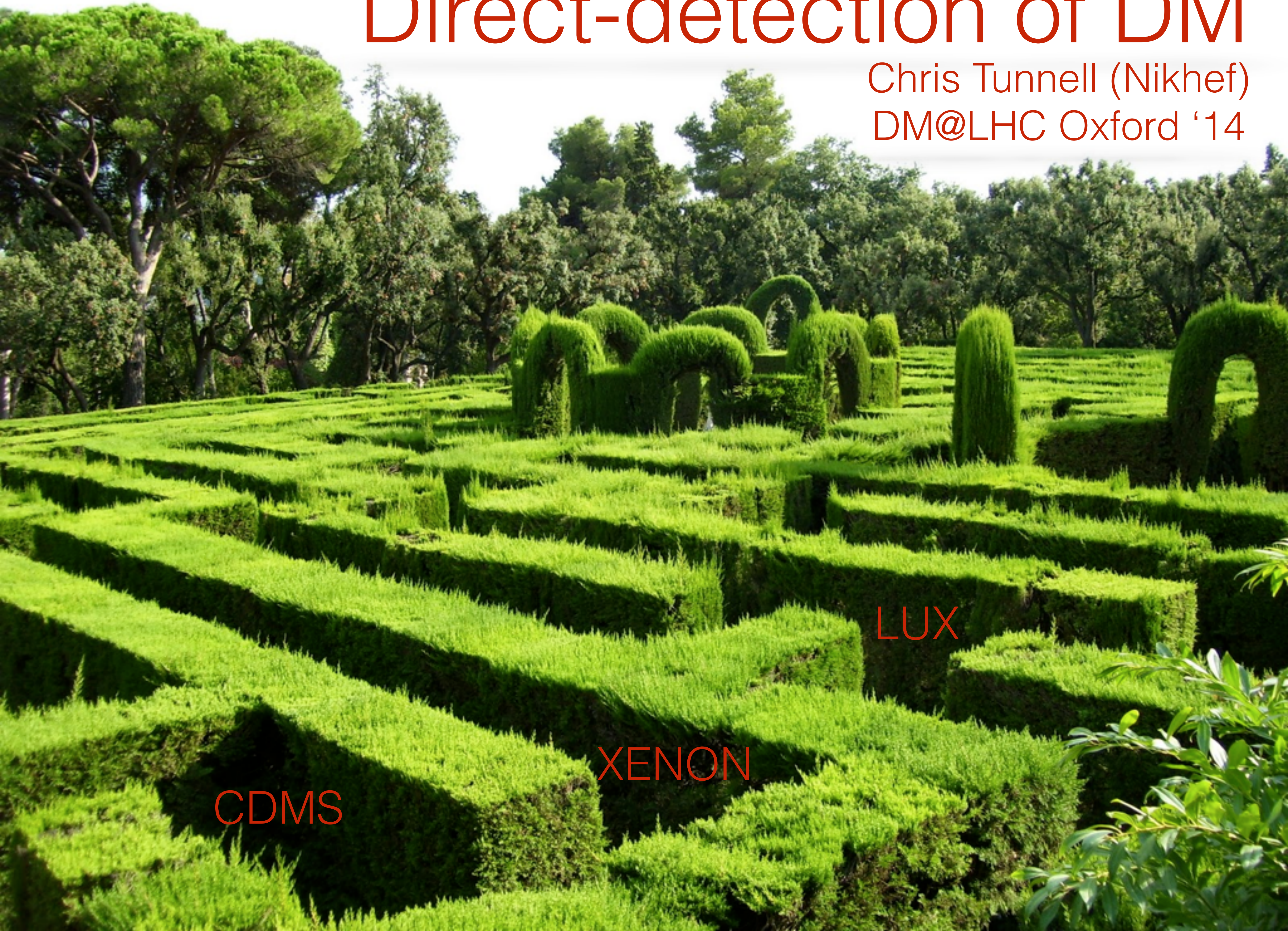
Direct-detection of DM

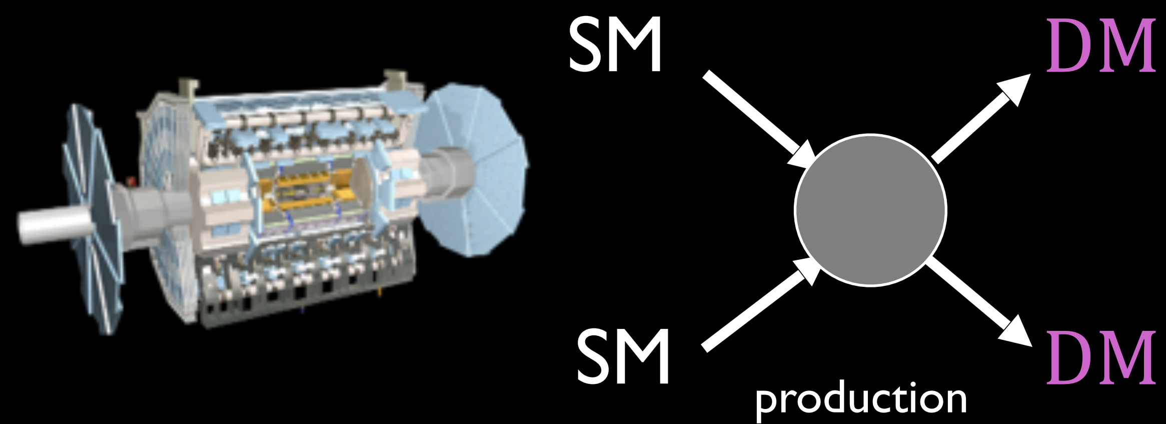
Chris Tunnell (Nikhef)

DM@LHC Oxford '14

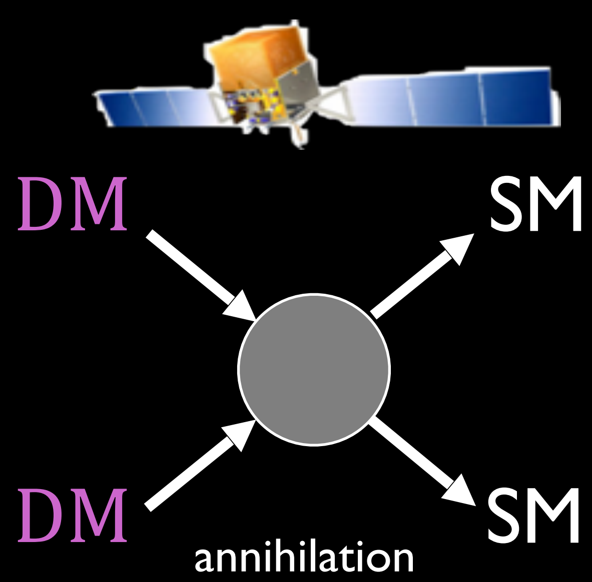


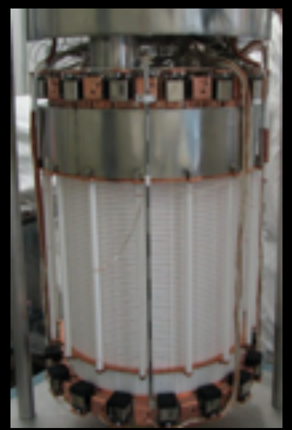
My goal: explain stream of claimed signals and refutations

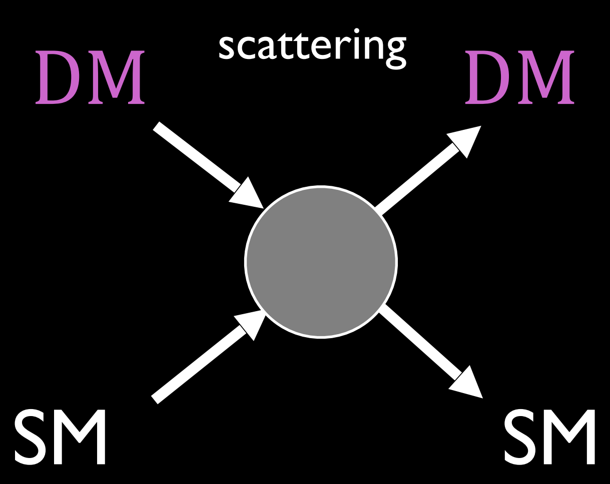
1. How direct detection is different and difficult ’10
2. Current ‘status’ of the field ’10
3. The future (e.g., XENON1T) ’10



Three different ways how Dark Matter particles may interact with normal Matter

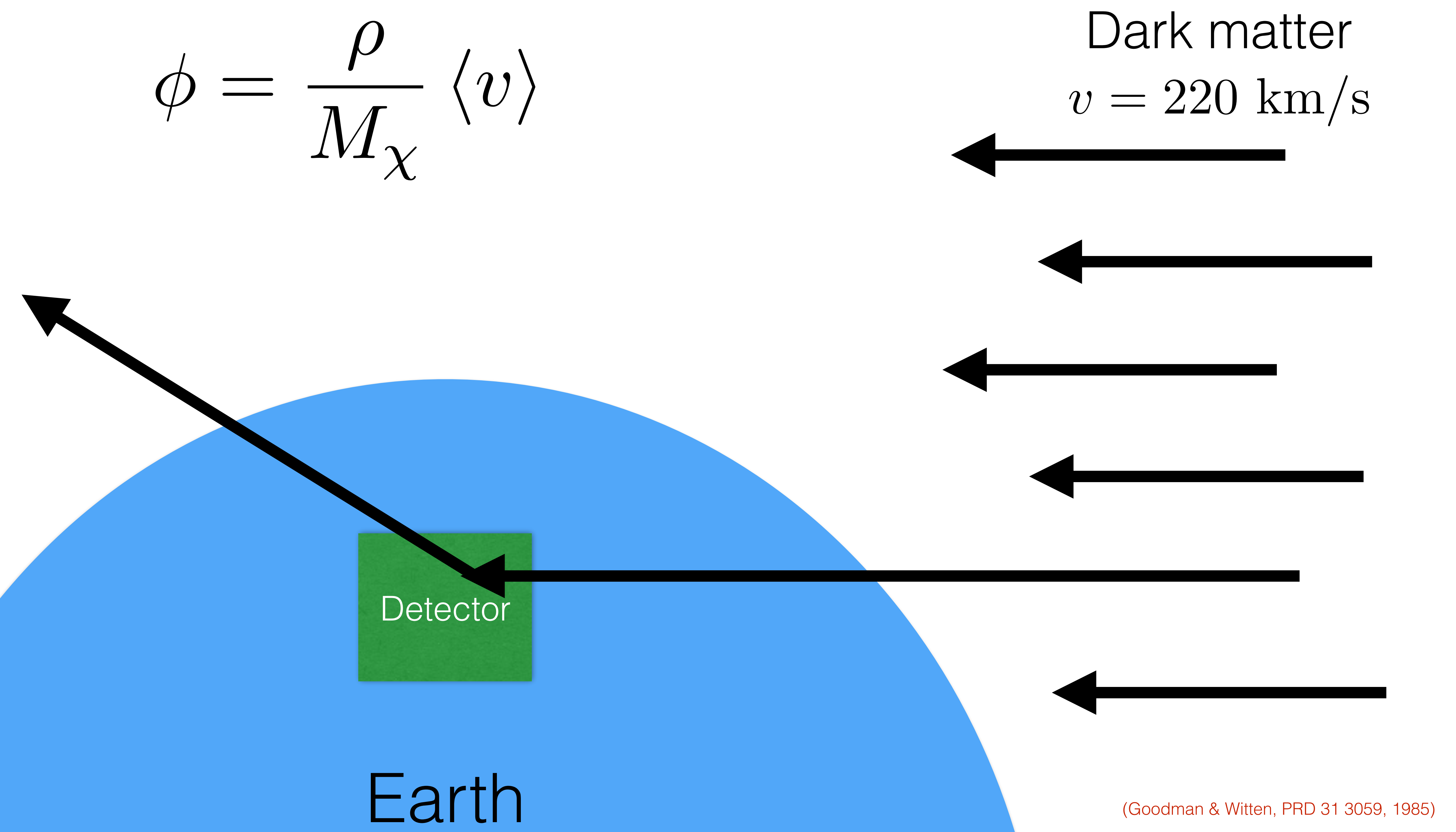






Direct-detection concept

$$\phi = \frac{\rho}{M_\chi} \langle v \rangle$$



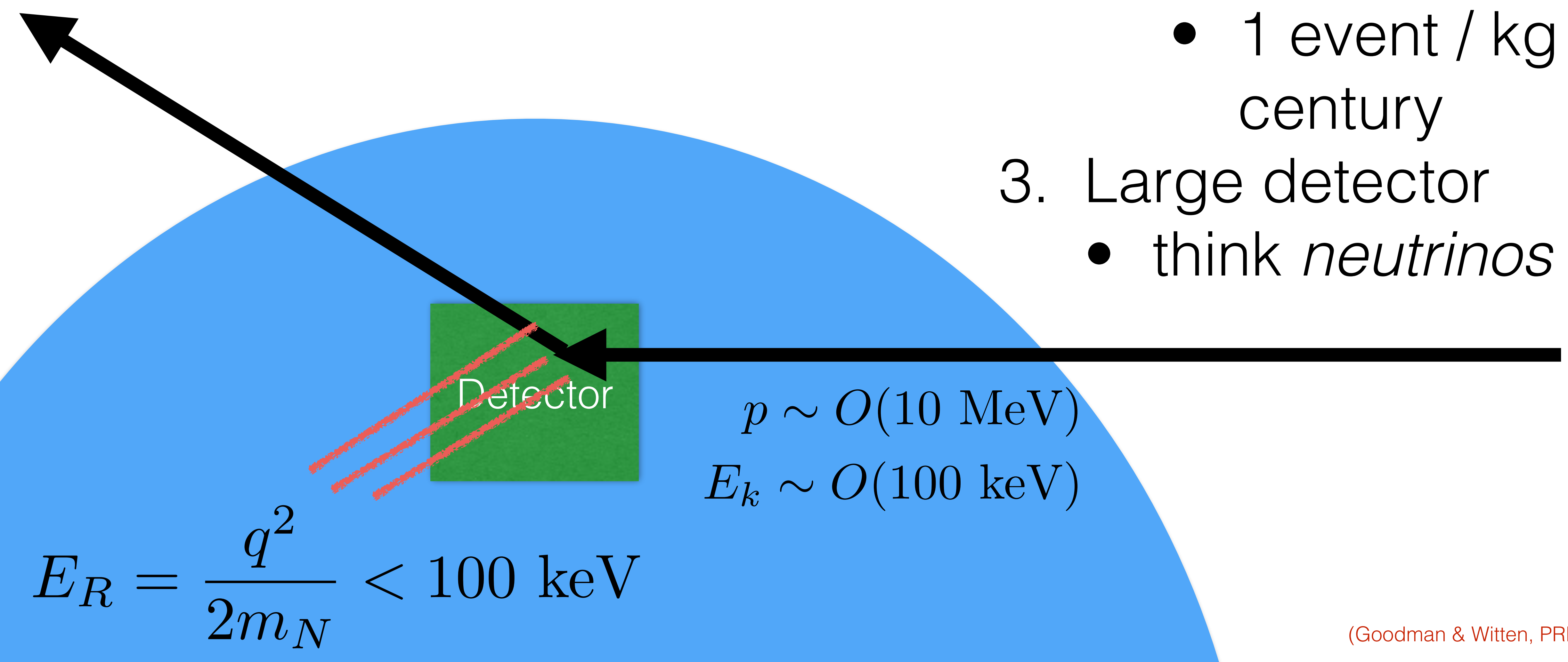
(Goodman & Witten, PRD 31 3059, 1985)

We can detect this bump.

$$\phi = \frac{\rho}{M_\chi} \langle v \rangle$$

Goals:

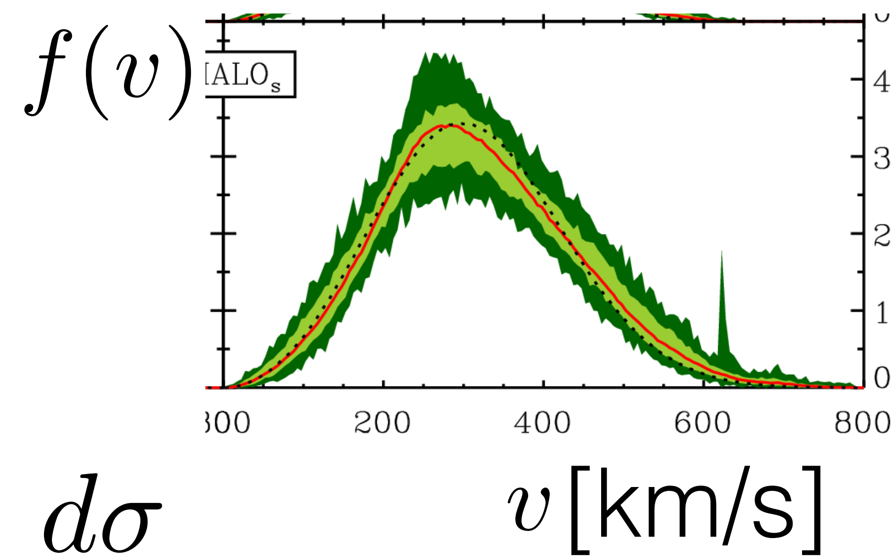
1. Low threshold
2. Low backgrounds
    - rare-event search
    - no *beam off*
    - 1 event / kg / century
3. Large detector
    - think *neutrinos*



(Goodman & Witten, PRD 31 3059, 1985)

(Baudis)

Astrophysical assumptions



(Kuhlen et al, JCAP 1002:030, 2010, arXiv:0912.2358)

Astrophysics

$$\frac{dR}{dE_R} = N_N \frac{\rho_0}{m_W} \int_{v_{\rm min}}^{v_{\rm max}} d\vec{v} f(\vec{v}) v \frac{d\sigma}{dE_R}$$

Particle/nuclear physics

$$v_{\rm min} = \sqrt{\frac{m_N E_{\rm th}}{2\mu_r^2}}$$

In practice, use simple models

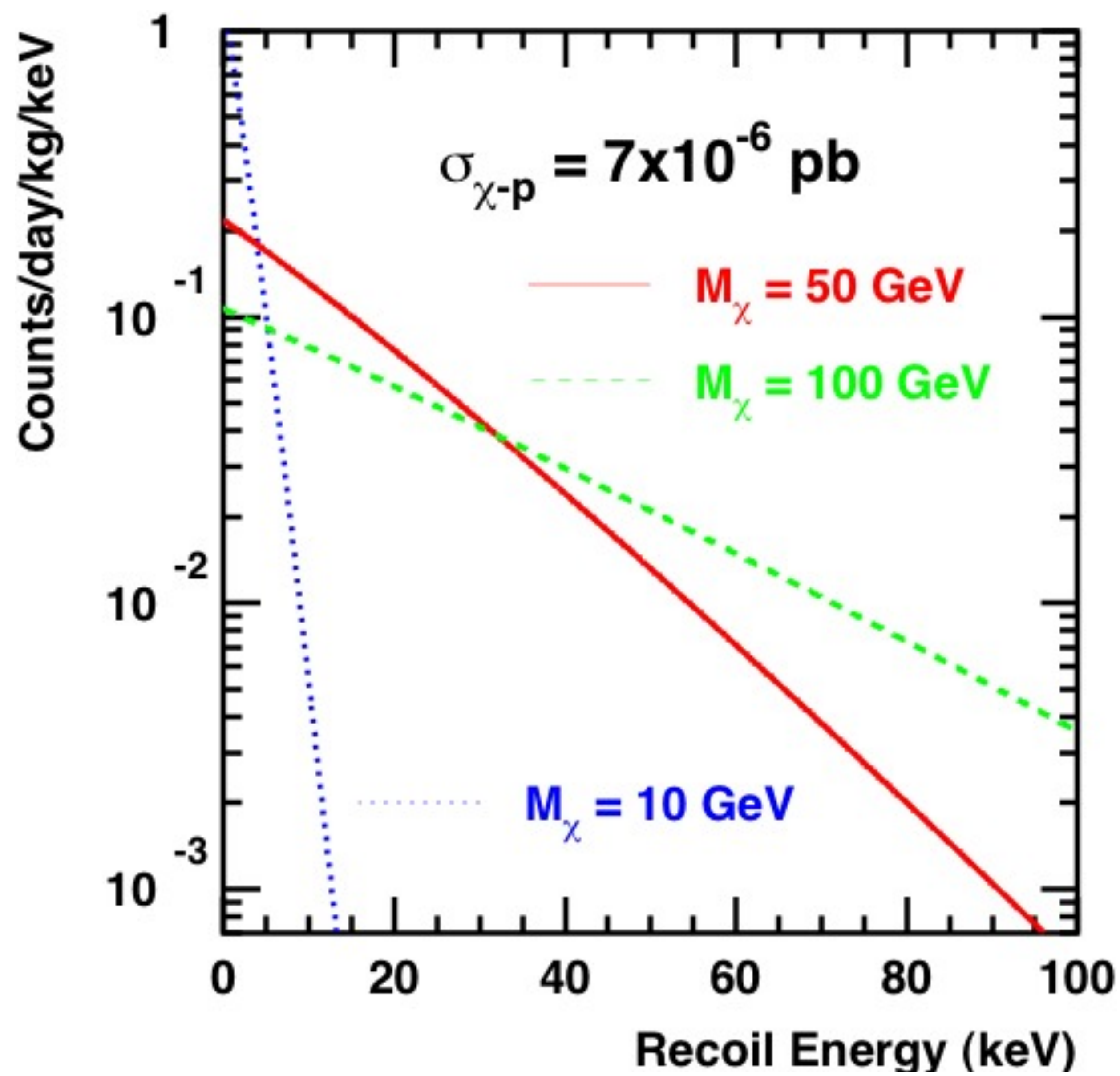
Apples to apples

see Felix's talk on Saturday

$$\rho(R_0) = 0.2 - 0.56 \text{ GeV cm}^{-3}$$

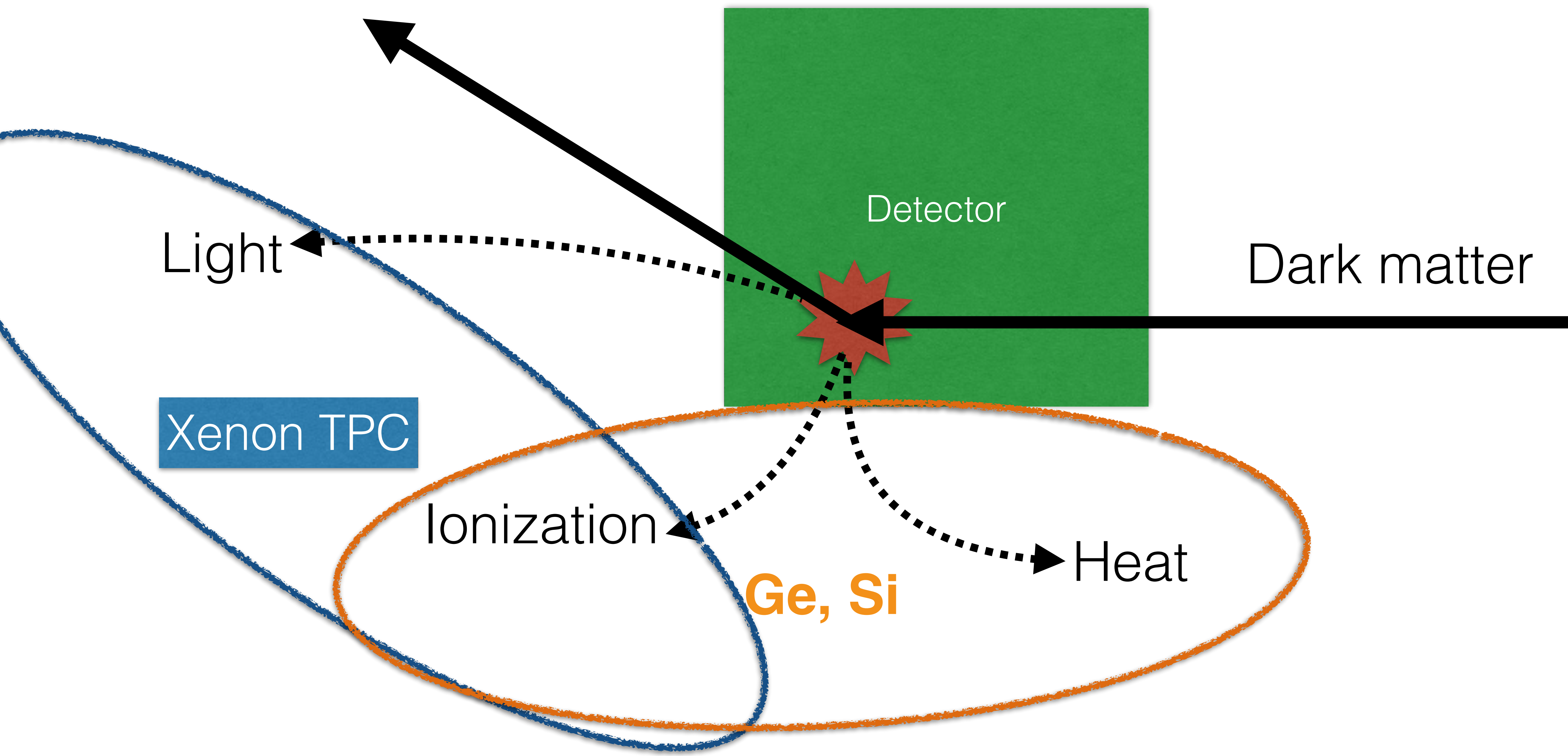
(Read 1404.1938)

No peak in spectrum

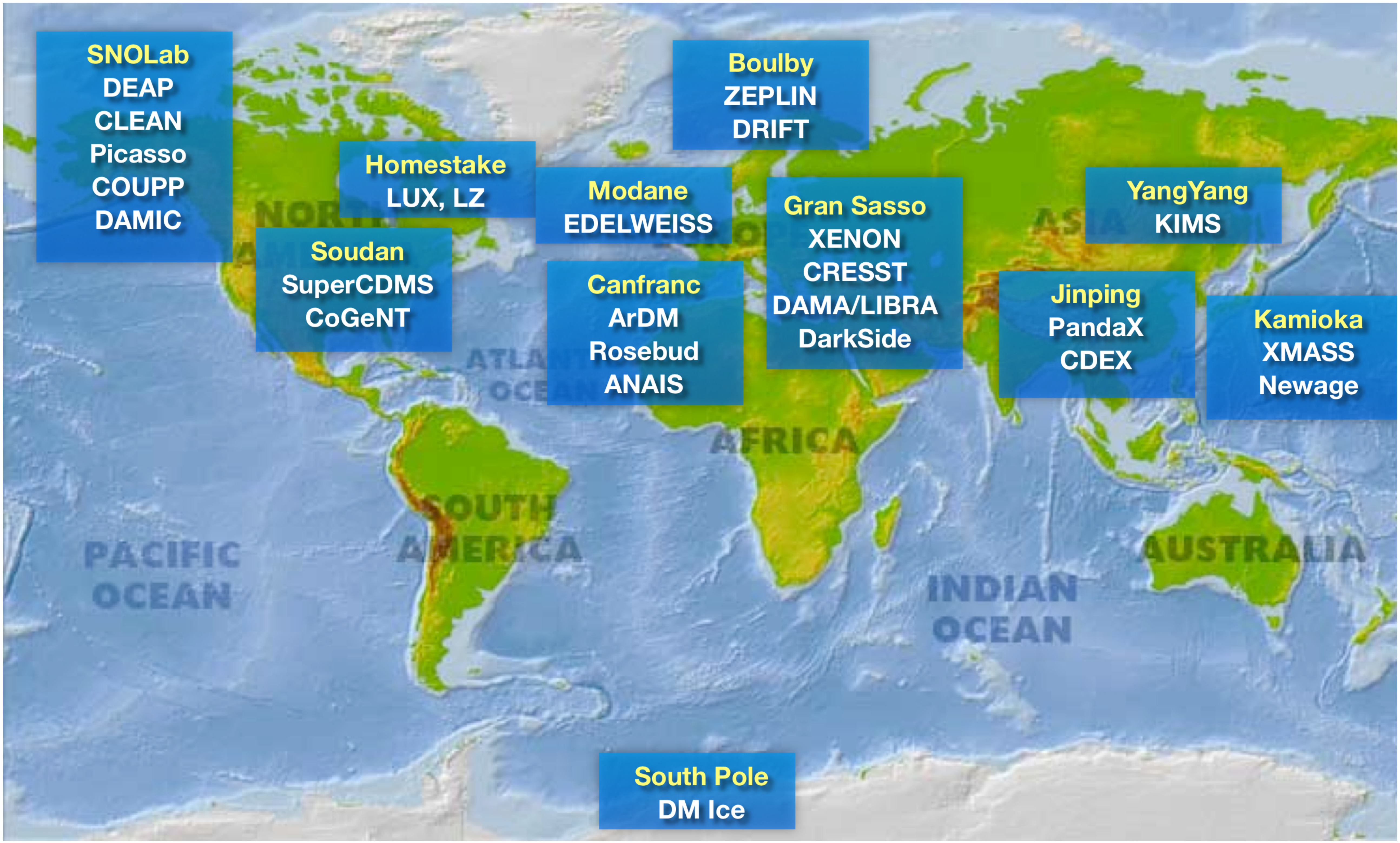


keV is not a typo…

How detect keV signals?

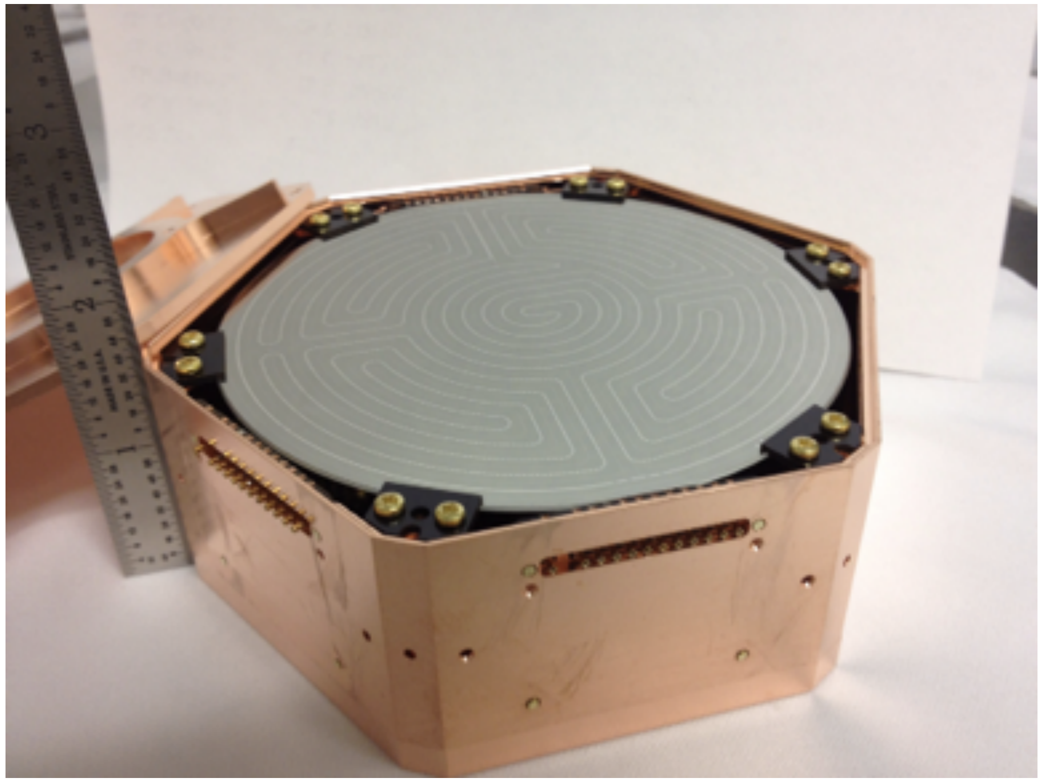


Many experiments and detector technologies

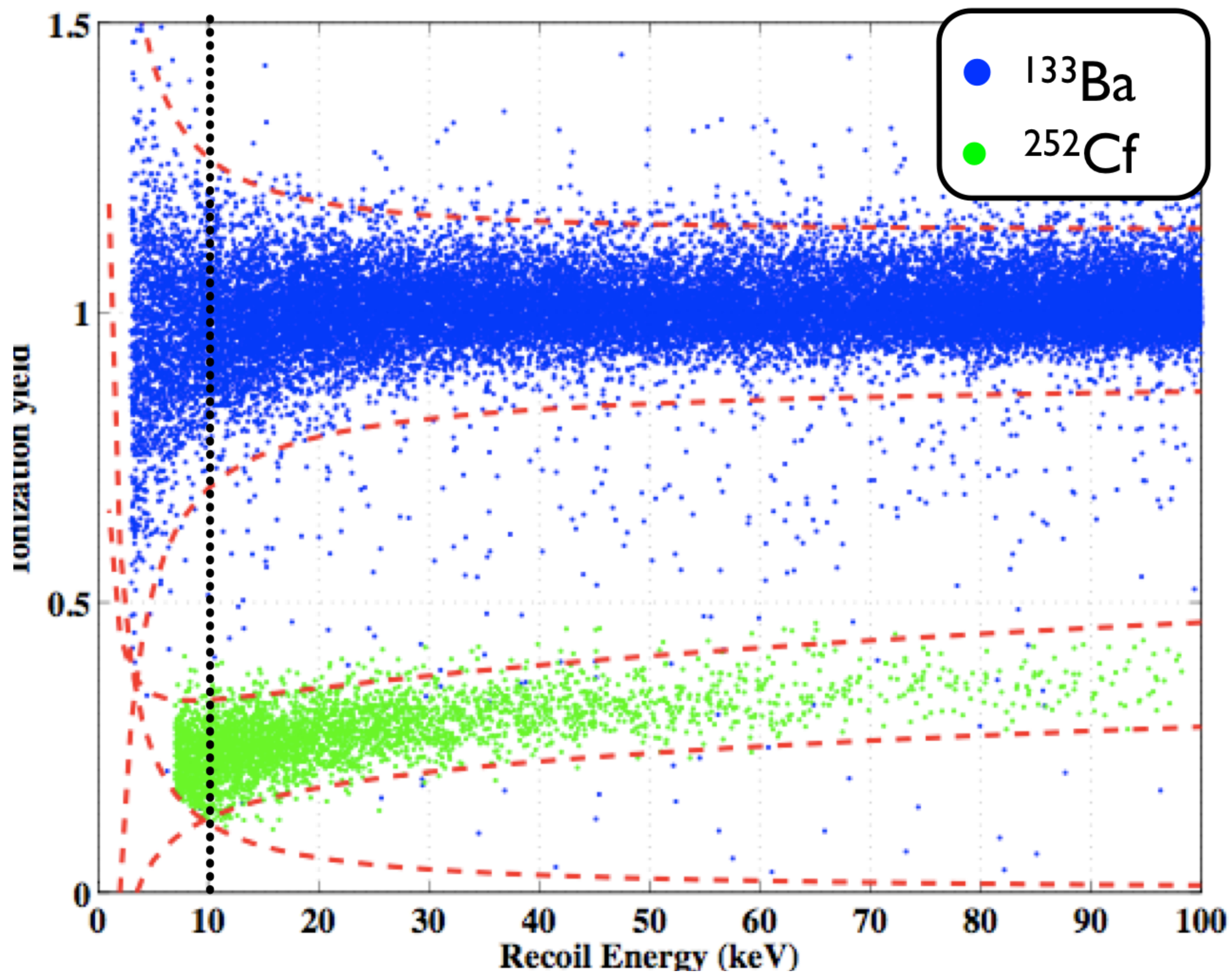


Cryogenic experiments at T ~ mK

- High sensitivity to nuclear recoils, good energy resolution, low-energy threshold (keV to sub-keV)
  - low-mass WIMPs!
- Ratio of light/phonon or charge/phonon:
  - nuclear versus electronic recoils discrimination -> separation of S and B



Ratio of charge (or light) to phonon



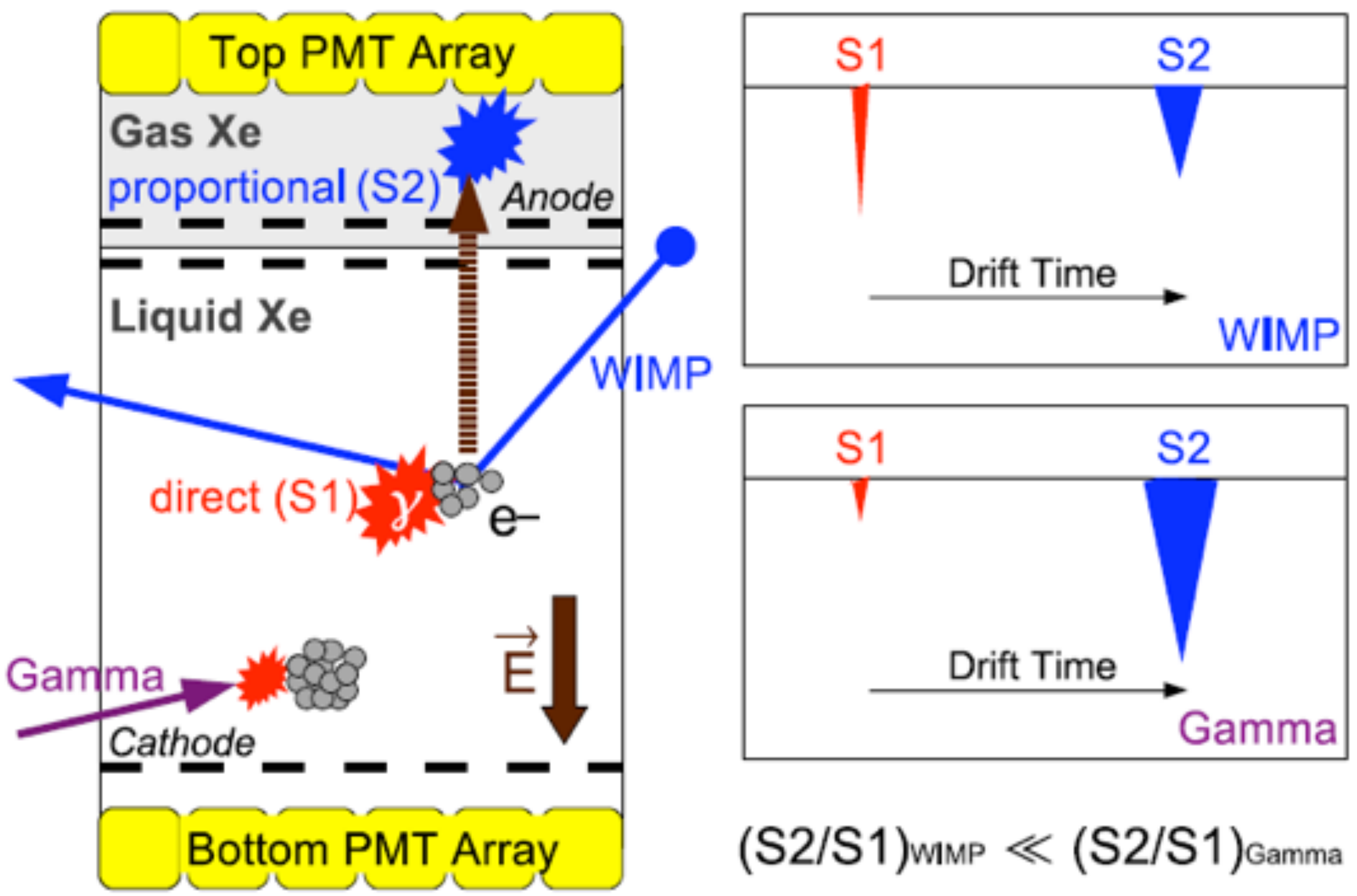
Background

Signal

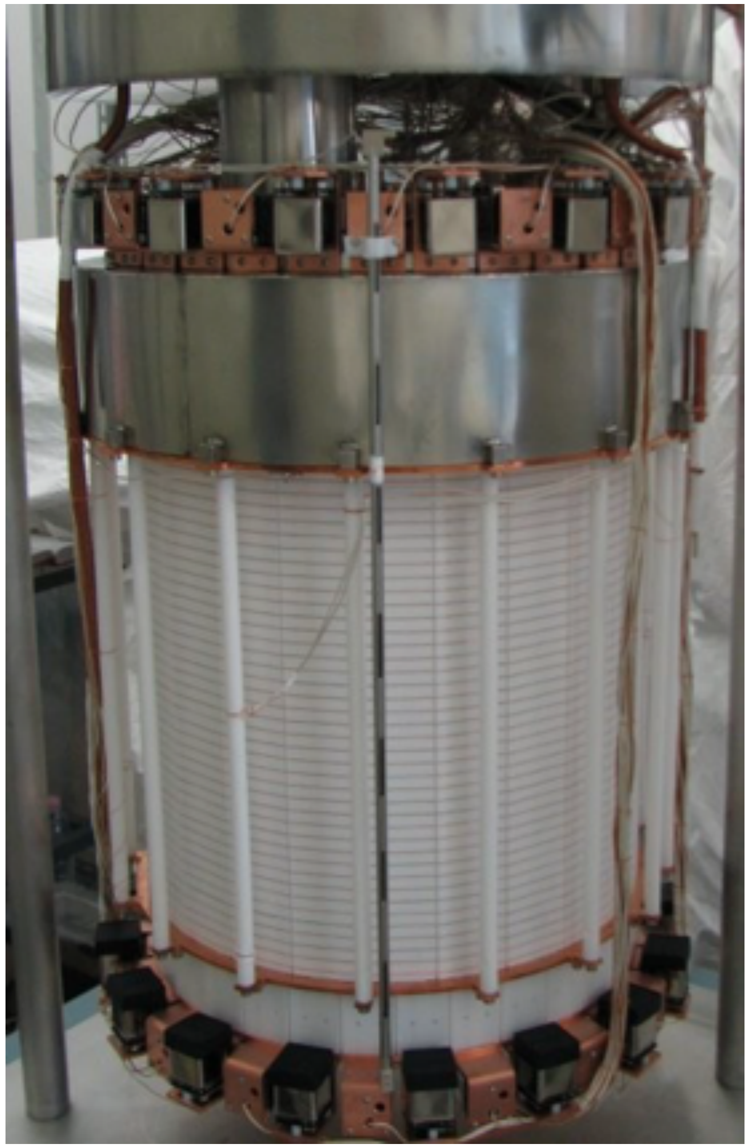
(Baudis)

Xenon time-projection chambers

Experiments: e.g., XENON100/LUX
Ionization and light
Xenon atom mass ~ WIMP
3D event reconstruction

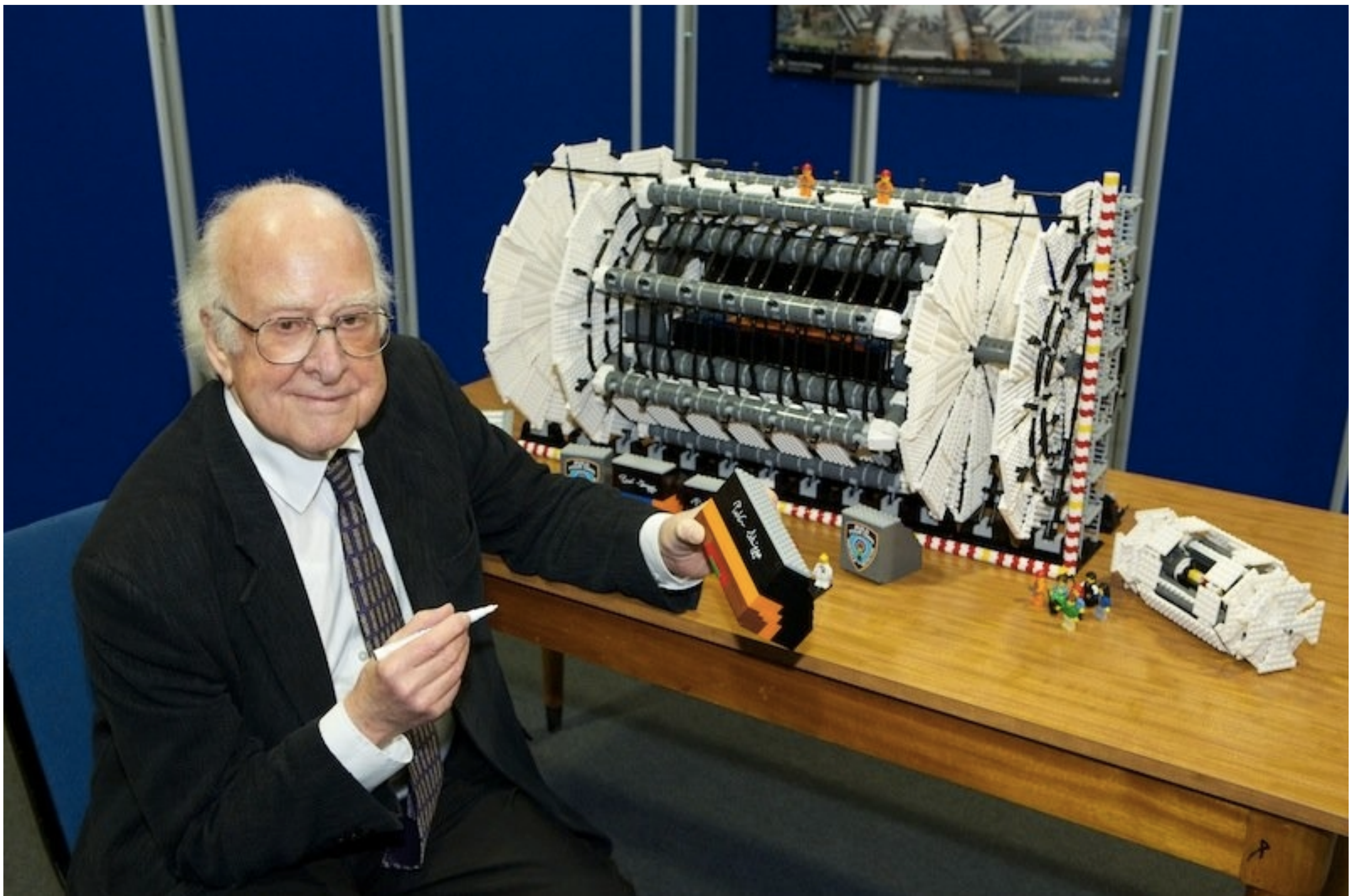


XENON100



ATLAS != XENON100

Lego 1/50 scale ATLAS detector is bigger than XENON100

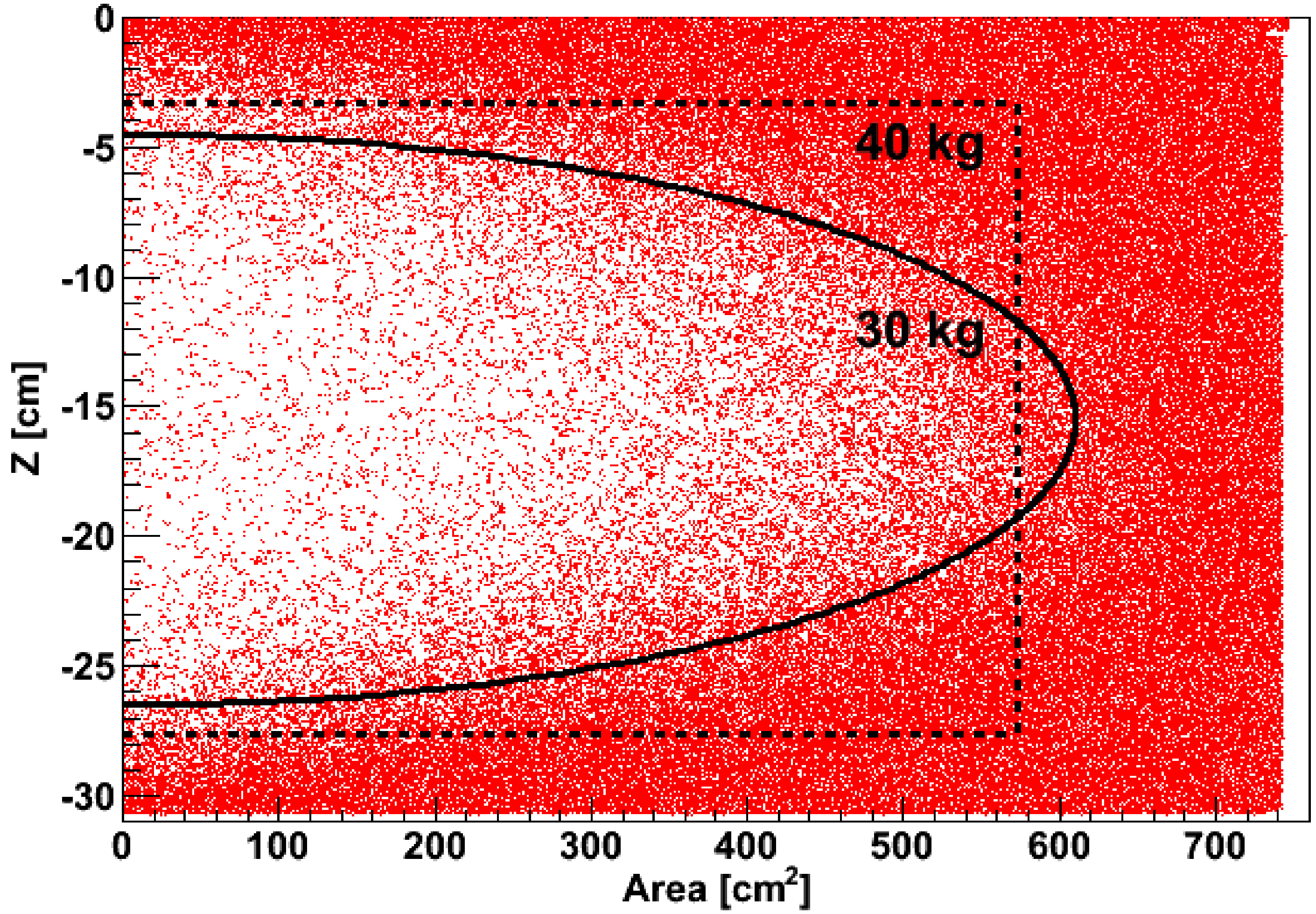


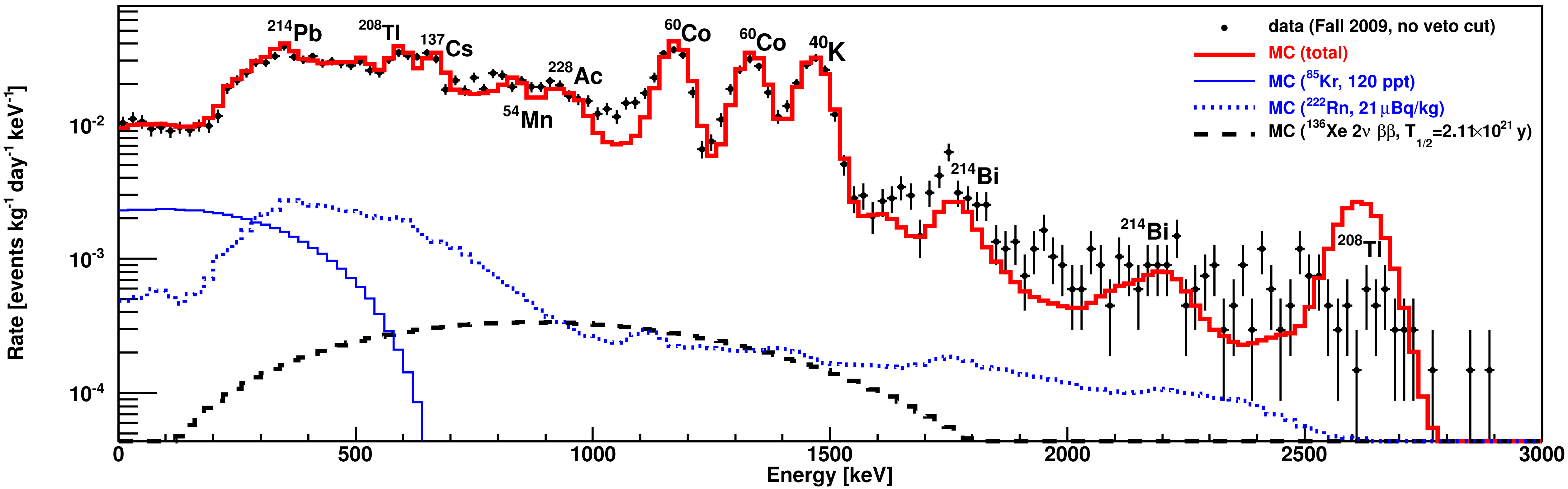
keV physicist's backgrounds

Everything is radioactive

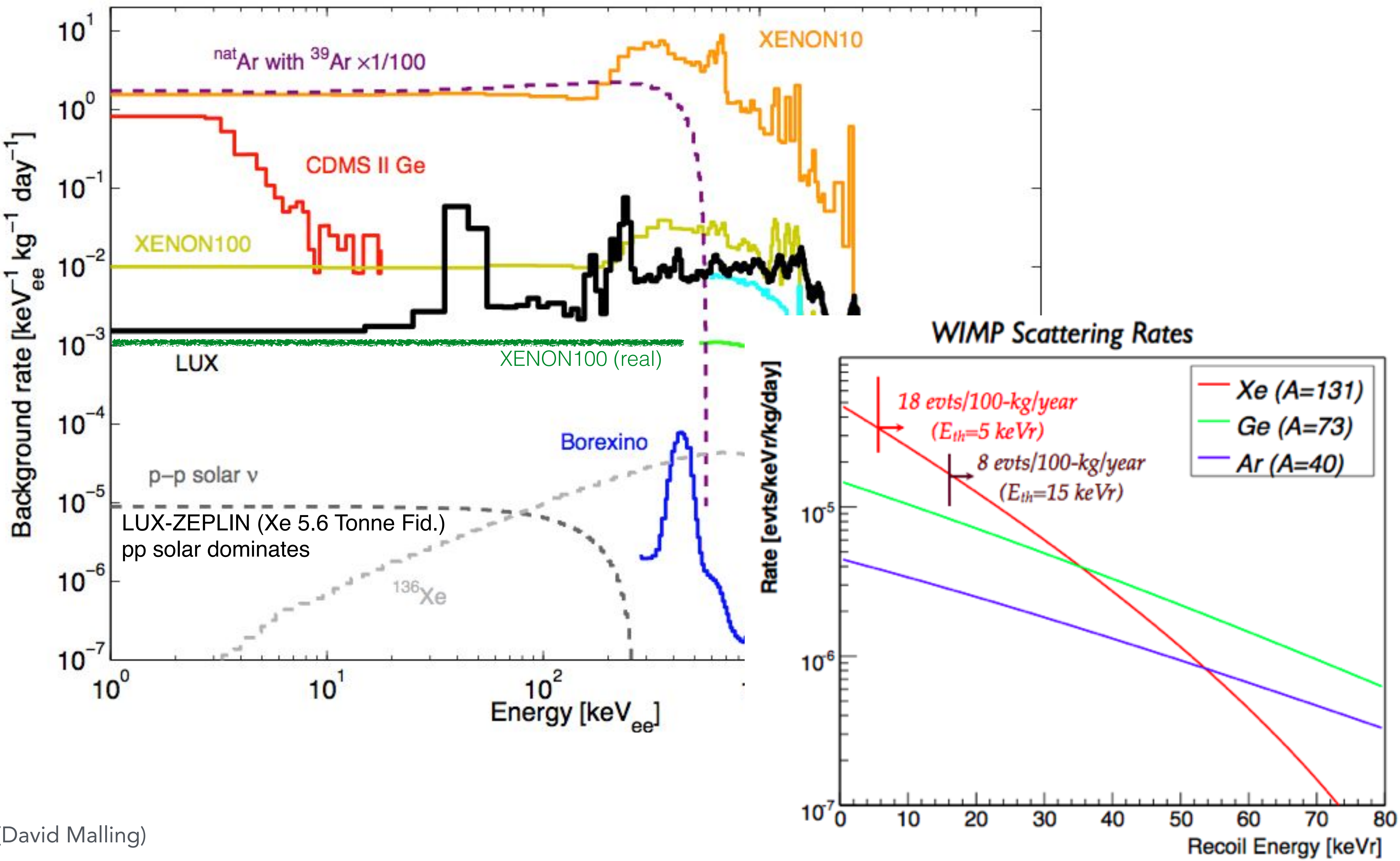
- Environmental radioactivity (Radon)
- Radioimpurity in detector materials
- Neutrons from (alpha, n and fission reactions
- Cosmic rays
- Activation of materials when at surface
- *Eventually: neutrinos*

(XENON EM paper)





Quiet place

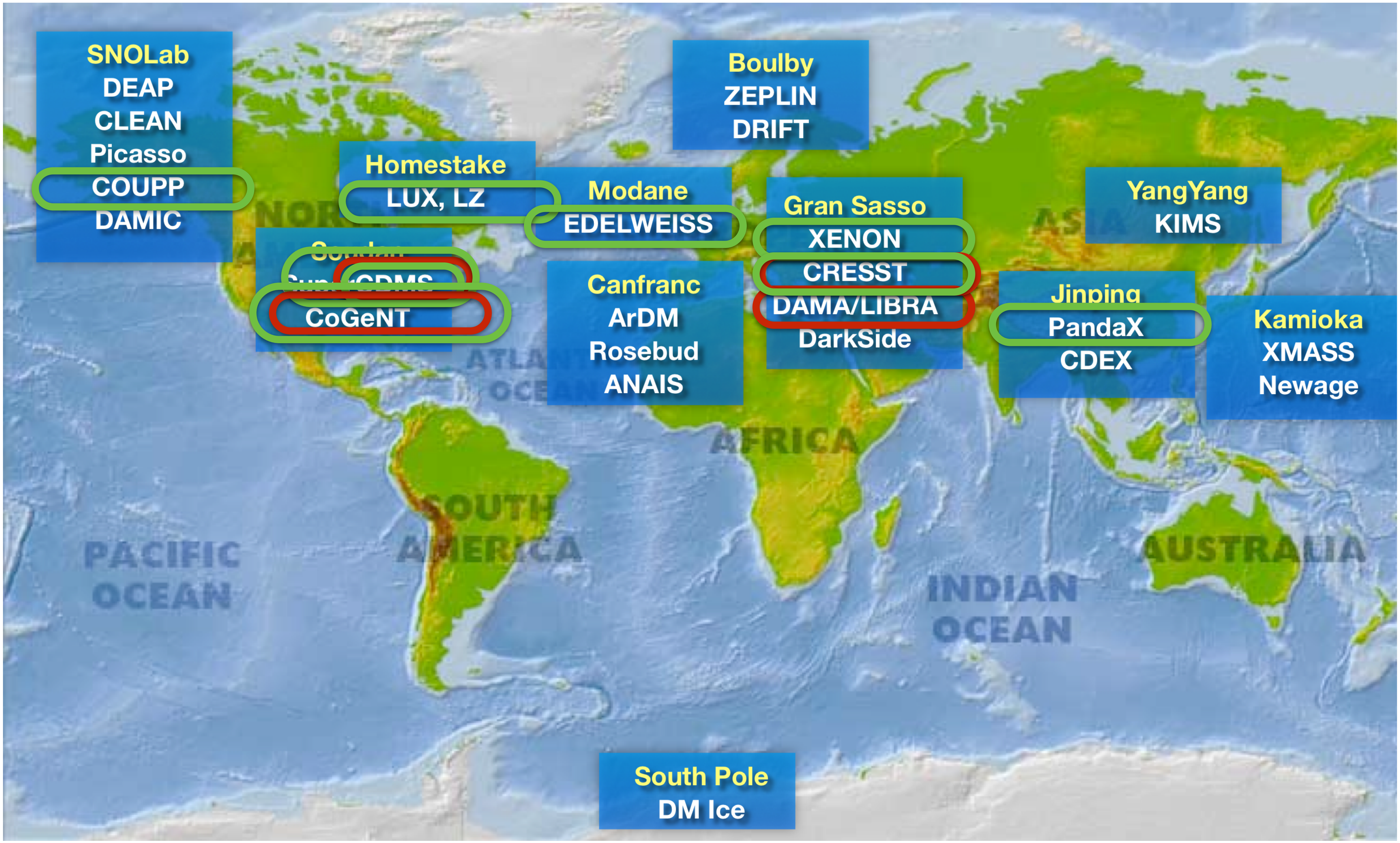


(David Malling)

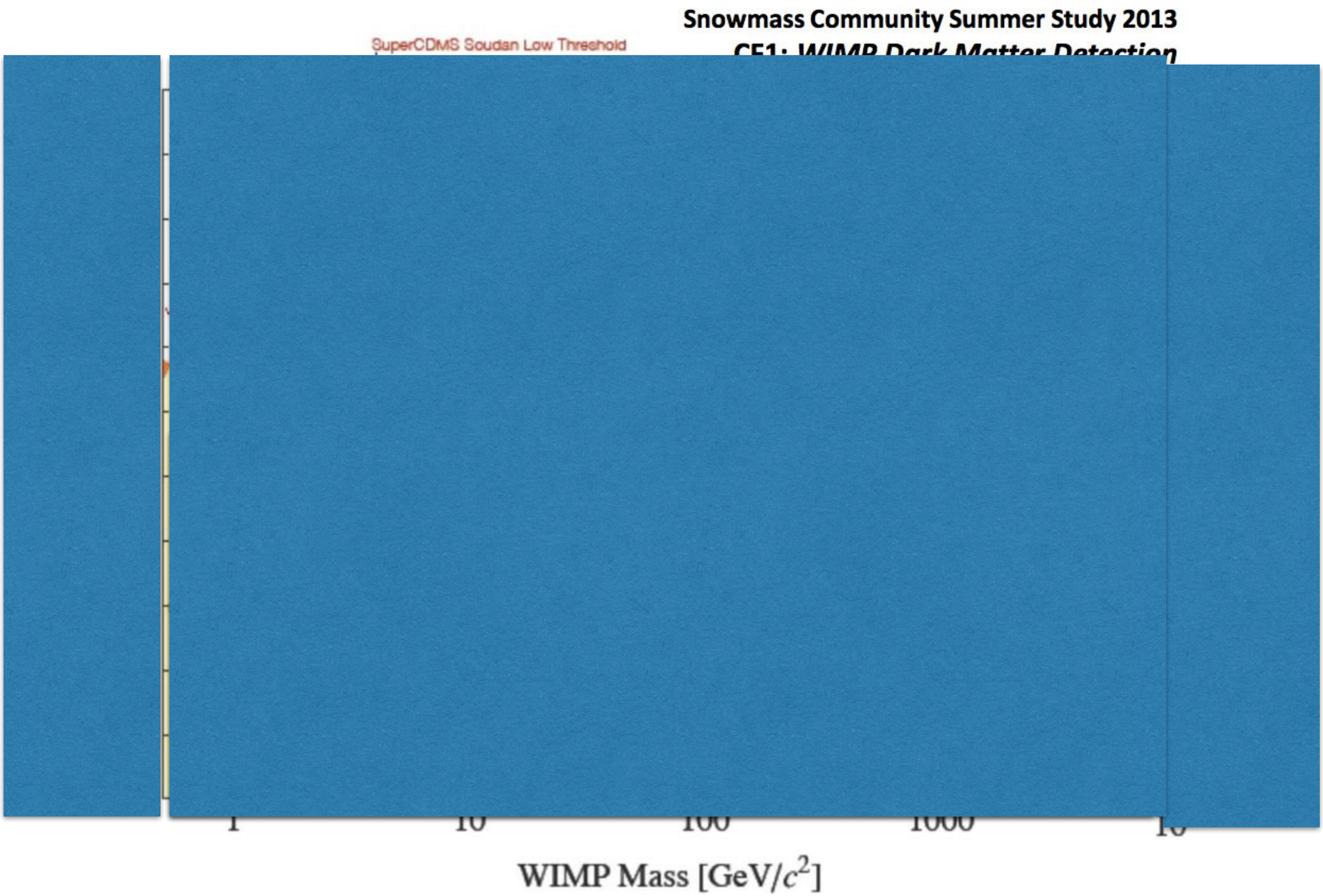
Who has seen what?

Not seen

Seen



WIMP landscape

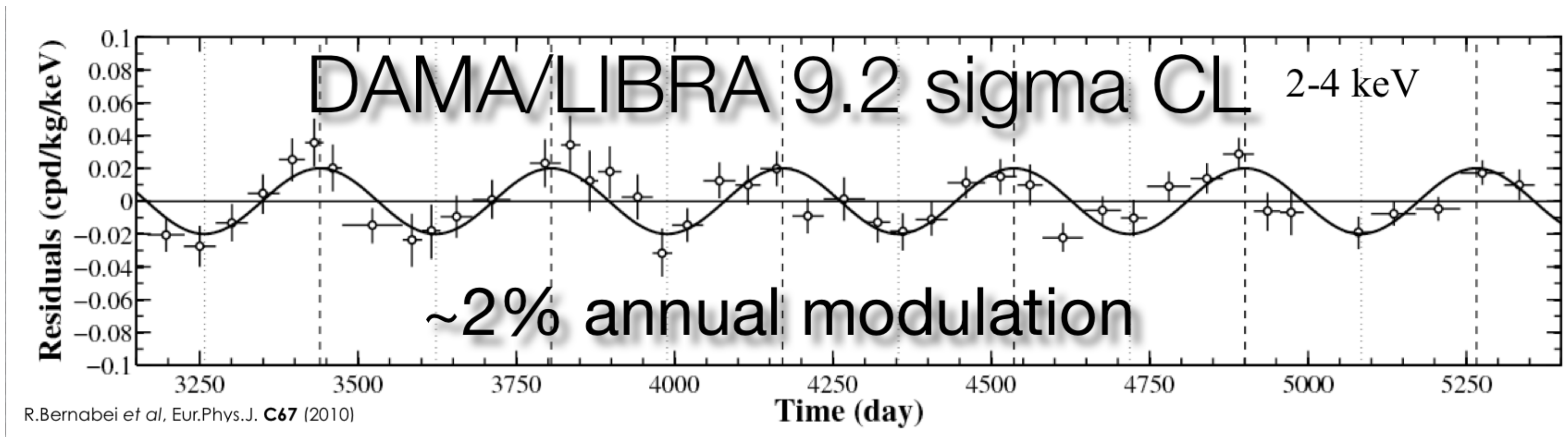


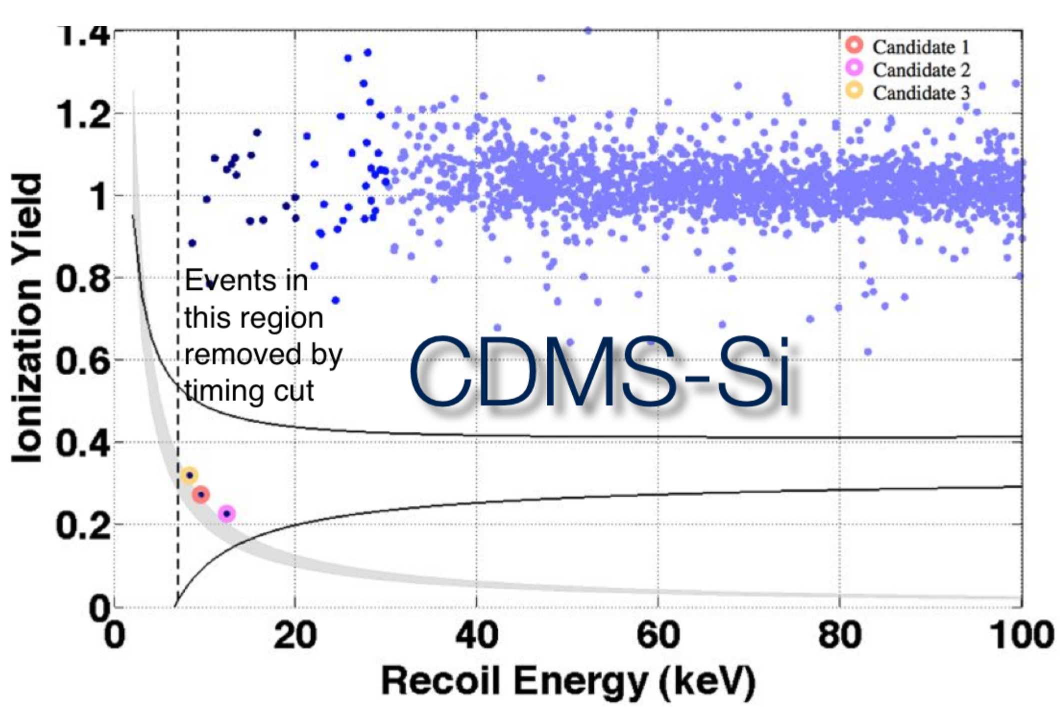
arXiv:1310.8327

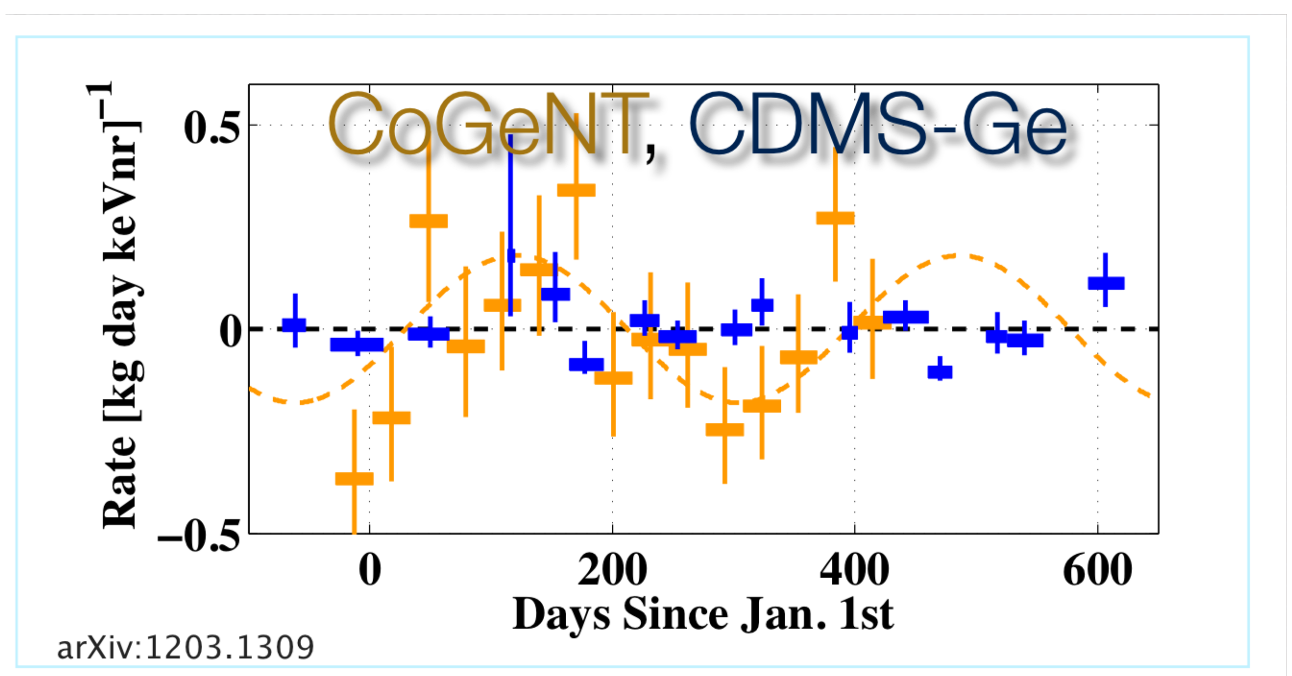
(Baudis)

Low-mass WIMPs?

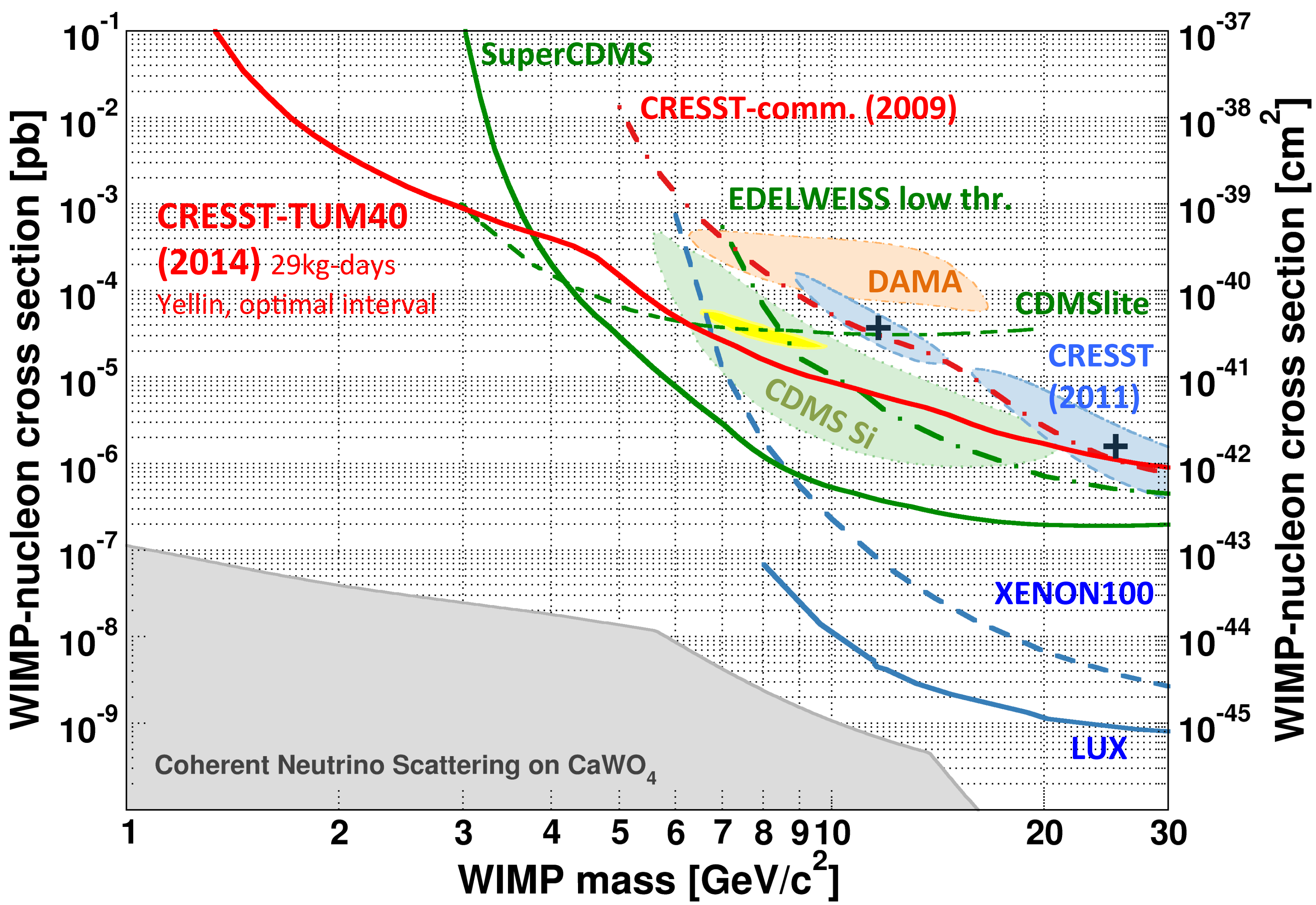
CDMS-Si, DAMA/LIBRA, CoGeNT, CRESST all see (different) signals above *known* backgrounds







Low-mass exclude by CDMS, LUX, XENON10, XENON100, CRESST, and PandaX

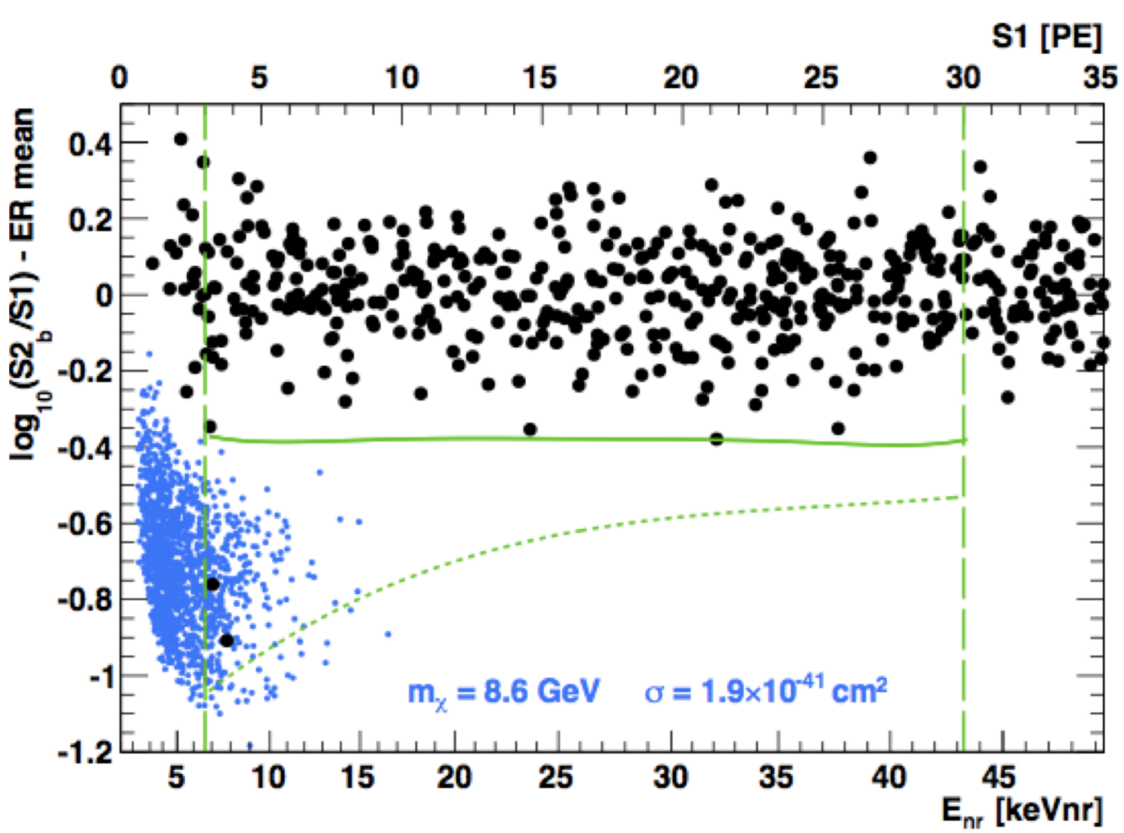


- CRESST (2011)
  - new run, excludes old signal
  - Strauss TeVPA/IDM
- CoGeNT
  - Kelso TeVPA/IDM
  - Davis 1405.0495
- CDMS-Si
  - Excluded SuperCDMS
  - 1402.7137
- DAMA/LIBRA
  - *still here…*

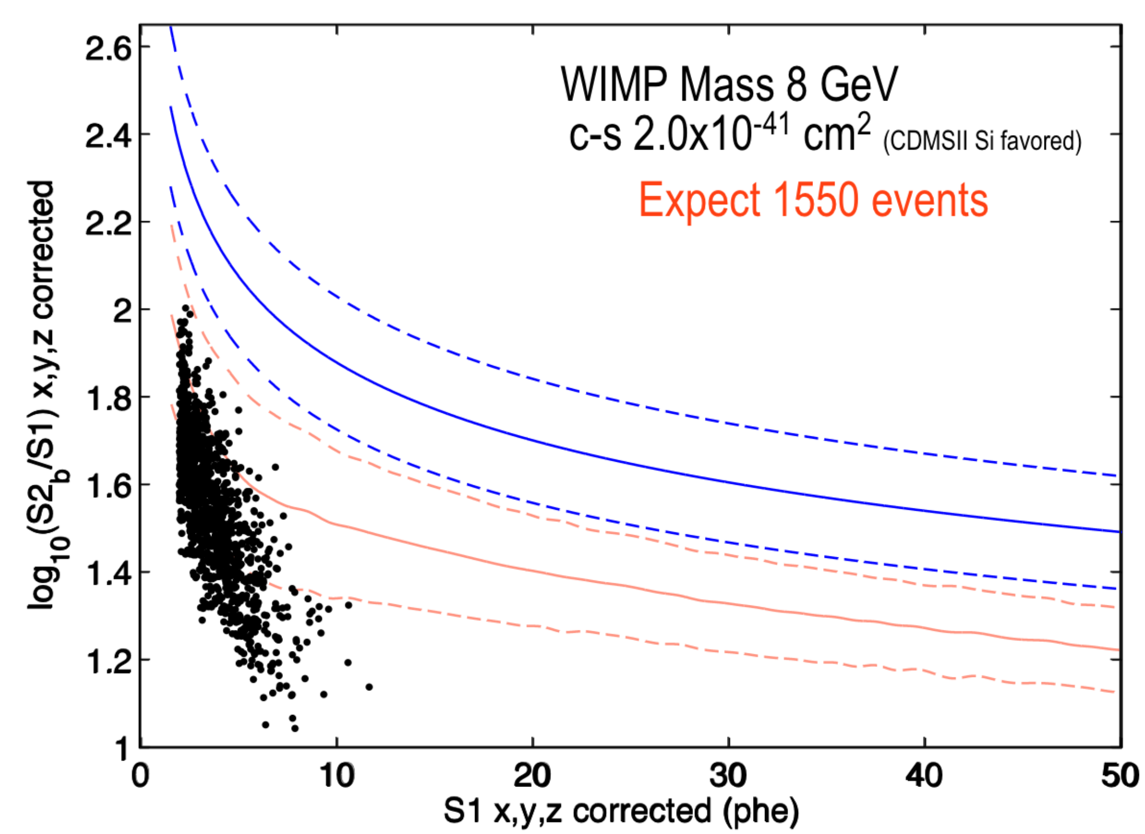
(Baudis)

What would low-mass WIMPs look like in Xenon TPCs?

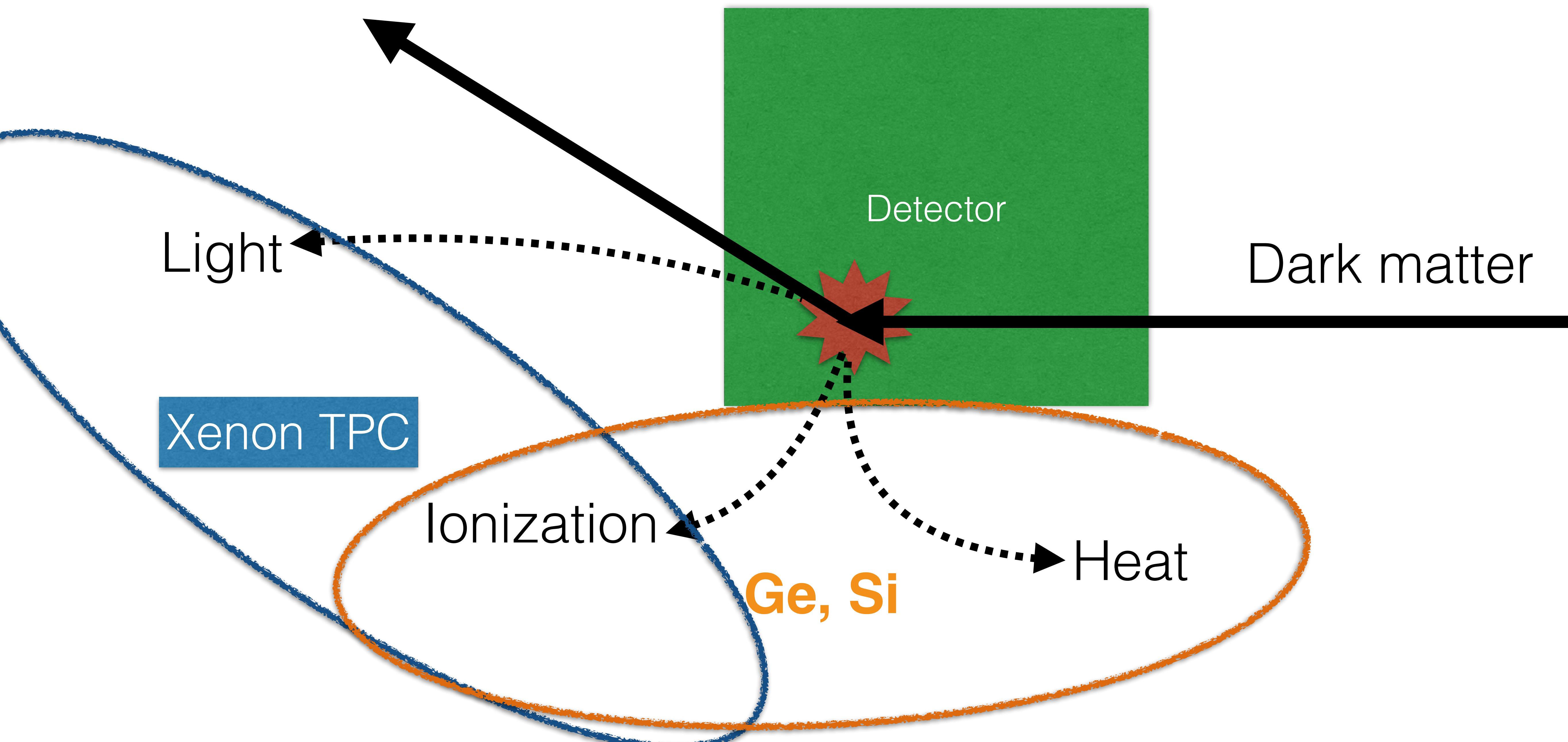
XENON100
Expected: 220 events



LUX
Expected: 1550 events



Ionization-only XENON10/ XENON100



Ionization-only XENON10/ XENON100

Dark-matter *wind*
v = 220 km/s

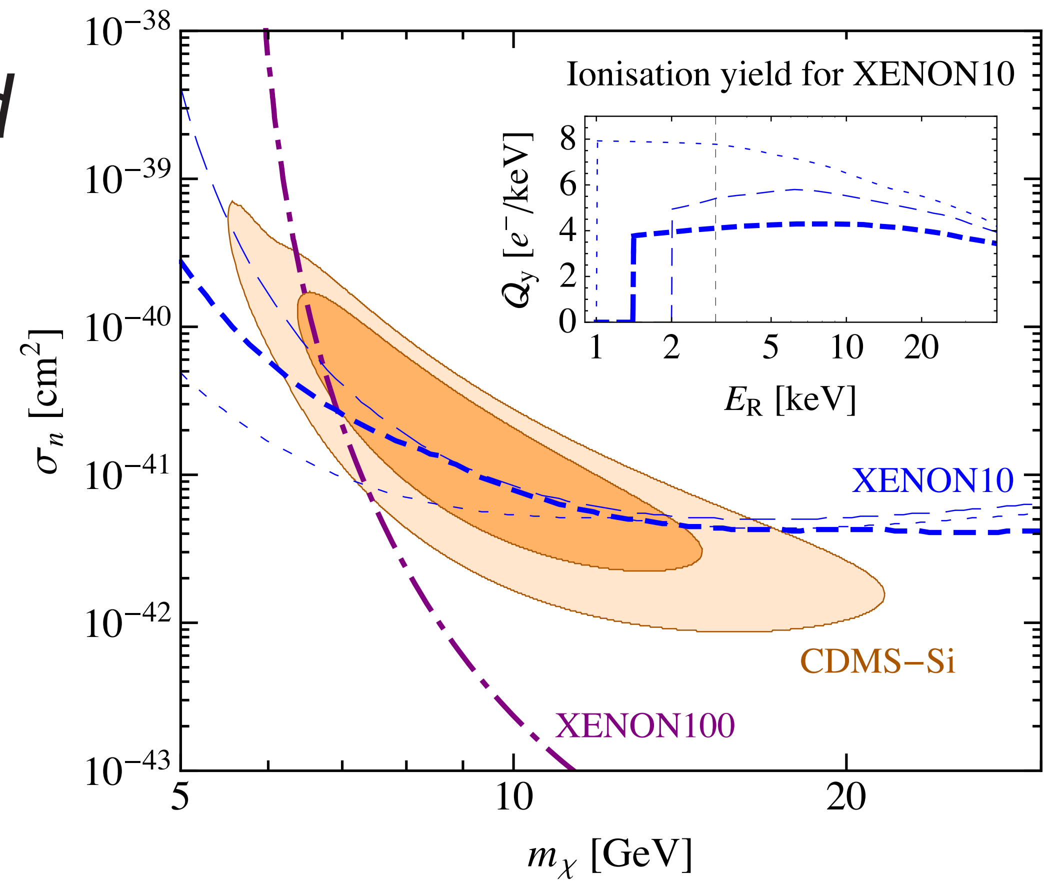
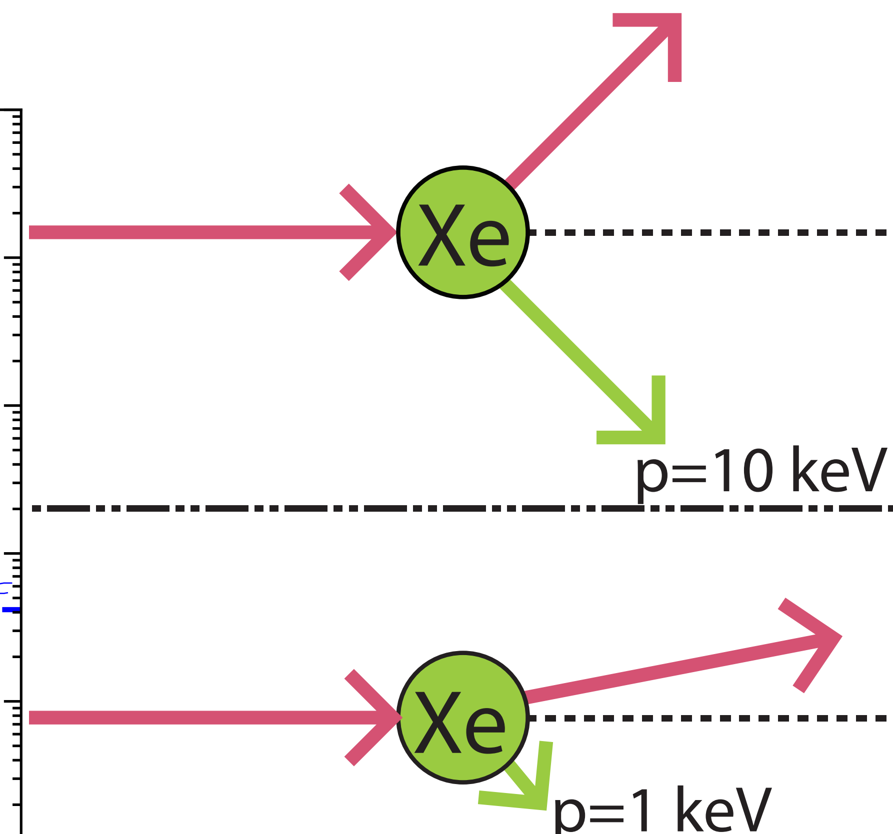


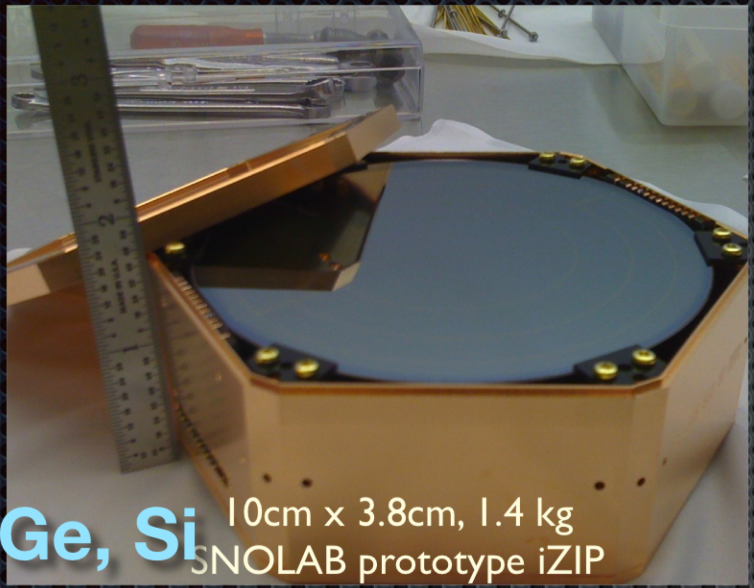
Figure 1. CDMS-Si confidence region (68% and 90% CL) together with the 90% exclusion curves from XENON10 and XENON100 from our analysis, assuming standard elastic spin-independent scattering and equal coupling to protons and neutrons. Our CDMS-Si confidence region and XENON100 bound agree well with the results from the respective collaborations [6, 22], however, our XENON10 bound is significantly weaker than the published one [5]. We consider three choices of the ionisation yield $\mathcal{Q}_y$ at low energy to illustrate the corresponding variation of the extracted bound.

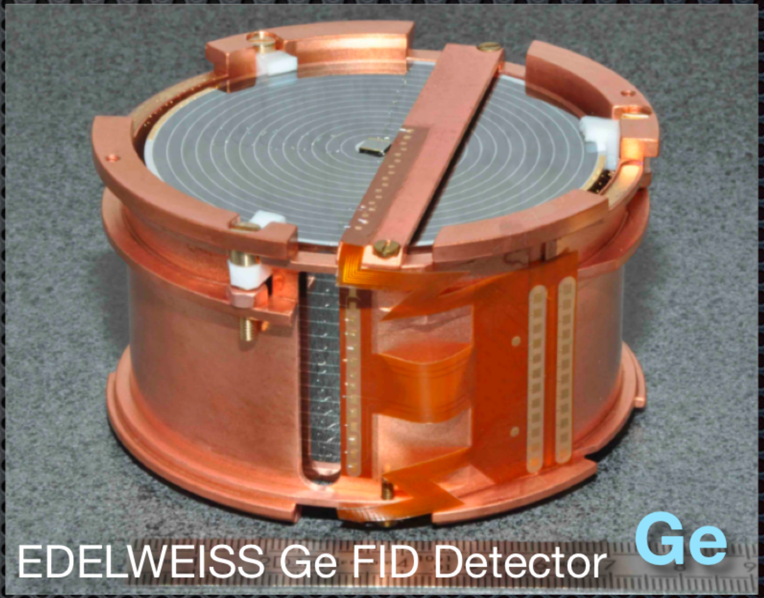


(Frandsen, Kahlhoefer, McCabe, Sarkar & Schmidt-Hoberg, arXiv:1304.6066)

New data from cryogenic experiments

- Absorber masses from ~ 100 g to 1400 g





SuperCDMS

new, leading results at low masses

proposed for SNOLAB:
Std: ~92 kg Ge, 11 kg Si
Lite: 5 kg Ge, 1.2 kg Si

CRESST

18 $CaWO_3$ detector modules (5 kg) installed at LNGS in 2013

low-background run in 2014, recent results and taking more data

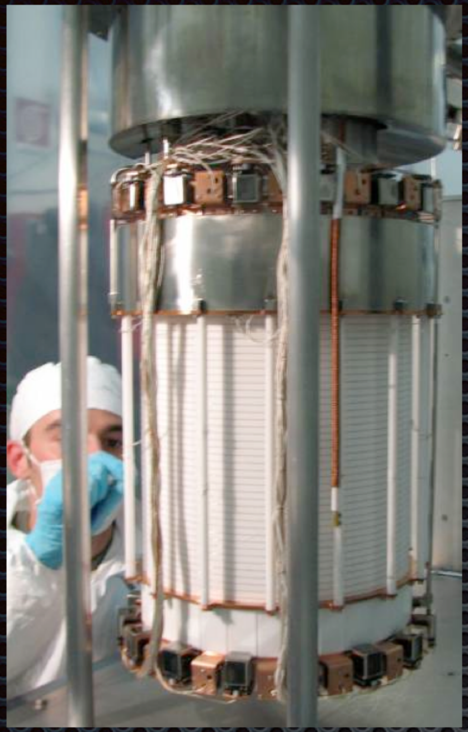
EDELWEISS-III

new run with 36 Ge FID800 (~ 30 kg) detectors since June 2014

End 2014/early 2015: reach 3000 kg x d (125 live days)

2016: reach 1.2 ton x days (500 live days)

New data from Ar and Xe TPCs



XENON100 at LNGS:

161 kg LXe
(~50 kg fiducial)

242 1-inch PMTs
close to unblinding of new data set

LUX at SURF:

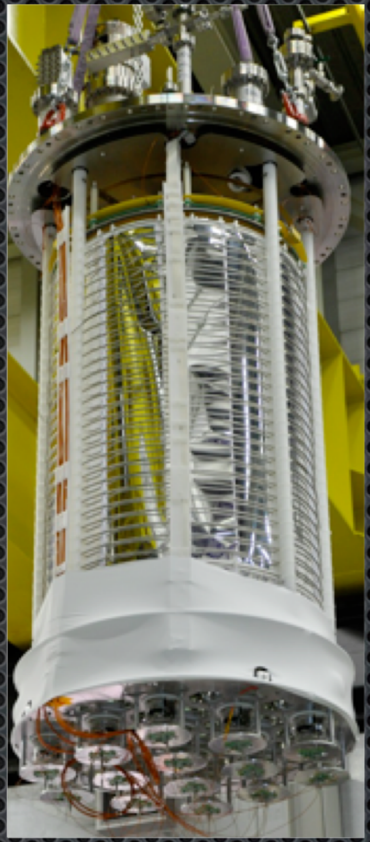
370 kg LXe
(100 kg fiducial)

122 2-inch PMTs
physics run and first results in 2013
new run in 2014

PandaX at CJPL:

125 kg LXe
(37 kg fiducial)

143 1-inch PMTs
37 3-inch PMTs
first results in August 2014



ArDM at Canfranc:

850 kg LAr
(100 kg fiducial)

28 3-inch PMTs
in commissioning
to run 2014

DarkSide at LNGS:

50 kg LAr (dep in ^{39}Ar)
(33 kg fiducial)

38 3-inch PMTs
first data with non-depl Ar in 2014

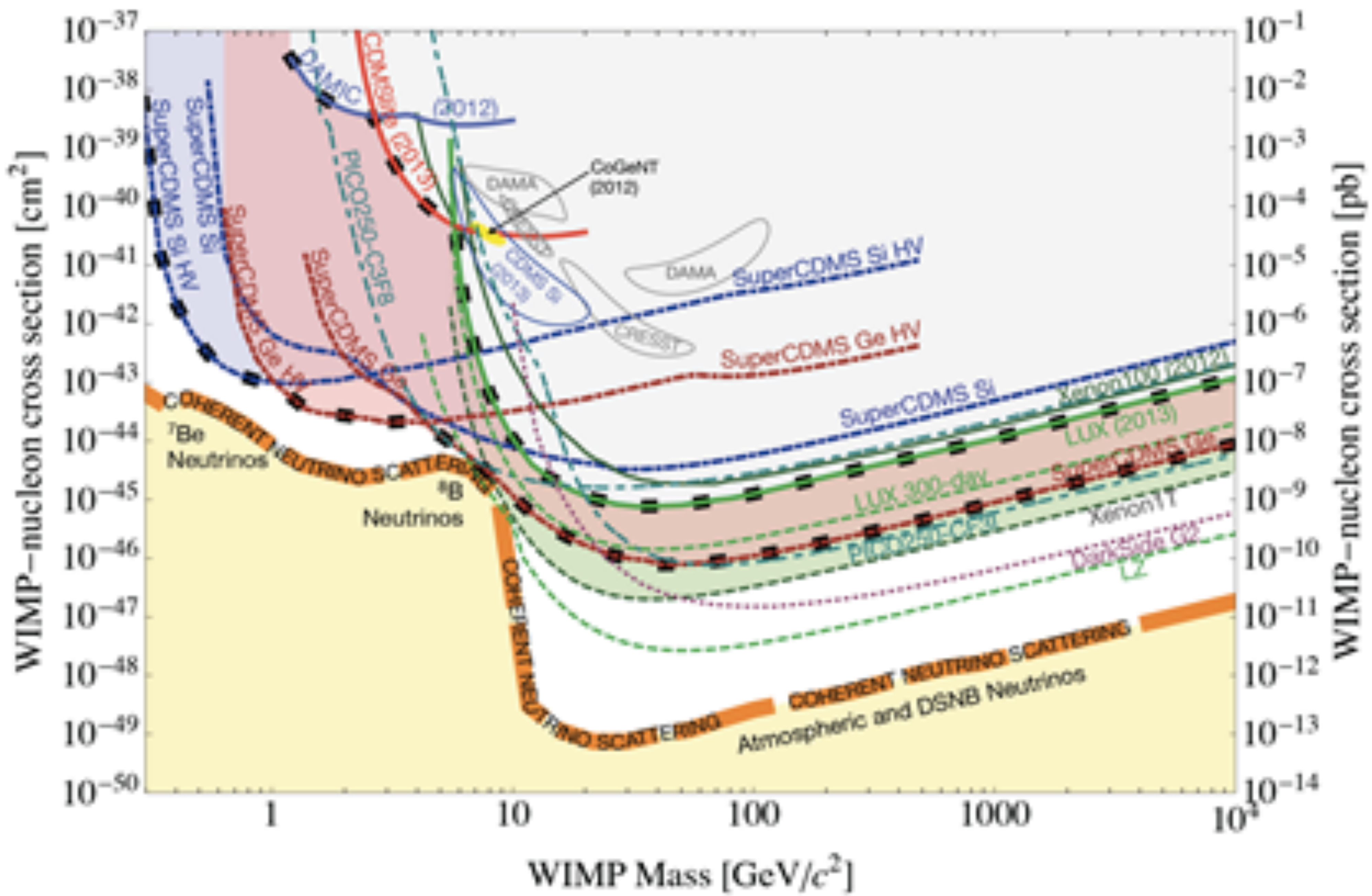
Laura Baudis, University of Zurich, COSMO2014, Chicago

What next: Direction-detection cookbook

- Collect O(100) physicists
- Buy 10 times more ‘target’ than you friends
- Locate deep hole in the ground
- Put physicists and material underground
- Wait few years
- …
- Publish

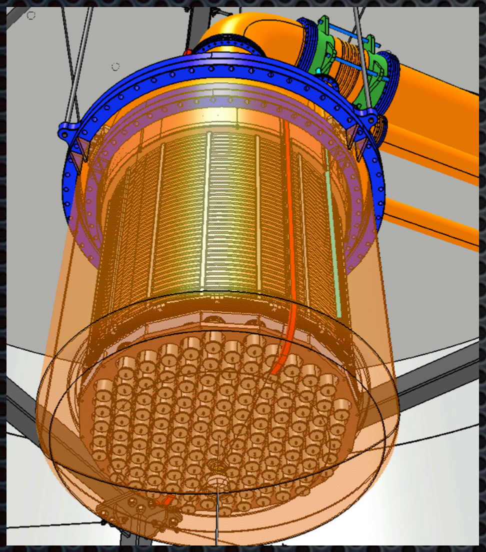
Future cryogenic experiments at T ~ mK

- SuperCDMS approved at SNOLab by NSF/DOE

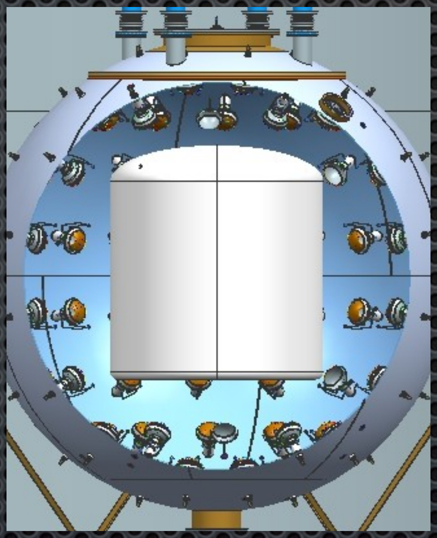


Future noble liquid detectors

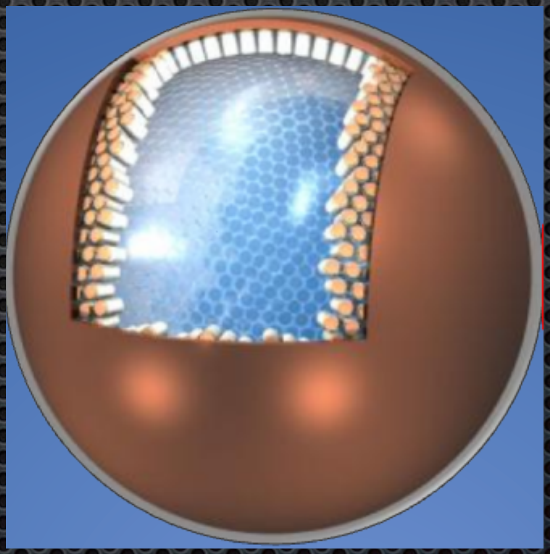
- **Under construction**: XENON1T at LNGS, 3.1 t LXe in total
- **Future:** LUX-ZEPLIN (7 t LXe) (approved by NSF&DoE), XENONnT (n=6-7 t LXe) (to be proposed), XMASS (5 t LXe), DarkSide (5 t LAr) (R&D funds)
- **Design and R&D:** “ultimate detector” DARWIN (~20 t LXe and/or 50 t LAr)



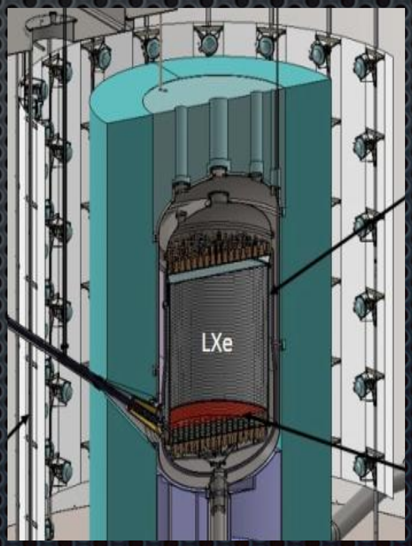
XENON1T: 3.3 t LXe



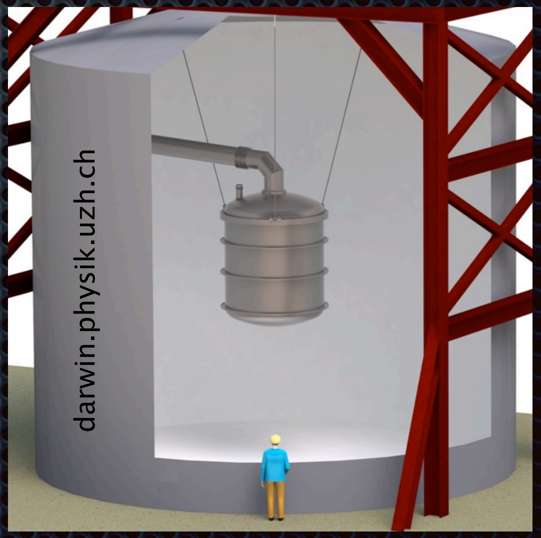
DarkSide: 5 t LAr



XMASS: 5t LXe



LZ: 7t LXe



DARWIN: 20 t LXe/LAr

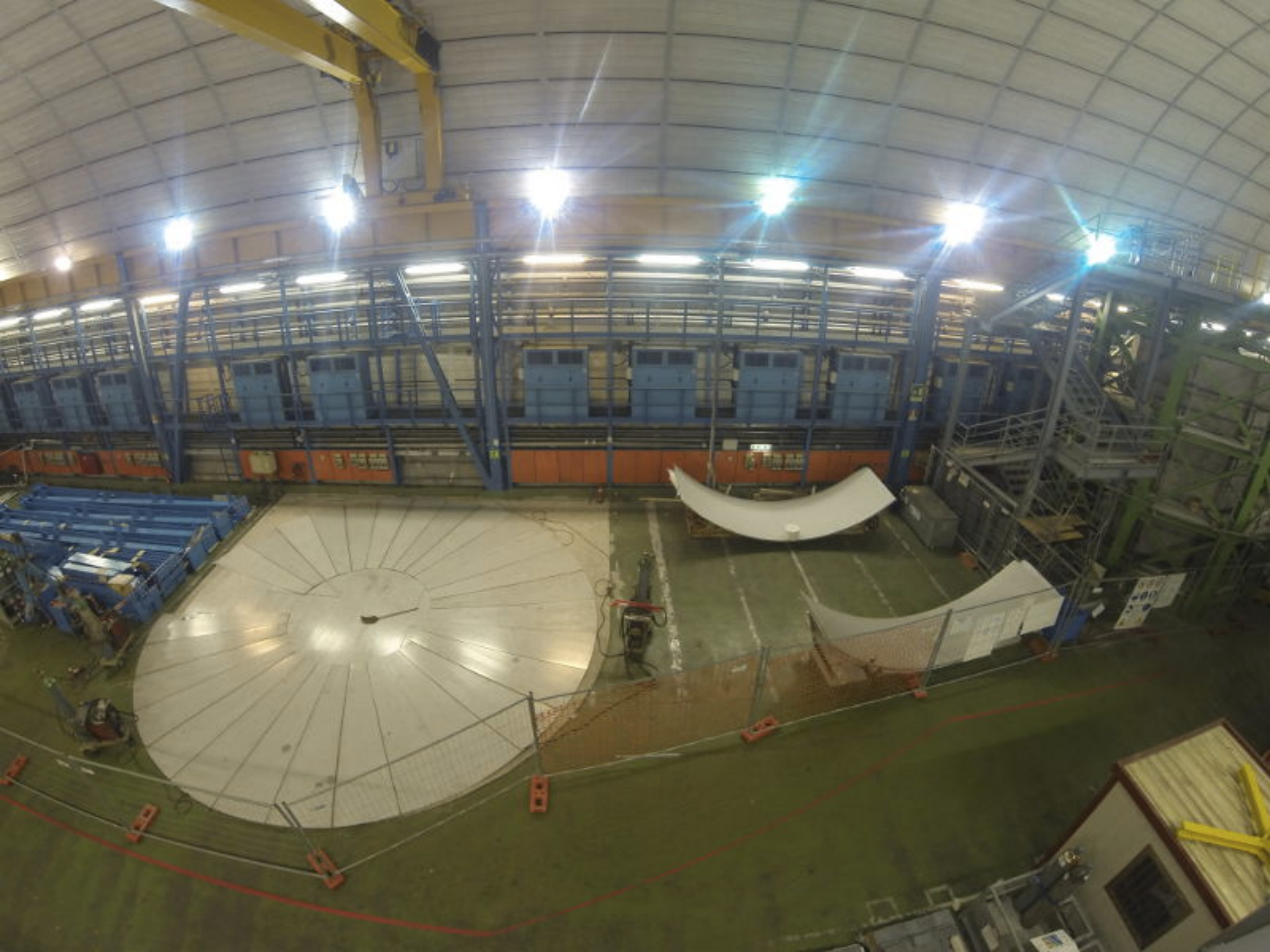
(Baudis)

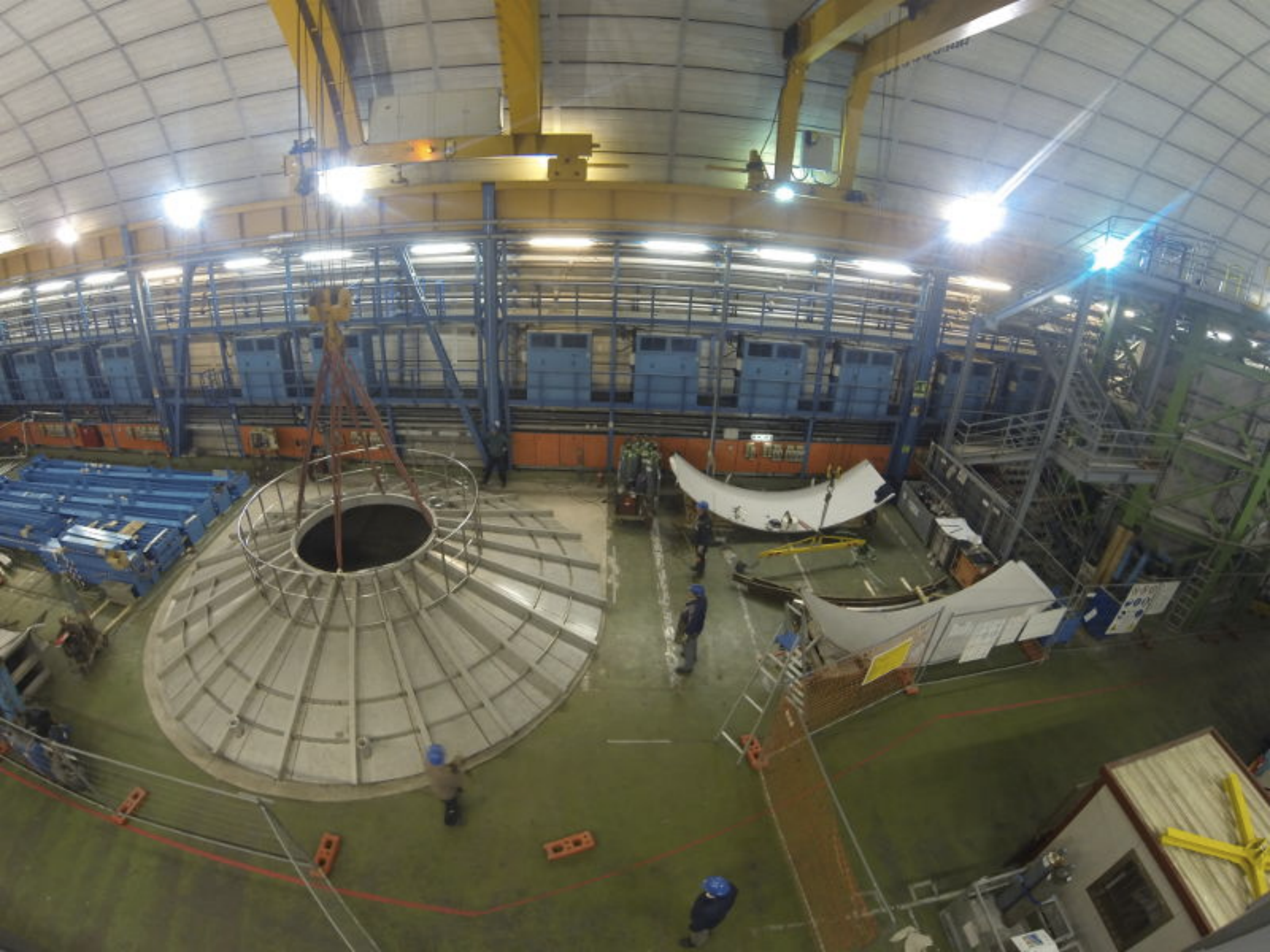
The XENON1T Experiment

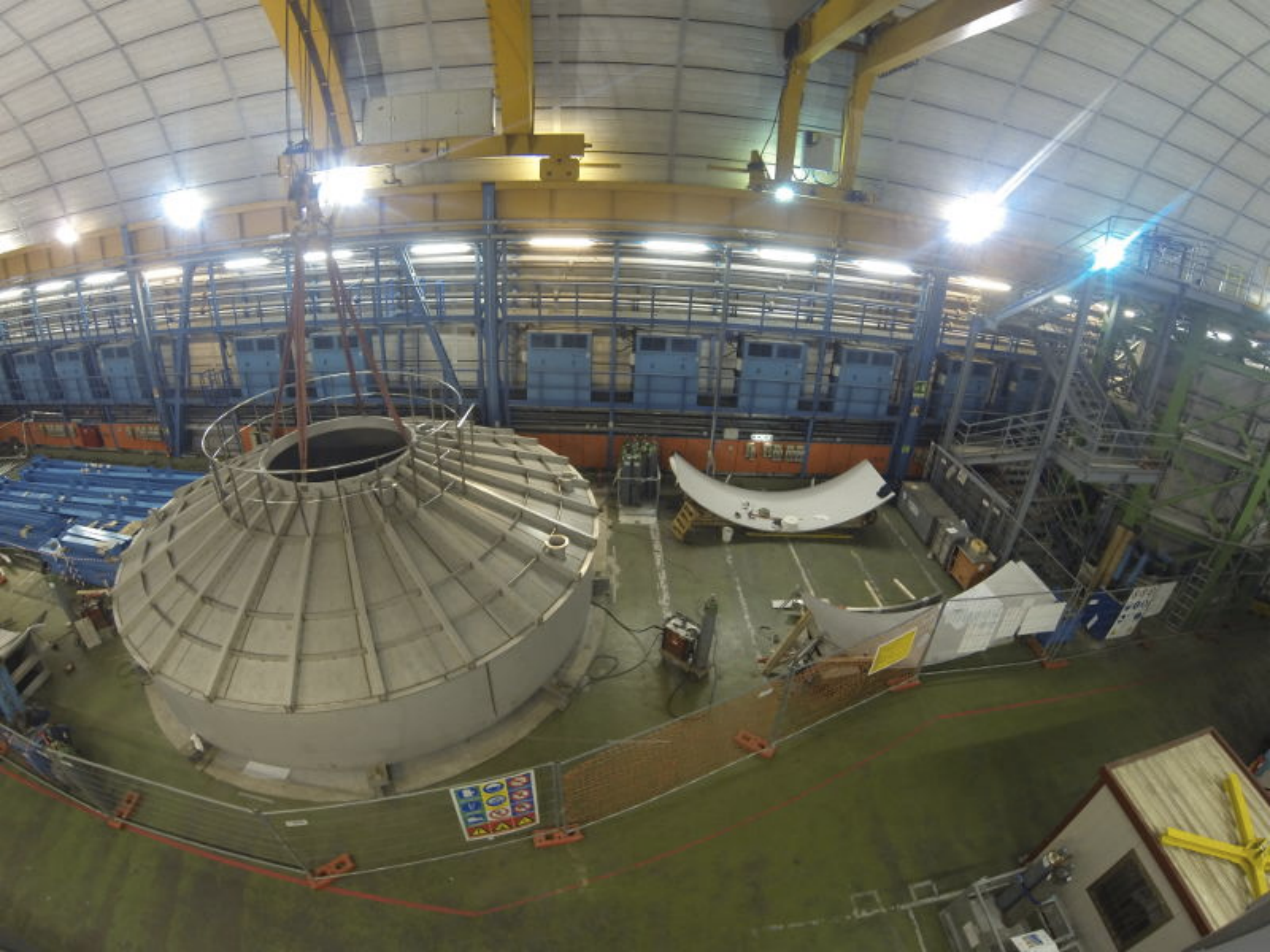
- Under construction at LNGS since fall 2013
- Total LXe mass: 3.1 t, 1 m charge drift; 248 3-inch PMTs; background goal: *100 x lower than XENON100, ~5 x 10^{-2} events/(t-d-keV)*
- Commissioning and science run: mid and late 2015
- Goal: 2 x 10^{-47} cm^2 at a WIMP mass of ~ 50 GeV

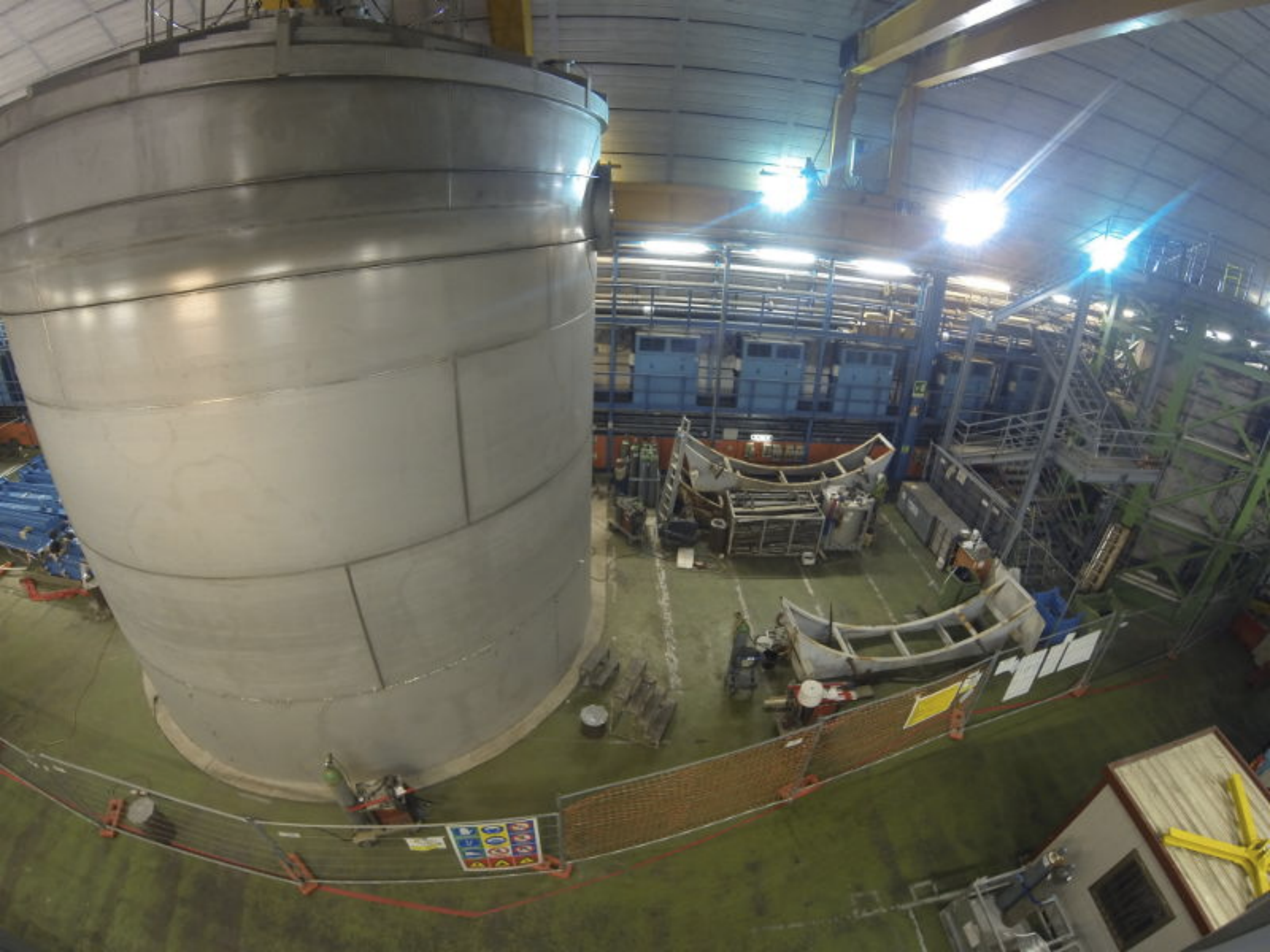
(Baudis)


23/9/2013

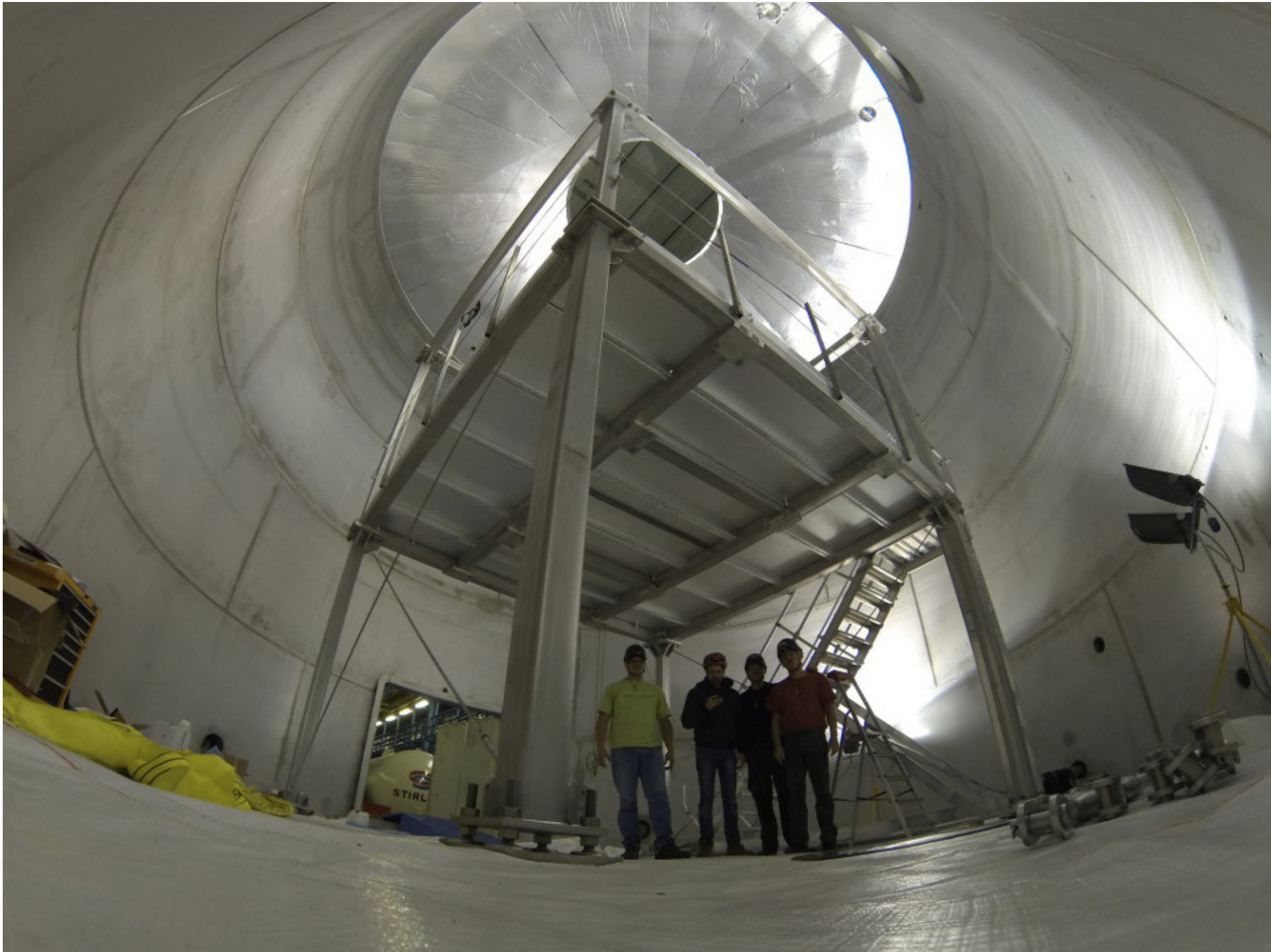




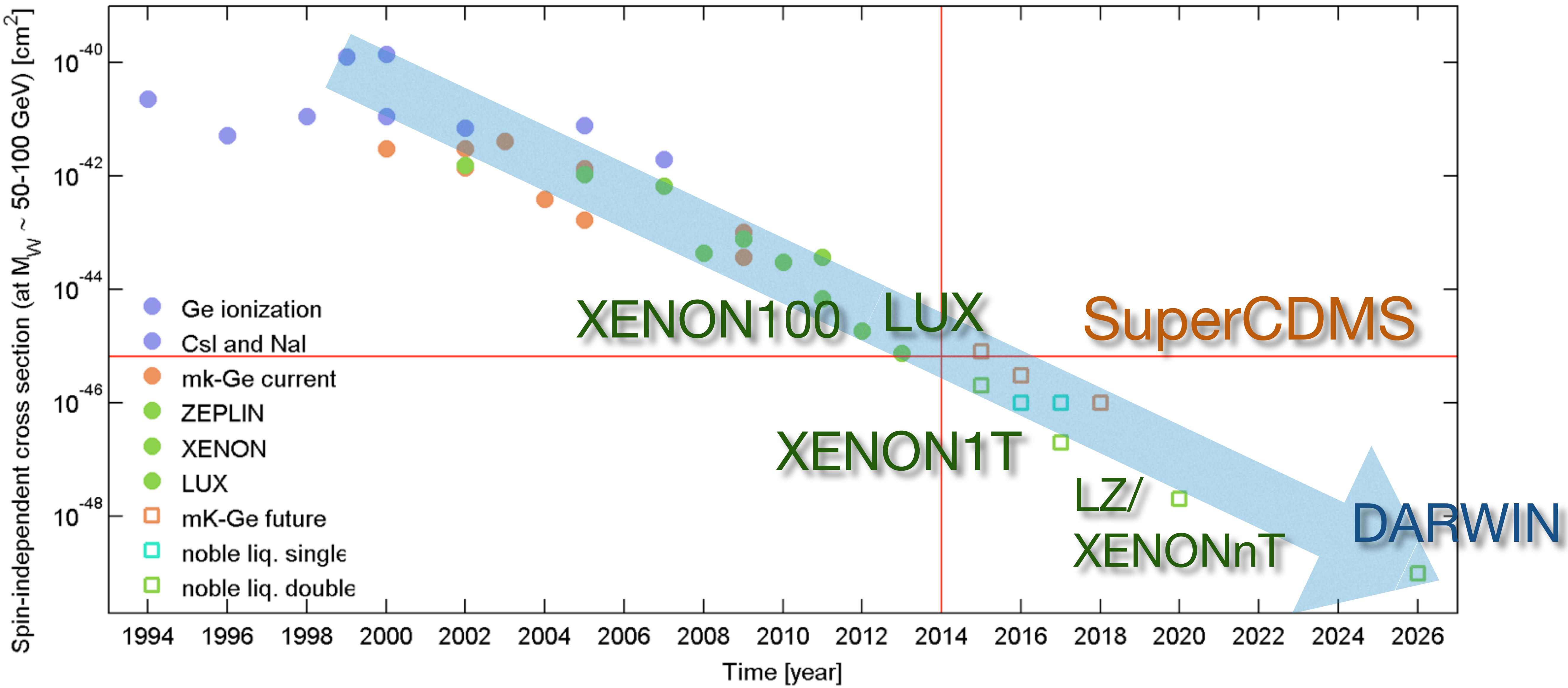





XENON1T
enlightening the Dark
XENON


STIRL


You’ve seen an empty room before…
…but what will it look like in one year?



(Baudis 1408.4371, and many other slides taken from Baudis)