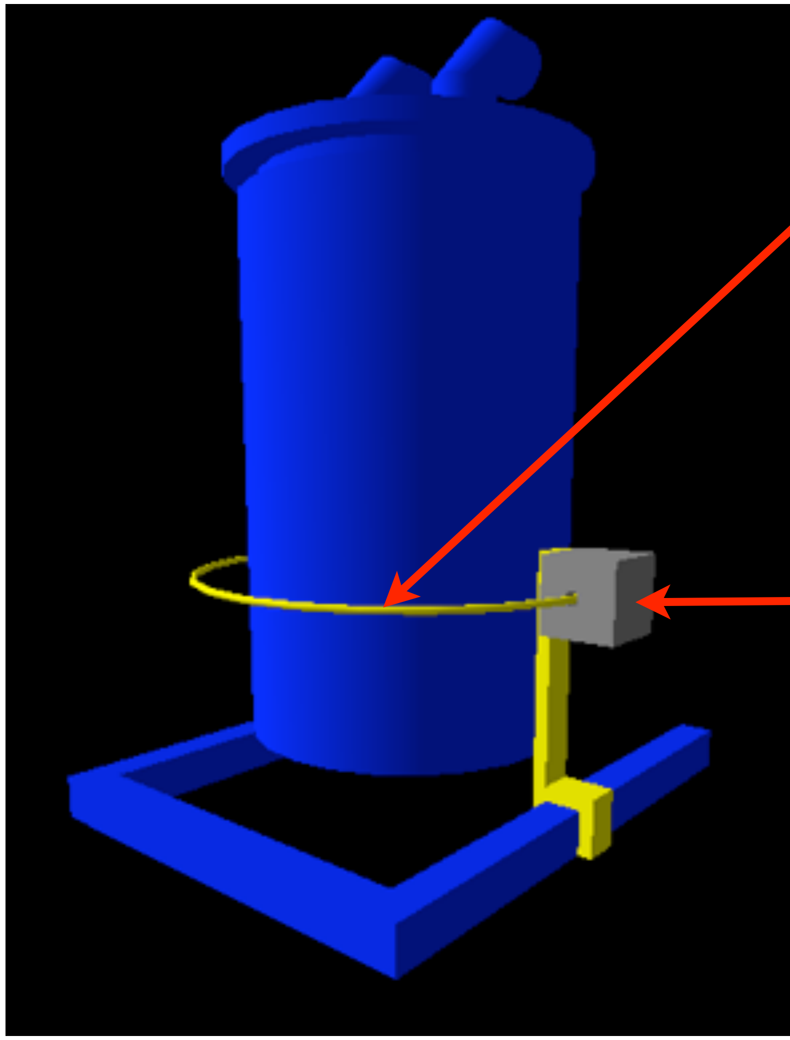


coincidence



Calibration with radioactive sources

- Calibration with point-like sources ^{137}Cs (662 keV), ^{57}Co (122 keV), ^{60}Co (1.17, 1.33 MeV), and Am-Be sources



Copper pipe around the cryostat for the source capsule

Lead brick for Am-Be calibration

- Calibration with internal uniformly distributed sources

- neutron activated xenon: ^{131m}Xe (164 keV; 11.8 d), ^{129m}Xe (236 keV; 8.9 d)

- ^{83m}Kr (9 keV, 32 keV, 41 keV; $T_{1/2}$ = 1.8 h) from ^{83}Rb decay

Spatially uniform calibration of a liquid xenon detector at low energies using ^{83m}Kr

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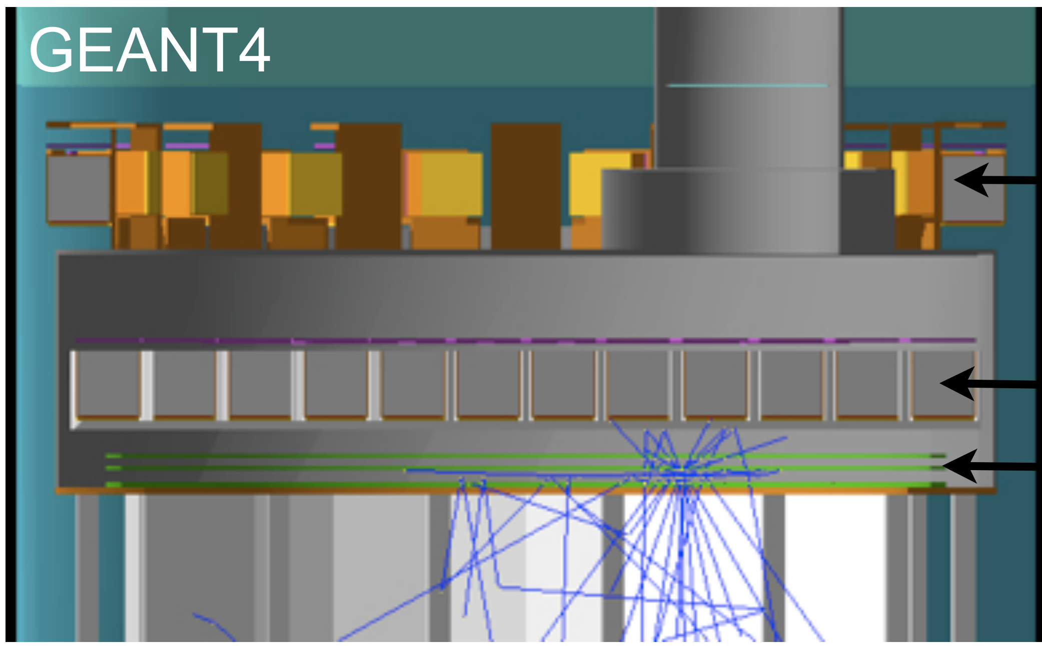
Reconstruction of the event vertex with neural network

- Z-position inferred by the delay time between the S1 and S2

- **XY reconstruction** with
- support vector machines
- $\chi 2$ minimization
- **neural network**

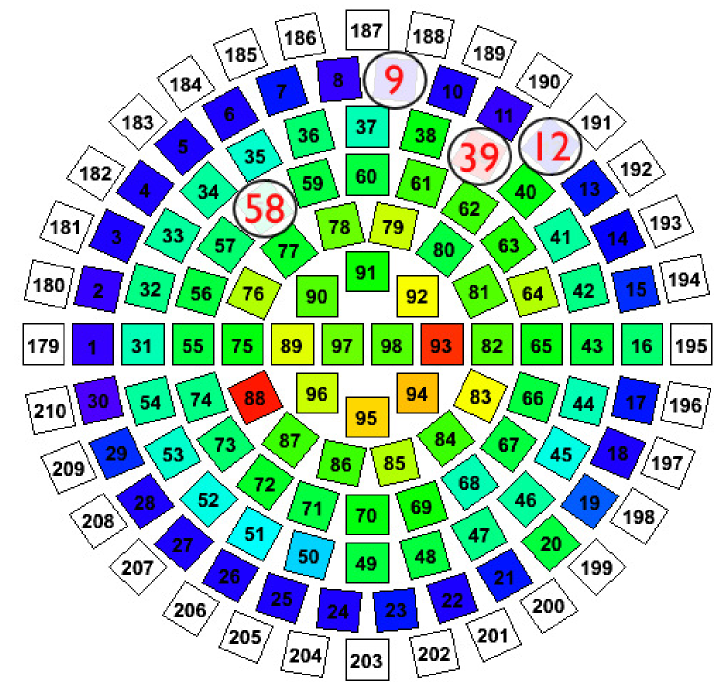
- algorithms trained on simulated light patterns

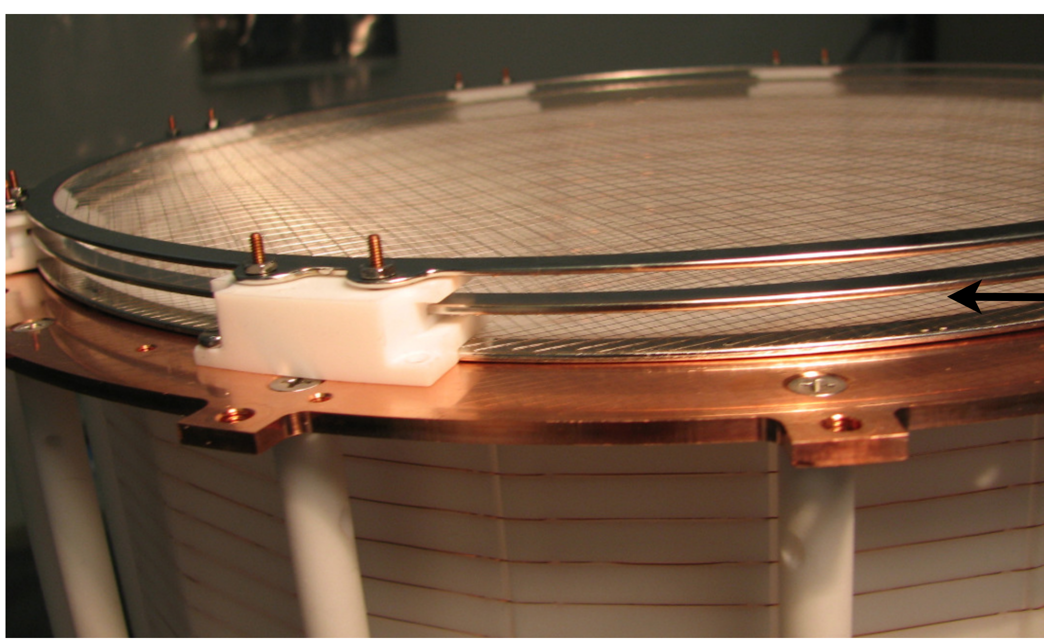


veto PMTs

top PMT array

anode stack



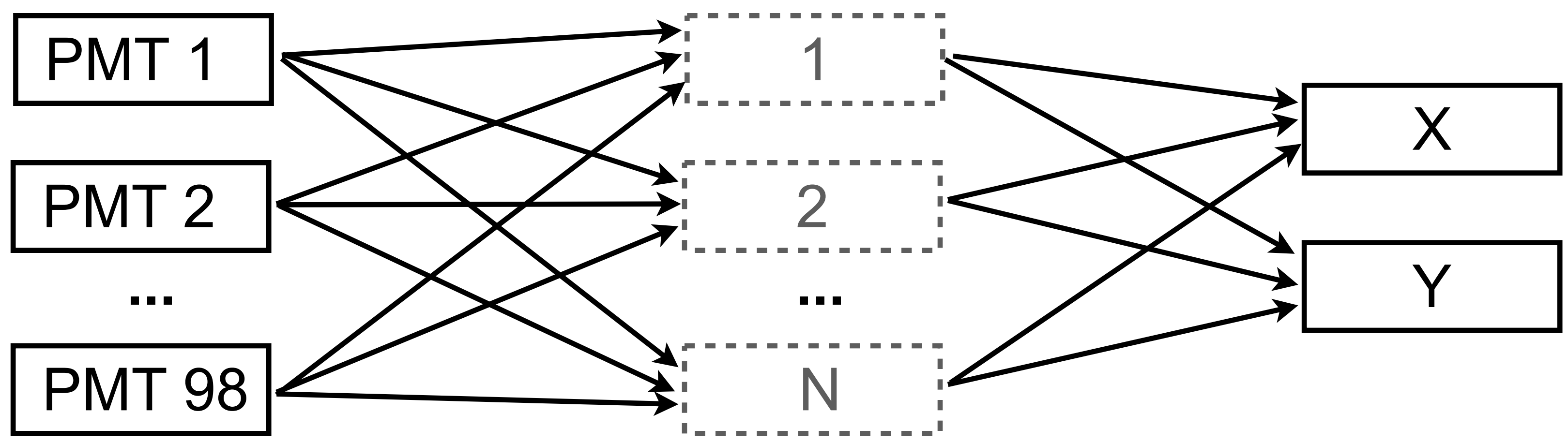


- liquid level between the anode and the lower mesh

- proportional scintillation in the gas phase

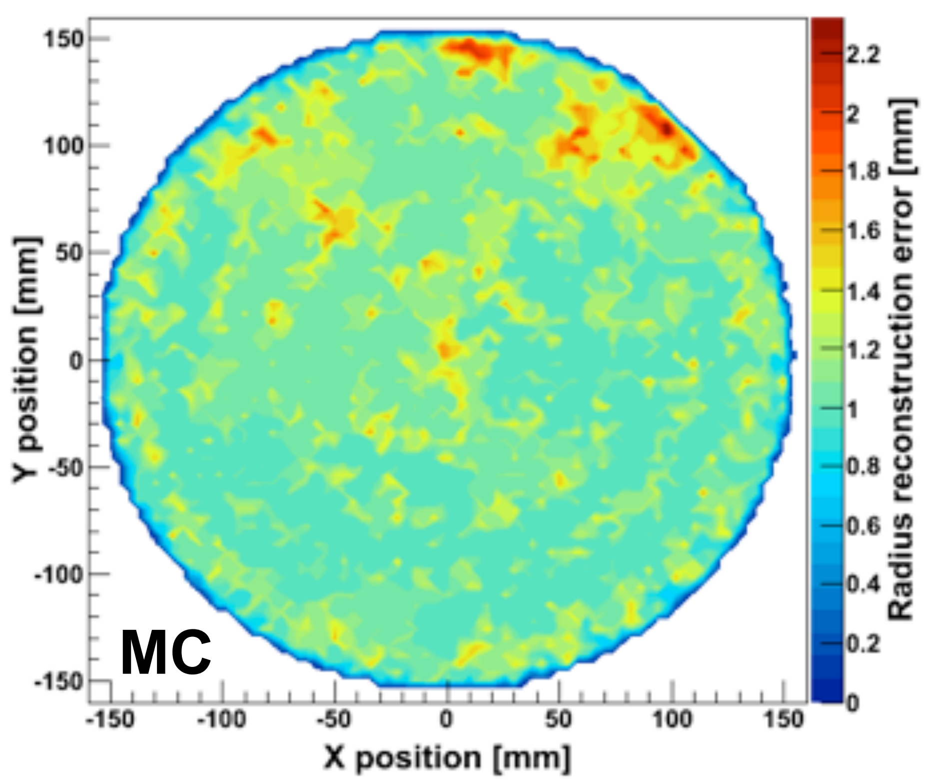
Reconstruction of the event vertex with neural network

- The neural network is a multi-layer perceptron with 98 input neurons (top PMT array) and two output neurons (*X* and *Y* coordinates of an event)

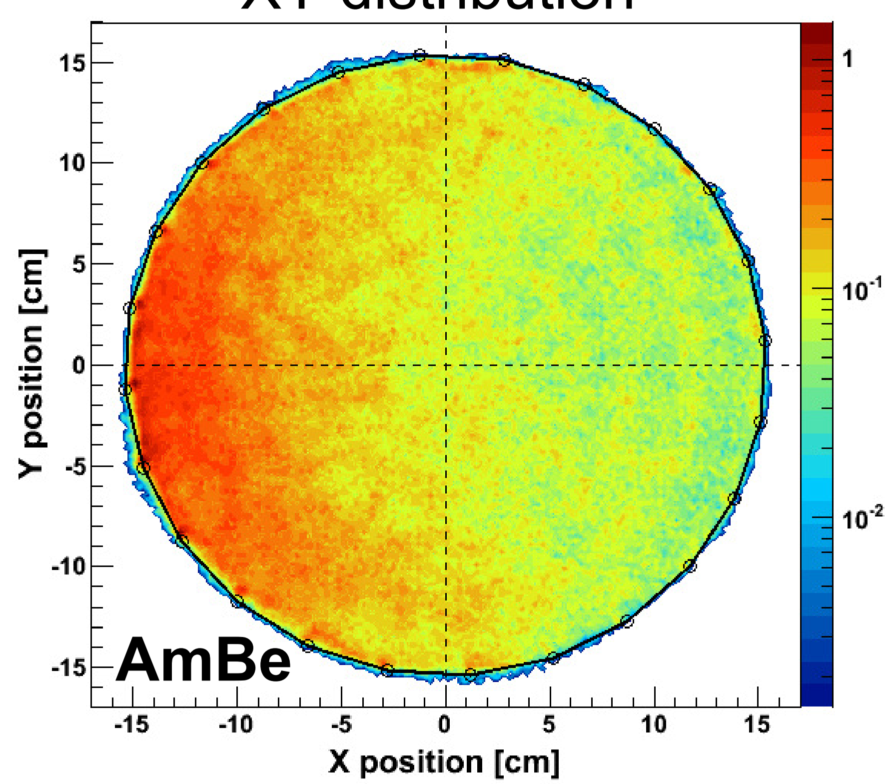


- Performance is verified on MC and measured data
- Reconstruction uncertainty of the radial position $\sigma < 2$ mm

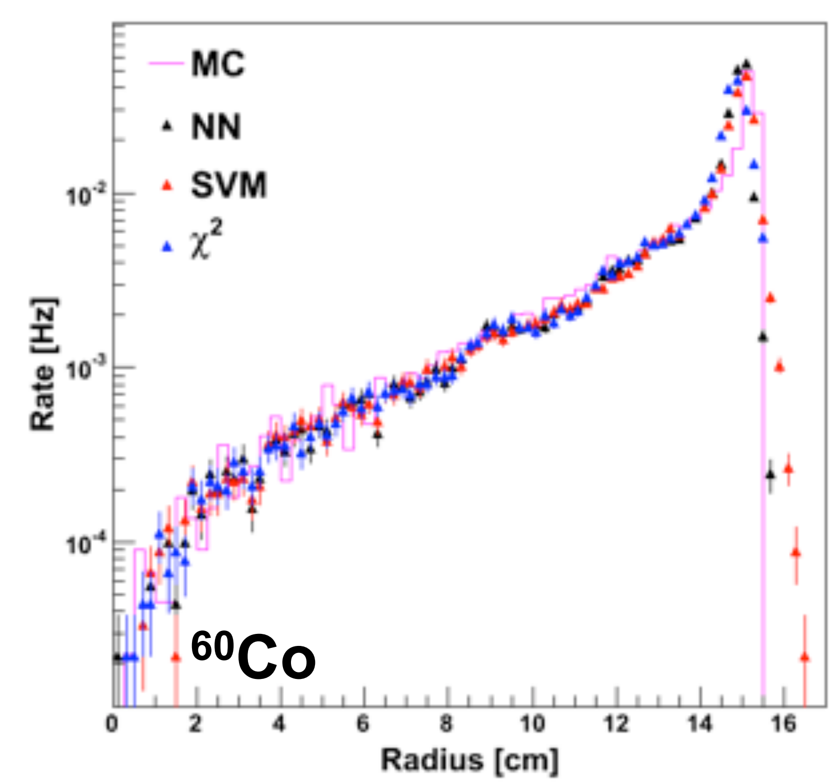
reconstruction error



XY distribution



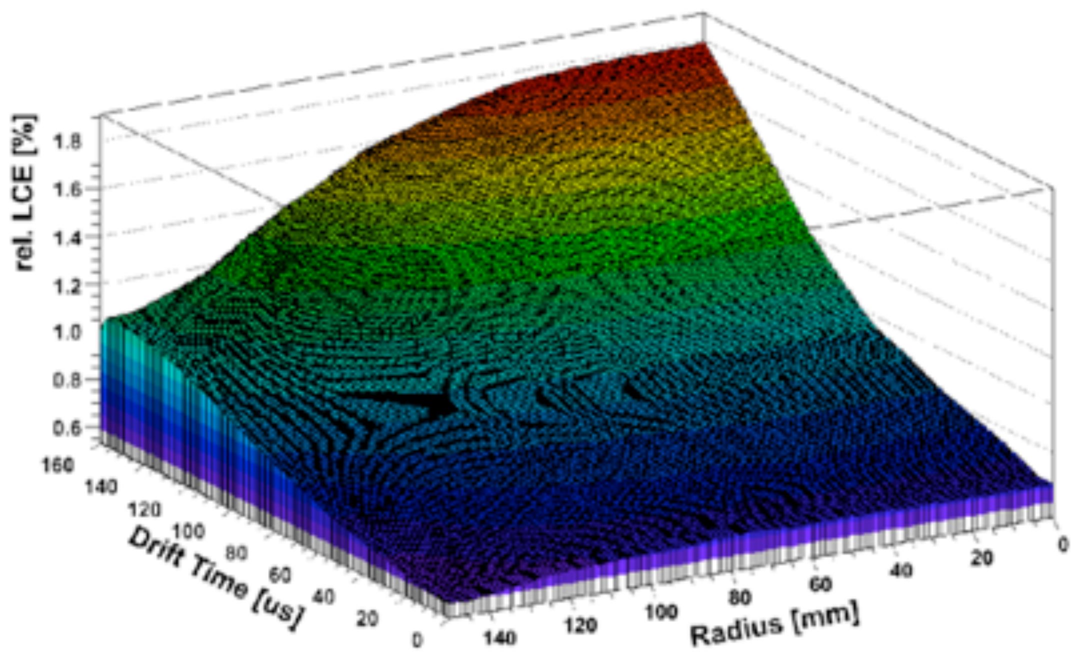
radial distribution



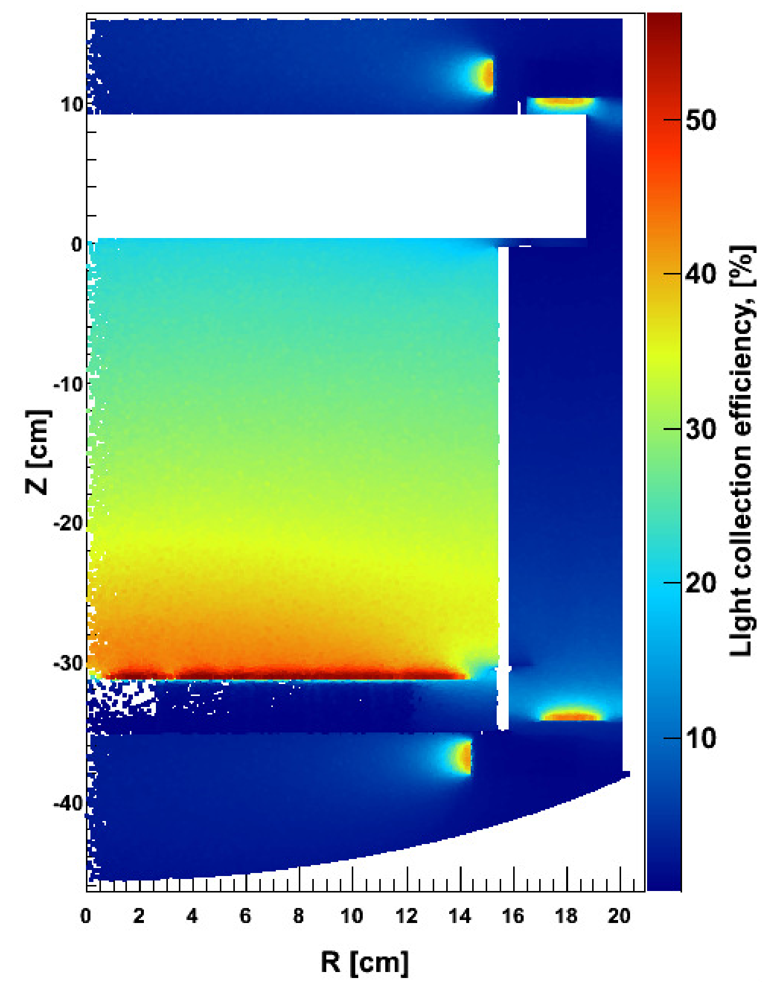
Light collection efficiency and spatial corrections for S1

- Collection efficiency for S1 signal
- simulated with GEANT4
- measured at 39.6, 164, 662 keV (agreement within 3%)
- detector response modeled with GEANT4

measurement (^{137}Cs)

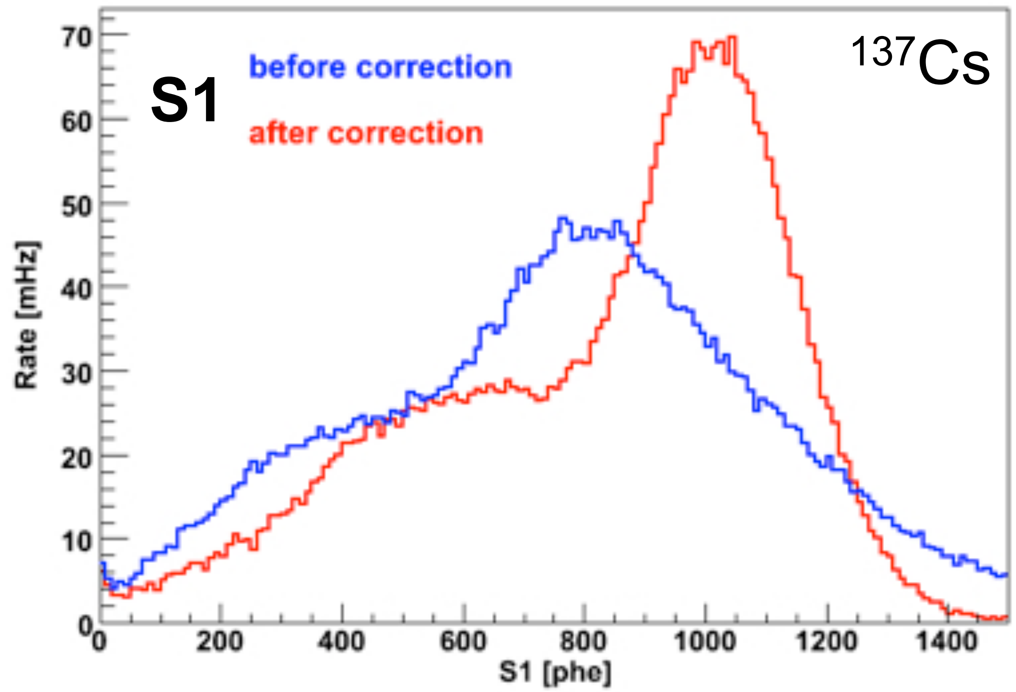


Monte Carlo



- Spatial corrections for S1

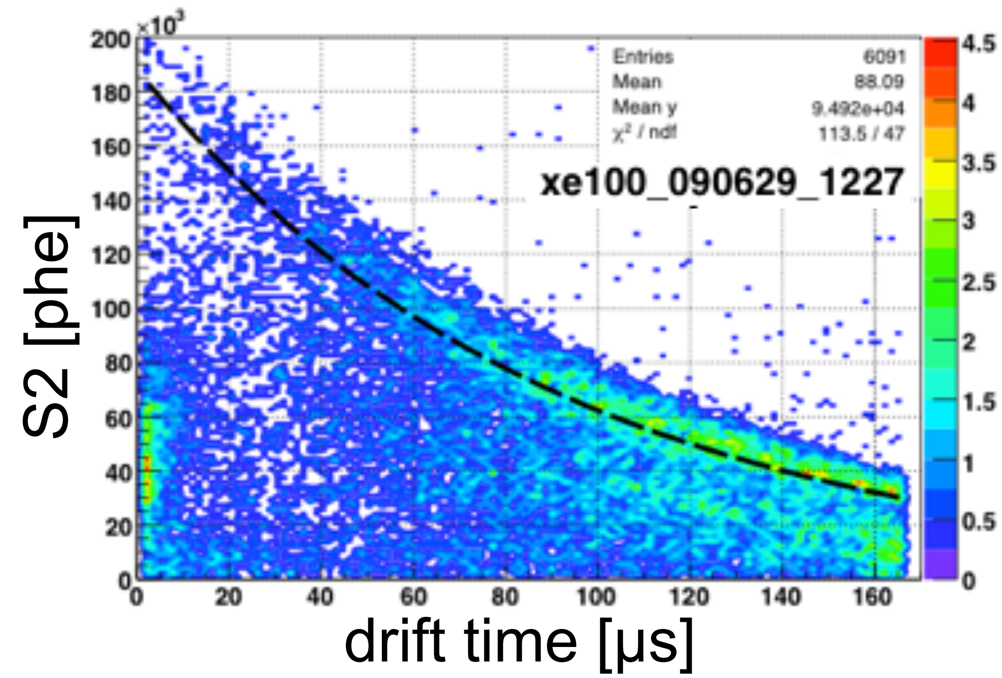
energy resolution improves from 24% to 13% at 662 keV



Collection efficiency and spatial corrections for S2

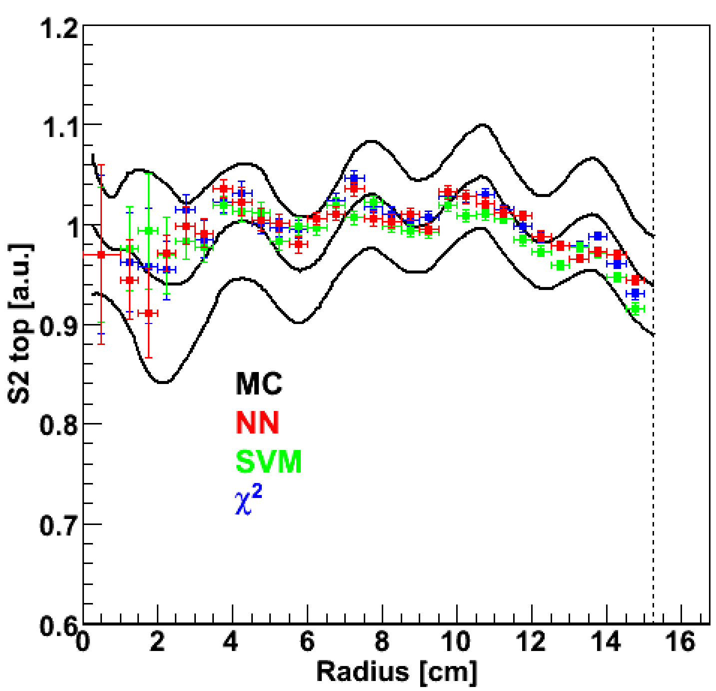
- Correction for increase of e⁻ lifetime in LXe

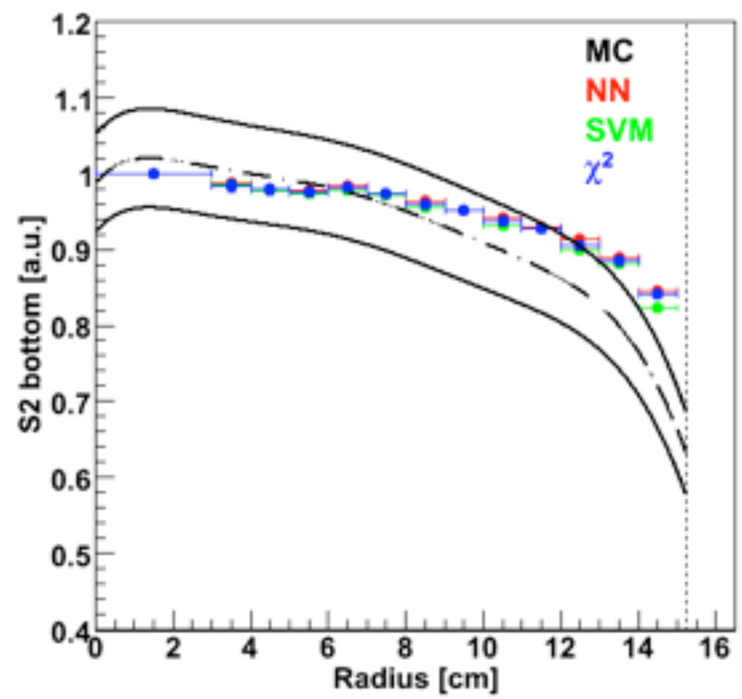
1st scientific run: 154μs → 192μs
correction 75% → 60%

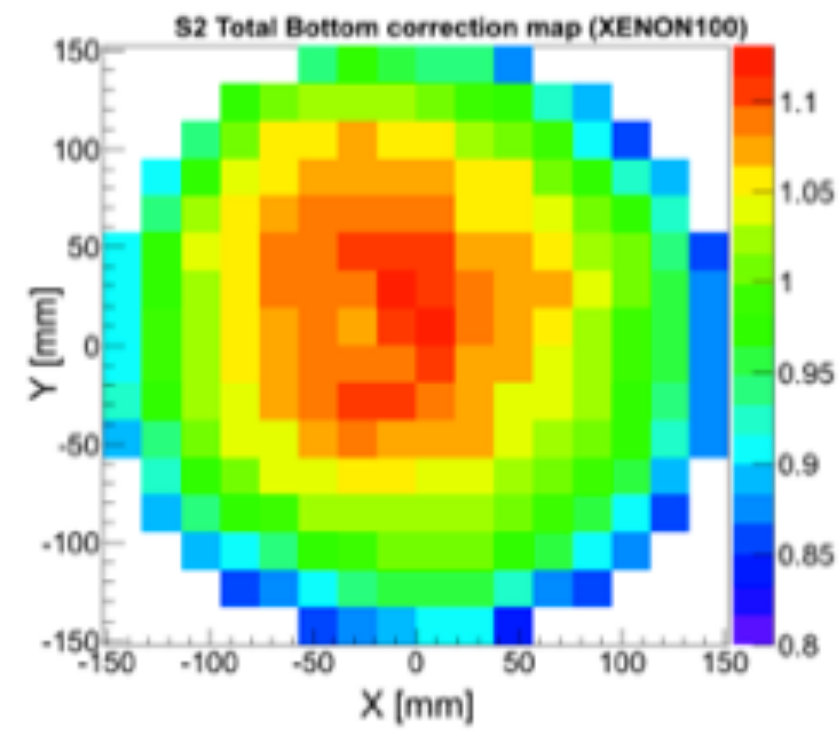


- Correction for the LCE variation

S2 energy resolution improves from 7.3% to 6.5%

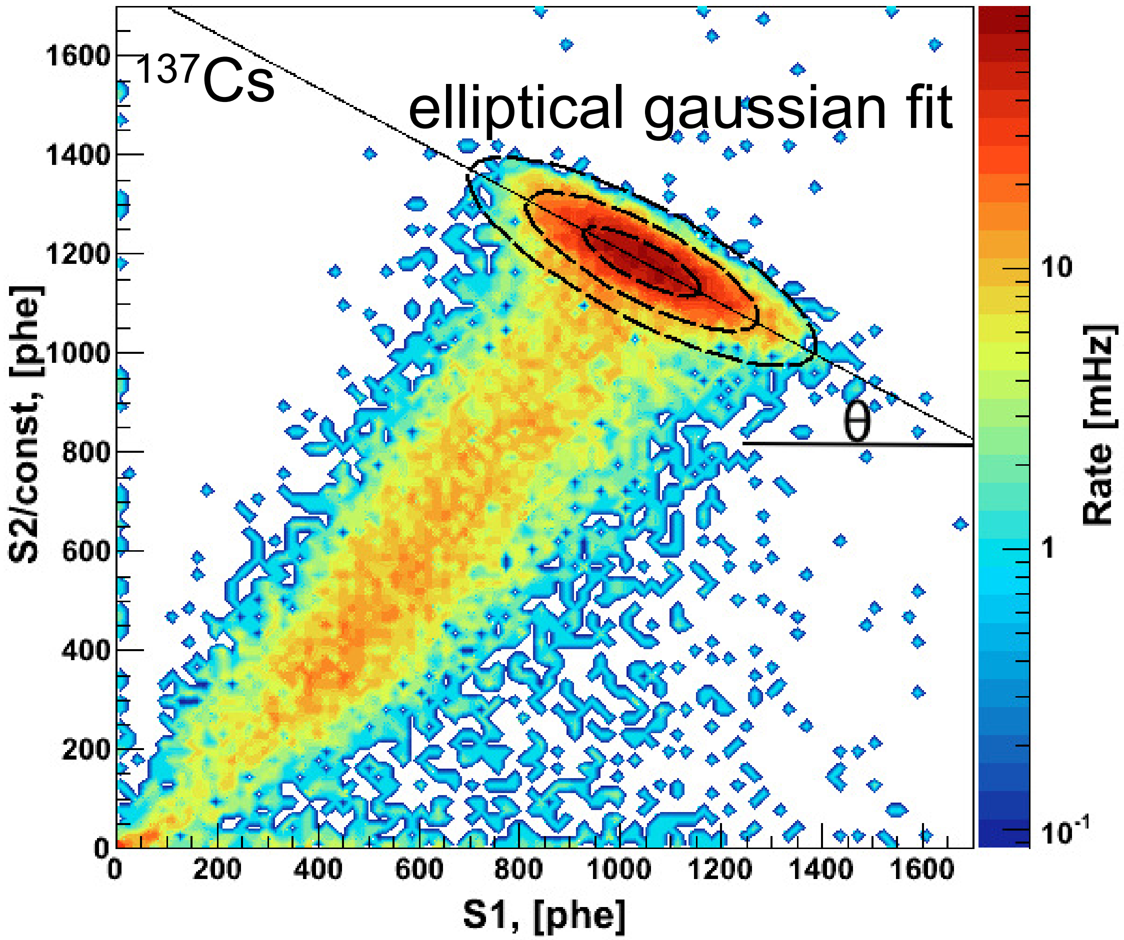


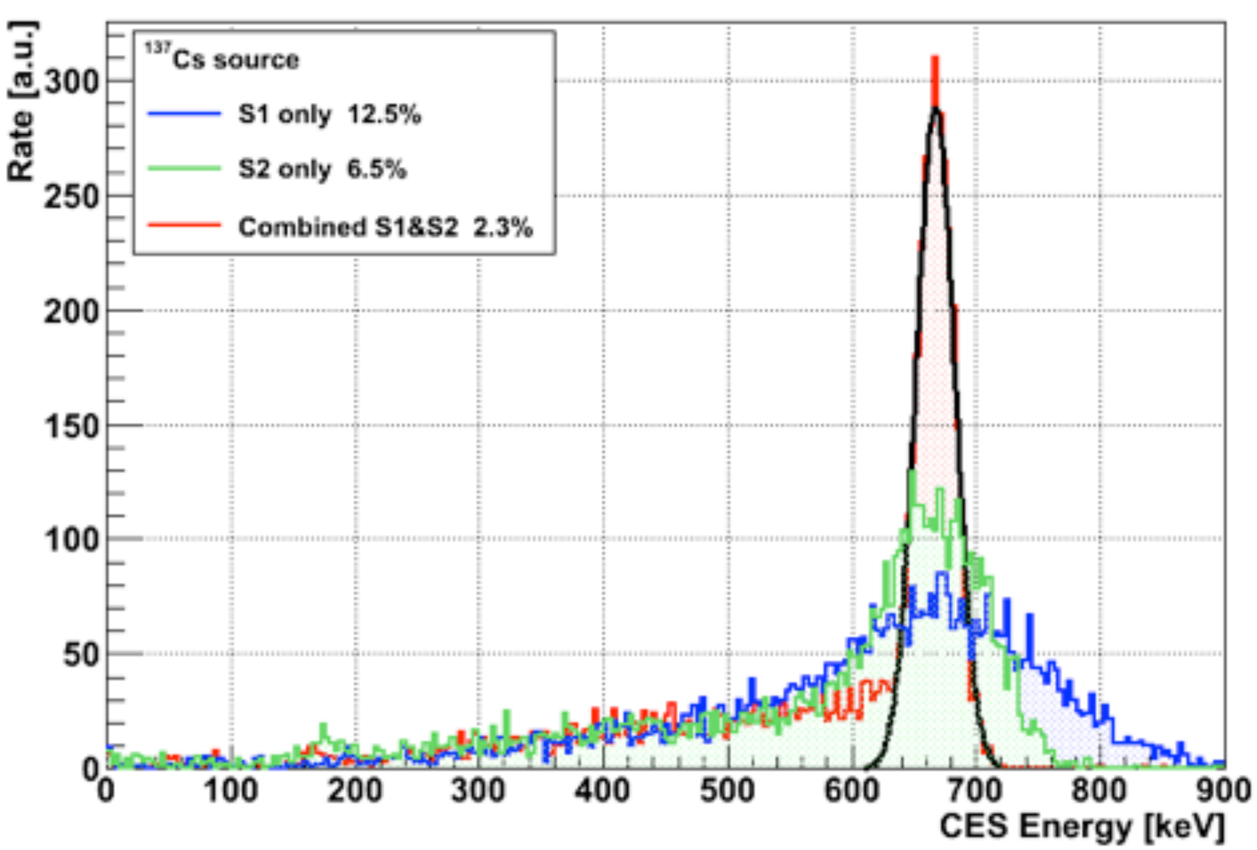


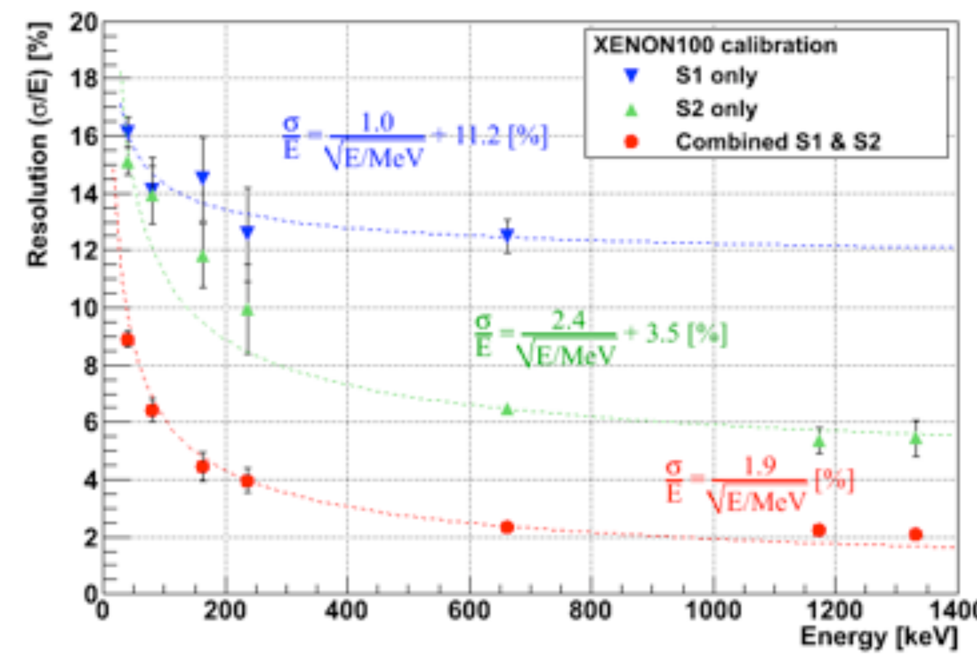


Combined energy scale

- recombination suppression by the external field results in more free electrons and less scintillation photons
- S1 and S2 are anti-correlated
- projection along the major axis of the ellipse provides field-independent combined energy scale







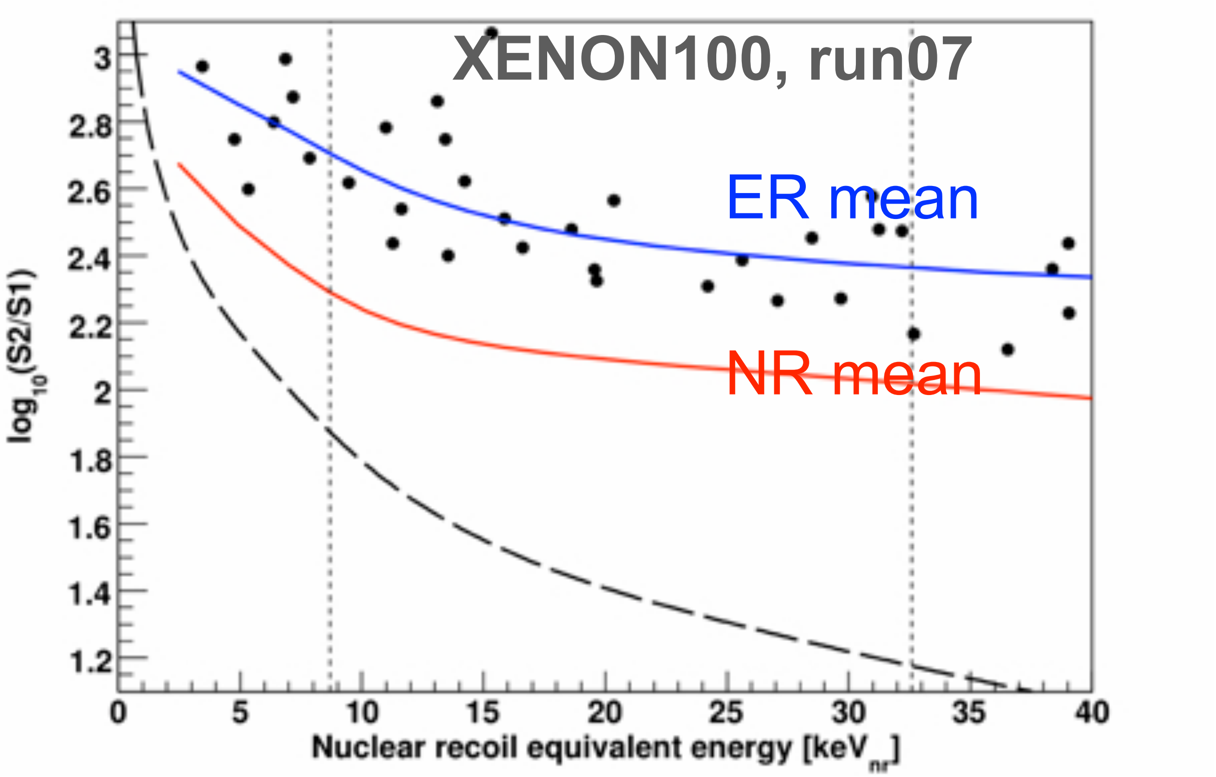
Backgrounds in the XENON100 experiment

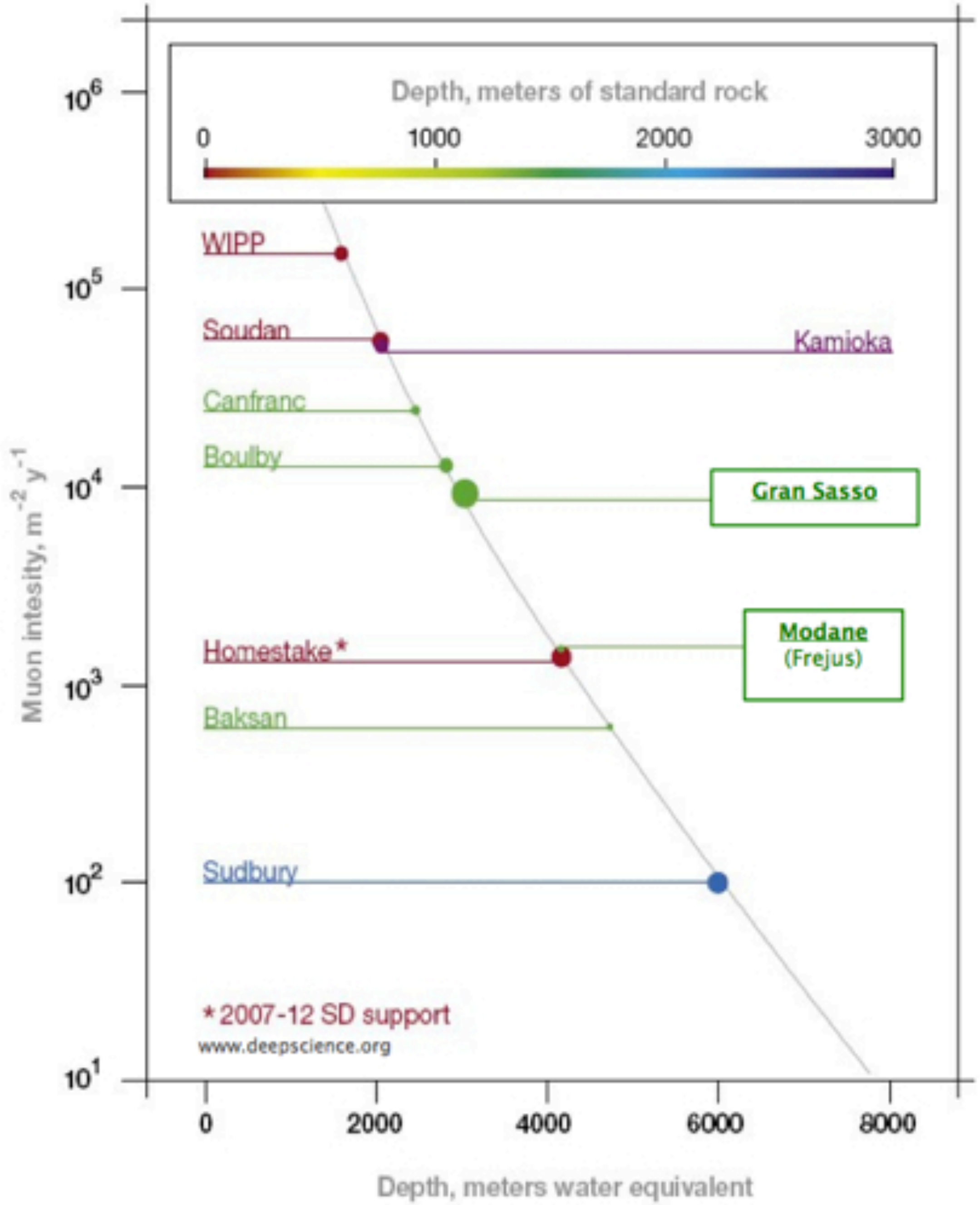
Sources of electron recoil background

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

Sources of nuclear recoil background

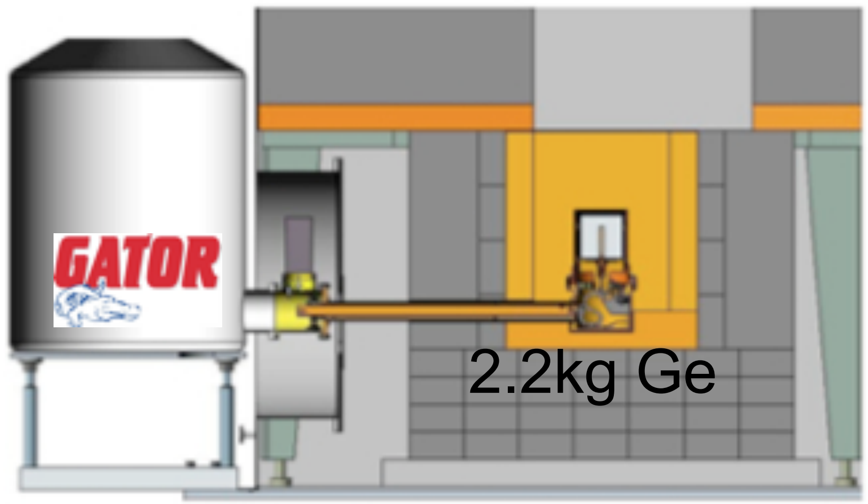
- (α,n) reactions from ^{232}Th, ^{238}U and ^{235}U decay chains and spontaneous fission of ^{238}U;
- muon-induced neutrons.



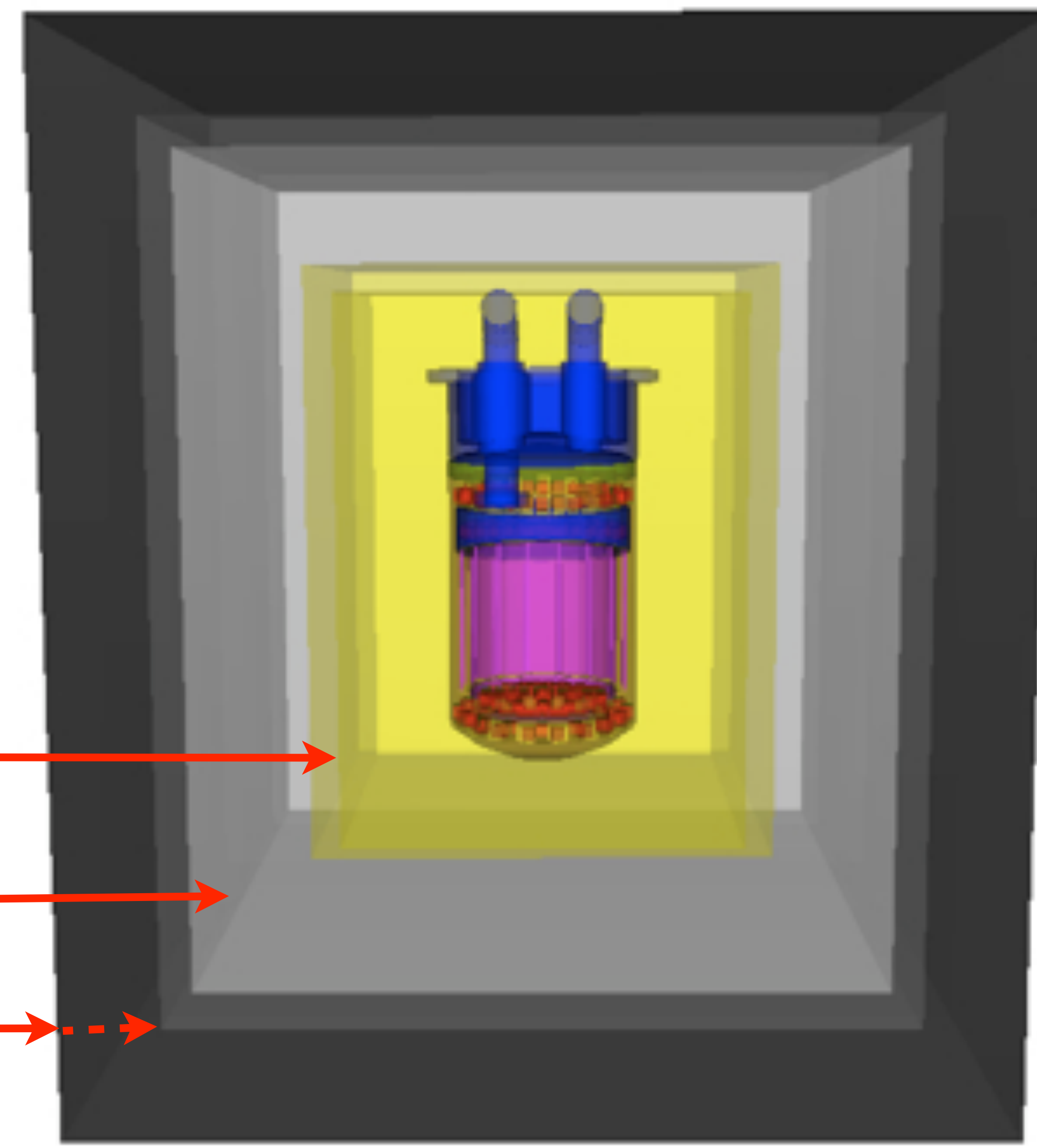


XENON100 background

- all materials screened for radioactive contamination
- screening facility at LNGS



- detector modeled with GEANT4 with high precision



XENON100 Shield:

copper, 5cm

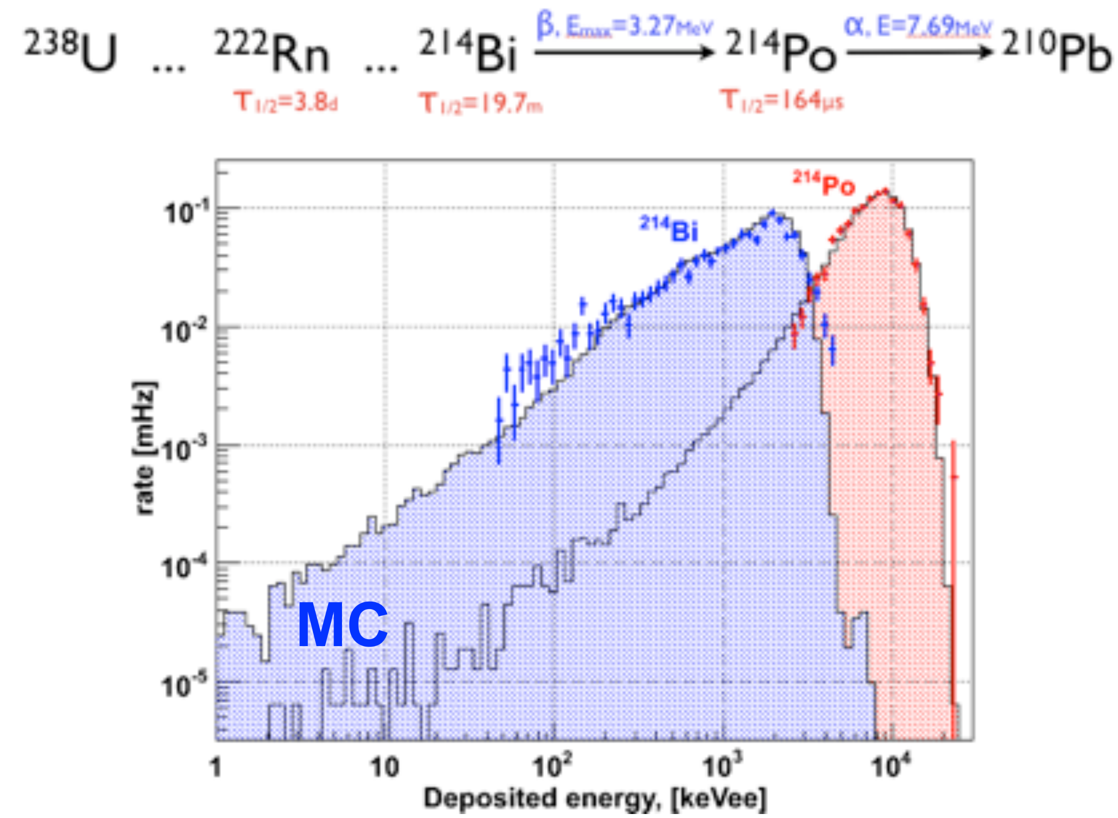
polyethylene, 20cm

lead, 20cm

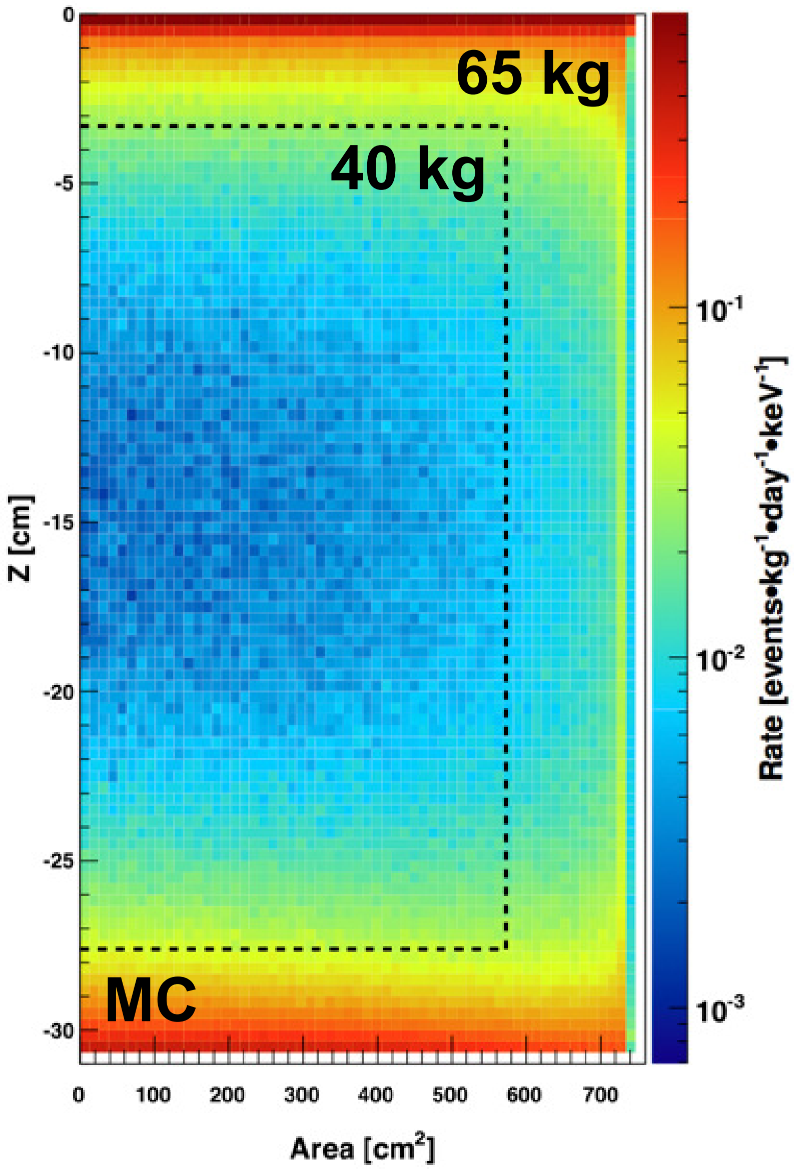
water tanks, 20cm

Electronic recoil background

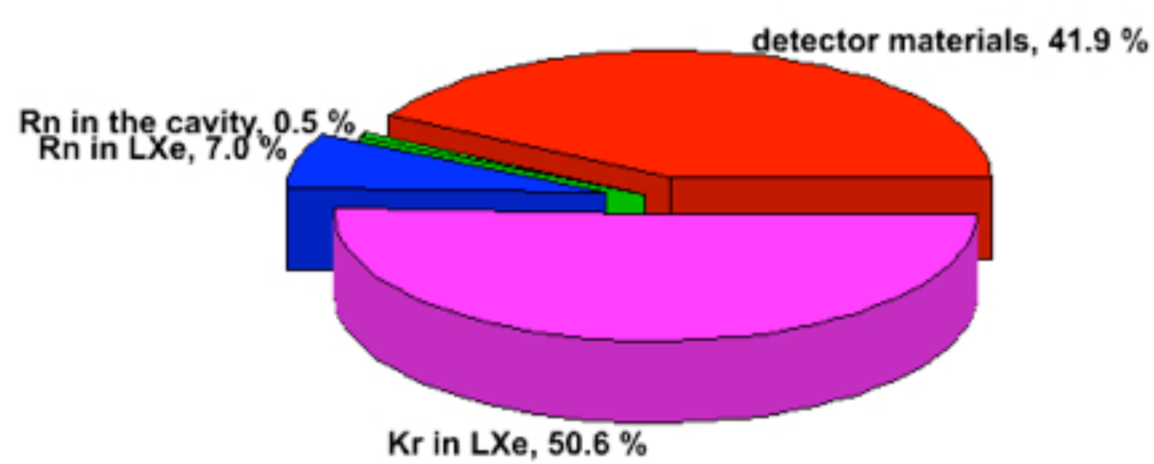
- Intrinsic radon contamination:
- ‘β-α’ delayed coincidence analysis
- upper limit 21μBq/kg



- Krypton in LXe:
- ‘β-γ’ delayed coincidence analysis
- ^{nat}Kr concentration (143^{+130}_{-90}) ppt (mol/mol)

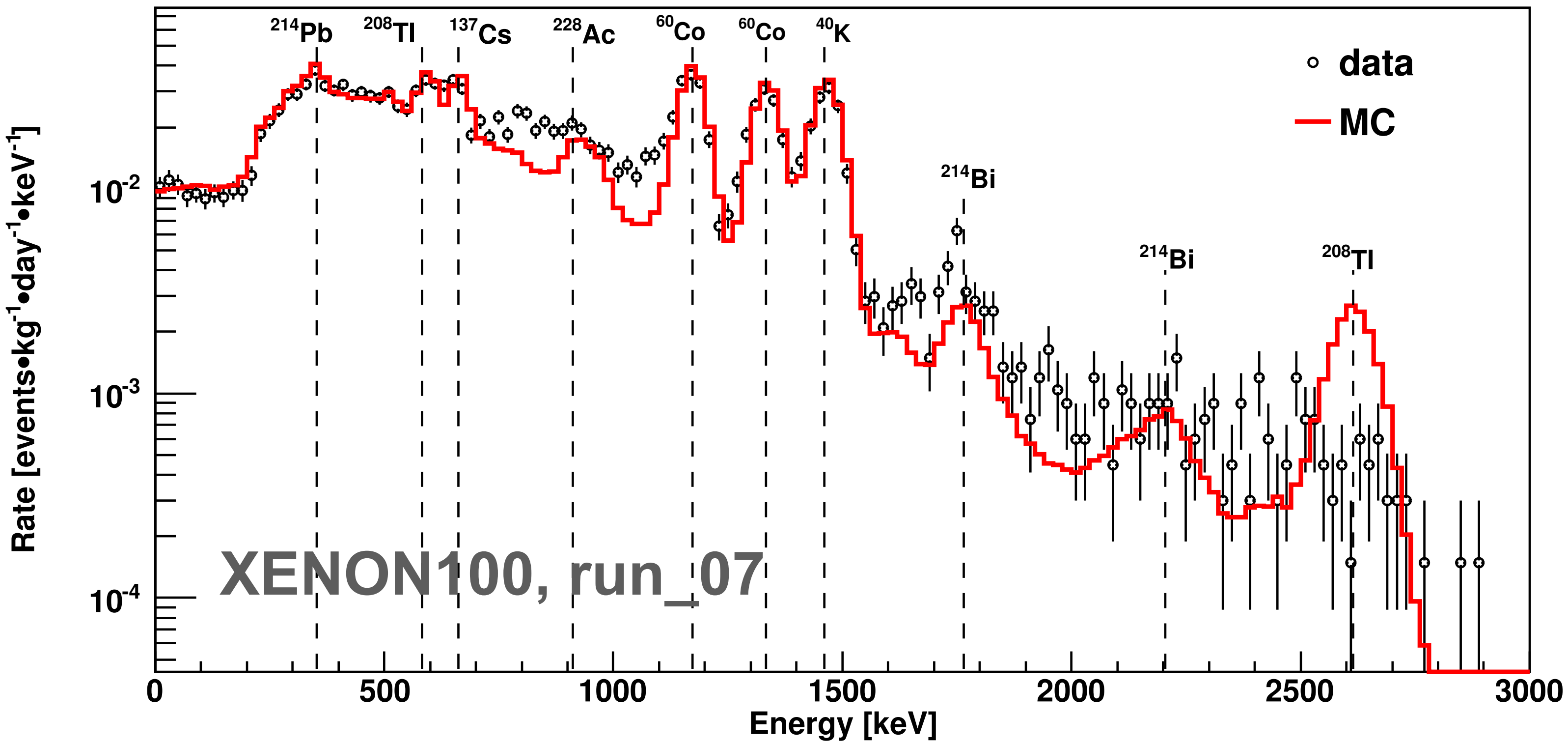


- 40 kg fiducial volume cut - 88% BG reduction
- veto coincidence cut - additional 70-75% reduction
- intrinsic ^{85}Kr dominates the BG in the inner volume

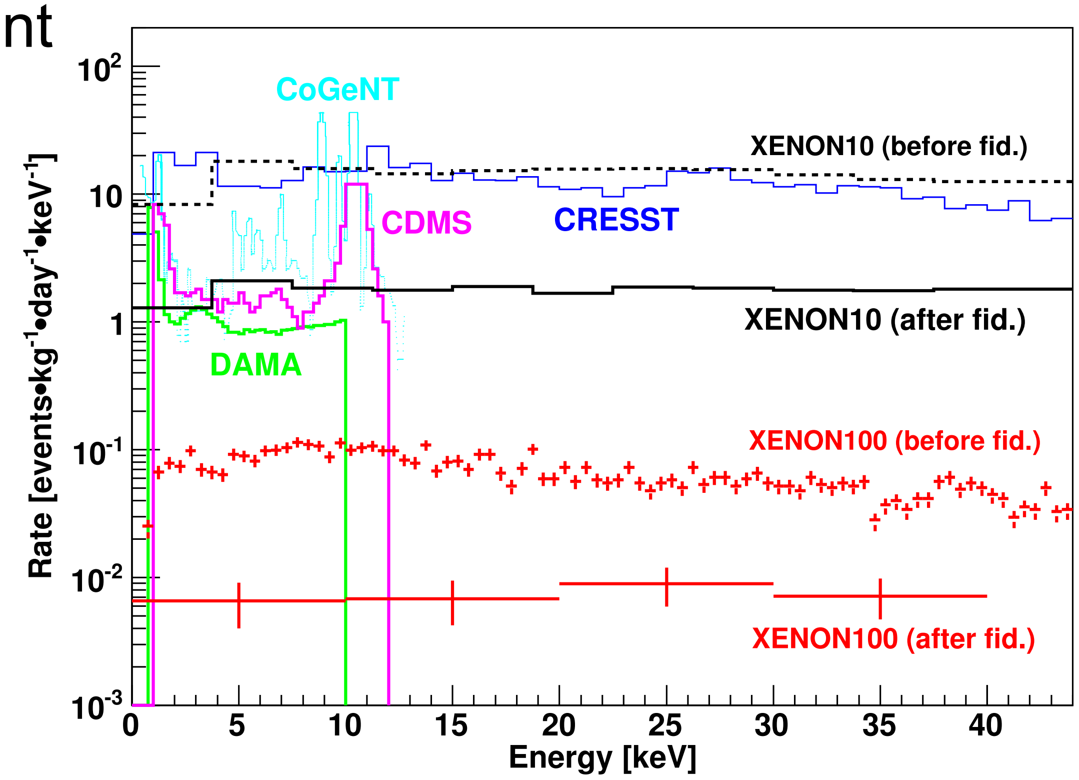


Electronic recoil background

- Good agreement of the background model with the measured spectrum



- Background in the fiducial volume two orders of magnitude lower than in XENON10, and any competing Dark Matter experiment

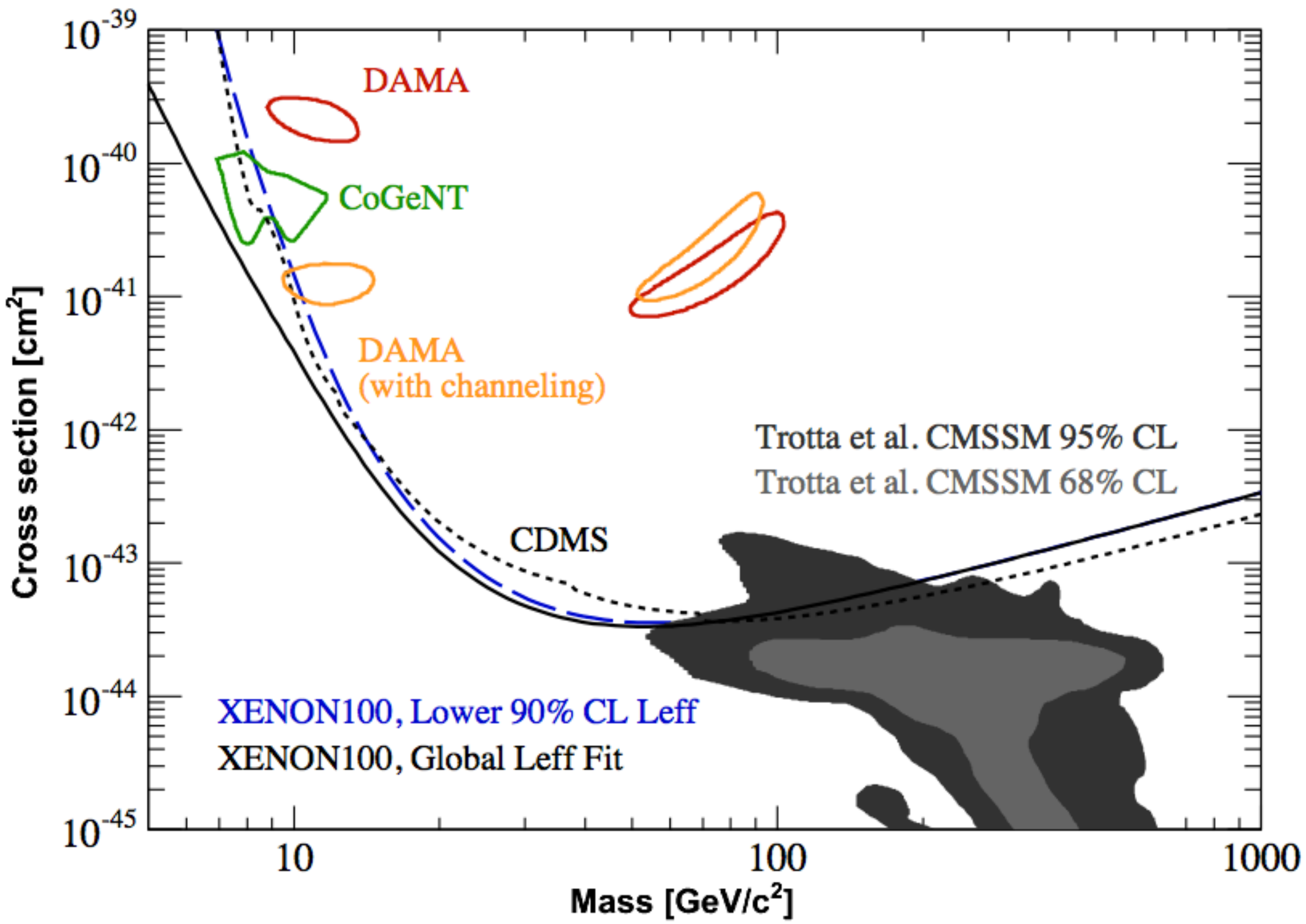


Summary and outlook

● This work helped to understand and improve the detector response (reconstruction of the event vertex, energy resolution)

● The lowest background in a dark matter experiment has been achieved and explained

● First results on the cross-section of the spin-independent WIMP-nucleon elastic scattering are obtained on 11.17 live days from run_07 and accepted for publication in PRL (arXiv:1005.0380)



● More than >100 live days of data are acquired in Run_08. Preparing to unblind.