Xe
XENON
Dark Matter Project

The *XENON1T* experiment

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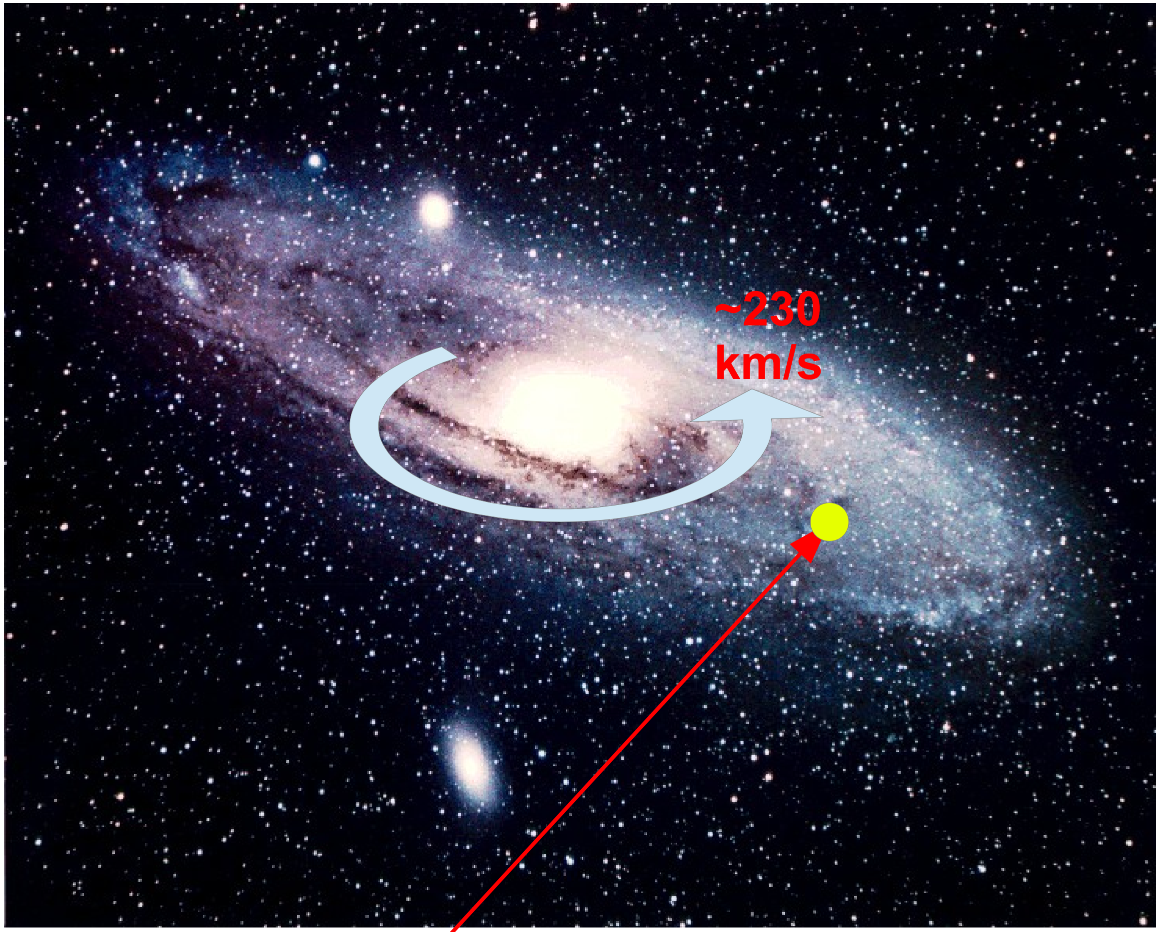
The *XENON1T* experiment

- Direct detection with xenon
- The *XENON* project
- *XENON1T/nT*

Quick introduction and reminder



We are here

The Galaxy rotates around the center (bulge)

DM is almost stationary – but has a virial velocity dispersion that depends on the position in the Galaxy

This means that we are “flying” through a cloud of DM, with a local density of ~0.3 GeV/cm^3

Some thumb rules for the interaction

- Assuming an isothermal halo $\rho_{DM} \approx 0.3\ \mathrm{GeV/cm^3}$
- Velocity of the sun around the Galaxy "rest frame" $v_0 \sim 230\ \mathrm{km/s}$, escape velocity $\sim 550\ \mathrm{km/s}$
- Recoil energy of a nucleus by elastic scattering:
  $E_{r,\max} = \frac{p_\chi}{2m_N} \sim \frac{(100\mathrm{GeV/c^2} \times 10^{-3} c)^2}{2 \times 100\mathrm{GeV/c^2}} \approx 50\ \mathrm{keV} \Rightarrow$ Low energy detectors
- Coherent scattering
  $\frac{\lambda_{\mathrm{DeBroglie}}}{2\pi} = \frac{\hbar}{p} \approx 1\mathrm{fm} \approx r_{\mathrm{nuc}} \Rightarrow \sigma_{SI} \propto A^2$
- Rate of interactions:
  $\Gamma = \Phi \sigma_{\chi,N} N_{\mathrm{Detector}} A^2$, for $\sigma_{\chi,N} = 10^{-45}\ \mathrm{cm}^2, m_\chi = 100\ \mathrm{GeV}$
  $\Gamma \sim 100$ events/ton/yr

True for elastic recoils only!

Of course, reality is a bit more complicated...

Dark Matter Direct Detection

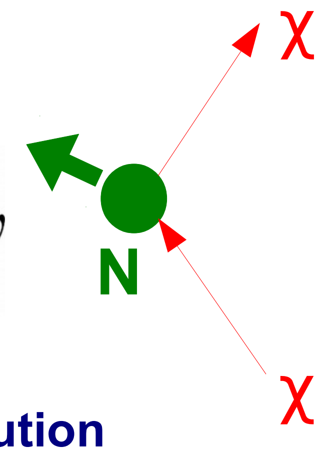
Goal: Observe WIMP interactions with some target material

Expected interaction rate

Number of targets · **WIMP density** · **Nuclear Form factor**

$$\frac{dR}{dE_{NR}} \propto N \frac{\rho_\chi}{2 m_\chi \mu^2} \sigma_N |F^2(E_{NR})| \int_{v_{min}}^{v_{esc}} \frac{f(\vec{v})}{v} d^3v$$

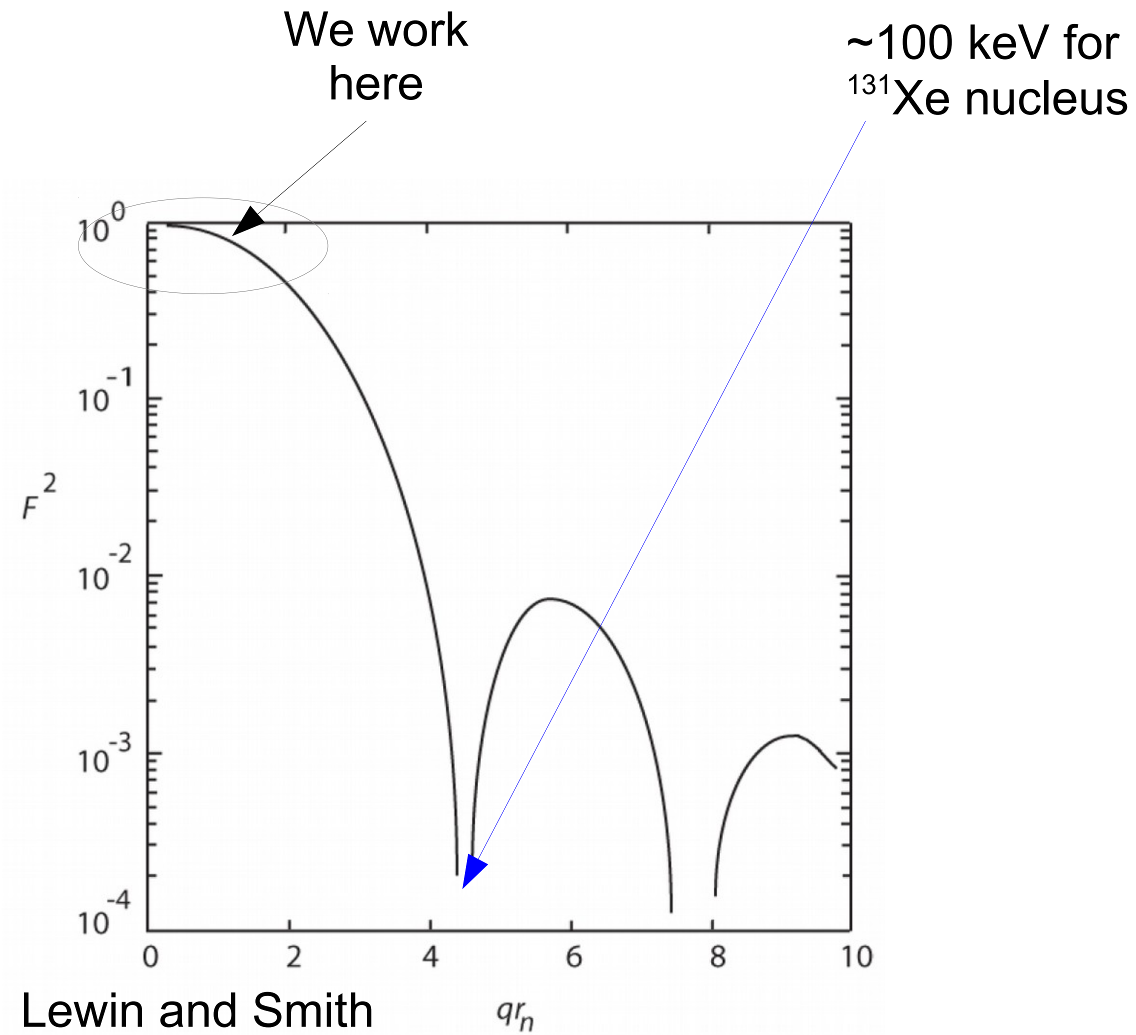
WIMP mass · **Interaction cross section** · **WIMP velocity distribution**



$$v_{min} = \sqrt{\frac{m_N E_{nr}}{2\,\mu^2}}$$

- Only those WIMPs with velocity above threshold will contribute to that energy
- For Spin Independent interactions the cross section is enhanced by a factor A^2 (coherent scattering)

Nuclear form factor



Lewin and Smith 1996

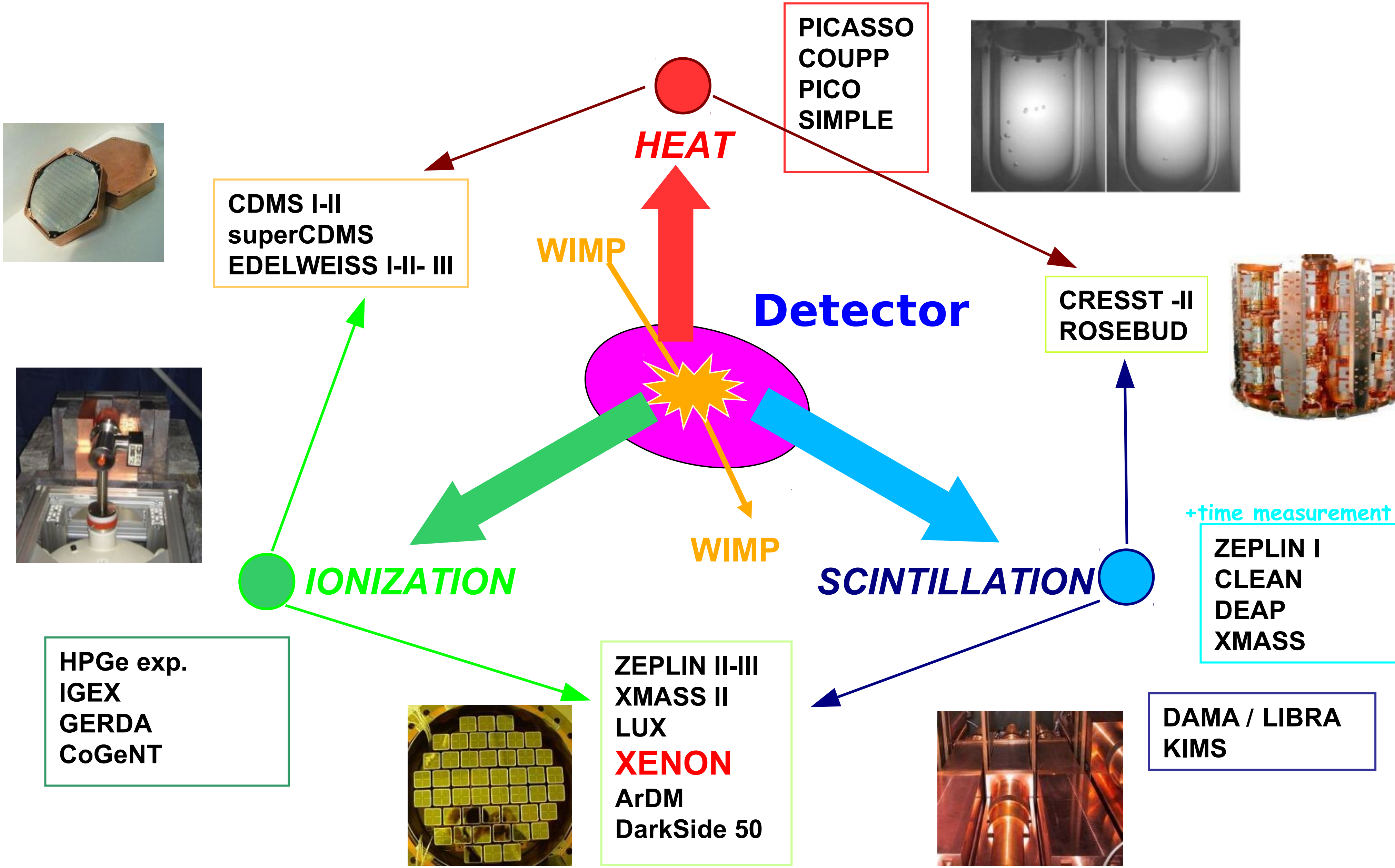
Large nucleus gains an A^2 factor for coherent scattering

However, nuclear form factor due to nuclear structure and first nuclear excitations complicate the picture

Therefore, it is customary to consider low momentum transfers, ~<40 keV

Helm Form Factor is typically adequate

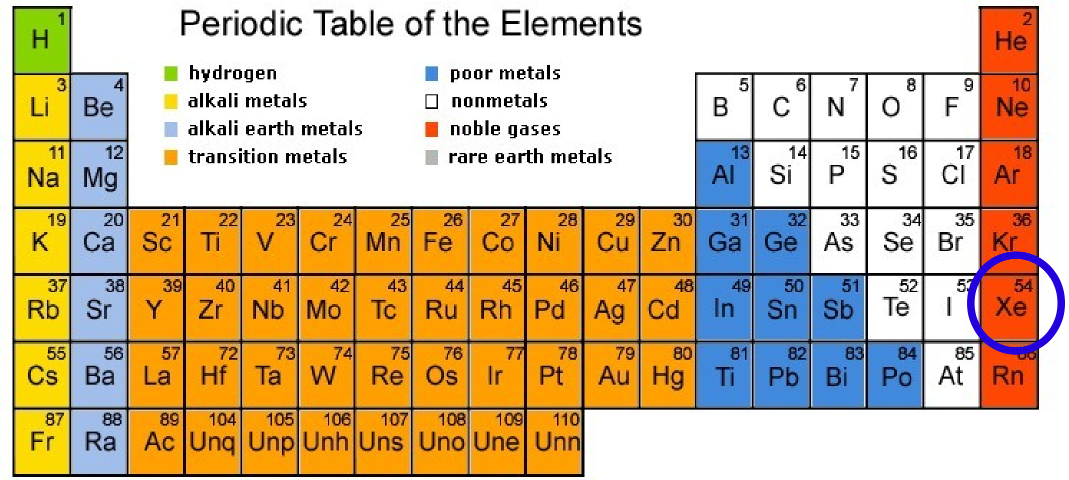
Dark Matter Direct Detection

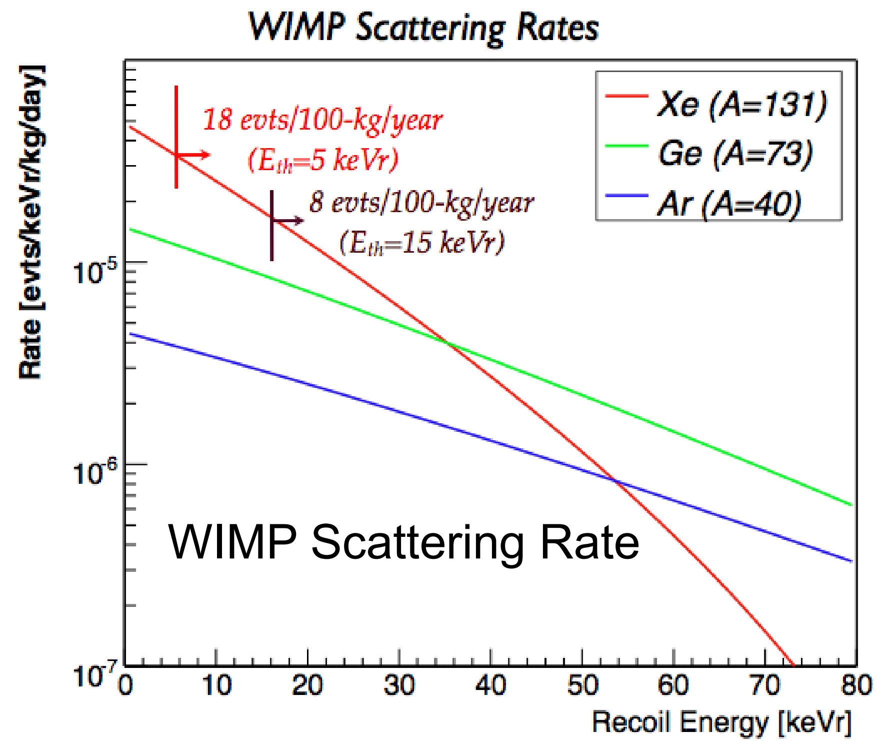


Xe XENON Dark Matter Project

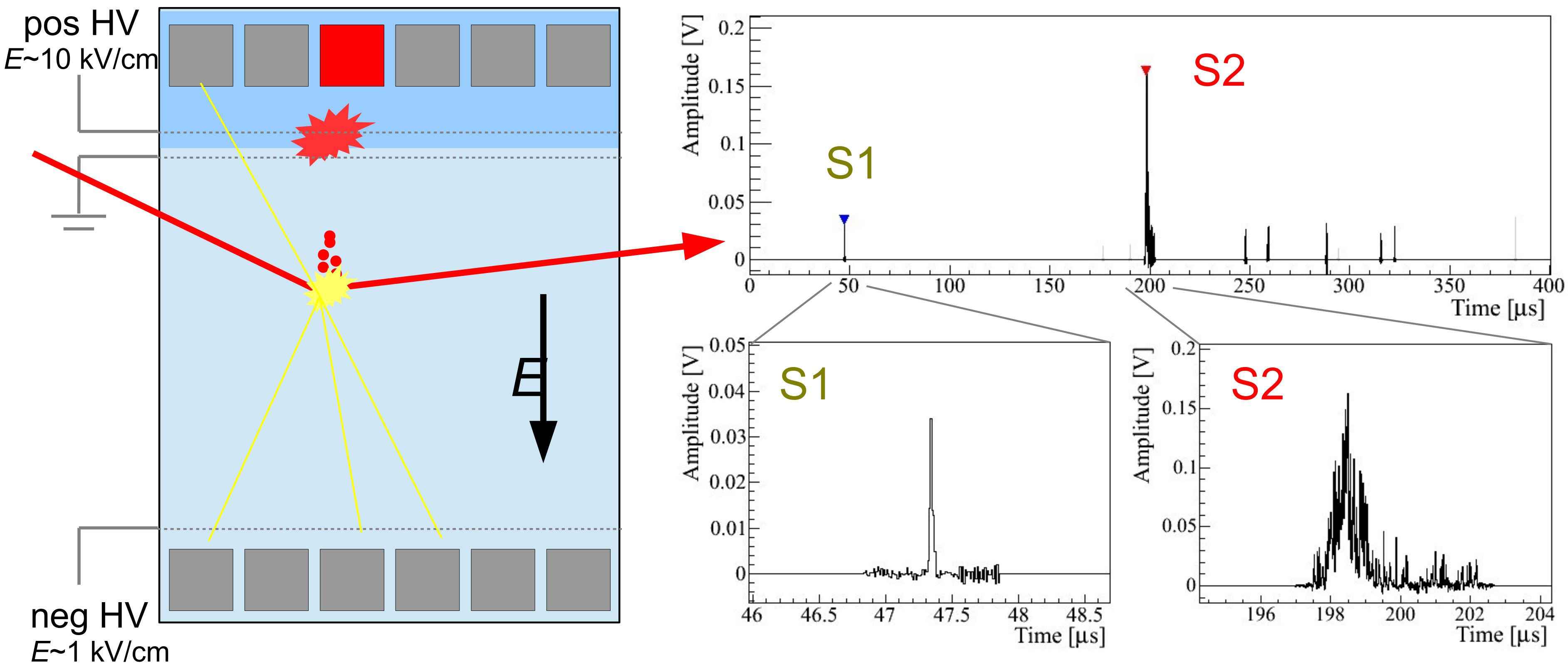
Liquid Xenon for Dark Matter Search

- Large atomic number A~131 best for SI interactions (σ~A²).
  Need low threshold.
- ~50% odd isotopes: SD interactions
  If DM detected: probe physics with the same detector using isotopically enriched media.
- No# long-lived Xe isotopes.
  But control Kr-85, Rn-222. #Xe-136 2νββ
- High Z (54) and density:
  compact & self-shielding
- Scalability to large mass.
- “Easy” cryogenics (-100°C).
- Efficient and fast scintillator.
- Good ionization medium, long drift.
- Background discrimination in TPC.
  - Ionization/Scintillation
  - 3D imaging of TPC



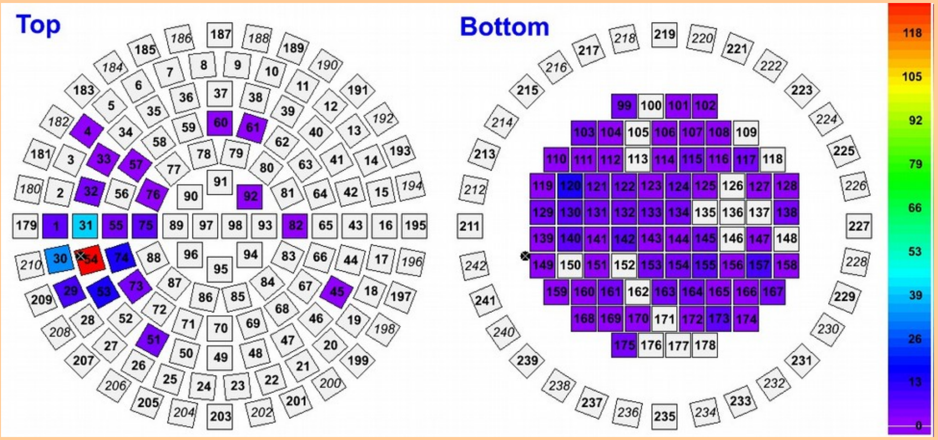


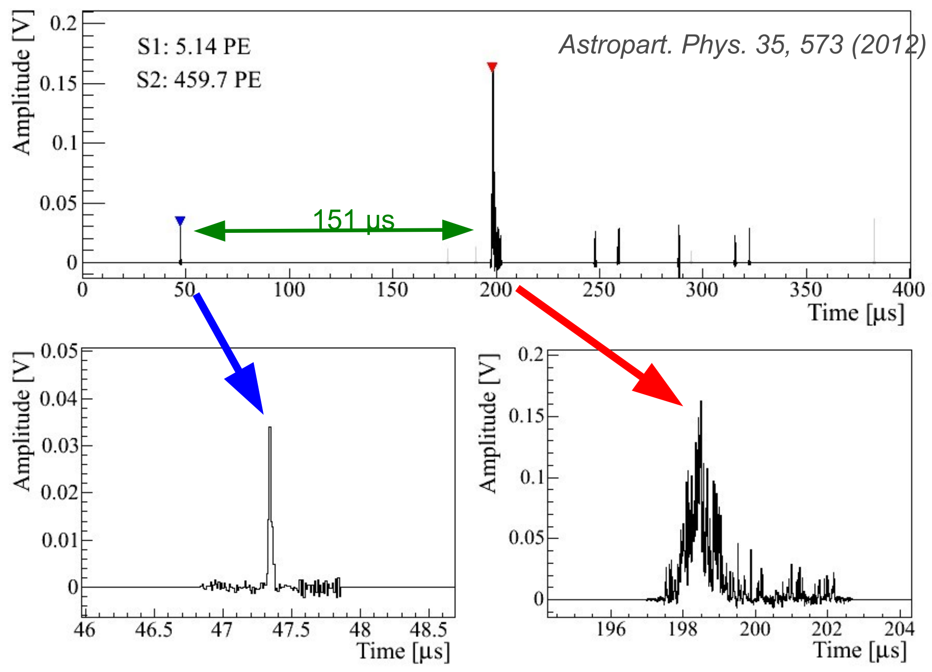
Dual Phase TPC



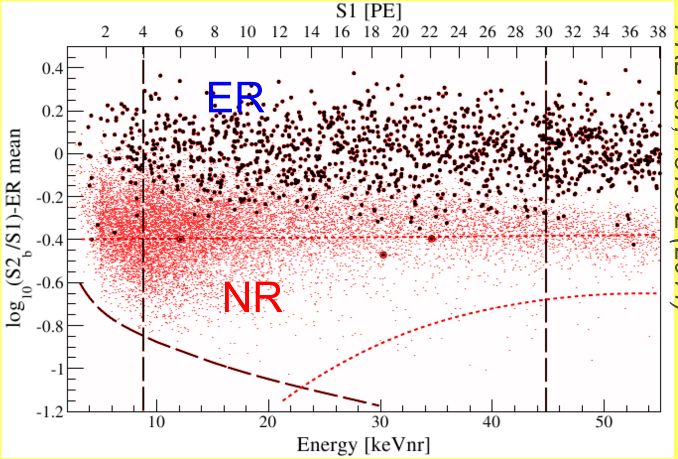
Dual Phase TPC

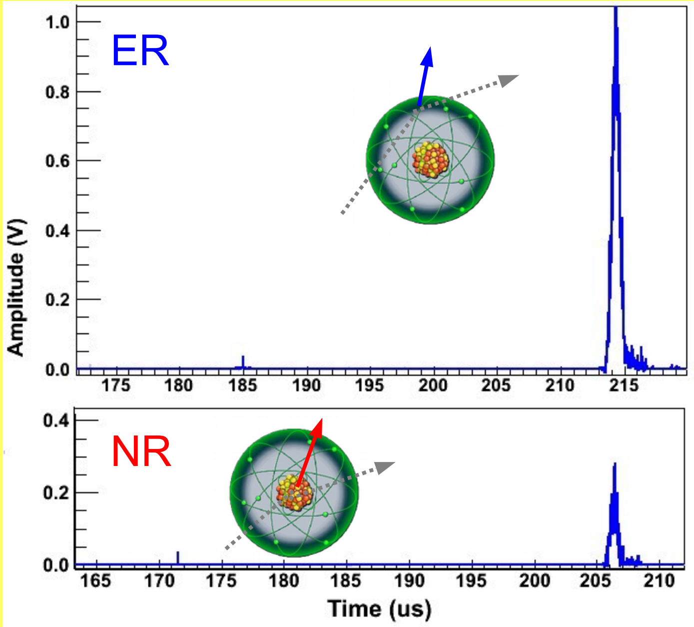
3d Vertex Reconstruction





Signal/Background Discrimination





The *XENON* program

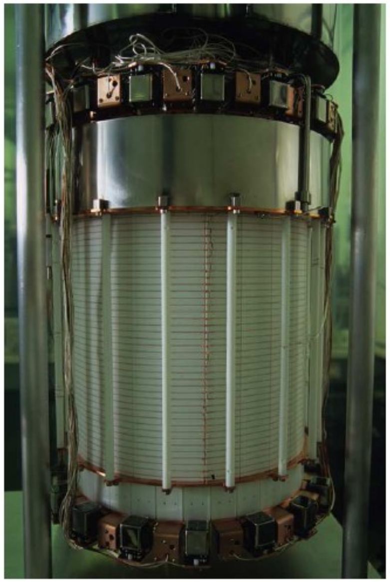
XENON10

2005-2007

25 kg

Achieved (2007)
$\sigma_{SI} = 8.8 \times 10^{-44}\ \mathrm{cm}^2$

XENON100

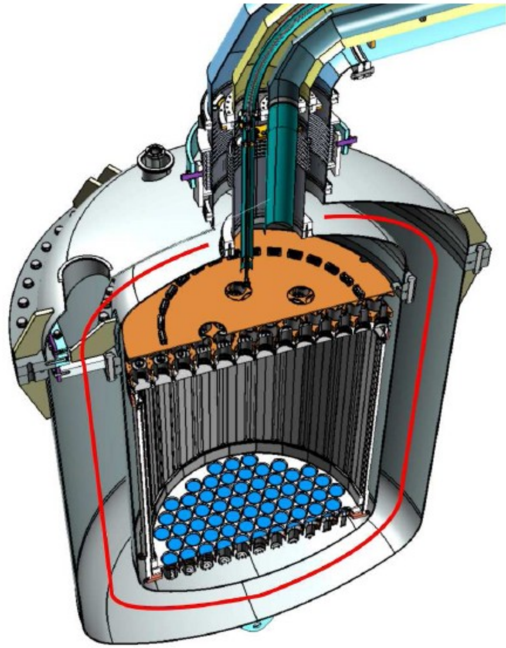


2008-2015

161 kg

Achieved (2011)
$\sigma_{SI} = 7.0 \times 10^{-45}\ \mathrm{cm}^2$
Achieved (2012)
$\sigma_{SI} = 2.0 \times 10^{-45}\ \mathrm{cm}^2$

XENON1T/XENONnT

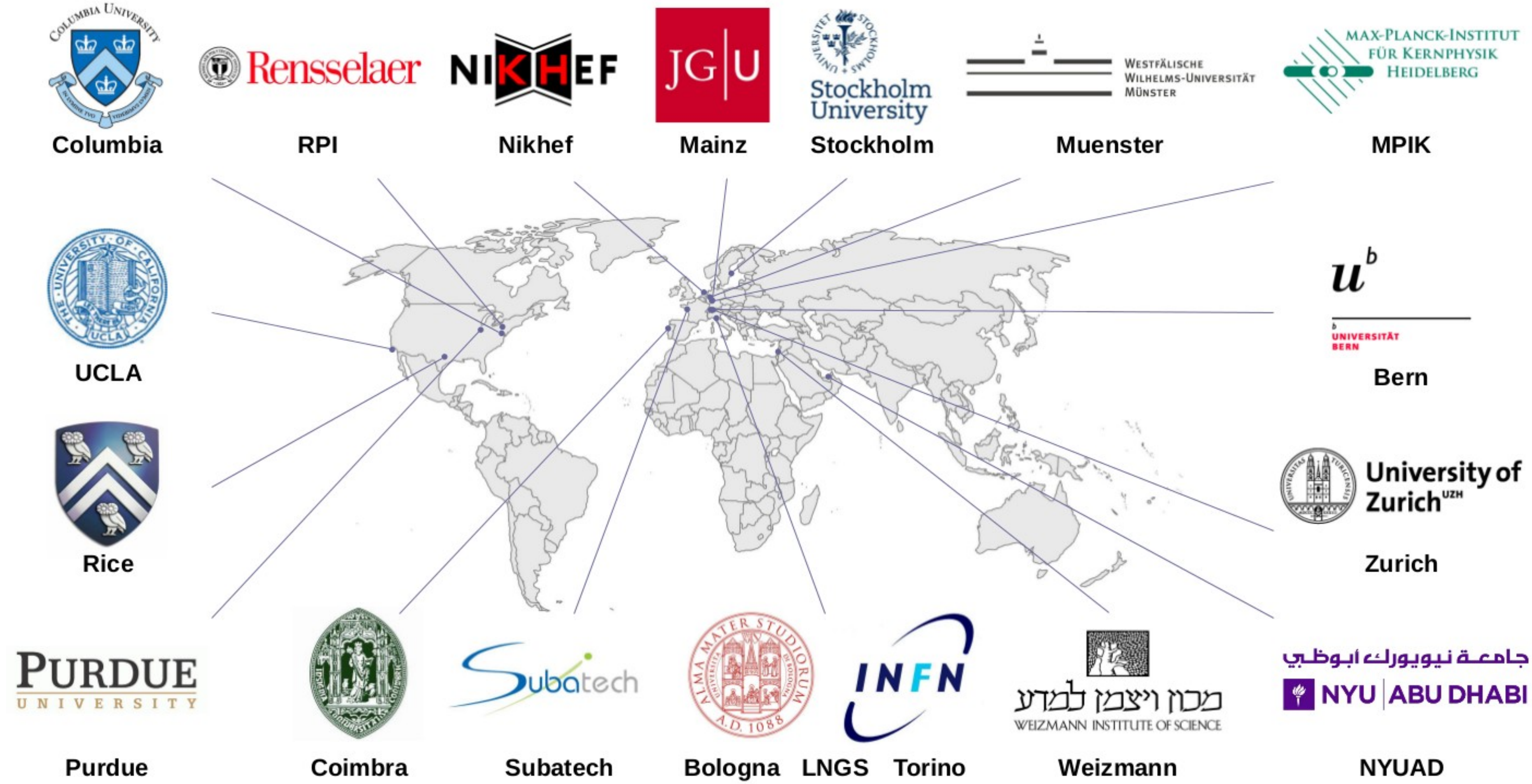


2012-2017 / ~2017-2022

3300 kg / 7000 kg

Projected (2017) / Projected (2022)
$\sigma_{SI} \sim 2 \times 10^{-47}\ \mathrm{cm}^2$ / $\sigma_{SI} \sim 3 \times 10^{-48}\ \mathrm{cm}^2$

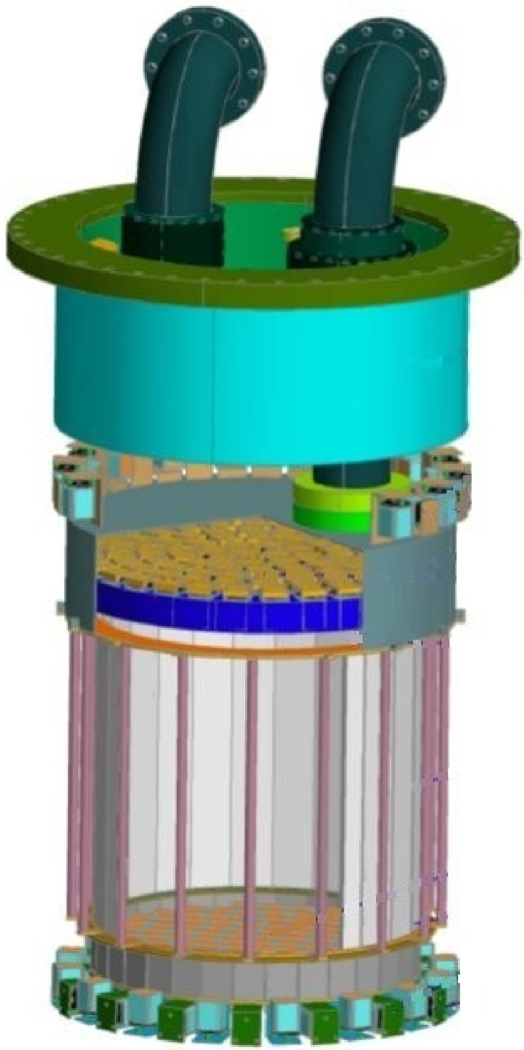
The *XENON* collaboration

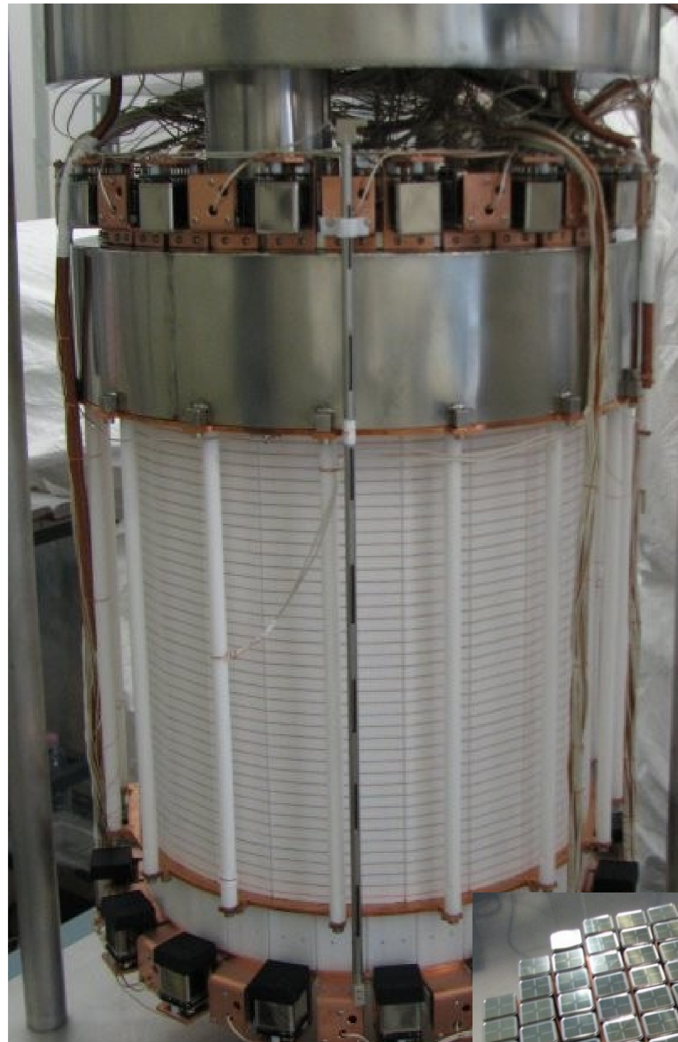


Today, about 100 scientists from 18 institutions

XENON100

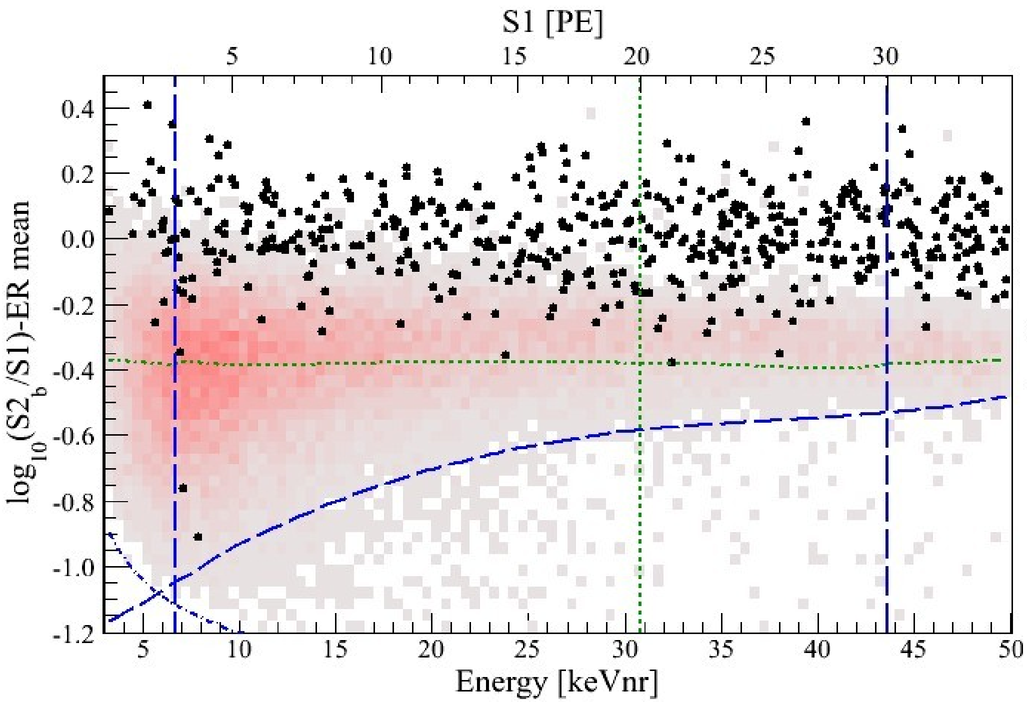
Astropart. Phys. 35, 573 (2012)

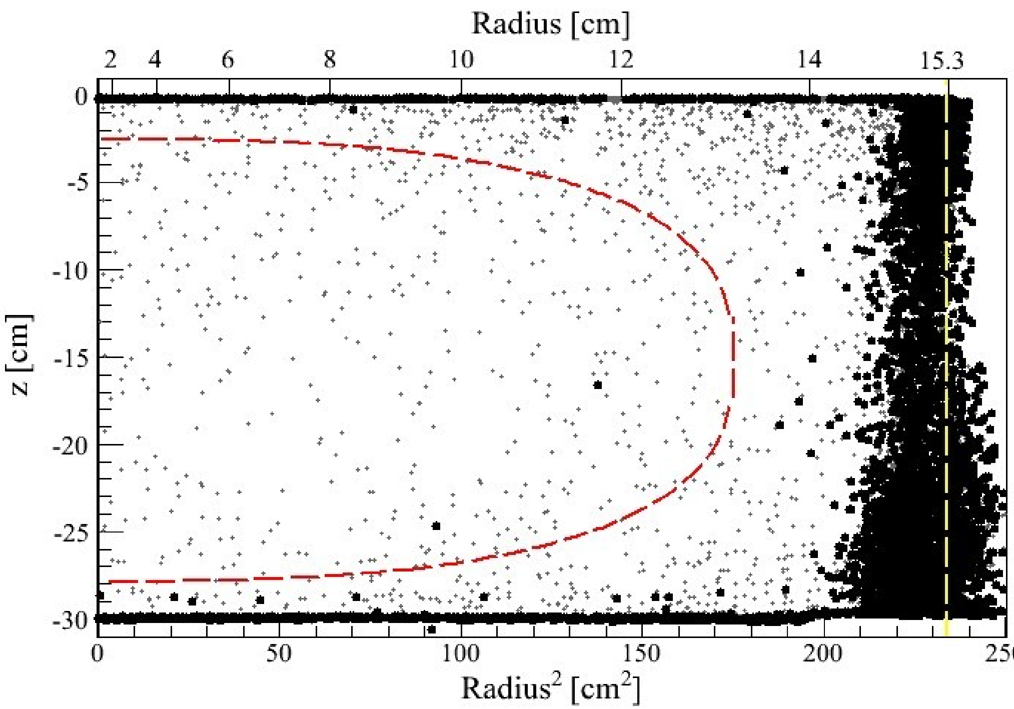




161 kg LXe, 62 kg in target
242 1" x1" PMTs

Unblinding of 225 live days





(1.0 $\pm$ 0.2) events expected

2 events observed

→ 26.4% probability that background fluctuated to 2 events

→ PL analysis cannot reject the background only hypothesis

No significant excess due to a signal seen in XENON100 data.

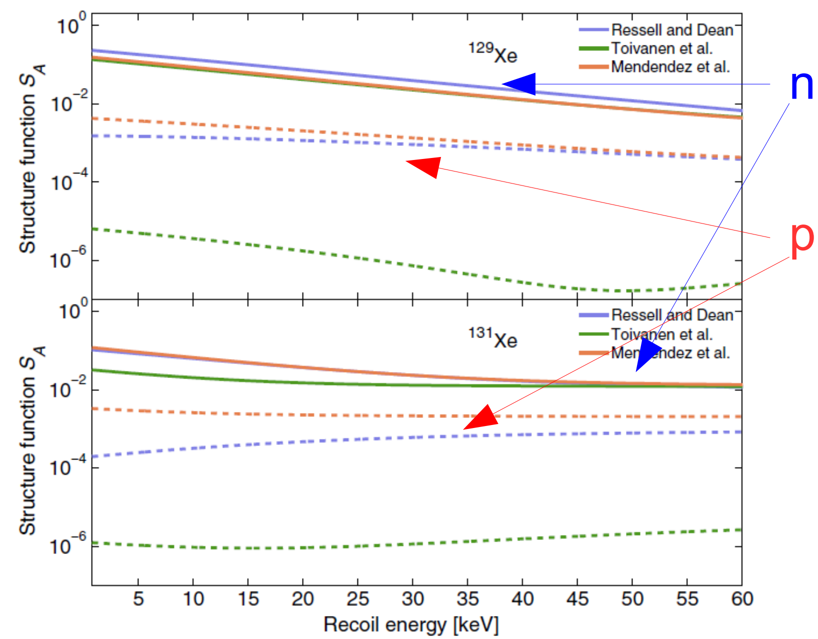
Alternative interpretation: Spin Dependent interaction

- Assume that the WIMP couples to the nuclear spin:

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

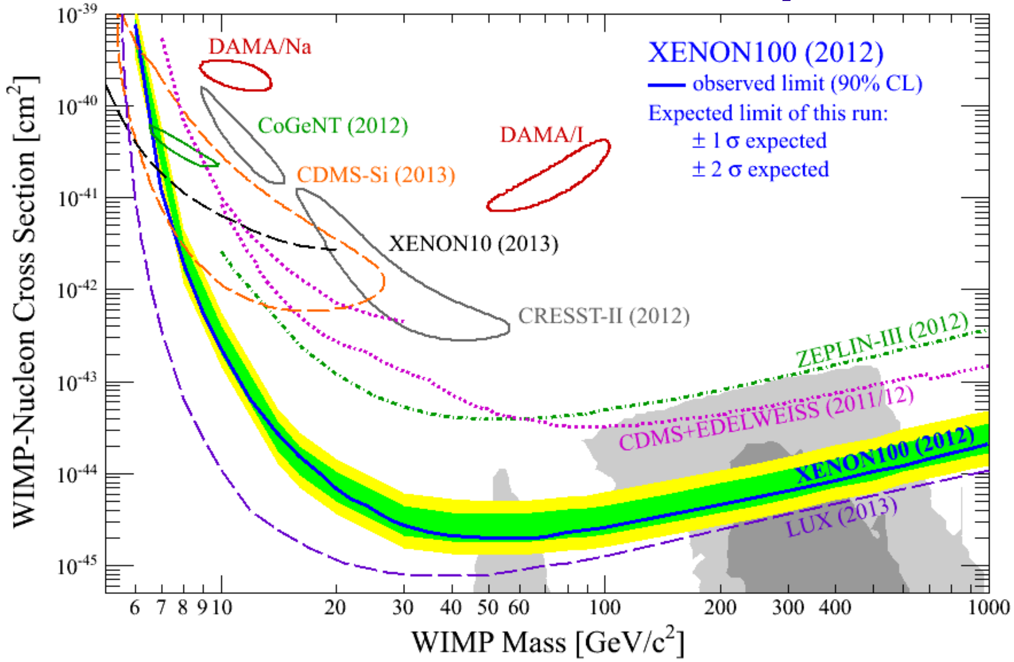
$$S_A(0) = \frac{(2J+1)(J+1)}{\pi J}\left[a_p\langle S_p\rangle + a_n\langle S_n\rangle\right]^2,$$

$$\sigma_{p,n}(q) = \frac{3}{4}\,\frac{\mu_{p,n}^2}{\mu_A^2}\,\frac{2J+1}{\pi}\,\frac{\sigma_{\mathrm{SD}}(q)}{S_A^{a_0=\pm a_1}(q)},$$



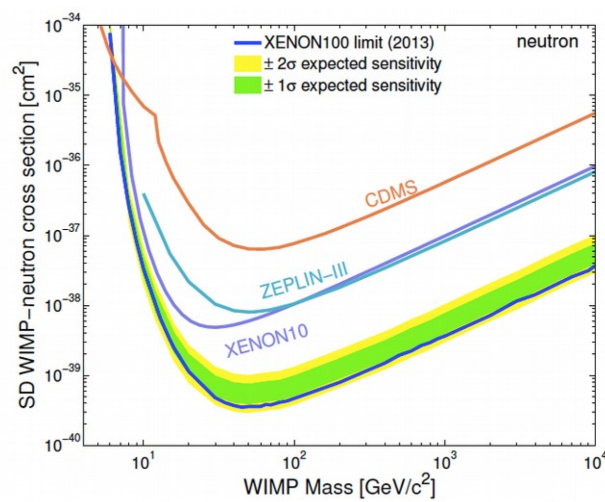
Russel and Dean 1997
Toivanen et. Al 2009
Menendez, Gazit, and Schwenk 2012
PRL 111, 021301 (2013, XENON100)

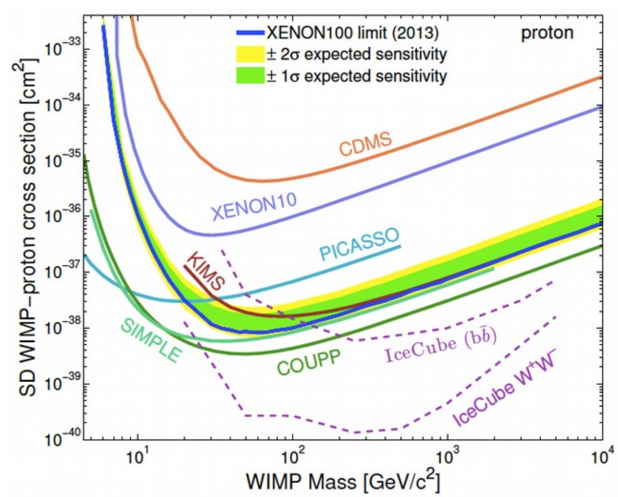
Results of direct detection – today's frontier



Spin independent

PRL 109, 18, 181301 (2012)





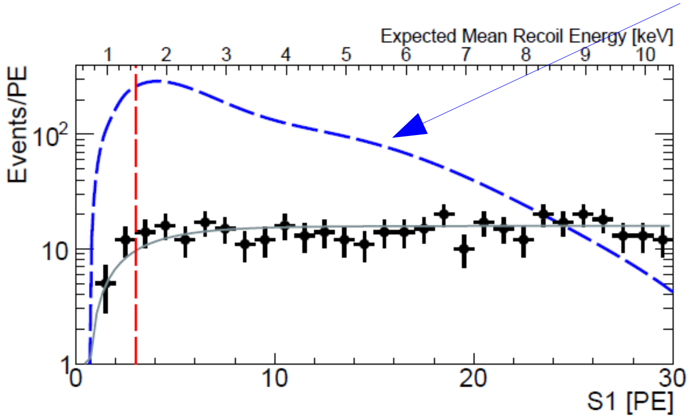
Spin dependent

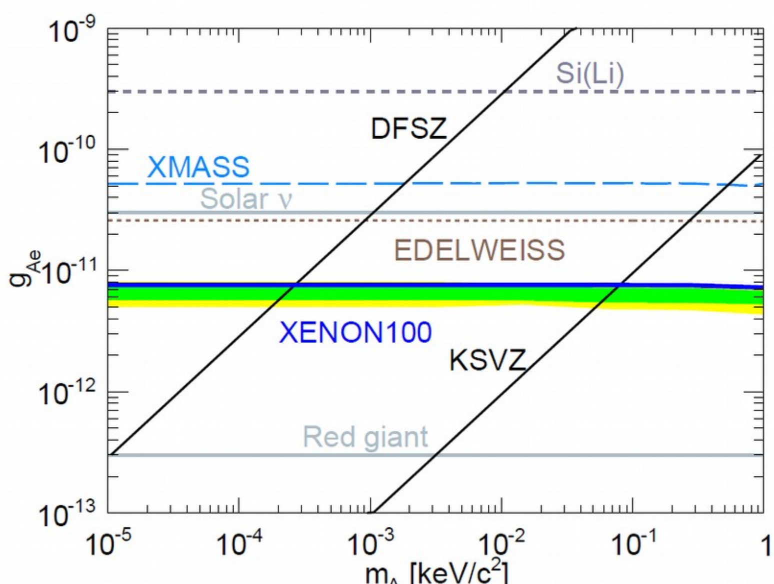
PRL 111, 021301 (2013)

Alternative interpretation: Putting constraints on axions

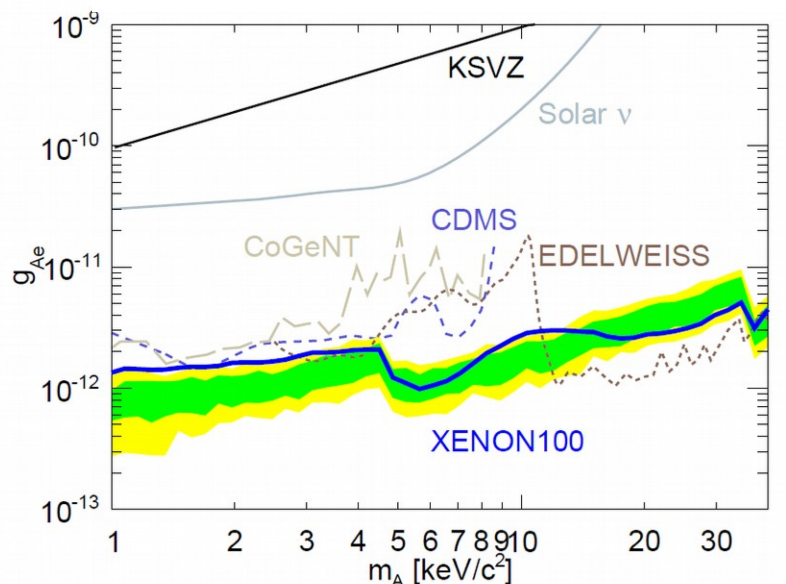
- Look for axion-electron interaction:

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





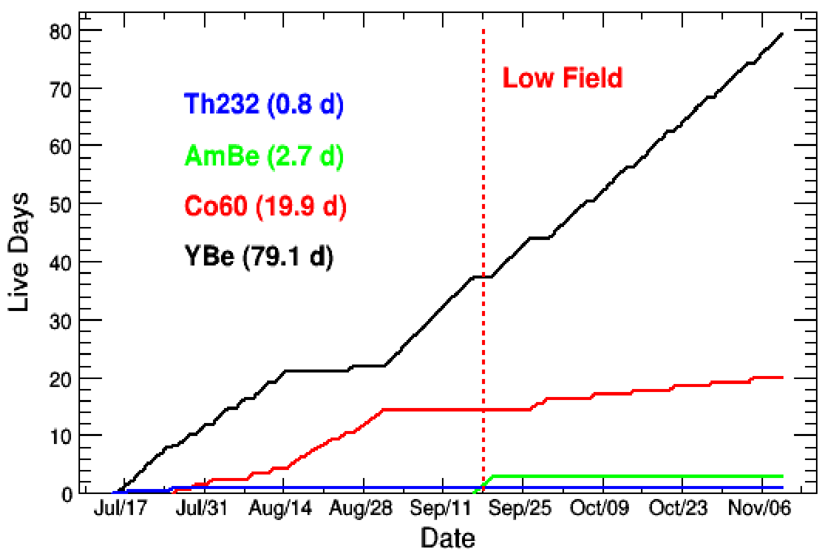
Solar axions



Galactic axions and ALPs

PRD 90, 6 , 62009 (2014)

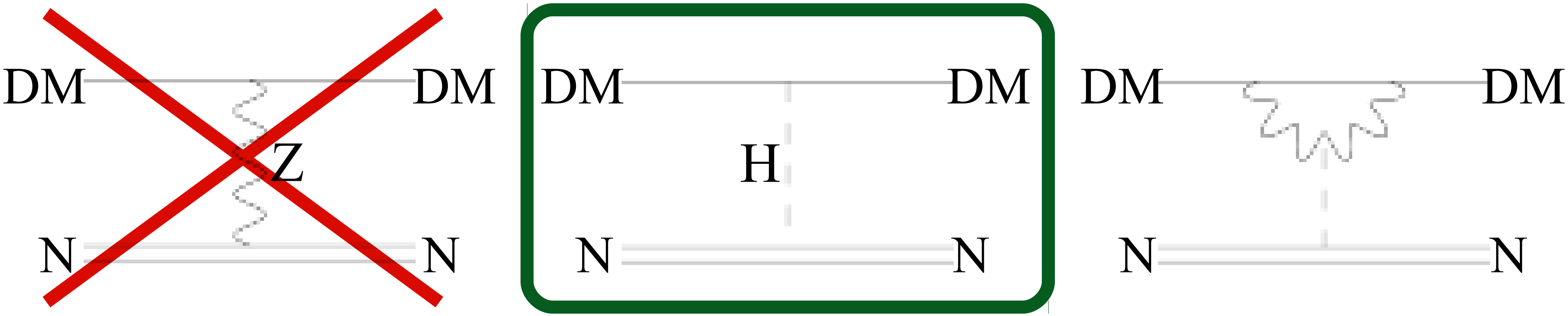
XENON100 still has an interesting future



<u>More to come soon:</u>

- Inelastic scattering off ^{129}Xe
- Annual modulation of e-recoil
- DAMA inspired models
- Low mass WIMPS with S2-only
- YBe for low mass sensitivity
- Extra 70% with new data acquired

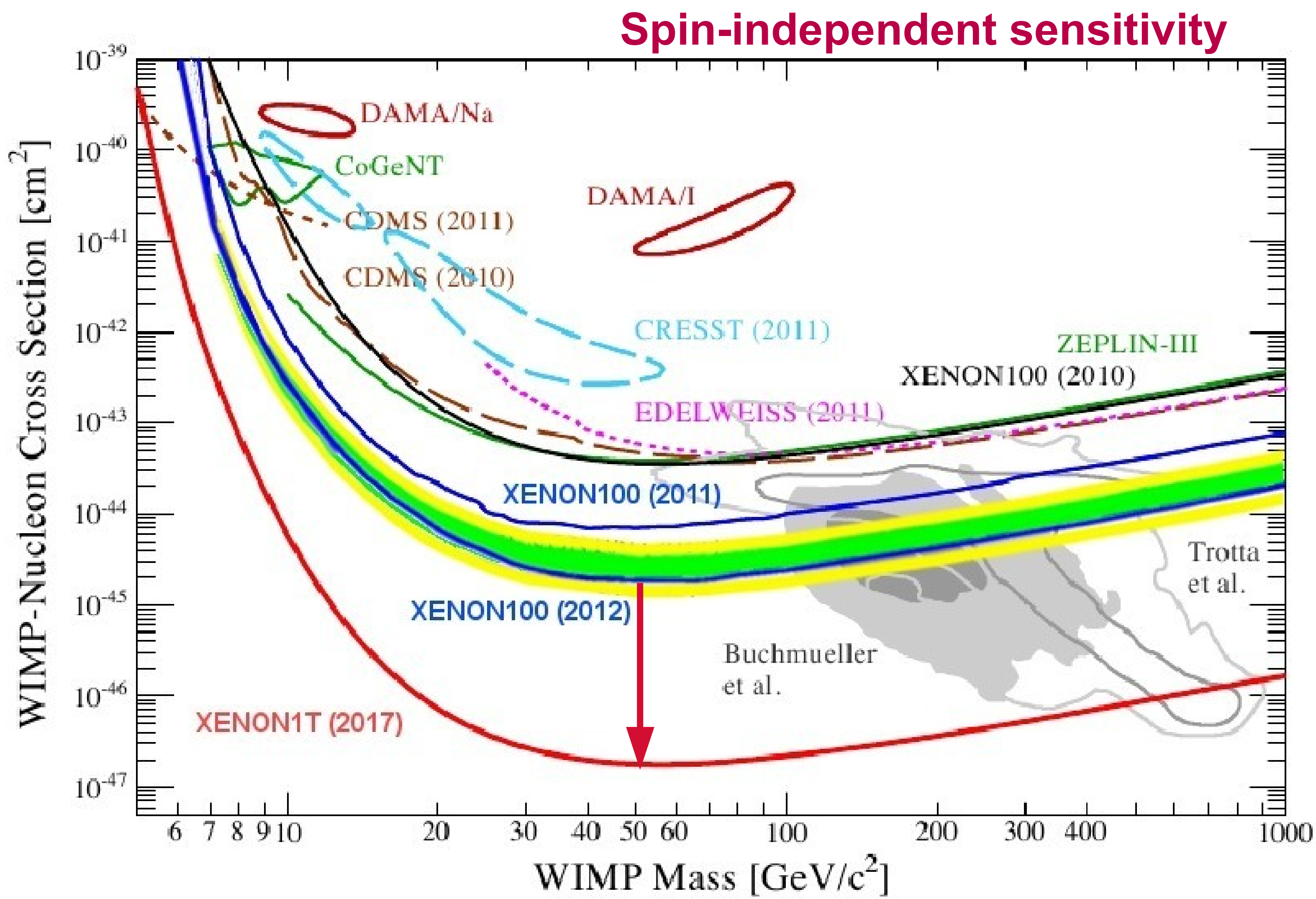
What Are We Probing?



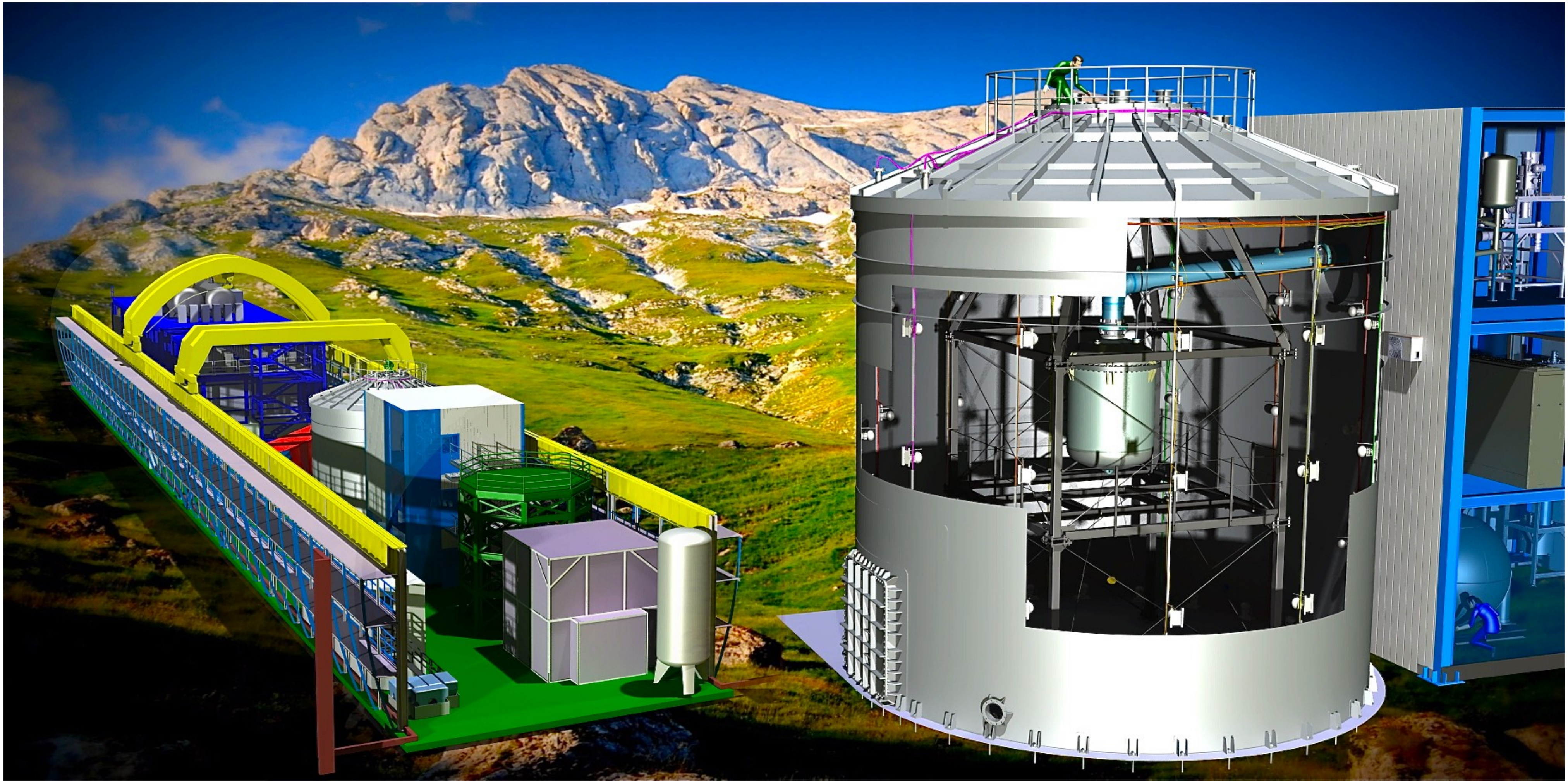
$\sigma_{\chi N} \sim 10^{-39}\ \mathrm{cm}^2$ $\sigma_{\chi N} \sim 10^{-44-46}\ \mathrm{cm}^2$ $\sigma_{\chi N} \sim 10^{-46-48}\ \mathrm{cm}^2$

Current Sensitivity

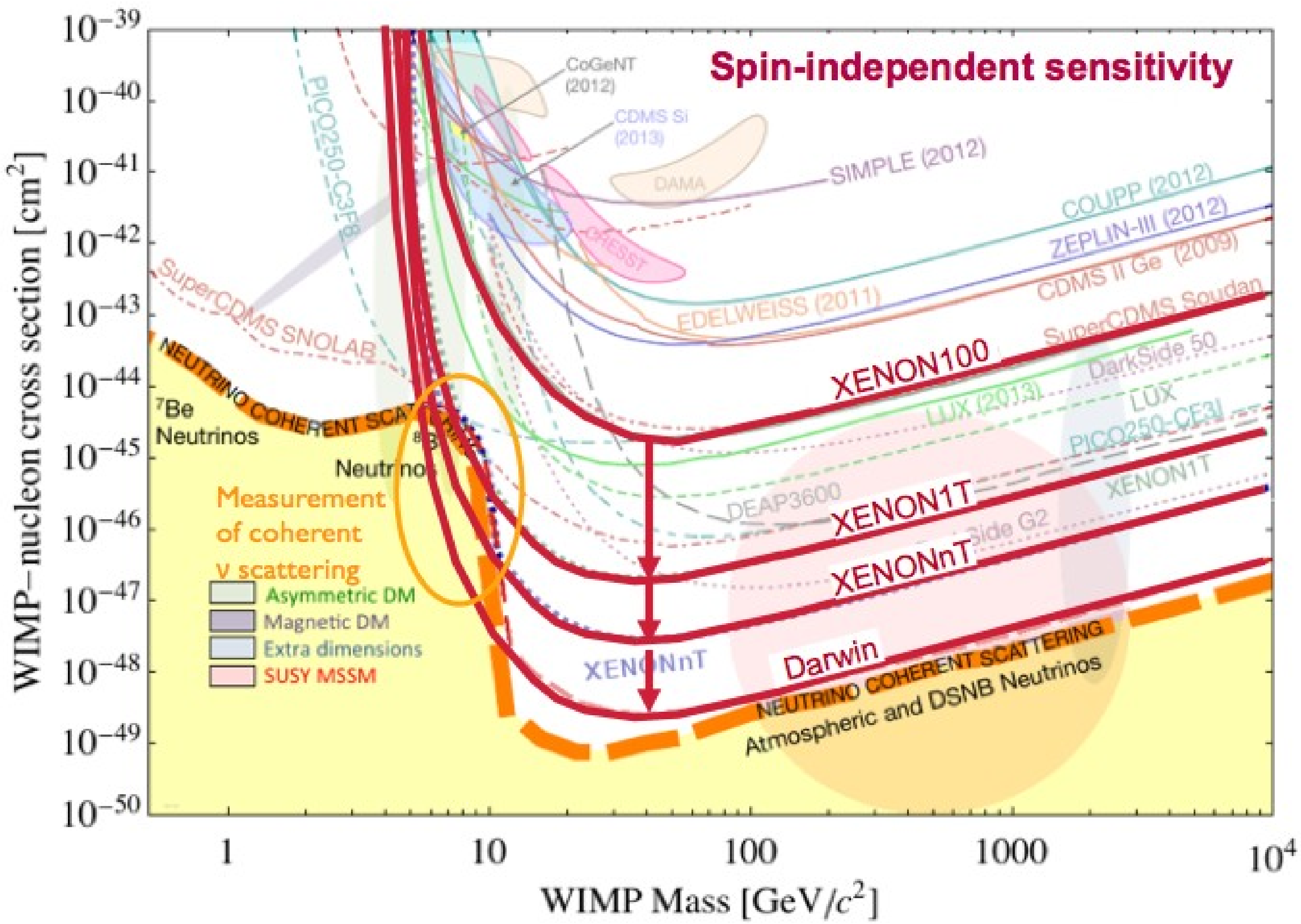
The Future of Direct Dark Matter Searches
(next ~5 years, the XENON perspective...)



XENON1T



Longer into the future: reaching the neutrino limit



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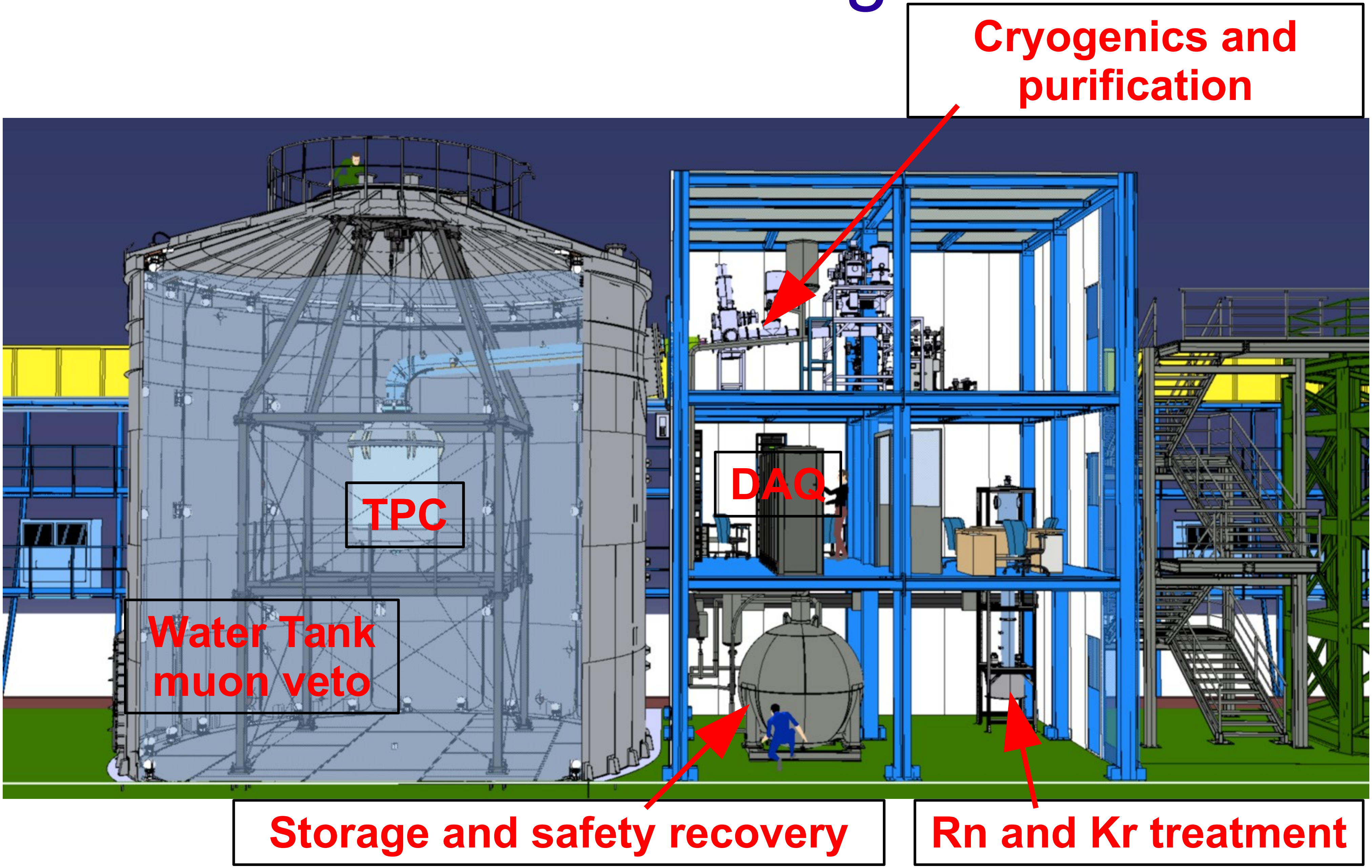
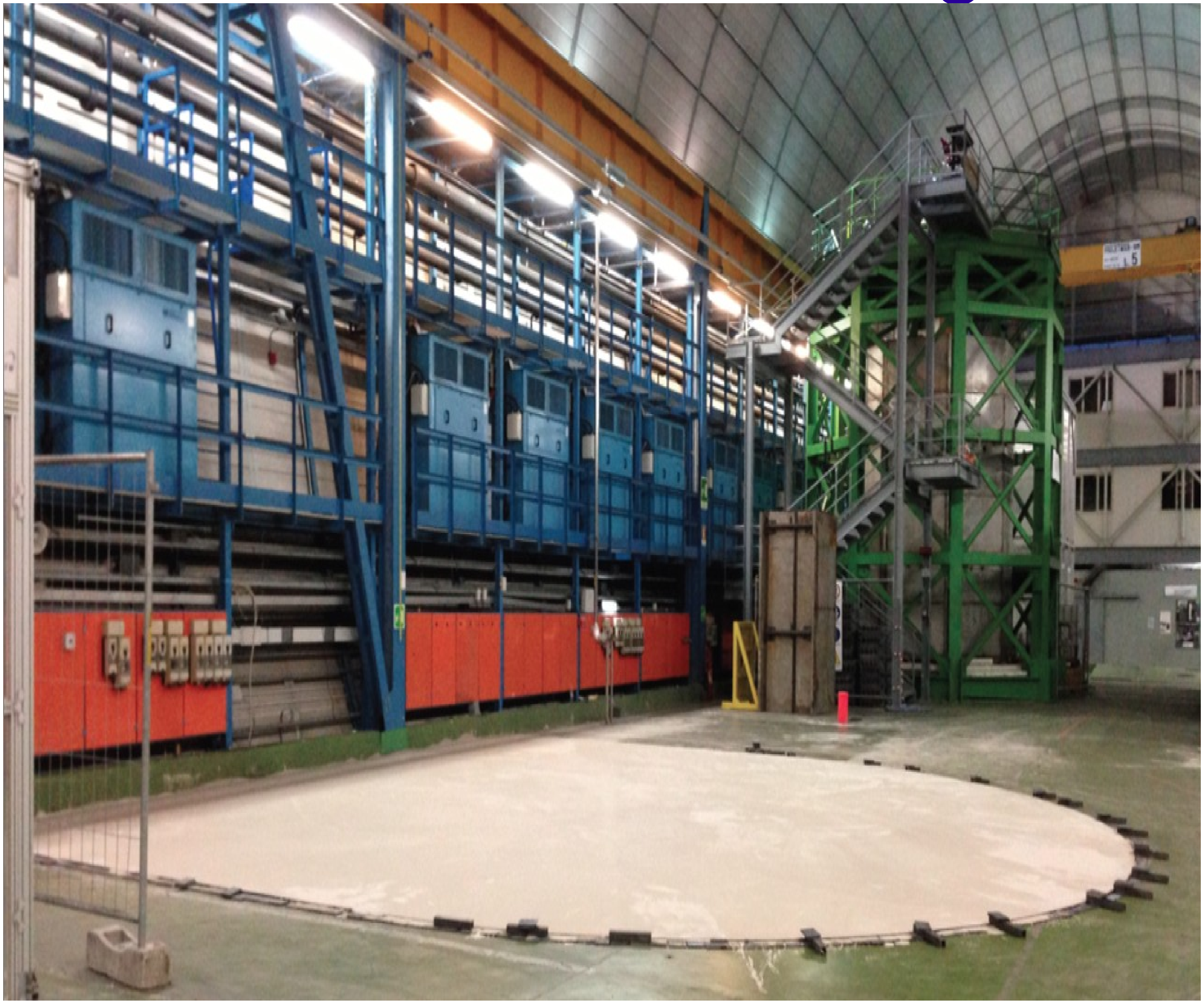
XENON1T at a glance



XENON1T commissioning

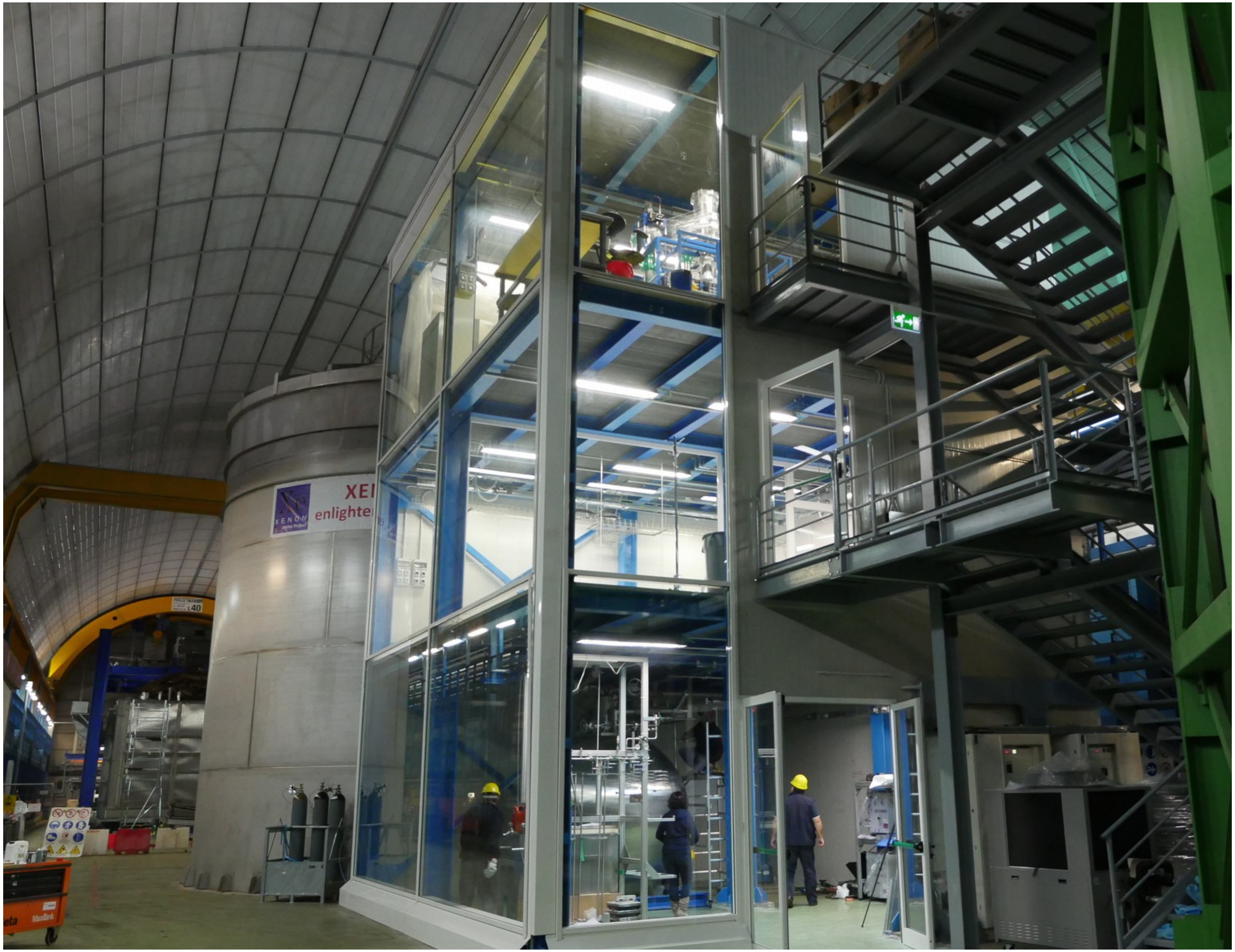


Jul.
2013

XENON1T commissioning

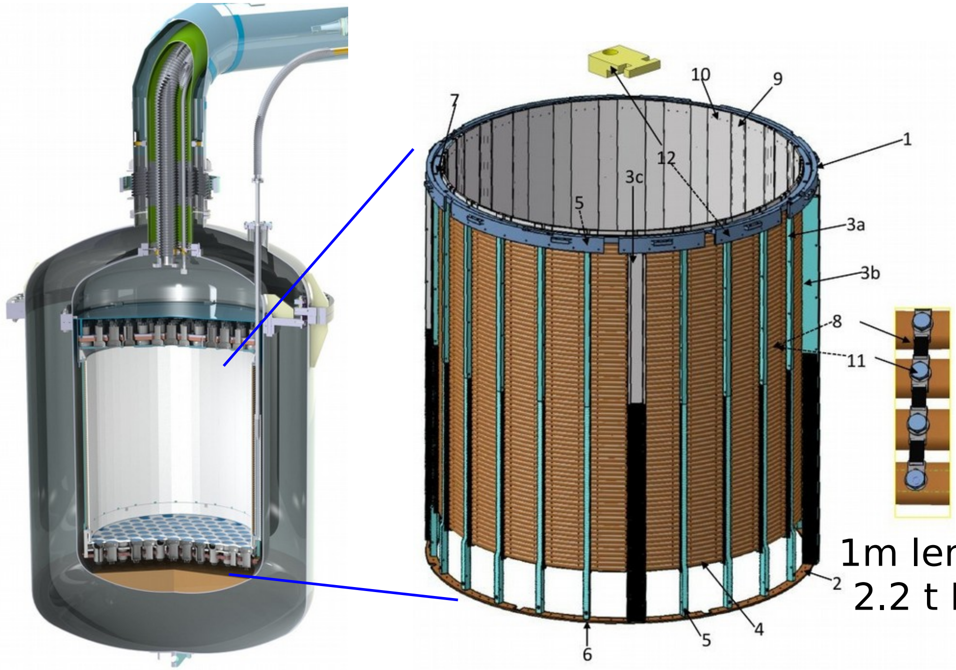
Feb. 2014

XENON1T commissioning

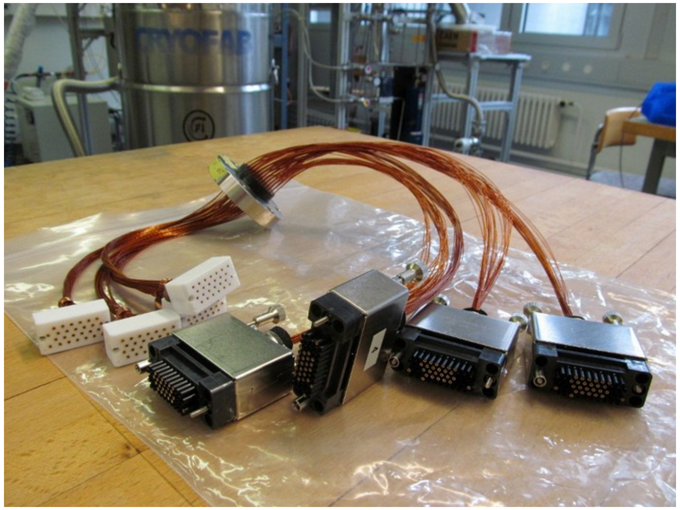


Oct.
2014

XENON1T at a glance



1m length, 1m diameter
2.2 t LXe instrumented



248 required for the TPC – Hamamatsu R11410-21
Average QE 34%

TPC, PMTs and cables

XENON1T at a glance

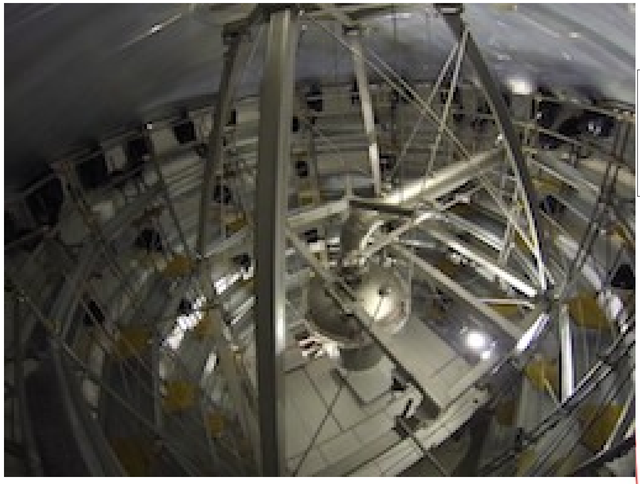
Cooling, purifying and storing up to 7t of Xe for years!

Cryogenics, purification and ReStoX

XENON1T at a glance

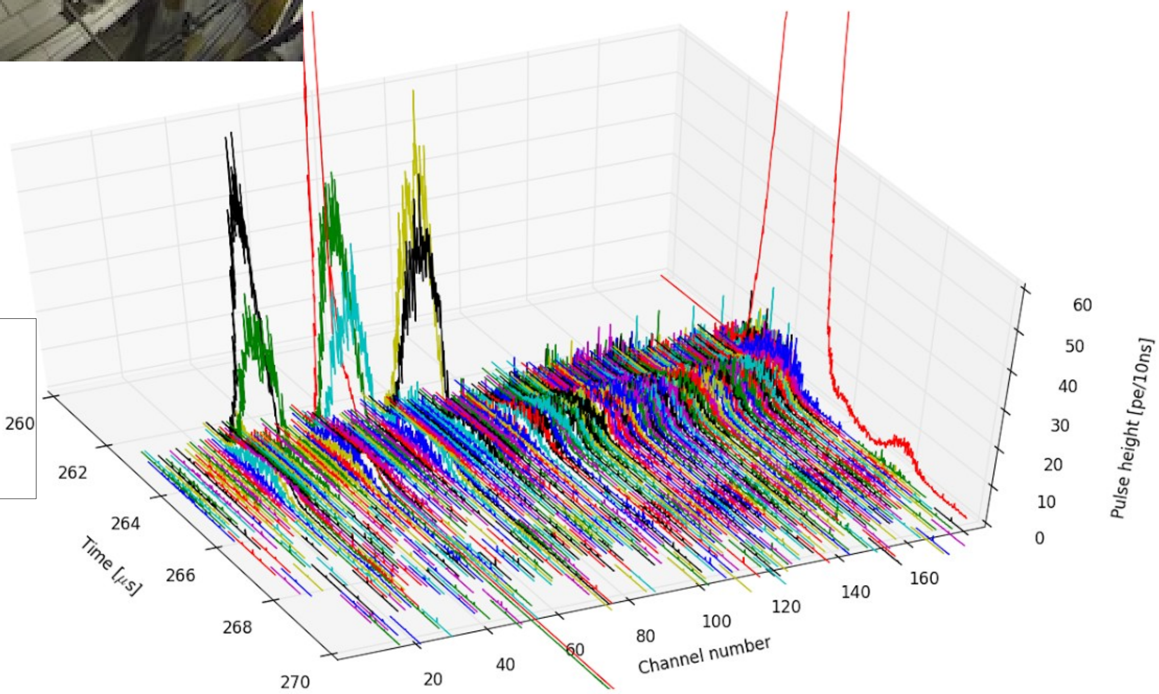
Cryostat and support

XENON1T at a glance



Installed PMTs, mounts and reflector for muon water-Cerenkov veto system

JINST 9, 11 (2014)



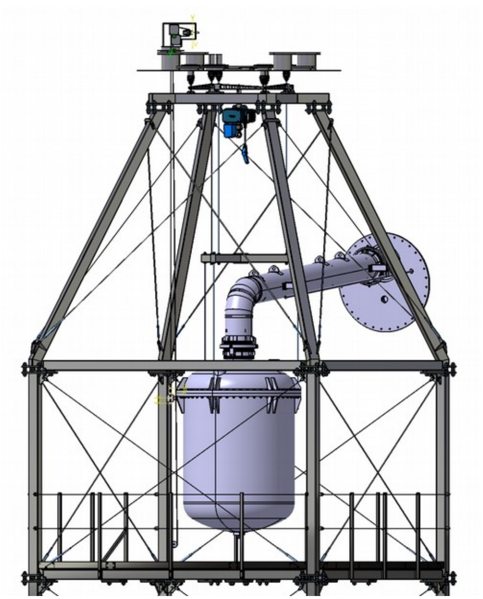
Software and hardware to handle DAQ at 1100 MHz of all channels continuously

DAQ, Muon Veto

XENON1T at a glance

Offline removal of Kr to <ppt
^{85}Kr - an irreducible backd

Tested on *XENON100* for optional online Rn removal, working "in reverse"



Calibration:
External sources (ER, NR, e-lifetime)
Dissolved sources (ER, e-lifetime)
PMT calibration

Distillation of Kr and Rn, calibration strategy

XENON1T: MC and backgrounds

Gamma background:
Single scatter, 1 ton fiducial volume, [2-12] keVee, 99.75% S2/S1 discrimination.

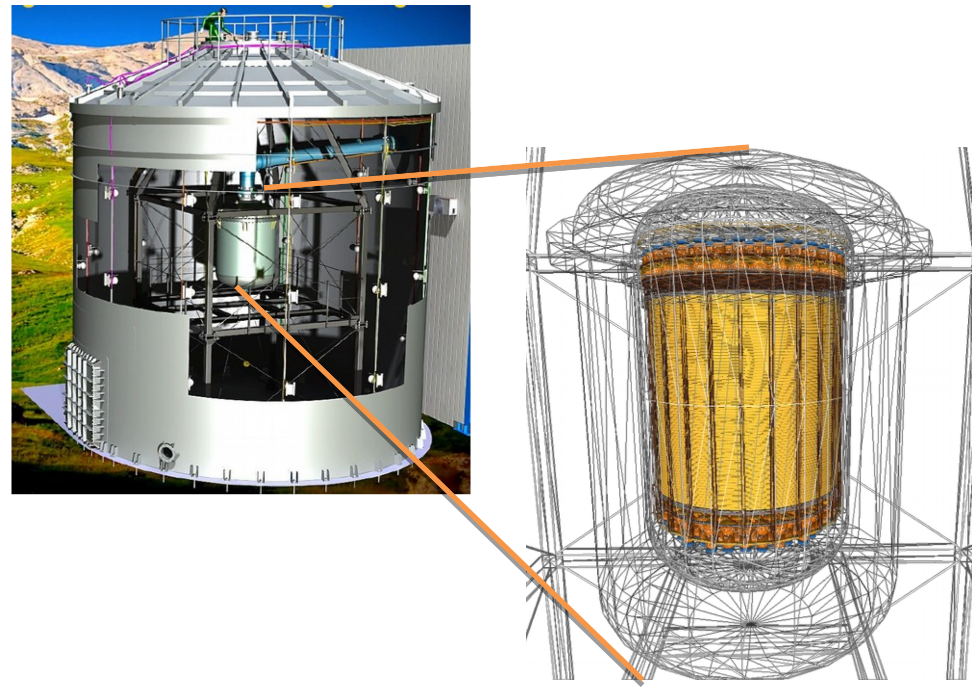
0.05 ev/y

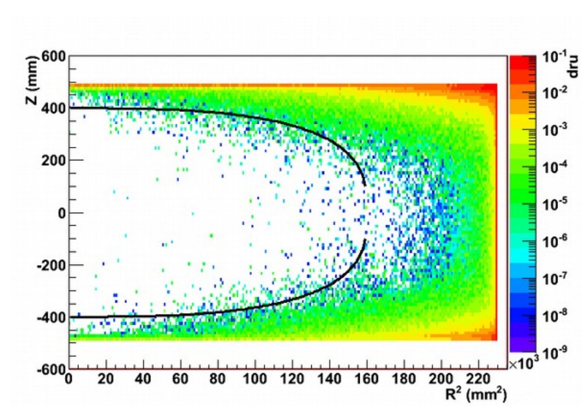
Mainly from the Cryostat (50%), PMTs (30%) and TPC components (< 10%)

Neutron background:
Single scatter, 1 ton fiducial volume, [5-50] keVr, 50% NR acceptance

0.2 ev/y

Mainly from Cryostat (30%), PMT+Bases (30%) and PTFE (20%).



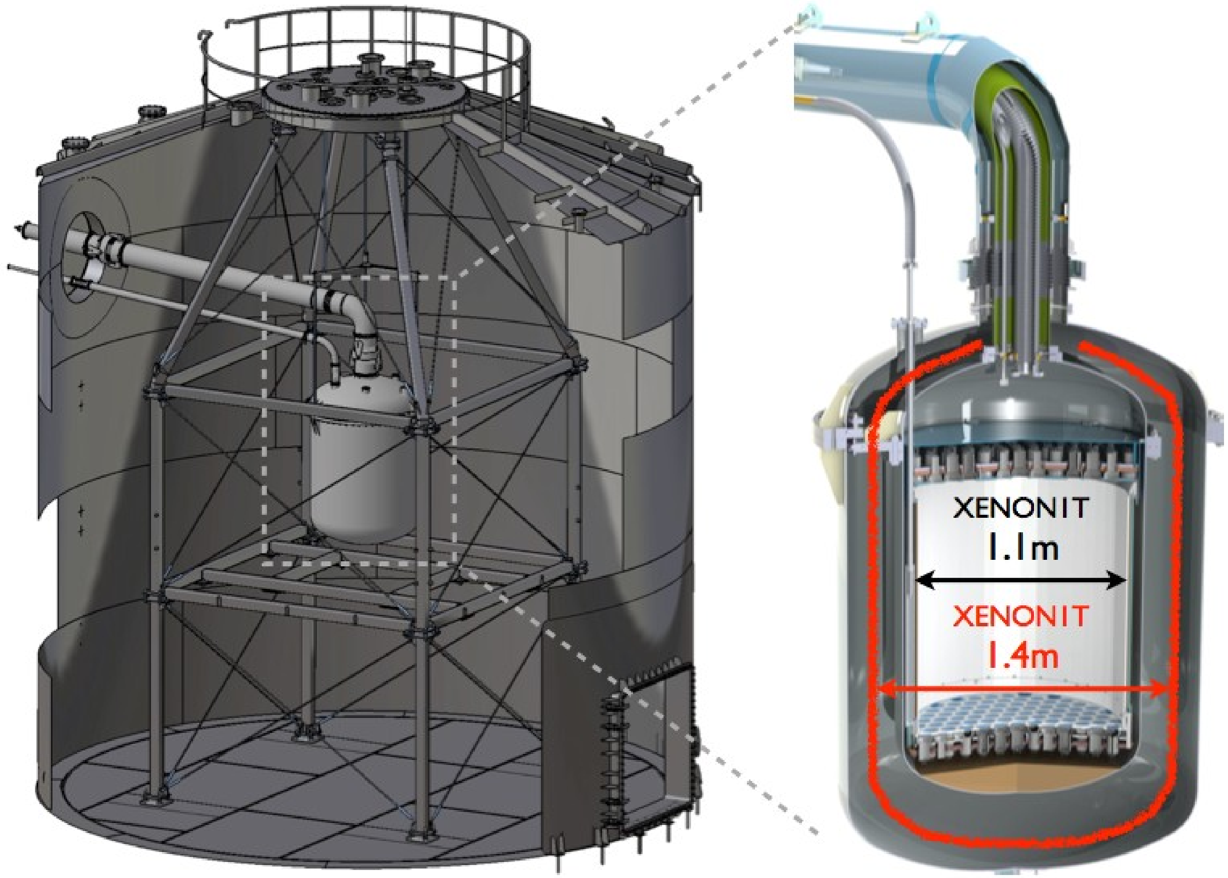


Xe XENON Dark Matter Project

XENON1T: Current status

- Service building, Water tank, cryostat, supports and connections **done**
- LXe handling almost completed, **tests started**. Will reach full scale by spring
- TPC will start assembly at LNGS in the spring
- First test runs expected in the summer
- **First science run should start within 2015!**

Upgrade to *XENONnT*: ~7t total mass



Only requires change in:

1. Inner cryostat
2. TPC
3. Adding 3t of Xe
4. Adding PMTs
5. Adding DAQ channels

Expected in 2017-2018

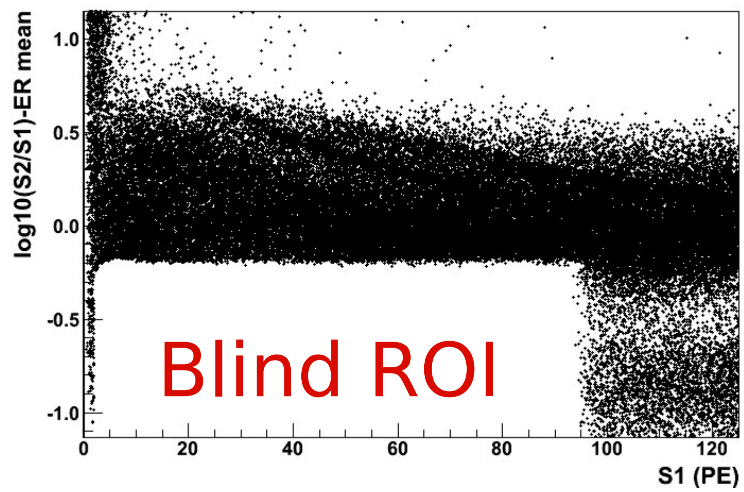
Summary

- *XENON100* has reached limit in the WIMP-nucleon cross section of **$2.0 \times 10^{-45} cm^2$** for a 50GeV WIMP
- Next on the agenda for *XENON100*:
  - Extra ~X2 with new data combination
  - More analyses of the data, e.g. Annual modulation, e^- recoil, Light WIMP, Sub-GeV DM ...
  - Testing new technologies for *XENON1T*
- We are commissioning *XENON1T* to reach a sensitivity of **$\sim 2 \times 10^{-47}$** cm^2 by 2017-2018
- Ongoing efforts keep improving our understanding of Xe detector physics, for better DM detection

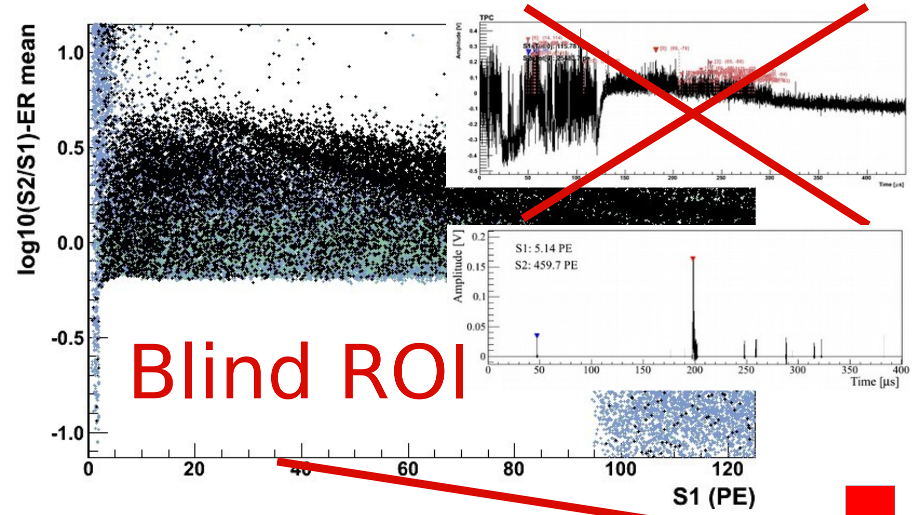
Extras

Analysis Sequence

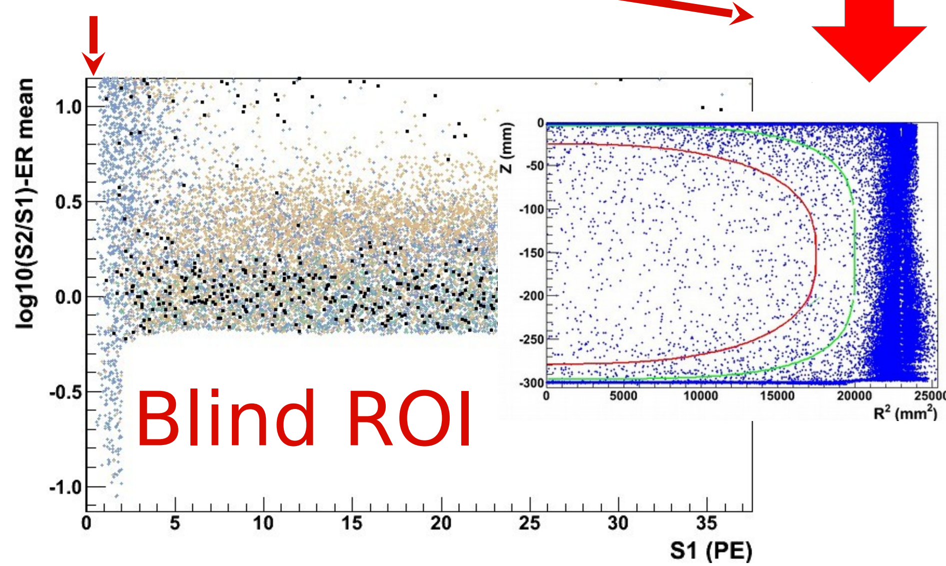
1) Start from all non-blind data



2) Basic quality and single scatter cuts



3) Energy threshold and FV cuts



4) Consistency cuts