University of Zurich

Xe XENON Dark Matter Project

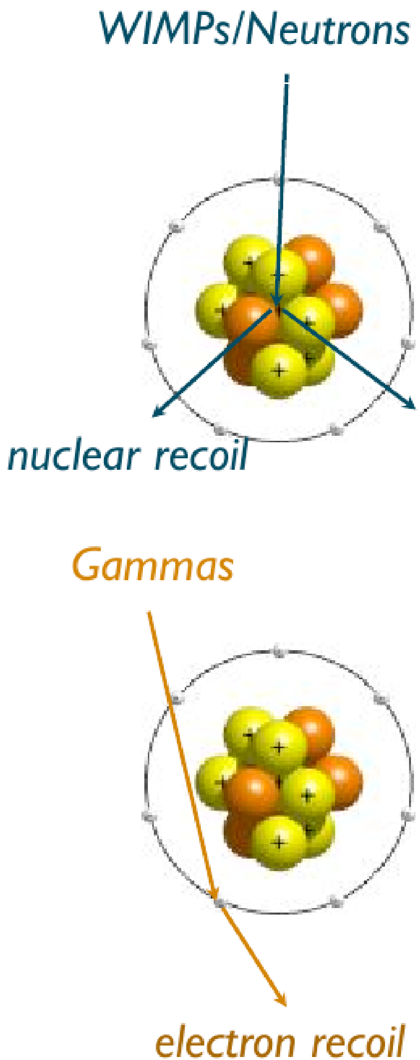
The XENON100 direct Dark Matter search Experiment

Alfredo Davide Ferella
University of Zurich (UZH)

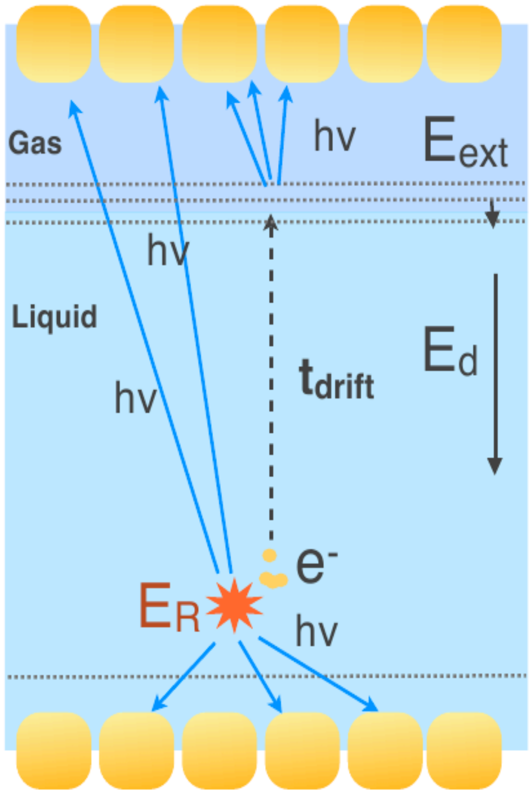
On Behalf of the XENON Collaboration

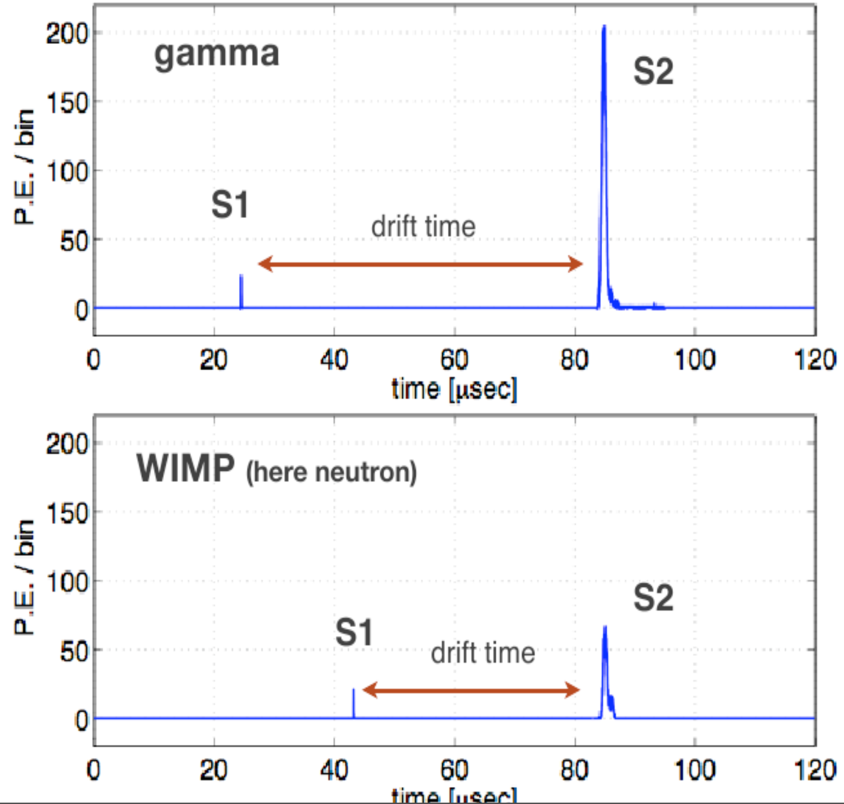
TeVPA
19 - 23 July 2010

Double phase TPC



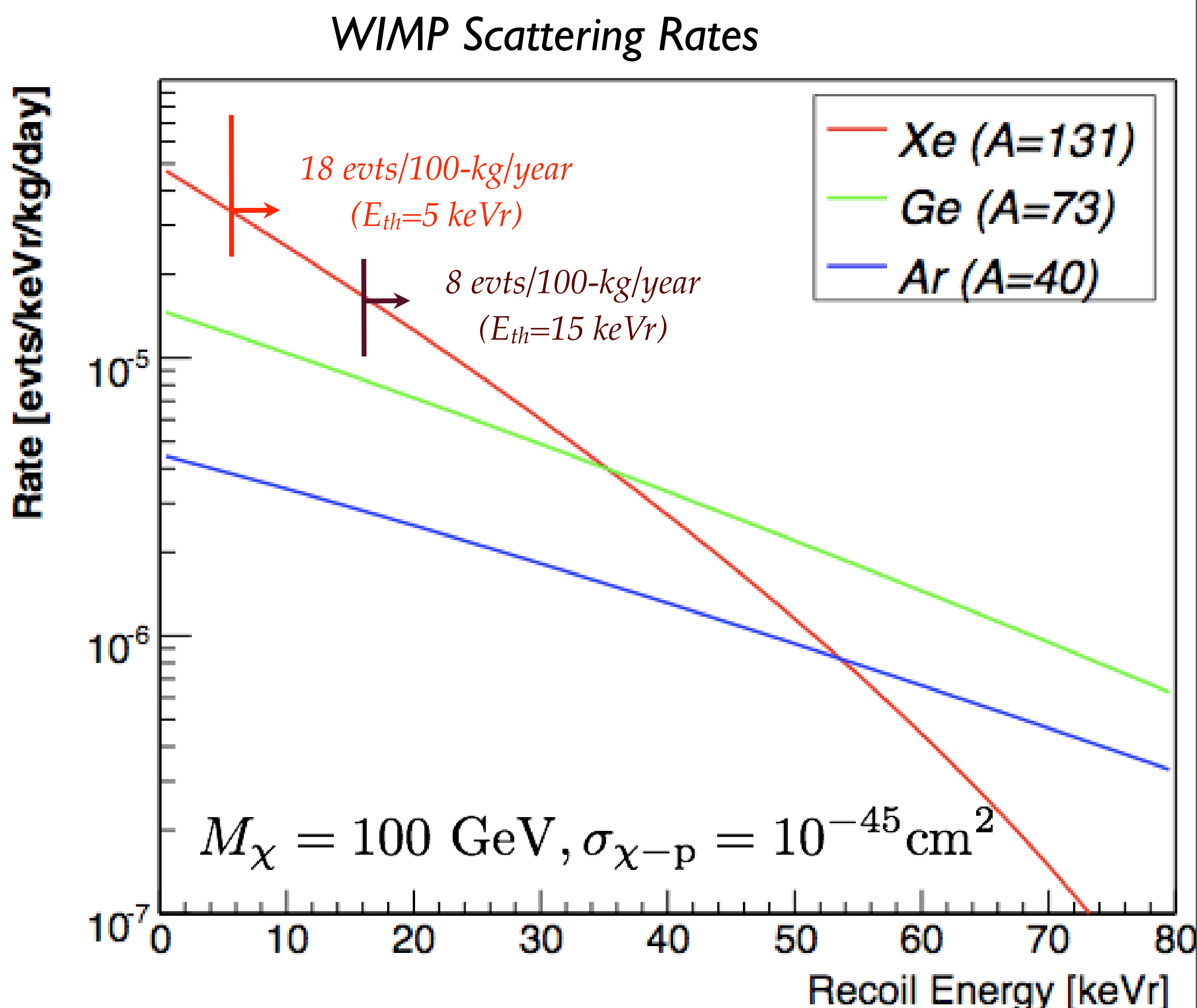
- Primary scintillation signal (S1)
- Electrons drift over 30 cm max distance
- Electrons are extracted and accelerated generating secondary scintillation signal
- The time difference between the two signals gives information on event position in z





Why Liquid Xenon?

- ✓ large mass (ton scale)
- ✓ easy cryogenics
- ✓ low energy threshold (a few keV)
- ✓ A~131 (good for SI)
- ✓ ~50% odd isotopes (SD)
- ✓ background suppression
  - good self shielding features (~3 g/cm^3)
  - low intrinsic radioactivity
  - gamma background discrimination
  - position sensitive (TPC mode)



Collaboration

USA, Switzerland, Portugal, Italy, Germany, France, China, Netherlands

COLUMBIA RICE UCLA ZURICH COIMBRA

LNGS MPIK BOLOGNA SHANGHAI

MUENSTER SUBATECH NIKHEF

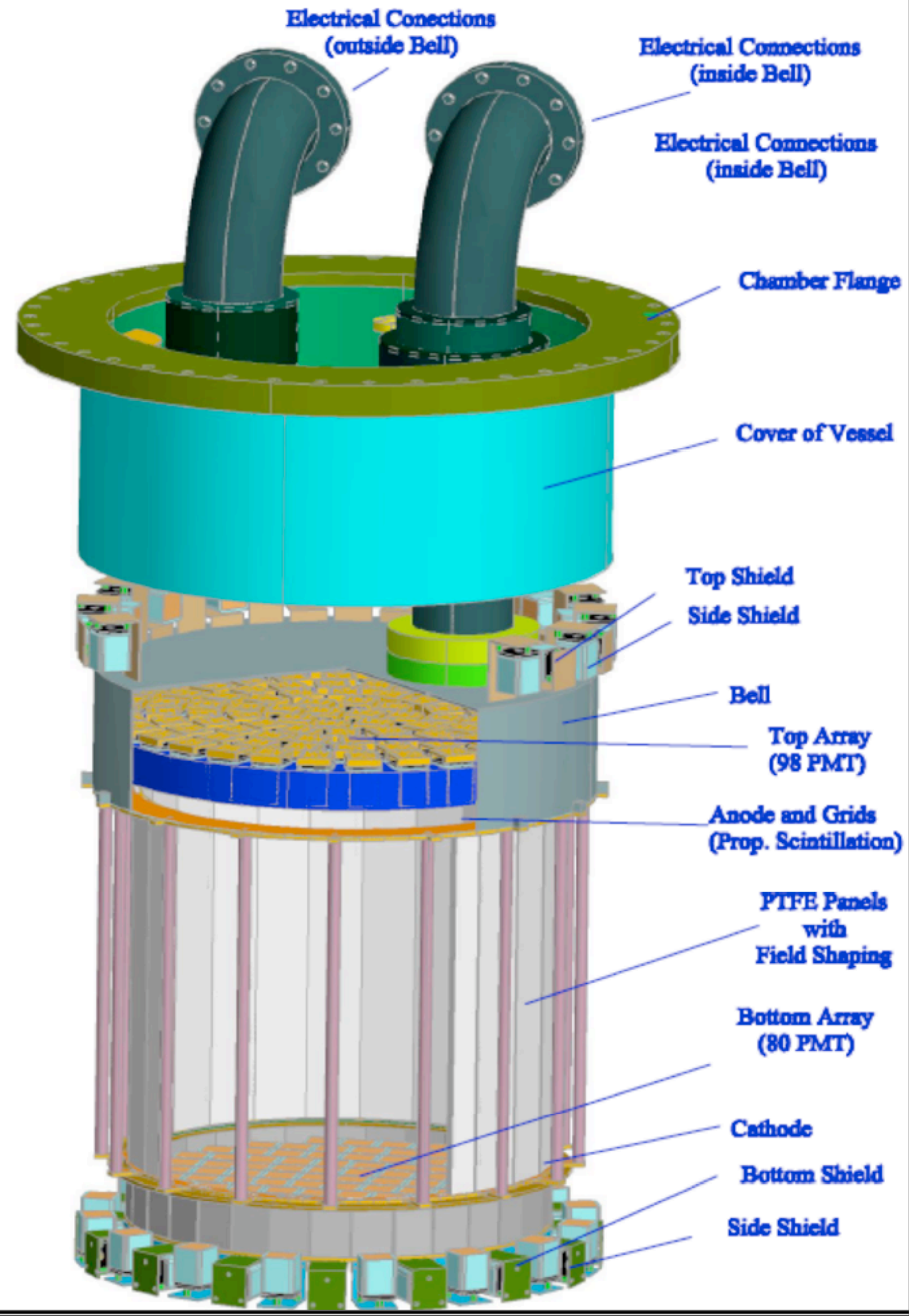
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Xenon100 design: TPC

- ~161 kg total / ~62 kg target LXe (15 cm radius , 30 cm drift)

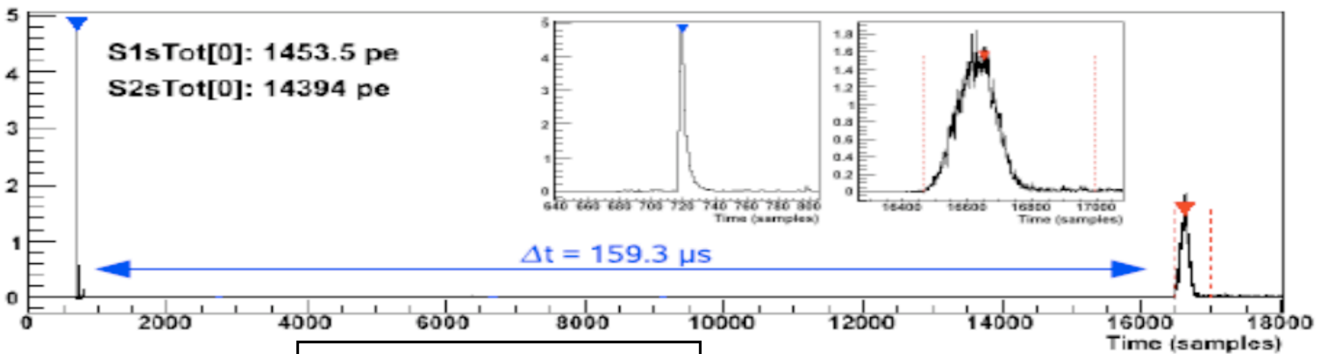
- Active LXe veto (64 PMTs)

- 70 new high QE (>32%@175nm) low activity 1” R8520 PMTs (total 242 PMTs)

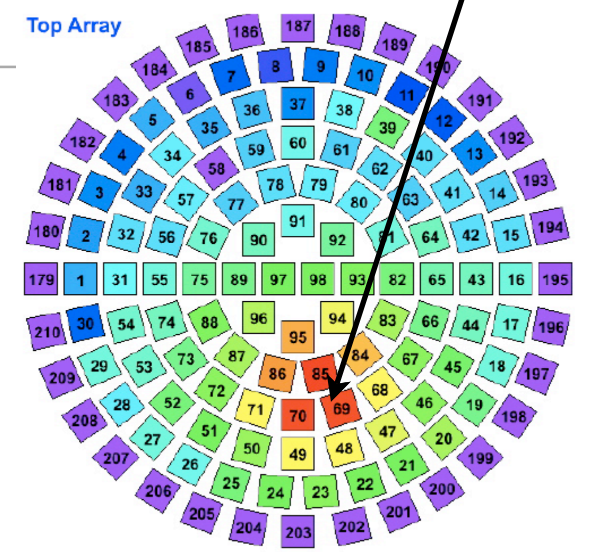


Very localized S2 hit pattern (xy position information)

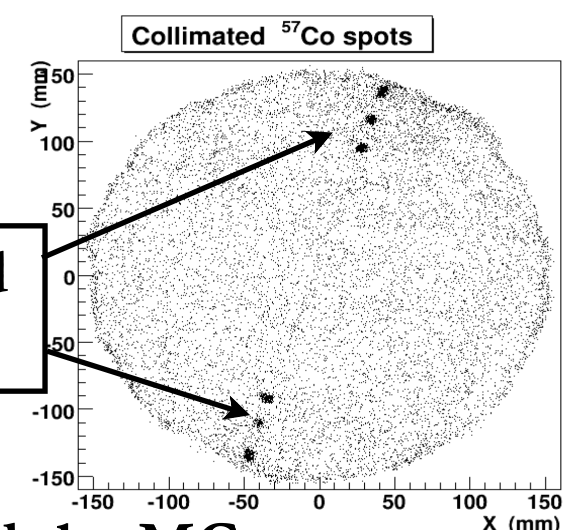
Xenon100: Position reconstruction



drift time -> z



3 different methods for xy position reconstruction:
neural network
support vector machine
Least squares minimization

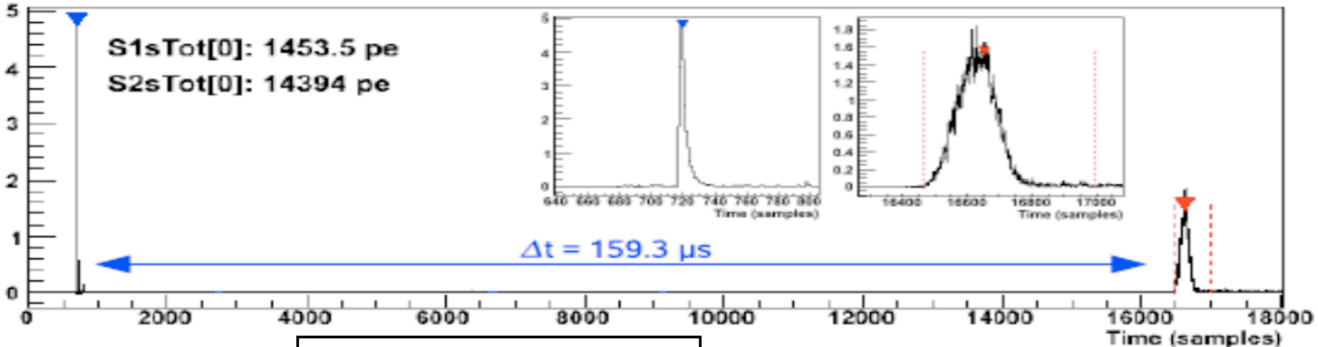


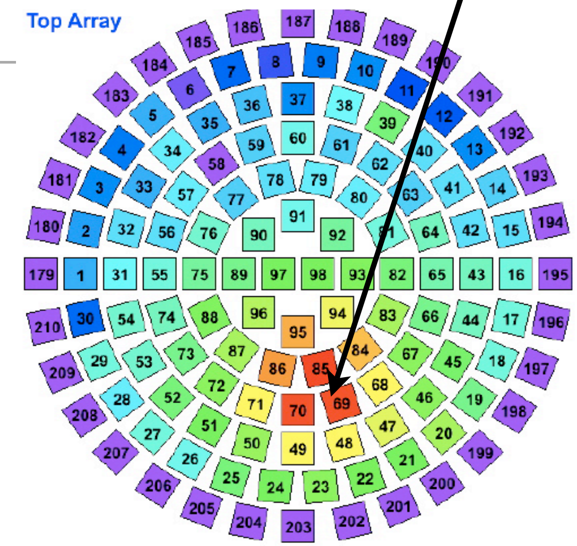
position resolution measured with collimated source

Agreement between the results and the MC yields a resolution ≤ 3 mm

Xenon100: Position reconstruction

Very localized S2 hit pattern (xy position information)





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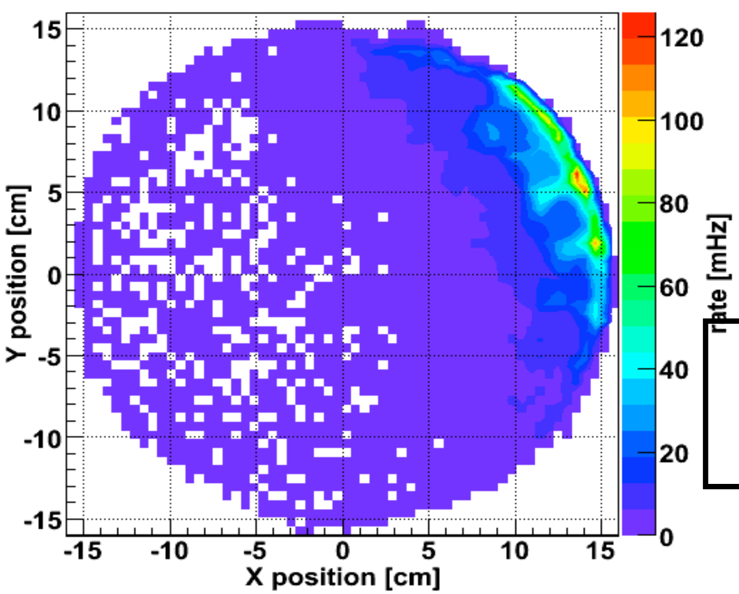


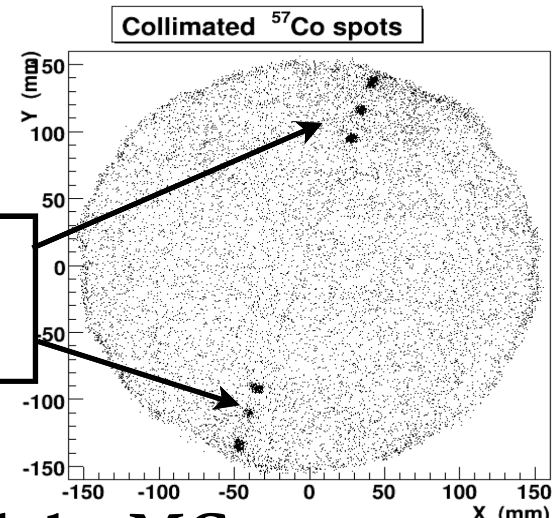
Cs137 from the side

3 different methods for xy position reconstruction:

neural network

support vector machine

Least squares minimization



position resolution measured with collimated source

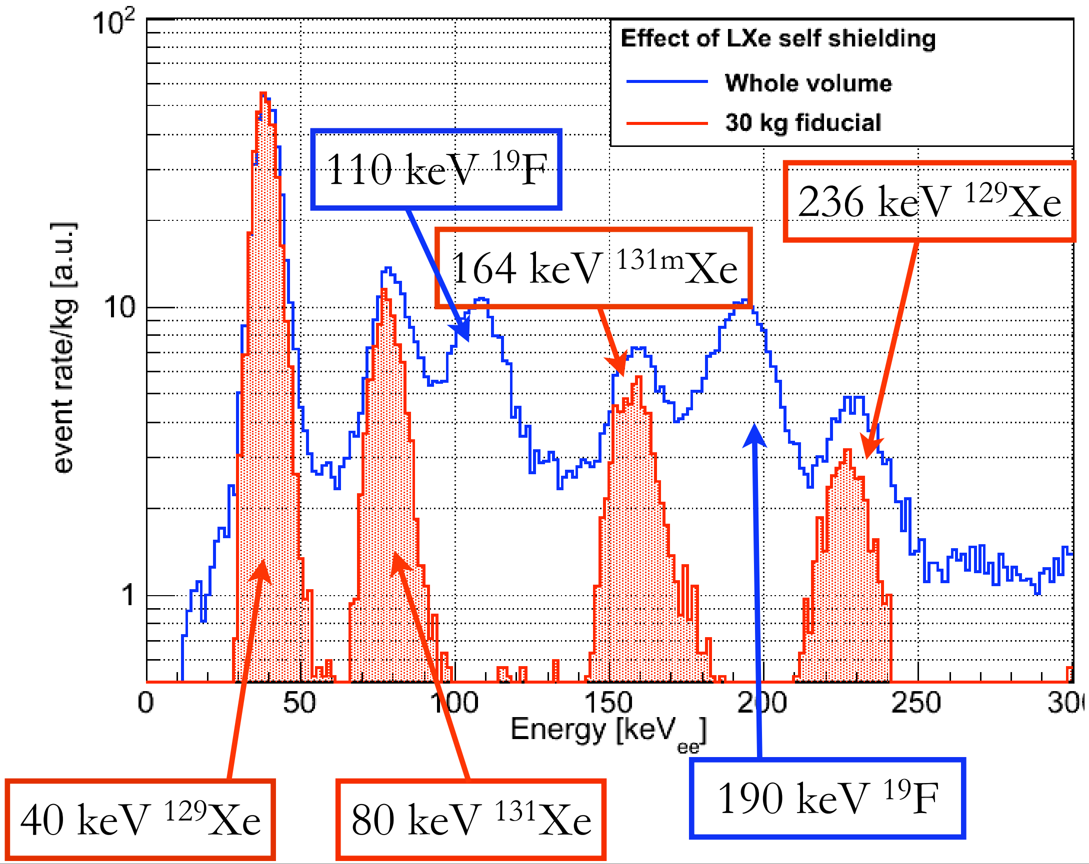
Agreement between the results and the MC yields a resolution ≤ 3 mm

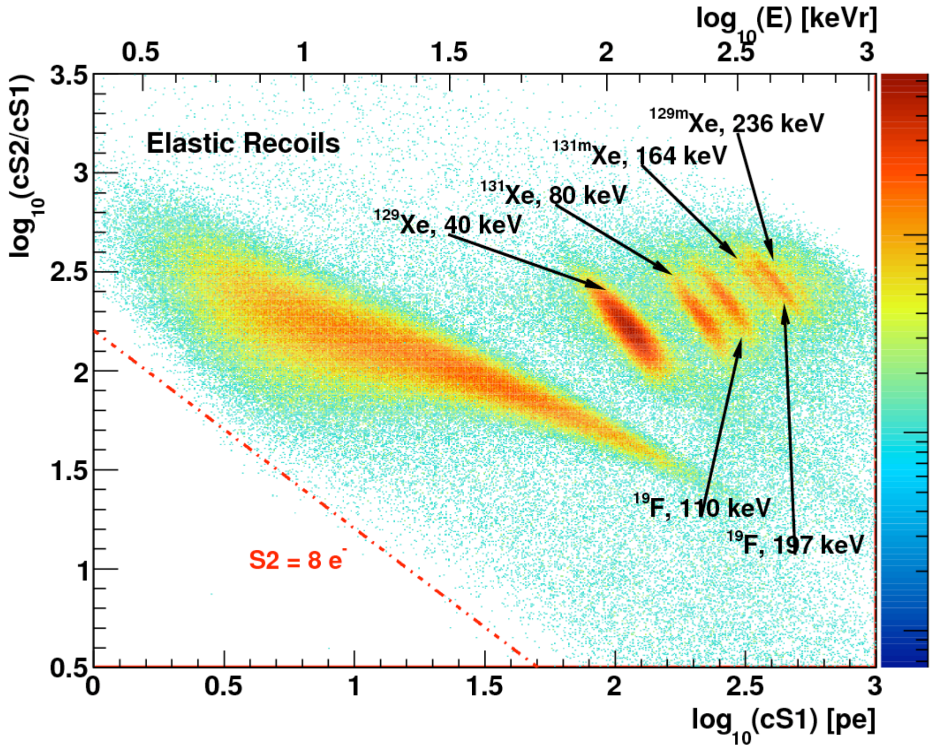
Xenon100: calibration

Gamma sources:

- ^{137}Cs for regular detector checks and calibration
- ^{60}Co electron recoil response determination
- Xenon inelastic and activation lines from AmBe run

Neutron source: $^{241}AmBe$

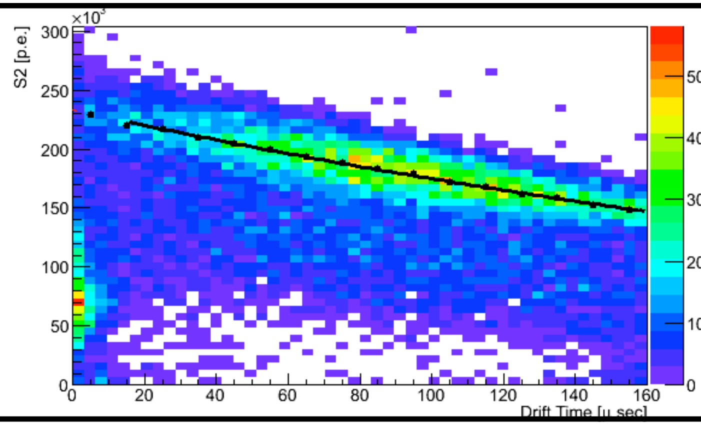


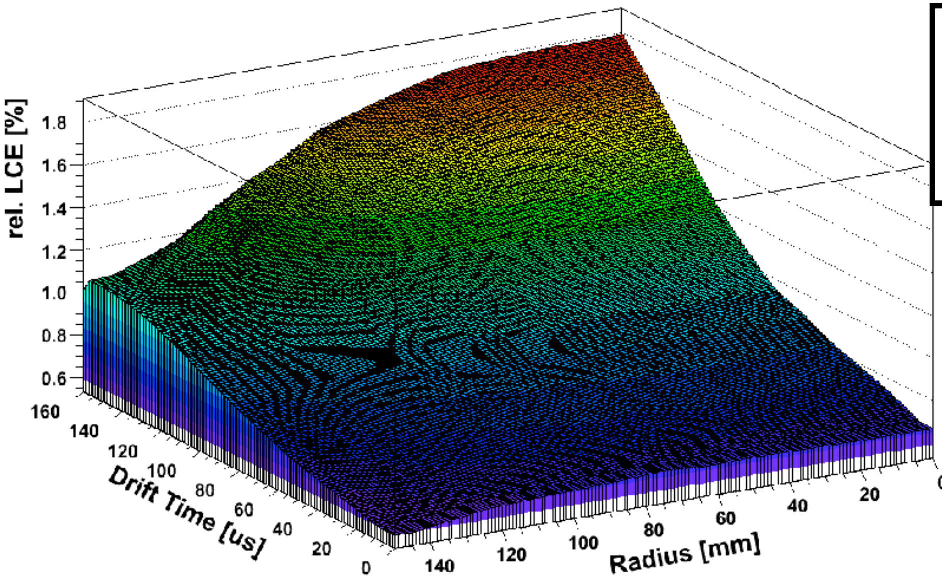


Xenon100: signal position dependence

- Light yield from different positions in the detector changes due to solid angle, absorption length and teflon reflectivity
- Several sources distributed in the active volume have been used to measure the collection efficiency of the detector
- The results from these sources (40 keV inelastic, 131mXe, and 137Cs) agree within each other

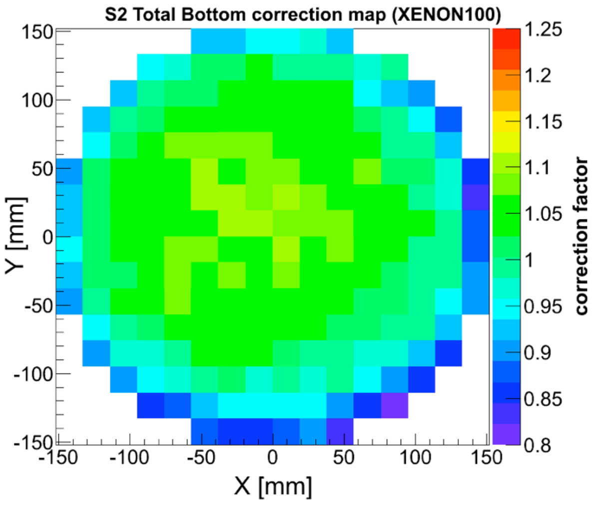
Signal corrected by the electron lifetime: $Q_o \sim Q\, e^{dt/T}$





Average light yield with electric field
2.2 pe/keV @ 122 keV

Differences in the signal due to the different solid angles in different XY positions are also corrected. No inhomogeneity is observed



Xenon100: calibration

Effect of the corrections:

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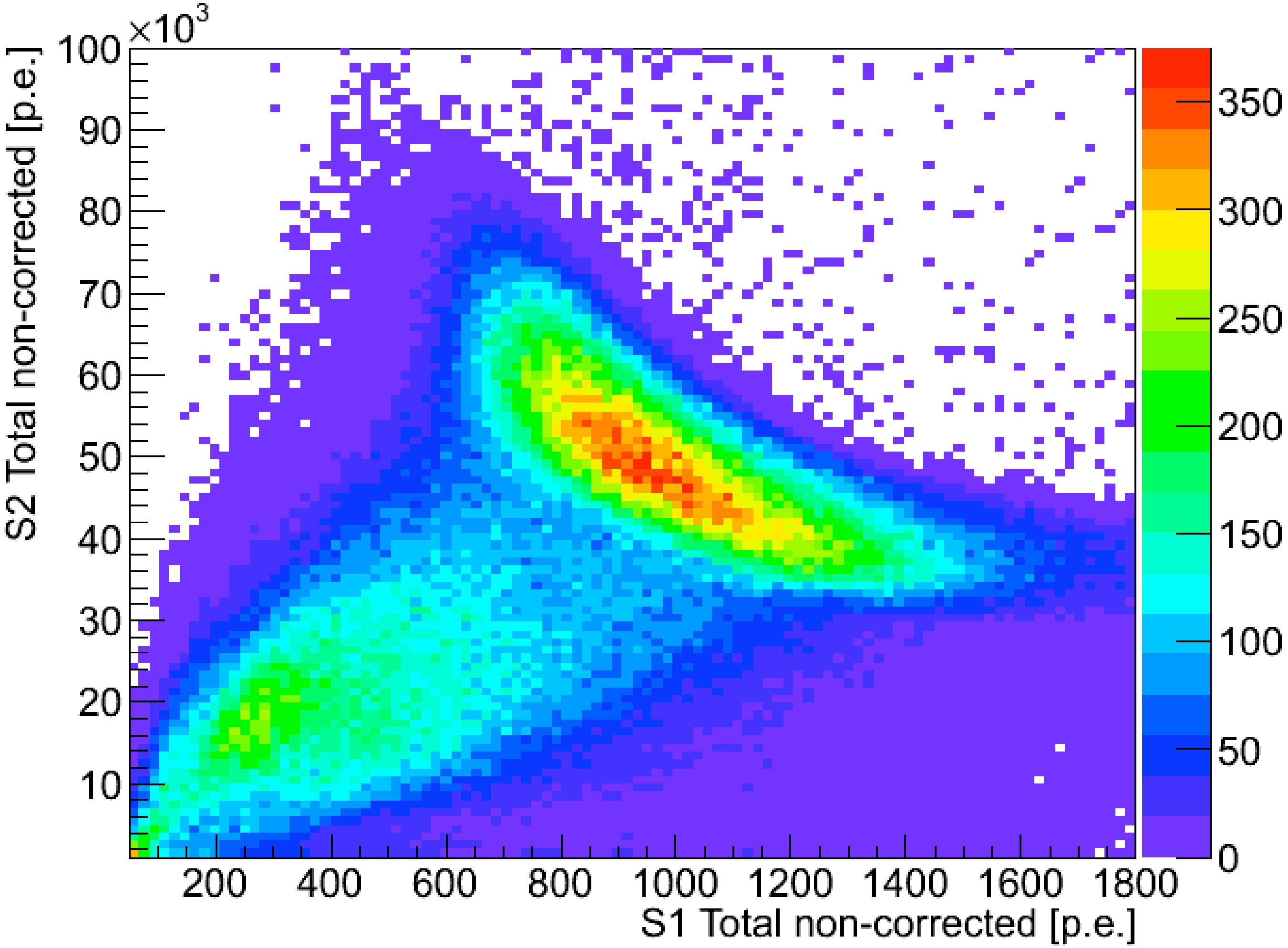

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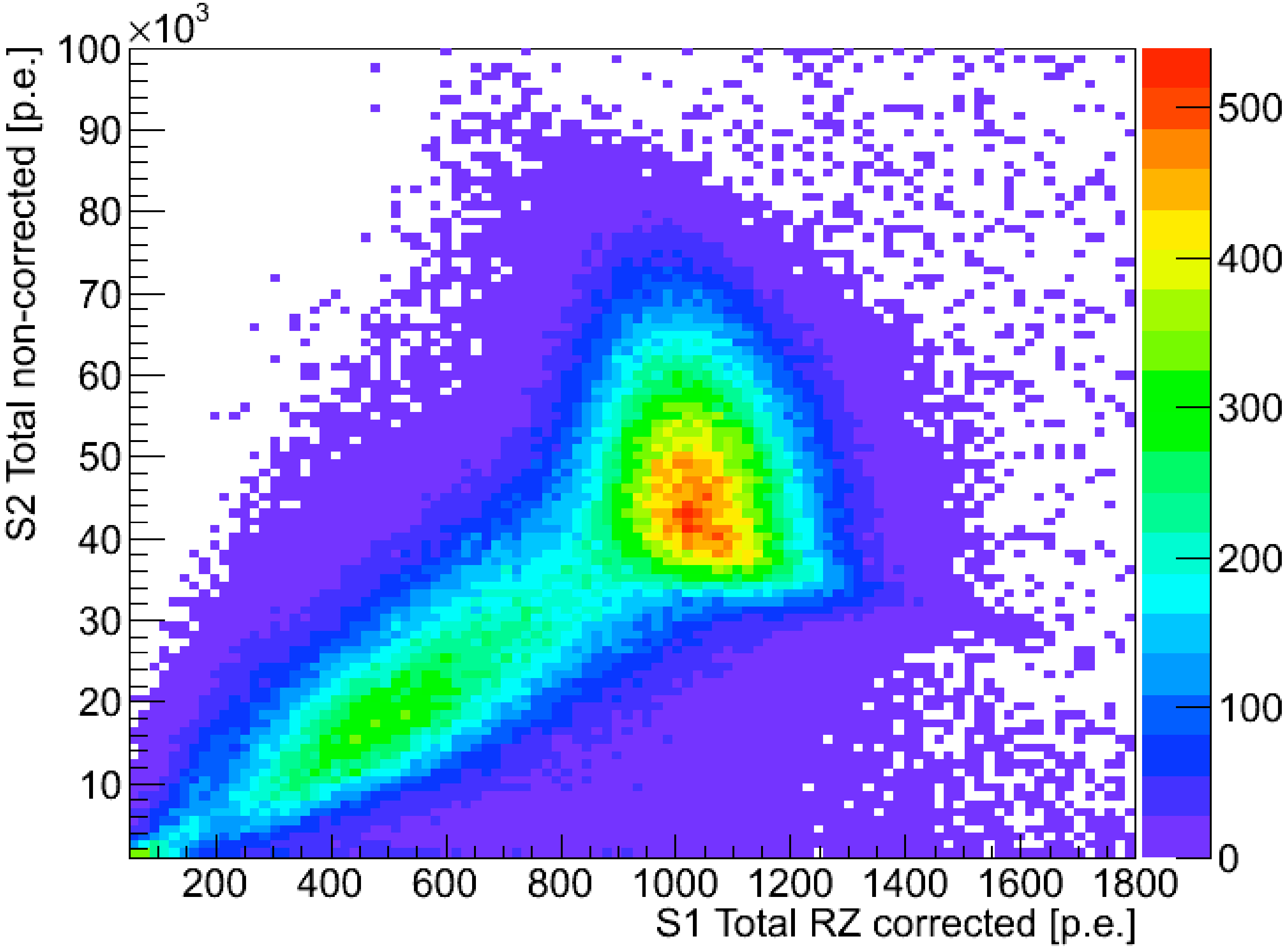

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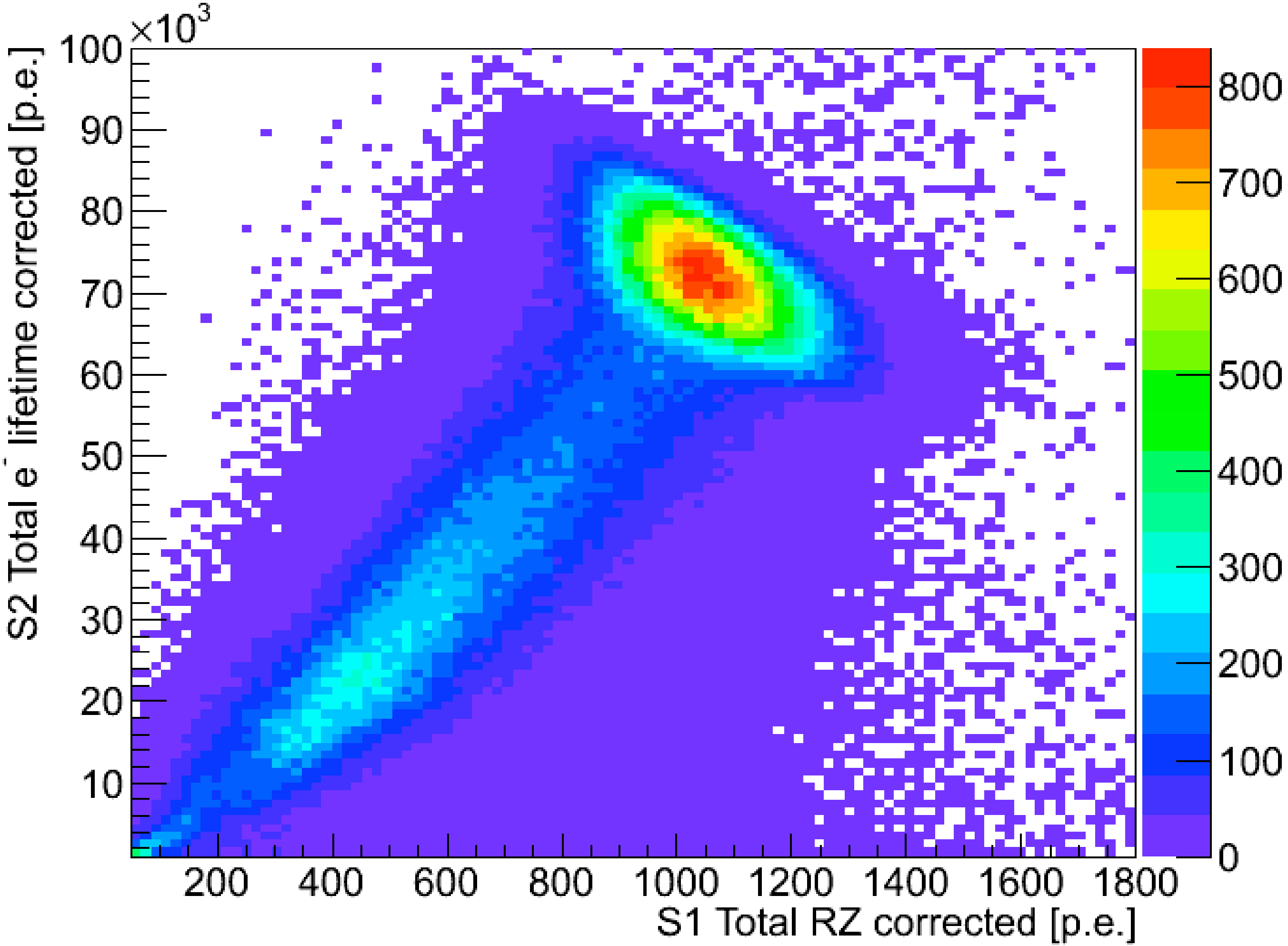

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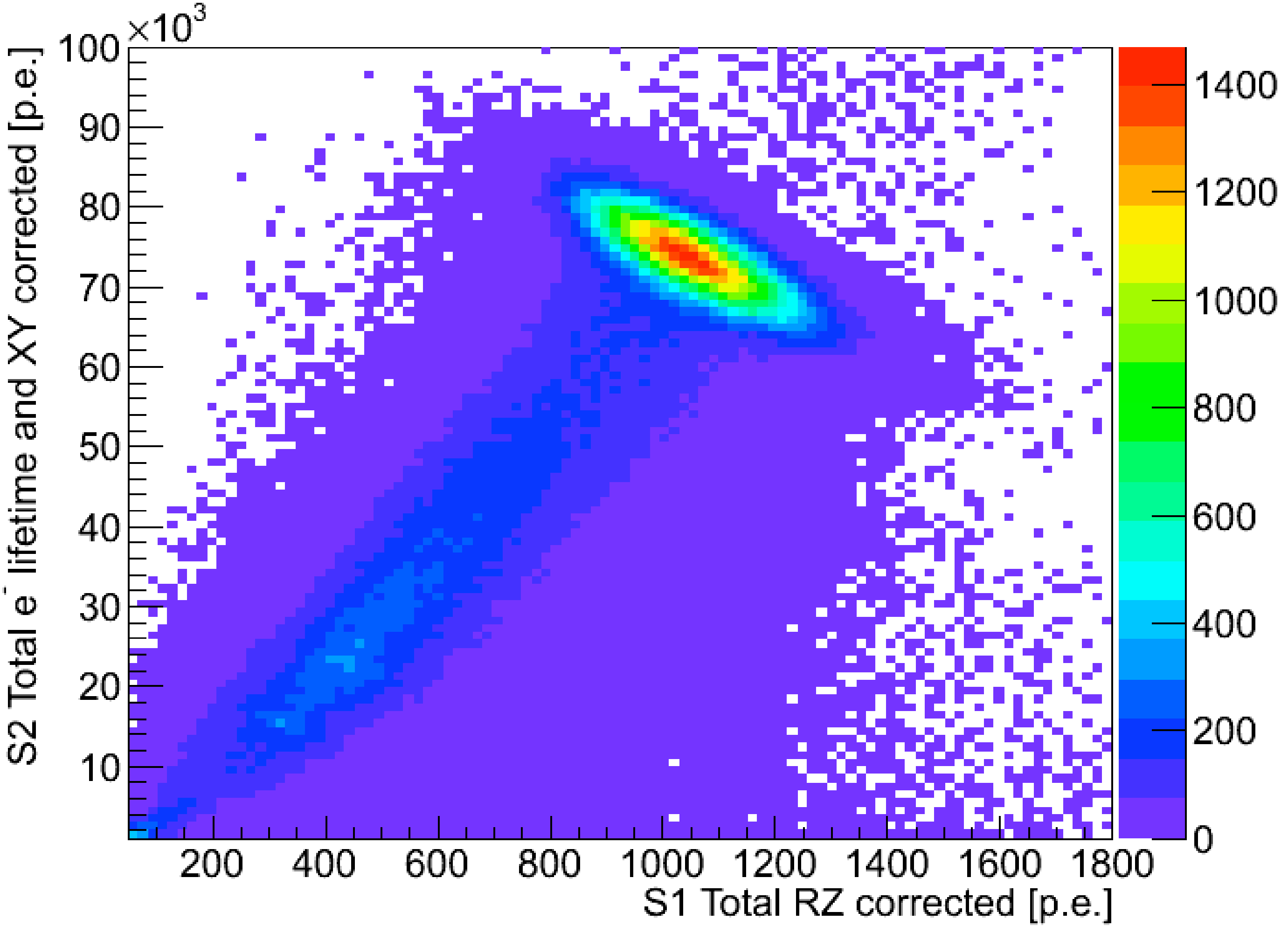
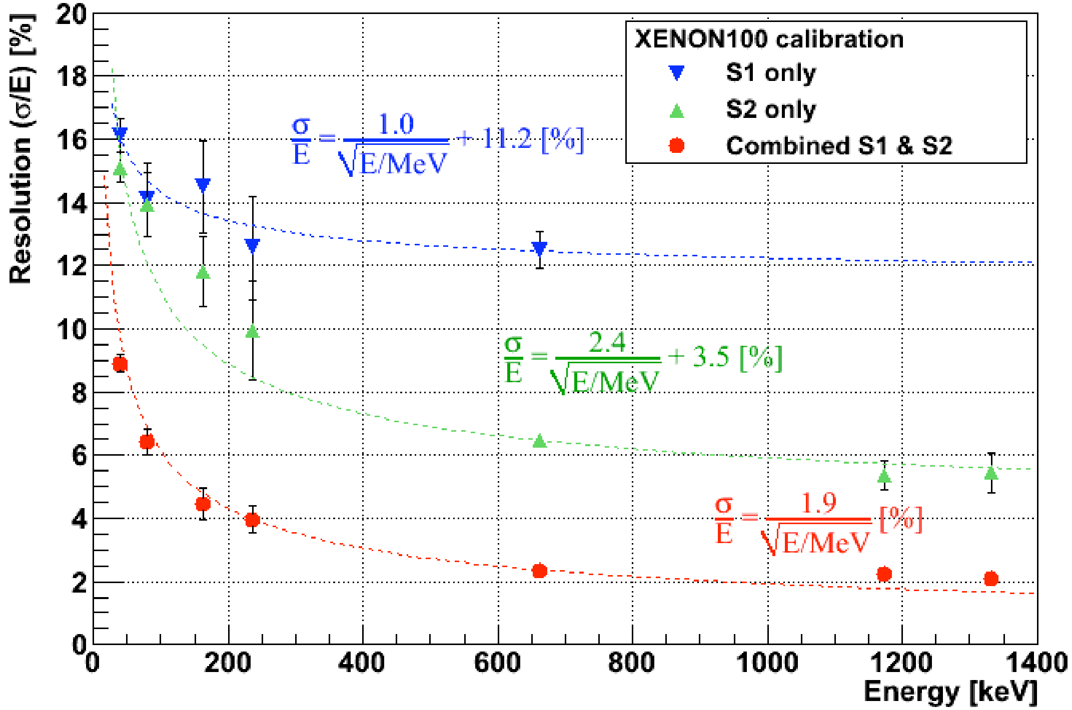
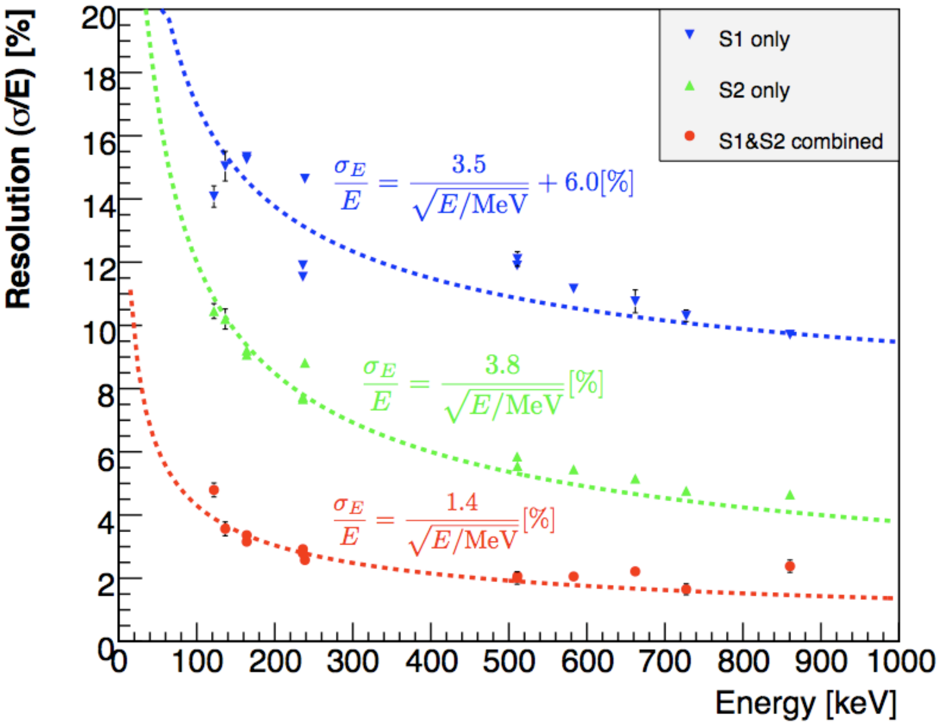
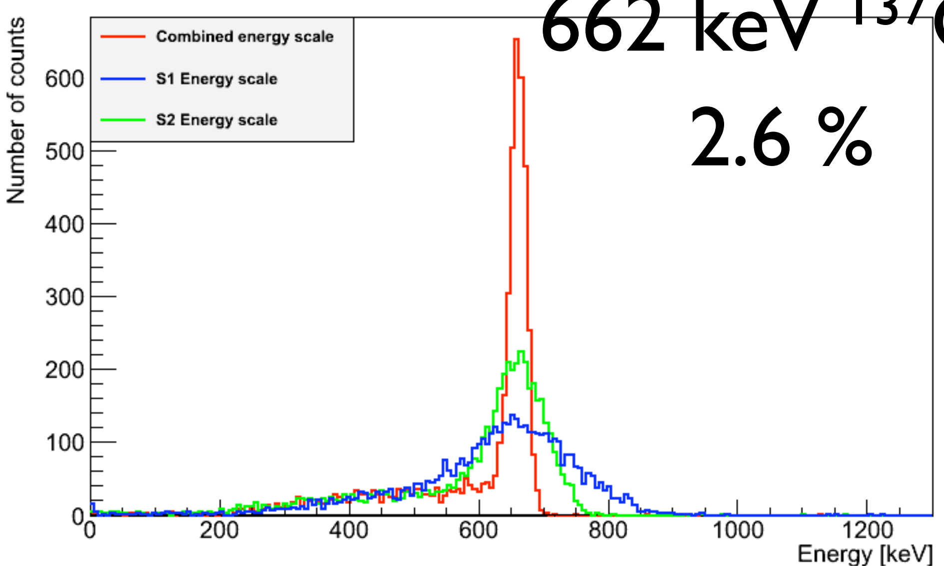


Xenon100: calibration





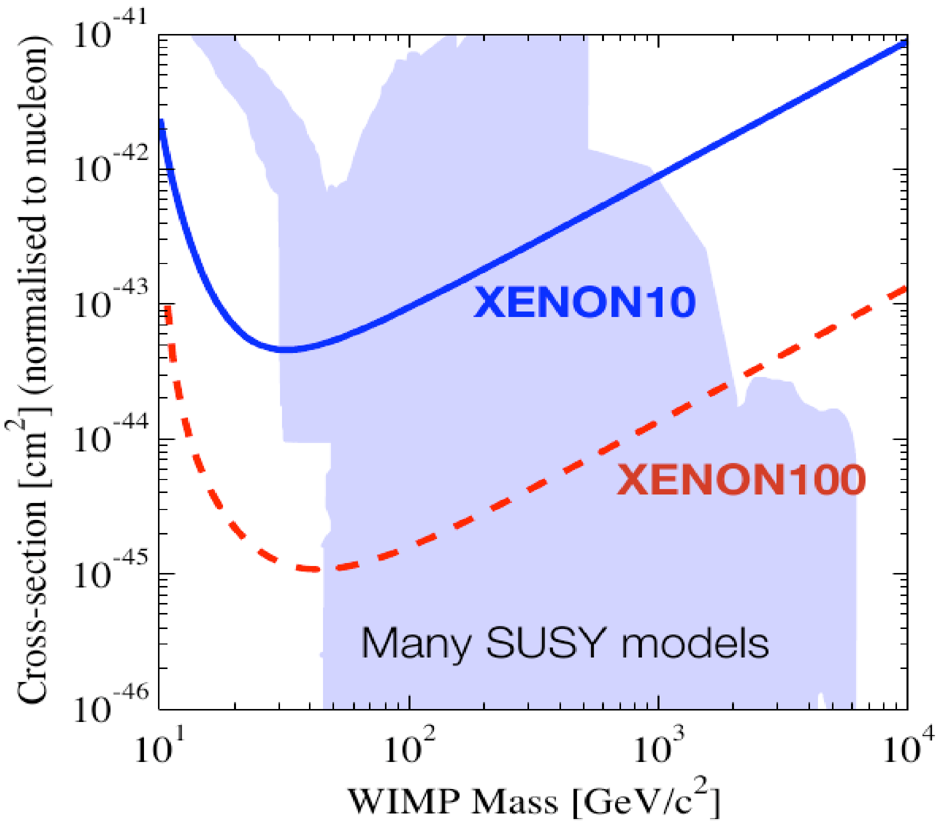


662 keV ^{137}Cs

2.6 %

Xenon100: goals

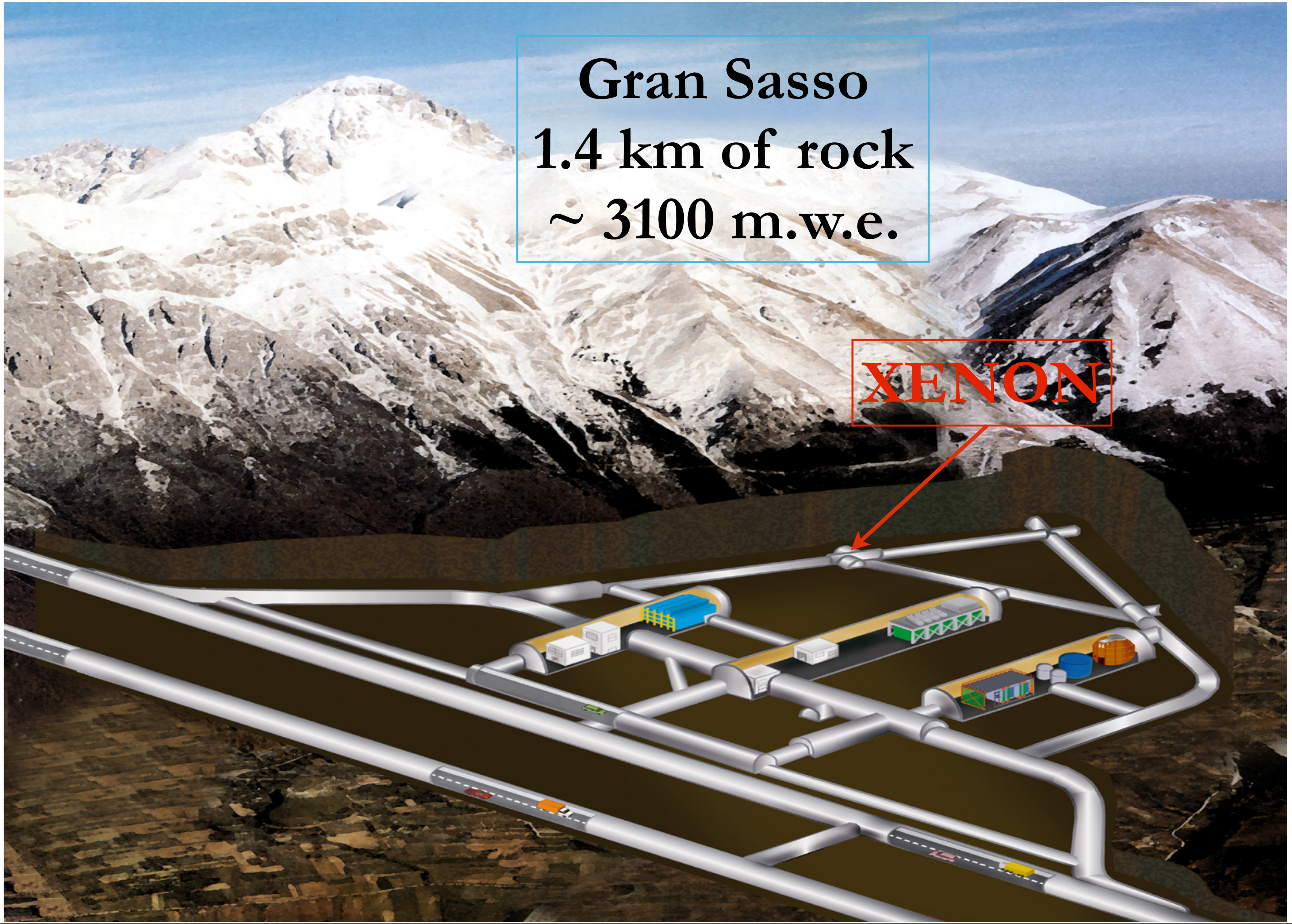
- Improve the sensitivity ~ 50 times over XENON10.
- Assuming same energy threshold and same discrimination power as XENON10, the required background in the fiducial volume needs to be 100 times lower with a mass increase of a factor 10.



XENON10 SI limit: PRL100, 021303 (2008)

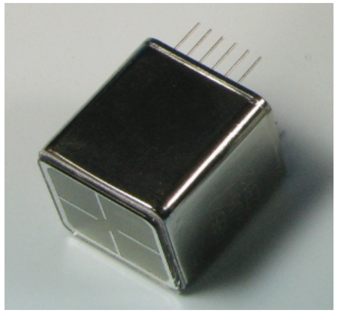
What was done in order to reach the goal?

Install the detector underground...

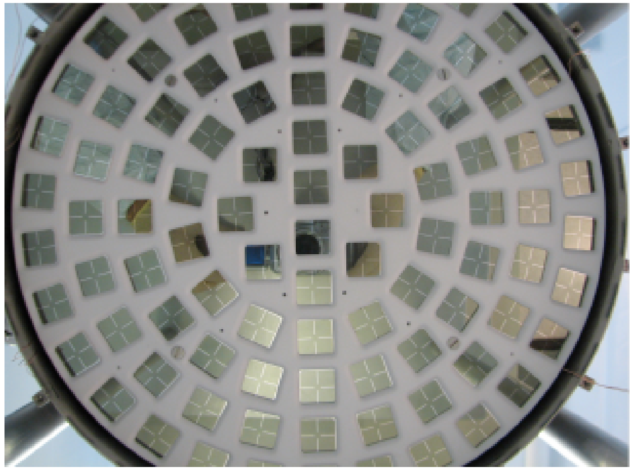


Most of the stuff goes outside of the shield (improved)...

What is inside has to be carefully selected



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



SS
PTFE
Copper
Cables
Screws

100 kg LXe Active veto
(side, top and bottom)

Material screening results (selection)

Stainless Steel

Material	238U [mBq/kg]	232Th [mBq/kg]	60Co [mBq/kg]	40K [mBq/kg]
25 mm SS Nironit (flange and bars)	< 1.3	2.9 ± 0.7	1.4 ± 0.3	< 7.1
2.5 mm SS Nironit (bottom cryo)	< 2.7	< 1.5	13 ± 1	< 12

Inner detector materials

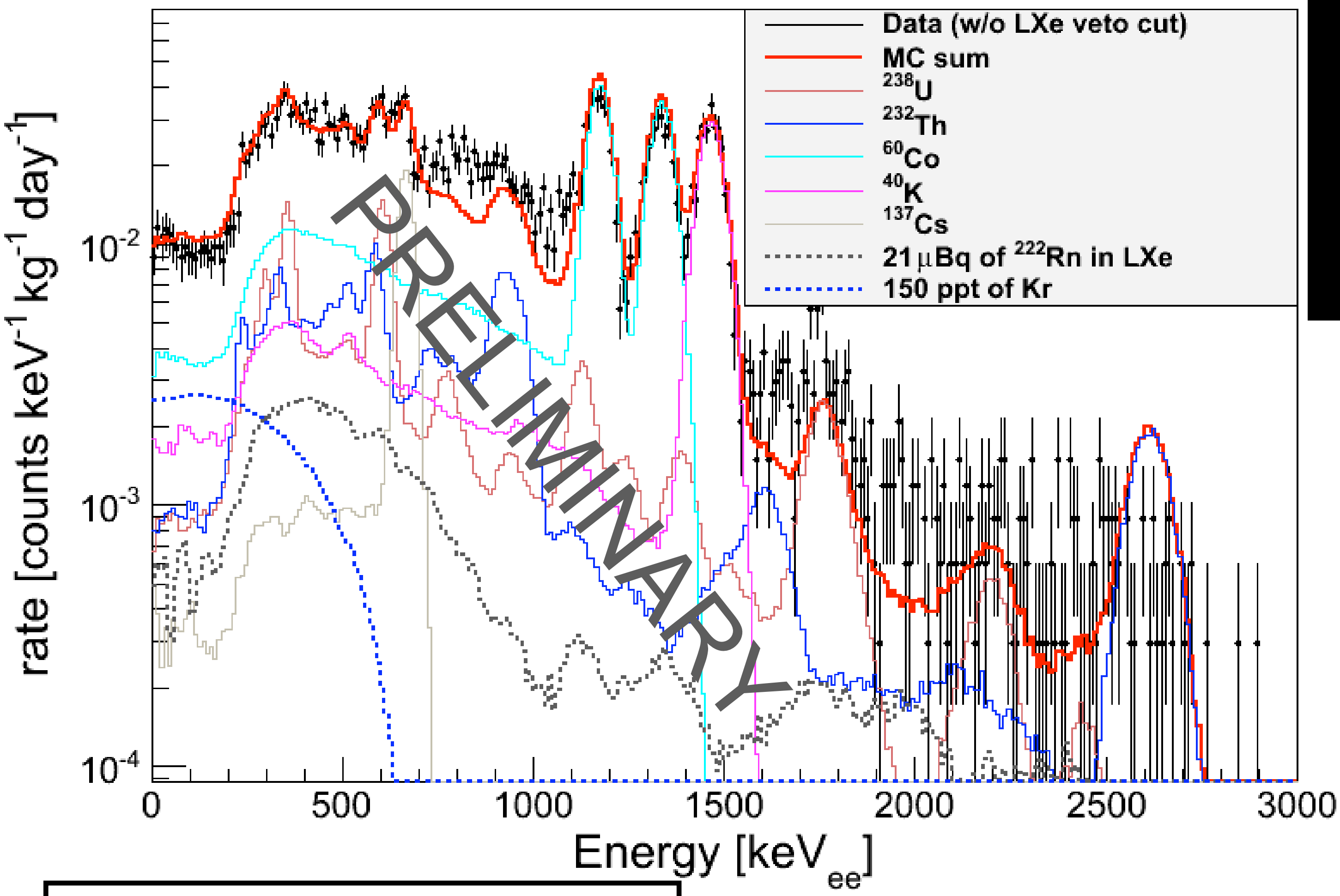
PMT Bases (Cirlex)	65 ± 8	31 ± 10	< 3.6	< 66
Teflon (in use)	< 0.31	< 0.16	< 0.11	< 2.25
Copper (TPC inner structure)	< 0.22	< 0.21	0.21 ± 0.07	< 1.34
Small Screws (SS)	< 9.2	16 ± 4	9 ± 3	< 46.4

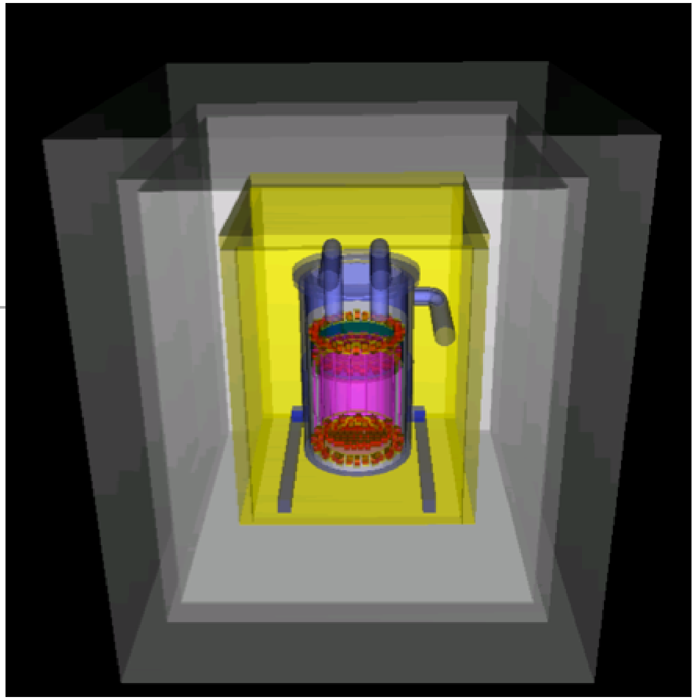
PMTs

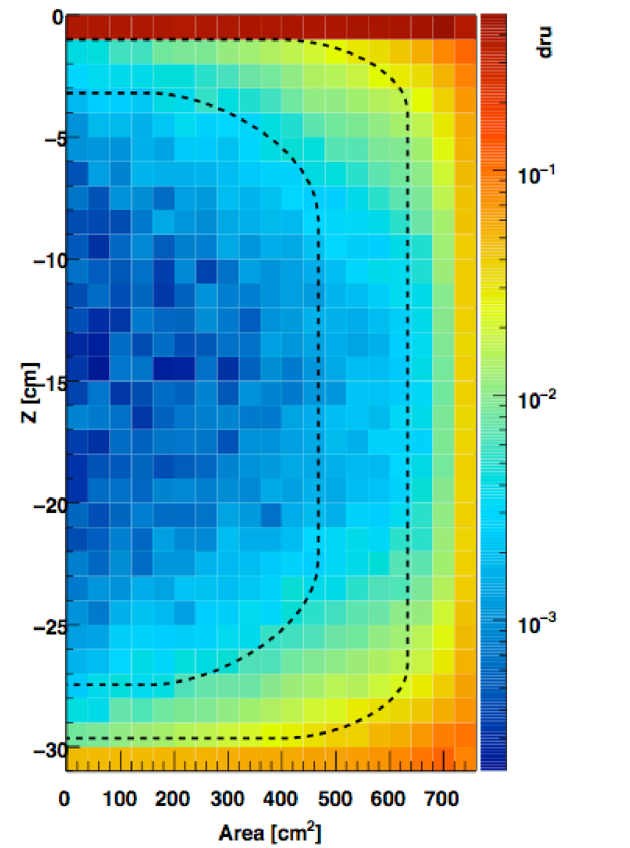
	238U [mBq/PMT]	232Th [mBq/PMT]	60Co [mBq/PMT]	40K [mBq/PMT]
39 PMTs	0.12 ± 0.01	0.11 ± 0.01	1.5 ± 0.1	6.9 ± 0.7
48 PMTs	0.11 ± 0.01	0.12 ± 0.01	0.56 +/- 0.04	7.7 +/- 0.8
22 HQE PMTs	< 0.64	0.18 ± 0.06	0.6 ± 0.1	12 ± 2
23 HQE PMTs	0.16 ± 0.05	0.46 ± 0.16	0.73 ± 0.07	14 ± 2

Special thanks to Matthias Laubenstein (LNGS screening facility)

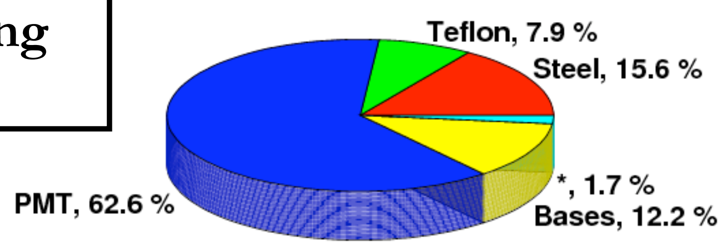
Gamma background







Only input from Screening
NO TUNING

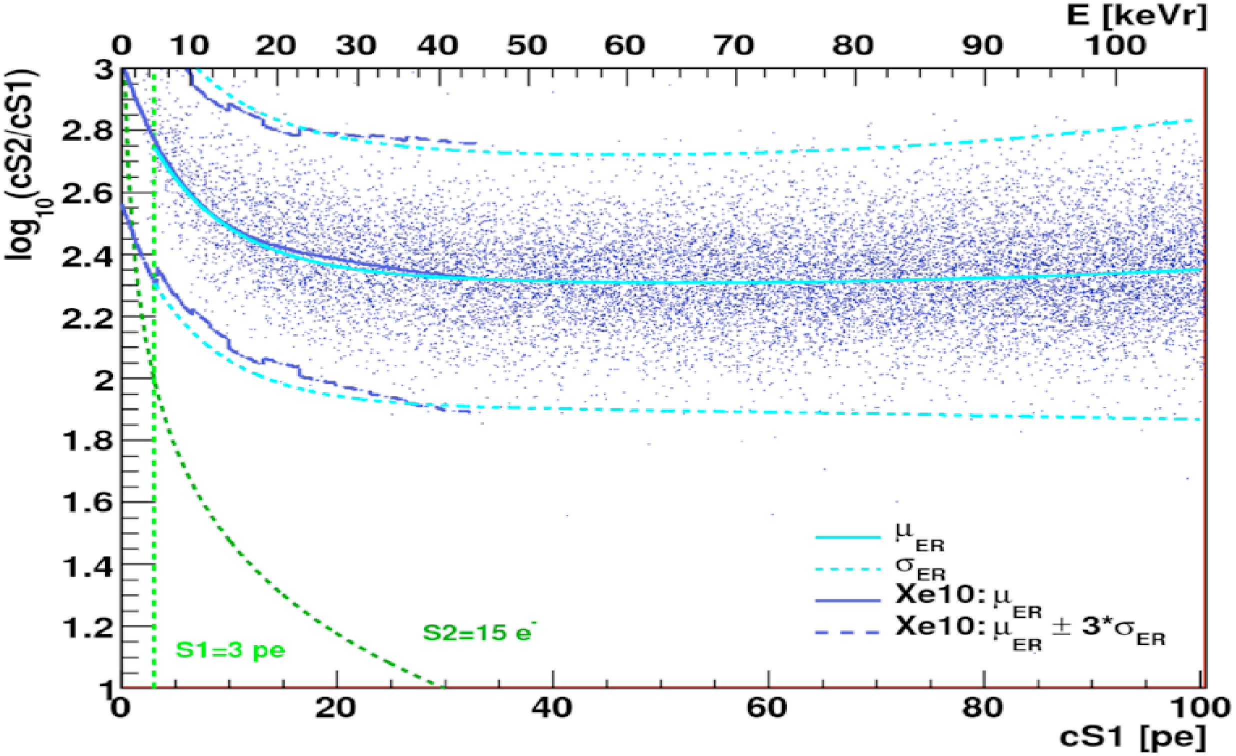


Xenon100: gamma band

Multiple calibrations with ^{60}Co to study the response of the detector to low energy electron recoils

Statistics achieved are more than 10 times the expected background

Results in good agreement with XENON10

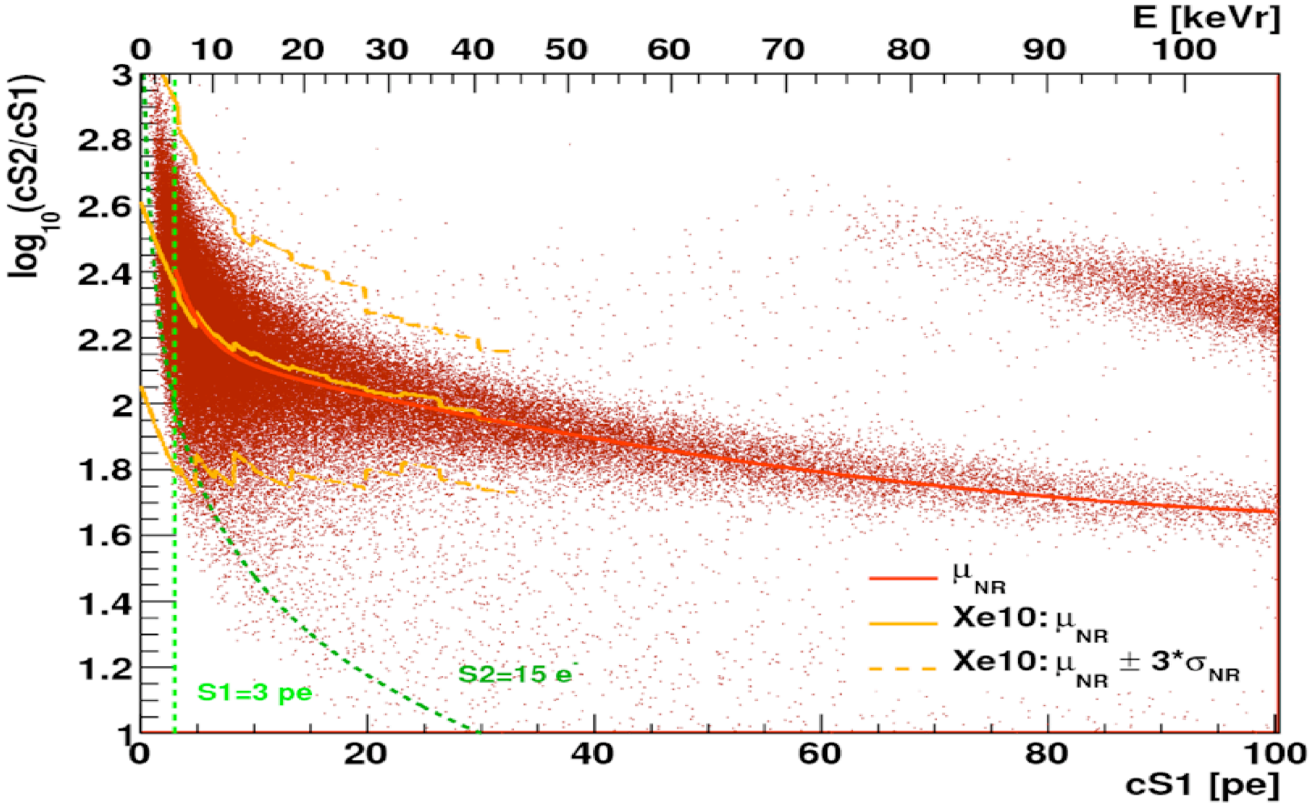


Xenon100: neutron band

Calibration of the detector using an AmBe source has been performed during December 2009

In addition to multiple gamma lines above 40keV, the detector response to low energy nuclear recoils has been studied

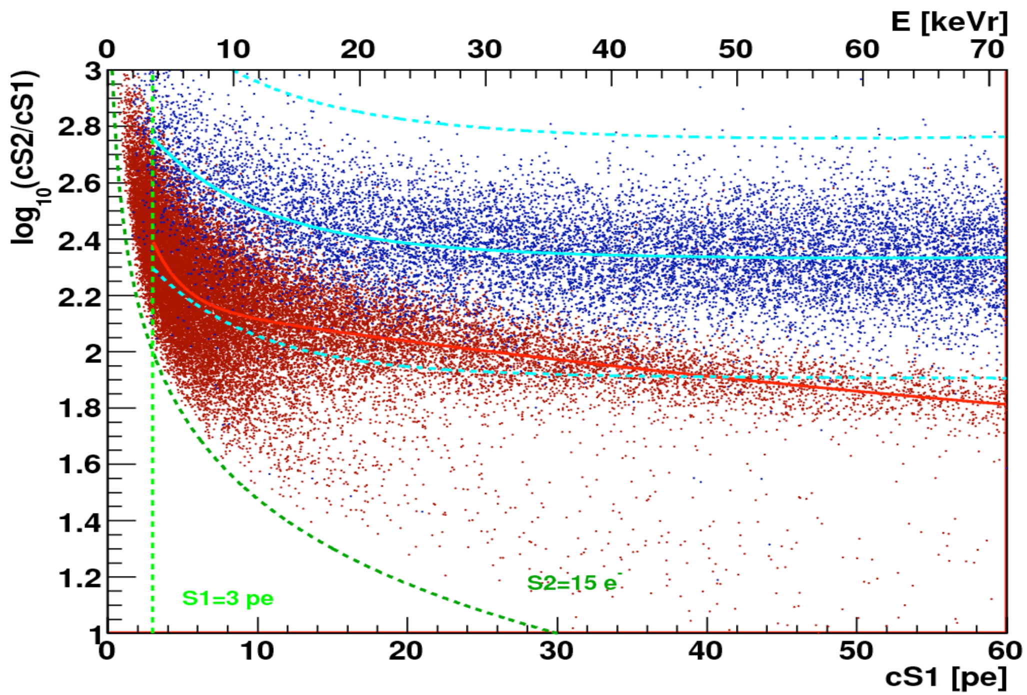
Results are in good agreement with XENON10

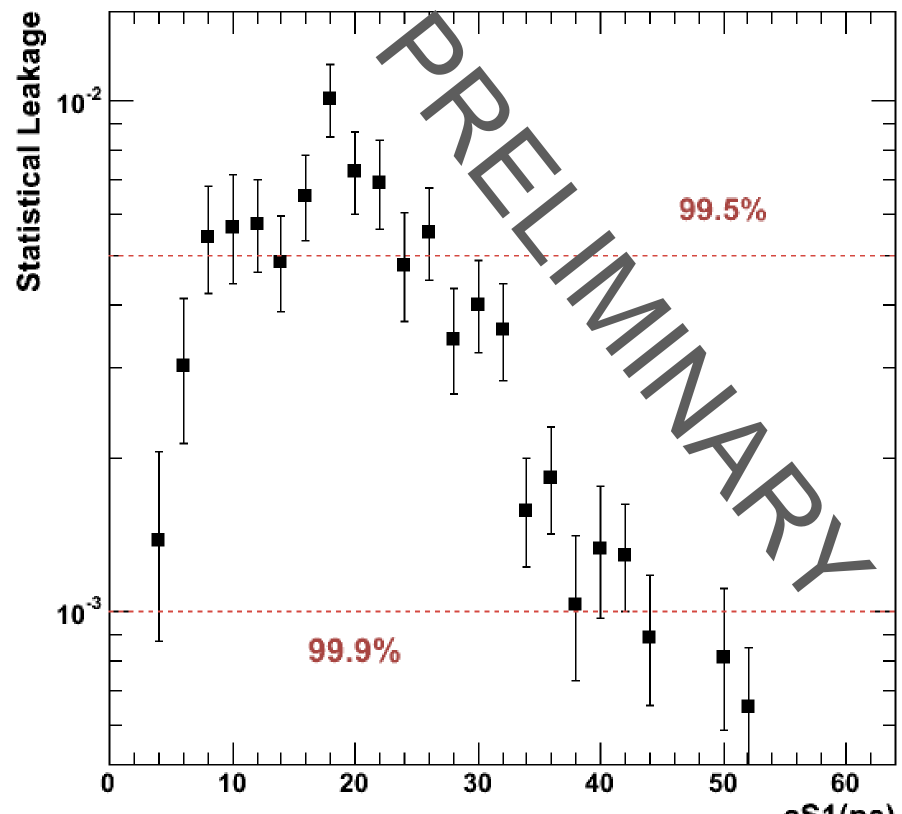


Xenon100: rejection power

It is possible to distinguish between nuclear recoils and electron recoils due to their different charge/light ratio

The rejection efficiency is ~ 99% in the range from 4 to 20 pe





Background analysis

11.2 days of non blinded data were taken in the period Oct-Nov 2009

Applied cuts are only optimized in calibration data

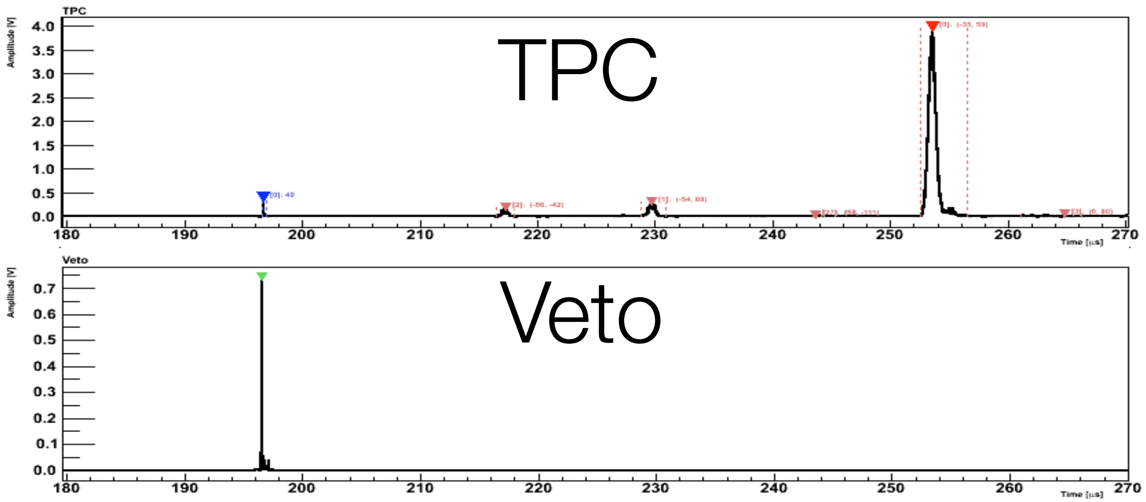
Only very basic cuts are used:

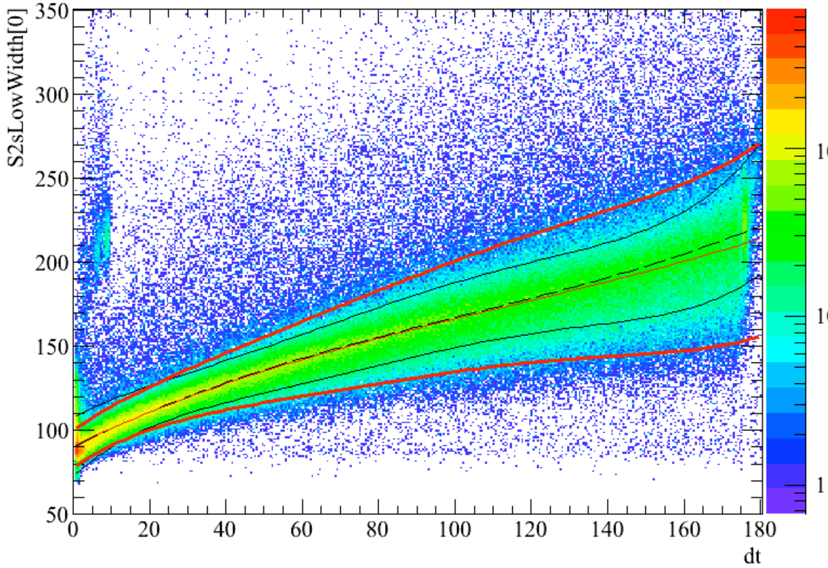
Single scatterers

Reasonable signal to noise ratio

Width and drift time of the event compatible(remove gas events)

Veto anticoincidence





Energy scale for nuclear recoils

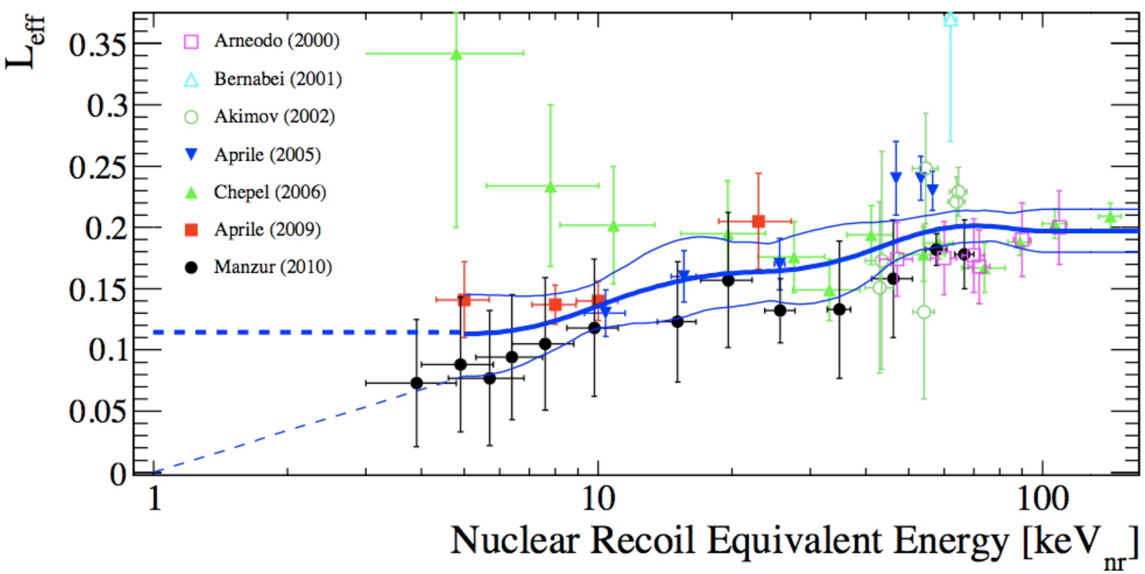
We use a global fit of the available data to compute the quenching factor for nuclear recoils

Ongoing efforts to measure this quantity with a better precision

In XENON100 [4-20] pe ~ [7-27]keVr

$$E_{nr} = \frac{S1}{L_y L_{eff}} \cdot \frac{S_e}{S_r}$$

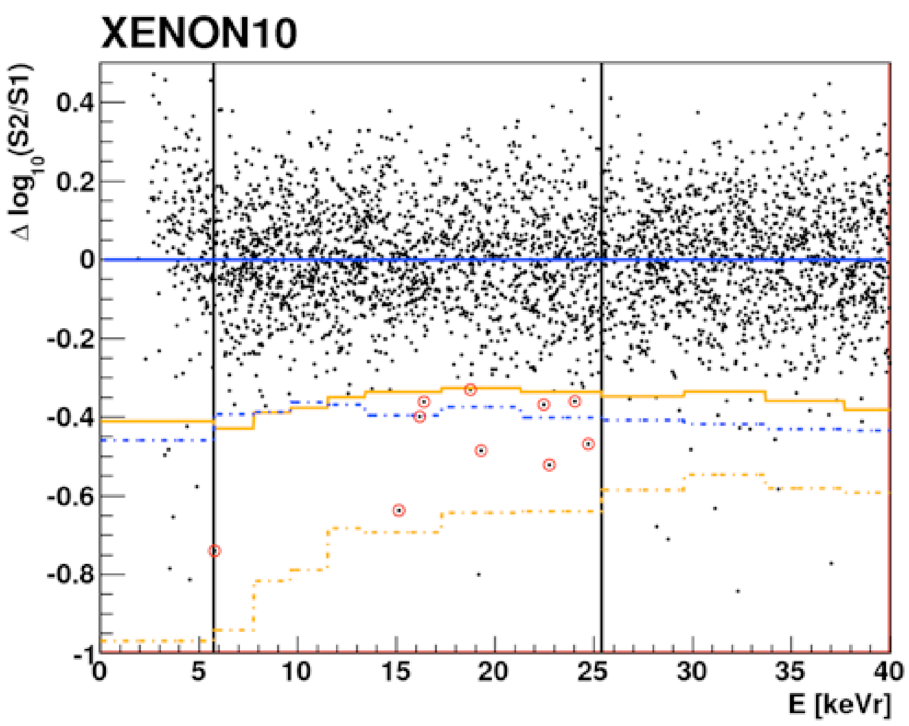
- $S1$: measured S1 signal in p.e.
- L_y: Light yield @ 122 keV
- L_{eff}: Scintillation efficiency at 0 field
- S_e: Scintillation light quenching due to the electric field
- S_r: Scintillation light quenching due to the electric field



Background analysis

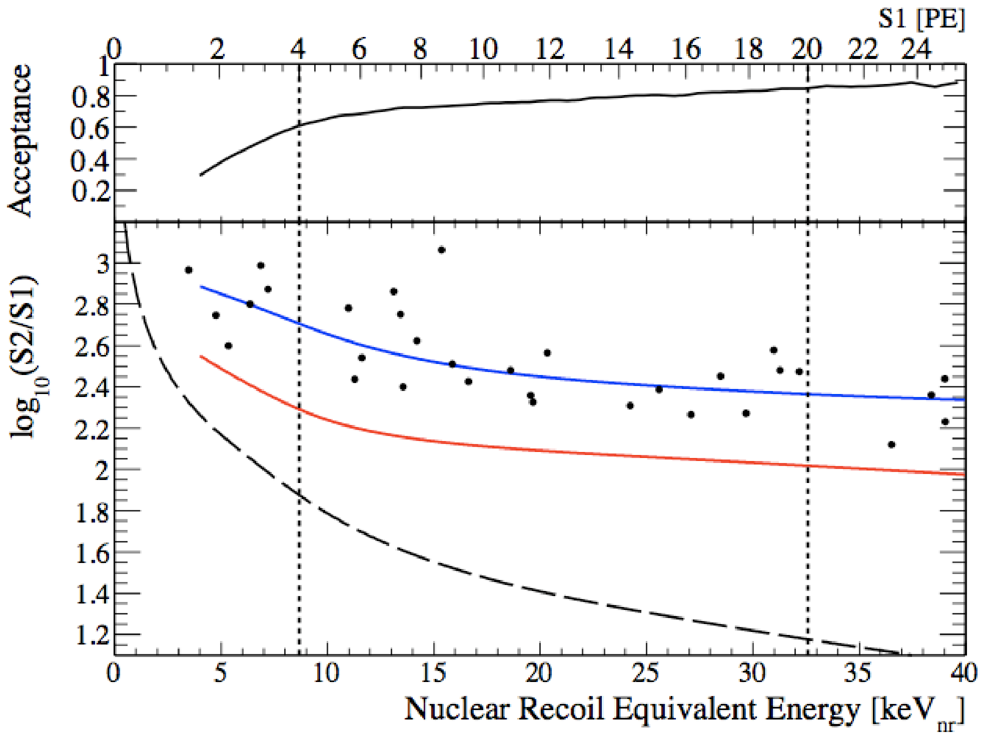
XENON10 PRL 100, 021303 (2008)

136 kg-days Exposure =
58.6 live days x 5.4 kg x 0.86 (ε) x 0.50 (50% NR)
(data collected between Oct.2006 and Feb.2007)



XENON100 PRL in preparation

161 kg-days Exposure =
11.2 live days x 40 kg x ε x 0.50 (50% NR)
(data collected between Oct.2009 and Nov.2009)



0 events with a bigger exposure than XENON10!!

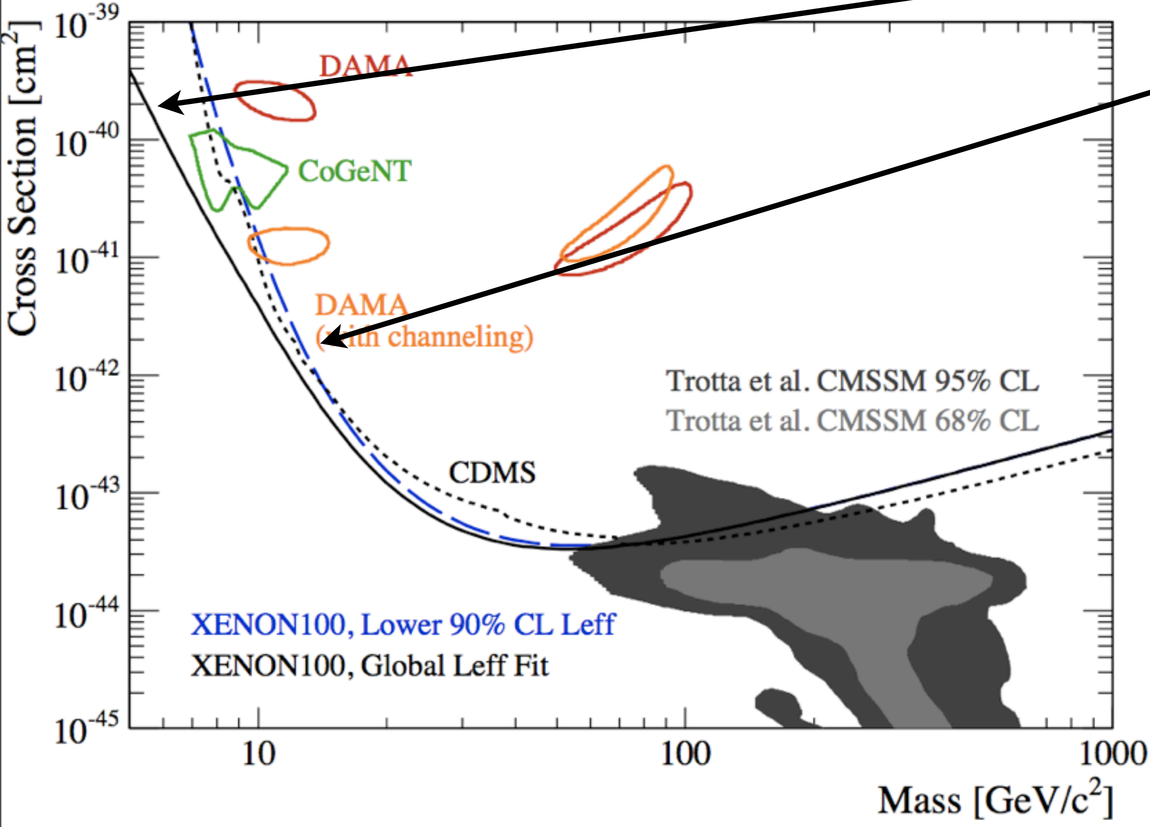
Background analysis

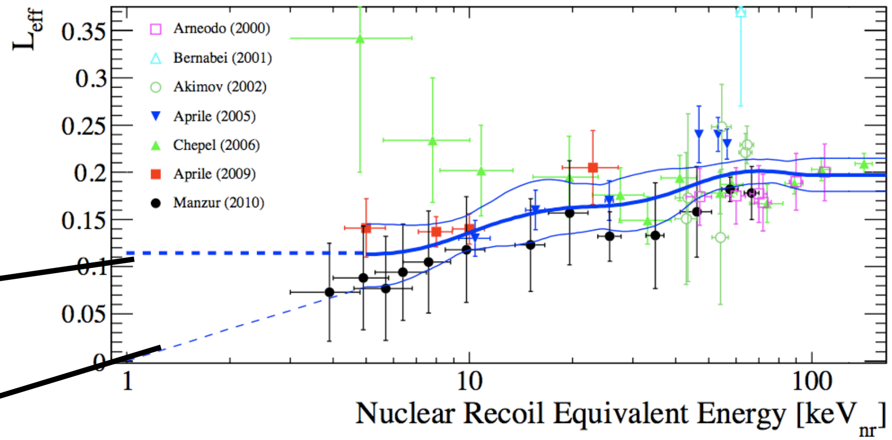
Standard astrophysical assumptions:

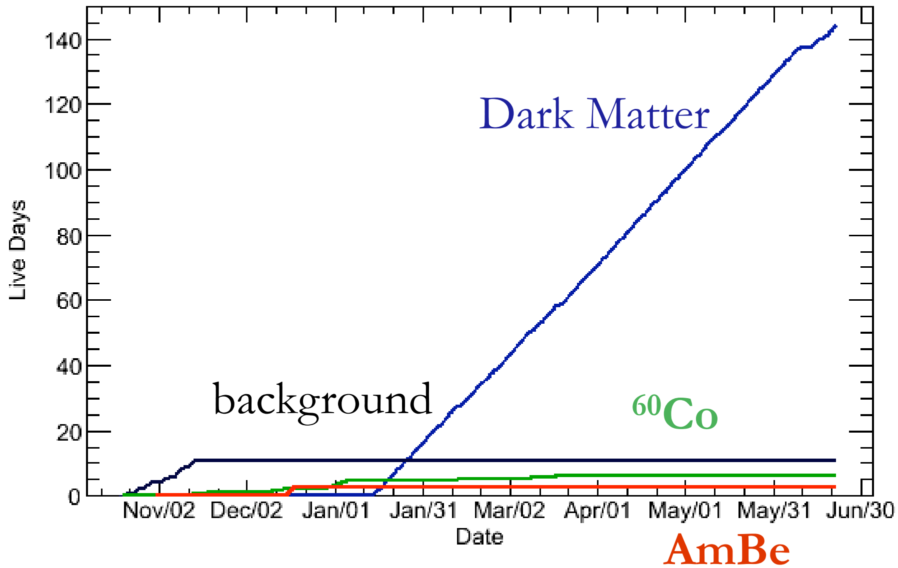
$v_o = 220\ km/s$

$\rho = 0.3\ GeV/c^2$

$v_{esc} = 544\ km/s$

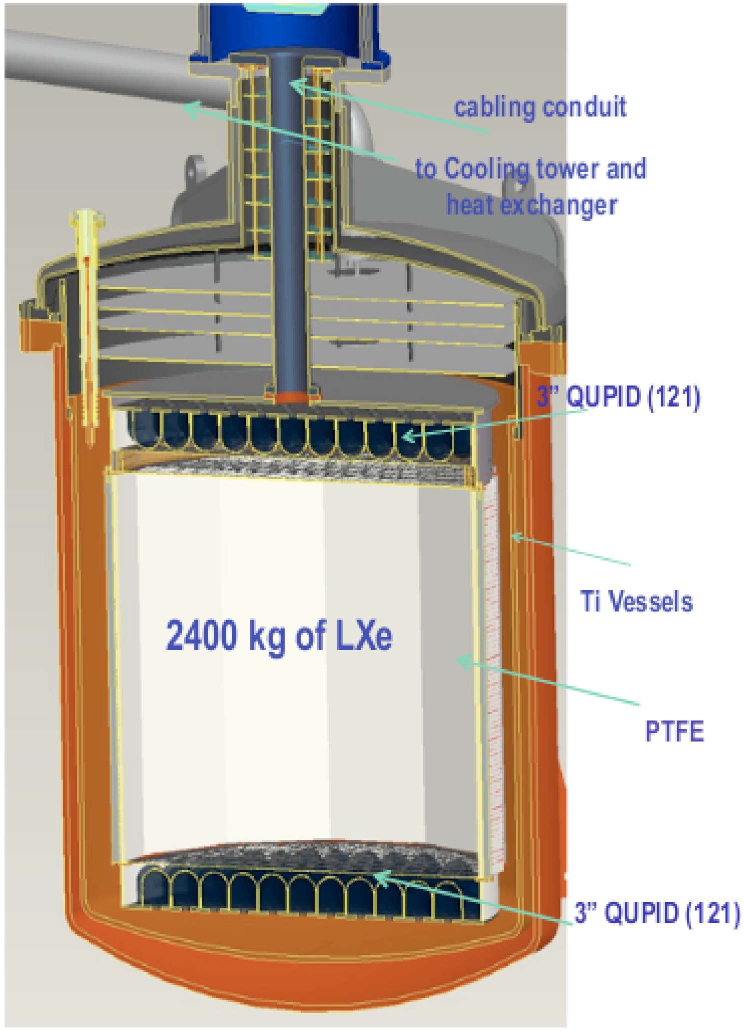






Future: XENON1T

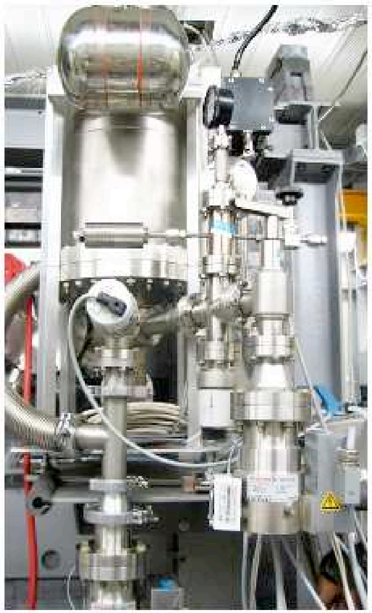
- ➡ The Xenon100 detector has been succesfully calibrated and is already taking science data, with a performance as good as expected
- ➡ Within this year, it will either see a signal or constrain significantly the models for WIMP SI or SD interactions
- ➡ In both cases, larger experiments with reduced backgrounds are needed
- ➡ Critical technologies developed within the XENON10/100 programs can be directly applied to the next scale. Risks and the costs are fully understood.
- ➡ A strong international collaboration, with valuable expertise and resources, is in place.
- ➡ A technical design proposal for a XENON1T is in preparation. With 50 - 50 share of resources between US and other groups, we plan to realize the experiment before 2015.

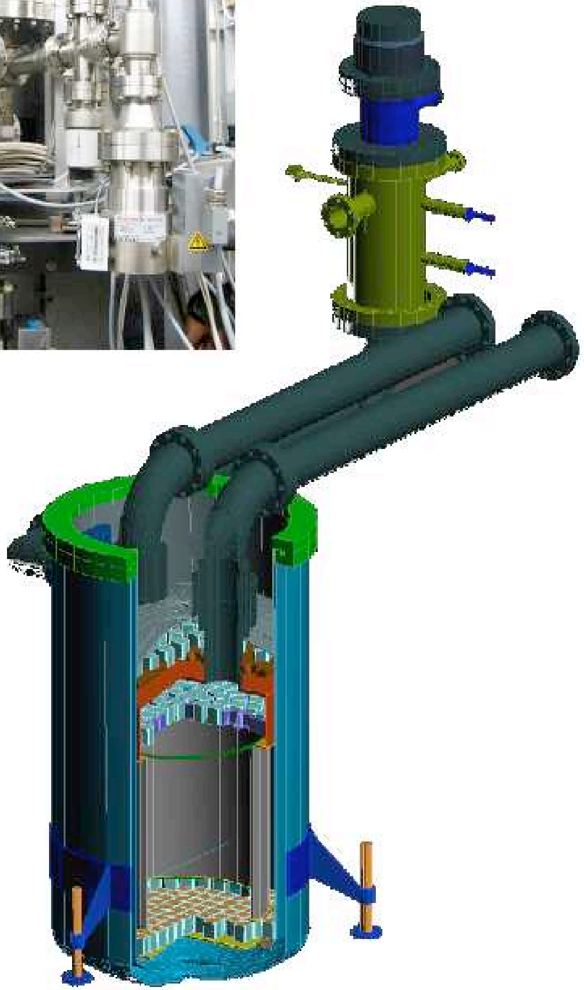


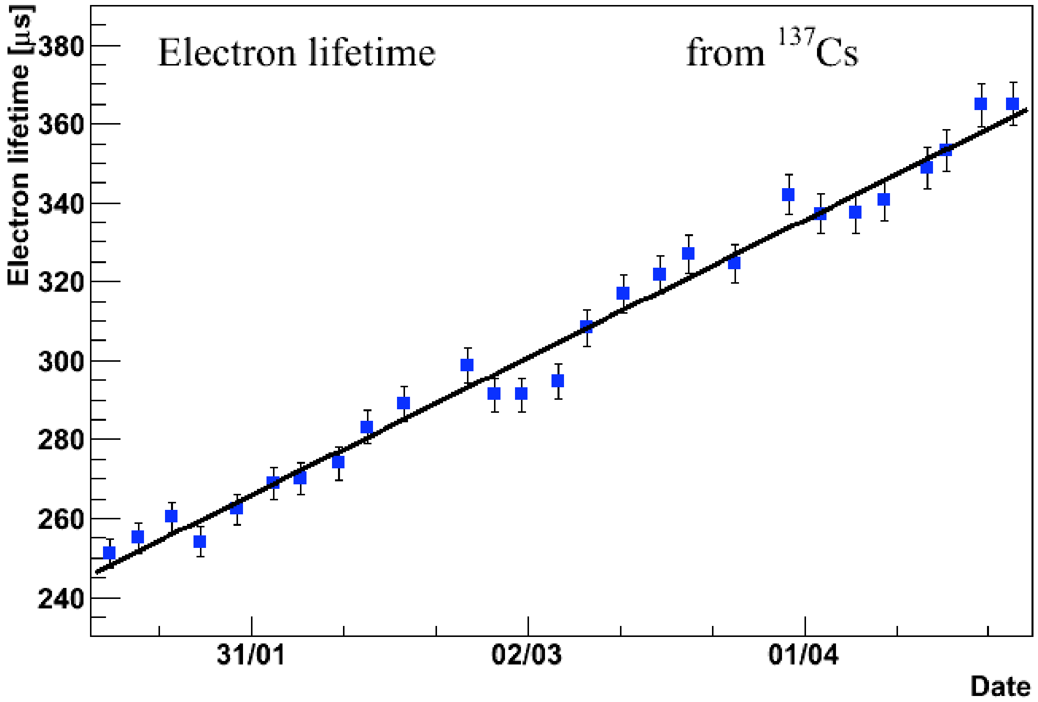
END

Xenon100 design: Cooling system

- The Xenon is continuously recirculated and purified through a hot getter (SAES)
- Cooling power is provided by a Pulse Tube Refrigerator (160W)
- Vaccum cryostat extends outside the shield to surround the cooling tower
- Recirculation in gas phase 10 SLPM

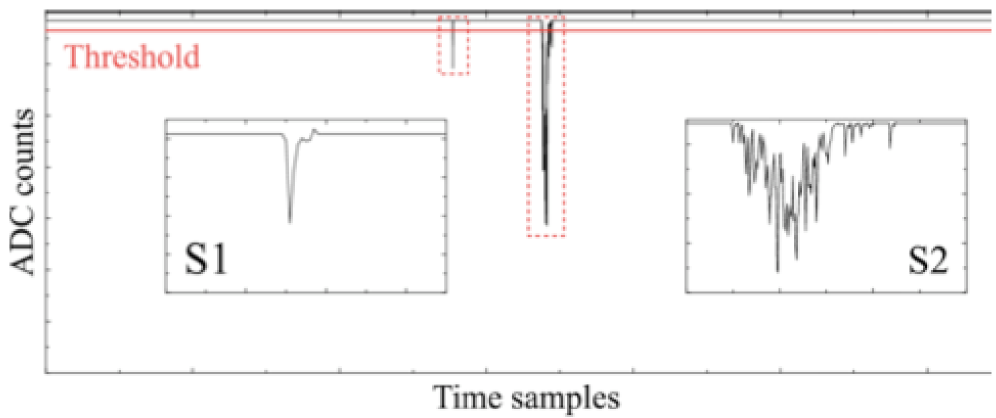




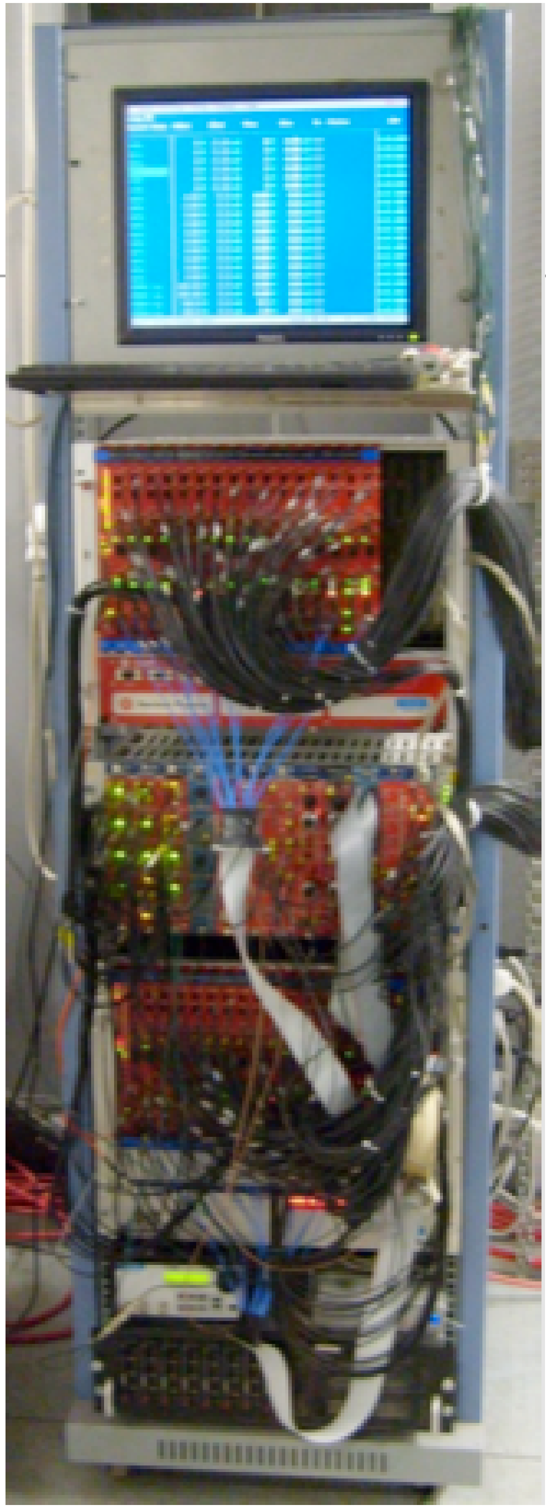


Xenon100: Data Acquisition

- CAEN V1724 100 MHz digitizer (14 bit resolution)
- Circular buffer -> dead time free
- Integrated FPGA for zero length encoding



- Slow control to monitor the detector crucial parameters
- sms alarms are sent to people on shift in case of emergency



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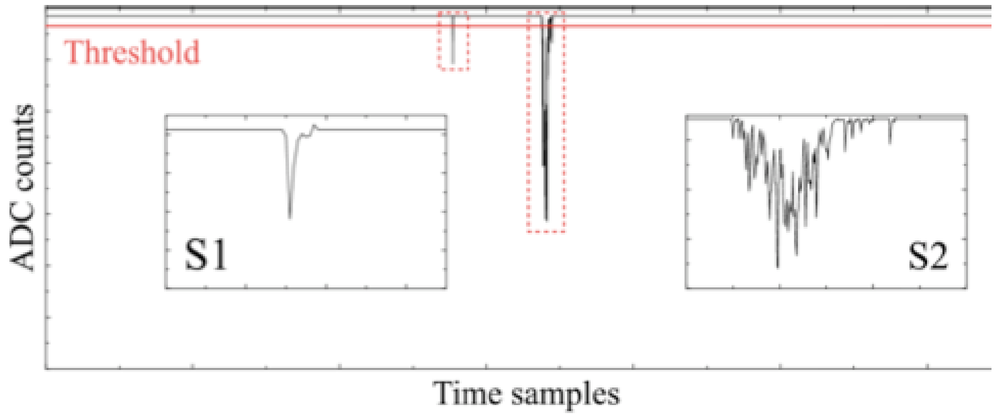

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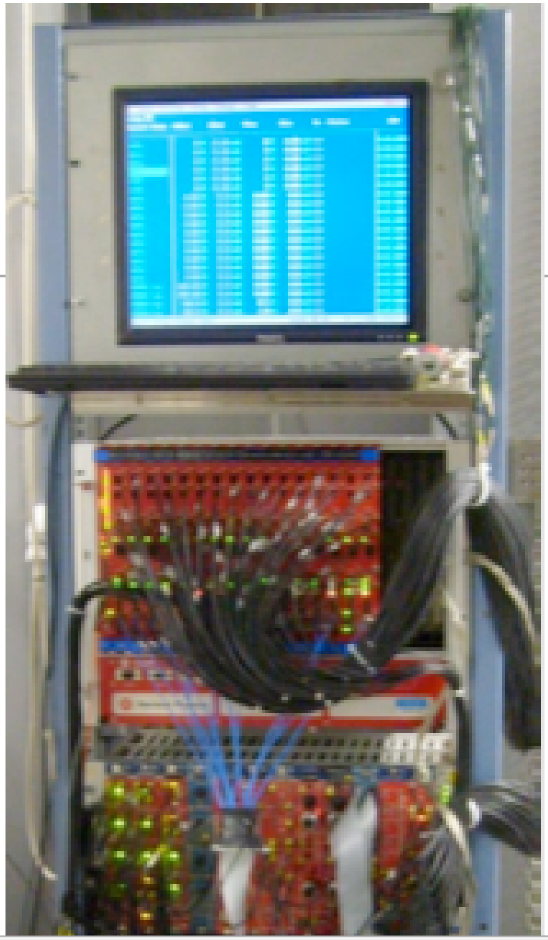
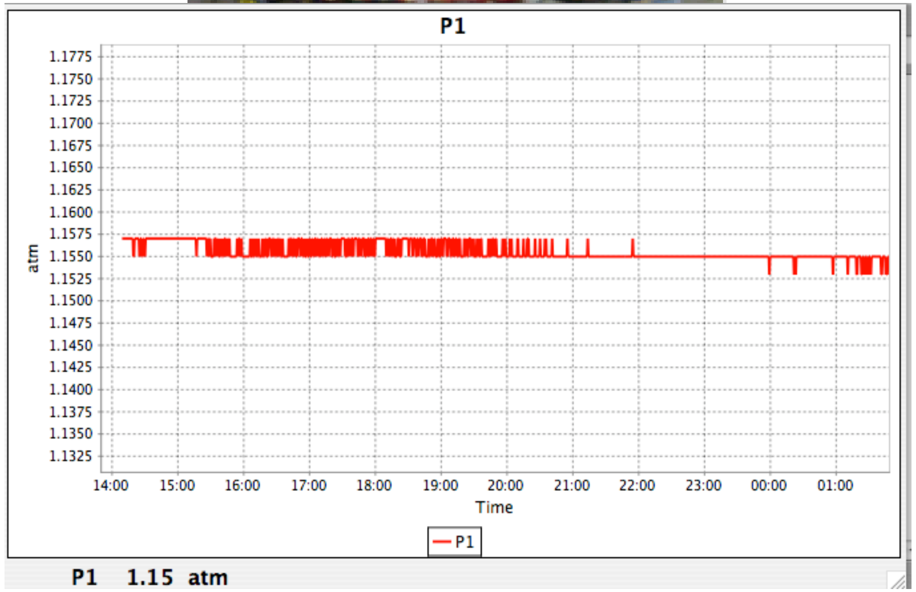
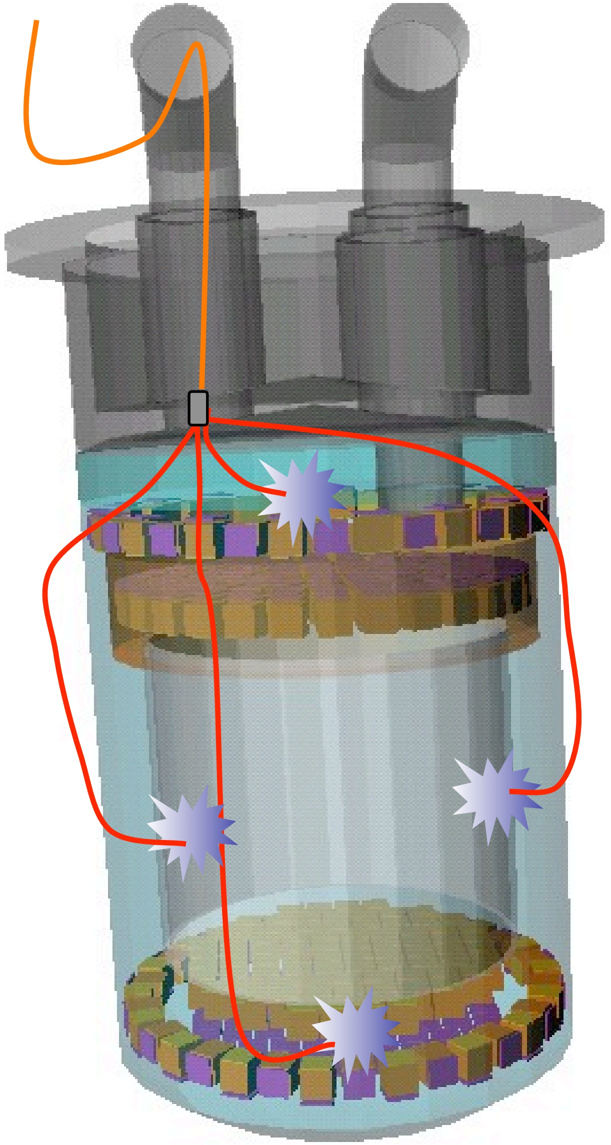
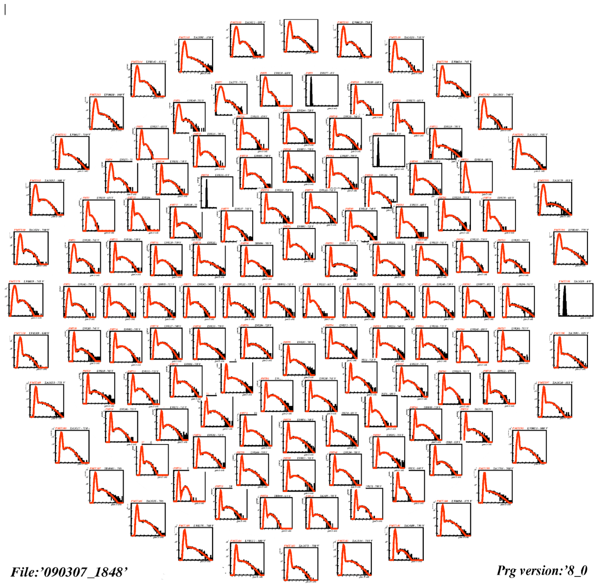


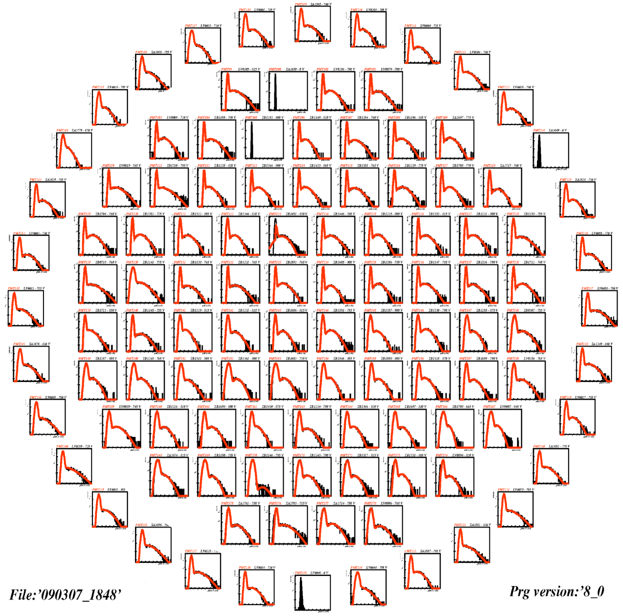


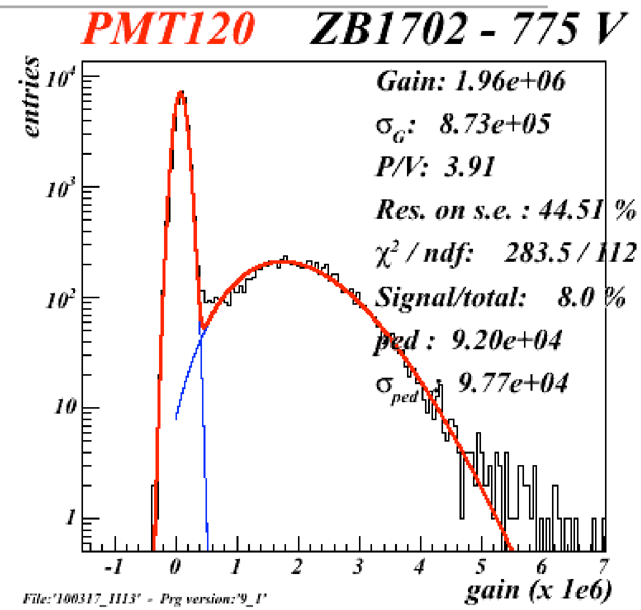
Xenon100: PMT light calibration

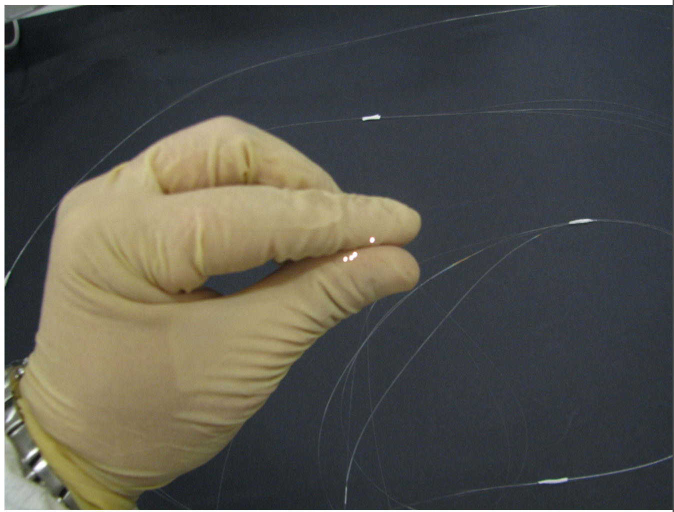
4 optical fibers





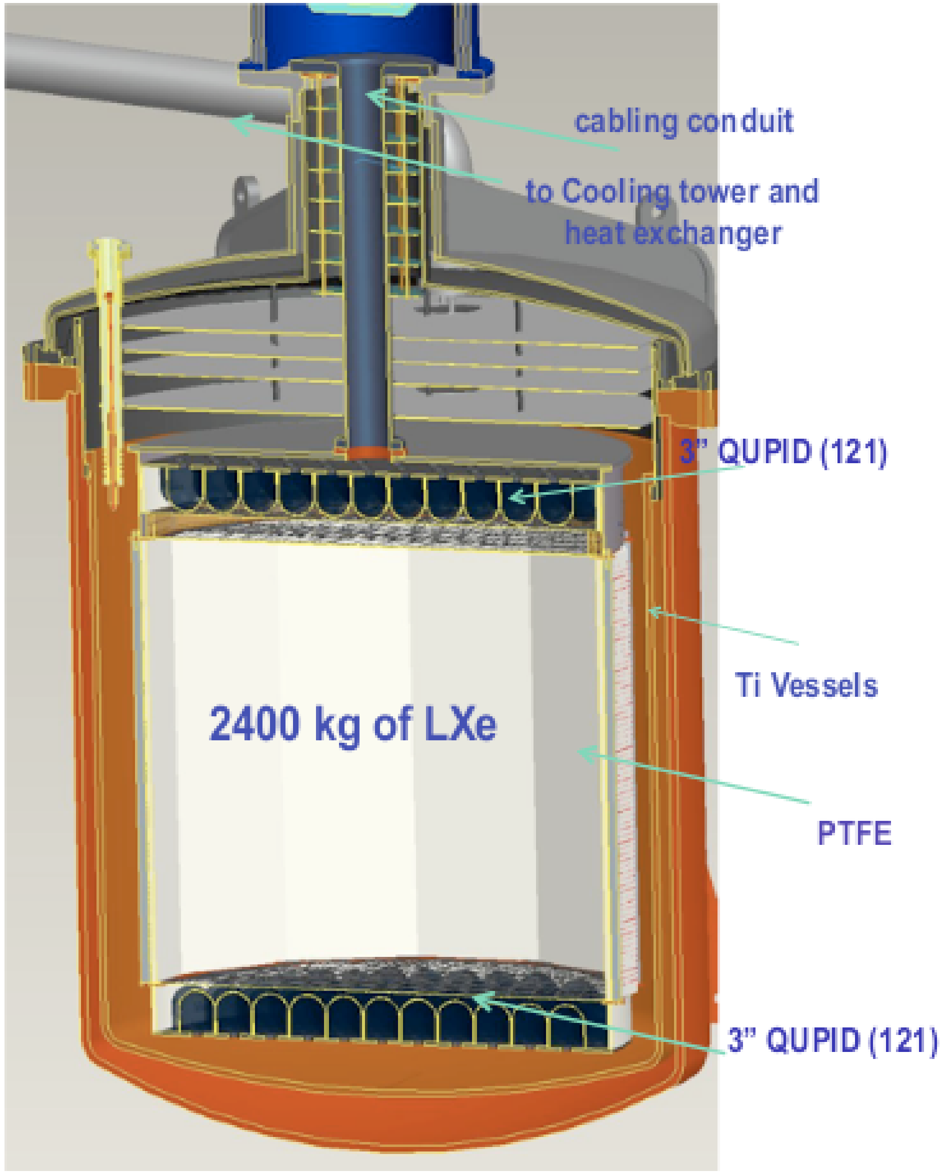






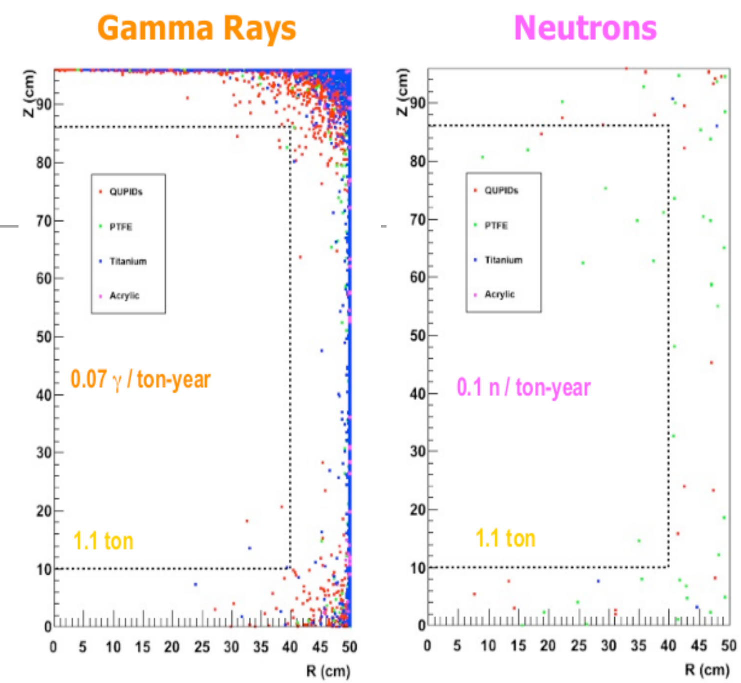
XENON1T: Detector design

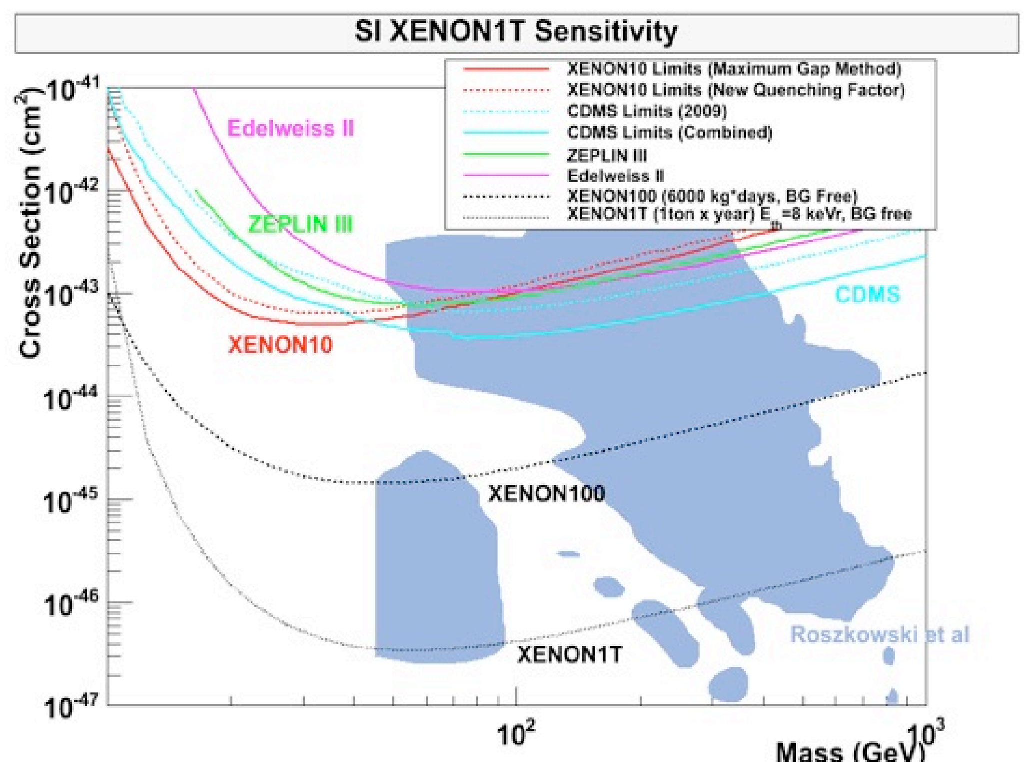
- ➡ Baseline design similar to XENON100 with improvements in different areas
  - lower radioactivity cryostat (Ti and Cu)
  - lower radioactivity PMTs (QUPIDs)
  - high efficiency heat exchanger
  - filling & recovery in liquid phase
- ➡ Design has been validated with detailed MC studies of internal/external background sources
- ➡ Capital cost ~ 8M$ shared equally between US and foreign groups



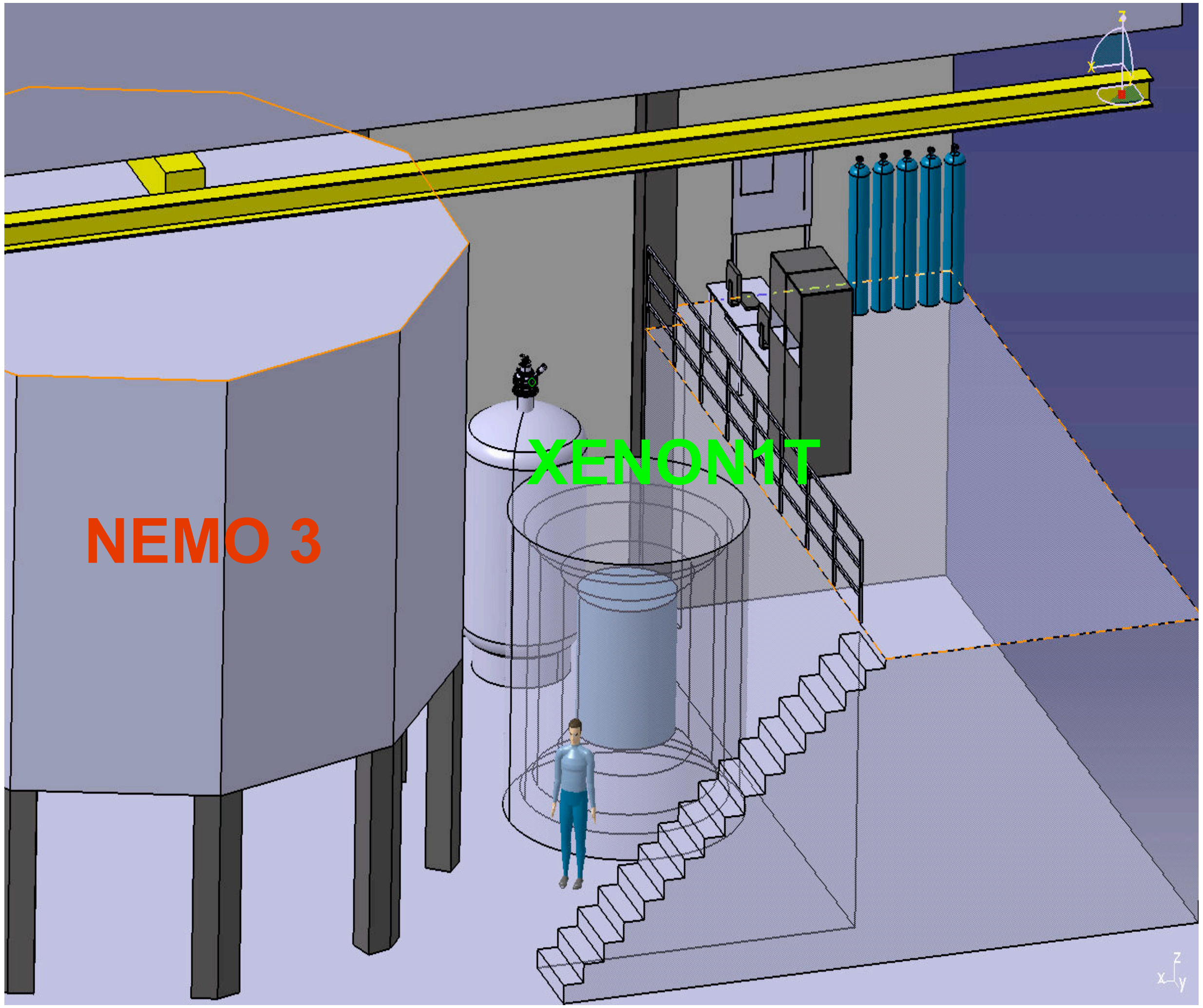
XENON1T: Scientific goal

- The detector will have a fiducial mass of ~1 ton of LXe
- QUPID sensors will measure the light from the interactions
- Simulations of the radioactivity from the material components show a background of less than 1 event/ton·year
- Extensive simulations in the proposed sites and with the proposed shield configurations are being carried out to show a similar level from external components
- After one year of background free measurement, the sensitivity will be $\sim 5 \cdot 10^{-47}$cm2, covering most of the CMSSM predicted region for SI interactions



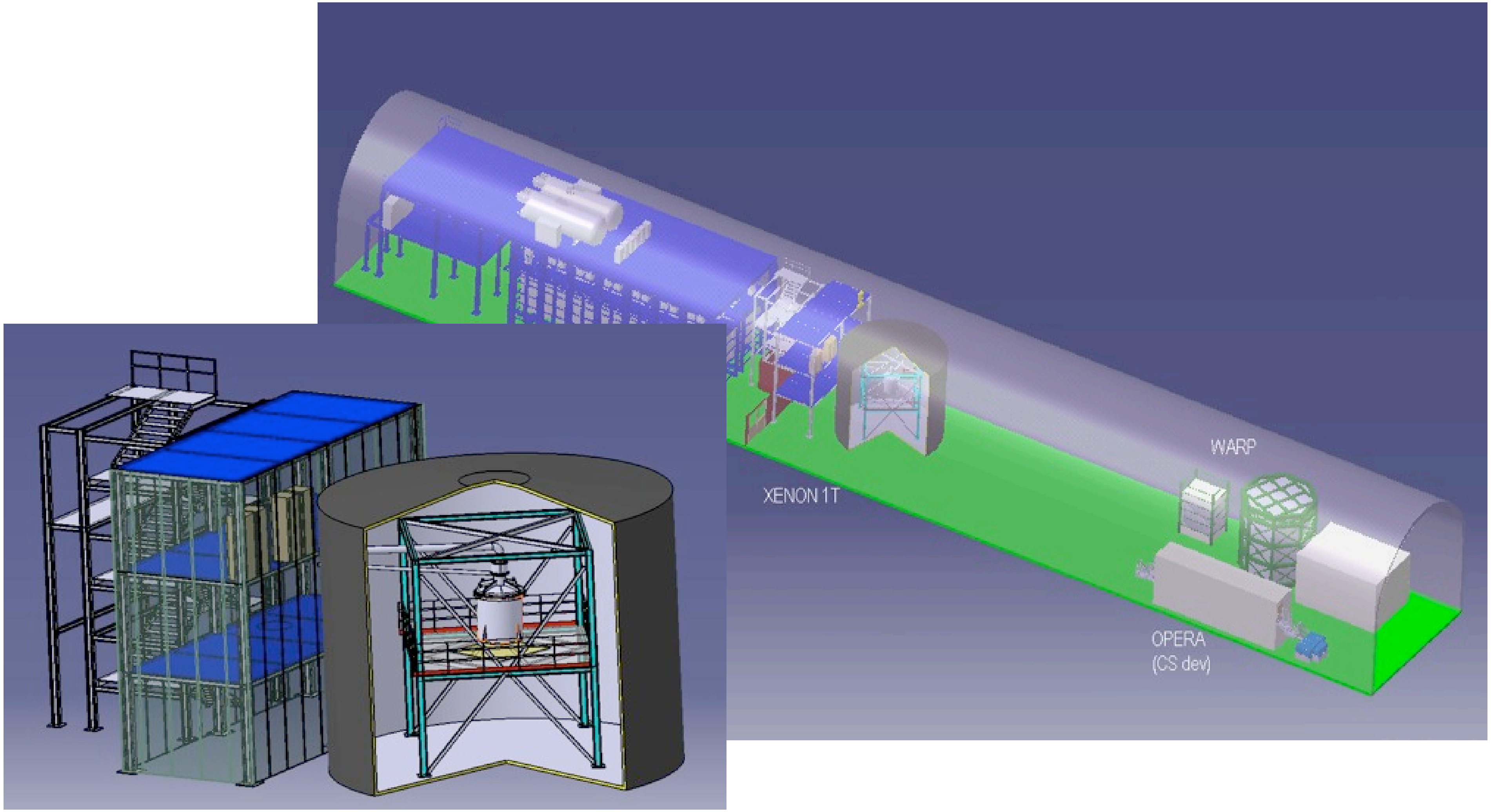


XENON1T where? @ LSM



Solid shield (55 cm Poly, 20 cm Pb, 15 cm Poly, 2 cm ancient Pb) plus >99 % muon veto

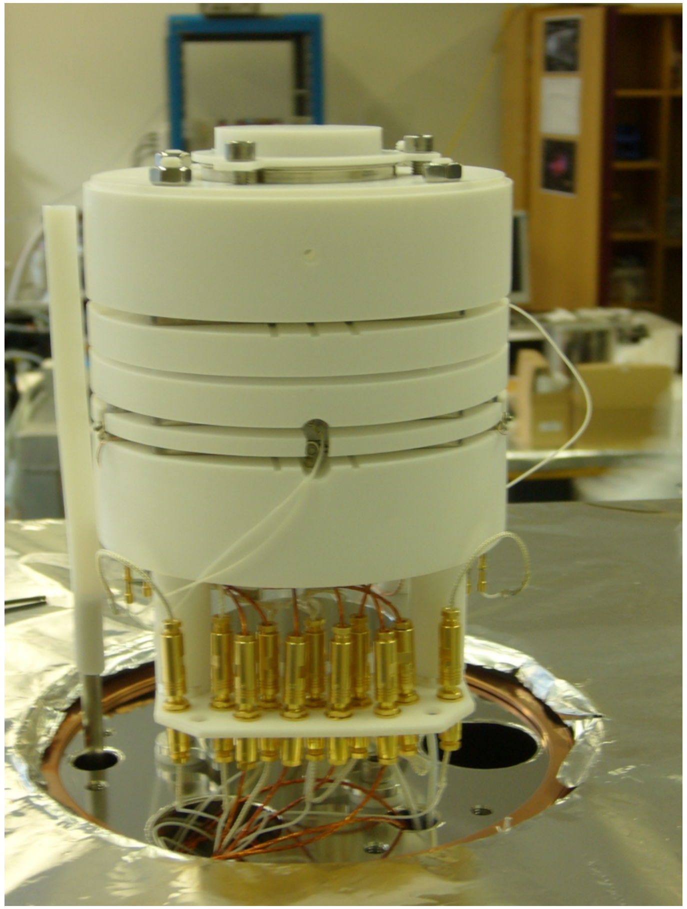
XENON1T where? @ LNGS

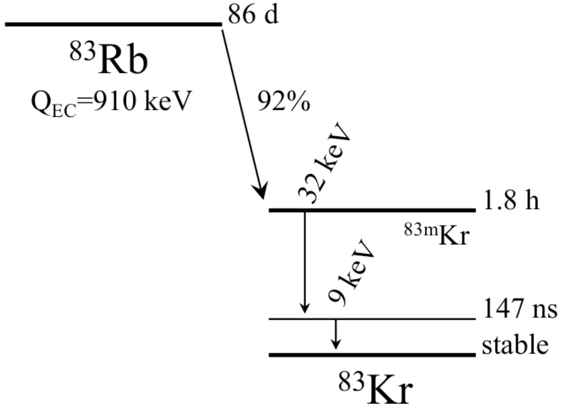


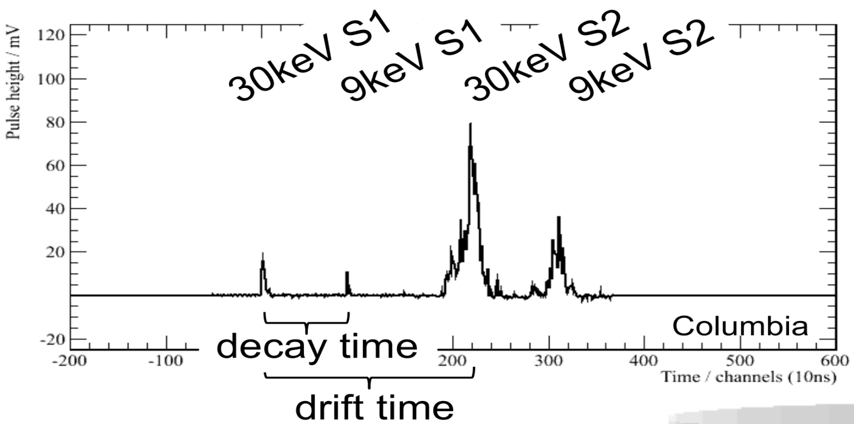
5 m-thick water shield

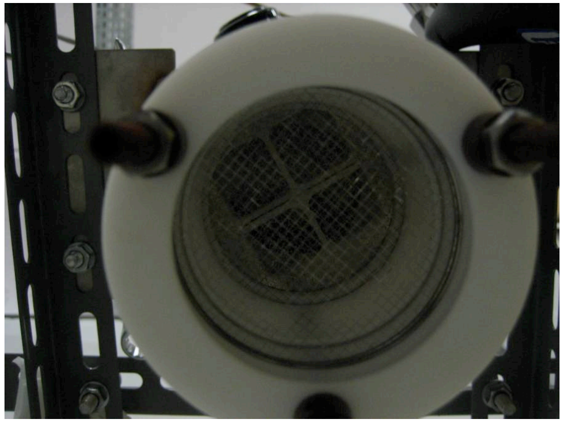
Xenon100: calibration

- ^{83}Kr is an ideal candidate for homogeneous calibration of the detector:
  - Not electronegative: no effect for electron attachment
  - Fast decay time ~2h
  - Provides 2 lines at low energies (32keV and 9keV) with a 147ns delay
- Principle demonstrated in two small setups at Zurich and Columbia
- Extensive R&D already done
- A calibration with ^{83m}Kr is planned



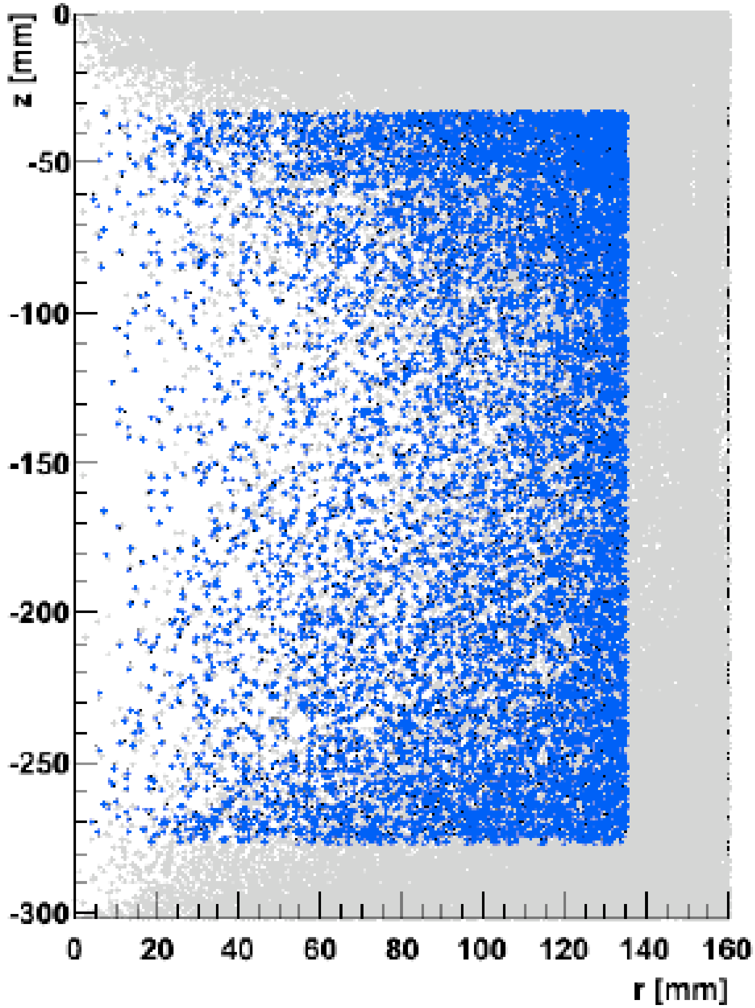




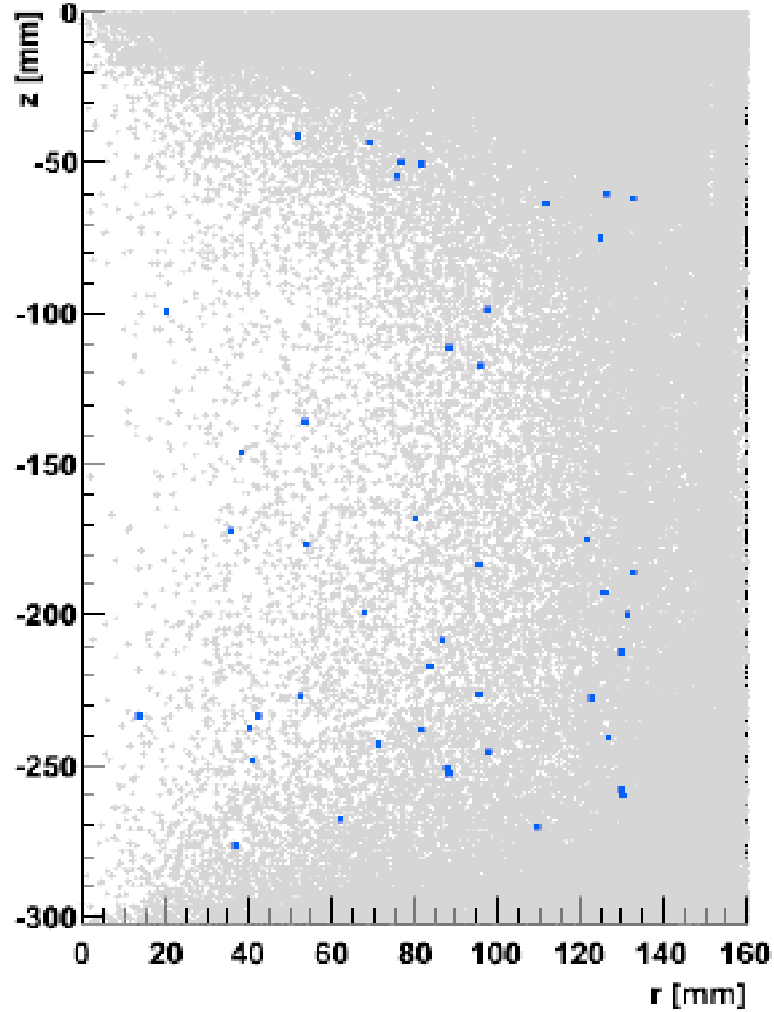


Background analysis

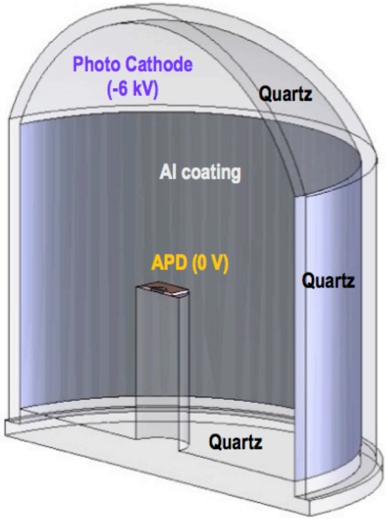
Selection of a 40kg cylindrical fiducial volume

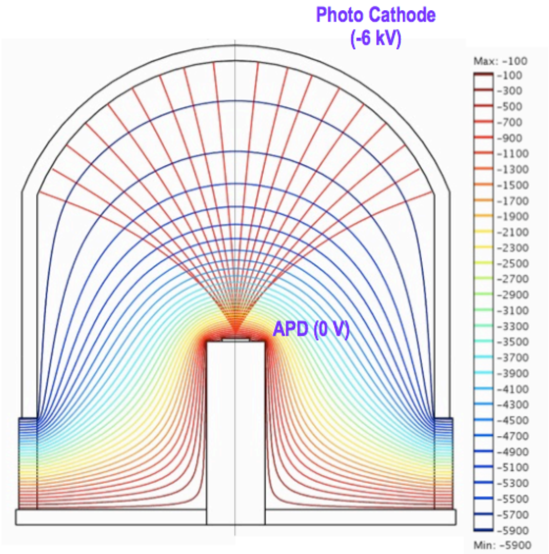


Energy range selection < 28 keV_r



XENON1T: QUPIDs (QUartz Photons Intensifying Detector)

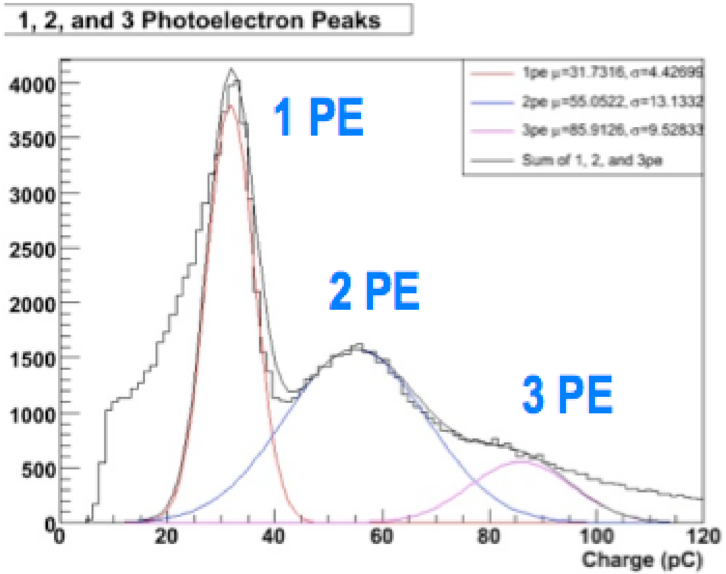


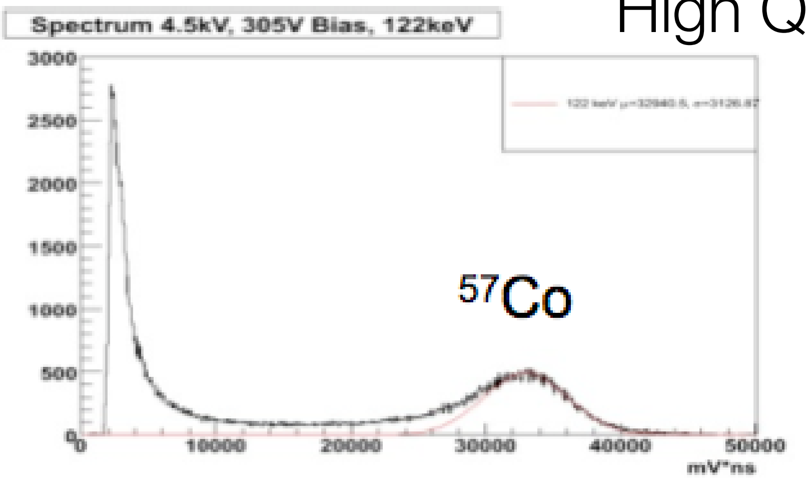


New concept of Light sensors

Very low radioactivity (<0.1 mBq ^{238}U/^{232}Th)

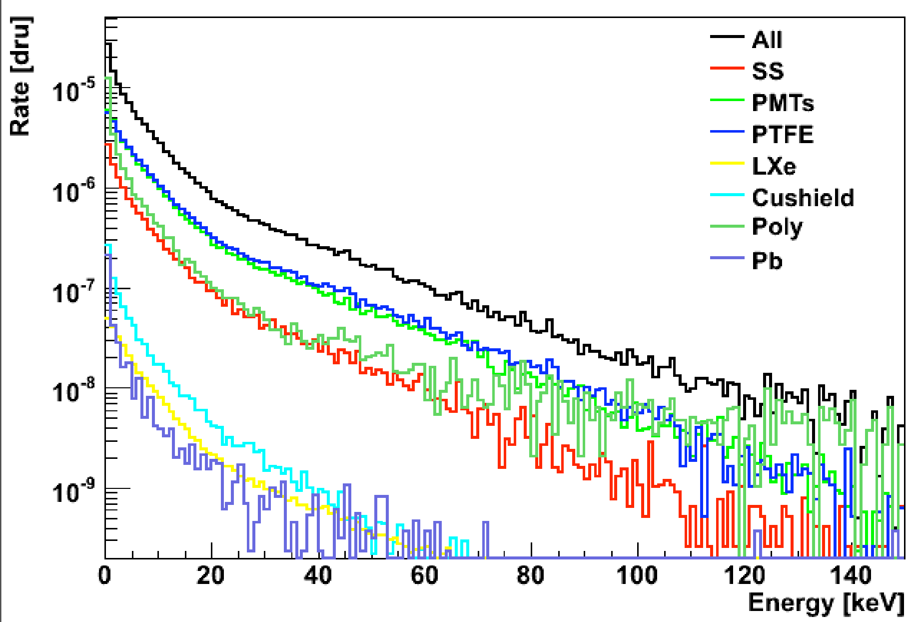
High QE photocathode

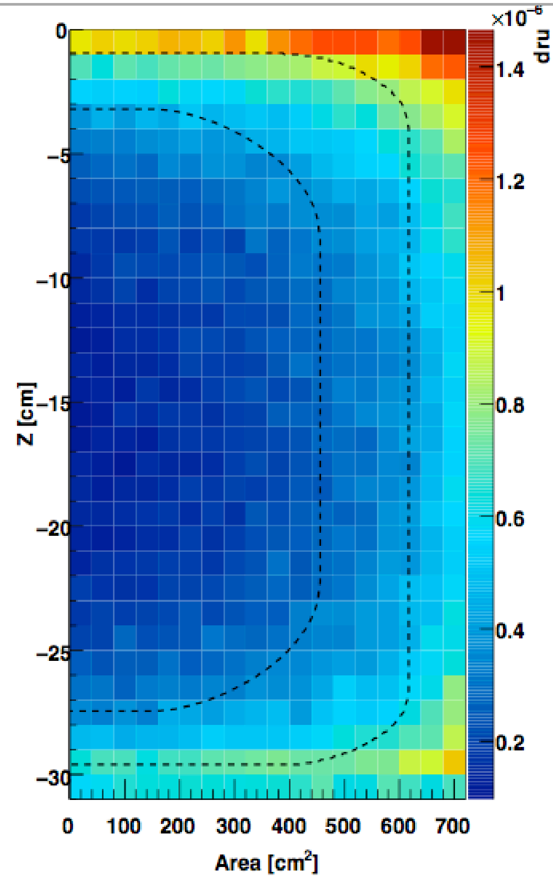




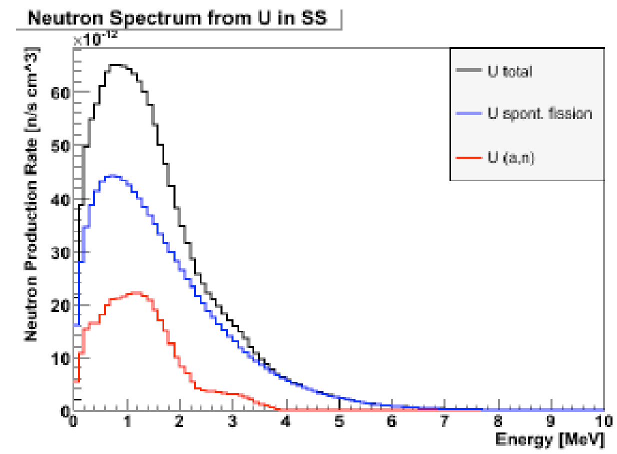
Neutron background

Single nuclear recoils in the whole active volume from materials





SOURCES4A code



Total single nuclear recoil rate [5,27] keV_r
(including rock and muons)

1.62 n/year (50 kg) 0.60 n/year (30 kg)