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Direct Searches for Dark Matter at DUSEL

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India-US Interaction Meeting

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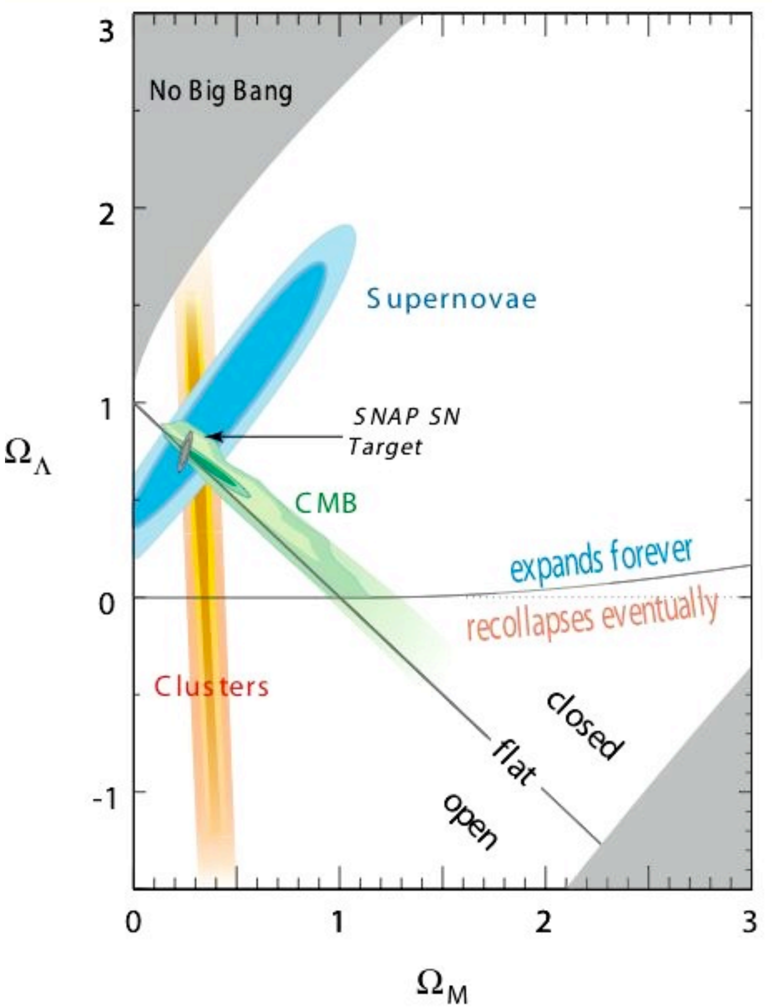
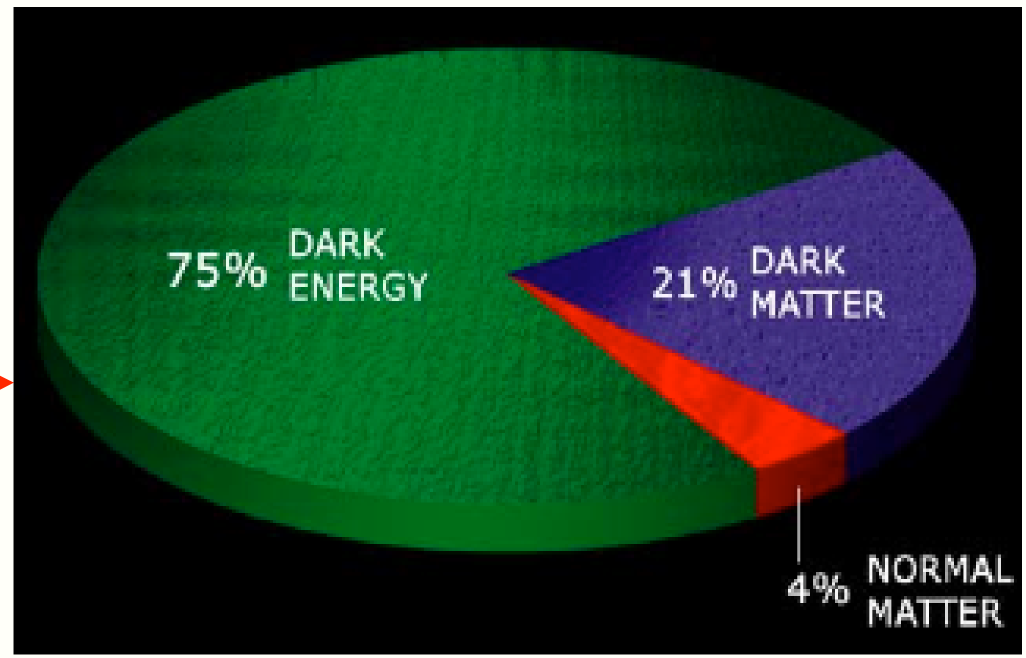
Outline

1. Brief introduction to WIMP dark matter
2. Current Experimental programs
   - Focus on Xenon
3. Future at DUSEL
4. Areas of Possible Collaboration

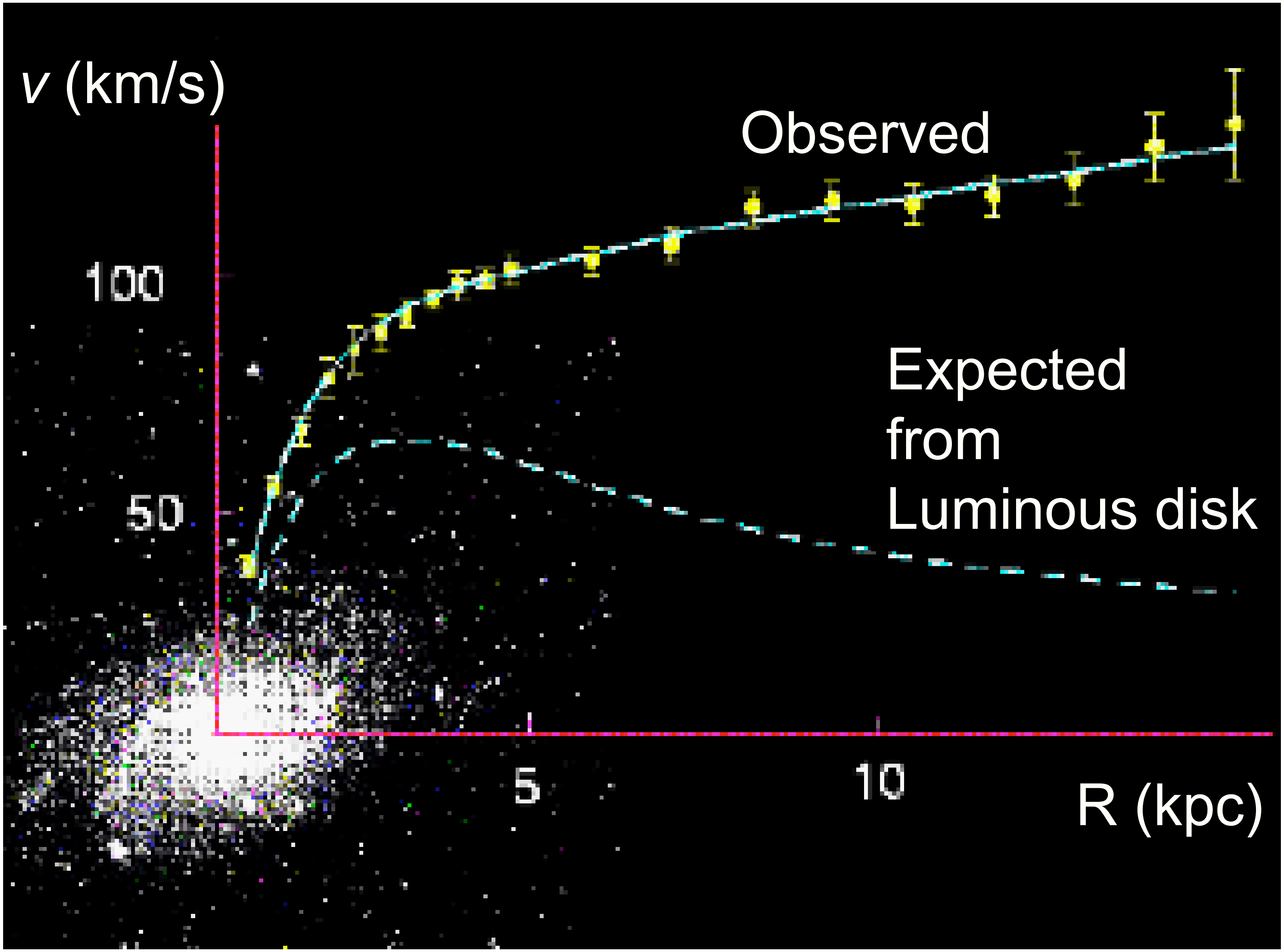
Standard Cosmology

A consistent picture has emerged, establishing the Dark Matter Content in the universe.





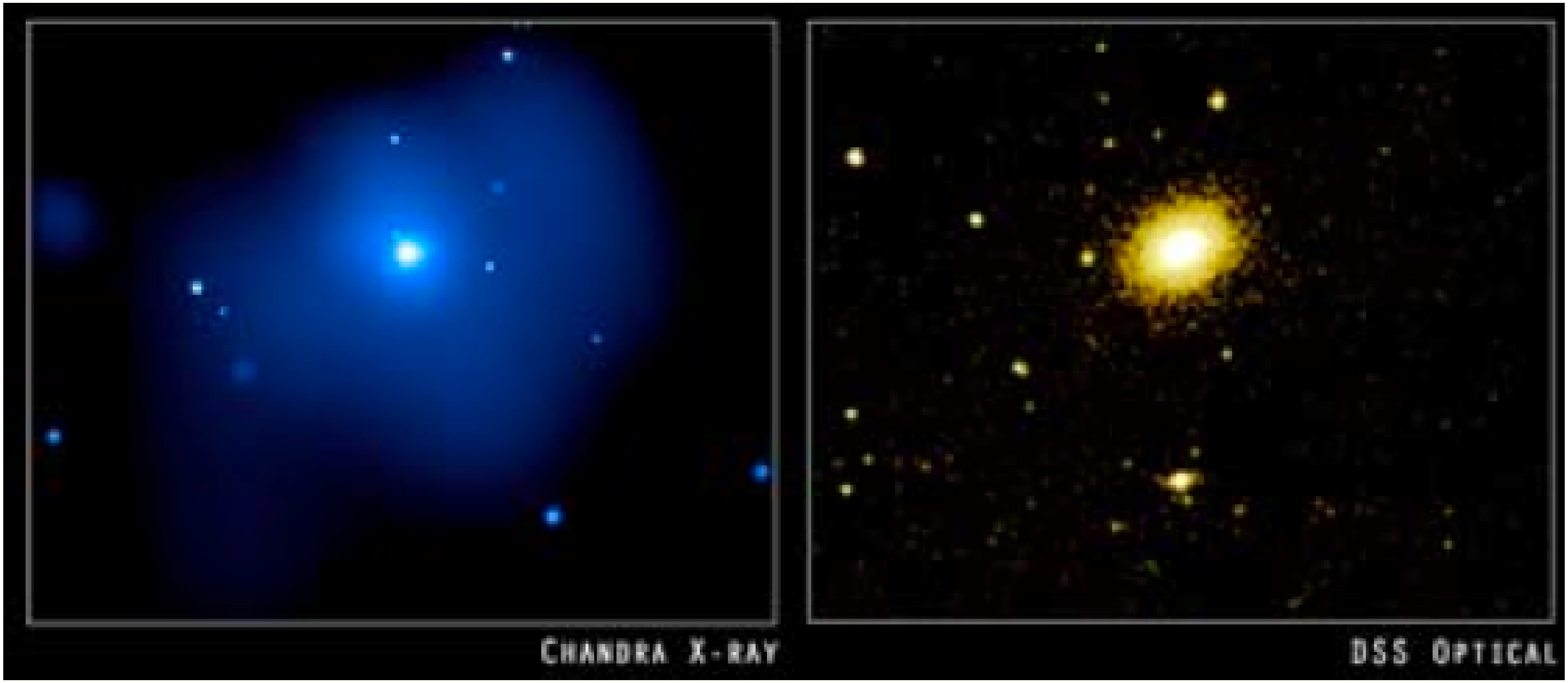
M33 Rotation Curve



The gas here is prevented from escaping by a large potential

DM Halo extends well past luminous matter.

Chandra Observation: NGC 4555



Large quantities of DM are needed to keep the gas from dispersing (~300x mass of gas or ~10x the mass of stars.

Rotational Curves

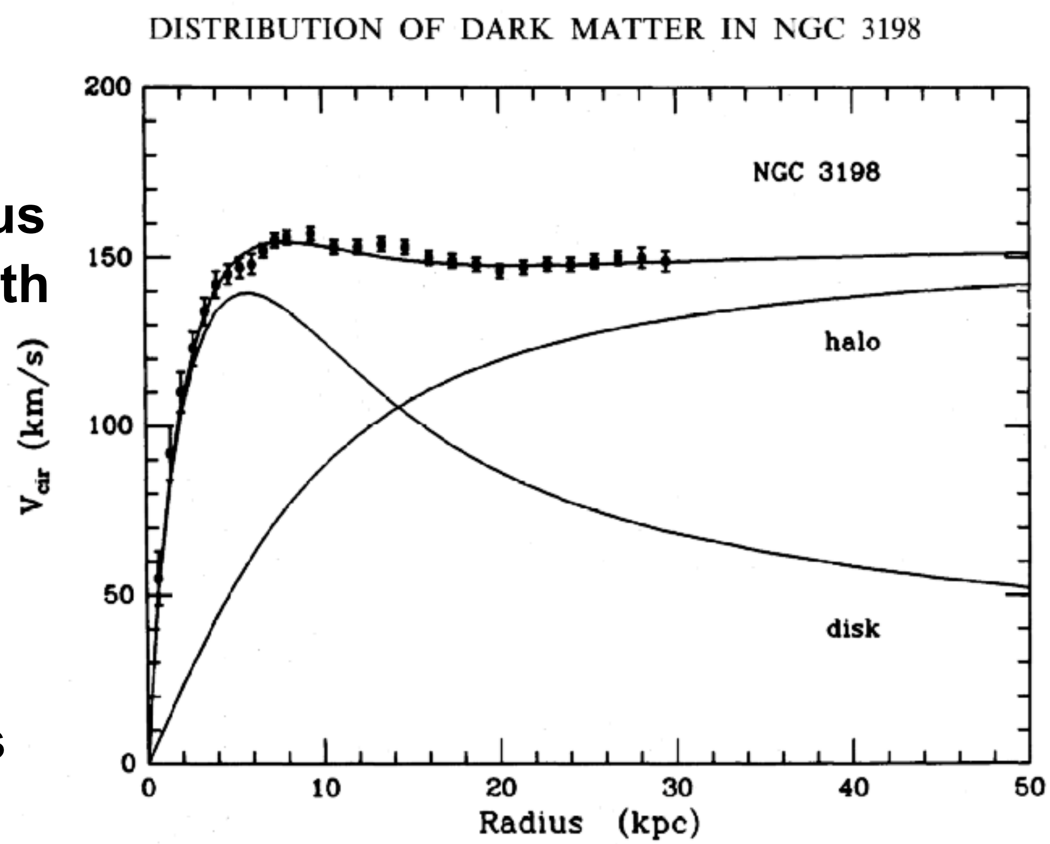
Newtonian Dynamics:

$$\frac{mv(r)^2}{r} = \frac{GmM(r)}{r^2}$$

$M(R) = 4\pi\int r^2 \rho(r)\, dr$

or, $Rv^2(R) = 4\pi G\int r^2 \rho(r)\, dr$

- For $\rho(r) = 0$ outside the luminous region, $v(R)$ will fall as $R^{-1/2}$ with increasing radius.
- Data indicate that at large R, v(R) actually remains constant or increases with R
- Postulate self-gravitating mass of ideal gas -- "Dark Matter"



Velocities inferred via redshift measurements.

Colliding Galaxies

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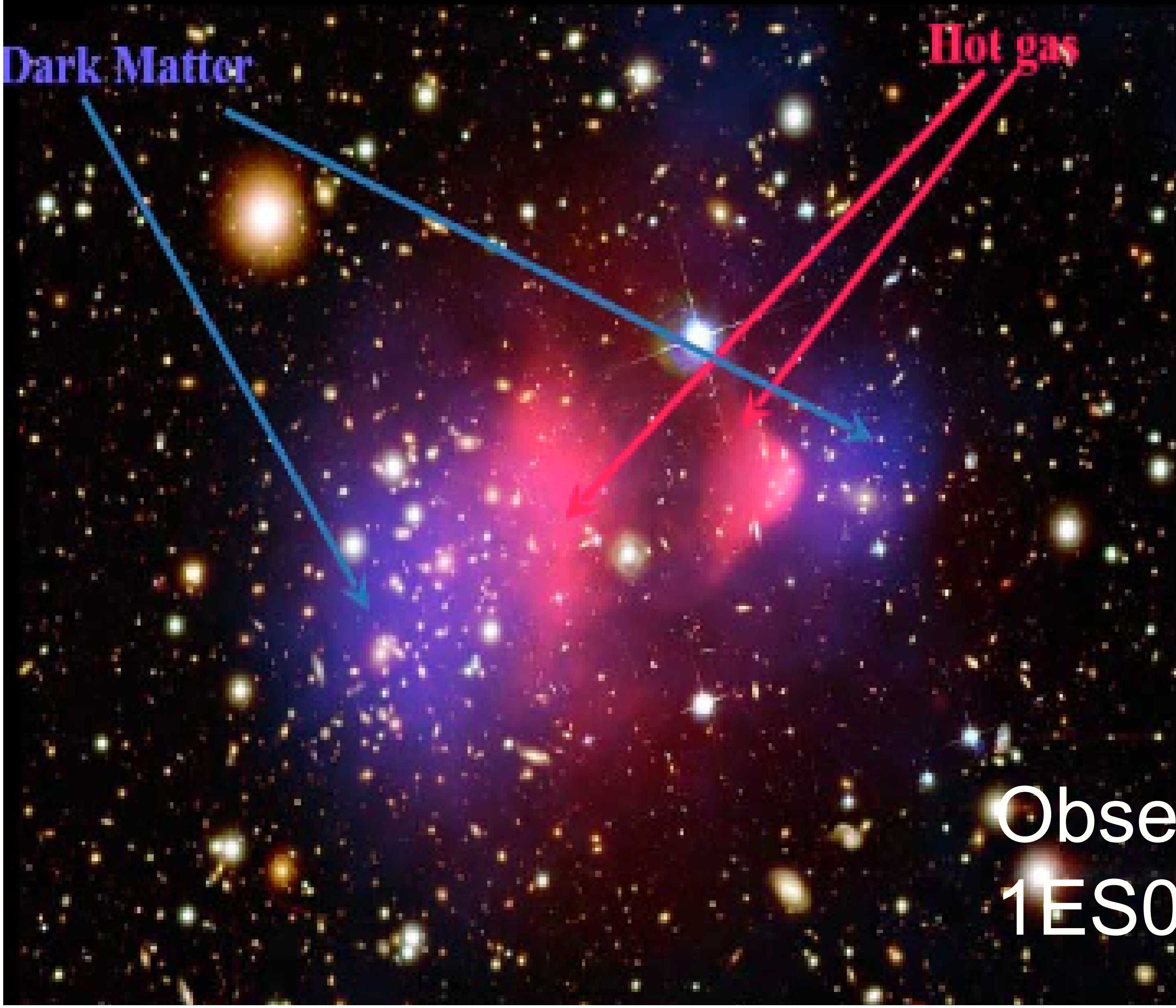


This makes it difficult for modified gravity.

Observation of 1ES0657-58

WIMP Miracle

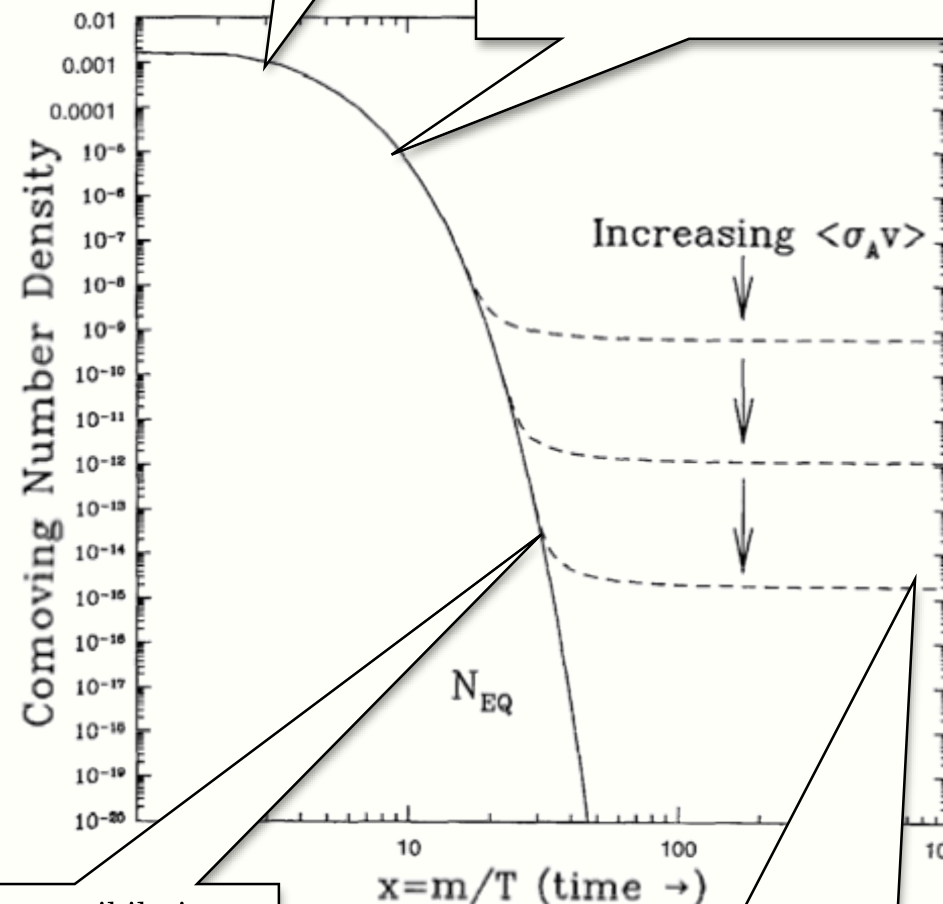
A happy coincidence implies that new physics at the TeV scale with appropriately weak cross section leads to a dark matter relic (with a new quantum number preventing decay).

$$\Omega_x h^2 = \frac{3\cdot 10^{-27}\, cm^3 / s}{\langle \sigma_A v \rangle} \approx 0.12$$

$$\Rightarrow \sigma_A \approx \frac{\alpha^2}{M_{EW}^2}$$

1. Flat region. Constant density. Equal production and annihilation.

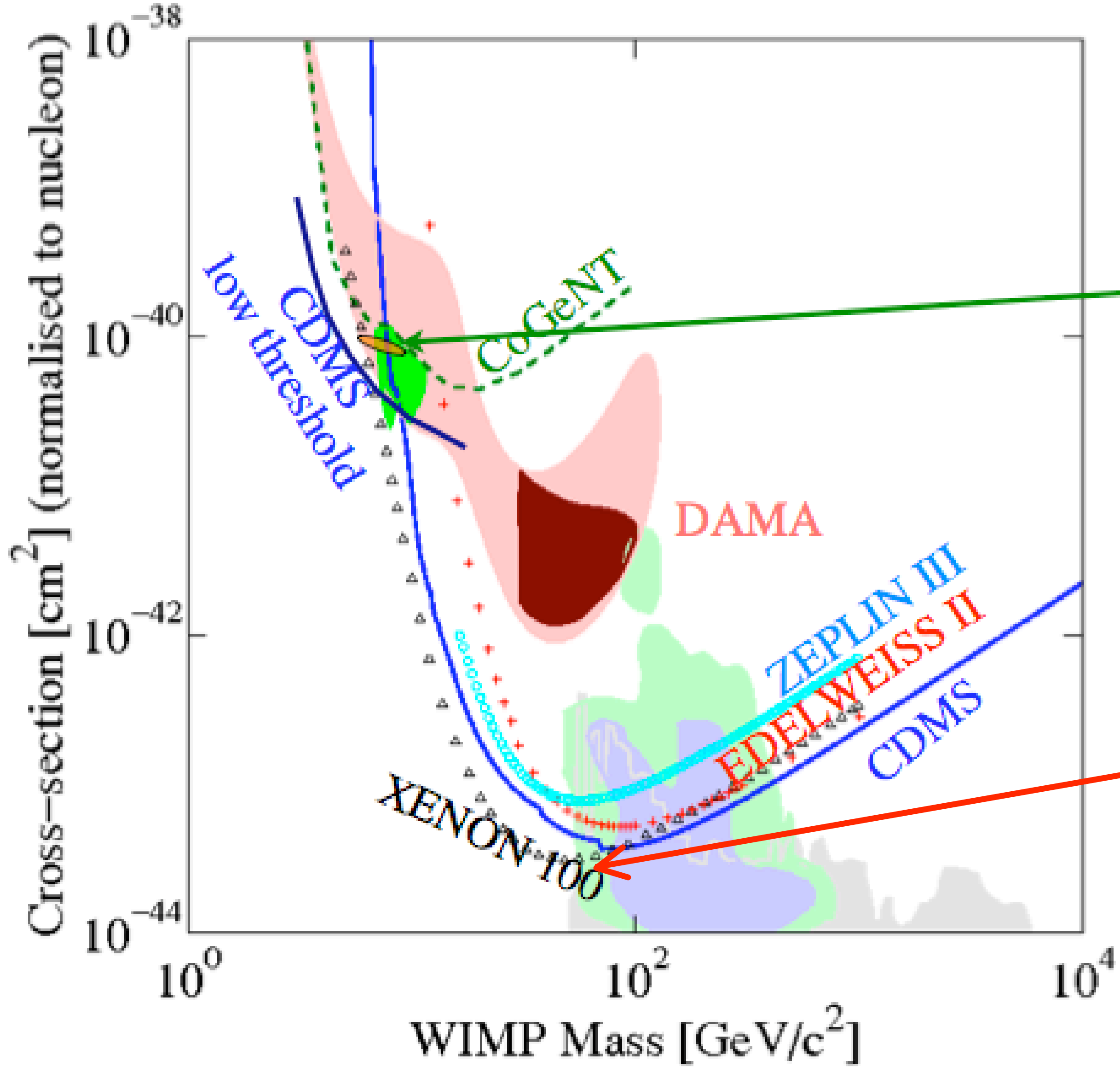
2. Exponential suppression as temperature falls below mass of dark matter particle.



3. Turn over as annihilation rate decreases, becoming smaller than the expansion rate.

4. Relic abundance remains. Larger cross-sections keep annihilations occurring for longer.

Current Limits

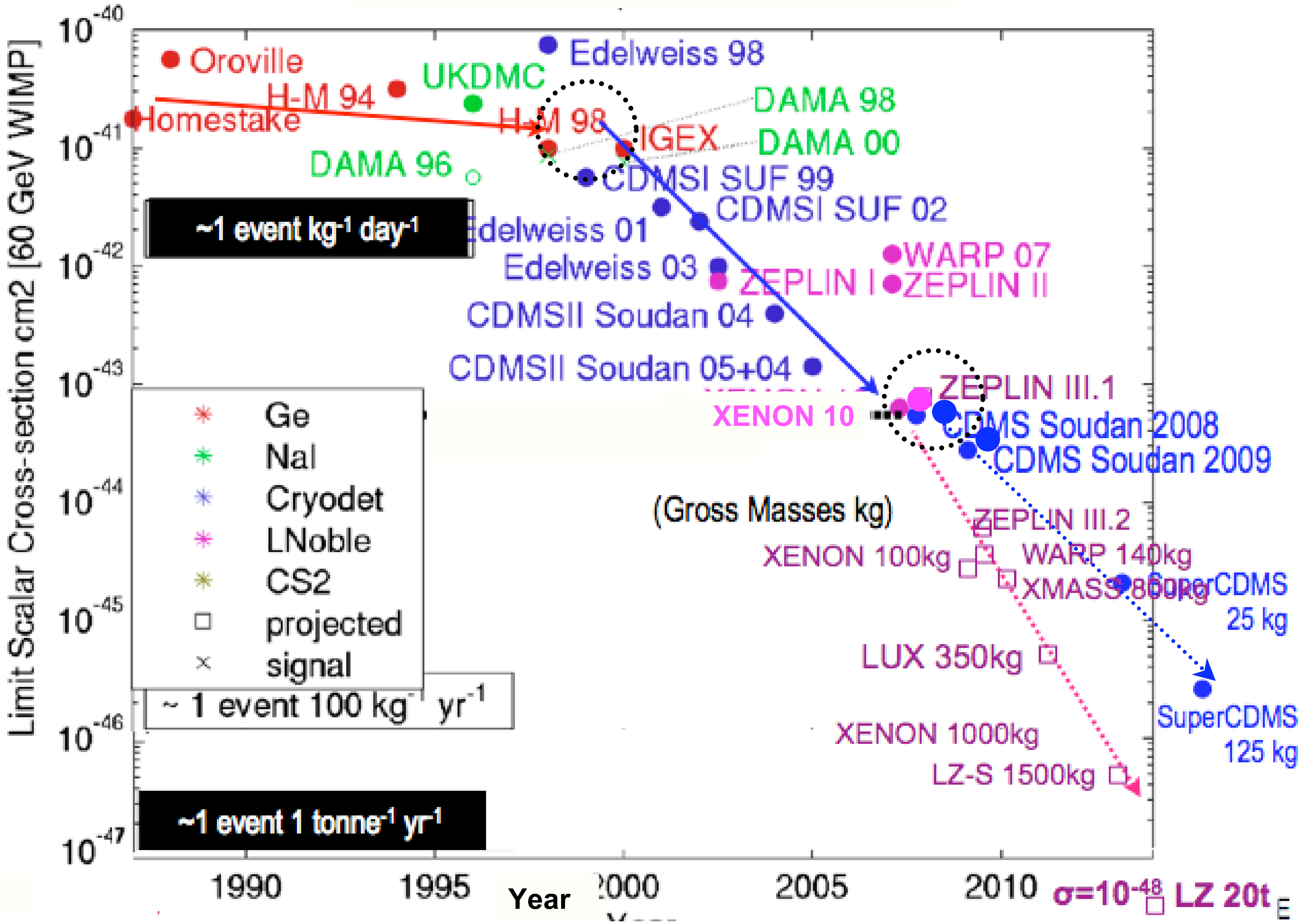


Possible signal at low mass?

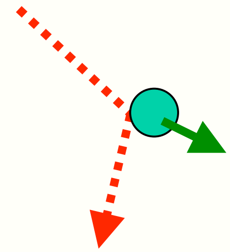
Current best limit.

Experimental Program

Direct DM Search - Progress/Breakthroughs



Detection Techniques



Basic goal: search for nuclear recoil from DM elastic scattering.

For most techniques, this requires large suppression of background gamma ray induced electron recoils. Discrimination is based on measuring two characteristic signals from the recoil.

	Liquid Xenon	Liquid Argon	Low temp. Ge	Bubble Chamber
Ionization	√	√	√	high density
Scintillation	√	√		
Phonons			√	
Other		Pulse shape	Pulse shape	Acoustic

Neutrons need to be eliminated:

- Deep underground deployment
- Use of ultra-low radioactivity materials and components
- Large external shields (water and/or lead)
- Active veto (e.g., gadolinium doped liquid scintillator)
- Double scatters (DM does not)

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Evolution of Collaborations/Technologies

1. Cryogenic Germanium

CDMS, CDMS-II, SuperCDMS, GeoDM …

2. Liquid Xenon

Xenon10, Xenon100, Xenon1T, MAX …

ZEPLIN-I, ZEPLIN-II, ZEPLIN-III

LUX-350, LUX-ZEPLIN @Sanford (LZS) , LZ@DUSEL (LZD)

} One Expt. at DUSEL?

3. Liquid Argon/Neon

Micro-Clean, Mini-CLEAN, DEAP, CLEAN …

WArP

DarkSide, MAX

} One Expt. at DUSEL?

4. Bubble Chambers

COUPP, COUPP-60, COUPP-Tonne Scale

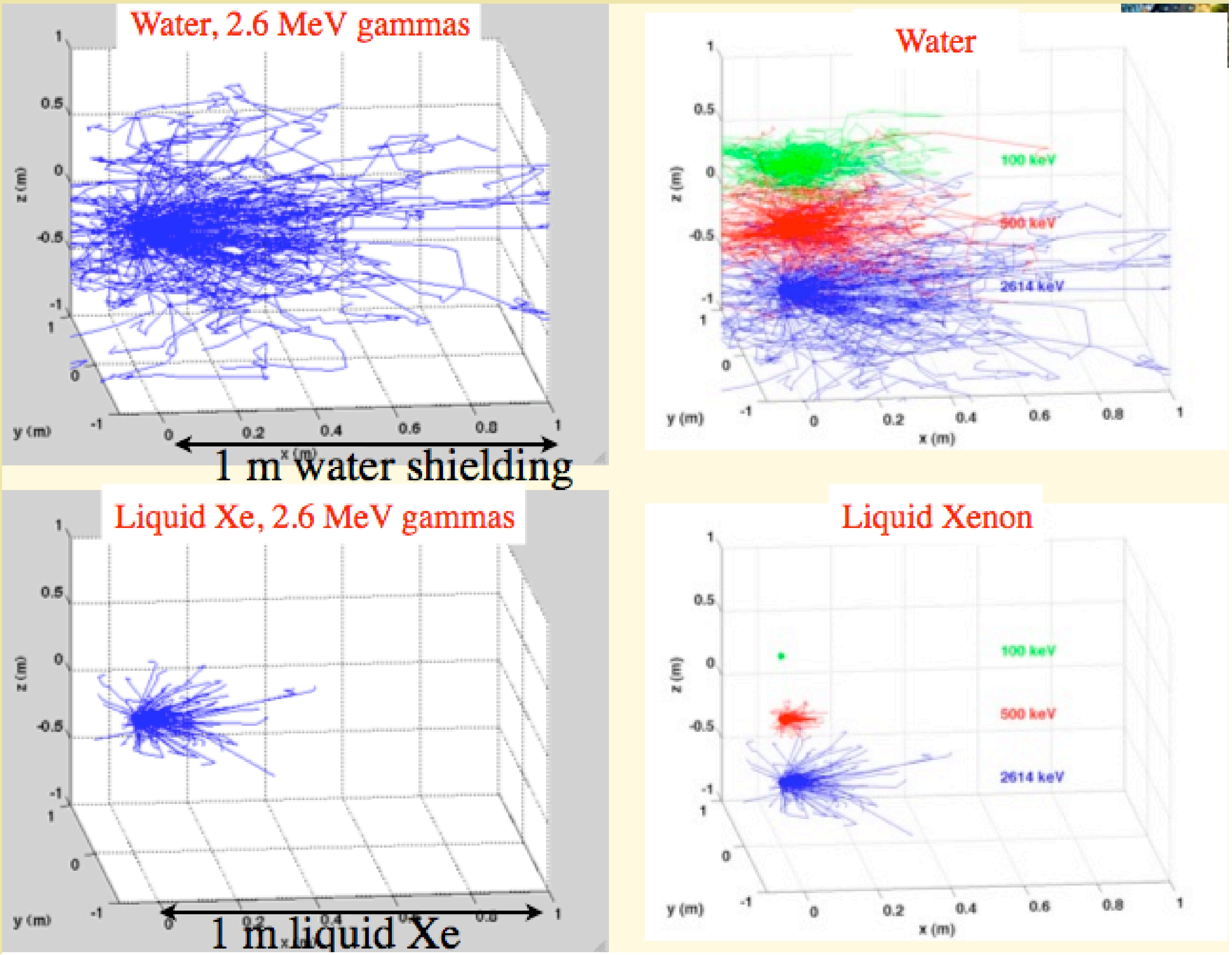
Why Noble Liquids?

Very powerful Self-shielding.

Effective when size > attenuation length

=> ~20 cm buffer for Xe

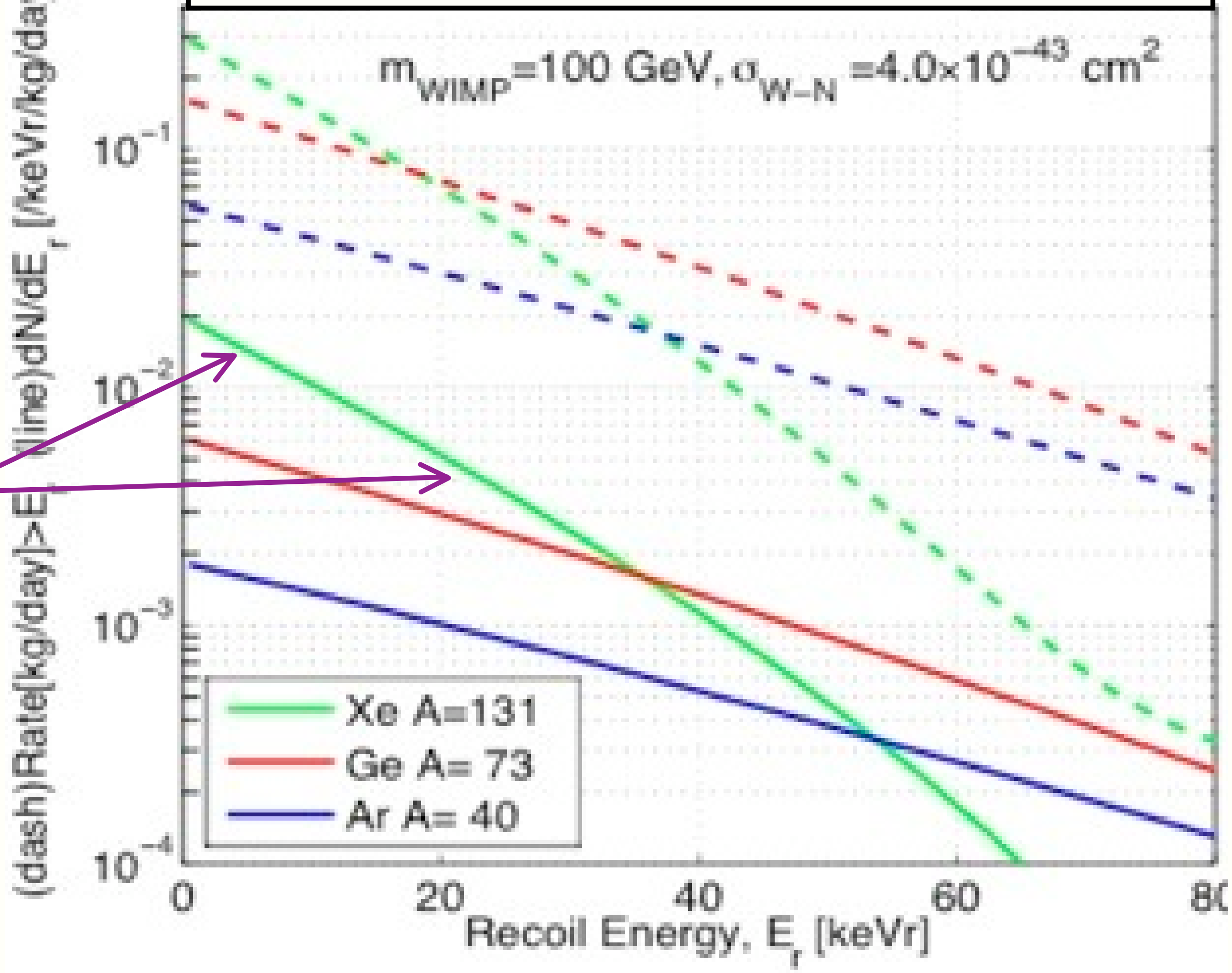
=> Fiducial Mass > 100 kg.



Why Xenon?

Higher Sensitivity
in the range
5 keV < E < 20 keV.

Recoil Spectra



γ/neutron Discrimination

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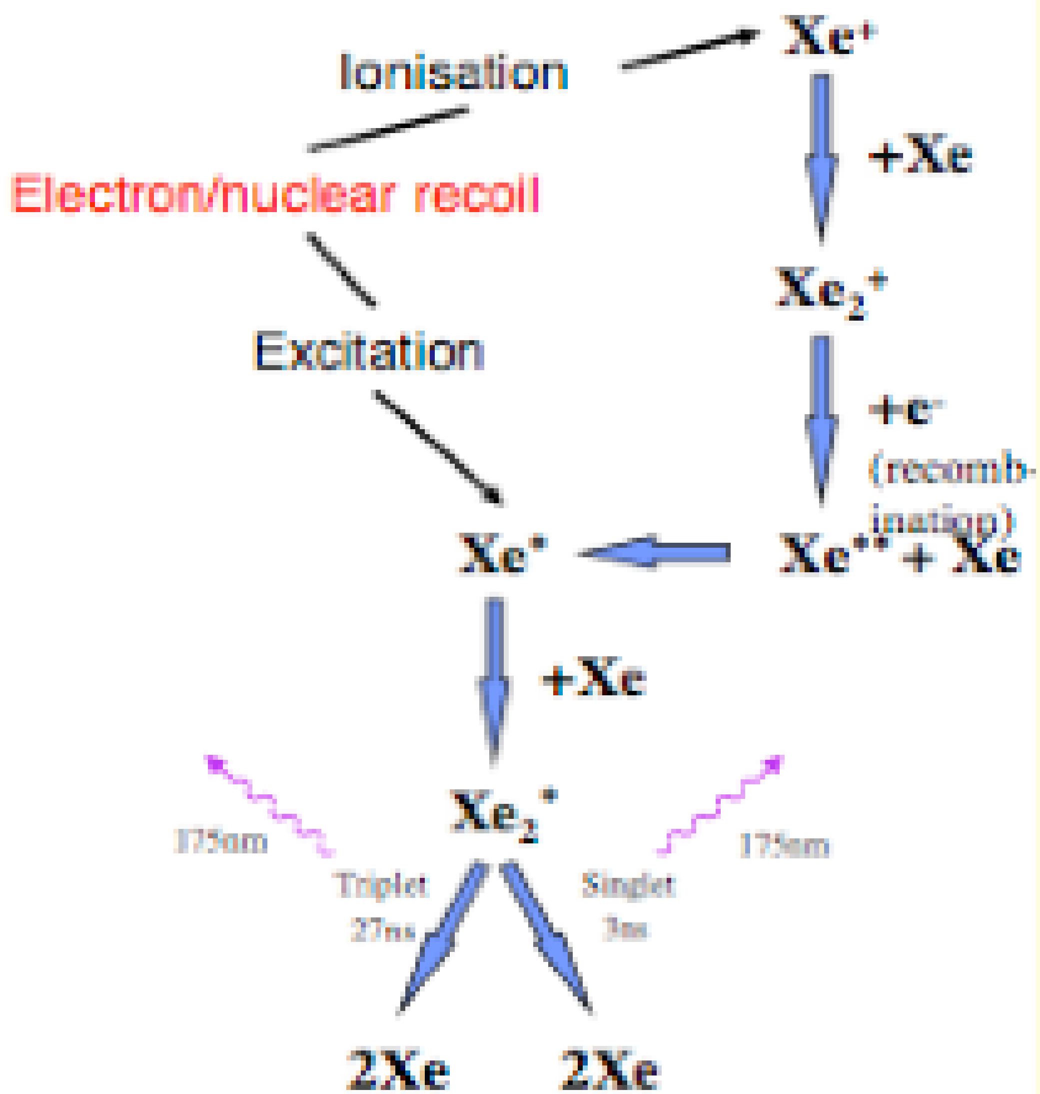

Xenon is transparent to its own scintillation light !

Differences in recombination efficiency is exploited to discriminate between electron and nuclear recoils.

Figure of merit derived from plots of:

Log (charge escaping recombination/total primary light produced)

… Next slide.

Two Signal Technique

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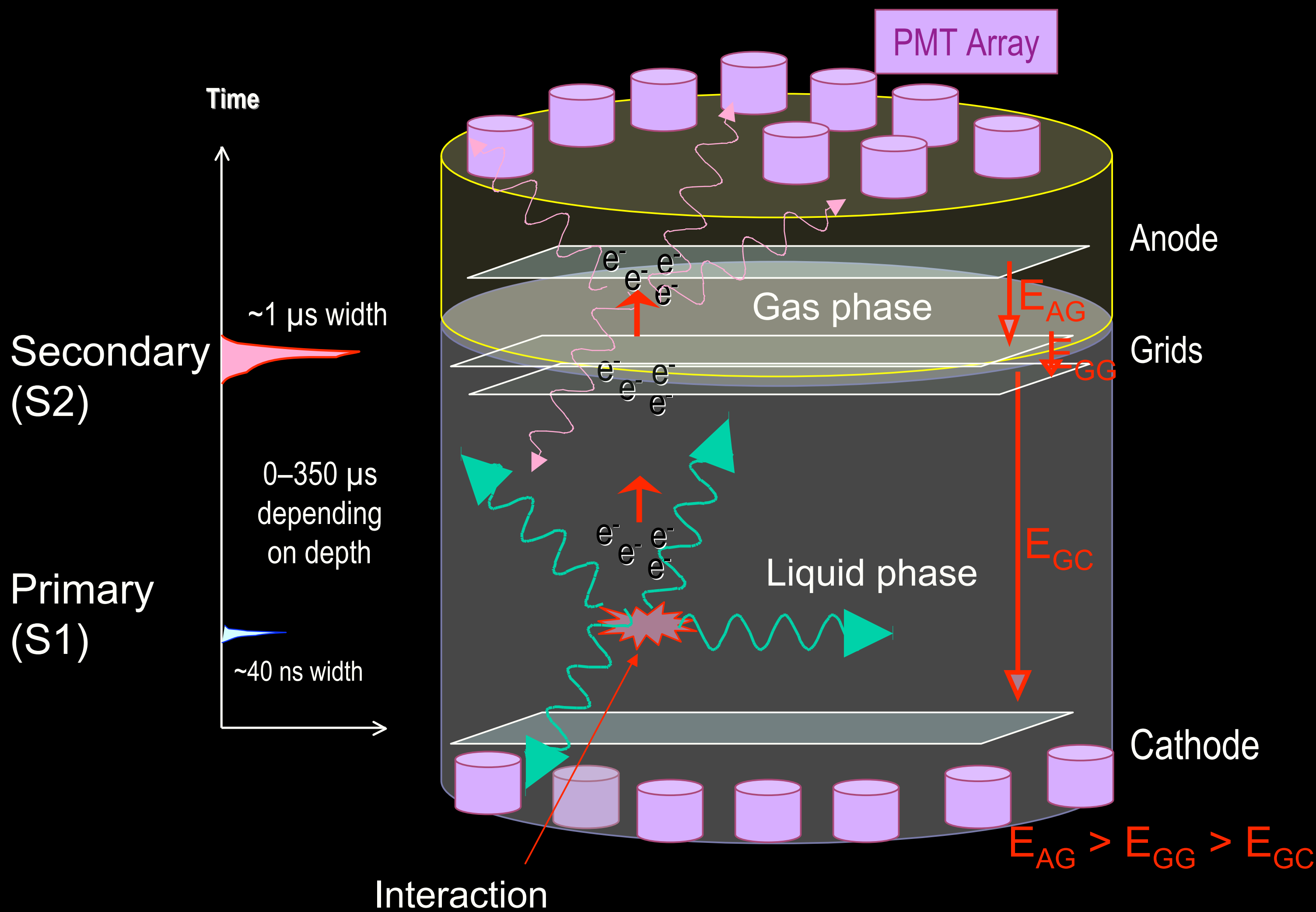

Calibration Data

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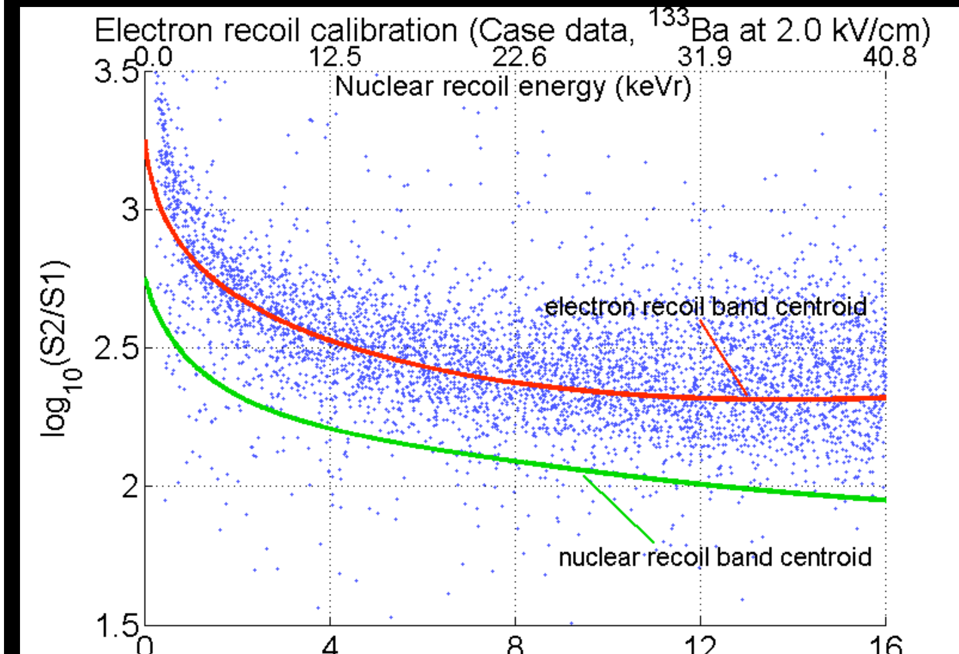
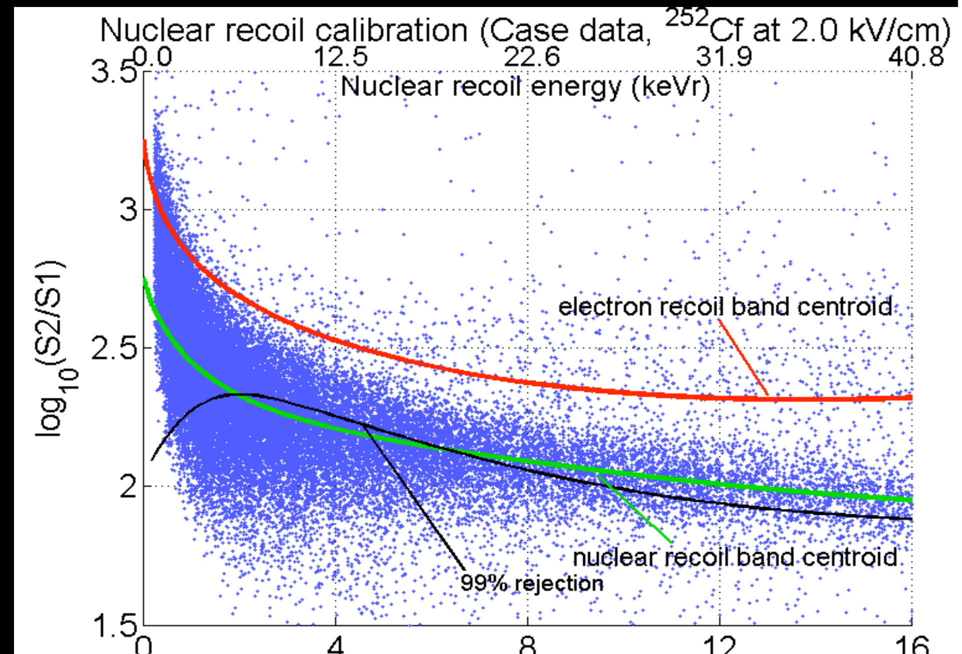
^{133}Ba Electrons



Recoil Energy (keVr)

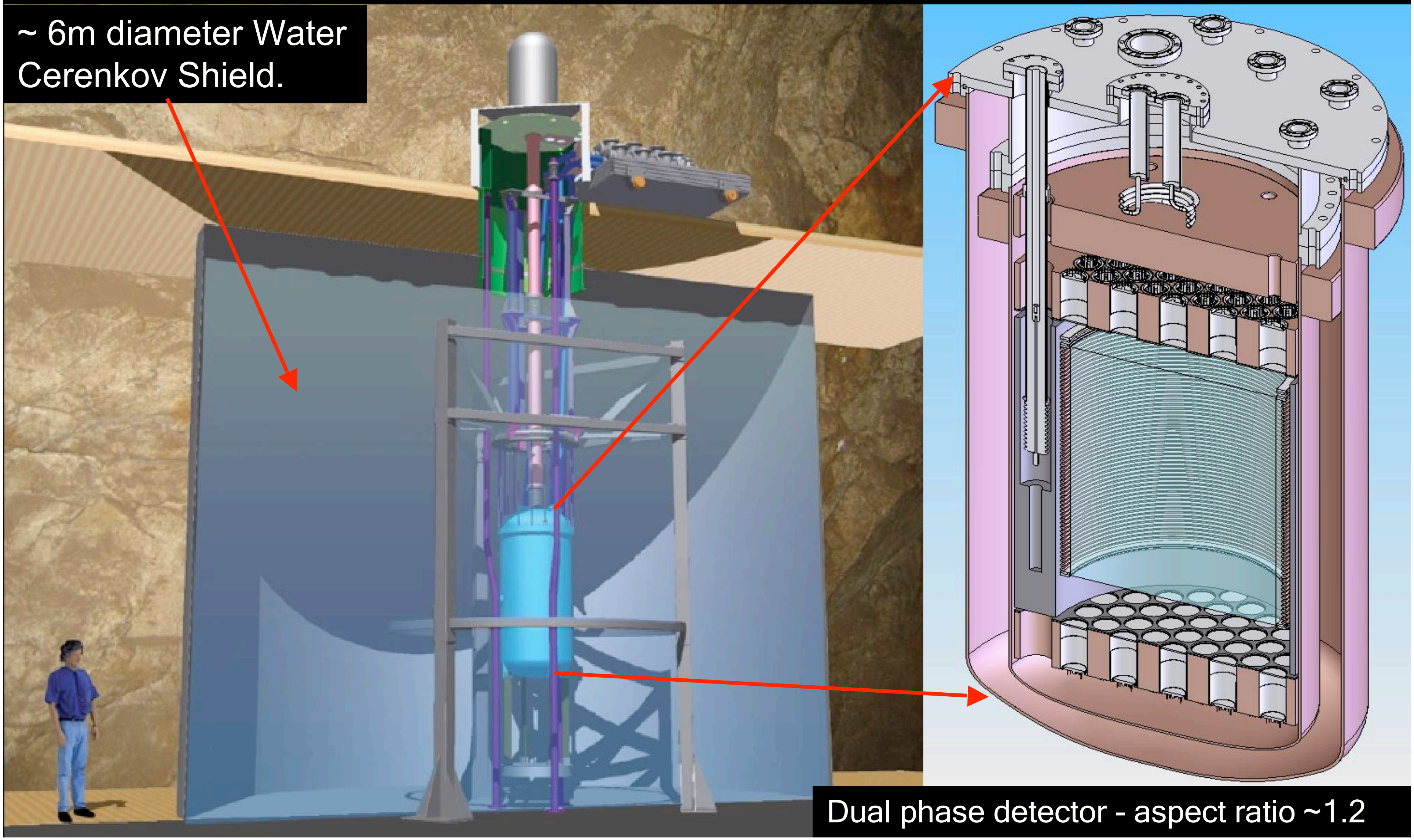
^{252}Cf Neutrons



Recoil Energy (keVr)

These measurements were made above ground, but agree well with Xenon10 experience.

The LUX detector



Backgrounds (Gamma)

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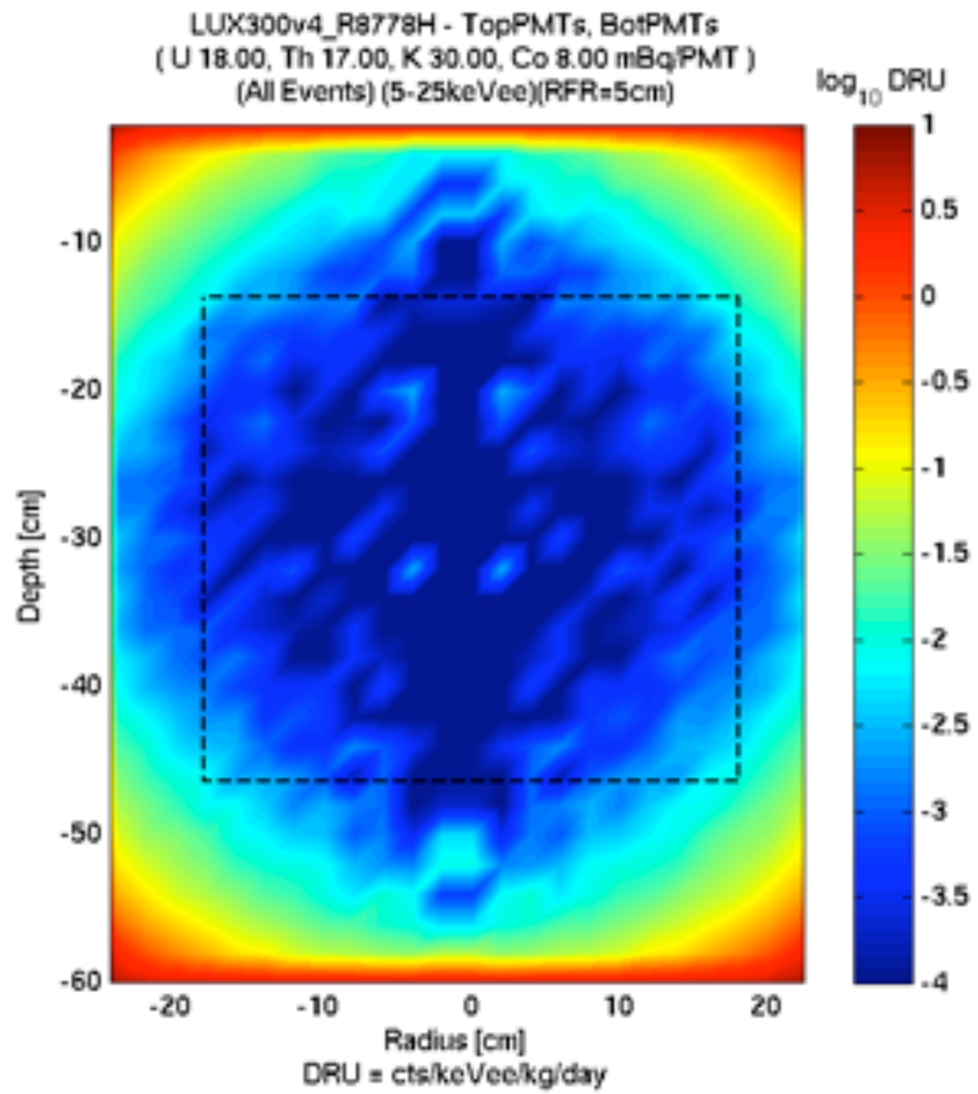
- Internal strong self-shielding against PMT activity (main source of background events). Double Compton scatters are rejected.
- External large water shield with muon veto. Very effective for cavern γ



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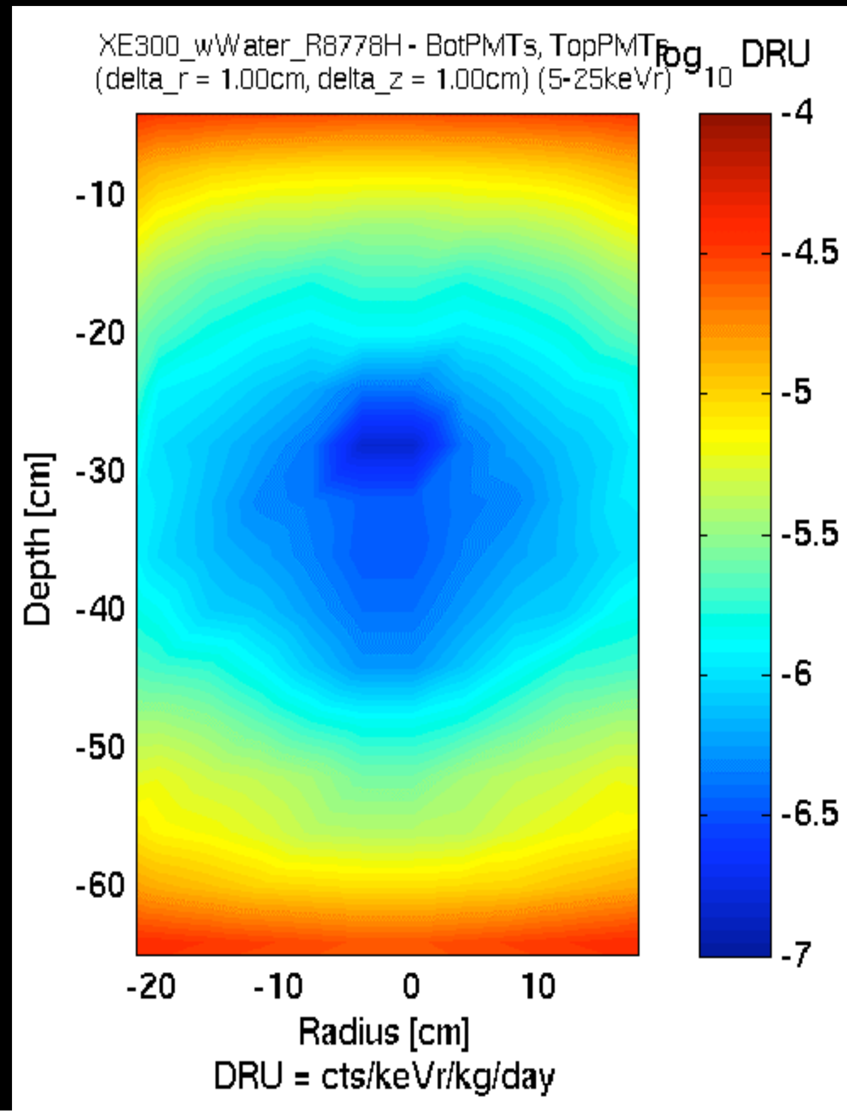
Backgrounds (Neutrons)

- Internal
  Neutrons (α,n) & fission << $\gamma + \beta$.
  ~65% double scatter.
  (PMTs are the main source)

- External large water shield with muon veto.
  - Very effective for cavern n, and HE neutrons from muons
  - Possible upgrade of adding Gd to the water.



Simulated Signal in LUX

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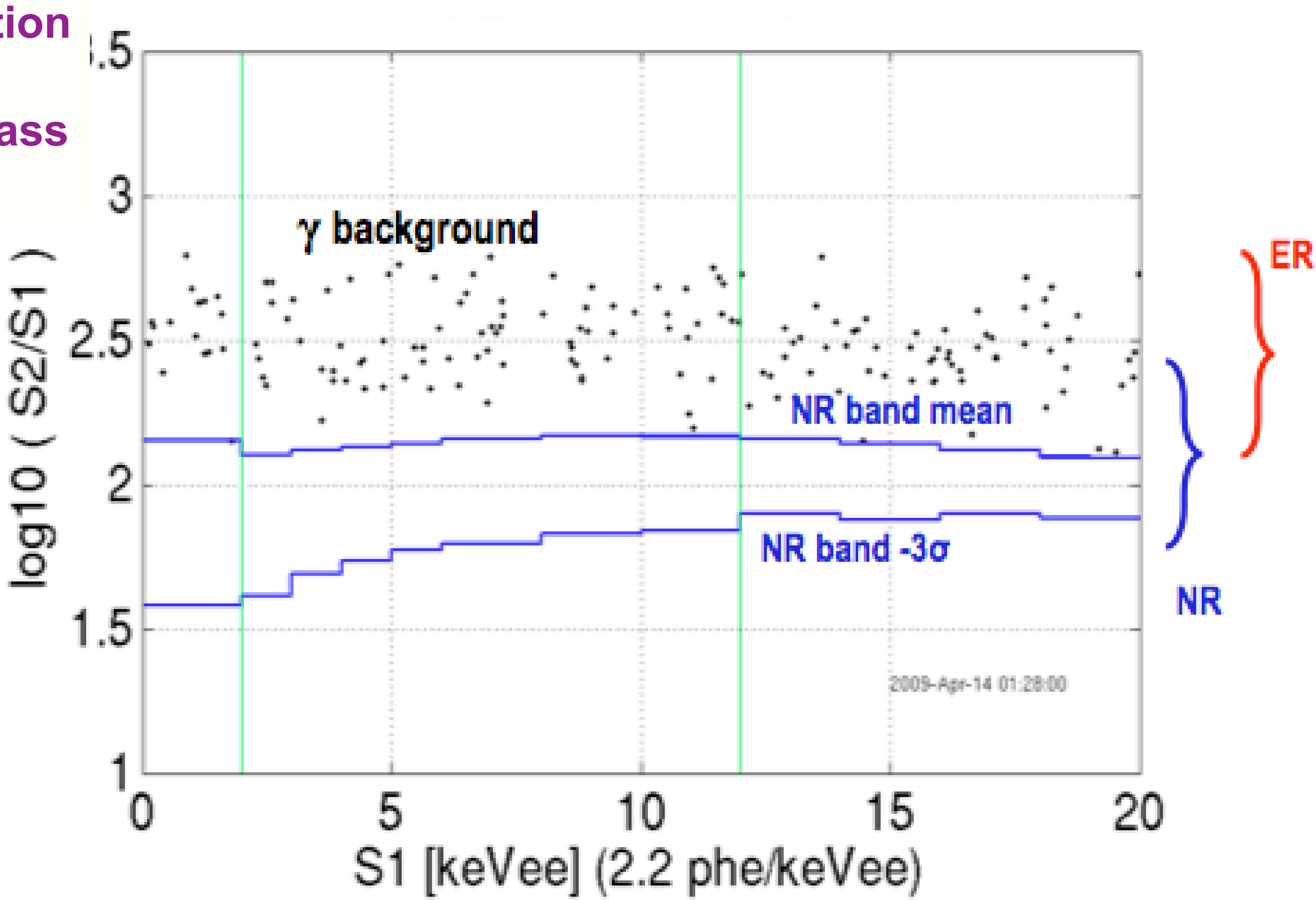
Electron recoil background ~2.6×10^{-4} dru (based on screening of materials)

300 days acquisition

100 kg fiducial mass



$L_{eff} = 0.19$

Using same
ER and NR bands
as XENON10

Power of self-shielding

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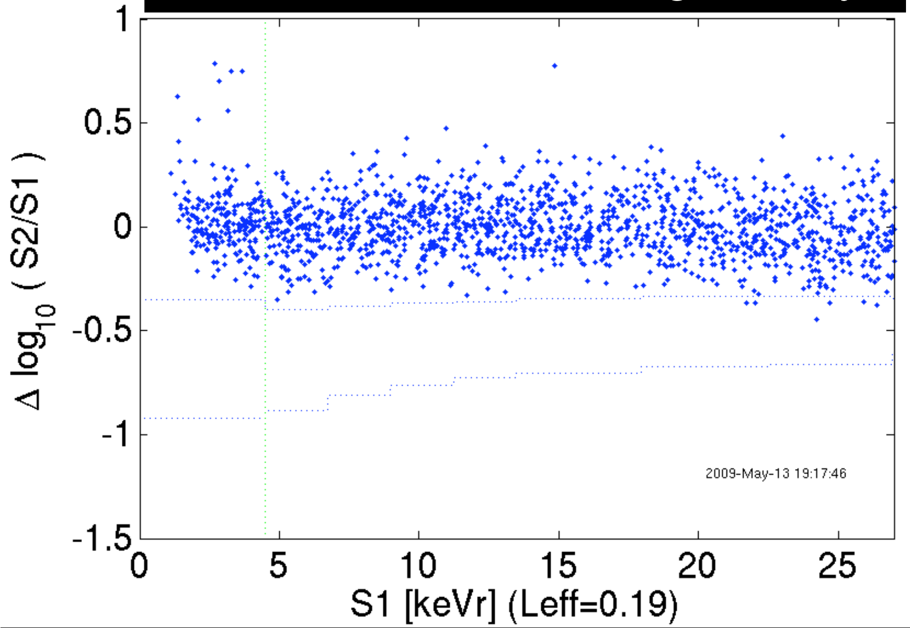
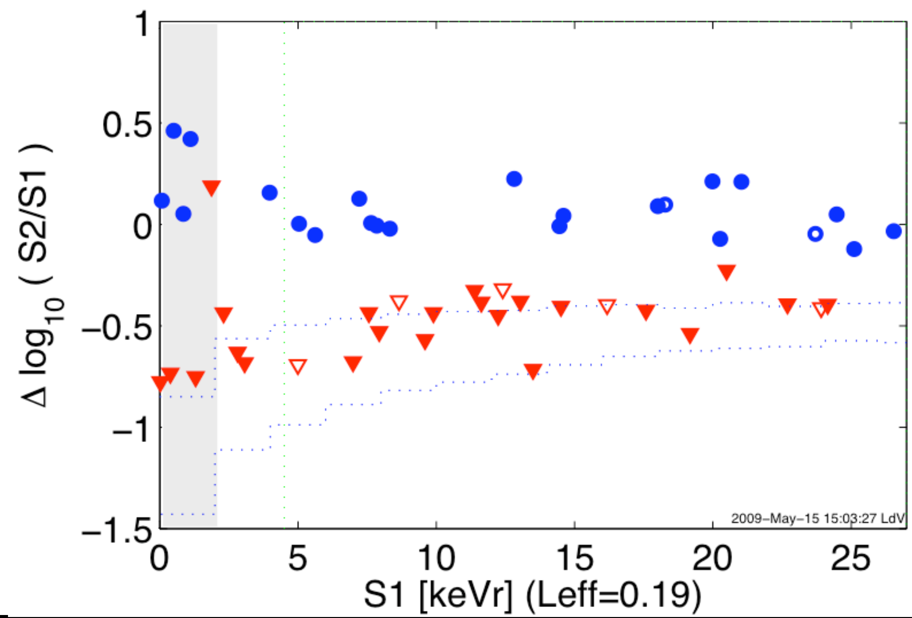
XENON10 Data -- 5.4 kg, 59 days

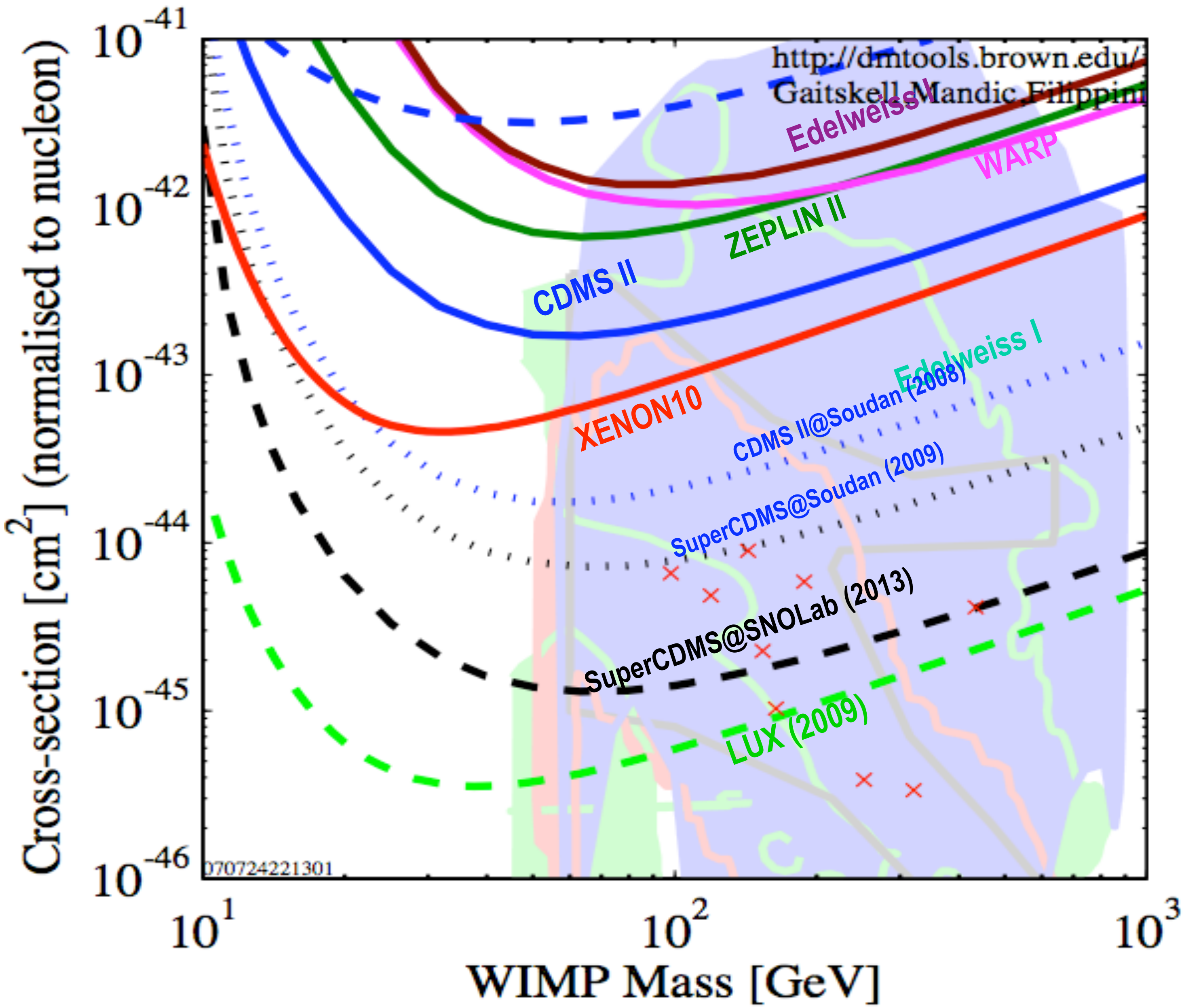


LUX Simulation -- 100 kg, 100 days



Red points are for a simulated signal of 100 GeV WIMP and a cross section 5×10^{-45} cm^2
Open points are for 25 kg fiducial.

LUX Goal



SuperCDMS Goal @ SNOLab: Gross Ge Mass 25 kg (x 50% fid) for 1000 days running)

Davis Cavern

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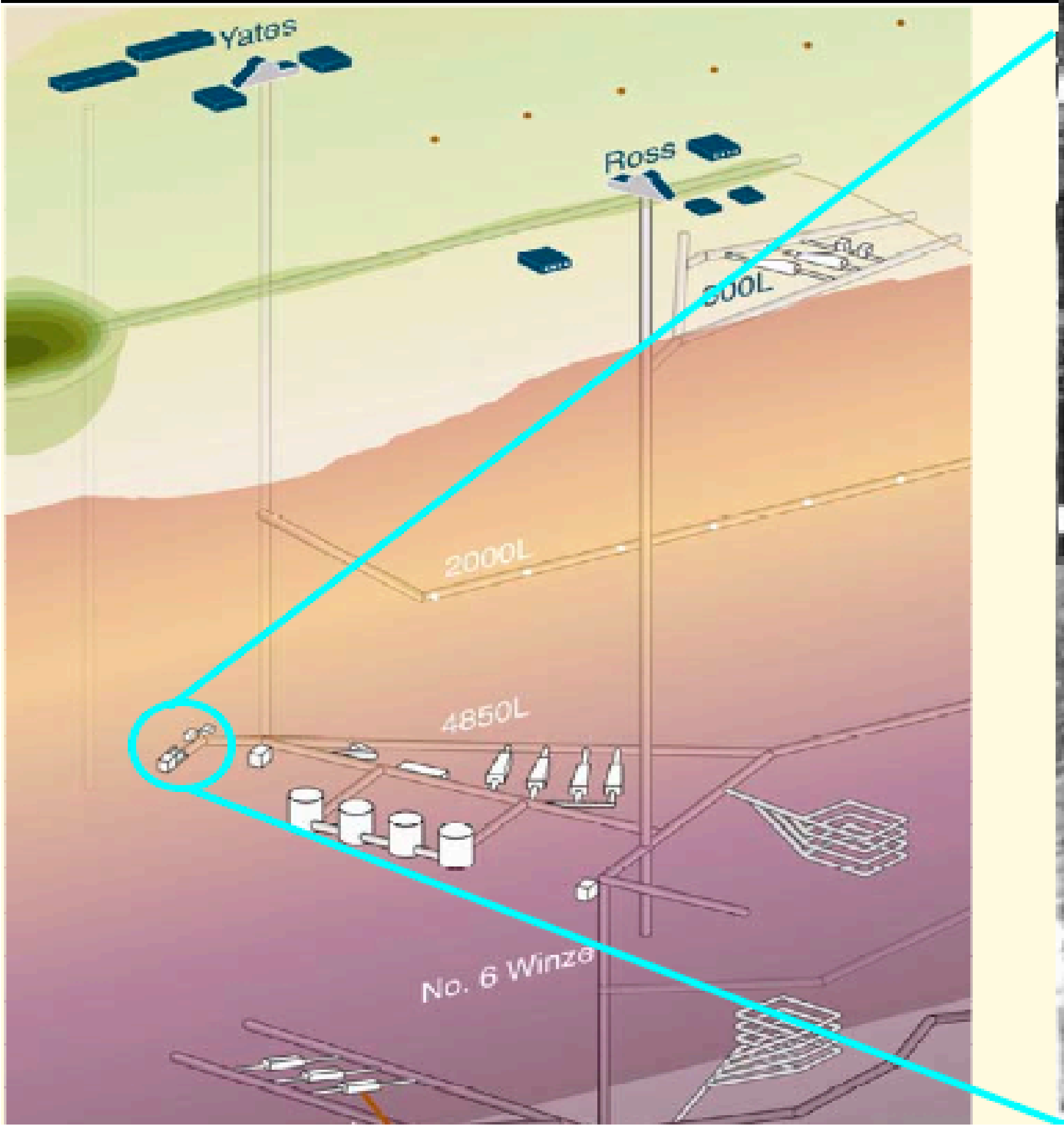

De-watering Milestone

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May 22, 2009. Inspection of 4850 ft level.

Excavation Completed

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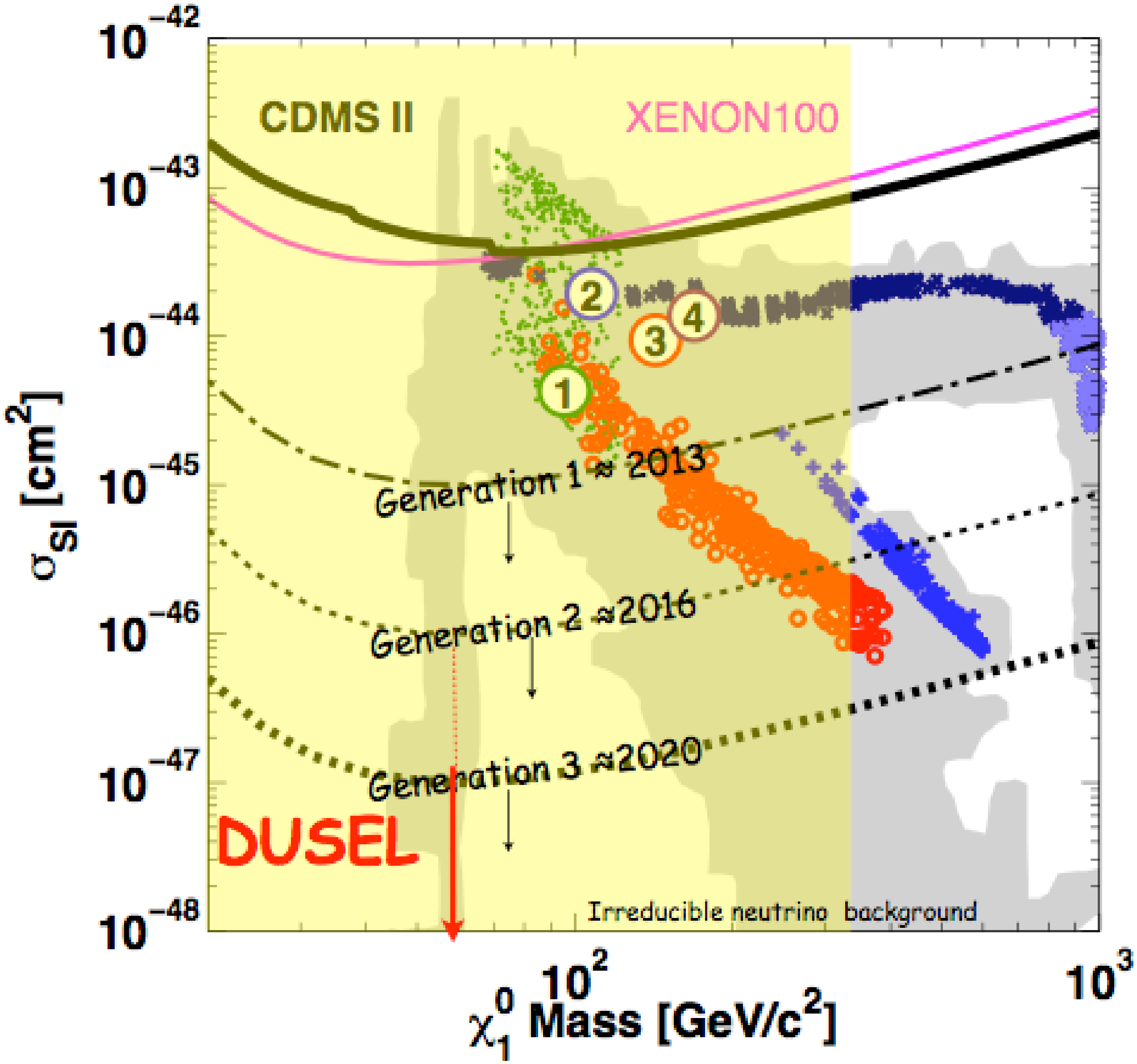
LUX Assembly completed in the surface facility at DUSEL.

DUSEL Program

Long term Program



3 Generations

DUSEL Experiments

Experiment	Mass Target	Sensitivity Scalar cm^2	Location Install. Date	Strengths	Challenges R&D	Estimated Costs
COUPP	16x500kg CF3I bubble ch.	dependent on α contamination	4850 ft 2017	γ rejection Cheap SD target	α (Acoustic Discrim.) Threshold detector	$21+11M
LZD	20t Xe dual phase	10^{-48}	4850 ft 2017	3D imaging Self shielding Scalable	Liquid purity HV	$55+28M
Max	20t depleted Ar 6t Xe dual phase	10^{-47}	4850 ft 2017	3D imaging Self Shielding QUPID Pulse shape rejection (Ar)	Liquid purity HV ^{39}Ar depletion	$70+35M
GEODM	1.5 t Ge phonons +ionization	2 10^{-47}	7400 ft 2017	Rejection + Background demonstrated 3D imaging	Cost/yield for large # of detectors high Ø Ge	$55+28M
CLEAN	50 t Ar single phase	few 10^{-47}	7400 ft 2017	Pulse shape rejection n self shielding Scalable	Rn contamin. Liquid purity	$60+30M

Estimate of Target Sensitivities

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(Assume 100 GeV, 4E-45 cm^2)

Akerib, Gaitskell et al (assume natural Ar)

Target	Energy Threshold * / assumed signal acceptance	Fiducial Mass required for 25 WIMP events in 100 live-days ††	Total number of ER events in Fiducial Mass for 100 live-days **	Max acceptable leakage in ER Rejection
Xe TPC	**2 keVr / 80%**	**100 kg**	**17**	**0.05**
Ar (†)	40 keVr / 90%	1.5 tonnes	2×10^8	**5×10^{-9}**
Ar (†)	80 keVr / 90%	6.5 tonnes	8×10^8	**1×10^{-10}**
Ge (CDMS)	10 keVr / 50%	350 kg	2×10^5	**5×10^{-6}**

LUX->LZ Sanford->LZ DUSEL

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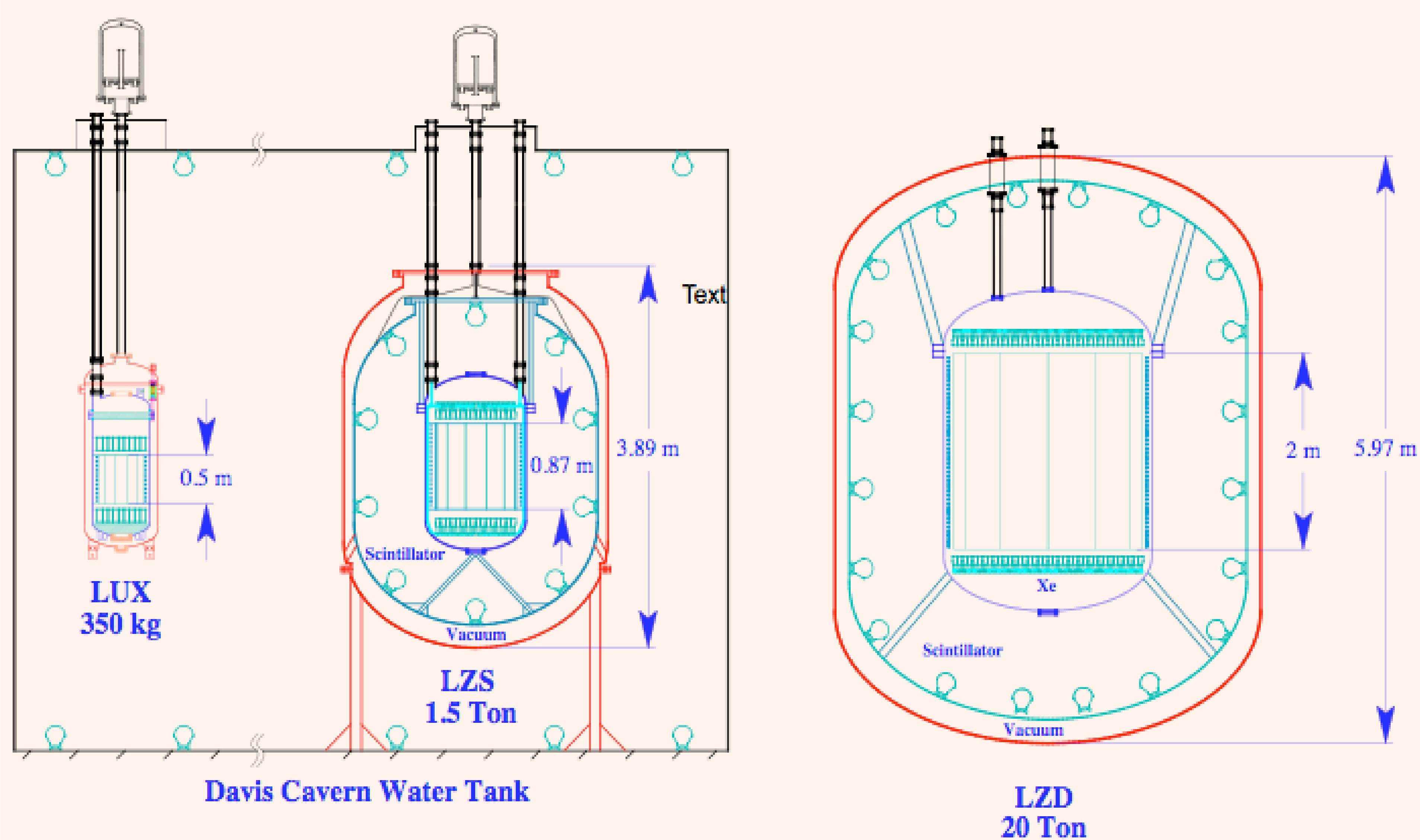

Projected Sensitivity

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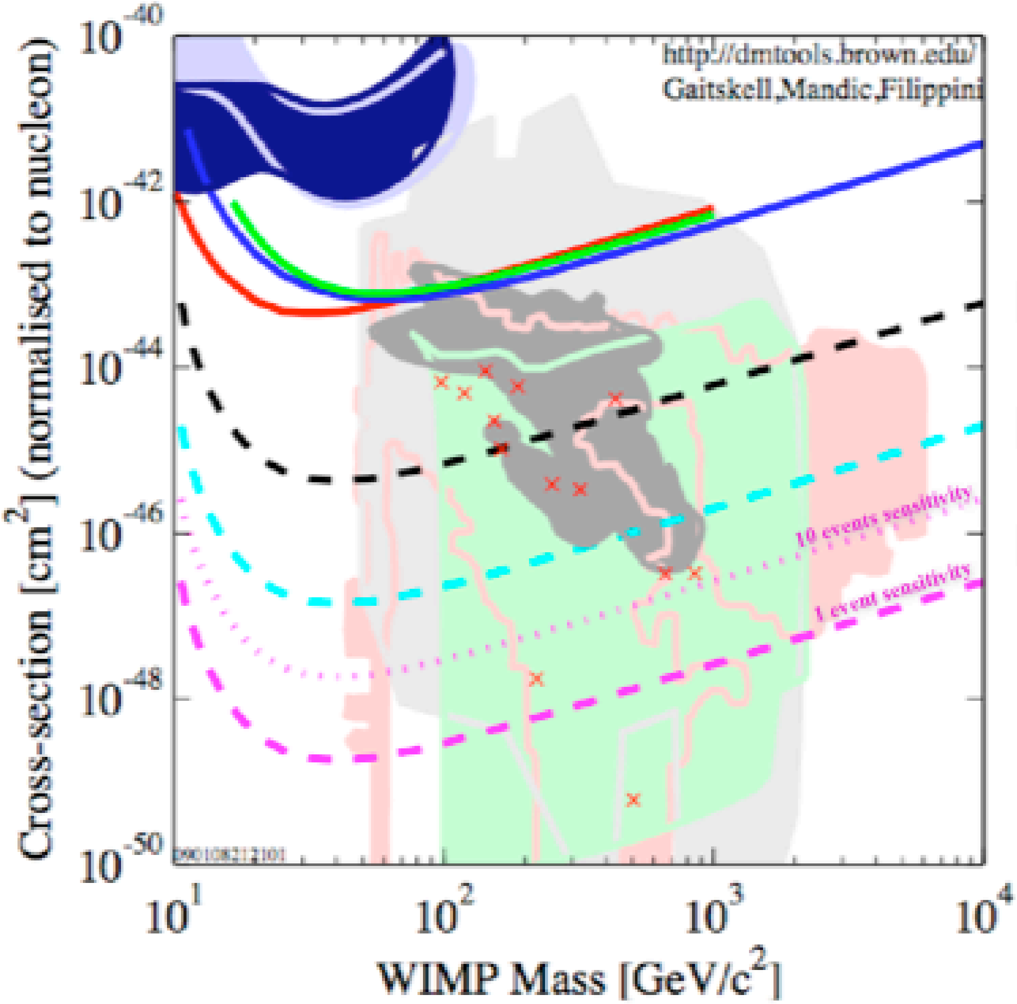


- Projections based on
  - Known background levels
  - Previously obtained e$^-$ attenuation lengths and discrimination factors

LUX (constr: 2009-2011, ops: 2011-2012)
100 kg x 300 days

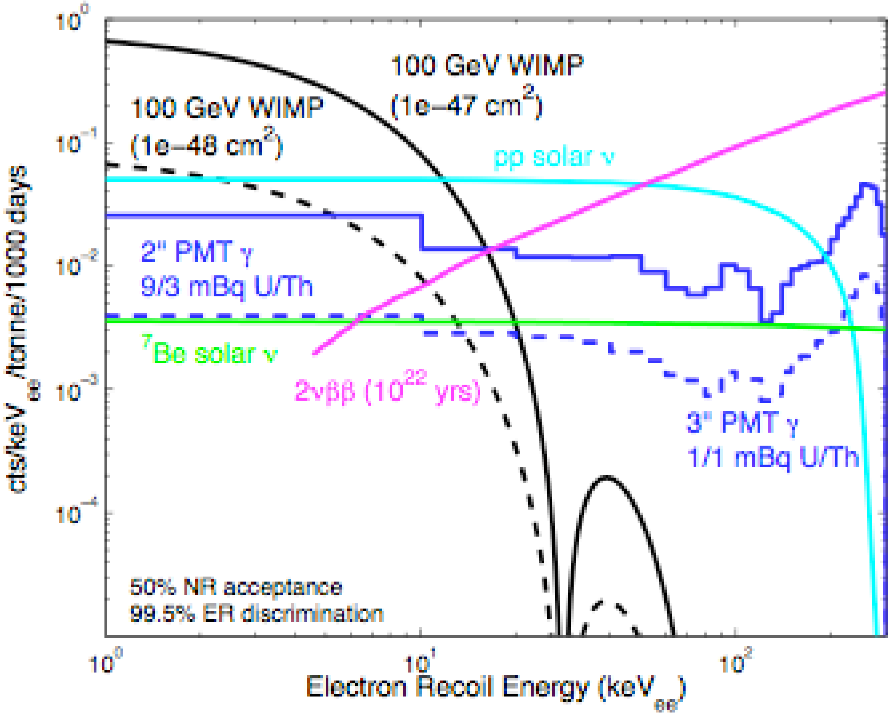
LZS (constr: 2011-2013, ops: 2013-2014)
1,200 kg x 500 days

LZD (constr: 2014-2017, ops: 2017-2022)
13,500 kg x 1,000 days

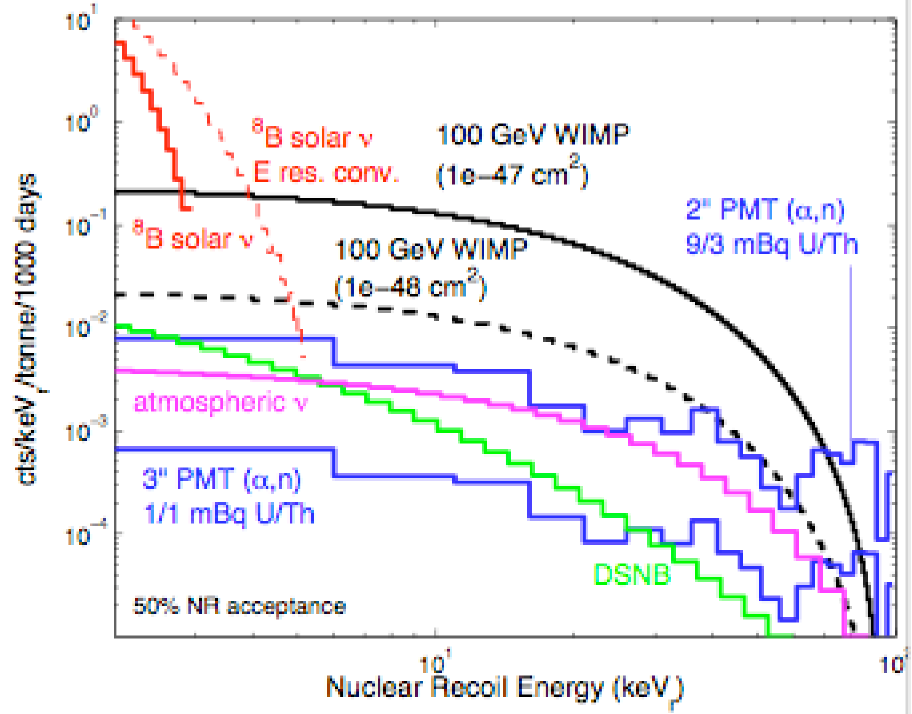
- Fiducial volumes selected to match < 1 NR event in full exposure

WIMPs and Backgrounds

Low Energy Electron Recoil Events



Low Energy Nuclear Recoil Events



Xe provides better than 99.5% ER/NR rejection at these energies

Collaboration Opportunities

Opportunities for Collaboration

1. High purity Ge (BARC)
   - Cost is the limiting factor for tonne scale Ge detectors.

2. Cryogenics/Xe purification (CAT?)
   - Tonne scale liquification and purification (incl. krypton removal) has not been demostrated.

3. Electronics (BARC electronics group)
   - Pulse shape discrimination electronics is directly relevant to Argon based DM detectors.
   - Chips being developed for INO can also find application with some modifications to the analog front-ends.

4. Simulations (Universities)

Opportunities (Contd)

5. Xenon Procurement (Indian Oxygen Limited)

- Xenon is a by-product of oxygen industry. (~10^{-7} of air is xenon). The world production is about 50-60 tonnes/year. A purchase of 20 tonnes for DM will perturb the market. A long term strategy is needed to accumulate xenon @~$1,000/kg. Xenon has very good re-sale value.

6. Photo-sensors (SiPM work at TIFR)

- The main advantage will be ultra-high radio-purity of such sensors. Cost needs to be brought down to PMT level (~$100/cm^2) from the current level which is 10x higher.

Opportunities (Contd)

7. Nuclear Activation Analysis (BARC)

   - Currently, we are using a 2 MWth TRIGA reactor for neutron exposure which has a large component of fast neutrons. We are planning a heavy water modulator, but a PHWR looks attractive. India operates ~20 heavy water reactors.

8. Liquid Scintillator R&D

   - Need to gain experience with operation at Lxe temperature. Study gadolinium doping.

9. Gamma-ray screening (Low background counting at SINP)

   - Goal is to detect 10 ppt levels of U/Th/K in materials being used in detector construction (Cu, Ti, Steel, Al, plastics).

Summary

1. The nature of Dark Matter is a leading problem of our times. The experimental program being planned for DUSEL will provide definitive limits on whether WIMPs are the answer.

2. Experiments are relatively modest and small groups can have a significant impact. Large nuclear physics community in India exists. A few groups joining in to the DM program can make a big difference.

3. Existing expertise in Indian laboratories is very relevant to the DM program.

4. With technical exchange gained in DUSEL context, mounting a DM detector at INO can be a possibility.