The XENON100 detector: Status and Results

Antonio Jesus Melgarejo Fernandez
on behalf of the
Xenon100 Collaboration

XENON Collaboration

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

COLUMBIA

RICE

UCLA

ZURICH

COIMBRA

LNGS

MPIK

BOLOGNA

SHANGHAI

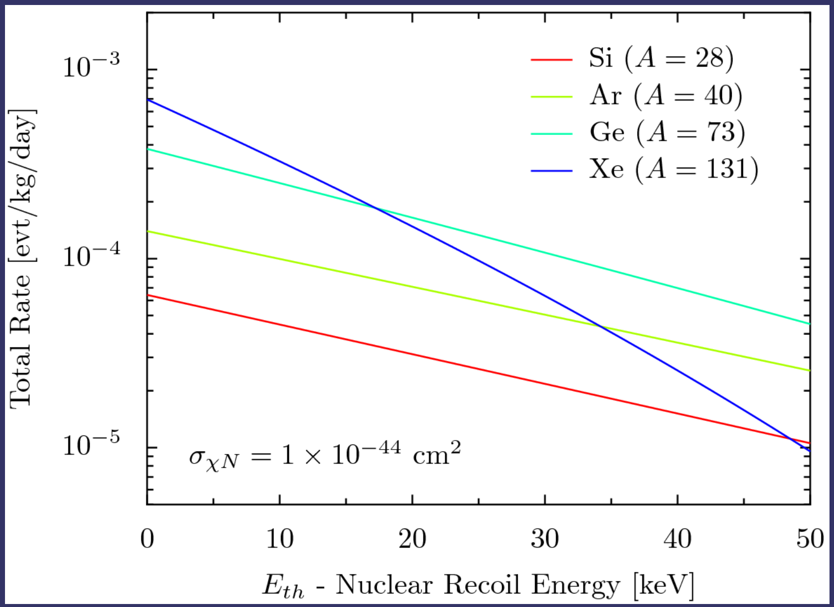
MUENSTER

SUBATECH

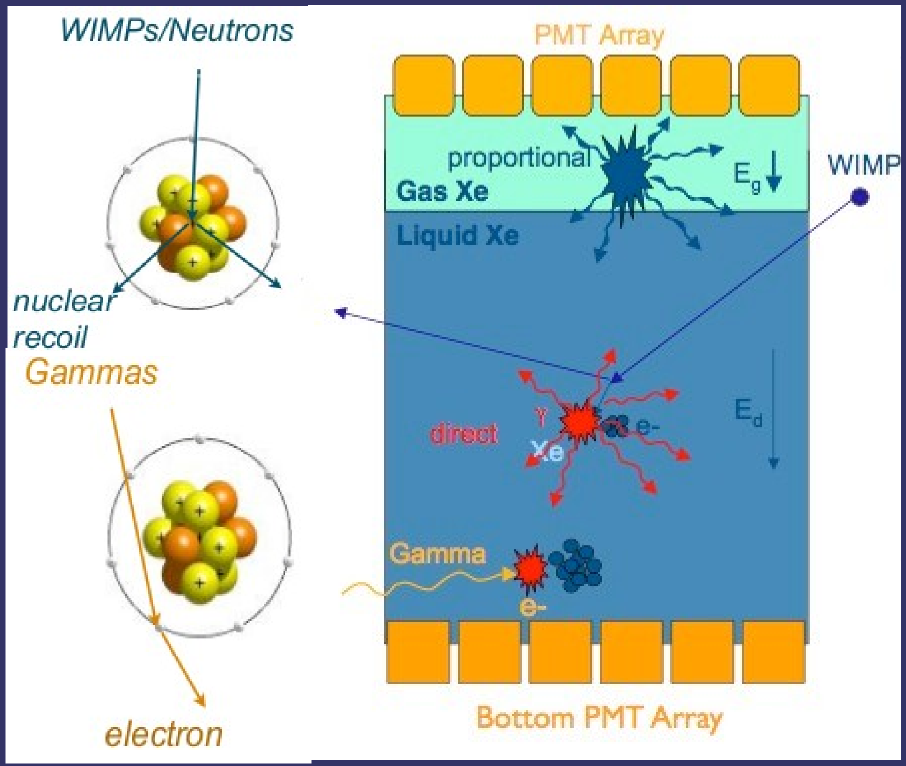
NIKHEF

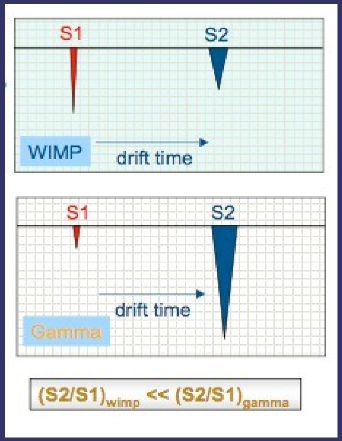
Why using Xe for dark matter sear-ches

- Large Mass number A (~131): high rate for SI if energy threshold for NR is low
- 50% of odd isotopes (^{129}Xe, ^{131}Xe): sensitive to SD interactions
- High stopping power (Z=54, ρ=3g·cm^{-3}): self-shielding capability
- Efficient scintillation (~80% of NaI) and ionization
- Intrinsically pure: No long lived isotopes and Kr/Xe reduction to ppt levels
- NR discrimination by simultaneous measurement of light and charge signals
- Scalability: relatively inexpensive for very large detectors



WIMP detection with a Xenon TPC

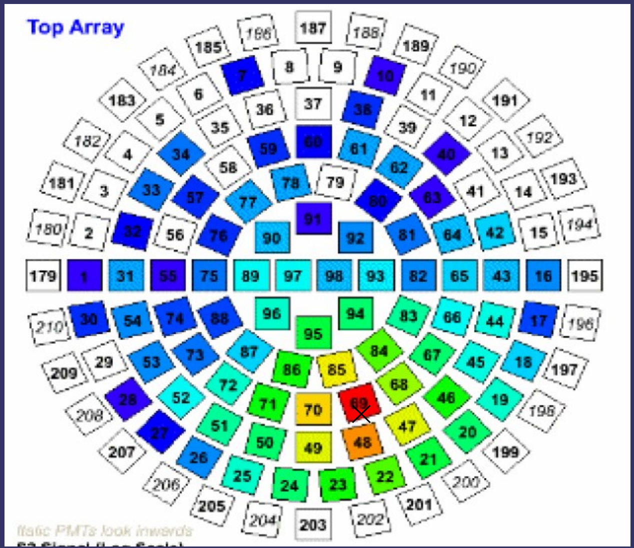


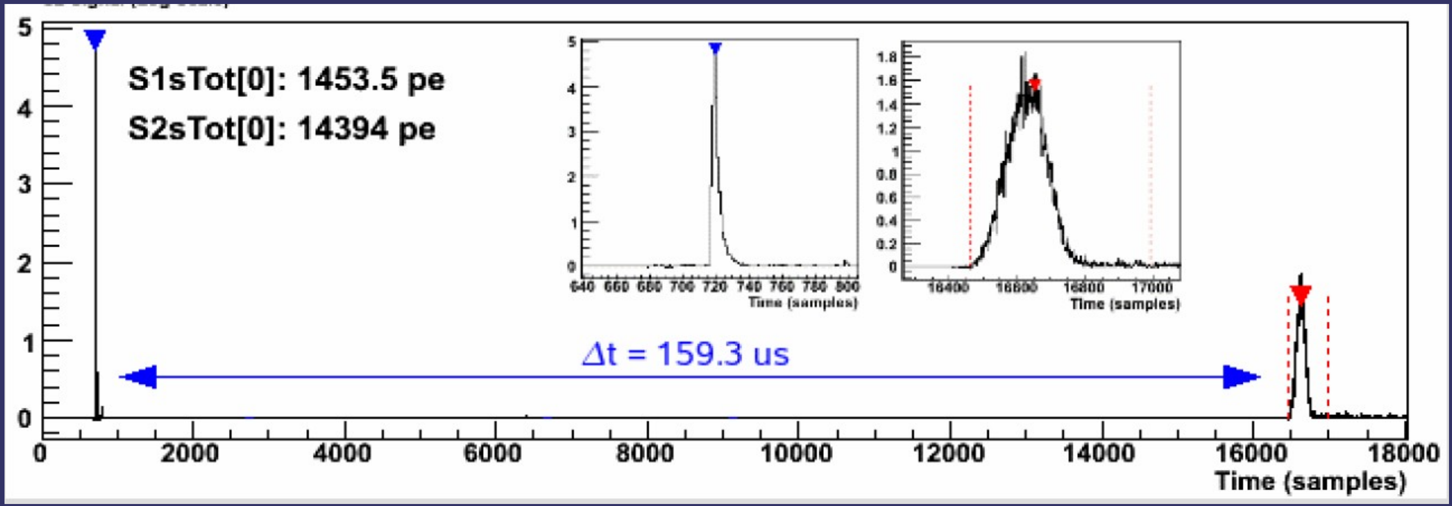


- Interactions in the detector produce scintillation and ionization
- Scintillation signal is recorded by two arrays of PMTs in the bottom and top of the detector
- Free electrons are drifted with an Electric Field and produce proportional scintillation in the gas gap below the anode, which is detected by the photosensors
- Different ionization/scintillation ratio allows for discrimination of nuclear recoils against electron recoils

WIMP detection with a Xenon TPC

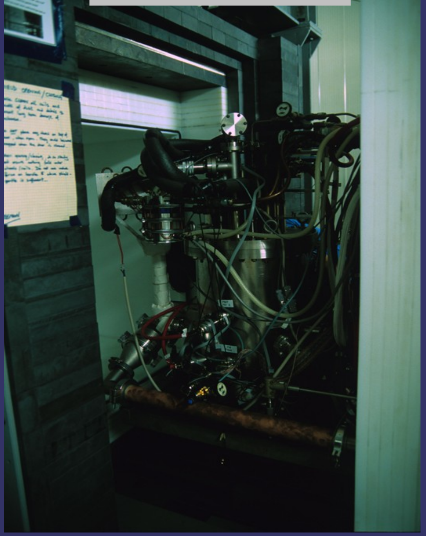
- The time difference between the primary and proportional scintillation allows for reconstruction of the depth of the interaction
- The PMT pattern of the proportional scintillation gives information about the XY position of the interaction





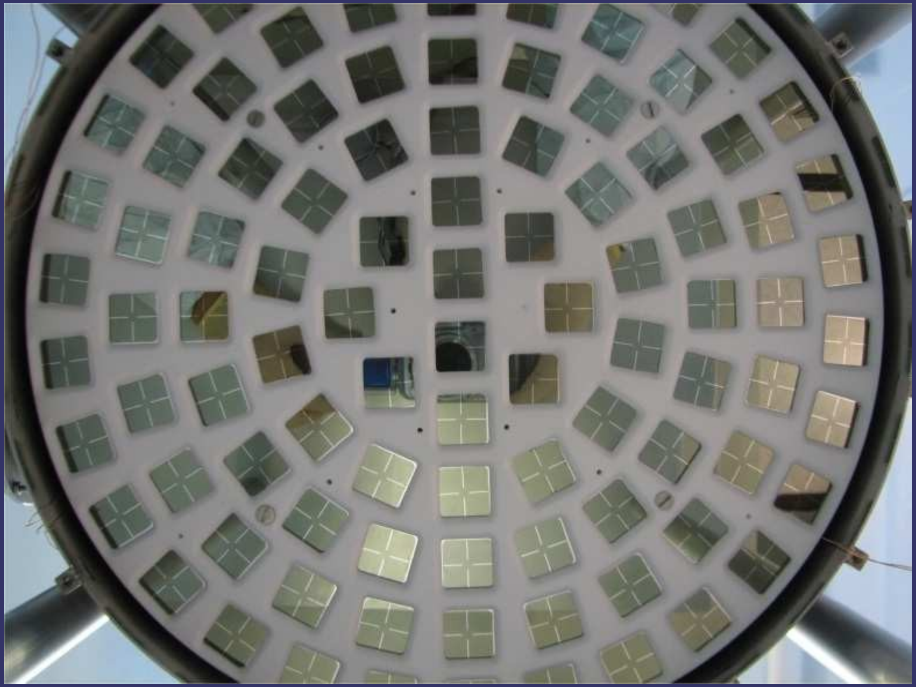
The XENON100 detector

XENON10



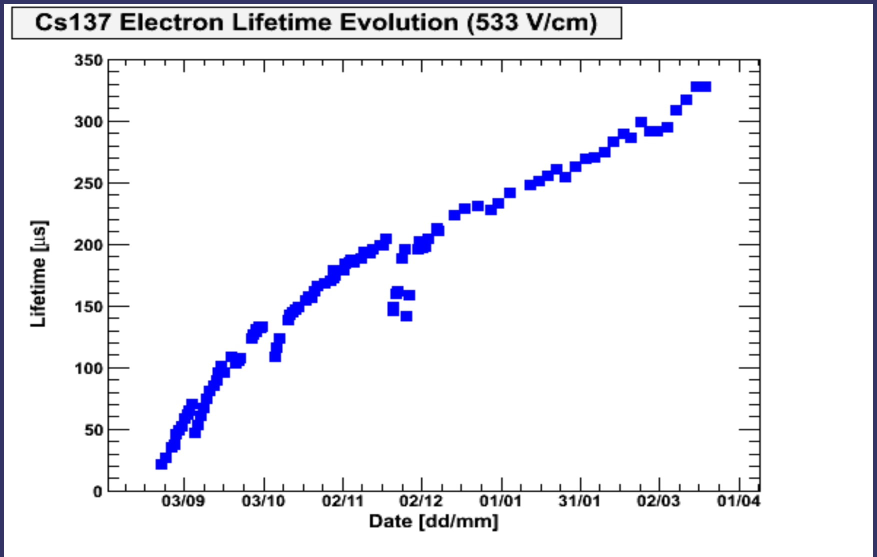
XENON100

- Goal: Build a detector with x10 more mass and x100 less background than XENON10
- 170 kg of LXe divided in:
  - 65kg fiducial region: 30cm heightx30cm diameter cylinder seen by two PMT arrays (178 PMTs total)
  - 105 kg active veto covering top, sides and bottom seen by 64 PMTs
- Multiple strategies for background reduction:
  - Passive shield: 5 cm Cu+20cm Poly+20 cm Pb +20 cm Water
  - Careful selection and screening of materials
  - Placement of all cryogenics outside the shield
  - Distillation column to reduce the Kr/Xe content



Cryogenics and purification

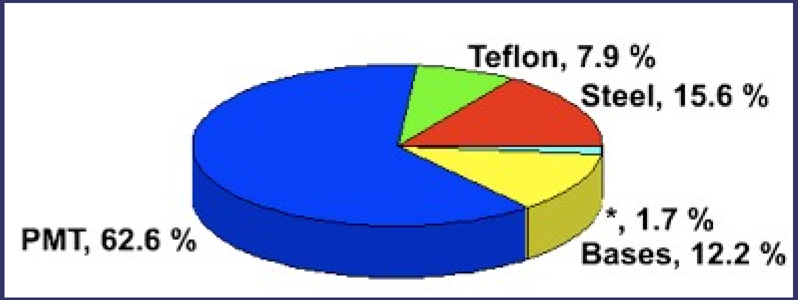
- The Xenon is continuously recirculated and purified through a hot getter (SAES)
- Cooling power is provided by a Pulse Tube Refrigerator (160W)
- Vaccum cryostat extends outside the shield to surround the cooling tower



Backgrounds: gammas from detector components

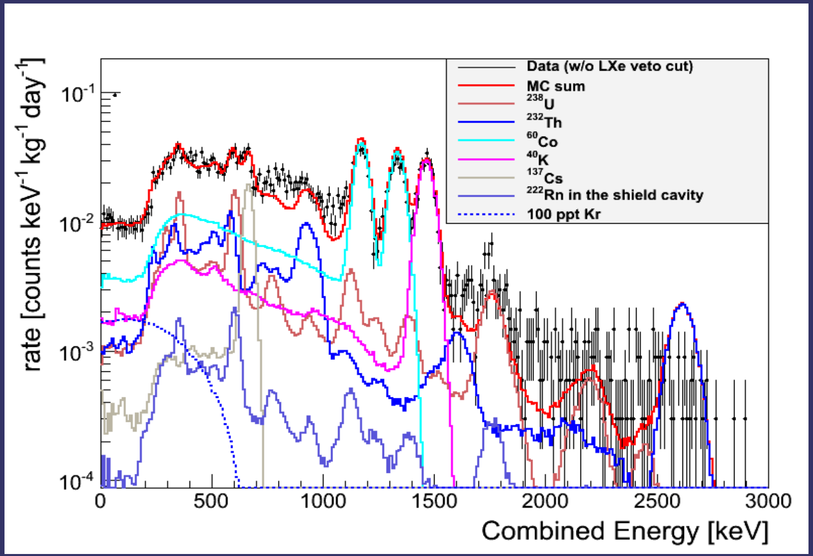
Material	Unit	^{238}U [mBq/unit]	^{232}Th [mBq/unit]	^{60}Co [mBq/unit]	^{40}K [mBq/unit]	^{210}Pb [Bq/unit]
Stainless steel	kg	< 1.7	< 1.9	5.5±0.6	< 9.0	
PTFE	kg	< 0.31	< 0.16	< 0.11	< 2.25	
PMTs	piece	0.15±0.02	0.17±0.04	0.6±0.1	11±2	
PMT bases	piece	0.16±0.02	0.07±0.02	<0.01	<0.16	
Support bars (steel)	kg	< 1.3	2.9±0.7	1.4±0.3	< 7.1	
Copper (inside)	kg	< 0.22	< 0.16	0.20±0.08	< 1.34	
Resistor chain	piece	0.027±0.004	0.014±0.003	< 0.003	0.19±0.03	
Cathode support ring	kg	3.6±0.8	1.8±0.5	7.3±1.3	< 4.92	
Top grids support rings	kg	< 2.7	< 1.5	13±1	< 12	
PMT signal cables	kg	< 1.6	3.7±1.8	< 0.69	35±13	
Polyethylene shield	kg	0.23±0.05	< 0.094	< 0.89	0.7±0.4	
Copper shield	kg	< 0.07	< 0.03	< 0.0045	< 0.06	
Lead shield (outer)	kg	< 0.92	< 0.72	< 0.12	14±3	530±70
Lead shield (inner)	kg	< 0.66	< 0.55	< 0.11	< 1.46	26±6

- Careful selection and screening of the detector materials
- Use of a dedicated Low Background facility with a Germanium detector (GATOR) at LNGS to know the radiactivity of all components. essential information for realistic MC studies



Backgrounds: ^{85}Kr

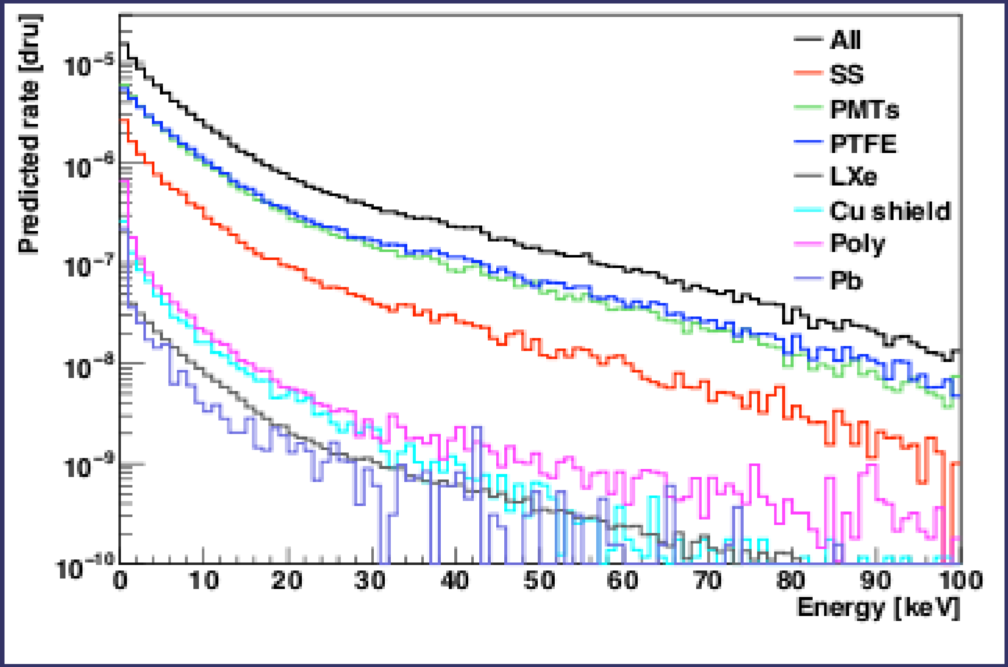
- Kr is present in commercial Xe
- Measured concentration with delayed coincidence method ~10ppb (^{85}Kr/Kr~10^{-11}). Xenon goal requires ~100ppt
- A cryogenic distillation column has been installed underground to process the Xenon. After processing delayed coincidence analysis gives ~150ppt (big errors due to small statistics)
- Comparison of the measured rate with MC simulations suggest ~100 ppt of Kr



Backgrounds: Neutrons

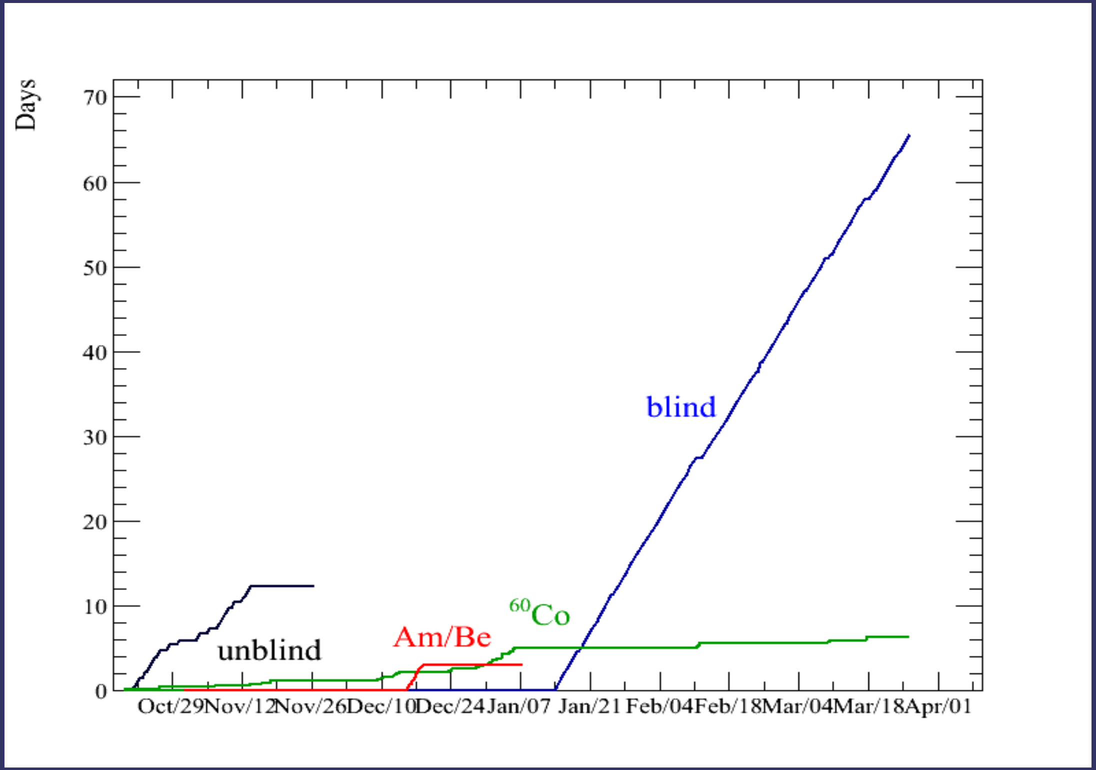
- Detailed MC has been performed including detector materials, rock radiactivity and muon-induced neutrons
- The short mean free path of the neutrons in liquid Xenon allows for multiple scatter discrimination
- Simulation results:
  - 1.5 neutrons/year in a 50kg fiducial volume
  - 0.5 neutrons/year in a 30kg fiducial volume

We expect to perform a background free dark matter search!!



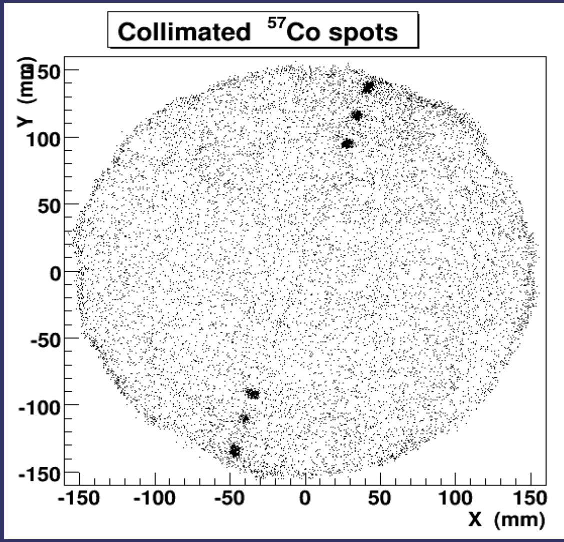
Current status of the XENON100 detector

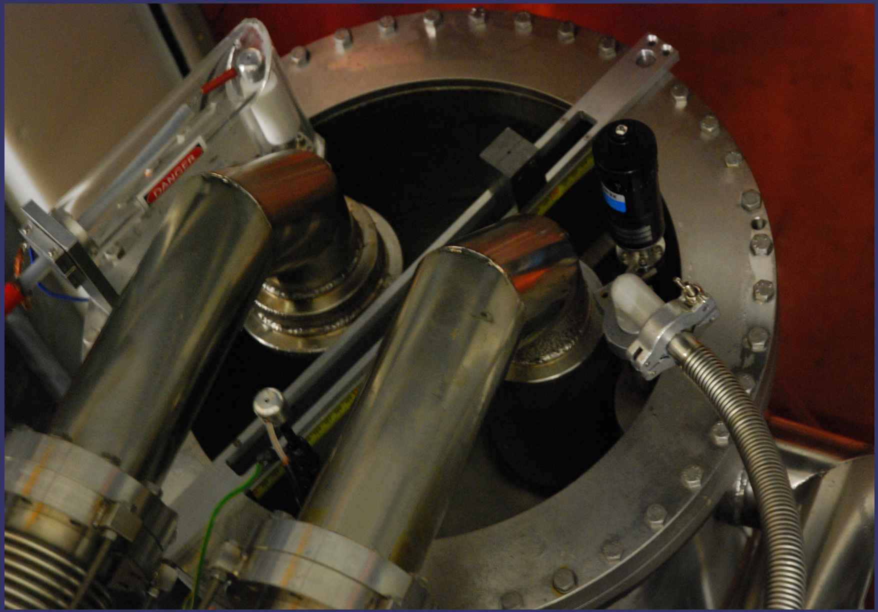
- The detector is installed in the LNGS (L'Aquila) since summer 2008
- Succesful calibration of the detector has been achieved during 2009
- Dark matter data taking started at the beginning of 2010. More than 4 tons·day have been already acquired



Calibration of the XENON100 detector: positioning

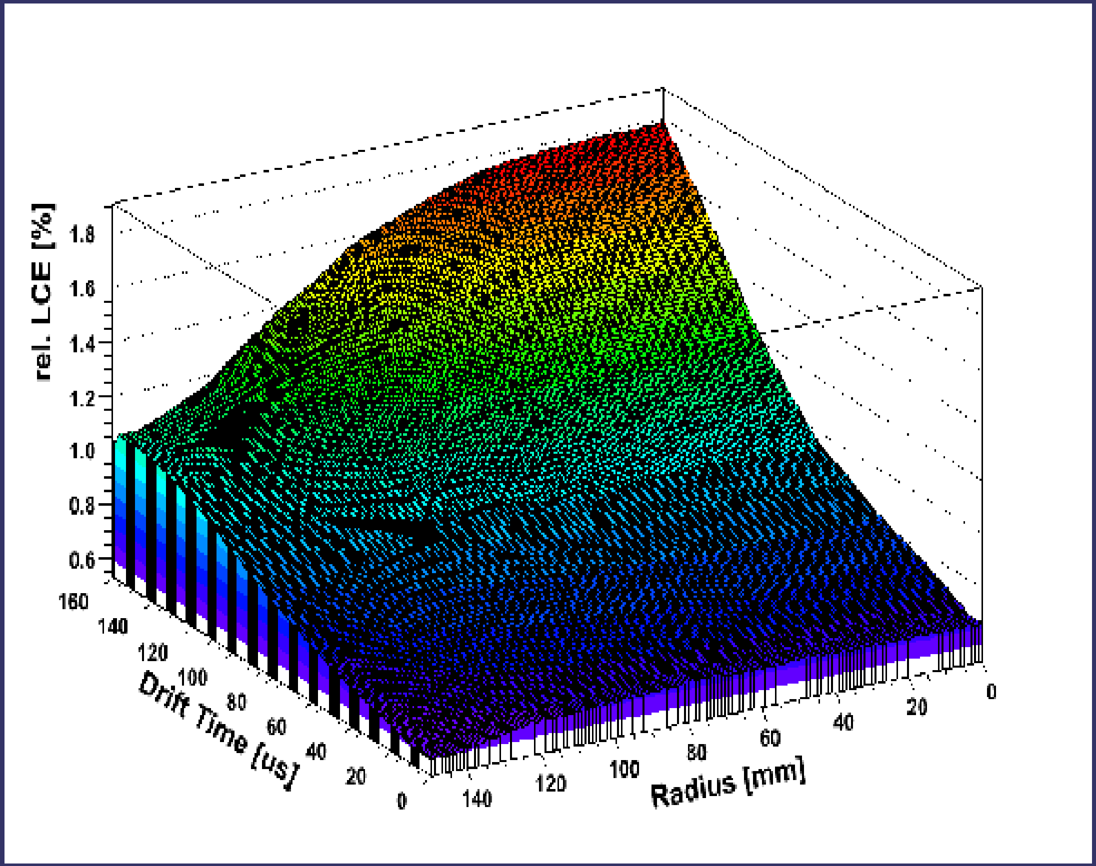
- 3 different position reconstruction algorithms have been developed
- A dedicated setup has been used to test them: a ^{57}Co source is placed in a lead collimator and data are taken at different radii
- Agreement between the results and the MC yield a resolution ≤ 3 mm





Calibration of the XENON100 detector: S1 response

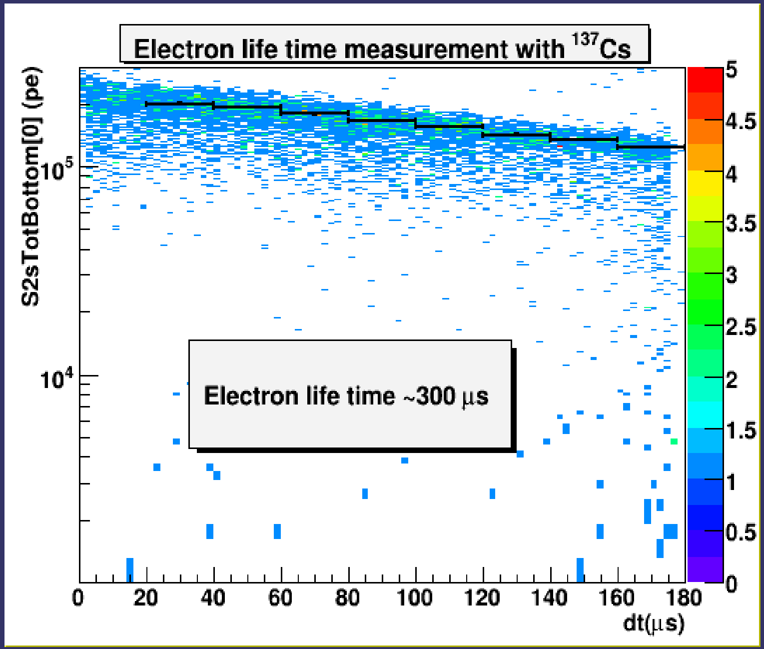
- Light yield from different positions in the detector changes due to solid angle, absorption length and teflon reflectivity
- Several sources distributed in the active volume have been used to measure the collection efficiency of the detector
- The results from these sources (40 keV inelastic, ^{131m}Xe,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

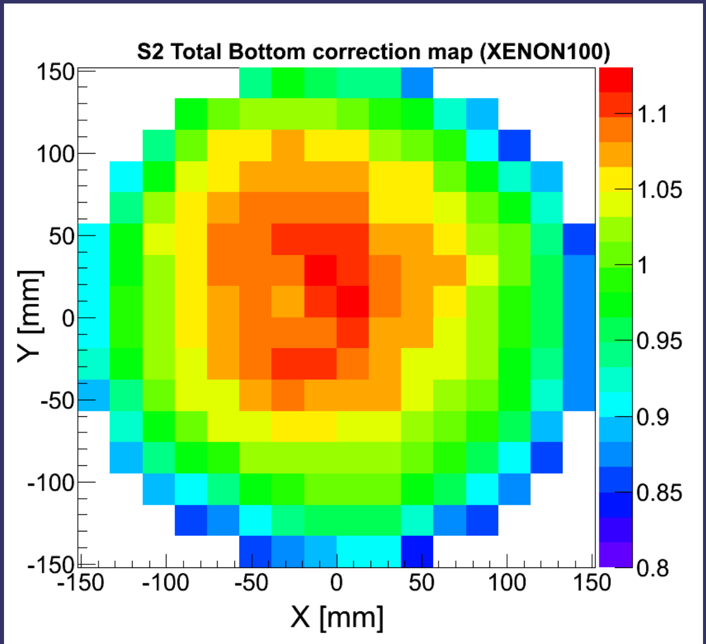


Average light yield with electric field
2.2 pe/keV @ 122 keV

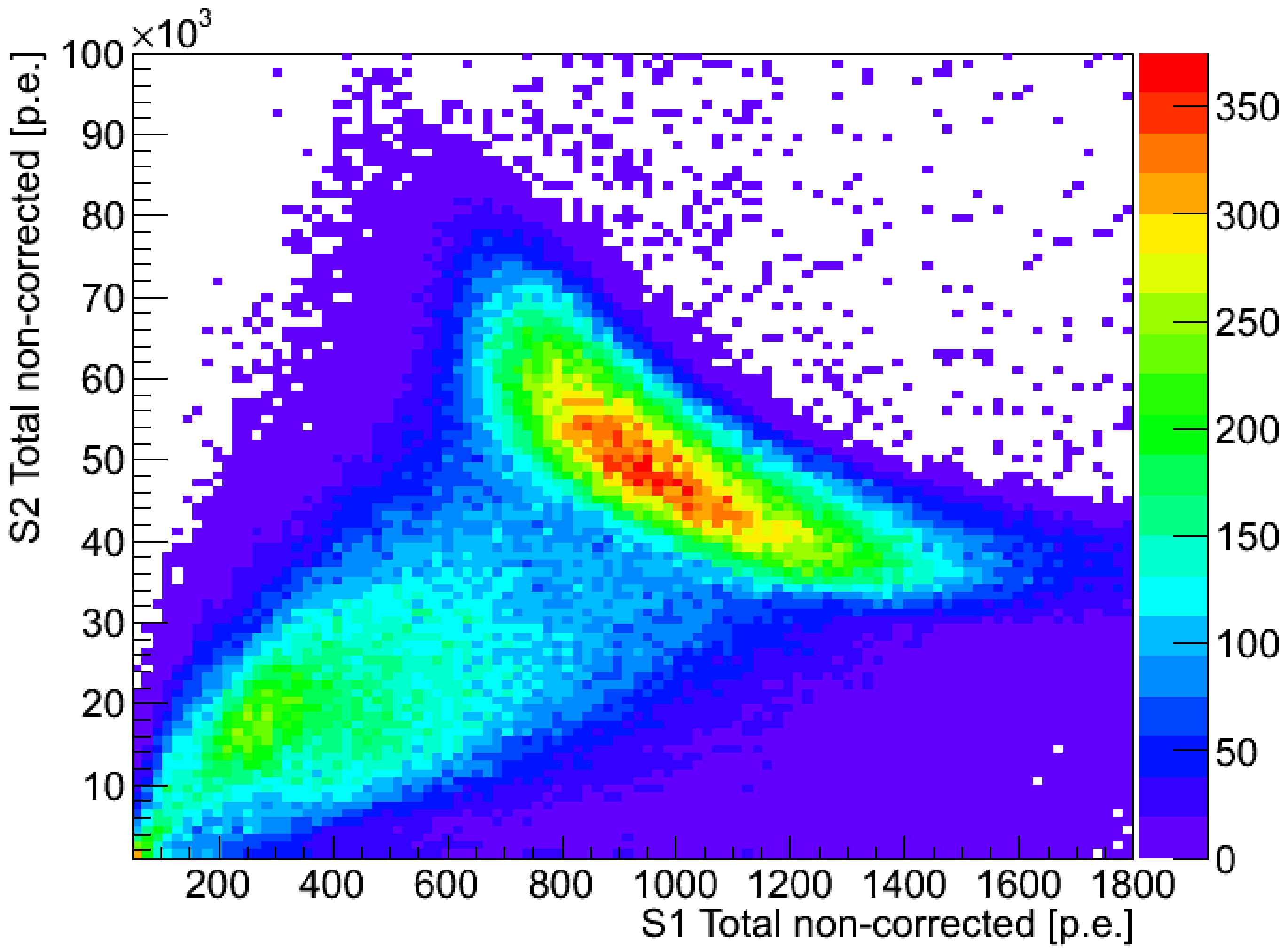
Calibration of the XENON100 detector: S2 response

- Drifting electrons can be captured by electronegative impurities
- Electron lifetime is monitored periodically and the signal can be corrected using the measured drift time: $Q_0 = Q \cdot e^{dt/\tau}$
- Differences in the signal due to the different solid angles in different XY positions are also corrected. No inhomogeneity is observed

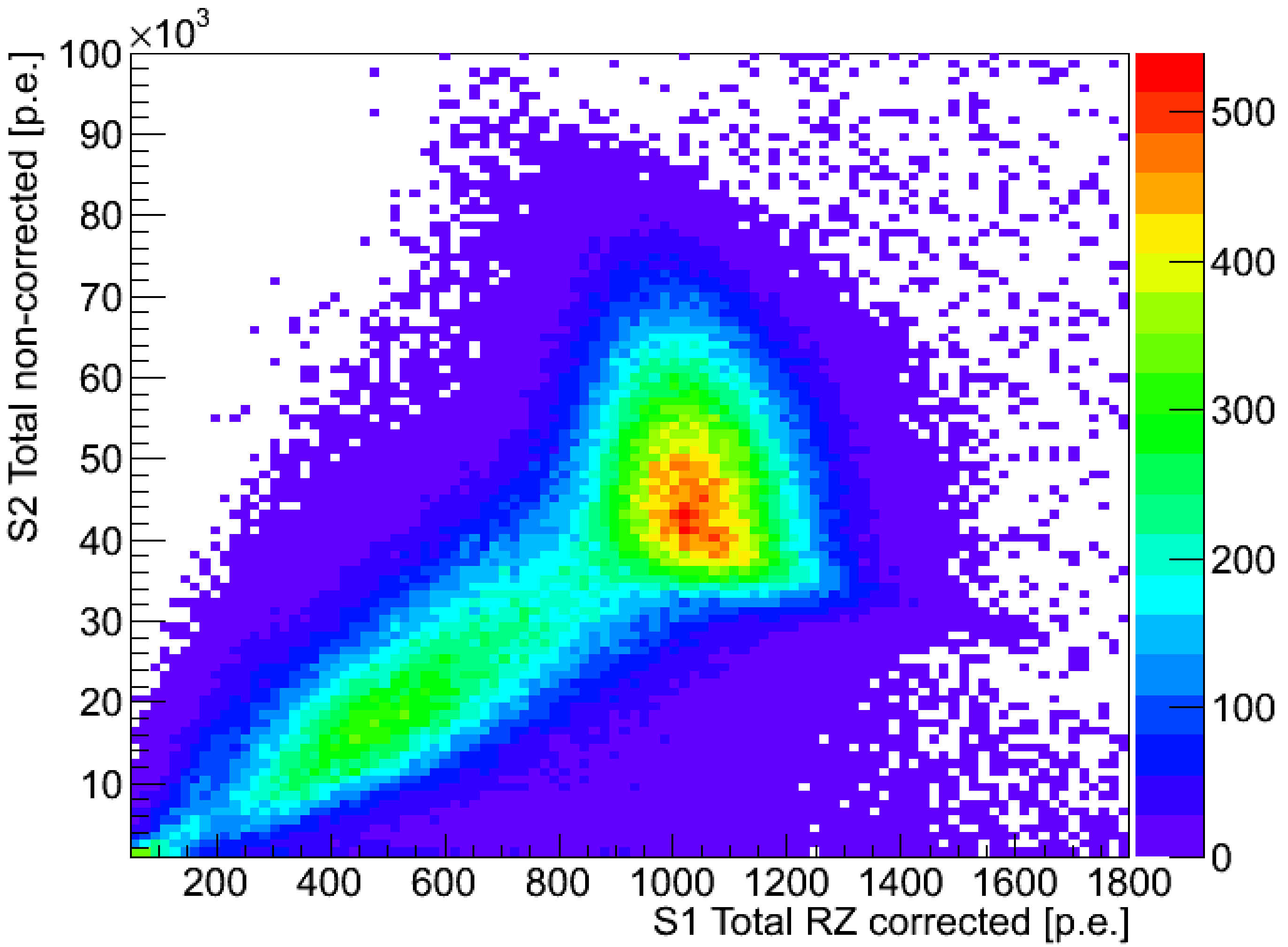




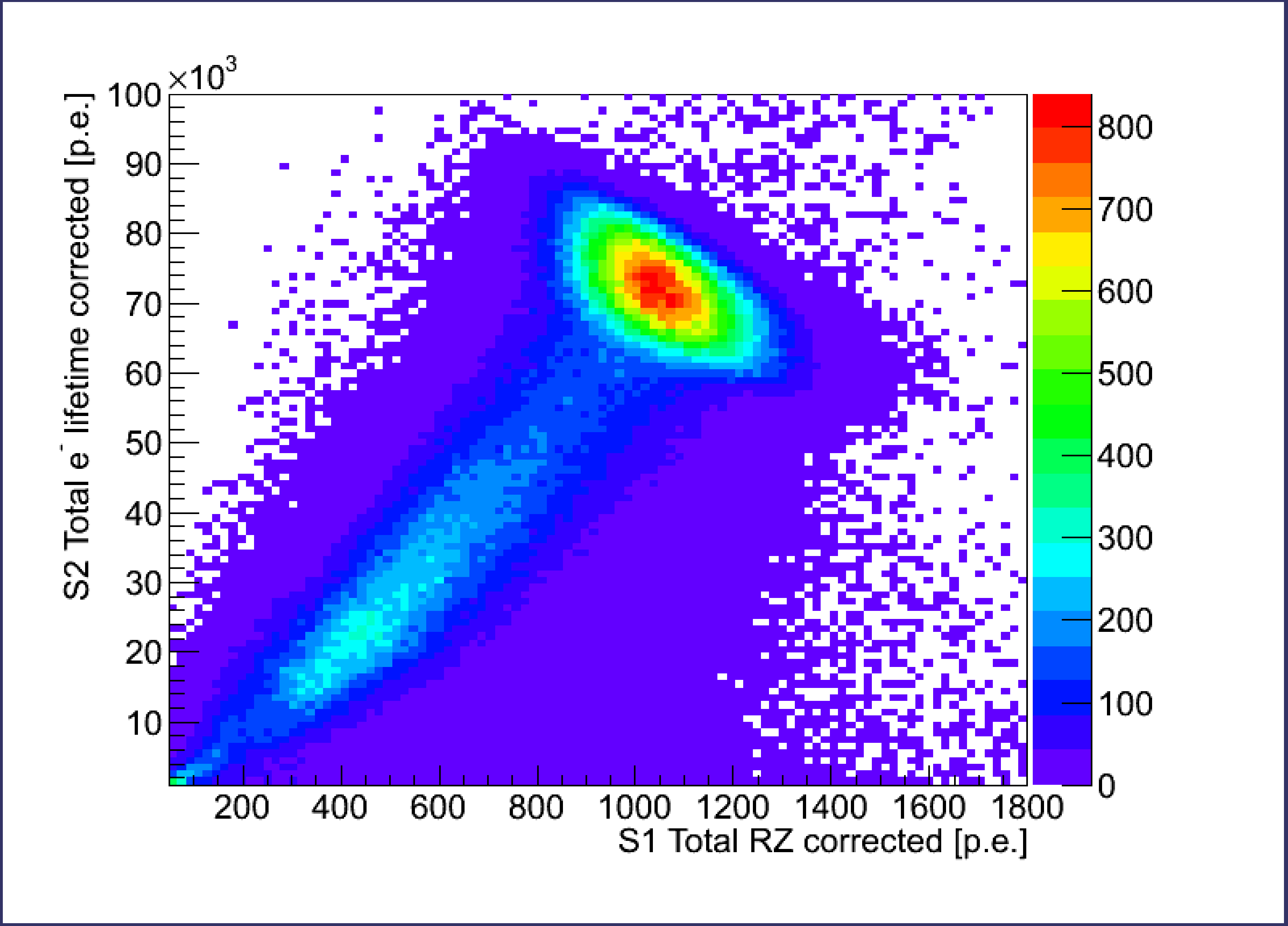
Position dependence: raw signals



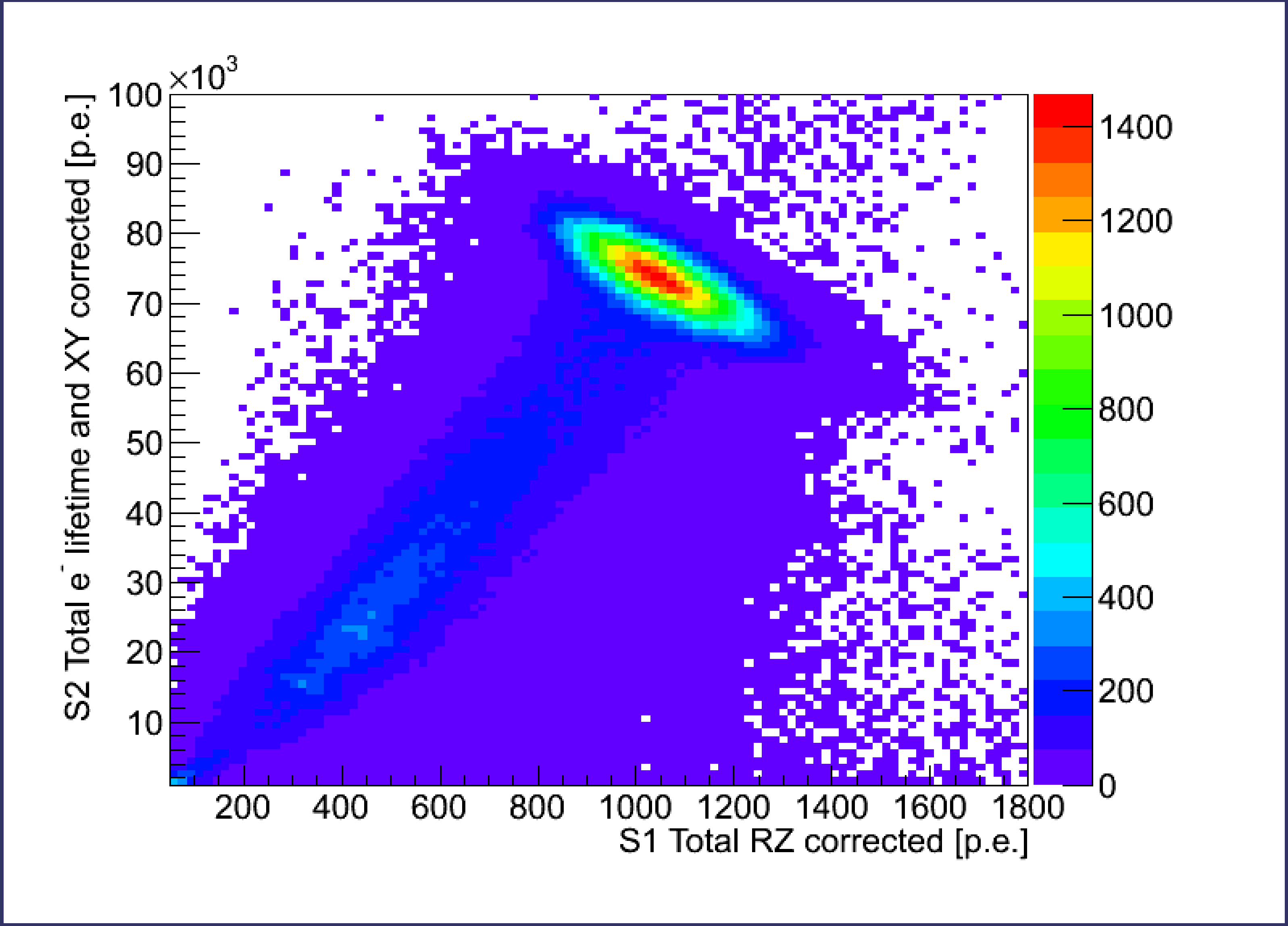
Position dependence: S1 corrected



Position dependence: S2 drift time corrected

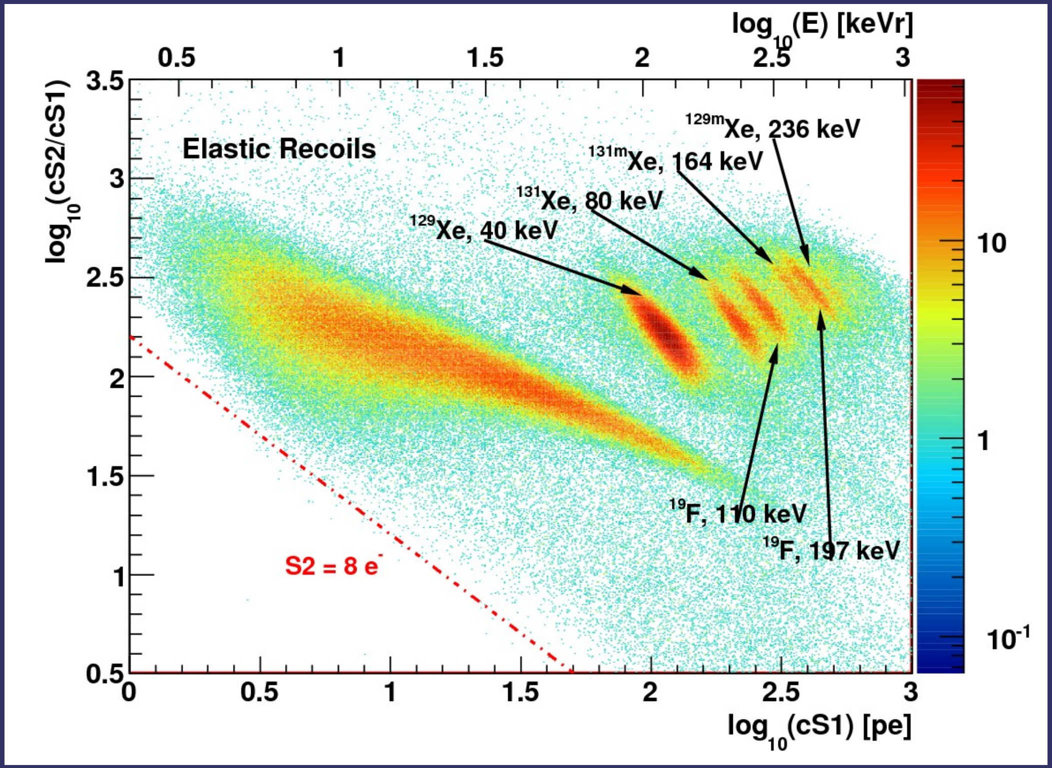


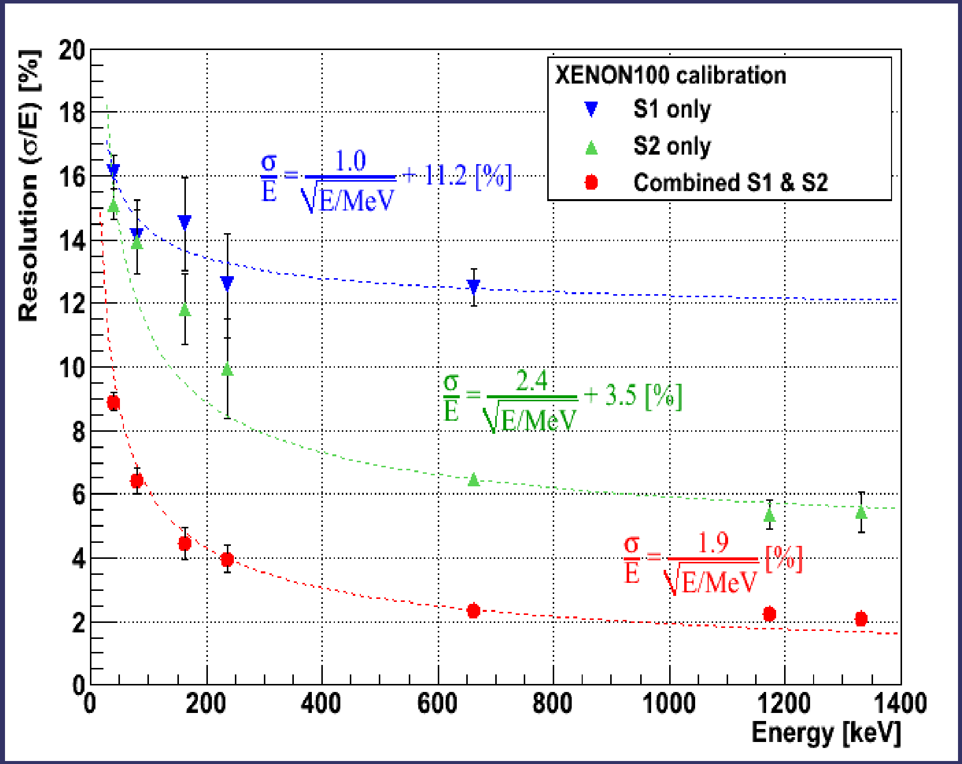
Position dependence: S1 and S2 corrected



Energy resolution

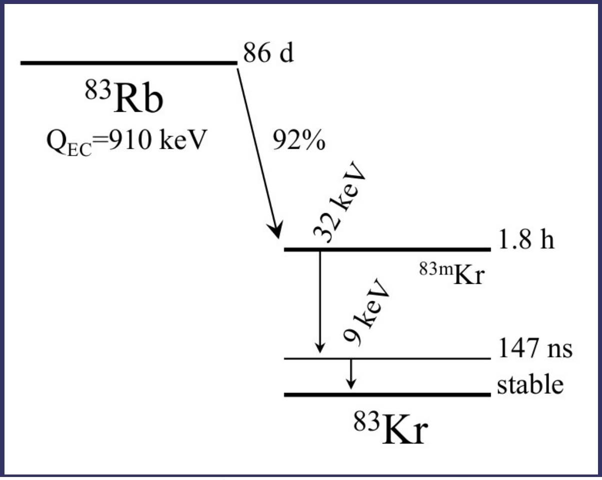
- Multiple lines available for the calibration of the detector: ^{137}Cs, ^{60}Co, ^{129m}Xe, ^{131m}Xe, inelastic neutron scattering)
- Energy resolution of 2.2% @ 662keV, similar to the XENON10 result

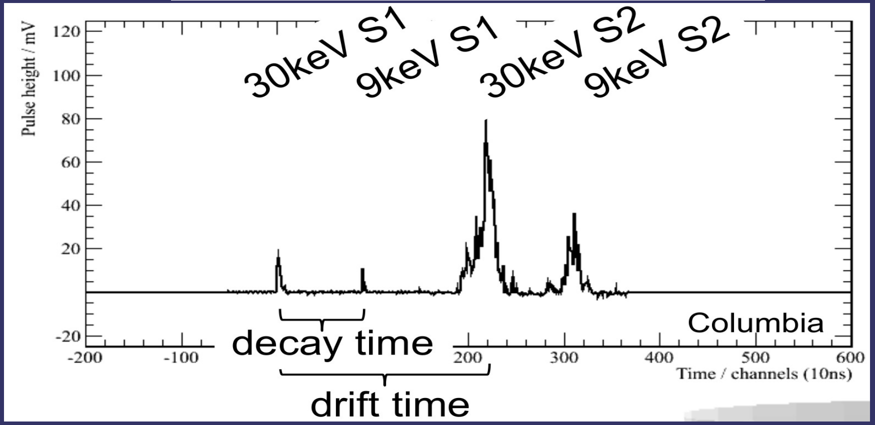


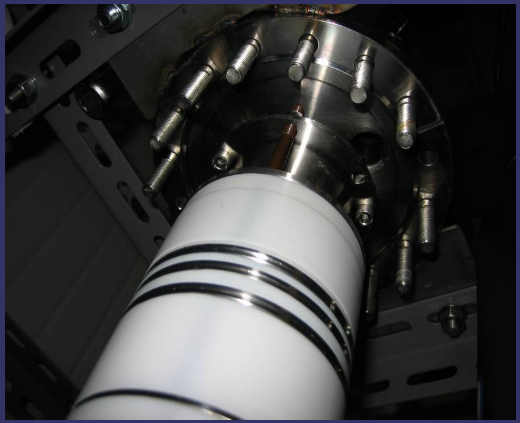


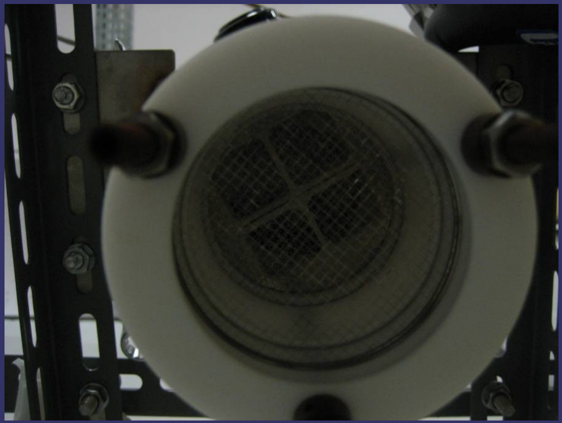
Calibration: Future improvements

- ^{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 going on



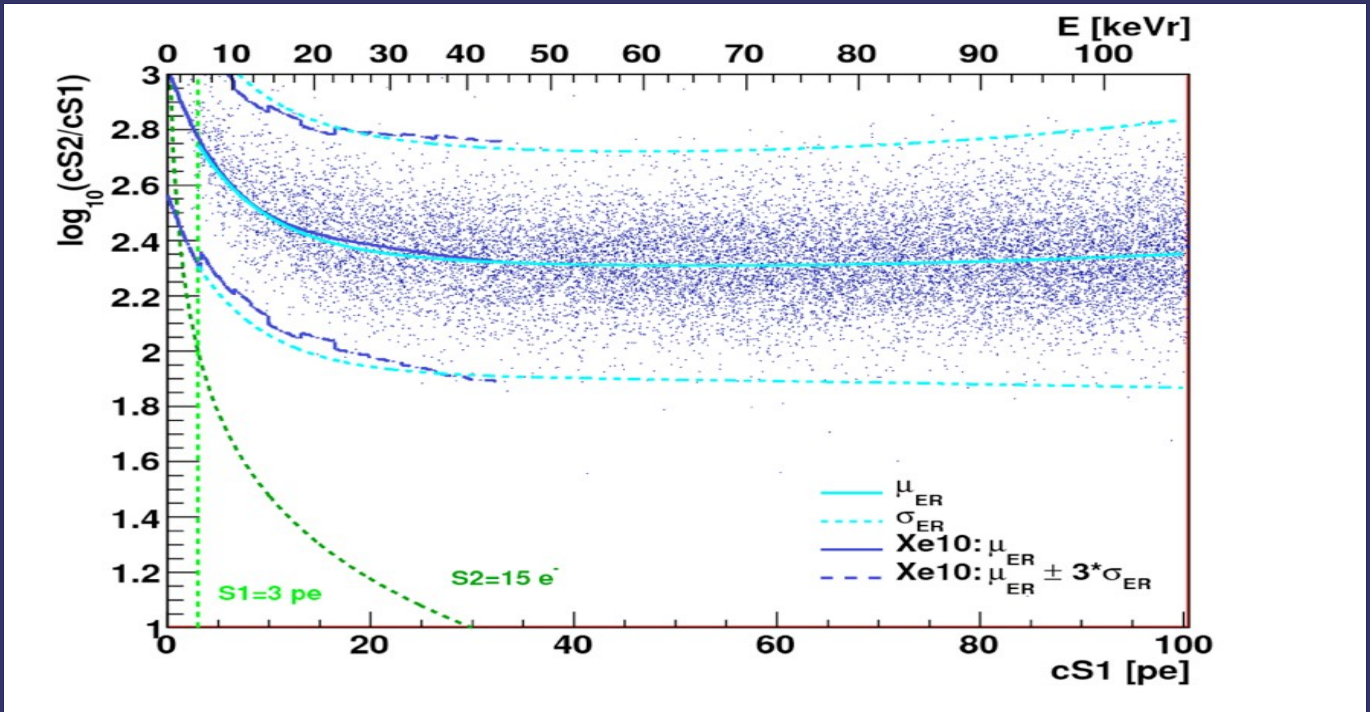






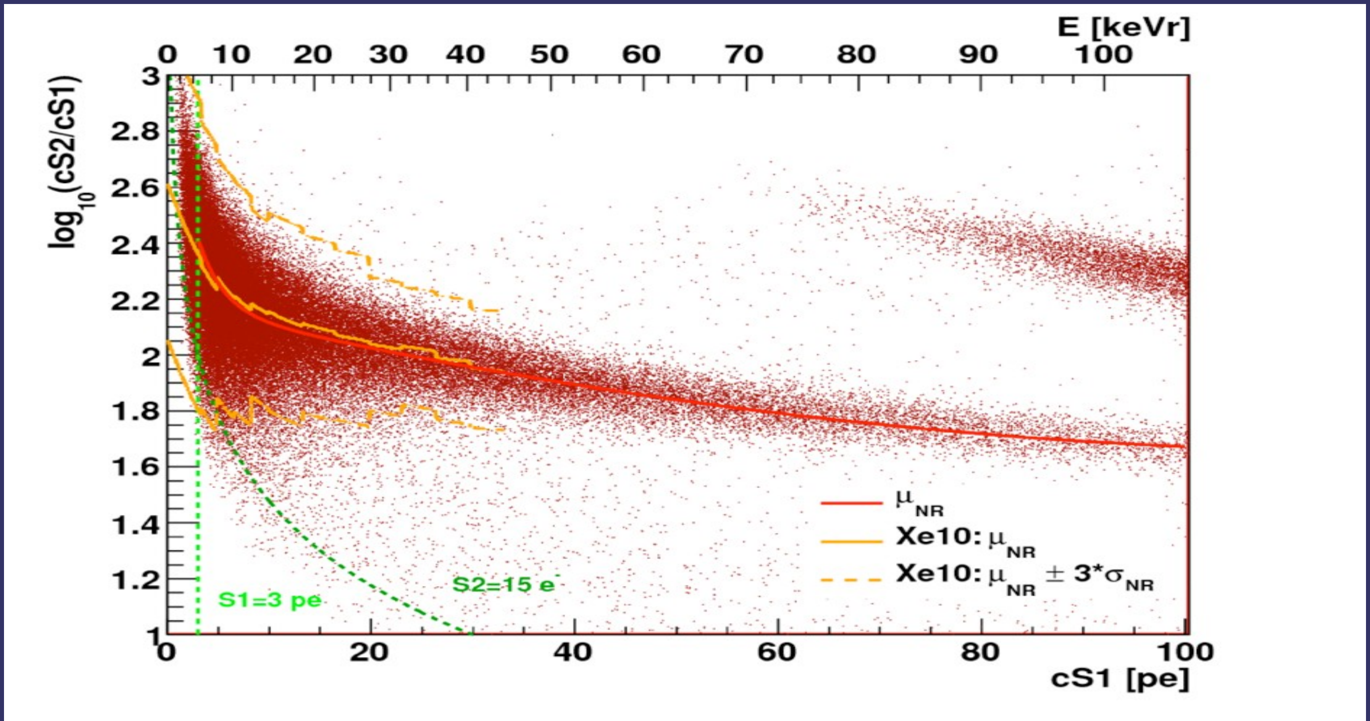
Gamma Band

- 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



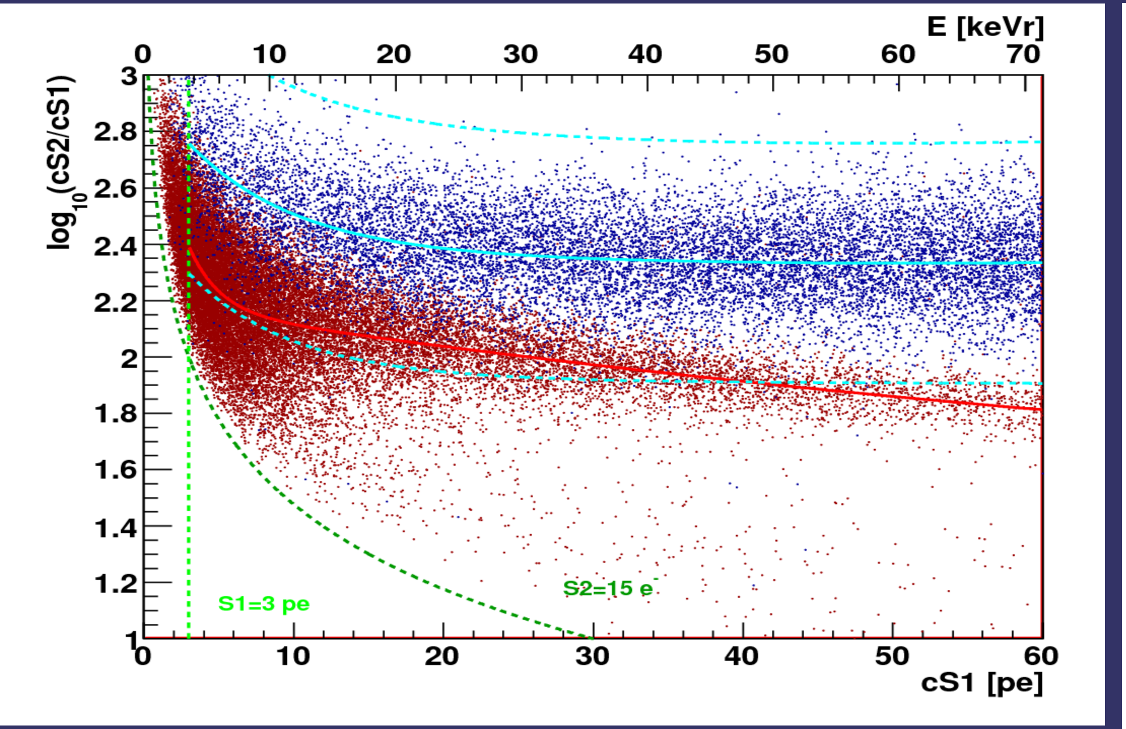
Neutron band

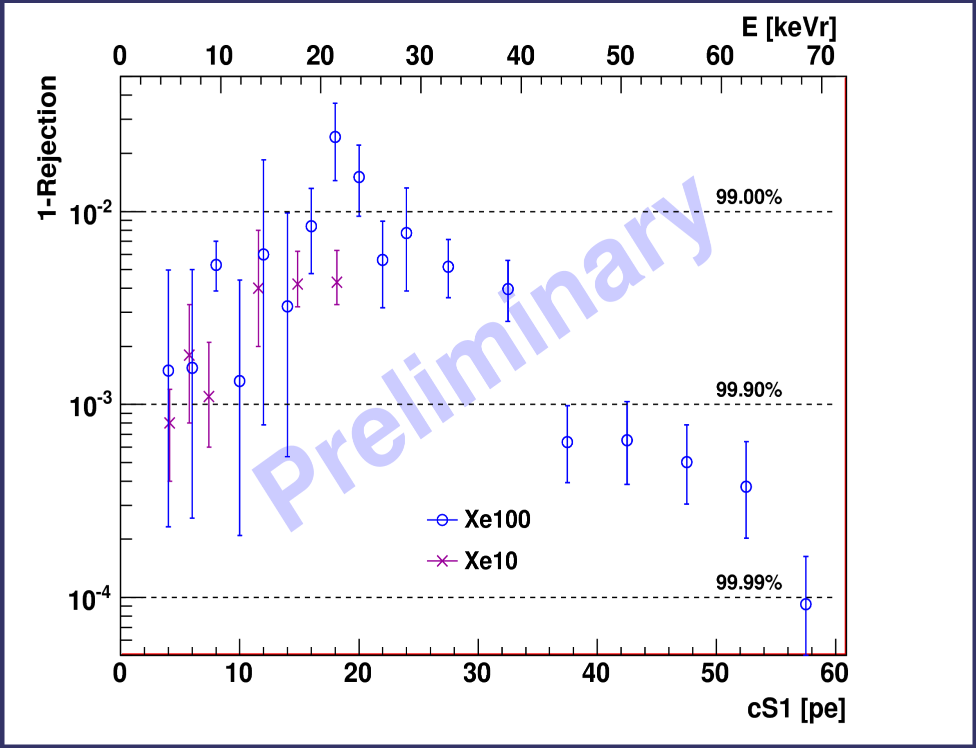
- Calibration of the detector using an AmBe source has been performed during December 2009
- In addition to multiple gamma lines above 40keV, the detector response to low energy nuclear recoils has been studied
- Results are in good agreement with XENON10



Rejection power

- It is possible to distinguish between nuclear recoils and electron recoils due to their different charge/light ratio
- The rejection efficiency is between 99.5%-99% in the range from 4 to 20 pe





Energy scale for low energy NR

Measured signal

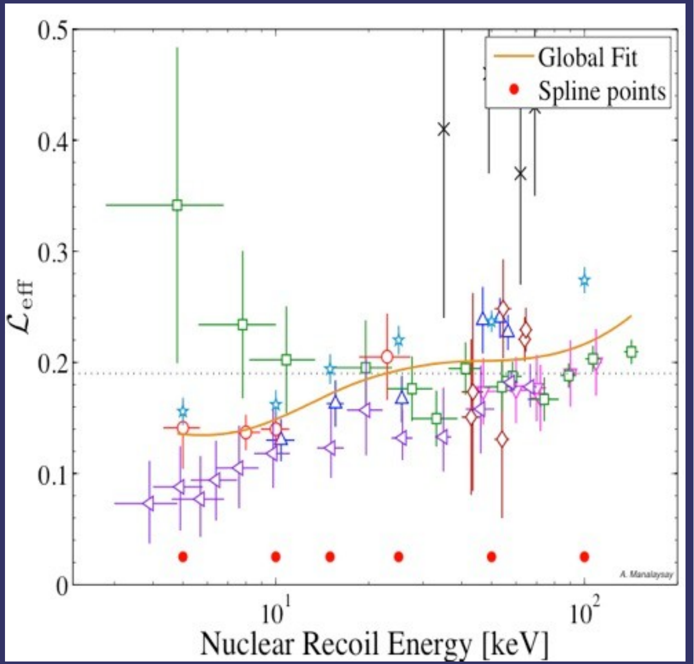
Light quenching due to electric field for gammas @122keV

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

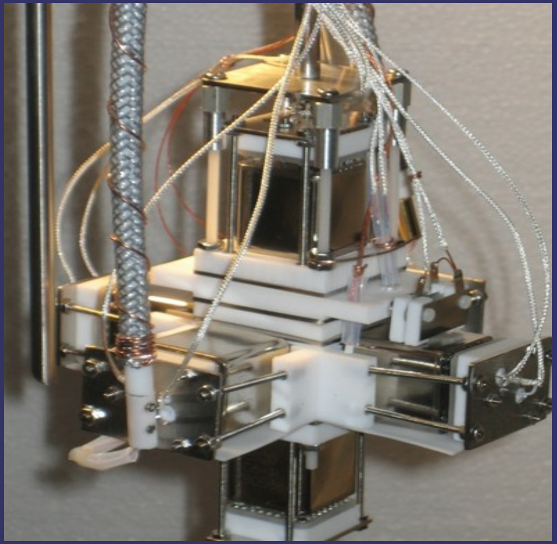
Light yield for gamma @122 keV

Scintillation eff. for nr at 0 field

Light quenching due to electric field For nuclear recoils

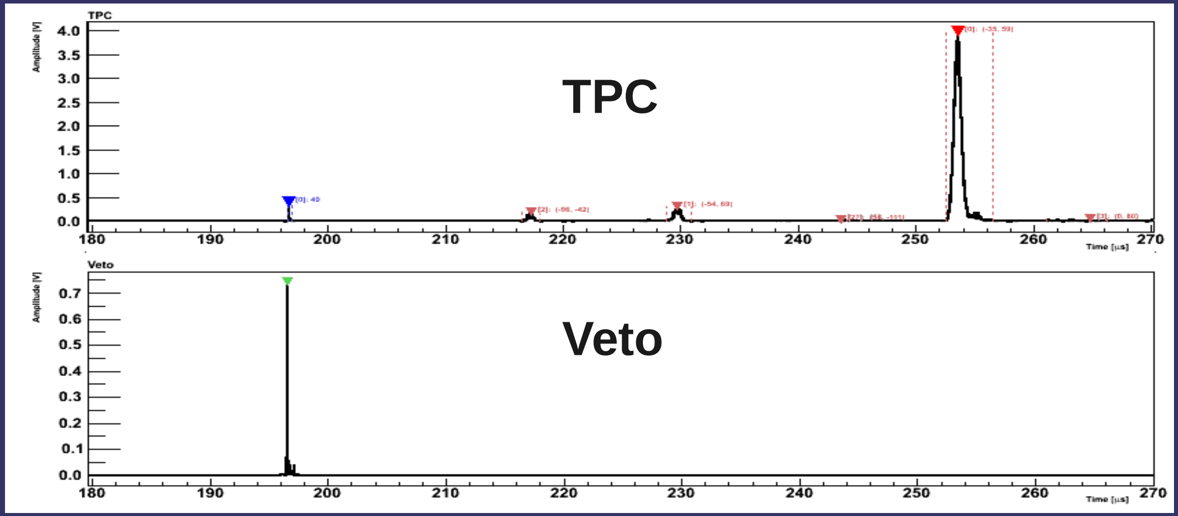


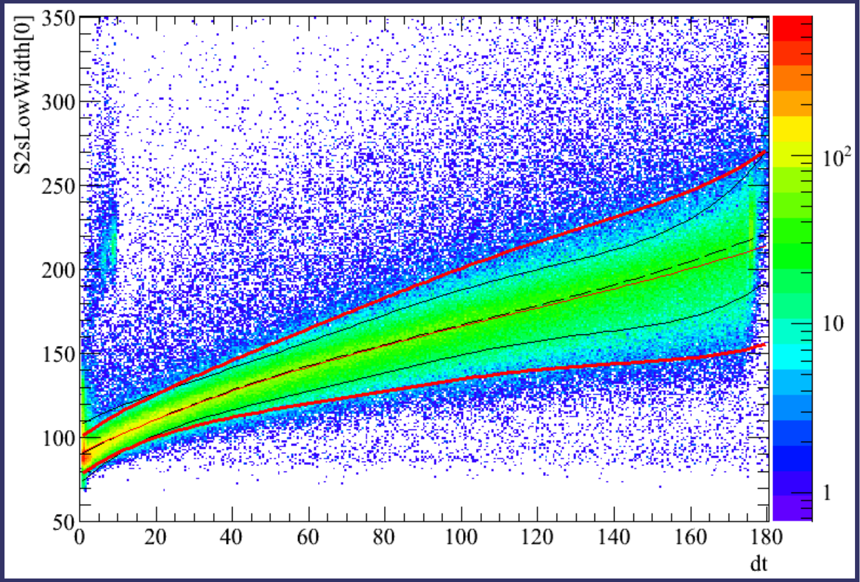
- We use a global fit of the available data to compute the quenching factor for nuclear re-coils
- Ongoing efforts to measure this quantity with a better precision
- In XENON100 [4-20] pe ~ [7-27]keVr



Background analysis

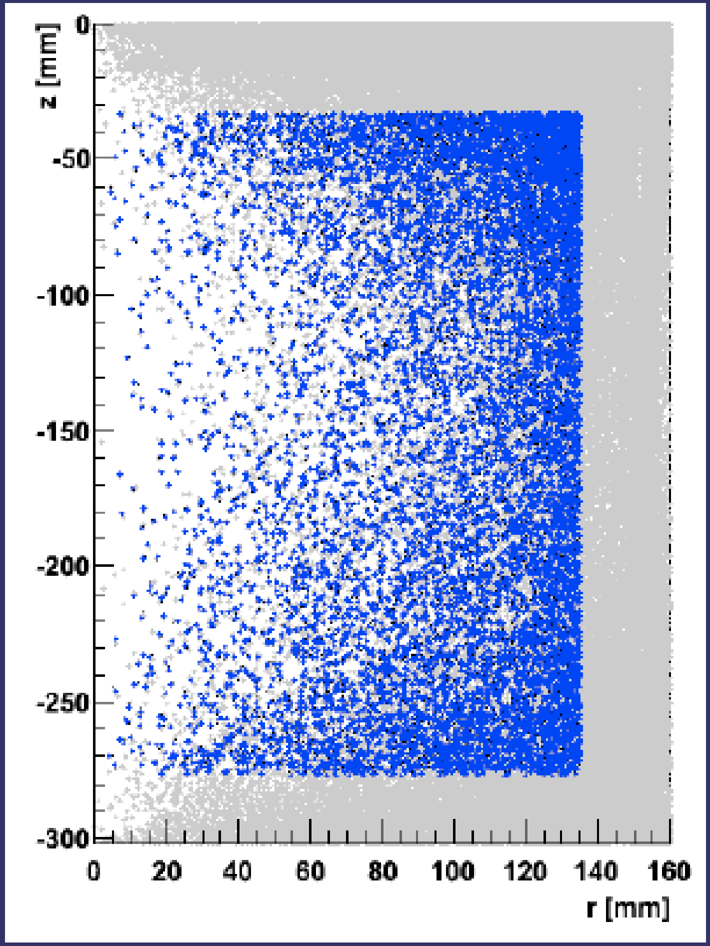
- ➲ 11.2 days of non blinded data were taken in the period Oct-Nov 2009
- ➲ Applied cuts are only optimized in calibration data
- ➲ Only very basic cuts are used:
- Single scatterers
- Reasonable signal to noise ratio
- Width and drift time of the event compatible(remove gas events)
- Veto anticoincidence



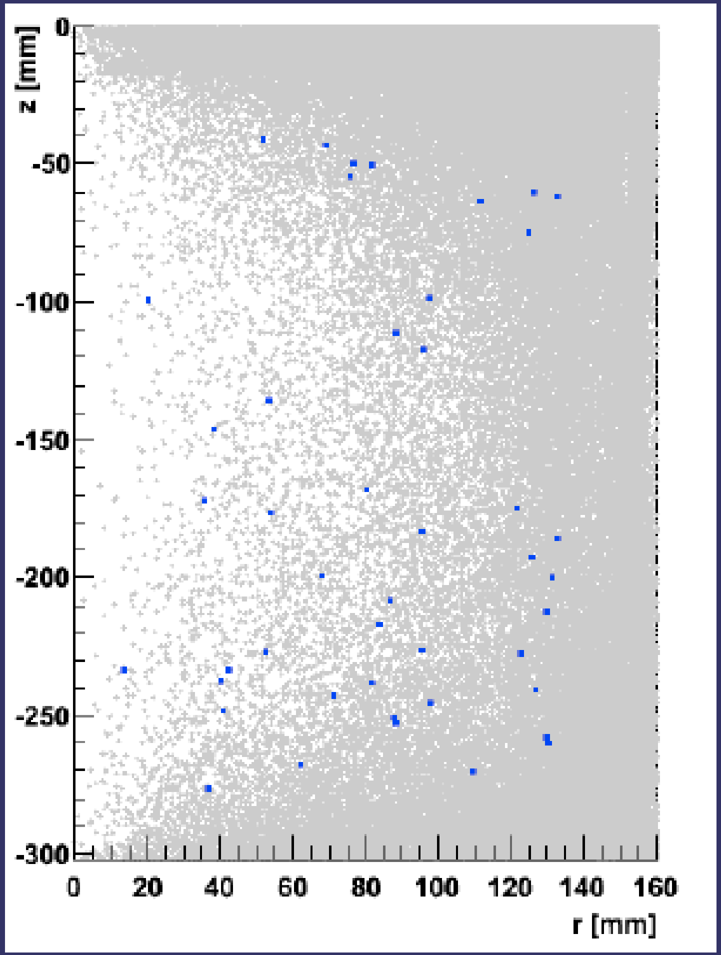


Background results: fiducialization and energy range

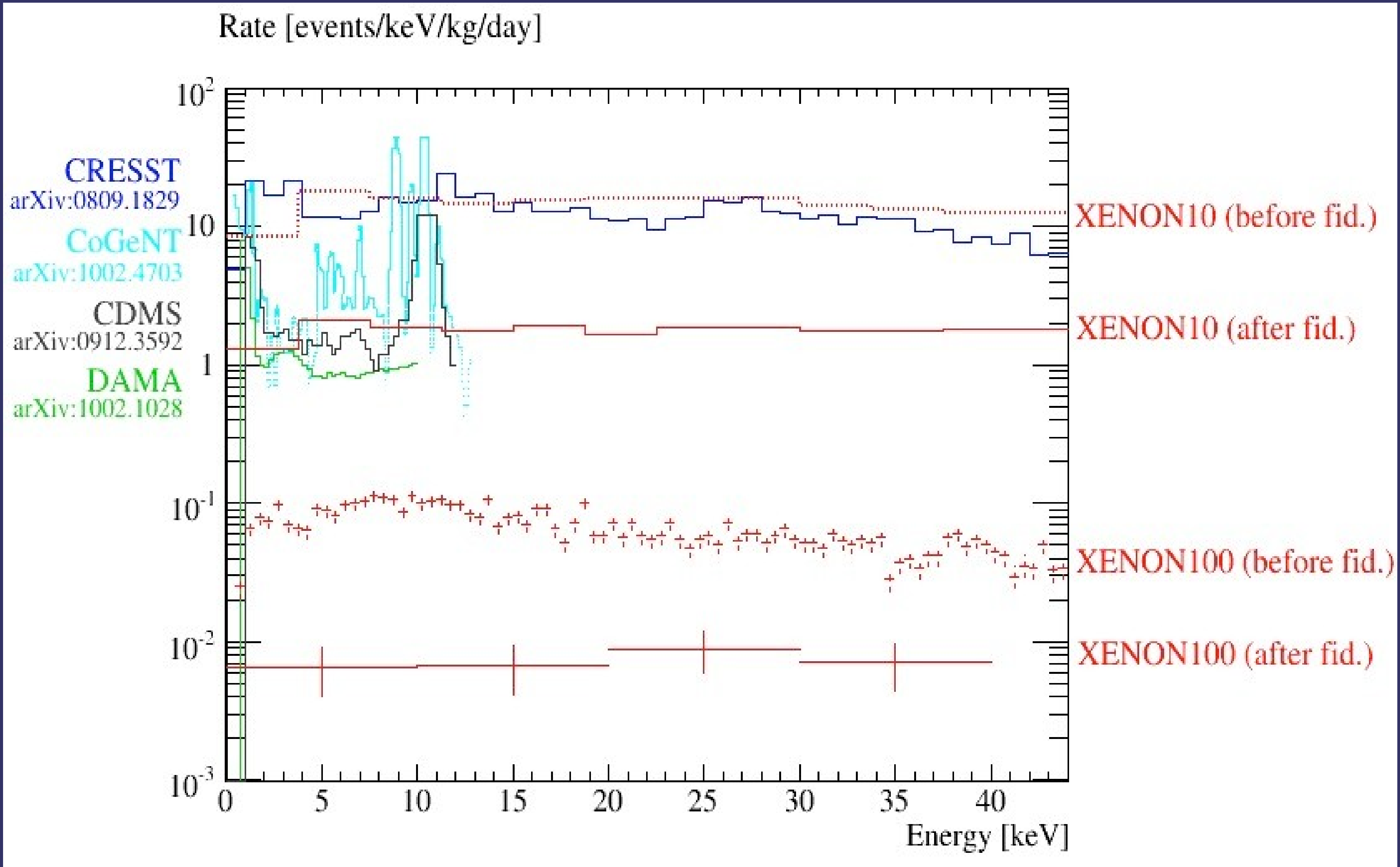
Selection of a 40kg cylindrical fiducial volume



Energy range selection <28 keVr

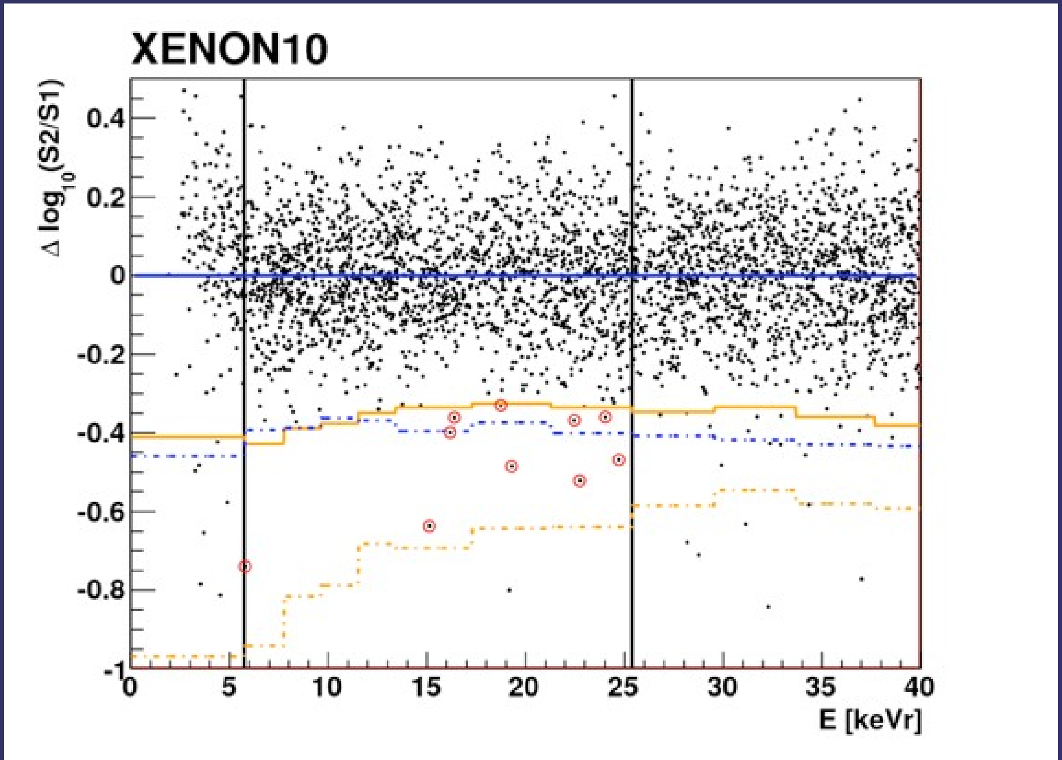


Background rate

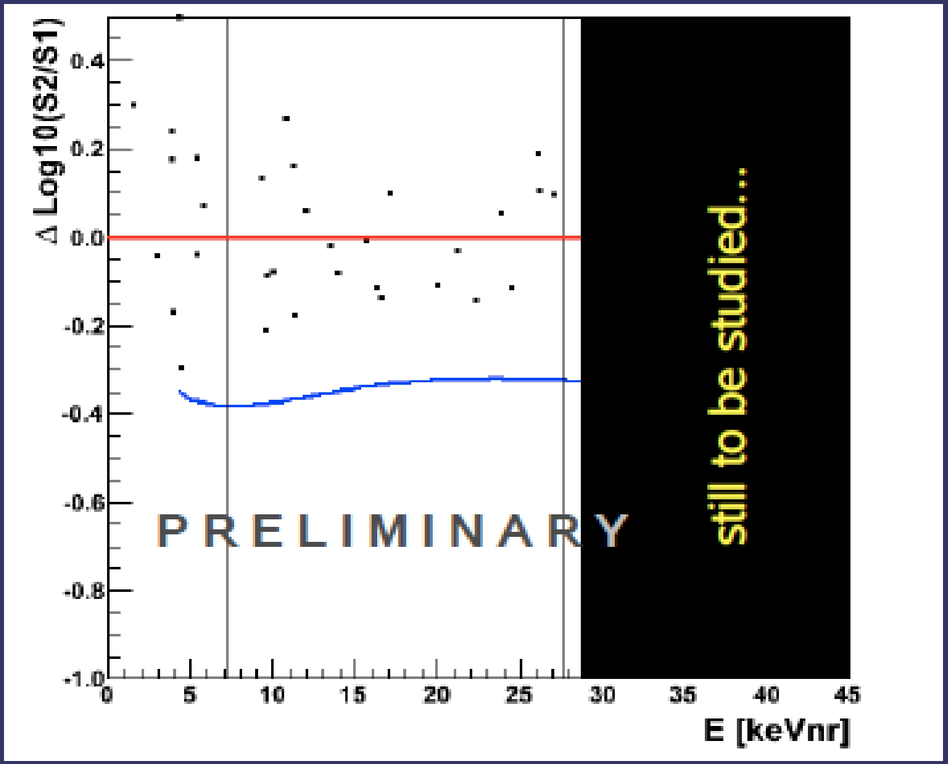


Background results after discrimina-tion

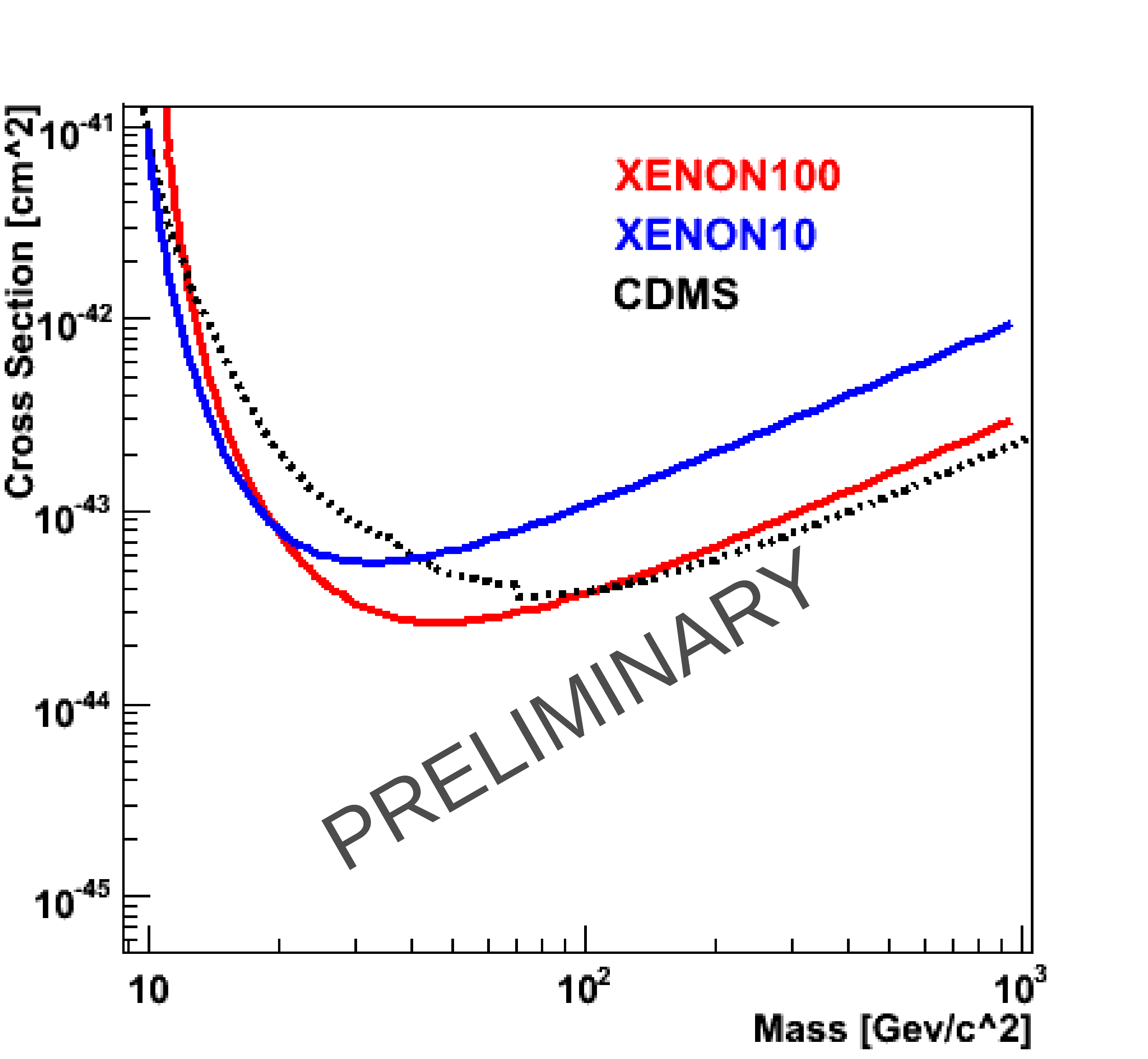
XENON10 PRL 100, 021303 (2008)
136 kg-days Exposure =
58.6 live days x 5.4 kg x 0.86 (ε) x 0.50 (50% NR)
(data collected between Oct.2006 and Feb.2007)



XENON100 PRL in preparation
190 kg-days Exposure =
11.2 live days x 40 kg x 0.85 (ε) x 0.50 (50% NR)
(data collected between Oct.2009 and Nov.2009)



0 backgrounds with a bigger exposure than XENON10!!

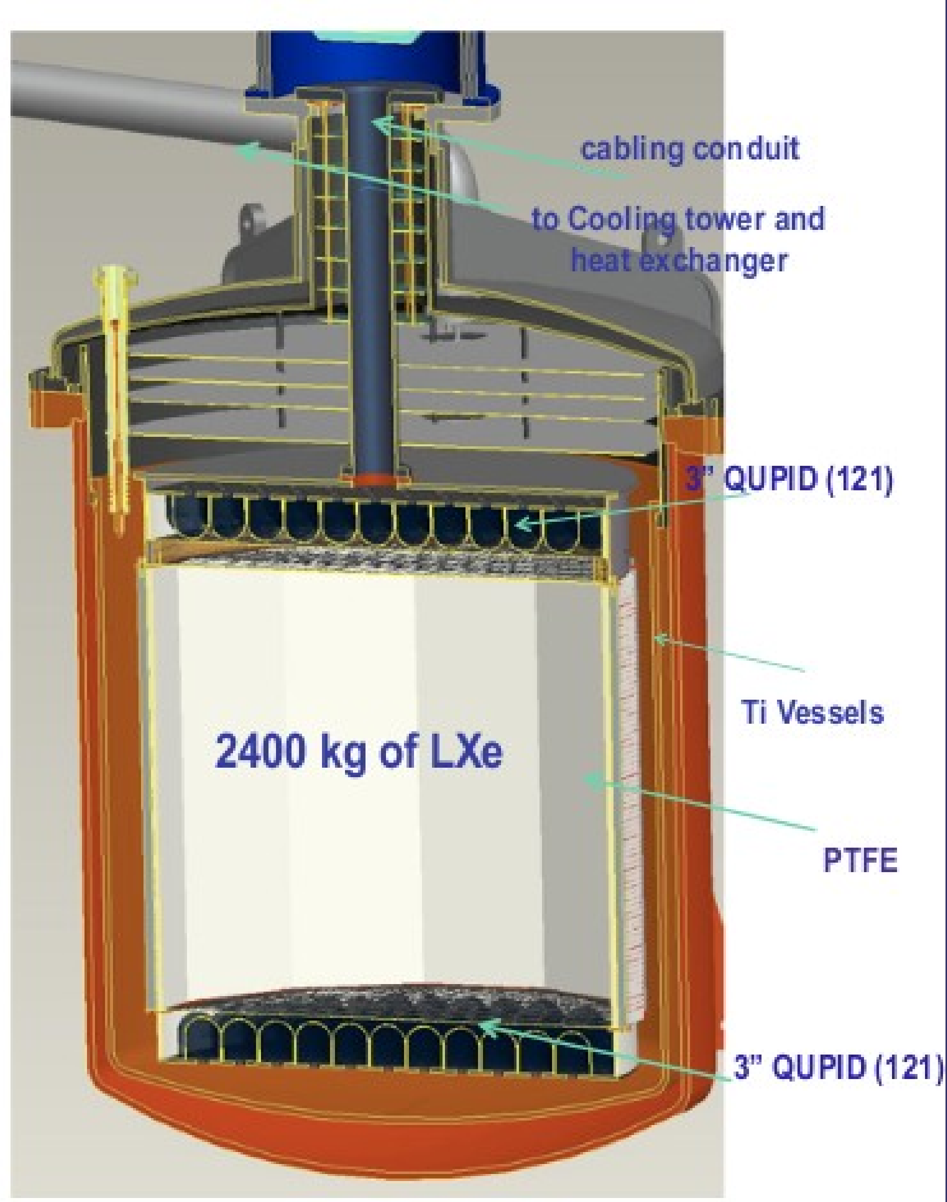

XENON100
XENON10
CDMS
PRELIMINARY
Cross Section [cm^2]
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10
10^{2}
10^{3}
Mass [Gev/c^2]

The case for 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.

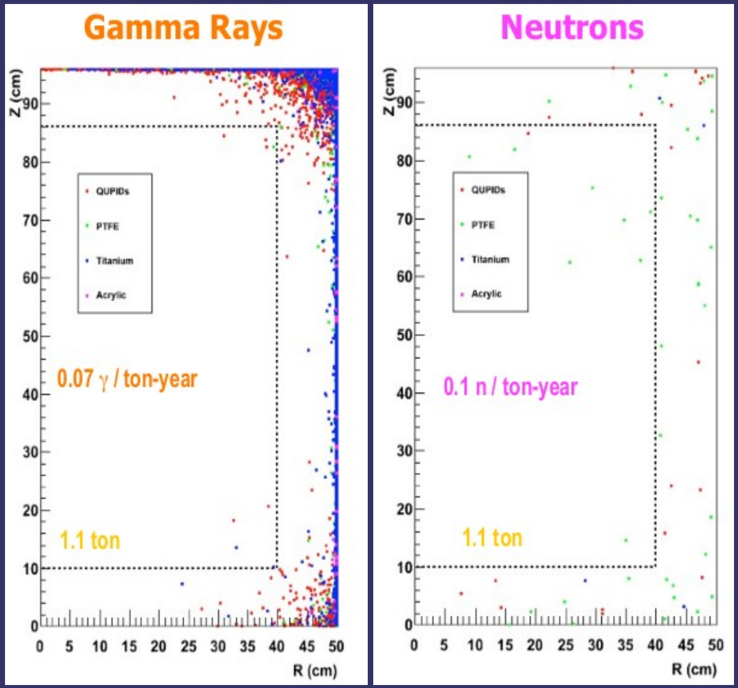
XENON1T: Detector overview

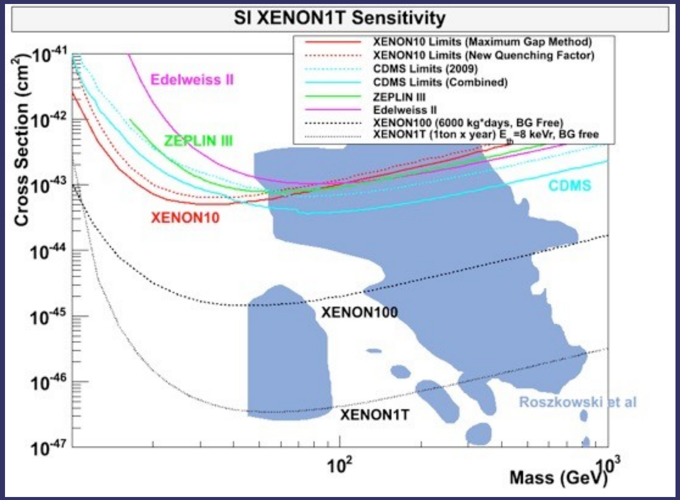
- Baseline design similar to XENON100 with improvements in different areas
  - lower radioactivity cryostat (Ti and Cu)
  - lower radioactivity PMTs (QUPIDs)
  - high efficiency heat exchanger: >98% achieved with Columbia setup
  - filling & recovery in liquid phase
- Design has been validated with detailed MC studies of internal/external background sources
- Capital cost ~ 8M$ shared equally between US and foreign groups



XENON1T: Scientific reach

- The detector will have a fiducial mass of ~1 ton of LXe
- QUPID sensors will measure the light from the interactions
- Simulations of the radiactivity from the material components show a back-ground of less than 1 event/ton·year
- Extensive simulations in the proposed si-tes and with the proposed shield configu-rations are being carried out to show a similar level from external components
- After one year of background free mea-surement, the sensitivity will be ~$5 \cdot 10^{-47} cm^2$, covering most of the CMSSM predictied region for SI interac-tions

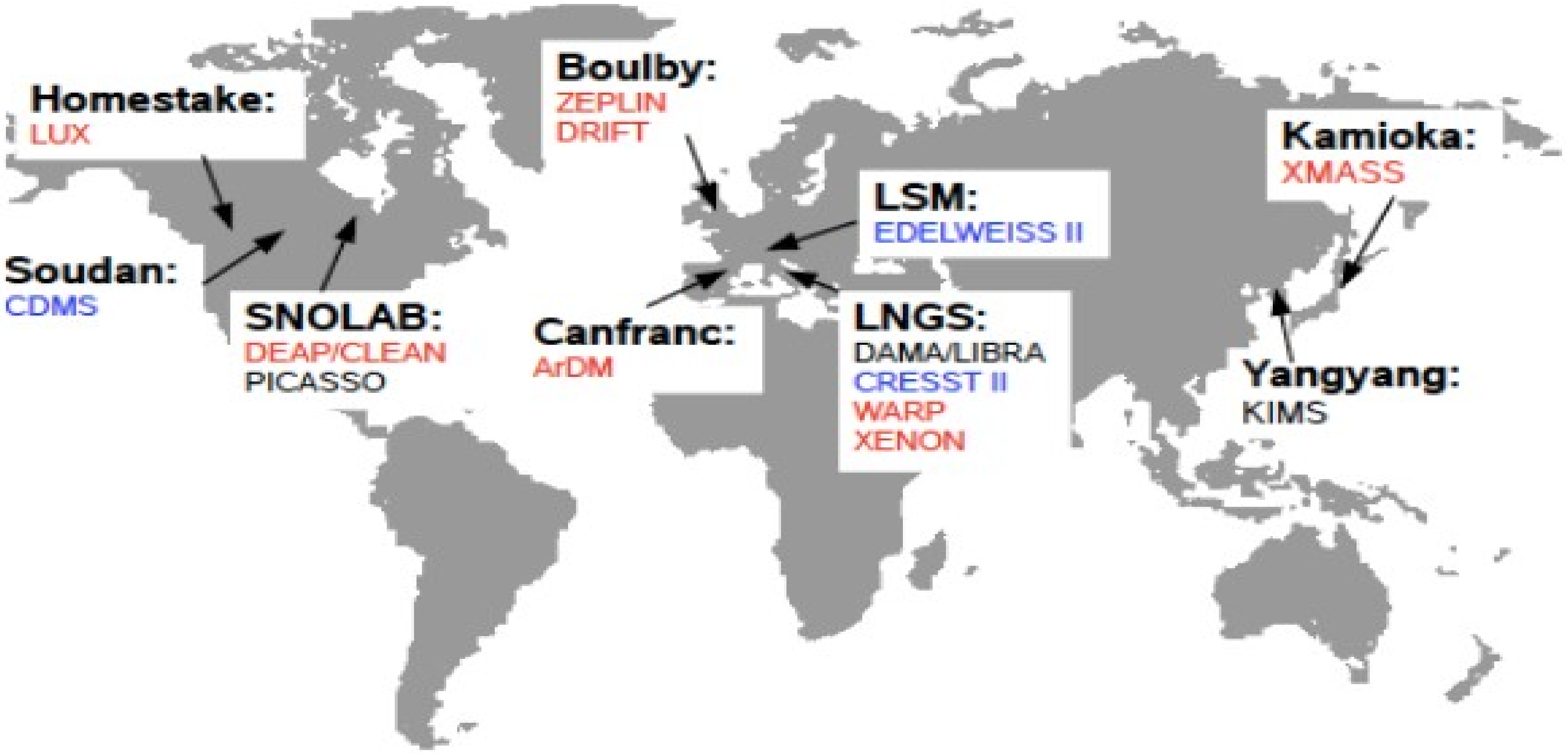




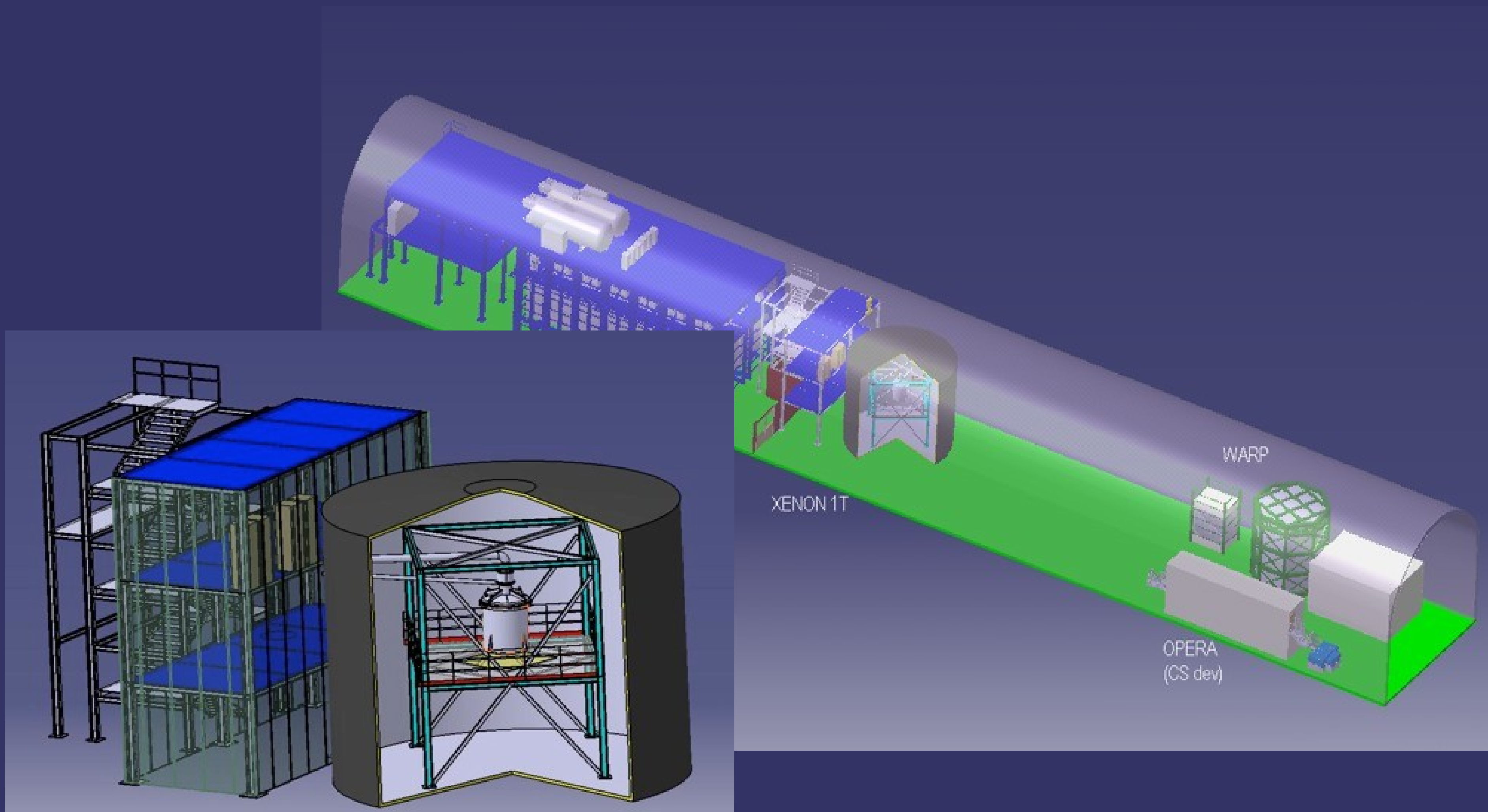
Location for Xenon 1T

Collaboration is studying two options for site and shield

- LNGS with a water tank acting as shield and muon veto
- LSM with a Polyethylene-Lead shield and plastic scintillators for muon veto

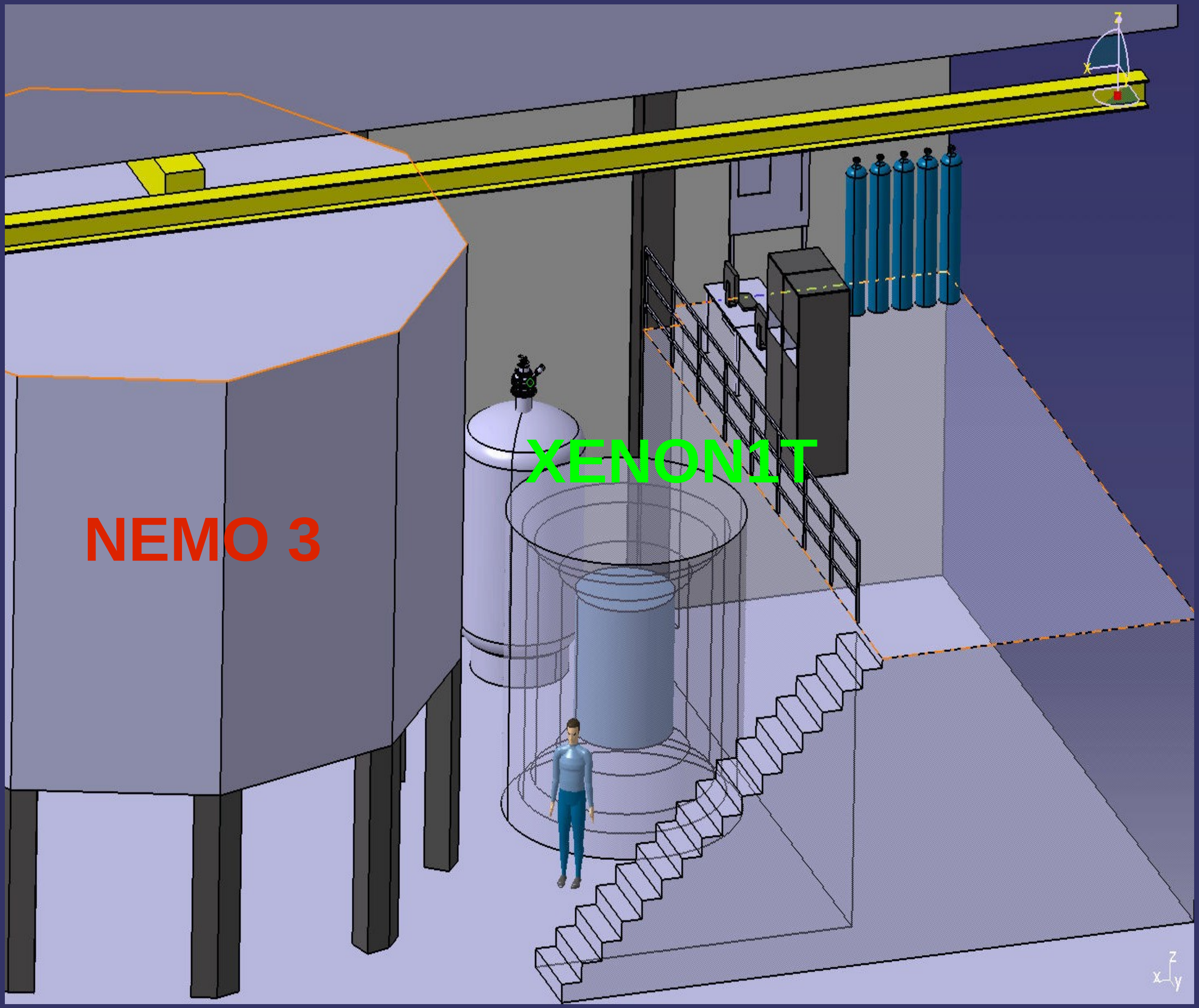


XENON1T at LNGS



5 m-thick water shield

XENON1T at LSM



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


The End