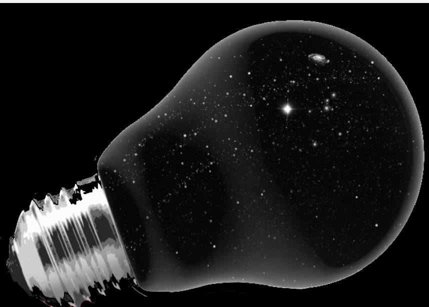
Rencontres de Blois

Particle Physics and Cosmology



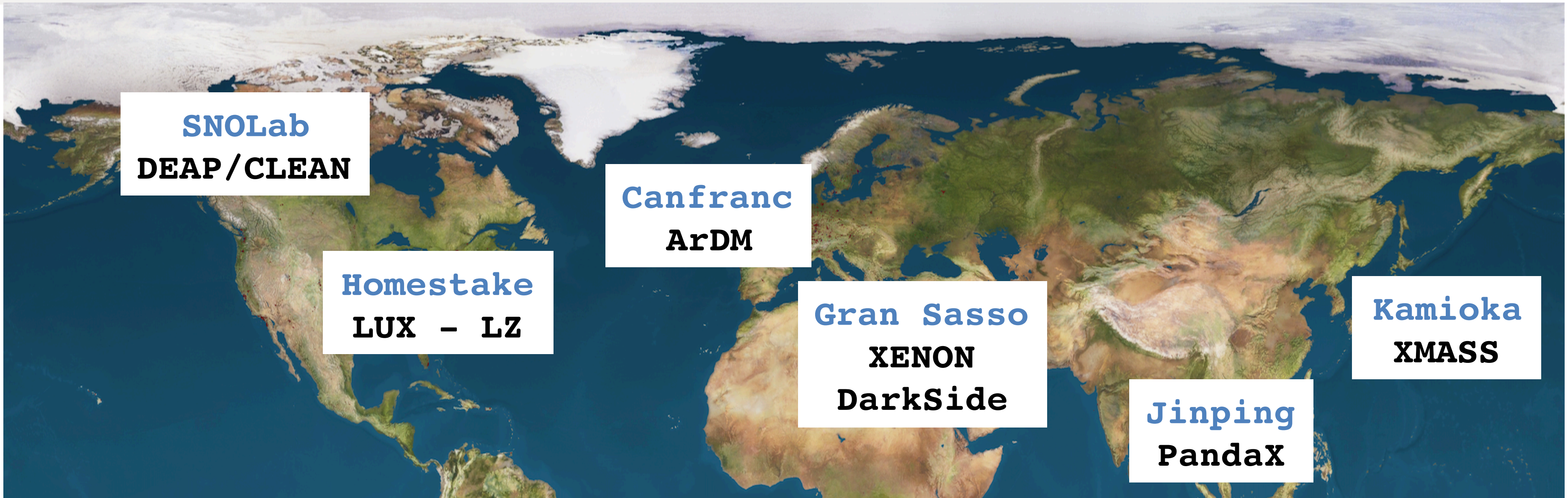
Status of Direct Detection with Noble Liquid Experiments

Davide Franco

APC

June, 3rd 2016

Noble liquids around the world



Fiducial Mass	Xenon		Argon	
≤ 0.15 ton	PandaX Xenon100* XMASS LUX	0.4 (0.05) ton 0.16 (0.06) ton 0.8 (0.1) ton 0.25 (0.15) ton	DarkSide-50**	0.15 (0.05) ton
≤ 1 ton	Xenon1T*	3.5 (1) ton	ArDM DEAP-3600	2 (0.5) ton 3.6 (1) ton
≤ 20 ton	LZ XenonNT	10 (5.6) ton 7 (xxx) ton	DarkSide-20k**	30 (20) ton
≤ 100 ton	DARWIN	50(40) ton	ARGO	xxx (100) ton

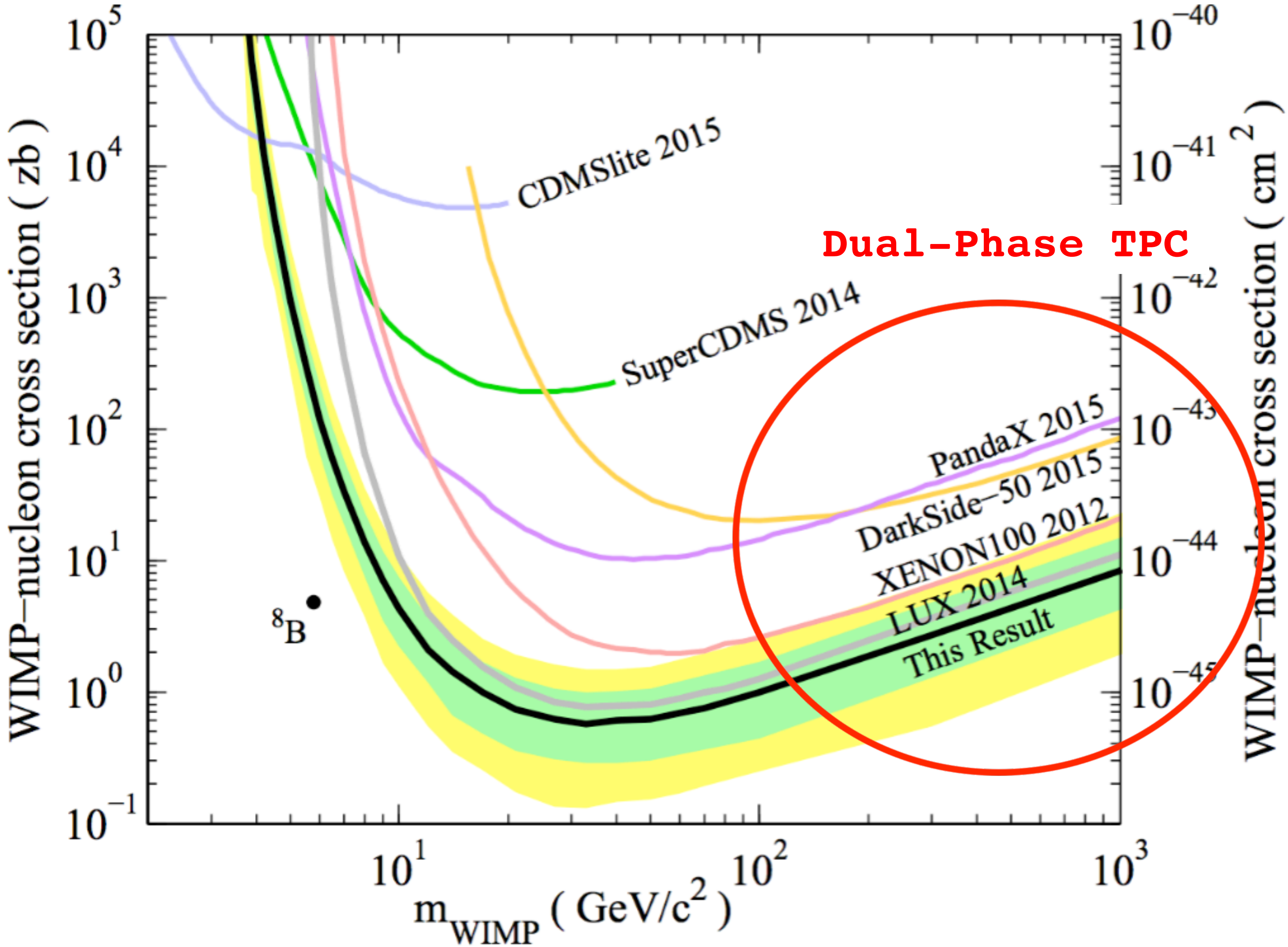
*See K. Micheneau's talk **See J. Maricic's talk

Xenon vs Argon

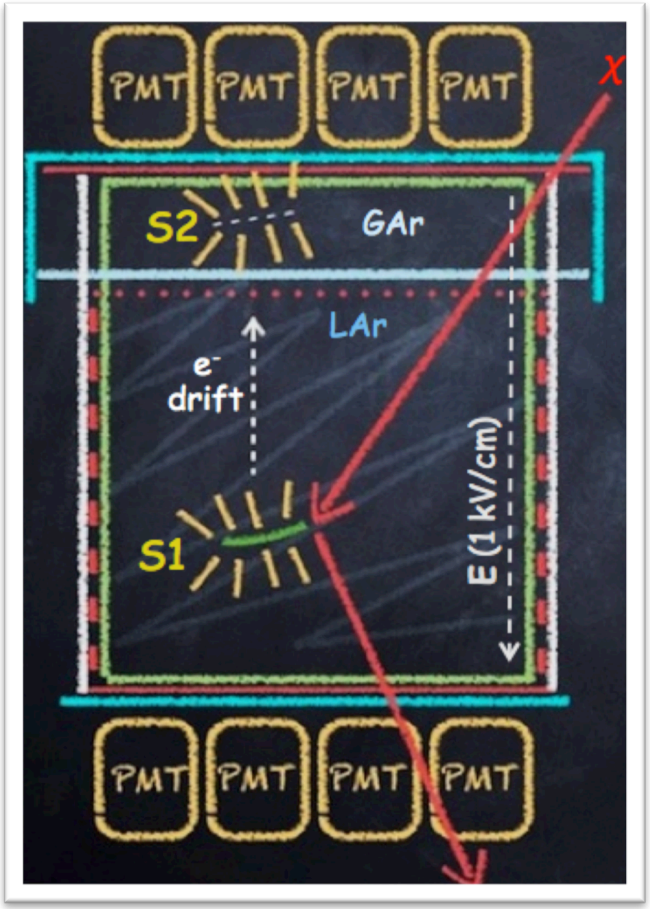
The keyword is "**complementarity**"

	Xenon	Argon
WIMP SI cross section	**Sensitive also to low masses**	**Limited to large masses (M_χ > 10 GeV)**
WIMP SD cross section	**Accessible**	**Not accessible**
Radio-purity	**Intrinsically pure**	^{39}Ar contamination (fixed: see next slides)
Temperature	166.4 K	**87.2 K** (close to nitrogen)
Density	**3.1 g/cm^3**	1.4 g/cm^3
S1 Pulse Shape Discrimination	Very limited (singlet: ~2 ns; triplet: ~27 ns)	**Yes (singlet ~7 ns; triplet ~1600 ns)**
Cost and availability	**Expensive** (~kDollar/kg) **Limited** world production	**Generically cheap** (~$/kg) + **extra costs** for underground extraction **Abundant**

The Status

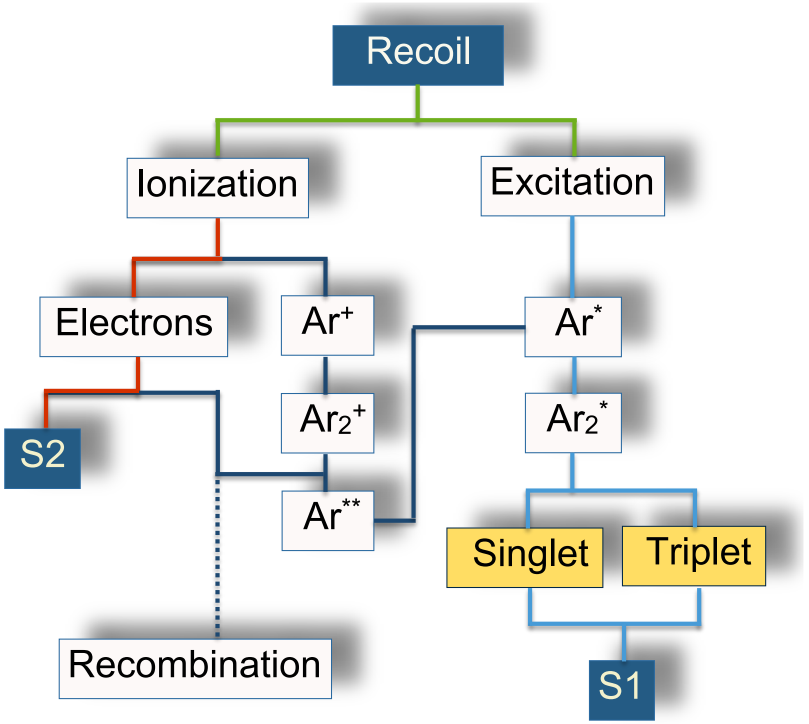


CDMSlite 2015
SuperCDMS 2014
Dual-Phase TPC
PandaX 2015
DarkSide-50 2015
XENON100 2012
LUX 2014
This Result
^{8}B
WIMP–nucleon cross section (zb)
WIMP–nucleon cross section (cm^2)
m_{WIMP} (GeV/c^2)

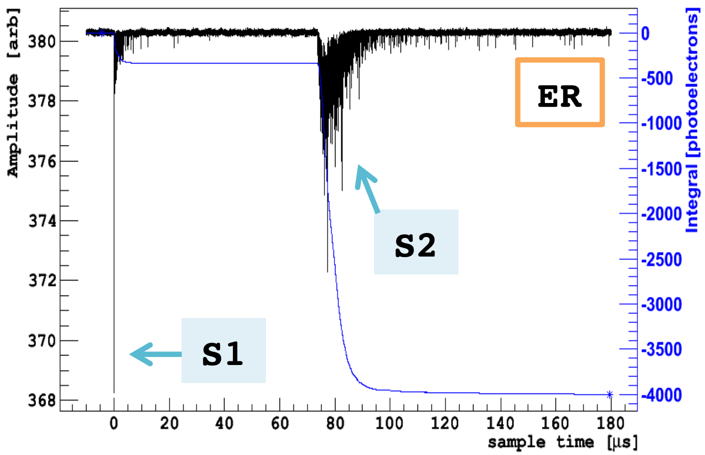


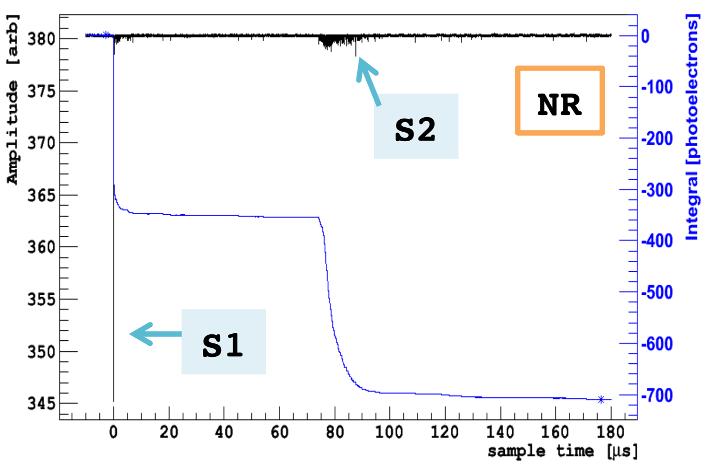
Particle discrimination through:

- Accurate 3D **position** identification
- **Multiple-scattering** rejection
- **S2/S1** ratio
- S1 **PSD** (if available)

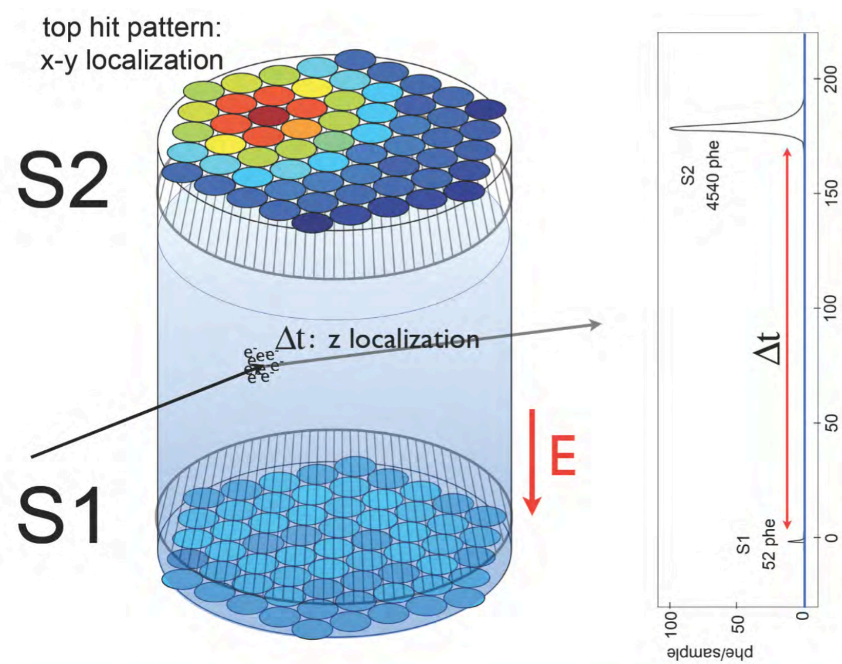


S2/S1 Particle Discrimination



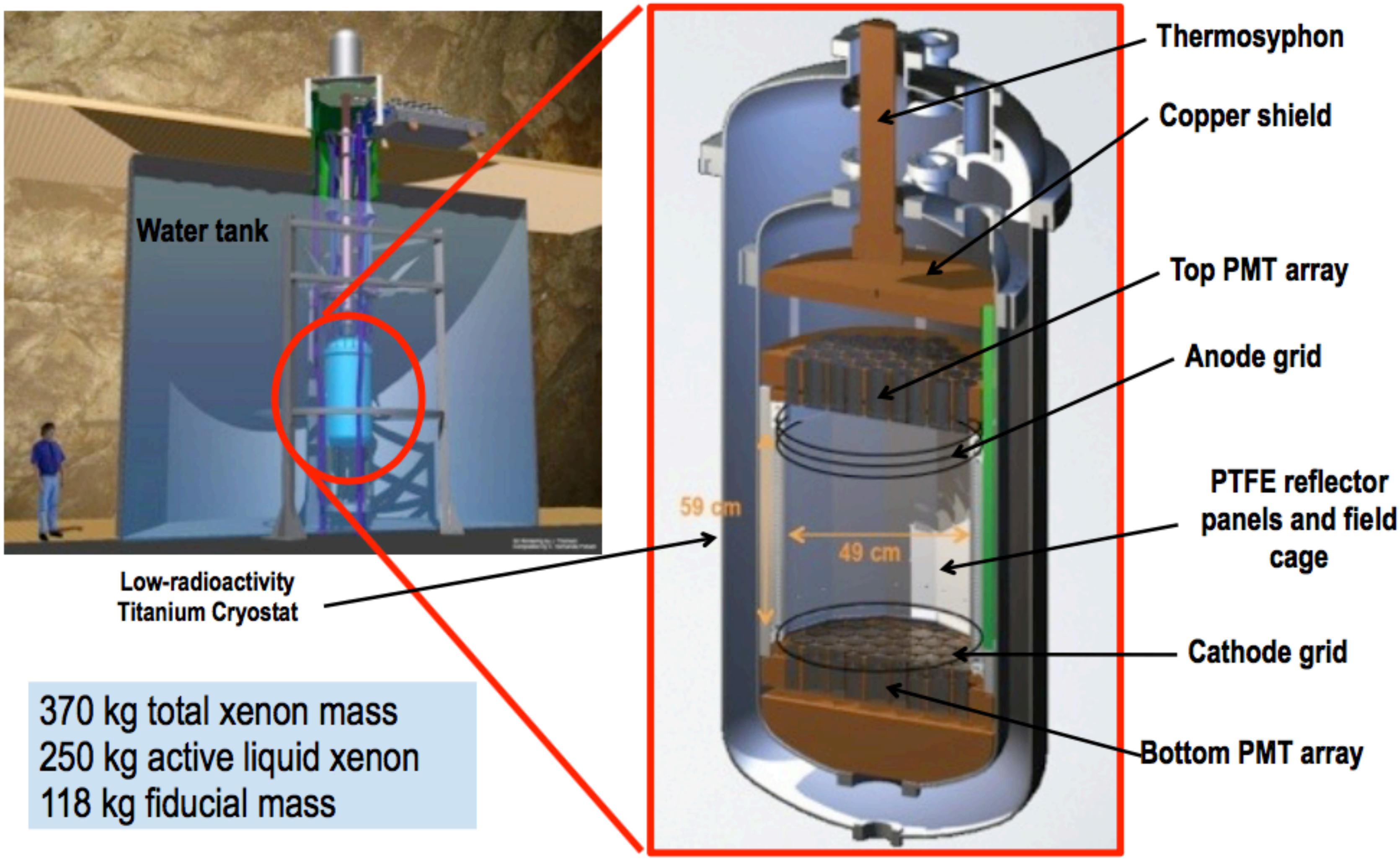


Position reconstruction and multiple scatter



Rejection factor ~ 10^2 – 10^3

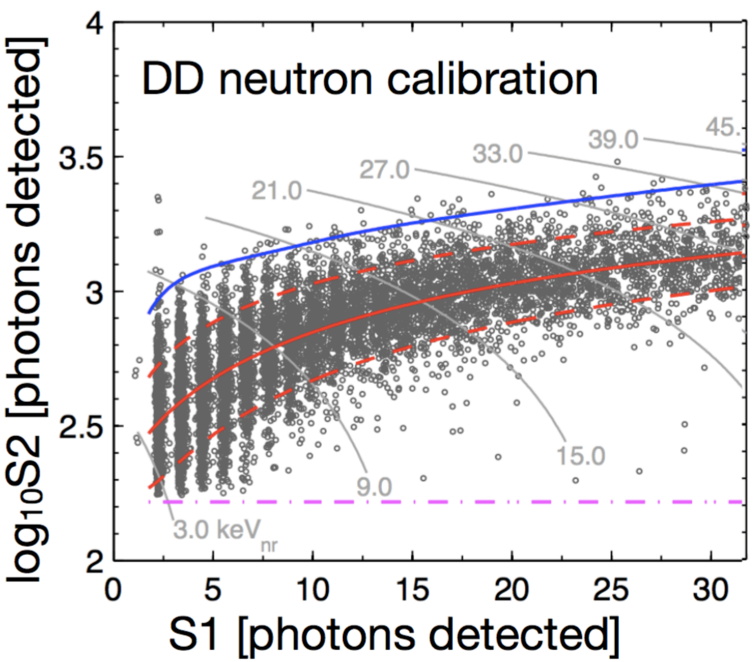
LUX

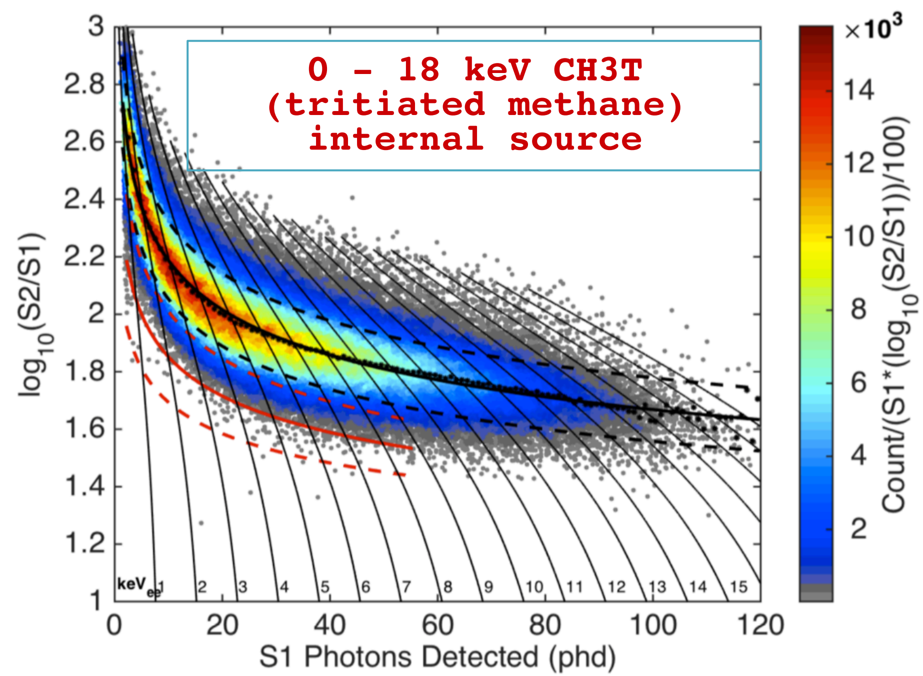


370 kg total xenon mass
250 kg active liquid xenon
118 kg fiducial mass

LUX

- Improved **PMT response** and light measurement
- Improved **calibration**
  - electronic recoil (ER): mono energetic sources, and CH3T internal source;
  - nuclear recoil (NR): mono energetic neutrons with in-situ D-D generator

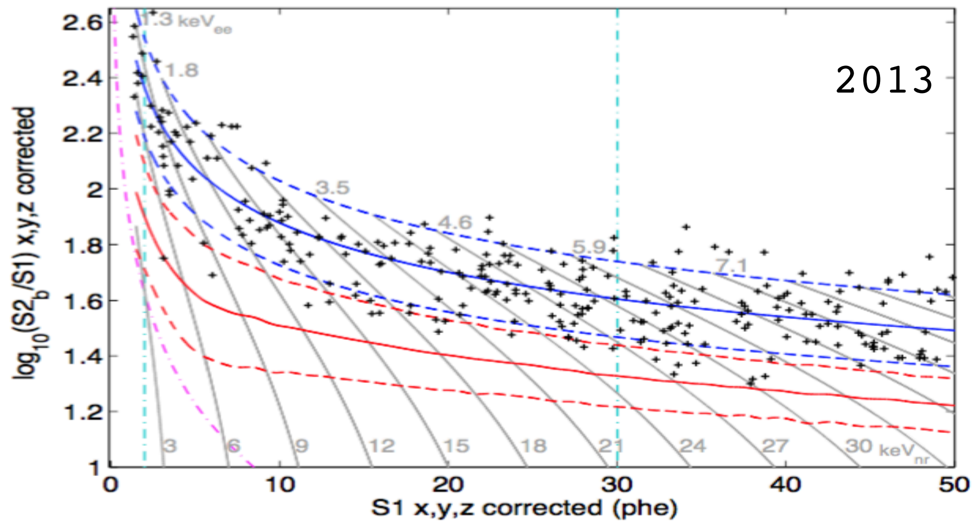


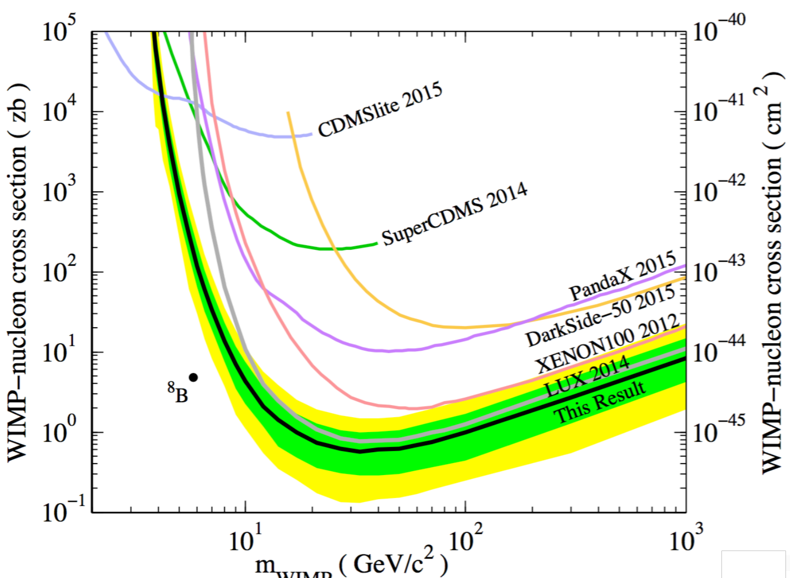


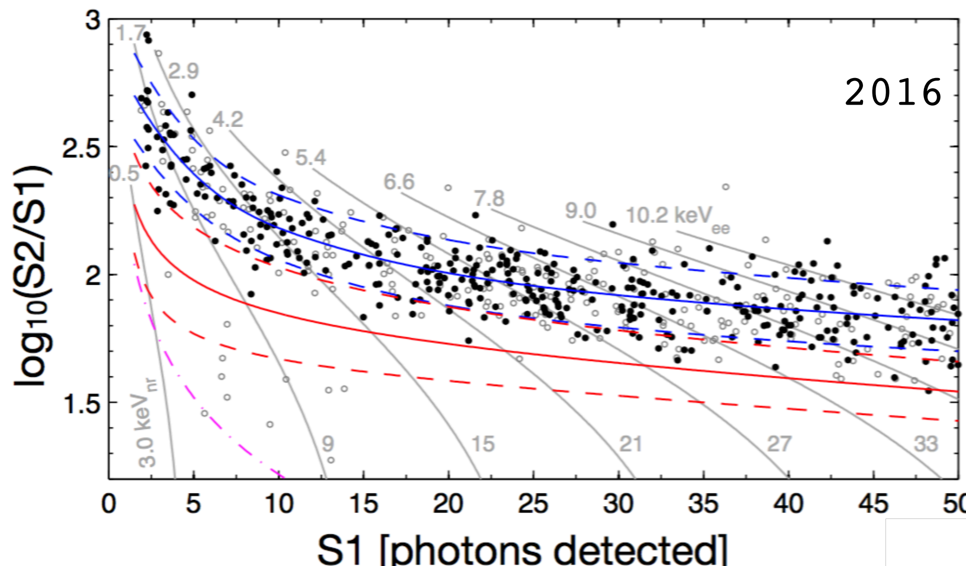
More statistics:
~**14,000** kg day

Profile likelihood ratio
(**PLR**) analysis

Lower energy threshold =>
lower WIMP masses: **from 3.0 keV (5.2 GeV) to 1.1 keV (3.3 GeV)**





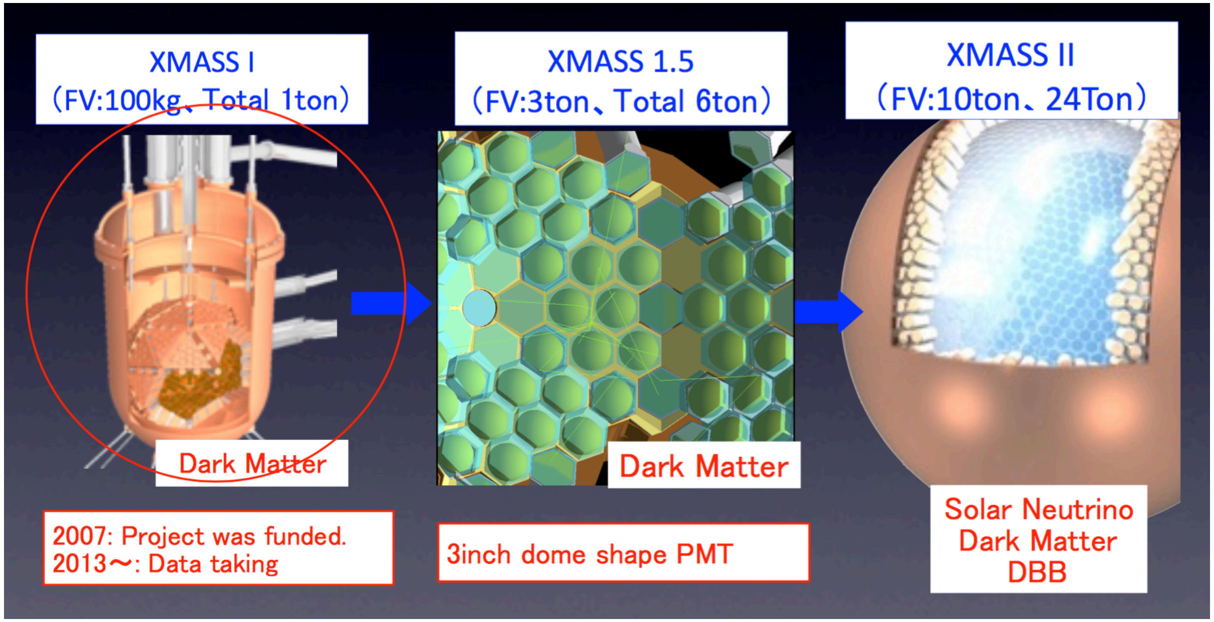


Single-phase: XMASS

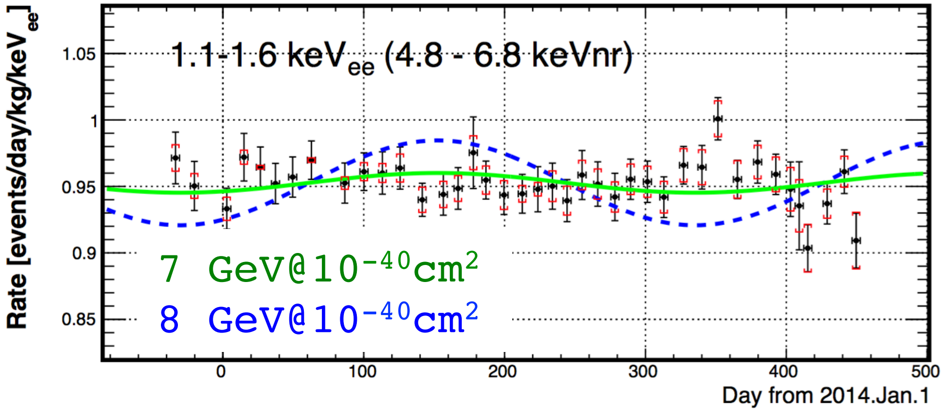
- 832 kg of Lxe (100 kg FV)
- Data taking ~1 year
- 642 2'' PMTs (62% optical coverage)
- **Light Yield: 15 pe/keV**
- Single phase: no ER discrimination => **looking for annual modulations**

Intrinsic BG of XMASS I: O(10^{-4} DRU) @ 40keV (arXiv: 1401.4737)

Larger size is advantageous for surface background, Kr, and Rn



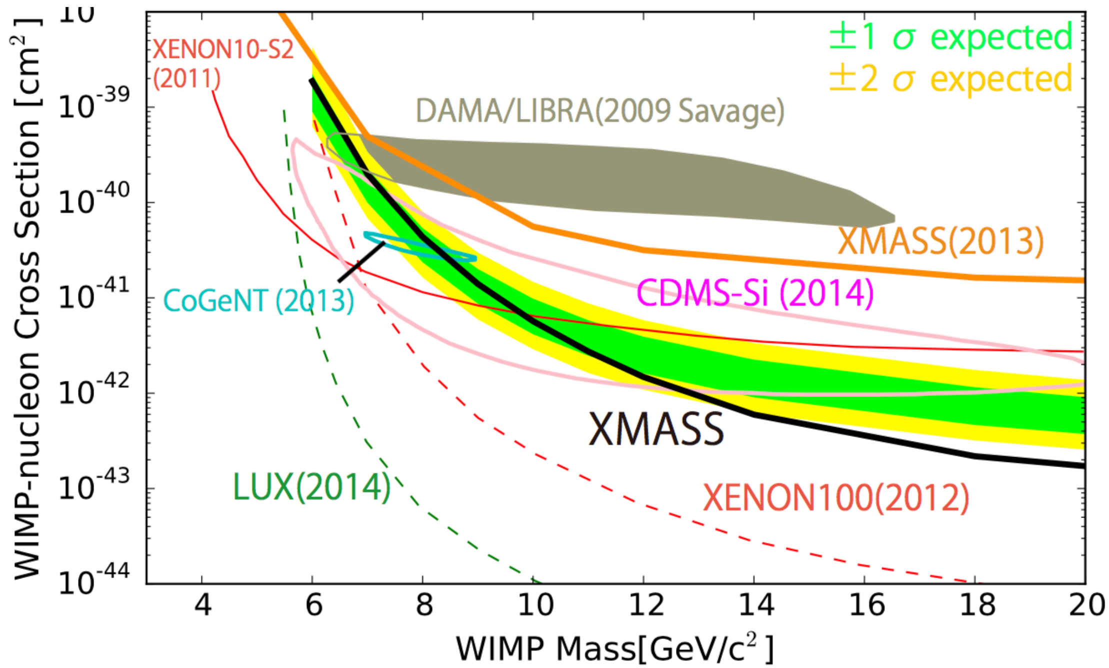
XMASS: new results



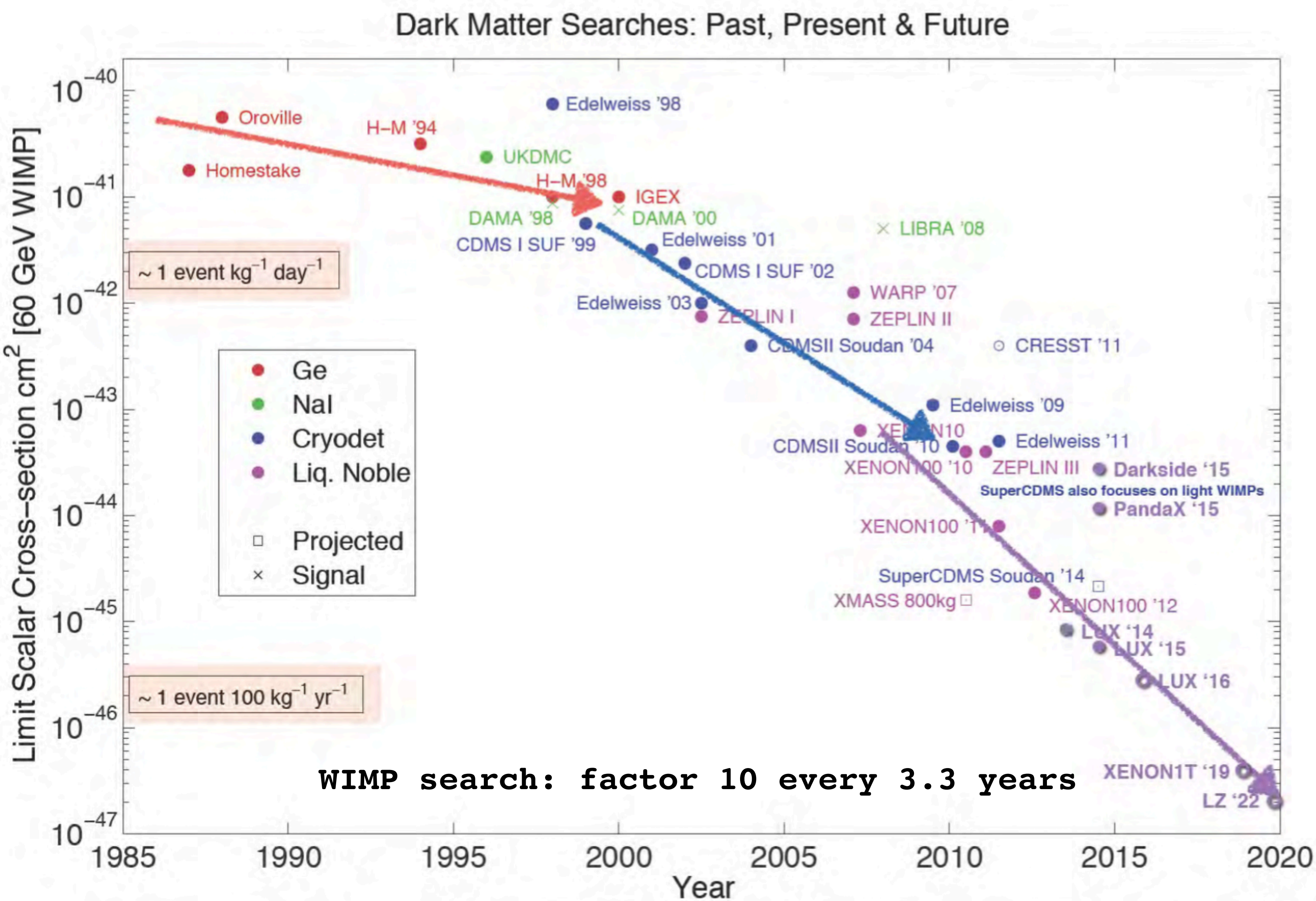
DAMA almost completed excluded

Full annual modulation analysis:

- Fixed phase
- Limit compatible with previous Xenon results



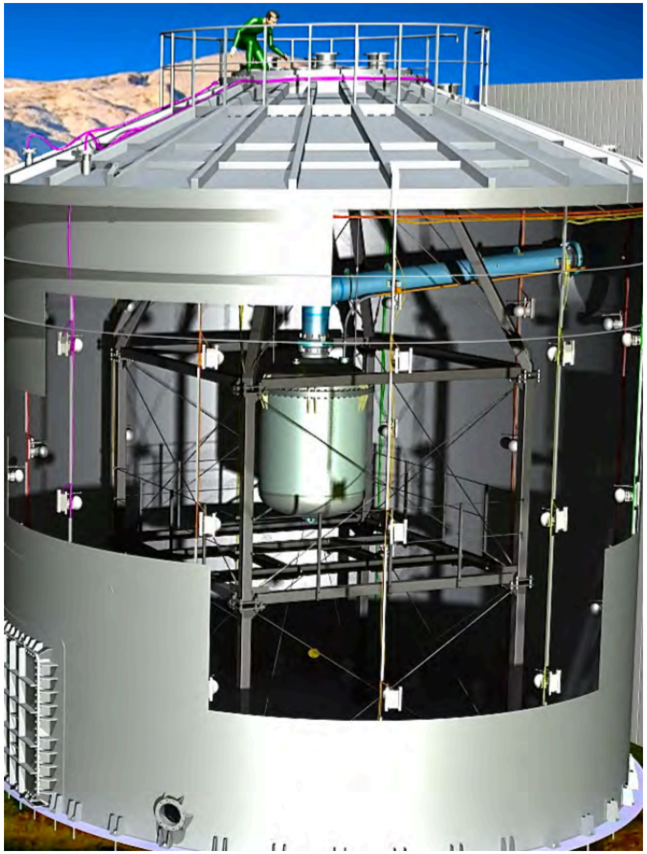
Perspectives in Direct Dark Matter Search



Slide from R. Gaitskell

Towards the ton / multi-ton phase

XENON1T



- 3.5 ton => 2.0 ton target mass
- TPC with ~1 m drift length
- ~1 kV/cm drift field
- 248 PMT's (RR11410-21)
- 10 m water tank for neutron shielding and muon veto

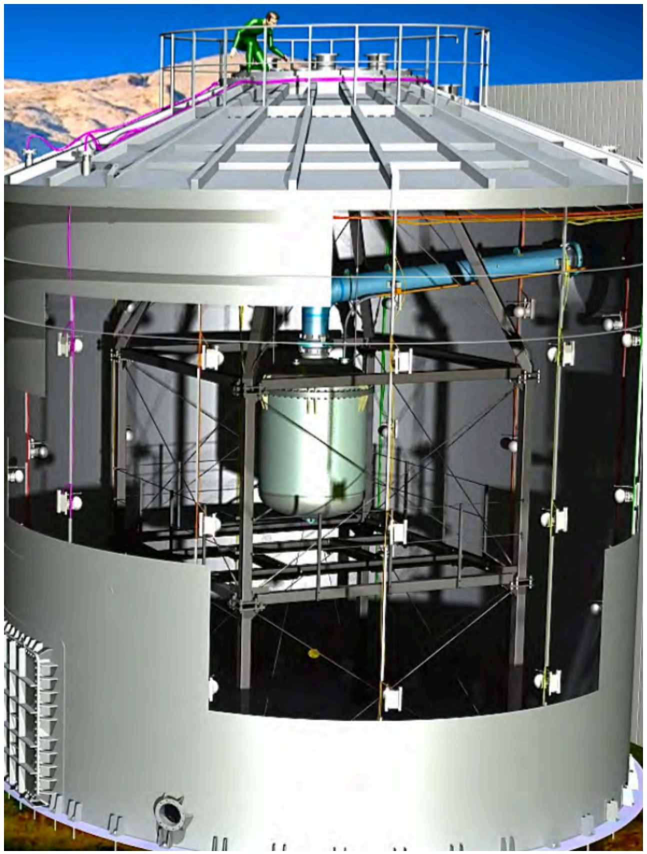
Currently in commissioning phase

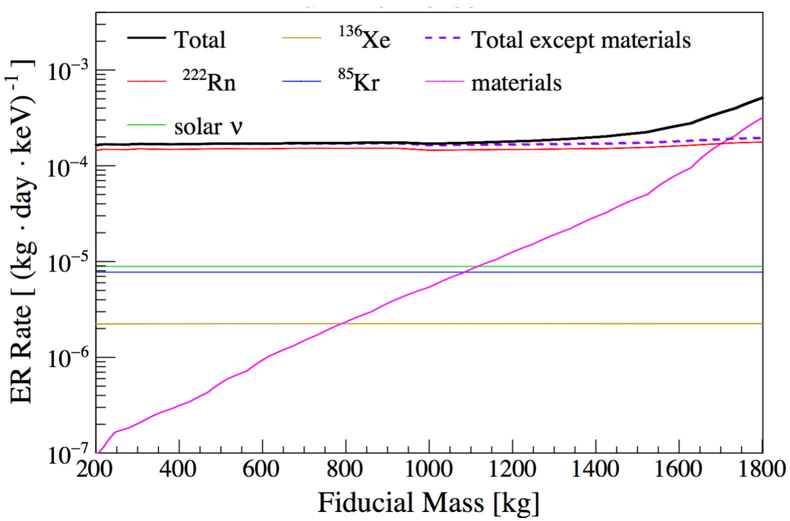
Data taking soon!

Can be extended to n-tons

Towards the ton/multi-ton phase

XENON1T





Background after **99.75% ER rejection: 2.08 events/(ton yr)** (in S1 range (3,70) PE):

ERs ~1.6 / (ton yr)

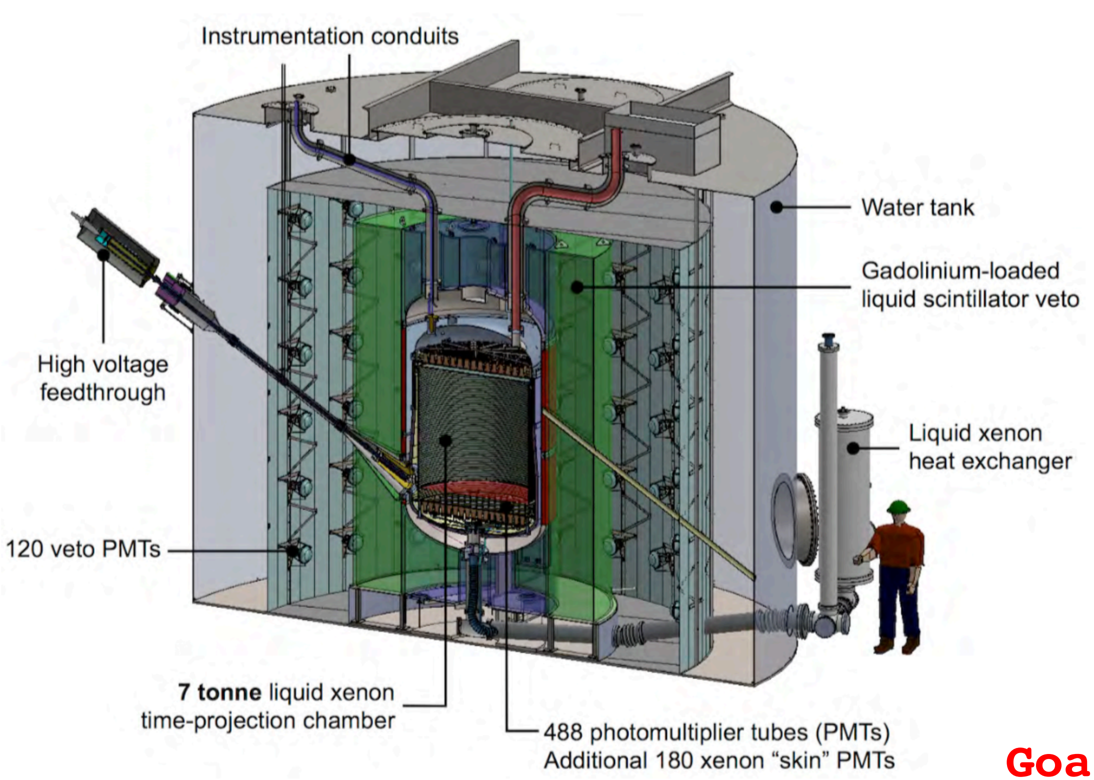
NRs ~0.5 / (ton yr)

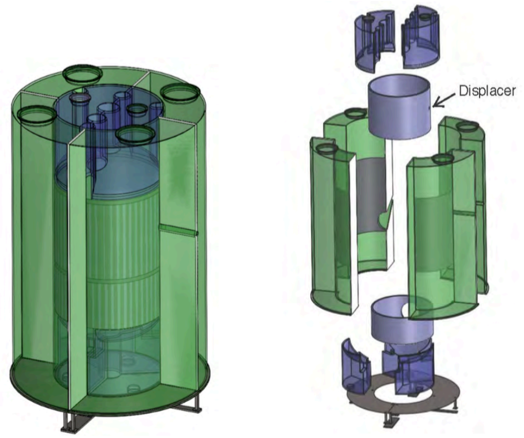
Goal: ~1E-47

Towards the ton/multi-ton phase

LZ

Innovation:
- **Titanium** cryostat (although stainless steel is being evaluated as an option)
- **Double veto:**
  - Active buffer LXe thanks to PMts between cryostat and TPC
  - External scintillator detector loaded with Gd

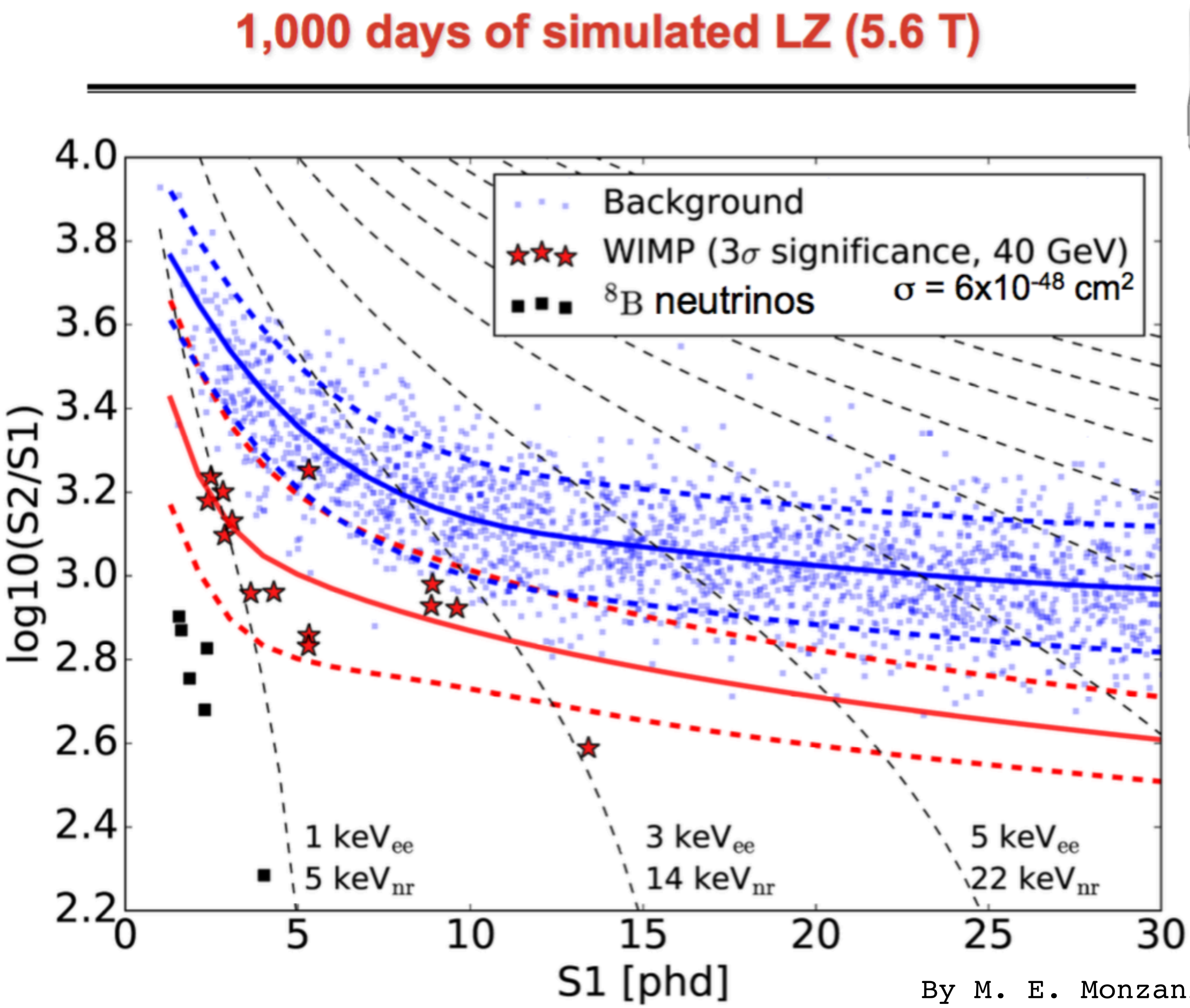




Expected background
ERs ~0.13 / (ton yr)
NRs ~0.03 / (ton yr)

Goal: ~1E-48

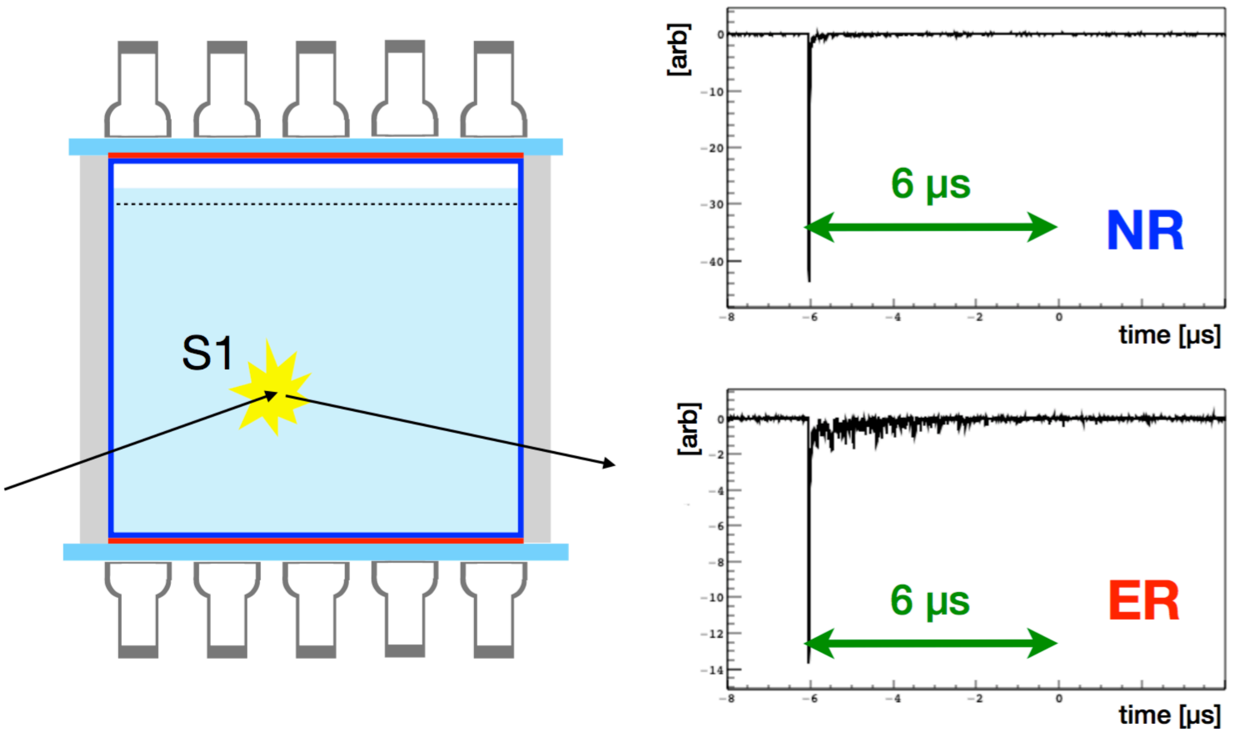
LZ



By M. E. Monzani

Can we build a background-free experiment?

The Pulse Shape Discrimination in Argon



~70% of the NR excites the singlet state (~7 ns)

~70% of the ER excites the triplet state (~1600 ns)

PSD parameter: **F90** = fraction of light in first 90 ns

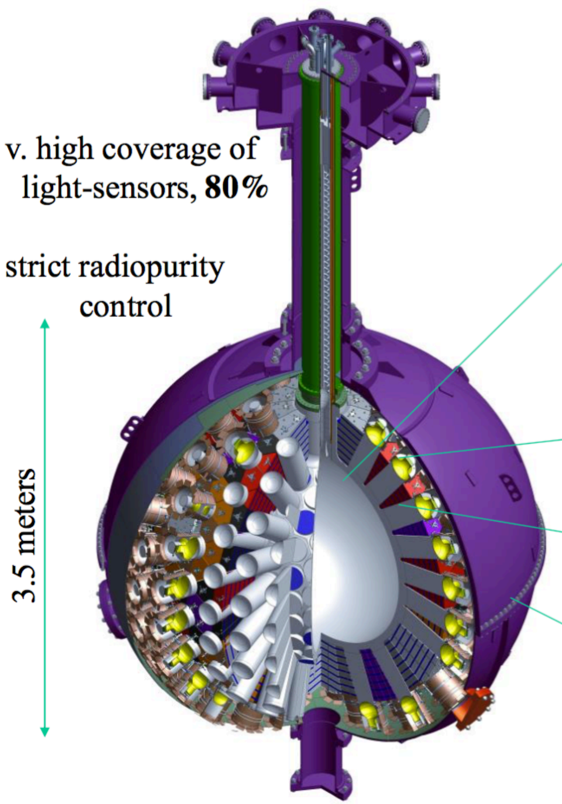
5

Rejection factor: 10^7–10^8

DEAP-3600 Detector

v. high coverage of light-sensors, **80%**

strict radiopurity control



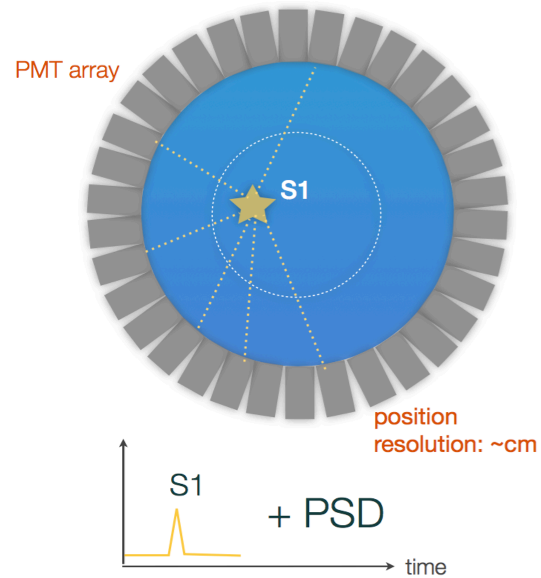
3600 kg argon in sealed ultraclean Acrylic Vessel (1.7 m ID)

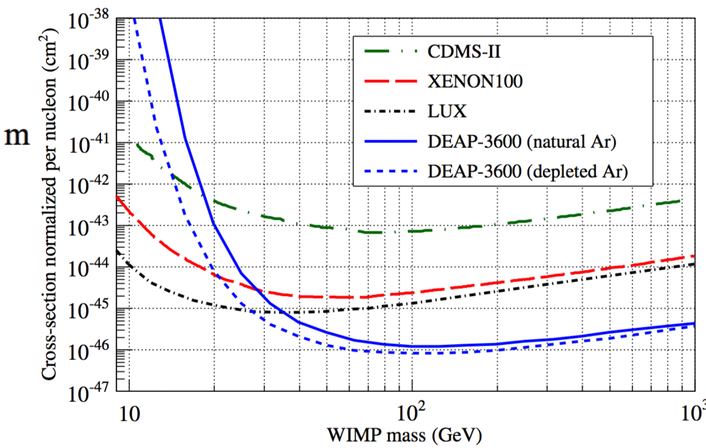
Vessel is “resurfaced” in-situ to remove deposited Rn daughters after construction

255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE)

50 cm light guides + PE shielding provide neutron moderation

Steel Shell immersed in 8 m water shield at SNOLAB



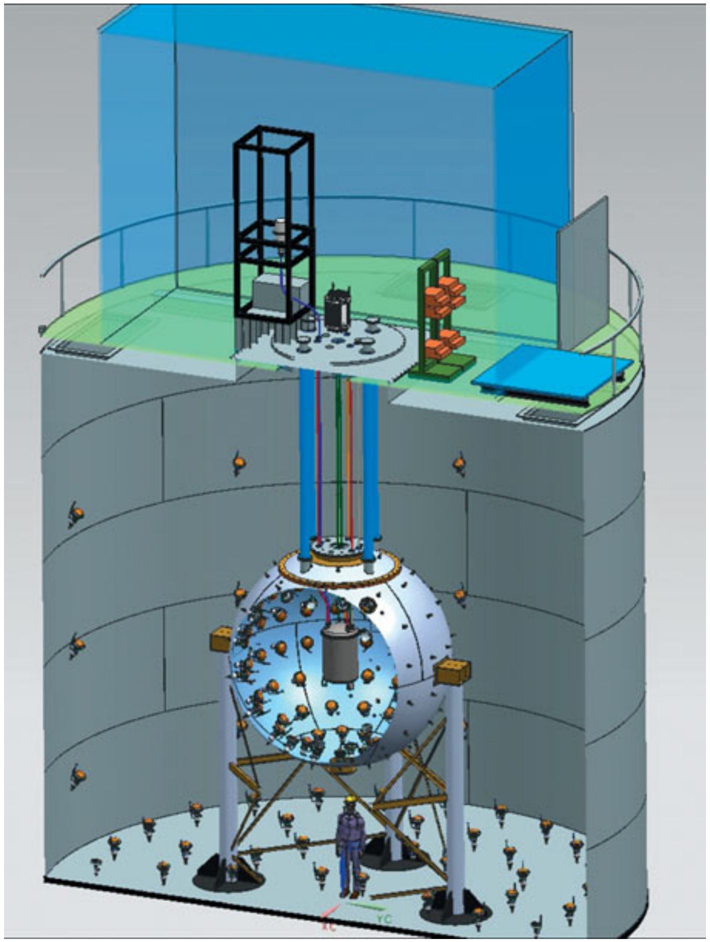


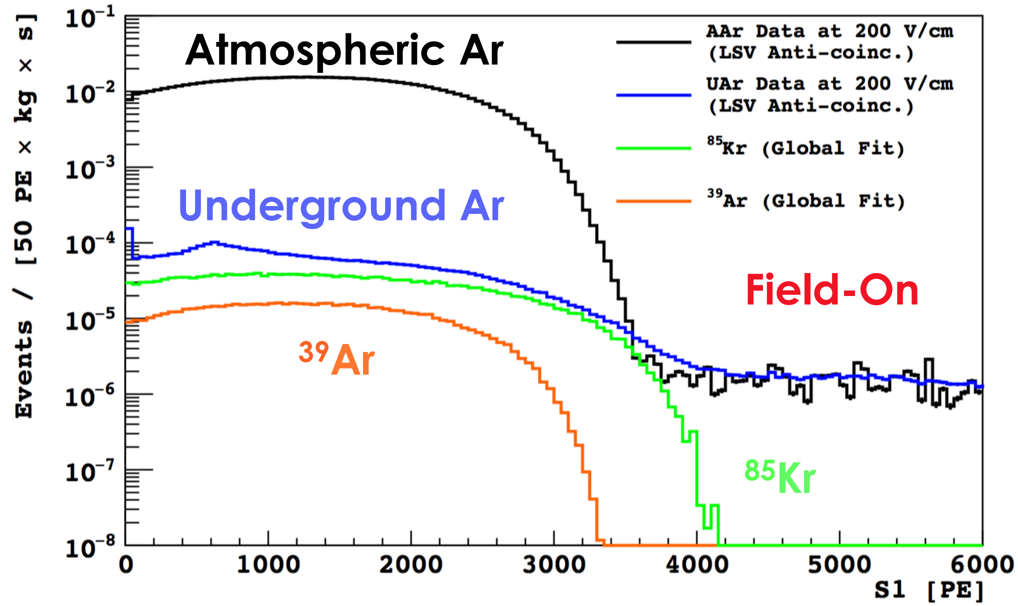
1000 kg fiducial mass
Light Yield ~8 pe/keV$_{ee}$

Data taking on going!

Project <0.6 background in 3 ton-yr, 1E-46 cm² reach

DarkSide50: LAr dual-phase TPC





Underground Ar:

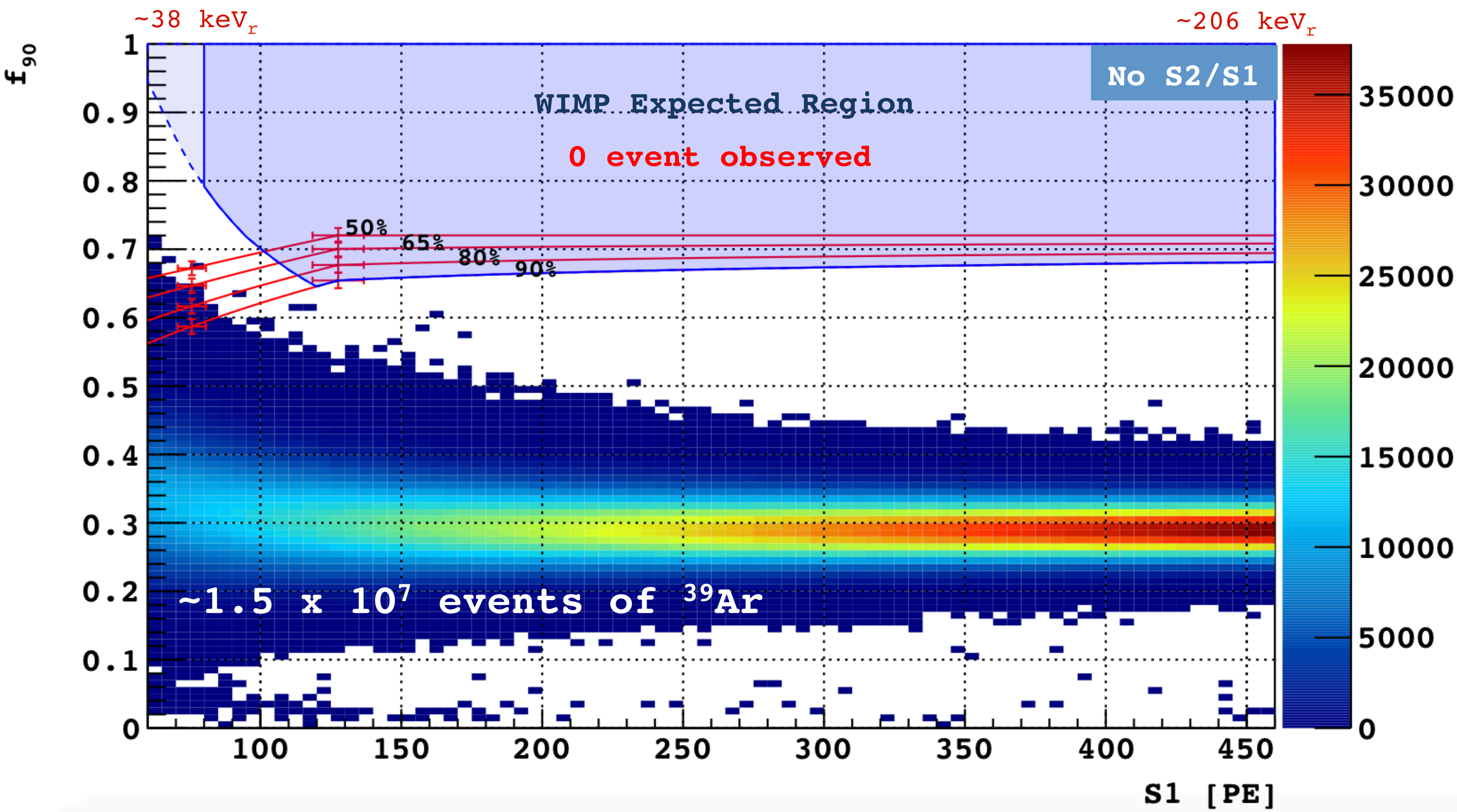
Naturally shielded against cosmic rays

Rate **~0.7 mBq/kg**

Depletion factor **~1400**

The PSD with DarkSide-50

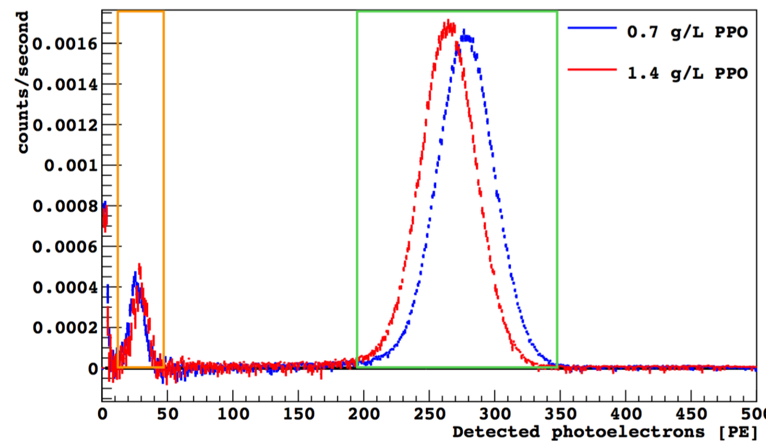
See J. Maricic's slides



The DarkSide-50 Neutron Veto

Liquid Scintillator Veto

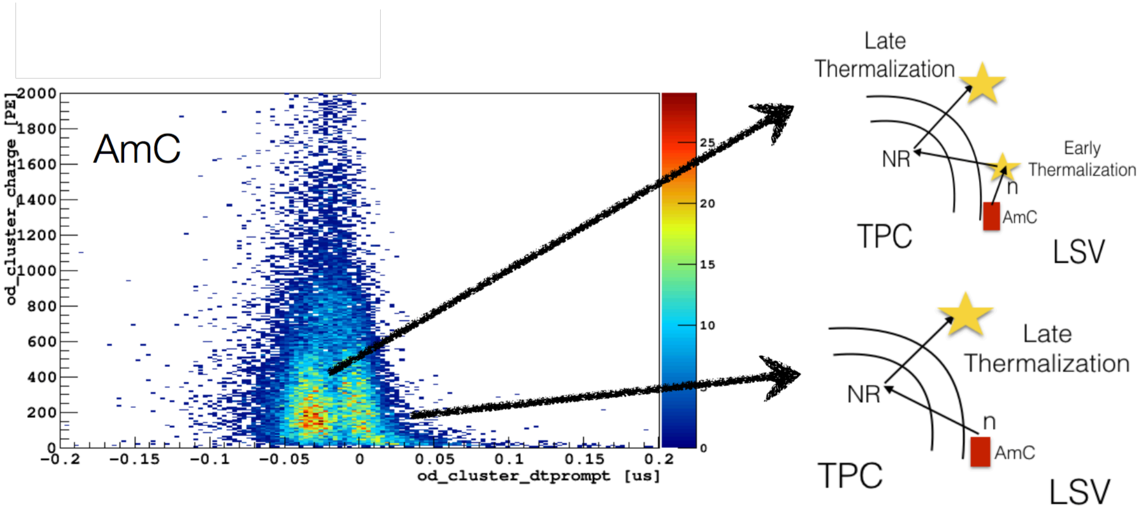
- 4 m diameter sphere
- Boron-loaded: 20:1 PC and TMB
- 110 8" PMTs
- LY ~ 500 pe/MeV



$$^{10}\mathrm{B} + n \rightarrow \alpha\,(1775\,\mathrm{keV}) + {}^{7}\mathrm{Li} \qquad (\mathrm{BR{:}}\,6.4\,\%)$$

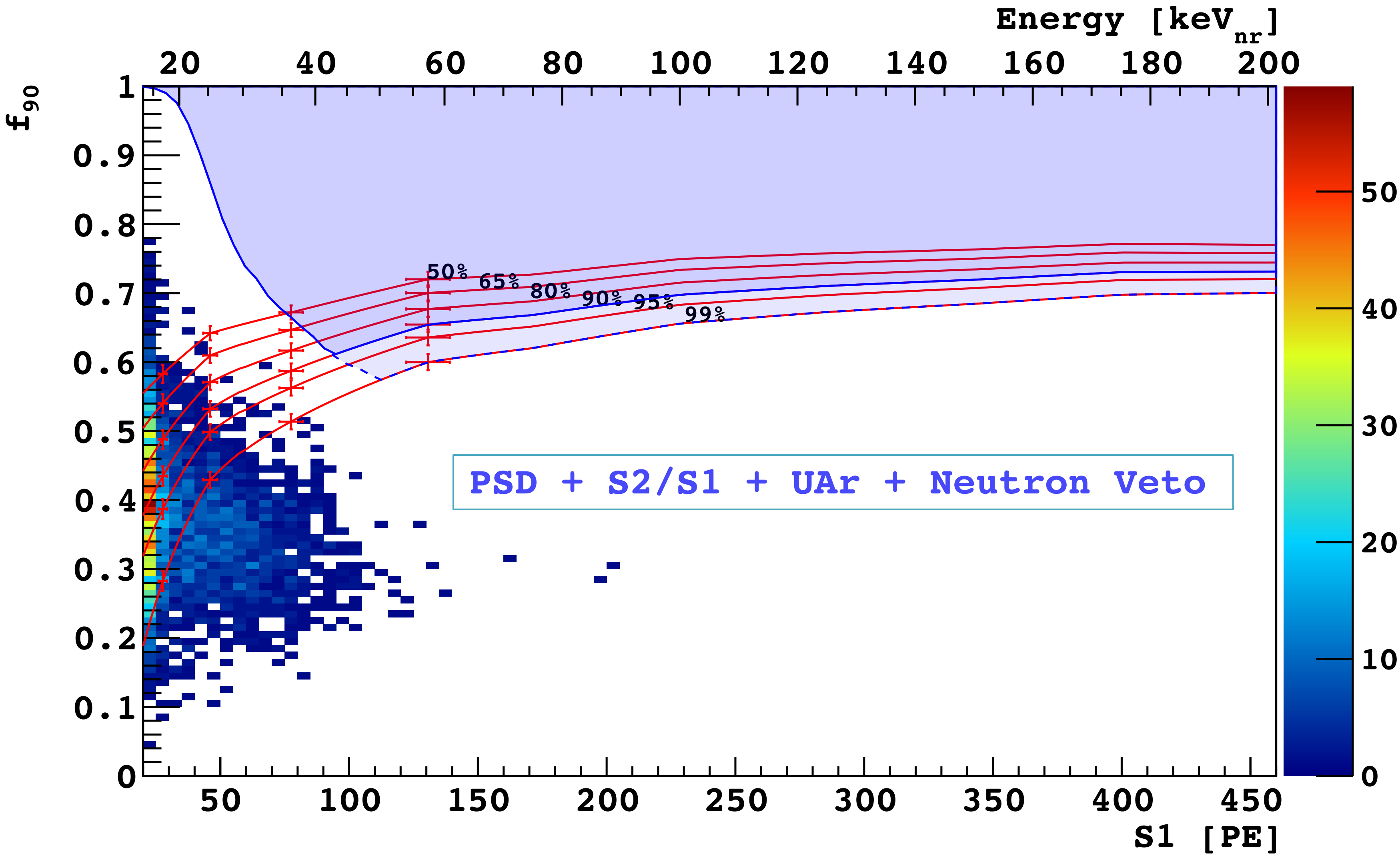
$$^{10}\mathrm{B} + n \rightarrow \alpha\,(1471\,\mathrm{keV}) + {}^{7}\mathrm{Li}^{*} \qquad (\mathrm{BR{:}}\,93.6\,\%)$$

$$^{7}\mathrm{Li}^{*} \rightarrow {}^{7}\mathrm{Li} + \gamma\,(478\,\mathrm{keV})$$



99.1% efficiency to veto neutrons from capture alone (AmBe + simulation)

+ neutron thermalization signal from the scintillator


Energy [keV$_{nr}$]
20
40
60
80
100
120
140
160
180
200
f_{90}
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
50%
65%
80%
90%
95%
99%
PSD + S2/S1 + UAr + Neutron Veto
50
100
150
200
250
300
350
400
450
S1 [PE]
50
40
30
20
10
0

Scaling to a multi-ton LAr detector

^{39}Ar rejection

1,422 kg day @AAr

x1400 (AAr/UAr)

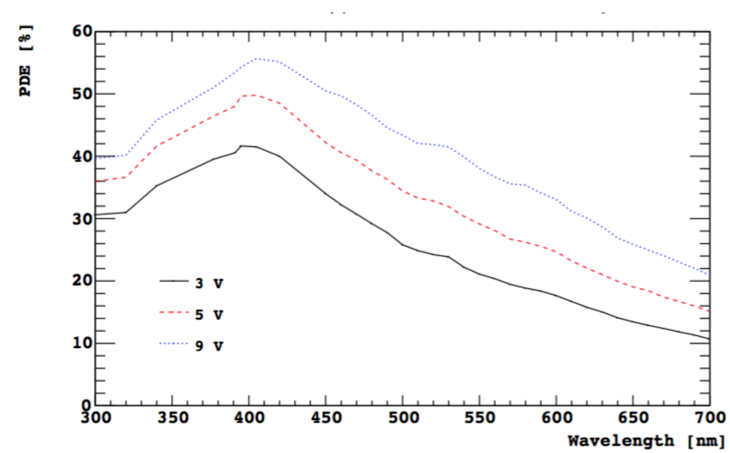
~5 ton year (UAr) background free

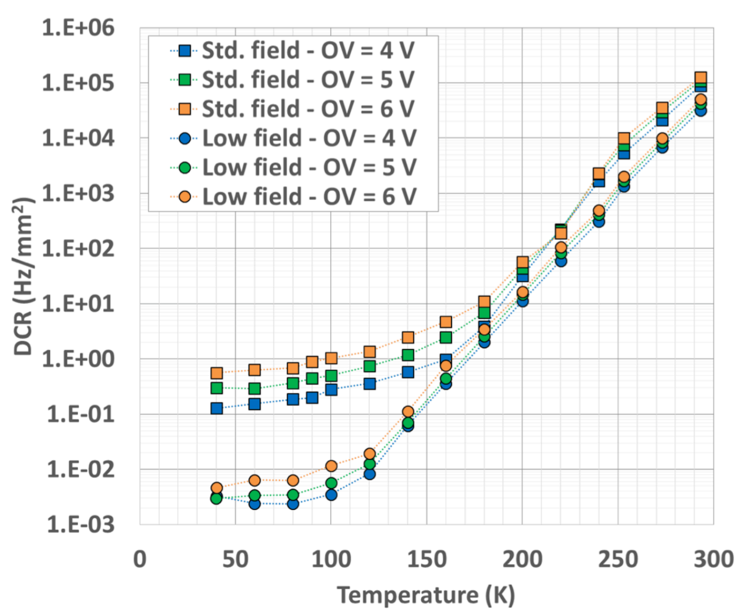
Need **~100 ton yr** for DS20k and **~1000 ton yr** for ARGO

ARIA: active isotopic depletion

Improving S2/S1 and PSD with **SiPMs**

DarkSide20k: the SiPM option





SiPM Requirements

PDE larger than 40% at 420 nm

Dark count rate (DCR) lower than 1 Hz/mm2

Total correlated noise probability (crosstalk + afterpulsing) lower than 40%

Inactive gap between devices smaller than 200 μm to maximize the tiling efficiency

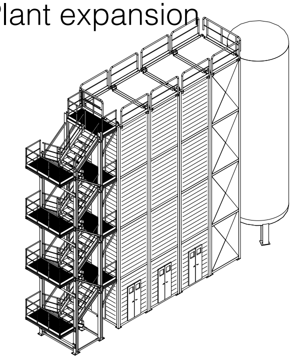
Photo-electron gain larger than 1M and a signal duration of less than 300 ns

Overall surface ~15 m^2

GOAL: 50% more in light yield

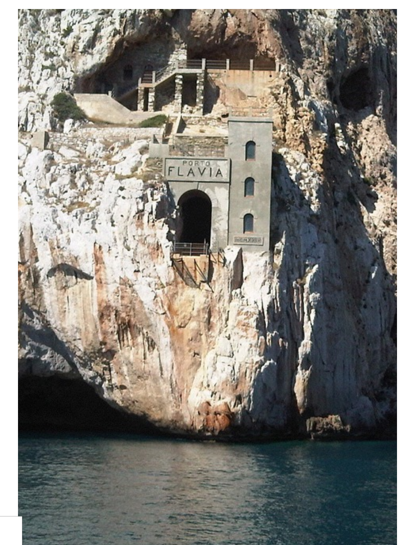
URANIA & ARIA

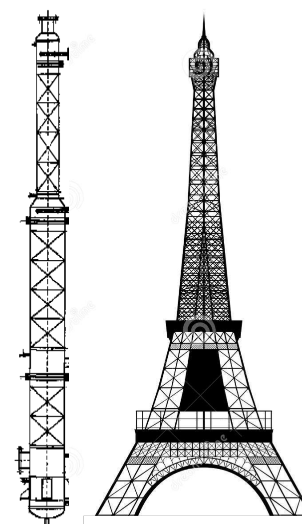
Plant expansion



URANIA

Replacement of the Ar extraction plant in Colorado to reach capacity of **100 kg/day** of UAr

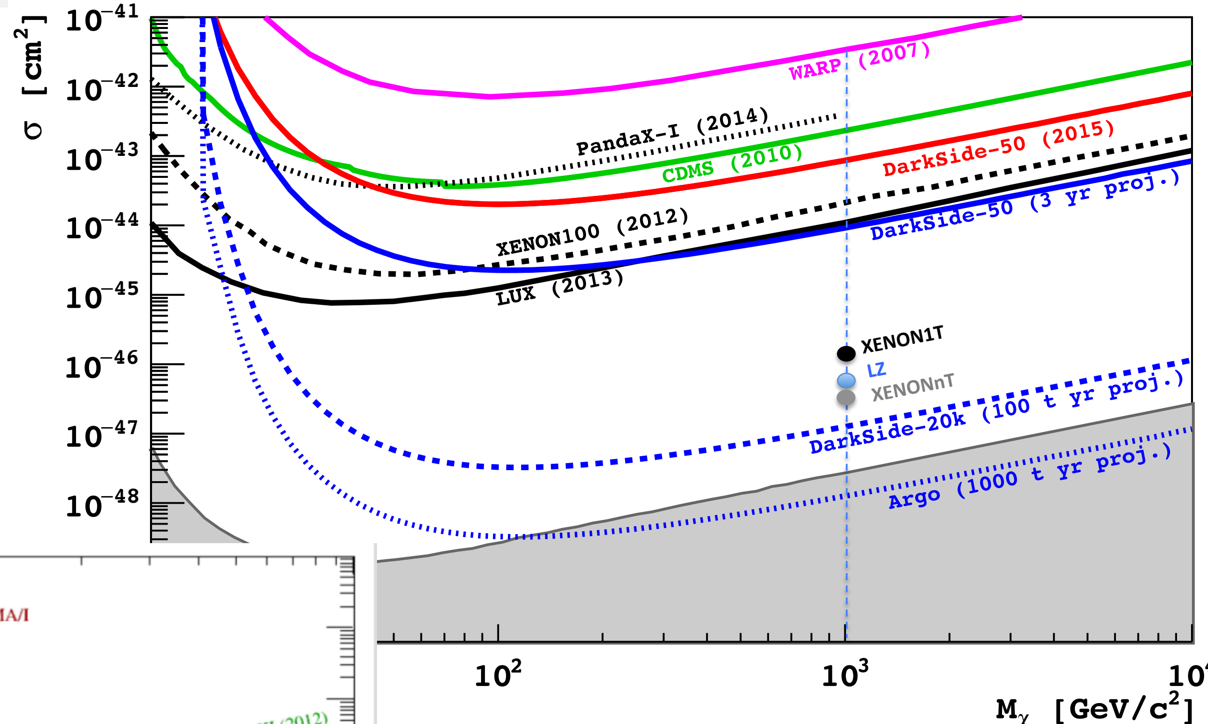


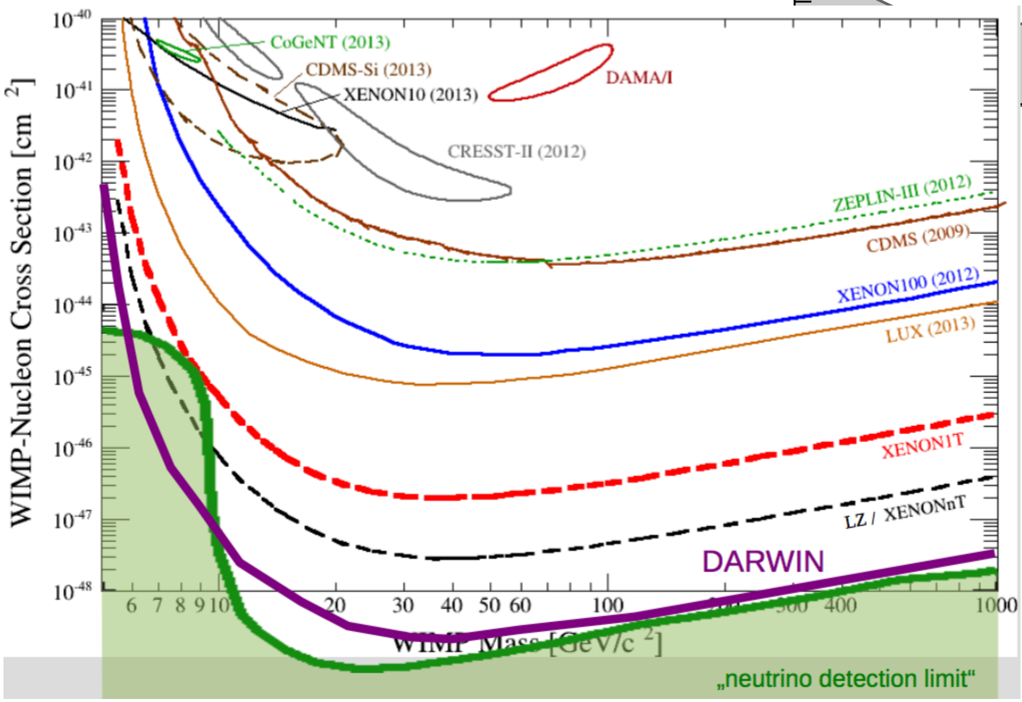


ARIA

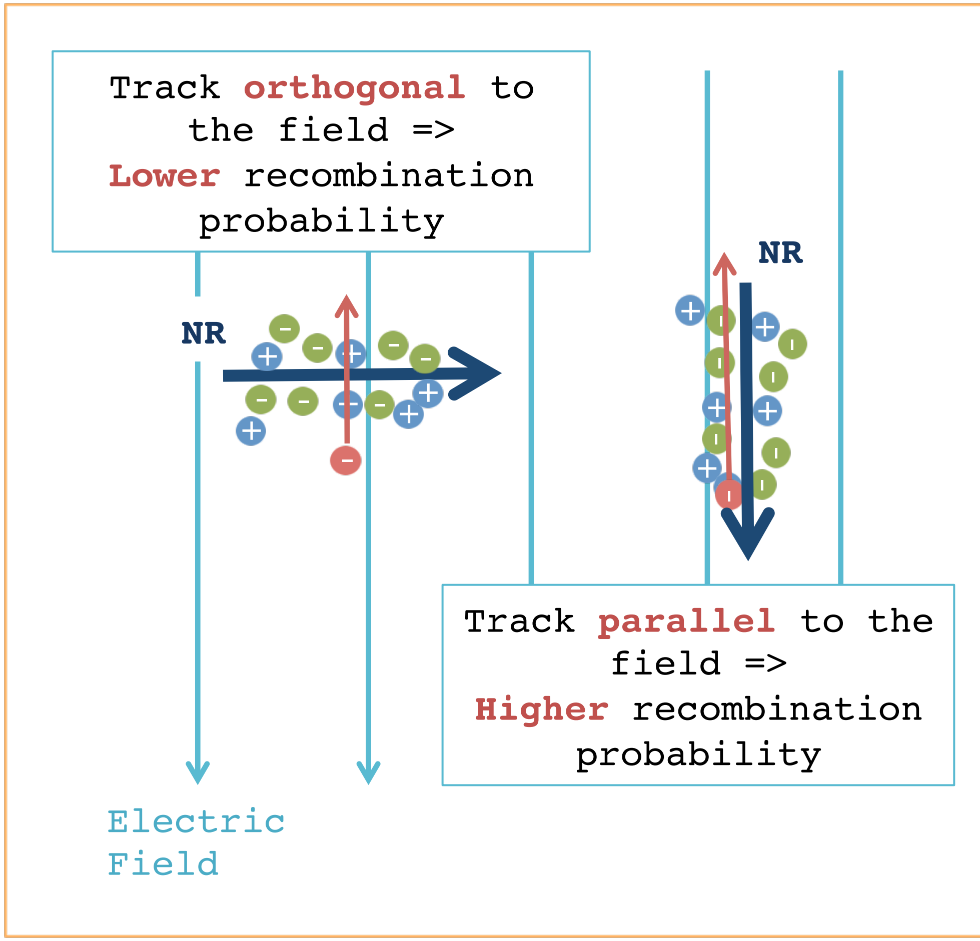
~350 m distillation column in Seruci mine (Sardinia) for chemical and isotopic purification of UAr

Exploits finite vapor pressure difference between $^{39}Ar/^{40}Ar$: ^{39}Ar reduction factor of 10 per pass at the rate of **100 kg/day**


σ [cm²]
10⁻⁴¹
10⁻⁴²
10⁻⁴³
10⁻⁴⁴
10⁻⁴⁵
10⁻⁴⁶
10⁻⁴⁷
10⁻⁴⁸
WARP (2007)
PandaX-I (2014)
CDMS (2010)
DarkSide-50 (2015)
XENON100 (2012)
DarkSide-50 (3 yr proj.)
LUX (2013)
XENON1T
LZ
XENONnT
DarkSide-20k (100 t yr proj.)
Argo (1000 t yr proj.)
10²
10³
10⁴
Mχ [GeV/c²]

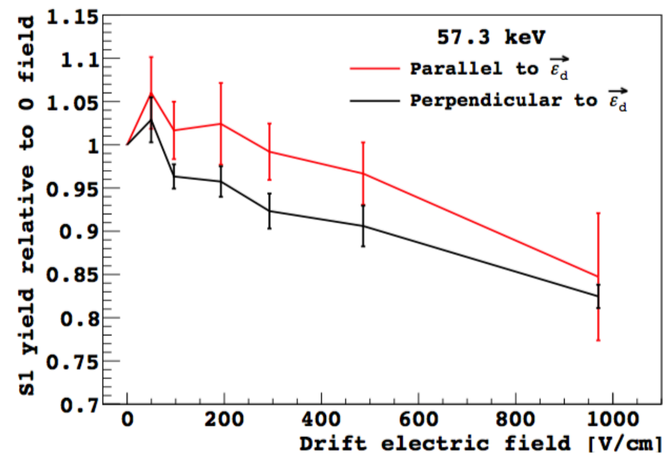

WIMP-Nucleon Cross Section [cm²]
CoGeNT (2013)
CDMS-Si (2013)
XENON10 (2013)
DAMA/I
CRESST-II (2012)
ZEPLIN-III (2012)
CDMS (2009)
XENON100 (2012)
LUX (2013)
XENON1T
LZ / XENONnT
DARWIN
6 7 8 9 10 20 30 40 50 60 100 400 1000
WIMP Mass [GeV/c²]
„neutrino detection limit"

Columnar recombination model



Effects of the track orientation on the measured energy

"Hint" from **SCENE** (small scale TPC exposed to a neutron beam)



ReD and **ARIS** will investigate the effect

Conclusions

- Several technological progresses in the last years
- New robust designs for the next generations
- But still to demonstrate that we can scale the current technology (light propagation? electron lifetime?)

Directionality?

1E-45 cm^2 1E-46 cm^2 1E-47 cm^2 1E-48 cm^2 1E-49 cm^2

~0.1 ton ~1 ton ~10 ton ~100 ton

2016 2020 202XXX

Neutrino floor