How a two-phase Xe TPC is a perfect way to look for WIMPs

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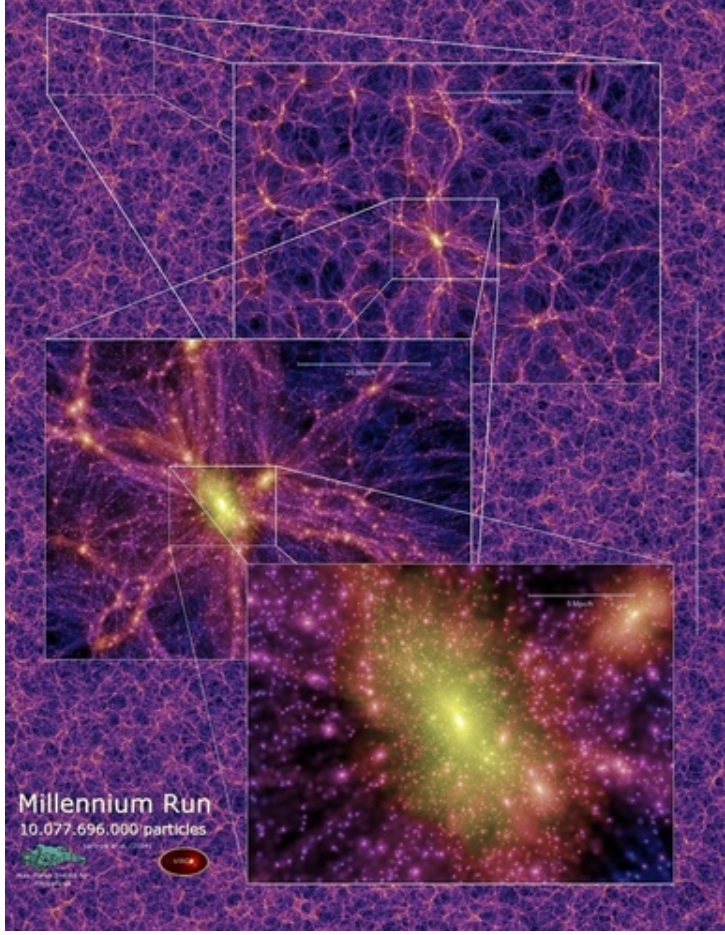
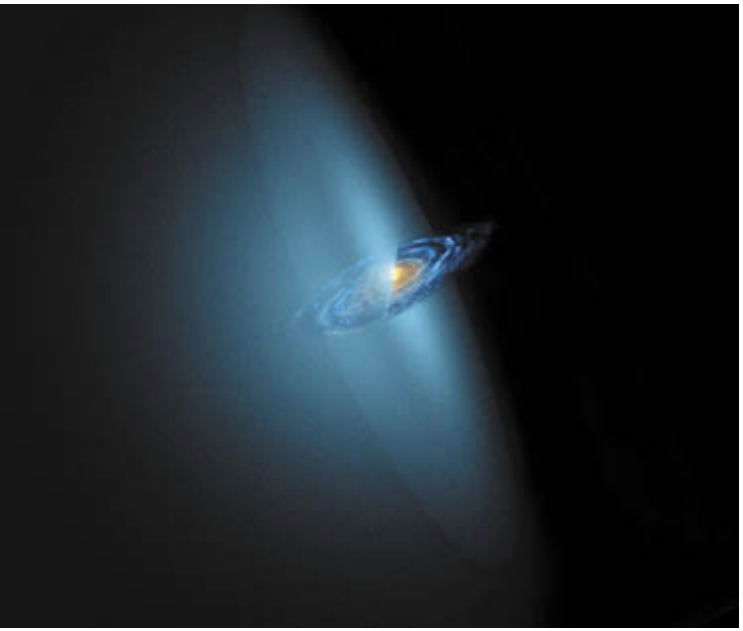
Dark Matter

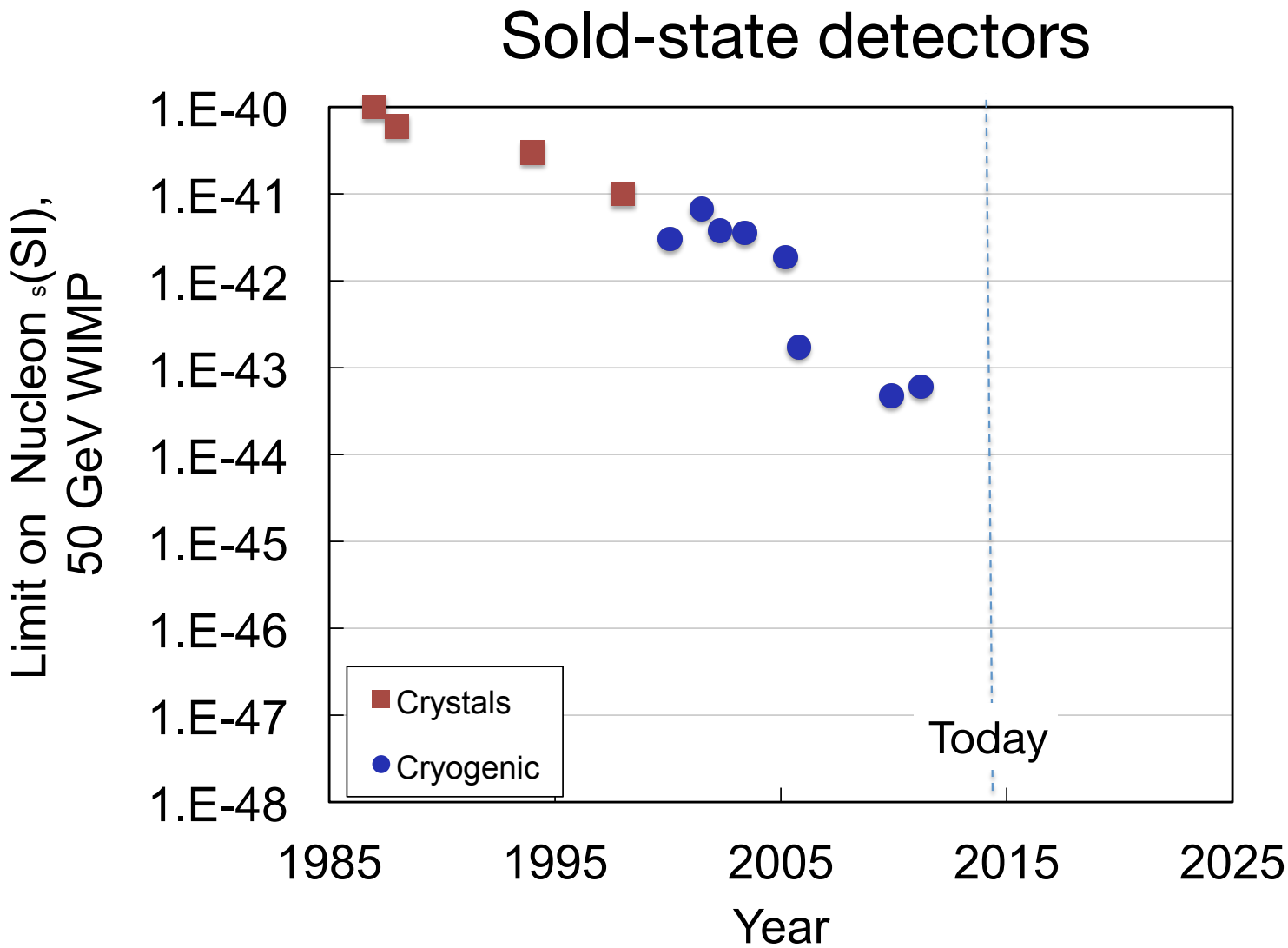
Dark energy	≈ 0.68
Dark matter	≈ 0.27
Baryons	≈ 0.05
(Stars+Planets	≈ 0.004)
Neutrinos:	≈ 0.001-0.015
Total	1



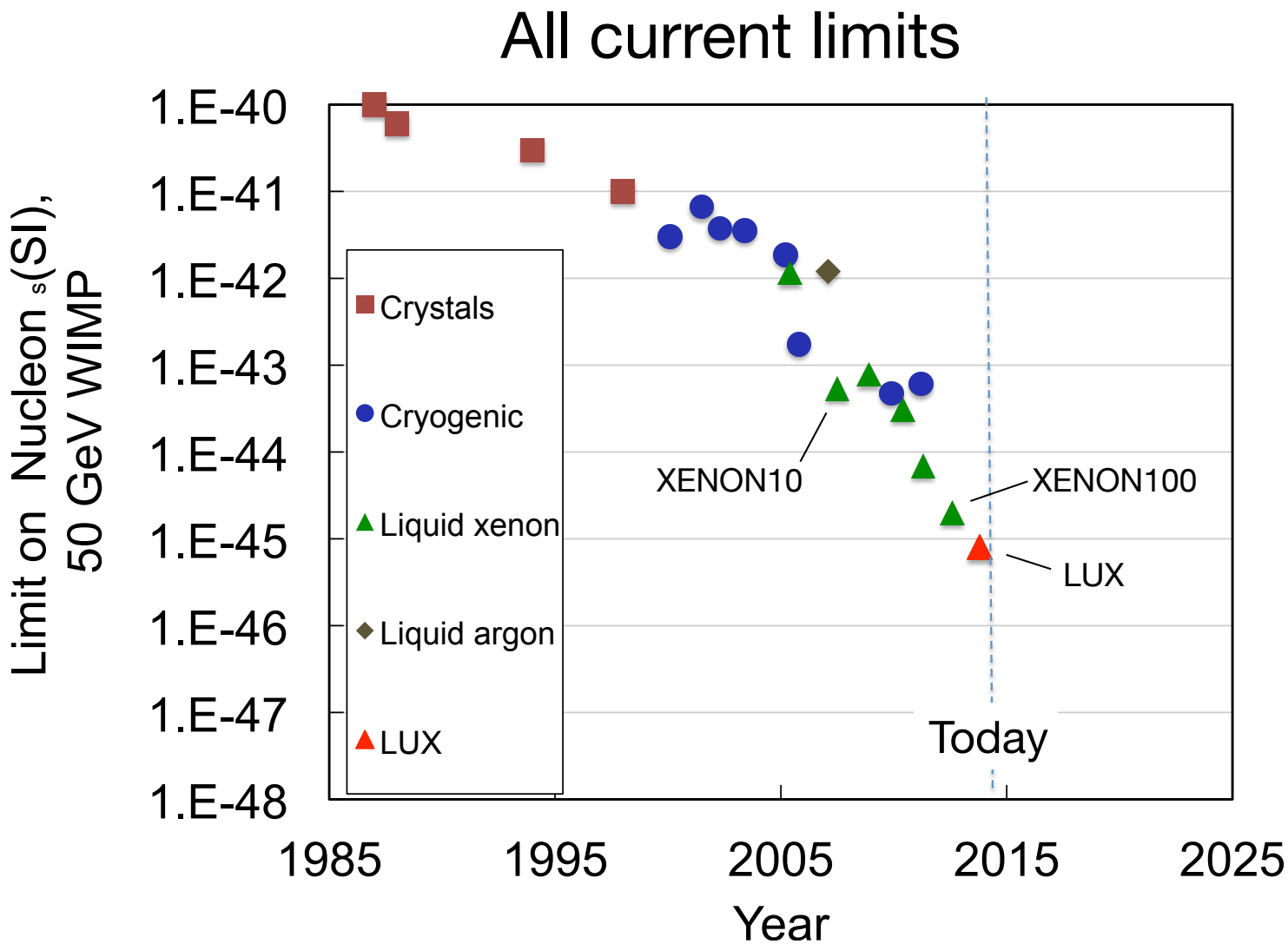


- In the lab:
  - 300 m_{proton} / liter
  - velocity ~ 10^{-3} c
- Elastic scattering on nuclei
  - Coherent: rate ~ A^2
- Rate < 1 /100kg/month

Search results for direct scattering

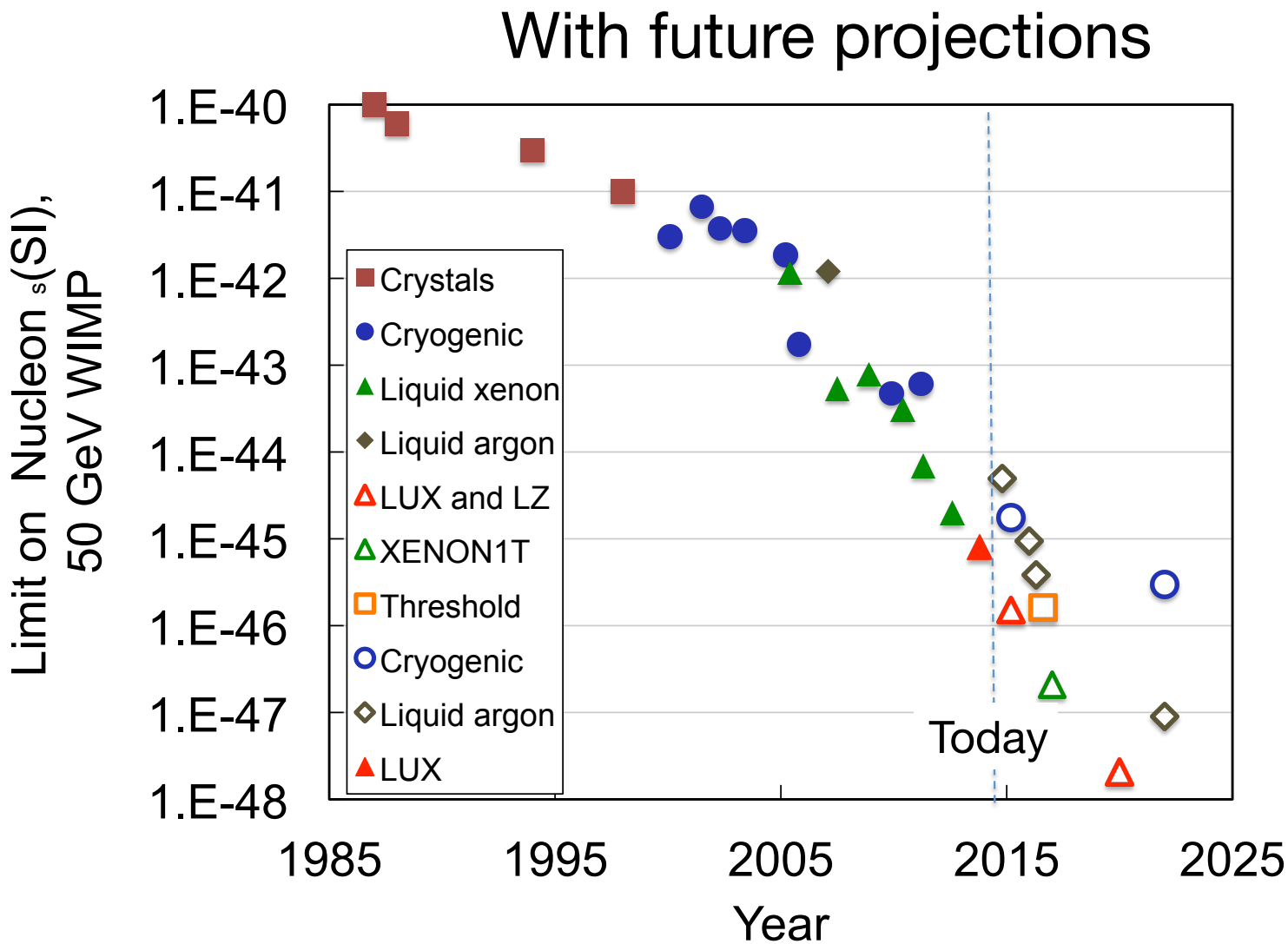


Search results for direct scattering



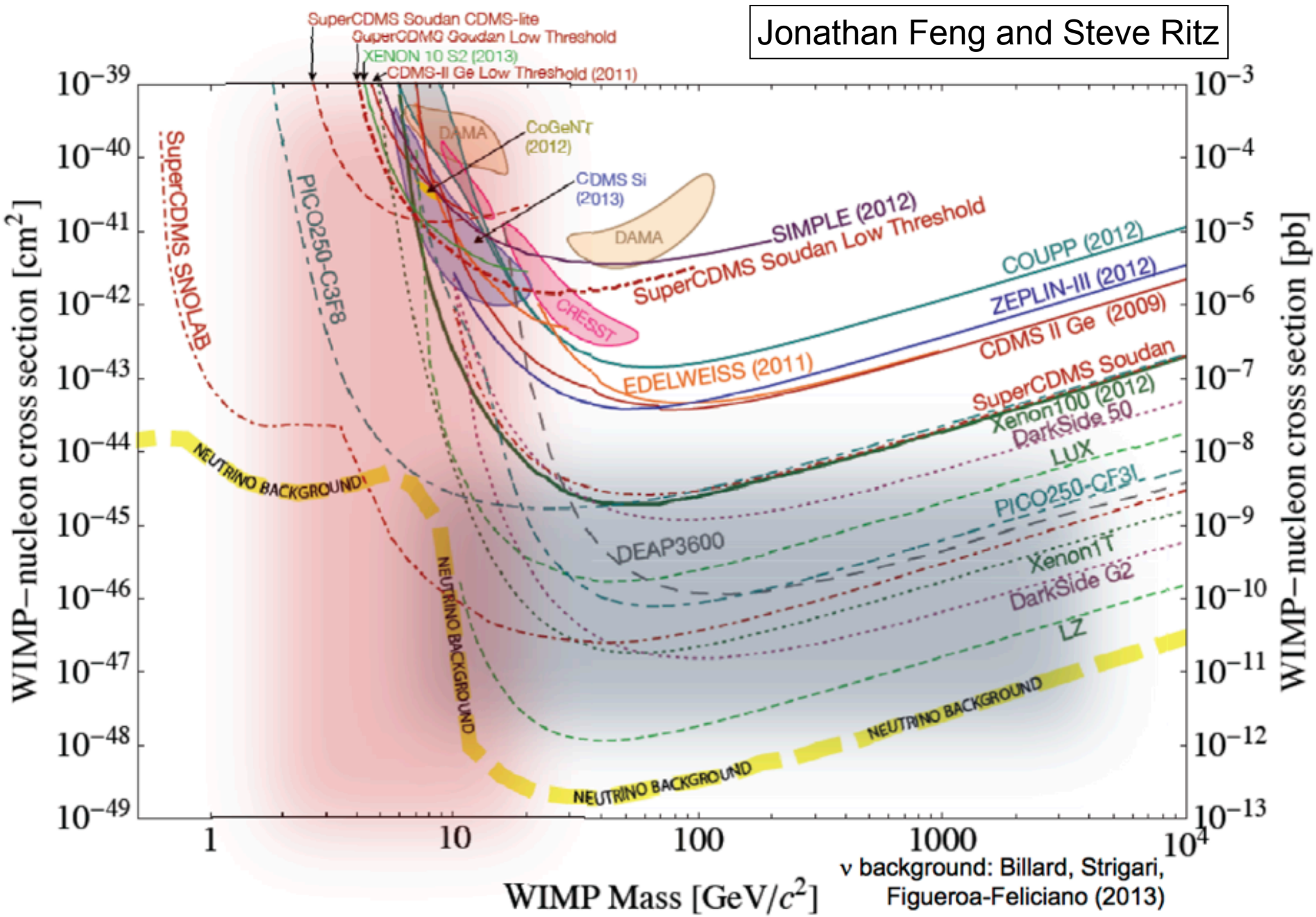
- Single phase Xe - 1990 (Dama), then UKDM + Cline/ICARUS - > ZEPLIN I.
- ~1997: ZEPLIN two phase UK/UCLA via ICARUS

Search results for direct scattering



CURRENT STATUS AND FUTURE PROSPECTS

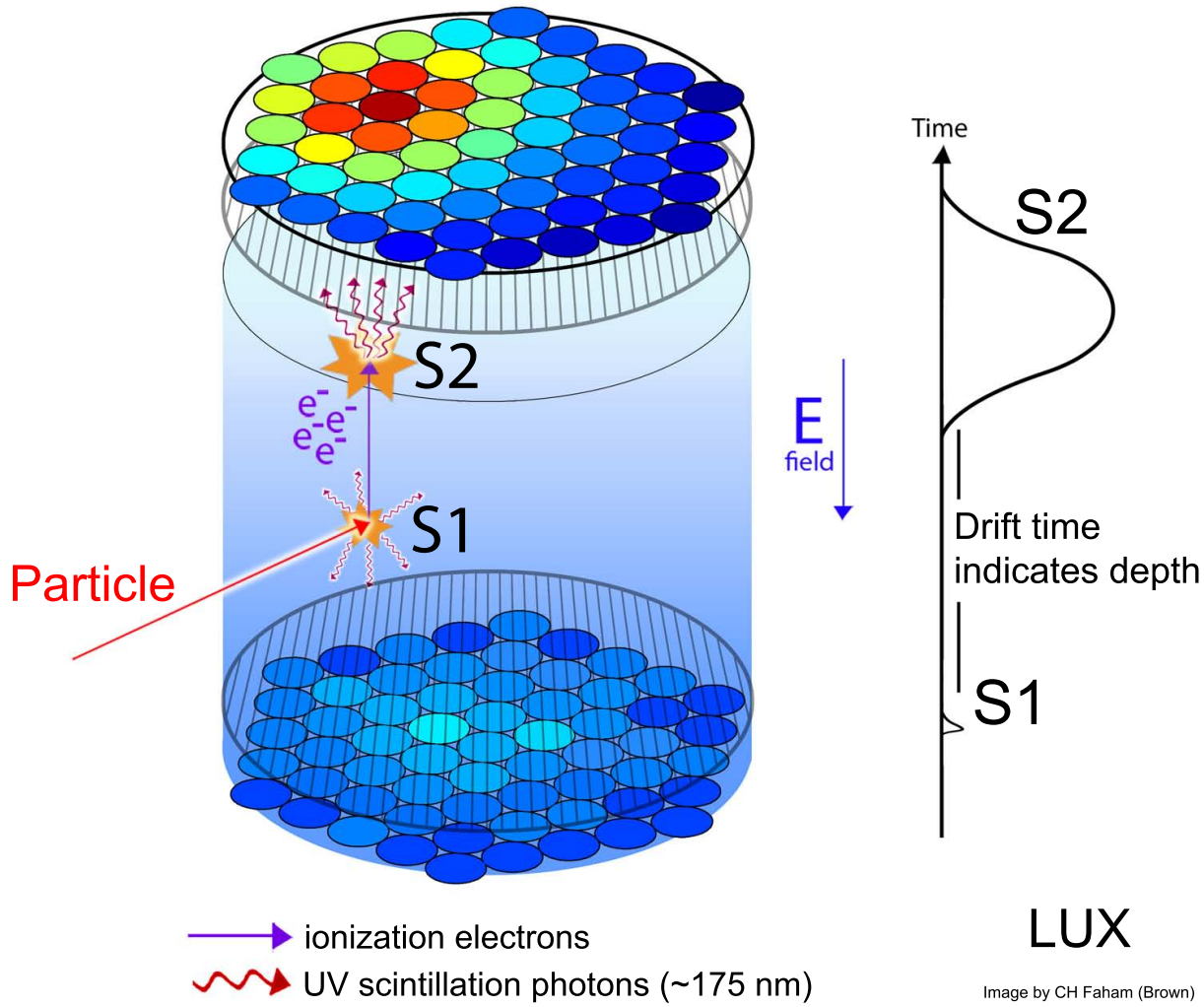
Jonathan Feng and Steve Ritz



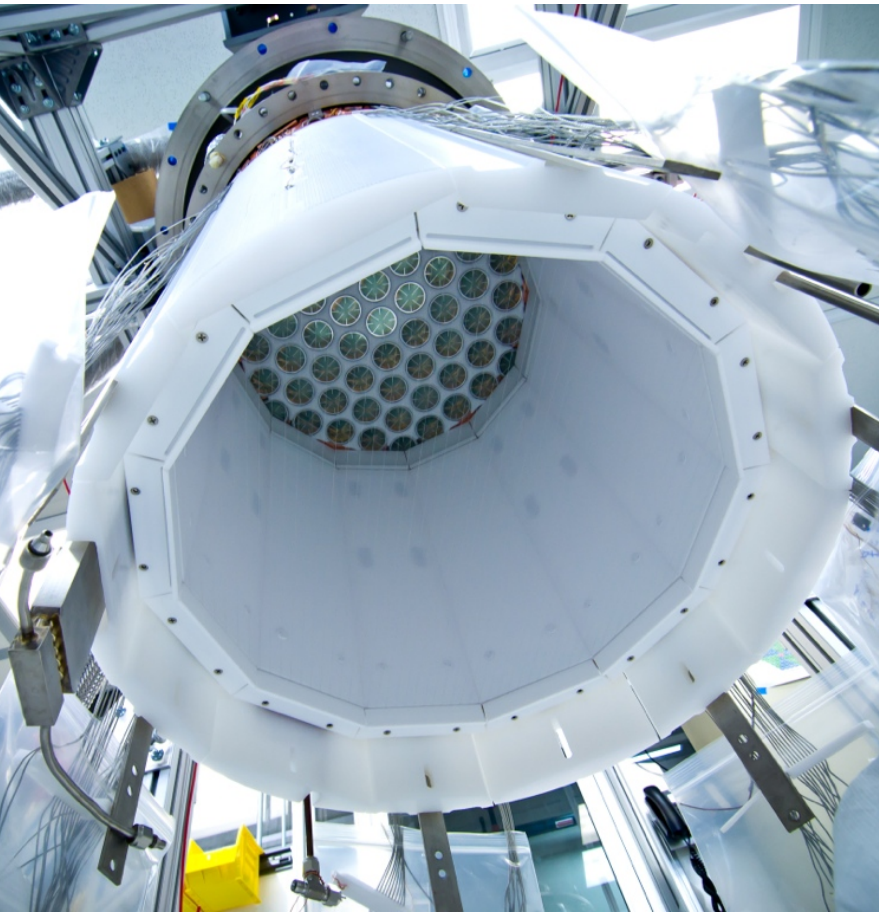
ν background: Billard, Strigari, Figueroa-Feliciano (2013)

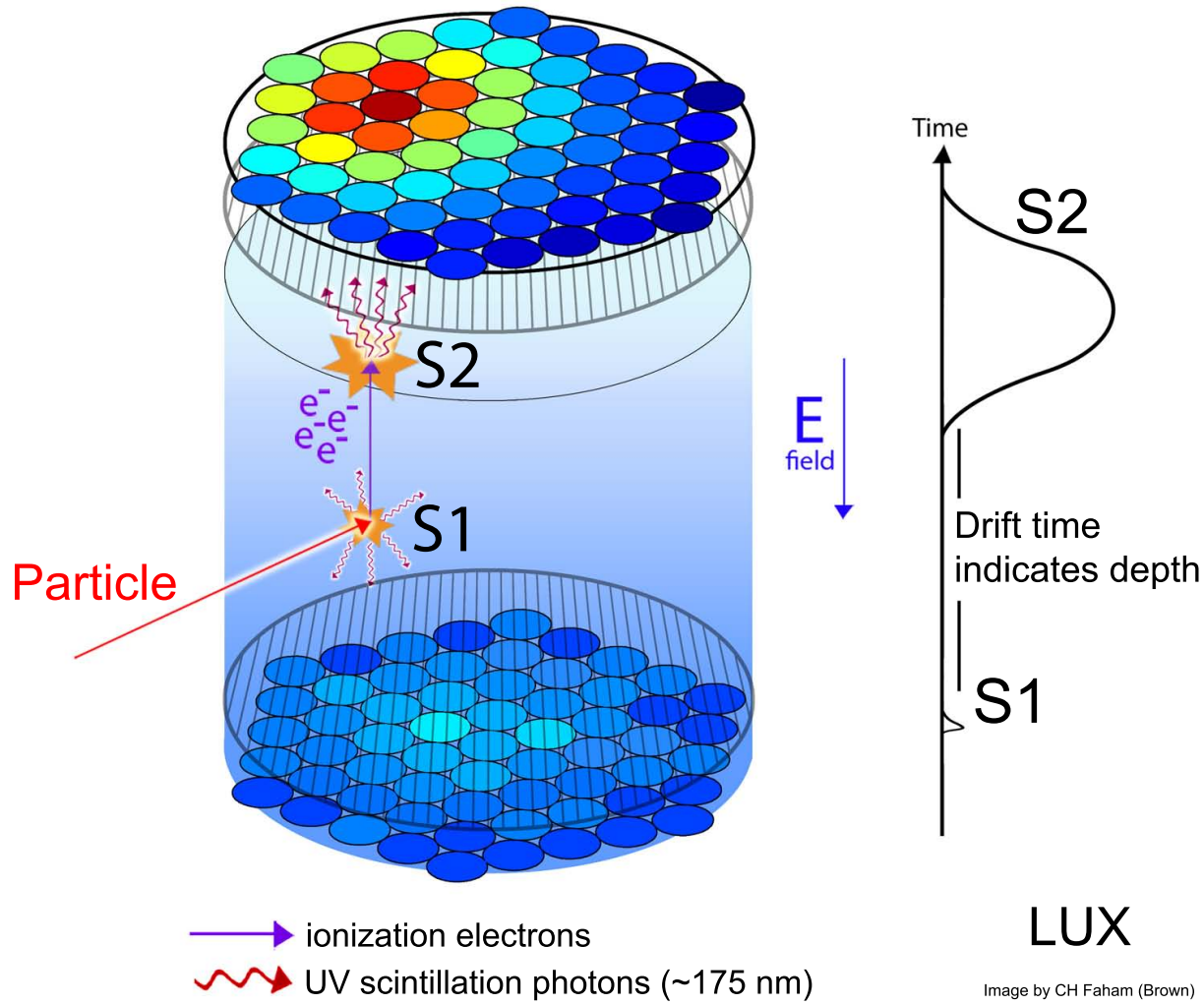
Dual phase Time Projection Chamber

- Liquid Xe - large signal, strong shielding of external backgrounds
- 3D event position
- Charge (S2) / light (S1) distinguishes electron recoil backgrounds
- Single electrons and photons



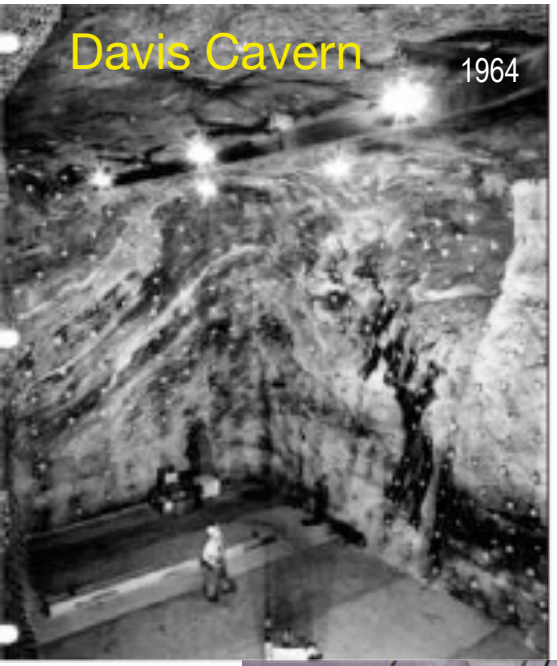
The LUX TPC





300 kg active Xe
122 2" Ø PMTs
Teflon walls
Low background Titanium cryostat

LUX @ SURF in the Homestake Mine



LUX collaboration

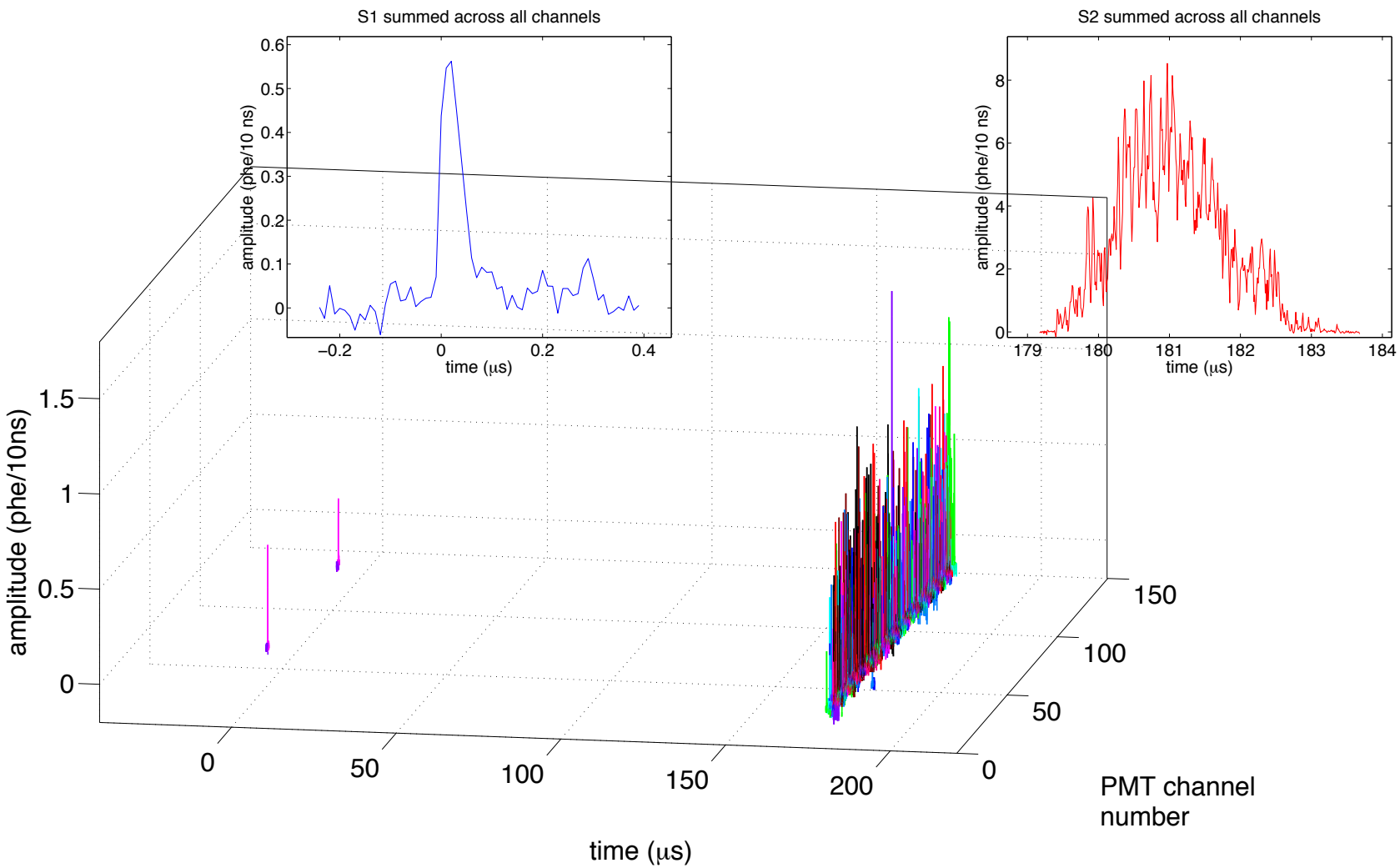
17 Institutions

Brown
Case
Edinburgh
Imperial College
Maryland
LLNL
LIP-Coimbra
Rochester
South Dakota
SD School of Mines
SDSTA
Texas A&M
UC Berkeley/LBNL
UC Davis
UC Santa Barbara
University College of London
Yale

Sturgis

HO ANDERSON & SON
HARDWARE AND FURNITURE
GOLD & SILVER SUPERSTORE
TATTOO CELLAR
GOLD & SILVER SUPERSTORE
RESTAURANT
Steaks · Burgers · Ribs
Bob's Family Restaurant

A “typical” event

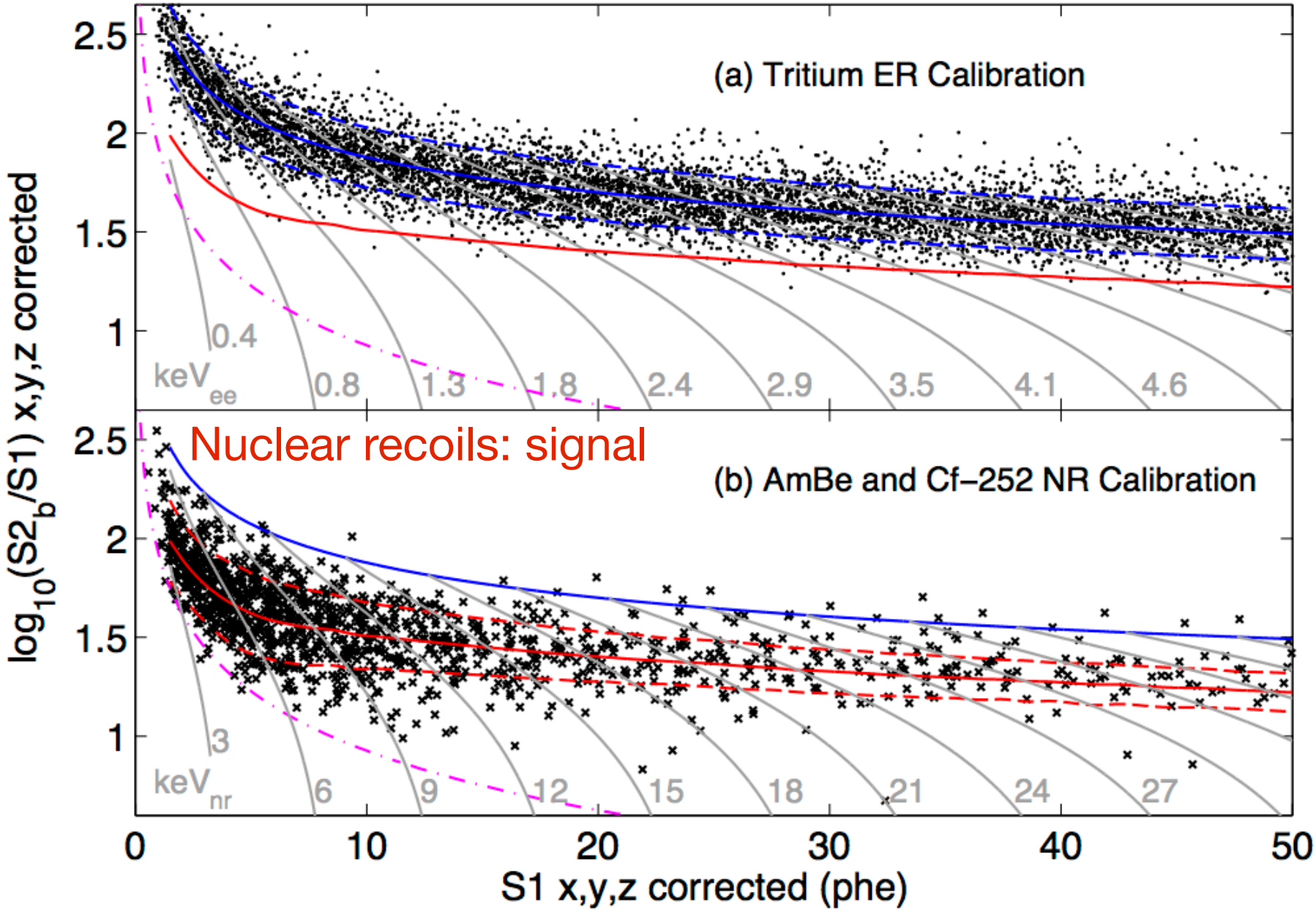


Requirements for WIMP search candidate events

- S2 trigger (at least 2 trigger ch. ≥ 8 phe within 2 μs)
- 2 phe (2-fold coincidence) ≤ S1 ≤ 30 phe
- 200 phe (8 e-) ≤ S2 ≤ 3300 phe
- total area of other pulses in the event < 100 phe

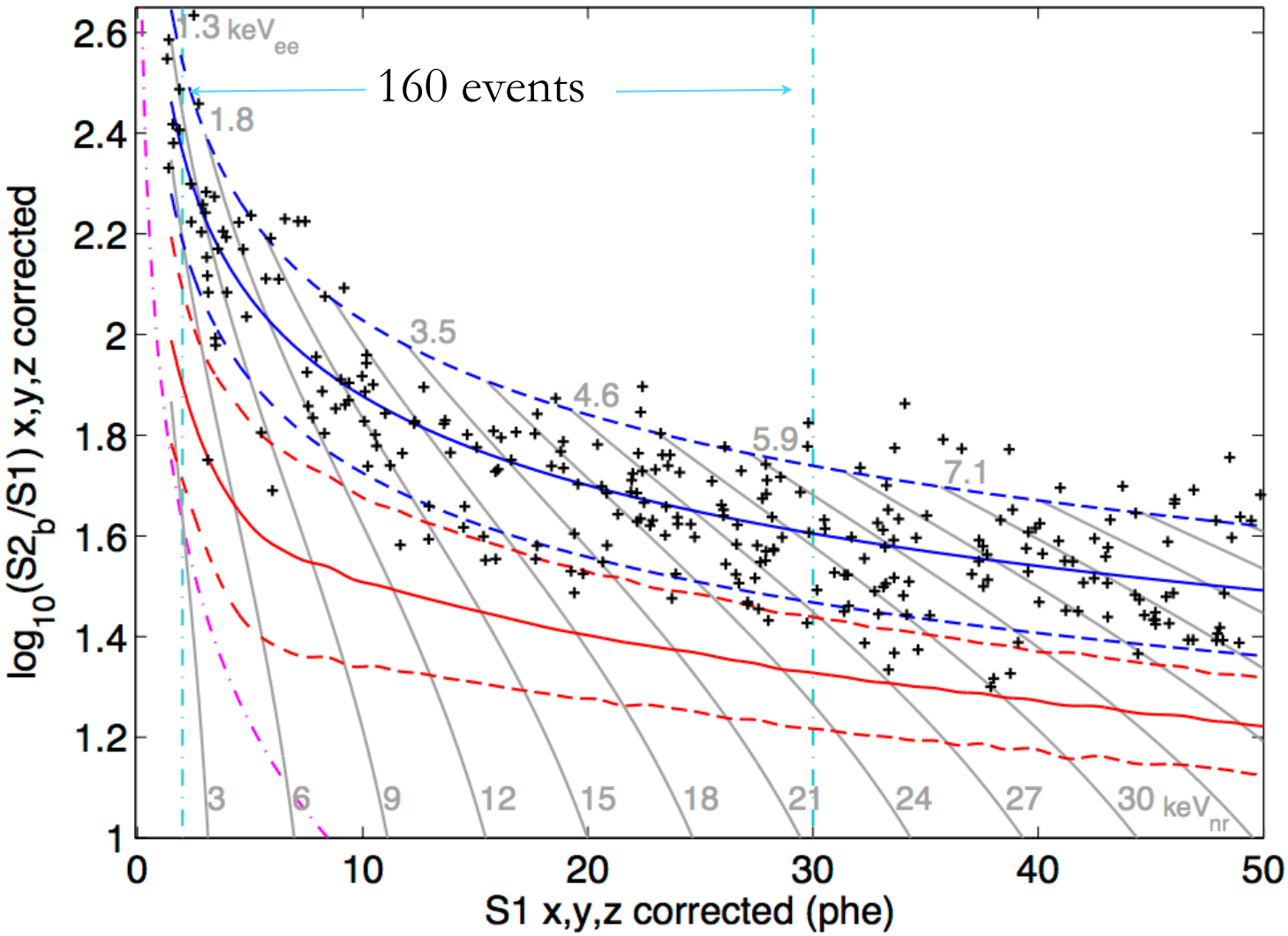
Background and Signal

Electron recoils: background



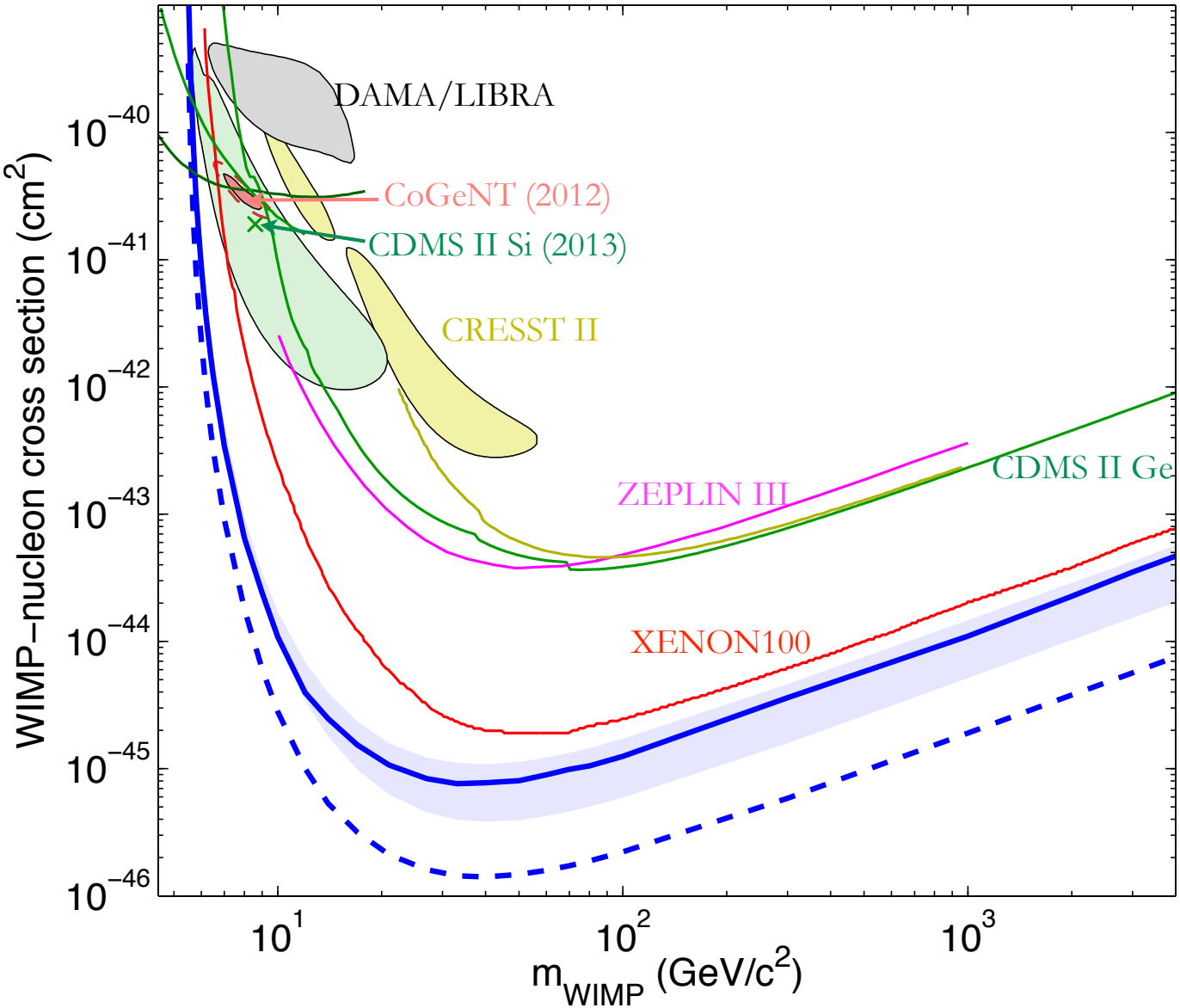
WIMP search data set

data for non-blind analysis, April 21 - August 8, 2013



118 fiducial volume: r < 18 cm, 7 < z < 47 cm

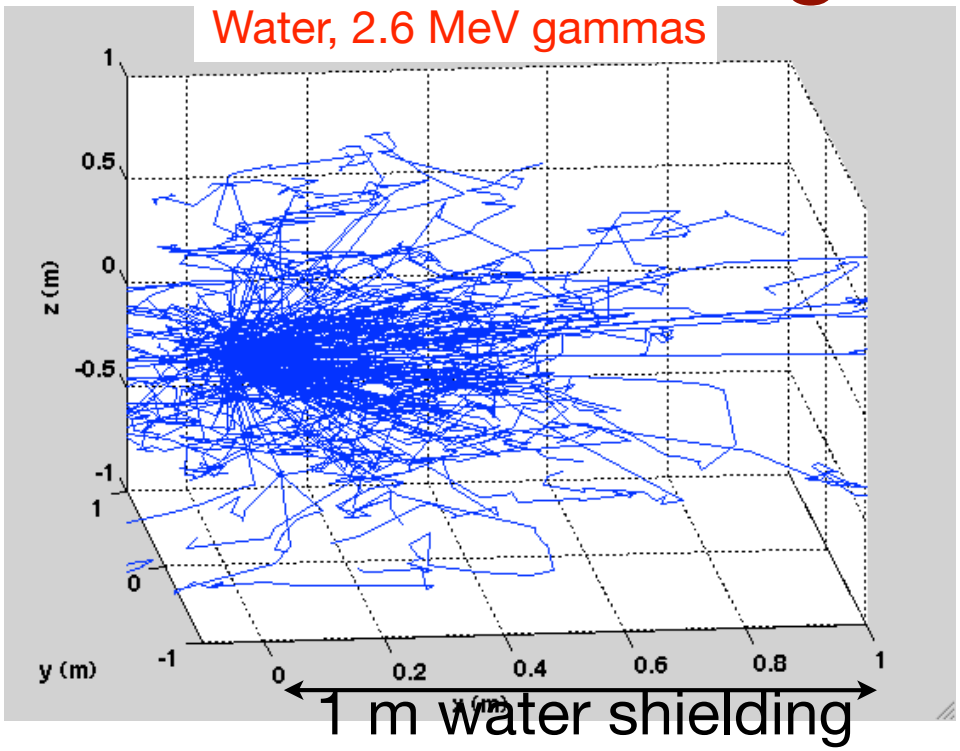
LUX spin-independent results

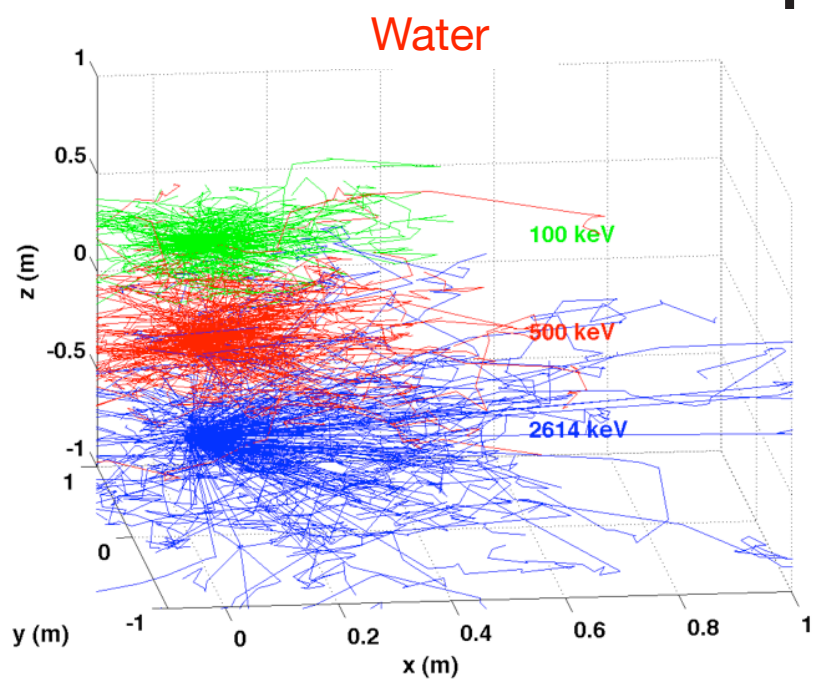


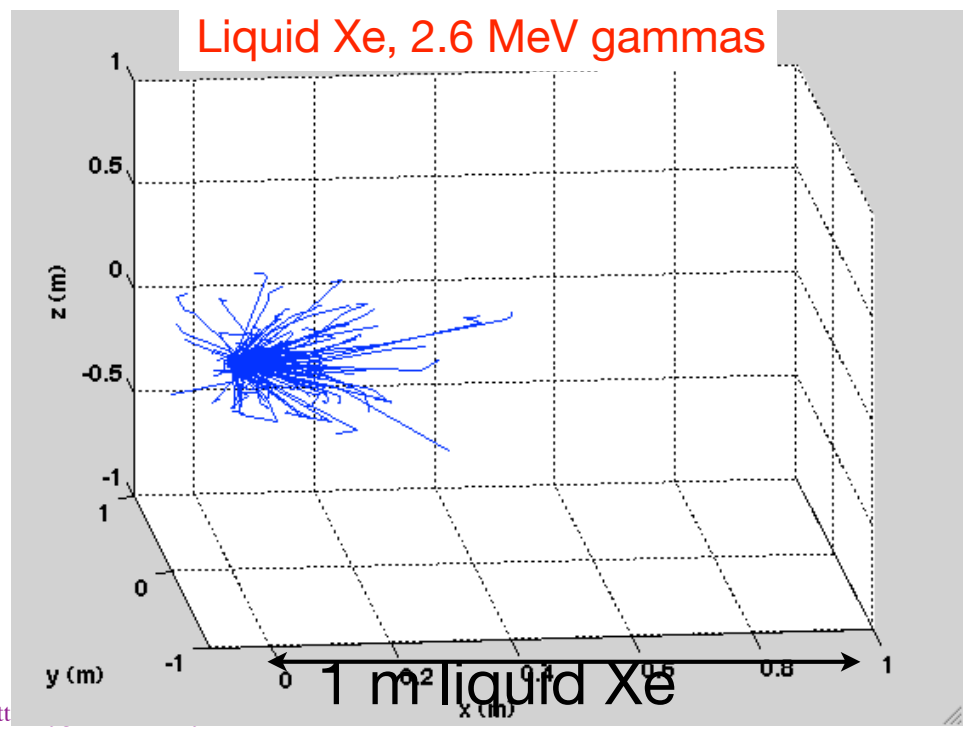
LUX 85d (2013),
with ±1σ expected bands

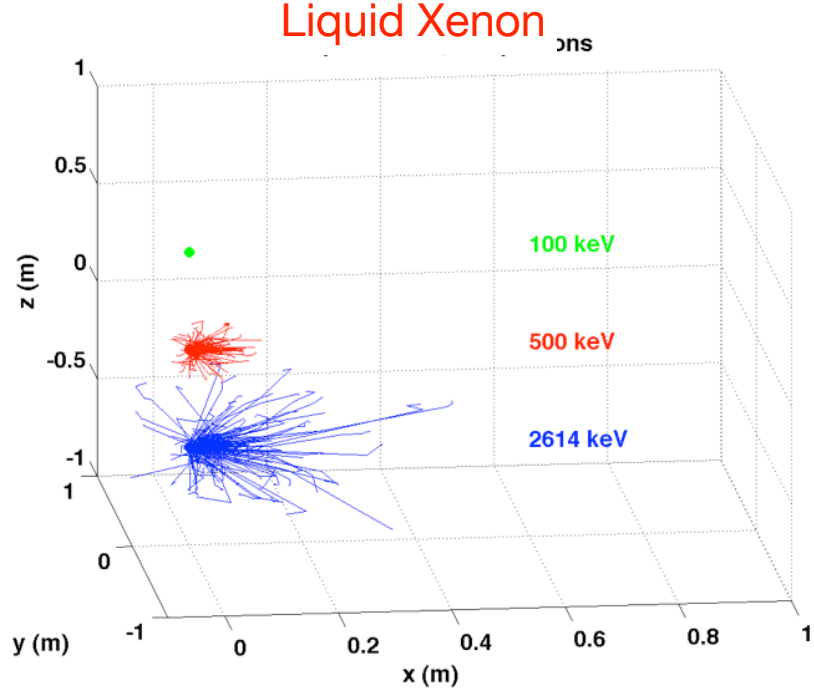
Projected LUX 300 d run (2014)

Shielding Gamma Rays



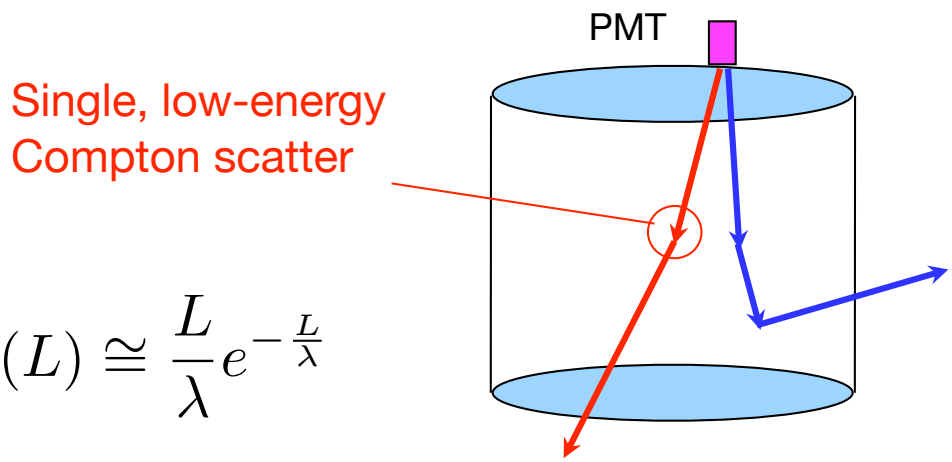






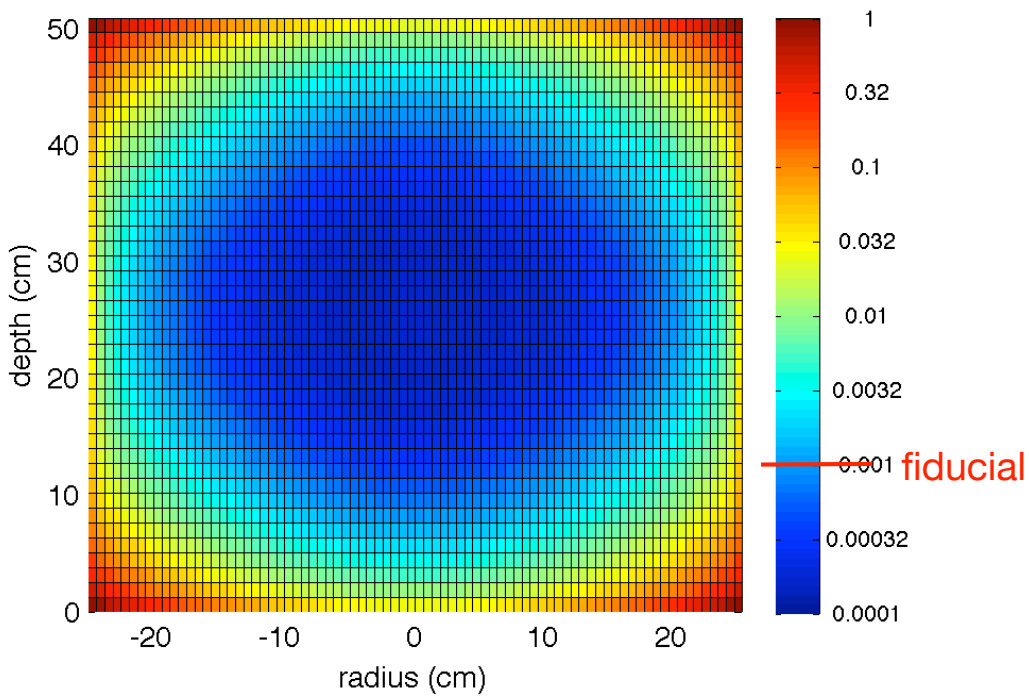
Self-shielding in liquid xenon

- MeV gammas and neutrons: λ ~10 cm

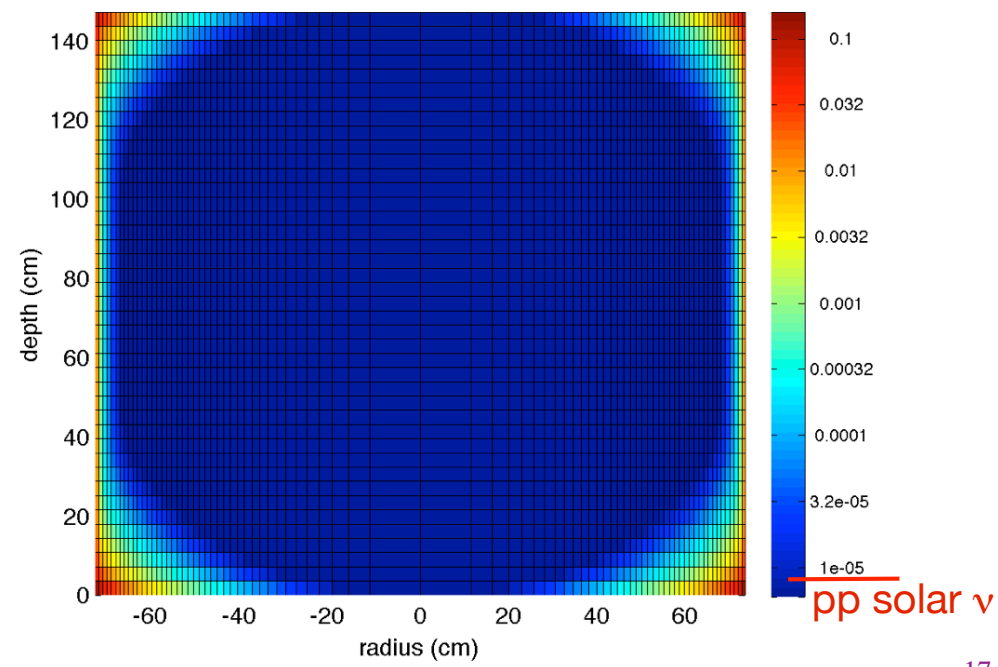


$$P(L) \cong \frac{L}{\lambda} e^{-\frac{L}{\lambda}}$$

300 kg LUX



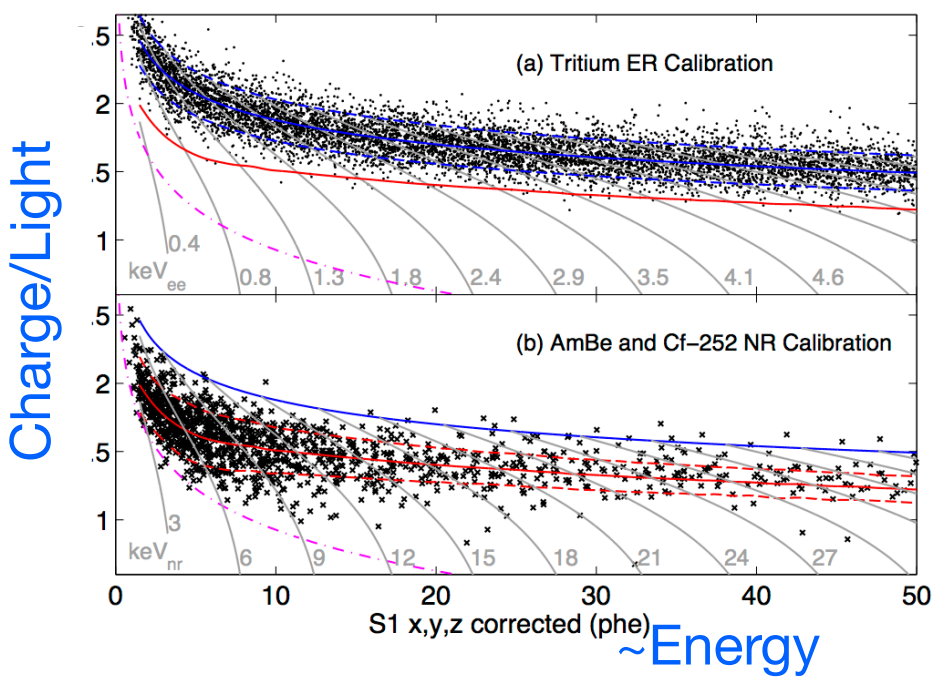
7 Ton LZ

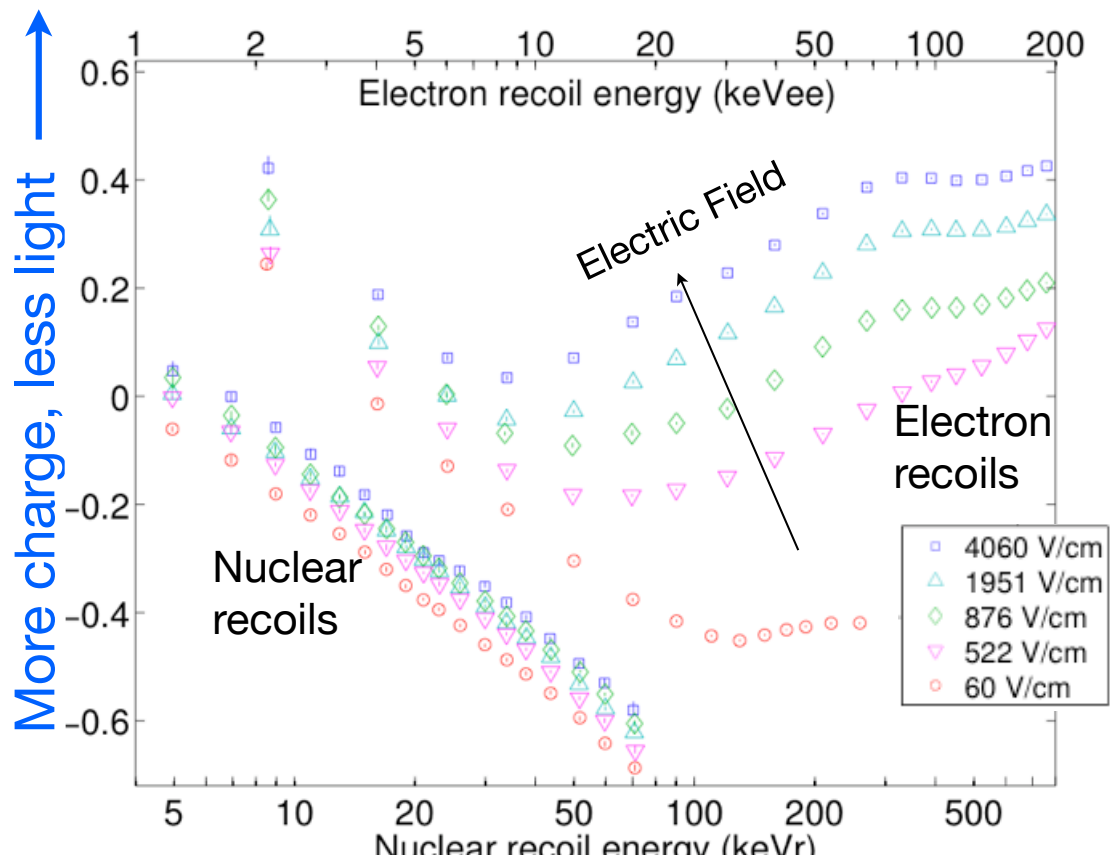


Charge and Light signals

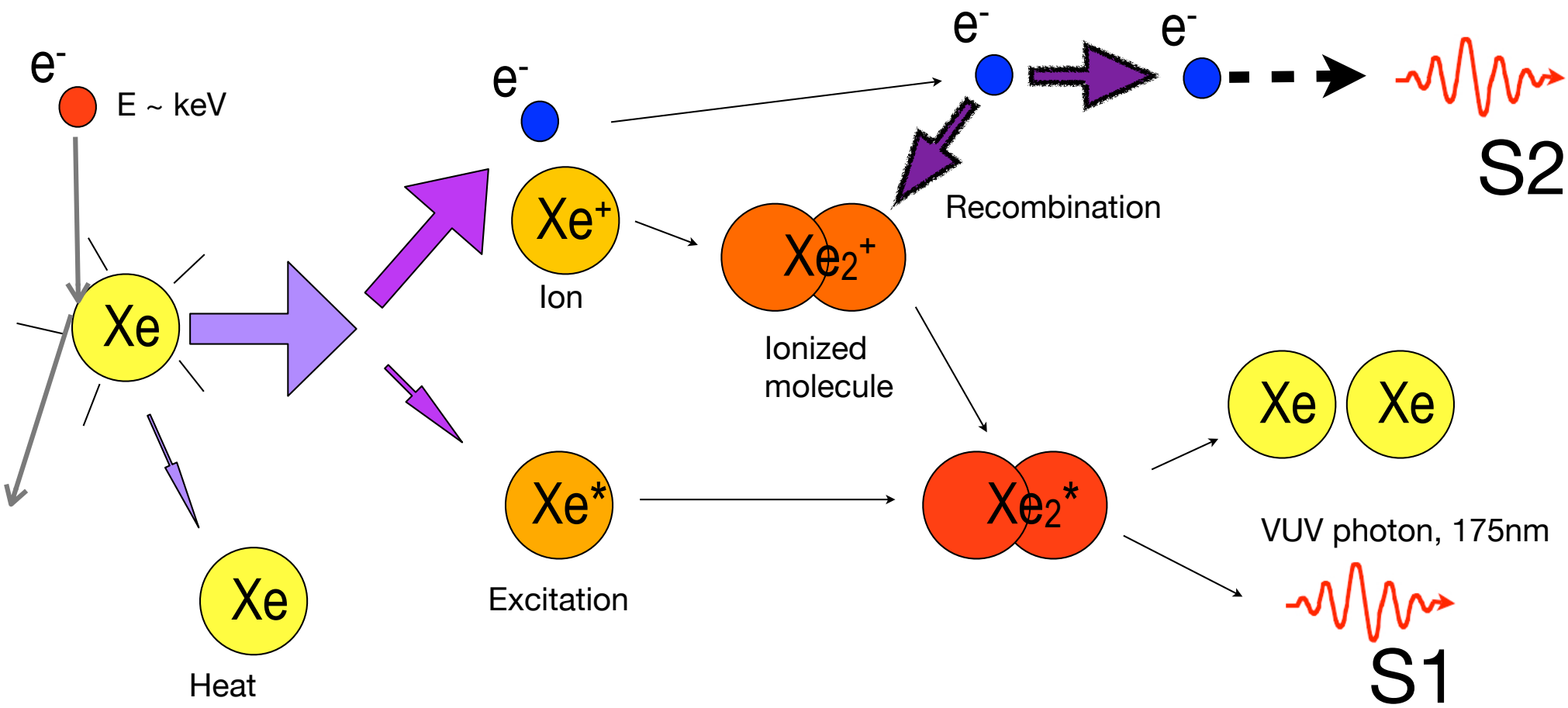
- Rejection of background depends on separation and width of electron recoil and nuclear recoil “bands”

- Complicated physics at play



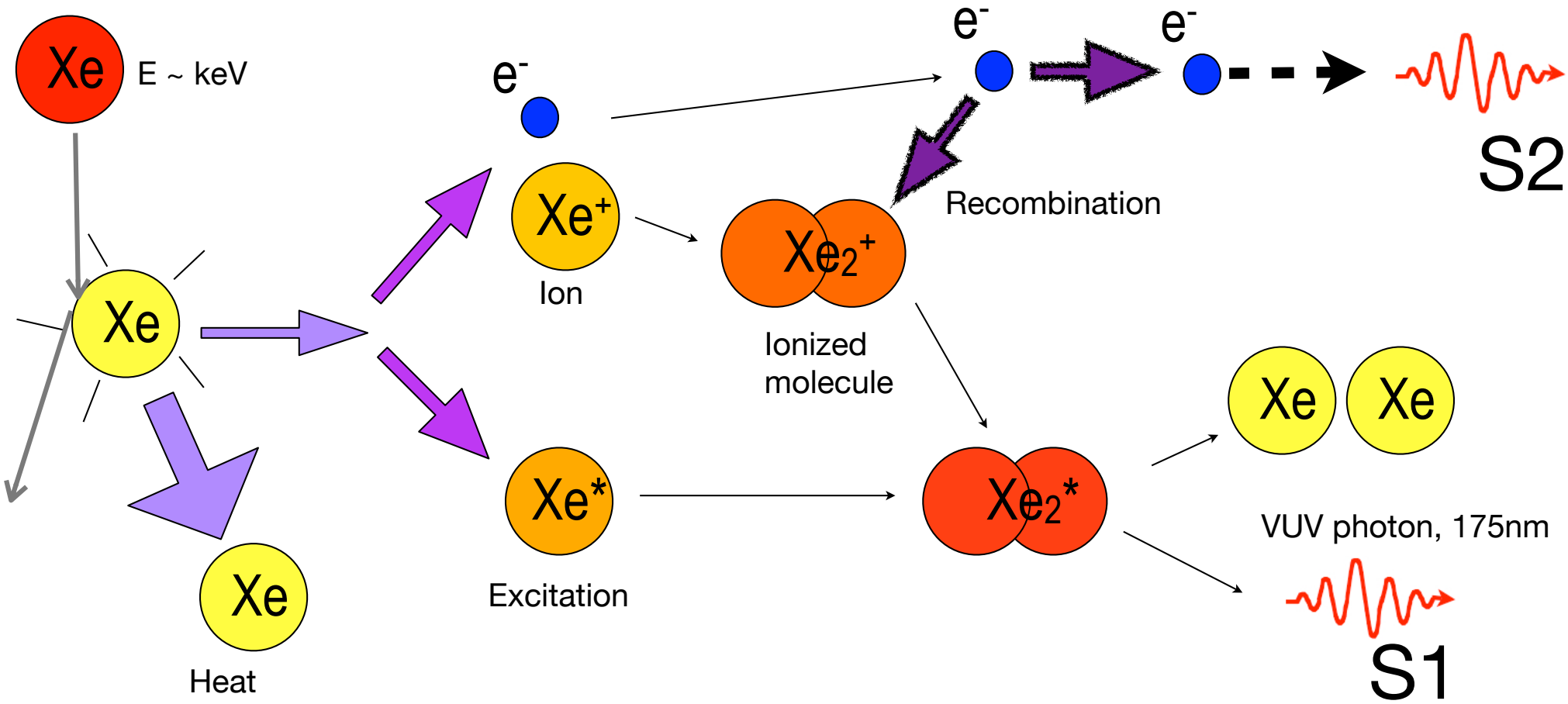


Signal production in liquid Xe



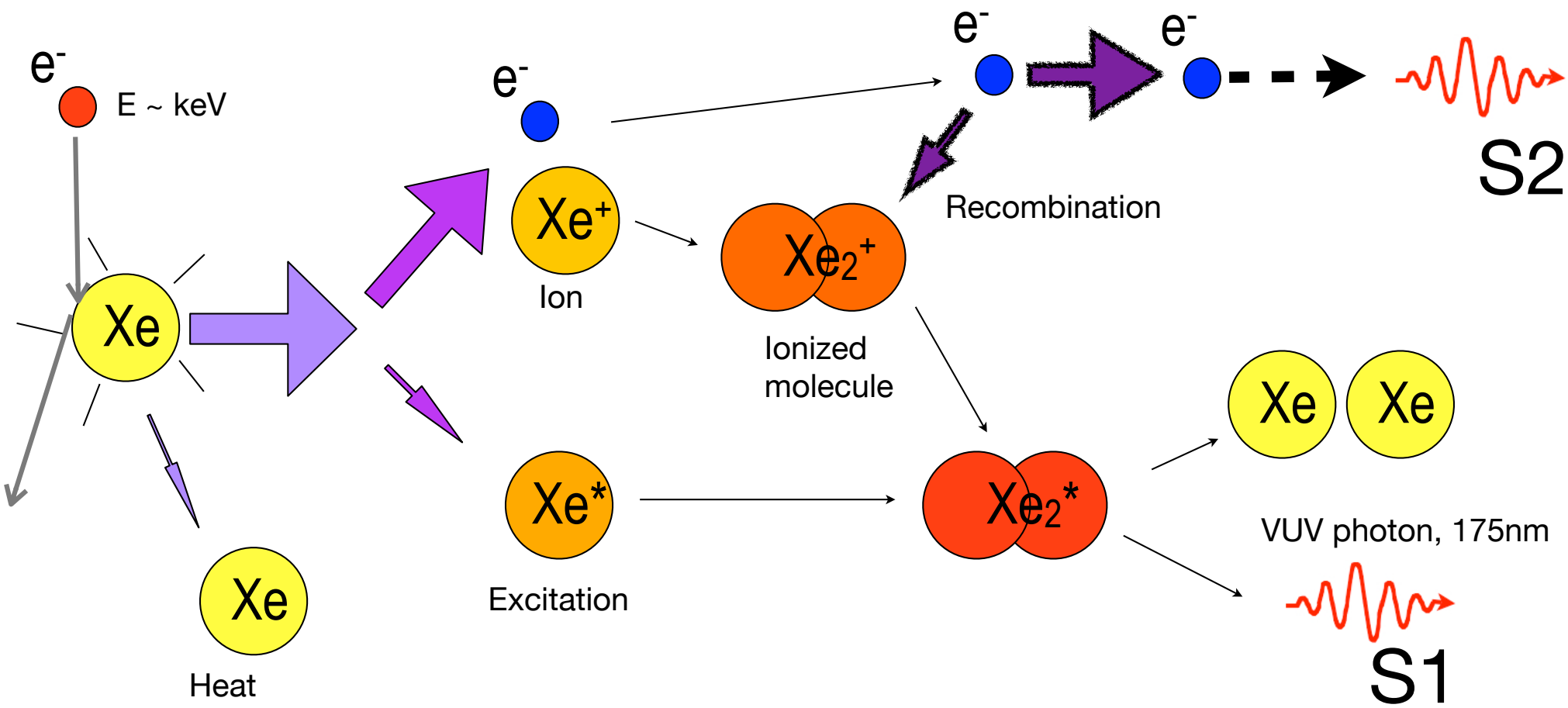
Electron Recoils

Signal production in liquid Xe



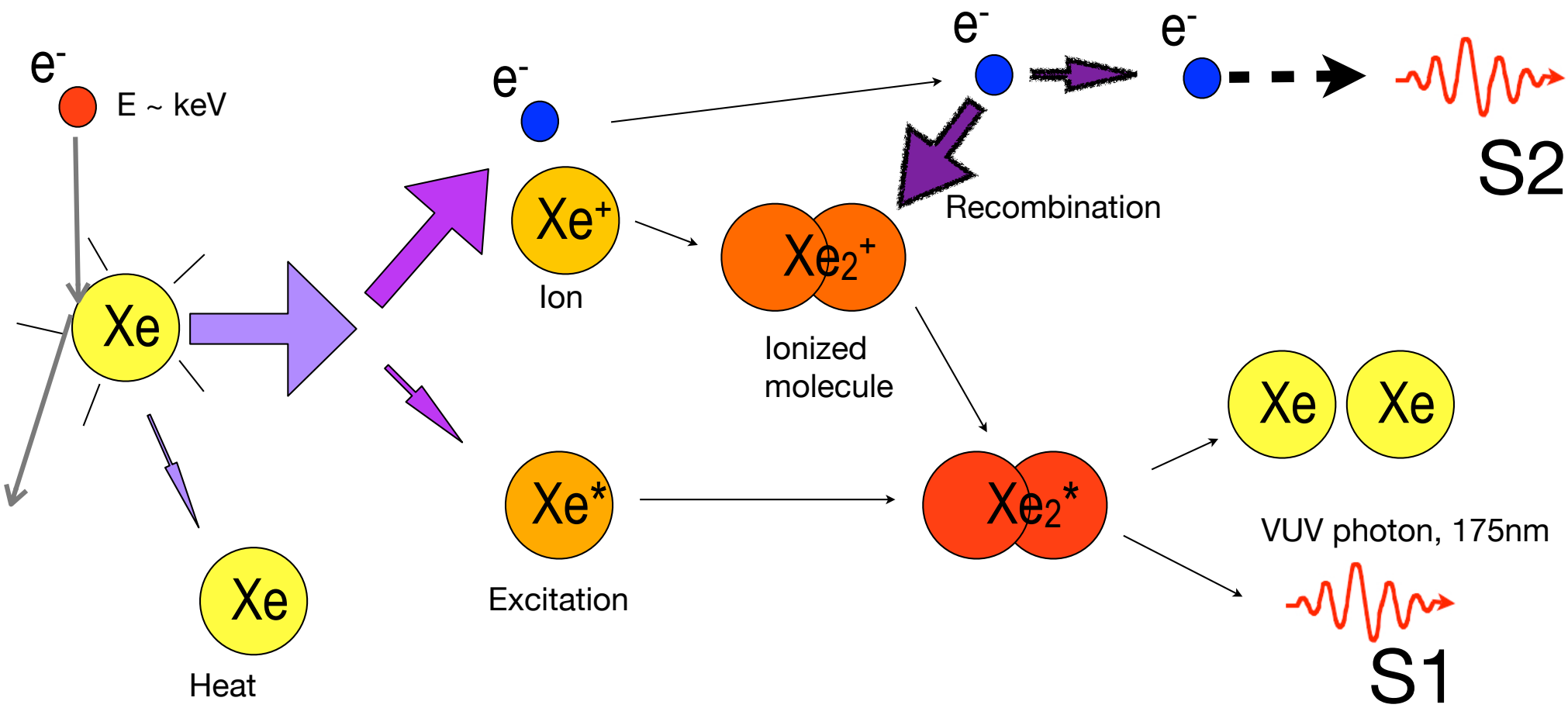
Nuclear Recoils

Signal production in liquid Xe



Electron Recoils - high electric field

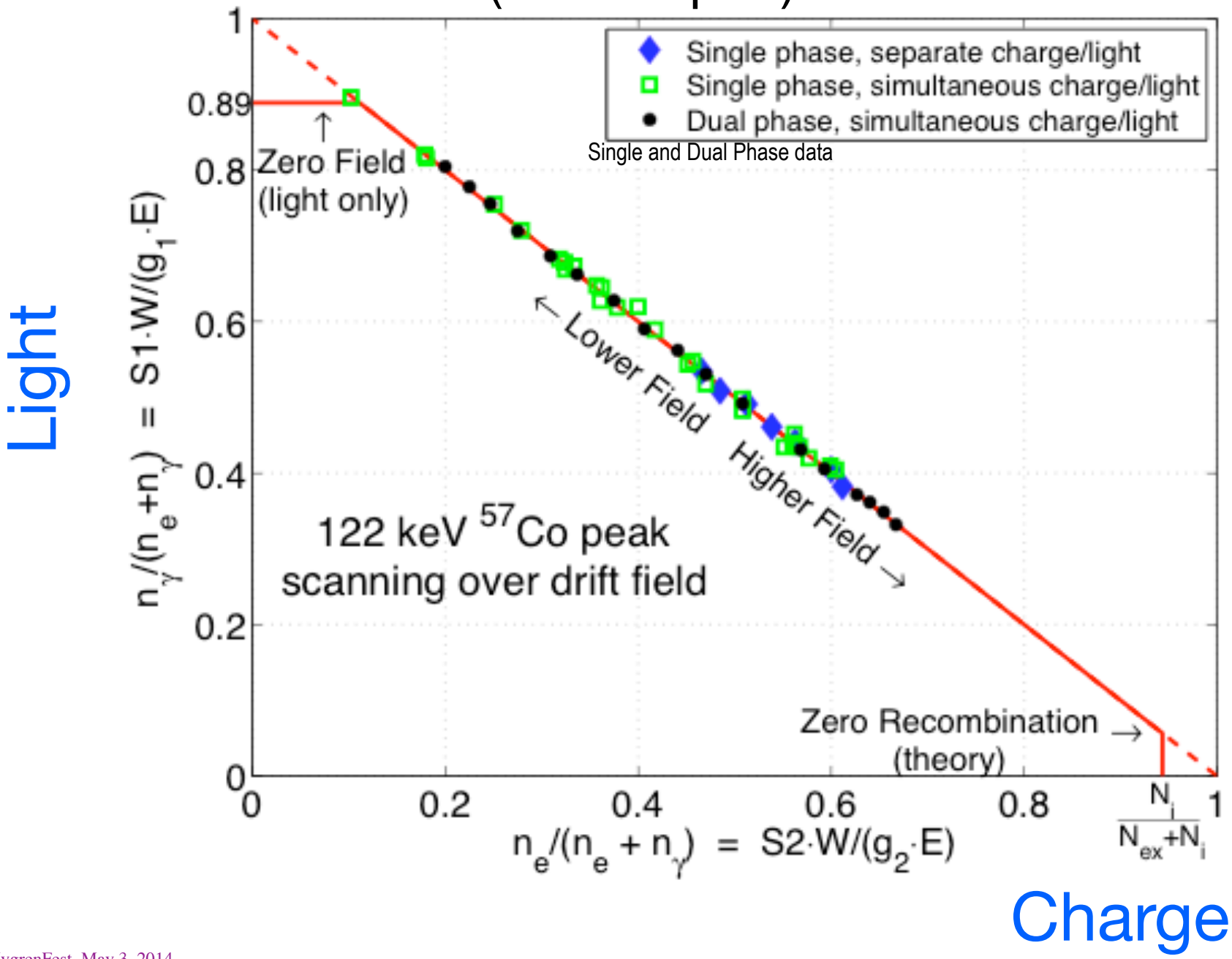
Signal production in liquid Xe



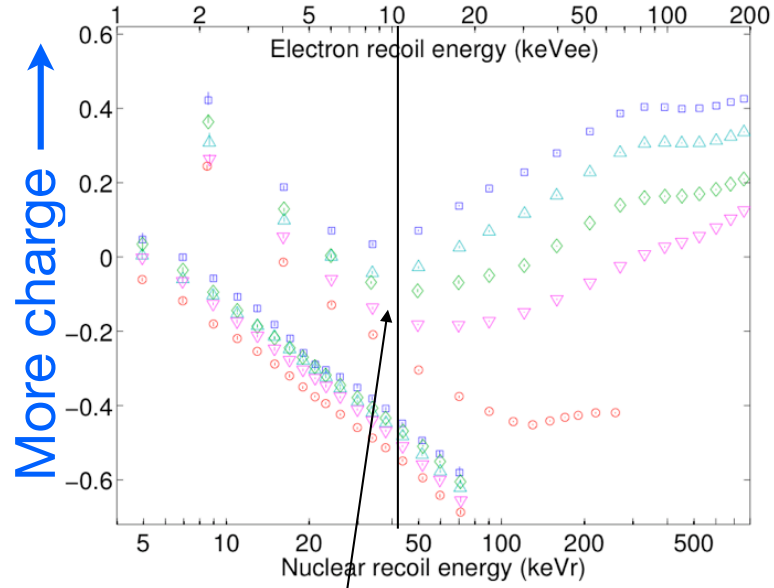
Electron Recoils - low electric field

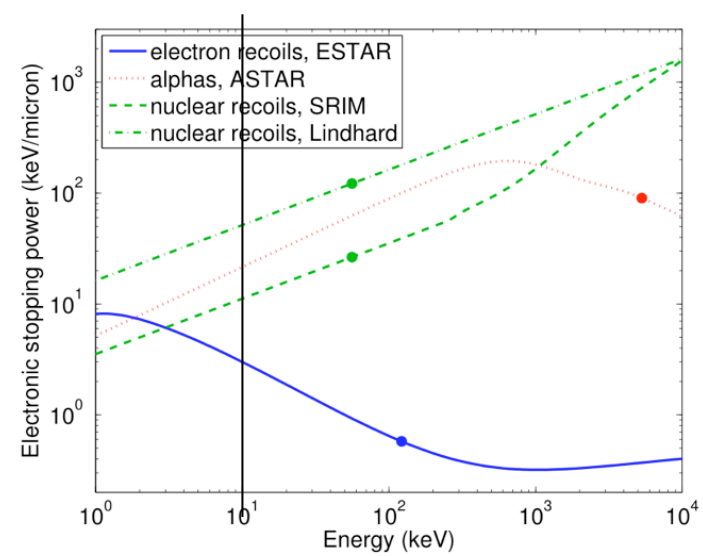
Anti-correlation data

("Doke" plot)



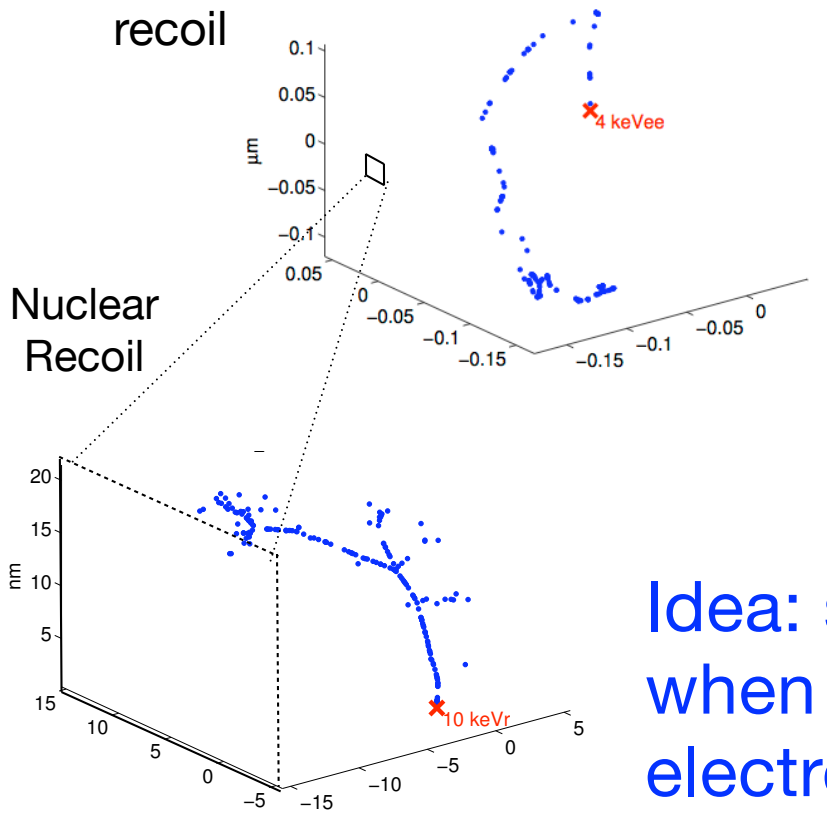
Bands not explained by dE/dx alone

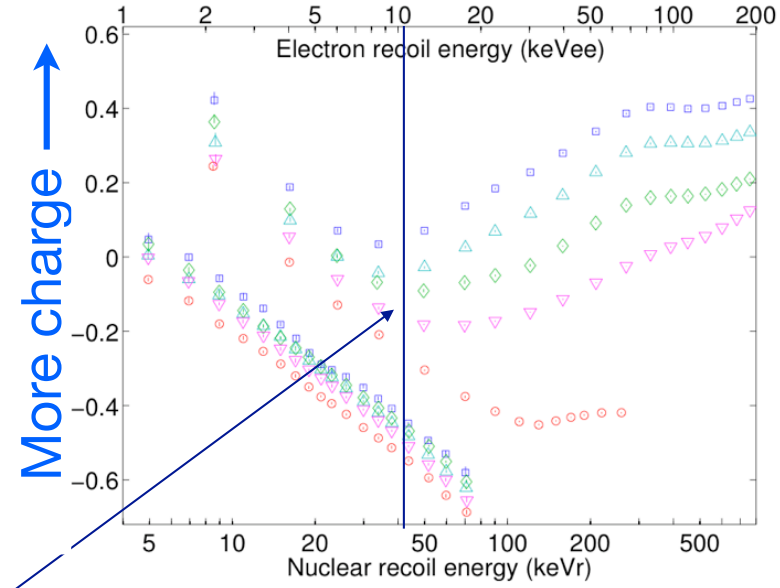




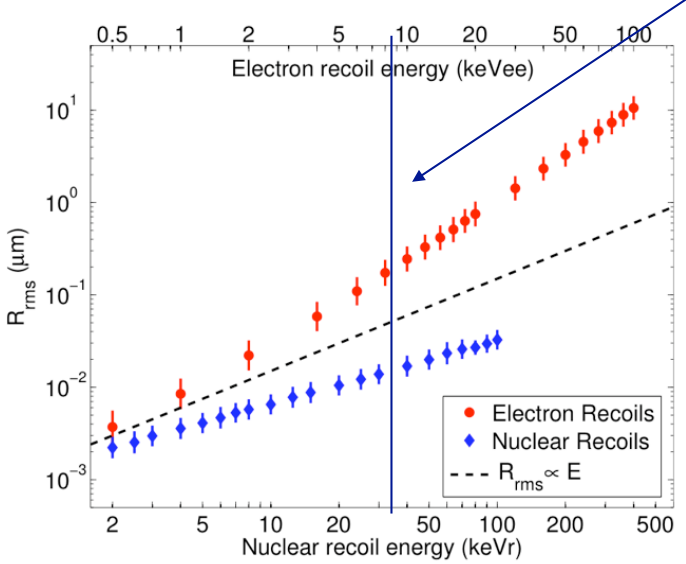
Electron recoil

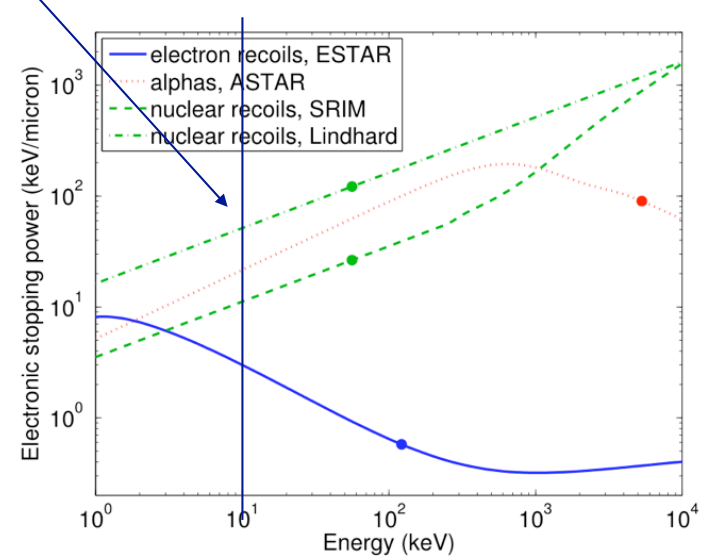
Nuclear Recoil





Idea: shift in electron recoil band occurs when track lengths drop below initial electron diffusion scale





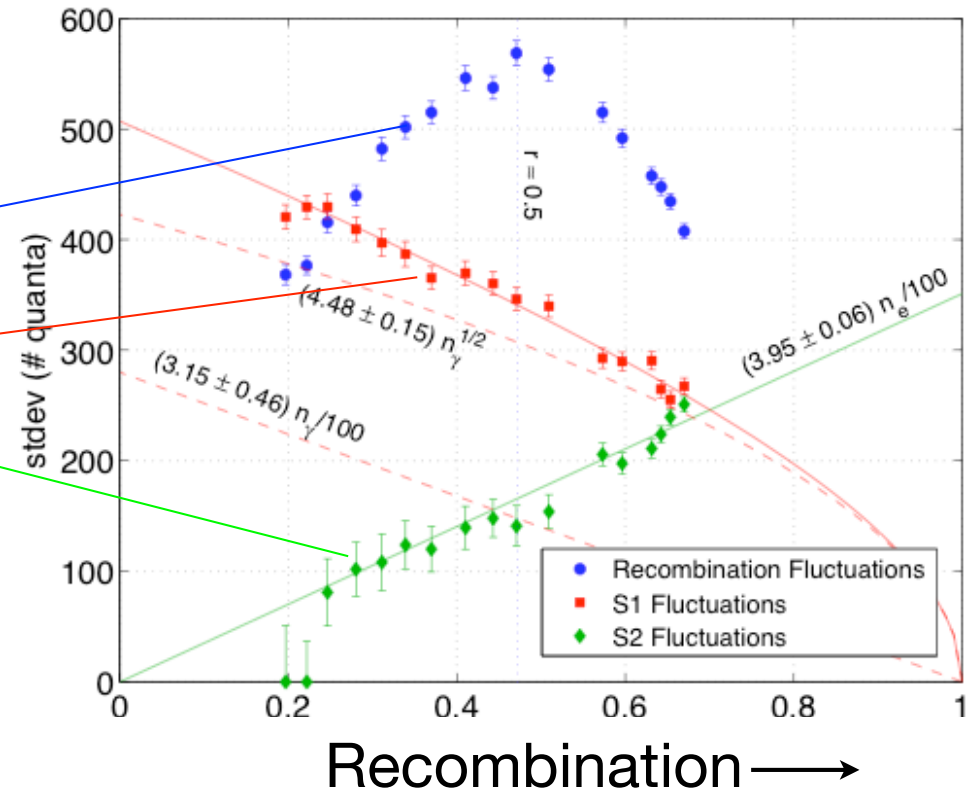
Band width

Electron Recoils At 122 keV

Recombination fluctuations

Light collection statistics

Linear S2 fluctuations



Electron recoil band width

This band width determines background discrimination

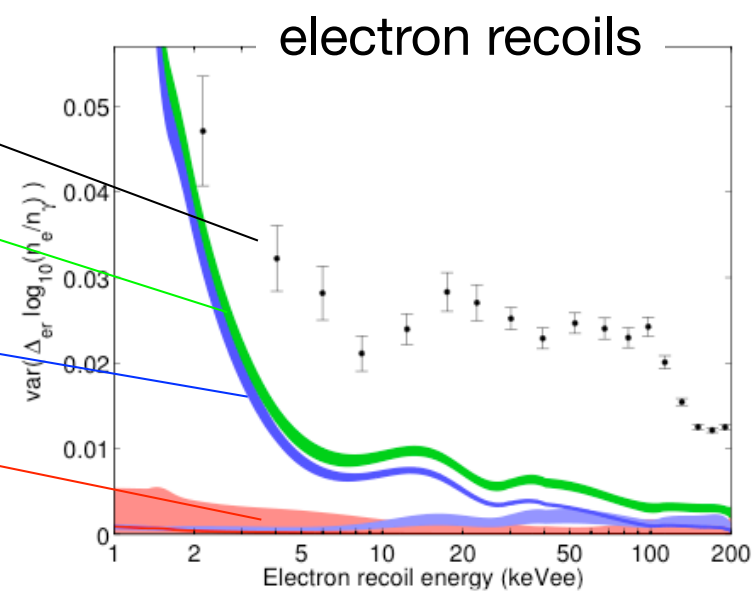
Energy Dependence

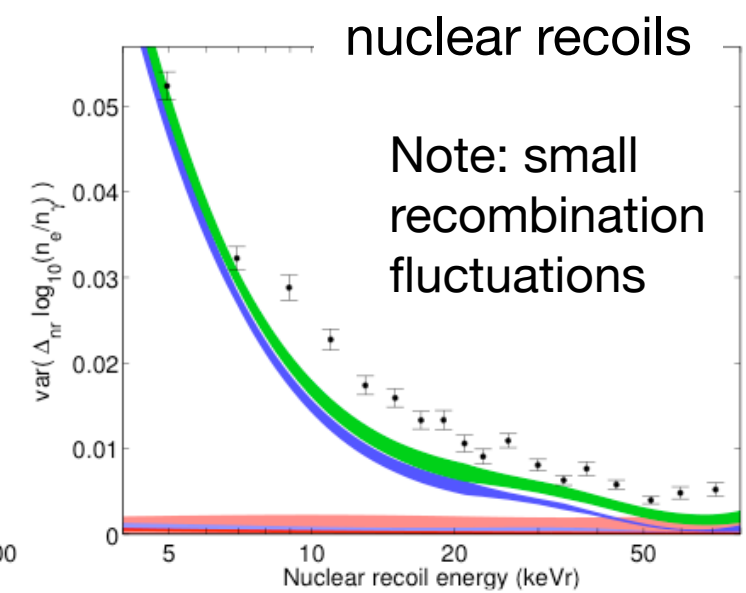
Total

S1+S2

S1 stat+inst

S2 inst+stat

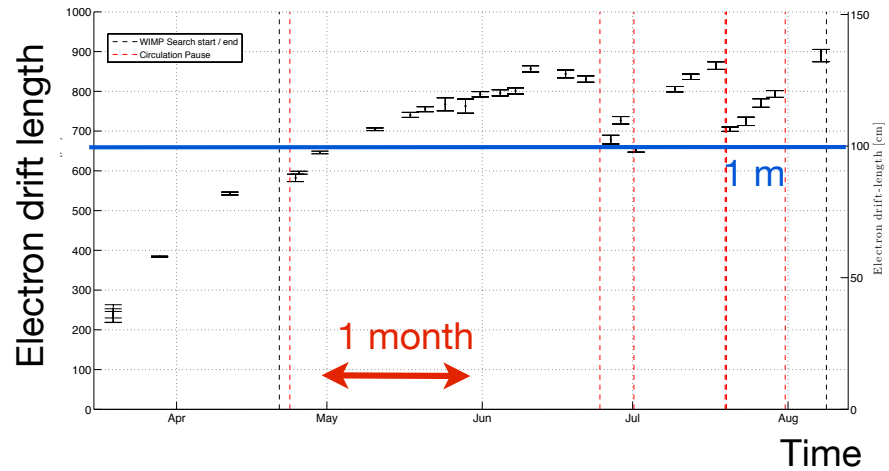




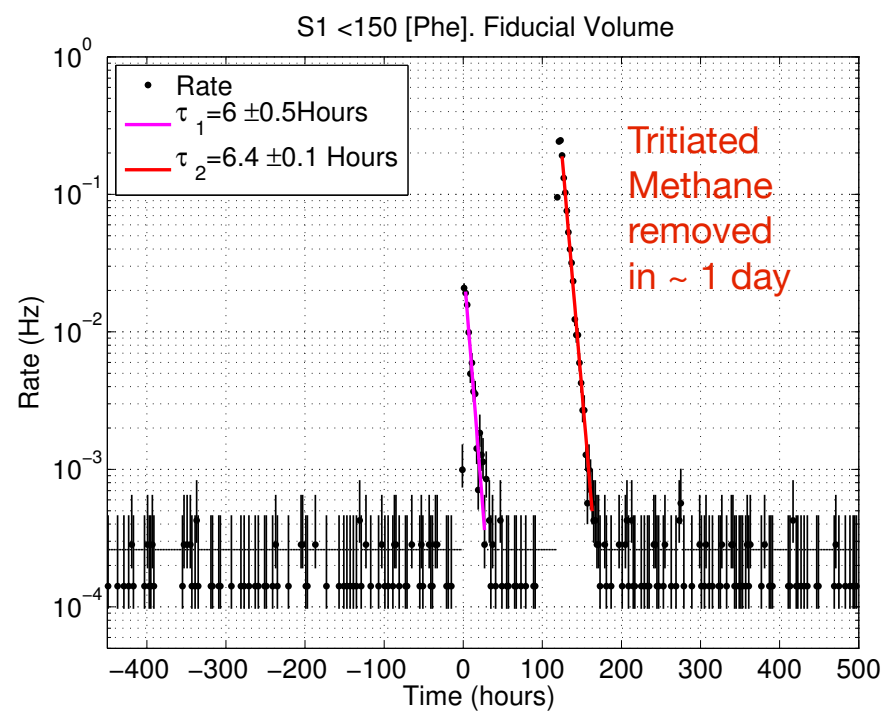
Note: small recombination fluctuations

Purification, Tritium

- Xe purity is challenging
- Heat exchange system for continuos processing.
  - 2-day turnover: 250 W -> ~10 W

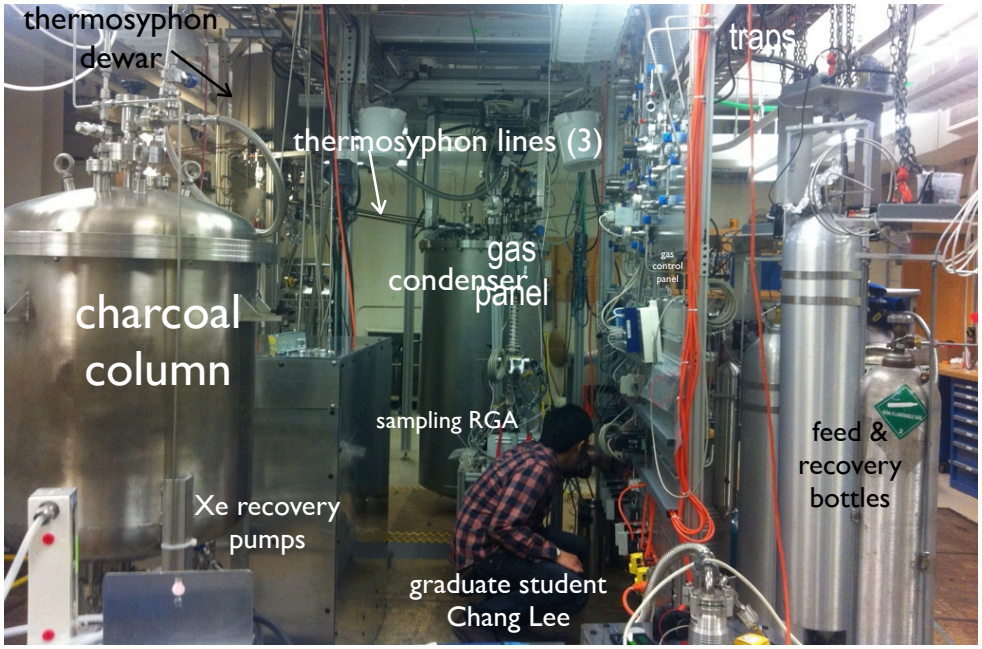


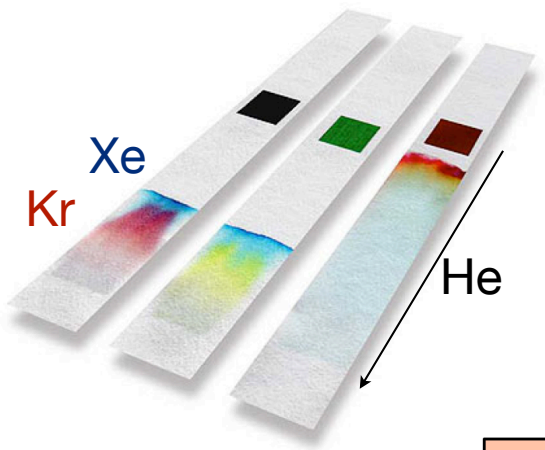
- Tritium injection:
  - Needed to calibrate center
  - *Only instance of injection of long-lived isotope into a low background experiment*

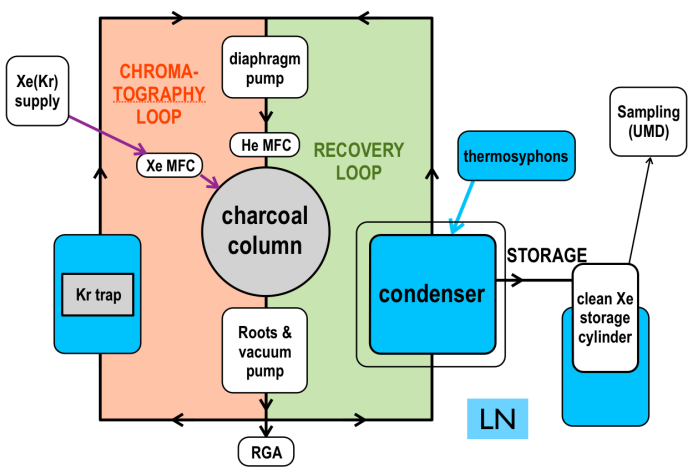


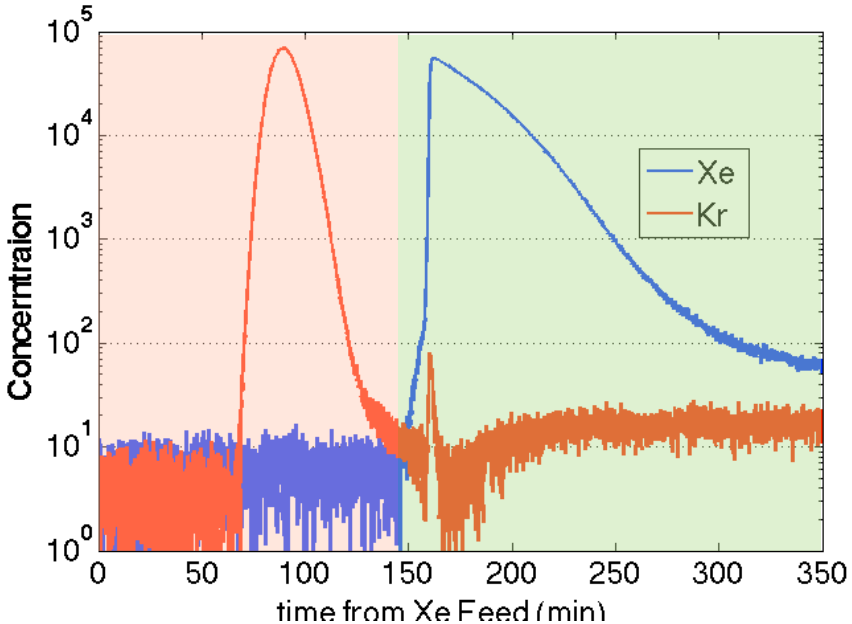
Krypton: kryptonite for Xe

Krypton-85:
- 10-y $T_{1/2}$ beta decay
- can't self-shield
- ~130 ppb in purchased Xe
  - 20 ppt ~ 122 PMTs
- noble gas: non-reactive





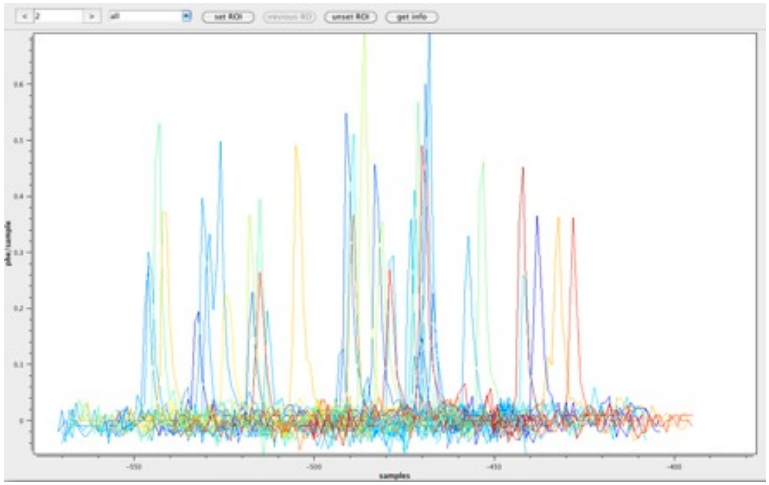




Life at threshold

- WIMP energy ~ keV
  - Light mass WIMPS -> 100 eV
- Every eighth photon, and every single electron generated in the TPC are measured
- Higher drift fields give better background rejection
  - Higher electron emission from grids
- An “interesting” environment in which to find WIMPs

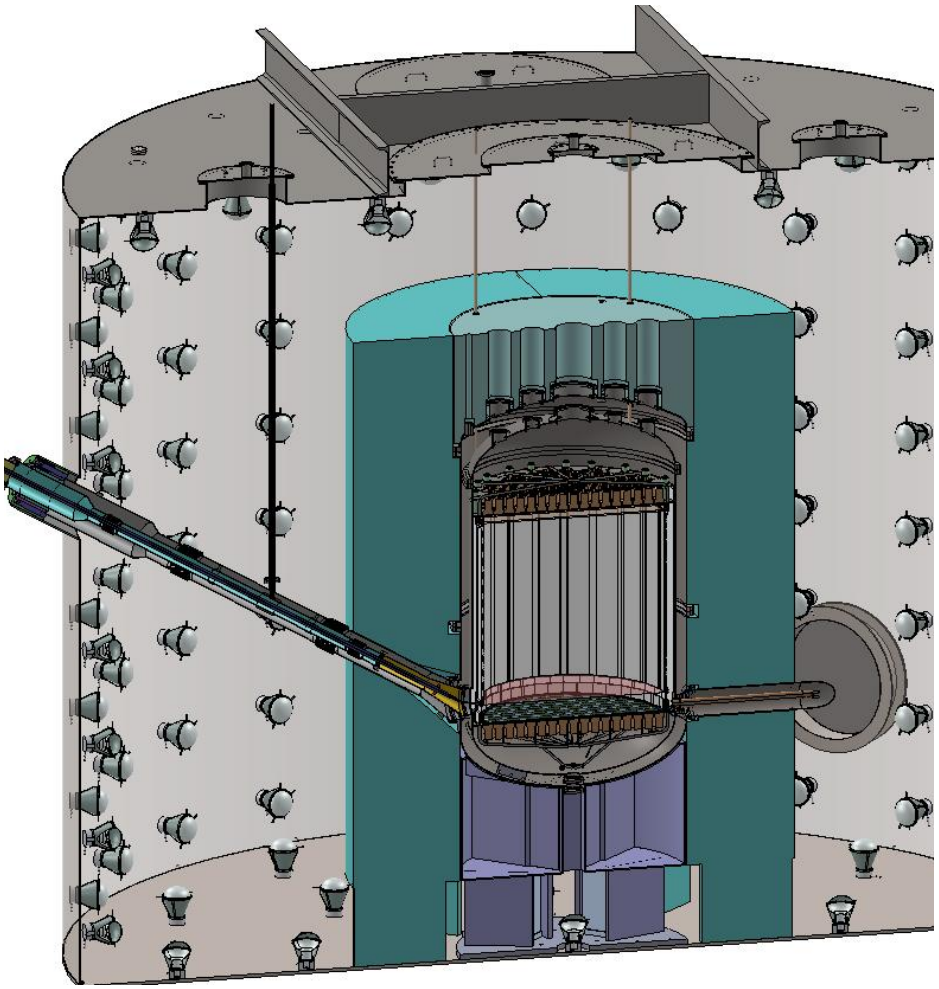
A single electron



~1 μsec

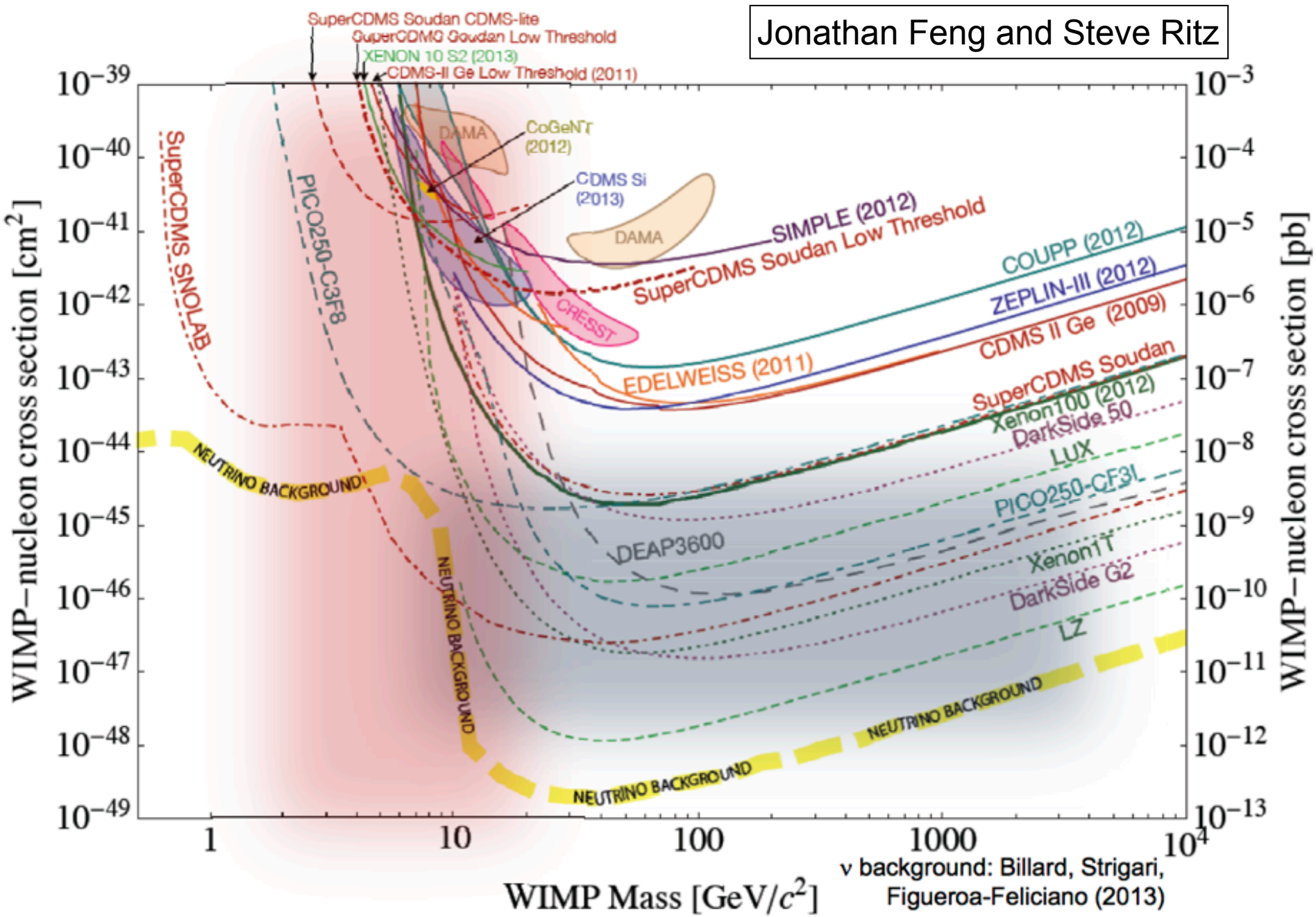
LZ: LUX + ZEPLIN

- 20-fold scale-up from LUX
- Gd-loaded scintillator + Xe "skin" outer detector
  - Effective for neutrons and gammas
- ~6 ton fiducial in which dominant background is neutrinos
  - Electron recoil channel: pp solar
  - Nuclear recoil channel: coherent scatter of atmospheric neutrinos



CURRENT STATUS AND FUTURE PROSPECTS

Jonathan Feng and Steve Ritz



ν background: Billard, Strigari, Figueroa-Feliciano (2013)

Future directions

- LZ is not quite at neutrino limit
- Background rejection might or might not be sufficient to defeat pp solar neutrino background
- Get rid of PMT radioactivity
  - Would enable simultaneous ßß-decay and DM search
- Please buy LED light bulbs