Future Noble Liquid Dark Matter Detectors

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NIKHEF

Noble Gases

- Monolithic detectors
- Good self-shielding and homogenous, with high electron mobility
- Inert and excellent scintillators

	Unit	Argon	Xenon
Z		18	54
A		40	~132
Liquid Density	g/cm^3	1.4	3.06
Energy Loss (dE/dX)	MeV/cm	2.1	3.8
Radiation Length	cm	14	2.8
Boiling Point @ 1 bar	°K	87.3	165
Scintillation Wavelength	nm	125	175
Scintillation	ph/keV	40	42
Ionization	e$^-$/keV	42	64
Lifetime of triplet molecule	ns	1600	22
Background Isotope		^{39}Ar (1 Bq/kg)	^{136}Xe
Price		$ (but UAr)	$$$

WIMP-nucleon spin-independent cross section grows as A^2
→ Using xenon attractive

Particle-dependent Response

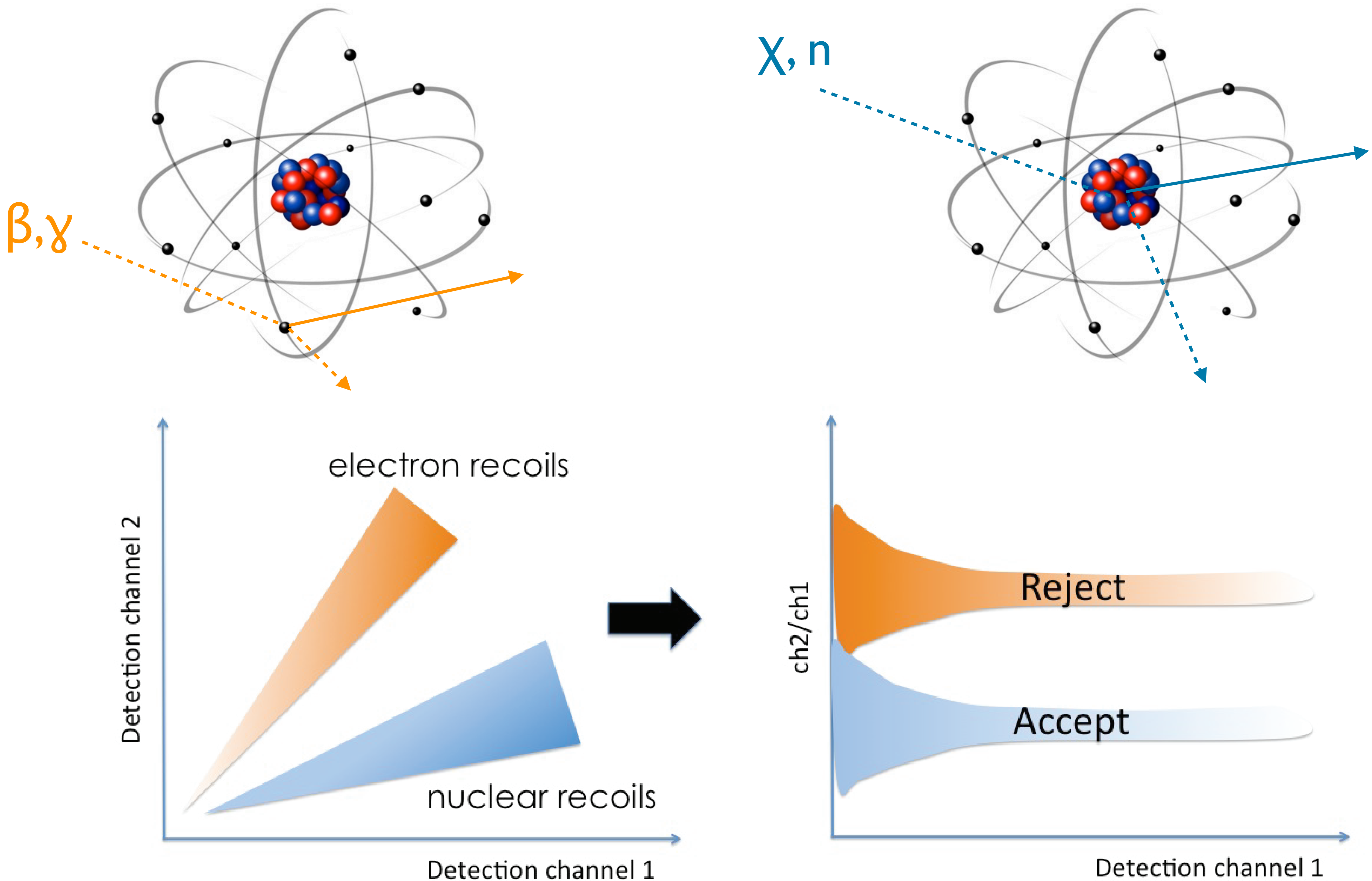
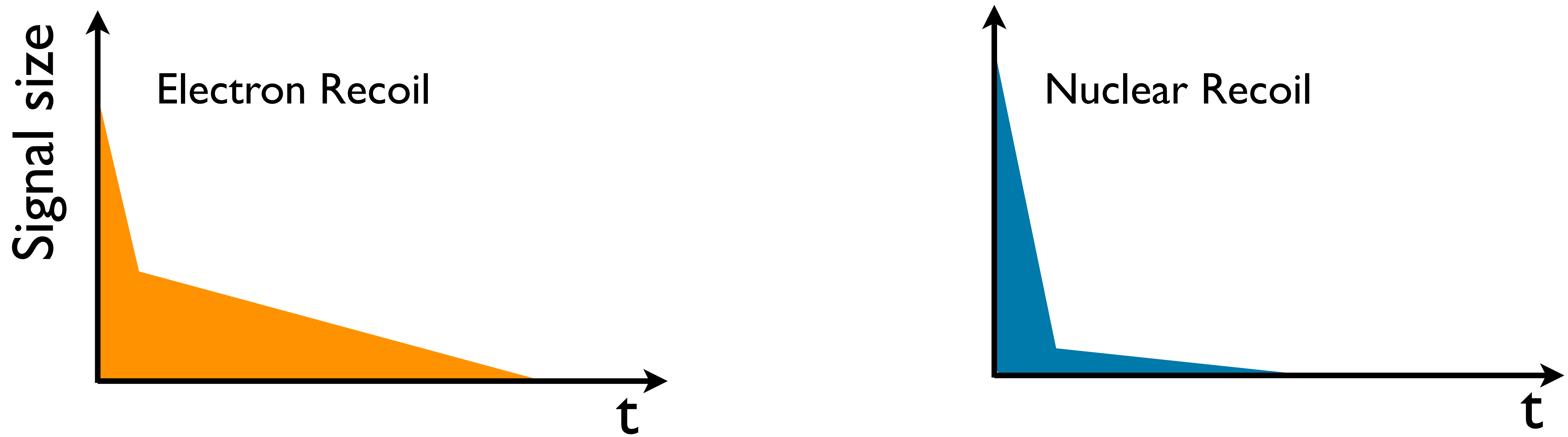


Image E.Pantic

Pulse Shape Discrimination

DEAP/CLEAN, KIMS,
DarkSide, XMASS etc.

Using scintillation light:



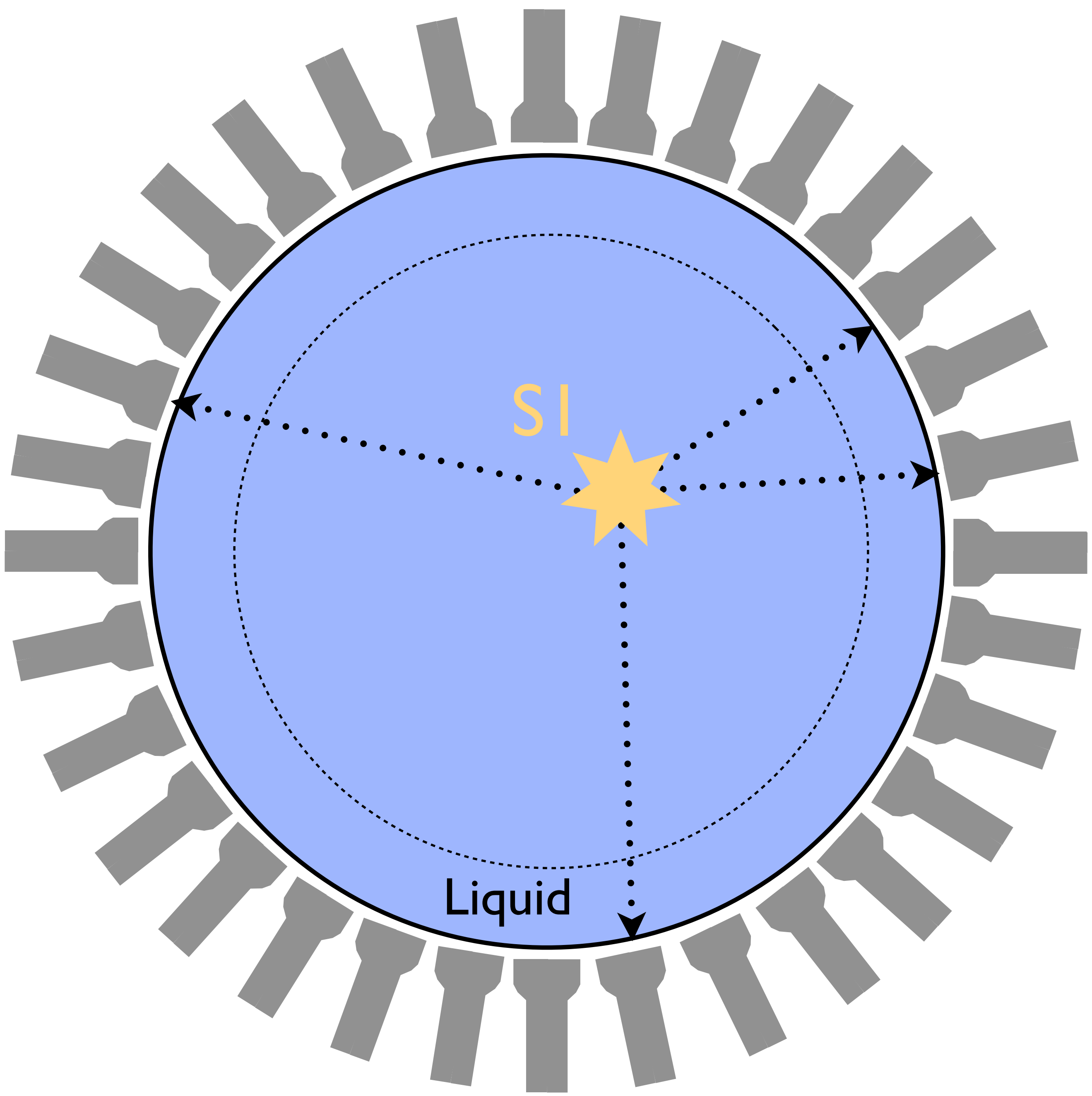
- Use ratio of fast-to-slow signal components
- Need many photons
- Works well in
  - LAr, LNe
- But also in
  - LXe, NaI, CsI

Possible to achieve very high ER/NR discrimination

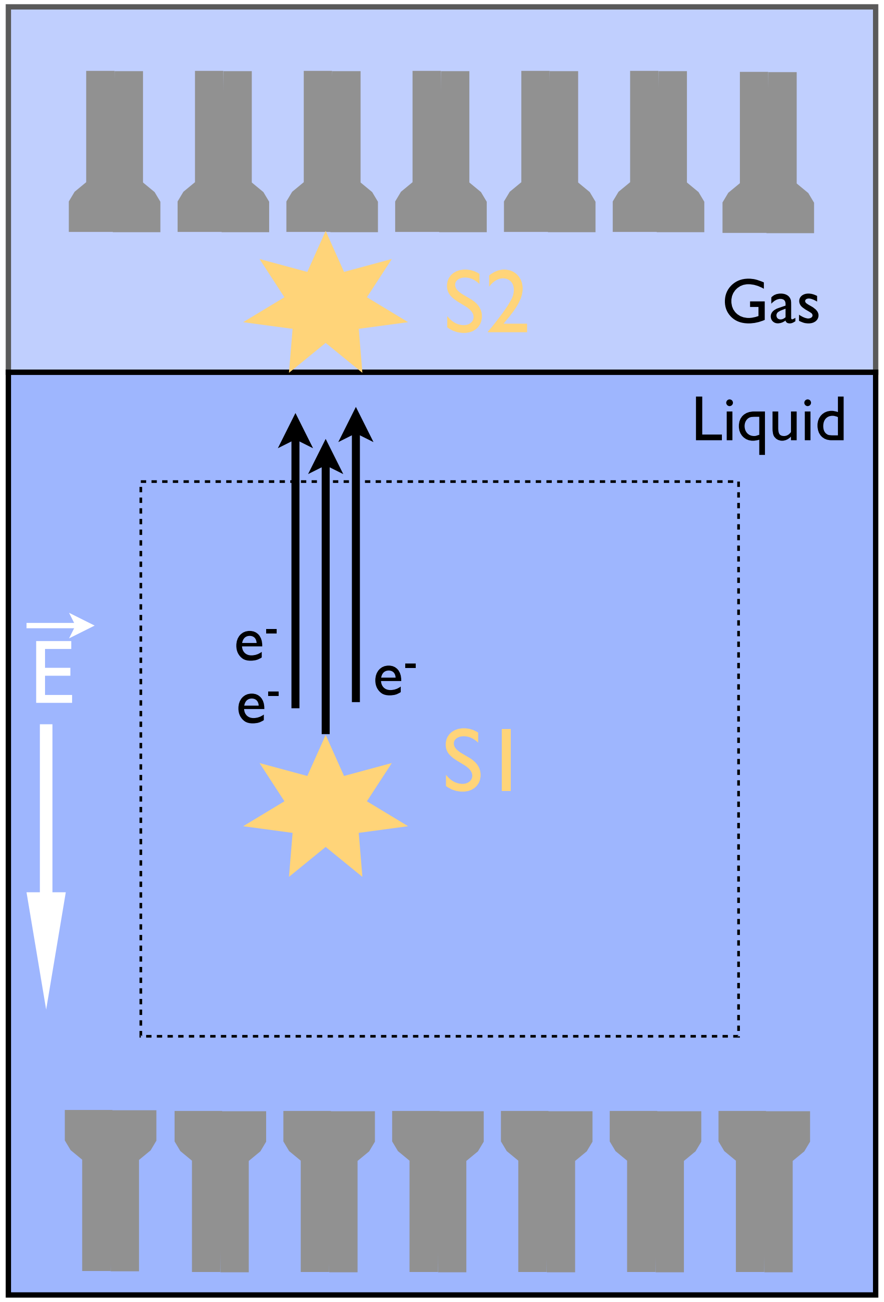
Typical ER/NR discrimination:
LXe [no PSD]: 99.75%
LAr [with PSD]: 99.9999%

General Considerations

Single Phase



Dual Phase



General Considerations

Single Phase

- Simple design
- 4pi PMT coverage
- Position reconstruction ~cm
- Large detector scalability

Dual Phase

- Electron drift allows ER / NR discrimination
- Position reconstruction ~mm
- Scalability up to a certain degree, then modularity

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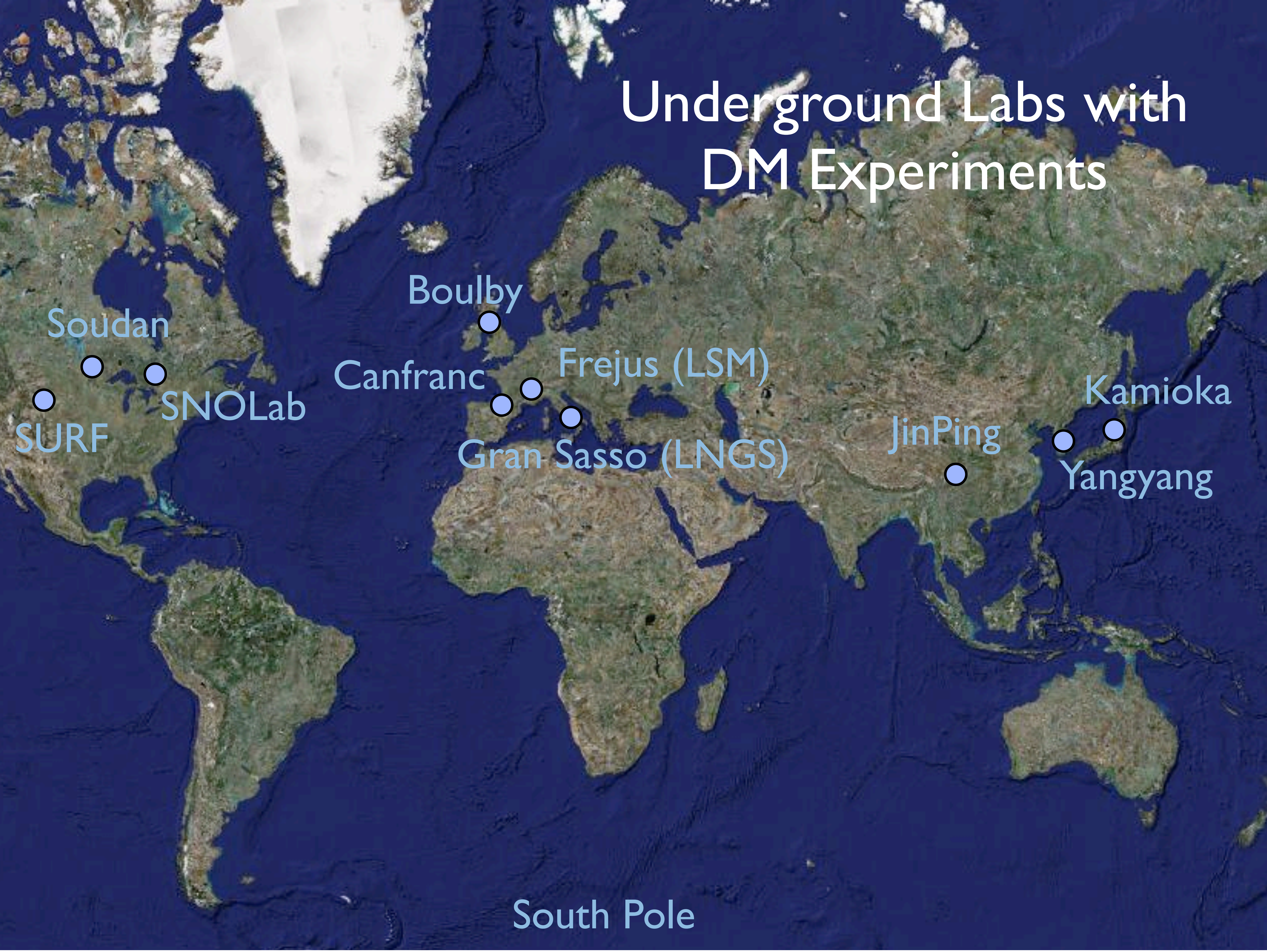
Argon

- Cheap material
- Pulse shape discrimination capability
- Does not have $2\nu2\beta$ decay isotope
- No isotope with spin
- ^{39}Ar decays at 1Bq/kg → underground argon
- Higher energy thresholds

Xenon

- Attractive WIMP-nucleon SI cross section scaling
- Excellent self-shielding
- Spin-dependent couplings
- Other than ^{136}Xe no natural radioactive isotopes
- Expensive per unit mass

Underground Labs with DM Experiments



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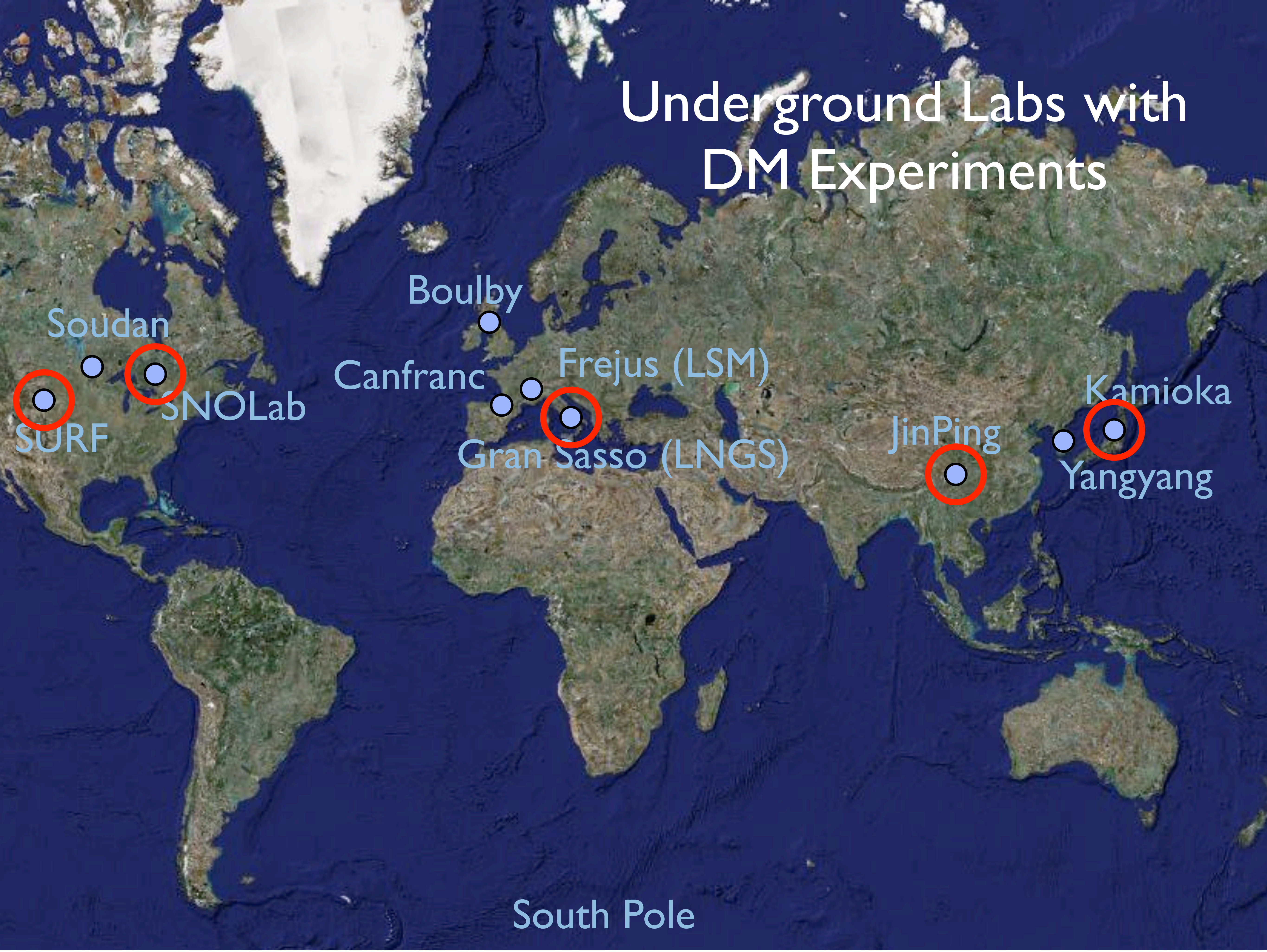
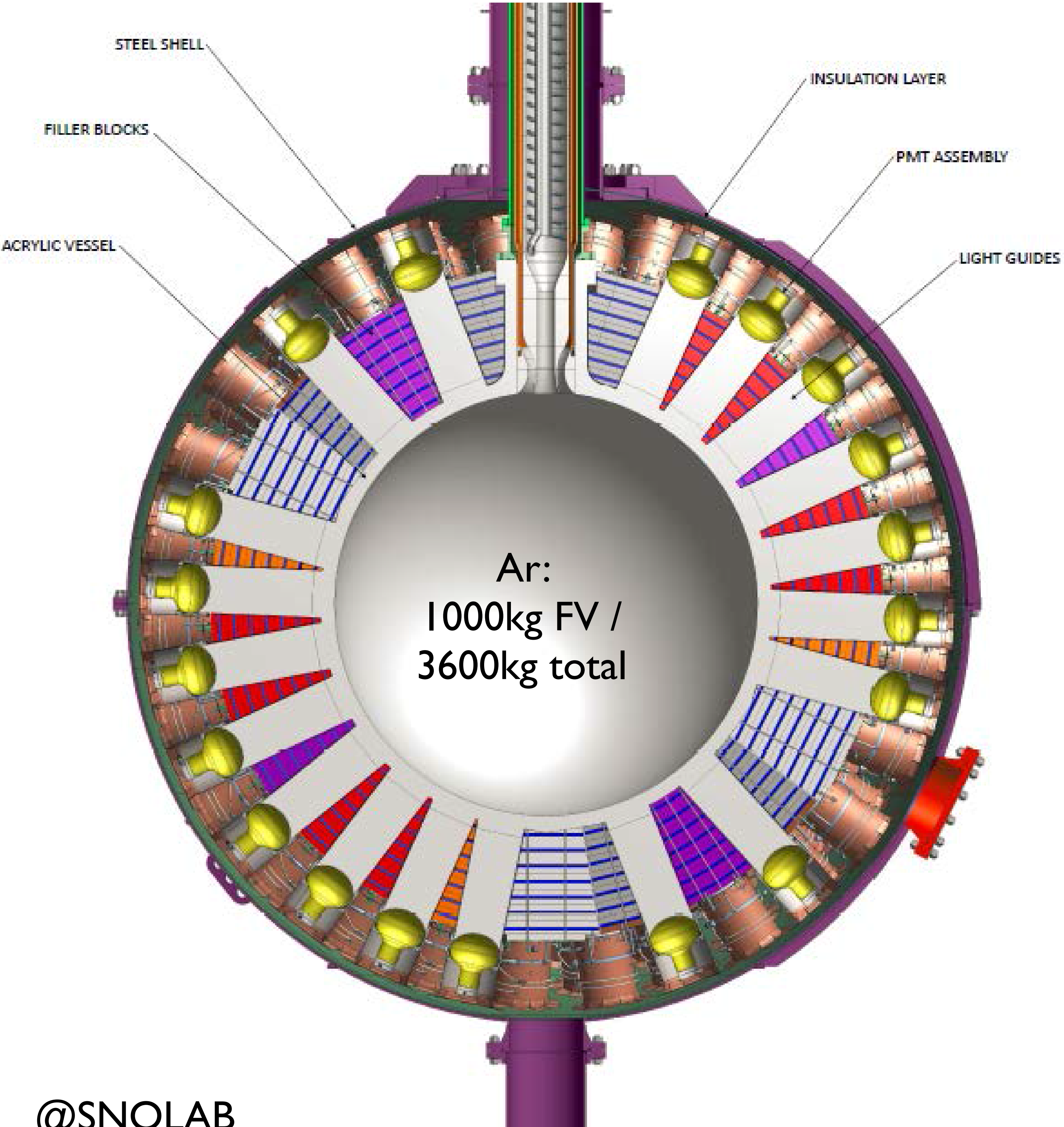


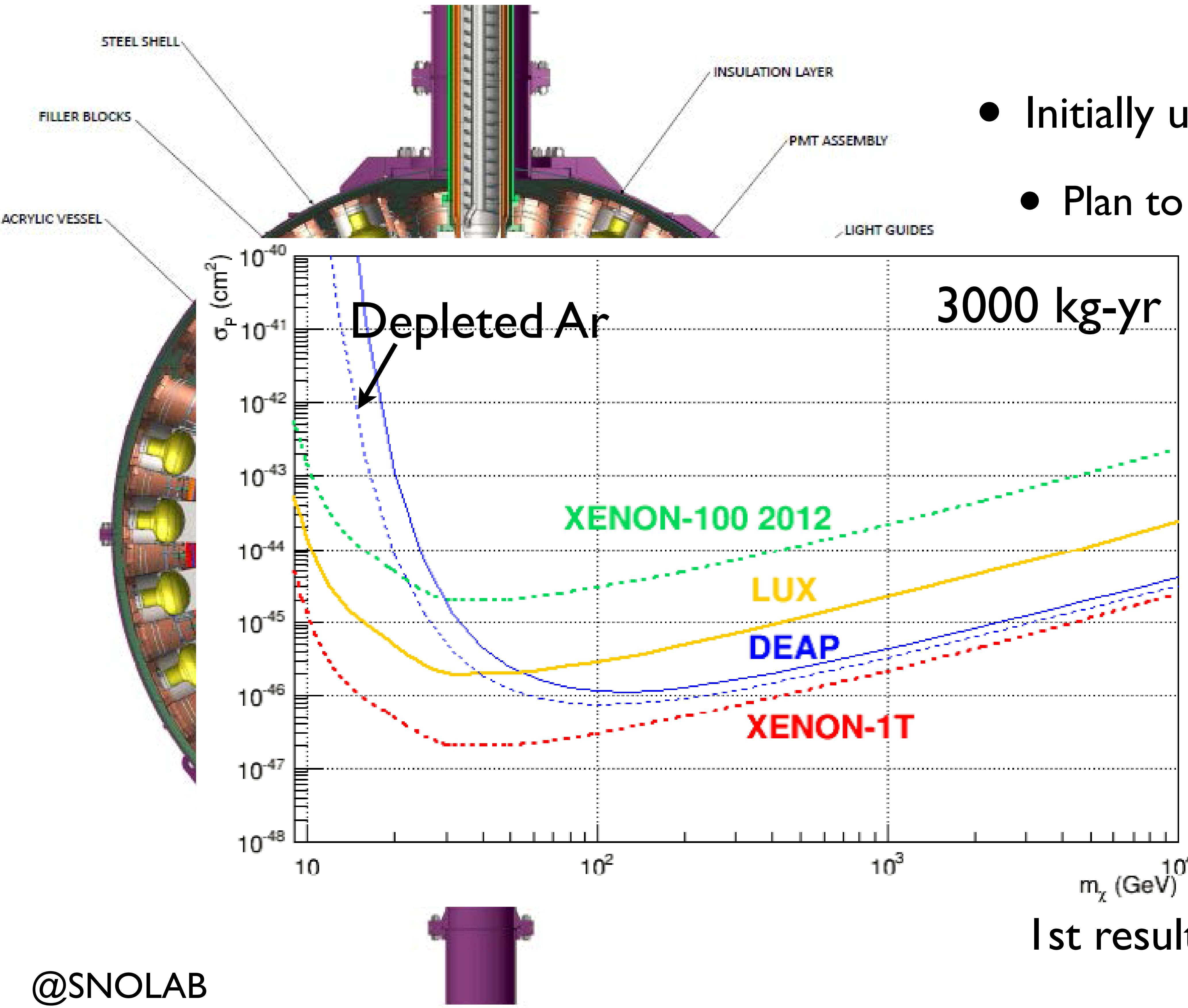
DEAP-3600



@SNOLAB

- Initially using atmospheric Ar
  - Plan to also use UAr
- 255 high-QE PMTs
- 50cm light guides for n-moderation
- Pulse Shape Discrimination
  - DEAP-1: 3×10^{-8} suppression
- Detector in 8m Water Tank
- Installation underway
- Start science in Oct 2014, 1st results in early 2015

DEAP-3600



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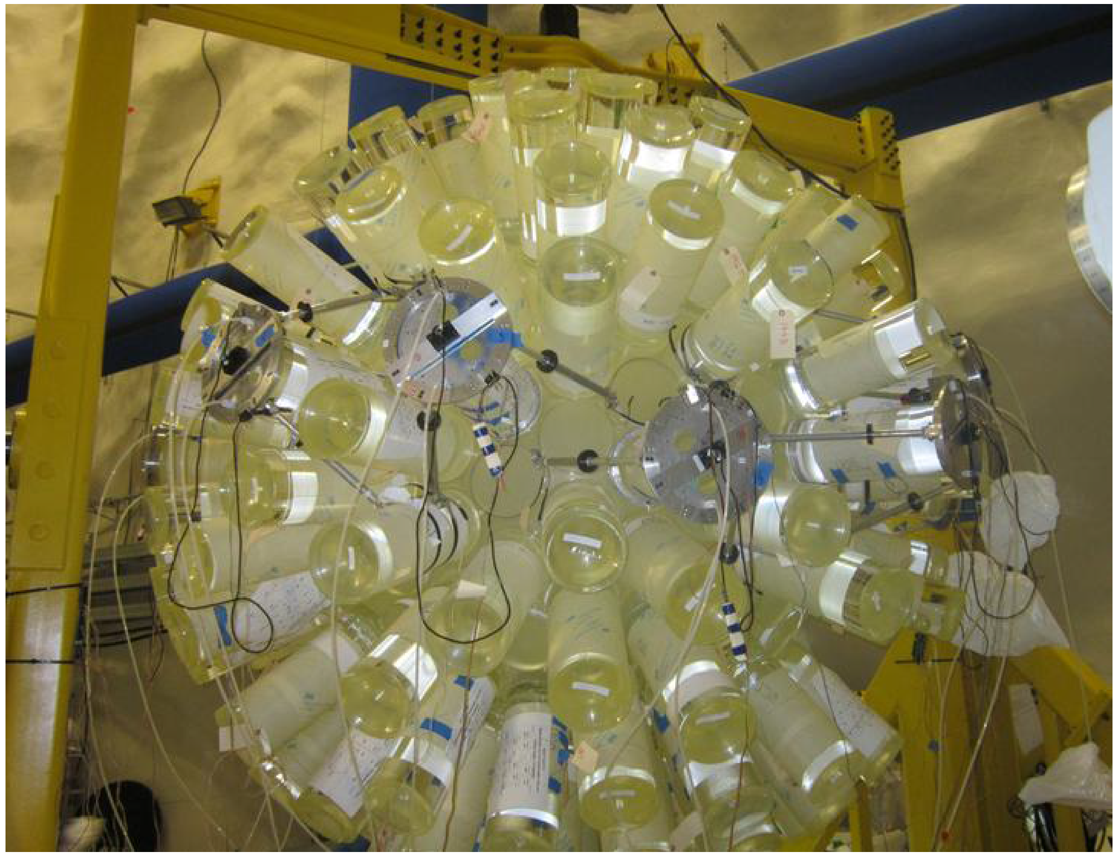
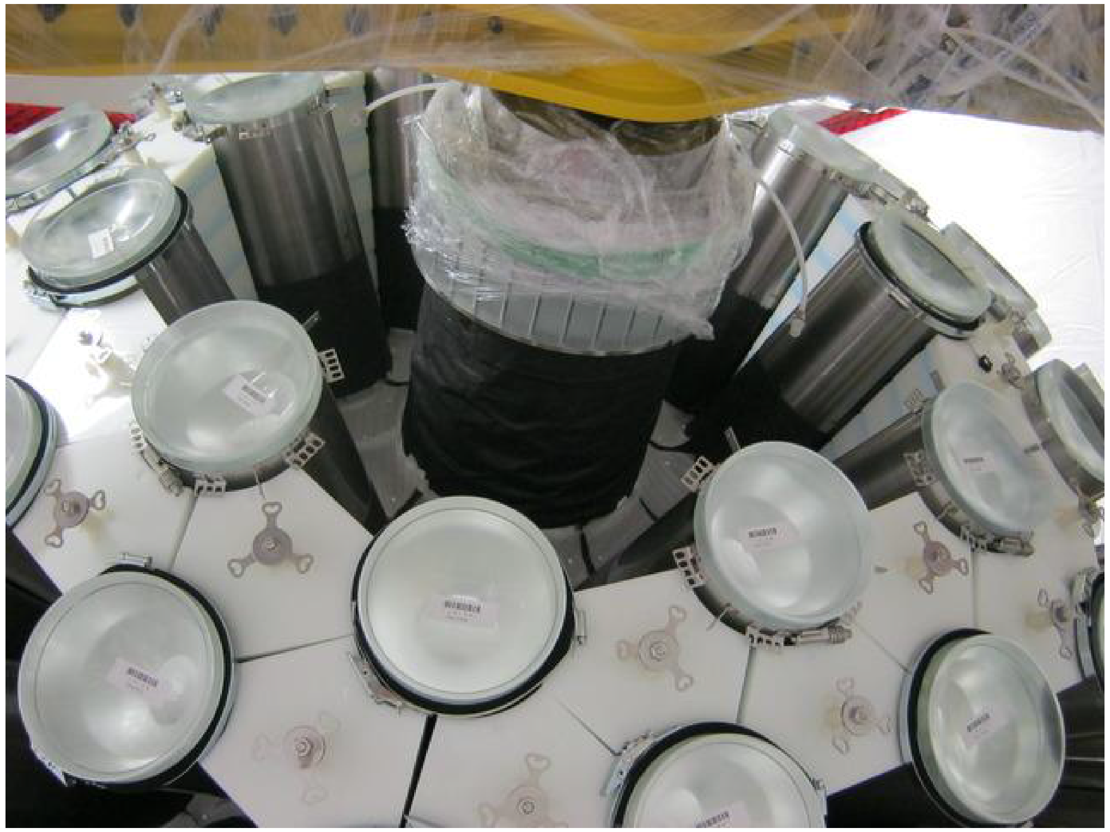
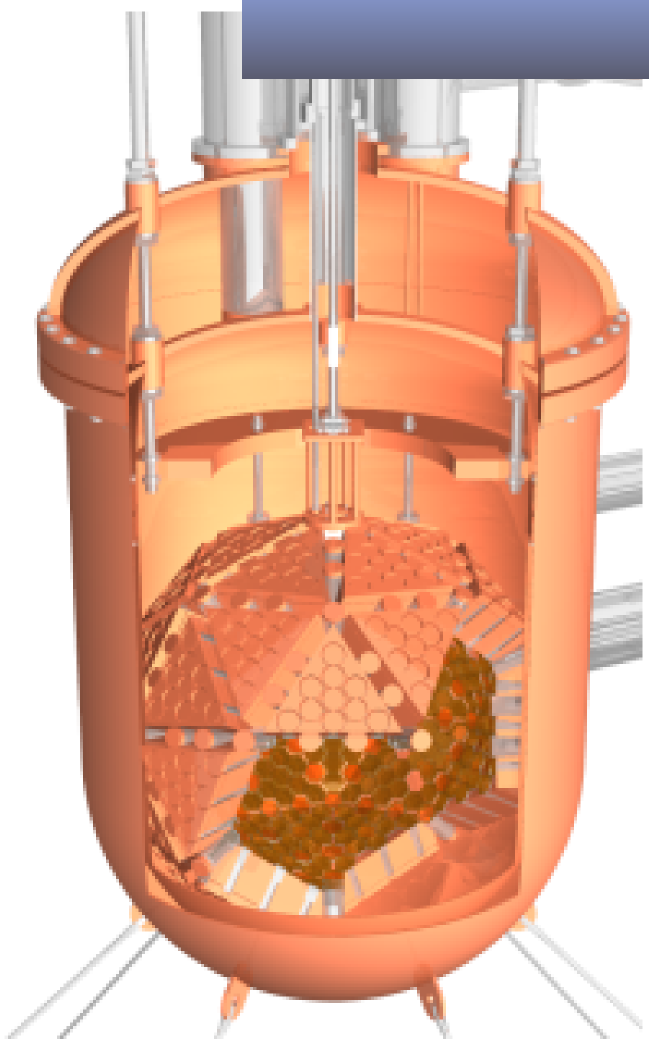
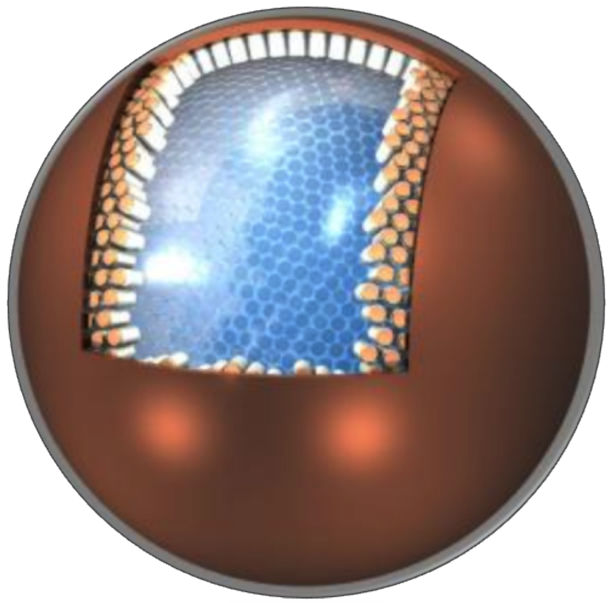
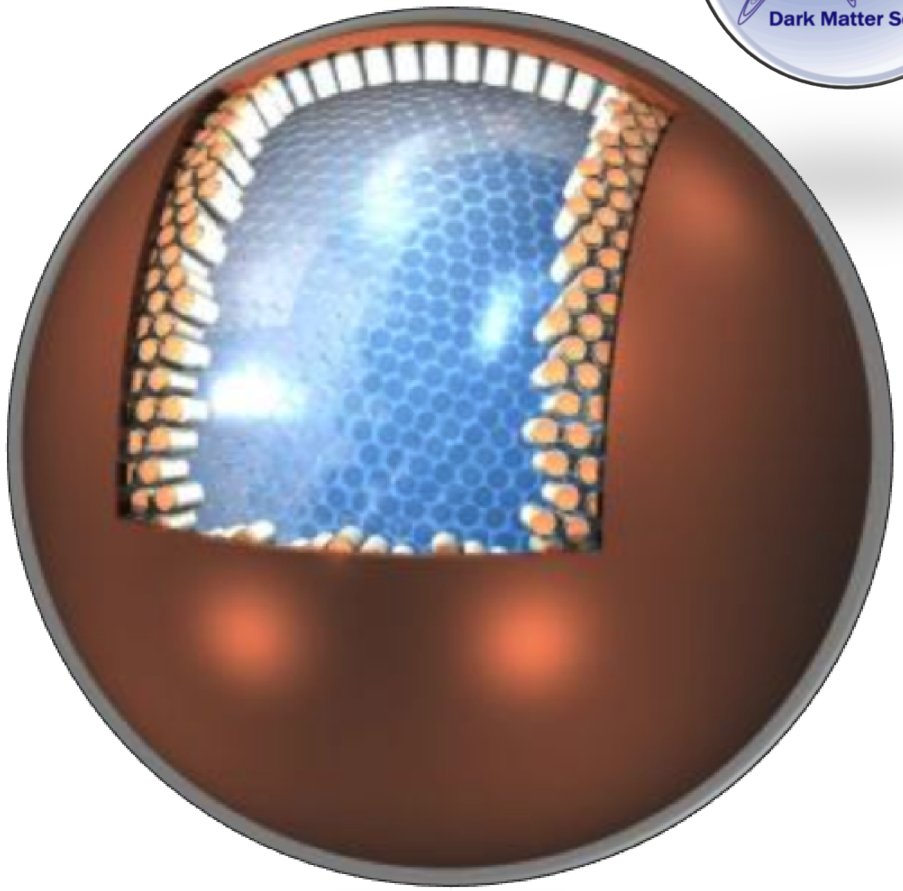




XMASS







XMASS-1

- 100kg / 835kg
- Dark Matter
- Commissioning Run
- BG among the lowest achieved so far:
  - 8.2±0.5 mBq ^{222}Rn
  - <0.28 mBg ^{220}Rn
  - < 2.7 ppt ^{nat}Kr
- 14.7 PE/keV

XMASS-1.5

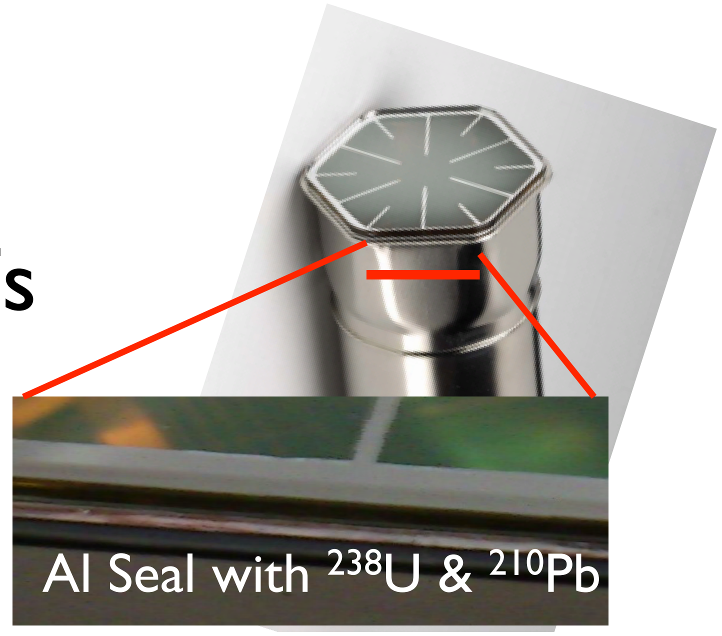
- 1ton / 5ton
- Dark Matter "XENON1T sensitivity"
- Construction 2014-2015
- Science 2016

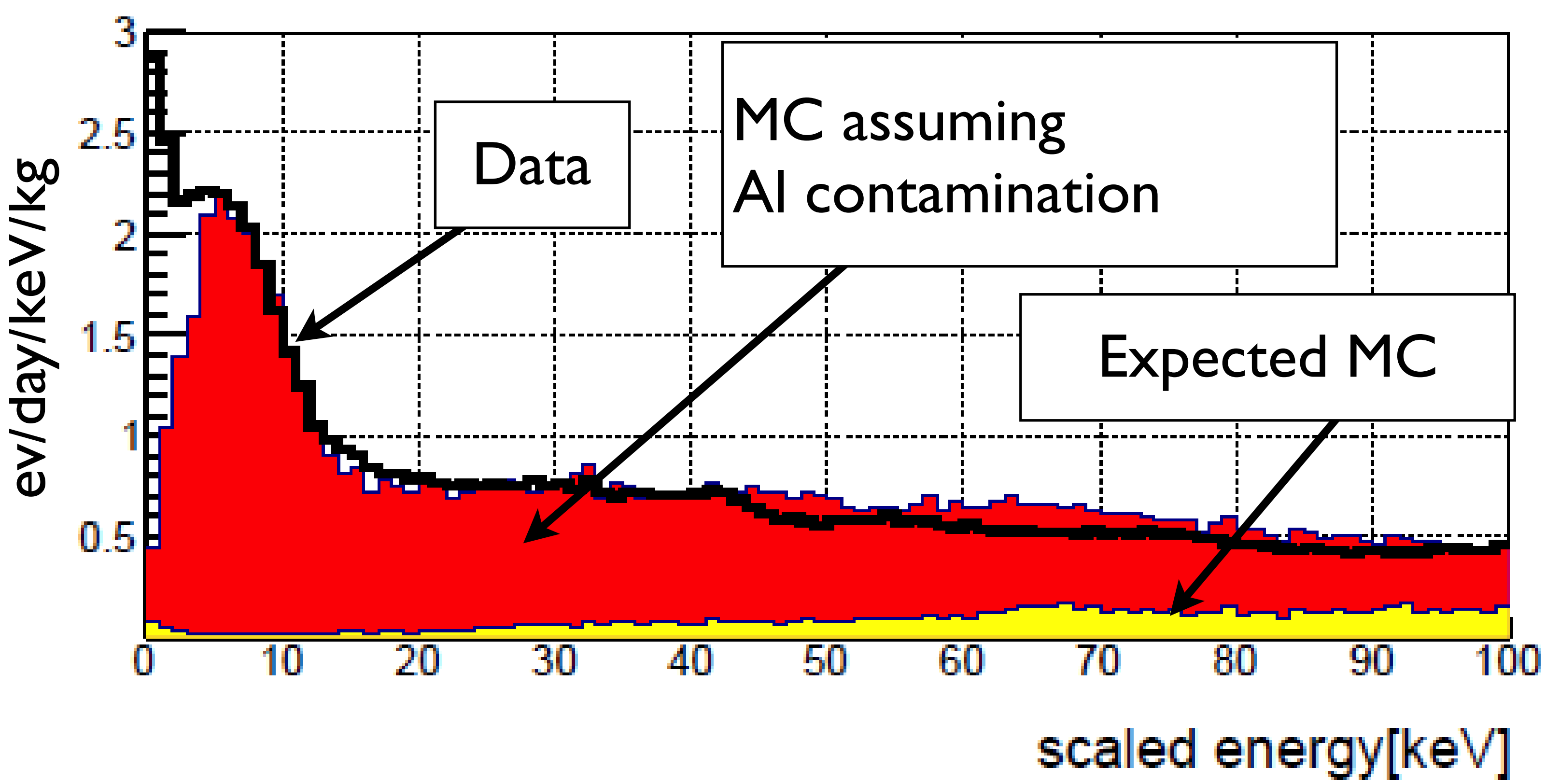
XMASS-II

- 10ton / 25ton
- Multi-purpose:
  - DM
  - solar pp-ν
  - 0ν2β

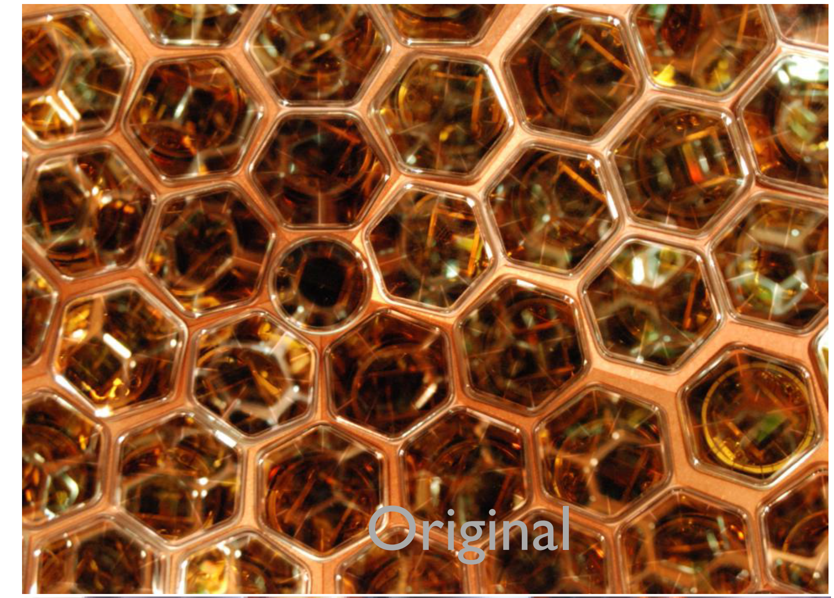
XMASS Background

All 680 PMTs





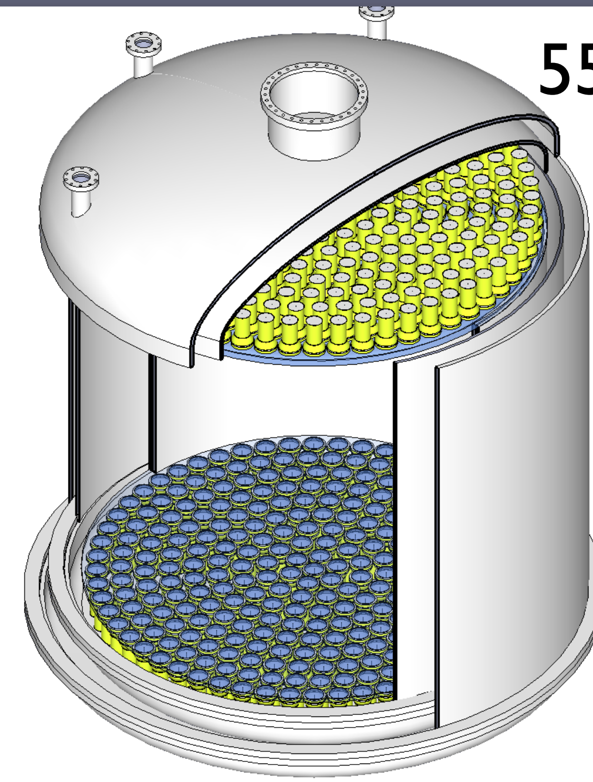
XMASS-I Refurbishment



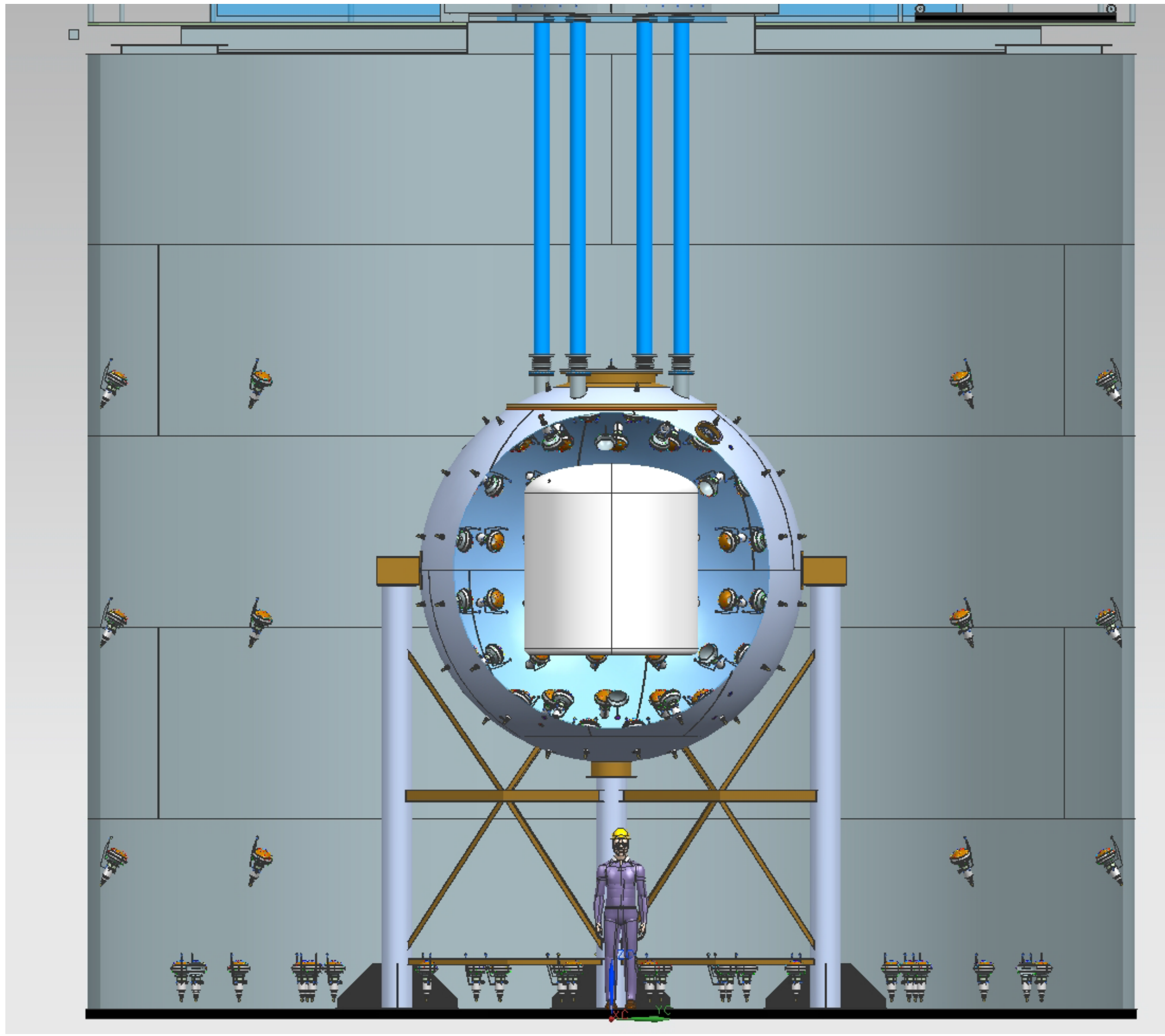
Refurbishment reduced BG to 1/100

→ New PMTs for XMASS 1.5

DarkSide-G2

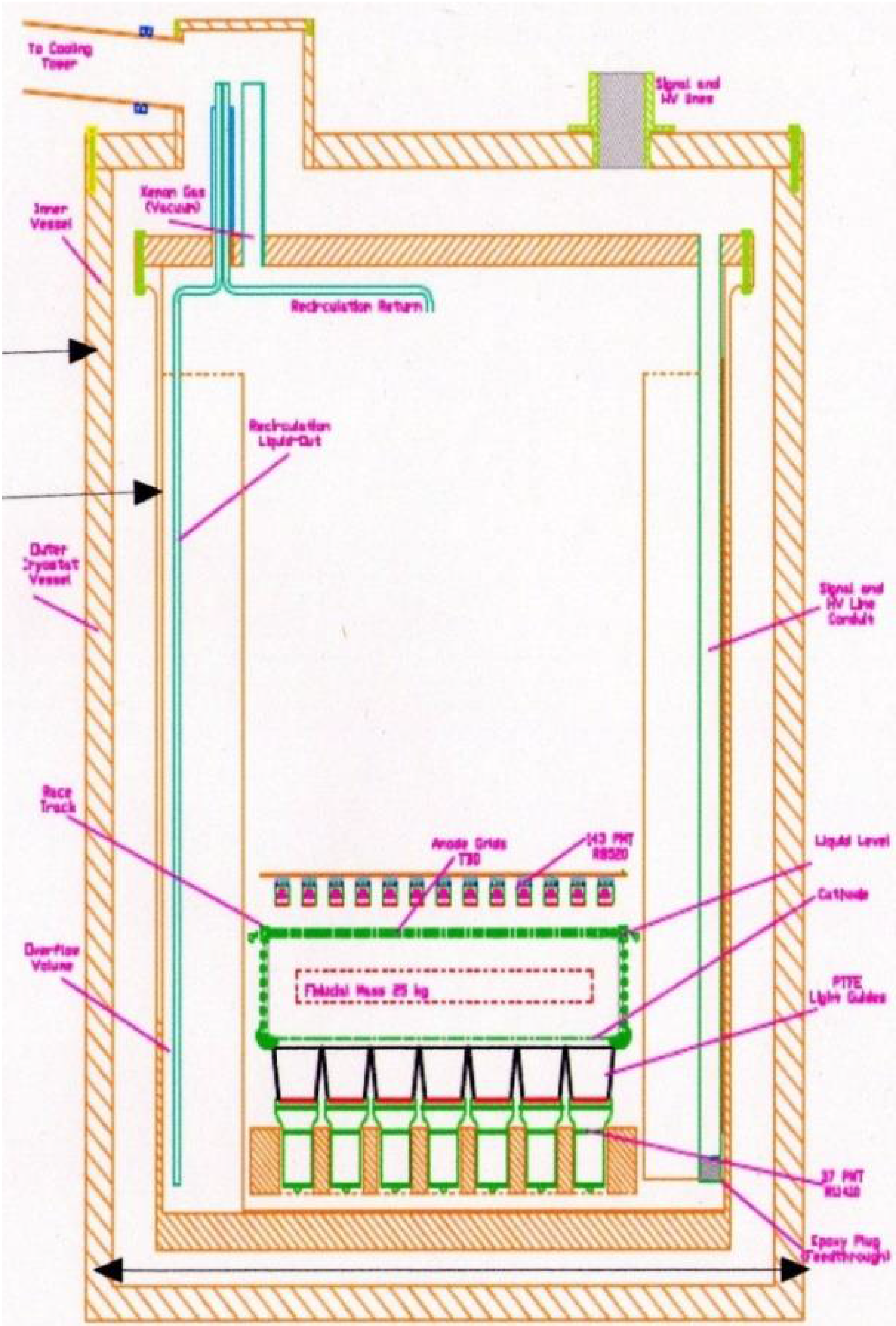


- Scale up of DS-50, using same Boron loaded Liq. Scint. neutron veto system
- ~3.6t fiducial / 3.8t active LUAr (e.g. depleted ^{39}Ar)
- Will use both S2/S1 identification and Pulse Shape Discrimination
  - Allows excellent BG rejection
- If funded, commissioning in 2017

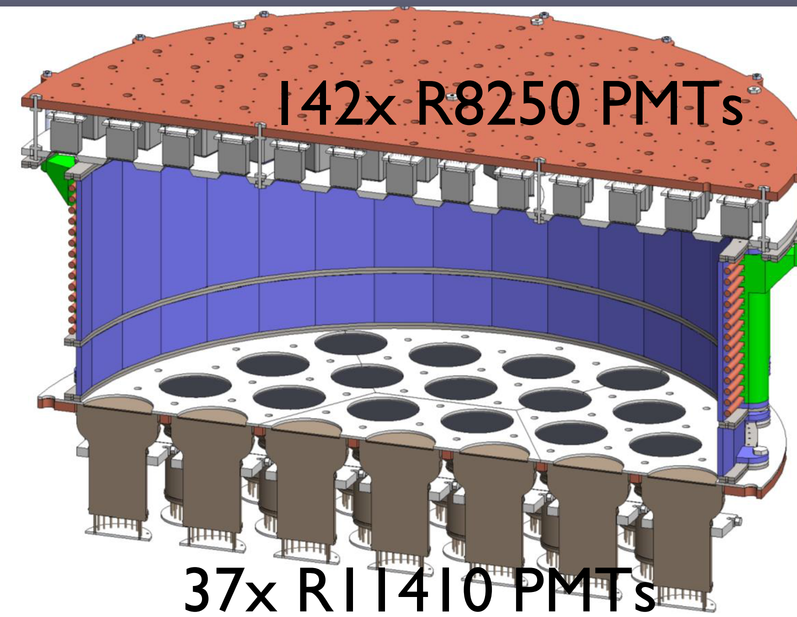


@LNGS

PandaX

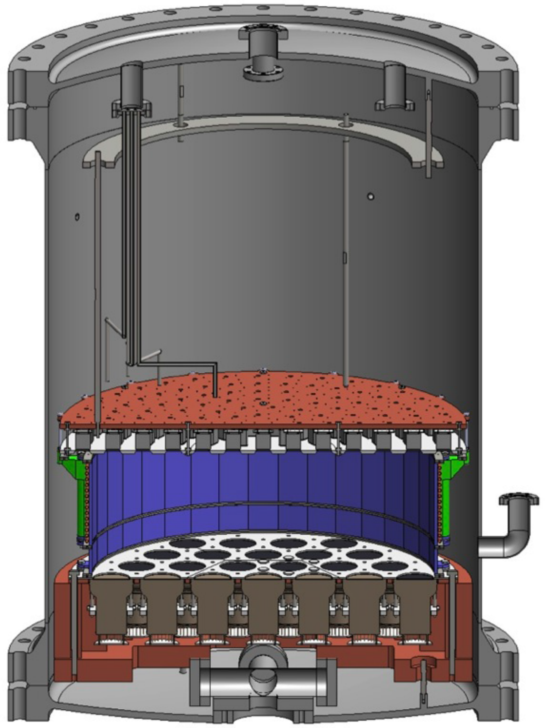


@Jinping

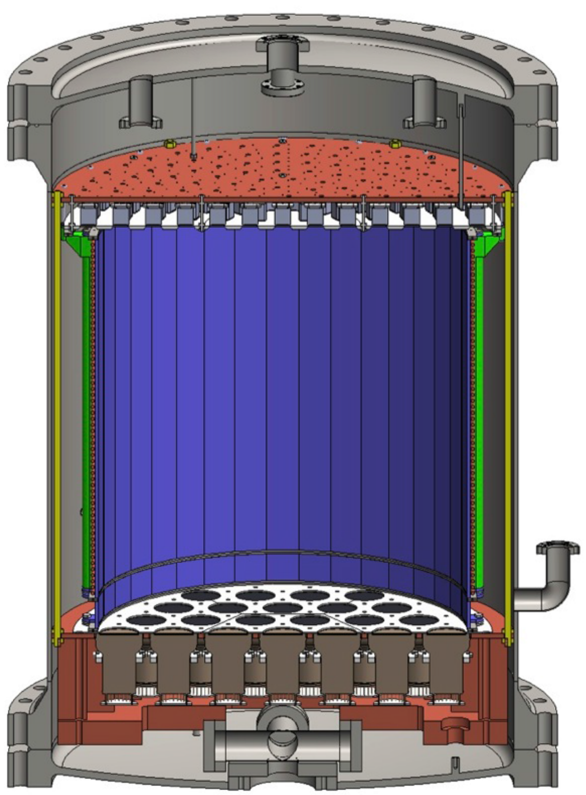


- Everything built for 1 ton target, staged approach:
  - Phase-1a:
    - 25kg fiducial / 120kg total [ongoing]
  - Phase-1b:
    - 300kg fiducial / 500kg total
  - Phase-2:
    - 1 ton fiducial / 1.5 total
- Phase-1a science run started ~Feb 2014
- Phase-1b late 2014

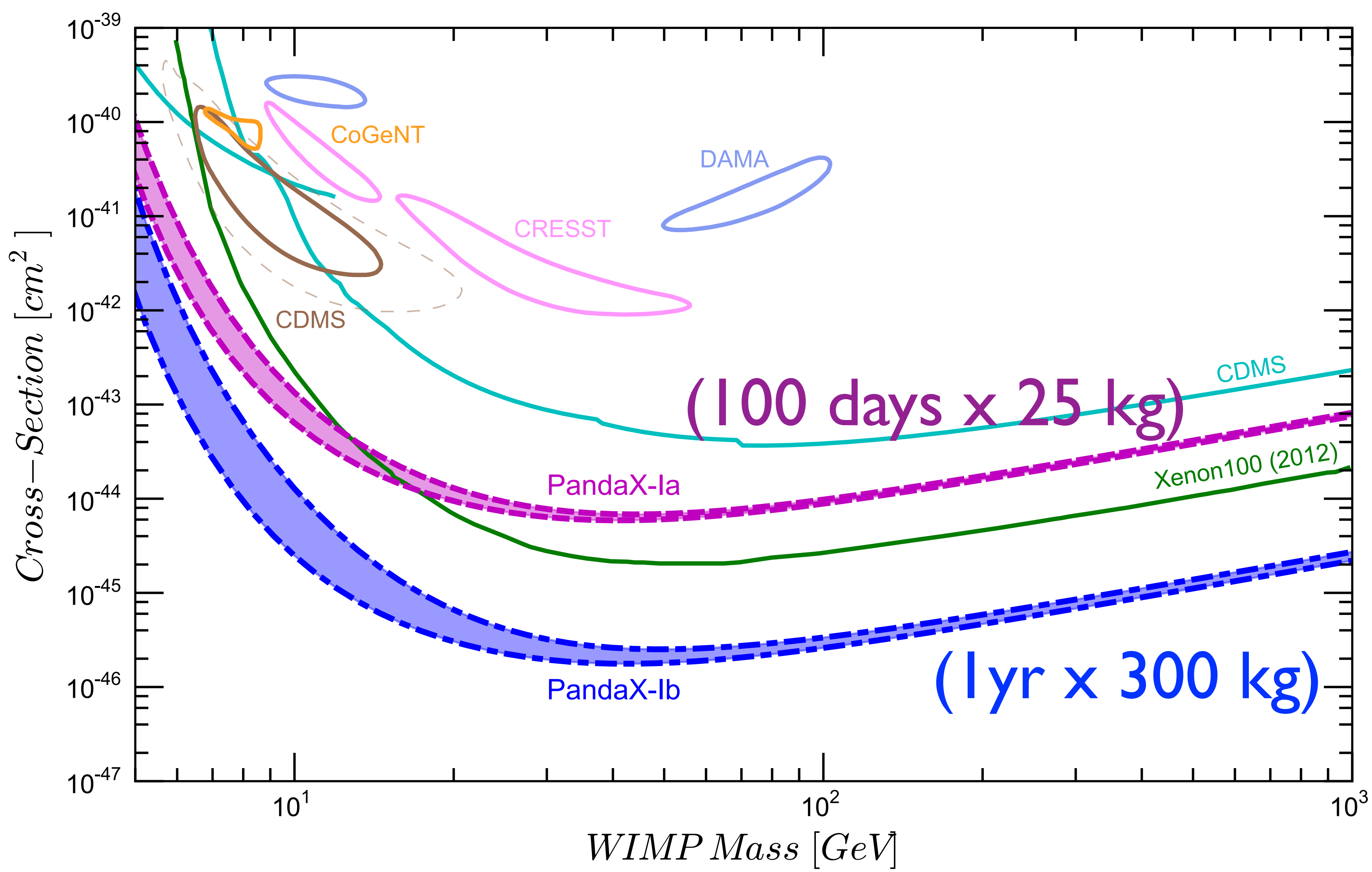
Projected PandaX Sensitivity



Phase-1a: 25 kg [ongoing]



Phase-1b: 300 kg



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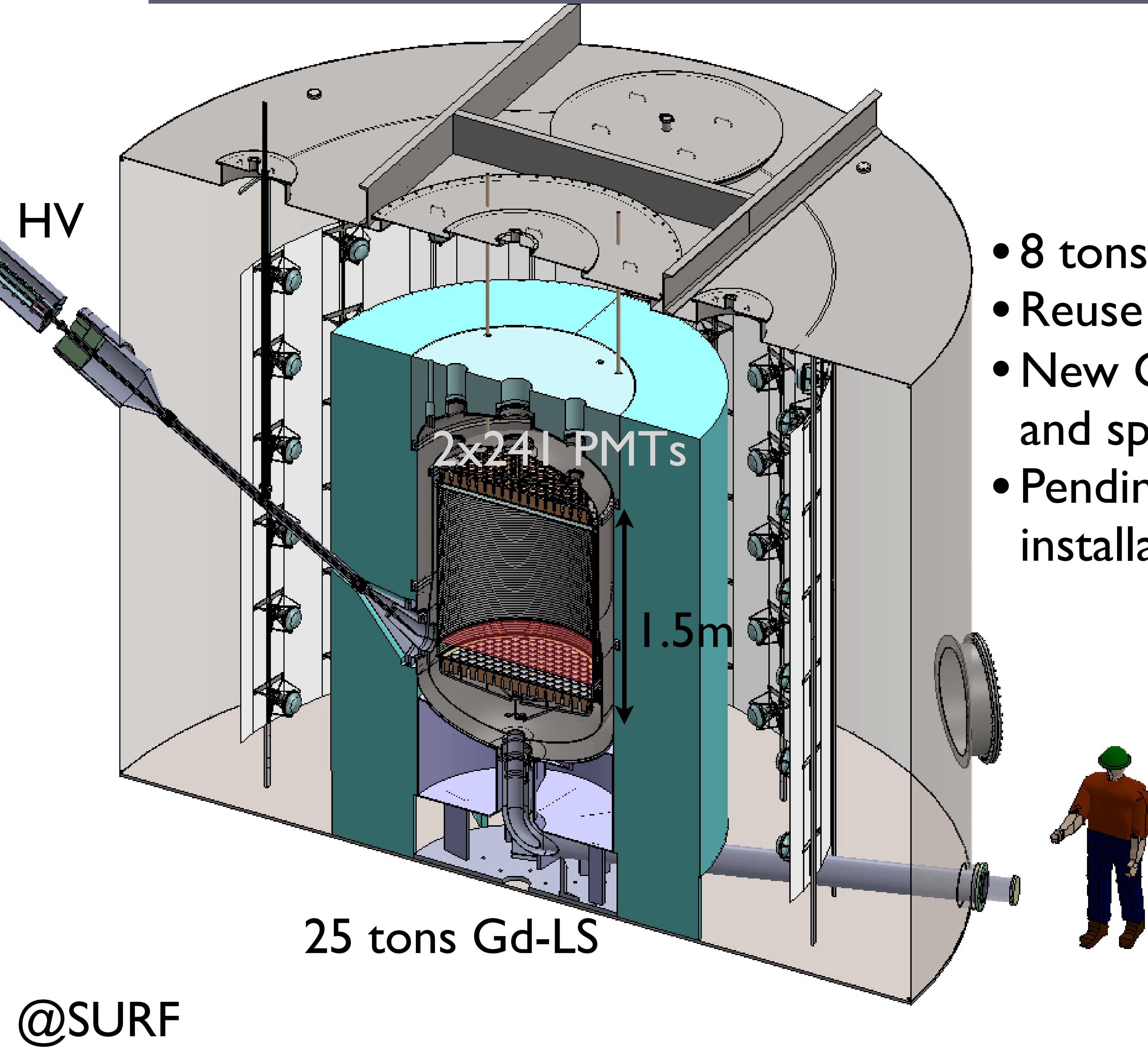
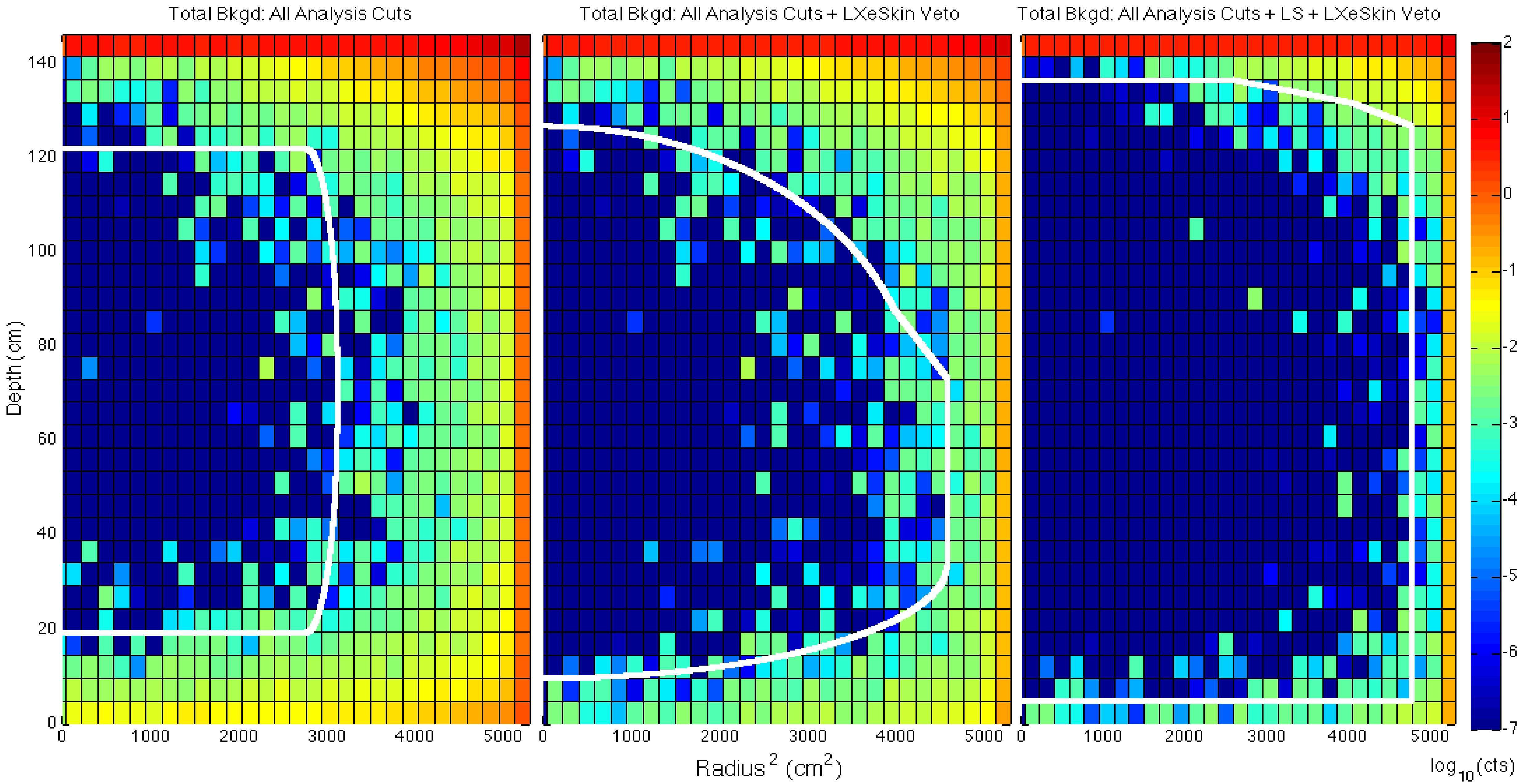
LZ



- 8 tons Xe - 5.6t fiducial
- Reuse LUX watertank
- New Gd-LS for (α,n) and spallation-n veto
- Pending funding, installation start 2016

LZ Fiducial Claim

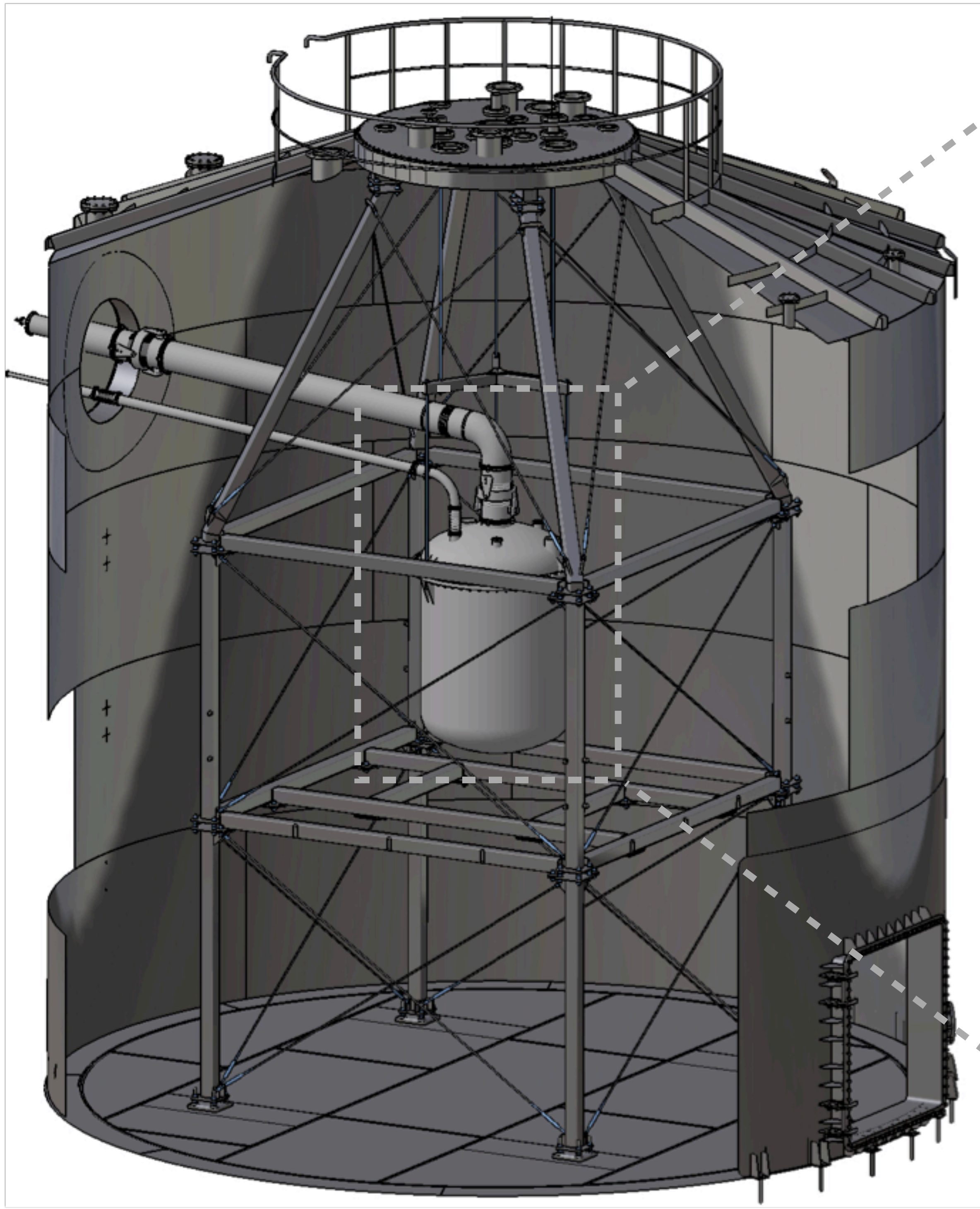


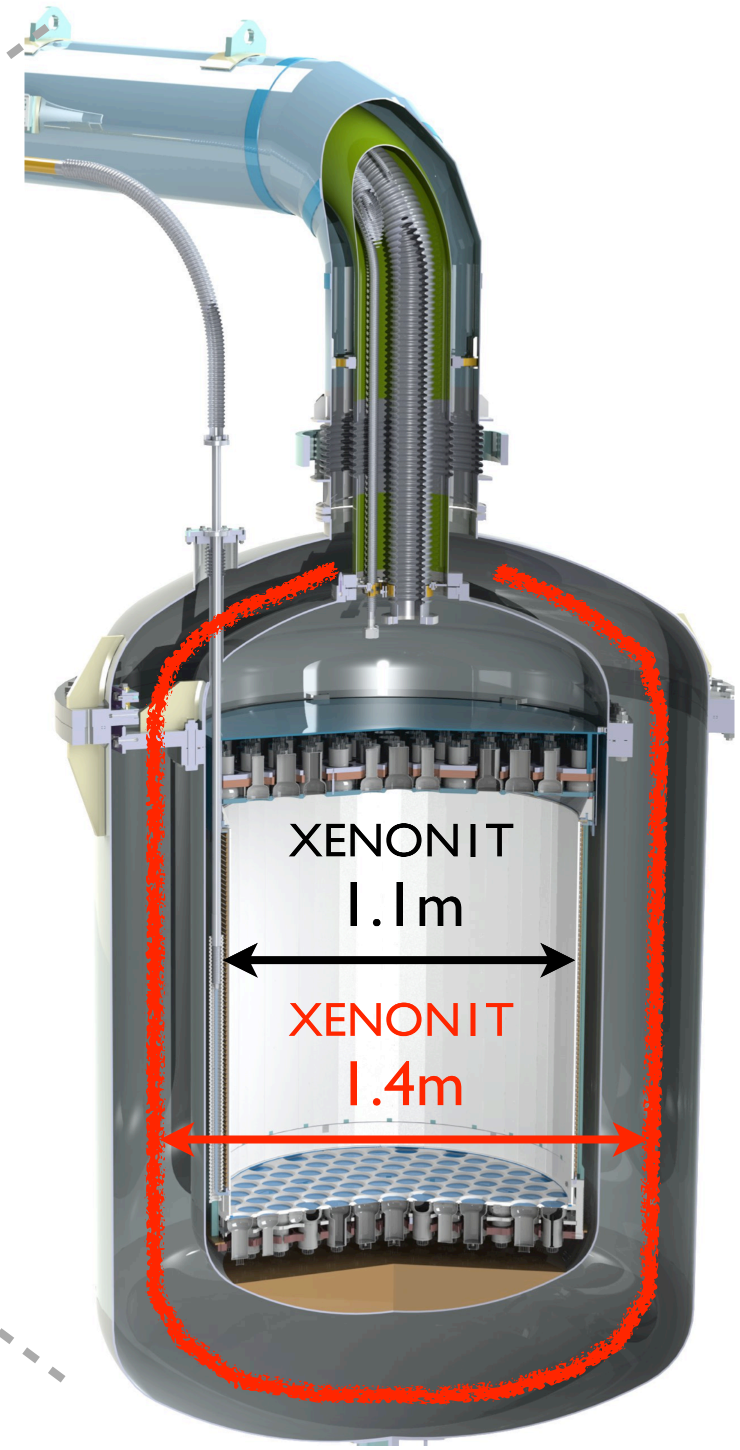
With nothing:
→2.8ton FV

Xe veto optically separated from main TPC
→4.1ton FV

<u>CLAIM:</u>
Xe veto+Gd-LAB
→5.6ton FV

XENONnT

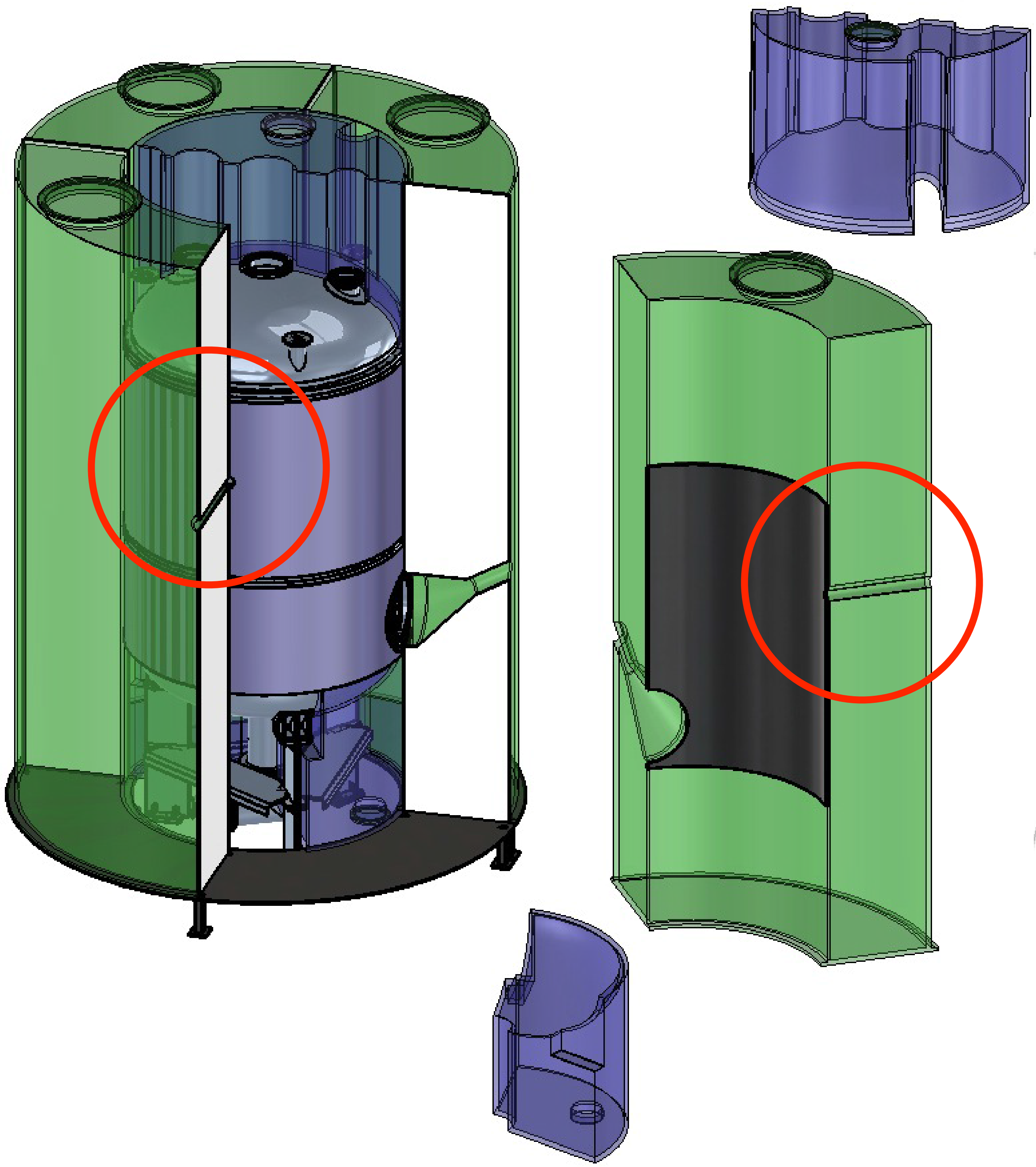




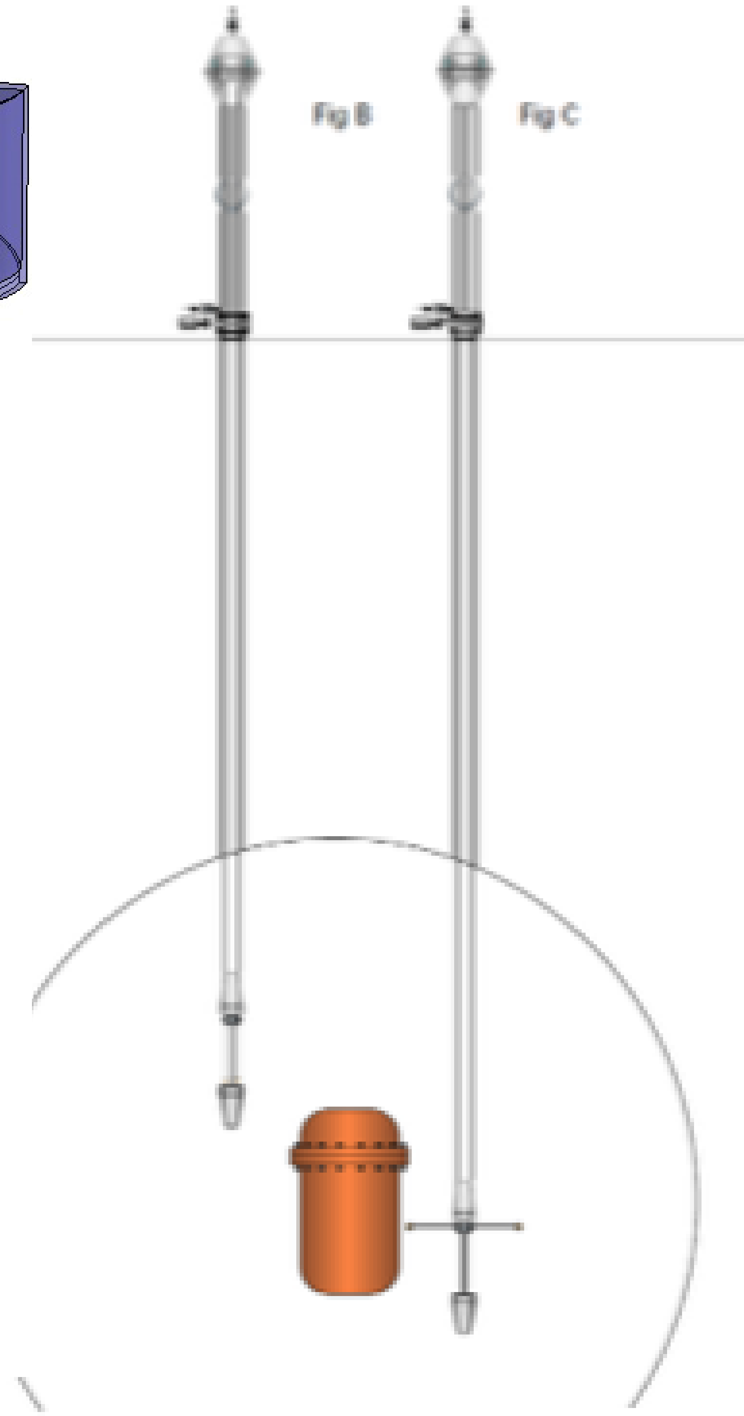
Double amount of LXe (~7 tons), ~double # PMTs
Design XENON1T with as much reuse as possible

Calibration Aspects

How to bring calibration sources close to the detector?



LZ



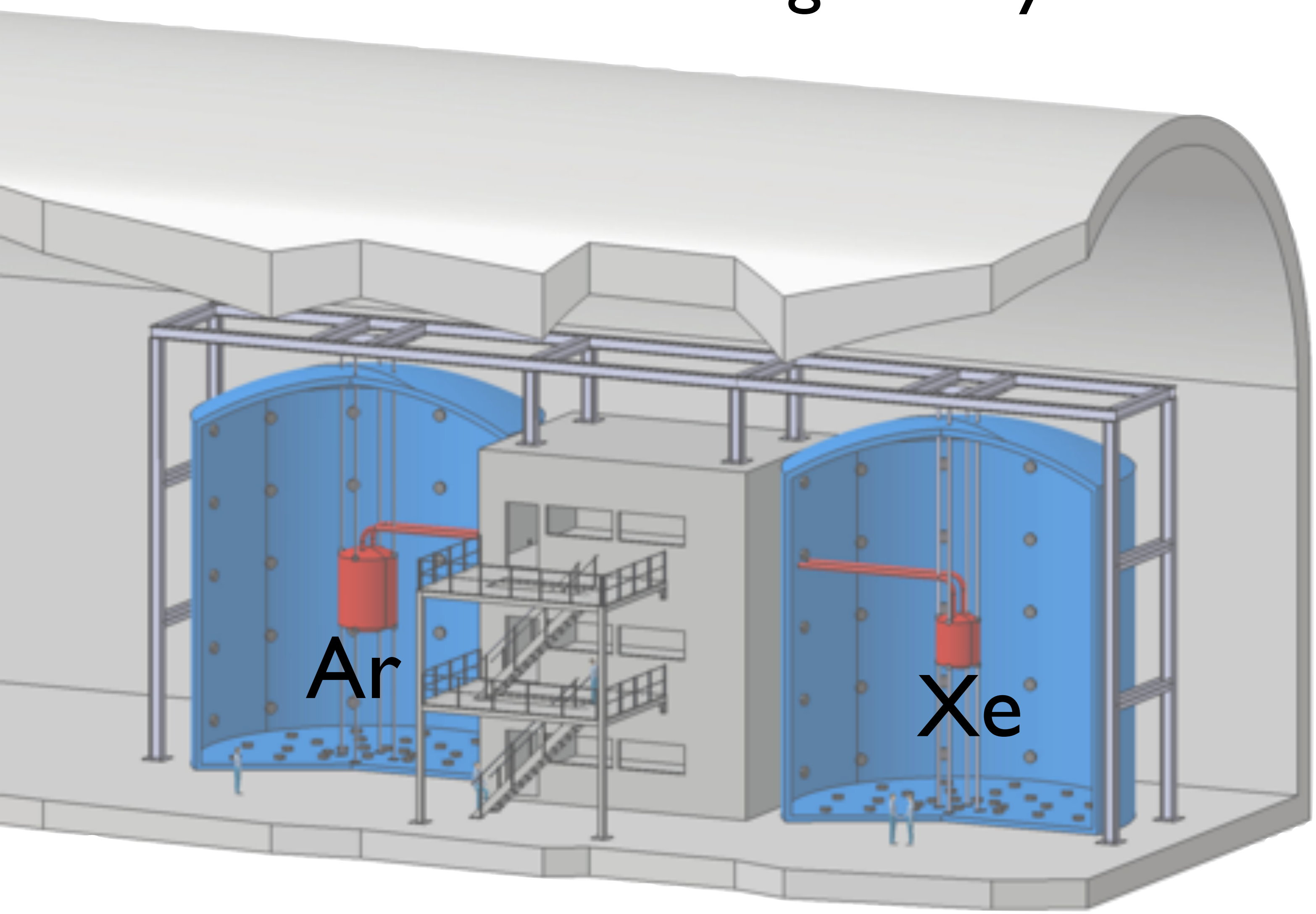
DarkSide-G2

"Articulated Arm"

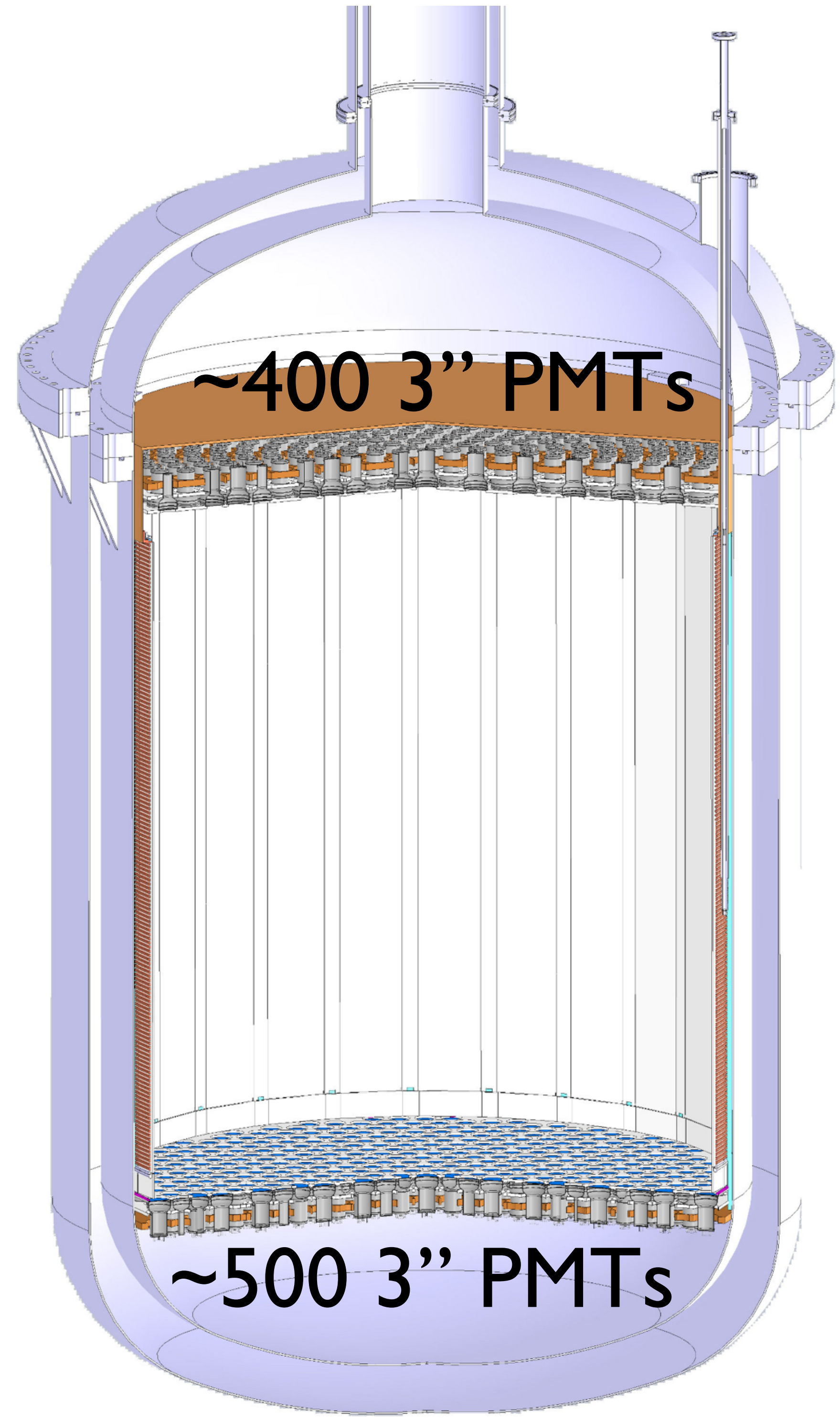
- In-situ calibration of ER
  - Tritium
  - ^{83m}Kr
- Neutron sources
  - DD
  - YBe
  - AmLi

DARWIN: the ultimate DM detector

ASPERA Design Study

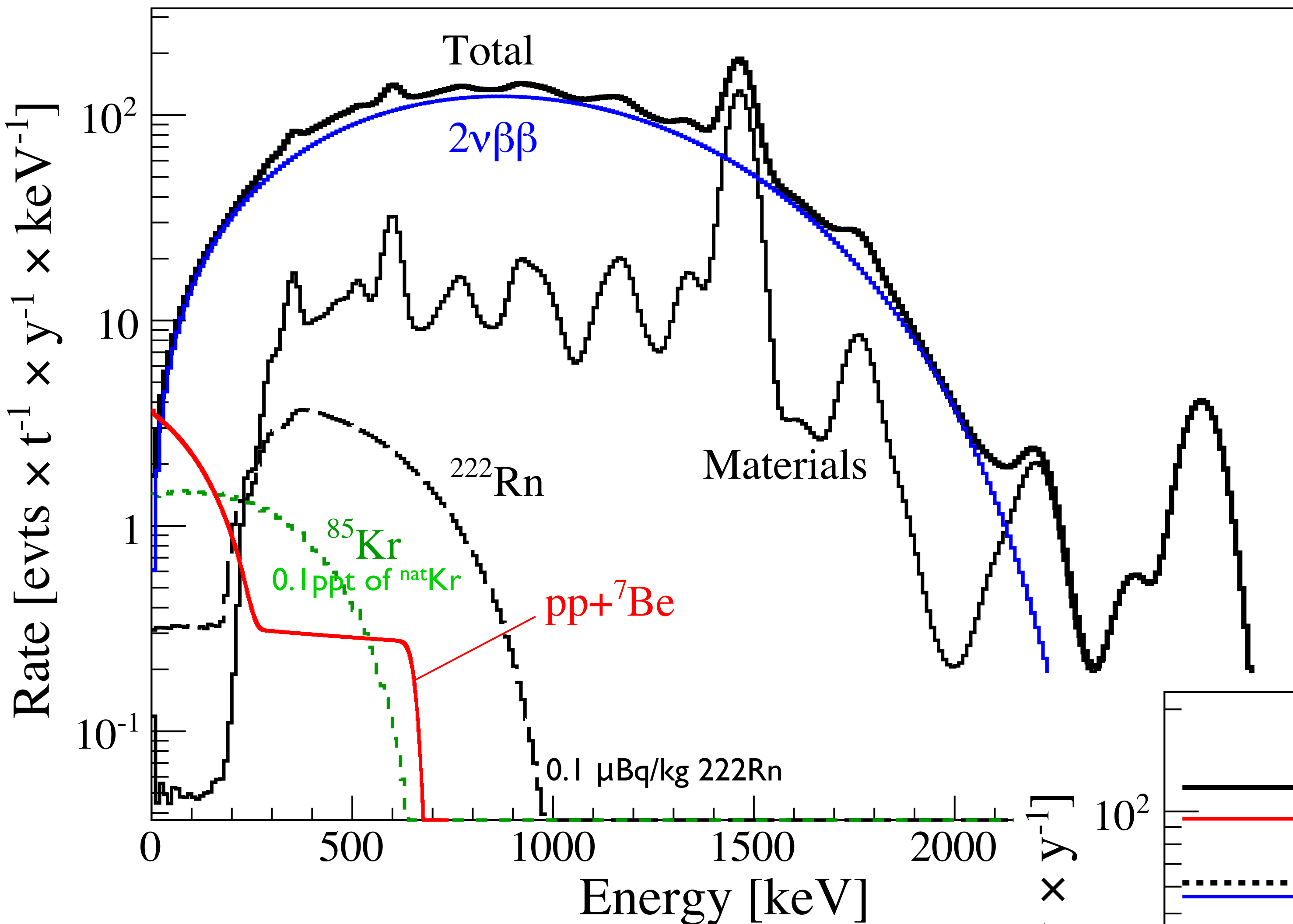


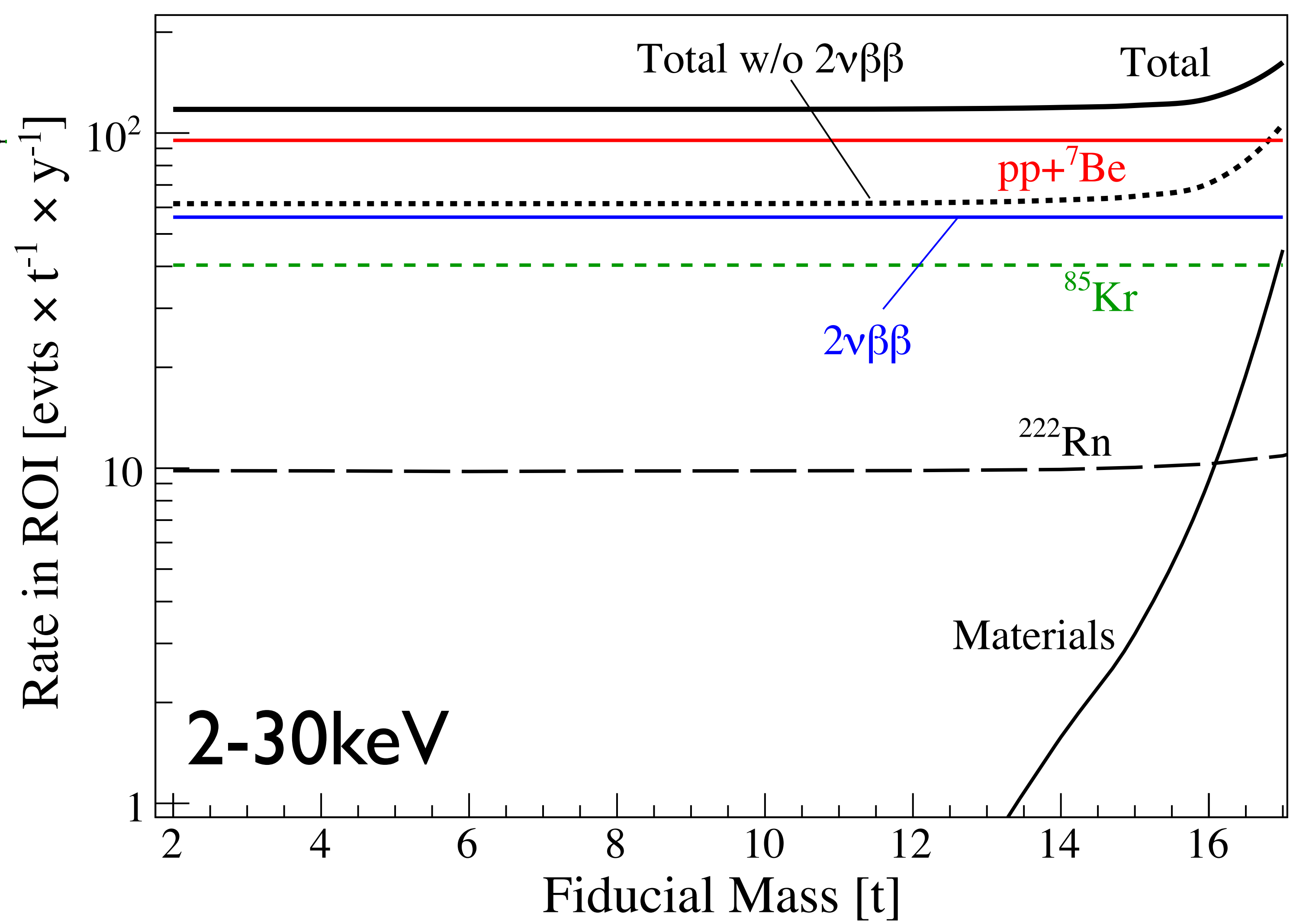
Start construction in 2020



21t LXe total → 14t Fiducial

DARWIN



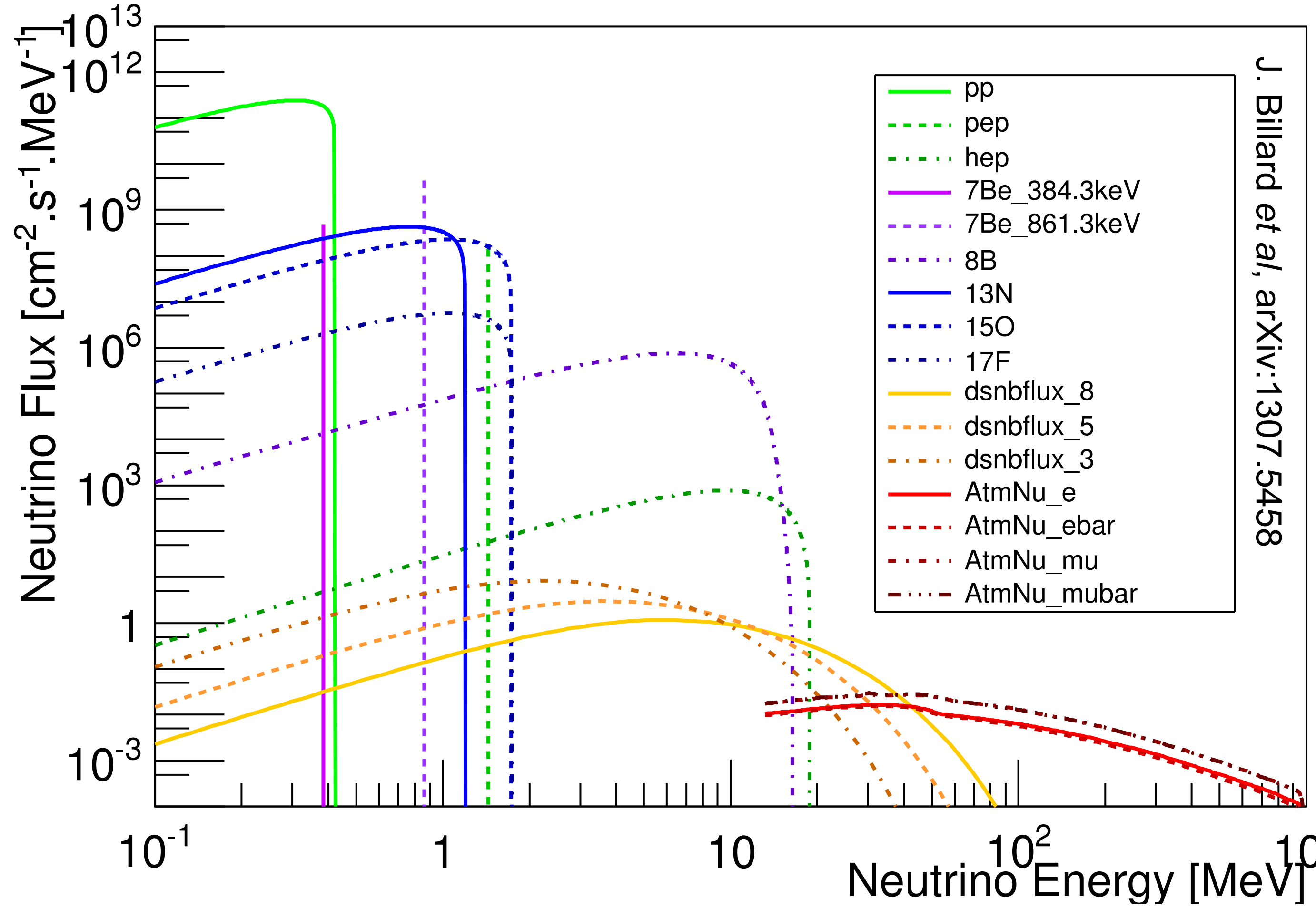


L. Baudis *et al*, arXiv:1309.7024

Background dominated by solar & 2ν2β neutrinos

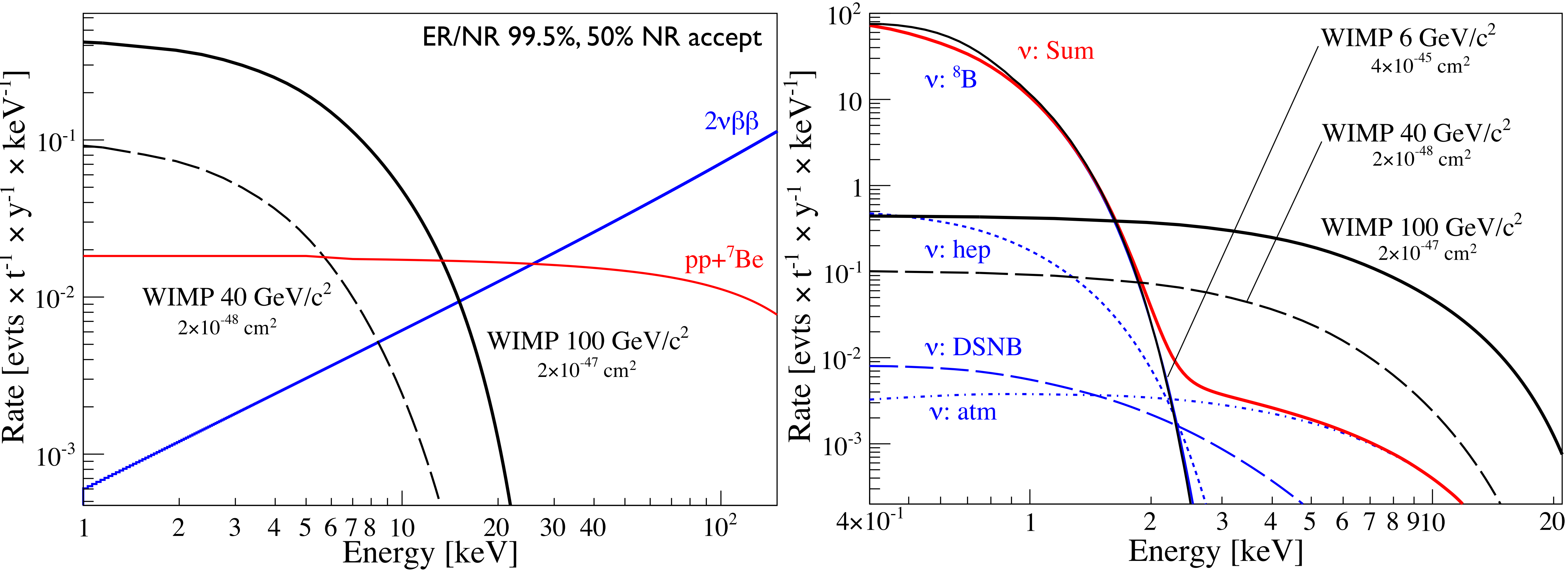
Neutrino fluxes

- Neutrino background will start to dominate
  - Solar neutrinos
  - Atmospheric neutrinos
- Electronic recoil discrimination
  - Finite discrimination → if sufficient ER events, they will leak into NR
- Coherent Neutrino Scattering
  - Nuclear recoil!



Neutrino Backgrounds

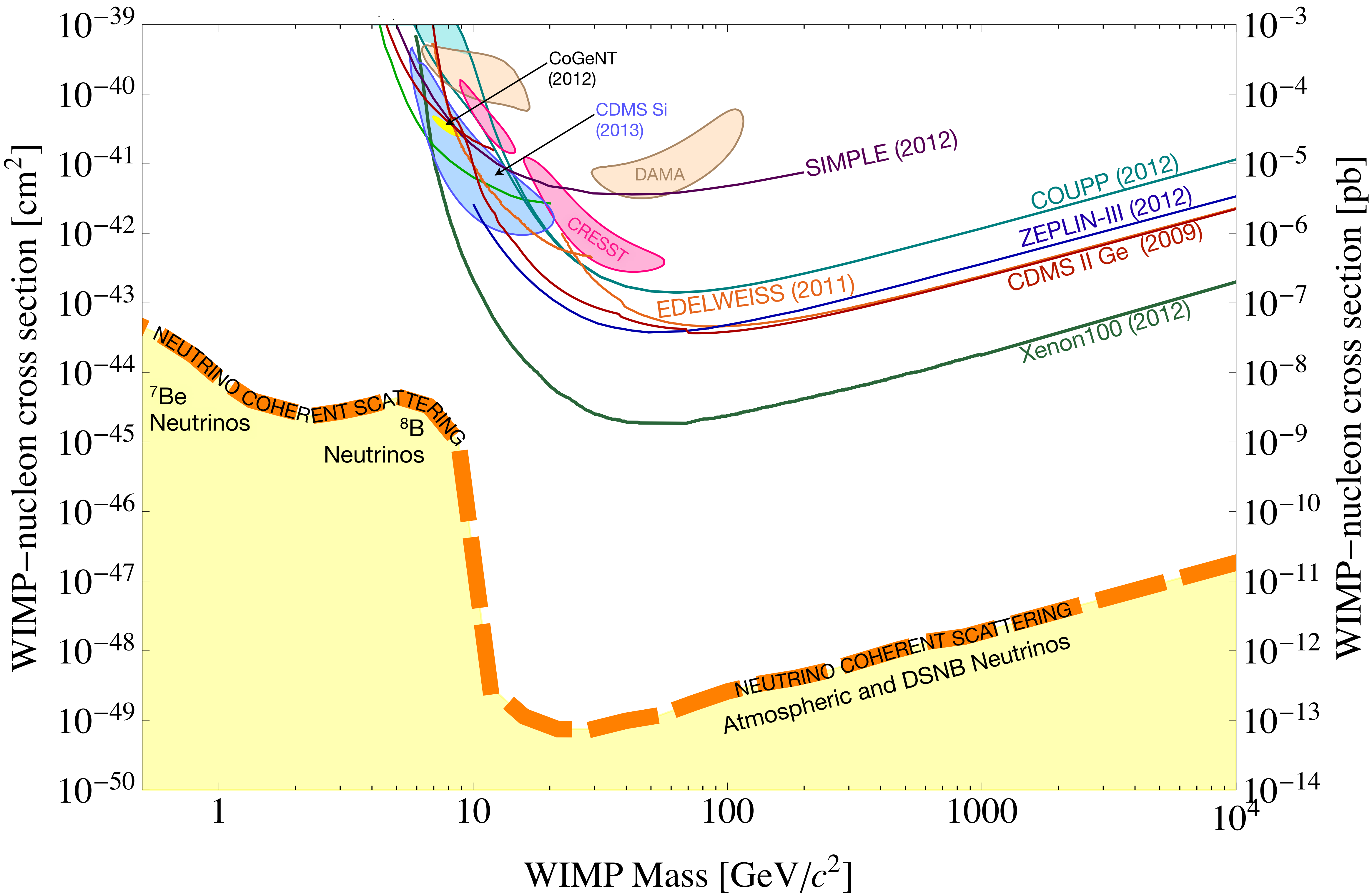
Expected recoil spectra in Xe



L. Baudis *et al*, arXiv:1309.7024

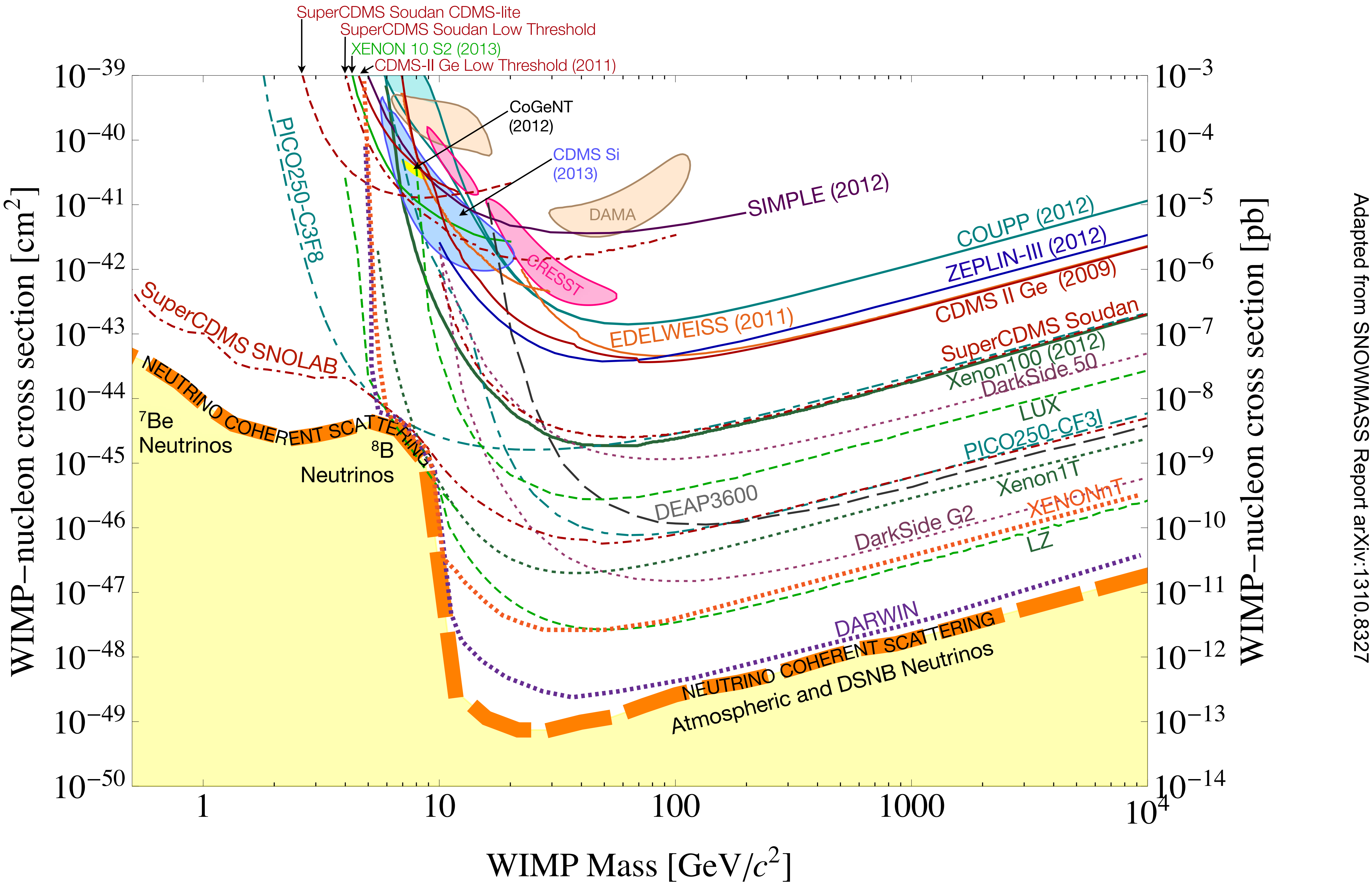
$\nu + e^- \rightarrow \nu + e^-$ $\qquad$ $\nu + N \rightarrow \nu + N$

Ultimate limits

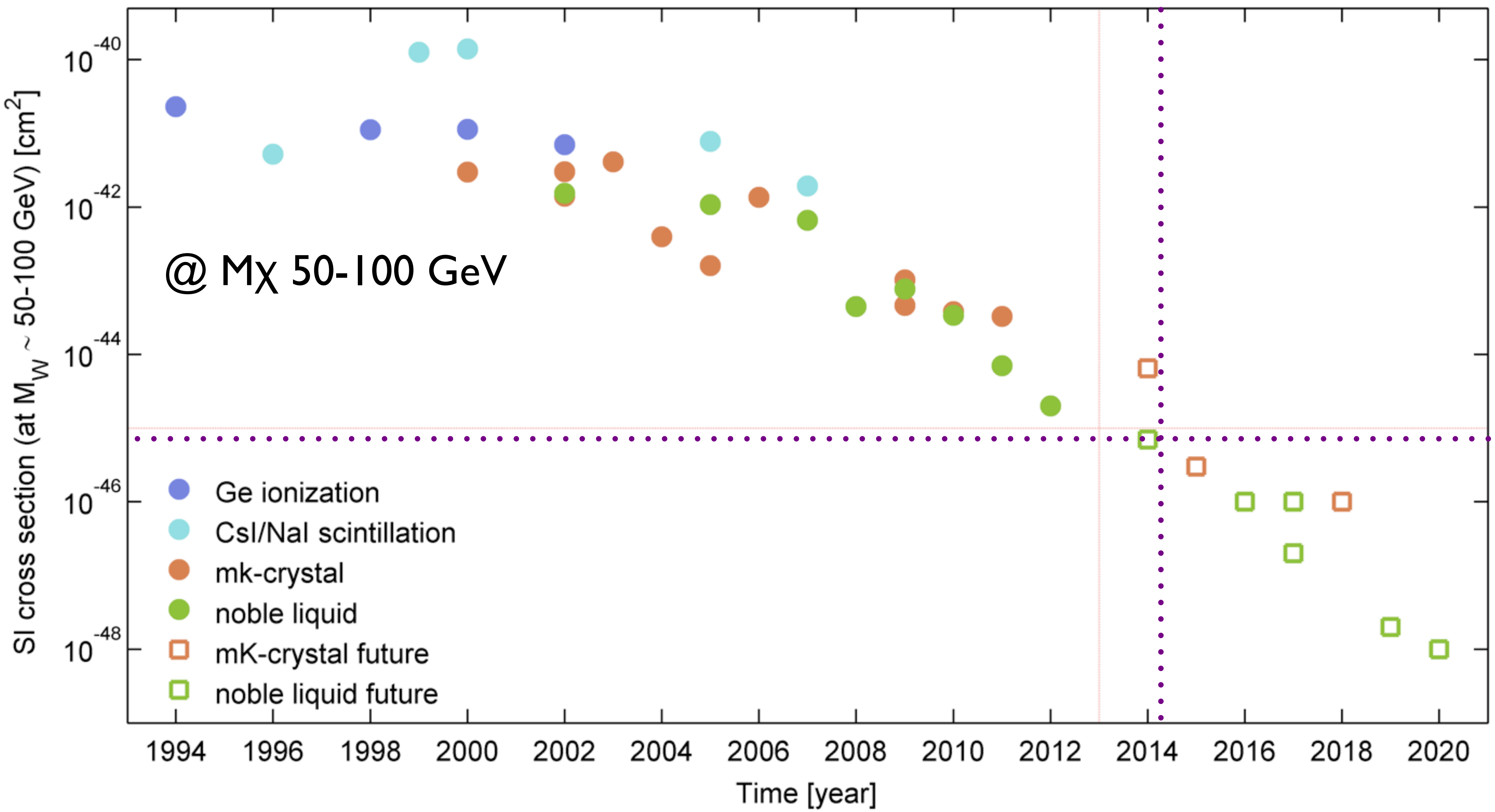


Adapted from SNOWMASS Report arXiv:1310.8327

Ultimate limits



Reach of Future Detectors



L. Baudis, Physics of the Dark Universe 1, 94 - 108 (2012).

Conclusions

- Due to scalability, many nobel liquid proposals to explore WIMP parameter space
- Next months will bring clarity into which projects will be selected in the G2-downselect in the US
- The ultimate backgrounds will be coming from neutrinos
- I hope we will not *only* discover coherent neutrino scattering…