Universität Zürich

XENON100: New Results

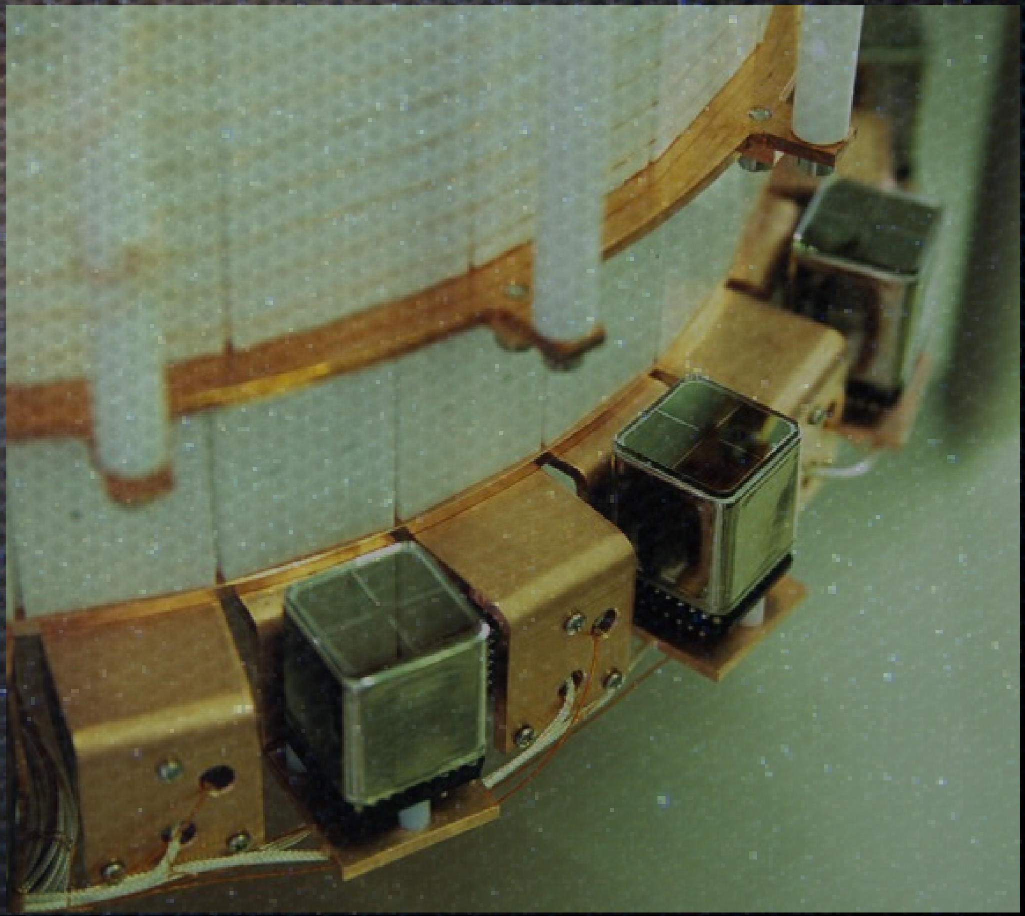
APS meeting

Anaheim, California

May 2, 2011

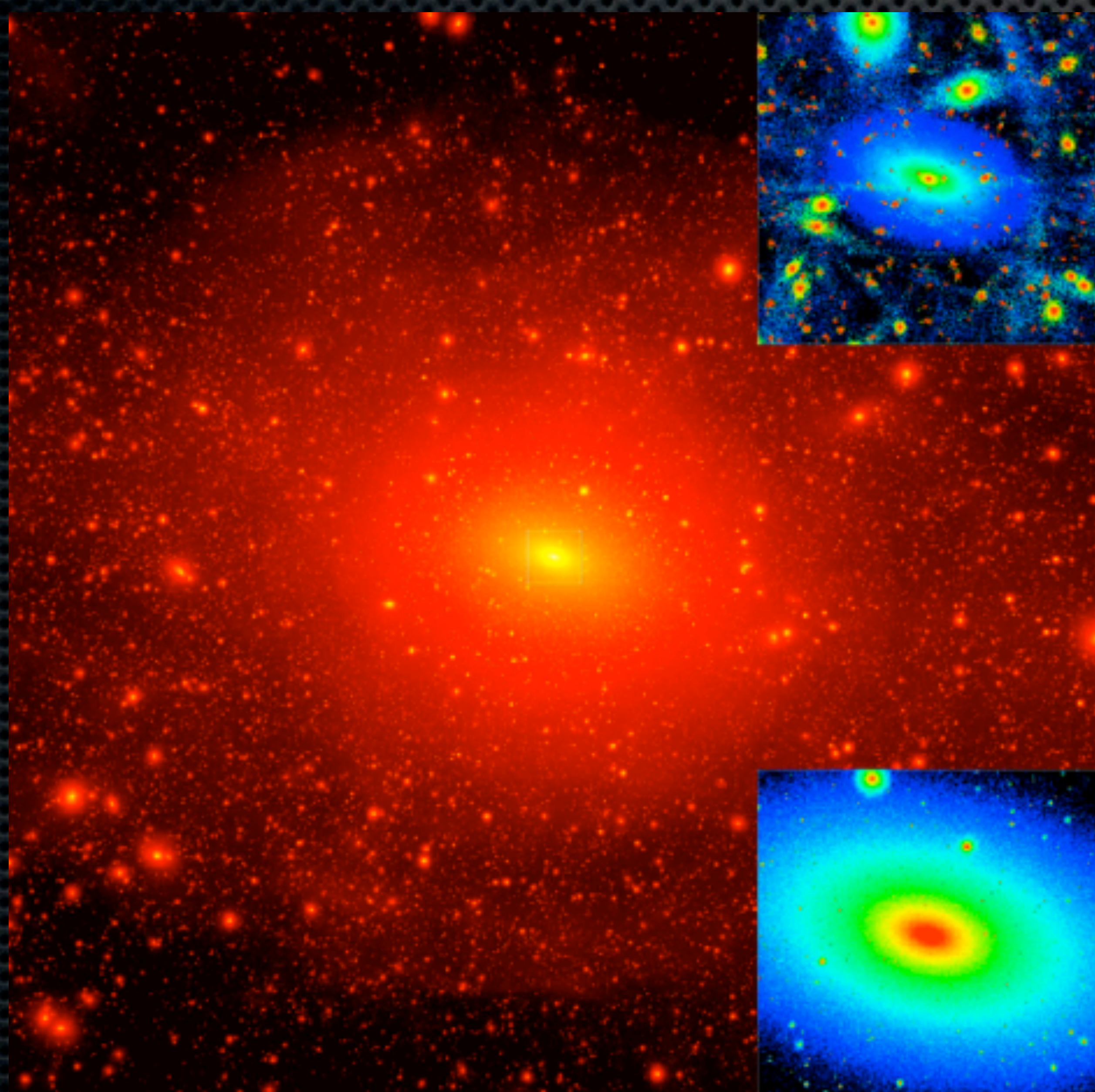
Laura Baudis

University of Zurich



The Milky Way's Halo

Dominated by cold dark matter, which could me made of Weakly Interacting Massive Particles (WIMPs)



~ 600 kpc (J. Diemand et all, Nature 454, 2008, 735-738)

$$\rho_{halo} = 0.1 - 0.7\mathrm{GeV cm}^{-3}$$

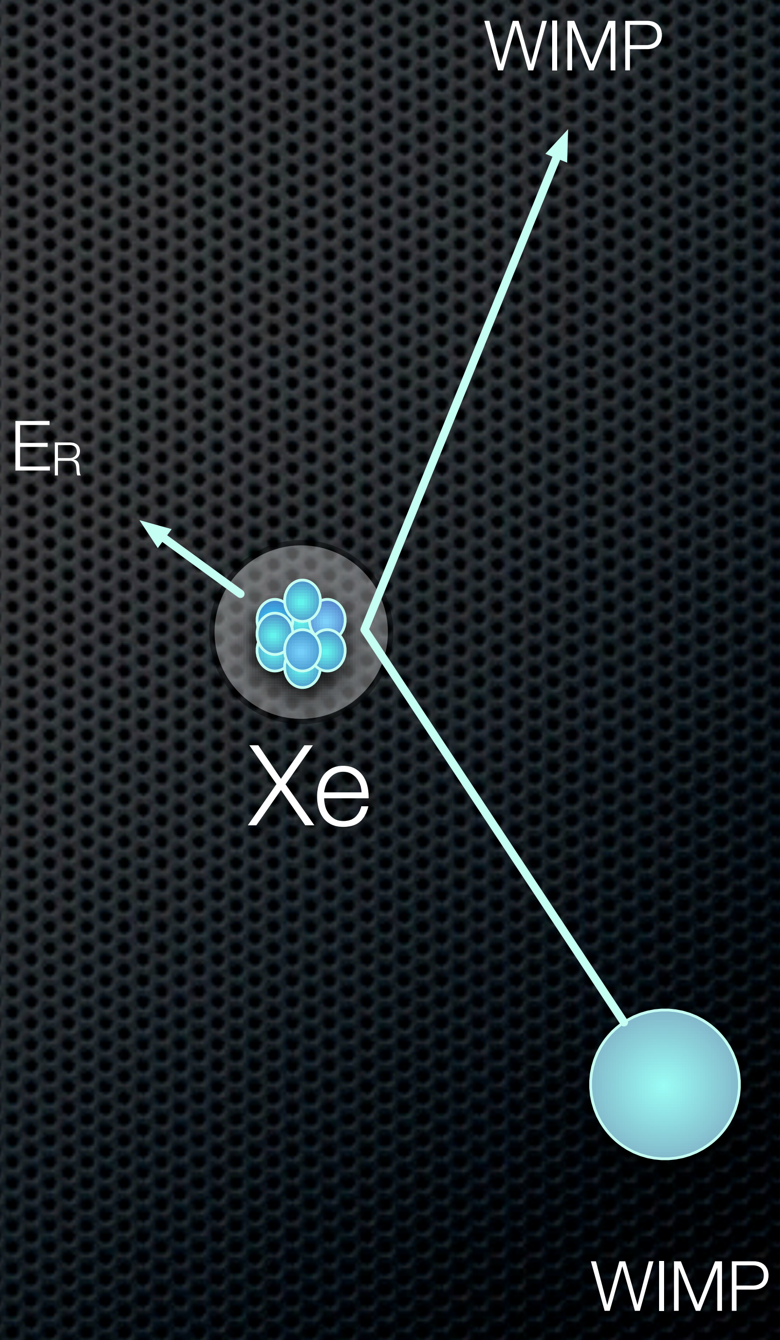
WIMP flux on Earth: ~ 10^5 $cm^{-2}s^{-1}$ (100 GeV WIMP, ρ_{halo} = 0.3 GeV cm^{-3})

Even though WIMPs are weakly interacting, this flux is large enough so that a potentially measurable fraction will elastically scatter off nuclei

Aim of the XENON project

- Detect Galactic dark matter particles directly, via their collisions with xenon nuclei
- Such particles are predicted to be heavy (GeV - TeV masses), weakly interacting and slow-moving ($v \approx 10^{-3}c$)
- The expected energy of the recoiling Xe nucleus has a maximum of a few tens of keV

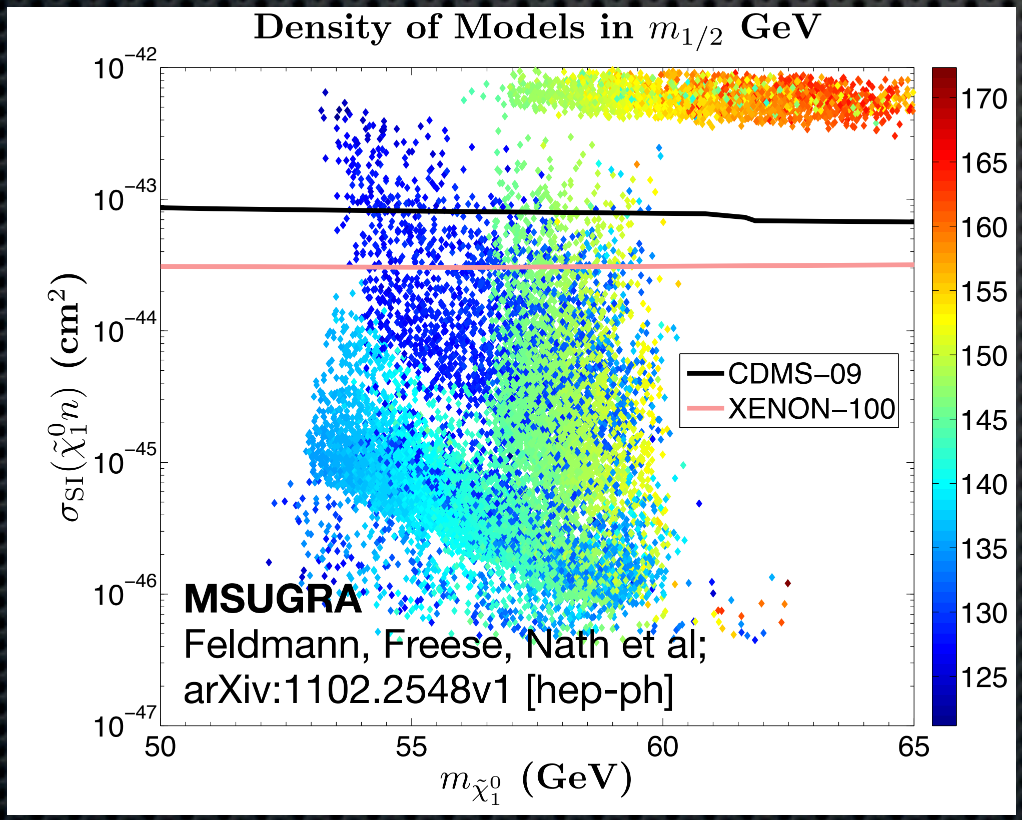
$$E_R = \frac{q^2}{2m_N} = \frac{\mu^2 v^2}{m_N}(1 - cos\theta)$$



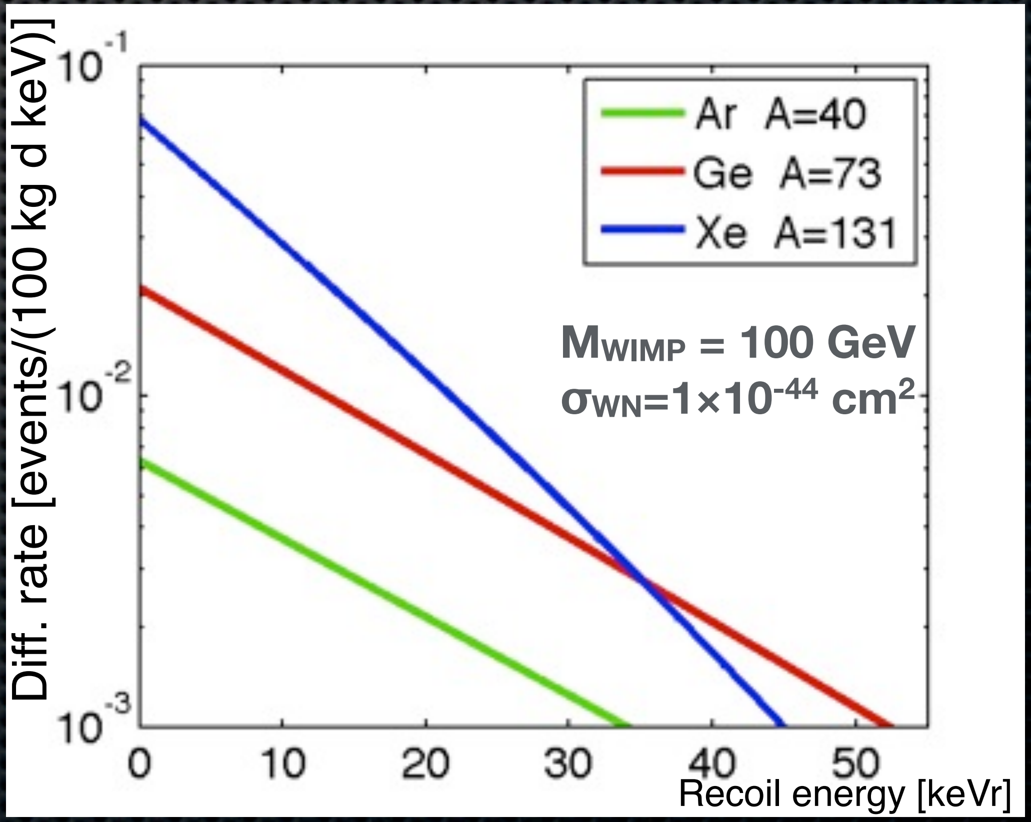
Aim of the XENON project

- Since predicted WIMP-nucleon cross sections are below ~10^{-43} cm^2, the expected recoil rates are well below 1 event kg^{-1} year^{-1}

$$\frac{dR}{dE_R} = \frac{\sigma_0 \rho_0}{2 m_\chi \mu^2} F^2(E_R) \int_{v>\sqrt{m_N E_R / 2\mu^2}}^{v_{max}} \frac{f(\vec{v},t)}{v} d^3v$$



Example for predictions from SUSY



Differential recoil rates

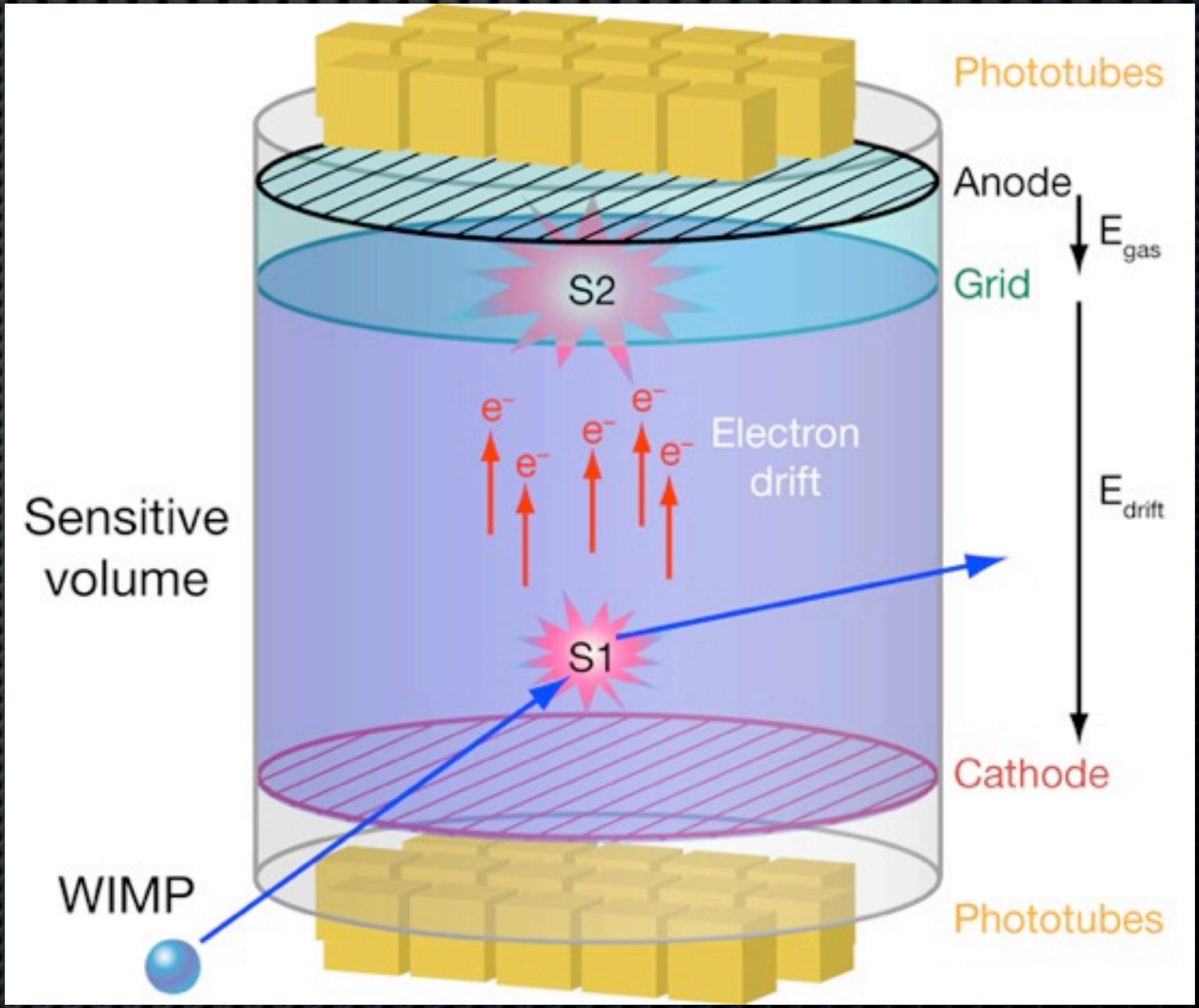
A Noble Liquid Time Projection Chamber

- Large, scalable, homogeneous and self-shielding detector
- Prompt (S1) light signal after interaction in the active volume
- Charge is drifted, extracted into the gas phase and detected as proportional light (S2)

- S2/S1 depends on dE/dx
- good 3D position resolution

=> particle identification

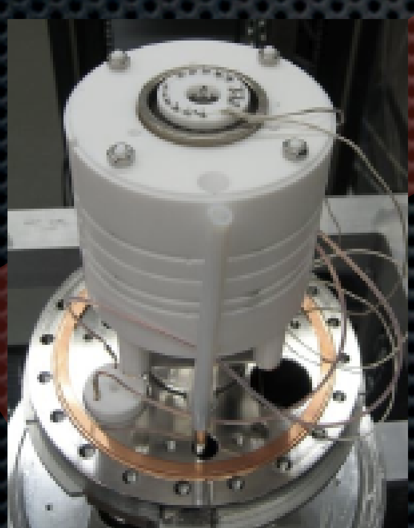
Working principle of the XENON100 TPC



Xe (A=131); λ = 178 nm

The XENON program

XENON R&D



ongoing

XENON10

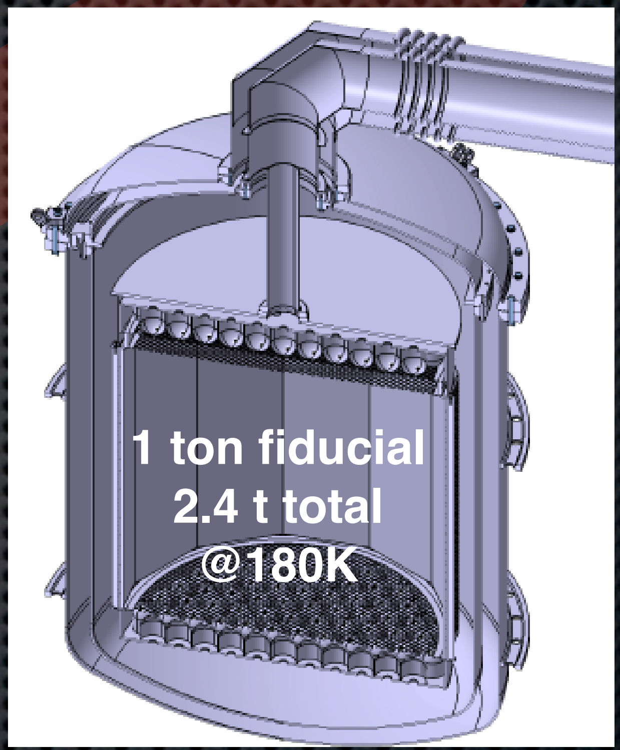
2005-2007

PRL100
PRL101
PRD 80
NIM A 601

XENON100

2008-2011
taking science data
first results: PRL105

XENON1T



2011-2015

Proposal submitted to LNGS in April 2010

TDR submitted to LNGS mid October, 2010

Approved by LNGS/ INFN in April 2011

The XENON collaboration

Columbia Rice UCLA Zürich Coimbra LNGS SJTU

Mainz Bologna Subatech Münster Nikhef Heidelberg Weizman

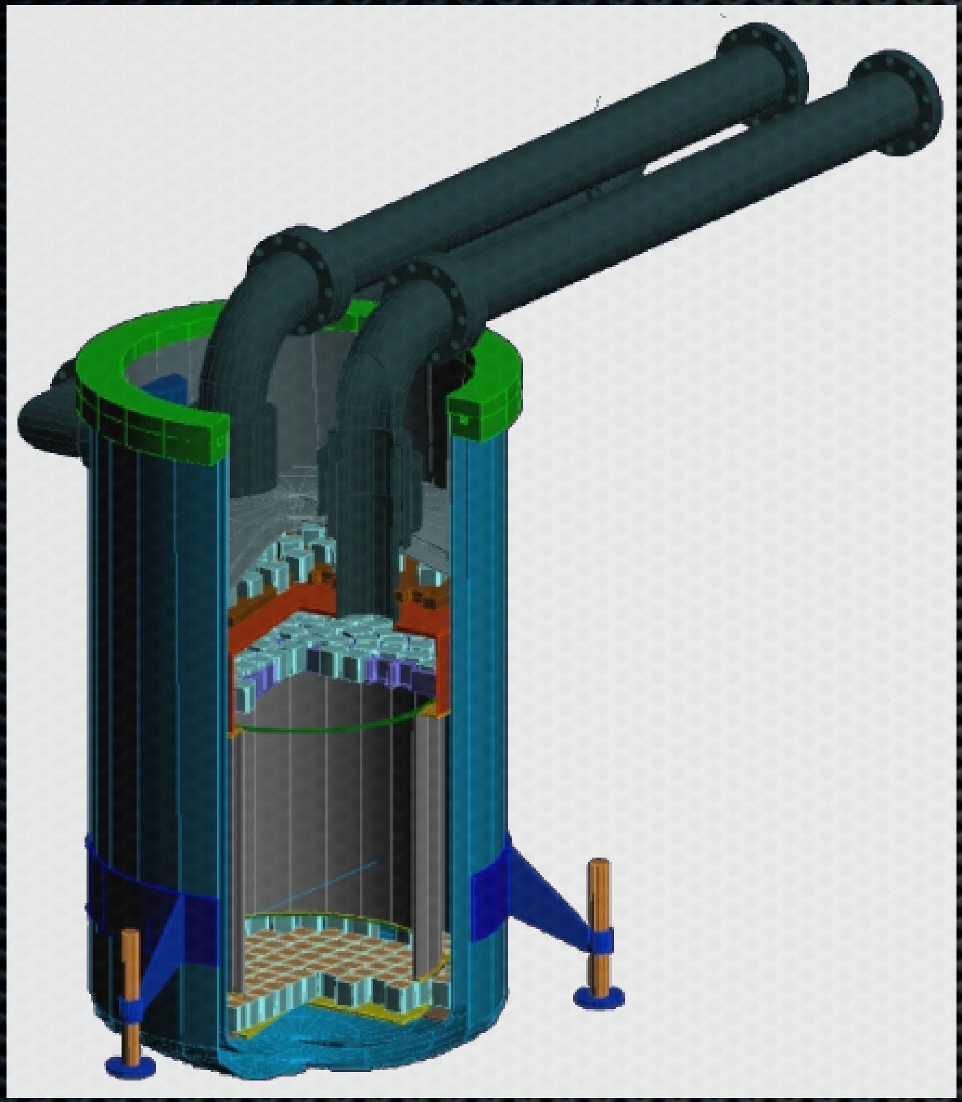
USA, Switzerland, Italy, France, Portugal, Germany, Netherlands, Israel and China

The XENON collaboration
LNGS, April 2011

XENON100 location and shield

- At the Gran Sasso Laboratory in Italy, below ~1.4 km of rock (3600 mwe)
- Operated in conventional passive shields (Cu, Poly, Pb, H_20)
- Detector housing constantly purged with boil-off N_2, to keep a Rn level < 0.5 Bq/m^3

XENON100 Detector Design



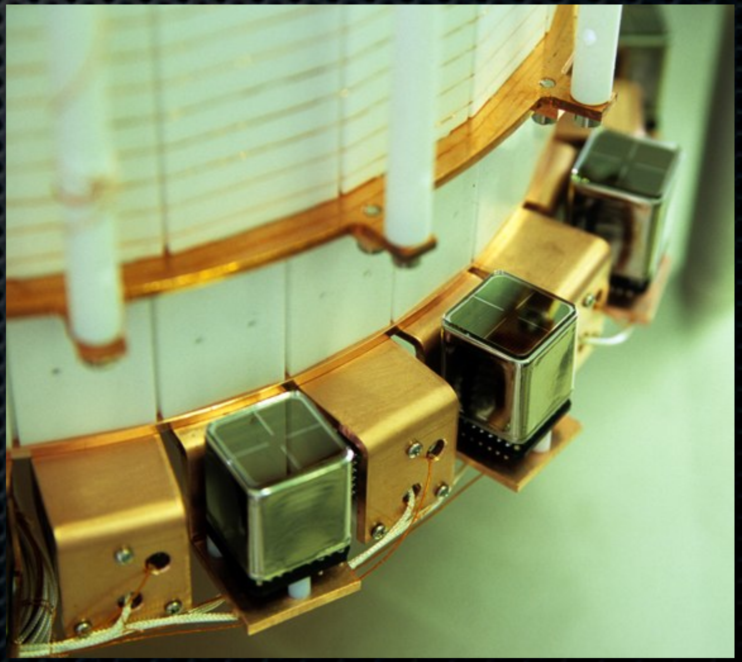
- TPC with 30 cm drift and 30 cm diameter
- Drift field of 0.53 kV/cm between cathode at -16 kV and grounded grid
- Cooling system and signal/HV feed-throughs outside the shield
- 242 low-radioactivity photomultipliers to detect the prompt and proportional scintillation light

The XENON100 Photodetectors

- 1-inch square R8520 Hamamatsu PMTs, optimized to work at LXe T and P
- Ultra-low radioactivity: ^{238}U, ^{232}Th < 1 mBq/PMT
- Quantum efficiency: 23% (top, veto array) and 34% (bottom array) at 178 nm

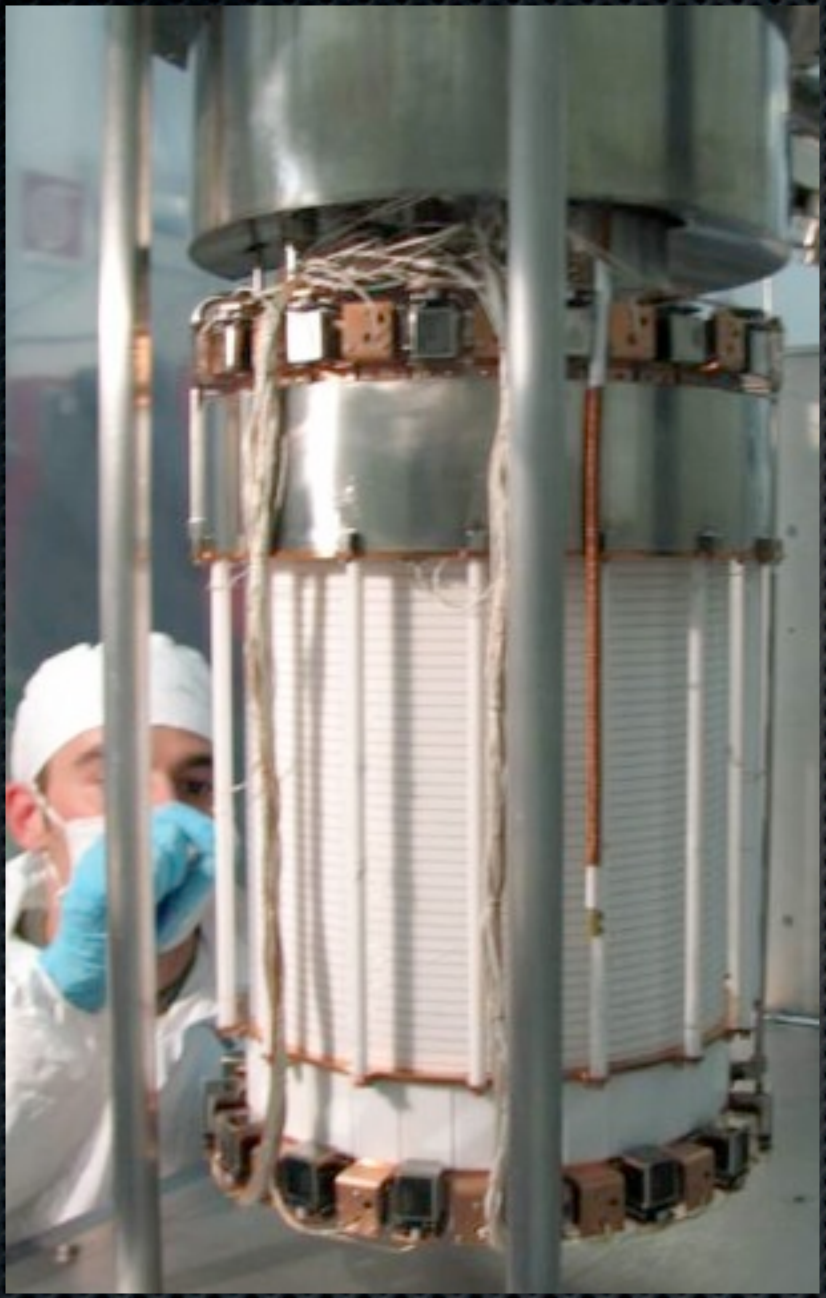
top array: 98 PMTs

bottom array: 80 PMTs



LXe veto: 64 PMTs

The XENON100 Inner Detector

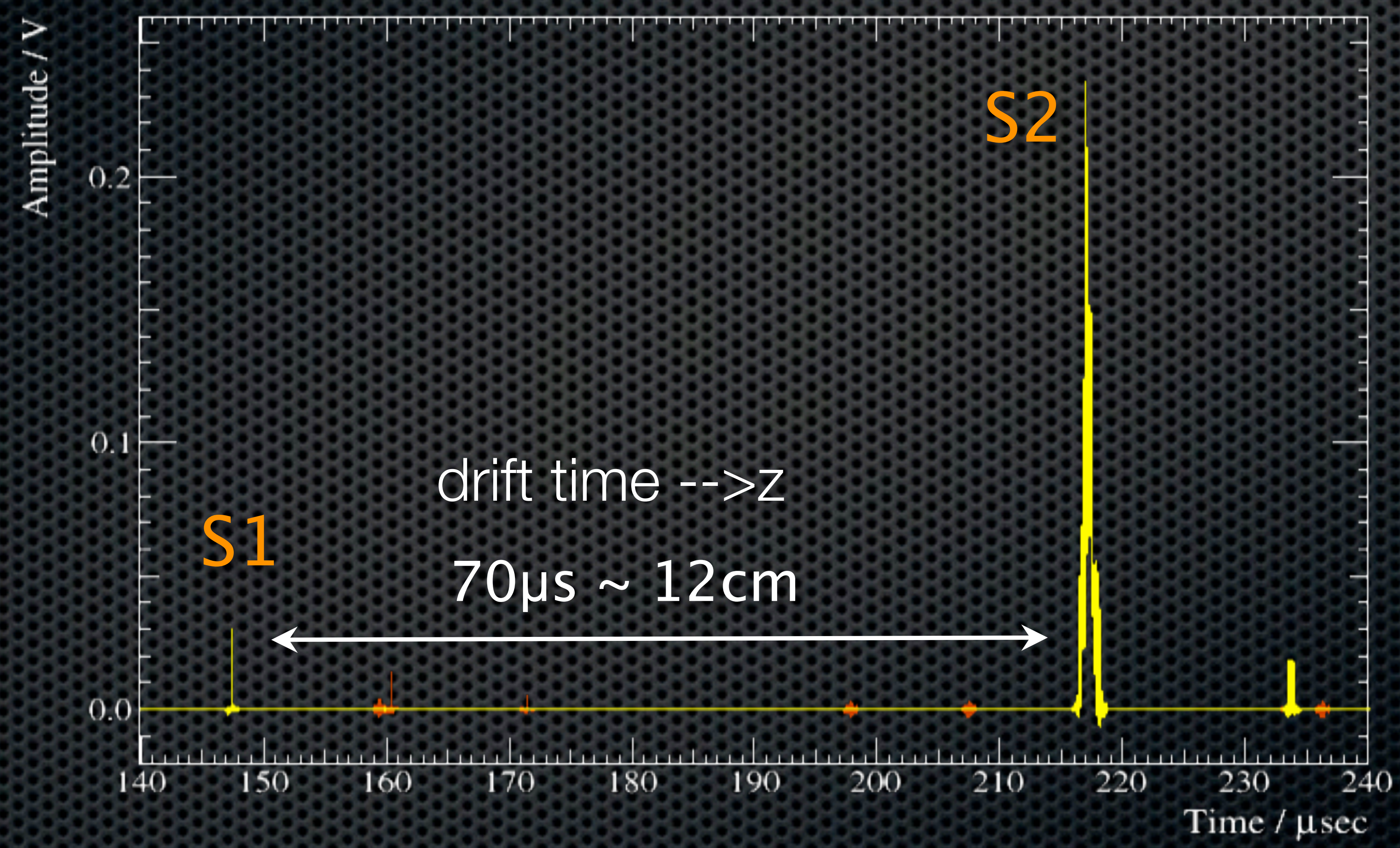


- 62 kg of LXe in the active detector volume
- 99 kg of LXe as an active veto surrounding the TPC from all sides
- Interlocking teflon panels used for optimal Xe light reflectivity* and very low radio-activity
- 40 copper field shaping rings for uniform drift field across the TPC

*Details: B. Choi, G13.5

Example of a 9 keV Nuclear Recoil Event

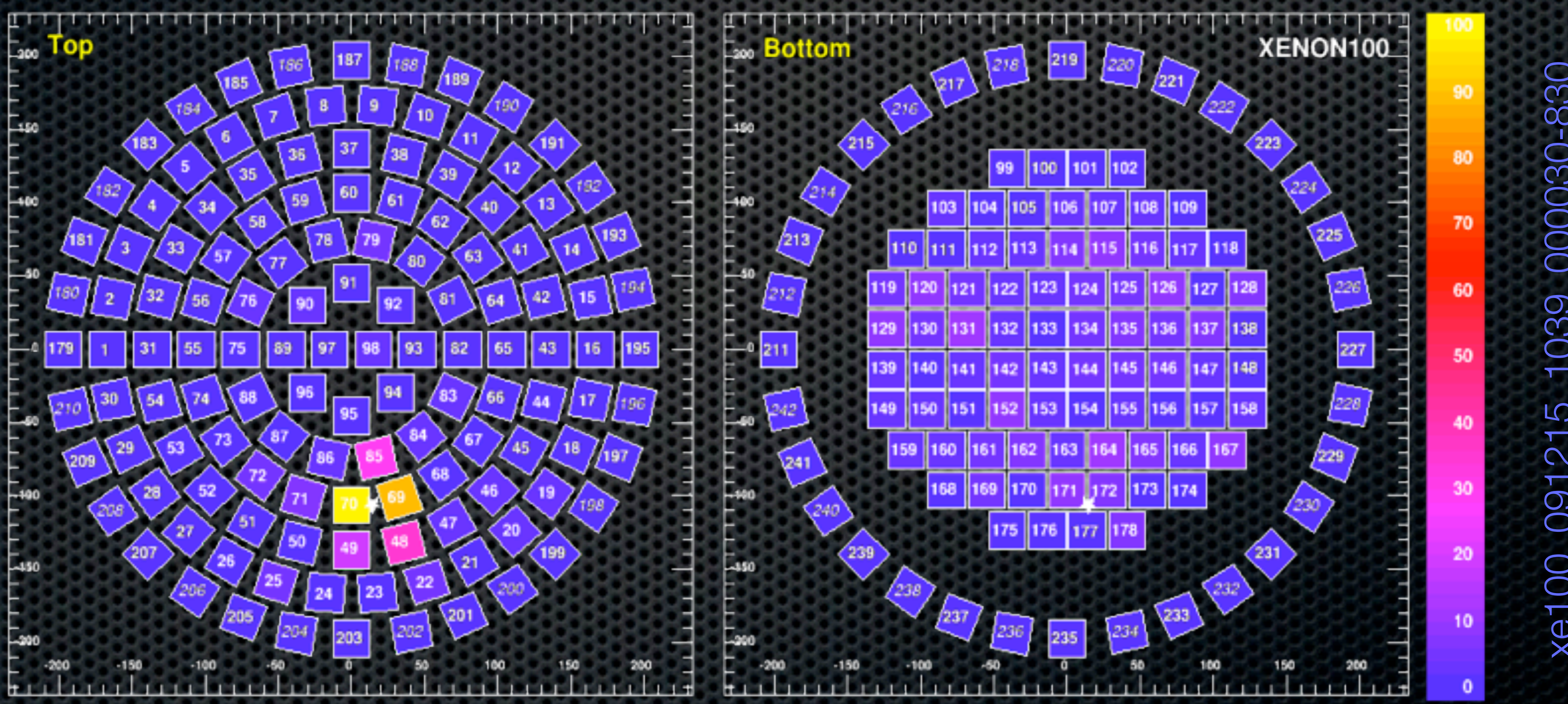
- **Event localization in z:** Δt between prompt (S1) and delayed (S2) signal with < 2 mm resolution



- 4 photoelectrons detected from about 100 S1 photons
- 645 photoelectrons detected from 32 ionization electrons which generated about 3000 S2 photons

Example of a 9 keV Nuclear Recoil Event

- **Event localization in x-y:** from light pattern in top PMT array (S2 signal is localized below top array) with < 3 mm resolution (as measured with collimated sources at different radii)

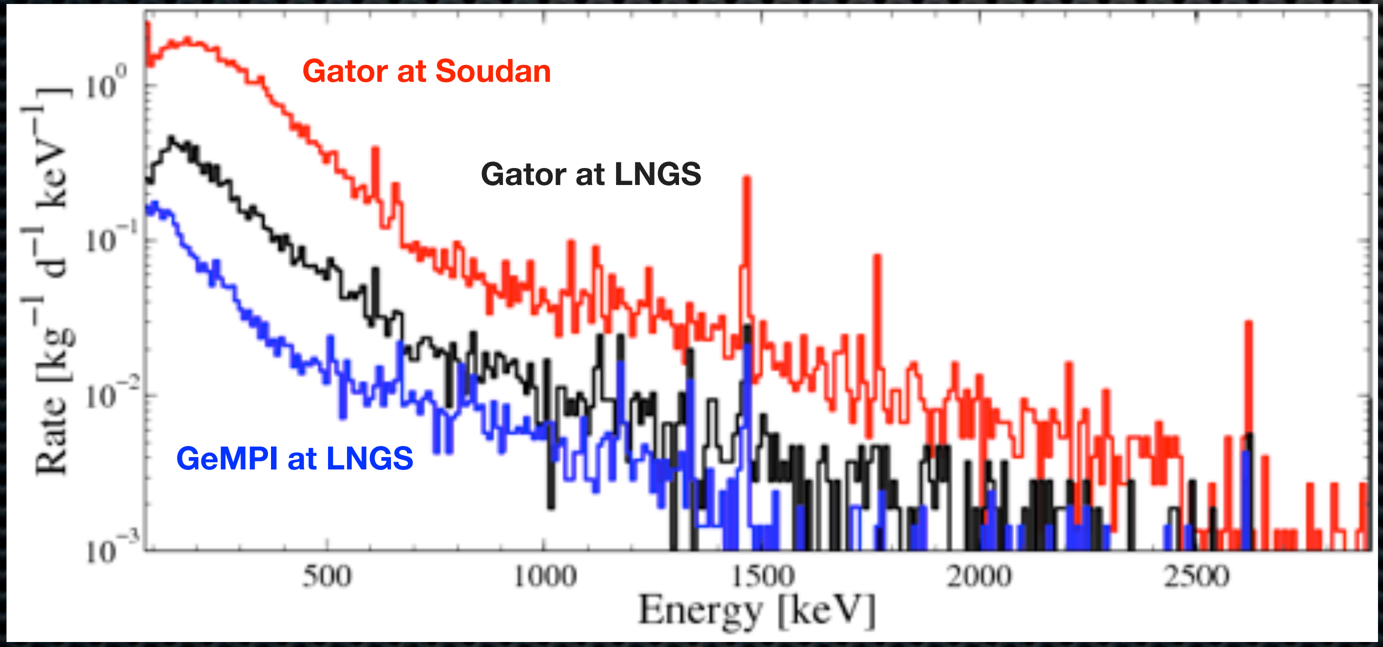


S2 details: E. Pantic, G13.1

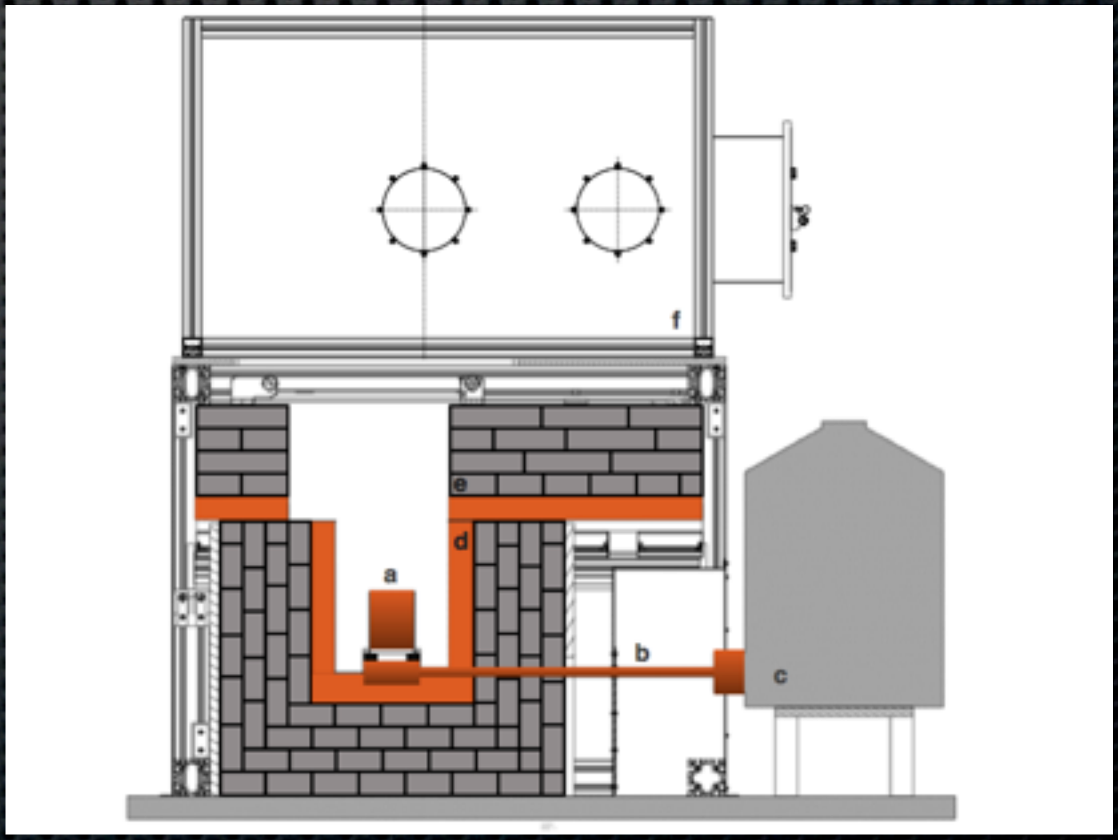
XENON100 Materials

- All detector and shield materials were screened with dedicated, ultra-low background HPGe facilities at LNGS and selected according to their radio-purity
- More than 60 components screened, results available: arXiv:1103.5831

Gator's background spectrum



The Gator HPGe facility at LNGS



L. Baudis et al., arXiv:1103.2125 [astro-ph.IM]

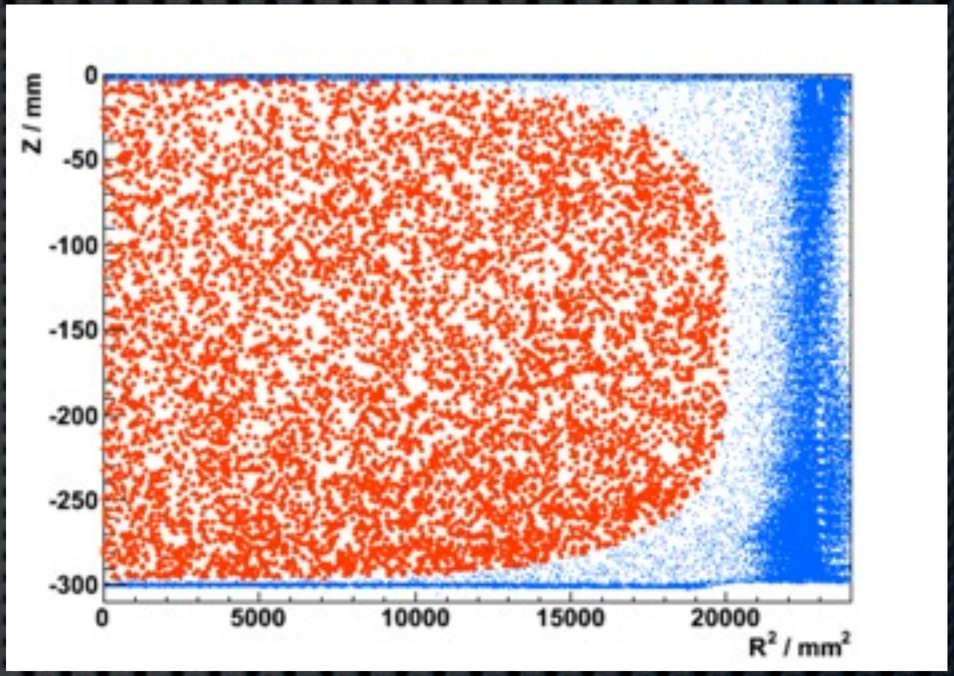
XENON100 Backgrounds

- **Electromagnetic radiation**
  - natural radioactivity in detector and shield materials
  - ^{222}Rn in shield cavity
  - ^{85}Kr and ^{222}Rn in LXe
  - cosmogenic activation of materials during storage/transportation at the Earth's surface
- **Neutrons**
  - radiogenic from (α,n) and fission reactions
  - cosmogenic from spallation of nuclei in materials by cosmic muons

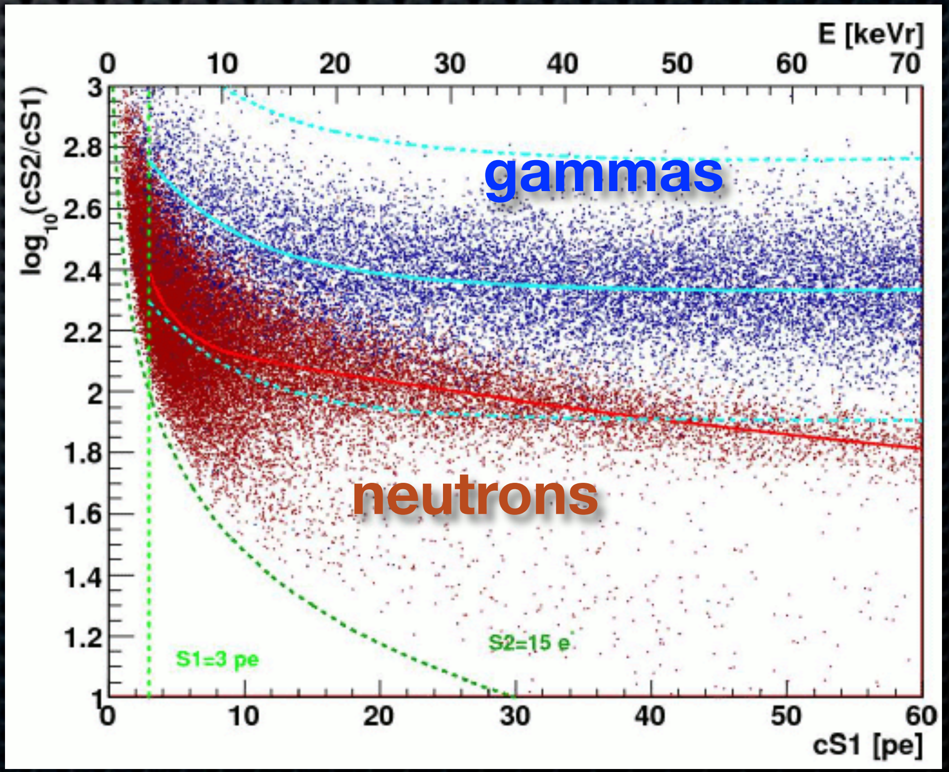
Background Rejection Methods

- LXe self-shielding from penetrating radiation
- Identification/rejection of gammas/neutrons by:
  - charge/light (S2/S1): > 99.5%
  - 3D event localization with few mm precision allowing for: a) fiducial volume definition b) rejection of multiple-scatters

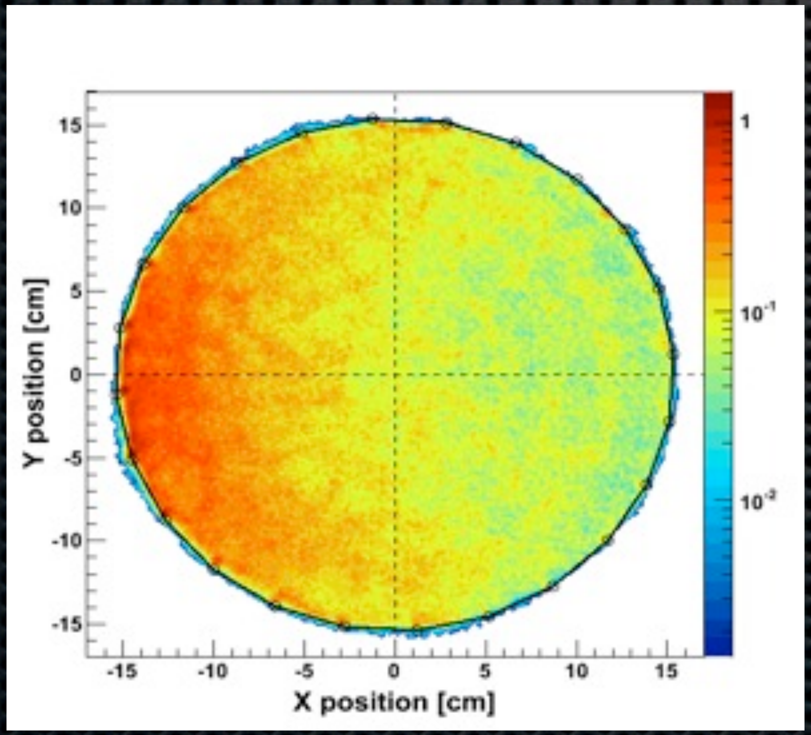
fiducial volume definition



light/charge- ratio



x-y position from external γ-source

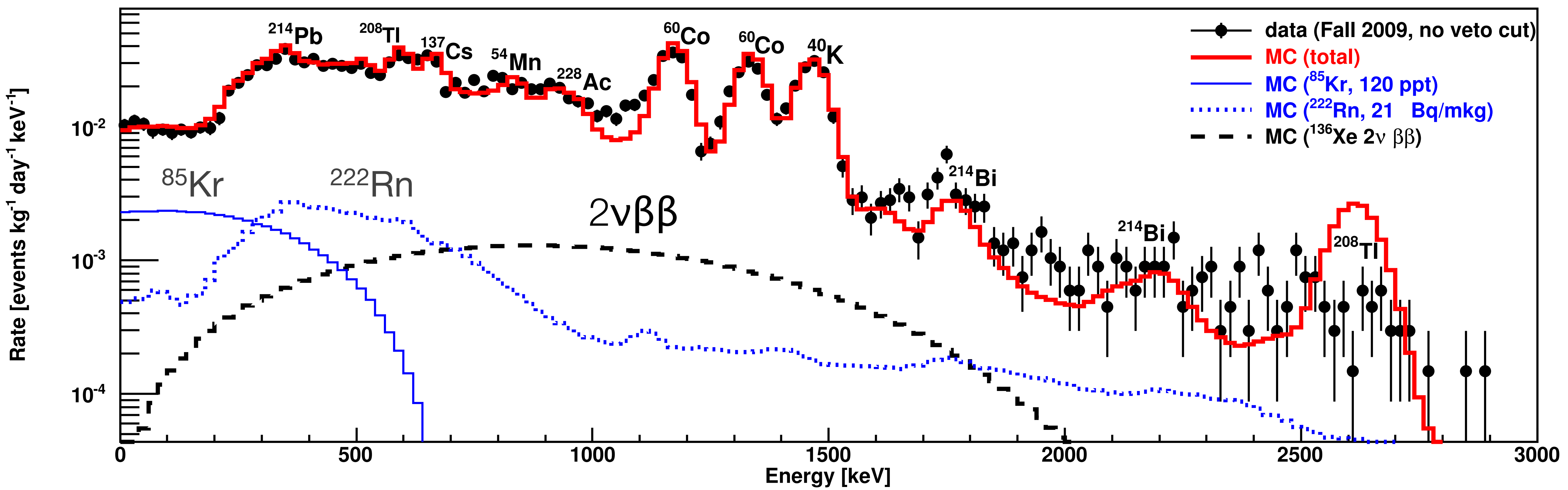


Details:
A. Melgarejo, T11.4,
Y. Mei, T11.5,
K. Lim: T11.6

Backgrounds: Data and Predictions

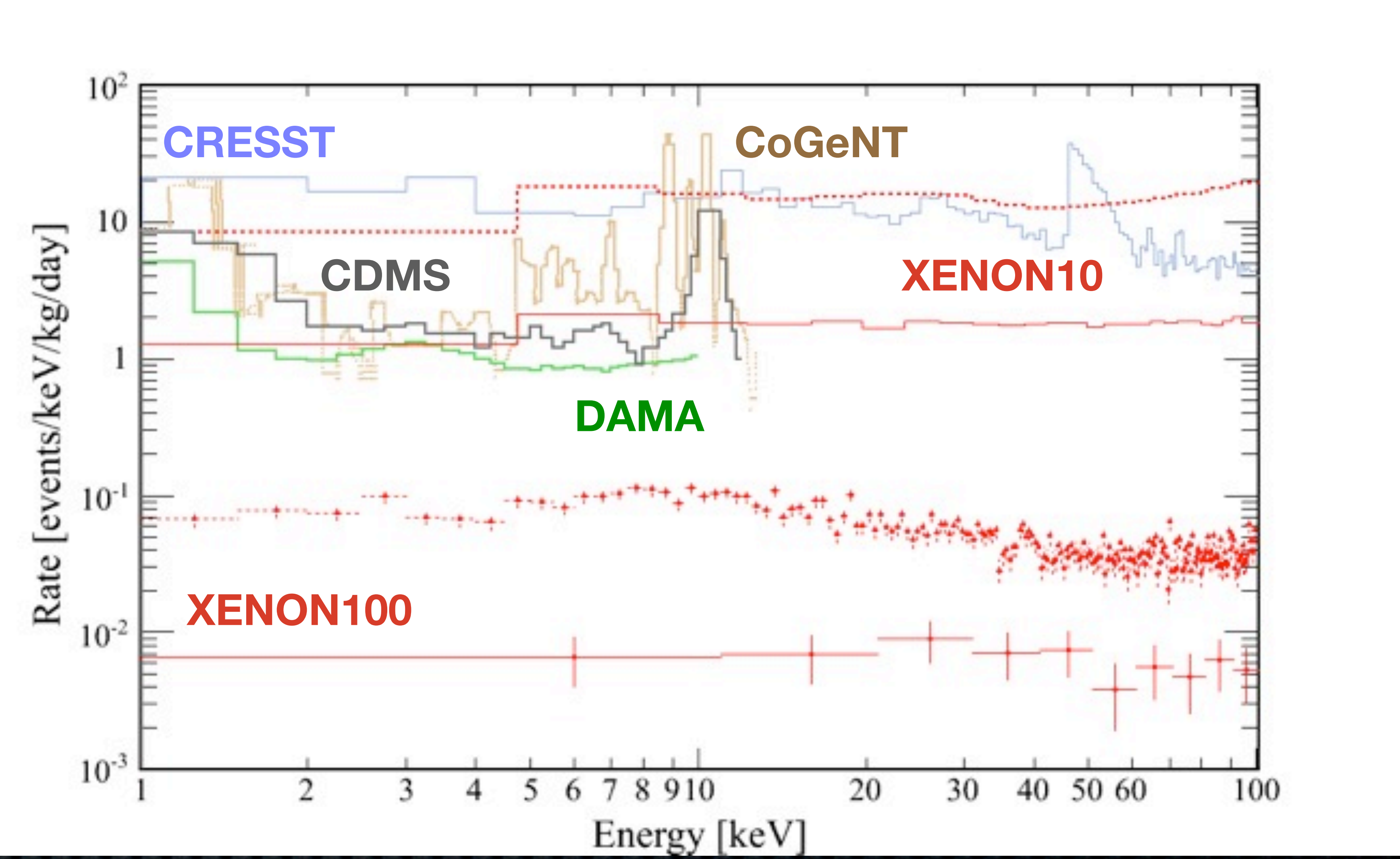
- Data versus Monte Carlo simulations (no MC tuning, input from screening values for U/Th/K/Co/Cs etc of all detector components); no active liquid xenon veto cut
- Background is 100 times lower than in XENON10 and meets design specifications

XENON100 collaboration, arXiv:1101.3866, PRD 83, 082001 (2011)



Backgrounds: Data and Predictions

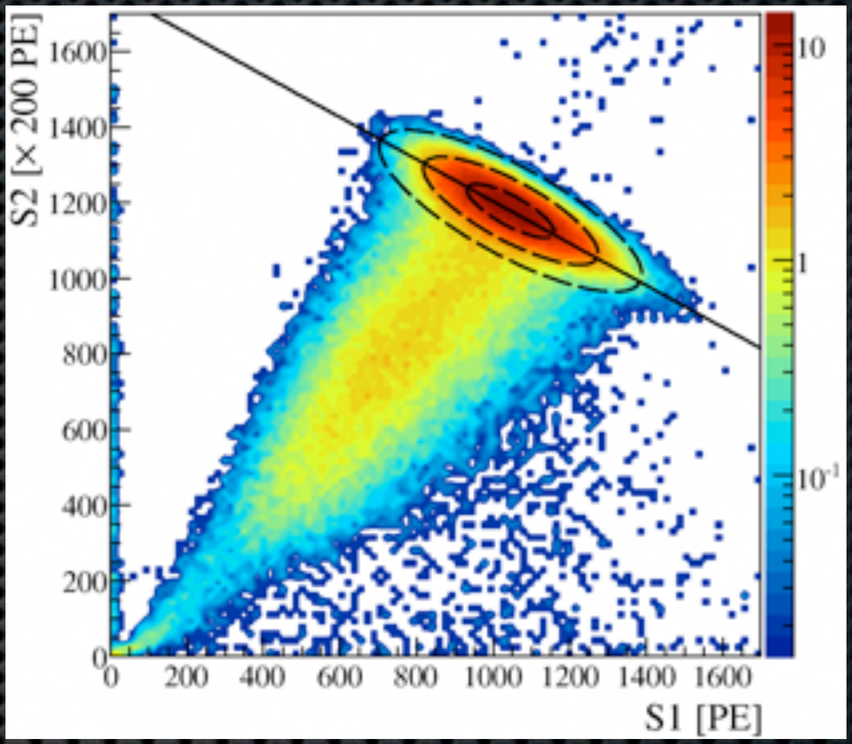
- Data versus Monte Carlo simulations (no MC tuning, input from screening values for U/Th/K/Co/Cs etc of all detector components); no active liquid xenon veto cut
- Background is 100 times lower than in XENON10 (and any other dark matter experiment) and meets design specifications



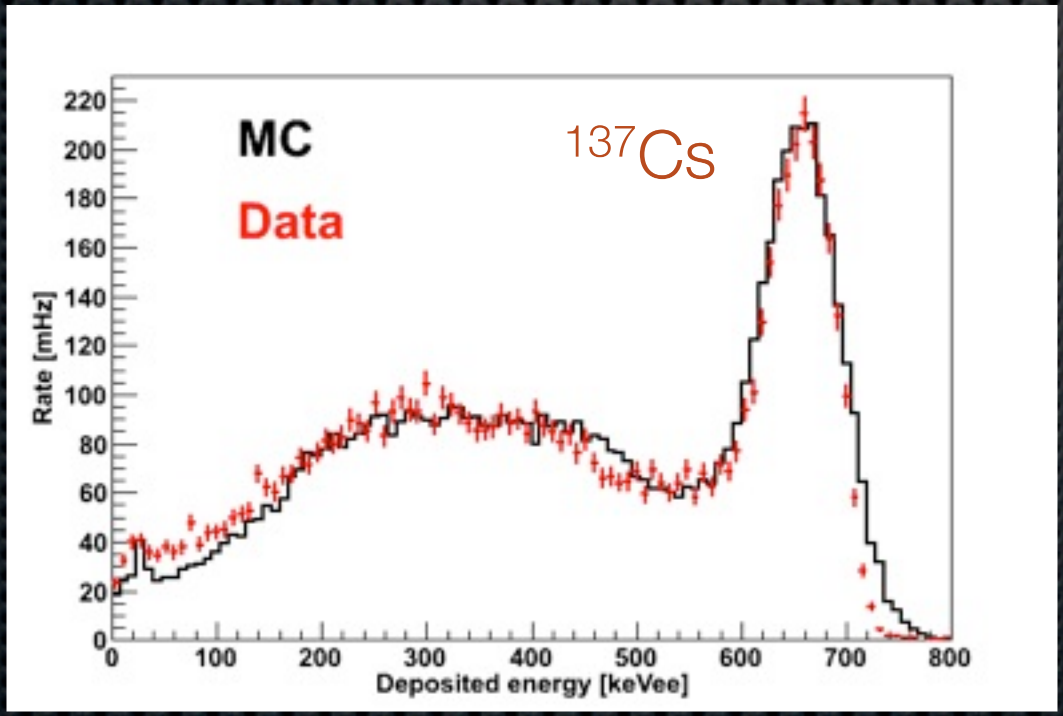
Gamma Calibrations

- ^{137}Cs to monitor the light yield
- ^{60}Co to map the electronic recoil band
- ^{232}Th to understand response up to high energies

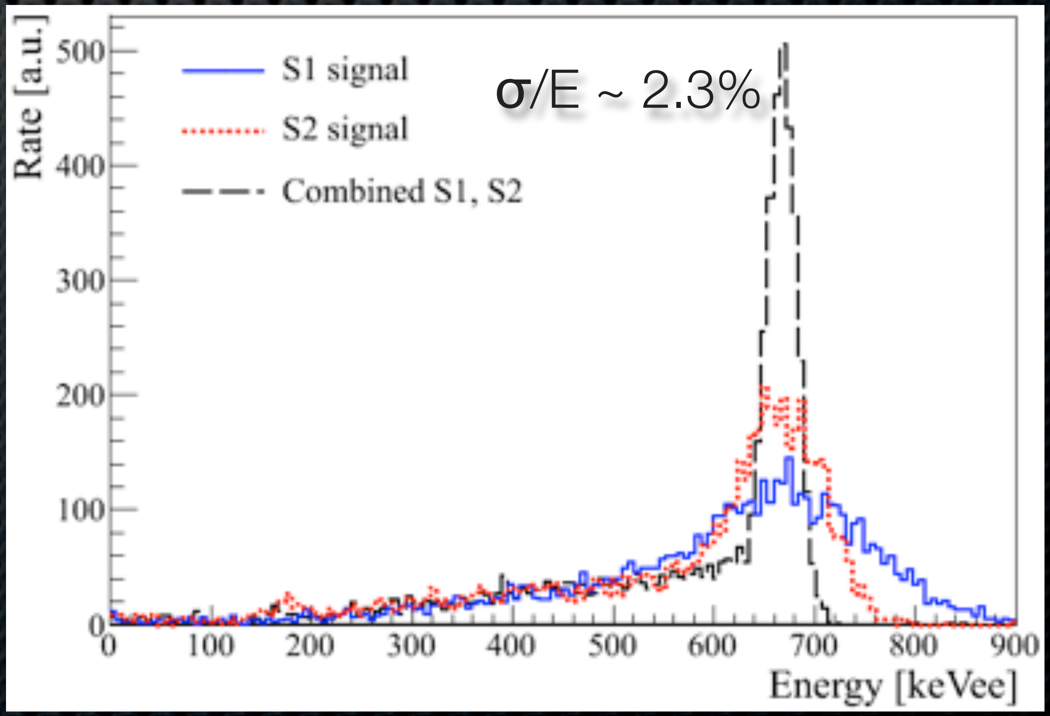
Charge-light anti-correlation



^{137}Cs calibration

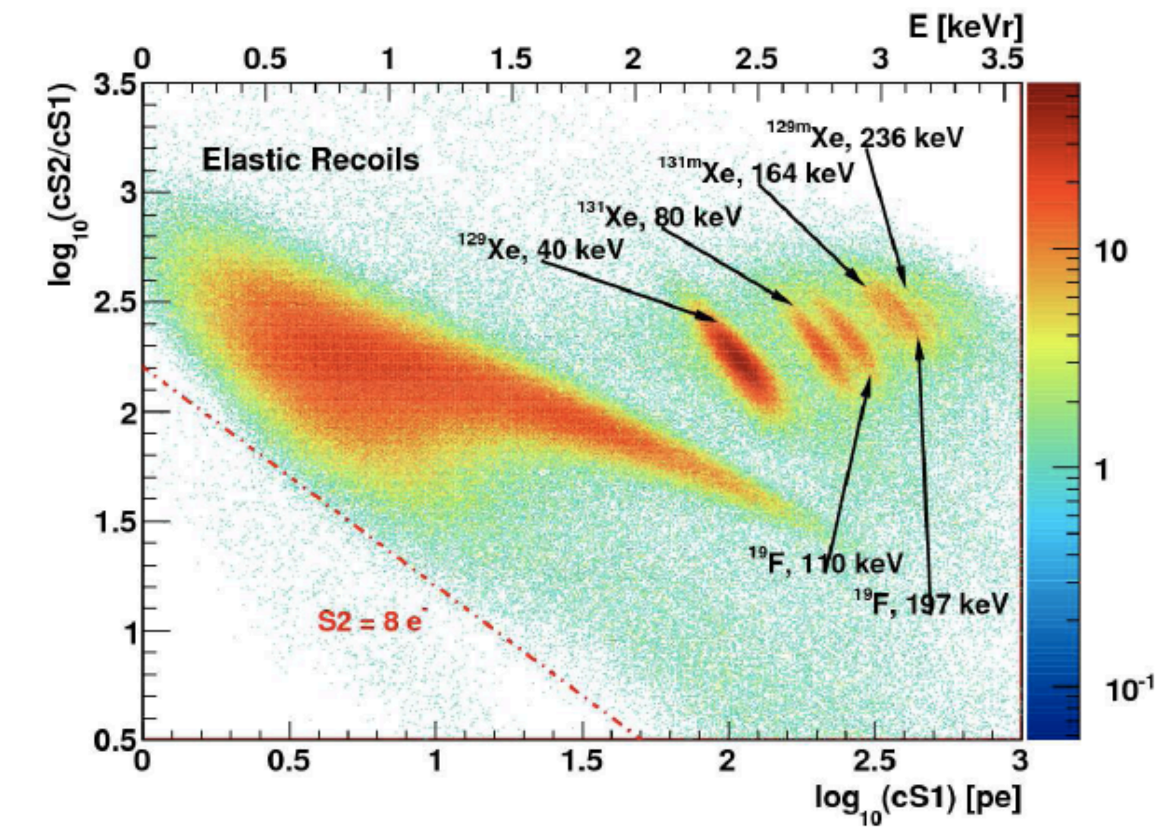


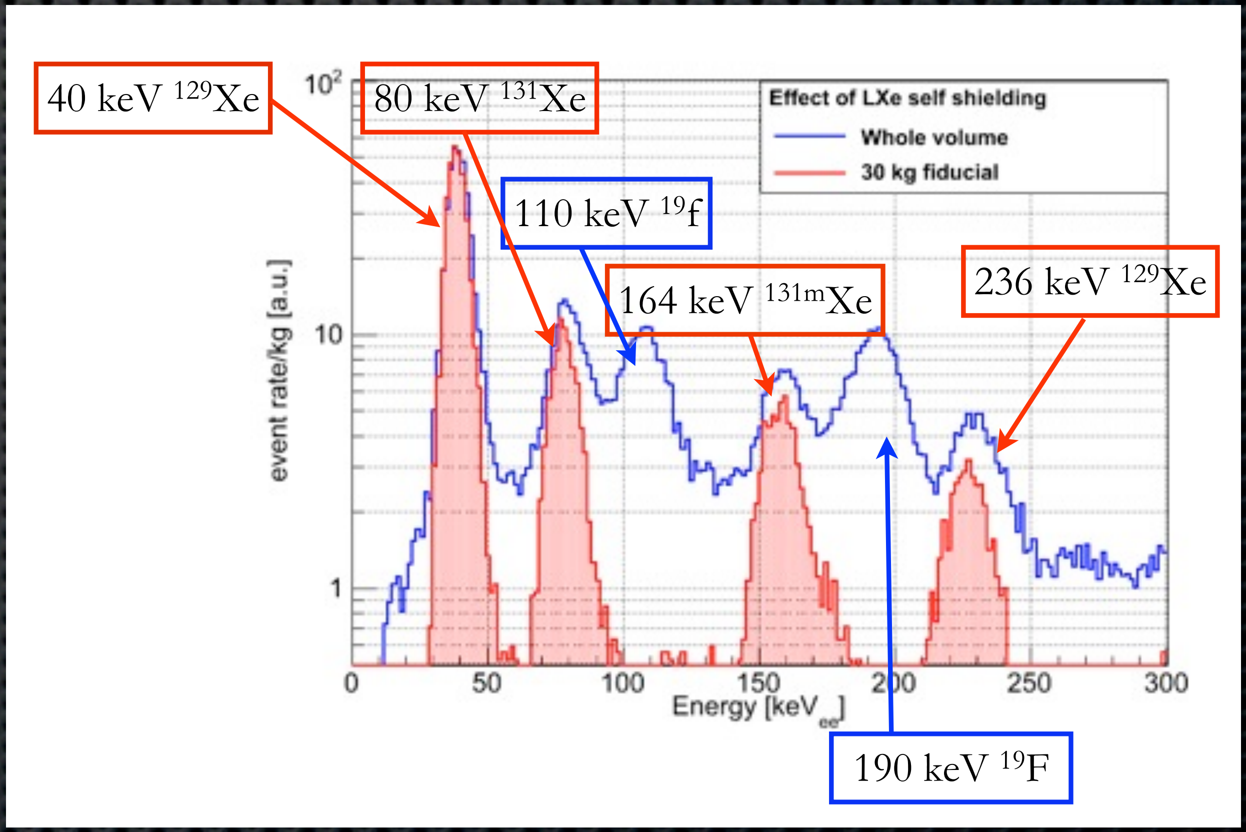
^{137}Cs: energy resolution improves when using both S1 and S2 signals



Neutron calibrations

- AmBe source (~ MeV neutrons, 220 n/s) to map the nuclear recoil band
- Inelastic n-scattering on Xe: $^{129,131}Xe + n \rightarrow {}^{129,131}Xe + n + \gamma$ (40 keV, 80 keV)





- Uniformly distributed gammas from inelastic collisions used to check/correct signal dependency with event position

Nuclear recoil equivalent energy scale

Energy of nuclear recoils (NRs)

Measured signal in nr. of p.e.

Quenching of scintillation yield for 122 keV γ's due to field (0.58 at ~ 0.5 kV/cm)

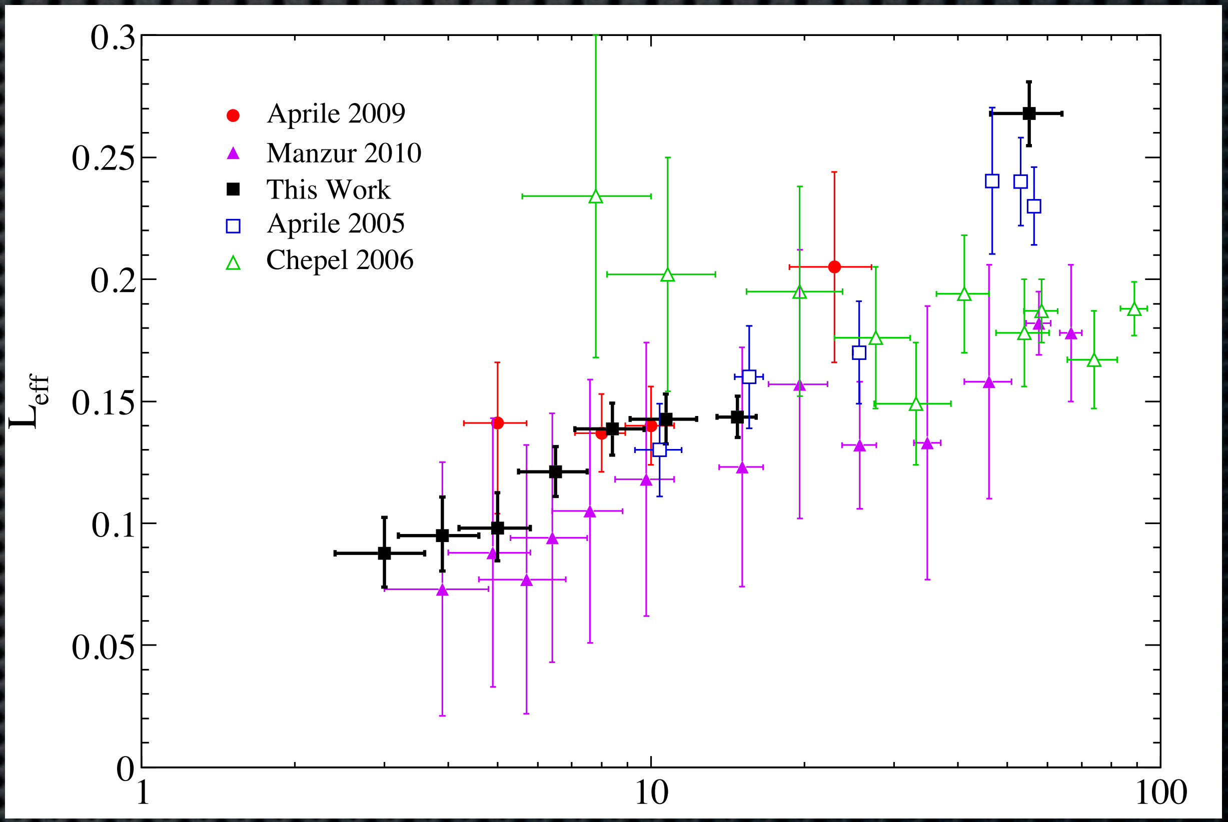
$$E_{nr} = \frac{S1}{L_y \cdot L_{\mathrm{eff}}} \times \frac{S_{er}}{S_{nr}}$$

Light yield for 122 keV γ in p.e. (2.2 ± 0.1) p.e./keV

Relative scintillation efficiency of NRs to 122 keV γ's at zero field

Quenching of scintillation yield for NRs due to field (0.95 at ~0.5 kV/cm)

New measurements of L_{eff} at Columbia down to 3 keVr



G. Plante et al., arXiv:1104.2587v1 [nucl-ex]

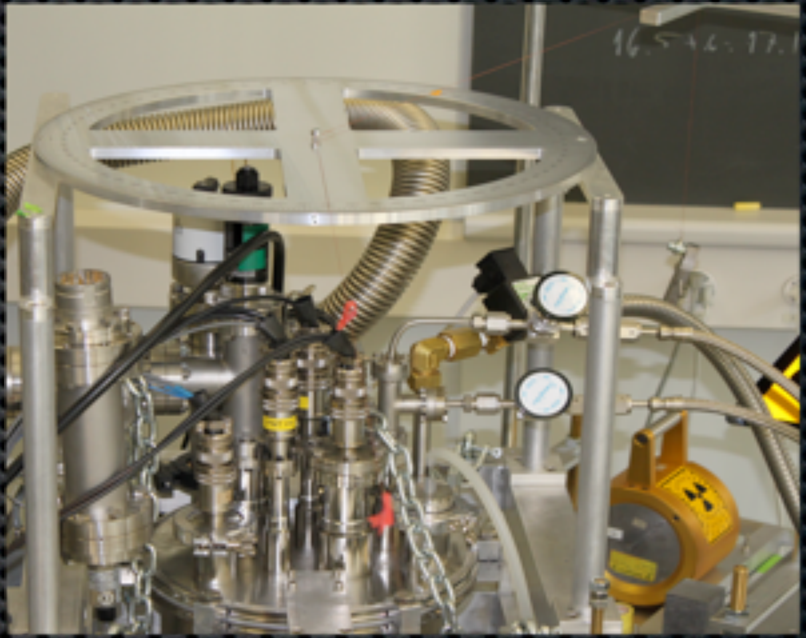
Details: G. Plante, G13.8

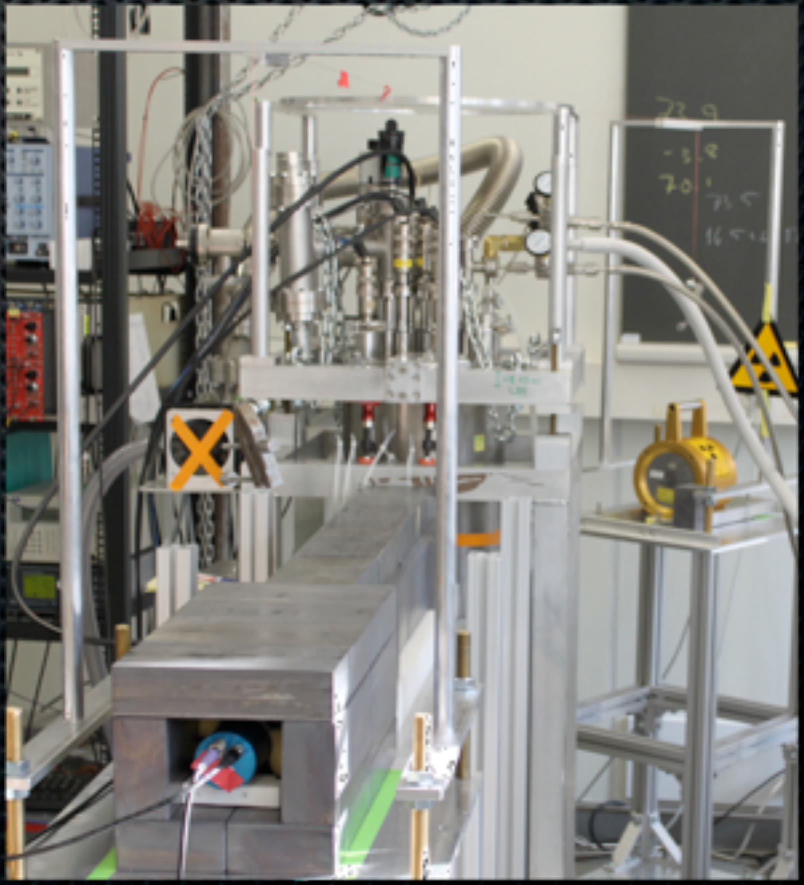
L_{eff} measures the nonlinear part of the scaling between the energy deposition and the scintillation output. The use of 122 keV introduces only a scaling term.

Light yield of low-energy electronic recoils in LXe

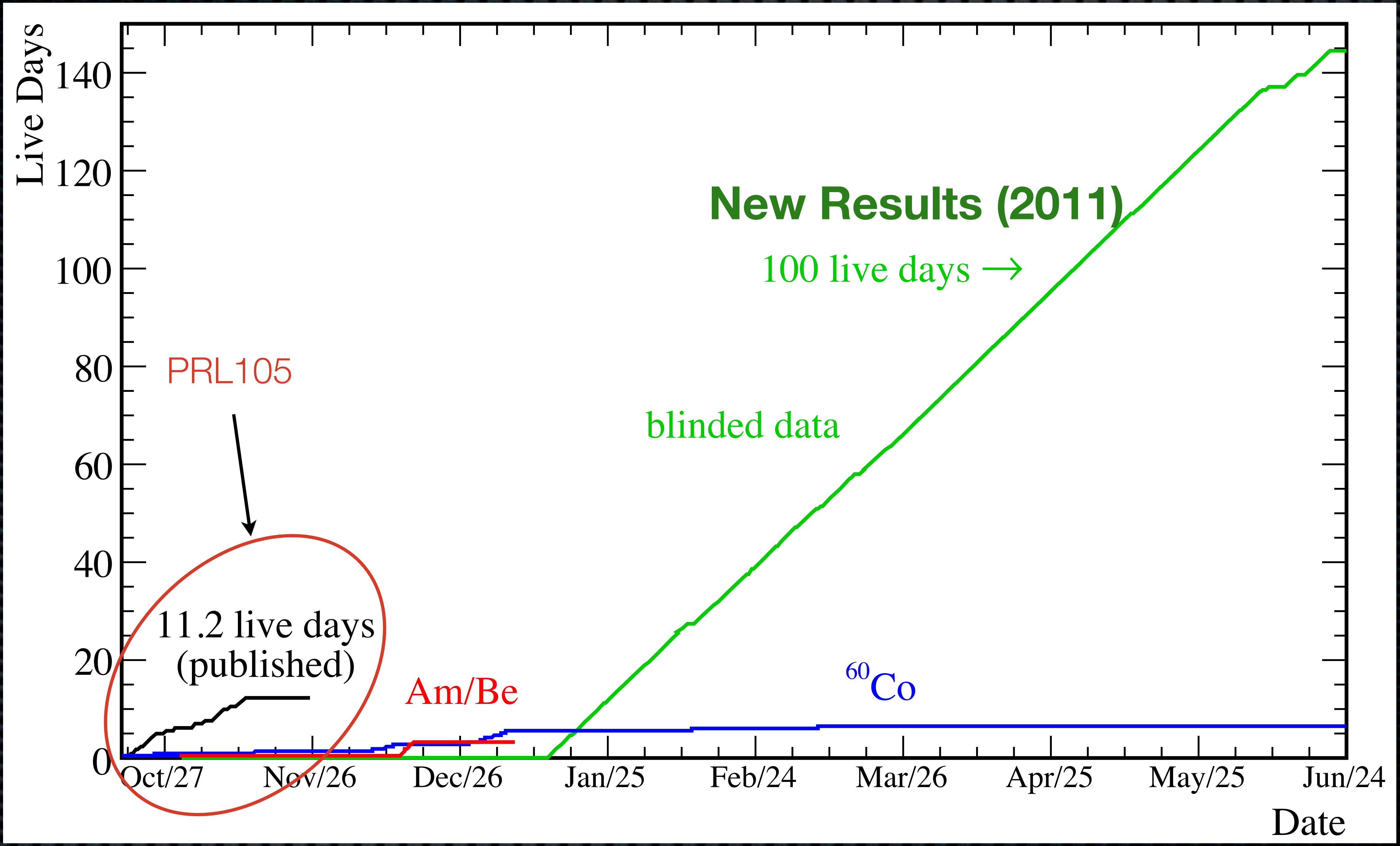
- Use strong ^{137}Cs source, LXe and NaI detector in coincidence to measure light yield of electronic recoils down to ~ 2 keV
- Measurements in progress at UZH

Angle [deg]	Energy [keV]
3.5	1.6
4.25	2.35
8.5	9.3
16	32
34.5	123





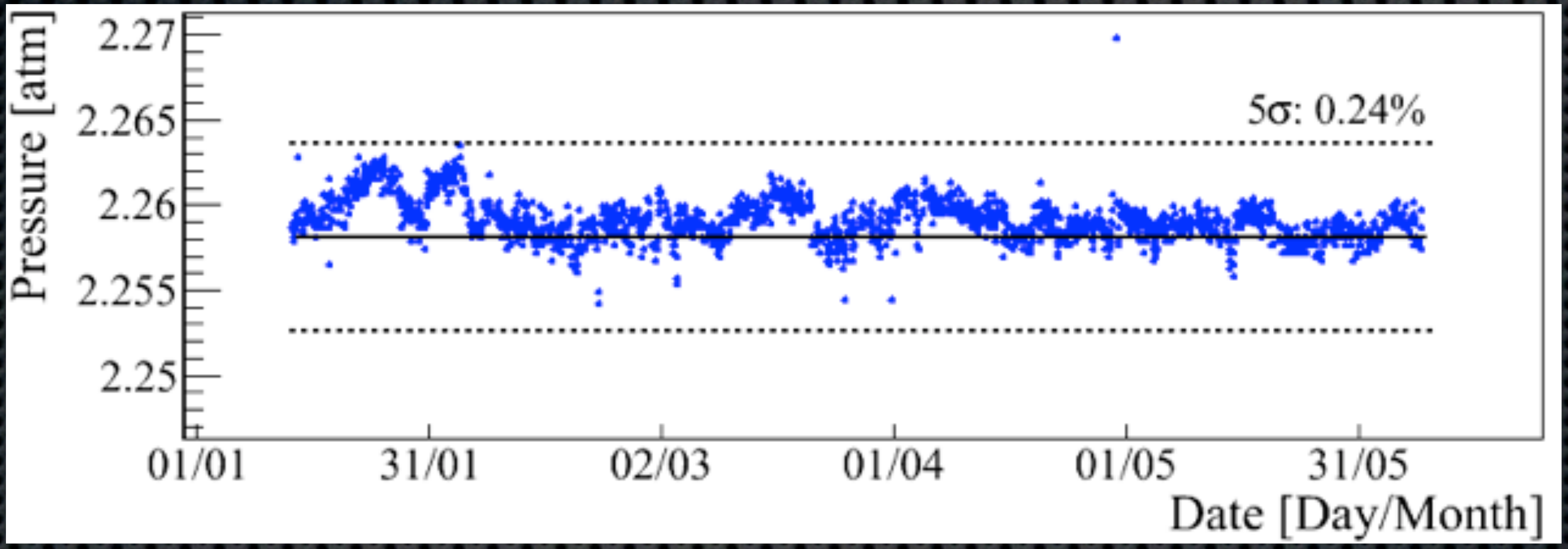
XENON100 2010 Dark Matter Run

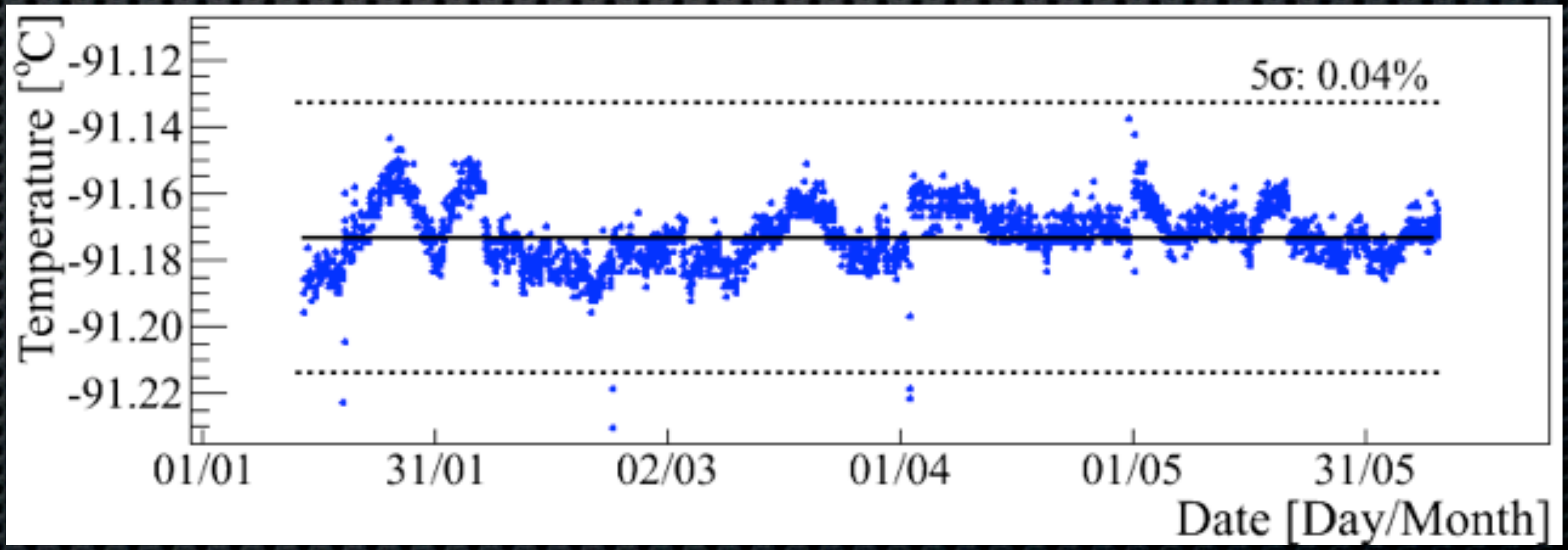


Oct 2009

June 2010

Pressure and temperature inside the TPC during the dark matter run





Schematics of data analysis

Low energy trigger generated by shaped sum signal of 84 PMTs passing a predefined hardware threshold

S2 trigger efficiency $> 99\%$ for S2 $>$ 300 PE

All recorded events are analyzed to check that they correspond to physical interaction inside the TPC

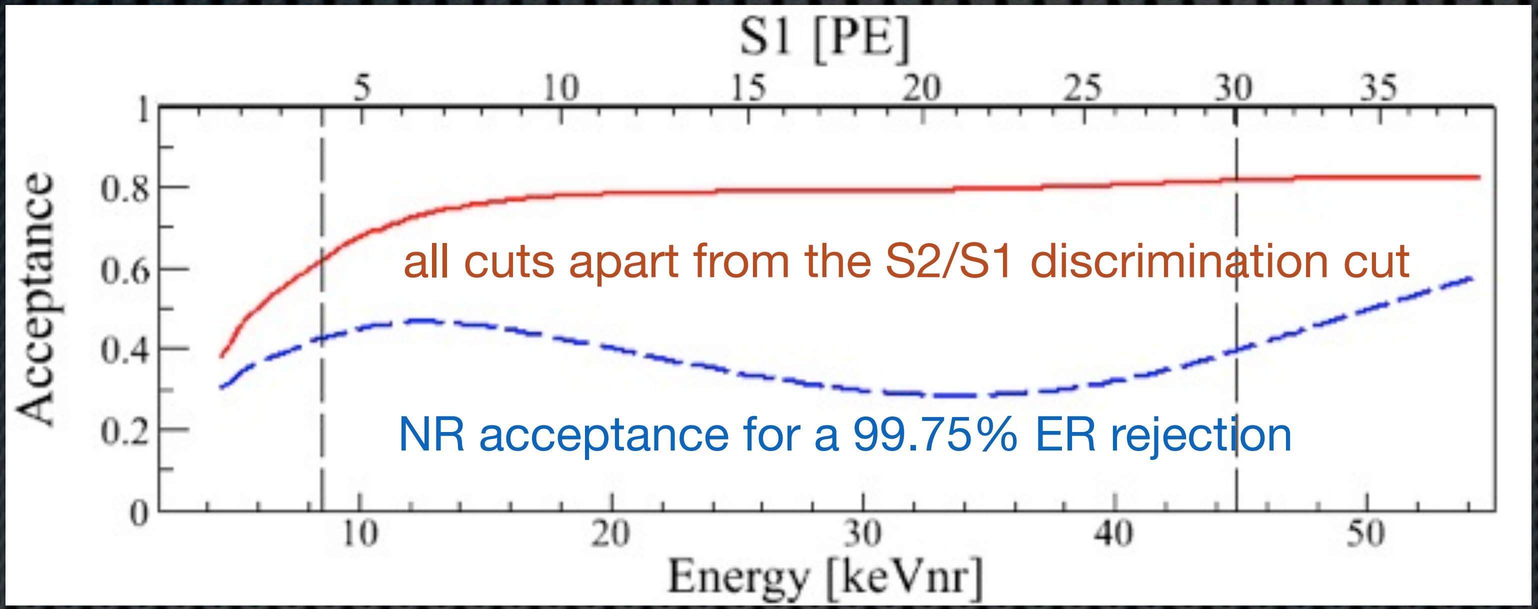
Remove noise events

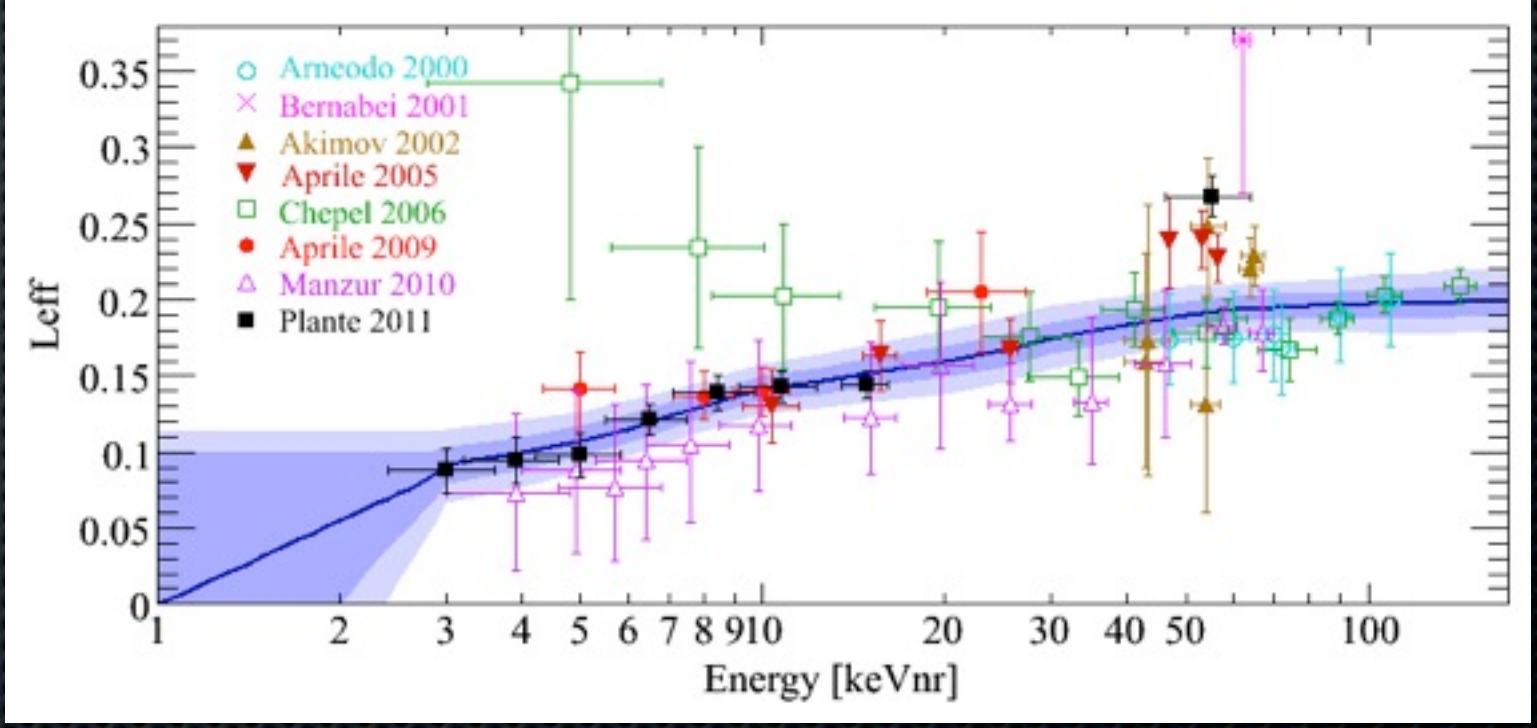
Remove events in which the S2 and S1 don't match the reconstructed position

Remove multiple scatters

Cuts acceptance and light yield parameterization

Energy range: 4 - 30 pe

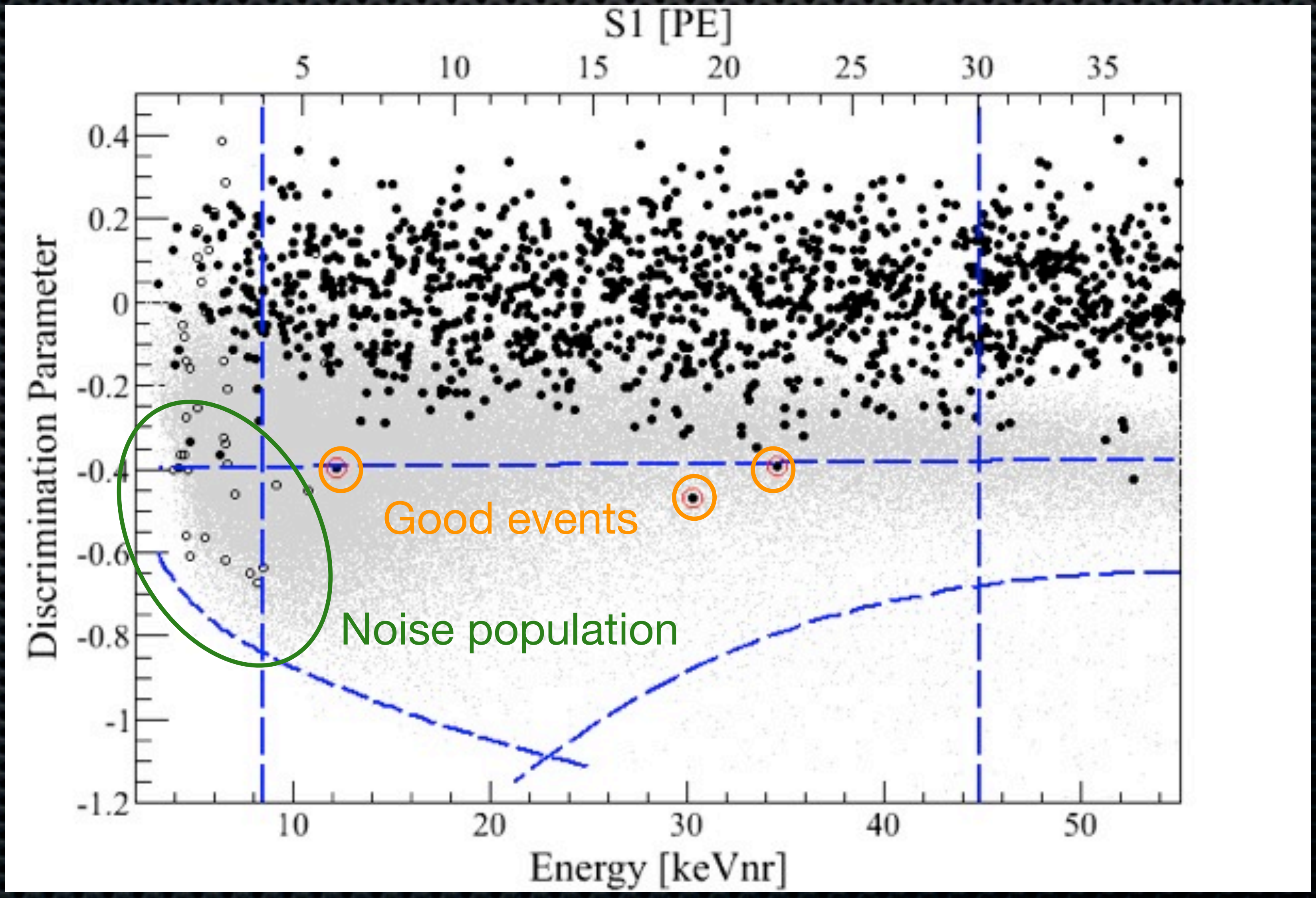




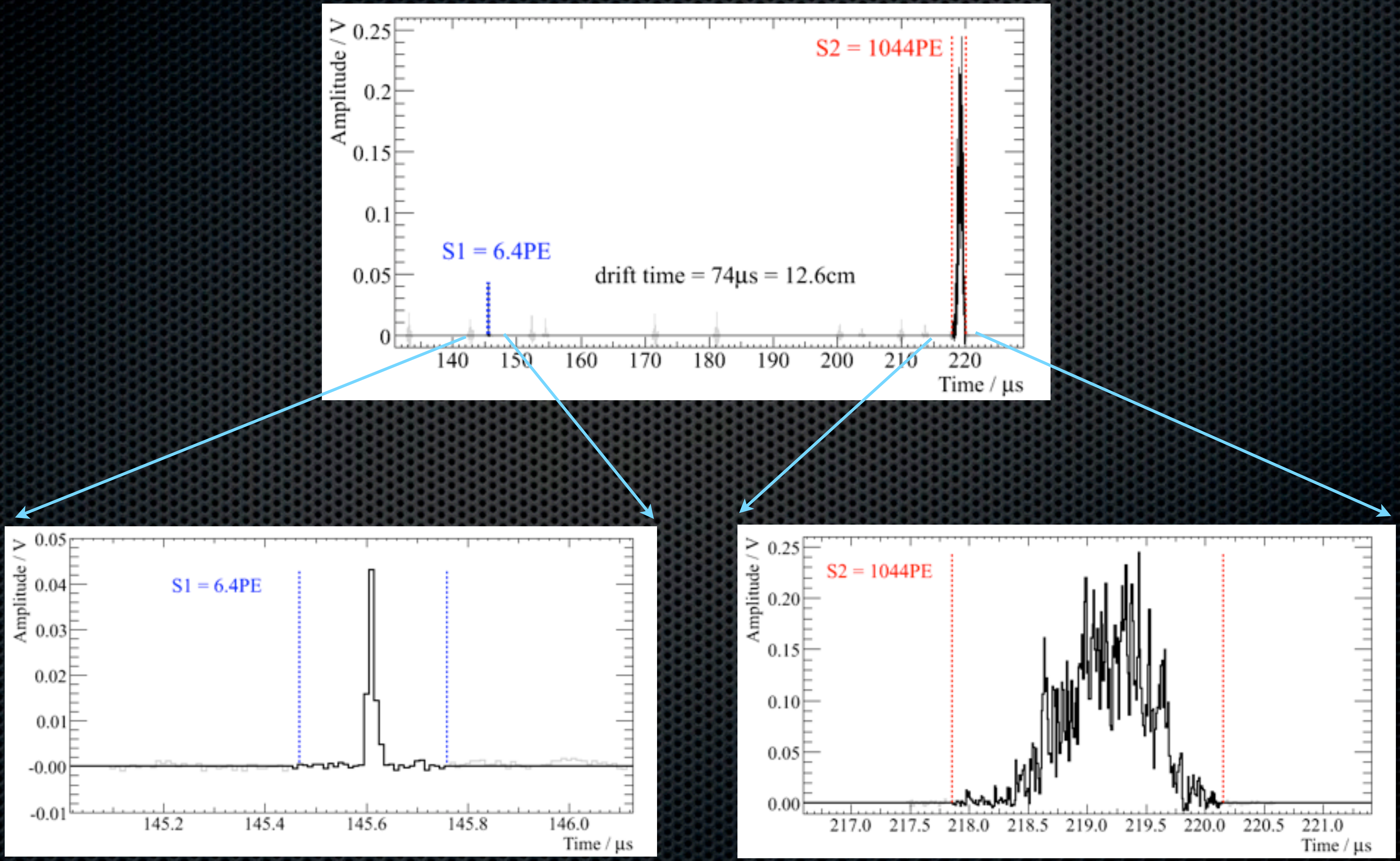
mean (solid) and 1-, 2-sigma uncertainties (blue bands) of L_{eff} direct measurements

After unblinding...

- 6 events observed in the WIMP search region (4 - 30 pe)
- However, 3 events (along with a population below 4 pe) were pure noise
- Cut (post-unblinding) on S1-width removes these events with > 99.7% efficiency for nuclear recoils

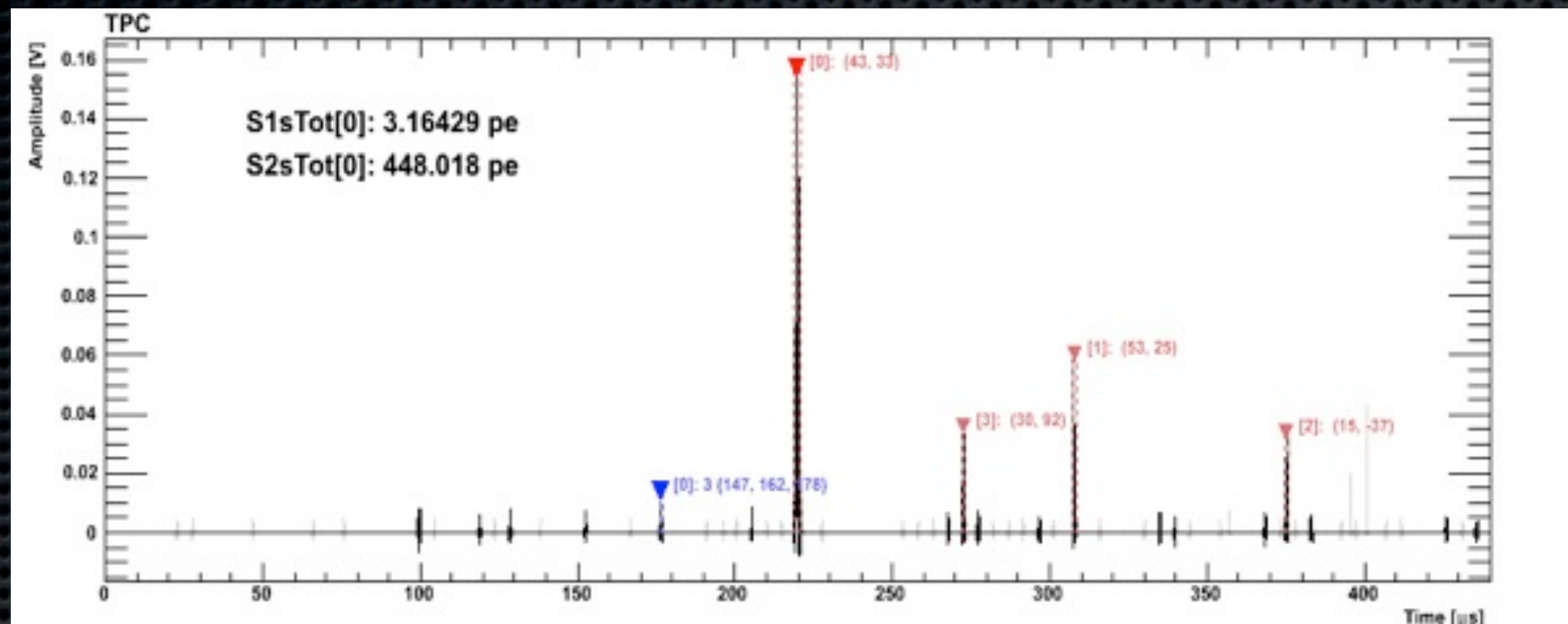


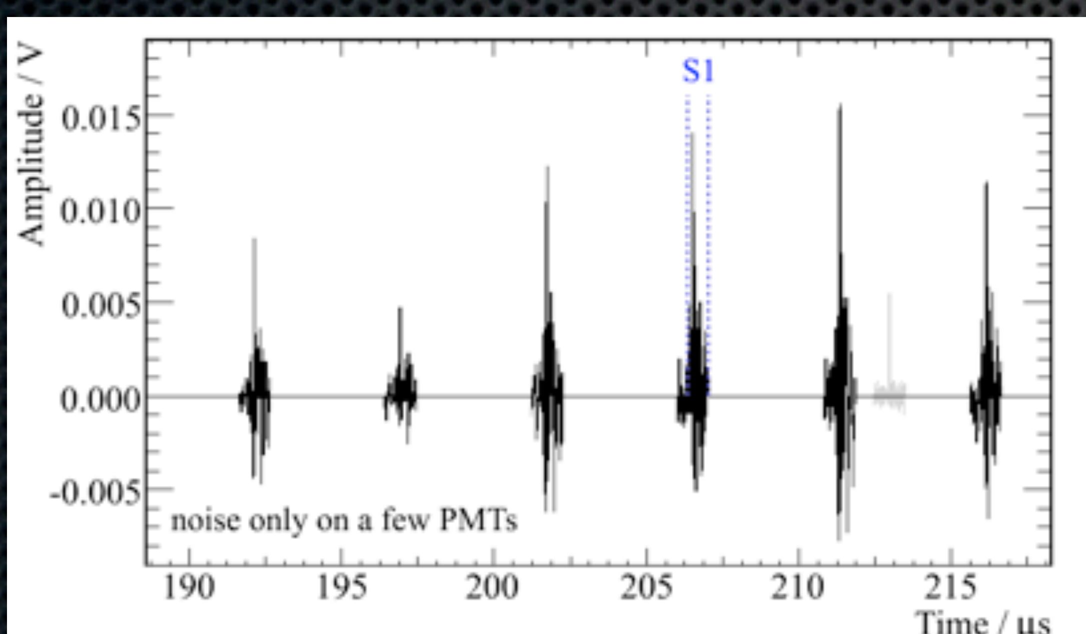
A good event

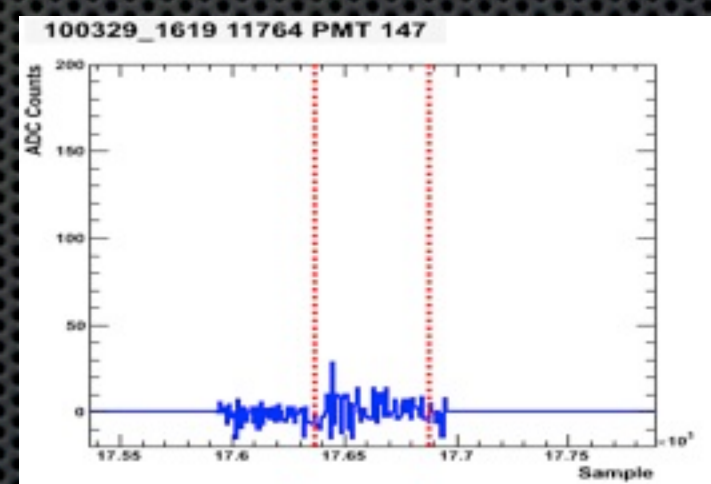


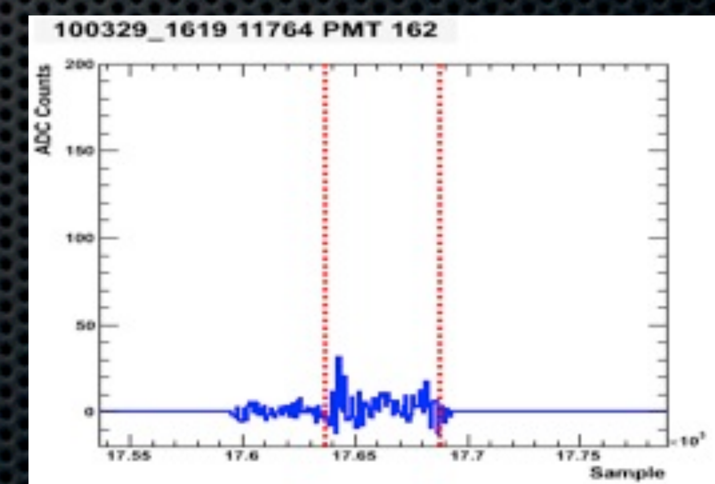
S2 = 1044PE
S1 = 6.4PE
drift time = 74μs = 12.6cm
Amplitude / V
Time / μs
S1 = 6.4PE
Amplitude / V
Time / μs
S2 = 1044PE
Amplitude / V
Time / μs

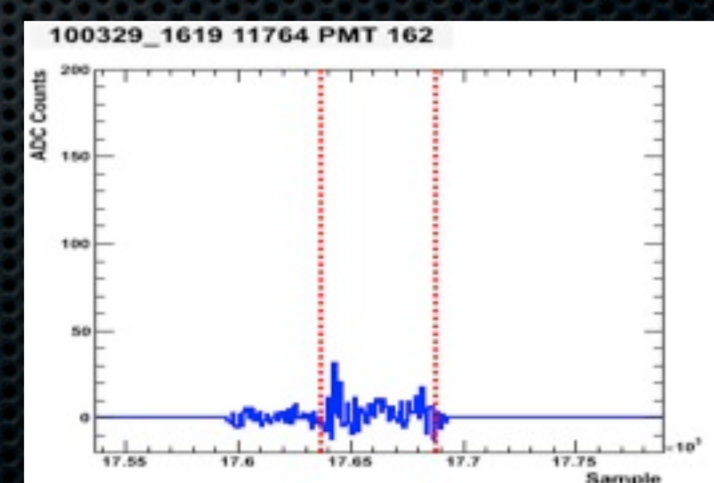
A noise event



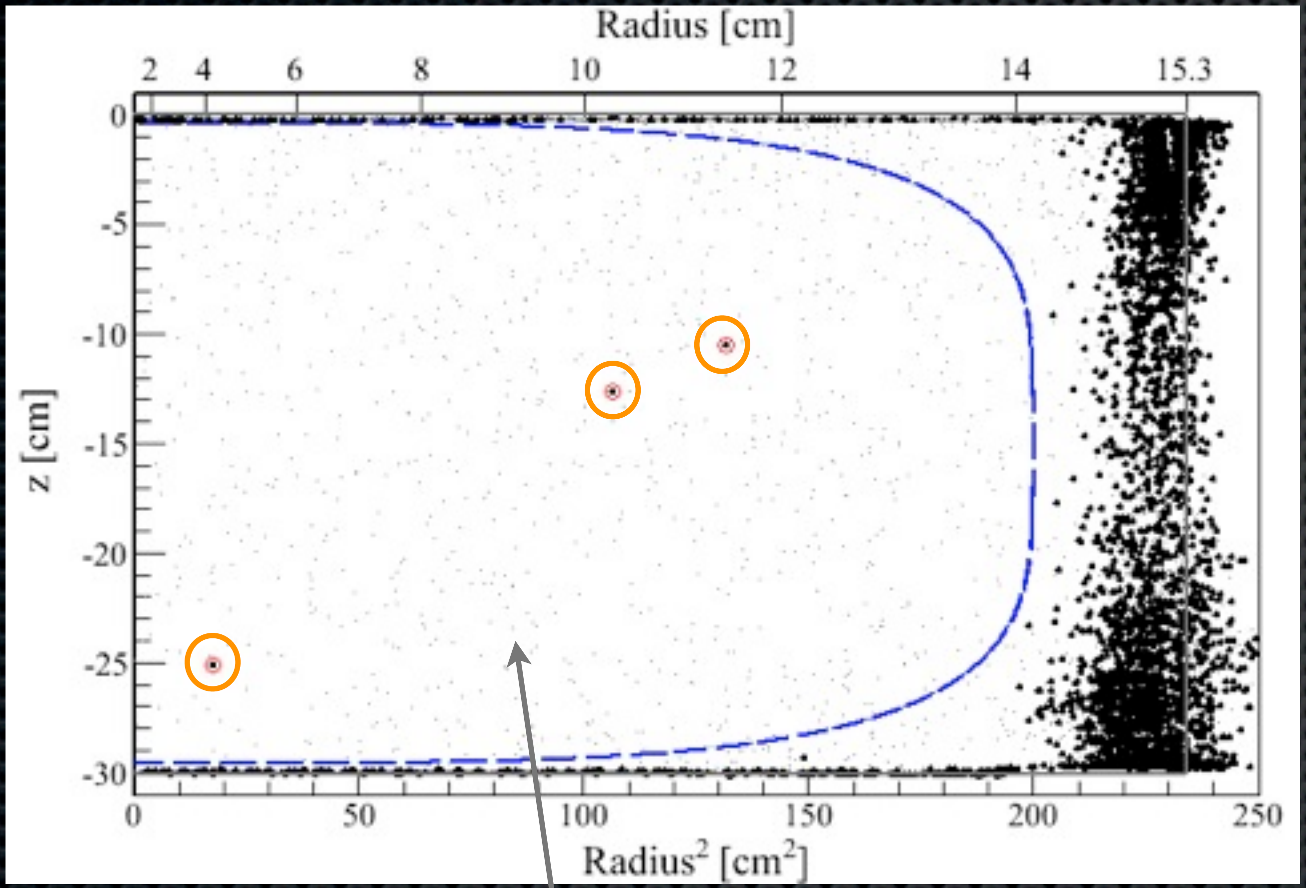


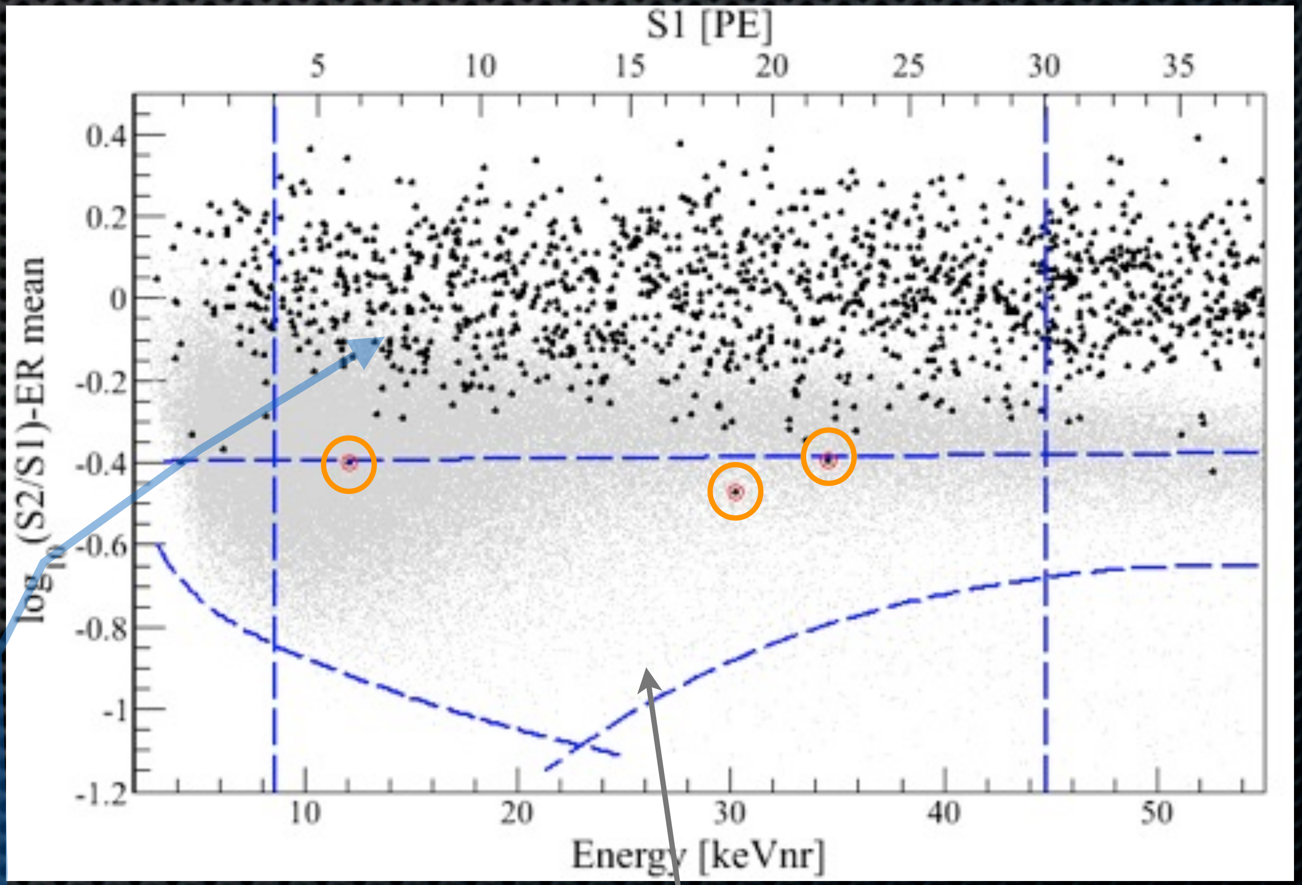






Distribution of events in the TPC





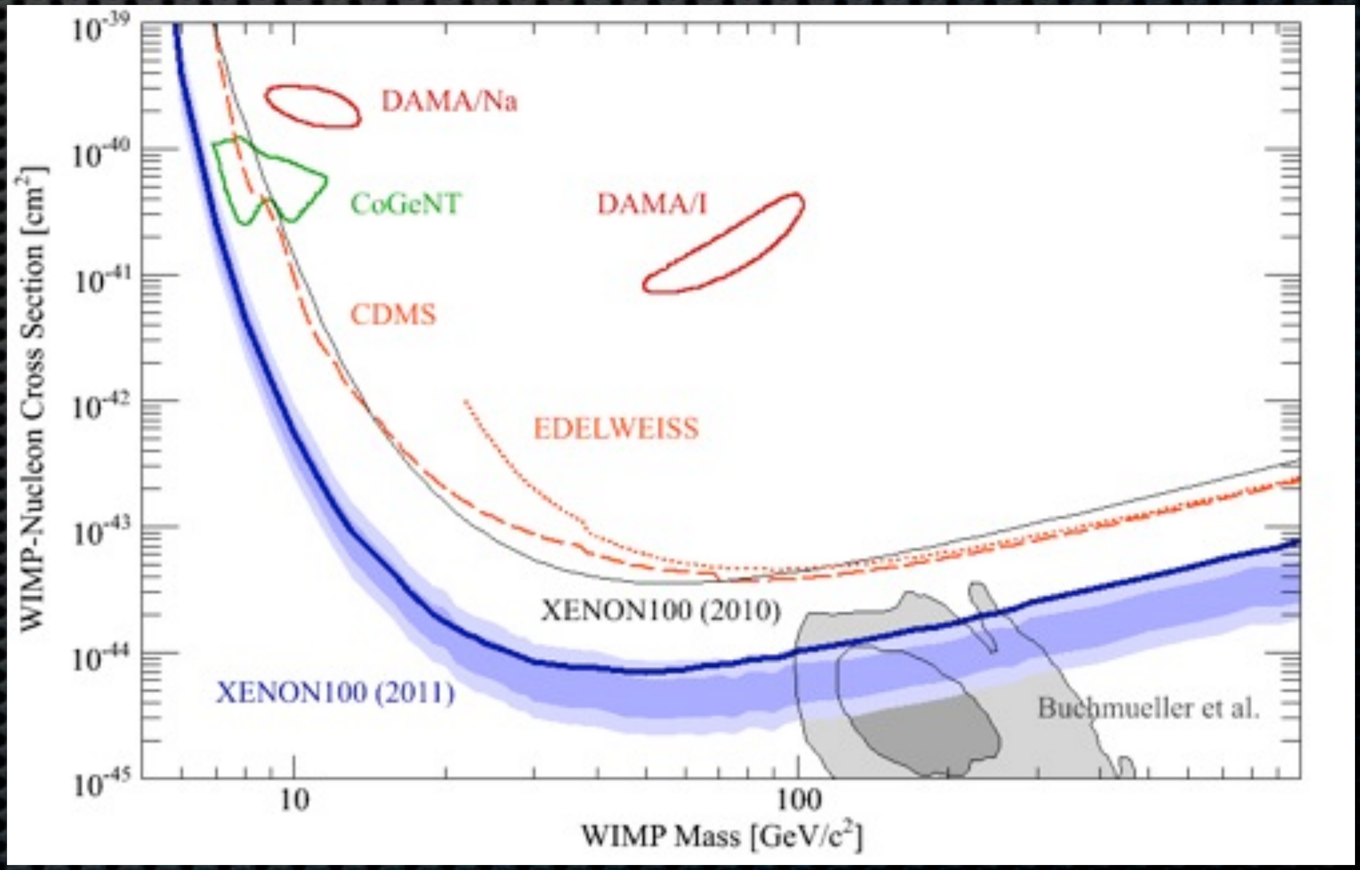
Fiducial mass region:
48 kg of liquid xenon
900 events in total

Signal region:
3 events are observed
1.8 ± 0.6 gamma leakage events expected
0.1 ± 0.08 ± 0.04 neutron events expected

New upper limit on spin-independent WIMP-nucleon cross sections

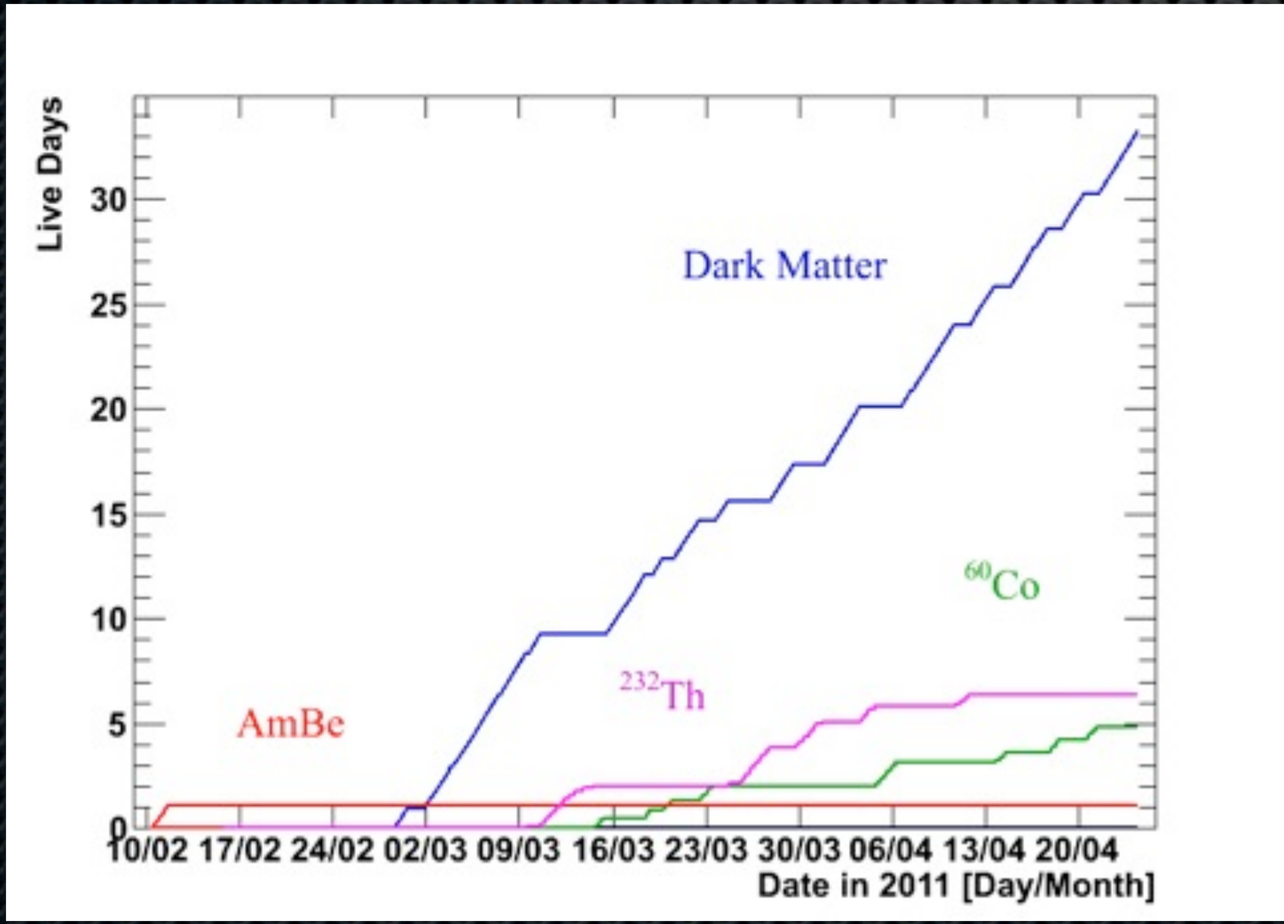
- Blue bands: 1- and 2-sigma expectations, based on zero signal
- Limit (dark blue) is 1.5-2 sigma worse than expectations, given 2 events observed at high S1
- At a WIMP mass of 50 GeV, the limit on the SI WIMP-nucleon cross section is 7 x 10^{-45} cm^2 (90% C.L.)
- Limit is robust against extrapolation of L_{eff} below 3 keVr

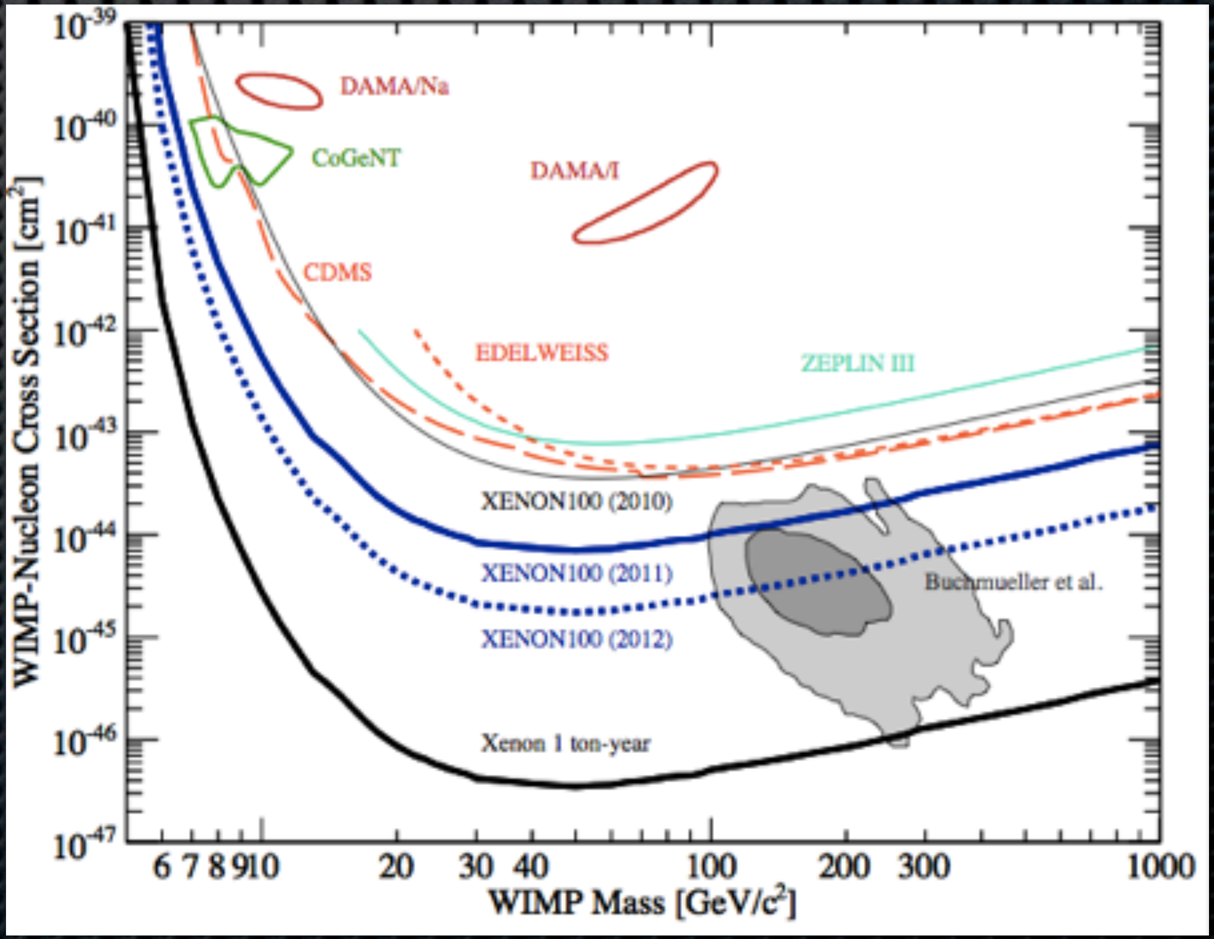
XENON collaboration, arXiv:1104.2549v1 [astro-ph.CO]



Current status and expected sensitivity

- New AmBe calibration run for nuclear recoils
- Regular ^{60}Co and ^{232}Th calibration runs
- New dark matter run started in March 2011
- Background back to level in 2009



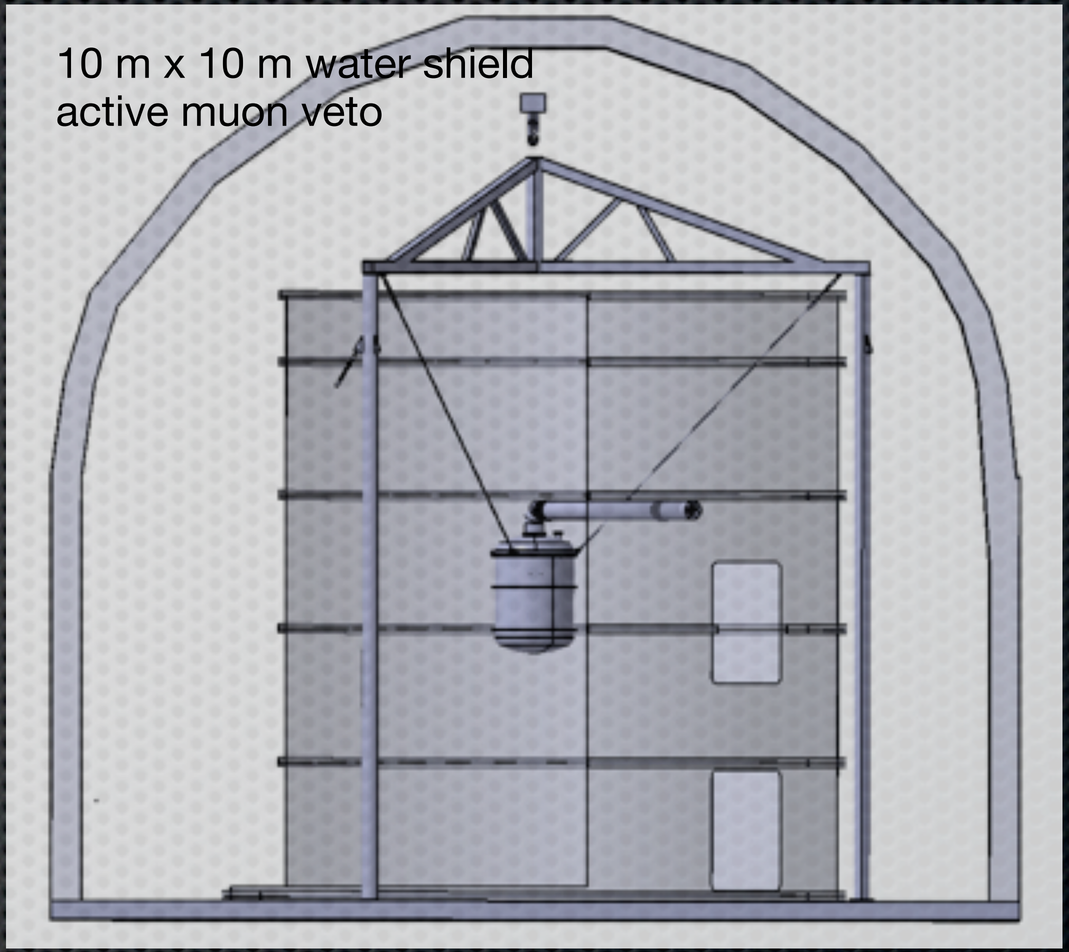


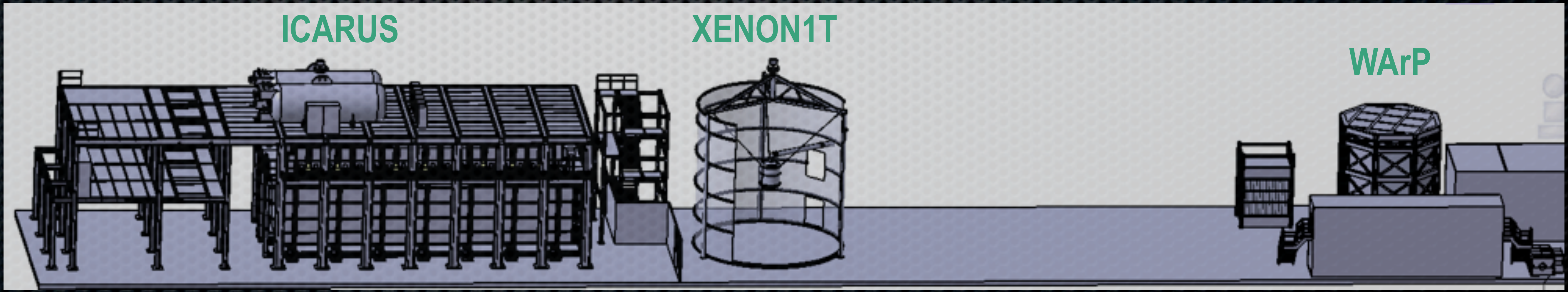
Next Phase: XENON1T

Designed to probe the σ-region down to 5×10^{-47} cm^2

Approved to be built at LNGS in April 2011

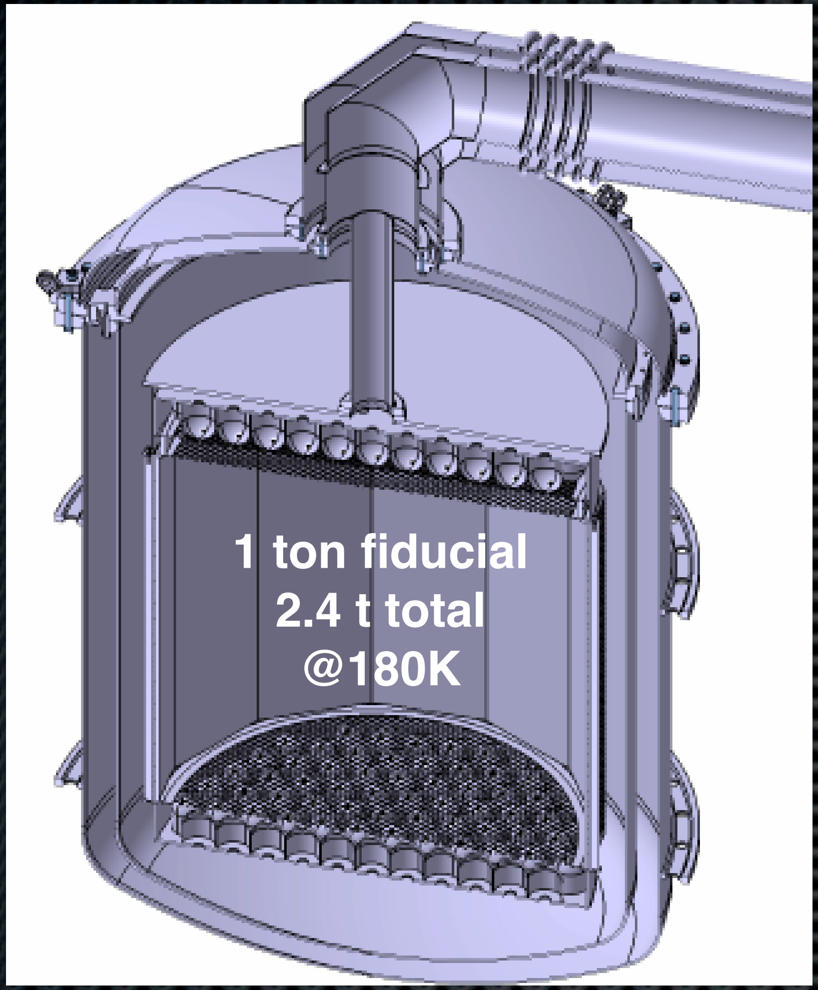
Construction to start in late 2011
Full physics reach by 2015





The XENON1T detector

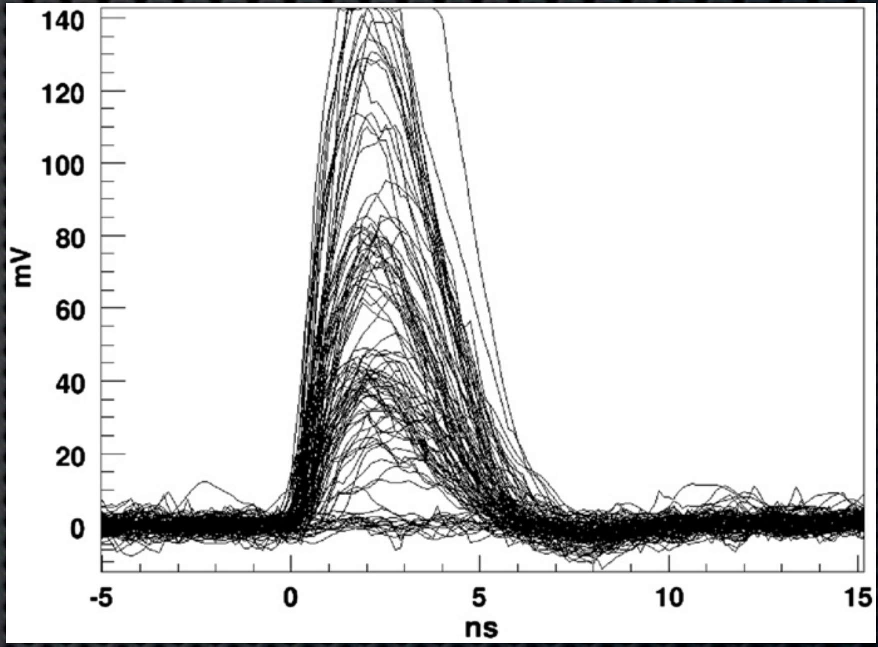
121 3” sensors top



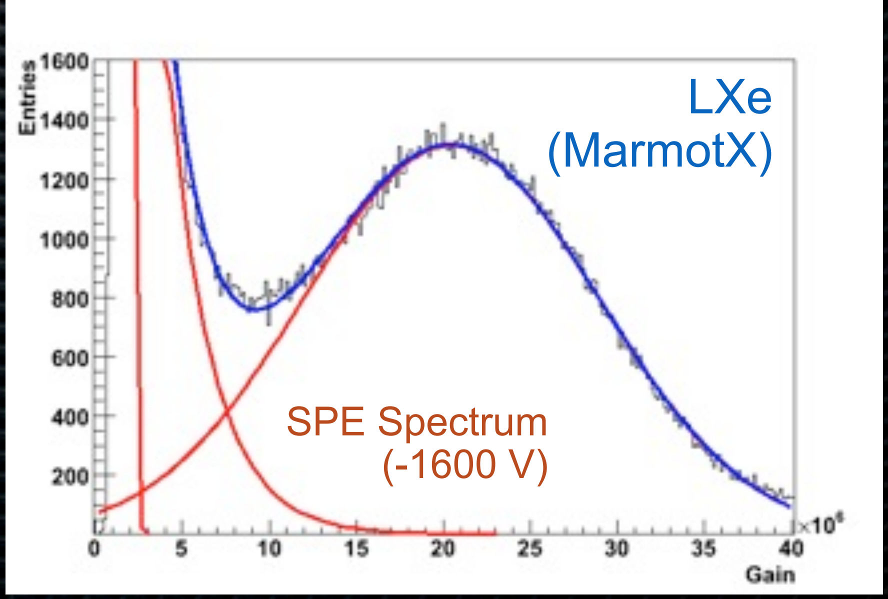
121 3” sensors bottom

Photosensors: QUPIDs -> tested at UCLA

K. Lung, G13.3, A. Teymourian G13.9



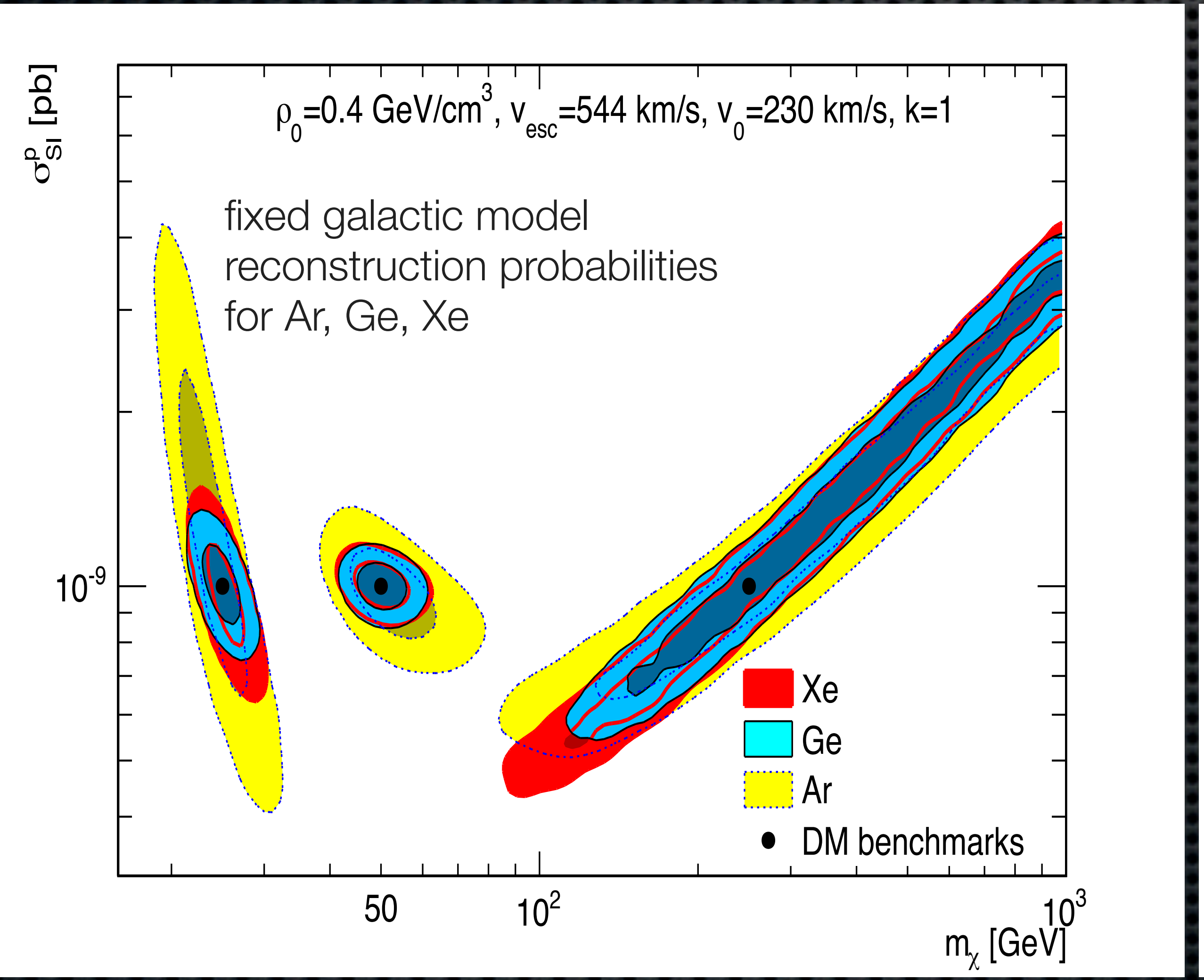
Photosensors: R11410 -> tested at UZH

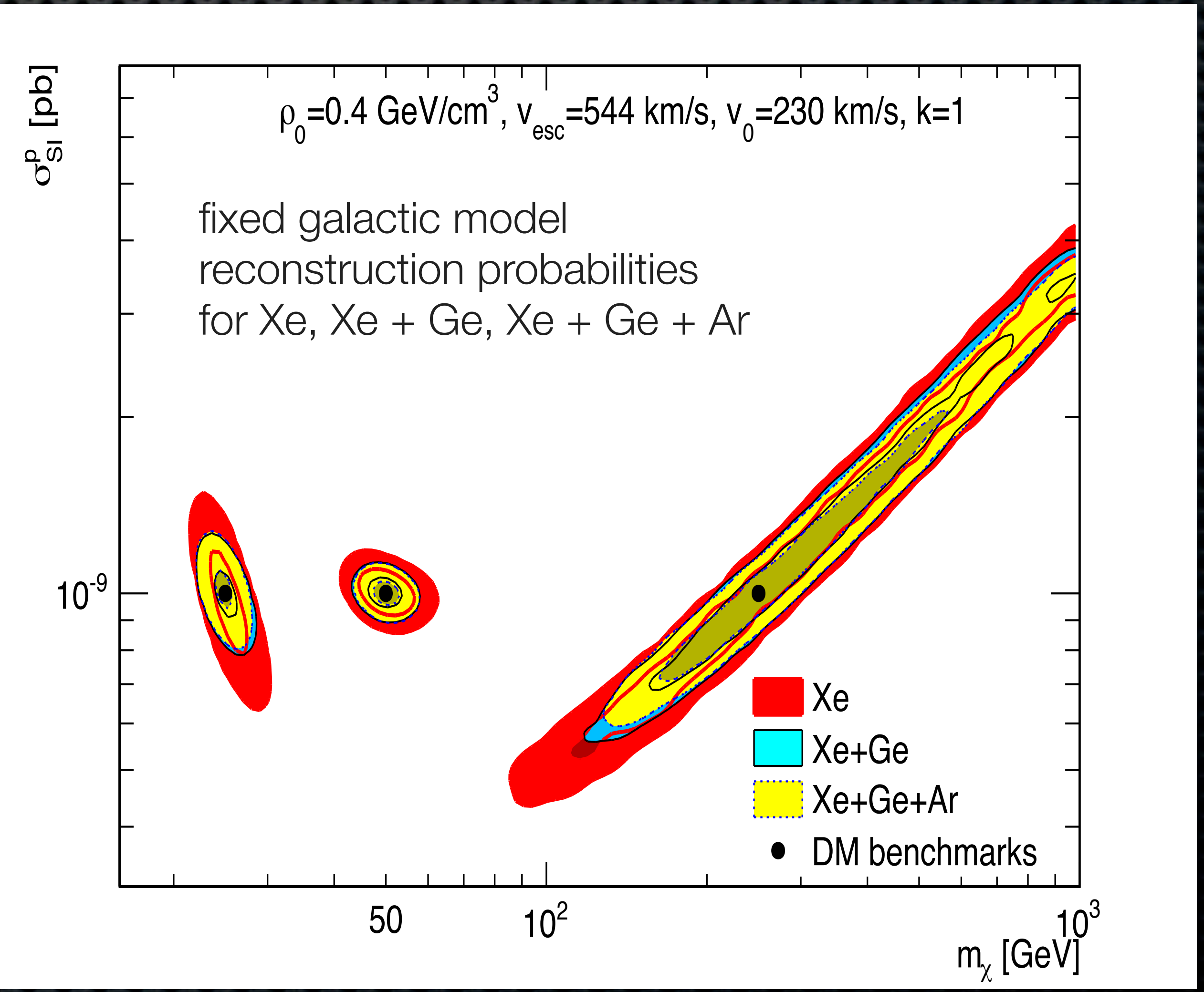


Beyond Current Detectors: DARWIN

- To reconstruct WIMP properties such a mass and scattering cross section we will (likely) need larger detectors for high-stats recoil spectra

astro-ph.CO: 1012.3458, accepted in PRD (2011)

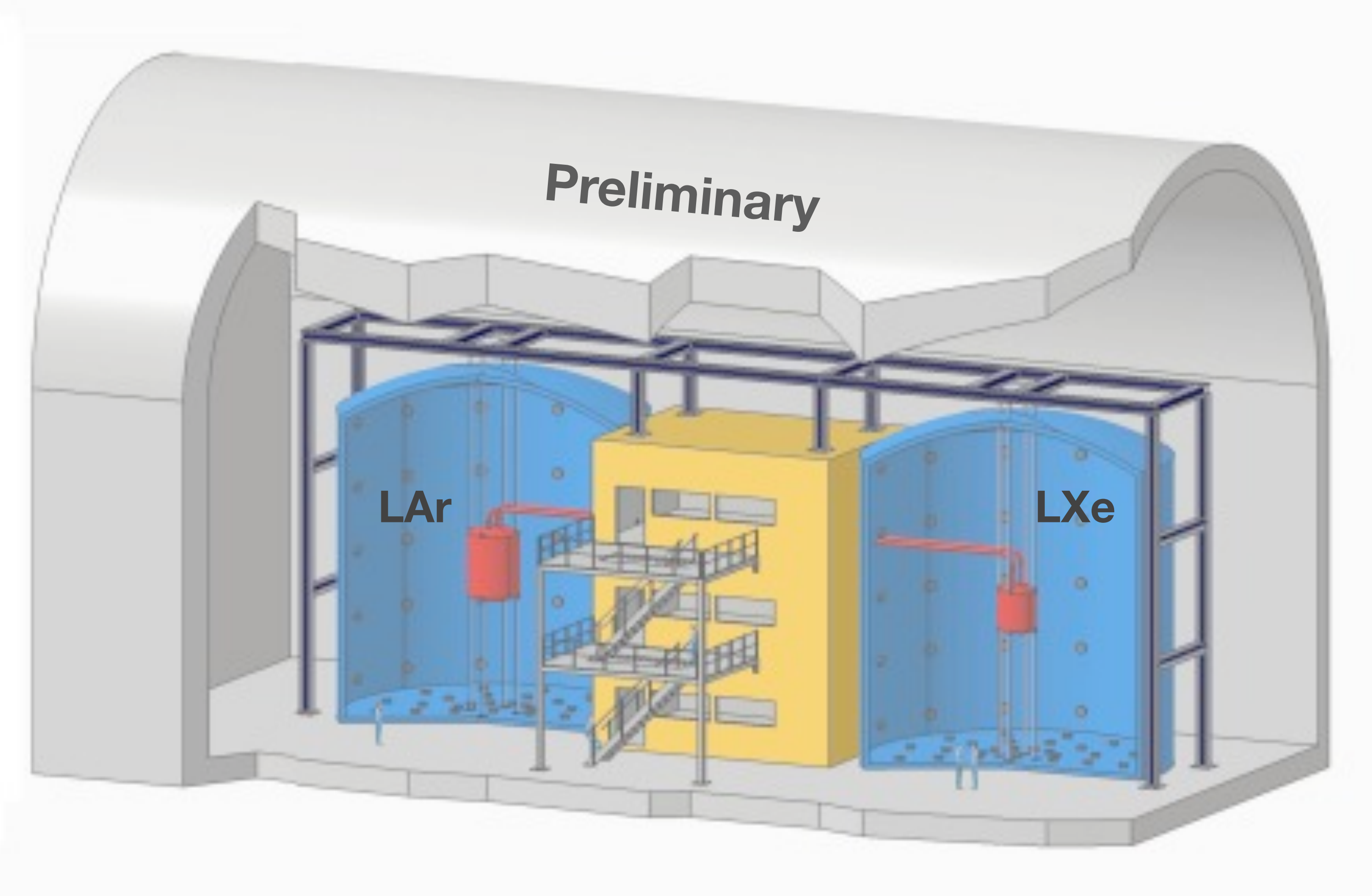




Miguel Pato, Laura Baudis, Gianfranco Bertone, Roberto Ruiz de Austri, Louis E. Strigari and Roberto Trotta

DARWIN: DARk matter WImp search with Noble liquids

- R&D and design study for next-generation noble liquid detector in Europe
- Location: Gran Sasso (Italy) or ULISSE (Modane Lab extension, France)
- Physics goal: prove WIMP-nucleon cross sections beyond 10^{-47} cm^2



DARWIN

2009 - 2012: R&D and Design Study
2013: Submission of LoI, engineering studies
2014 - 2015: Construction and commissioning
2016 - 2020: Operation, physics data

(darwin.physik.uzh.ch)

arXiv:1012.4764v1

Summary

- XENON100 reached its design goal: 10 × more mass and 100 × less background than in XENON10
- A dark matter run in 2010 revealed no WIMPs, and resulted in the lowest limits on spin-independent WIMP-nucleon cross section reported so far
- A new dark matter run with lower backgrounds started in March 2011, the detector is running smoothly
- XENON1T (2.4 LXe tons in total) is approved to be built at LNGS, construction is expected to start in fall 2011
- DARWIN, a multi-ton scale Ar/Xe dark matter facility, approved by ASPERA in late 2009, is designed to detect WIMPs with high statistics and measure WIMP properties

End