XENON Dark Matter Search
XENON100 and XENON1T

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29-Oct-2013

LNGS Scientific Committee Meeting

XENON World Map

Columbia | Nikhef | Mainz | Muenster | MPIK

UCLA | Bern

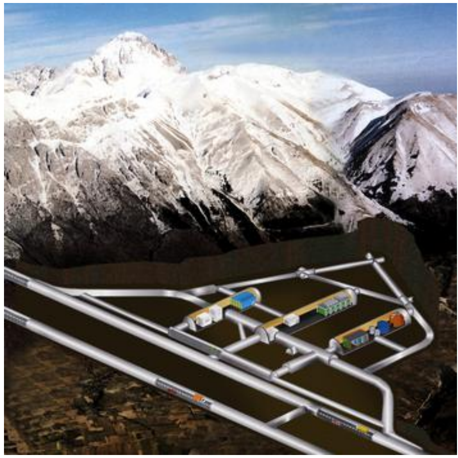
Rice | Zurich

Purdue | Coimbra | Subatech | Bologna | LNGS | Torino | Weizmann

~100 scientists, 16 institutions

The XENON Program

GOAL: Explore WIMP Dark Matter to a sensitivity of σ_{SI}~10^{-48} cm^2.



Location: LNGS

CONCEPT:

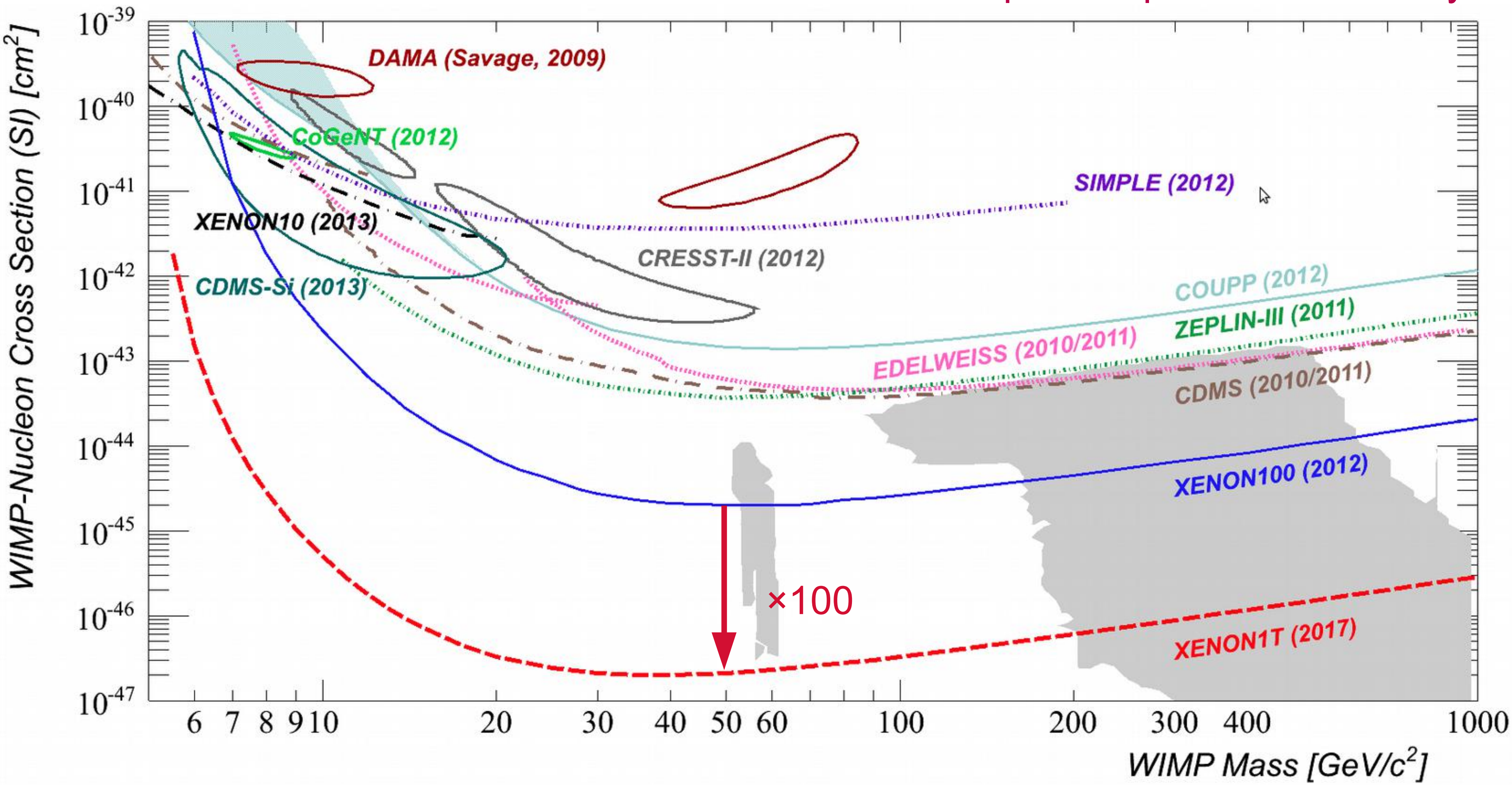
- Target LXe: excellent for DM WIMPs scattering.
  Sensitive to both axial and scalar coupling.
- Detector: two-phase LXeTPC: 3D position sensitive calorimeter.
- Background discrimination:
  - simultaneous charge & light detection
  - single site interactions, fiducialization, self shielding
- High light yield + proportional scintillation
  → low energy threshold for nuclear recoils (~6 keV).

PHASES:

R&D	XENON10	XENON100	XENON1T	XENONnT
Start: 2002	2005-2007	2007 → ...	2011 → DM search '15	2018 →
	Proof of concept. Total mass: 14 kg 15 cm drift. Best limit in '07: σ_{SI}~10^{-43} cm^2	Ongoing DM search. Total mass: 161 kg 30 cm drift. Best limits since '11. '12: σ_{SI}~ 2 x 10^{-45} cm^2	Construction ongoing. Total mass: ~ 3.5 t 1 m drift. Goal: σ_{SI} ~ 2 x 10^{-47} cm^2	Goal: σ_{SI} ~ 10^{-48} cm^2

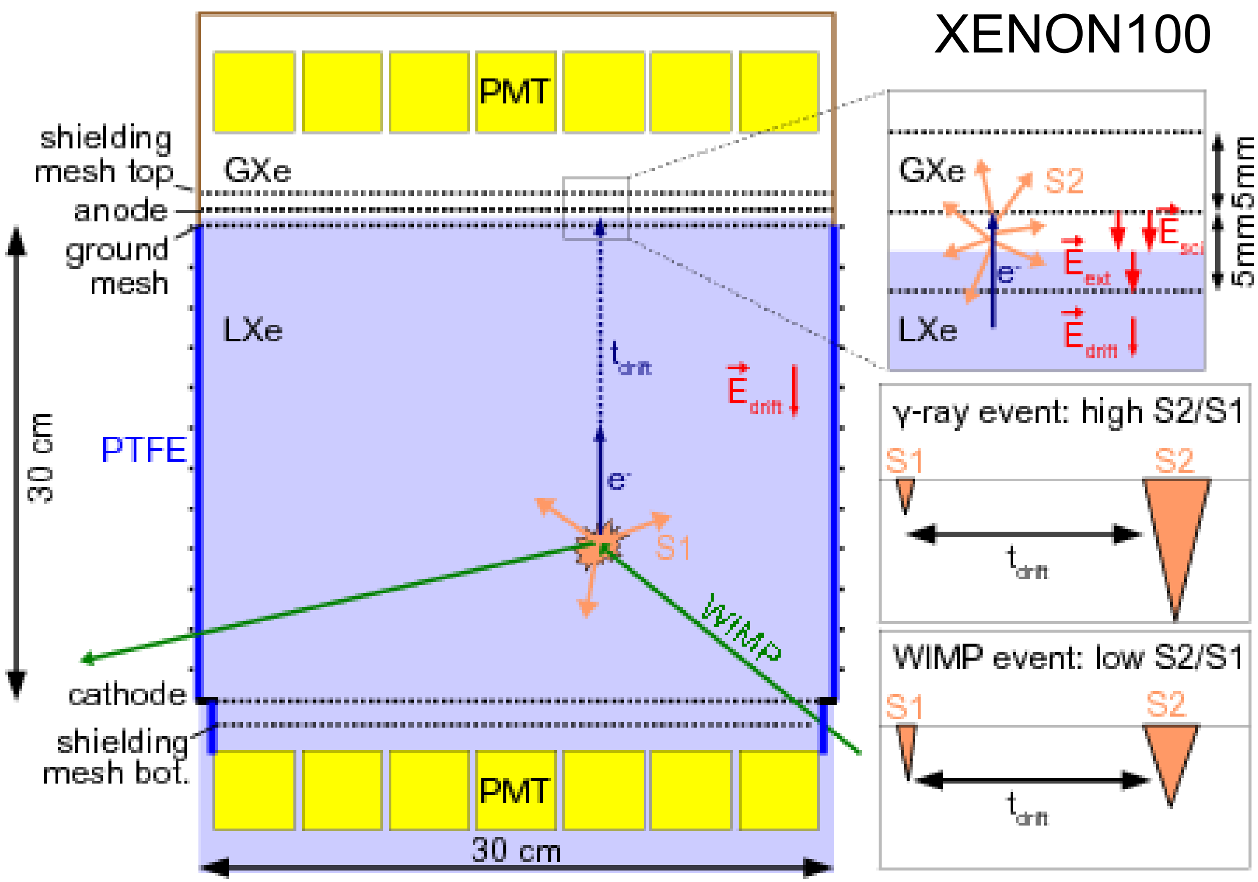
XENON1T Sensitivity

Spin-independent sensitivity



The Liquid Xenon Dual Phase TPC

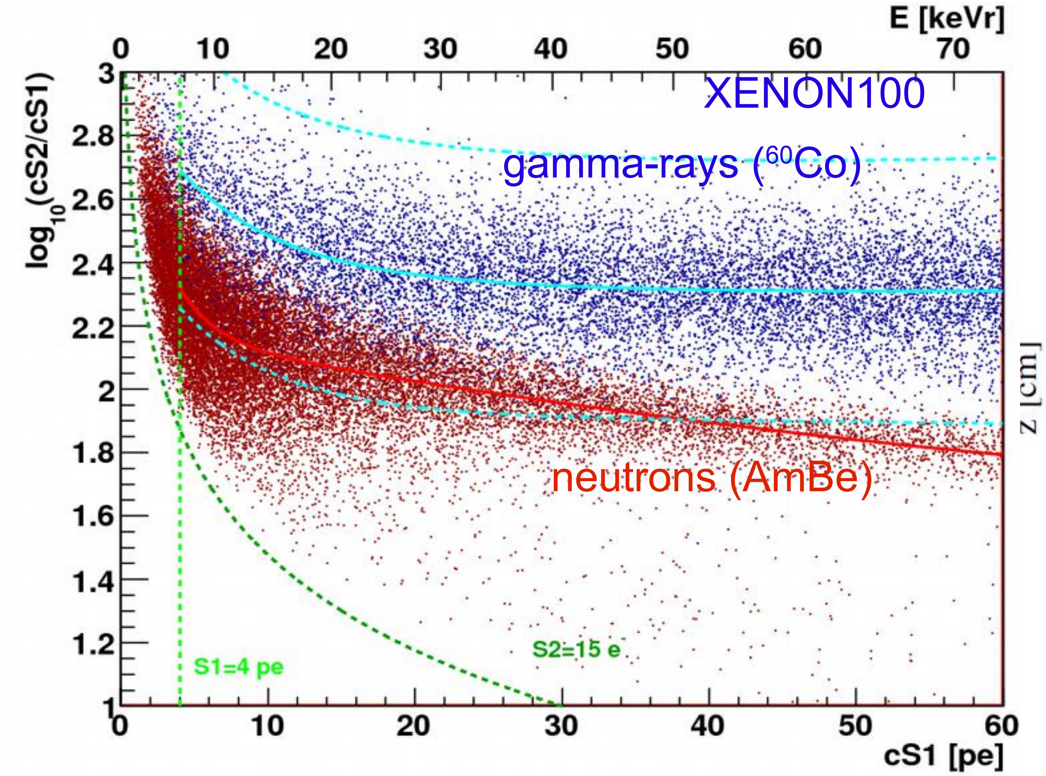
- WIMP recoil on Xe nucleus in dense liquid (2.9 g/cm^3)
  → Ionization + UV Scintillation
- Detection of primary scintillation light (S1) with PMTs.
- Charge drift towards liquid/gas interface.
- Charge extraction liquid/gas at high field between ground mesh (liquid) and anode (gas)
- Charge produces proportional scintillation signal (S2) in the gas phase (12 kV/cm)



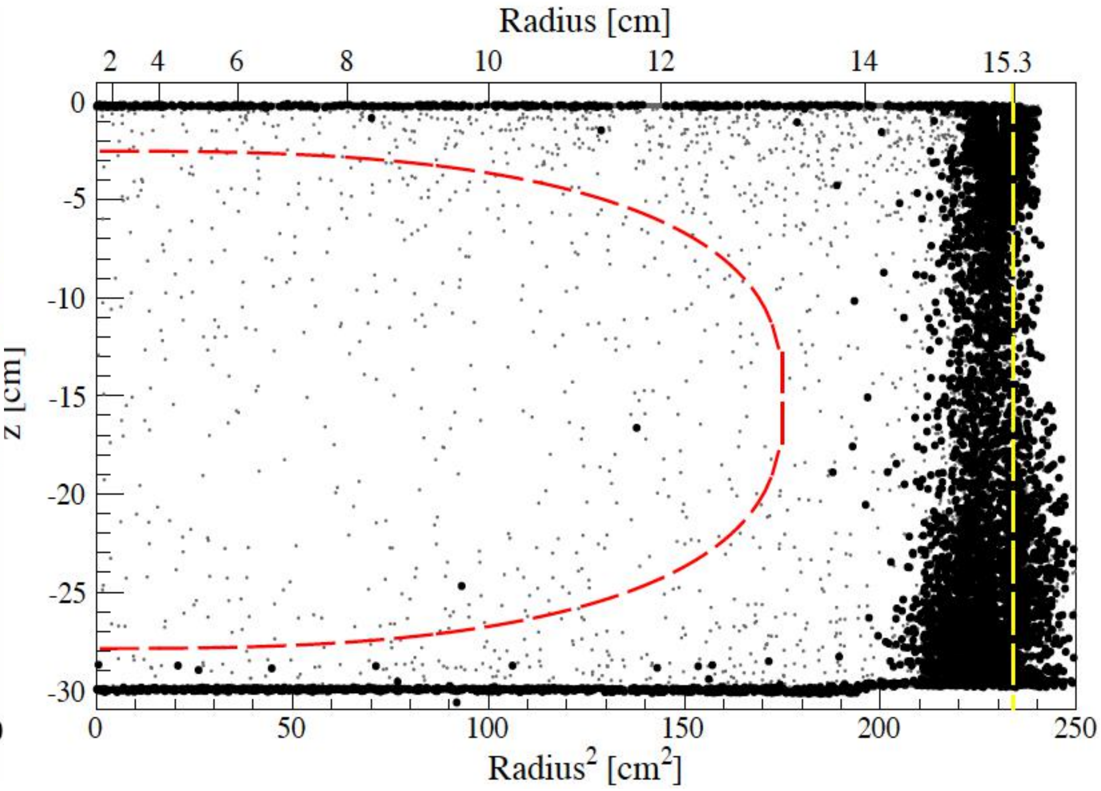
- **3D position measurement**
  - X/Y from S2 signal. Resolution few mm.
  - Z from electron drift time (~0.3 mm).

Background Discrimination in Dual Phase Liquid Xenon TPC's

Ionization/Scintillation Ratio S2/S1

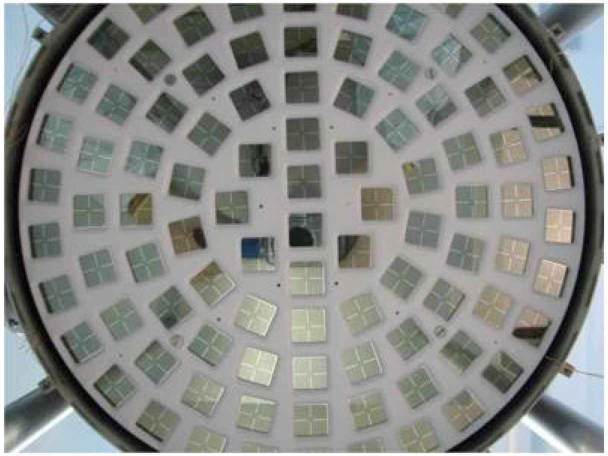


3D Position Resolution: fiducial cut, singles/multiples



The XENON100 TPC

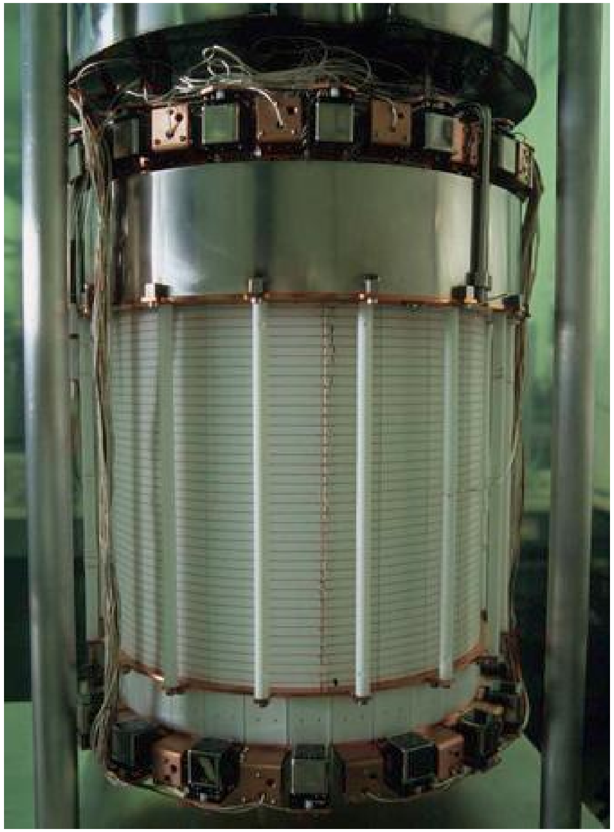
Top array: 98 PMTs



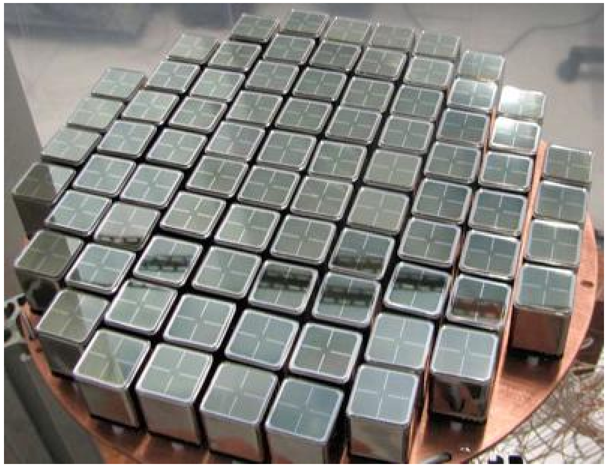
gamma event localized

Top PMT array

TPC



R8520, QE >32% @ 178 nm
Bottom array: 80 PMTs

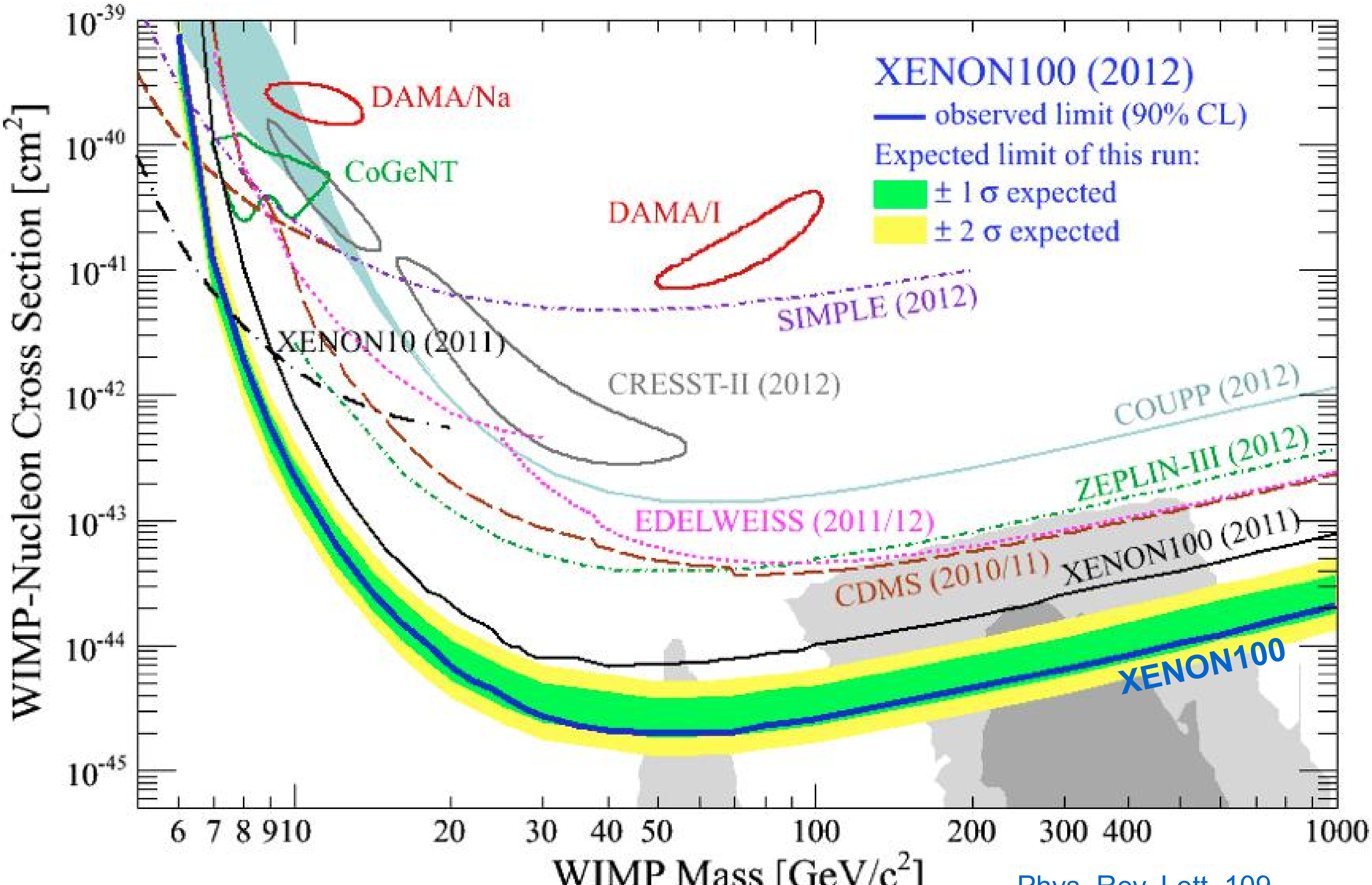


- 161 kg Xe, 62 kg target
- 30 cm drift
- radiopurity:
  - material screening
  - ^{85}Kr: distillation column
  - ^{222}Rn: avoid/monitor
- LXe veto
- Passive shielding: water, Pb, PE, copper

Veto PMTs

XENON100 Results: Spin-Independent

World-best limit: $\sigma_{SI} < 2.0\times10^{-45}$ cm^2 @ 55 GeV/c^2 (90% CL)



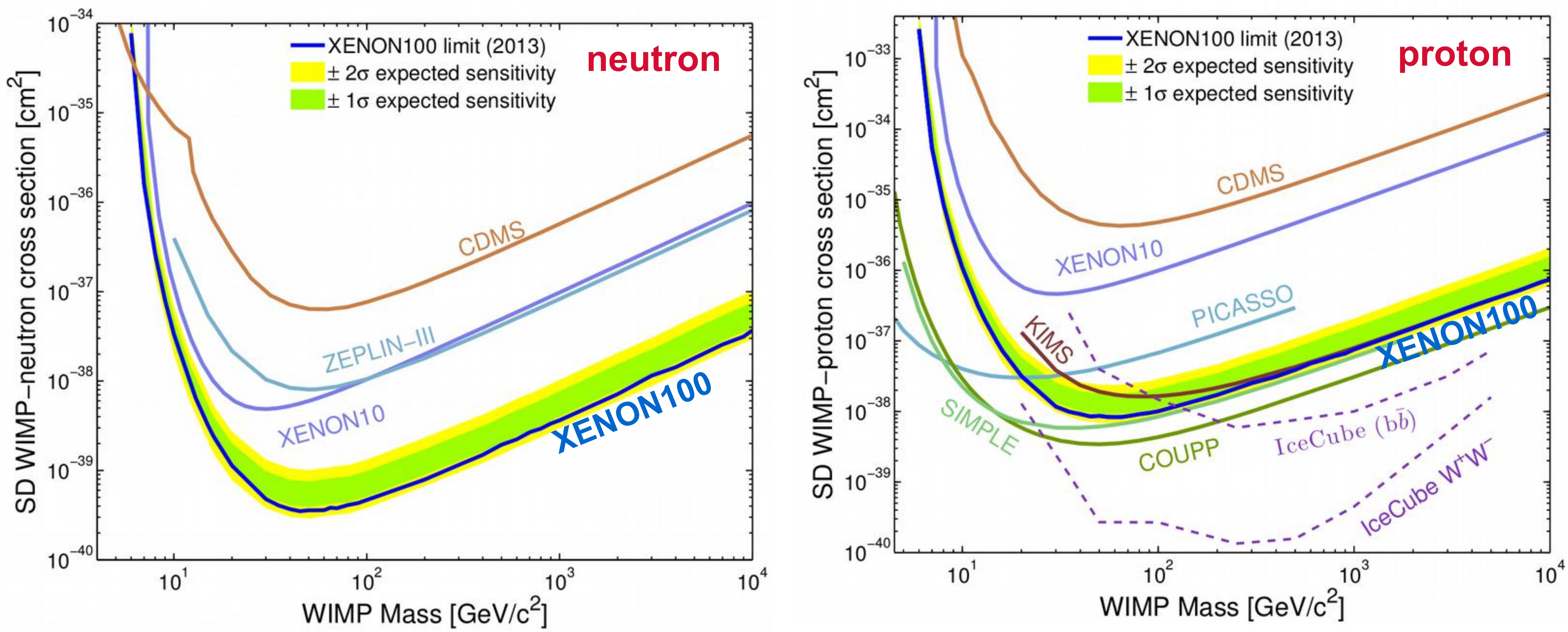
Phys. Rev. Lett. 109, 181301 (2012)

XENON100 Results: Spin-Dependent

World-best limit for neutron coupling:
$\sigma_n < 3.0\times10^{-40}$ cm^2 @ 45 GeV/c^2 (90% CL)

$$\frac{d\sigma_{SD}(q)}{dq^2} = \frac{8G_F^2}{(2J+1)v^2} S_A(q)$$

$$S_A(0) = \frac{(2J+1)(J+1)}{\pi J}\left[a_p\langle S_p\rangle + a_n\langle S_n\rangle\right]^2$$

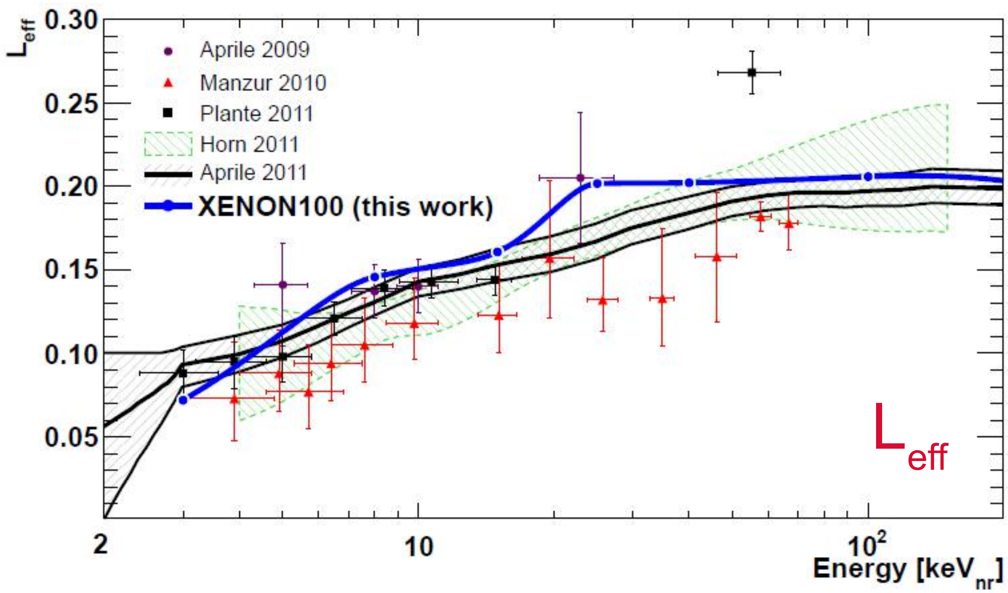


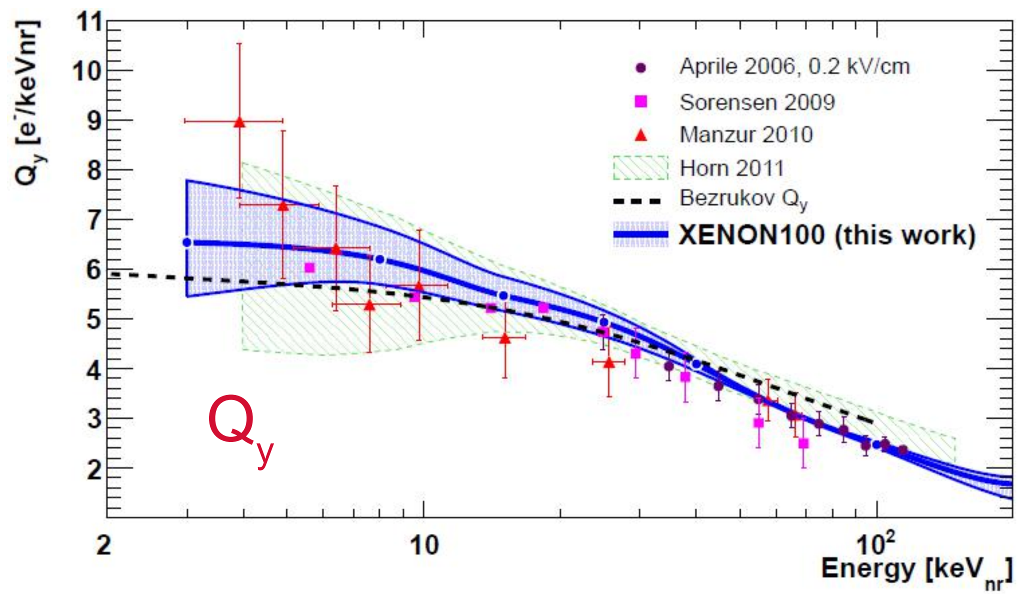
Phys. Rev. Lett. 111, 021301 (2013)

Nuclear Recoil Energy Scale: Calibration vs. Simulation

Energy relation for **S1**	Energy relation for **S2**
$$E = \frac{S1}{L_y} \frac{1}{\mathcal{L}_{\rm eff}(E)} \frac{S_{\rm ee}}{S_{\rm nr}}.$$	$$E = \frac{S2}{L_q} \frac{1}{\mathcal{Q}_y(E)}$$
Light yield of 122keV γ-rays (L_y)	**Secondary Amplification** of electron signals (L_q)
Quenching–factor of nuclear recoils ($\mathcal{L}_{\rm eff}(E)$)	**Charge yield** of nuclear recoils ($\mathcal{Q}_y(E)$)
Electric field dependecy ($S_{\rm nr}$)	

PRD 88, 012006 (2013)



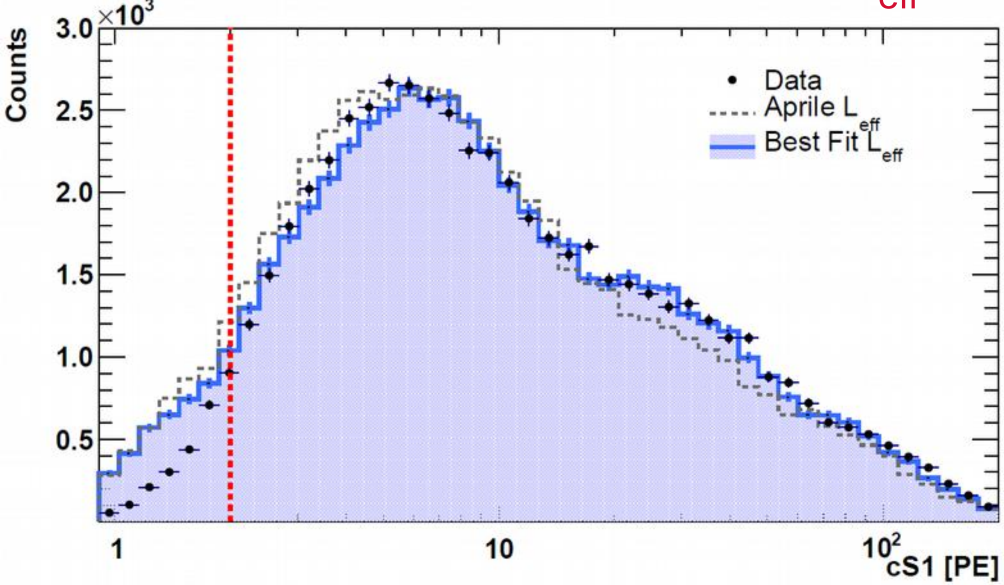


Nuclear Recoil Energy Scale: Calibration vs. Simulation

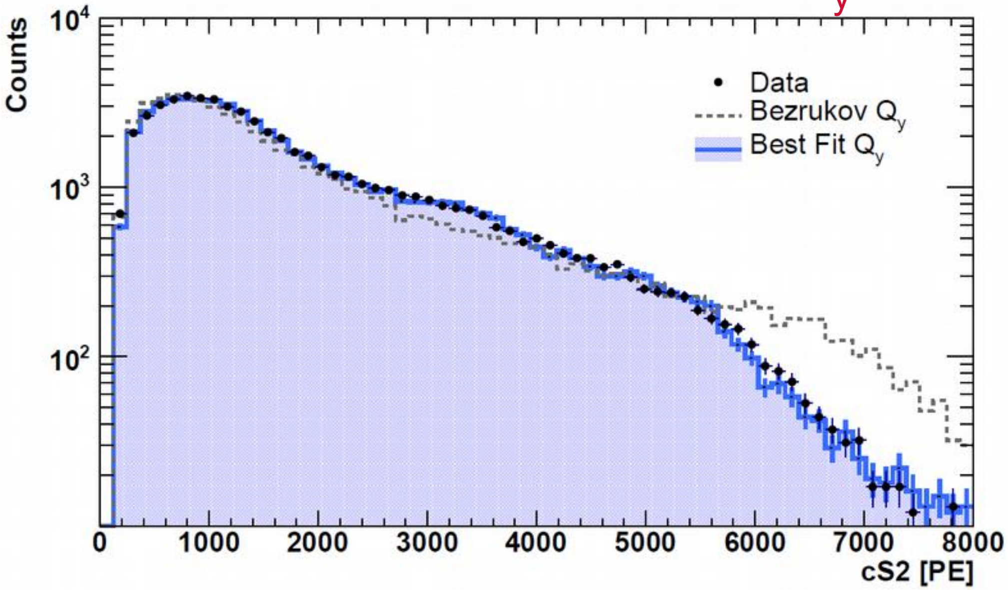
PRD 88, 012006 (2013)

- **Absolute** neutron flux calibration at PTB Braunschweig: 160 ± 4 n/s
  → fixed parameter in fit! (If left free, we find 159 n/s for the source!)
- Most accurate comparison of neutron calibration and MC simulations in DM driect searches to date.
- This suggests that we understand the low energy threshold and acceptance of XENON100 well (relevant for low-mass WIMPs).

S1 profile for best-fit L_{eff}

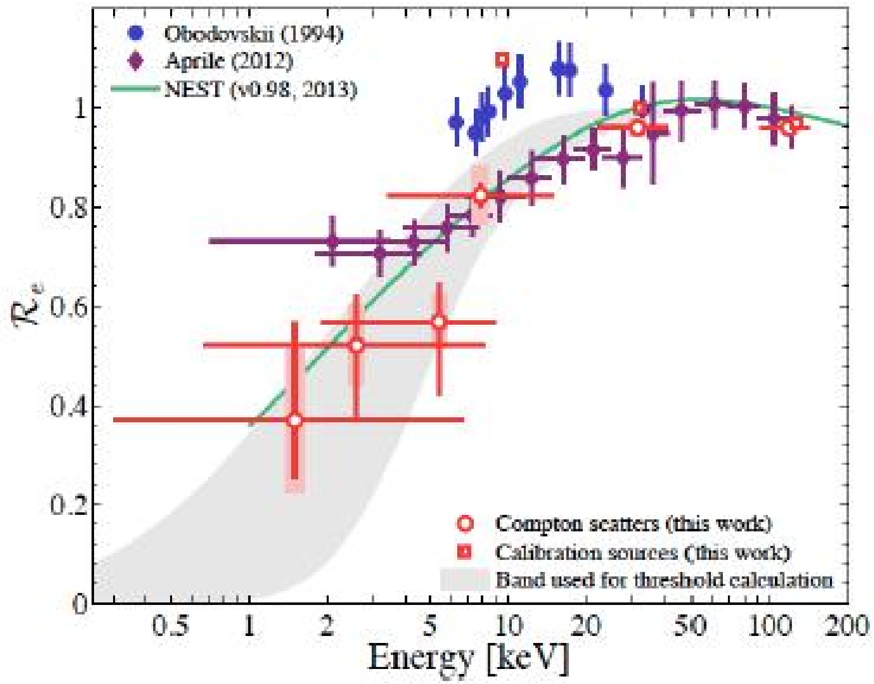


S2 profile for best fit Q_y

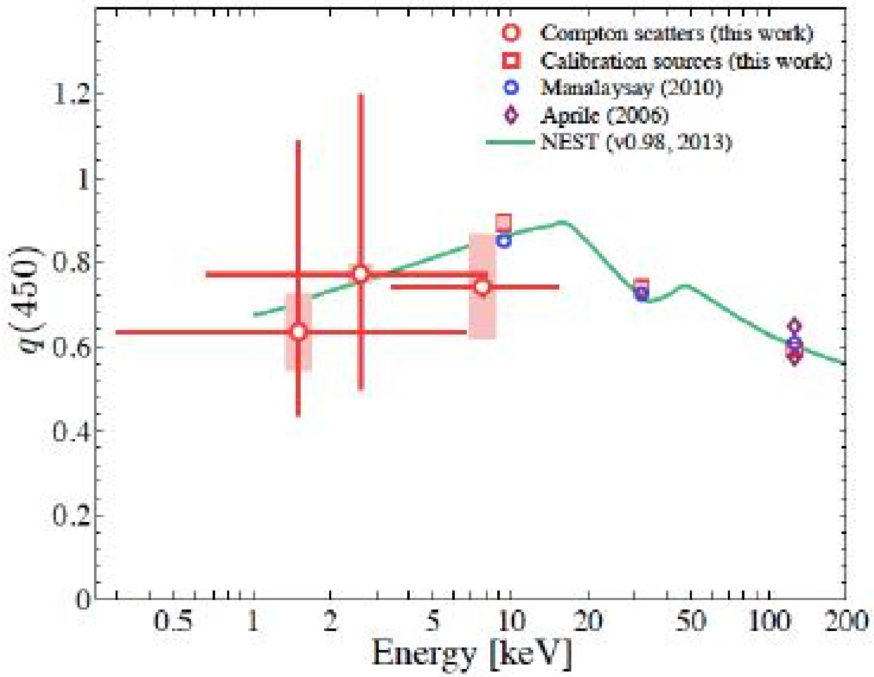


Electron Recoil Energy Scale

Light Yield



Field Quenching



- Light yield decreases at 0-field below 50 keV
- Field quenching $\sim$ 75% at low energies

o Derived XENON100 energy threshold: 2.3 keV
$\rightarrow$ sensitive to DAMA signal! Results coming soon

Columbia results: Aprile *et al.*, Phys. Rev. D 86, 112004 (2012)
Zurich results including field quenching: Baudis *et al.*, Phys. Rev. D 87, 115015 (2013)

More measurements coming!

Electron Recoil Energy Scale

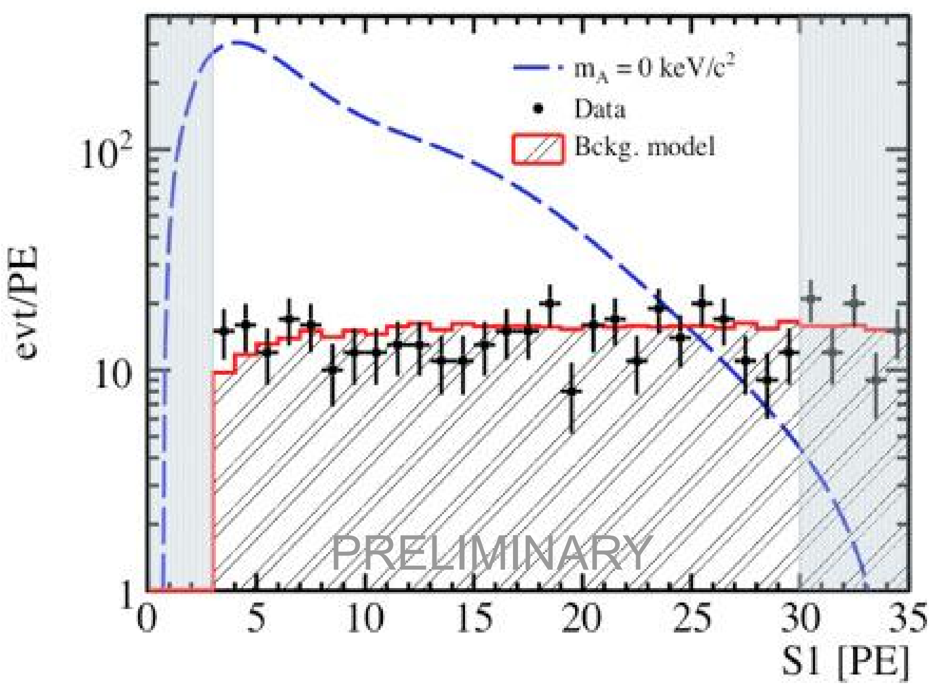
Use to study in XENON100:

- Comparison with DAMA
- Searches for annual modulation
- Searches for solar and galactic axions and ALPs

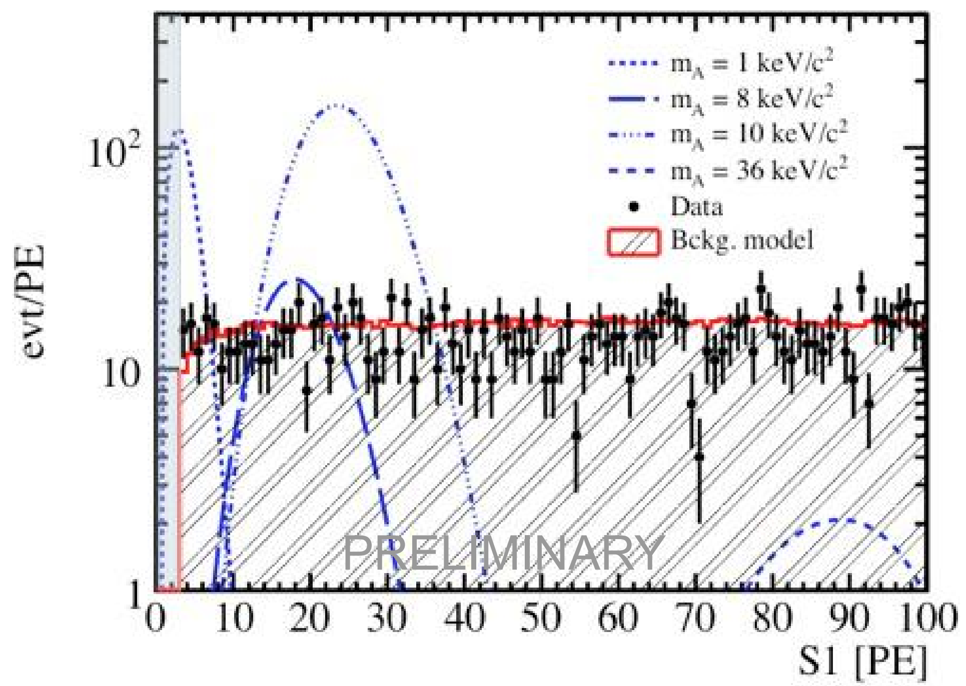
In the works: Axion and ALPs Searches

- Astrophysical models: expected flux for solar axions (continuum spectrum) and galactic (monoenergetic) axions.
  → Search for expected spectra in XENON100.
- Gamma source calibration data used to predict the expected XENON100 background.

Solar Axion Search

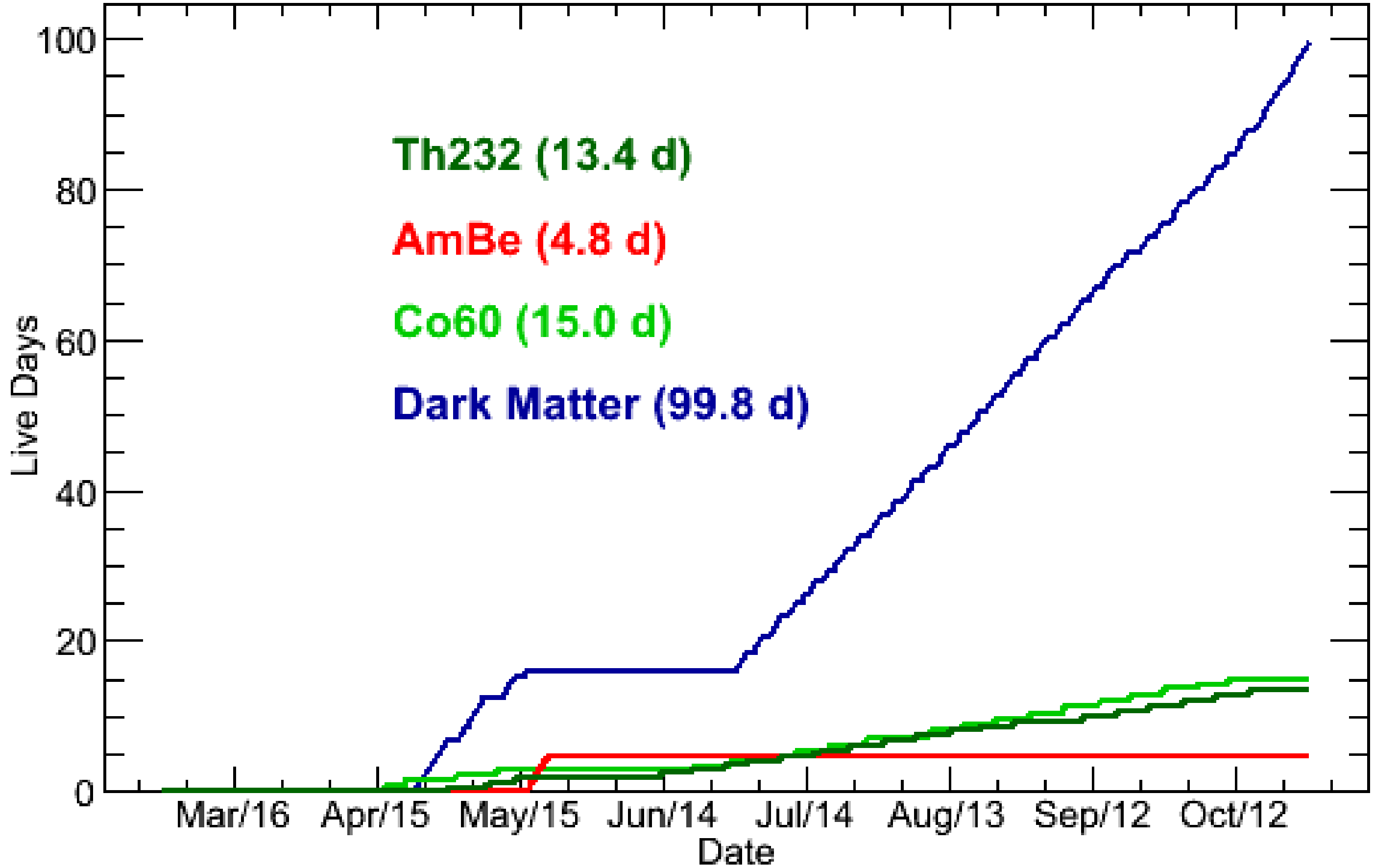


Galactic Axion Search



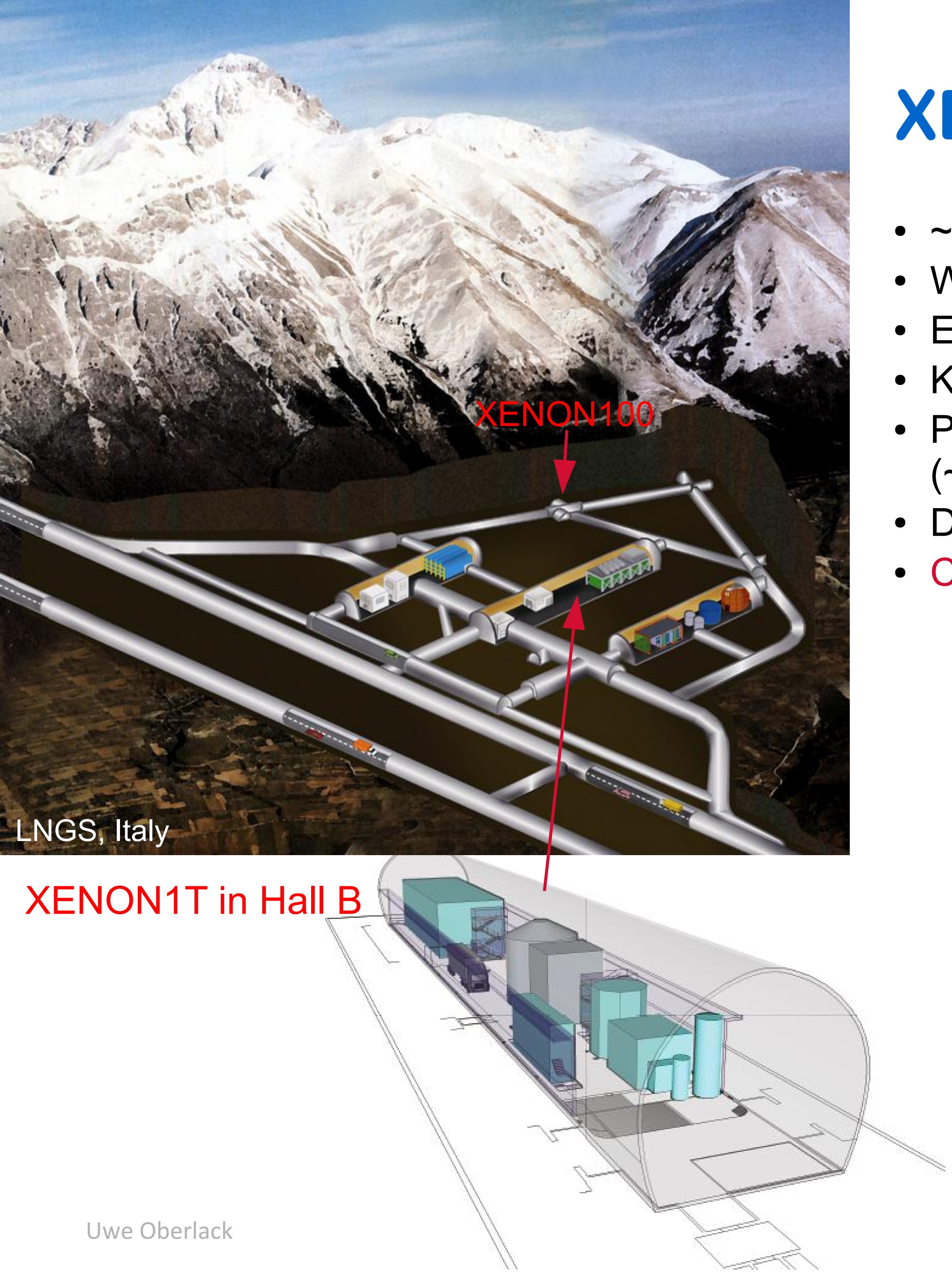
Ongoing XENON100 Run:
New Exposure 2013

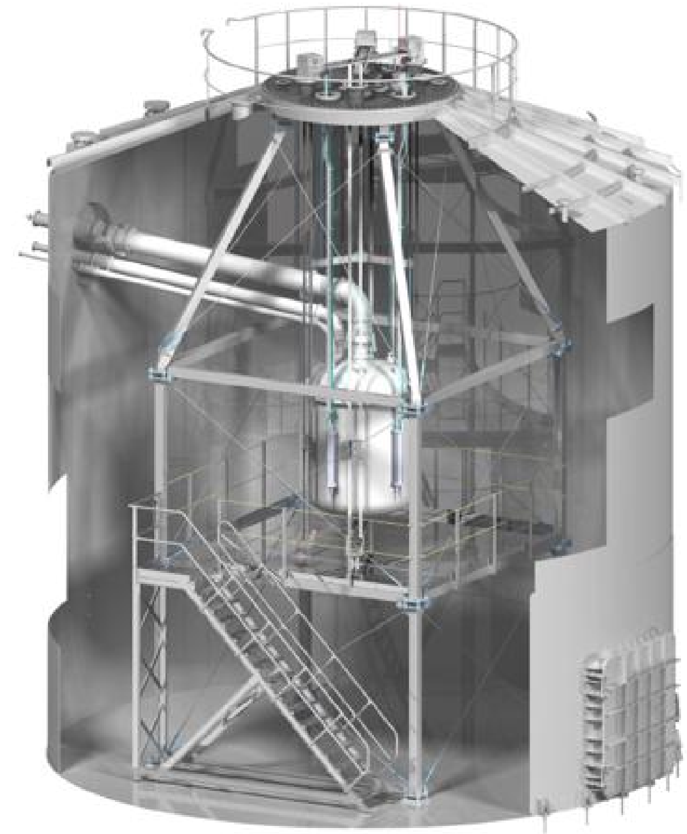
- Lowered Kr contamination to ppt level to demonstrate capability for XENON1T.
- New AmBe calibration confirms agreement with MC study.
- Detector parameters stable and performance excellent. (Electron lifetime ~700 μs)
- Extended run improves sensitivity in searches for annual modulation.
- 100 d of additional exposure (blind) so far.



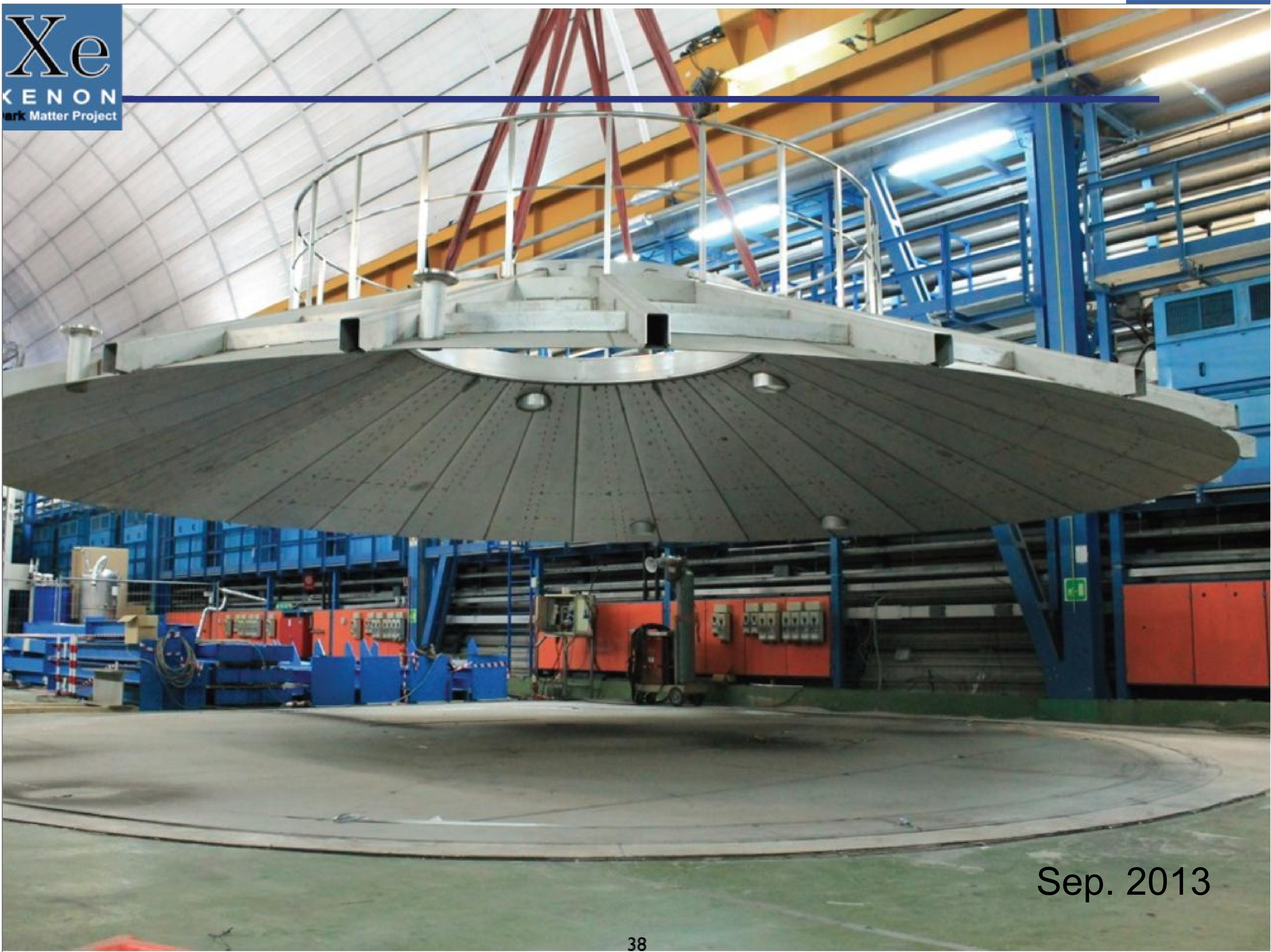
XENON1T

- ~ 1 m³, ~ 3.5 t LXe, ~ 1 t fiducial mass
- Water Cherenkov Muon Veto ~10 m x 9.6 m
- ER background < 5 x 10-5 DRU
- Kr/Xe < 0.5 ppt & Rn/Xe < 1 µBq/kg
- Project approved and funded (~50% NSF, ~50% Europe + Israel)
- Design of major systems completed
- Construction in Hall B ongoing.






July 2013



Sep. 2013


Oct. 2013

~10 days ago

and in between – cladding of reflective foil

Water Cherenkov Muon Veto

Concept:

- Water tank: ~10 m high and 9.6 m in diameter
- 84 high QE 8” PMTs Hamamatsu R5912 with water-tight base
- Specular Reflector: foil DF2000MA by 3M

Also a passive shield:

- after 3 m of shield external neutron and gamma flux negligible

Trigger requirements:

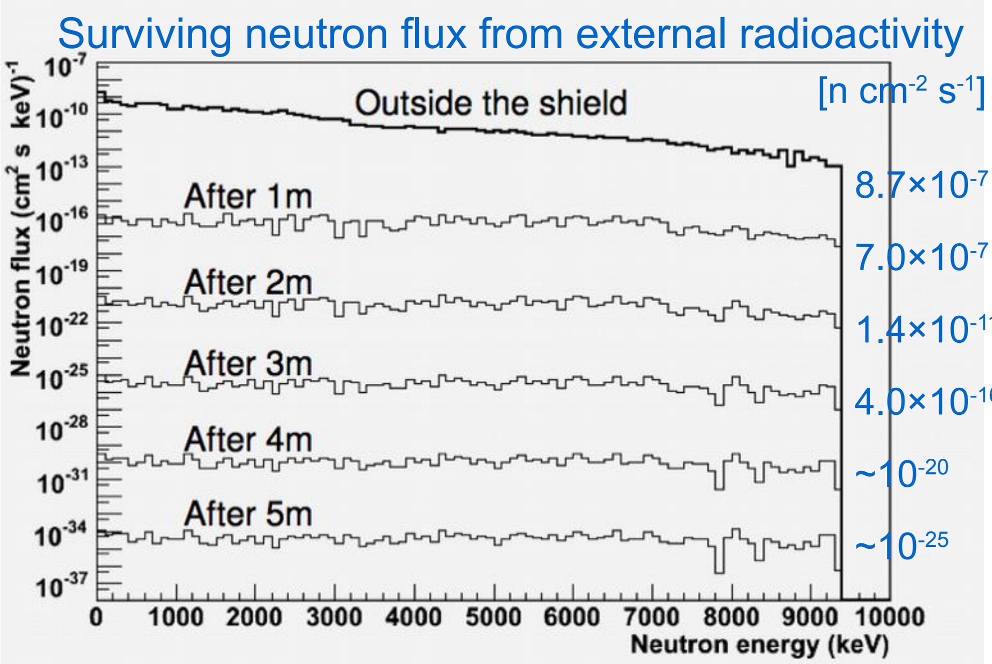
- single photoelectron
- 4 fold coincidence
- time window: 300 ns

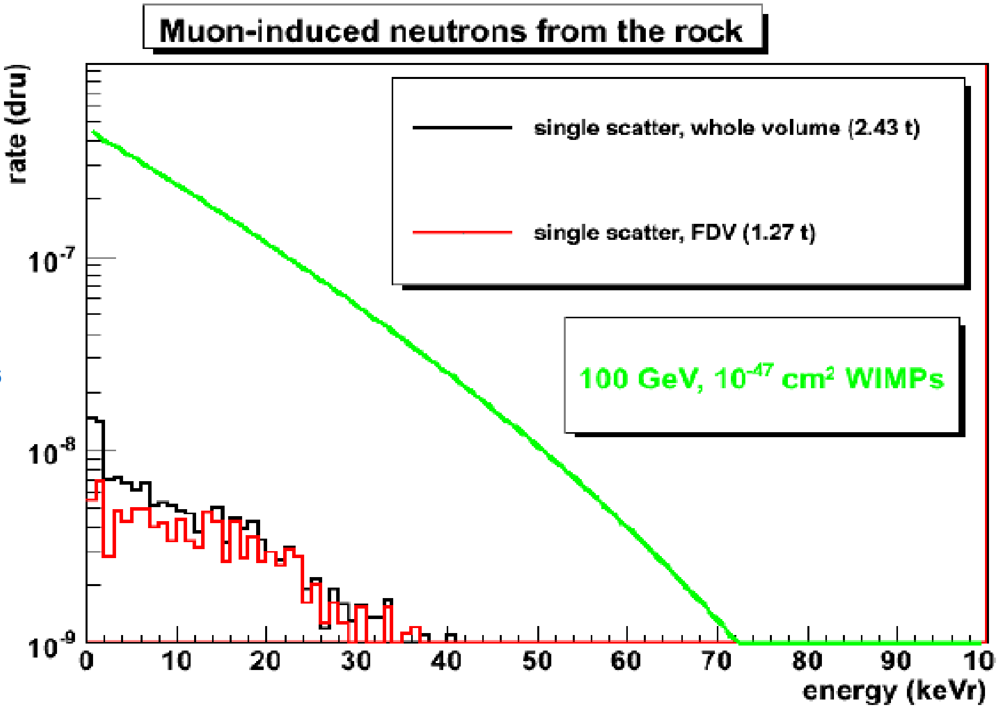
Trigger efficiency

- > 99.5% for neutrons with muons in WT
- ~ 72% for neutrons with μ's outside WT

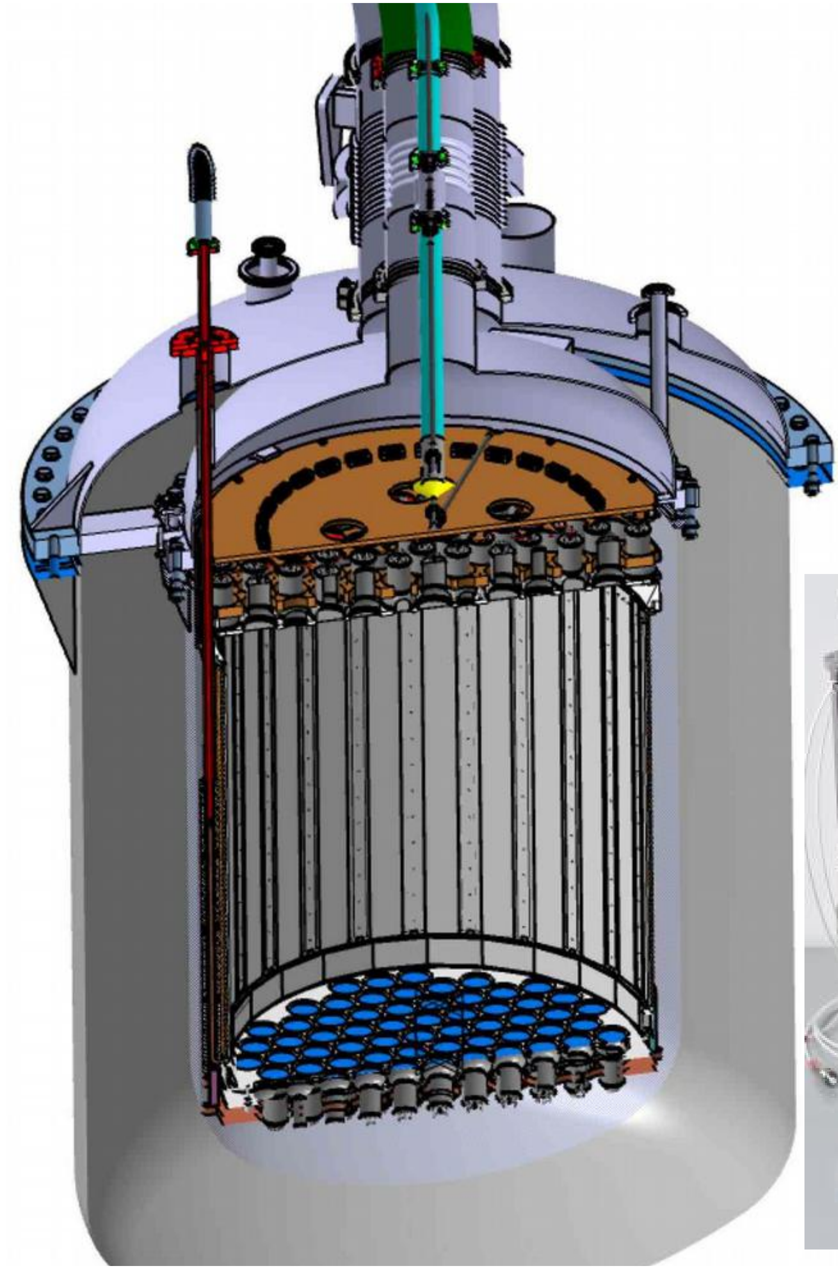
μ-induced neutron background

- 0.01 per year
- ≪ WIMP signal

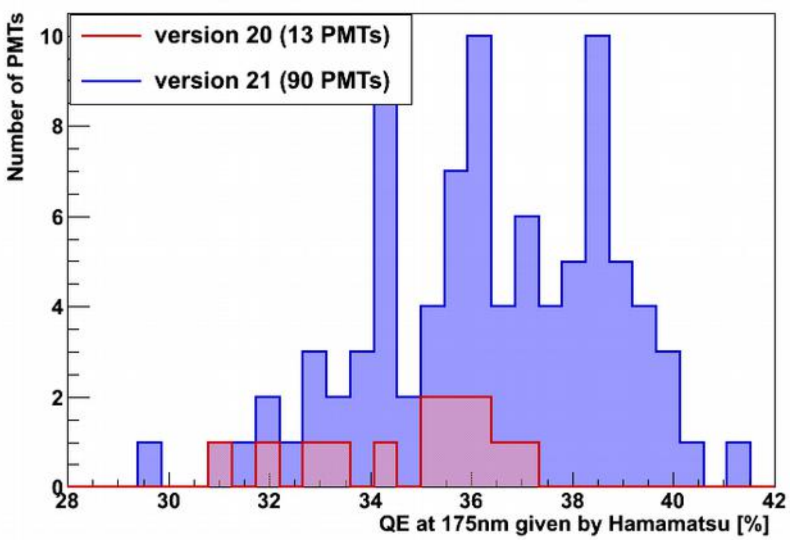




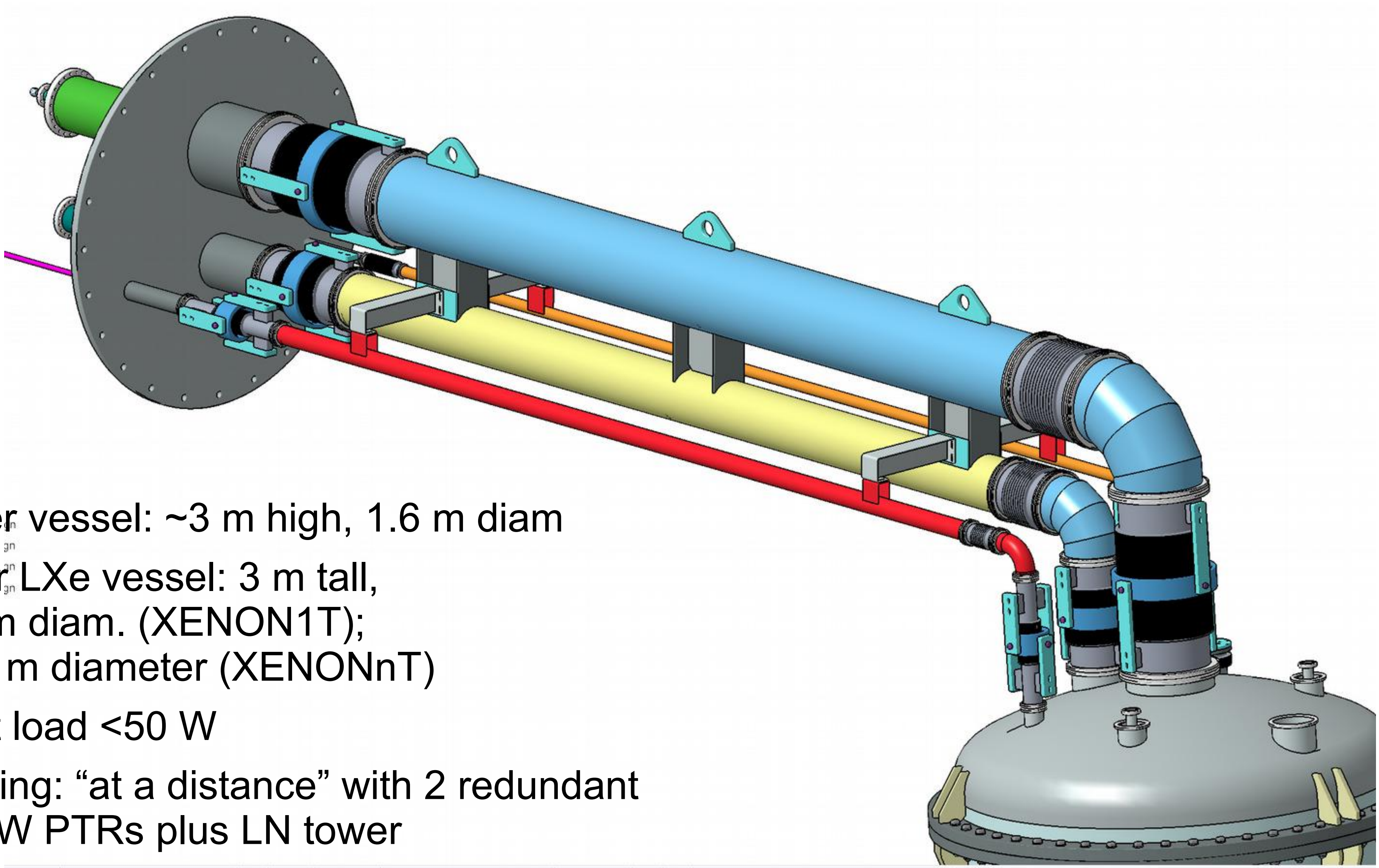
XENON1T TPC



- 300 3" PMTs Hamamatsu R11410-21
- XENON1T version:
  high QE (36% @ 175 nm)
  low radioactivity: <1mBq/PMT in U/Th
- all delivered PMTs screened and tested at room temperature:
  DC rate, HV scan, after-pulsing, transit time
- repeated cool-down at <2K/min
- Teflon for reflectivity (no wavelength shifting)

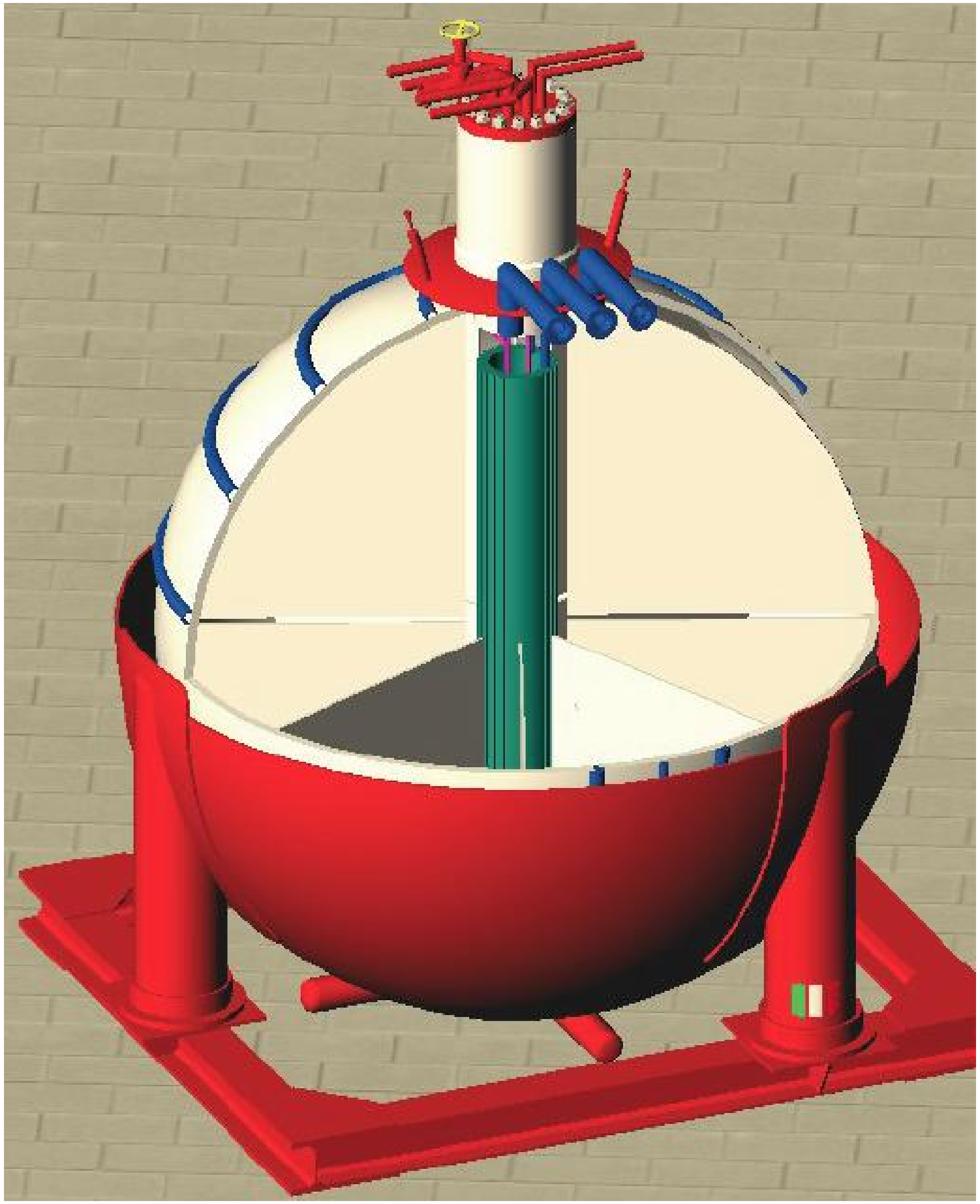


Cryostat and Cryogenics



- Outer vessel: ~3 m high, 1.6 m diam
- Inner LXe vessel: 3 m tall,
  1.1 m diam. (XENON1T);
  1.35 m diameter (XENONnT)
- Heat load <50 W
- Cooling: “at a distance” with 2 redundant
  200 W PTRs plus LN tower

Xe Storage and Recovery

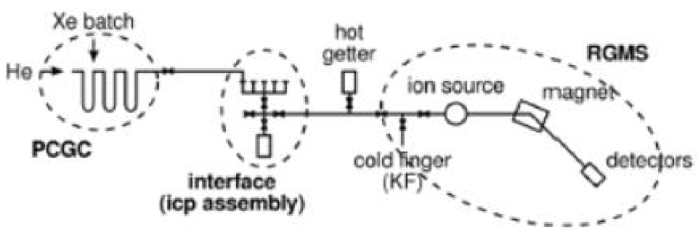


- Vacuum-insulated high-pressure (70 bar) SS sphere
- LN_2 cooled:
  sphere + internal 3 kW condenser
- Storage of > 6 tons of Xe in liquid or gaseous form
- fast recovery (hours) in case of emergency

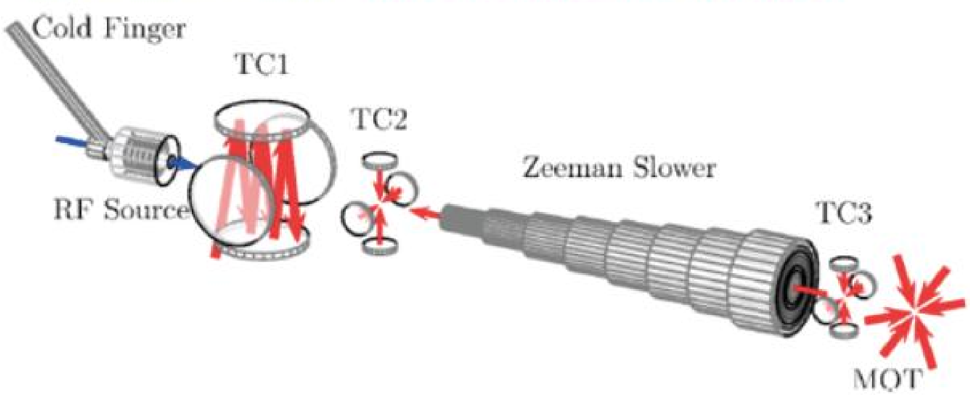
Kr Reduction and Measurement

- Goal is to reduce Kr/Xe to < 0.5 ppt
- after last distillation XENON100: (0.97 ± 0.19) ppt
  ⇒ less than 0.04 mDRU from ^{85}Kr
- 5m distillation column with 3kg/hr @ 10^4 separation (3m version built and under testing)
- two analysis tools developed by Collaboration to measure Kr/Xe at ppt level

RGMS (arXiv:1308.4806)

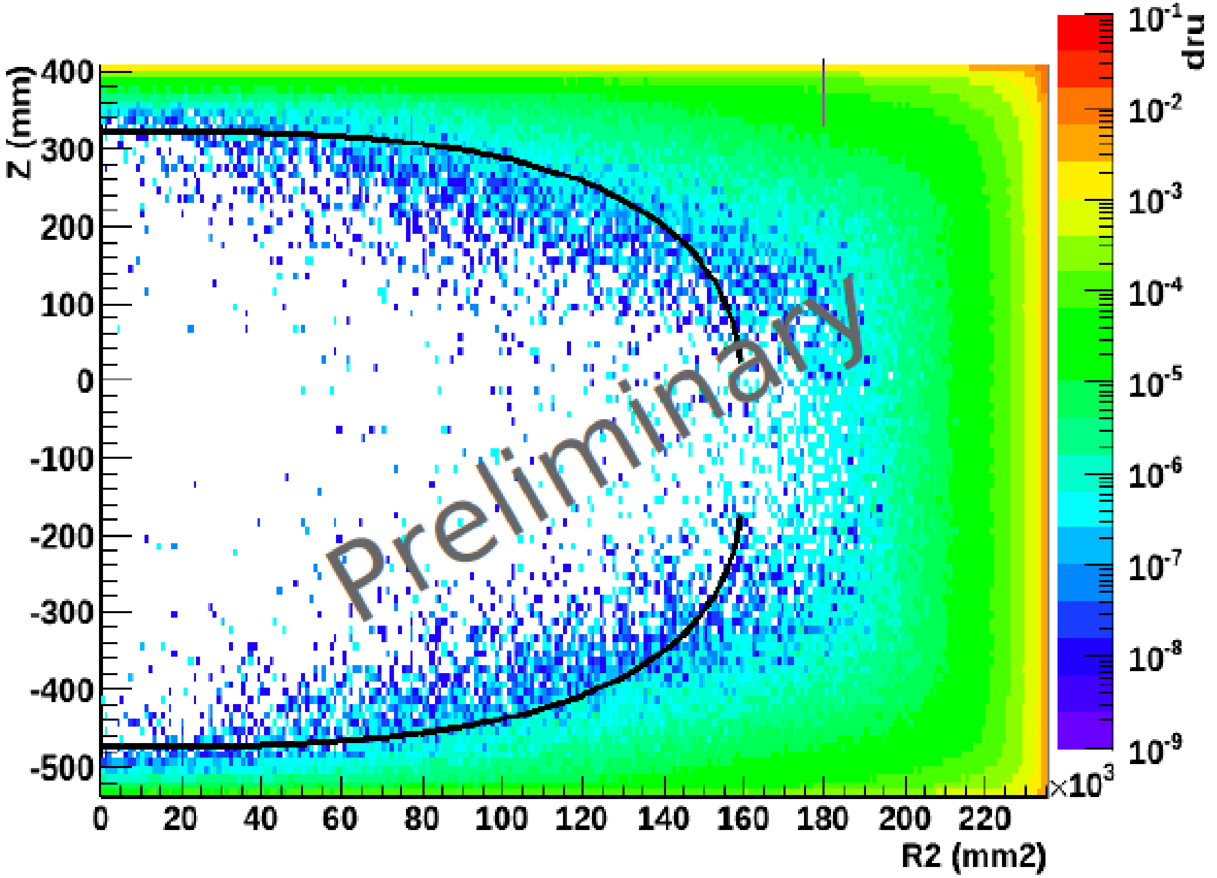


ATTA (arXiv:1305.6510) Rev. Sci. Instrum. 84 (2013)



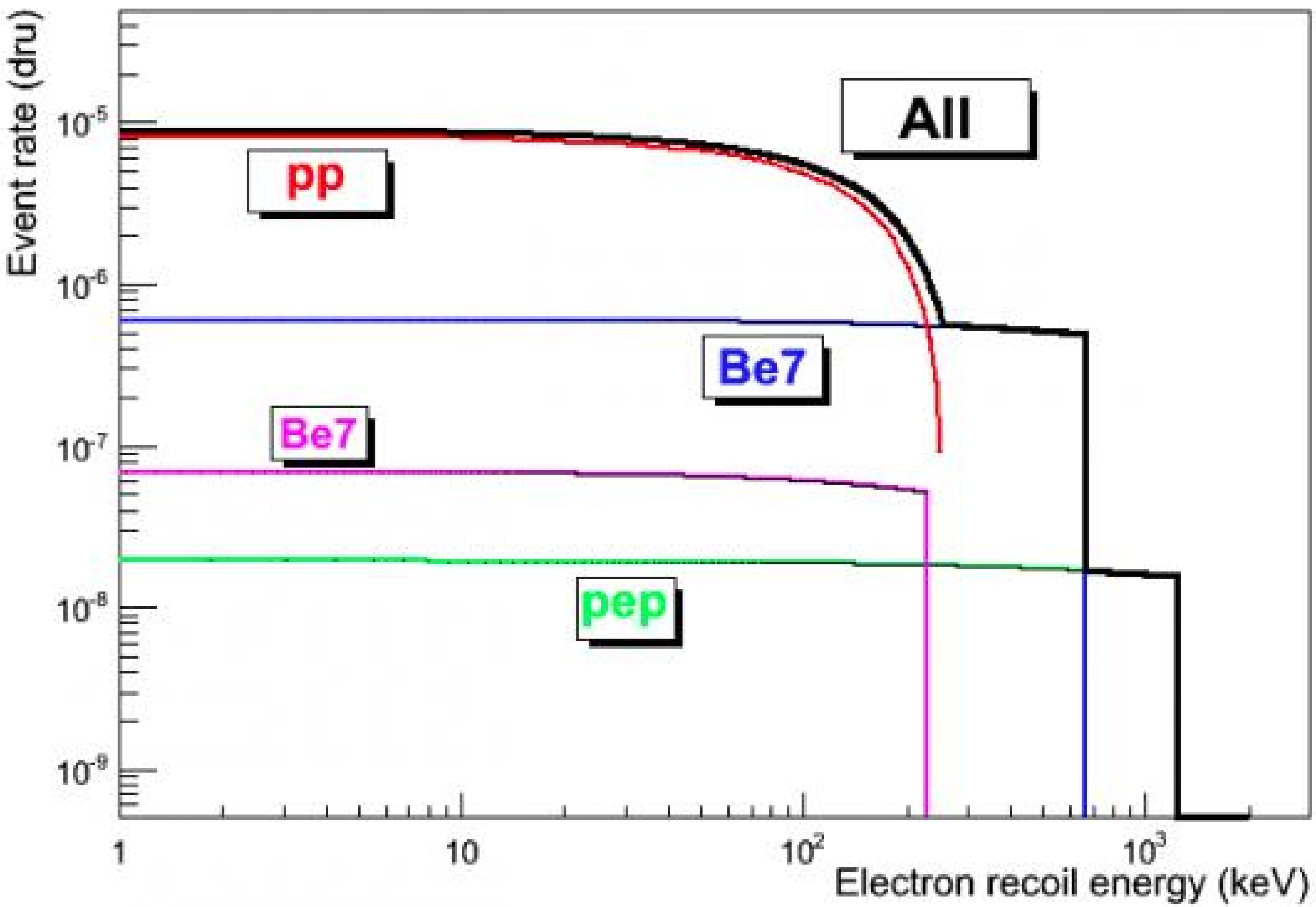
XENON1T Background Estimate

- Complete Monte Carlo simulation of the detector: TPC, PMTs, cryostat, water, shield in GEANT4. Informed by material screening.
- Neutrons from (α,n) predicted with SOURCES-4A.
- Breaking of secular equilibrium taken into account.



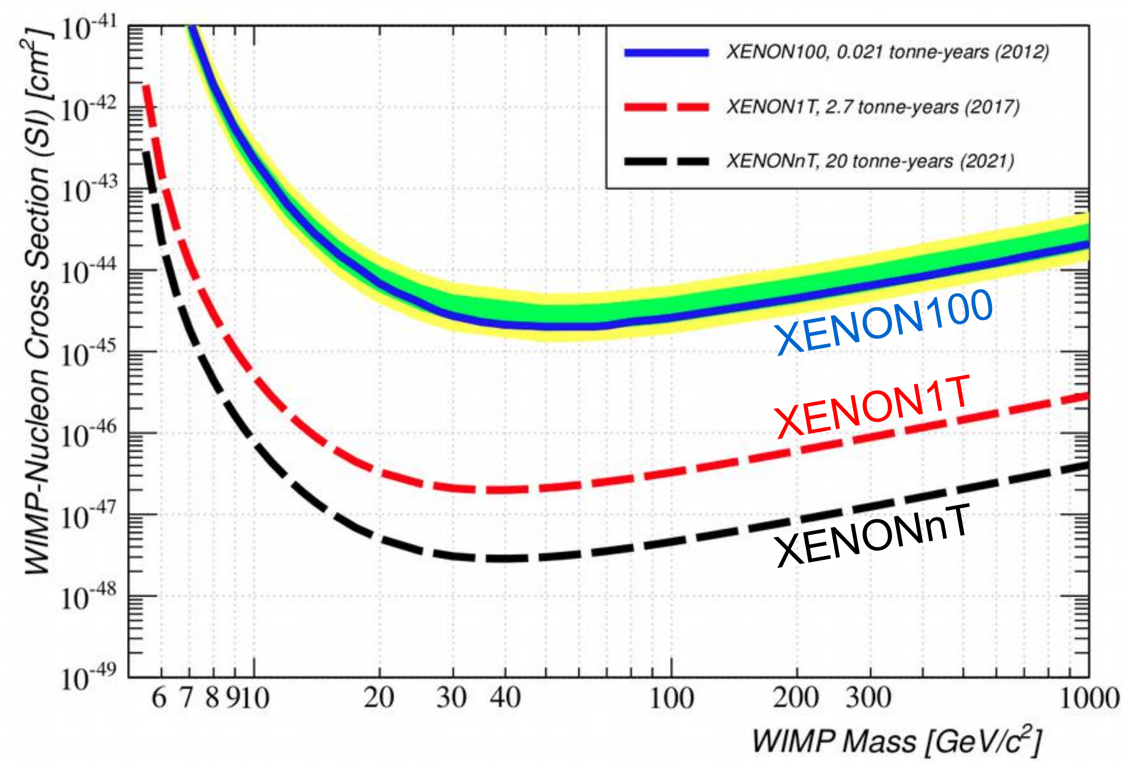
Irreducible Background: Solar Neutrinos

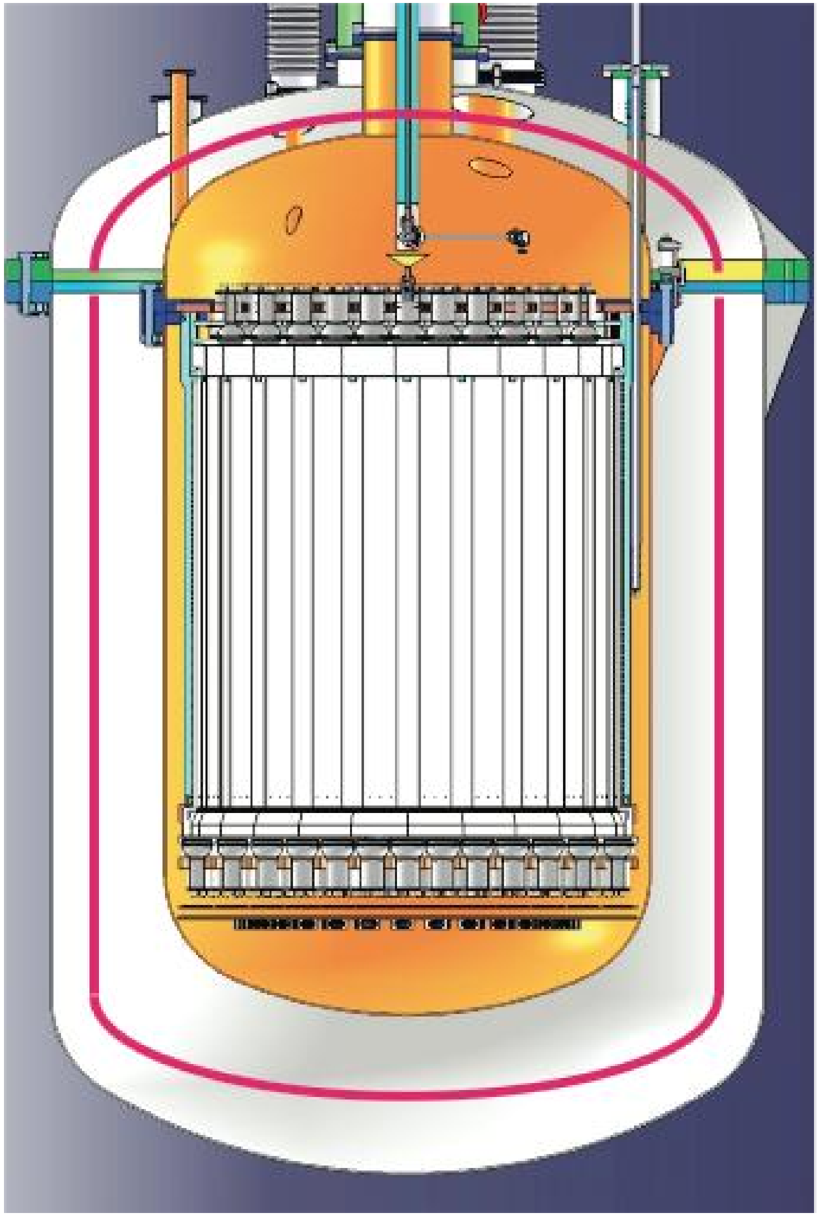
- Elastic scattering of solar neutrinos (mainly pp) off electrons: ~40 events / ton / year **before** NR selection.
- At 99.75% S2/S1 discrimination: surviving background 0.1 / ton / year



XENONnT

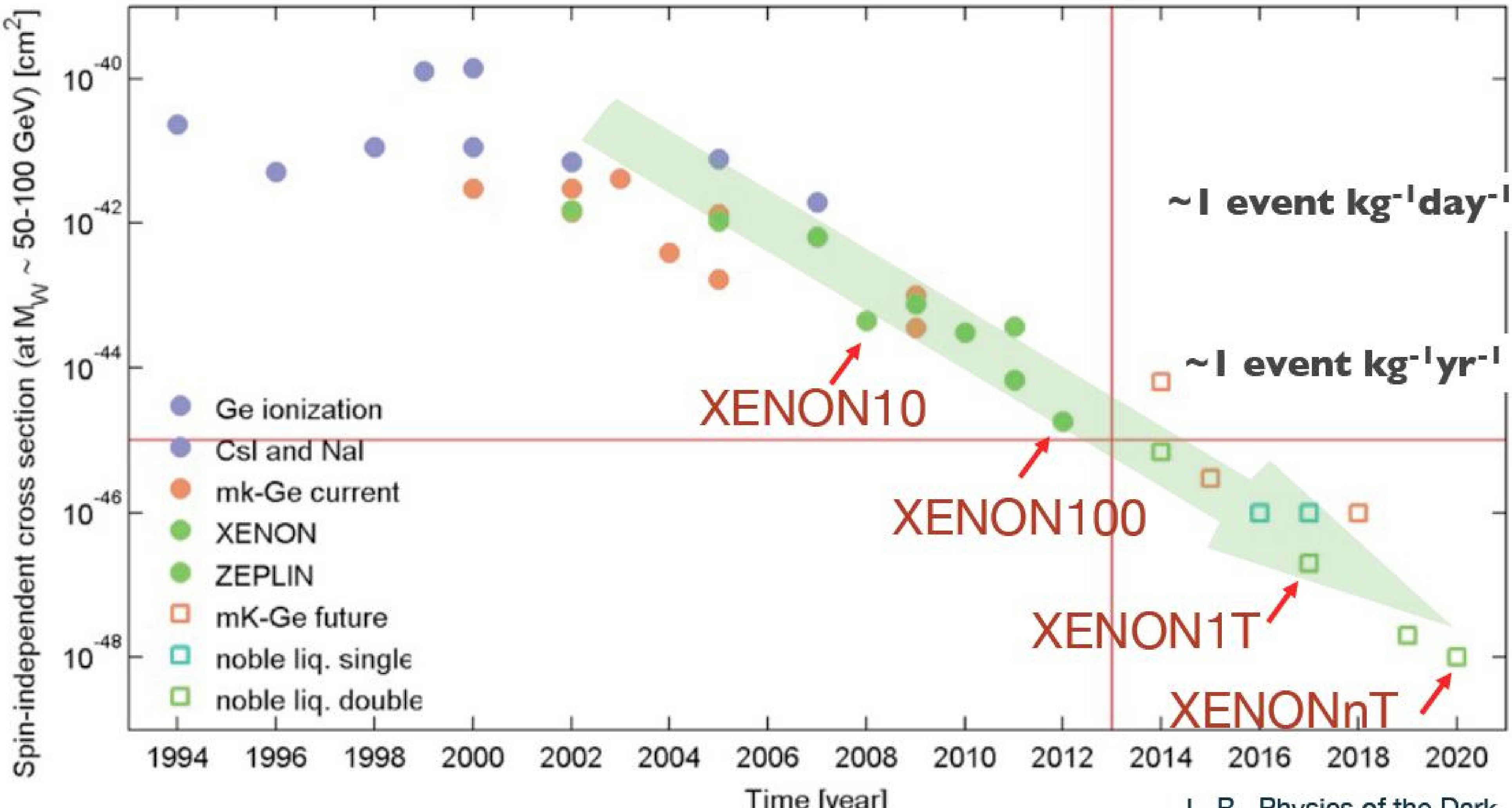
- XENONnT: larger TPC & larger inner cryostat to fit inside XENON1T outer cryostat.
  Other systems will be largely reused.
- Aim: 20 ton-years exposure, reduced background to reach few 10^{-48} cm^2 sensitivity.
- Start: ~2018





Outlook

Rate of progress: ~1 decade in sensitivity per 3 years
– driven by XENON!



L. B., Physics of the Dark Universe 1, 94 (2012)