University of Zurich[UZH]

International Conference on Technology
and Instrumentation in Particle Physics
2 – 6 June 2014, Amsterdam

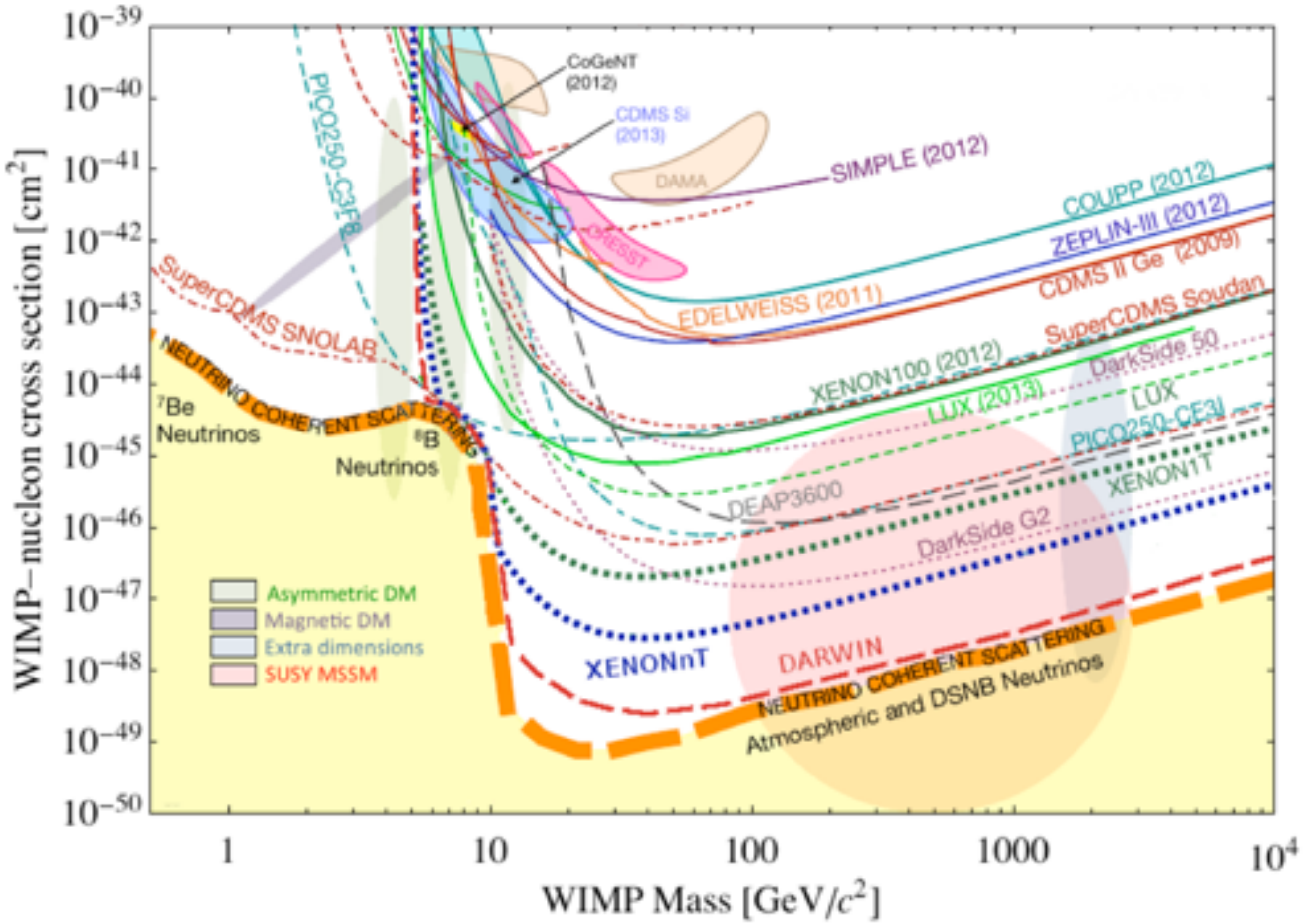
dark matter wimp search in noble liquids
DARWIN

Xe
XENON
Dark Matter Project

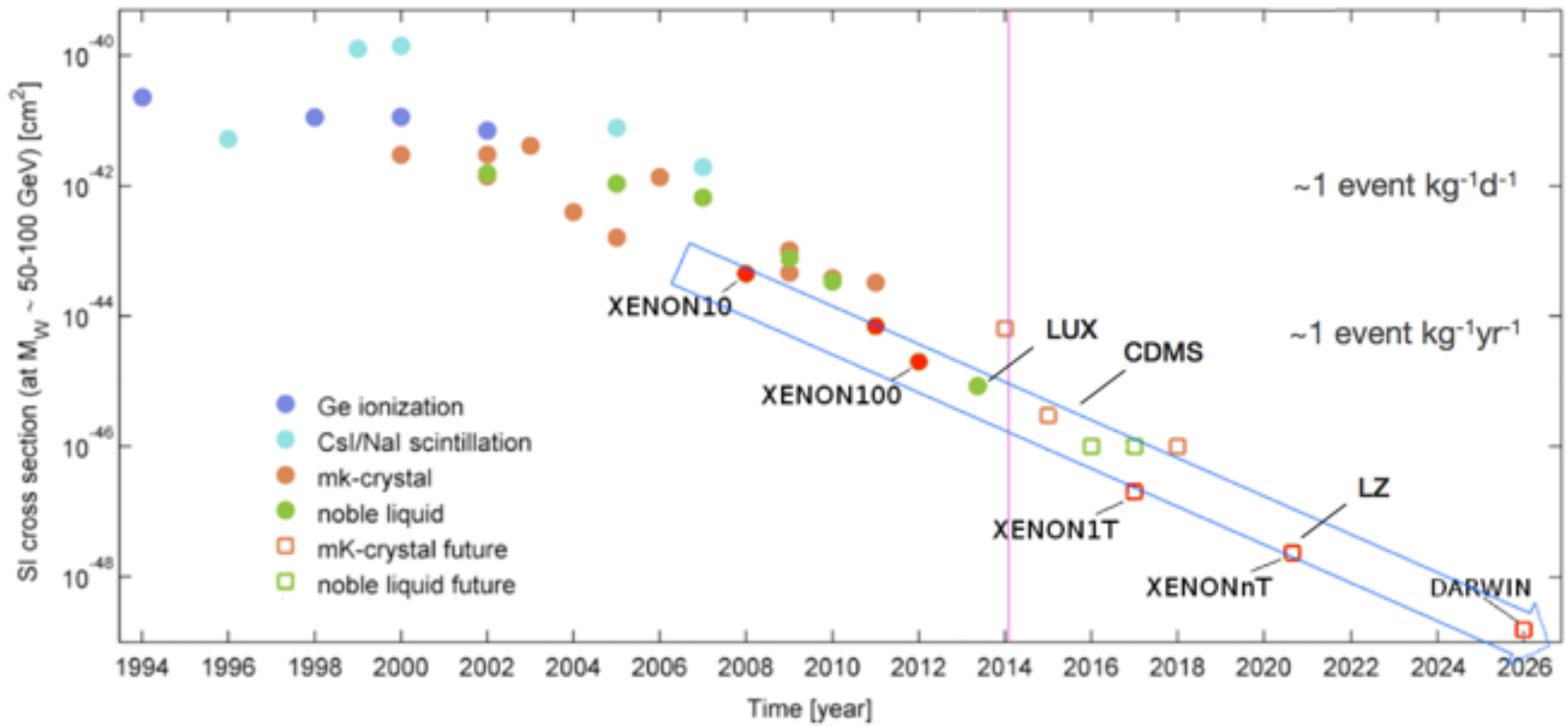
Direct dark matter detection with the XENON and DARWIN experiments

Alex Kish
Physics Department, University of Zürich

Experimentally available parameter space for WIMPs

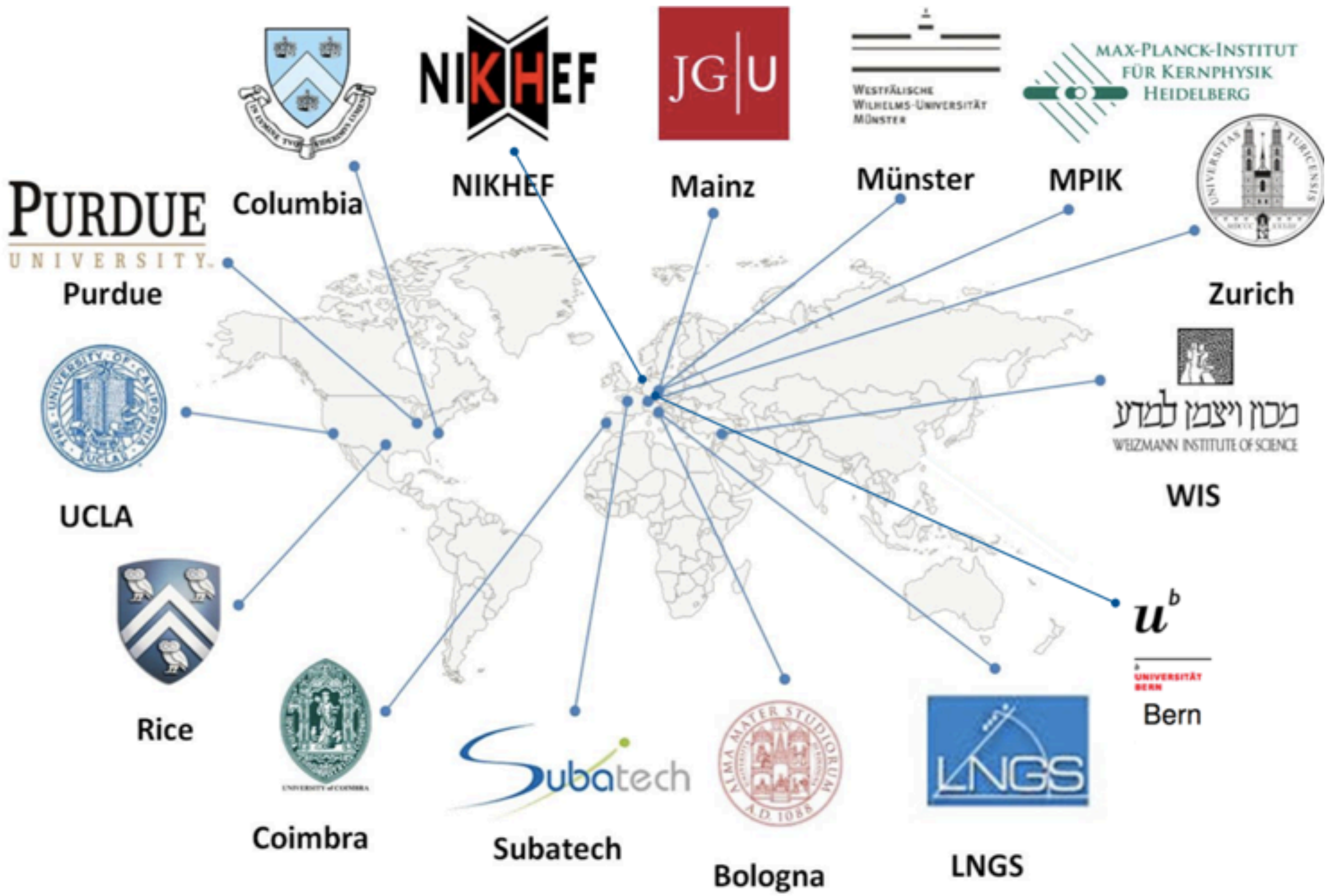


- Sensitivity at WIMP masses above ~6 GeV/c²V is dominated by noble liquid time-projection chambers
- XENON1T projected sensitivity 2×10^{-47} cm² for a 50 GeV/c² WIMP
- The entire experimentally available parameter space for WIMPs can be probed with DARWIN



The XENON Collaboration

- ~120 researches from 16 institutions



Particle Detection Principle with Xenon Detector

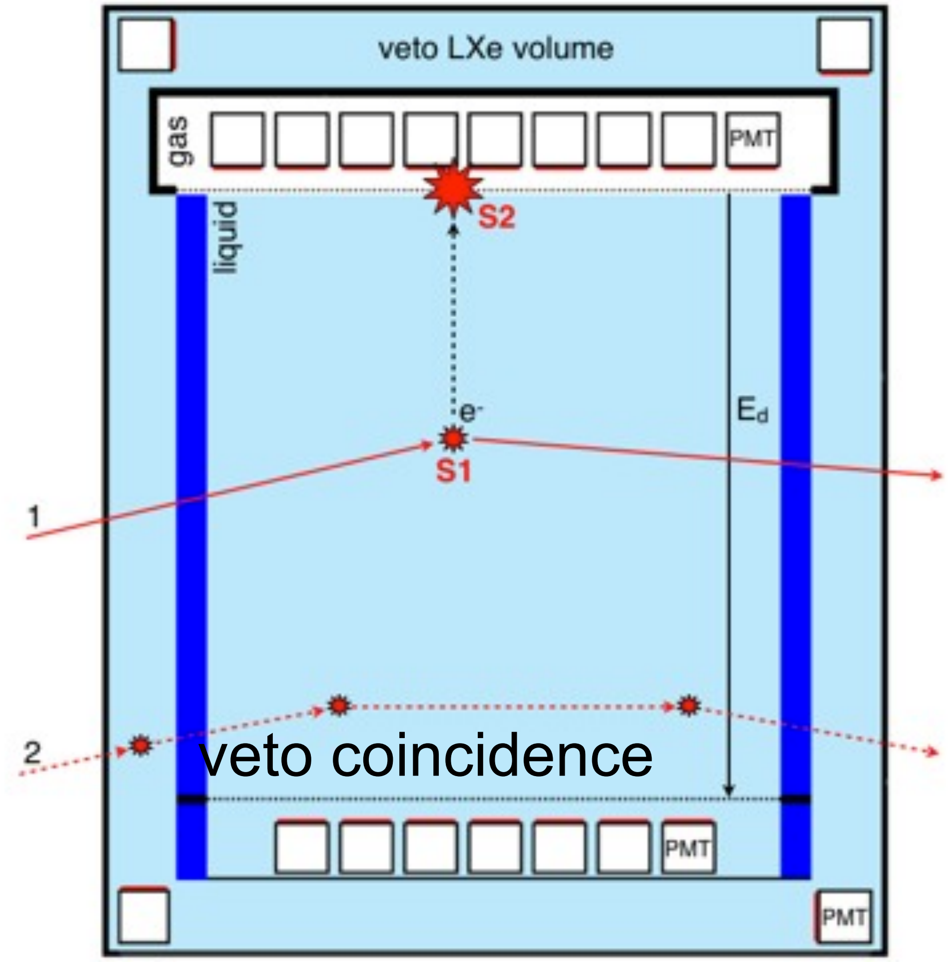
- particle interaction with the LXe target:

$\xrightarrow{h\nu}$ prompt scintillation (S1), λ = 178 nm

light detection with photomultiplier tubes

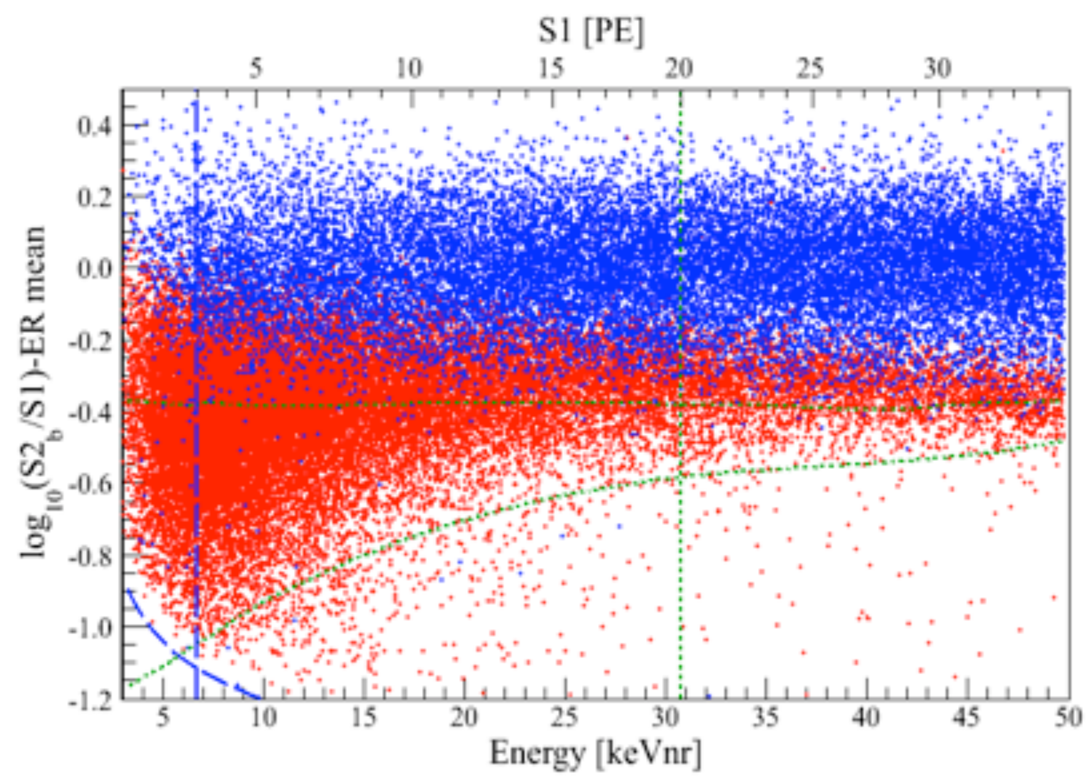
$\xrightarrow{e^-}$ ionization

charge is drifted and extracted into the gas phase, detected by PMTs as proportional scintillation light (S2)



- electronic recoil discrimination based on the ratio of scintillation and ionization, with efficiency >99%

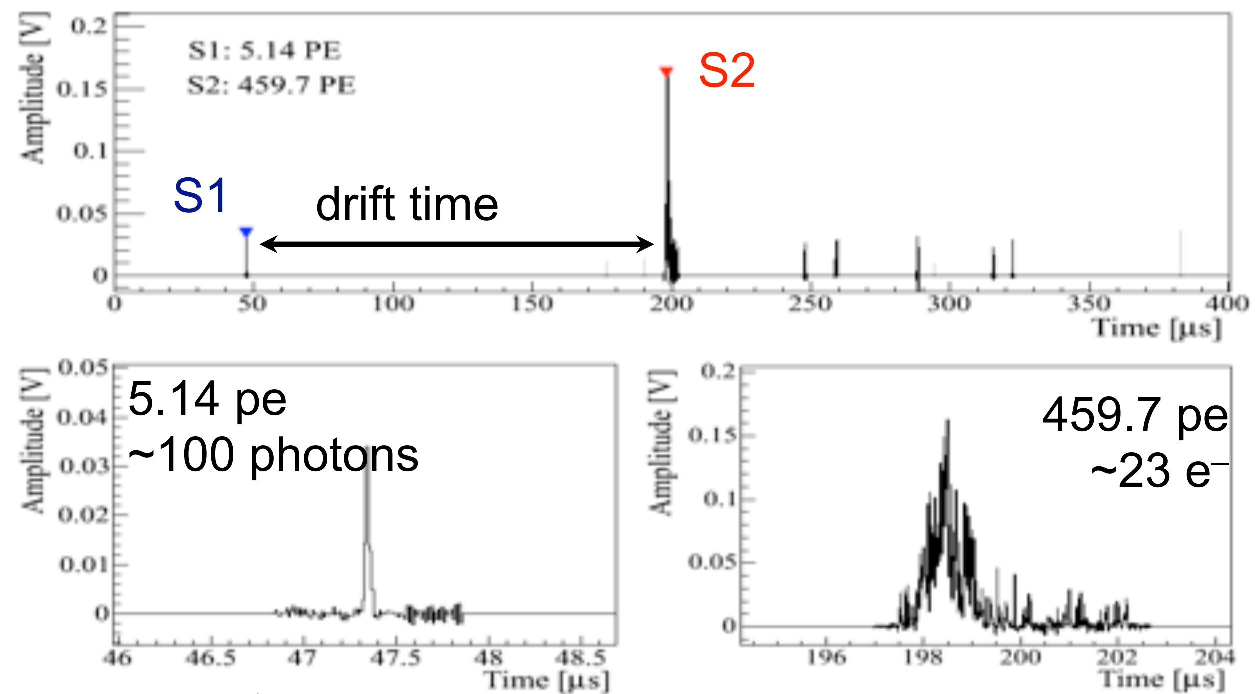
$(S2/S1)_\gamma > (S2/S1)_{WIMP}$



Reconstruction of the Interaction Vertex

- Z-coordinate (interaction depth) is inferred from the delay time between S1 and S2, Z position resolution 3mm

- X and Y coordinates are reconstructed via light pattern identification with Neural Networks, Support Vector Machines, χ^2-minimization, etc.



prompt scintillation signal (S1)

proportional scintillation signal (S2)

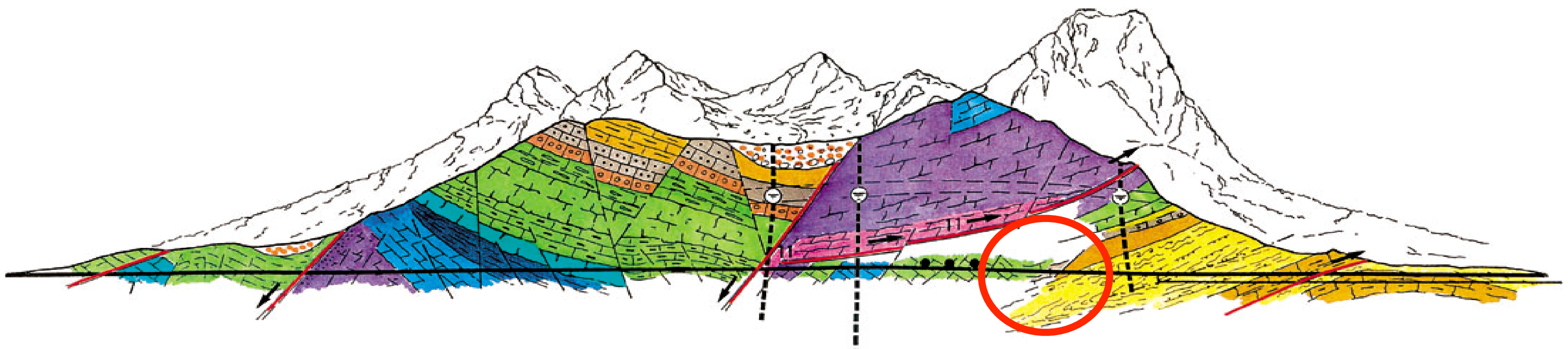
- Radial position resolution:

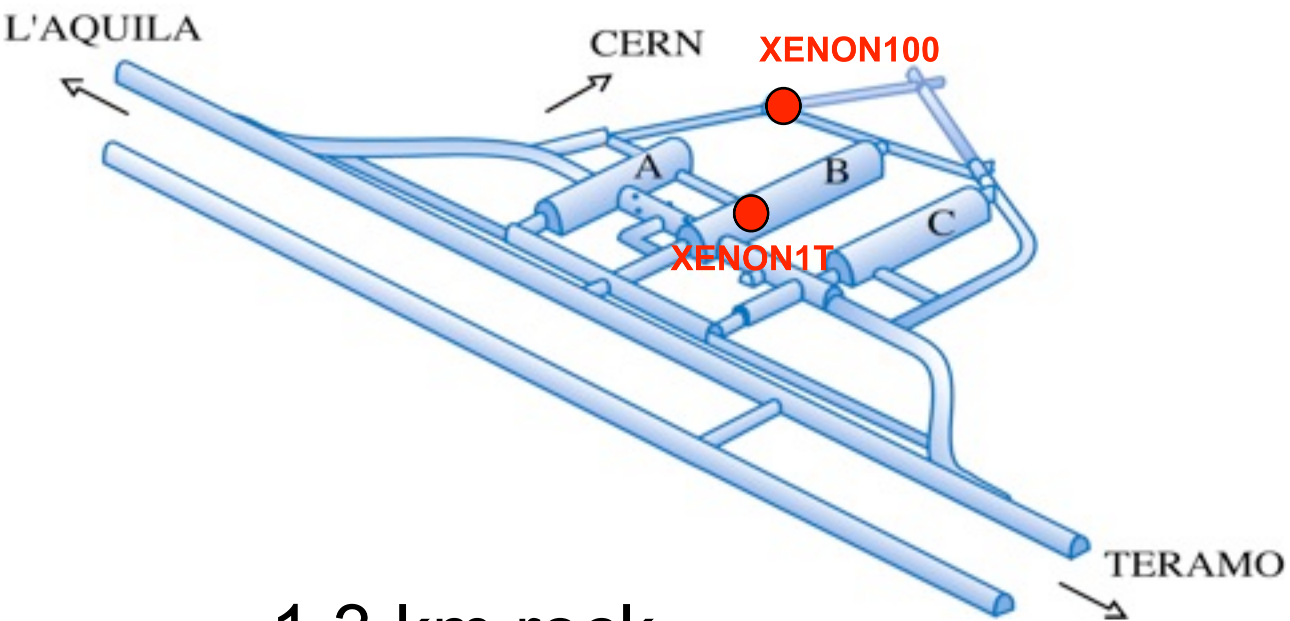
XENON100	1" PMTs:	3 mm
LUX	2" PMTs:	5 mm
XENON1T, XENONnT		
DARWIN	3" PMTs:	8 mm

→ error on the FV calculation <0.1%

- Challenge: long e^- drift time in large detectors (XENON100: 30 cm drift = 176 µs at 0.53 kV/cm)

Location of the XENON Experiment





1.3 km rock

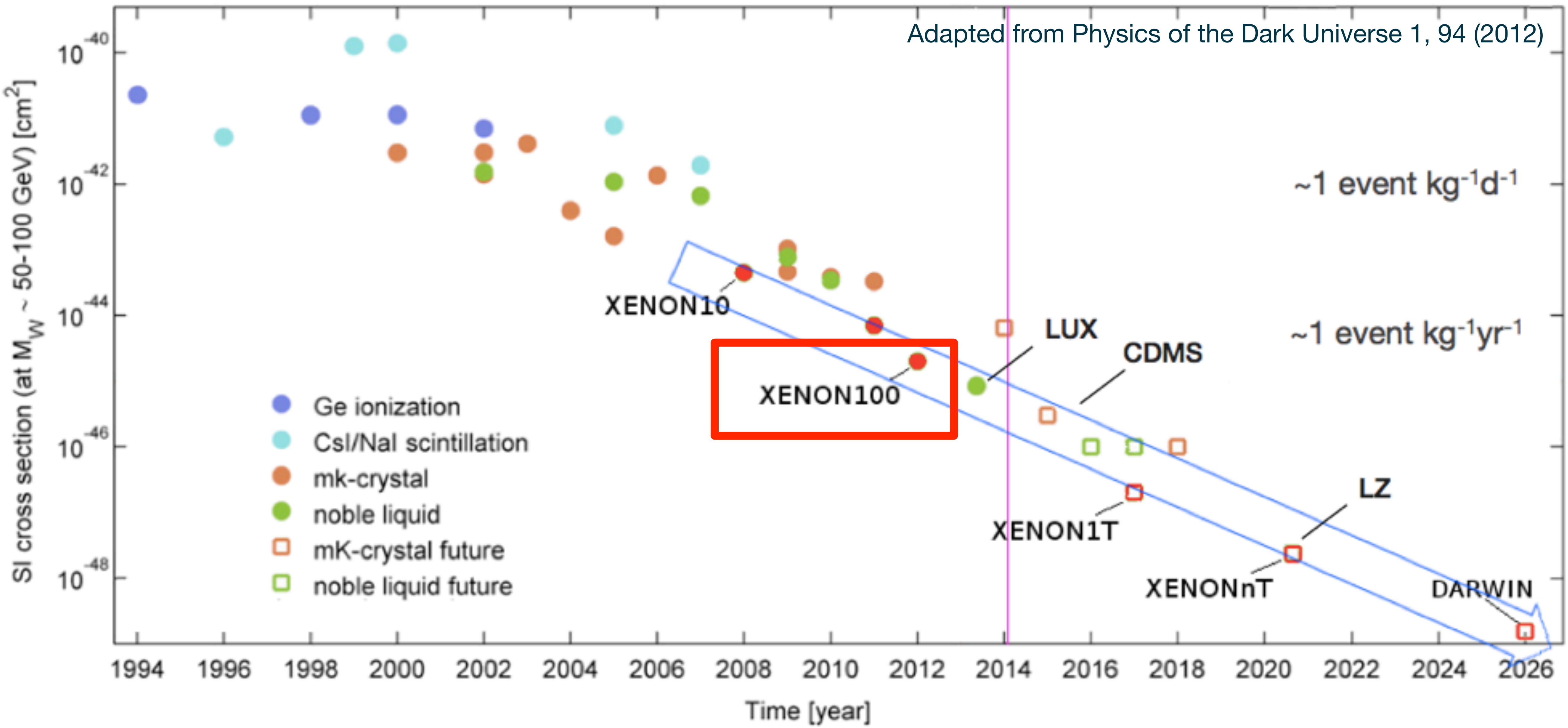
↓

3.1 km water equivalent shielding from cosmic rays

↓

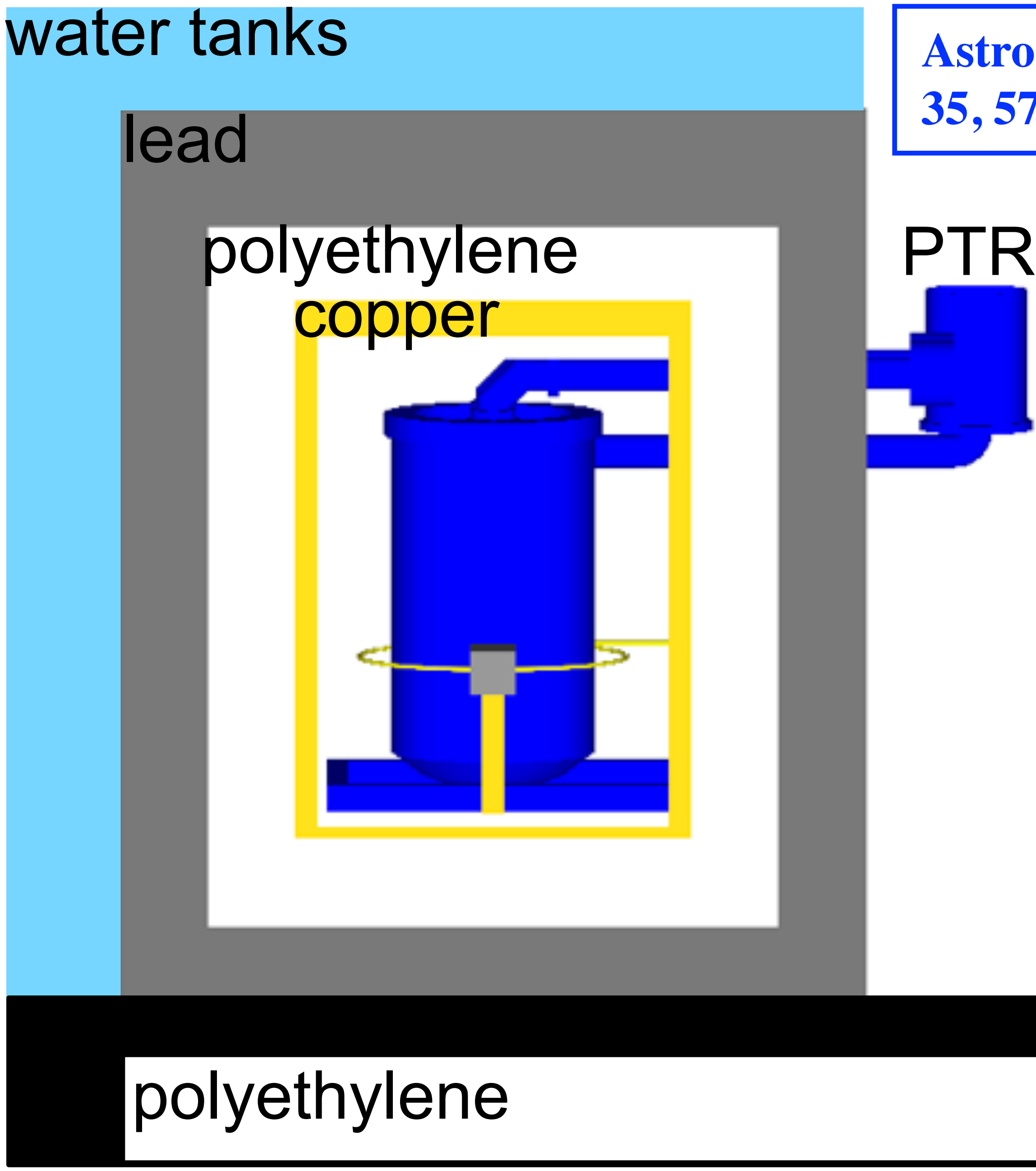
factor 10^6 reduction of muon flux

XENON100



Adapted from Physics of the Dark Universe 1, 94 (2012)
SI cross section (at M_W ~ 50-100 GeV) [cm^2]
10^{-40}
10^{-42}
10^{-44}
10^{-46}
10^{-48}
~1 event $kg^{-1}d^{-1}$
~1 event $kg^{-1}yr^{-1}$
XENON10
XENON100
LUX
CDMS
XENON1T
LZ
XENONnT
DARWIN
Ge ionization
CsI/NaI scintillation
mk-crystal
noble liquid
mK-crystal future
noble liquid future
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
Time [year]

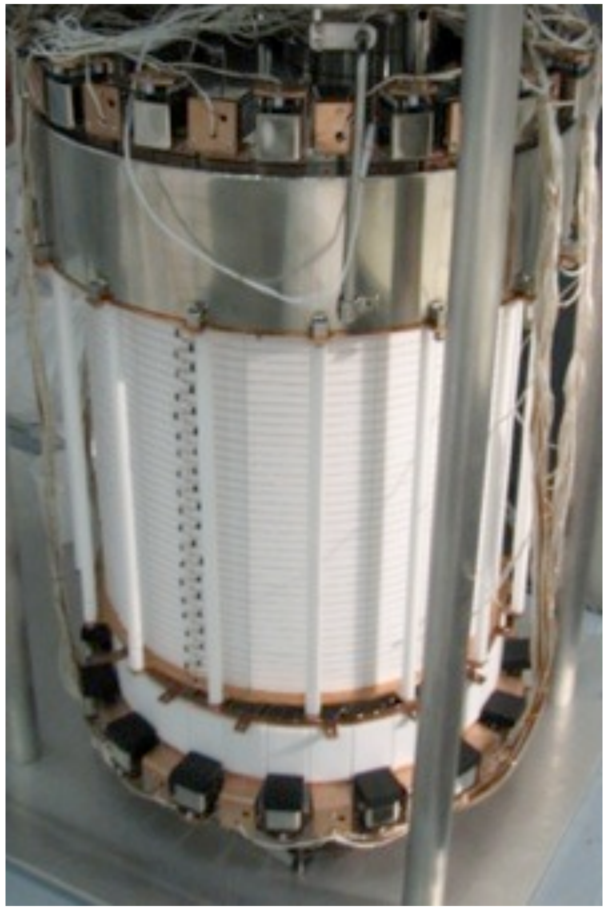
The XENON100 Detector



Astroparticle Physics 35, 573 (2012)

water tanks	thickness 20 cm	→ neutrons
lead	15 and 5 cm (low ^{210}Pb), 33 t	→ gamma
polyethylene	20 cm thick, 1.6 t	→ neutrons
copper	5 cm thick, 2 t	→ gamma from outer shield
nitrogen flushing	~20 liters/minute	→ ^{222}Rn in the shield cavity

The XENON100 Detector



Cryostat:
- double walled (1.5 mm thick)
- low radioactivity stainless steel
- total weight 70 kg

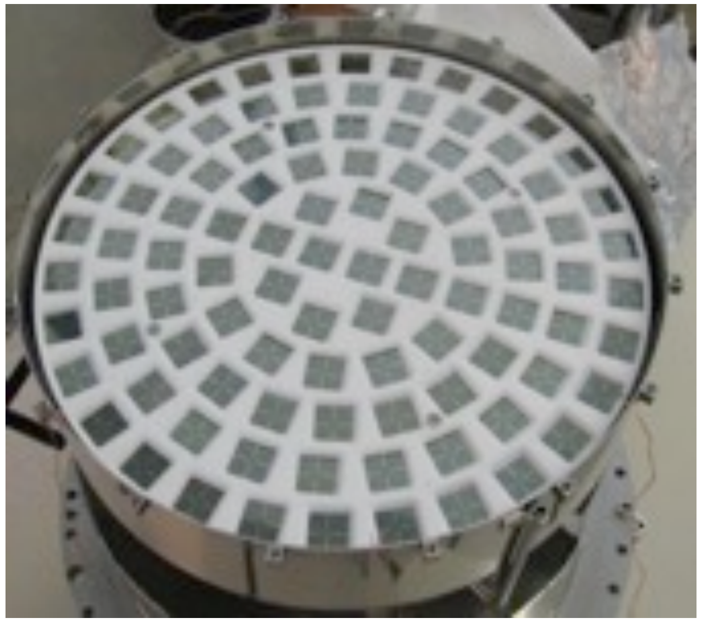
PTFE structure:
- 24 interlocking panels
- total weight of teflon 12 kg
- UV light reflector

'Diving bell':
- stainless steel
- weight 3.6 kg

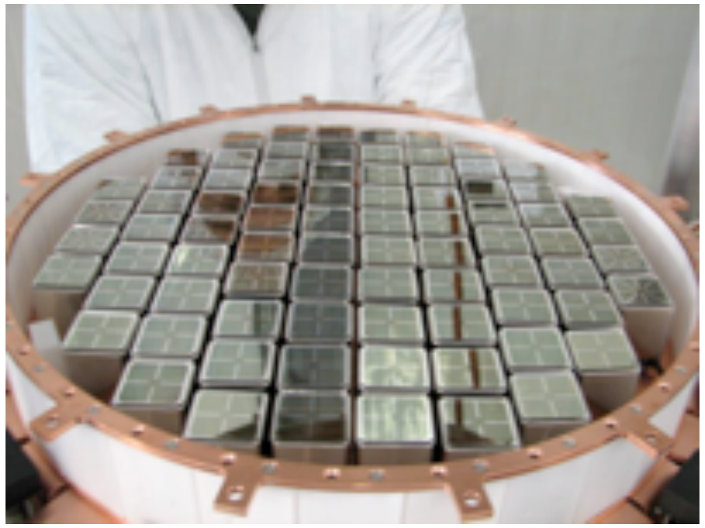
Target:
- 62 kg of LXe
- 30 cm diameter, 30 cm height

Veto:
- 99 kg of LXe
- average thickness 4 cm
- instrumented with 64 PMTs

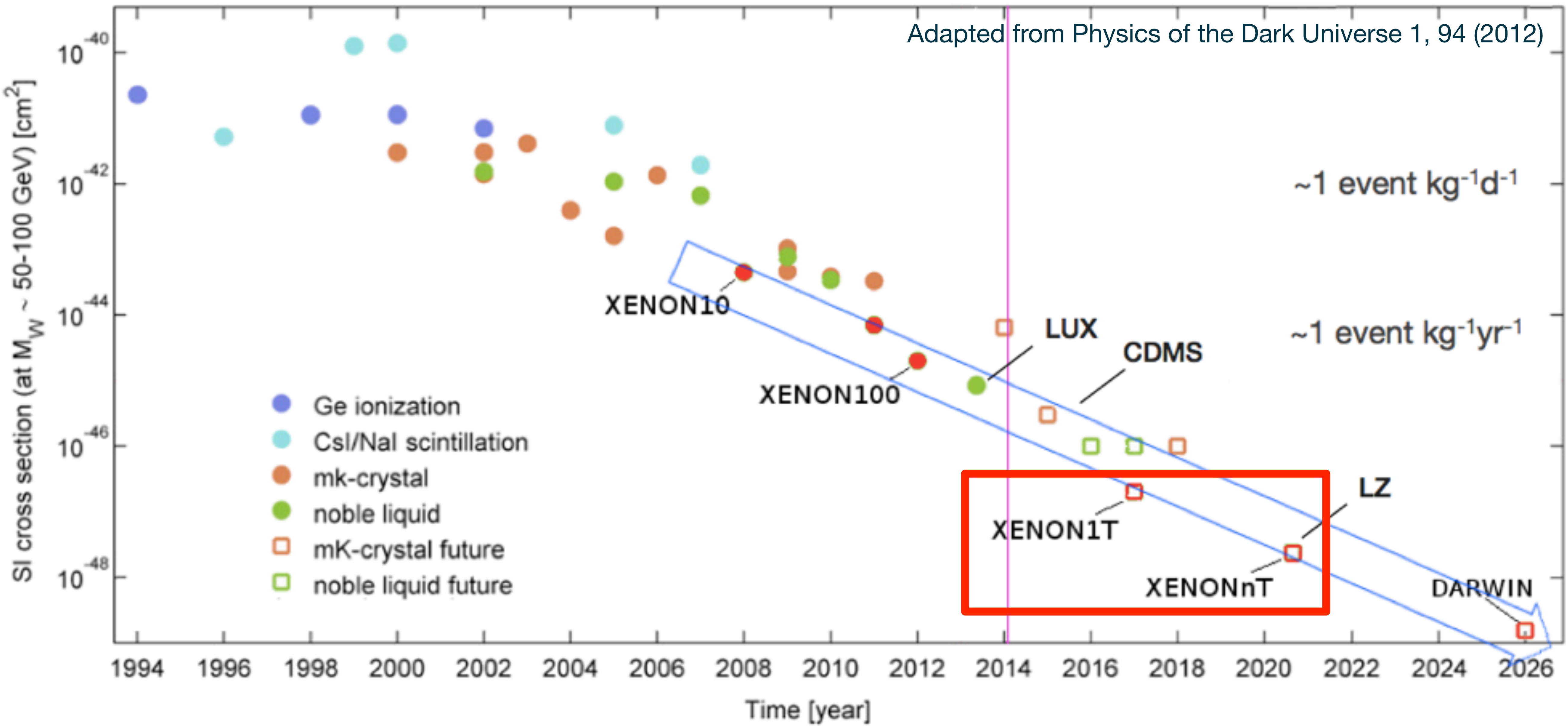
98 PMTs
in the top array
QE ≈ 25%



80 PMTs
on the bottom
QE ≈ 32%



XENON1T



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DARWIN
1994
1996
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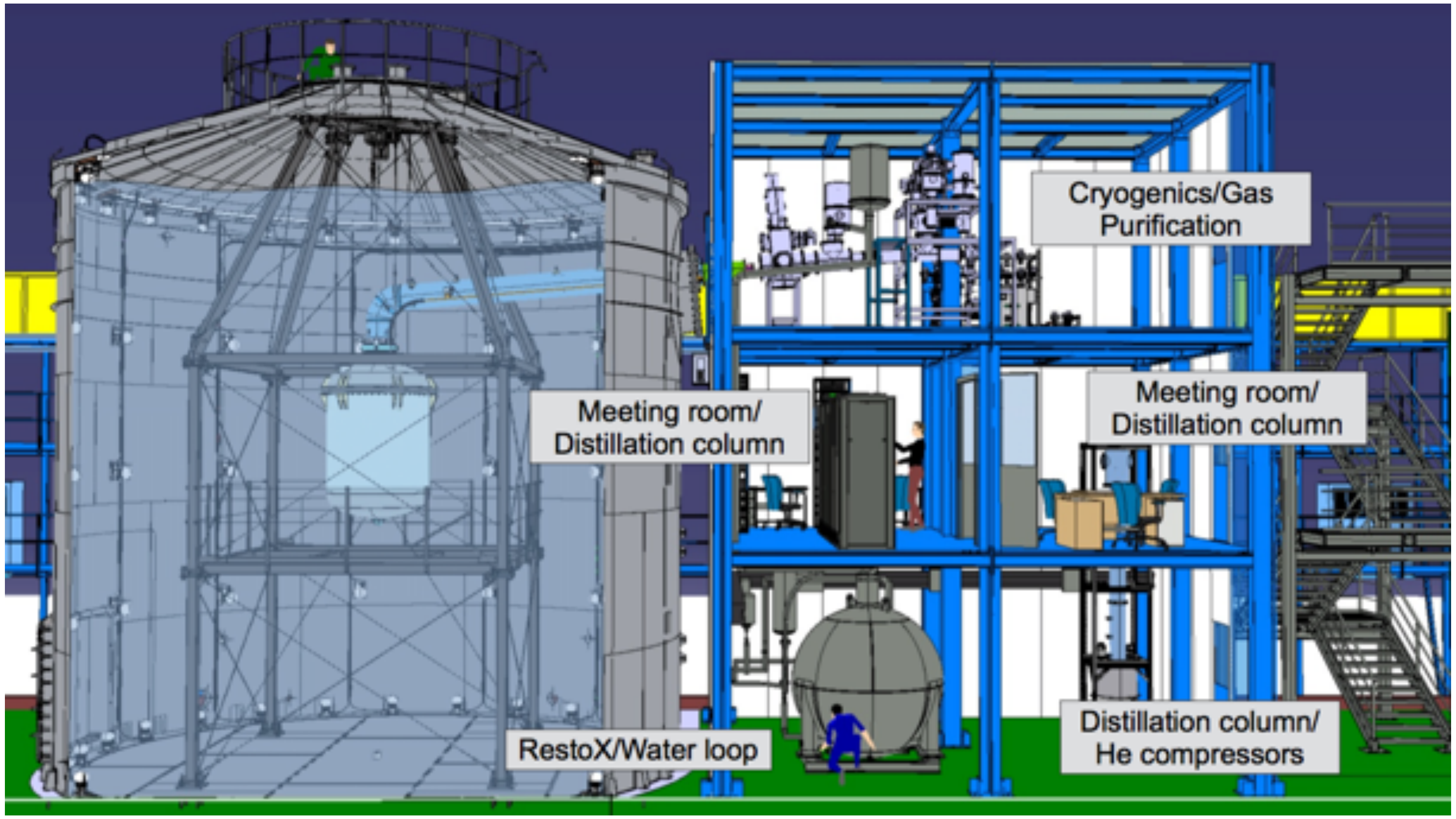
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
2020
2022
2024
2026
Time [year]

The XENON1T Experiment

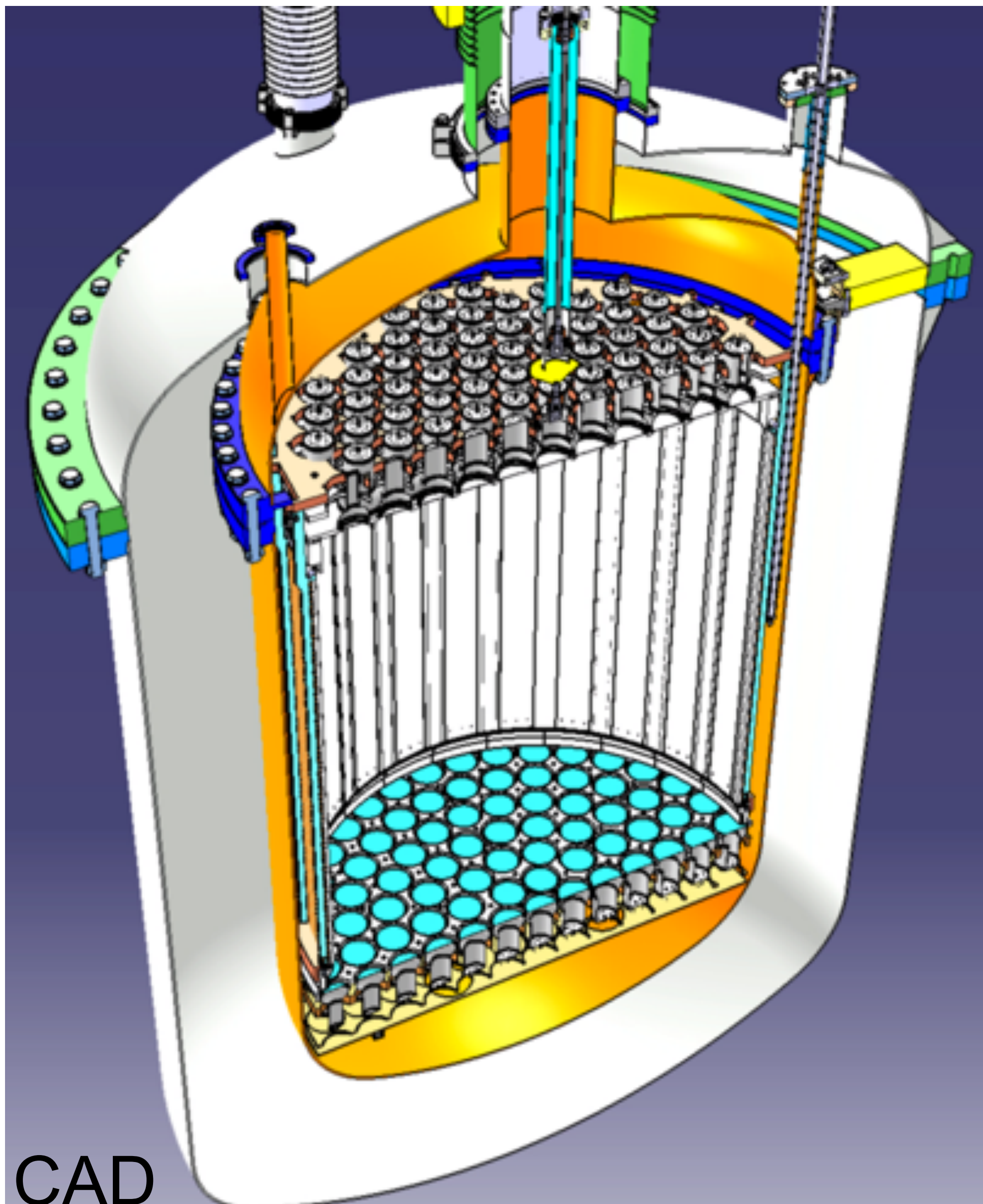
- Under construction at LNGS
- Background level 2 orders of magnitude lower than in XENON100
- 10m high and 9.6m diameter water tank (~700m^3)
- Čerenkov light is detected with 84 × 8” PMTs

● Many subsystems will be reused for the upgrade (XENONnT):

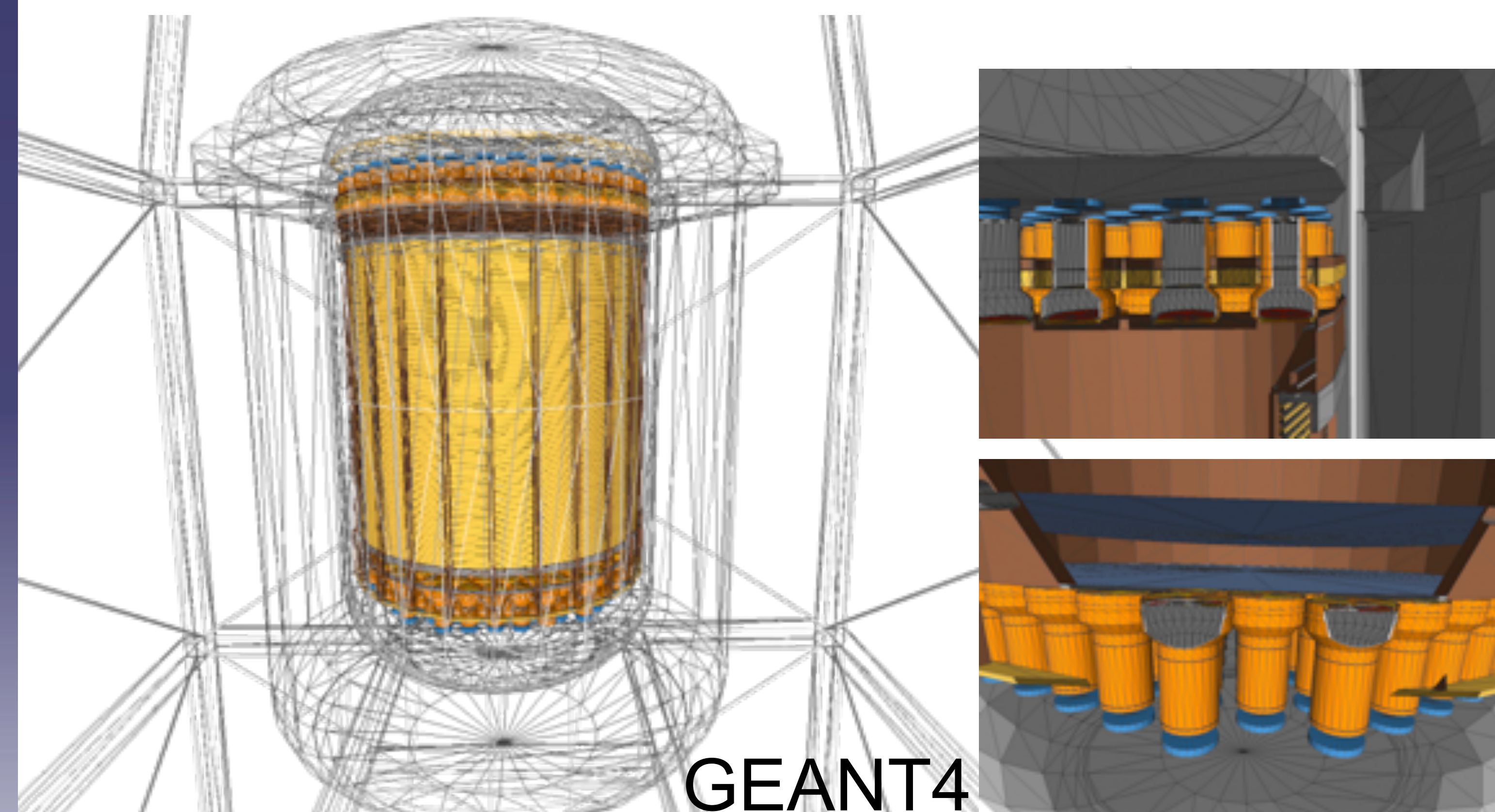
– water shield,
– cooling and support systems,
– outer cryostat,
– DAQ and cabling,
– xenon storage and purification,
– distillation column



- Dual-phase LXe TPC: ~3t of LXe in total (~2.2t active, ~1t fiducial)
- TPC out of OFHC and interlocking PTFE panels
- Low-background double-walled stainless steel cryostat
- 248 Hamamatsu R11410-21 PMTs

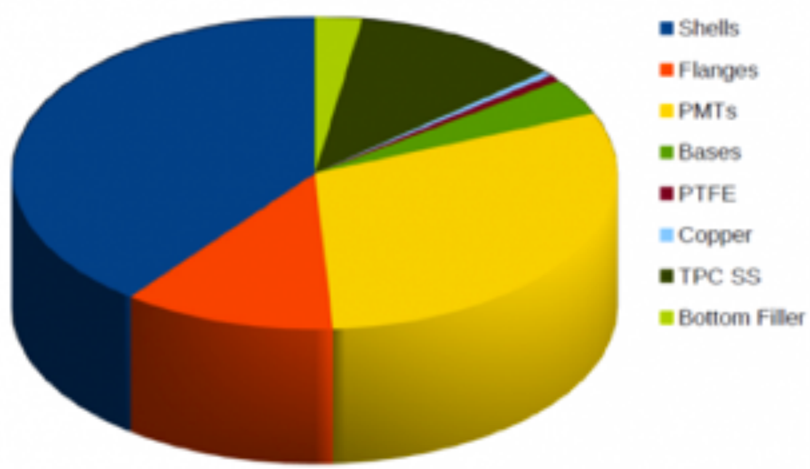


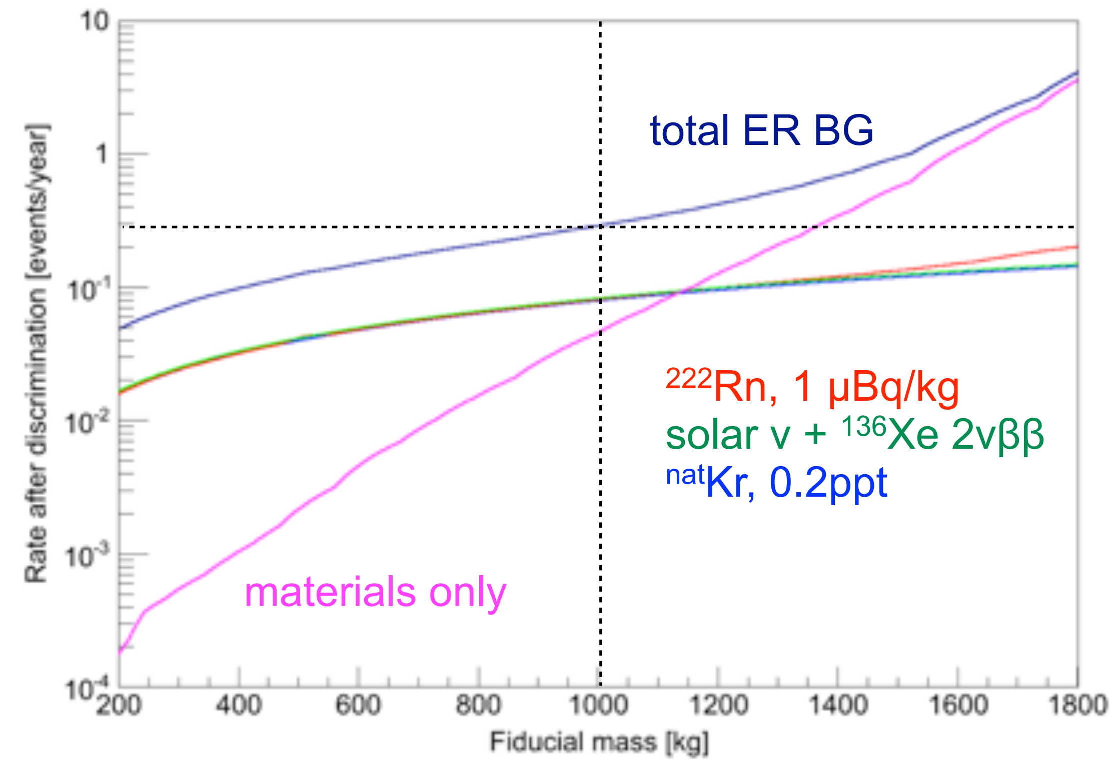
- Background goals:
  < 1 event (ER +NR) in 2 years
  < 0.5ppt of ^{nat}Kr
  < 1μBq/kg of ^{222}Rn
- MC simulations with detailed GEANT4 model



Backgrounds in XENON1T

- ER: single scatter interactions in 2-10 keV_{ee} range, 99.75% discrimination





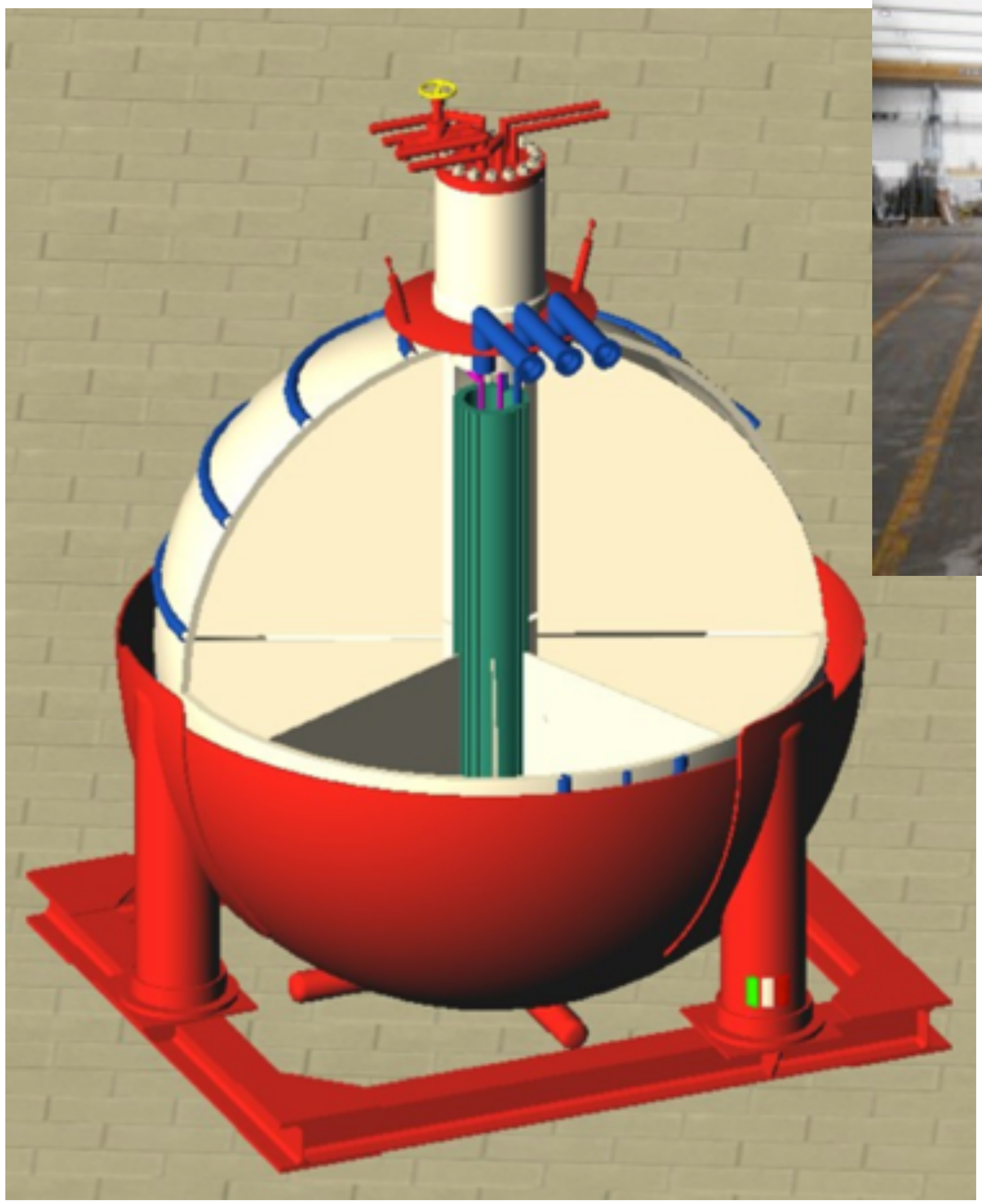
- NR: energy range 5-50 keV_{nr} (3-46 PE), 50% acceptance, taking into account energy threshold and resolution

Table D.1: Background events from radiogenic neutrons in [3,46] pe, in 1 ton FV								
ID	**Component**	**Background events (ev/y)**						
		U238	**U235**	**Ra226**	**Th232**	**Th228**	**Total**	**%**
1	Shell	0.0251	0.000407	0.00181	3.01e-06	0.00685	**0.0342**	15.4
2	Flange	0.00402	6.52e-05	0.00309	9.27e-07	0.0232	**0.0304**	13.7
3	Stem	0.0156	0.0079	0.00859	1.12e-05	0.00824	**0.0404**	18.2
4	Quartz	0.00472	0.000305	0.000327	1.35e-06	0.000602	**0.00596**	2.7
5	PMTSS	0.000733	0.000121	0.000131	3.47e-07	0.000654	**0.00164**	0.7
6	PMTKovar	0.00102	5.6e-06	0.000241	9.14e-09	0.00253	**0.00379**	1.7
7	Bases	0.0185	0.00125	0.00615	3.34e-05	0.00102	**0.0269**	12.1
8	PTFE	0.00118	0.000826	0.00907	0.000477	0.0267	**0.0383**	17.2
9	Copper	0.000405	6.37e-07	1.14e-05	3.37e-09	4.73e-05	**0.000464**	0.2
10	Bottom Filler	0.0122	0.000196	0.000359	1.87e-06	0.00401	**0.0167**	7.5
11	Cathode, Anode, Support Ring	0.000604	1.03e-05	0.000493	9.4e-08	0.00358	**0.00469**	2.1
12	Lateral Bell	0.0149	0.00025	0.0003	2.92e-07	0.000974	**0.0165**	7.4
13	Top and Bottom Rings	0.000138	2.27e-06	1.01e-05	1.49e-08	3.8e-05	**0.000189**	0.1
14	Top Plate	0.0017	2.83e-05	0.000126	1.78e-07	0.000464	**0.00232**	1.0
	Total						**0.222**	

Single Scatter, 1 ton Fiducial Volume, [2, 12] keVee, [5, 50] keVr, 99.75% S2/S1 discrimination, 50% NR acceptance	
Source	**Background (ev/y)**
ER from materials	0.05
Kr85 (0.2 ppt of ^{nat}Kr)	0.07
Rn222 (1 μBq/kg)	0.08
Solar neutrinos + 2ν2β	0.09
NR from materials	0.2
Total	**0.5**

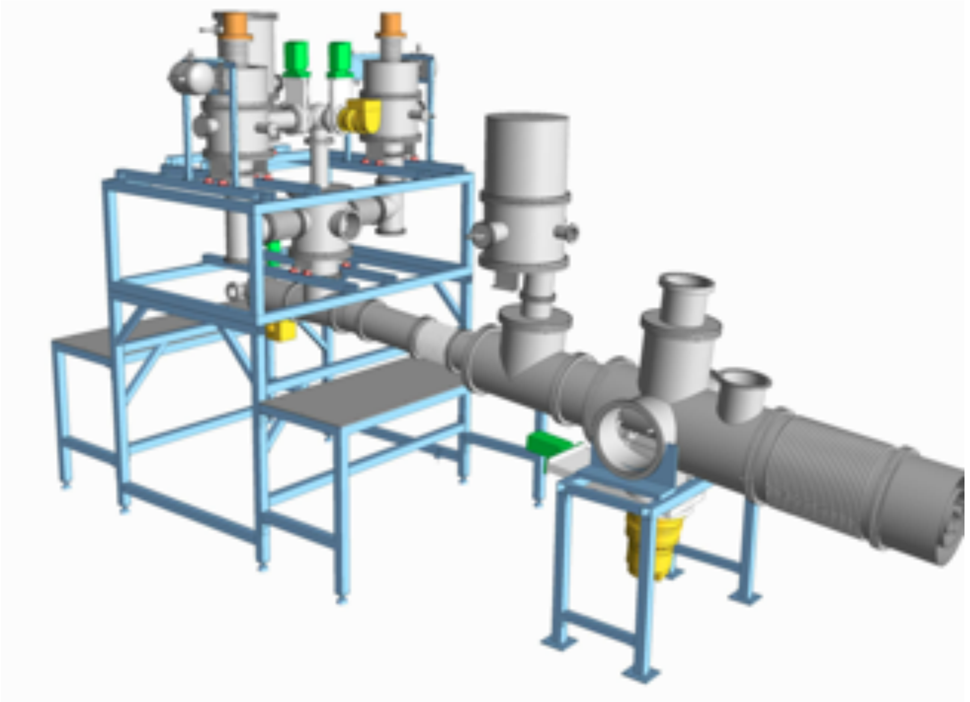
Xenon Storage and Recovery

- Xe storage and fast recovery system (ResToX)
- Capable to store 7.6t of Xe either in gas or liquid phase under high purity conditions
- Double-walled, high pressure (70atm) sphere (stainless steel + copper)
- LN_2 based 3kW condenser, large surface area (~5m^2) to minimize icing
- 1.5kW heater to melt Xe ice during TPC filling after emergency cooling



XENON1T Cryogenics and Purification

- Cooled by 2 redundant PTRs. “Stand-alone” LN_2 backup cooling tower



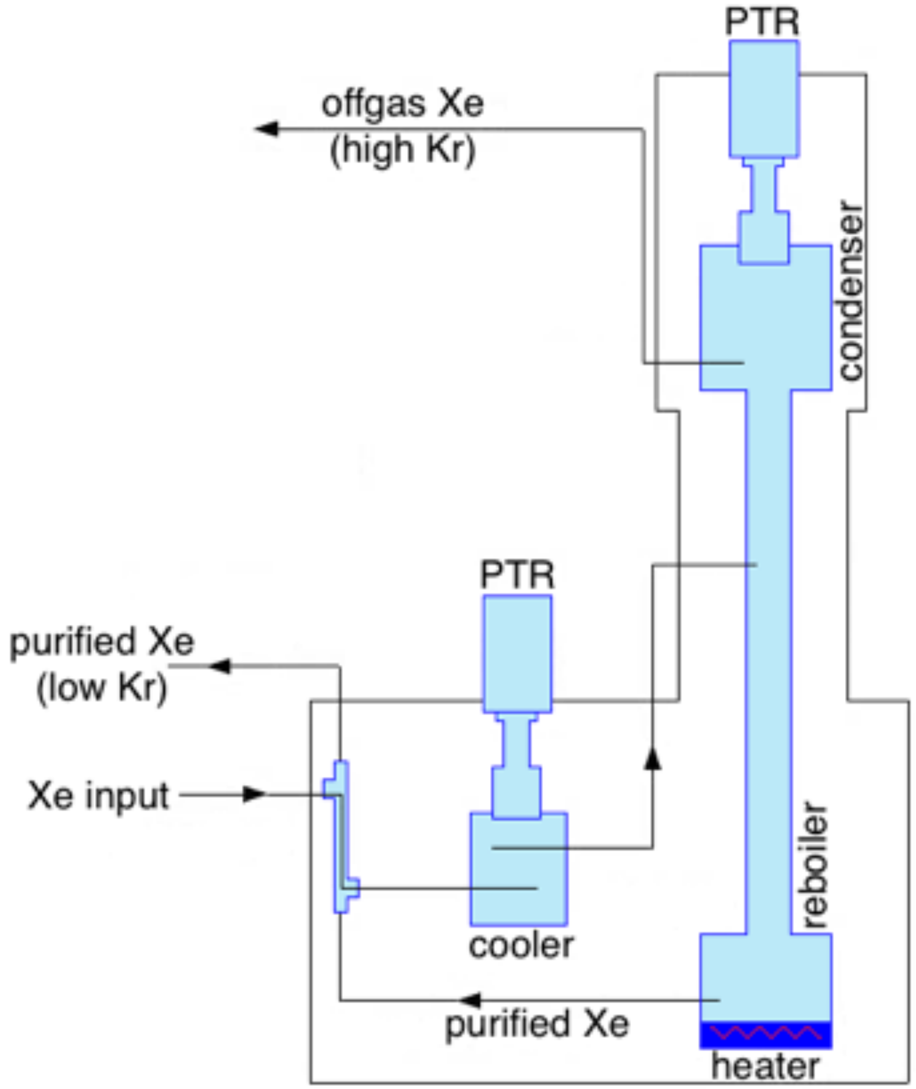
- Recirculation pumps, mass flow controllers, HALO oxygen and water monitor, RGA + cold trap, baking equipment, automatic introduction of internal calibration sources

Xenon Purification

- On-site purification with a cryogenic distillation column (Kr removal)

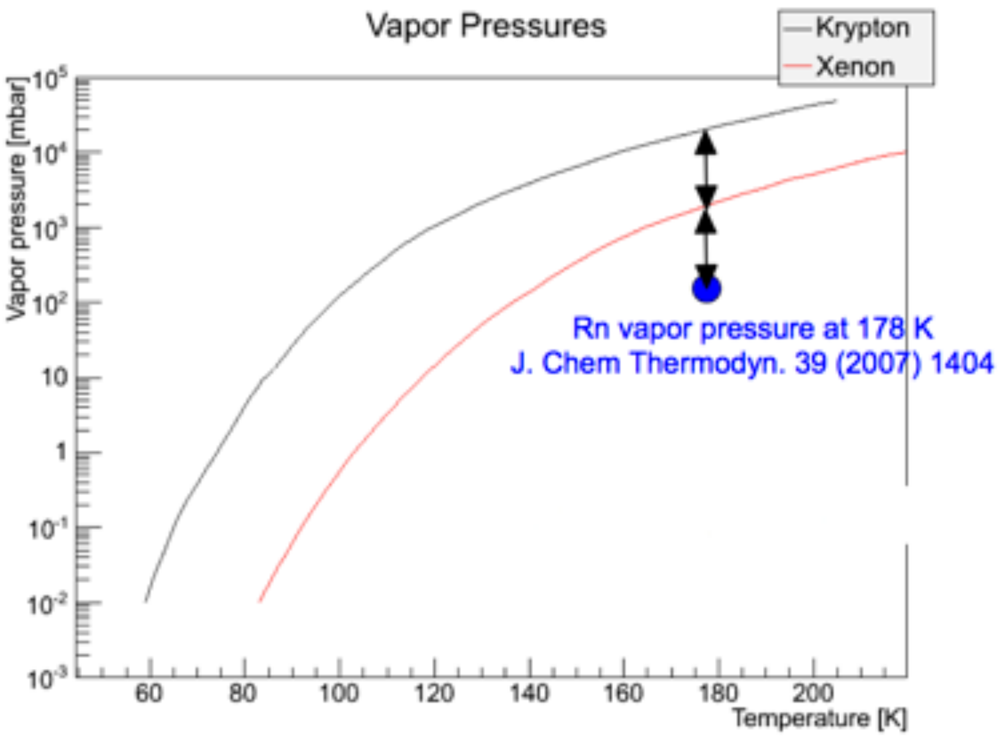
- Preliminary result from a distillation run at 8.5 slpm:
  - in-gas concentration $^{nat}Kr/Xe = (136 \pm 22)$ ppt
  - purified liquid out $^{nat}Kr/Xe < 28$ ppq

  $\Rightarrow$ separation factor > 5000 at 90% C.L.

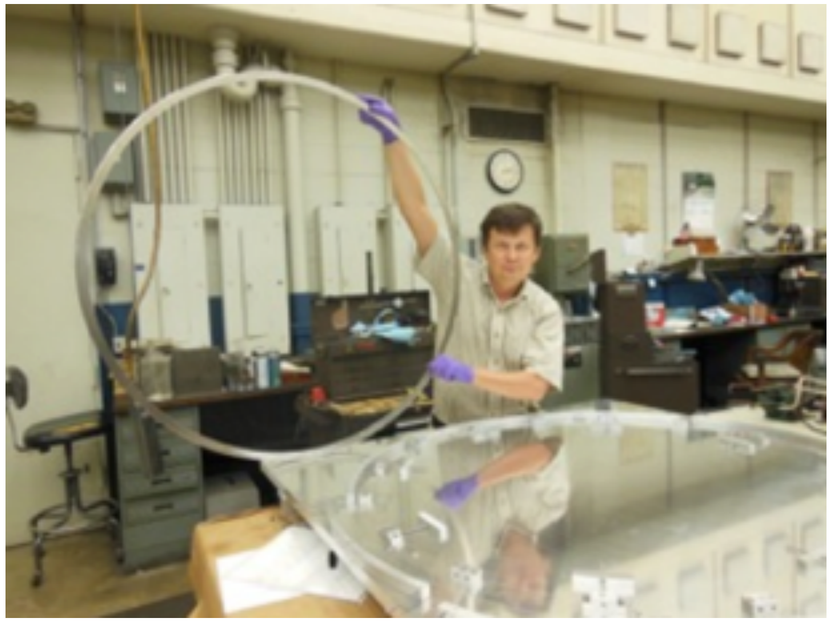


- Recirculation rate up to 16 slpm possible

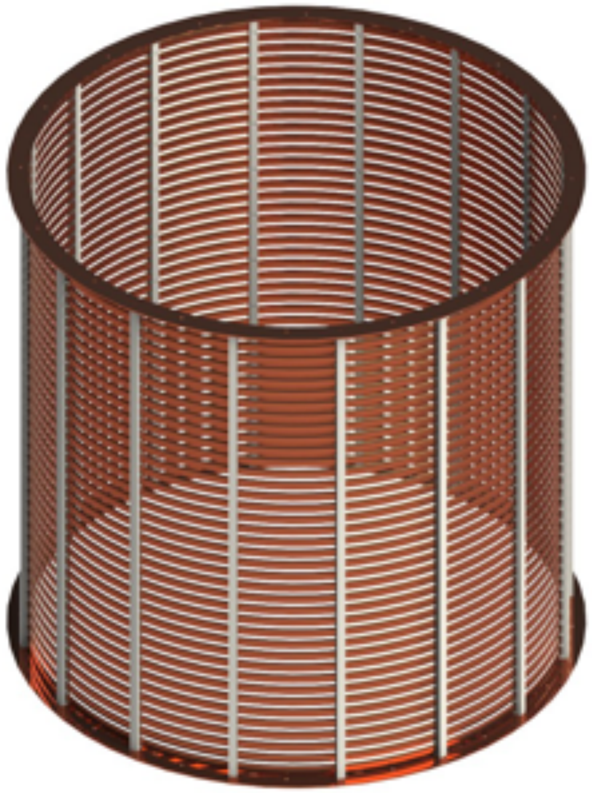
- Rn removal with distillation at R&D stage

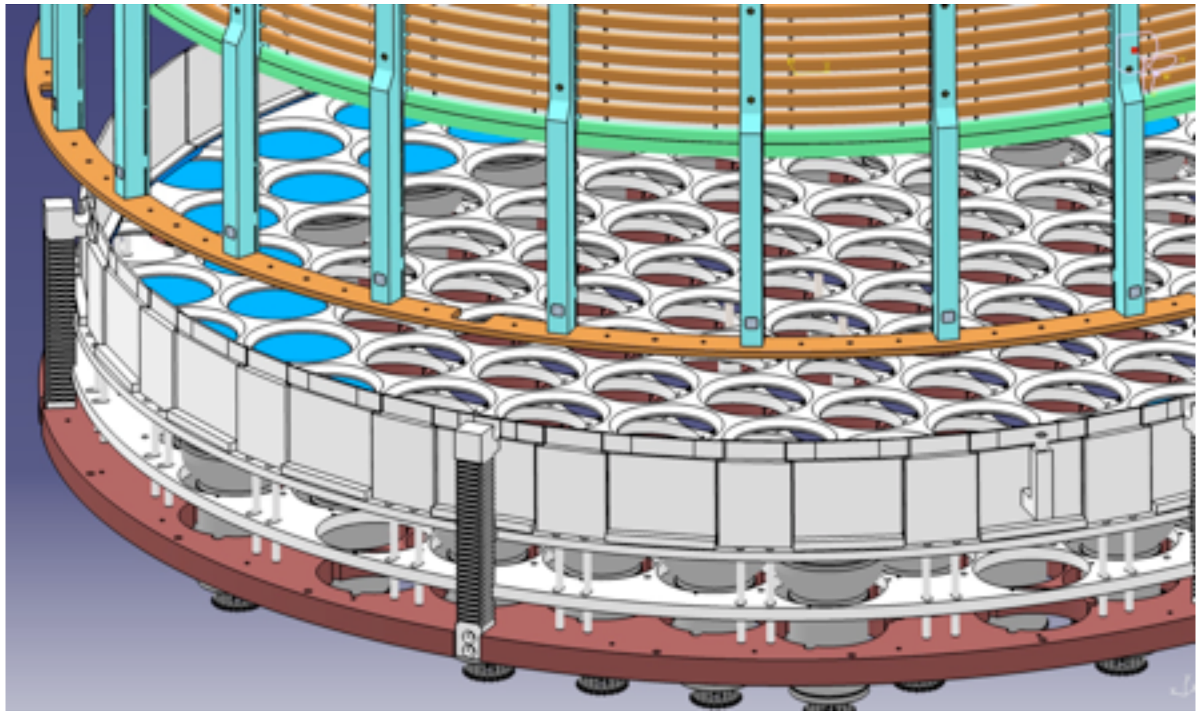


XENON1T Electric Field Cage



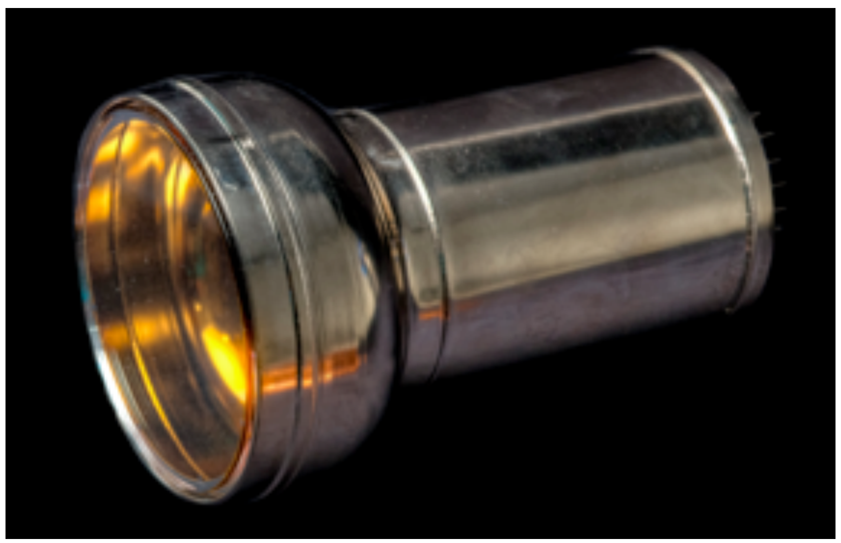
- Electrodes: 1m diameter wire grids
- Equidistant field shaping rings
- Total weight: 86kg OFHC, 16kg PTFE
- 100kV custom feedthrough
- Electric field optimization with COMSOL and KEMField (boundary element method) simulations

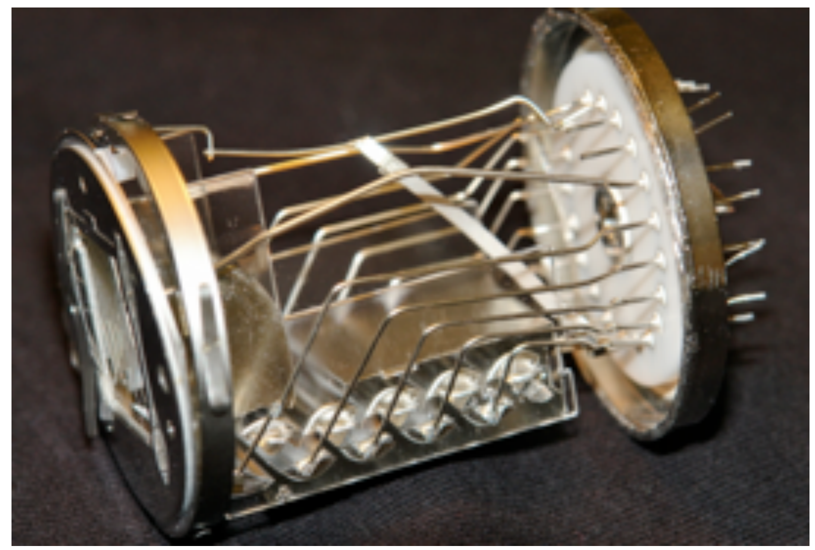


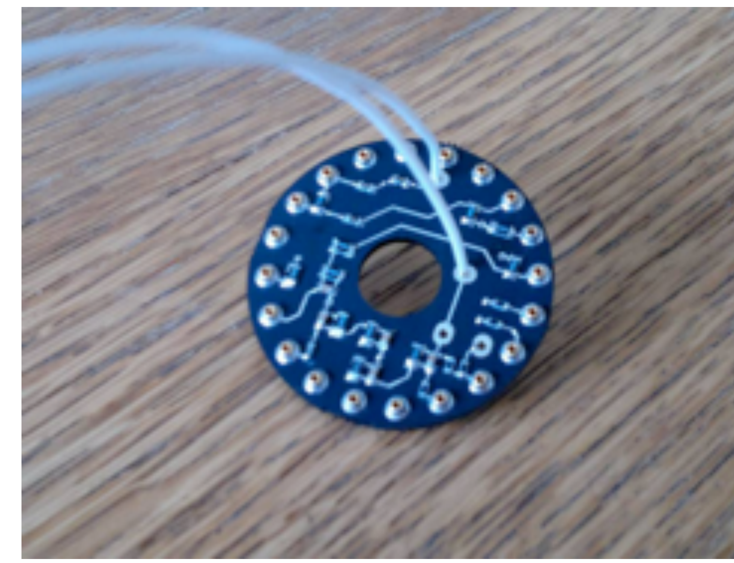


Photosensors

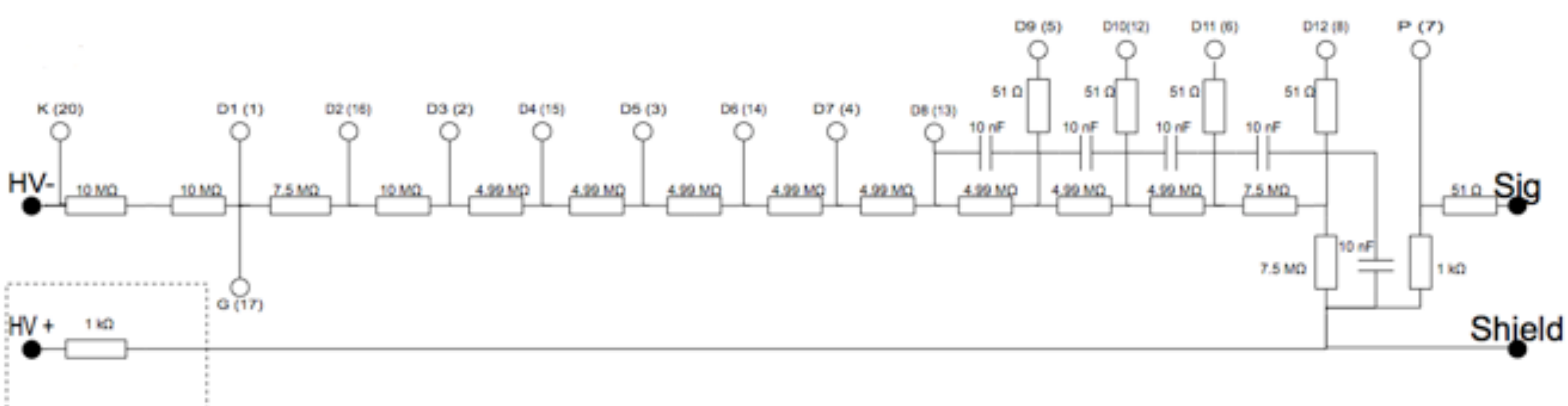
- 3-inch Hamamatsu R11410-21 PMTs
- Average quantum efficiency 36% (at λ=178nm)
- Optimized to operate in LXe conditions, minimized radioactive contamination
  JINST 8, P04026, 2013
- Gain 2÷5×10^6 at ~1.5kV

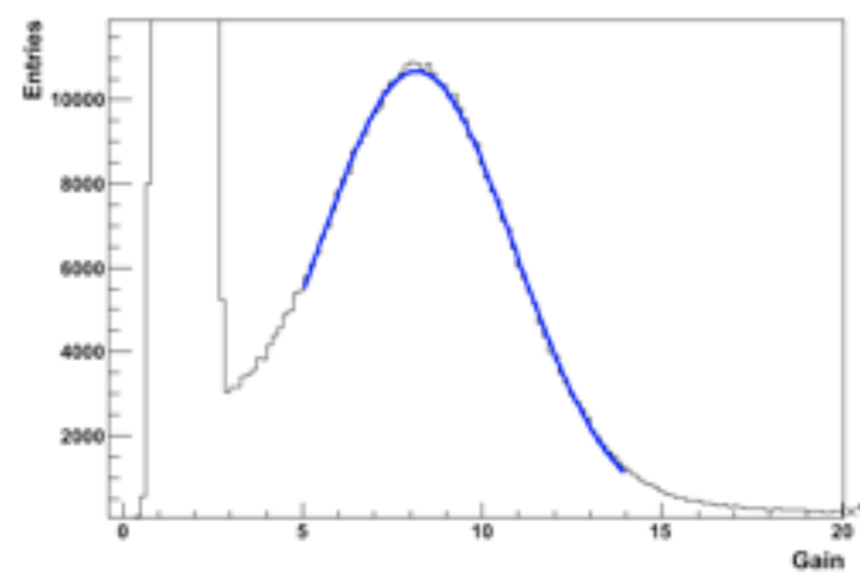




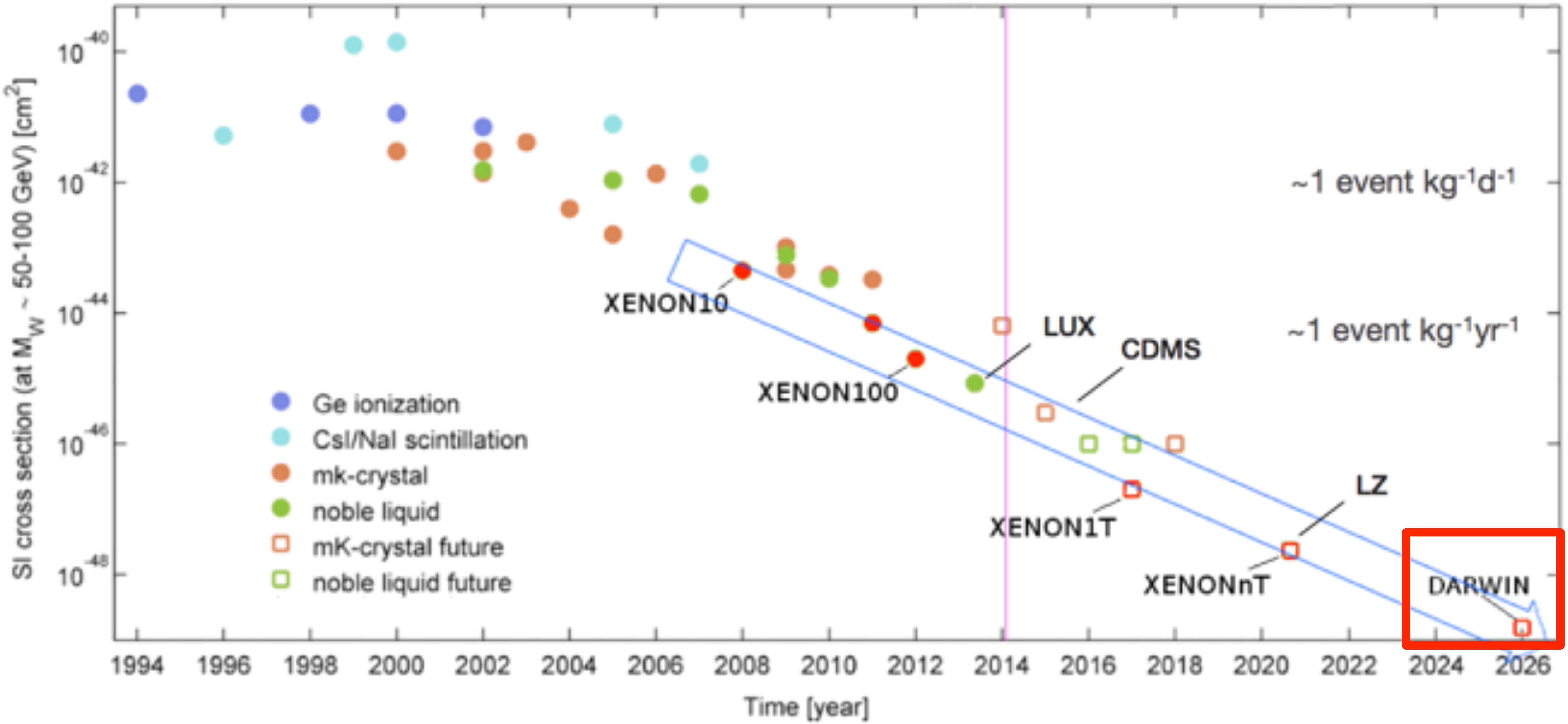


- Voltage divider network on cirlex substrate
- Optimized linearity and power consumption





DARWIN



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DARWIN
Ge ionization
CsI/NaI scintillation
mk-crystal
noble liquid
mK-crystal future
noble liquid future
1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016 2018 2020 2022 2024 2026
Time [year]

The DARWIN Consortium

- 29 groups from 9 countries; joined effort of Xe- and Ar-based experiments

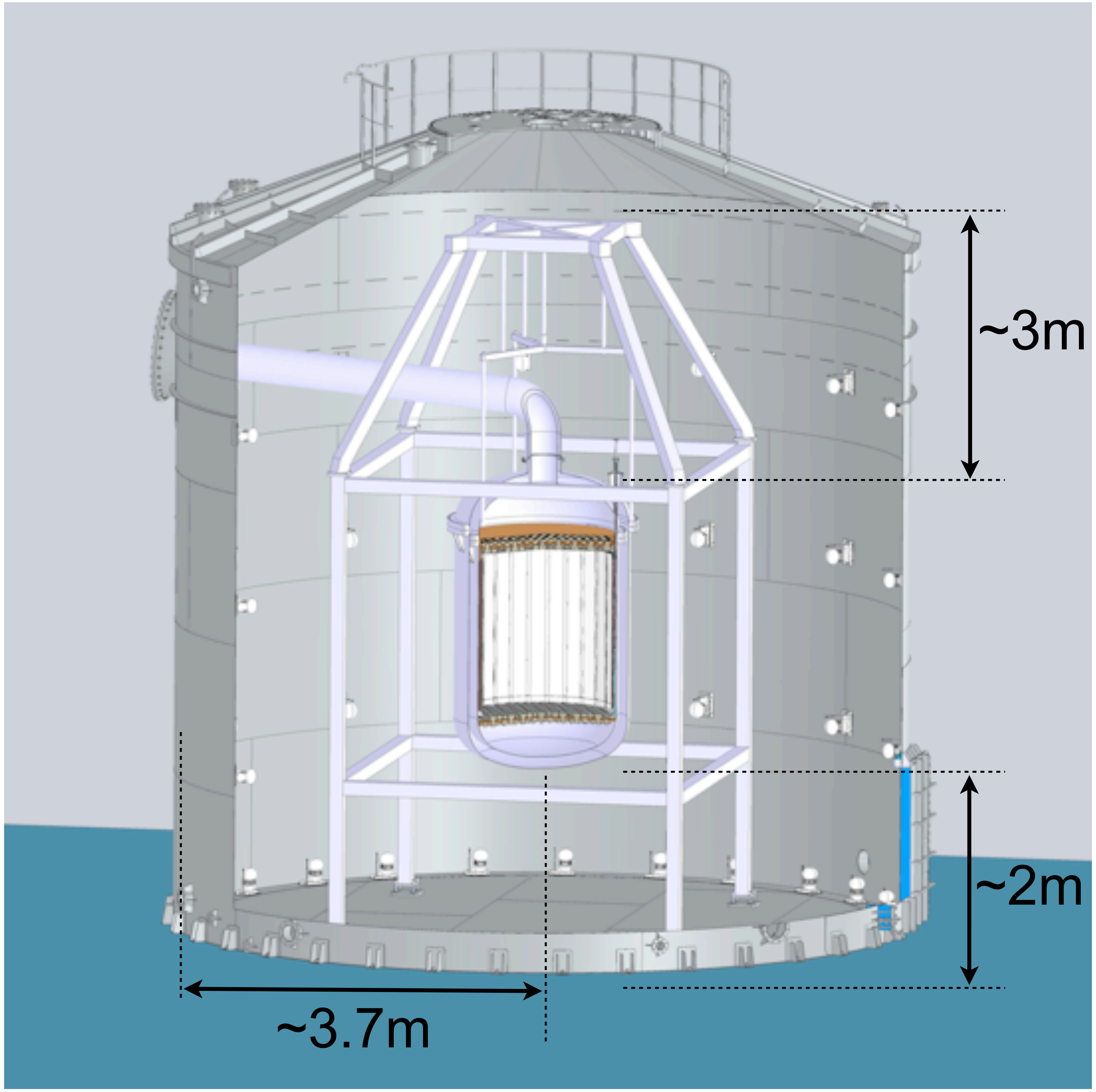
- Time schedule:

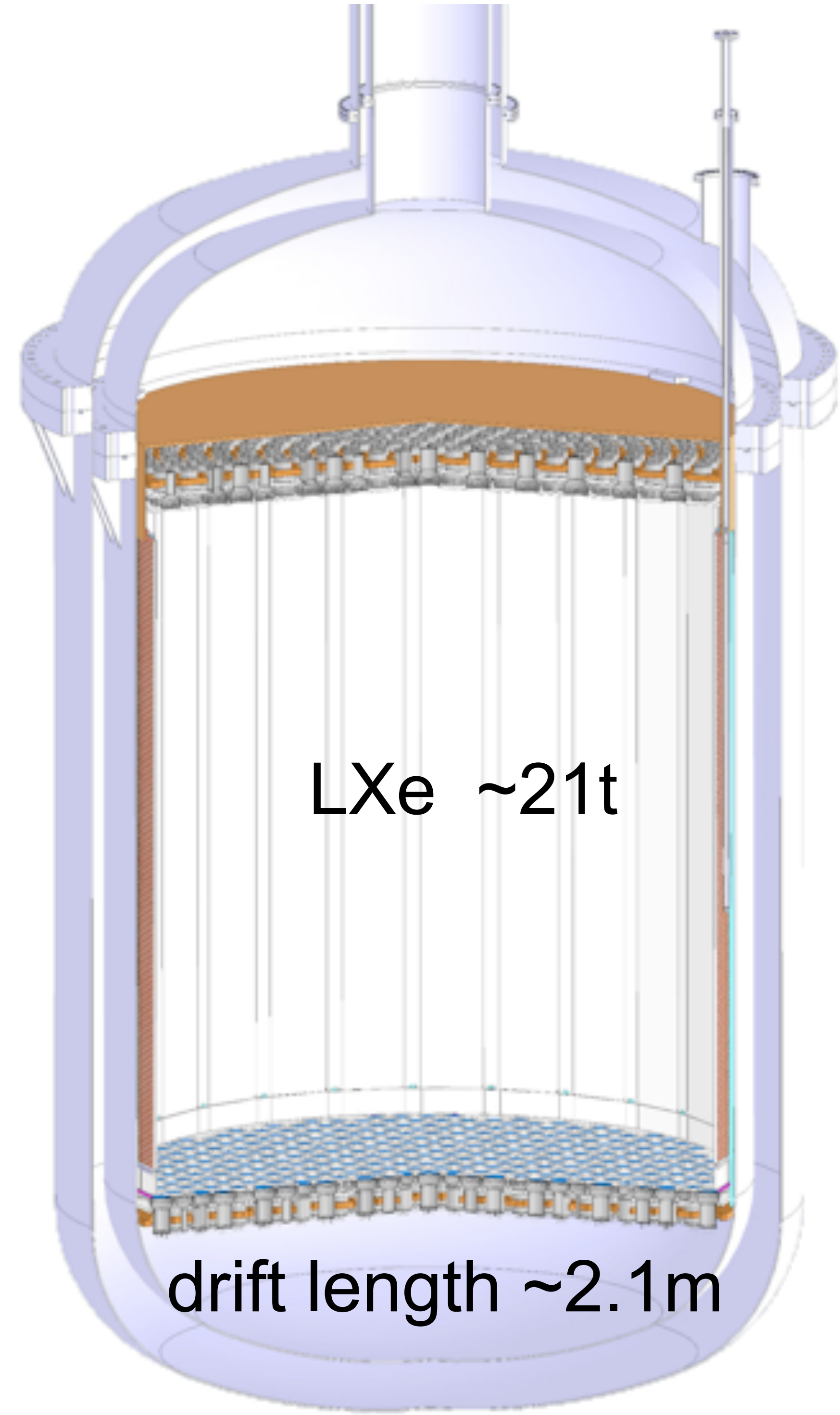
2010 – 2013	First R&D phase, Aspera funded
2014 – 2018	R&D and design
2018 – 2020	Engineering study
2020 – 2030	Construction, commissioning, science run

The DARWIN Detector Design (Xe part example)

- Can be installed in the XENON1T water tank

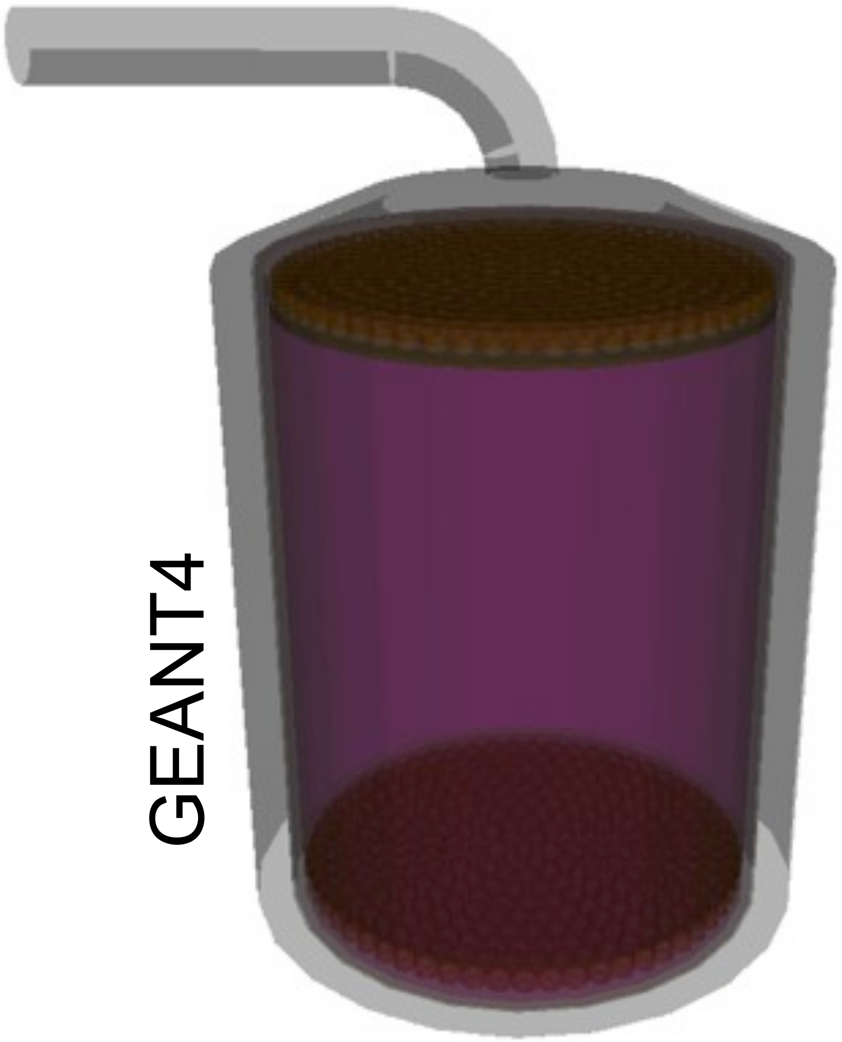
JCAP 01,044 (2013)





DARWIN: Backgrounds from Natural Radioactivity

GEANT4



- Studied Xe-based part of the project
- Copper for cryostat vessels (5 cm thick): inner cryostat 1.8t, outer vessel 2.2t
- PTFE for the TPC (~300 kg)
- The modeled photosensors are 3” Hamamatsu R11410 PMTs (1050 in total)
- The best results from XENON100 and XENON1T screening campaigns have been selected

JCAP 01,044 (2013)

- Intrinsic contamination:
  0.1 ppt of ^{nat}Kr,   0.1µBq/kg of ^{222}Rn

  XENON100: (1.0±0.2) ppt of krypton
  EXO-200: (3.7±0.4) ppt of radon

DARWIN: Neutrino and WIMP detection with Xe Detector

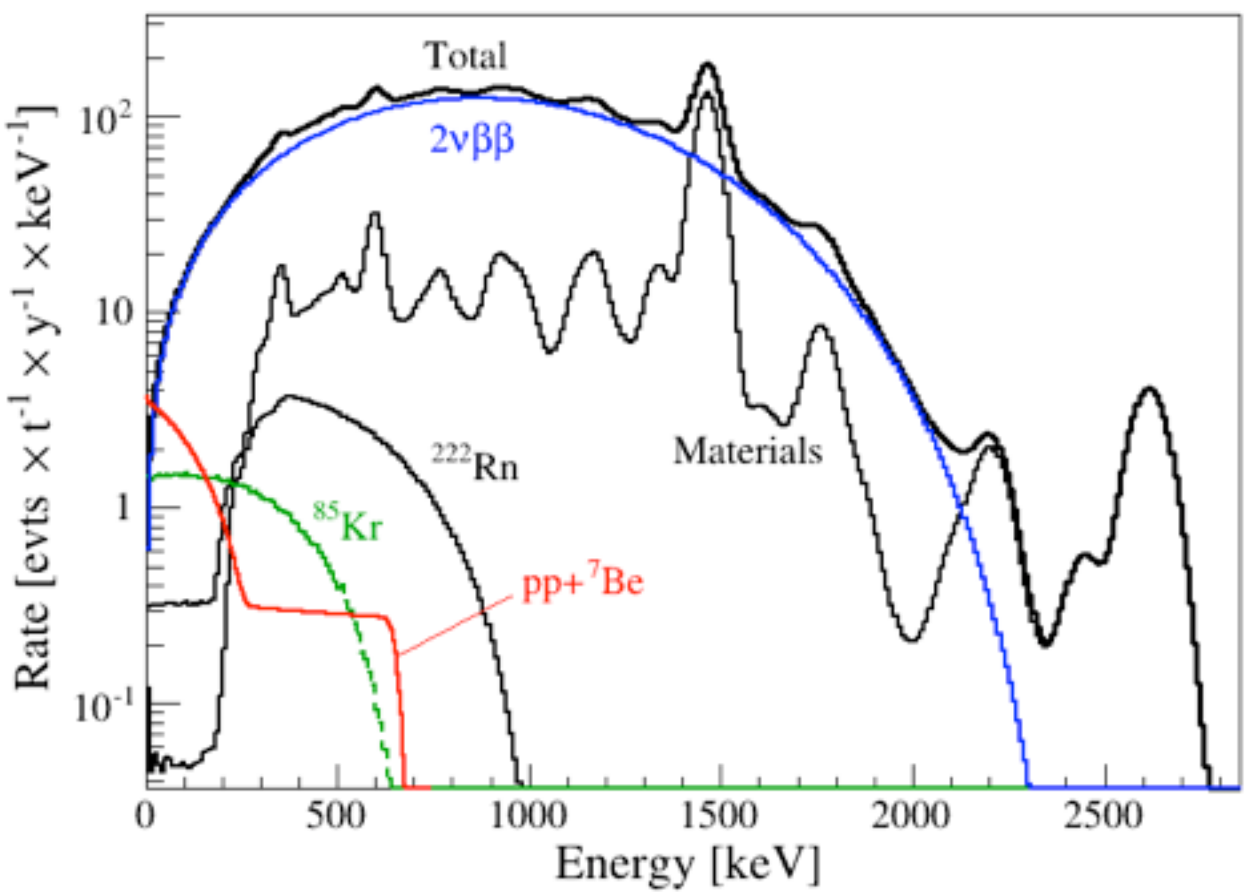
JCAP 01,044 (2013)

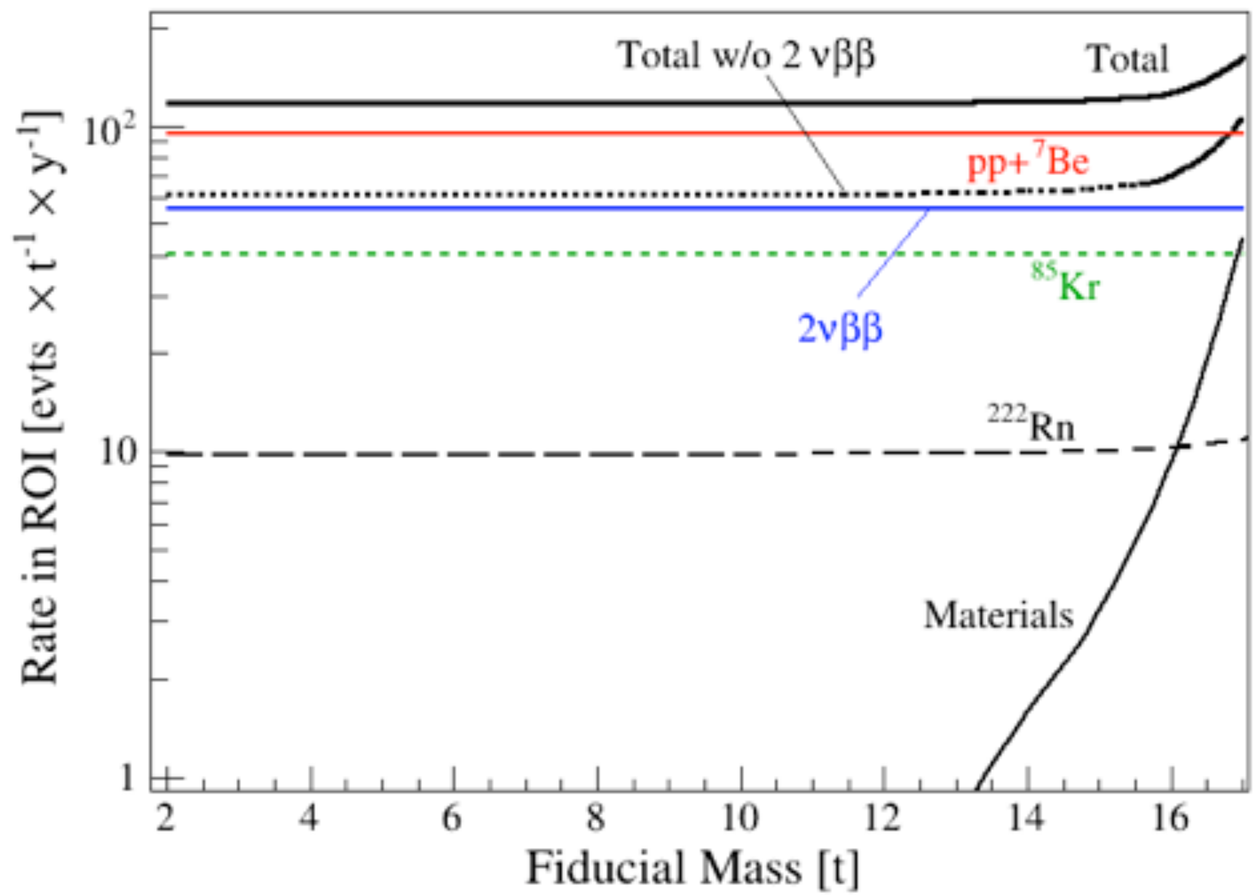
- The total background at low energies is dominated by 2νββ-decays of ^{136}Xe ($T_{1/2} = 2.165\times10^{21}$ years, as measured by EXO-200), followed by krypton

- Fiducialize 14t of LXe in the central detector region

- Energy range for neutrino measurement up to 30 keV_{ee} (intersect with ^{136}Xe 2νββ curve)

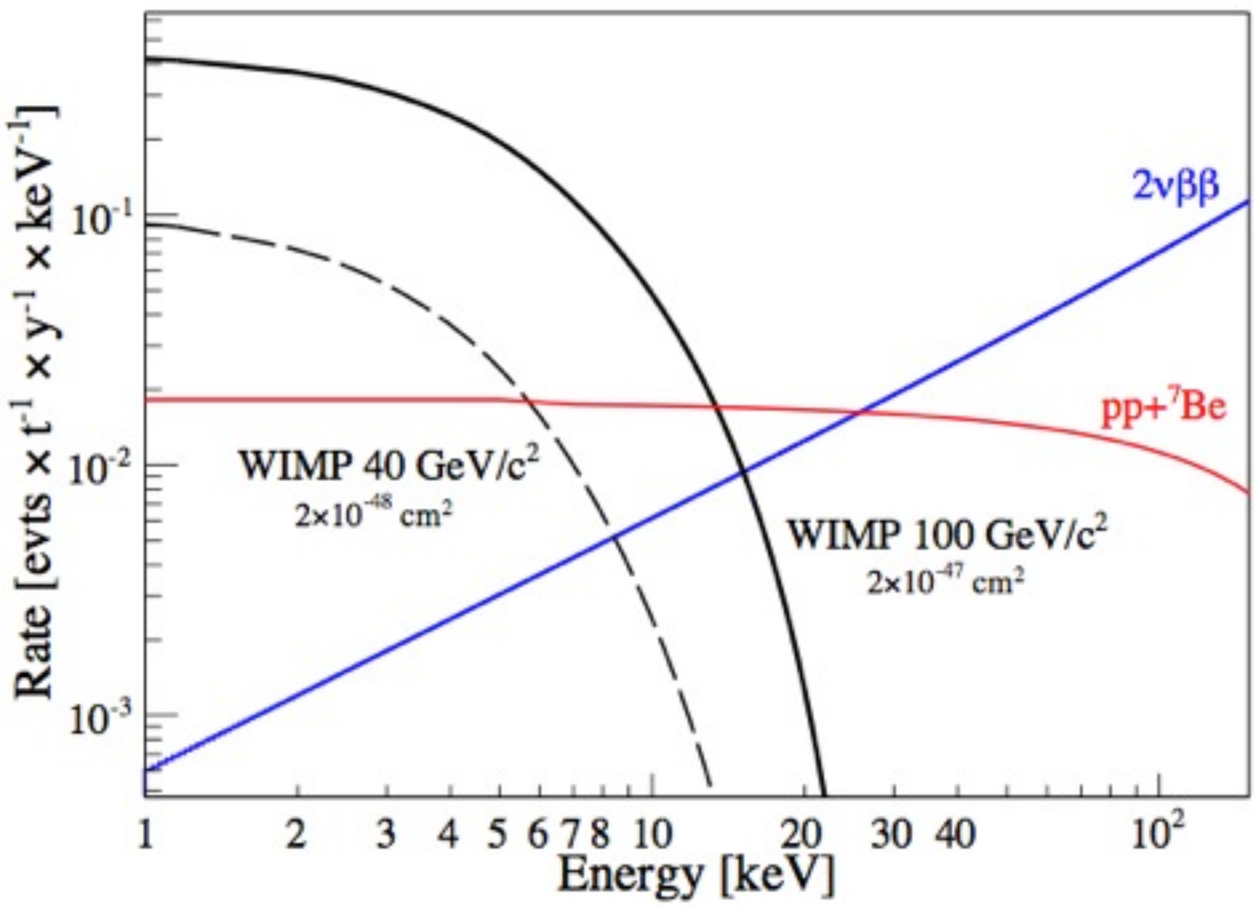
- WIMP ROI up to 2–10 keV_{ee} + electronic recoil rejection 99.5%

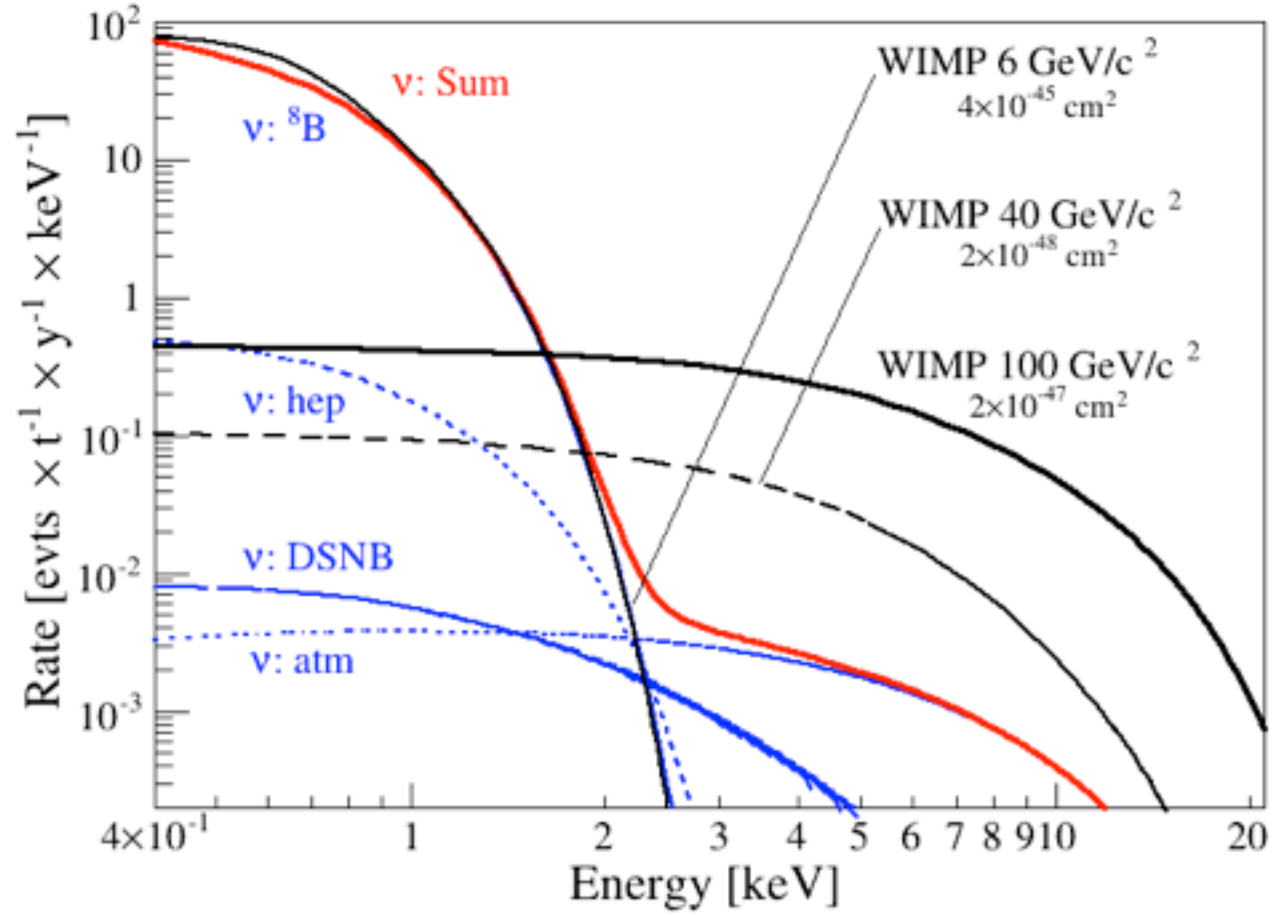




DARWIN: WIMP and Neutrino Sensitivity with Xe Detector

● Assuming electronic recoil rejection 99.5%, nuclear recoil acceptance 50%





● Electronic recoil neutrino BG limits DM search channel (spin-independent WIMP-nucleon coupling) around cross-sections of 2×10^{-48} cm^2, dominated by interactions of pp-neutrinos

● Coherent neutrino-nucleus elastic scattering (mostly ^{8}B and hep neutrinos) affects the sensitivity to low-mass WIMPs

● Atmospheric and diffuse supernovae neutrinos become relevant at 10^{-48} cm^2

Summary

XENON100
● Still in operation after 5 years. Recent DM-search data is blinded

XENON1T
● Construction is on schedule
● Commissioning of the cryostat and cryogenic plants in July 2014
● TPC installation by Spring 2015

XENONnT
● The detector upgrade has been proposed. To start in 2018

DARWIN
● Planned for 2020-2030
● Limiting backgrounds for WIMP-search channel:
– solar pp-neutrinos: WIMP-nucleon cross-sections below ~2×10^{-48} cm^2 and WIMP masses around 50 GeV/c^2
→ another physics channel: statistical uncertainty of the measured flux ~1%)
– NRs from coherent scattering of solar neutrinos: sensitivity to WIMP masses below 6 GeV/c^2 to cross-sections above ~5×10^{-45} cm^2