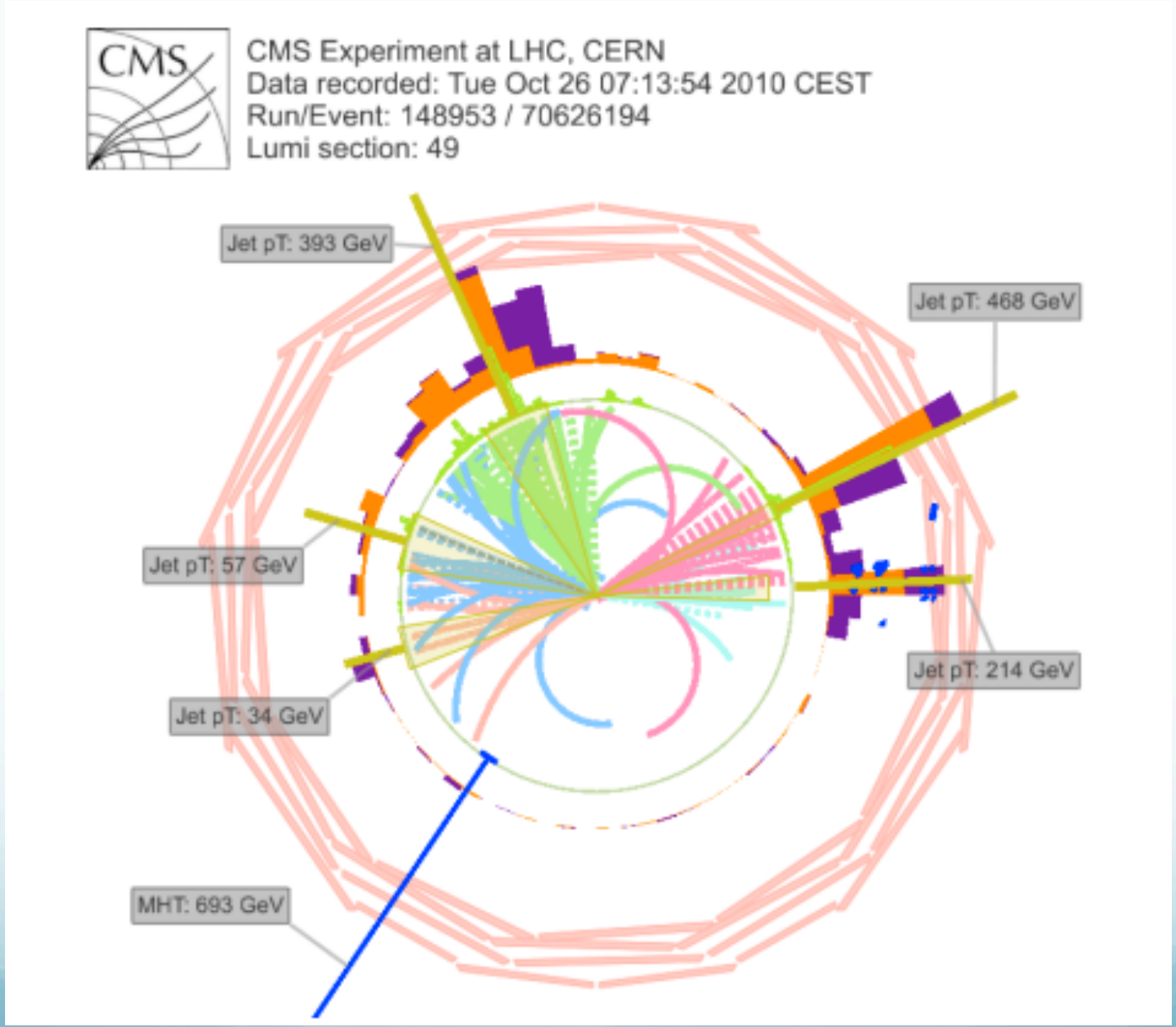
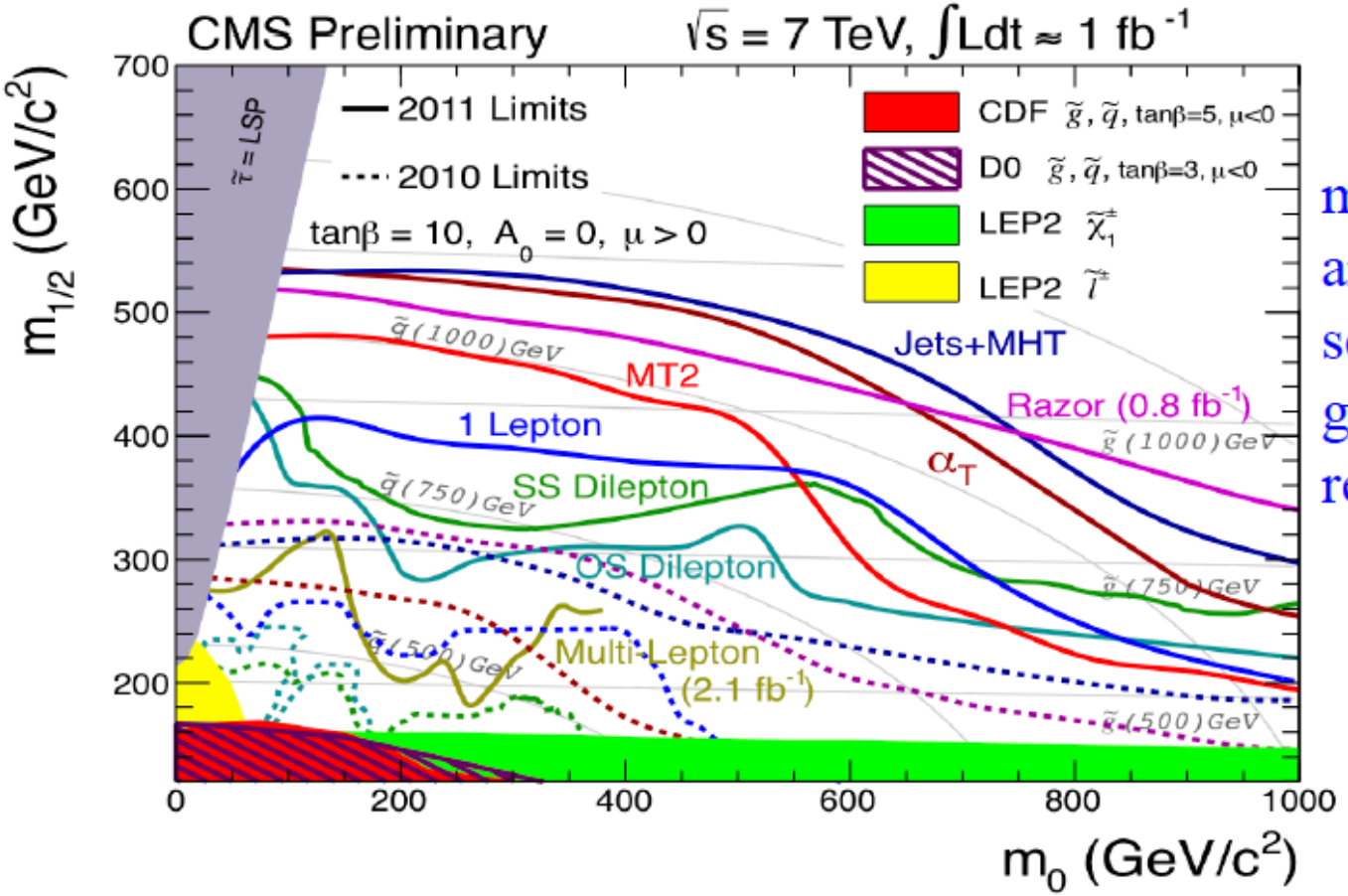
The Search for Dark Matter with Very Large Liquid Noble Gas Detectors

David B. Cline
Astroparticle Physics, UCLA

1. Introduction: Brief history of LNG Detectors
2. XENON 1T
3. MAX/DarkSide
4. LZ
5. PANDA X
6. DARWIN
7. Summary


CMS
CMS Experiment at LHC, CERN
Data recorded: Tue Oct 26 07:13:54 2010 CEST
Run/Event: 148953 / 70626194
Lumi section: 49
Jet pT: 393 GeV
Jet pT: 468 GeV
Jet pT: 57 GeV
Jet pT: 214 GeV
Jet pT: 34 GeV
MHT: 693 GeV

CMS: some SUSY searches results in CMSSM (m_0,$m_{1/2}$) plane



m_0 and $m_{1/2}$ are universal scalar and gaugino masses, respectively

- 2010 vs 2011 exclusion contours, the area below the curves is excluded

New theoretical results from M_{h0} 125 GeV

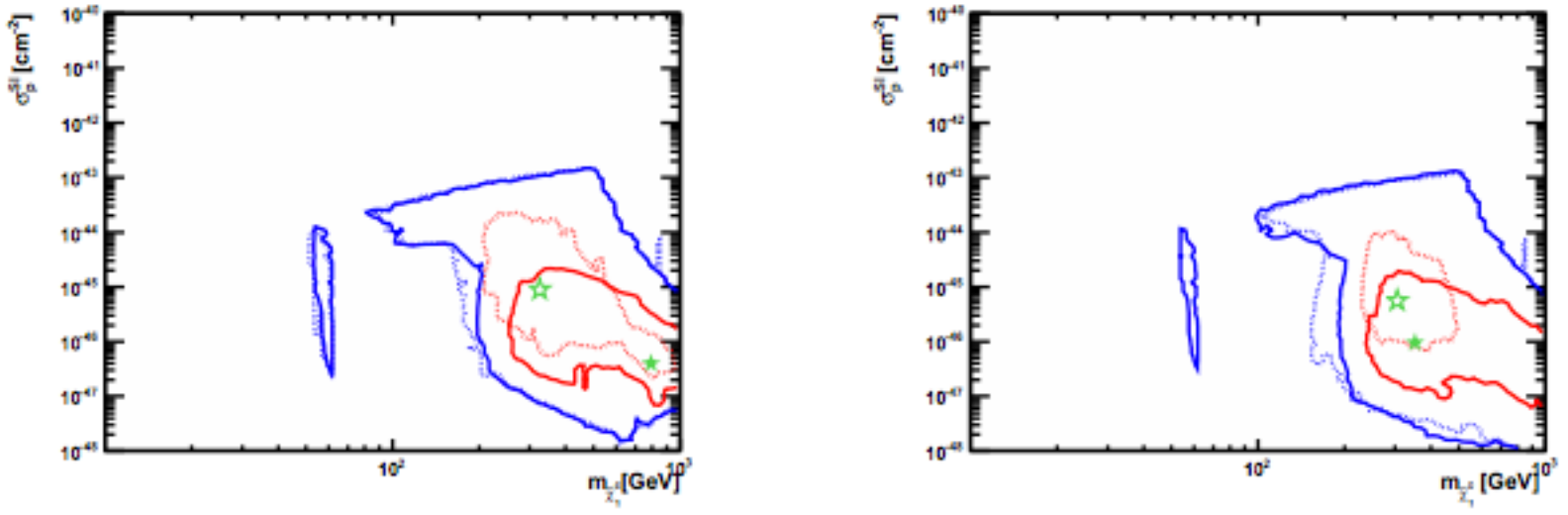
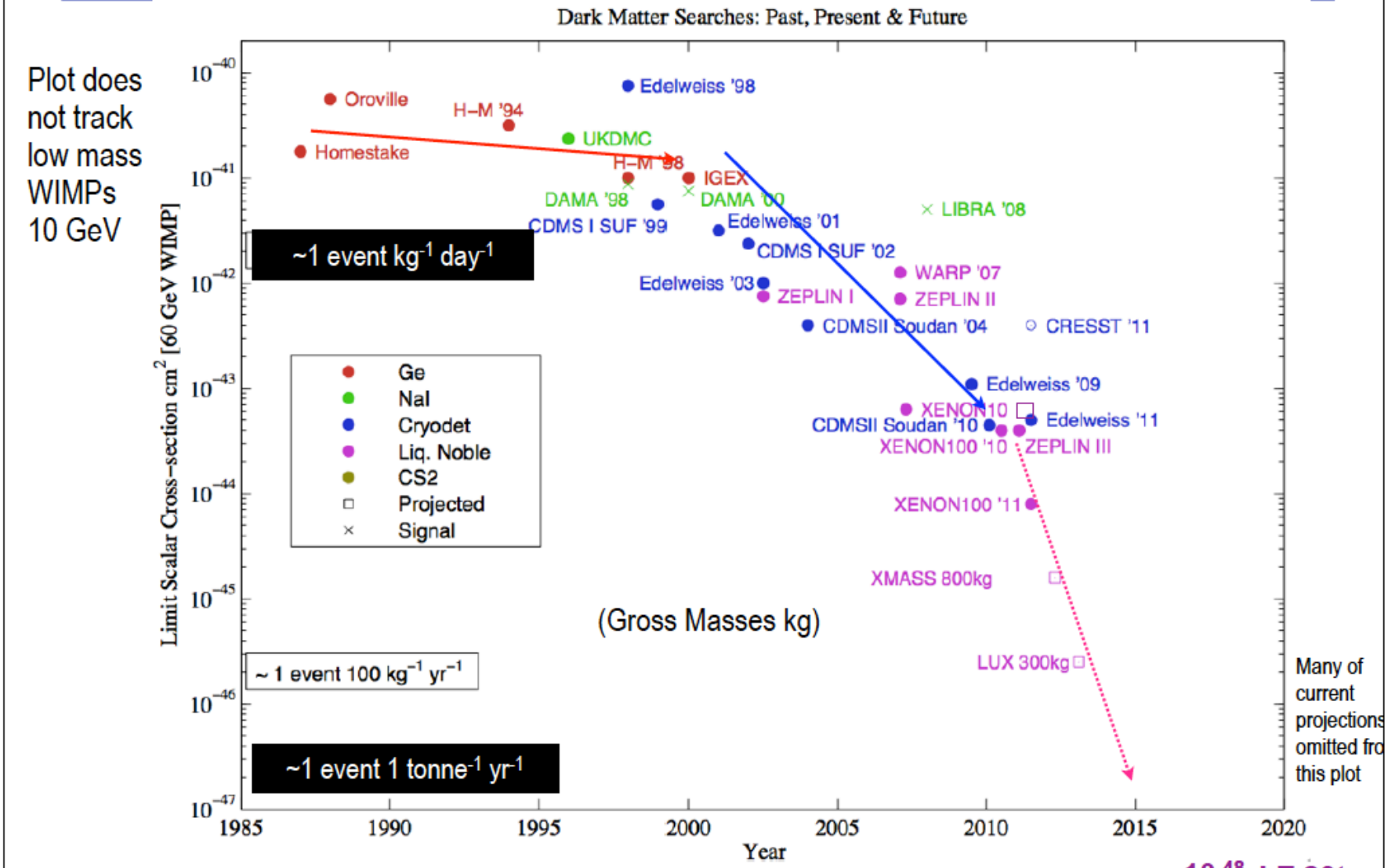


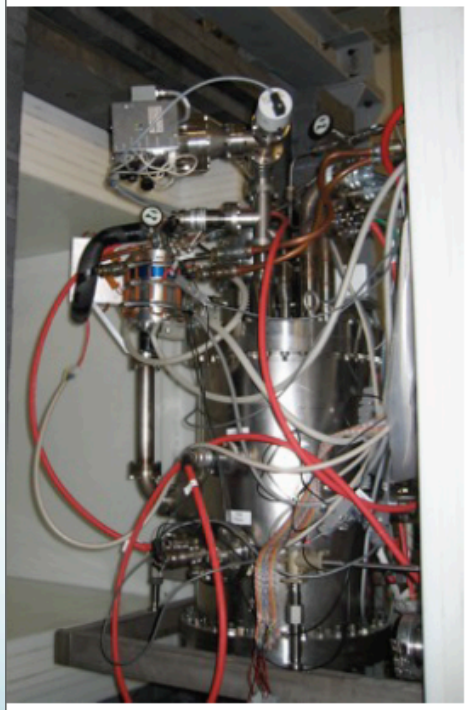
Figure 8. *The $(m_{\tilde{\chi}_1^0}, \sigma_p^{SI})$ planes in the CMSSM (left) and the NUHM1 (right), for $M_h \simeq 125$ GeV. The notations and significations of the contours are the same as in Fig. 2.*

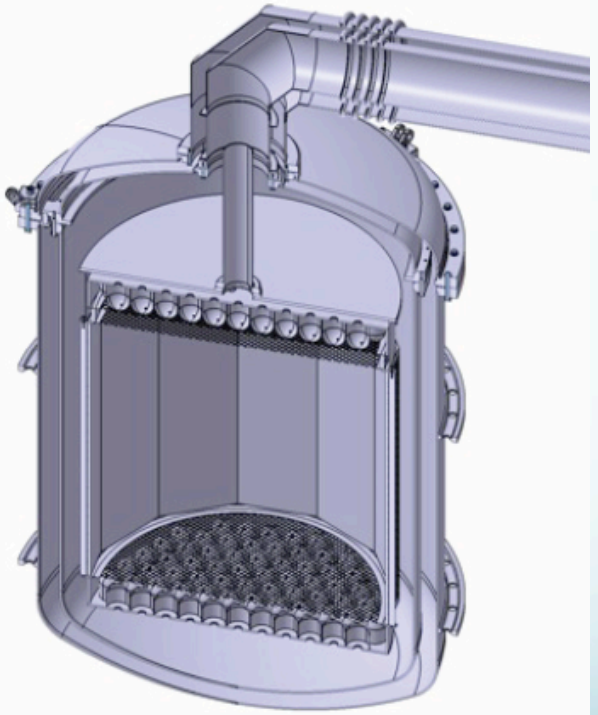
DM Direct Search Progress Over Time (2012)



The XENON Dark Matter Program

past (2005 - 2007)	current (2007-2012)	future (2012-2017)





XENON10

Achieved (2007) σ_{SI}*=8.8 x10*$^{-44}$ *cm*^{2}

XENON100

Achieved (2011) σ_{SI}*=7.0 x10*$^{-45}$ *cm*^{2}

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

XENON1T

Projected (2017) $\sigma_{SI} \sim 10^{-47}$ cm^2

The XENON COLLABORATION

COLUMBIA

RICE

UCLA

PURDUE

ZURICH

COIMBRA

LNGS

INFN

MPIK

BOLOGNA

SJTU

MUENSTER

SUBATECH

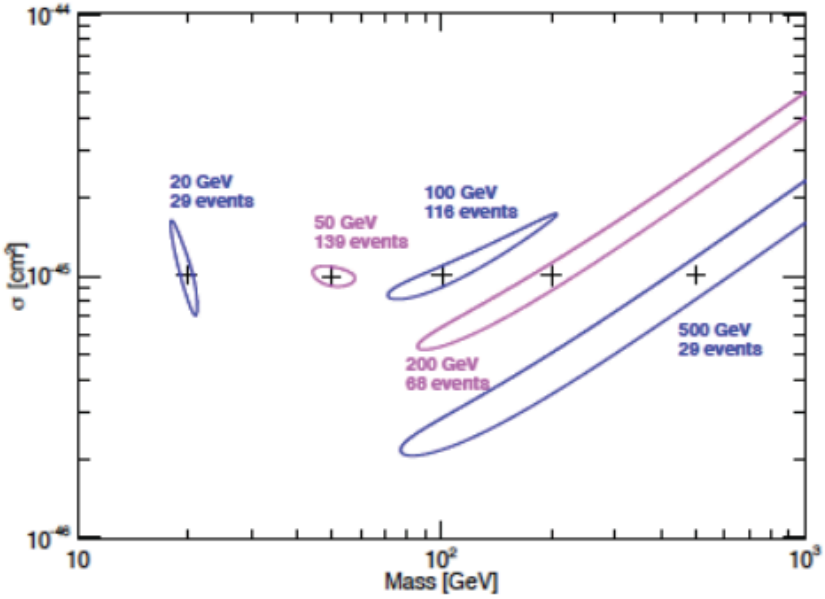
NIKHEF

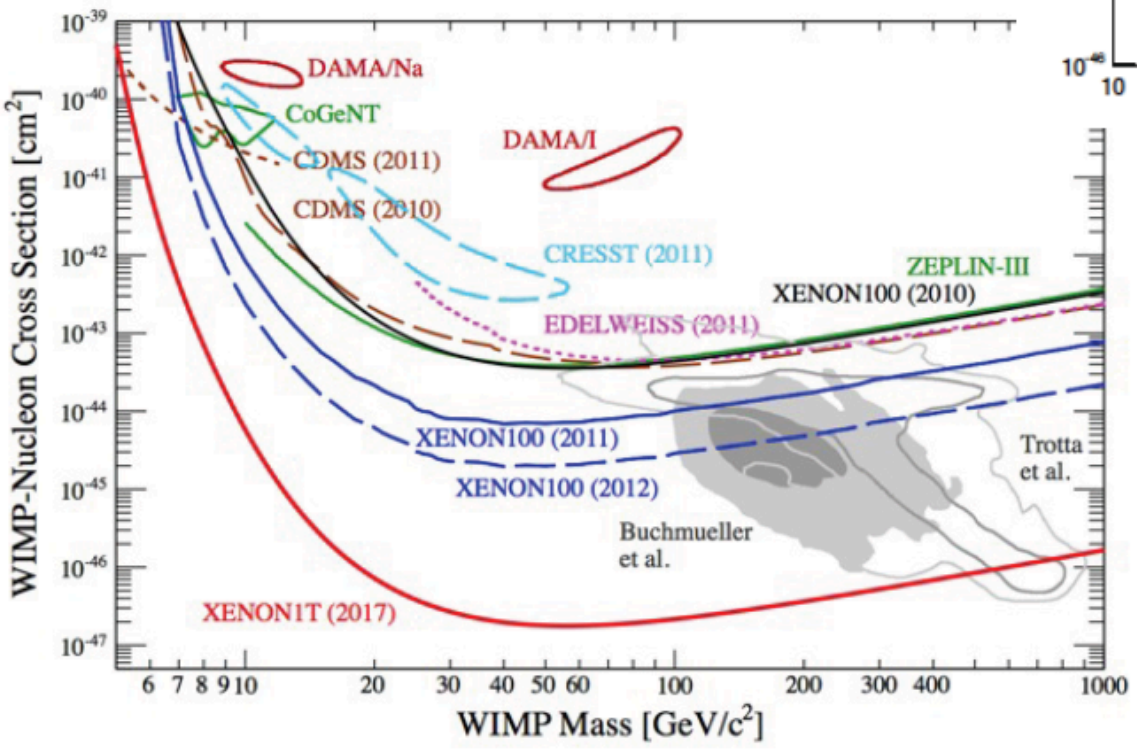
WEIZMANN

The XENON1T Science Case

a statistically significant WIMP signal after 2.2 ton-years of data

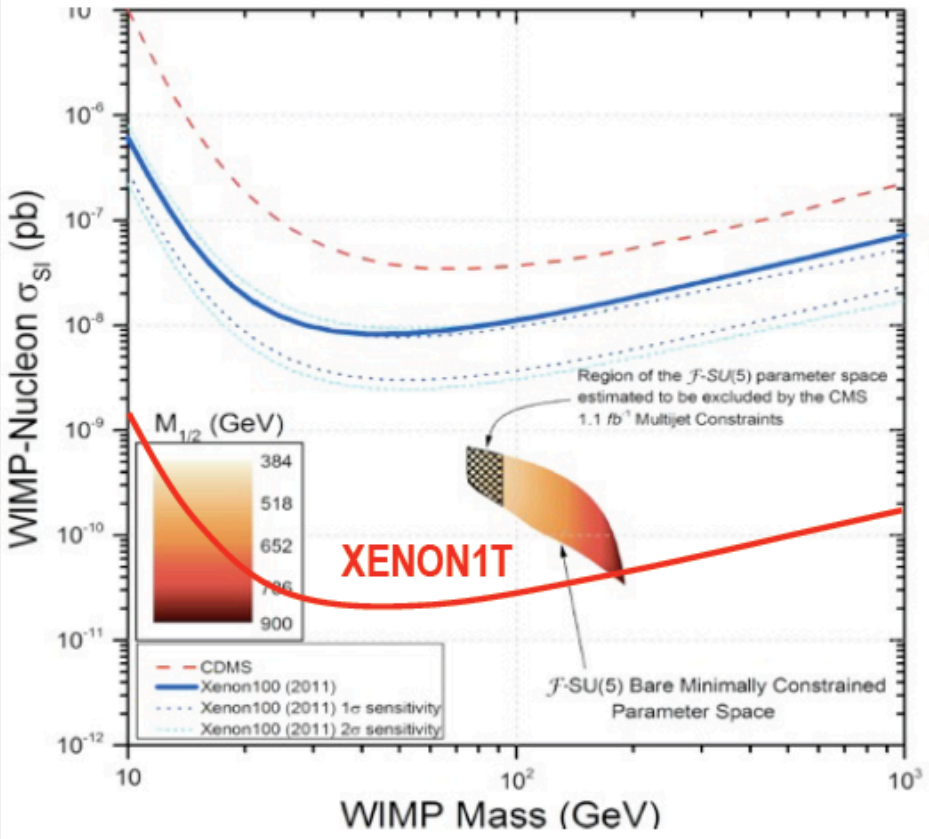
~100 events if cross section at 10^{-45} cm^2



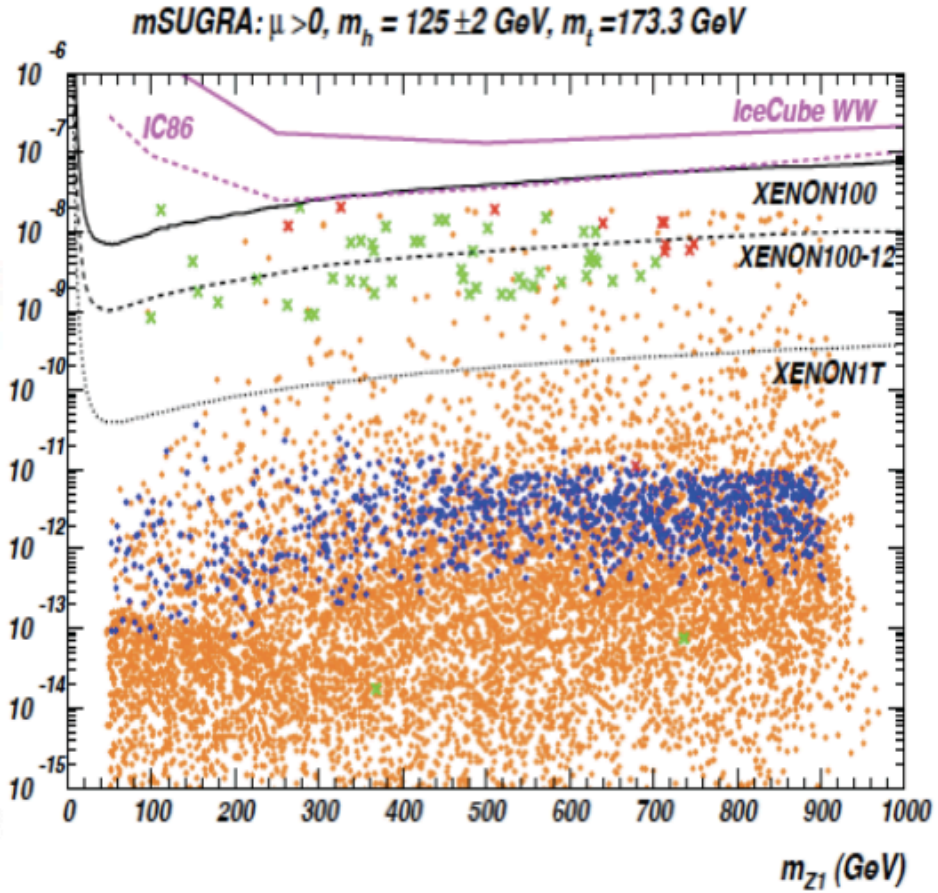


two orders of magnitude improvement in SI cross-section sensitivity w/r to XENON100

The XENON1T Science Case



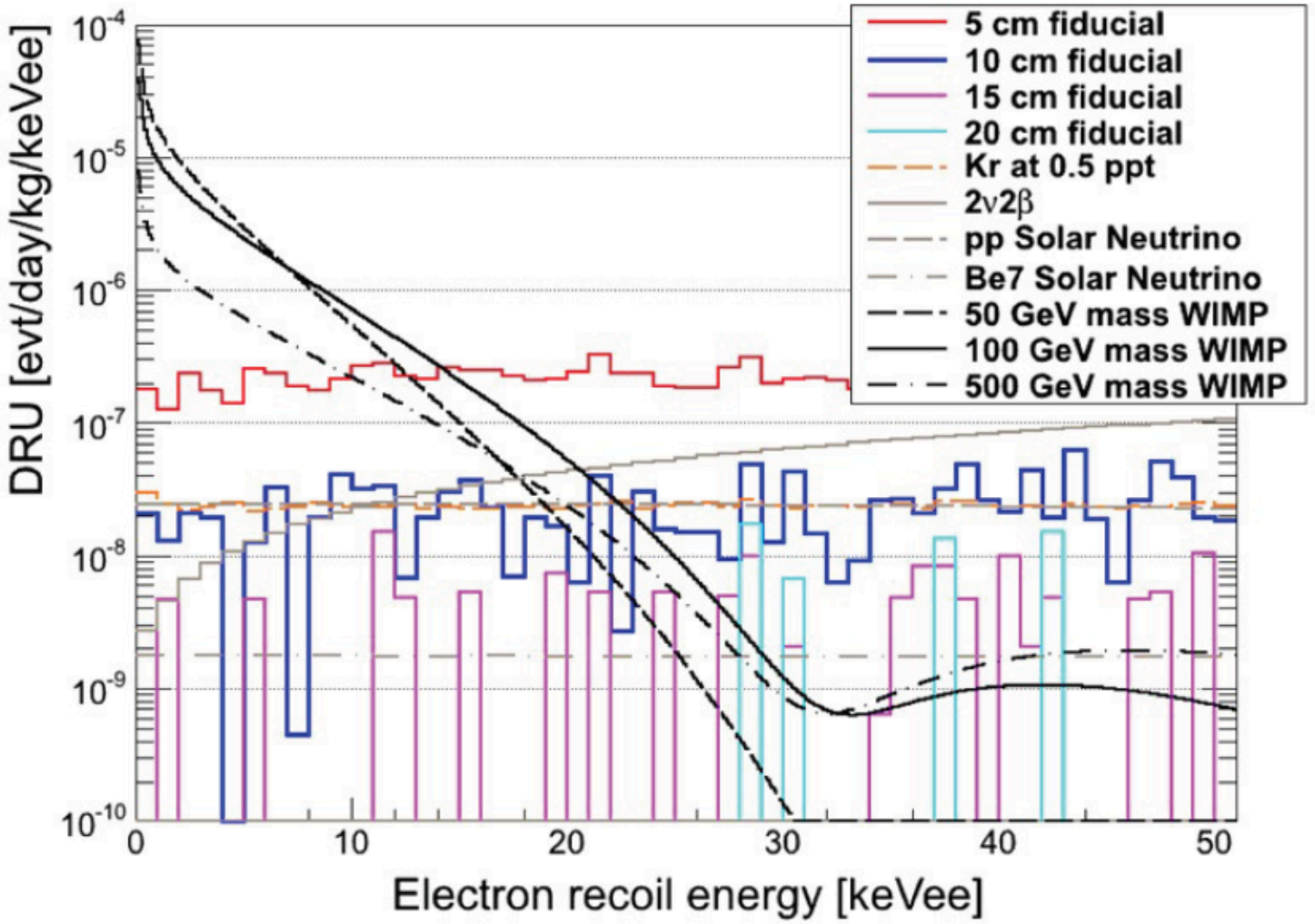
F-SU(5) Supersymmetry
Dimitri Nanopoulos



Neutralino dark matter in mSUGRA/CMSSM with a 125 GeV light Higgs scalar

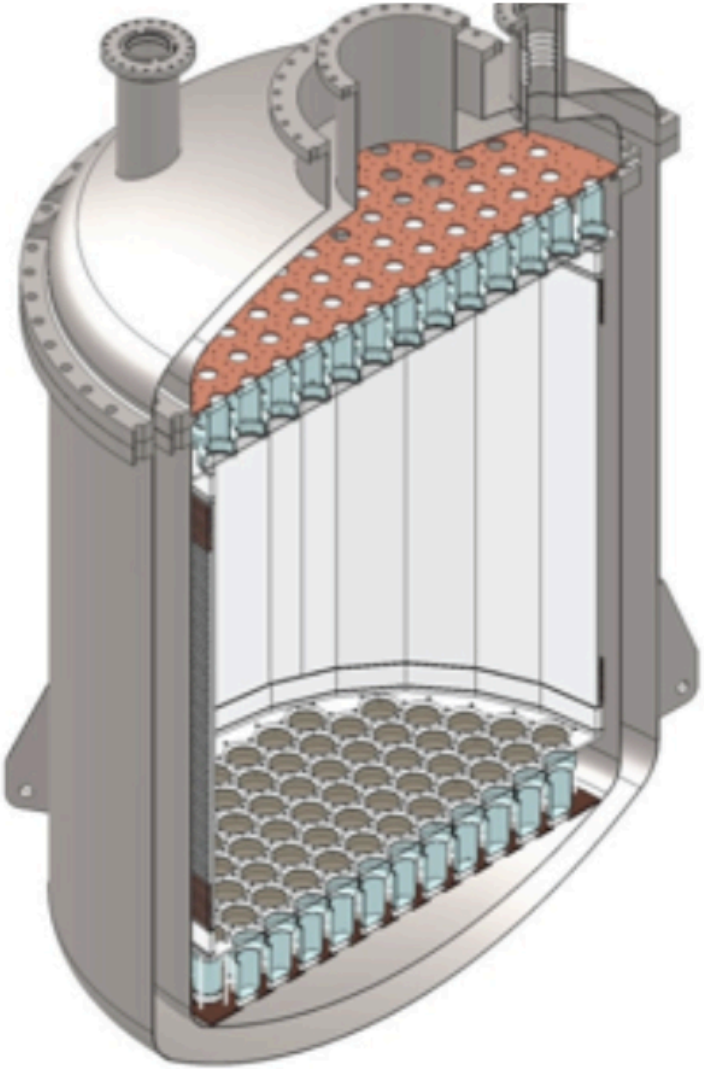
Howard Baer[a], Vernon Barger[b] and Azar Mustafayev[c]

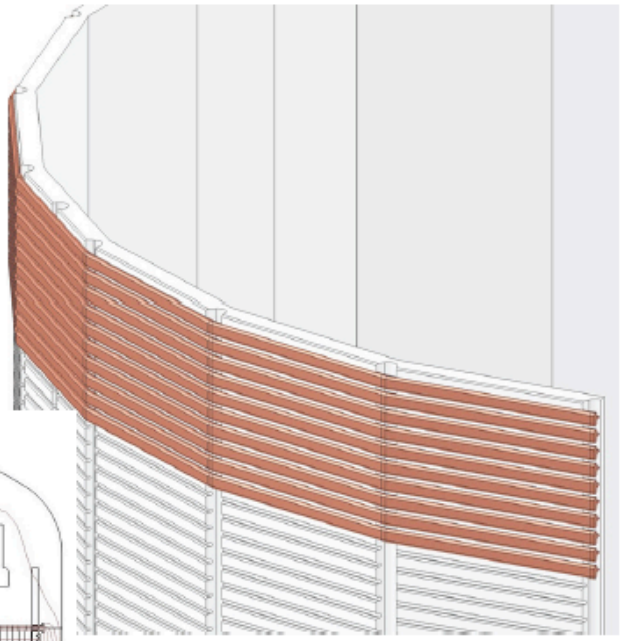
Expected Backgrounds in XENON1T

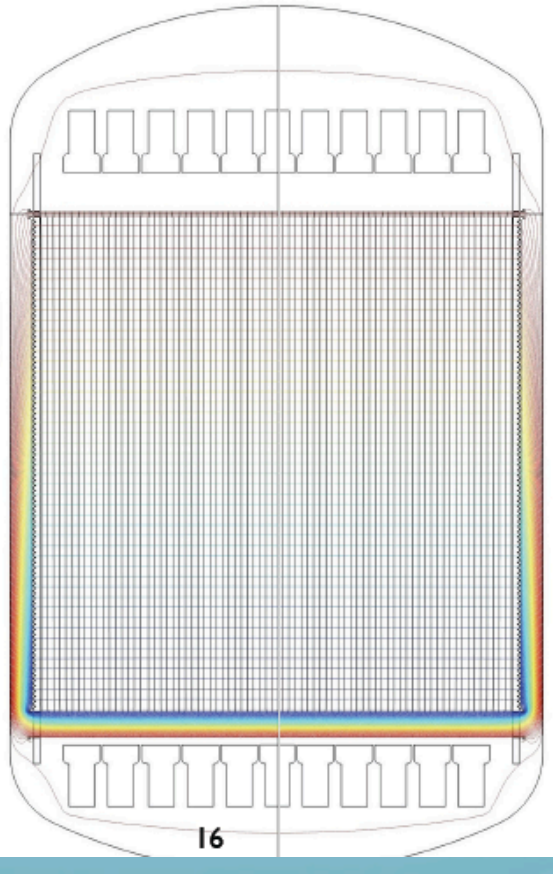


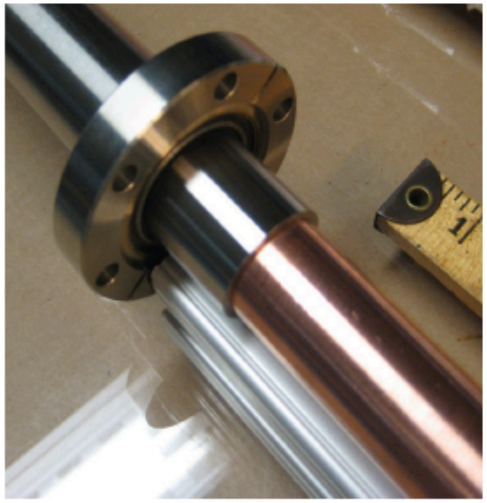
LNGS Underground Laboratory – Hall B

XENON1T TPC







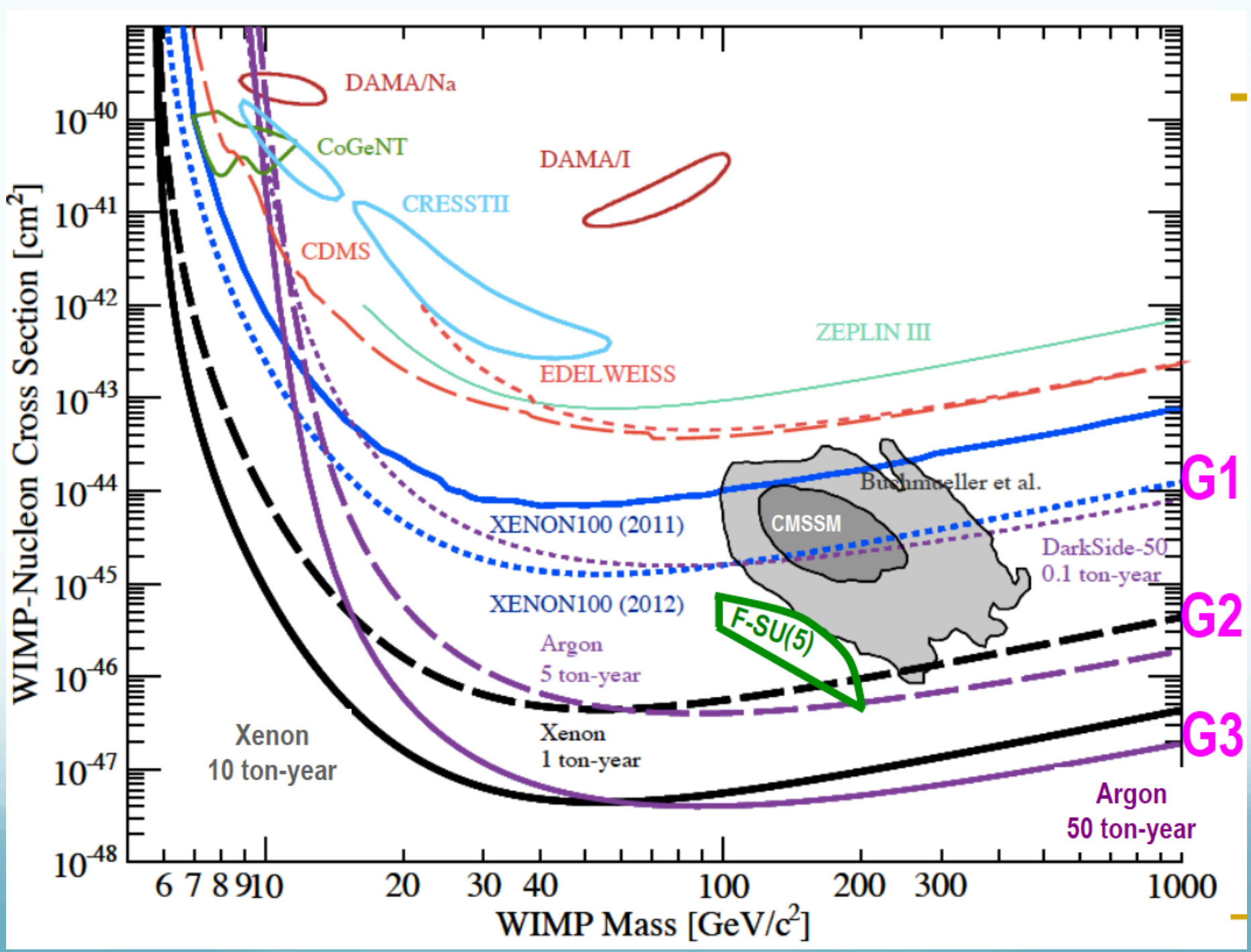


Columbia-UCLA-Rice-Zurich

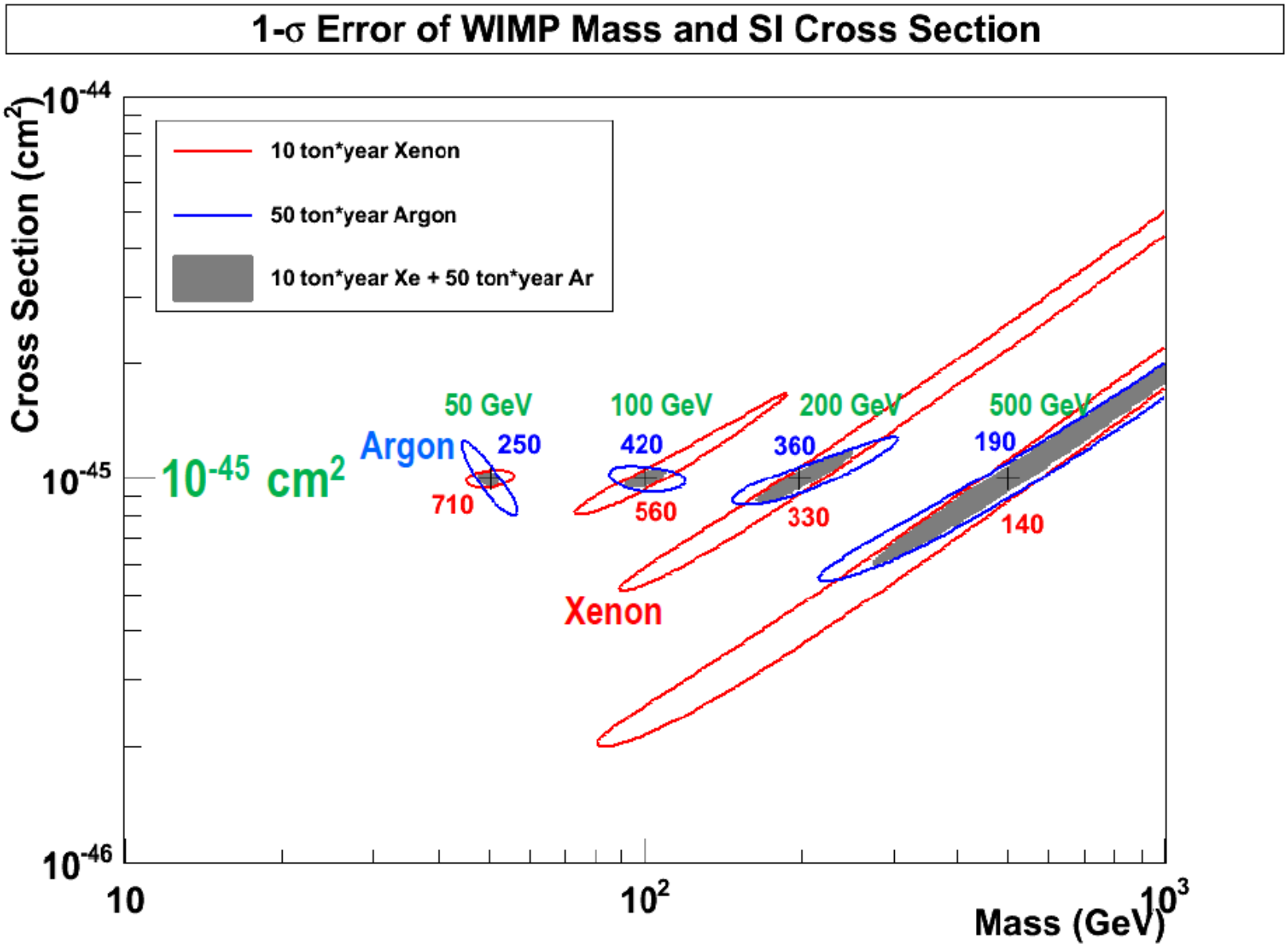
MAX - Multi-ton Argon & Xenon

MAX Collaboration = DarkSide + XENON

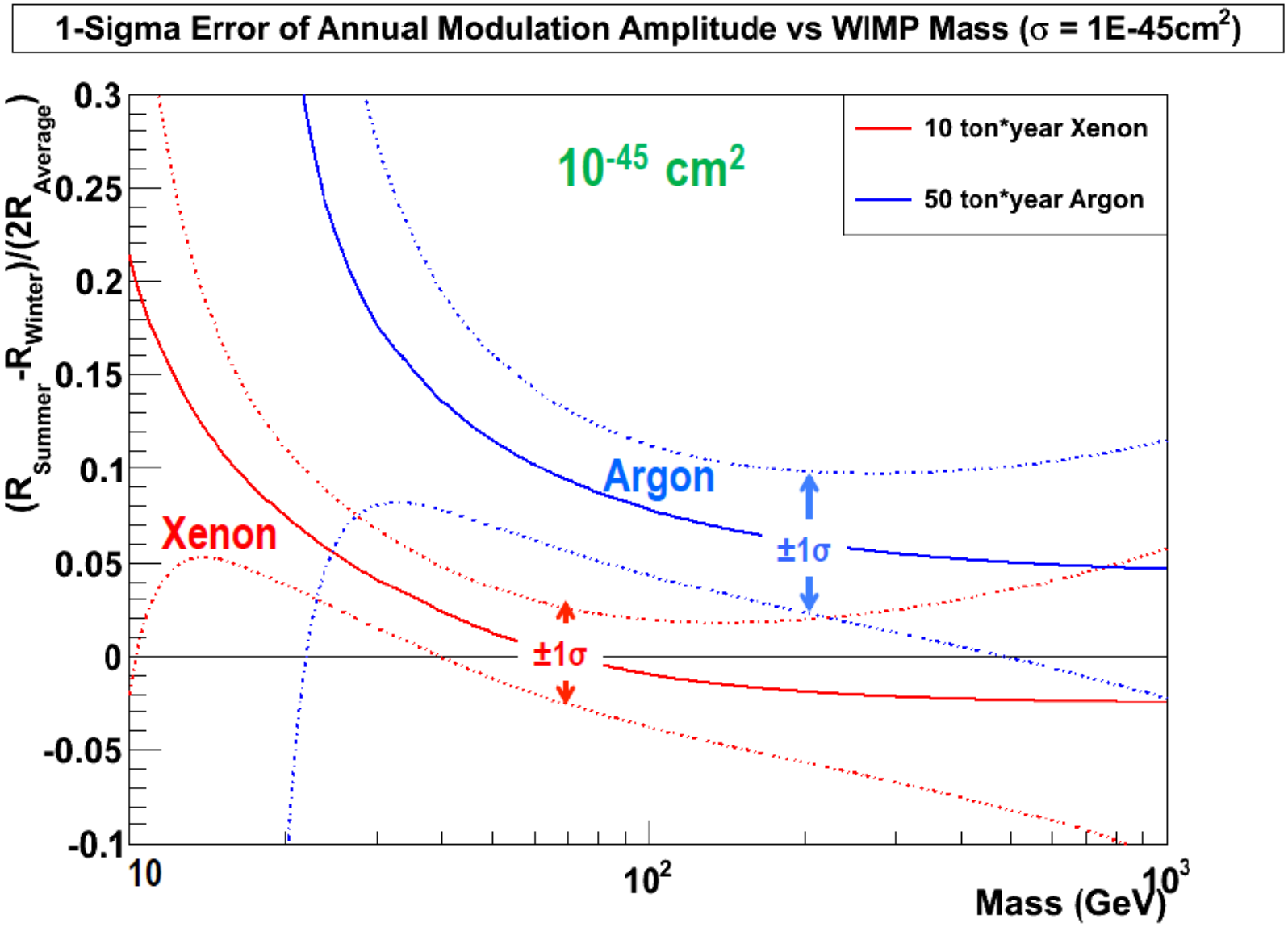
**UMass Amherst, Arizona State University,
Augustana College, Black Hills State University,
Coimbra University, Columbia University, Fermilab,
University of Houston, INAF, LNG, MIT, University of Münster,
University of Notre Dame, Princeton University, Rice University,
Temple University, UCLA, University of Virginia,
University of Zürich**


DAMA/Na
CoGeNT
DAMA/I
CRESSTII
CDMS
ZEPLIN III
EDELWEISS
Buchmueller et al.
CMSSM
XENON100 (2011)
DarkSide-50
0.1 ton-year
XENON100 (2012)
F-SU(5)
Argon
5 ton-year
Xenon
10 ton-year
Xenon
1 ton-year
Argon
50 ton-year
G1
G2
G3
WIMP-Nucleon Cross Section [cm^2]
WIMP Mass [GeV/c^2]
10^{-40}
10^{-41}
10^{-42}
10^{-43}
10^{-44}
10^{-45}
10^{-46}
10^{-47}
10^{-48}
6 7 8 9 10 20 30 40 100 200 300 1000

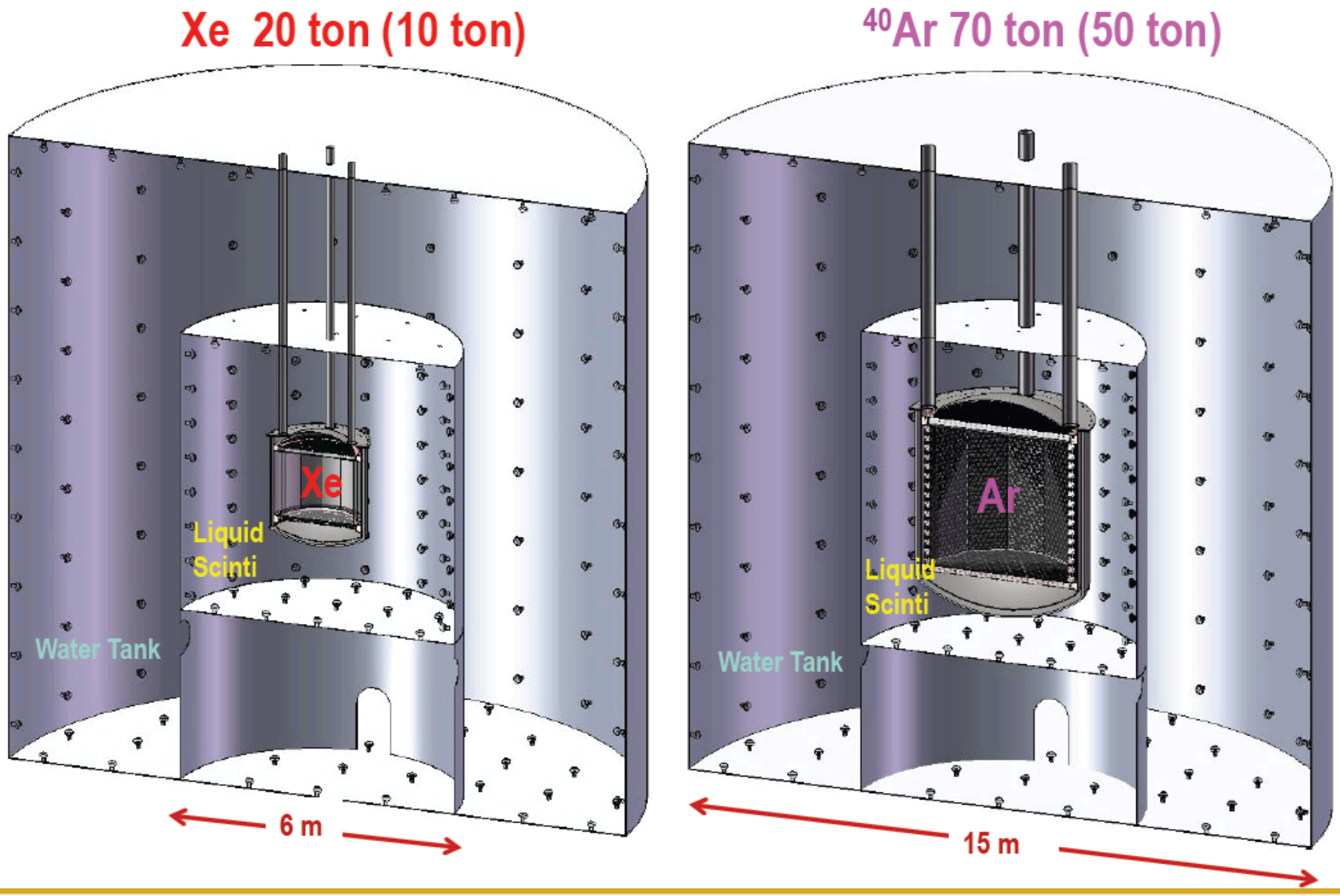
1-σ Error of WIMP Mass vs SI Cross Section (10 ton*year Xe and 50 ton*year Ar)



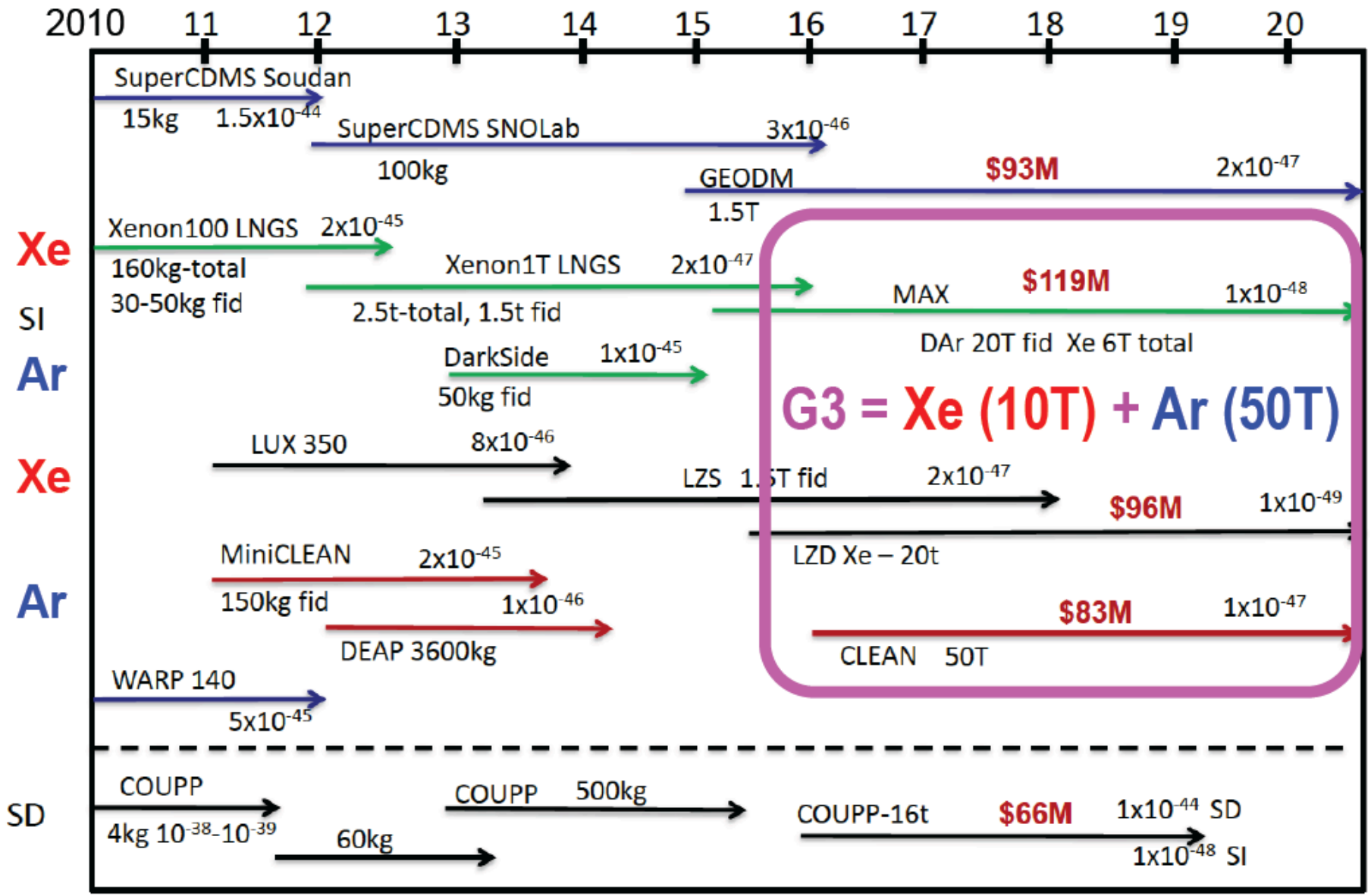
±1 σ Error of Annual Modulation Amplitude vs WIMP Mass (10 ton*year Xe and 50 ton*year Ar, Cross Section = 10^{-45}cm^2)

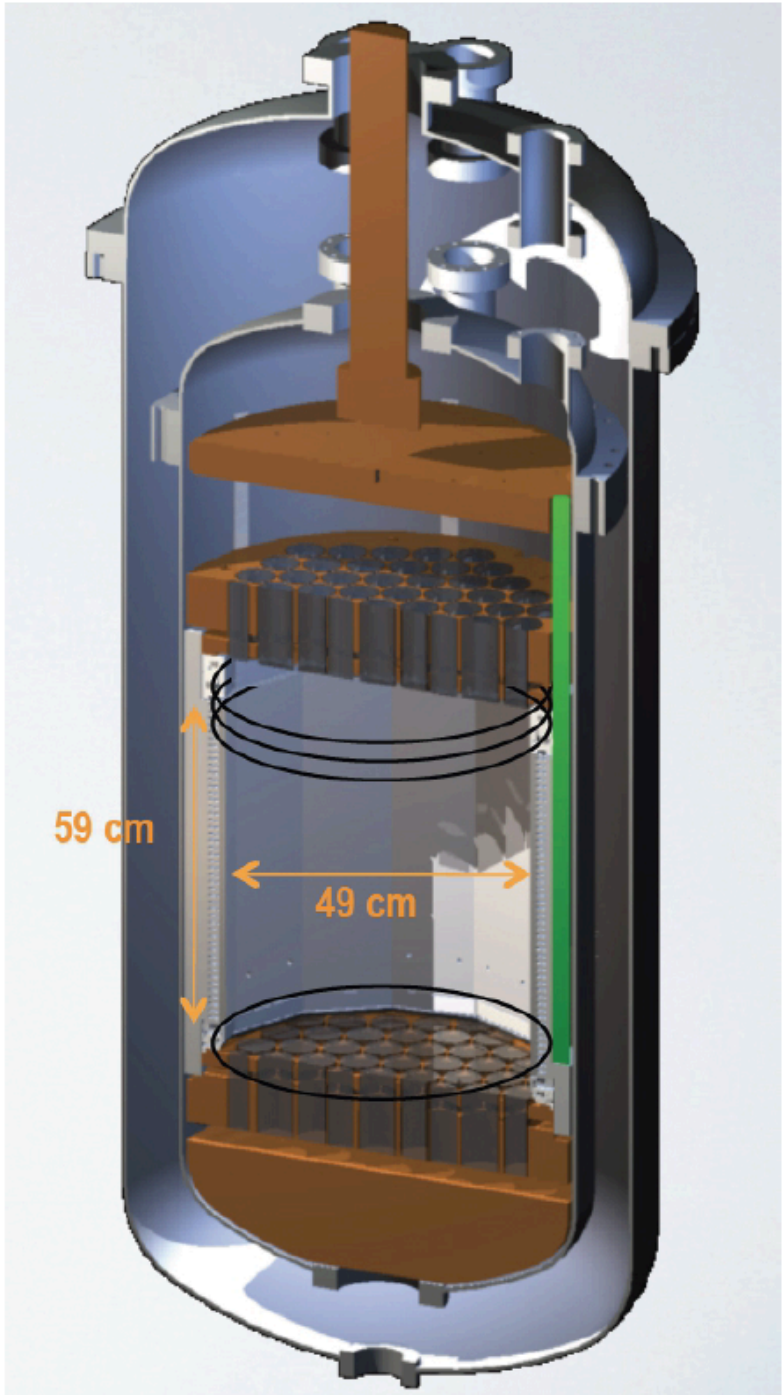


MAX G3 Detector (at DUSEL)

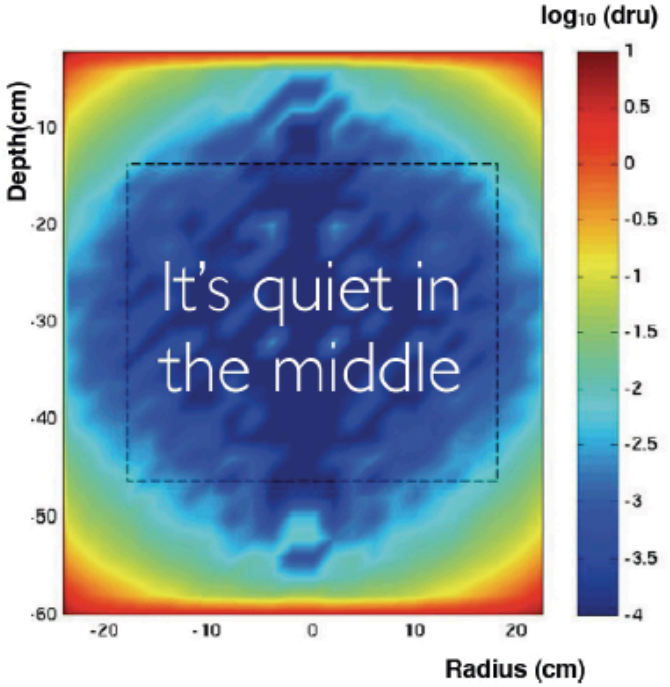


US Dark Matter Programs

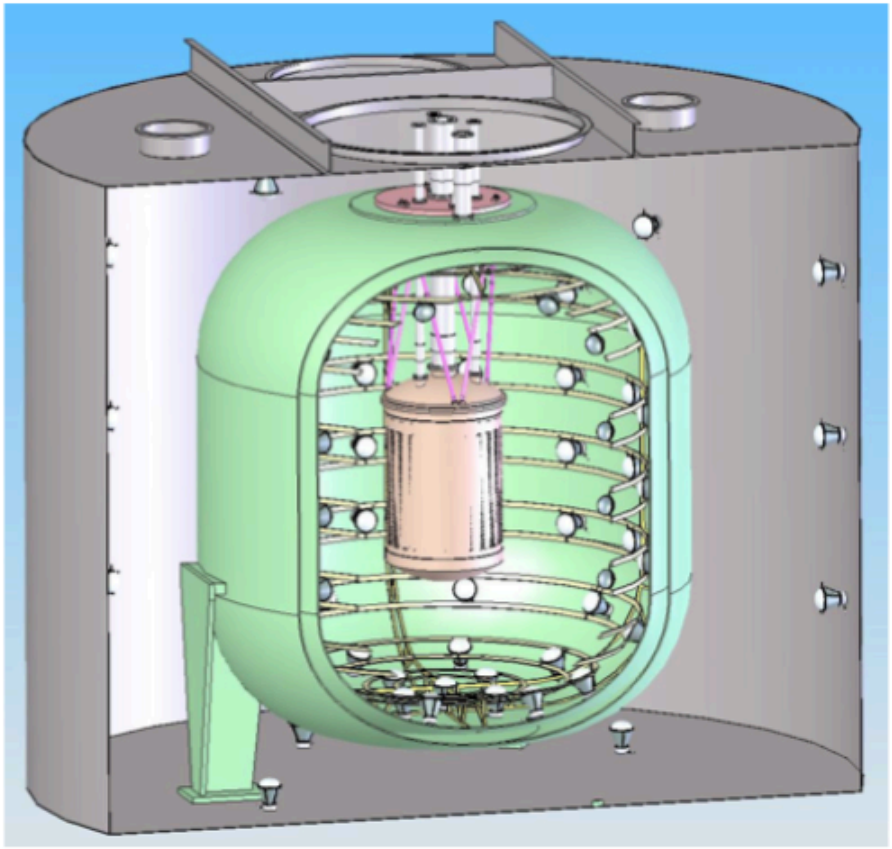




LUX



350kg total LXe




Thermosyphon
dewar
Scintillator
cell

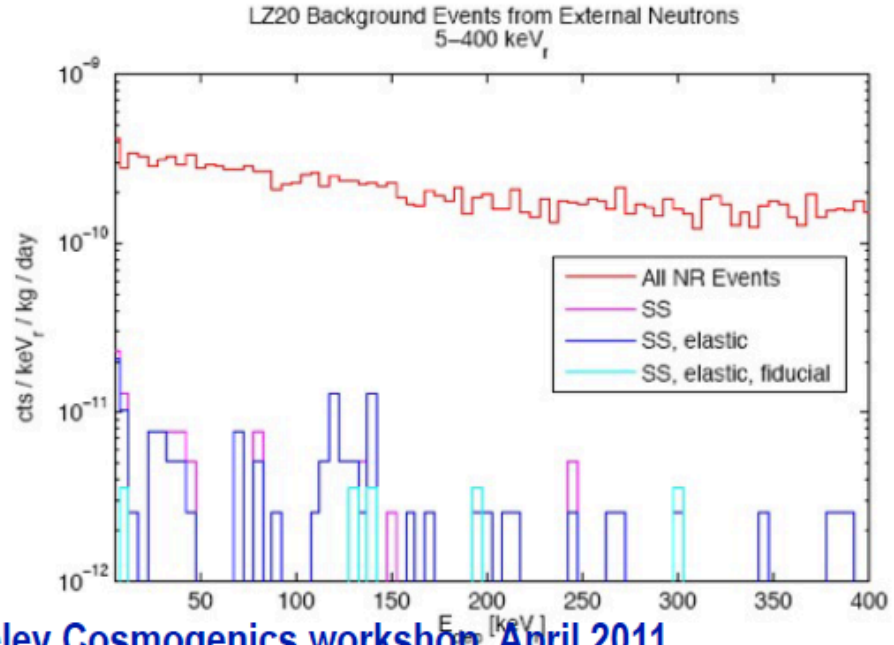
Monte-Carlo Efforts

- **LZ Shielding**
  - Muon-induced neutrons production, propagation through 12 m diameter water shield
    - NR event rate in LZ 20 tonne detector ~0.3 ndrur in [5 – 25 keVr], before any cuts
    - Fiducial, single scatter, EM component cuts, allow two more orders of magnitude rejection
  - Effect of 1 m thick liquid scintillator active veto
    - With threshold at 100 keV, rejection of external neutrons >99.3%
  - Effect of Ti and steel vessels thickness

→ Safe for LZS or LZD by several OoM

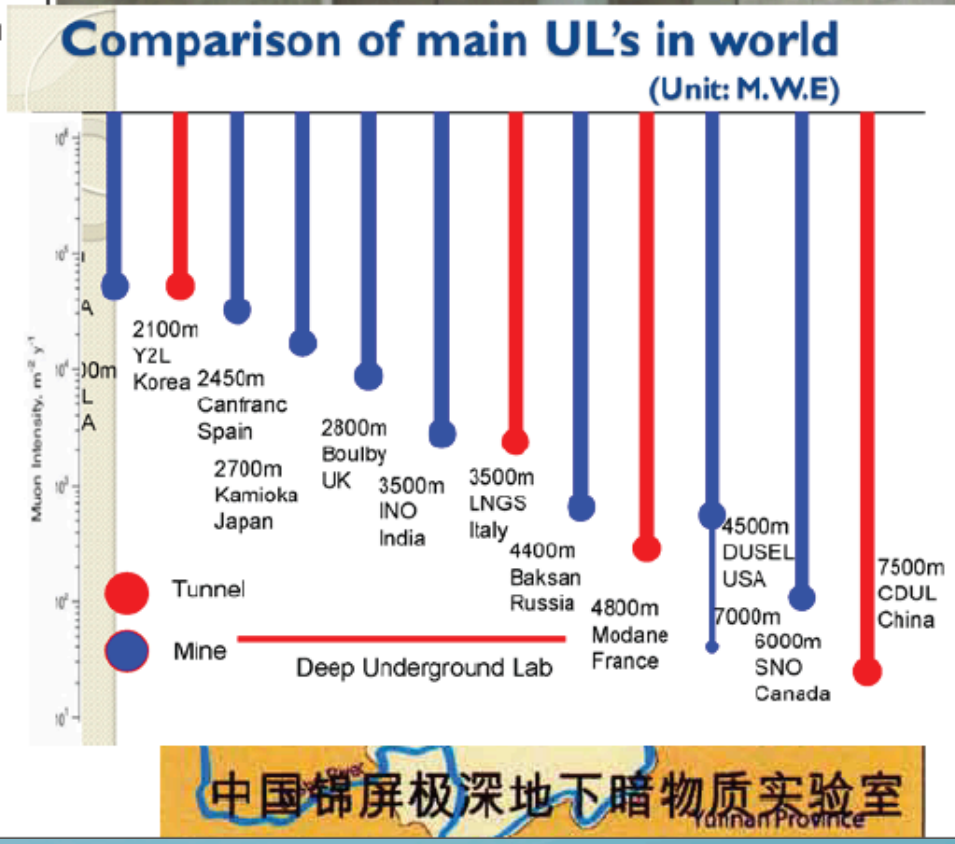
- **LUX internals screening and background modeling program**
  - Extensive cataloguing of parts/materials
  - Identify hot spots for similar designs
  - Built-in modeling tool/map for quick estimate

- **Cross-check of MC parameters with the international community**
  - One LUX/LZ member on advisory panel of Berkeley Cosmogenics workshop, April 2011

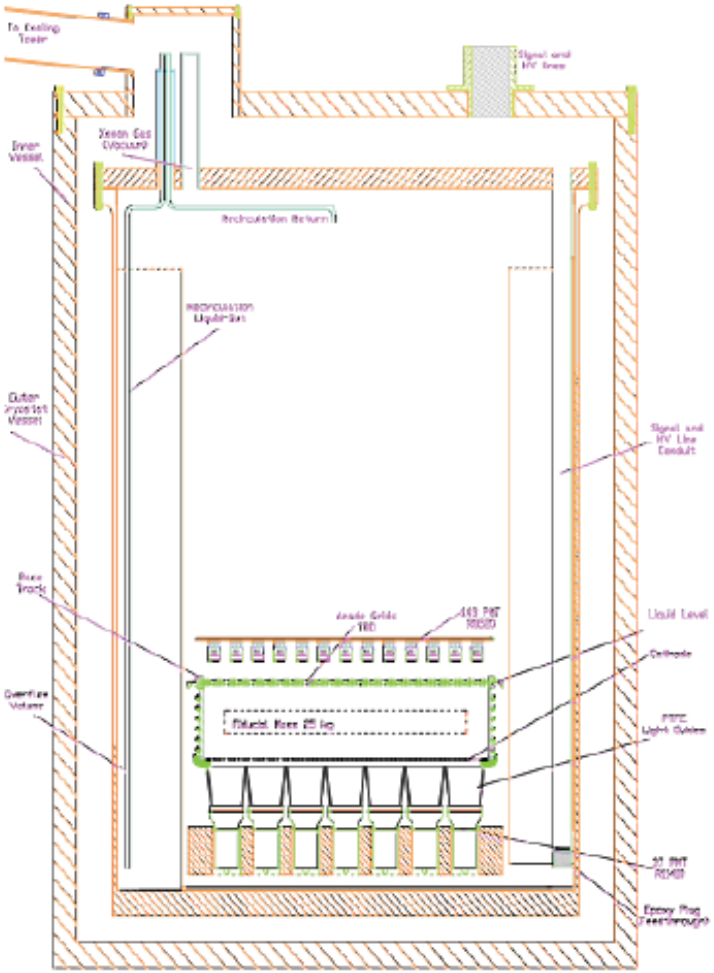


The China Jinping Underground Laboratory

- Hydropower tunnels under construction by Ertan Power Co. in Sichuan Province, Southern China.
- Underground lab constructed (Tsinghua University and Ertan Power Co.) in 2009. Rapid progress since.
- Deepest underground lab in operation 7500 mwe (50 $\mu/m^2/yr$)
  - < 0.002 n-induced bkg events/yr (Stage Ia)
  - μ veto shield unnecessary
- "Marble" mountain (relatively radio-pure)
  - Water shield not needed
- Cavern floor and walls coated w/Rn blocking paint.
- Middle of 18 km tunnel (easy access)

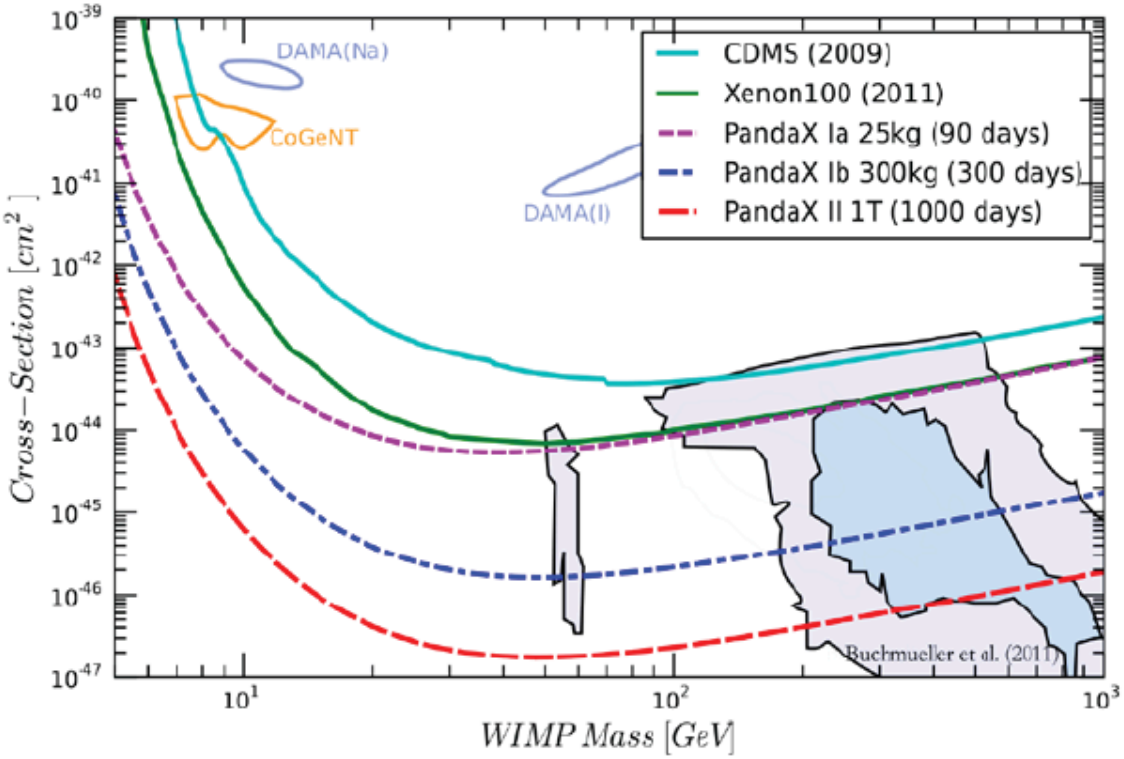


PandaX: A Staged Approach



- Infrastructure designed to ultimately accommodate ton-scale detector.
- Three stages:
  - Stage Ia: 25 kg fiducial (120 kg sensitive mass)
  - Stage Ib: 300 kg fiducial (500 kg sensitive mass)
  - Stage II: Ton-scale sensitive target
- Stage II will require larger inner vessel.

Expected Sensitivity



PandaX Stage Ia:

- light yield: 4 -5 pe/keV$_{ee}$ (w/ field)
- S1 energy range: 3-30 pe
- exposure: 25 kg x 90 days
- NR acceptance: 0.35
- estimated bkg events: 0.3

PandaX Stage Ib:

- light yield: 2.5 pe/keV$_{ee}$ (w/ field)
- S1 energy range: 3-30 pe
- exposure: 300 kg x 300 days
- NR acceptance: 0.35
- estimated bkg events: 0.5

PandaX Stage II:

- light yield: 2.5 pe/keV$_{ee}$ (w/ field)
- S1 energy range: 3-30 pe
- exposure: 1000 kg x 1000 days
- NR acceptance: 0.35
- estimated bkg events: < 1.2 (Kr dominated)

DARWIN

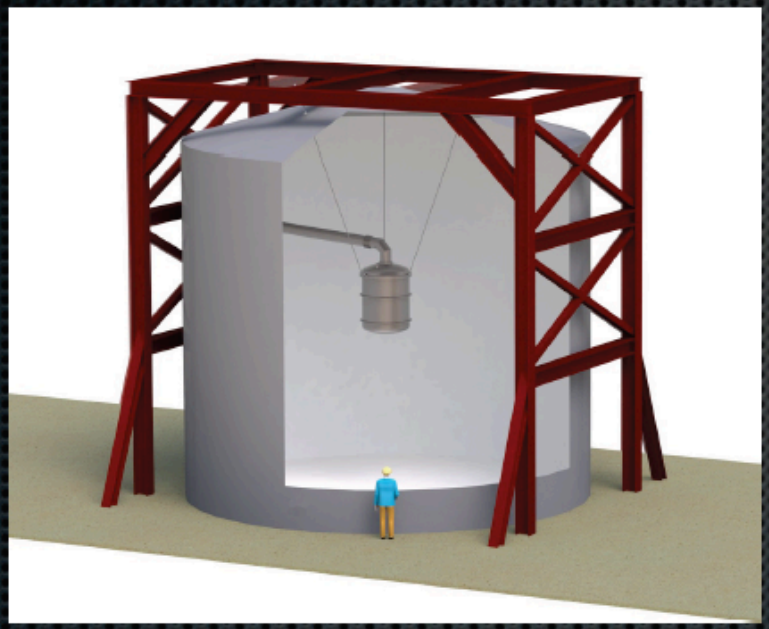
The Consortium

- R&D and design study for a next-generation noble liquid facility in Europe

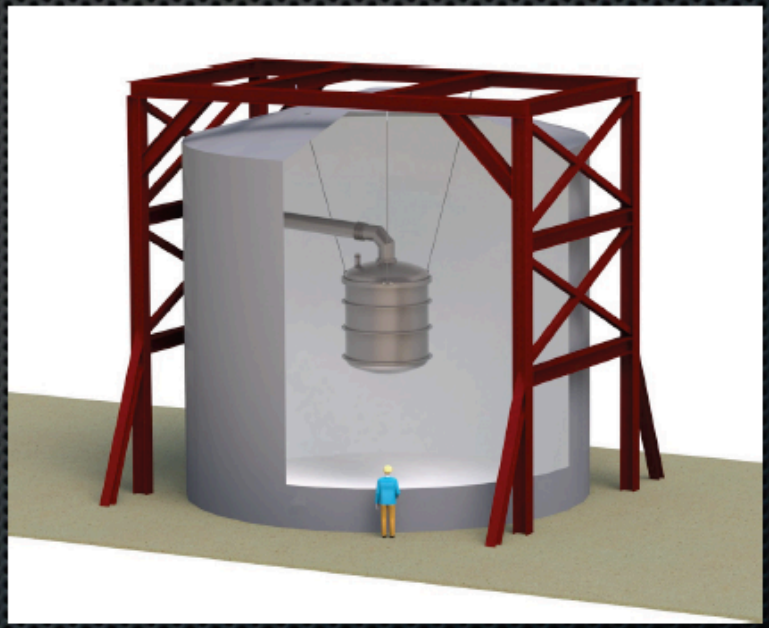
- **A total of 25 groups from ArDM, DarkSide, WARP, XENON**
- **Europe: UZH, INFN, ETHZ, Subatech, Mainz, MPIK, Münster, Nikhef, KIT, TU Dresden, Israel: WIS, USA: Columbia, Princeton, UCLA, Arizona SU**

DARWIN

Comparison: XENON1T and DARWIN



XENON1T



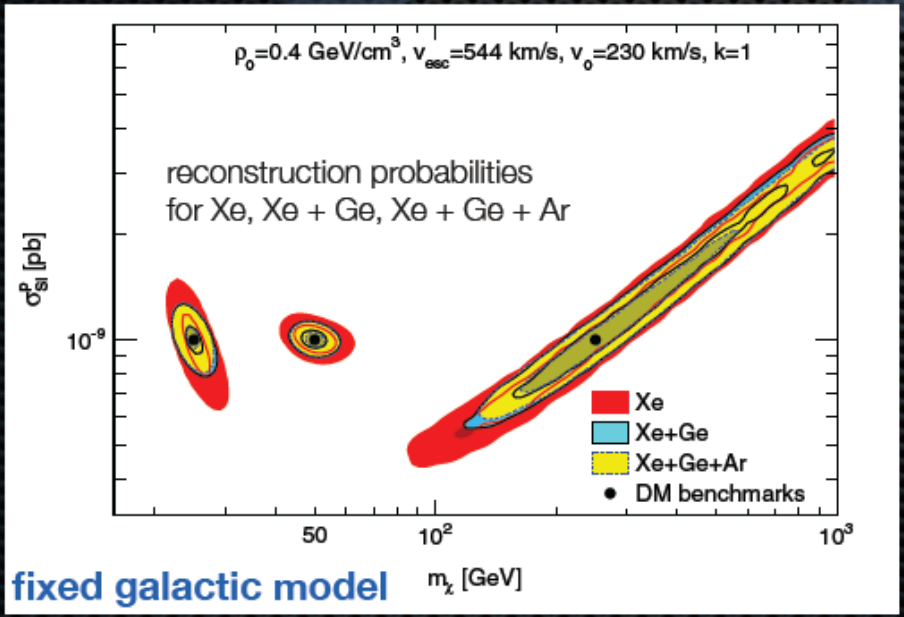
DARWIN
(LXe part, 20 tons in total)

DARWIN

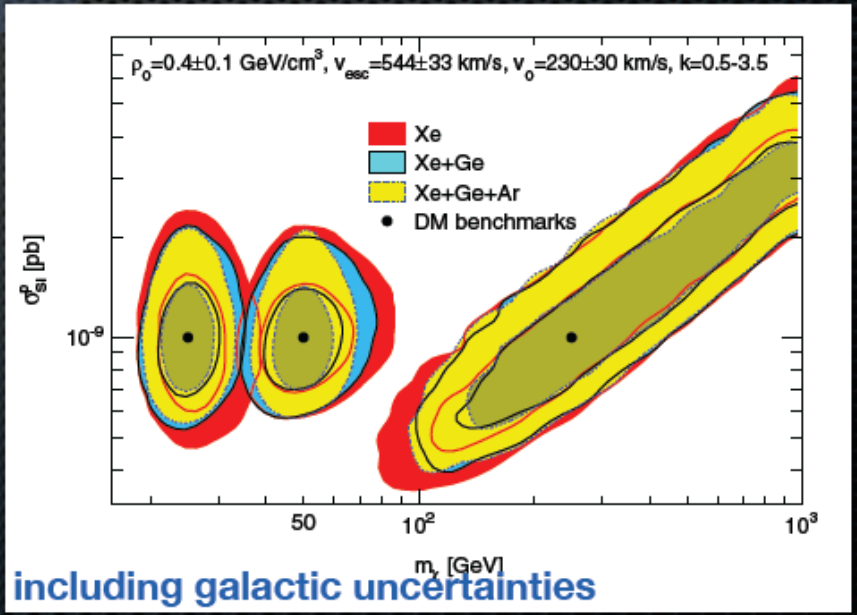
Physics Motivation, II

- Reconstructing WIMP properties:
- *different targets are sensitive to different directions in the m_χ- σ_{SI} plane*

target	ϵ [ton×yr]	η_{cut}	A_{NR}	ϵ_{eff}	[ton×yr]	E_{thr} [keV]	$\sigma(E)$ [keV]	background events/ϵ_{eff}
Xe	5.0	0.8	0.5	2.00		10	Eq. (7)	< 1
Ge	3.0	0.8	0.9	2.16		10	Eq. (6)	< 1
Ar	10.0	0.8	0.8	6.40		30	Eq. (8)	< 1



fixed galactic model



including galactic uncertainties

Miguel Pato, Laura Baudis, Gianfranco Bertone, Roberto Ruiz de Austri, Louis E. Strigari and Roberto Trotta

Phys. Rev. D 83, 083505 (2011)

DArkSide Project

* Null background strategy for direct Dark Matter searches - looking for rare nuclear recoils induced by WIMPs in a specialized low background detector.

* Multi Step program @ LNGS foreseeing:
  - G1 experiment: DS-50 - 10^{-45} cm^2 GOAL
  - G2 experiment: DS-5k - 10^{-47} cm^2 GOAL
  - Plus few prototypes for technical measurements...

DS-10kg detector

Two-phase Argon TPC prototype used to test the effects on the two phase argon technology of new solutions pursued by DarkSide program.

10 kg active mass of Atmospheric Ar

7 PMT (3" Hamamatsu) at the top

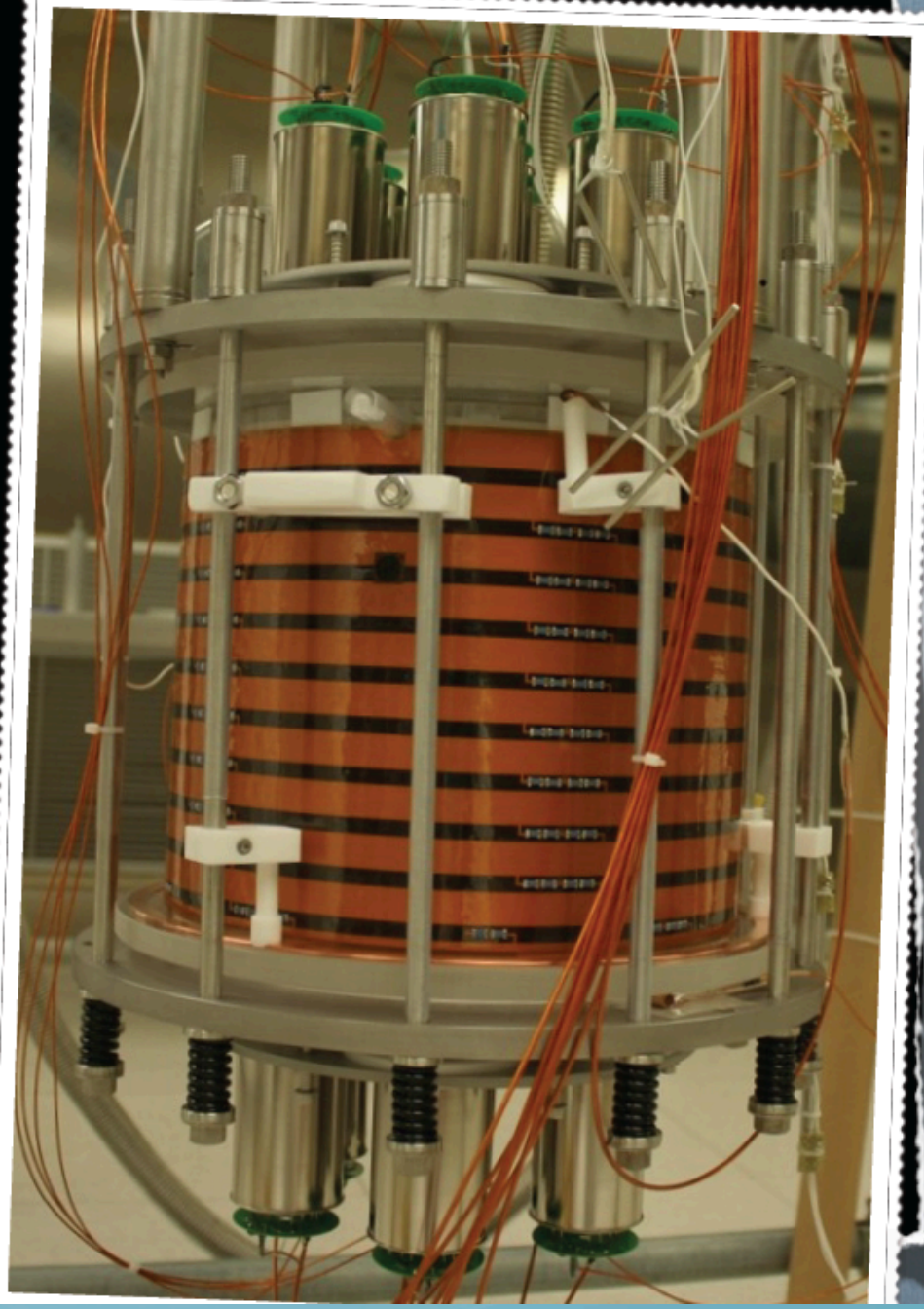
7 PMT (3" Hamamatsu) at the bottom

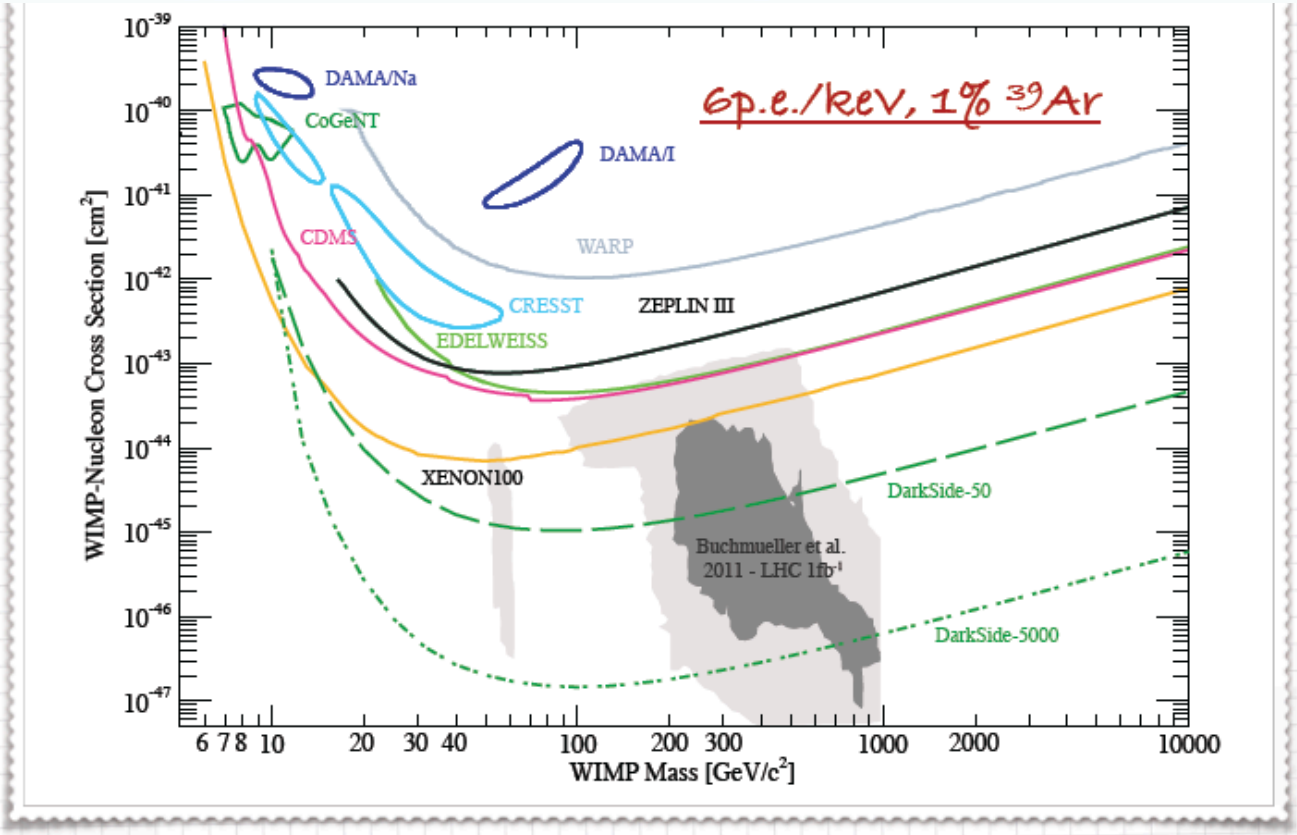
~20cm drift region

~2cm multiplication region

ITO layers for anode and cathode on fused silica windows (instead of conventional grid)

New HHV feedthroughs





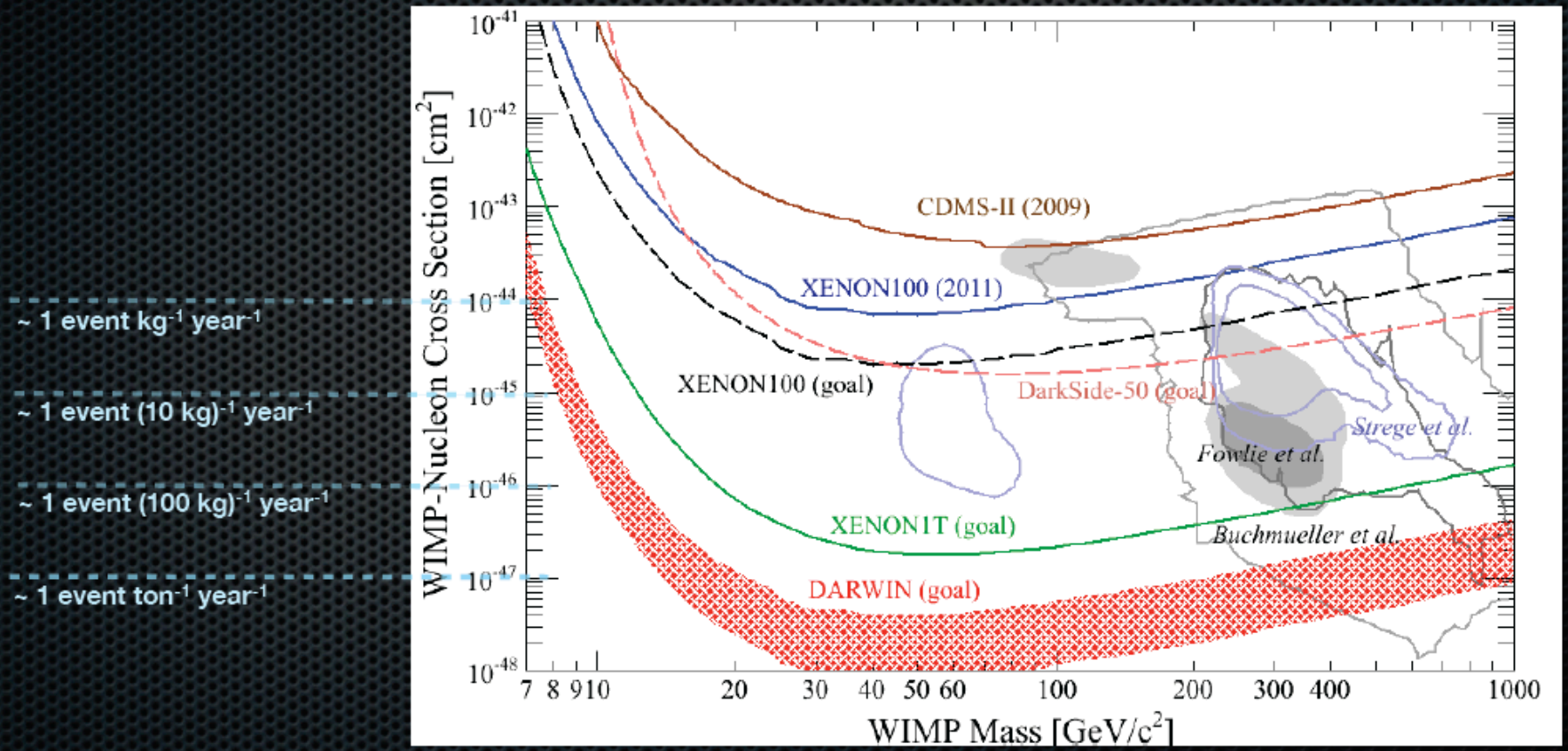
The unique combination of background rejection techniques coming from Argon technology and the extremely powerful veto system, leads to expected background lower than 0.1 events in 0.1 ton-year.

The projected sensitivity with a threshold of ~20keV$_{rec}$ is the order of ~1 x 10^{-45} cm^2 for a 100GeV WIMP (3 years of background free exposure).

DARWIN

Expected sensitivity

- However, goal is not exclusion limits, but WIMP detection



Summary

- The early work of the ICARUS-UCLA Torino team 1990-2000 set up the concept of the 2-phase liquid Xenon and liquid Argon dark matter detector. All these results are published.
- The ZEPLIN II detector was the first large scale (30 kg) 2-phase detector to take data and publish.
- The XENON 10 detector provided a major advance. XENON 100 has provided the most sensitive search to date.
- The constructed LUX detector and the XENON 1Ton detectors will provide an advance to reach 10^{-45} – 10^{-47} cm^2 cross section in the DM search followed by DarkSide (5 Ton) at the LNGS.
- There is now a worldwide effort to construct multiton detectors to either (i) go below 10^{-47} cm^2 or (ii) study dark matter if it has been discovered. This is one of the most difficult searches in the history of science.