Recent results from the XENON100 experiment and future goals of the XENON project

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on behalf of the XENON Collaboration

VULCANO Workshop 2014, May 20th, 2014

The XENON Dark Matter Program

2005 - 2007

XENON10

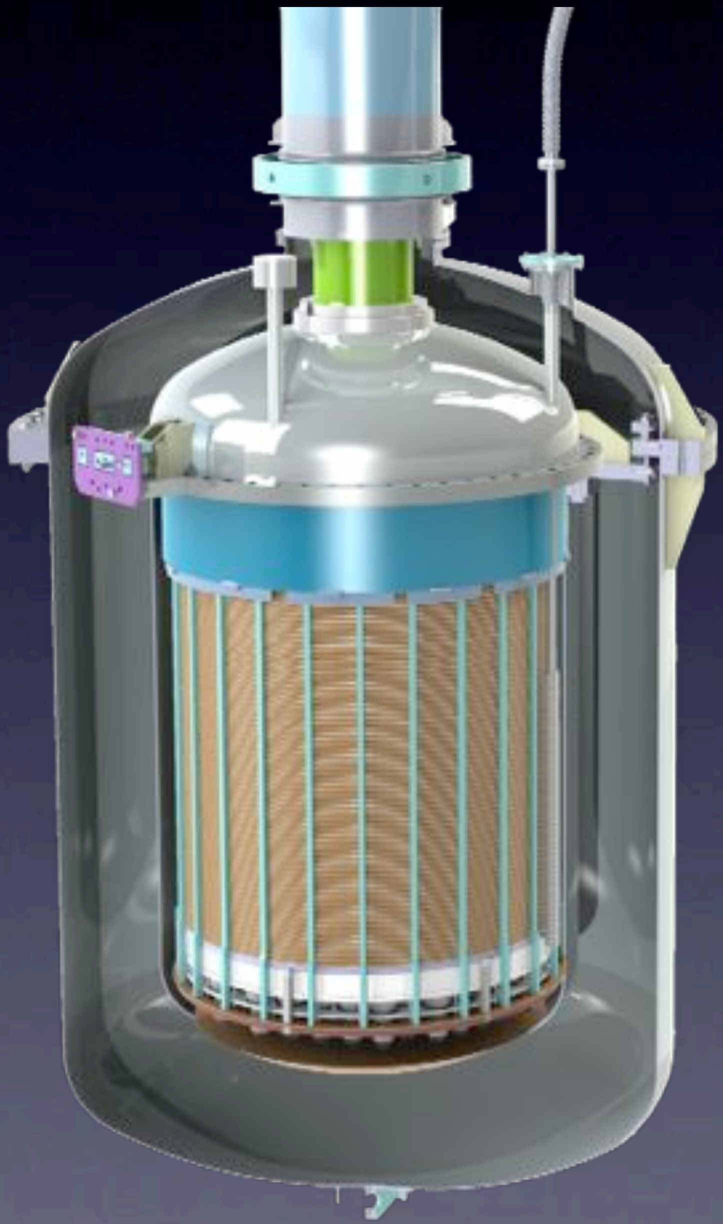
15 cm drift TPC - 25 kg

2008-2015

XENON100

30 cm drift TPC - 161 kg

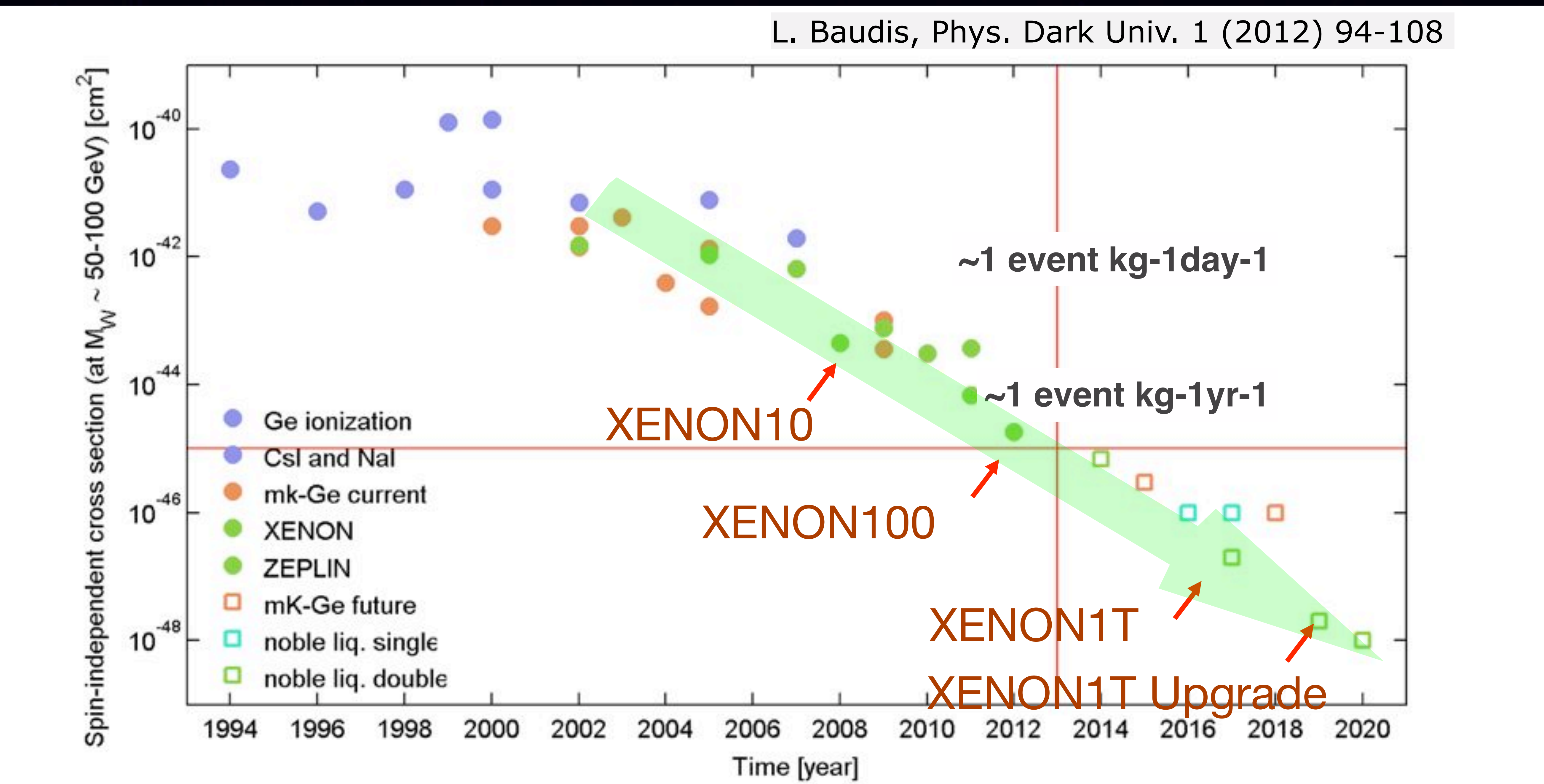
2012- 2017



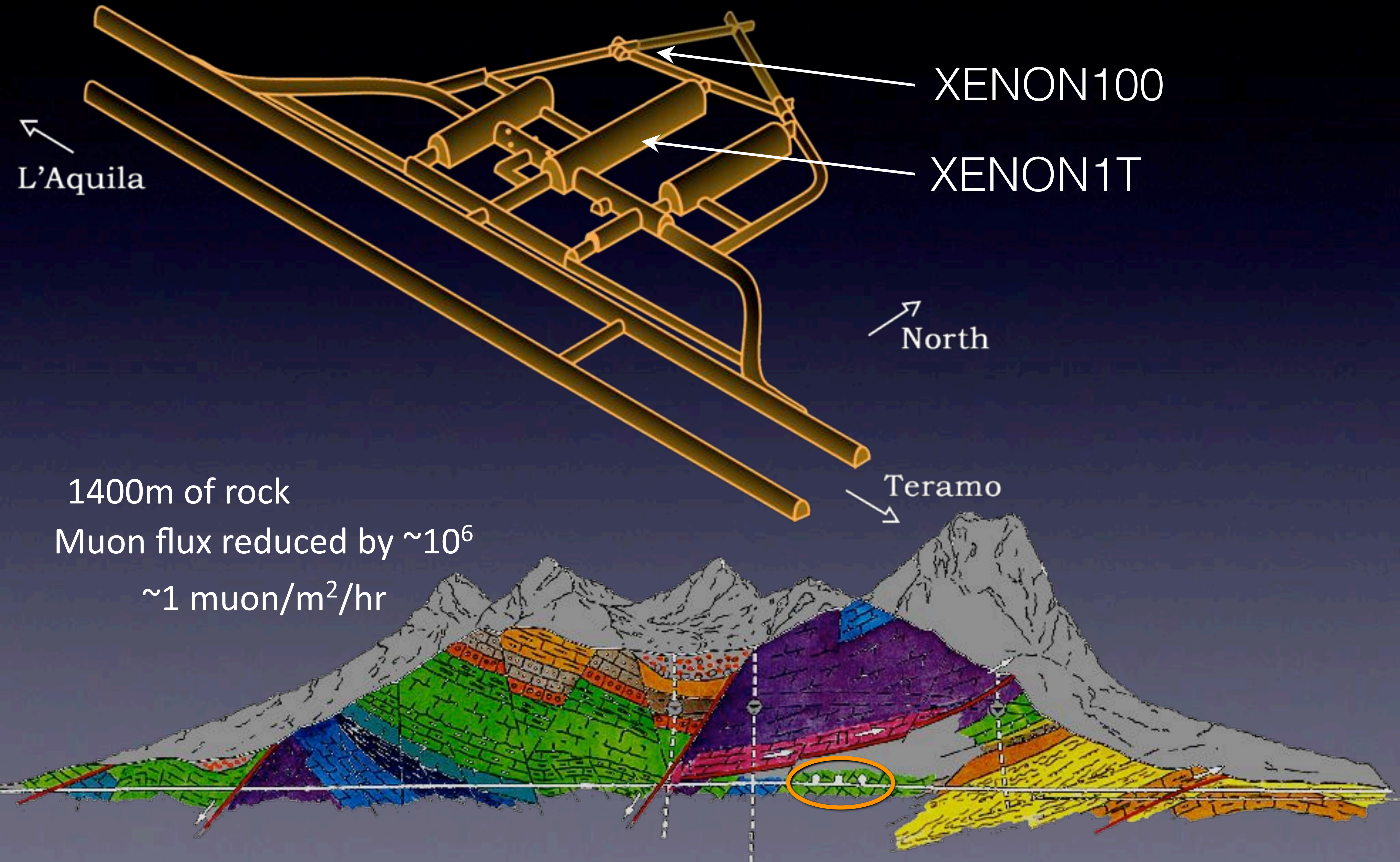
XENON1T

100 cm drift TPC - 3300 kg

Direct detection: progress over time



Gran Sasso Underground Laboratory



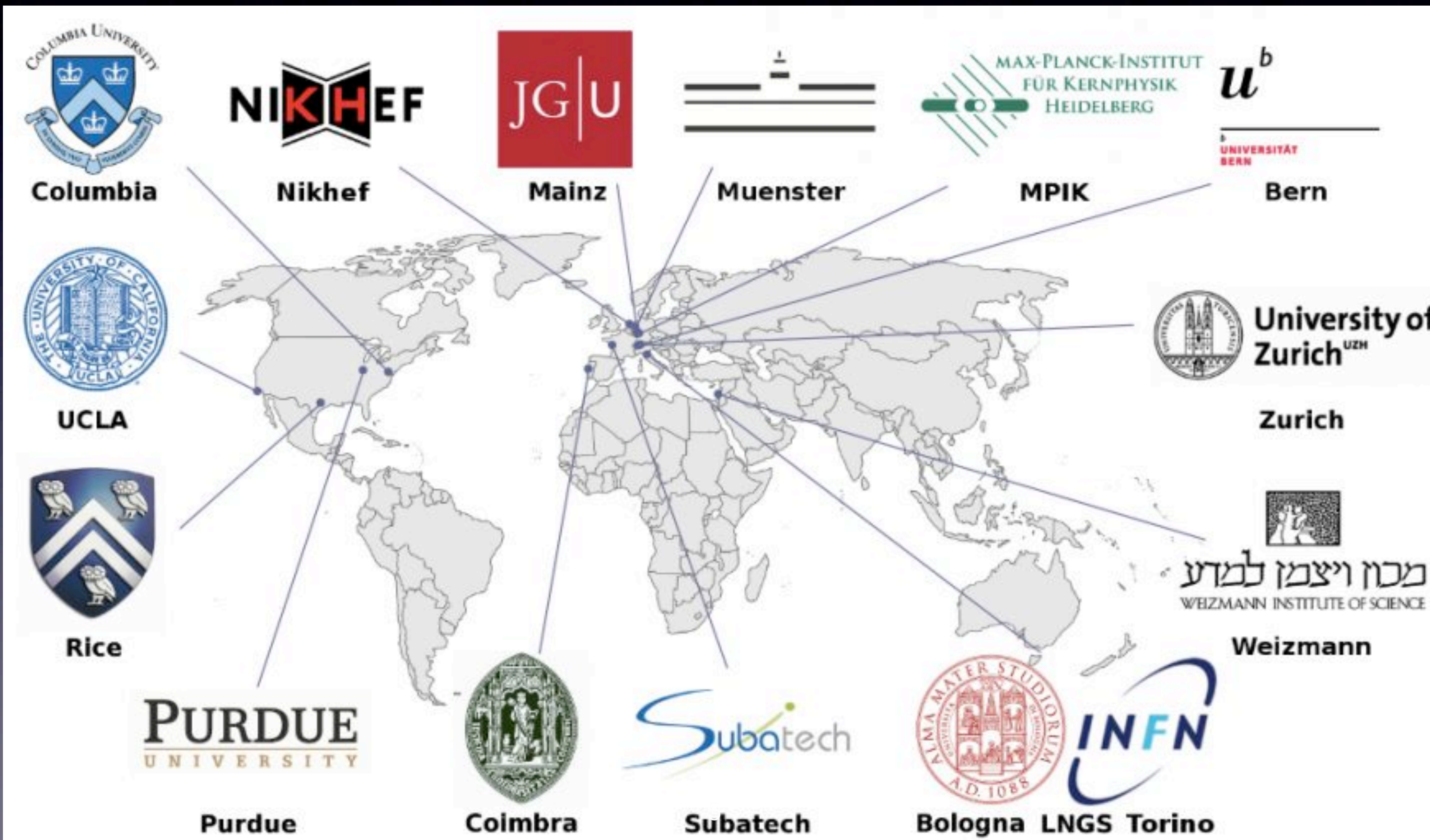
1400m of rock

Muon flux reduced by ~10^6

~1 muon/m^2/hr

The XENON Collaboration

US led and NSF supported since start of project
~100 scientists from 15 institutions



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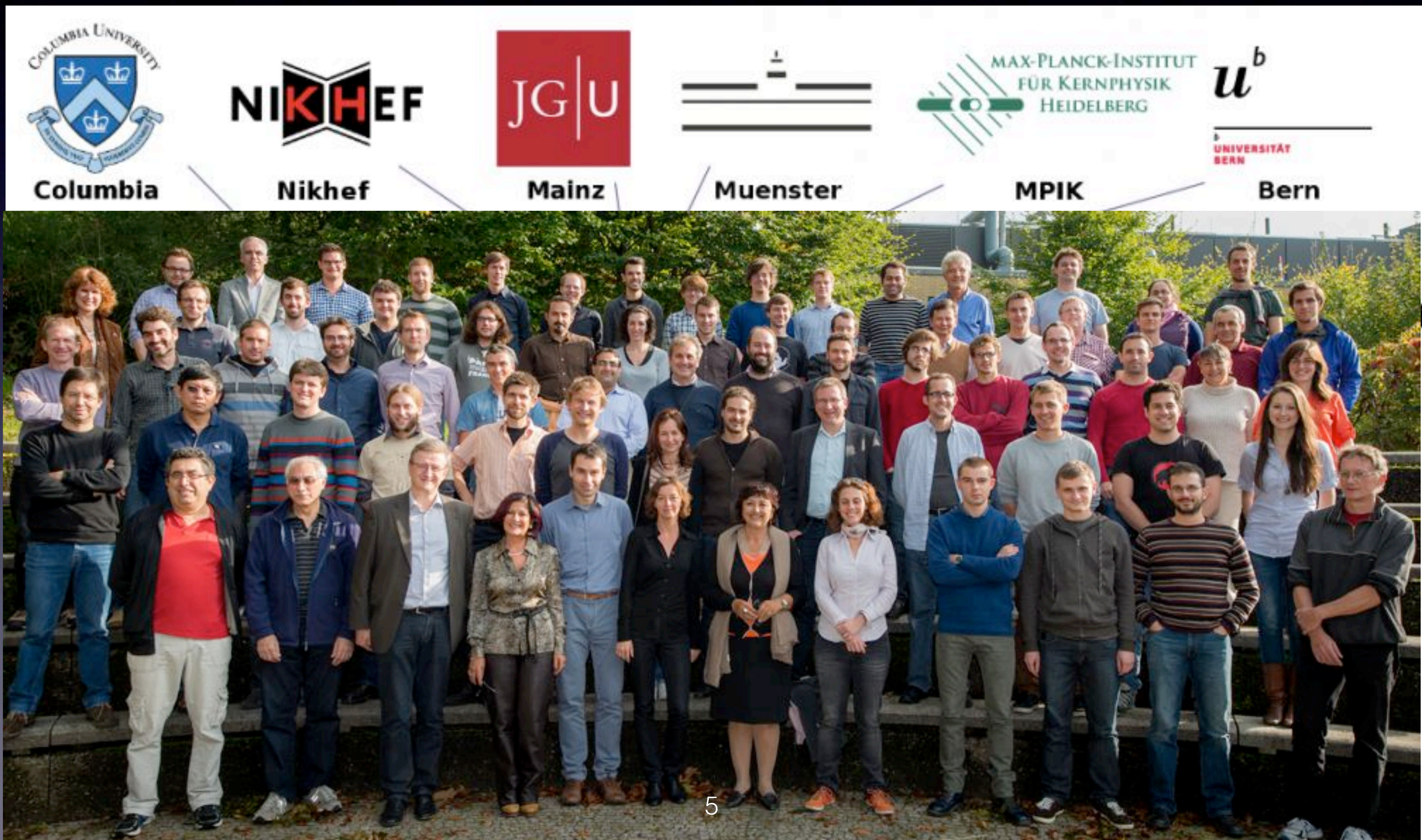
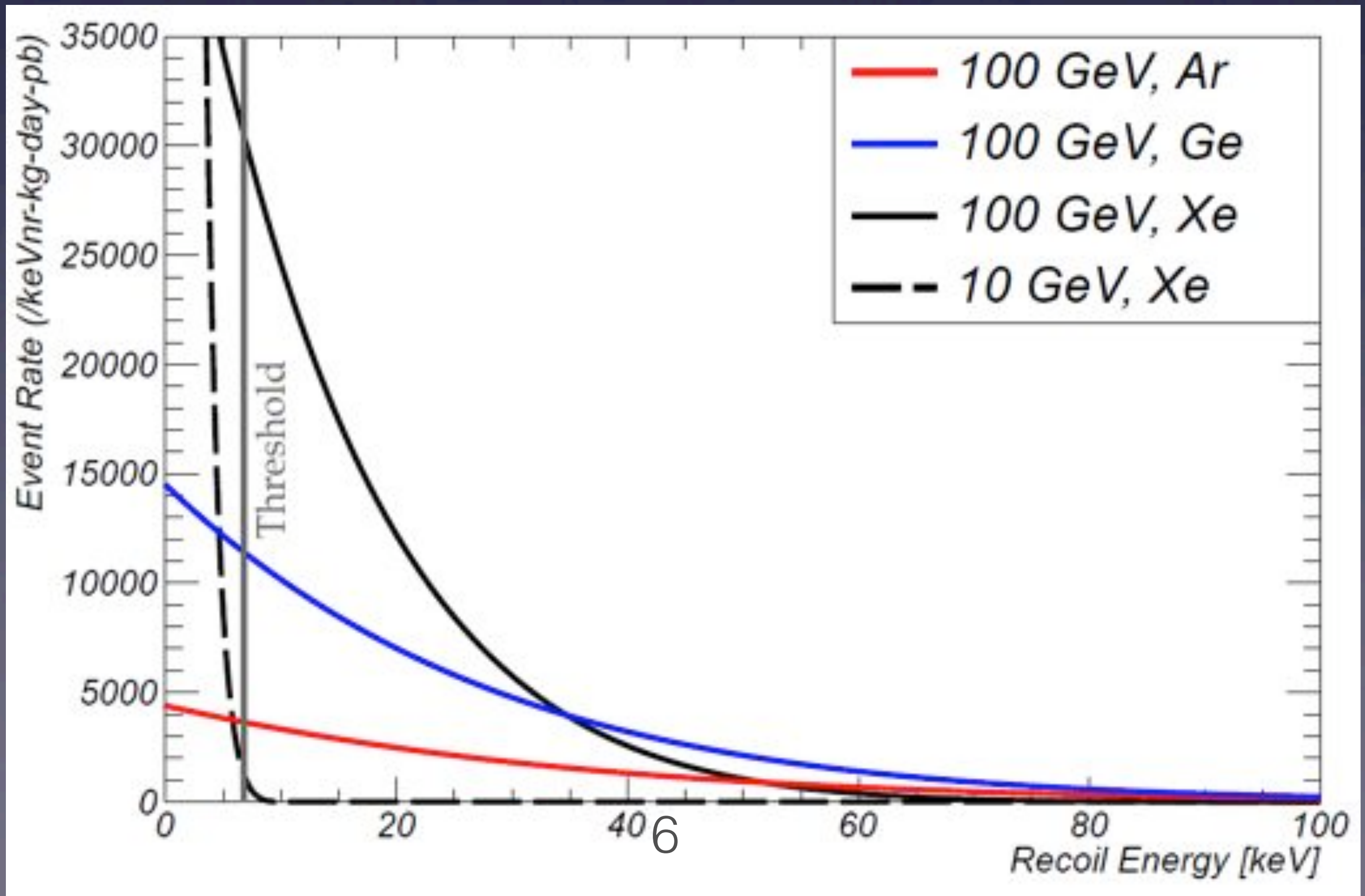


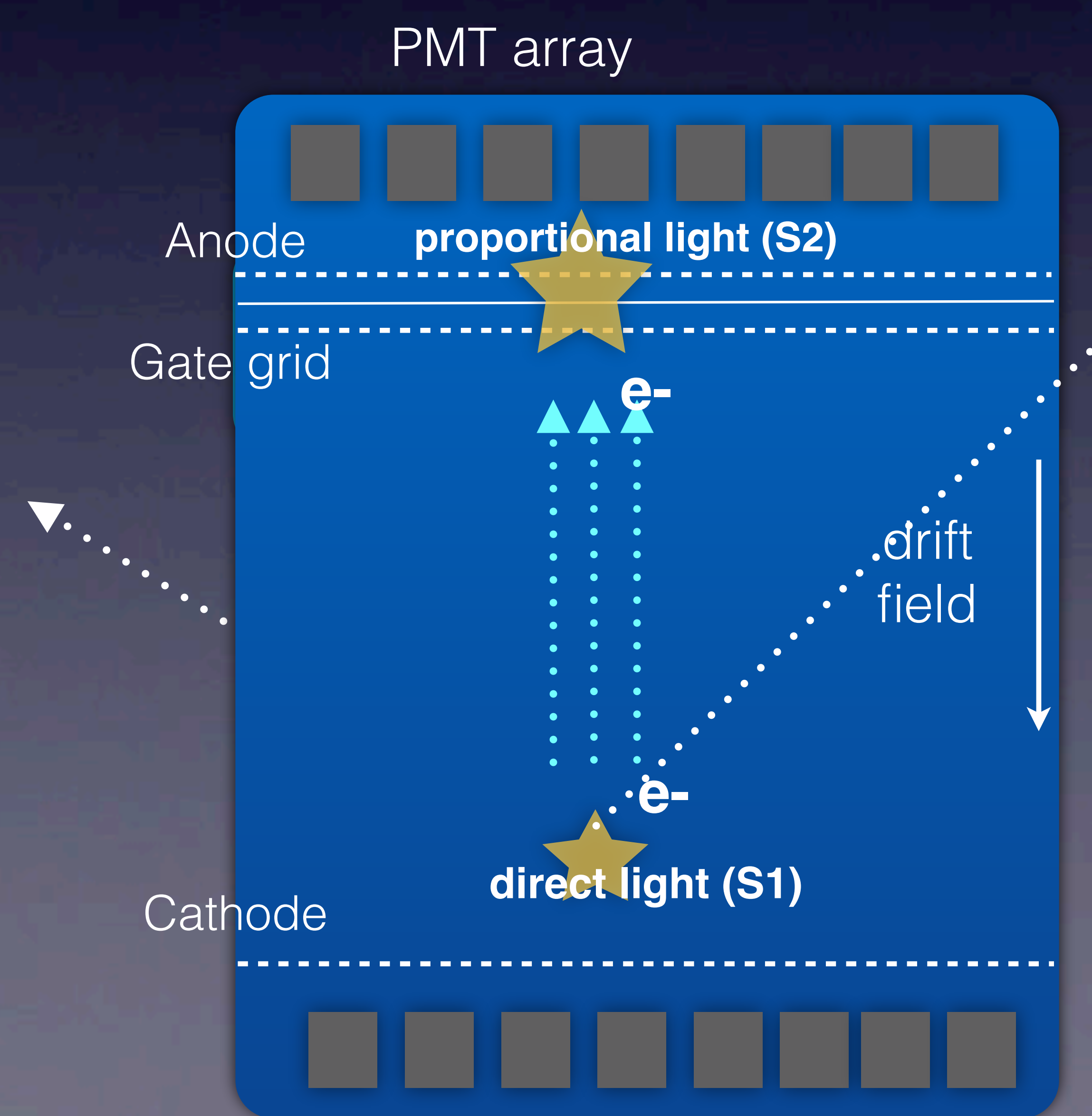
Liquid Xenon for a WIMP Detector

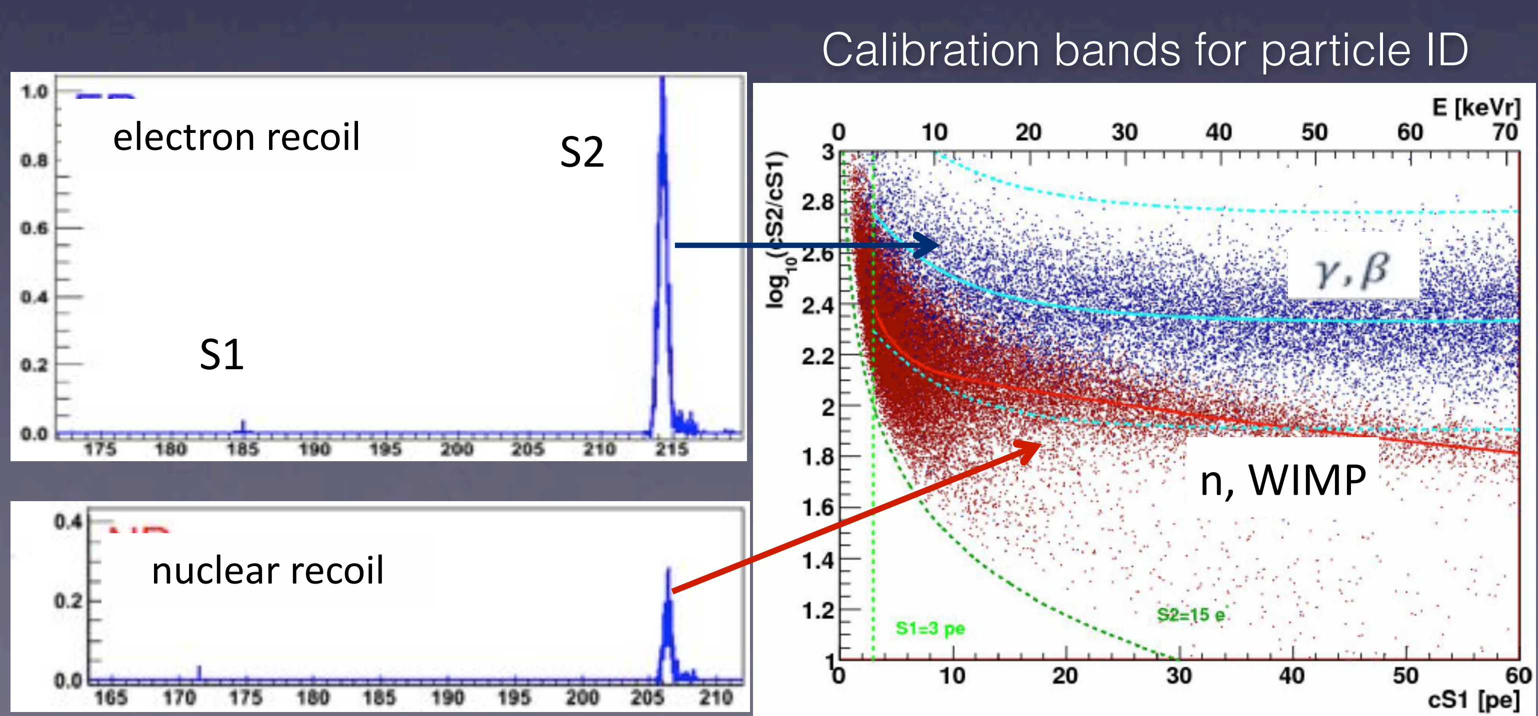
- Good target for both SI (A~131) and SD WIMP-N interactions (^{129}Xe & ^{131}Xe)
- Highest event rate for massive WIMPs
- Unique ability to measure single e^- with a two-phase TPC:
  - allows detection of light WIMPs through charge-channel only
- Enables large mass, homogeneous, self-shielded, easily scalable detector.
- Highest ionization and scintillation yield among all noble liquids
- Simultaneous charge and light detection enables ER/NR discrimination
- 3D event localization, double-scatter rejection and self-shielding provide powerful background rejection
- Excellent dielectric, inert, no long-lived radioactive isotopes.



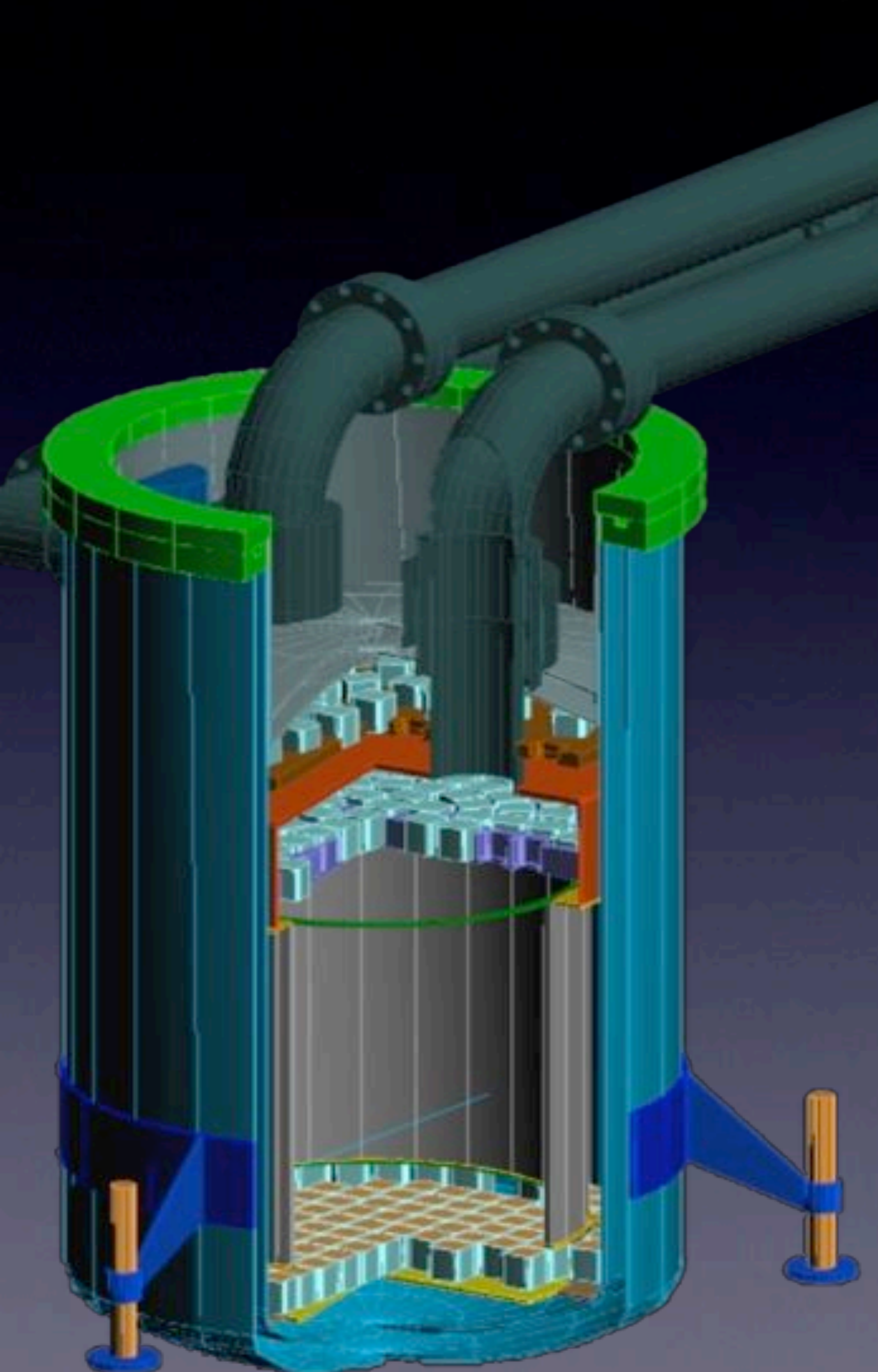
Two-phase Xe Time Projection Chamber

- Particle interaction in the active volume produces prompt scintillation (S1) and ionization electrons
- Electrons which reach the liquid/gas interface are extracted, accelerated in the gas gap and detected as proportional light (S2)
- PMTs in liquid and gas detect S1 and S2
- Charge/light depends on dE/dx: $(S2/S1)_{WIMP} << (S2/S1)_{gamma}$
- 3D-position sensitive detector with particle ID





The XENON100 Experiment



TPC with 30 cm drift and 30 cm diameter

Drift field in LXe ~ 0.5 kV/cm

Amplification field in GXe ~10 kV/cm

161 kg Xe (62 kg as target; 99 kg as active veto)

Cooled with 200W PTR outside shield

Read-out with 242 PMTs with ~1 mBq (U/Th)

S1 yield: 2.3 pe/keV (@122 keV and 0.5 kV/cm)

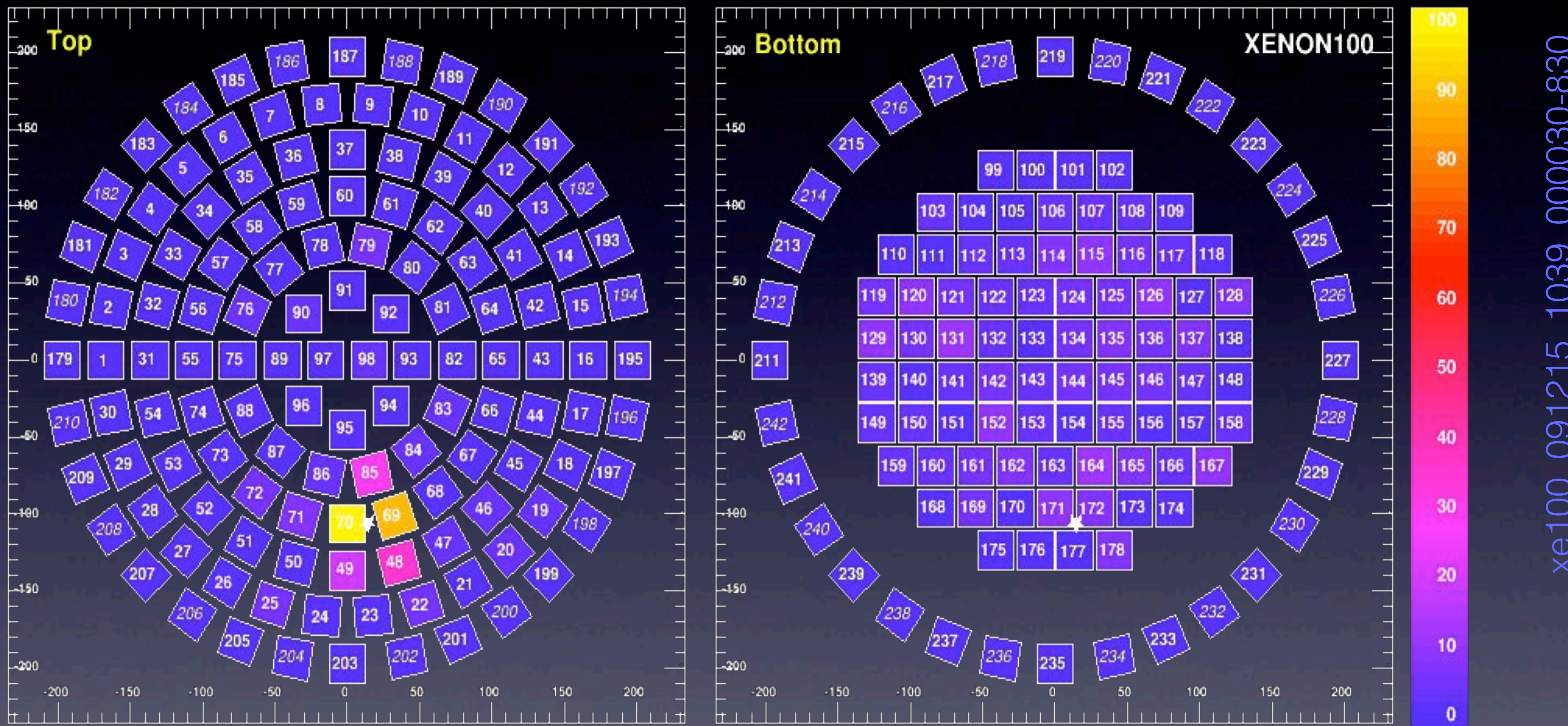
S2 yield: 19 pe/e (single electron sensitive)

Kr/Xe level reduced to ppt with cryogenic distillation

Passive shielding: water/Pb/Poly/Cu

Aprile et al., Astropart. Phys. 35, 573 (2012)

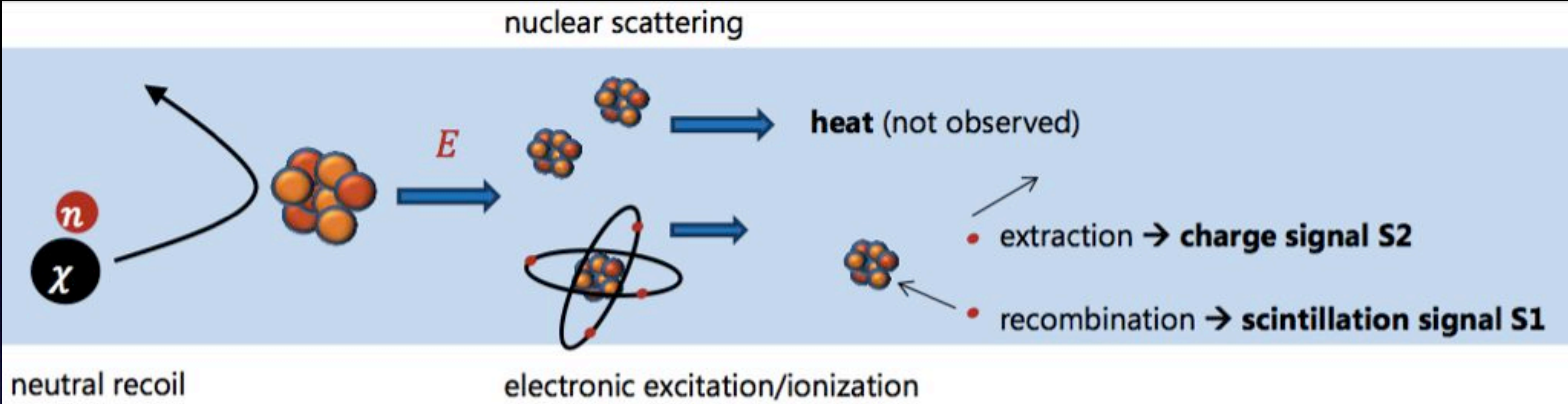
Event Localization in XENON100



position reconstruction based on top S2 hit pattern

$\Delta r < 3$ mm $\Delta z < 0.3$ mm, $\Delta z < 2$ mm for double-scatter separation

Energy Scale: from measured photoelectrons to keV



Energy relation for **S1**	Energy relation for **S2**

$$E = \frac{\mathrm{S1}}{L_{\mathrm{y}}} \frac{1}{\mathcal{L}_{\mathrm{eff}}(E)} \frac{S_{\mathrm{ee}}}{S_{\mathrm{nr}}}.$$

Light yield of 122keV γ-rays

Quenching-factor of nuclear recoils

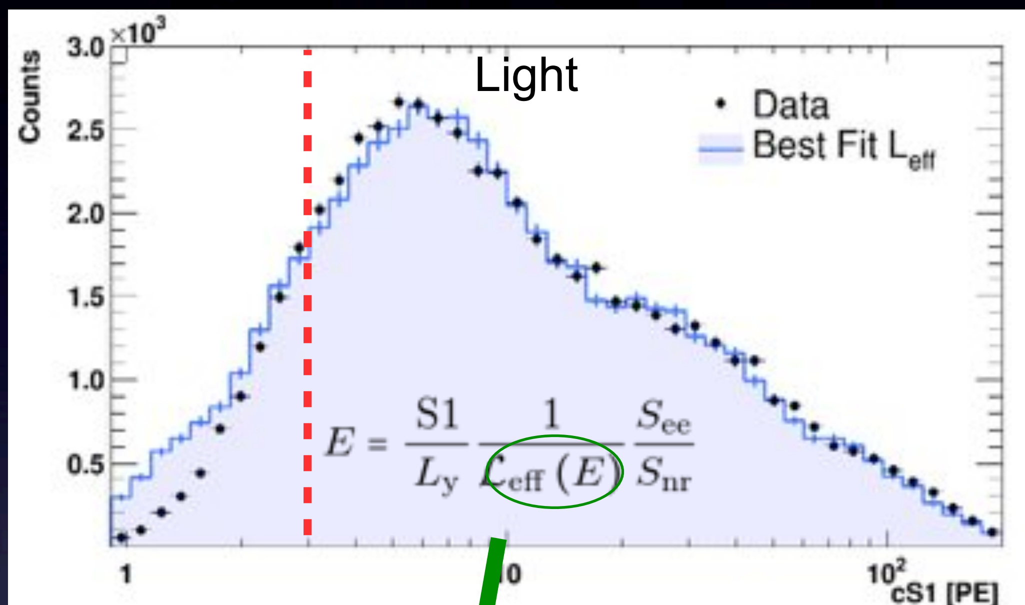
Electric field dependency

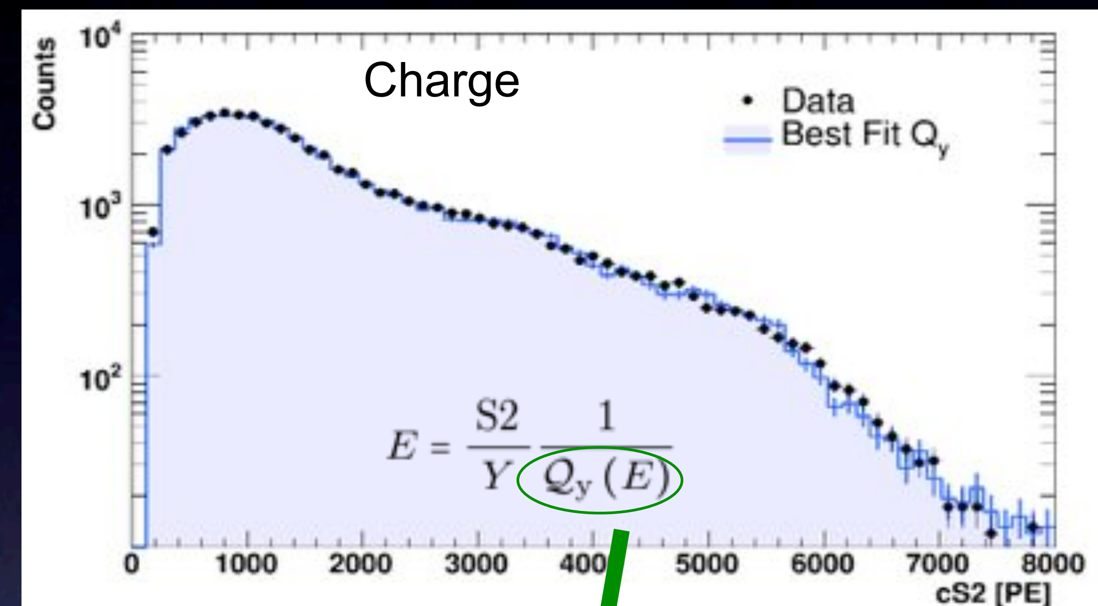
$$E = \frac{\mathrm{S2}}{L_{\mathrm{q}}} \frac{1}{\mathcal{Q}_{\mathrm{y}}(E)}$$

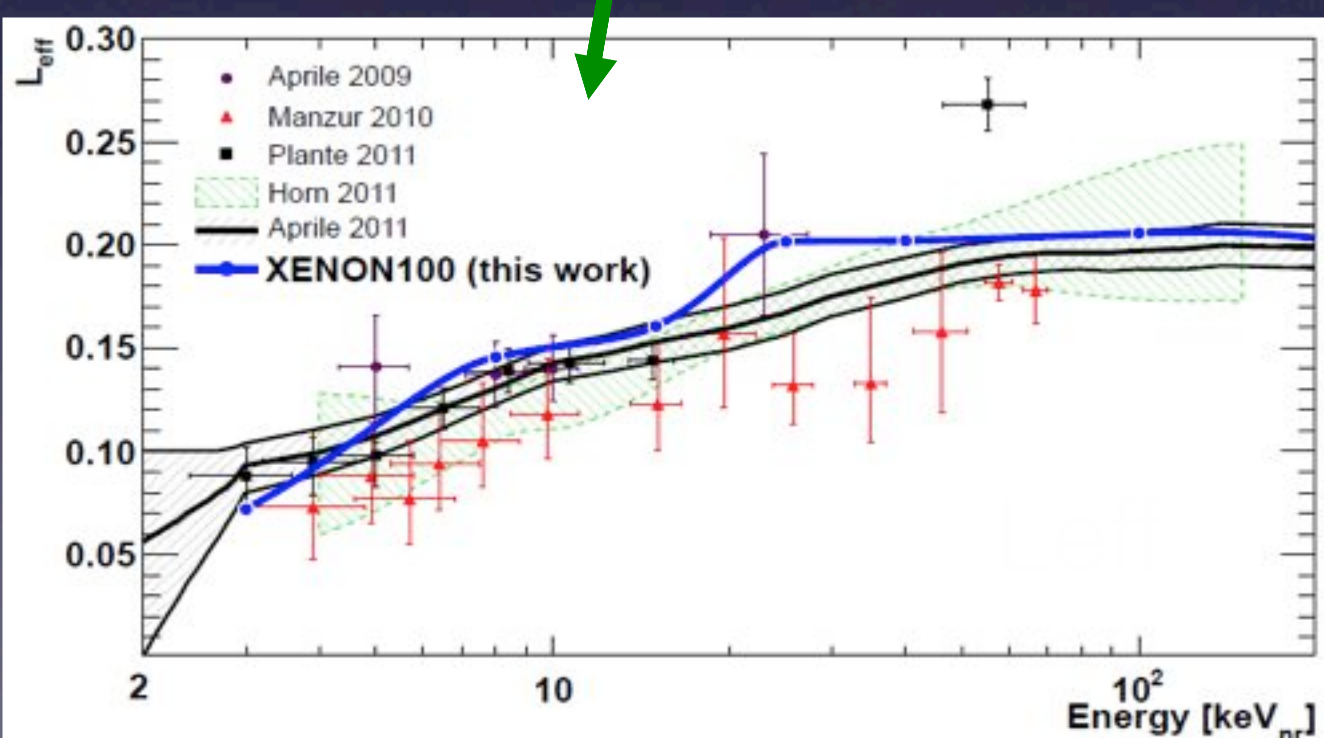
Secondary Amplification of electron signals

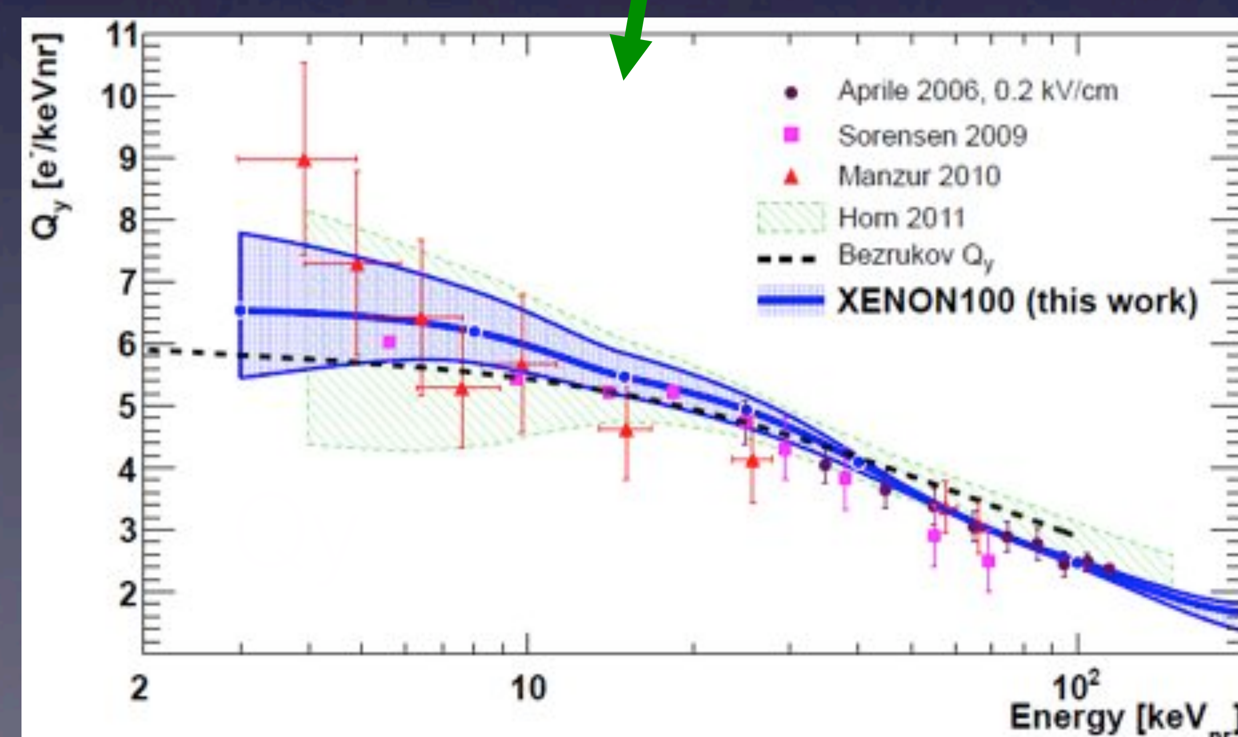
Charge yield of nuclear recoils

XENON100 Response to Nuclear Recoils









Aprile et al. (XENON100) PRD 88, 012006 (2013)

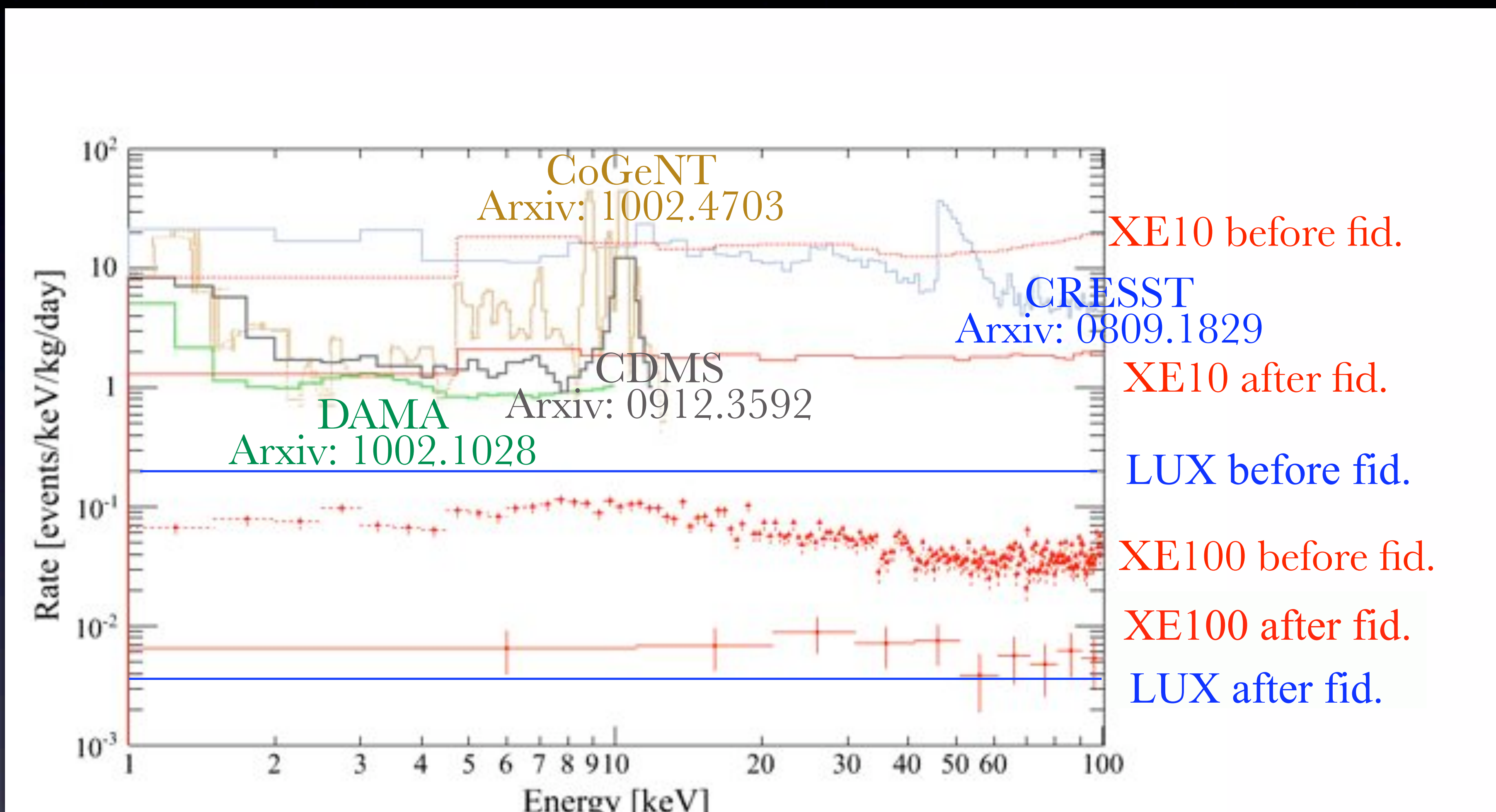
Ongoing measurements of ERs and NRs in LXe to nail energy and field dependence down to a few keV

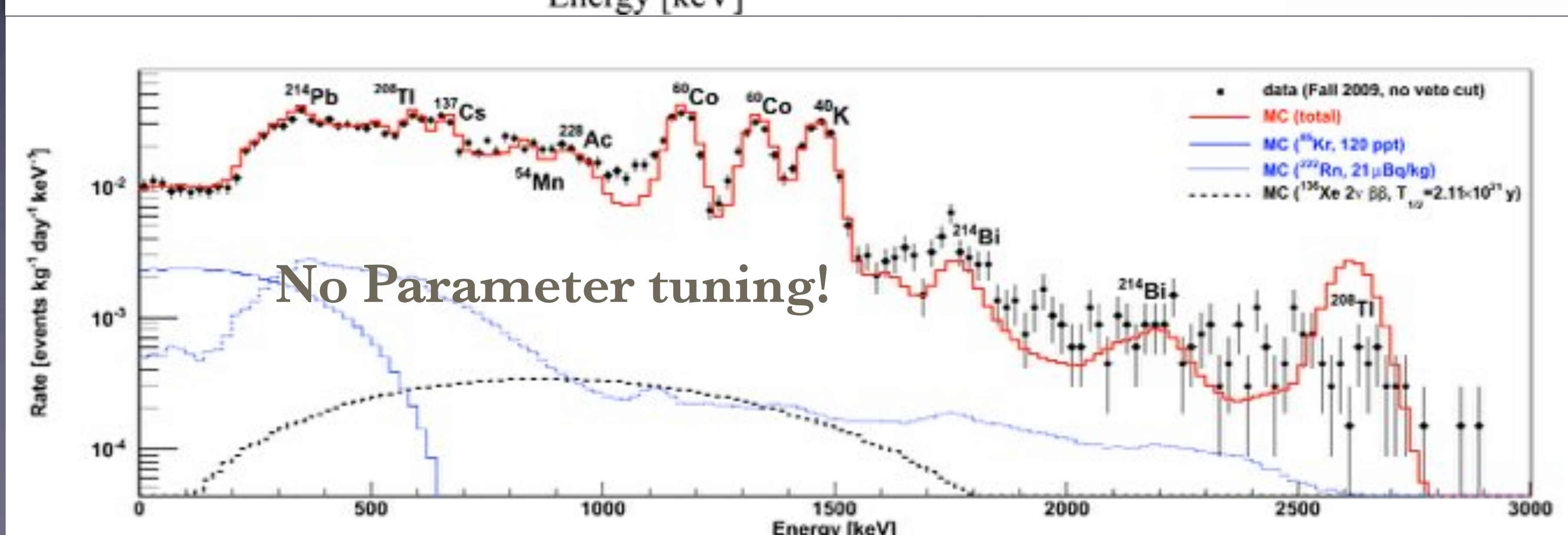
Similar apparatus and techniques (Compton scattering and nuclear scattering) used for the last measurement of Leff and of the relative scintillation efficiency of ERs at zero field (Aprile et al. Phys. Rev. D 86 (2012). New detector (two-phase TPC with fine spatial resolution and high LY)

12

XENON100: an ultra-low background experiment

~5x 10^{-3} evts/kg/keV/day after veto cut and before S2/S1 discrimination

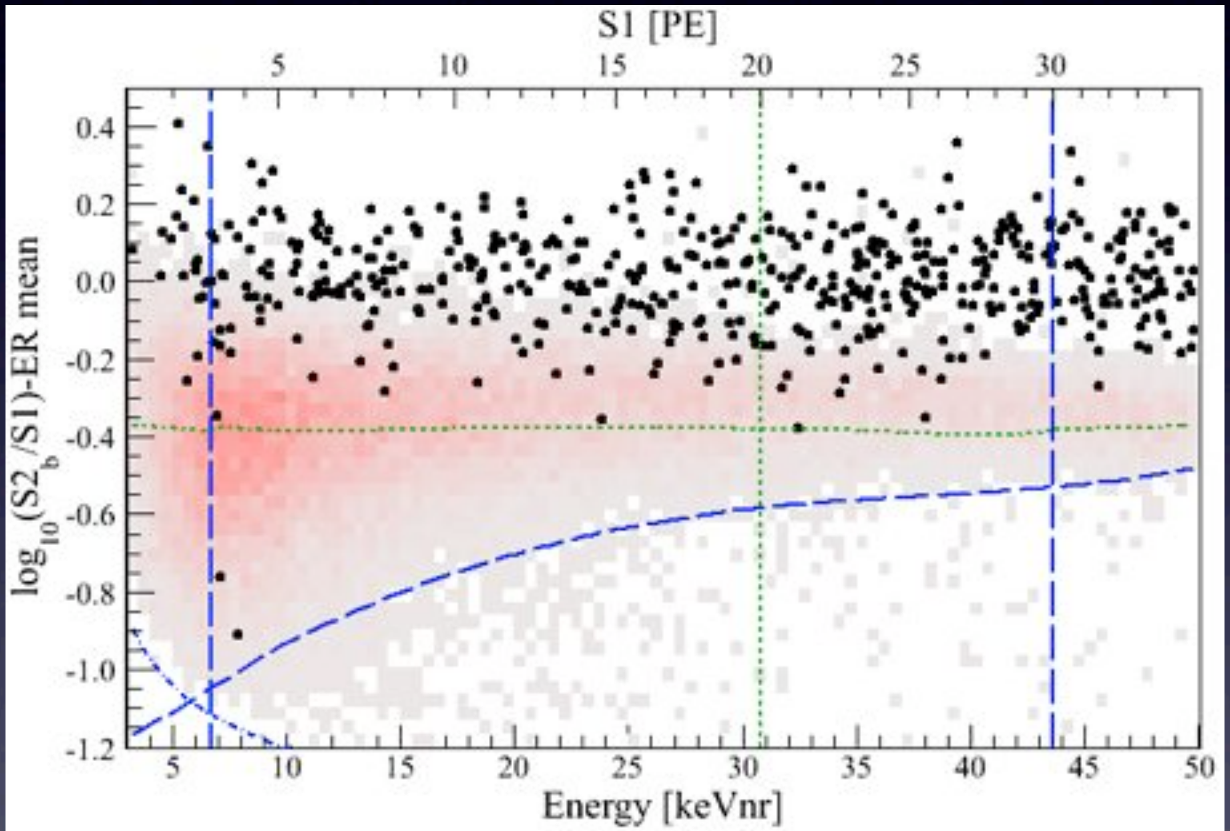


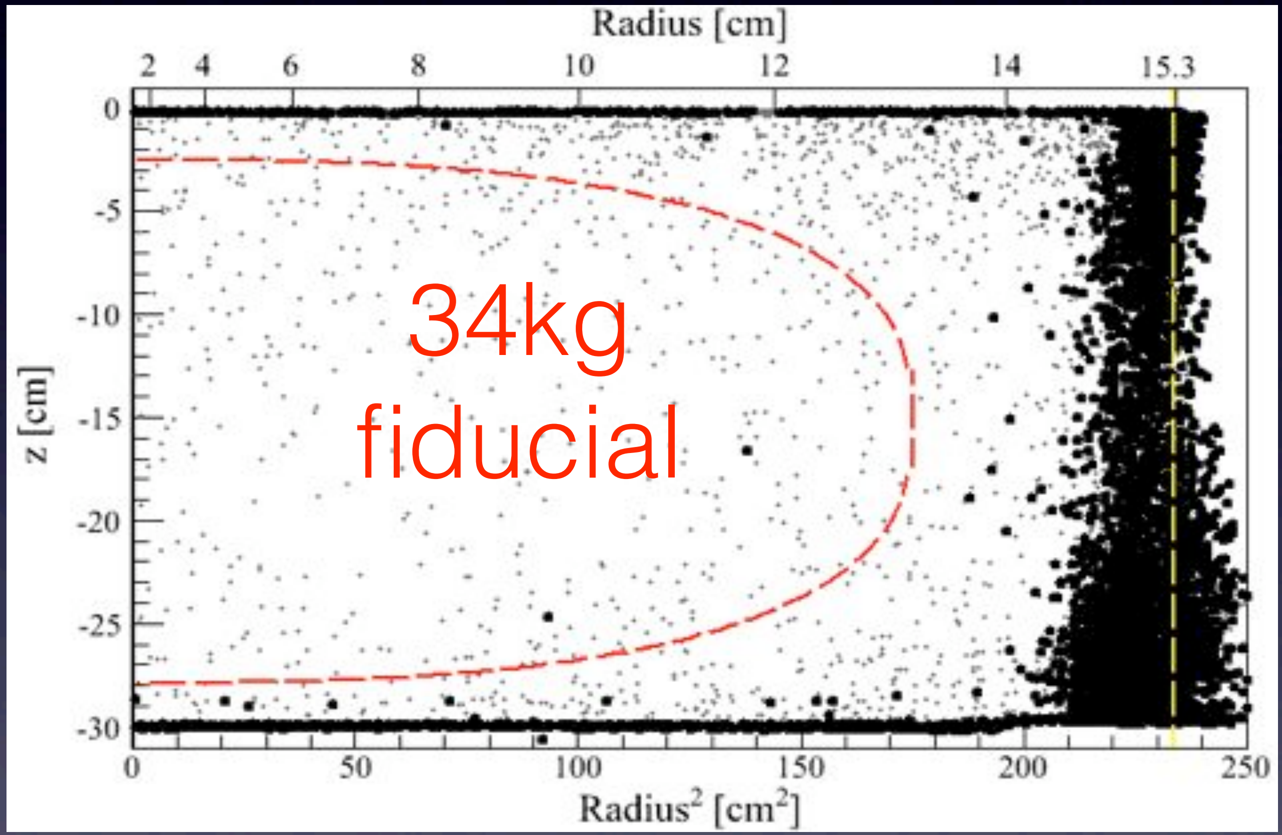


Phys. Rev. D 83, 082001 (2011)

Enables powerful background suppression by volume fiducialization and event multiplicity

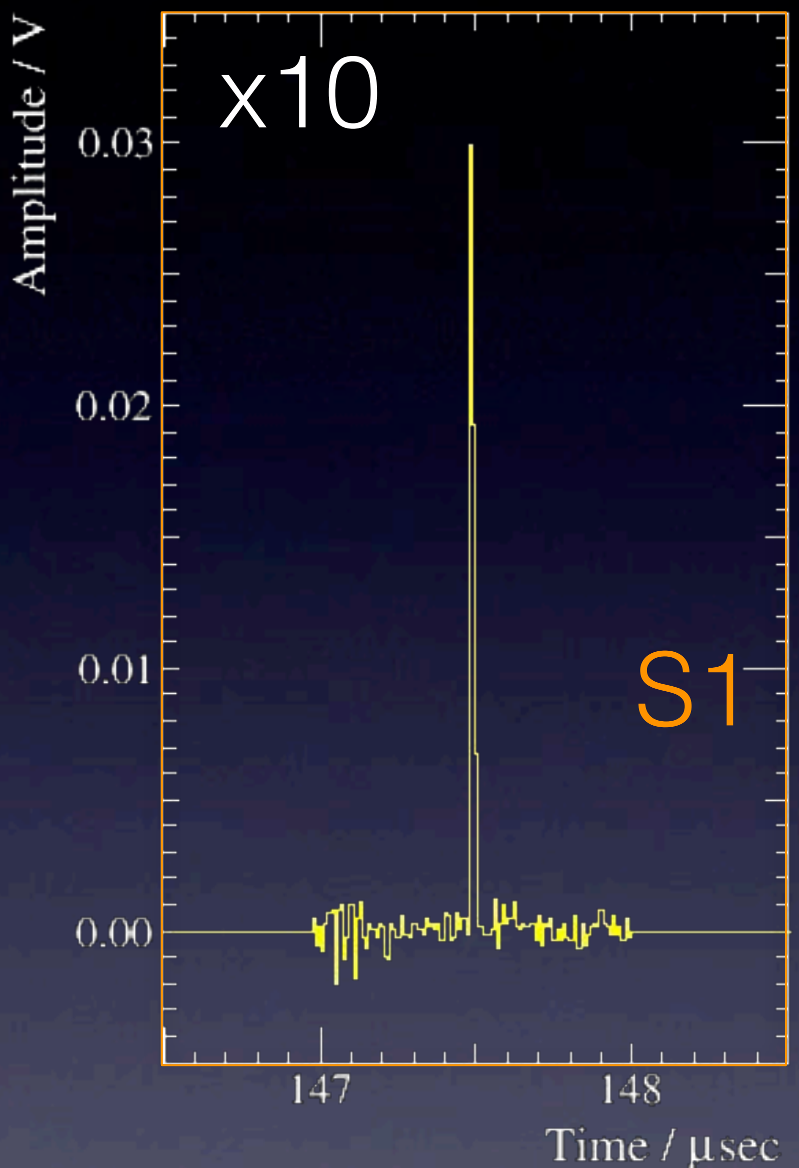
single scatter events after 225 live days of data taking 2011/2012: (trigger rate ~1Hz)

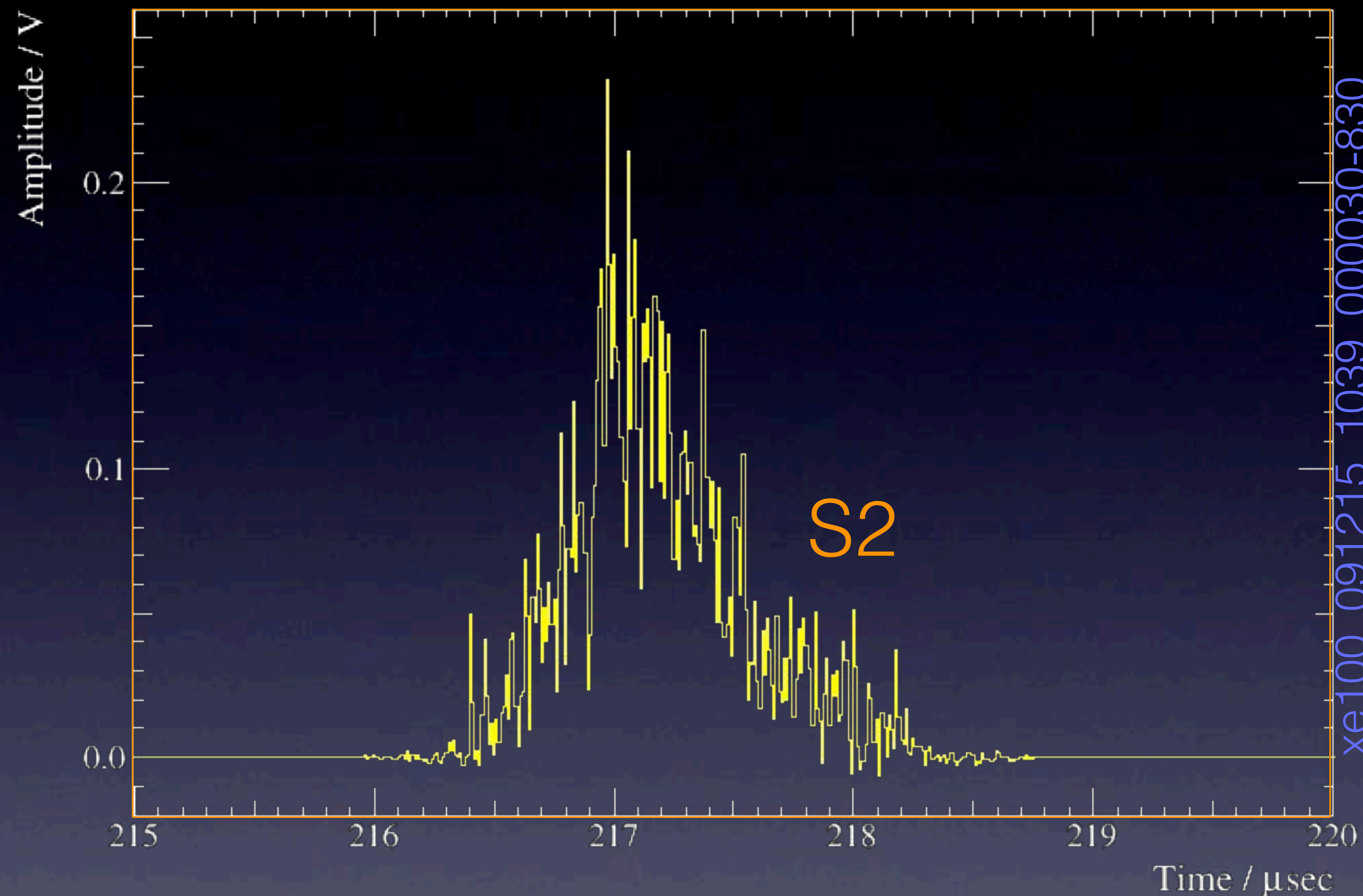




- 2 events observed with 1.0 ± 0.2 events expected
- 26.4% probability of upward background fluctuation
- No significant excess due to signal seen in XENON100 data

WIMP-like Event as seen in XENON100



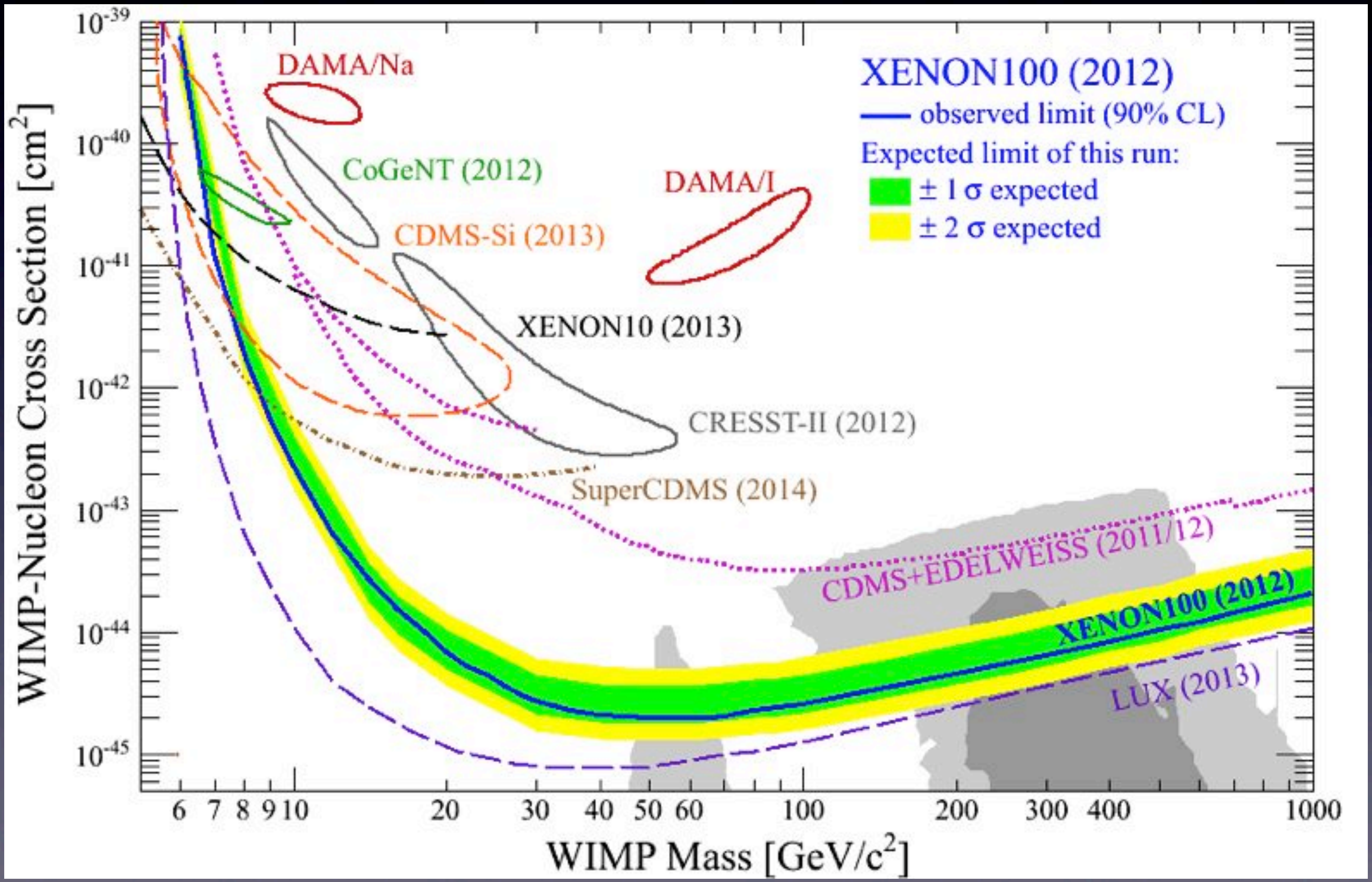


3.6 PE detected
(from ~100 S1 photons)

645 PE detected
(from 32 ionization electrons which generated ~3000 S2 photons)

XENON100: Spin Independent/Dependent Limit

Aprile et al.(XENON100),Phys. Rev. Lett. 109 (2012)



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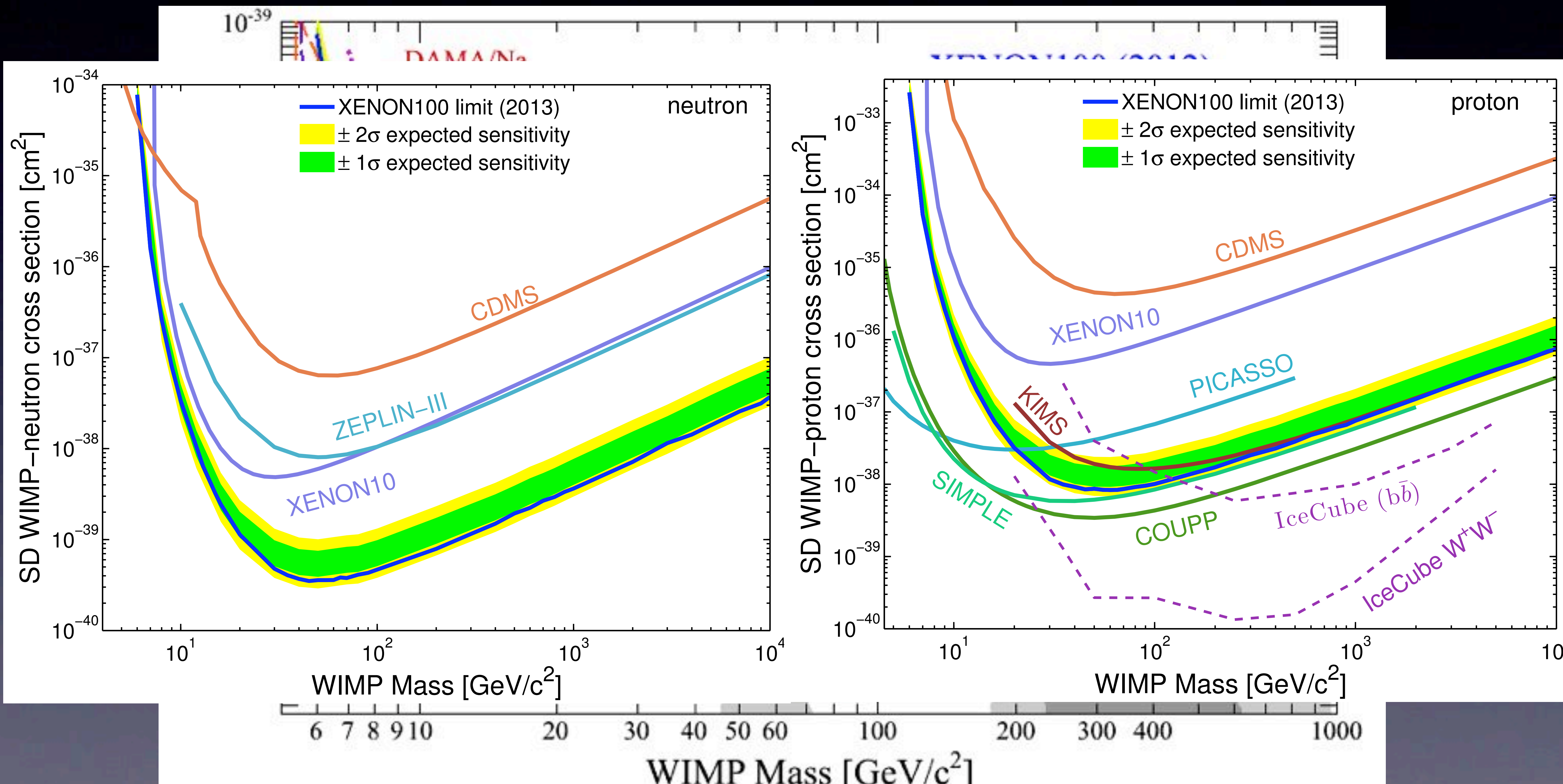


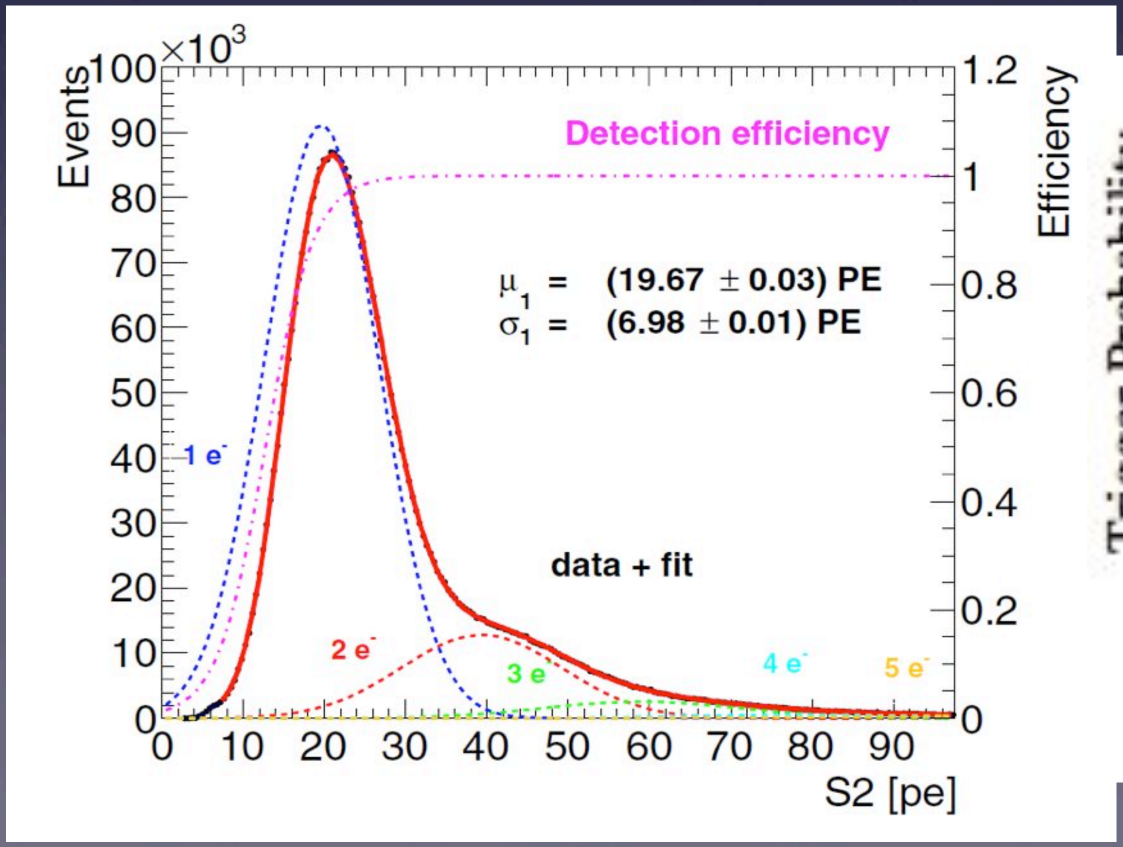
Aprile et al. (XENON100) Phys. Rev. Lett. 111 (2013)

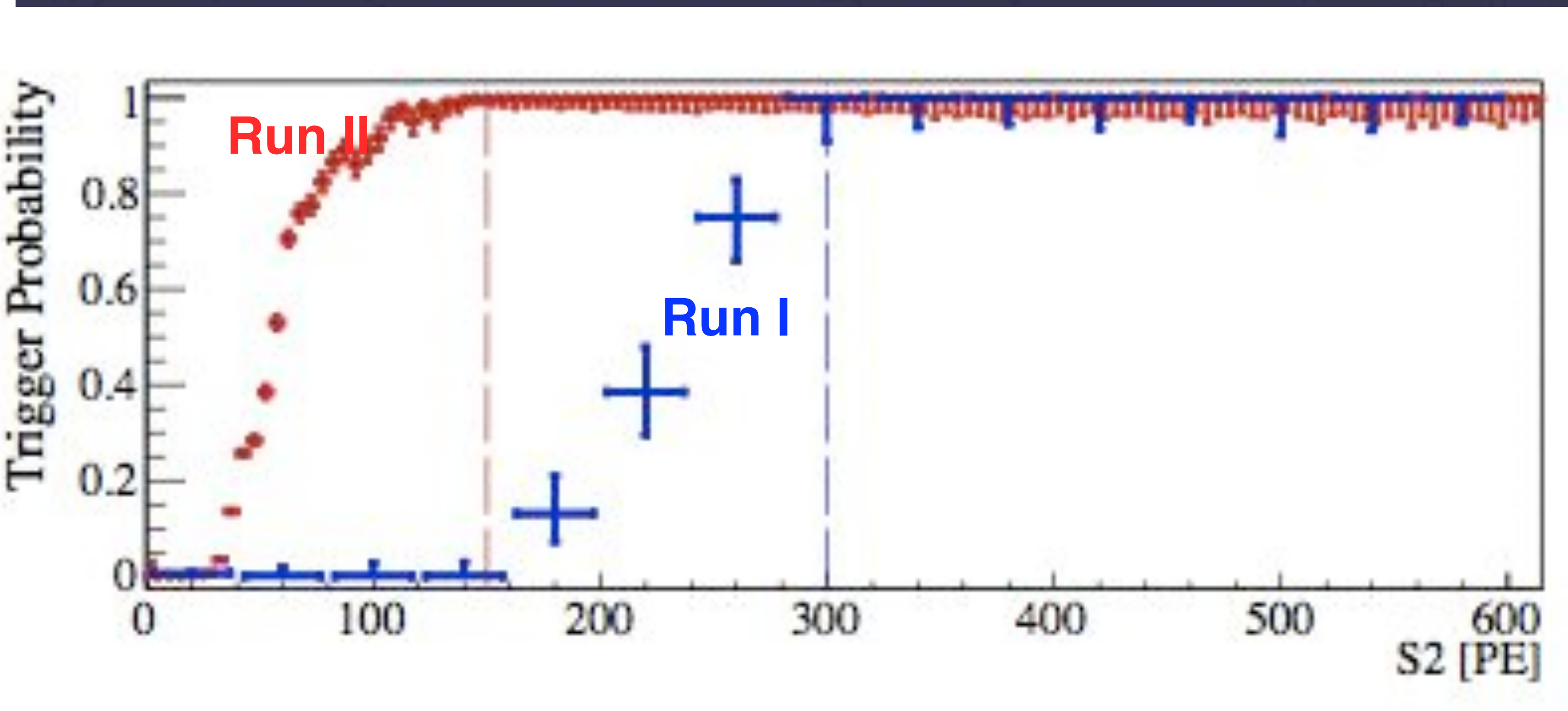
Light DM Search with XENON100 Data

Search for MeV/GeV WIMPs using only S2 signal and annual modulation signature

1-8 GeV WIMPs will give NRs with a few electrons which can be detected in XENON100 thanks to 100% trigger efficiency for events with >8 electrons (~20pe/e gain) Aprile et al PRL 109 (2012)

WIMPs with ~50 MeV can eject a few electrons of Xe atoms, detectable via S2 only analysis and the single-e detection ability of a two-phase TPC Aprile et al Phys.G: Nucl.Part.Phys. 41(2014)



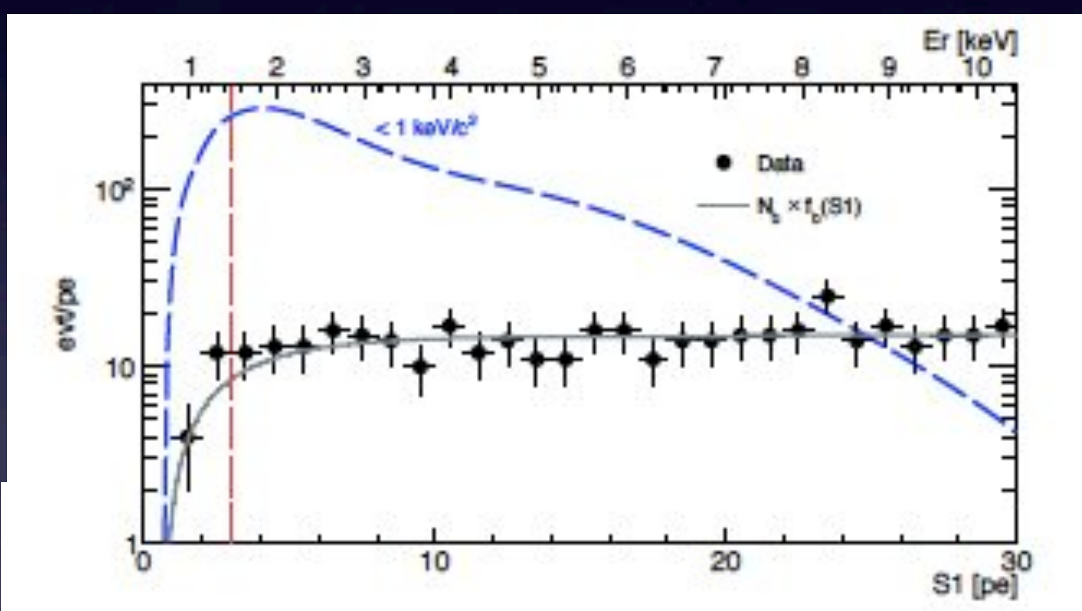


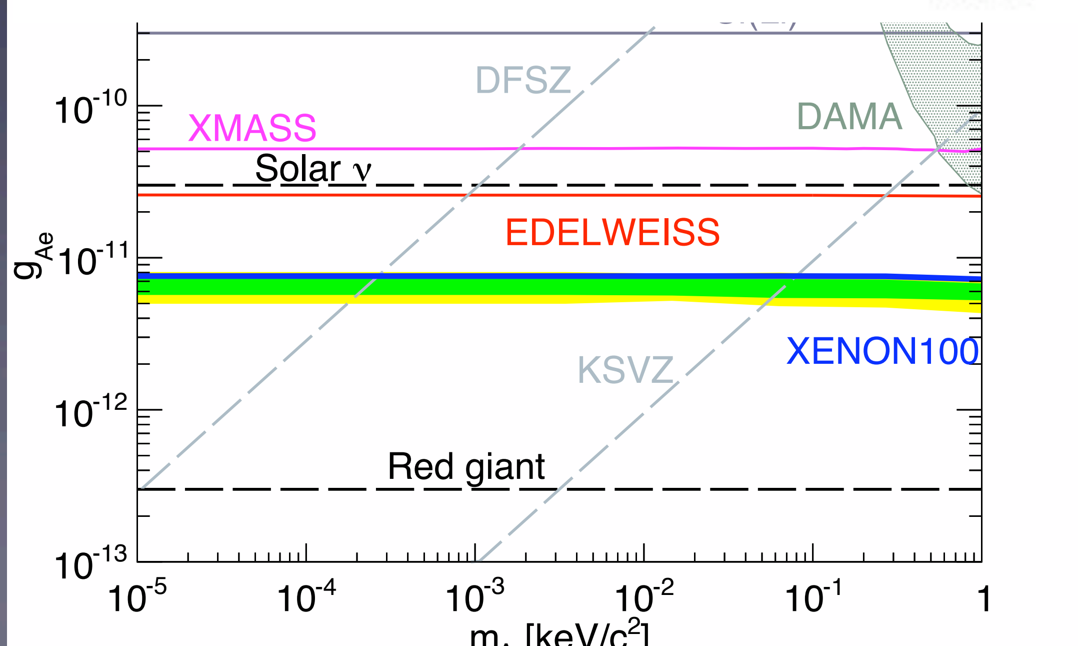
Axion Search with XENON100 Data

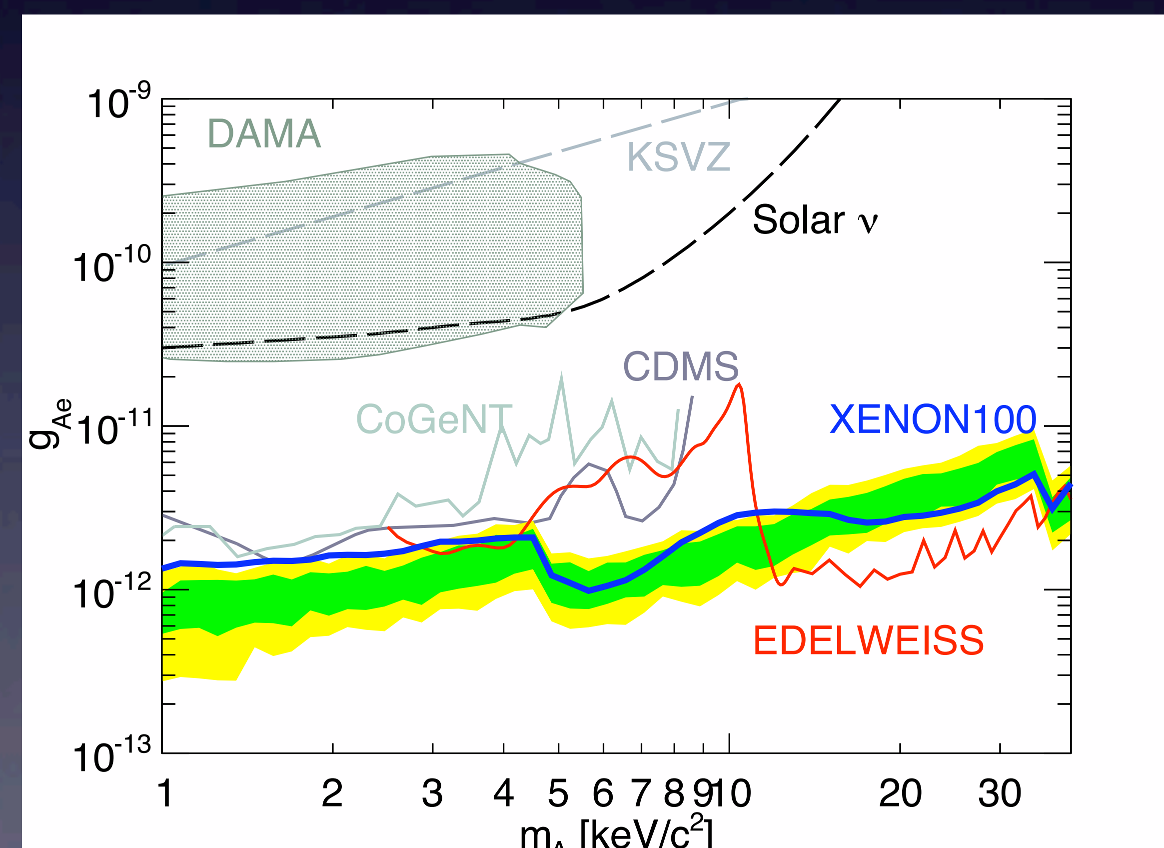
arXiv:1404.1455

Axions and ALPs can interact with atomic electrons via the axioelectric effect producing ERs with energy equal to axion mass minus e-binding energy in Xe → solar axions (continuum spectrum) and galactic (monoenergetic) ALP.

The low background in XENON100 and its low ER threshold allows a very sensitive search. S1(PE) converted to keV_{ee} based on recent measurements of scintillation efficiency and its quenching with field by Columbia and UZH groups. 3PE threshold corresponds to 2 keVee.

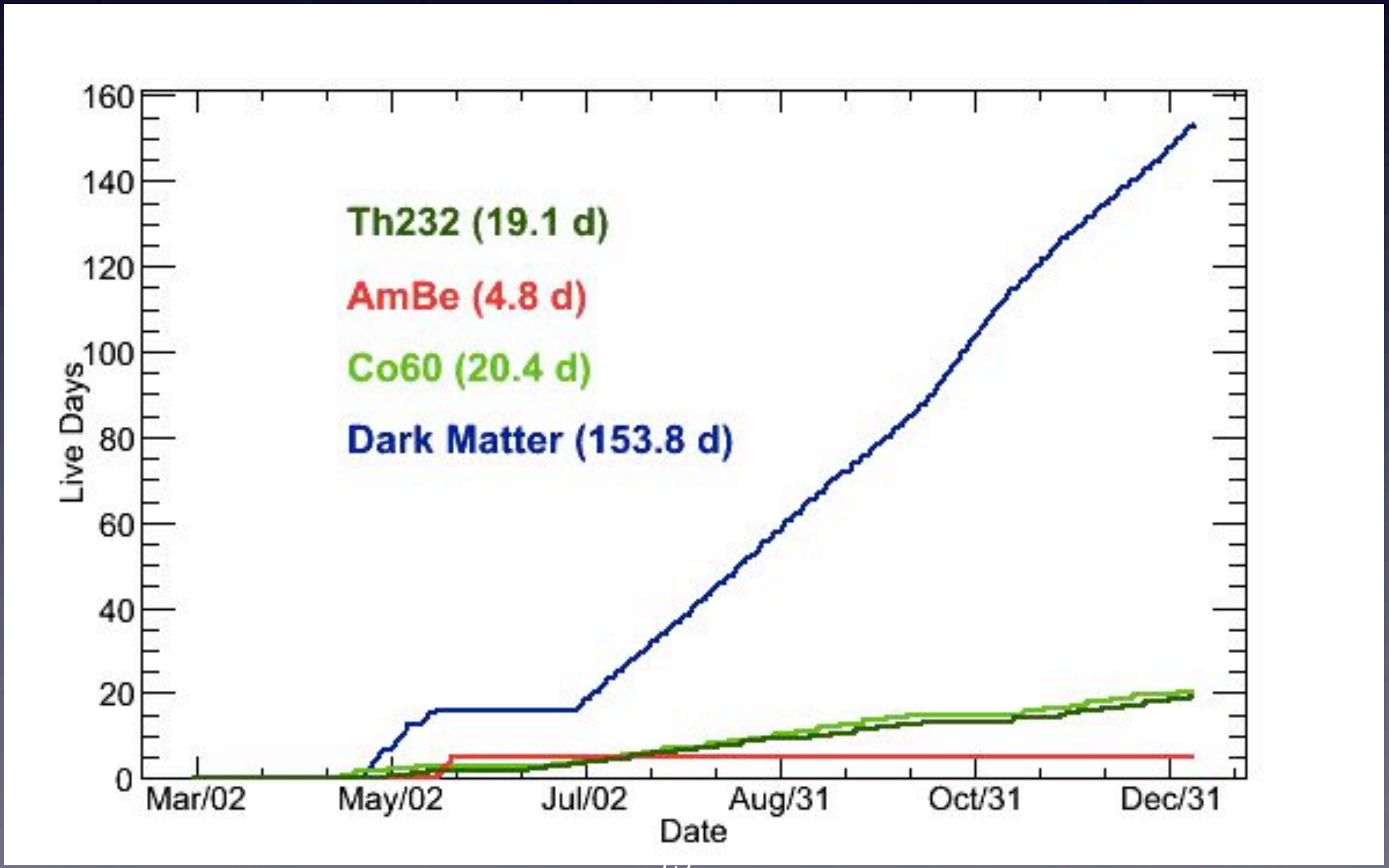




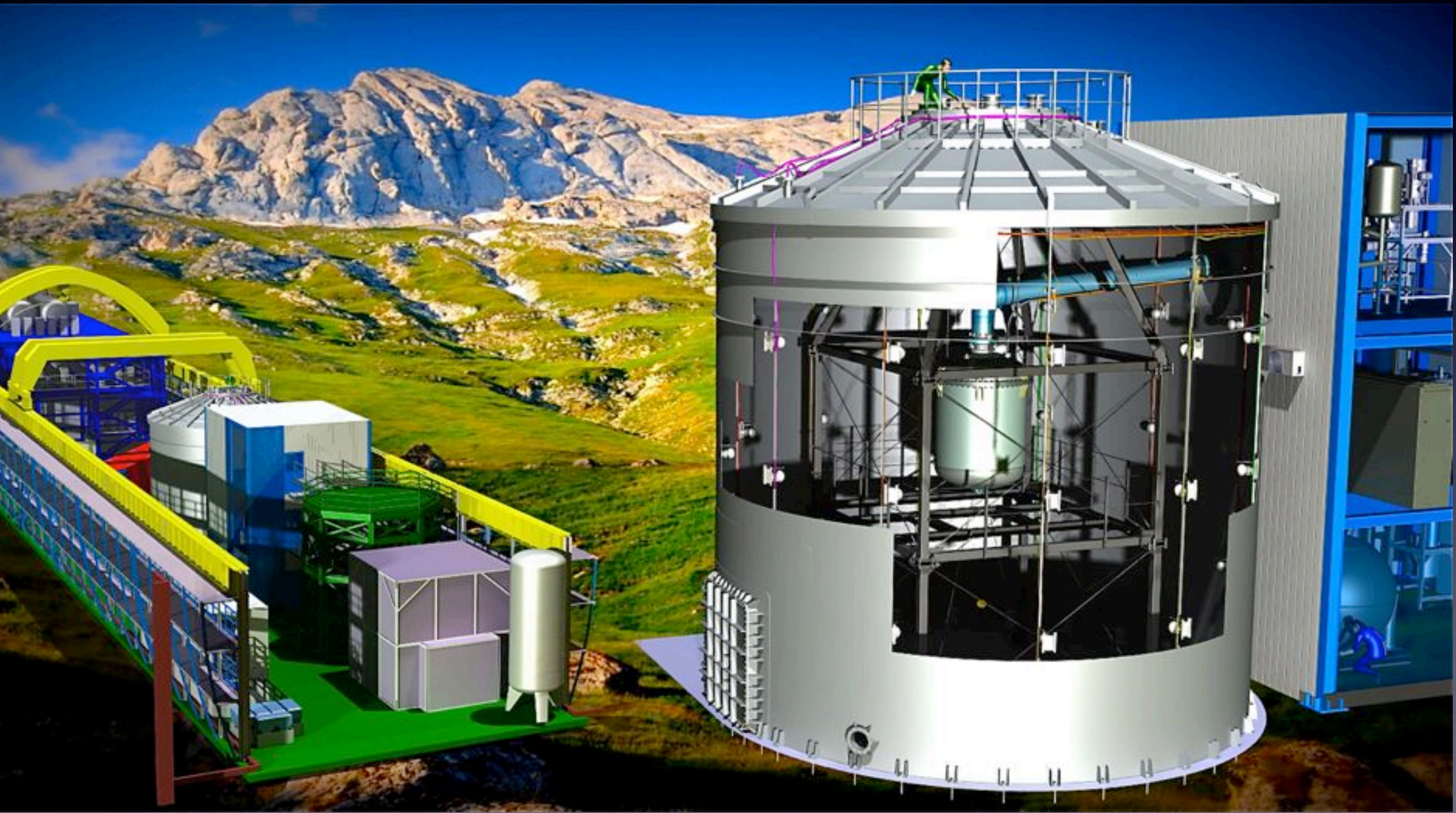


XENON100 Still Taking Data

- 154 days of new DM data in 2013 (blinded) under analysis
- Combine with previous data for a more precise annual modulation search.
- Detector light yield enables search down to 2 keVee. Very stable performance
- Measured Kr/Xe < 1ppt level (demonstration for XENON1T)
- New neutron sources calibration (demonstration for XENON1T)
- We are currently modifying the shield to host the Y-Be source for low energy NR calibration



XENON1T

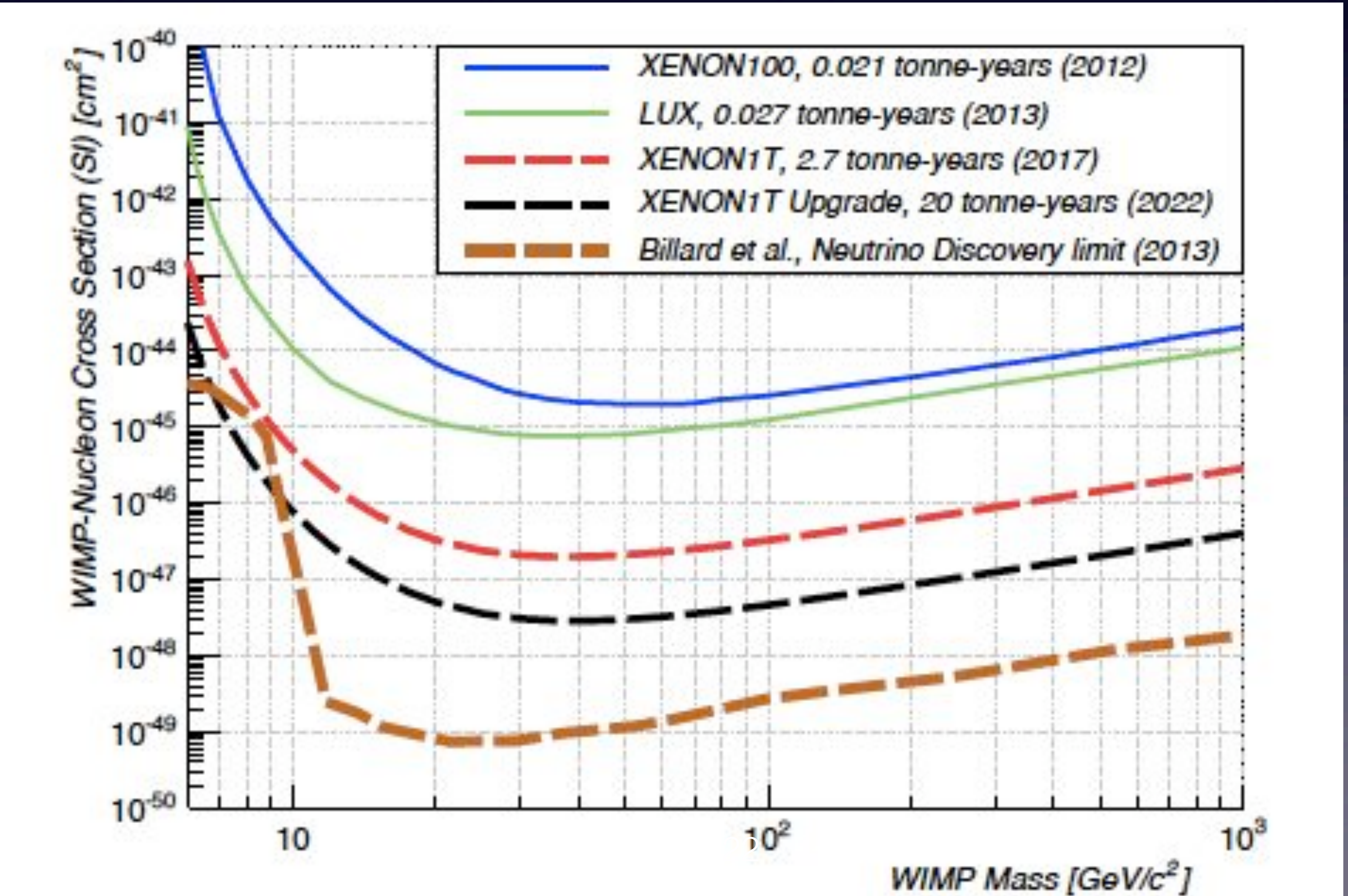


From XENON100 to XENON1T

- Two-phase TPC with 1 meter drift and ~1 m diameter electrodes exploiting ~3.3 tonnes of Xe
- Experiment designed to enable a fast upgrade to a larger diameter TPC exploiting ~7 tonnes of Xe
- Detector/associated systems use largely proven technologies developed for XENON100
- New challenges presented by the scale-up addressed with multiple R&D set-ups
- New 3 inch PMTs developed for XENON1T: average QE~40% at 178 nm and low activity
- Detector shielded by water implemented as Cherenkov muon veto
- Developing methods to control the most challenging backgrounds: from ^{85}Kr beta-decays (reduce Kr/Xe < 0.5 ppt) and from ^{214}Pb beta-decays (reduce ^{222}Rn in LXe to ~1 mBq/kg)
- Schedule: under construction at LNGS started fall 2013
- Science Goal: 2×10^{-47} cm^2 with 2 ton-years of data or by 2017
- Funded with 50% of capital cost covered by NSF and the rest from Europe and Israel.

Science Reach of XENON1T Program

- 100 x more sensitive than XENON100 - 1000 x more after upgrade
- either exclude much of favored SUSY WIMPs parameter space
- ~100 events from a 50 GeV WIMP at $2x10^{-47}$ cm^2 with 2 tonne-year



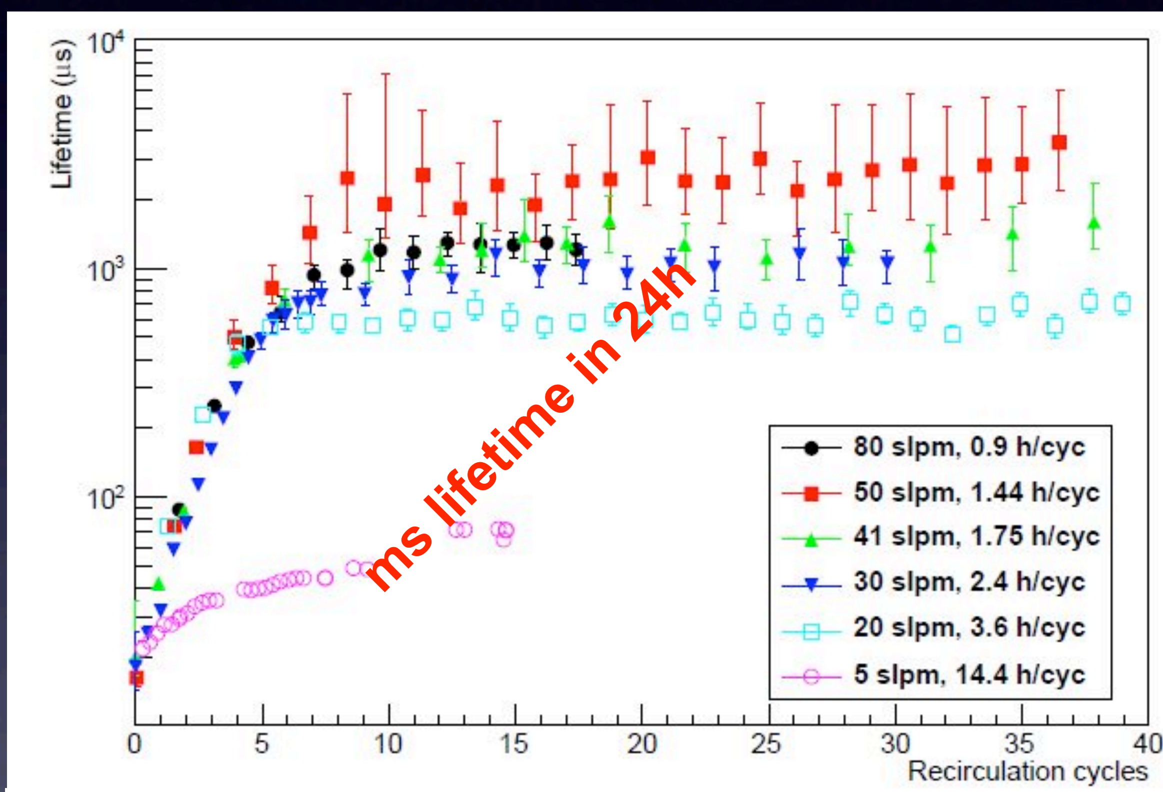
XENON1T Demonstrator at Columbia

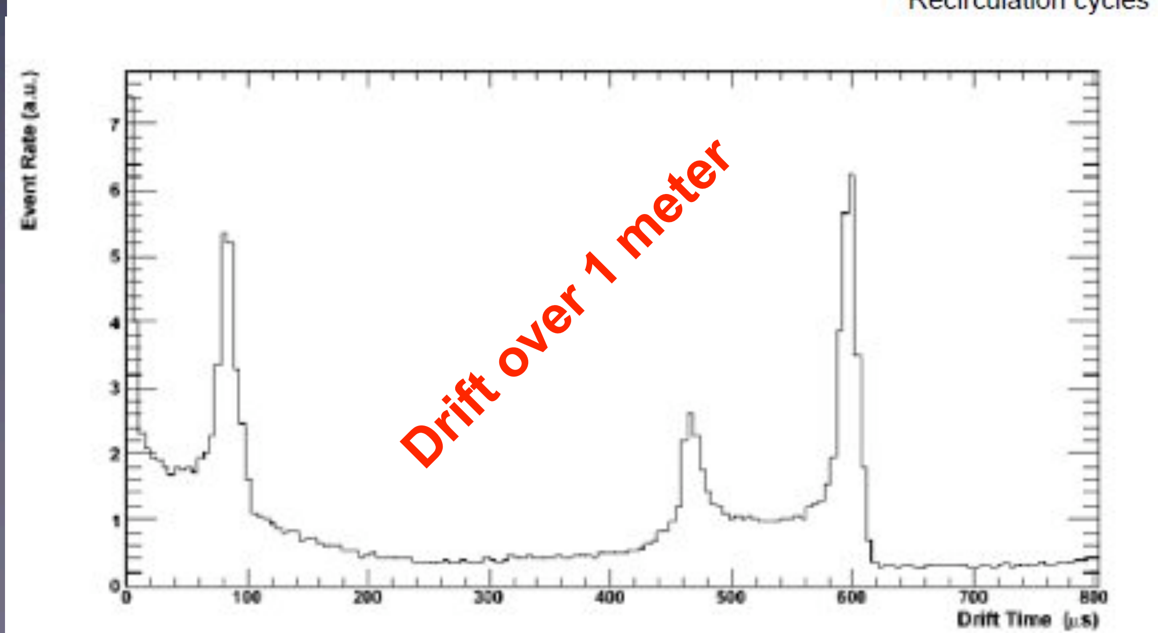
To test technologies/inform design of XENON1T detector

1. cooling by Pulse Tube Refrigerator with efficient heat exchange

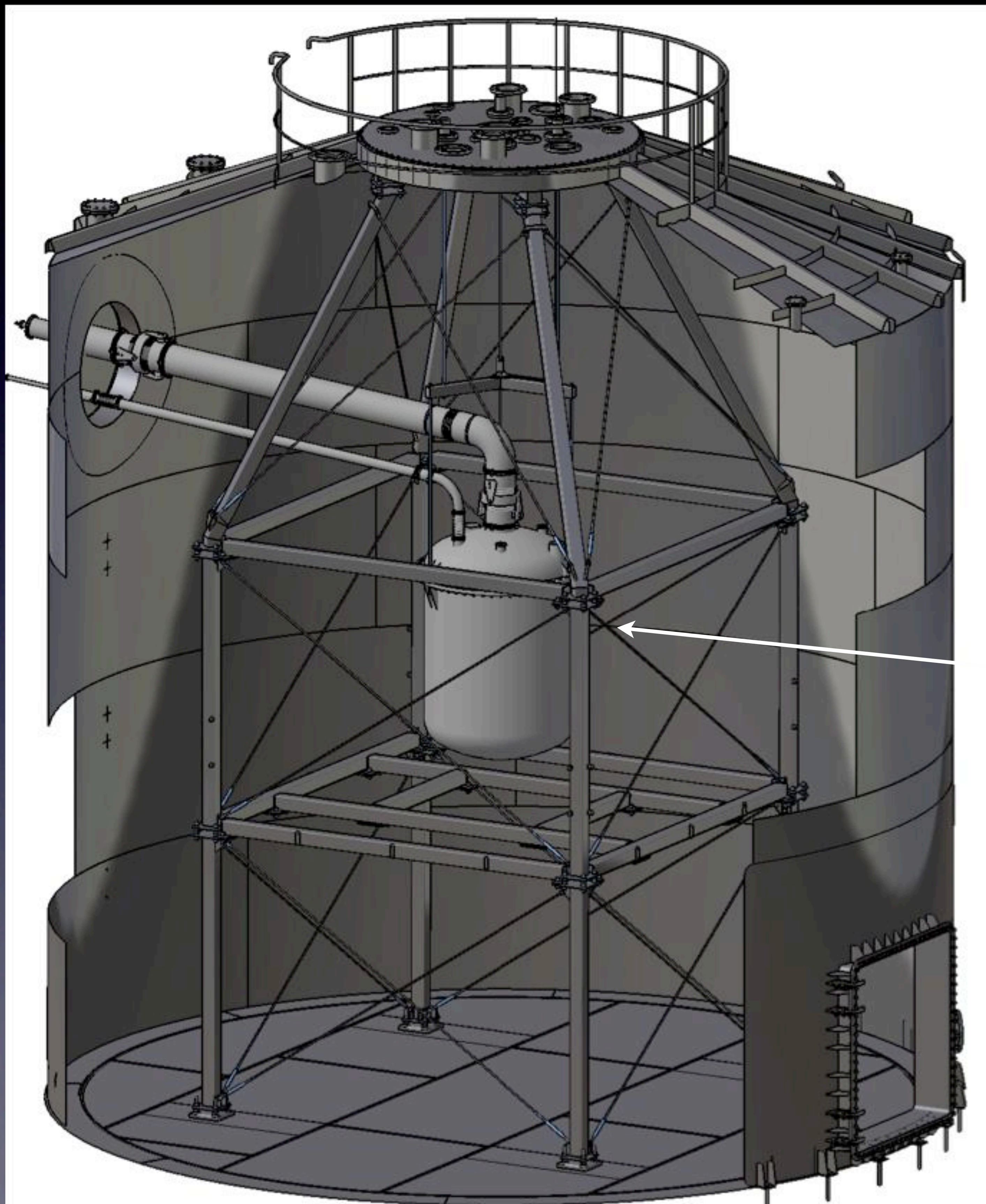
2. continuous purification of Xe with flow > 50 SLPM

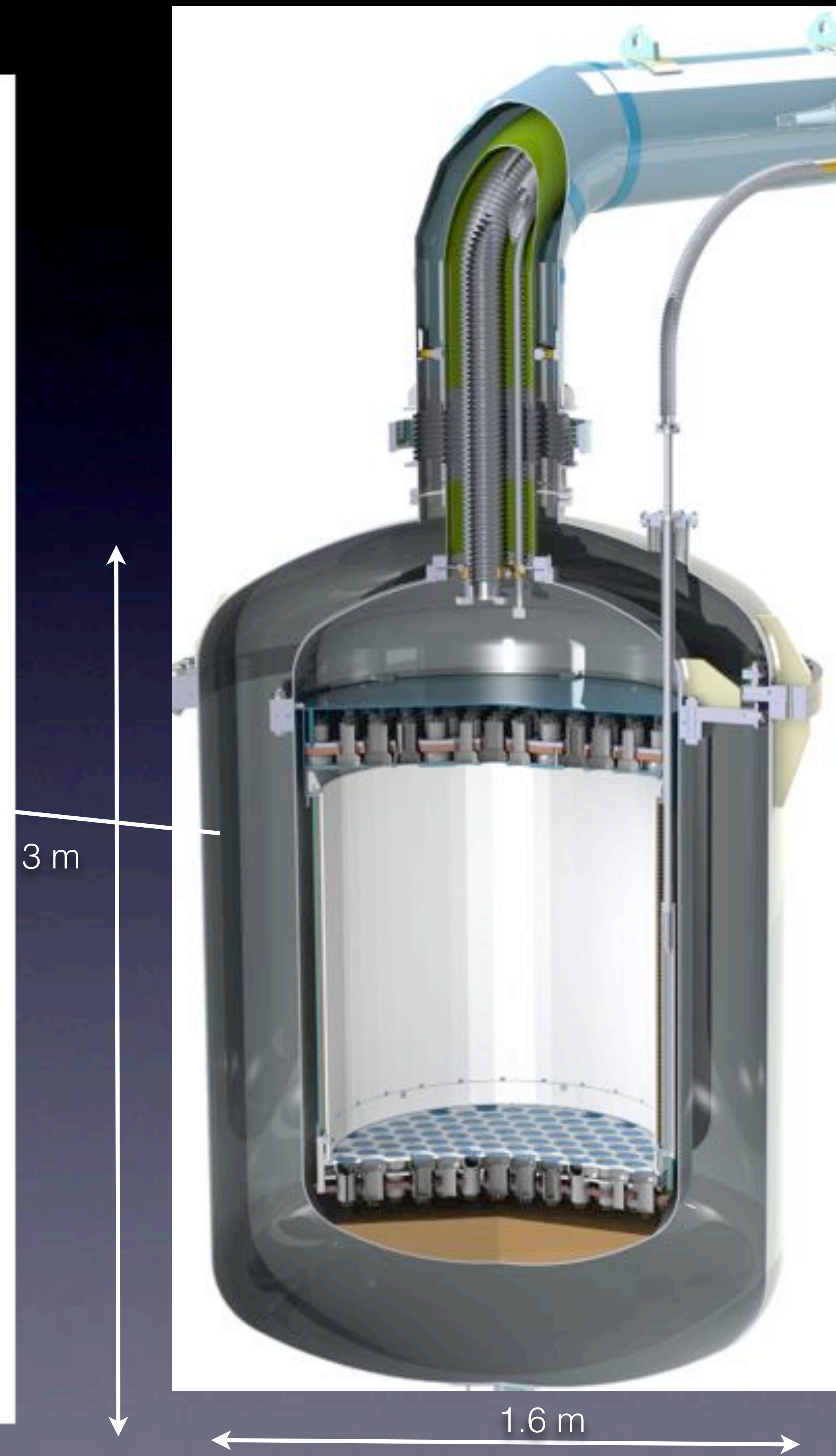
3. demonstrate purity and HV with a 1 m-drift TPC



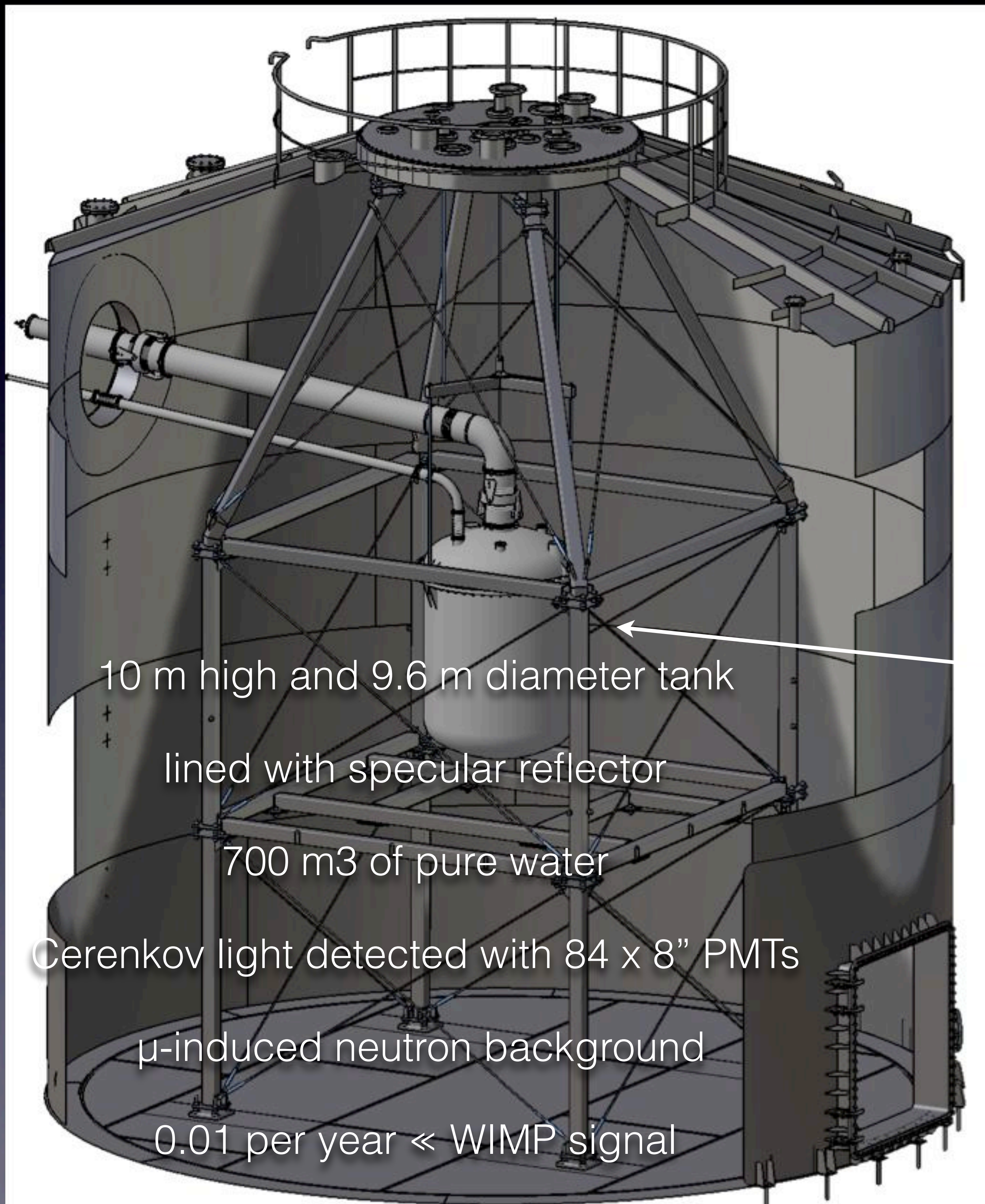


XENON1T Detector



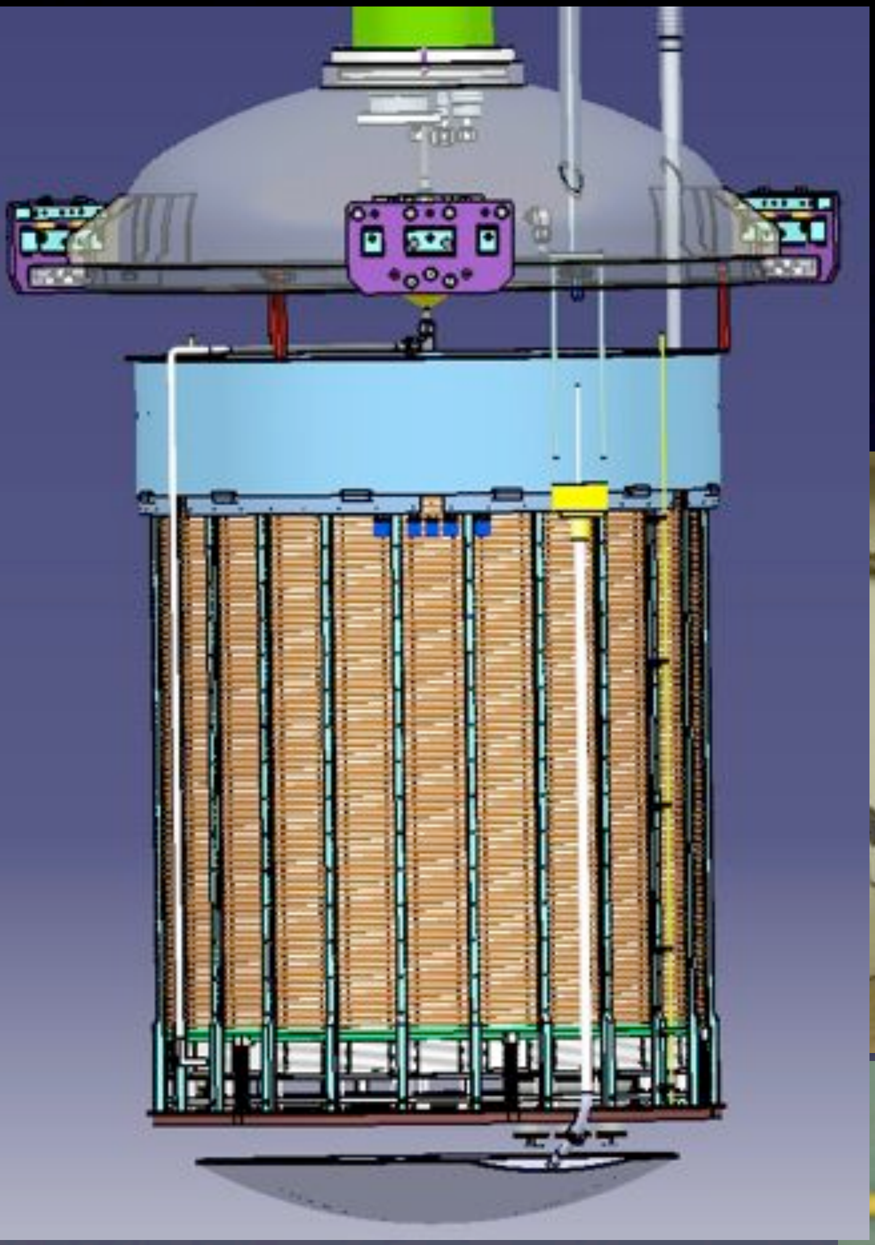


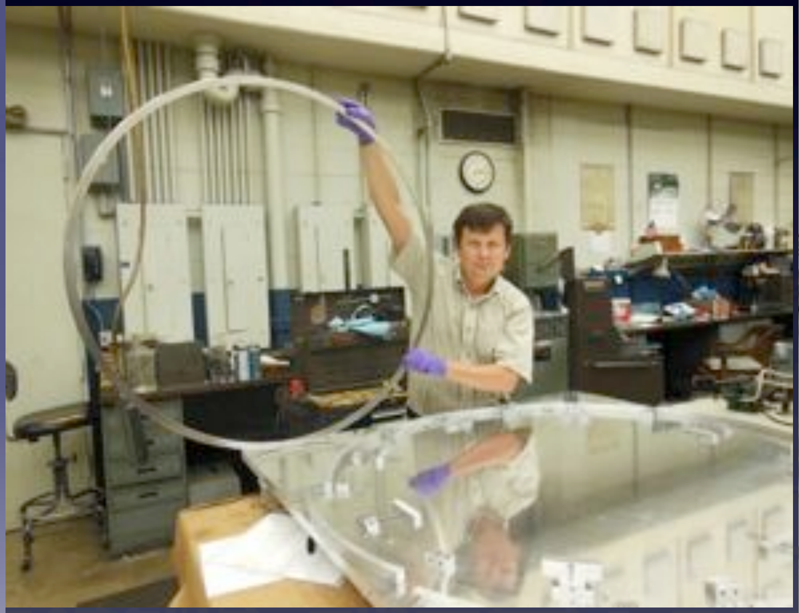
XENON1T Detector

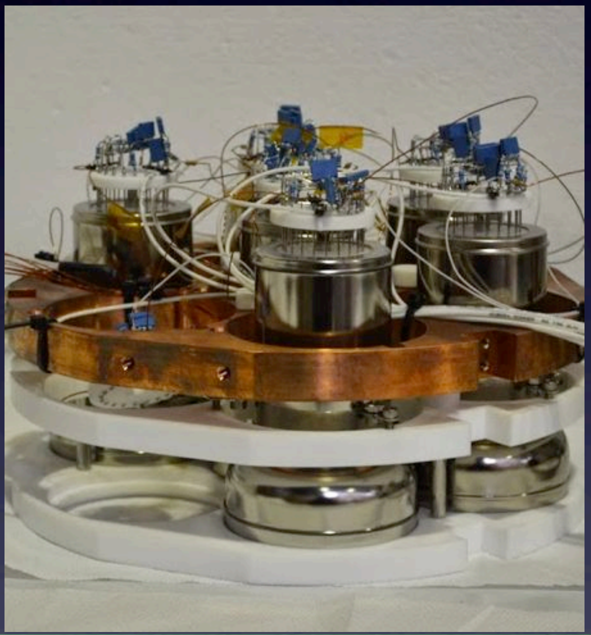


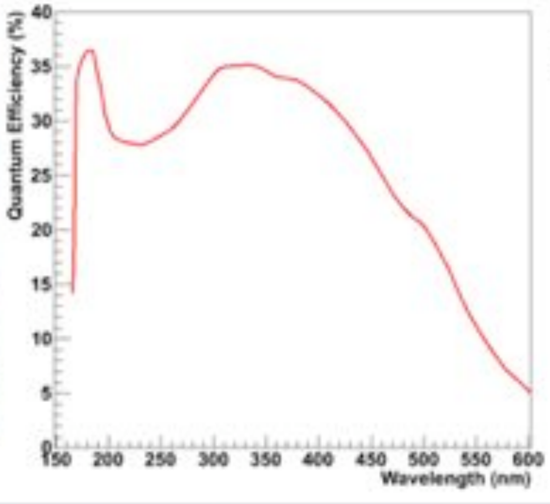
TPC details

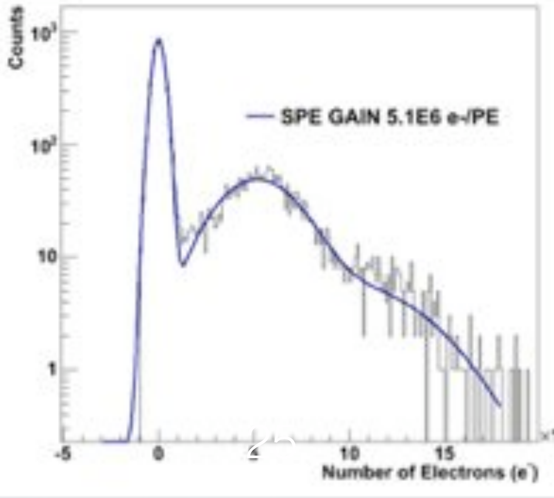
- Electrodes: 1 meter diameter wire grids
- Field cage: Cu-rings; PTFE reflector
- PMTs: 248 x 3" Hamamatsu R11410-21: ~40% QE @ 175 nm; <1mBq/PMT in U/Th
- HV: 100kV custom-made feedthrough
- TEP mock-up at LNGS

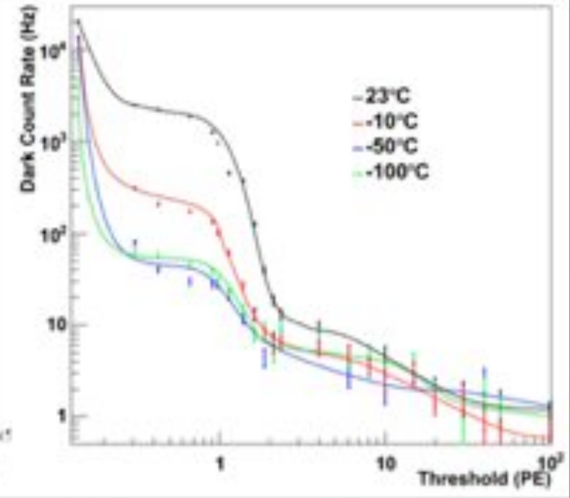




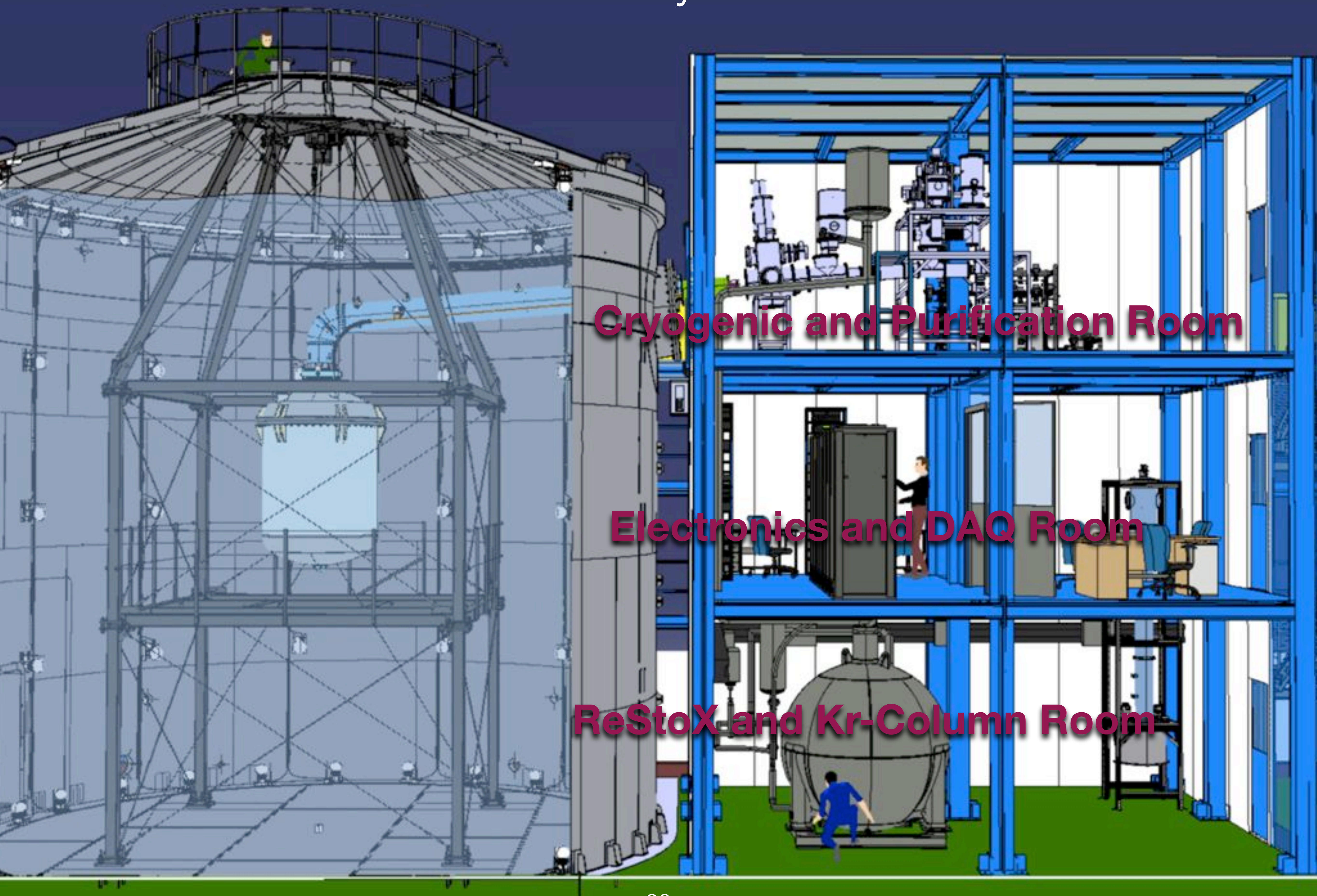








XENON1T Systems



XENON1T in Hall B of LNGS
(pictures gallery)

Xe Cryogenic & Purification

- under construction at Columbia and Munster
- commissioning at LNGS starts beginning of July
- Largely based on XENON100 and Demonstrator R&D

ResToX (fast recovery system) and Cryostat

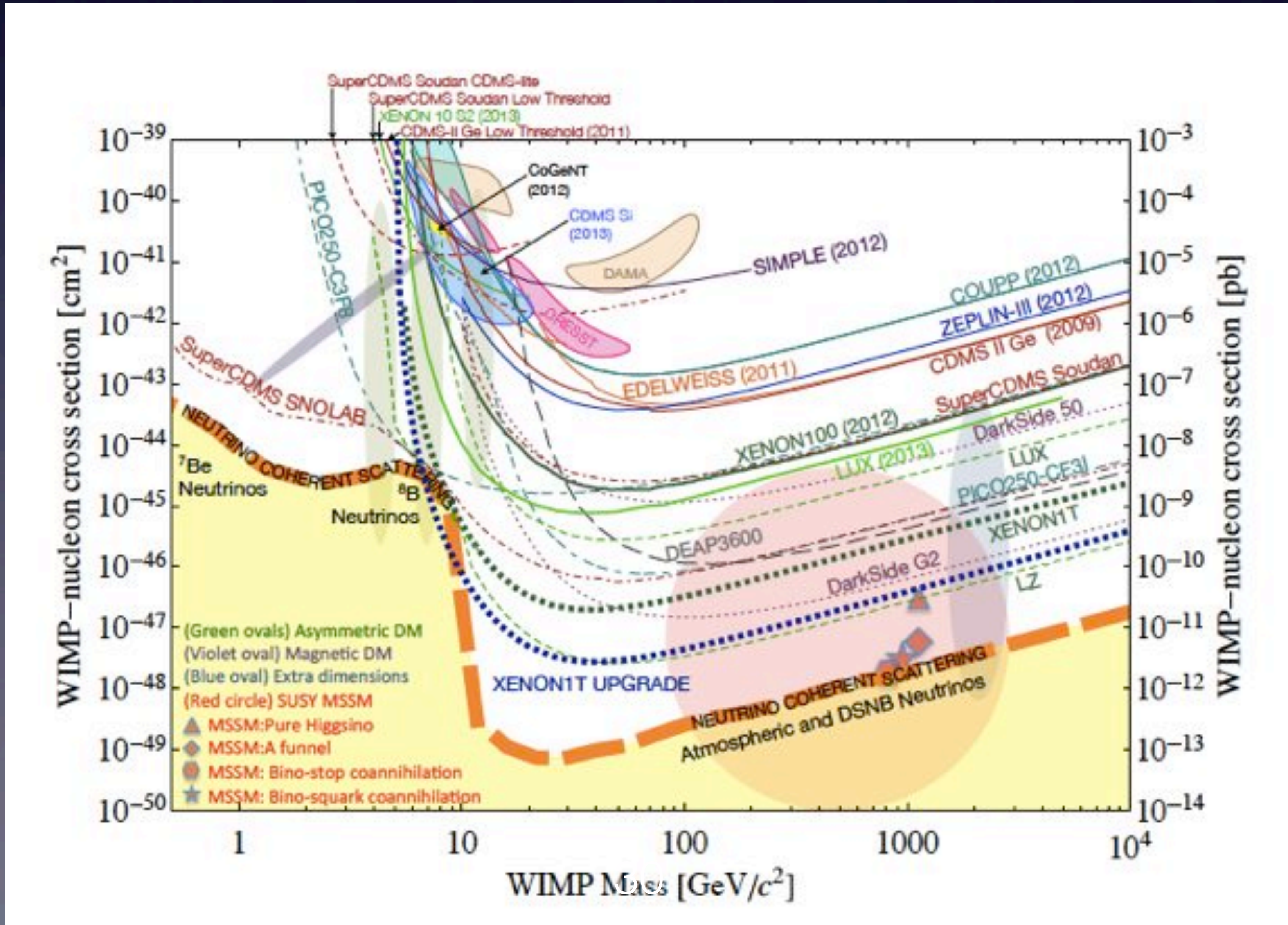
- Double-walled, high pressure (70 atm), vacuum-insulated, LN2 cooled sphere
- Capable to store 7.6 tons of Xe either in gas or liquid/solid phase under high purity conditions
- It is aimed at recovering in a safe and controlled way LXe from detector.
- In case of emergency all LXe is recovered in a few hours

Cryostat under construction

- The outer vessel is capable to host an enlarged inner vessel to increase the active target from 3.3 to 7 tonnes.

Summary

- XENON100 is still in operation after 5yr. New DM data still blinded.
- New calibration sources will be tested also for XENON1T
- XENON1T construction is on schedule
- Commissioning of the cryostat and all cryogenic plants will start in July. We expect a full validation by end 2014. TPC will be installed by Spring 2015
- XNON1T data taking is expected by Summer 2015. After 2 ton-yr of data sensitivity reach is as shown
- An upgrade of XENON1T has been proposed to the NSF. Planned to start in 2018



arXiv:1310.8327