Westfälische Wilhelms-Universität Münster

XENON Dark Matter Project

Results and Status of the XENON Dark Matter Project

On Behalf of the **XENON** collaboration

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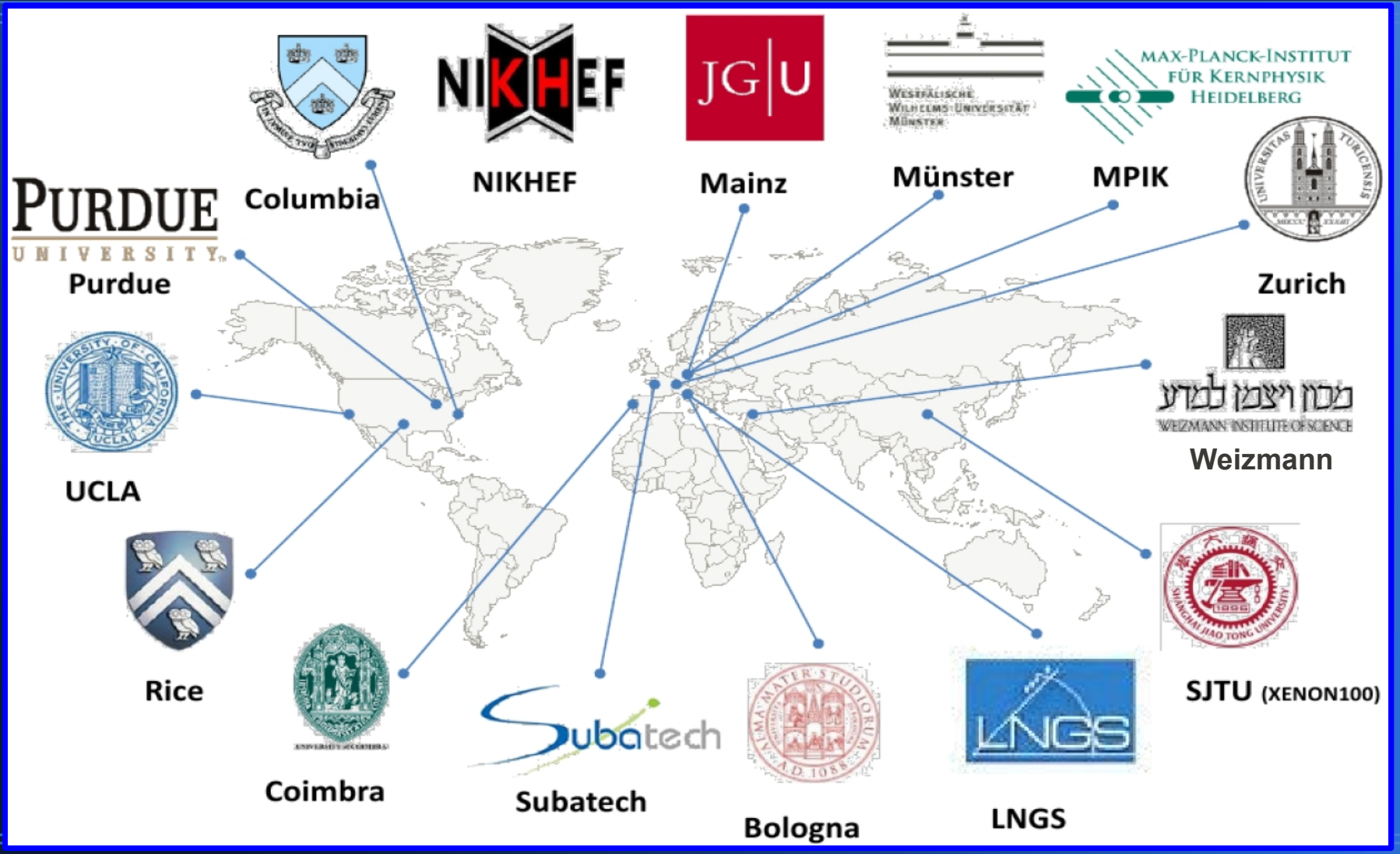
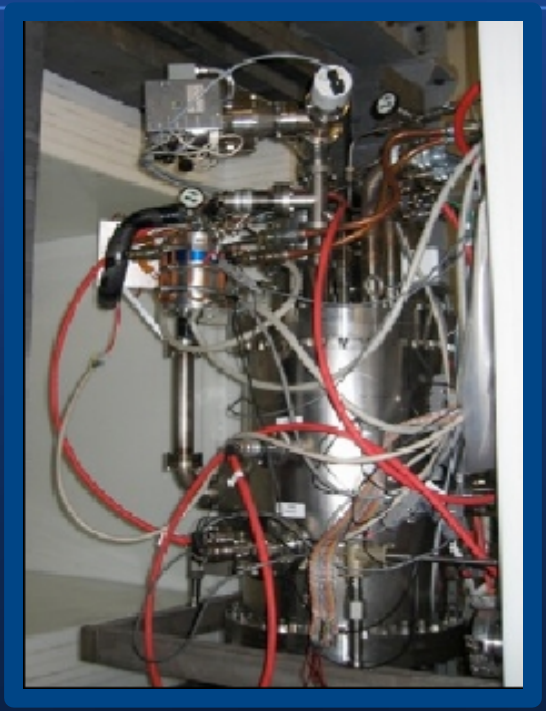
Dark Matter Silver Jubilee Symposium – June 19, 2012

XENON Collaboration



XENON Program



Past: 2005 - 2007

XENON10

$\sigma_{SI} < 8.8 \times 10^{-44}$ cm^2

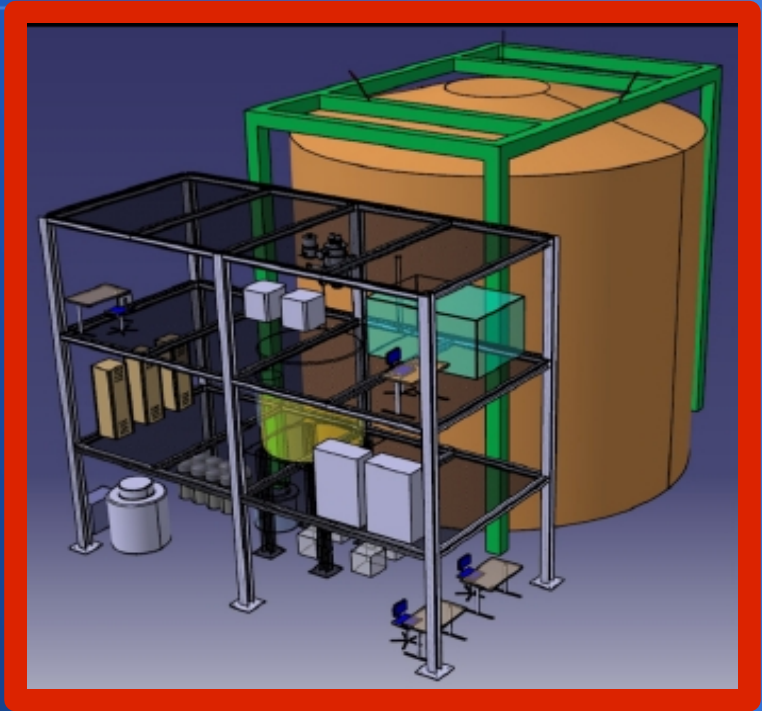
Present: 2008 - 2012

XENON100

$\sigma_{SI} < 7.0 \times 10^{-45}$ cm^2

Final Sensitivity:

$\sigma_{SI} = 2.0 \times 10^{-45}$ cm^2



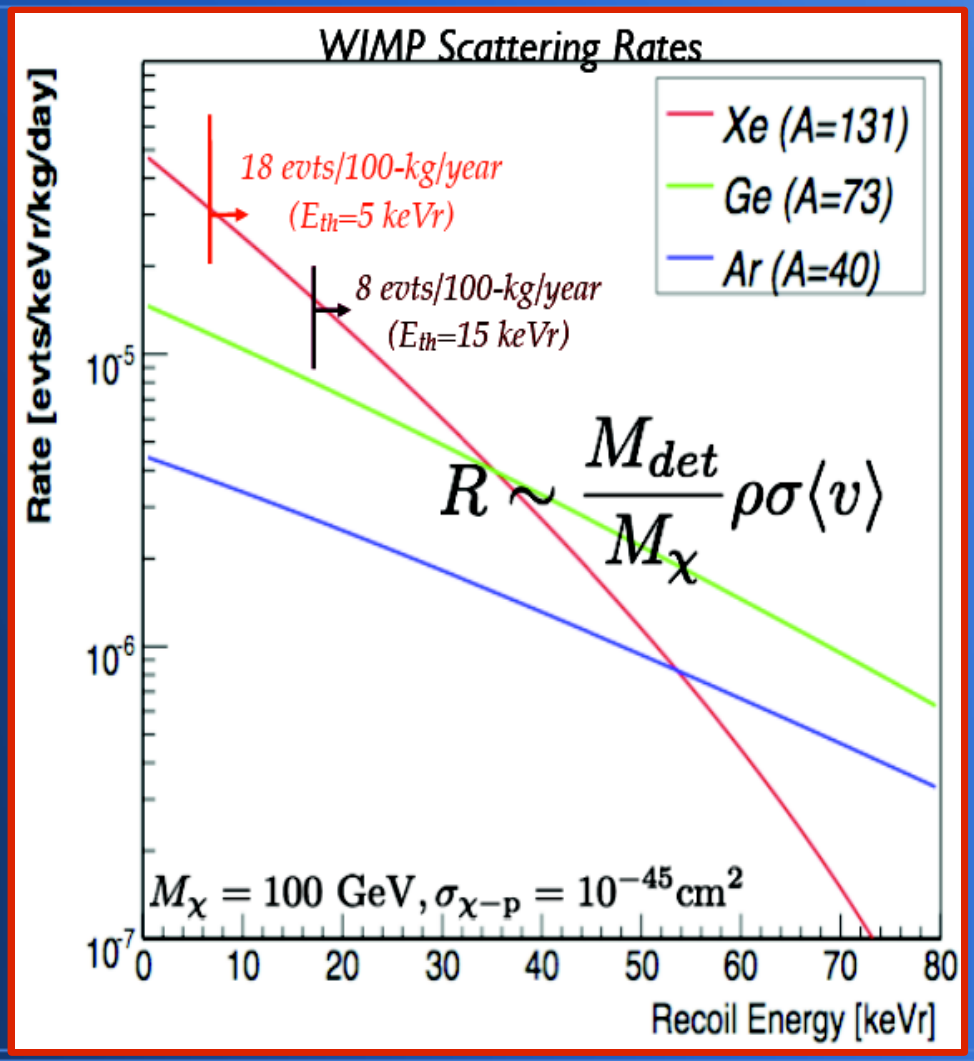
Future: 2012 - 2017

XENON1T

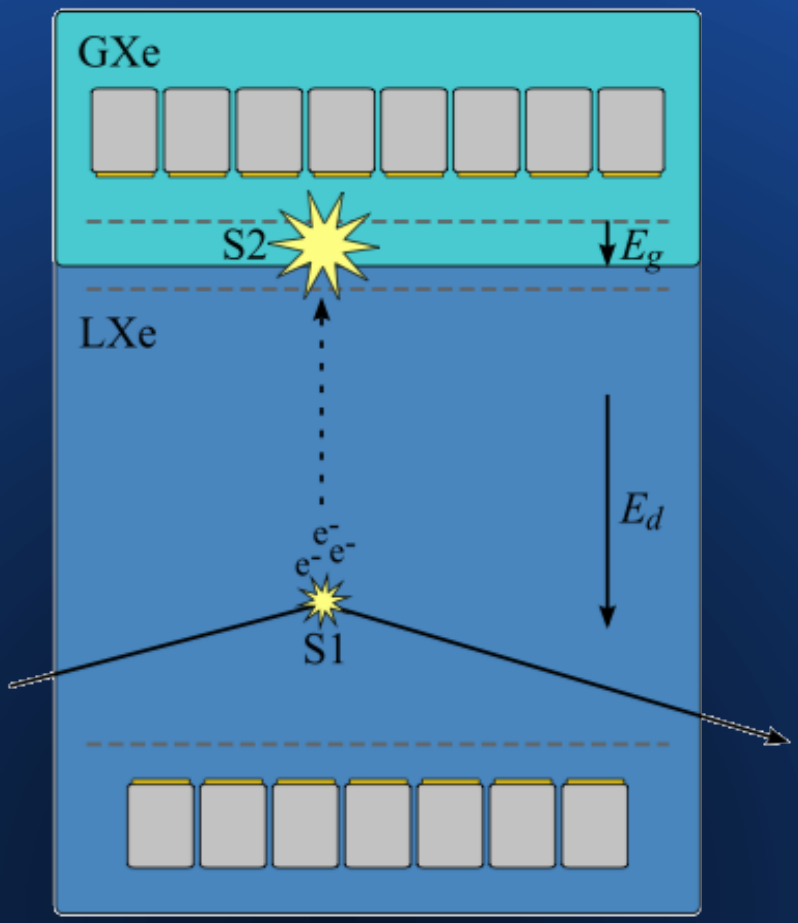
$\sigma_{SI} \sim 10^{-47}$ cm^2 (projected)

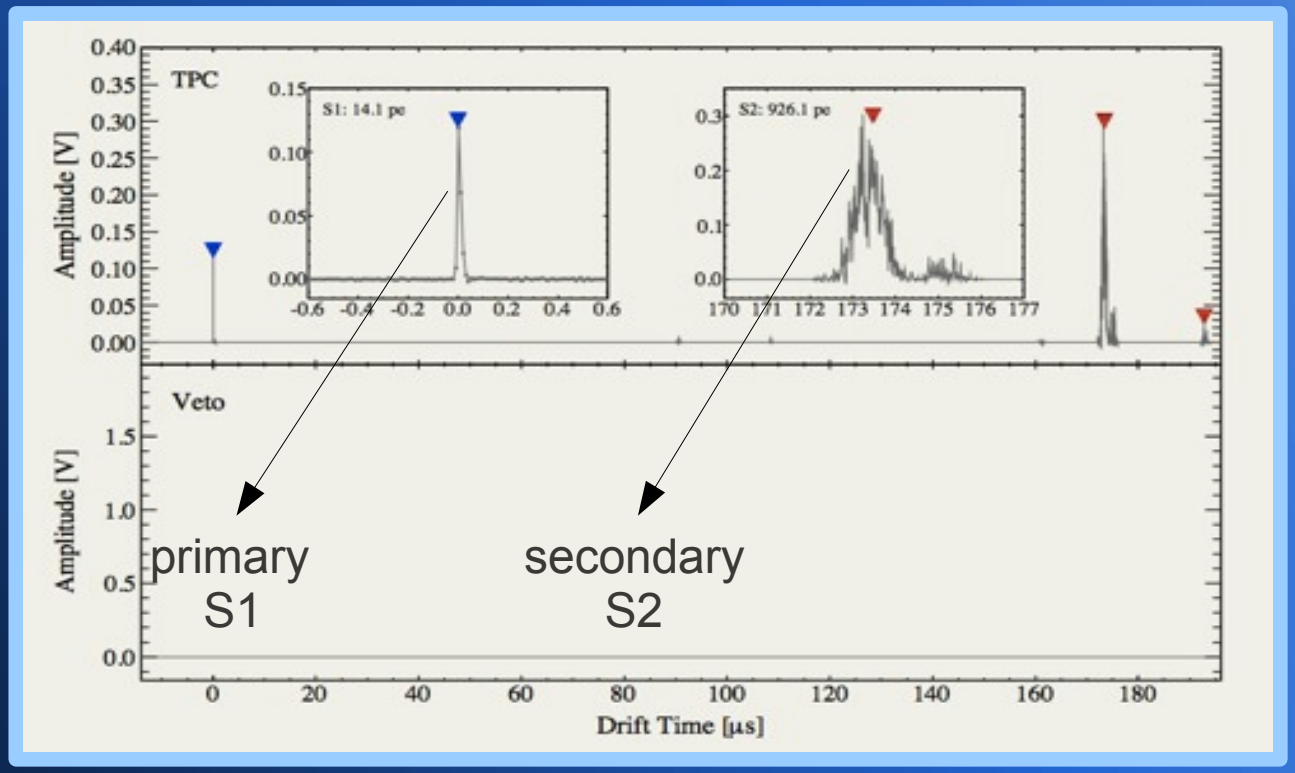
Reminder on the Properties of Xenon

- Heavy nucleus (A~131): good for SI (coherent scattering off all nucleons) plus SD sensitivity (~50% odd isotopes)
- Charge & Light: highest yield among noble liquids and best self-shielding
- Low energy threshold: PMTs within liquid for efficient light detection
- Background rejection: by charge-to-light ratio, 3D-event reconstruction and fiducialization, LXe self-shielding
- Intrinsically pure: no long-lived radioactive isotopes
- Scalability: massive target at modest cost (<1k$/kg), effort scales with surface while sensitivity scales with volume



Xenon Dual Phase TPC





Detect two signals with photomultipliers:

→ Prompt scintillation (S1)

→ Ionization via proportional scintillation (S2)

The XENON100 Detector

TPC:

- 30 cm drift length and 30cm ϕ
- 161 kg total (62 kg sensitive volume)
- Material screening and selection
- Active liquid xenon veto
- 100x lower background than XENON10

E. Aprile et al. Phys.Rev.D83:082001,2011

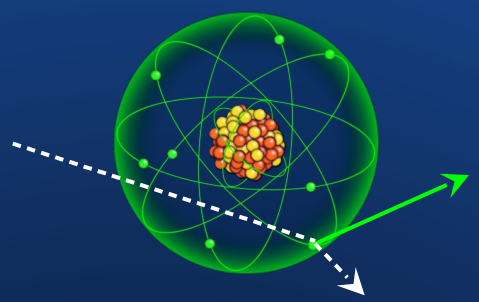
PMTs:

- 242 Hamamatsu R8520 in TPC and Active Veto
- High QE: Bottom tubes > 30%
- Low Radioactivity: < 10 mBq/PMT

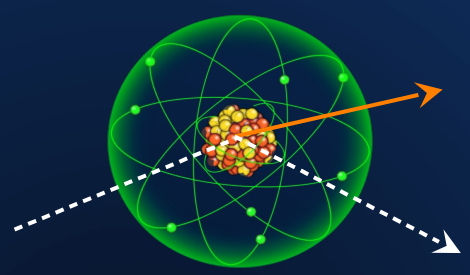
E. Aprile et al. (XENON100), Astroparticle Physics 35, 573 (2012).

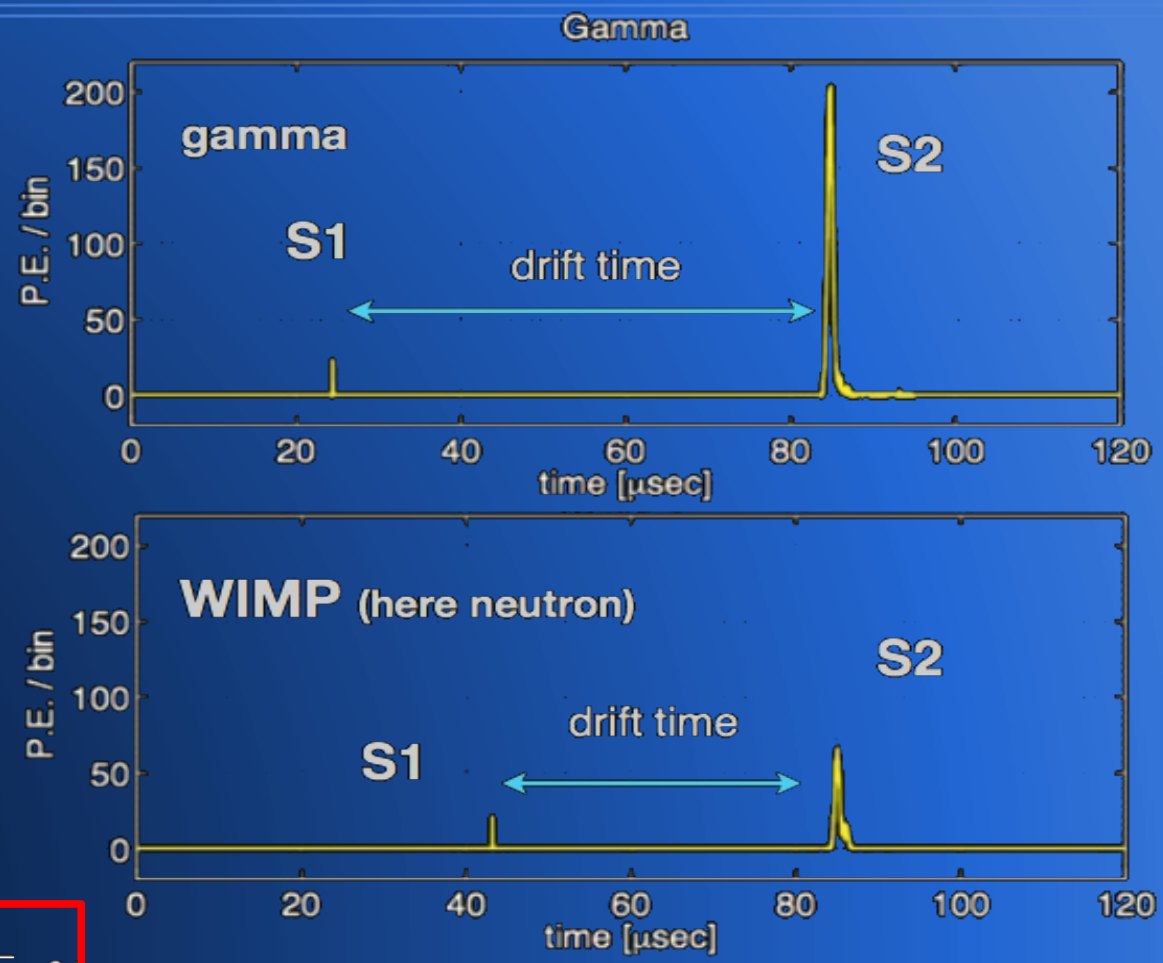
Recoil Discrimination

e-/γ: electronic recoil



n/WIMPs: nuclear recoil





$$(S2/S1)_{n,\chi} << (S2/S1)_{e^-,\gamma}$$

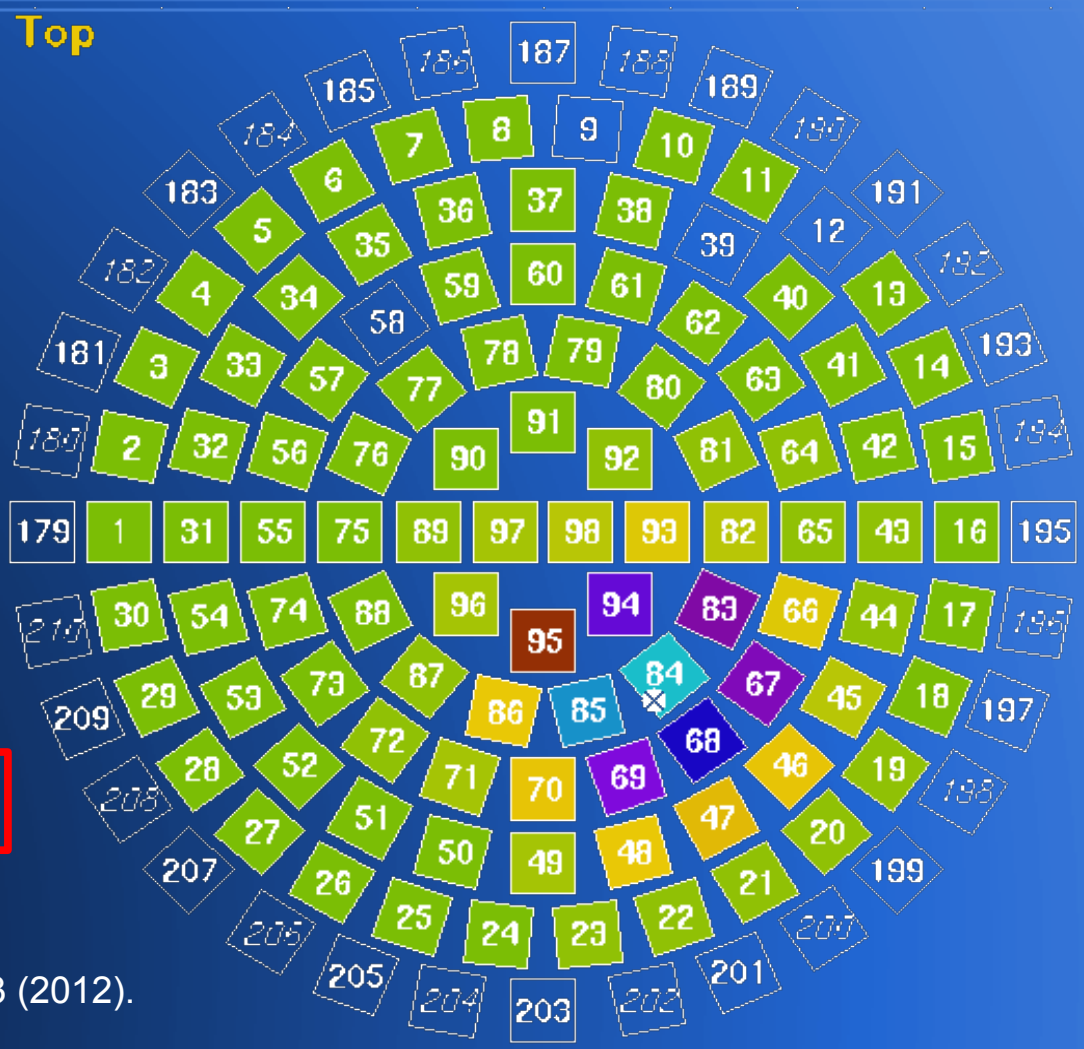
Position Reconstruction

- Z position given by drift time measurement, t(S2) - t(S1):

→ $\delta z < 300\ \mu m$

- XY position given by S2 hit pattern:

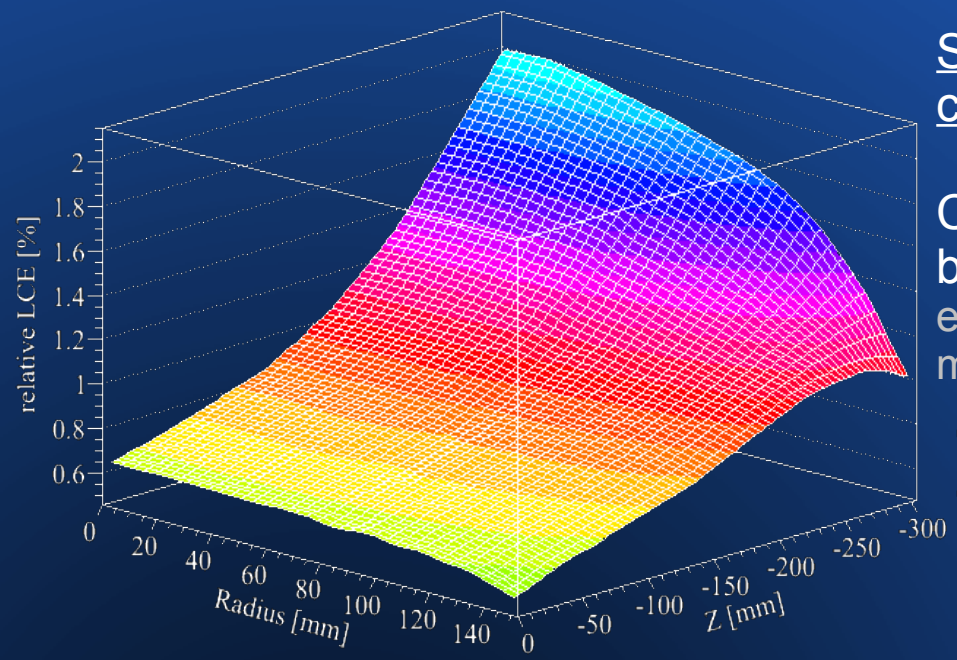
→ $\delta r < 3mm$



3D position reconstruction

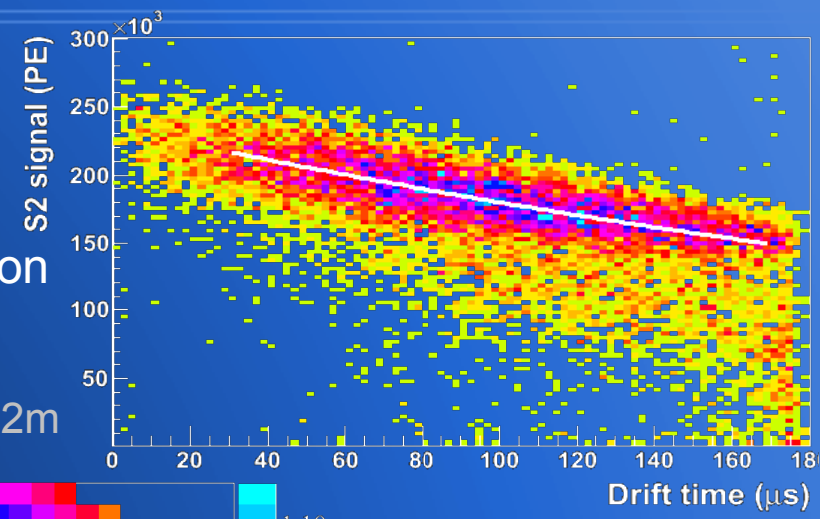
E. Aprile et al. (XENON100), Astroparticle Physics 35, 573 (2012).

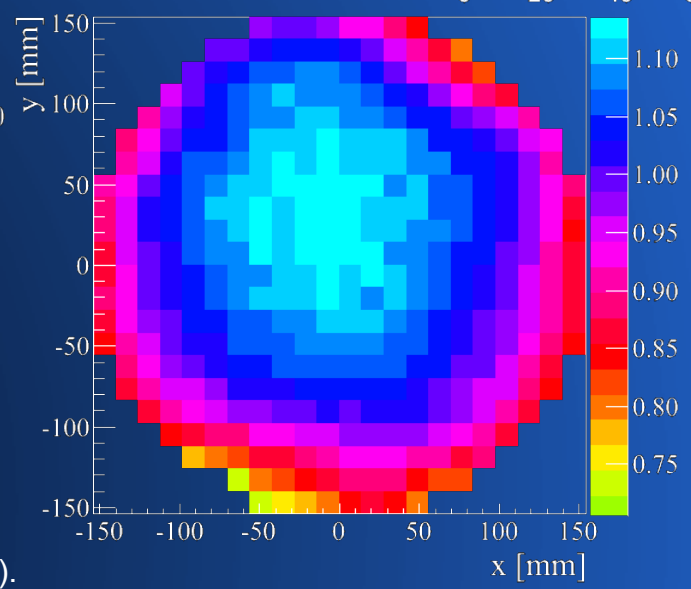
Position Dependent Corrections



S2 based correction:

Charge attenuation by drift time:
e-lifetime ~ 700 us
mean free path ~1.2m





S1 based correction:

Local differences in light yield (in 3D) measured by ^{137}Cs, ^{241}AmBe, ^{131m}Xe

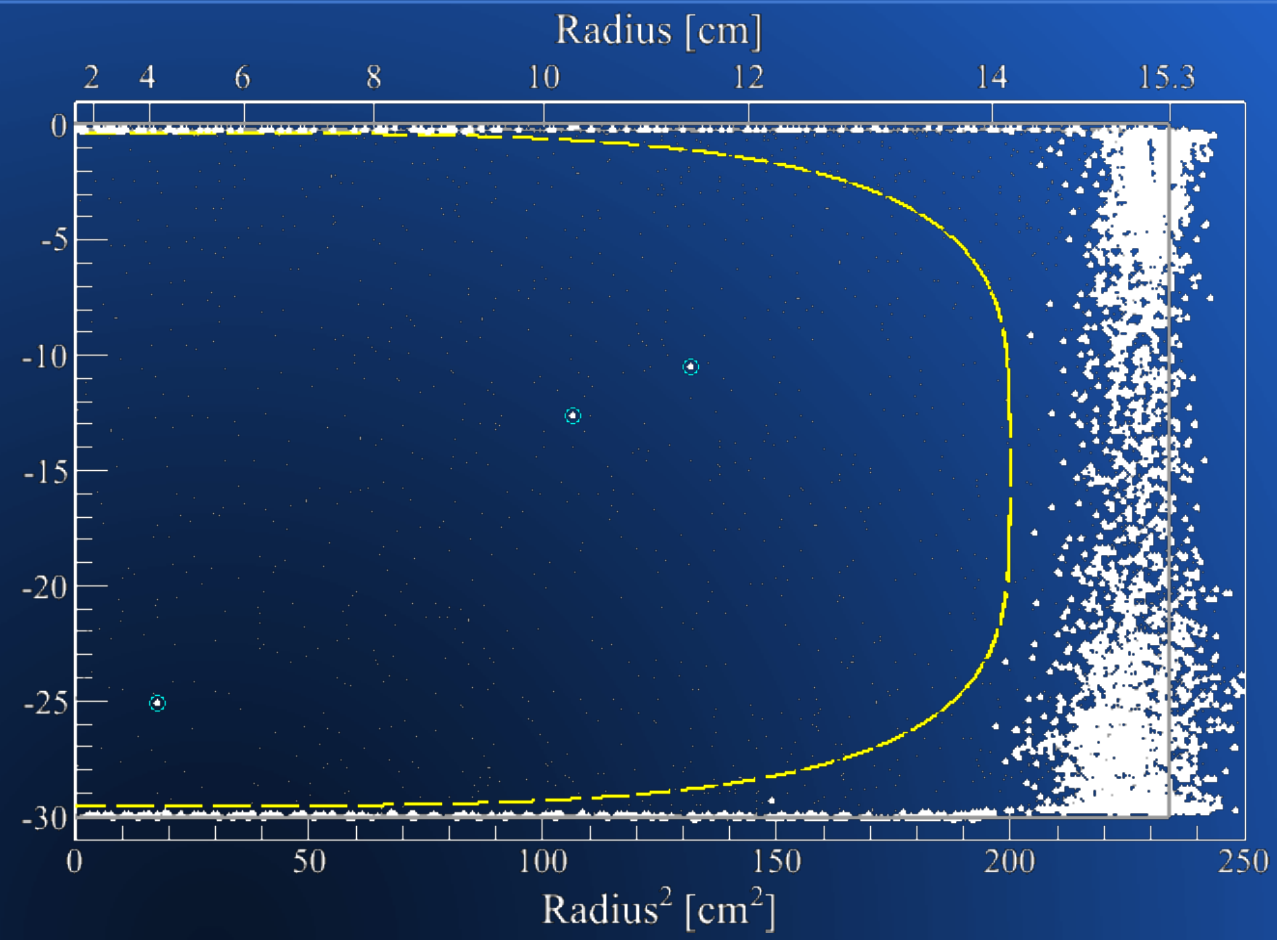
S2 based correction:

XY correction

E. Aprile et al. (XENON100), Astroparticle Physics 35, 573 (2012).

Fiducialization

E. Aprile et al., Phys. Rev. Lett. 107 (2011) 131302



Background for published data

- Look only in quiet central region
- Take advantage of LXe self shielding
- Gammas from external sources and detector components stopped at edges
- Remaining BG dominated by internal impurities (eg ^{85}Kr)

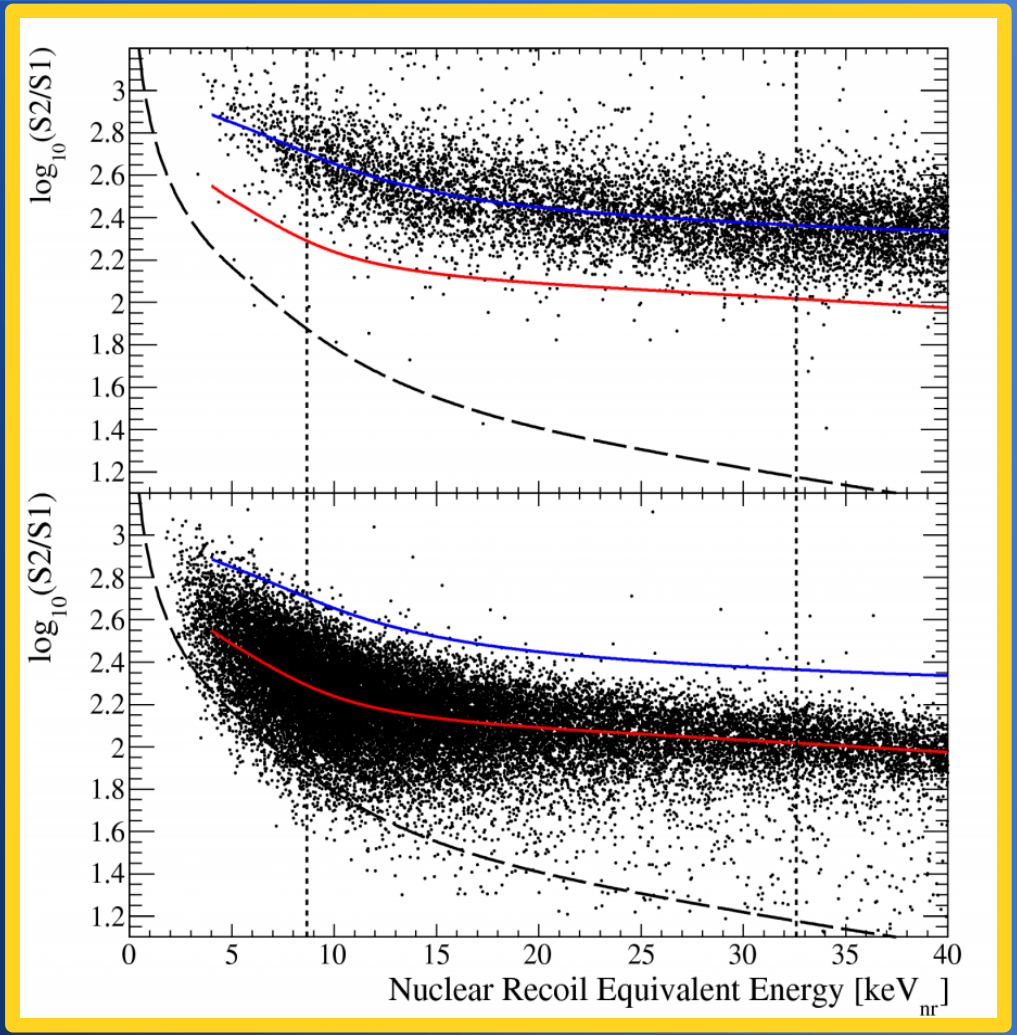
Calibrations

Gamma Calibration Using:

- 662 keV (^{137}Cs)
- 1.17/1.33 MeV (^{60}Co)
- 40 keV (^{129}Xe (n,n'γ)^{129}Xe) by ^{241}AmBe
- 80 keV (^{131}Xe (n,n'γ)^{131}Xe) by ^{241}AmBe
- 164 keV (^{131m}Xe) by ^{241}AmBe
- 236 keV (^{129m}Xe) by ^{241}AmBe

Neutron Calibration Using:

- Nuclear recoils with ^{241}AmBe



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

Nuclear Recoil Energy

- Defining nuclear recoil energy scale:

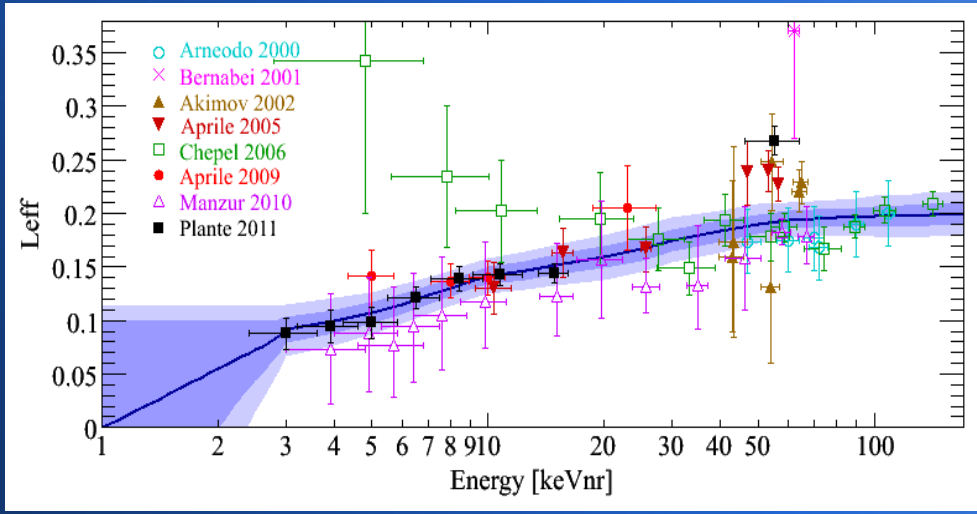
$$E_{nr} = \frac{S1}{L_Y(E_{nr})_E} = \frac{S1}{L_Y(E_{nr})_{E=0} \cdot S_{nr}} \cdot \frac{L_Y(E_{ee}=122\text{ keV})_{E=0}\, S_{ee}}{L_Y(E_{ee}=122\text{ keV})_E} = \frac{S1}{L_Y(E_{ee}=122\text{ keV})_E} \frac{1}{L_{eff}(E_{nr})} \frac{S_{ee}}{S_{nr}}$$

$$L_{eff}(E_{nr}) = \frac{L_Y(E_{nr})_{E=0}}{L_Y(E_{ee}=122\text{ keV})_{E=0}}$$

Fit and extrapolation in good agreement with latest data and theoretical models!

Bezrukov et al, arXiv:1011.3990v2

- S_{ee} , S_{nr} : field quenching terms
- $L_Y(E_{ee} = 122\text{ keV})_E$ measured
- L_{eff} measured in dedicated experiments



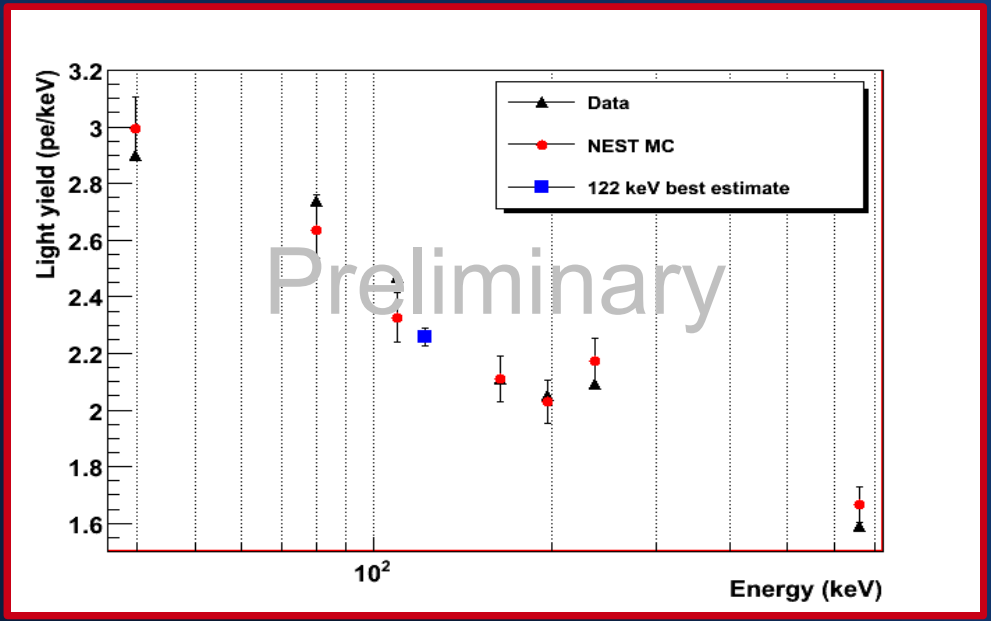
Plante et al.,Phys. Rev. C 84, 045805 (2011)

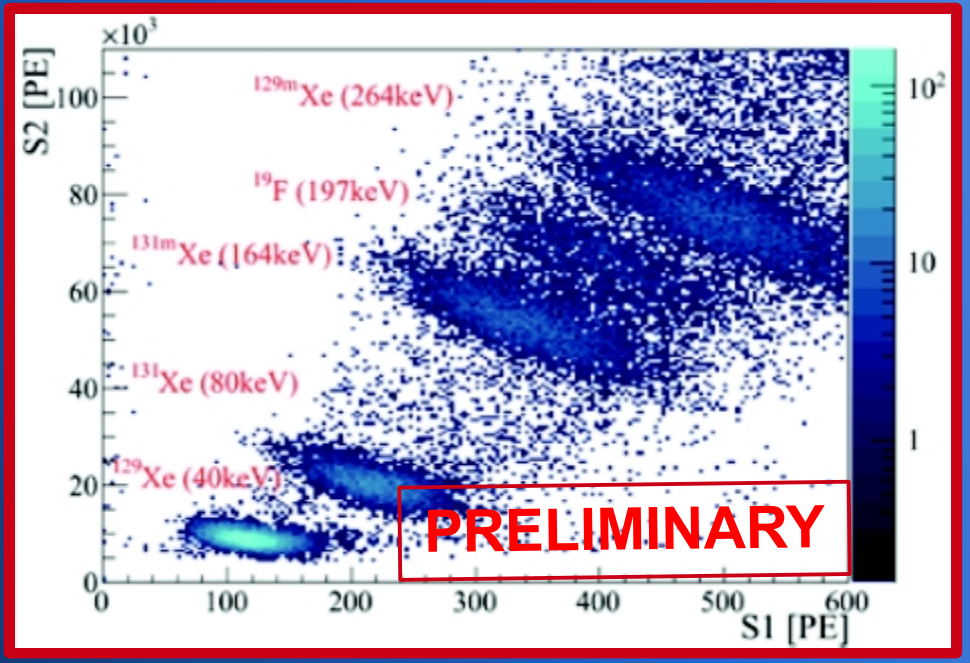
- Use global fit to available data
- Extrapolate below measured values
- Use Profile Likelihood Analysis to account for systematic uncertainties

Light Yield at 122 keV

Estimation of LY at 122keV by:

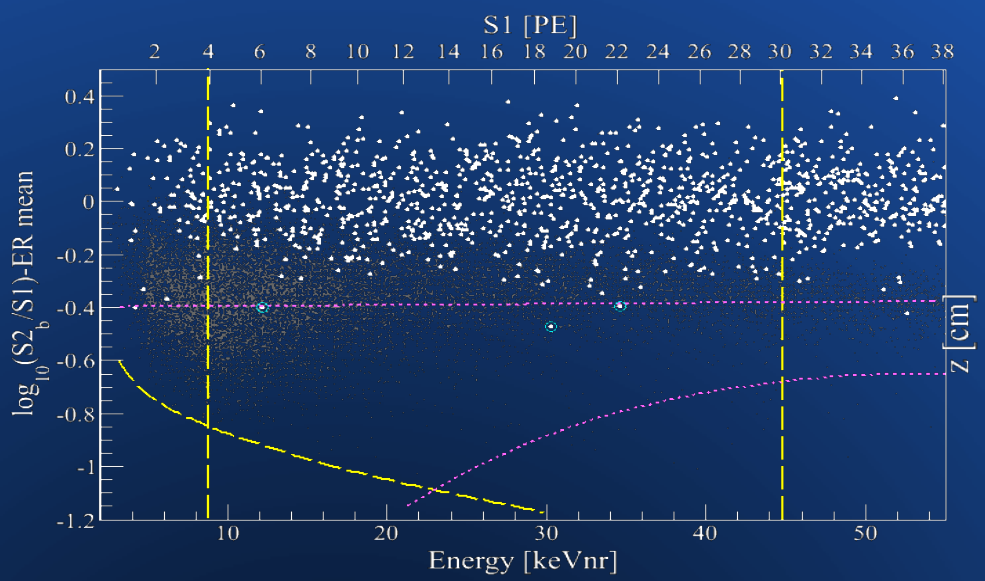
- Calculating LY from lines in ^{241}AmBe, ^{137}Cs
  → Reduce and understand systematic uncertainties
- Using NEST Monte Carlo model
  → Accurately model scintillation process

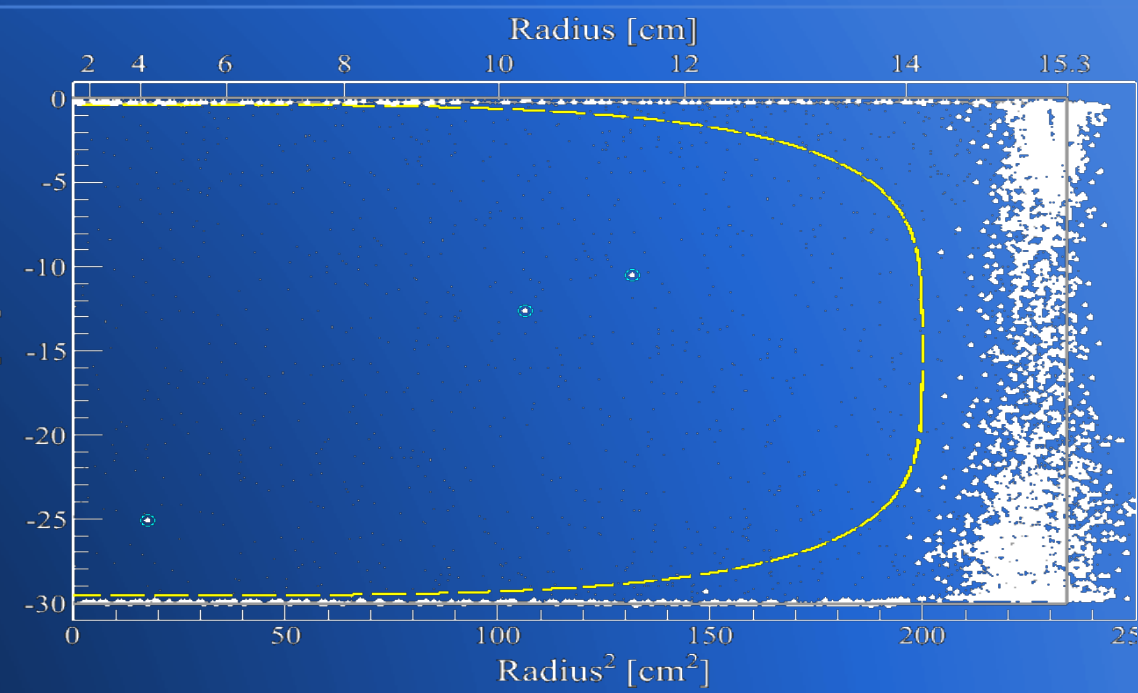




$LY_{122\ keV}$ = 2.26 +- 0.03 pe/keVee

100 Days Dark Matter Search (run8)





Background Prediction:

Electron Recoils:

- Statistical Leakage : 1.14 ±0.48 events
- Anomalous Leakage : $0.56^{+0.21}_{-0.27}$ events

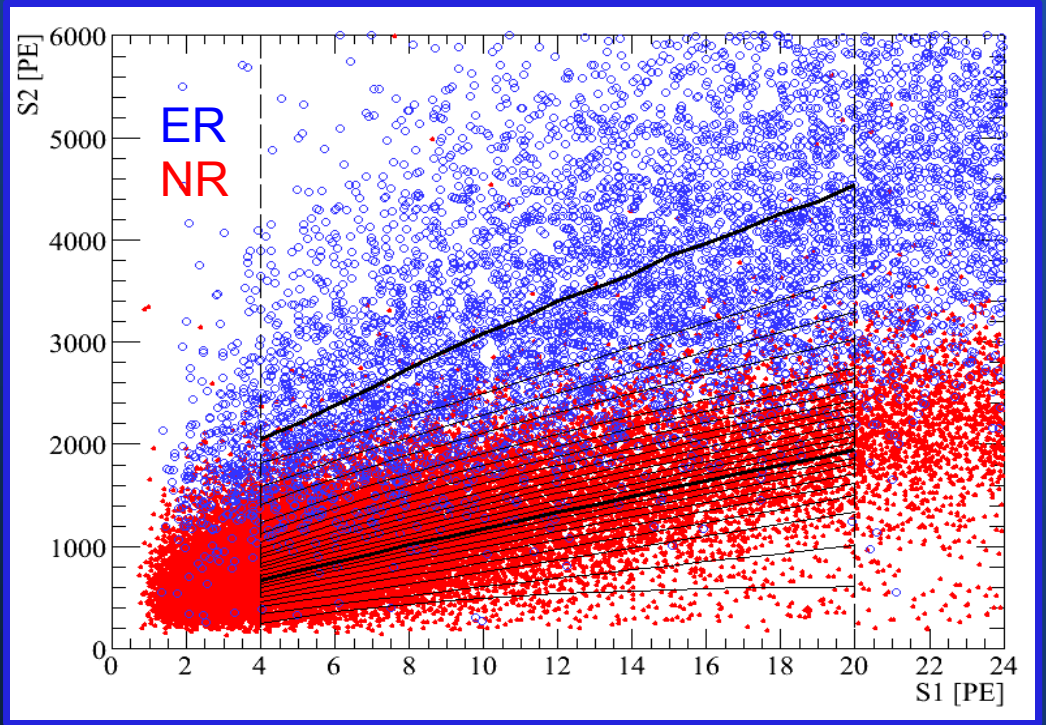
Nuclear Recoils : $0.11^{+0.08}_{-0.04}$ events

Total Expected Background: 1.8 ± 0.6

3 WIMP candidates in search region

E. Aprile et al., Phys. Rev. Lett. 107 (2011) 131302

Profile Likelihood Analysis



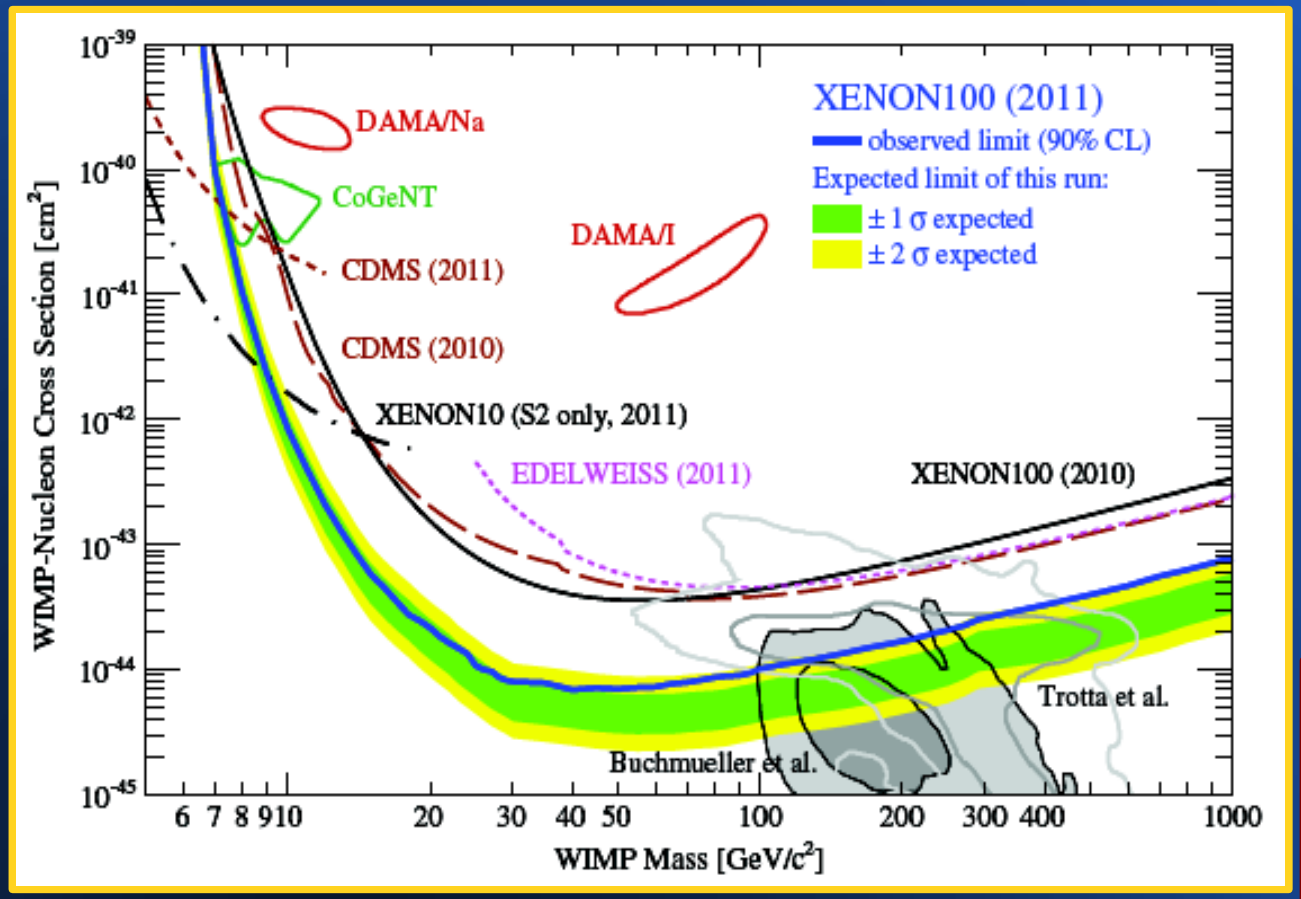
Phys. Rev. D 84, 052003 (2011)

- Consider ALL variables as parameters:
  - All data points from
    - calibration
    - DM run
  - Include systematic uncertainties
    - L_{eff}
    - v_{esc}
- Profile out parameters to perform likelihood analysis

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

Based on all data VS other methods based on events in a box

Results from 100 Days SI Search (2011)



E. Aprile et al., Phys. Rev. Lett. 107 (2011) 131302

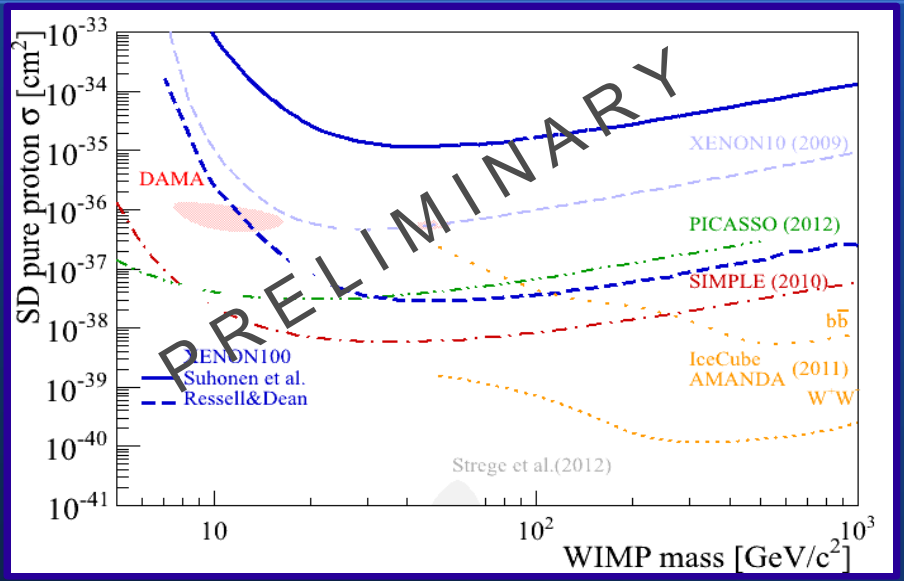
- Profile likelihood analysis used to interpret data

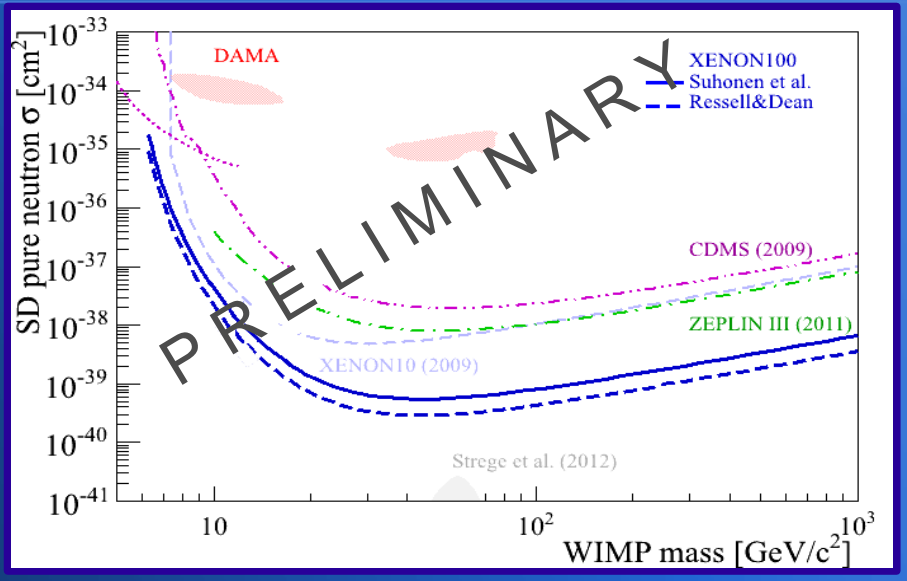
Result not consistent with WIMP signal

World's best upper limit on cross section for a 50GeV/c² WIMP :

$\sigma_{SI} < 7\times10^{-45}\ cm^2$

New Spin Dependent Results from Run8 Data





- Search for spin dependent coupling of WIMPS to ^{129}Xe (26.2%) and ^{131}Xe (21.8%)
- Same 100.9 days data as 2011 SI results
  - → same event selection
  - → profile likelihood analysis

  Phys. Rev. D 84, 052003 (2011)

Two nuclear models used:
- Suhonen et al.
- Ressell & Dean

Pure neutron coupling:
- New best limit worldwide
- Minimal nuclear model dependence

Pure proton coupling:
- Strong nuclear model dependence

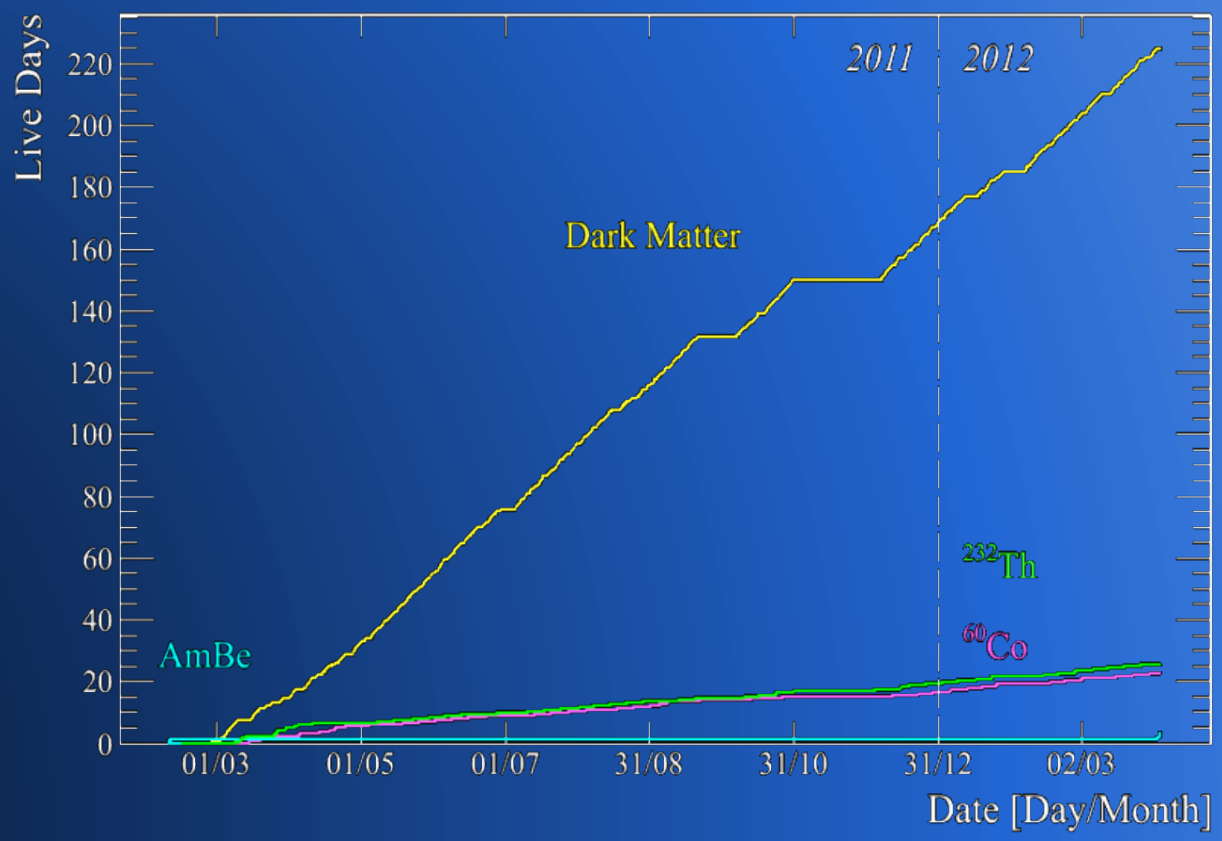
220 Live Days Blinded Dark Matter Data (run10)

- Data Mar 2011 – May 2012

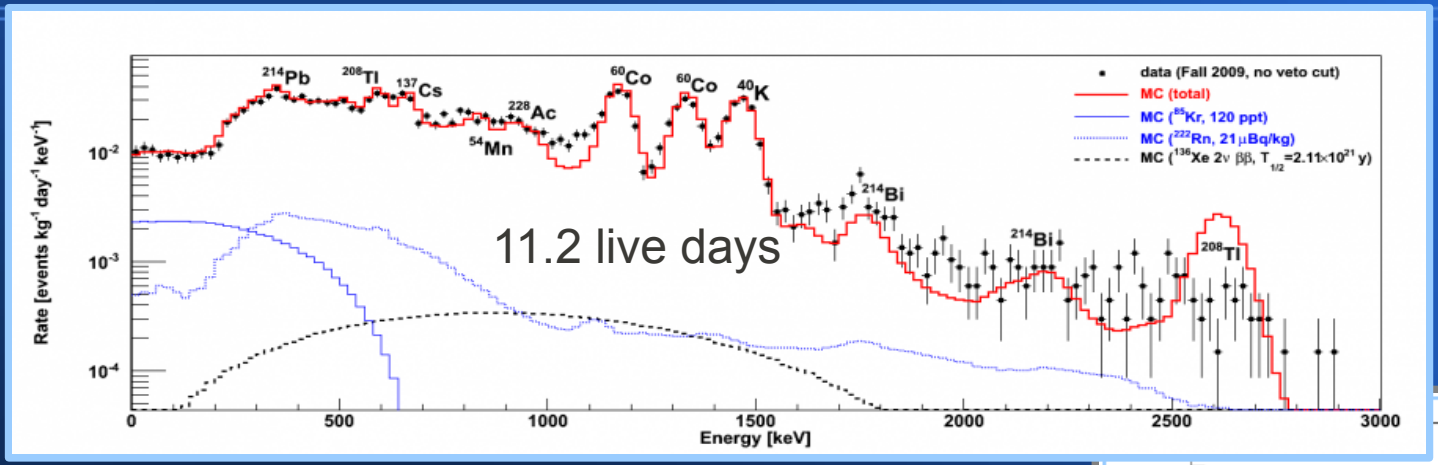
- Decreased ^{85}Kr Background
  - ↳ Kr/Xe significantly reduced
- Lower trigger threshold

- New electron recoil data
- Increased statistics in ^{60}Co, ^{232}Th calibration
- Acquired uniformly over run

- Increased nuclear recoil data
- Two ^{241}AmBe calibrations at beginning and end of DM run

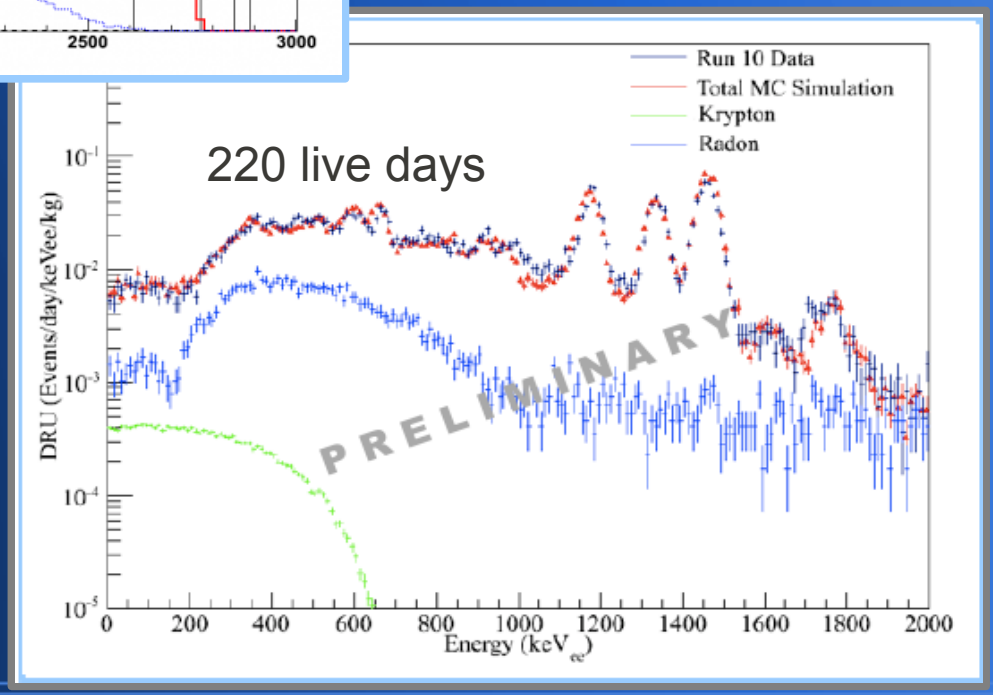


Data – MC Comparison



E. Aprile et al. Phys.Rev.D83:082001,2011

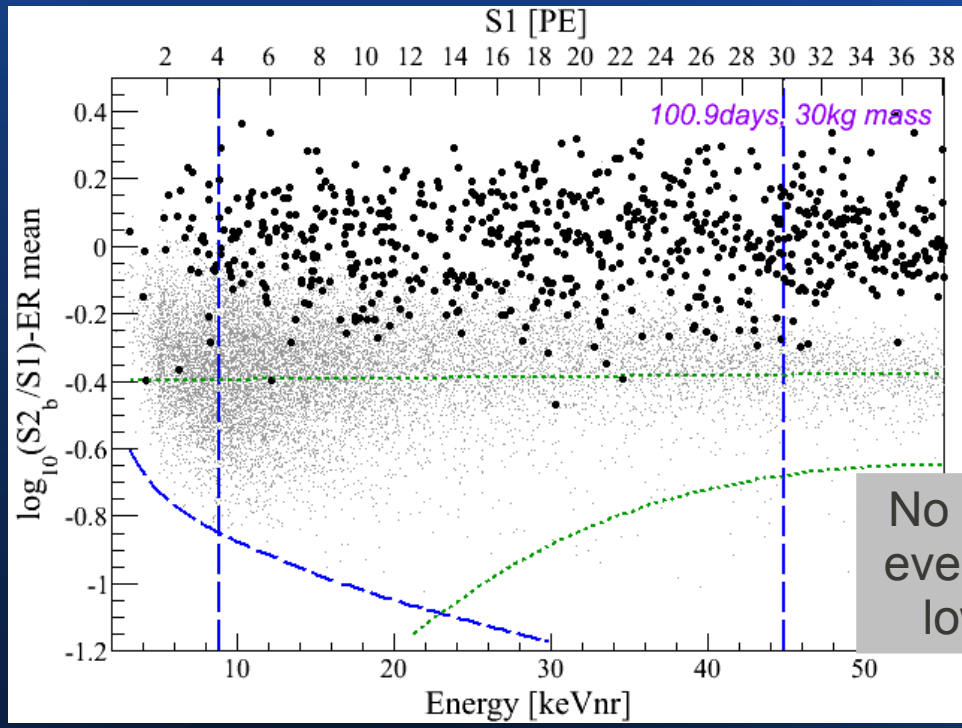
- Excellent agreement
- No fine tuning required
- Radioactivities taken from measurements



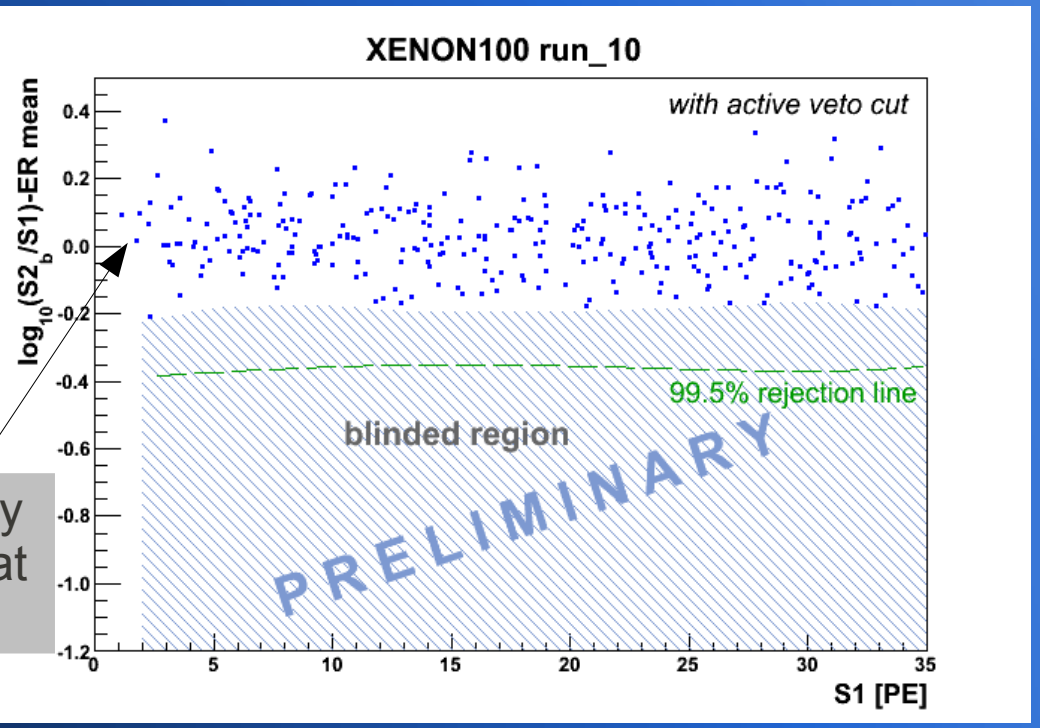
- Rate below 100 keV significantly reduced
- Kr reduced to 19±1 ppt in run10 as measured by rare gas mass spectrometry

Background Comparison

30 kg, 100.9 days, run_08



30 kg, 198 days, run_10



No noisy events at low E

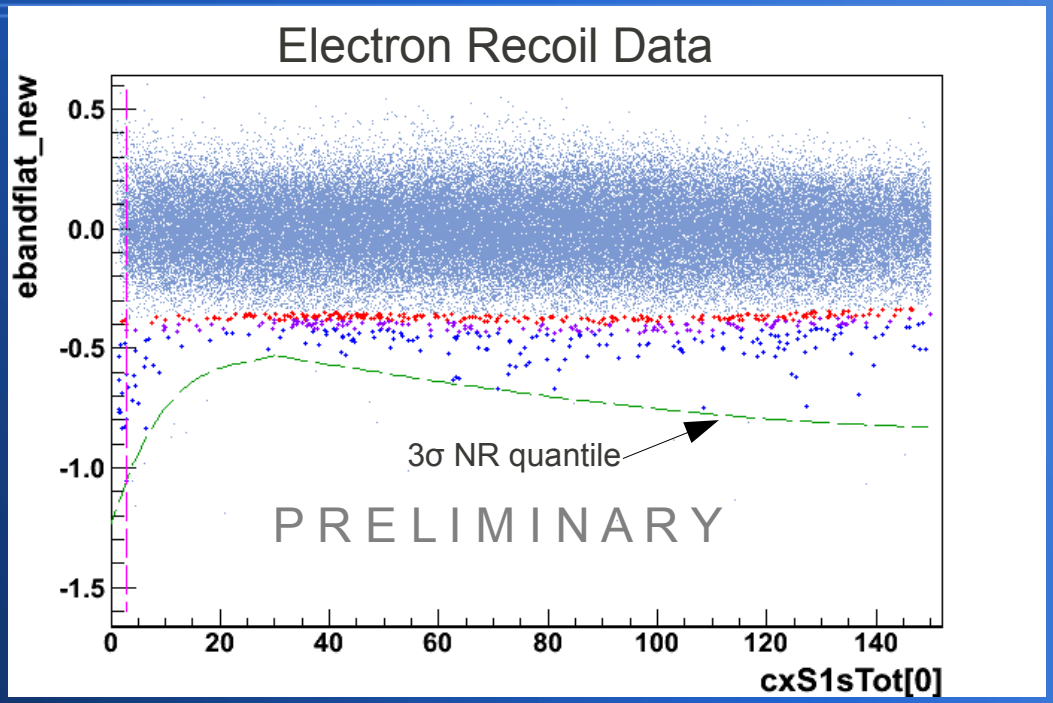
E. Aprile et al., Phys. Rev. Lett. 107 (2011) 131302

Background now at level of run_07 (XENON100 First Results)

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

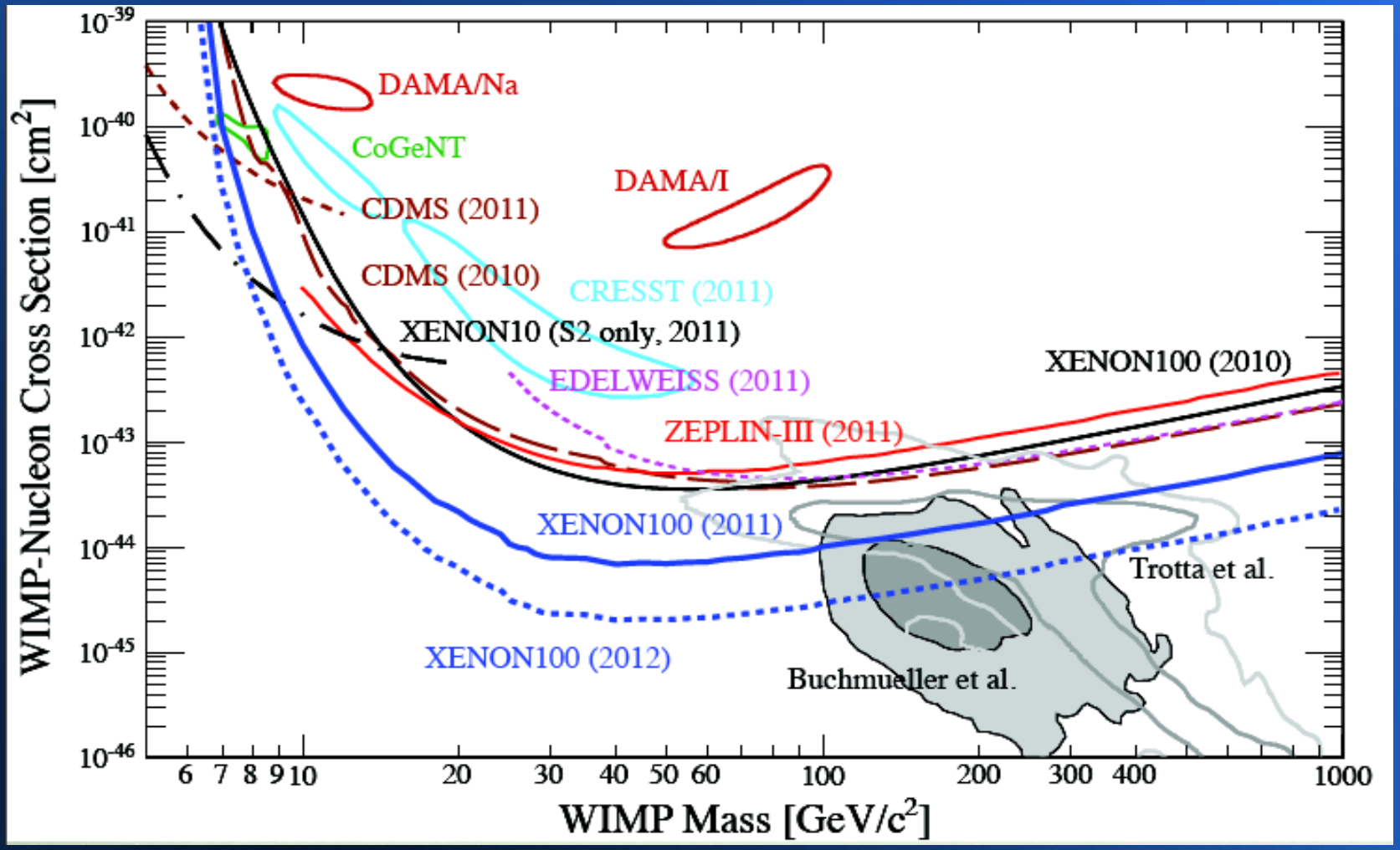
Steps to Unblinding

- All DM search data blinded:
  - 2 < S1 < 100 pe (much larger than DM region of 3 < S1 < 30 pe)
  - Below 90% upper quantile of NR band
    → Conservative box
  - Provides buffer to allow for flexibility in analysis
- Unblinding in steps:
  - Unblind regions still outside the DM region
  - Allows for test of unblinding procedure
    → test robustness of analysis



- Use ER data to predict # events in NR band
- 3 steps unblinding:
  1) Unblinded data, S1 > 100 pe
  2) Blinded data outside the DM region
  3) Final unblinding of DM data

XENON100 Projected Sensitivity

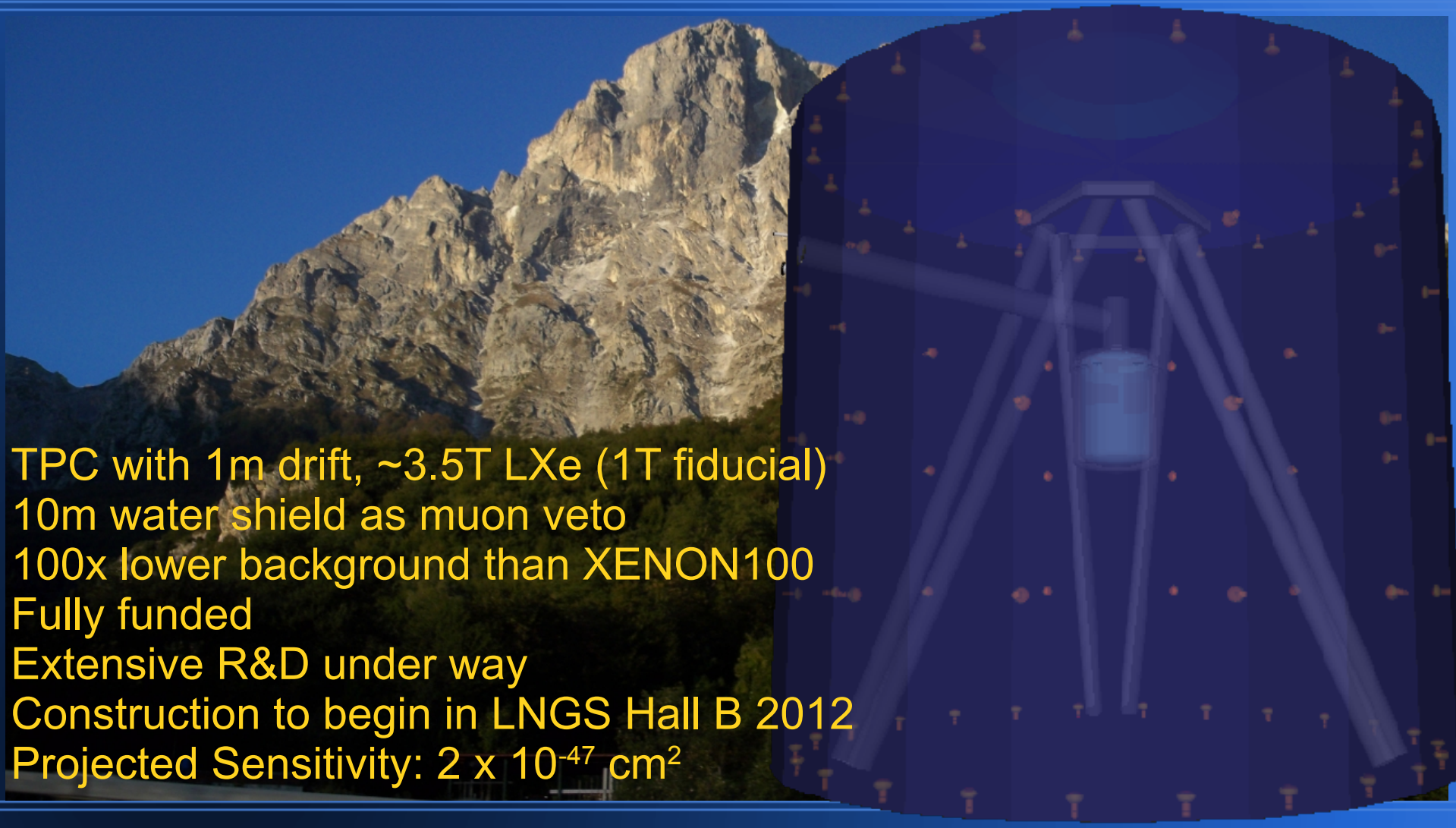


Expected sensitivity: ~2.0x10^{-45} cm^2

Results coming very soon...

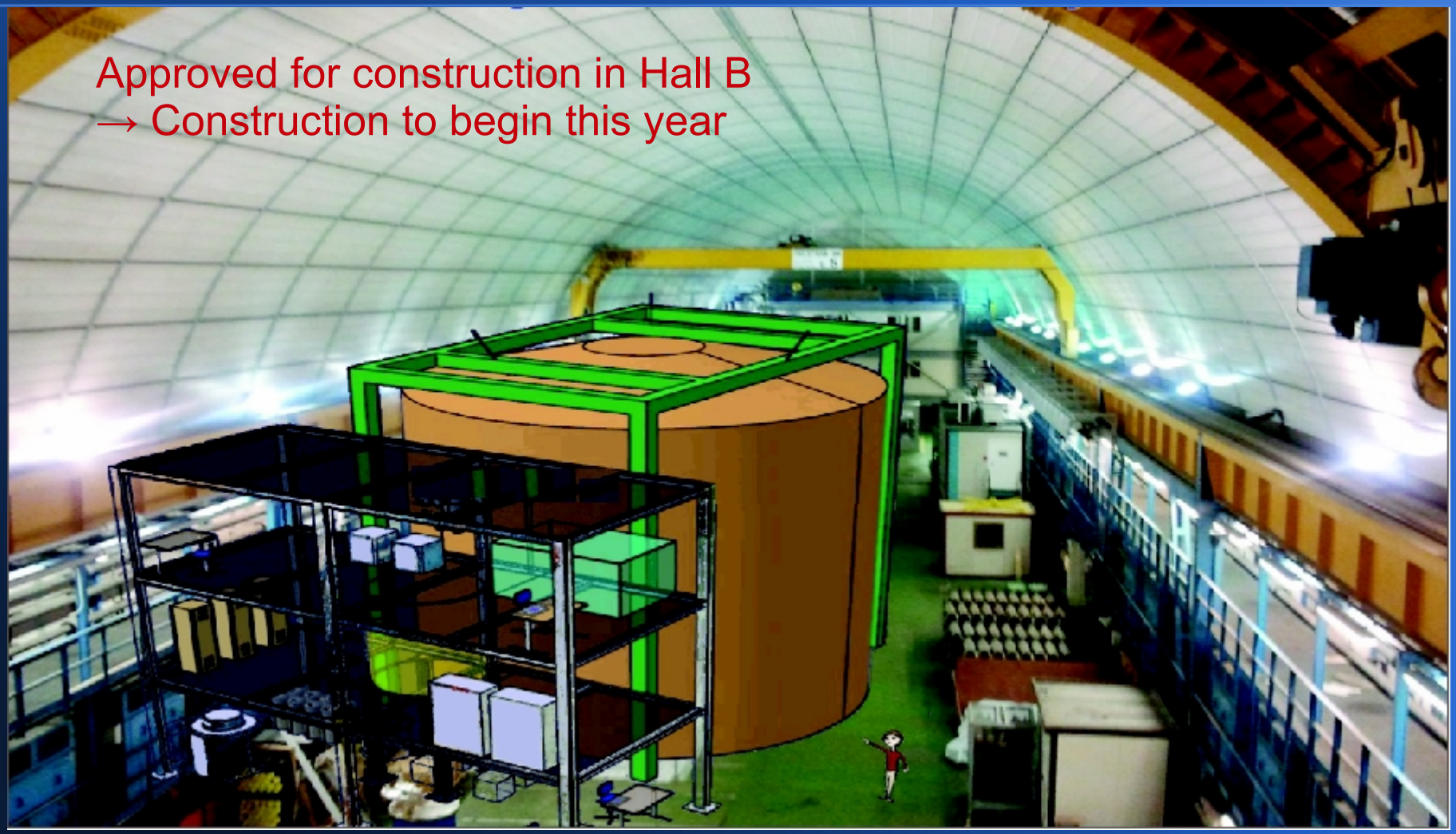
Stay tuned!

What's next? XENON1T (2012 - 2017)



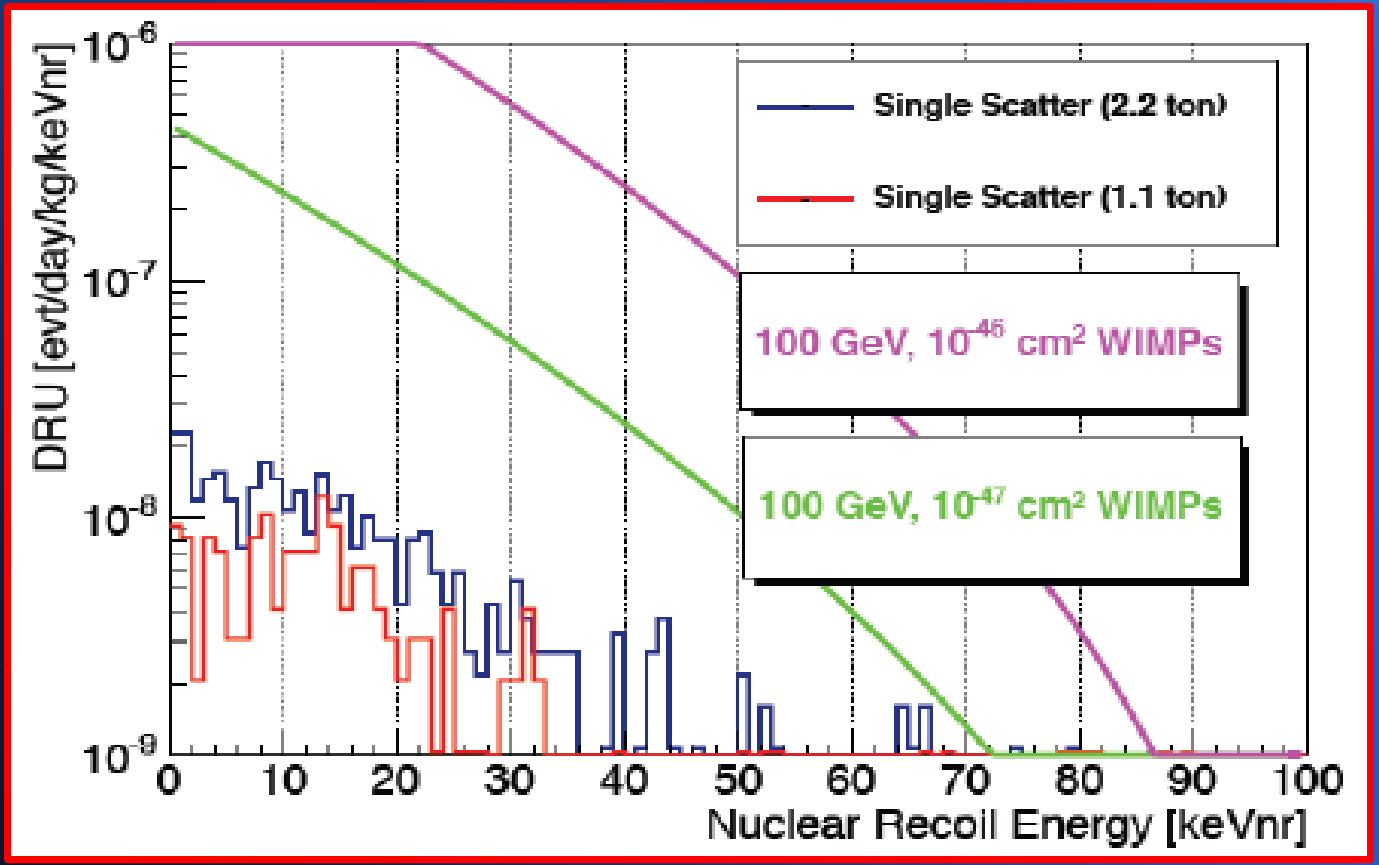
- TPC with 1m drift, ~3.5T LXe (1T fiducial)
- 10m water shield as muon veto
- 100x lower background than XENON100
- Fully funded
- Extensive R&D under way
- Construction to begin in LNGS Hall B 2012
- Projected Sensitivity: 2×10^{-47} cm^2

XENON1T at LNGS



R&D: Shielding

Goal: < 0.01 neutron/yr in LXe fiducial volume → Water Tank as active veto



Neutron Background

R&D: Purification

GOAL: 2.4 tons LXe → 1m charge drift length

- Reduce Electronegative impurities
  → sub ppb level
- Circulate xenon through heated getter (current state of the art)
  → High flow rate (up to 100 SLPM possible due to efficient use of heat exchangers)
- Borrow technology from high vacuum applications
- Ultra clean electropolished surfaces, orbital welding

Münster Prototype

GOAL: Remove internal radioactive impurities

- ^{85}Kr, uniform beta background
  → at current purity limit for XENON100
  → Remove via cryogenic distillation
  → Sub ppt level needed
- ^{222}Rn and daughters
  → Remove via charcoal filter

Columbia Prototype

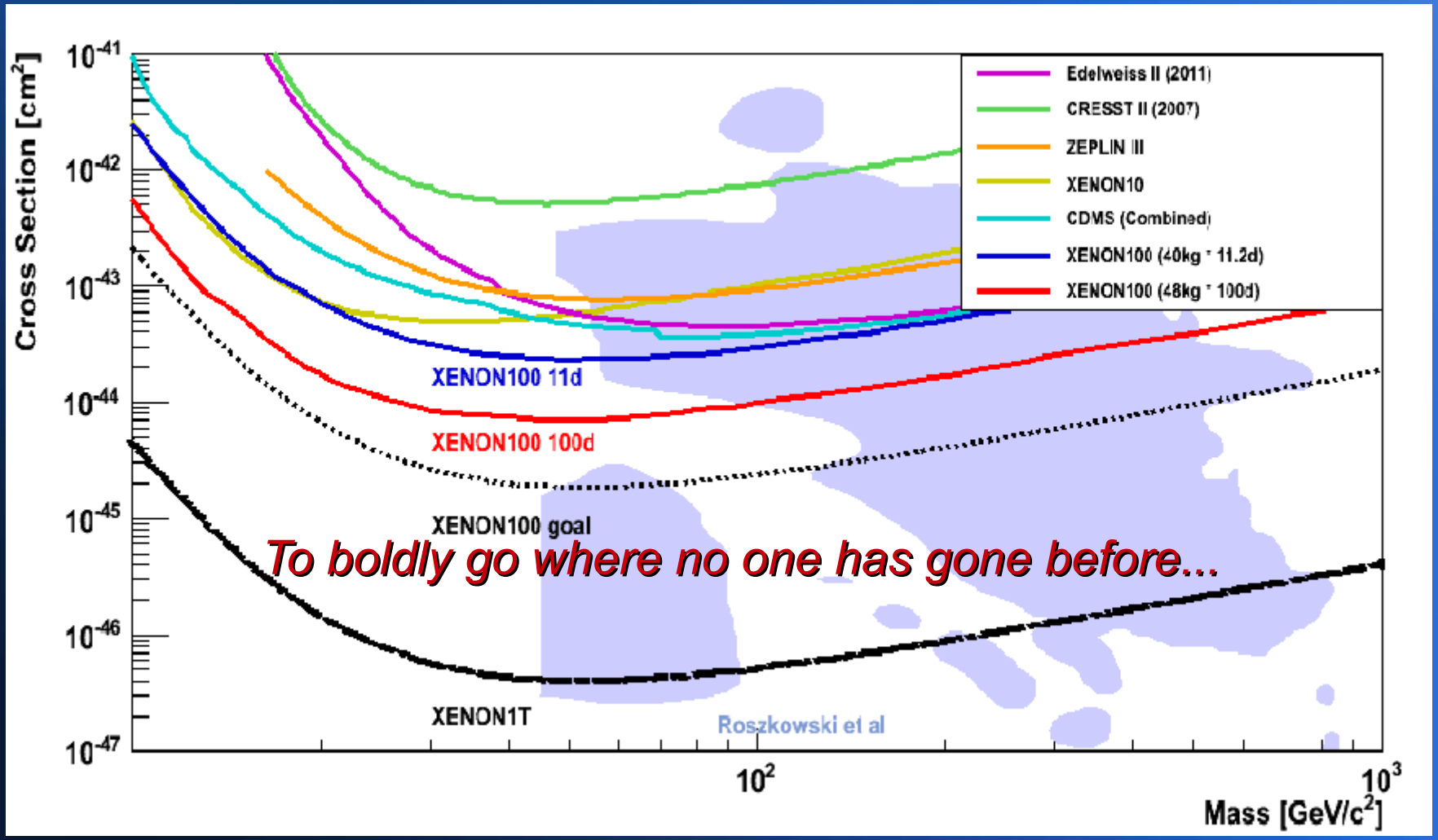
R&D: Much much more...

Sub-systems split into task groups with well defined goals and deadlines

- Infrastructure
- Muon veto
- Water tank
- Detector: TPC, Grids, HV
- PMTs
- Cryostat, incl support, platform
- Cryogenics
- Cryogenic storage vessel
- Slow control
- Material screening and selection
- Distillation column
- Purification
- Gas purity and analytics
- Calibration
- Monte Carlo simulations
- DAQ, trigger and computingInfrastructure

First science run to begin in 2015

Projected Sensitivity of XENON1T (2017)



To boldly go where no one has gone before…

Summary

XENON100

- Detector in stable operation since 2009
- Most sensitive WIMP SI wimp limit (2011)
- New SD limit (publication in internal referee phase)
- World's best limit on pure neutron coupling
- Pure proton coupling sensitive to nuclear model
- 220 days blinded data on tape
- Final stages of blinded analysis

XENON1T

- Approved for construction in LNGS Hall B
- Funding already there
- Construction beginning this year
- Extensive R&D underway
- Detailed schedule in place
  → Start of science run: 2015

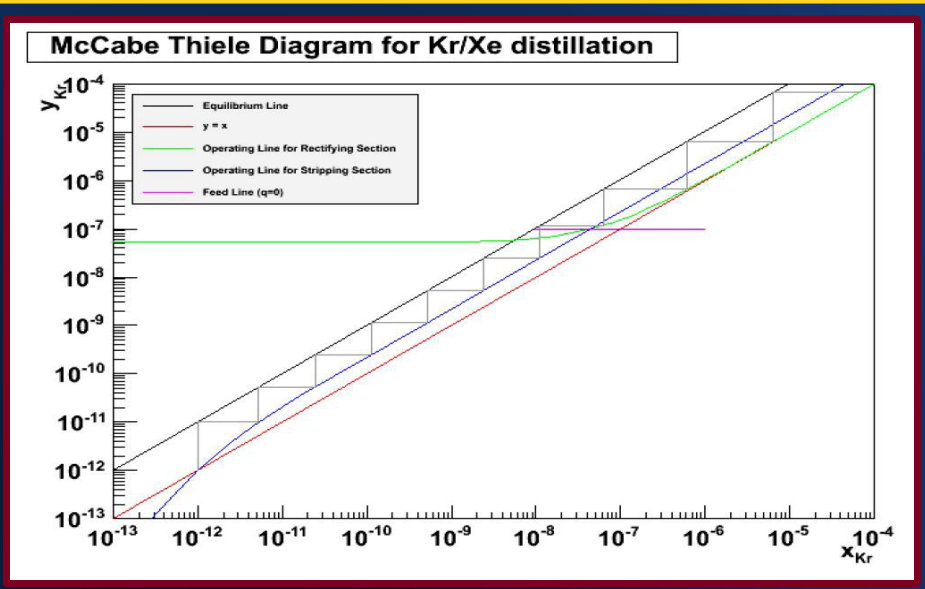
Thank You for Your Attention

Back up

R&D: Kr Distillation Column

GOAL: Reduce ^{85}Kr background by removing Kr from Xe →Kr/Xe < 1ppt (XENON100 achieved 20 ppt in run10)

- Multi-stage distillation with partial reflux → Rectification
- Based on McCabe-Thiele method → Break down limit? Need testing



Completion by Spring 2014

Many diagnostics tools developed:

- ^{83m}Kr Tracer
- Atom trap trace analysis
- RGA + cold trap
- Gas chromatography + RGMS