Recent results in direct dark matter search with the XENON program

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on behalf of the XENON Collaboration

Rencontres de Moriond
EW Interactions and Unified Theories
March 2nd - 9th, 2013

מכון ויצמן למדע
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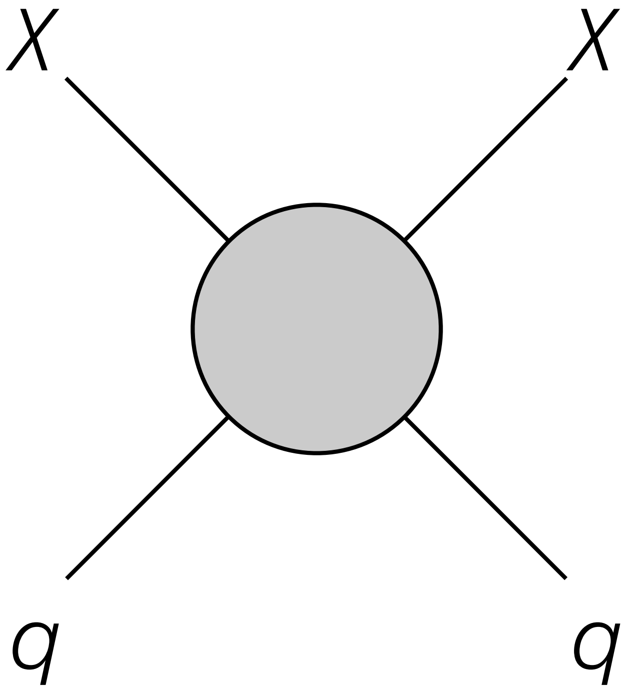
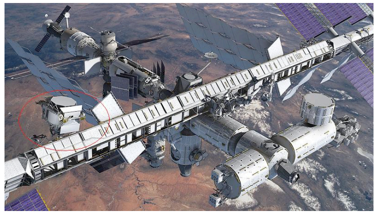
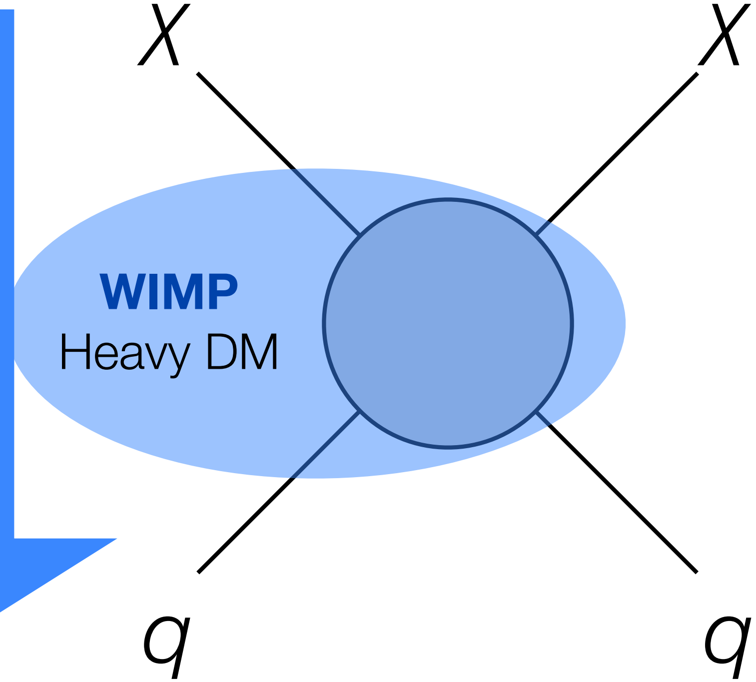
Testing the WIMP hypothesis



Testing the WIMP hypothesis

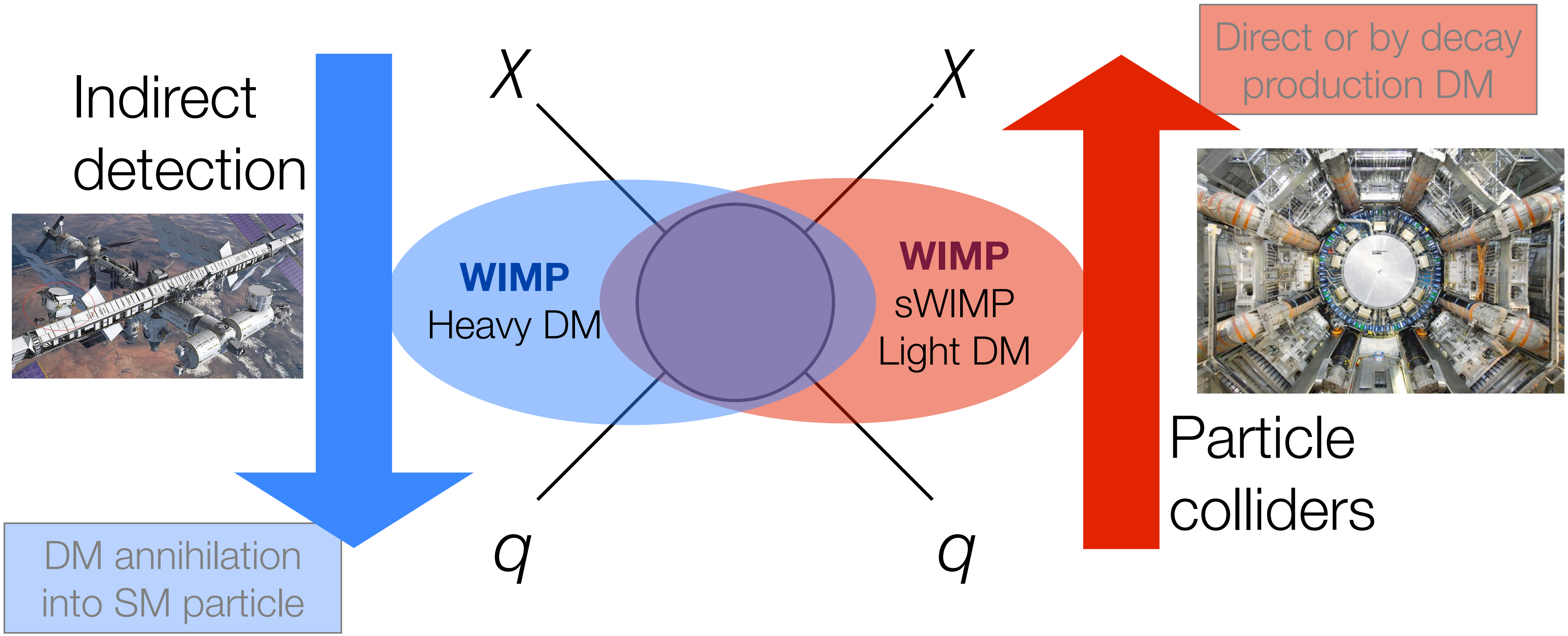
Indirect detection





DM annihilation into SM particle

Testing the WIMP hypothesis



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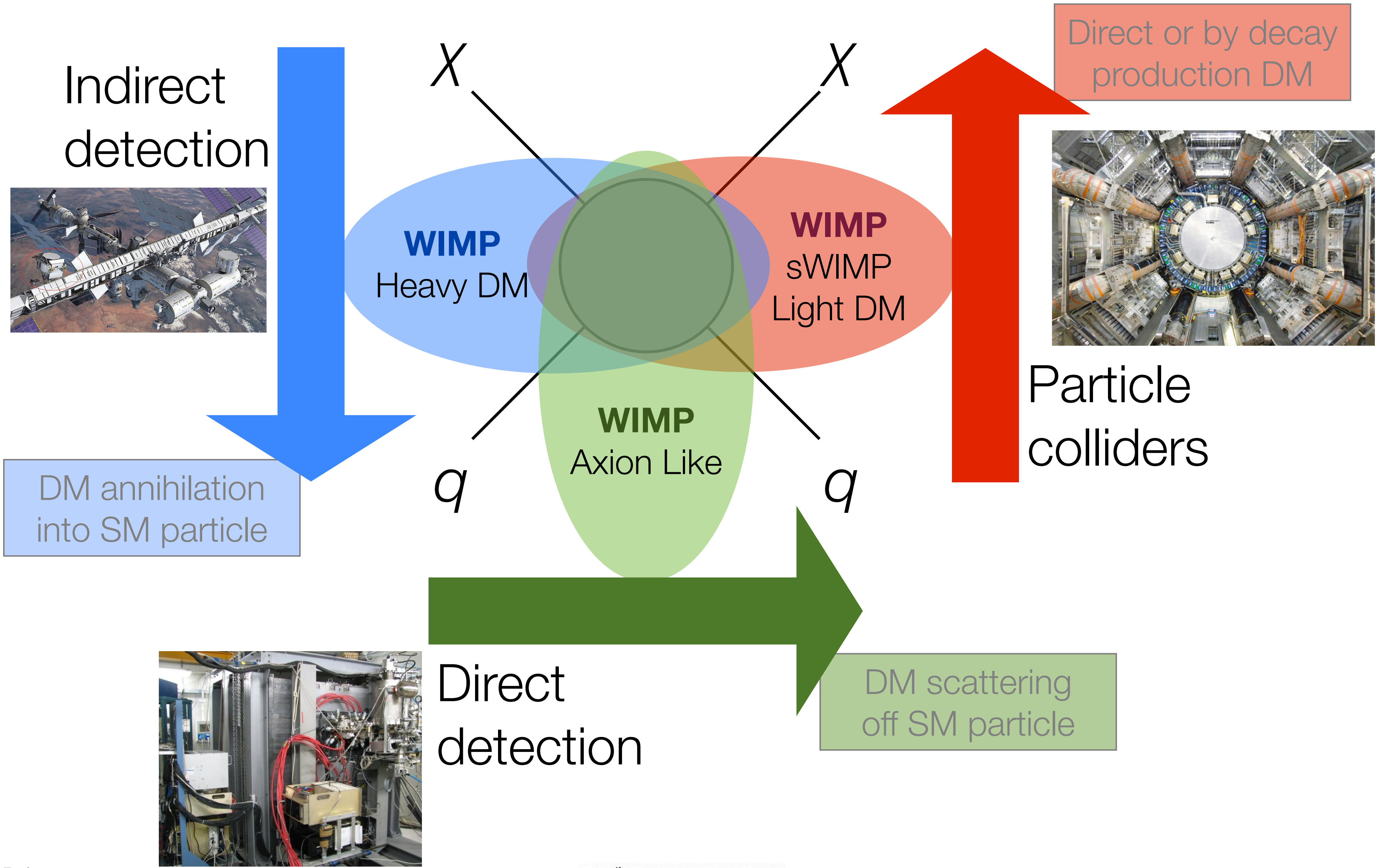

Xenon as detection medium

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

DRU = evts/keV/kg/day

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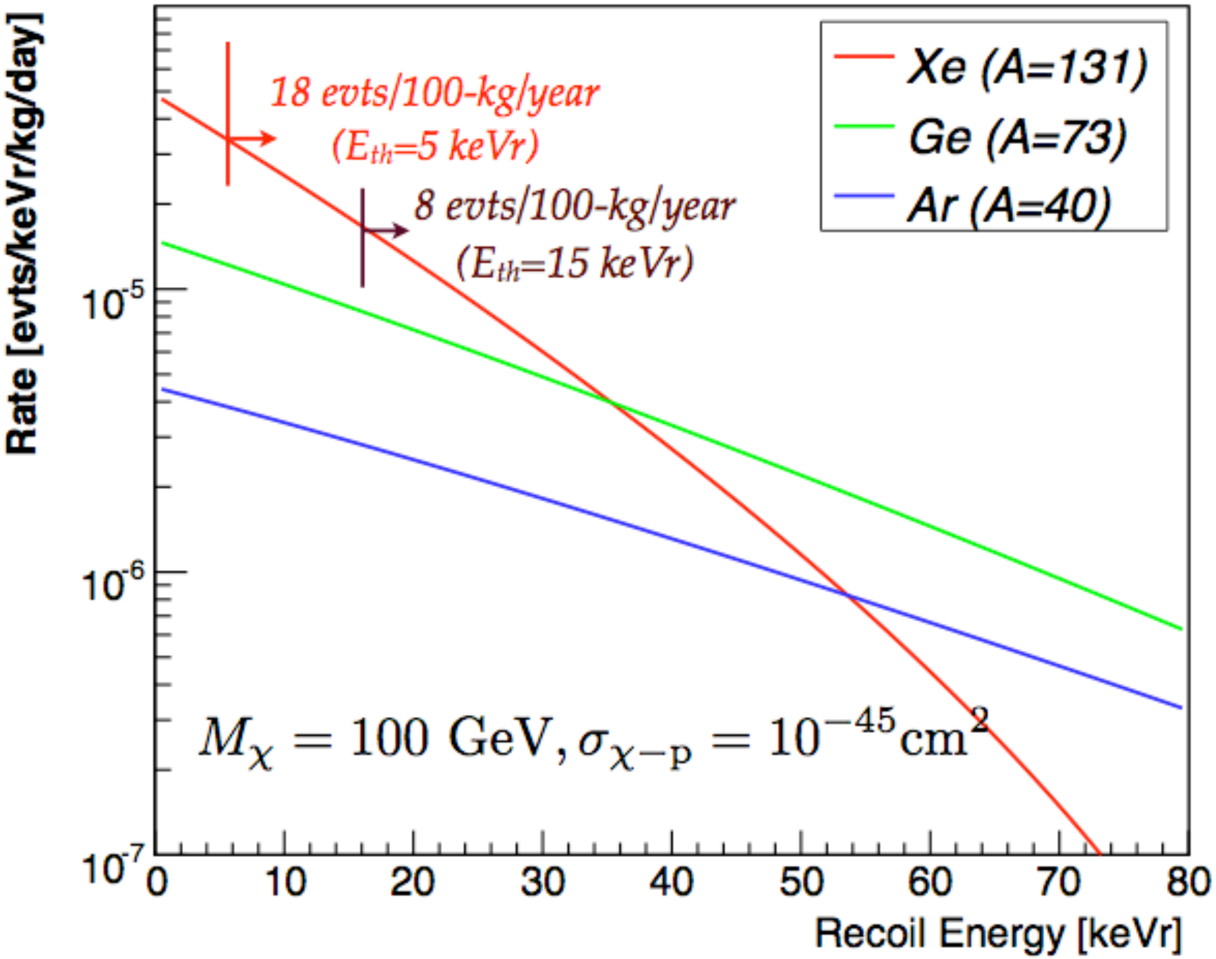

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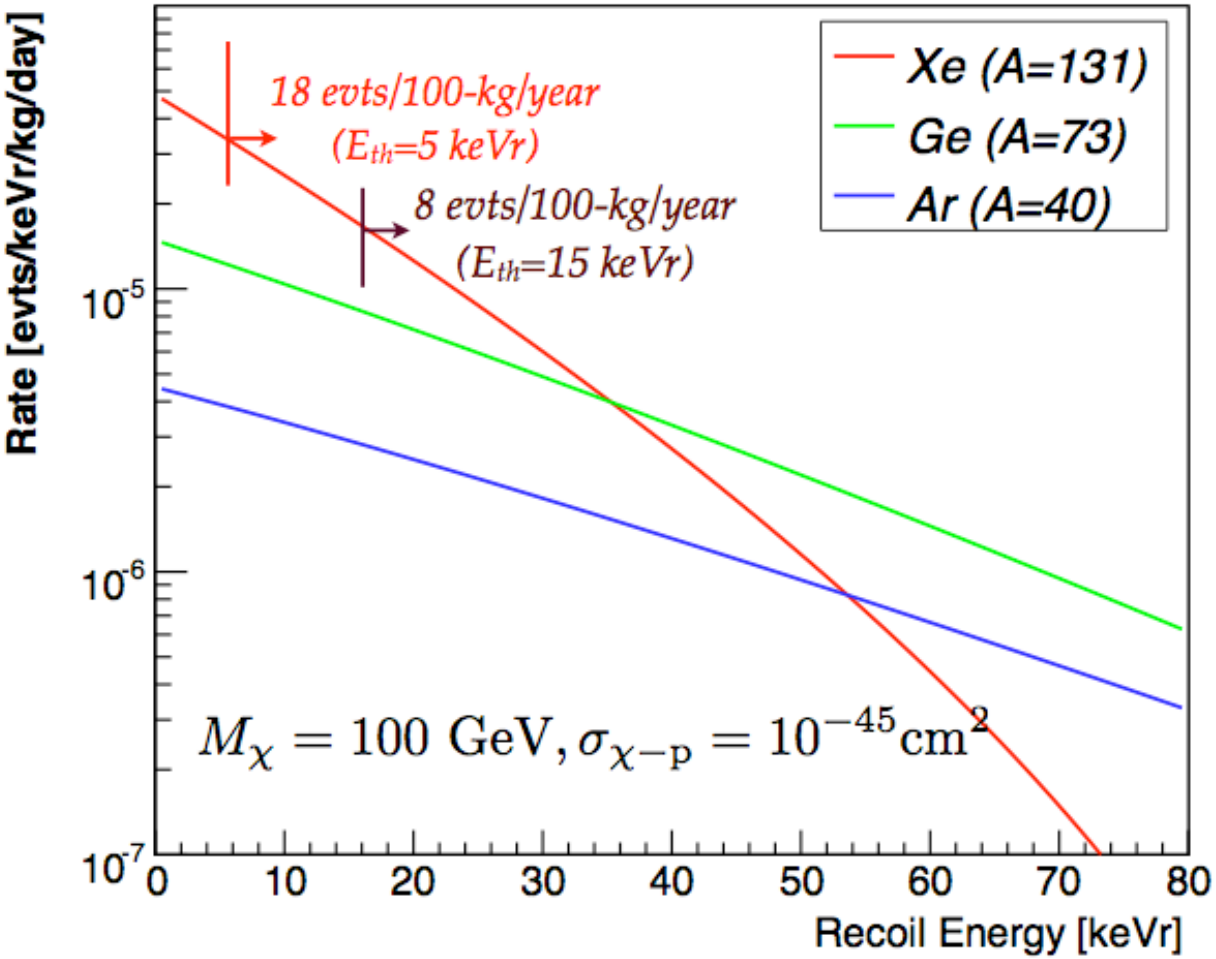
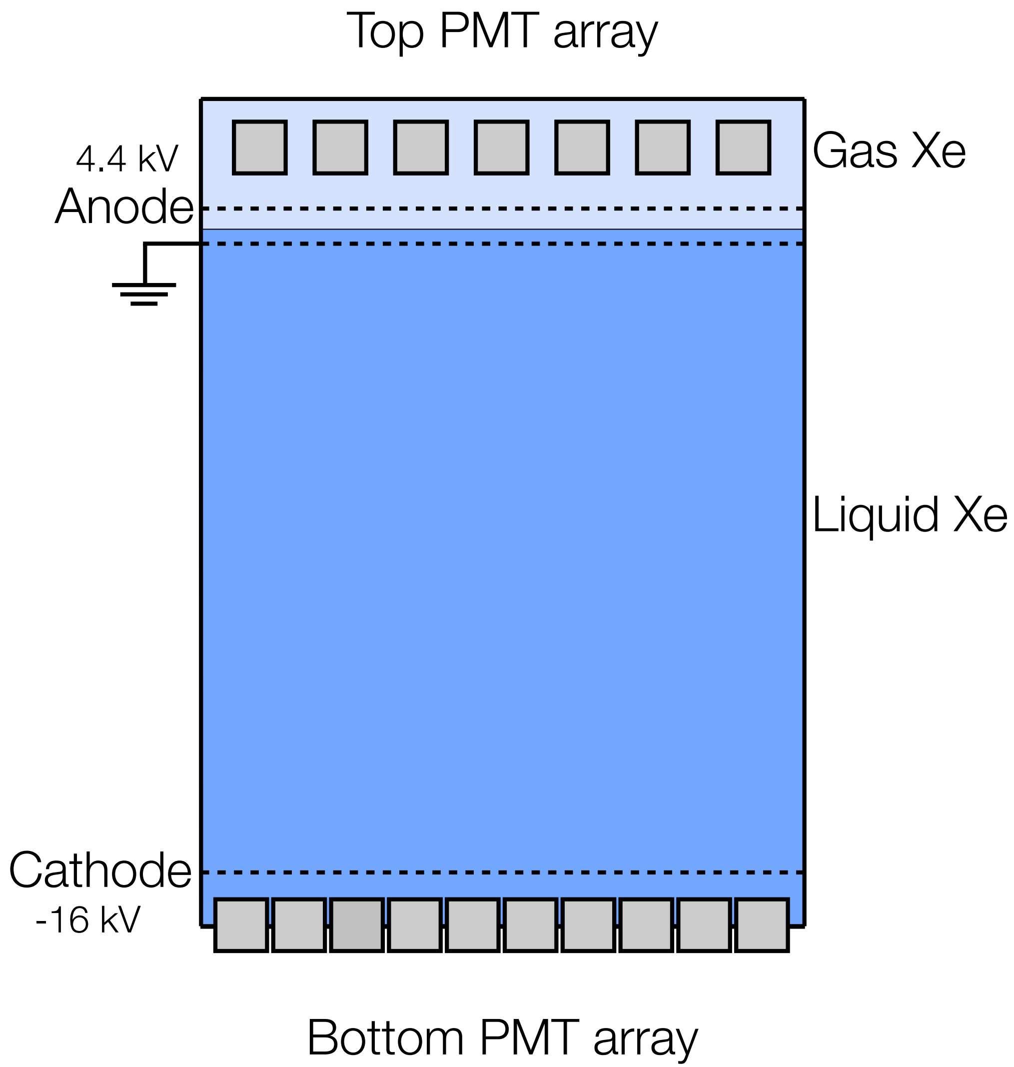


- Scalability
- Simple cryogenic: ~ -100 ºC
- High atomic mass: A~131
- Self shielding: high atomic number and density (Z = 54 and 3 g/cm^3)
- Intrinsically pure: no long-lived radioactive isotopes, Kr/Xe reduction to ppt level
- Low energy threshold
- Light (S1) and charge (S2) signals:
  - background identification and reduction
  - charge-to-light ratio
  - 3D localization

Double-phase Time Projection Chamber



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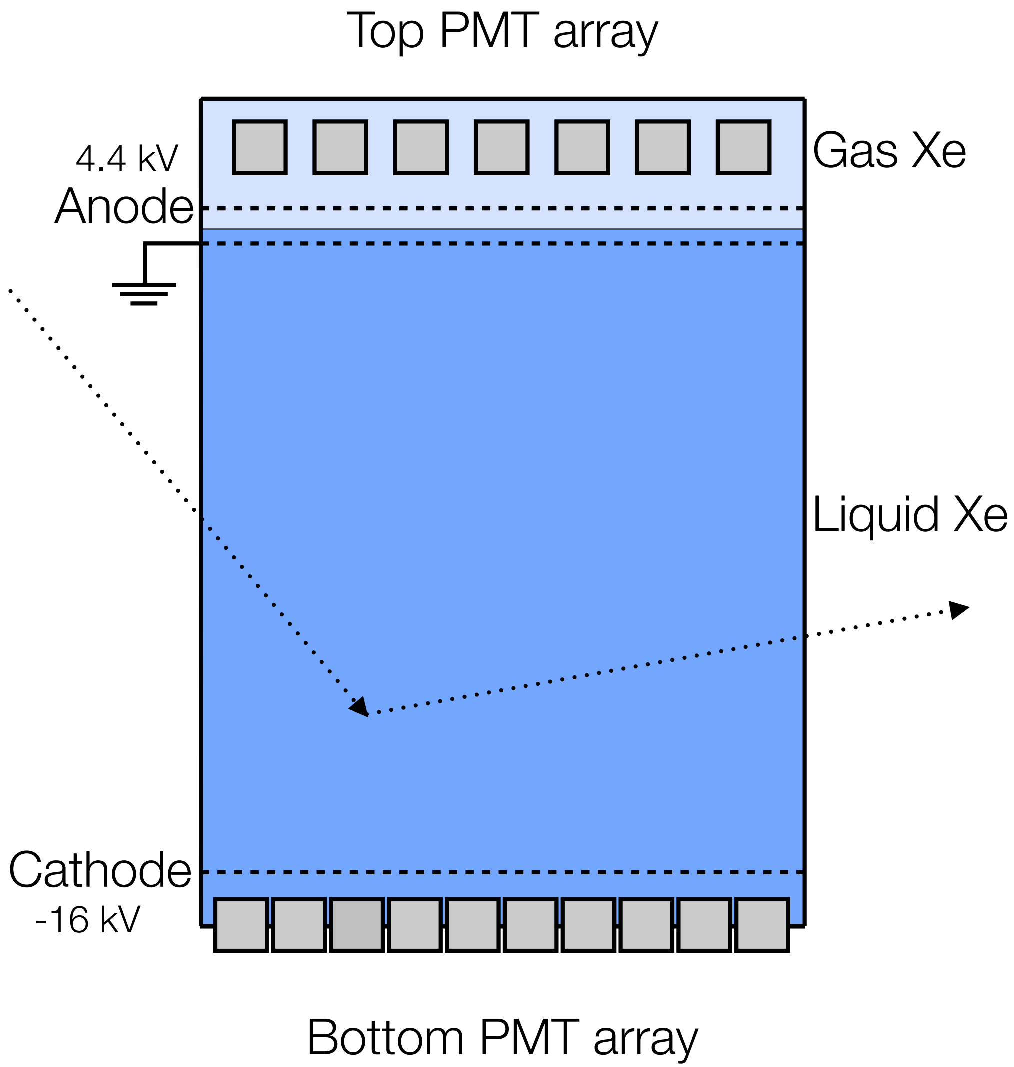

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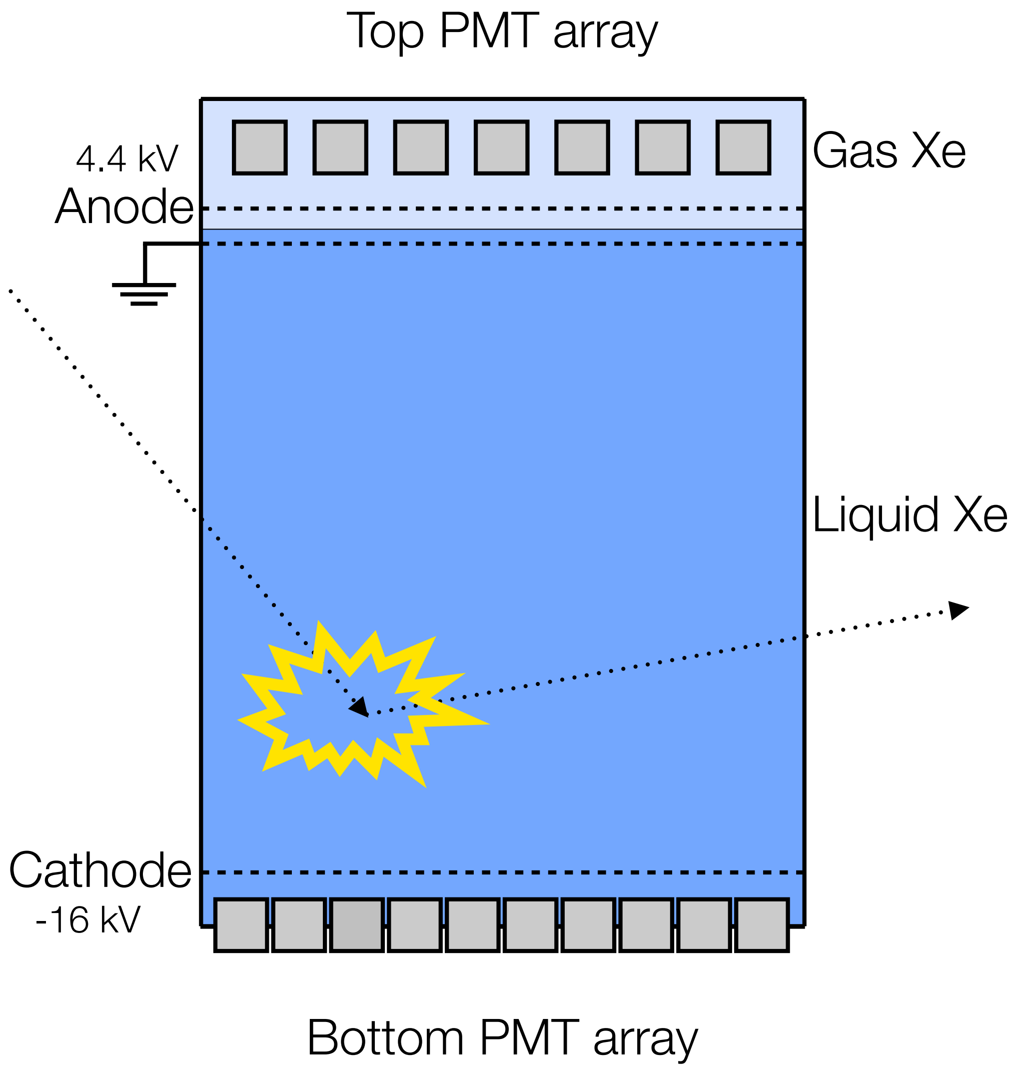

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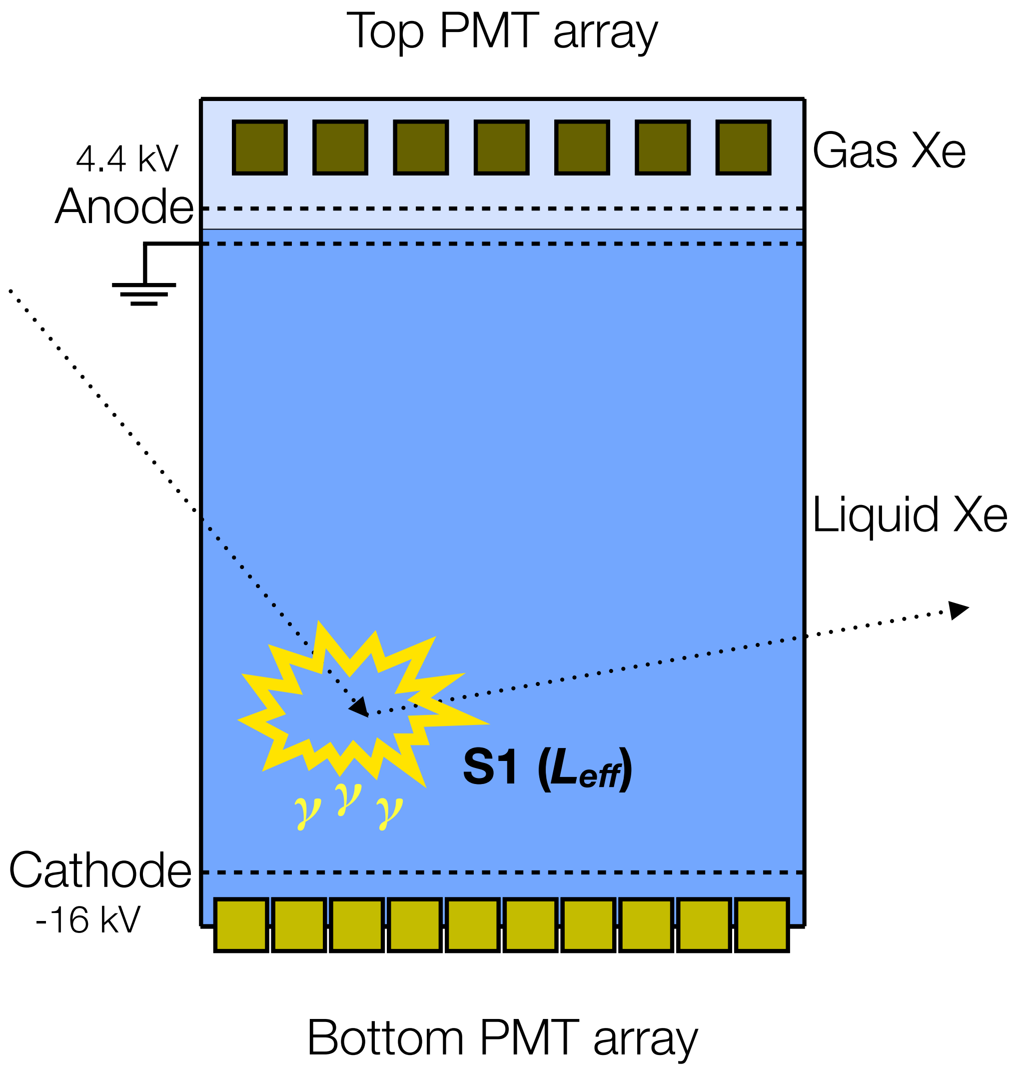

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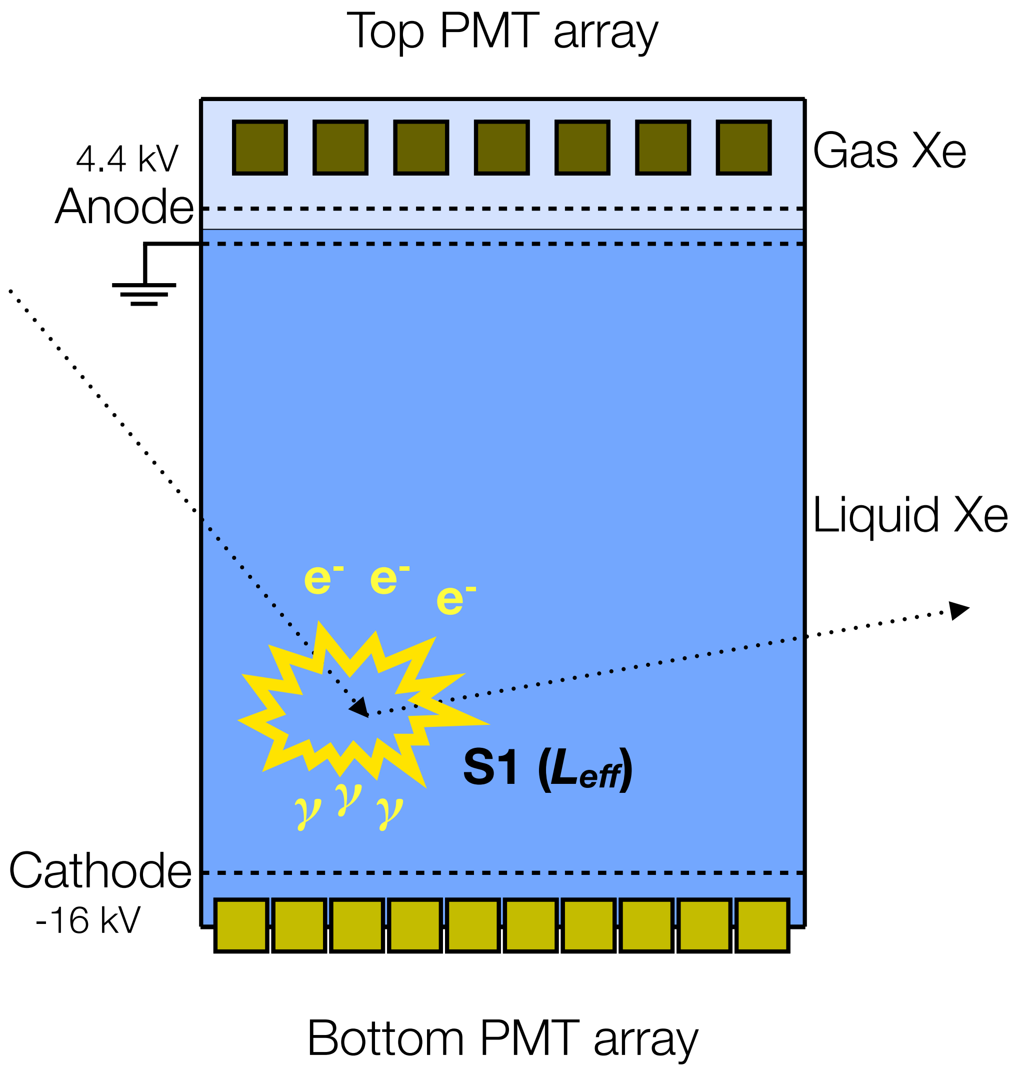

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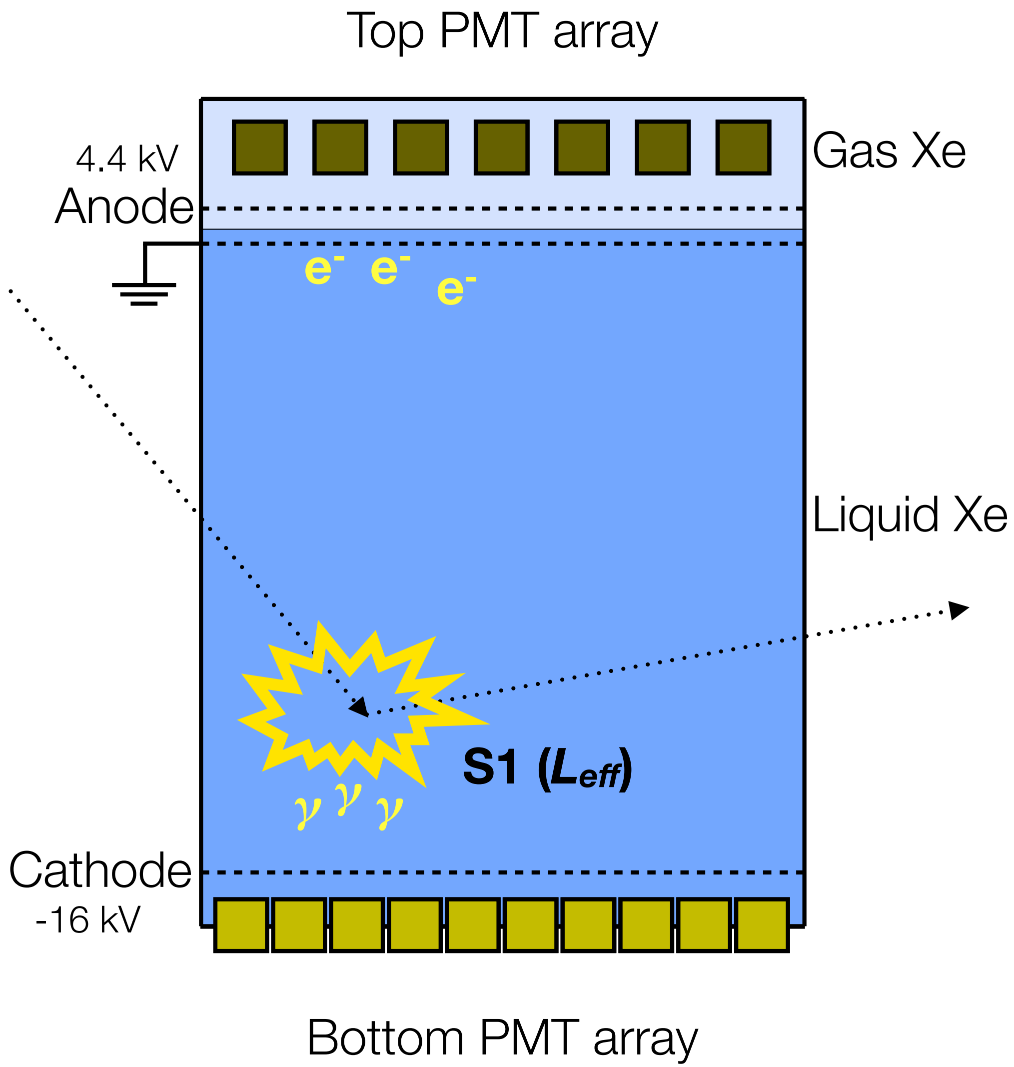

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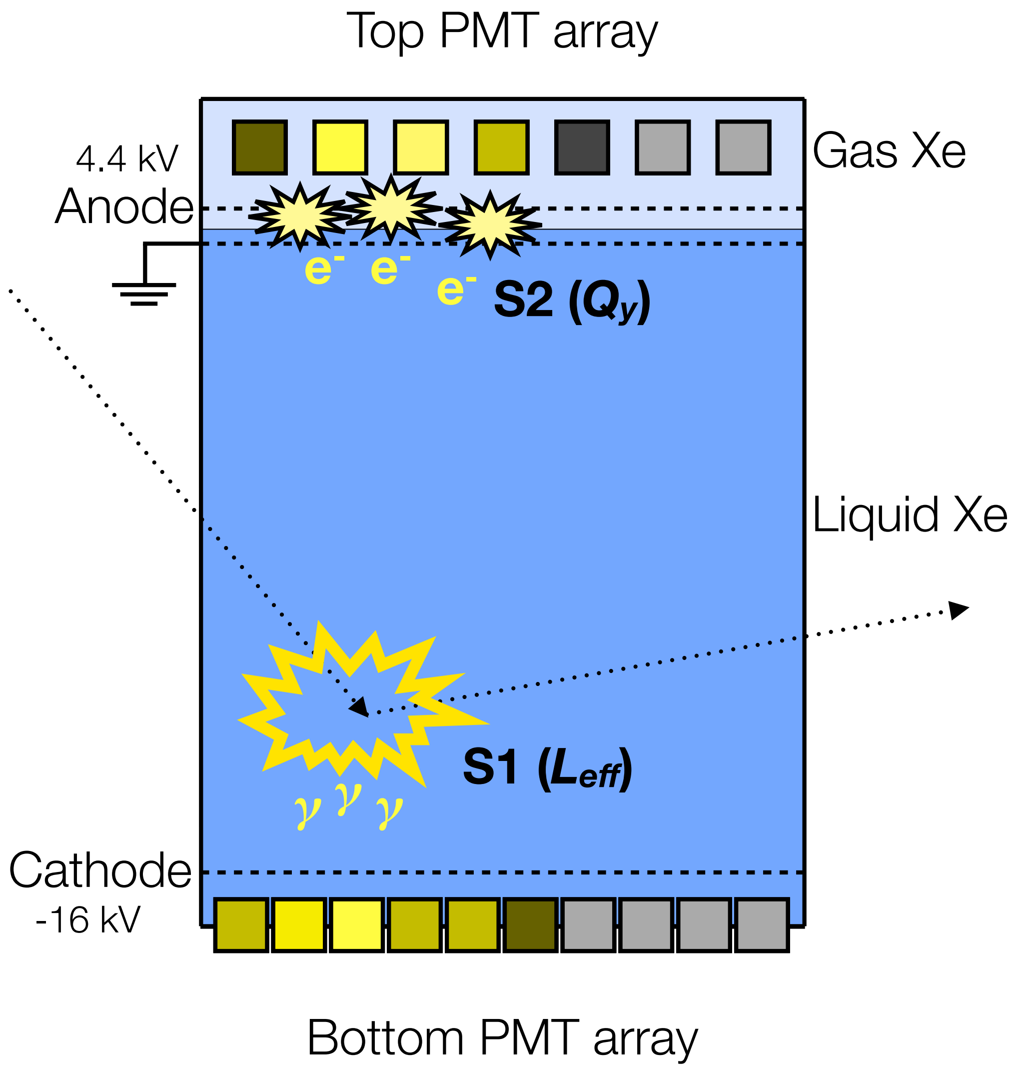
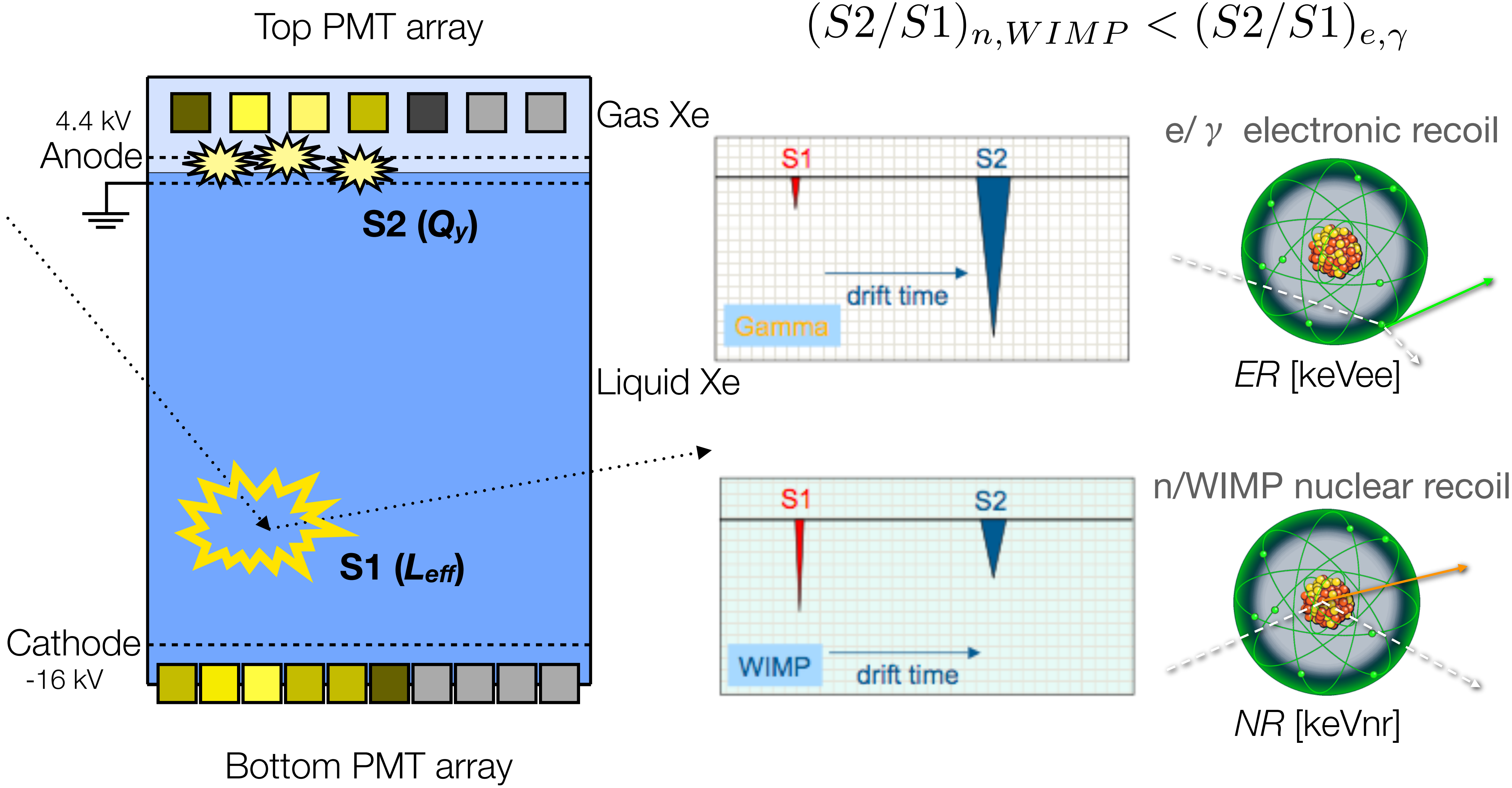
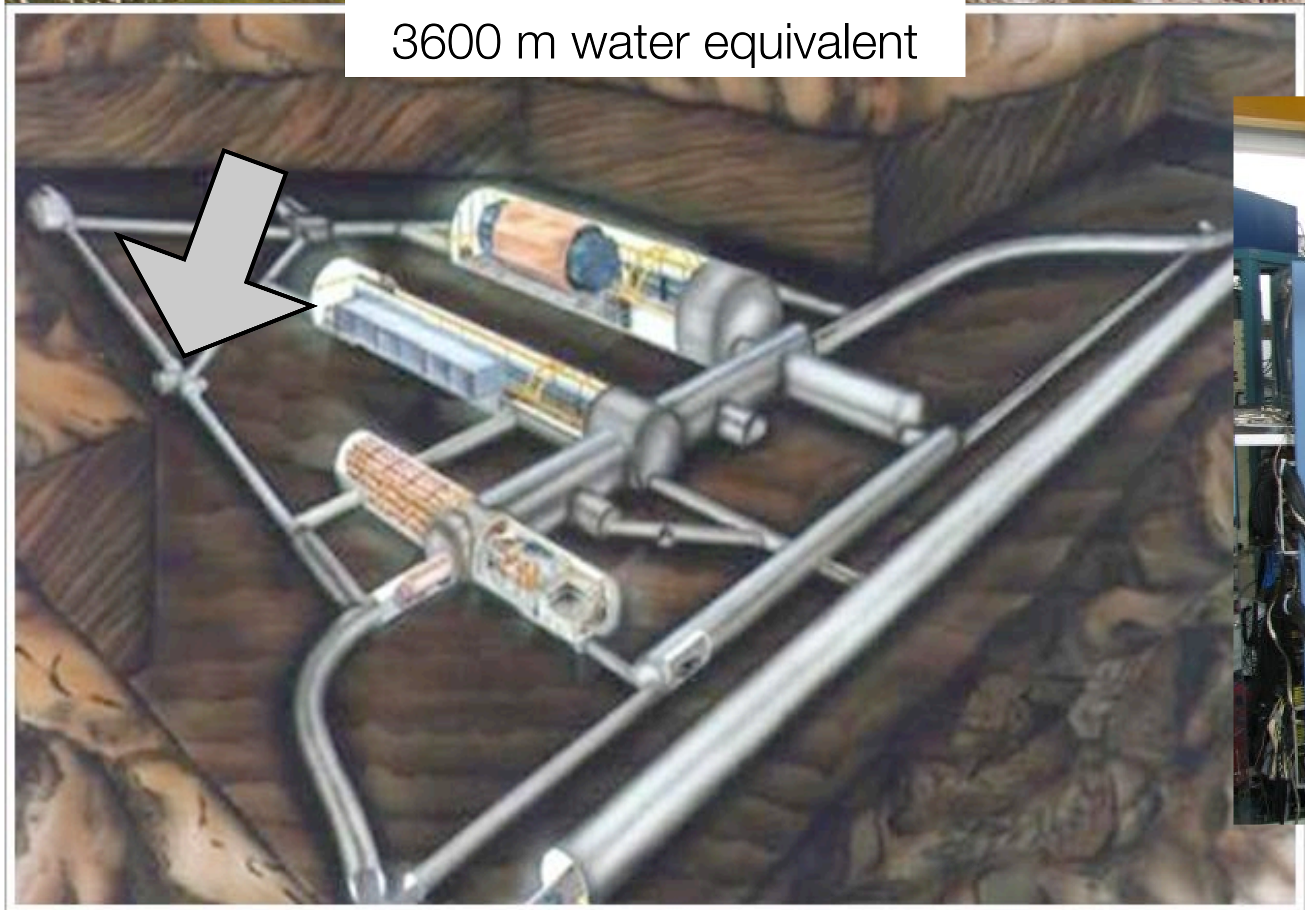


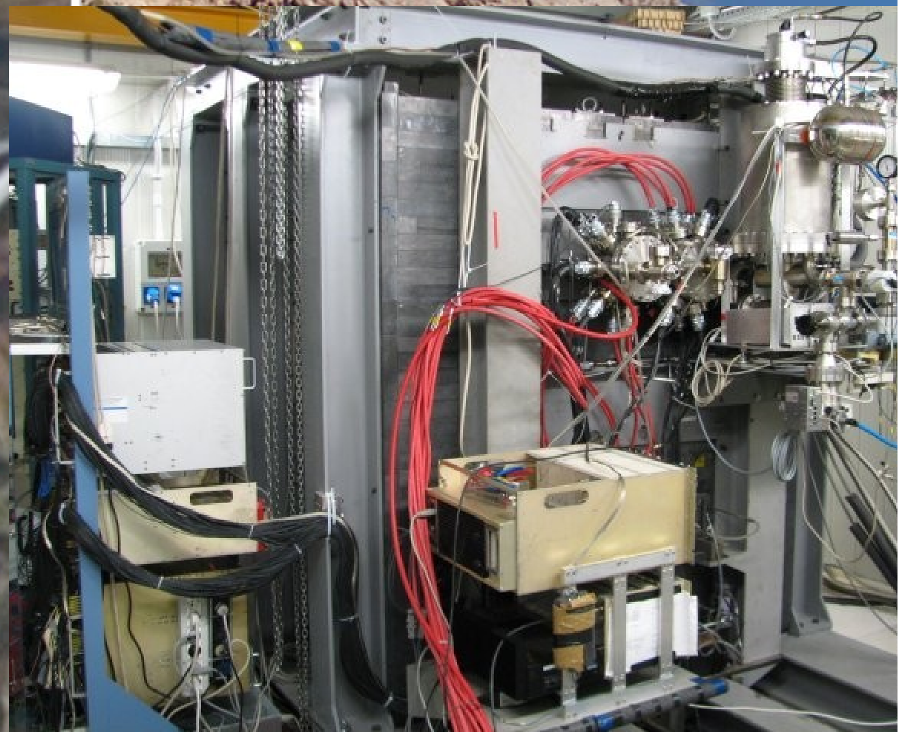
Double-phase Time Projection Chamber

$$(S2/S1)_{n,WIMP} < (S2/S1)_{e,\gamma}$$

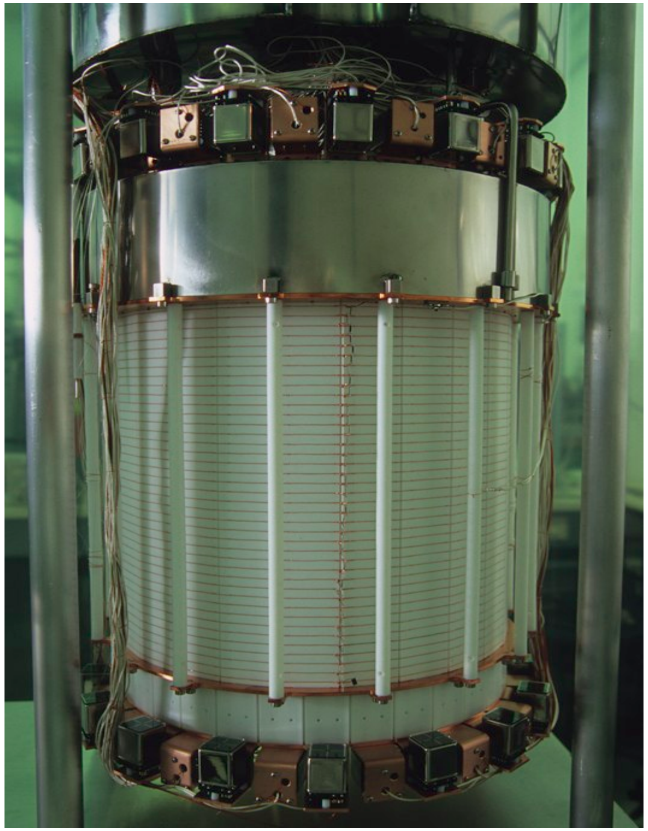


XENON100 @ LNGS





The XENON100 detector



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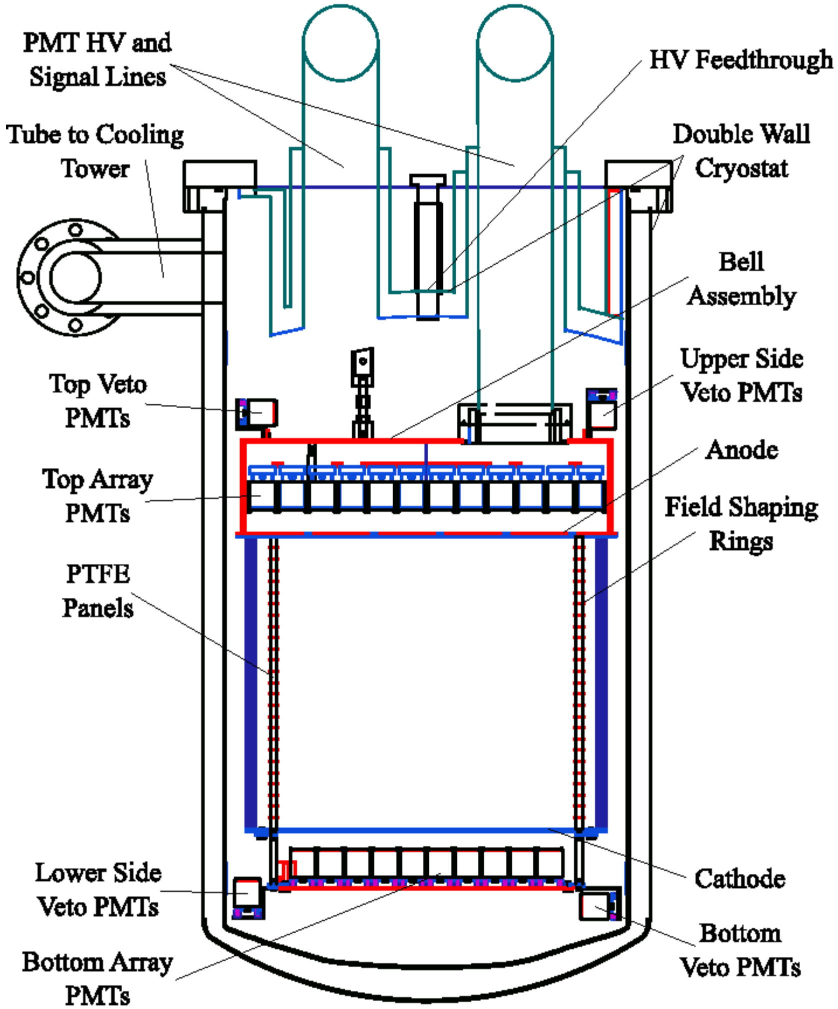
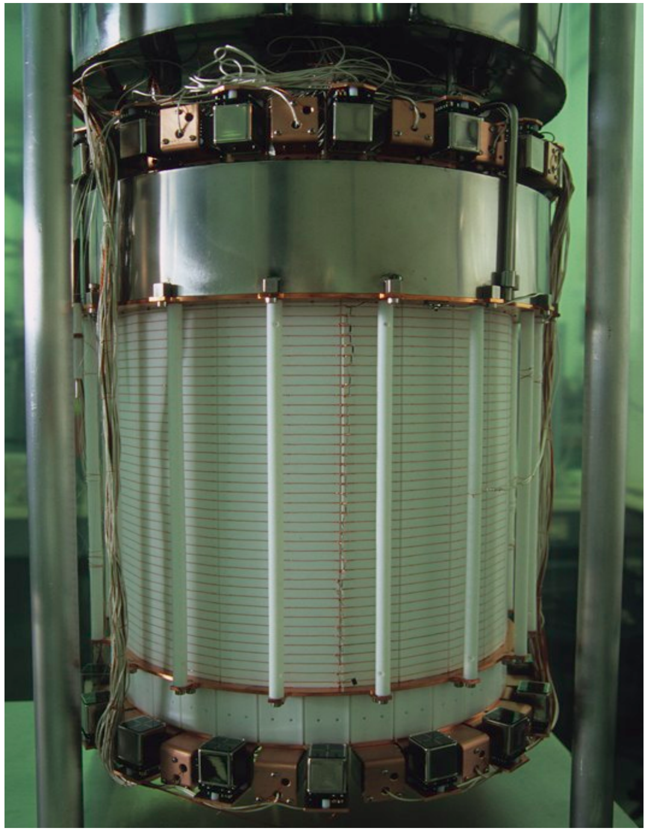
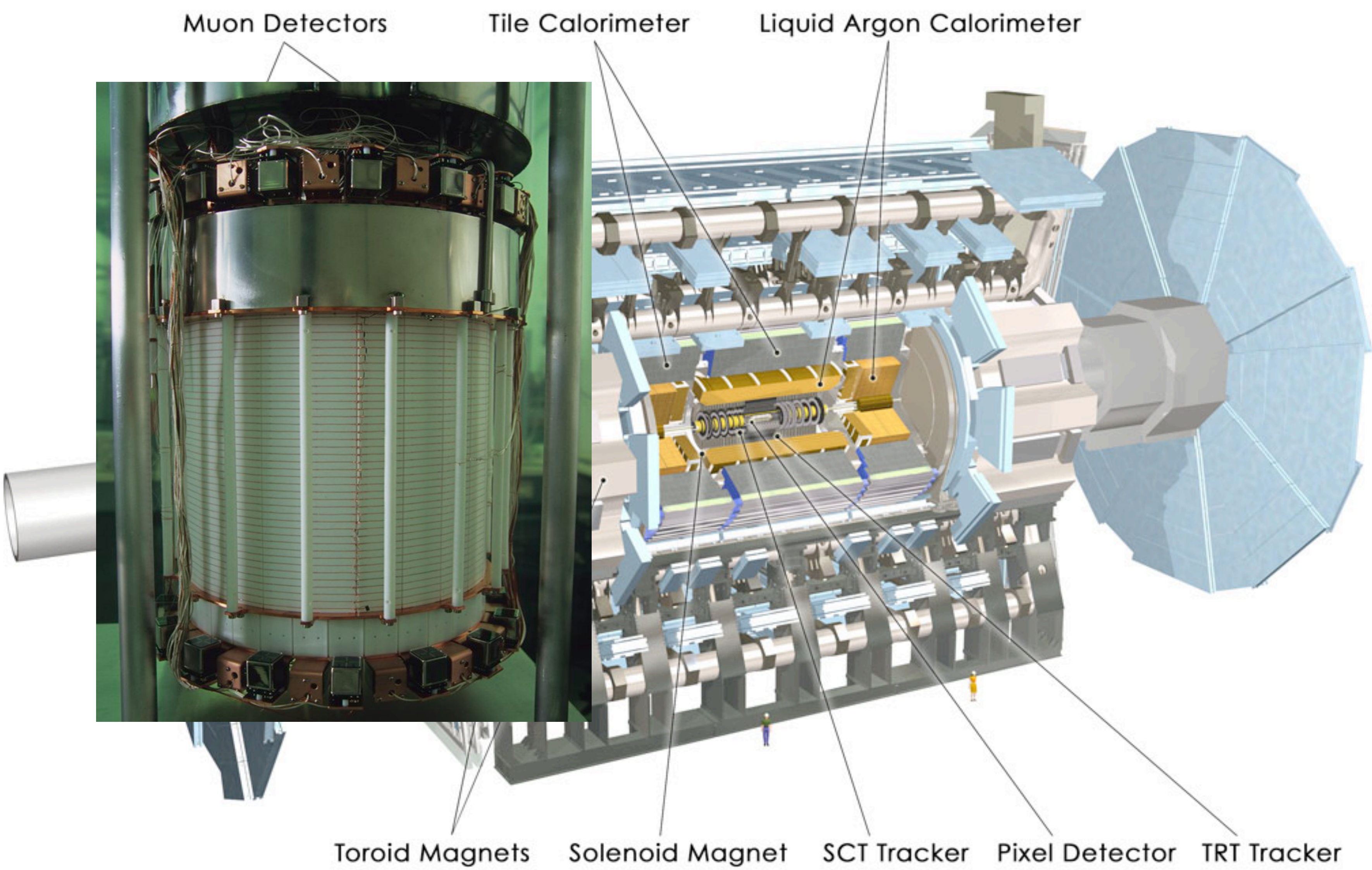
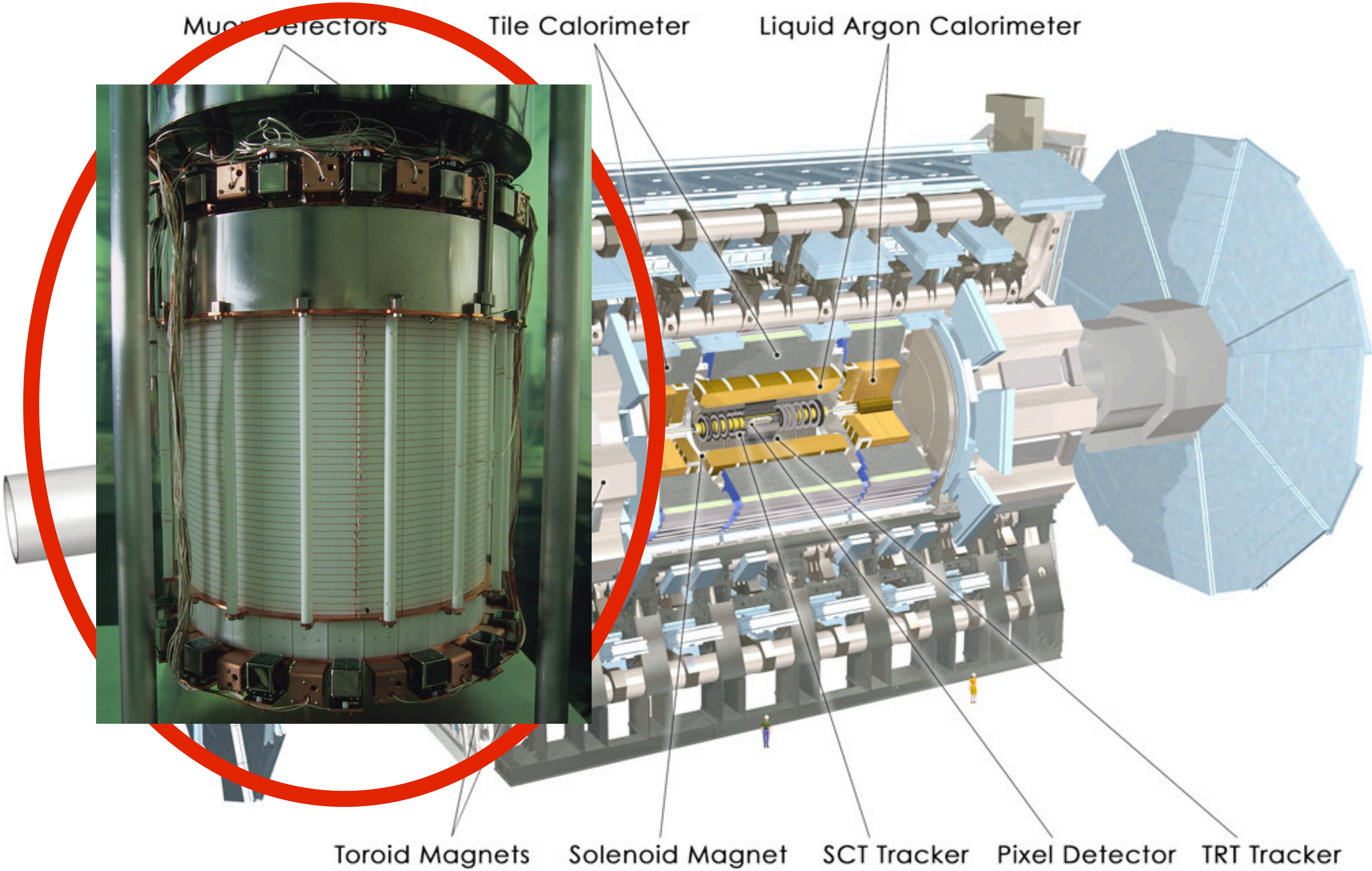


- 161 kg of LXe. TPC: 30 cm height x 30 cm diameter. Active veto: 4 cm tick.
- 242 PMTs (R8520) 1-inch x 1-inch. Top array (QE~23%). Bottom array (QE~33%).
- Electric field: E_{drift} = 0.53 kV/cm. E_{extr} = ~12 kV/cm.
- Shielding: 5 cm Cu, 20 cm Poly, 15 + 5 cm Pb, 20 cm H_2O. Radio-pure detector materials. Cryocooler, FT outside.
- Radio-pure Xe: Kr distillation column
- 3D position reconstruction:
  - X/Y from S2 signal: few mm resolution
  - Z from electron drift time: ~0.3 mm resolution

Astropart. Phys. 35, 43-49 (2011)




Muon Detectors
Tile Calorimeter
Liquid Argon Calorimeter
Toroid Magnets
Solenoid Magnet
SCT Tracker
Pixel Detector
TRT Tracker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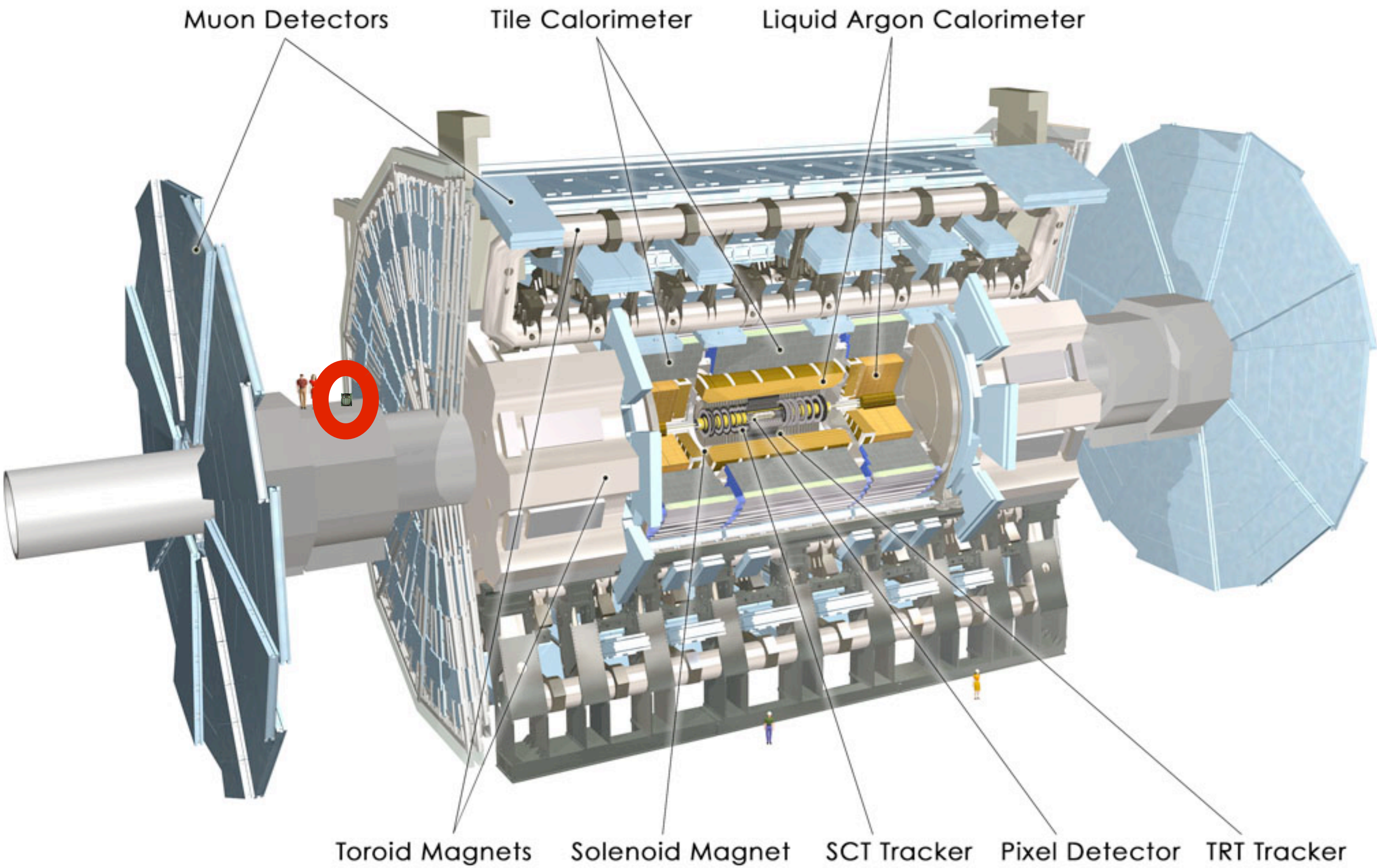
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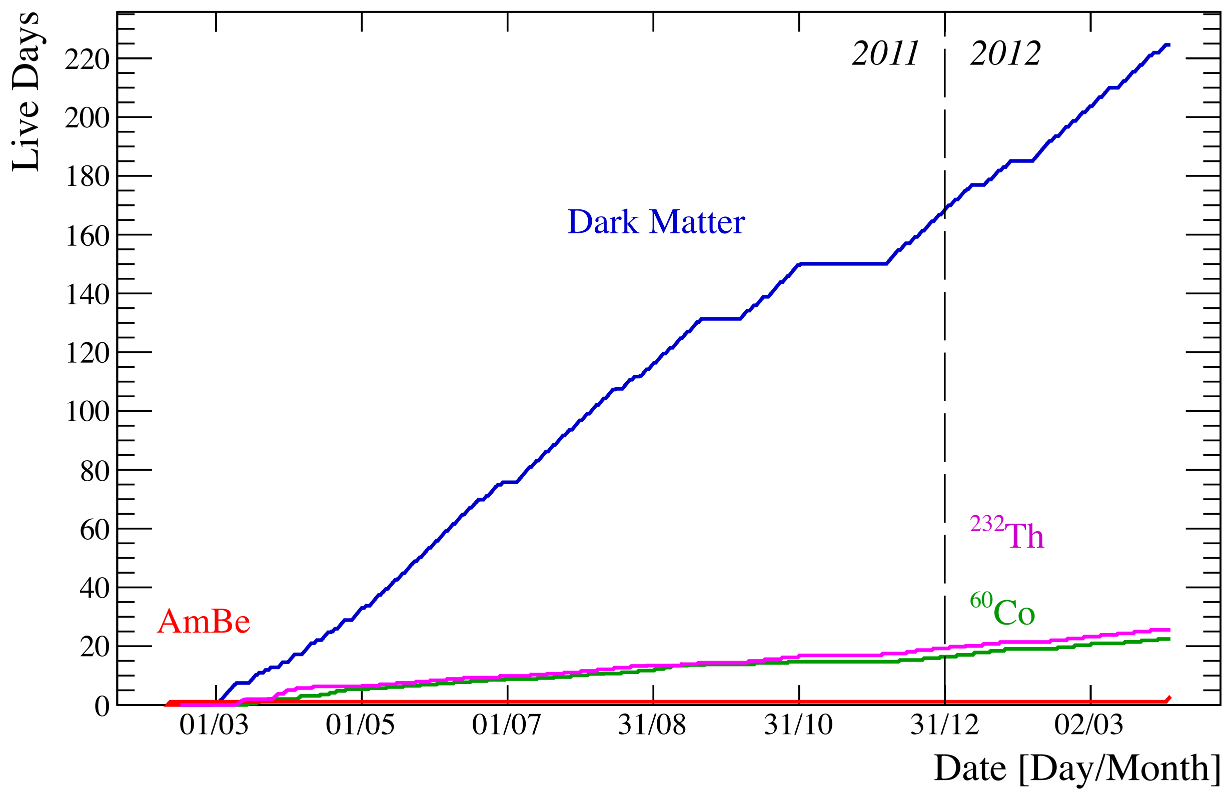
2011/2012 science run
& spin independent limit

2011/2012 data taking



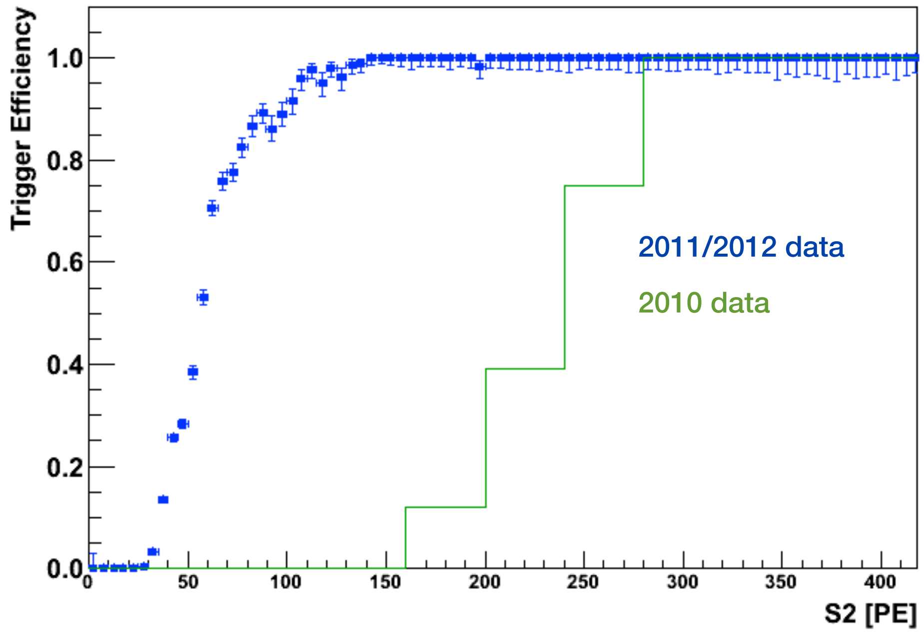
- Data taking: Feb. 28, 2011 to March 31, 2012
- Excellent stability of the detector parameters: *T* variation < 0.16% and *P* variation < 0.7%
- Data following maintenance periods removed from analysis

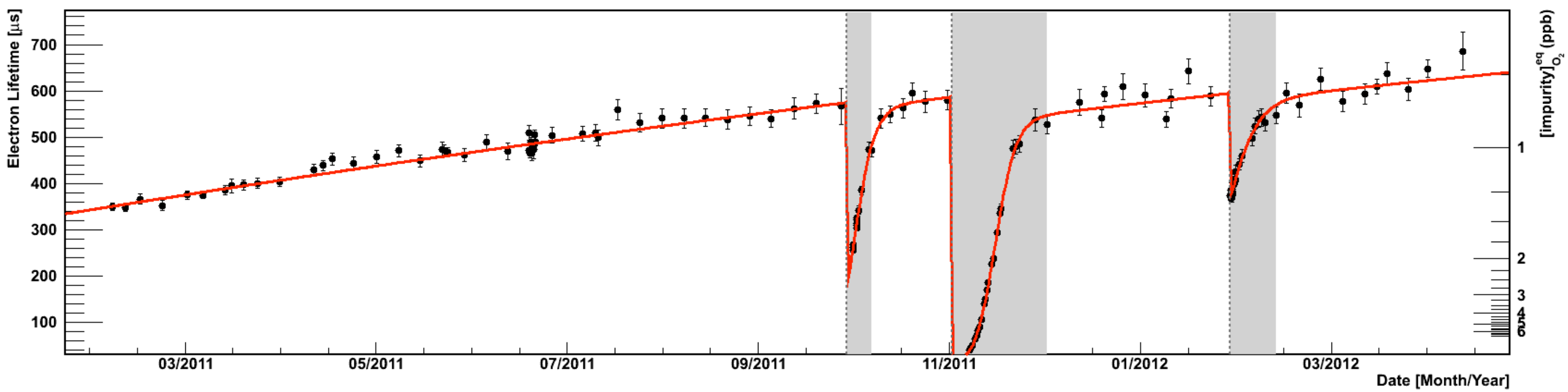
=> 224.6 live days of dark matter data

Longest run of a liquid xenon detector

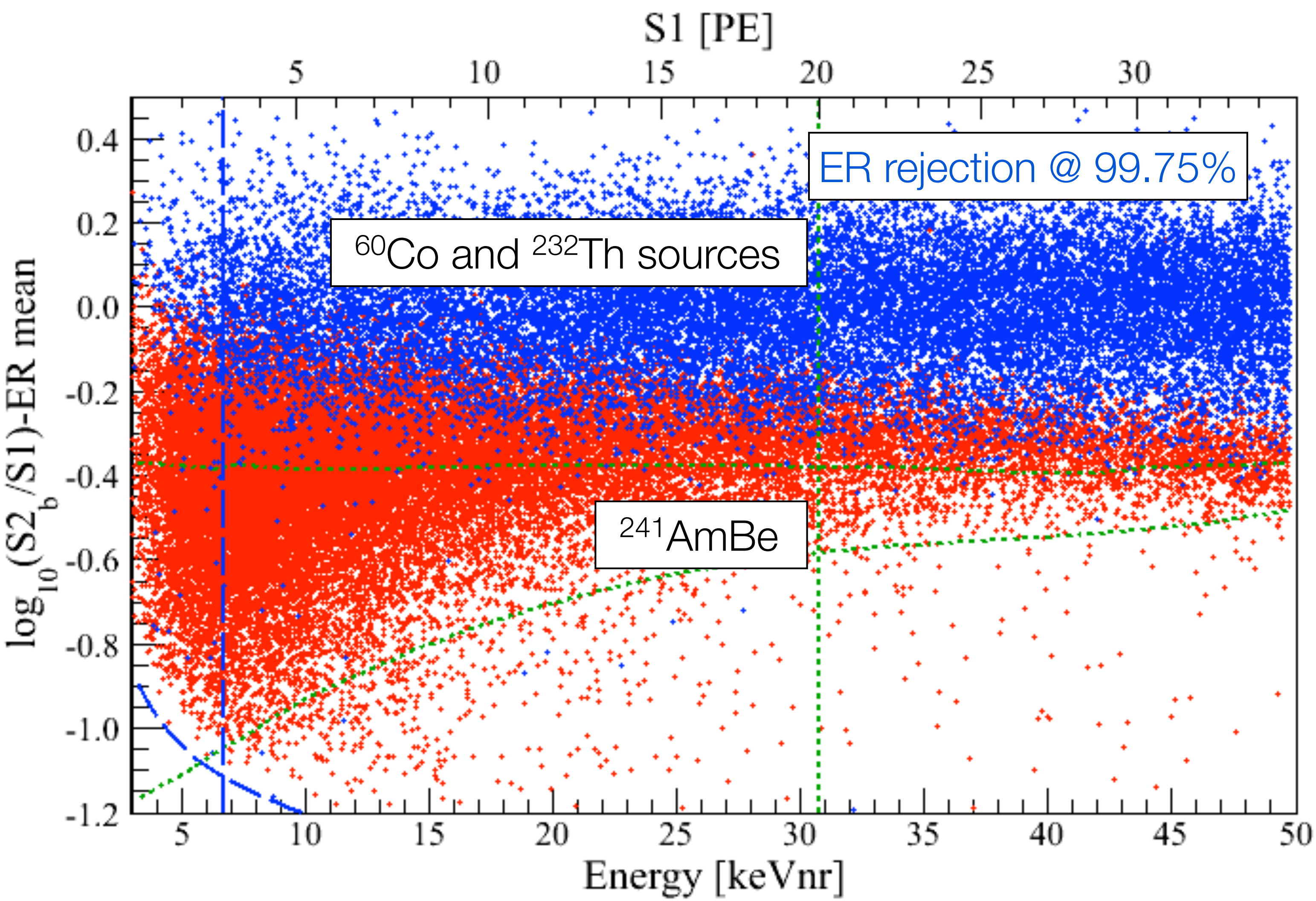
Improvements to the previous science run

- More than double exposure
- Lower threshold:
  S2 > 150 pe and S1 > 3 pe (6.6 keVnr)
- Reduced noise and improved cuts to identify/reject "noisy" events
- Reduced Kr/Xe contamination (19 ppt)
- More calibration data:
  35x more ER calibration
  AmBe before and after the run
- Electron lifetime monitored with ^{137}Cs source increasing from 375 to 610 μs





ER & NR calibration data



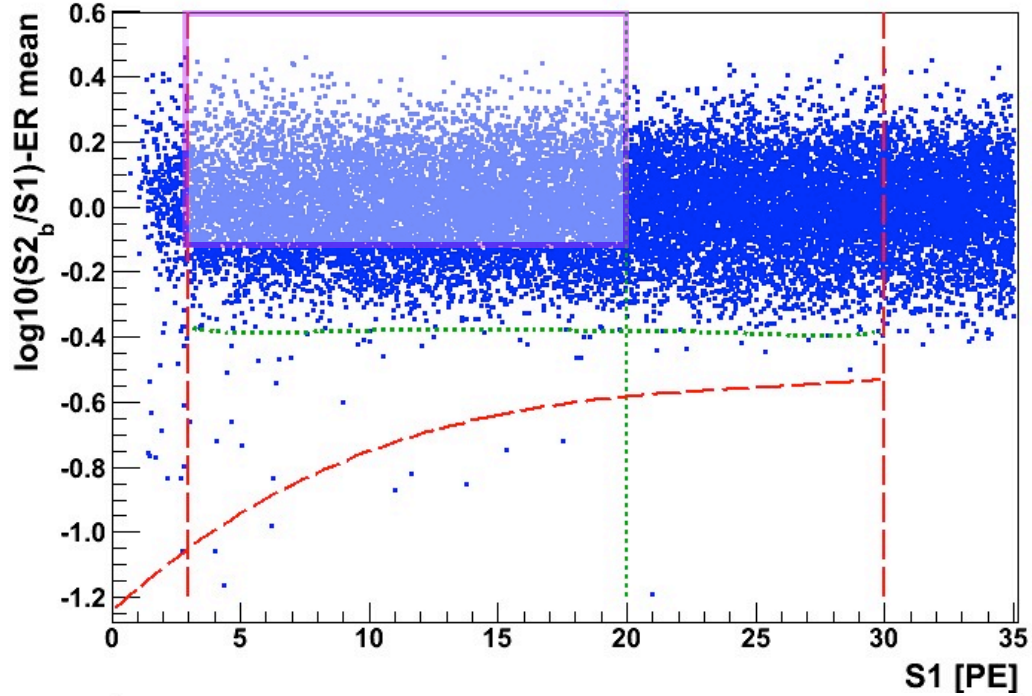
Background prediction

ER background

- Radioactivity of the detector
- Intrinsic radioactivity of the LXe

➡ ER calibration data to model the background by scaling it to the observable DM data

(0.79 +/- 0.16) events

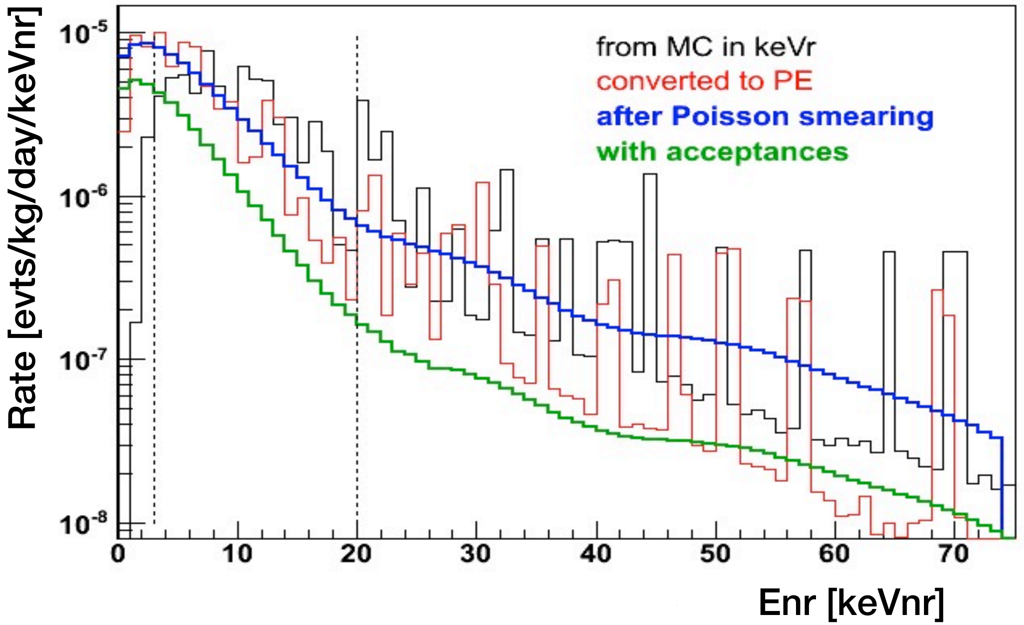


NR background

- (α,n) + S.F. and muon induced neutron

➡ MC simulation with XENON100 geometry and screening measurements

($0.17\ ^{+0.12}_{-0.07}$) events



Total expected background
1.0 +/- 0.2

Analysis and selection cut acceptance

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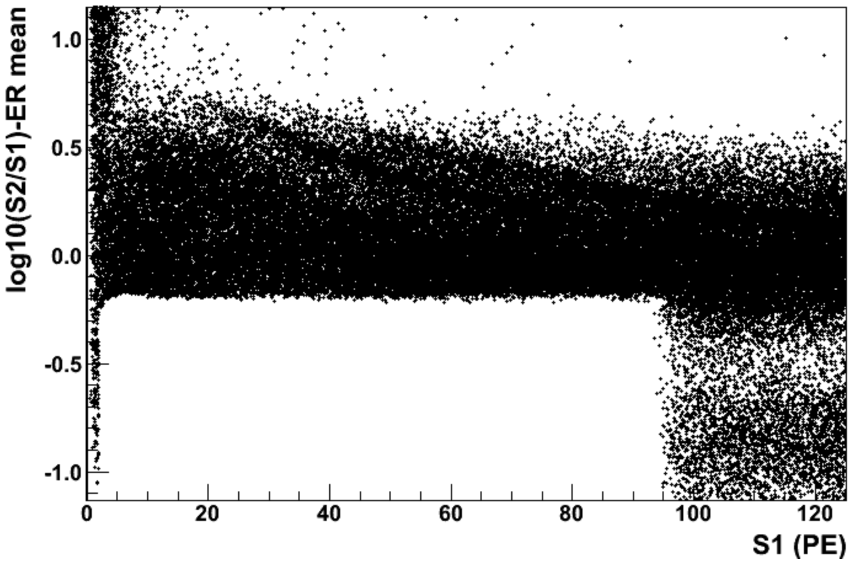
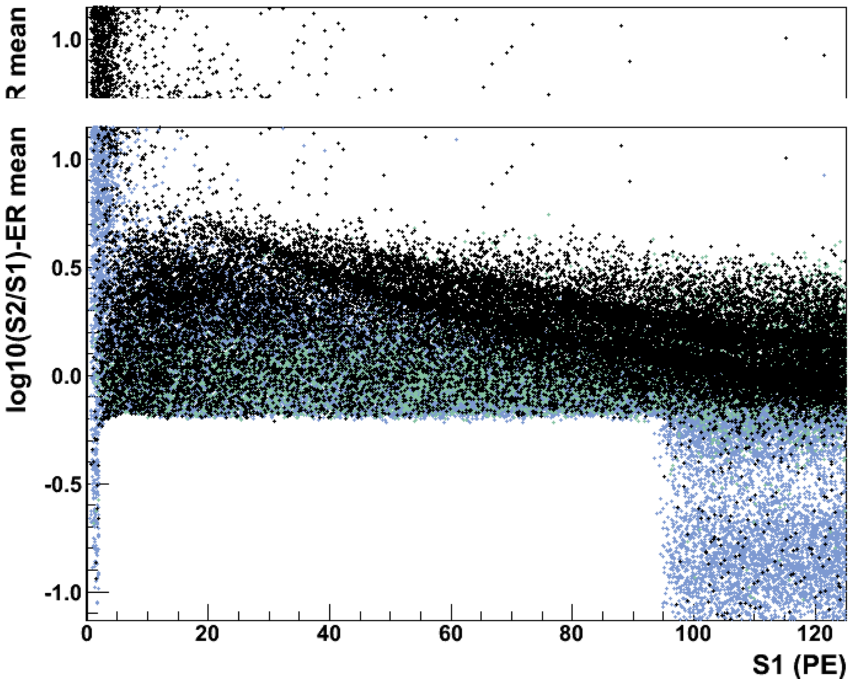


All non blind data in 48 kg fiducial volume

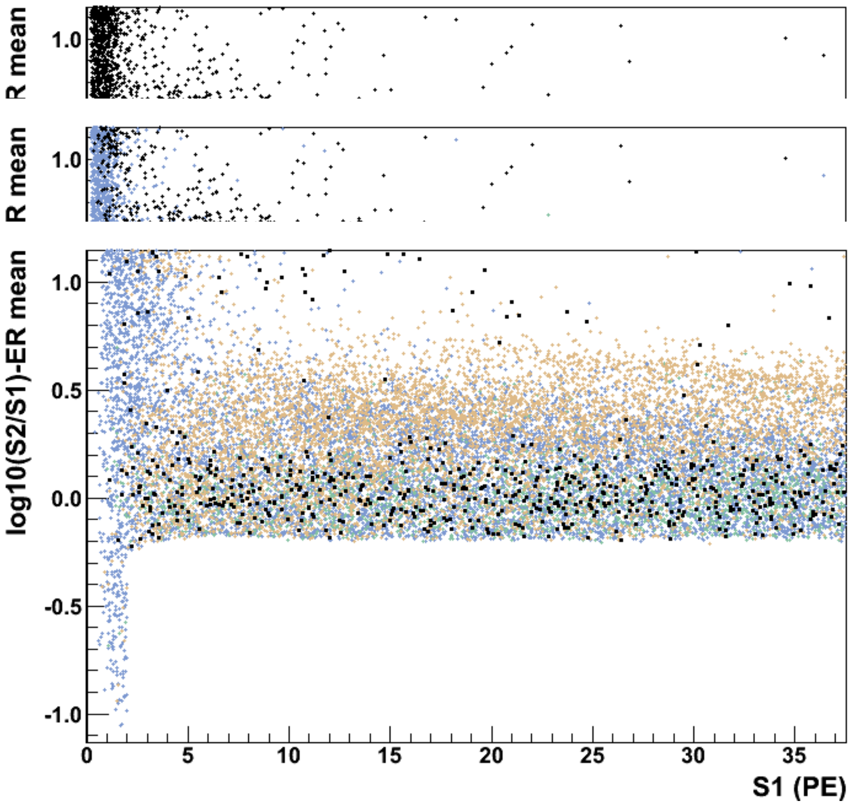
Analysis and selection cut acceptance



All non blind data in 48 kg fiducial volume

Basic quality cuts and single hit in the TPC

Analysis and selection cut acceptance



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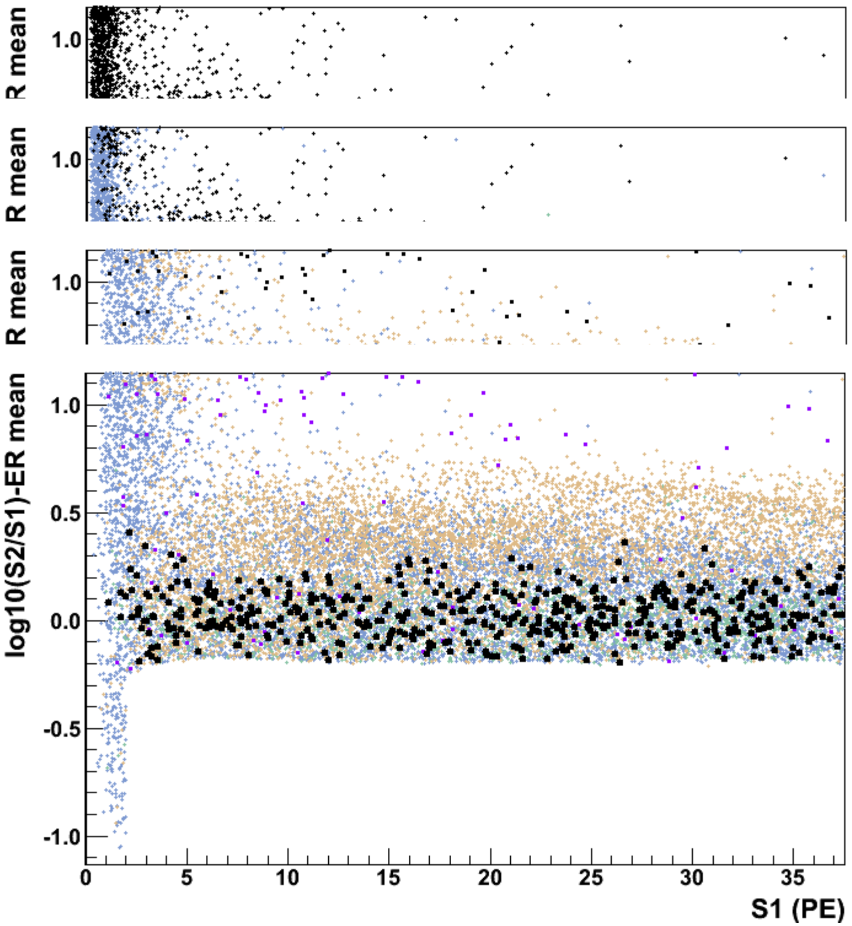
Basic quality cuts and single hit in the TPC

Energy ROI and fiducial volume

Analysis and selection cut acceptance



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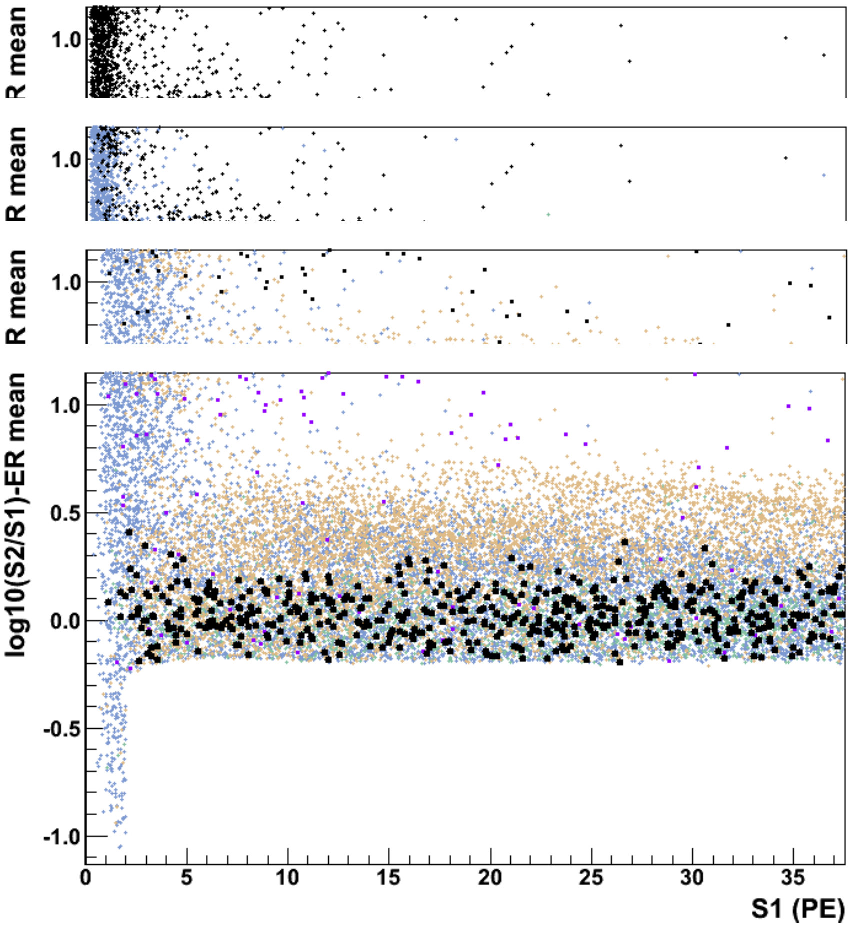
Basic quality cuts and single hit in the TPC

Energy ROI and fiducial volume

Consistency cuts

Analysis and selection cut acceptance



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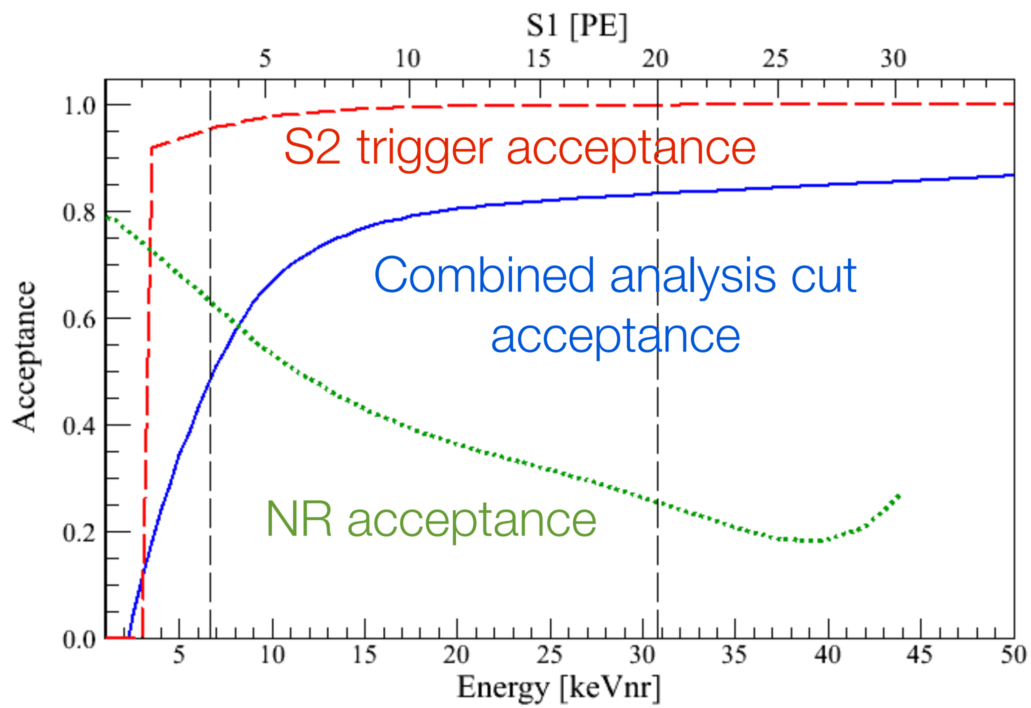
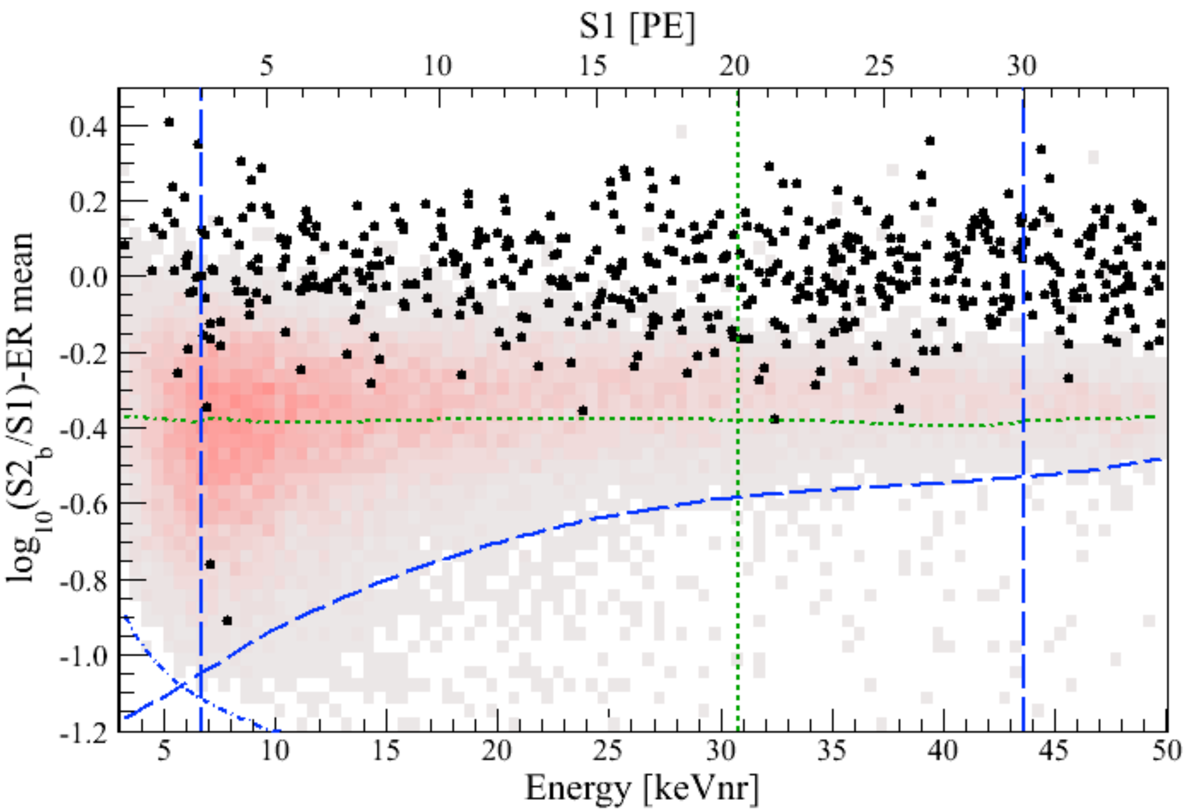
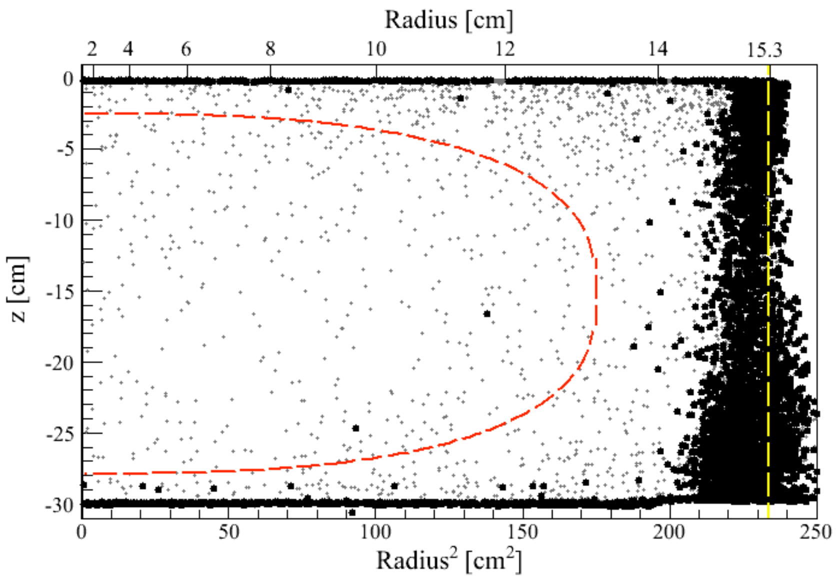
arXiv:1207.3458



224.6 days x 34 kg exposure



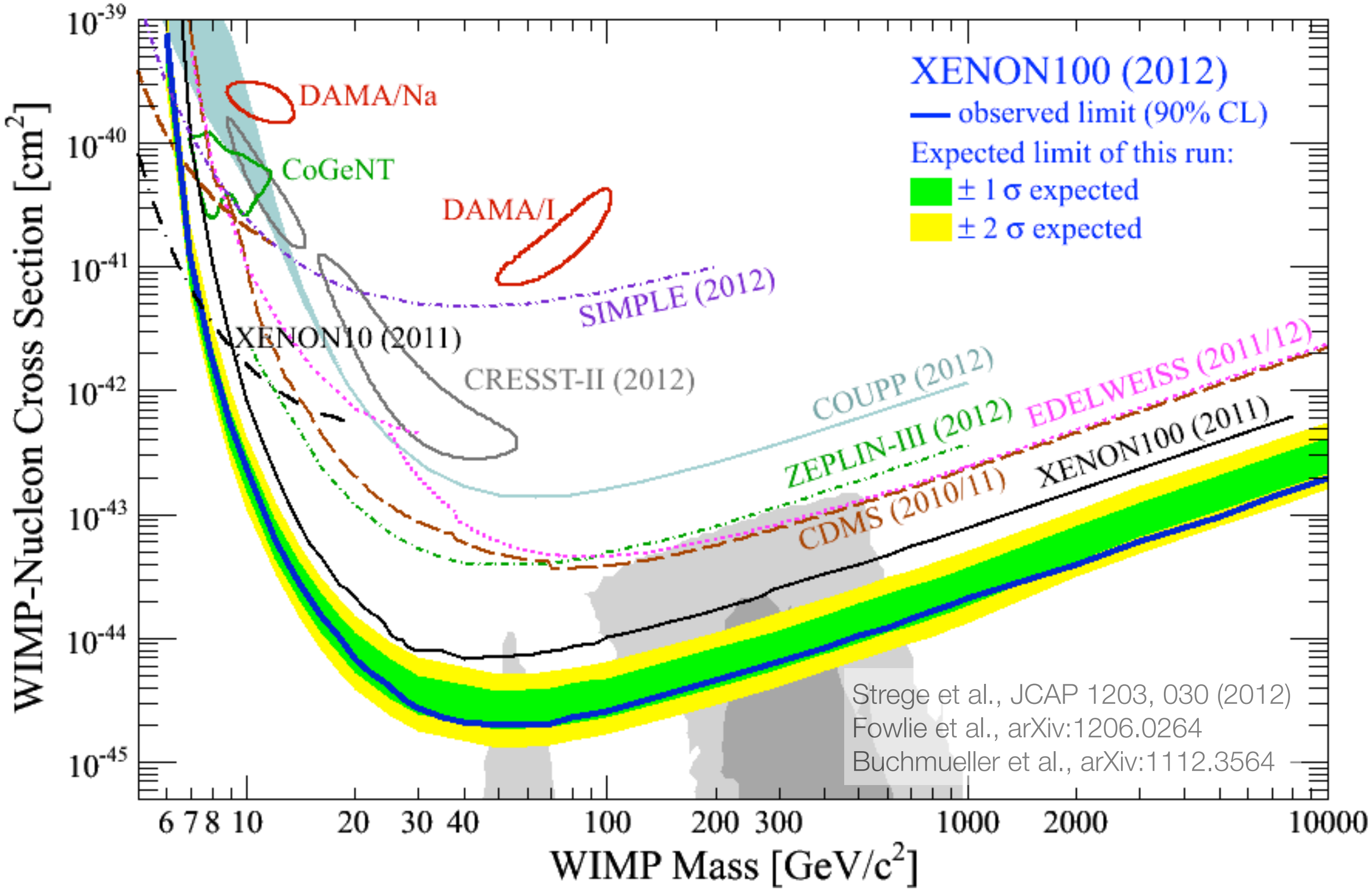


- 2 events observed with 1 +/- 0.2 events expected
- 26.4% probability that background fluctuated
- No significant excess due to signal seen in XENON100 data

XENON100 spin independent limit

- 2011/2012 data taking: 224.6 days x 34 kg exposure
- Dark matter isothermal halo: maxwellian velocity distribution v_c = 220 km/s, Galactic escape velocity v_{esc} = 544 km/s, local density of ρ = 0.3 GeV/cm^3
- Limits extracted via Profile Likelihood method

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



$\sigma = 2.0 \times 10^{-45}$ cm^2, M_χ = 55 GeV/c^2 (90% CL)

Further new results

Spin dependent limit

Nuclear recoil detector response

XENON100 spin dependent

- Spin dependent coupling of WIMPs to ^{129}Xe and ^{131}Xe (unpaired N)
- Abundance in XENON100: ^{129}Xe (26.2%) and ^{131}Xe (21.8%)

$$\sigma_{p,n}(q) = \frac{3}{4}\frac{\mu_{p,n}^2}{\mu_A^2}\frac{2J+1}{\pi}\frac{\sigma_{SD}(q)}{S_A(q)} \qquad S_A(0) = \frac{(2J+1)(J+1)}{\pi J}[a_p < S_p > + a_n < S_n >]^2$$

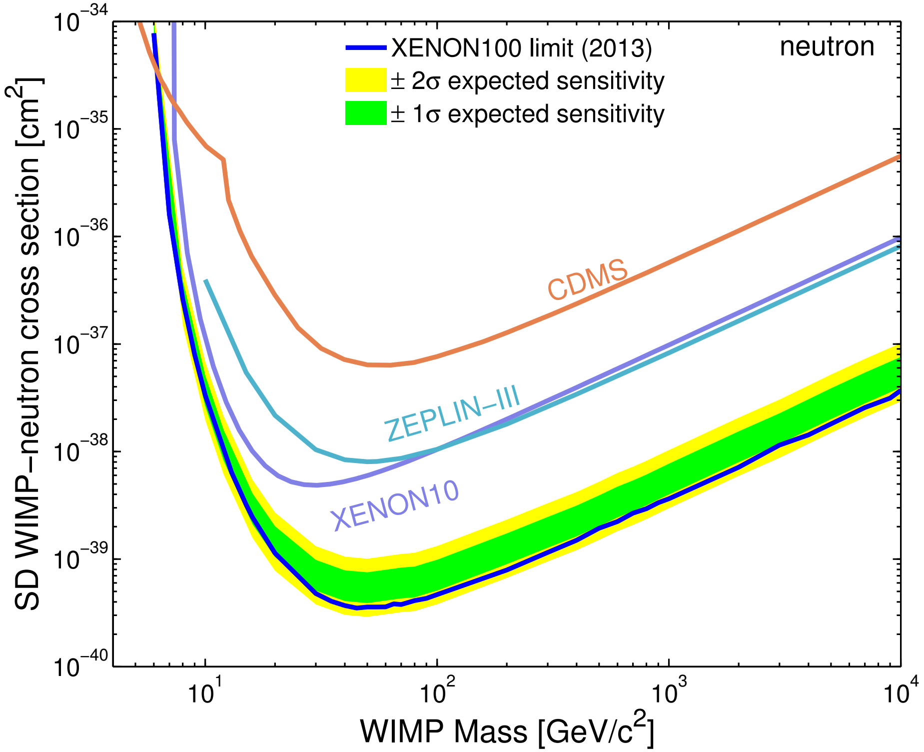
- Axial-vector structure function $S_A(q)$ from three different $<S_n>$ and $<S_p>$ calculations
  - Ressell and Dean (Phys. Rev. C56, 535 (1997))
  - Toivanen et al. (Phys. Rev. C79, 044302 (2009))
  - Menendez et al. (Phys. Rev. D86, 103511 (2012))

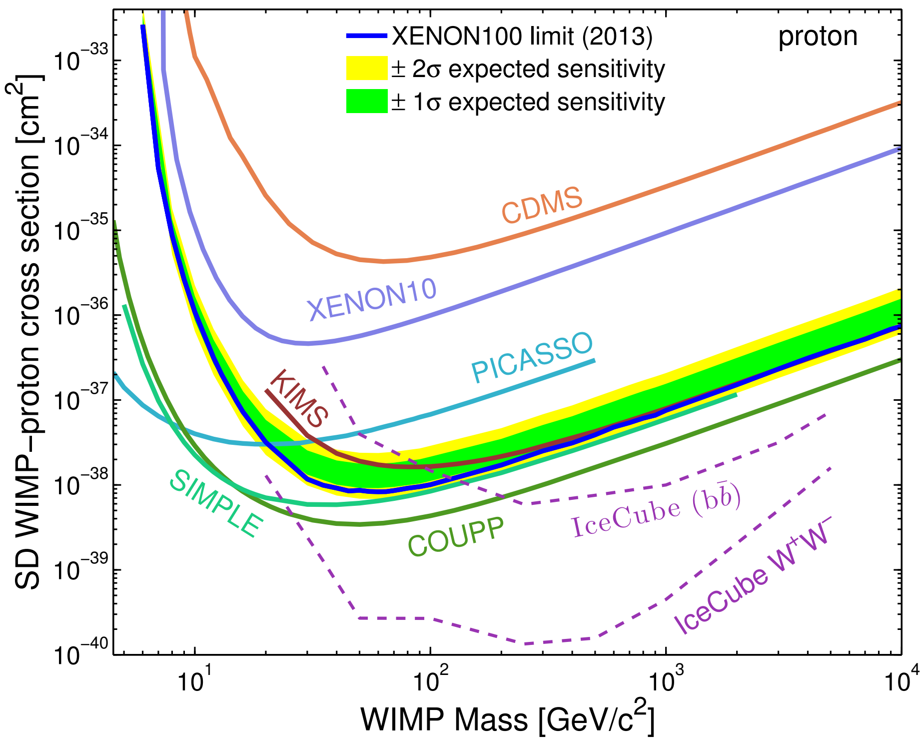
		Ressell and Dean		Toivanen et al.		Menendez et al.	
Nucleus	J^P	$\langle S_n \rangle$	$\langle S_p \rangle$	$\langle S_n \rangle$	$\langle S_p \rangle$	$\langle S_n \rangle$	$\langle S_p \rangle$
^{129}Xe	$\left(\frac{1}{2}\right)^+_{g.s.}$	0.359	0.028	0.273	−0.0019	0.329	0.010
^{131}Xe	$\left(\frac{3}{2}\right)^+_{g.s.}$	−0.227	−0.009	−0.125	−0.00069	−0.272	−0.009

XENON100 spin dependent

- 2011/2012 data taking 224.6 days x 34 kg exposure
- Menendez et al. structure function
- Same galactic assumptions and analysis selection cuts of SI analysis and Profile Likelihood technique

arXiv:1301.6620

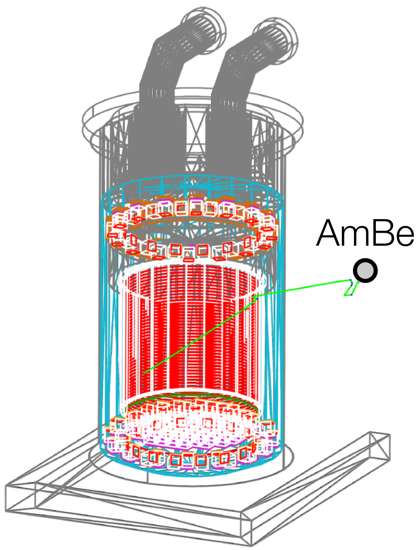




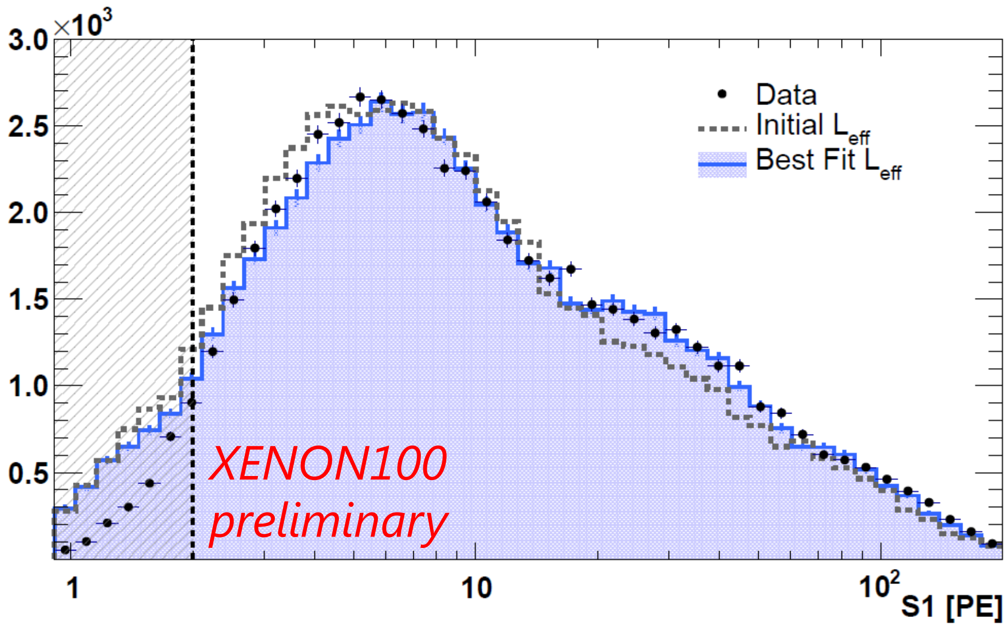
Lowest limit (WIMP masses > 6 GeV/c^2)

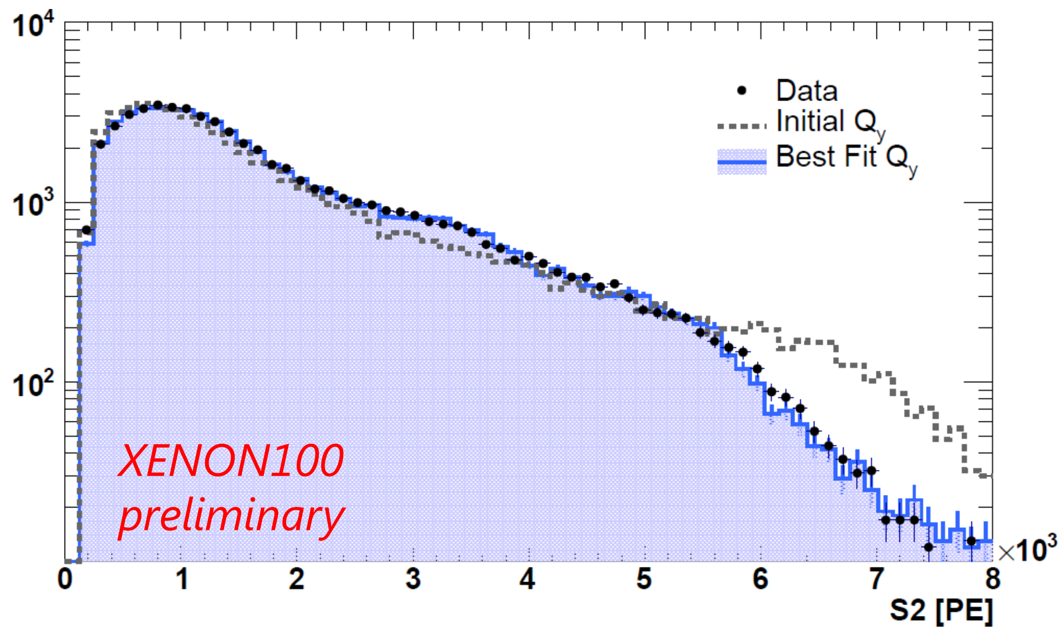
$\sigma_{X\text{-}n} = 3.5 \times 10^{-40}$ cm^2, $M_X = 45$ GeV/c^2 (90% CL)

XENON100 Nuclear Recoil detector response



- AmBe data matching with MC simulation
- Simulation of scintillation and ionization channels
- Dramatic improvement of detector signal response understanding
- 2D signal analysis with WIMP simulation





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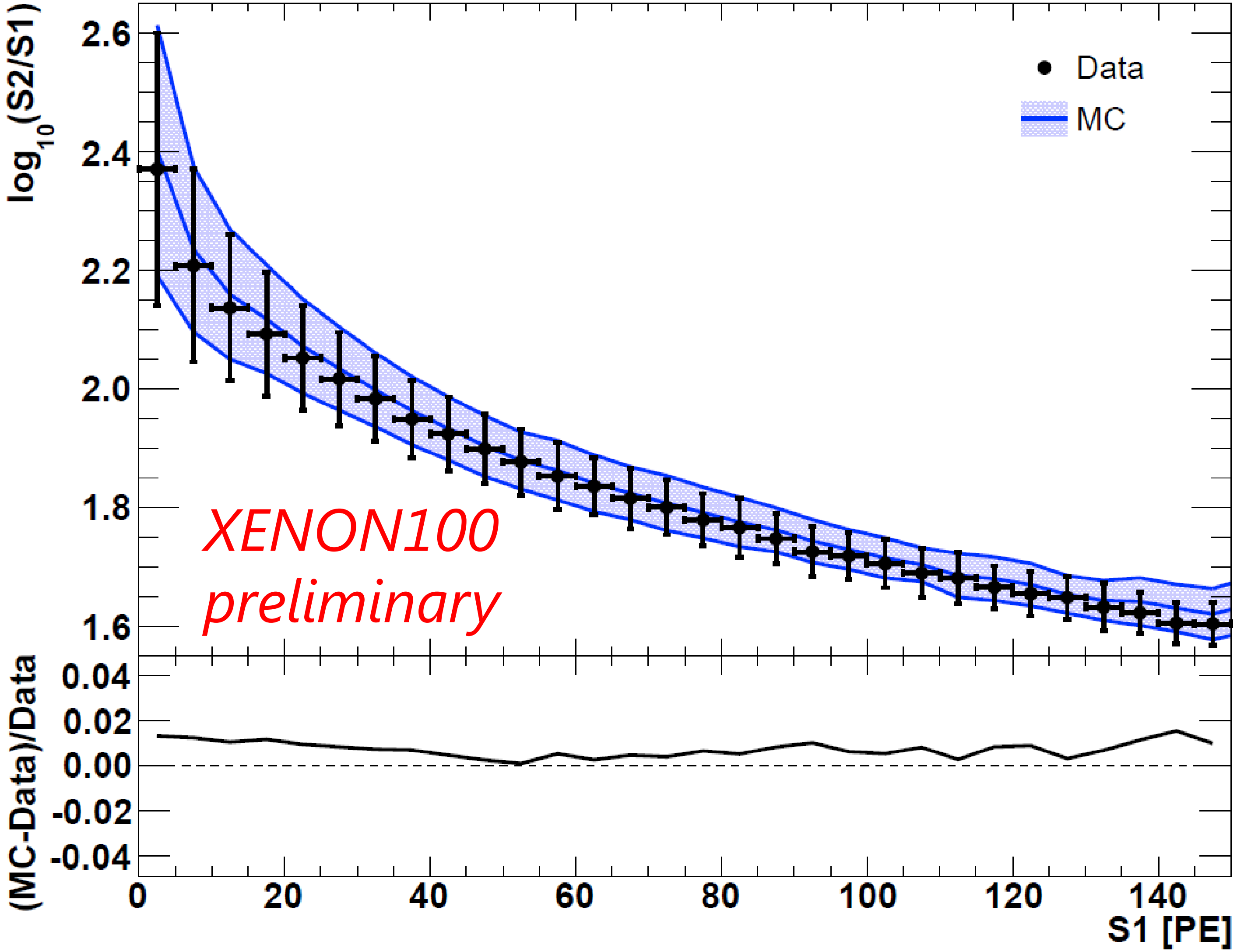

Ongoing with XENON100

- Monte Carlo study of Nuclear Recoil background
- Detector response to single electron
- Annual modulation in low-energy ER
- Axion and super-WIMPs search
- Light dark matter with S2 only analysis
- 2D analysis with S1 and S2 energy scales combined and WIMP simulation

- S1 energy scale measurement for ER @ Columbia and UZH

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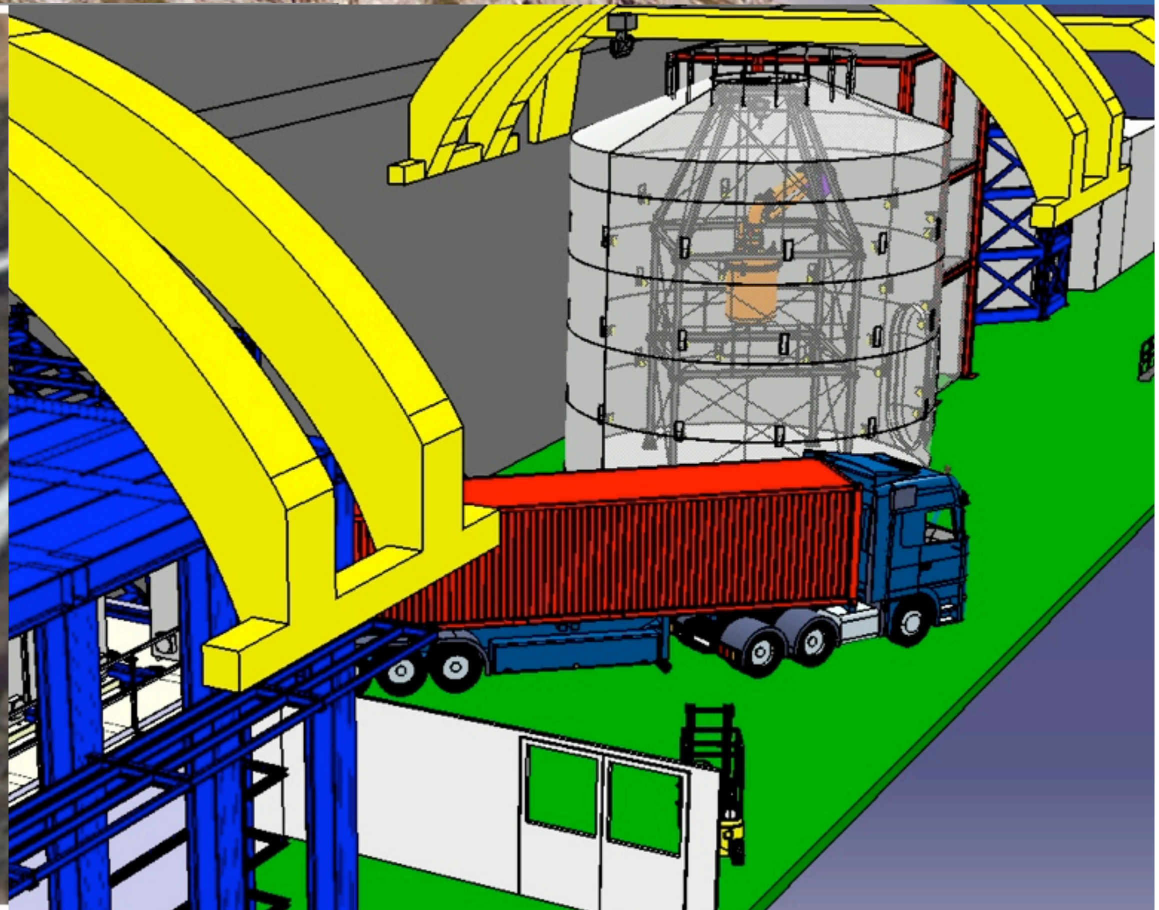
... old hens make the best soup

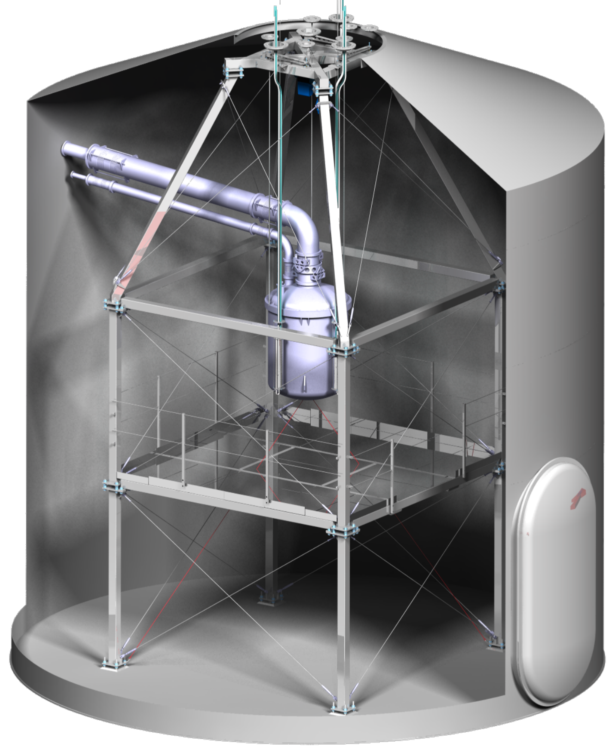
XENON1T @ LNGS

- Project approved and funded
- Design of major infrastructures completed
- Construction in Hall B from April 2013



XENON1T

- > 3 t LXe (1 m^3 detector)
- 1 t fiducial mass => 20x larger than XENON100
- lower radioactivity components: 100x lower background
- background goal: < 1 background event in 2 years



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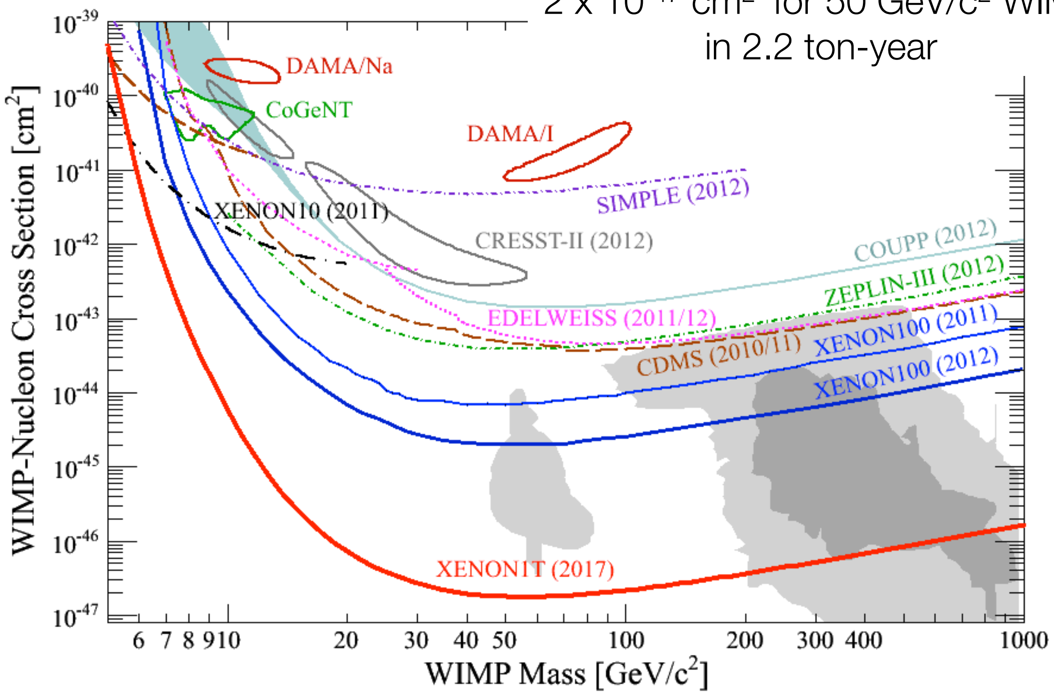

2 x 10^{-47} cm^2 for 50 GeV/c^2 WIMP
in 2.2 ton-year

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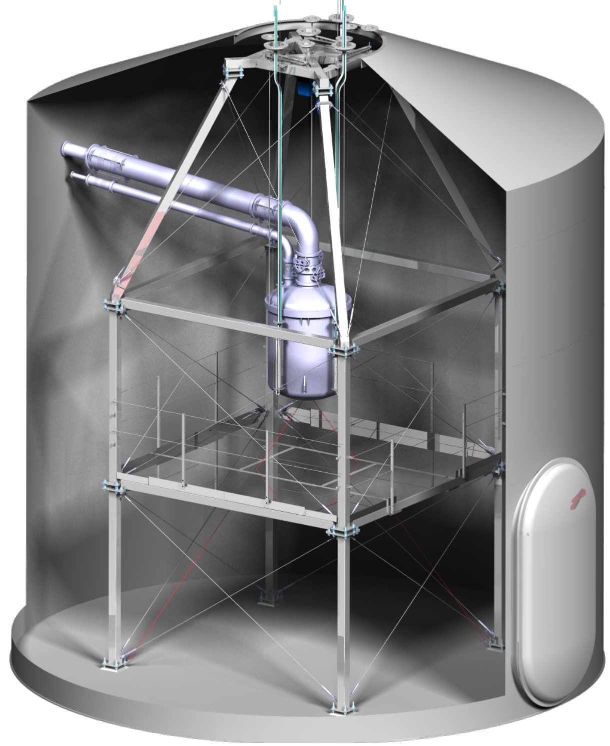

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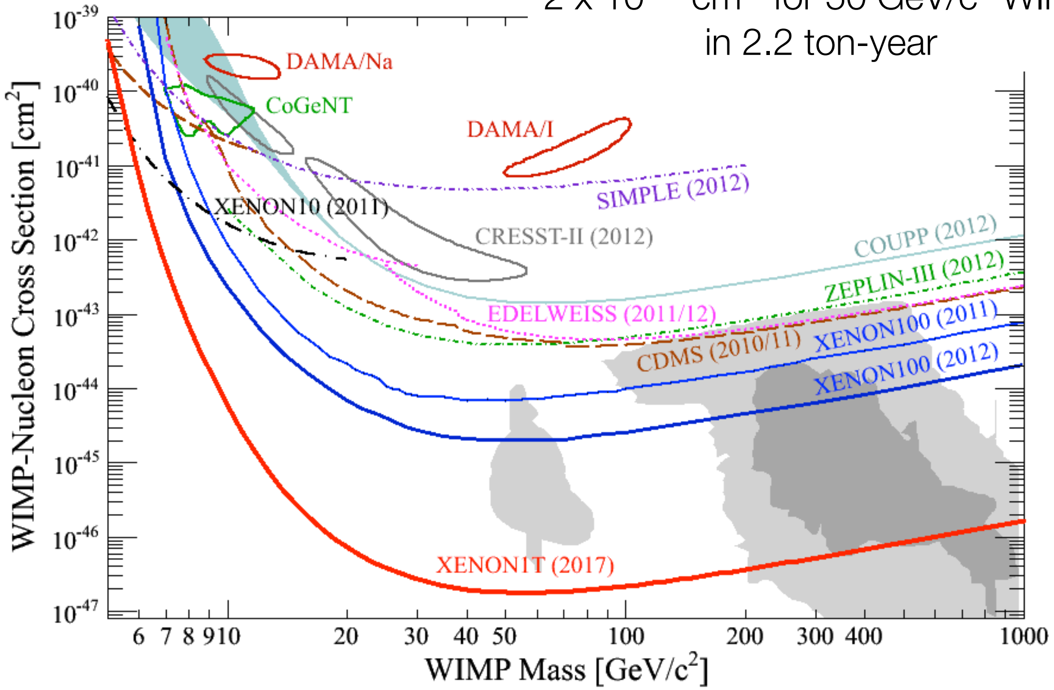
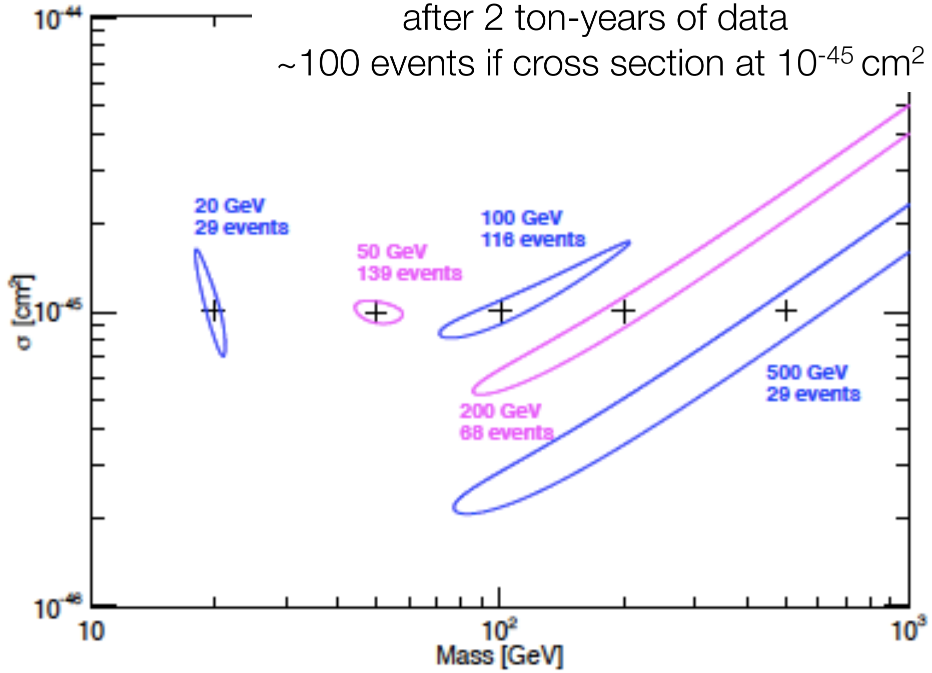


Statistically significant WIMP signal after 2 ton-years of data
~100 events if cross section at 10^{-45} cm^2



Columbia Rice UCLA Zürich Coimbra LNGS INFN Purdue

Bologna Subatech Münster Heidelberg Nikhef Weizmann Mainz Bern

שומר מה מלילה

"Watchman,

What is left of the night?"

Isaiah 21:11