XENON

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Latest Results in Dark Matter Searches, Stockholm, May 12, 2014

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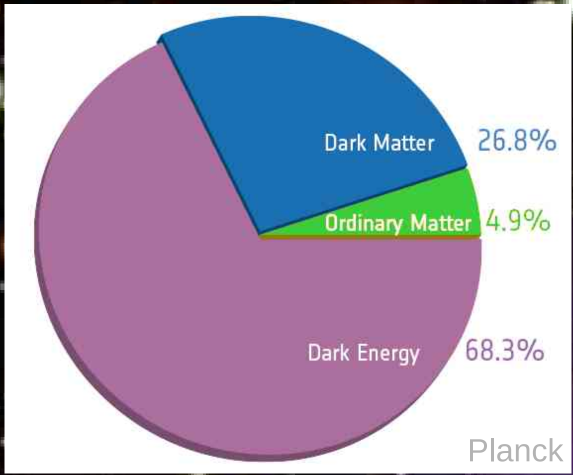
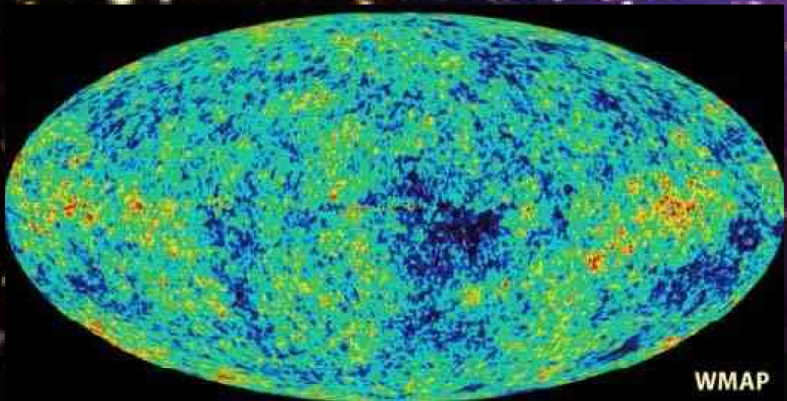
Xe XENON Dark Matter Project

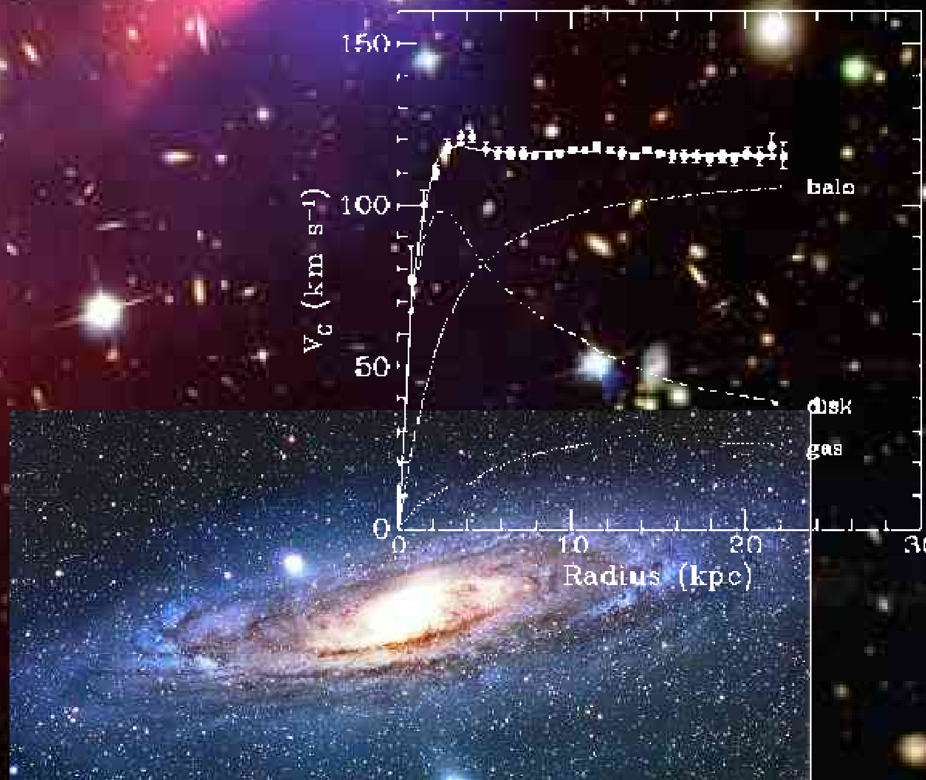
Dark Matter: (indirect) Evidence



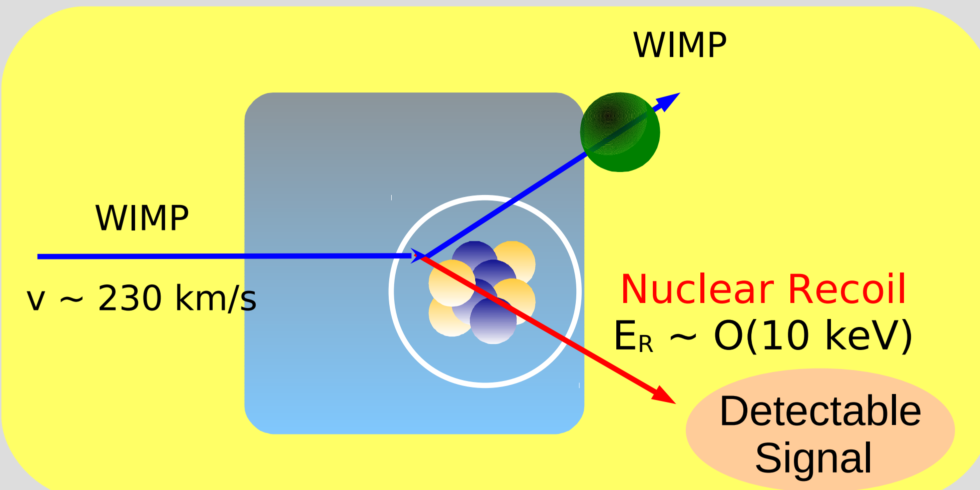
Particle Dark Matter Candidates:

- WIMP → *„WIMP miracle“*
- Axion
- SuperWIMPs
- sterile neutrinos
- WIMPless dark matter
- Gravitino
- ...





Direct WIMP Search

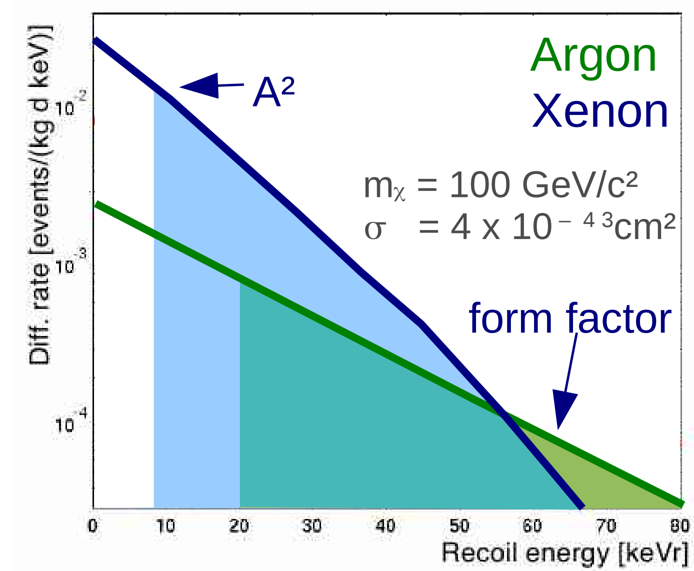


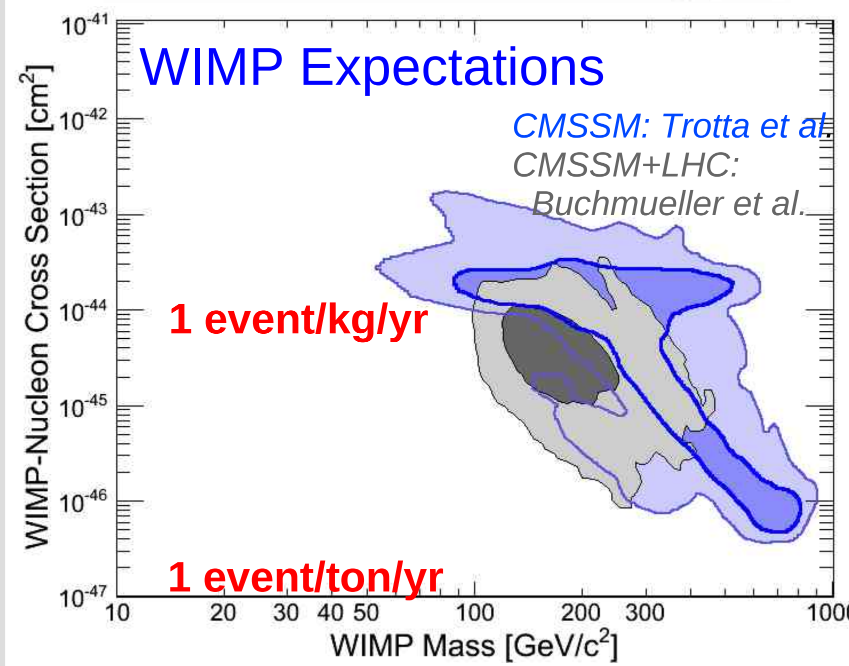
Recoil Energy: $E_r \sim \mathcal{O}(10\ \mathrm{keV})$

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

Detector — Local DM Density — Physics

$\rho_\chi \sim 0.3\ \mathrm{GeV/c^2}$





Direct WIMP Search

Summary: Tiny Rates

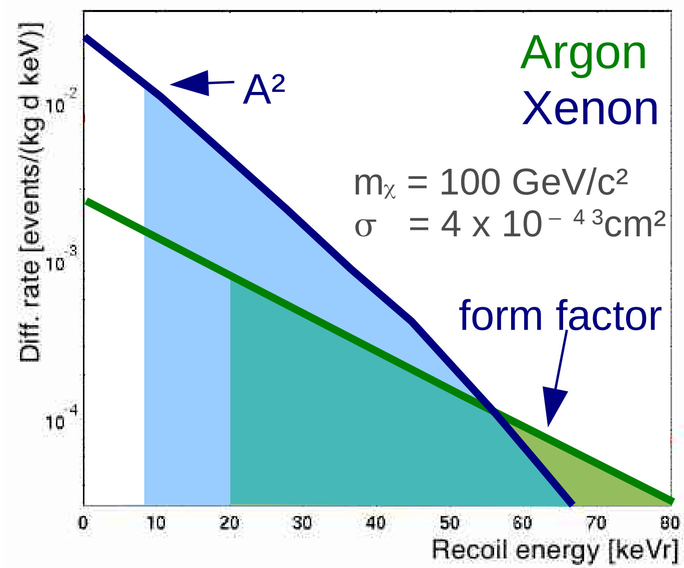
$R < 0.01$ evt/kg/day
$E_R < 100$ keV

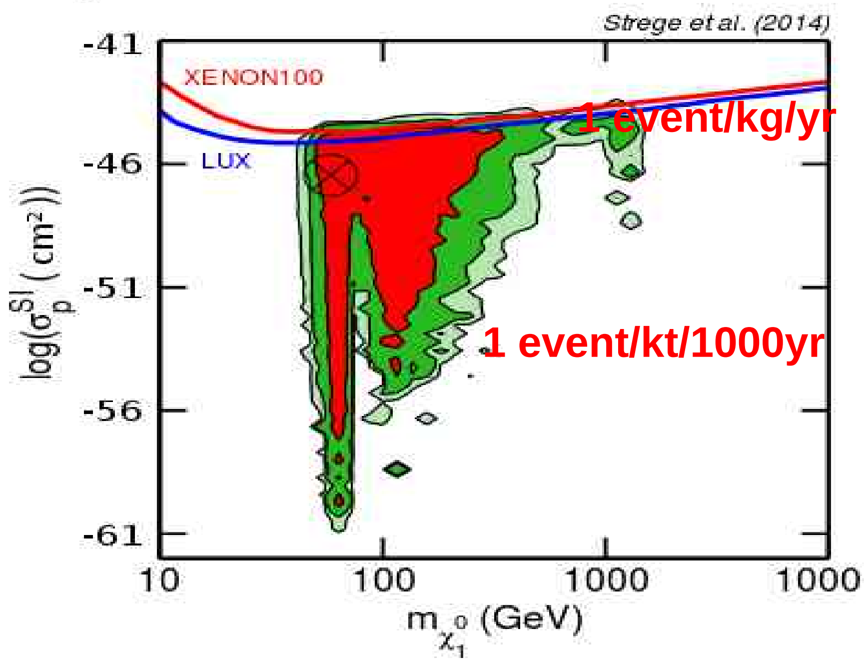
How to build a WIMP detector?

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

Xenon

+ high mass number, high Z
+ no long-lived Xe isotopes
o fair background discrimination
+ „easy cryogenics“
+ scalability to larger detectors
– only modest E resolution

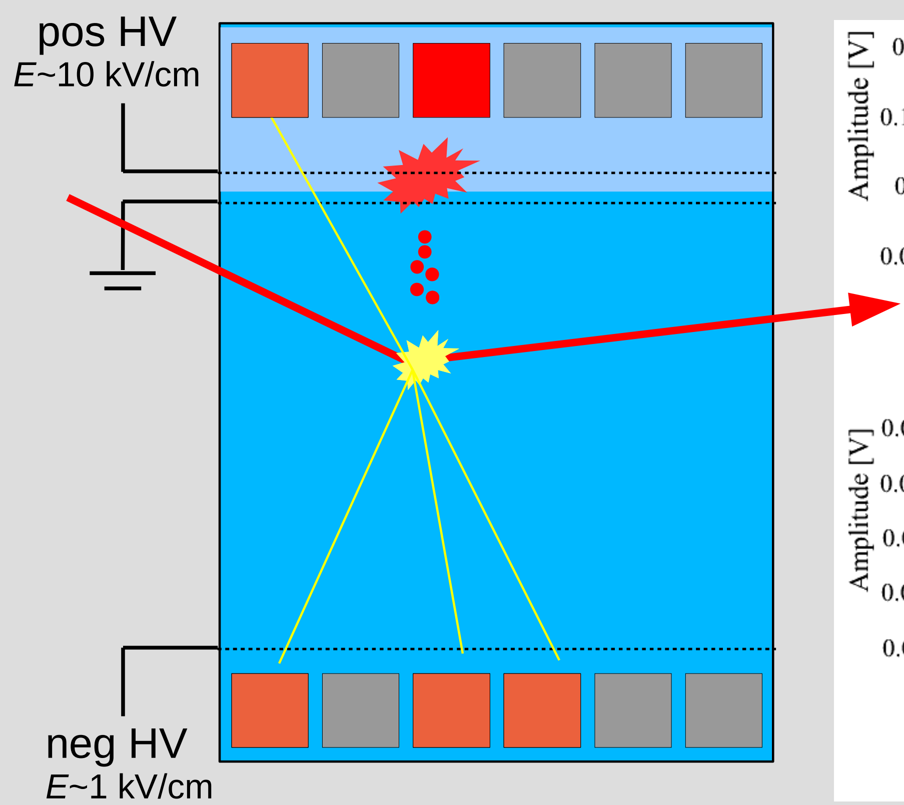


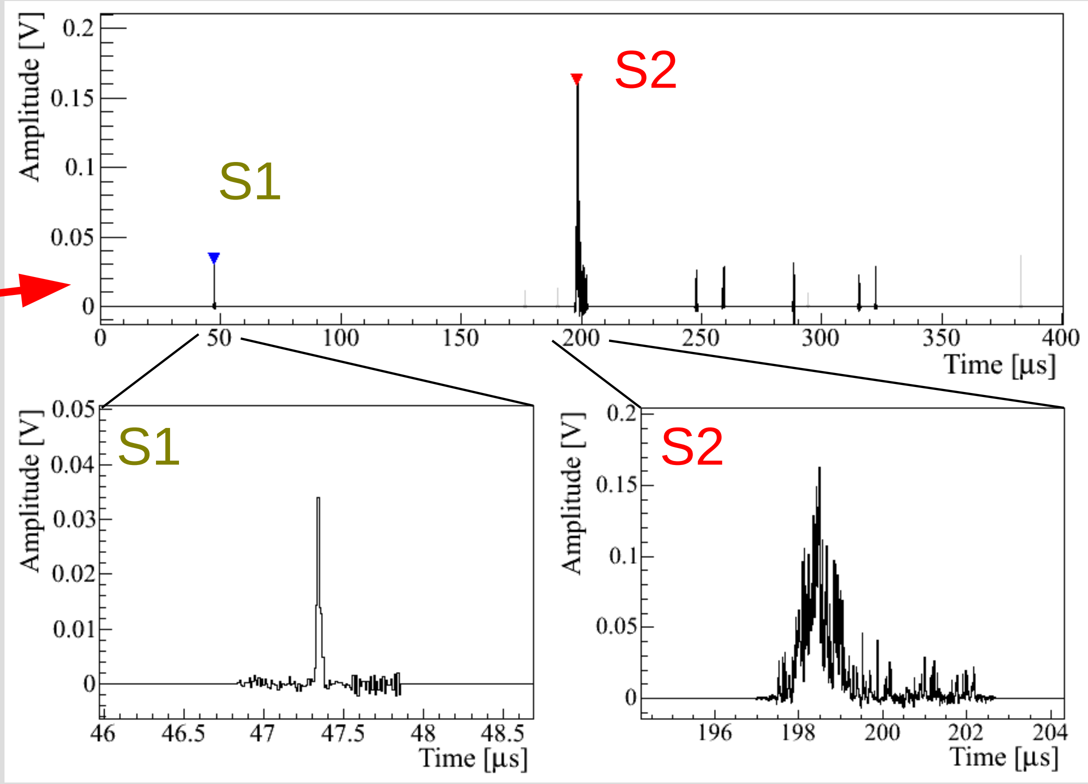


Dual Phase TPC

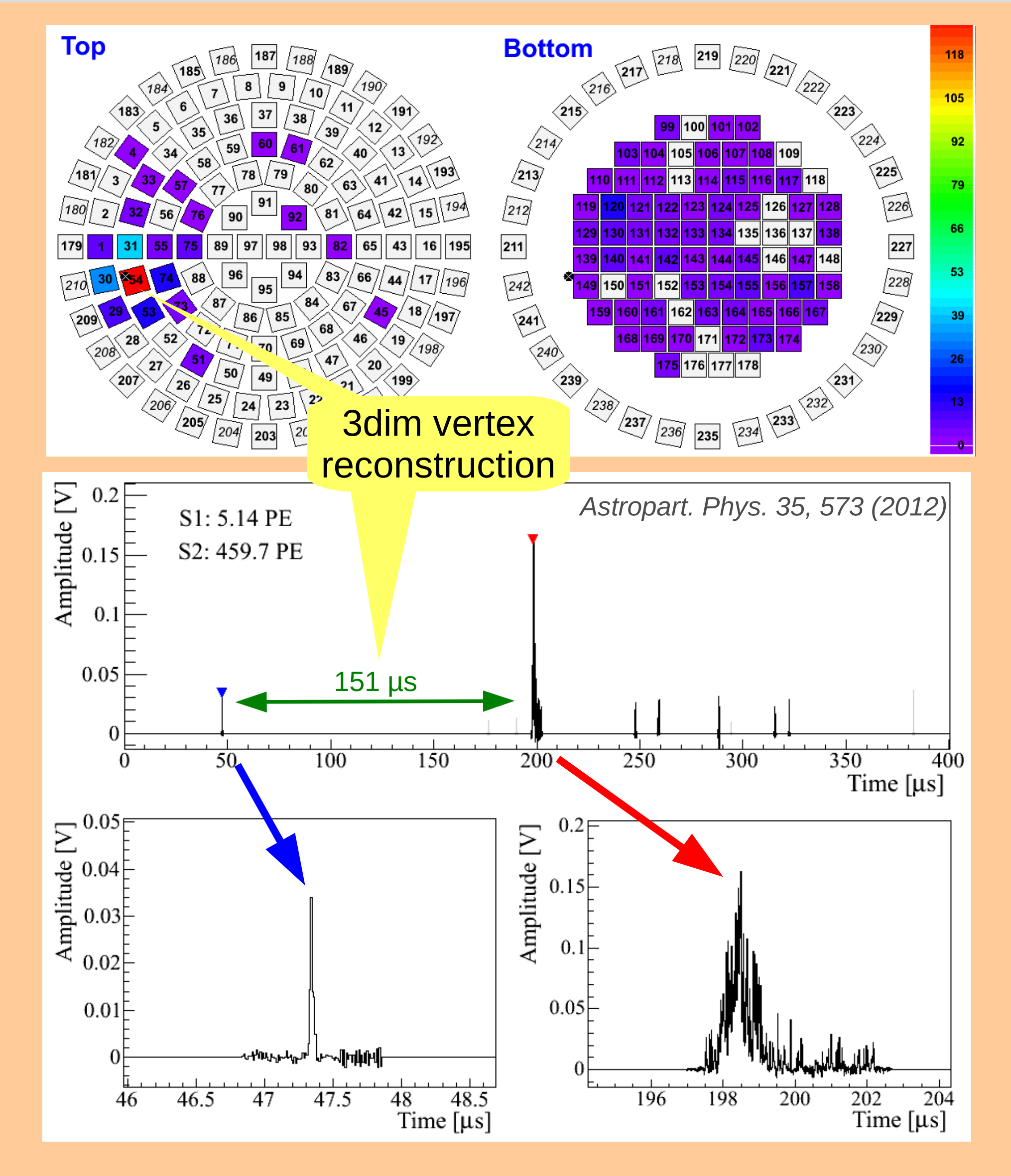
Dolgoshein, Lebedenko, Rodionov, JETP Lett. 11, 513 (1970)

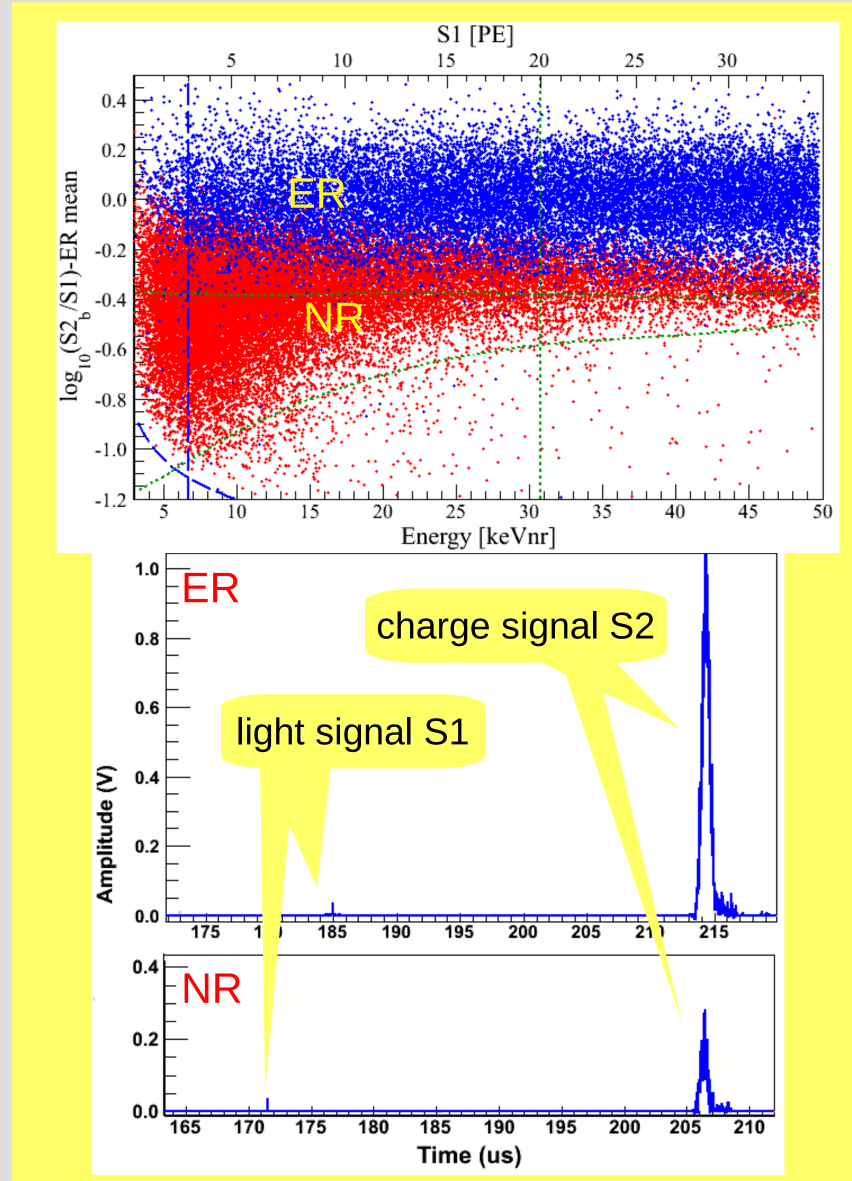
TPC = time projection chamber





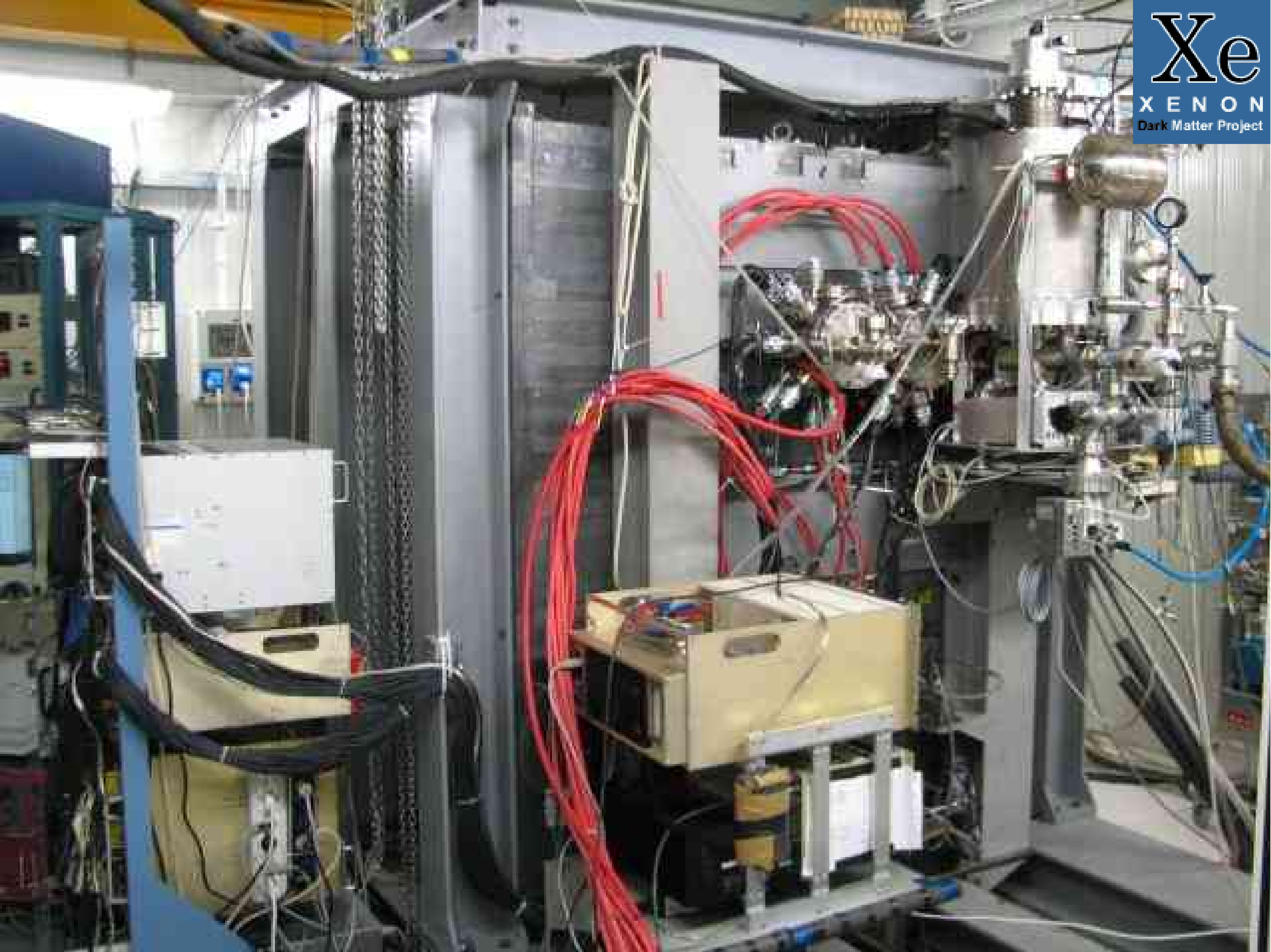
Dual Phase TPC





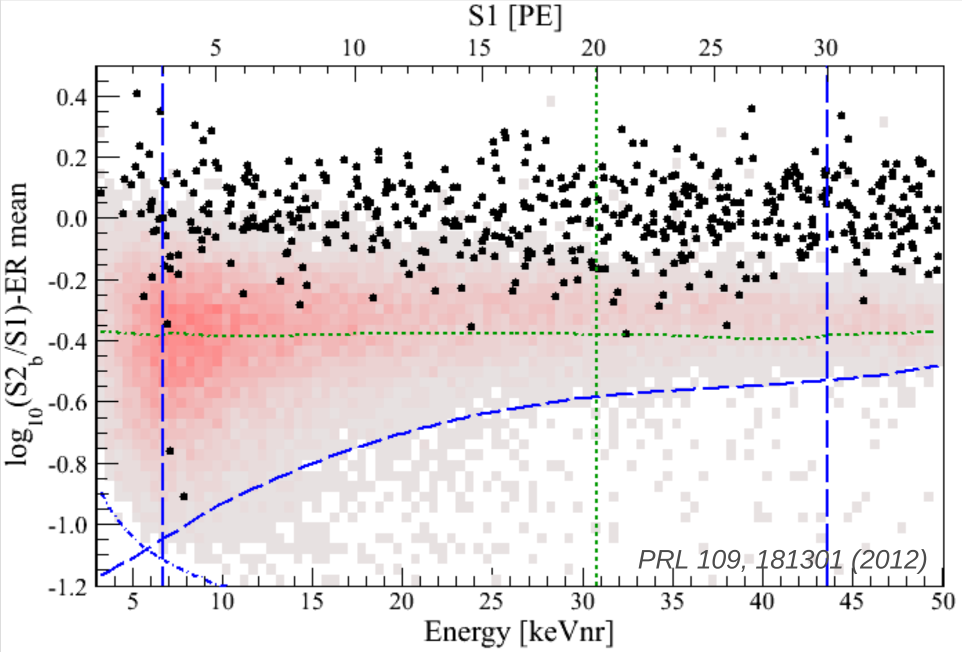
Figures from XENON100

Laboratori Nazionali del Gran Sasso


Xe
XENON
Dark Matter Project


Xe
XENON
Dark Matter Project

XENON100



Quick Facts

- 62 kg **LXe** target
- active LXe veto
- 242 PMTs
- running @ LNGS (IT)

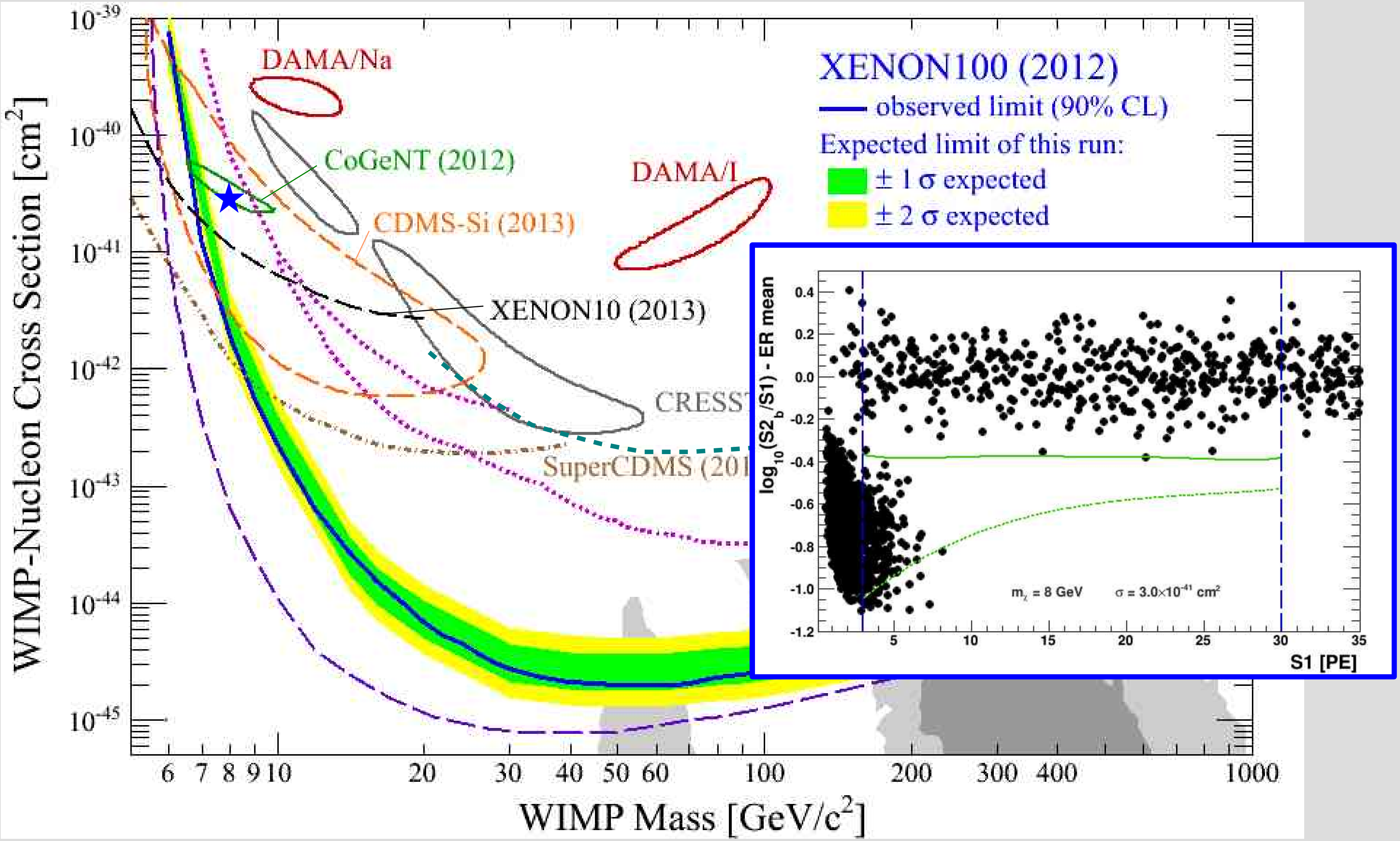
Astropart. Phys. 35, 573 (2012)

Last science run: *PRL 109, 181301 (2012)*

7636 kg x d raw exposure
2324 kg x d acpt. corrected (100 GeV/c^2)

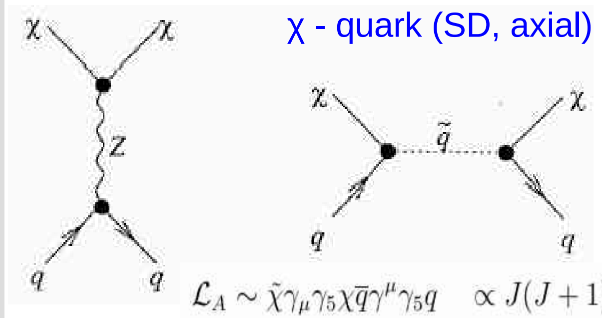
2 events observed
→ compatible with background expectation of (1.0 ± 0.2) evt
→ best WIMP limit over large mass range (at time of publication)

The current WIMP Landscape



Spin-dependent Sensitivity

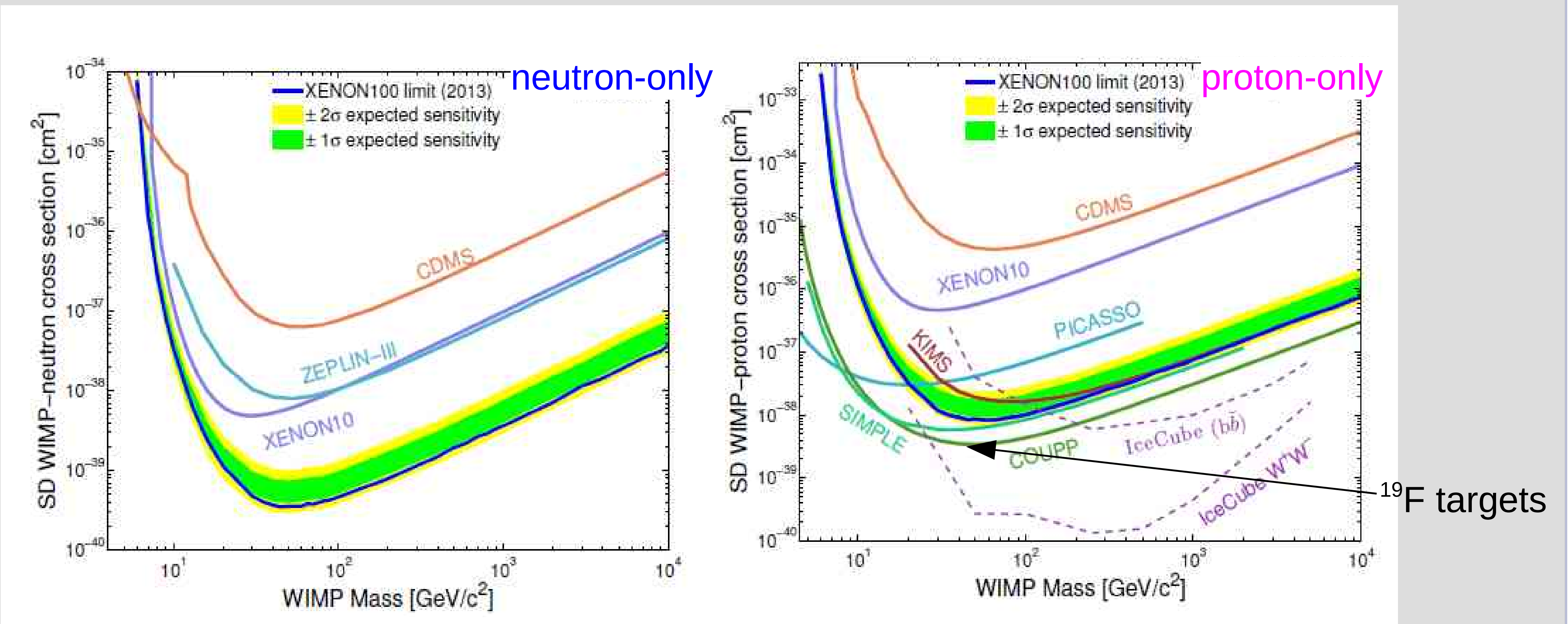
same 225d of data analyzed in terms of spin-dependent axial-vector interactions of WIMPs with ^{129}Xe and ^{131}Xe



$$\frac{d\sigma}{d|\mathbf{q}|^2} = \frac{C_{spin}}{v^2} G_F^2 \frac{S(|\mathbf{q}|)}{S(0)}$$

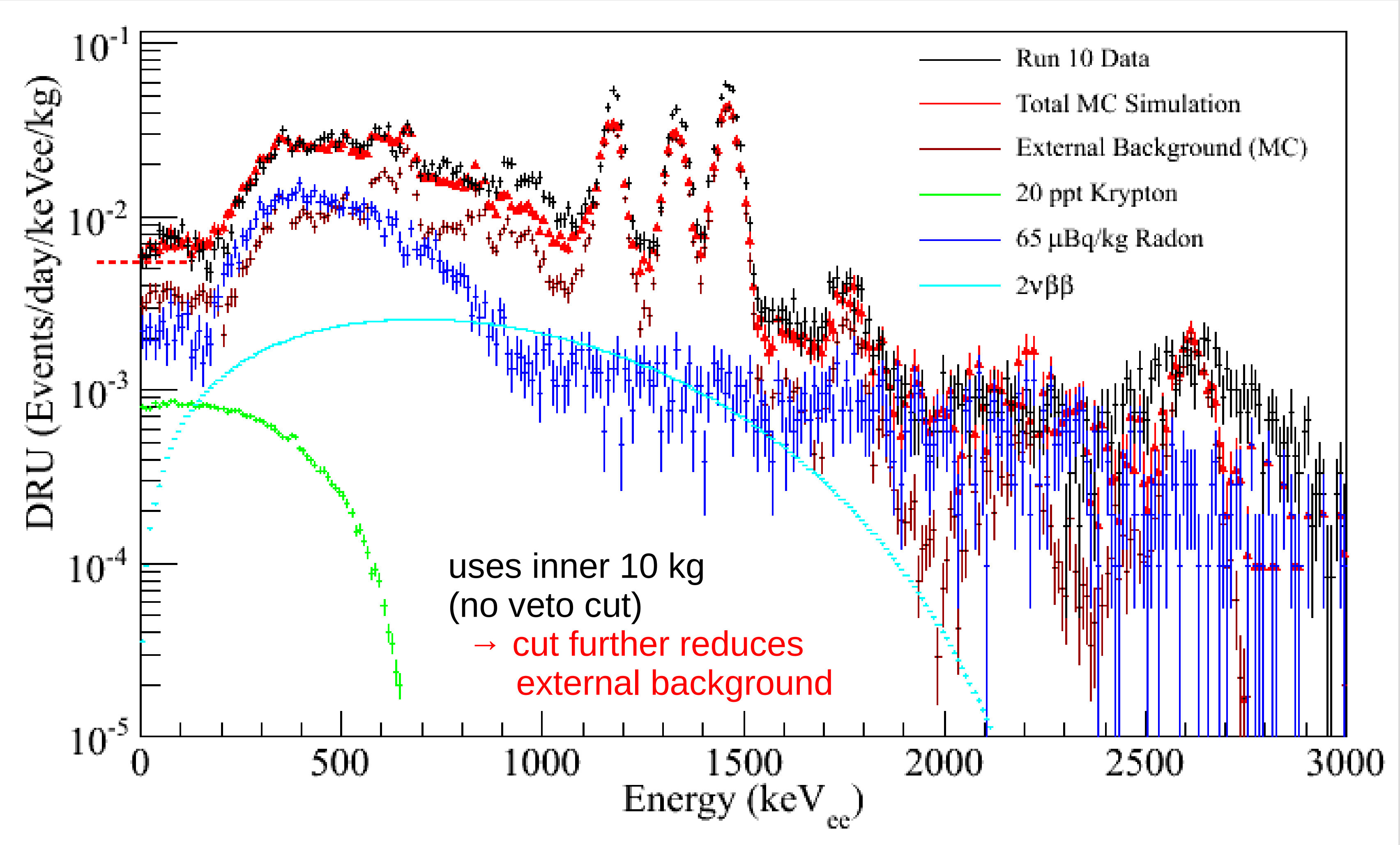
$$C_{spin} = \frac{8}{\pi}[a_p\langle S_p\rangle + a_n\langle S_n\rangle]^2 \frac{J+1}{J}$$

$$\mathcal{L}_A \sim \tilde{\chi}\gamma_\mu\gamma_5\chi\bar{q}\gamma^\mu\gamma_5 q \quad \propto J(J+1)$$



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

XENON100: ER Backgrounds



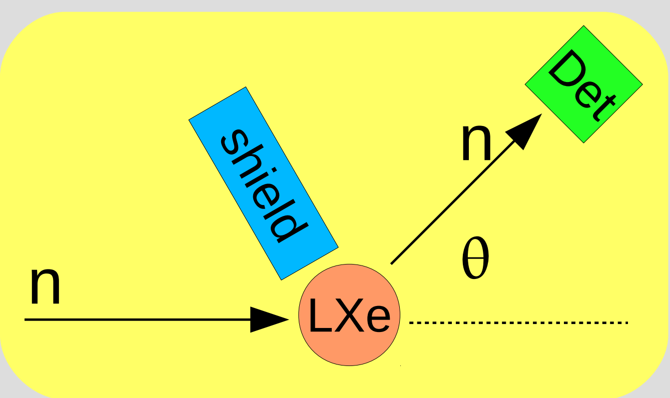
XENON100: 80% of background is from ERs

Nuclear Recoil Energy Scale

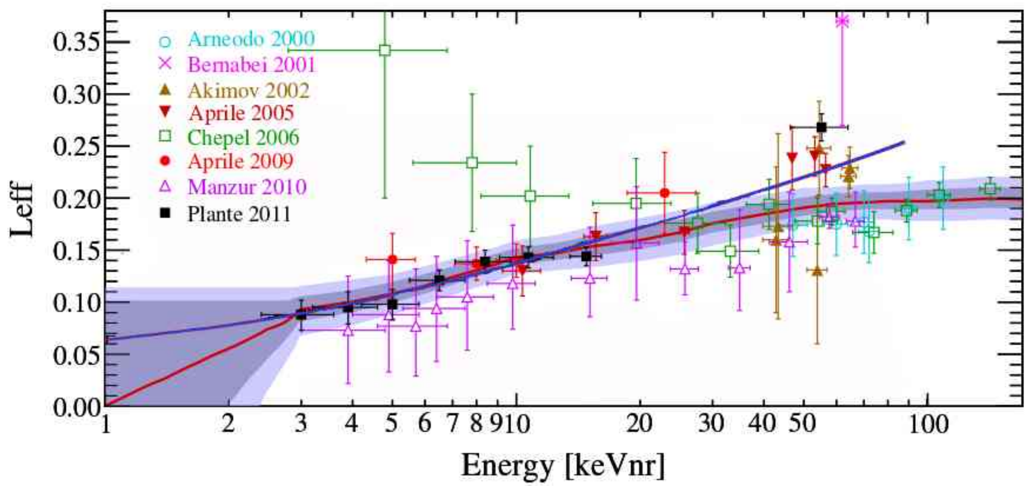
- WIMPs interact with Xe nucleus
  ➞ nuclear recoil (*nr*) scintillation (β and γ's produce electronic recoils)
- absolute measurement of *nr* scintillation yield is difficult
  ➞ measure relative to ^{57}Co (122keV)
- relative scintillation efficiency *L*eff:

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

measurement principle:



average over all direct measurements

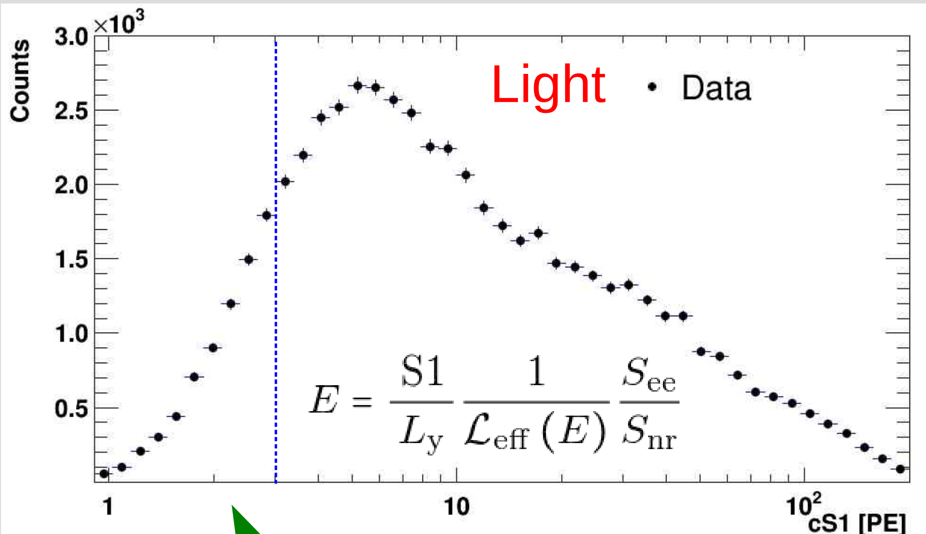


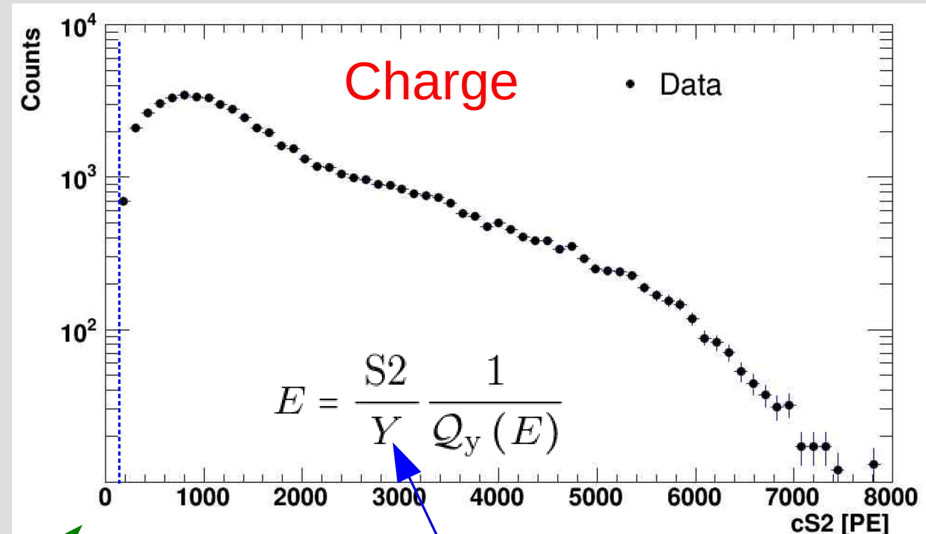
most recent measurements:
■ *Plante et al., PRC 84, 045805 (2011)*
△ *Manzur et al., PRC 81, 025808 (2010)*

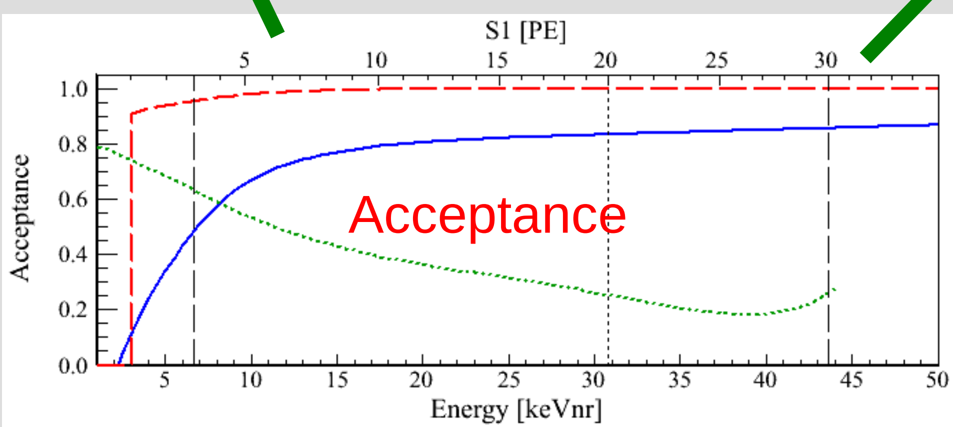
for discussion of possible systematic errors see *A. Manalaysay, arXiv:1007.3746*

XENON100: Low E response

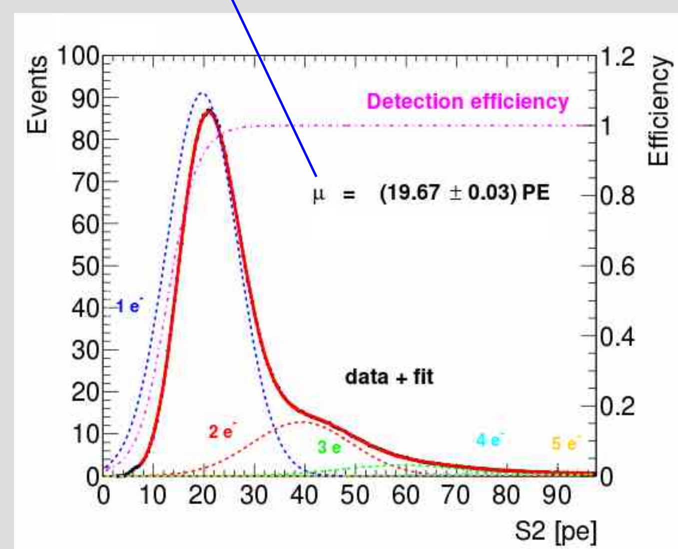
PRD 88, 012006 (2013)







PRL 109, 181301 (2012)

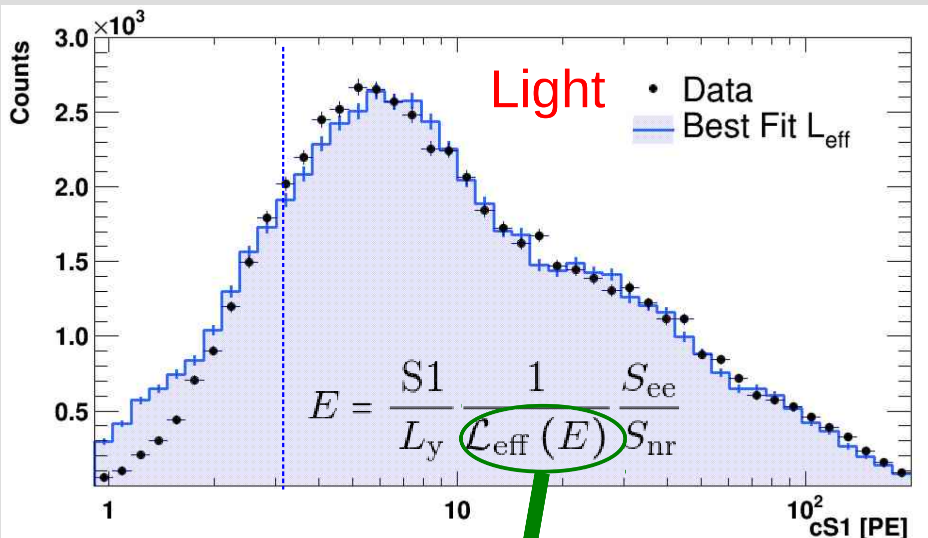


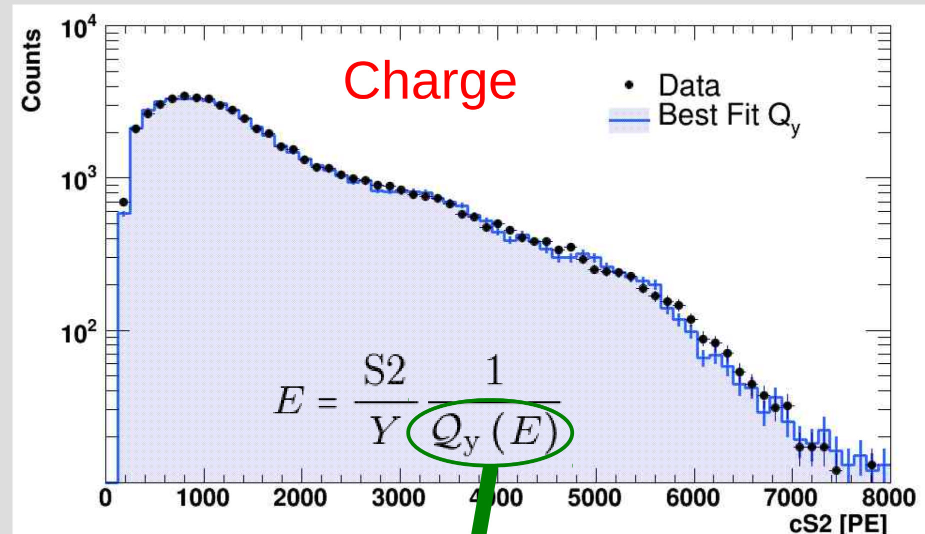
J. Phys. G 41, 035201 (2014)

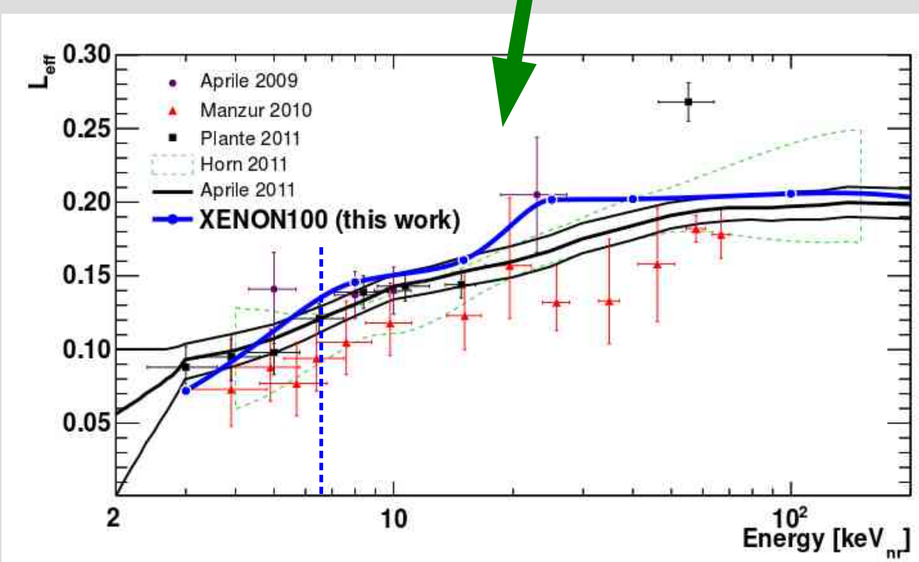
XENON100: Low *E* response

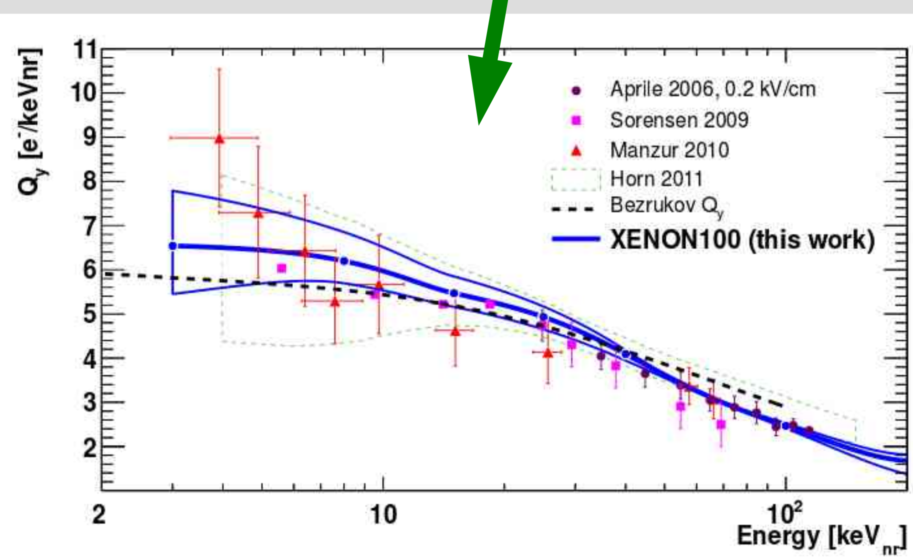
PRD 88, 012006 (2013)

→ successful absolute neutron data/MC matching down to ~3 keVr

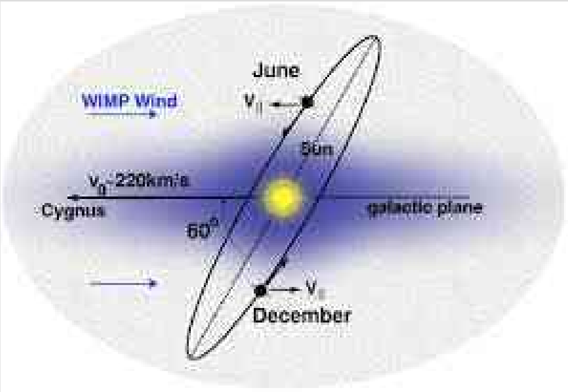


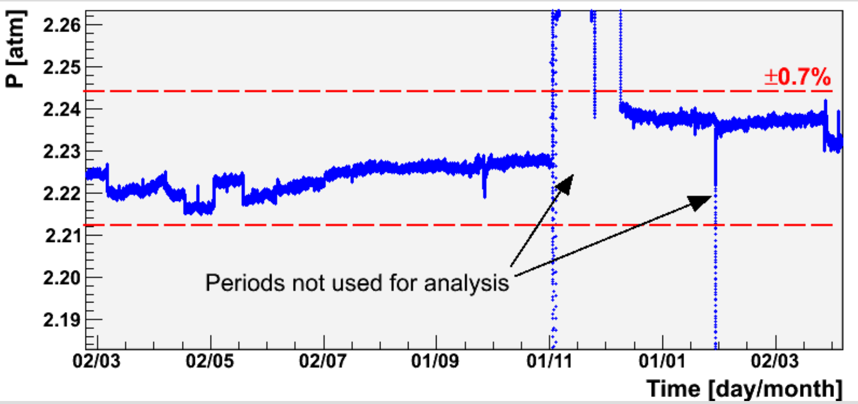


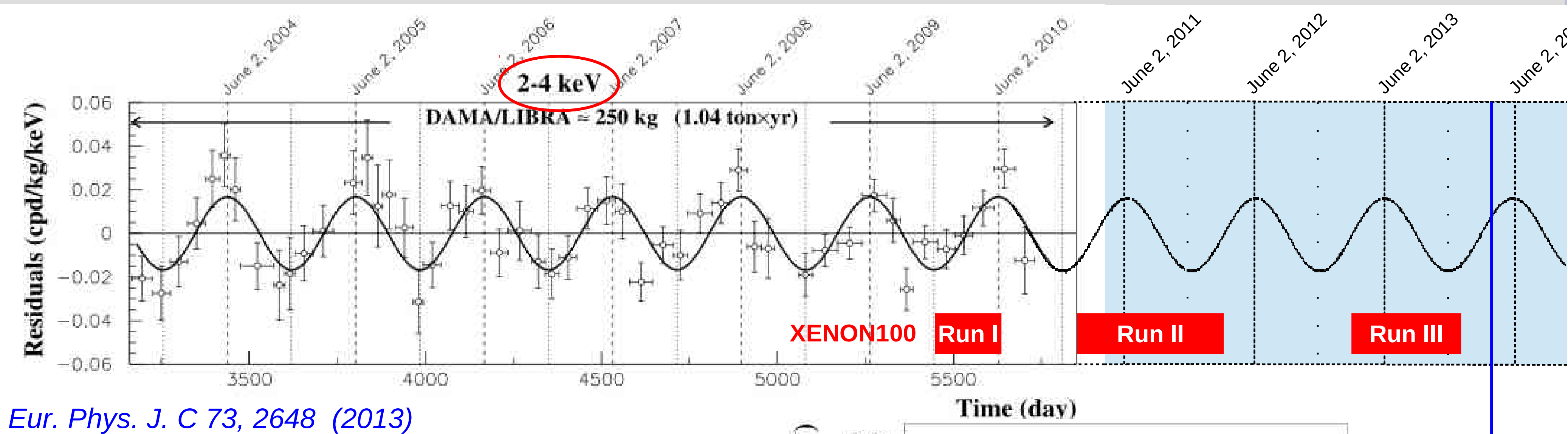




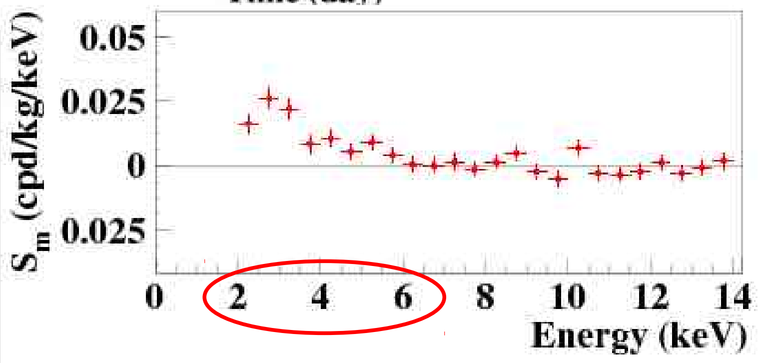
Annual Modulation



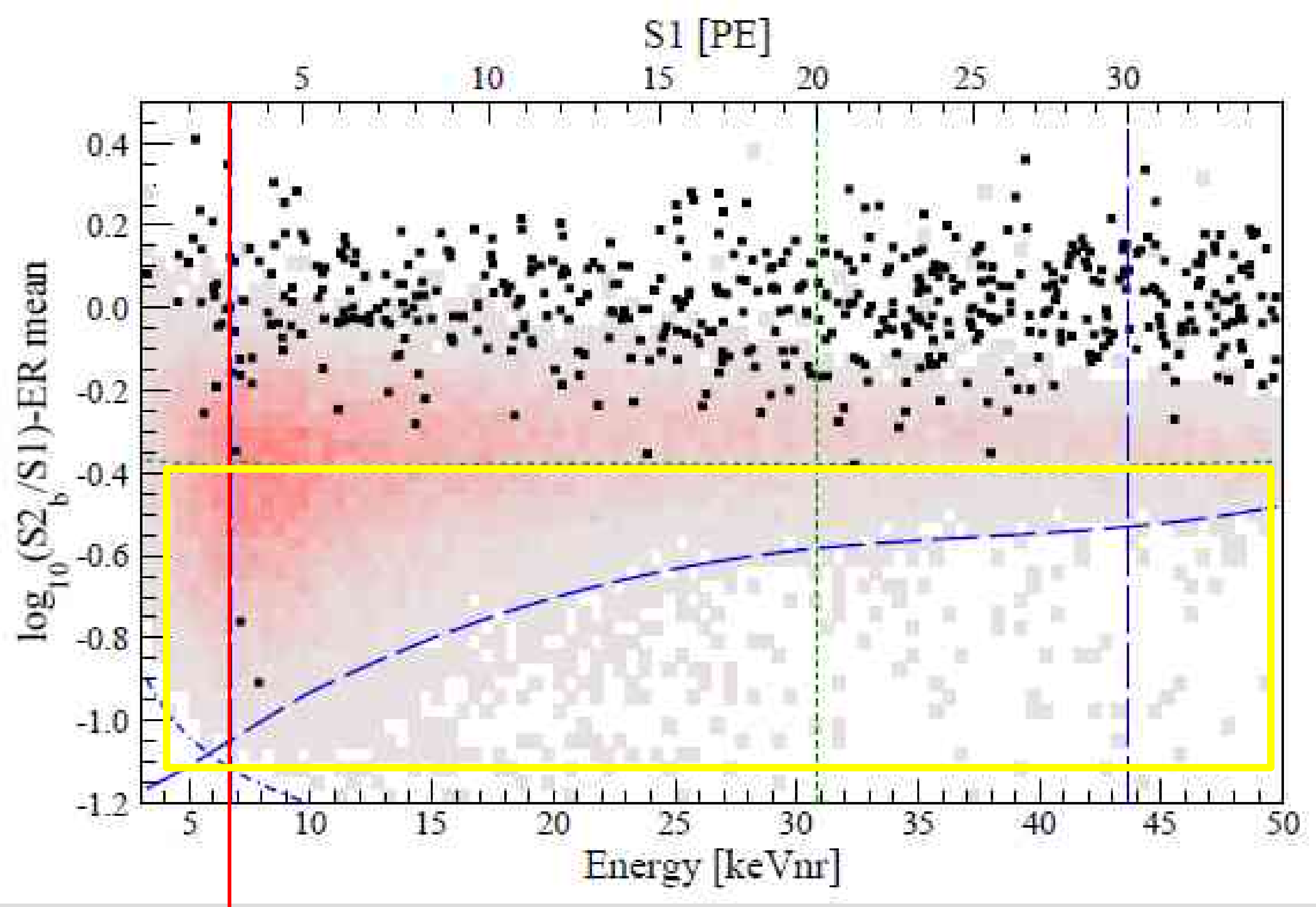




Eur. Phys. J. C 73, 2648 (2013)



Modulation in XENON100?



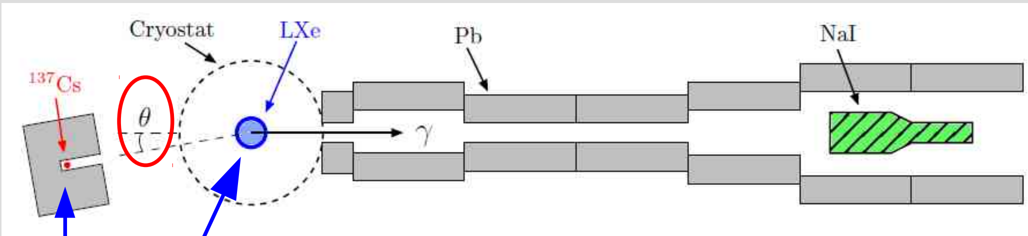
Nuclear Recoils

PRL 109, 181301 (2012)

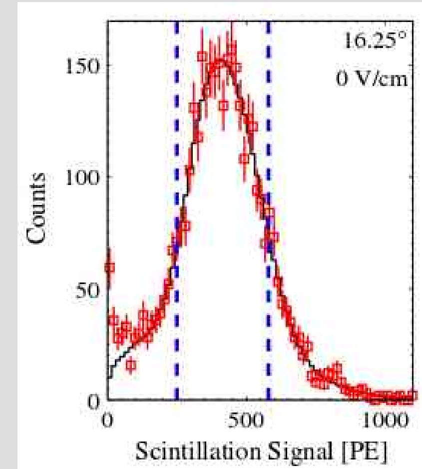
analysis threshold: 6.6 keVr < DAMA: 2 keVee = 8 keVr (Na: QF~0.25)

22 keVr (I: QF~0.09)

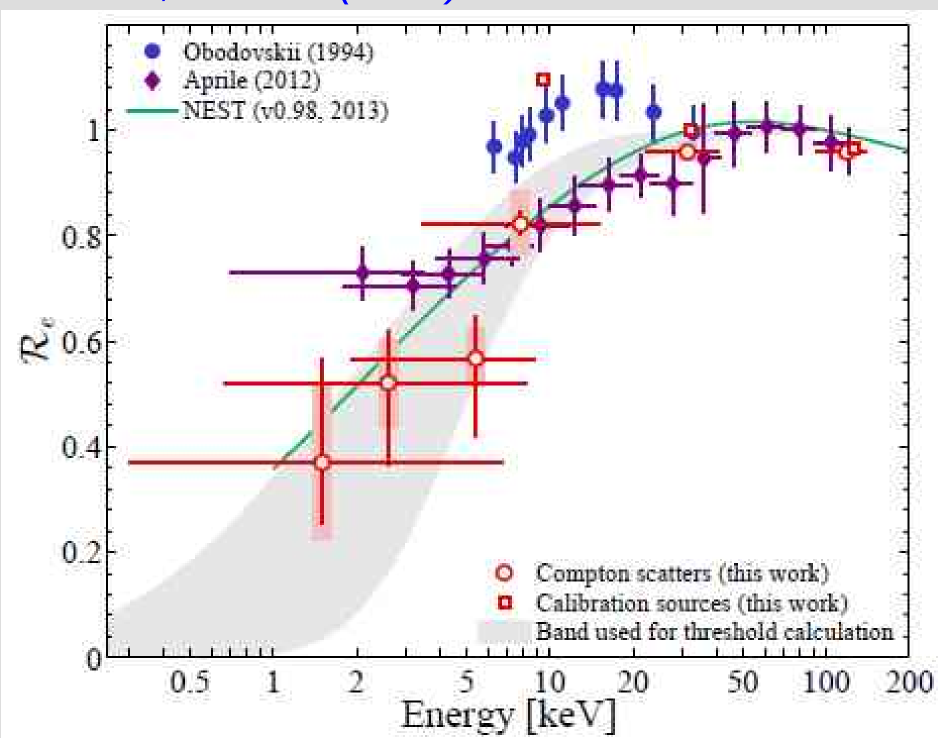
LXe Response to electronic recoils

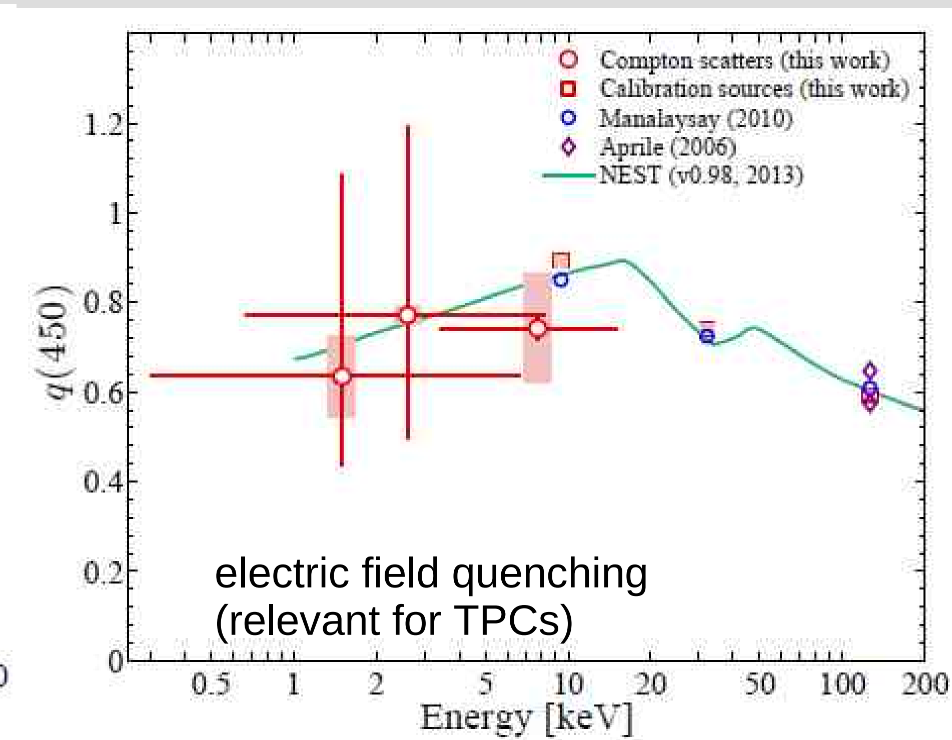


$$E'_e(\phi) = E_\nu \left(1 - \frac{1}{1+\frac{E_\nu}{m_e c^2}(1-\cos(\phi))}\right)$$



PRD 87, 115015 (2013)

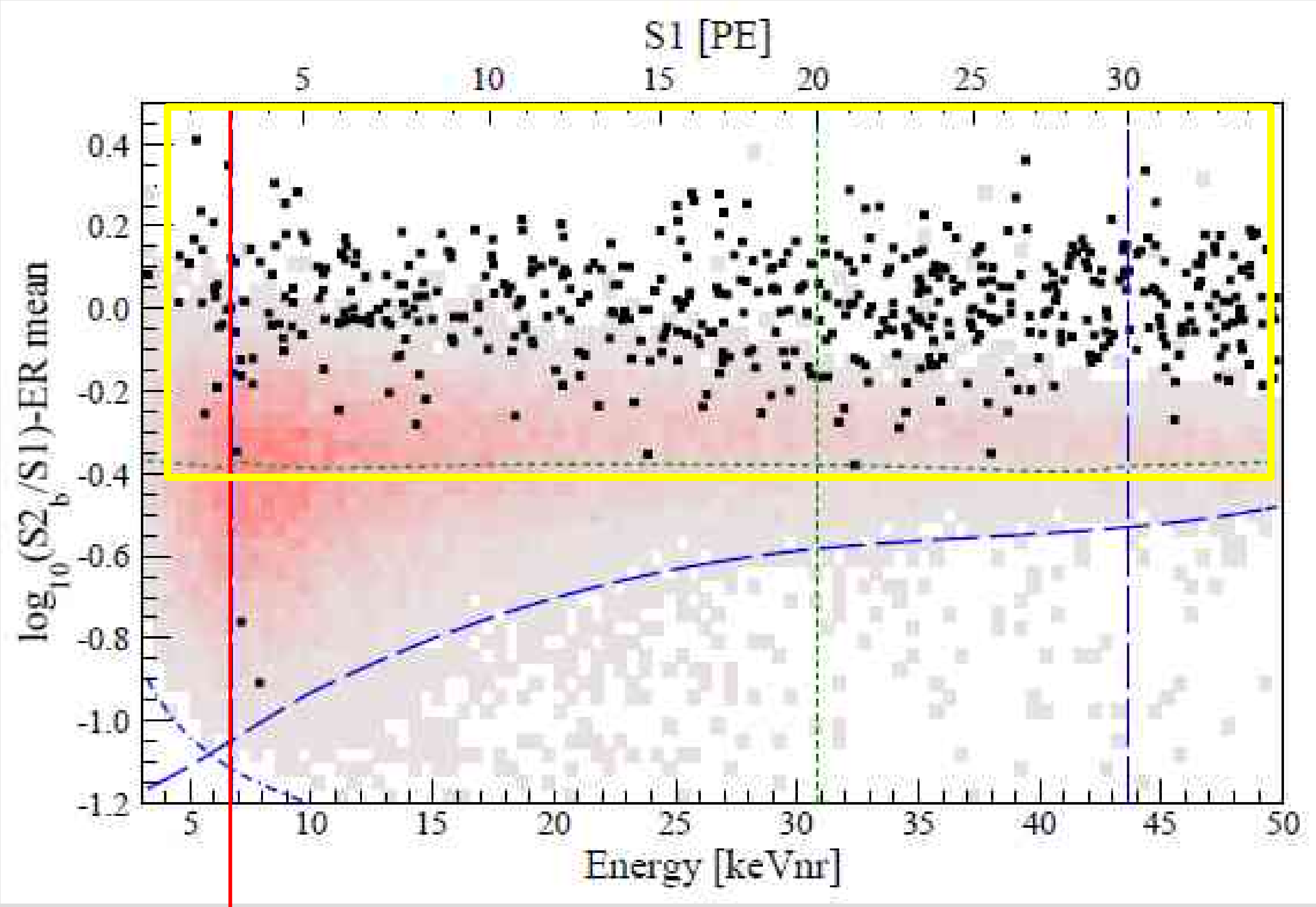




electric field quenching
(relevant for TPCs)

Modulation in XENON100?

Electronic Recoils

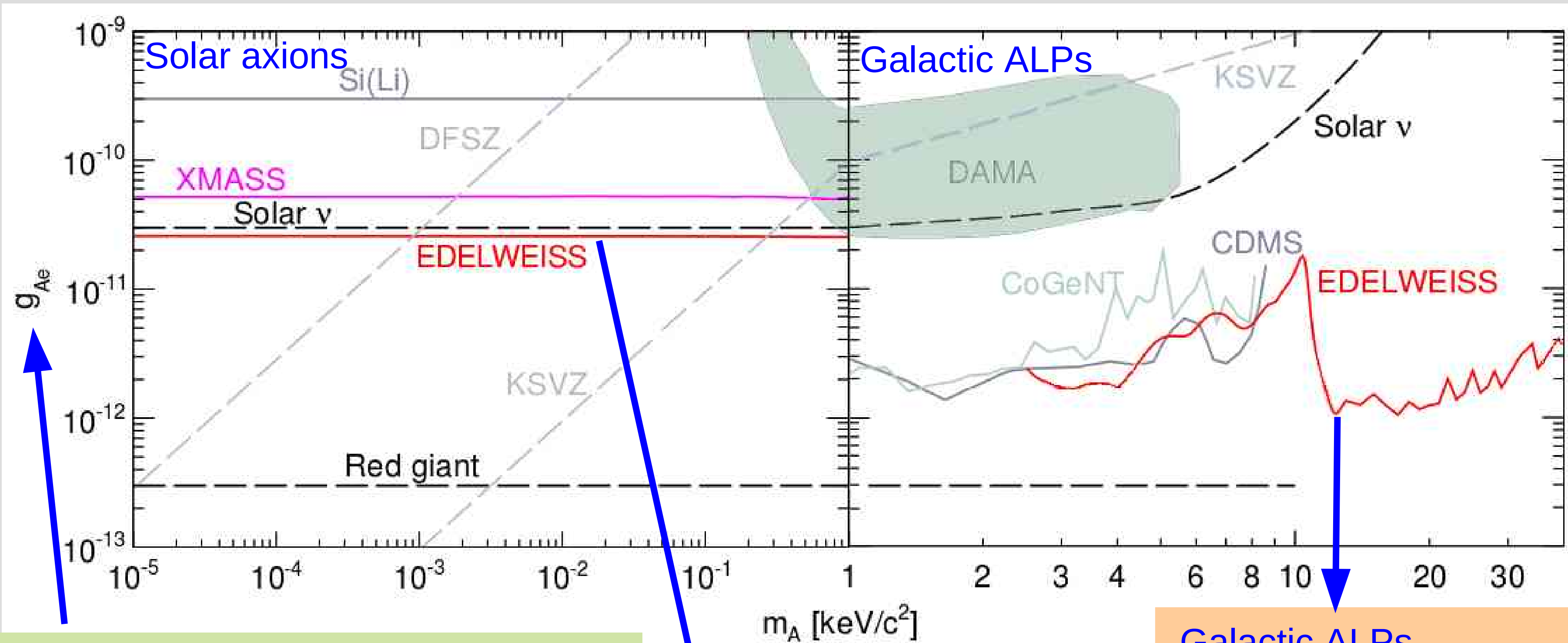


PRL 109, 181301 (2012)

analysis threshold: (2.0±0.3) keVee

→ similar to DAMA/Libra
XENON100 result coming soon

Solar Axions and Dark Matter ALPS



Axions and ALPs couple to xenon via **axio-electric-effect**

$$\sigma_{Ae}(E_A) = \sigma_{pe}(E_A)\frac{{g_{Ae}}^2}{\beta_A}\frac{3{E_A}^2}{16\pi\,\alpha\,{m_e}^2}\left(1-\frac{\beta_A}{3}\right)$$

→ axion ionizes a Xe atom

Solar axions

production and detection depends on g_{Ae}

$$\frac{dR^{Solar}}{dE_R} = \int \sigma_A \left(\frac{d\Phi^{BCA}}{dE_A}\right) dE_A \propto g_{Ae}^4$$

Galactic ALPs

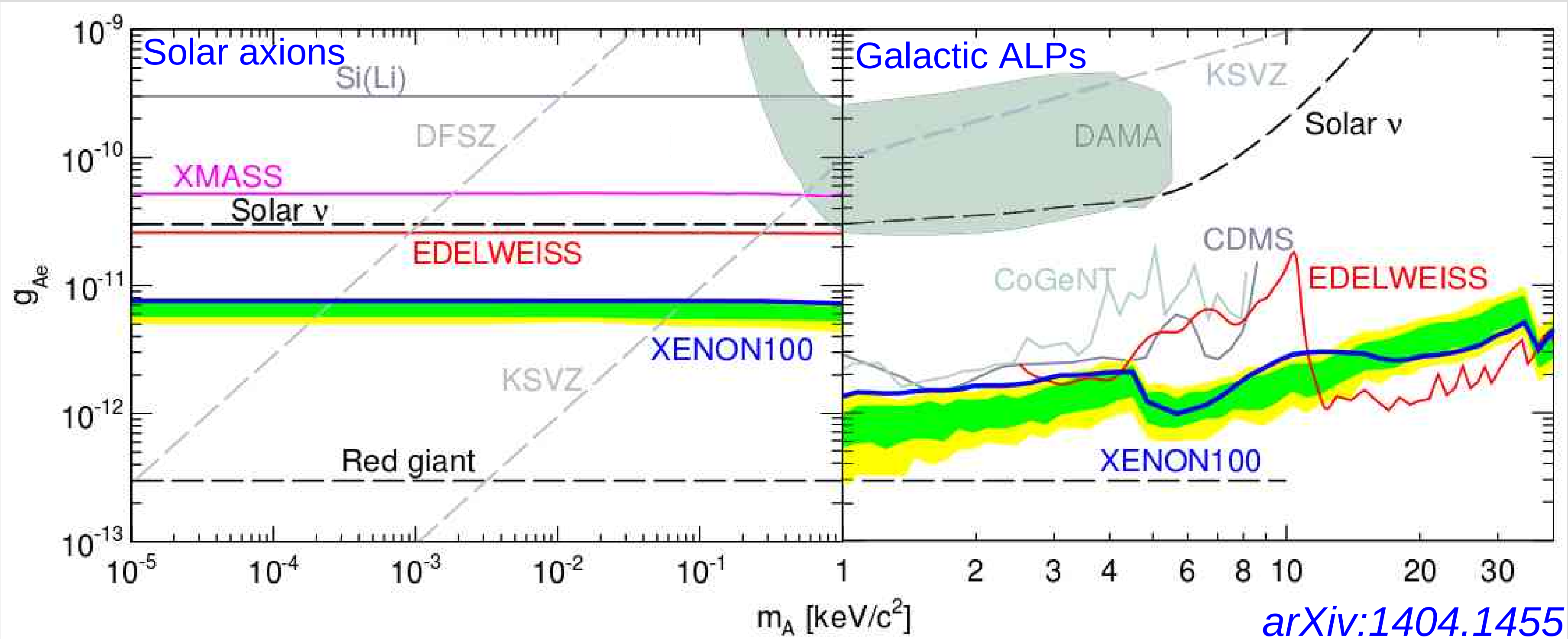
assume: local DM is from ALPs

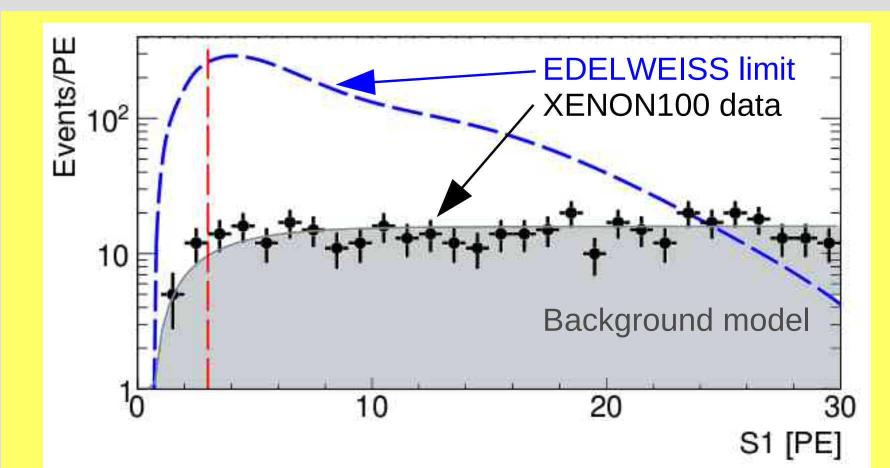
ALPs created in early Universe, no g_{Ae} dependence of flux:

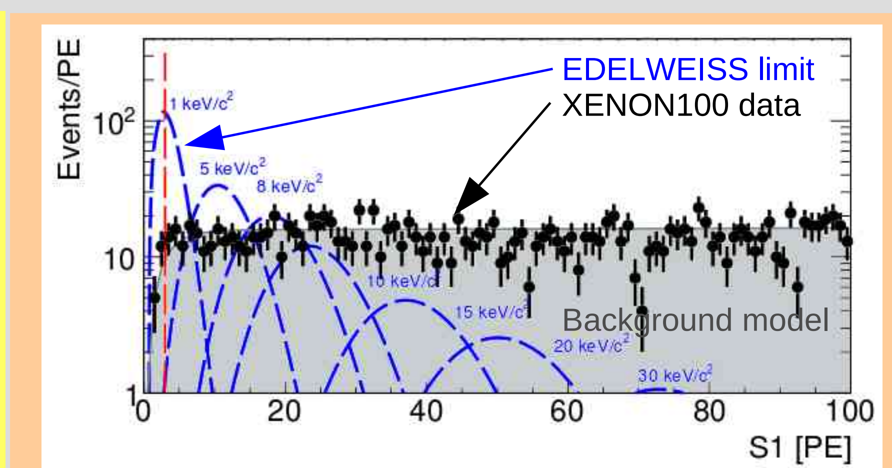
$$\Phi^{DM} = 9.0\times 10^{15}\frac{\text{keV}}{m_A}\beta_m$$

$$\frac{dR^{DM}}{dm_A} = \sigma_A\Phi^{DM} = \left(\frac{1.29\times10^{19}}{A}\right)g_{Ae}^2\,m_A\sigma_{pe}$$

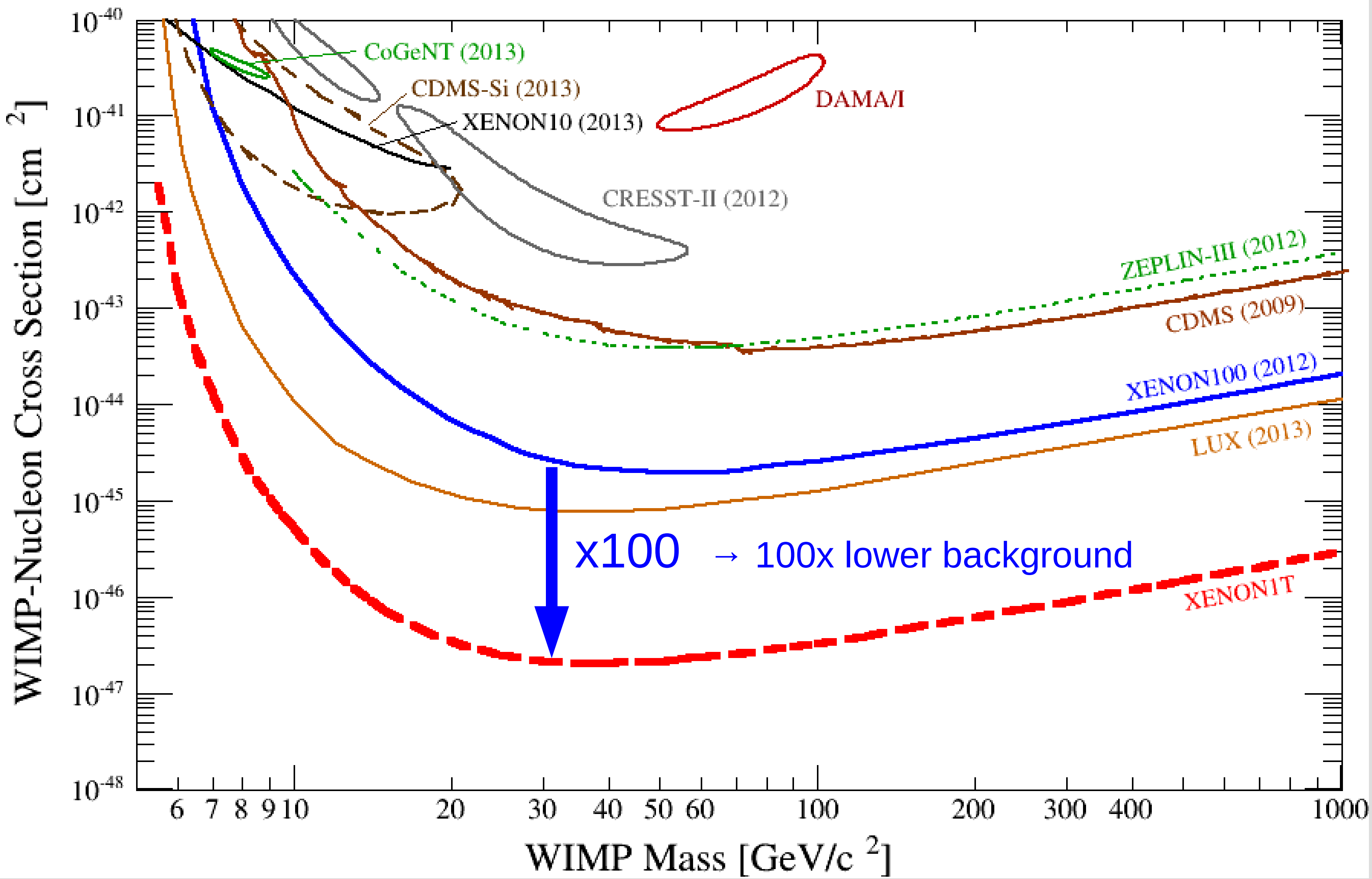
Solar Axions and Dark Matter ALPS



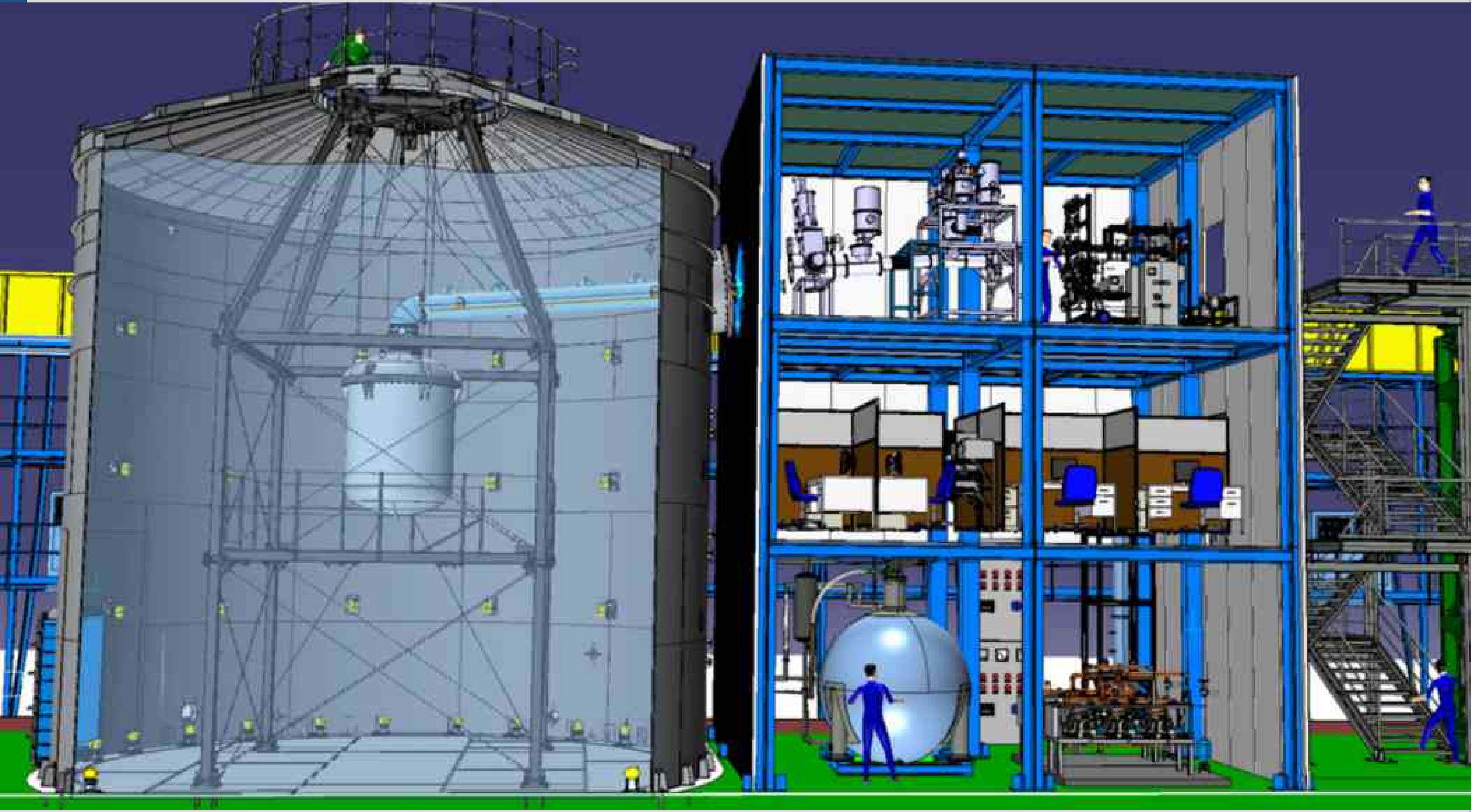




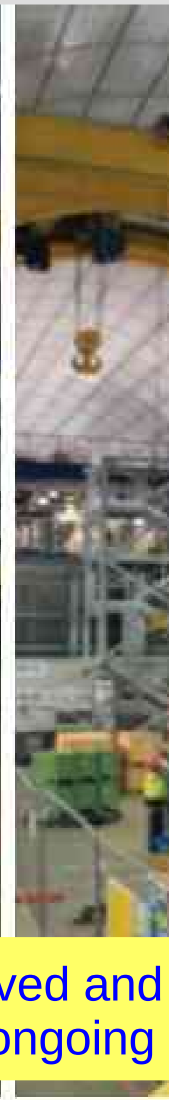
The XENON Future



XENON1T in Hall B @ LNGS

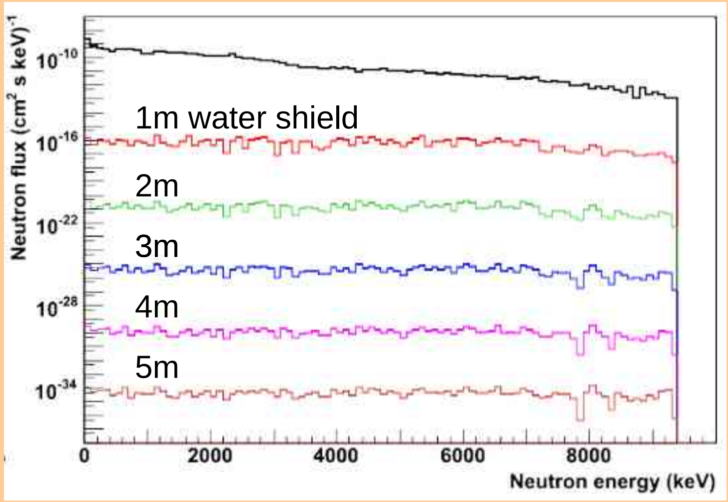


XENON1T in Hall B @ LNGS



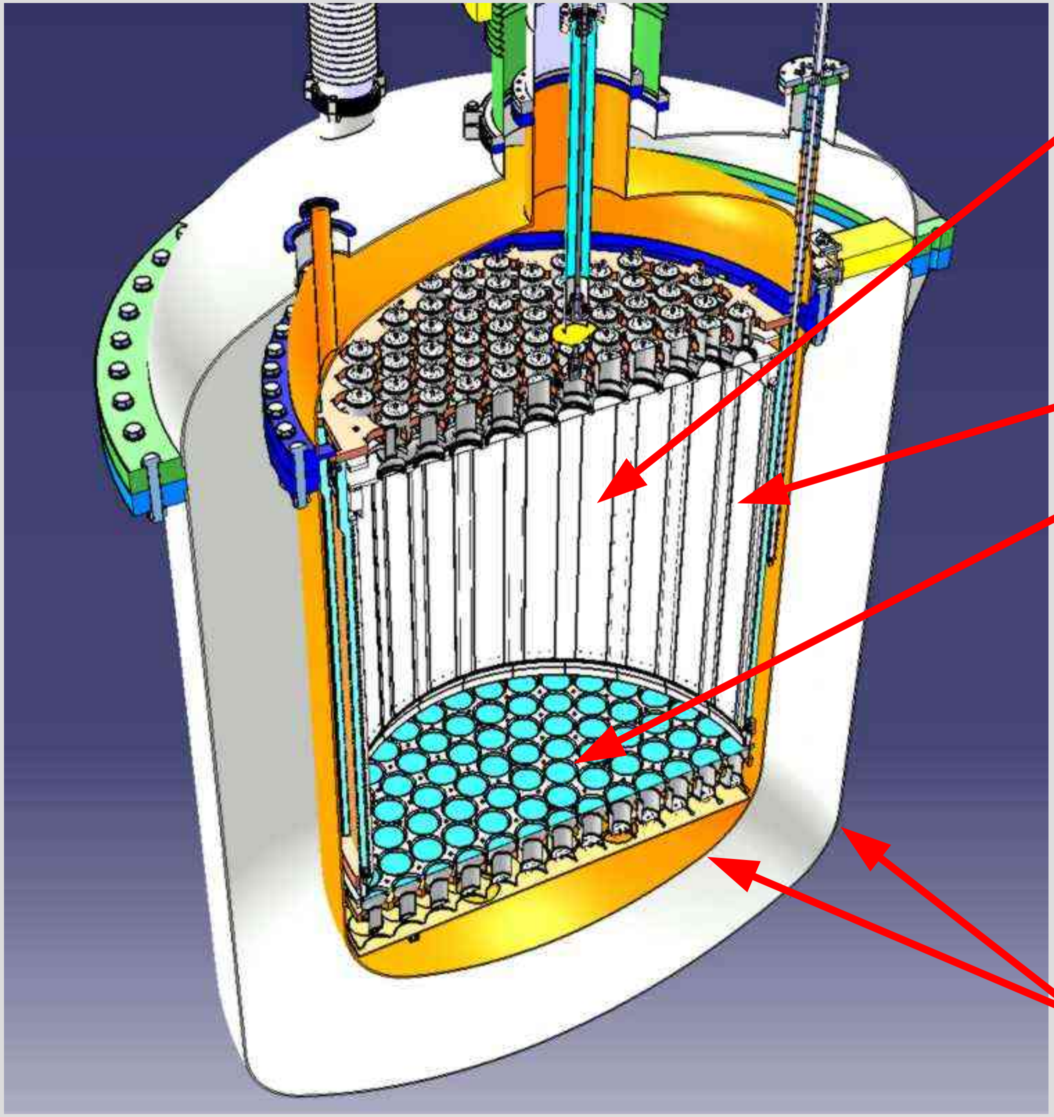
Water Cerenkov Shield
- 9.6m diameter, 10m height
- external γ, neutrons irrelevant
- muon induced NRs irrelevant

→ dominating background of XENON1T will be intrinsic



project approved and funded, construction ongoing

XENON1T



dual-phase LXe TPC
- total mass ~3 t
- active mass ~2.2 t
- fiducial mass: ~1 t

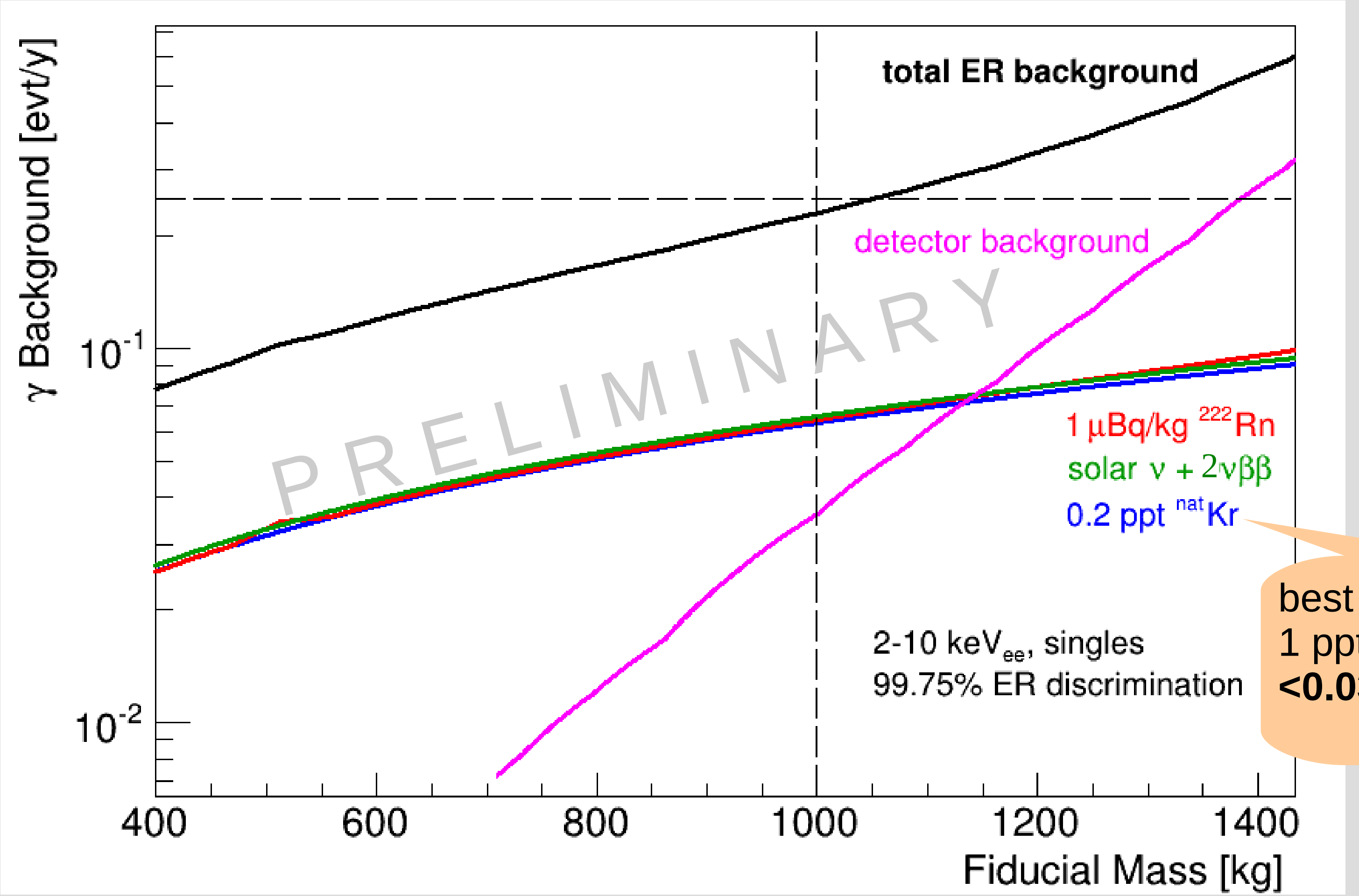
TPC made from OFHC and PTFE

248 photomultipliers
- Hamamatsu R11410-21
- low background
- high QE (36% @ 178nm)
- extensive testing in cryogenic environments *JINST 8, P04026 (2013)*

Low-background stainless steel cryostats

XENON1T Background

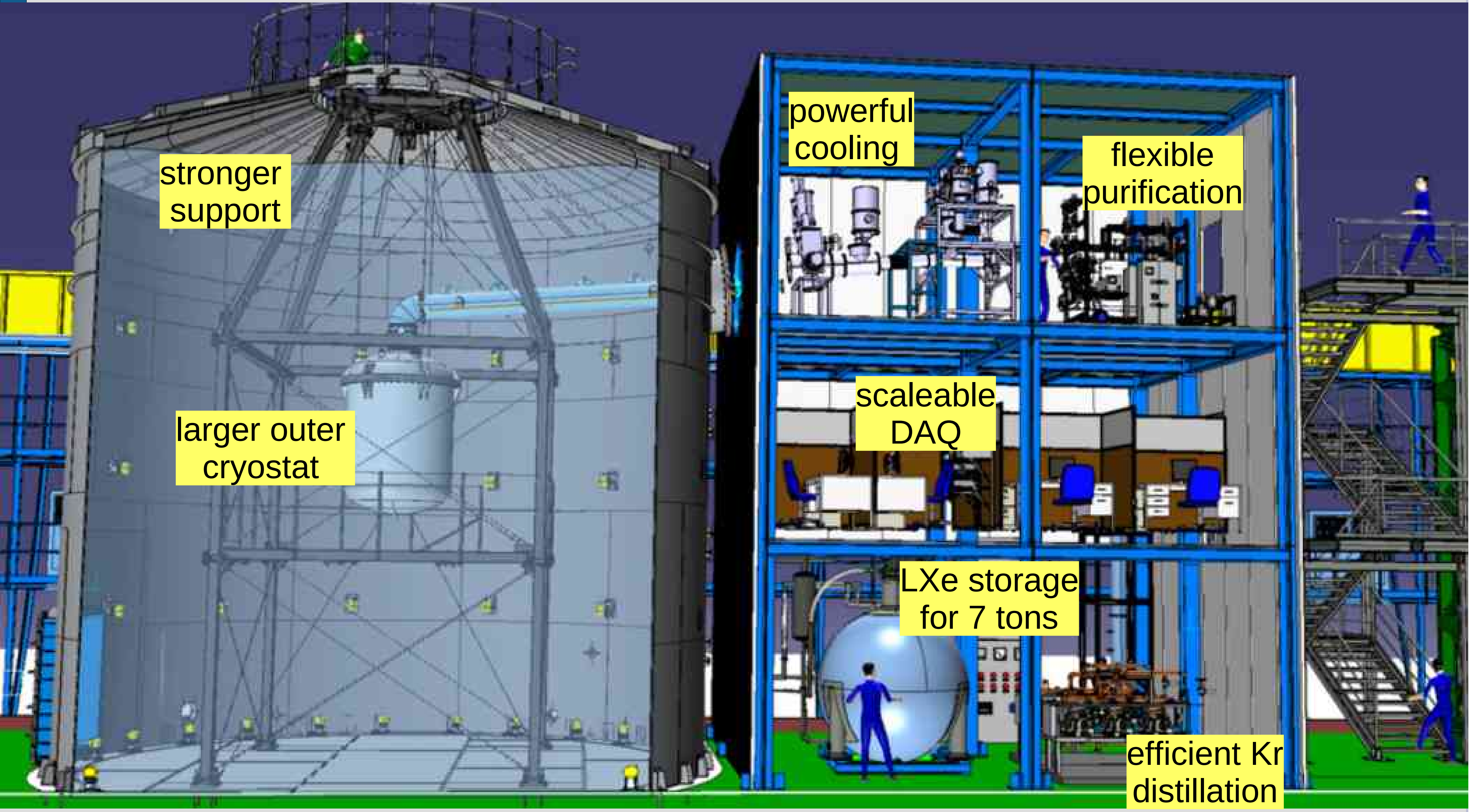
detailed MC simulation: use measured radioactive contamination as input



best values achieved:
1 ppt in XENON100
<0.03 ppt from XENON1T distillation column

Background goal: <1 evt in 2 years (ER+NR)

XENONnT in Hall B @ LNGS



The XENON Future