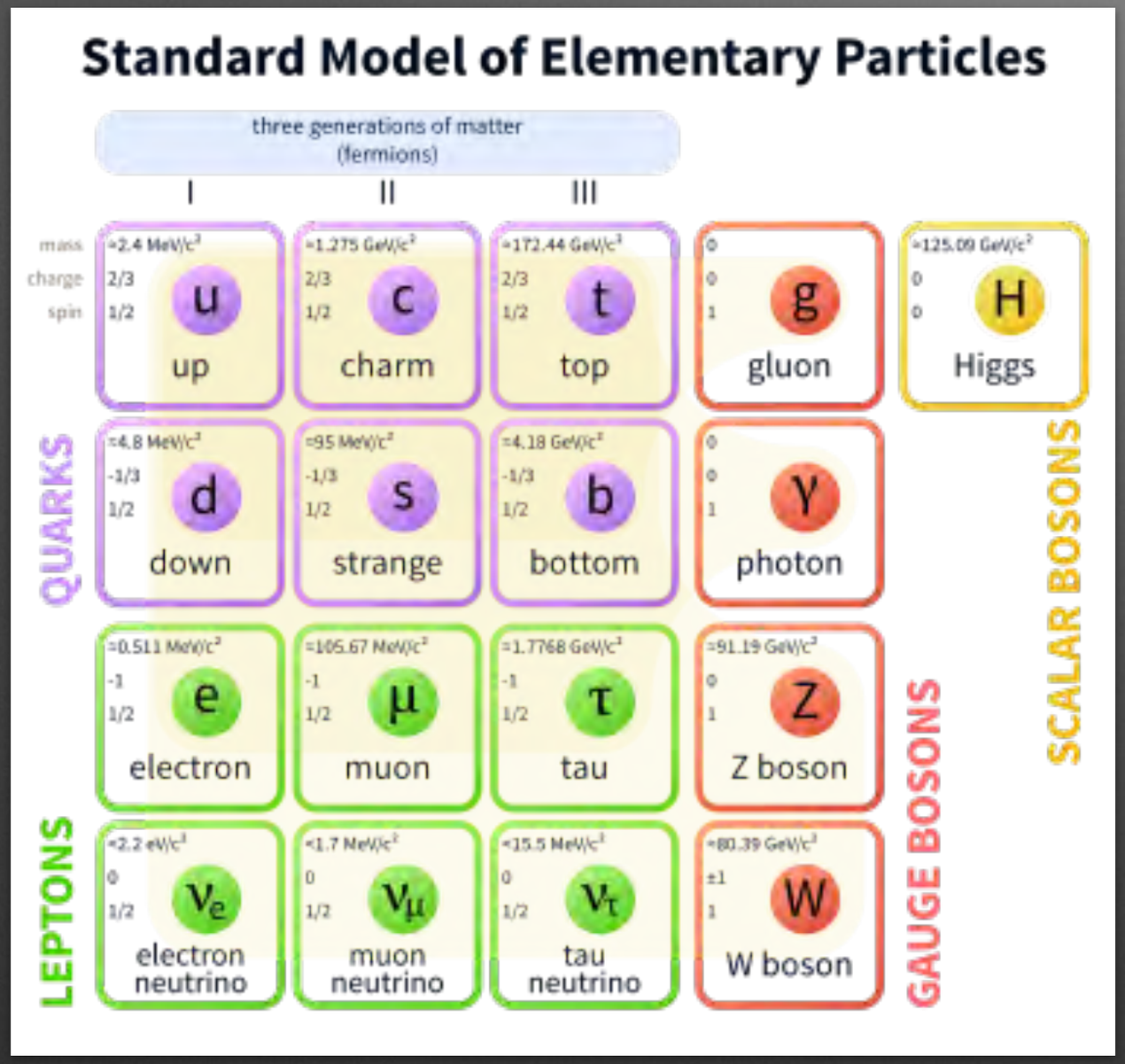
LZ and Direct Dark Matter Detection

Kimberly J. Palladino

May 1, 2018

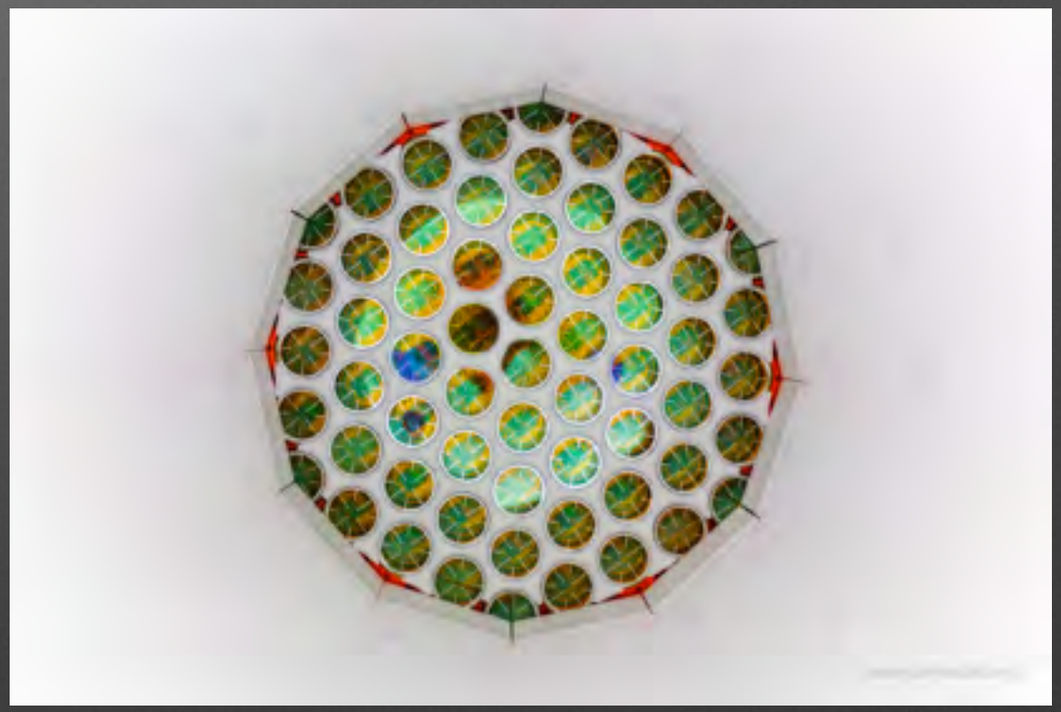
What is the universe made of?



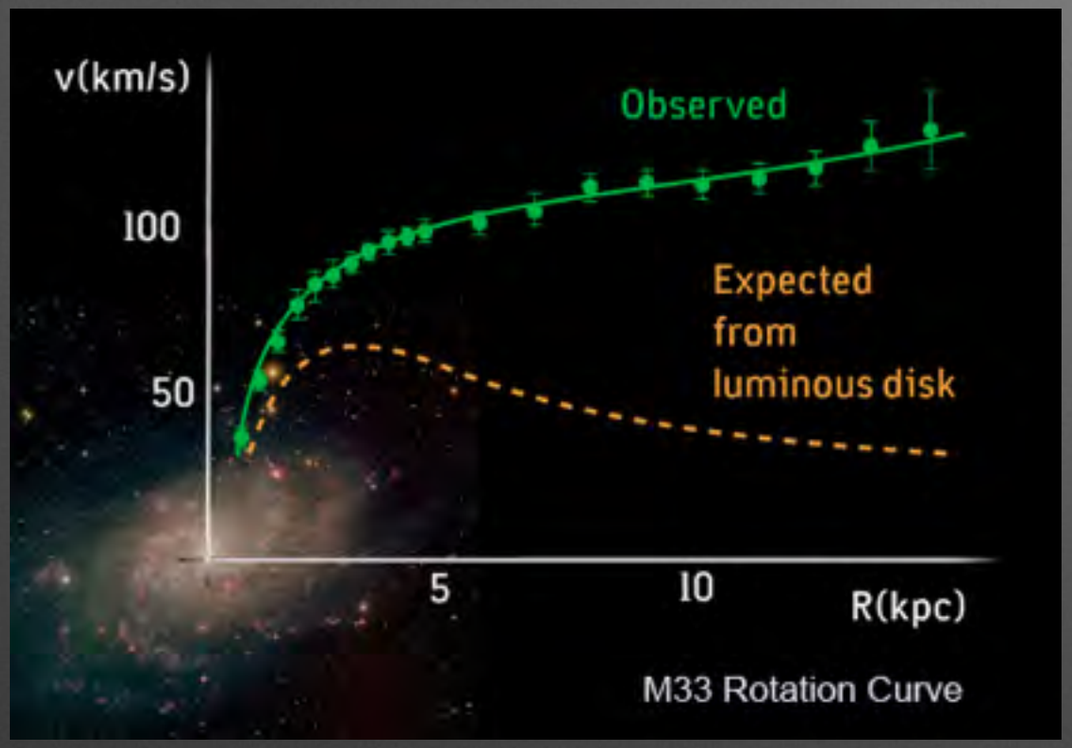
Reconciling what we measure on Earth with what we see in the cosmos

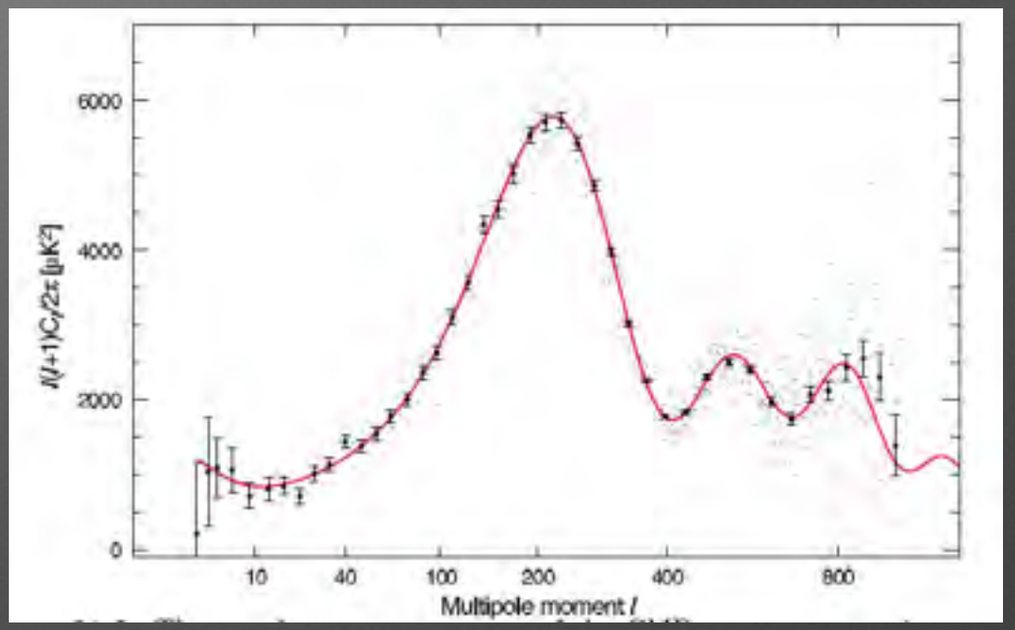
Outline

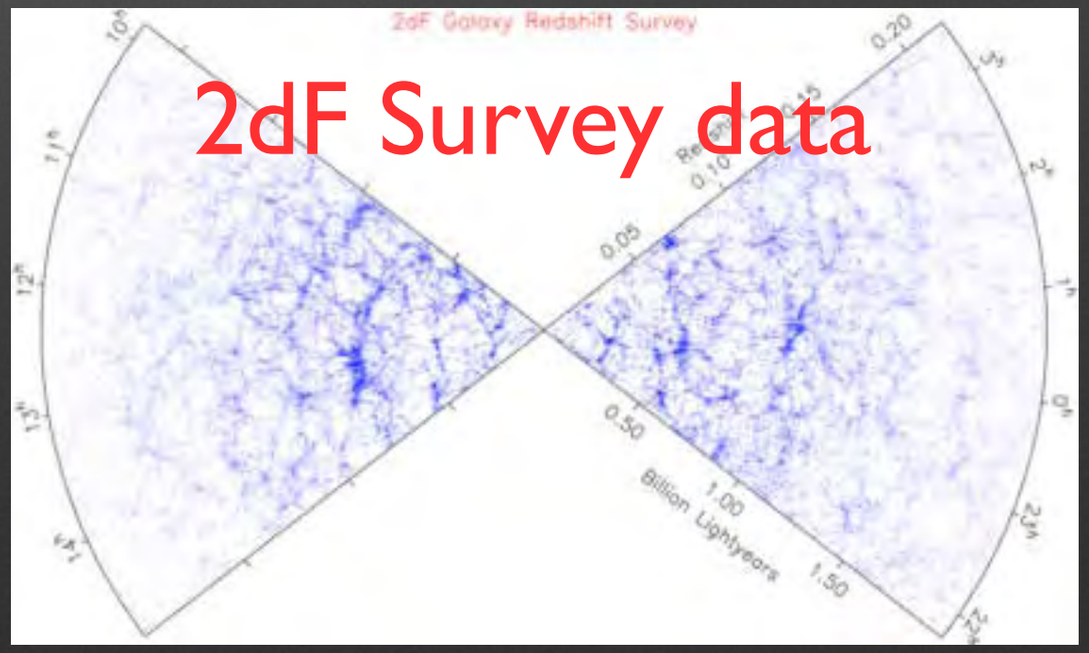
- Dark Matter Evidence and Models
- Direct Detection Overview
- Liquid Noble Detection
  - LUX Experiment
- LZ Experiment
  - What UW Madison does



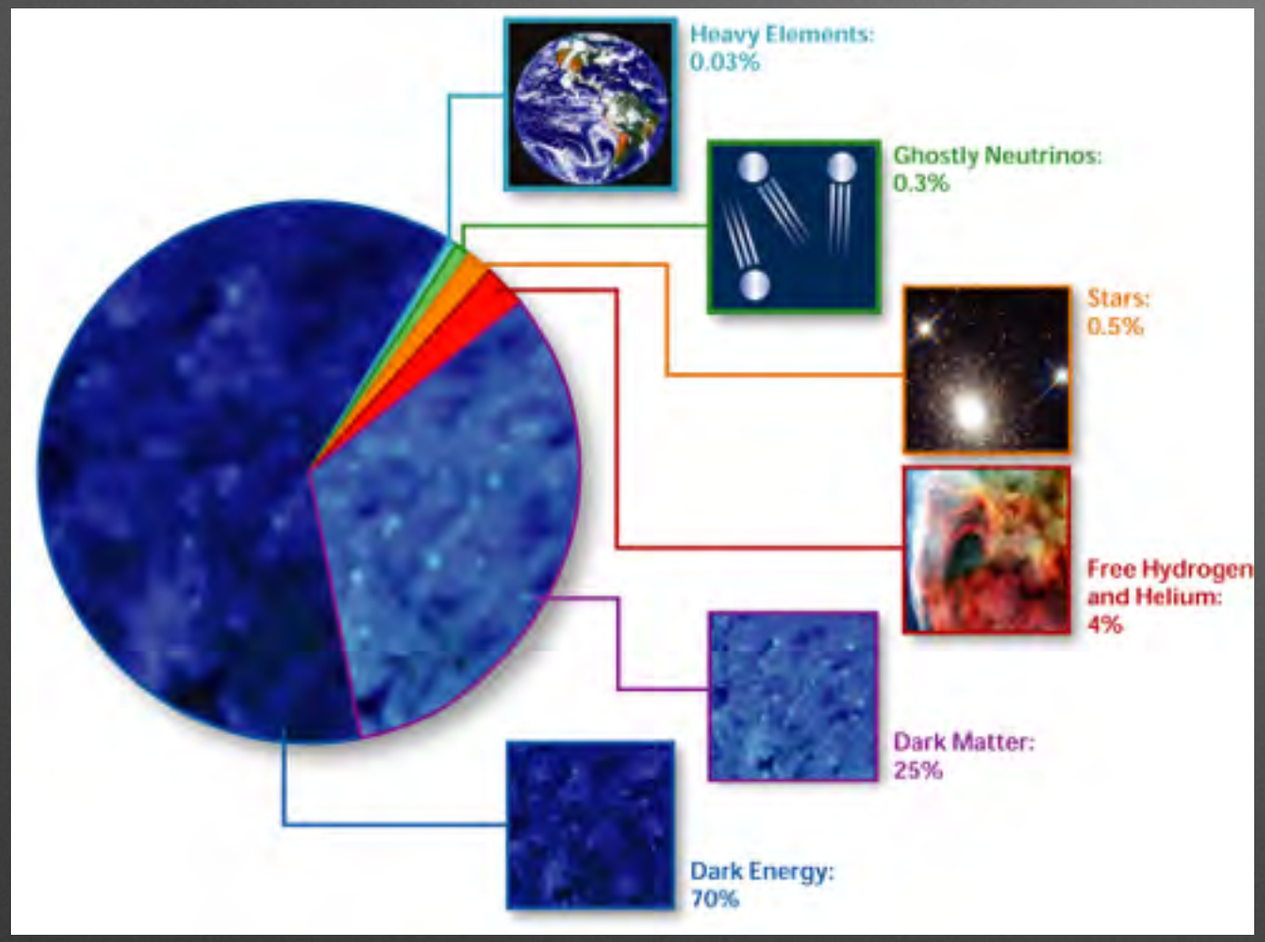
Standard evidence

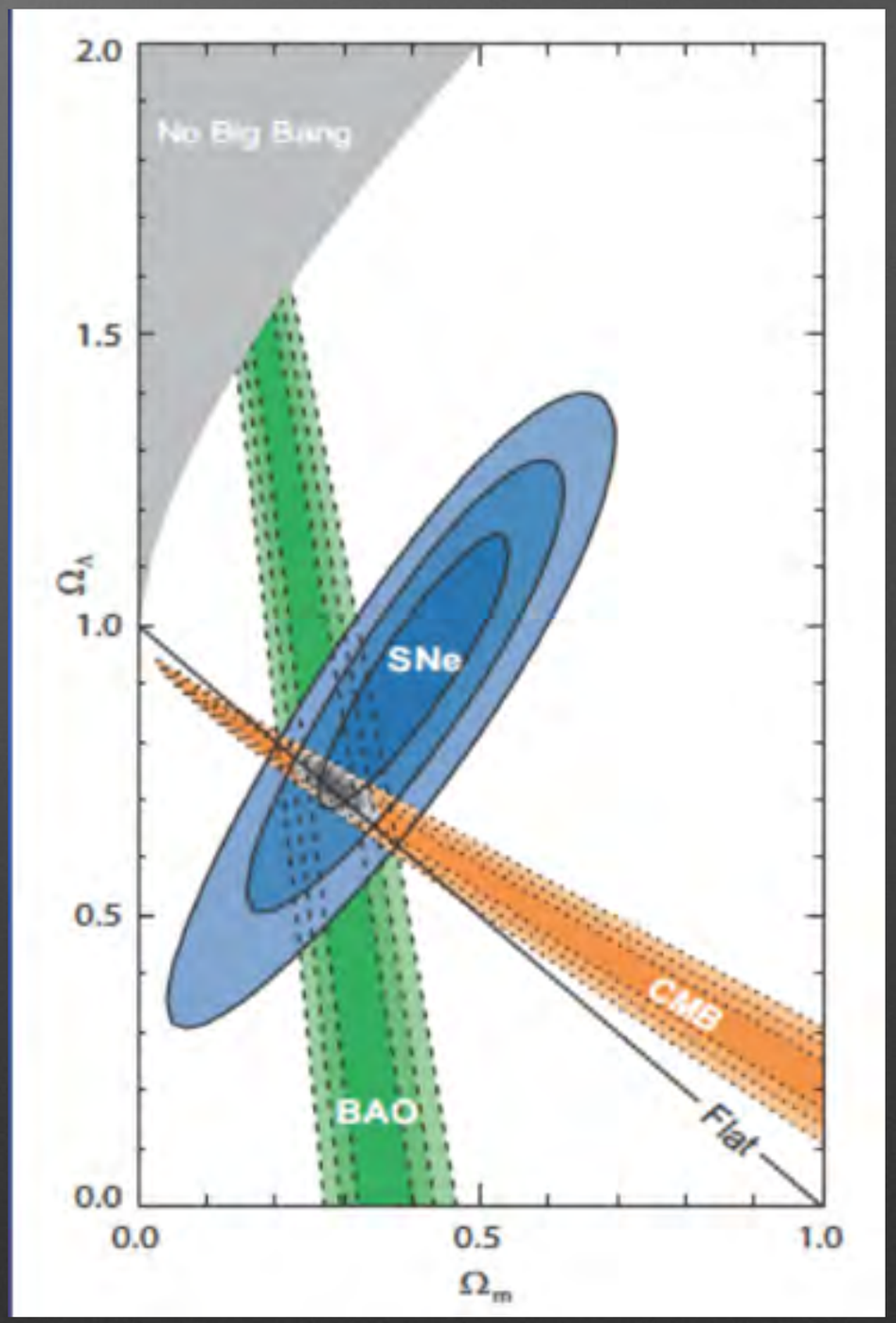






What We Know

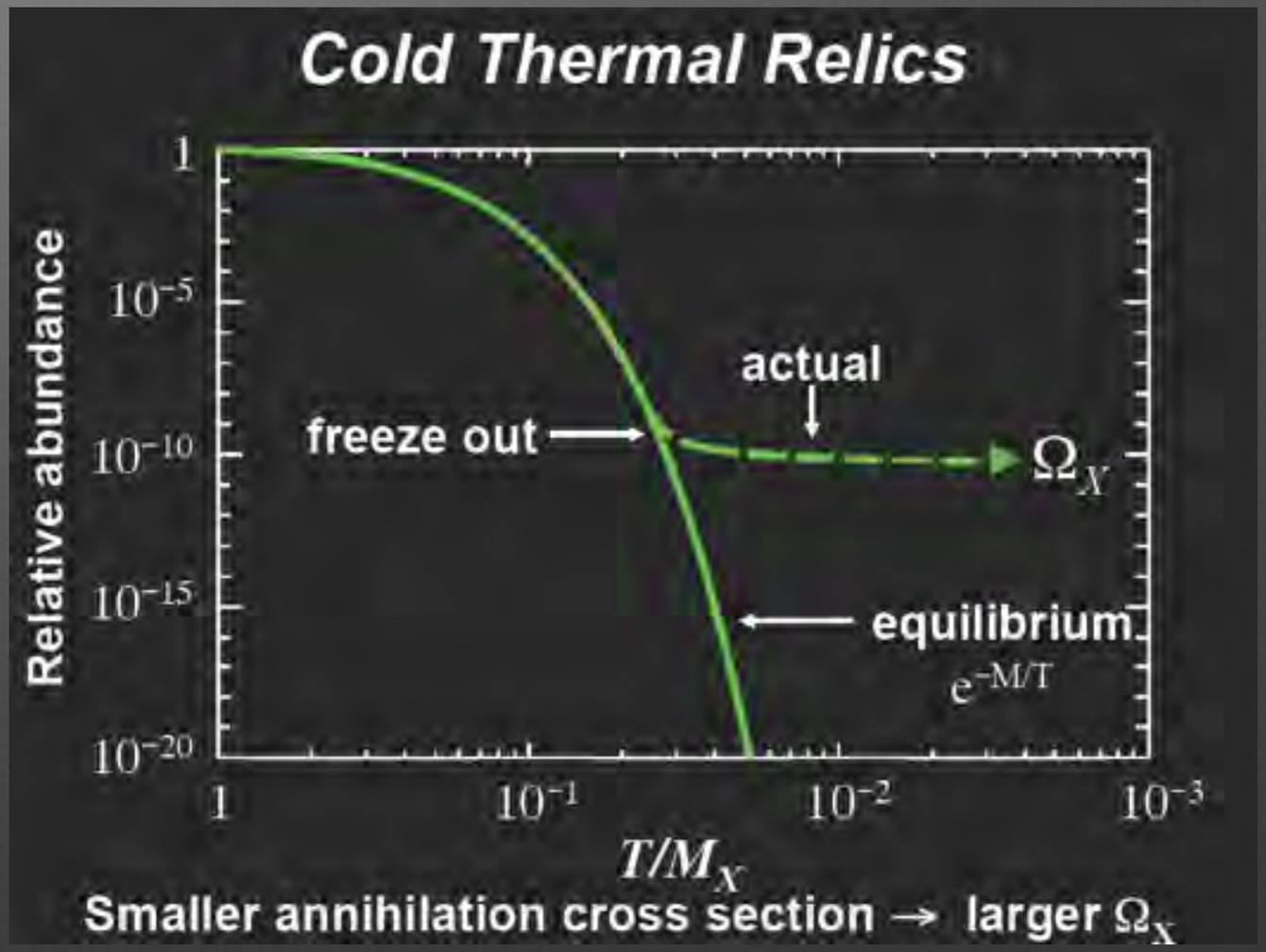




- Isotropy, homogeneity, flat universe, dark energy, cold dark matter, big bang, inflation
- Local Dark Matter density: 0.3 GeV/cm^3

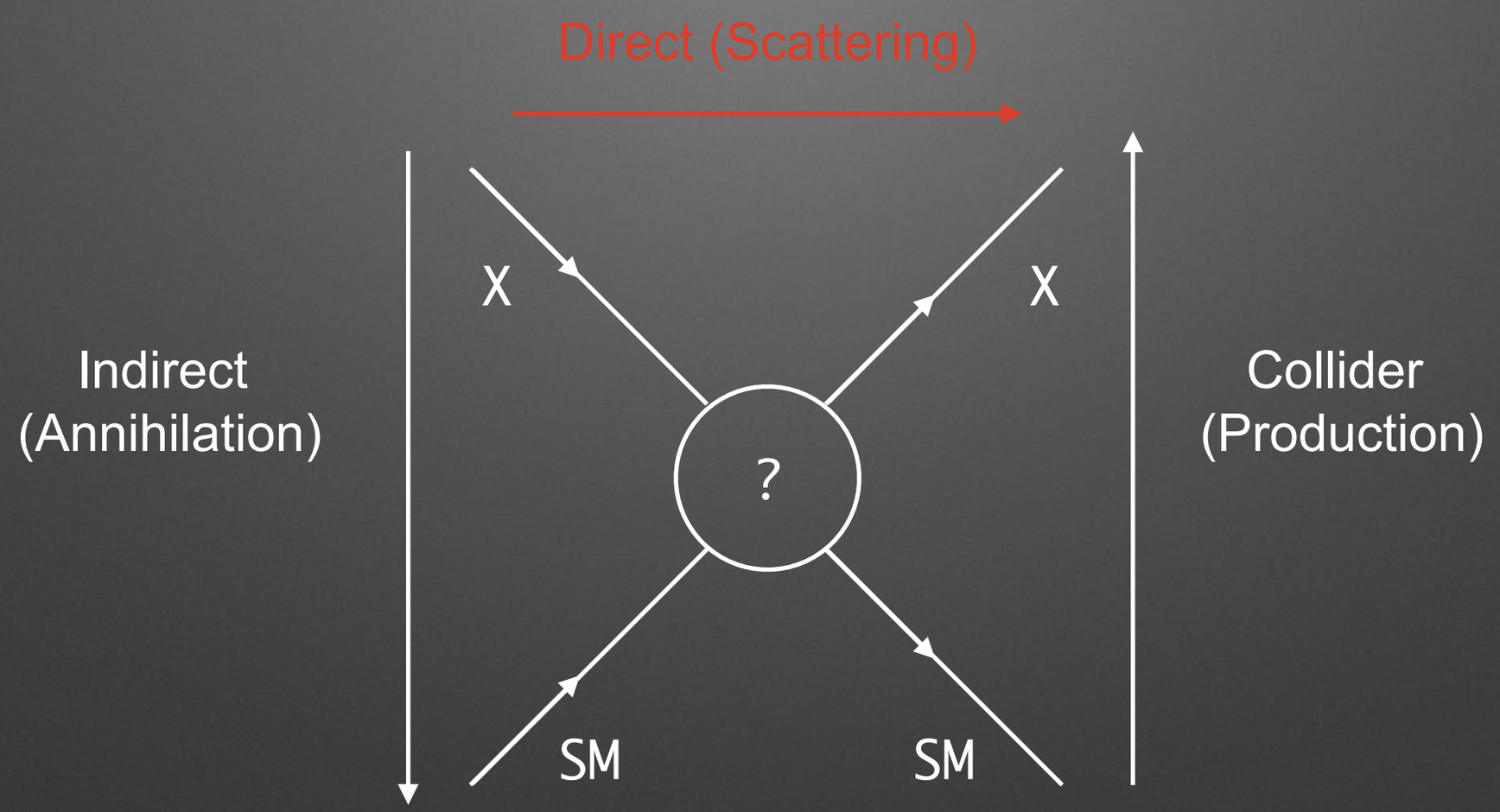
WIMPs

Particles with masses of ~100 GeV and interactions at the weak scale would give current dark matter density of .3 GeV/cm^3

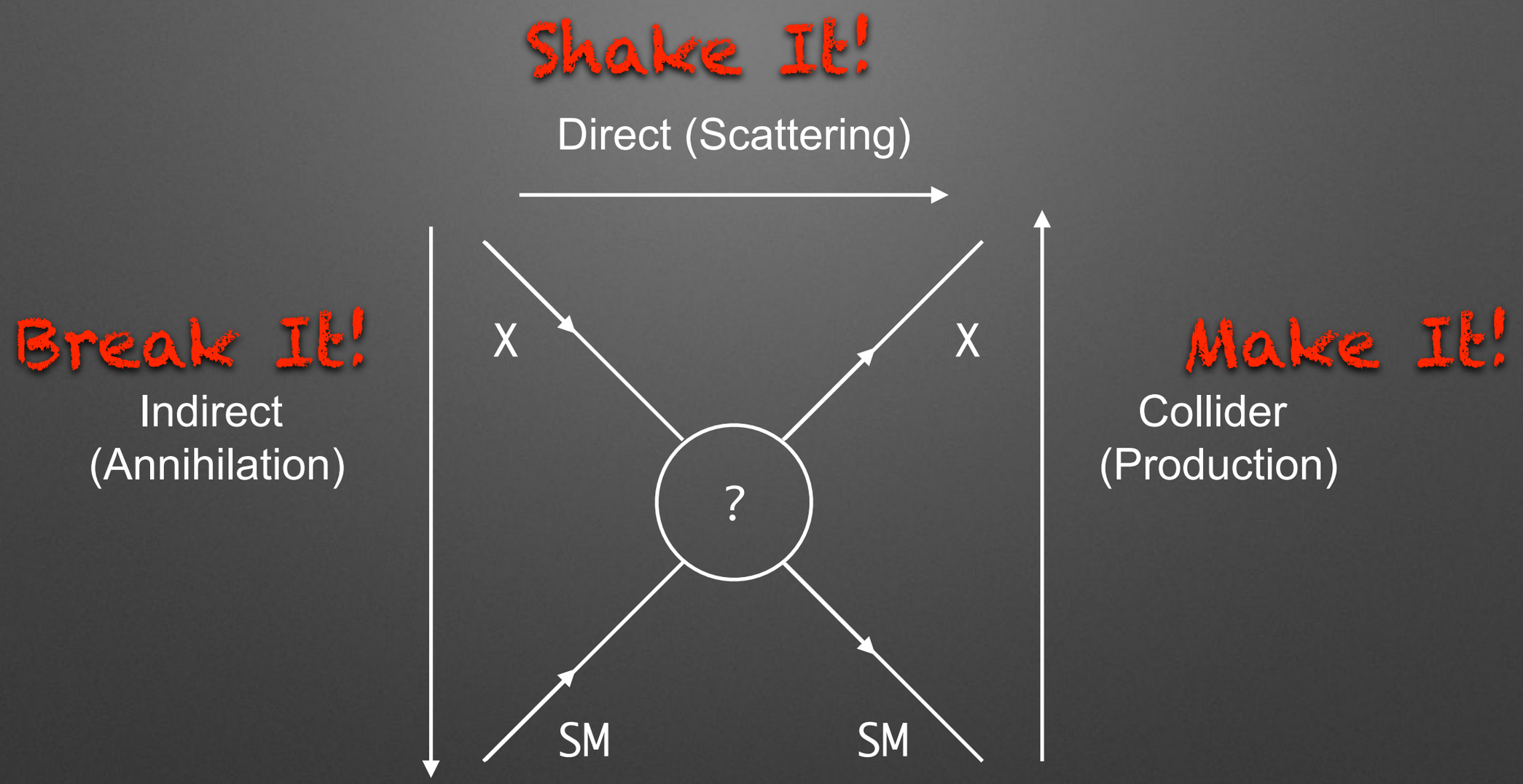


WIMPs fit naturally with SuSY: lightest neutralino, the LSP

Searching for WIMPs



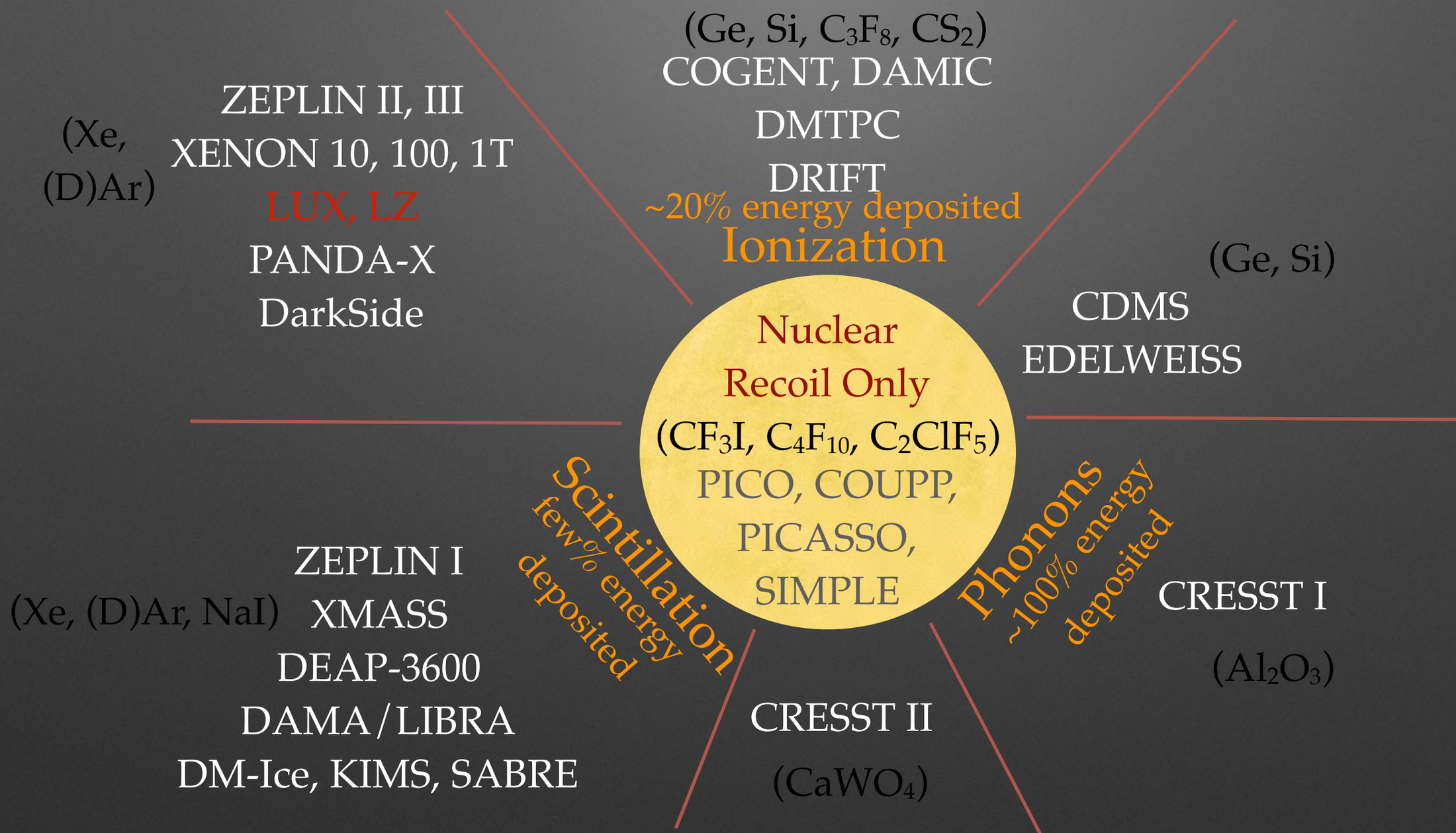
Searching for WIMPs



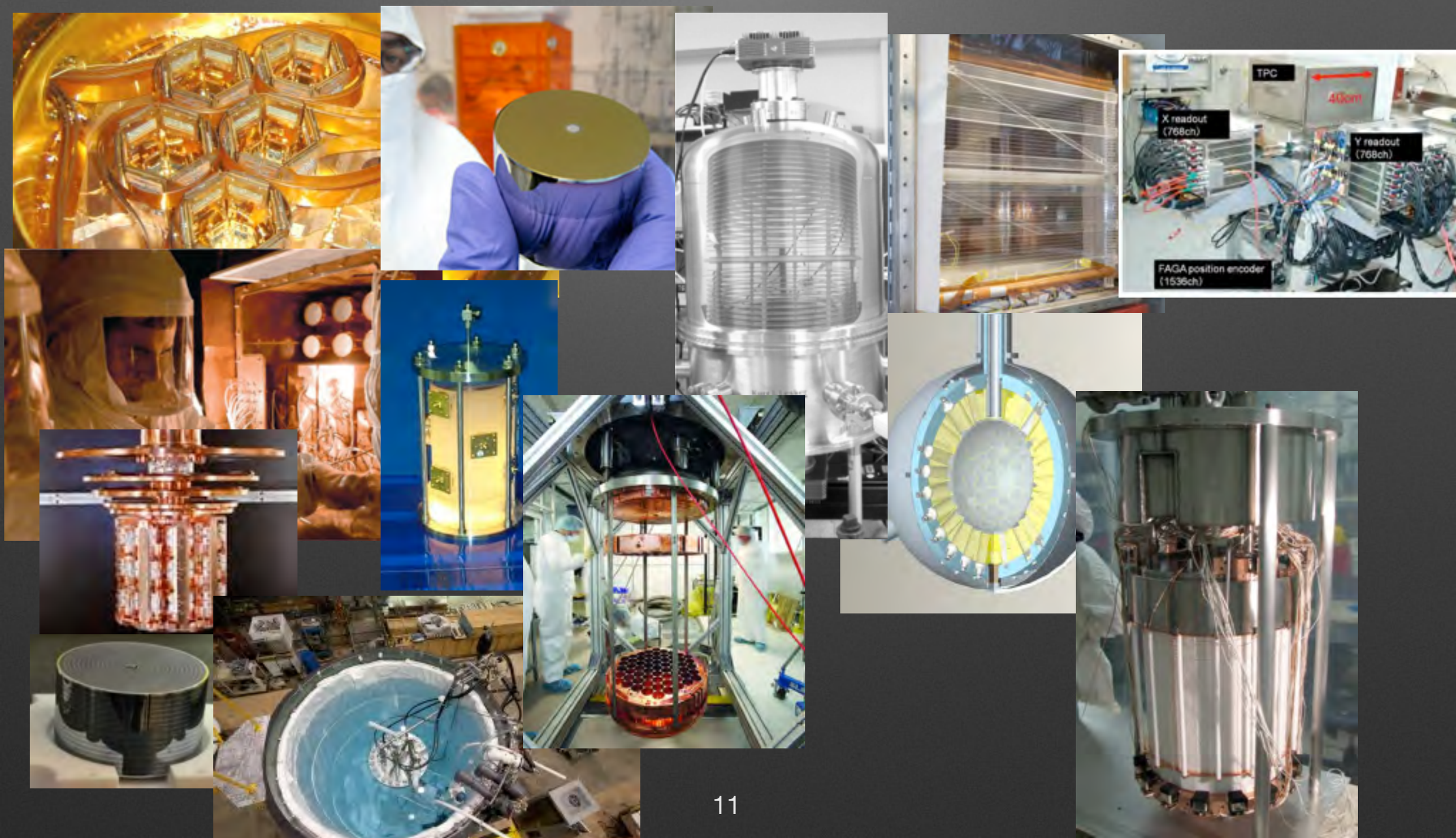
Direct Detection Needs

- Ability to see low energy WIMP induced recoils
  - Radiogenically pure
  - Low threshold (< 10s keV)
- Ability to distinguish nuclear recoils
  - Difference between electronic recoils & nuclear recoils
  - Difference between alphas and nuclear recoils
  - Position reconstruction and fiducialization
- Shielding from radiogenic and cosmogenic backgrounds

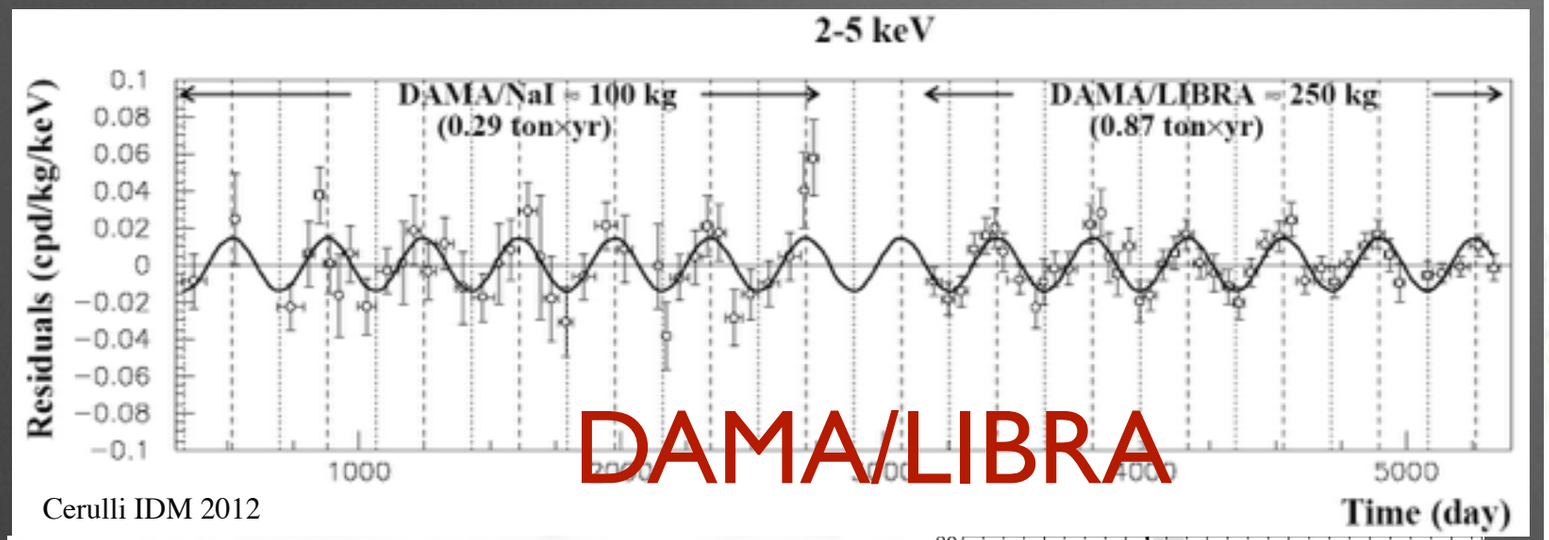
Searching for WIMPs



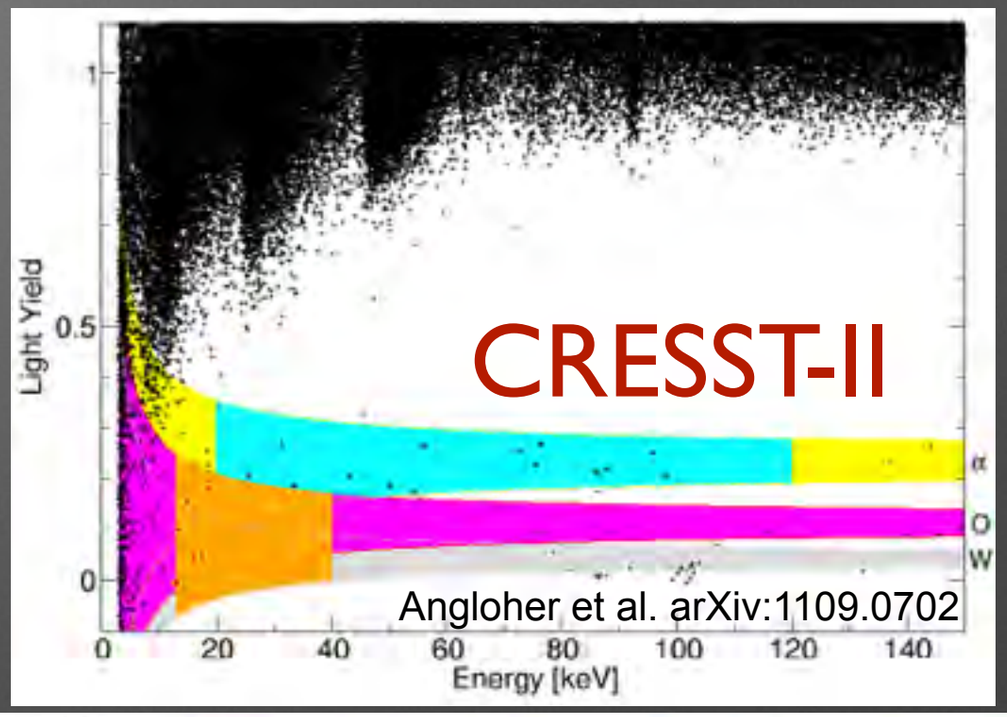
Direct Detection Techniques



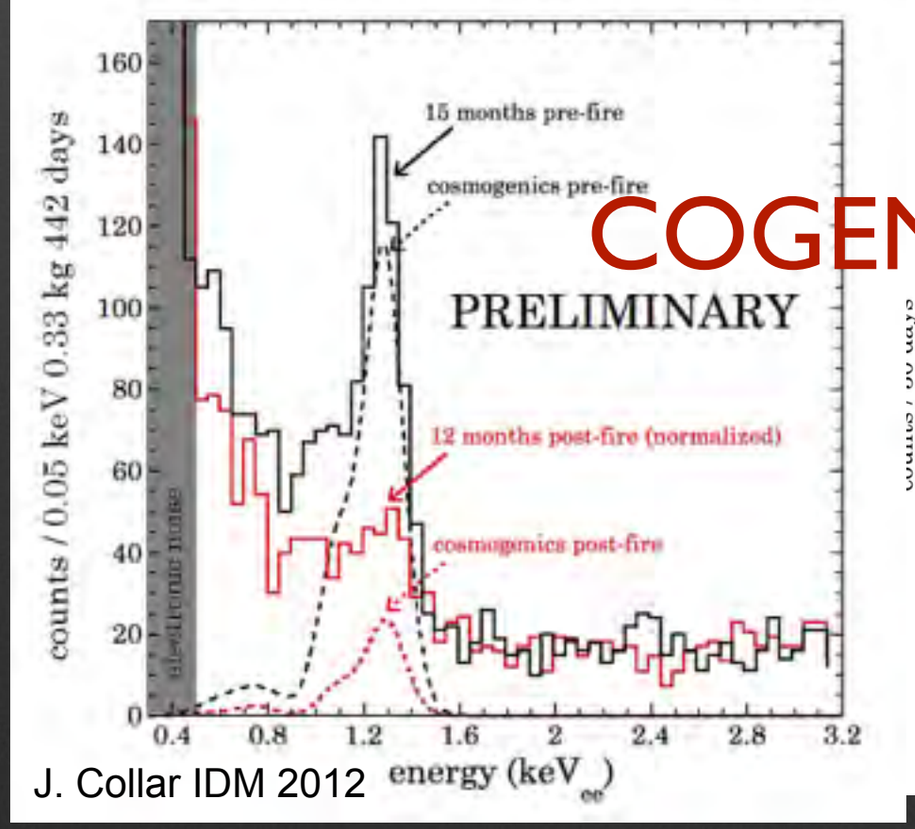
Direct Detection Signals?



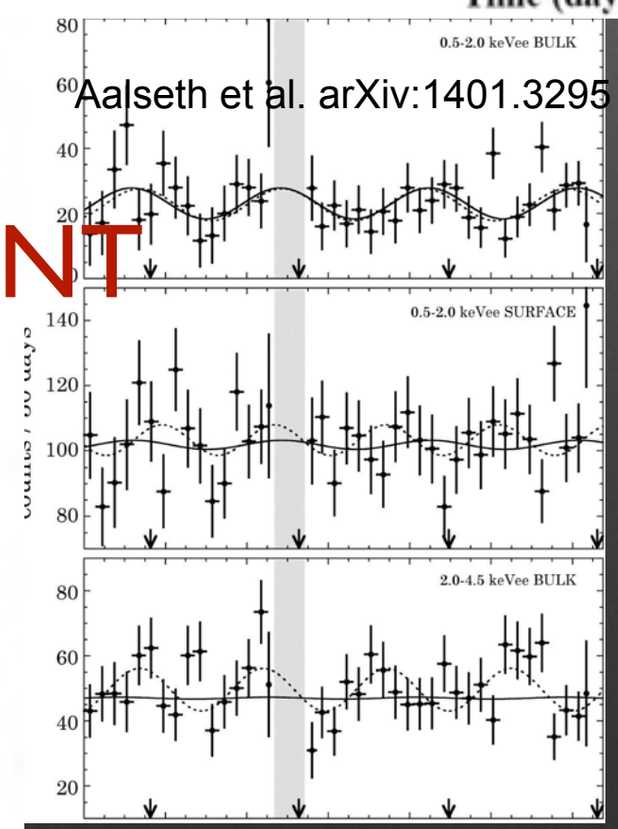
Cerulli IDM 2012



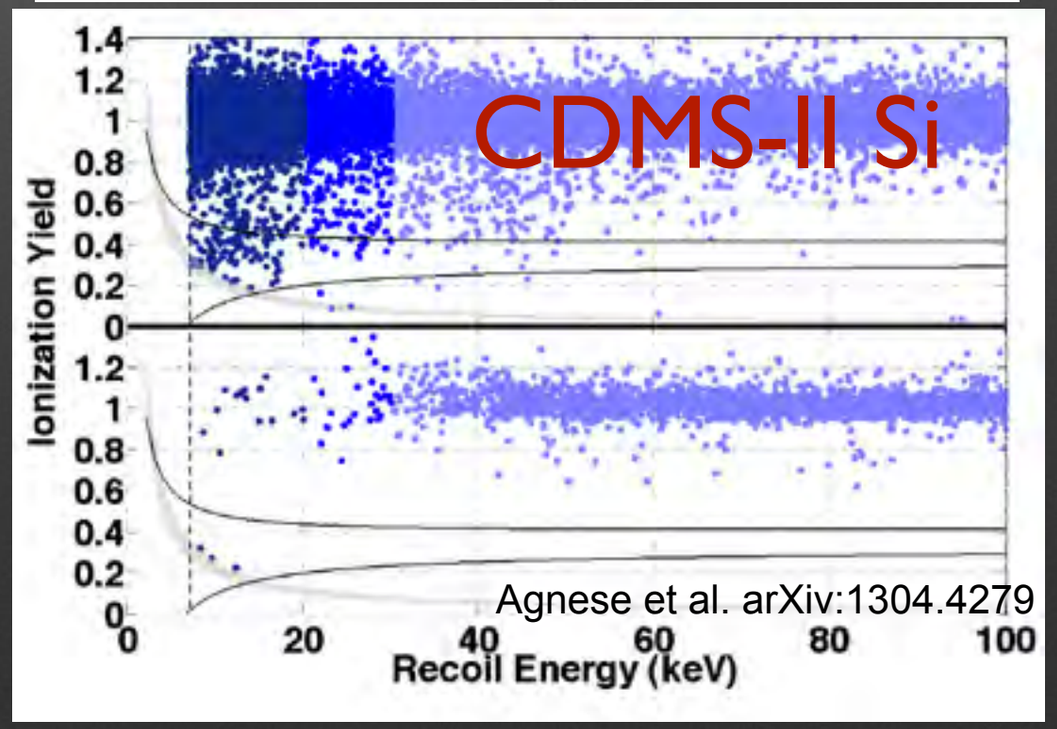
Angloher et al. arXiv:1109.0702



J. Collar IDM 2012

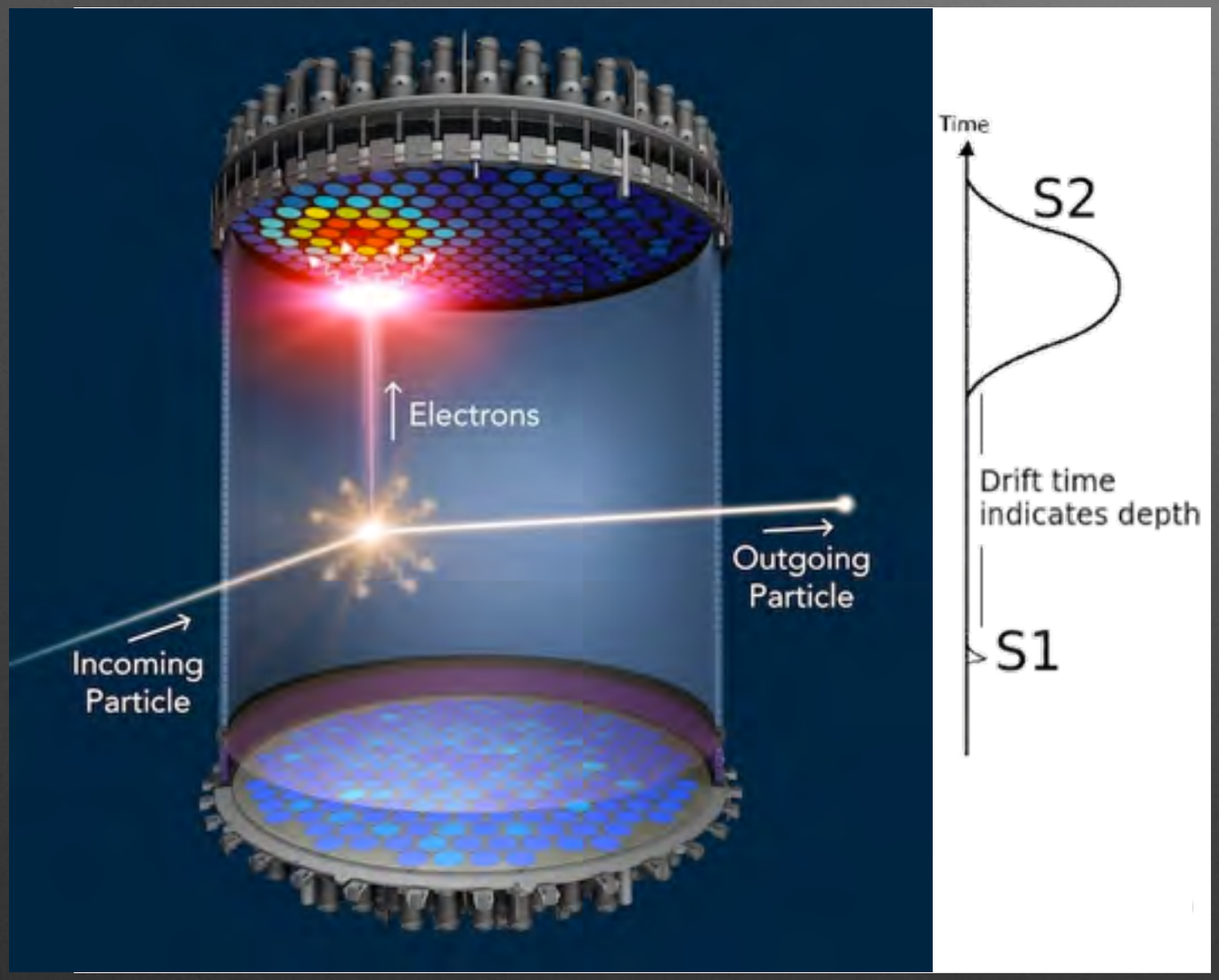


Aalseth et al. arXiv:1401.3295



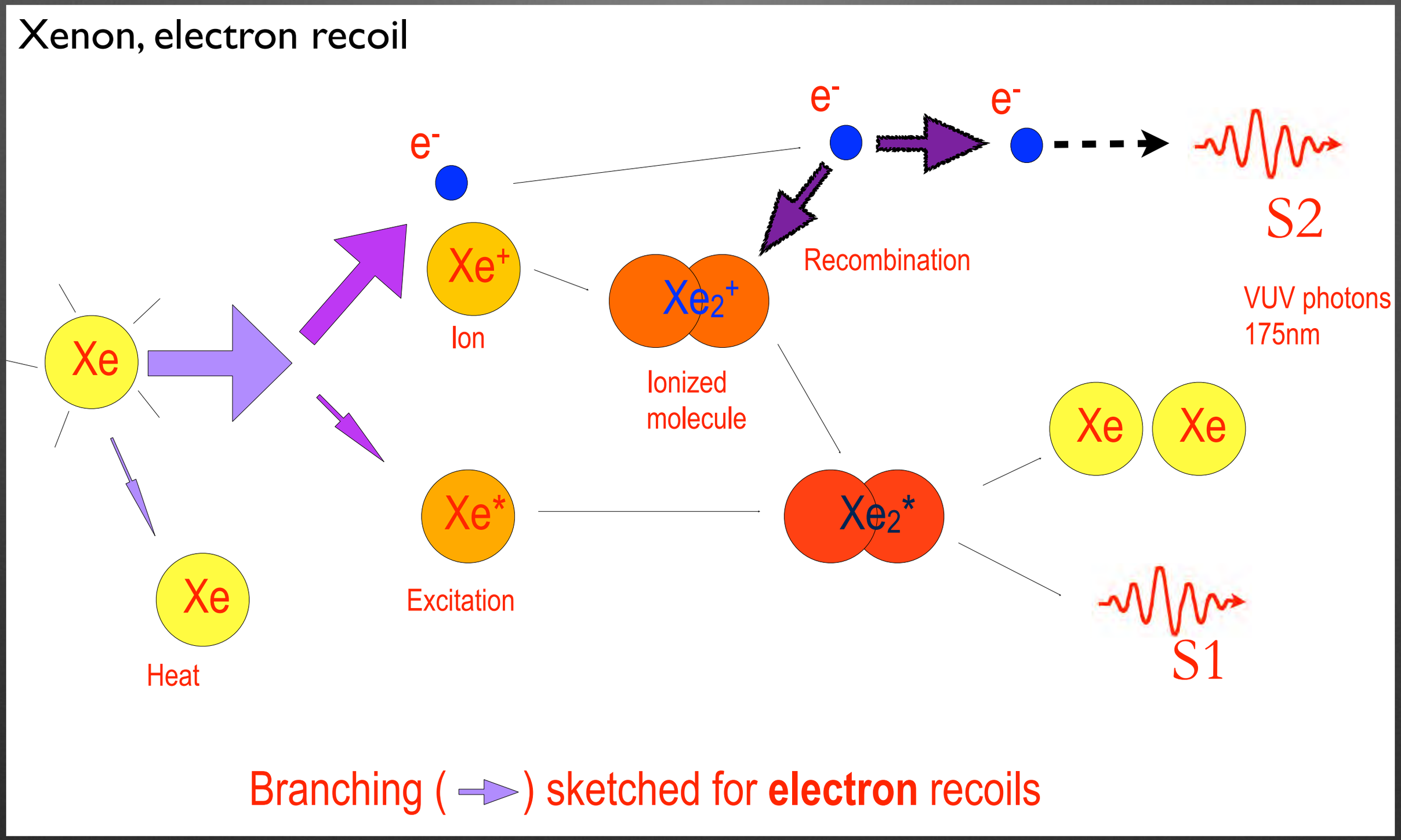
Agnese et al. arXiv:1304.4279

Liquid Xenon TPCs



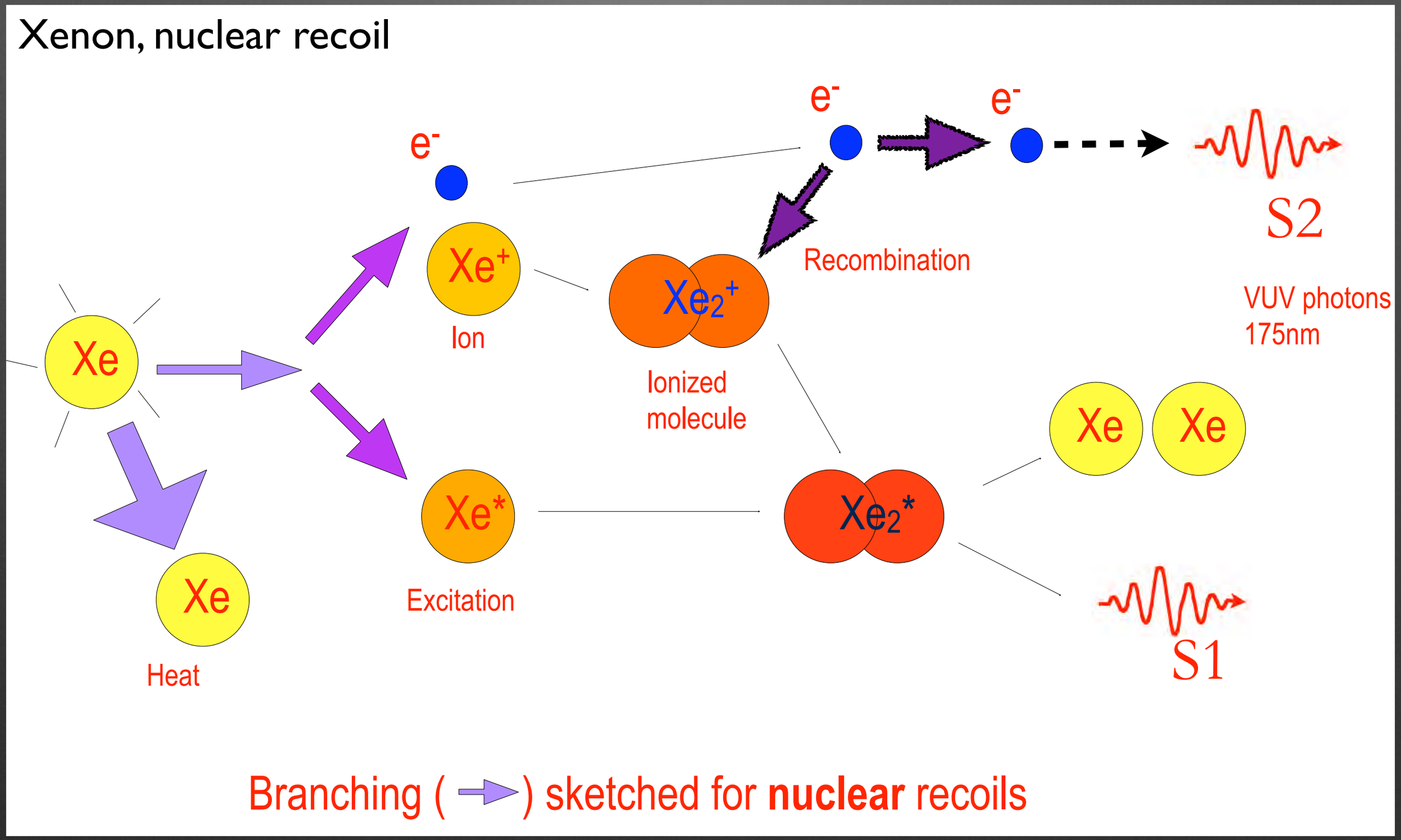
- Ionized and excited states
- Primary Scintillation (S1) with some recombination and de-excitation in the liquid
- Ions drift in TPC electric field
- Amplification region in gas creates proportional light (S2)
- S2/S1 provides particle ID
- Events are hundreds of microseconds (set by electron drift velocity)
- Strong position reconstruction

Xenon: Electron Recoil



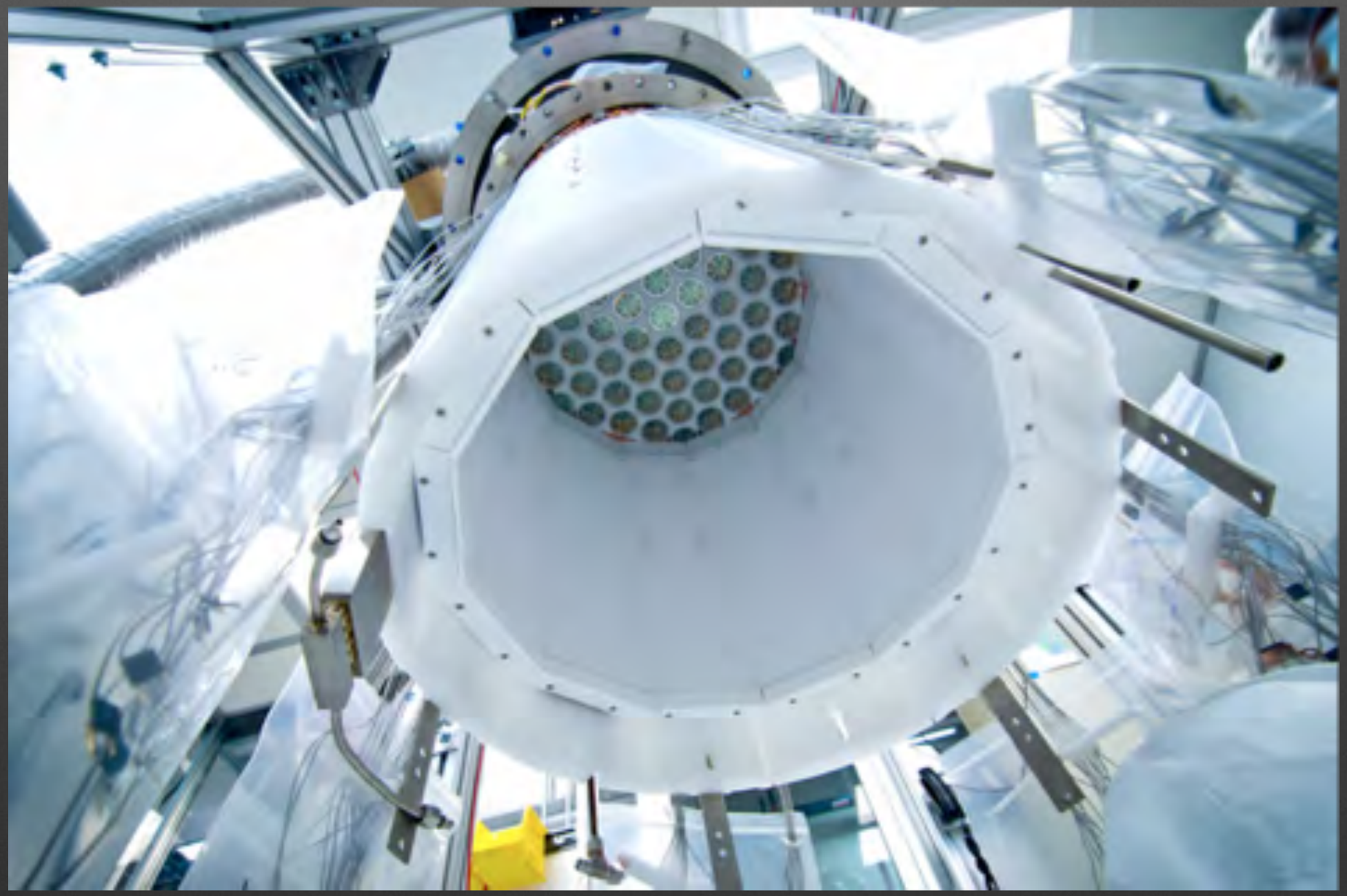
cartoons from Akerib and Shutt

Xenon: Nuclear Recoil

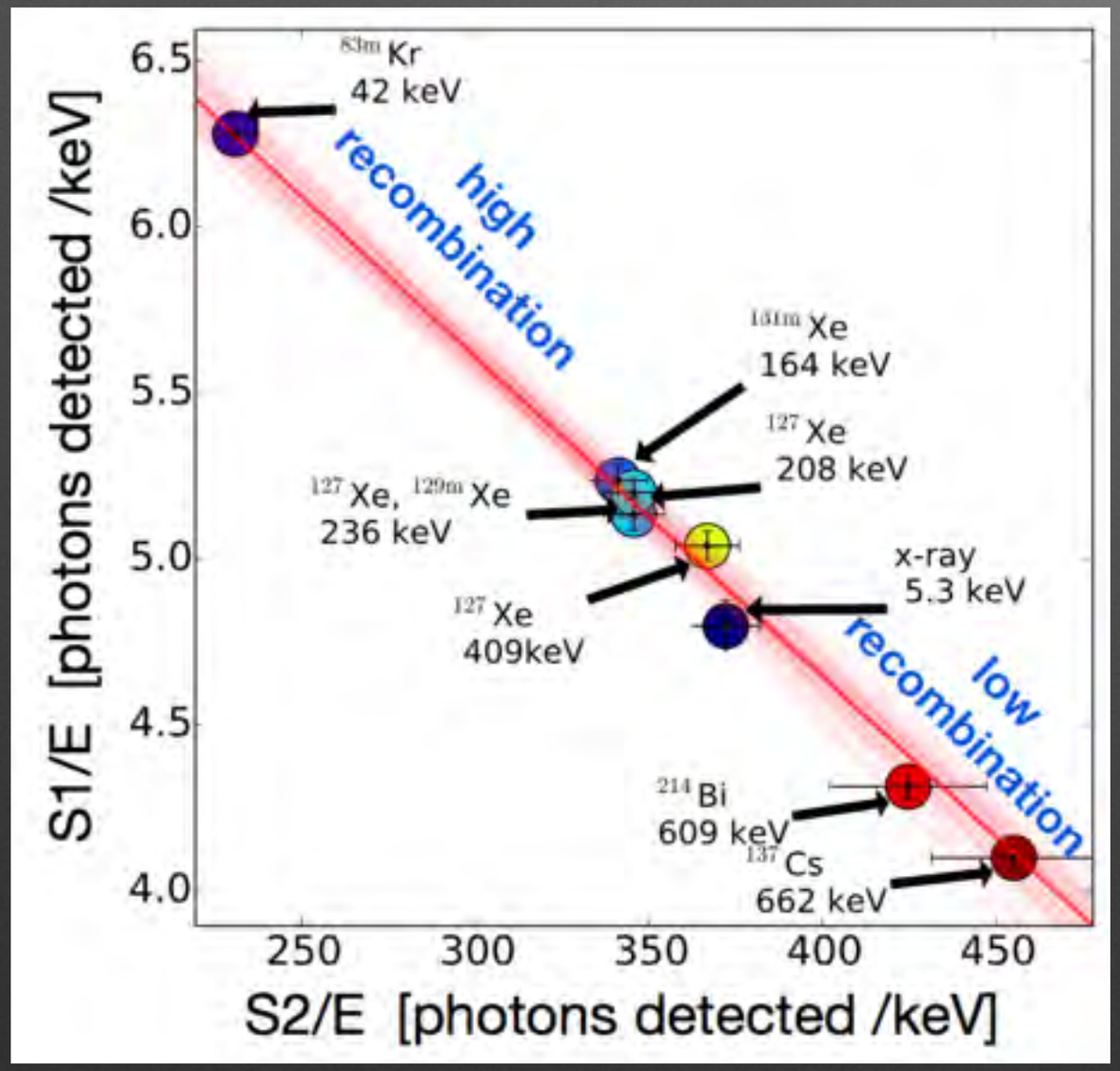


cartoons from Akerib and Shutt

LUX results



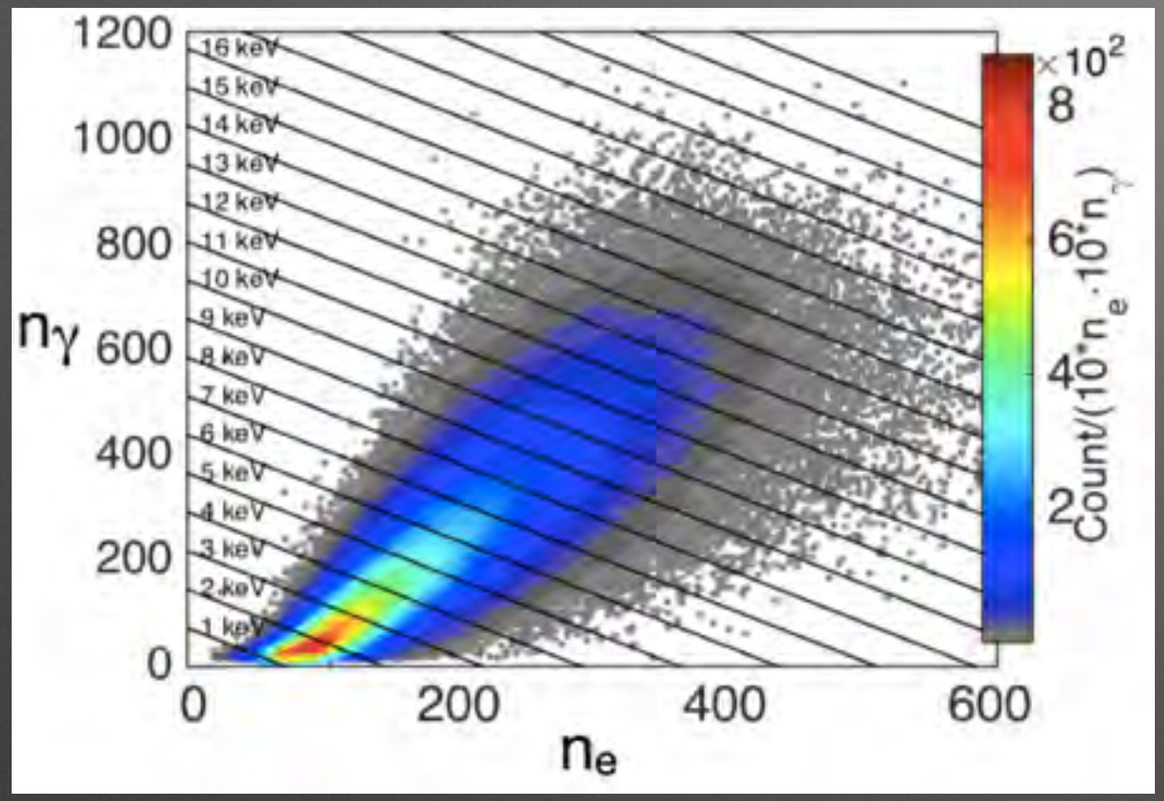
Energy Calibration: Doke Plot

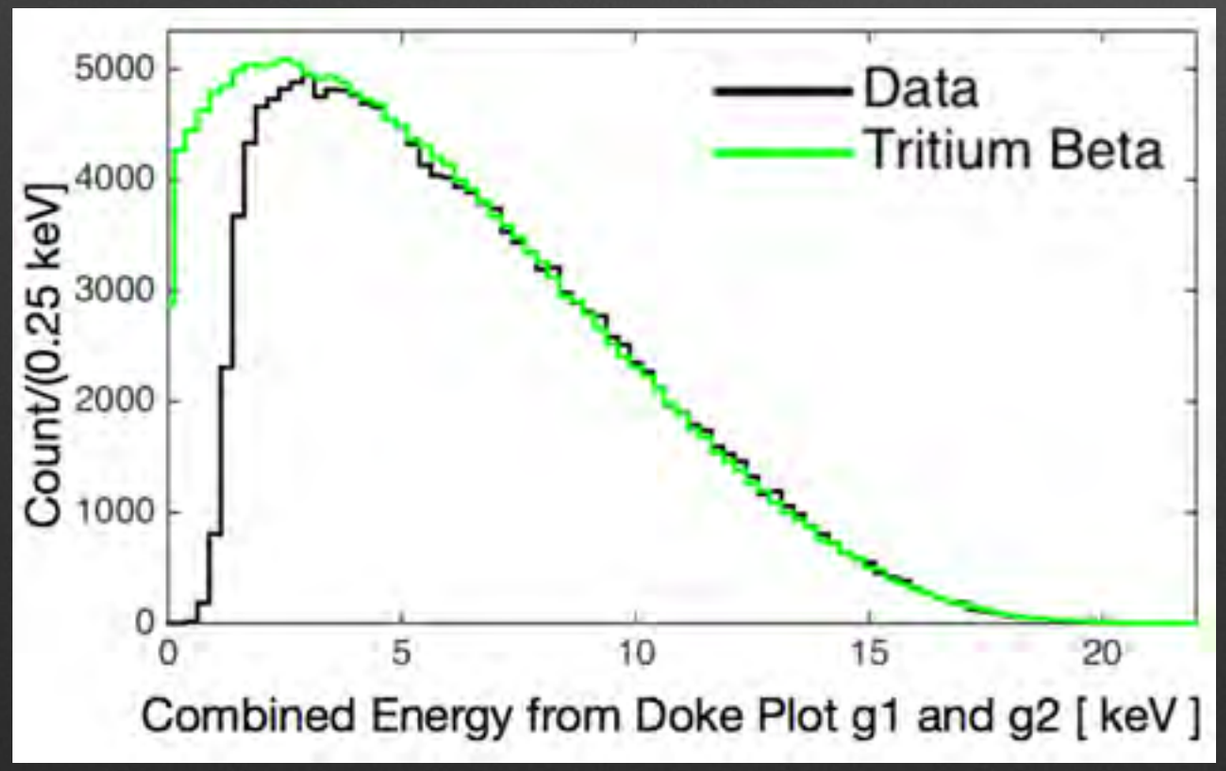


- Electron recoils with energy dependent varying recombination
- Total quanta remain, W=13.7 eV

$$\langle S1 \rangle \text{ [phd]} = [0.1167 \pm 0.003]\ n_\gamma$$
$$\langle S2 \rangle \text{ [phd]} = [12.05 \pm 0.83\ ]\ n_e$$

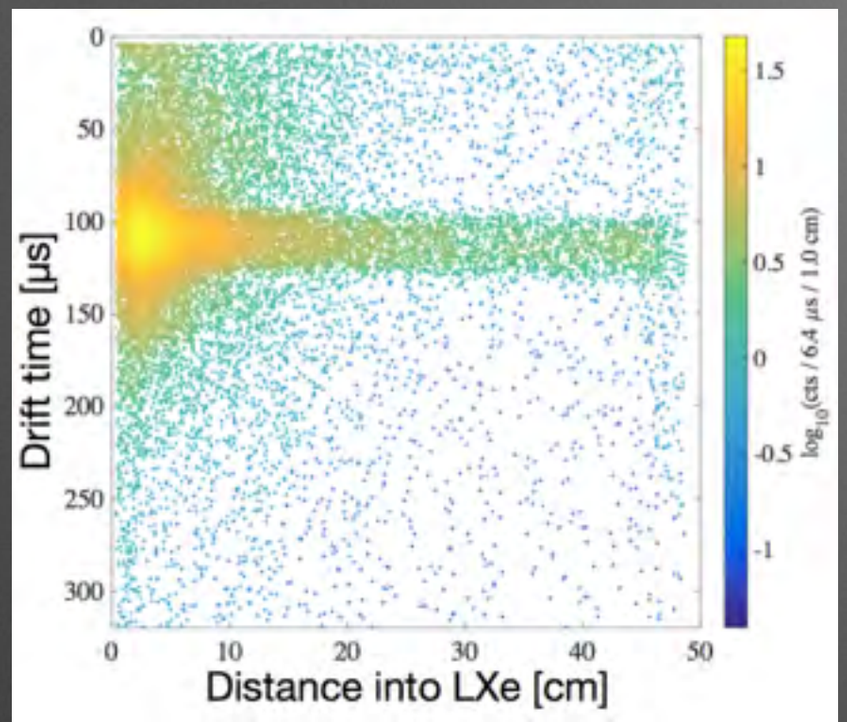
Electronic Recoils

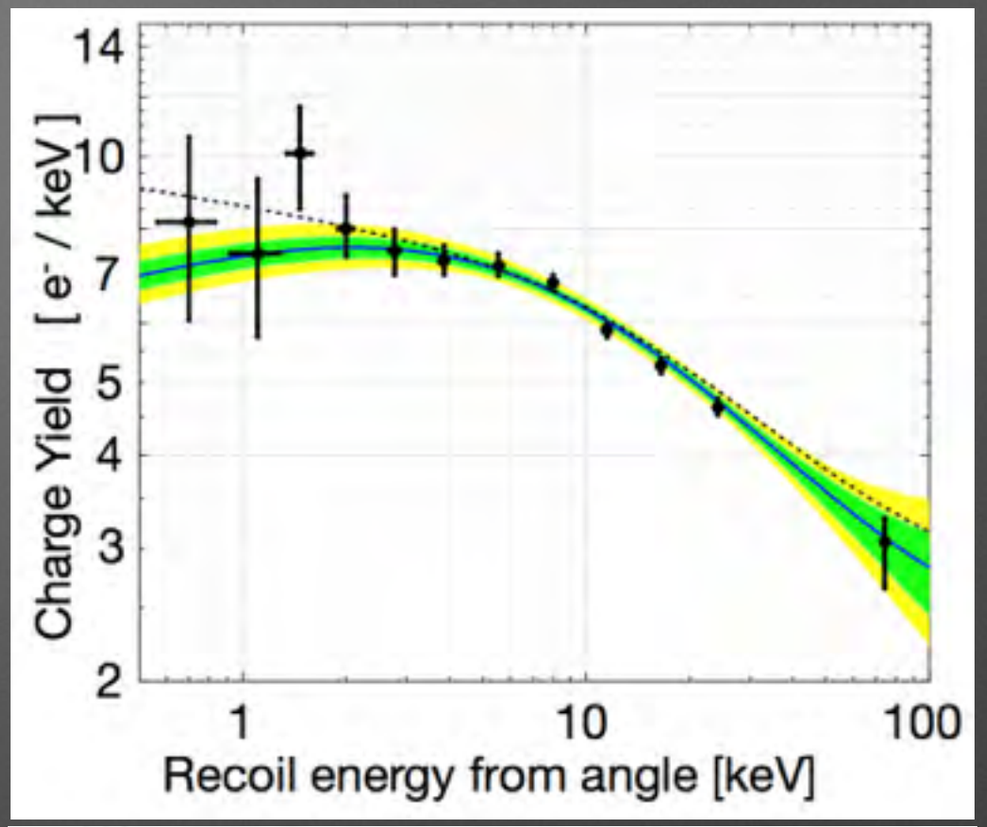


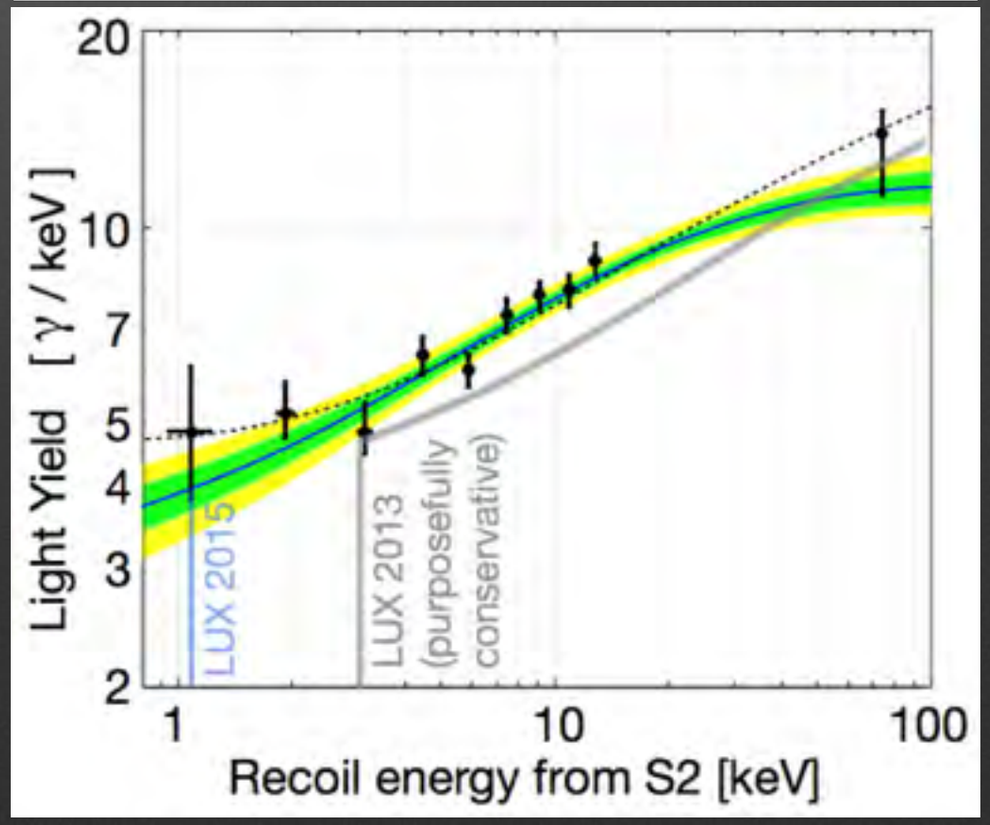


- Inject gas source of tritiated methane
- Tritium populates the background model
- Utilizes energy scale from the Doke plot

Nuclear Recoils

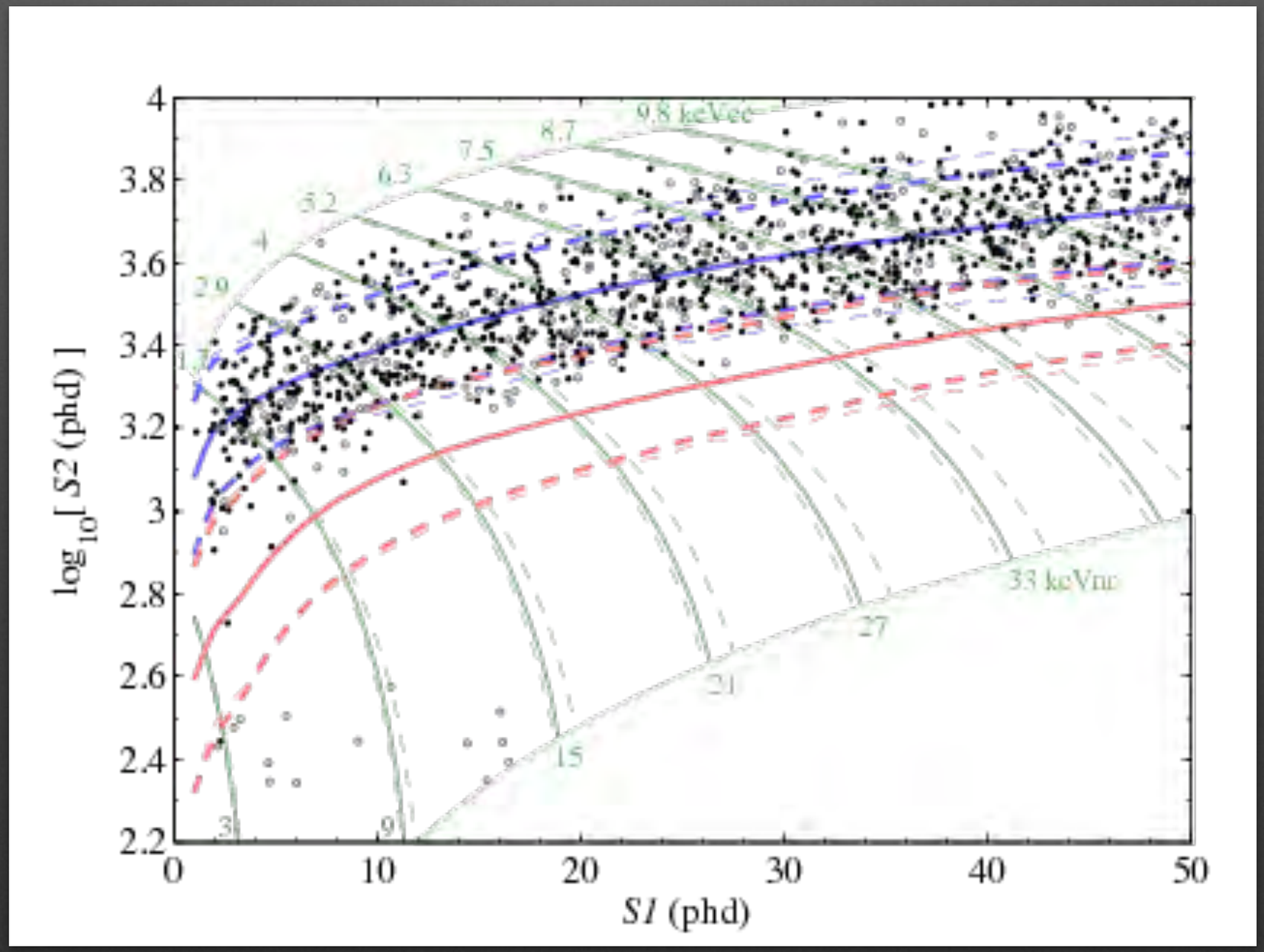




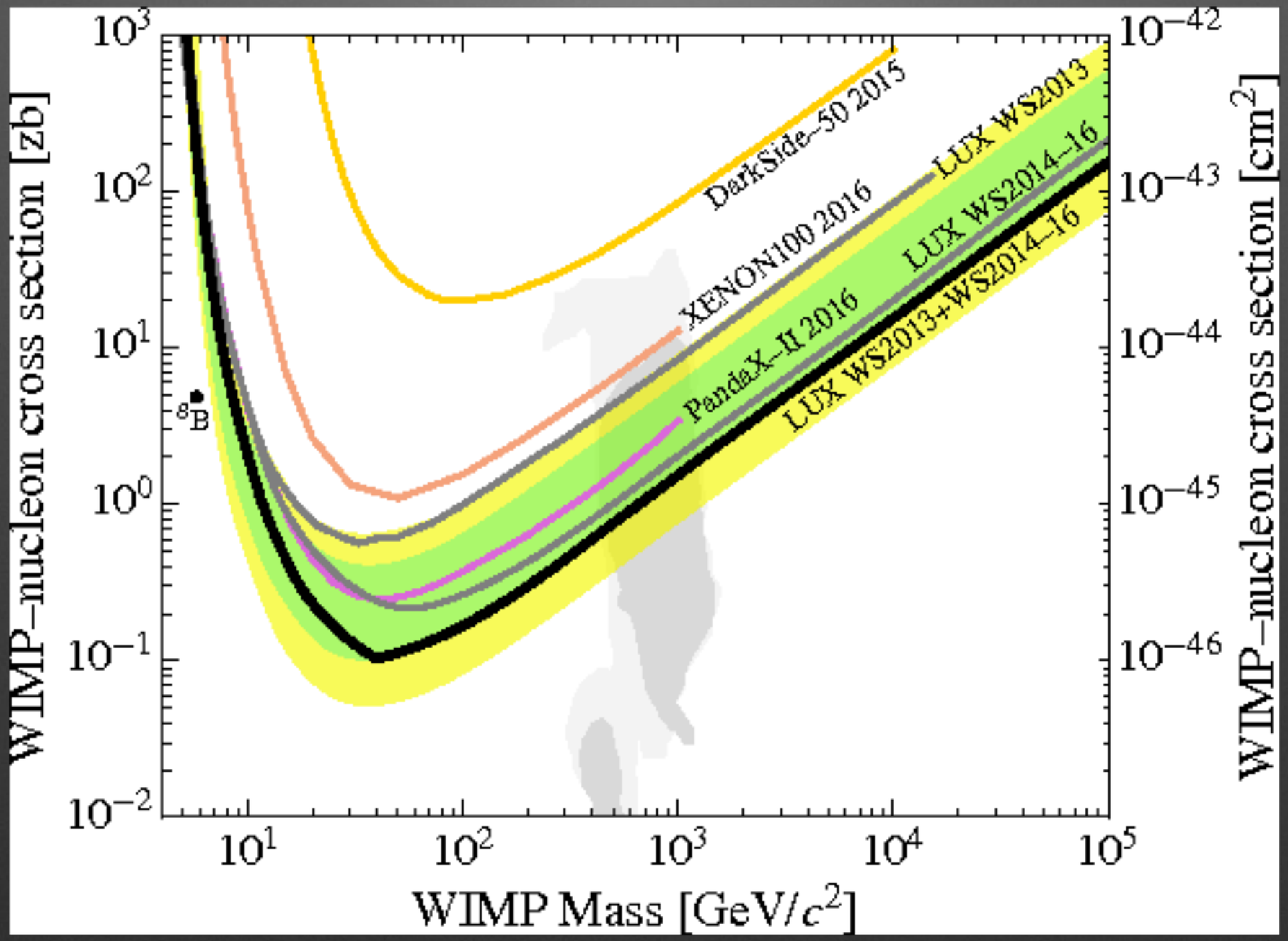


- Mono energetic D-D Neutron beam (2.45 MeV)
- Double scatters kinematically give energy of first scatter for charge yield
- Single scatters studied for light yield

Events


4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
0
10
20
30
40
50
$\log_{10}[S2$ (phd)]
$S1$ (phd)
9.8 keVee
8.7
7.5
6.3
5.2
4
2.9
1.7
33 keVnr
27
21
15
9
3

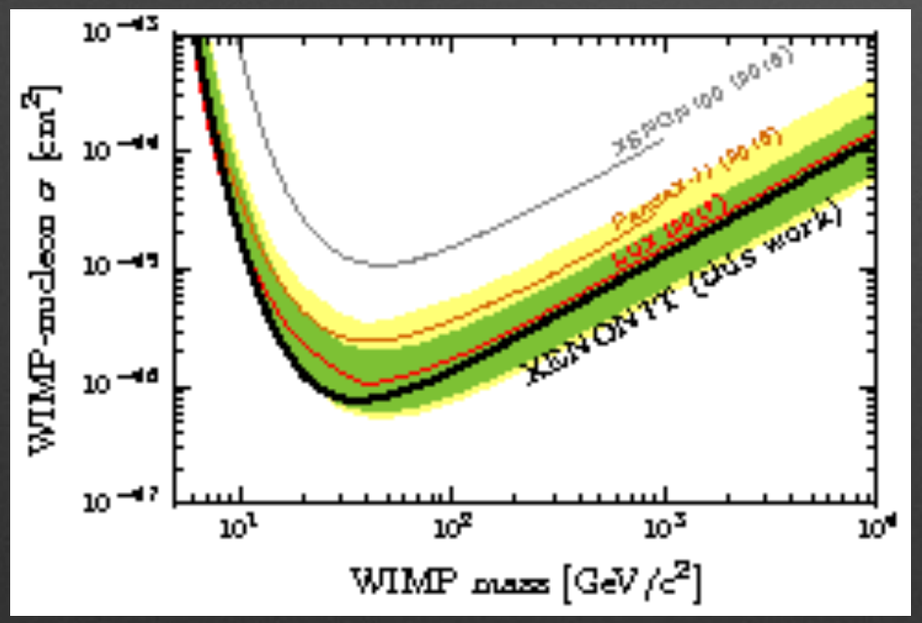
Spin Independent Result



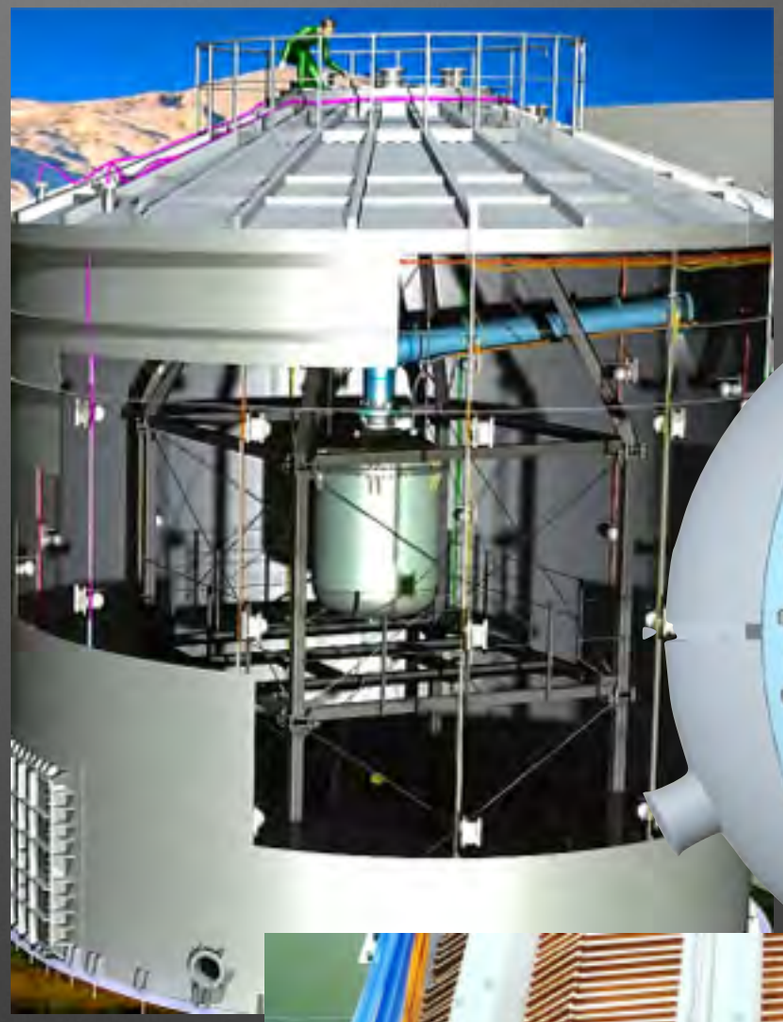
From Summer 2017

Null results from:

DEAP-3600, PandaX-II, XENON1T



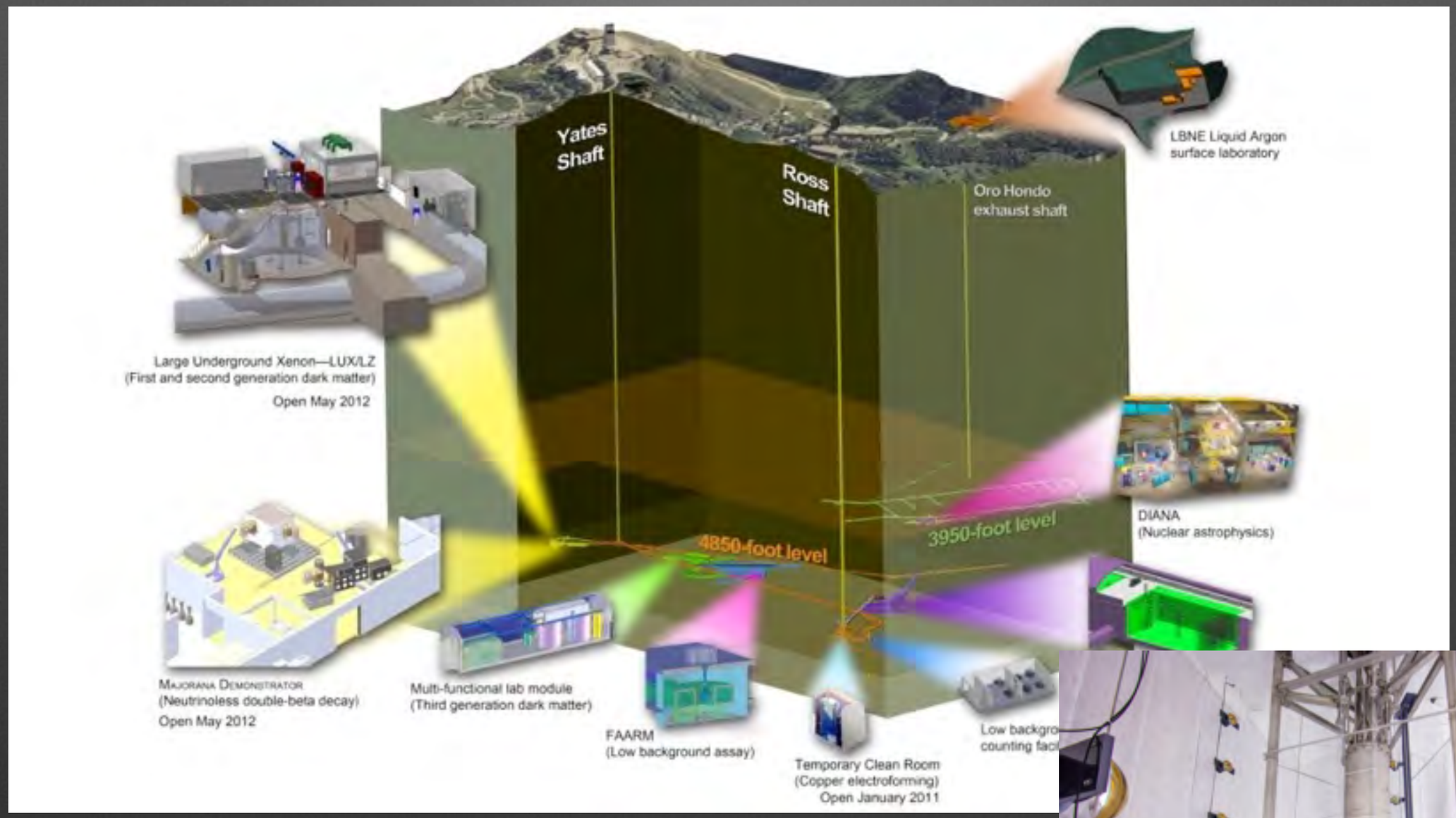
Phys.Rev.Lett. 119 (2017) no.18, 181301



Direct Detection Coming of Age

- Mature computing framework and simulations
  - Including evaluation of simulation tools
- Benchmarking fundamentals
  - Reflectivity, scattering and absorption lengths
- Developing designs and procedures
  - Cleanliness, materials handling
- Detector reliability and automation
- Likelihood analyses
- Full operator treatment of interactions

LUX to LZ


Yates Shaft
Ross Shaft
Oro Hondo exhaust shaft
LBNE Liquid Argon surface laboratory
Large Underground Xenon—LUX/LZ
(First and second generation dark matter)
Open May 2012
4850-foot level
3950-foot level
DIANA
(Nuclear astrophysics)
Majorana Demonstrator
(Neutrinoless double-beta decay)
Open May 2012
Multi-functional lab module
(Third generation dark matter)
FAARM
(Low background assay)
Temporary Clean Room
(Copper electroforming)
Open January 2011

LZ @ SURF

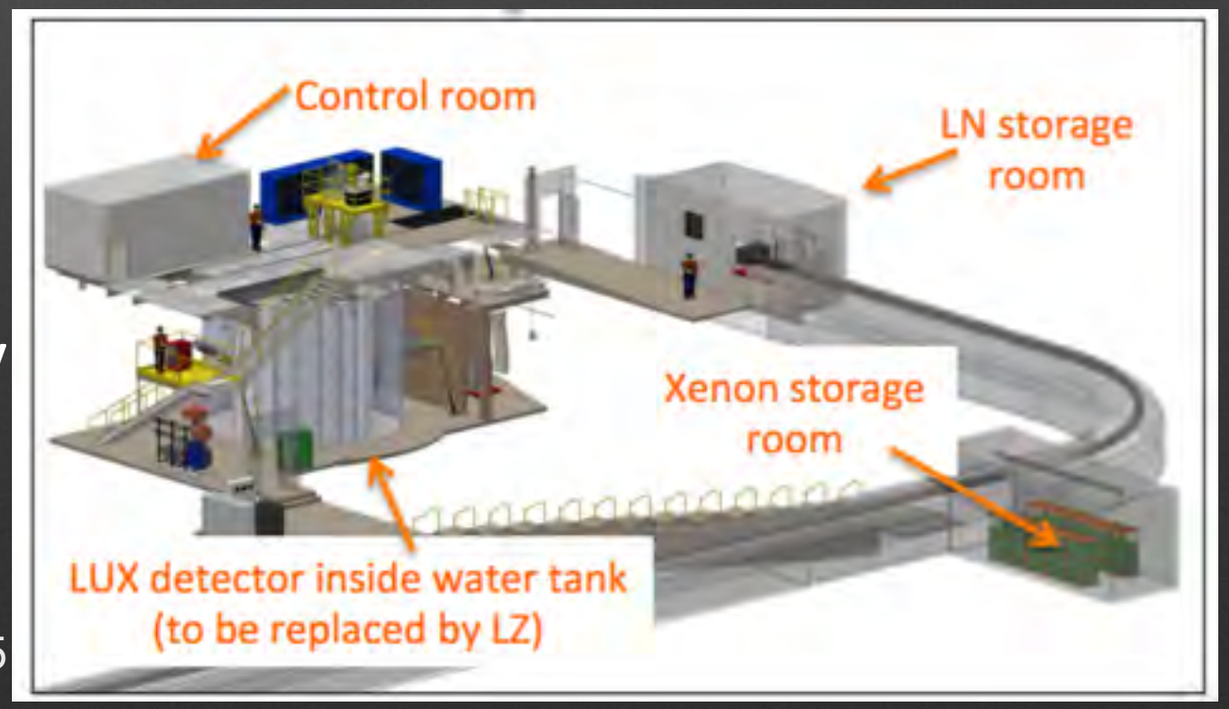
Davis Cavern 1480 m

(4200 m water equivalent)

Sanford Underground Research Facility

Homestake Gold mine

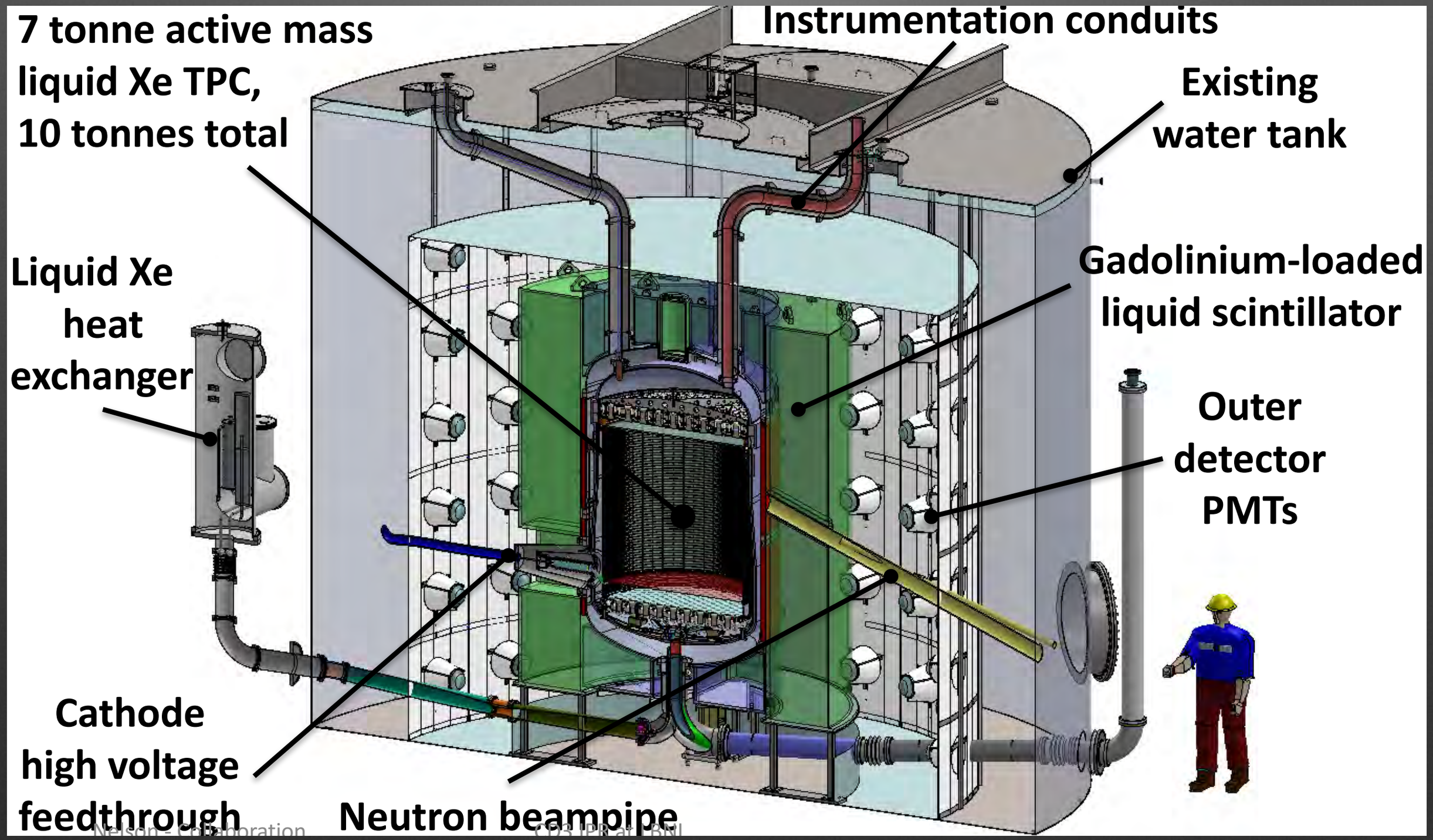
Lead, SD (near Deadwood)



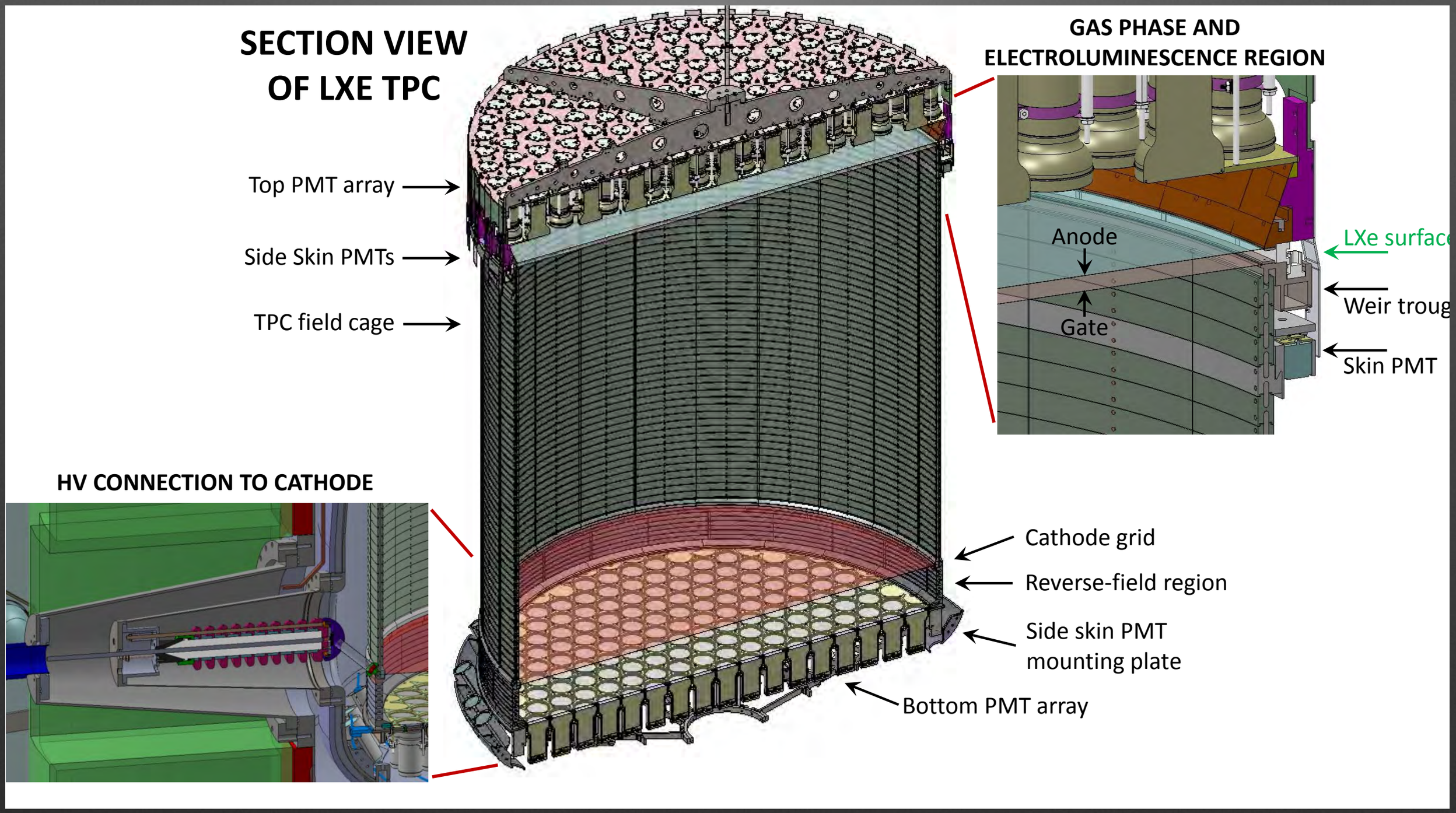
LZ: 38 Institutions & 250 scientists, engineers and technicians

1) Center for Underground Physics (South Korea)
2) LIP Coimbra (Portugal)
3) MEPhI (Russia)
4) Imperial College London (UK)
5) Royal Holloway University of London (UK)
6) STFC Rutherford Appleton Lab (UK)
7) University College London (UK)
8) University of Bristol (UK)
9) University of Edinburgh (UK)
10) University of Liverpool (UK)
11) University of Oxford (UK)
12) University of Sheffield (UK)
13) Black Hill State University (US)
14) Brandeis University (US)
15) Brookhaven National Lab (US)
16) Brown University (US)
17) Fermi National Accelerator Lab (US)
18) Lawrence Berkeley National Lab (US)
19) Lawrence Livermore National Lab (US)
20) Northwestern University (US)
21) Pennsylvania State University (US)
22) SLAC National Accelerator Lab (US)
23) South Dakota School of Mines and Technology (US)
24) South Dakota Science and Technology Authority (US)
25) Texas A&M University (US)
26) University at Albany (US)
27) University of Alabama (US)
28) University of California, Berkeley (US)
29) University of California, Davis (US)
30) University of California, Santa Barbara (US)
31) University of Maryland (US)
32) University of Massachusetts (US)
33) University of Michigan (US)
34) University of Rochester (US)
35) University of South Dakota (US)
36) University of Wisconsin – Madison (US)
37) Washington University in St. Louis (US)
38) Yale University (US)

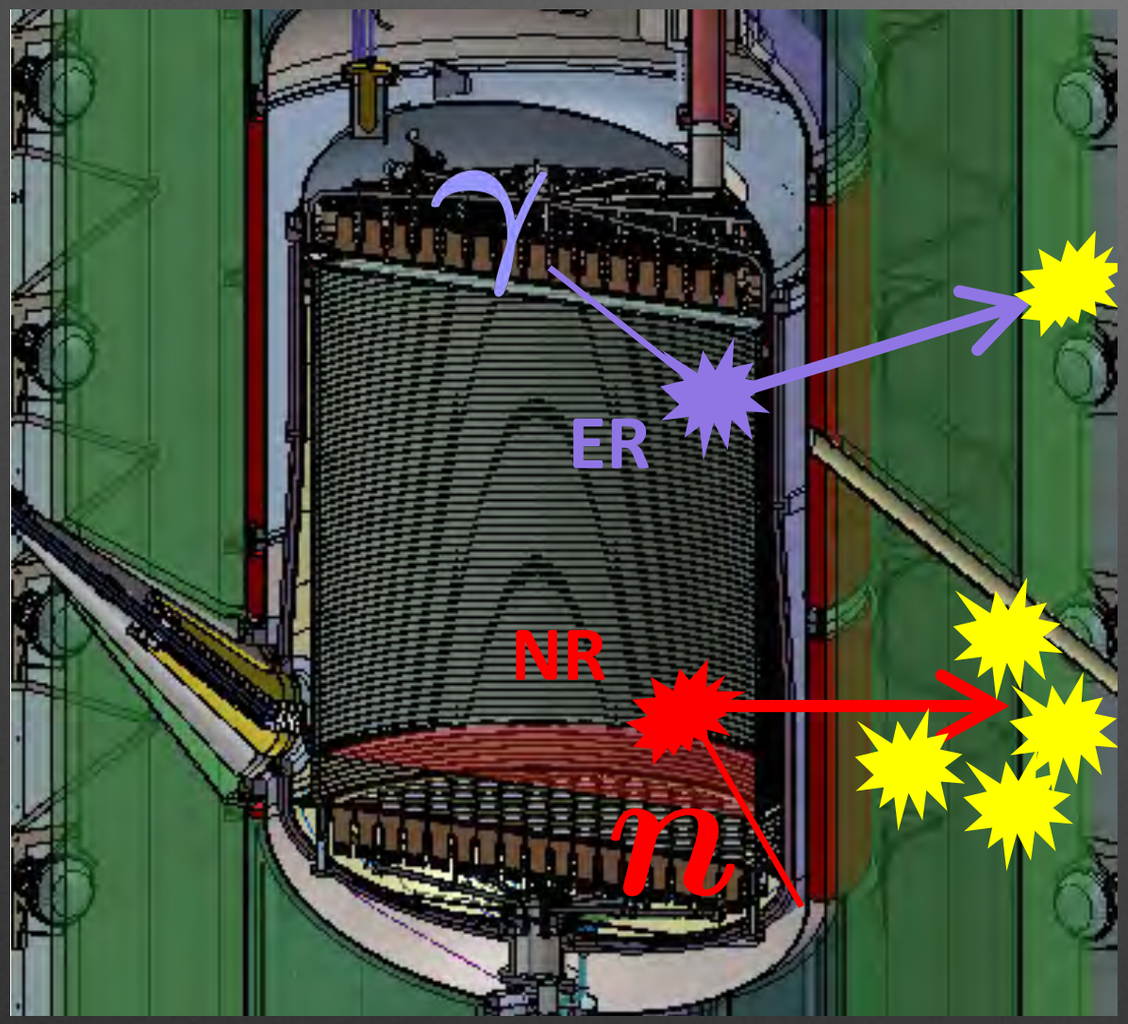
LZ design


7 tonne active mass liquid Xe TPC, 10 tonnes total
Instrumentation conduits
Existing water tank
Liquid Xe heat exchanger
Gadolinium-loaded liquid scintillator
Outer detector PMTs
Cathode high voltage feedthrough
Neutron beampipe

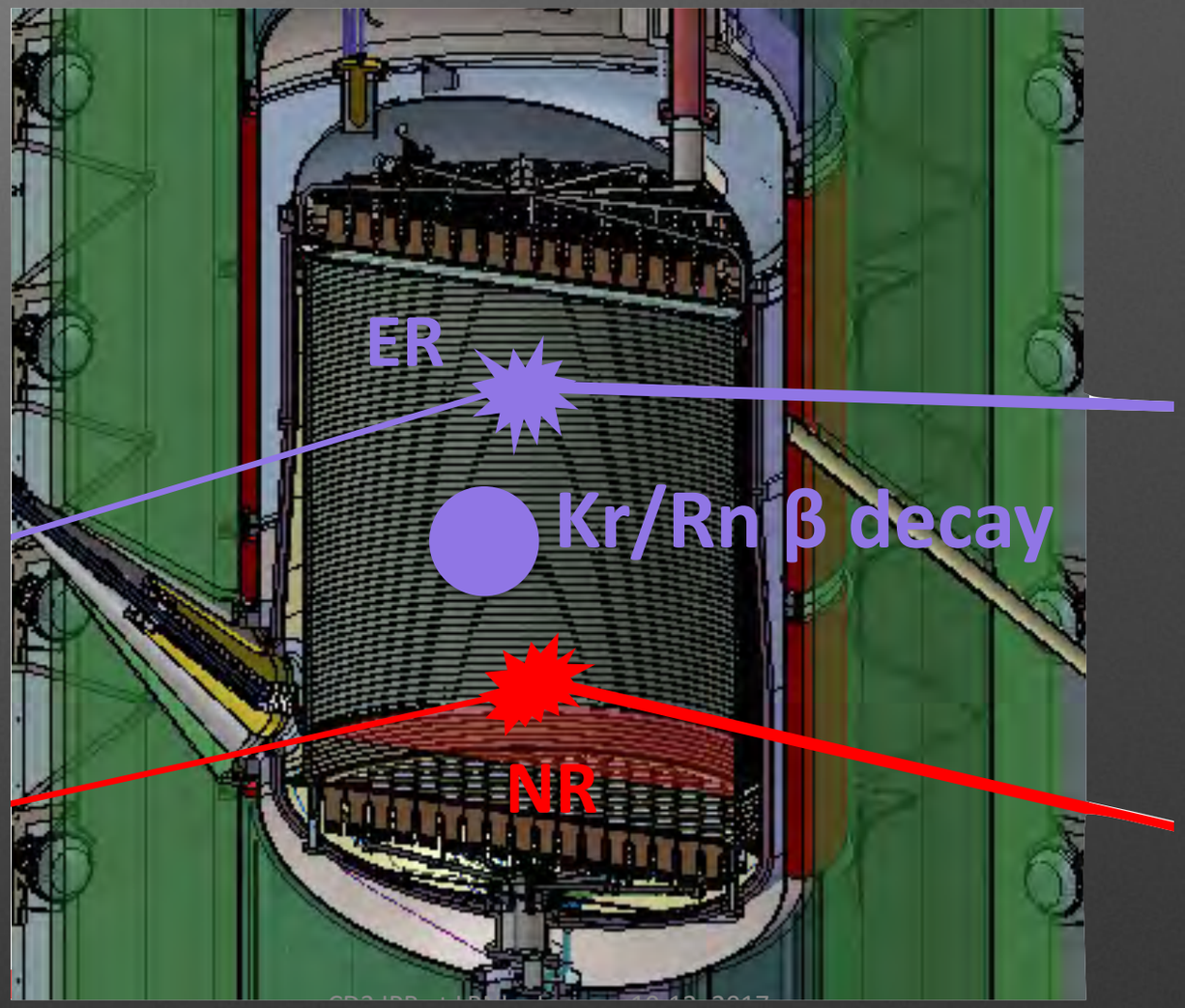
TPC design


SECTION VIEW OF LXE TPC
Top PMT array
Side Skin PMTs
TPC field cage
GAS PHASE AND ELECTROLUMINESCENCE REGION
Anode
Gate
LXe surface
Weir troug
Skin PMT
HV CONNECTION TO CATHODE
Cathode grid
Reverse-field region
Side skin PMT mounting plate
Bottom PMT array

LZ Backgrounds

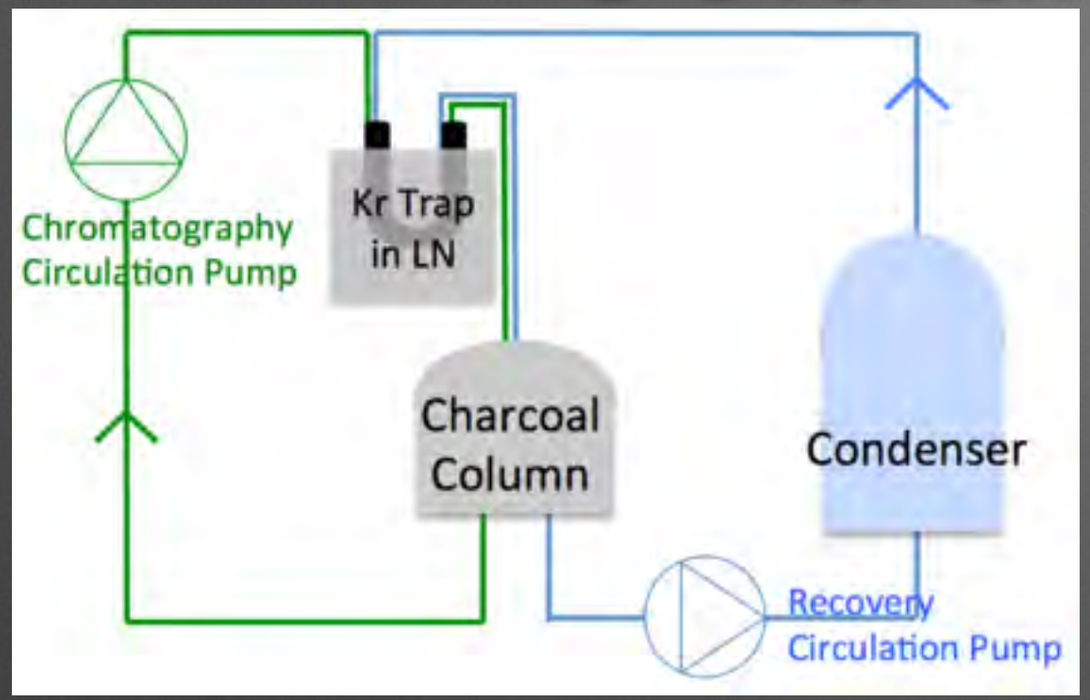


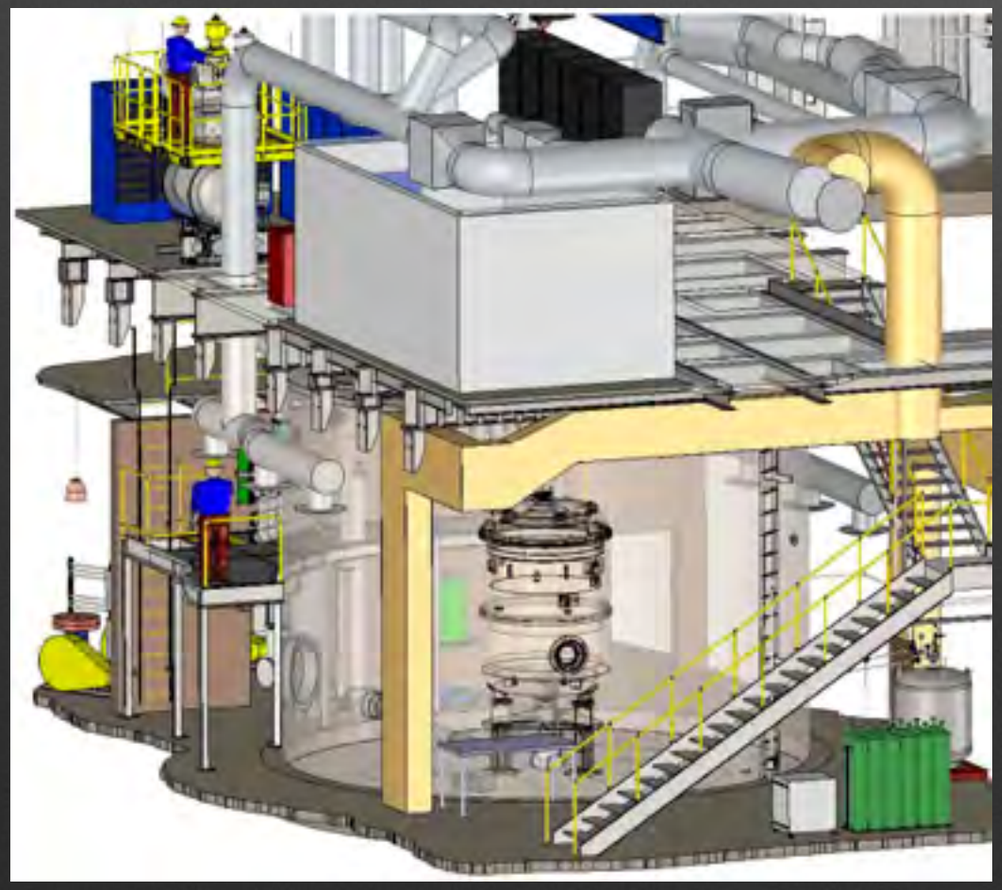
External Materials



Uniform in LXe

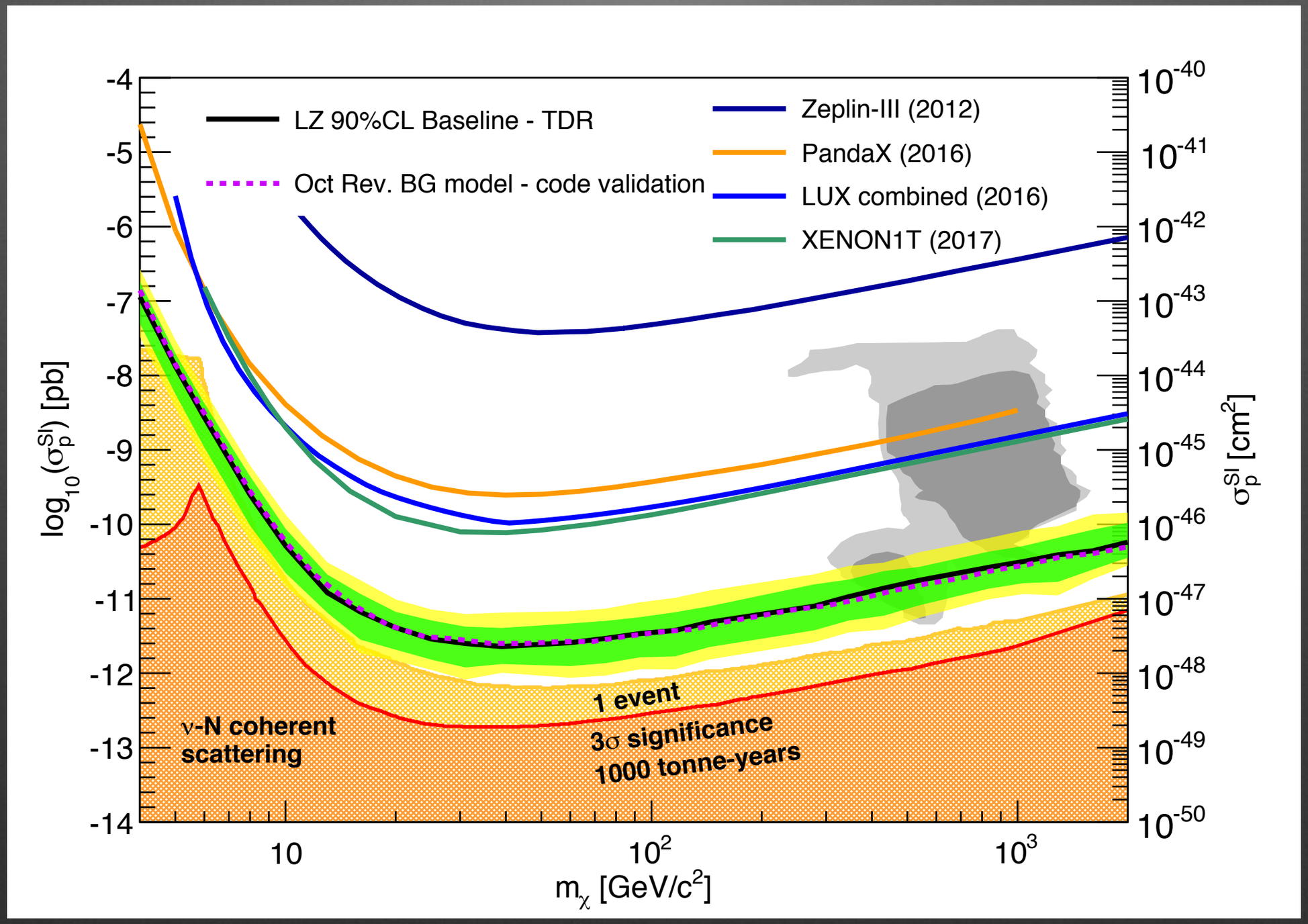
Cold and Pure LXe



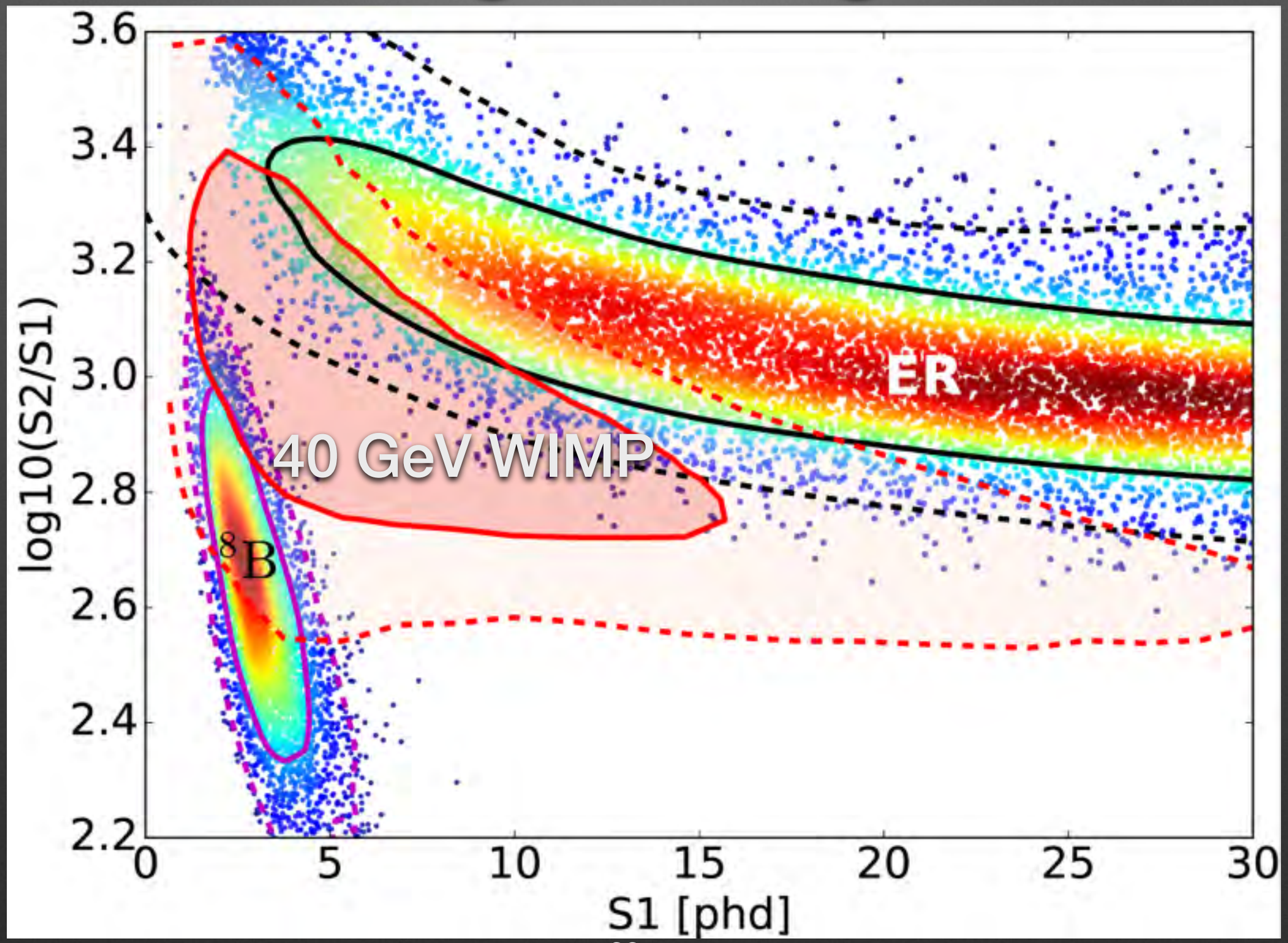


- Ex-situ removal of Kr via charcoal chromatography
- Constant removal of reactive impurities with a hot gas getter, flows at 500 slpm
- Gas circulation allows for injection of radioactive calibration sources
  - Kr83m, Xe131 workhorses
  - CH3T quarterly; must be removed with getter

LZ Projected Limit

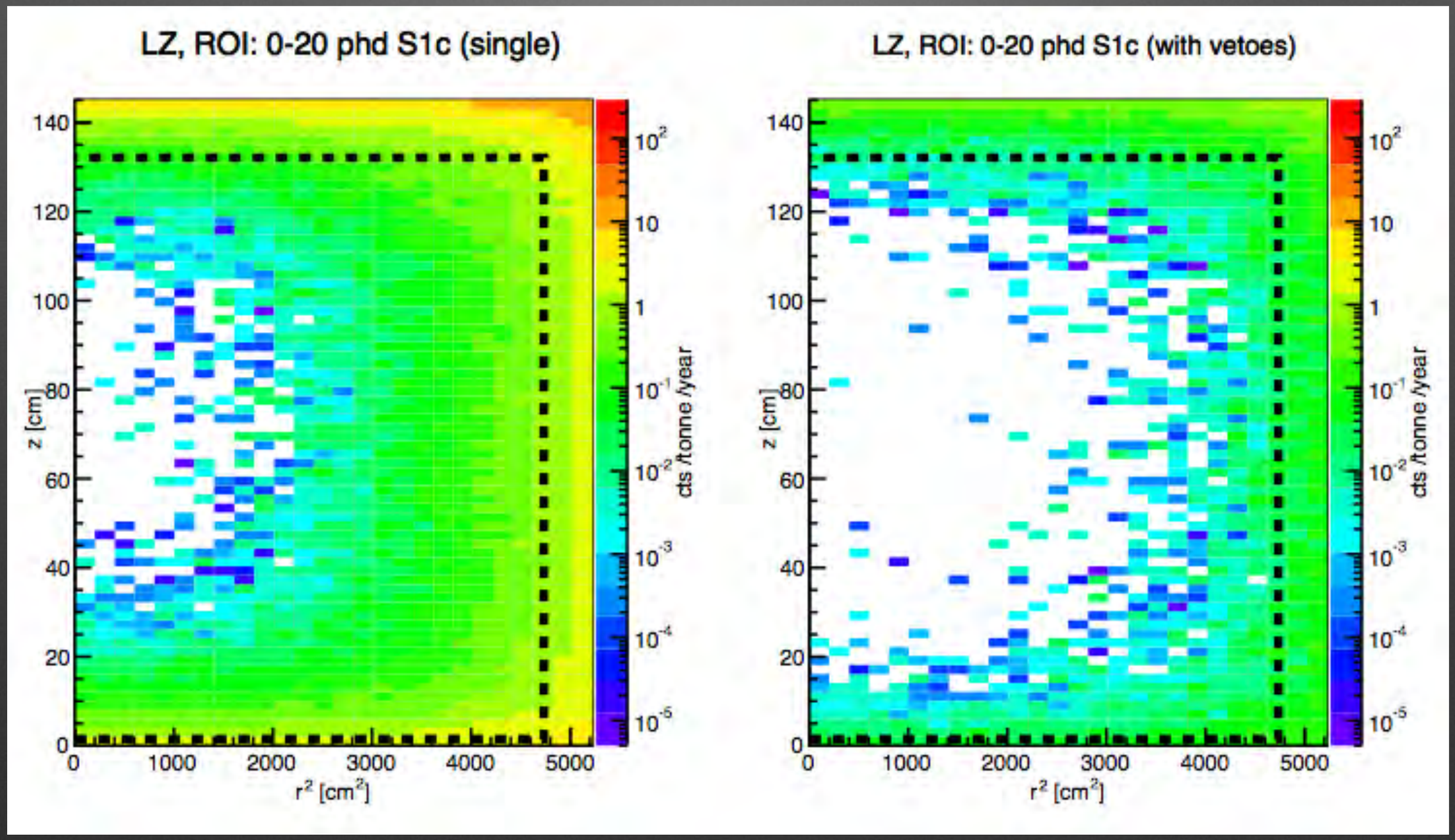


LZ Signal Region

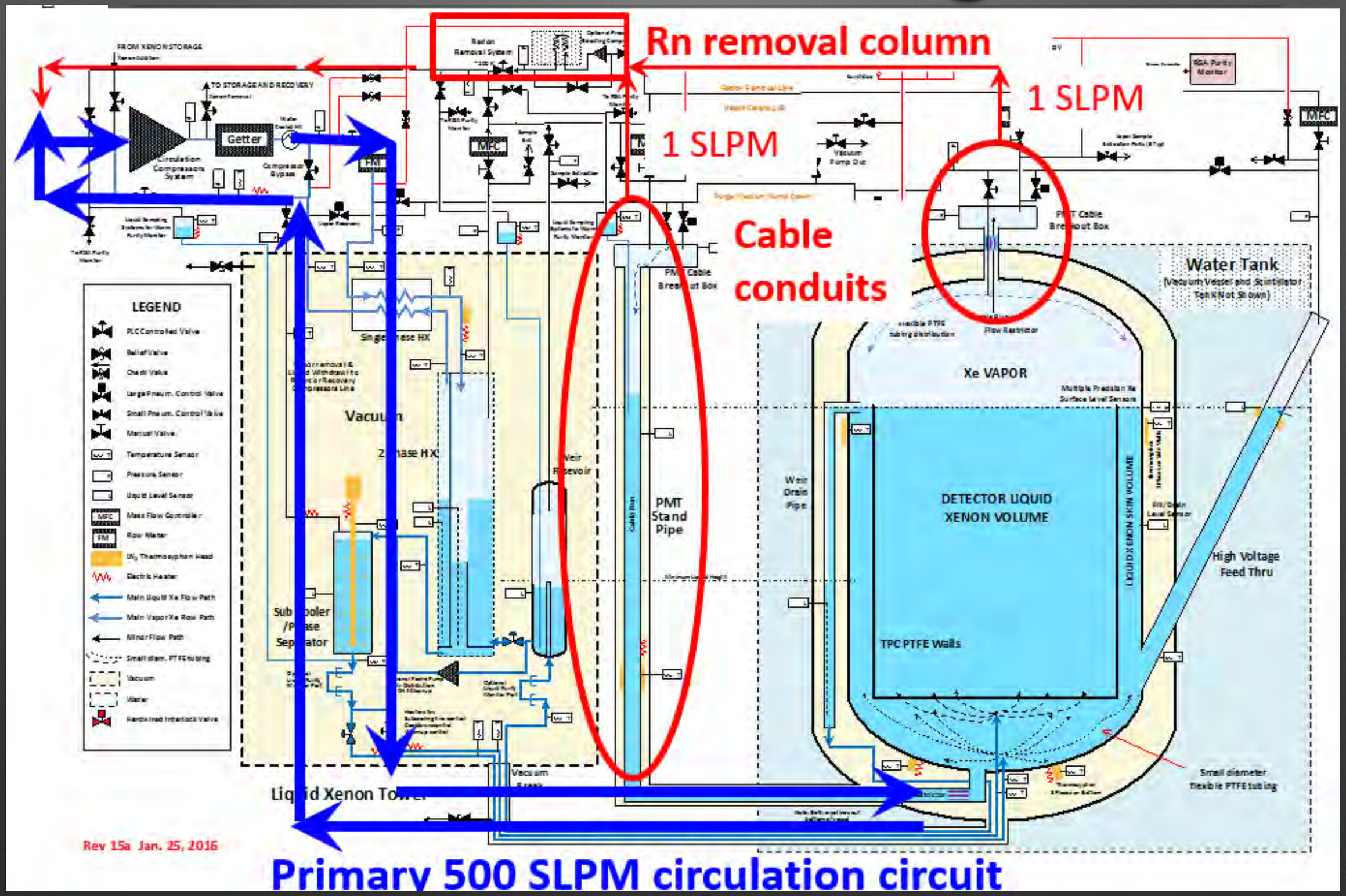


LZ @ UW Madison

Simulations

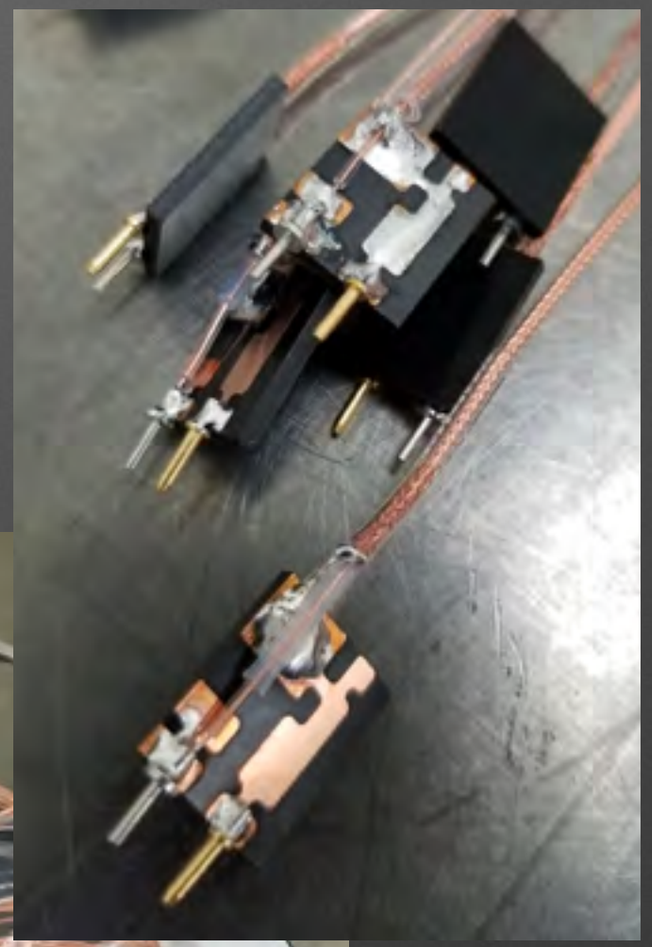


LXe Handling



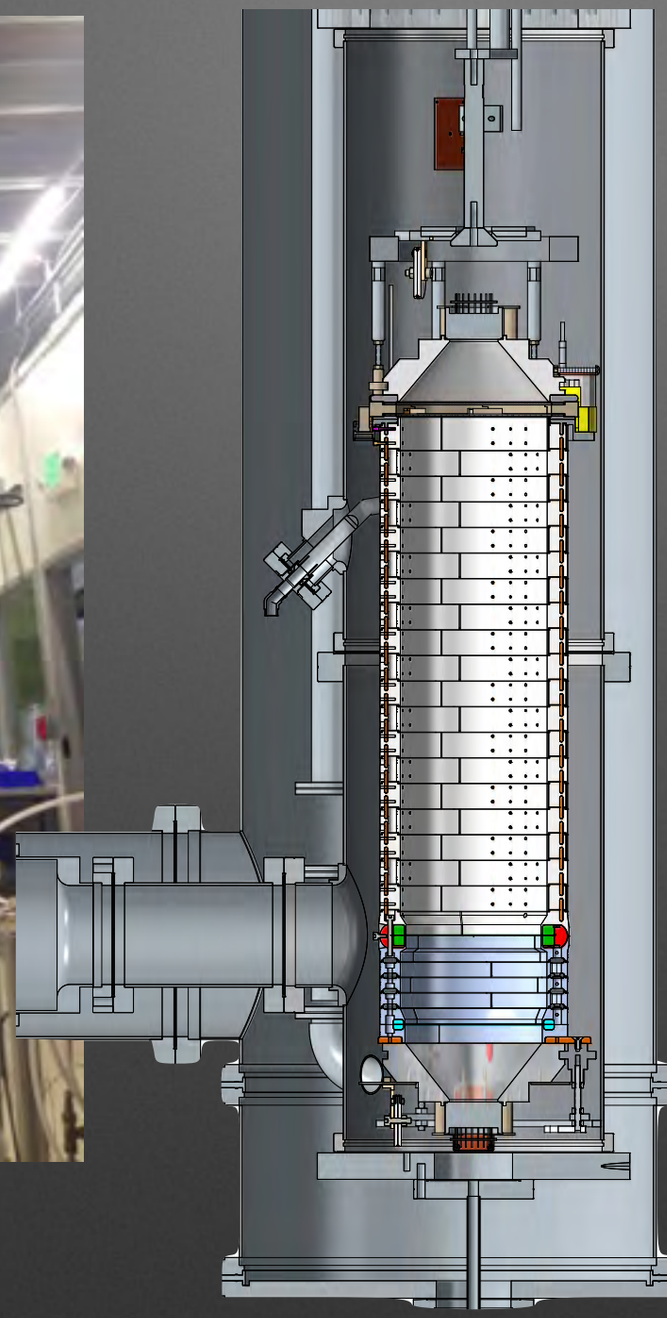
Packs, Panels and Cables

- PSL staff and UW students will fabricate, clean and test:
  - Xe space coaxial cable
  - Xe gas storage packs
  - Xe gas panels

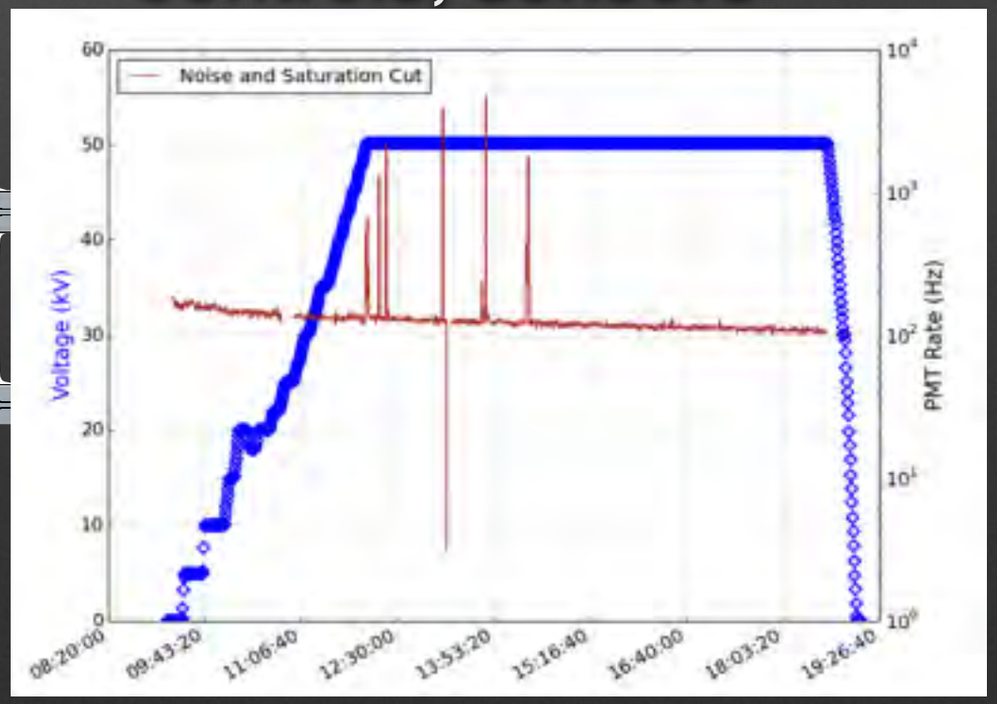


SLAC System Test Platform

System Test TPC



- Test Grid High Voltage with single photon and single electron sensitivity
- Prototype many subsystems: circulation, slow controls, sensors



Phase 2 System Test

- Test 1.5 m diameter final grids
- Engineering provided by PSL

Conclusion

- LUX has presented world-leading limits with the most sophisticated dark matter analysis to date.
- Direct Dark Matter Detection is entering a new era of discovery capability, along with a more mature detector design and collaboration organization
- LZ will be the most sensitive to conventional ~100 GeV WIMPs, as well as being a versatile detector for other exotic searches
- The broad dark matter field, with collider, indirect, and direct detections will have interesting results over the next 7= 2pi years
- UWMadison is a great place to be working on LZ!

Searching for WIMPs