XENON100 – The new Results

Marc Schumann *University of Zürich*

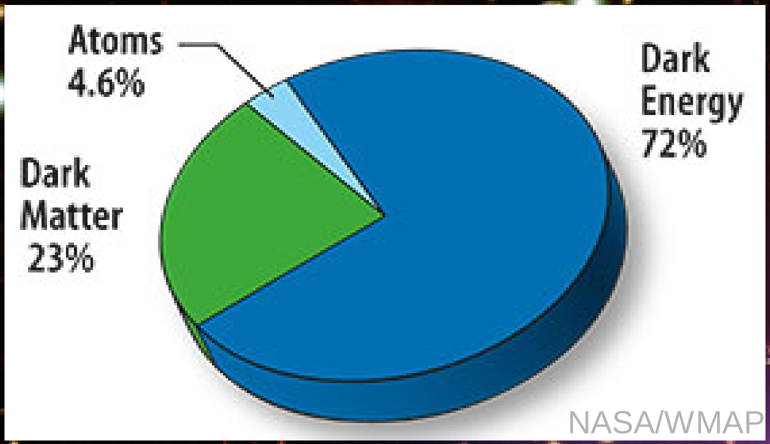
Axion WIMP 2012, Fermilab, 20.07.2012

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

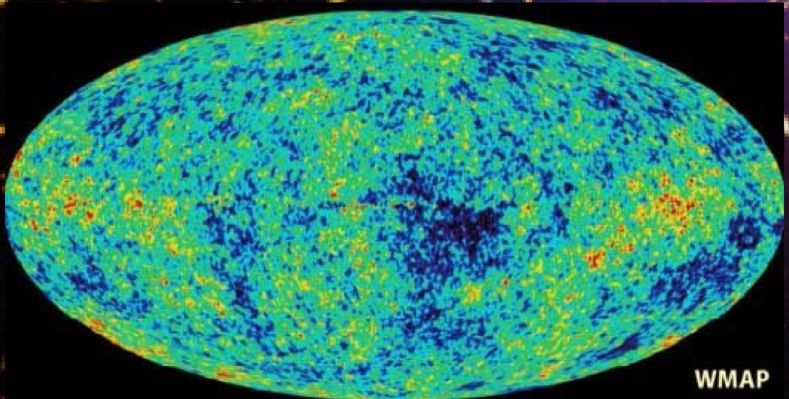
95% of the Universe is dark!

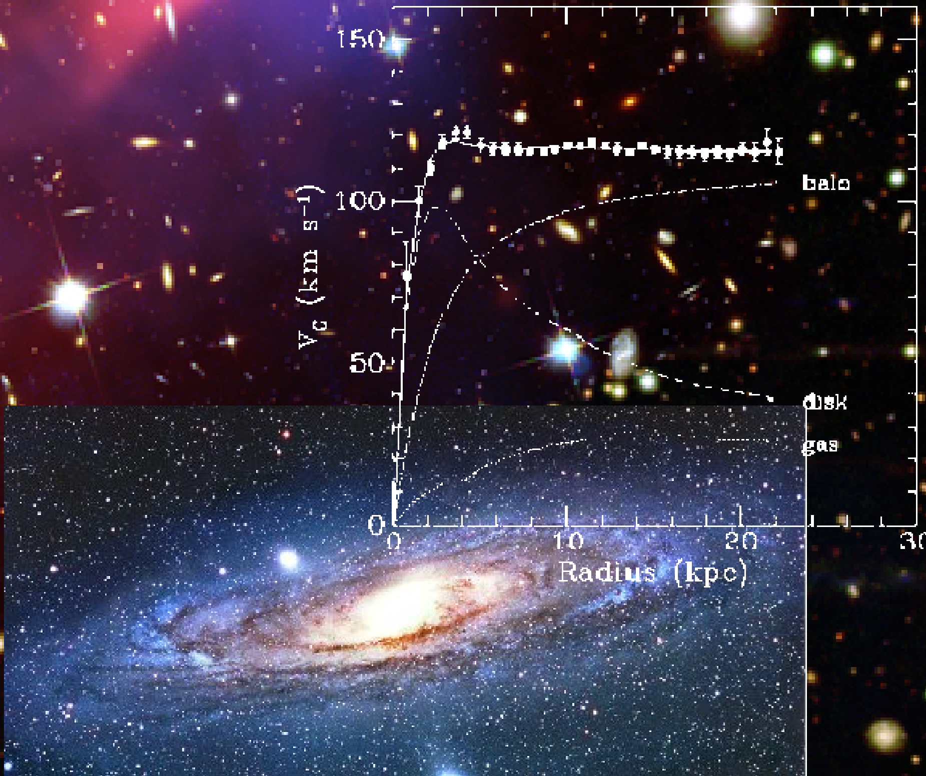
Dark Energy????

Dark Matter: (indirect) **Evidence**

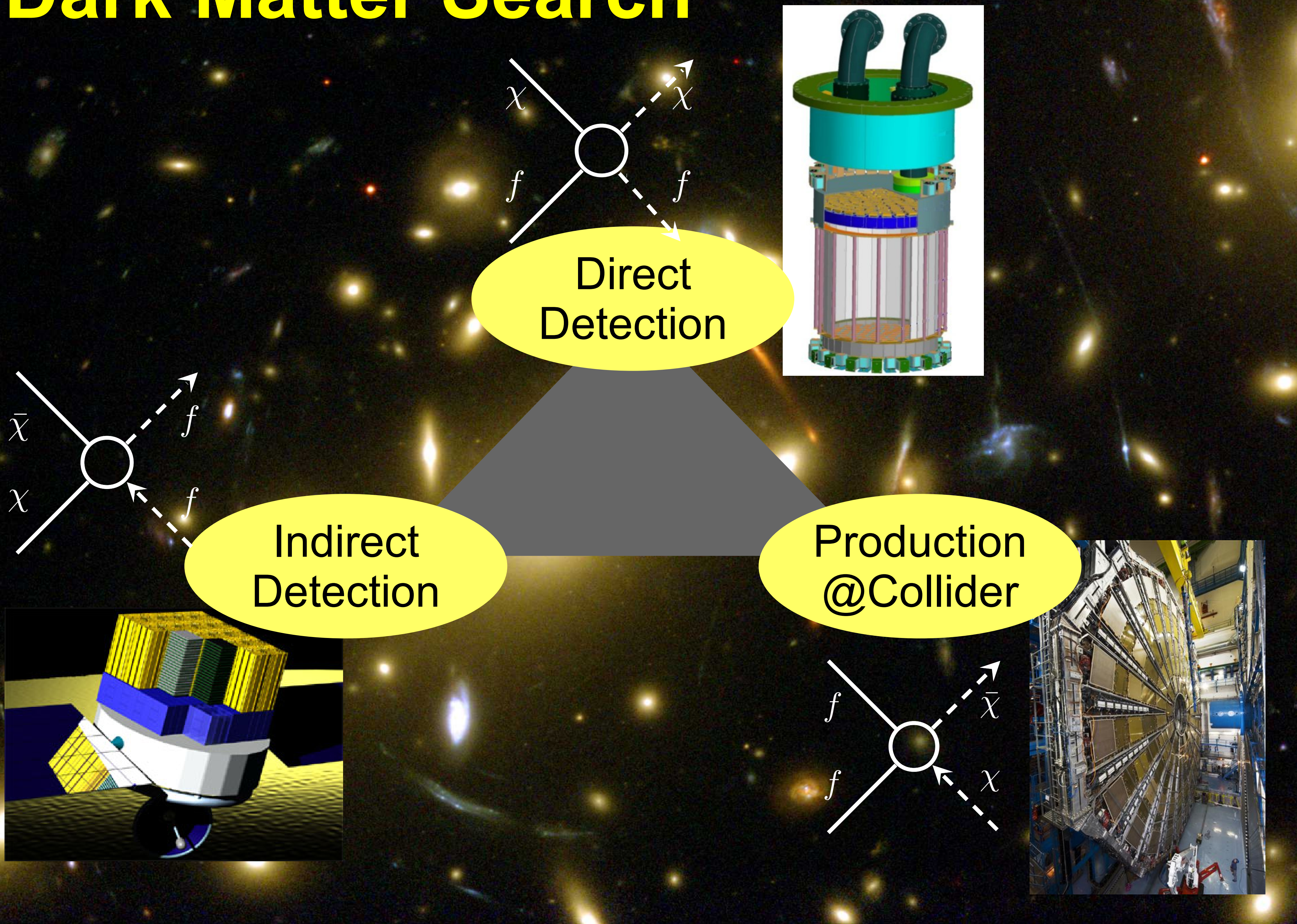


Particle Dark Matter Candidates:
- WIMP → *„WIMP miracle“*
- Axion
- SuperWIMPs
- sterile neutrinos
- WIMPless dark matter
- Gravitino
- ...



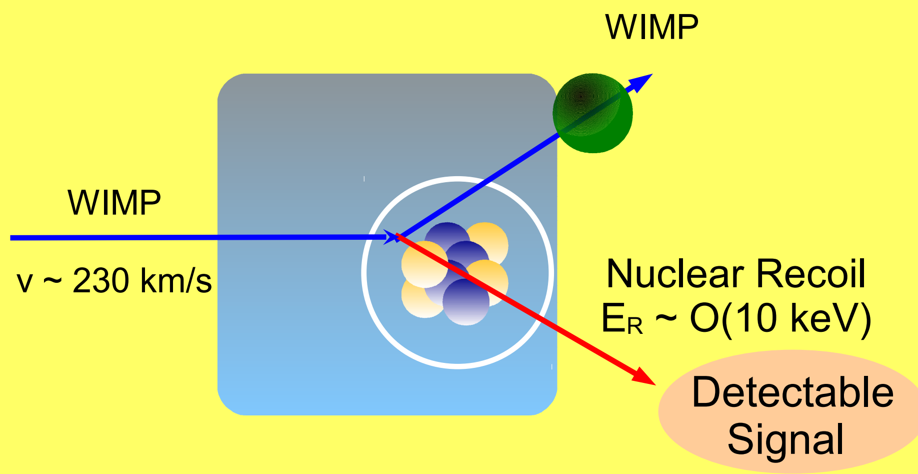


Dark Matter Search



Direct WIMP Search

Elastic Scattering of WIMPs off target nuclei
→ nuclear recoil



Recoil Energy: $$E_r = \frac{|\vec{q}|^2}{2m_N} = \frac{\mu^2 v^2}{m_N}(1-\cos\theta) \sim \mathcal{O}(10\ \mathrm{keV})$$

Event Rate: $$R \propto N \frac{\rho_\chi}{m_\chi} \langle \sigma_{\chi-N} \rangle$$

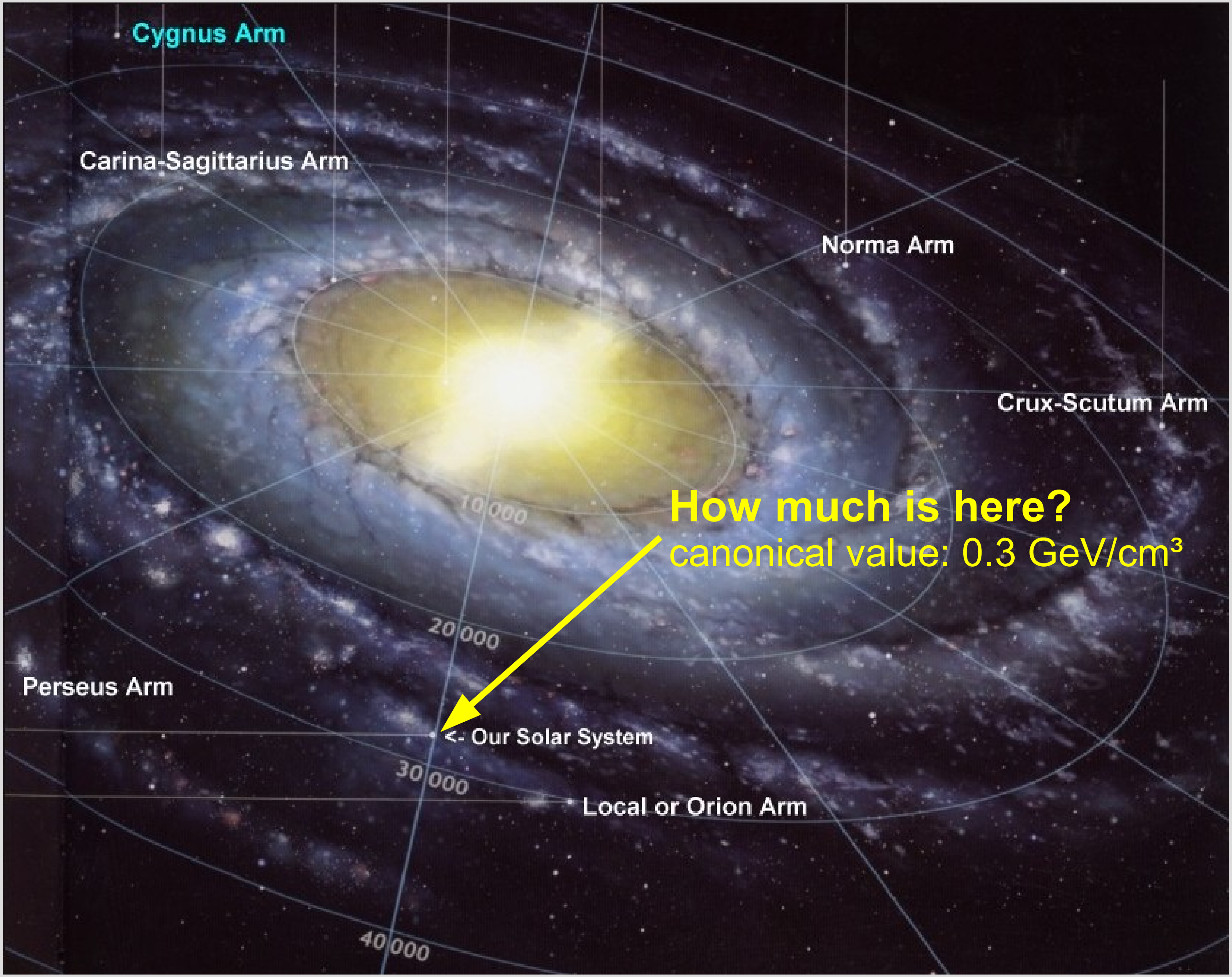
Detector

Local DM Density

Physics

N	number of target nuclei
ρ_χ/m_χ	local WIMP density
$<\sigma>$	velocity-averaged scatt. X-section

Dark Matter around us?



XENON Dark Matter Project

arXiv.org > astro-ph > arXiv:1204.3924

Astrophysics > Galaxy Astrophysics

Kinematical and chemical vertical structure of the Galactic thick disk II. A lack of dark matter in the solar neighborhood

C. Moni Bidin, G. Carraro, R. A. Mendez, R. Smith

We estimated the dynamical surface mass density Sigma at the solar position between Z=1.5 and 4 kpc from the Galactic plane, as inferred from the kinematics of thick disk stars.

We extrapolate a dark matter (DM) density in the solar neighborhood of 0+-1 mM_sun pc^-3,

In particular, our results may indicate that any direct DM detection experiment is doomed to fail, if the local density of the target particles is negligible.

arXiv.org > astro-ph > arXiv:1205.4033

Astrophysics > Galaxy Astrophysics

On the local dark matter density

Jo Bovy, Scott Tremaine (IAS)

An analysis of the kinematics of 412 stars at 1-4 kpc from the Galactic mid-plane by Moni Bidin et al. (2012) has claimed to derive a local density of dark matter that is an order of magnitude below standard expectations. We show that this result is incorrect and that it arises from the invalid assumption that the mean azimuthal velocity of the stellar tracers is independent of Galactocentric radius at all heights; the correct assumption---that is, the one supported by data---is that the circular speed is independent of radius in the mid-plane.

we find that the data imply a local dark-matter density of 0.3 +/- 0.1 Gev/cm^3

Perseus Arm

arXiv.org > astro-ph > arXiv:1206.0015

Astrophysics > Galaxy Astrophysics

A new determination of the local dark matter density from the kinematics of K dwarfs

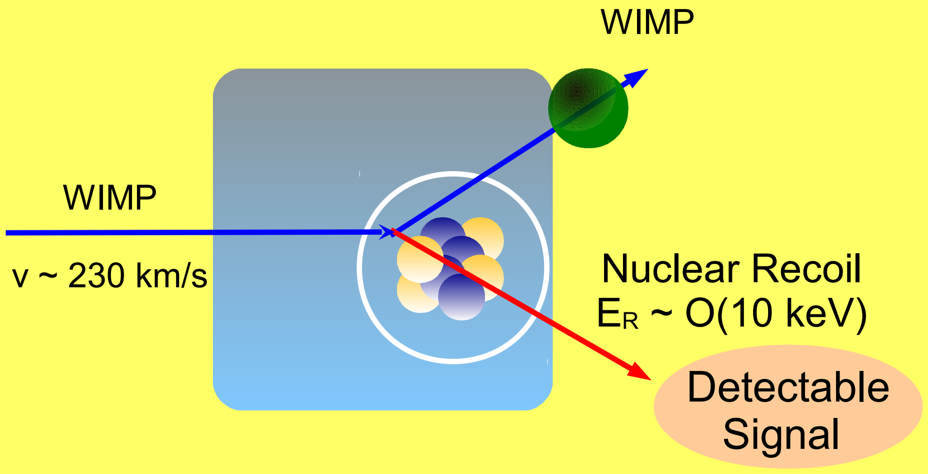
Silvia Garbari, Chao Liu, Justin I. Read, George Lake

We apply a new method to determine the local disc matter and dark halo matter density to kinematic and position data for \sim2000 K dwarf stars taken from the literature.

We perform a series of tests to demonstrate that our results are insensitive to plausible systematic errors in our distance calibration, and we show that our method recovers the correct answer from a dynamically evolved N-body simulation of the Milky Way. We find a local dark matter density of (0.95+0.53-0.49 GeV cm^-3) at 90% confidence assuming no correction for the non-flatness of the local rotation curve, and (0.85+0.57-0.50 GeV cm^-3) if the correction is included.

Direct WIMP Search

Elastic Scattering of WIMPs off target nuclei
➡ nuclear recoil



Recoil Energy: $E_r \sim \mathcal{O}(10\ \mathrm{keV})$

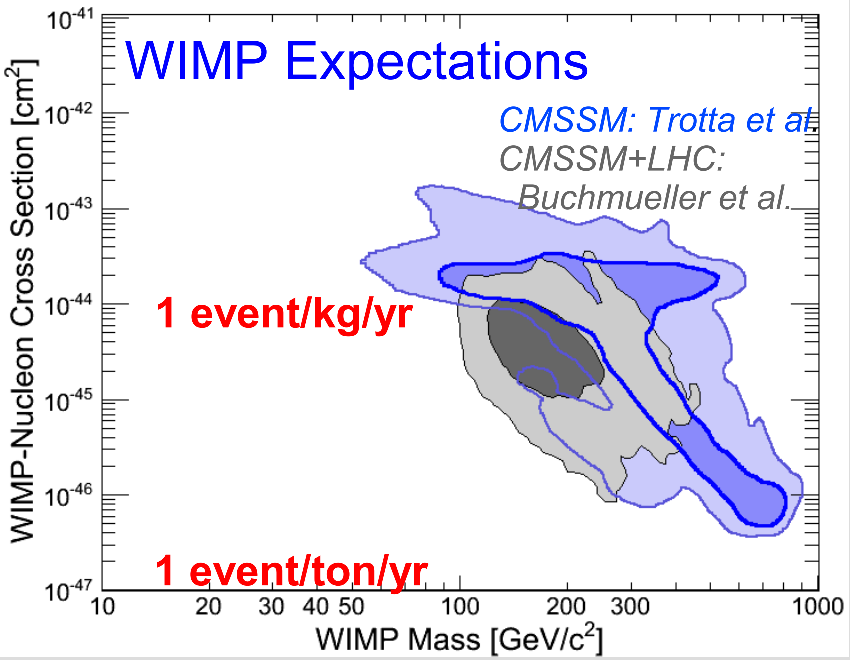
Event Rate: $R \propto N \frac{\rho_\chi}{m_\chi} \langle \sigma_{\chi-N} \rangle$

Detector

Local DM Density

ρ_χ~0.3 GeV/c²

Physics



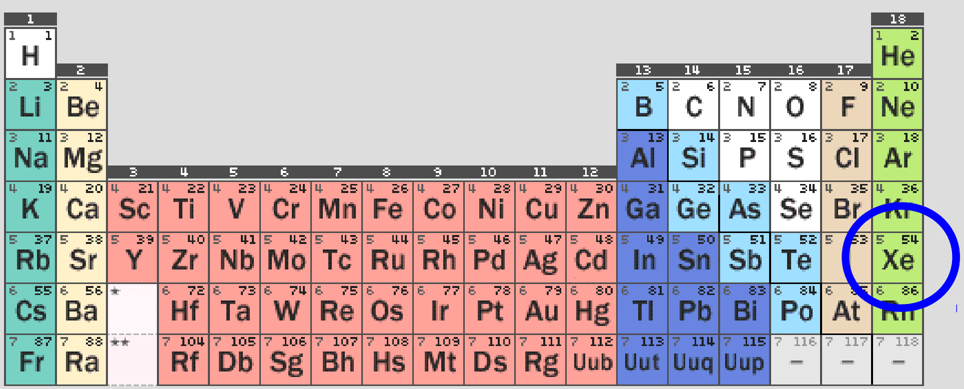
Direct WIMP Search

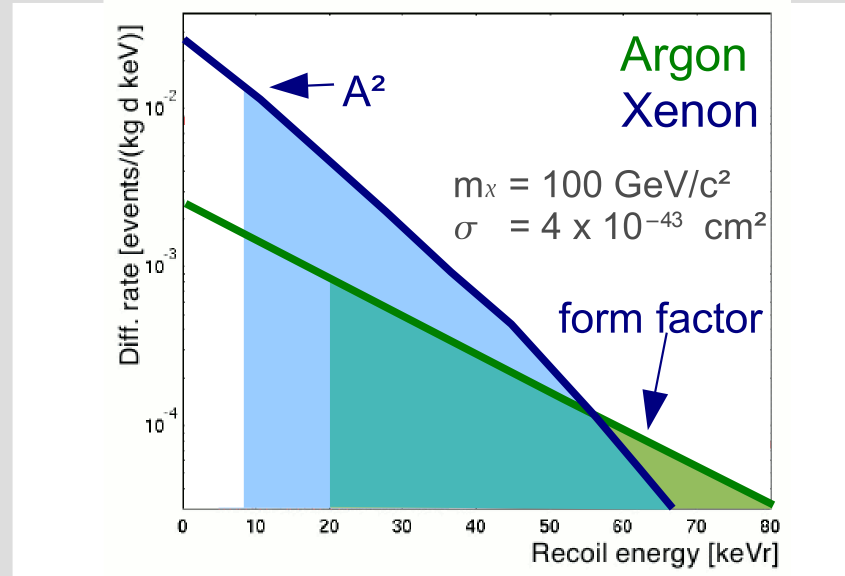
Summary: Tiny Rates

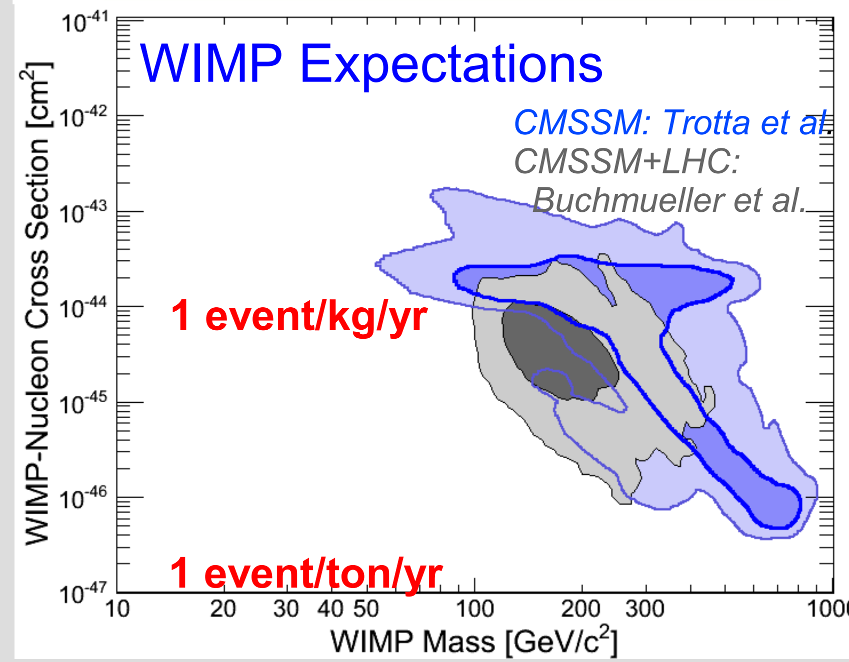
R < 0.01 evt/kg/day
E_R < 100 keV

How to build a WIMP detector?

- large total mass, high A ✔ for Xe
- low energy threshold ✔ for Xe
- ultra low background ✔ for Xe
- good background discrimination ✔ for Xe







Backgrounds

Experimental Sensitivity

without background: $\propto (mt)^{-1}$
with background: $\propto (mt)^{-1/2}$

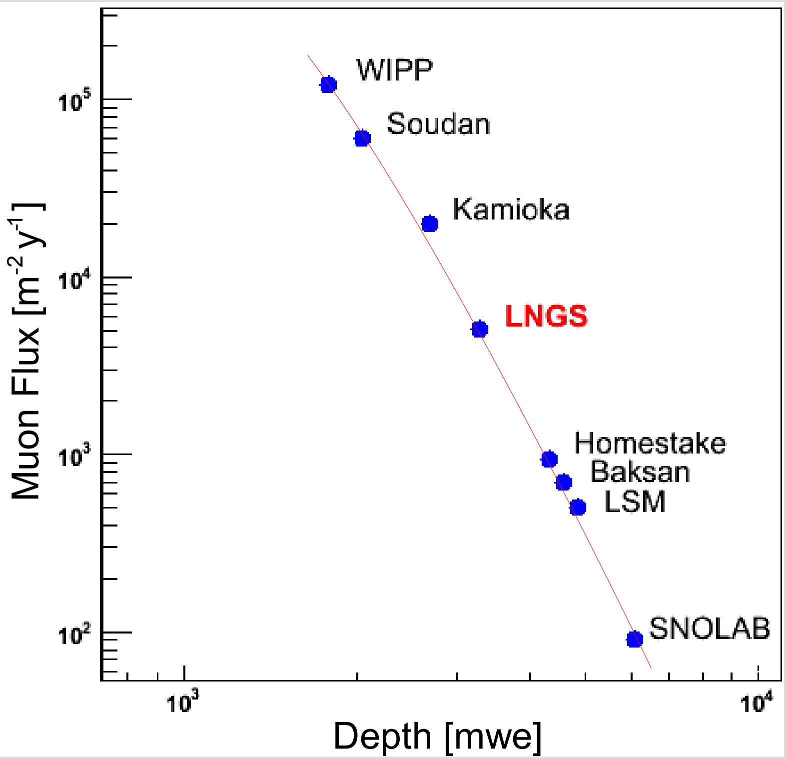
Background Sources

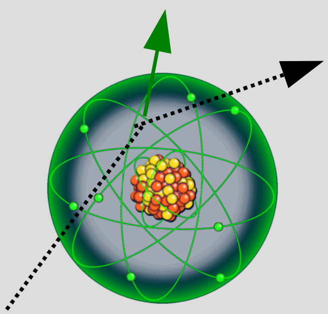
environment: U, Th chains, K

$$^{238}\mathrm{U} \xrightarrow[\alpha]{} {}^{234}\mathrm{Th} \xrightarrow[\beta]{} {}^{234m}\mathrm{Pa} \xrightarrow[\beta]{} {}^{234}\mathrm{U} \xrightarrow[\alpha]{} {}^{230}\mathrm{Th} \xrightarrow[\alpha]{} {}^{226}\mathrm{Ra} \xrightarrow[\alpha]{} {}^{222}\mathrm{Rn} \xrightarrow[\alpha]{} {}^{218}\mathrm{Po} \ldots$$

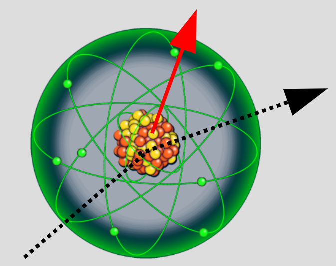
$$^{232}\mathrm{Th} \xrightarrow[\alpha]{} {}^{228}\mathrm{Ra} \xrightarrow[\beta]{} {}^{228m}\mathrm{Ac} \xrightarrow[\beta]{} {}^{228}\mathrm{Th} \xrightarrow[\alpha]{} {}^{224}\mathrm{Ra} \xrightarrow[\alpha]{} {}^{220}\mathrm{Rn} \xrightarrow[\alpha]{} {}^{216}\mathrm{Po} \ldots$$

- γ and β decays (electronic recoil)
- alphas no big problem for LXe
  (technology dependent)
- neutrons from (α,n) and sf in rocks and detector parts
- neutrons from cosmic ray muons





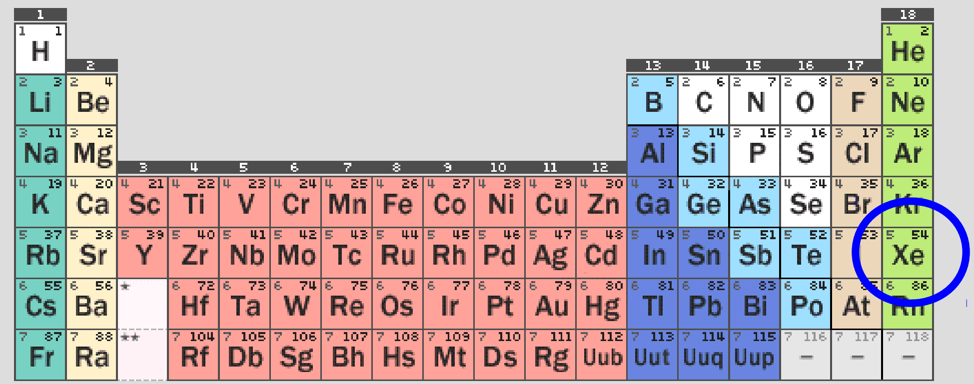
Electronic Recoils
(gamma, beta)

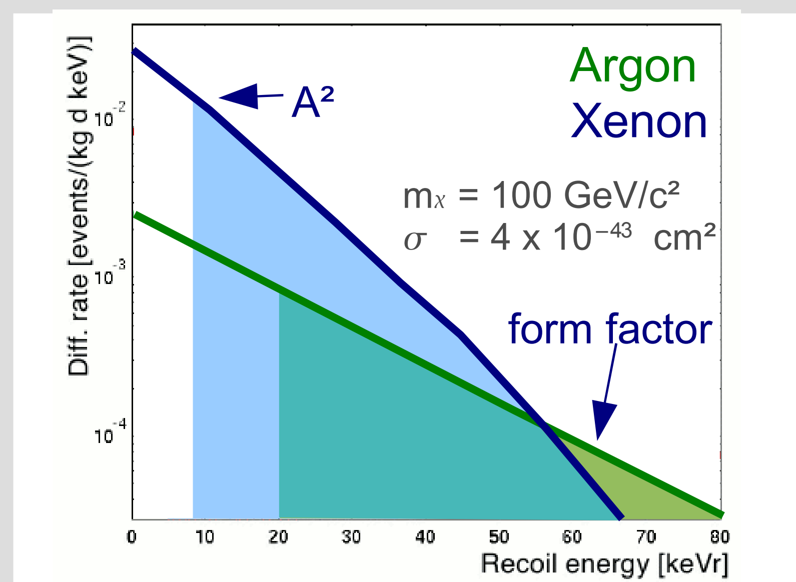


Nuclear Recoils
(neutron, WIMPs)

Why WIMP Search with Xenon?

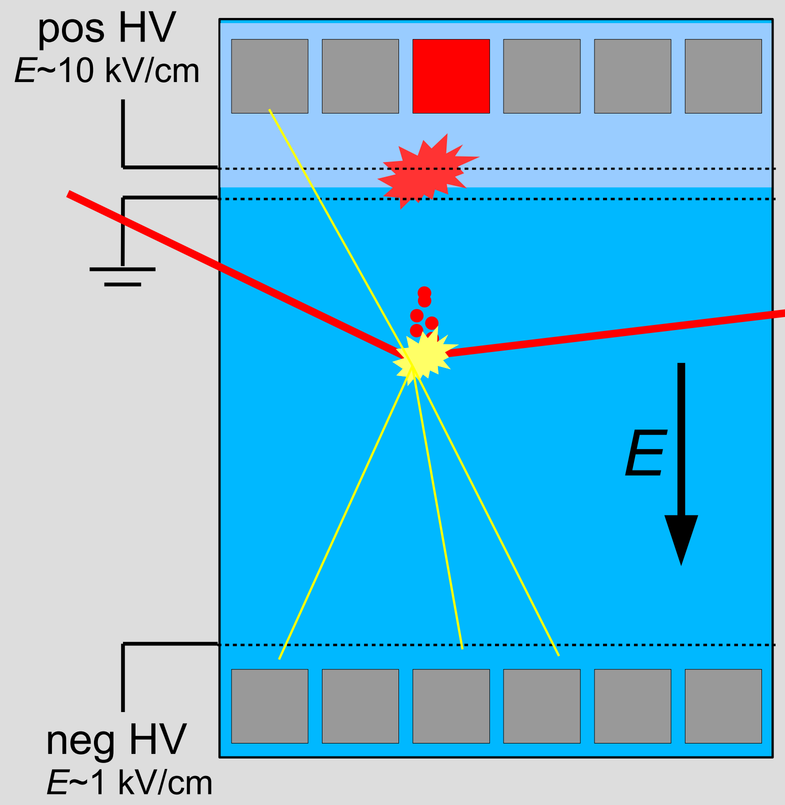
- efficient, fast scintillator (178nm)
- high mass number *A*~131:
  SI: high WIMP rate @ low threshold
- high *Z*=54, high ρ~3 kg/l:
  self shielding, compact detector
- SD: 50% odd isotopes
  allows further characterization after detection by testing only SI or SD
- no long lived Xe isotopes
  Kr can be removed to ppt level
- "easy" cryogenics @ –100°C
- scalability to larger detectors
- in dual-phase TPC:
  good background discrimination

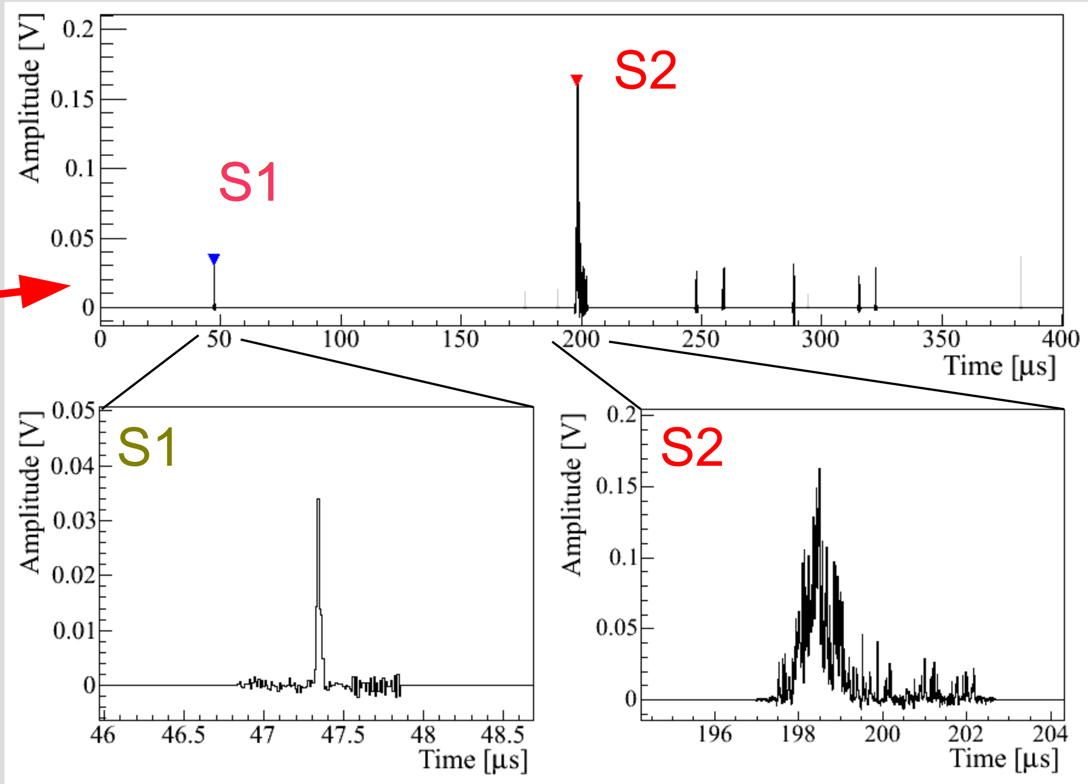




Dual Phase TPC

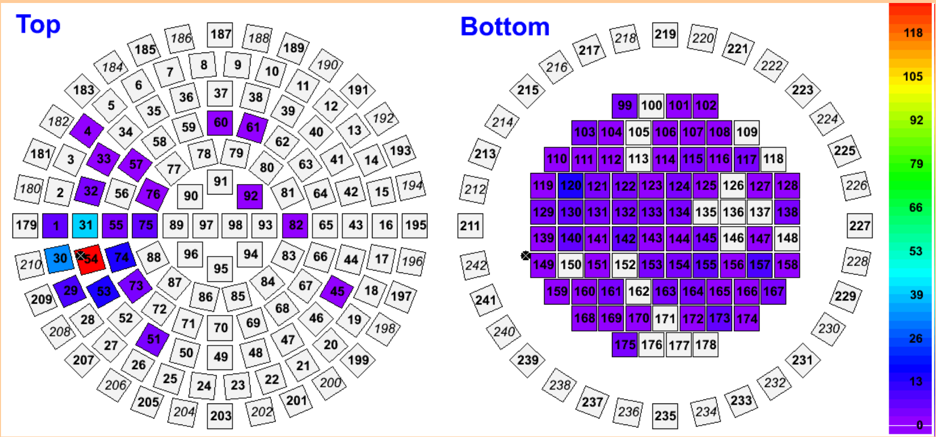
TPC = time projection chamber

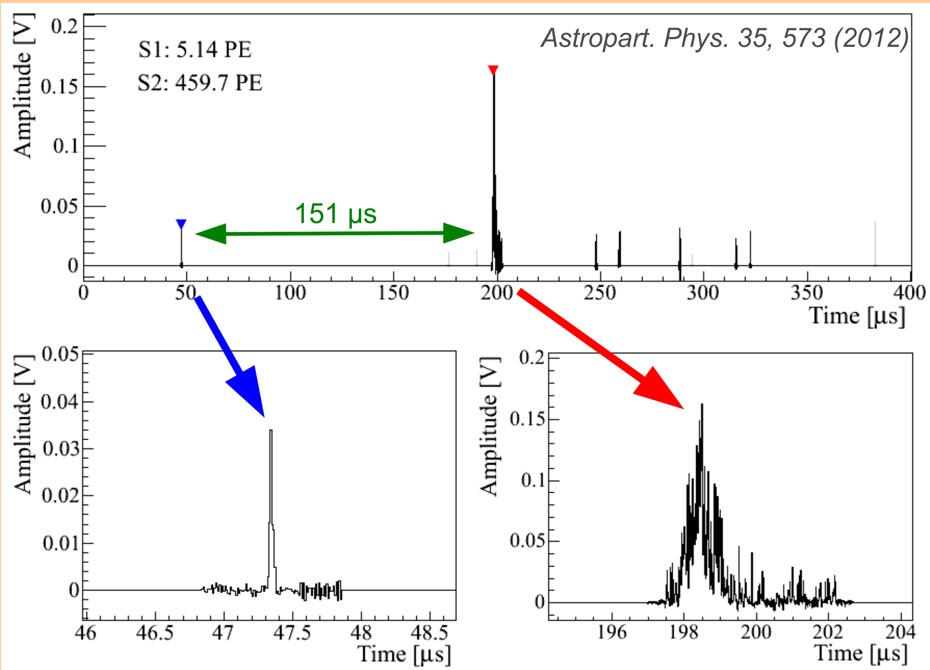




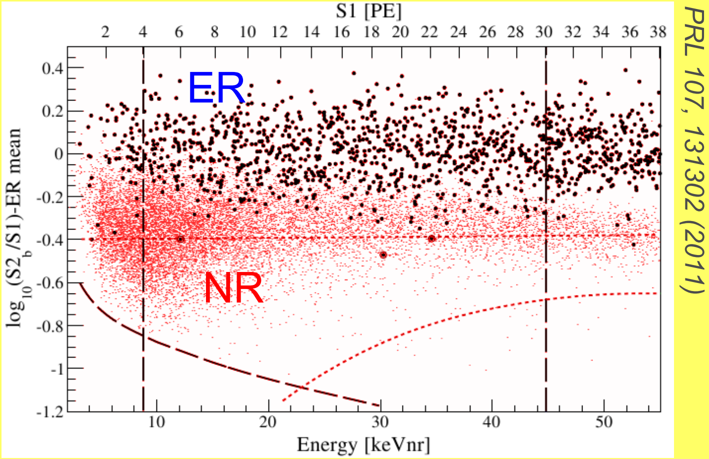
Dual Phase TPC

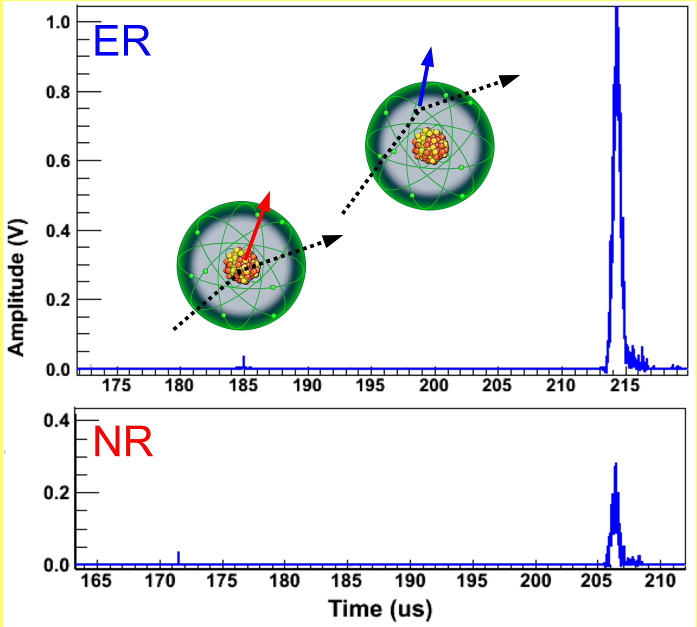
3d Vertex Reconstruction





Signal/Background Discrimination

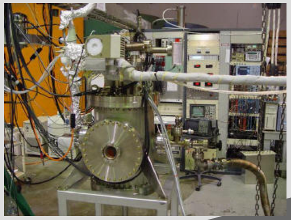




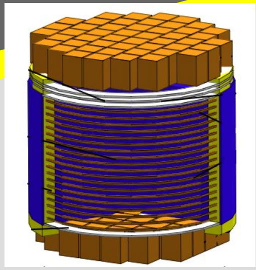
The XENON program

XENON: A phased WIMP search program

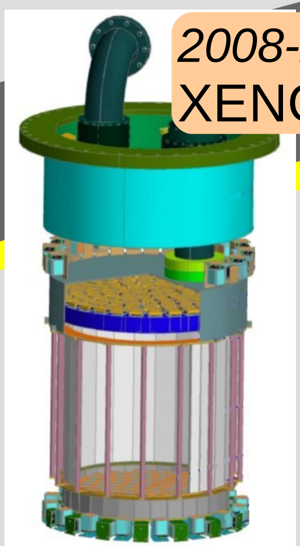
XENON
R&D



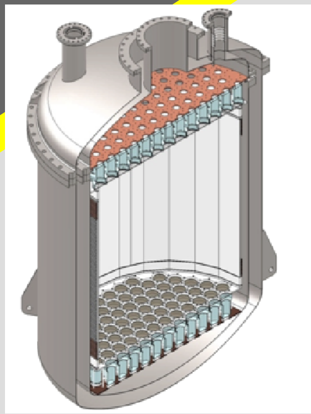
2005-2007:
XENON10



2008-201x:
XENON100



2010-2015:
XENON1T



Columbia *Rice* *UCLA* *U Zürich* *Coimbra* *LNGS* *Mainz* *SJTU*

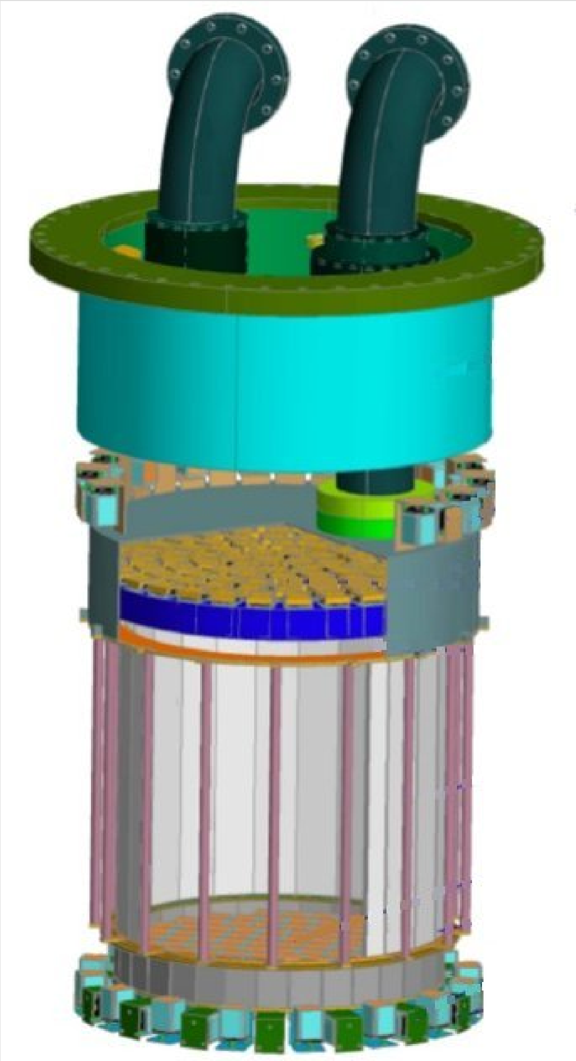
Bologna *MPIK* *NIKHEF* *Purdue* *Subatech* *Münster* *WIS*

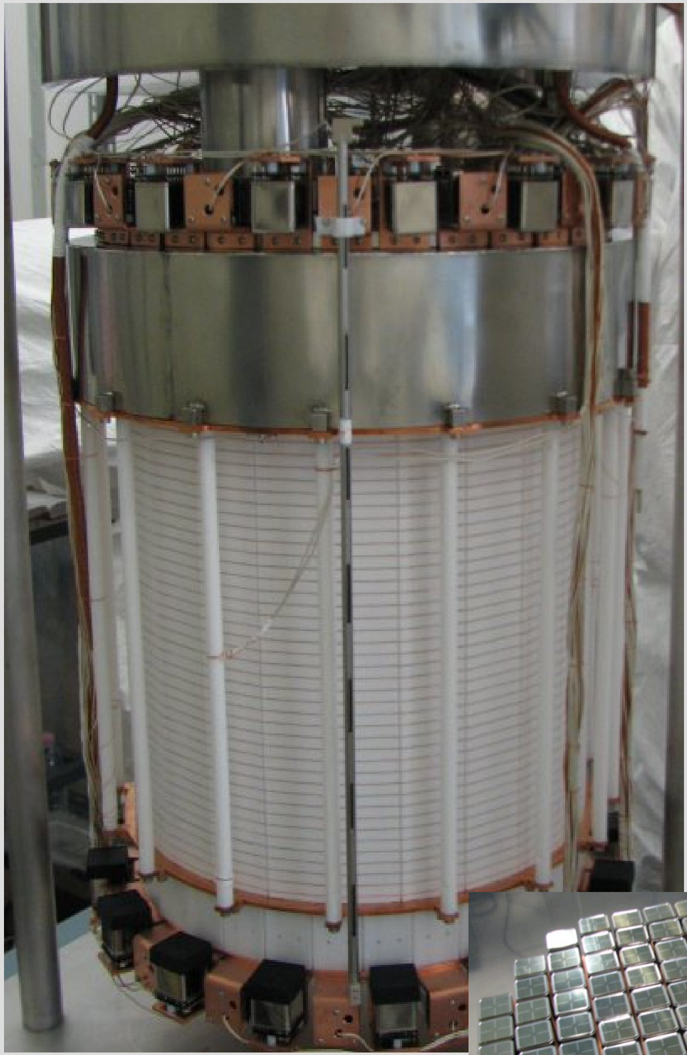
XENON Collaboration

XENON Collaboration Meeting, LNGS, April 2012

XENON100

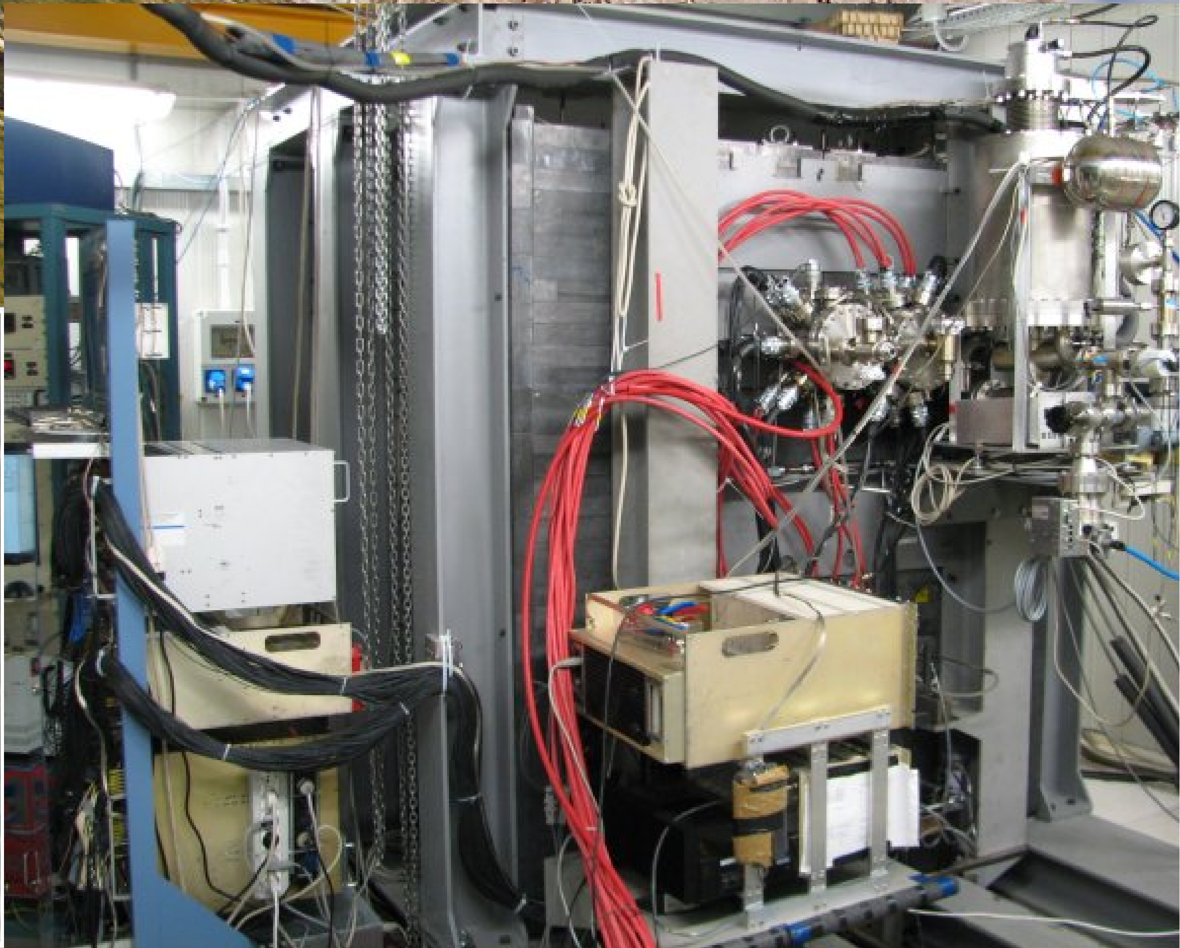
Astropart. Phys. 35, 573 (2012)



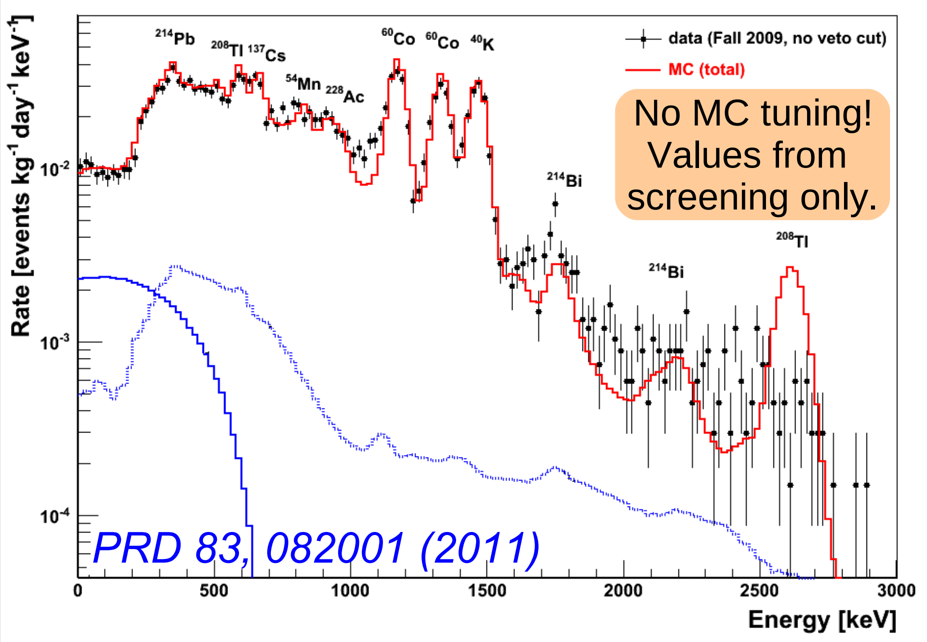


161 kg LXe, 62 kg in target
242 1" x1" PMTs

Laboratori Nazionali del Gran Sasso



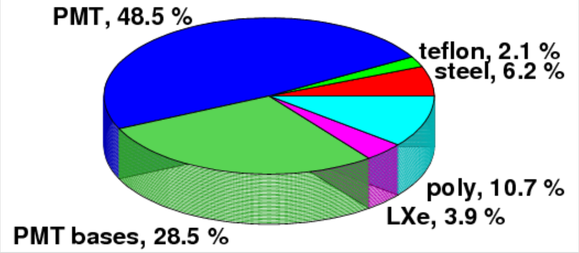
XENON100 Background



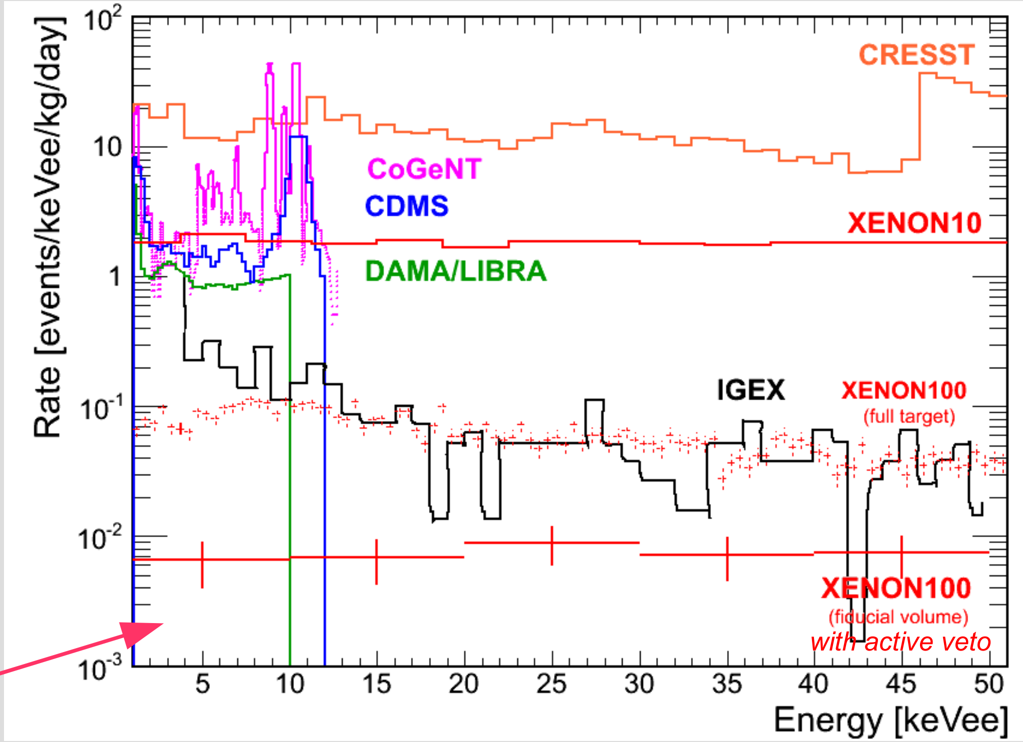
Measured Background in good agreement with MC prediction.

At low energies: Lowest background ever achieved in a Dark Matter Experiment!

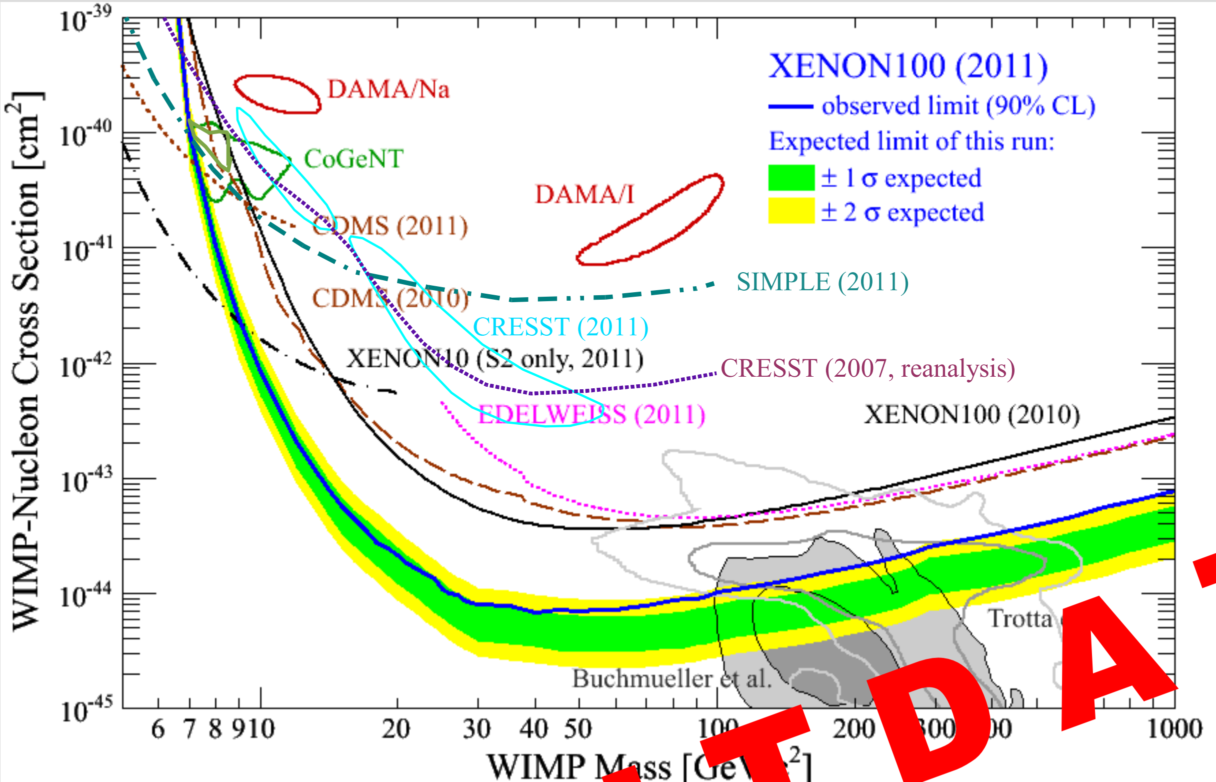
- 30 kg fiducial mass
- active LXe veto not used for this plot
- exploit anti-correlation between light and charge for better ER-energy scale



Xenon keVee-Scale not precisely known below 9 keVee



(spin-independent) WIMP Limit 2011

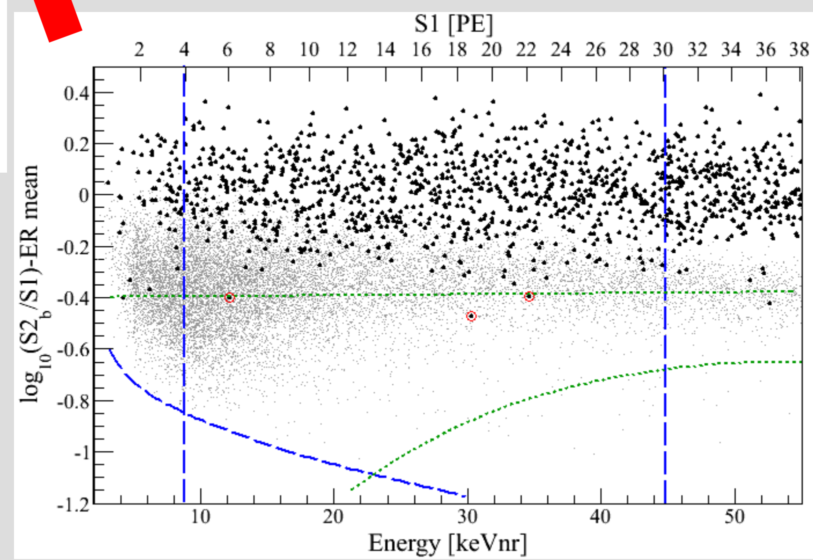


PRL 107, 131302 (2011)

already cited 362x

Limit derived with Profile Likelihood method
PRD 84, 05[illegible]3 (2011)

OUTDATED!!!



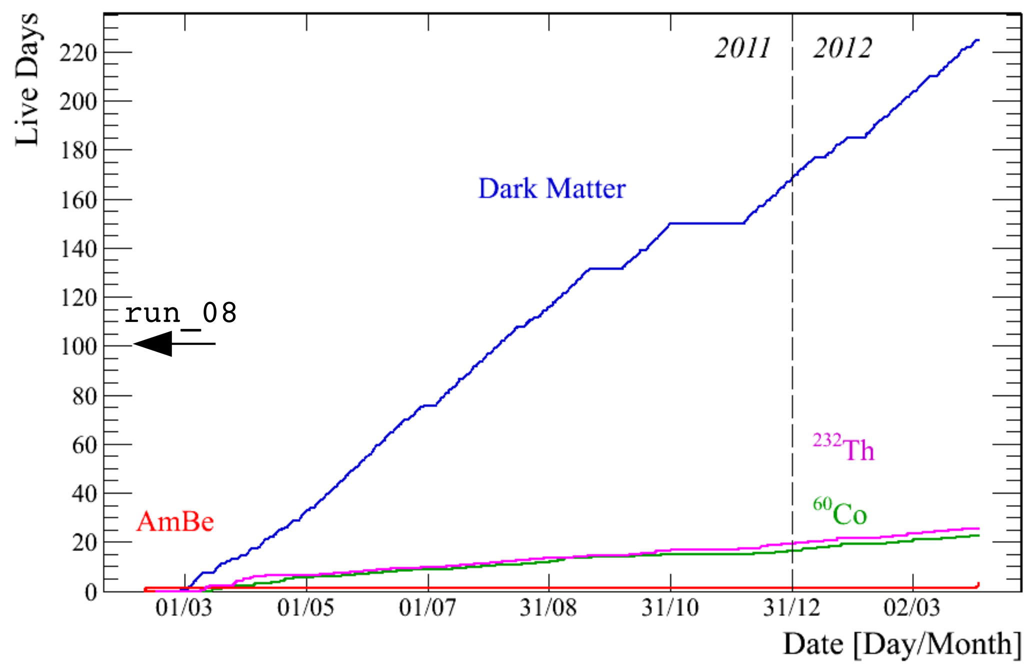
XENON100 sets the most sensitive limit over a large WIMP mass range

Challenges the CoGeNT, DAMA, CRESST-II signals as being due to light mass WIMPs

XENON100 –
New results of 2012

Data Taking

Data Collection

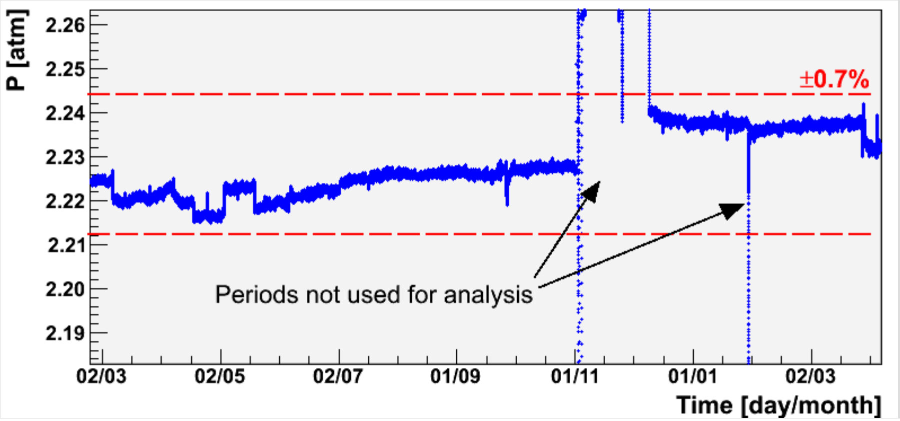


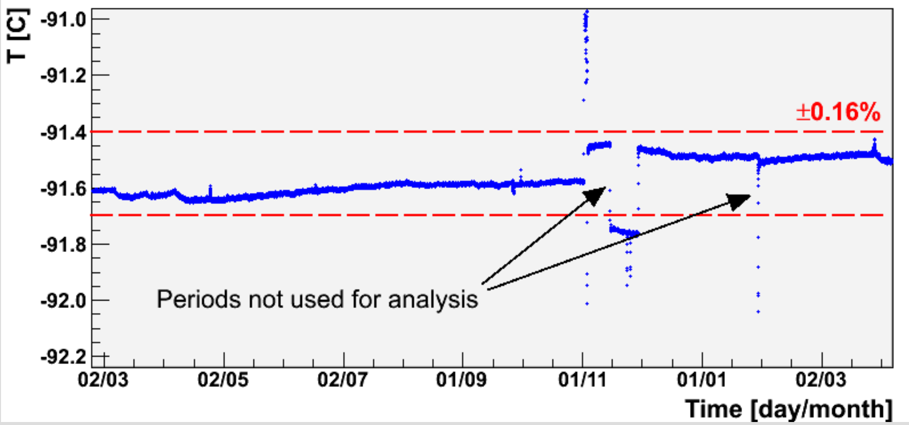
Data taking over 13 months
from Feb 28, 2011 to March 31, 2012
→ full annual cycle

3 interruptions for maintenance

224.56 live days of dark matter data

Stability

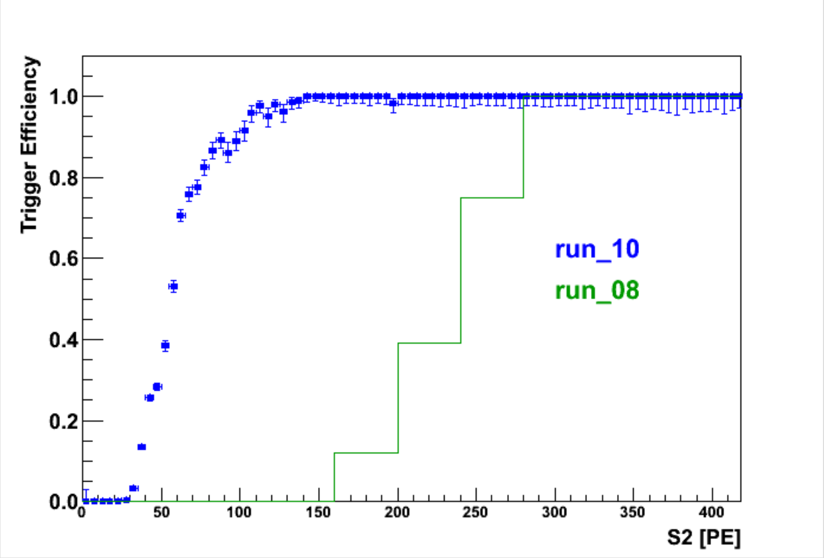


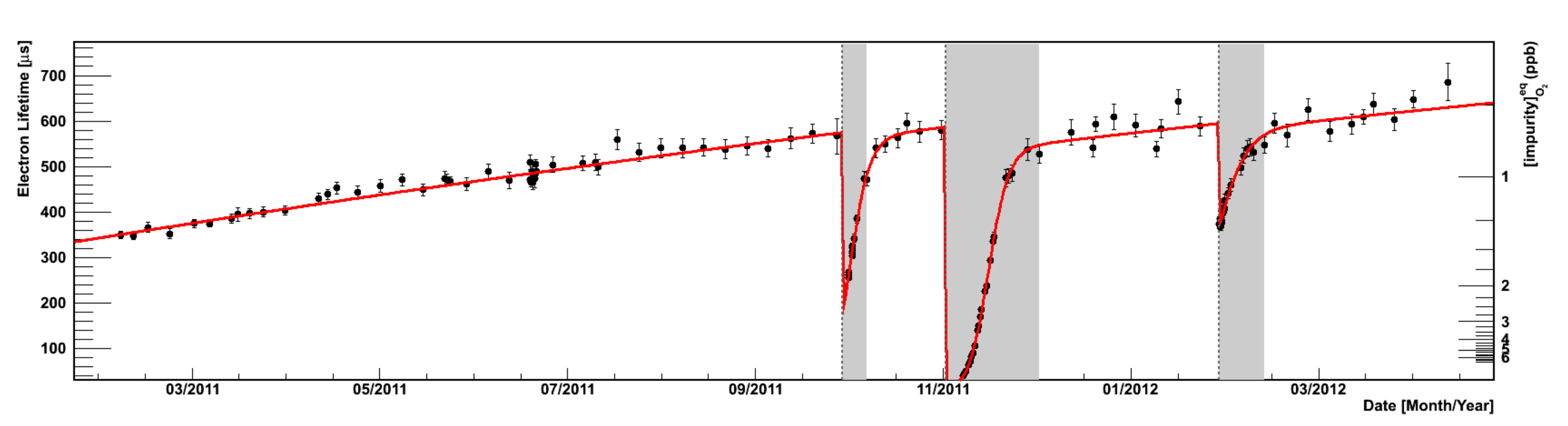


To our knowledge, no large LXe detector has ever been operated under such stable conditions for that long

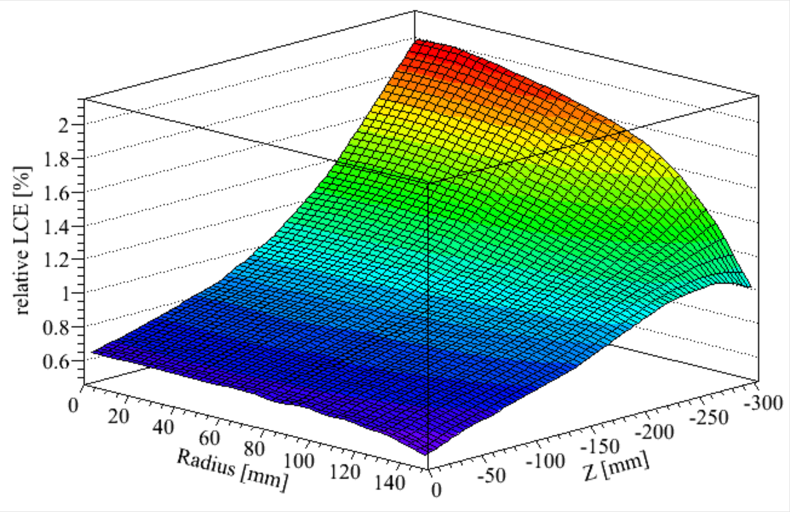
Improvements

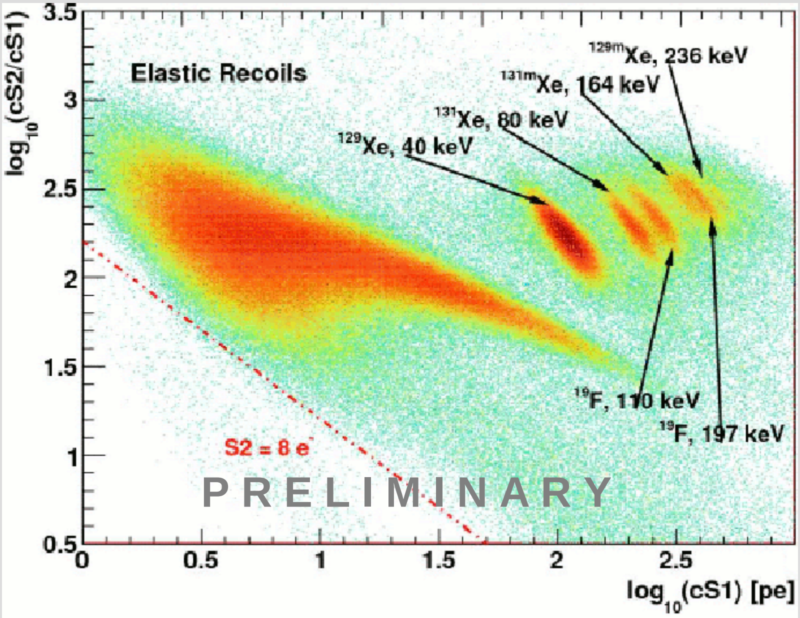
- Exposure more than doubled
- Lower threshold
  S2>150 PE, S1>3 PE (6.6 keVr)
- Lower Background
- Much more calibration data
  35x more ER calibration in ROI
  AmBe before and after run
- Higher LXe purity → smaller corrections





Selected Calibrations





arXiv:1107.2155

Position dependent Corrections:
Cs137, AmBe inelastic (40 keV),
Xe* (164 keV)
Kr83m (planned)

➡ Agreement better than 3%

Electron Lifetime:
Cs-137

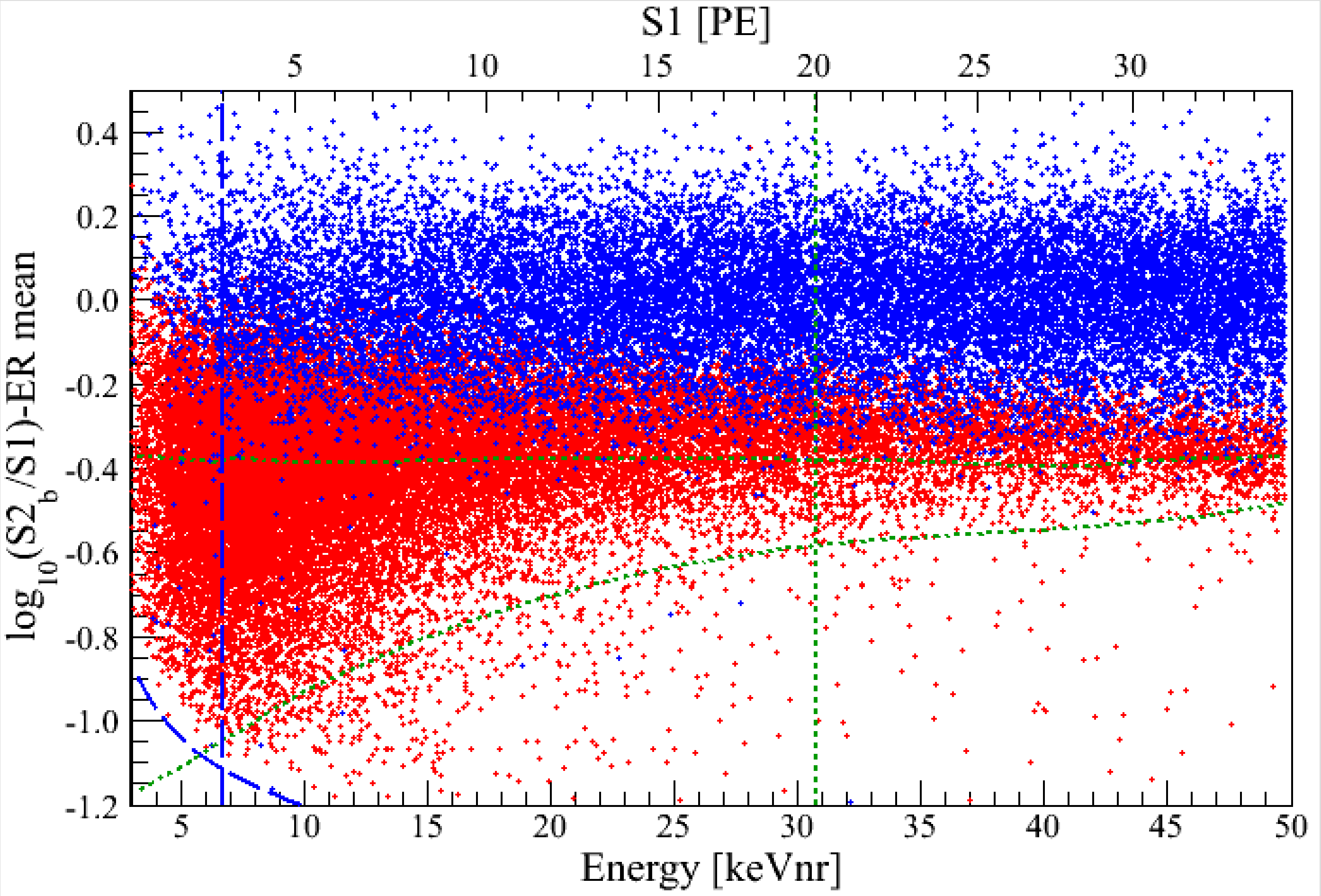
➡ 375 – 610 µs (average 514 µs)

Electron Recoil Band (Background):
Co60, Th232

Nuclear Recoil Band (Signal):
Neutrons: AmBe

➡ definition of WIMP search region, discrimination

ER/NR Discrimination



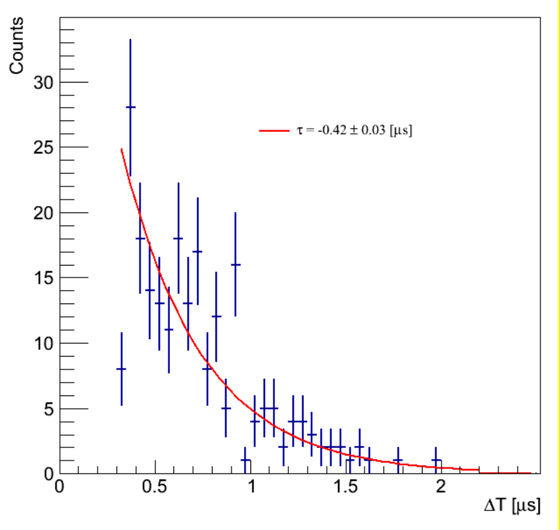
Discrimination comparable to previous runs:
~99.5% ER rejection @ 50% NR accpetance

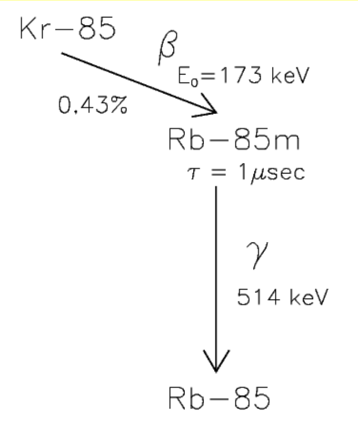
Background of this Run

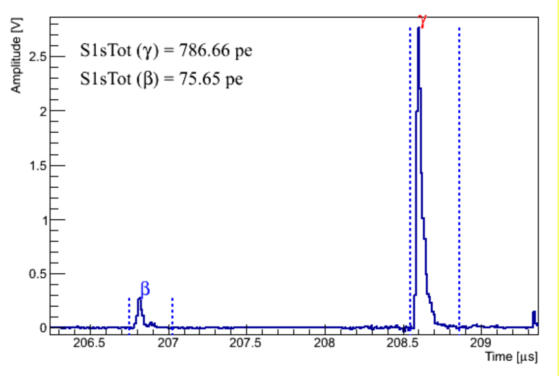
Kr85

Rare gas mass spectrometry (RGMS)
Kr concentration: (19 ± 1) ppt

consistent with delayed coincidence tagging

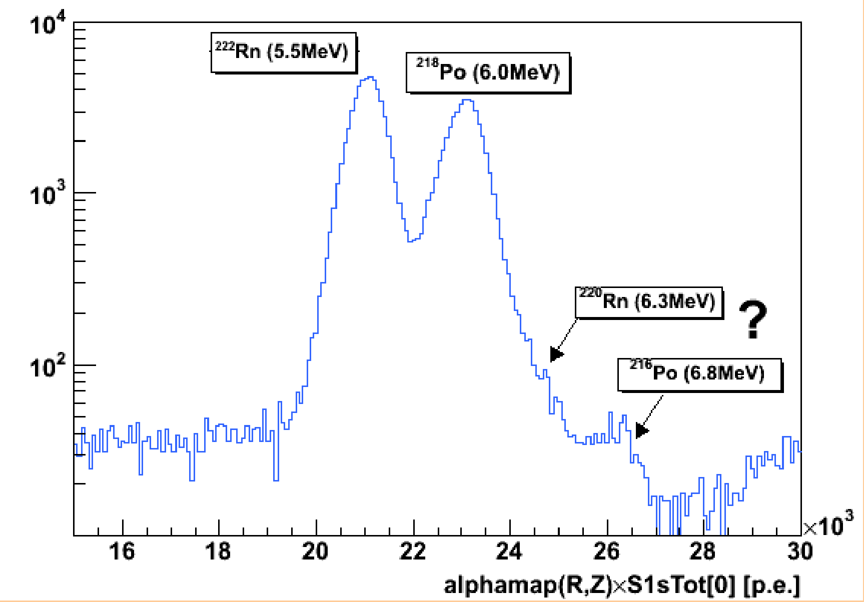


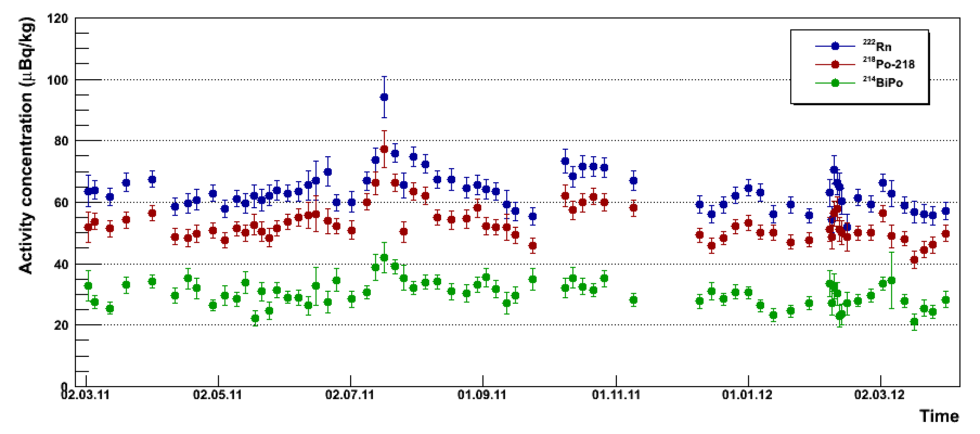




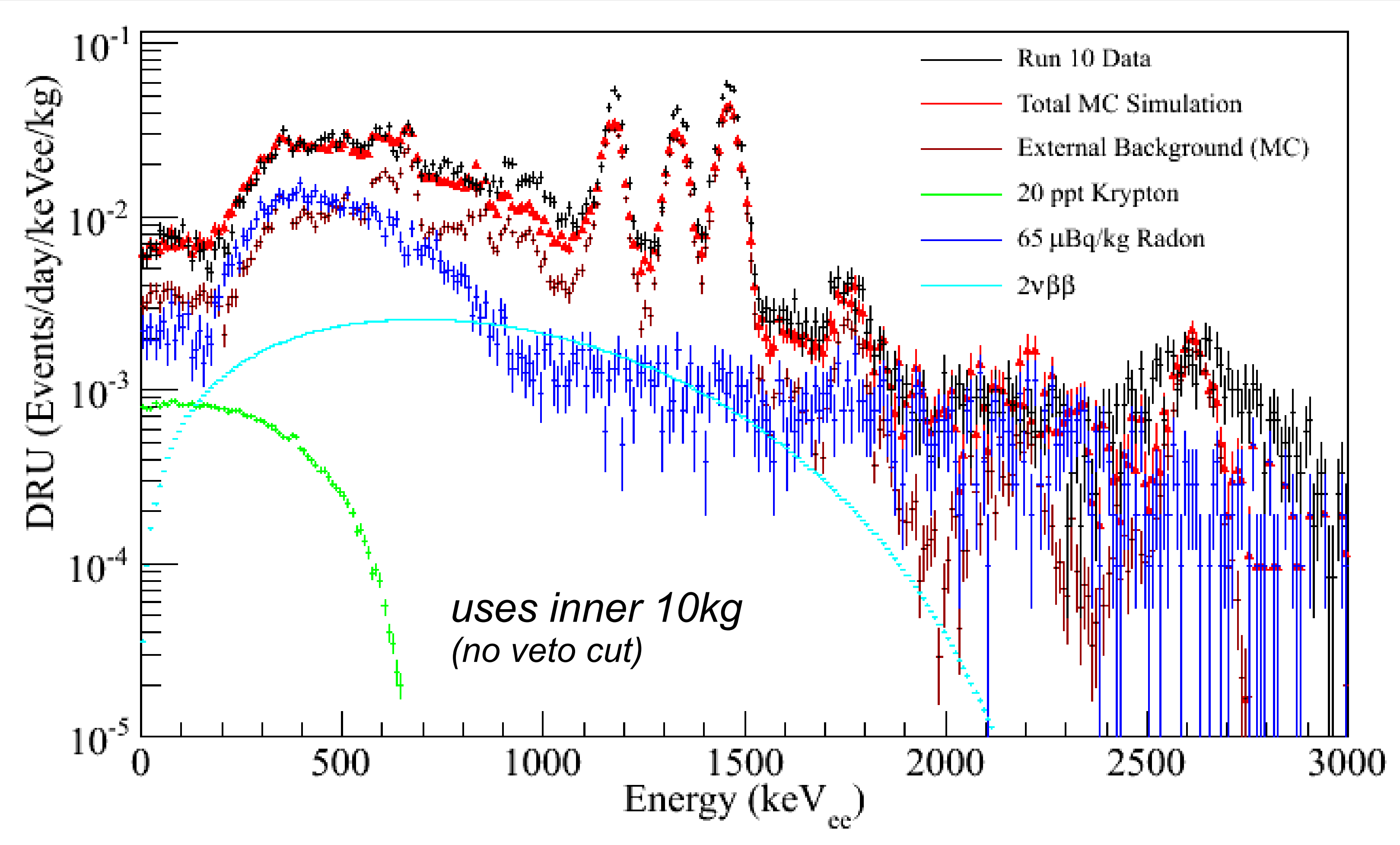
Rn222 chain

alpha tagging: ~62 μBq/kg





Total ER Background

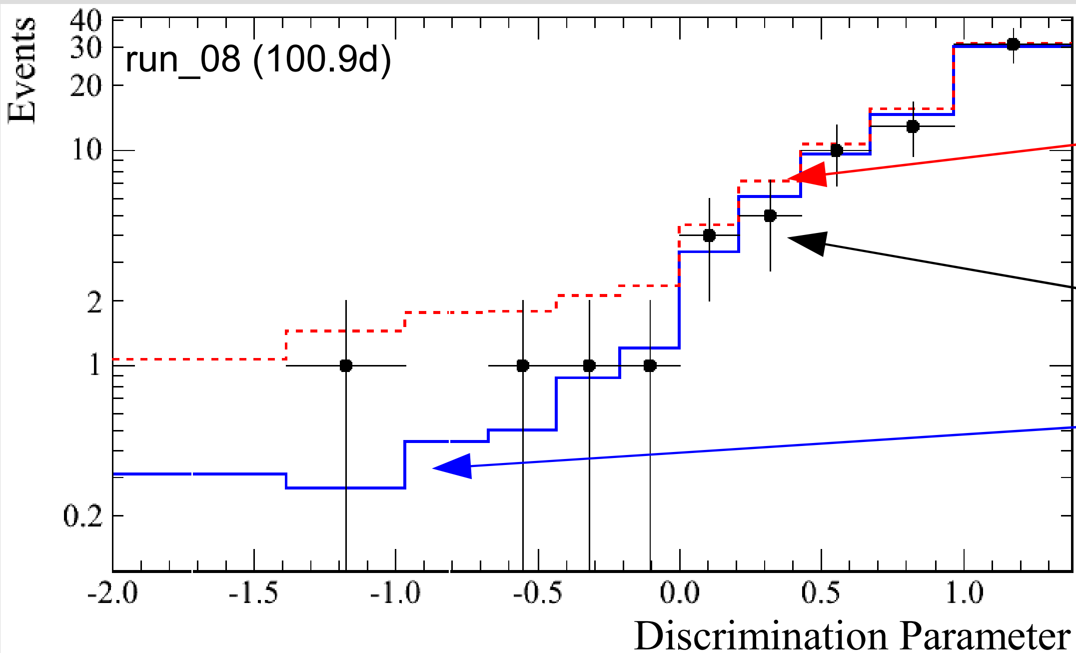


ER Background: $(5.3 \pm 0.6) \times 10^{-3}$ events/keV/kg/day

(with active veto) → before discrimination

Profile Likelihood Method

PRD 84, 052003 (2011)



background + WIMP signal
(100 GeV/c² at 10^{-44} cm², 13 events)

observed Signal

expected background

Construct Likelihood function:

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

NR scale measurement

dark matter measurement

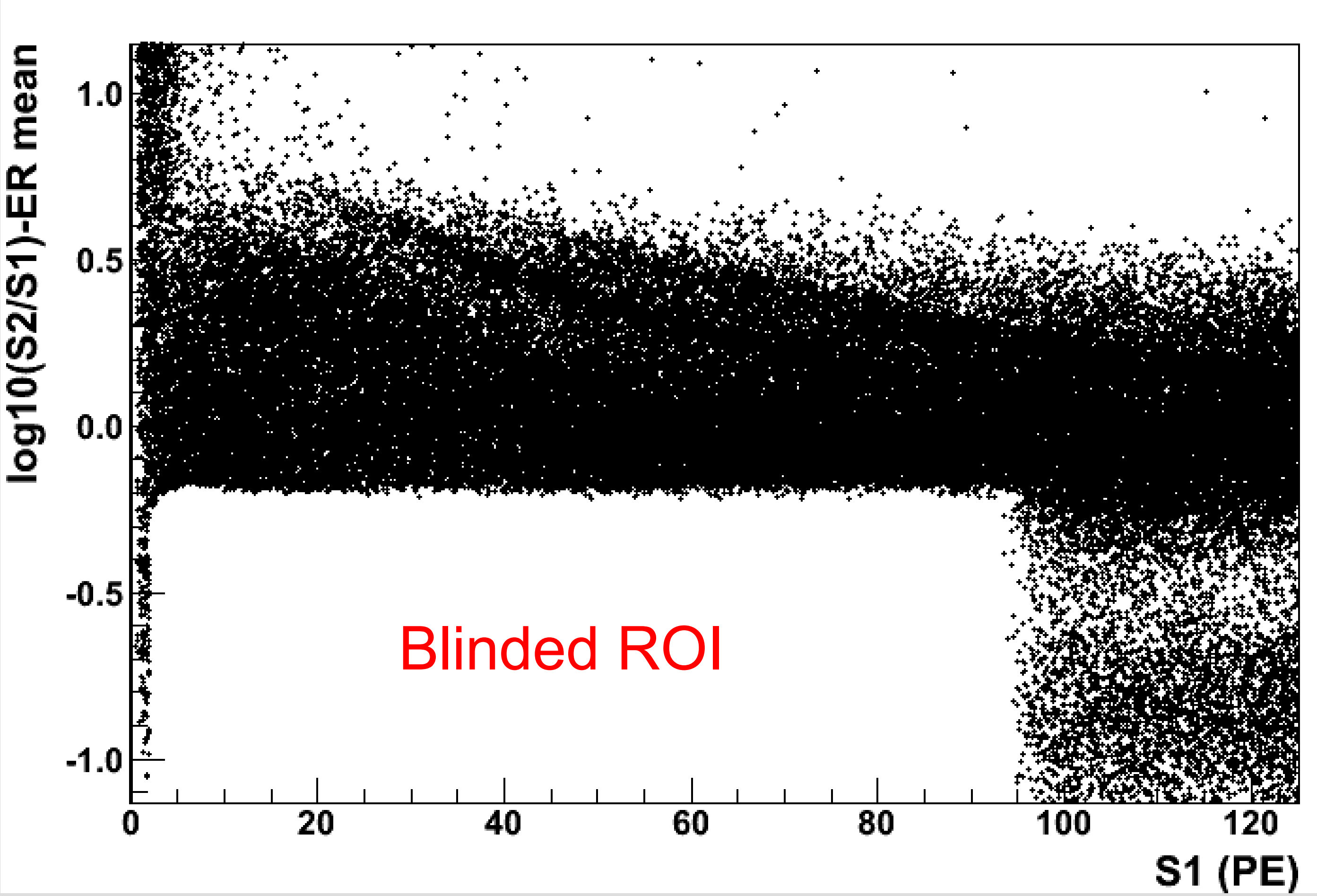
„NR like“ sideband measurement

„ER like“ sideband measurement

need good understanding of background („background model“)

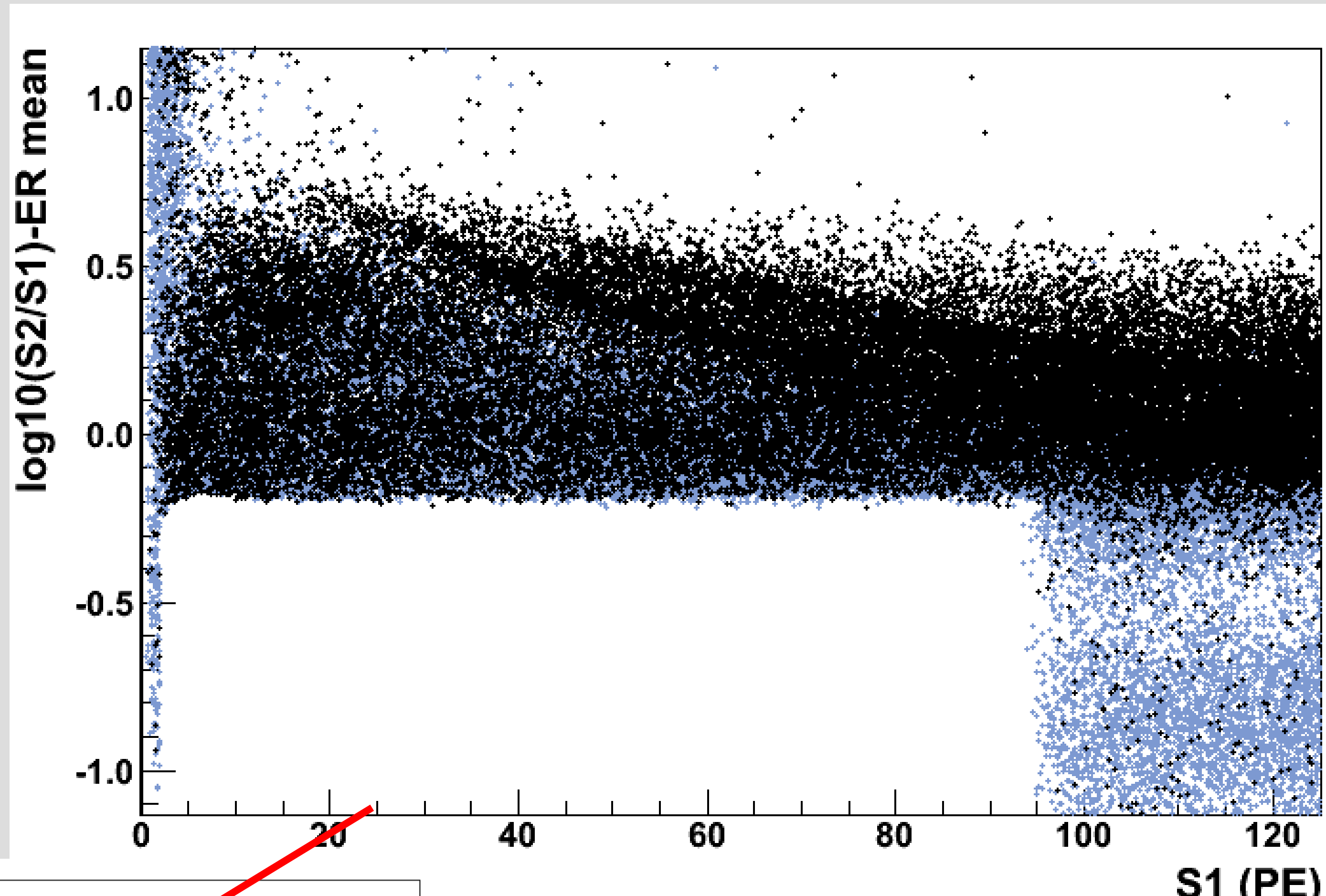
➞ but this is required by any low background experiment
(regardless of the type of analysis)

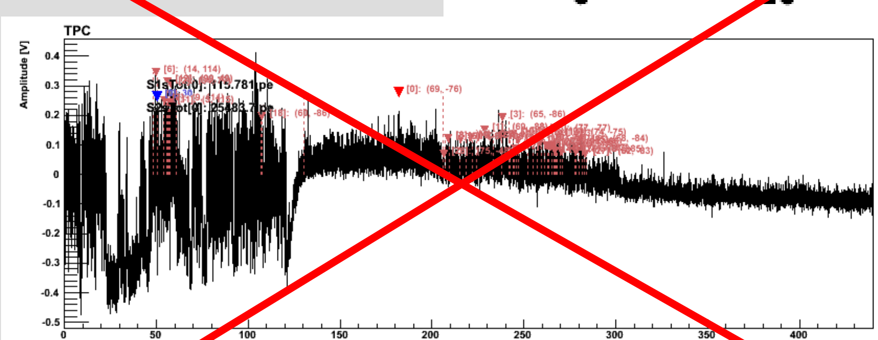
Data Analysis: All data



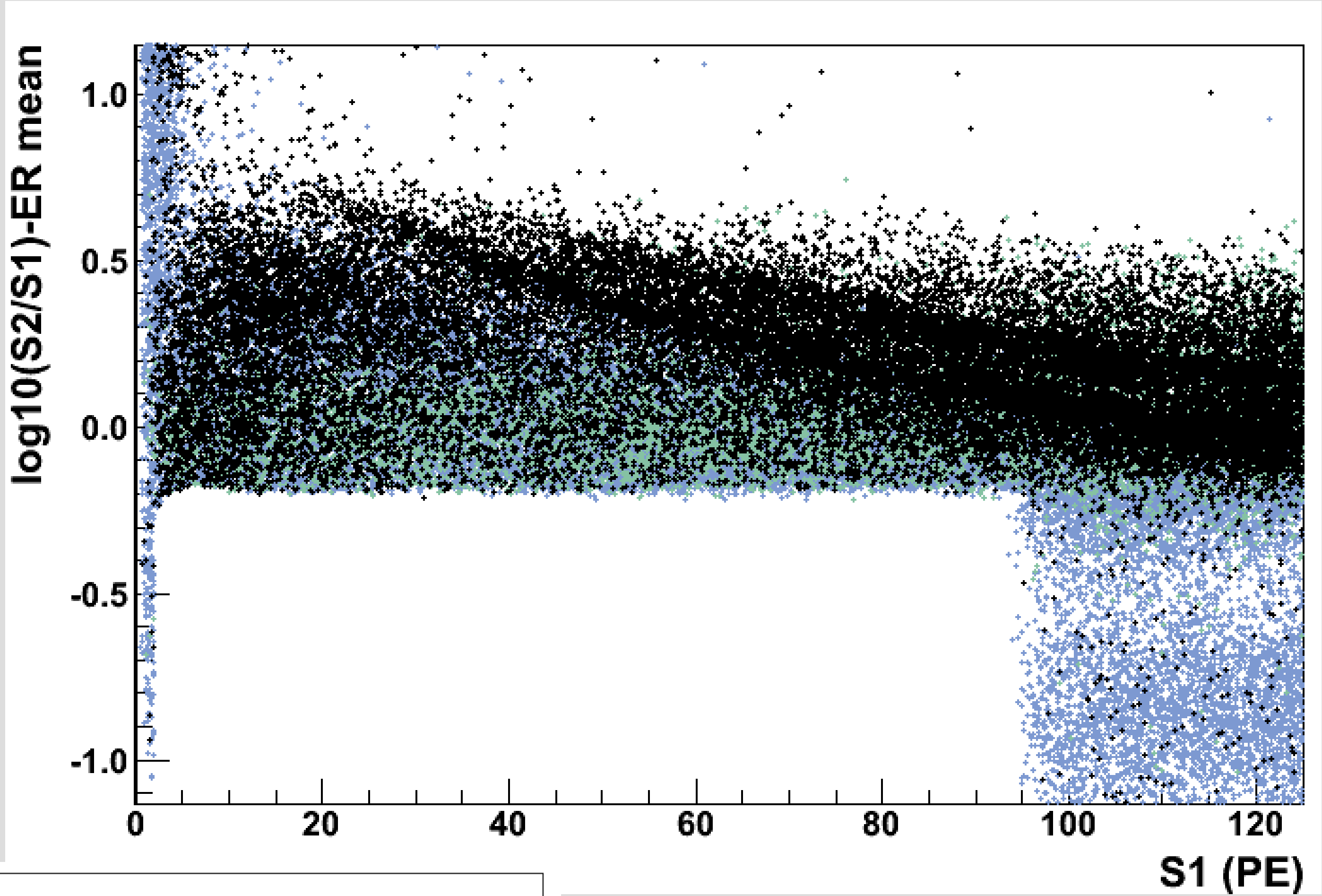
More information on XENON100 data analysis in arXiv:1207.3458

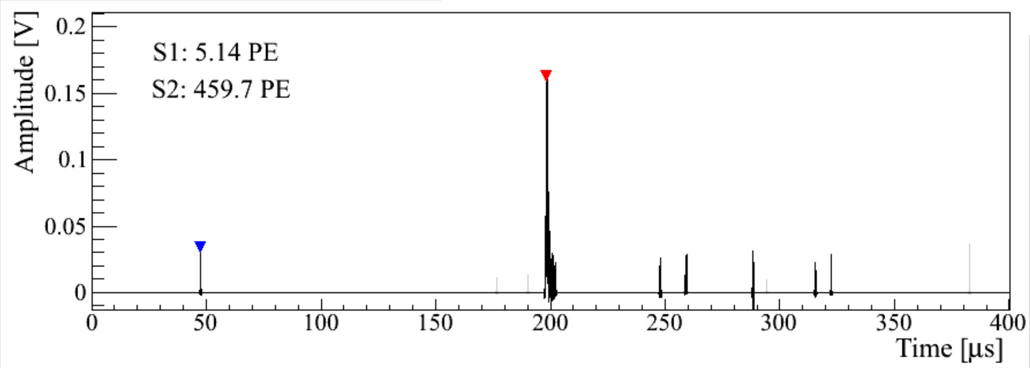
Basic Quality Cuts



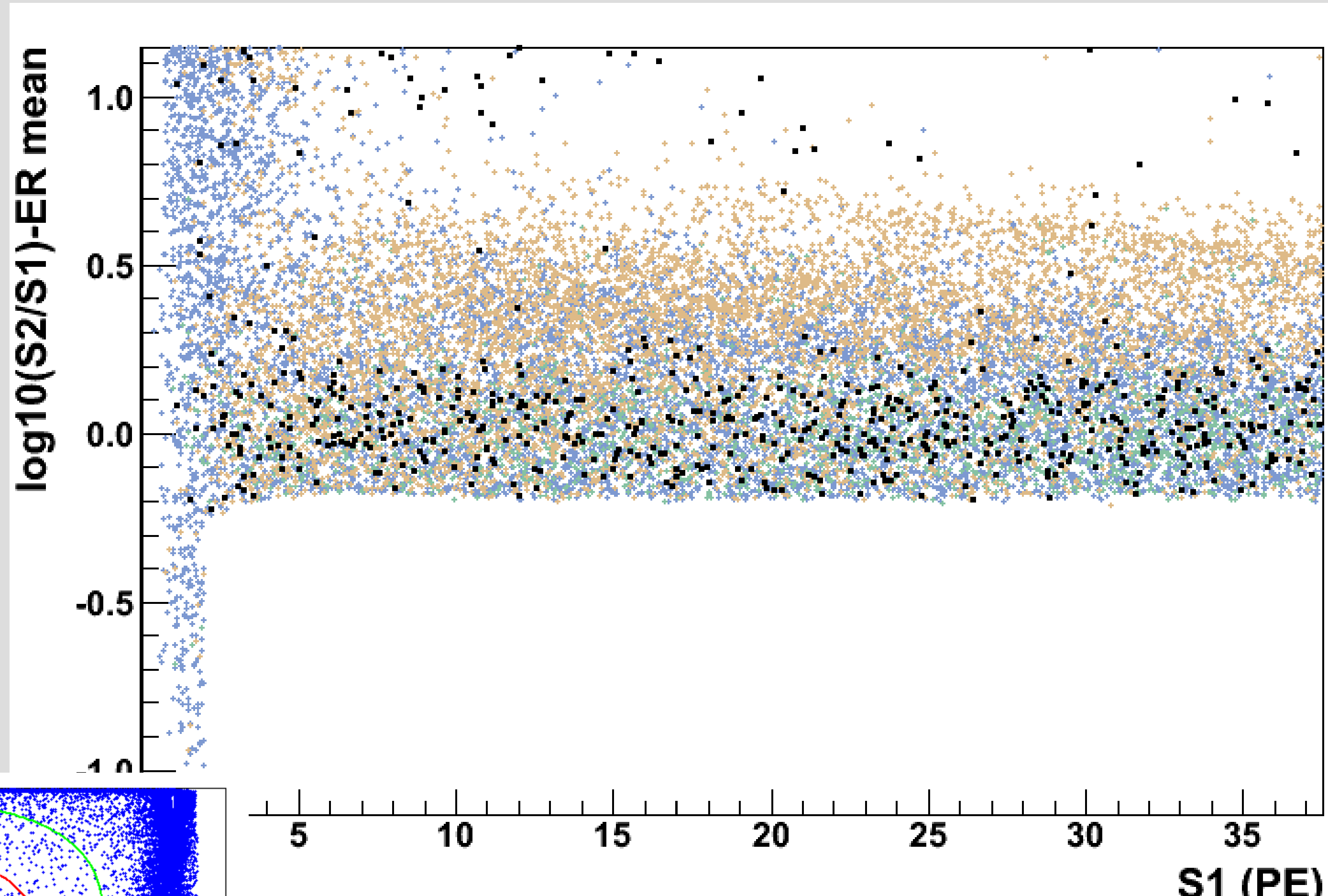


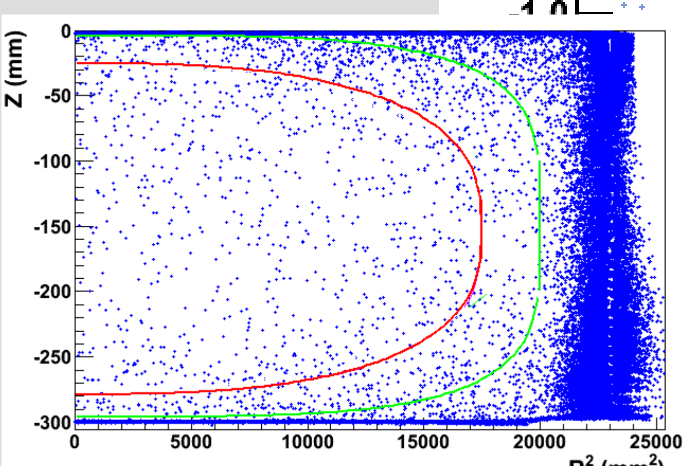
Single Scatter Selection





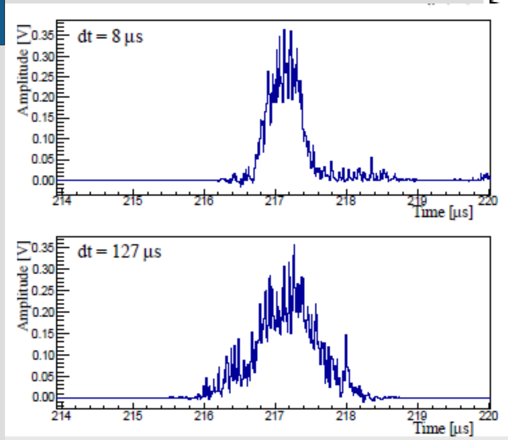
Threshold and Fiducial Volume

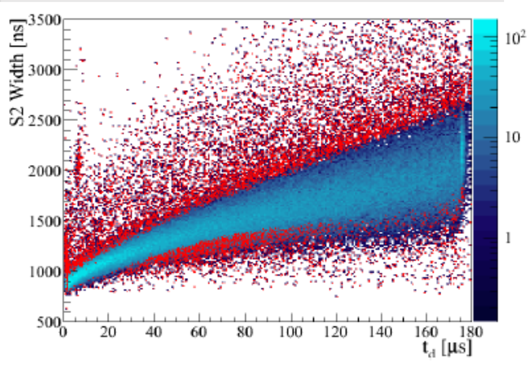


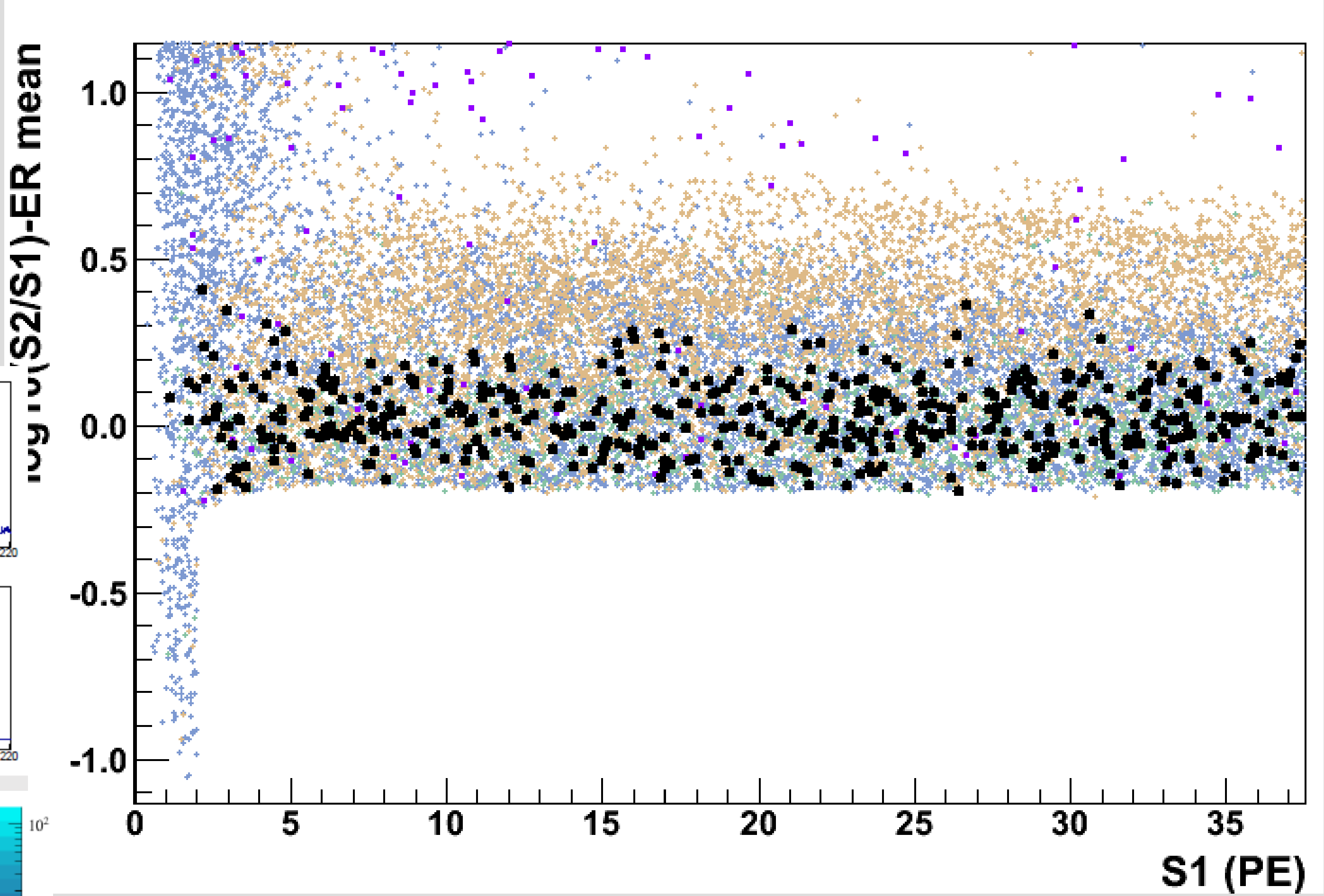


Consistency Cuts

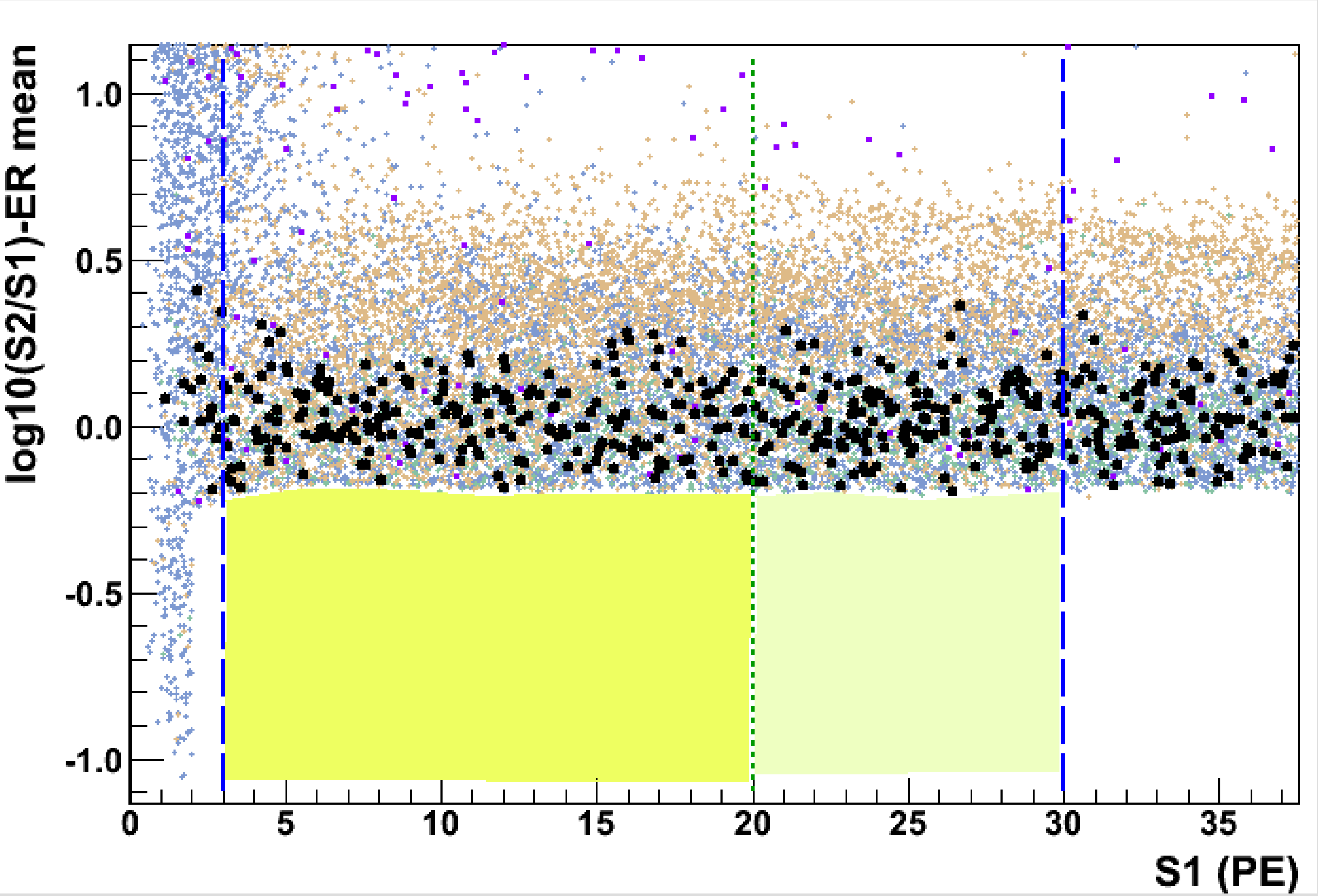
S2 Width:



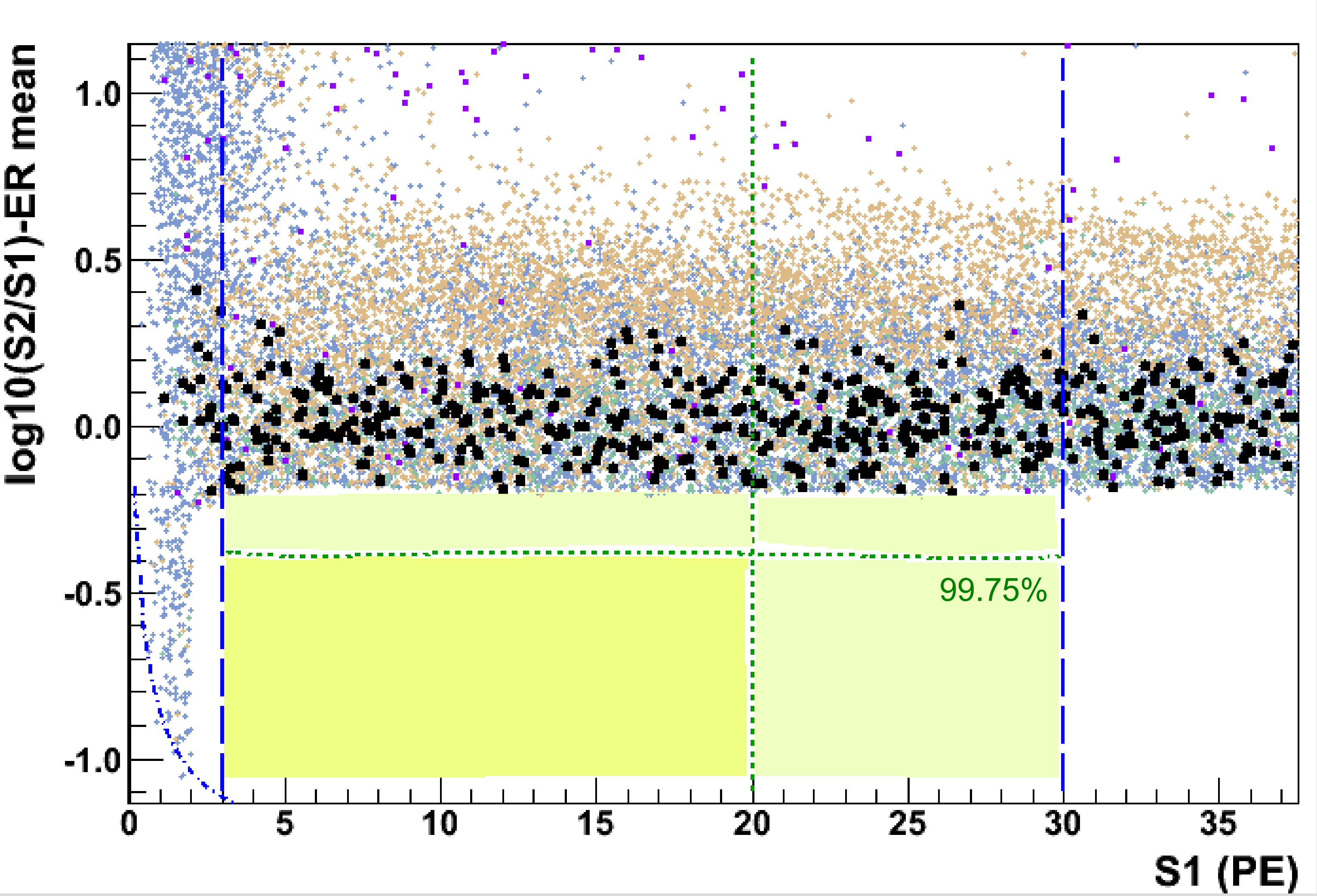




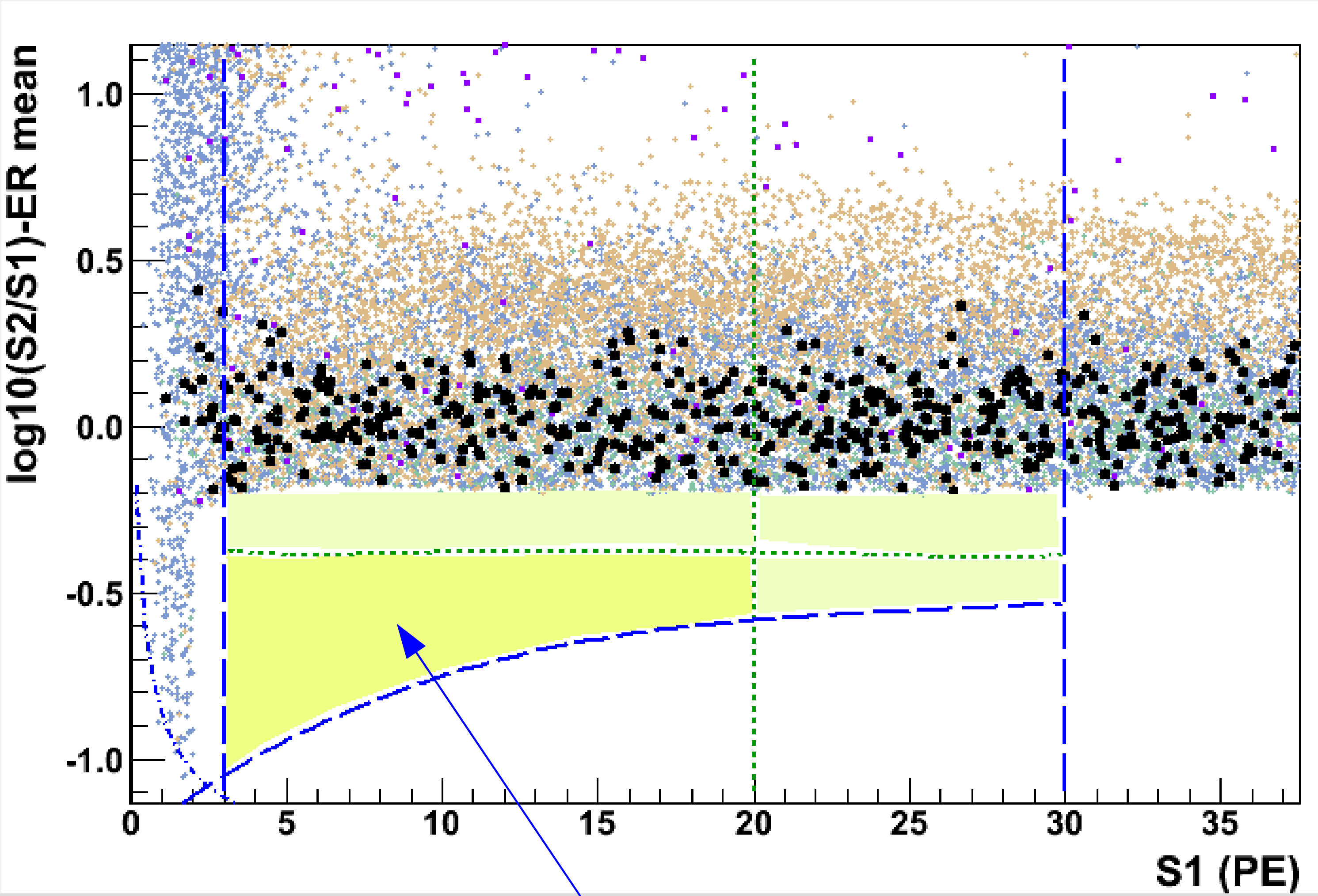
Select Energy Range



ER Rejection



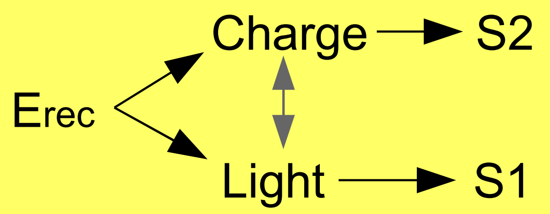
WIMPs are Nuclear Recoil-like

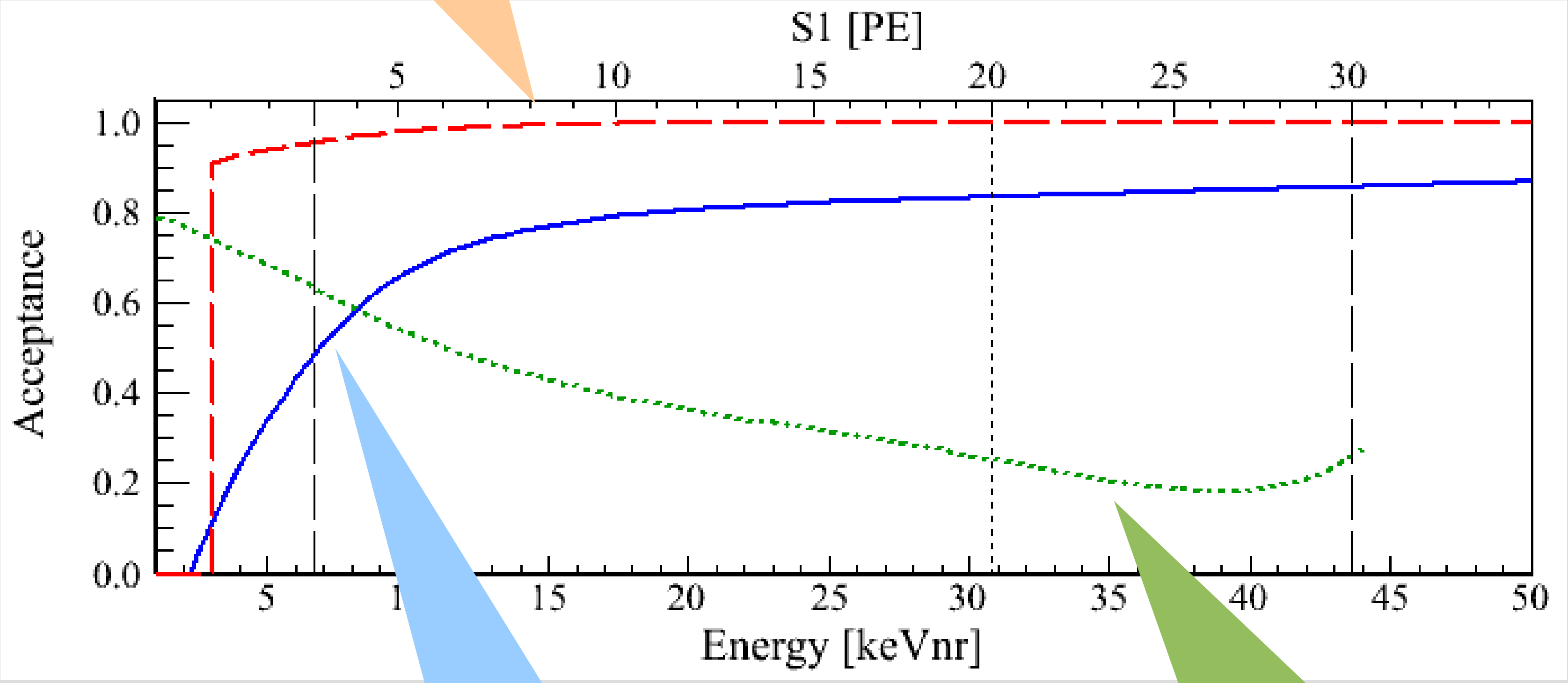


„Benchmark Region“

Cuts and Acceptance

S2 Threshold acceptance
(to be applied before S1 smearing)





details: *arXiv:1207.3458*

Cuts Acceptance

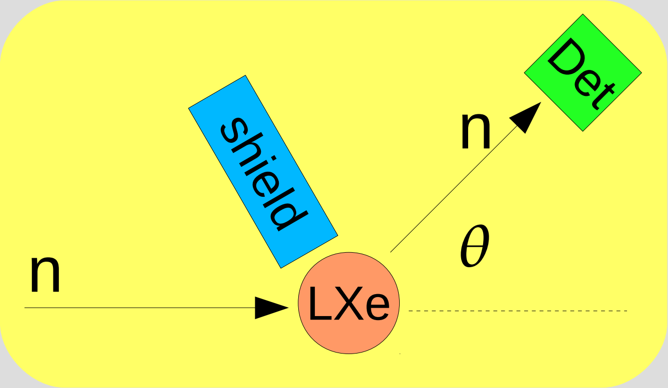
NR acceptance
(benchmark region only)

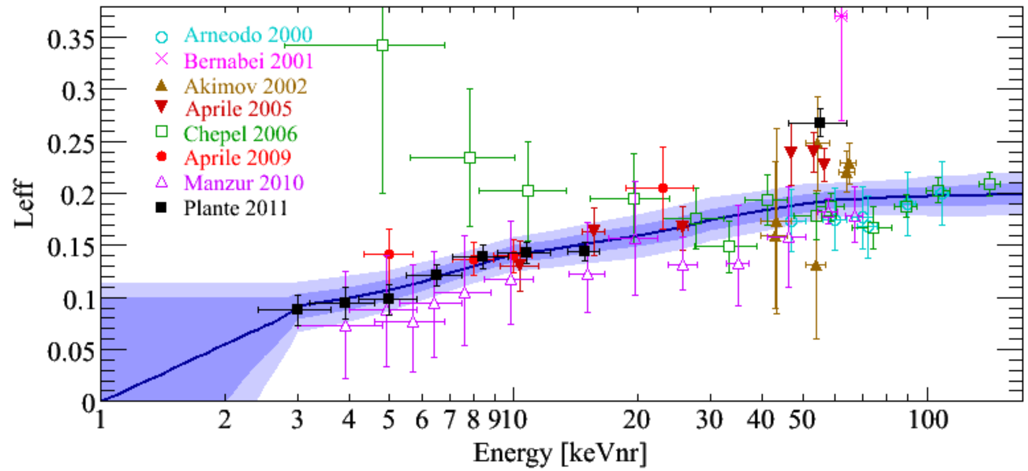
Nuclear Recoil Energy Scale

- WIMPs interact with Xe nucleus
  ➞ nuclear recoil (*nr*) scintillation (β and γ's produce electronic recoils)
- absolute measurement of *nr* scintillation yield is difficult
  ➞ measure relative to ^{57}Co (122keV)
- relative scintillation efficiency *L*eff:

$$\mathcal{L}_{\mathrm{eff}}(E_{\mathrm{nr}}) = \frac{\mathrm{LY}(E_{\mathrm{nr}})}{\mathrm{LY}(E_{\mathrm{ee}} = 122\ \mathrm{keV})}$$

measurement principle:





most recent measurements:
■ *Plante et al., PRC 84, 045805 (2011)*
△ *Manzur et al., PRC 81, 025808 (2010)*

for discussion of possible systematic errors see *A. Manalaysay, arXiv:1007.3746*

Background Prediction

Neutron background:
- (α,n)+sf and muon induced neutrons
- MC simulation using the exact XENON100 geometry and measured contaminations

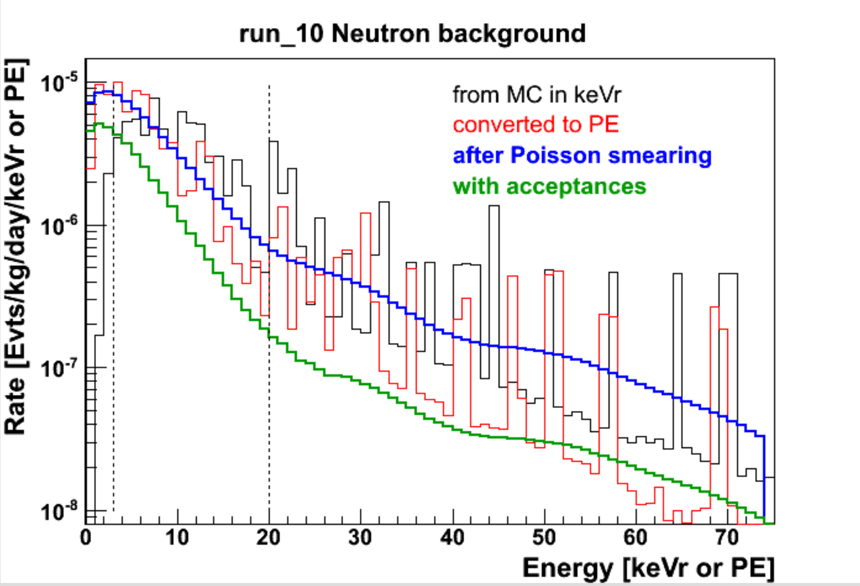
Expect: (0.17 +0.12 –0.07) events

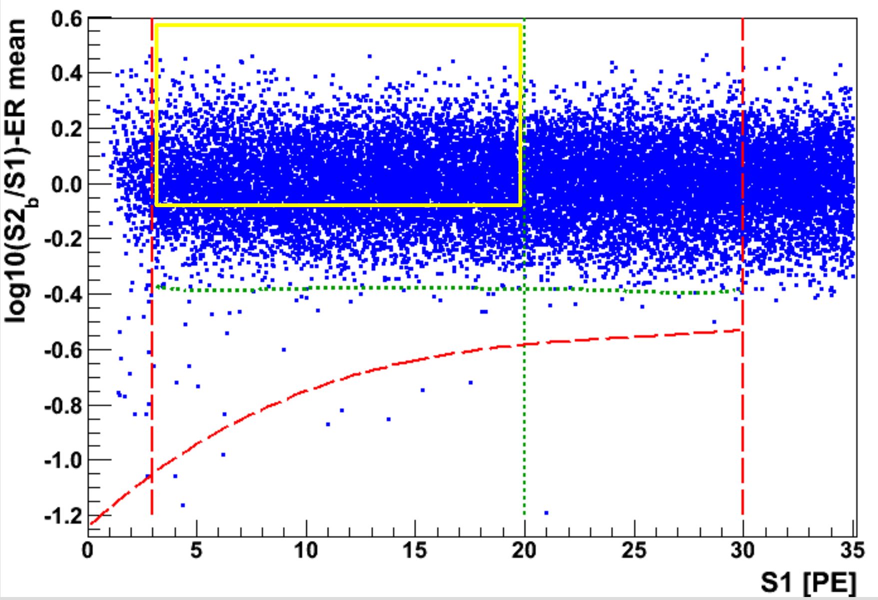
ER background:
- γ activity of the detector and shield
- intrinsic radioactivity in the LXe (→ considerably lowered this run)
- use ER calibration to model background by scaling it to the observable DM data

Expect: (0.79 +-0.16) events

Sum: (1.0 +- 0.2) events

The same background model is implemented in the PL analysis

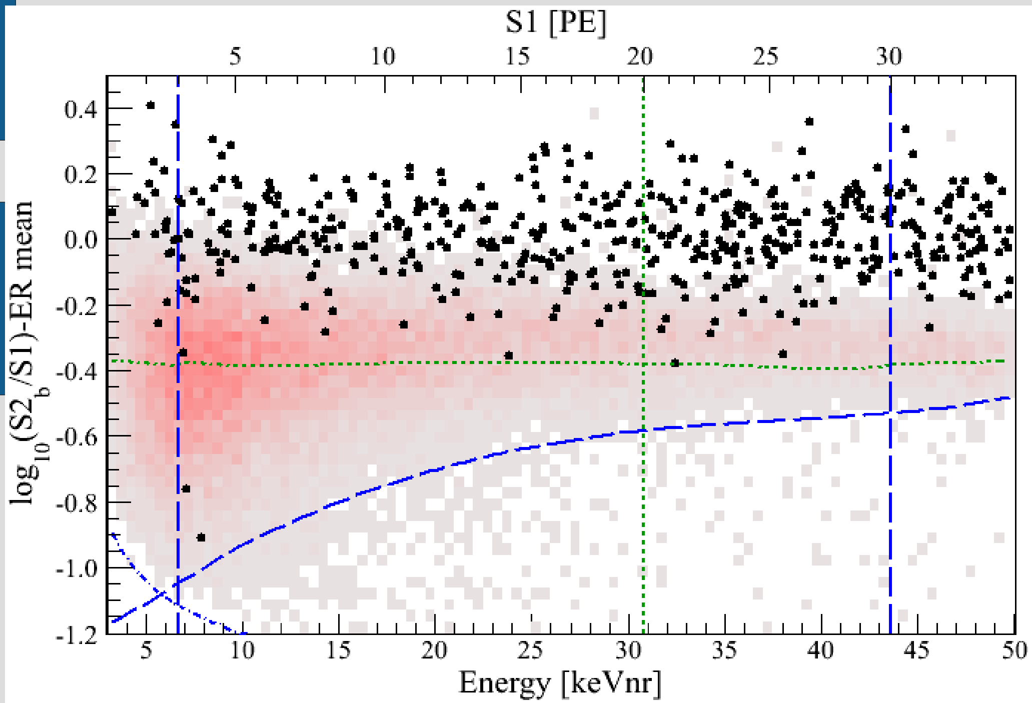


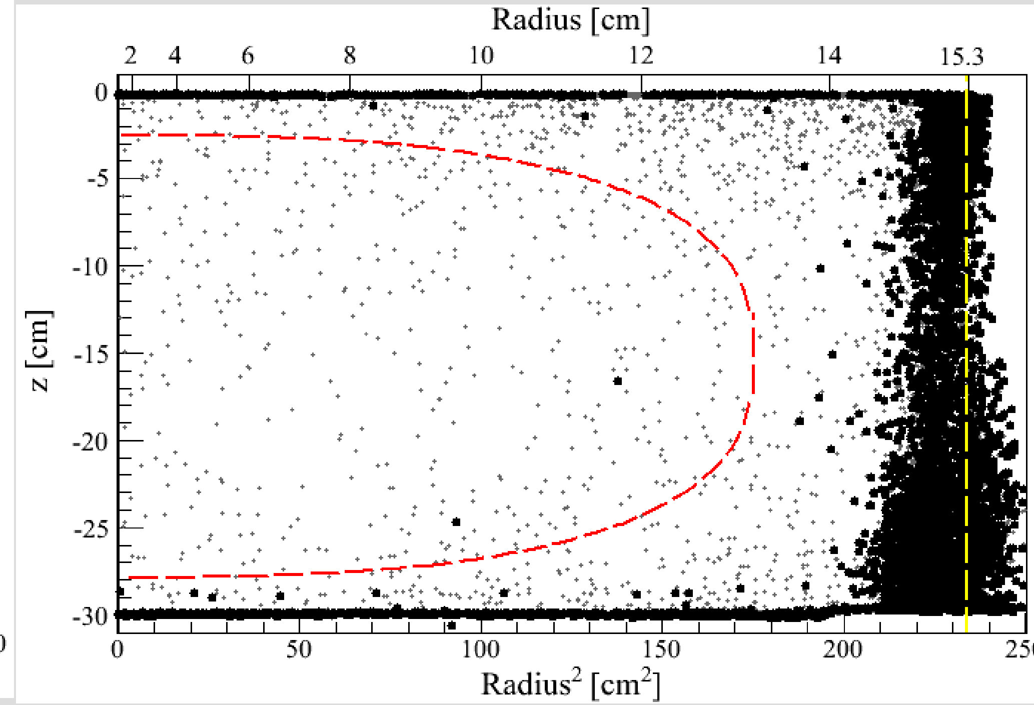


During ...

… and after ...

… Unblinding





(1.0 ± 0.2) events expected

2 events observed

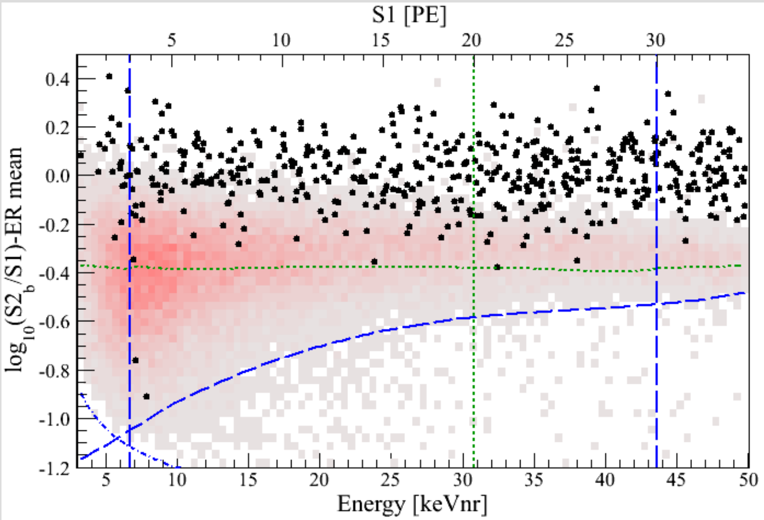
→ 26.4% probability that background fluctuated to 2 events

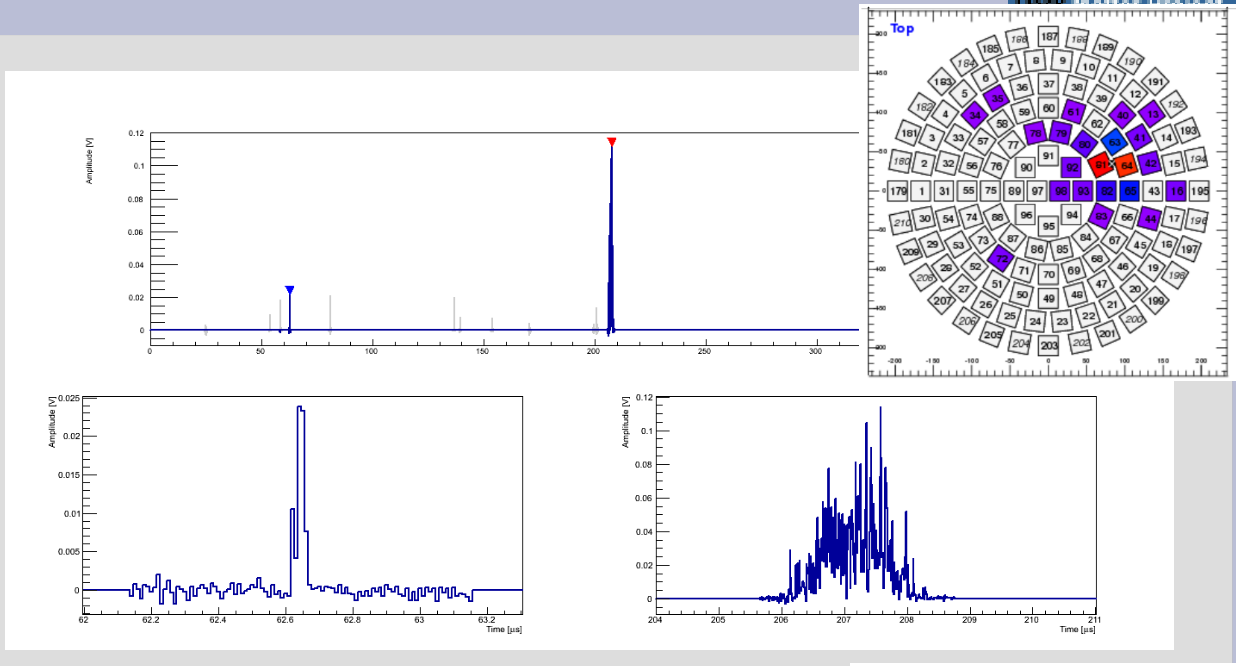
→ PL analysis cannot reject the background only hypothesis

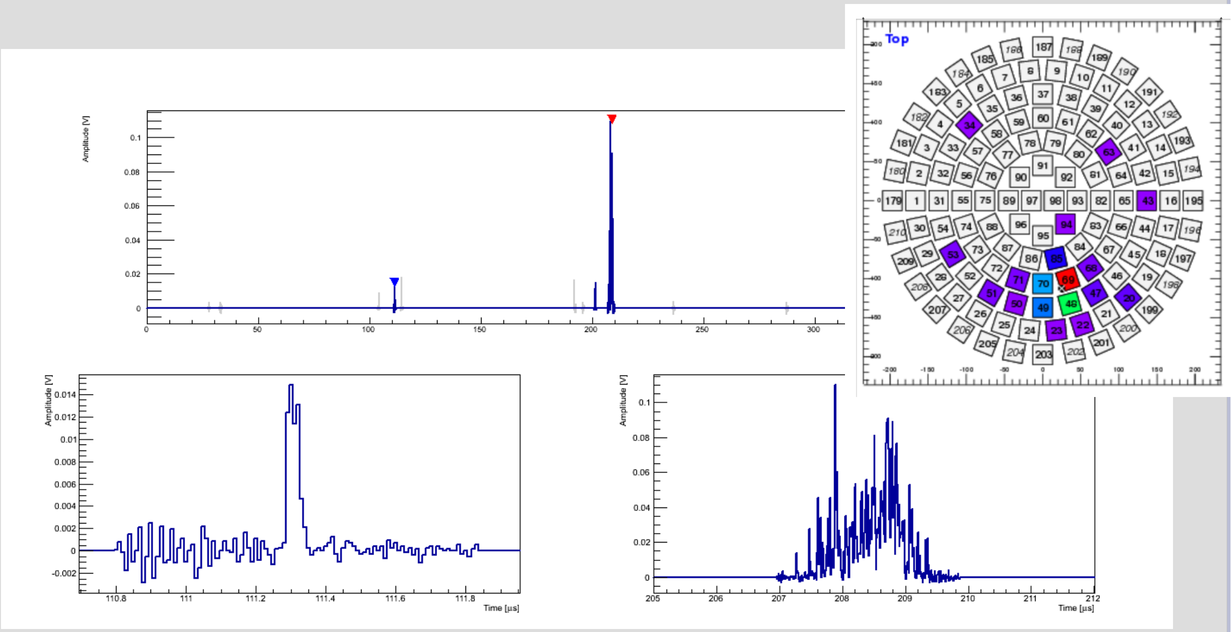
No significant excess due to a signal seen in XENON100 data.

Events in Benchmark Region

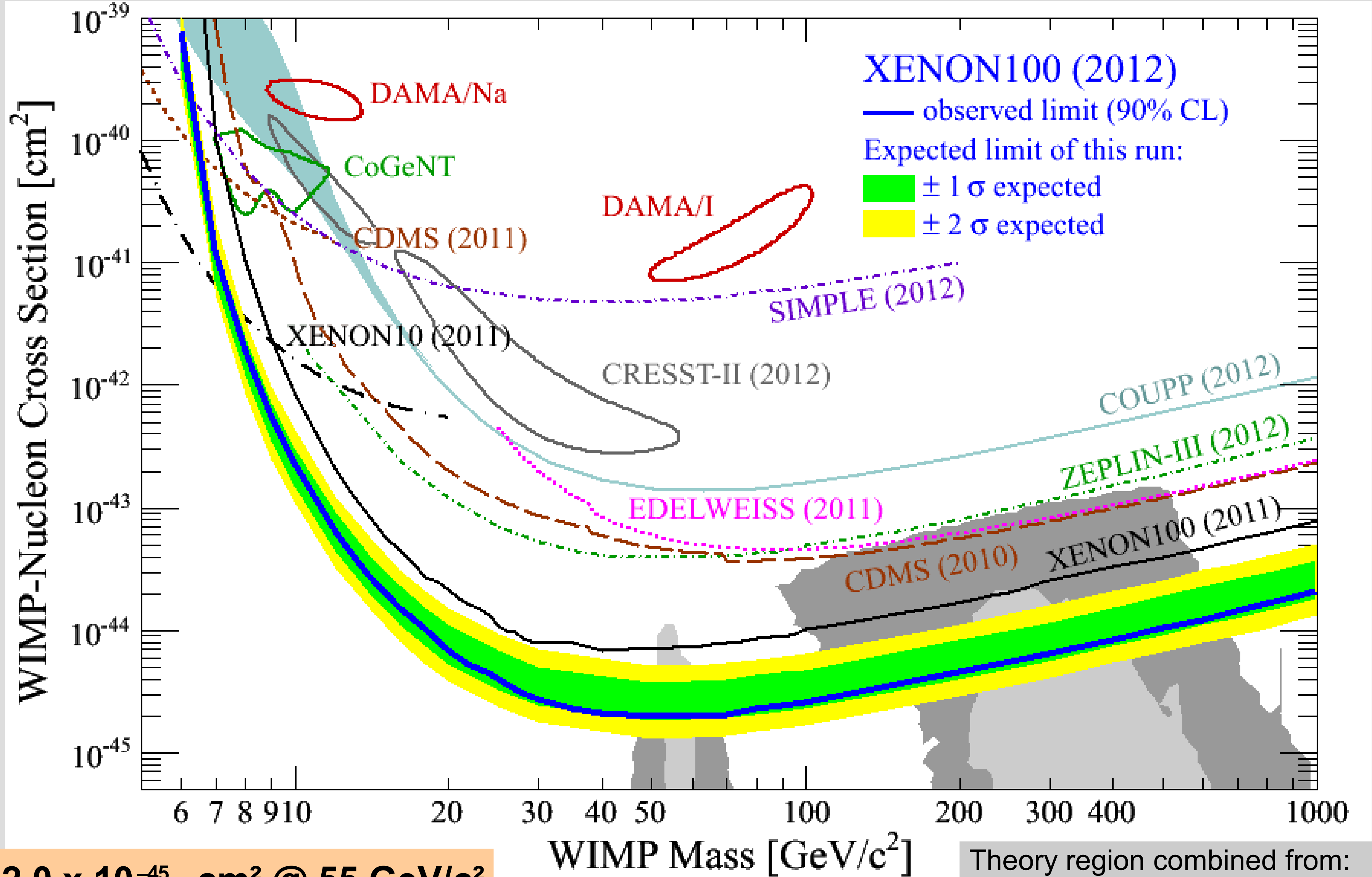
- visual inspection:
  valid waveforms
- at 7.1 keVr and 7.8 keVr
  both events between
  3 and 4 PE
- rather low wrt the
  NR calibration data
- no low S2/S2-events
  below threshold







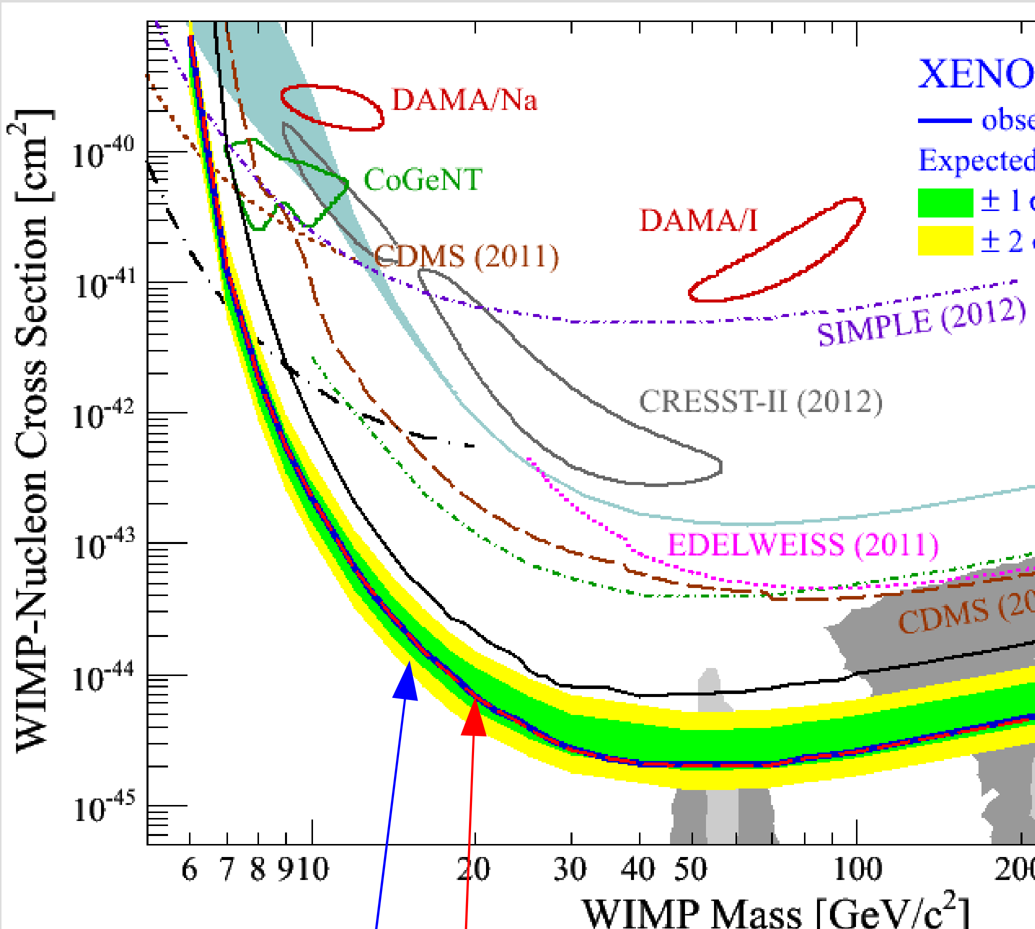
The new XENON100 Limit

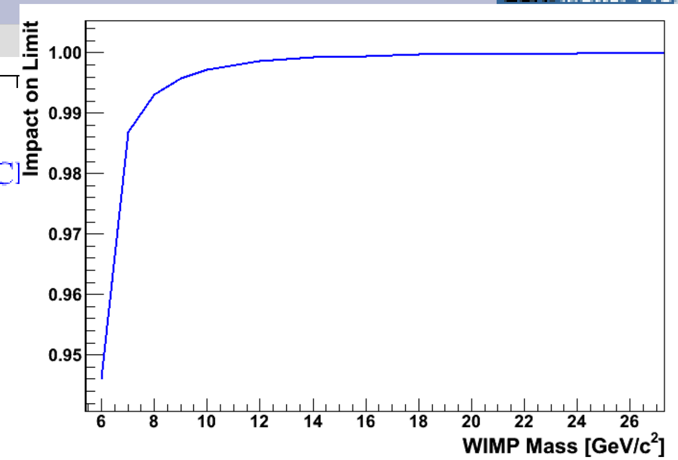


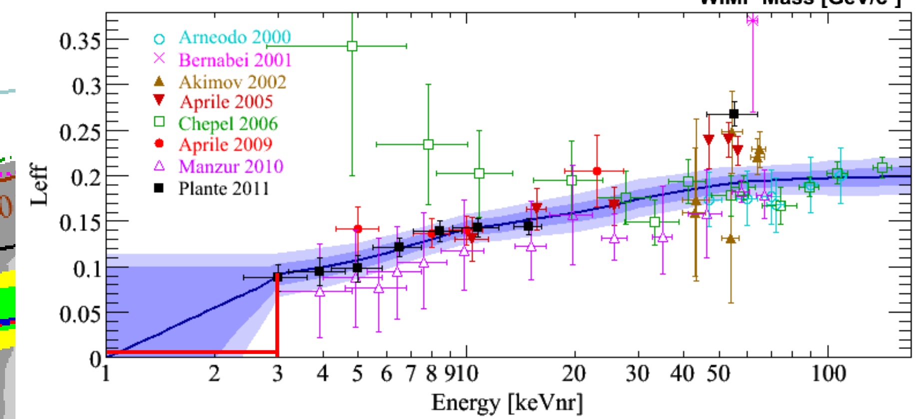
2.0×10^{-45} cm² @ 55 GeV/c²

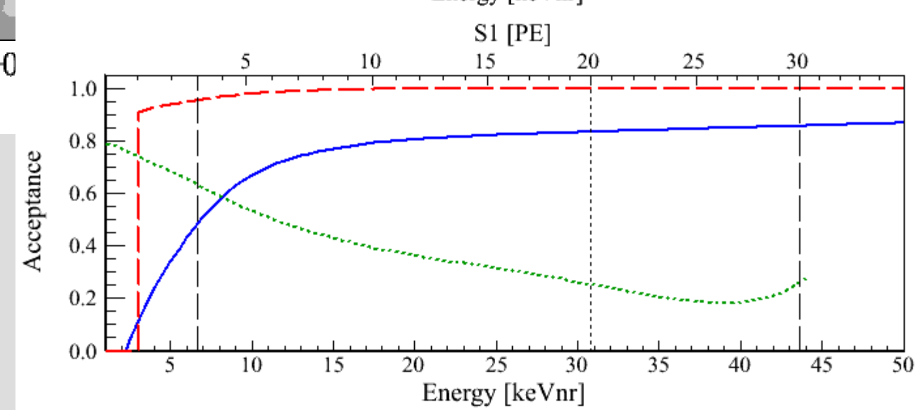
Theory region combined from:
Strege et al., JCAP 1203, 030(2012)
Fowlie et al., arXiv:1206.0264
Buchmueller et al., arXiv:1112.3564

No Impact of Leff below 3 keVr





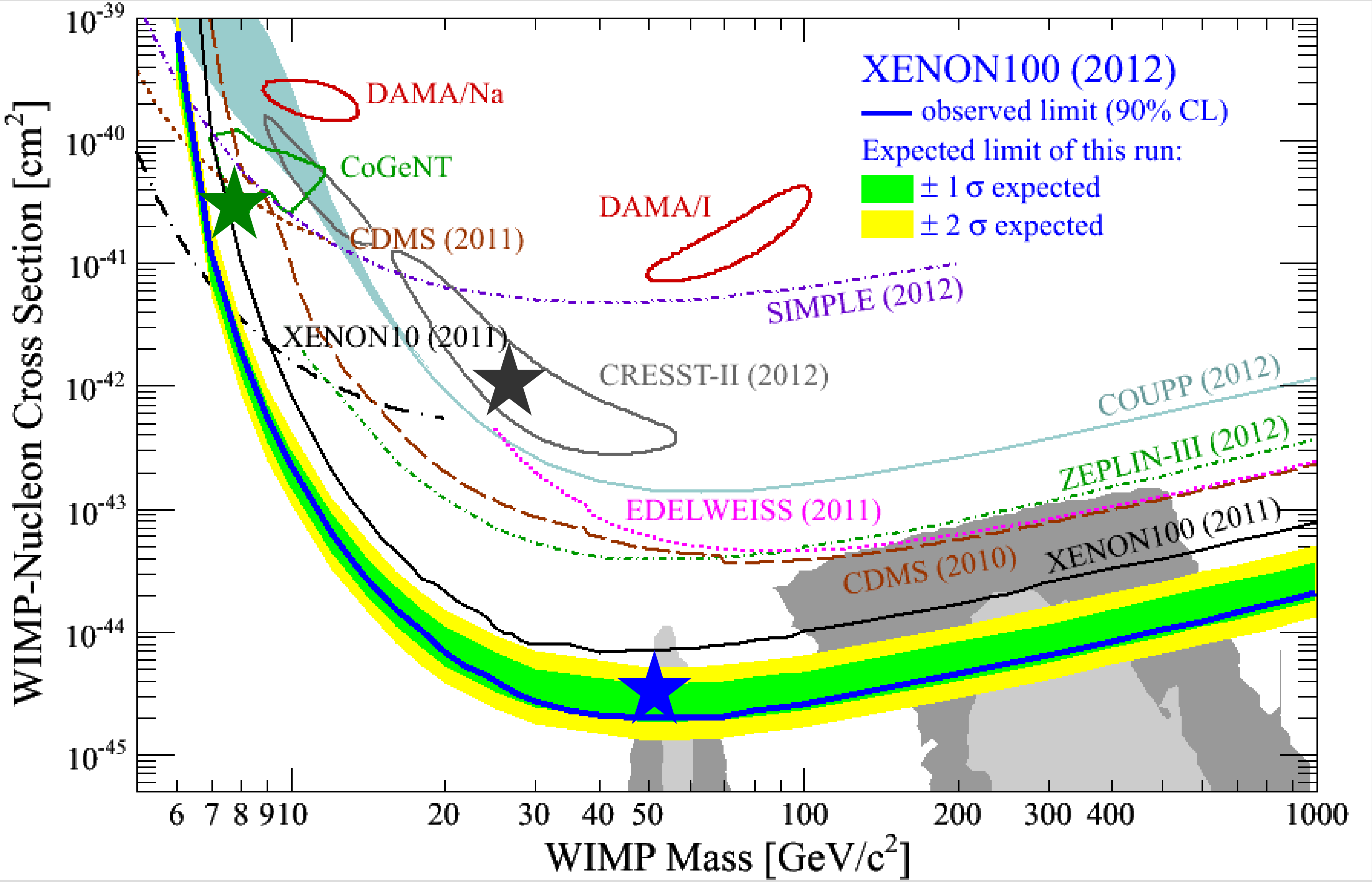




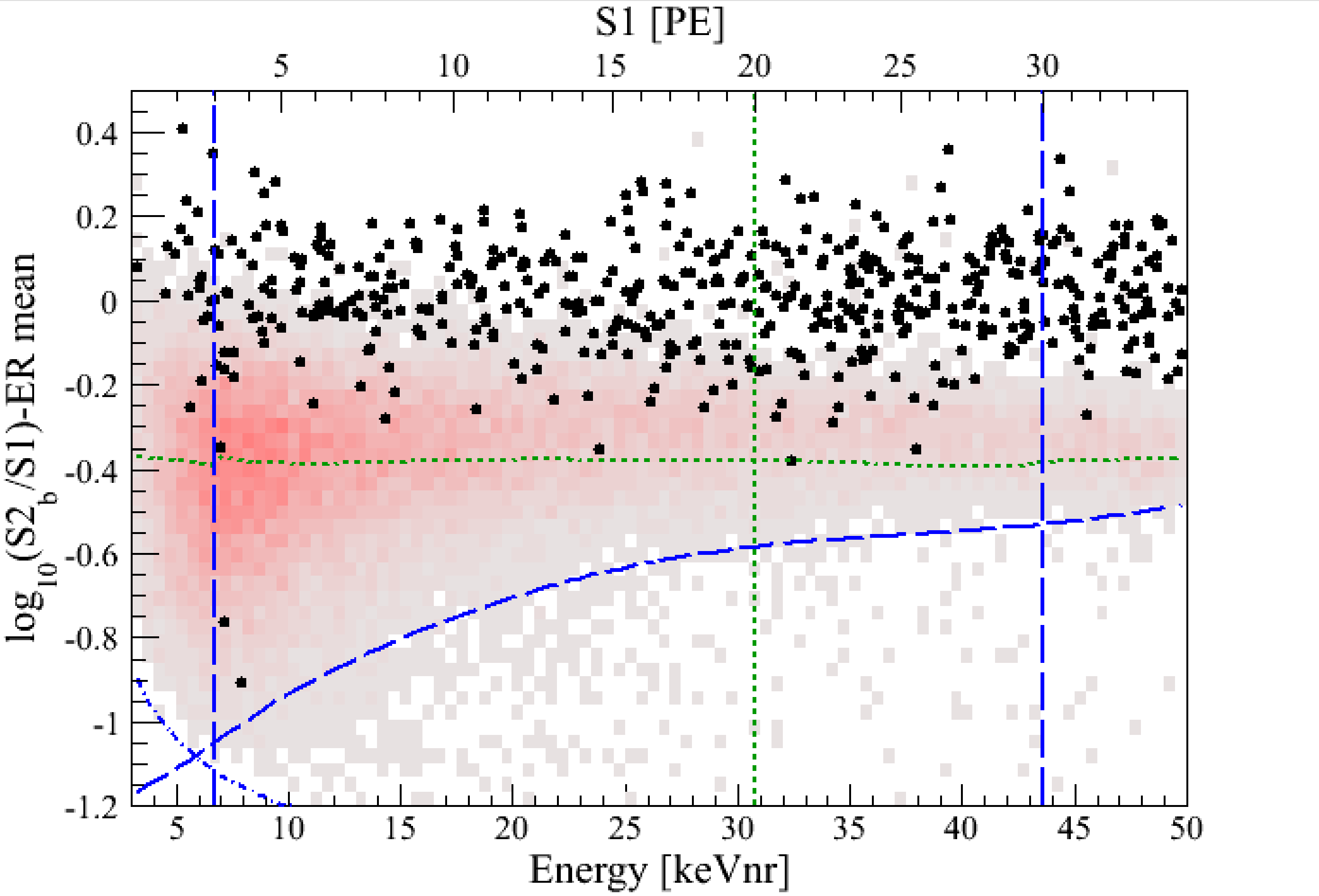
„standard" Leff

Leff=0 below 3 keVnr

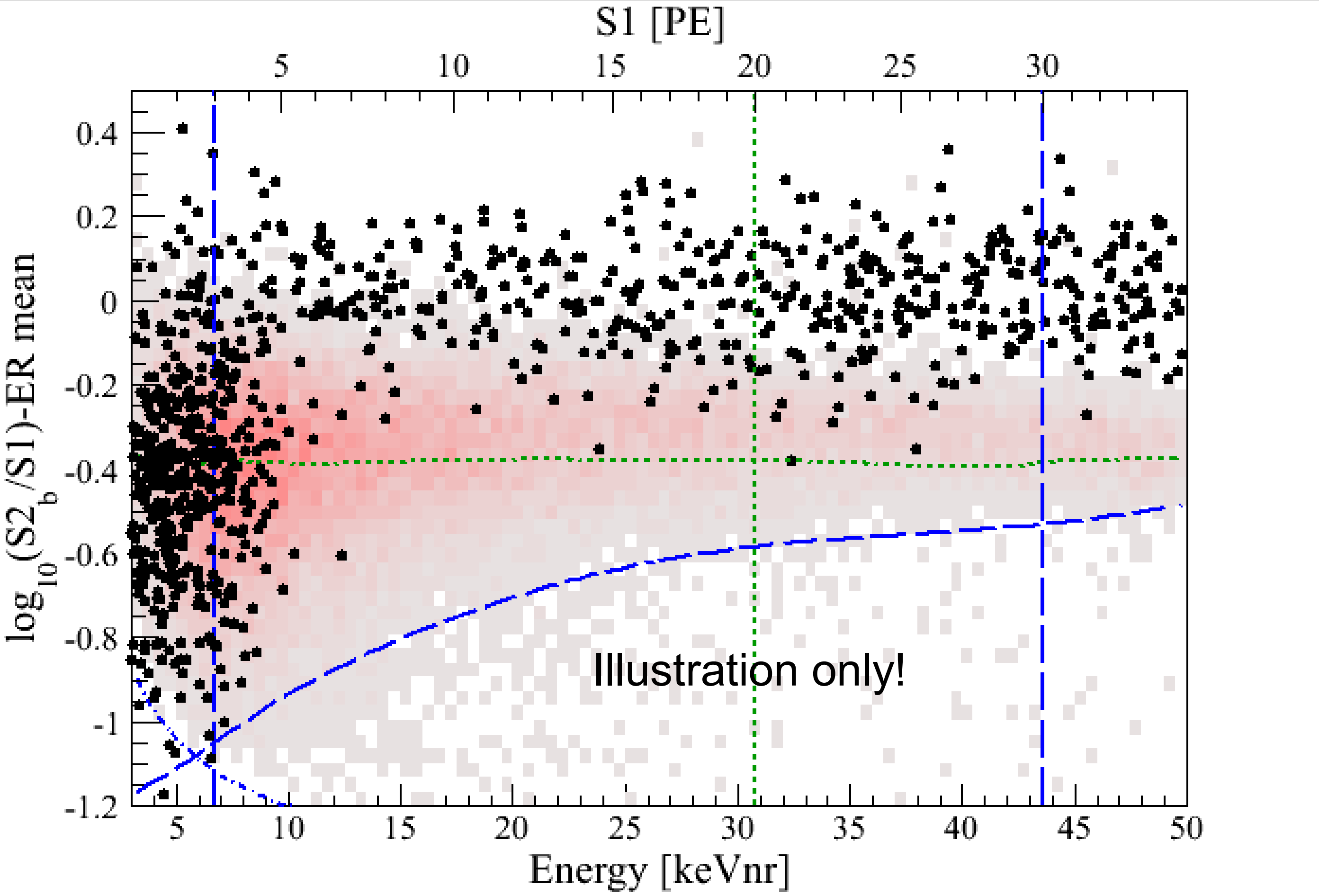
The new XENON100 Limit



What XENON100 sees...

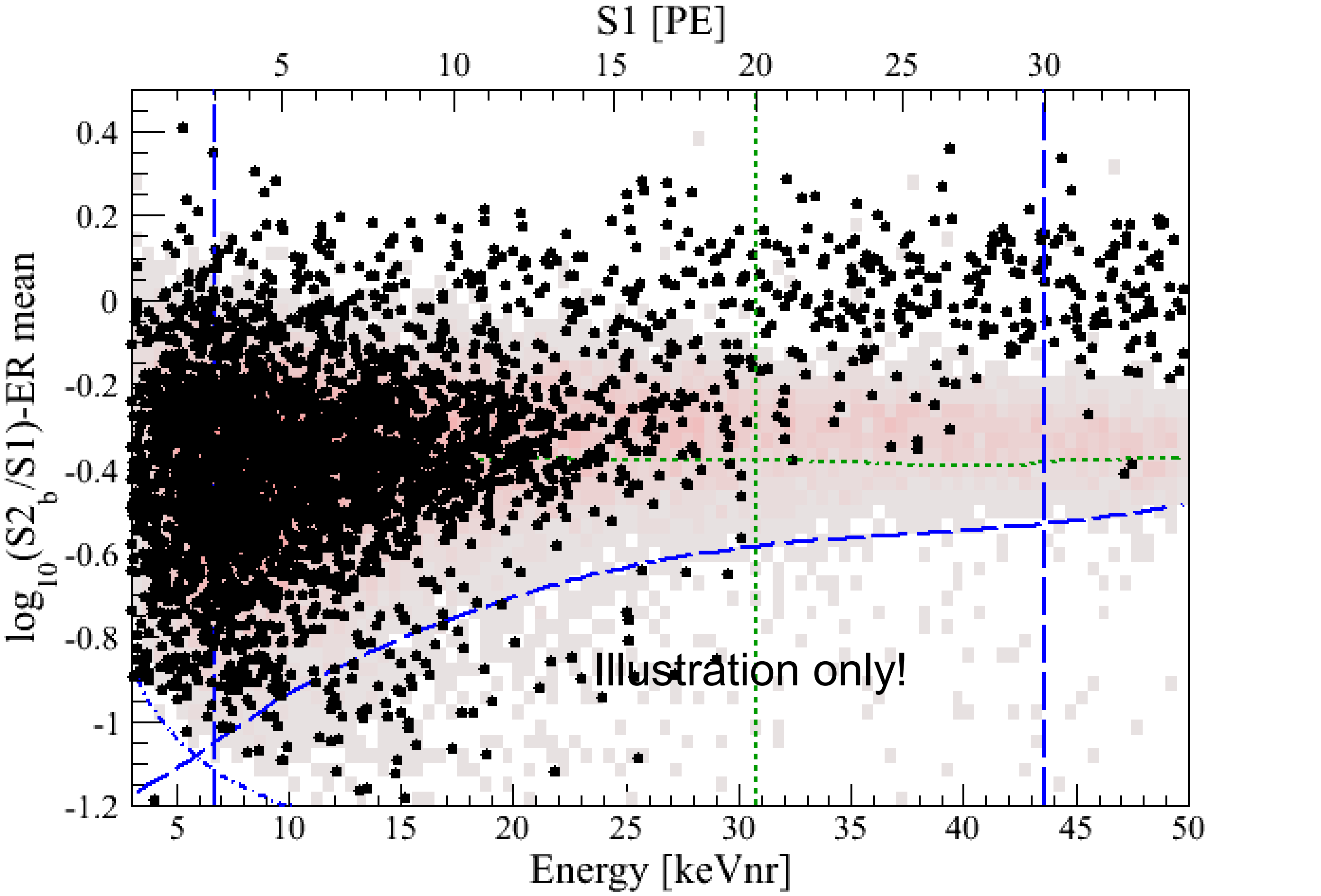


A light mass WIMP...



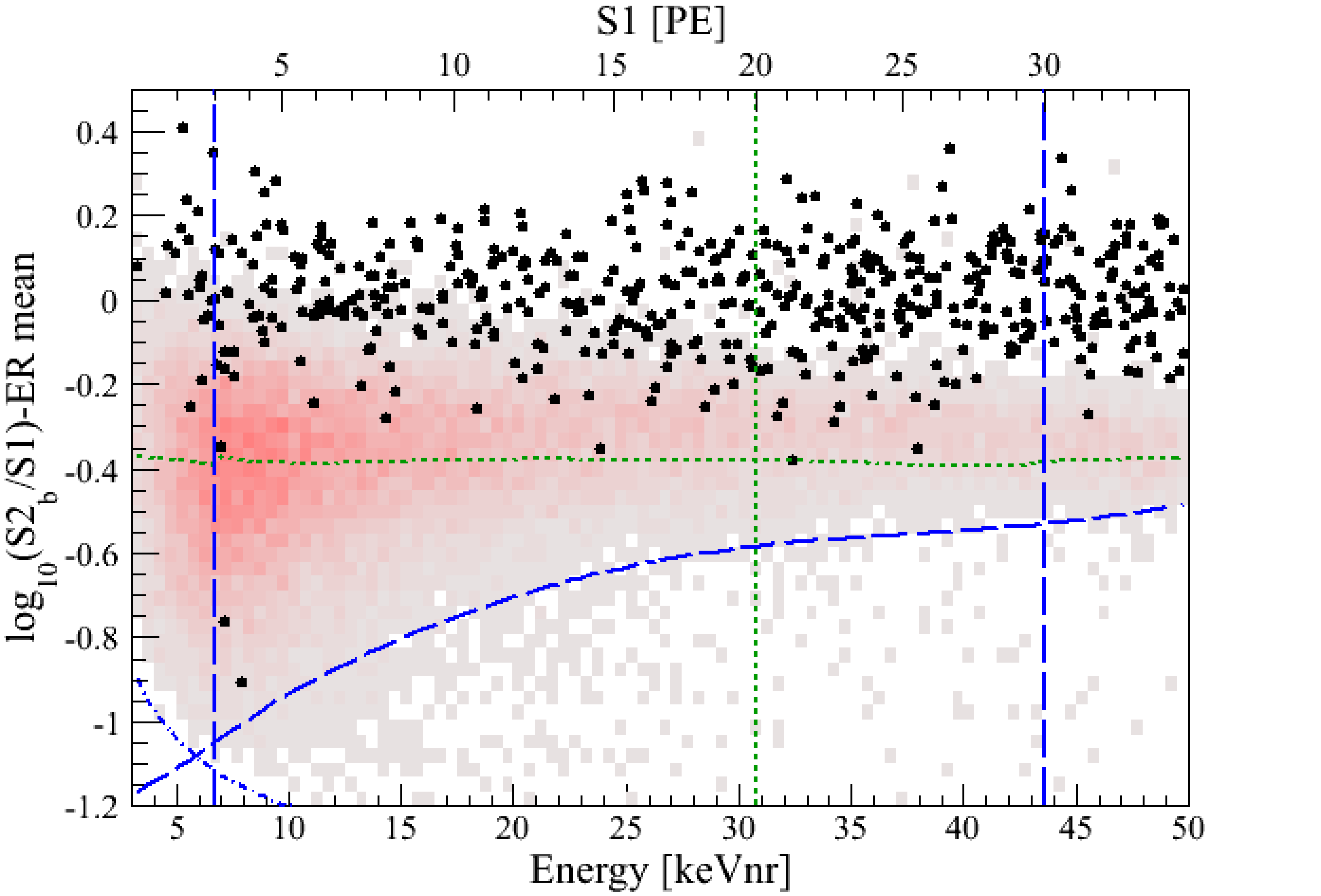
m_χ= 8 GeV/c² σ=1.0x10^{-40} cm²

A CRESST-like signal...

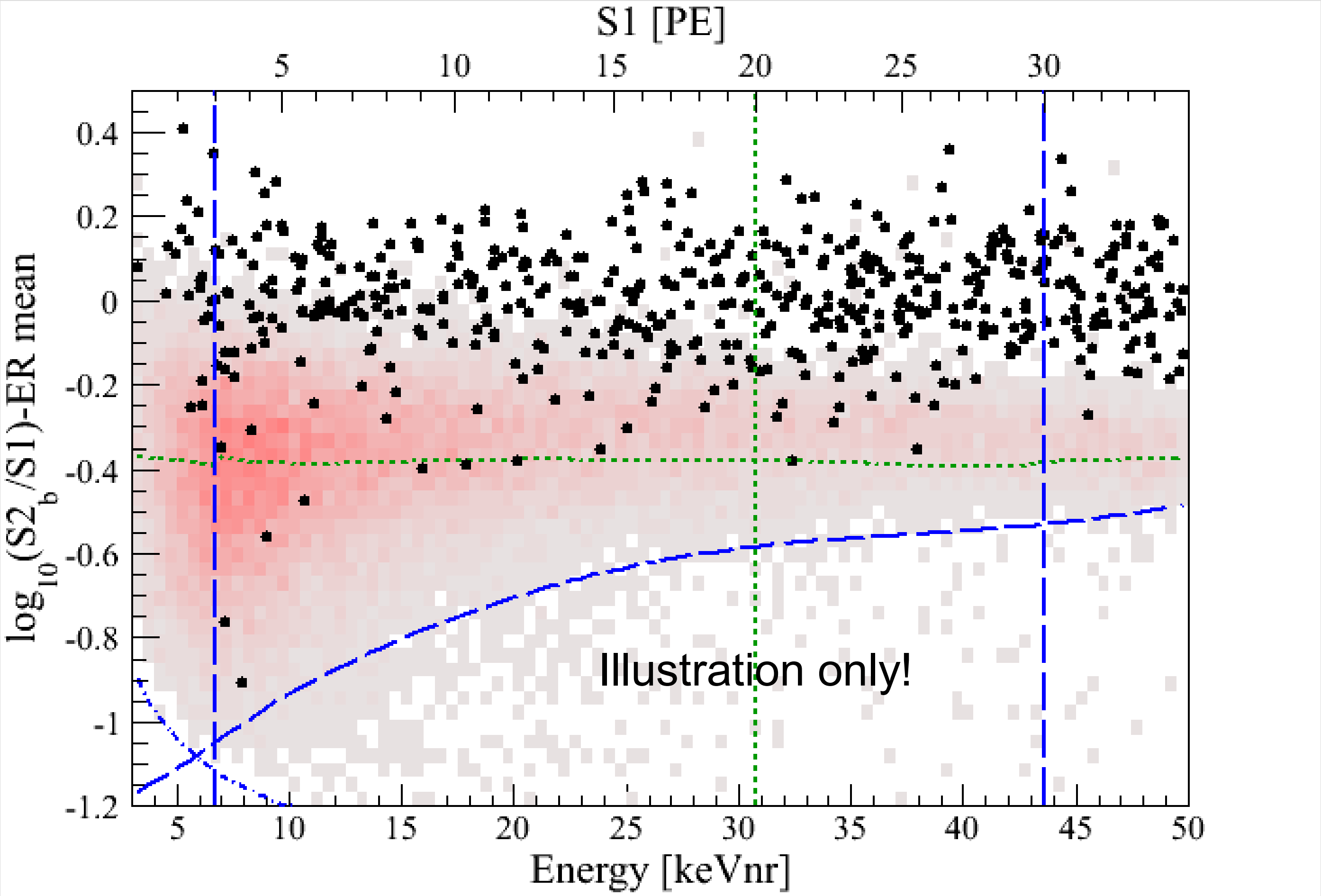


m_χ= 25 GeV/c² σ=1.6 x10^{-40} cm²

What XENON100 sees...

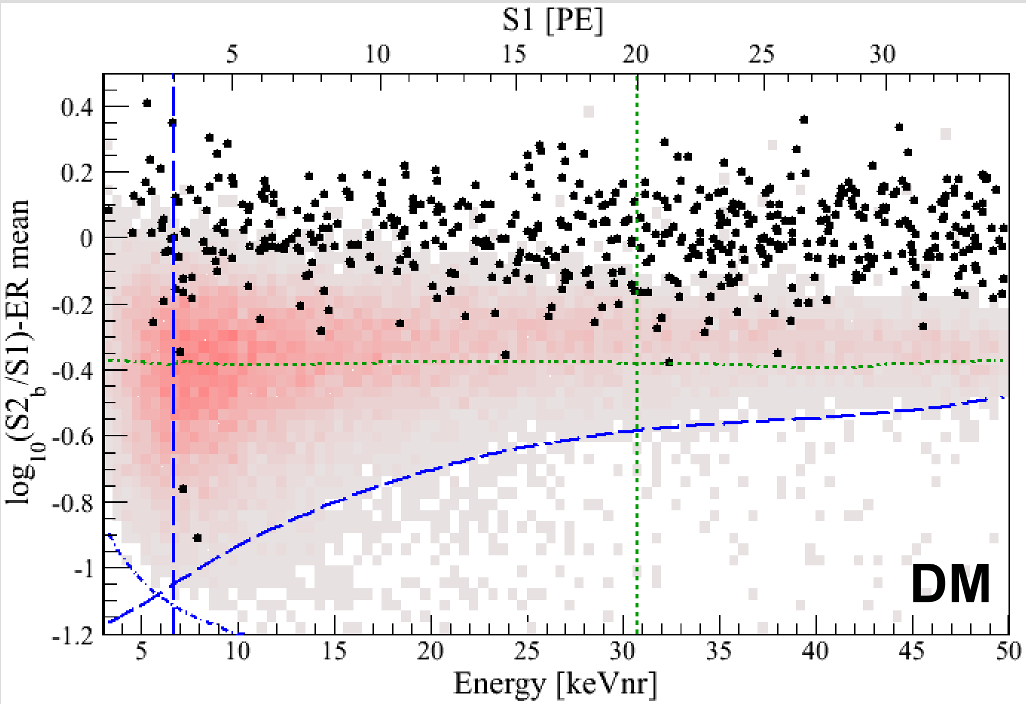


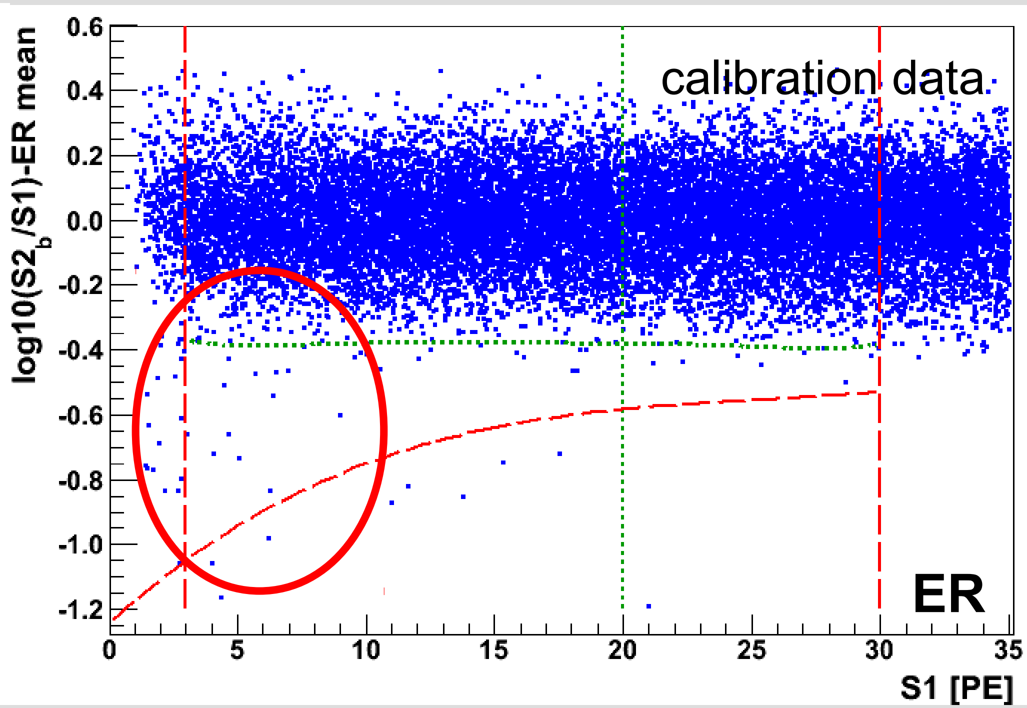
What XENON100 excludes...



m_χ= 50 GeV/c² σ=3.0 x10^{-45} cm²

What could the Events be?



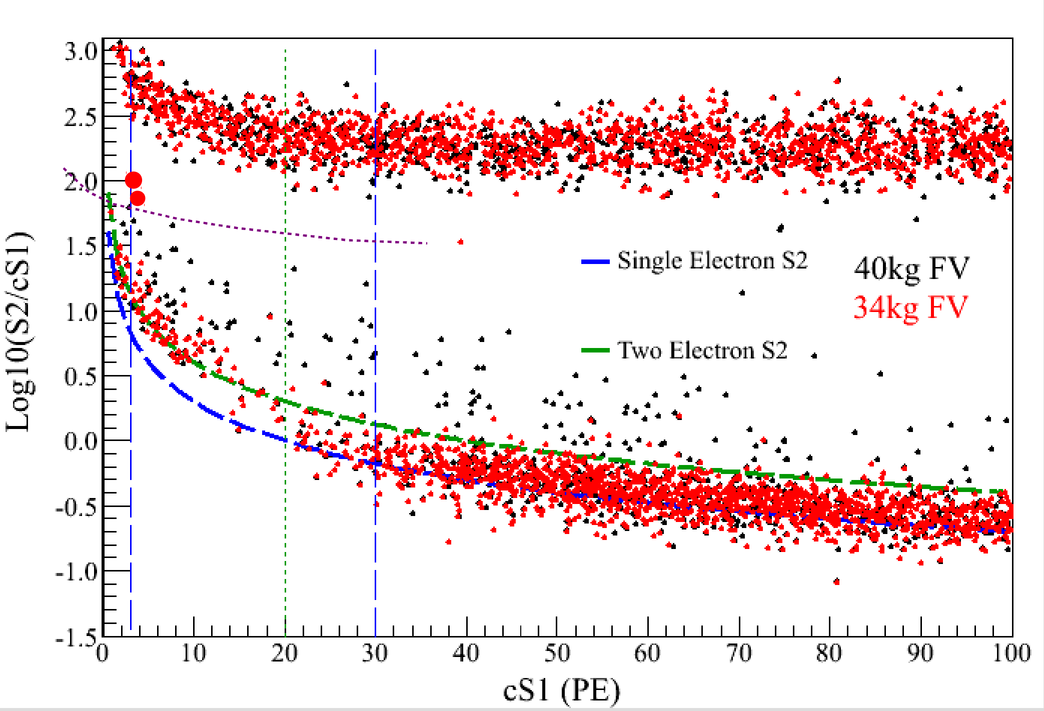


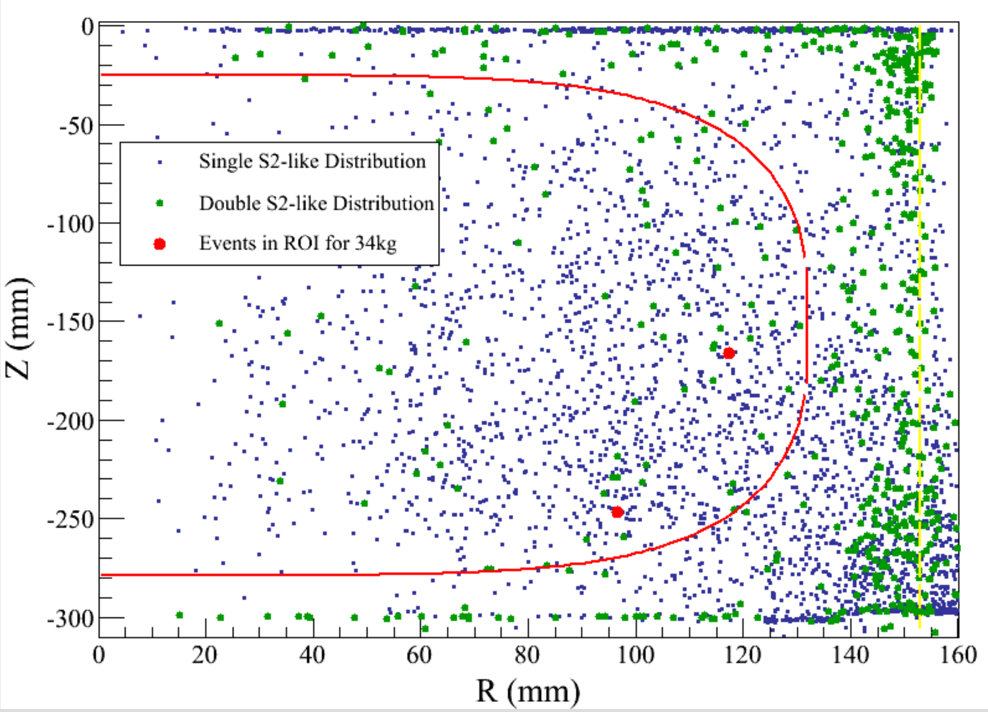
Reminder:

Background is modeled using ER calibration data from Co60 and Th232
This data shows an increased probability for anomalous leakage below ~8 PE

Background prediction depends on the information which is put into the model

Sensitivity to single electrons

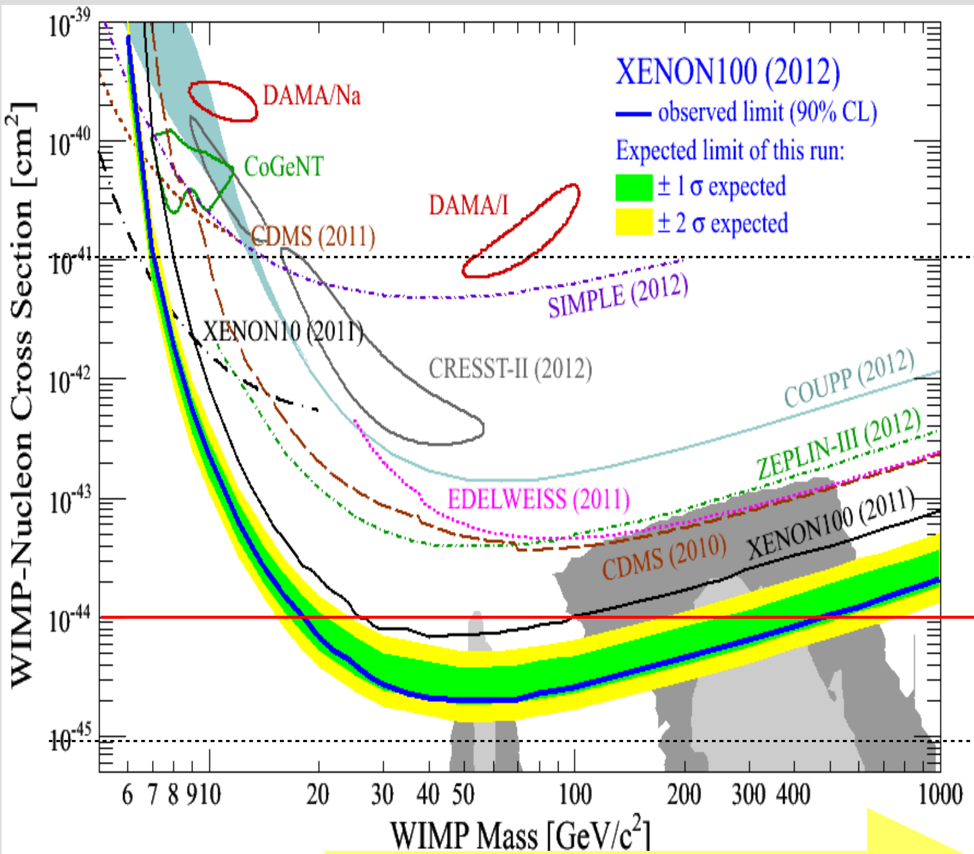


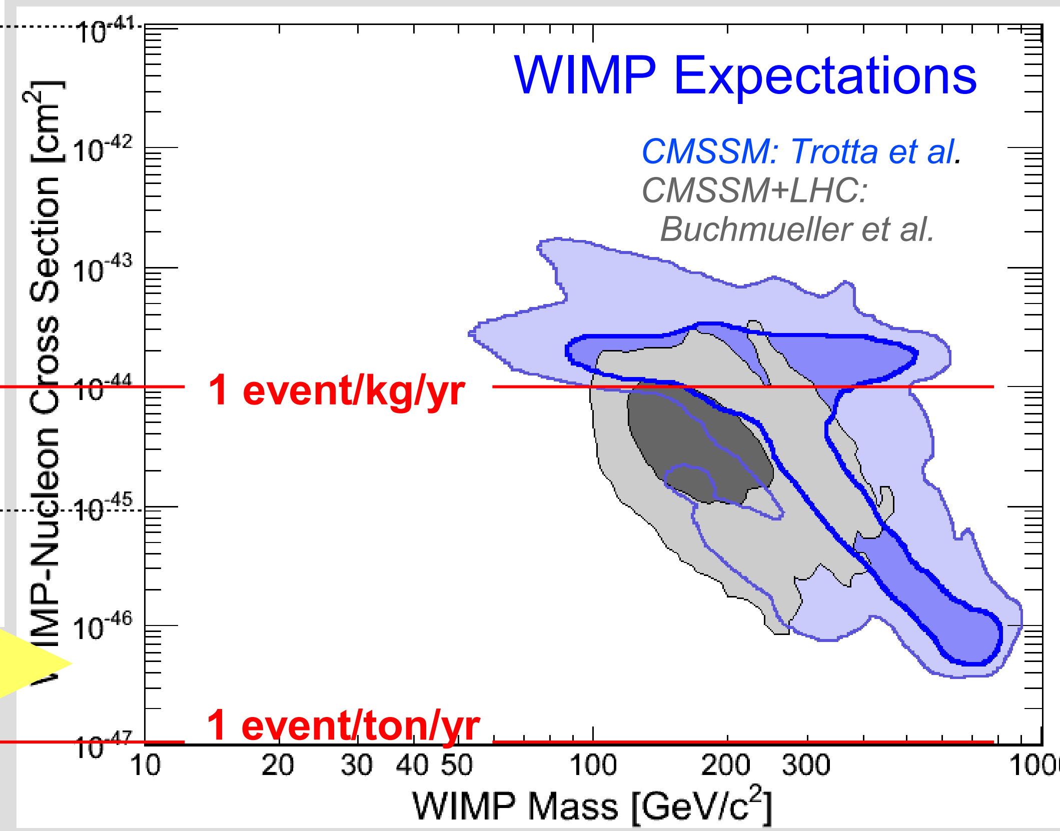


Relaxing the S2 threshold condition (S2>150 PE)
leads to a band of events at very low S2/S1(below signal range)

→ can the 2 events be in the tail of this band???
→ further studies are required
→ aim: quantify and put into background model for the next run

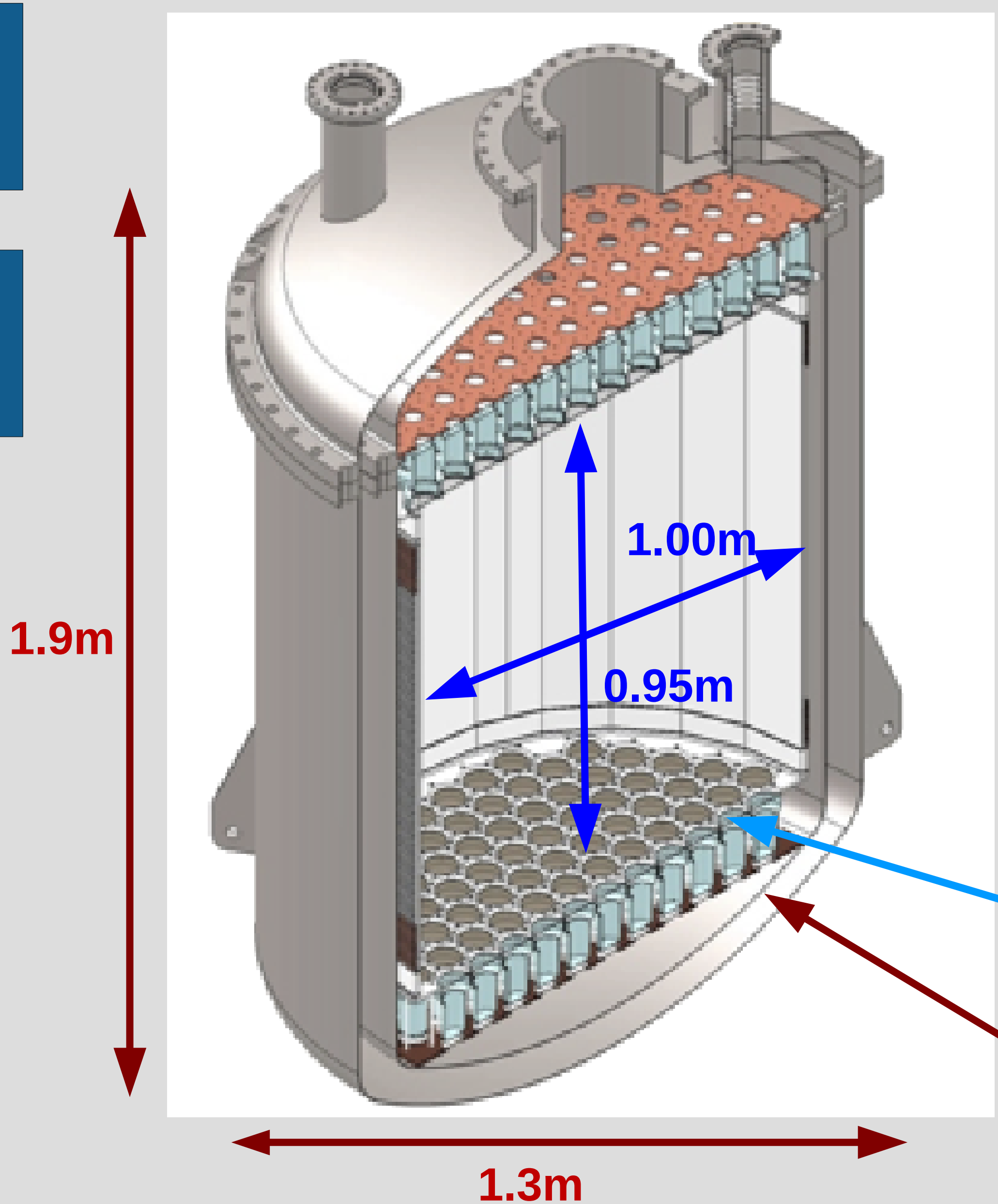
XENON: What next?





How do we get there?

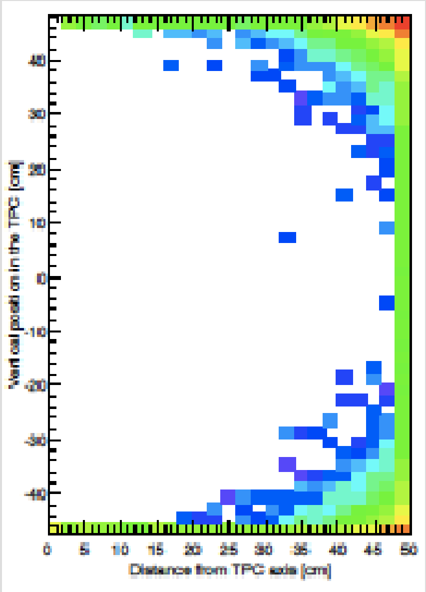
The next step: XENON1T



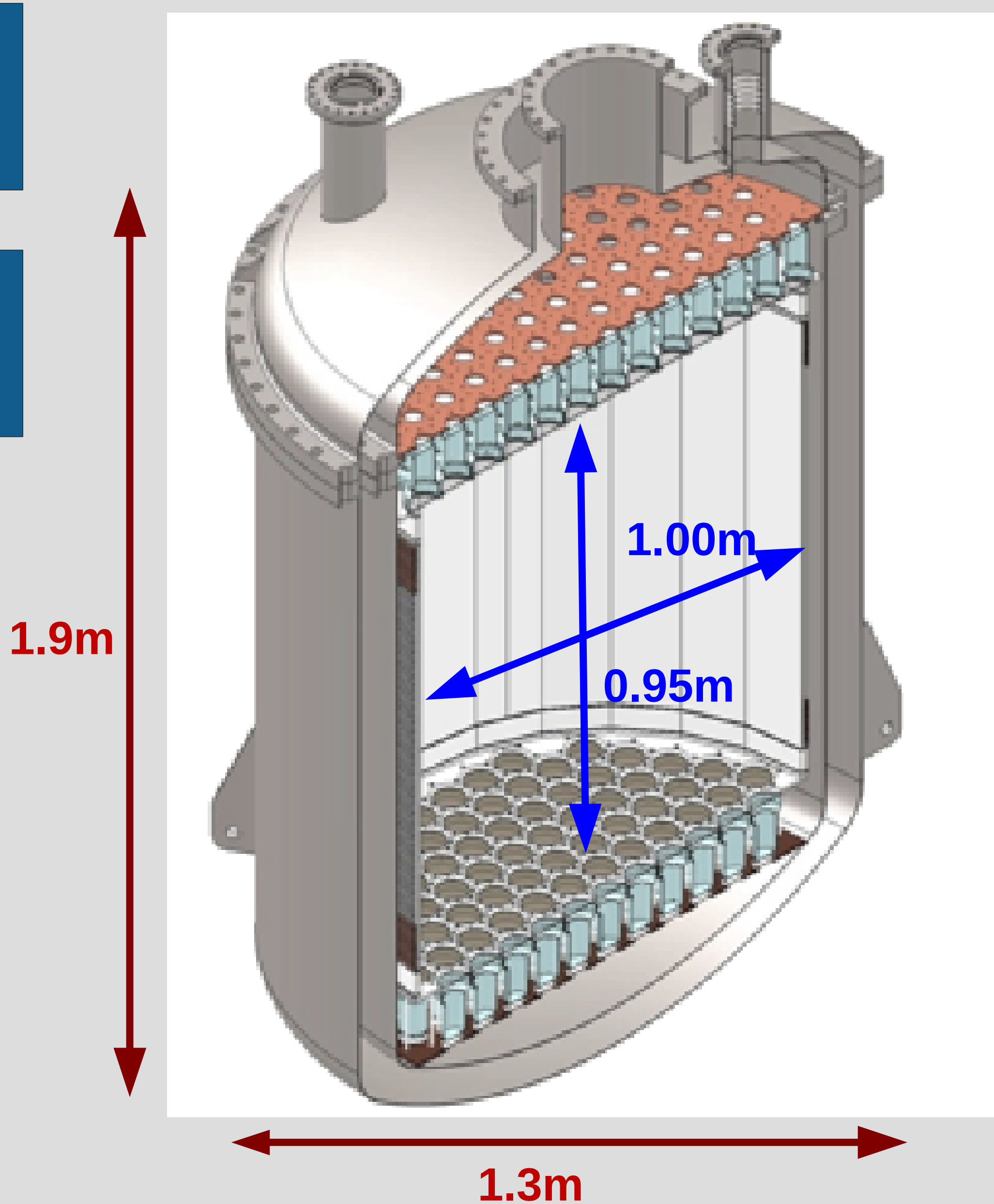
- 3t LXe ("1m³ detector")
  1t fiducial mass → 20x larger
- 100x lower background
  (~10 cm self shielding,
  low radioactivity components)
- background goal: <1 evt in 2 years

Low Radioactivity
Photon Detectors
(3”, Total ~250)

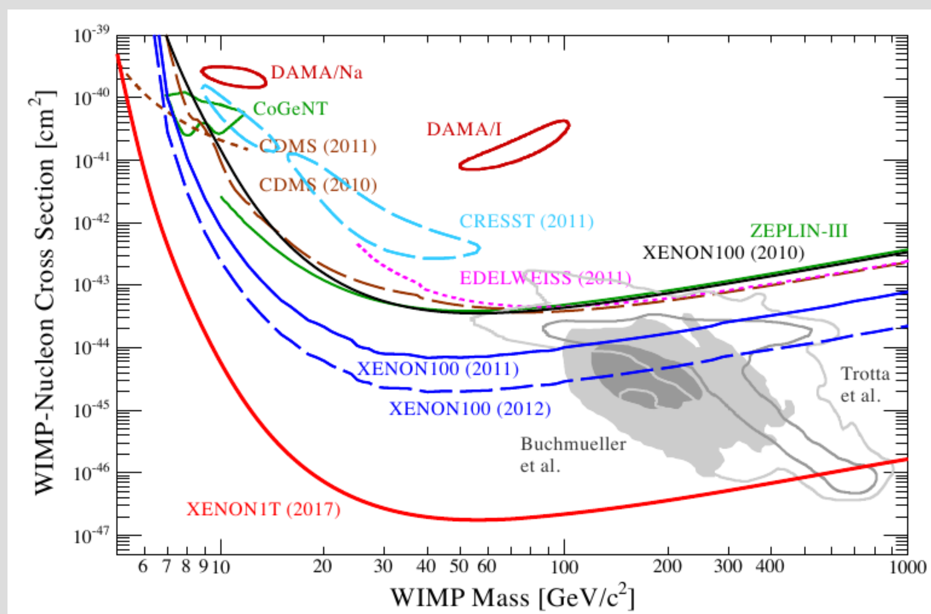
Ti Cryostat
(or low rad.
stainless steel)



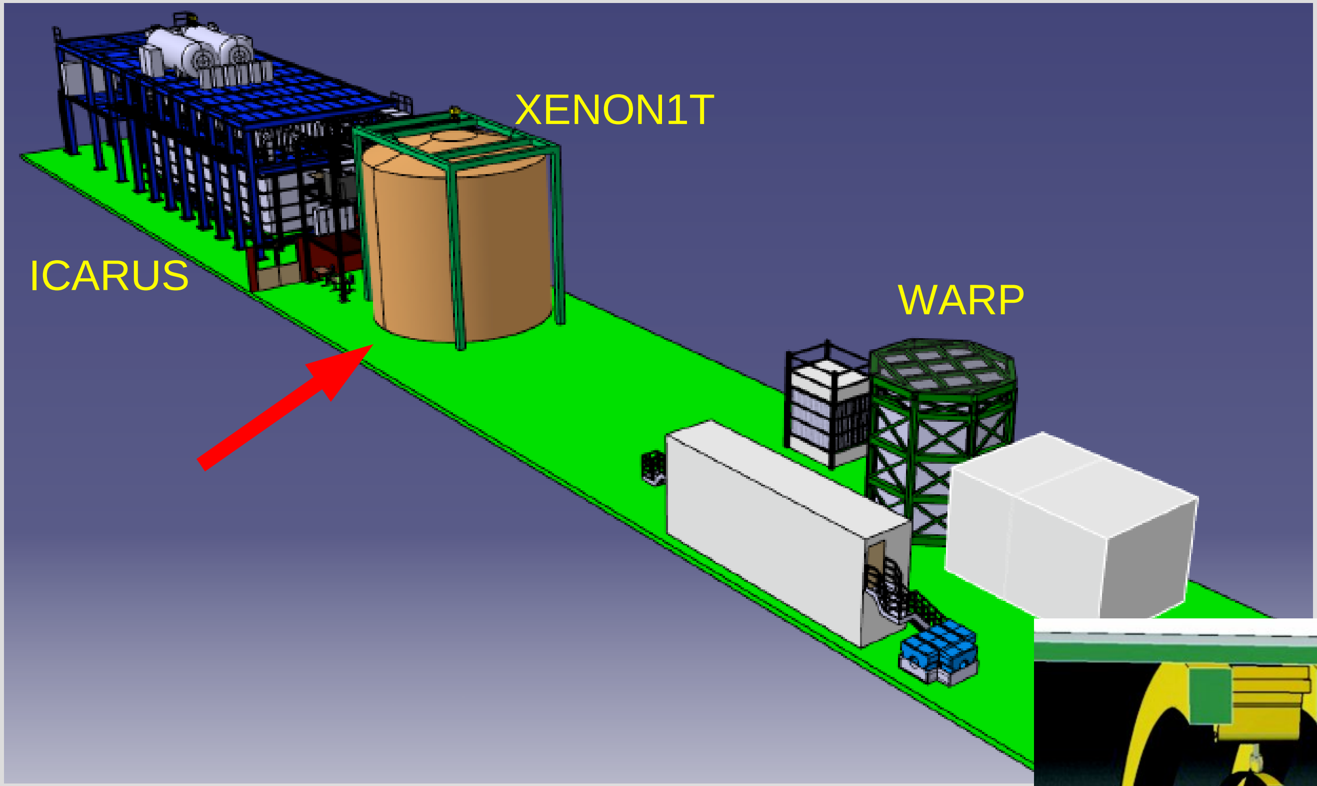
The next step: XENON1T



- 3t LXe ("1m³ detector")
  1t fiducial mass → 20x larger
- 100x lower background
  (~10 cm self shielding,
  low radioactivity components)
- background goal: <1 evt in 2 years
- Timeline: 2010 – 2017
- start construction in 2012



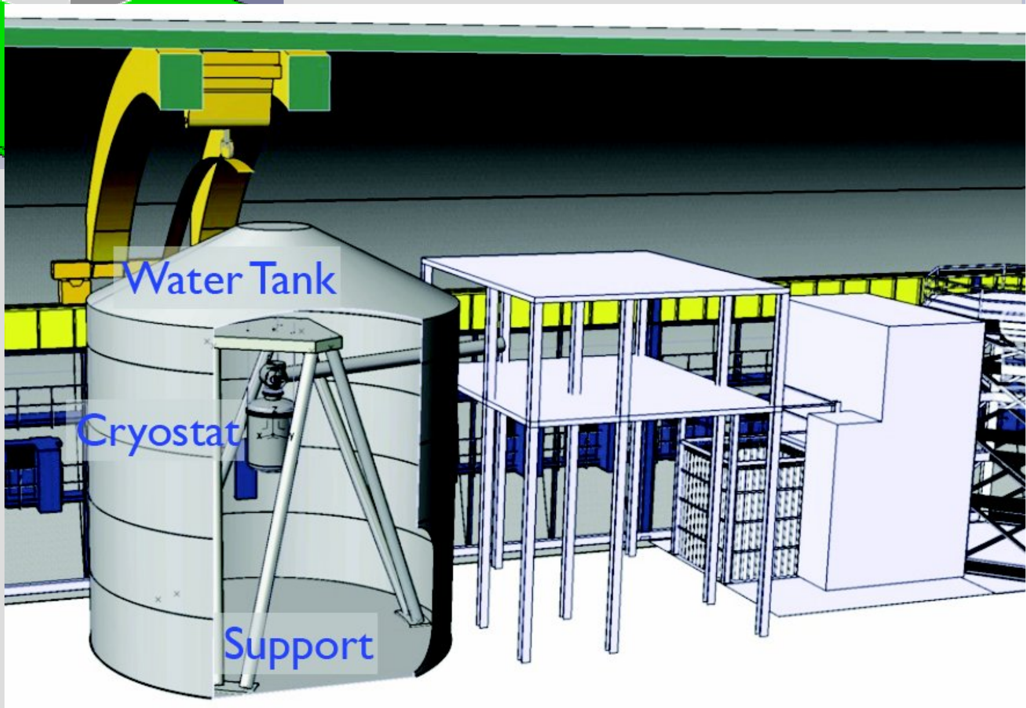
XENON1T @ LNGS



XENON1T
@ LNGS (Hall B)
➞ 4.8 m radius water shield acting as active muon veto

See talk by
Uwe Oberlack
tomorrow

- Proposal and TDR submitted to LNGS
- Approved by INFN end of April 2011
- Approved by NSF (US) May 2012



The new WIMP Landscape