The XENON Dark Matter Project

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Columbia University
US-Italy Physics Program at LNGS
Princeton, October 15, 2013

The XENON Dark Matter Program

- Goal: WIMP Dark Matter Search with a sensitivity of ~ 10^{-48} cm^2

- Strategy: phased program with detectors of increasing fiducial target mass (from 10kg to 100kg to 1000kg) and decreasing overall background (XENON100 has achieved 5 x 10^{-3} evts/kg/keVee/day before discrimination)

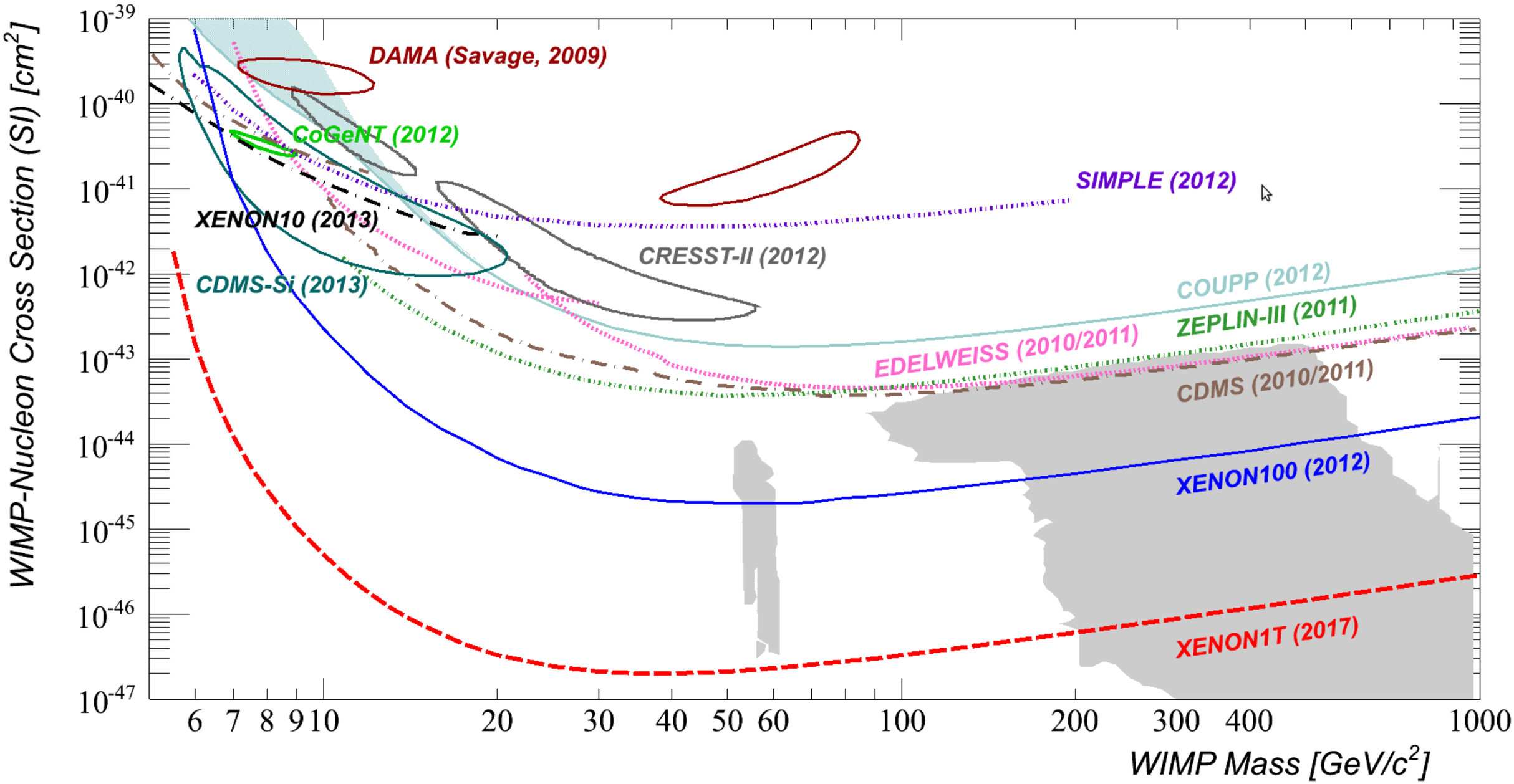
- Detector: LXe (sensitive to both scalar and axial coupling) two-phase XeTPC with simultaneous charge and light detection via PMTs. 3D-event imaging with millimeter spatial resolution. Low energy threshold (~6 keVr)

- Background Reduction and Signal Discrimination: a) LXe self-shielding; b) Volume fiducialization; c) multiple-scatter events rejection; d) NR/ER discrimination via charge/light ratio

- Status: XENON100 continues to take data (~90 live-days to-date); multiple analyses (solar axions, low-mass WIMPs, annual modulation..) being finalized with 225 live-days. Construction of XENON1T ongoing and on schedule. Science data taking expected in 2015

The Sensitivity of XENON1T

➔ goal: $\sigma < 2 \times 10^{-47}$ cm^2 for $M_{WIMP} = 50$ GeV after 2t*year

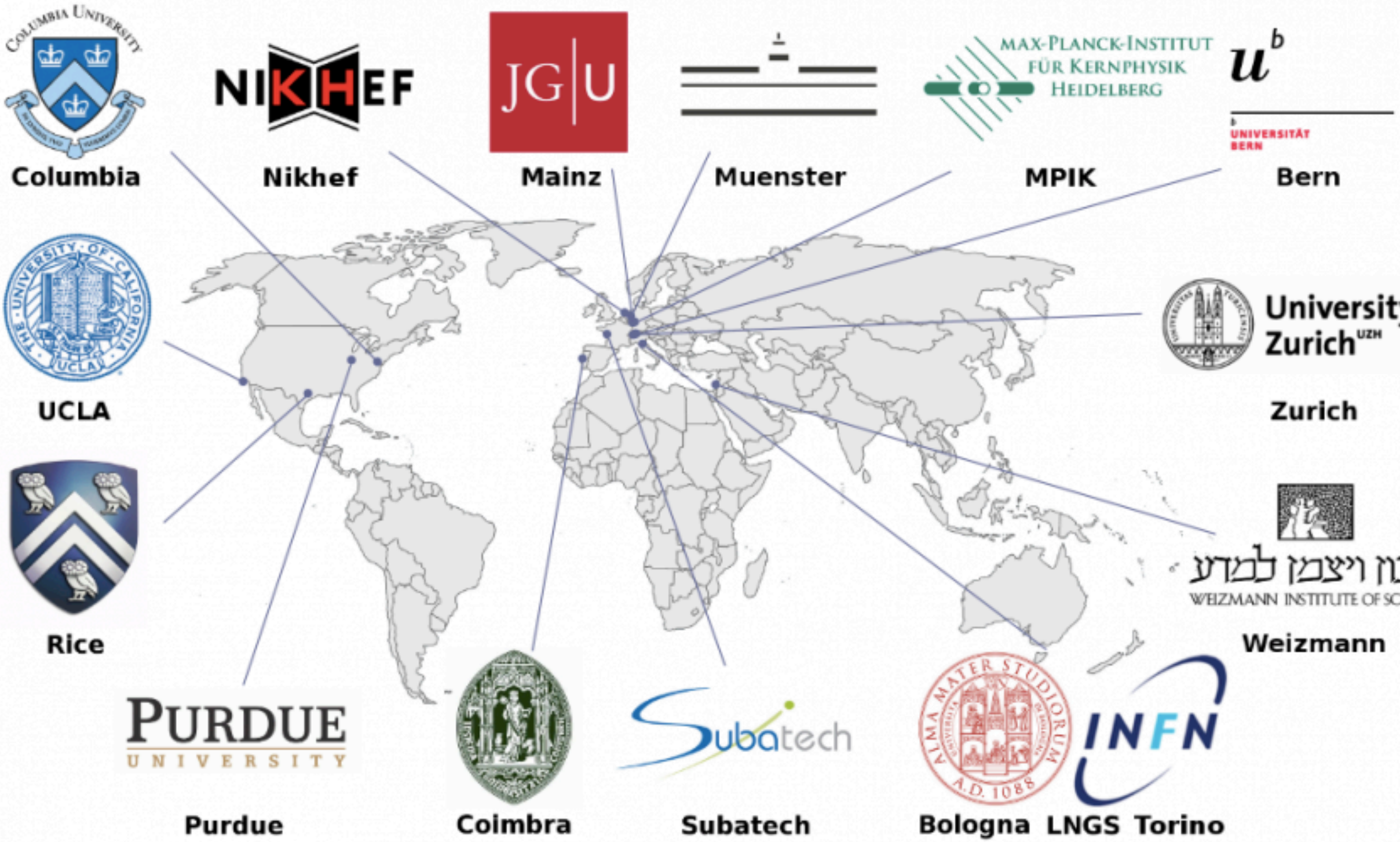


The XENON Collaboration

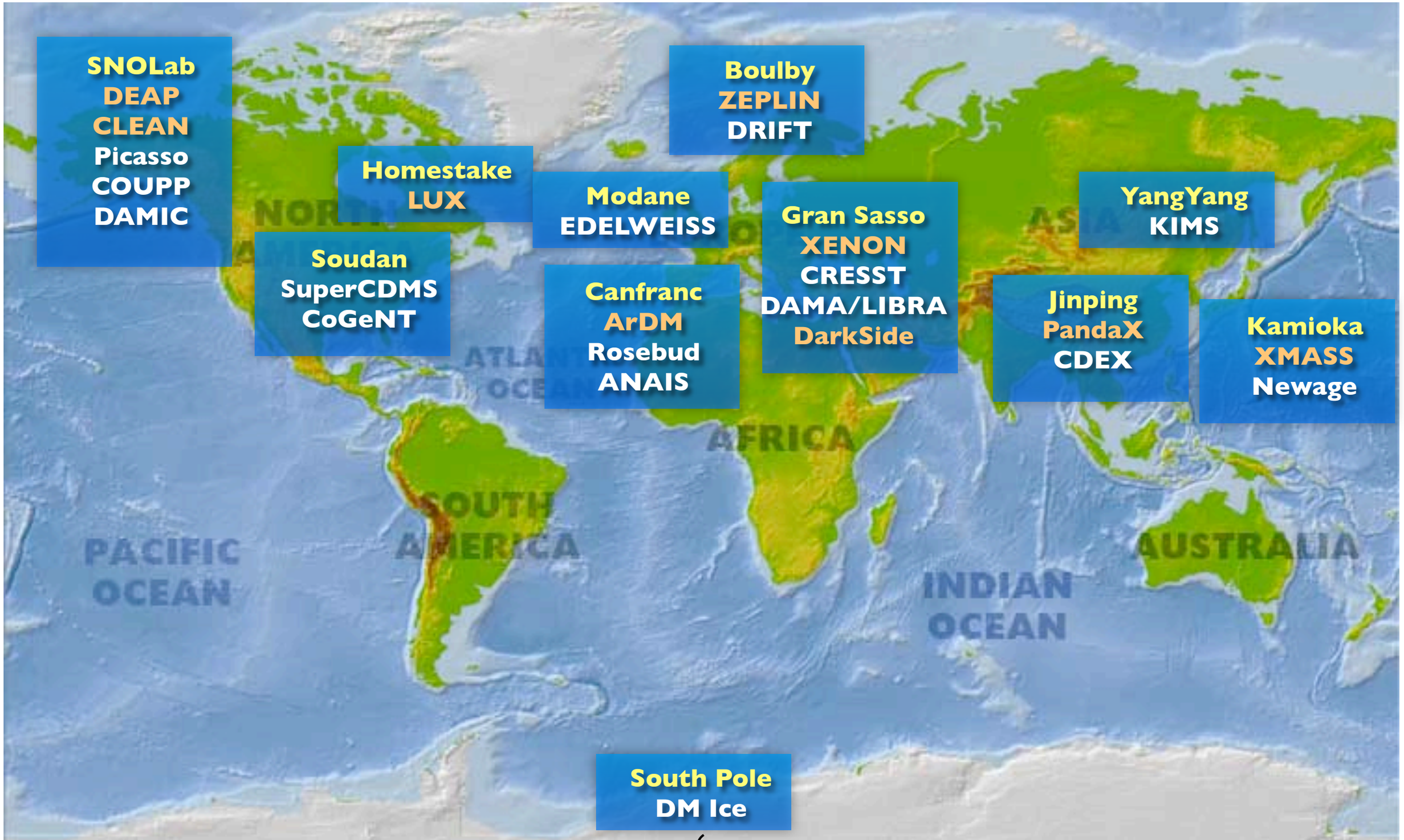
US led and NSF supported since start of project
~100 scientists from 15 institutions

The XENON Collaboration

XENON Dark Matter Project

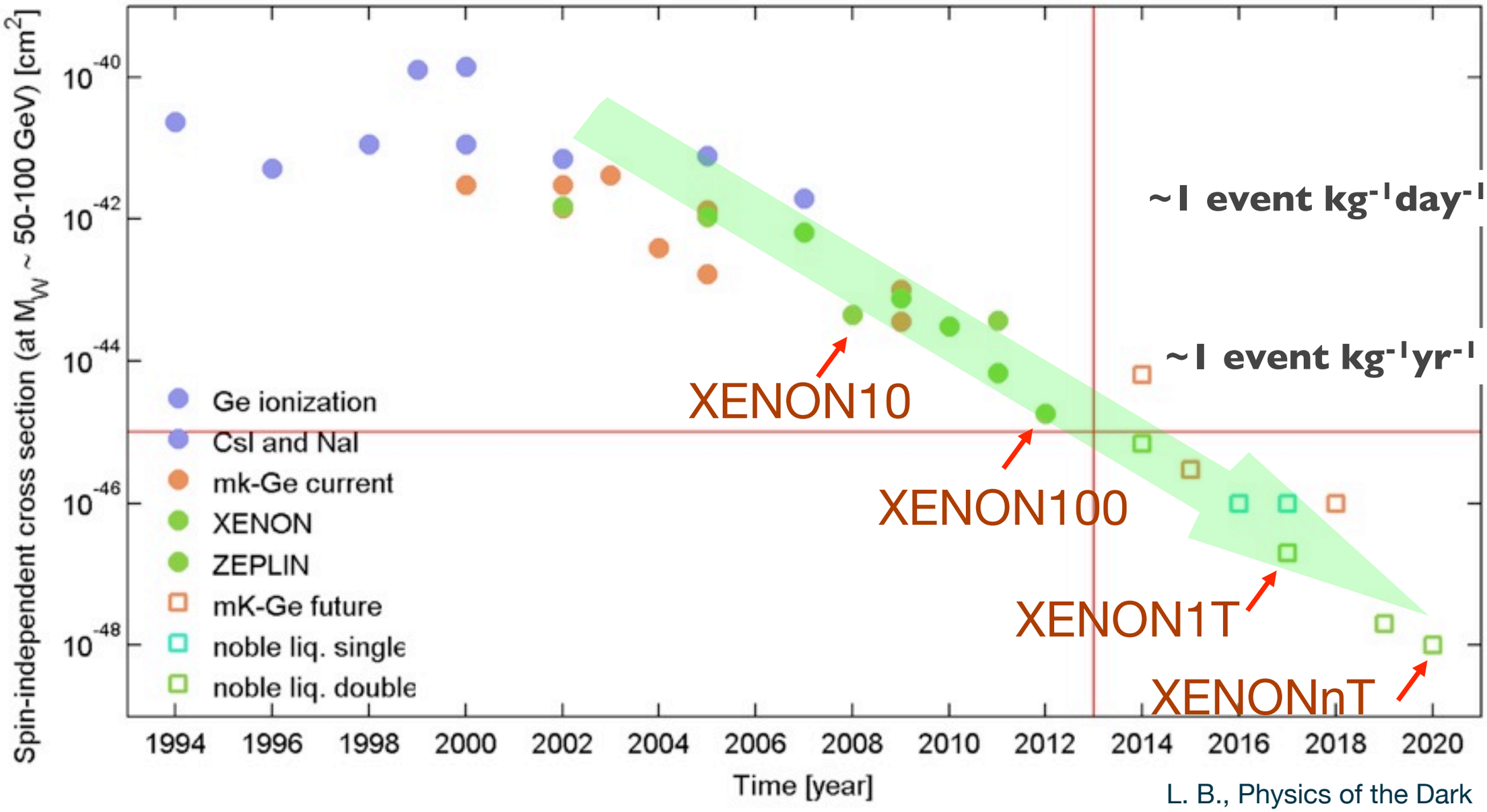


A world-wide effort to search for WIMPs



Direct detection: progress over time

Factor ~ 10 every two years
DRIVEN BY XENON!



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

The phases of XENON

Past: 2005-2007

XENON10

15 kg active mass

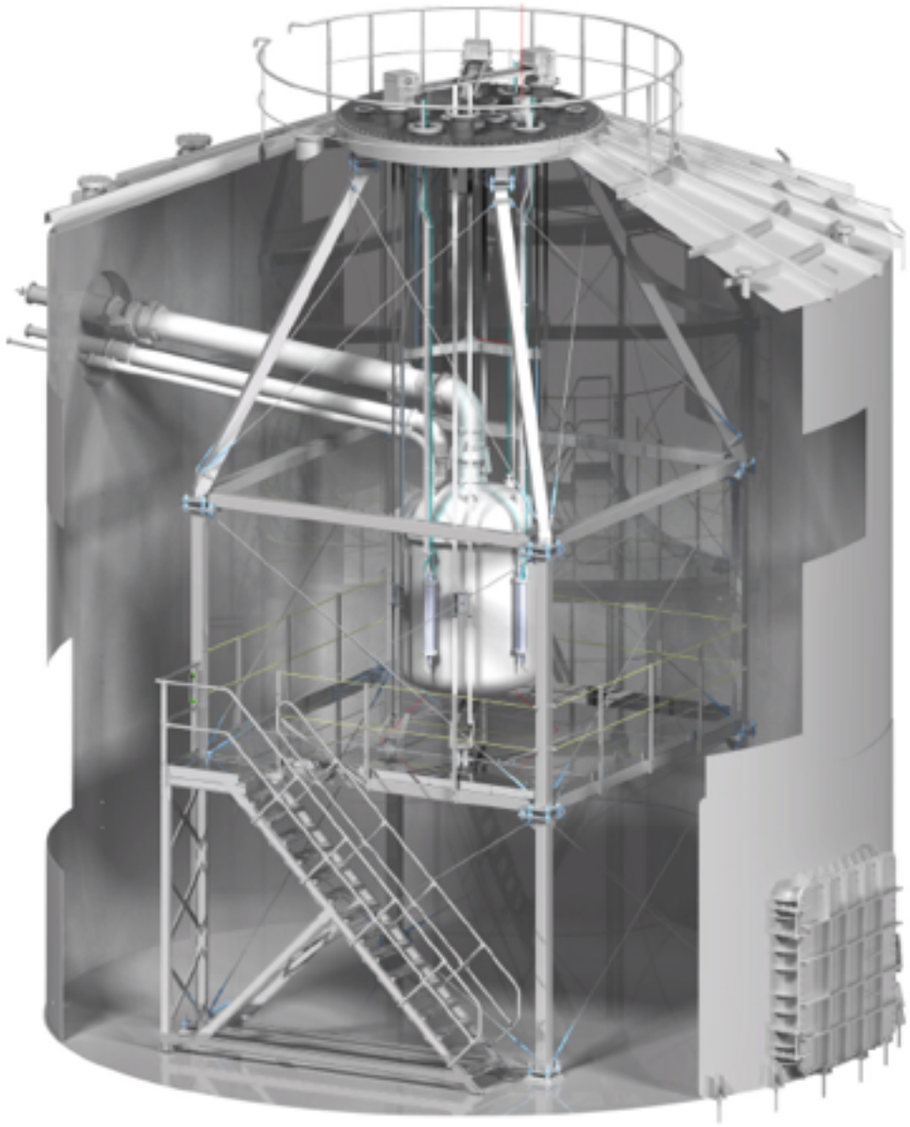
$\sigma_{SI} < 8.8 \times 10^{-44}$ cm^2 (2007)

Present: 2008-201?

XENON100

62 kg active mass

$\sigma_{SI} < 2.0 \times 10^{-45}$ cm^2 (2012)



Future: 2010-2017

XENON1T

~ 2.2 ton active mas

$\sigma_{SI} \sim 2 \times 10^{-47}$ cm^2 (*proj.*)

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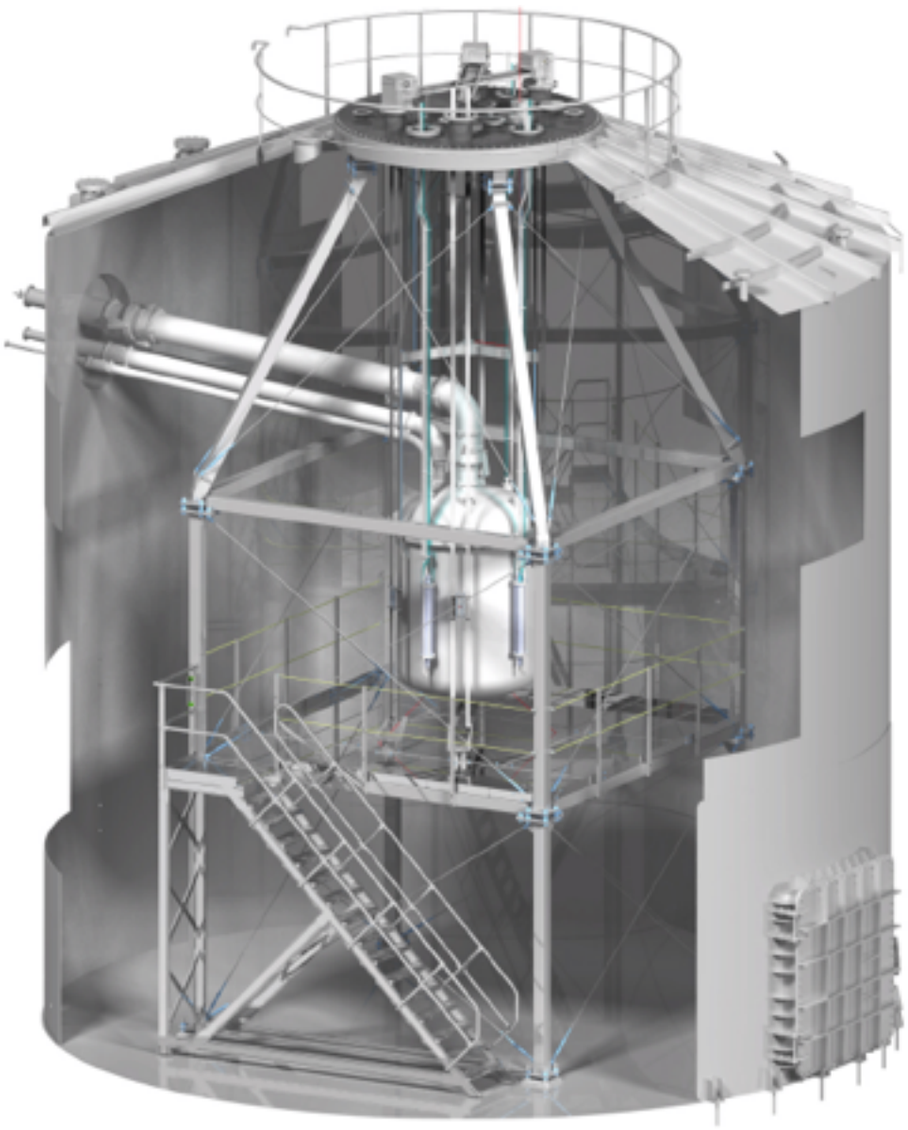

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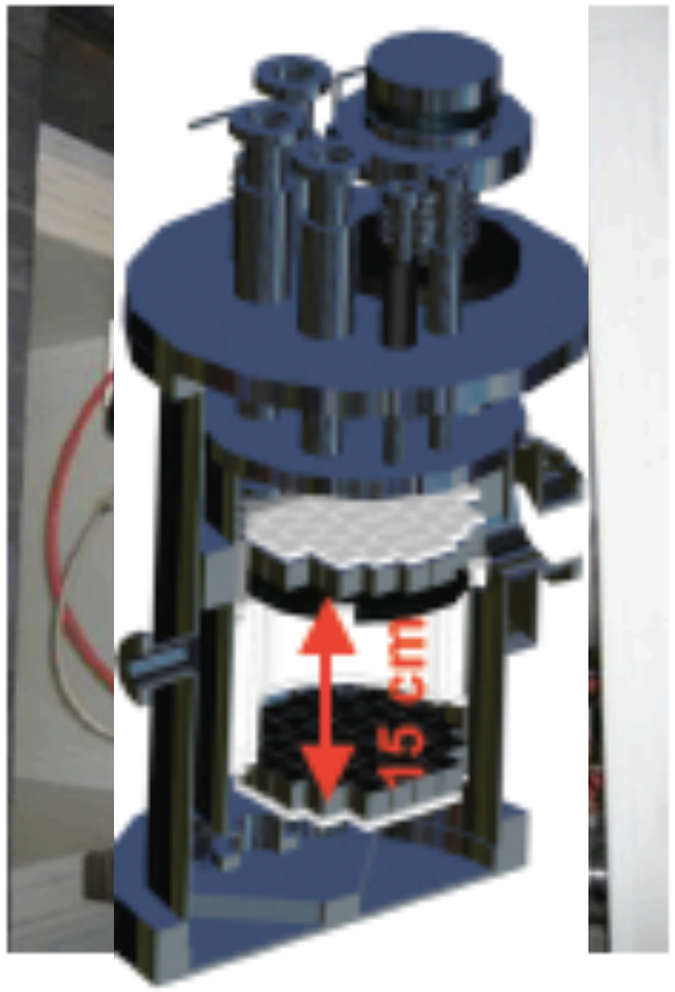

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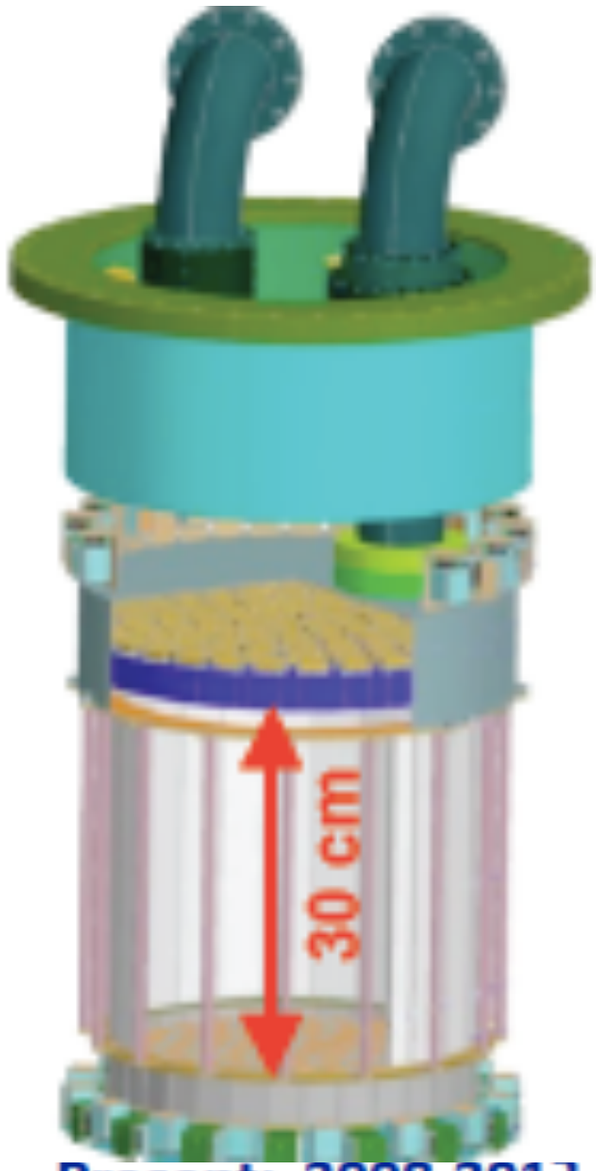

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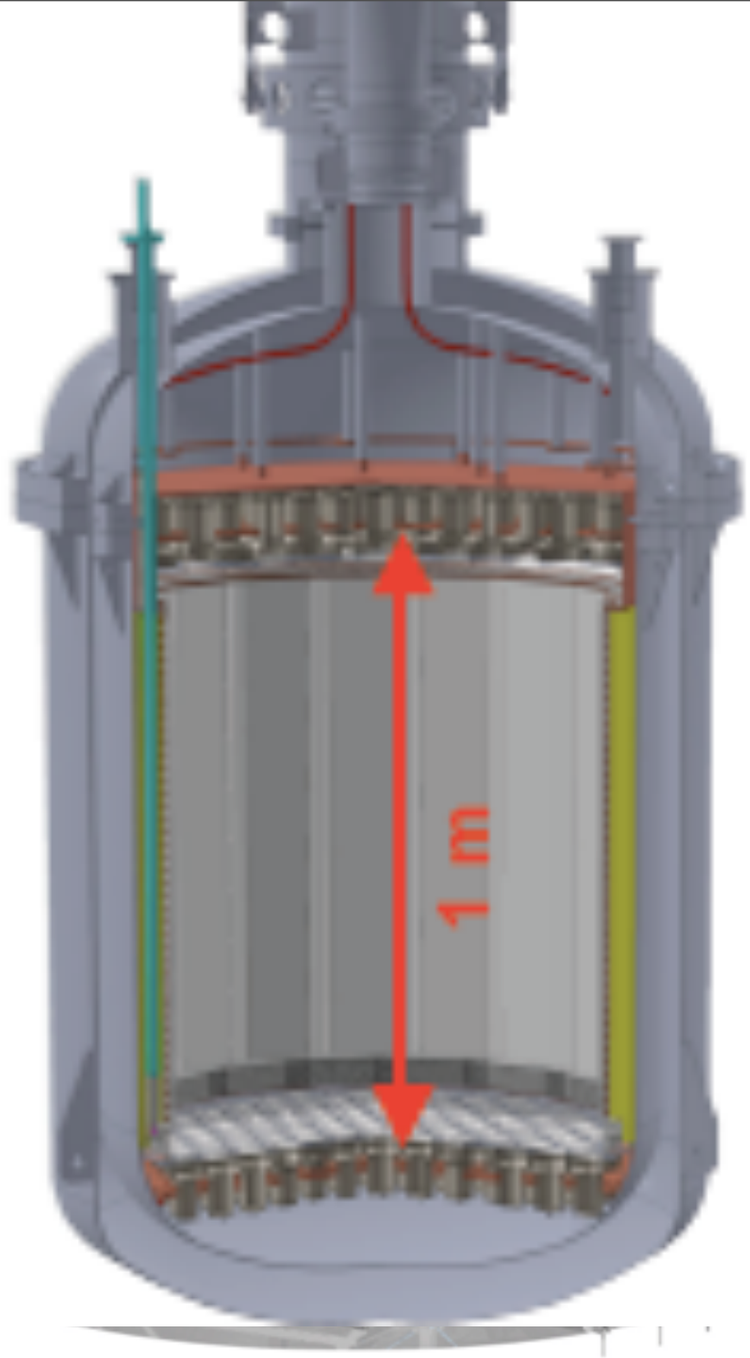

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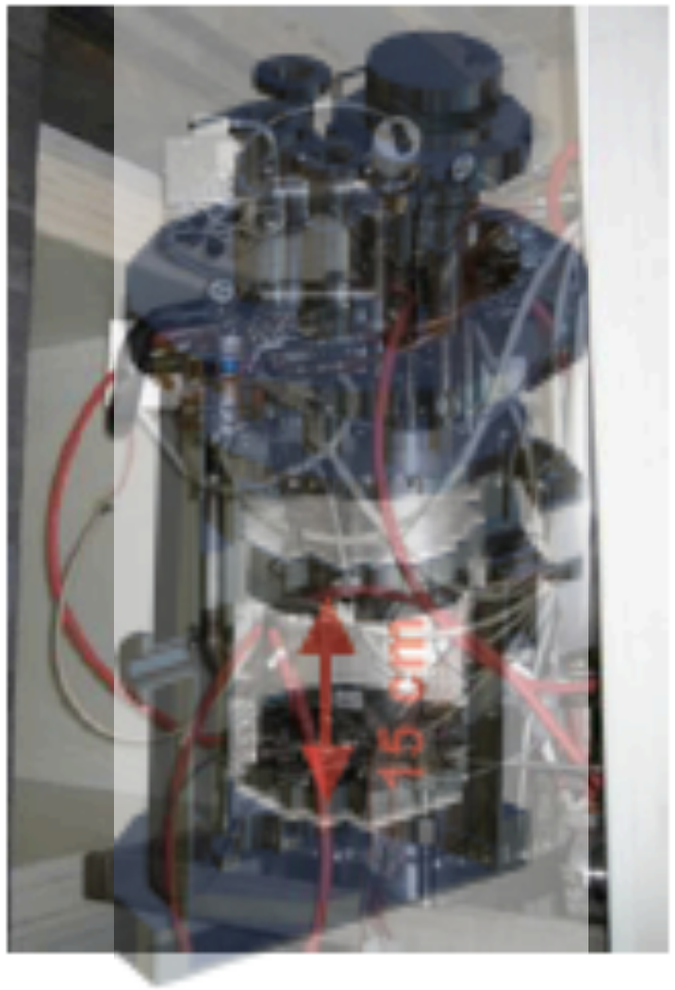

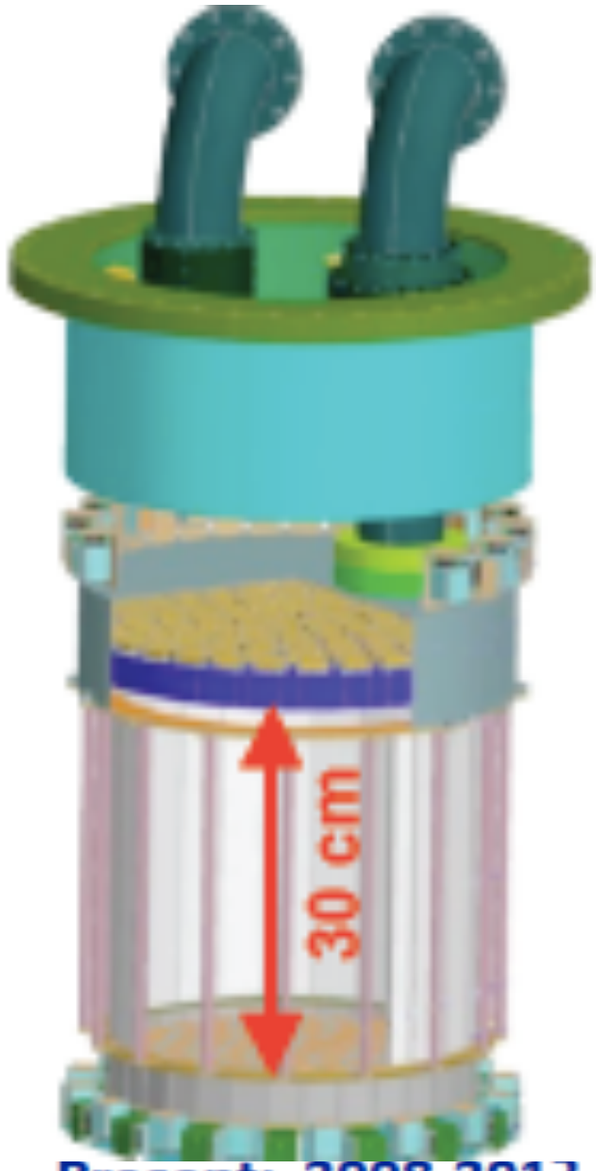

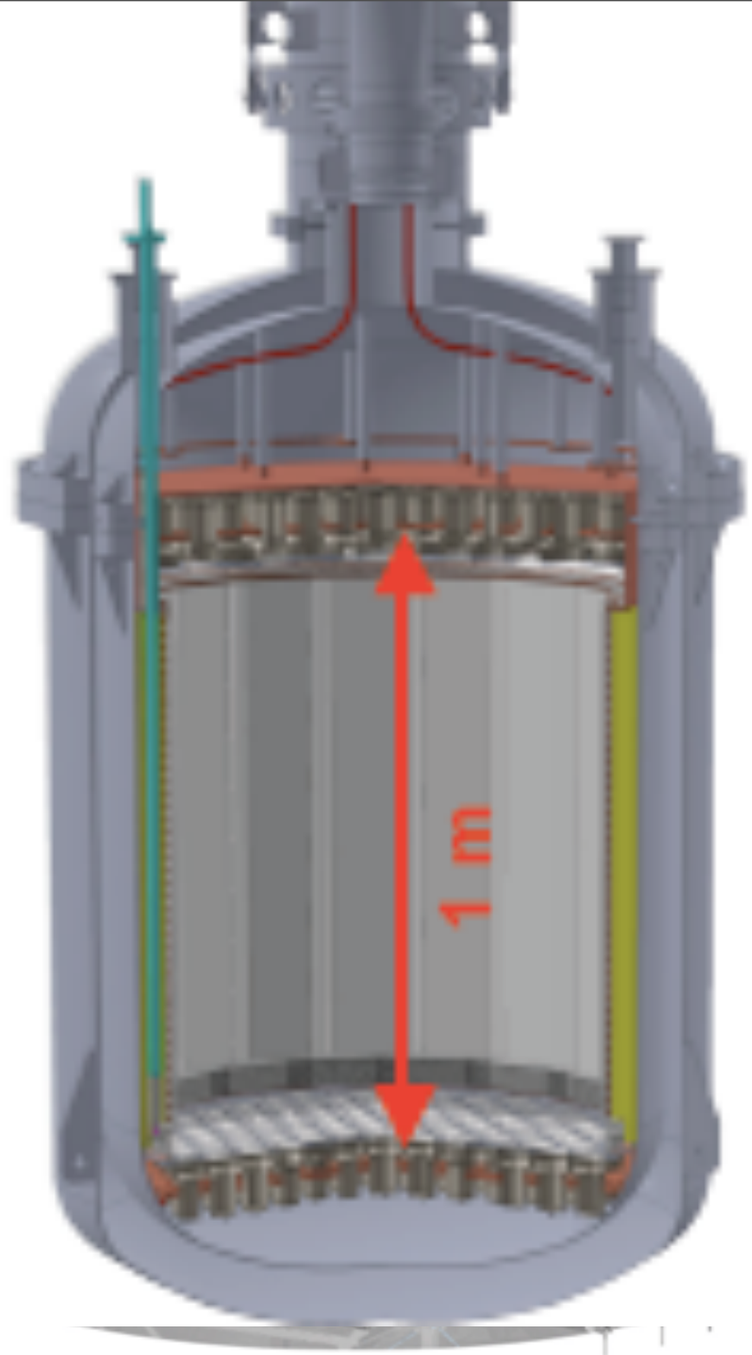

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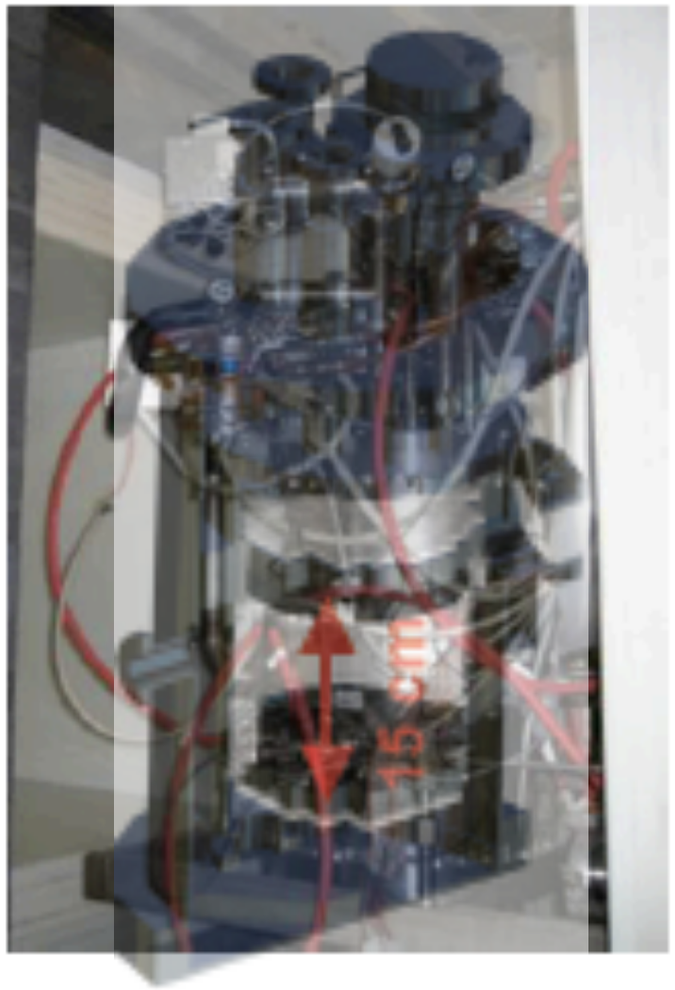

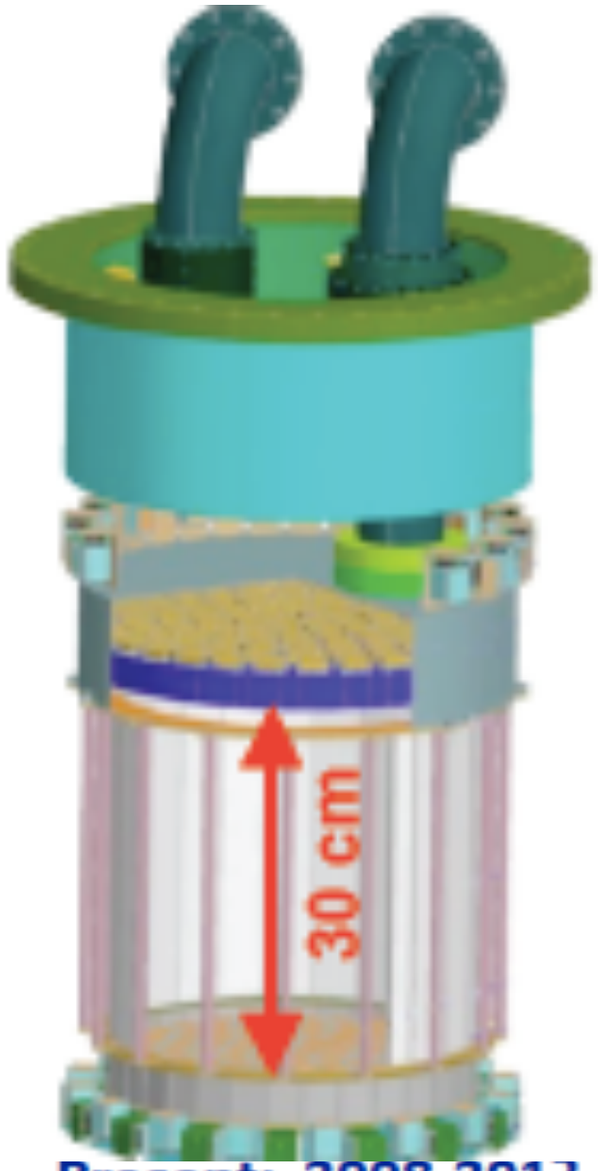

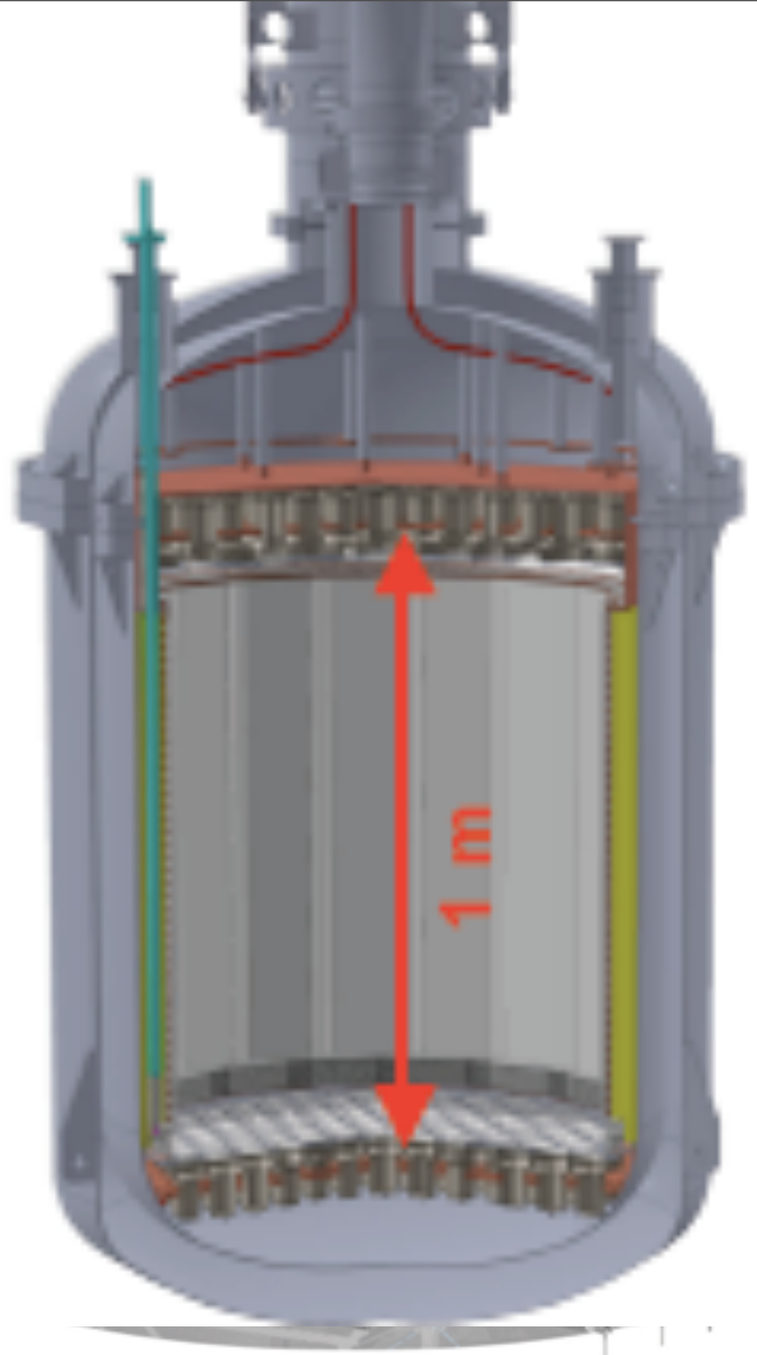

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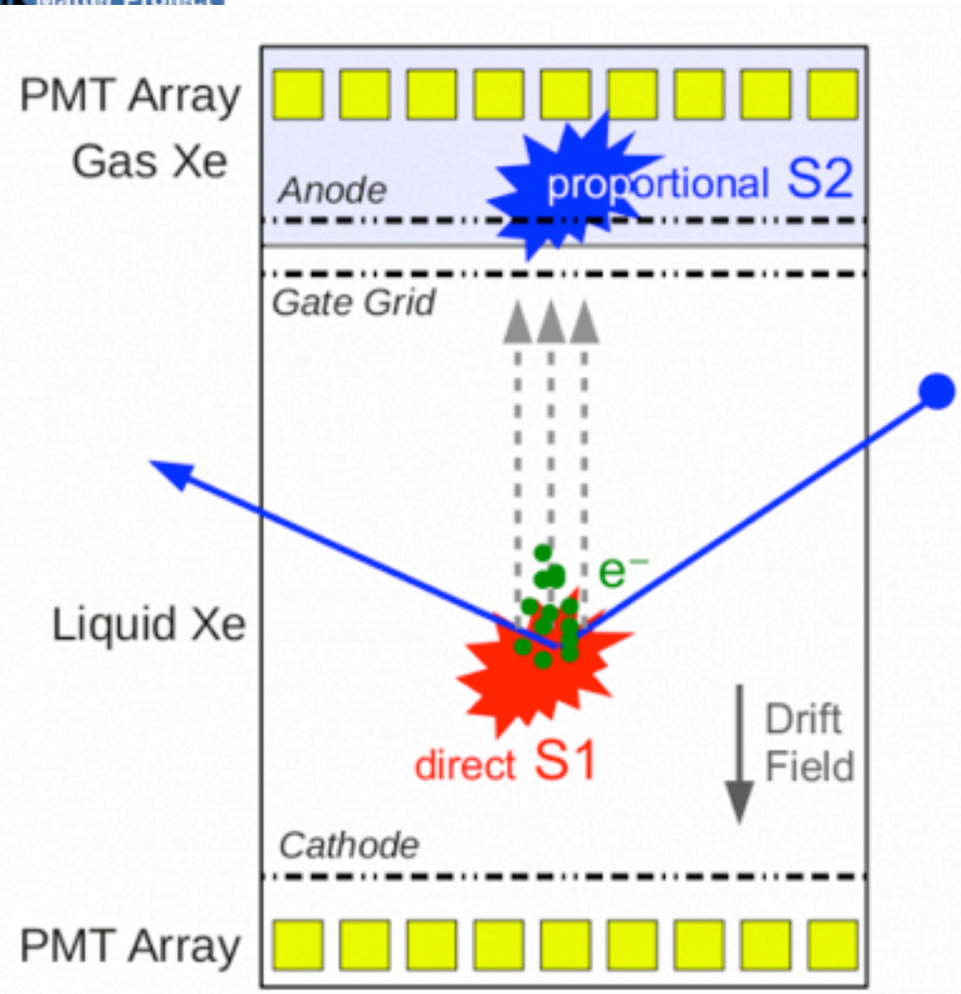
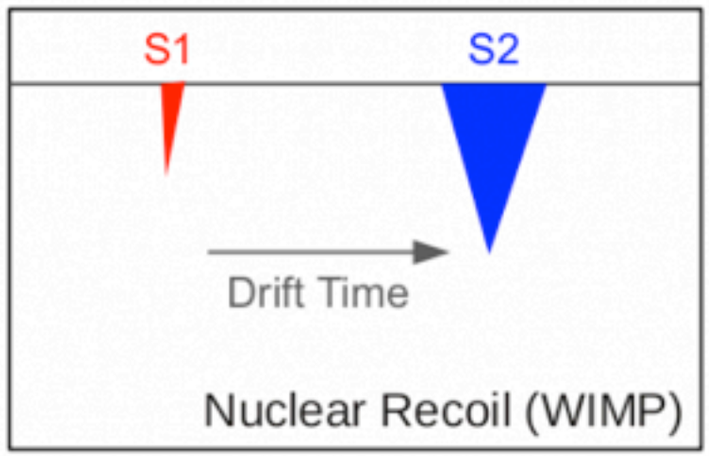
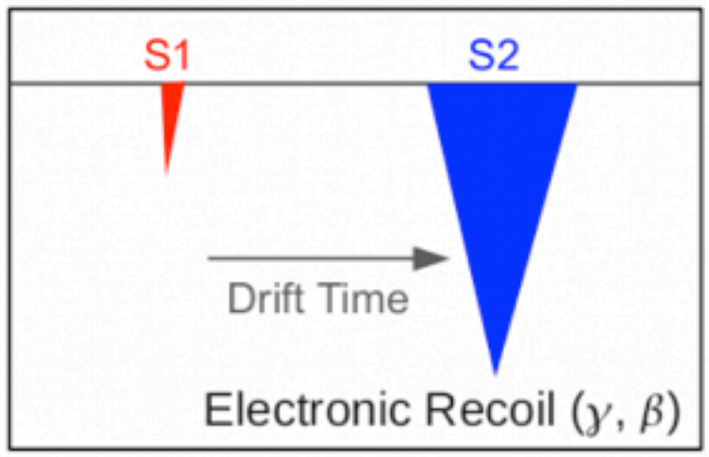
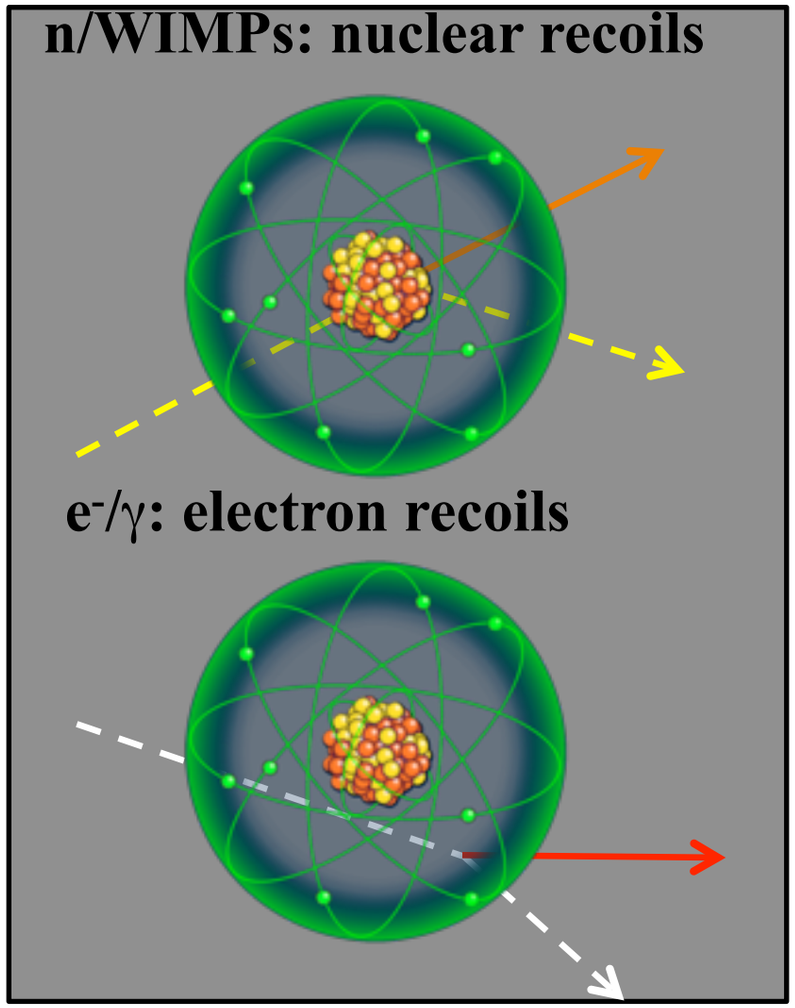
The XENON Detector : a 2-phase TPC









Discrimination of e^-/γ and nuclear recoils: $\mathbf{(S2/S1)_{n,WIMP} < (S2/S1)_{e,\gamma(}}$ > 99% ER rejection

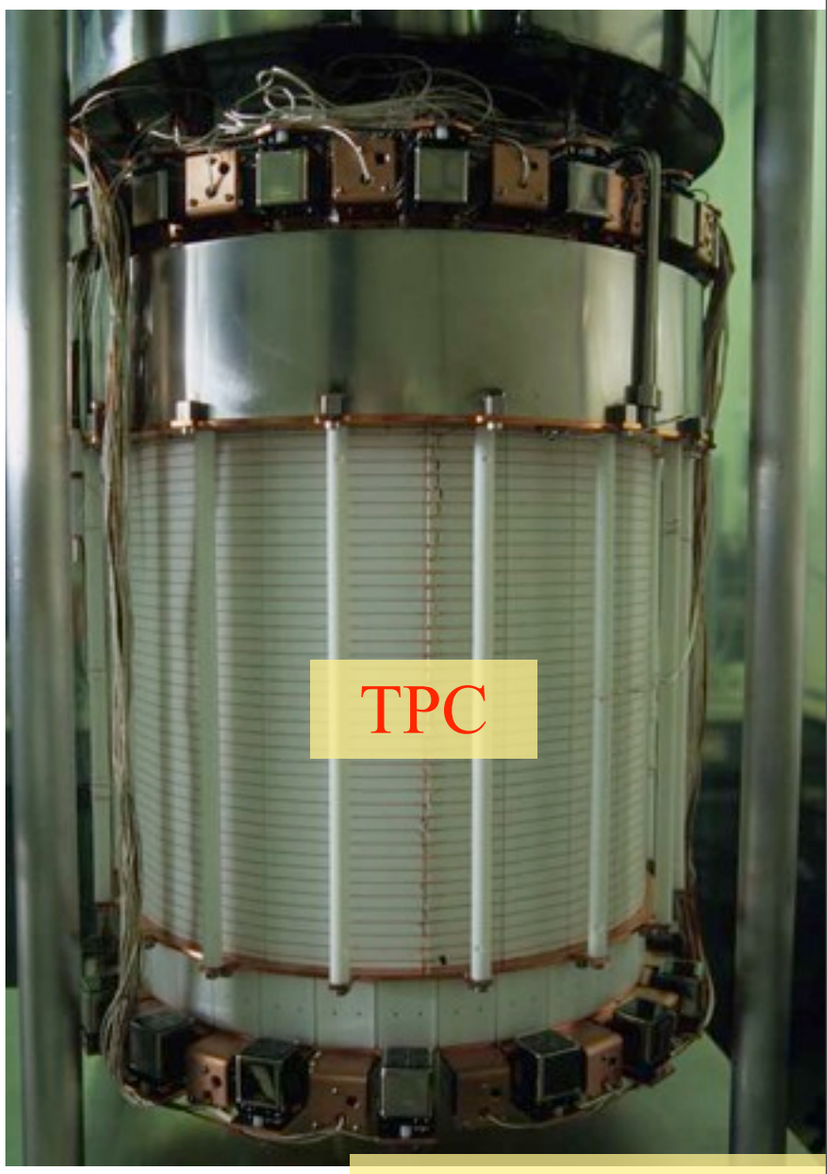
3D event position: drift time -> z (<0.3mm); PMT pattern -> x,y (<3mm)

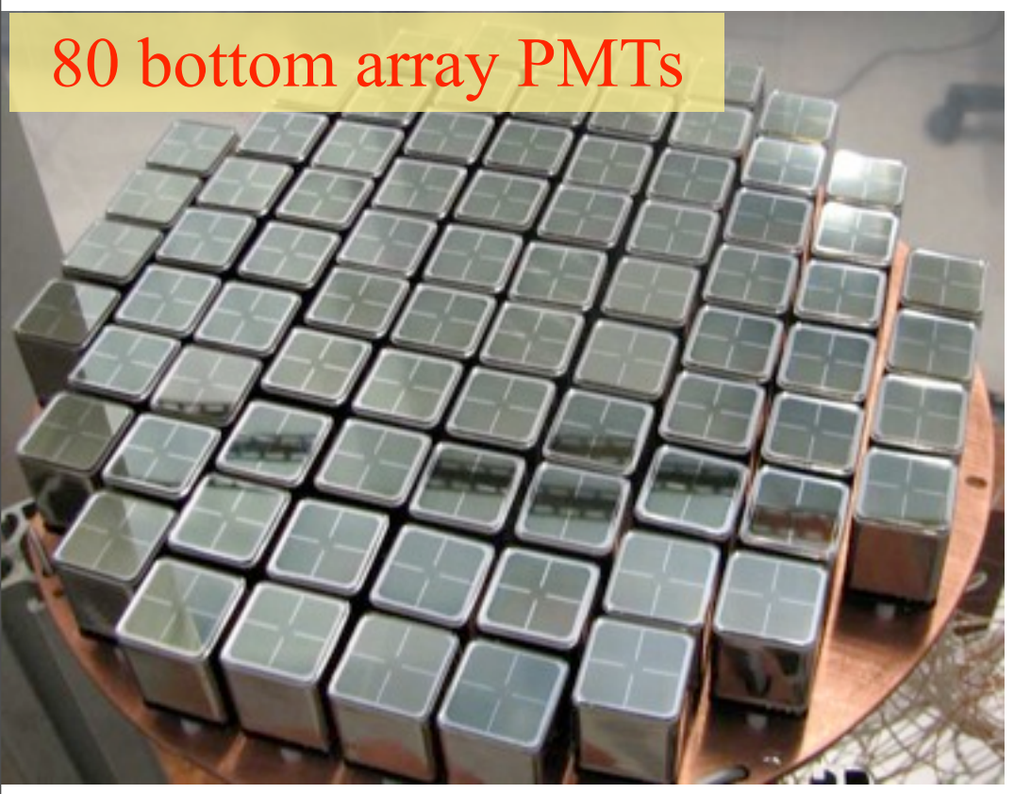
precise fiducial inner volume (avoid BG in outer volume)

Discrimination of single/multiple scattering

screening materials/purification of Xe -> further background reduction

The XENON100 Detector

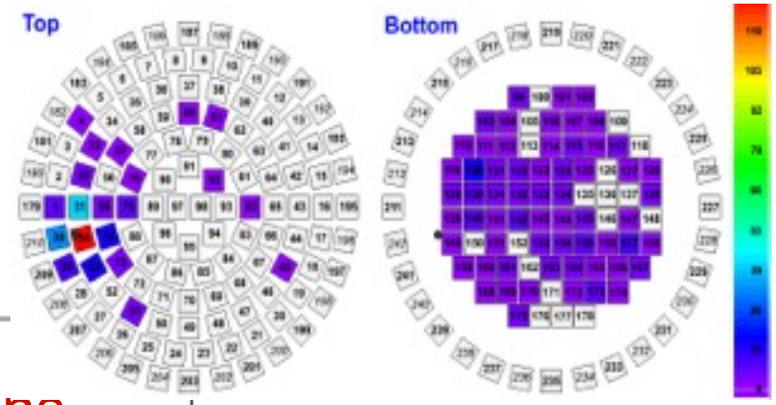


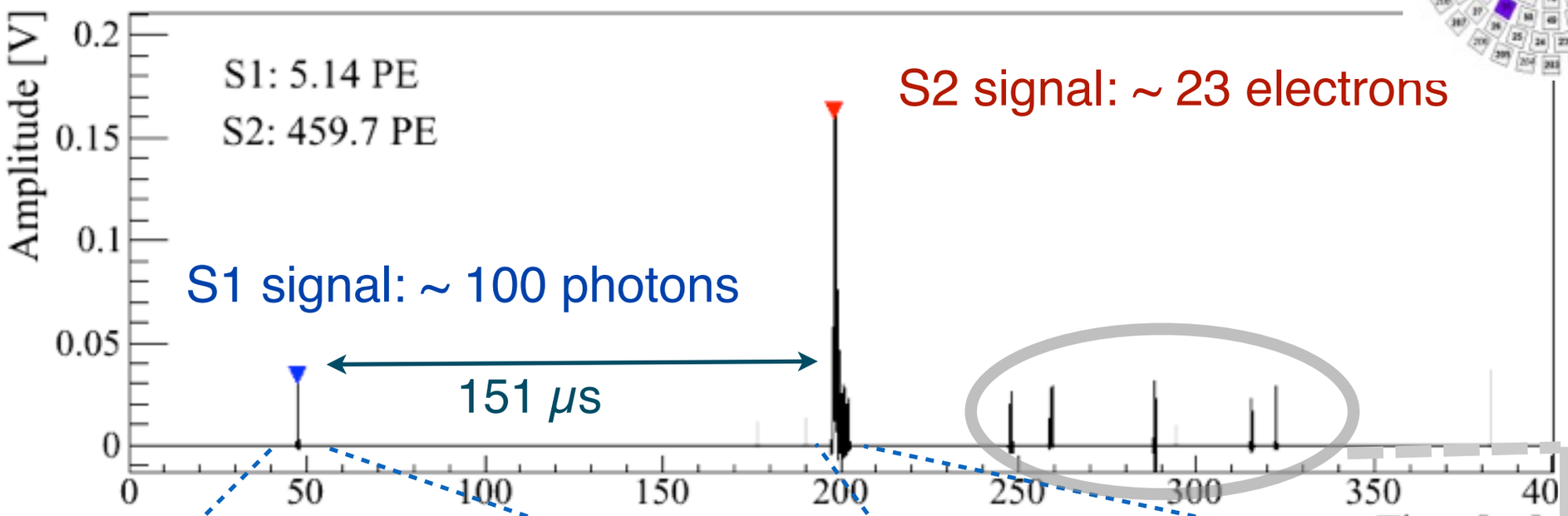


- 161kg Xe, 62kg target
- 30cm drift length
- radio-purity → material screening
- ^{85}Kr → distillation column
- ^{222}Rn emanation → avoid/monitor
- passive shielding: water, lead, PE, copper

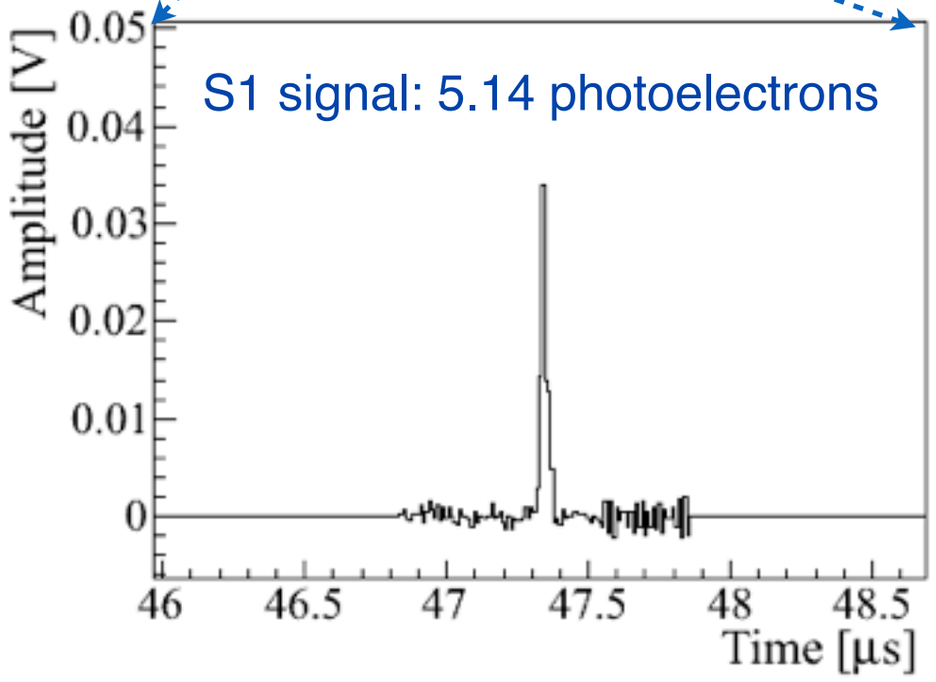
Example of a low-energy event in XENON100

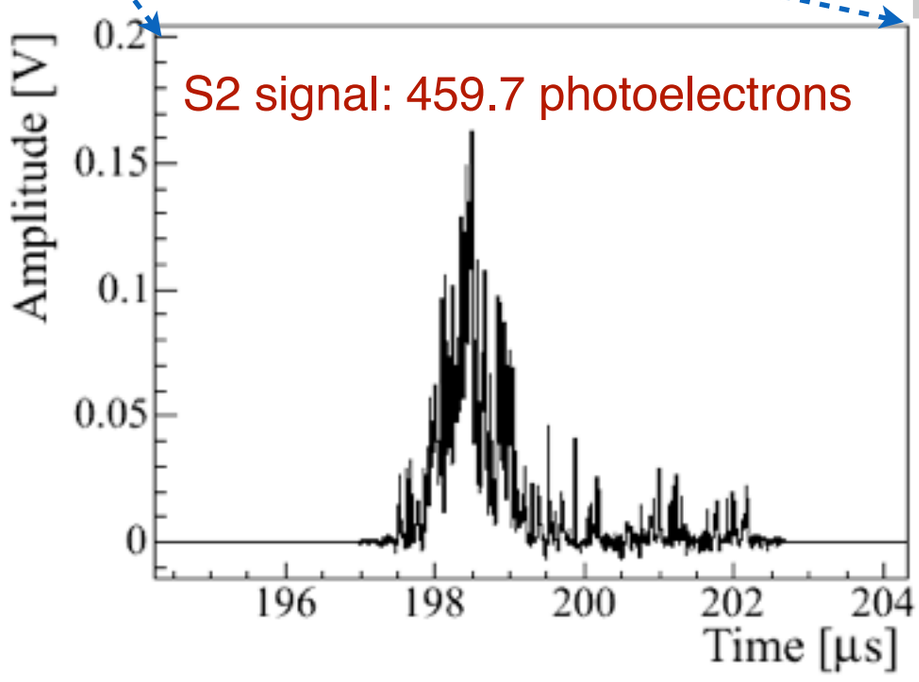
The maximum electron drift time at 0.53 kV/cm is 176 μs



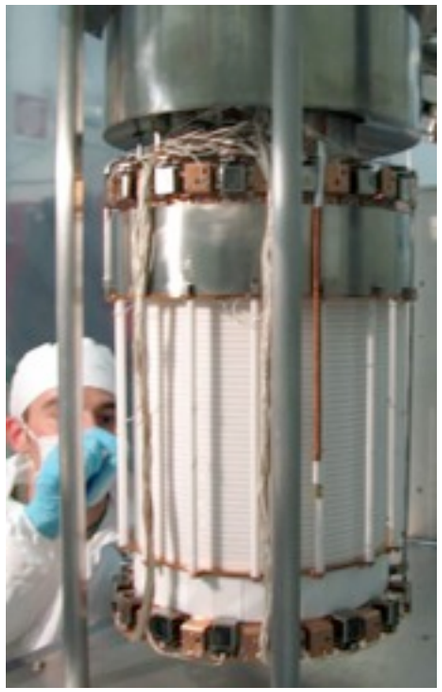


- Delayed scintillation
- Secondary ionization
- Single electrons





2-phase TPCs for DM searches



XENON100 at LNGS:

161 kg LXe
(~50 kg fiducial)

242 1-inch PMTs
taking new science data

LUX at SURF:

350 kg LXe
(100 kg fiducial)

122 2-inch PMTs
physics run since spring 2013
first result by the end of this year

PandaX at CJPL:

125 kg LXe
(25 kg fiducial)

143 1-inch PMTs
37 3-inch PMTs
started in 2013

ArDM at Canfranc:

850 kg LAr
(100 kg fiducial)

28 3-inch PMTs
in commissioning
to run 2014

DarkSide at LNGS

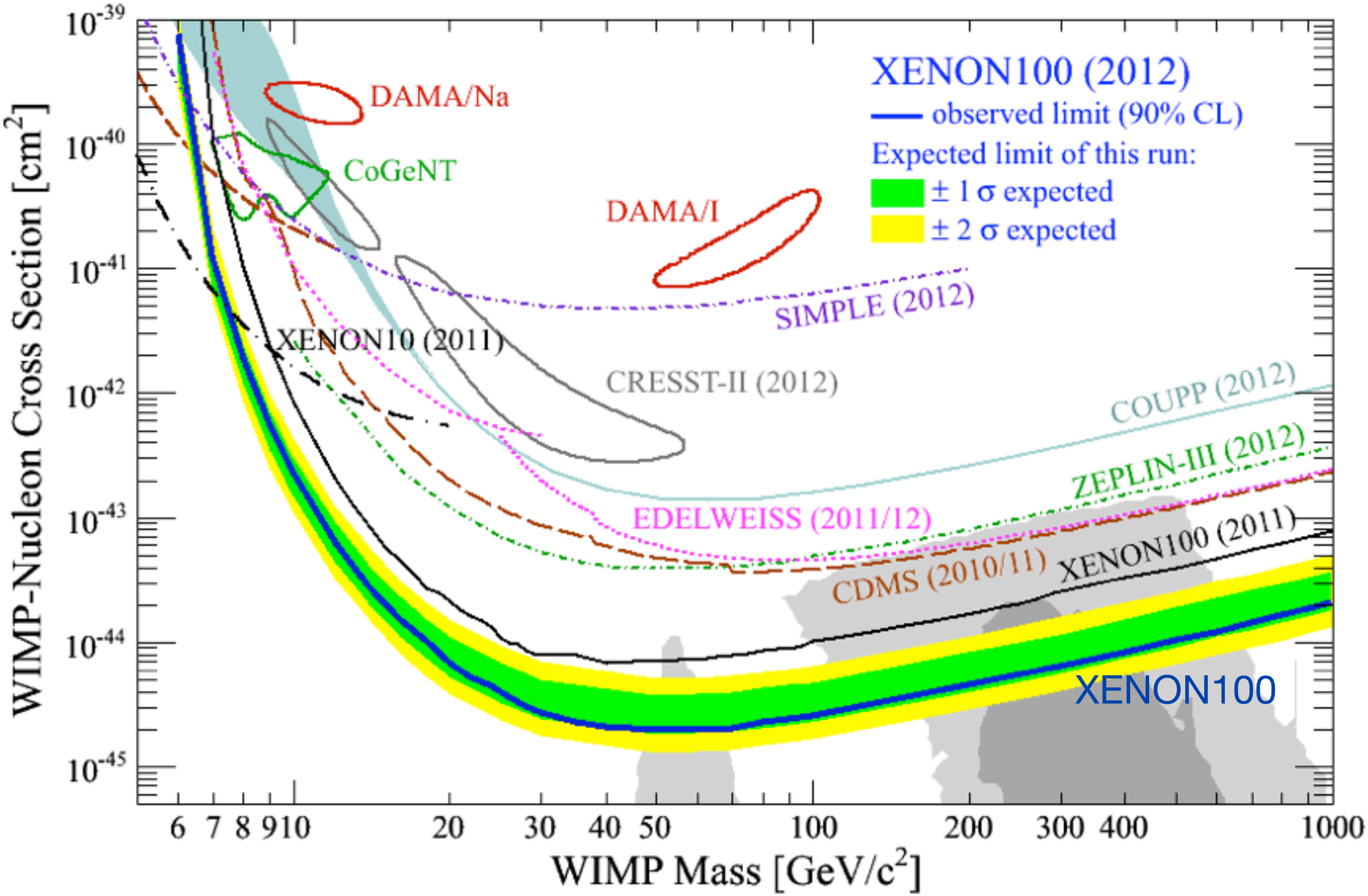
50 kg LAr (dep in ^{39}Ar)
(33 kg fiducial)

38 3-inch PMTs
in commissioning since May 2013
to run in fall 2013

Results from XENON100: spin-independent

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

Best upper limit on WIMP-nucleon cross section: 2×10^{-45} cm^2 at M_W = 55 GeV



Results from XENON100: spin-dependent

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

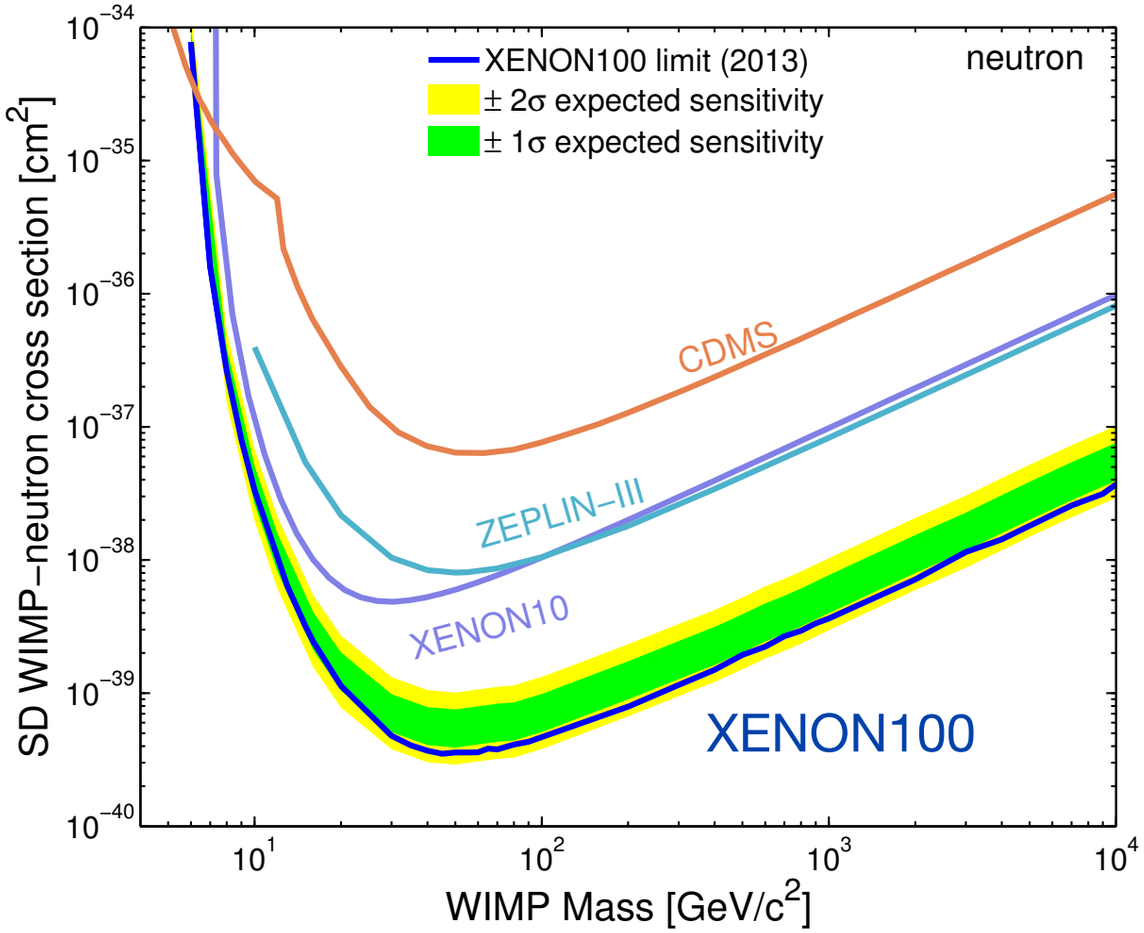
^{129}Xe (spin-1/2) and ^{131}Xe (spin-3/2), two isotopes with J ≠ 0 and 26.2% and 21.8% abundance

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

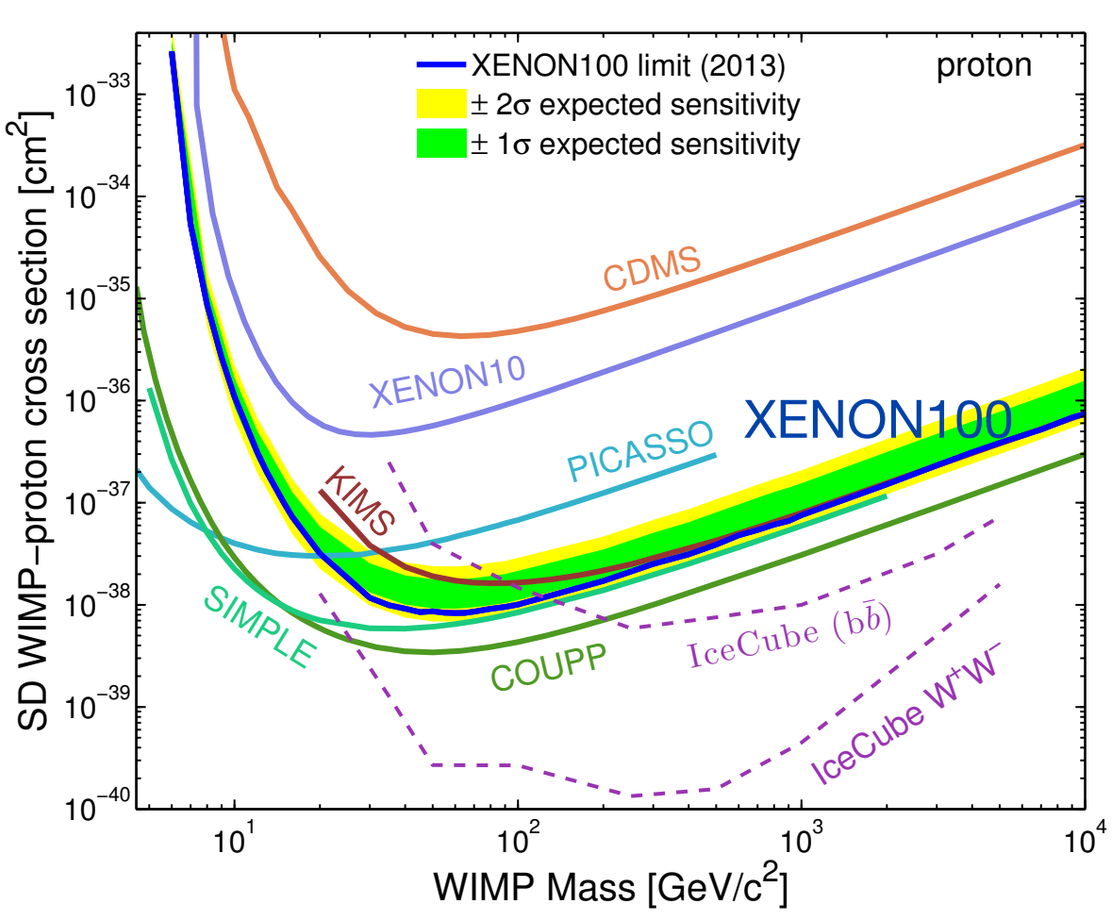
$$S_A(0) = \frac{(2J+1)(J+1)}{\pi J}[a_p\langle S_p\rangle + a_n\langle S_n\rangle]^2$$

Best sensitivity for neutron coupling : 3x10^{-40} cm^2 at M_W = 45 GeV

WIMP-neutron coupling

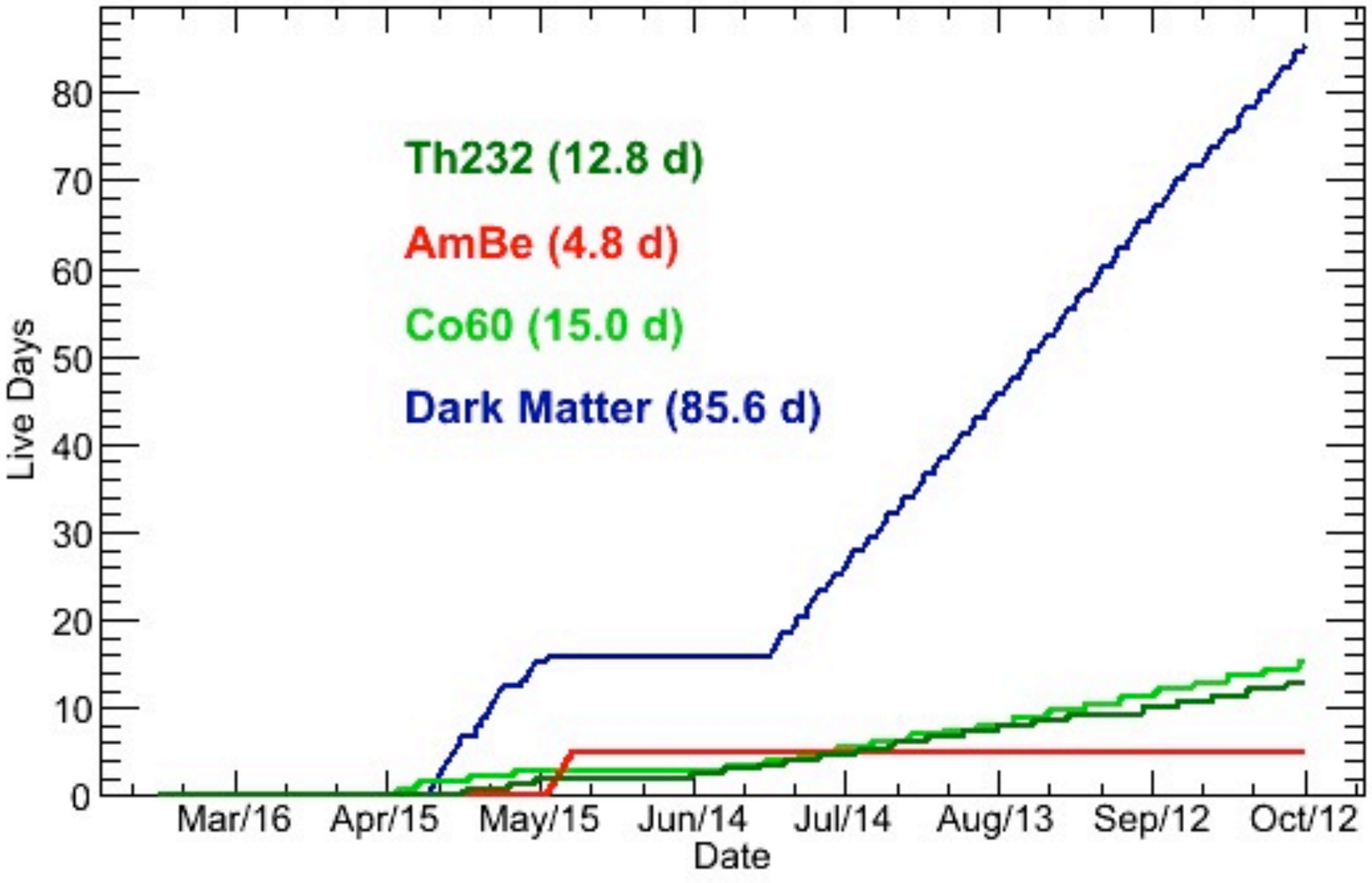


WIMP-proton coupling

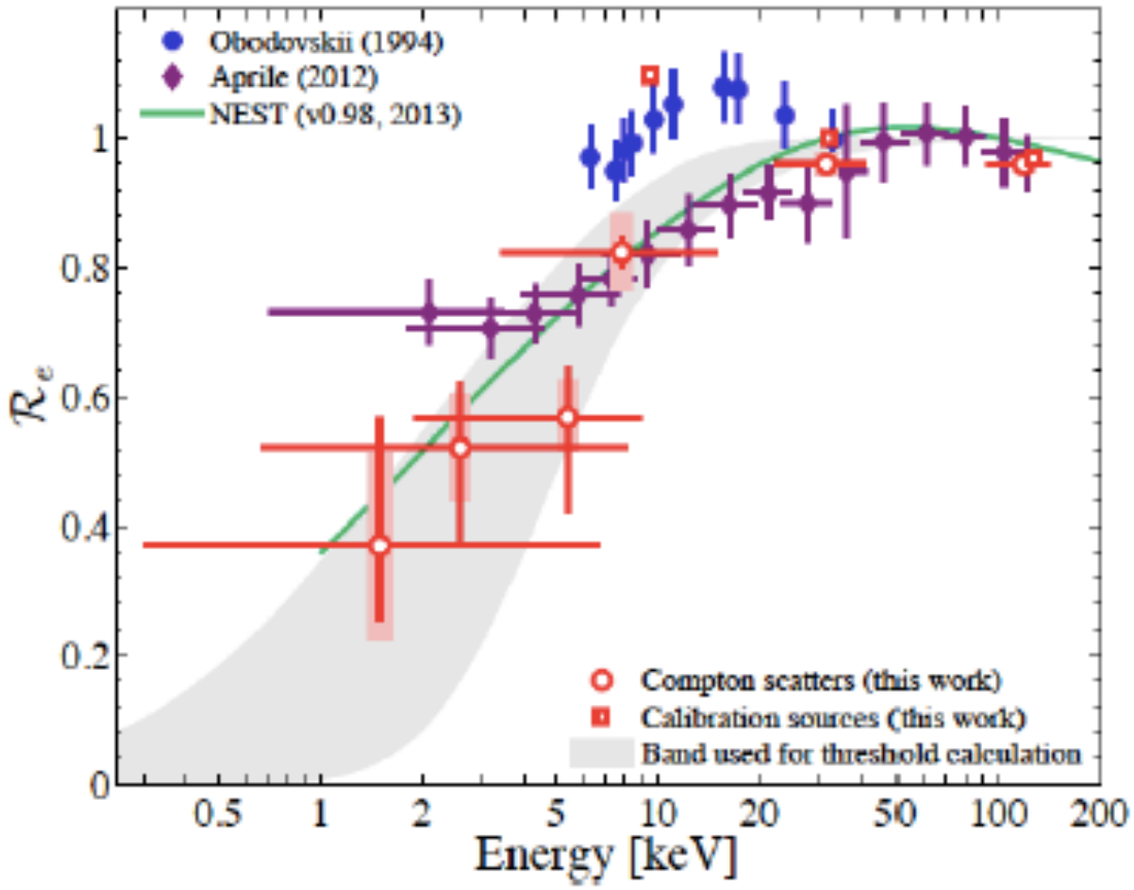


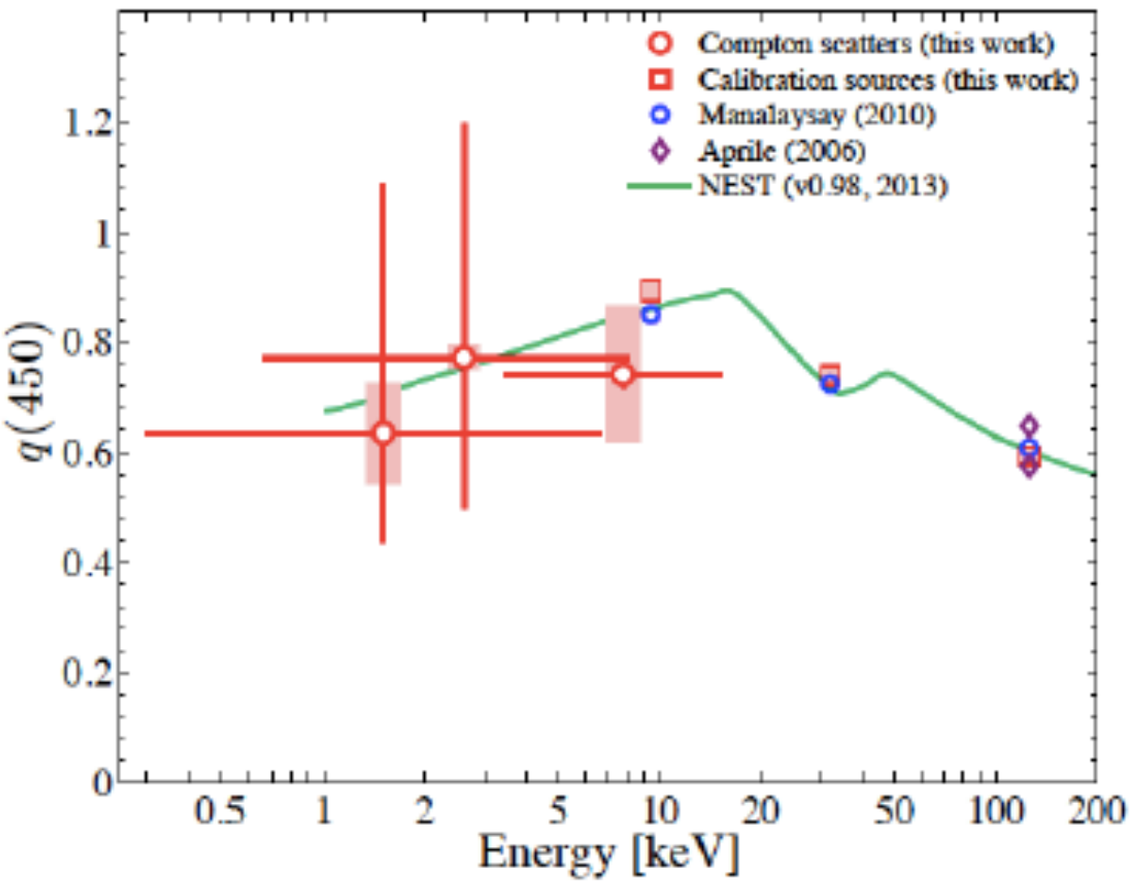
XENON100 New Exposure (2013)

- Lowered Kr/Xe contamination to ppt level to demonstrate capability for XENON1T
- Performed new AmBe calibration and confirmed excellent agreement with MC study
- Detector parameters are stable and performance excellent
- Primary goal is to take another full year of data and possibly more years to study annual modulation. R&D work at Columbia & Zurich continue to measure the ER energy scale



Results on ER Energy Scale

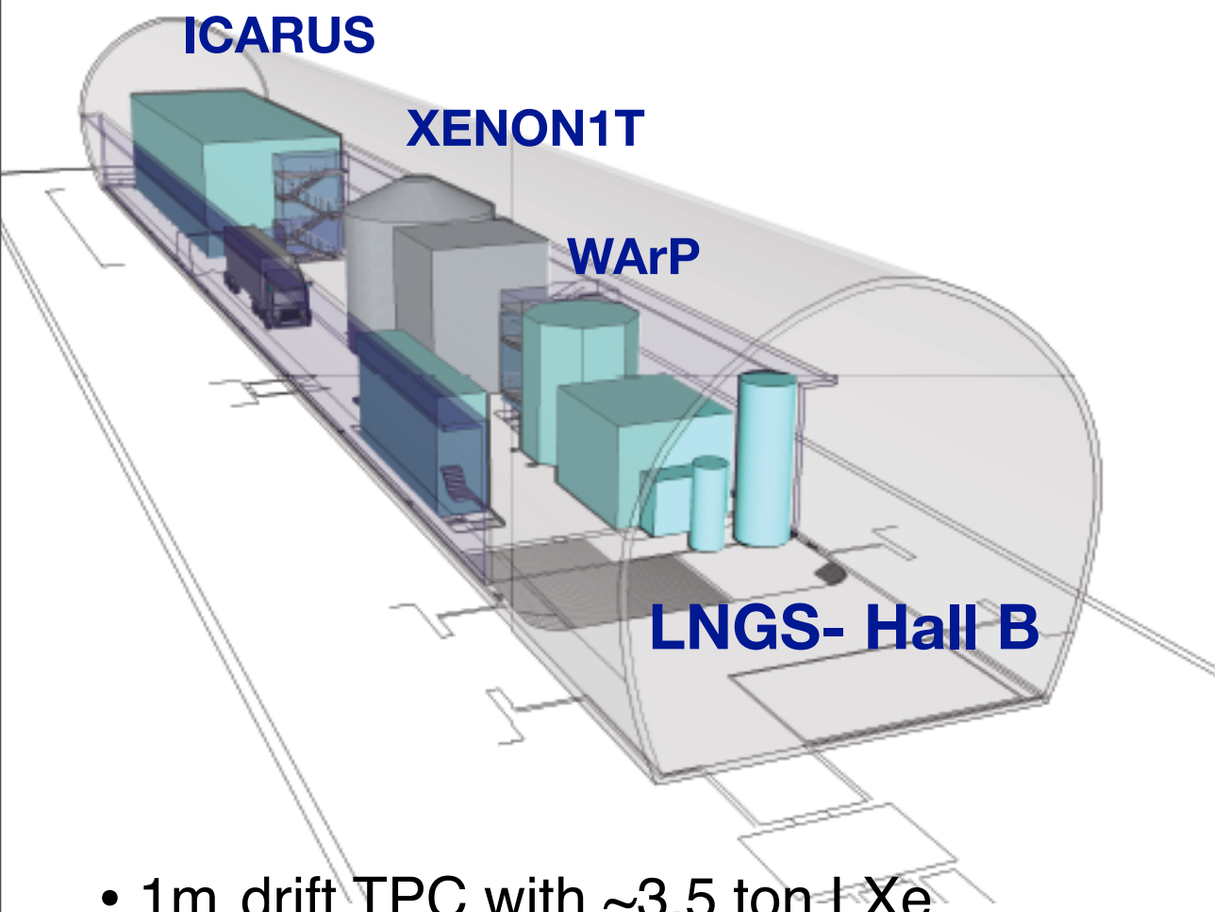


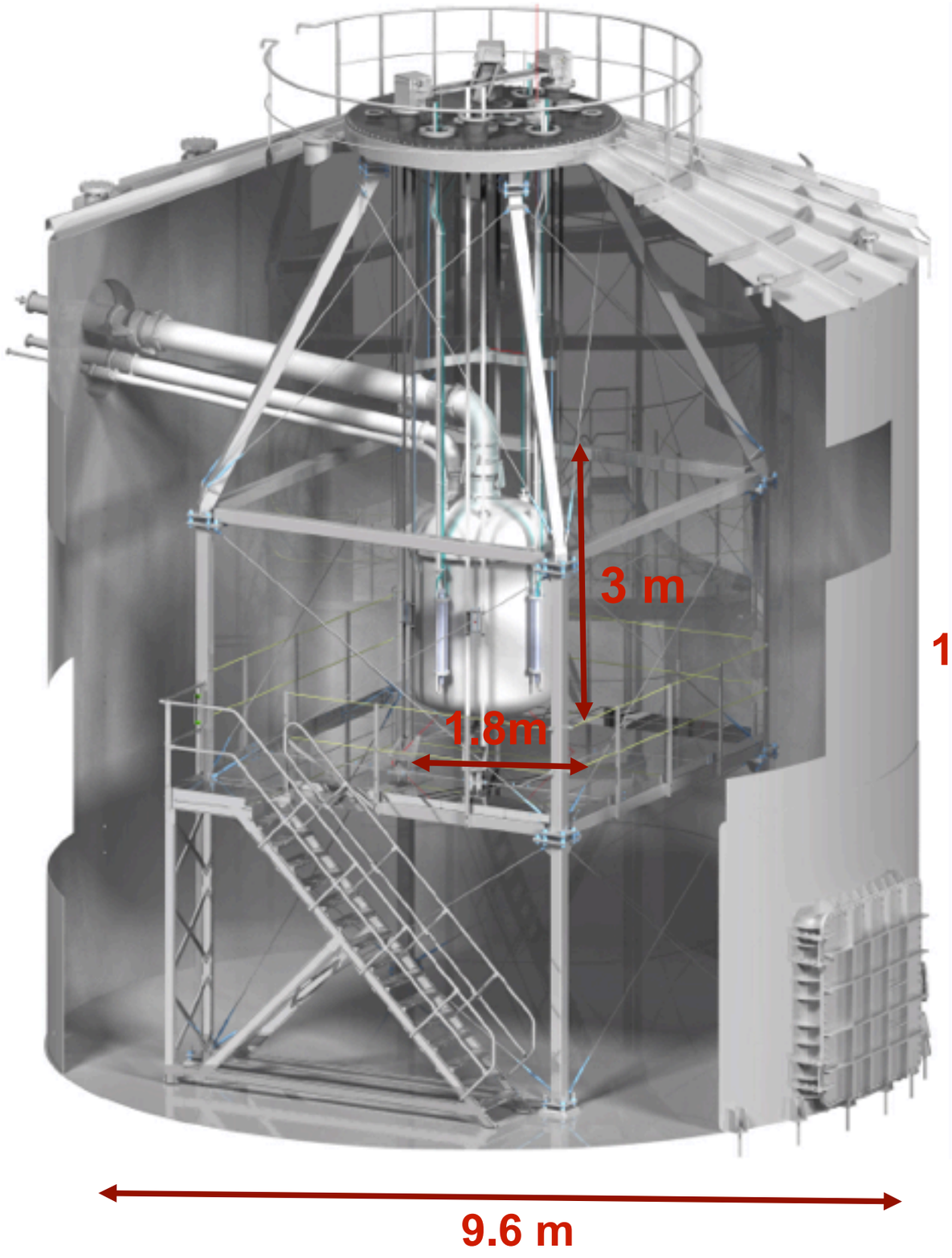


- Light yield decreases at 0-field below 50 keV
- Field quenching ~ 75% at low energies
- Derived XENON100 energy threshold: 2.3 keV
  → sensitive to DAMA signal! Results coming soon

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)

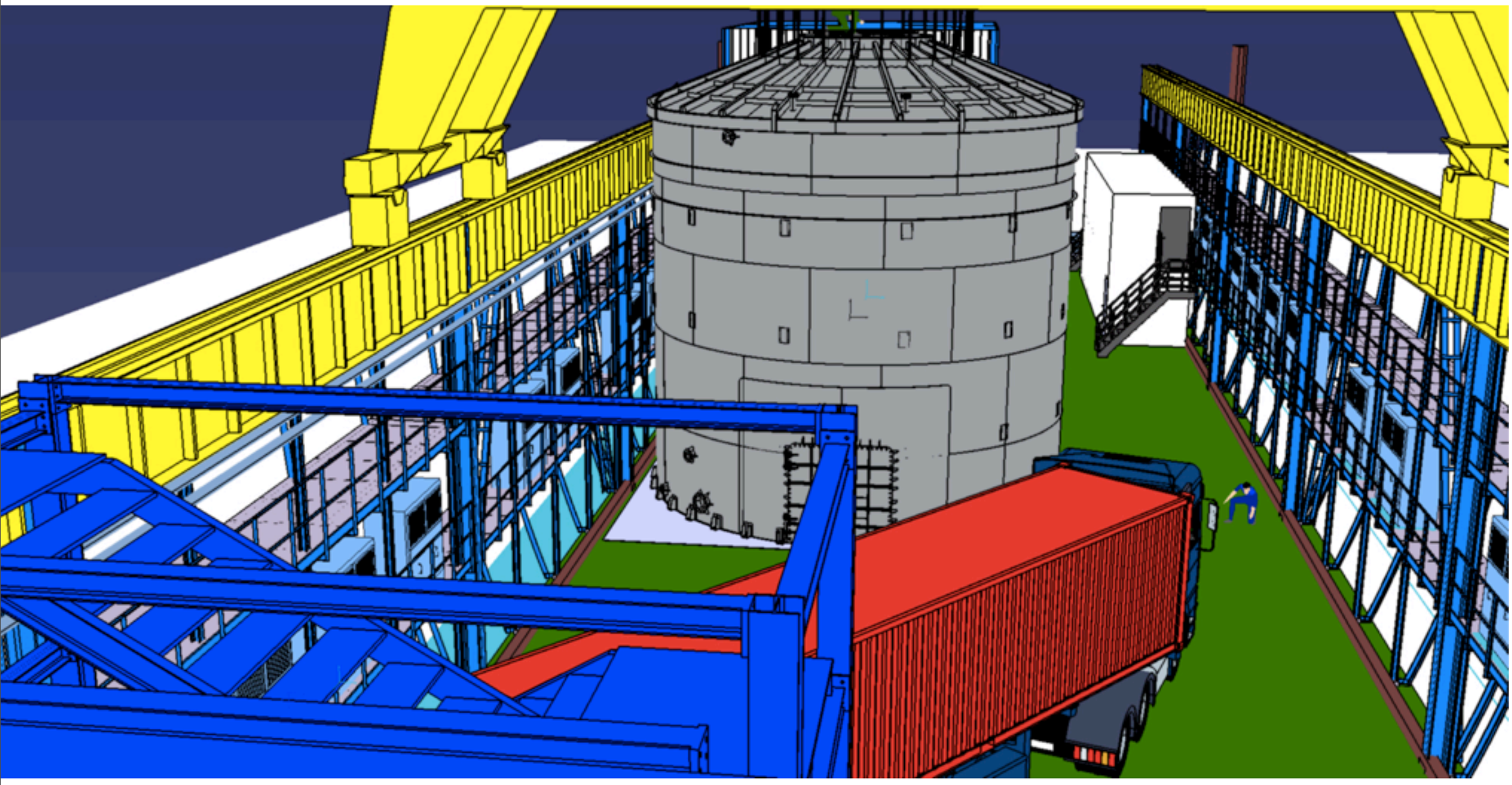
XENON1T





- 1m drift TPC with ~3.5 ton LXe
- Water shield as Cherenkov Muon Veto
- ER background < 5 x 10^{-5} DRU
- Kr/Xe < 0.5 ppt & Rn/Xe < 1 μBq/kg
- Project approved and funded
- 50% of project costs covered by NSF
- Design of major systems completed
- Construction in Hall B ongoing

XENON1T at LNGS: from design..



..to construction

Water Tank : 10 m High; 9.6 m diameter


Xe
KENON
ark Matter Project

XENON1T Background Suppression

Requirement: < 1 event in the full exposure

•External γ's:

- suppression via self-shielding (ρ_{LXe} ~ 3g/cm^3)
- material screening and selection

•Internal BGs (^{222}Rn and ^{85}Kr)

- cryogenic distillation column (Kr)

  < 1 ppt Kr/Xe achieved in XENON100
- online Rn removal by Rn tower

•Neutrons

- muon veto and material selection
- low U and Th contaminations

→ low α and (α,n) production

Example: Development of
low radioactivity PMTs with Hamamatsu
<1mBq/PMT in U and Th

Muon veto design

Background rejection power:

> 99.5% neutrons with a μ

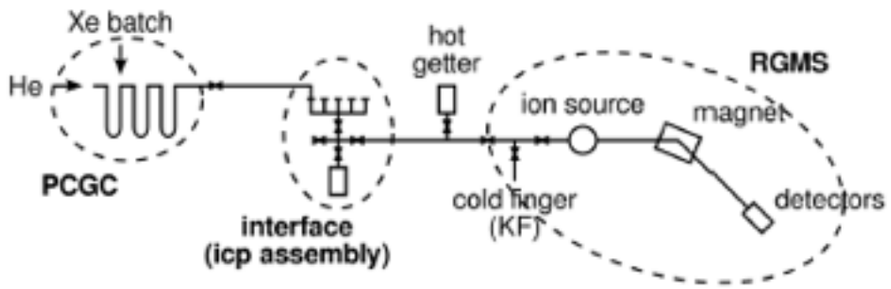
tagged in the veto -> muon-induced n-back:

0.01/ year -> negligible

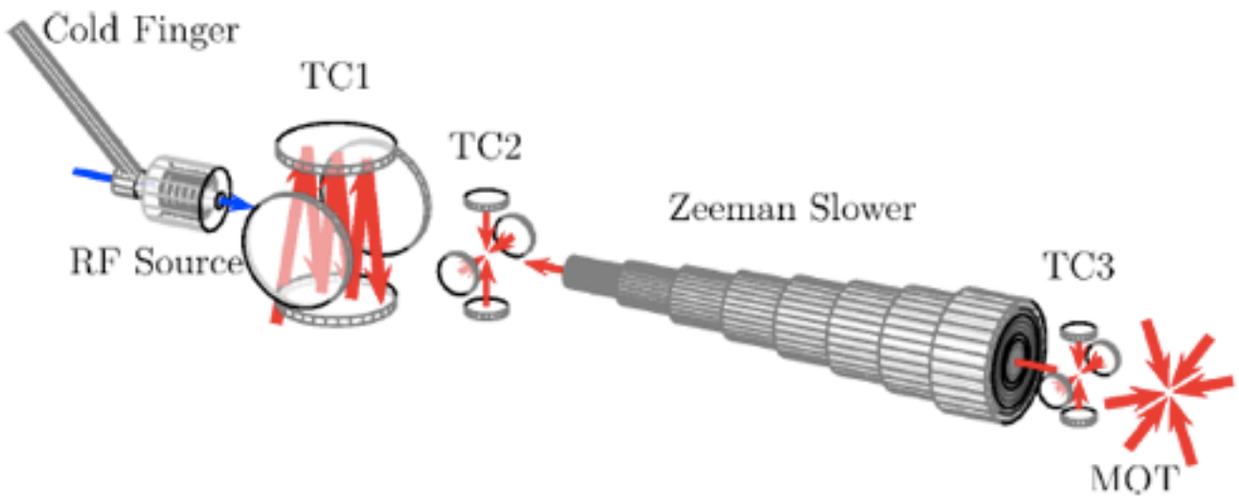
Kr Reduction and Measurement

- 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

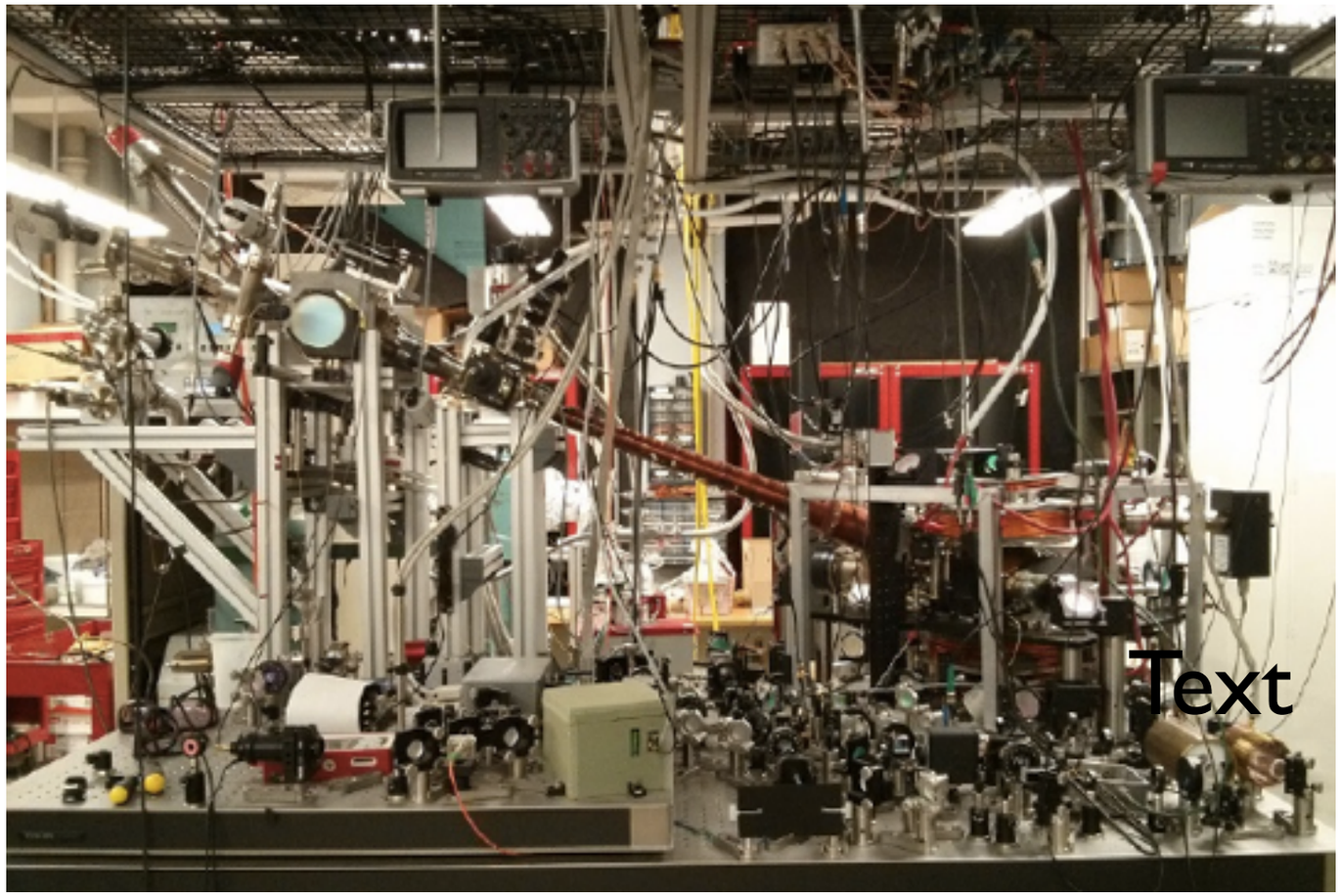
RGMS (arXiv:1308.4806)

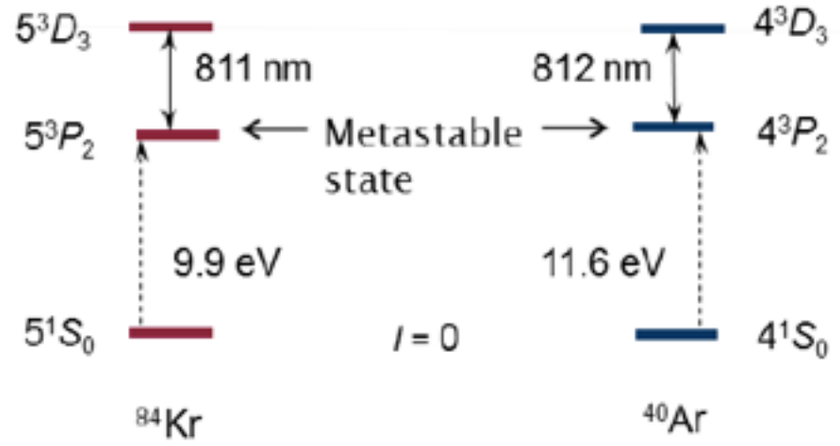


ATTA (arXiv:1305.6510) Rev. Sci. Instrum. 84 (2013)

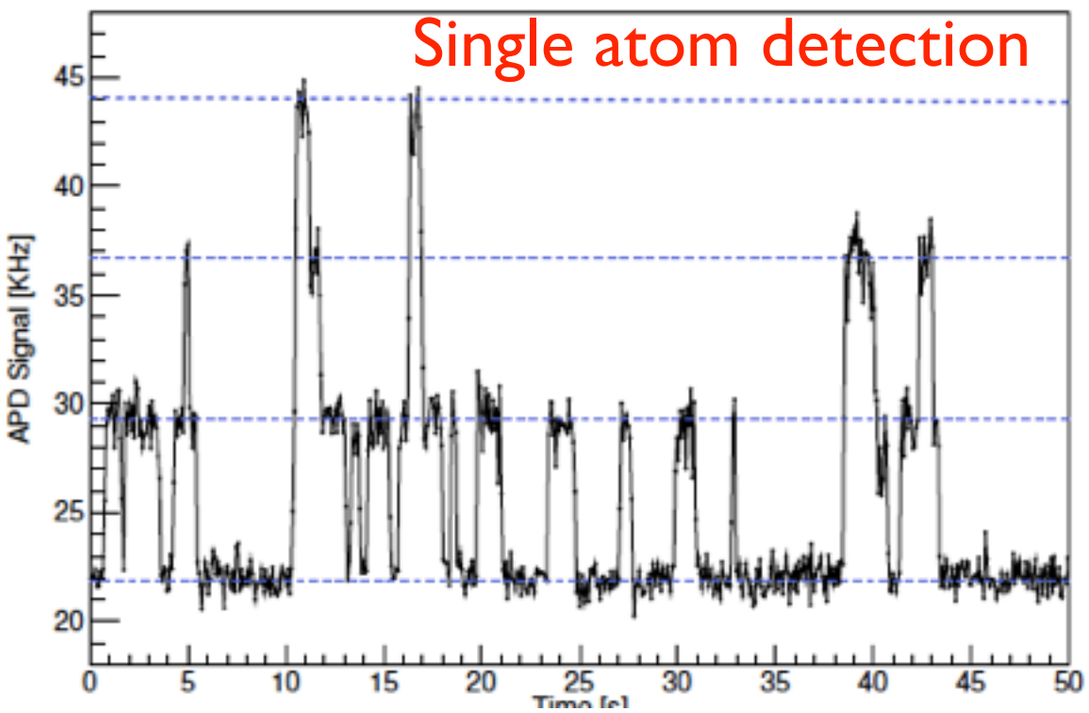


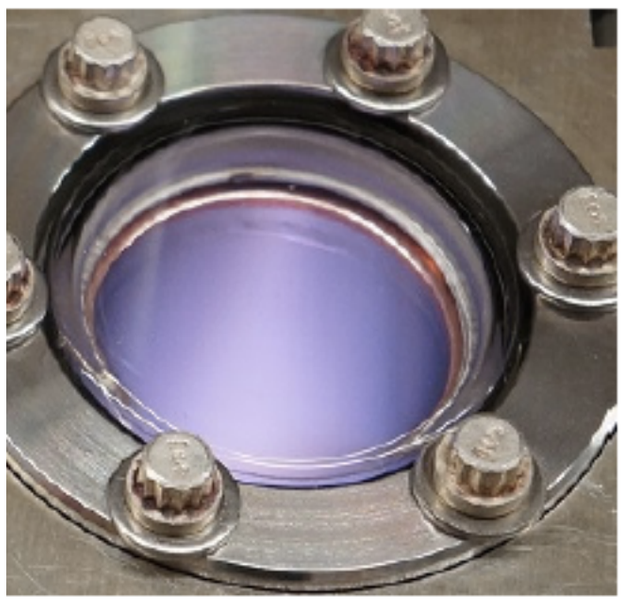
The Columbia Atom Trap



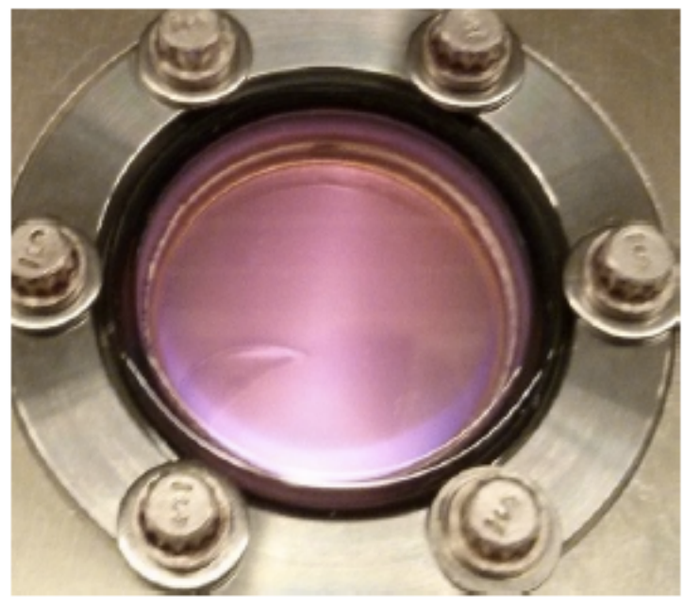


- Transition between 5^3D_3 and 5^3P_2
- ^{40}Ar to avoid contamination by Kr
  - $\lambda_{^{40}Ar} = 811.7542$ nm, $\lambda_{^{84}Kr} = 811.5132$ nm
  - Achieved by a single diode laser



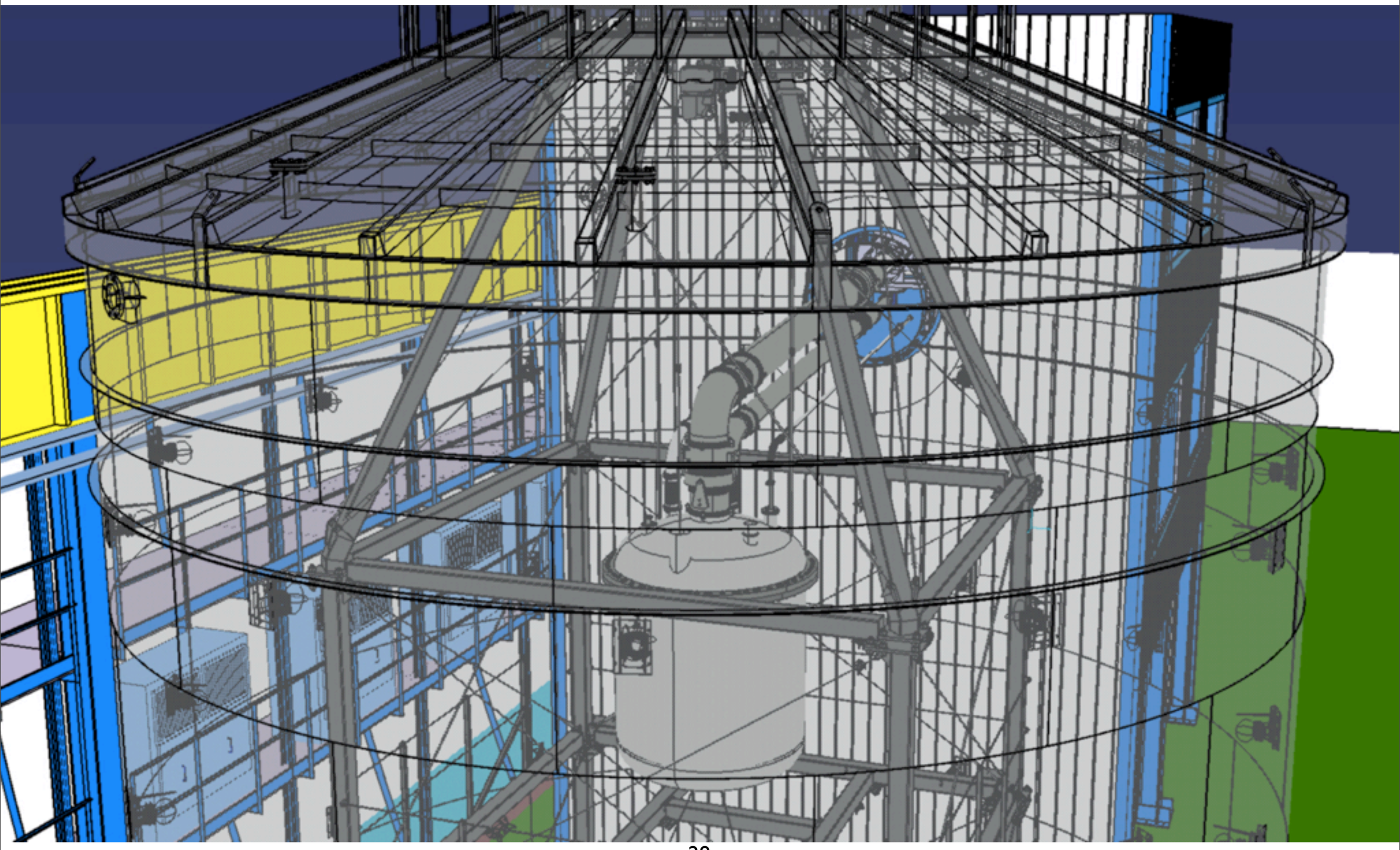


Ar discharge

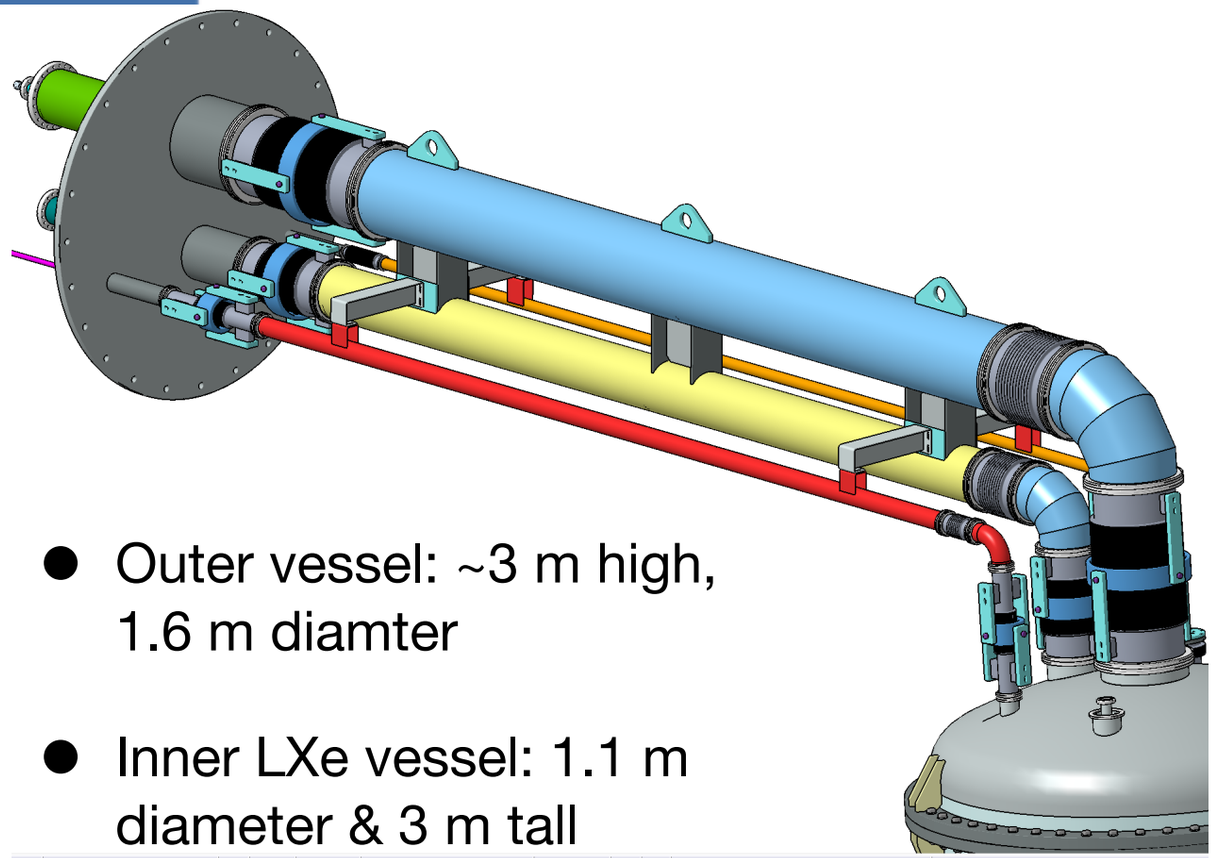


Xe discharge

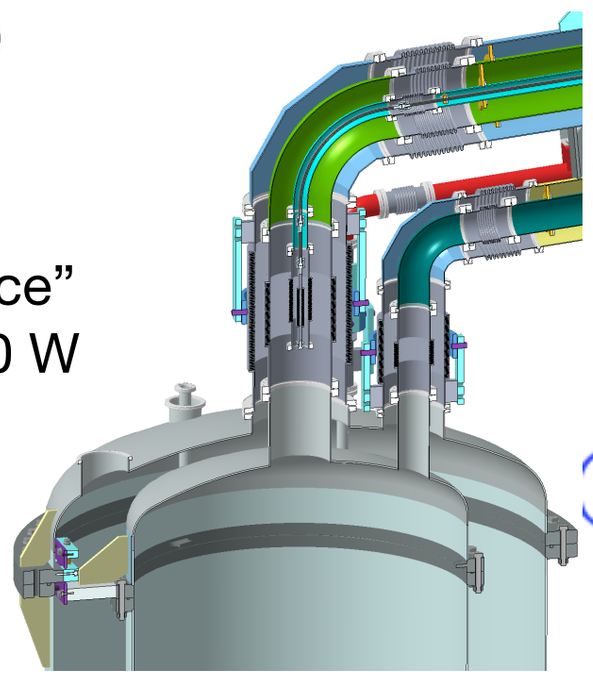
The XENON1T Detector

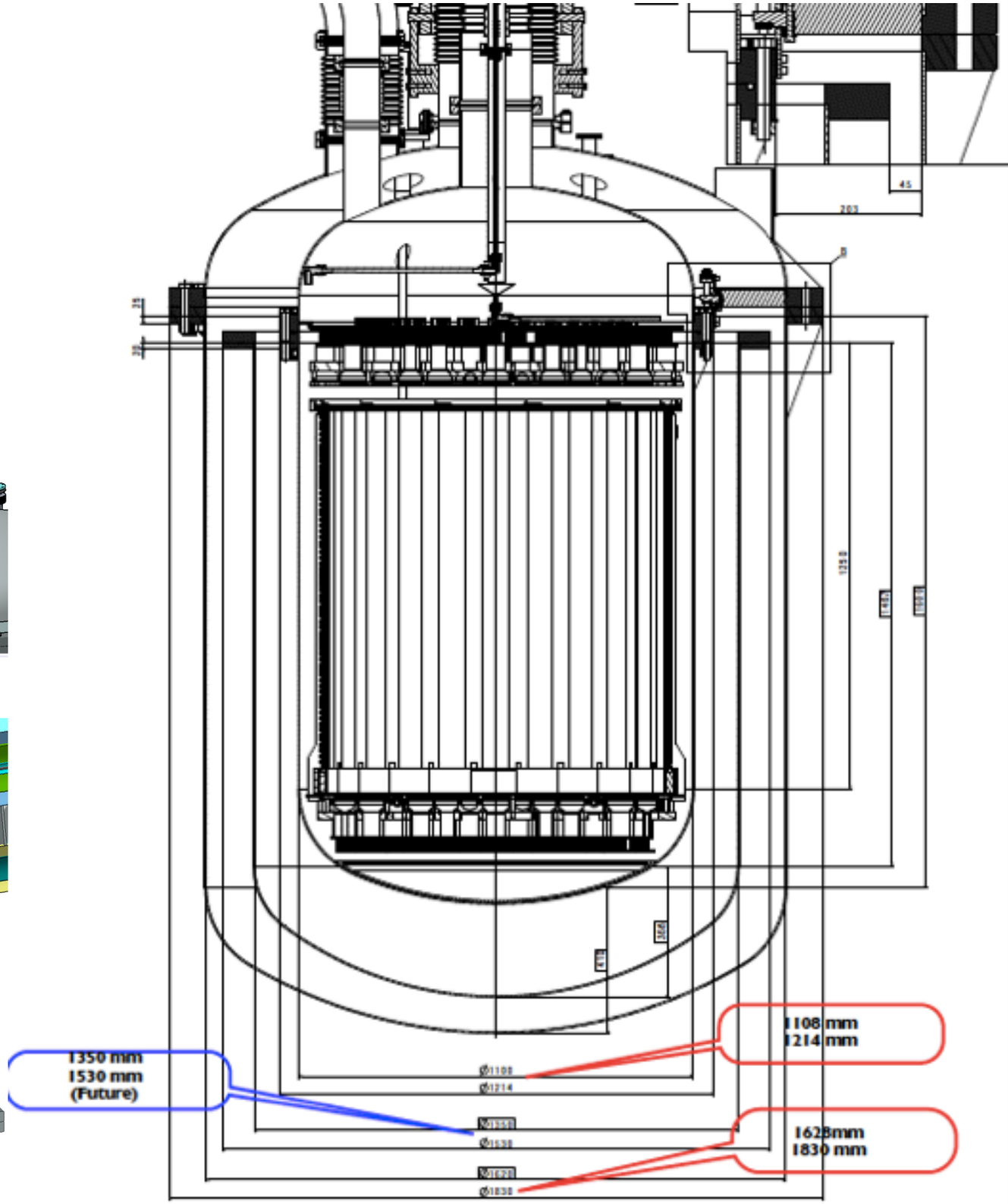


CRYOSTAT

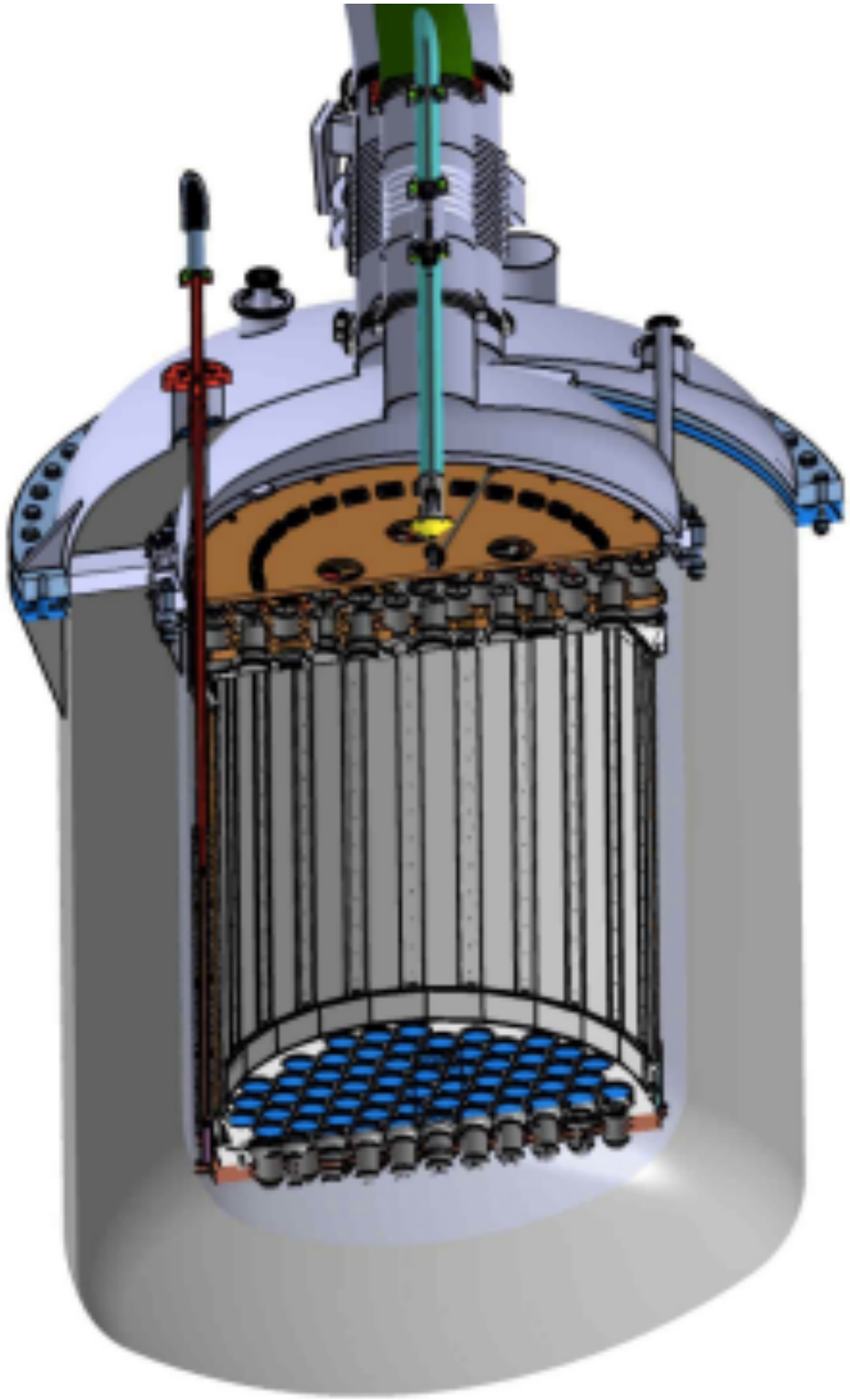


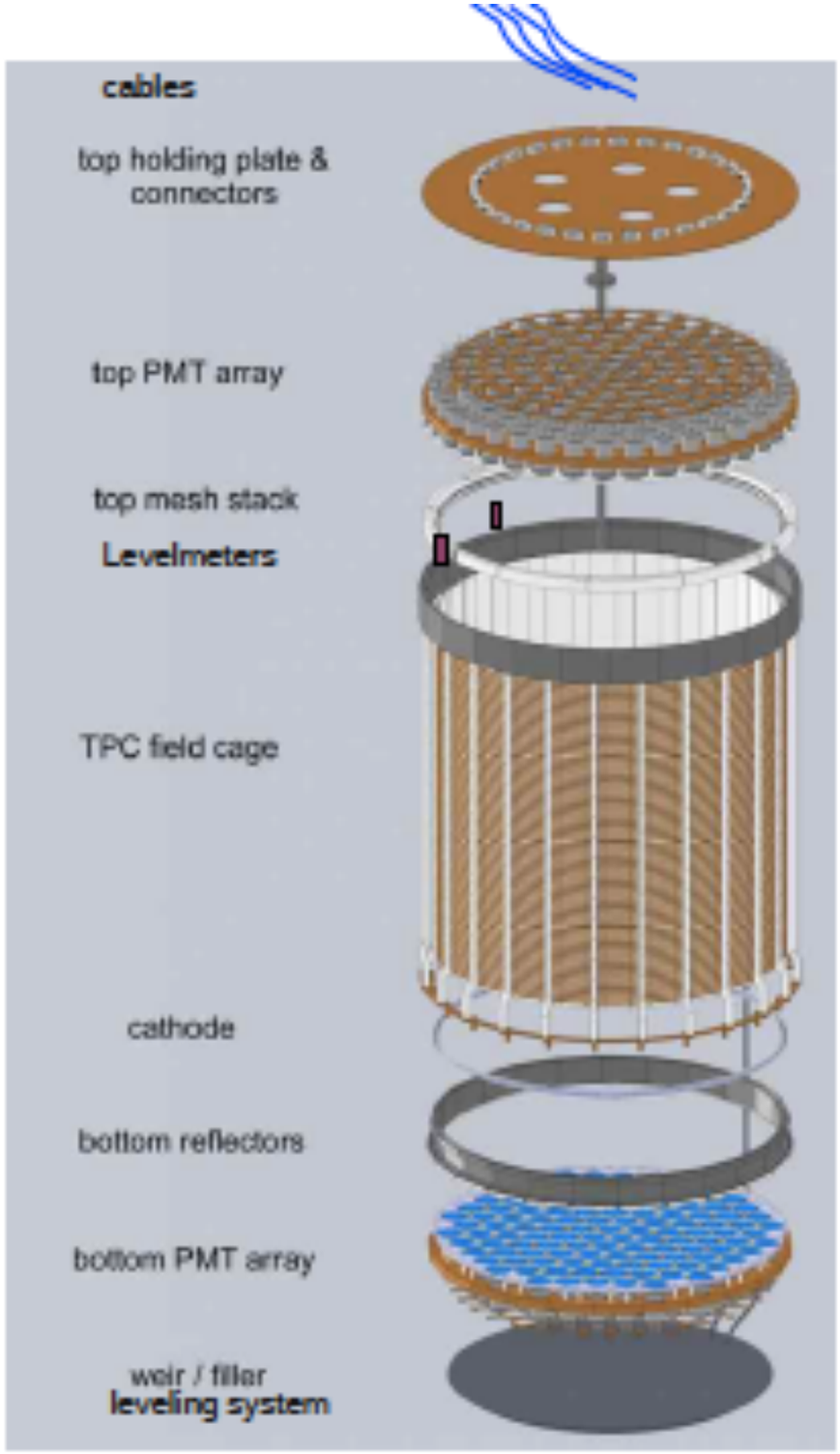
- Outer vessel: ~3 m high, 1.6 m diamter
- Inner LXe vessel: 1.1 m diameter & 3 m tall (XENON1T); 1.35 m diameter (XENONnT)
- Heat load <50 W
- Cooling: “at a distance” with 2 redundant 200 W PTRs plus LN tower





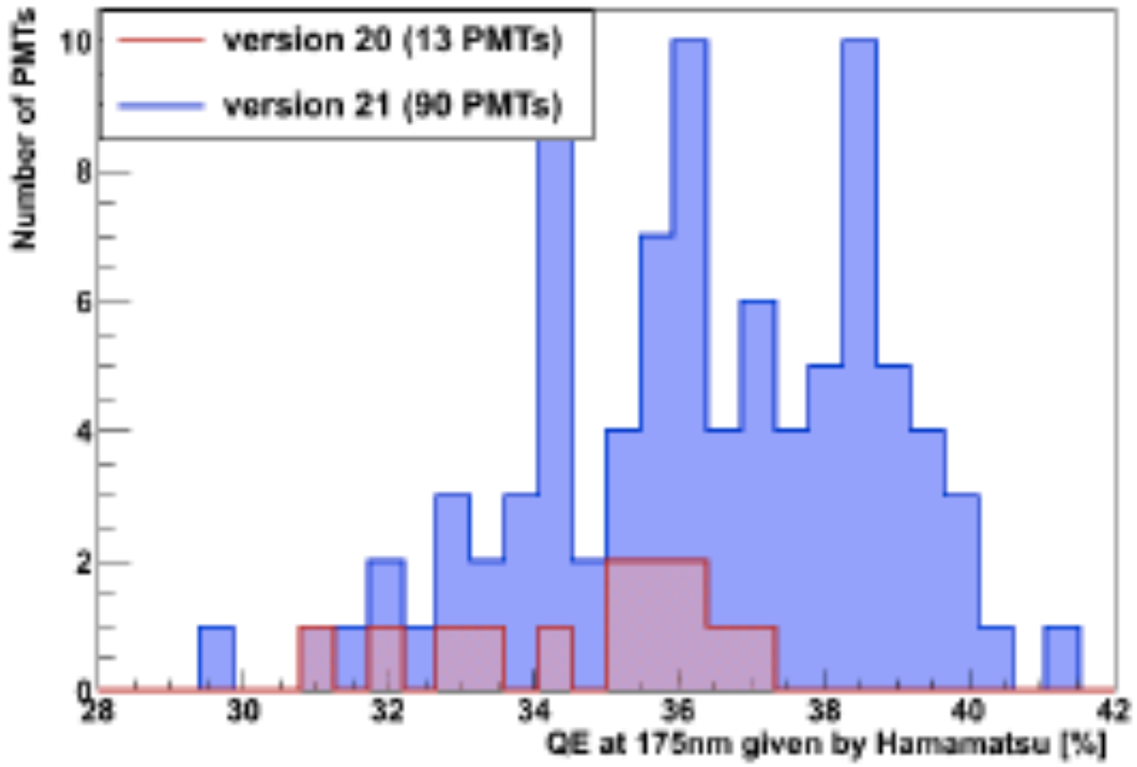
TPC



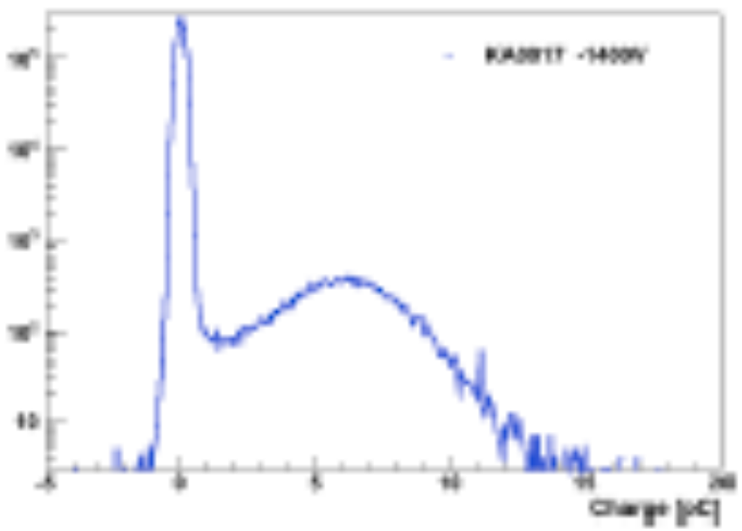

cables
top holding plate & connectors
top PMT array
top mesh stack
Levelmeters
TPC field cage
cathode
bottom reflectors
bottom PMT array
weir / filler
leveling system

PMTs

- 300 Hamamatsu R11410-21
- XENON1T version: high QE (average 36% @ 178nm) and low radioactivity (< 1mBq/PMT in U/Th)
- all PMTs screened and tested at room temperature (DC rate, HV scan, after-pulsing, transit time,)
- repeated cool-down at <2K/min



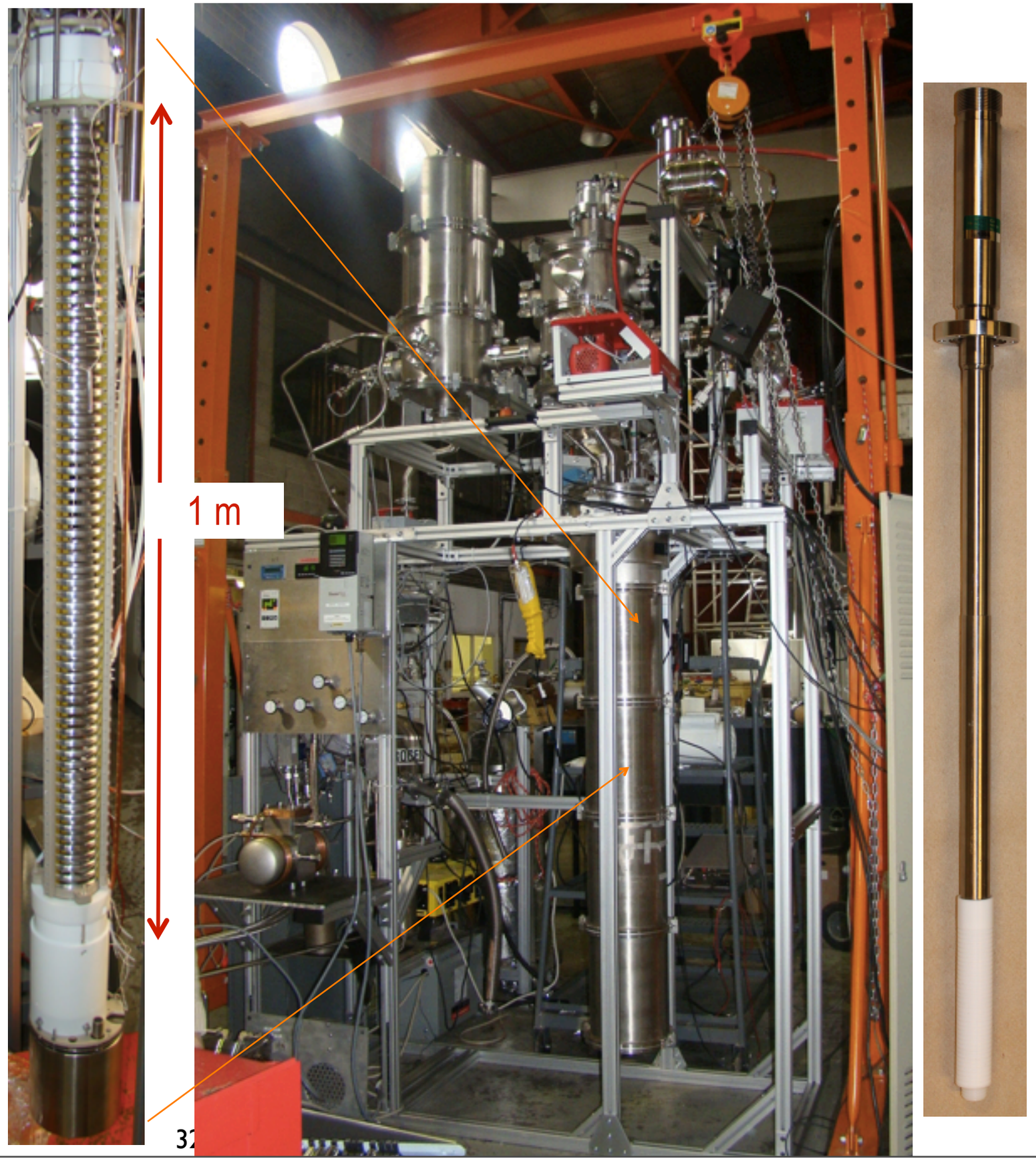
PMT mounted in low radioactive holders



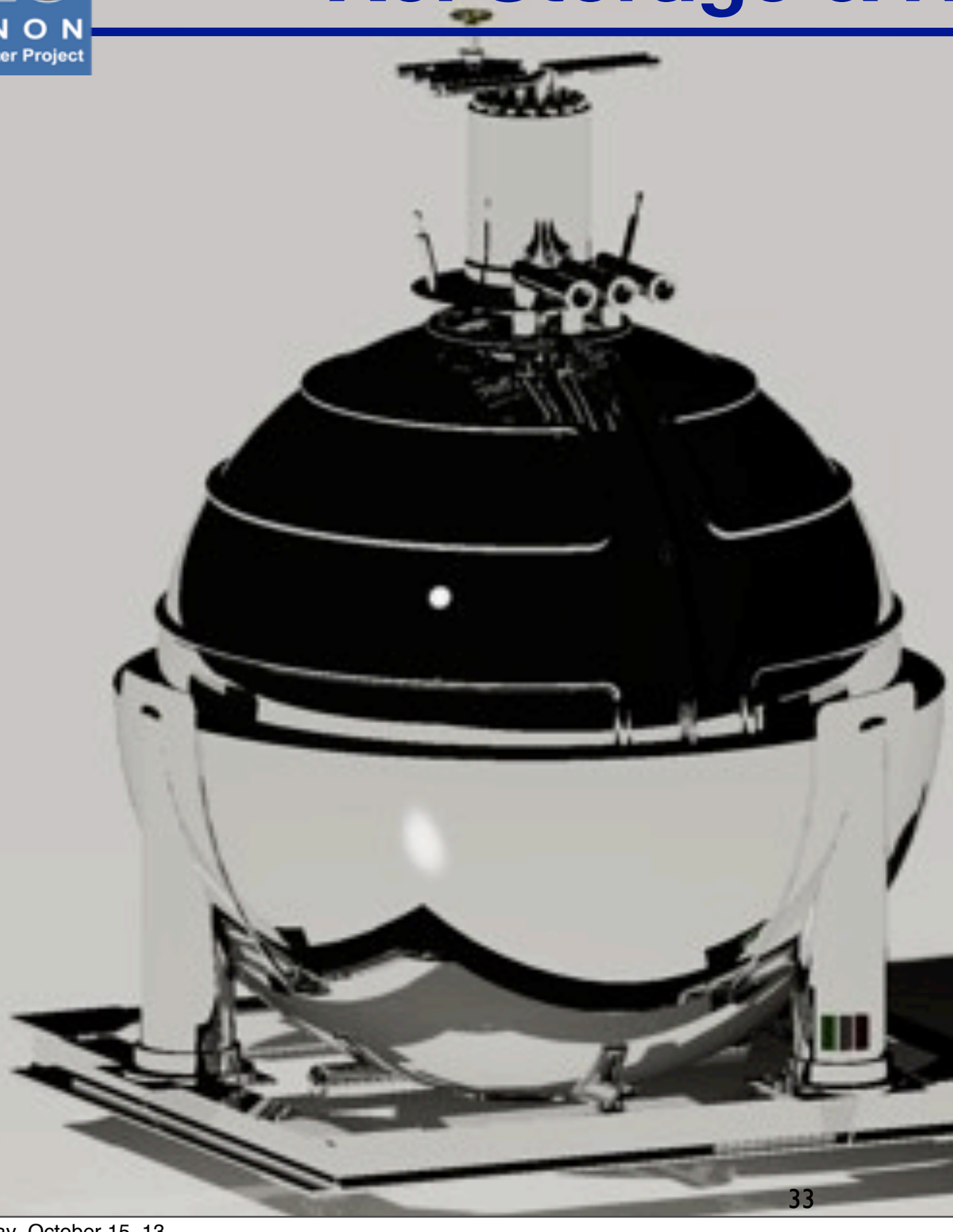
XENON1T Demonstrator

A facility built at Columbia Nevis Lab to demonstrate:

- high speed (~100 SLPM) Xe circulation and purification on short time scale
- long electron lifetime for 1m drift in a 2-phase TPC (a vertical slice of XENON1T)
- high voltage (~100 kV) with custom-made low radioactivity feedthroughs
- performance of R11410 PMTs in LXe and with field



Xe: Storage & Recovery



- Vacuum-insulated, LN-cooled, high-pressure (70 bar) SS sphere
- store > 6 tons of Xe in gas or liquid phase under high purity conditions
- fast (hours) recovery of Xe from detector in case of emergency

Thank You INFN and LNGS!