The Search for Dark Matter with XENON

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XENON100 Collaboration

Columbia

Rice

UCLA

Zürich

Coimbra

LNGS

SJTU

Mainz

Bologna

Subatech

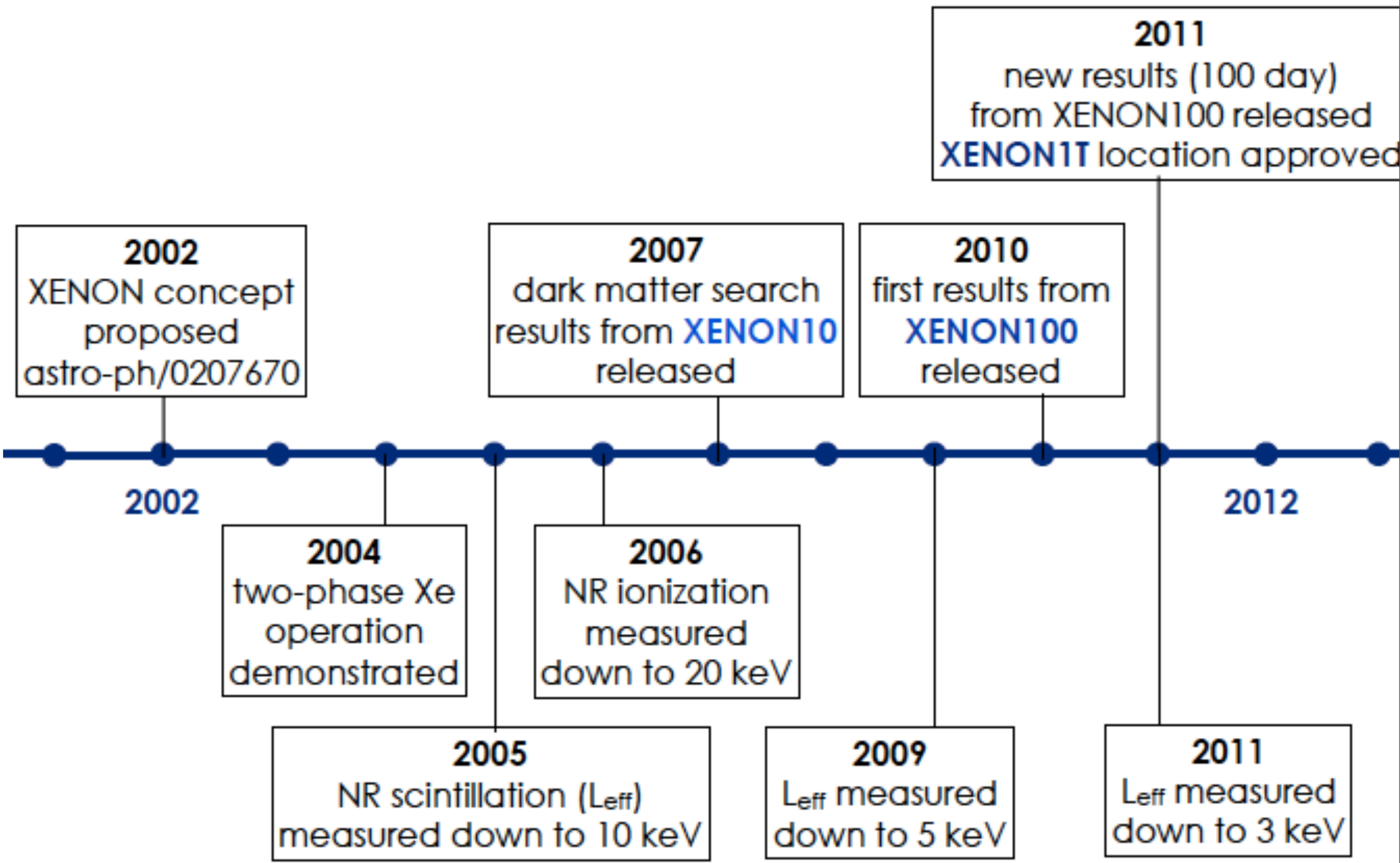
Münster

Nikhef

Heidelberg

Weizman

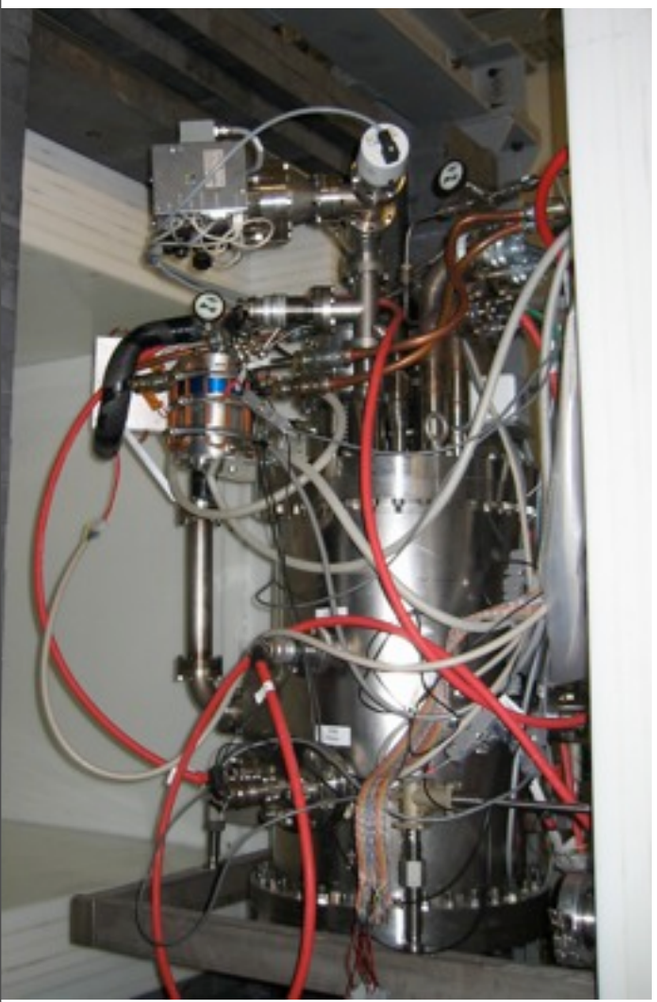
Evolution of the XENON Dark Matter program

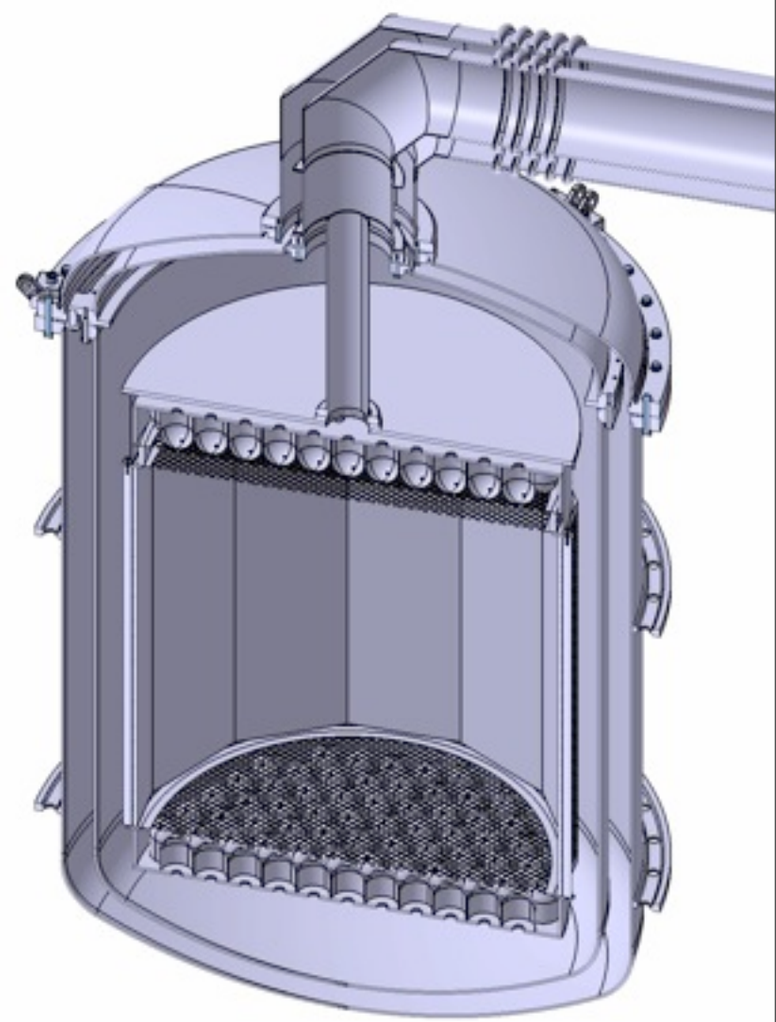


The XENON Family of Detectors

XENON
Dark Matter Project

past (2005 - 2007)	*current* (2007-2011)	*future* (2011-2015)





XENON10

Achieved (2007) σ_{SI}*=8.8 x10*$^{-44}$ *cm*^{2}

XENON100

Achieved (2011) σ_{SI}*=7.0 x10*$^{-45}$ *cm*^{2}

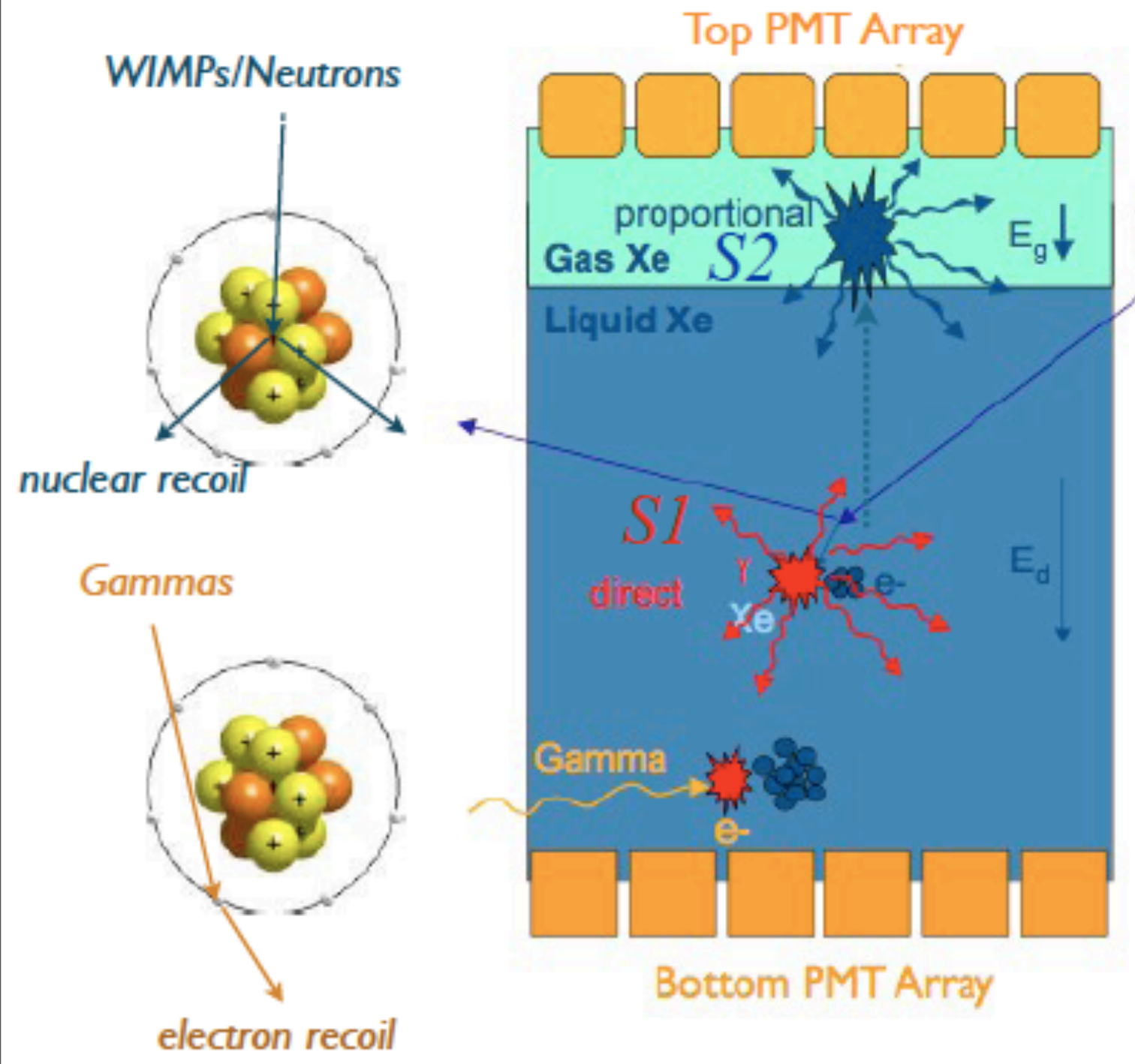
Projected (2012) $\sigma_{SI} \sim 2 \times 10^{-45}$ cm^2

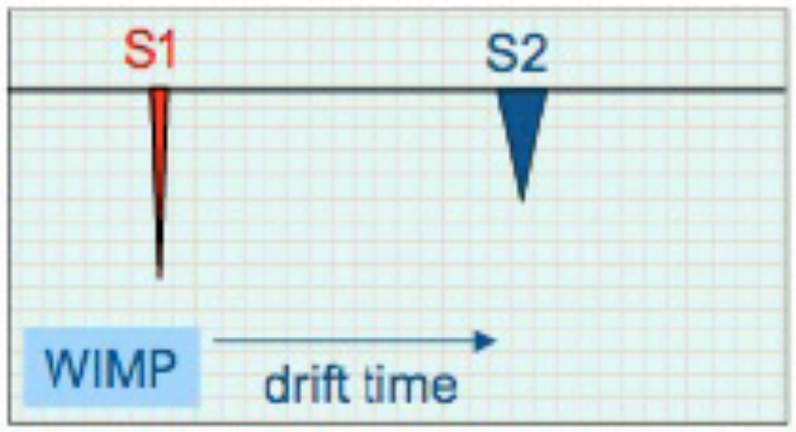
XENON1T

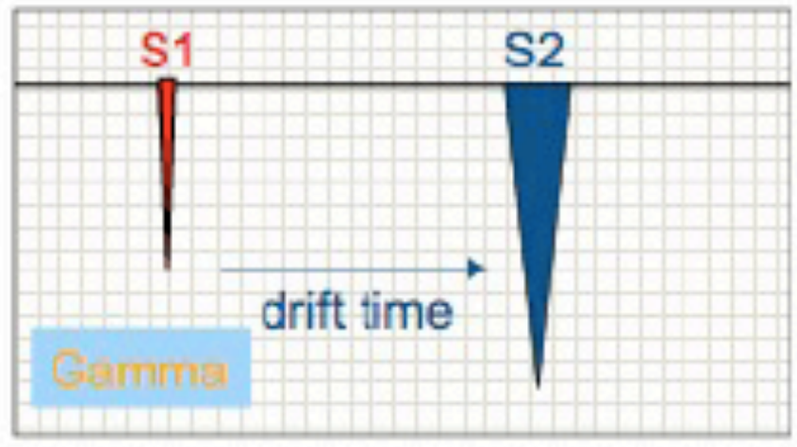
Projected (2015) $\sigma_{SI} \sim 10^{-47}$ cm^2

The XENON Two-Phase TPC

a large, scalable, homogeneous, self-shielding, position-sensitive detector

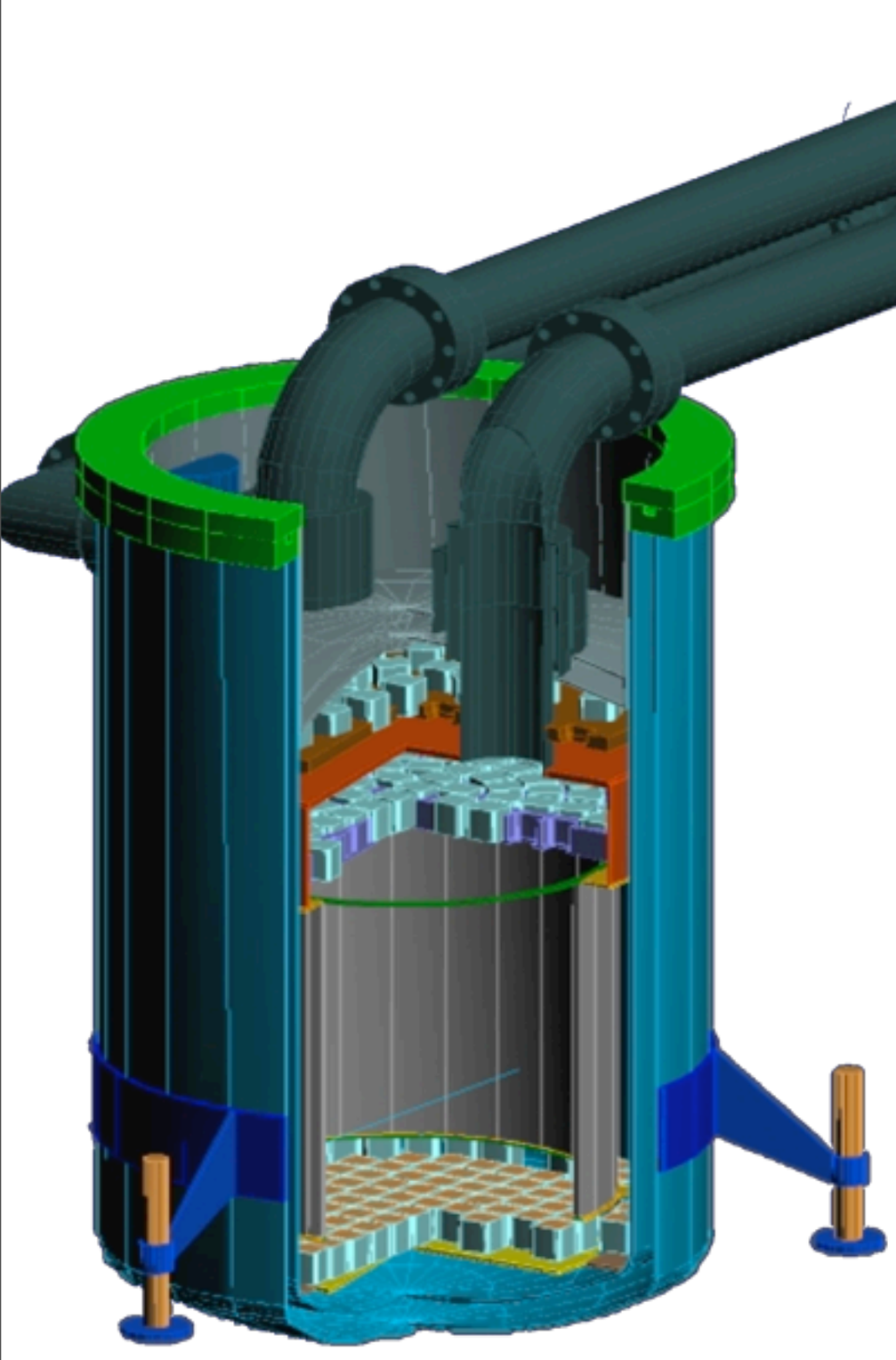






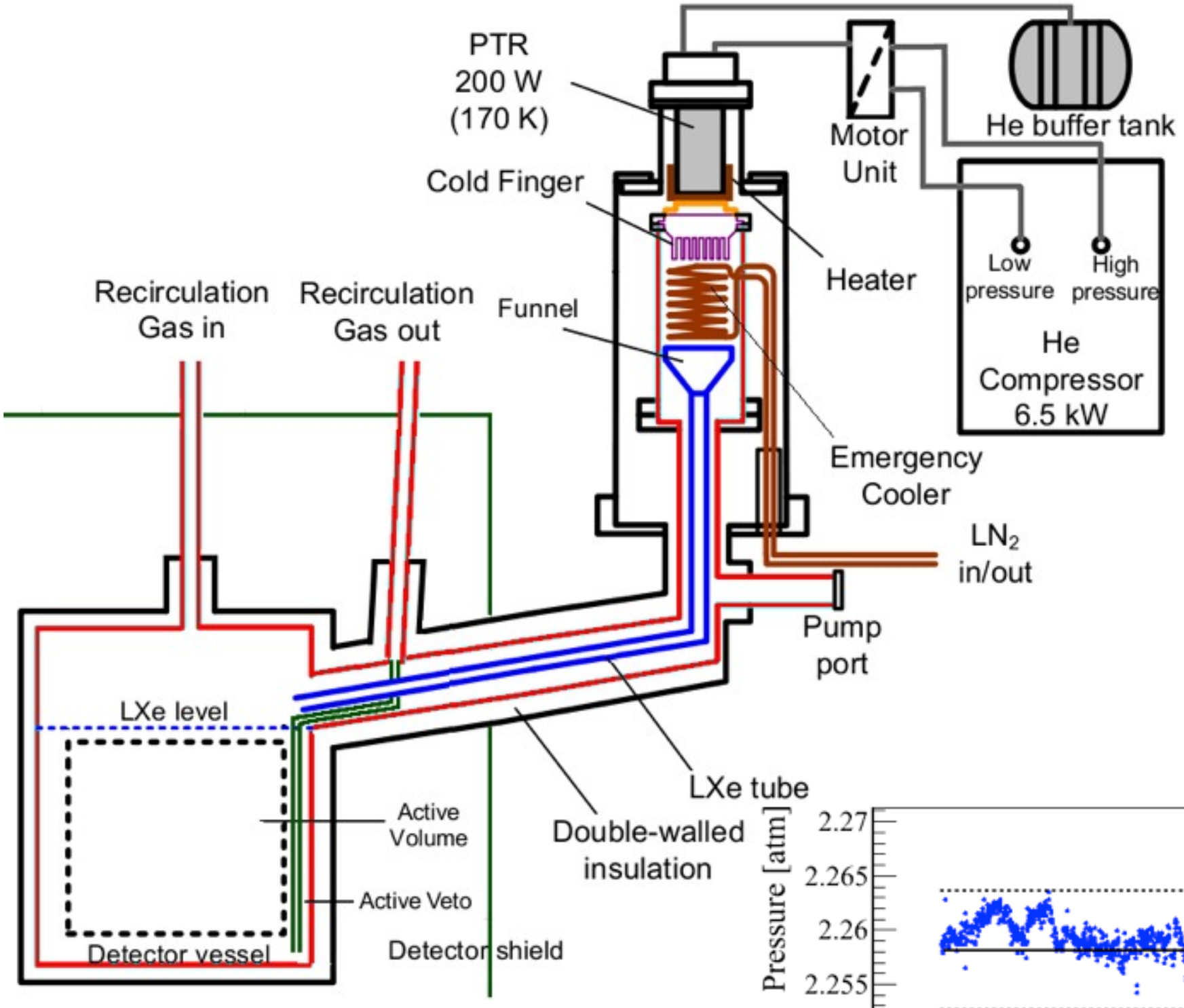
$(S2/S1)_{wimp} << (S2/S1)_{gamma}$

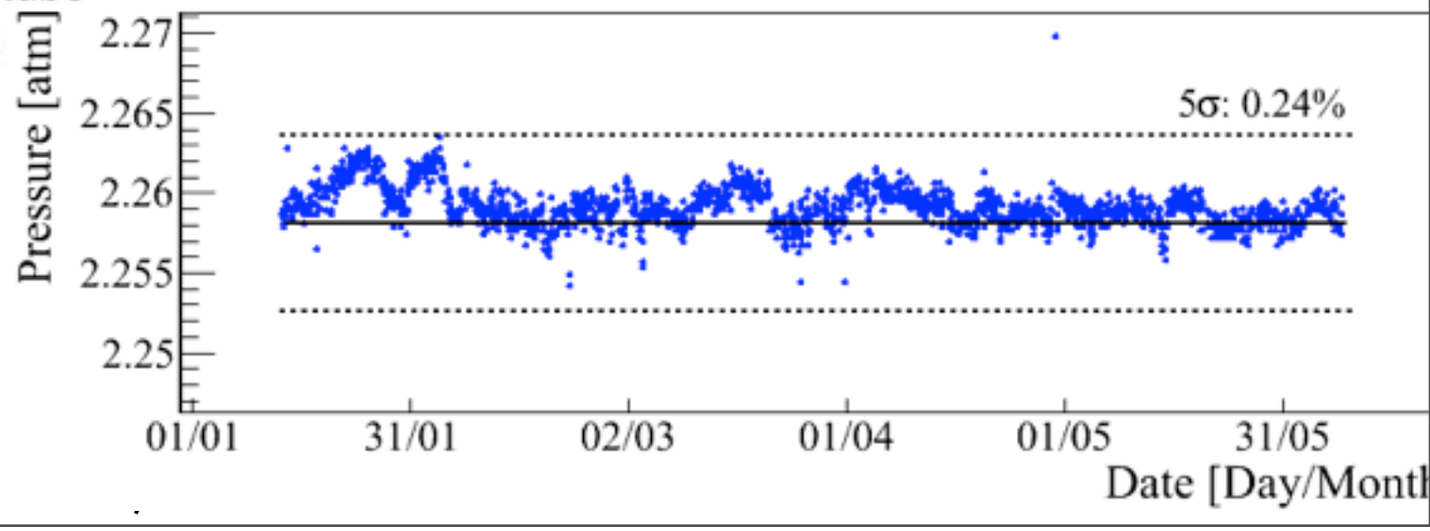
The XENON100 Detector



- TPC with 30 cm drift x 30 cm diameter
- Drift field in LXe ~ 0.5 kV/cm
- Amplification field in GXe ~10 kV/cm
- Total 161 kg high-purity Xe: <1ppb O_2/Xe and <100 ppt Kr/Xe contamination
- 62 kg as active target; 99 kg as active LXe scintillator veto
- 242 PMTs with ~1 mBq (U/Th)
- S1 yield :2.2 pe/keV (122 keV and 0.5 kV/cm)
- S2 yield: 18 pe/e (single electron sensitive!)
- 200W Cryocooler and FTs outside shield
- Materials screened for low-radioactivity

The XENON100 Cryogenic System

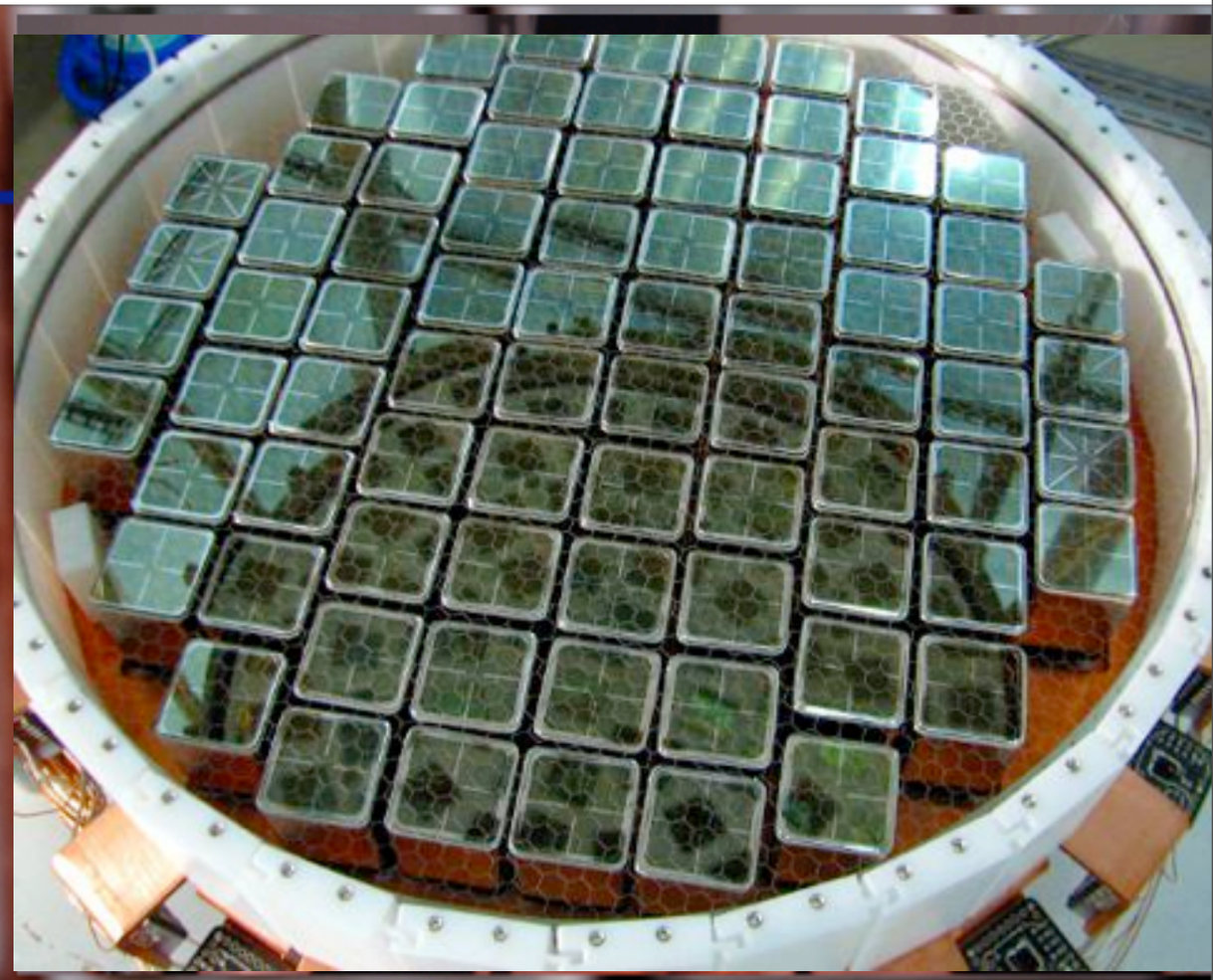


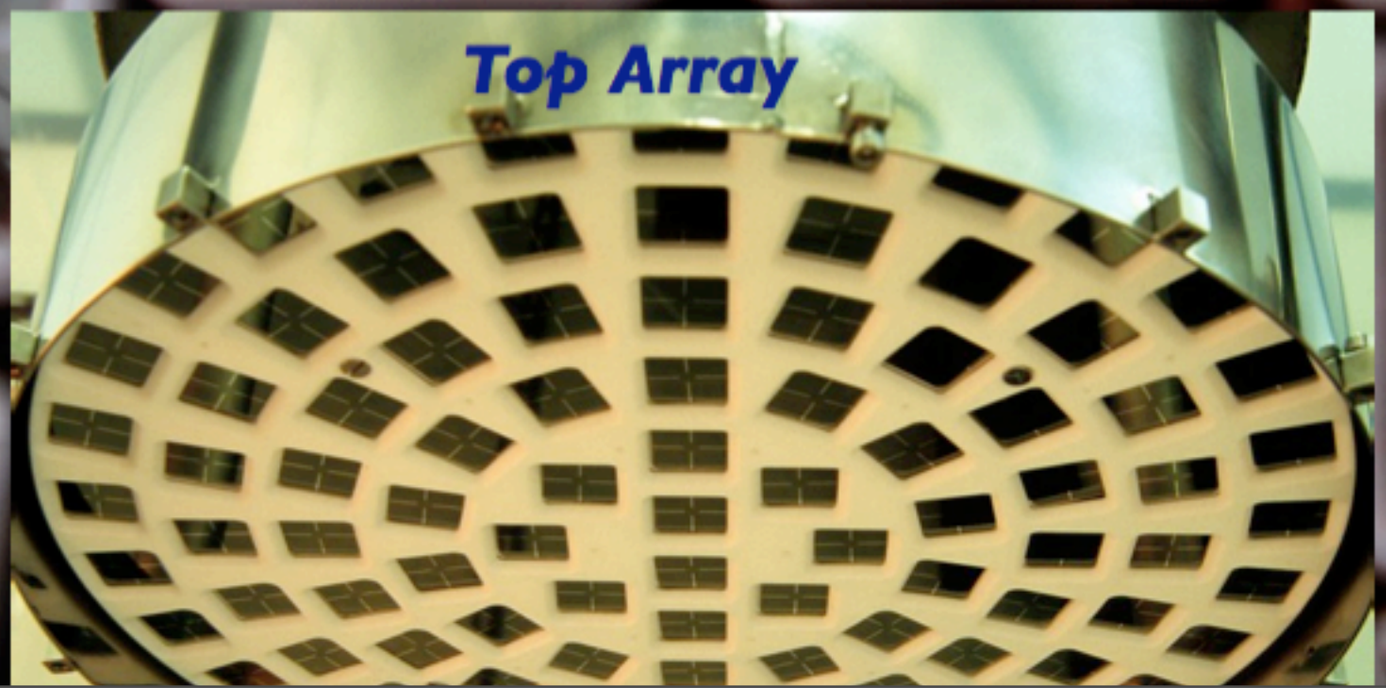


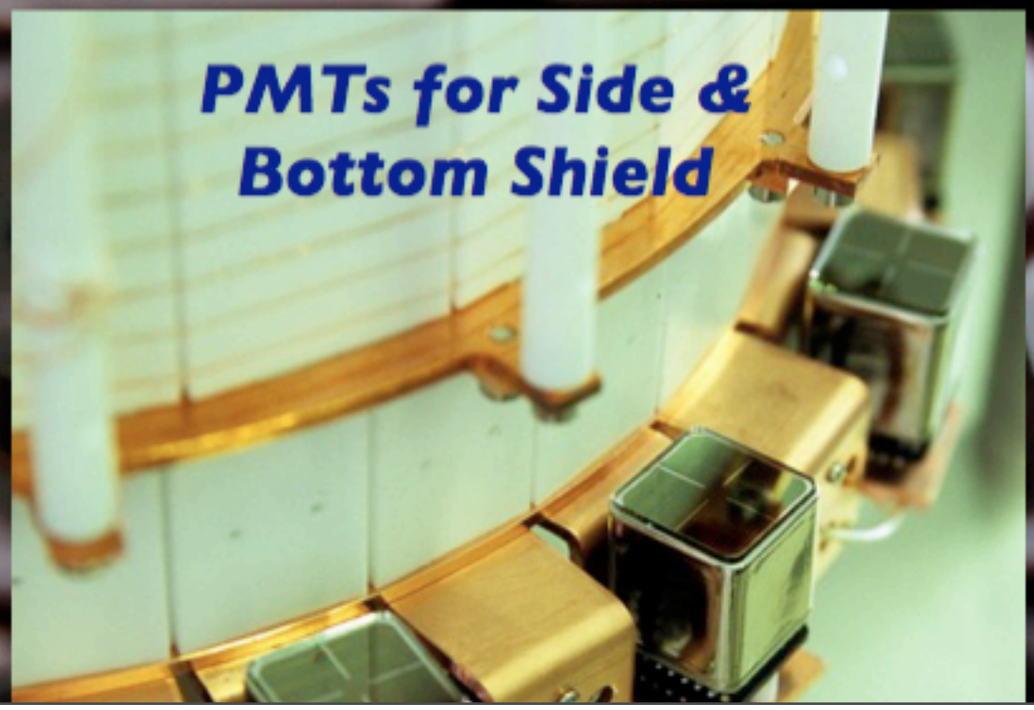
The XENON100 PMTs

XENON100: The PMTs

- 242 PMTs (Hamamatsu R8520-06-Al)
- 1 " square metal channel developed for XENON
- Low radioactivity (<1 mBq U/Th per PMT)
- 80 PMTs for bottom array (33% QE)
- 98 PMTs for top array (23% QE)
- 64 PMTs for top/bottom/side Veto (23% QE)







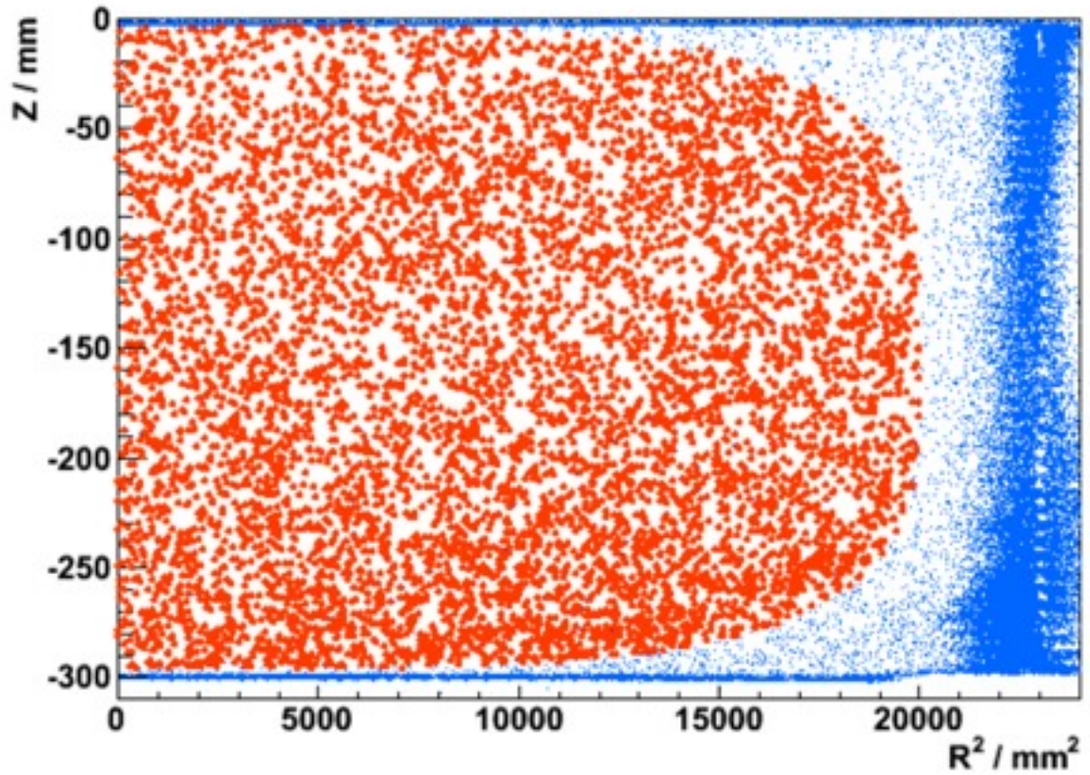
3D Event Localization in XENON100 TPC

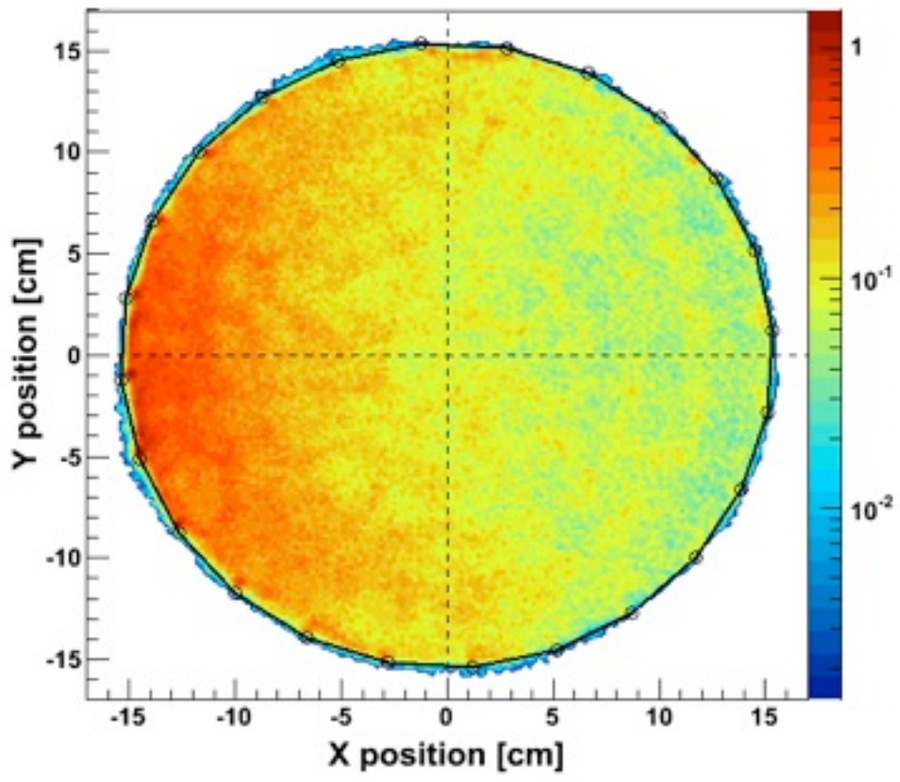
1" PMTs allow event position reconstruction in X-Y (from S2 signals) with millimeter precision

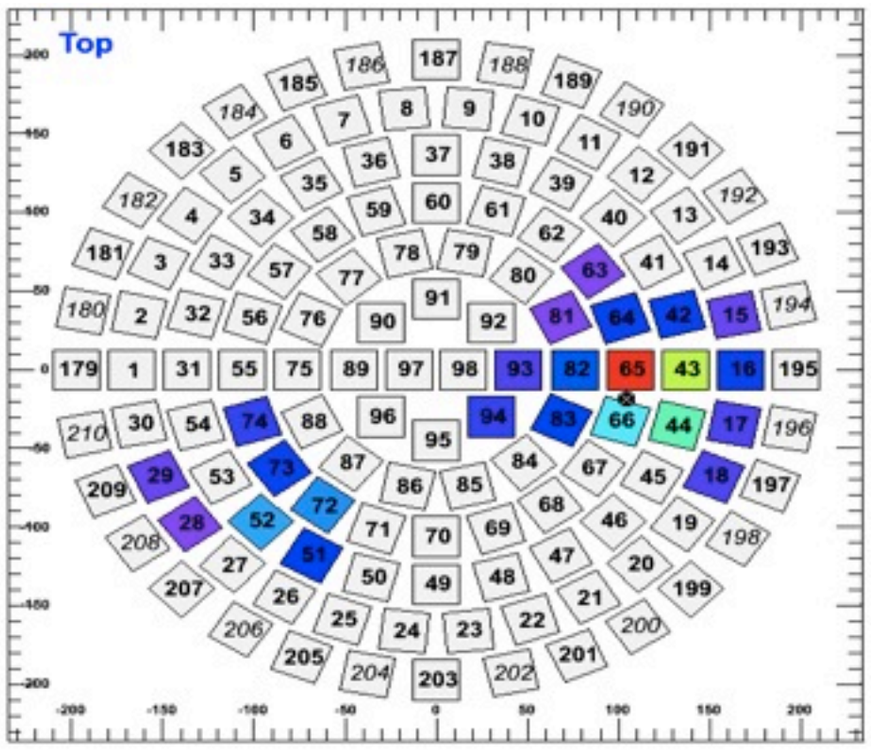
Drift time measurement gives Z coordinate with sub-millimeter precision

3D event localization powerful for background rejection: 1) Fiducial Volume and 2) Single/Multiple Scatters

Fiducialization

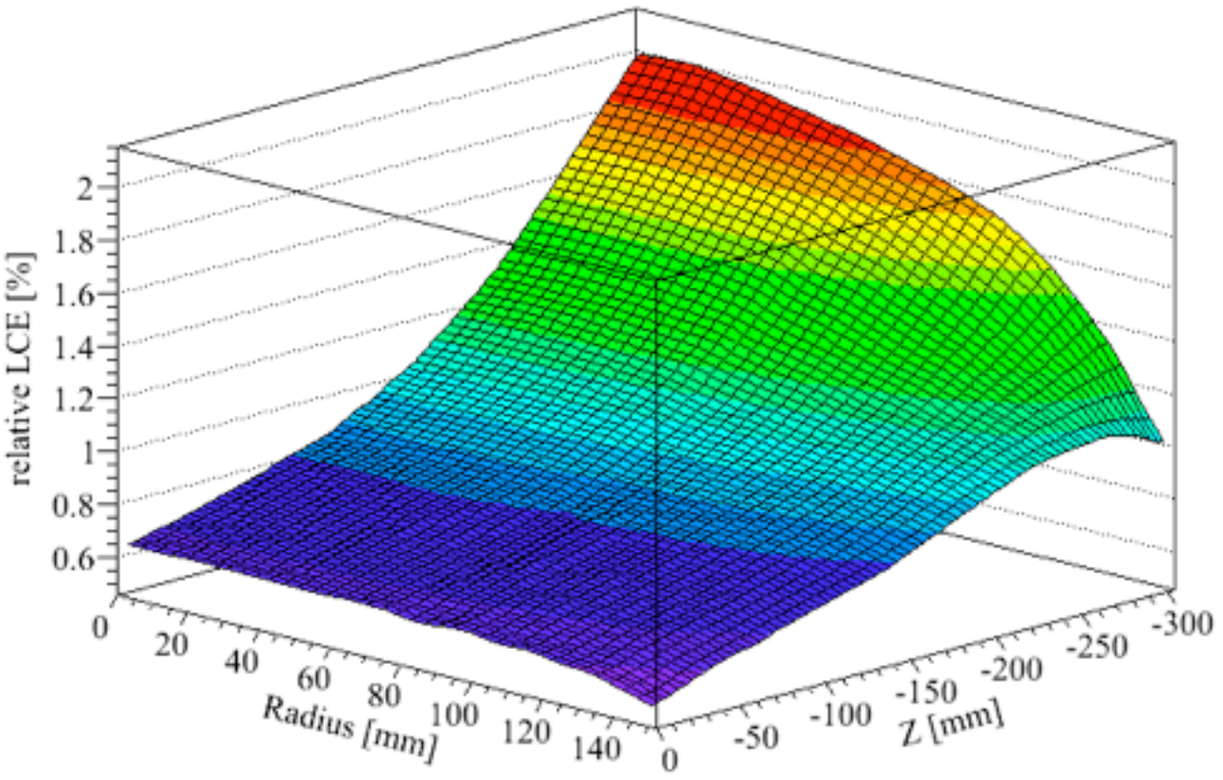






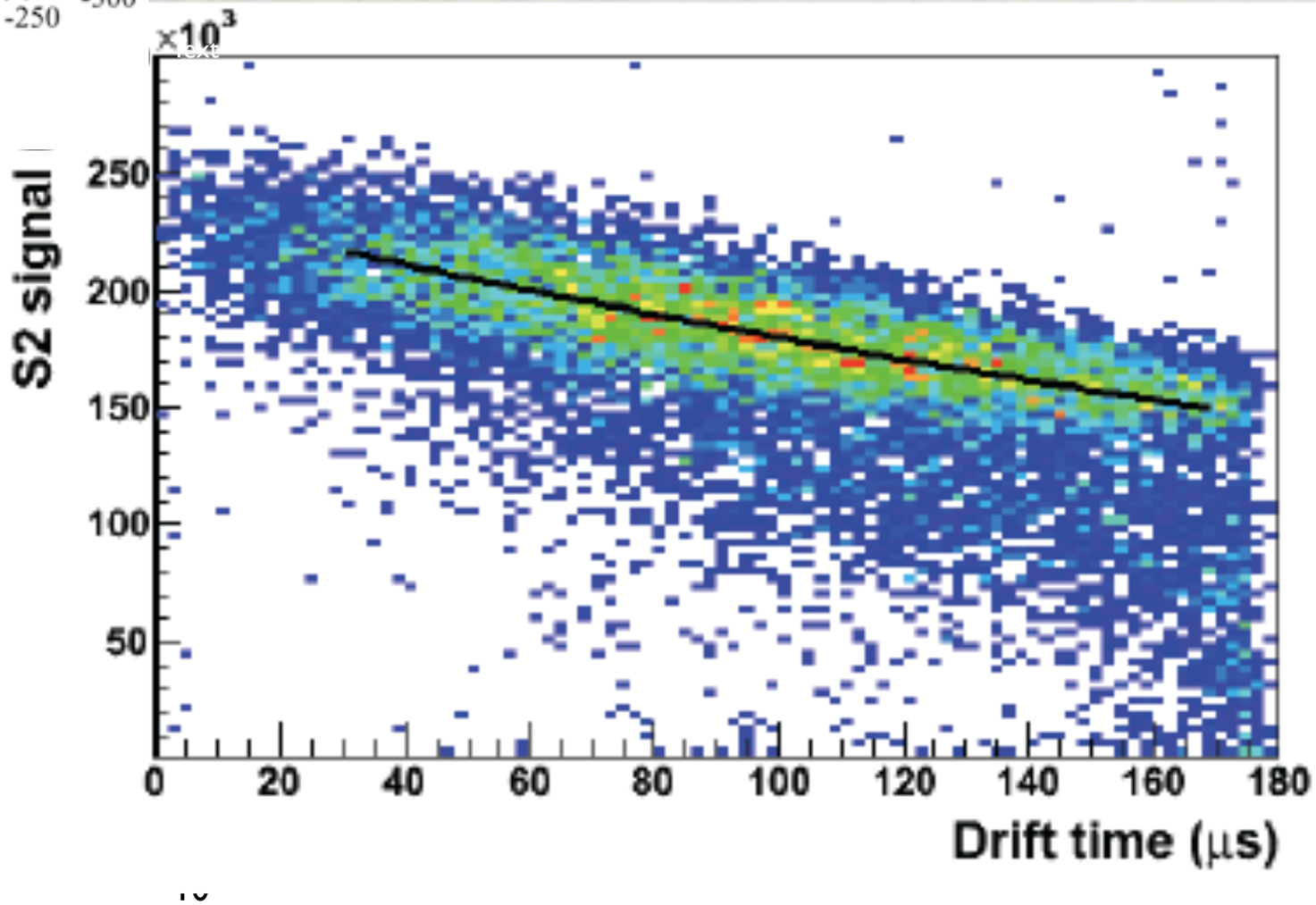
Position-dependent Signals corrections

S1 Light Collection Map



S1 dependence on XYZ
(a factor of 3 difference from bottom to top)

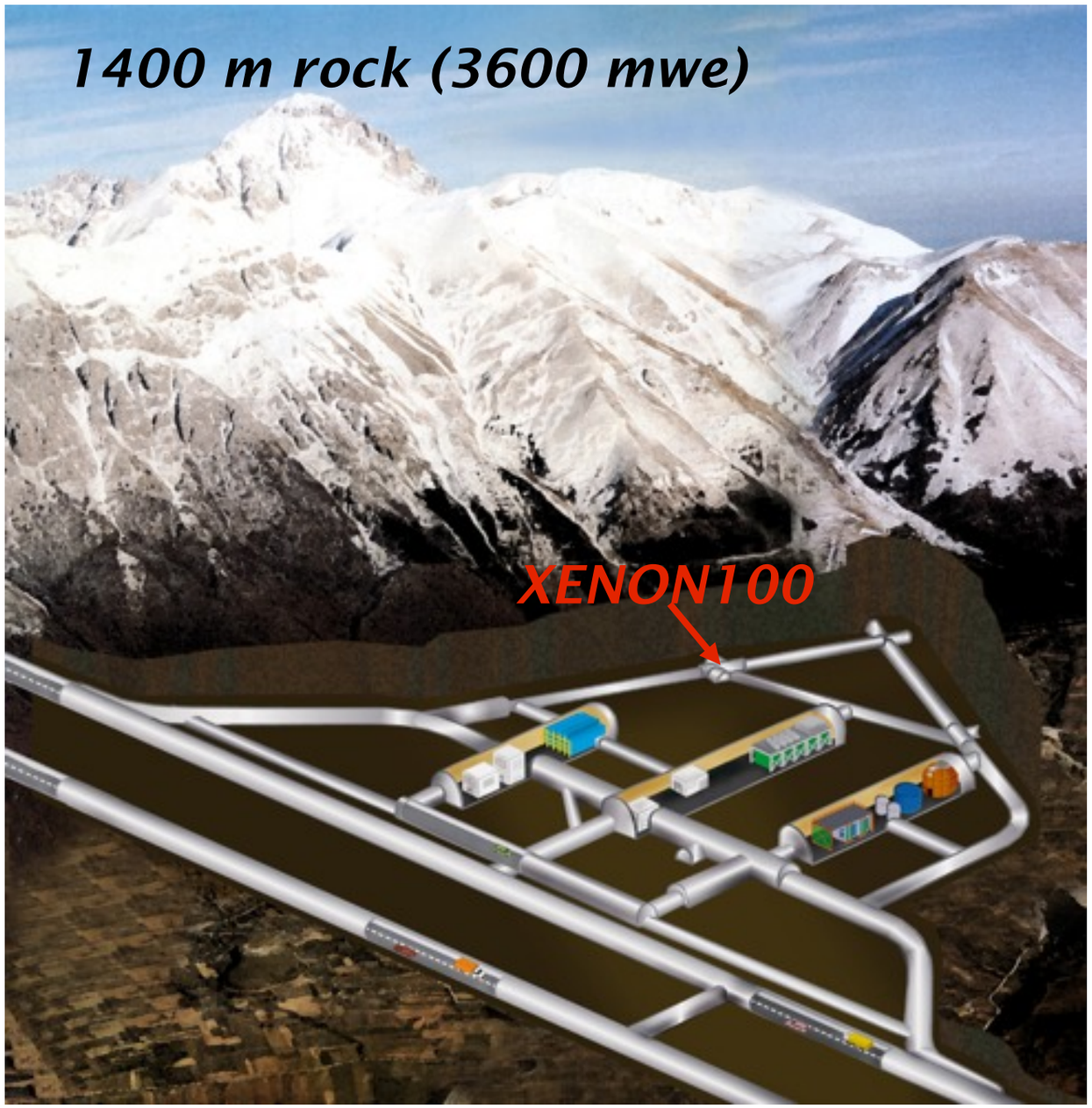
S2 dependence on Z
(depends on the impurity level in Xe)



XENON100 @ LNGS

Shield: 20cm H_2O, 20cm Pb, 20cm PE, 5cm Cu

Shield cavity purged with N_2 to keep Rn level < 0.5 Bq/m^3



Background Sources in XENON100

Neutrons

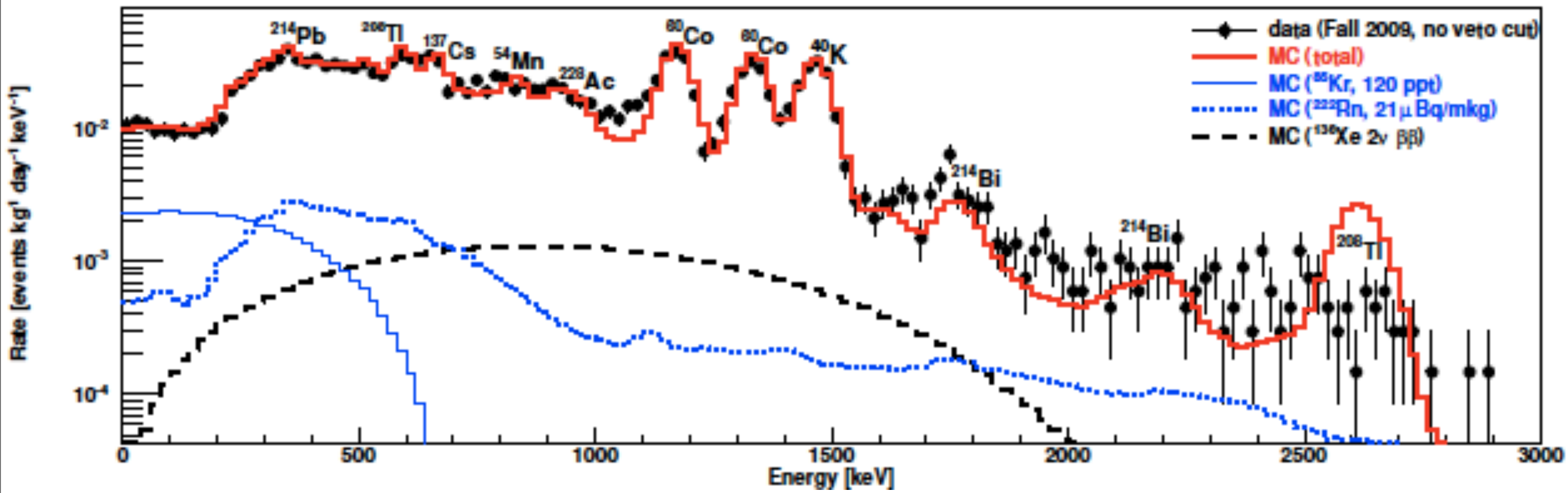
- radiogenic from fission and (a,n) reactions in detector and shield materials
- cosmogenic from spallation of nuclei in materials by high-energy muons

Electromagnetic Radiation

- natural radioactivity in detector and shield materials
- ^{222}Rn in shield cavity
- ^{85}Kr and ^{222}Rn in LXe
- cosmogenic activation of detector materials and of LXe during production and storage on Earth' surface

Measured Background

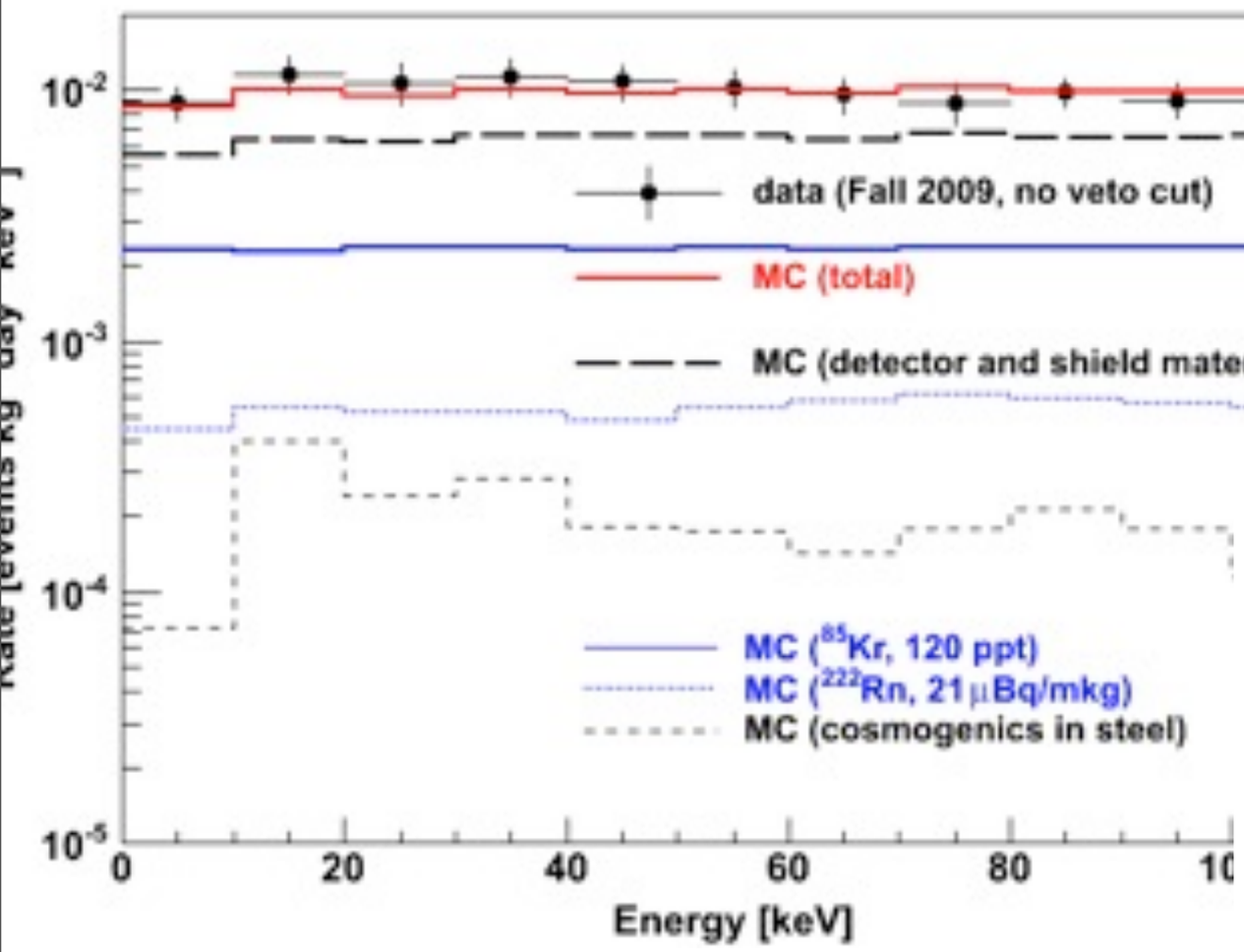
E. Aprile at al. (XENON100), Phys. Rev. D 83, 082001 (2011)



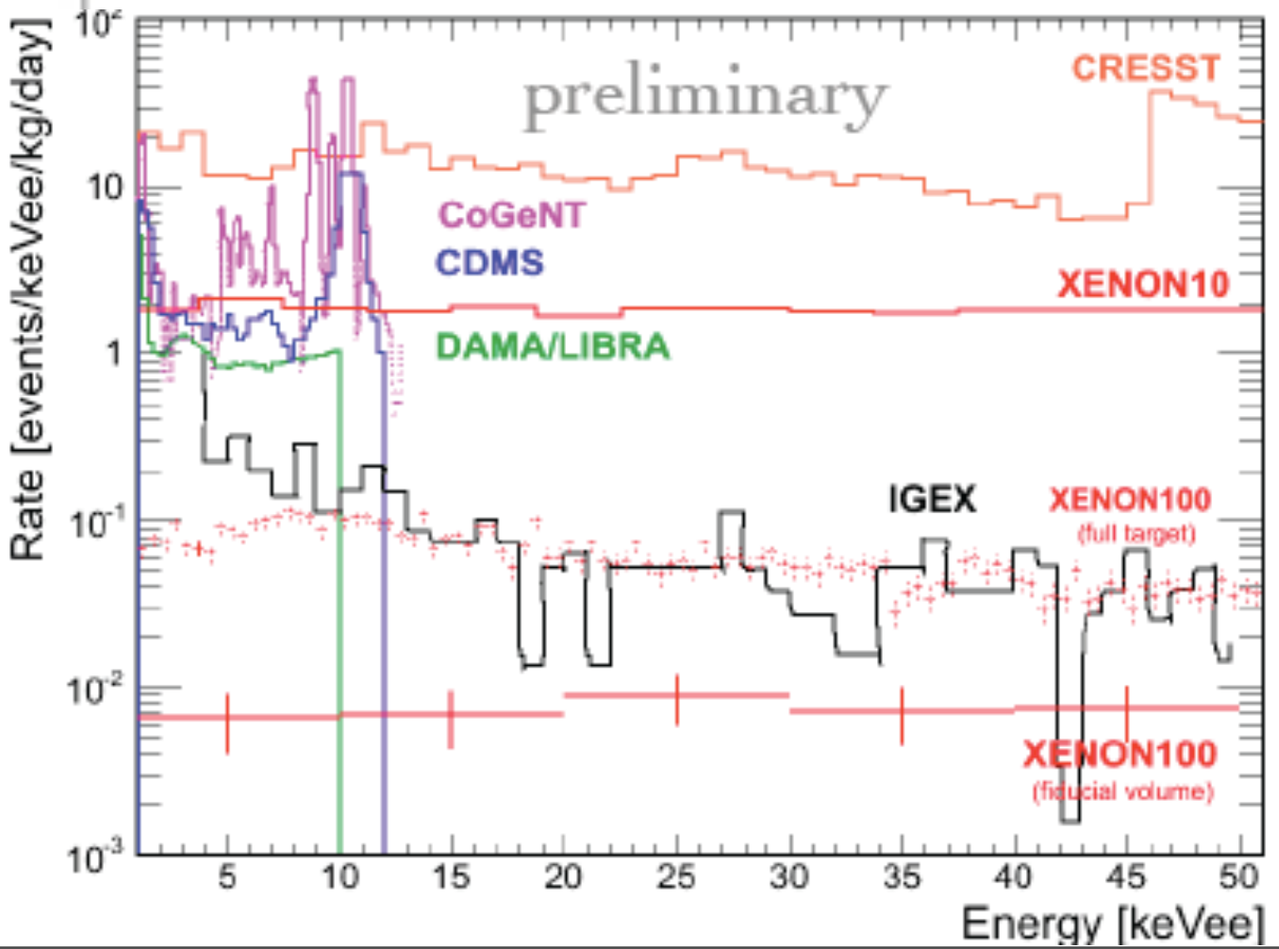
In good agreement with Monte Carlo simulations based on detailed mass model and measured values for U/Th/K/Co/Cs from radioactivity in all screened XENON100 materials. No LXe veto cut

..the lowest of any Dark Matter experiment

- In 30kg fiducial volume background rate is ~10 mdru even before the LXe veto cut
- The LXe veto reduces rate to ~5 mdru, where ^{85}Kr in LXe starts to dominate



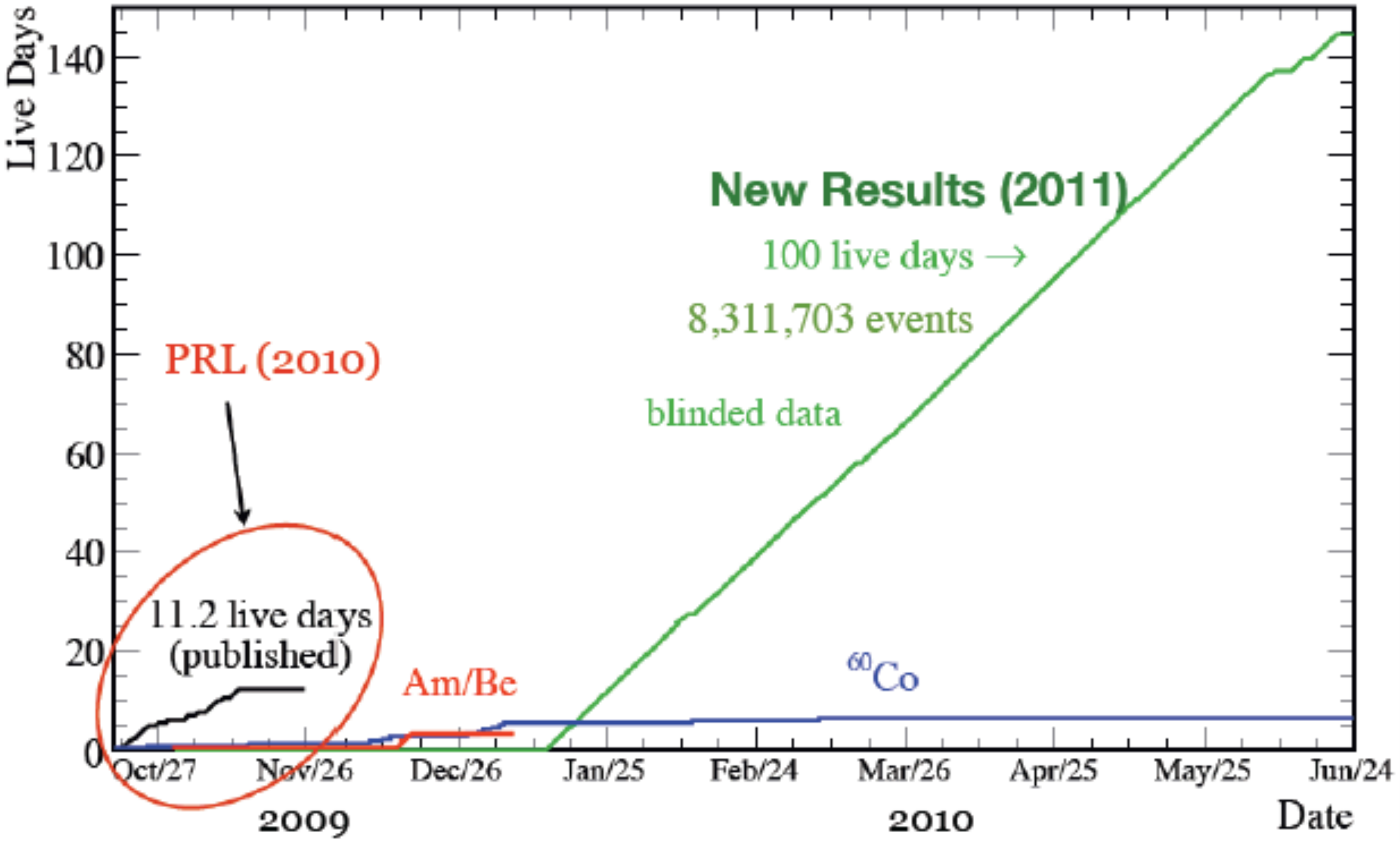
- Factor 100 less than XENON10 and than other DM experiments



XENON100 Dark Matter Search with 100 days of data during 2010

Aprile et al. submitted to Physical Review Letters arxiv:1104.2549

XENON DATA Taking 2009-2010



Analysis Steps

PMT gain calibration data

calibration data (AmBe, Co60, Cs137)

background data (previously released 11.2 day, 100 day signal region blinded)

raw data processing
turn digitized PMT waveforms into physical quantities (energy, positions)

reject noises
remove noise events
remove events not in target
remove multiple scatter evts
etc.

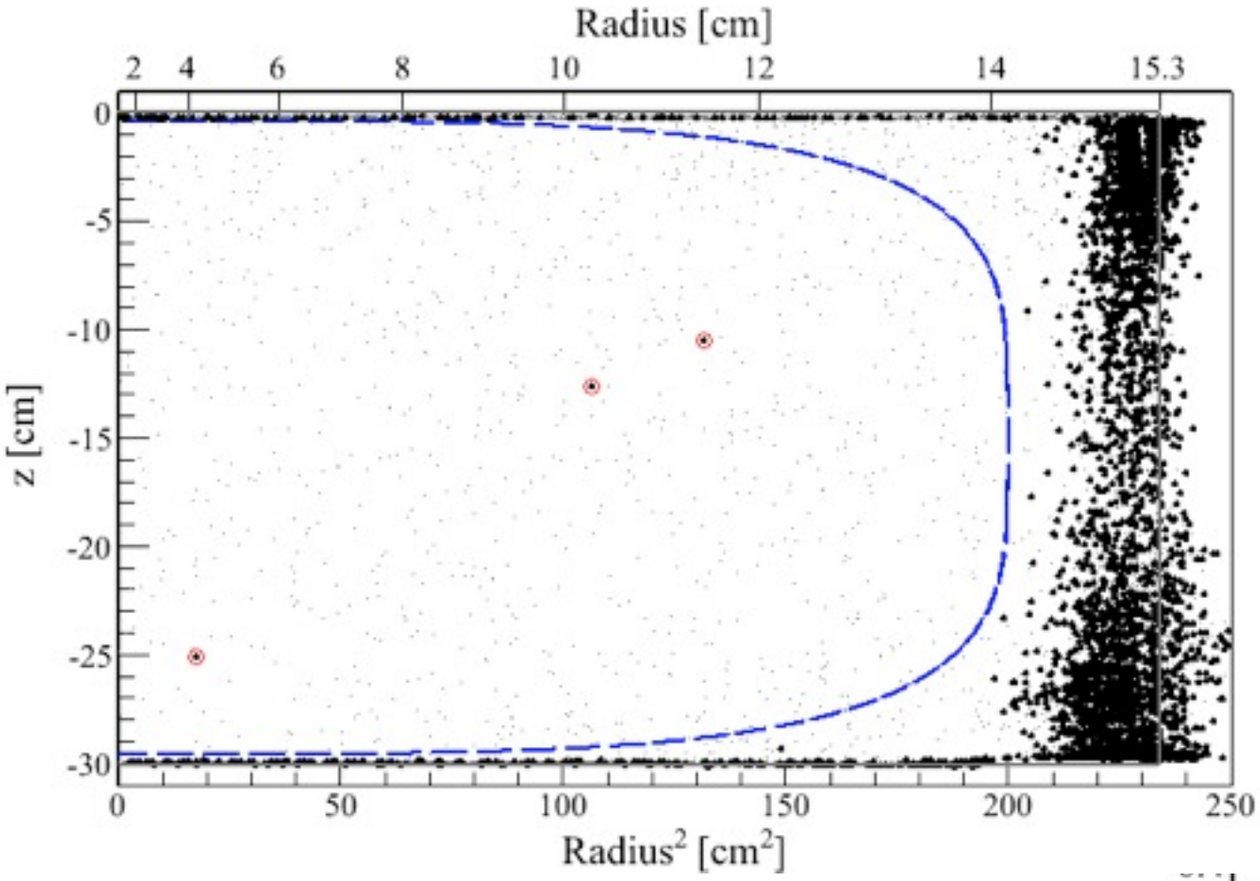
dealing with signals
signal corrections
define energy region
define fiducial volume cut
define S2/S1 cut

Look for Dark Matter
unblind the signal region in 100 day data

Expected Background in Signal Region in 48kg and 100 days

- from radioactivity of detector's materials and estimated 700 ppt Kr in Xe
    - 1.70 electron recoils after 99.75% S2/S1 rejection
    - 0.03 nuclear recoils
- from muon-induced nuclear recoils (Monte Carlo): 0.08
- Total expected background in signal region: 1.8 +- 0.6
- Prediction from data and Monte Carlo; verified on high energy side band

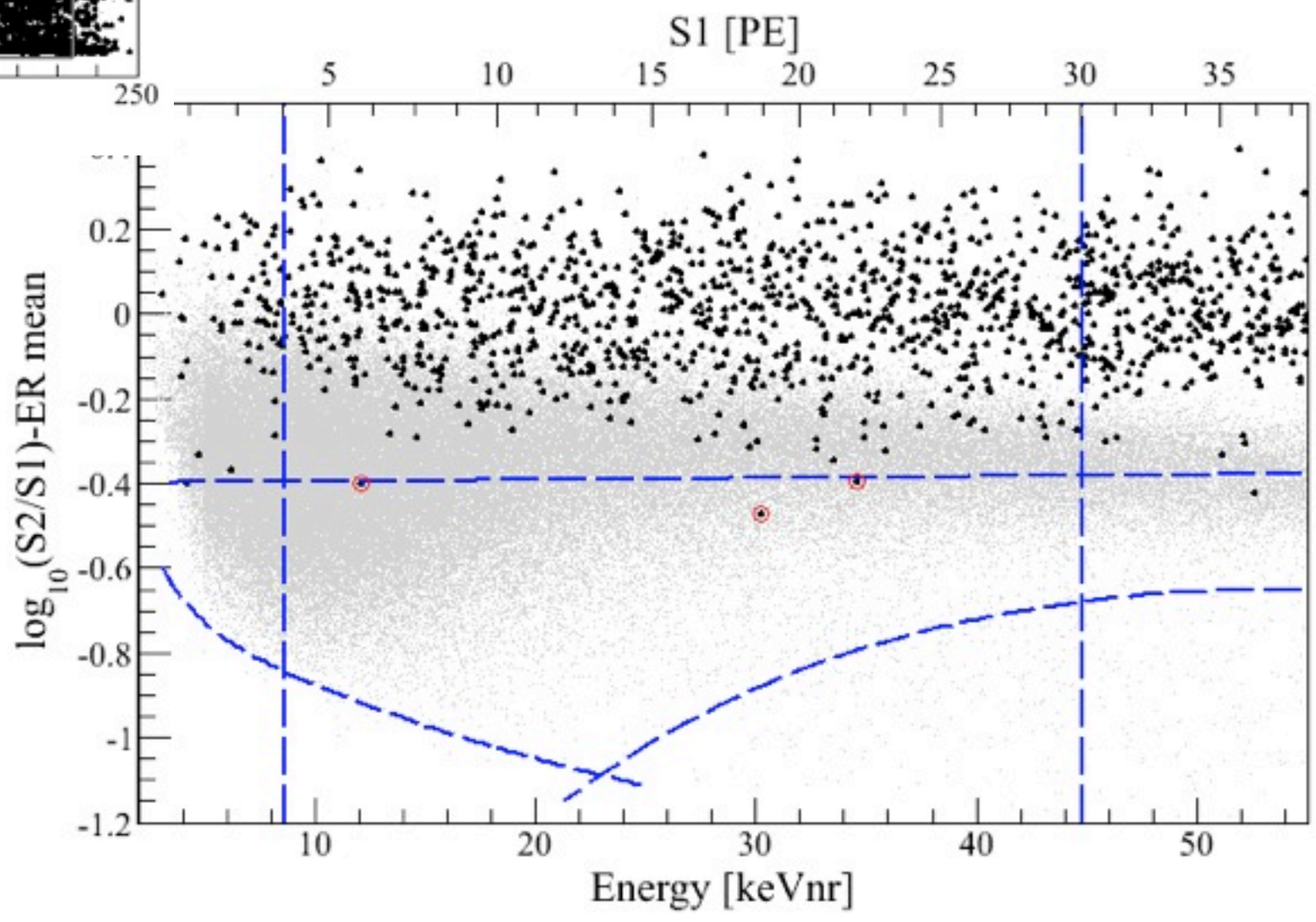
Search Result



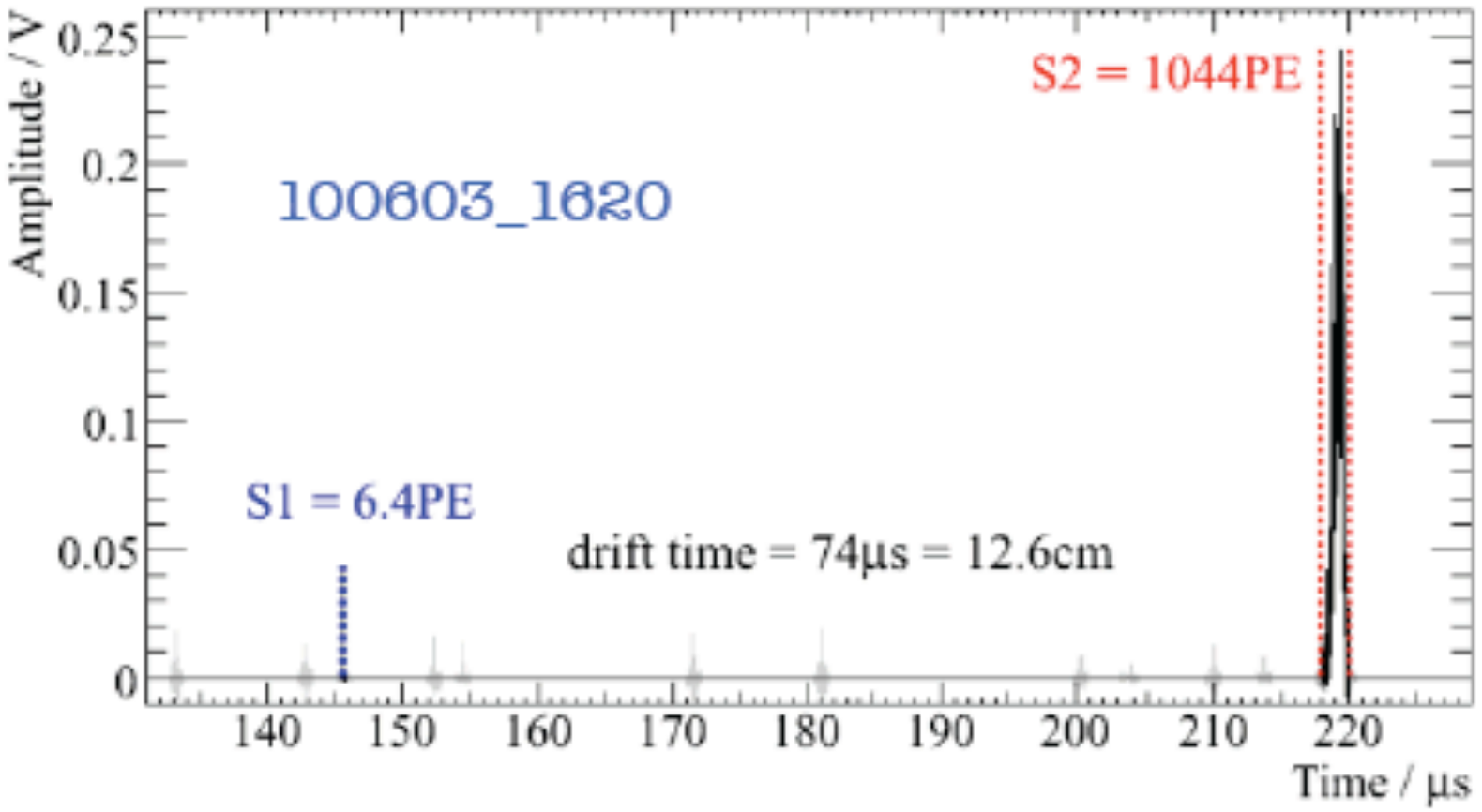
Exposure 1471 kg x days

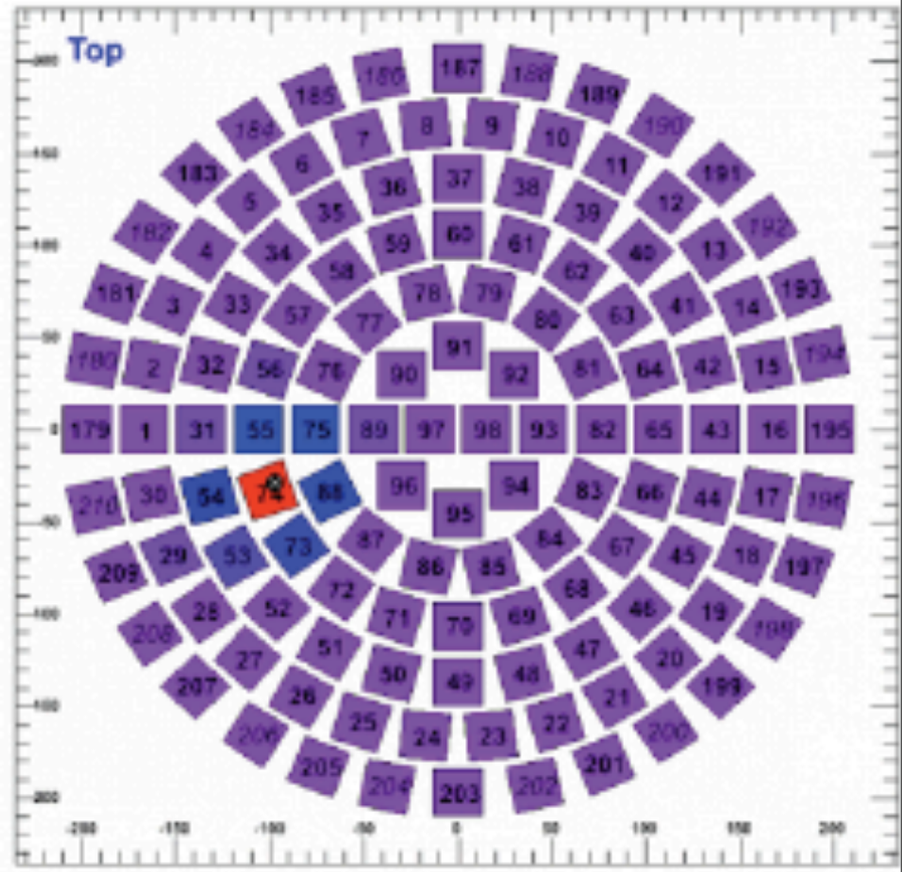
- Total events: 8,311,703
- 4pe < S1 < 30pe: 608,532
- 48 kg Fiducial Volume cut: 898

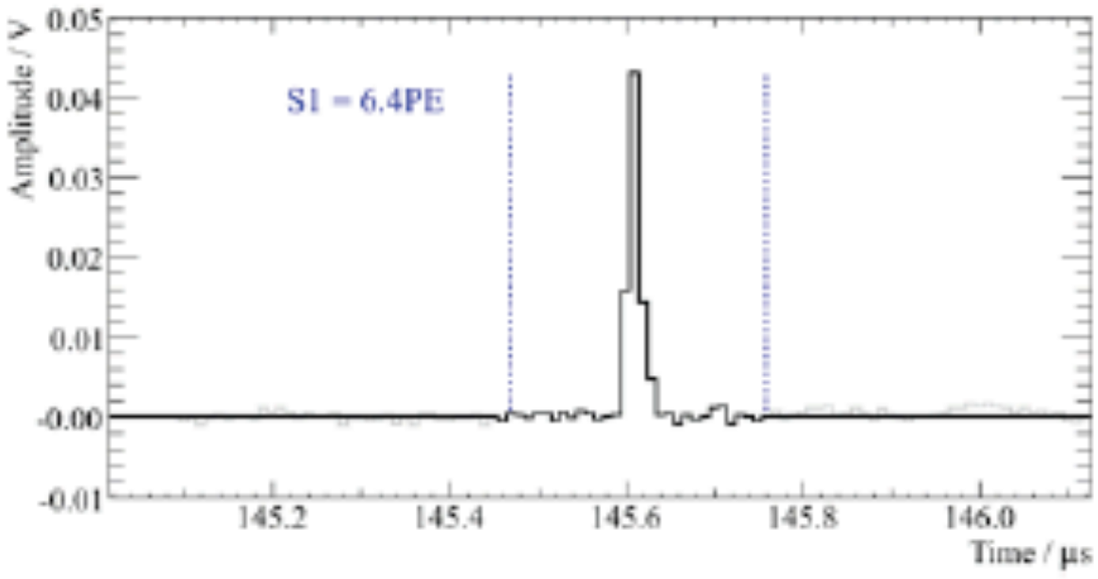
- In signal region (S2/S1): 3 Events
- Expected total background: 1.8 +- 0.6
- 28% probability for 3 or more events
- Profile Likelihood analysis also gives no significant signal

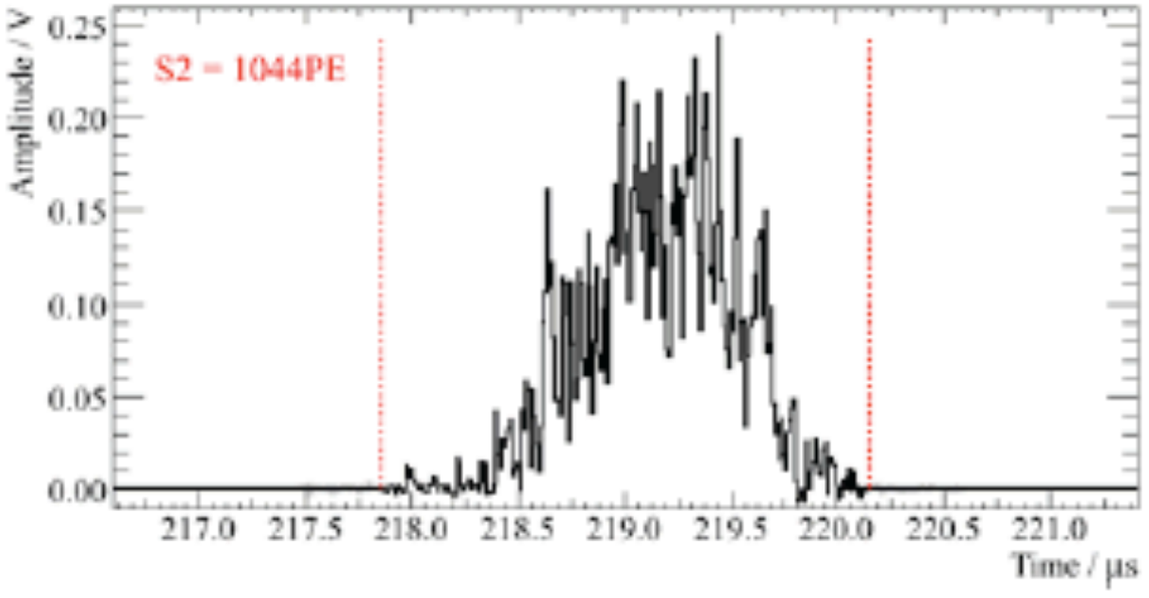


One of the 3 Candidate Events



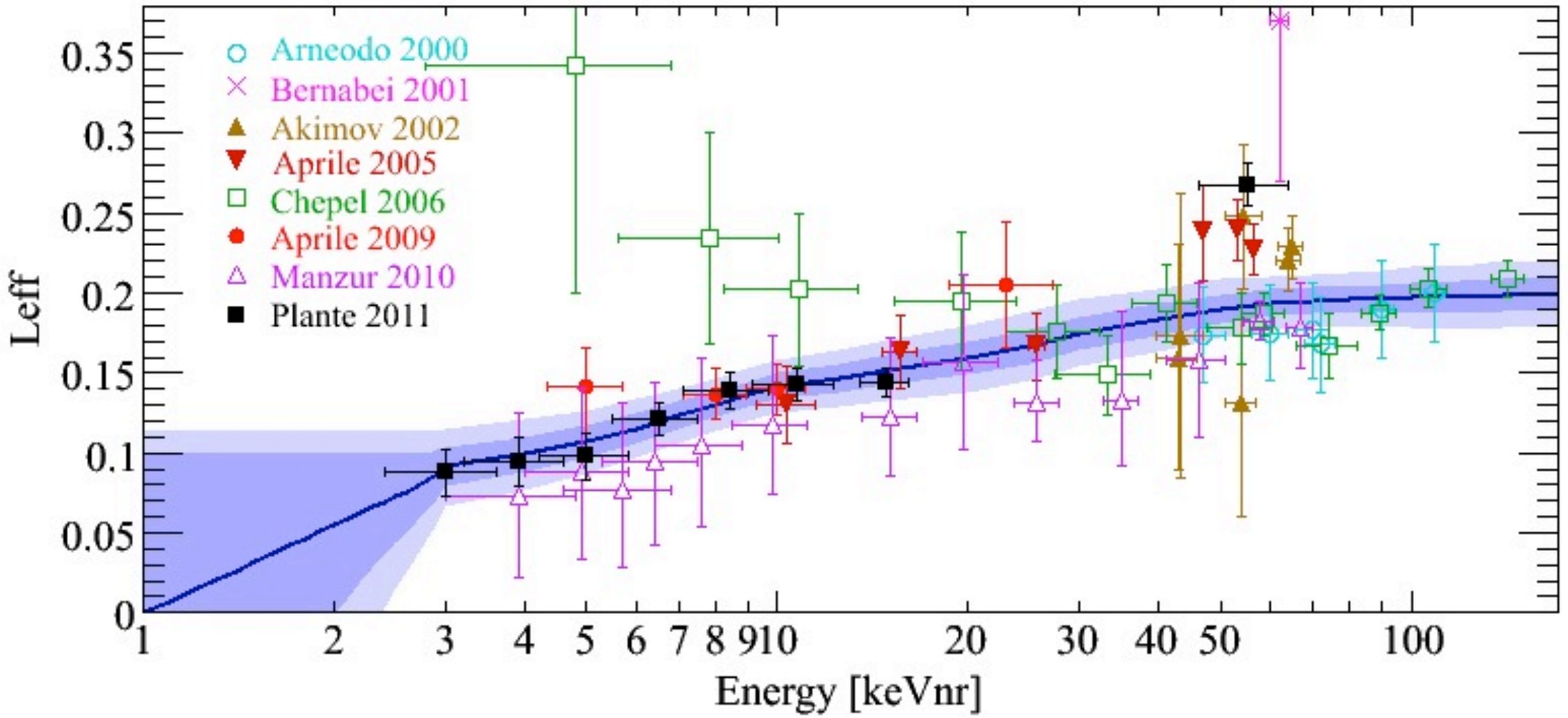






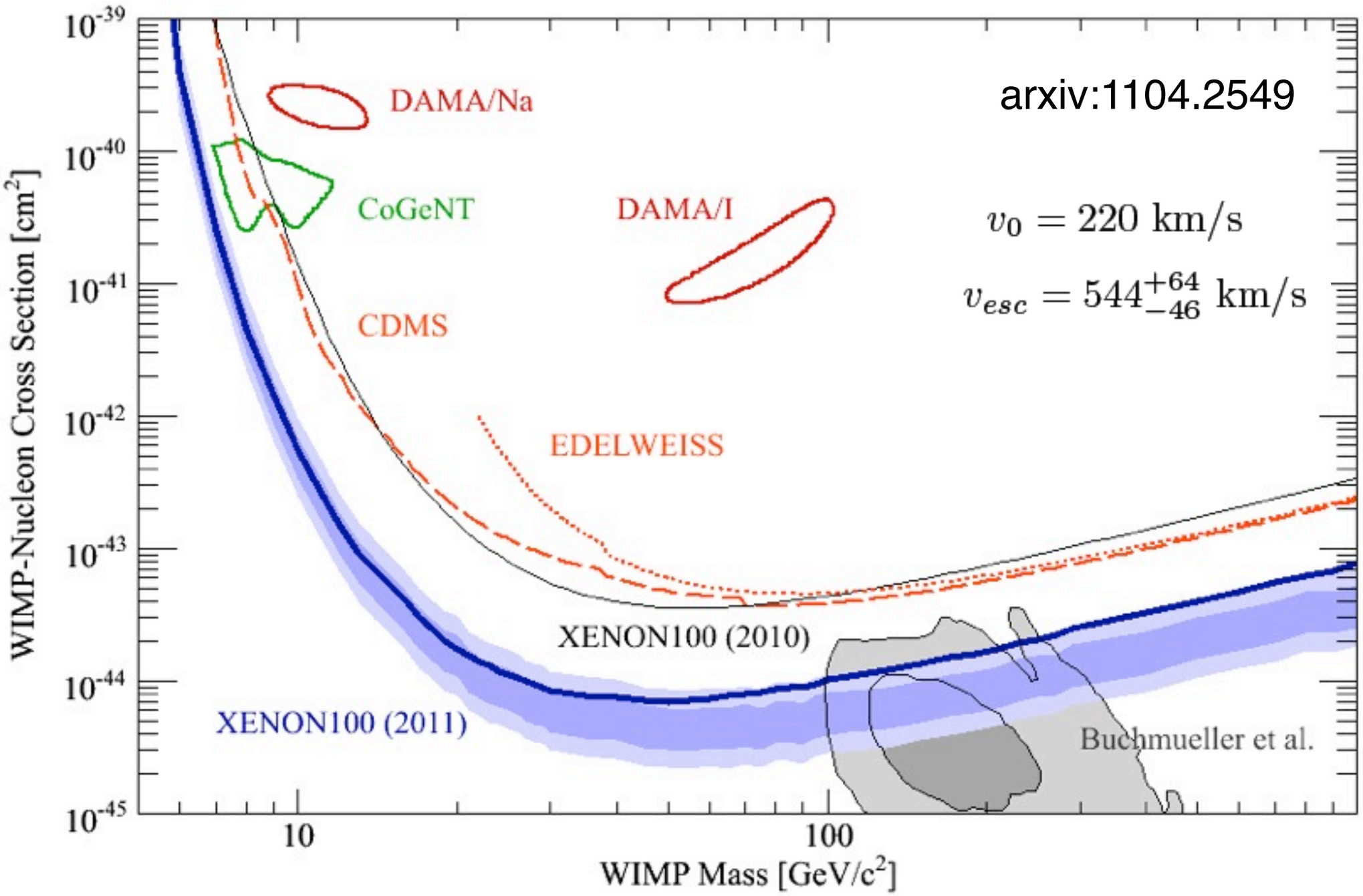
Nuclear Recoil Energy Scale

$$\mathcal{L}_{\text{eff}} = \frac{L_{y,\text{nr}}}{L_{y,\text{er}}} = \frac{1}{L_y}\frac{N_{\text{pe,nr}}}{E_{\text{nr}}}$$



Plante et al. - submitted to Phys. Rev. C

XENON100 Dark Matter Limit (90% CL)

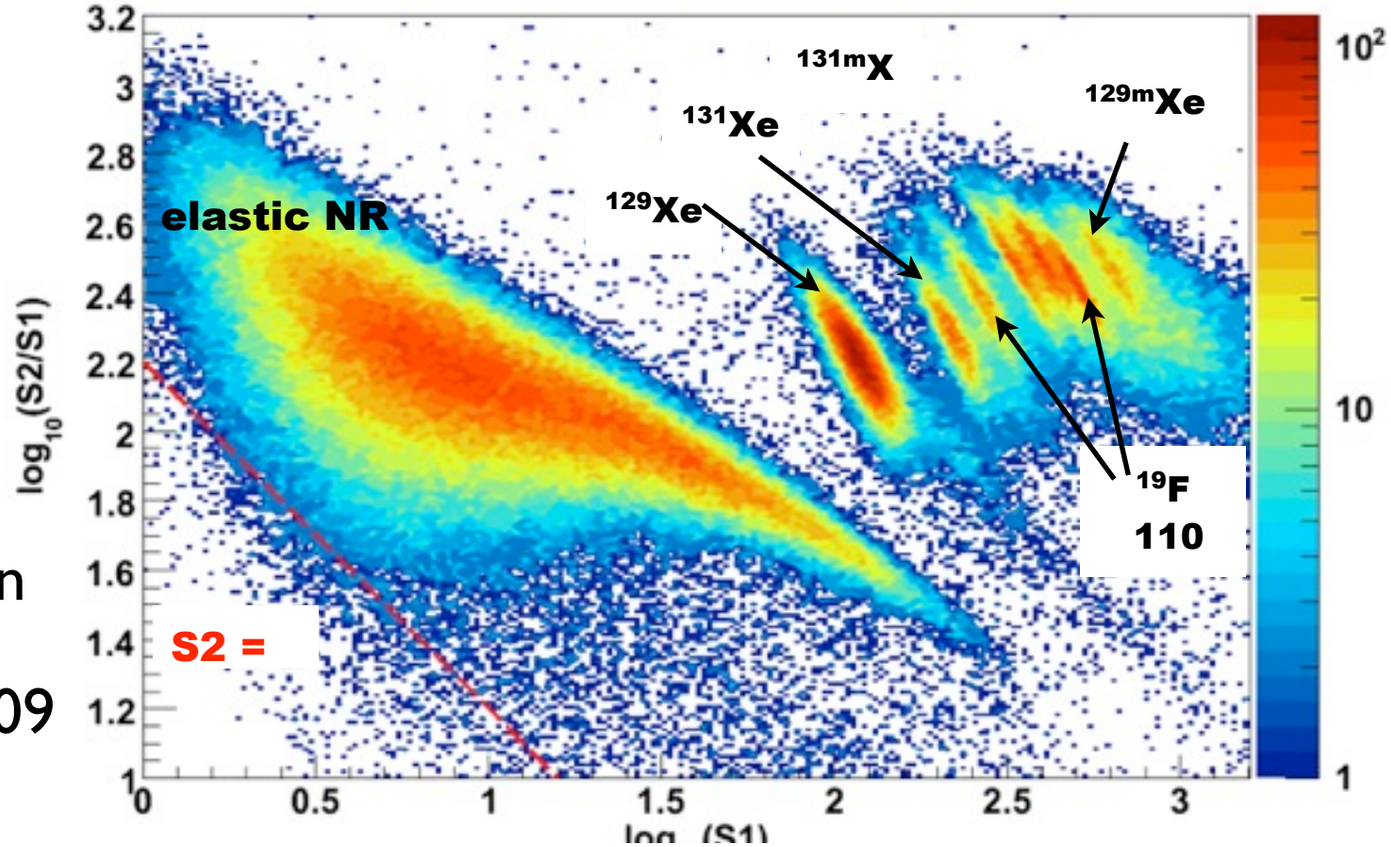


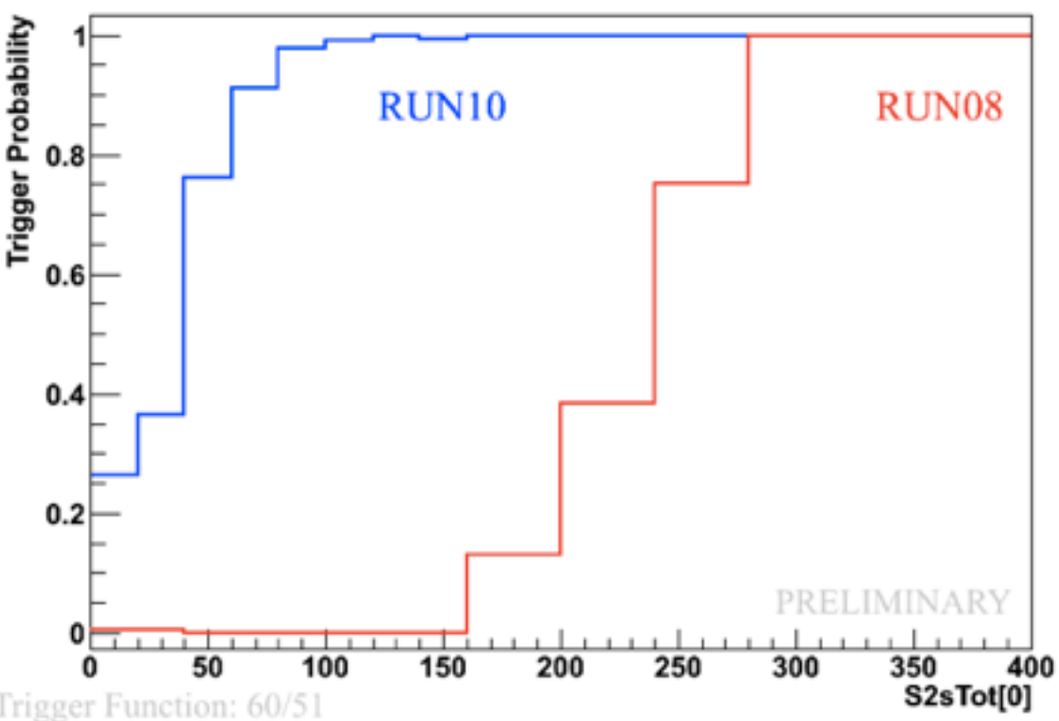
Blue bands are 1 and 2 sigma expectations (PL) based on zero signal

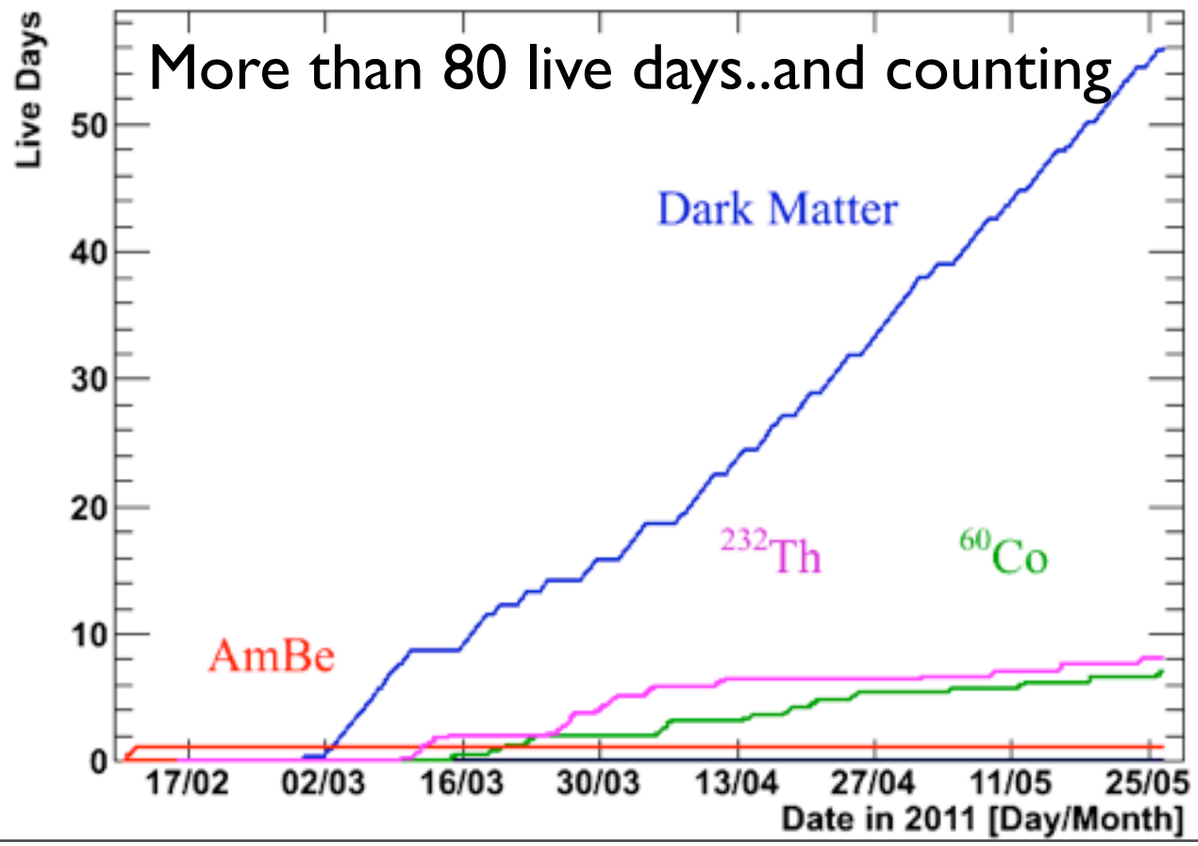
Minimum at 7 x 10 $^{-45}$ cm^2 @ 50 GeV

XENON100 Status & Outlook

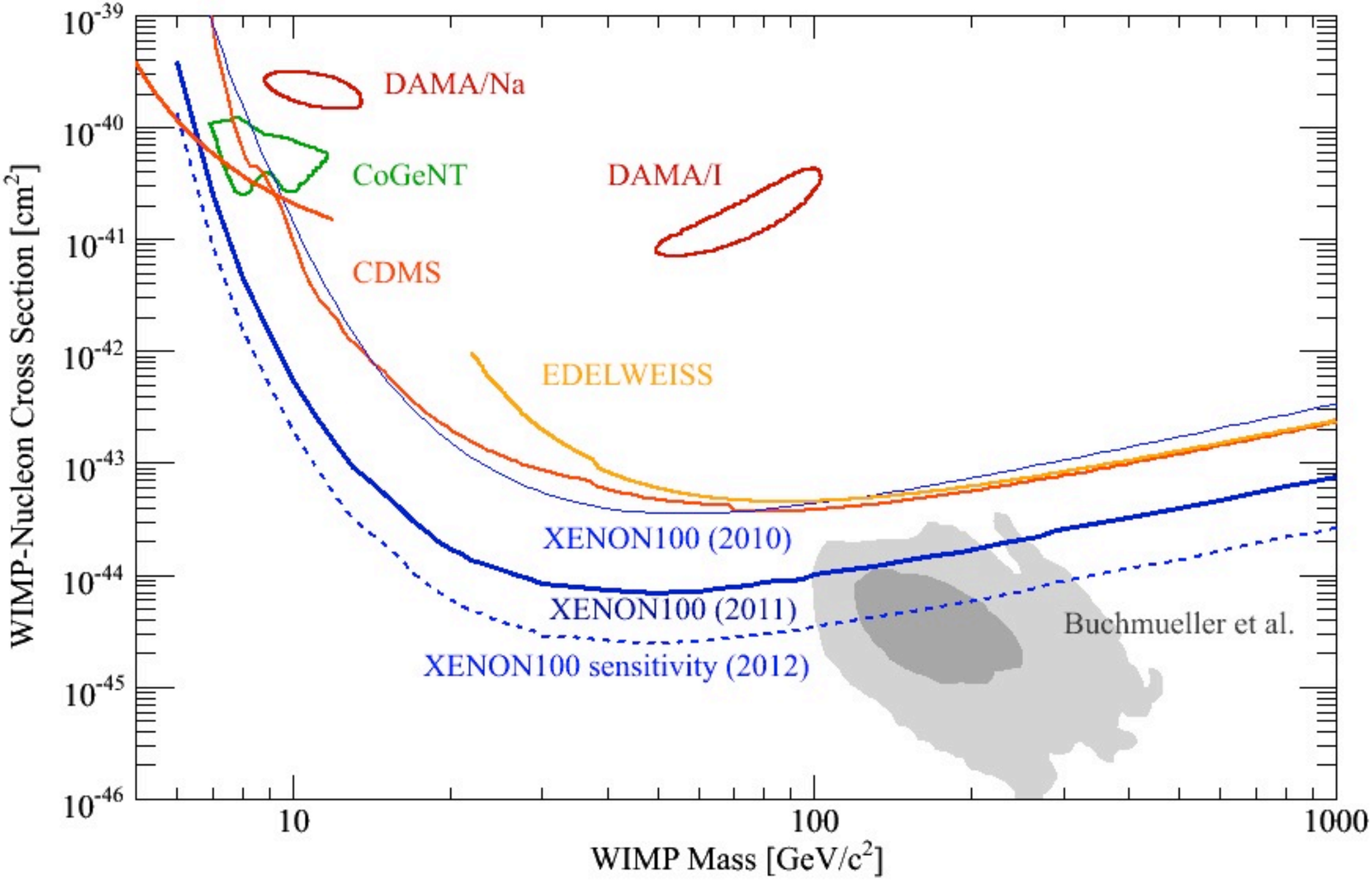
- Serviced Cryogenic System
- Run Kr distillation column
- Lowered S2 Trigger Threshold
- Completed new AmBe Calibration
- Taking large Co60 & Th232 Calibration
- Background at the same level as in 2009
- Detector Parameters very stable





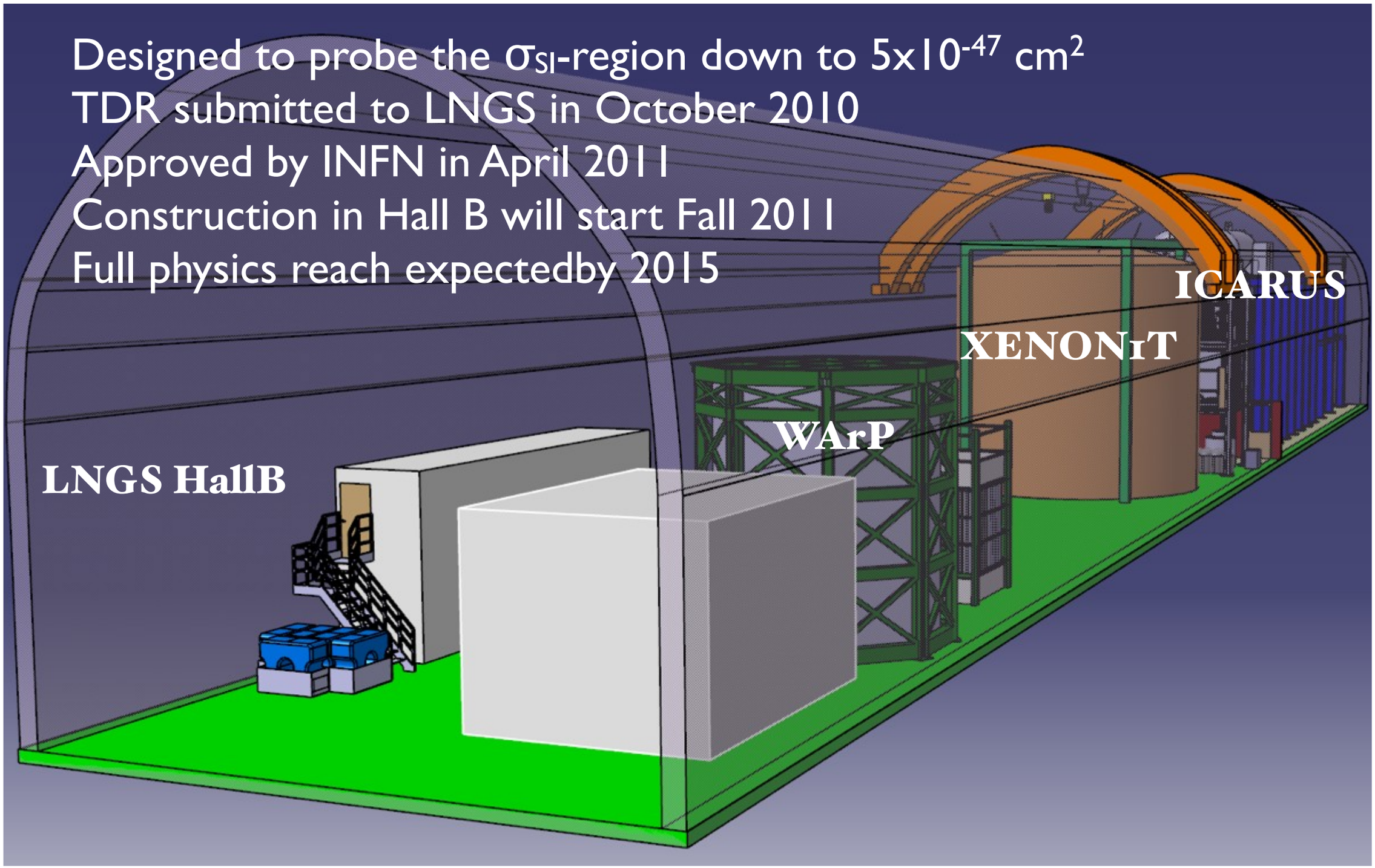


XENON100 by 2012



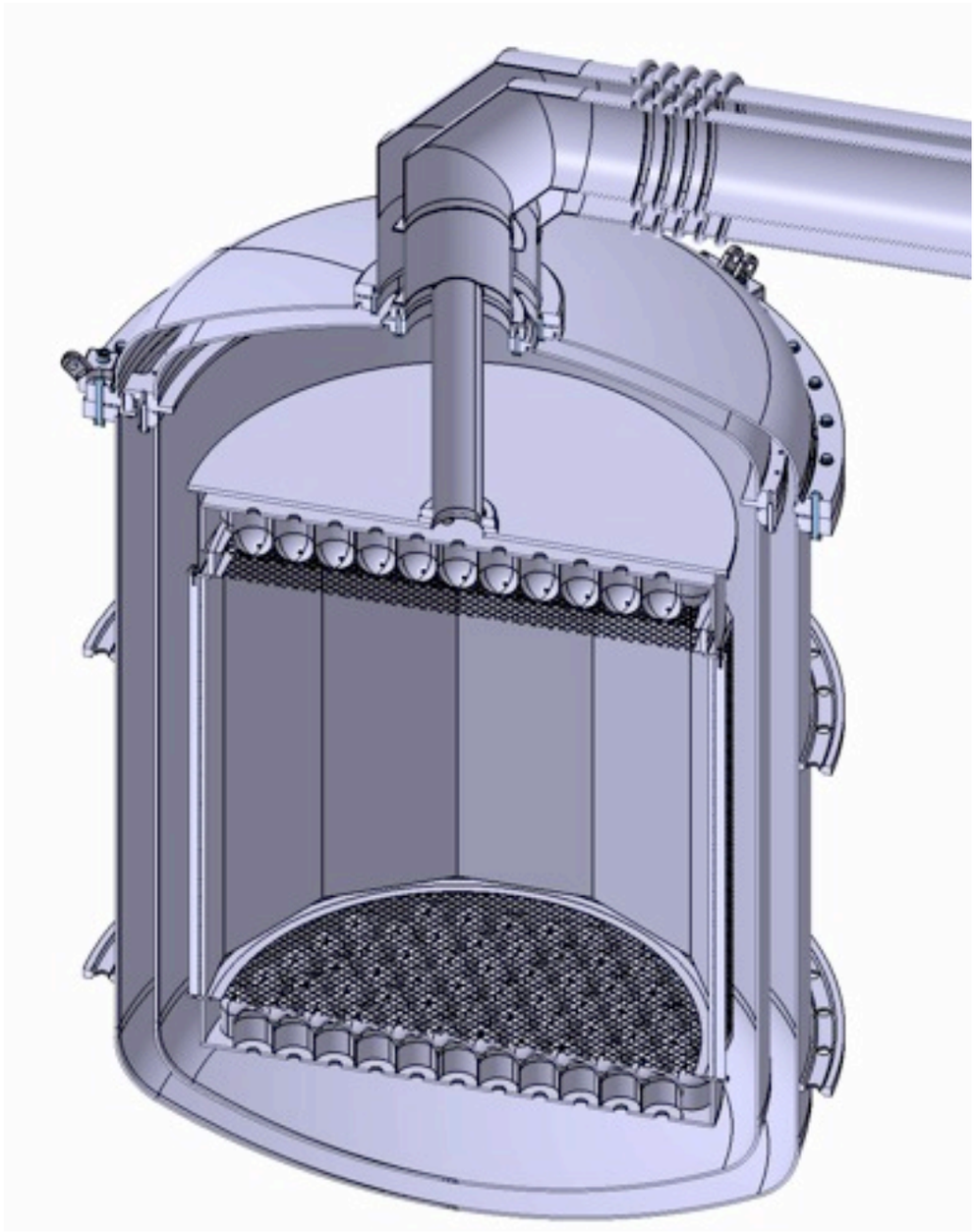
The XENONnT Experiment

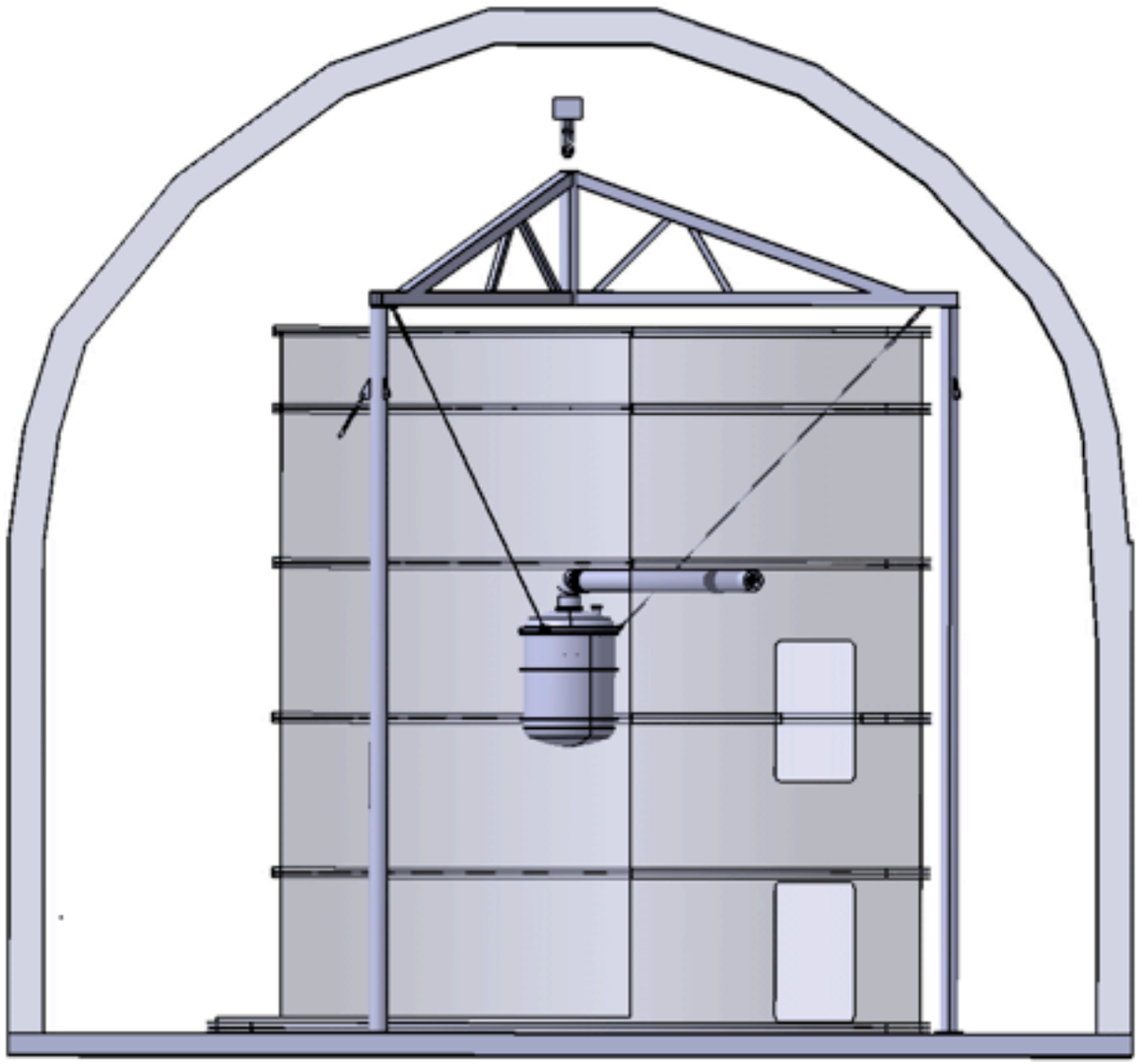
Designed to probe the σ_{SI}-region down to 5×10^{-47} cm^2
TDR submitted to LNGS in October 2010
Approved by INFN in April 2011
Construction in Hall B will start Fall 2011
Full physics reach expectedby 2015



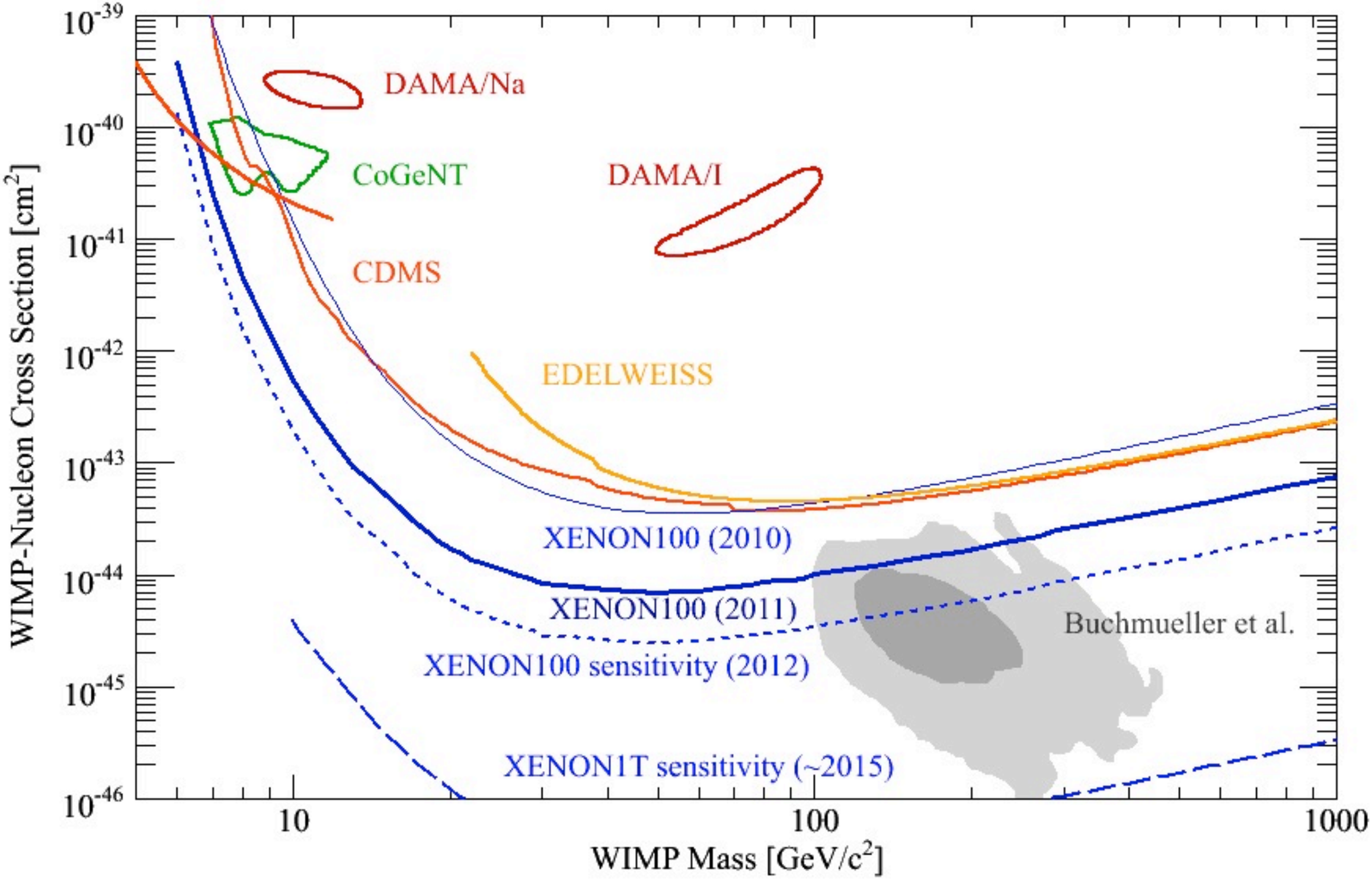
XENONnT at LNGS

- 2.5 t LXe (1 m^3 TPC) for 1t fiducial target mass
- Goal is 100 x lower background: LXe self-shielding, Ti vessels, low radioactivity PMTs and 10 m x 10 m water shield as active muon veto





XENONnT by 2015



Summary

- XENON100 has achieved its design goal of 100 times less background than XENON10 and is currently the most sensitive WIMPs direct search.
- No evidence for WIMPs in 100 days of data from 2010 search.
- Placed the most stringent limit on spin-independent WIMP-nucleon cross section. Minimum at 7 x 10^{-45} cm^2 @ 50 GeV. Started to probe favorite SUSY models.
- XENON100 result does not support low mass WIMPs and exclude iDM.
- New Dark Matter search with lowered intrinsic background ongoing. We expect to reach XENON100 design goal of 2 x 10^{-45} cm^2 by 2012.
- XENON1T design advances, with feedback from R&D studies on enabling technologies. Experiment approved by INFN to be located at LNGS HallB.
- Sensitivity reach is 5 x 10^{-47} cm^2 by 2015. Important synergy with other direct searches, with the LHC and indirect searches