Status of the XENON100 experiment

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www.physik.uzh.ch/groups/groupbaudis/xenon/

Outline

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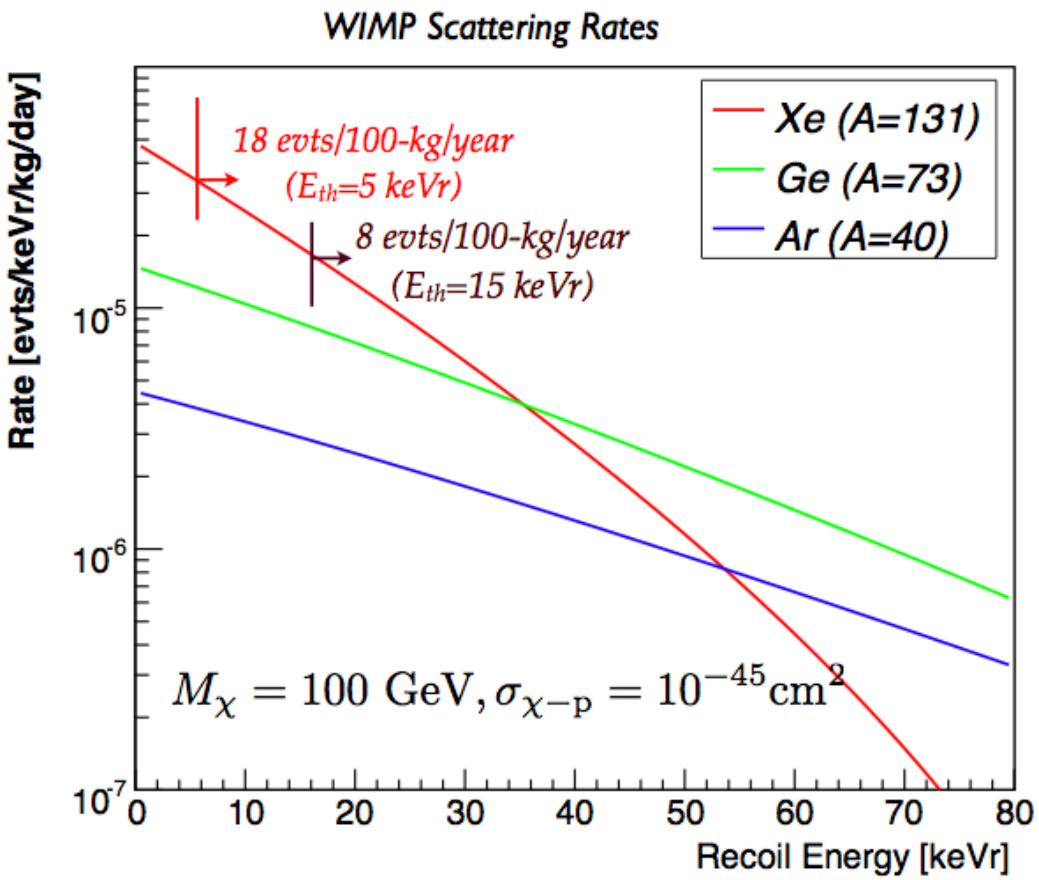
Xenon as detection medium

Detection via scatter off nuclei

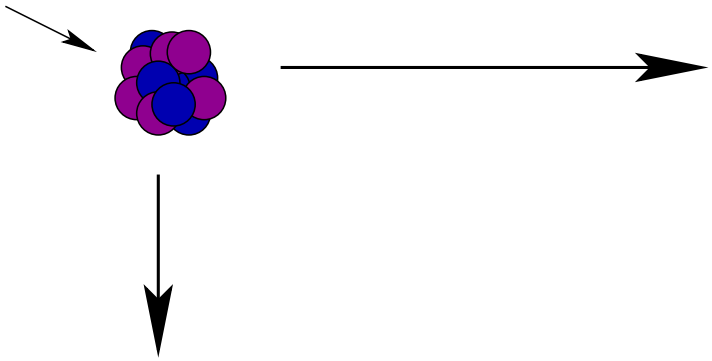


Xe

- Self-shielding
  → High stopping power
- 178 nm UV photons
  → No wavelength-shifter
- Simple cryogenics
  $\sim$ 180 K = - 93°
- High atomic mass $A \sim 131$
  → spin-indep. interactions
- ^{129}Xe and ^{131}Xe
  → spin-dep. interactions

Noble gas scintillation process

Nuclear recoil



Excitation: R^*

$$R^* + R \rightarrow R_2^*$$

$$R_2^* \rightarrow 2R + h\nu$$

singlet triplet

Ionization: R^+ and e^-'s

$$R^+ + R \rightarrow R_2^+$$

$$R_2^+ + e^- \rightarrow R^{**} + R$$

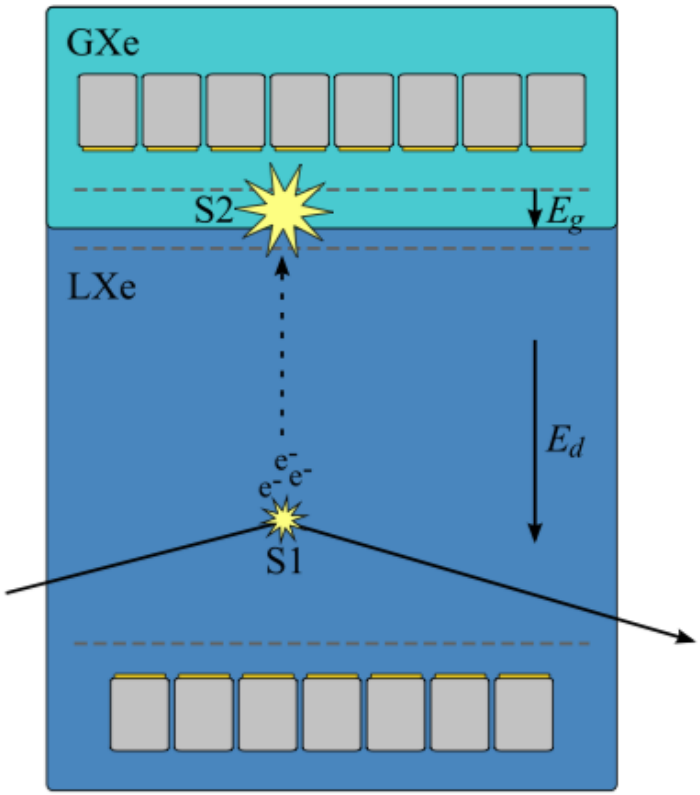
$$R^{**} \rightarrow R^* + \text{heat}$$

$$R^* + R \rightarrow R_2^*$$

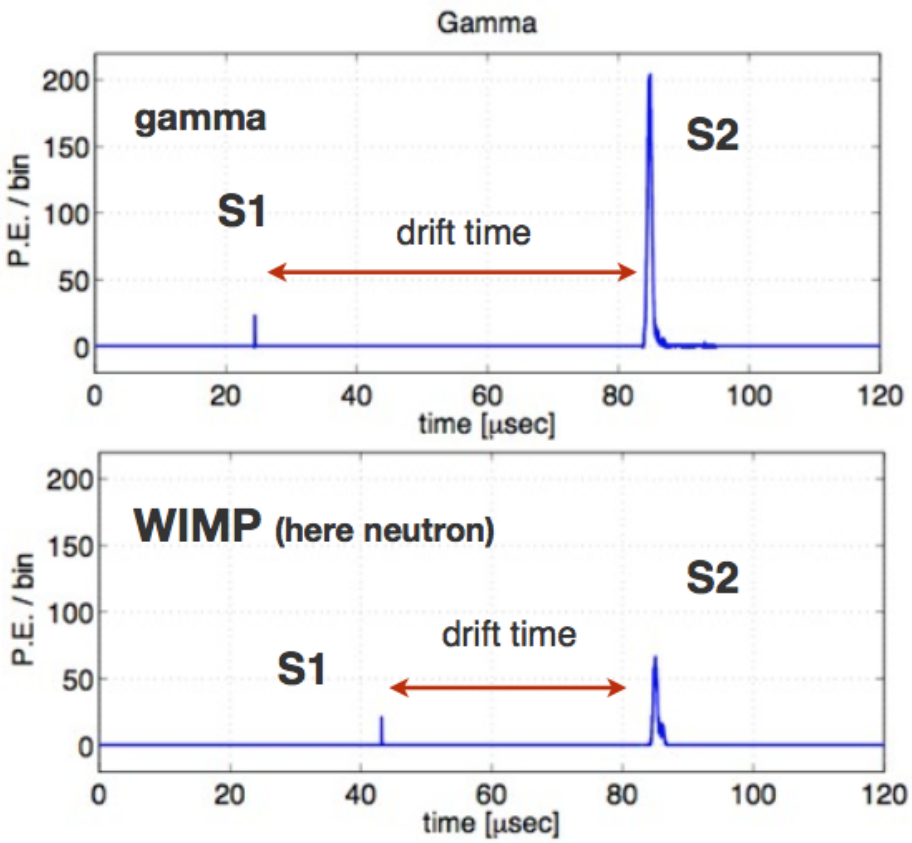
$$R_2^* \rightarrow 2R + h\nu$$

singlet	triplet	
19 ns	15 μs	Neon
5 ns	1.6 μs	Argon
3 ns	25 ns	Xenon

Two phase noble gas TPC



- Scintillation signal (S1)
- Charges drift to the liquid-gas surface
- Proportional signal (S2)



Electron recombination is stronger for nuclear recoils

→ Electron- / nuclear recoil discrimination

Outline

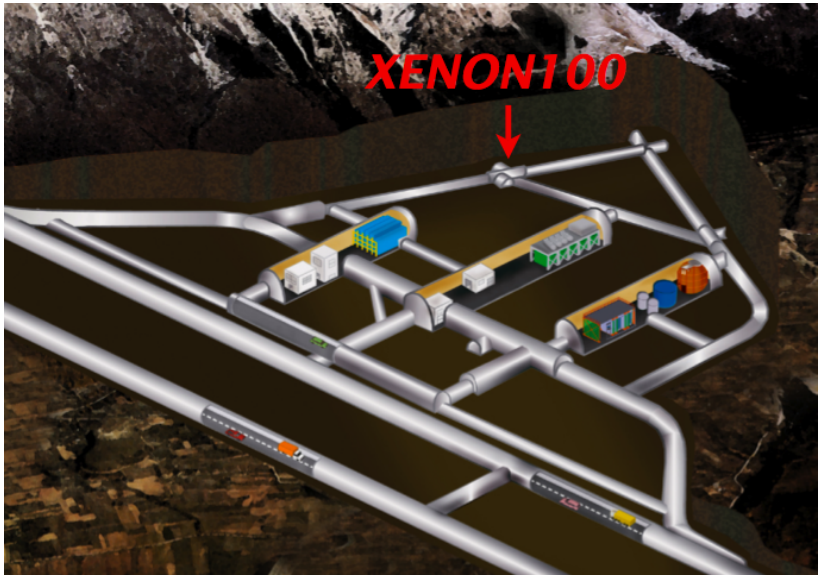
XENON experiment

- Laboratori Nazionali del Gran Sasso (Italy)
- $\sim$ 3 650 m.w.e. shielding

- XENON10: 15 kg active volume
  - Finished: No evidence for DM

    J. Angle *et al.*, Phys. Rev. Lett. 100, 021303 (2008)
    J. Angle *et al.*, Phys. Rev. Lett. 101, 091301 (2008)
    J. Angle *et al.*, Phys. Rev. D80, 115005 (2009)
- XENON100: 62 kg active volume
  - Currently running

    E. Aprile *et al.*, Phys. Rev. Lett. 105, 131302 (2010)



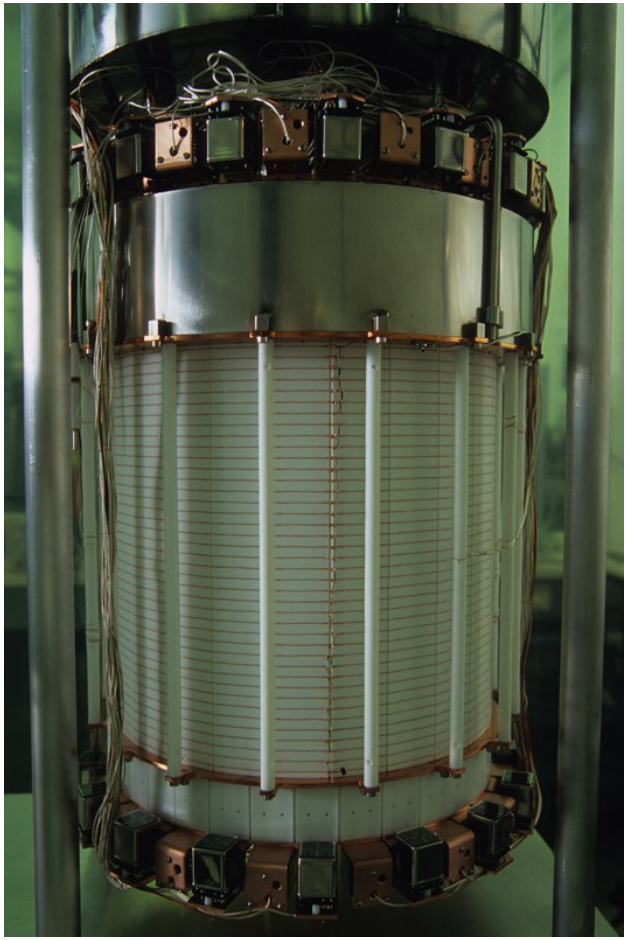
XENON100 Collaboration

Columbia | Rice | UCLA | Zürich | Coimbra | LNGS | SJTU

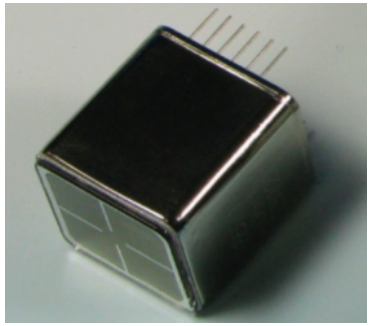
Mainz | Bologna | Subatech | Münster | Nikhef | Heidelberg | Weizman

US, Switzerland, Portugal, Italy, China, Germany, Holland, France and Israel

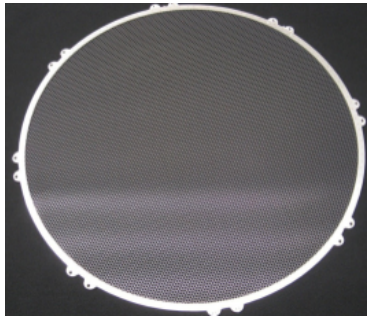
XENON100 detector



- 30 cm drift length and 30 cm ∅
- 161 kg total (30-50 kg fiducial volume)
- ∼ 100x less background than XENON10
- Material screening and selection
- 242 low activity 1” PMTs (R8520)
- Cooling (PTR) outside the shield
- Active liquid xenon veto



1 inch PMTs



30 cm ∅ meshes

XENON100 detector

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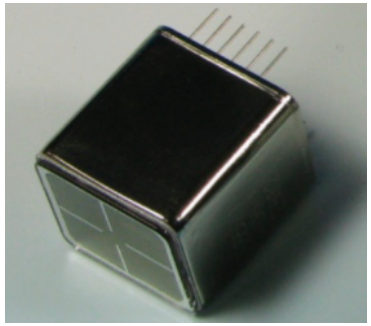
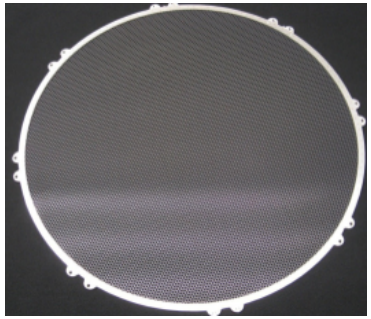


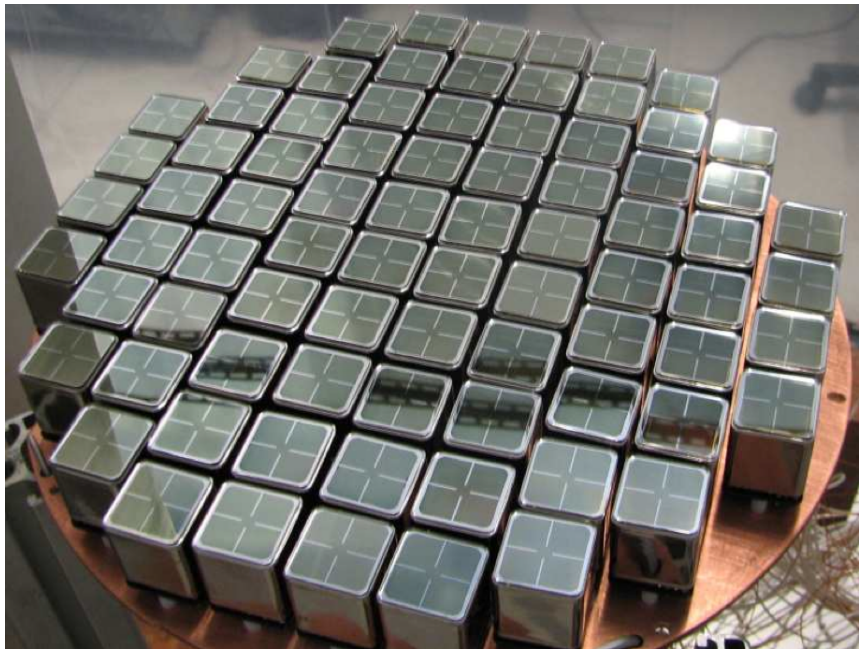
1 inch PMTs



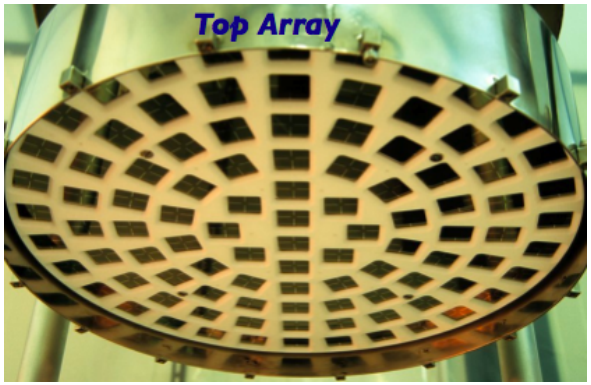
30 cm ∅ meshes

Light and charge read out

- Bottom PMTs: high quantum efficiency (on average >30% @178 nm)

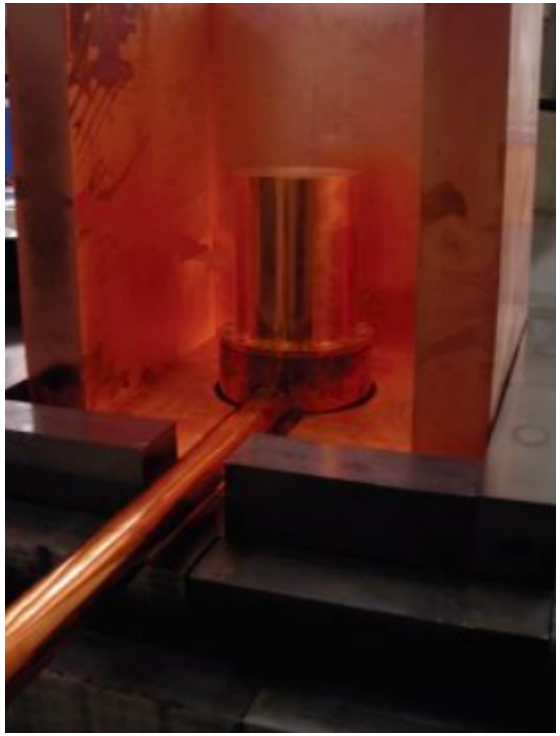


- 3 Dim. position reconstruction
  - XY from light pattern in the PMTs
  - Z from the drift time
- 3 mm resolution in XY and 2 mm in Z

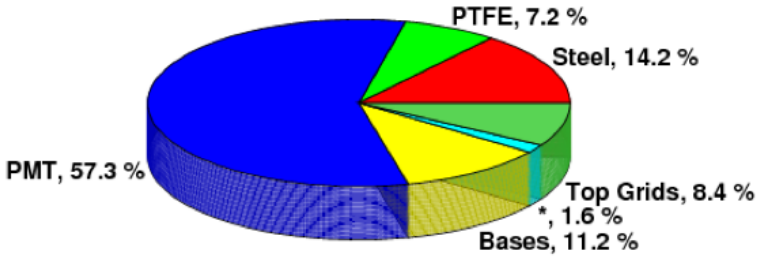


Background prediction

Material screening underground with a 2.2 kg HP Ge detector



- Gamma background expected in WIMP search region:
  - $5 \cdot 10^{-3}$ evts/kg/keV/d (before S2/S1 discrimination)

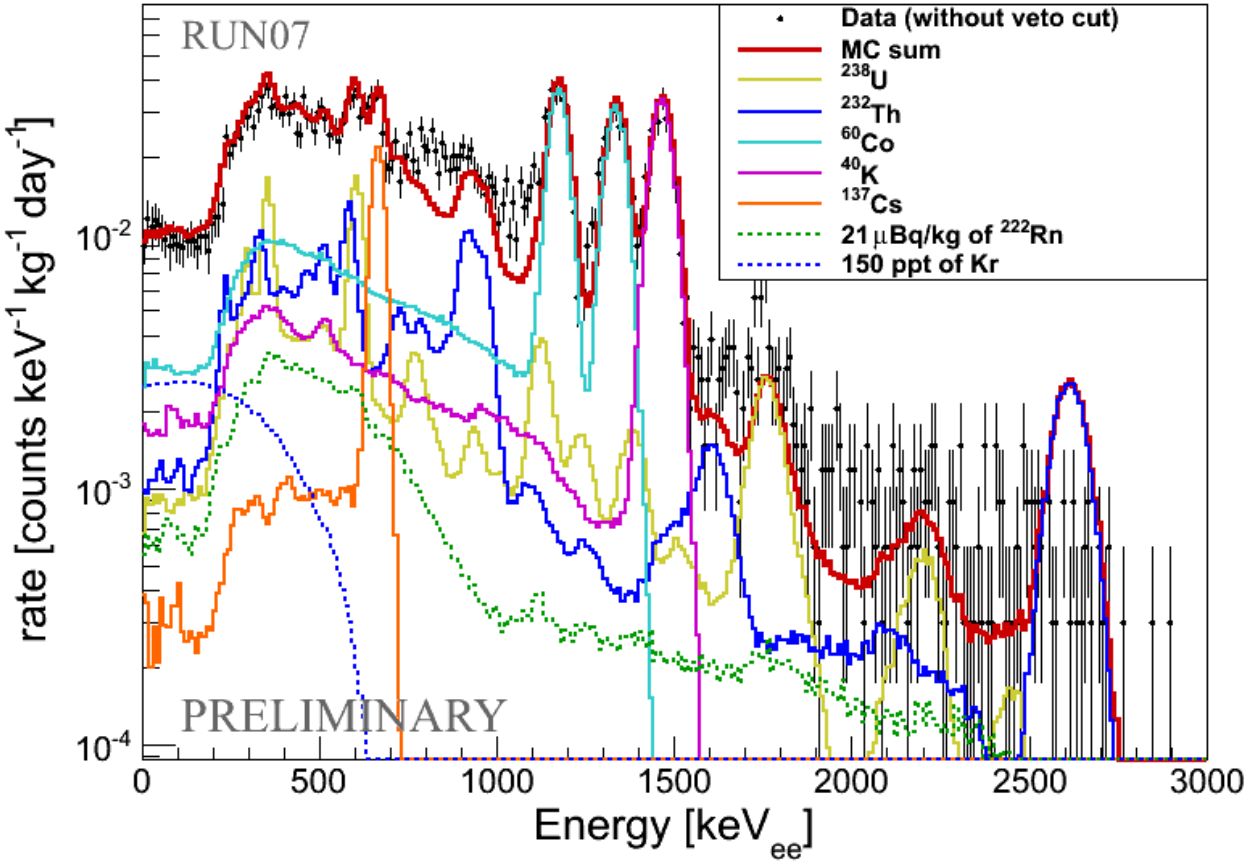


- Neutron bg from simulations:
  - 2/3 from radioactivity and 1/3 muon-induced

- Removal of ^{85}Kr: distillation column
  - Kr/Xe $\sim$ ppm-ppb commercially available
  - Measurement in XENON100 after purification:

$\rightarrow$ RUN07: $\sim$ 150 ppt via delayed gamma-beta coincidence

Measured background spectrum



- No tuning of the Monte Carlo
- The measured single scatter rate below 100 keVee is 10^{-2} evts/kg/keV/d without veto cut

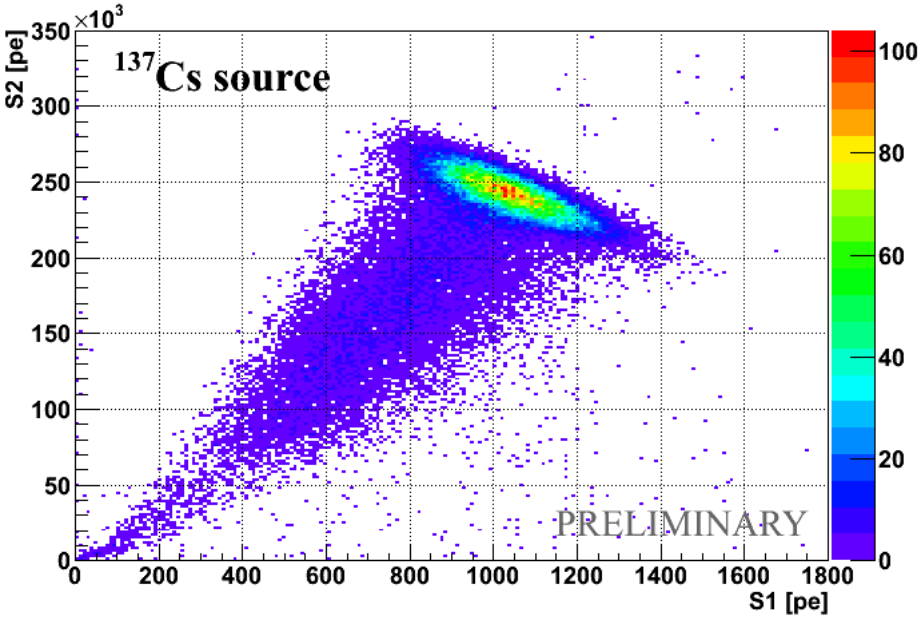
→ is reduced by 50% with veto cut!

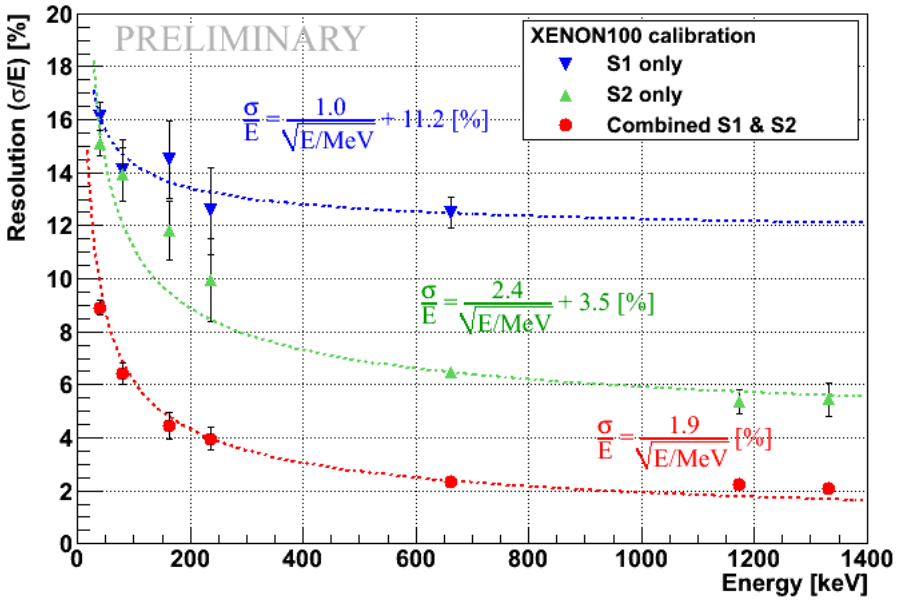
- Factor 100 less than in XENON10 achieved!

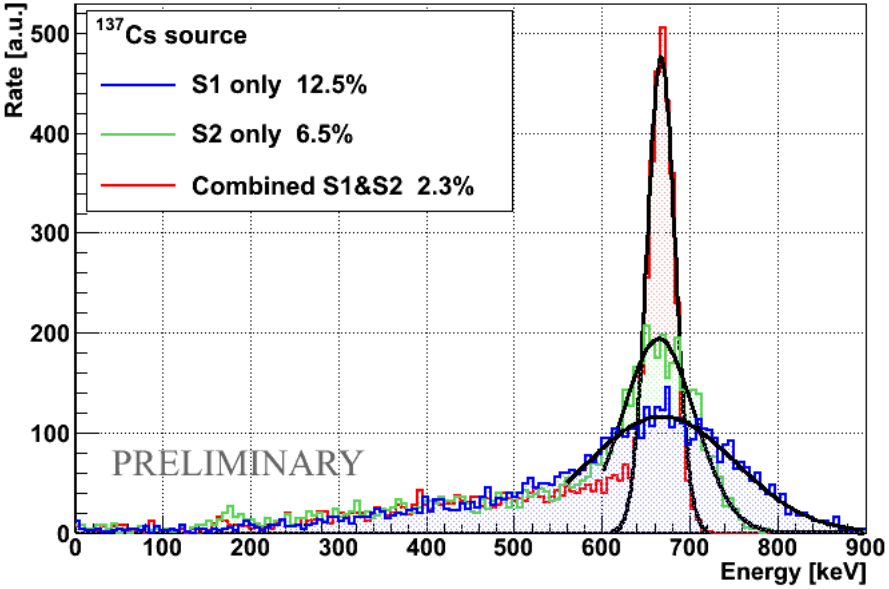
→ currently optimizing the data/MC comparison

Outline

Calibration with gamma sources



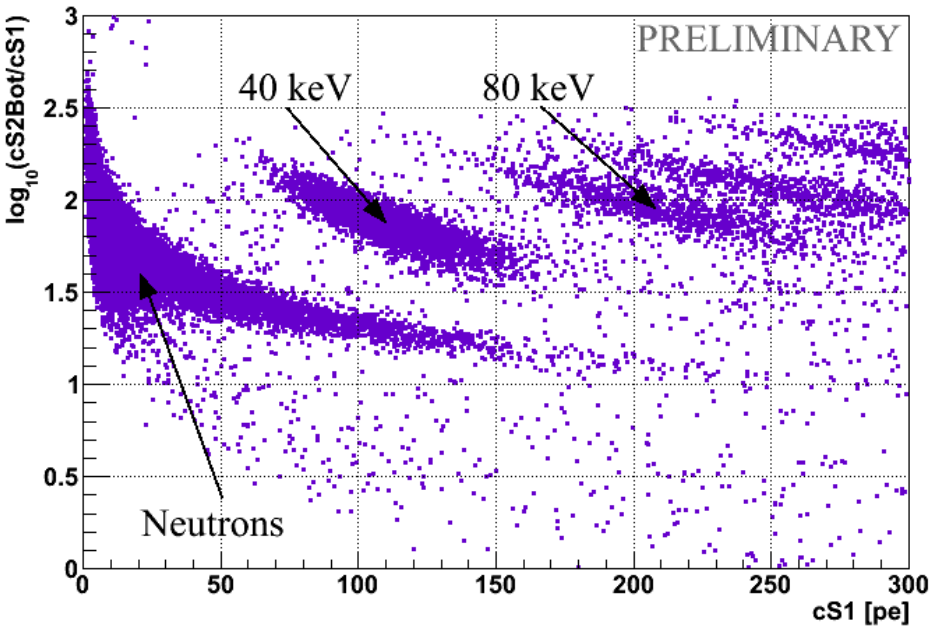


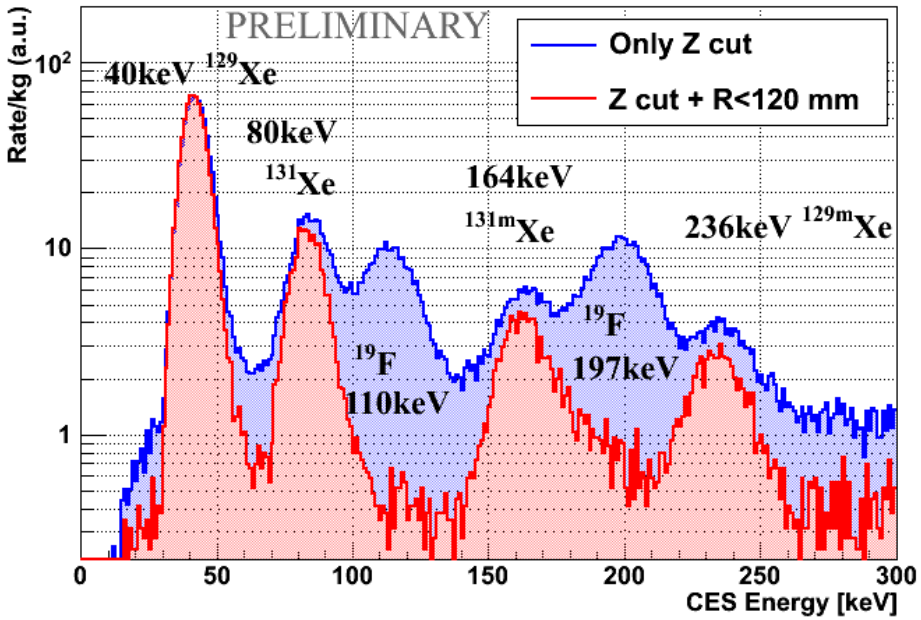


- Energy dependence of resolution in light (S1), charge (S2) and CES signals
- CES: combined energy scale

→ using anticorrelation between S1 and S2 signals

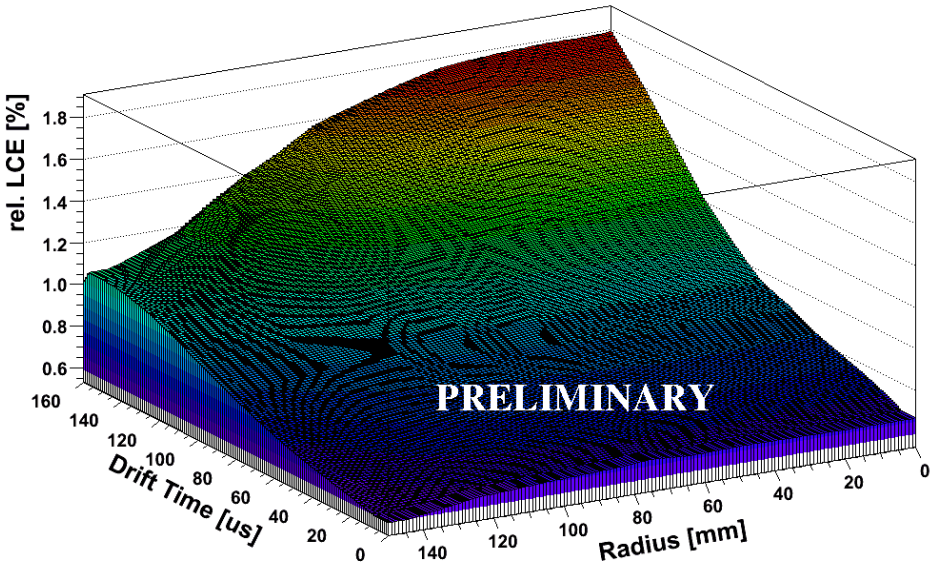
Neutron calibration

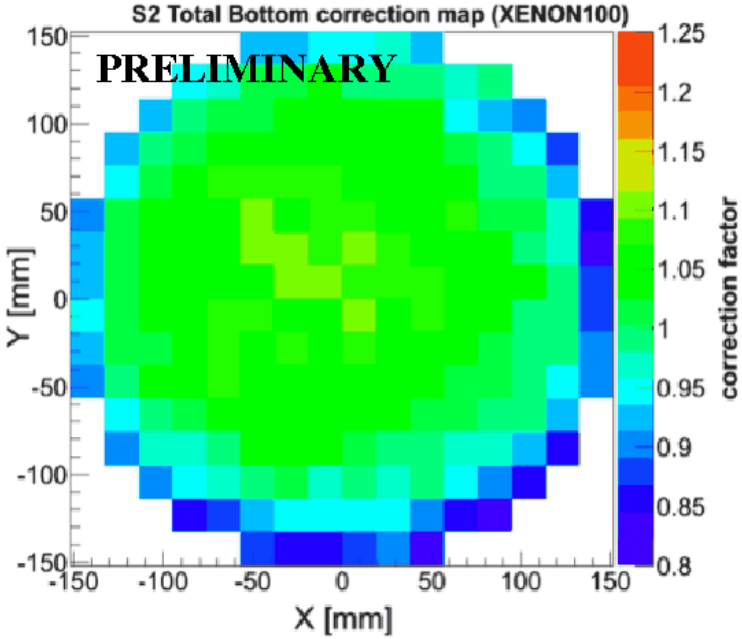




- Source: AmBe with 220n/s
- Determination of nuclear recoil band
- Further calibration lines from inelastic recoils in xenon

Corrections on the S1 and S2 signals

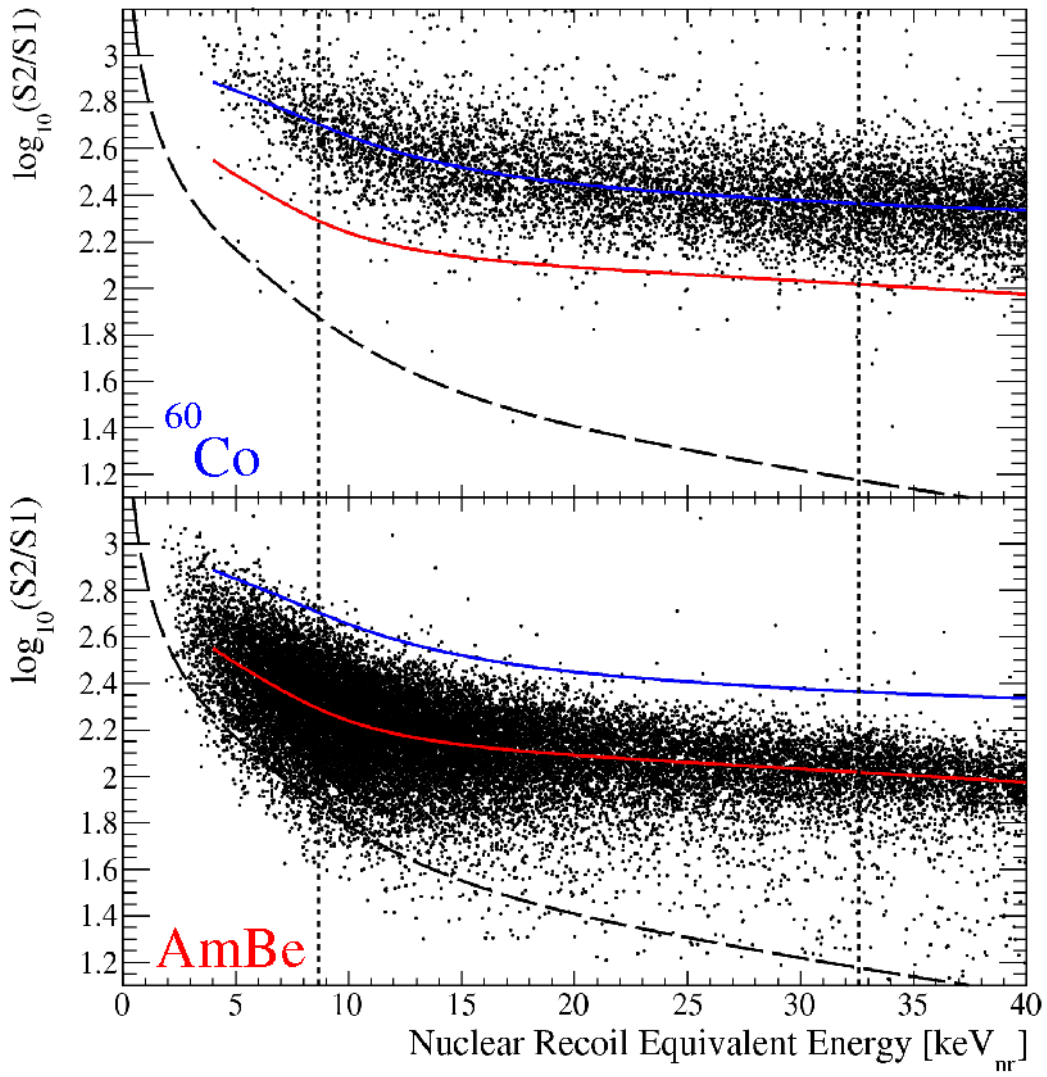




- Data is corrected for:
  - S1 light collection
  - S2 XY-collection
  - Electron lifetime
- Sources used for corrections:
  - 40keV, inelastic line
  - ^{137}Cs (external)
  - 164 keV, activated xenon

→ Results from different sources compatible within few %

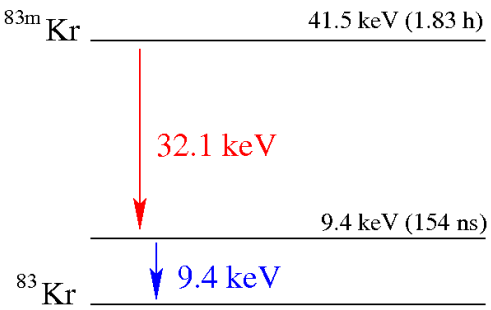
Electronic and nuclear recoil bands

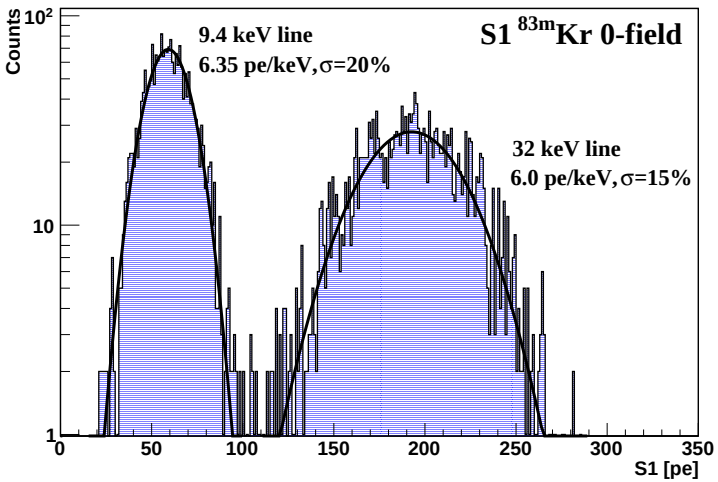


- Electronic recoil band: defined with ^{60}Co source
- Nuclear recoil band: defined with AmBe neutron source
- Discrimination better than 99% @ 50% nuclear recoil acceptance

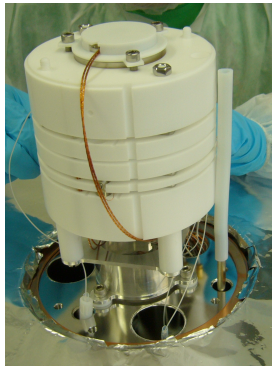
Low energy calibration of xenon detectors

- ^{83m}Kr calibration source:
  - EC decay-product of ^{83}Rb
  - Lines at 9.4 and 32.1 keV
  - Uniform distribution



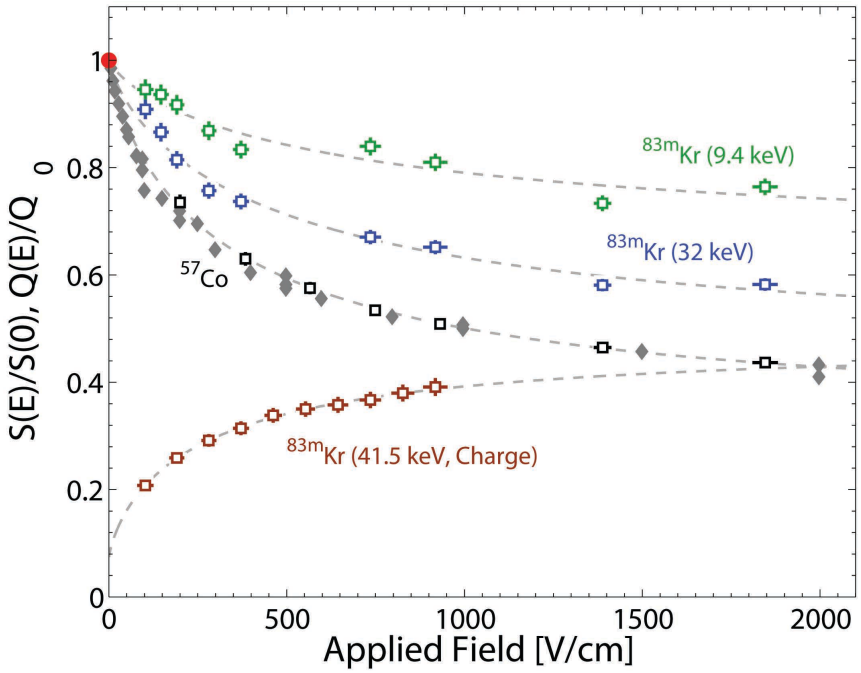


→ ^{83m}Kr calibration planned in XENON100



- Target mass: ∼ 0.1 kg Xe
- Volume: 3 cm drift length and 3.5 cm diameter
- Two R9869 PMTs
- 6 pe/keV in double phase

→ at University of Zürich



A. Manalaysay *et al*, Rev. Sci. Instrum. **81**, 073303 (2010)

Calibration of the nuclear recoil energy scale

- Nuclear recoil energy (E_{nr}):

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

$S1$: measured signal in p.e.

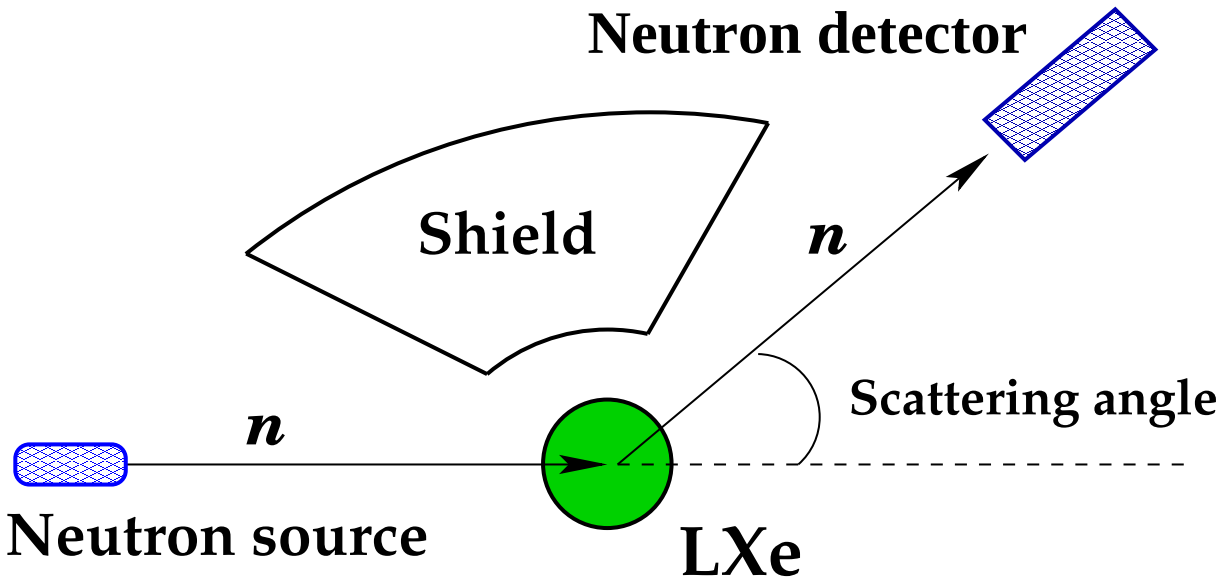
L_y: LY for 122 keV γ in p.e./keV

S_e/S_r: quenching for 122 keV γ/NR due to drift field

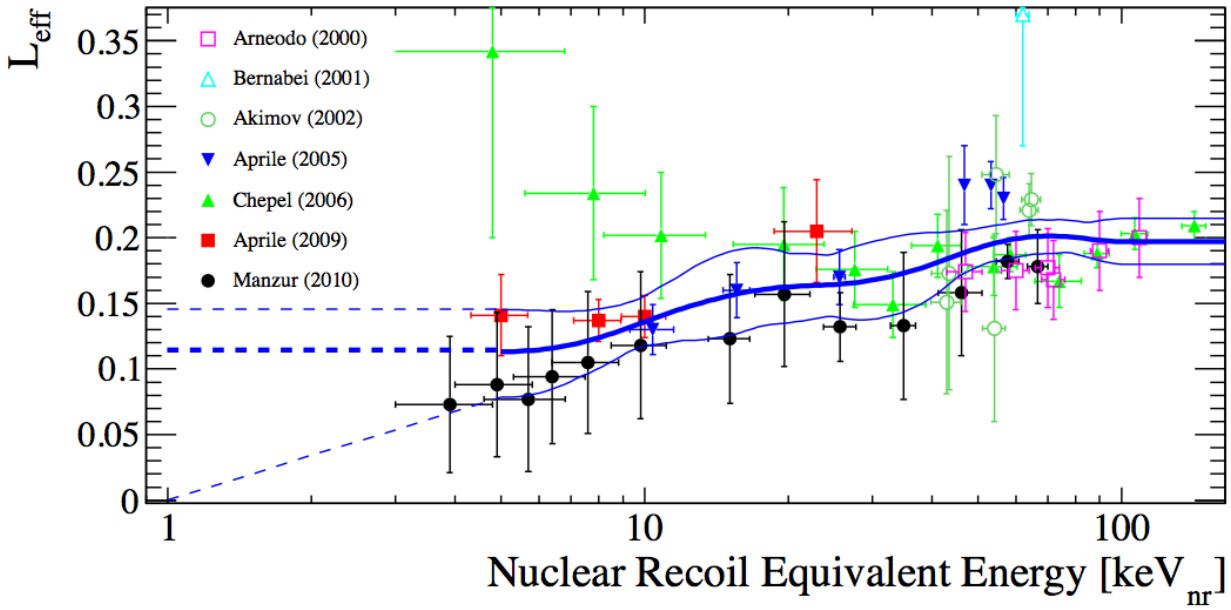
- Relative scintillation efficiency of NR to 122 keV γ at 0-field

$$L_{eff} = q_{nucl} \times q_{el} \times q_{esc}$$

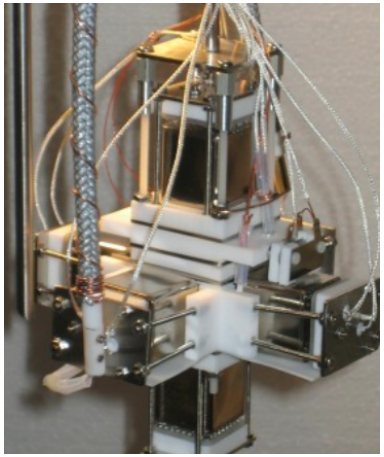
  - q_{nucl}: Linhard quenching
  - q_{el}: Electronic quenching
  - q_{esc}: Escape e^-'s at 0-field

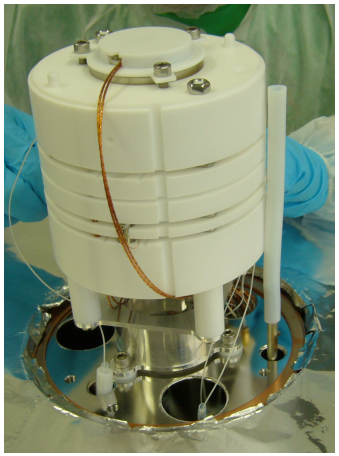


Measuring the nuclear recoil scale



- Efforts within the collaboration to measure below 5 keV_{nr}





→ Columbia and Zürich chambers

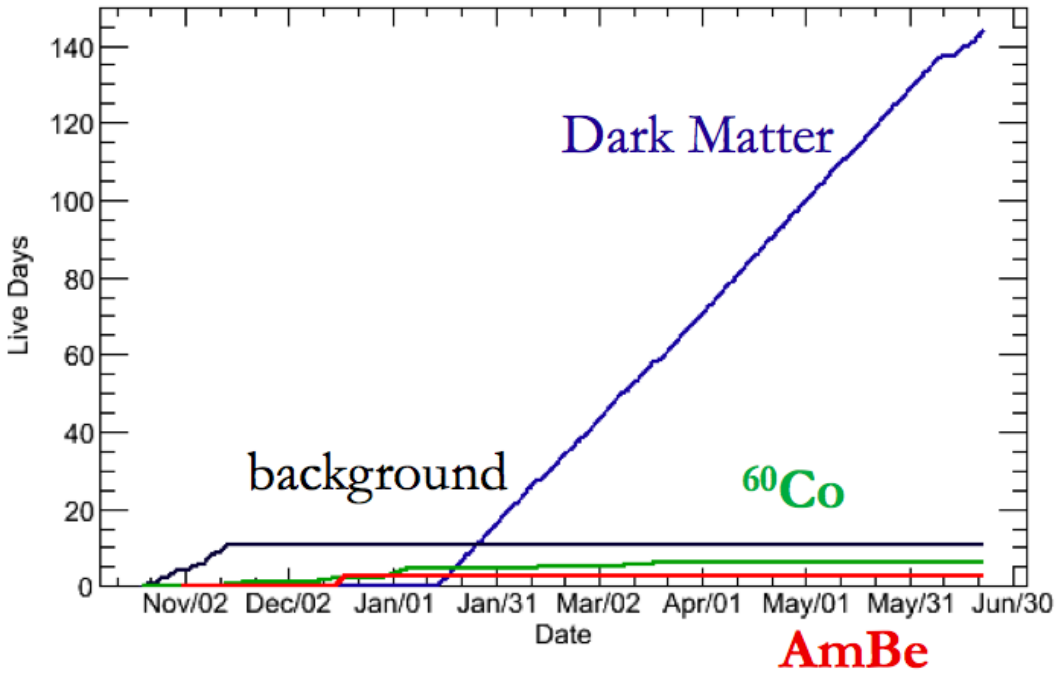
- First measurements done at Columbia!

Discussions on Leff measurements:
A. Manalaysay, arXiv:1007.3746

Outline

Data sample

Overview of the data taking:



→ Analysis of non-blinded data

→ Main data sample still blinded

- 11.17 life days
- Data selection based on stable conditions:
  - no activation
  - stable HV operation
  - low and constant Rn level
- Period:

  October-November 2009
- Cuts defined on calibration data: AmBe and ^{60}Co

Cuts applied to the data

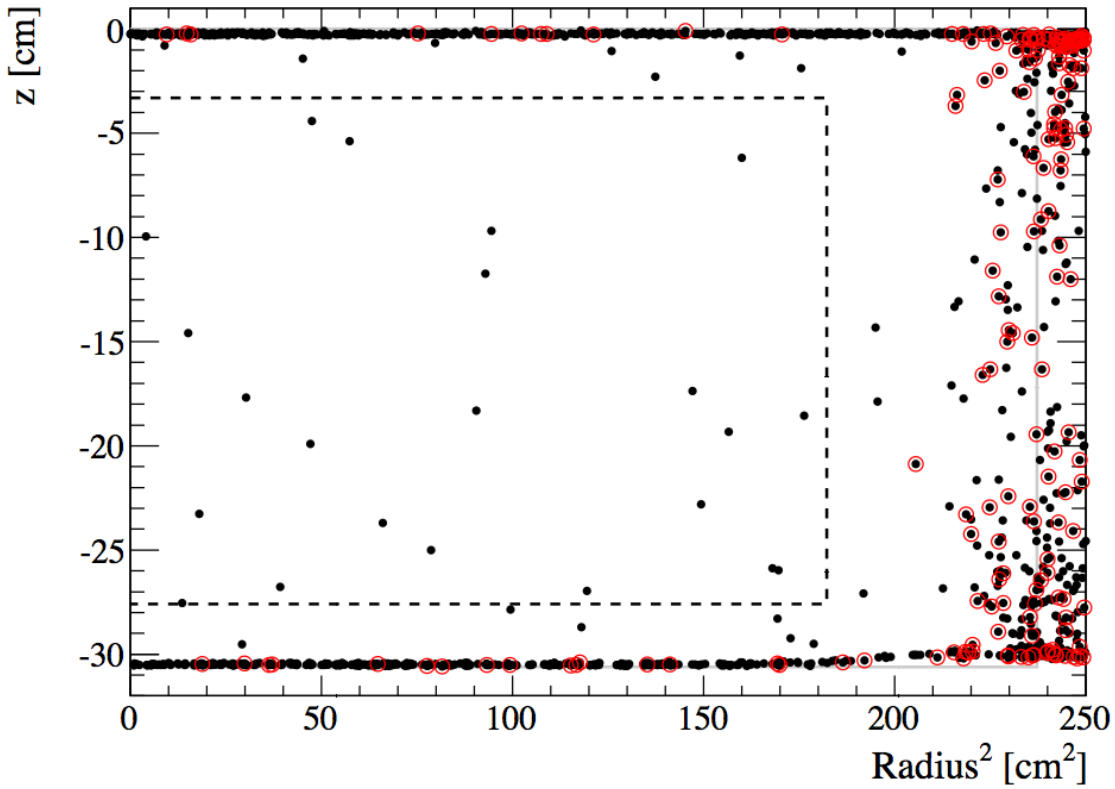
- Signal/noise ratio cut
- Single S1 peak: remove accidental coincidences
- Single S2 peak: select single scatter events
- Remove events in gas phase
- Apply active veto cut

- Energy cut: Select events with energies lower than 28 keV_{nr} (keV nuclear recoil equivalent)

!! Self-shielding: Most of the low energy events are located close to the edges of the detector

→ remaining events in fiducial volume: mostly intrinsic contamination

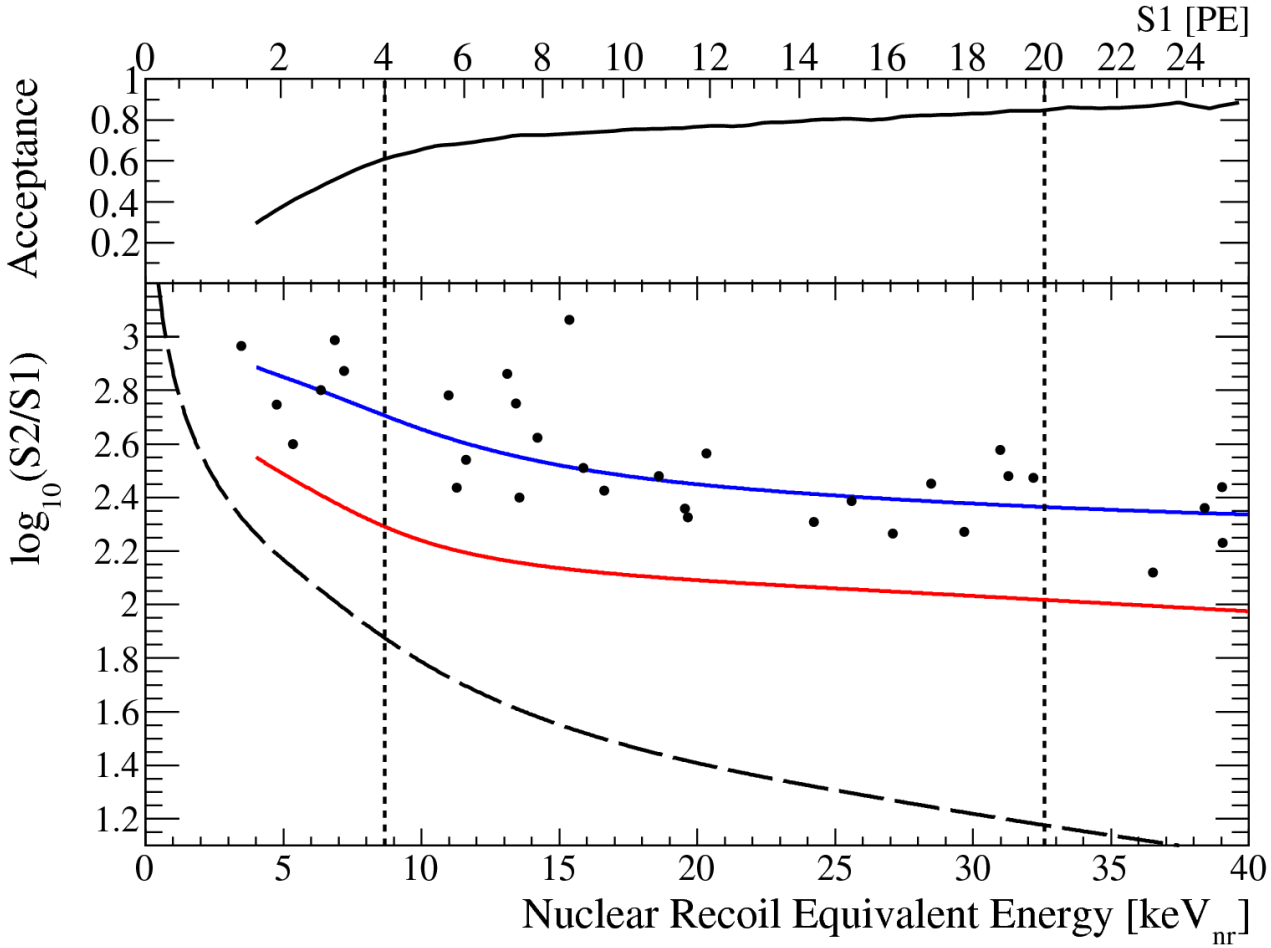
Fiducial volume



- 3-D position reconstruction:
  allows the selection of the inner part of the detector
  - events with energies below 28 keV$_{nr}$
- Current fiducial volume: cylindrical shape with 40 kg mass

$\longrightarrow$ will be further optimized

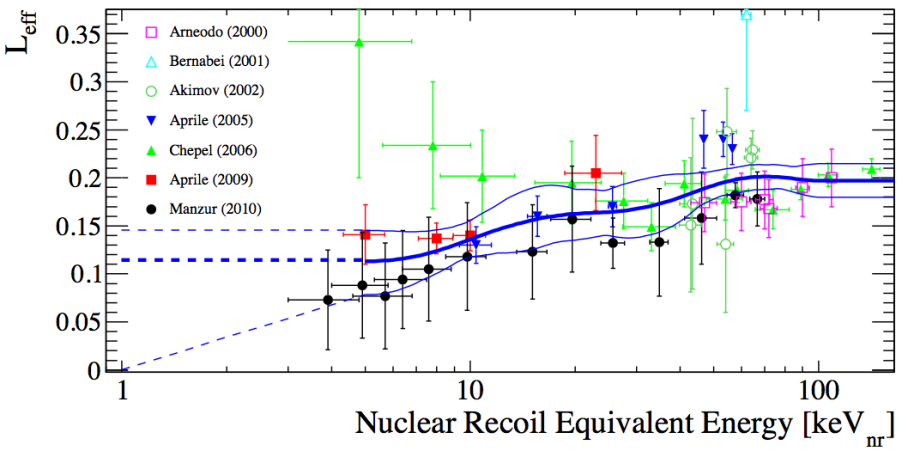
Background data



- 'Background free': in the 11.17 days after discrimimation
- Comparison to XENON10: for approximately the same exposure

→ much cleaner detector

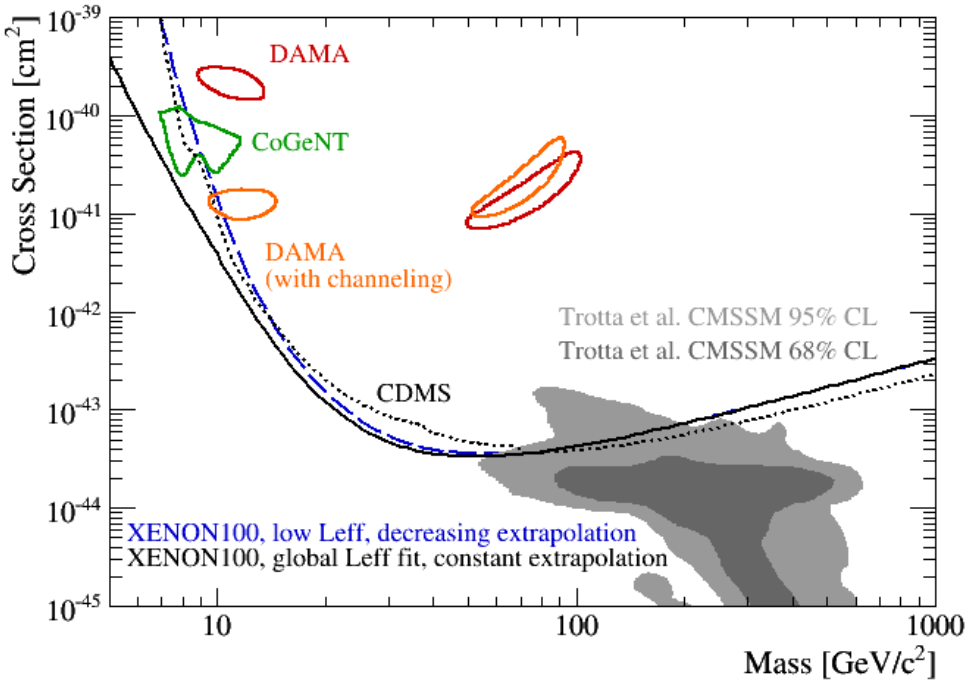
Limit from non-blinded data analysis



- Excellent sensitivity: even for few days of data

→ Sensitivity to low WIMP masses depends on L_{eff}

- Spin independent limit: for standard halo parameters

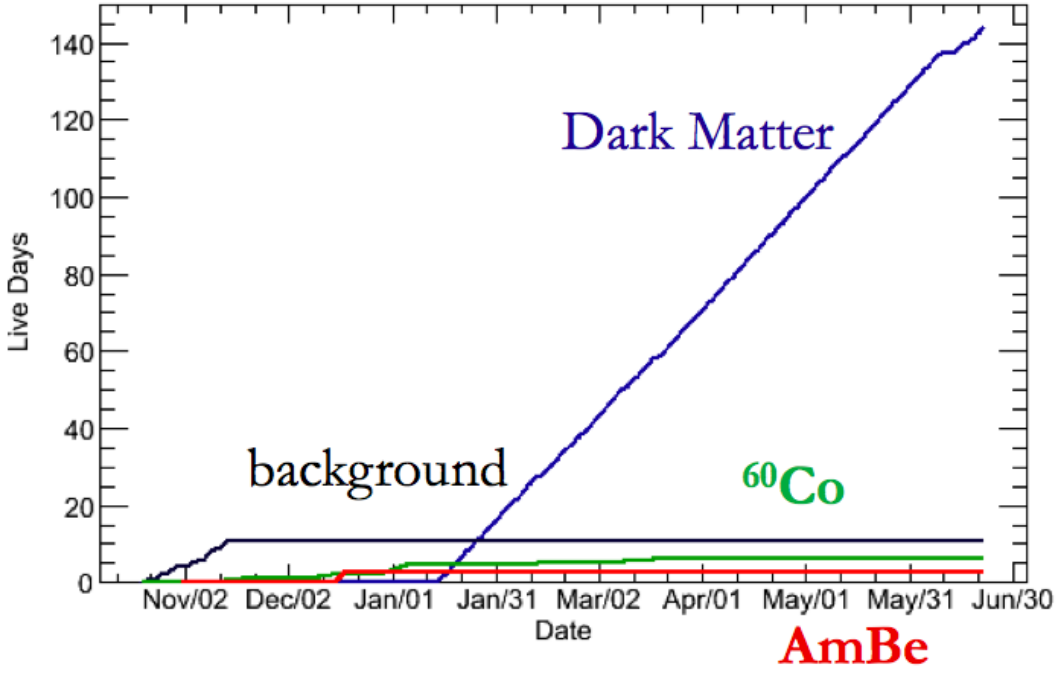


E. Aprile *et al.* (XENON100 Collaboration), Phys. Rev. Lett. 105, 131302 (2010)

Outline

Highlights of run08: Overview

Long data set being analyzed:



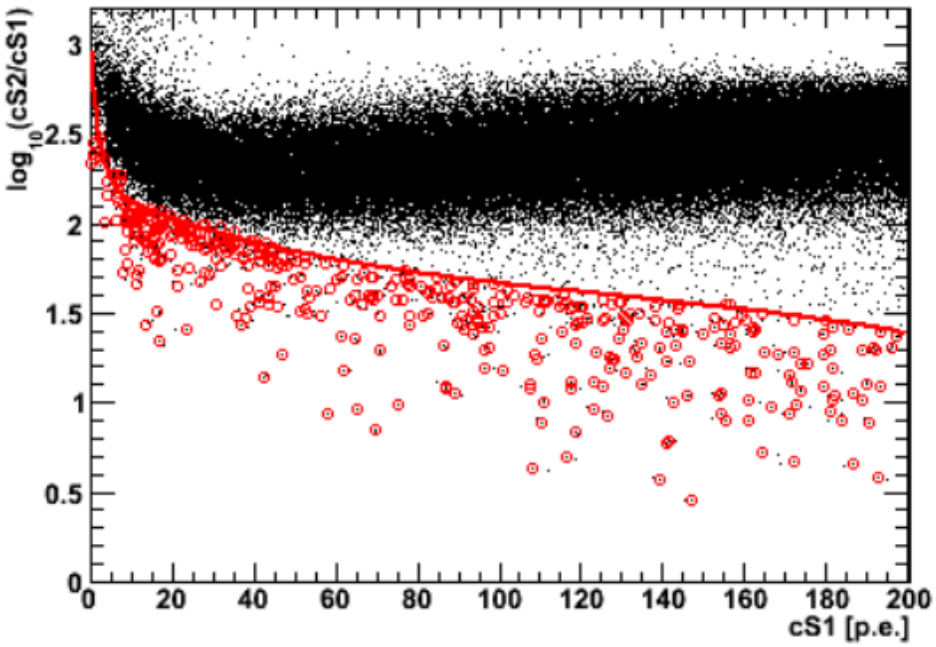
→ preparing the unblinding for end of the year/beginning of next year

- New likelihood for anomalous pattern recognition
- New position reconstruction algorithms
- Improved corrections:

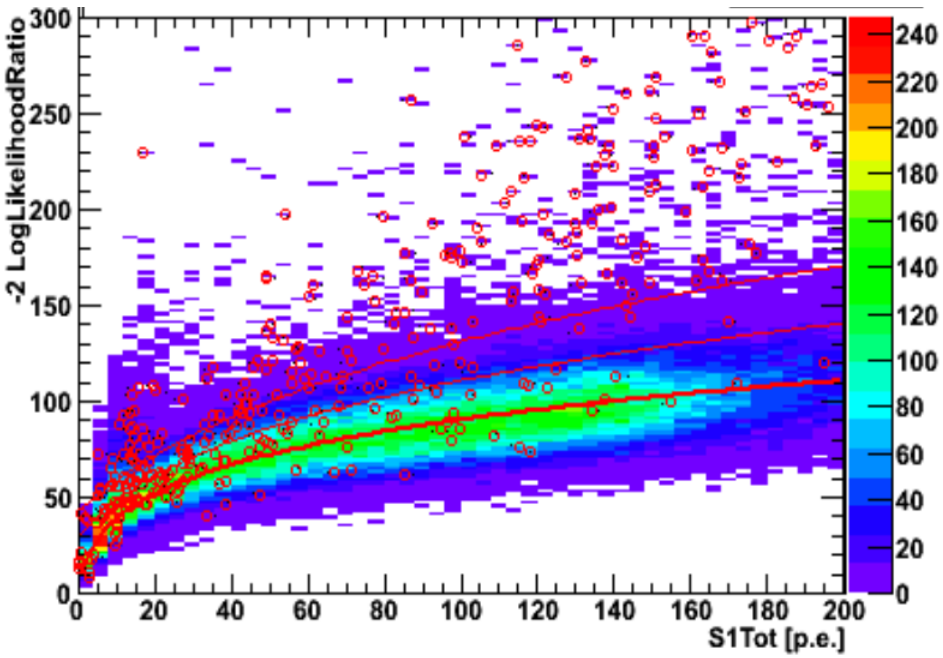
  XY and Z
- New analysis of sensitivity based on likelihood methods

Highlights of run08: likelihood for anomalous patterns

Events leaking into the nuclear recoil band



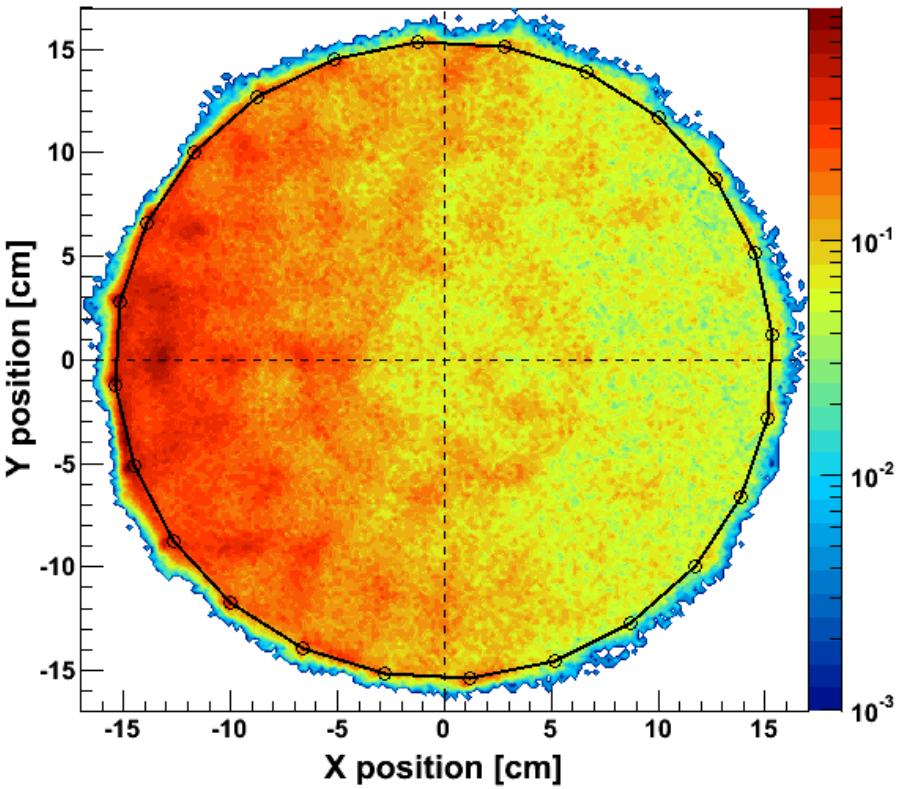
Log Likelihood cut defined as 97.5% acceptance of the NR



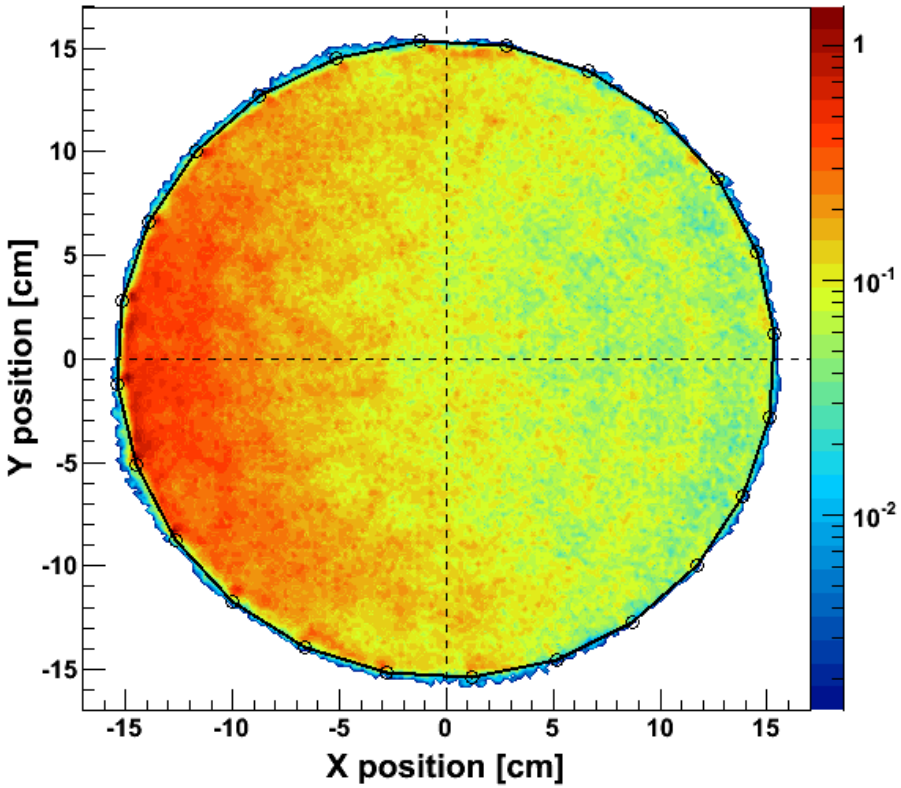
- Gamma-X events: double scatters where one of them takes place in a charge insensitive region

Highlights of run08: position reconstruction

SVM position reconstruction used for run07 analysis



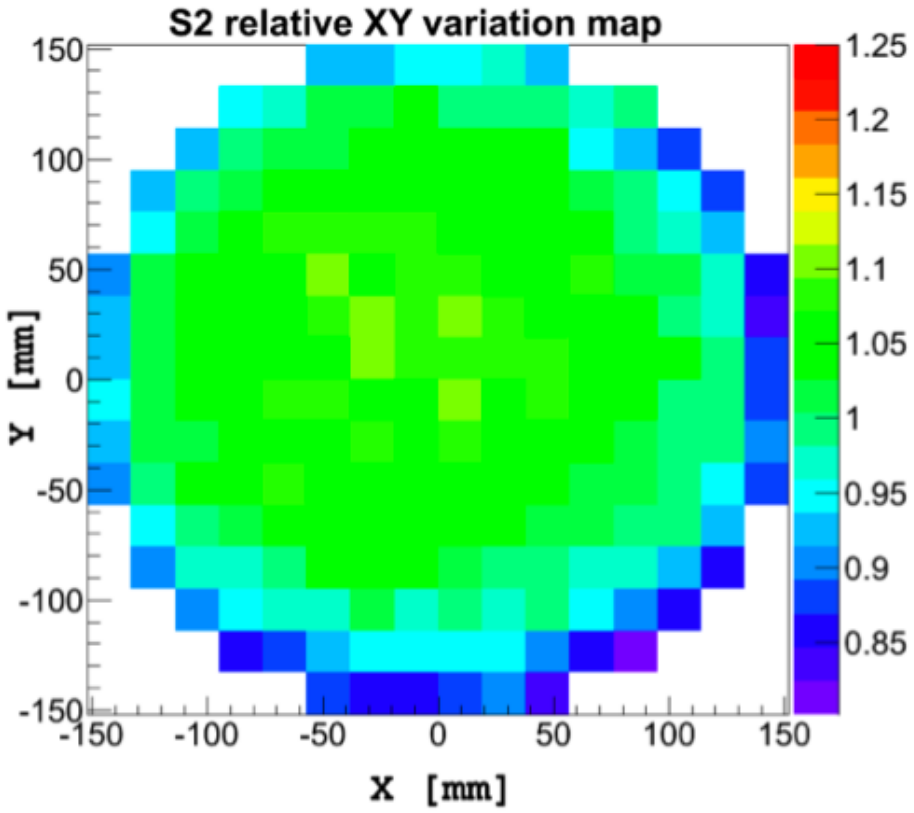
Improved NN position reconstruction

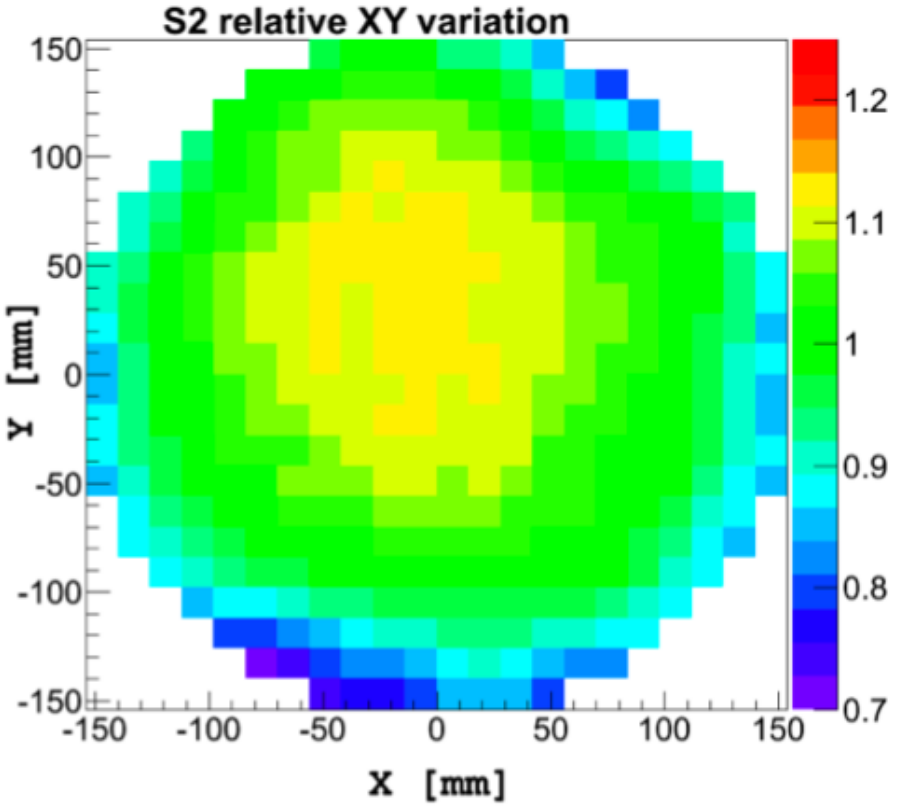


Highlights of run08: new corrections

Run07 S2 XY correction determined with ^{137}Cs or 40 keV

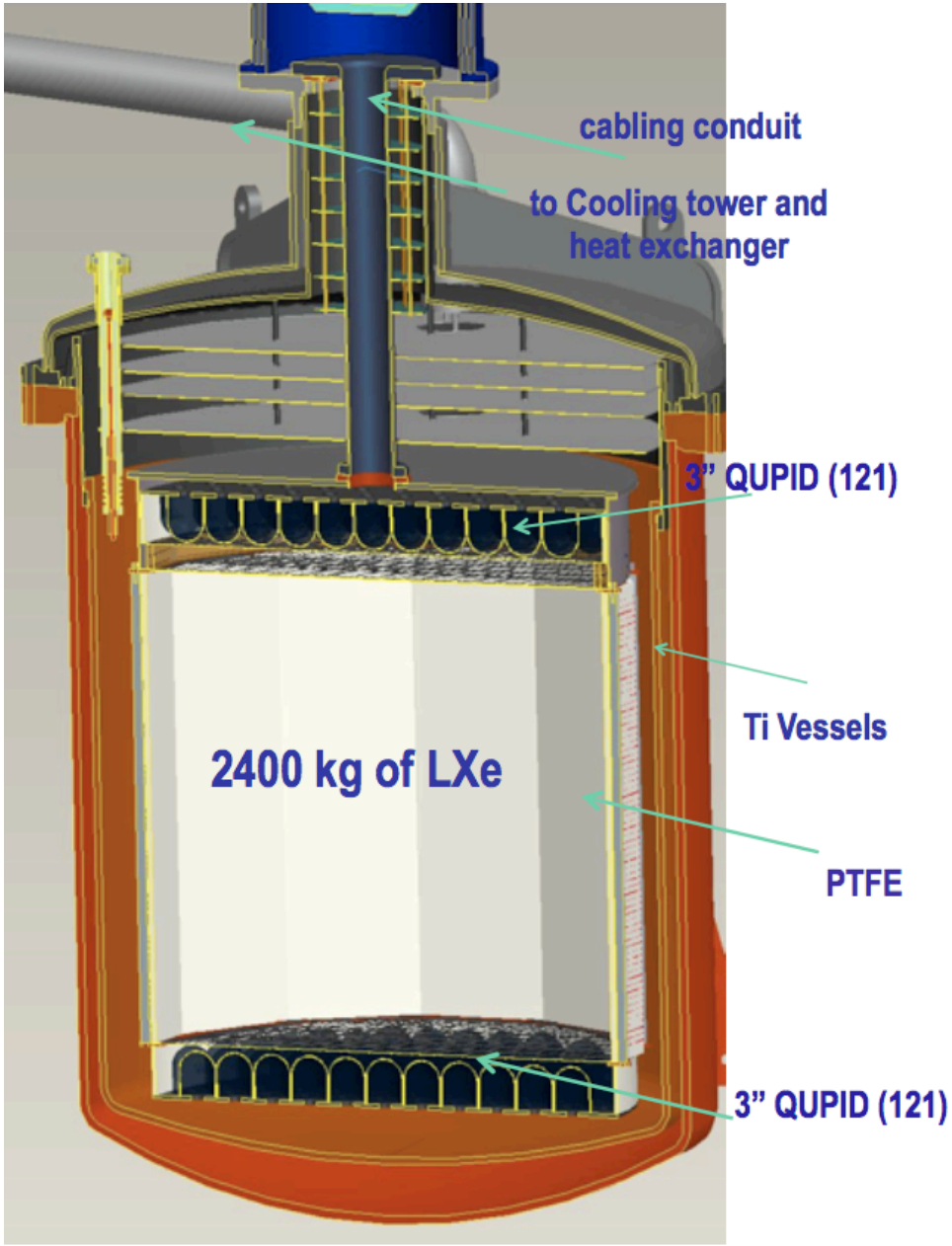
Improved Run08 improved map, more statistics allow for finer binning





Outline

Future: XENON1T



- 1 ton fiducial mass (total of 2.4 ton LXe)
- Drift length = $\sim$90 cm
- 100x background reduction
- Muon veto
- Copper/titanium cryostat
- New photo-detectors: QUPIDs

$\longrightarrow$ New collaborators

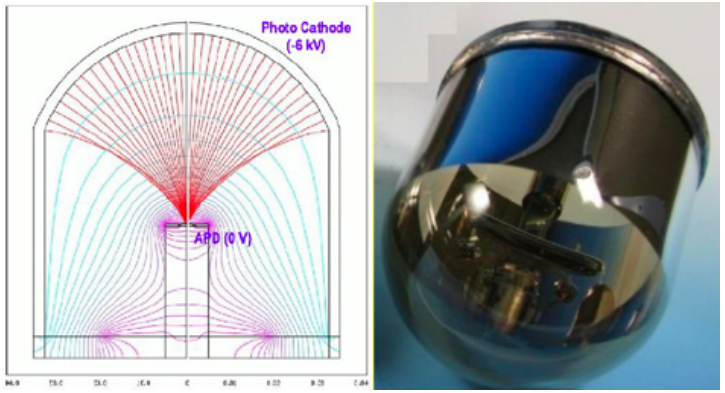
$\longrightarrow$ Currently working on MC simulations and design

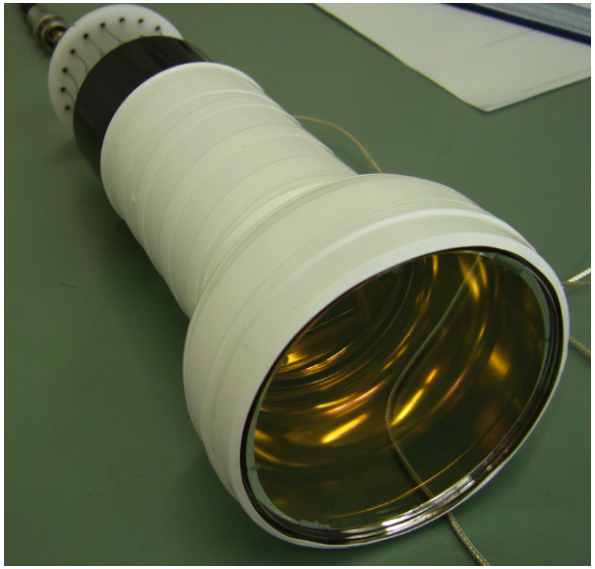
- Timeline: 2011 - 2014

Light readout

- **QU**artz **P**hoton **I**ntensifying **D**etector (hybrid detector)
- Development by UCLA & Hamamatsu for LXe and LAr detectors

  - Ultra-low radioactivity ($\sim$ 0.1 mBq)
  - High QE and high SPE resolution

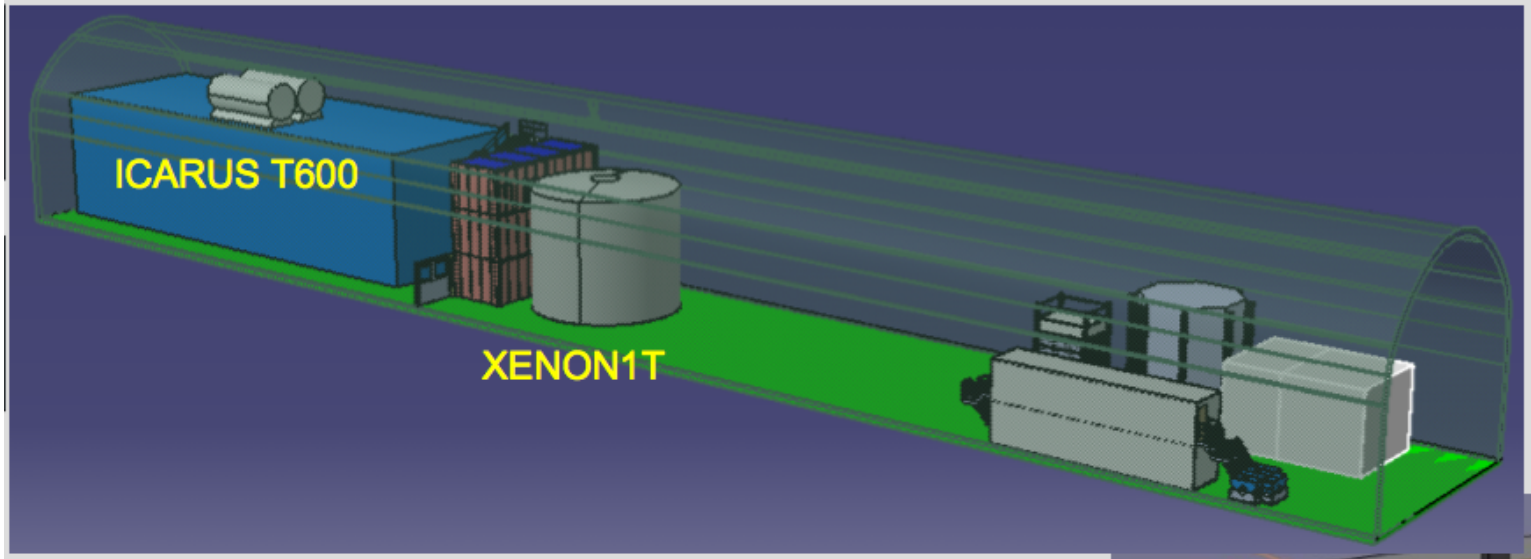




- Alternative solution
  - Low radioactivity R11410 3” PMT
  - High QE: $>$ 34% at 175 nm

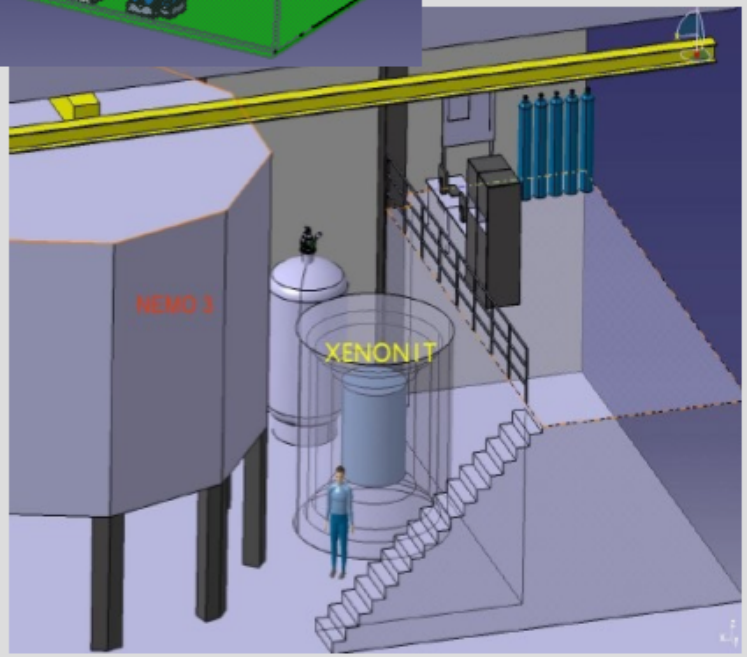
  $\rightarrow$ PMTs being currently tested at University of Zurich

Status of location

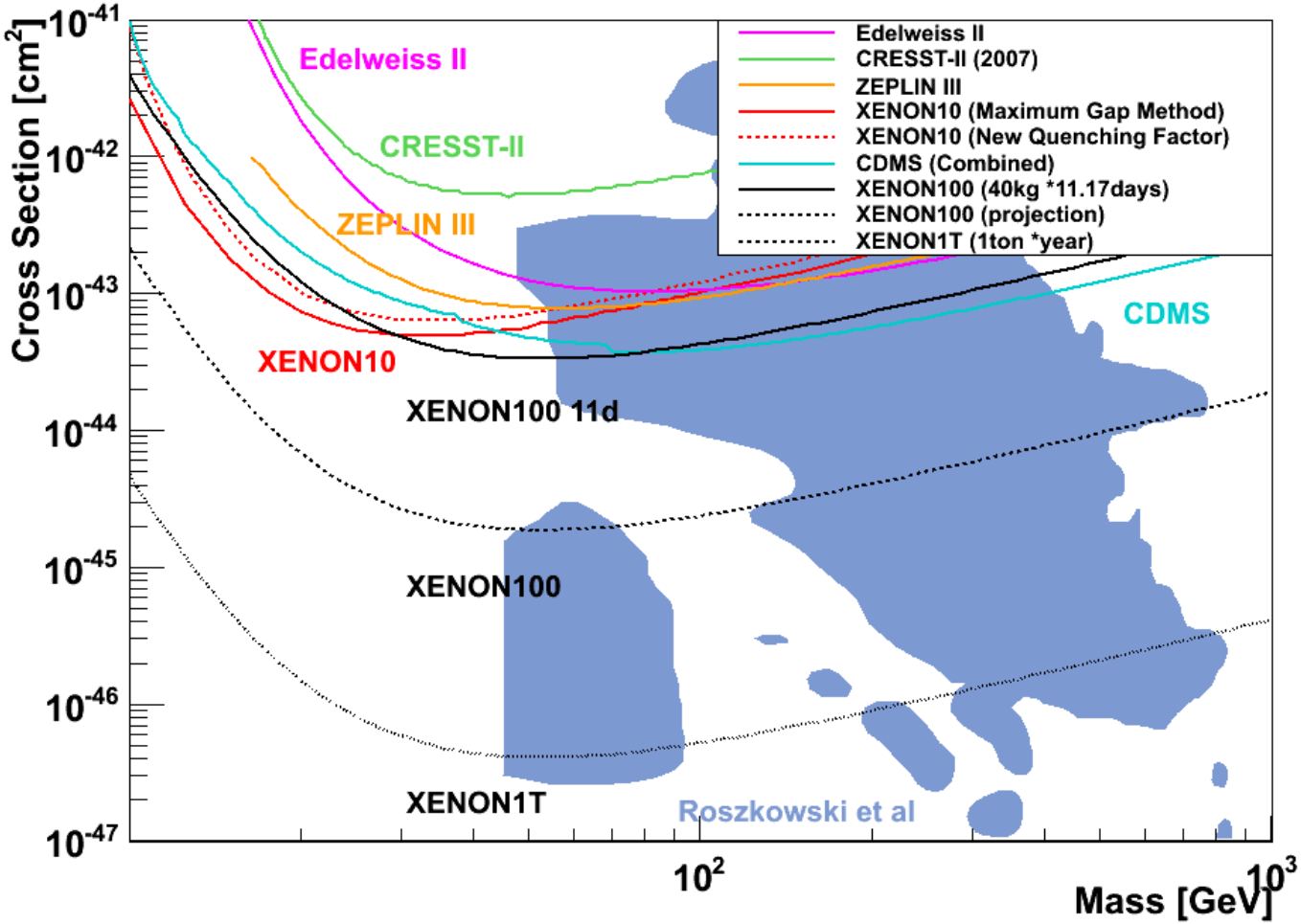


XENON1T @ LNGS (Hall B)
→ 4 m water shield

XENON1T @ LSM
→ solid shield (55cm poly, 20cm Pb, 15cm poly, 2cm ancient Pb, >99% muon veto)



XENON sensitivity



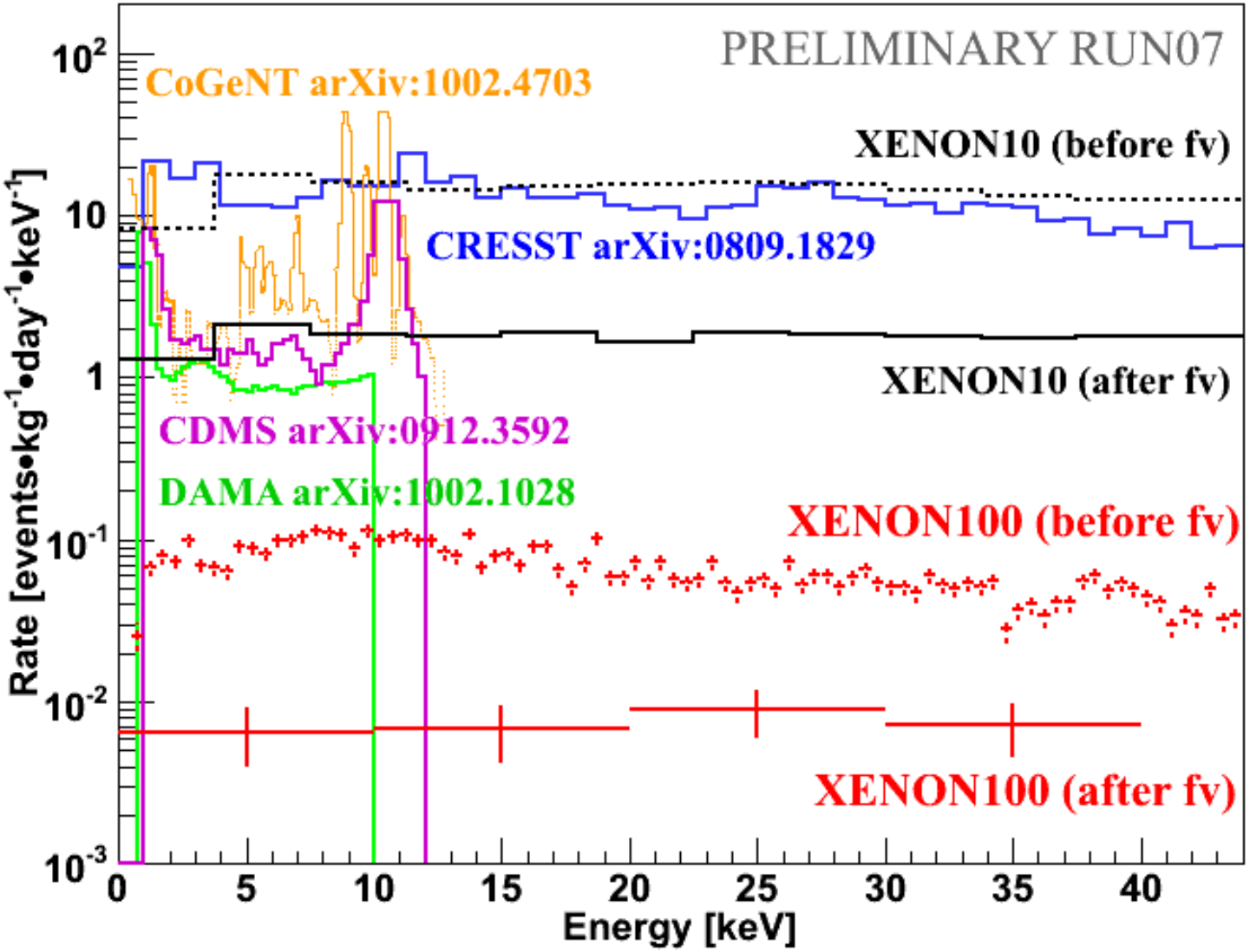
- XENON100 sensitivity for 6 000 kg days (200 d $\times$ 30 kg bg free)
- Capability to detect about 10 events for 100 GeV mass for a WIMP-nucleon cross section of $\sim 10^{-44}$ cm^2

Outline

Summary

- Liquid xenon is a promising detector material to discover dark matter
  - Large nucleus (A^2 enhancement on σ)
  - Dual-phase: particle discrimination and fiducialization
  - Self-shielding (large detectors)
- XENON100 is taking dark matter data
  - Design low background level achieved!
  - First non-blinded data analyzed
  - $\rightarrow$ first results published, also arXiv:1005.0380
  - Run08 data is being analyzed ($\sim$ 100 days)
  - $\rightarrow$ new results coming ...
- XENON1T currently under design
  - TDR submitted to Gran Sasso in October

Background in the low energy range



→ Lowest ever measured background rate in a dark matter experiment