

Direct Searches for Galactic Dark Matter



The
University
Of
Sheffield.



Neil Spooner, University of Sheffield

- ▶ **Why Dark Matter, Why WIMPs**
- ▶ **Direct Search Update, UK bits**
- ▶ **Scale-up and the Future**
- ▶ **My pet topic - directionality**

Thanks to those from whom I have borrowed slides and info

Sorry not to cover all experiments
- there are many

For the Latest

- ▶ To know more —> **IDM2016**
- ▶ **Sheffield, 18-22 July**

11th International Conference

Identification of Dark Matter

IDM 2016

Direct detection
Indirect detection
Accelerator searches
Dark matter candidates
Astrophysical observations
Particle physics and cosmological models
Future prospects and techniques
Underground sites and missions

20th Anniversary


International Advisory Committee

Daniel Akerib	Lawrence Krauss
Elena Aprile	Vitaly Kudryavtsev
Elizabetta Barberio	Reina Maruyama
Pierluigi Belli	Kentaro Miuchi
Rita Bernabei	Harry Nelson
Gianfranco Bertone	Kaixuan Ni
Juan Collar	Leszek Roszkowski
Joakim Edsjo	Bernard Sadoulet
Katherine Freese	Pierre Salati
Carlos Frenk	Daniel Santos
Richard Gaitskell	Pierre Sikivie
Gilles Gerbier	Daniel Snowden-Ifft
Paolo Gondolo	Neil Spooner
Anne Green	Tracy Slatyer
Dan Hooper	Max Tegmark
Karsten Jedamzik	Karl van Bibber
Xiangdong Ji	Christoph Weniger
Yeongduk Kim	Konstantin Zioutas

Local Organising Committee


Susan Cartwright	Stacey Perkin
Anthony Ezeribe	Matthew Robinson
Vitaly Kudryavtsev	Angela Rollinson
Matthew Malek	Andrew Scarff
Frederic Mouton	Neil Spooner

Public Talk by Prof. Katherine Freese at The Diamond



<http://idm2016.shef.ac.uk/>

Sheffield UK, 18-22 July 2016

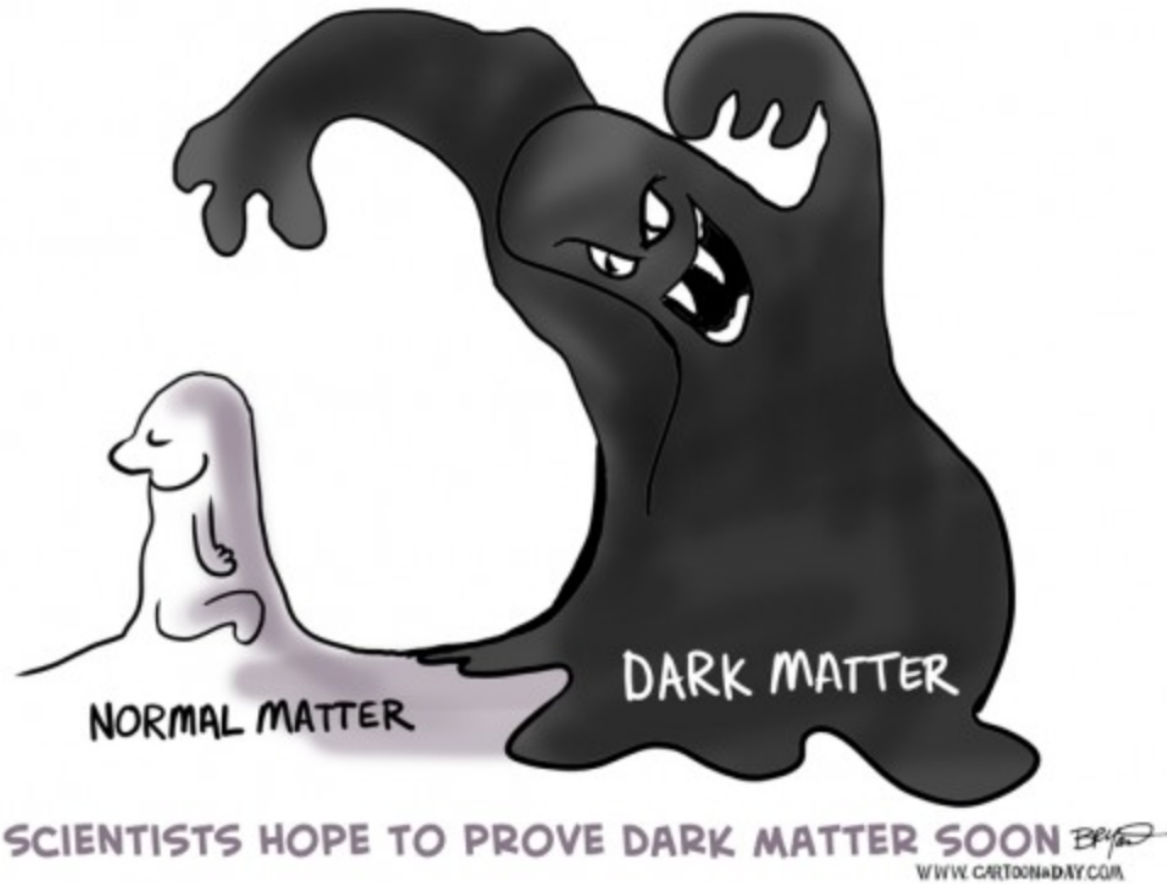


Question for the Student



SCIENTISTS HOPE TO PROVE DARK MATTER SOON 
WWW.CARTOONADAY.COM

Question for the Student



Q: What fraction of the Universe is made of stars?

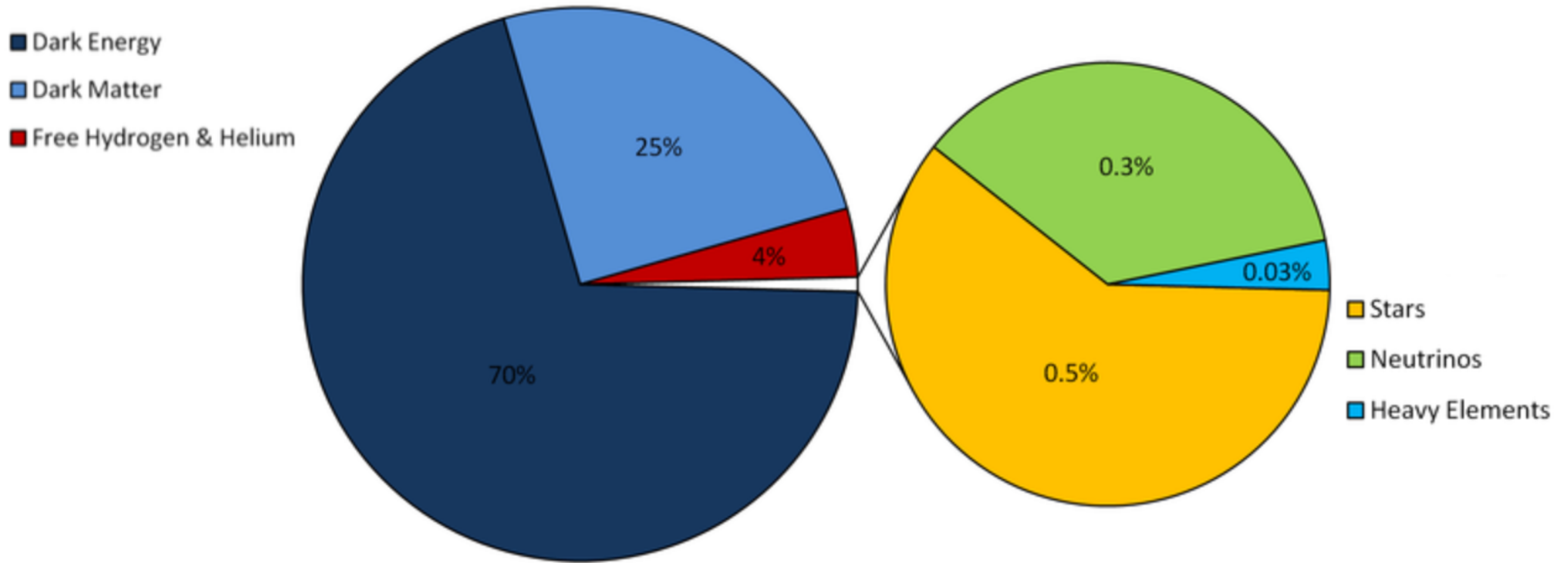
Question for the Student



Q: What fraction of the Universe is made of stars?

ANS: 0.5%

The Composition of the Universe



$$\Omega = \Omega_{\text{matter}} + \Omega_{\Lambda}$$

Matter density
0.29+/-0.07

of which

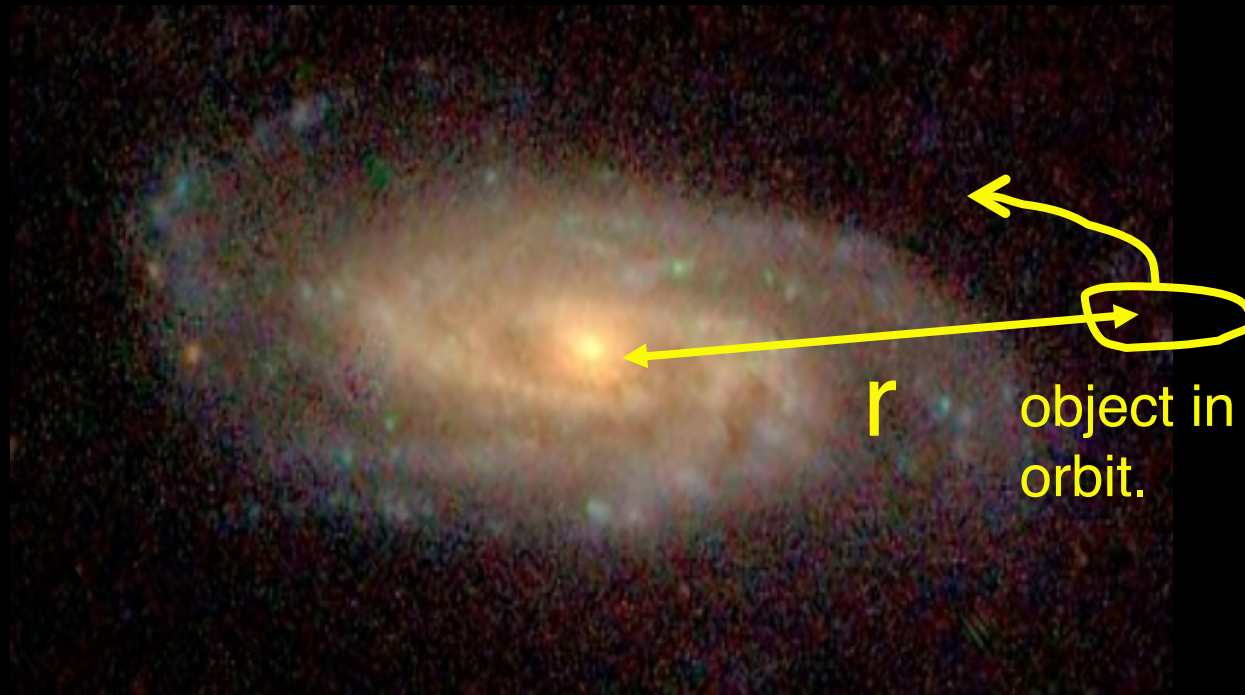
0.05 : baryons

0.24 : dark matter

Dark energy /cosmological
constant quintessence

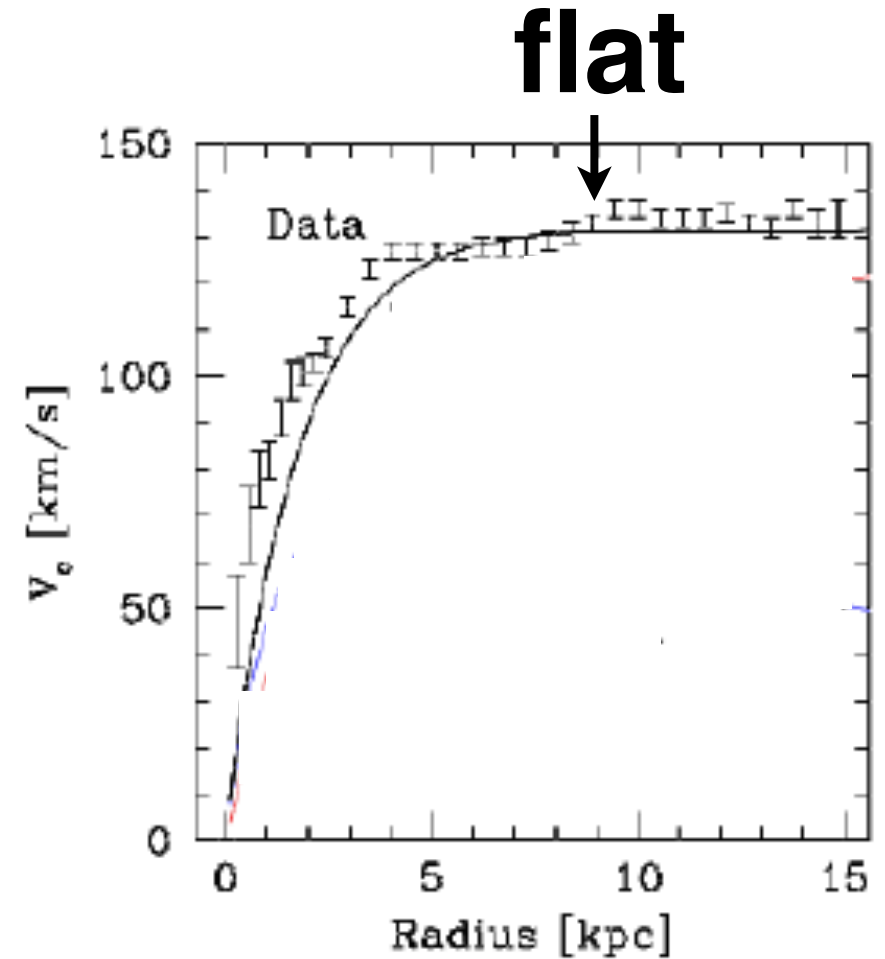
0.71+/-0.07

Evidence from GALAXIES



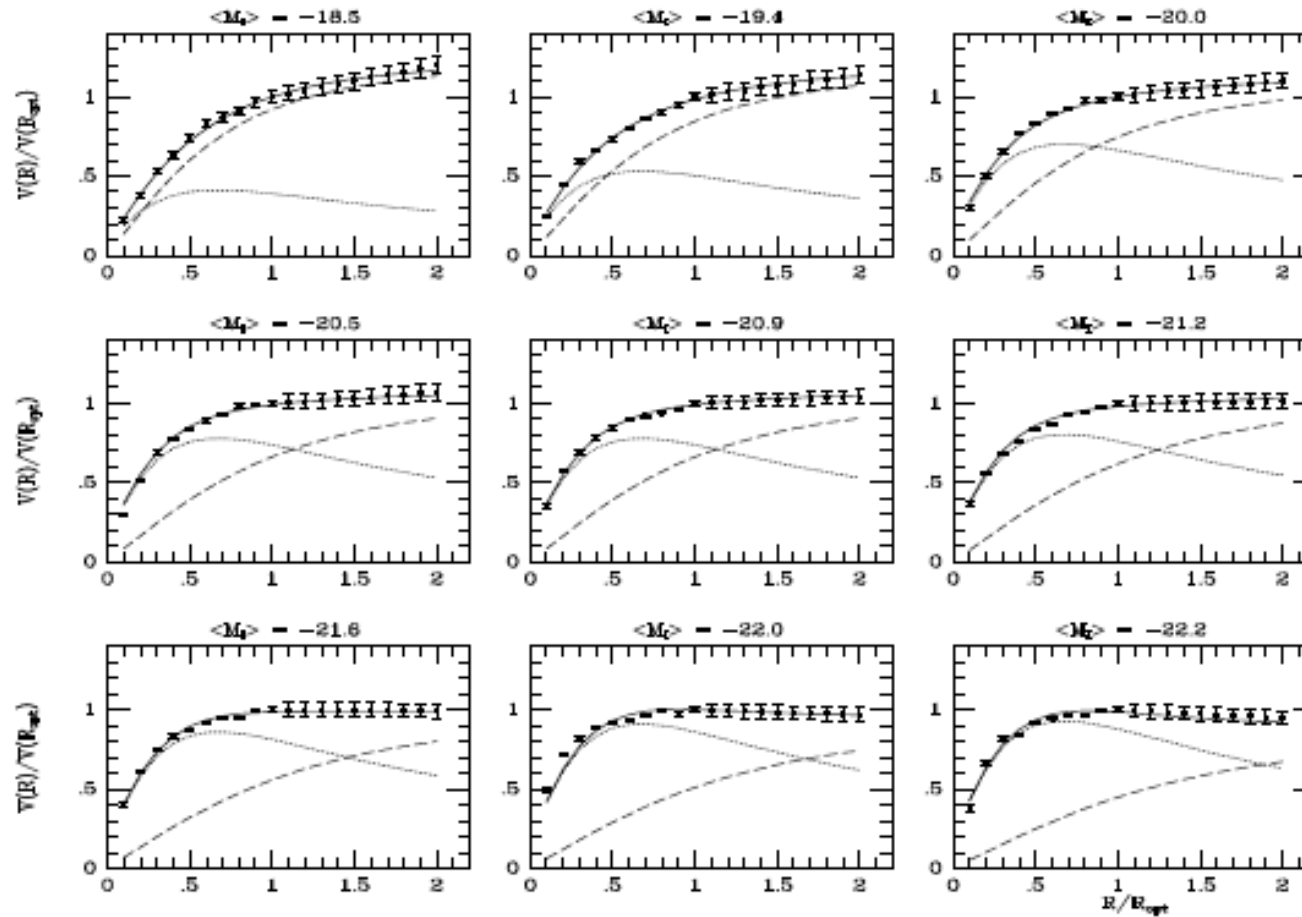
e.g. NGC3198

Example

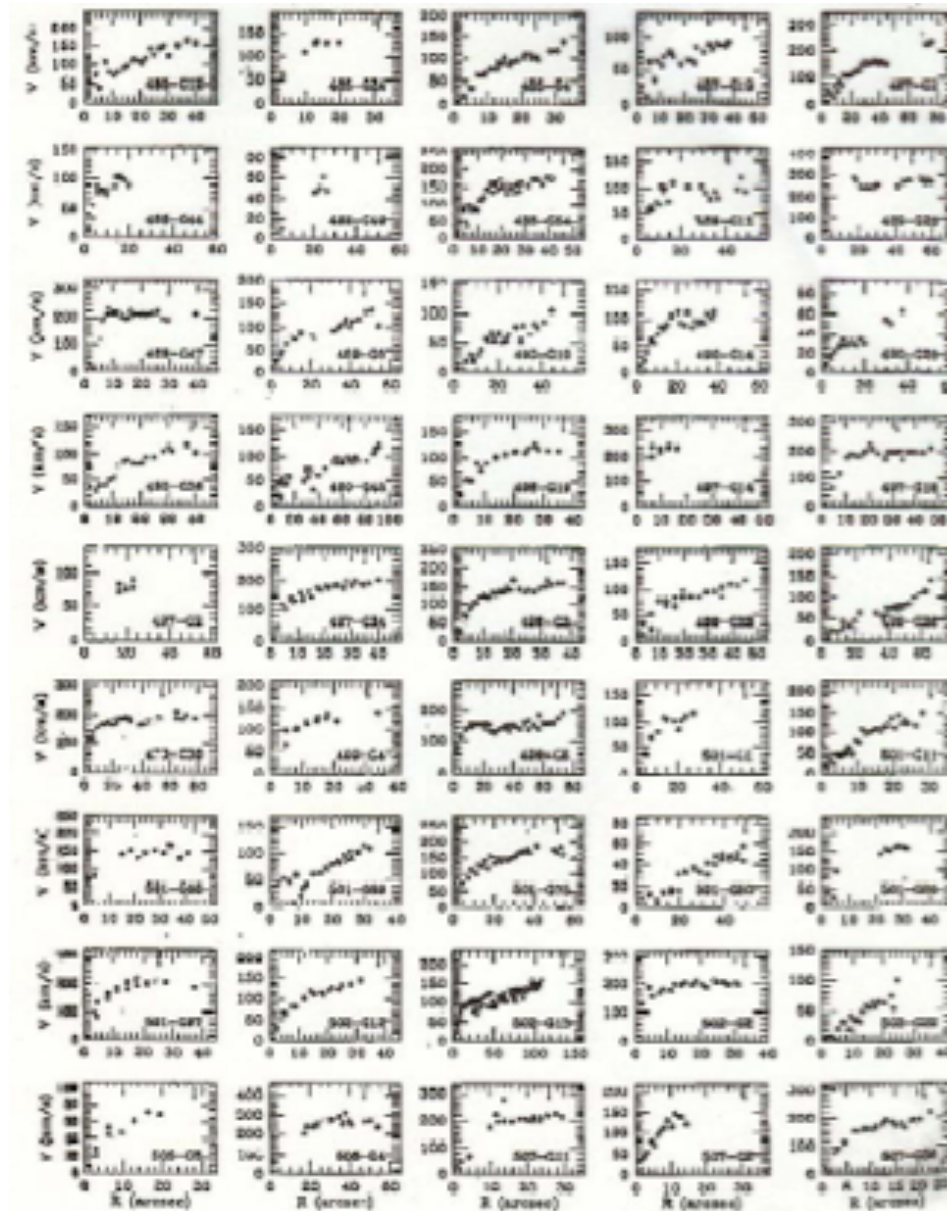


the “flat rotation curve”

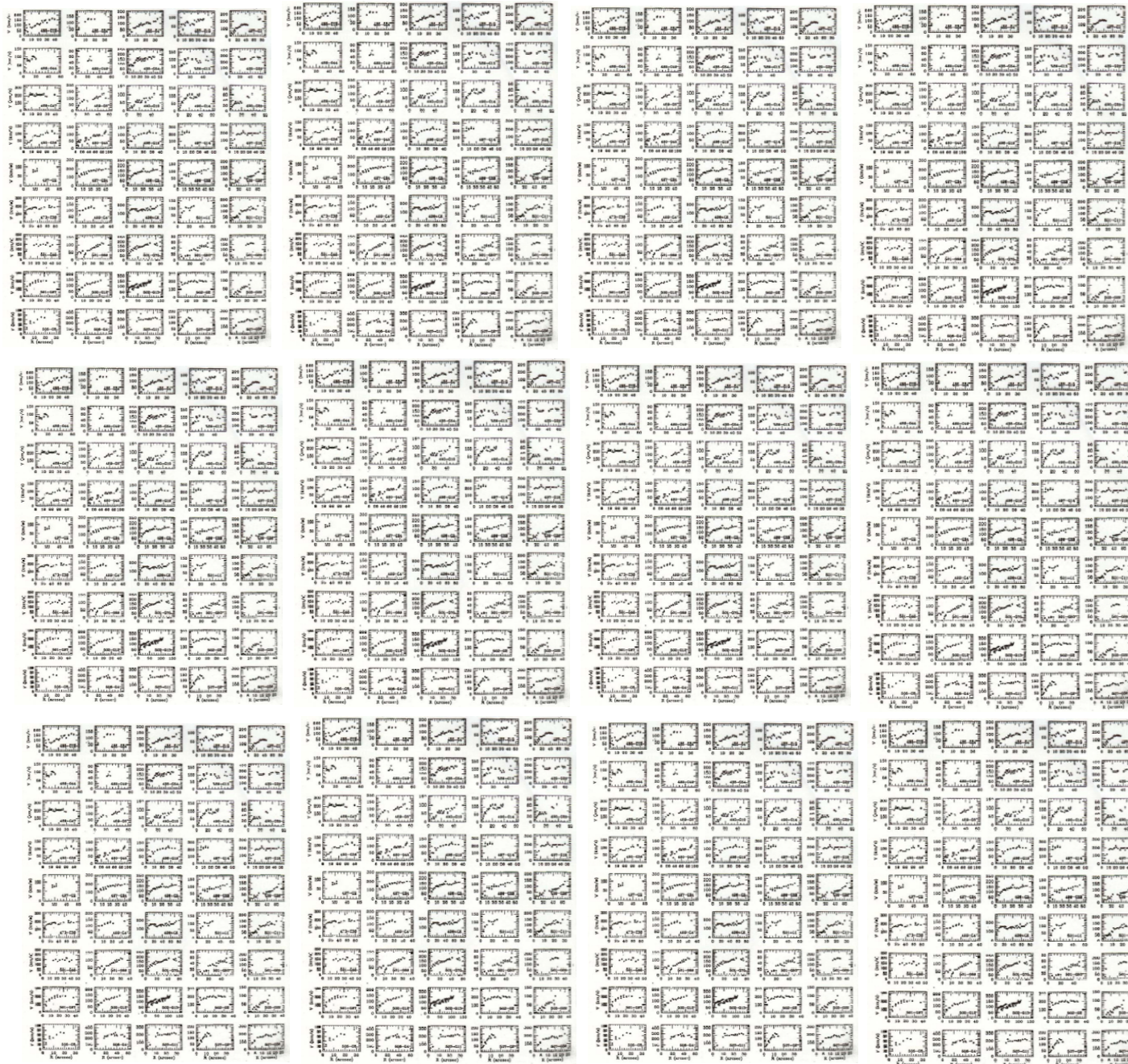
And more examples



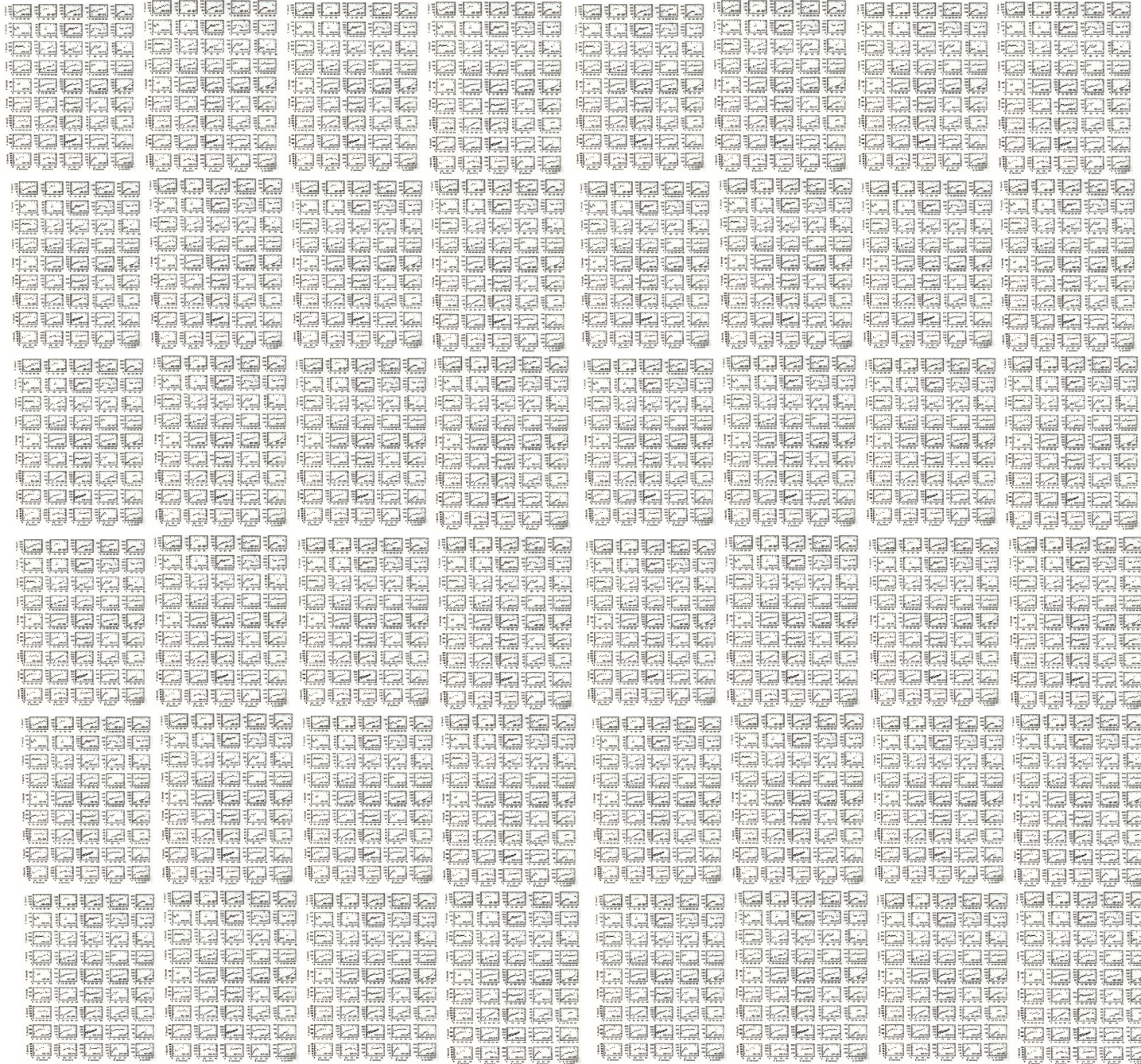
And more



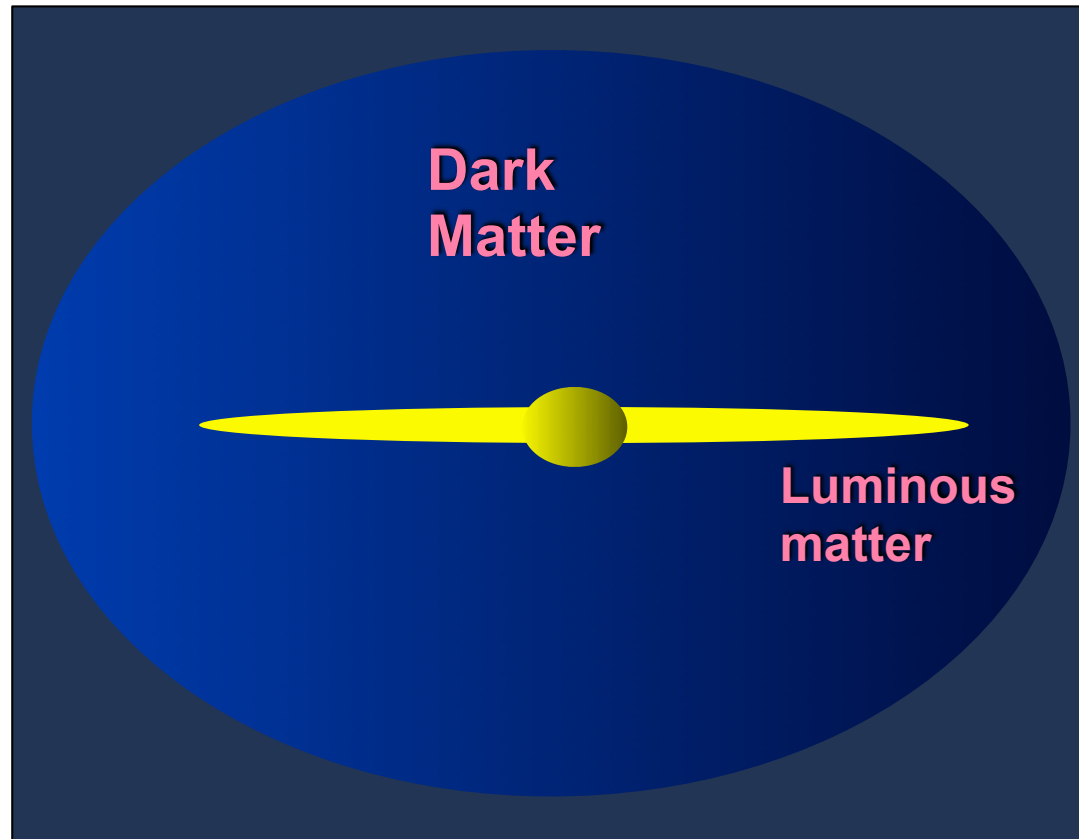
And more....



And more....



So Galaxies are 90% Dark Matter

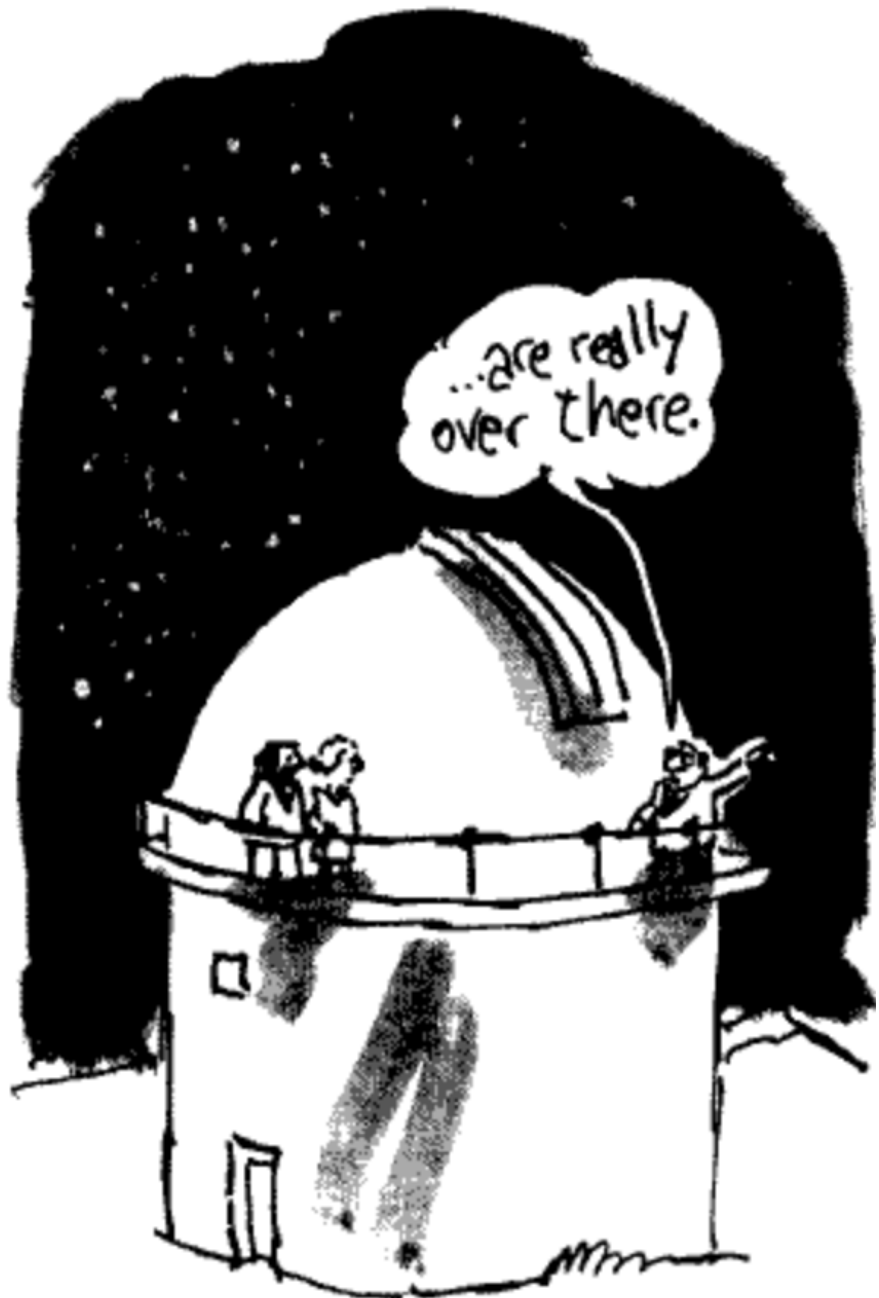
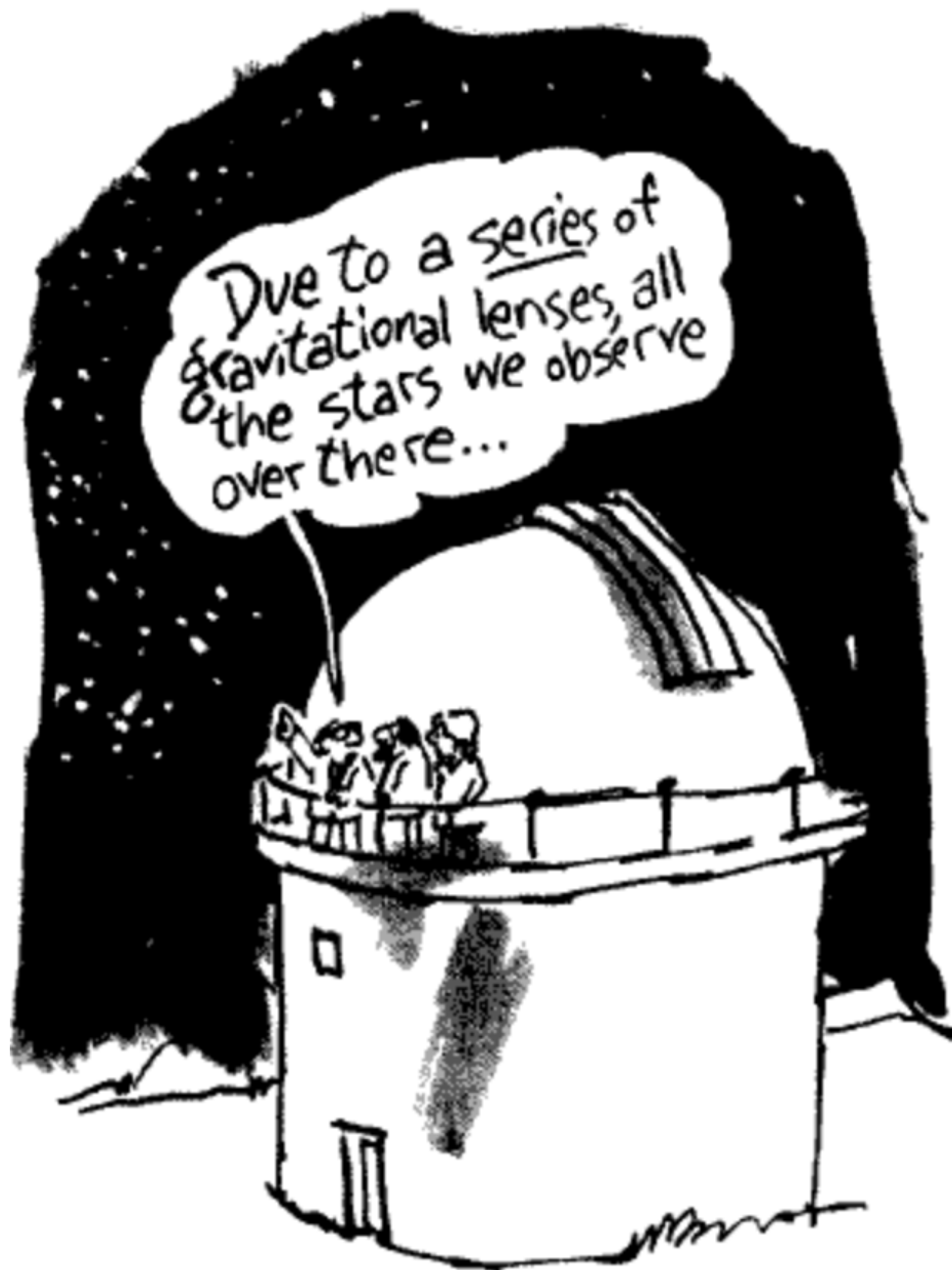




Evidence from Gravitational Lensing

Abell 370

The image shows a field of galaxies with several prominent lensing features. A large, bright, yellowish-white galaxy is located in the lower right quadrant. To its right, a long, curved, reddish-brown filament of light stretches across the frame, representing a lensed image of a background galaxy. Numerous other galaxies are visible, some appearing as multiple images or distorted shapes, which are characteristic of gravitational lensing. The background is dark with scattered stars and faint galaxy images.



S. H. M. S.

Baryons

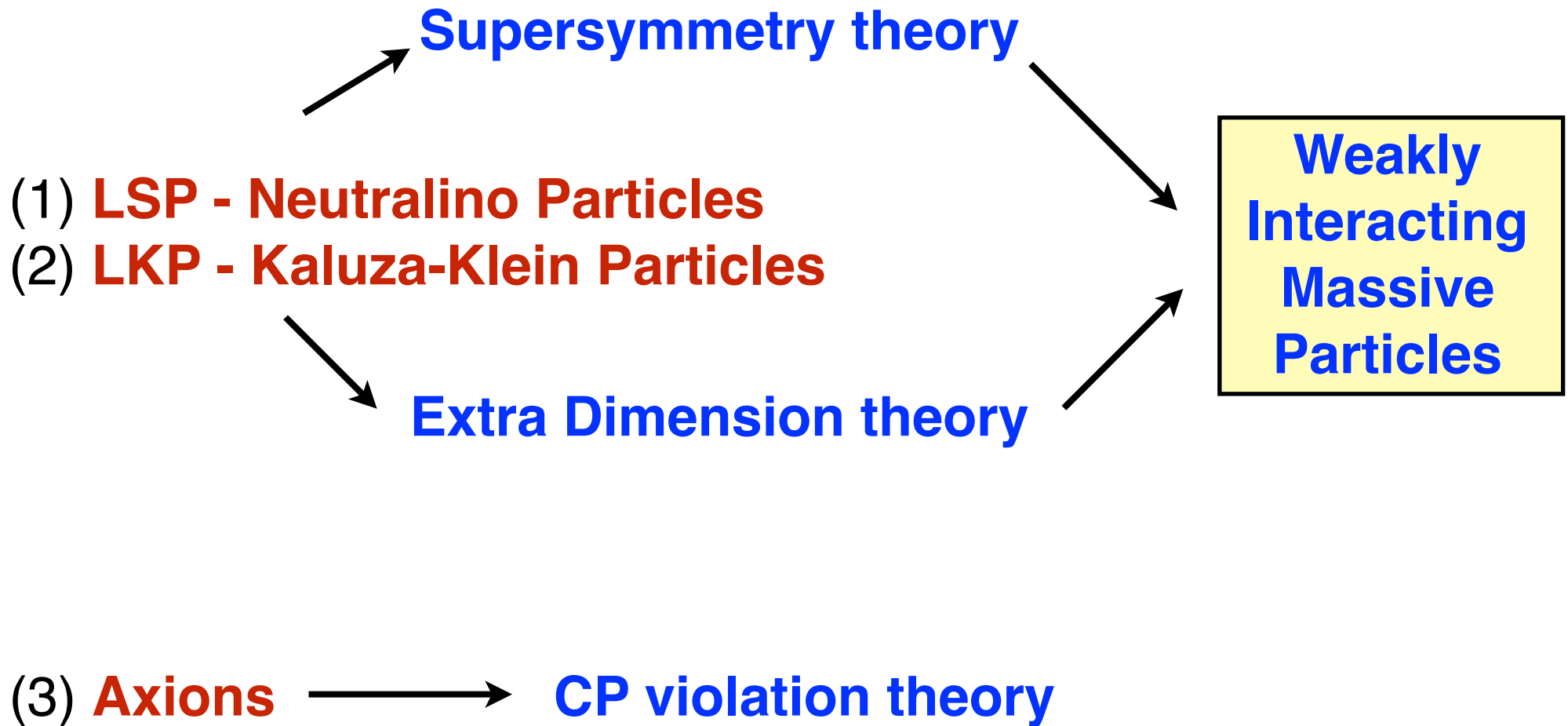


Baryons



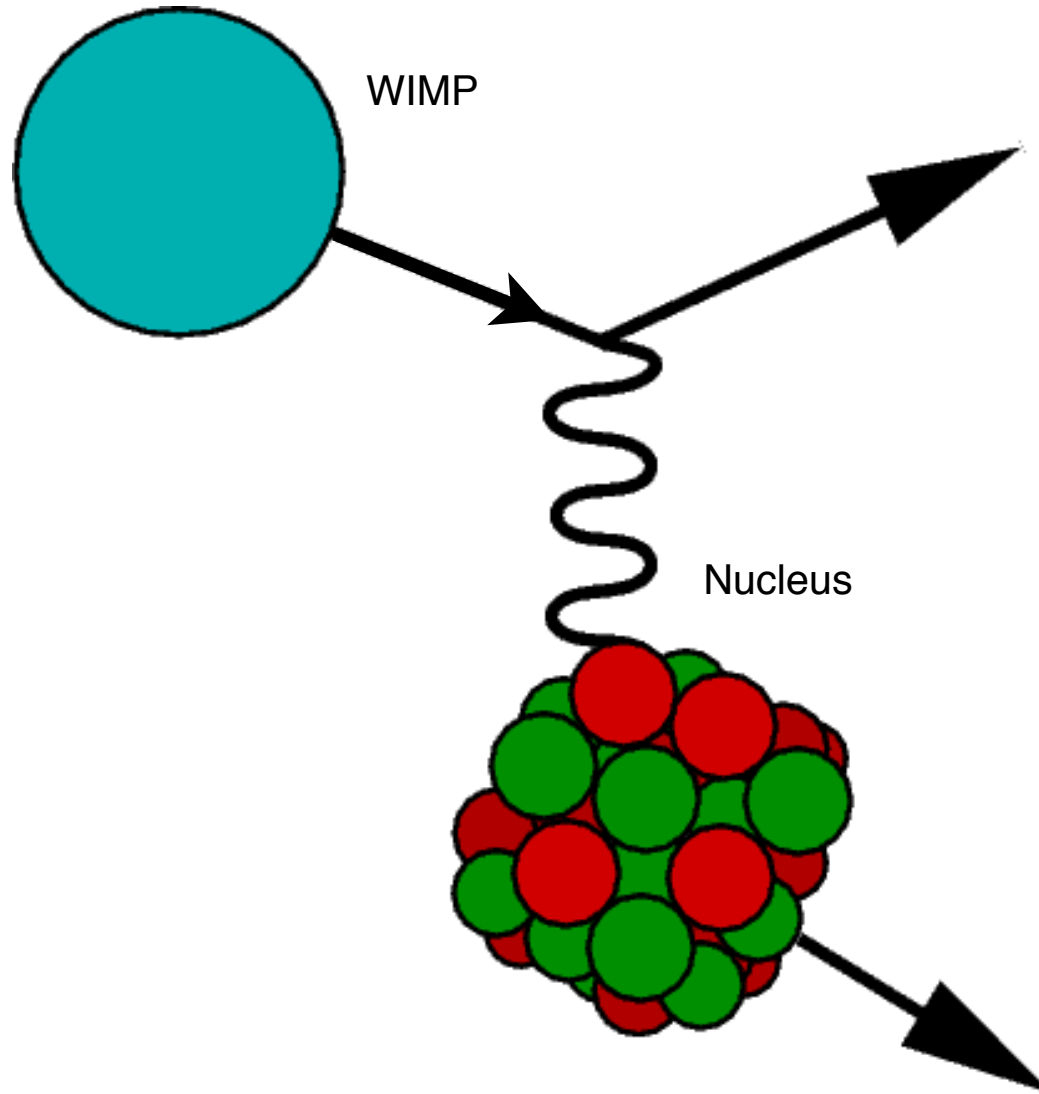
nope

Theoretically Most Likely

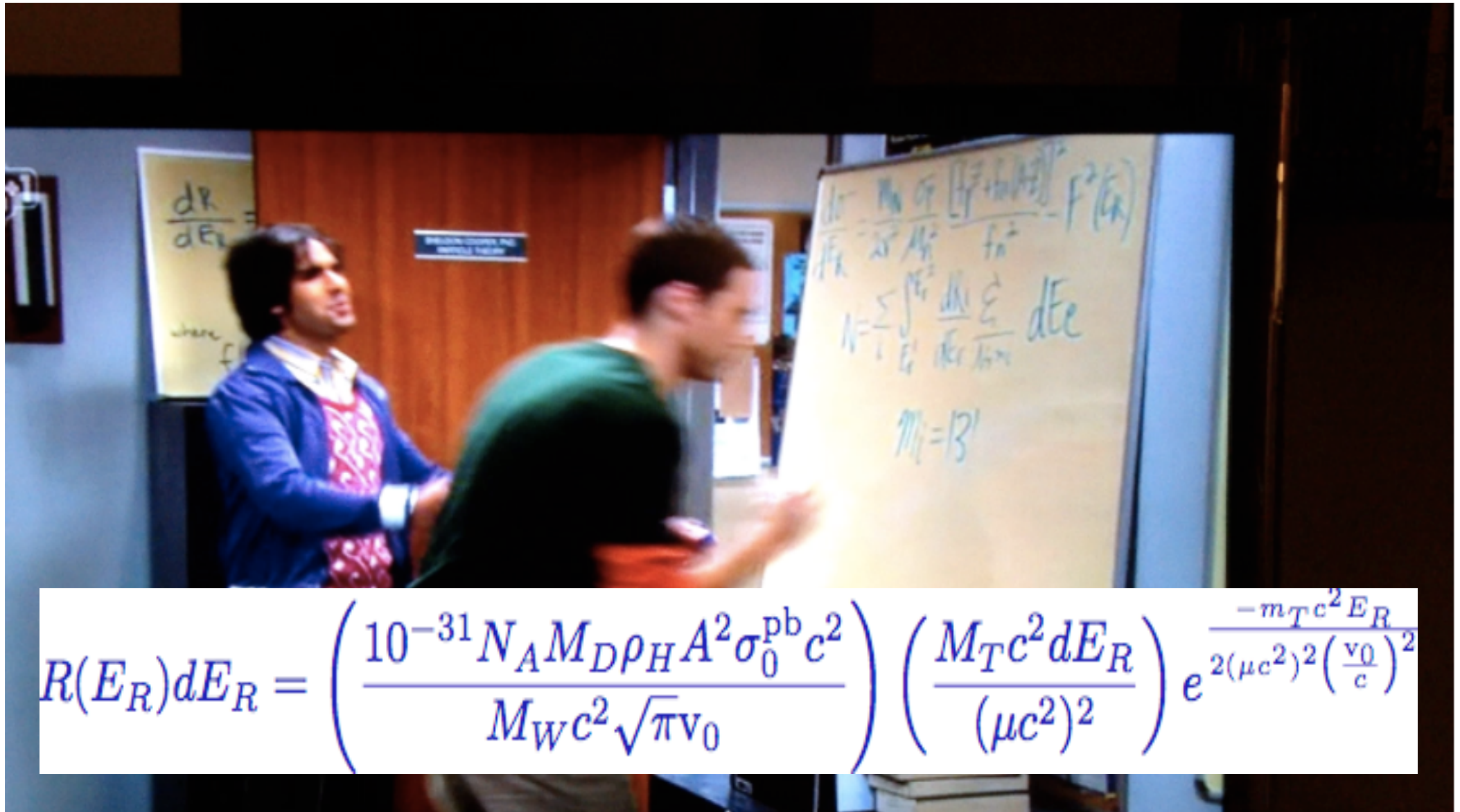


What Does a WIMP do in Matter?

► “Billiard Ball Kinematics”

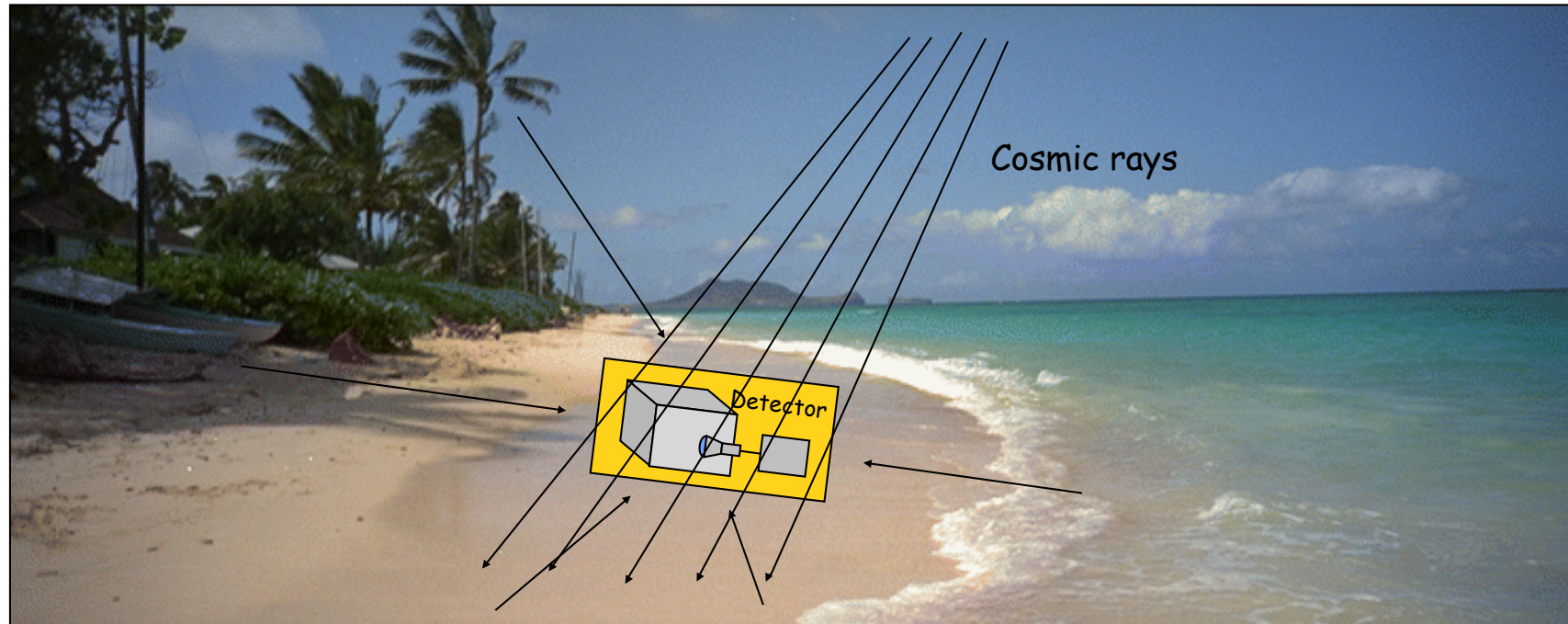


Bang goes the Recoil Equation



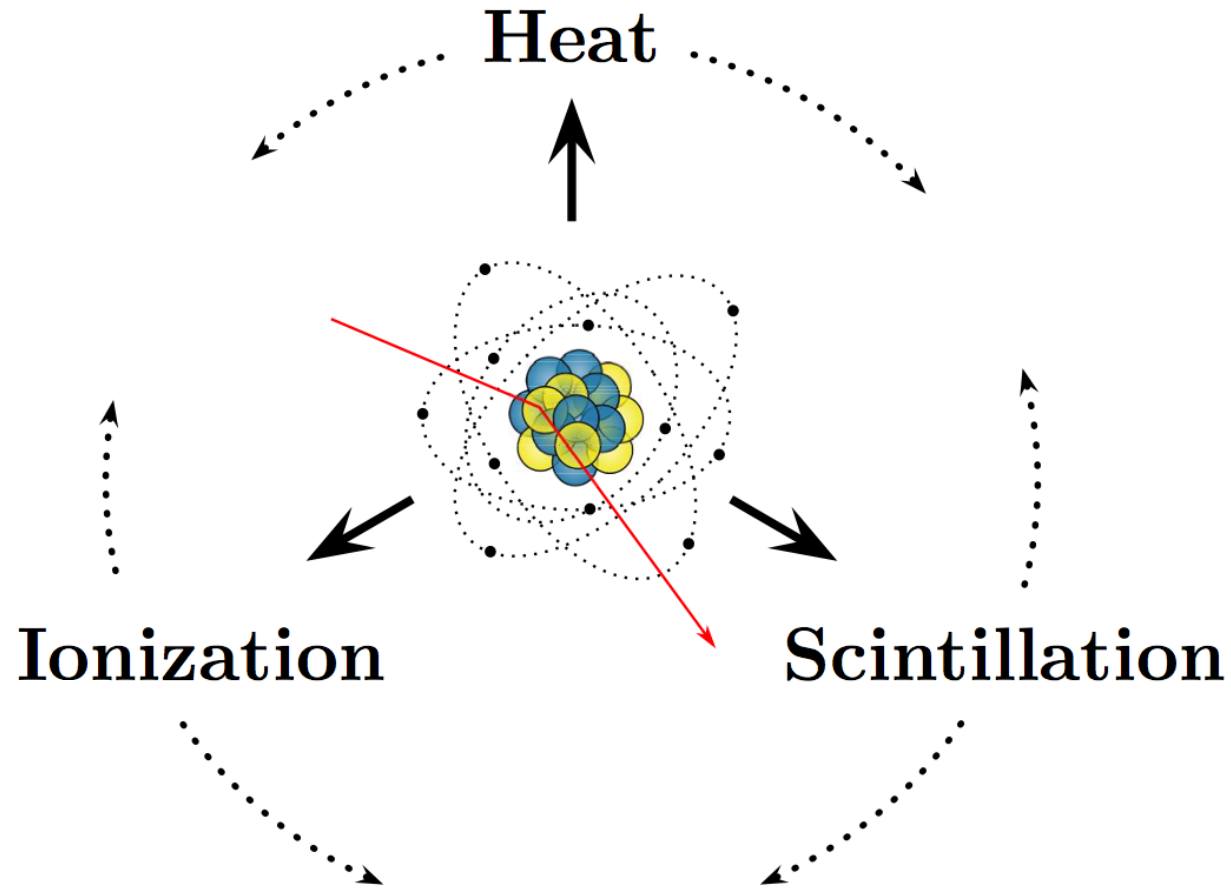
$$R(E_R)dE_R = \left(\frac{10^{-31} N_A M_D \rho_H A^2 \sigma_0^{\text{pb}} c^2}{M_W c^2 \sqrt{\pi} \nu_0} \right) \left(\frac{M_T c^2 dE_R}{(\mu c^2)^2} \right) e^{\frac{-m_T c^2 E_R}{2(\mu c^2)^2 \left(\frac{\nu_0}{c}\right)^2}}$$

Oh Dear Background Radiation!



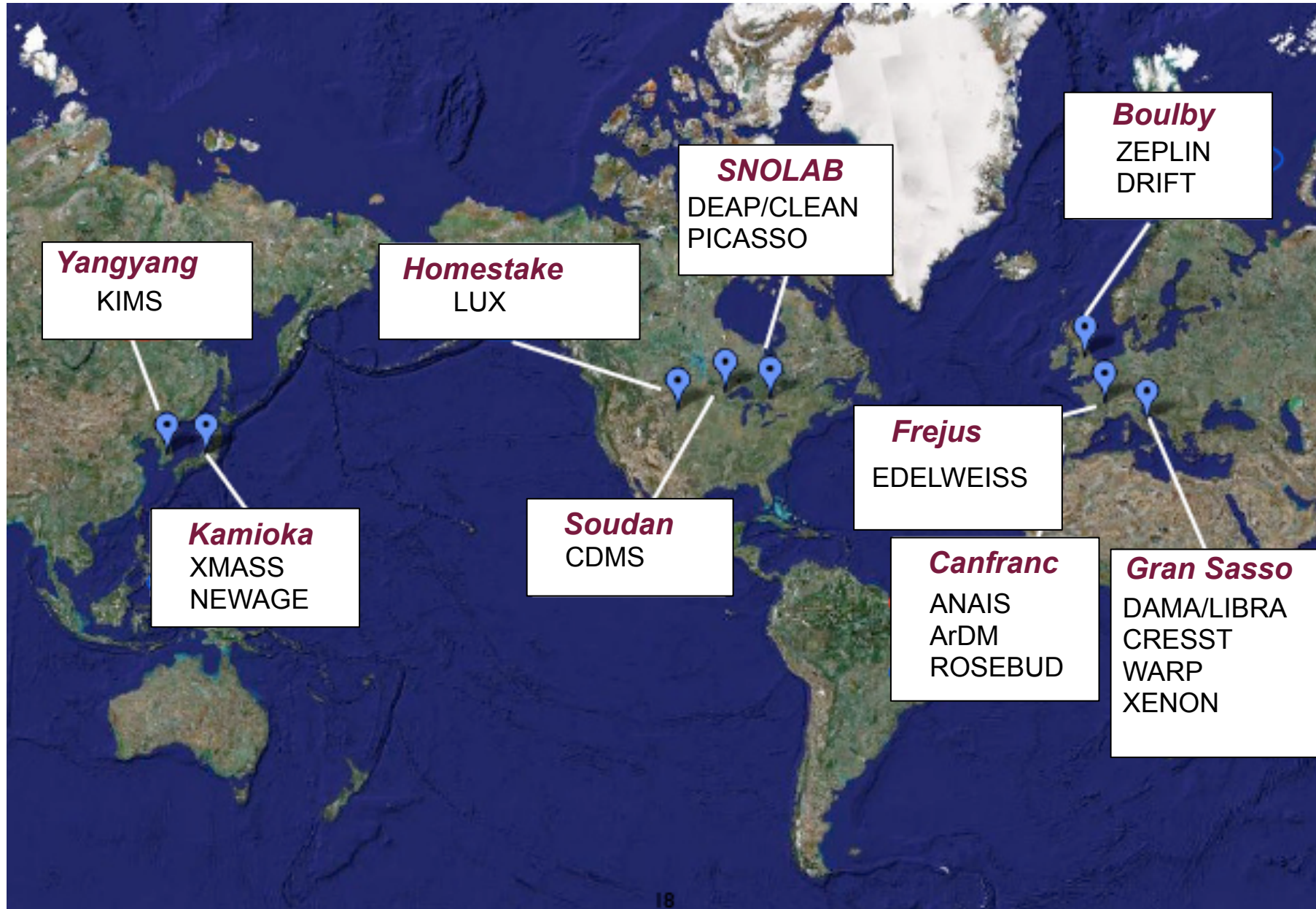
- ▶ Alpha, beta, gamma, neutron, cosmic rays
- ▶ U, Th, K.... radon

A Route to WIMP Direct Detection

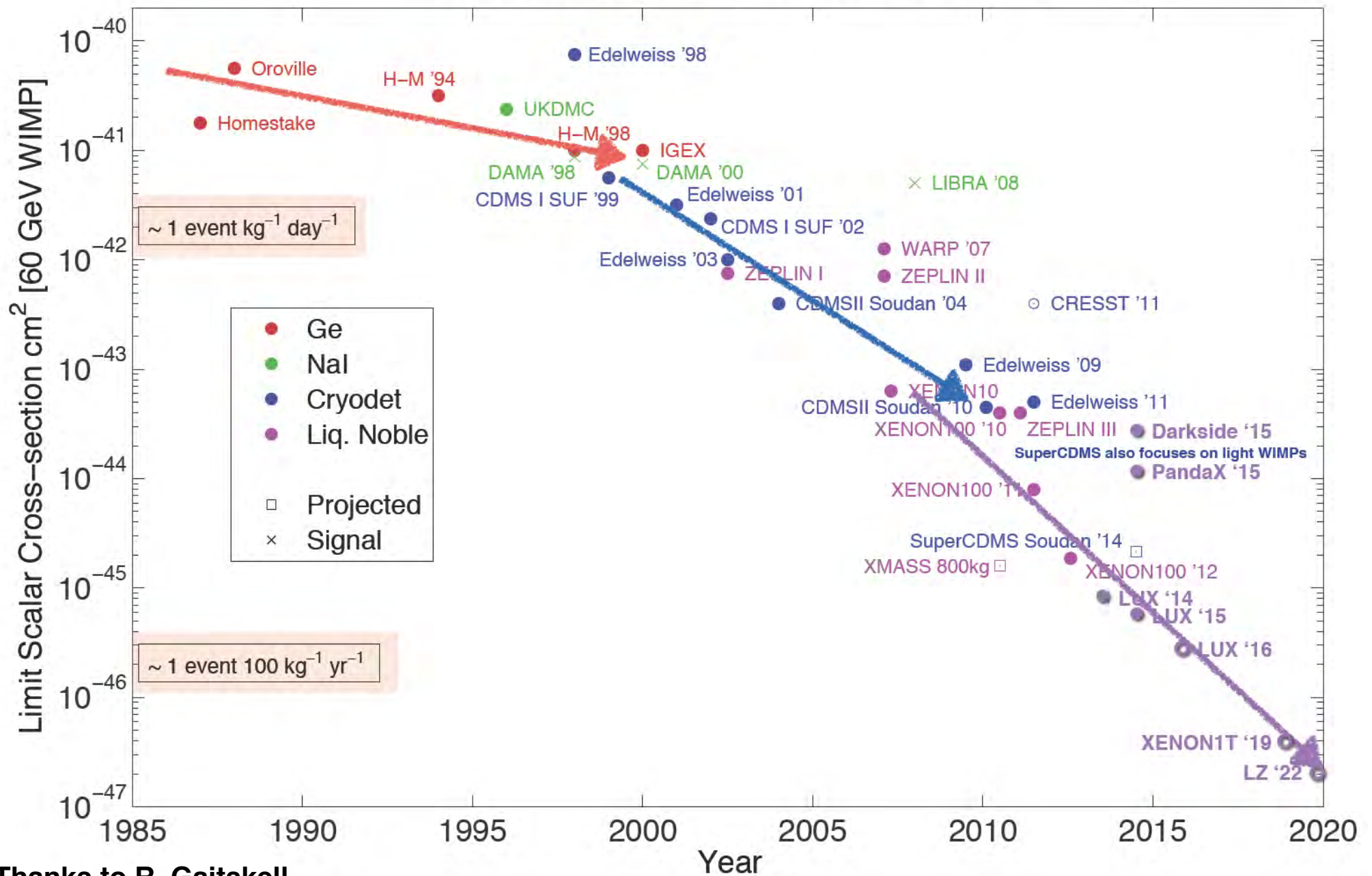


Many Experiments Worldwide

- ▶ Go underground to get away from cosmic rays



Experiments - Past, Present, Future



Thanks to R. Gaitskell

~Current Situation

► at High Mass

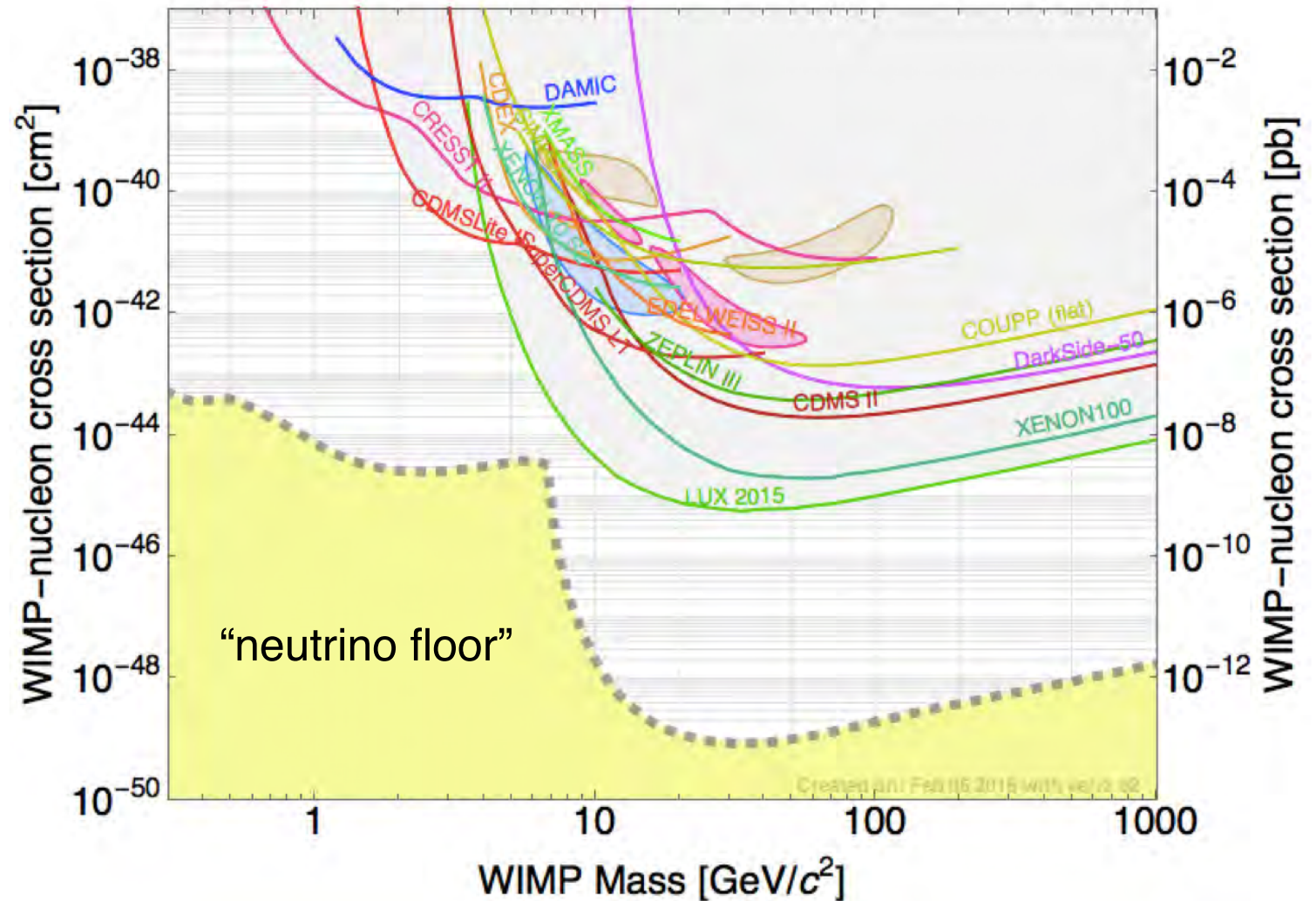
Nothing so far
Consistent with the
absence of SUSY@LHC

► at Low Mass

Some closed contours,
and strong limits

What is going on?

► Are the closed regions a hint or just unreliable calibration



Many Recent Technical Advances

but oh dear, no signal, what to do?:

Many Recent Technical Advances

but oh dear, no signal, what to do?:

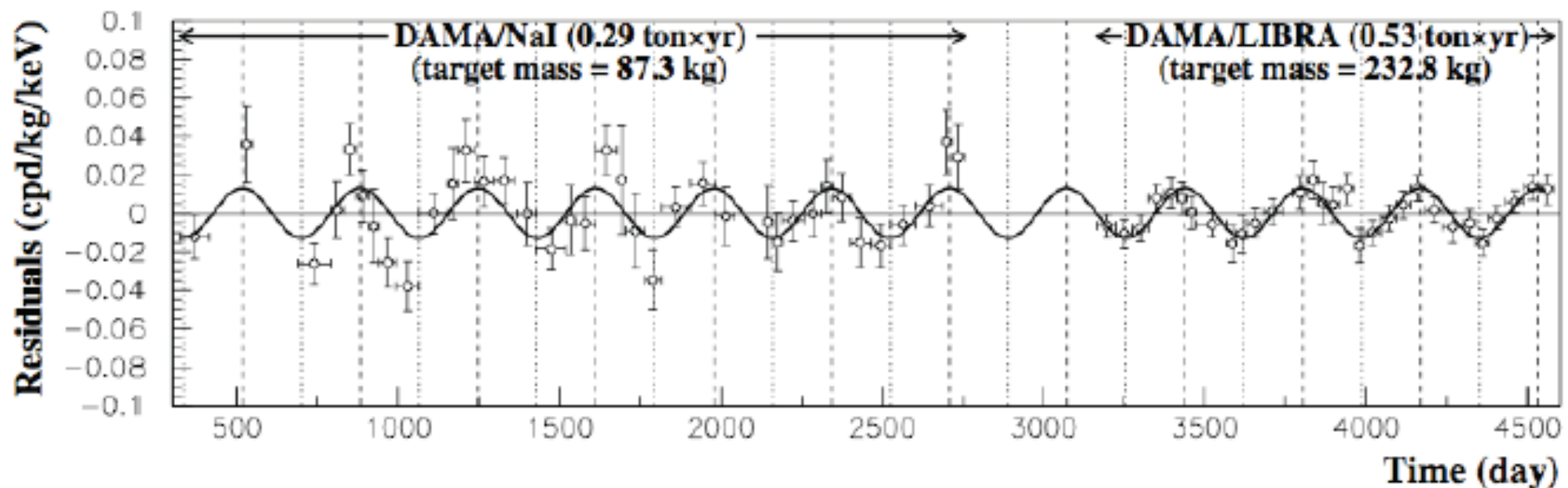
- **try low WIMP mass**
- **try bigger targets for high WIMP mass**
- **double check old “signals”**
- **seek better signal**
- **try something else!**

WIMPs Found? or Not?

- ▶ DAMA collaboration in Italy see an Annual Modulation and claim it is WIMPs!
- ▶ Changed Phototubes to high QE - Results 2017?



Rita Bernabei



Annual Modulation Attack

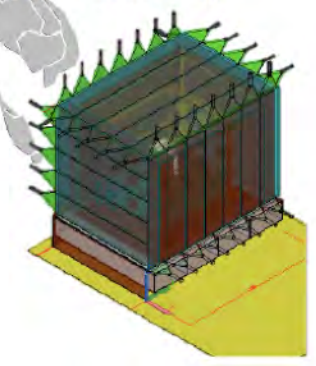
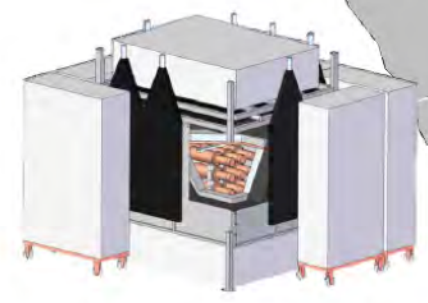
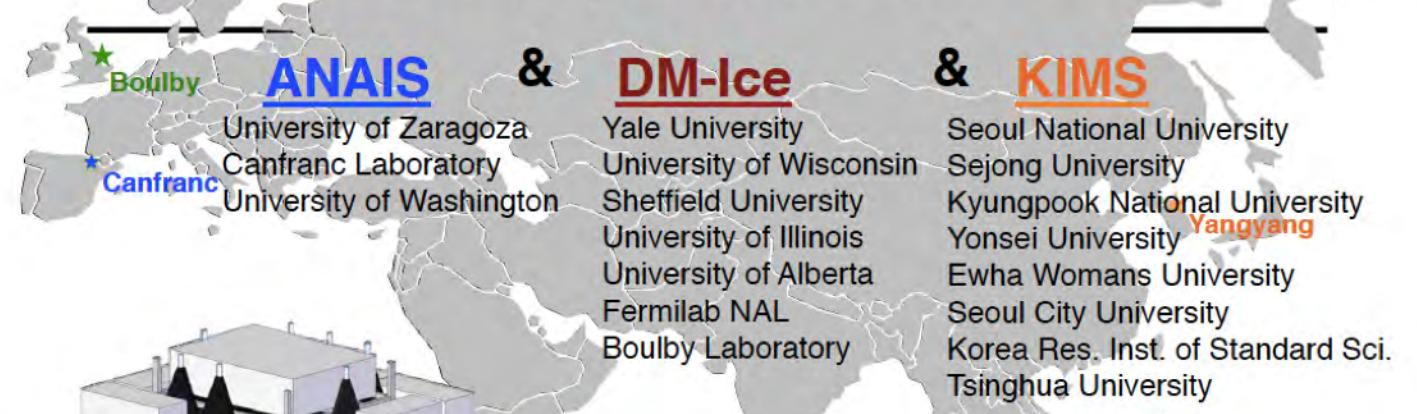
▶ Renewed global efforts of annual modulation in NaI

- ▶ ANAIS (Spain)
- ▶ DM-ICE (US-UK)
- ▶ KIMS (S. Korea)
- ▶ Sabre (US-Italy)

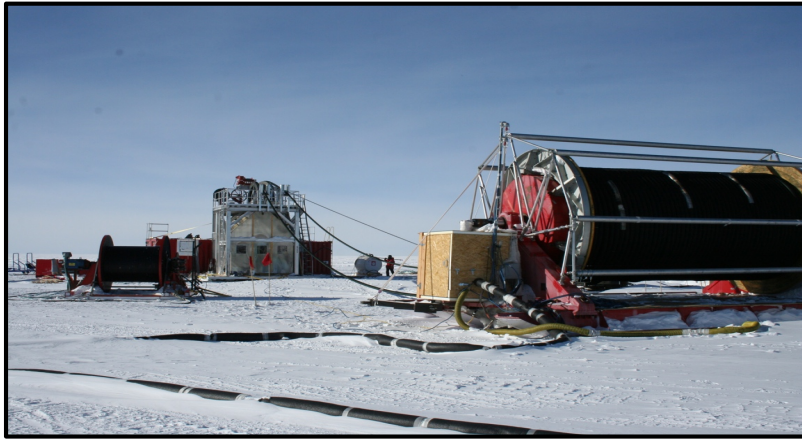


COSINE (joint analysis)

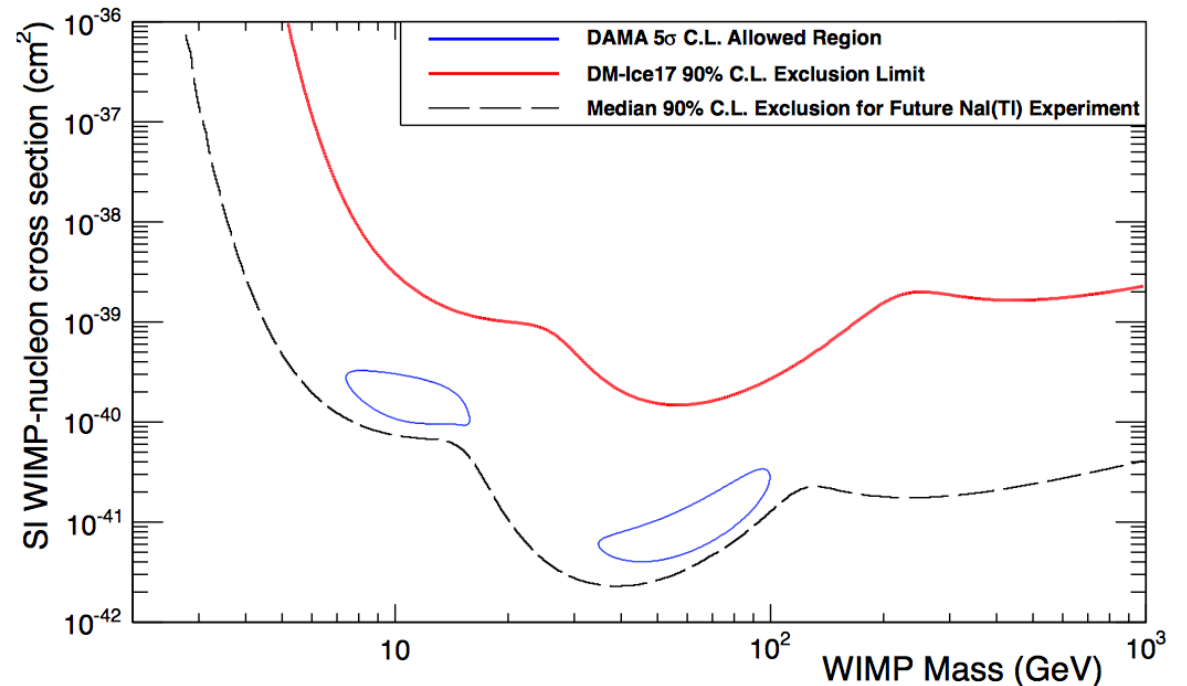
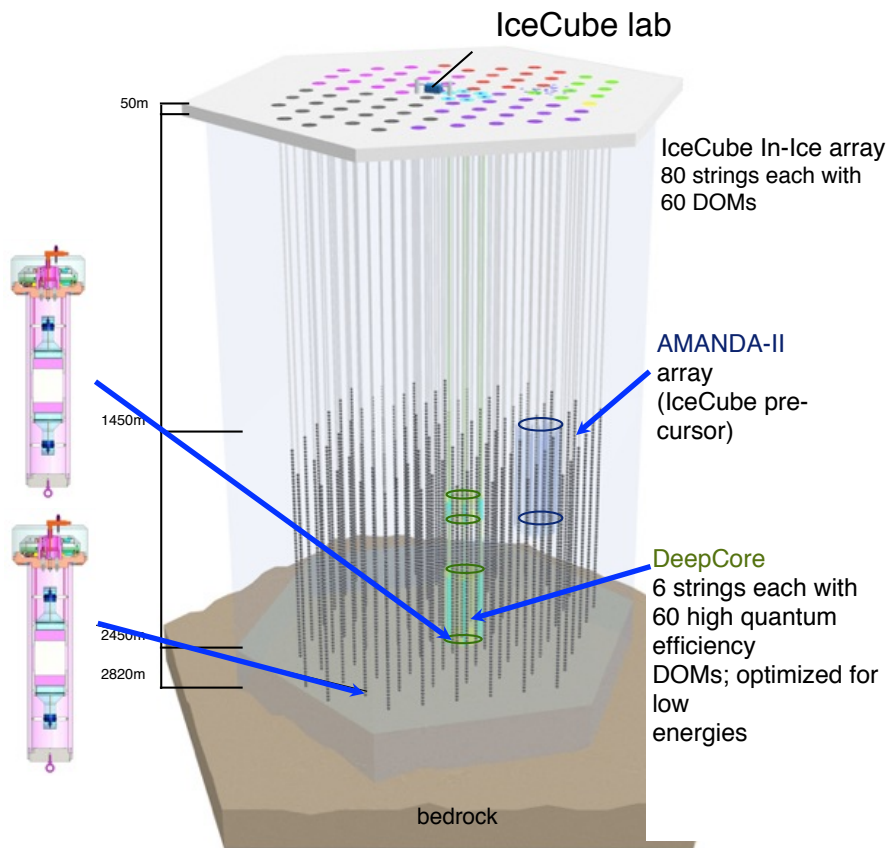
Global NaI(Tl) Collaborative Effort



First DM-ICE Result Just Published



- ▶ 17 kg, 2.5 km below South Pole
- ▶ Original UK NAIAD experiment NaI crystals from Boulby



~Current Situation

► at High Mass

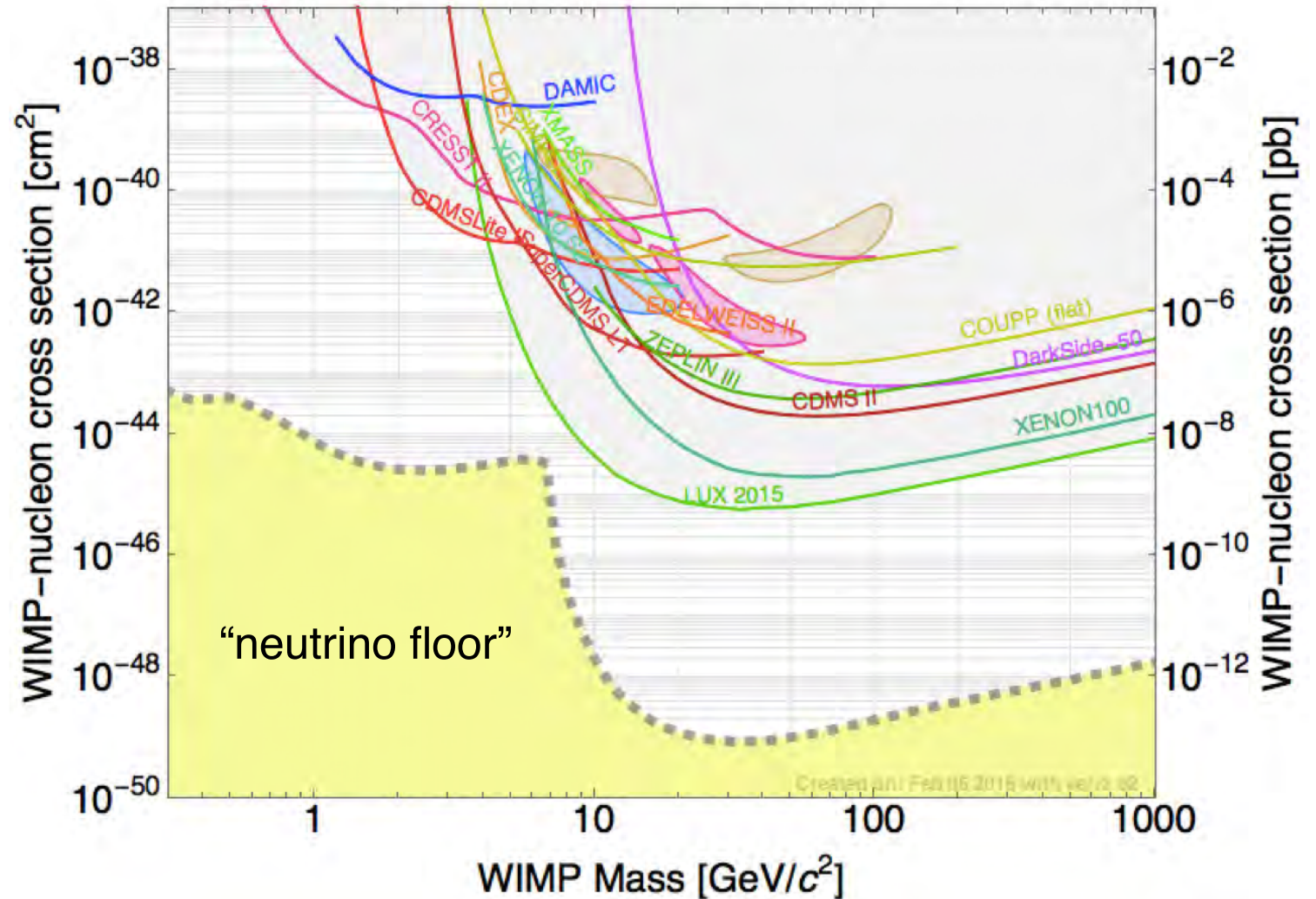
Nothing so far
Consistent with the
absence of SUSY@LHC

► at Low Mass

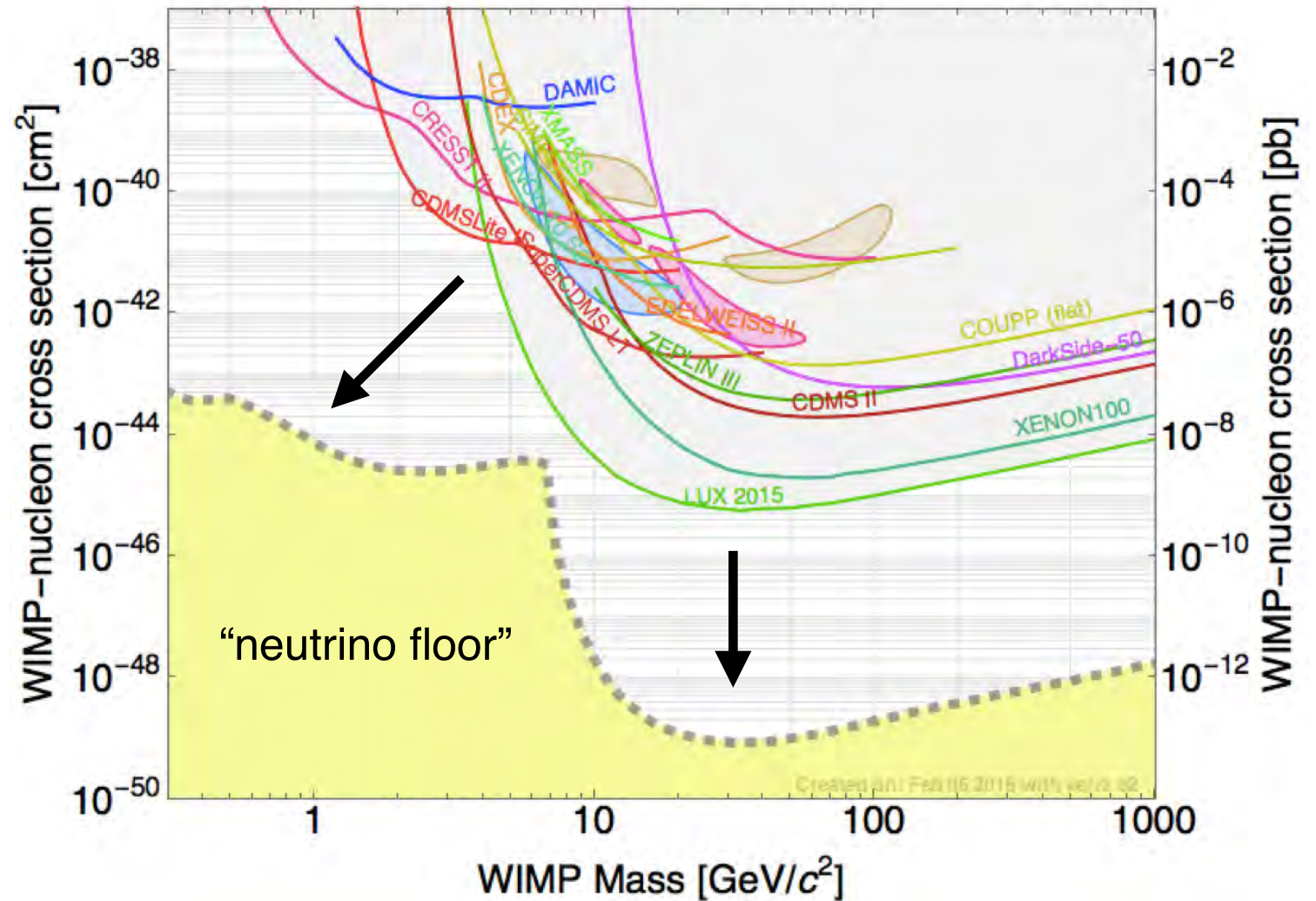
Some closed contours,
and strong limits

What is going on?

► Are the closed regions a hint or just unreliable calibration



~Current Situation

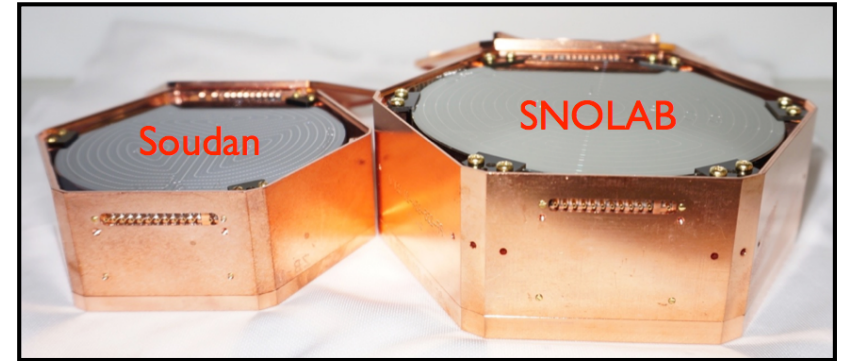
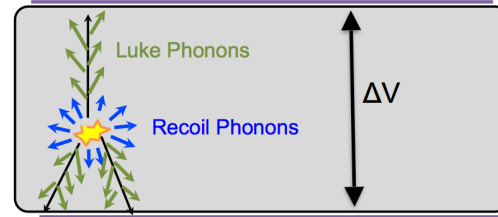
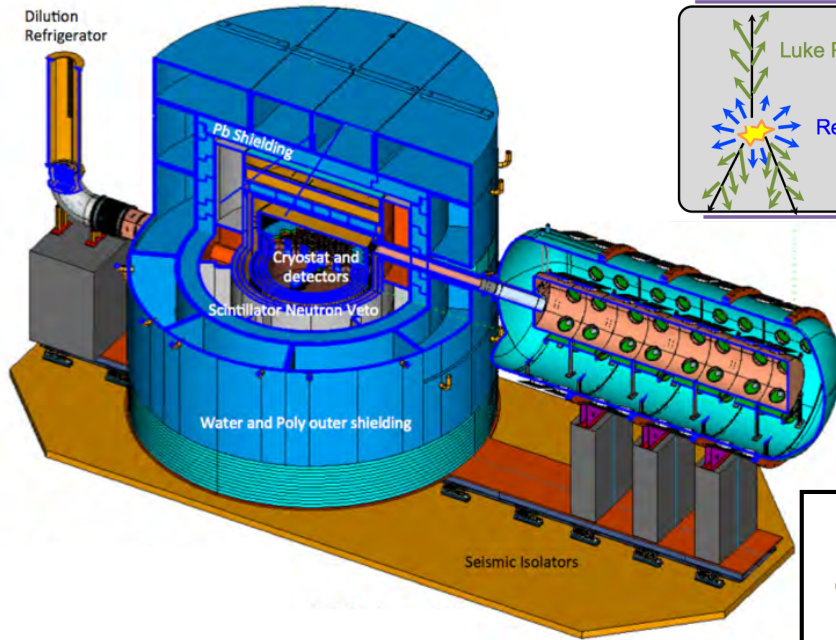


► Strategy

1. Improve sensitivity at low mass (lower the threshold)
2. Improve sensitivity at large mass (increase target mass)

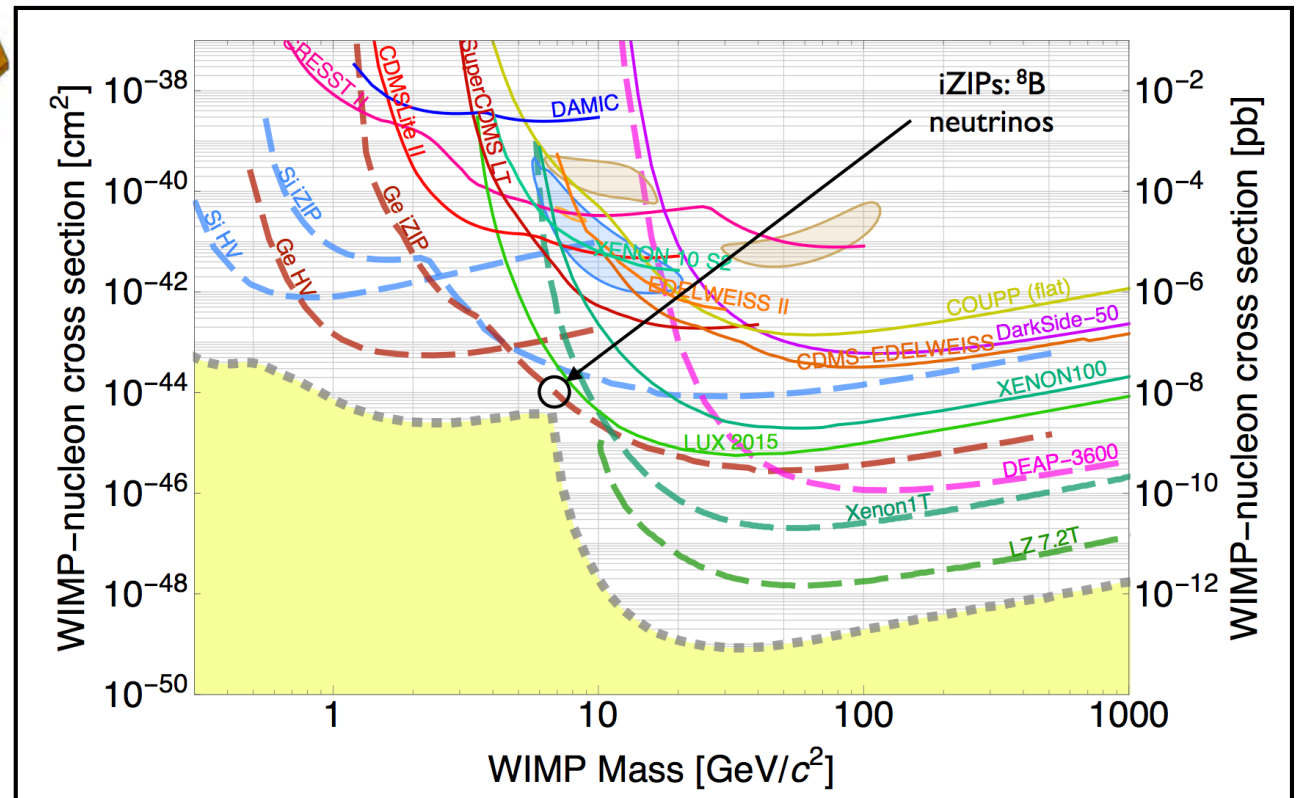
Low Mass: Bolometers superCDMS

- Abandon discrimination - go for low threshold



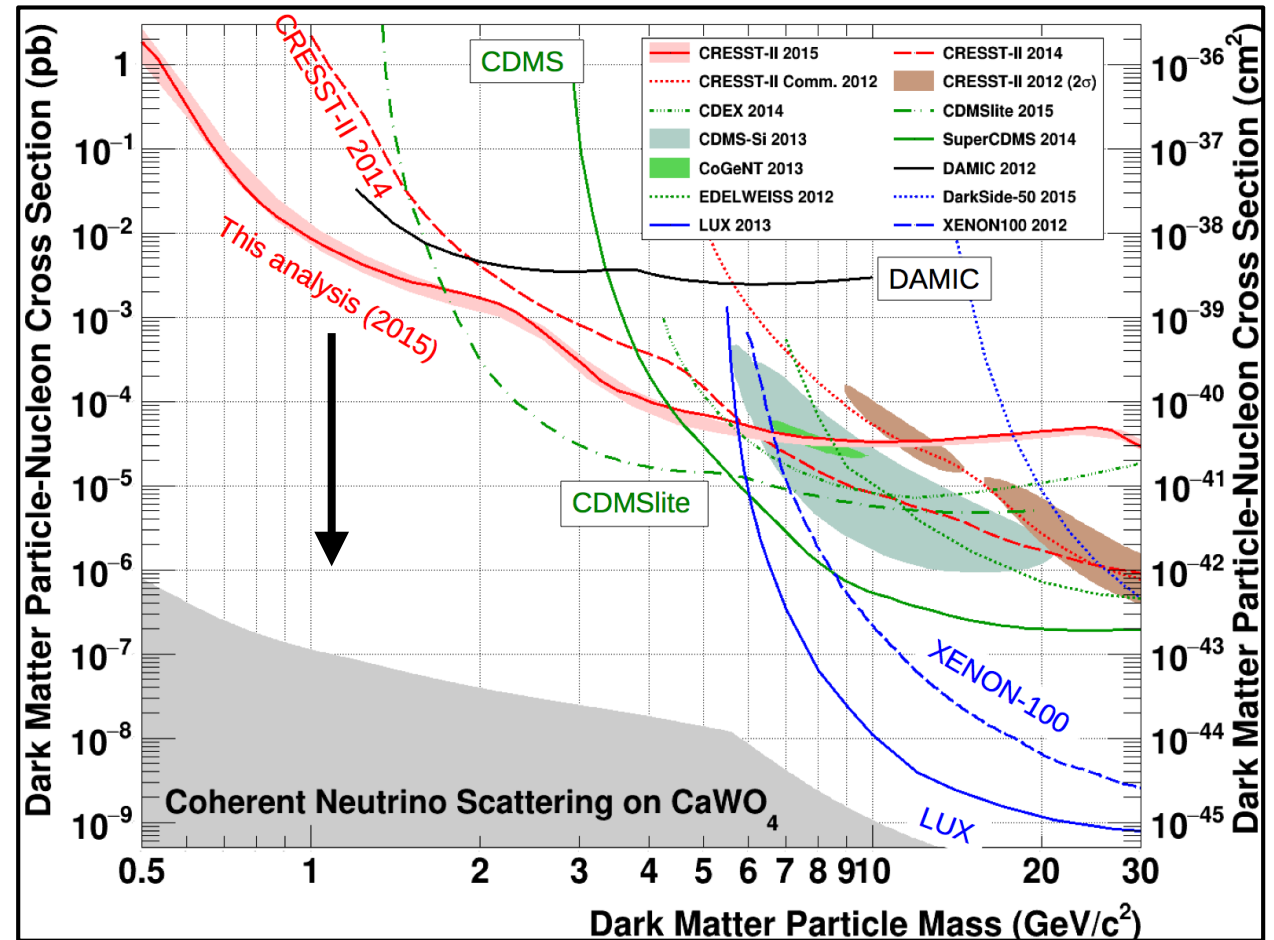
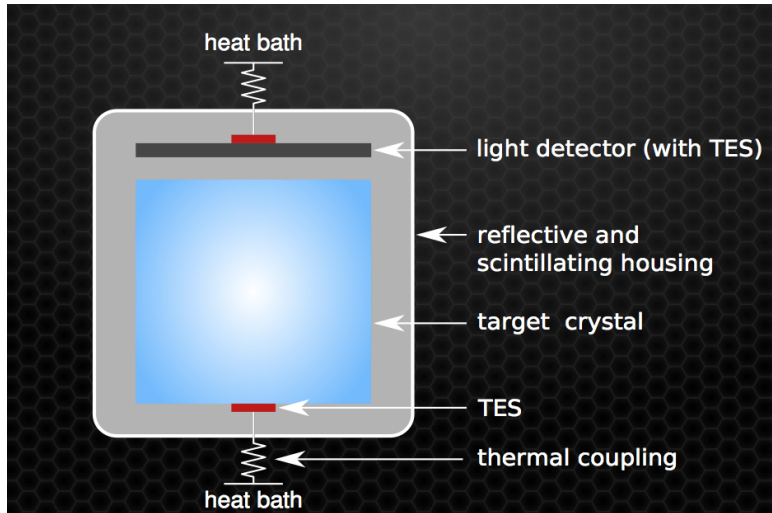
- Capacity for 400 kg - 2019+ @ SNOLAB

- Also Edelweiss - merger with CDMS to form EURECA?

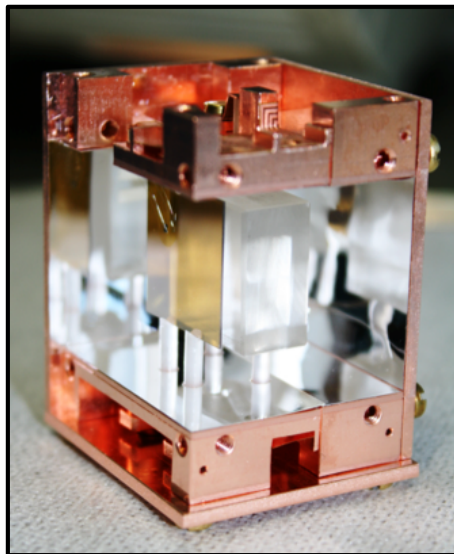


Low Mass: Bolometers CRESST

- ▶ Some/previous UK involvement
- ▶ CaWO_4 bolometric scintillator @ Gran Sasso



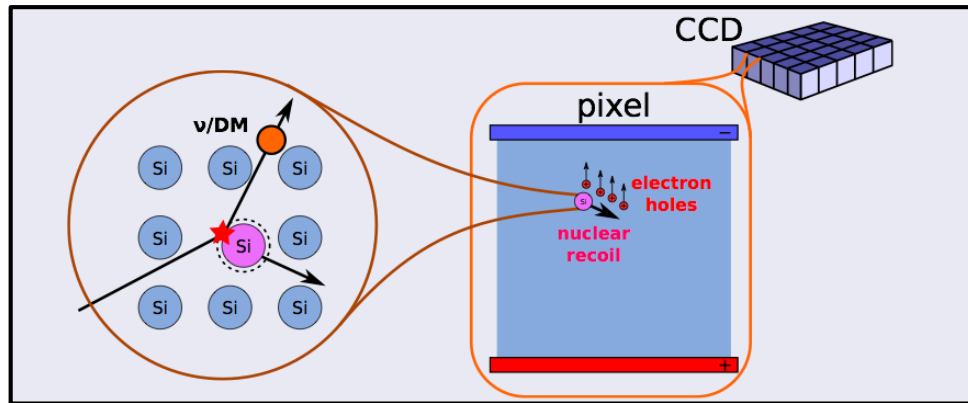
- ▶ New low threshold designs to 100 eV



- ▶ Plans to reach towards neutrino floor (100 tonne-days, x100 lower background)

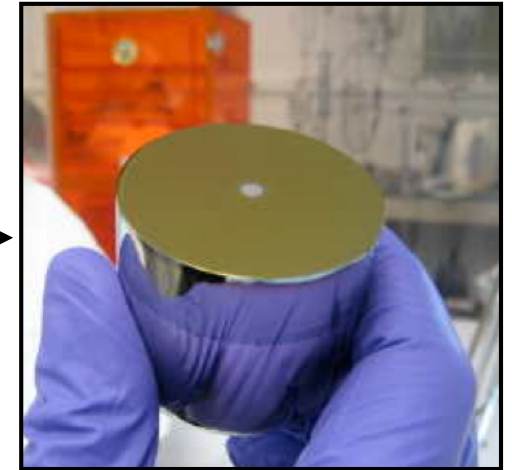
Low Mass: New Alternatives

► Straight Ge (PPC) or Si ionisation

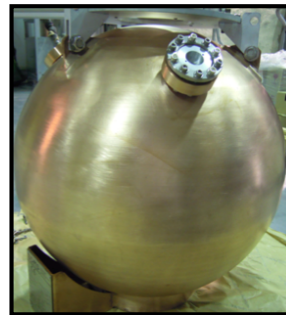
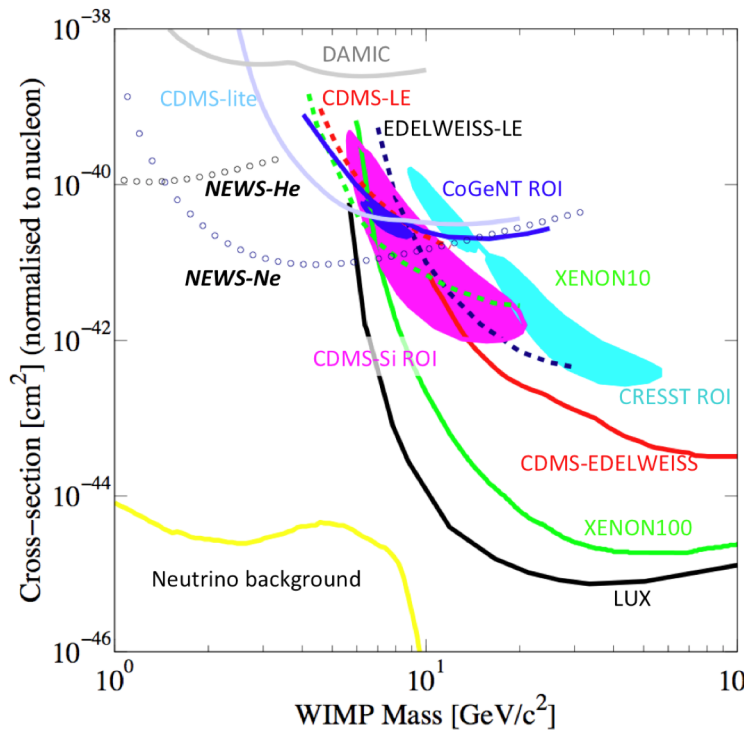


DAMIC

CoGent

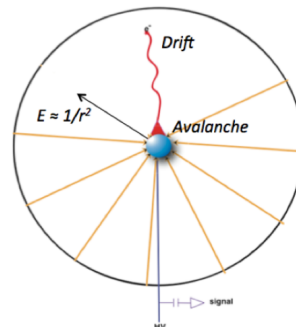
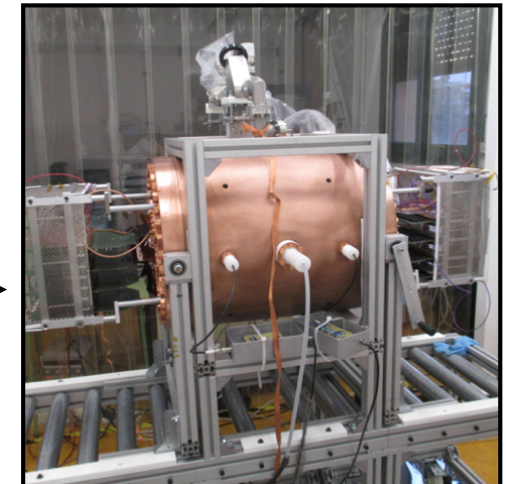


► Low threshold gas TPC



NEWS
(SNOLAB)

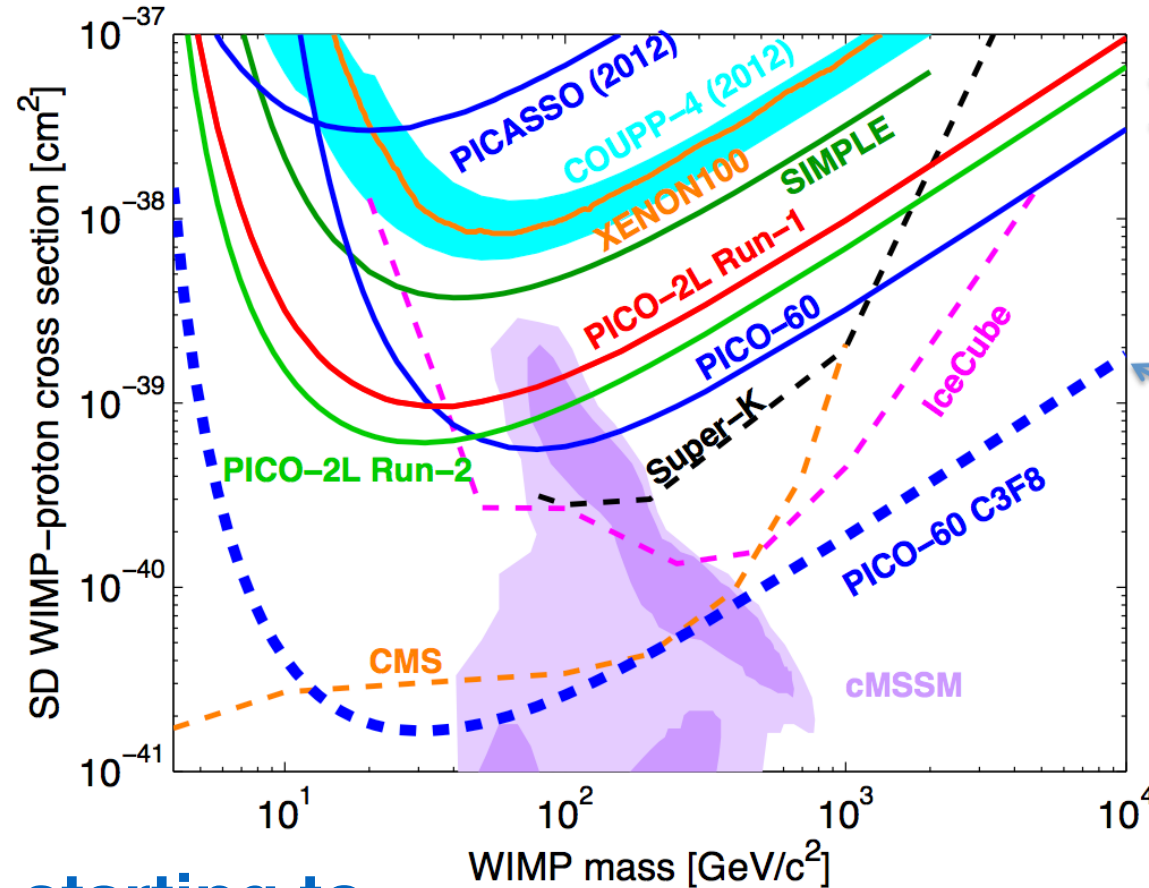
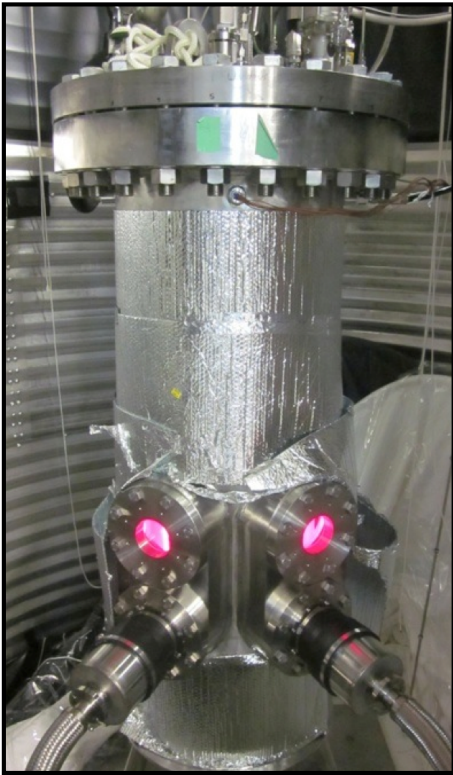
TREX
(~CANFRANC)



► **Low aim for low energy threshold, ~no discrimination**

Spin Dependent

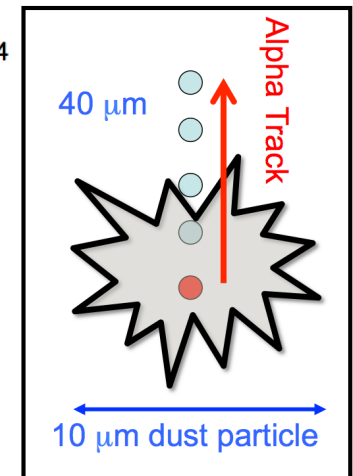
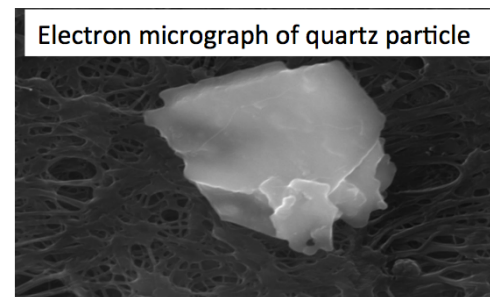
- ▶ PICO 2L, 60 (old Coupp, Piccaso) - C_3F_8 target
- ▶ Bubble chamber technology - low threshold, high particle ID



Current results

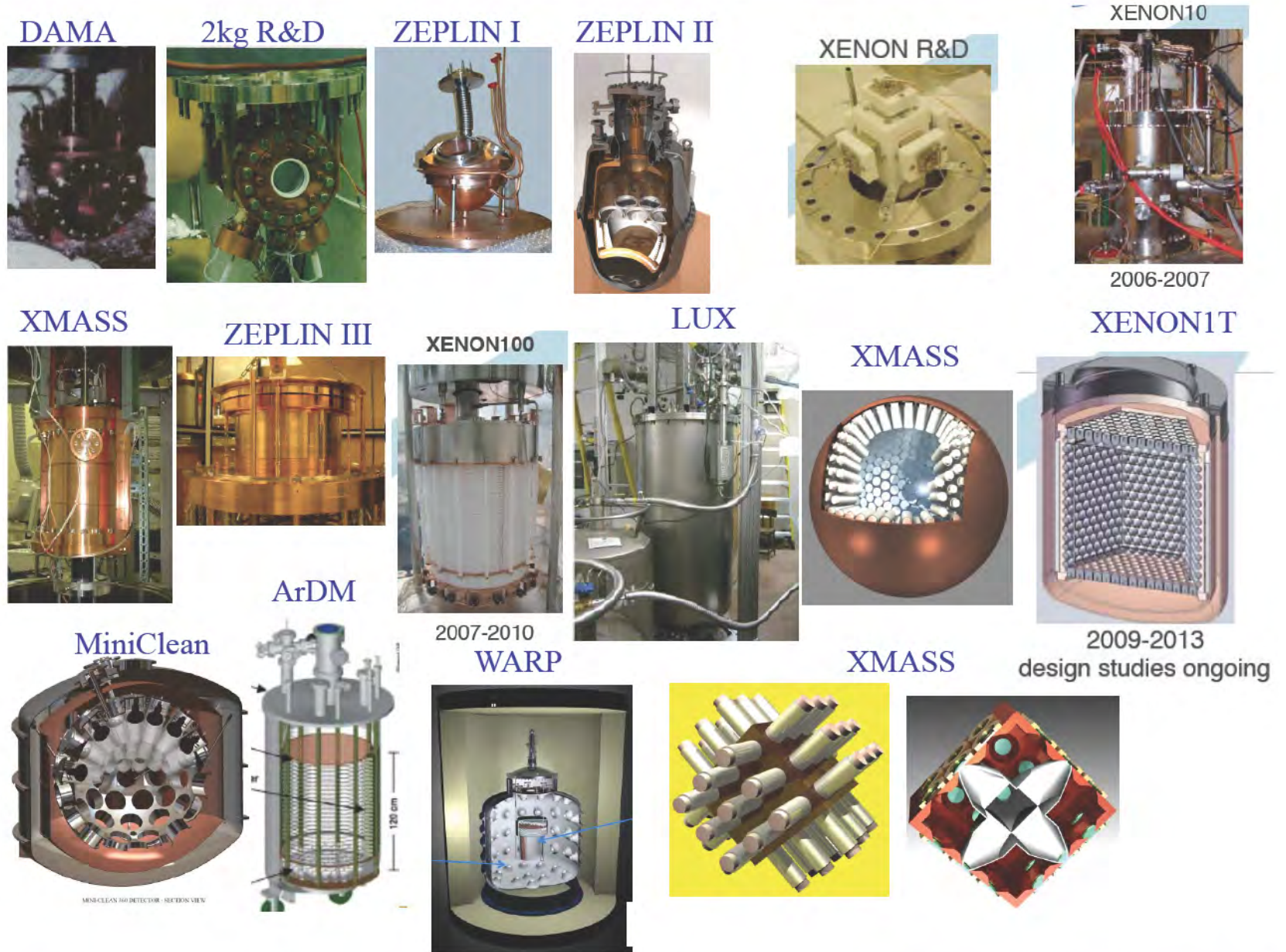
Projection
8000 kg-days,
No background

- ▶ Latest limits starting to enter SUSY region
- ▶ Issue with unknown particulate backgrounds



High WIMP Mass: Liquid Noble Gas

- ▶ Impressive development of liquid xenon & argon technology
- ▶ LAr came later -new ^{39}K reduction makes this promising

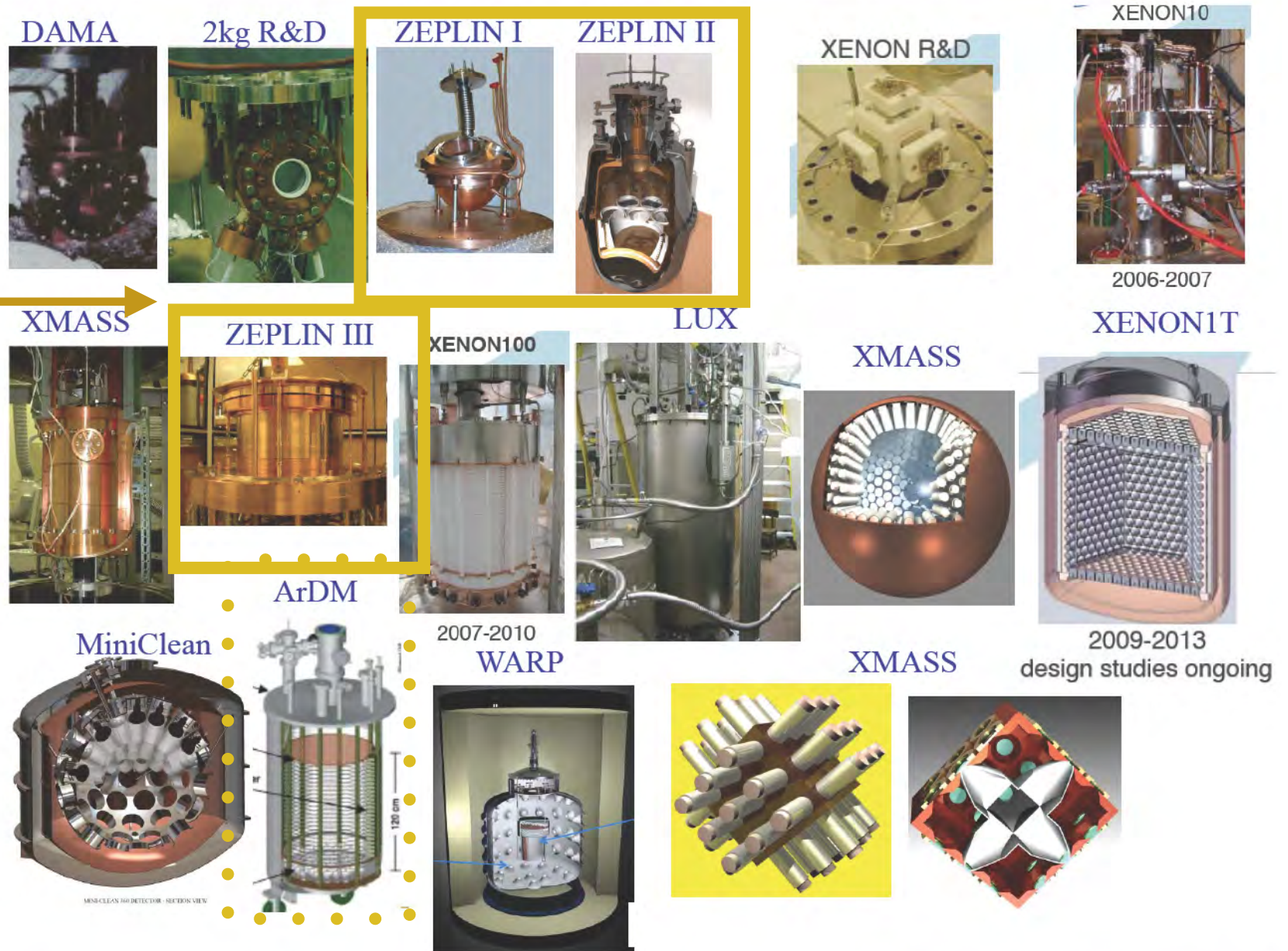


Thanks to H. Wang

High WIMP Mass: Liquid Noble Gas

- ▶ Impressive development of liquid xenon & argon technology
- ▶ LAr came later - new ^{39}K reduction makes this promising

▶ Much UK pioneering work



Liquid Xe and Liquid Ar

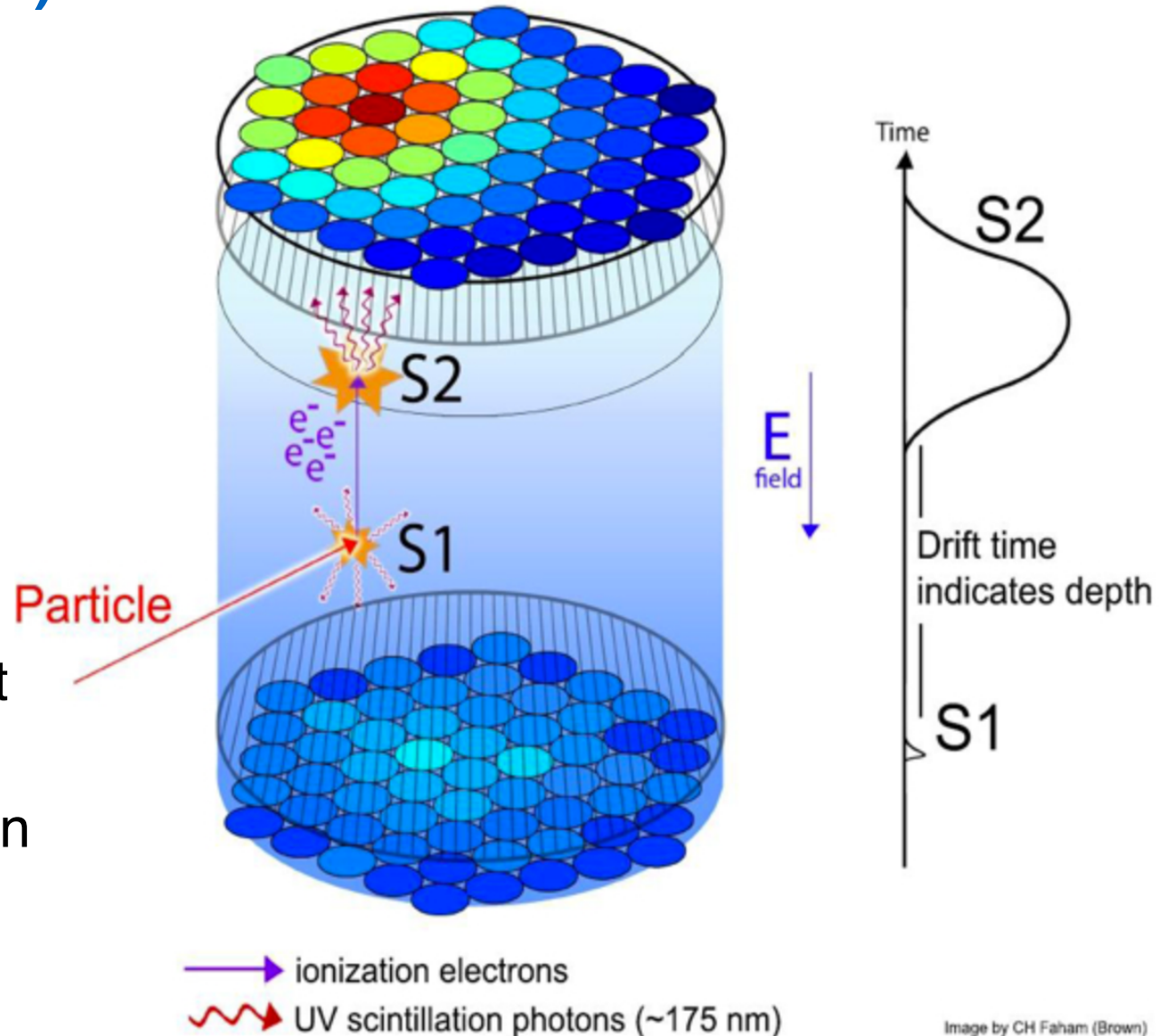
▶ Particle ID by scintillation (single phase) or Scintillation + ionisation (dual phase)

▶ 3D imaging rejects external backgrounds

▶ Electron-recoil backgrounds identified by charge / light ratio

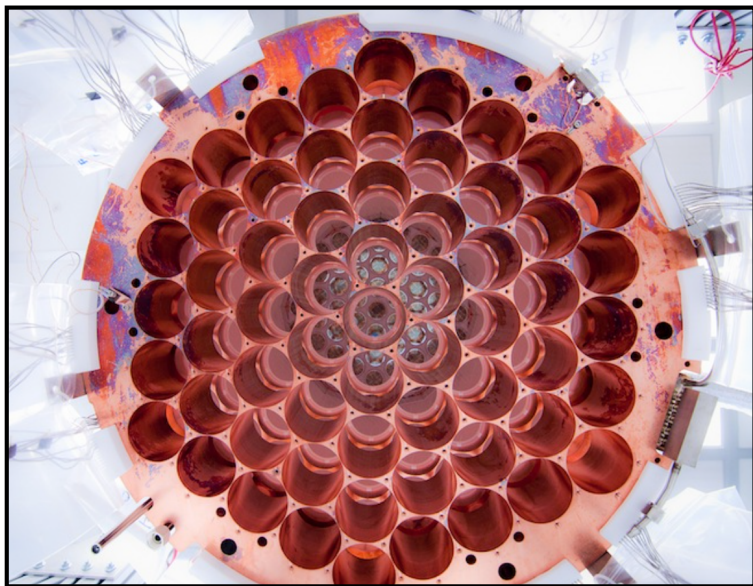
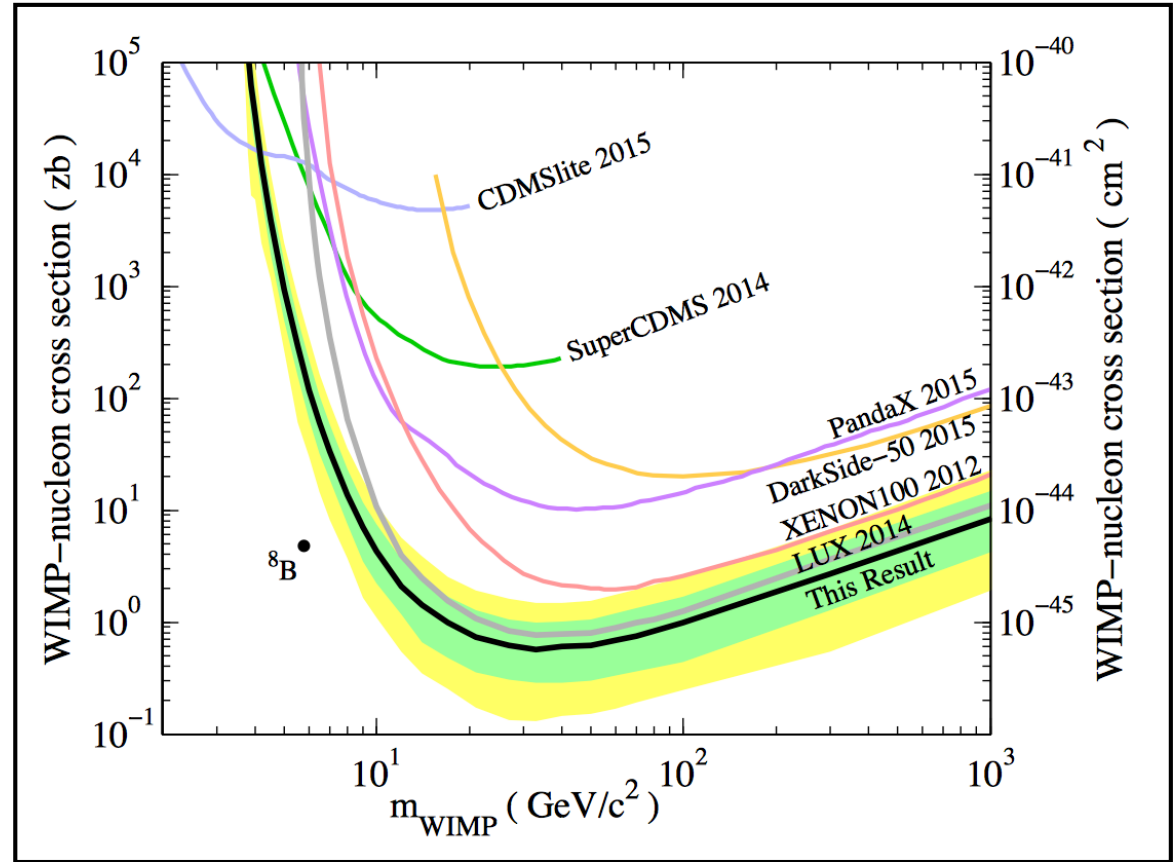
▶ High purity LXe/LAr target

▶ Single photon and electron sensitivity



LUX

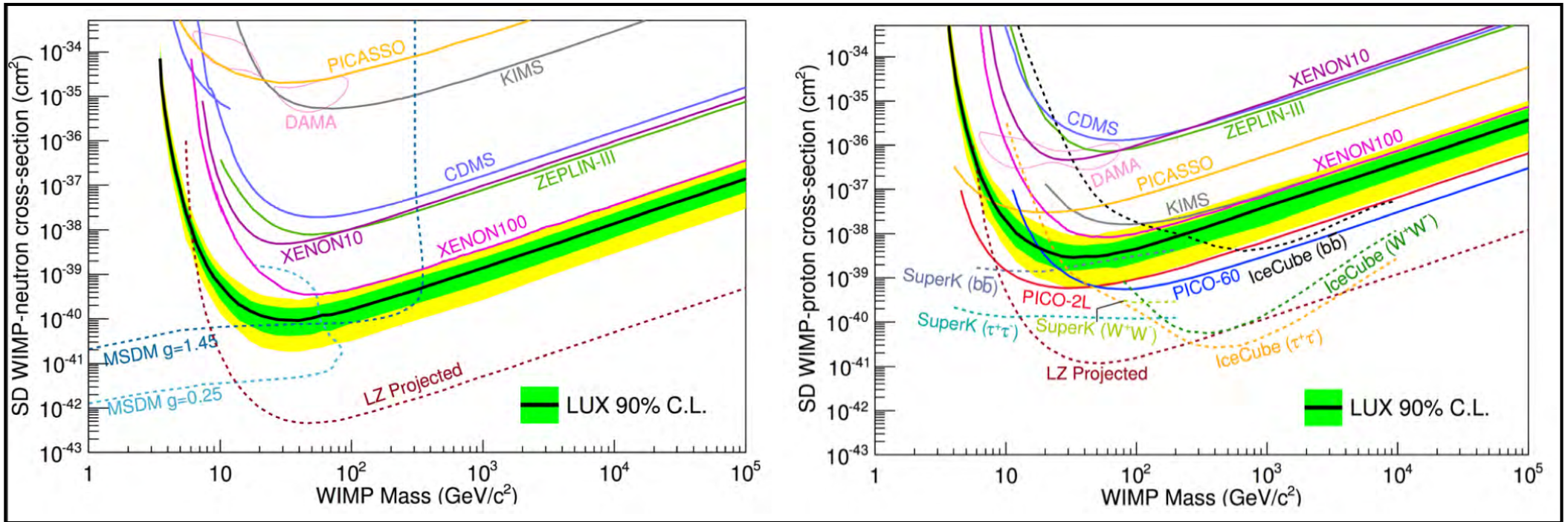
- ▶ 370 kg LXe target at SURF lab S. Dakota (UK involvement)
- ▶ Current best spin independent limits, and WIMP-neutron SD



- ▶ recent work calibrations effort and pushing to 4 GeV threshold
- ▶ Competitive WIMP-proton SD

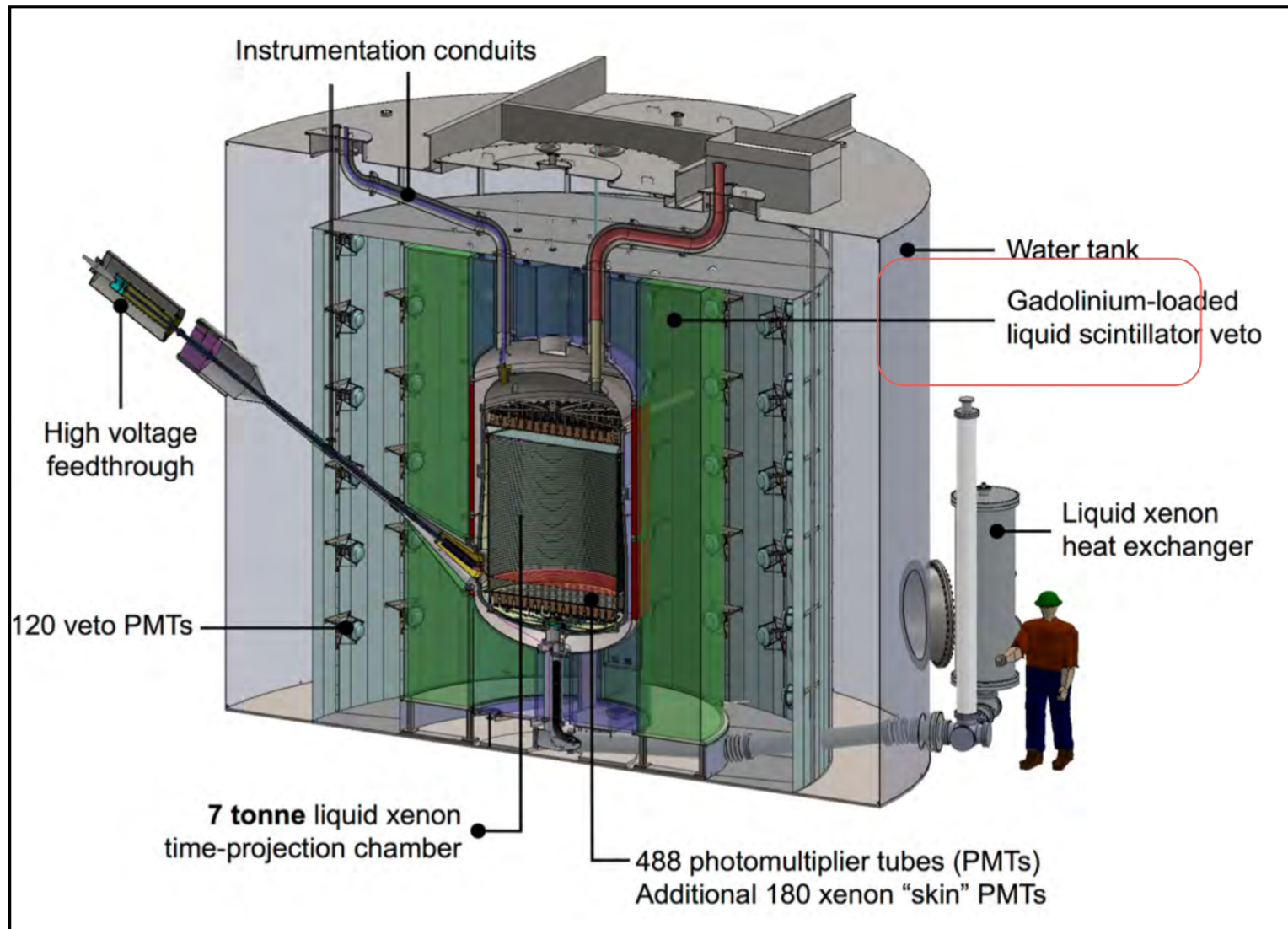
LUX

- ▶ 370 kg LXe target at SURF lab S. Dakota (UK involvement)



LUX-ZEPLIN (LZ)

- ▶ Replaces LUX at the Sanford Underground Facility (SURF)
- ▶ Goal: neutrino-limited sensitivity of $\sim 1 \times 10^{-48} \text{ cm}^2$
- ▶ Main UK investment (STFC)



▶ Challenges

Backgrounds

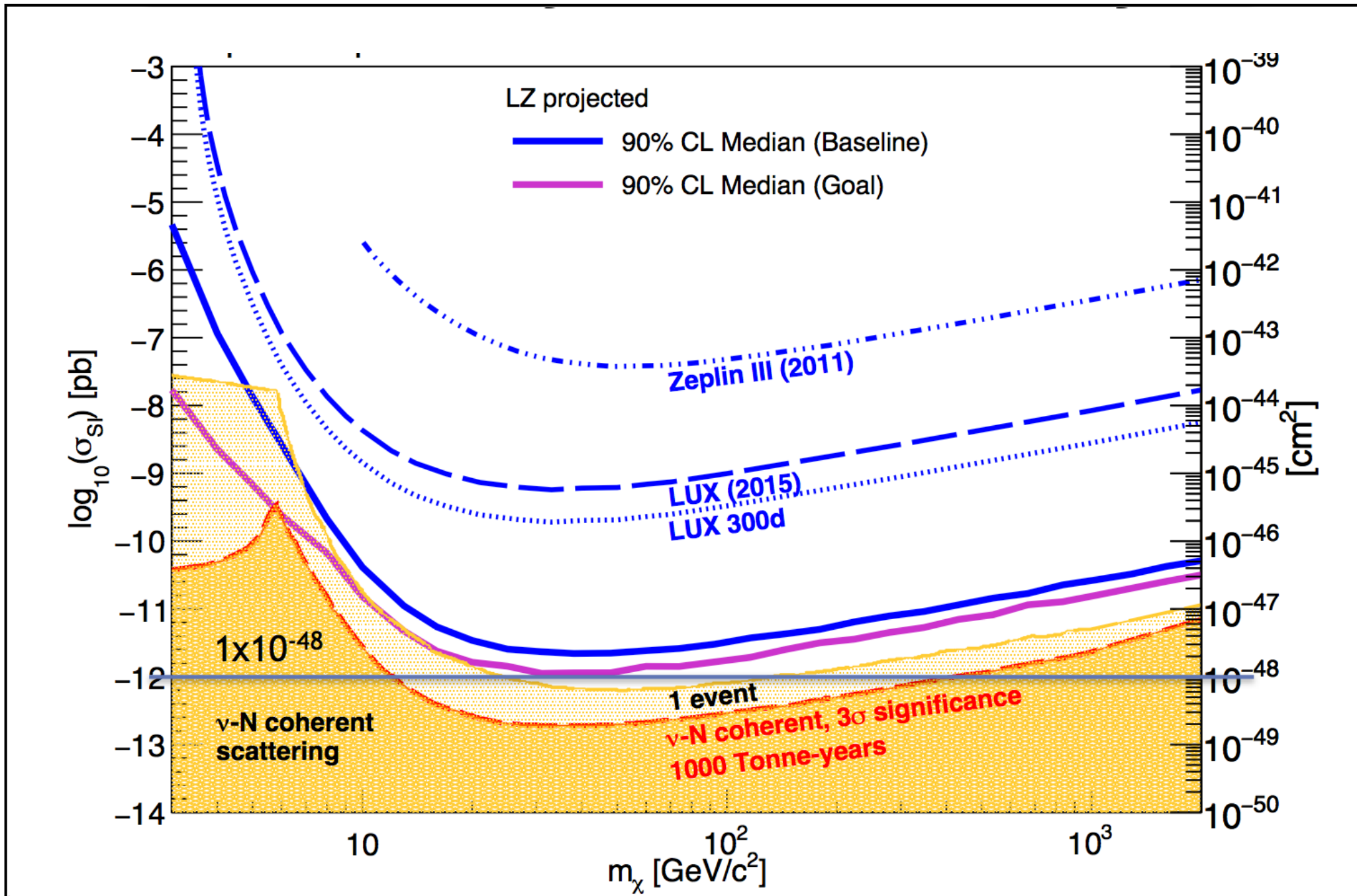
Calibrations

Purity for charge drift

Light Collection

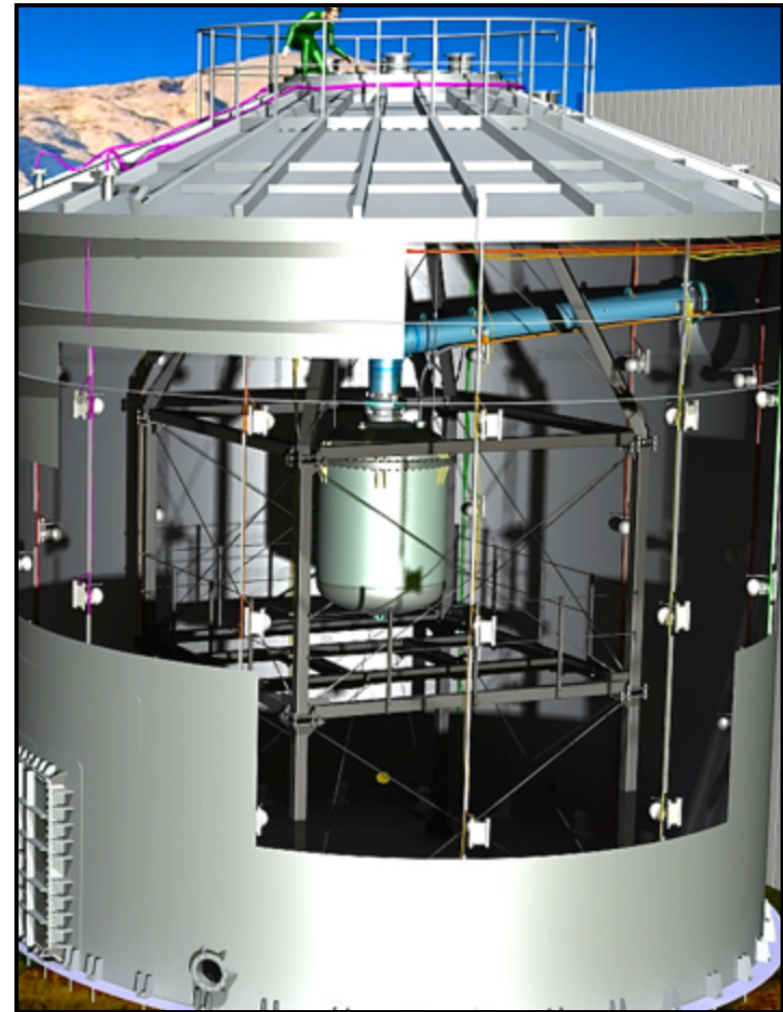
Drift field, low electron + photon emission

LZ Projected Sensitivity



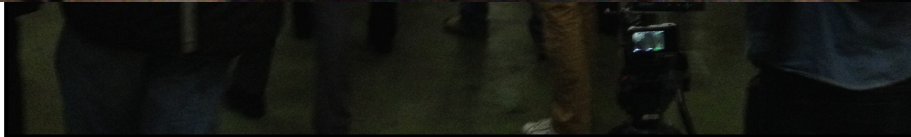
XENON 1T Experiment

- ▶ 1 tonne dual phase LXe @ Gran Sasso - European/US
- ▶ Impressive schedule keeping
- ▶ Inauguration Nov 2015
- ▶ Engineering cold runs now
- ▶ Rapid scale-up to 7 tonnes



XENON 1T Experiment

► 1 tonne dual phase LXe @ Gran Sasso - European/US



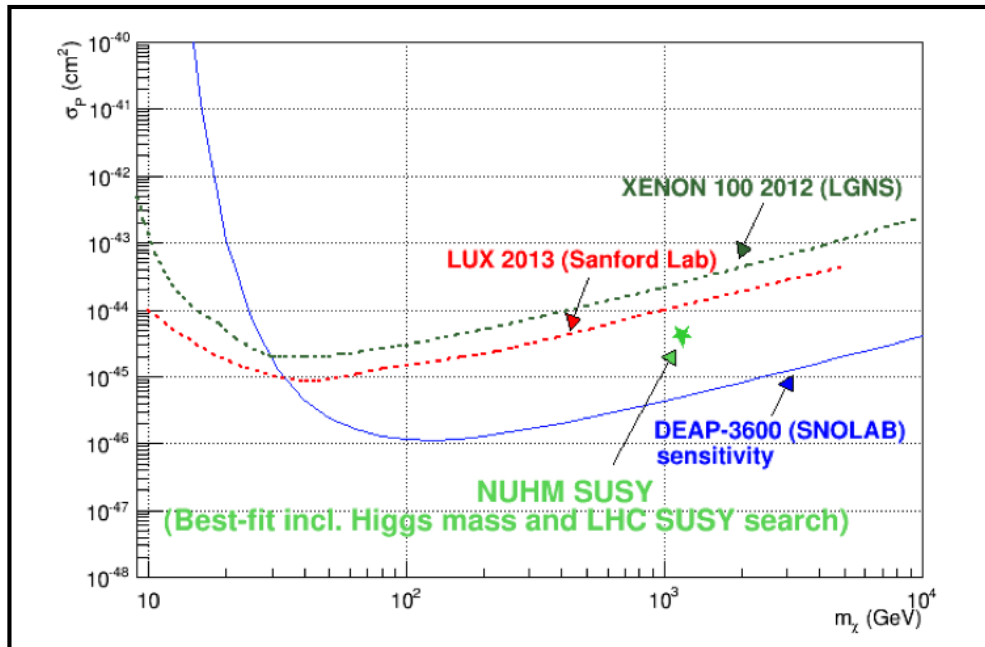
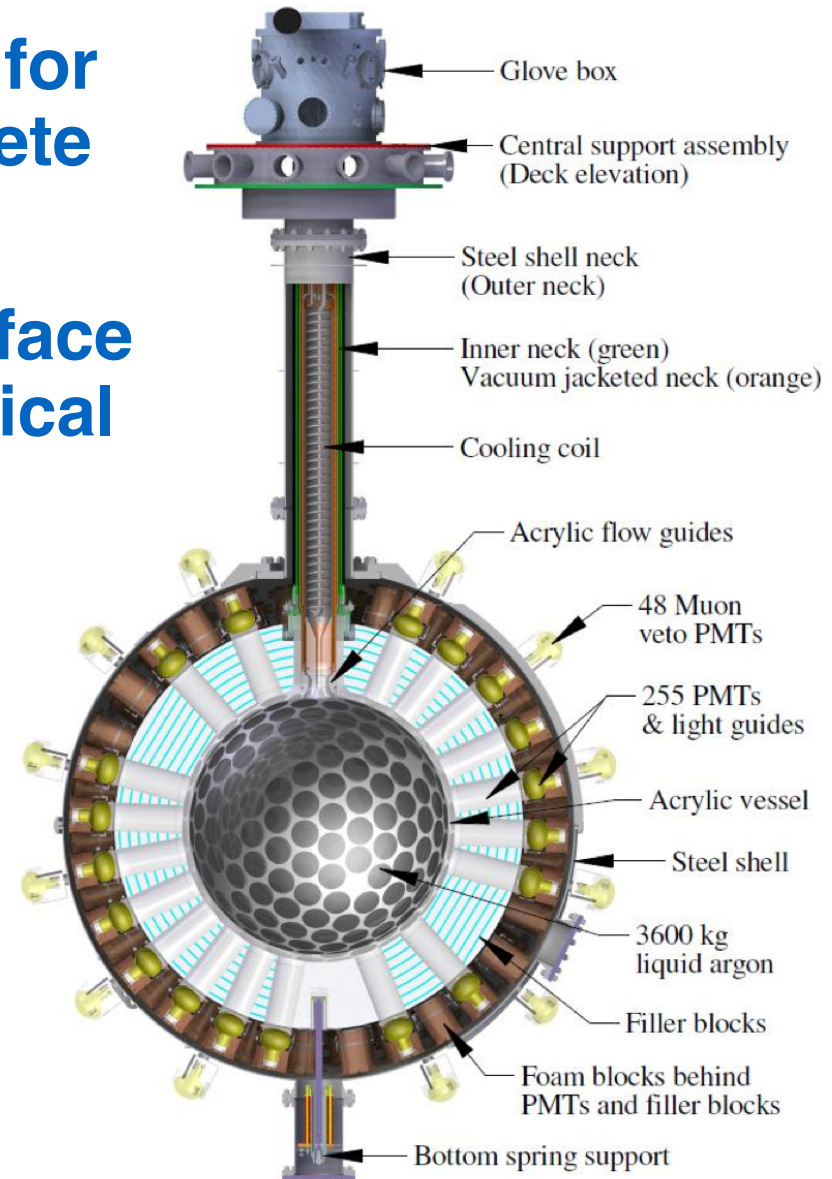


DEAP-3600 Experiment

► LAr single phase @ SNOLAB (UK involvement)



- Now cooling down, expect data 2016
- Prospects for argon deplete of ^{39}Ar
- Radon/surface control critical



Future Massive WIMP Detectors (?)

▶ LZ

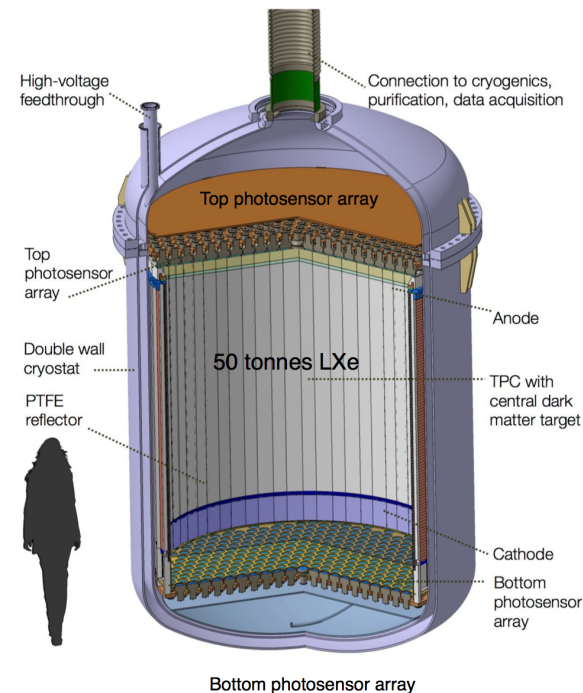
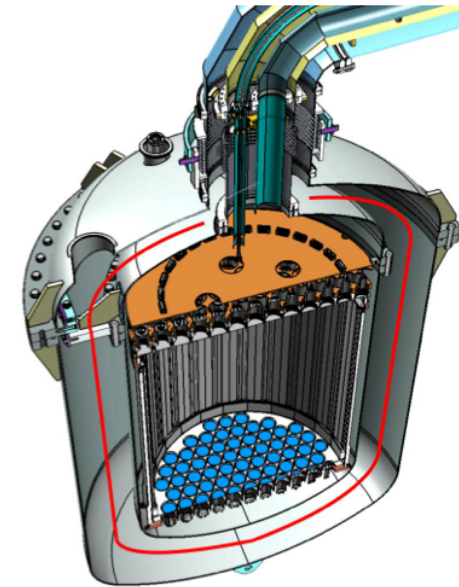
▶ XENON nTonne

▶ DEAP-50 (LAr - depleted)

▶ DARWIN (design study)

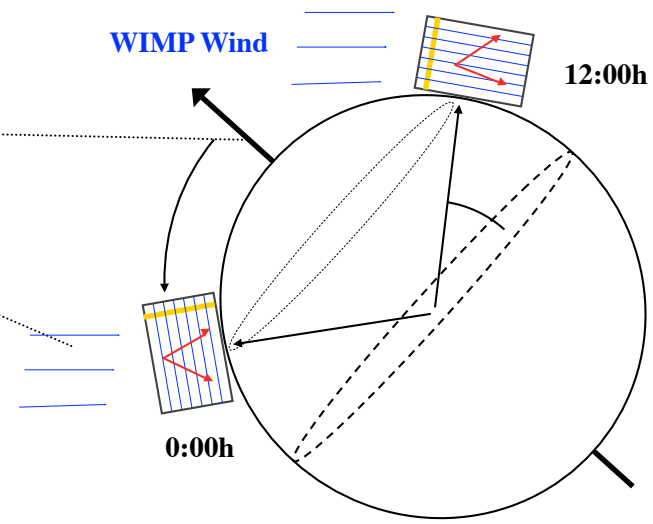
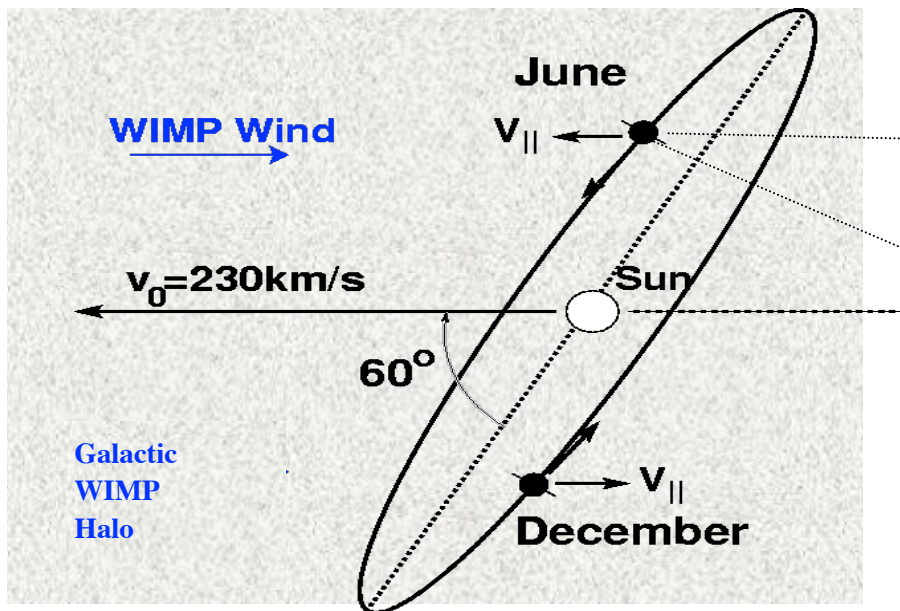
▶ DarkSide-20K, ARGO

▶ Others.....

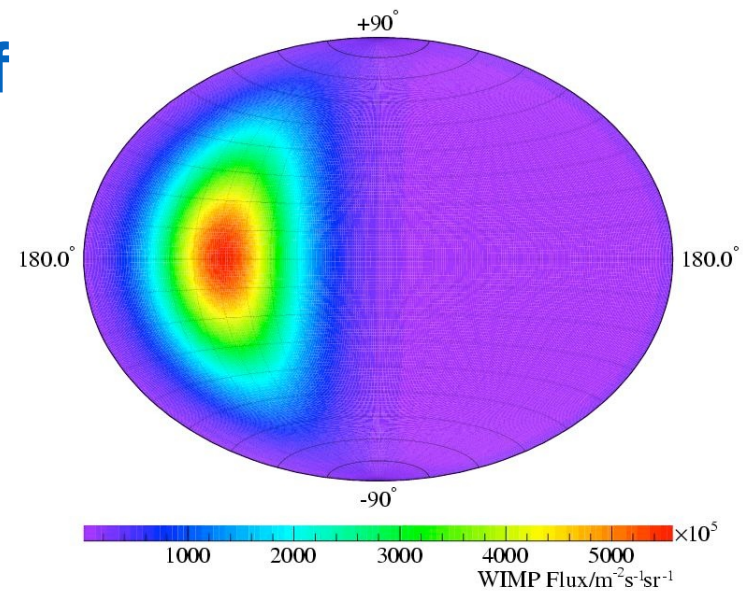
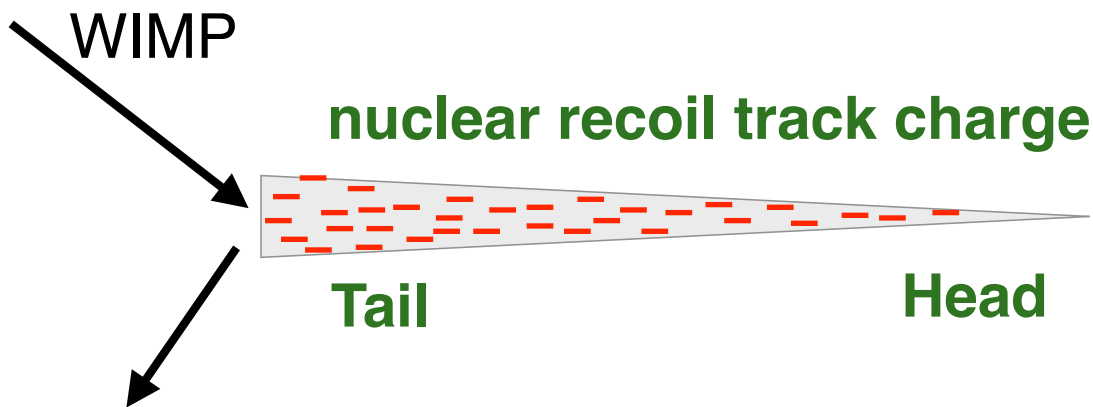


What About a Signal for WIMPs?

- ▶ A directional recoil signal is a very powerful proof
- ▶ Lets be prepared!

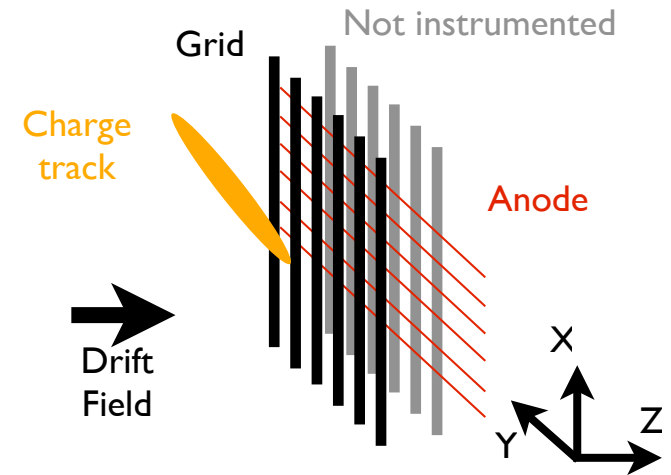
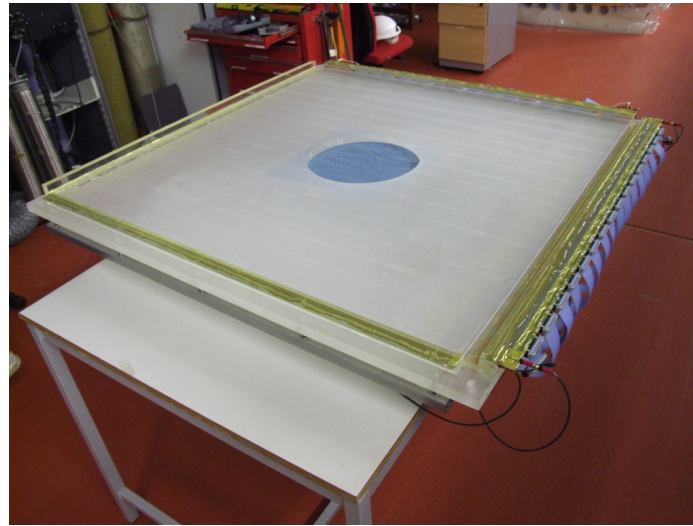


- ▶ Measure the nuclear recoil track itself and determine the head from the tail



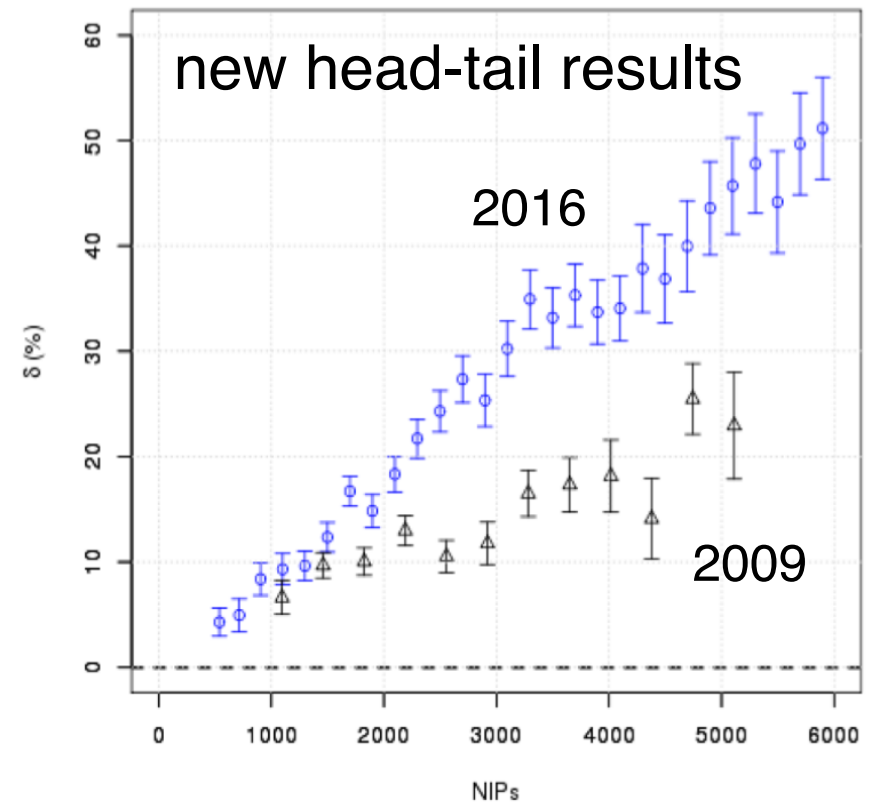
DRIFT is Pioneer (US-UK) at Boulby

- ▶ Use low pressure negative ion gas



Significant advances recently:

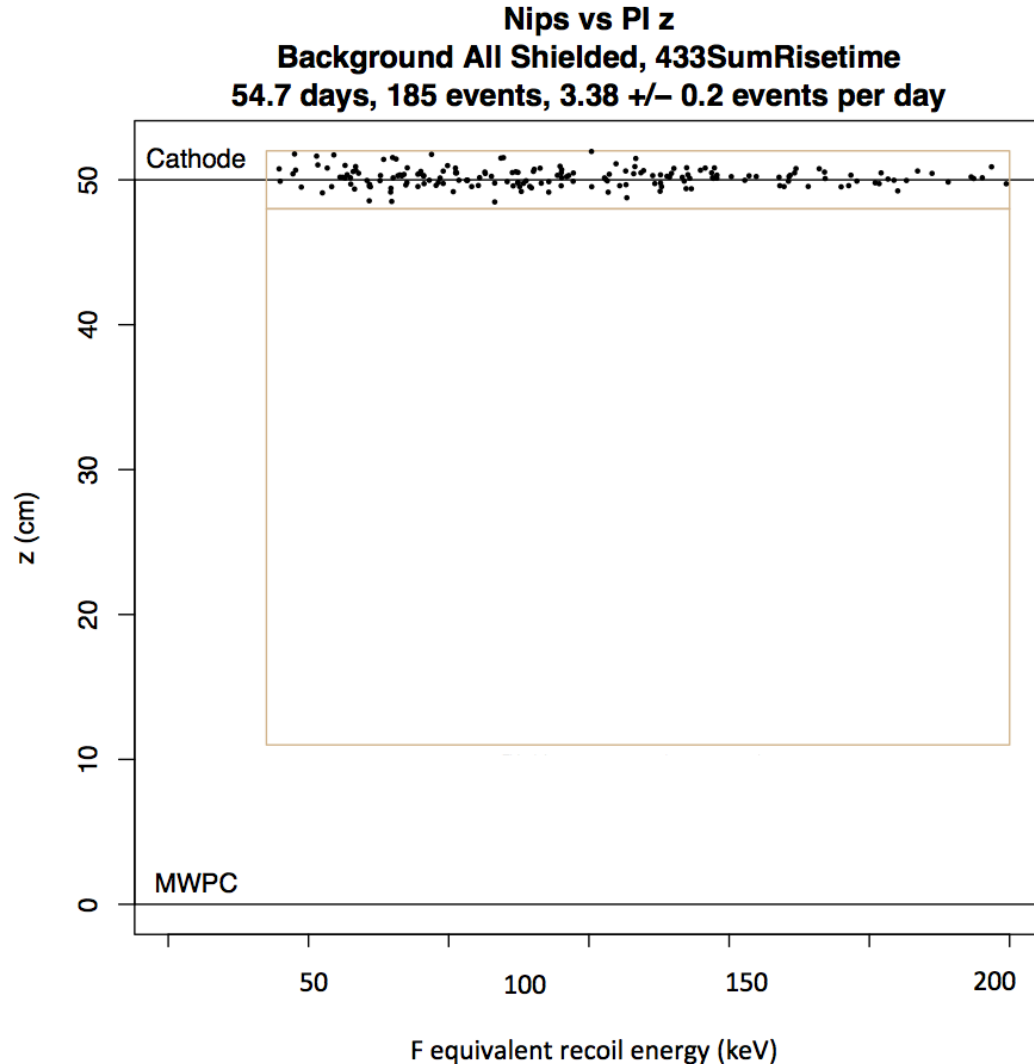
- ▶ Z- fiducialisation using minority carriers, -ve ion $\text{CS}_2:\text{CF}_4:\text{O}_2$
- ▶ Good head-tail sensitivity with this mixture
- ▶ Use of SF_6 -ve ion drift - improved target mass



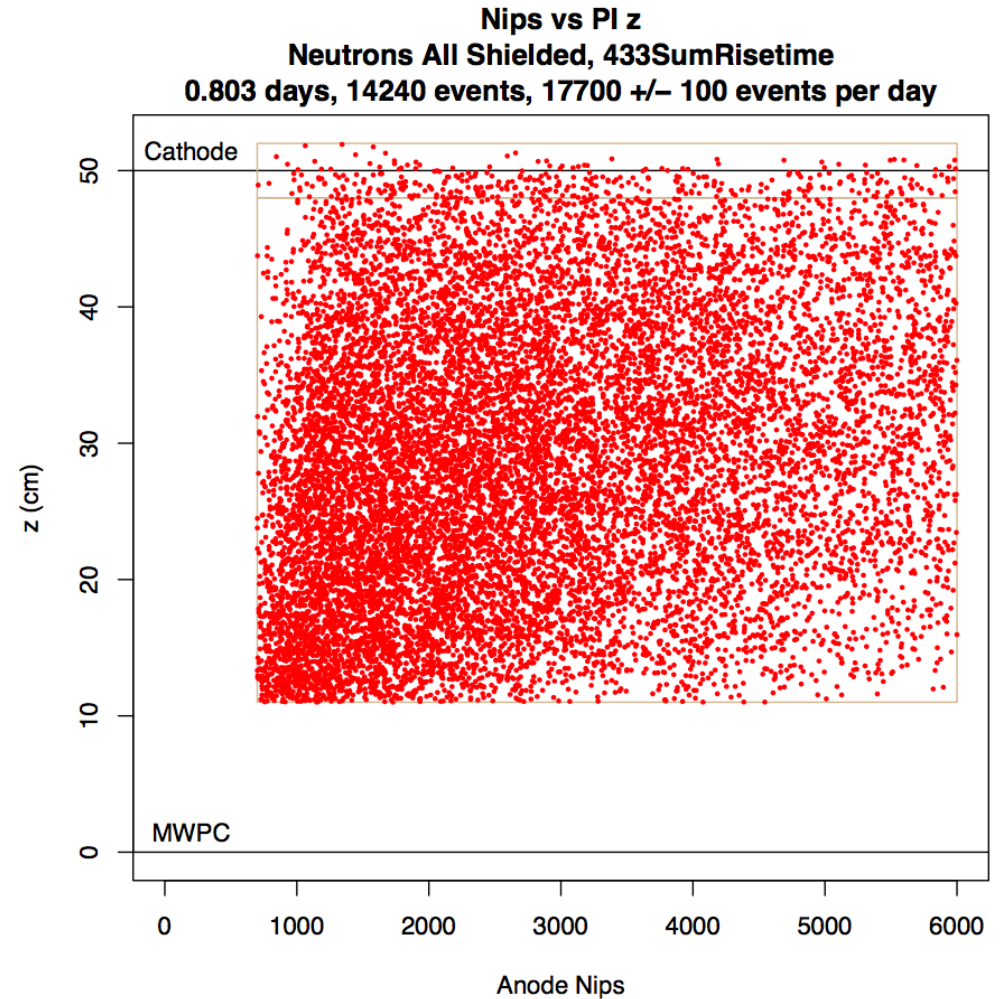
DRIFT - 3D Fiducial with Head-Tail

- ▶ DRIFT-Id now runs zero background, only volume limited

Shielded 30-10-1 CS₂-CF₄-O₂ Data



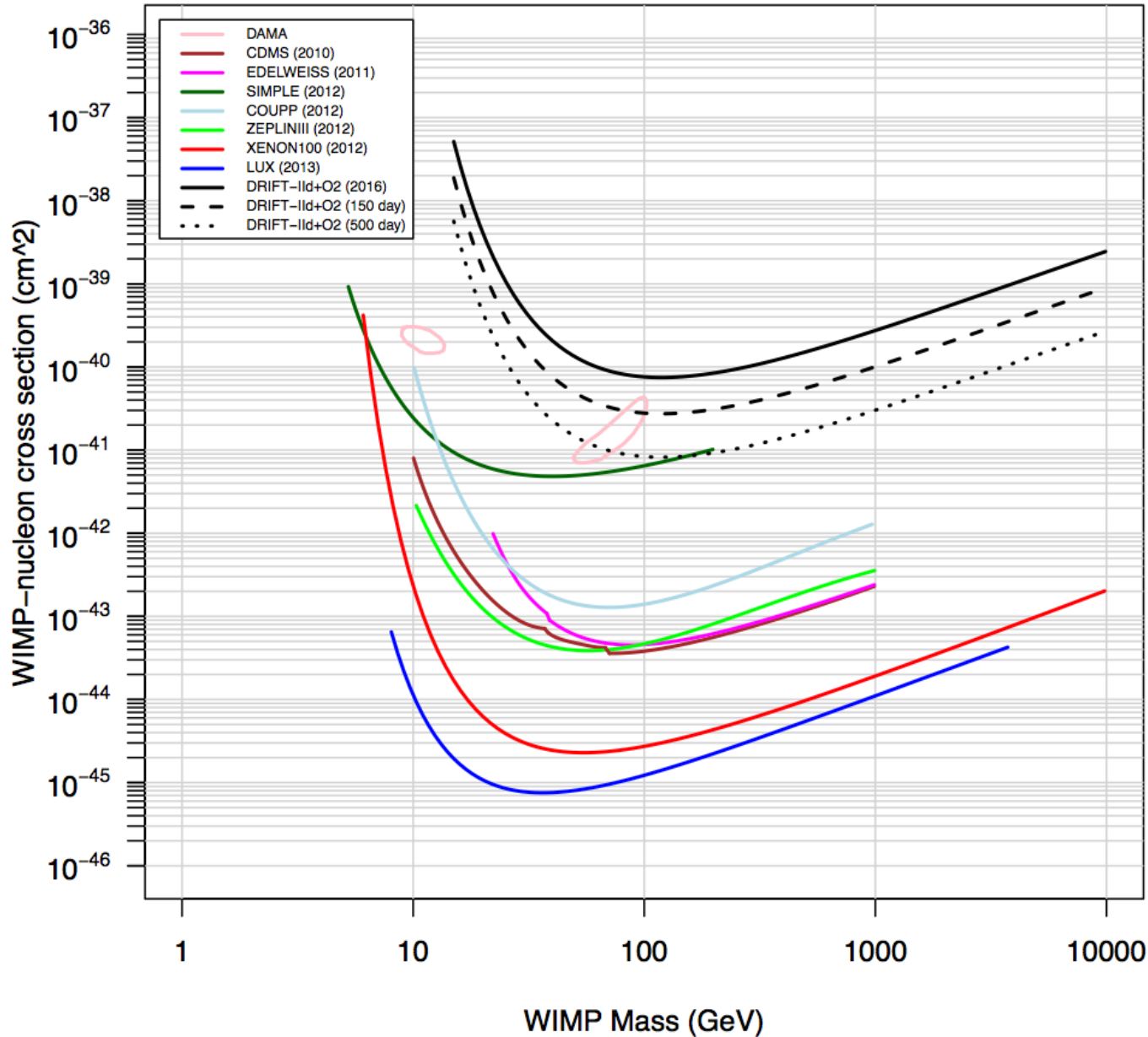
Cf-252 Neutron Calibration Data



DRIFT-II - 3D Fiducial with Head-Tail

► Towards ruling out DAMA - with Directionality

Spin-Independent WIMP Limits

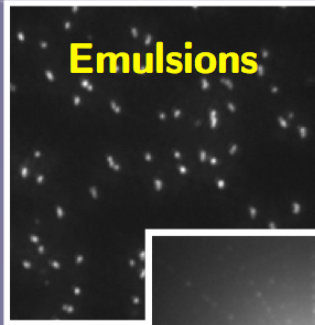


► Achieved with
~130 g target

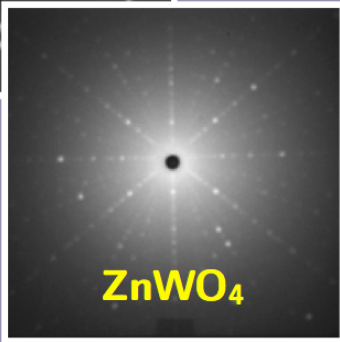
CYGNUS-TPC Ton-scale Directional

CYGNUS

Emulsions



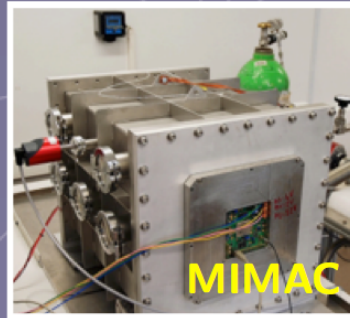
ZnWO₄



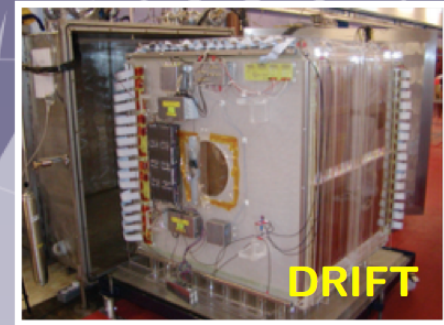
HPXe



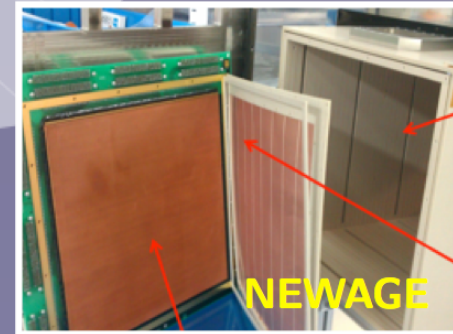
MIMAC



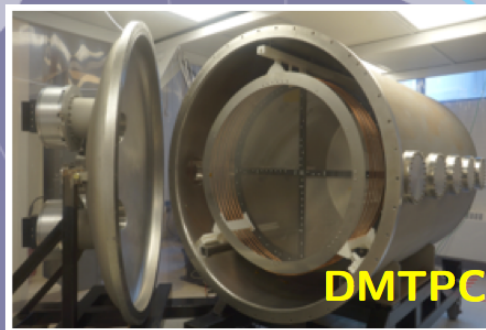
DRIFT



NEWAGE



DMTPC

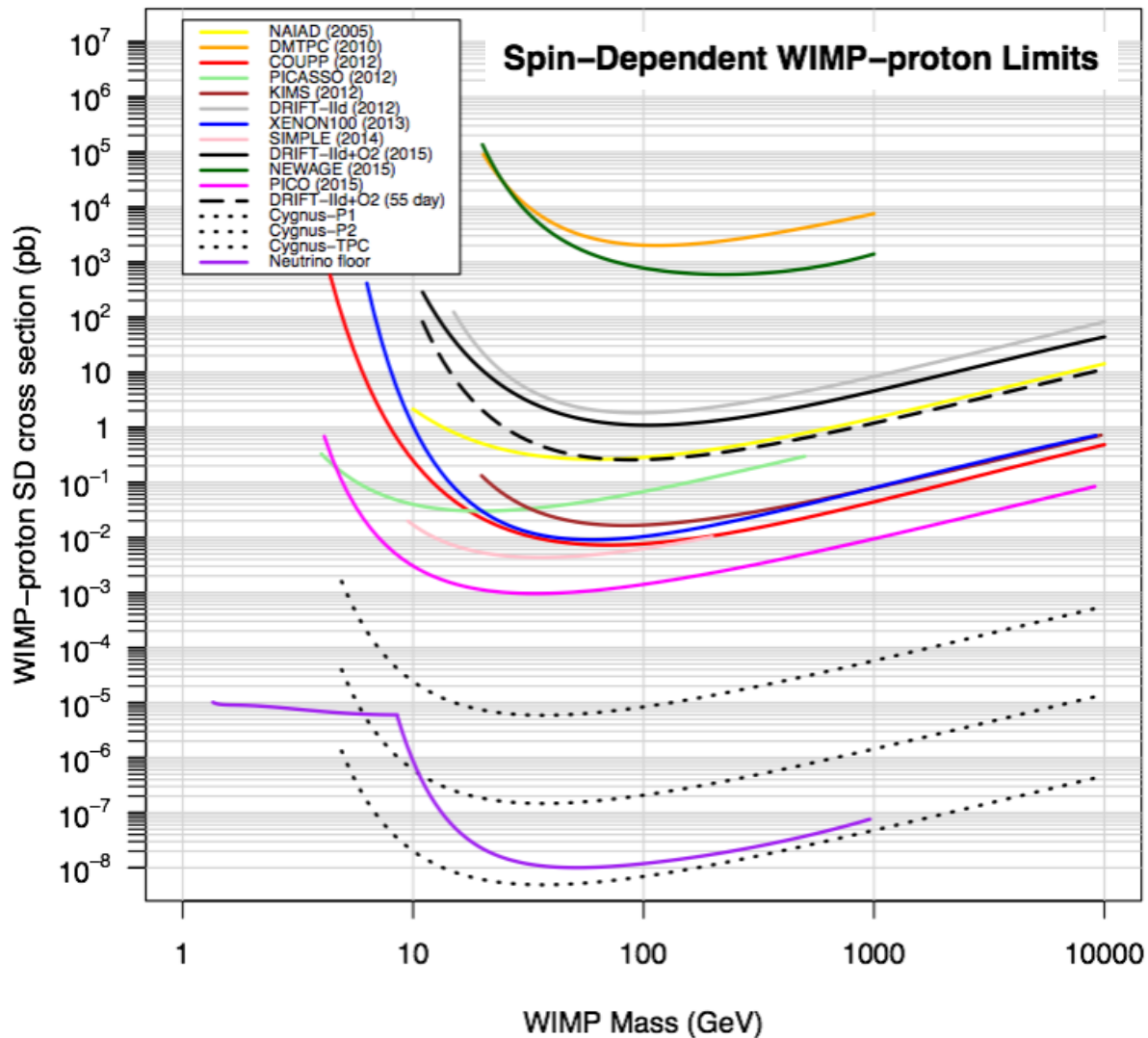


D³



CYGNUS-TPC Global Concept

- ▶ SF_6 target ($\sim x5$ more F per volume than current)
- ▶ Fiducialisation, -ve ion drift, head-tail sensitivity
- ▶ Multi-tonne, multi-underground site,
- ▶ Staged programme - low WIMP mass, high WIMP mass



**Australia, China, France,
Italy, Japan, UK, US**



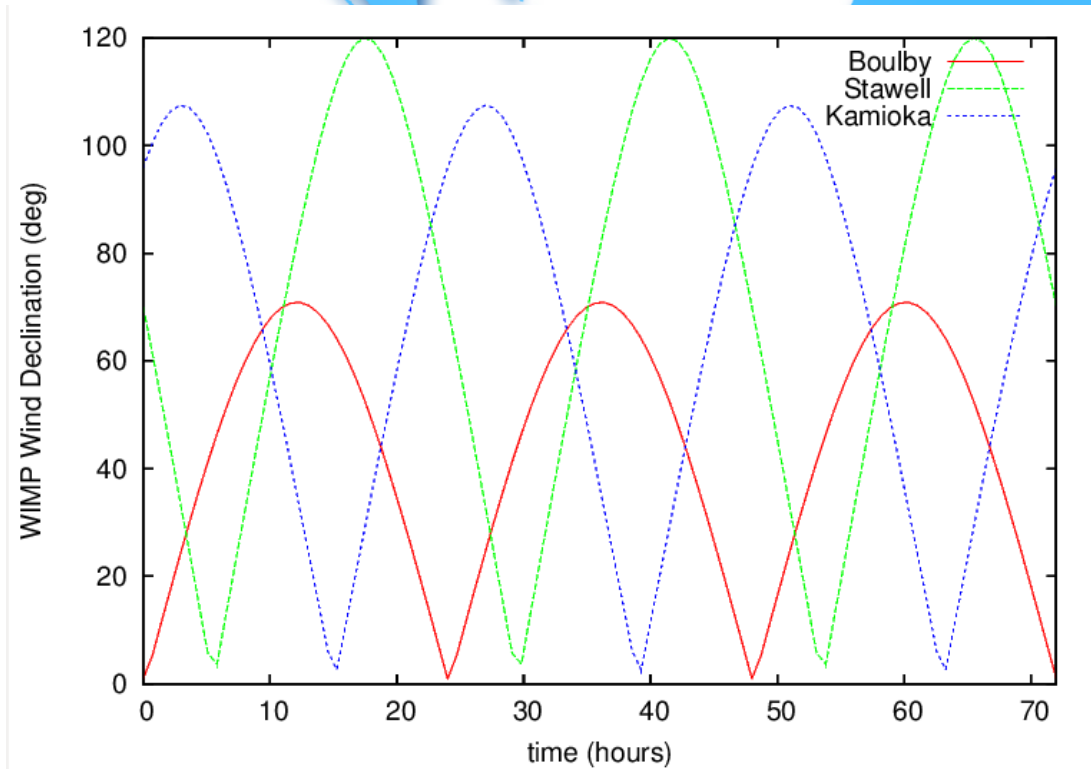
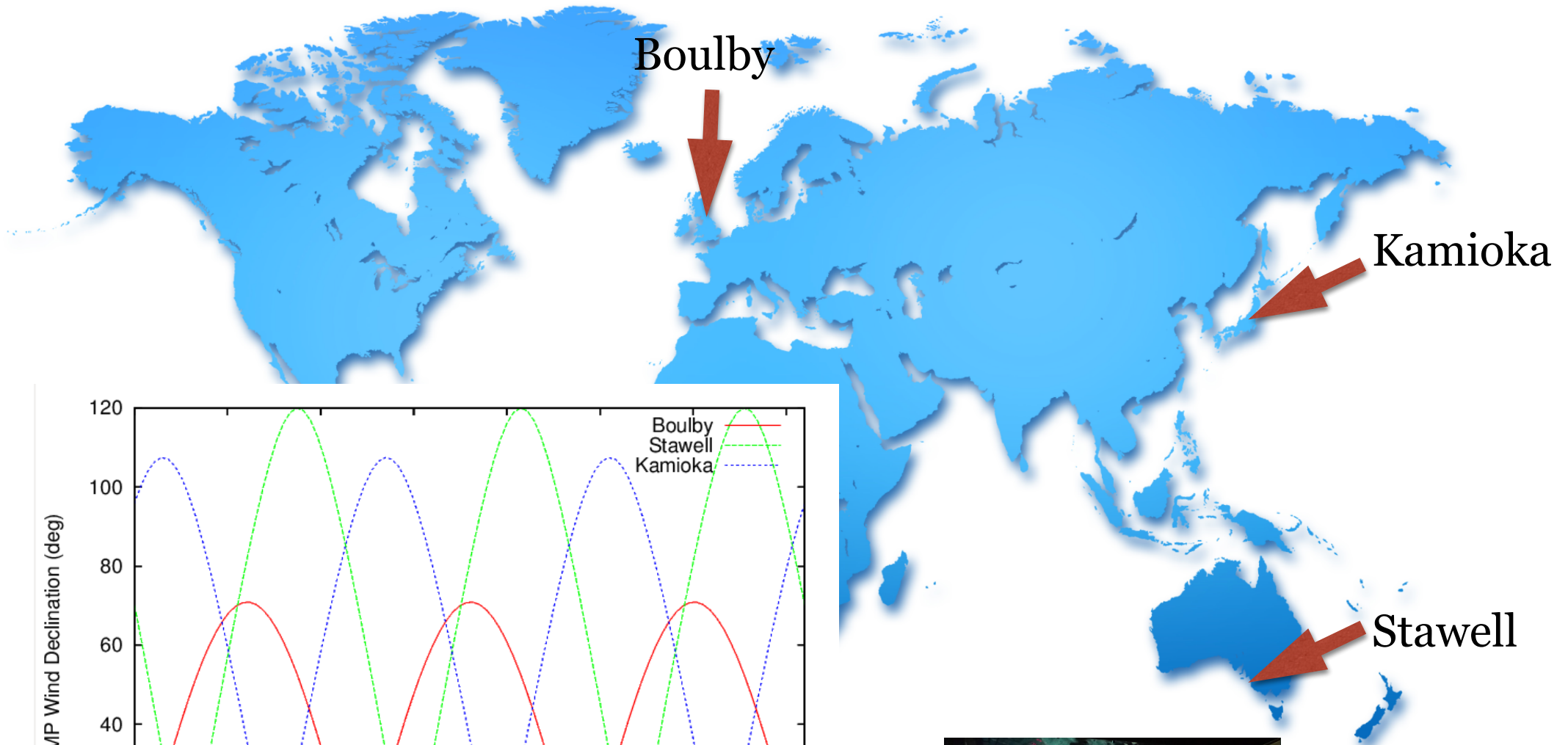
- ← CYGNUS - Pathfinder 1
- ← CYGNUS - Pathfinder 2
- ← CYGNUS - TPC

How Not to be Afraid of Large TPCs

- ▶ Example - something the size of ICARUS (used for LAr)
- ▶ Size: 2 x ~18 x 3 x 3 m, central cathode, 1.5m drift
- ▶ Would contain ~ 0.5 Tonne Fluorine (SF_6) @ 200 Torr
- ▶ Size is ~ 100th scale of proposed DUNE liquid argon TPC



CYGNUS-TPC - Multiple Sites



new lab
funded in
Australia

CYGNUS R&D at New Boulby Lab



CYGNUS R&D at New Boulby Lab



What if it's not WIMPs?



"I can't tell you what's in the dark matter sandwich. No one knows what's in the dark matter sandwich."

Not Baryons or WIMPs!



Not Baryons or WIMPs!



AXION

Not Baryons or WIMPs!



Peter Smith

AXION

Sterile neutrino

Warm DM (sub-keV)

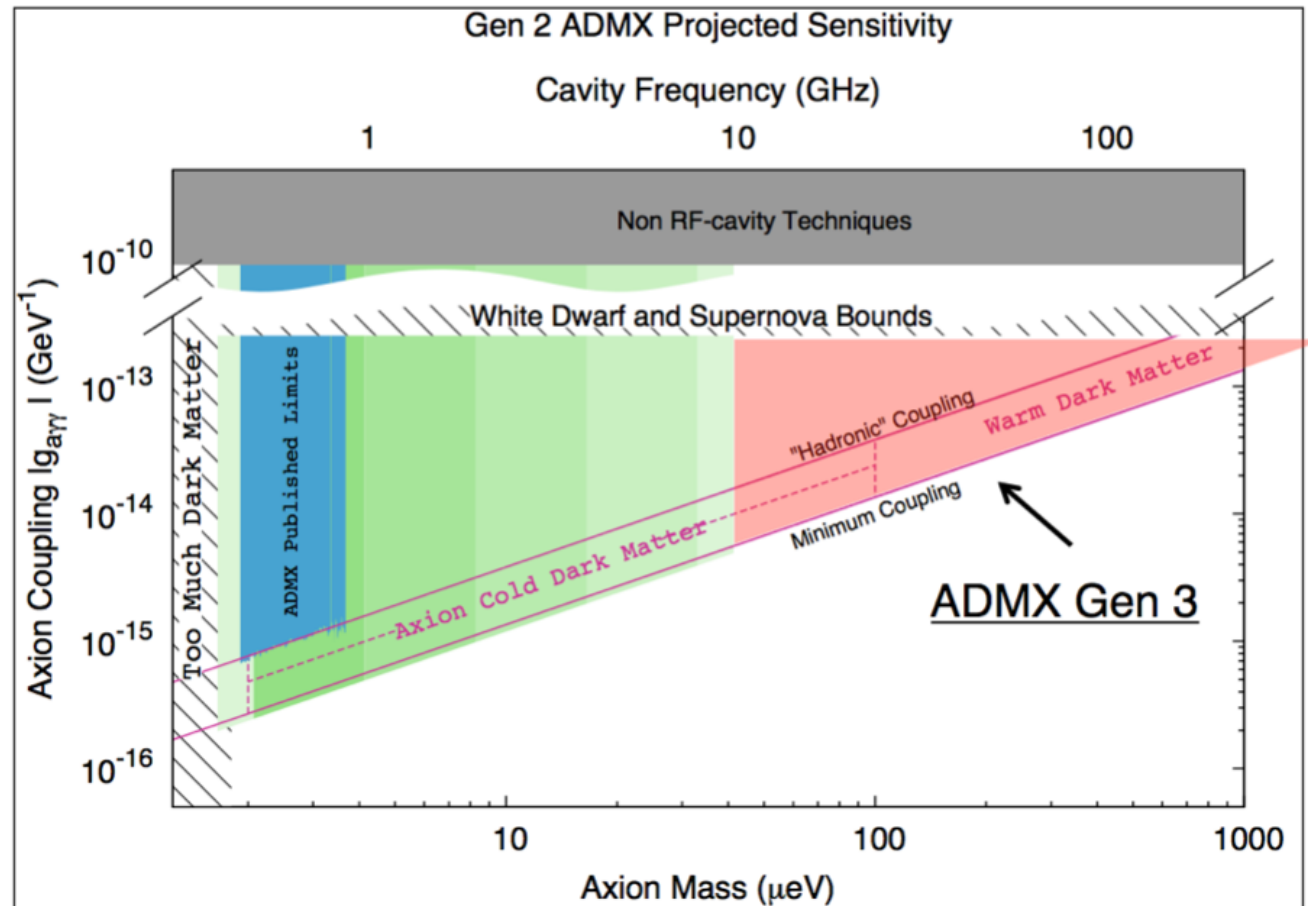
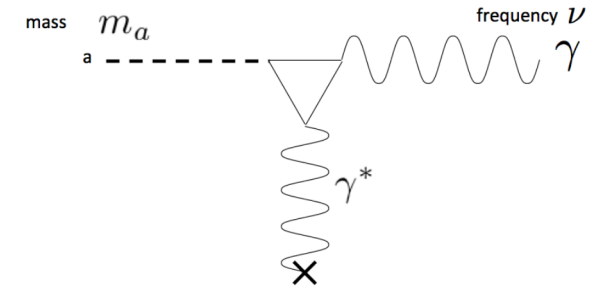
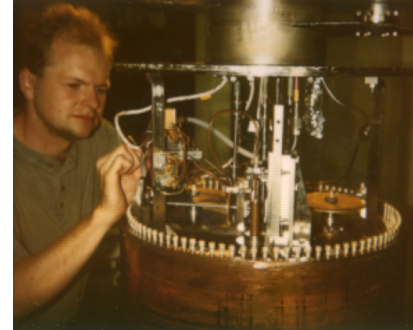
Dark Photons

Some other particle

2000 – 2010: > 40 papers & reviews confirming that a keV-mass sterile ν matches DM requirements

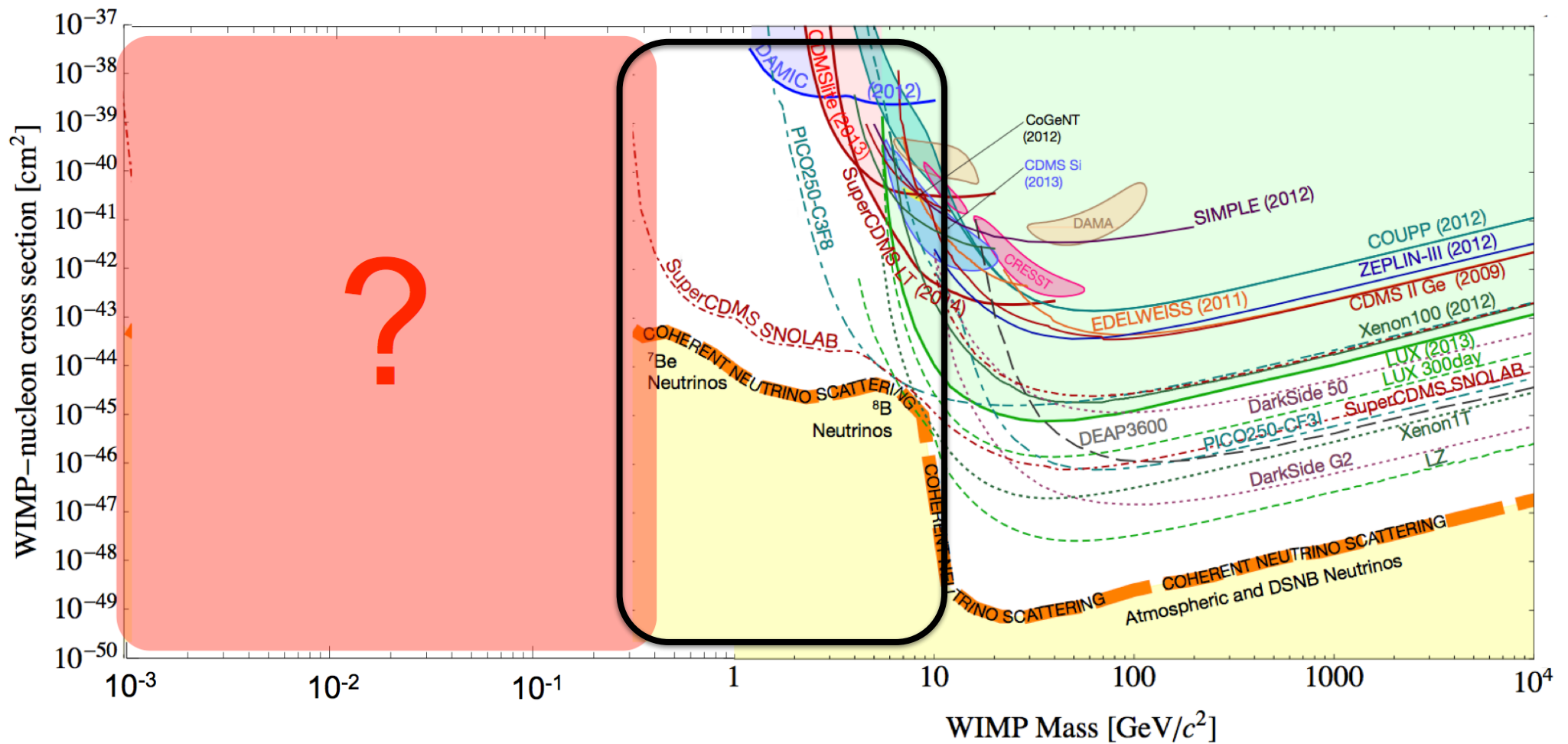
ADMX - AXION Search (US-UK)

- ▶ Peccei Quinn Mechanism - explain why strong nuclear interactions preserves CP symmetry
- ▶ Axions couple to photons
- ▶ Use tuned microwave cavity
- ▶ Chosen by DOE as Gen2
- ▶ Some UK work - Ed Daw



Power of Gas TPCs?

- ▶ Prospects in 1 GeV region and below by electron scattering
- ▶ Threshold in gas: 30 eV?



Conclusion

- ▶ **A fascinating time, if complex and frustrating time!**
- ▶ **Phenomenal technical progress**
- ▶ **Many new results coming:**
 - DEAP3600 (liquid argon)**
 - XENON 1T (liquid xenon)**

Thoughts

- ▶ **Need to search broadly and to keep an open mind:**
 - Multiple targets (Xe, Ar, Ge, F etc)**
 - High and low WIMP mass**
- ▶ **Understanding (unusual) backgrounds is key**
- ▶ **Understanding calibrations is key**
 - What makes a convincing signal**