New results from the XENON100 experiment

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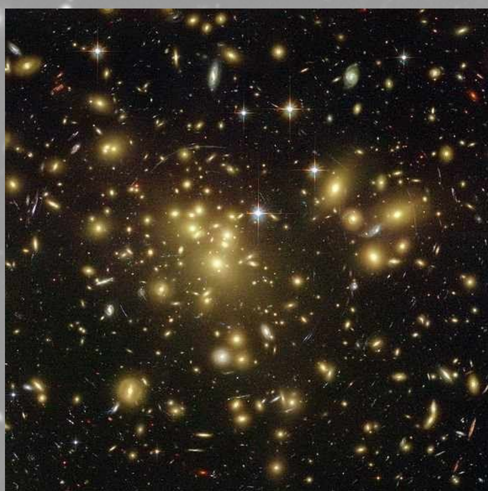
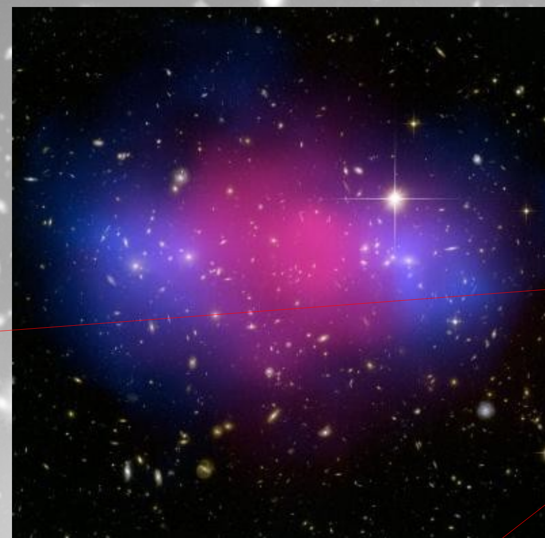
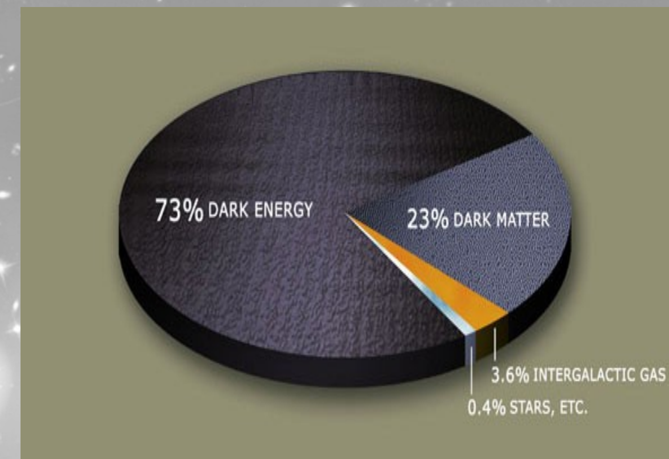
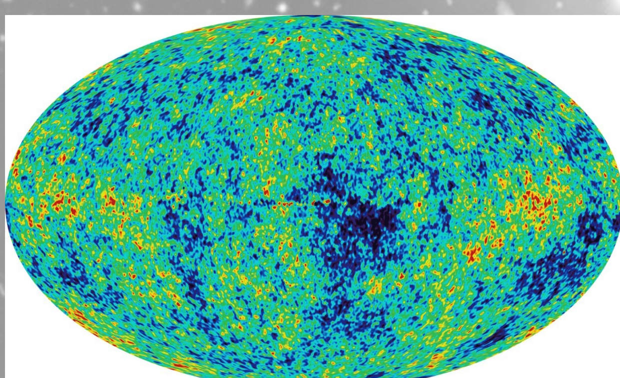
Columbia University
on behalf of the
XENON100 Collaboration

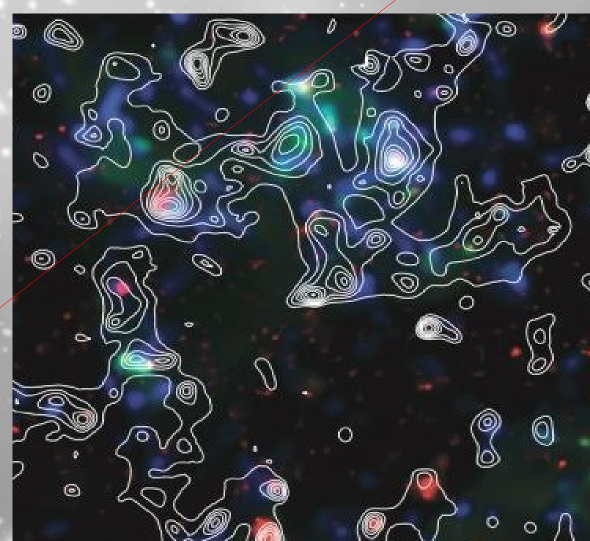
Dark Matter Signatures

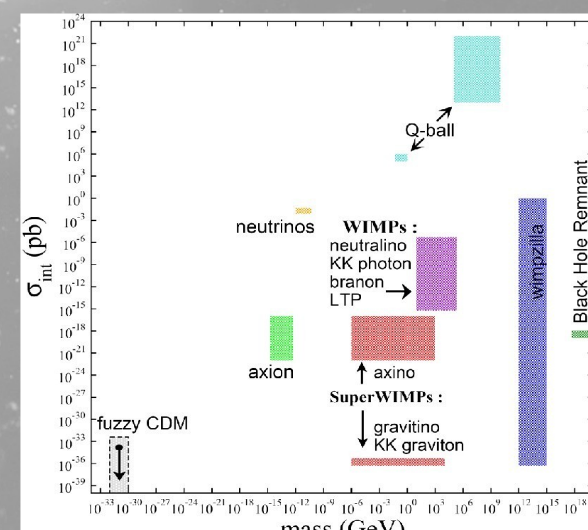












Dark Matter Direct Detection

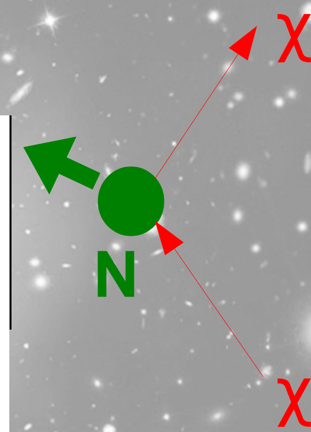
Goal: Observe WIMP interactions with some target material

Expected interaction rate

Number of targets | **WIMP density** | **Nuclear Form factor**

$$\frac{dR}{dE_{nr}} \propto N \frac{\rho_\chi}{2\, m_\chi \mu^2} \sigma_N \left|F^2(E_{nr})\right| \int_{v_{min}}^{v_{esc}} \frac{f(\vec{v})}{v} d^3v$$

WIMP mass | **Interaction cross section** | **WIMP velocity distribution**

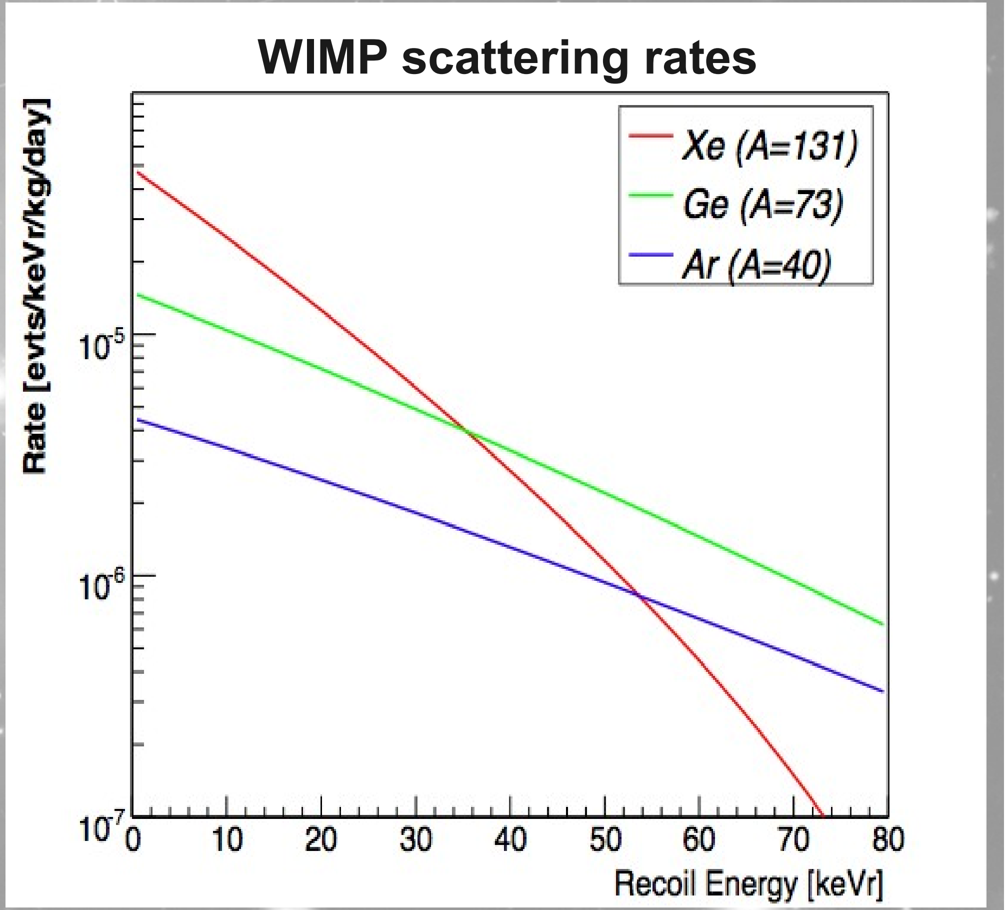


$$v_{min} = \sqrt{\frac{m_N E_{nr}}{2\, \mu^2}}$$

- Only those WIMPs with velocity above threshold will contribute to that energy
- For Spin Independent interactions the cross section is enhanced by a factor A^2 (coherent scattering)

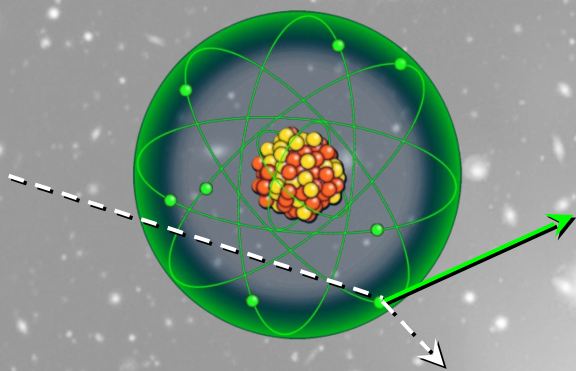
Liquid Xenon for Dark Matter Searches

- **Scalability:** relatively inexpensive for very large detector (today ~$1000/kg)
- **Xe nucleus (A~131):** good for SI plus SD sensitivity (~50% odd isotopes)
- **Self shielding:** High atomic number Z=54 and density 2.8kg/l
- **Charge & Light:** highest yield among noble liquids and best self-shielding
- **Low energy threshold:** photosensors within liquid for efficient light detection
- **background reduction:** by charge-to-light ratio and 3D-event localization
- **Intrinsically pure:** no long-lived radioactive isotopes; Kr/Xe reduction to ppt level with established methods

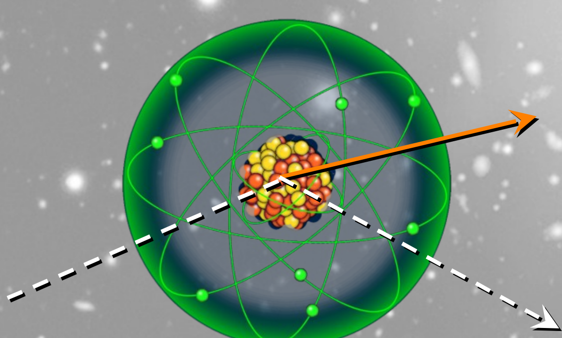


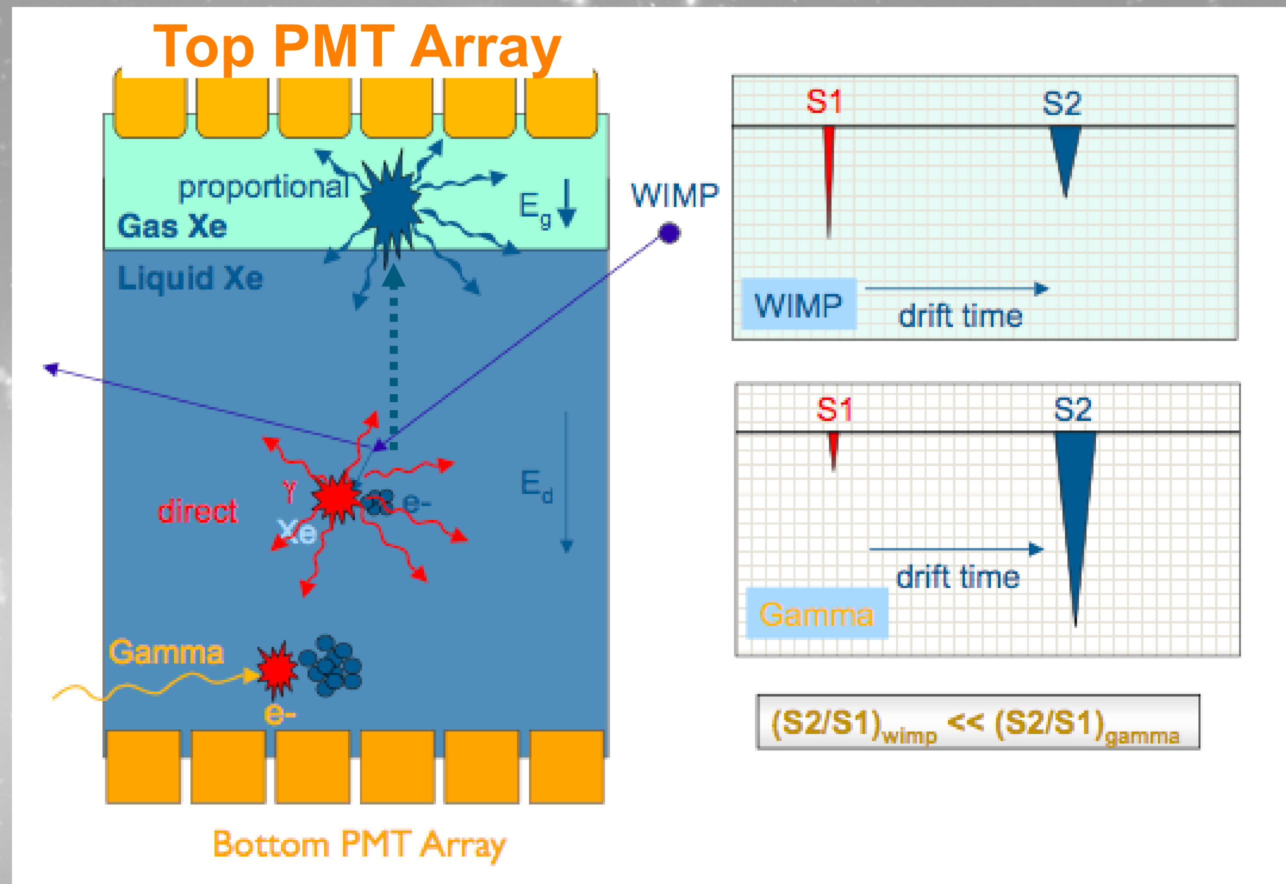
The XENON Two Phase TPC

e^-/γ: electron recoil



n/WIMPs: nuclear recoil





- **Single electron and single photon measurement sensitivity**
- **> 99.5% ER rejection via Ionization/Scintillation ratio (S2/S1)**
- **3D event-by-event imaging with millimeter spatial resolution**

The XENON Roadmap

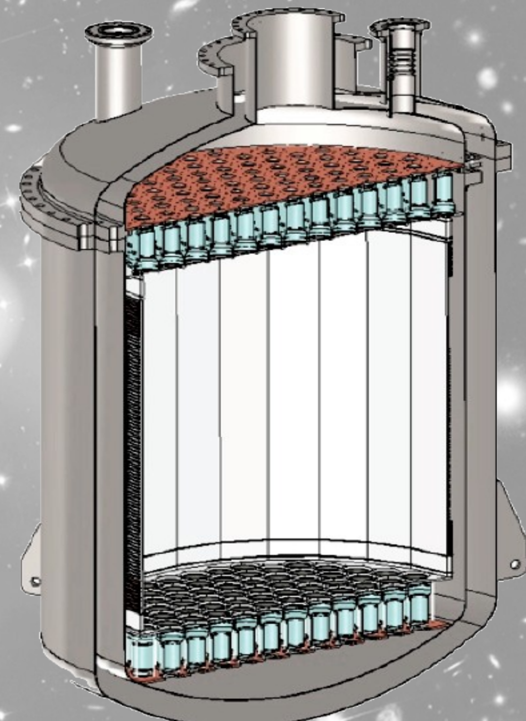
XENON10

2005-2007
PRL100
PRL101
PRL 107
PRD 80
NIM A 601

XENON100

2008-2013
first results:
PRL105, PRL107, PRD84
More to come soon

XENON1T



2012-2017
Projected sensitivity
$2x10^{-47}cm^2$

The XENON100 Detector

- XENON100 was designed to be ~100 times more sensitive than XENON10
- Target: 30 cm drift x 30 cm diameter TPC
- 162 kg ultra pure LXe (target + veto)
- Cryocooler and FTs outside shield
- Selection of materials for low radioactivity

- 242 1-inch square PMTs: 1 mBq (U/Th) and ~30% QE
- LXe veto around target on all sides
- Multilayer passive shield (Cu,Poly, Pb+Water)

XENON100 Collaboration

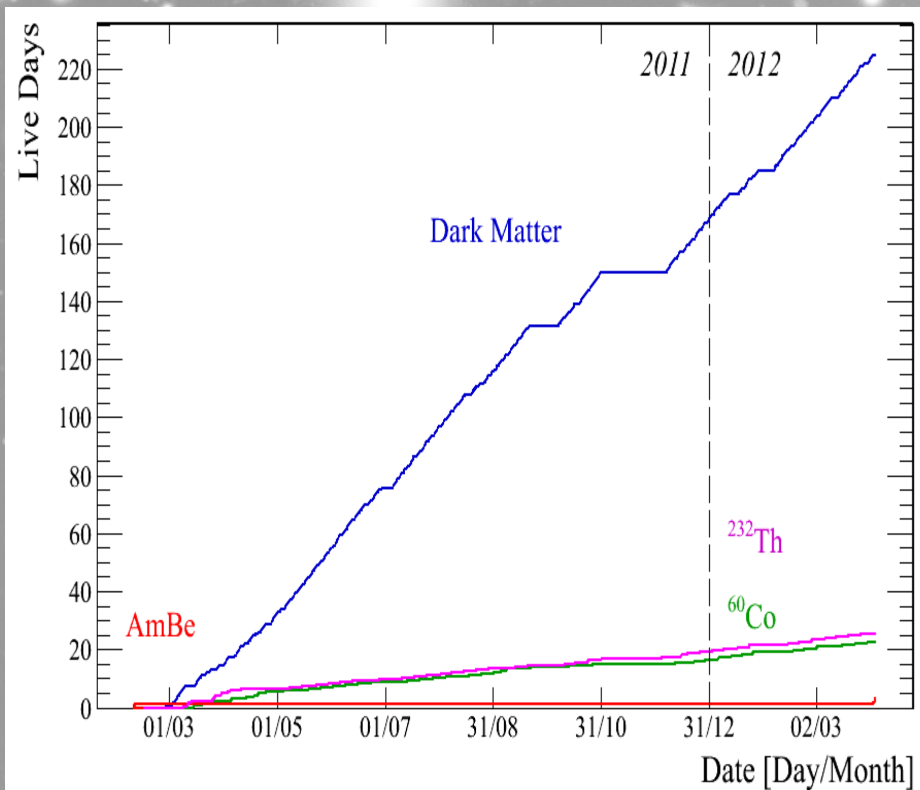
Columbia, Rice, UCLA, Zürich, Coimbra, LNGS, SJTU

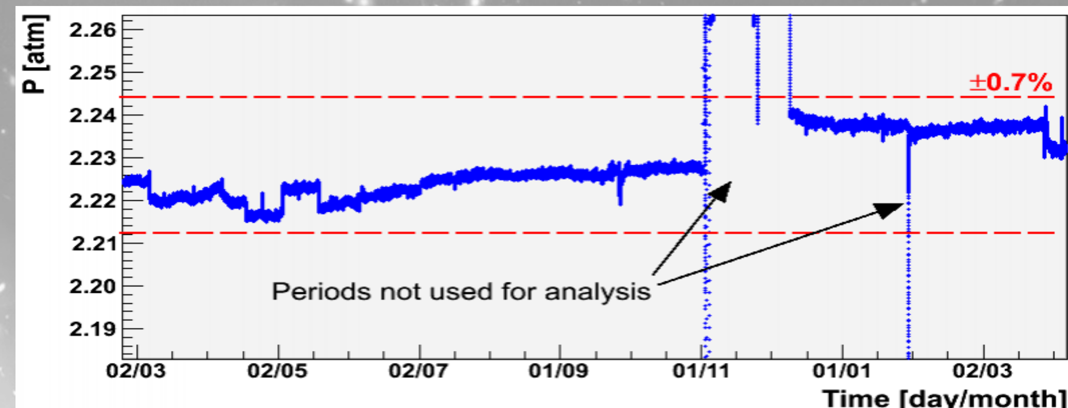
Mainz, Bologna, Subatech, Münster, Nikhef, Heidelberg, Weizman

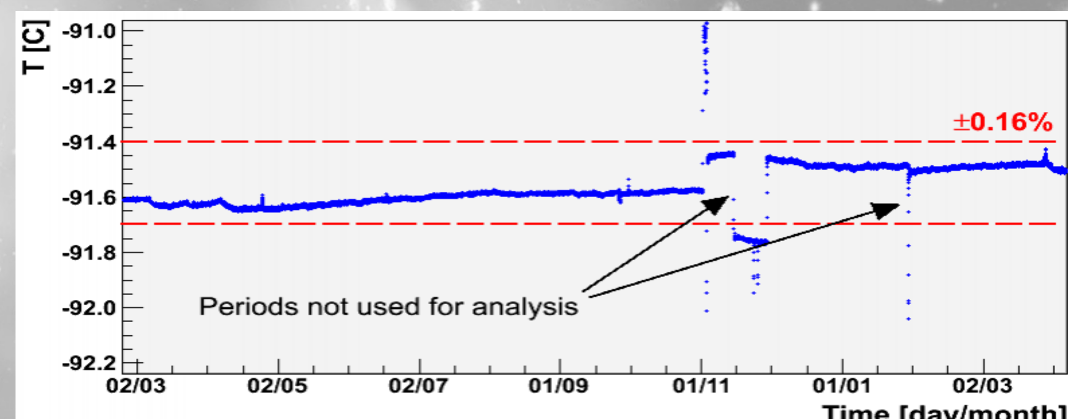
XENON100 at LNGS

taking data since the first decade of the millenium

New Run Data

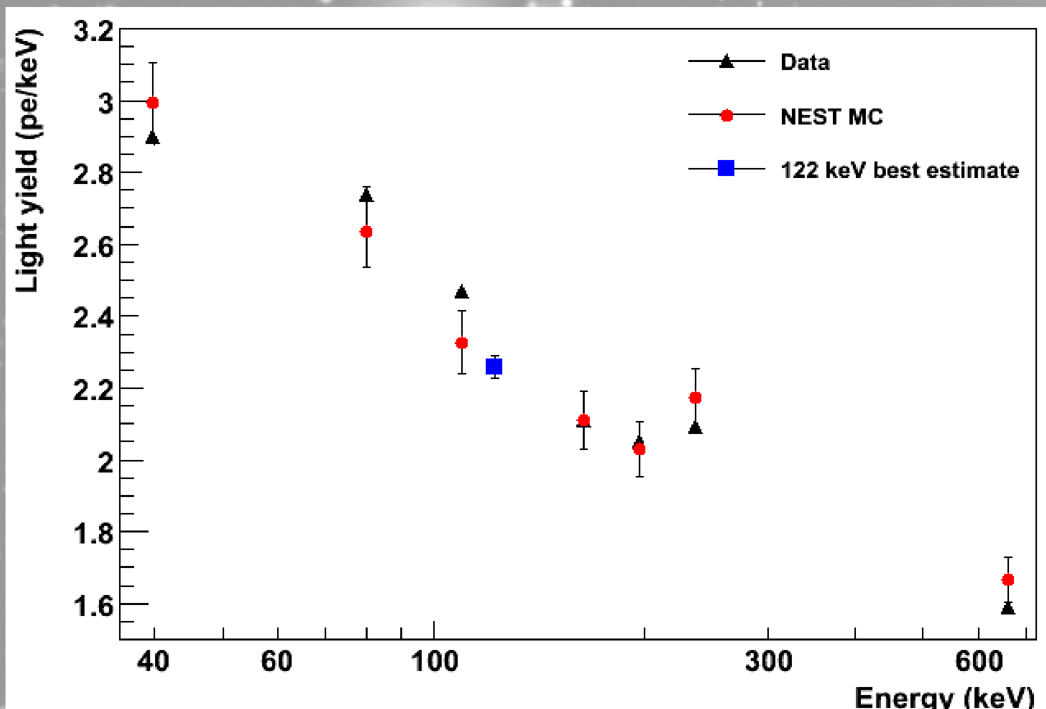




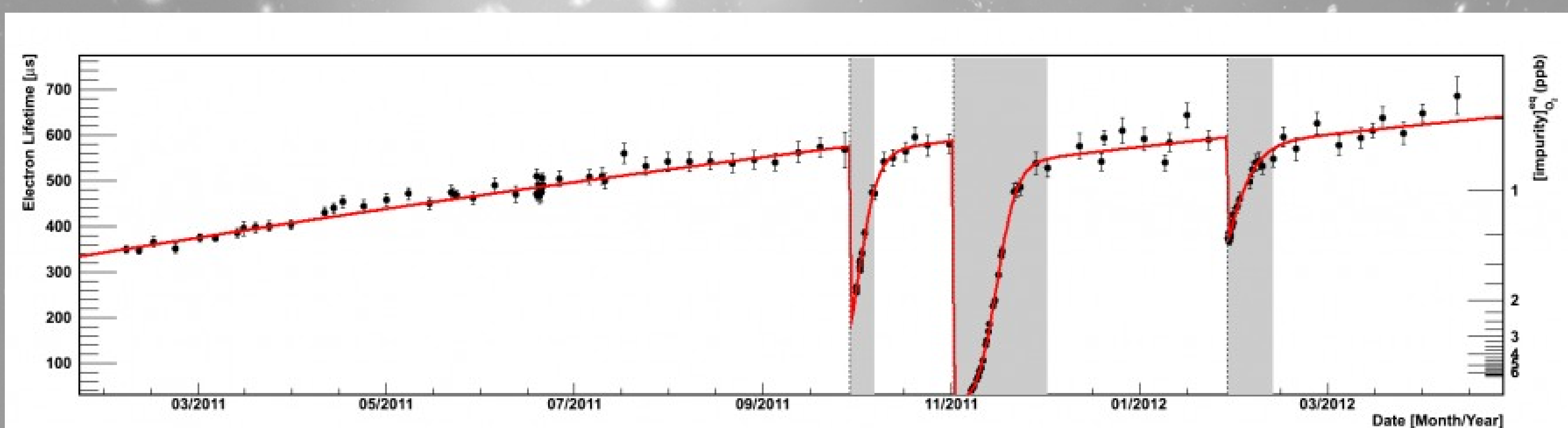


- **Data taken between February 2011 and March 2012**
- **Data following maintenance periods removed from analysis**
- **Excellent stability of the detector parameters**
- **Longest run of a liquid xenon detector (to our knowledge)**

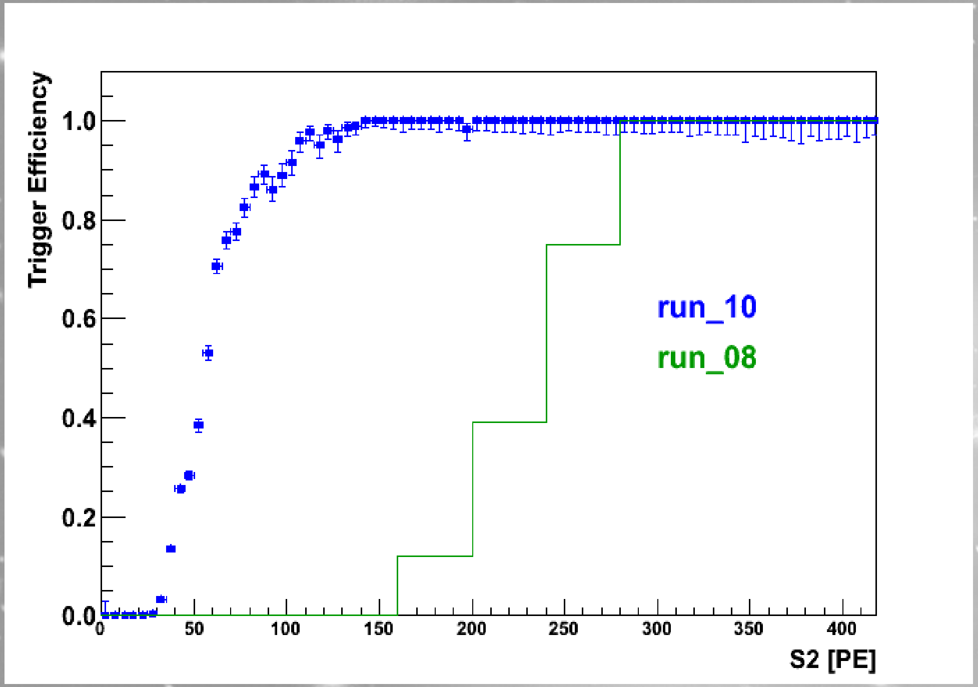
Electron Lifetime and Light Yield



- The electron lifetime is continuously monitored with a ^{137}Cs source. During this run it increased from 374 to 611 μs
- The light yield is measured with different sources at different energies
- An interpolation to 122 keV is performed using the NEST model and yielding a result of 2.28±0.03 pe/keV



Improved Data Taking Conditions

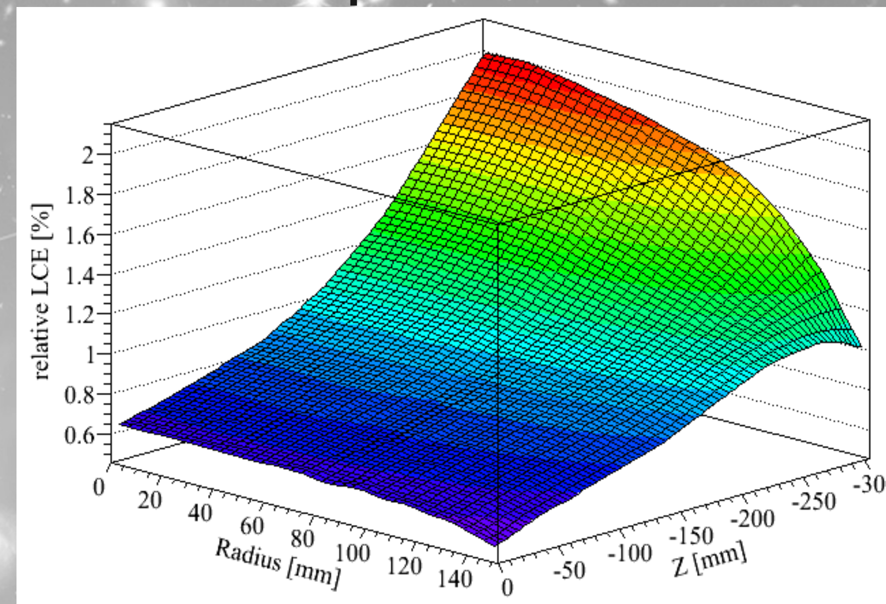


- Trigger threshold lowered to about 10 electrons in S2
- 100% efficiency for events with S2>150pe
- S1 Energy threshold decreased to 3 pe (~6.6 keV_{nr})
- Reduced noise and improved cuts to identify/reject "noisy" events
- Reduced Kr/Xe contamination (19 ppt measured by RGMS)

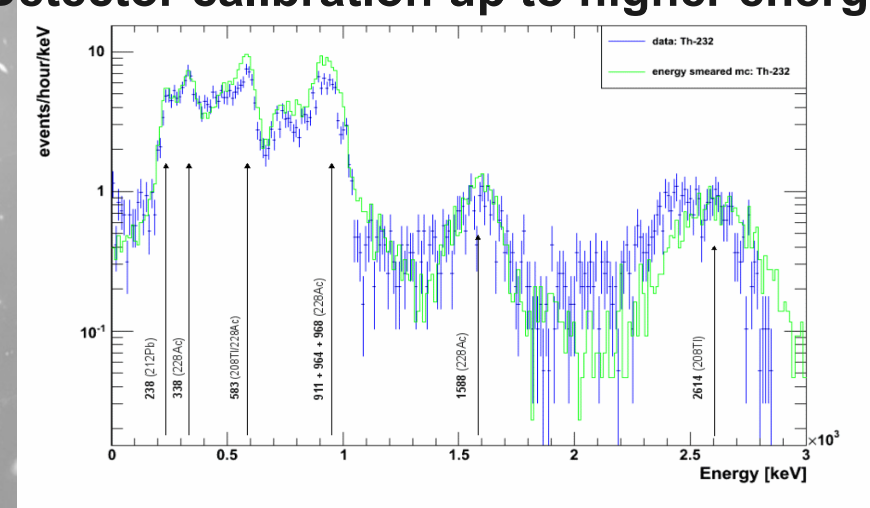
Gamma Calibration

- **Performed during the run to study multiple aspects of the behaviour of the detector**
- **A new Th-232 source is used in addition to a Co-60 source**
- **Acquired more than 35 times the amount of science data interactions**
- **Weekly Cs-137 calibration to measure the electron lifetime**

New 3D position corrections

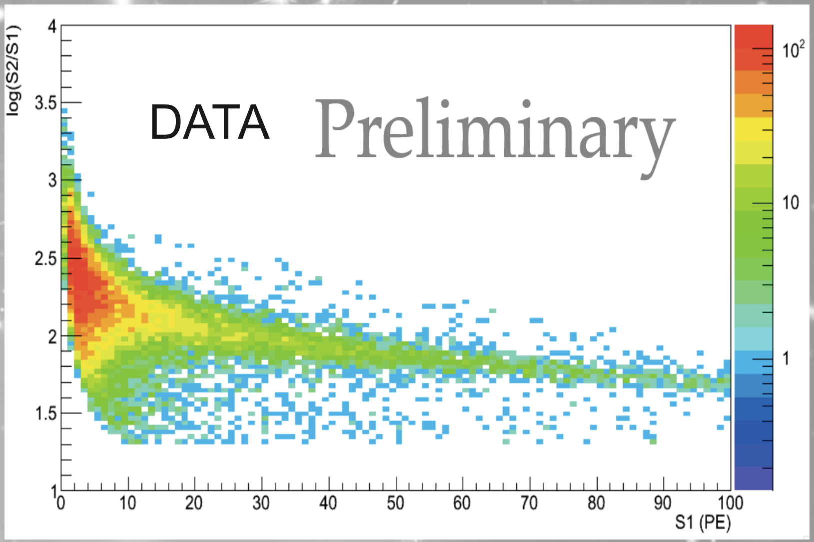


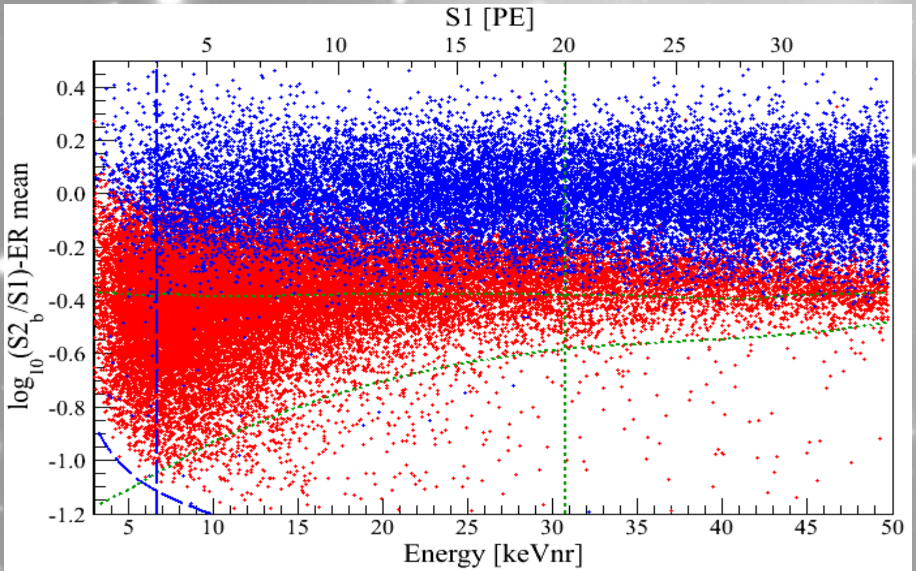
Detector calibration up to higher energies

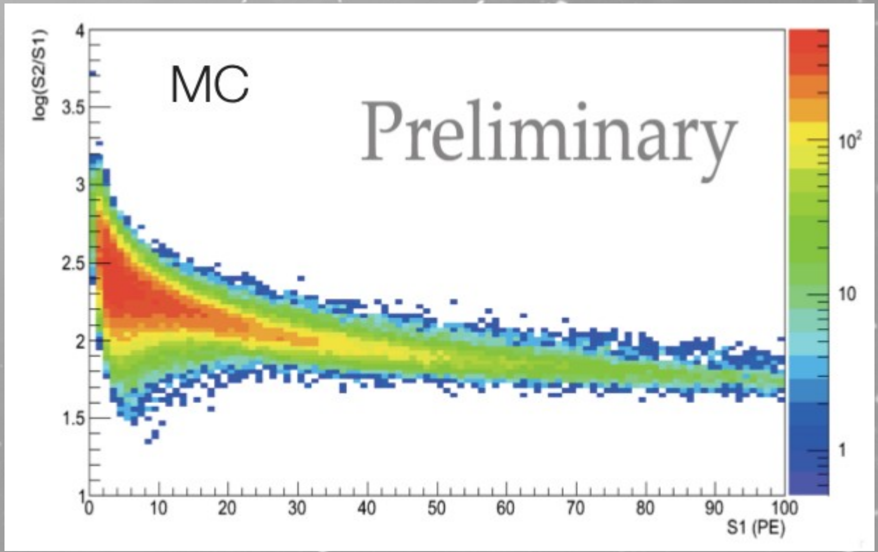


AmBe Calibration

- Calibrations with an AmBe source were performed at the beginning and the end of the run
- Allow to to understand LXe response to nuclear recoils and to establish detector's discrimination
- Improved understanding of the NR interactions in our detector

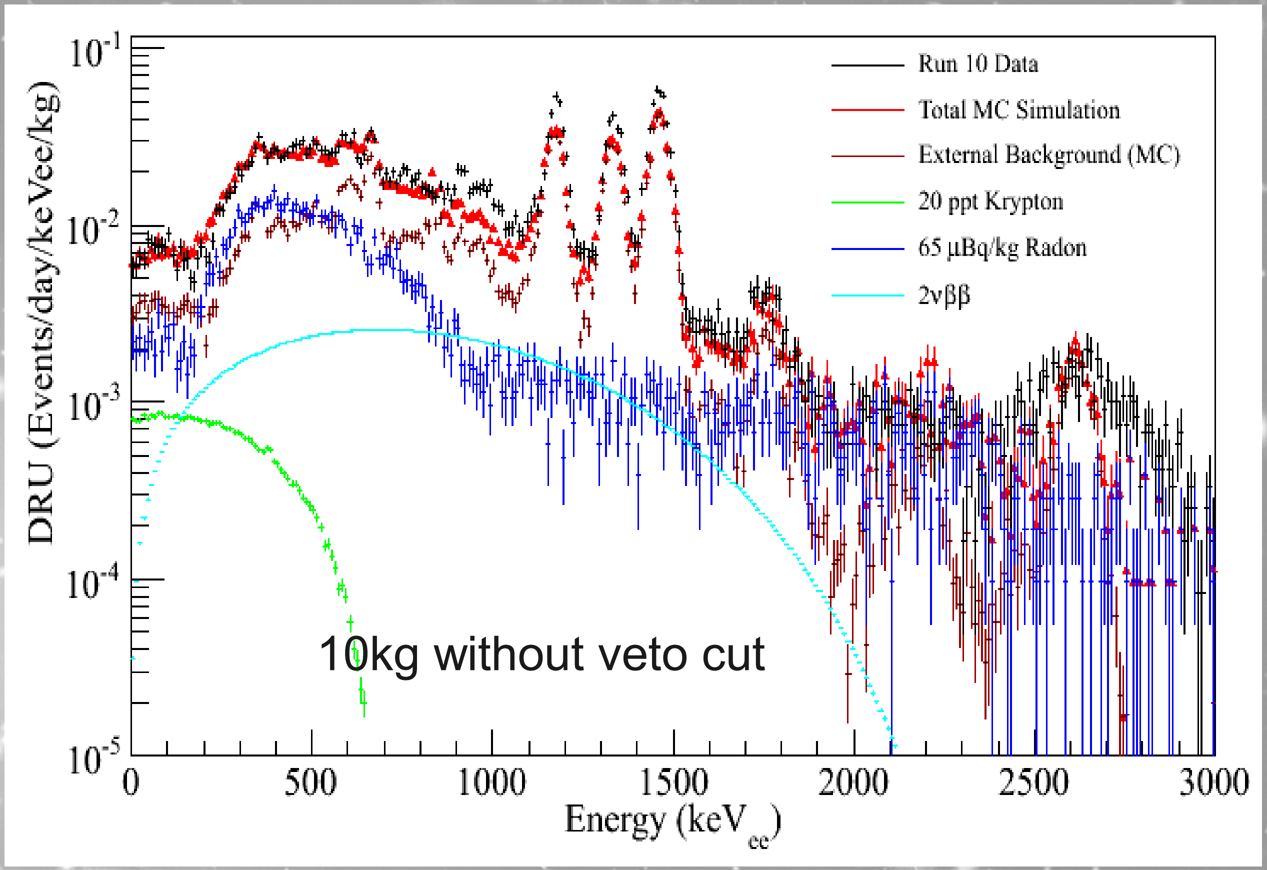




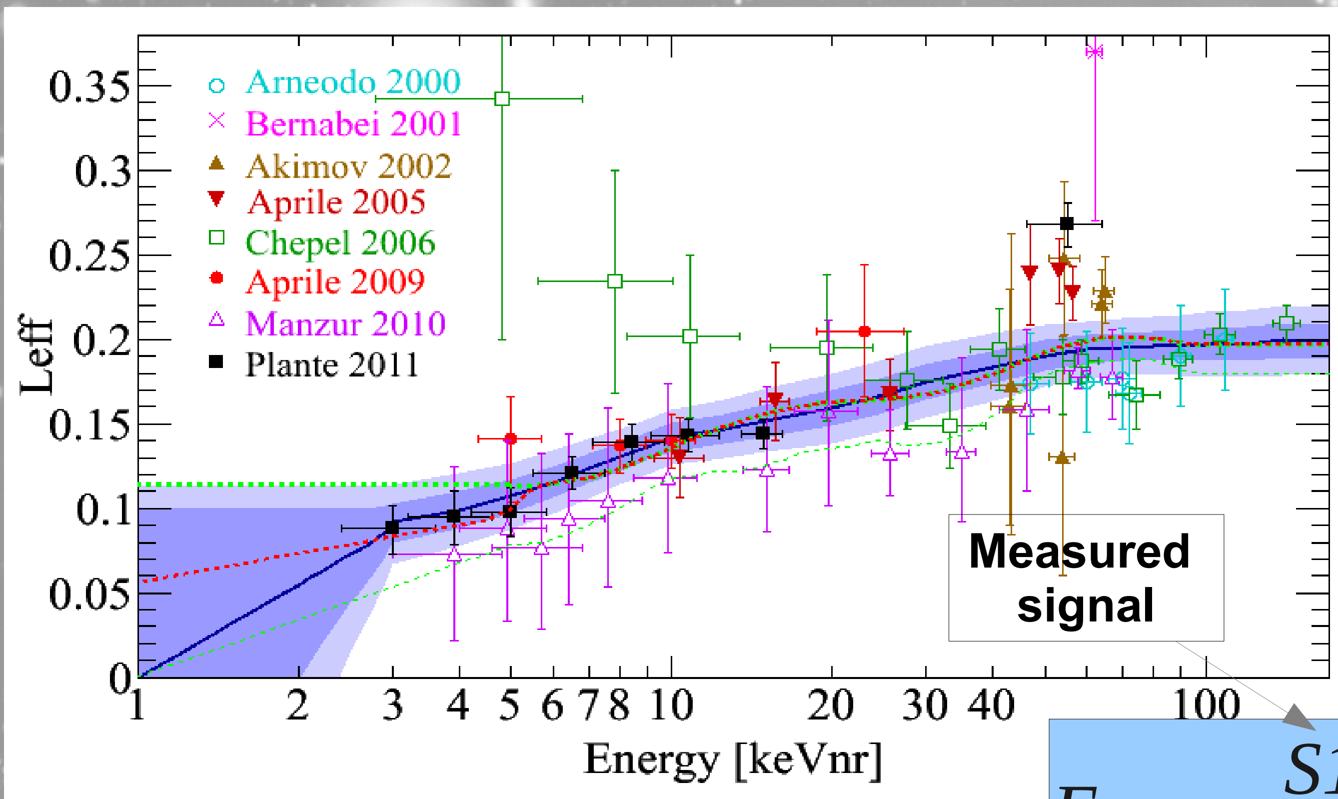


Background of This Run

- Gamma emission from detector's materials radioactivities is the main source of EM Background
- Radioactivities intrinsic to LXe (Kr and Rn) add to this background
- Kr contamination measured by RGMS to be 19±1 ppt. Delayed coincidence result agrees. Reduction of more than a factor 10 with respect to previous run
- Rn contamination studied via alpha spectroscopy and delayed coincidence analysis (BiPo)
- Excellent agreement between our measurements and a MonteCarlo simulation
- Measured background is 5.3±0.6 mdru before discrimination



Energy Scale



Measured signal

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

Light quenching due to electric field for gammas @122keV

Light quenching due to electric field For nuclear recoils

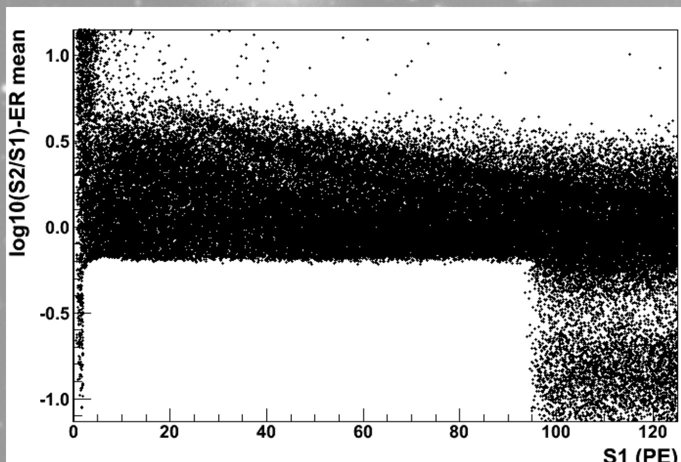
Light yield for gamma @122 keV

Scintillation eff. for nr at 0 field

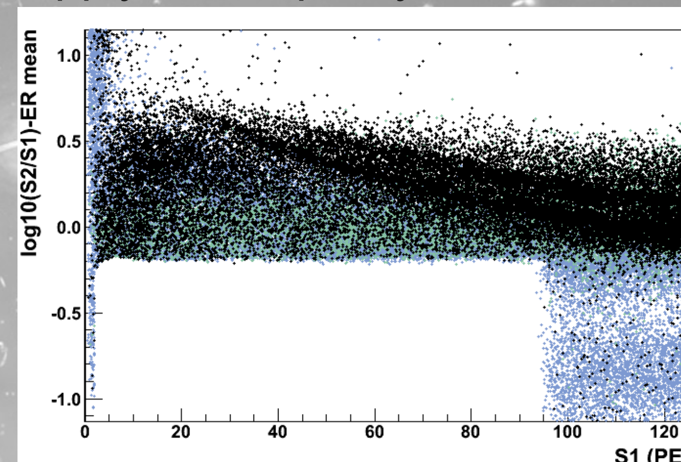
Analysis Procedure

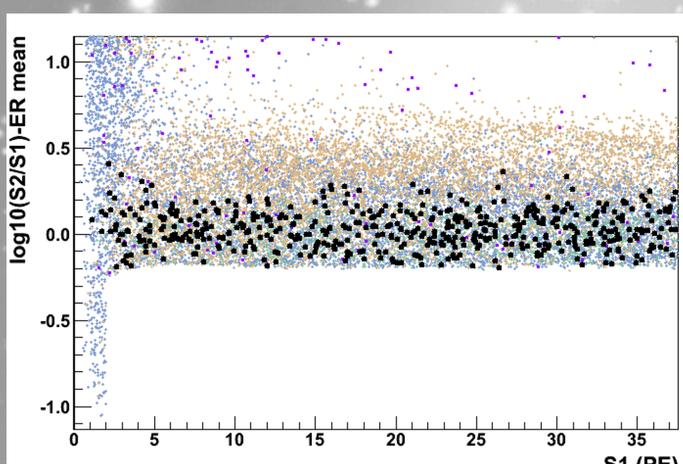
(Different colors represent the events removed with the successive cuts)

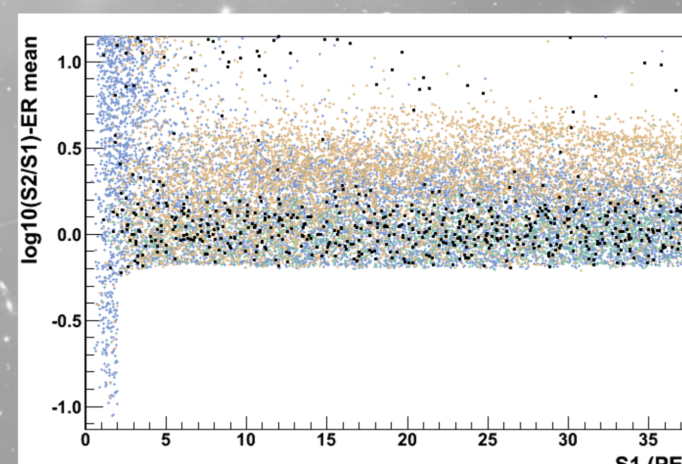
(1) We start from all non-blind data in 48kg FV



(2) We apply basic quality cuts and single scatter



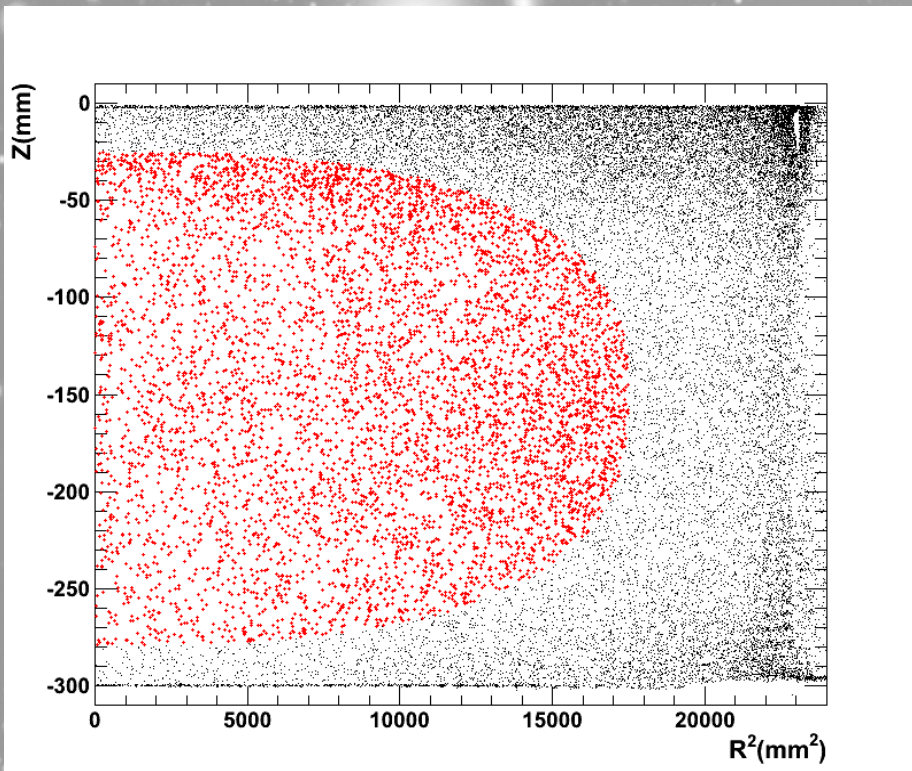




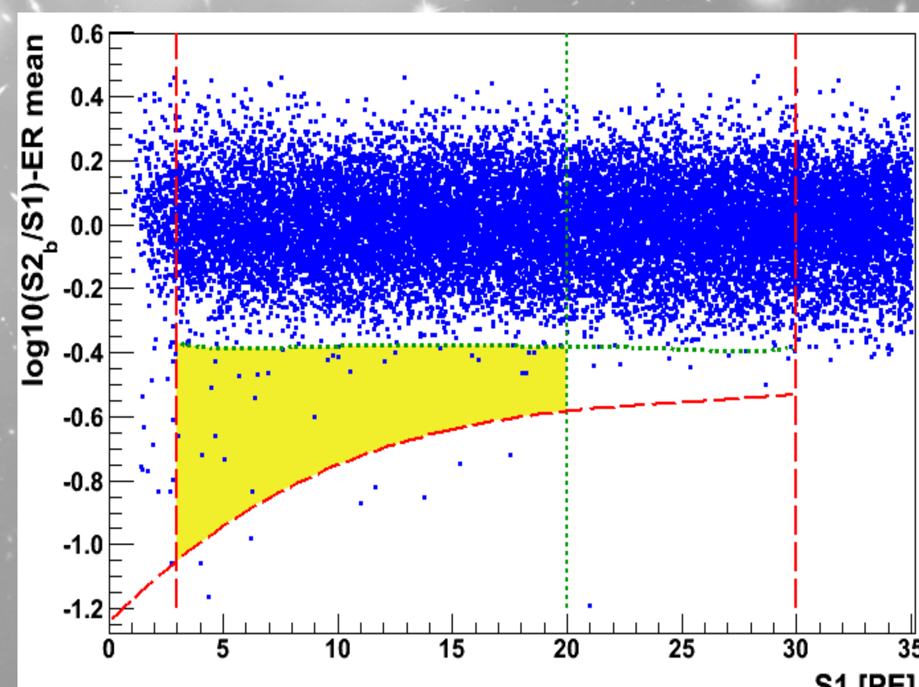
(4) Add consistency cuts for the remaining events

(3) Set low energy threshold, restrict to low energies and apply FV cut

Optimization of the Fiducial Volume and Signal Region



- The fiducial volume and signal region are simultaneously adjusted to maximize sensitivity
- Given the lower beta background in this run, we choose a smaller FV (34kg) to benefit from LXe self-shielding

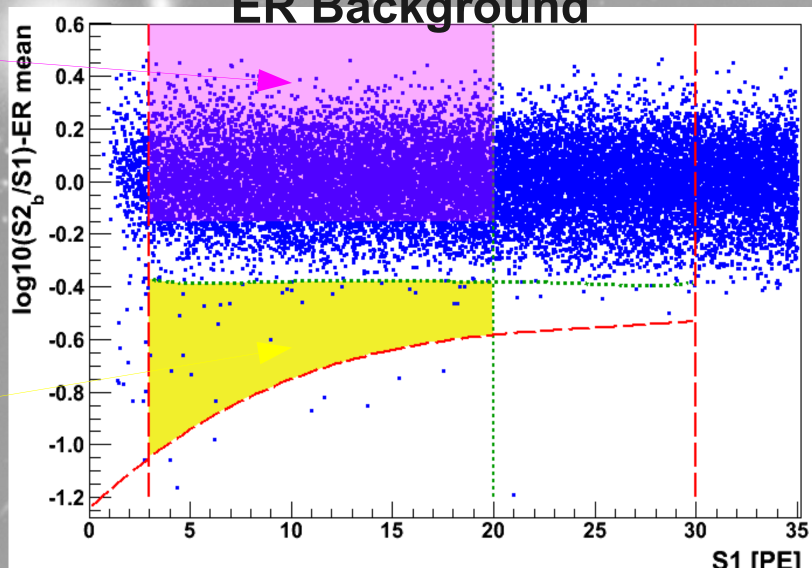


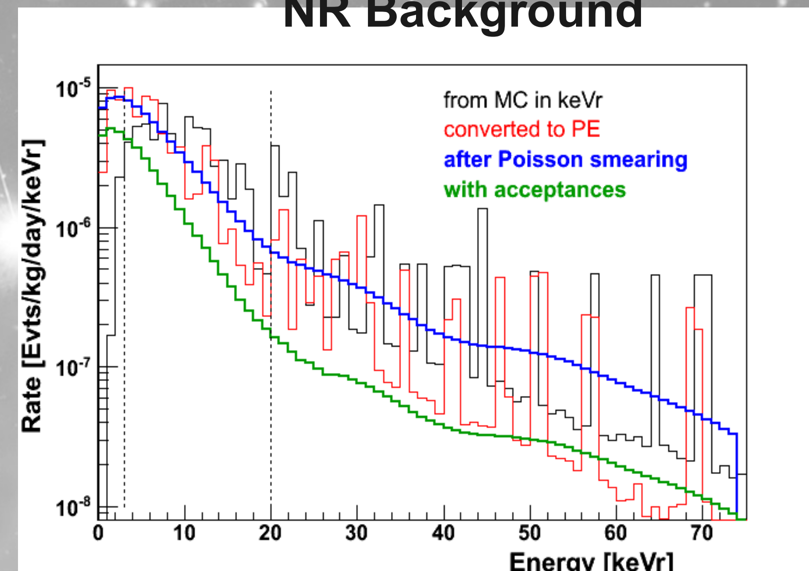
- The signal region is chosen below the 99.75% constant rejection line for ER
- The signal region for the cuts based analysis is set between 3 and 20 pe

Background Expectation (Cut Based Analysis)

Scaling region

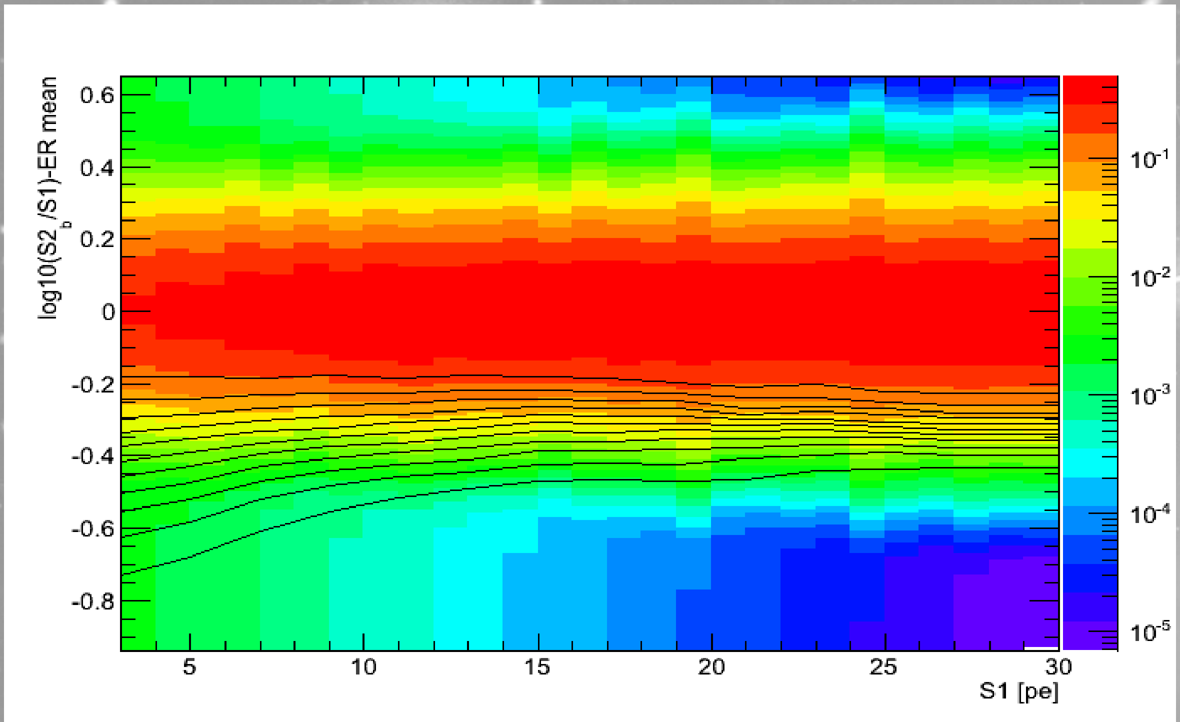
Signal region





- The background expectation is computed from the calibration data
- The number of events in the signal region from ER calibration data is counted
- That number is scaled to the number of events in the non-blinded region
- An additional contribution from neutrons from the materials is added to the final number and scaled to the total exposure
- Background expectation: ER:(0.79 ± 0.16); NR: (0.17 + 0.12 -0.07); Total background: **(1.0 ± 0.2) events**

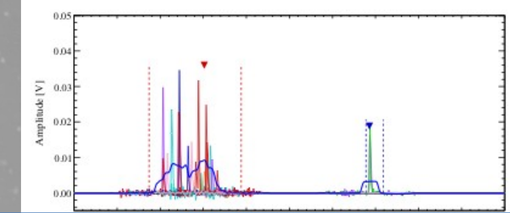
Background Expectation (Profile Likelihood Analysis)



$$\mathscr{L} = \mathscr{L}_1(\sigma, N_b, \epsilon_s, \epsilon_b, \mathcal{L}_{\mathrm{eff}}, v_{\mathrm{esc}}; m_\chi) \times \mathscr{L}_2(\epsilon_s) \times \mathscr{L}_3(\epsilon_b) \times \mathscr{L}_4(\mathcal{L}_{\mathrm{eff}}) \times \mathscr{L}_5(v_{\mathrm{esc}}).$$

- The ER calibration data are modelled in a two dimensional distribution
- This model has been tested with a likelihood analysis to properly represent the data
- The background contamination in every band used for to compute the likelihood is calculated from the model
- An additional contribution from neutrons is added to the final background
- Both expectations (Cuts and PL) use the same data as input

Raw data to result

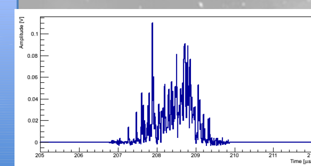


Trigger

new majority trigger
efficiency >99% for S2>150 pe

Data acquisition

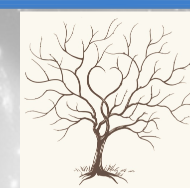
sample PMT traces @ 100 MS/s in windows around signals > 0.35 pe



PMT waveforms

Raw data processing

- baseline & noise measurement
- S1, S2 signal recognition
- signal integration
- position reconstruction
- signal corrections (gain, spatial)



root data trees

Event selection

- remove bad events
  - noise
  - S1/S2 not matching, …
- select single interaction events

Acceptances!

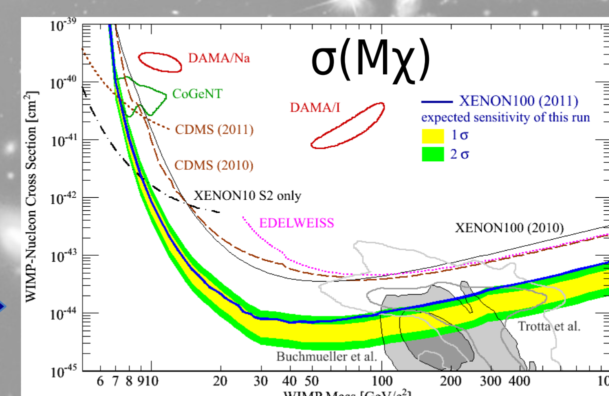
reduced data

Physics analysis input

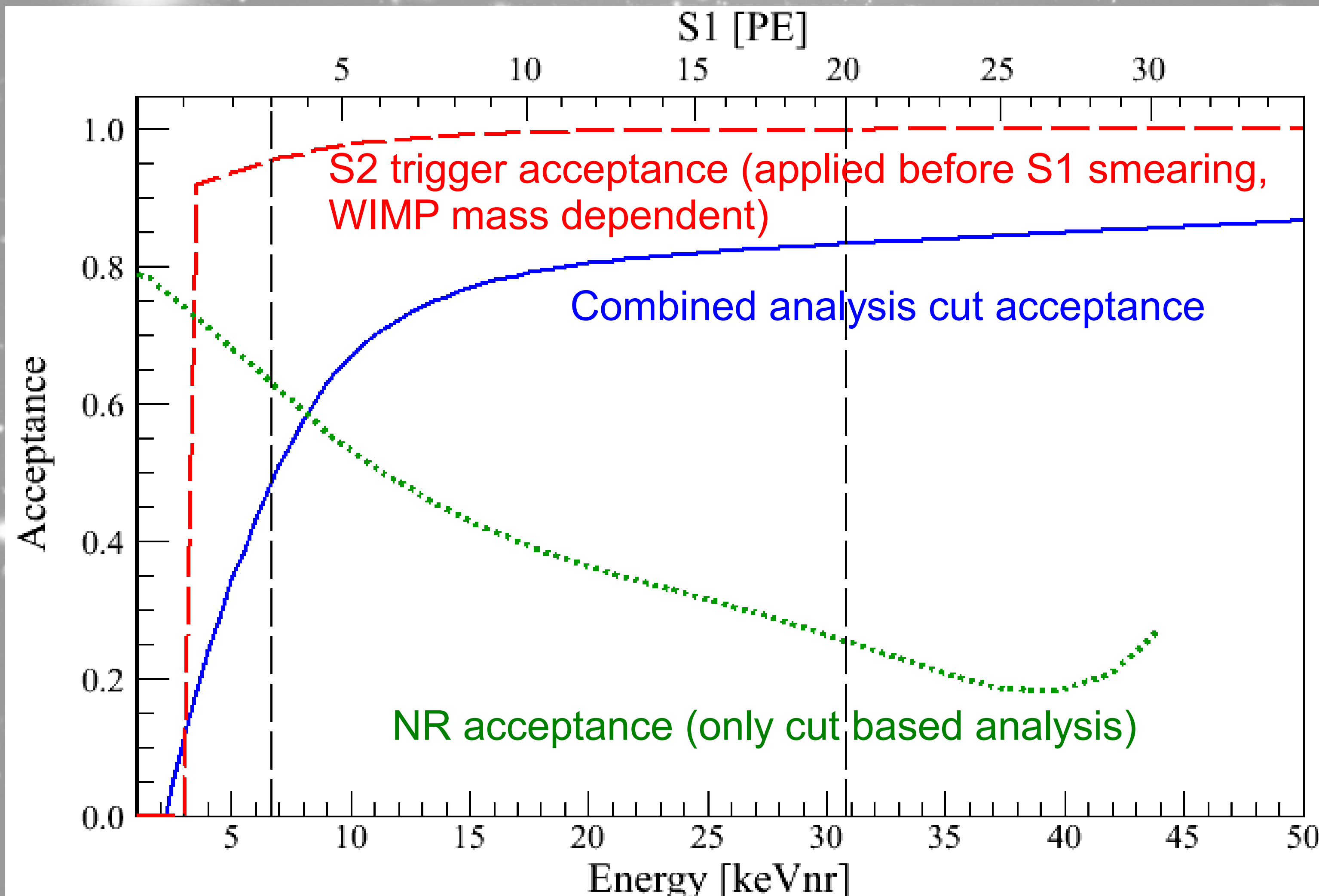
- Astrophysics
- Nuclear physics
- DM data sidebands, blind
- NR calibration
- ER calibration

response, background

Profile Likelihood

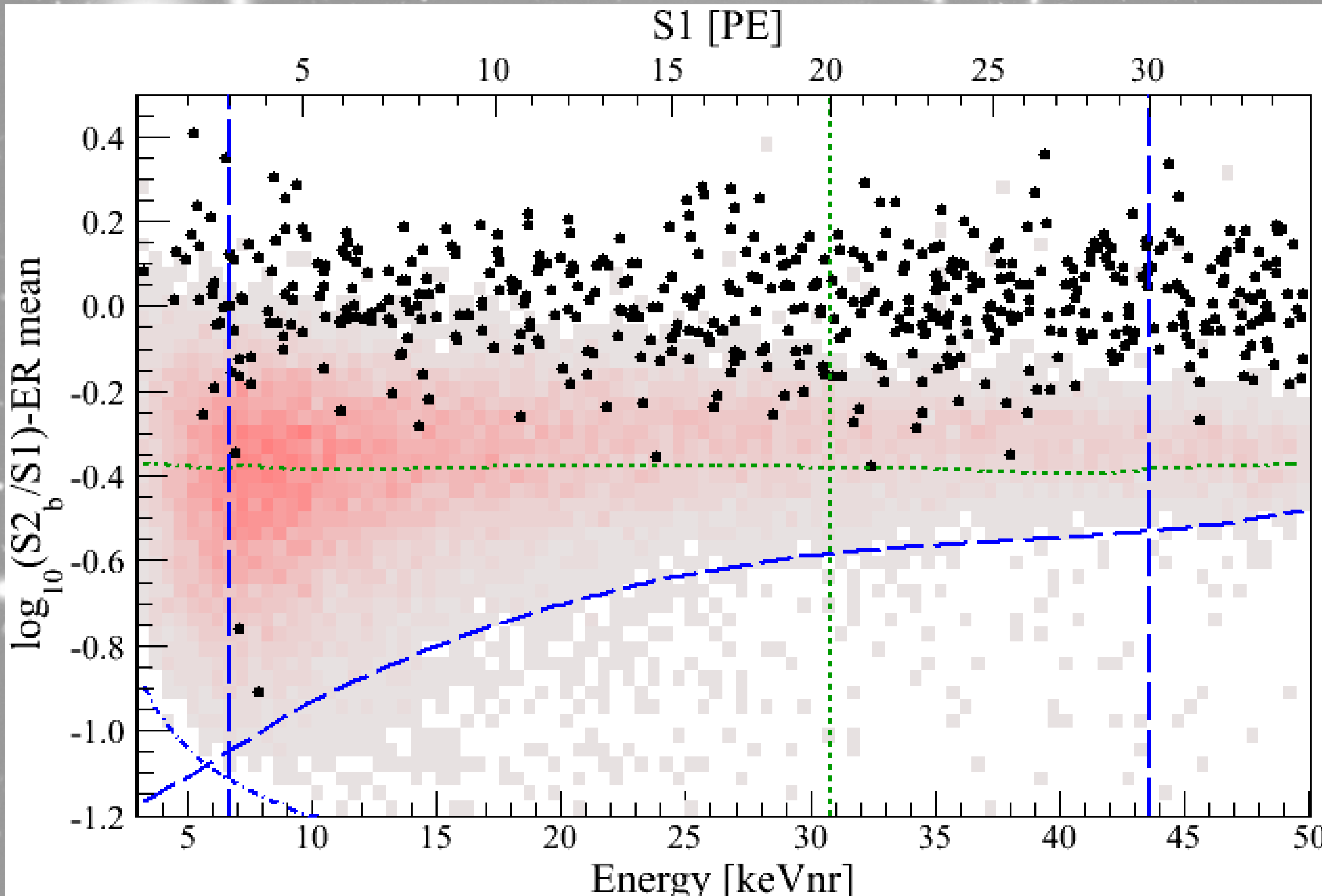


Cuts acceptances



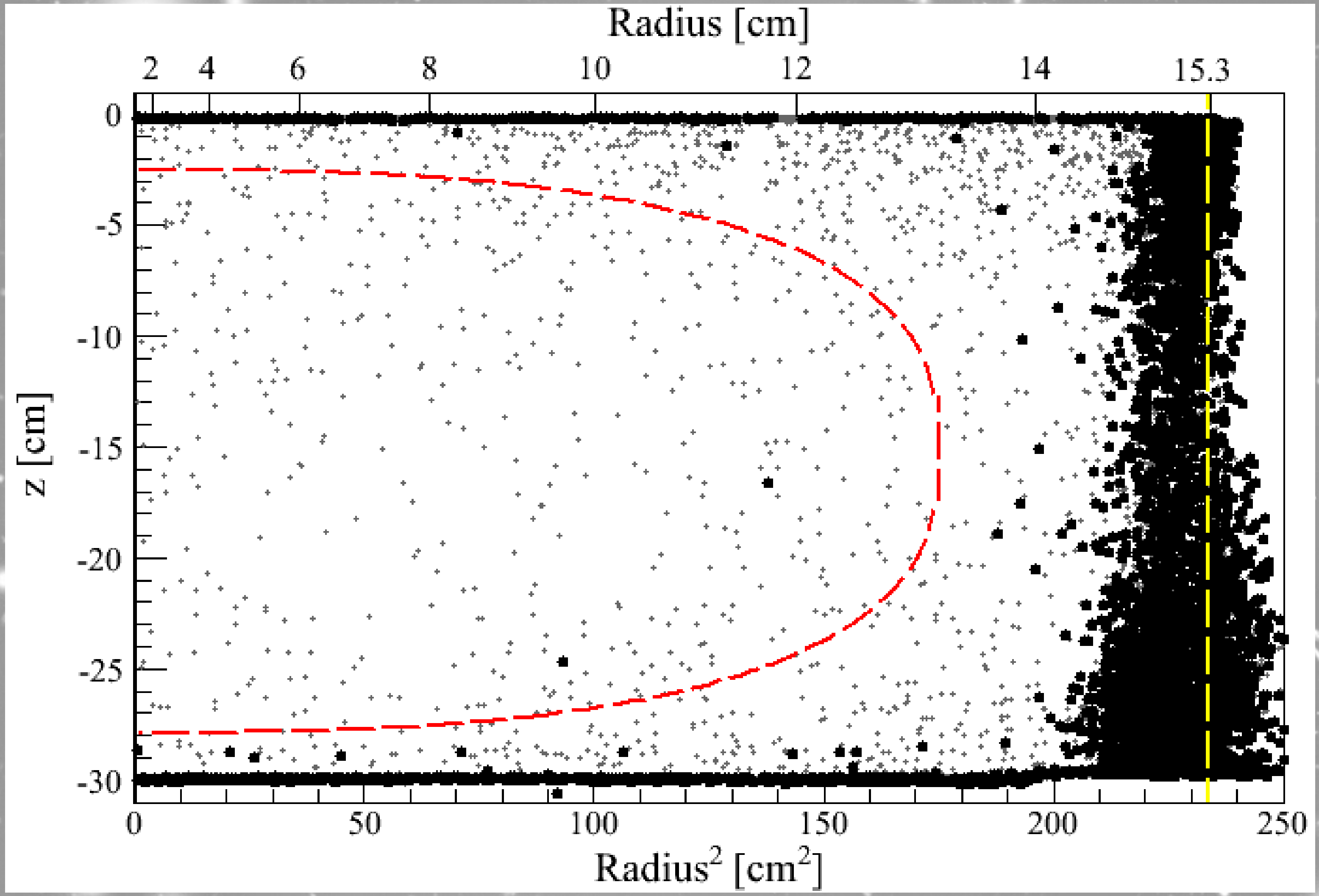
Unblinding

Unblinding results

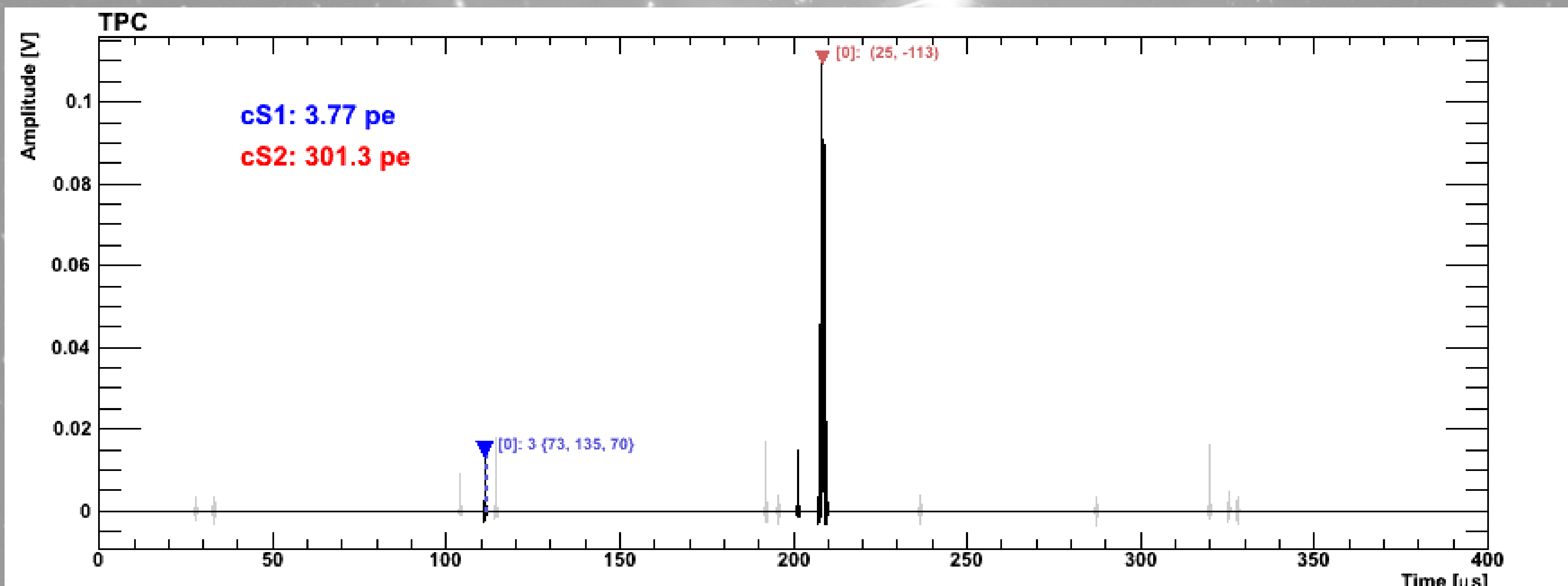


- 2 events observed in the signal region with (1±0.2) expected
- No events below the signal threshold

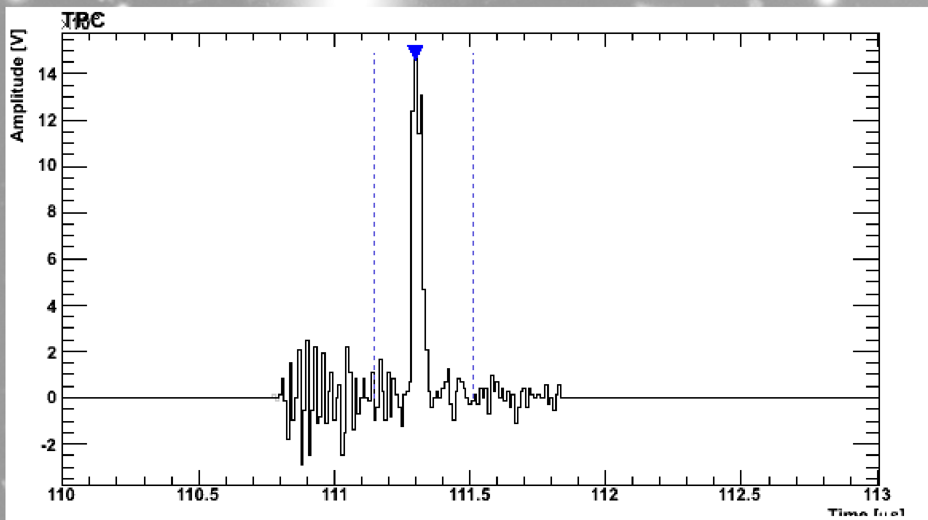
Unblinding results

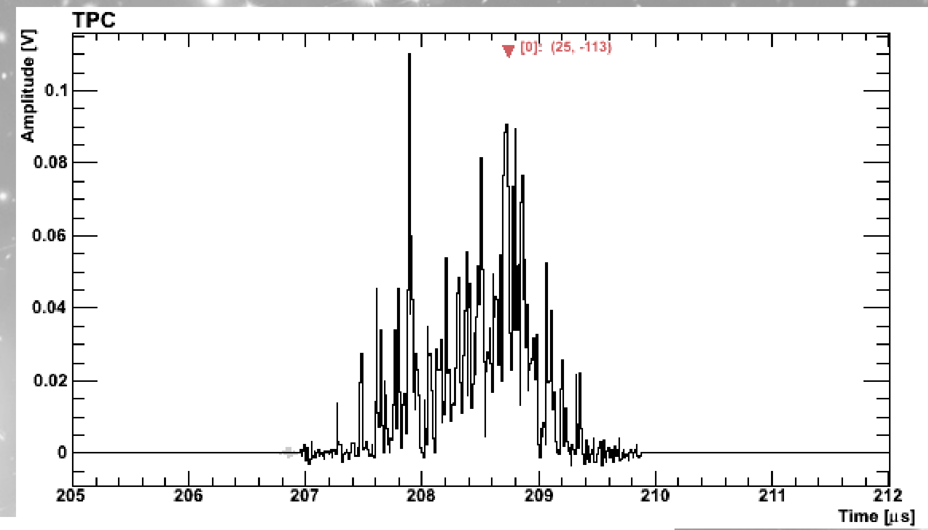


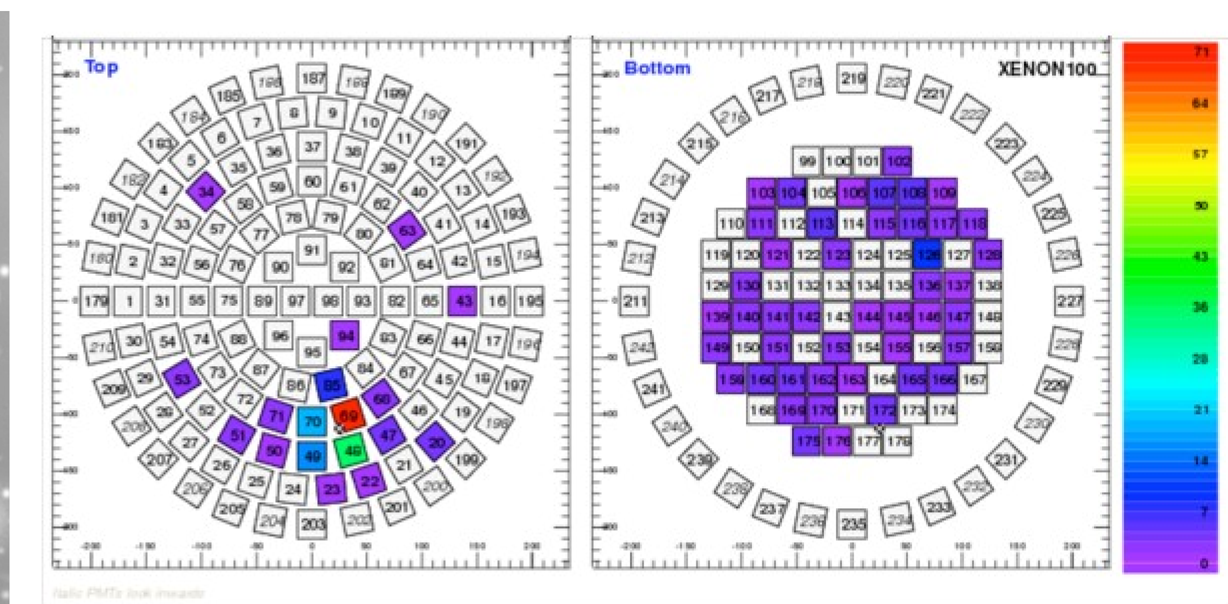
Candidate Events: Event I
xe100_111023_1101_000023-859



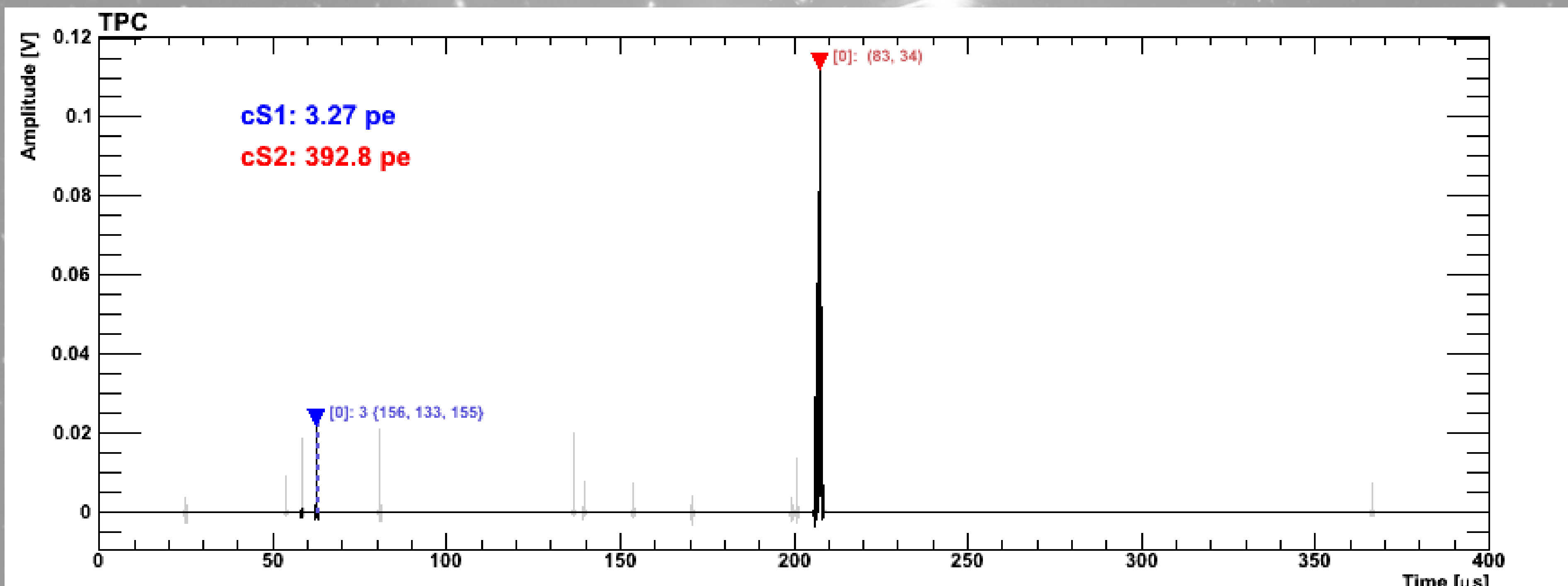
Candidate Events: Event I



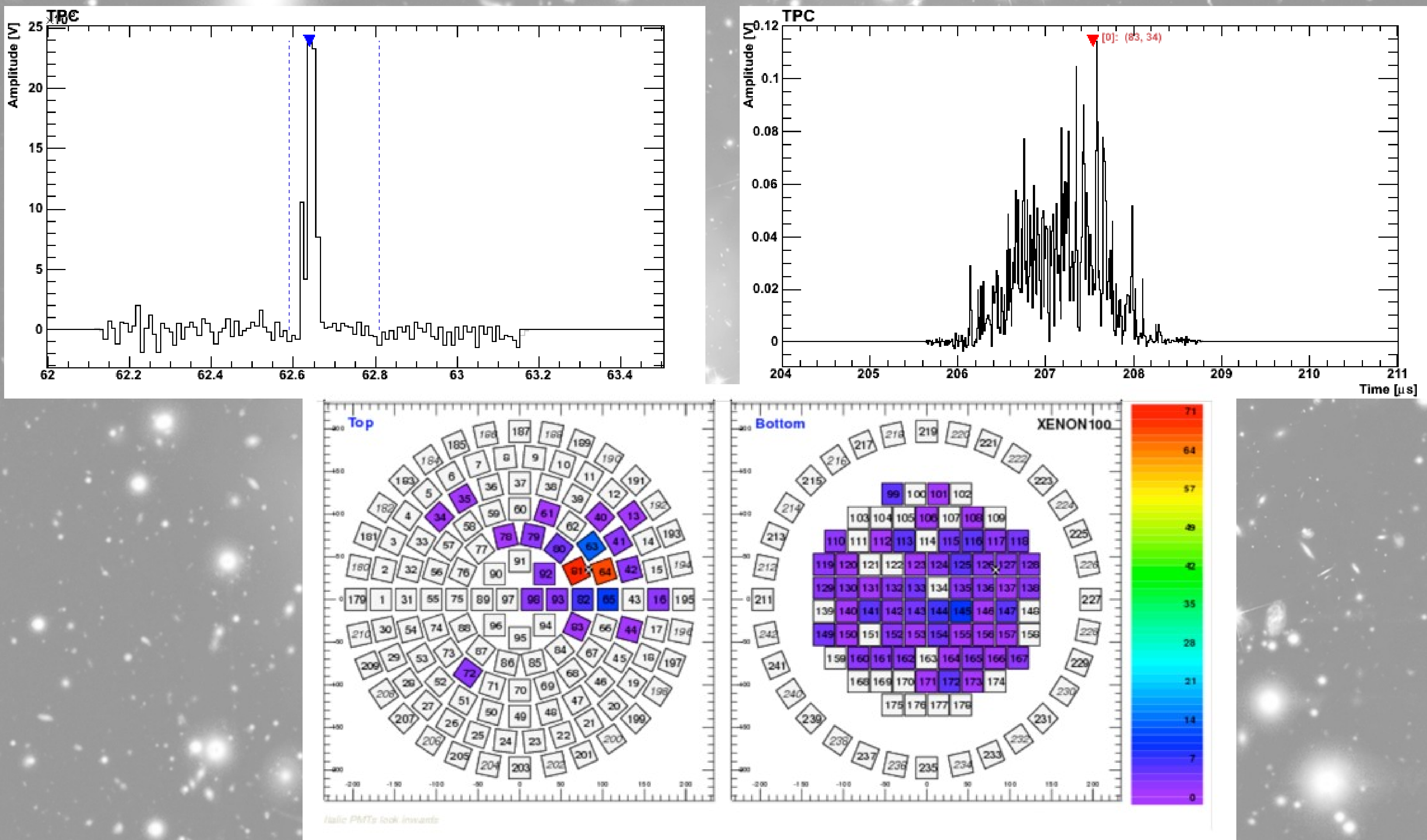


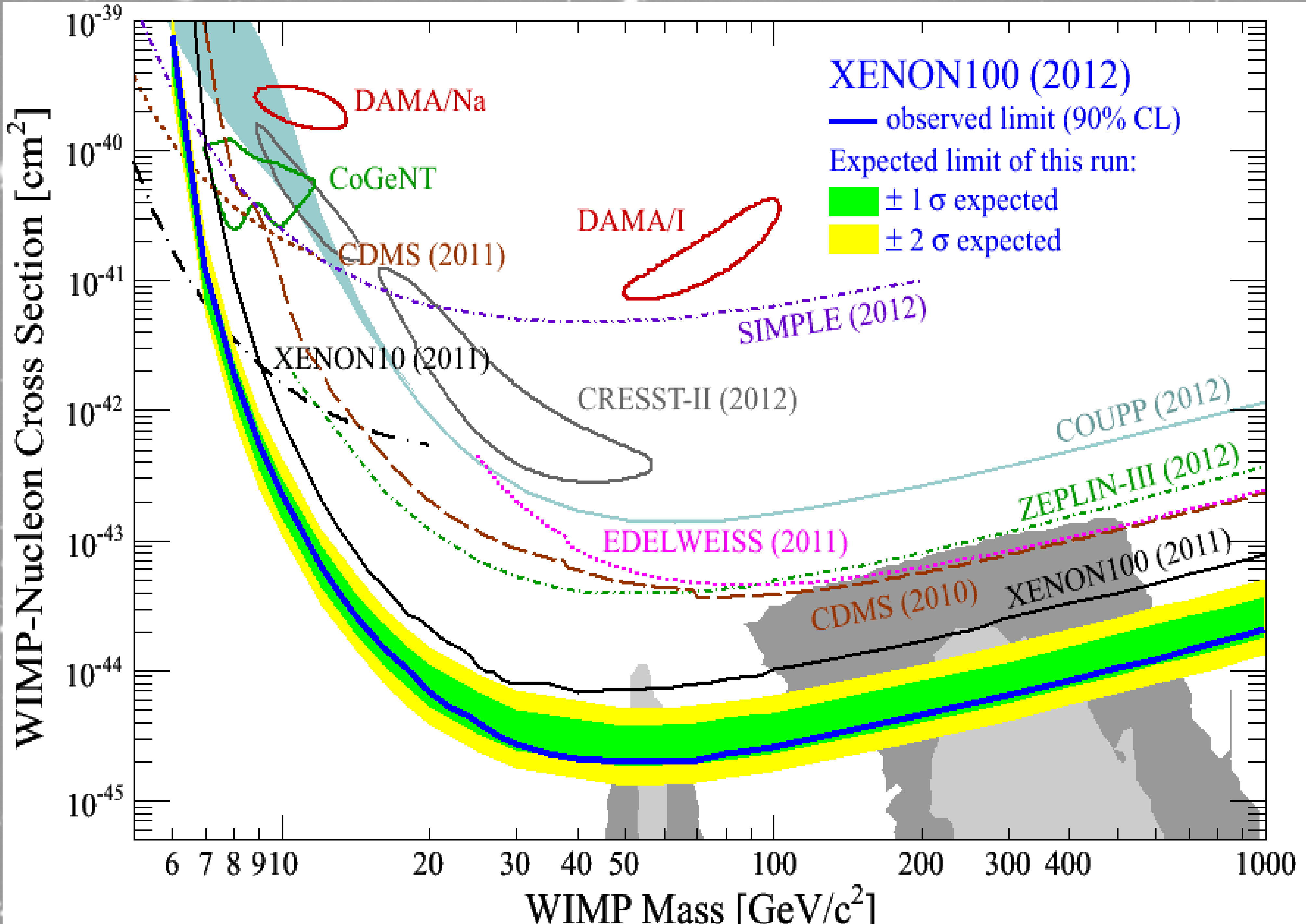


Candidate Events: Event II
xe100_120111_1920_000040-253



Candidate Events: Event II



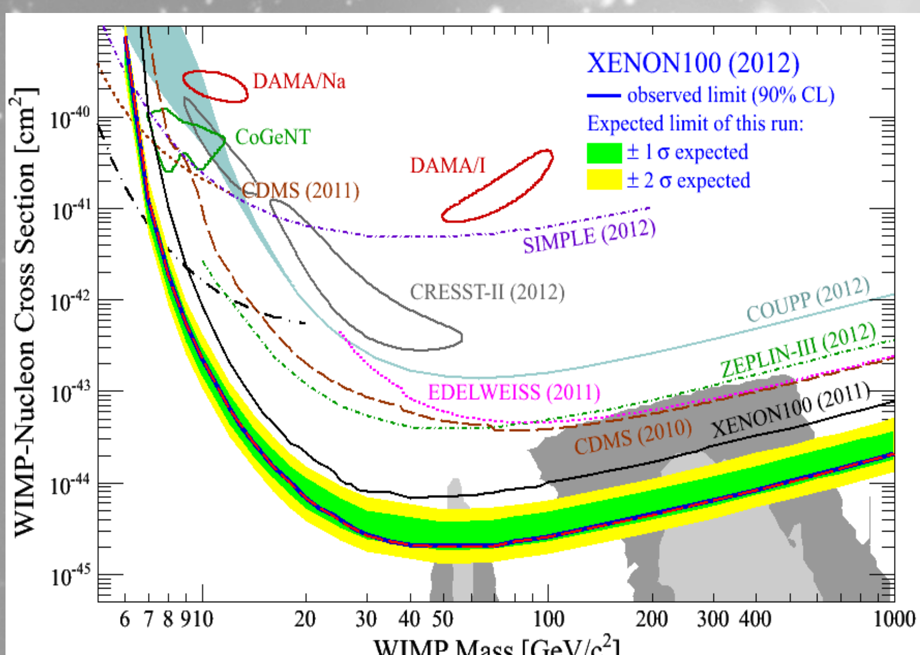

XENON100 (2012)
observed limit (90% CL)
Expected limit of this run:
± 1 σ expected
± 2 σ expected
DAMA/Na
CoGeNT
DAMA/I
CDMS (2011)
SIMPLE (2012)
XENON10 (2011)
CRESST-II (2012)
COUPP (2012)
ZEPLIN-III (2012)
EDELWEISS (2011)
XENON100 (2011)
CDMS (2010)
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]

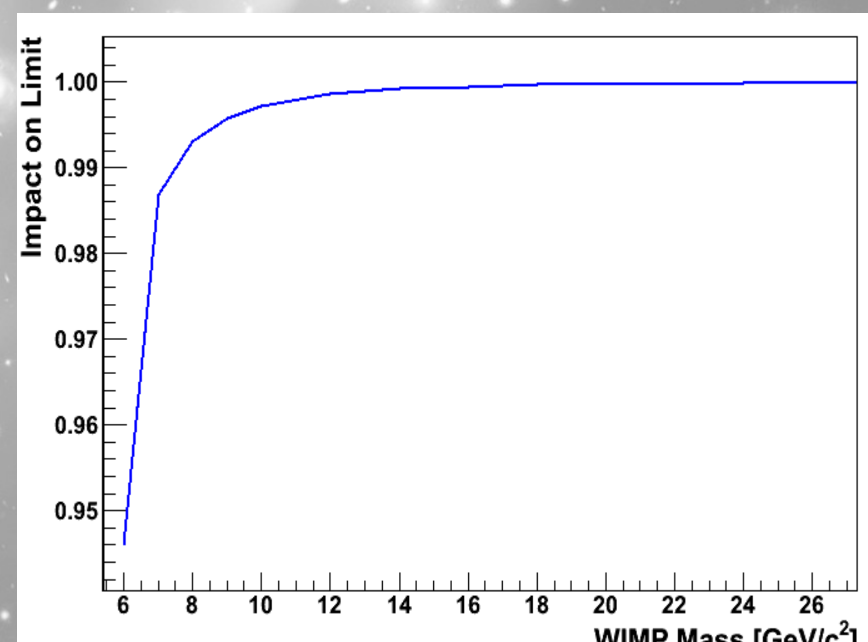
Comparison with Previous Run

	Run 10	Run 08
Livetime	224.6 days	100.8 days
Fiducial mass	34 kg	48 kg
S1 Threshold	3 pe	4 pe
S2 Threshold	150 pe	300 pe
Expected ER Background	0.79±0.16	1.72±0.55
Expected NR Background	0.17+0.12-0.07	0.11+0.8-0.04
Expected background	1.0±0.2	1.8±0.6
Observed events in the benchmark region	2	3
90% CL cross section at 50GeV	$2.0\times10^{-45}cm^{2}$	$7.0\times10^{-45}cm^{2}$

Impact of Leff

- As an excersise, we have computed the same limit with the approximation that Leff is 0 below 3 keVnr (red line in the figure)
- The impact on the limit is below 5% for all the relevant mass range





Conclusions

- We have successfully operated XENON100 for more than 1 year in reduced background conditions
- The observation of 2 events with a background expectation of 1 enables to set a 90% CL limit in the WIMP-nucleon cross section of $2.0x10^{-45} cm^2$ for a 50GeV WIMP
- Still quite some work ahead
  - Complete the analysis of the new data:
    - SD analysis, annual modulation and more..
  - Continue XENON100 with lower Kr and Rn
  - Start construction of XENON1T and reach a sensitivity of $2x10^{-47}$ cm^2(see talk by R. Budnik on July 25th)