Direct Detection Overview

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UNIVERSITEIT VAN AMSTERDAM

NIKHEF

This week's Direct Detection Talks

Session	Experiment	Speaker
Tuesday Morning	XENON100	E.Pantic
	SuperCDMS	J. Hall
	XMASS	K. Kobayashi
Wednesday Morning	Neutrino Backgrounds	T. Figueroa
	LUX	R. Gaitskell
	XENON1T	R. Lang
Thursday Morning	DAMA/LIBRA	P. Belli
	KIMS	Y. Kim
	DM-Ice	R. Maruyama
Saturday Morning	COUPP	R. Neilson
	PandaX	S. Stephenson
	DM-TPC	J. Battat
Saturday Afternoon	DEAP/CLEAN	K. Palladino
	Future with Noble Liquid	D. McKinsey
	Future with Solid State Devices	R. Schnee

15 x 20-25min

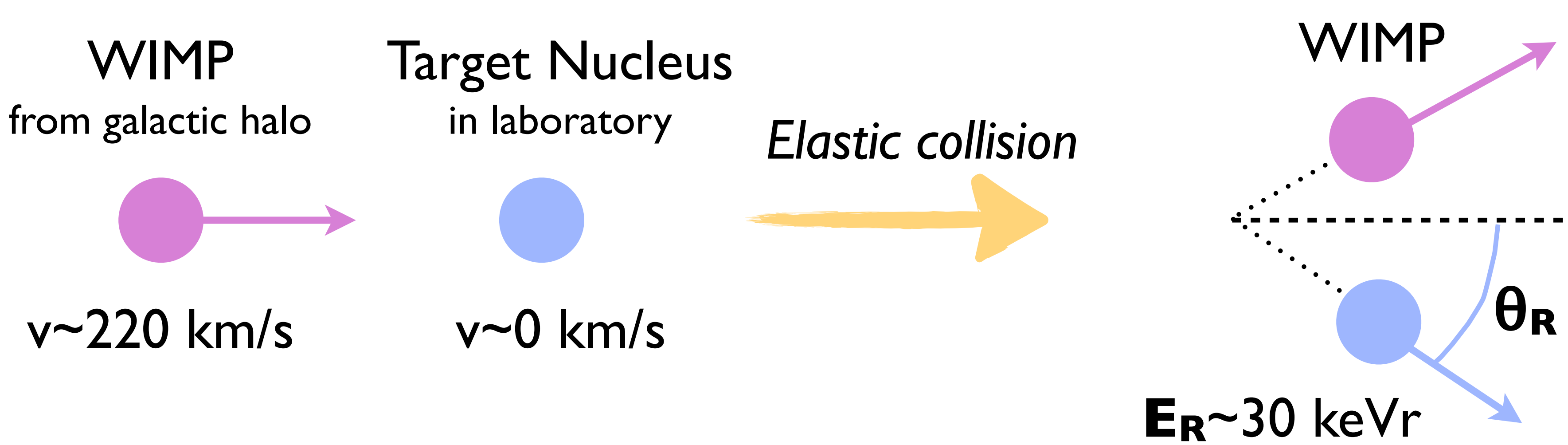
+Axion Session

Preliminaries

Sun velocity vector pointing roughly to Cygnus

Assume WIMP is not only gravitationally interacting

M. W. Goodman and E. Witten, Phys. Rev. D 31, 3059 (1985).



$$E_R = \frac{\mu^2 v^2}{m_T}(1 - \cos\theta)$$

$$v_{\min} = \sqrt{\frac{m_T E_{th}}{2\mu^2}}$$

Preliminaries II

Measure:

$$\frac{dR(t)}{dE_R} = N_T \frac{\rho_\chi}{m_\chi} \int_{v_{\rm min}}^{v_{\rm esc}} d^3v \frac{d\sigma}{dE_R} v f(v, v_e(t))$$

Need input from Astrophysics

with scalar (SI) and axial-vector (SD) couplings:

$$\frac{d\sigma}{dE_R} = \frac{m_T}{2\mu^2 v^2} \left[\sigma_{SI} F^2_{SI}(E_R) + \sigma_{SD} F^2_{SD}(E_R)\right]$$

WIMP-nucleus cross sections:

$$\sigma_{SI} = \frac{4\mu^2}{\pi} \left[Z f_p + (A-Z) f_n\right]^2 \propto A^2$$

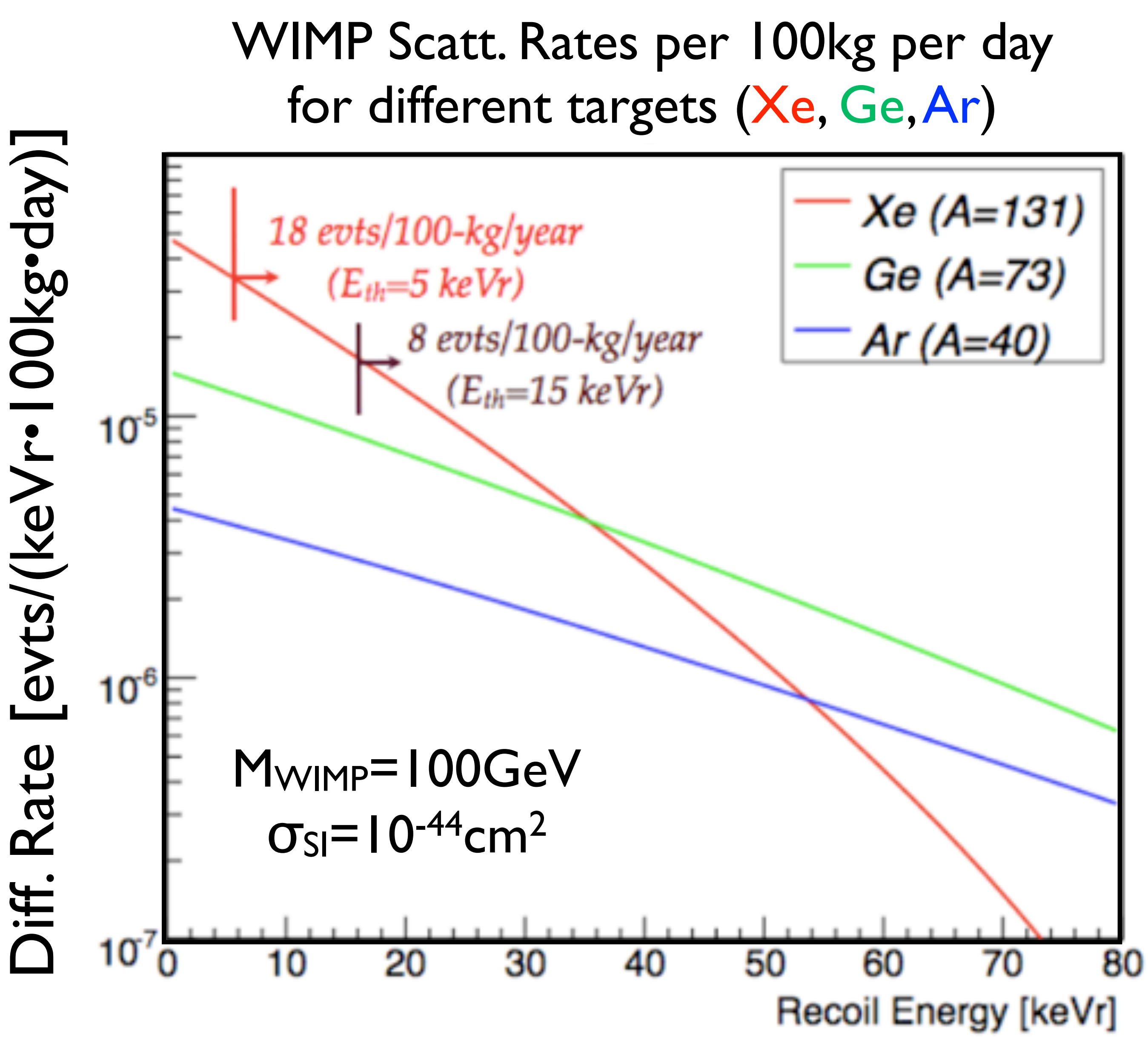
Better sensitivity with high A

$$\sigma_{SD} = \frac{32\mu^2}{\pi} G_F^2 \frac{J+1}{J} \left[a_p \langle S_p \rangle + a_n \langle S_n \rangle\right]^2$$

Need nucleus with spin:

^{19}F, ^{23}Na, ^{73}Ge, ^{127}I, ^{129}Xe, ^{131}Xe, ^{133}Cs (but no Ar!)

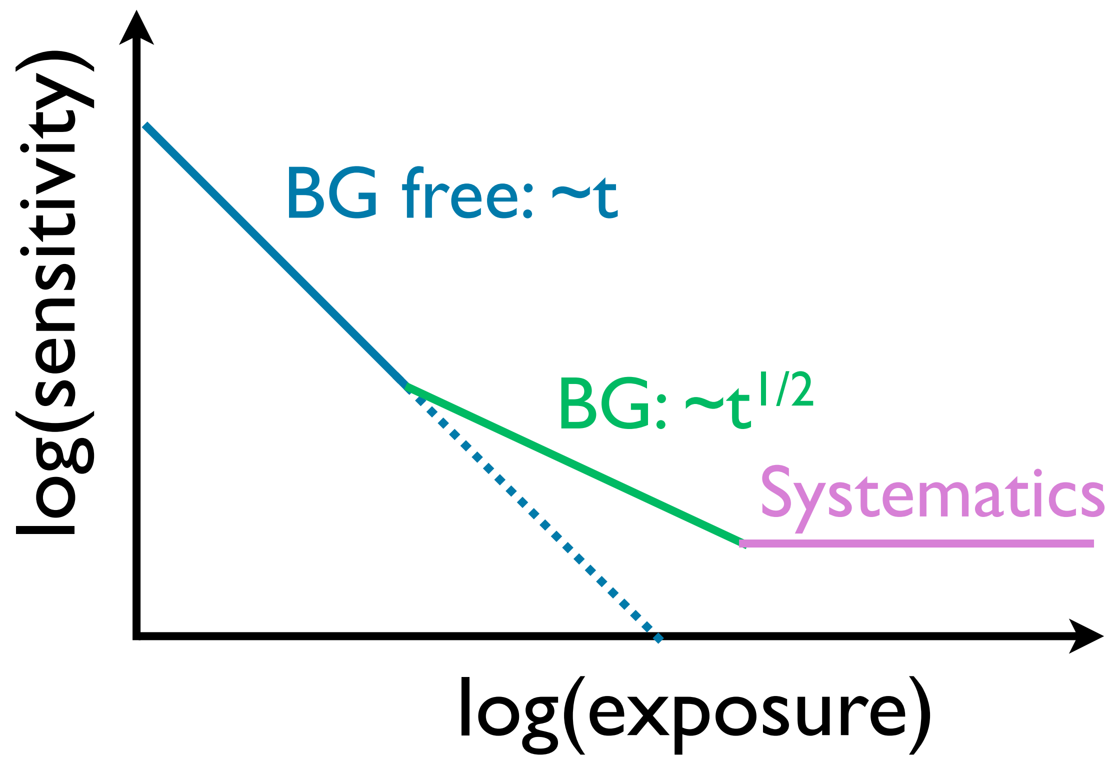
Expected Energy Spectrum



- Elastic collisions with nuclei
  - WIMP velocity ~10^{-3}c
- Energy of recoiling nucleus is tiny : <50 keV
- Rates are uncertain, since they depend on model
- Spectrum is featureless (no peaks)

Minimizing Backgrounds

- Critical aspect of any rare event search - minimize backgrounds!
- Purity of materials
  - Copper, germanium, xenon among the cleanest with no natural occurring long-lived isotopes
  - Ancient lead, if free of ^{210}Pb
- Shielding
  - External U/Th/K backgrounds
- Krypton and Radon mitigation
- Material handling and assaying
  - Surface preparation, cosmic activation
- Underground siting and active veto
  - Avoid muon-induced neutrons
- Detector-based discrimination



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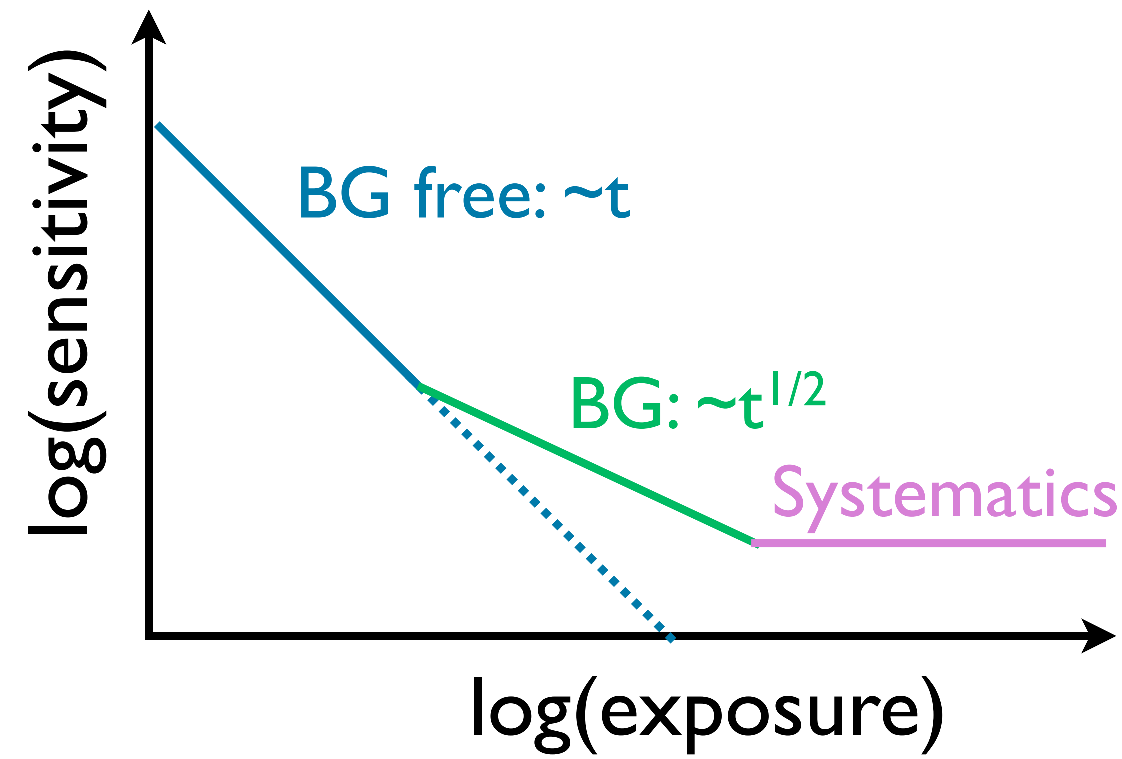
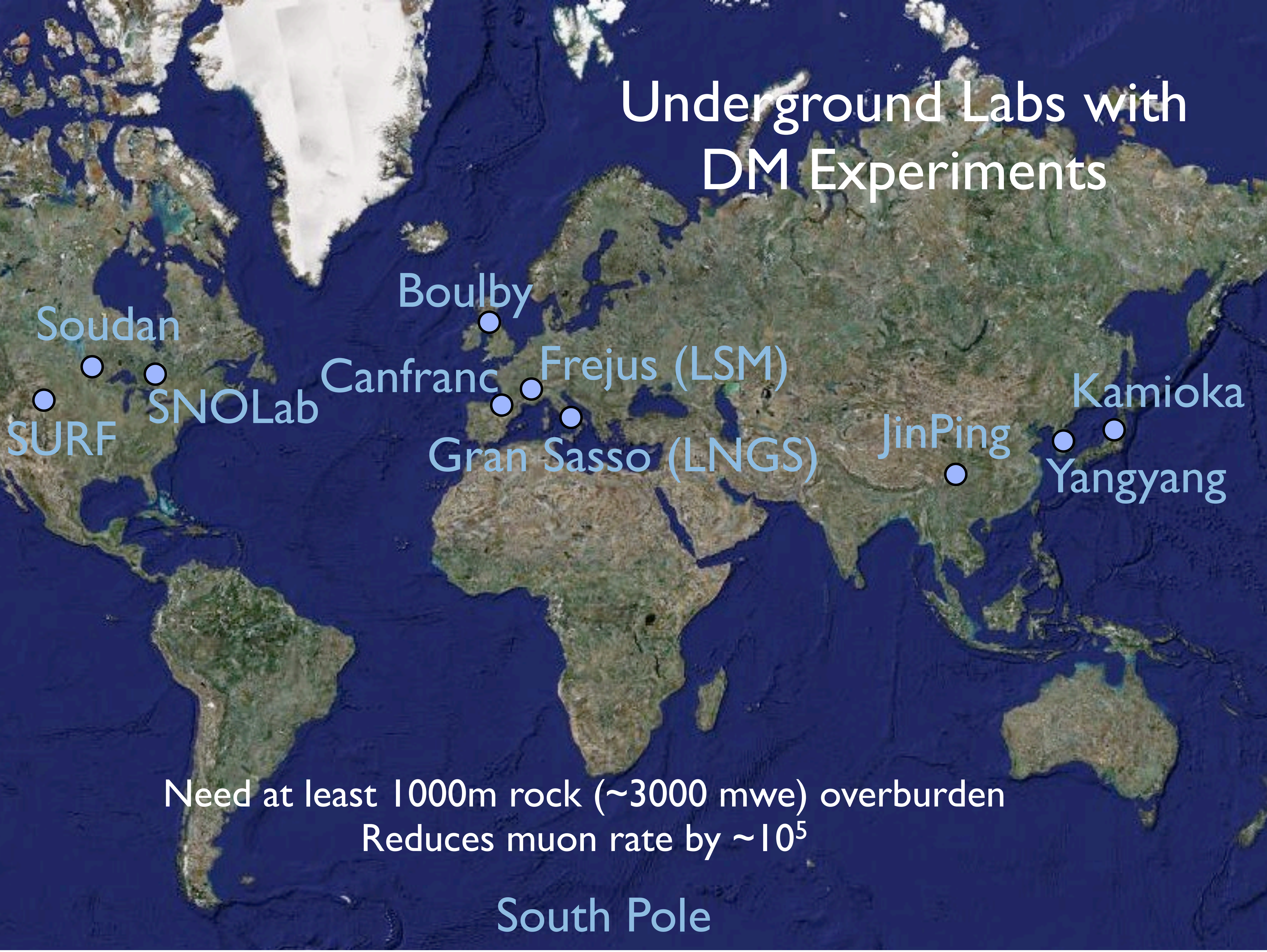


Current state-of-the-art: <1 ev/(kg·yr)
Moving to: 1 ev/(ton·yr)

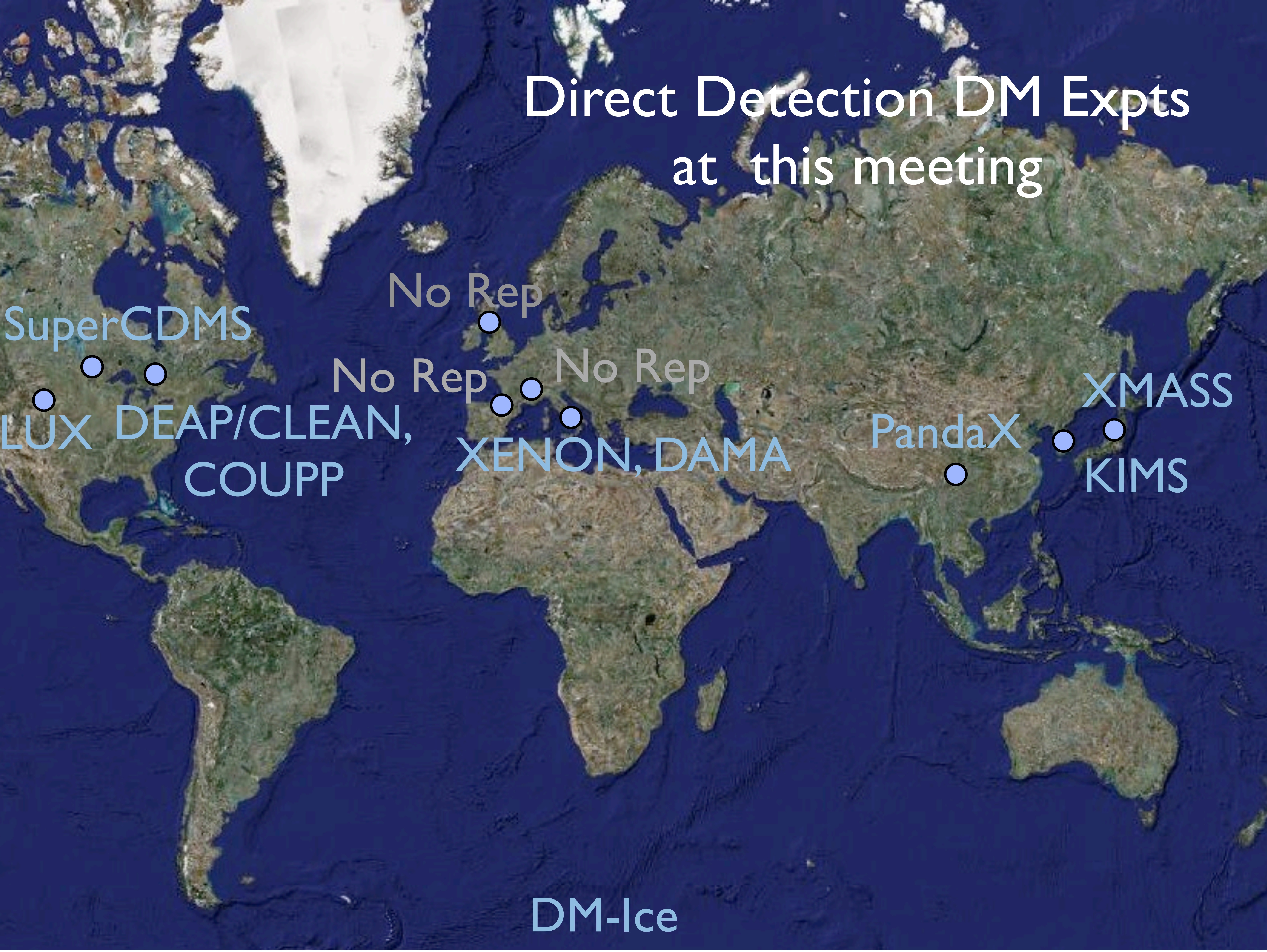
Underground Labs with DM Experiments



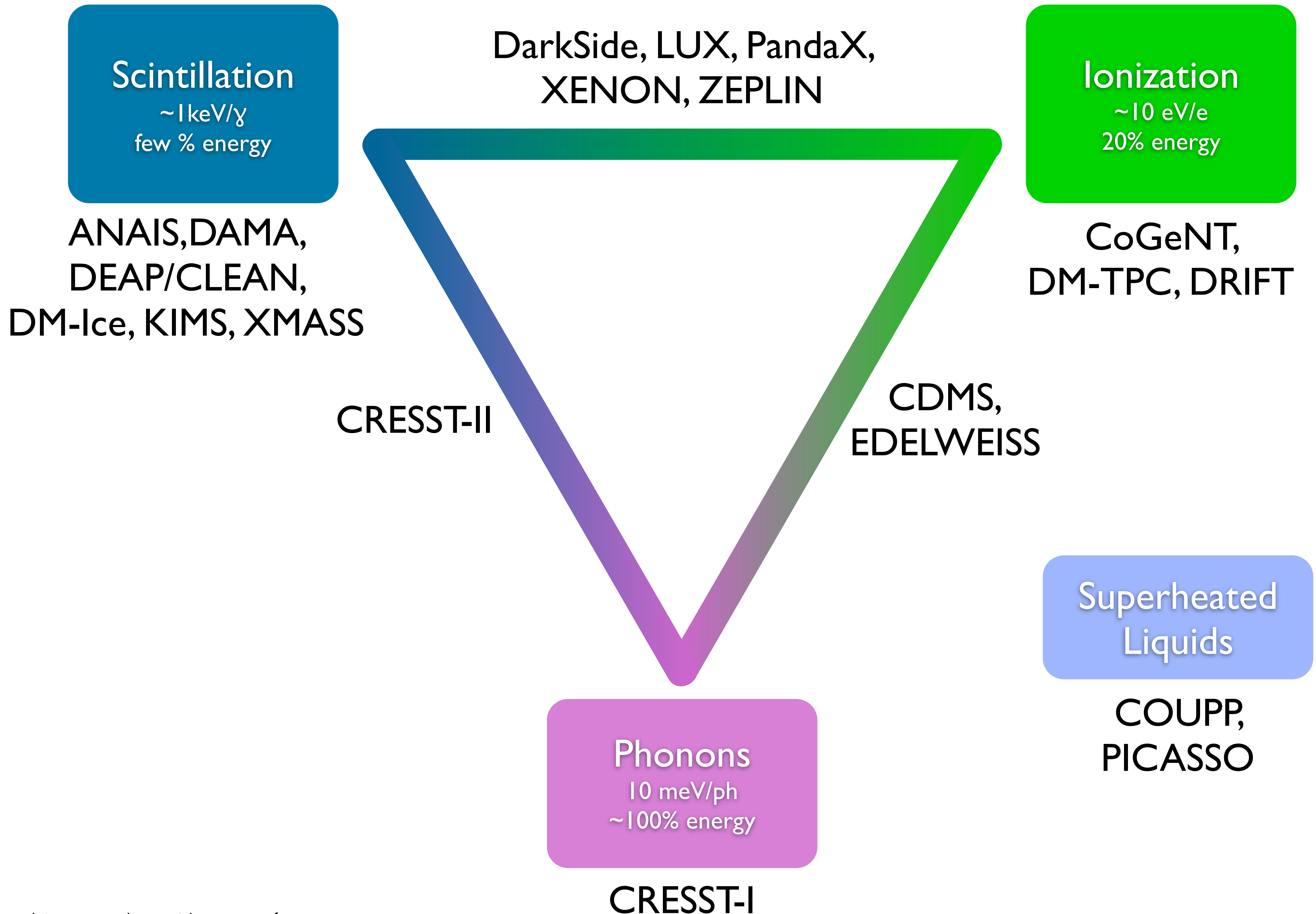
Need at least 1000m rock (~3000 mwe) overburden

Reduces muon rate by $\sim 10^5$

Direct Detection DM Expts at this meeting



Detection Techniques



Particle-dependent Response

CDMS, CRESST, DarkSide, LUX, XENON etc.

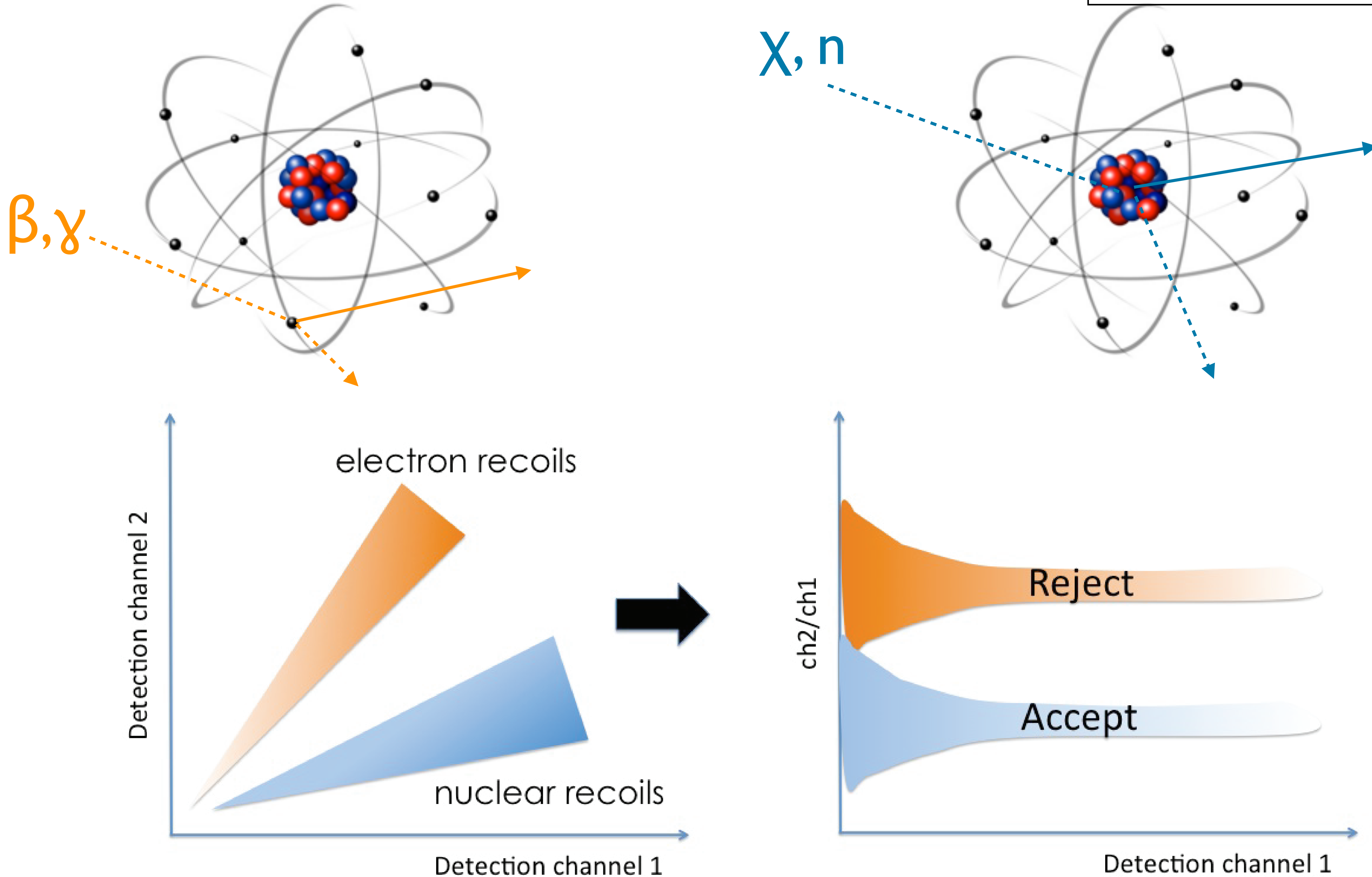
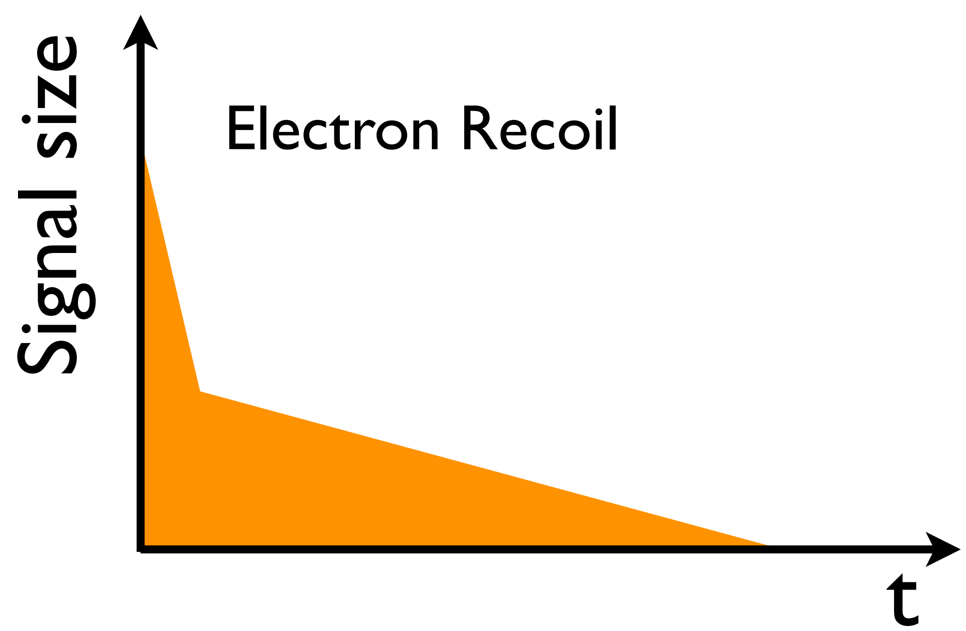


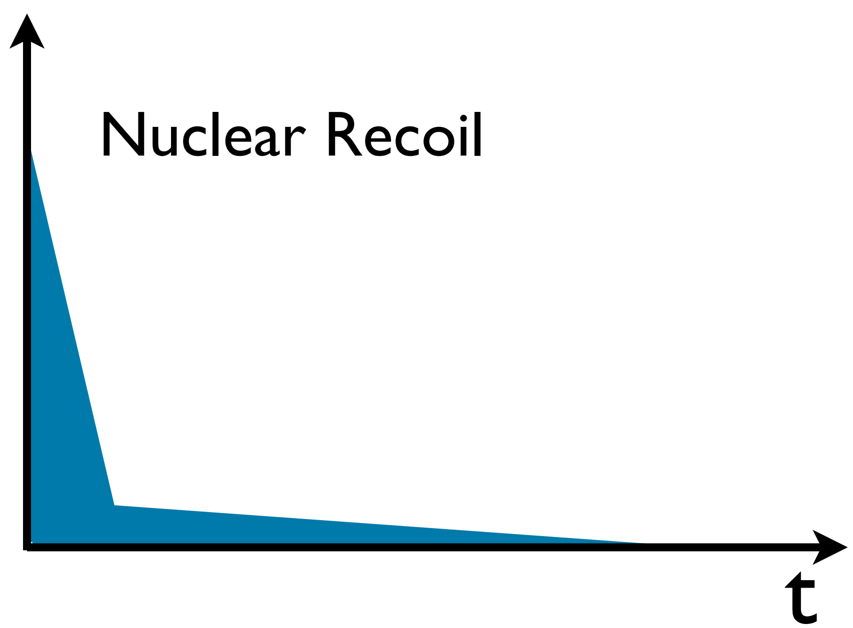
Image E.Pantic

Pulse Shape Discrimination

Using scintillation light:

DEAP/CLEAN, KIMS, DarkSide, XMASS etc.



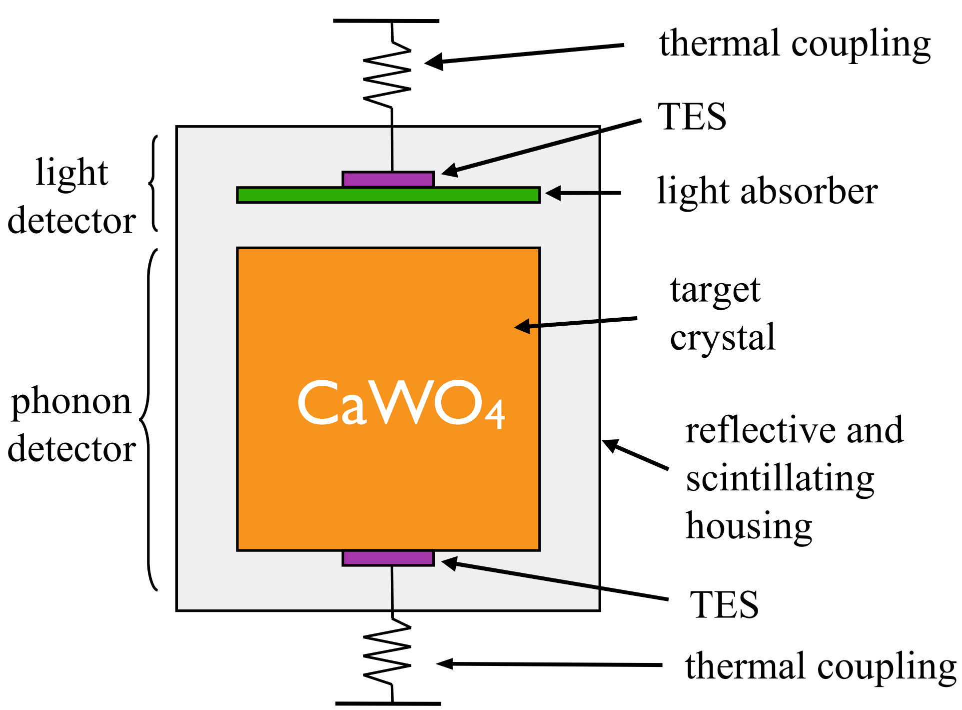


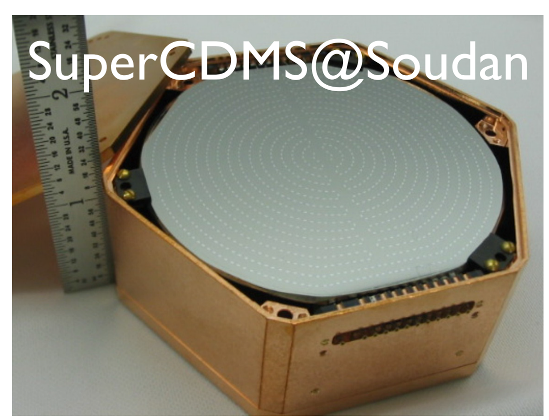
- Use ratio of fast-to-slow signal components
- Works well in
  - LAr, LNe
- But also in
  - LXe, NaI, CsI

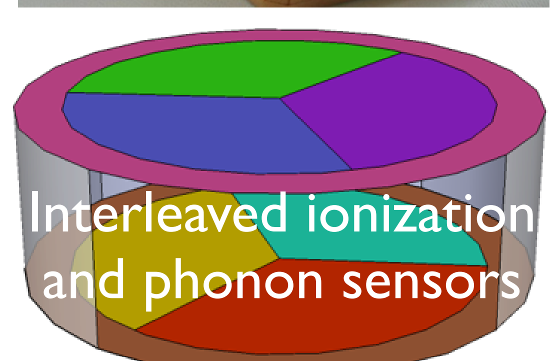
Possible to achieve very high ER/NR discrimination $>10^{-7}$

Solid State Cryogenic Detectors

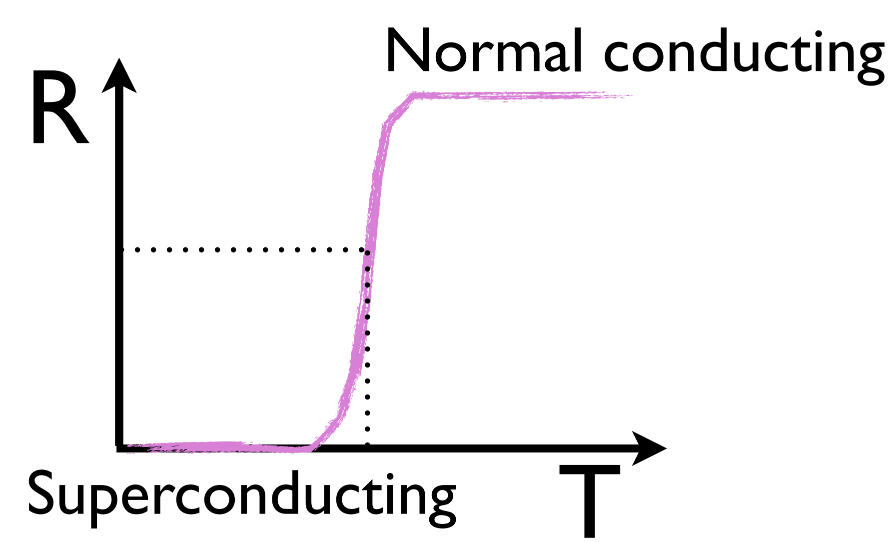
- Cryogenic detectors @ sub-K temperatures
  - Low energy threshold (<10keV)
  - Excellent energy resolution (<1%)
  - Differentiate NR from ER on Event-by-Event basis
  - T^3-dependence on heat capacity of dielectric crystal
  - **SuperCDMS**, CRESST, EDELWEISS, …





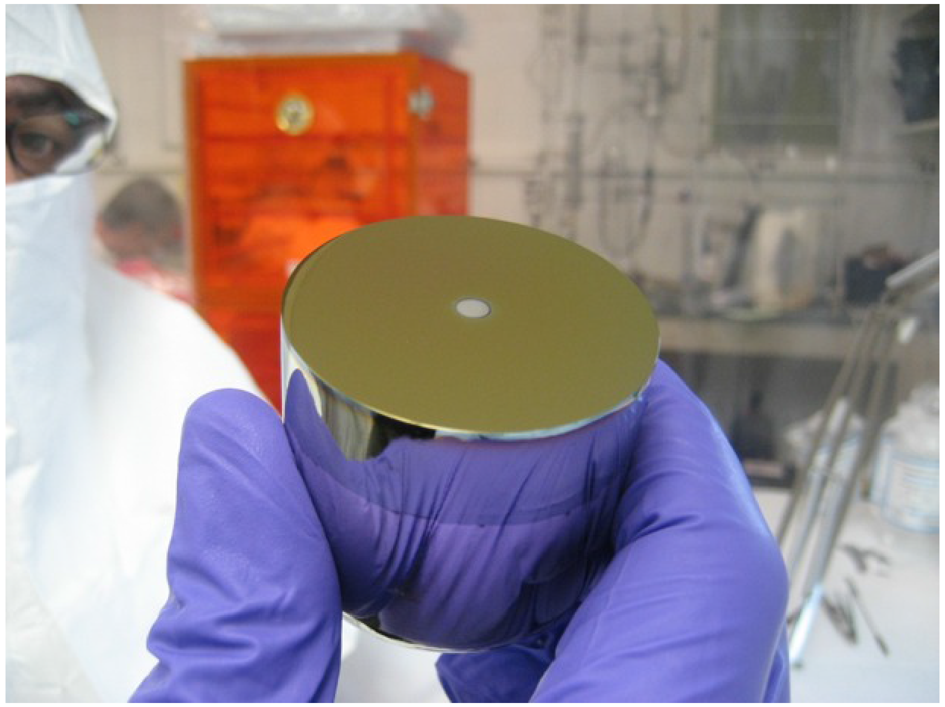


Transition Edge Sensor

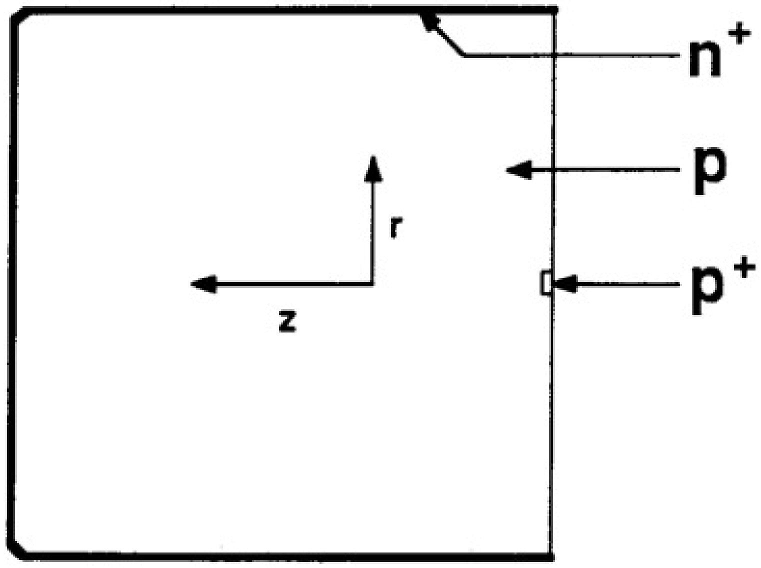


Solid State Cryogenic Detectors II

- Germanium detectors @ 77K
  - Sub-keV energy threshold, low intrinsic BG
  - No ability to differentiate NR from ER on EbE
  - PSD to discriminate surface from bulk events
  - CoGeNT, TEXONO

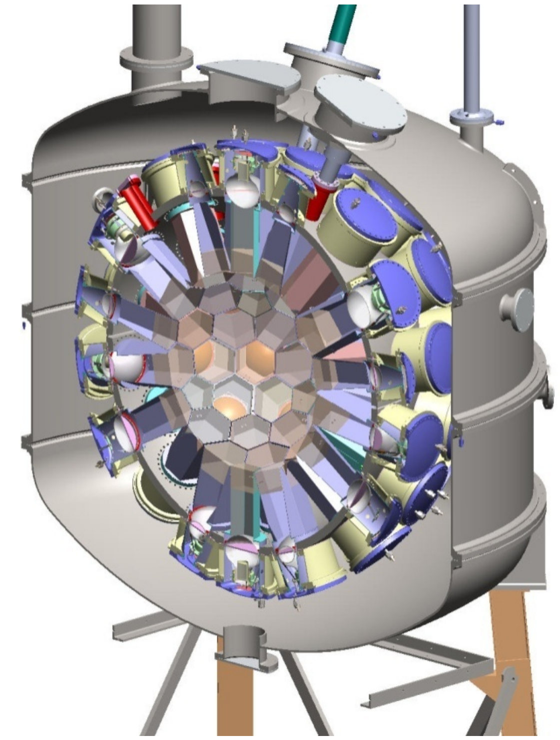


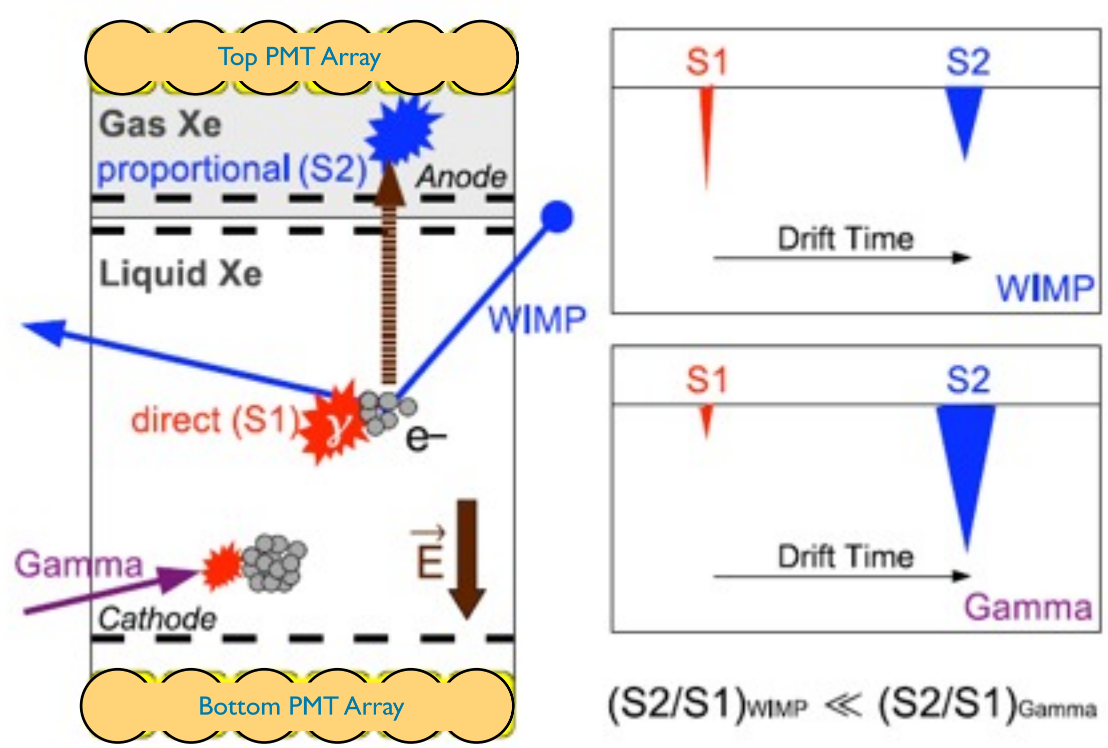
P-type Point Contact (PPC)



Noble Liquid Detectors

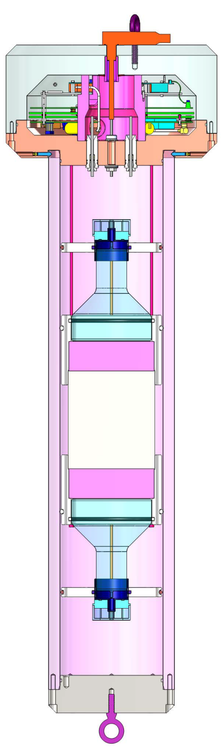
- Good self-shielding, homogeneous
- Relative ease to scale up to large mass and purify
- LXe and LAr good scintillators
- Single-phase
  - **DEAP/CLEAN**, **XMASS**
  - Use pulse shape discrimination
- Dual-phase
  - Ionization and scintillation
  - Excellent 3D position reconstruction (TPC)
  - **XENON**, **LUX**, **PandaX**



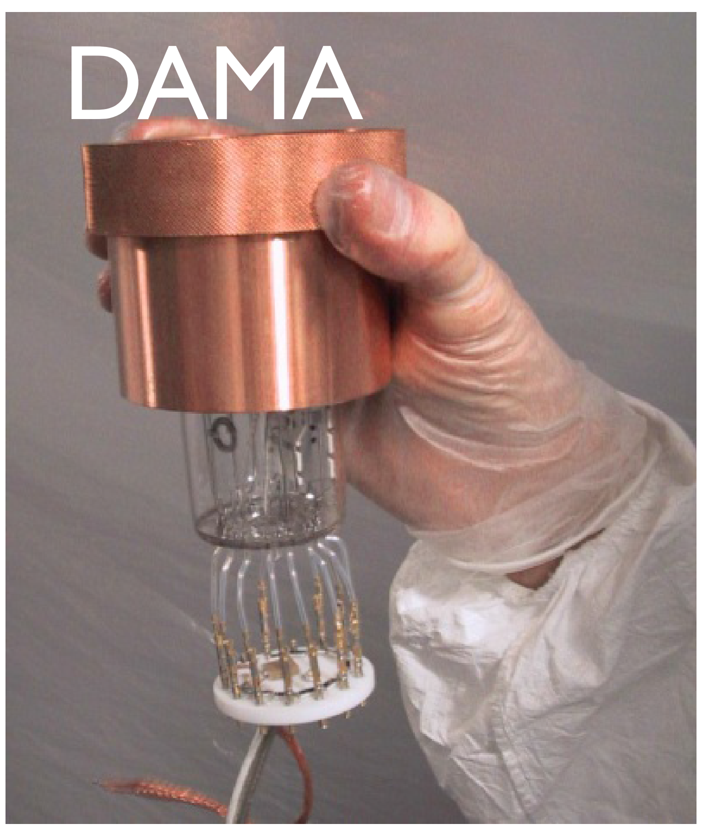


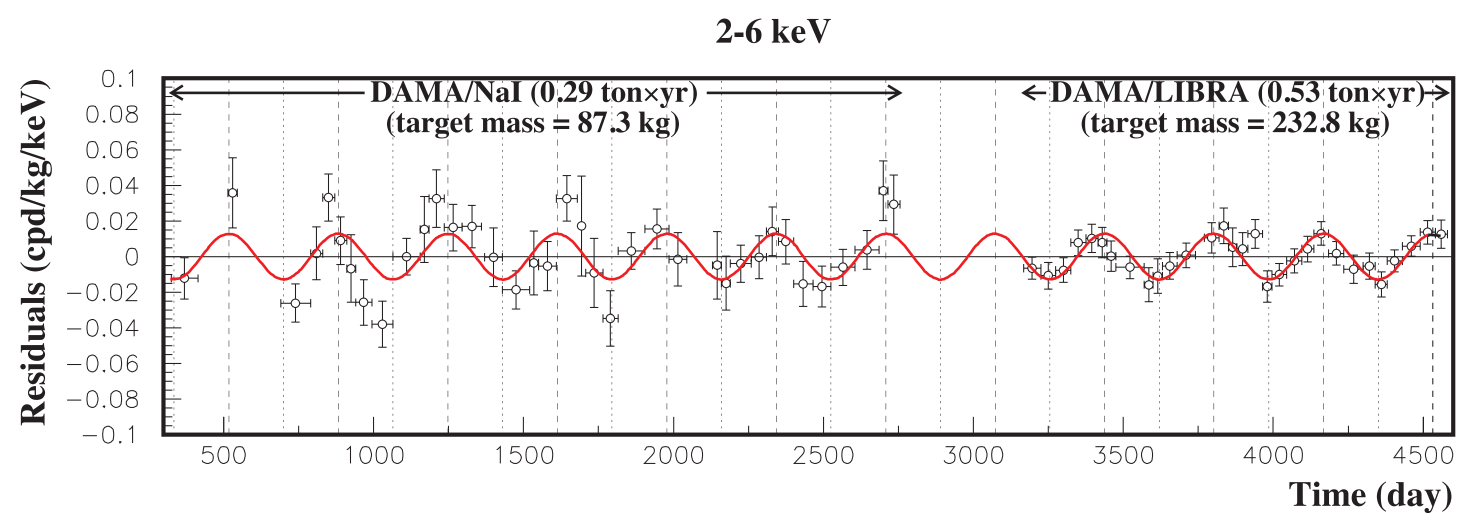
Scintillating crystals

- Reasonable light yield and energy resolution
- keV energy threshold
- **DAMA/LIBRA** [NaI(Tl)], **KIMS** [CsI(Tl)], ANAIS [NaI (Tl)], **DM-Ice** [NaI(Tl)]



DM-Ice

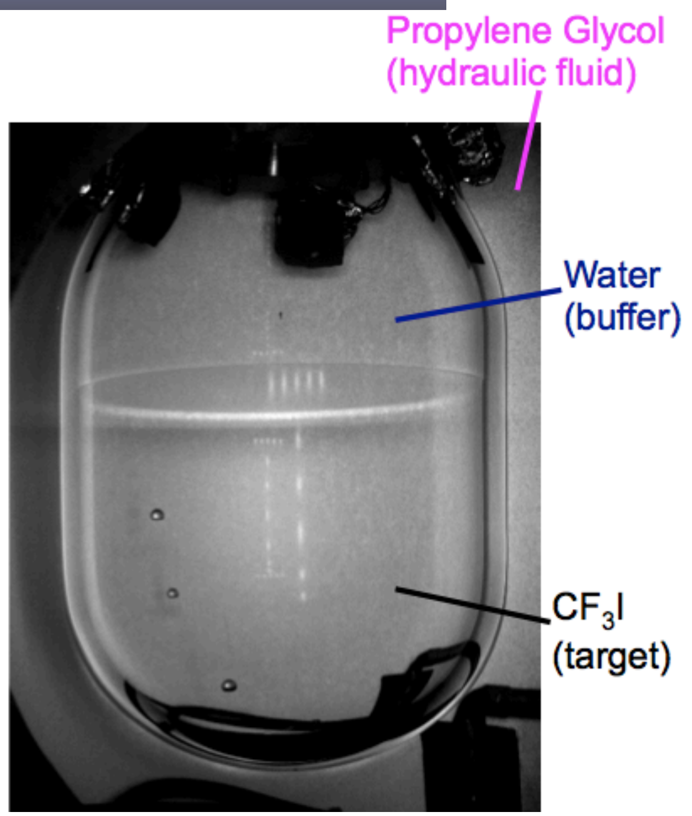


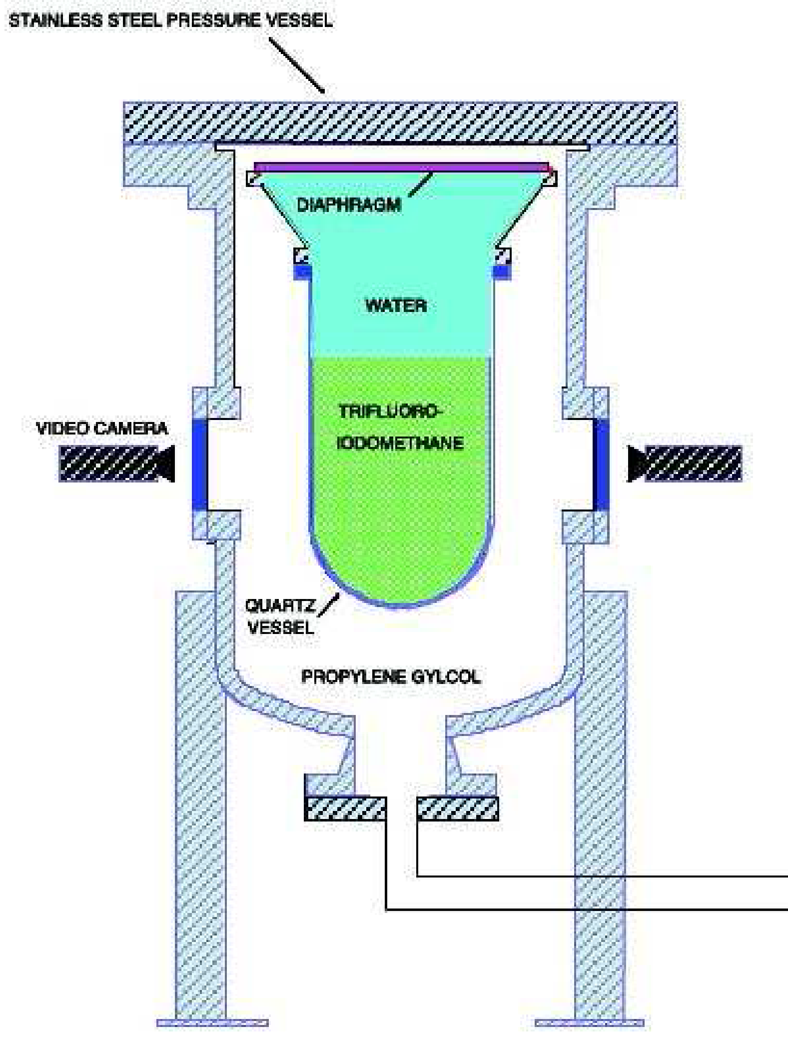


KIMS

Superheated Liquid Detectors

- Superheated liquid in a metastable state
- Energy deposit can destroy metastable state forming bubbles
  - Can make experiment only sensitive to nuclear recoils by adjusting P an T → threshold detector
  - Distinguish α acoustically from other nuclear recoils
- All experiments use some form of ^{19}F
  - Spin carried mostly by an unpaired proton → very good sensitivity to SD interactions
- **COUPP** (CF_3I), PICASSO (C_4F_{10}), SIMPLE (C_2ClF_5)

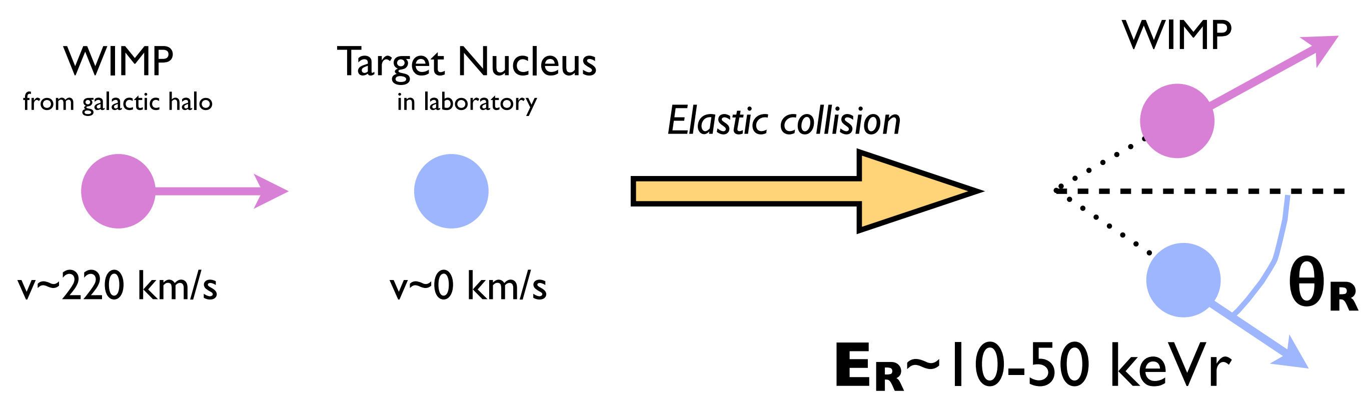




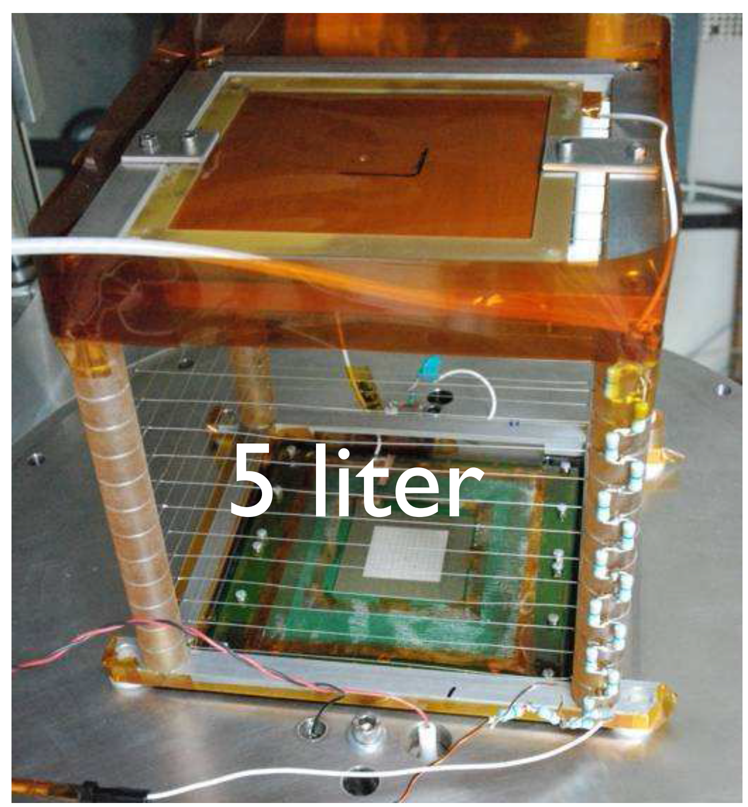
Direction Detection

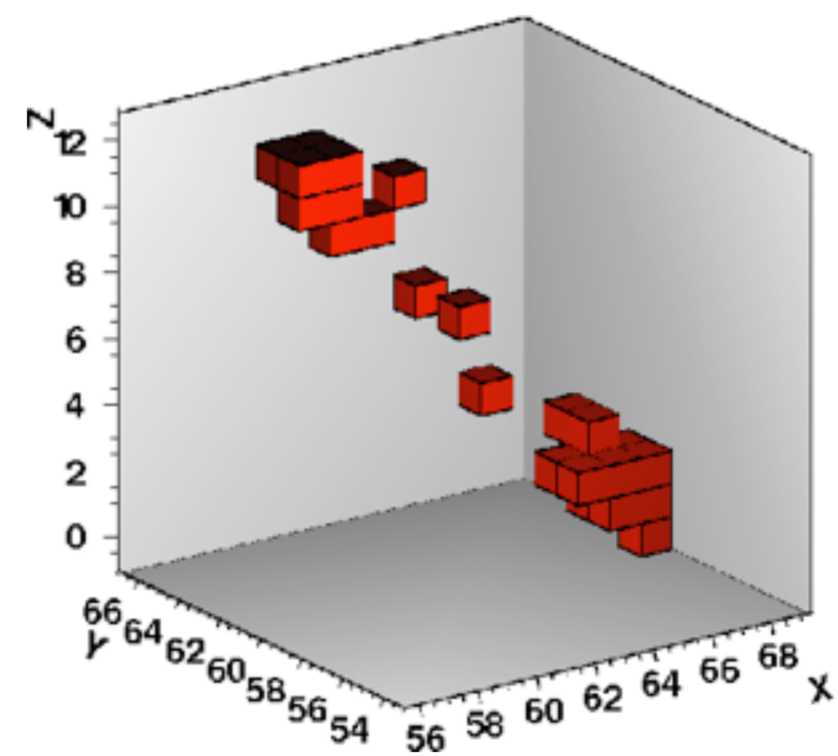
- Experiments aim to simultaneously measure
  - Recoil energy E_R
  - Reconstruct recoil track direction
- Low pressure TPC
  - Gas mixture (e.g. MIMAC): 70% CF_4 + 30% CHF_3 @ ~100mbar
  - Sensitive to SD interactions
  - Tracks are a few mm
  - DRIFT, **DM-TPC**, MIMAC

$$\frac{dR(t)}{dE_R} \rightarrow \frac{d^2R(t)}{dE_R d\theta_R}$$

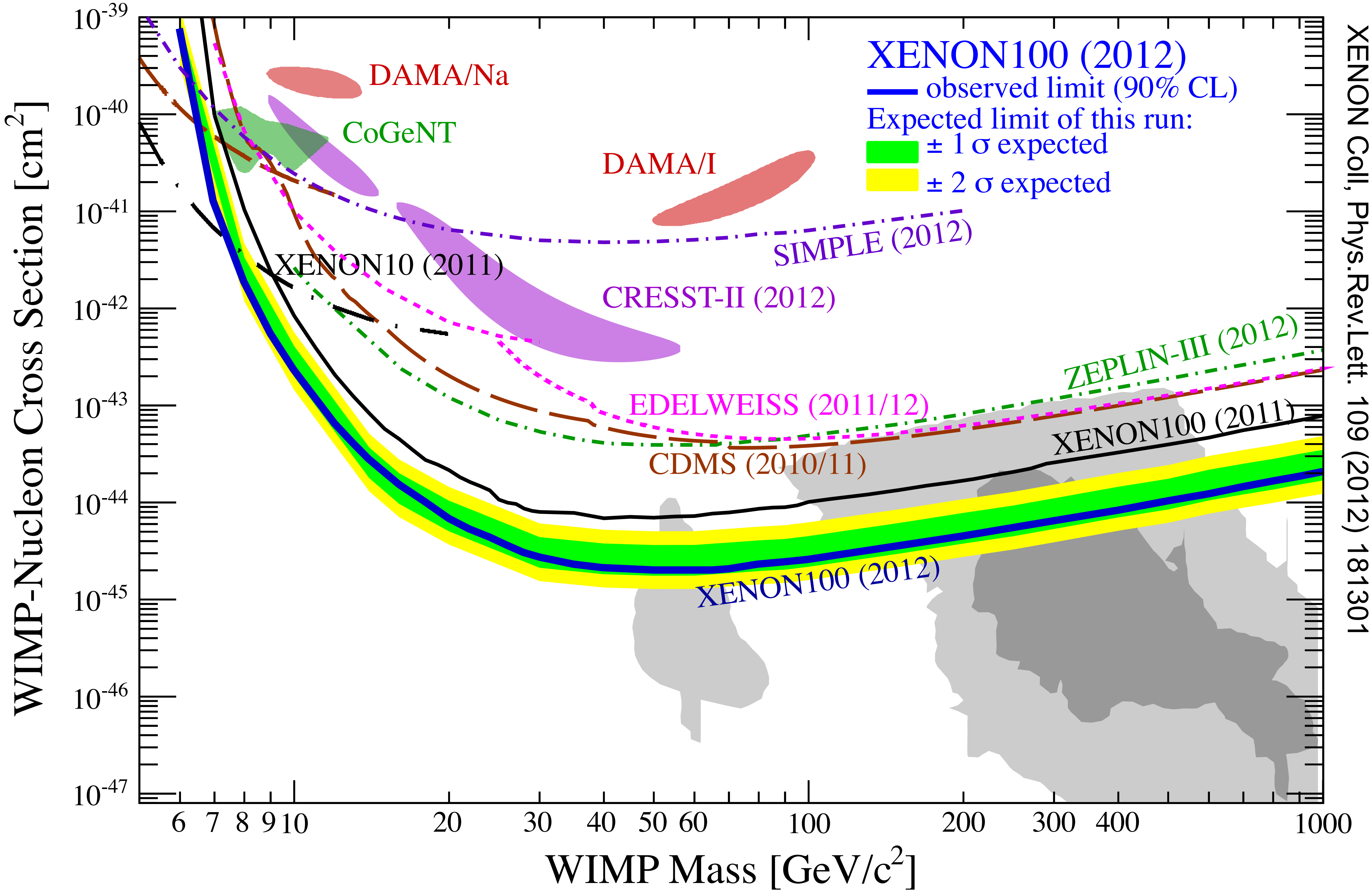


Daily directional modulation: forward-backward asymmetry

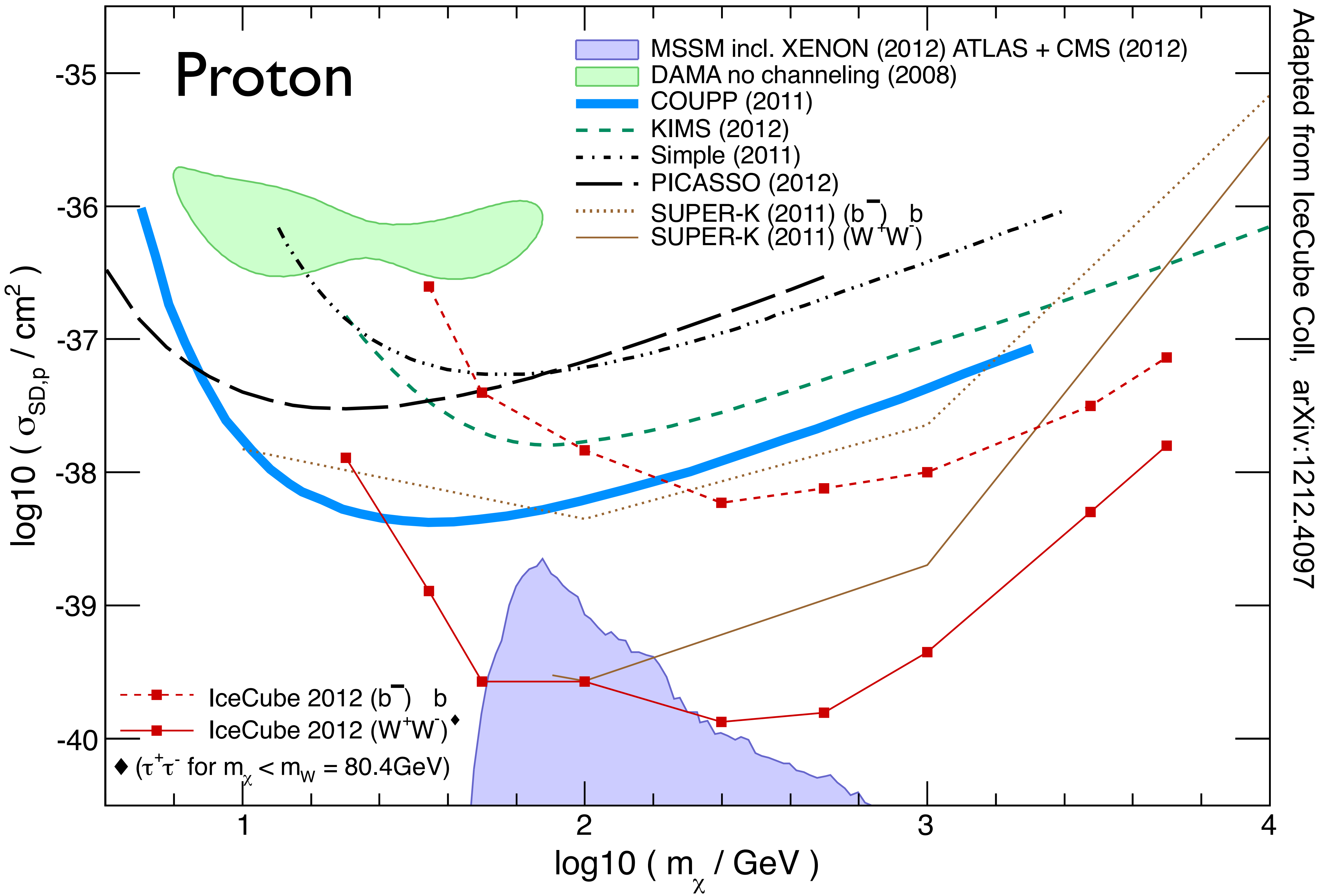




Spin Independent Interactions

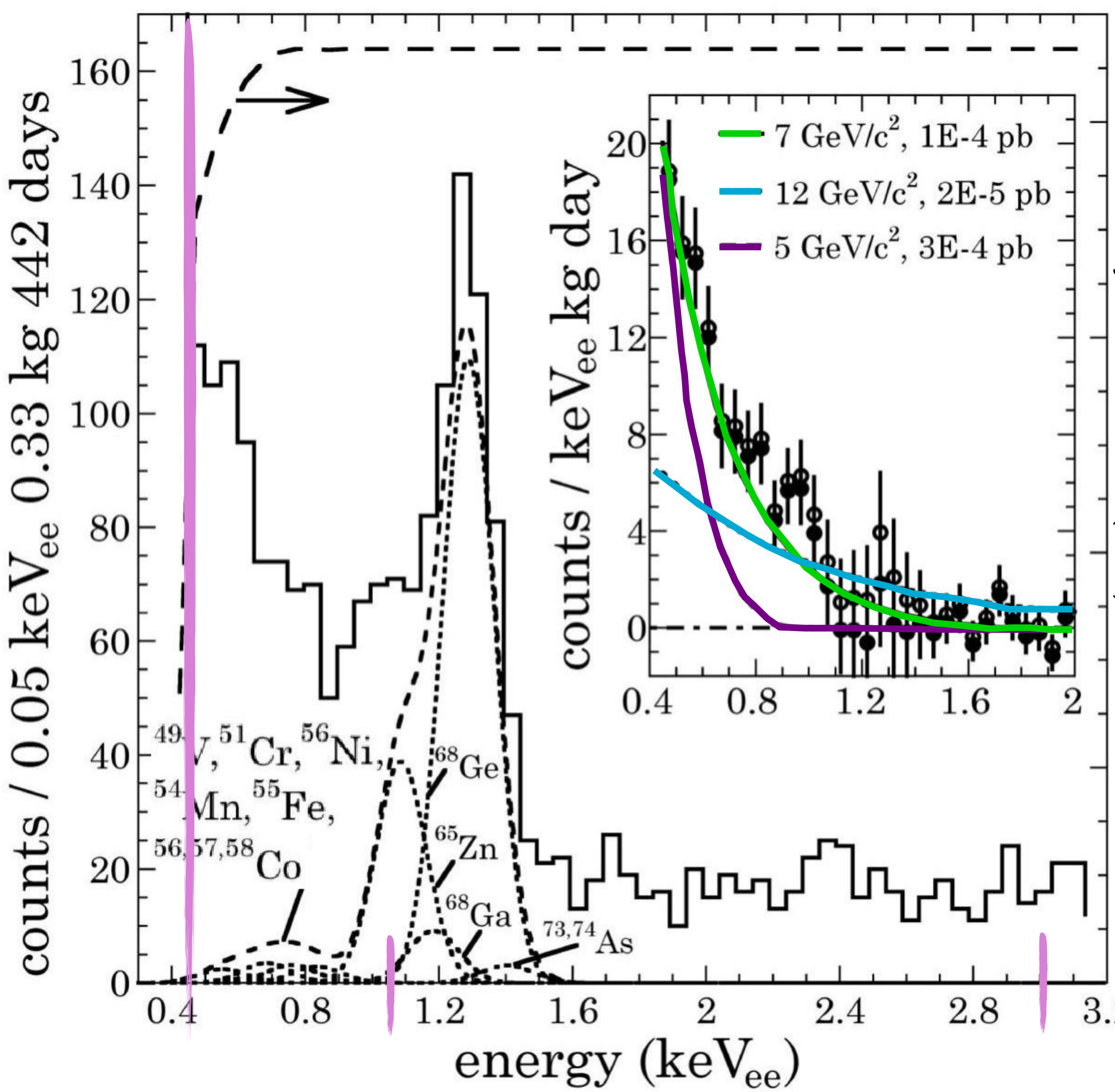


Spin-dependent Interactions

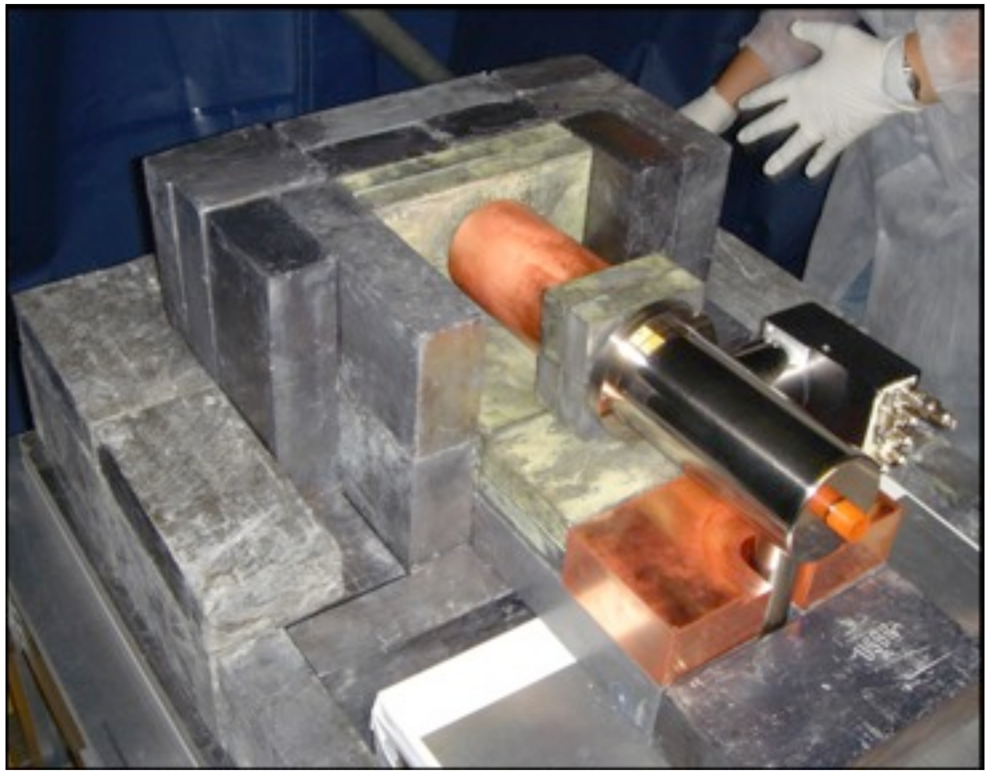


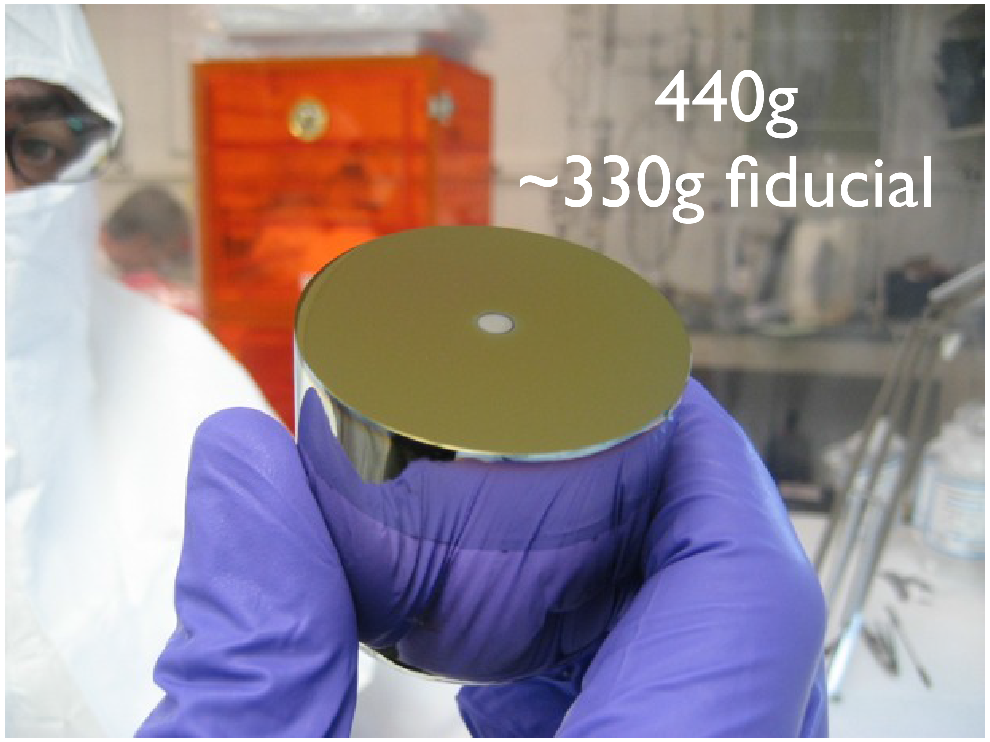
CoGeNT

P-type point contact high-purity Ge detector operating in Soudan

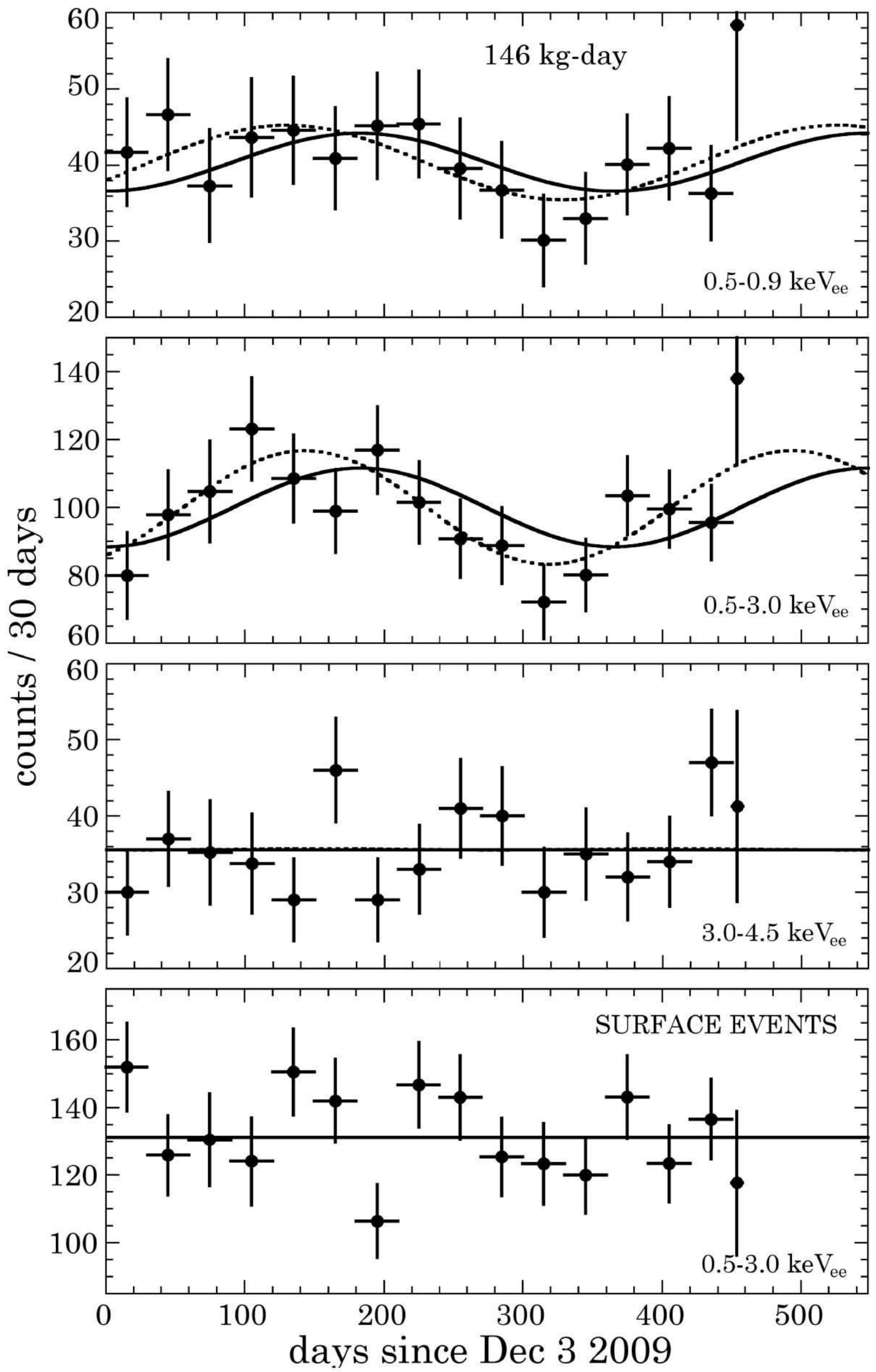


CoGeNT Coll, Phys. Rev. Lett. 107 (2011) 141301 - arXiv:1106.0650

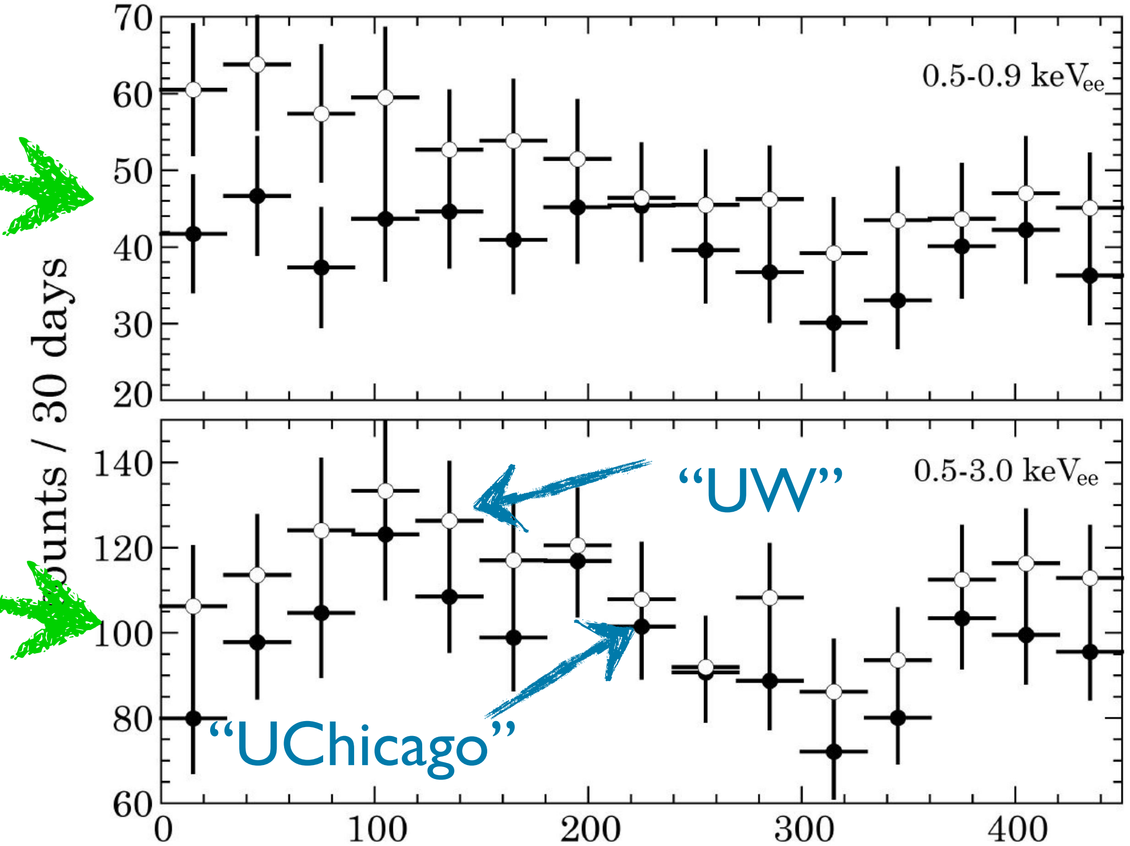




CoGeNT Results

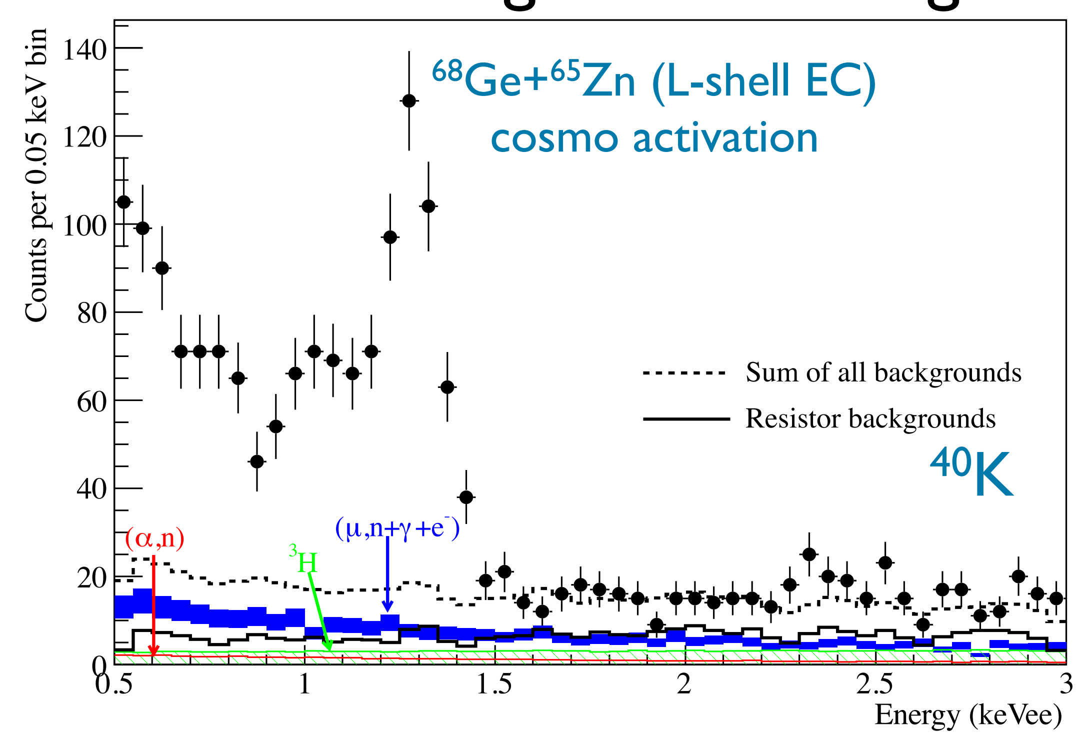


Two independent data pipelines



CoGeNT coll, [arXiv:1208.5737](https://arxiv.org/abs/1208.5737)

Extensive background investigation



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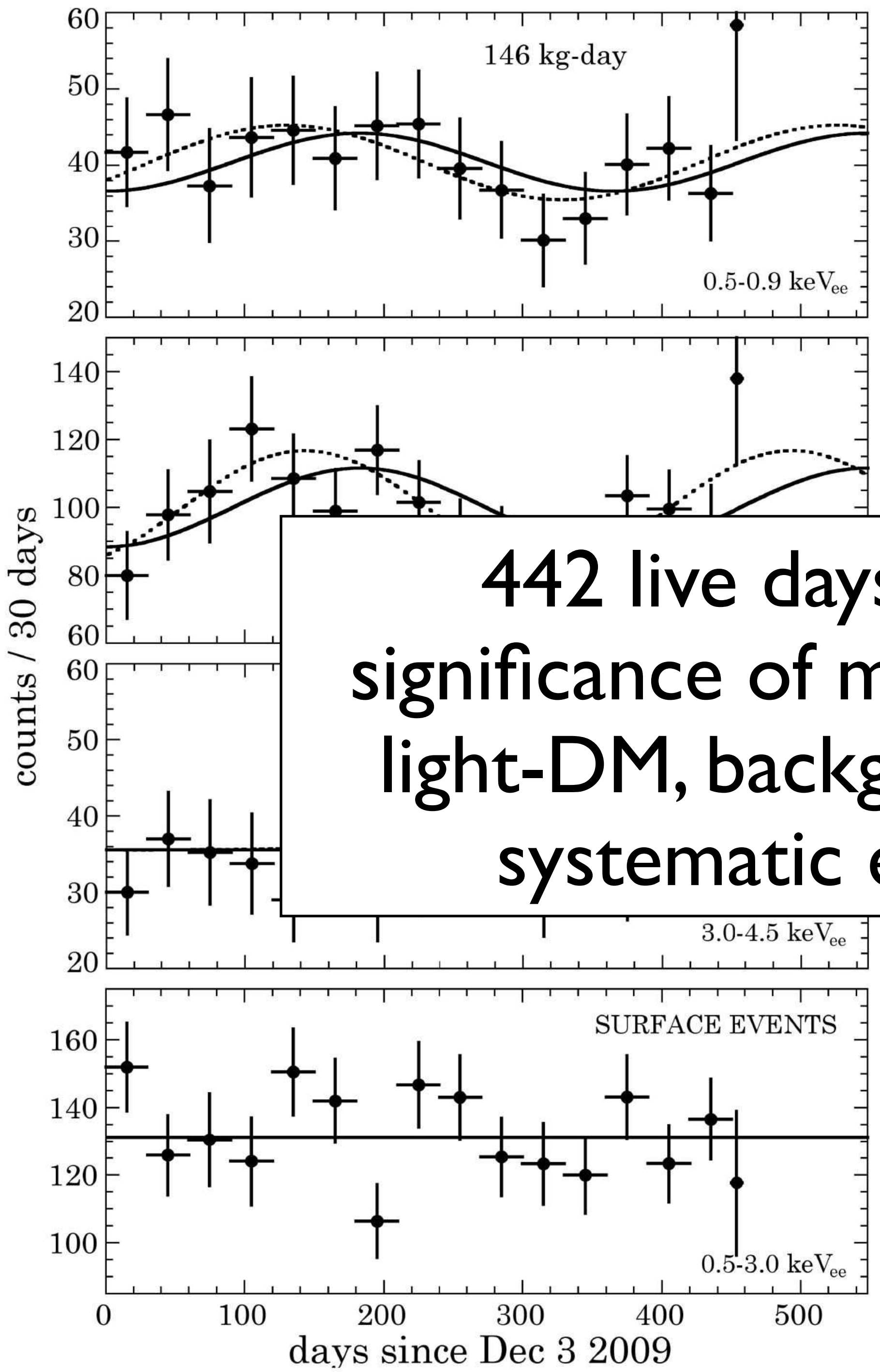

442 live days, 2.8σ significance of modulation: light-DM, background or systematic effect?

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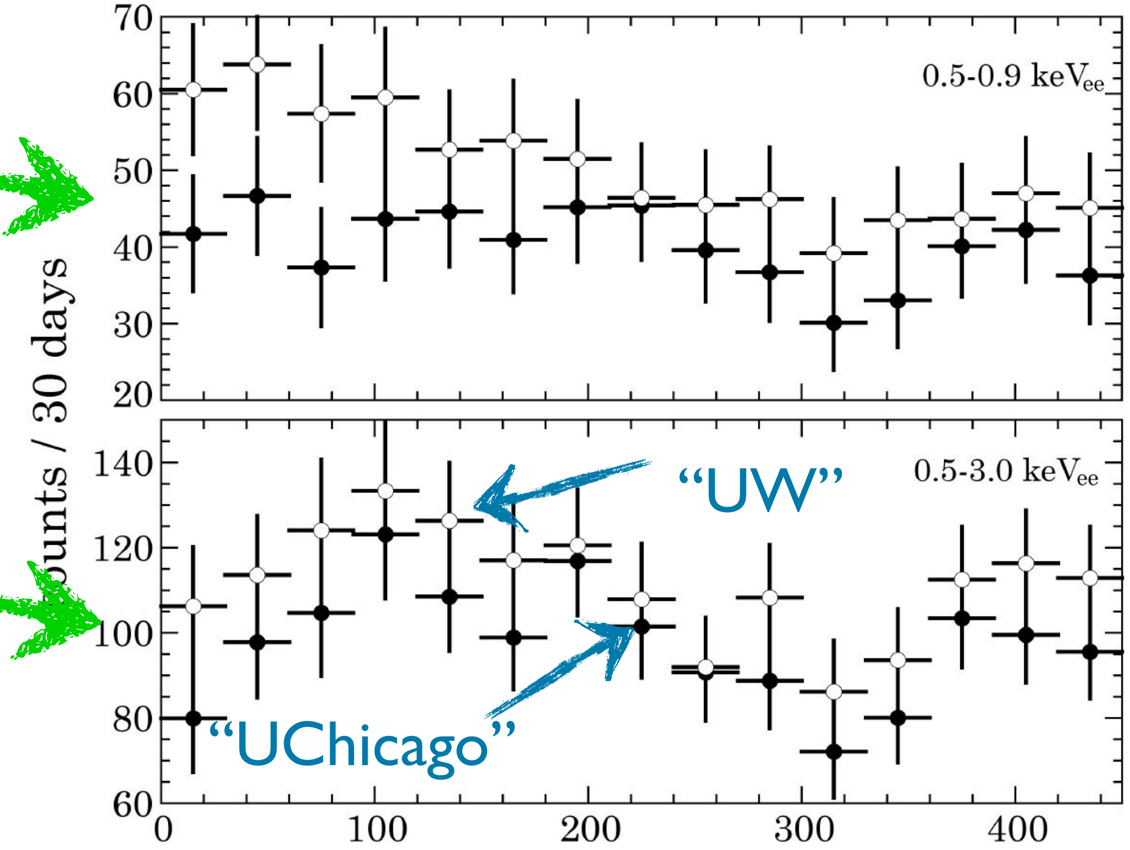

CoGeNT coll, [arXiv:1208.5737]

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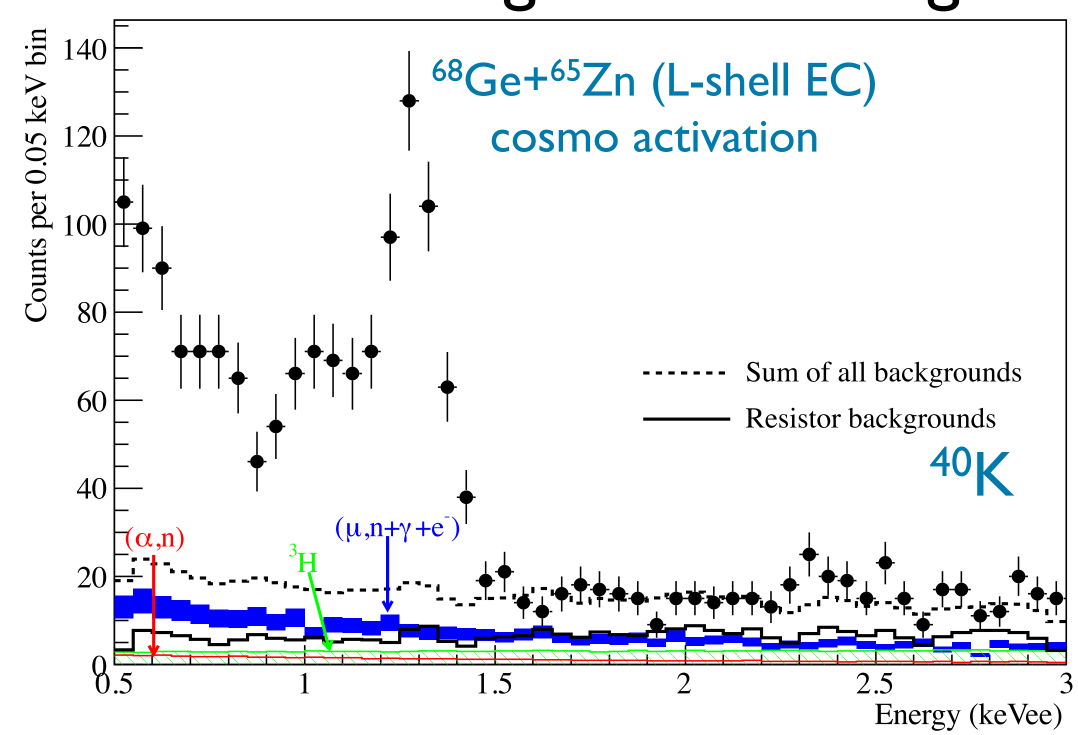

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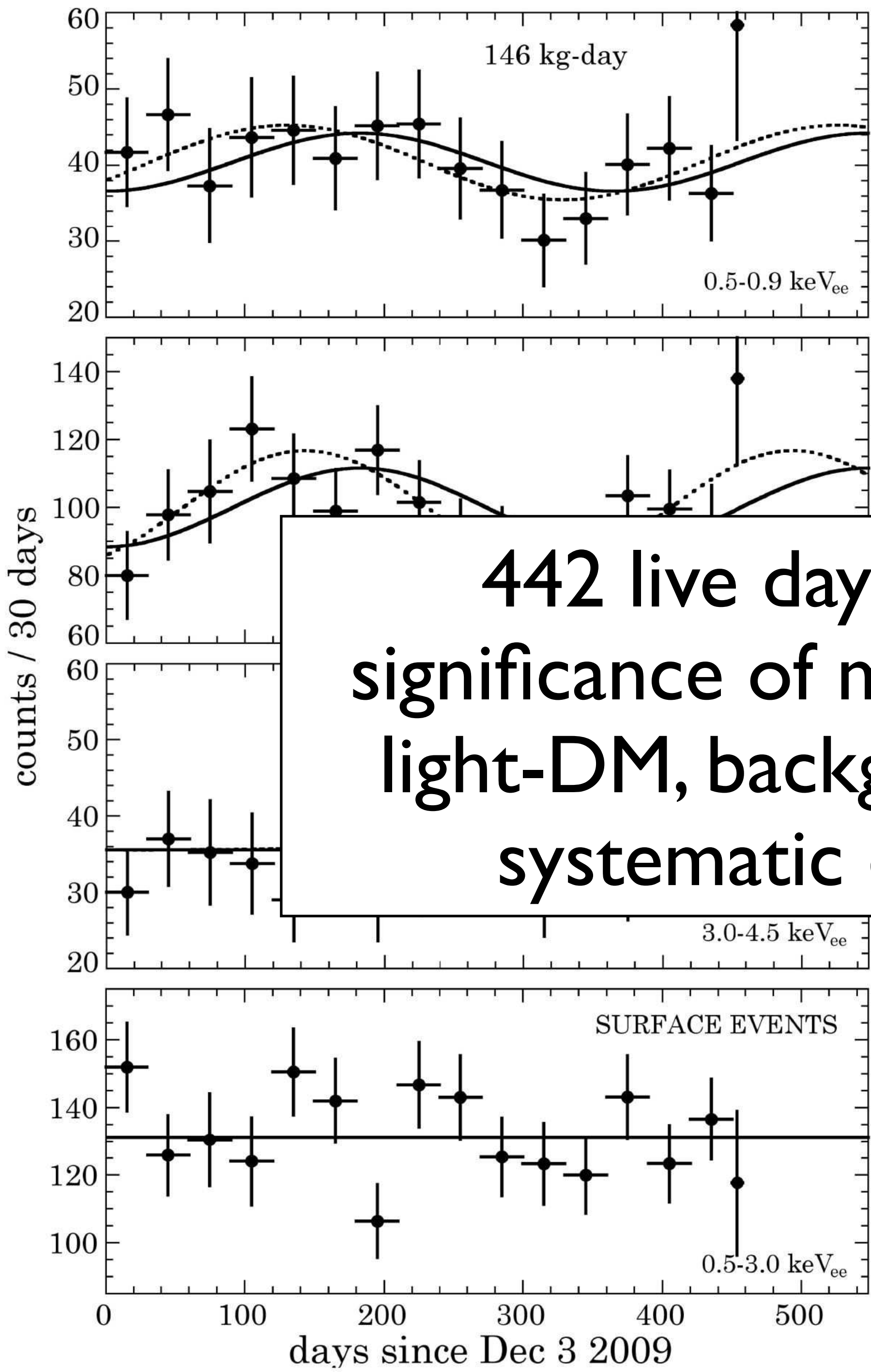

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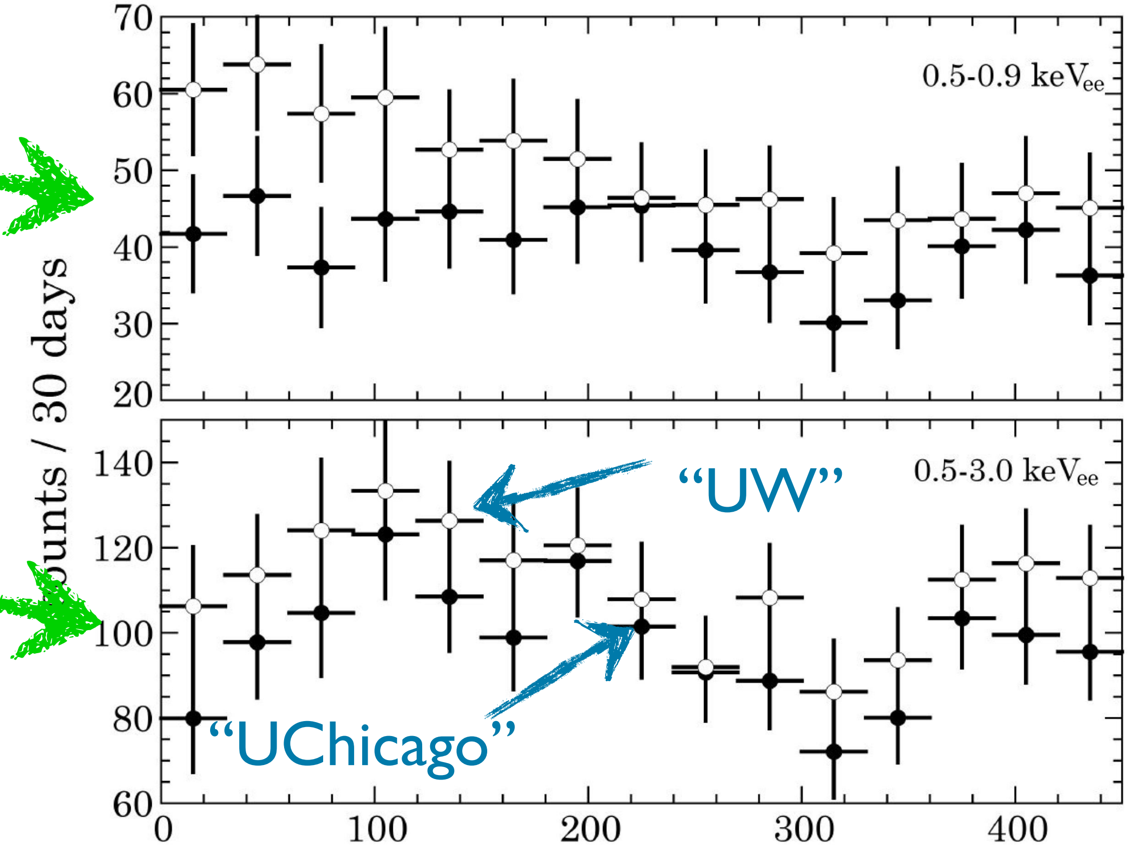

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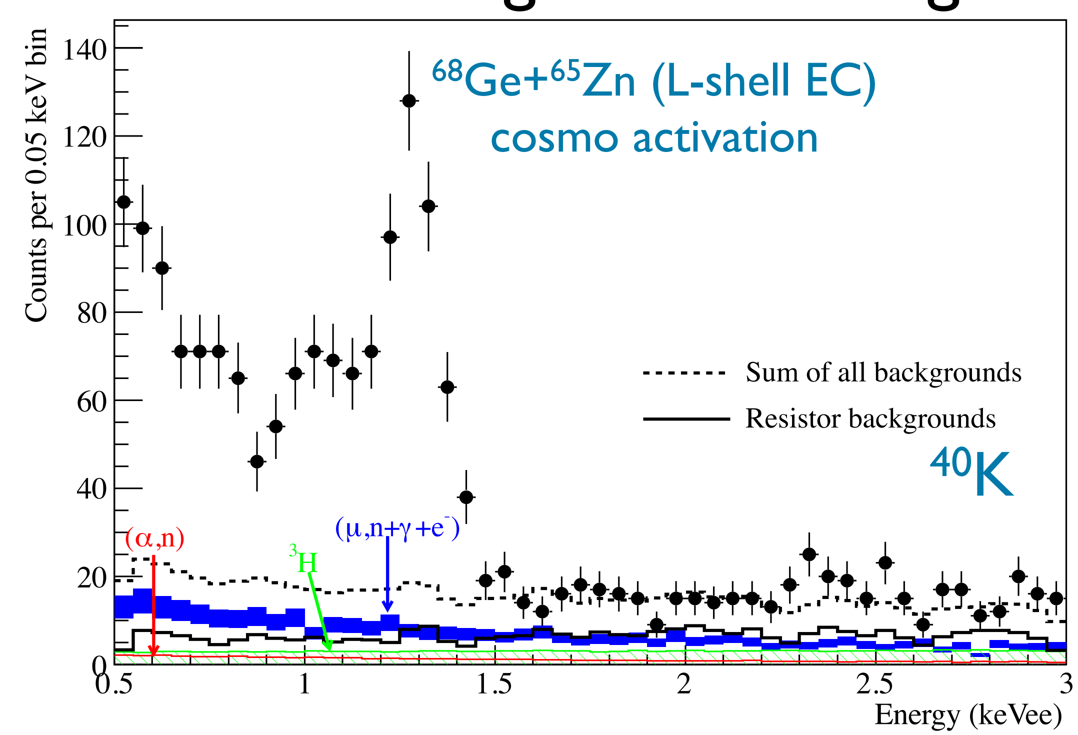
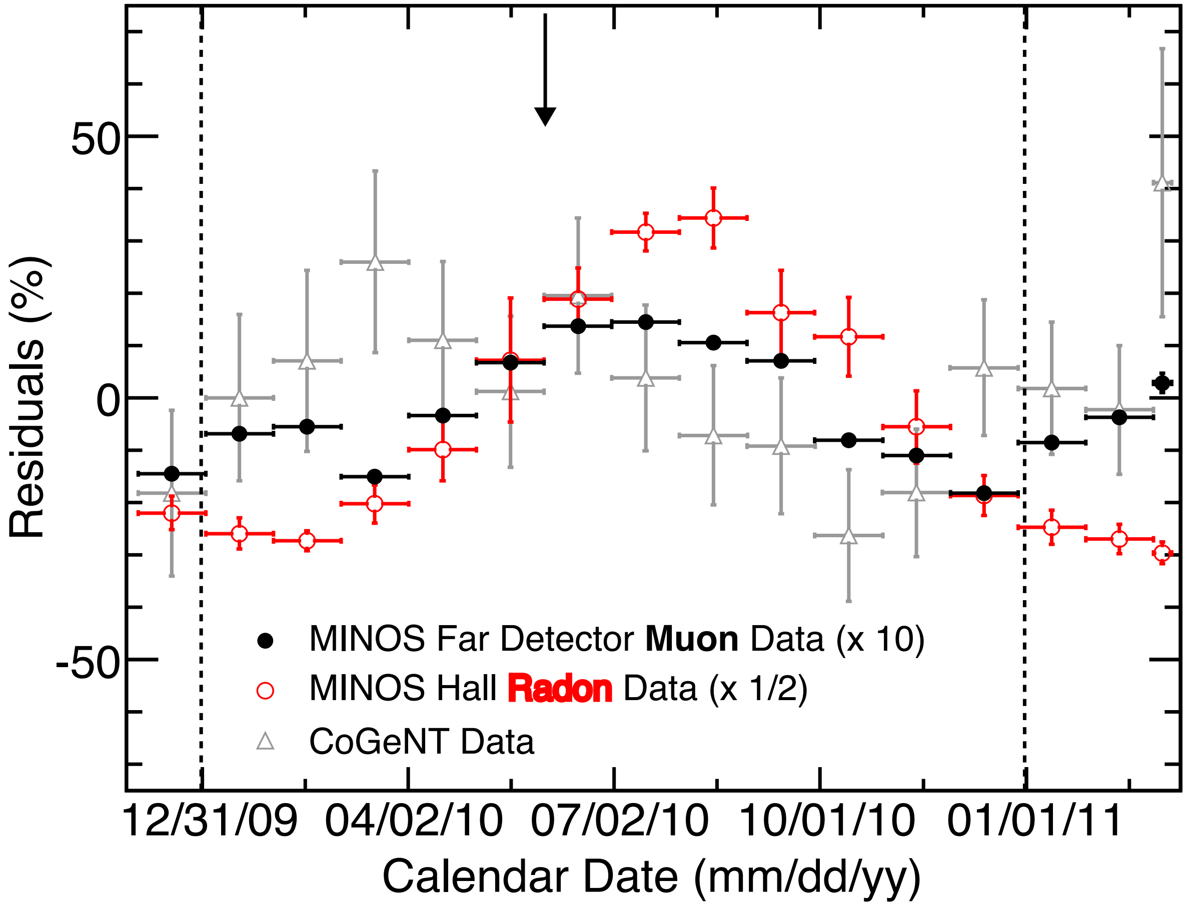


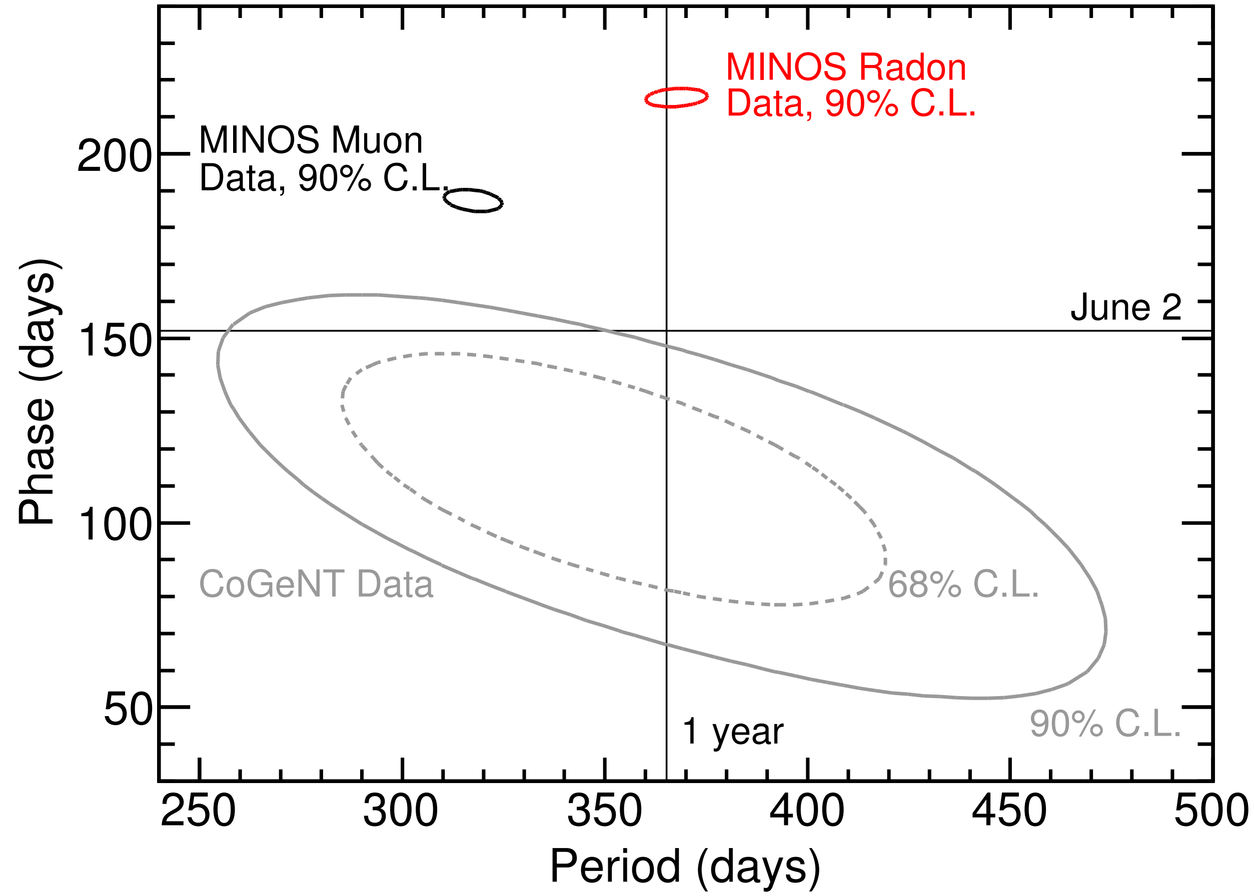
Experiment continues to take data since June 2011… (i.e. 602 days and counting!)

MINOS - CoGeNT correlation

MINOS is in close proximity to CoGeNT

MINOS Coll, arXiv:1212.1776

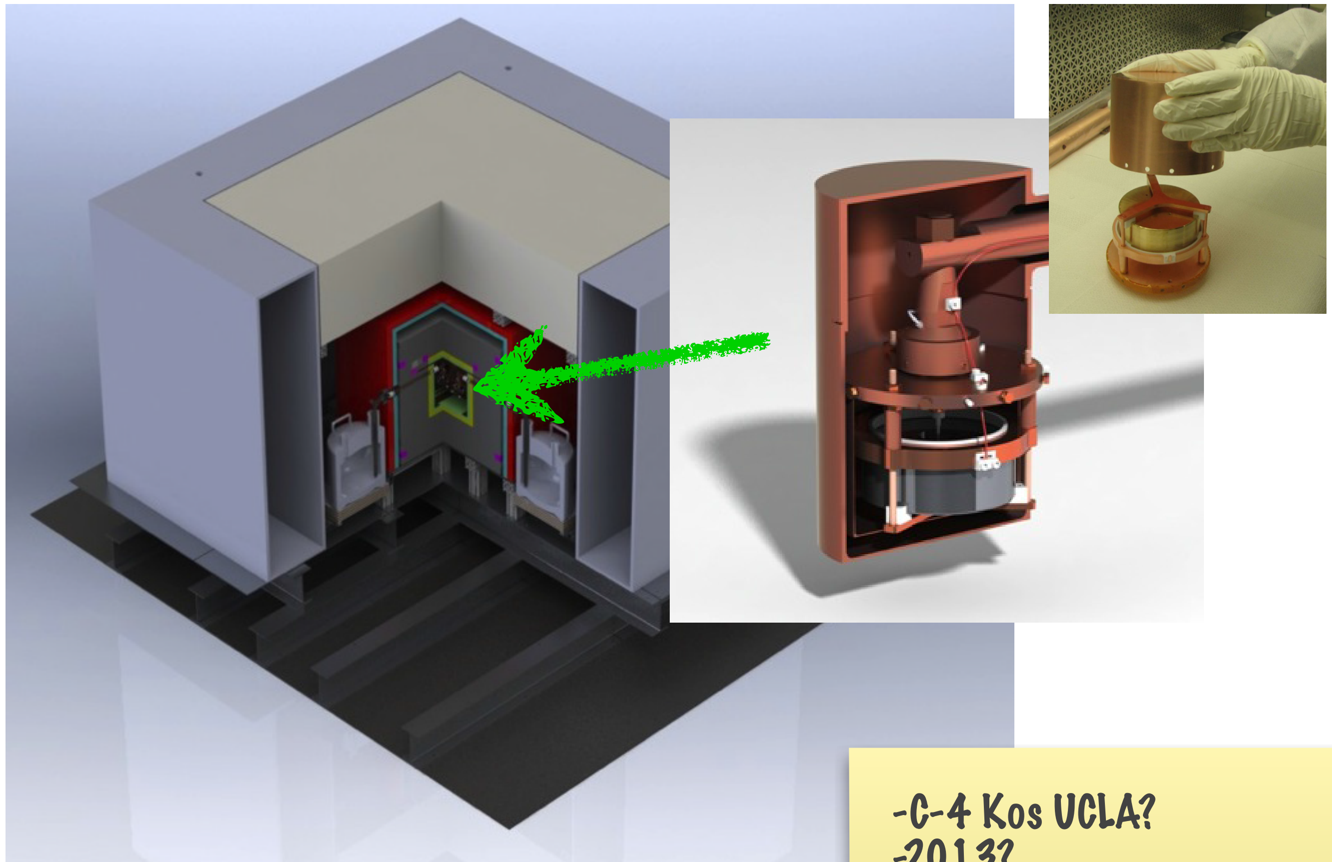




CoGeNT annual modulation as due to Radon or Atmospheric muon flux modulation inconsistent at 3σ

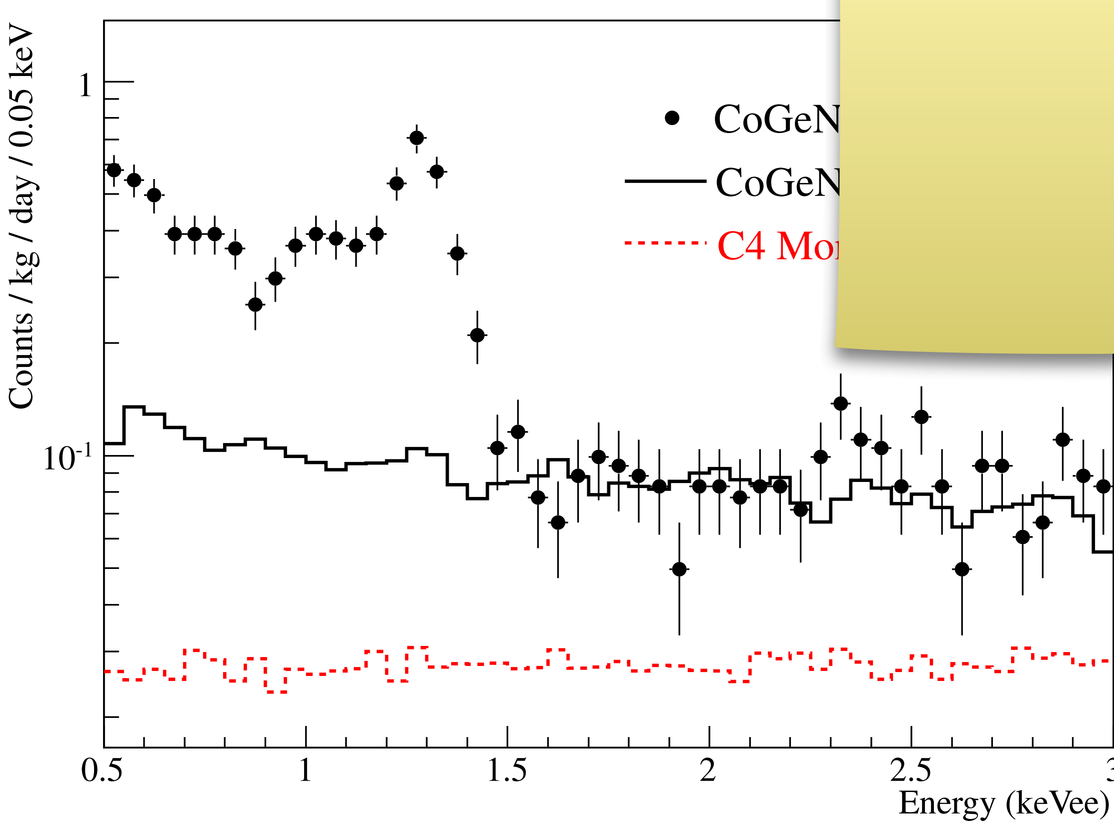
[17% amplitude CoGeNT signal vs ~2% muon flux variation]

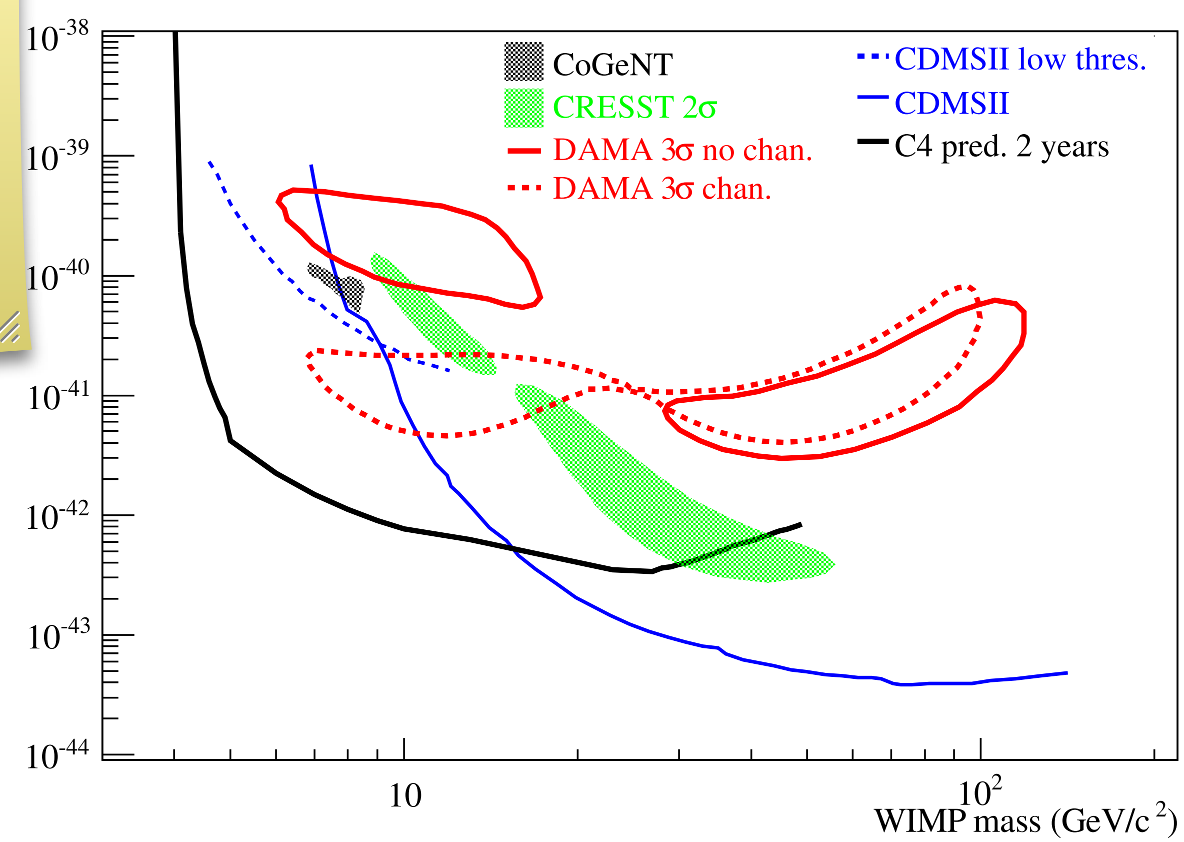
C-4



- C-4: same technology as CoGeNT
  - 10x larger Ge mass
  - Lower backgrounds and thresholds
  - In construction

-C-4 Kos UCLA?
-2013?

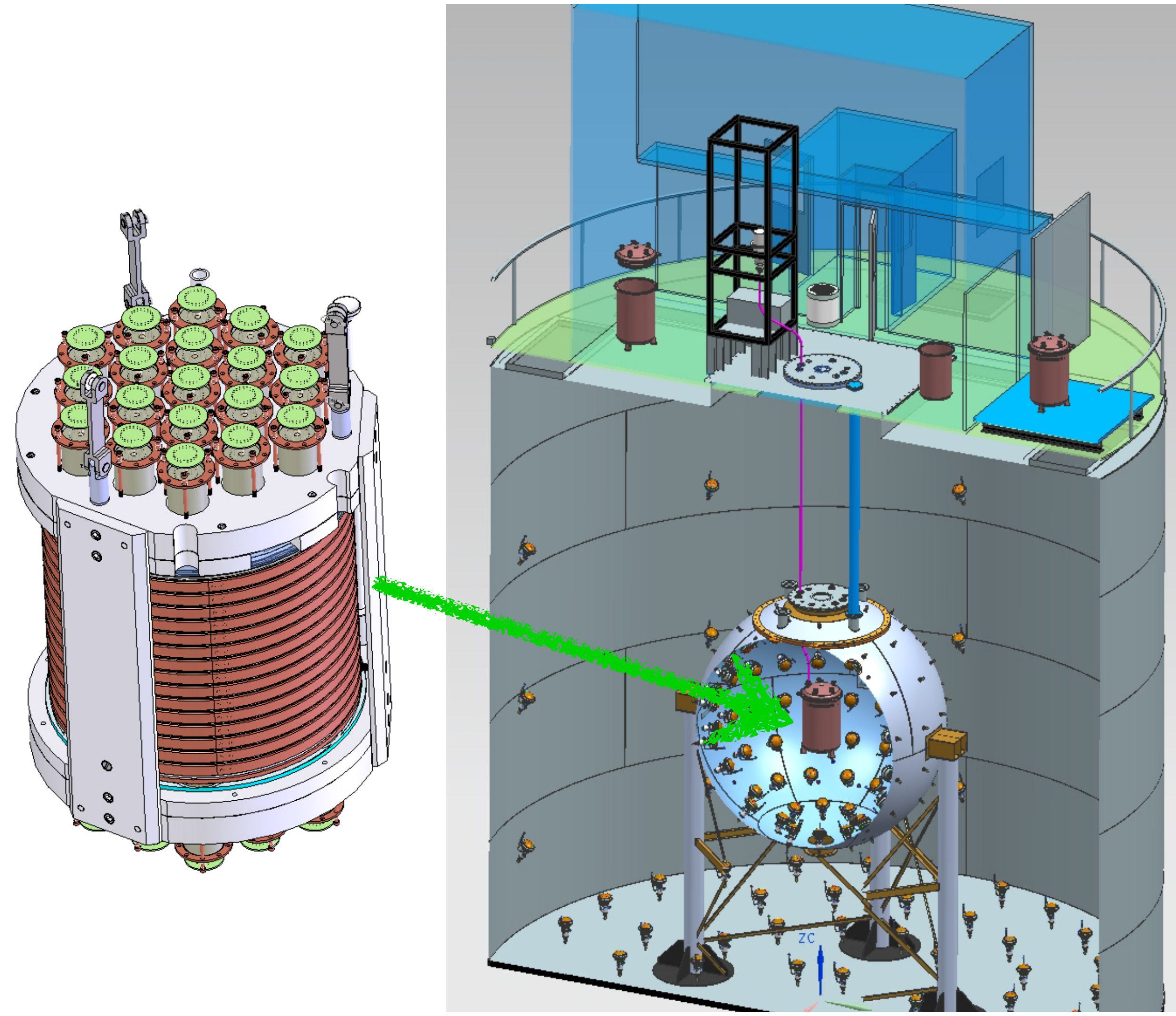


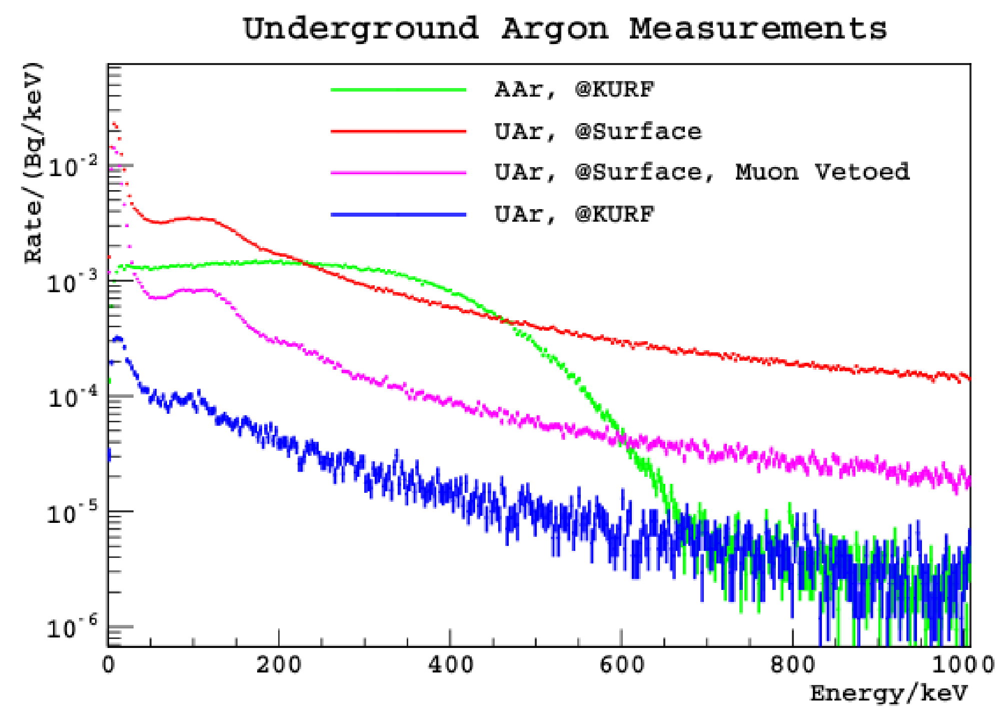


C-4 Coll, arXiv:1210.6282

DarkSide-50

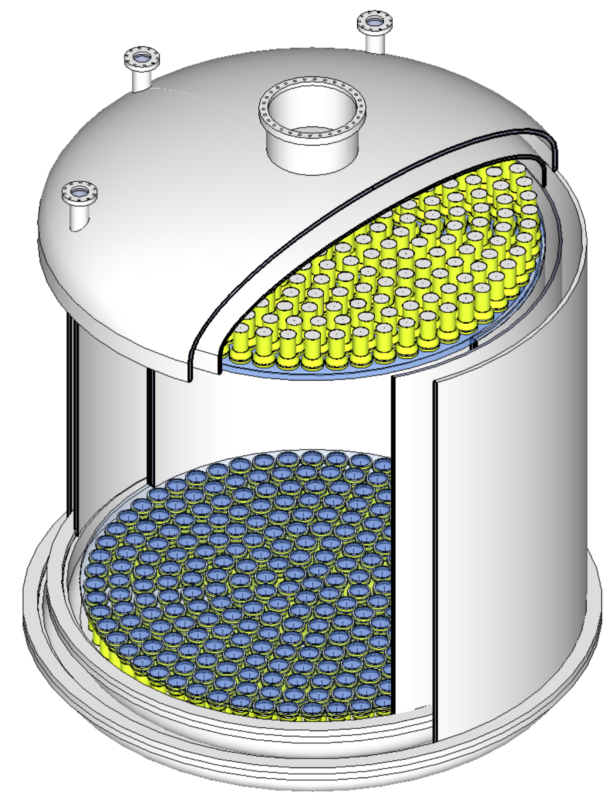
- Dual-phase LAr experiment
  - Uses S1 vs S2 discrimination
  - And Pulse Shape Discrimination
- Depleted Argon: ^{39}Ar < 1% of Atmo Ar
  - Produced in upper atmo due to CR
  - ^{39}Ar 1Bq/kg background
- Liquid scintillator neutron veto
- Uses existing CTF watertank as muon veto and neutron shield
- DS-50: 50kg (~33kg fiducial)
- First data in 2013, 3yr data taking



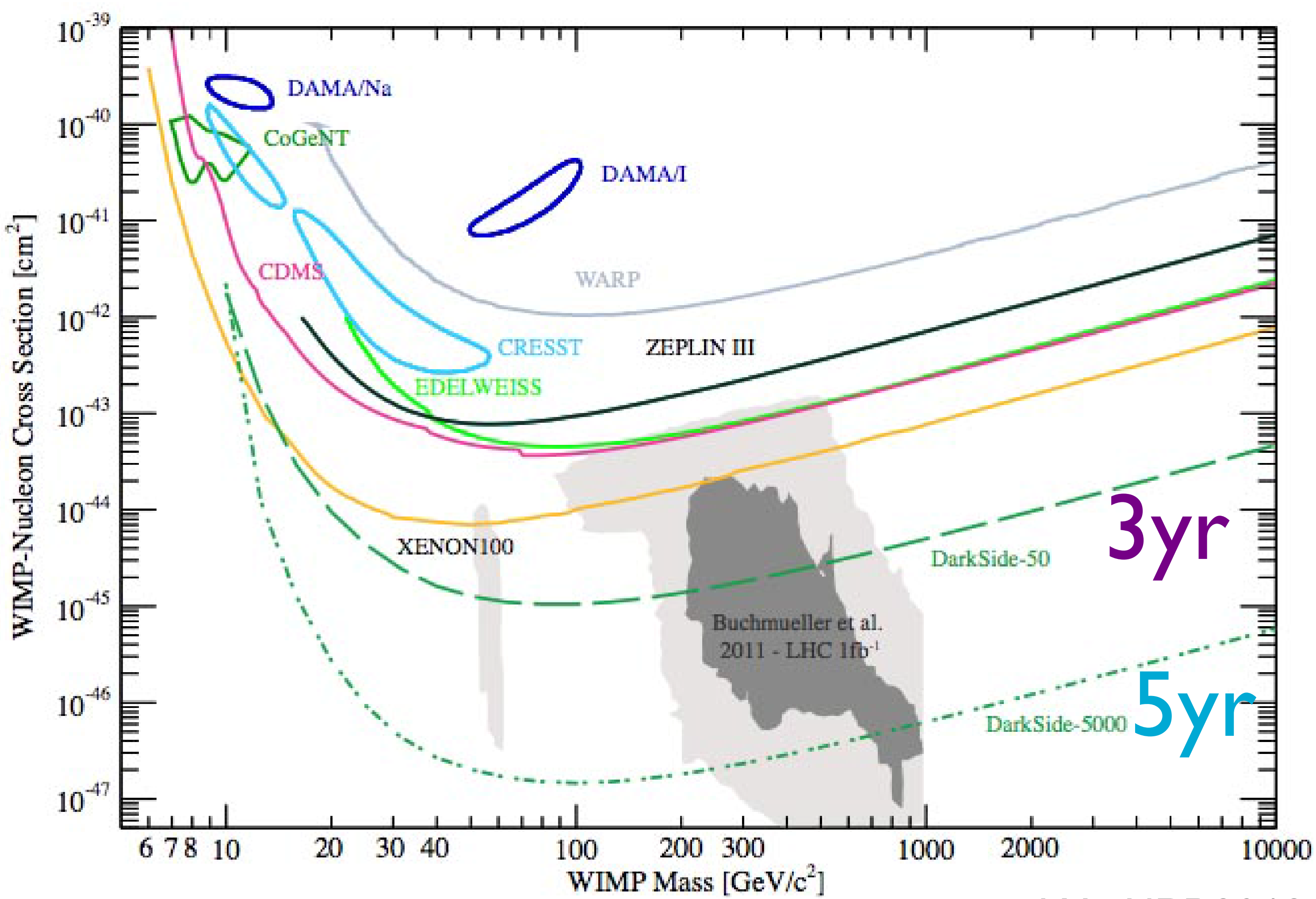


DarkSide-5000

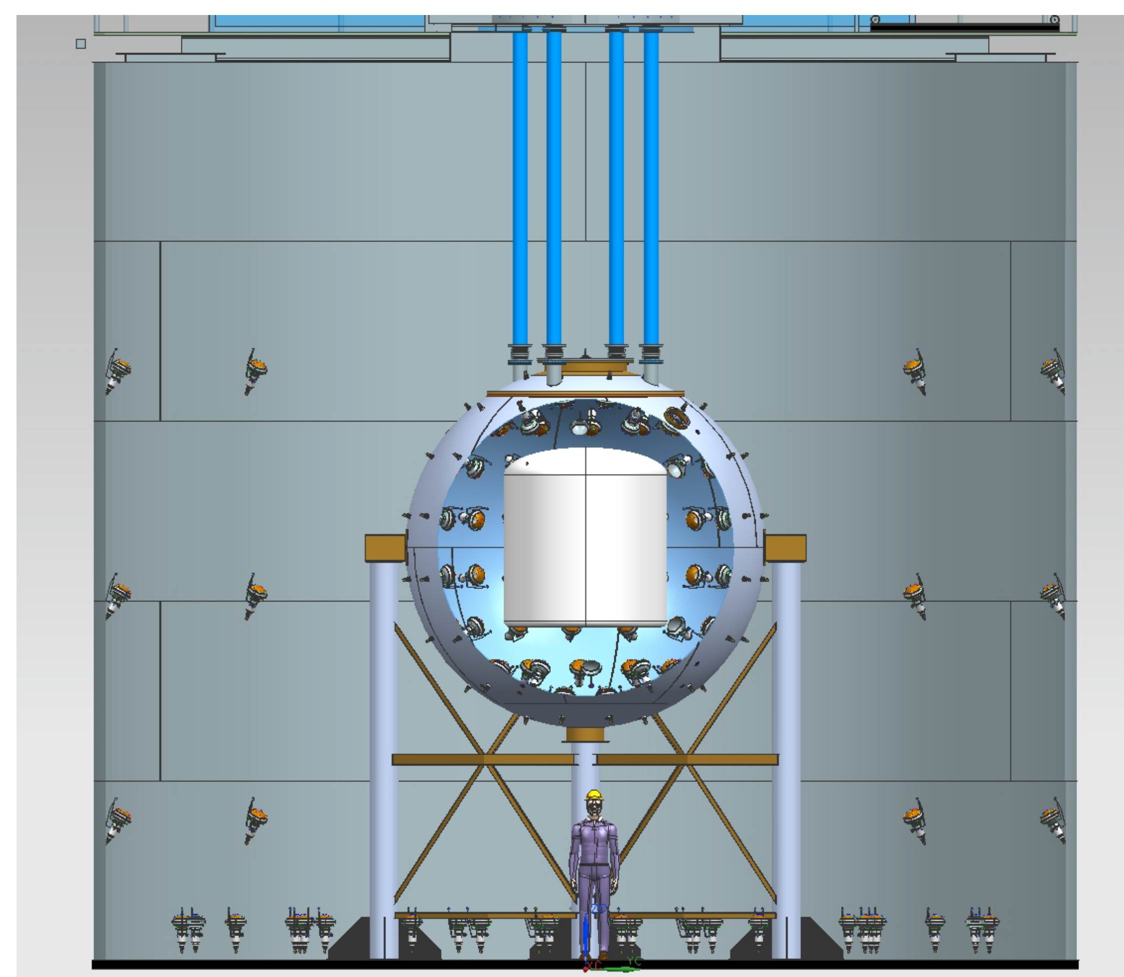
- DS-5000: ~3.3t active (~2.8t fid) LAr
- Scale up of DS-50, using same veto system



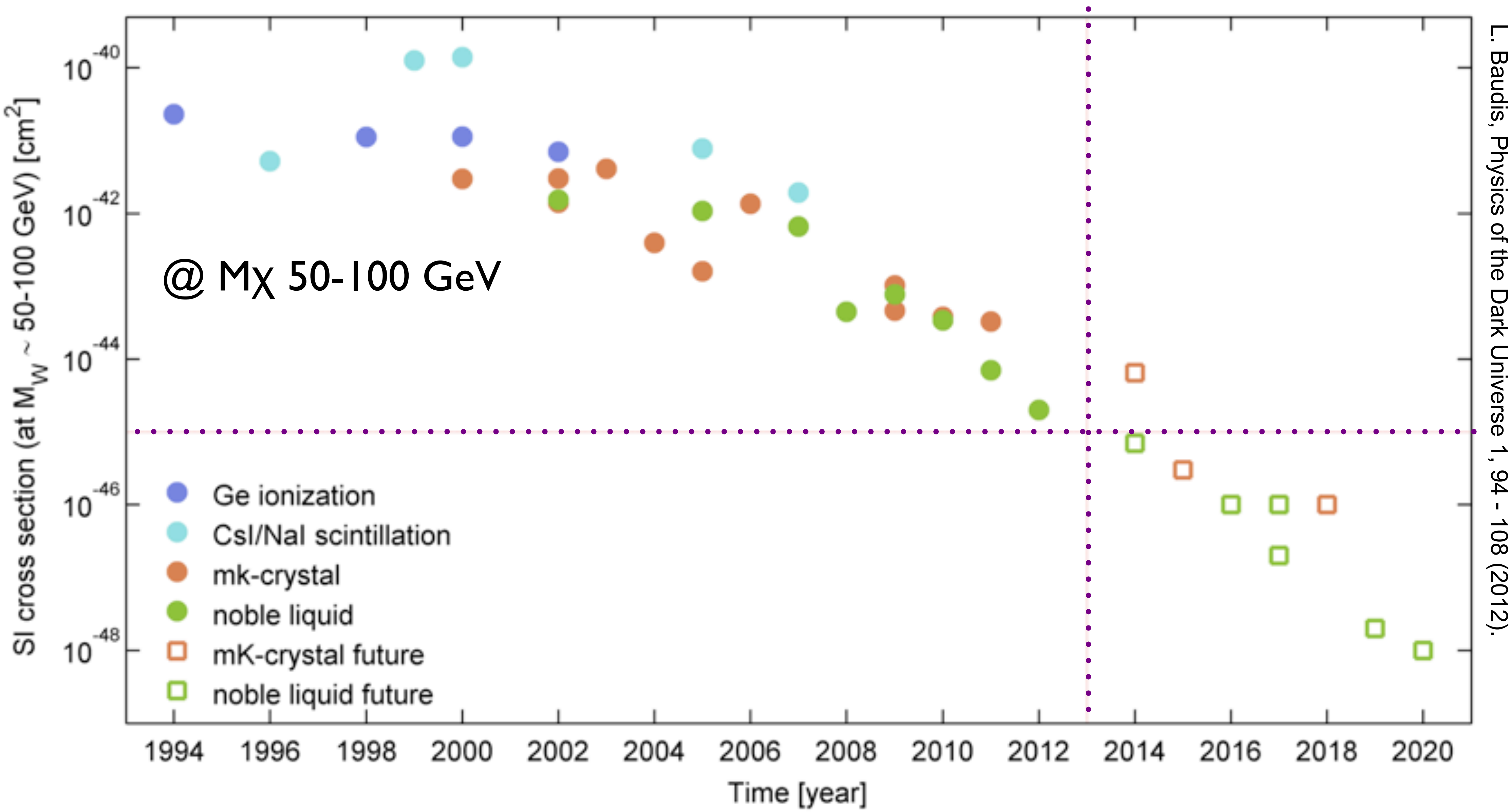
558 3” PMTs



J.Xu NPB2012

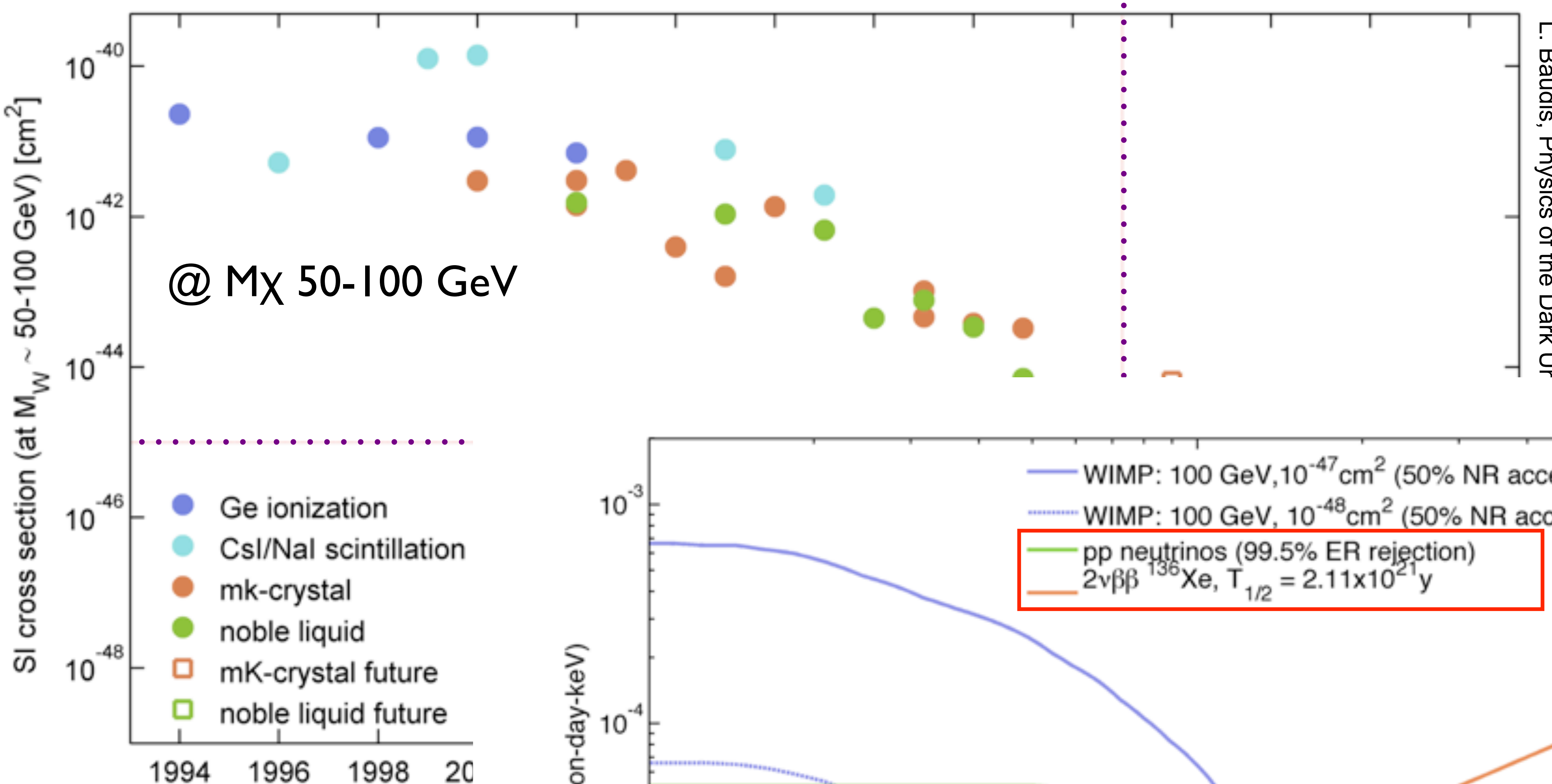


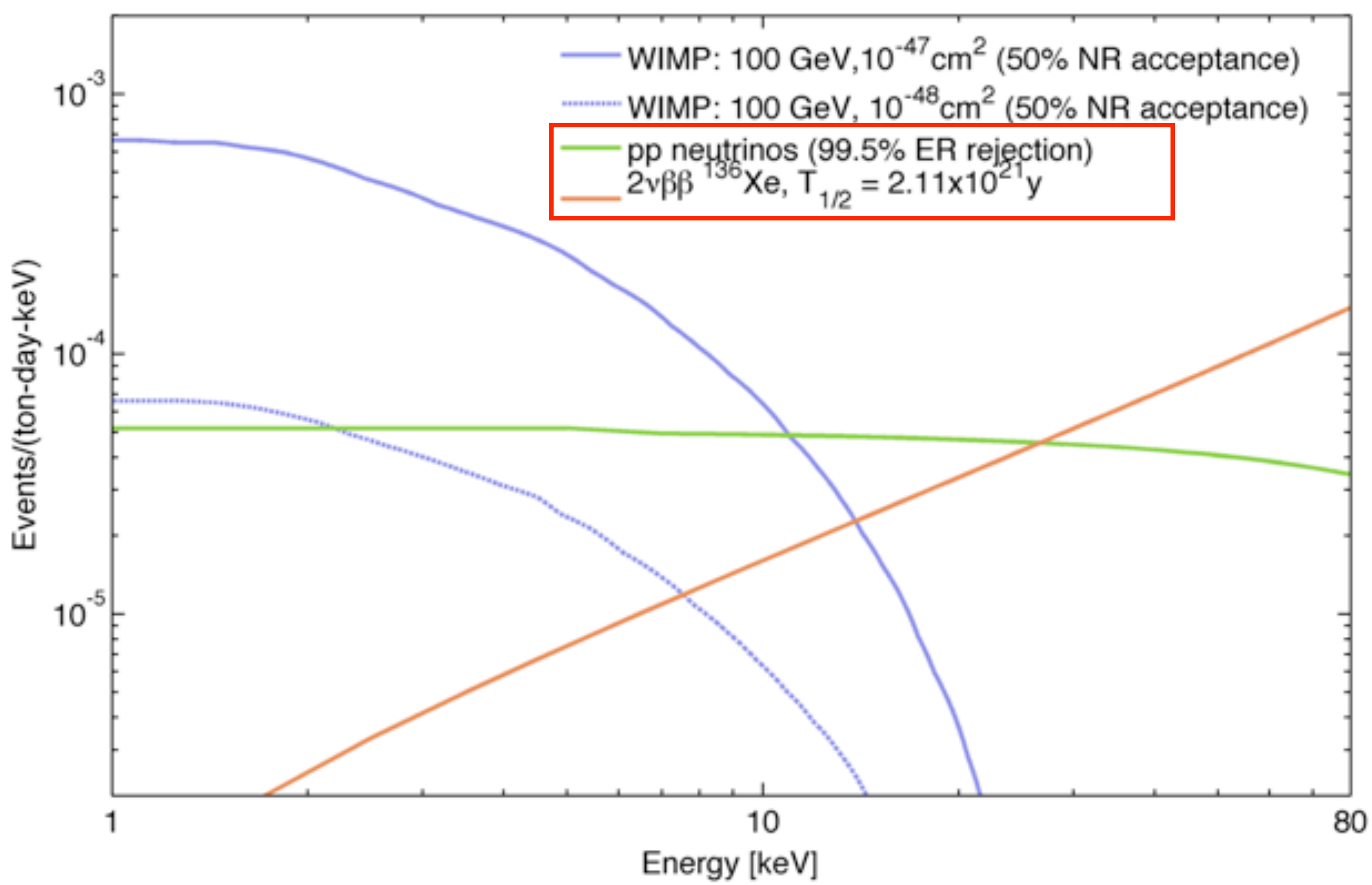
Reach of Future Detectors



<u>Sat. afternoon</u>
Future Noble Liq
D.McKinsey
Future Solid State Dev
R. Schnee

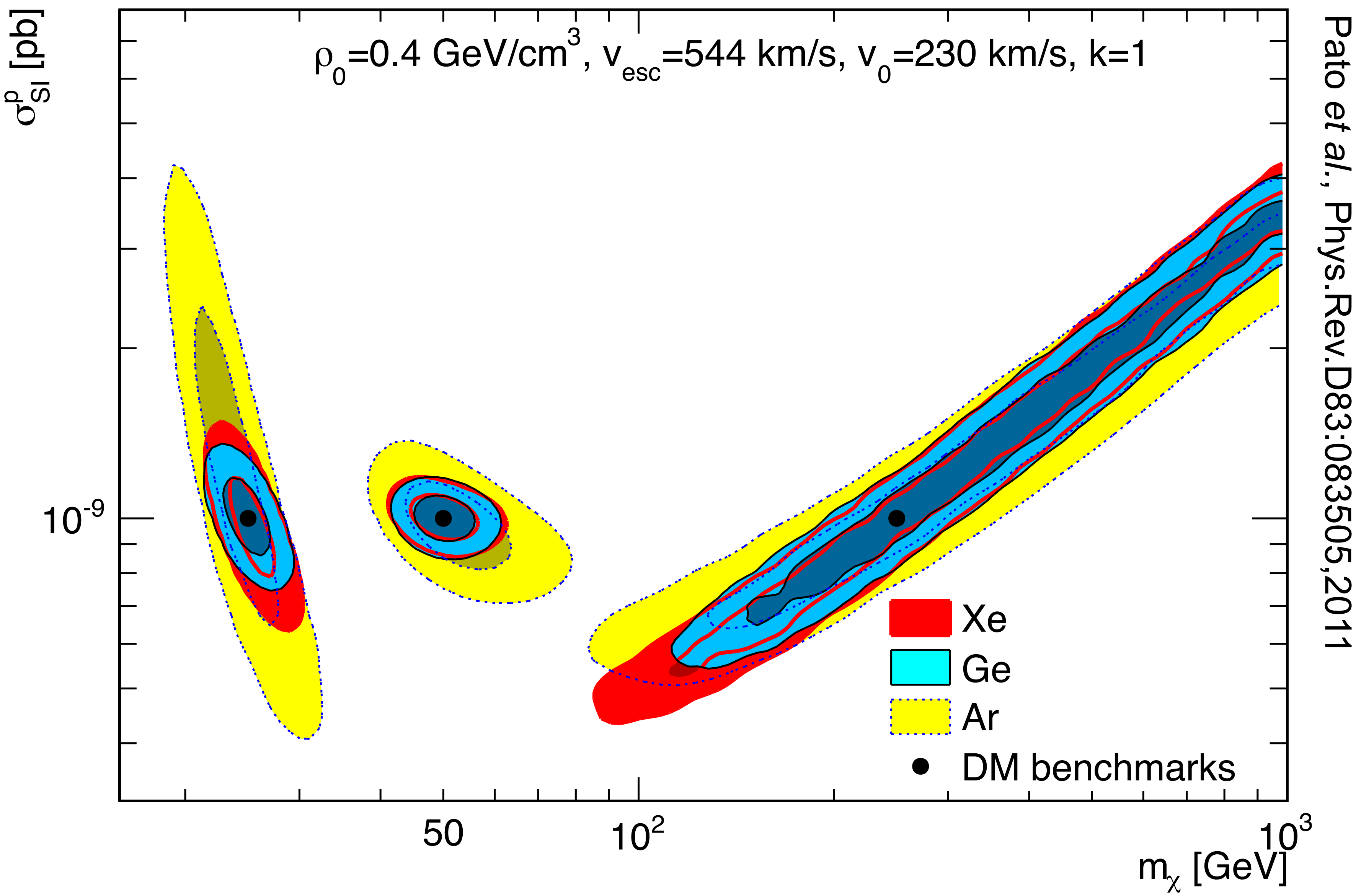
Reach of Future Detectors



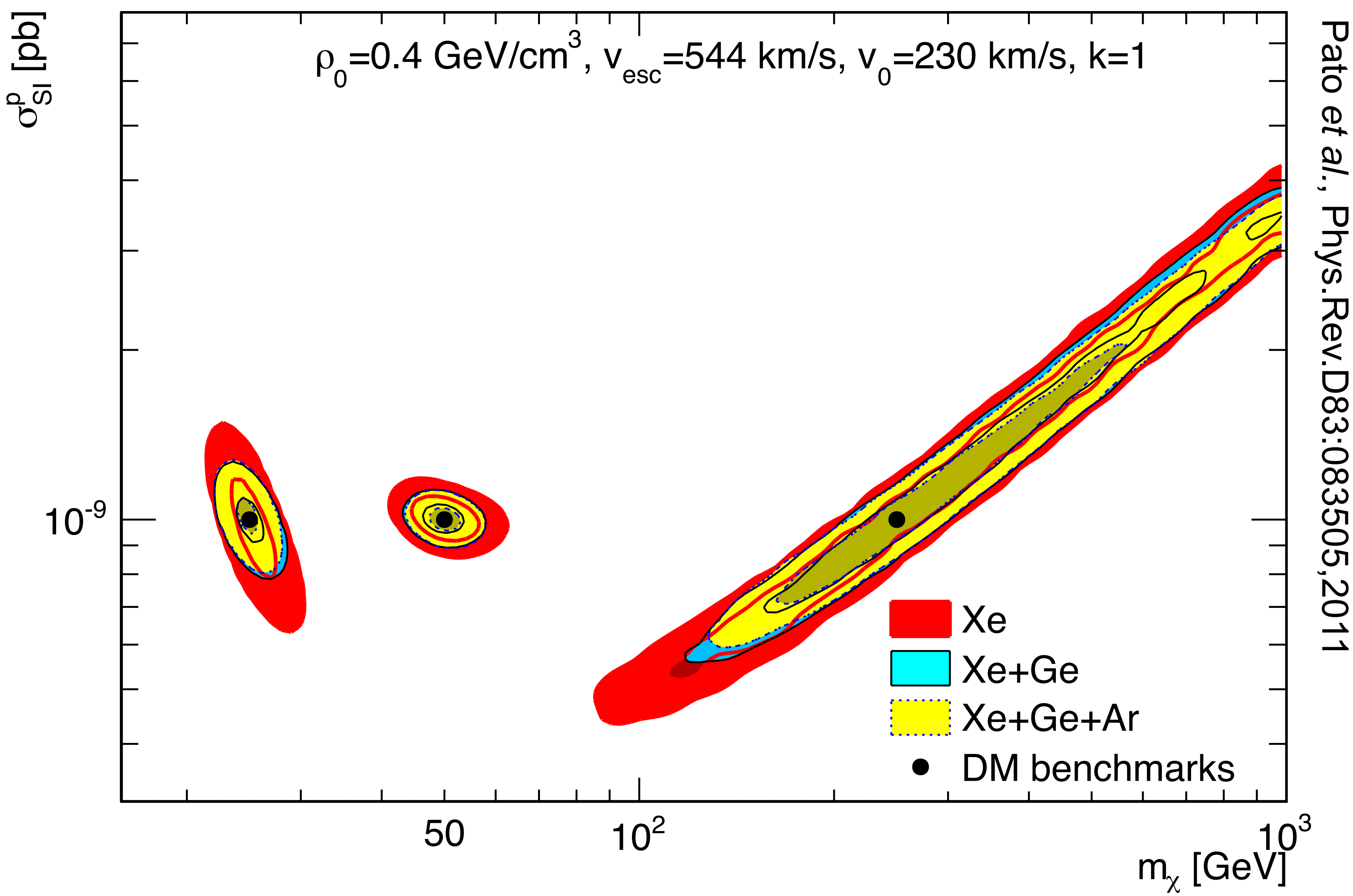


Wed. morning
Nu backgrounds
T.Figueroa

Astrophysical Uncertainties

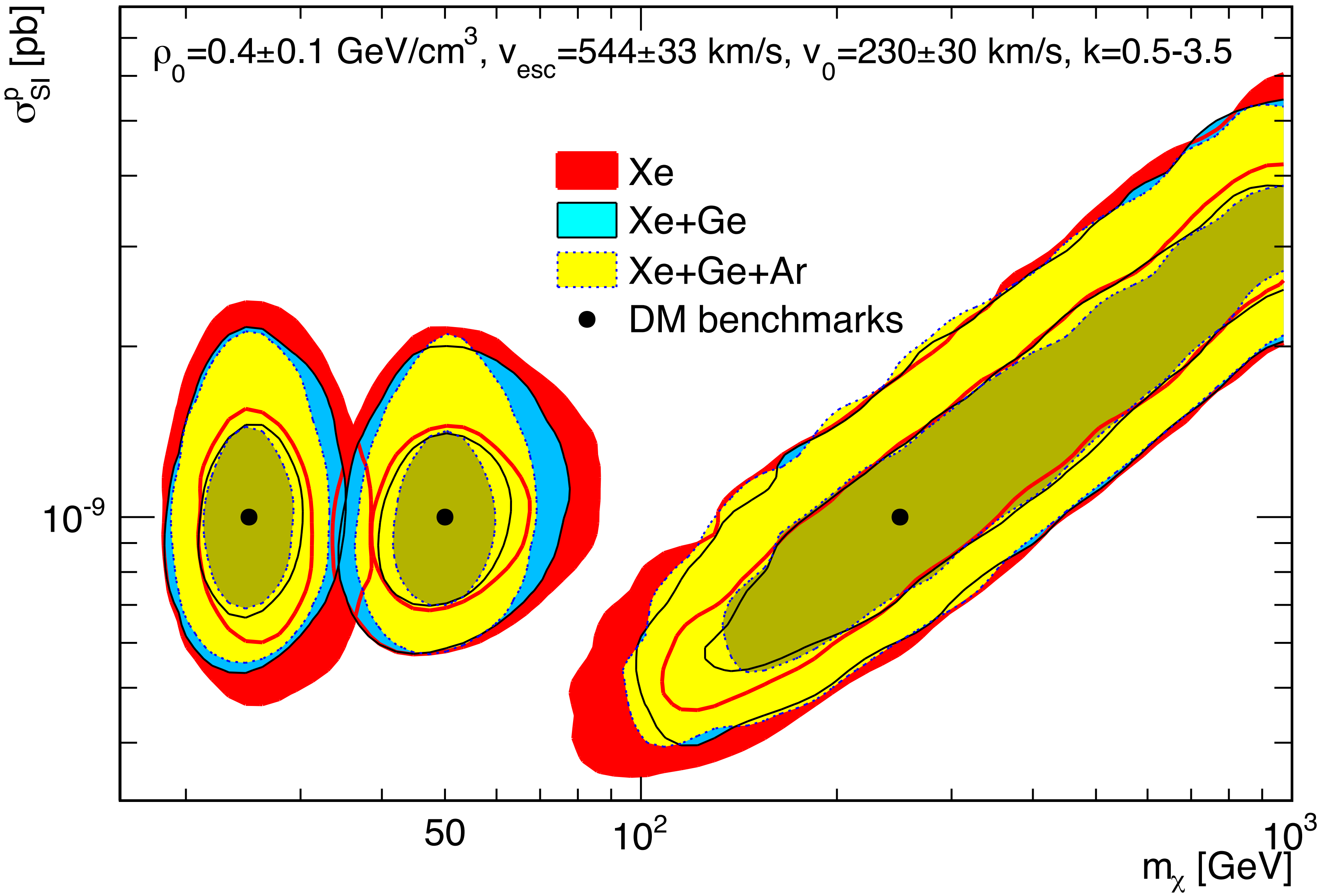


Astrophysical Uncertainties



Patrick Decowski - Nikhef/UvA

Astrophysical Uncertainties



Pato *et al.*, Phys.Rev.D83:083505,2011

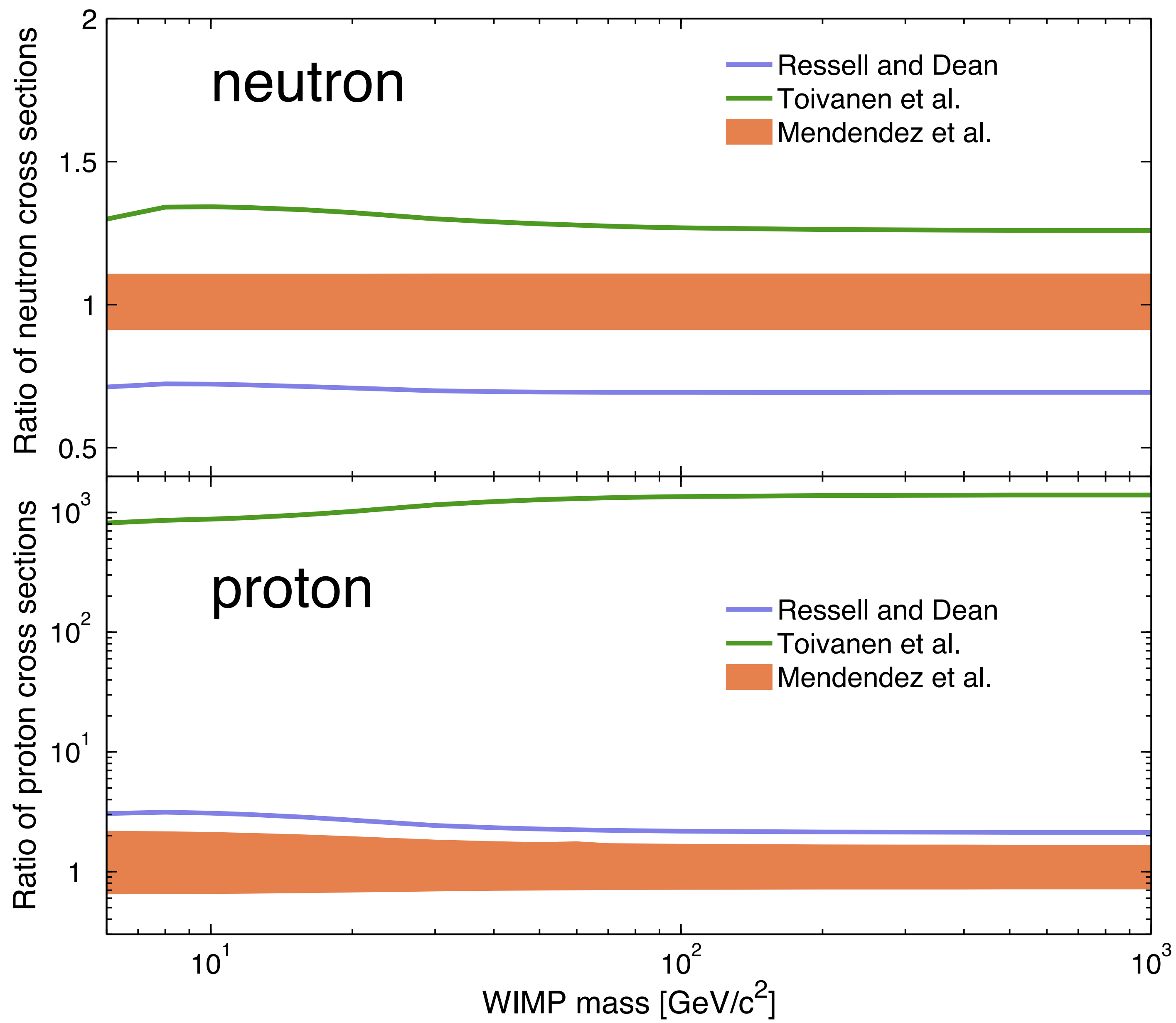
Interpreting SD limits

Rate on nucleus → Nuclear Model → WIMP-nucleon spin-dependent limits

Xe specific case… (others?)

$$\sigma_{p,n}(q) = \frac{3}{4}\frac{\mu_{p,n}^2}{\mu_A^2}\frac{2J+1}{\pi}\frac{\sigma_{SD}(q)}{S_A(q)}$$

Nuclear structure uncertainties



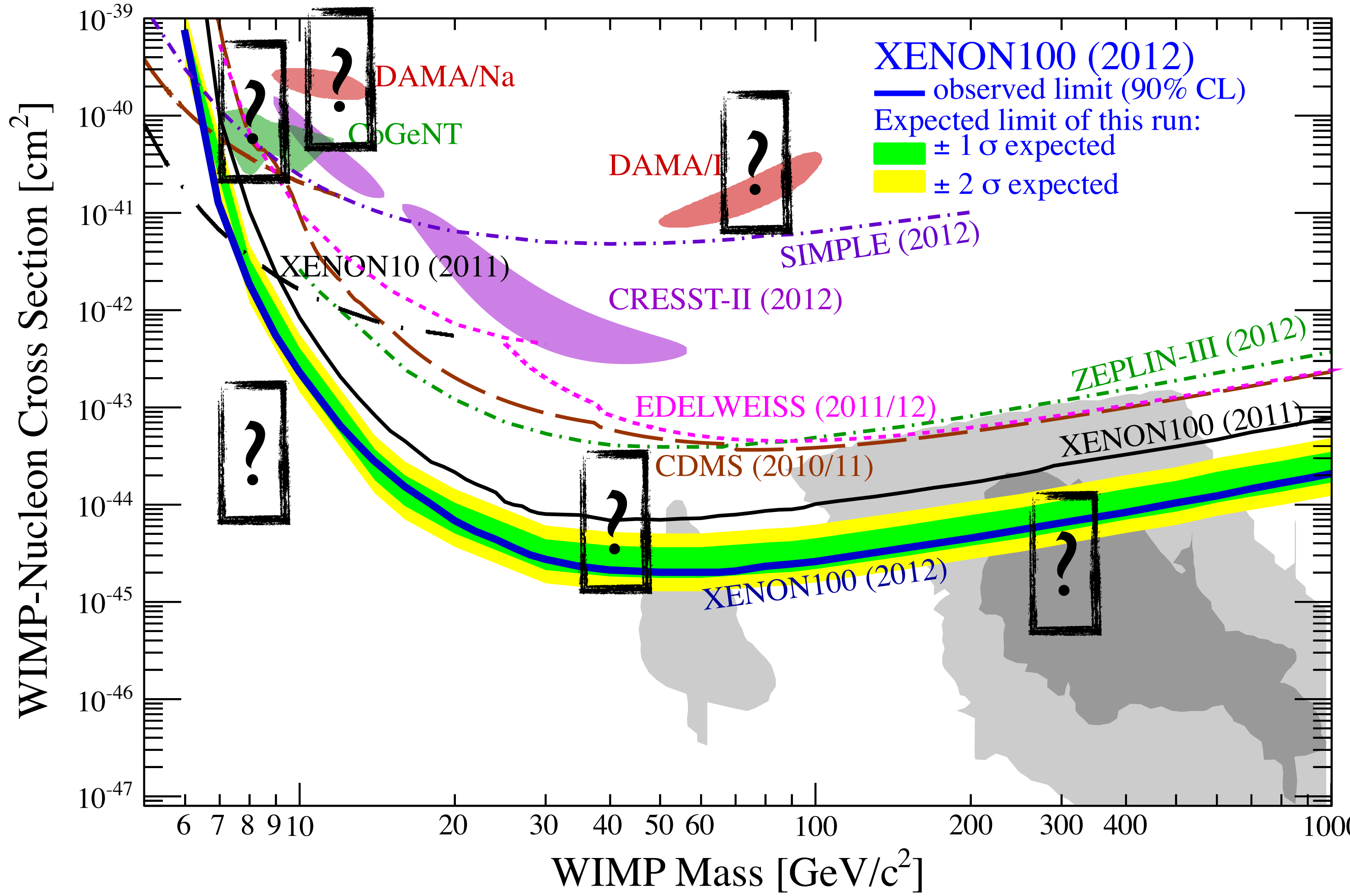
30% variation

O(1000) difference!

Affects **interpretation** of WIMP-proton SD limits.
Measurements to help constrain nuclear models?

What will 2013 bring?

- LUX running
- XMASS back running
- DarkSide-50 running
- COUPP-60…
- DEAP-3600 Fall 2013
- CoGeNT? C-4?



- DAMA running high QE PMTs since Dec 2010…
- …[all the experiments that I missed or that simply quietly continue to take data]

2013 will be an exciting Direct Detection DM year!

This week's Direct Detection Talks

Session	Experiment	Speaker
Tuesday Morning	XENON100	E.Pantic
	SuperCDMS	J. Hall
	XMASS	K. Kobayashi
Wednesday Morning	Neutrino Backgrounds	T. Figueroa
	LUX	R. Gaitskell
	XENON1T	R. Lang
Thursday Morning	DAMA/LIBRA	P. Belli
	KIMS	Y. Kim
	DM-Ice	R. Maruyama
Saturday Morning	COUPP	R. Neilson
	PandaX	S. Stephenson
	DM-TPC	J. Battat
Saturday Afternoon	DEAP/CLEAN	K. Palladino
	Future with Noble Liquid	D. McKinsey
	Future with Solid State Devices	R. Schnee