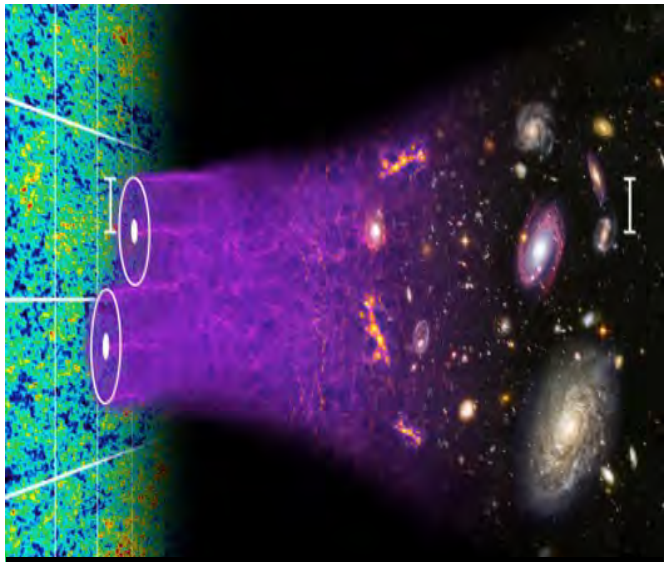
Do WIMPs Rule?
The LUX & LZ Experiments and the Search for Cosmic Dark Matter

Dan Akerib

SLAC National Accelerator Laboratory
Kavli Insitute for Particle Astrophysics & Cosmology

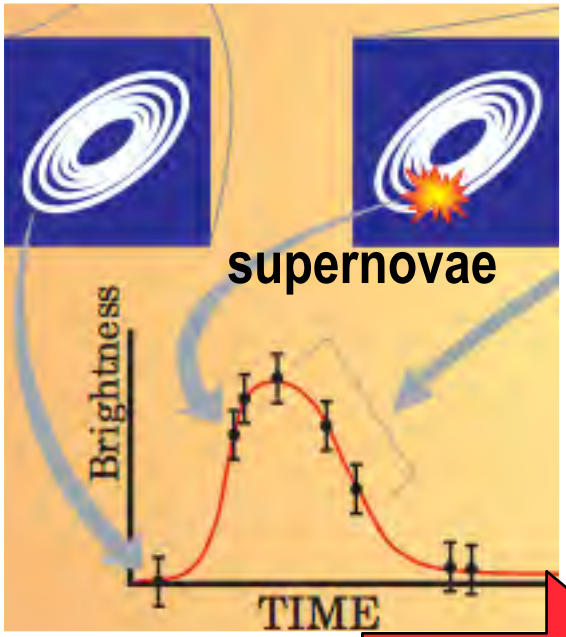
Standard cosmology: An inventory of the universe

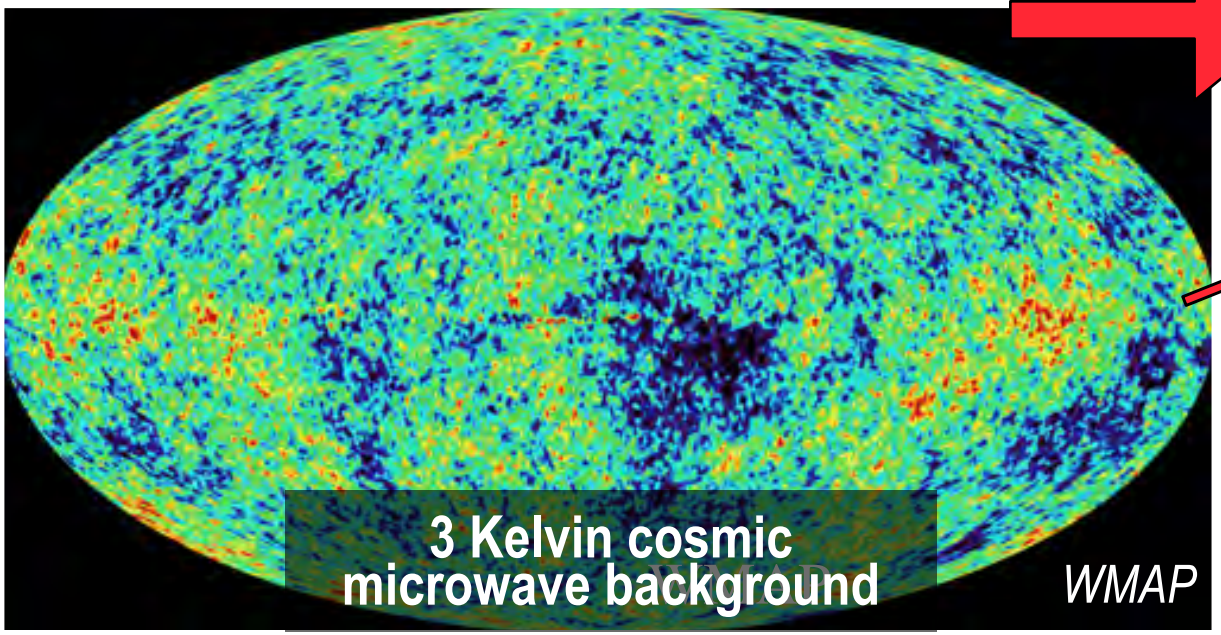
SDSS-III / BOSS



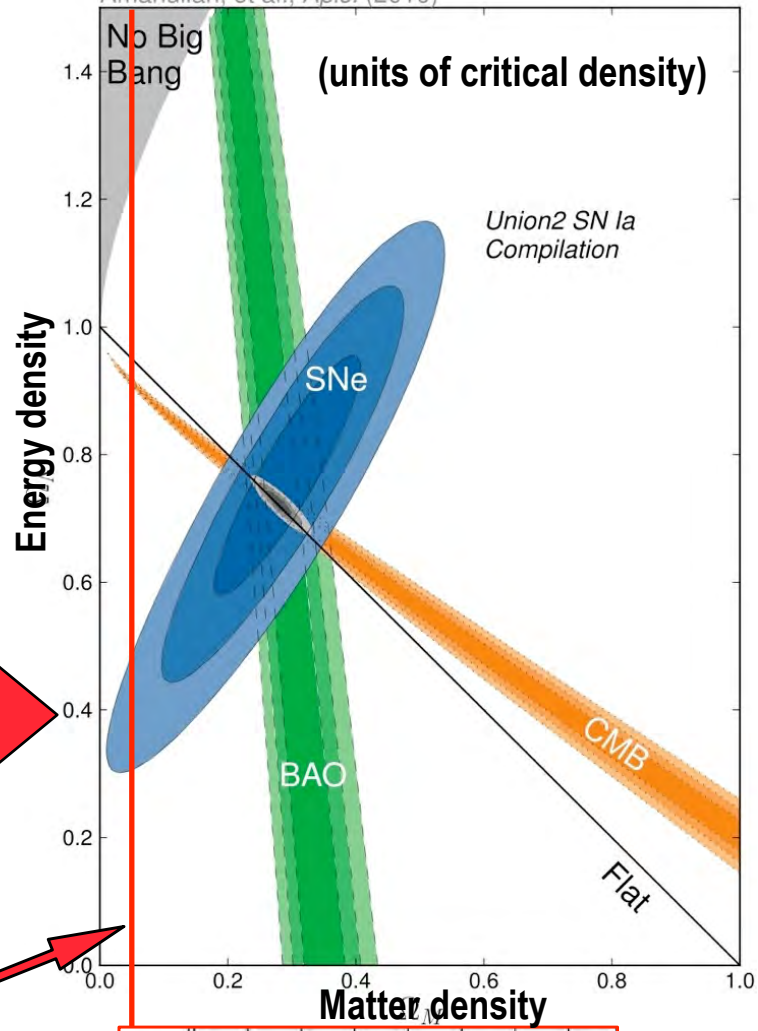
Baryon acoustic oscillations

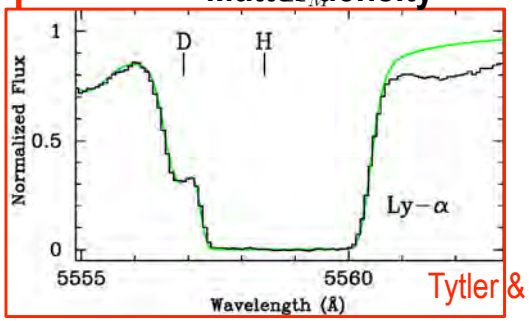
from Perlmutter, Phys. Today





Supernova Cosmology Project
Amanullah, et al., *Ap.J.* (2010)





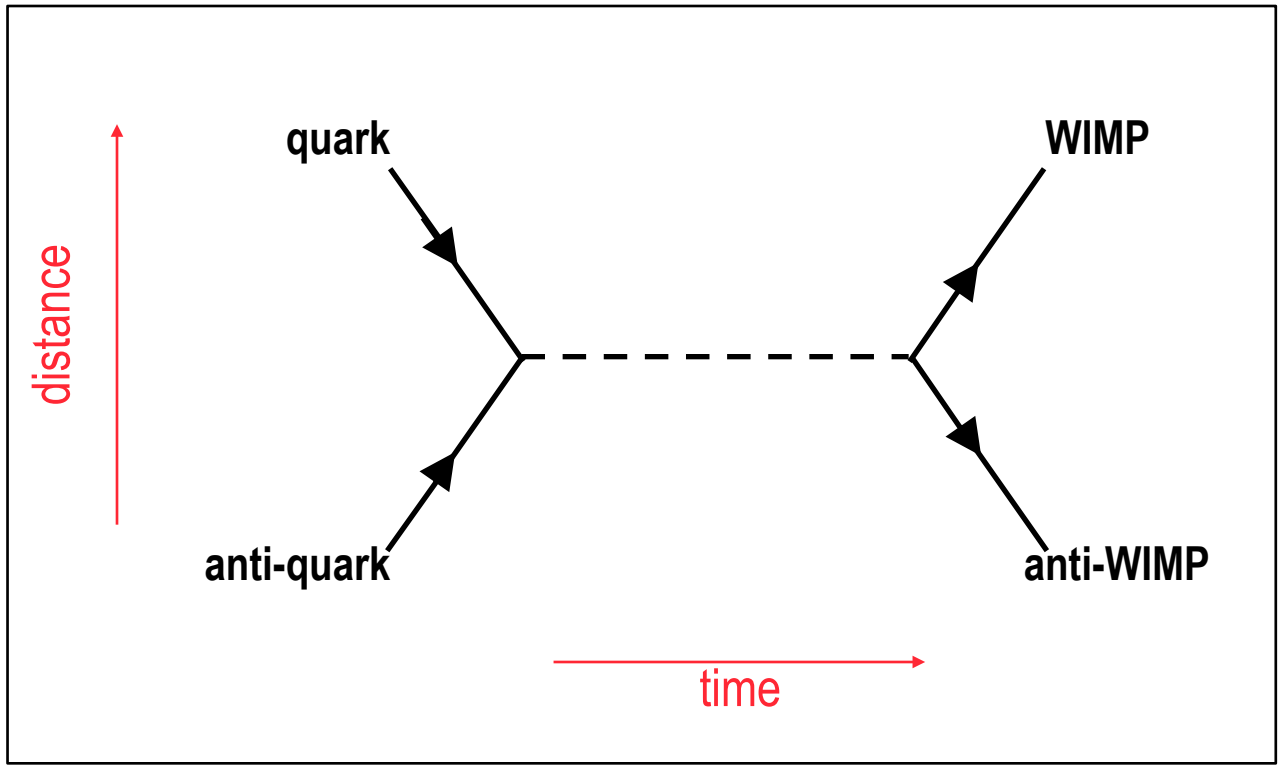
Tytler & Burles

WIMP Hypothesis

- Early Universe as Particle Factory
  - Not enough protons and neutrons produced in the Big Bang

Convert energy to mass

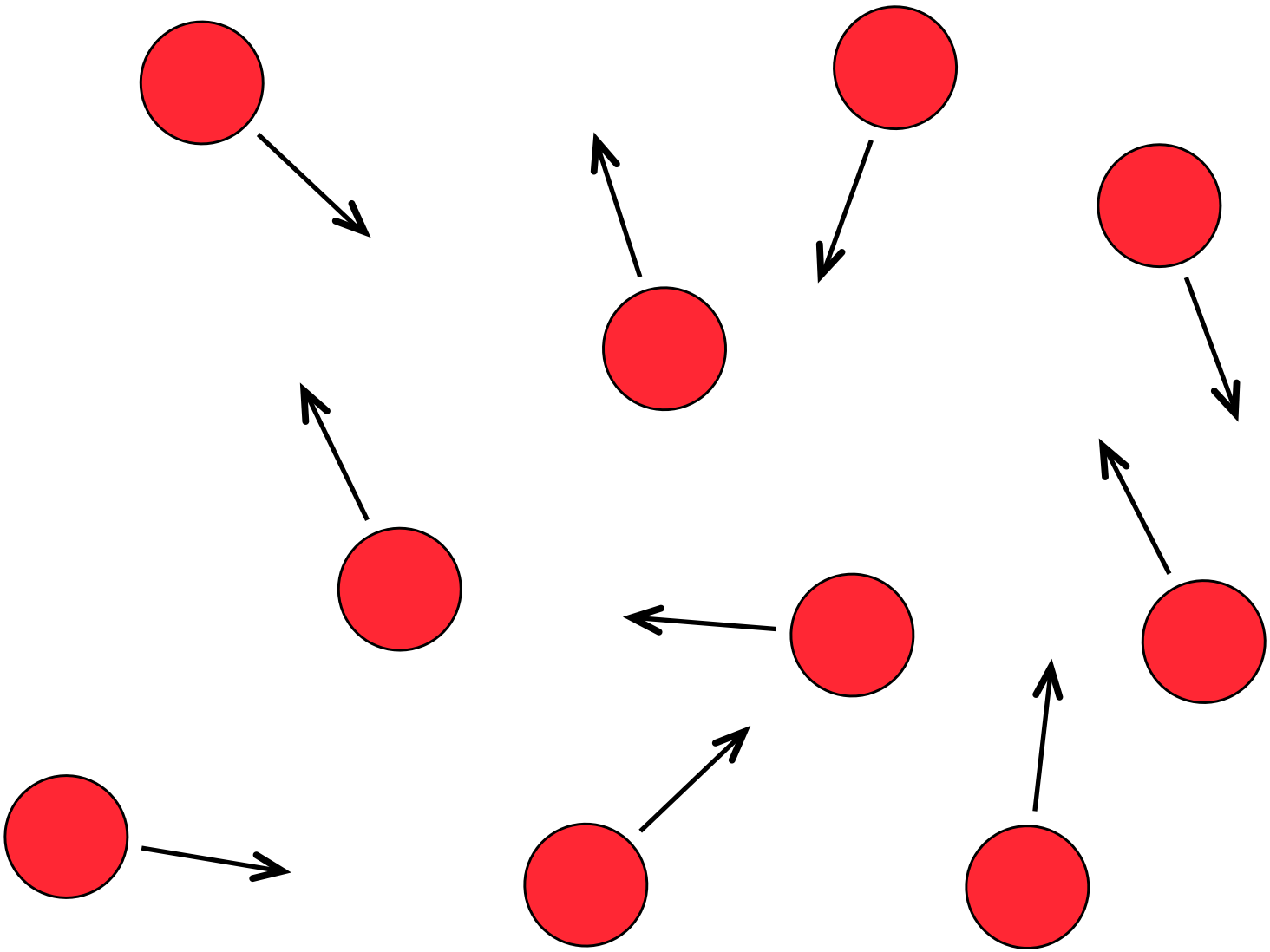
$E=mc^2$



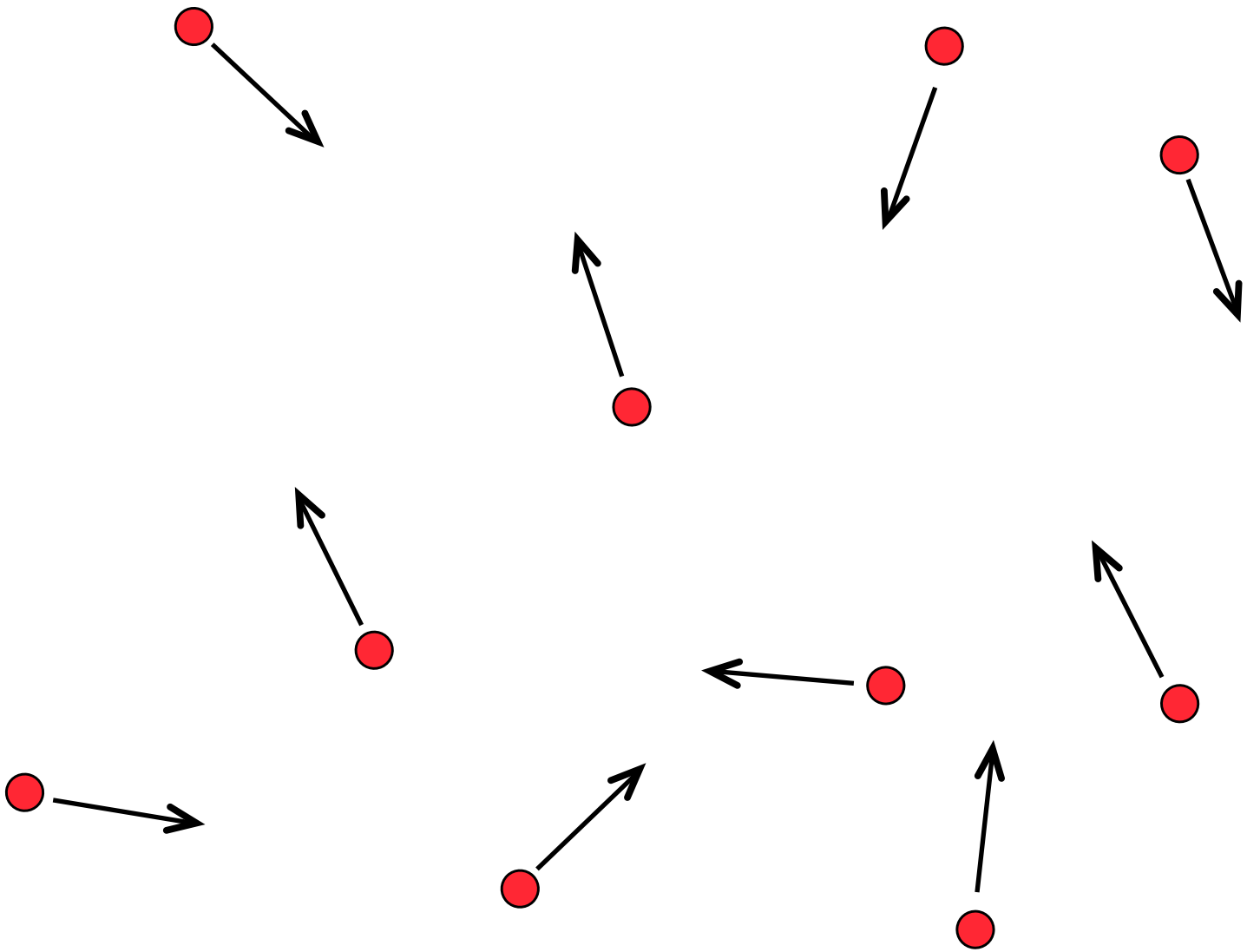
- ***A new type of particle:*** **WIMPs = weakly interacting massive particles**

Massive: source of gravity **Weakly-interacting: not star forming**

cross section → annihilation rate



cross section → annihilation rate



WIMP freezeout

- **WIMP pairs produced in equilibrium**
- **Annihilation *stops* when number density falls too low**

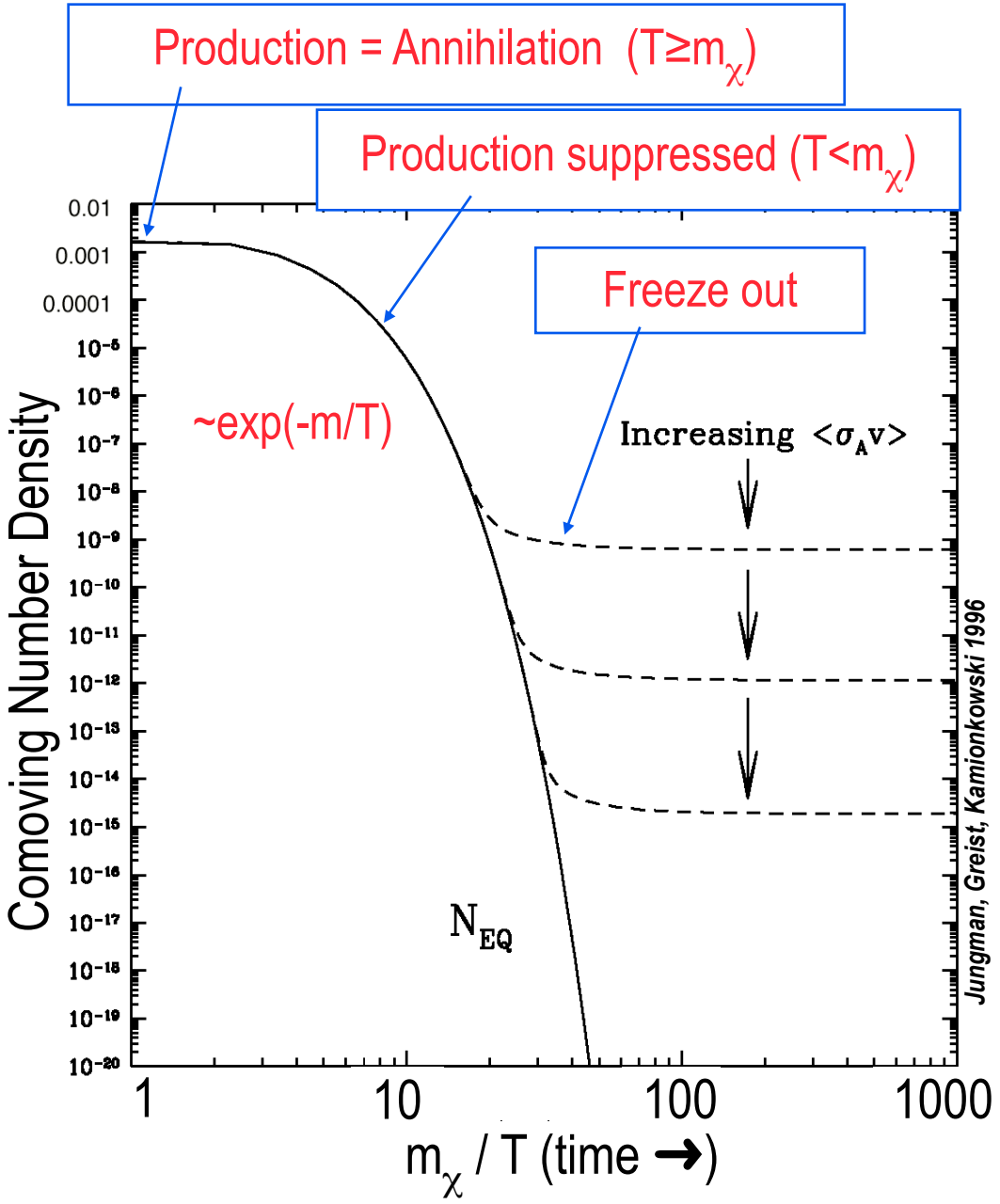
$$H > \Gamma_A \sim n_\chi \langle \sigma_A v \rangle$$

→ annihilation rate slower than Hubble expansion ("freeze out")

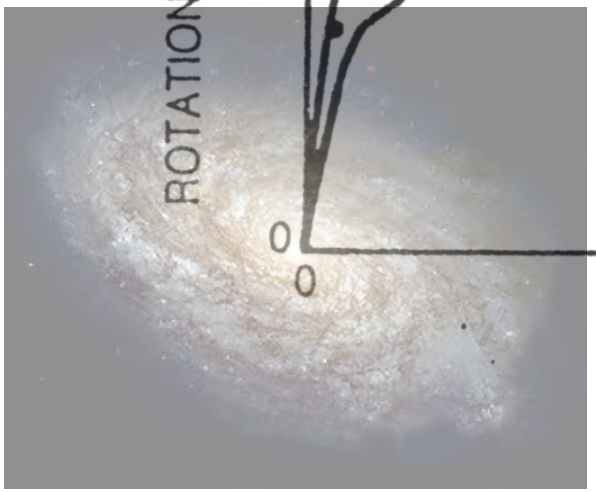
→ mean free time > age

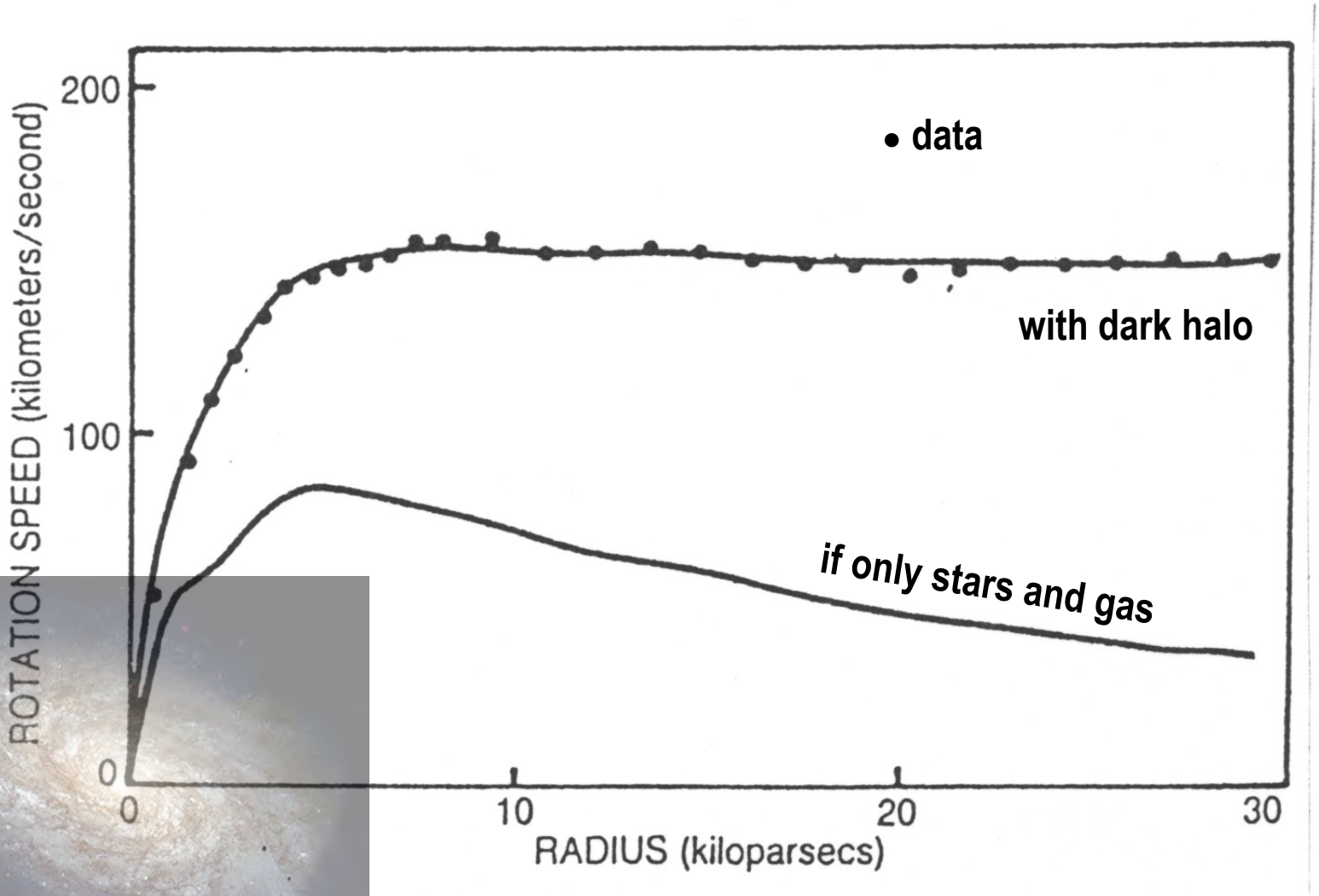
- **For $\Omega_\chi \approx 1$**
  - **M ~ 10-1000 GeV**
  - **σ_A ~ electroweak**

SUSY/LSP?



Dark Matter in Galactic Halos





Vera Rubin and Kent Ford, 1978

Scattering experiment

WIMP

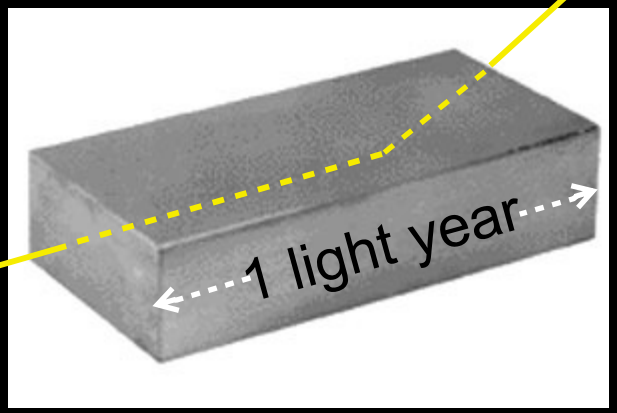
density, speed

dark matter halo

10^{16} WIMPs/year

10^{-16} light years

detector

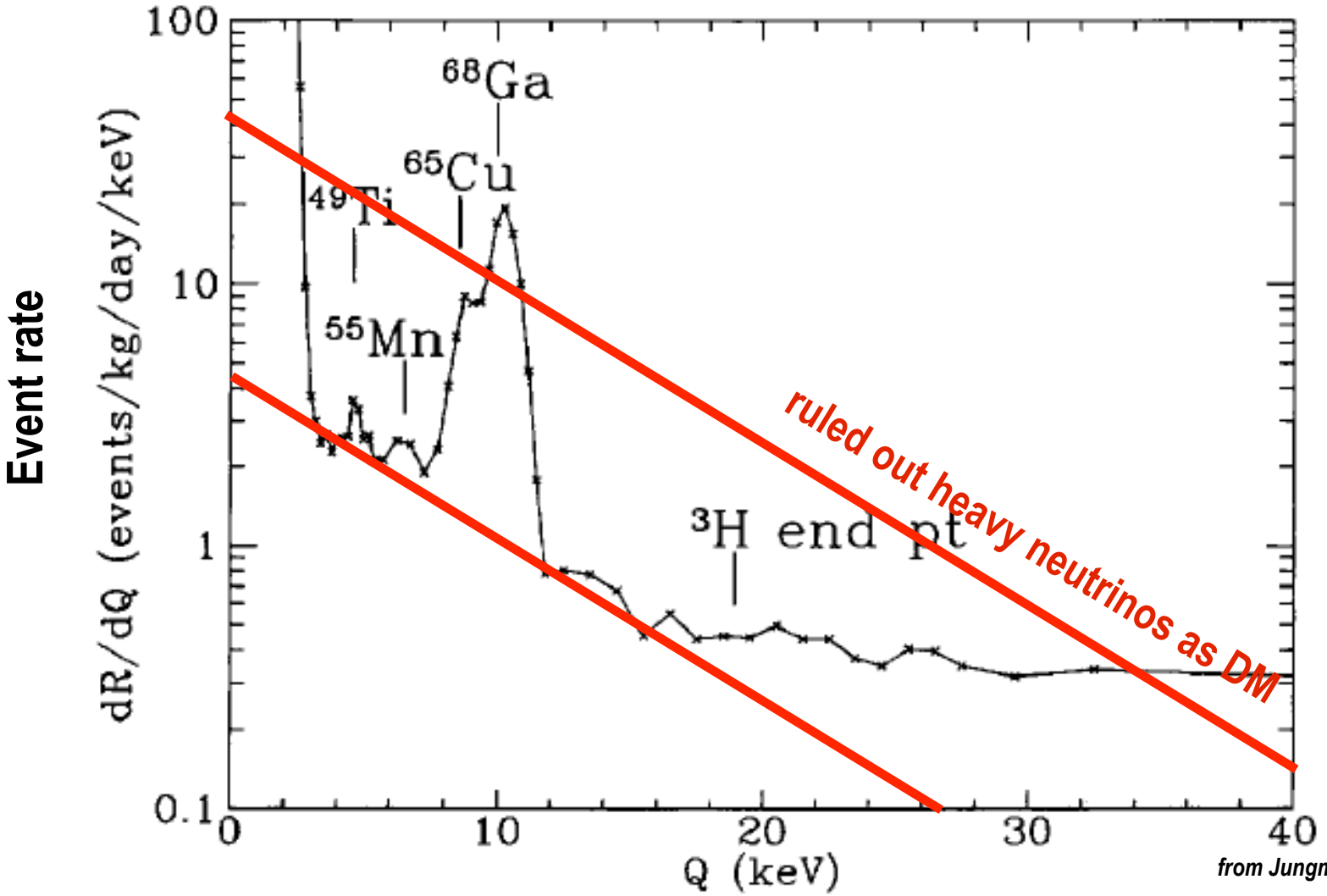


Cross section: WIMP scatters once in a light year of lead

Rate ~ few events / year

WIMP search - c.1988: converted *neutrino* detector

- Germanium ionization detector at the Oroville Dam, CA searching for double beta decay - progenitor to Majorana



from Jungman et al. (D.O. Caldwell et al.)

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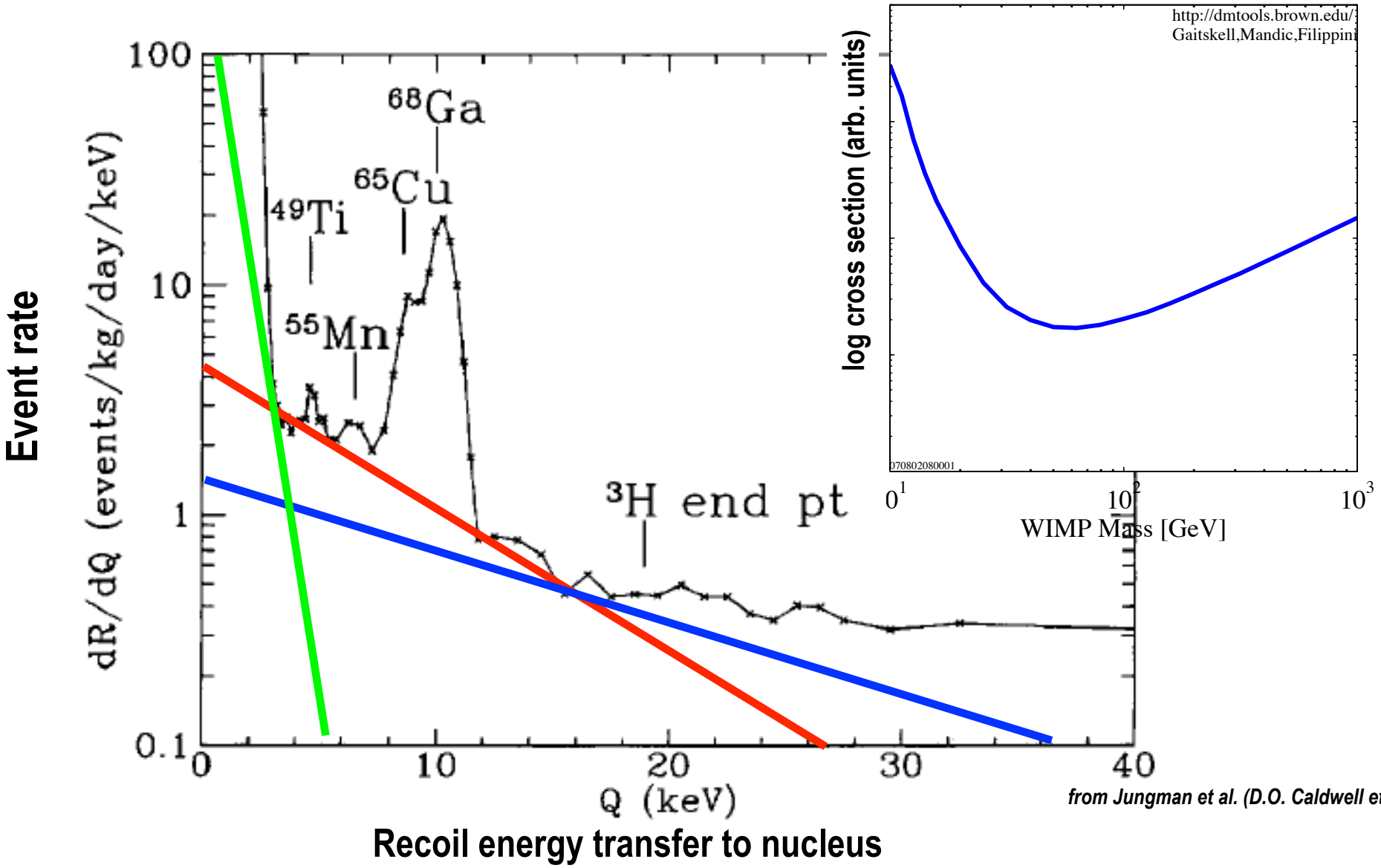
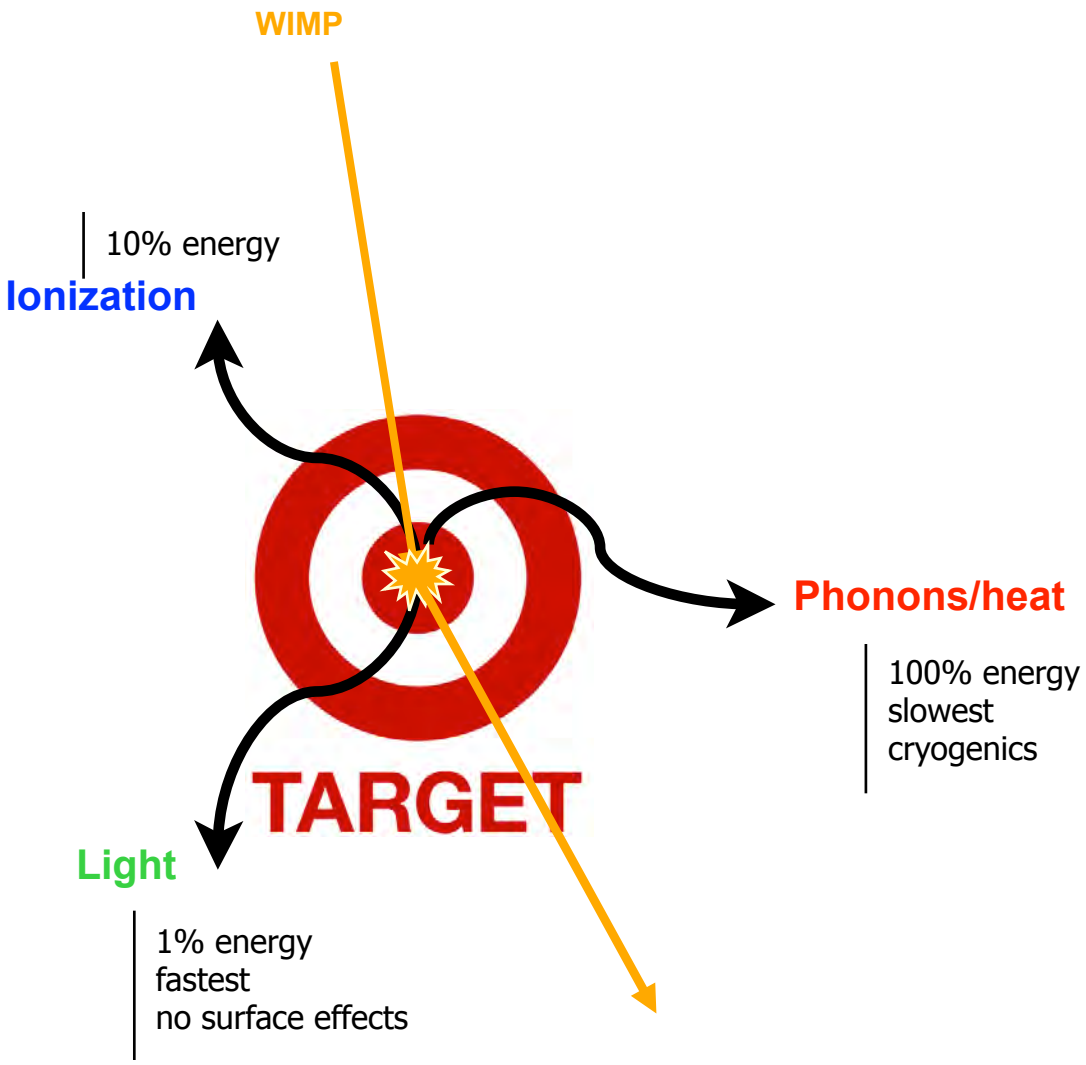
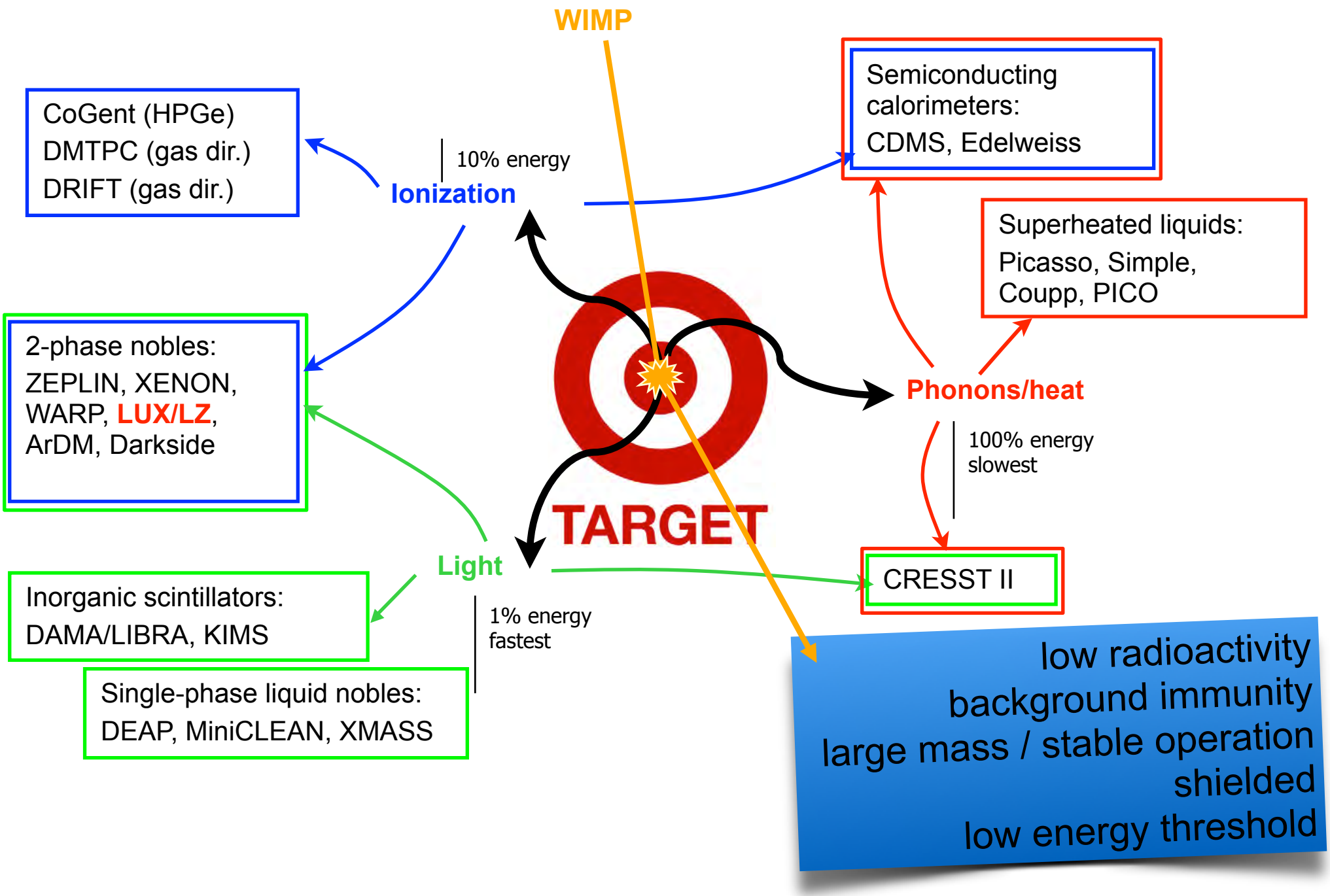


from Jungman et al. (D.O. Caldwell et al.)

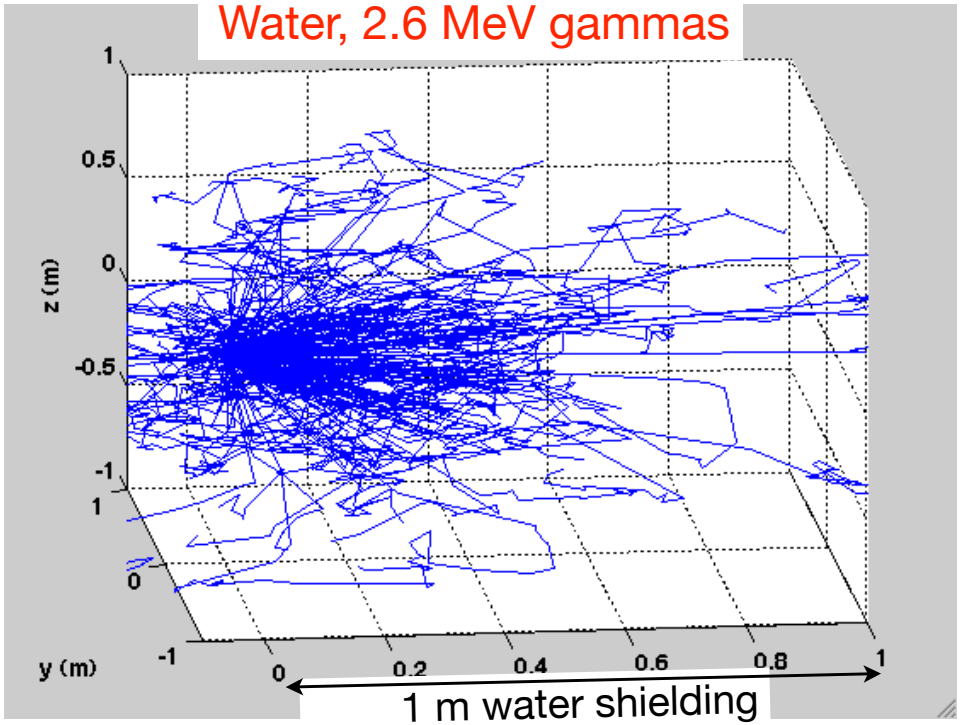
Energy deposition

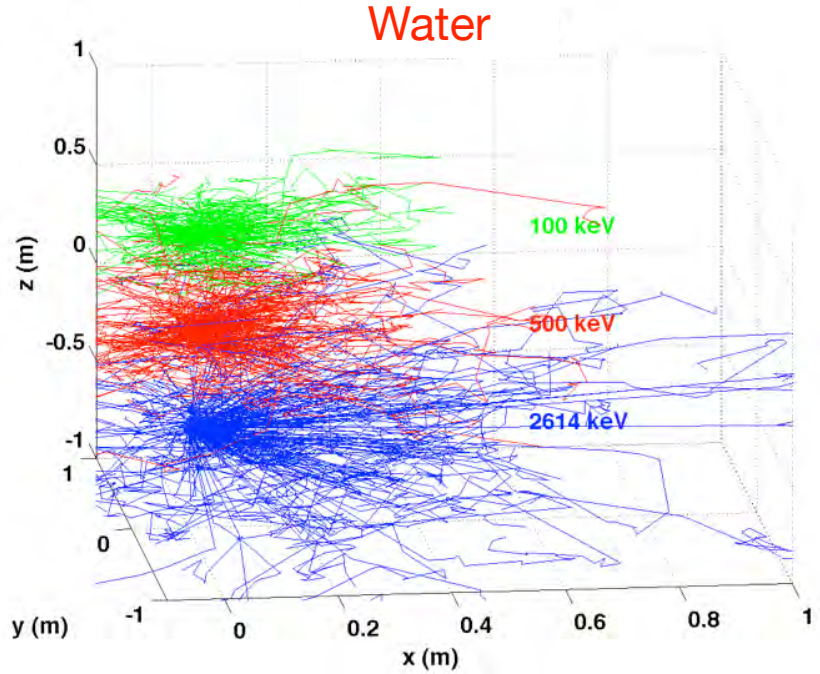


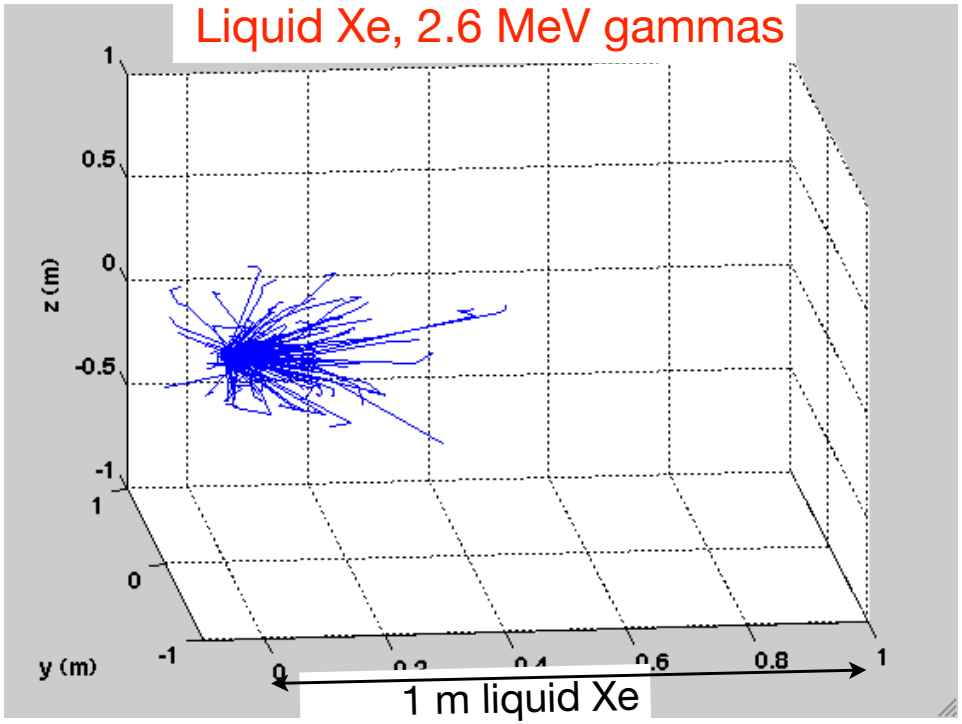
An active field with many approaches!

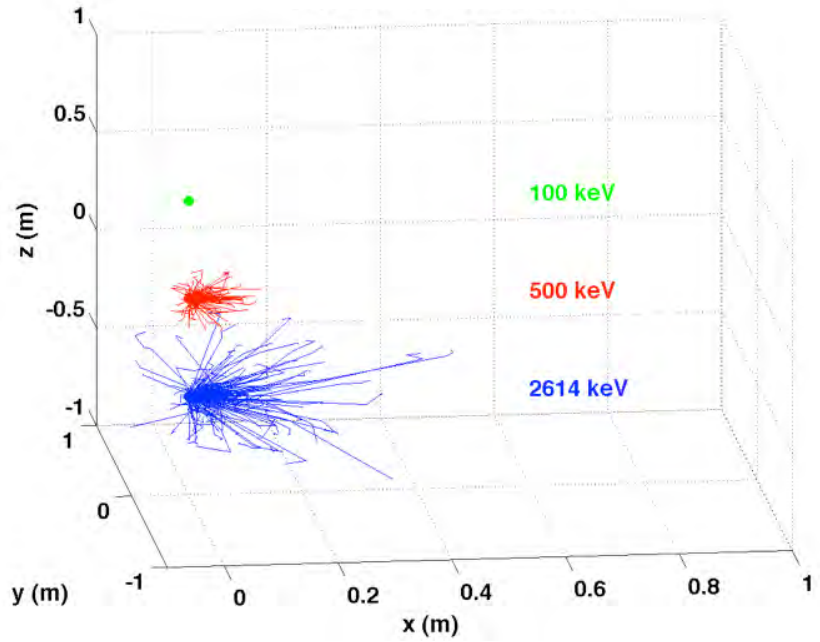


Shielding Gamma Rays

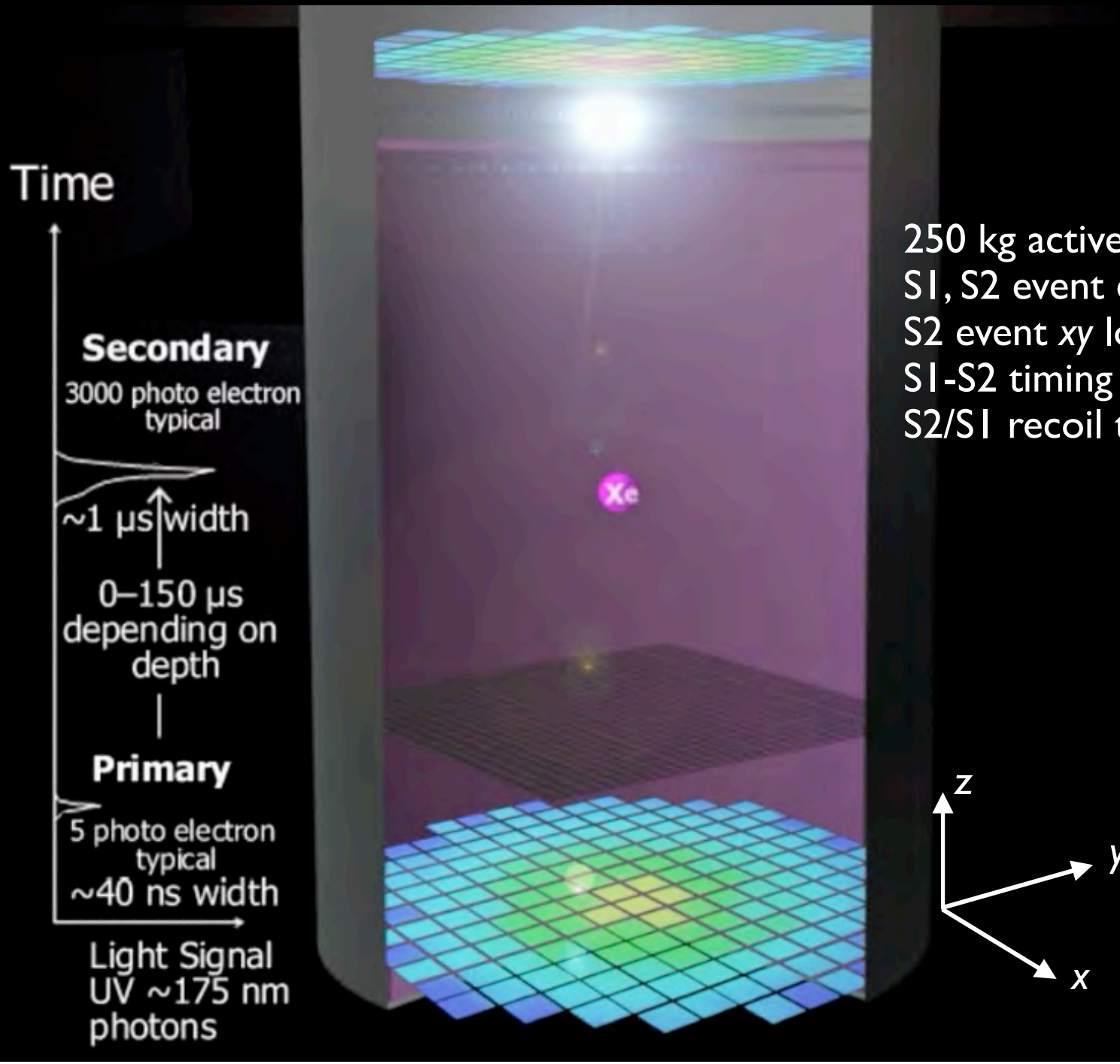








The Large Underground Xenon Detector



250 kg active LXe @ 170 K
S1, S2 event energy
S2 event *xy* location
S1-S2 timing *z* location
S2/S1 recoil type

The LUX Experiment

Inside the LUX/LZ water tank
Sanford Underground Research Facility
4850-foot deep Davis Cavern
Homestake Gold Mine
Lead, SD

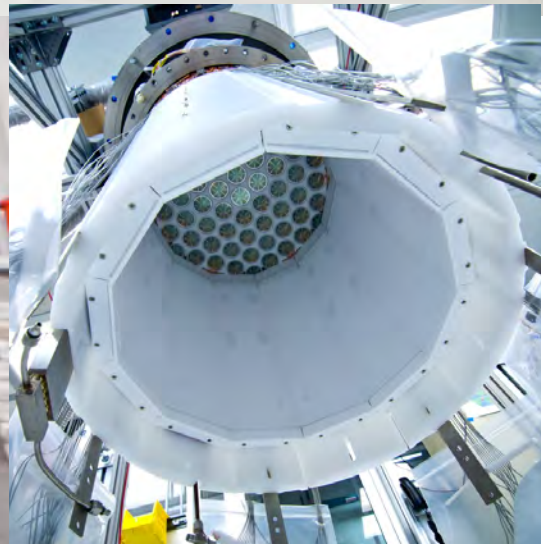
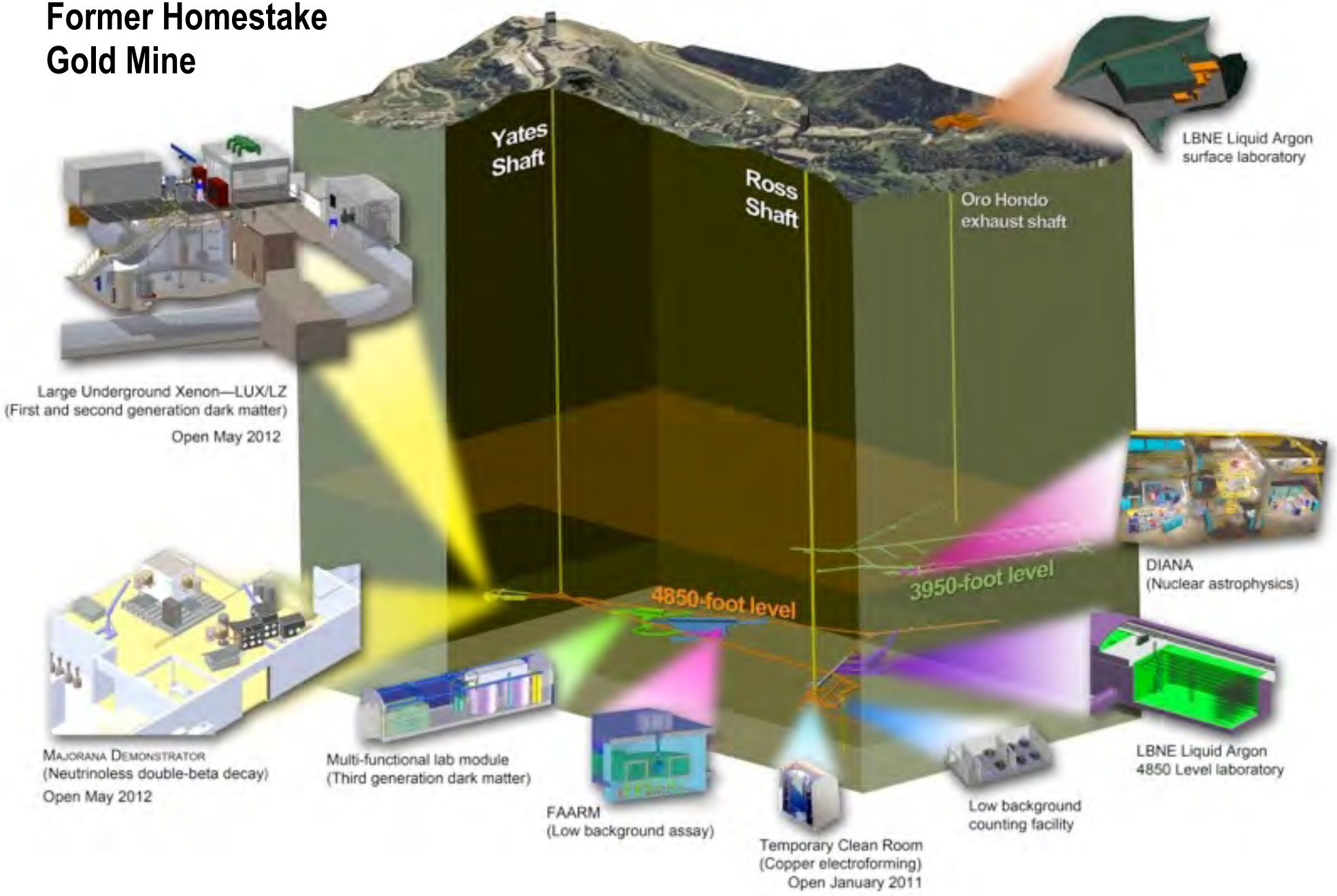
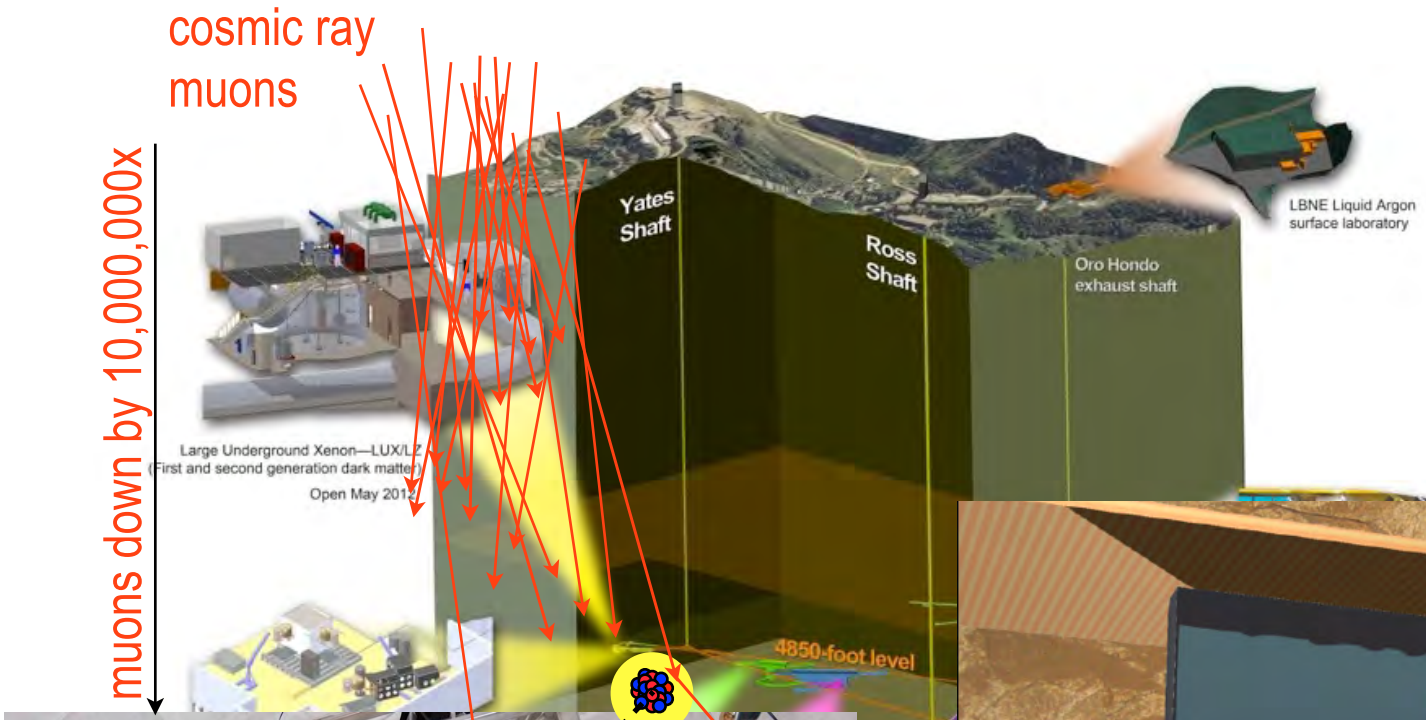


photo credits: Matt Kapust, SURF

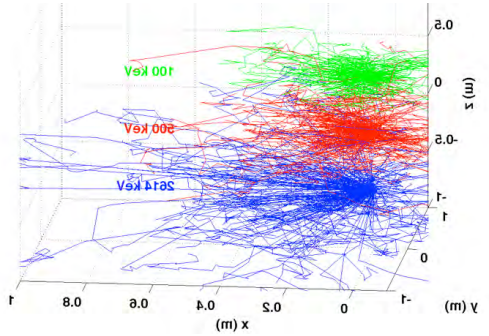
Sanford Underground Research Facility

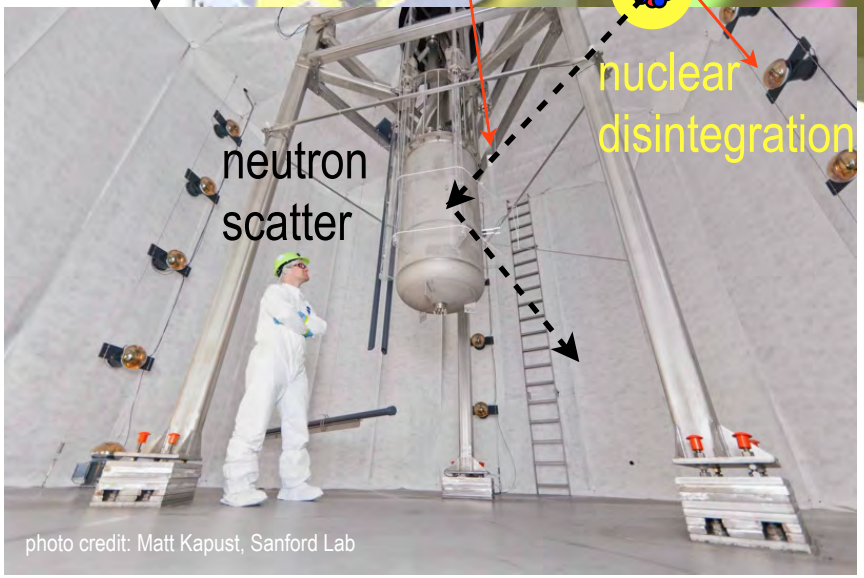


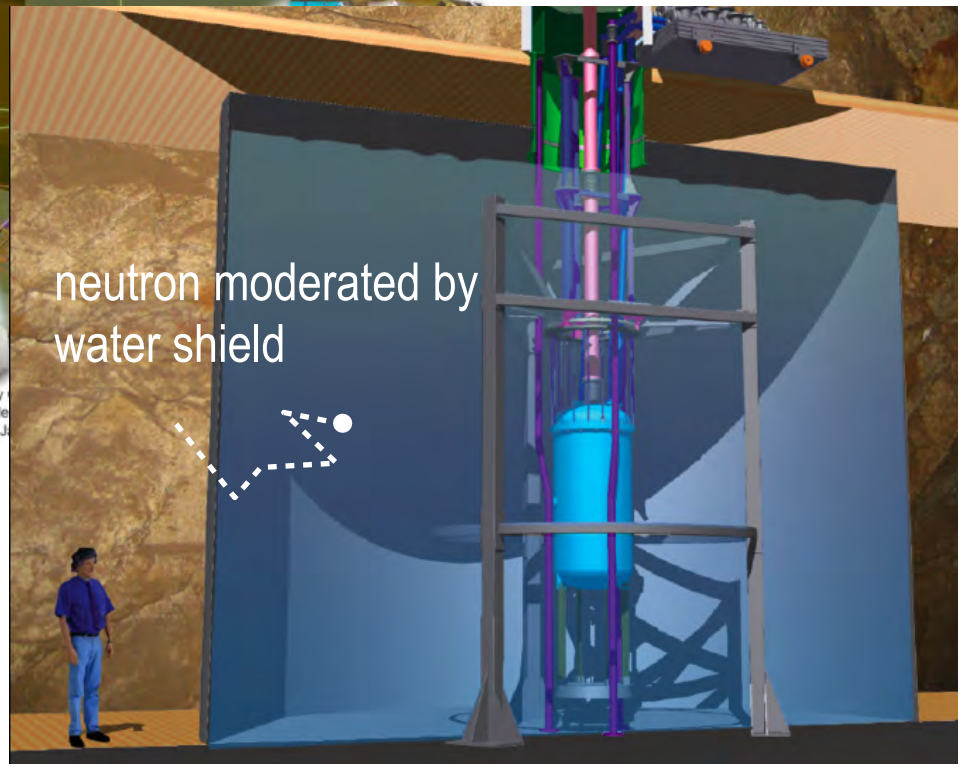
Backgrounds: neutrons



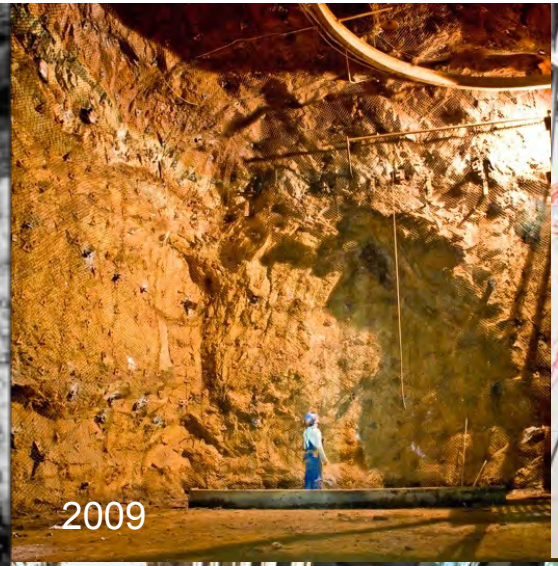
Gammas in Water

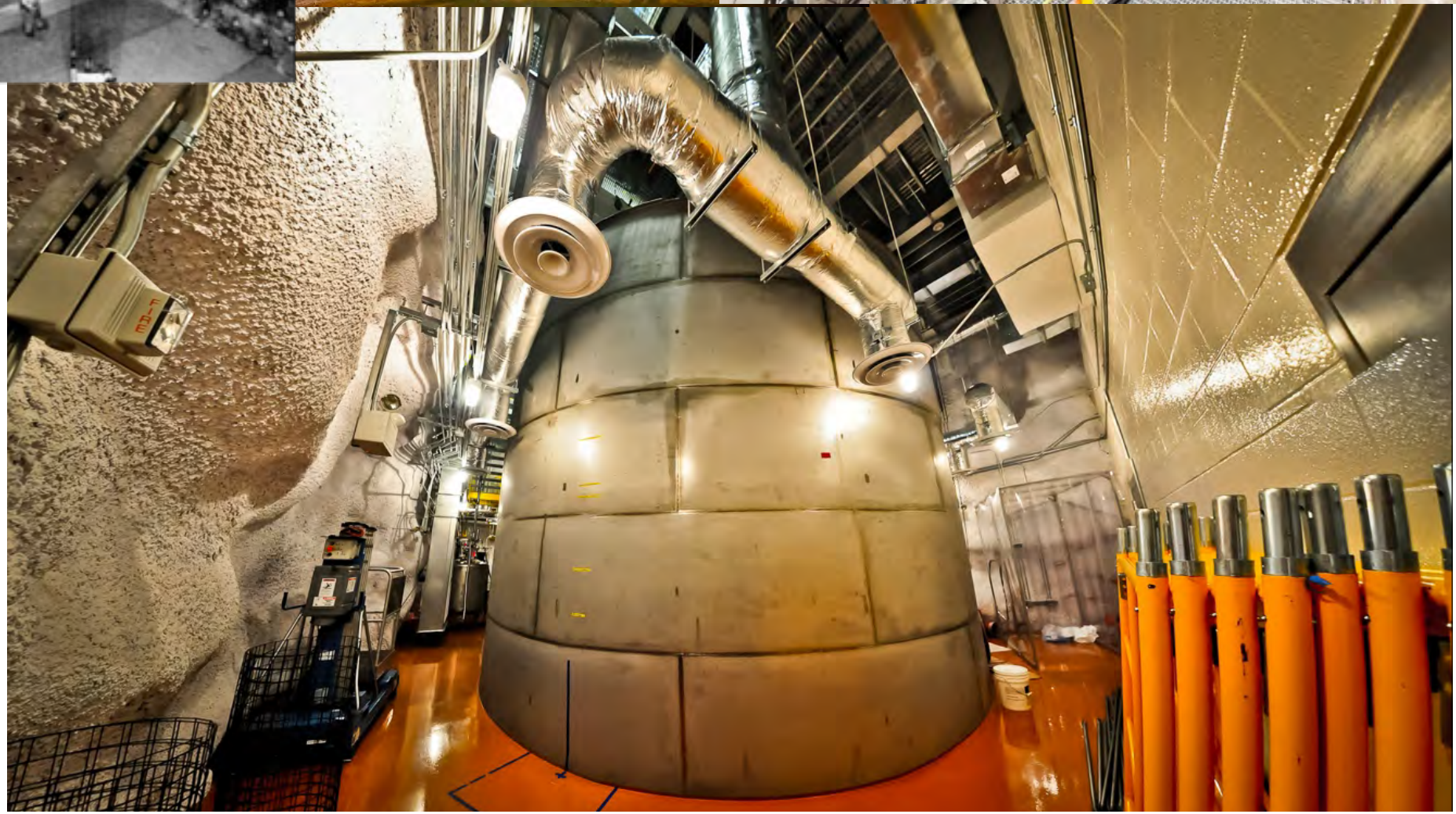






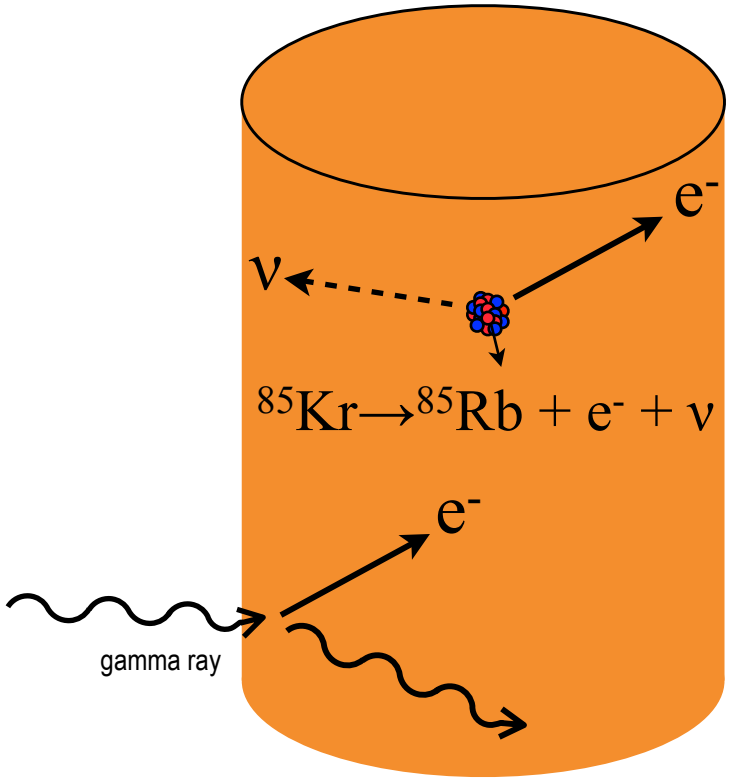
1964


2009

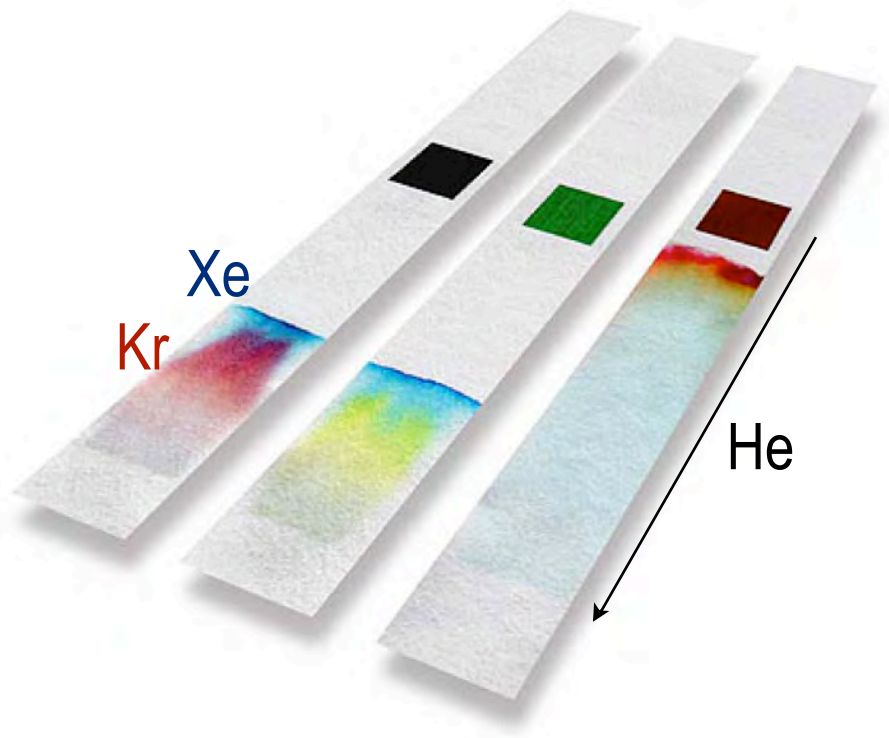


Internal dangers: radioactive ^{85}Kr

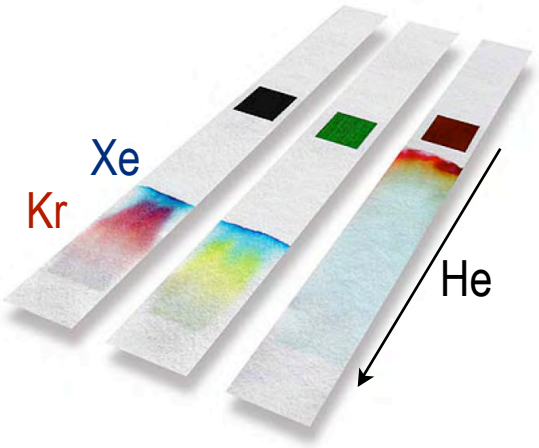
- 10-y $T_{1/2}$ beta decay
- Can't self-shield
- Noble gas: non-reactive
- ~130 ppb in purchased Xe
  - LUX background "floor" from 122 PMTs ~ 20 ppt Kr/Xe

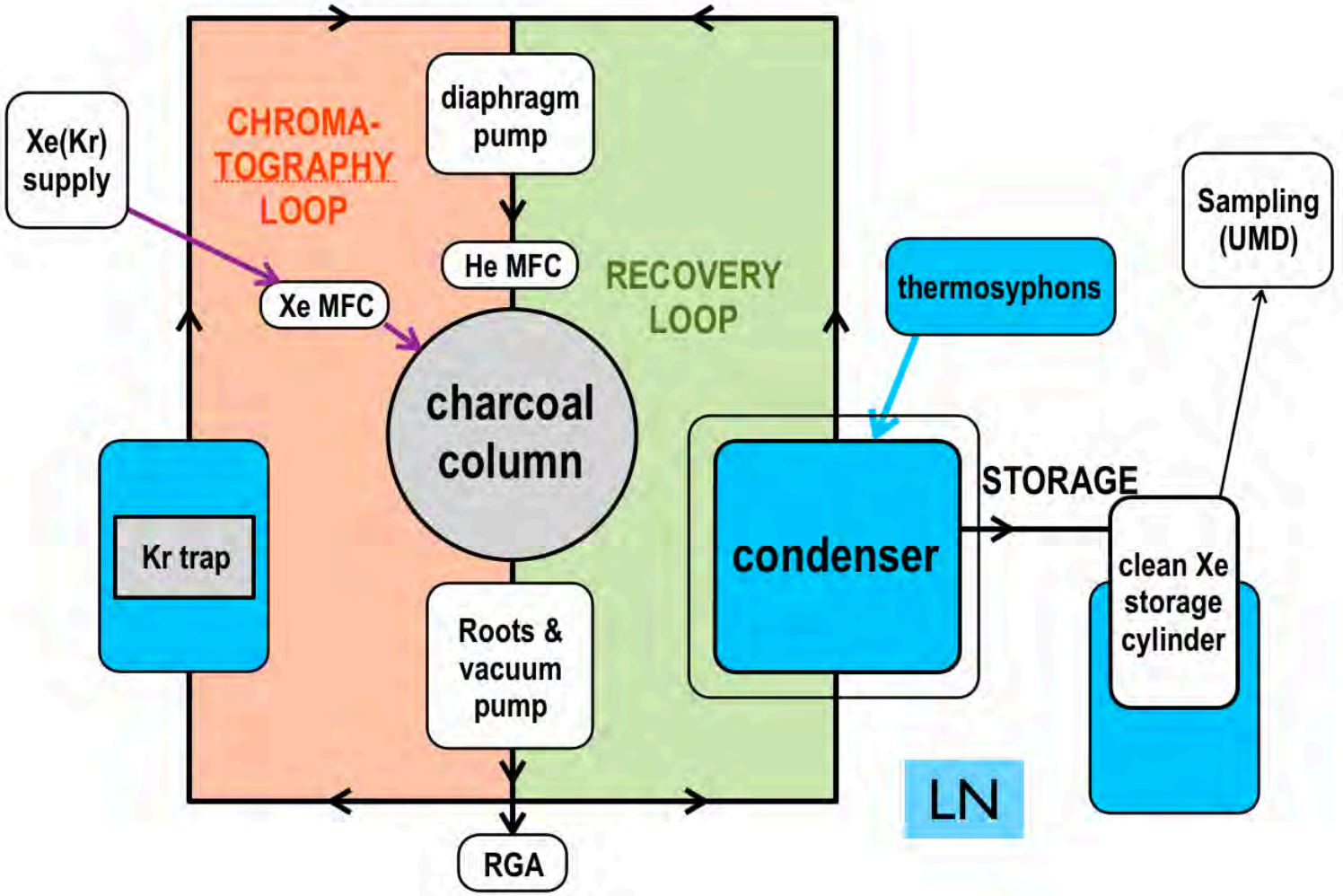


Chromatography

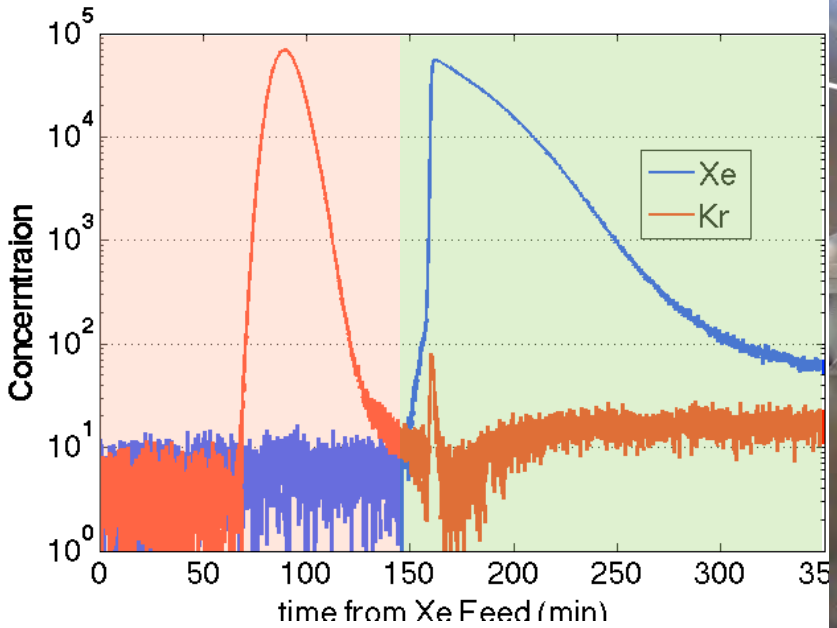


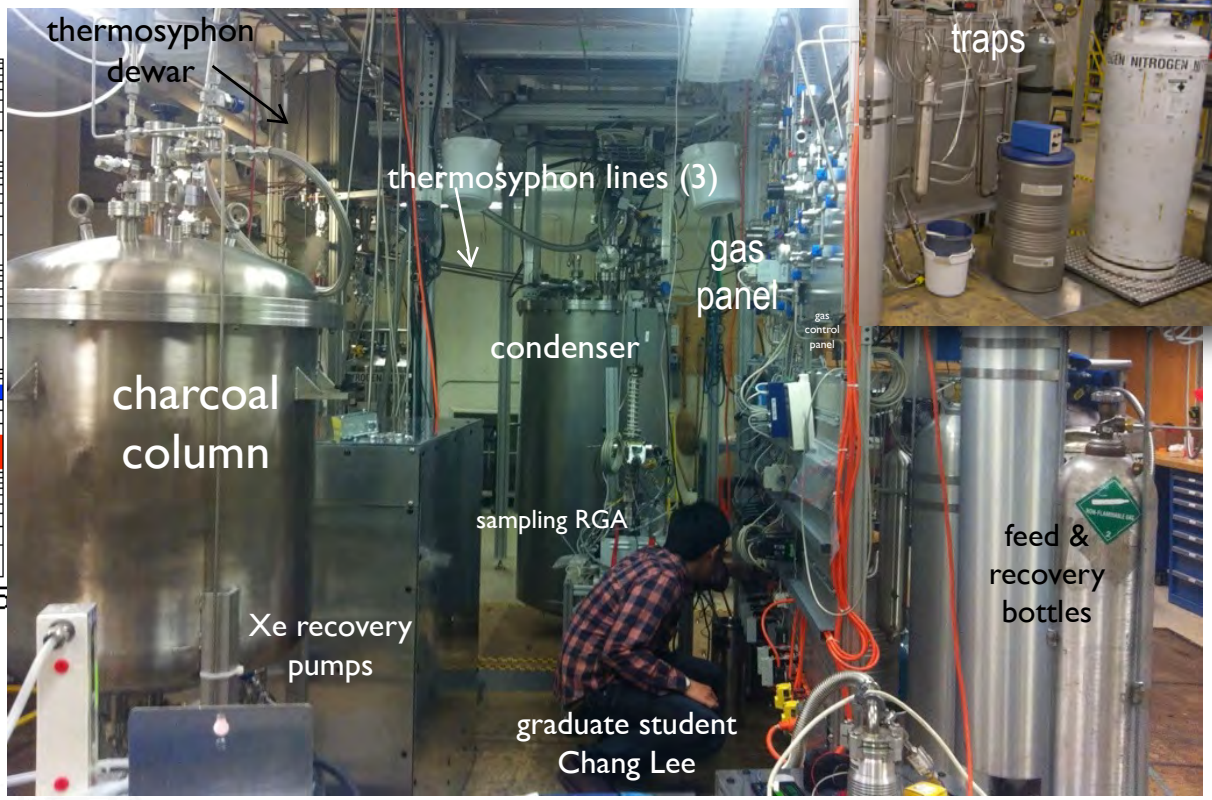
Gas charcoal chromatography Kr removal

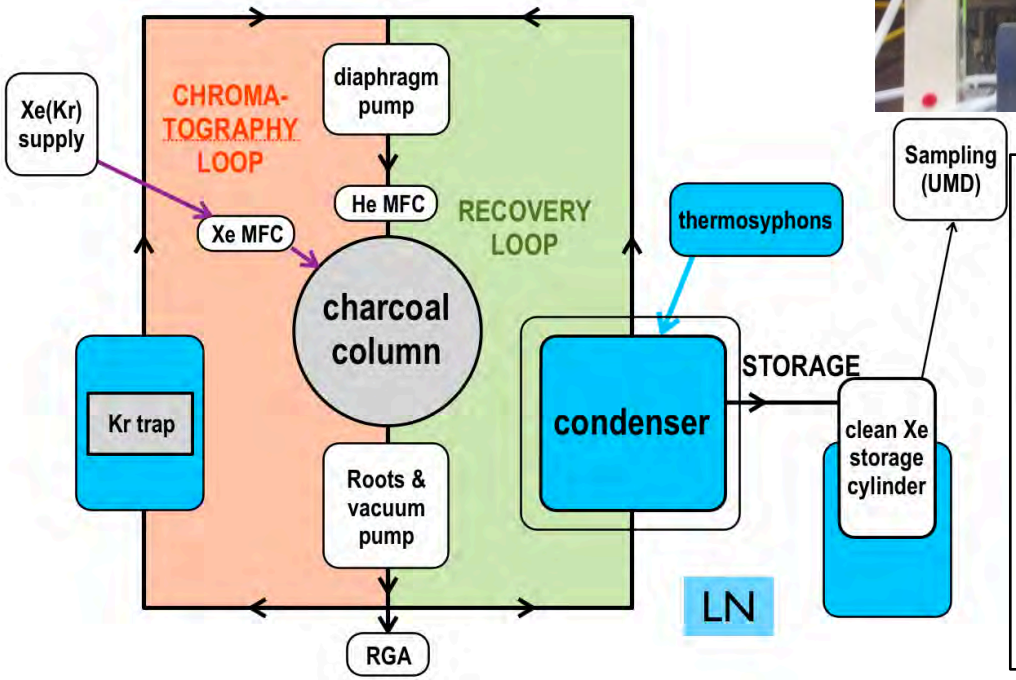


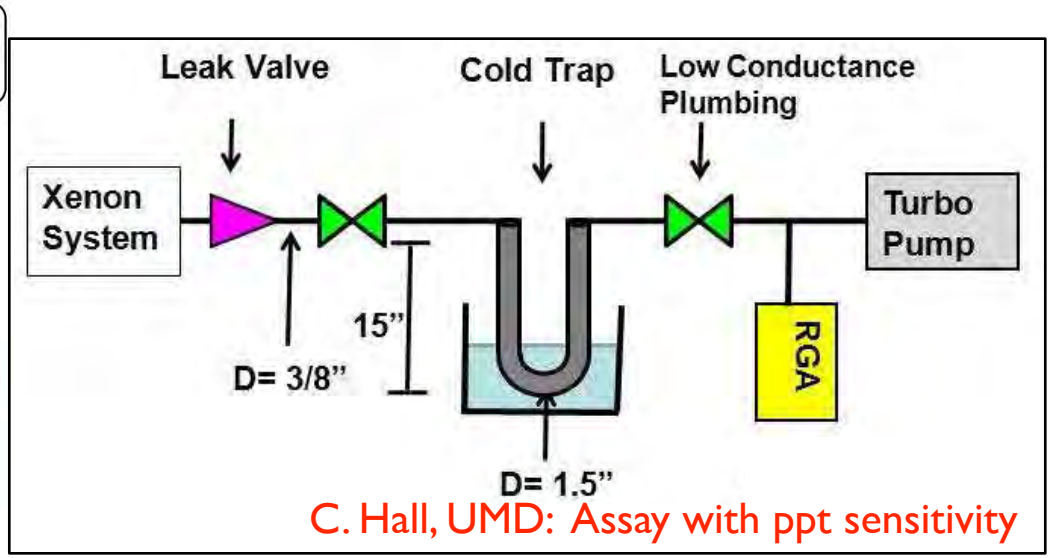


400 kg Xe at Case: 130 ppb to 4 ppt

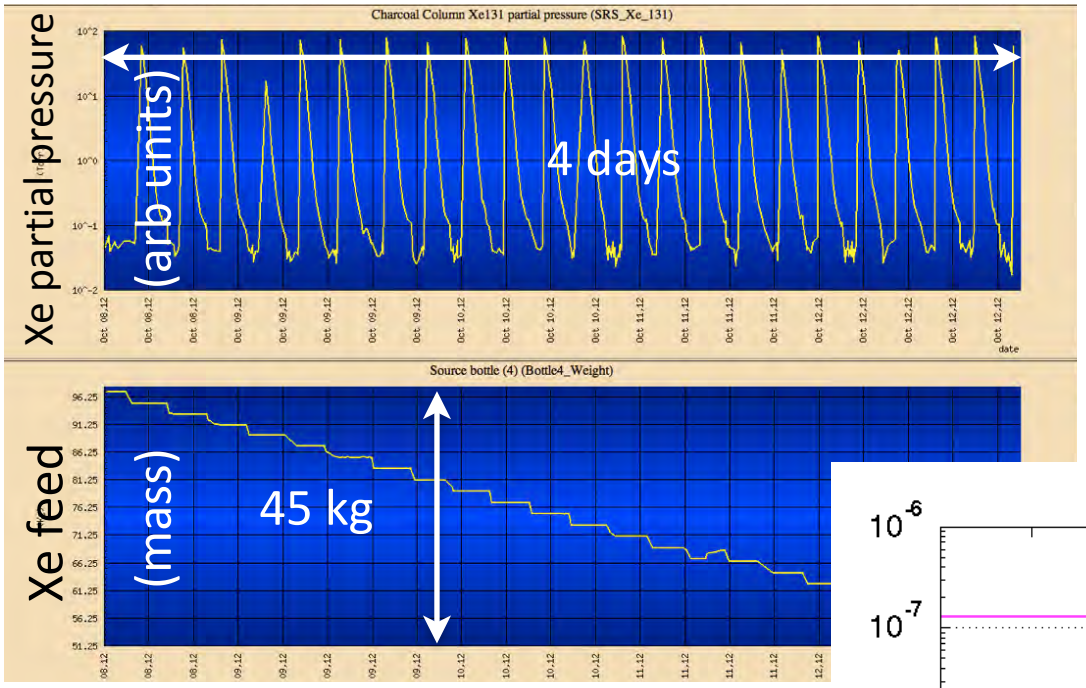


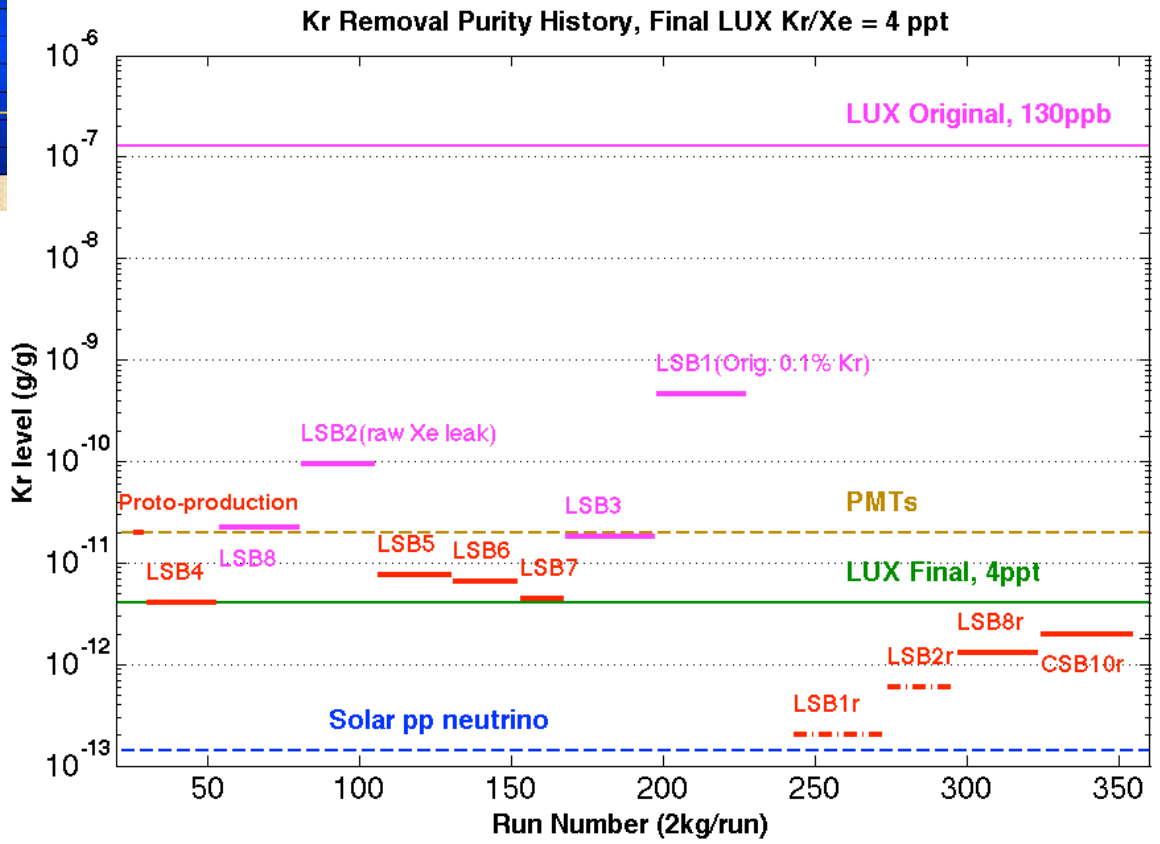






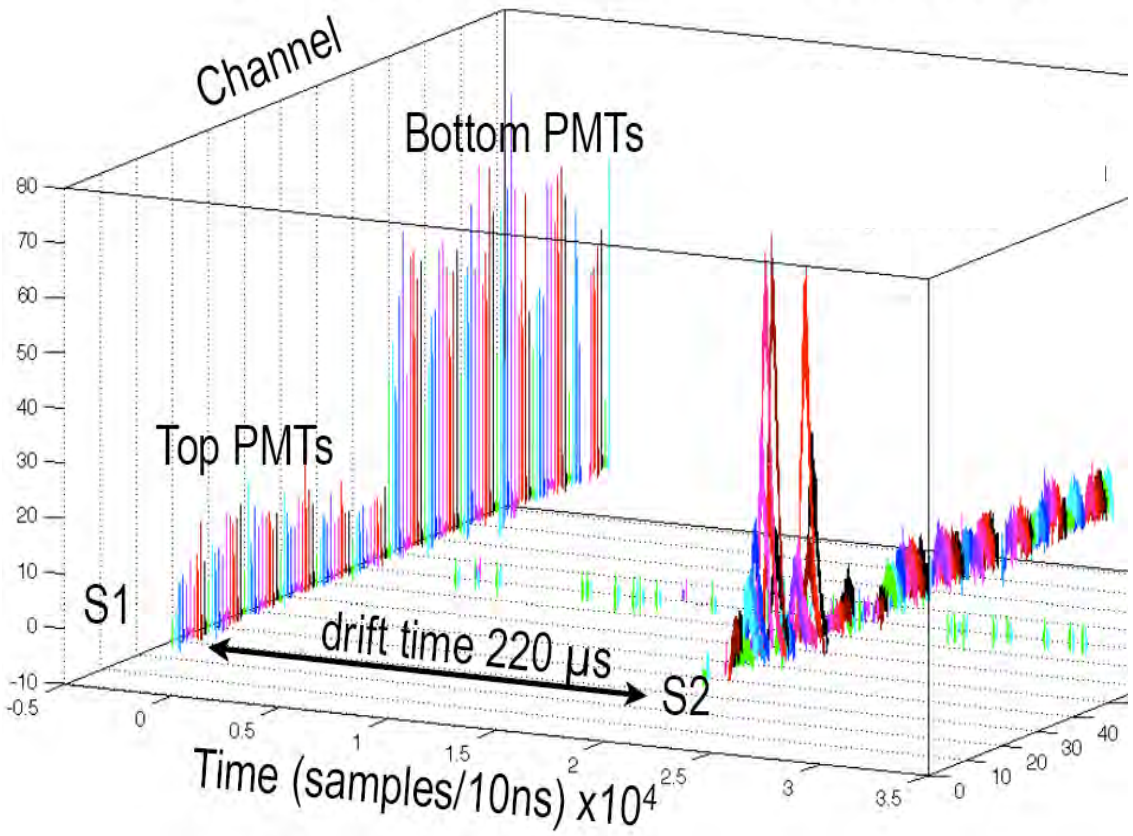
50 kg / week processed for LUX

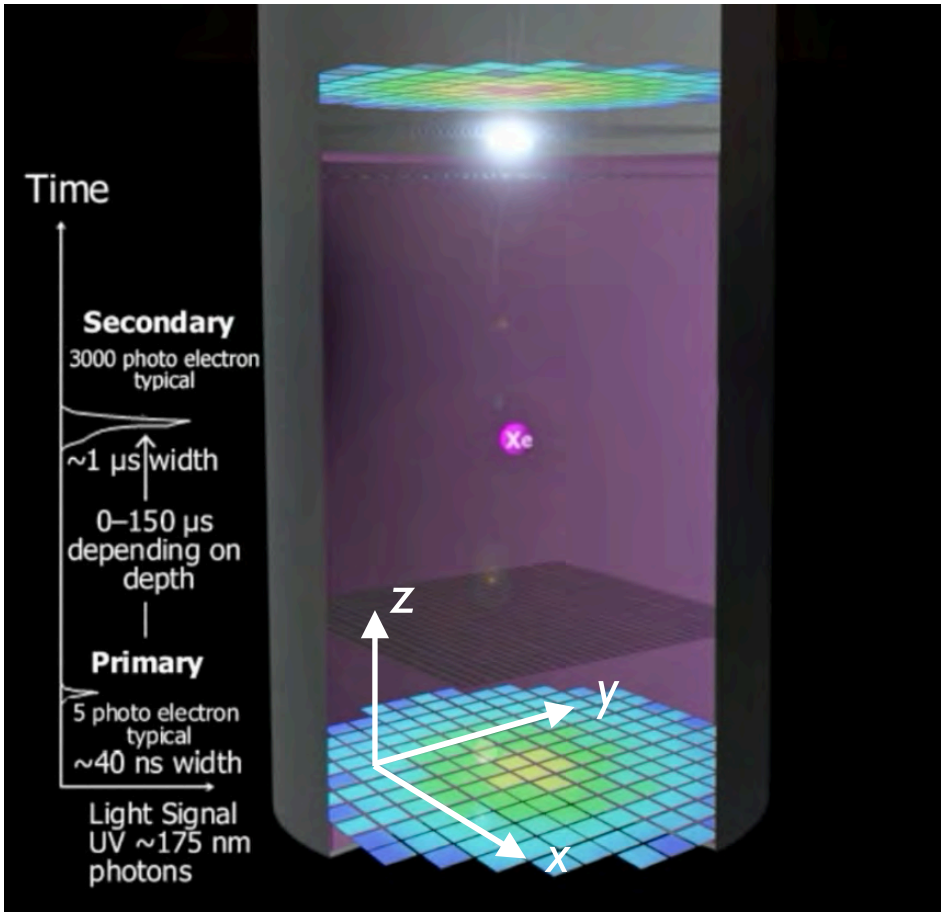




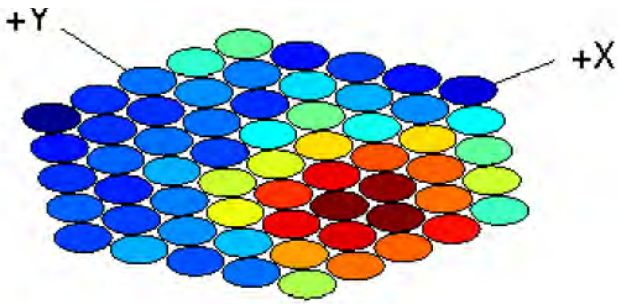
Raw signals in LUX

Depth from timing difference

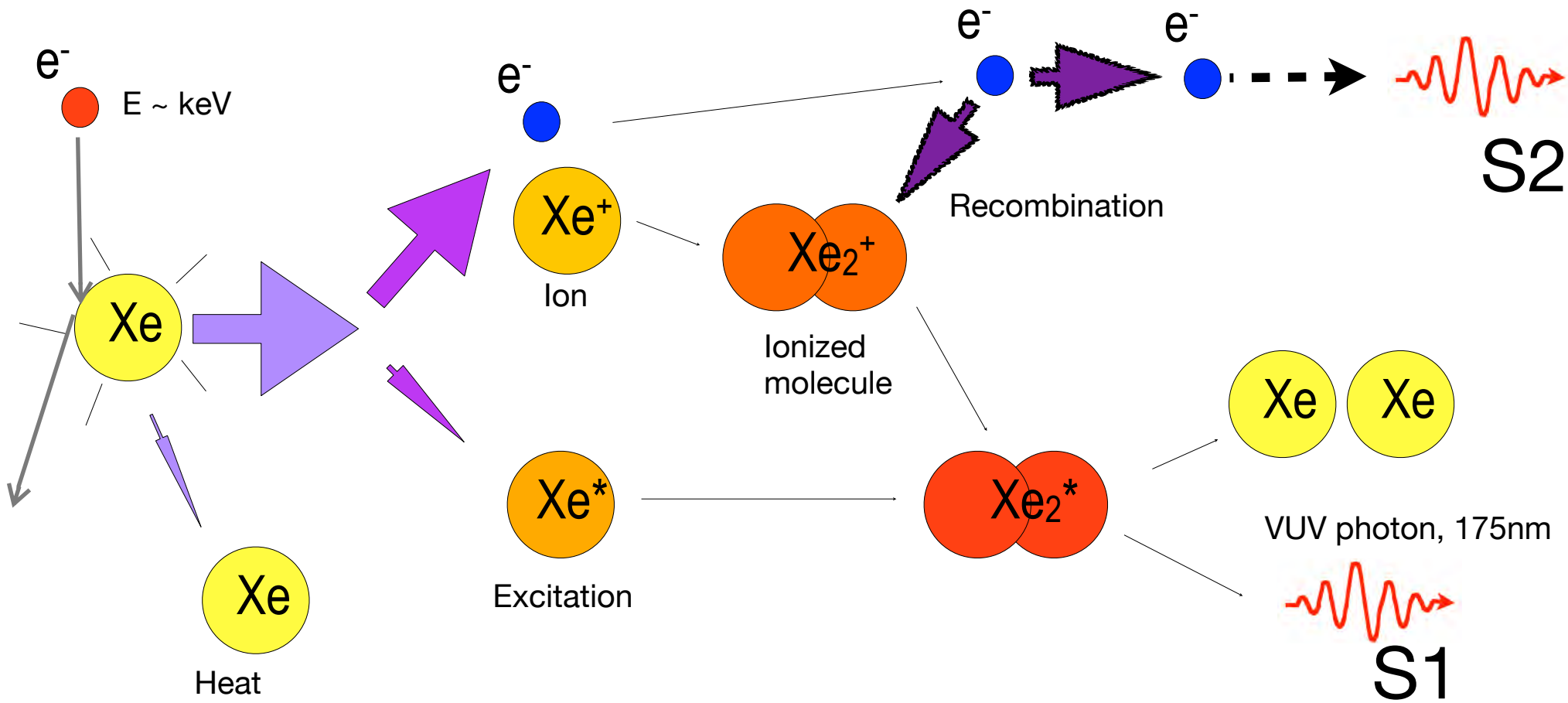




Lateral location from top PMT Array

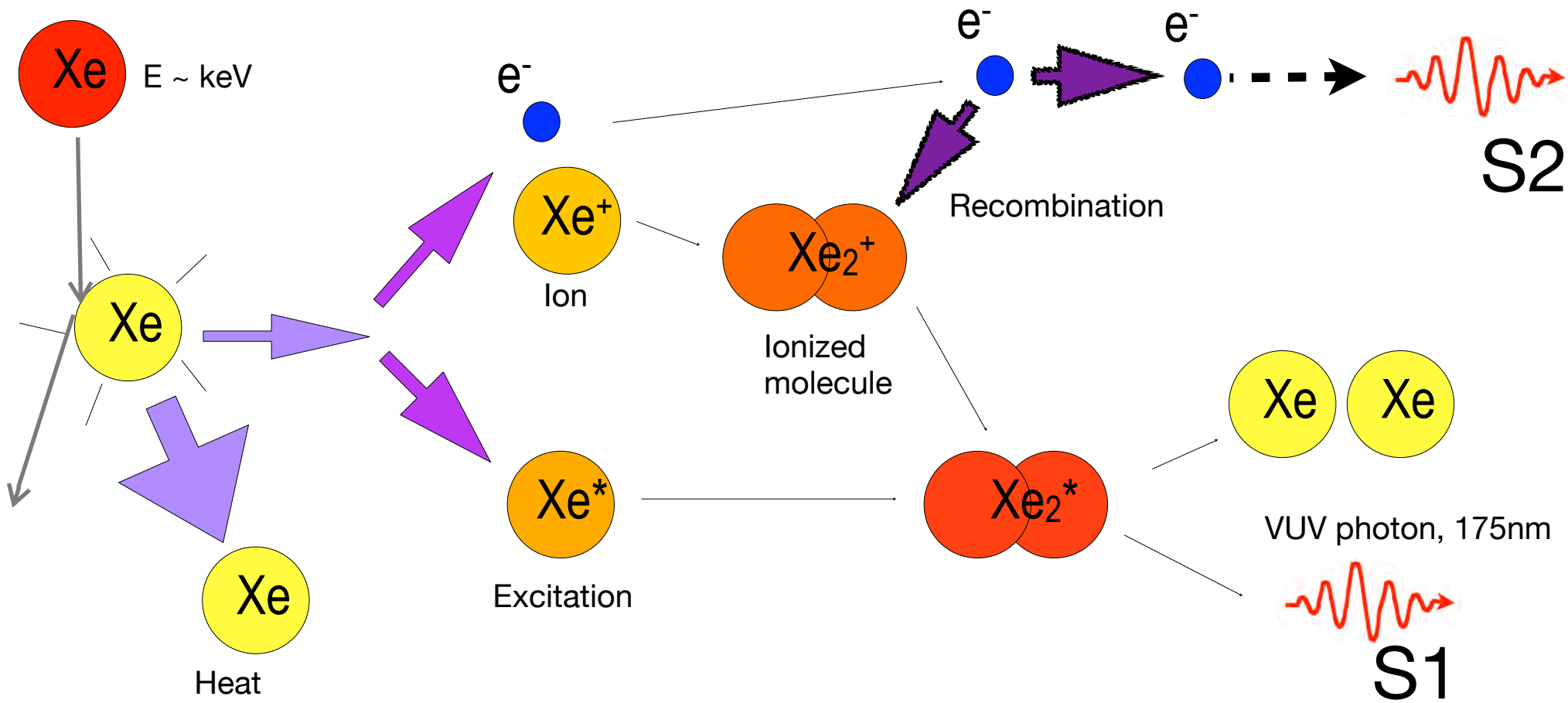


Signal production in liquid Xe



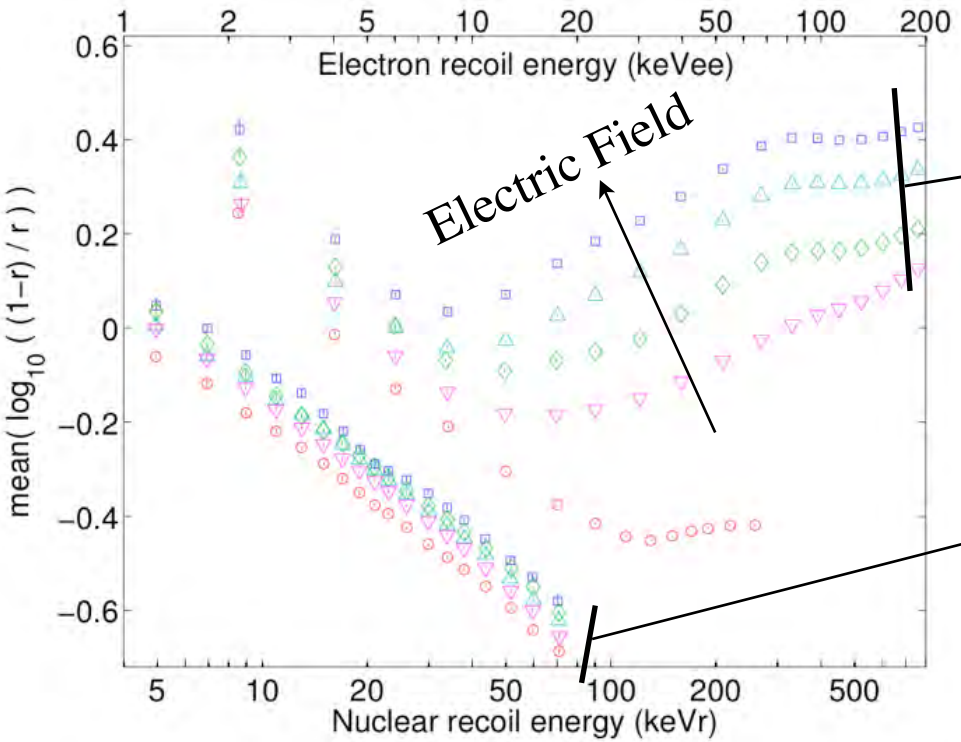
Electron Recoils

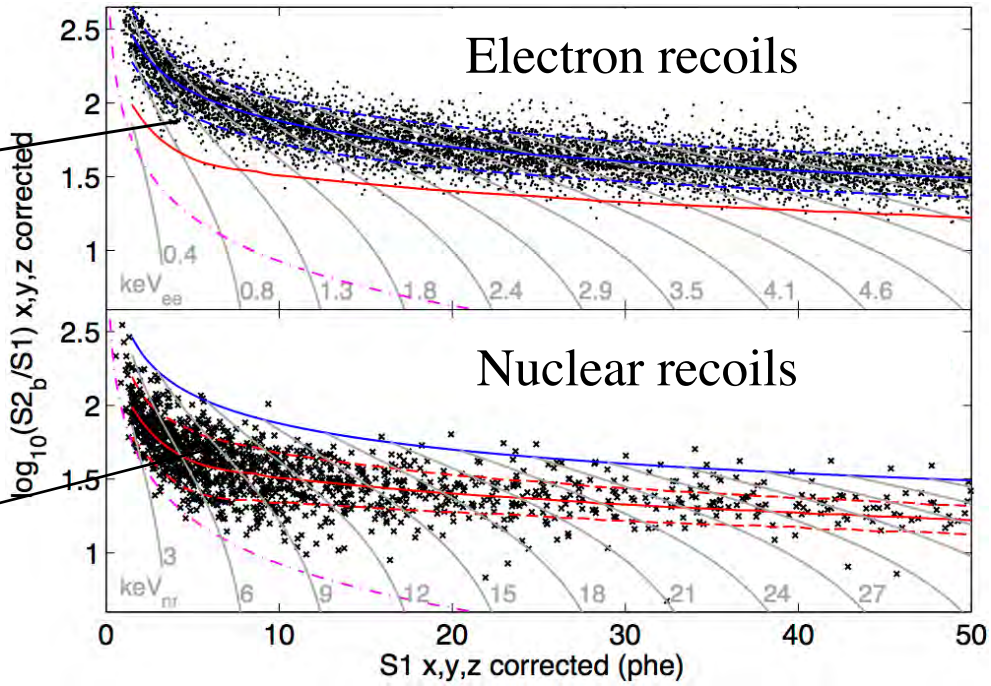
Signal production in liquid Xe



Nuclear Recoils

Understanding light and charge





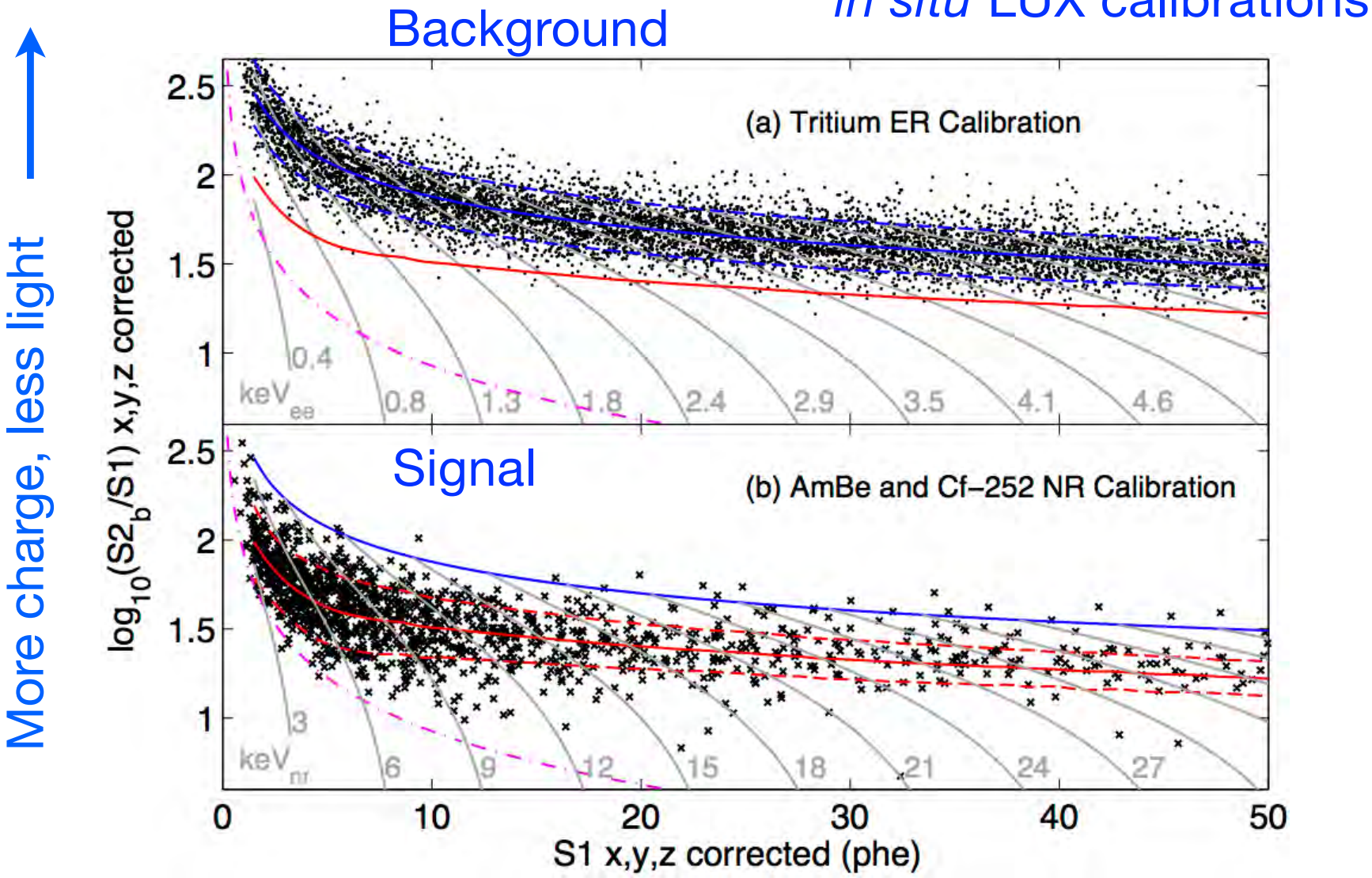
Puzzling low energy behavior

Comprehensive model, only 2 fit parameters (Dahl, PhD thesis, 2009)

Robust Monte Carlo framework: NEST
(M. Szydagis et al., JINST 6, p10002 (2011))

Background and Signal Distinction

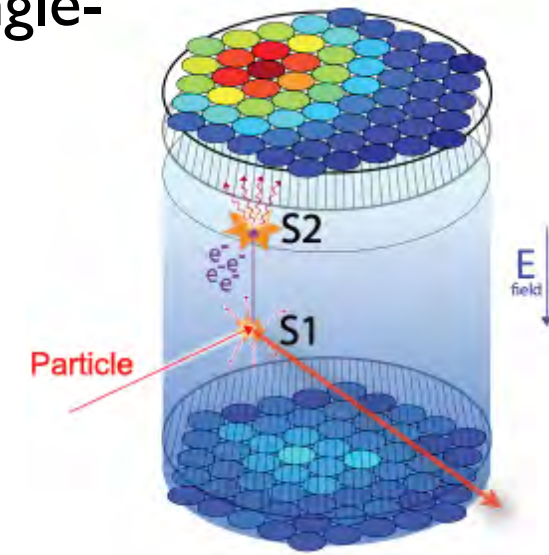
in situ LUX calibrations

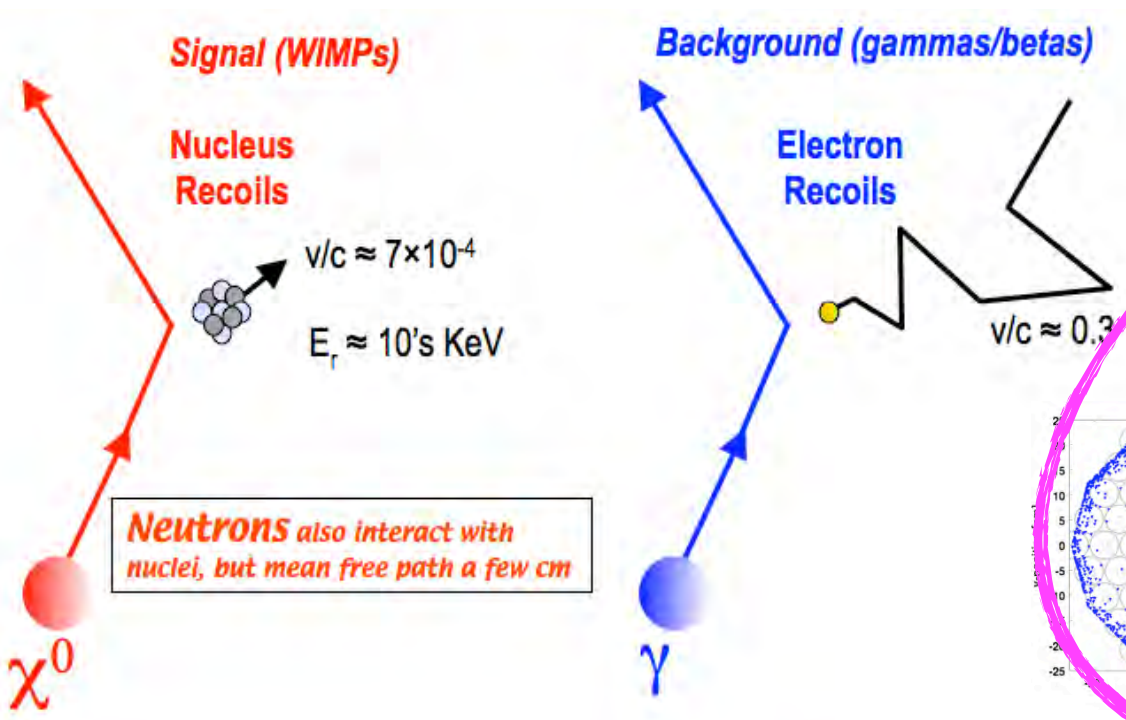


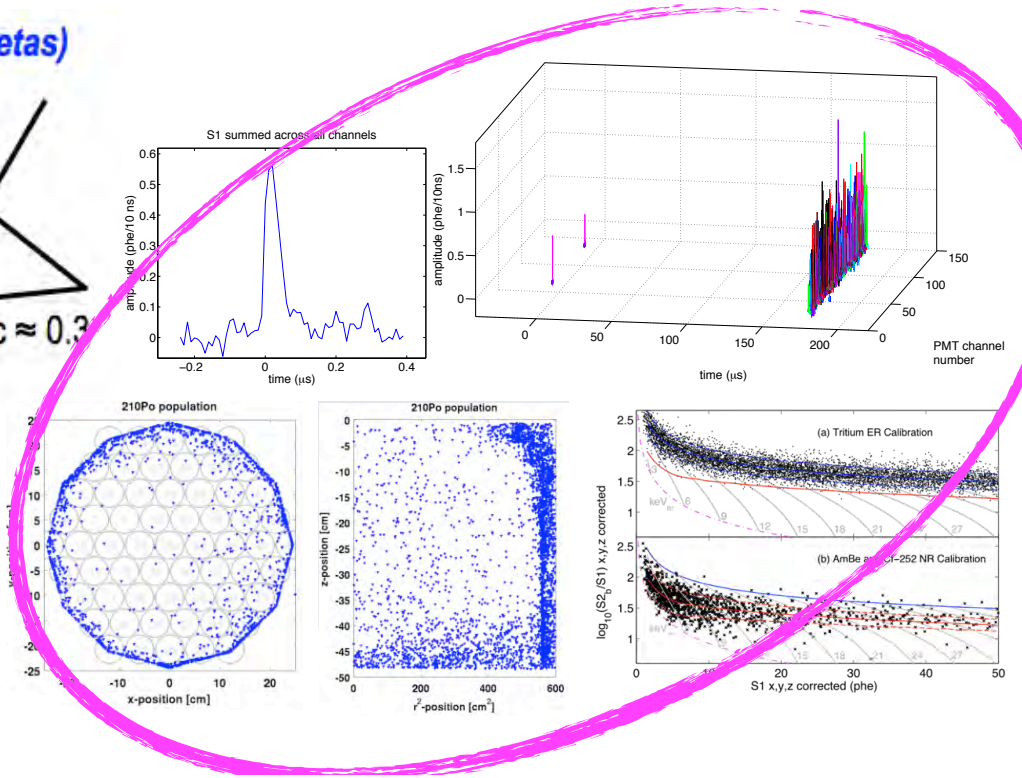
Internal tritium source (purified away with τ ~ 7 hours)

WIMP signal

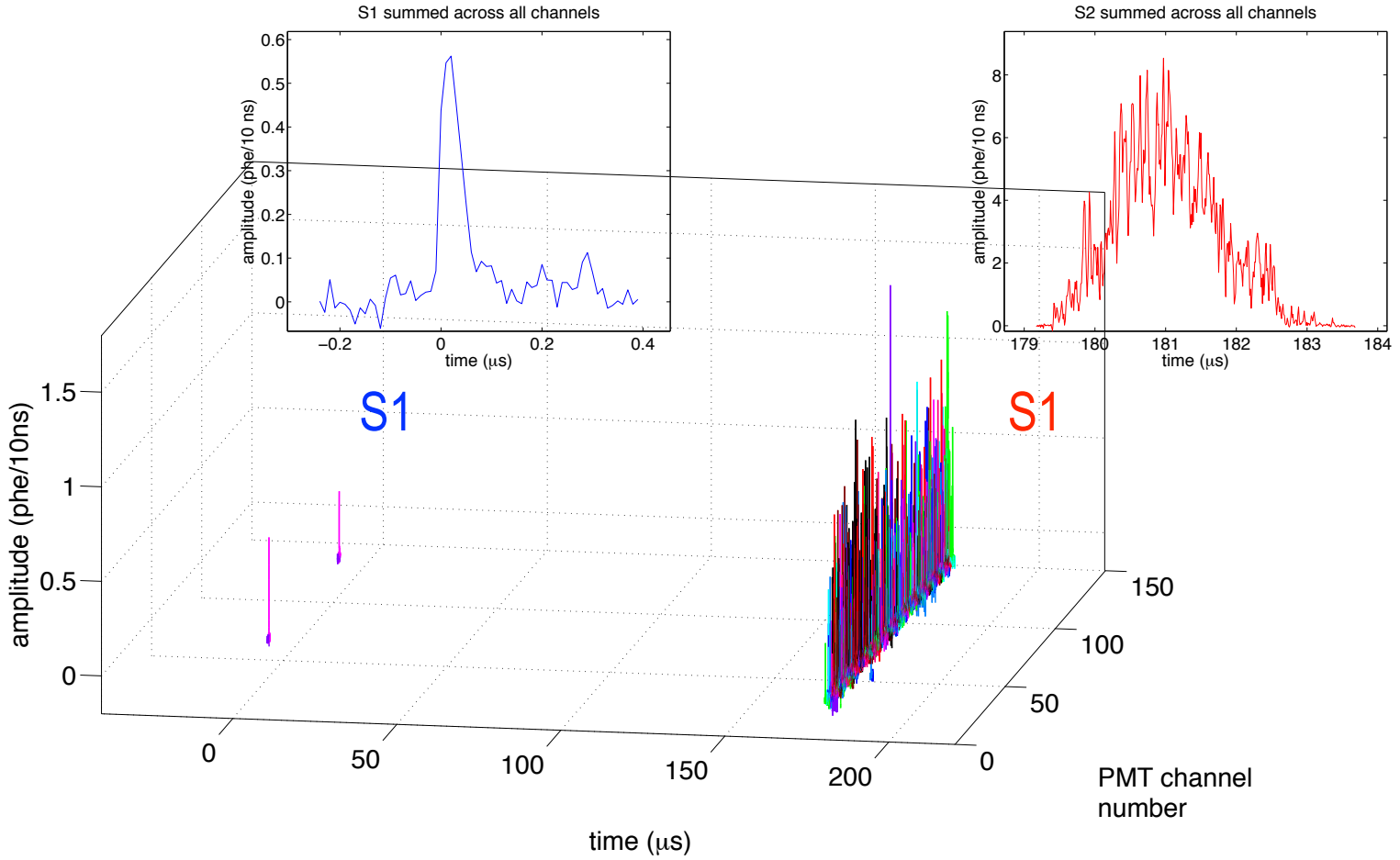
- Signal region: a quiet place where low-energy single-scatter nuclear recoils away from the walls can emerge from among:
  - external gamma rays into the fiducial volume
  - wall events (206Pb)
  - dissolved backgrounds (Rn-progeny, 85Kr, 127Xe)
  - delayed electrons from previous large S2's







Event selection

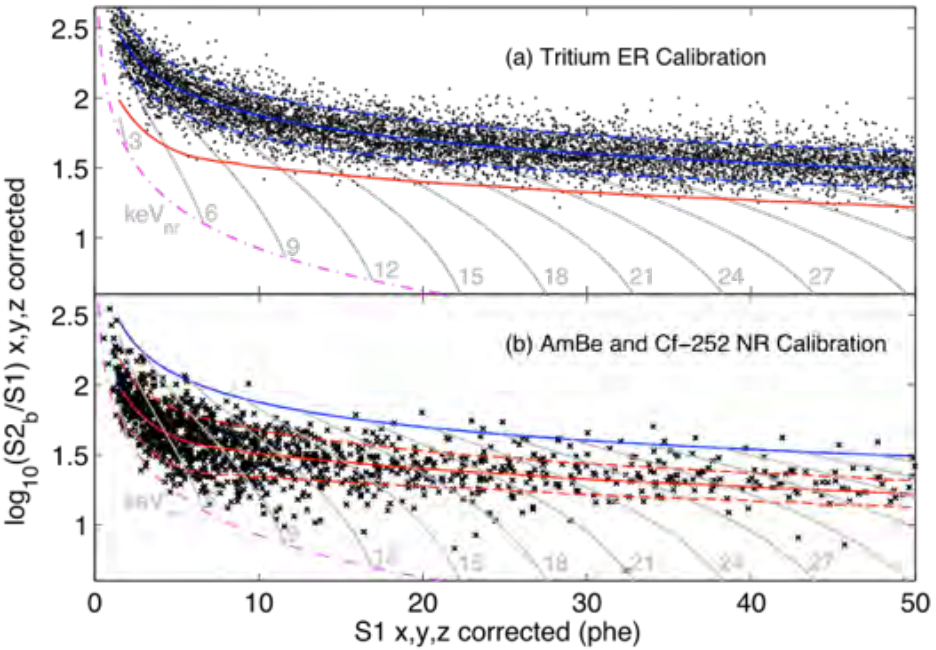


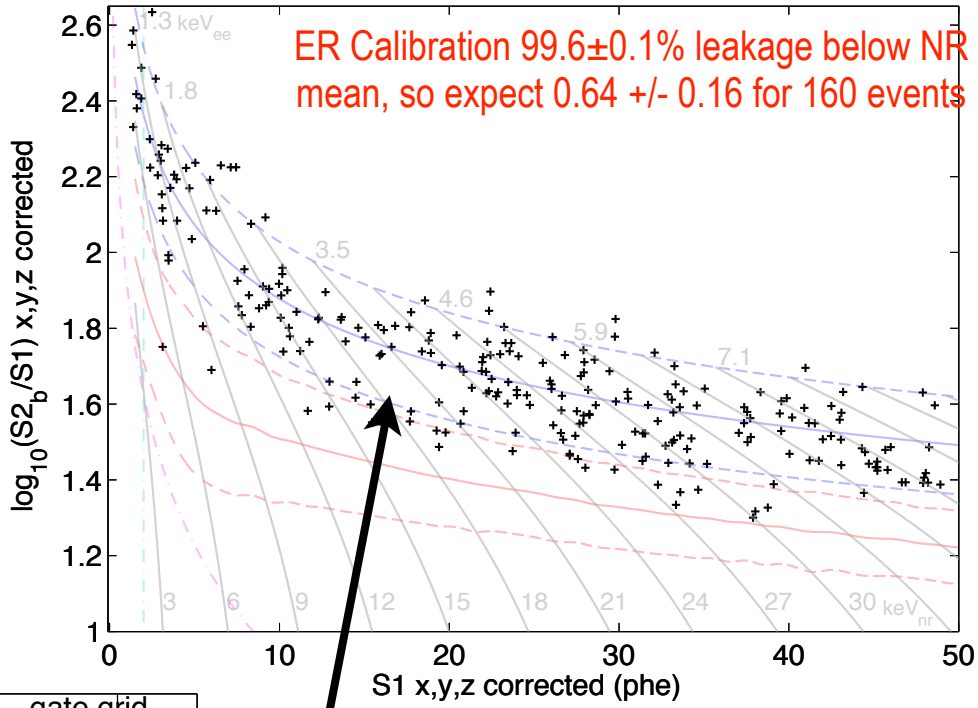
Requirements for WIMP search candidate events

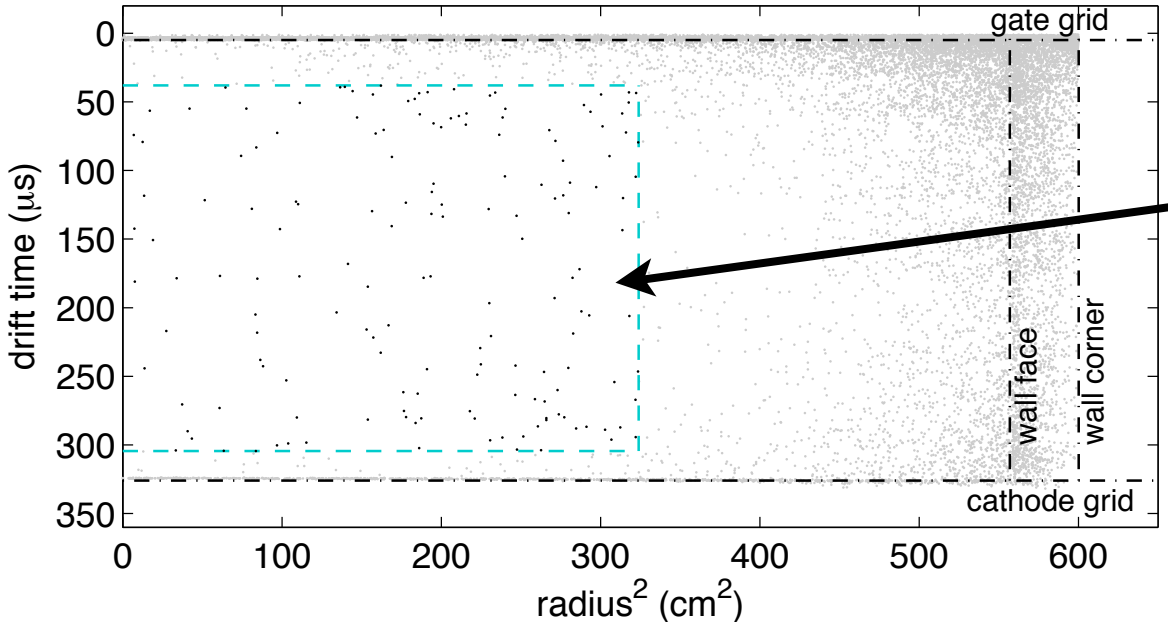
- S2 trigger (at least 2 trigger ch. ≥ 8 phe within 2 μs) [lower threshold than S1]
- 2 phe (2-fold coincidence) ≤ S1 ≤ 30 phe [quiet enough to see this in 'look back']
- 200 phe (8 e-) ≤ S2 ≤ 3300 phe [require good *xy* measurement]
- total area of other pulses in the event < 100 phe [confusion from previous large S2's]

LUX WIMP Search, 85 live-days, 118 kg

calibration







160 events in ER band / 118 kg fiducial

Extended Likelihood Treatment

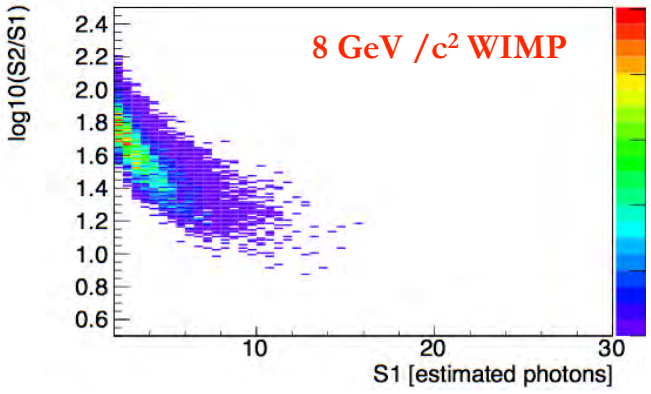
$$\mathcal{L}_{WS} = \frac{e^{-N_s - N_{Compt} - N_{Xe-127} - N_{Rn222}}}{\mathcal{N}!} \prod_{i=1}^{\mathcal{N}} N_s P_s(\boldsymbol{x}; \boldsymbol{\sigma}, \boldsymbol{\theta_s}) + N_{Compt} P_{ER}(\boldsymbol{x}; \boldsymbol{\theta_{Compt}}) + N_{Xe-127} P_{ER}(\boldsymbol{x}; \boldsymbol{\theta_{Xe-127}}) + N_{Rn} P_{ER}(\boldsymbol{x}; \boldsymbol{\theta_{Rn}})$$

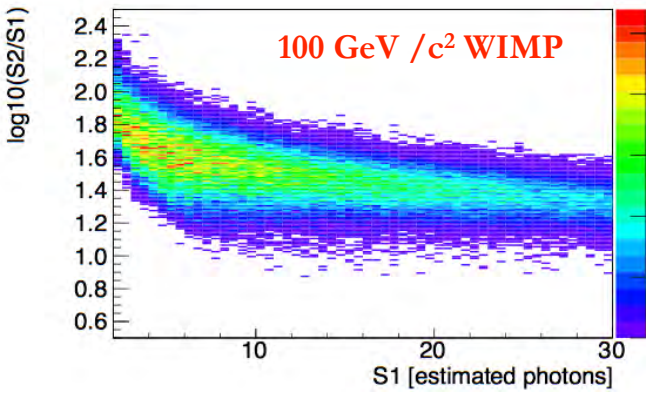
Observables: x = (S1, $\log_{10}$(S2/S1), r, z)

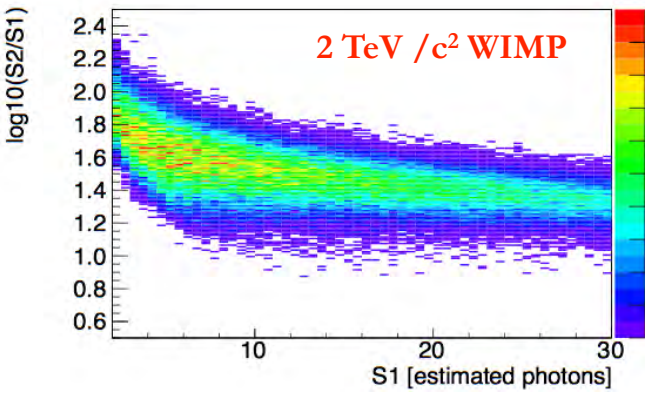
Parameter of interest: N_s

Nuisance parameters: N_{Compt}, $N_{Xe\text{-}127}$, $N_{Rn/Kr\text{-}85}$

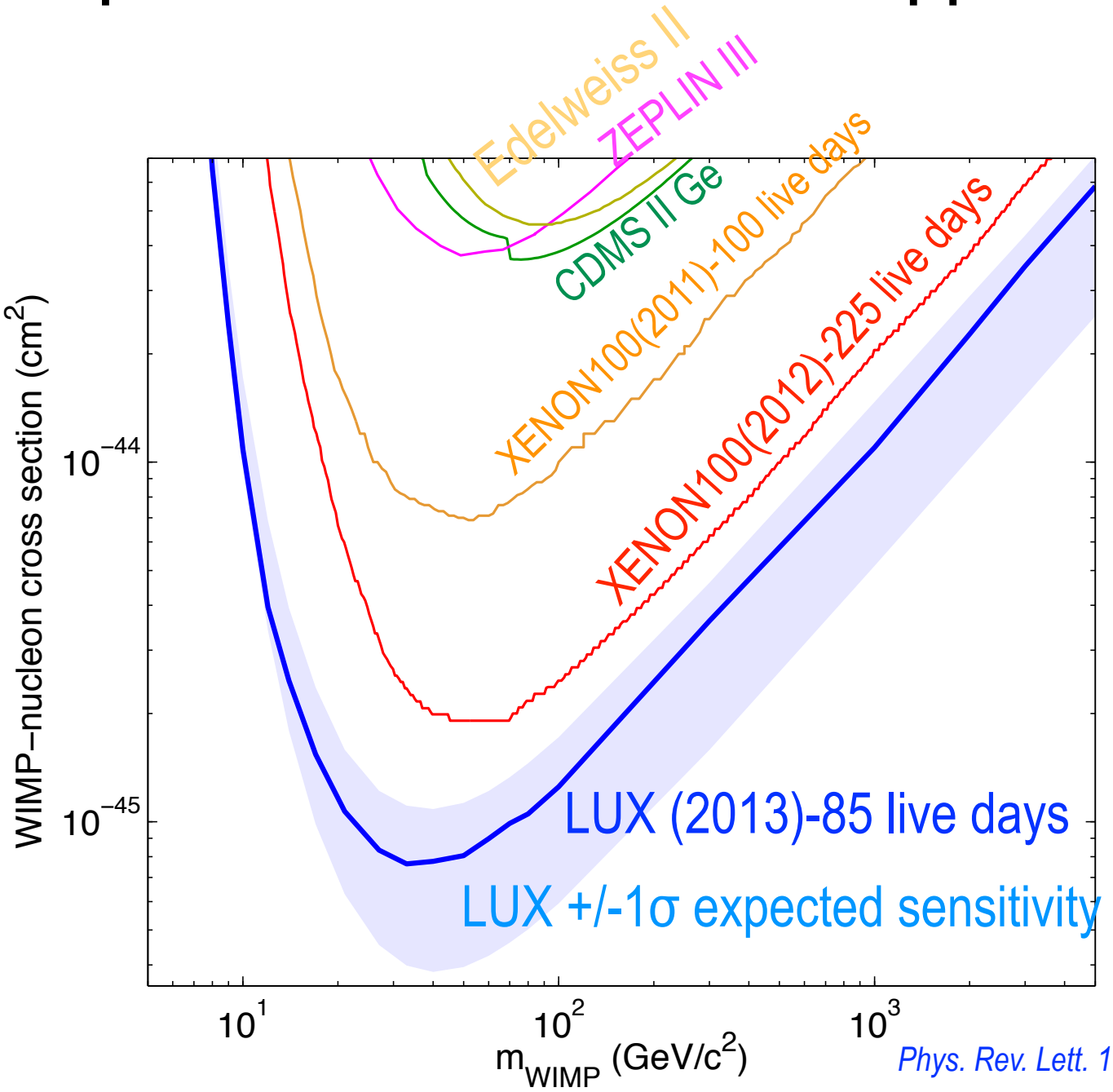
Modeled WIMP signal, including resolution and efficiencies





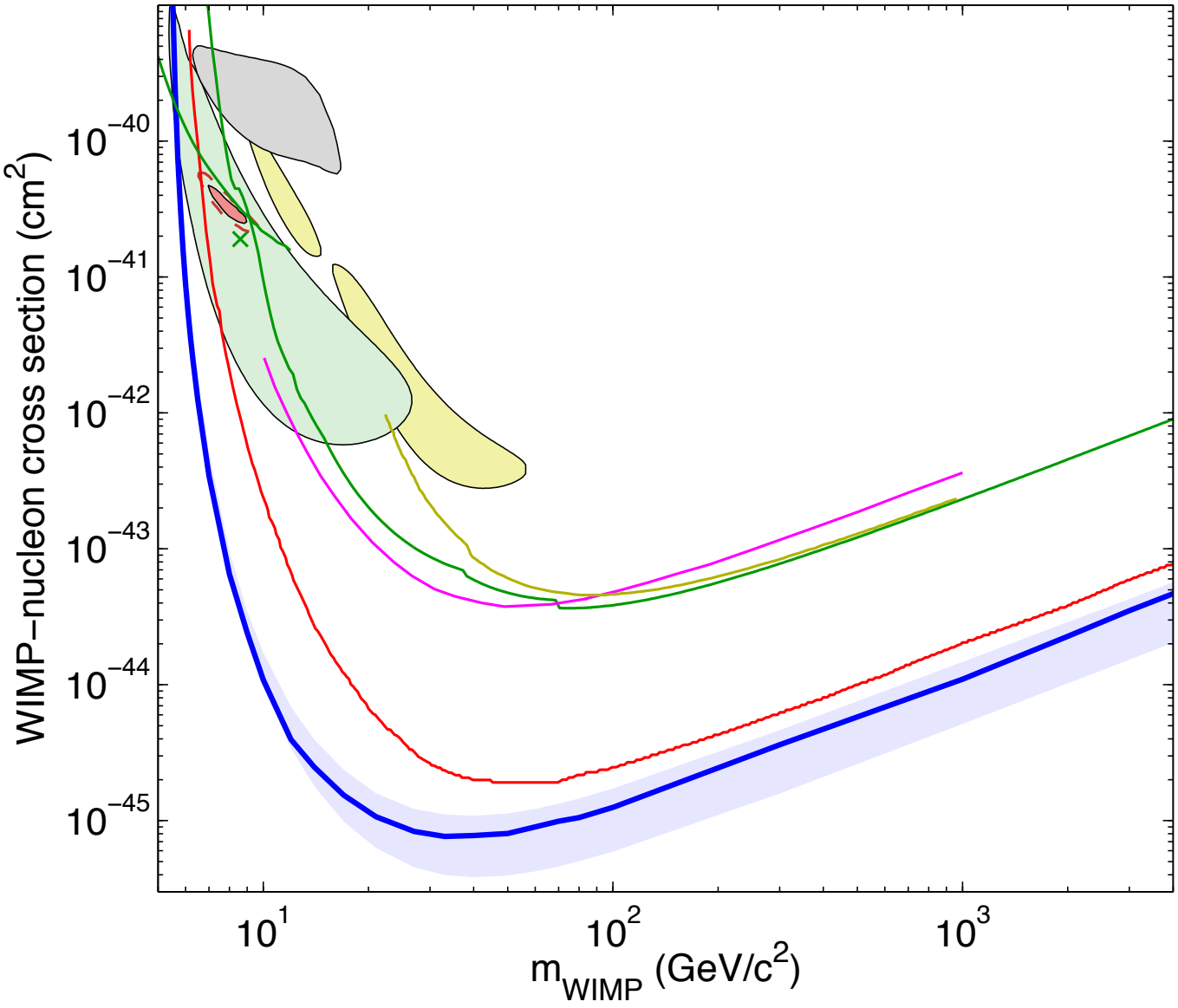


Spin Independent Cross Section Upper Limit

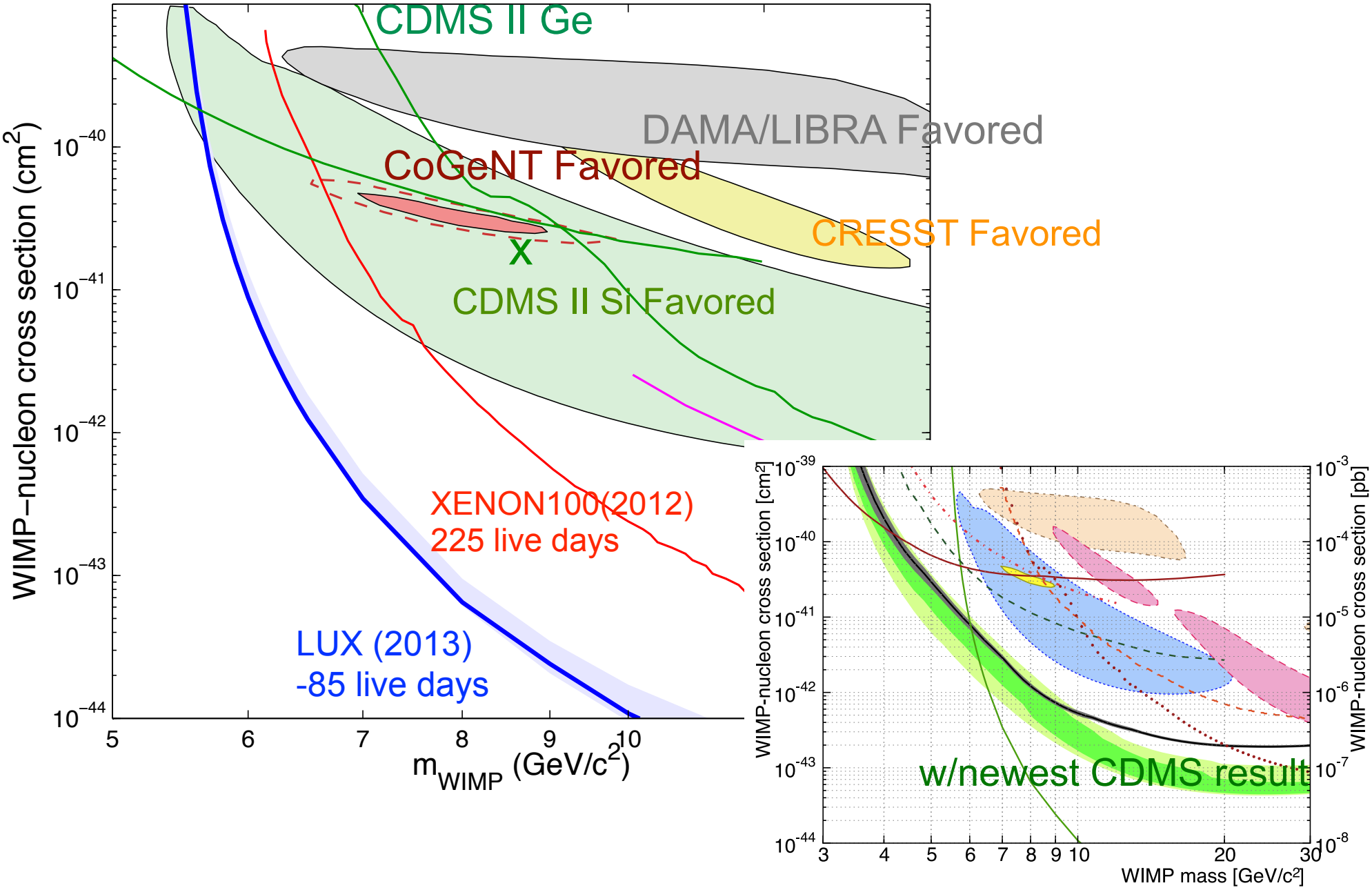


Phys. Rev. Lett. 112, 091303 (2014)

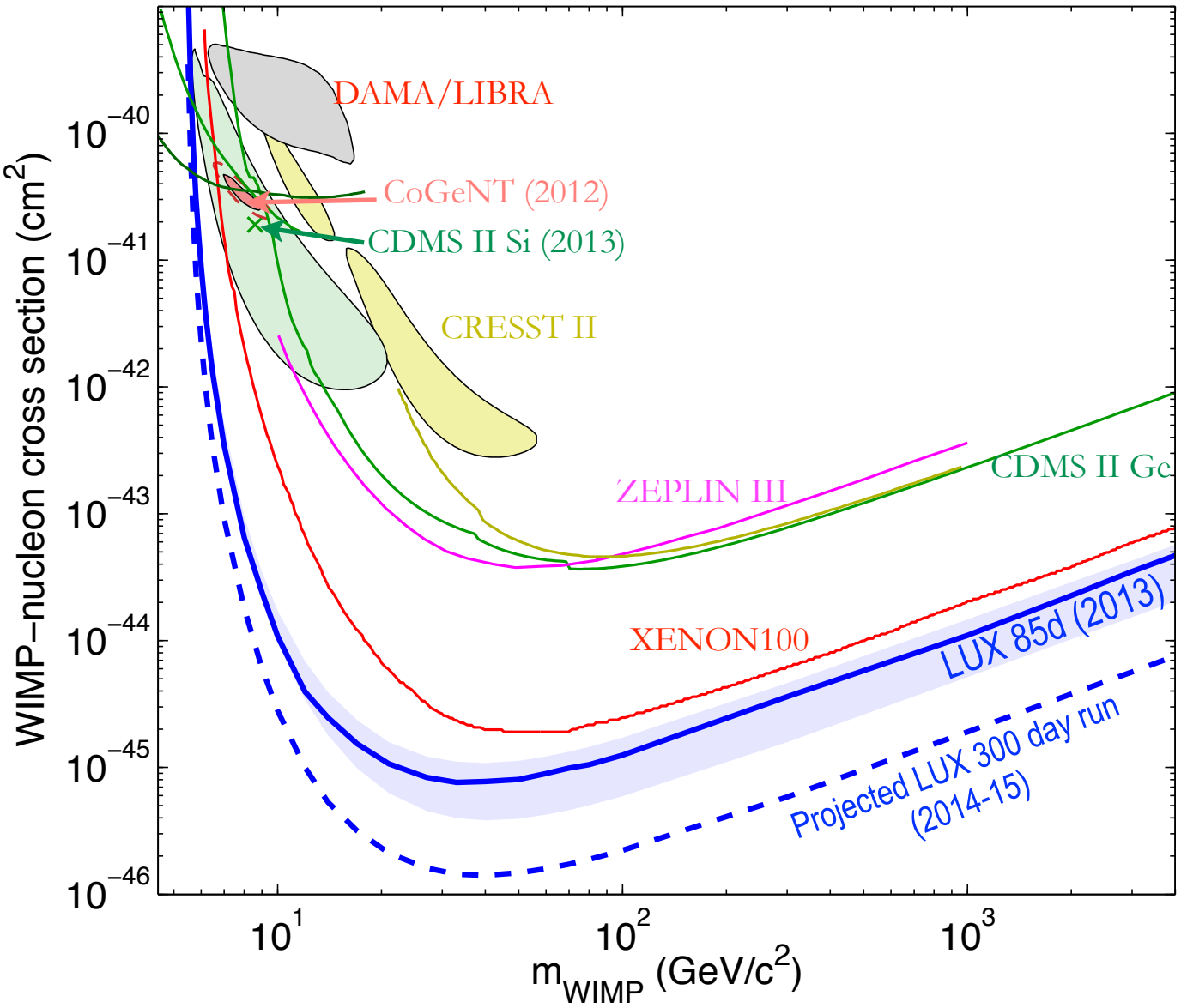
Spin Independent Cross Section Upper Limit



Low Mass WIMPs



Next for LUX



Updated analysis of 85d

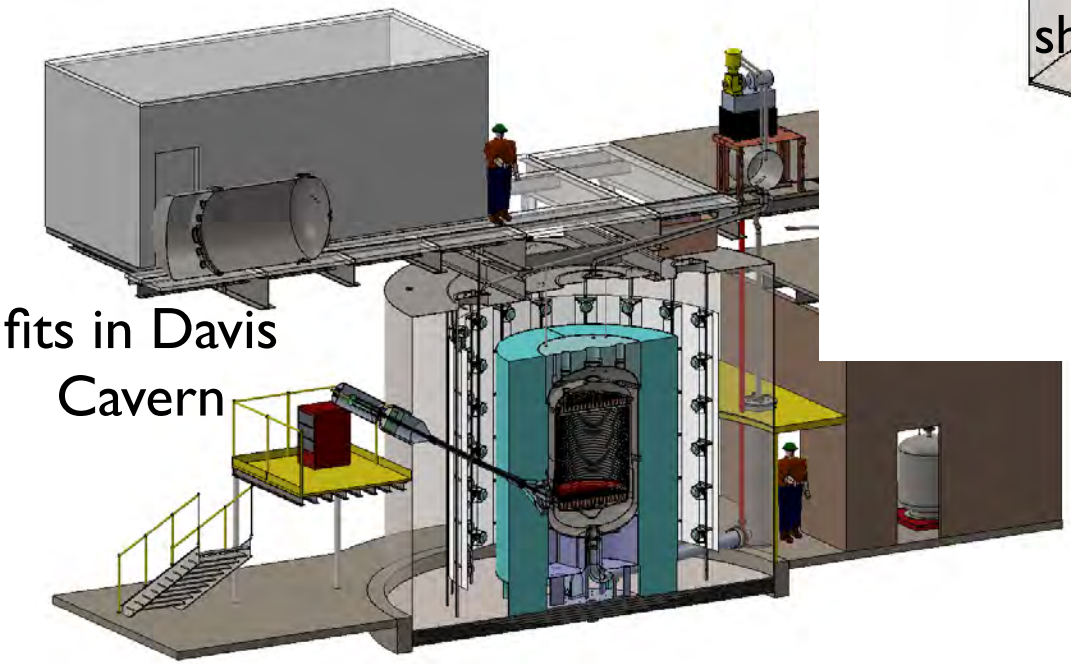
- improved reconstruction
- lower threshold
- wall distribution into PLR?
- complete DD calibration
- NEST update

300d run: above +

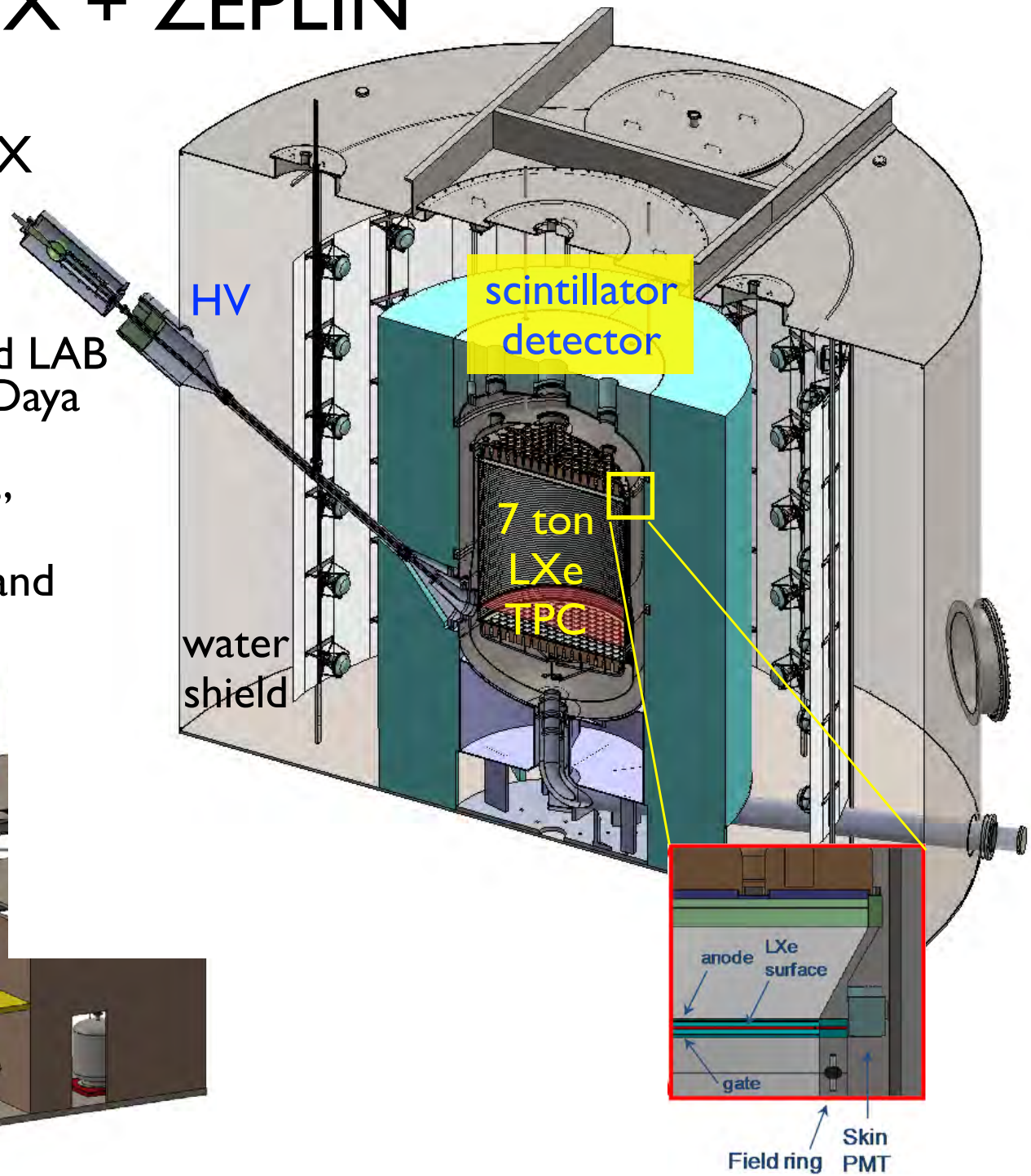
- improved extraction field
- ^{127}Xe decayed away

LZ: LUX + ZEPLIN

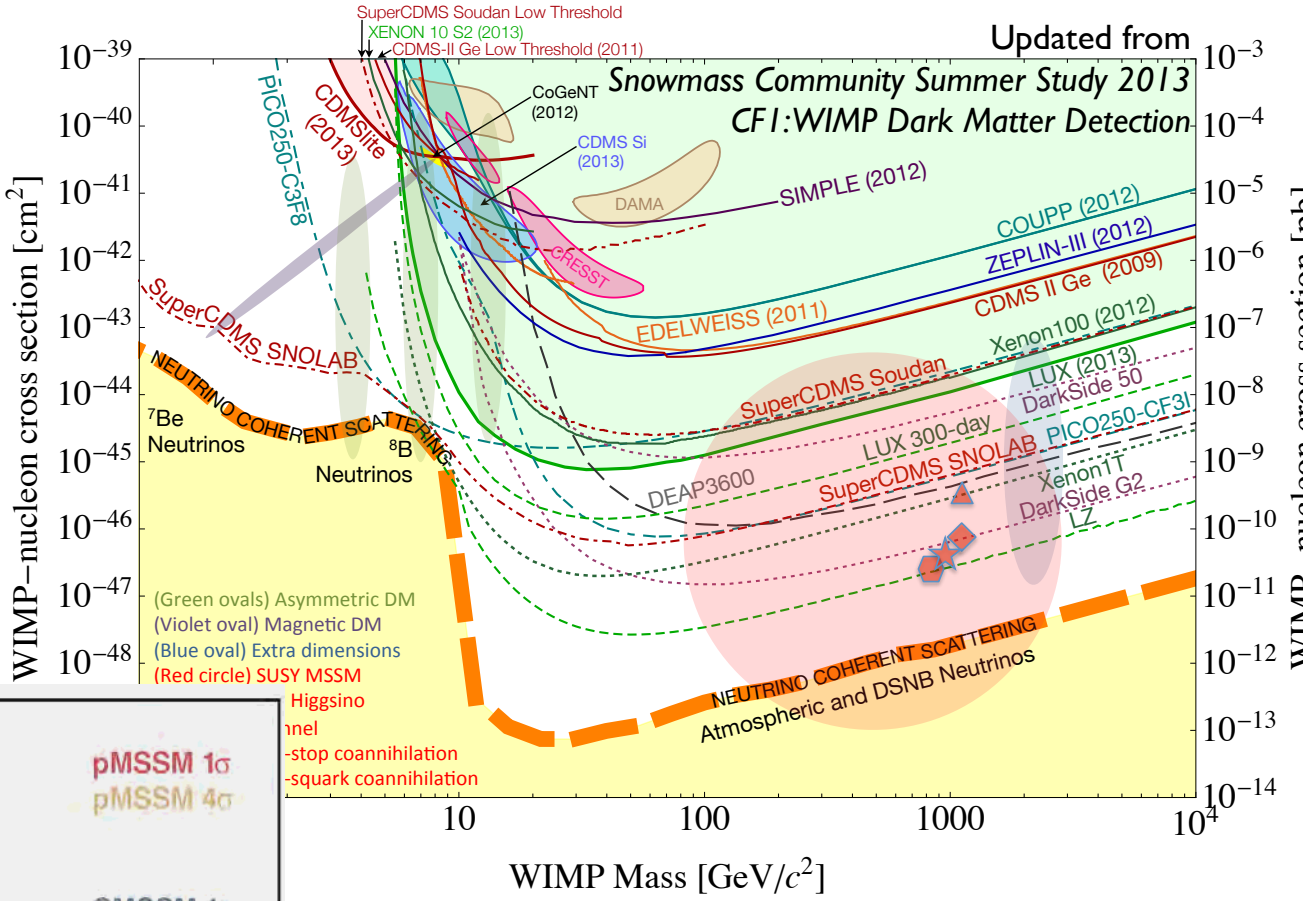
- 20-fold scale-up from LUX
- Two-component outer detector system
  - 0.75 m thick Gd-loaded LAB scintillator shield (c.f.: Daya Bay)
  - Instrumented Xe "skin"
  - Effective for neutrons and gammas

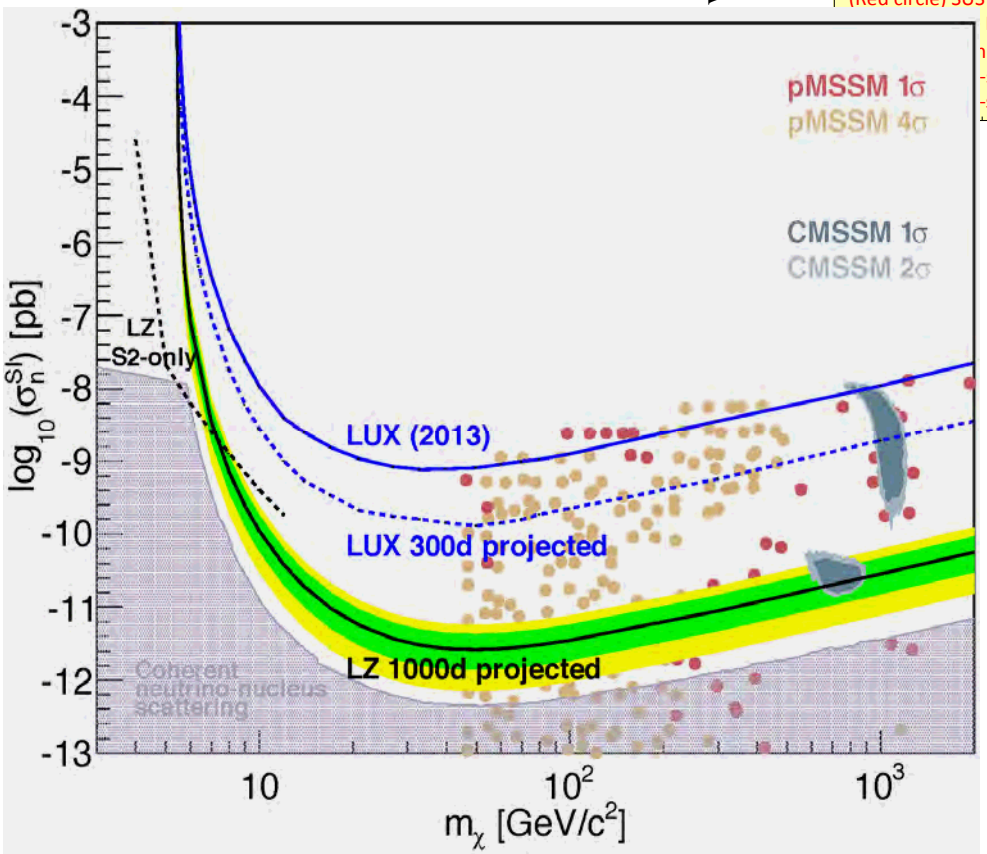


fits in Davis Cavern



LZ Reach and Snowmass



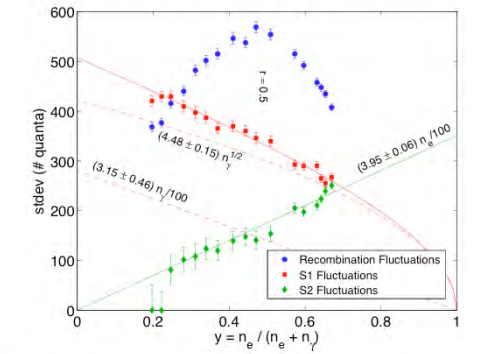


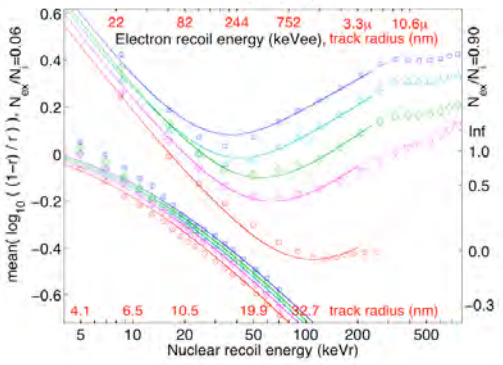
3 year run, limited primarily by (electron recoil) background of *pp* solar neutrinos

limited by nuclear scatter background? reach to 10^{-49} cm^2 neutrino floor depends on rejecting *pp* solar

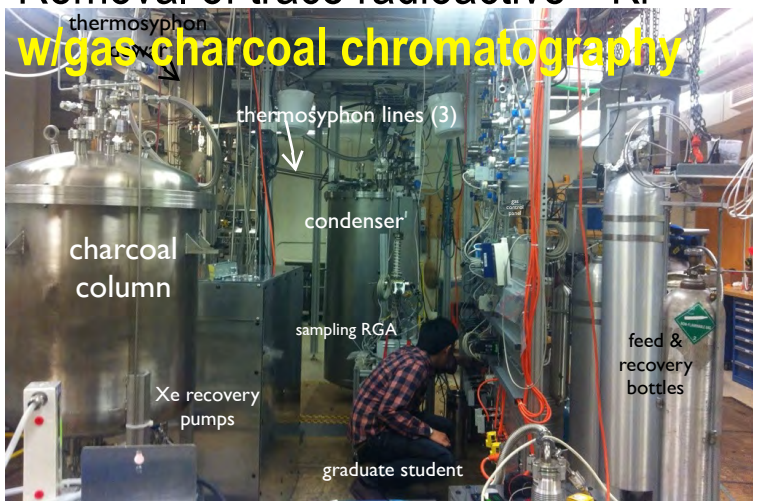
Lab Activities at SLAC

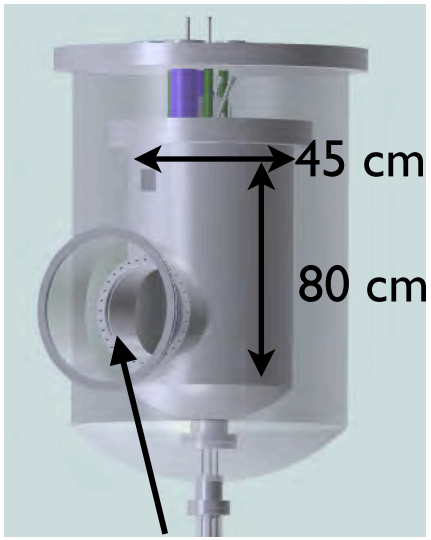
Fundamental measurements





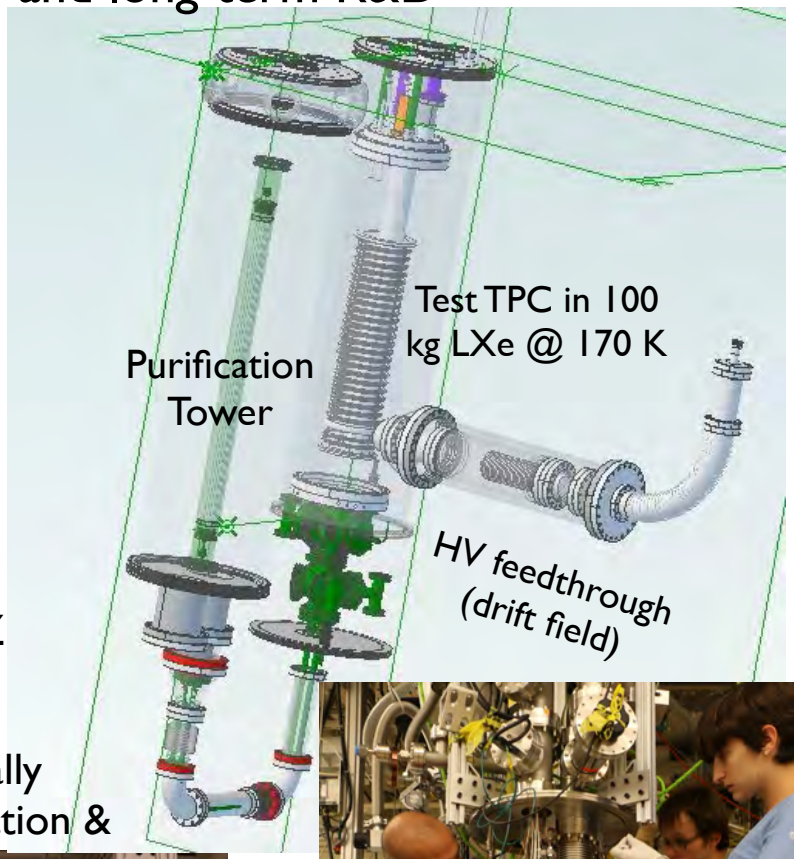
Removal of trace radioactive ^{85}Kr w/gas charcoal chromatography



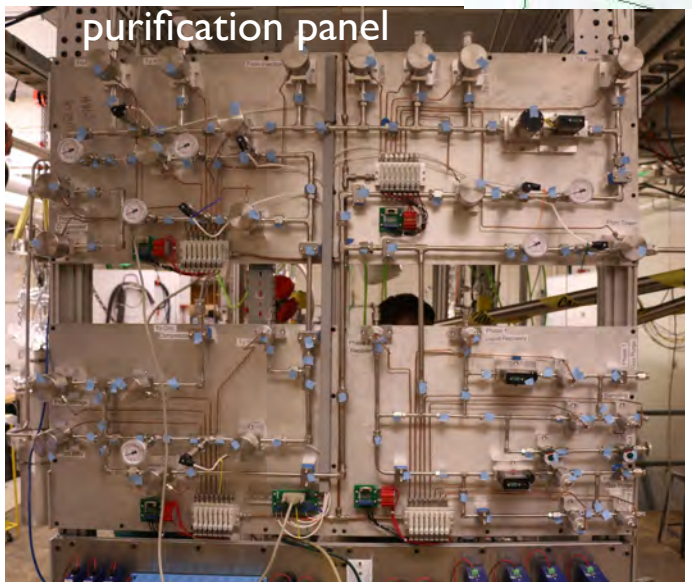


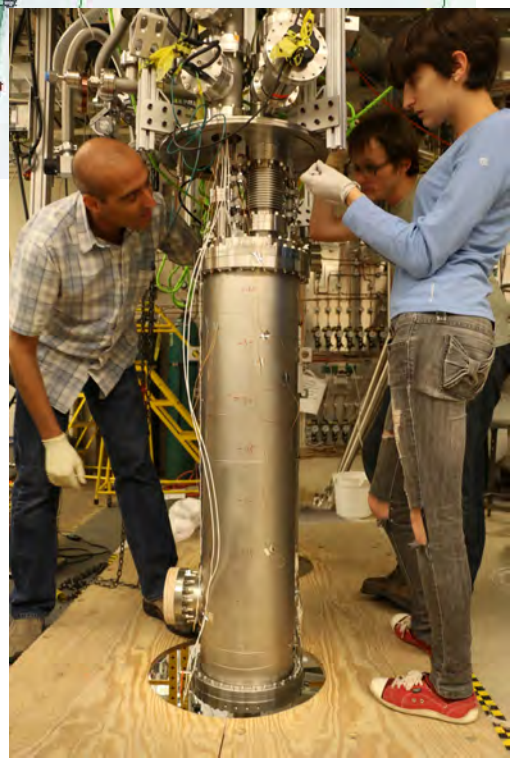
LXe vessels w/200 kV feedthrough ports for LZ system test

Test platform for LZ prototyping and long-term R&D

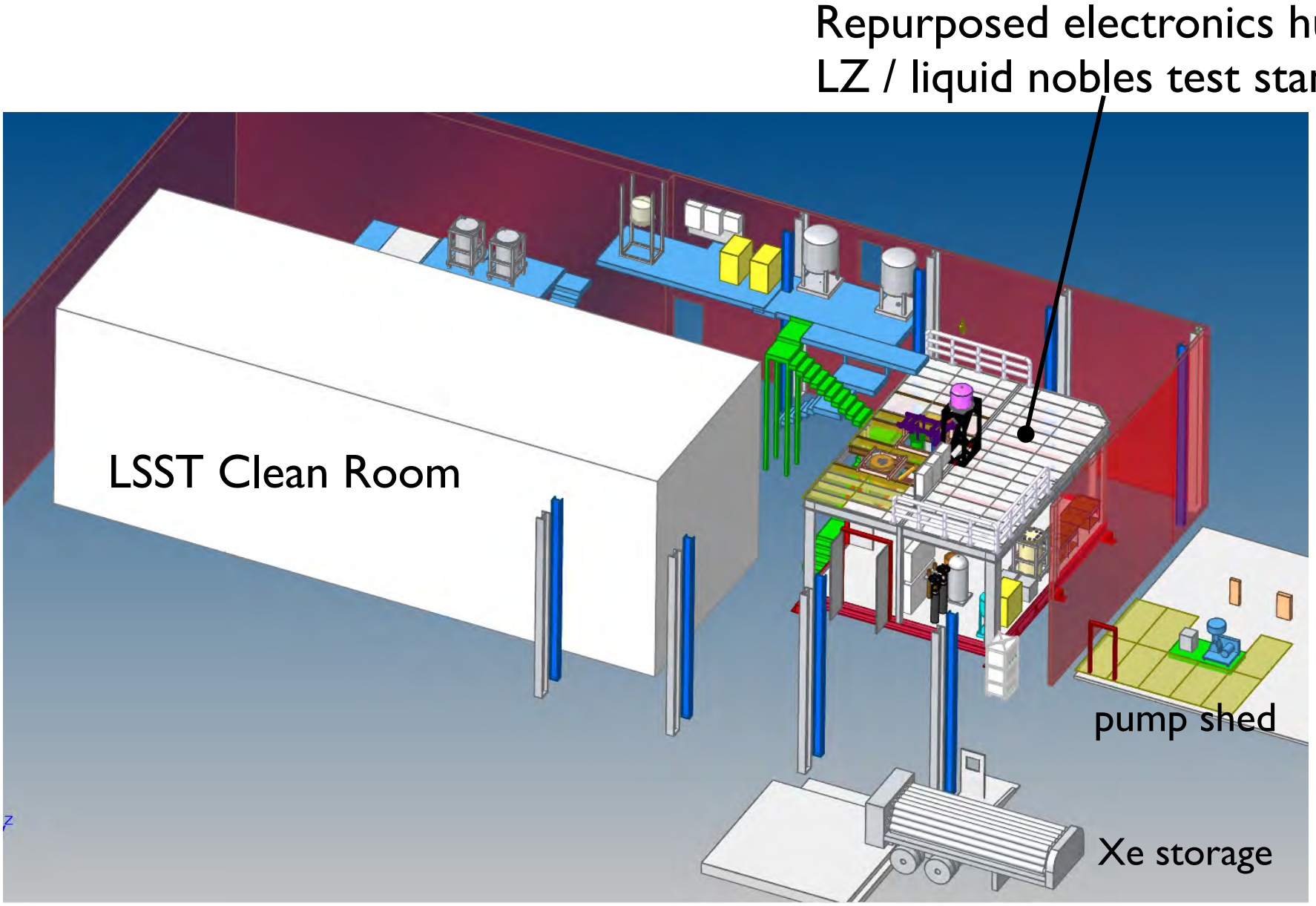


high-flow pneumatically controlled Xe circulation & purification panel

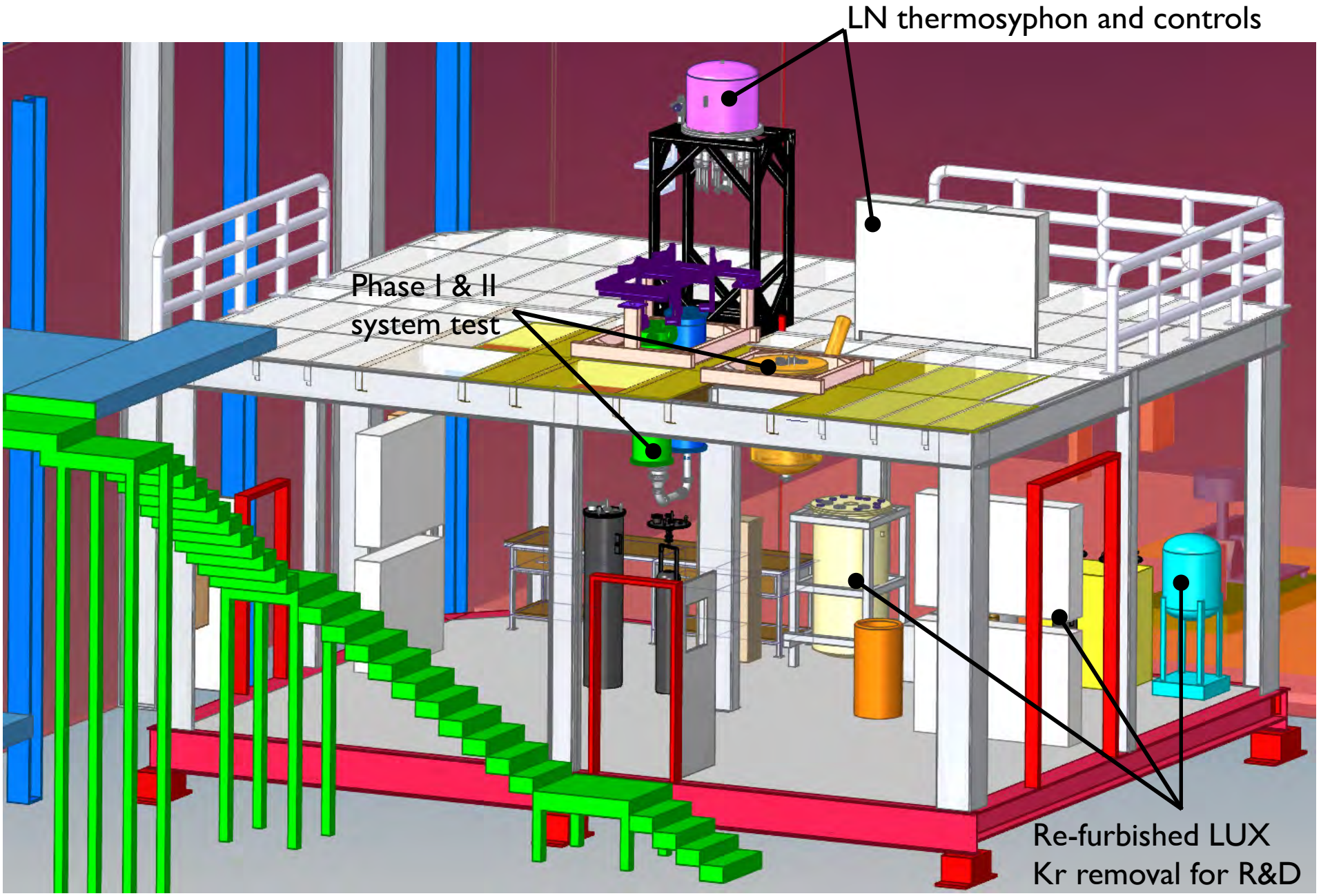




Former BaBar "IR2" complex



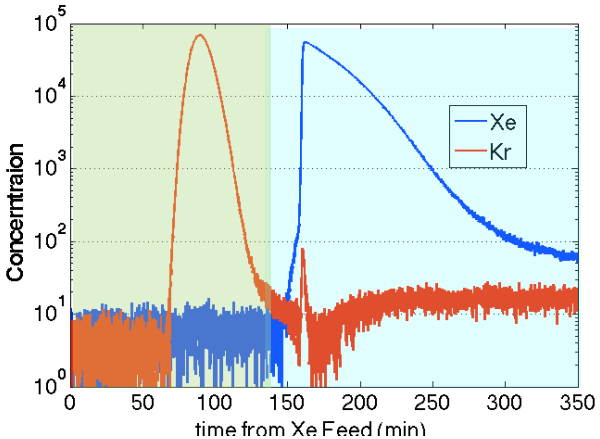
LZ / liquid nobles test stand



Kr removal: reduction to 0.015 ppt ~ 10% pp solar ν

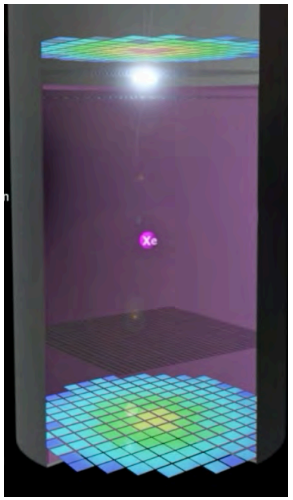
10 tons / 60 days @ 200 kg/day X 2 passes

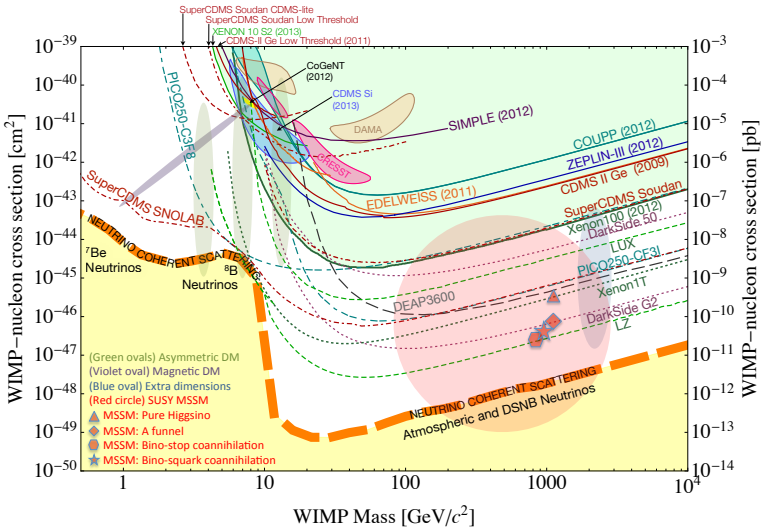
500 mbar
500 SLPM He
(Fluitron compressor)
16 kg
Xe
250 SLPM He
(dry backing pump)
100 mbar
thermosyphon
LN
cryocooler
charcoal
500 kg
cooled Kr trap
filter
RGA
sampling
50 SLPM Xe
2 bar
80 bar
Xe storage
10 mbar
250 SLPM He
(Roots booster)
Xe/Kr
chromatography
He
feed/purge ~ 120 min
Xe recovery
~ 120 min
condensers
200 kg capacity
24 hour cycle
(per condenser)
Xe
automation of all 3 cycles

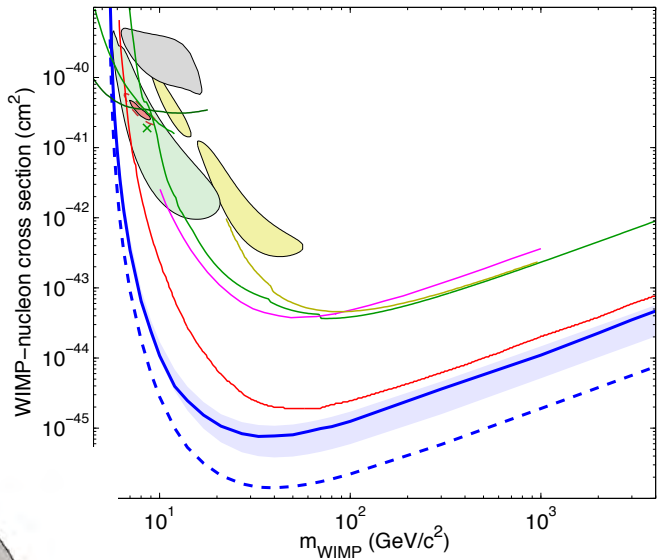


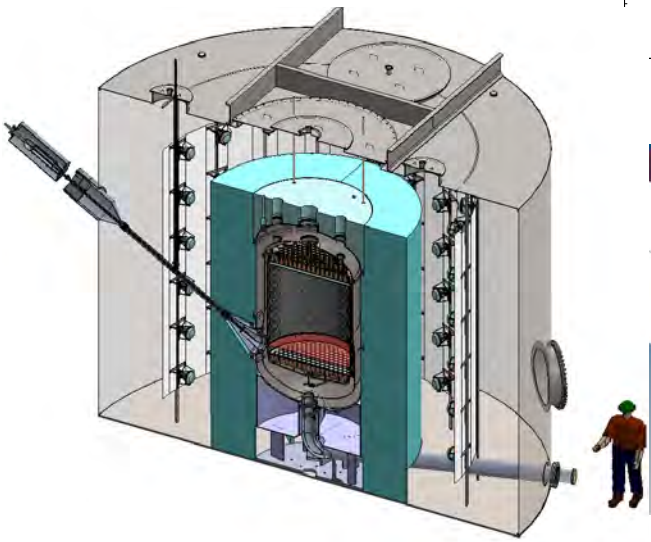
Summary

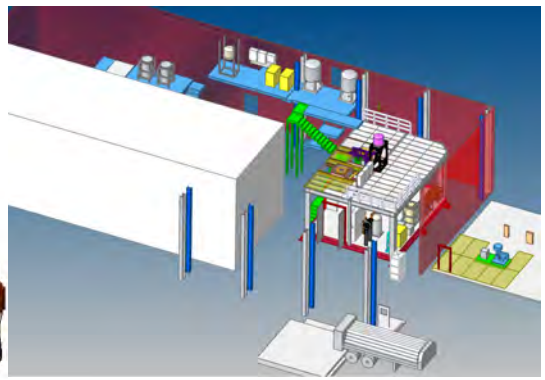
- Dark matter detection - exciting future
- Liquid xenon TPCs playing key role
- 300-day data set for LUX ~ 4-5x
- LZ approaches neutrino floor











Thank you…

…visit us at *luxdarkmatter.org*