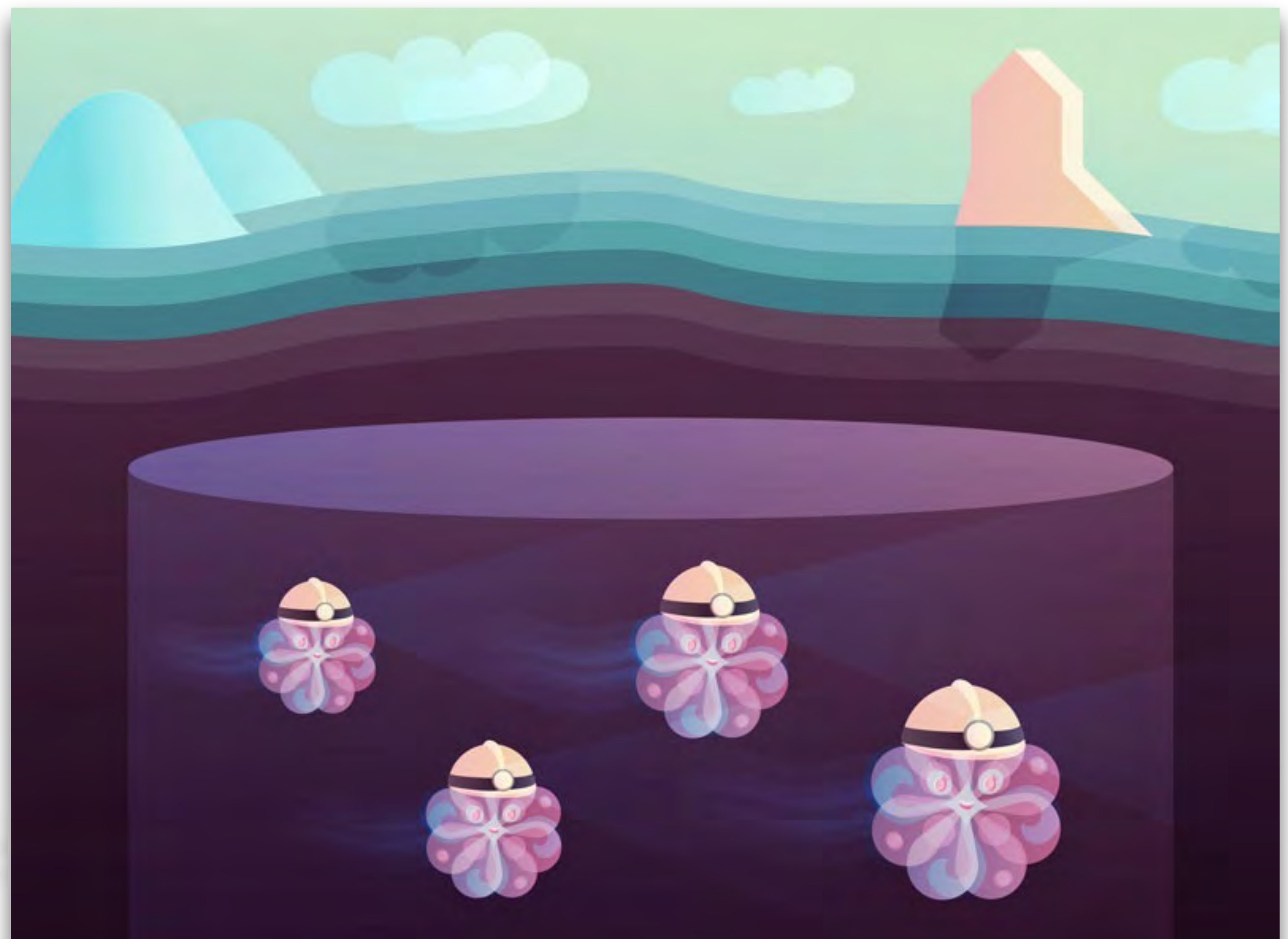
Direct Dark Matter Searches with the LUX and LZ Experiments

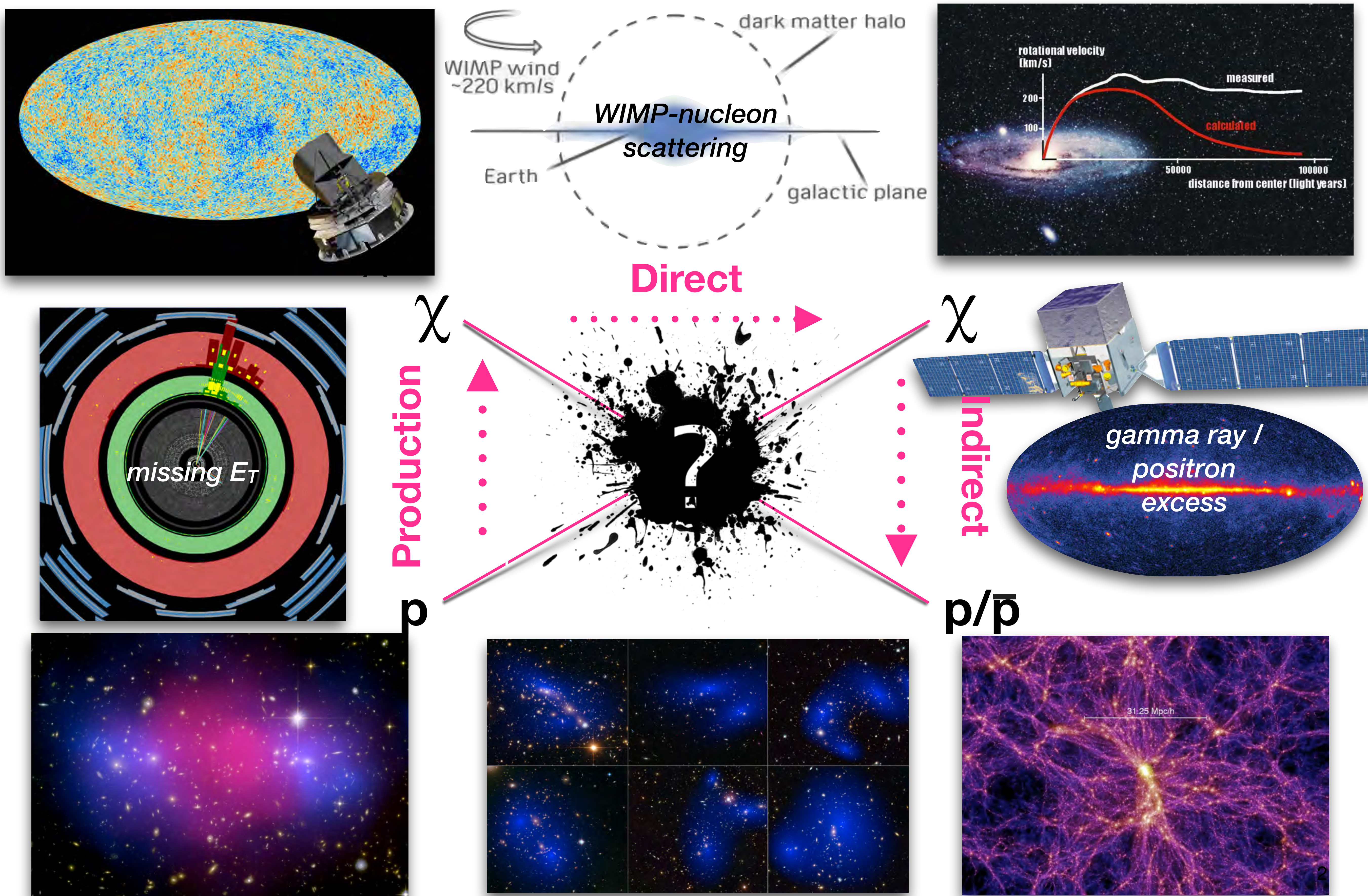
Sally Shaw

IoP HEP & APP Joint Meeting

22nd March 2016

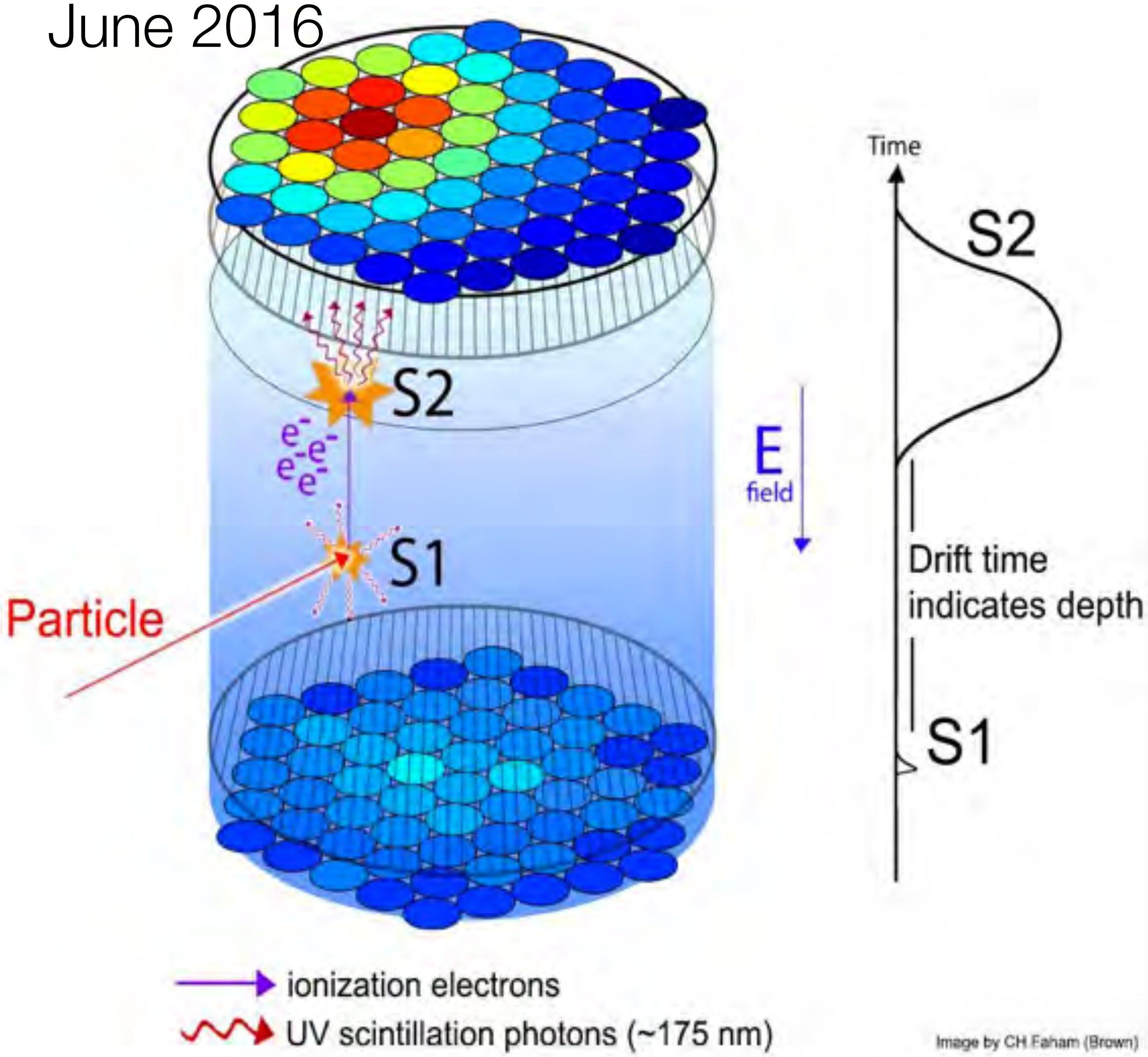


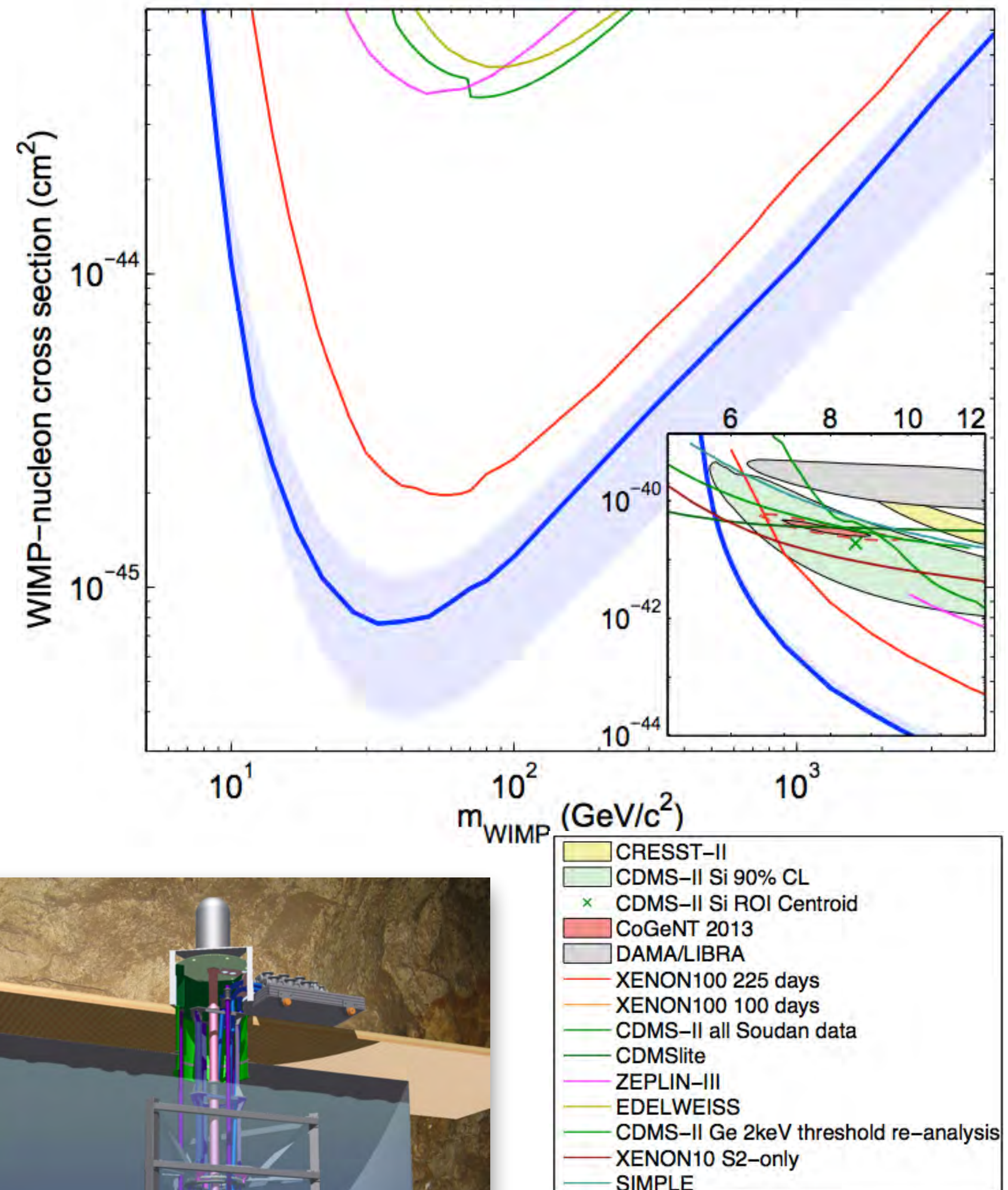
Dark Matter Detection

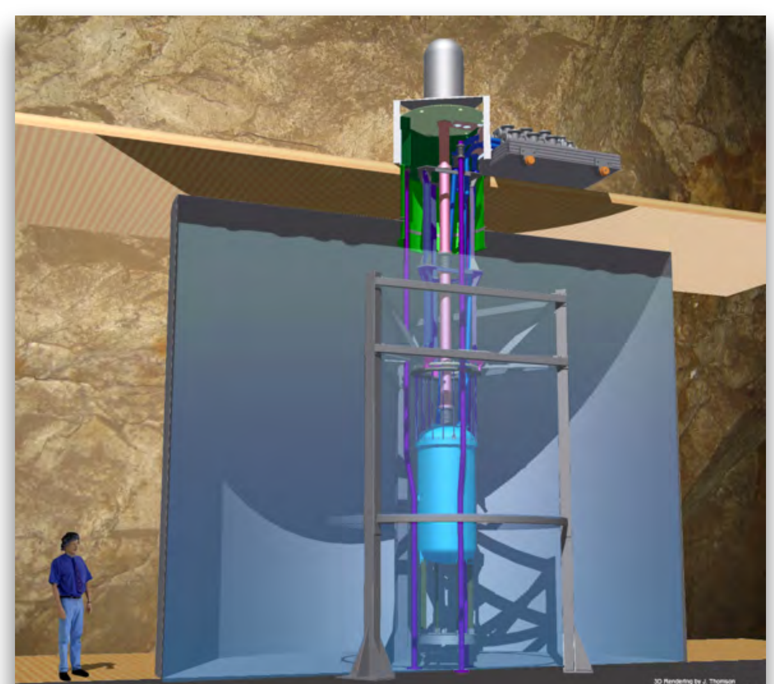


LUX

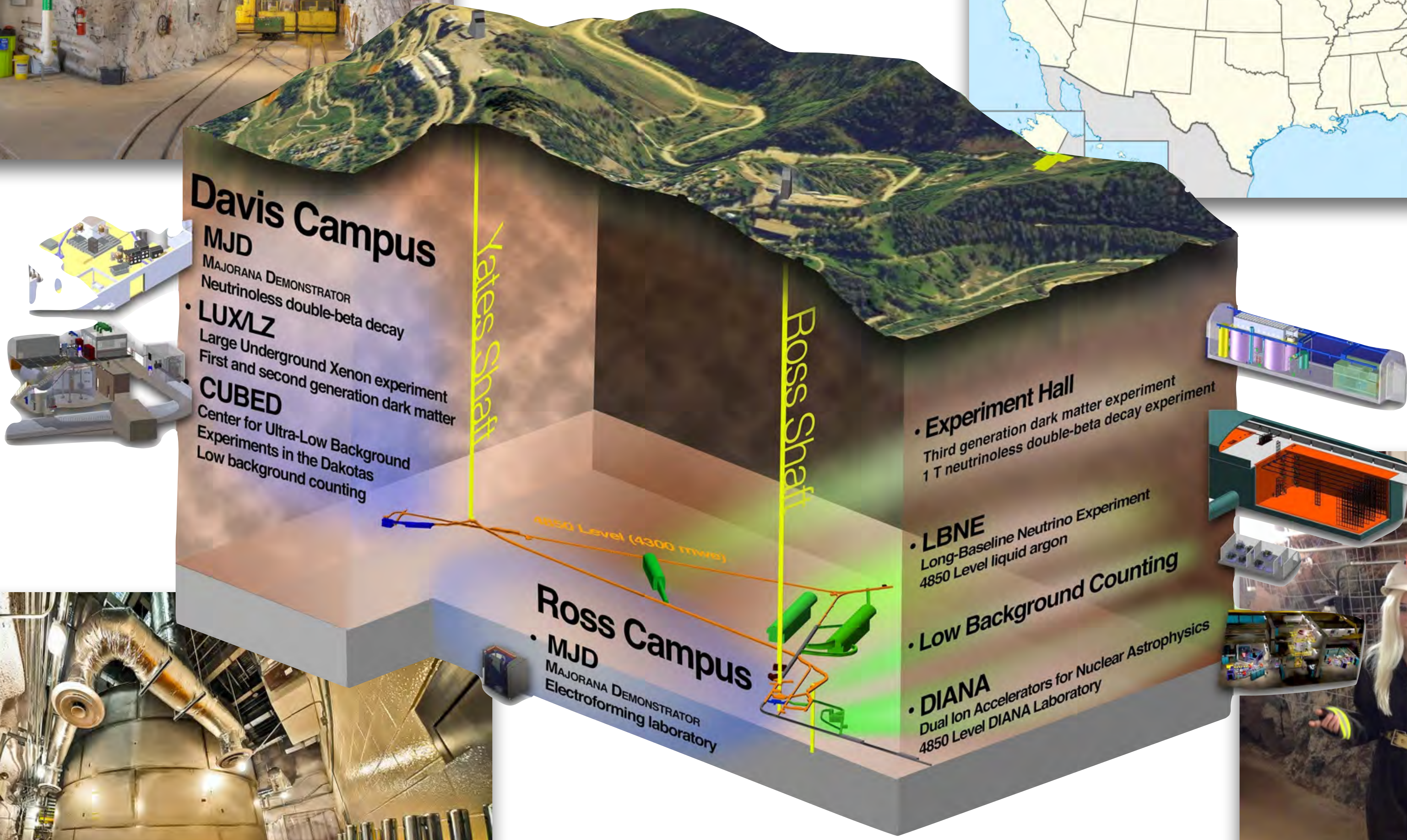
- **Large Underground Xenon** detector
- Dual-phase Xenon TPC with 3D position reconstruction and 99.6% electron recoil (ER) nuclear recoil (NR) discrimination
- World's first sub-zeptobarn detector
- Status: WIMP search mode for Run 4, done by June 2016

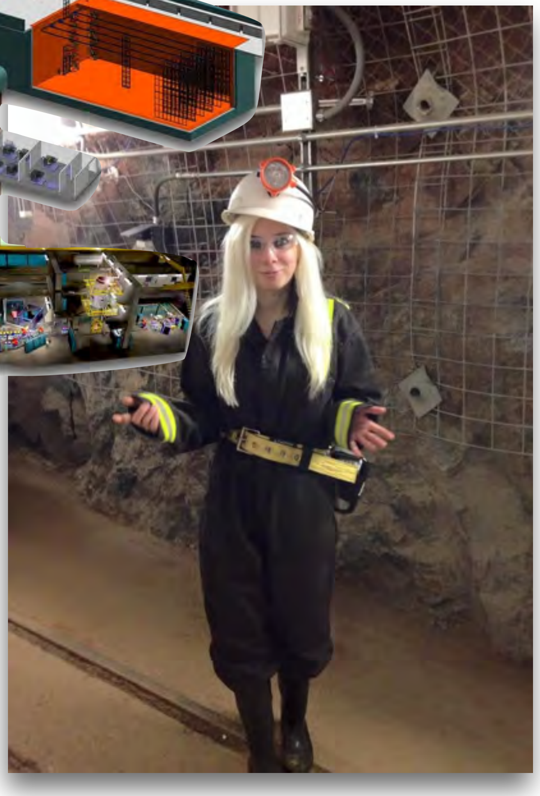






Sanford Lab, South Dakota





Improvements to LUX Analysis

- More accurate estimation of detected photons
- More livetime - further 10 days (1.4×10^4 kg · days)
- Improved background model allowing a larger fiducial volume (118kg → 147kg)
- Better determination of g1 and g2 for energy reconstruction:

S1/g1 **S2/g2**

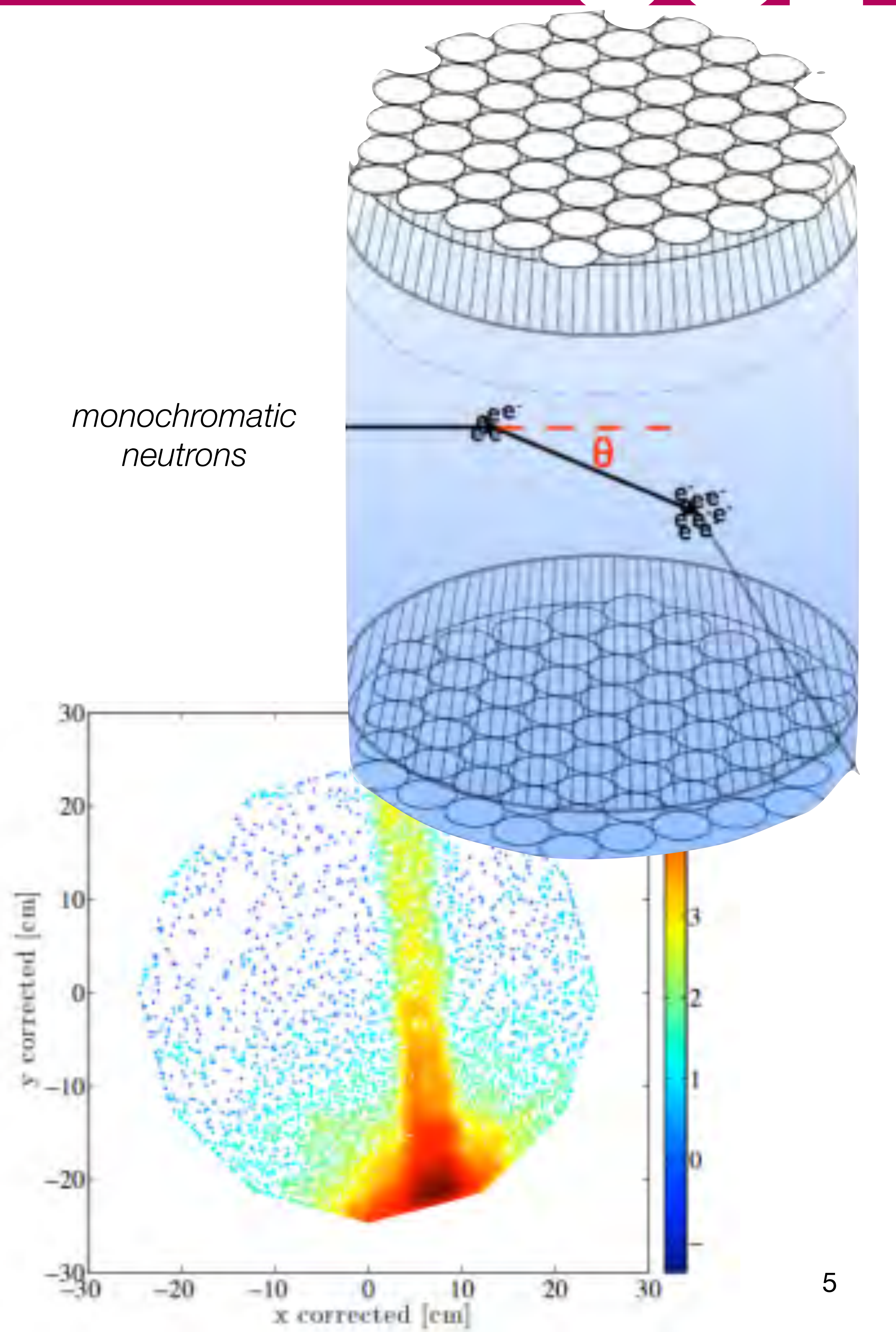
$$E = \frac{1}{\mathcal{L}(E)} W(n_{ph} + n_e)$$

Lindhard factor- energy loss to heat

13.7 keV_{ee}

- In situ NR calibration - light and charge yield measured, low energy threshold 3 keV → 1.1 keV

$$E_r = E_n \frac{4 m_n m_{Xe}}{(m_n + m_{Xe})^2} \frac{1 - cos\theta}{2}$$

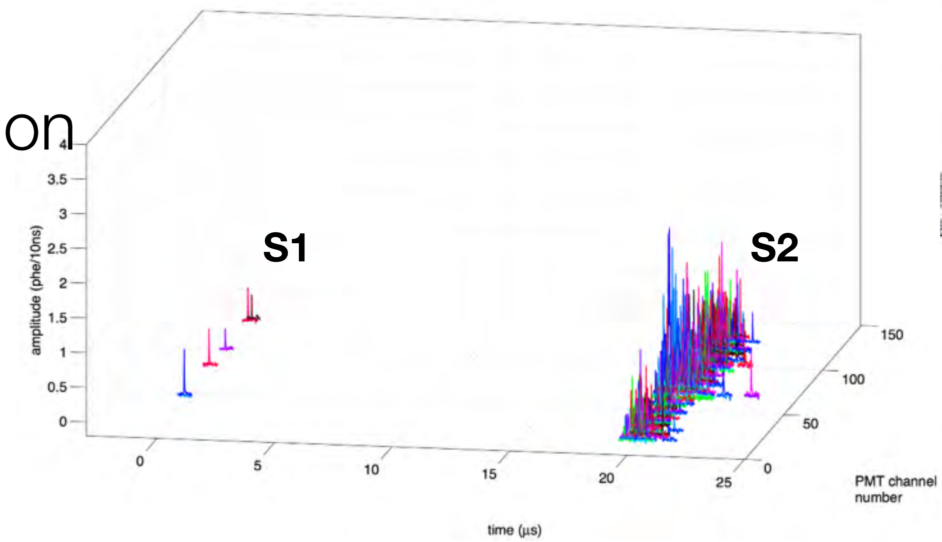


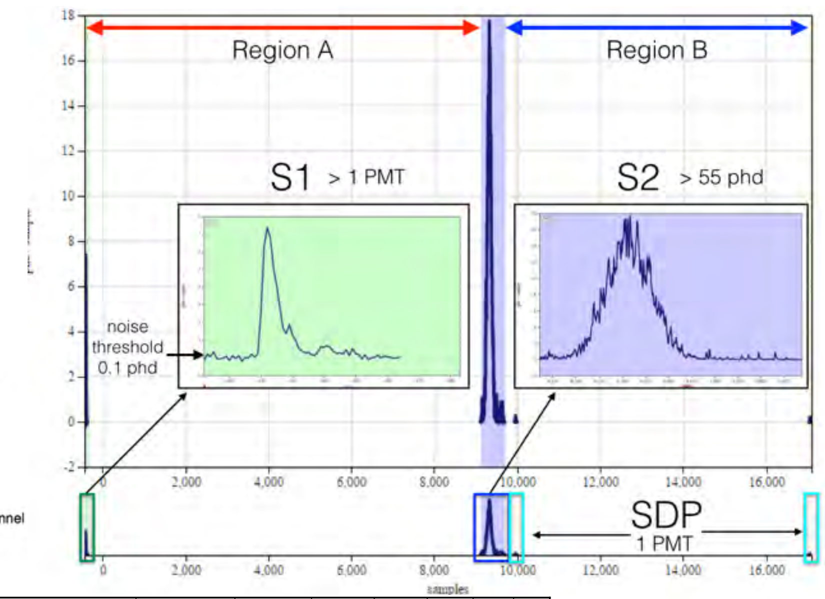
DD paper coming soon

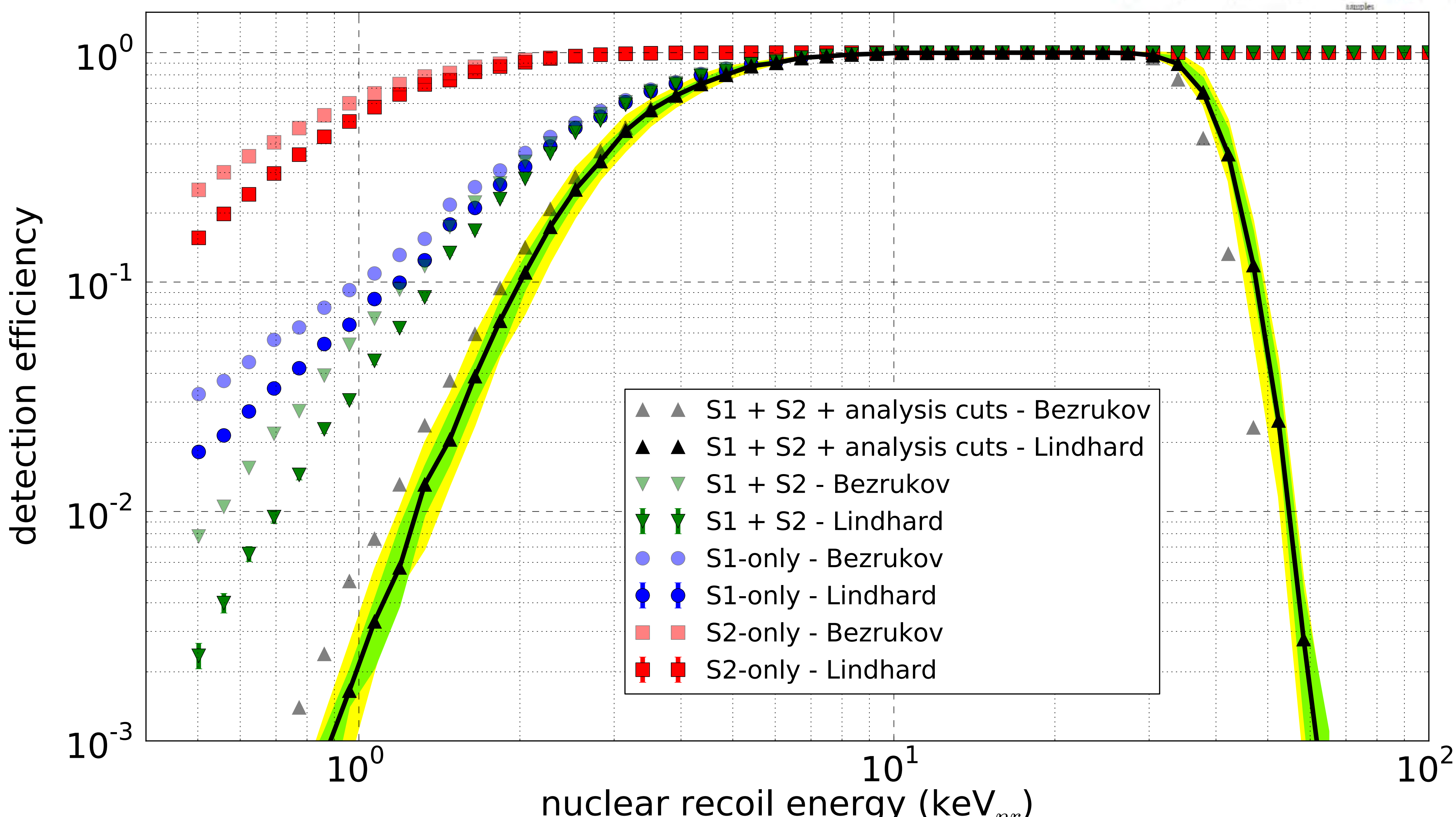
Pulse Identification & Event Selection

Contributions:

- Pulse finding and classification
- Event classification
- WIMP search selection cuts
- Nuclear recoil efficiencies

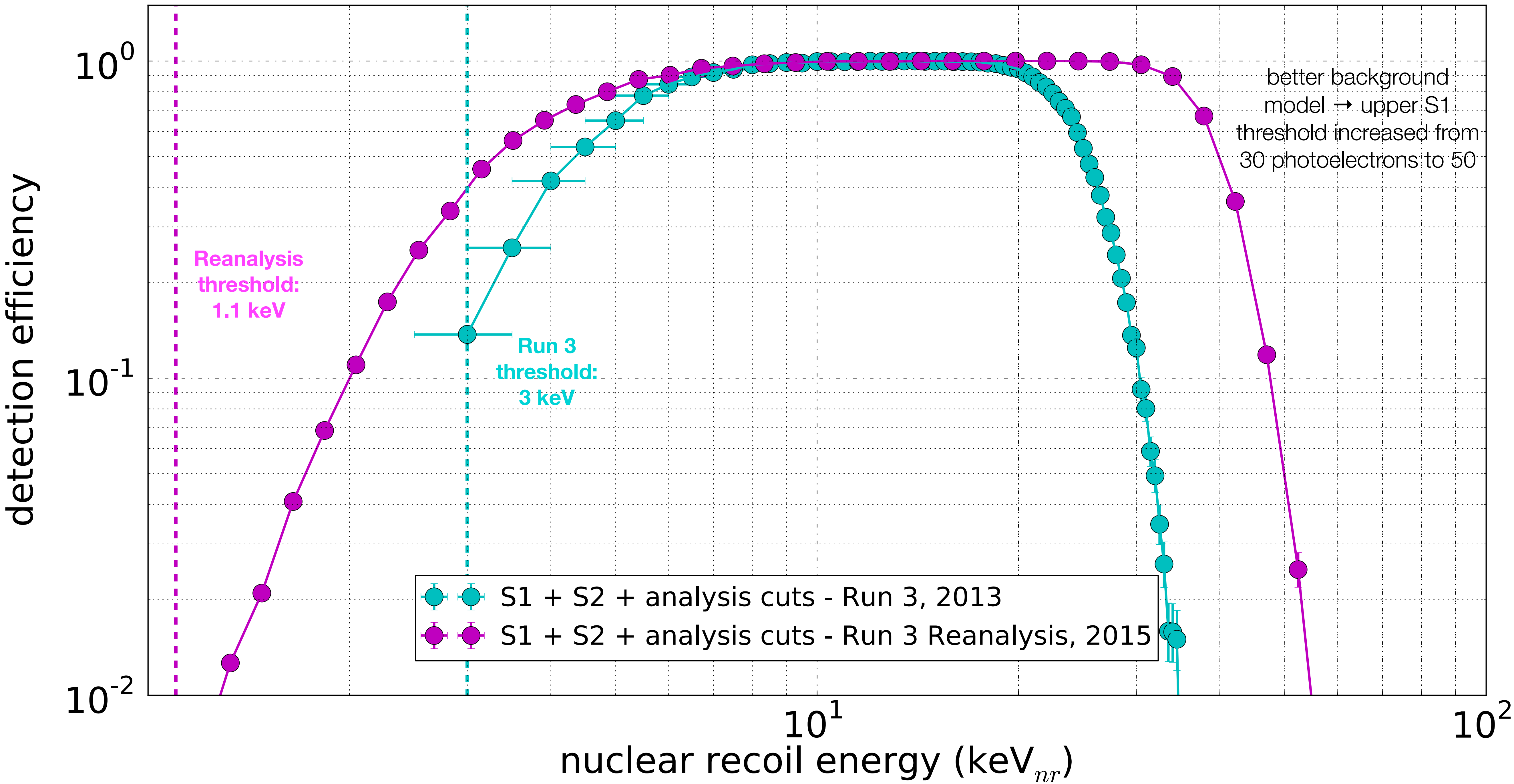






NR Efficiency Improvement

- **lowered S1 & S2 thresholds**
  - **threshold: minimum size (in photoelectrons) for a given classification**
- **algorithm improvements for both pulse finder and classifier**
  - **multiple scatter identification**
  - **bug fixes**

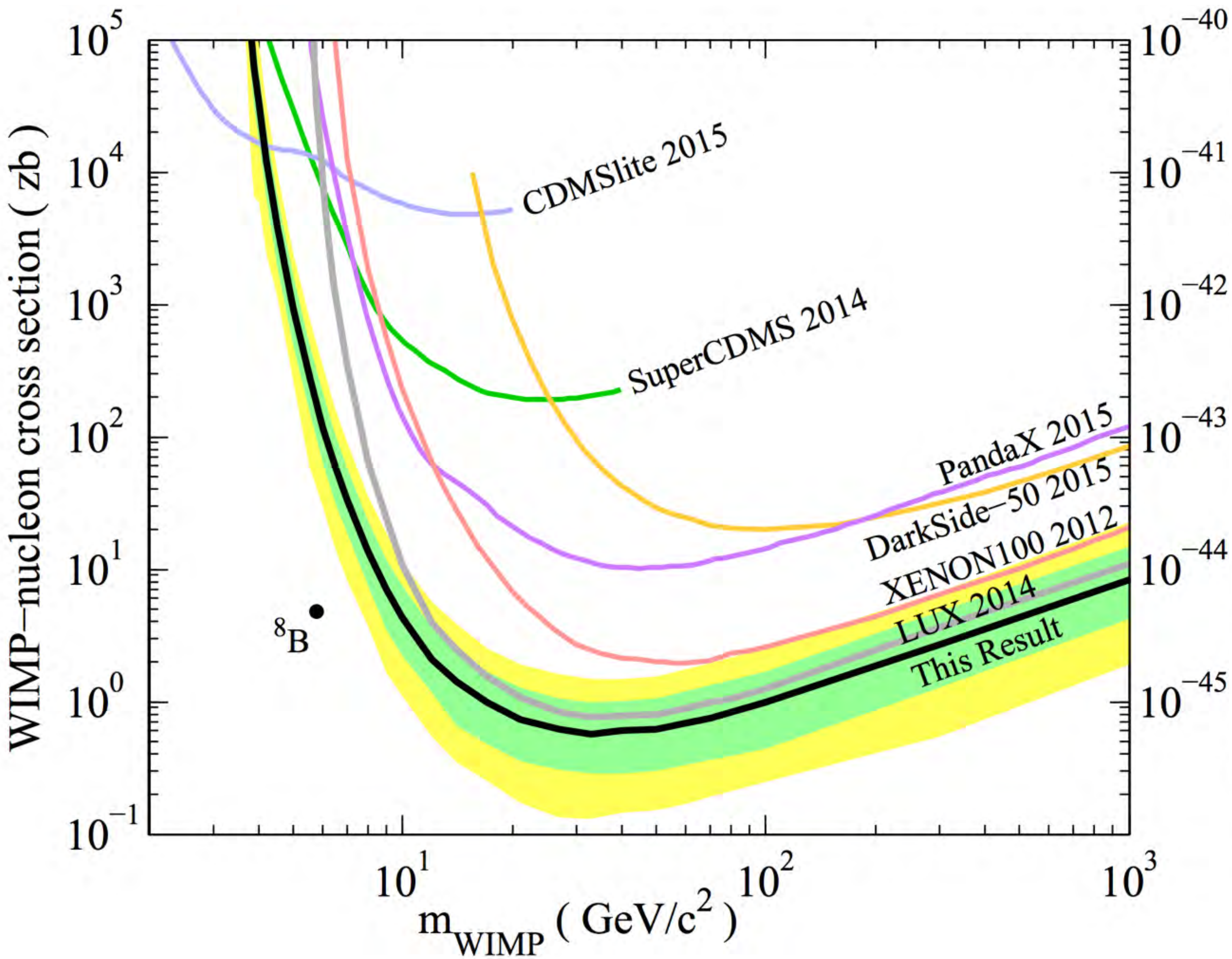


LUX New Results

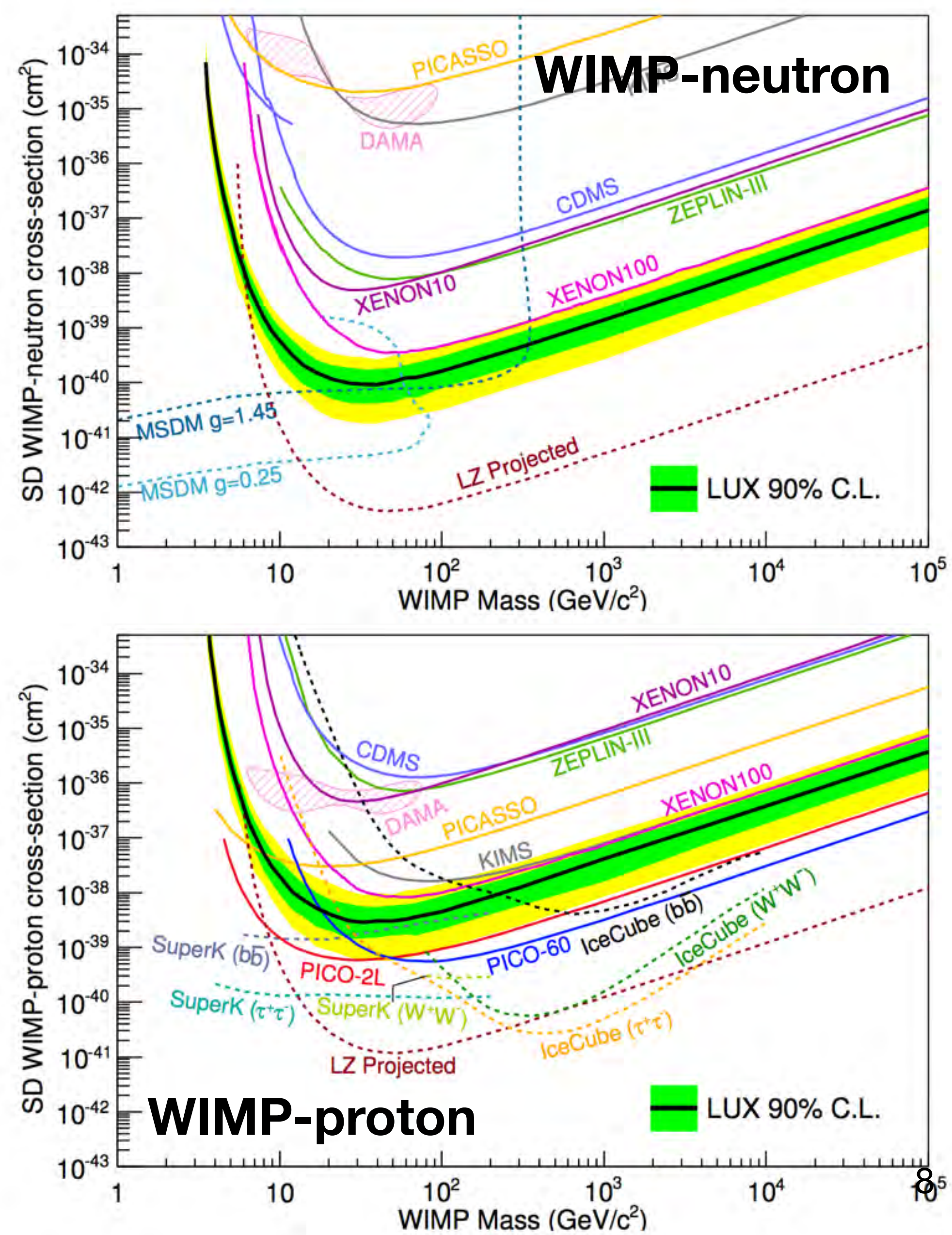
UCL

- Main improvement at low WIMP mass (ie low recoil energy)
- 33 GeV WIMP: 90% CL upper limit minimum 0.6 zb

Better spin-independent result
arXiv:1512.03506



First spin-dependent results
arXiv:1602.03489

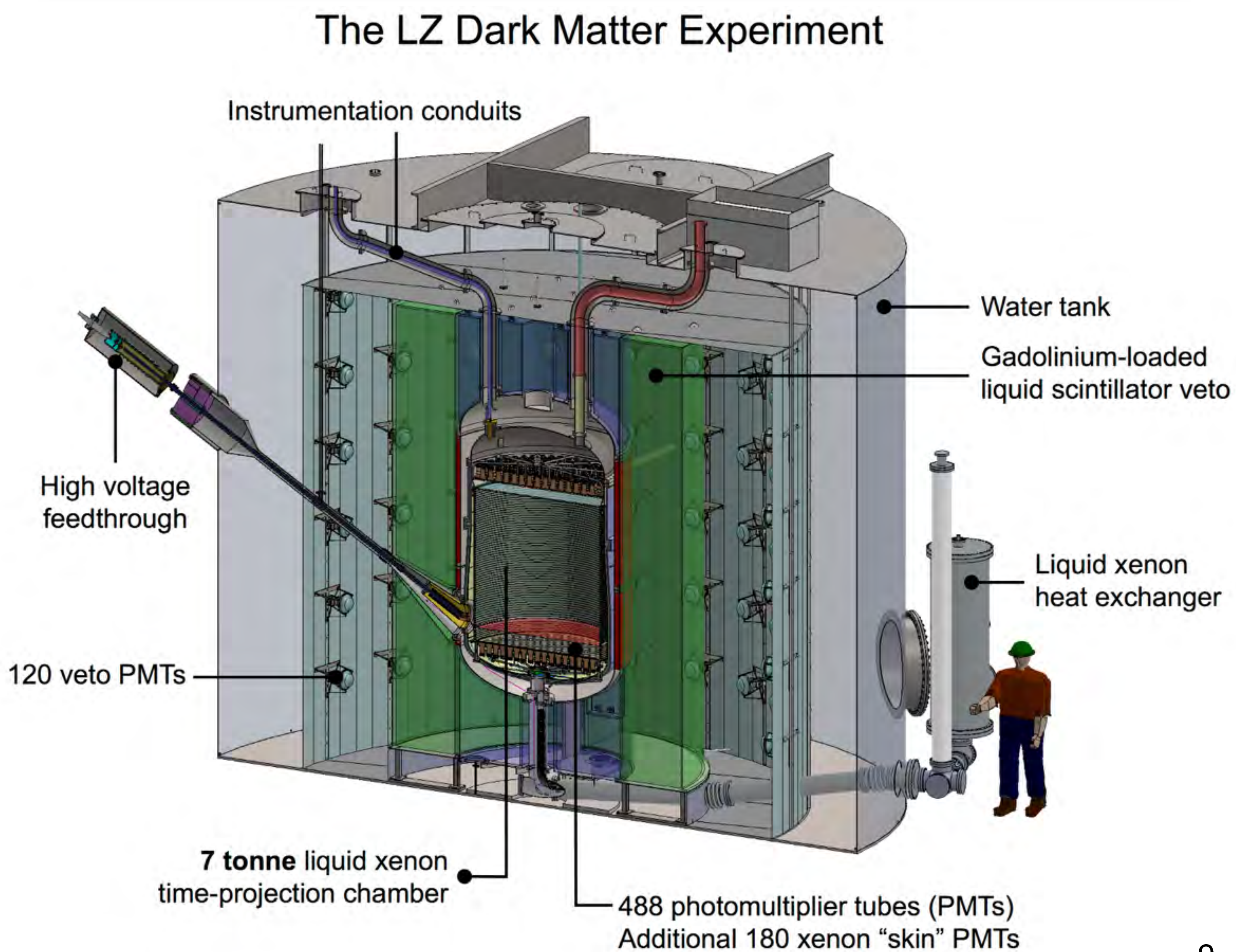


LUX-ZEPLIN

UCL

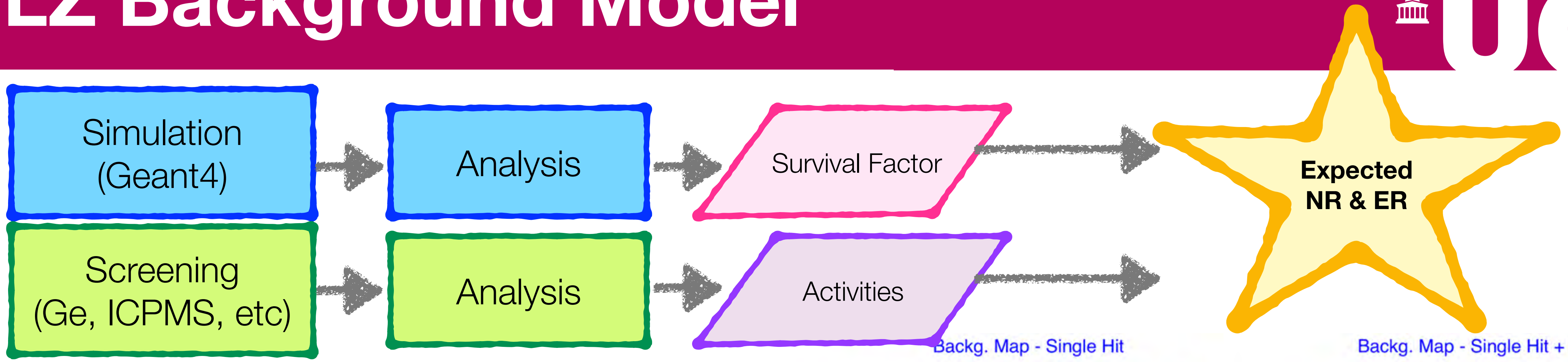
- Schedule: LUX removed late 2016, LZ commissioning 2019
- 10 tonnes of LXe - 7 tonne fiducial (c.f. LUX 118kg)
- 488 xenon PMTs (c.f. LUX 122)
- Outer detector system:
  - Gd-loaded LAB scintillator
  - 120 veto PMTs in water tank
  - Xenon skin veto
  - 180 skin PMTs
- Projected sensitivity: 2×10^{-48} cm^2 for 50 GeV WIMP
- **High precision background model needed**

LZ CDR: arXiv:1509.02910



See:
Status of the LUX-ZEPLIN experiment, Paolo Beltrame 14.00 Session 2D (next!)

LZ Background Model



Simulations

Detector components

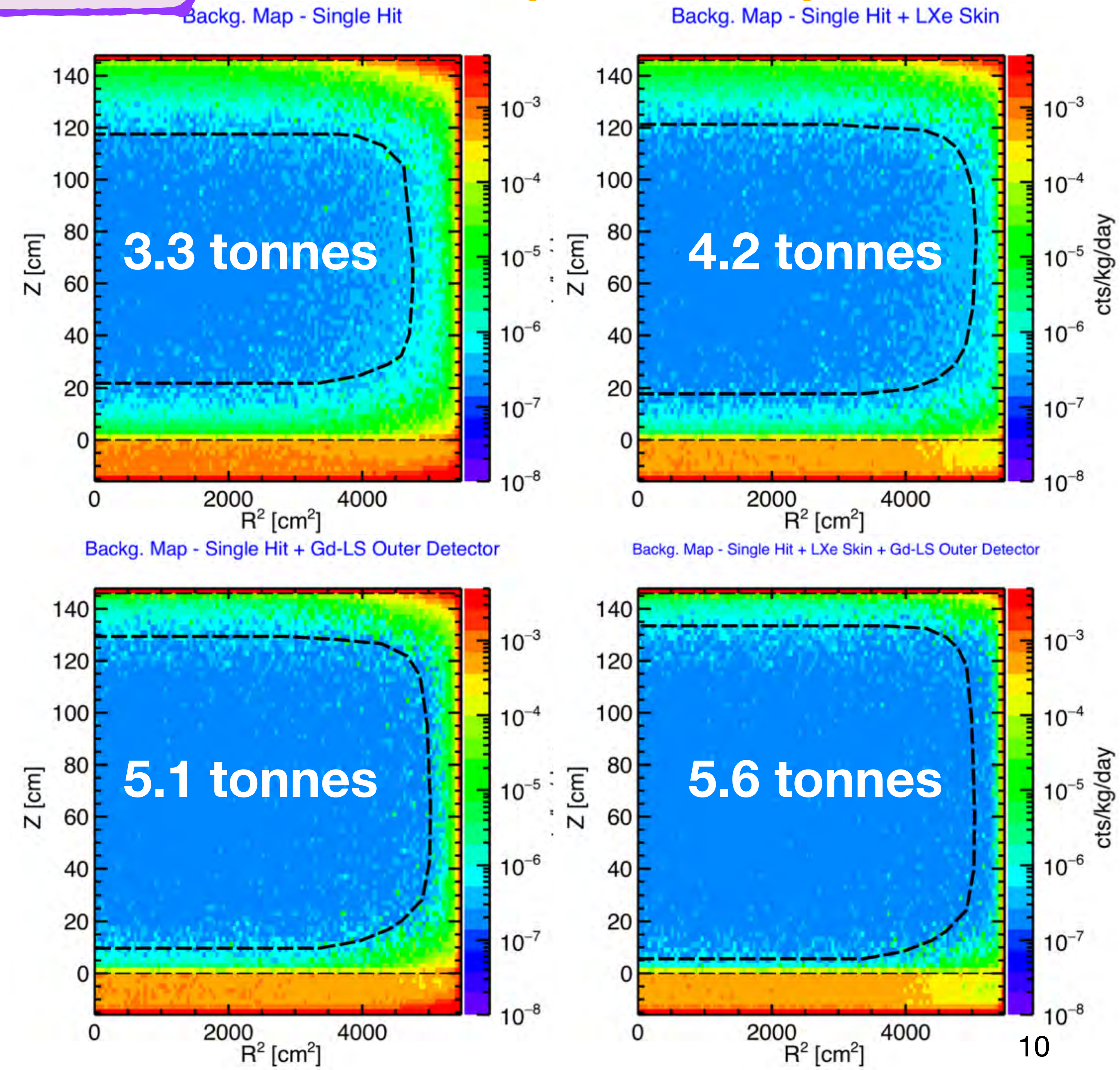
- Gammas:
  - U238 chain
  - Th232 chain
  - K40
  - Co60
  - Sc46
- Neutrons:
  - U early (α,n)
  - U late (α,n)
  - Th (α,n)

Other

- Rock/cavern gammas
- Radon

Analytical

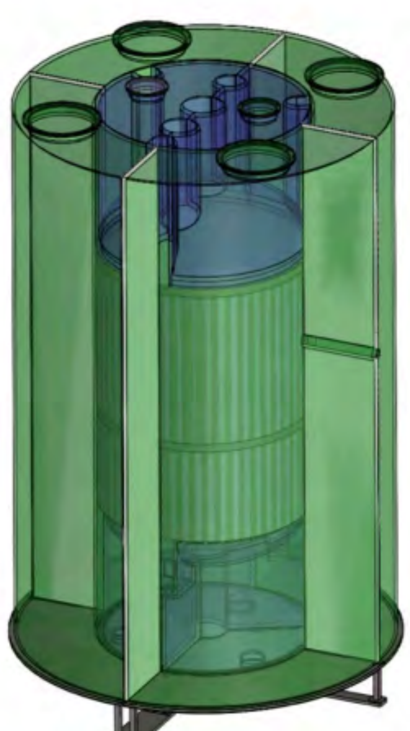
- Dust & plateout
- Intrinsic Xe (Kr, Ar)
- Neutrinos

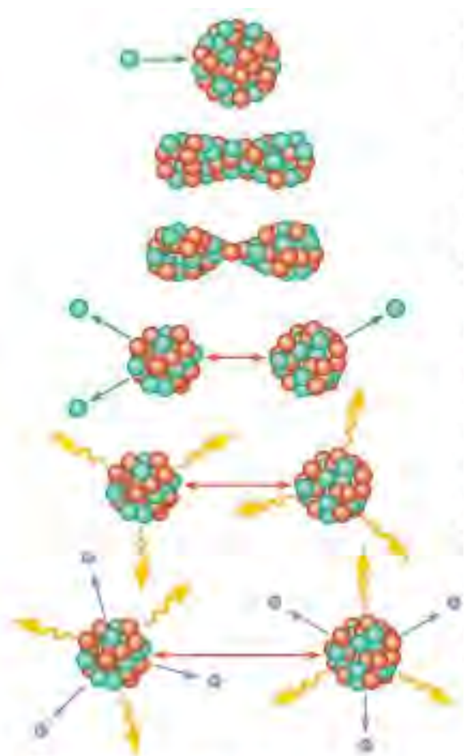


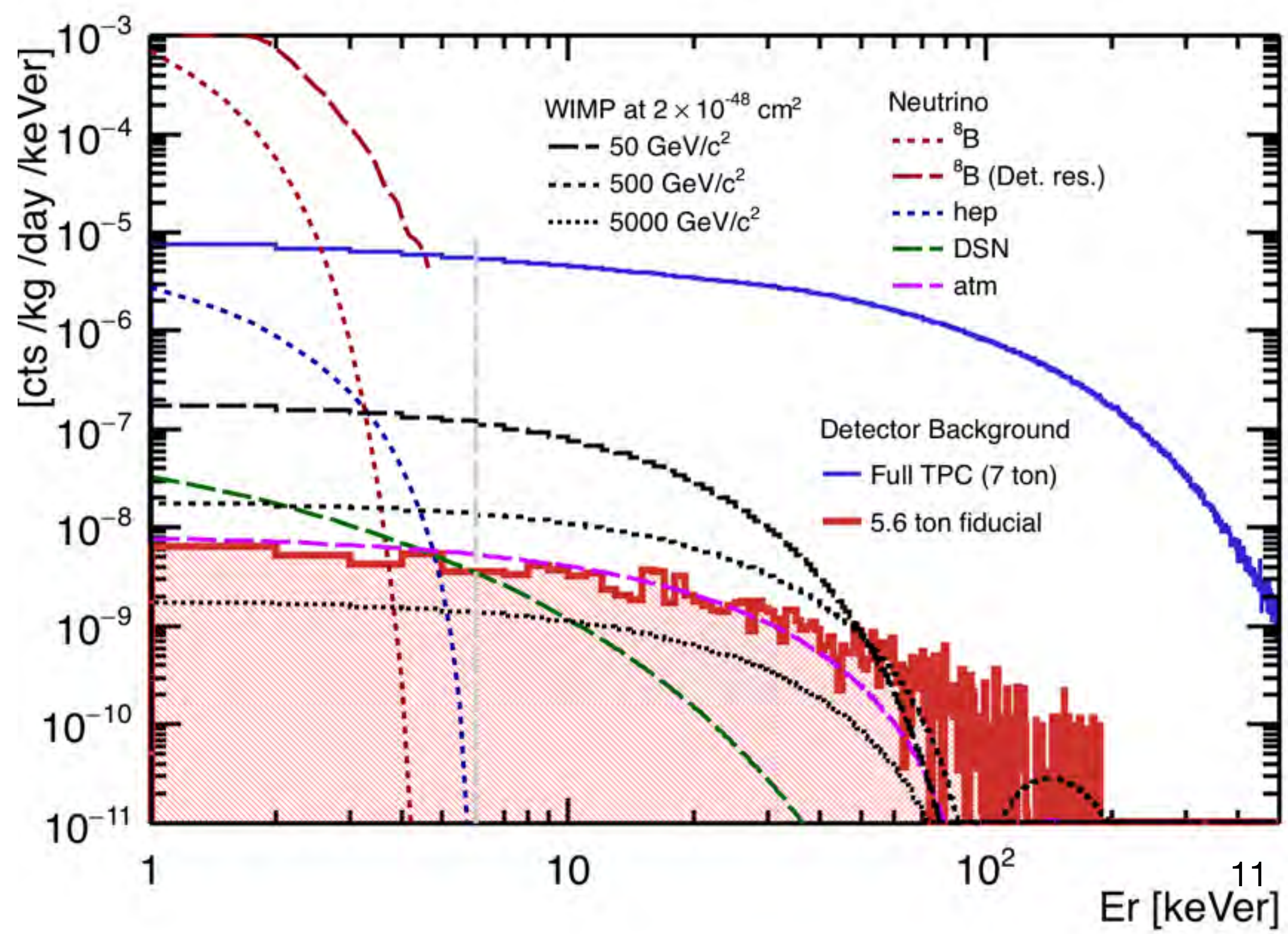
See:
UK materials screening for the LZ dark matter direct detection experiment and future rare event searches - Jim Dobson
17.15 Session 3D

LZ Simulation Work

- Backgrounds analysis code and cut validation
- NR & ER counts for Technical Design Review Backgrounds Table
- Correct treatment of Uranium spontaneous fission events
- Geometry - updating LZSim (Geant4) to latest CAD models
- Expected background rate in scintillator veto
- Validation of neutron & gamma survival probabilities in different detector materials

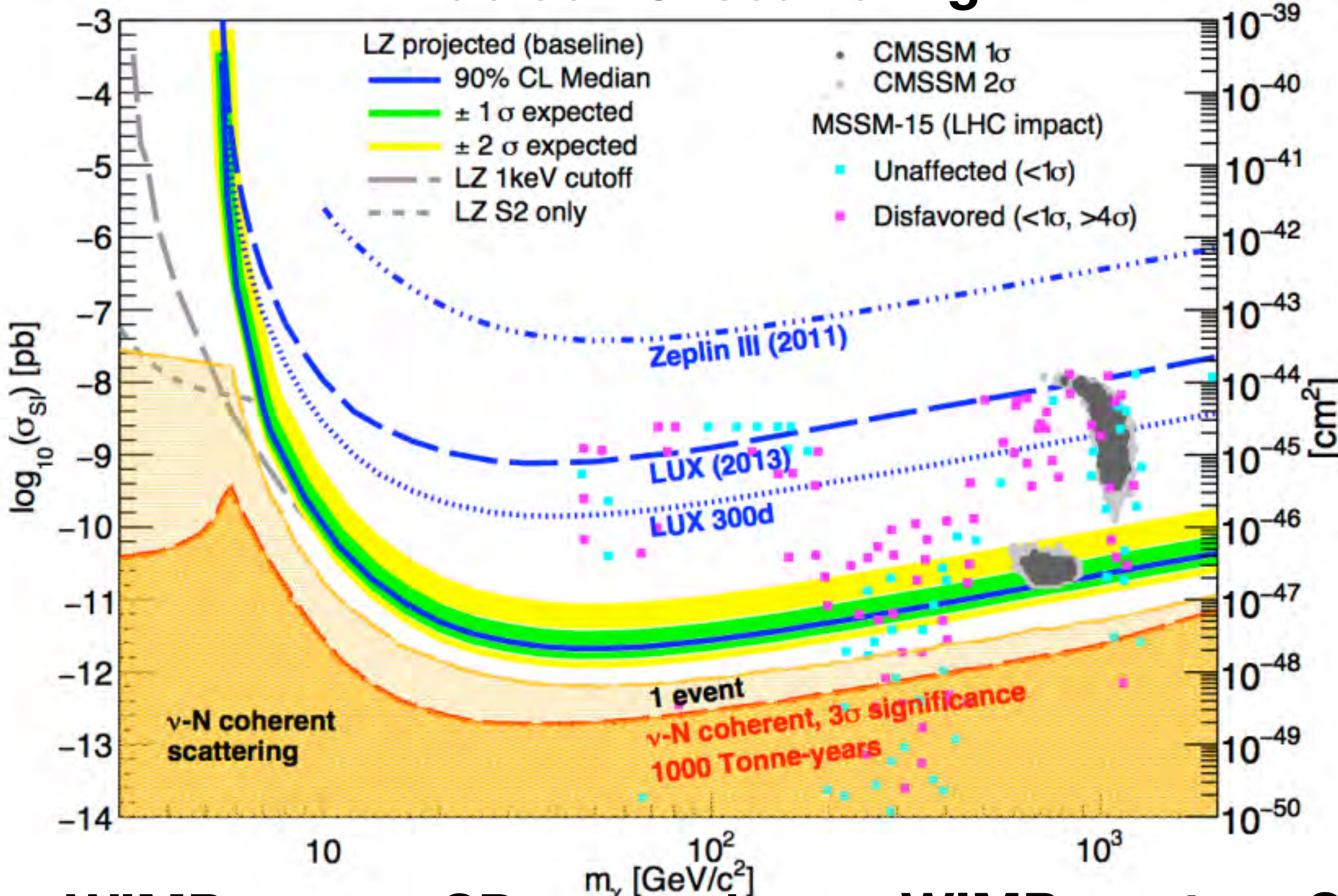






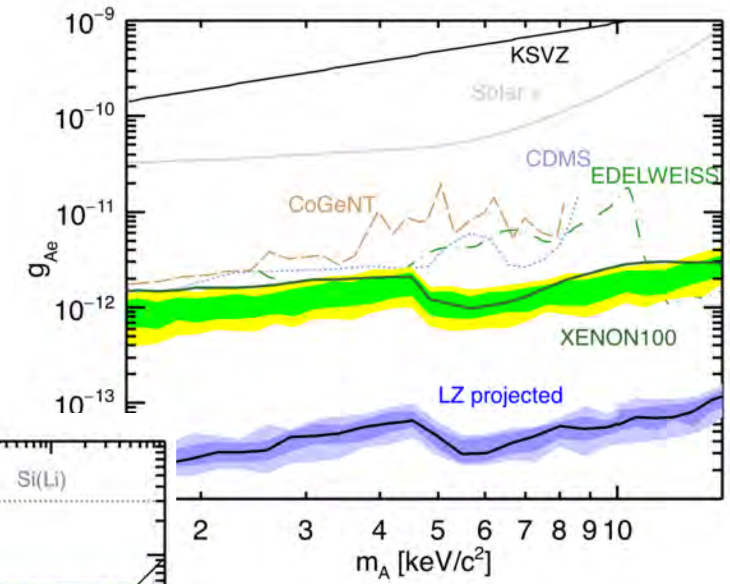
LZ Sensitivity

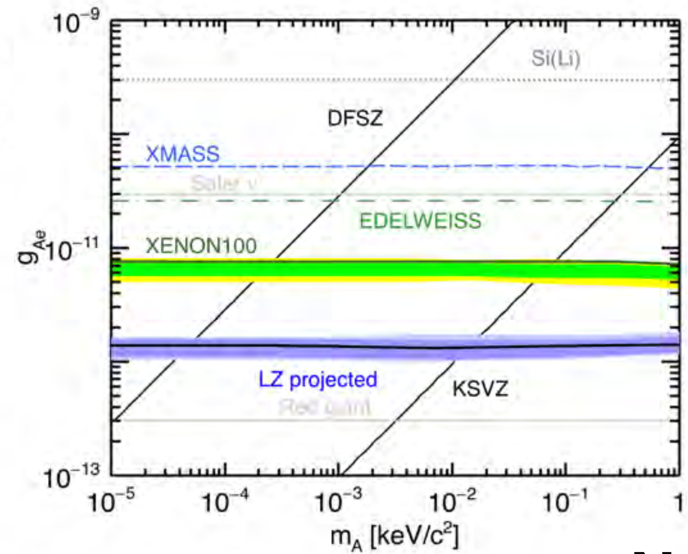
WIMP-nucleon SI scattering



arXiv:1509.02910

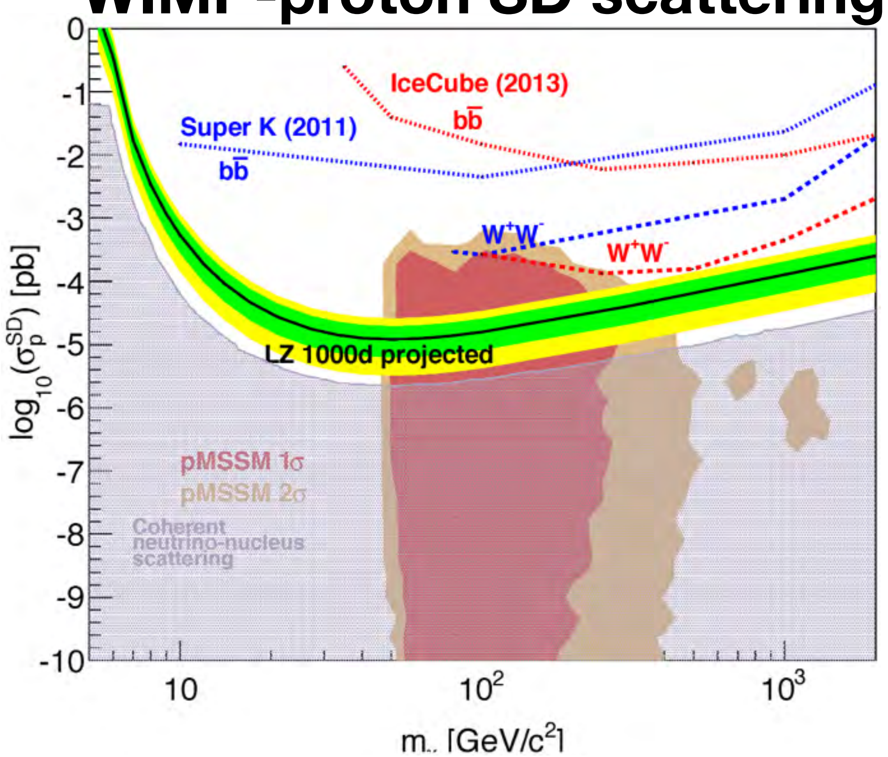
Solar axion



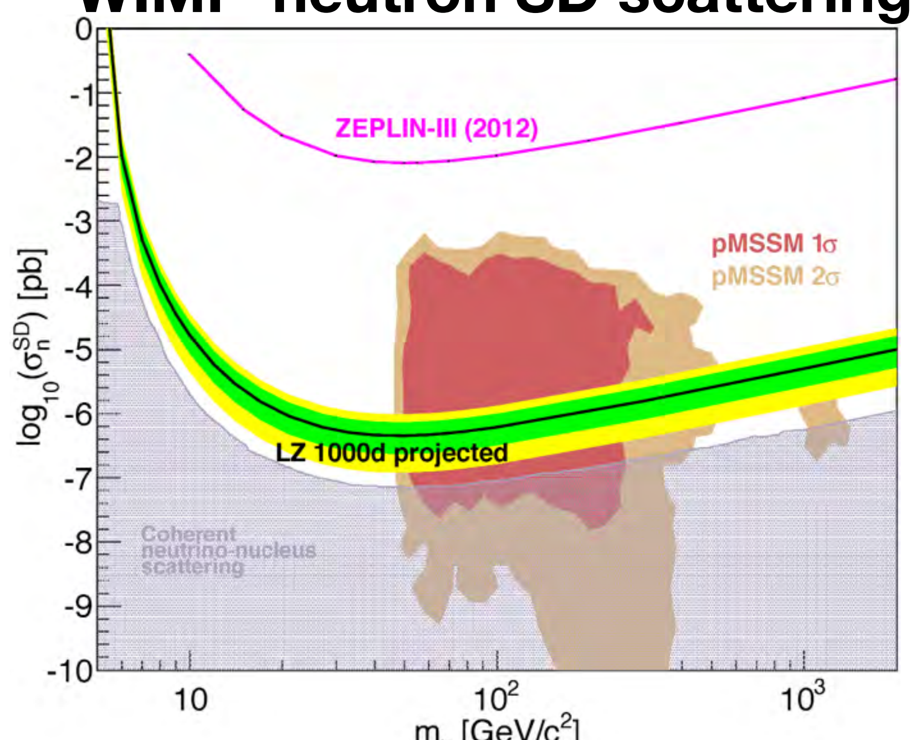


Dark matter axion

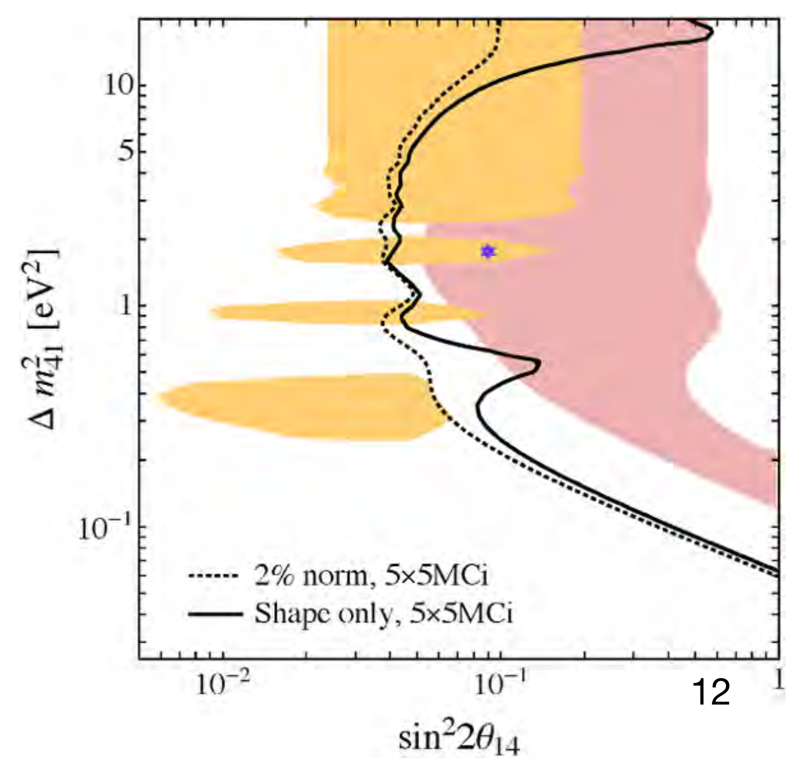
WIMP-proton SD scattering



WIMP-neutron SD scattering

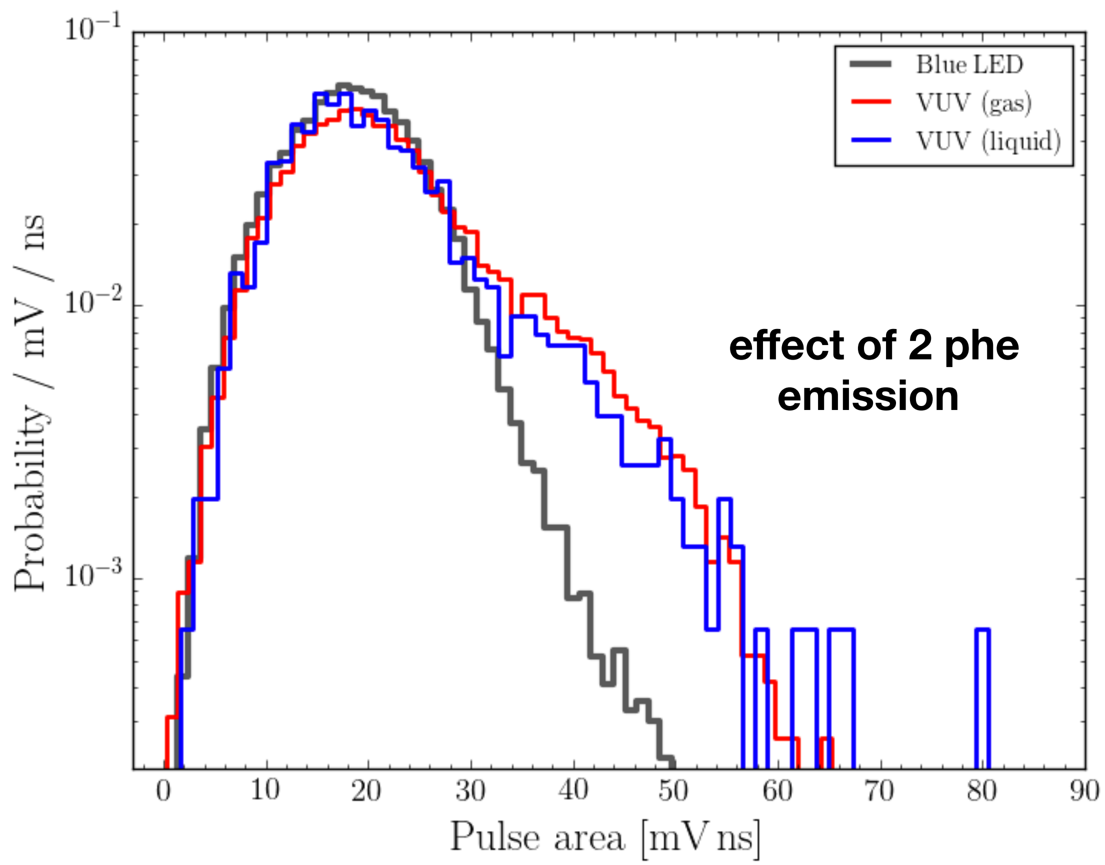


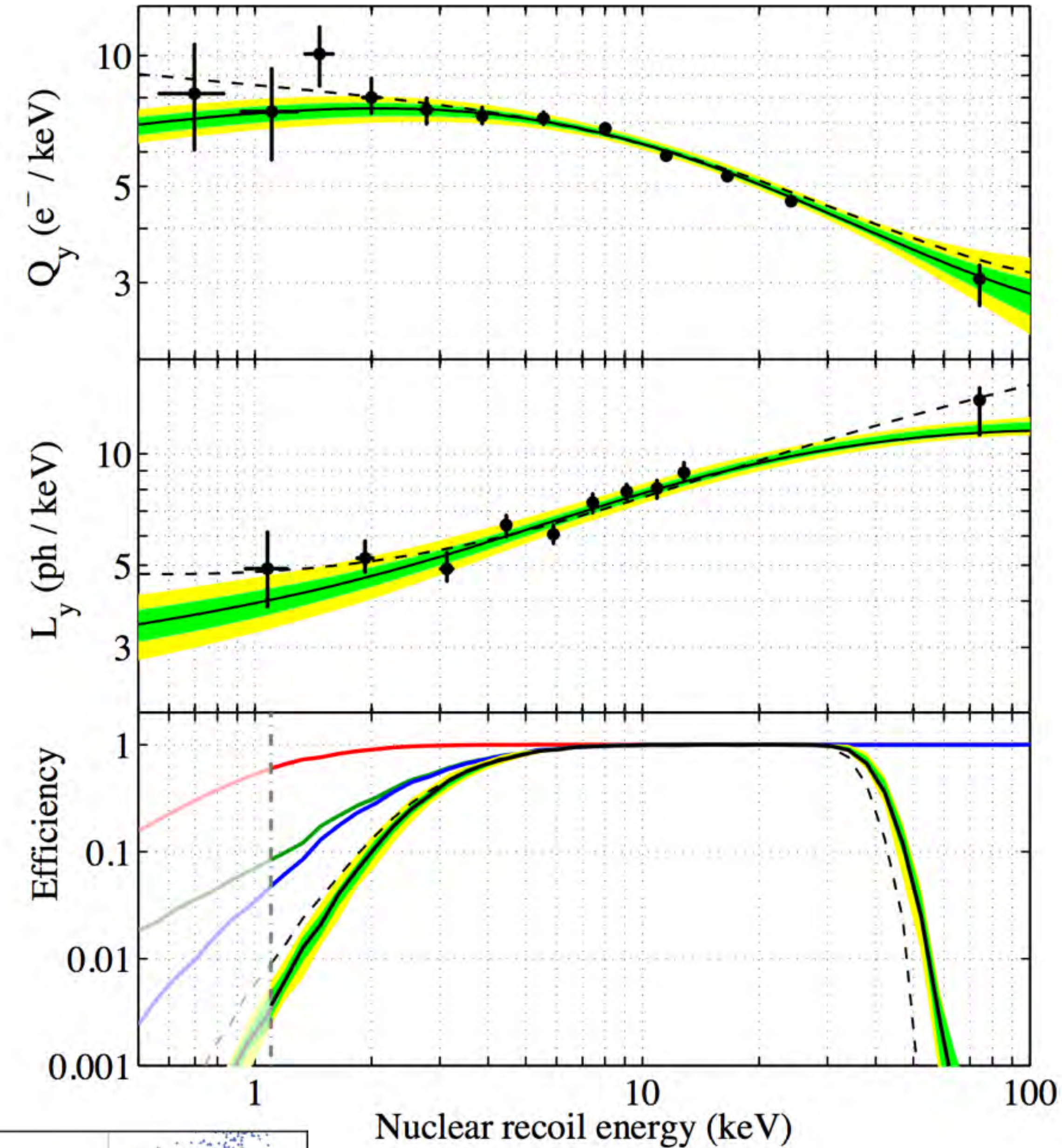
Neutrino physics



Thanks for listening!

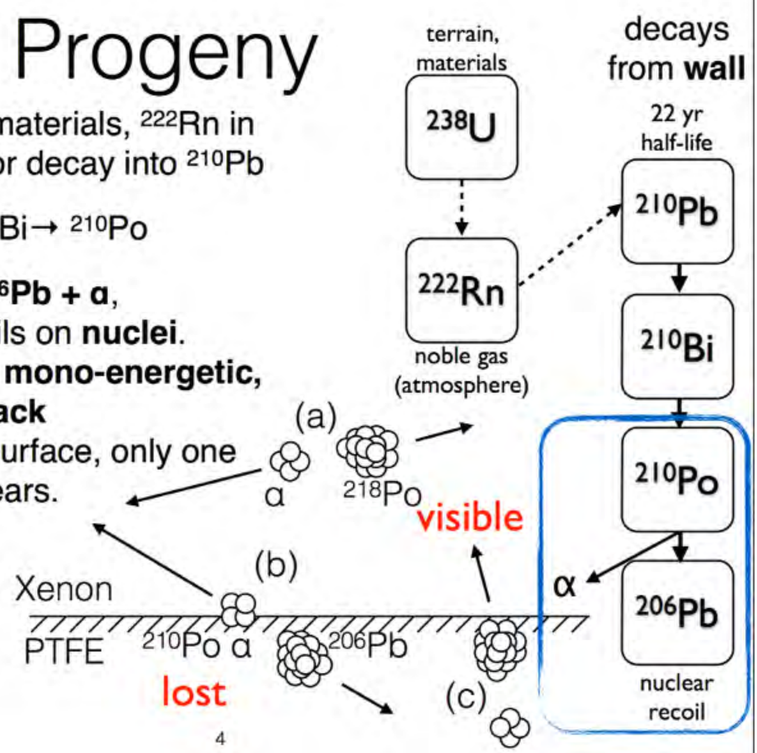
Back-up Slides

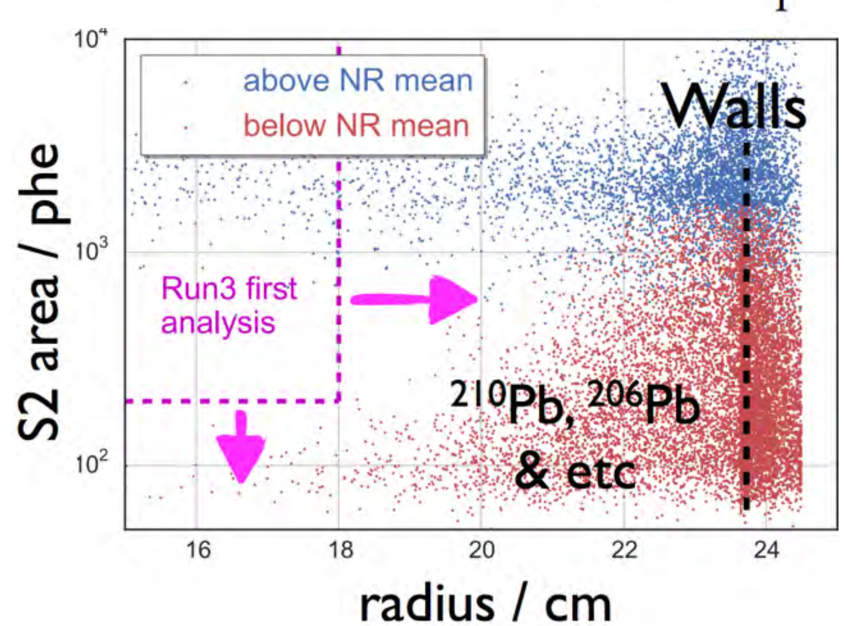




^{222}Rn Progeny

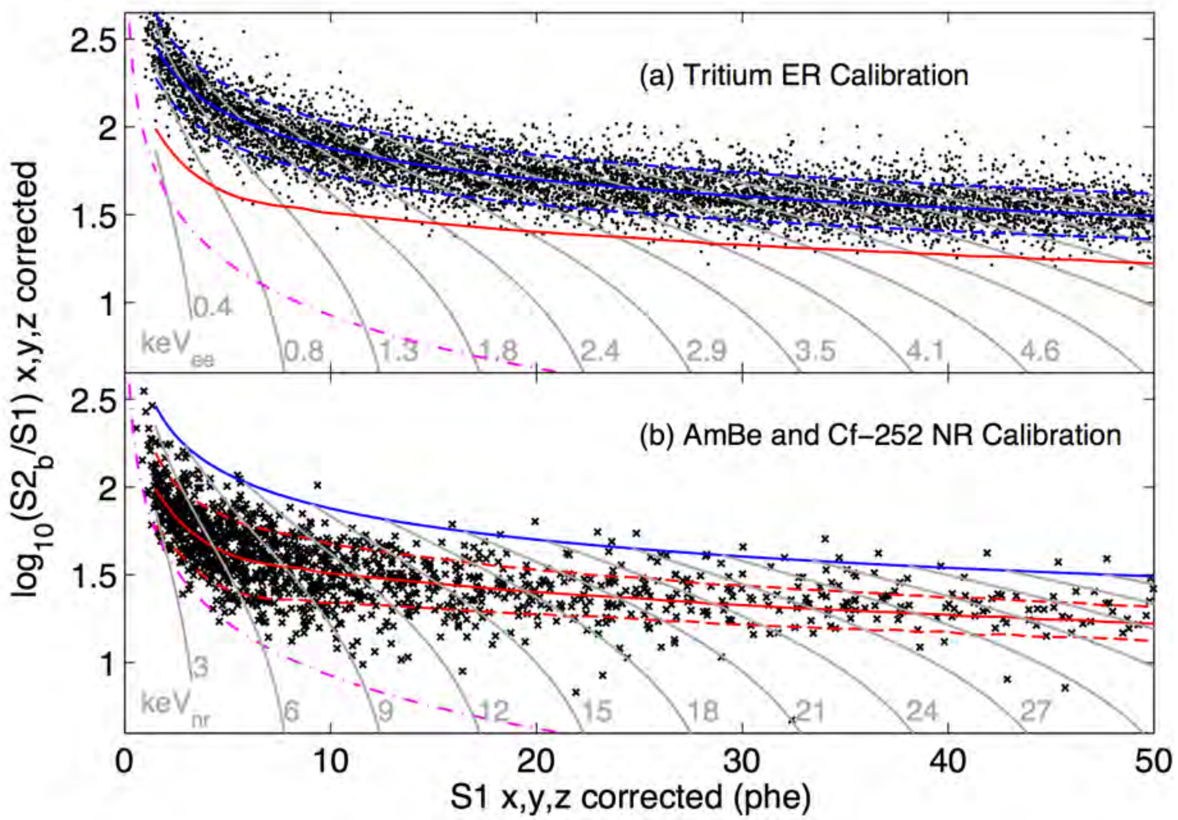
- ^{238}U from materials, ^{222}Rn in the detector decay into ^{210}Pb
- ^{210}Pb→ ^{210}Bi→ ^{210}Po
- **^{210}Po → ^{206}Pb + α, ^{206}Pb** recoils on **nuclei**. Two-body: **mono-energetic, back-to-back** From the surface, only one recoil appears.





Light yield measured down to 0.7 keV, charge yield 1.1 keV

LUX Calibrations



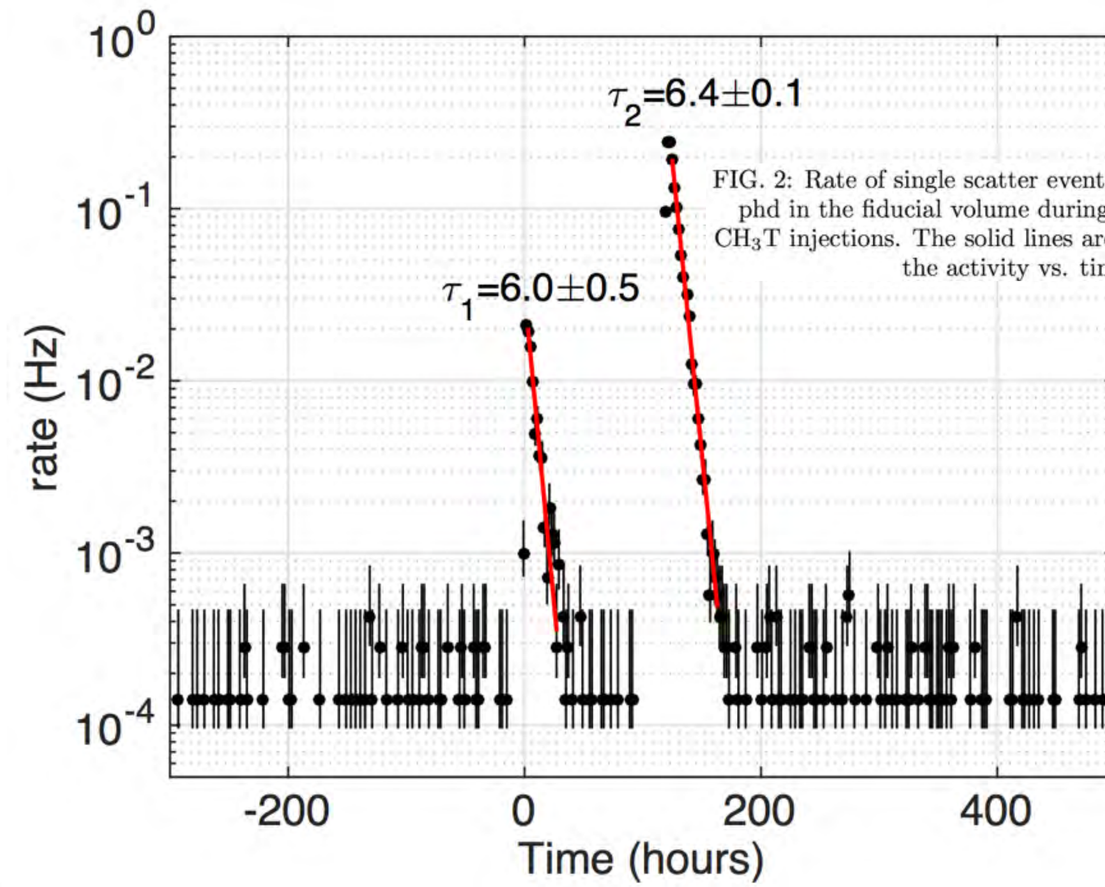
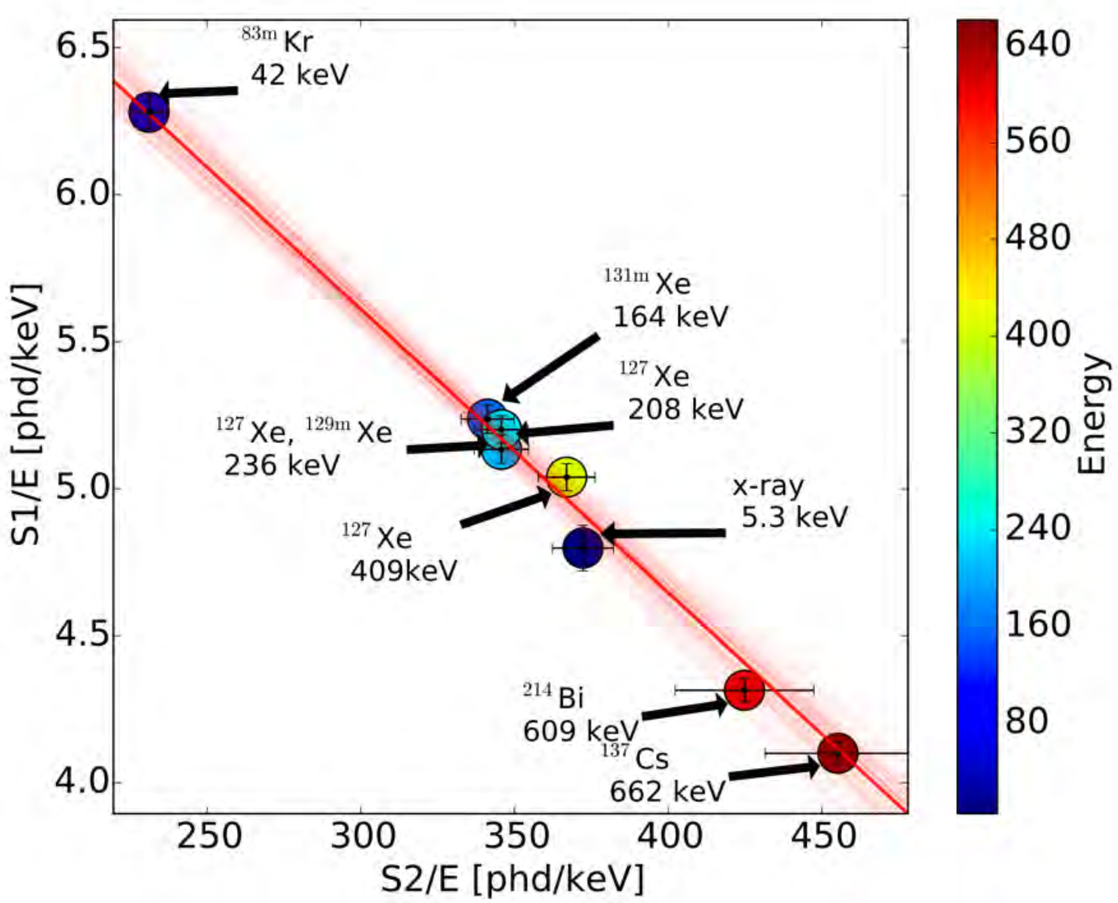
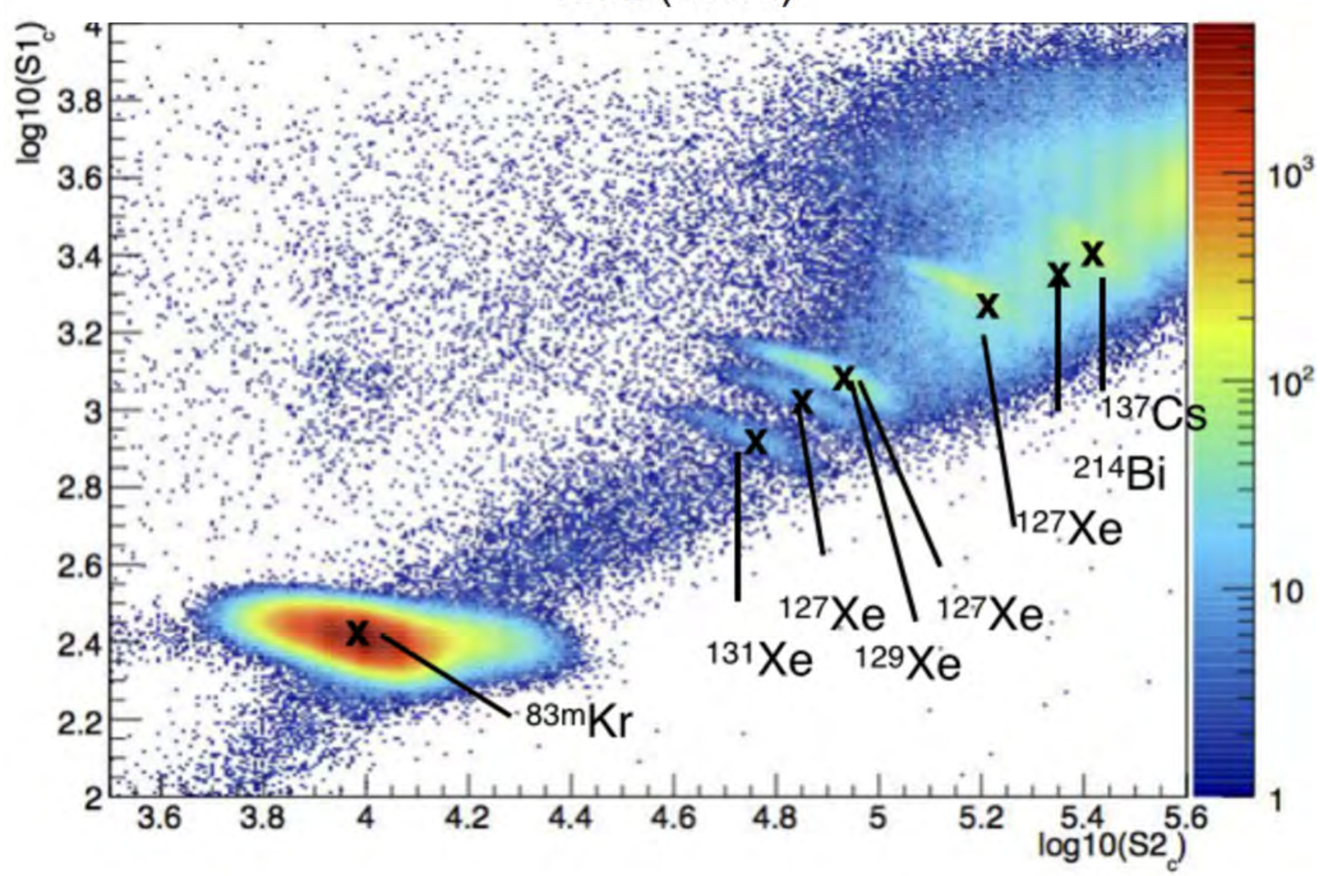
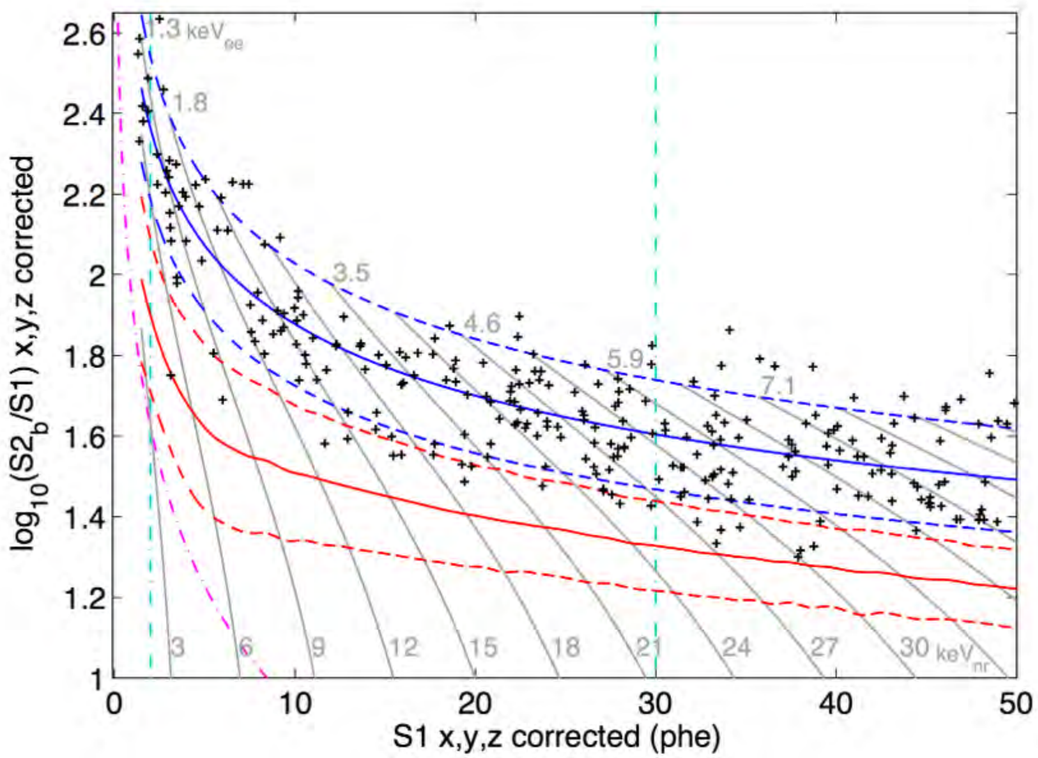


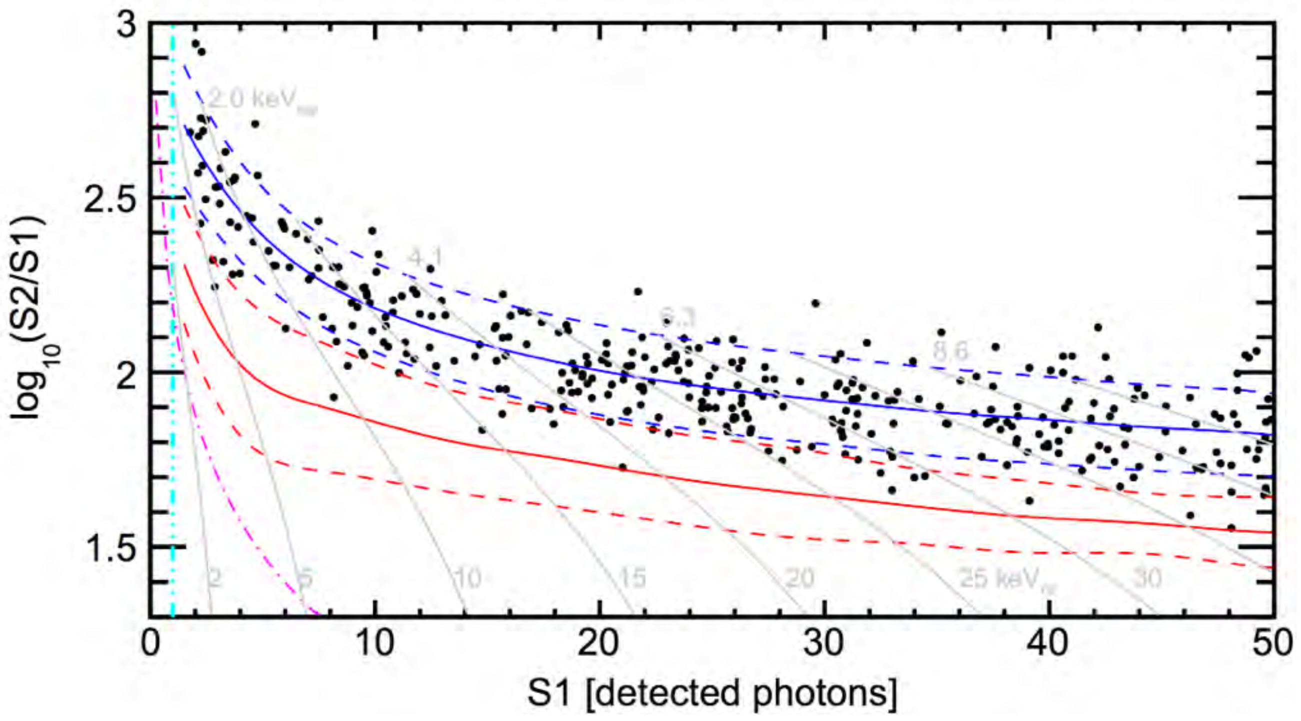
FIG. 2: Rate of single scatter events with S1 below 150 phd in the fiducial volume during the August 2013 CH_3T injections. The solid lines are exponential fits to the activity vs. time.

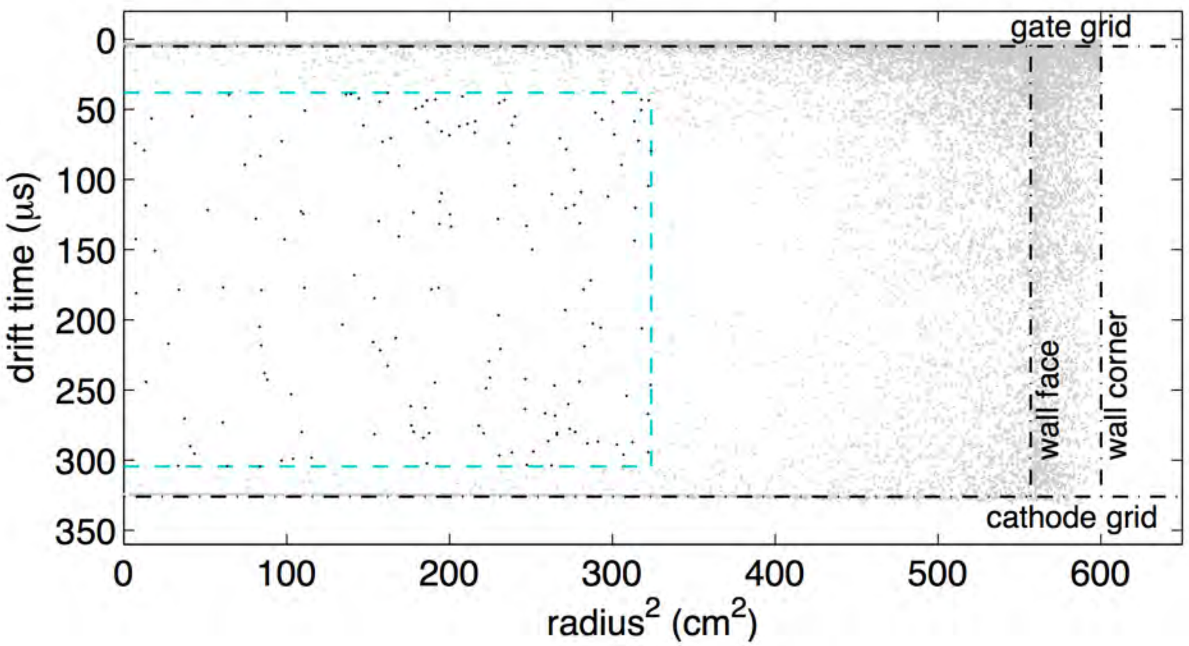


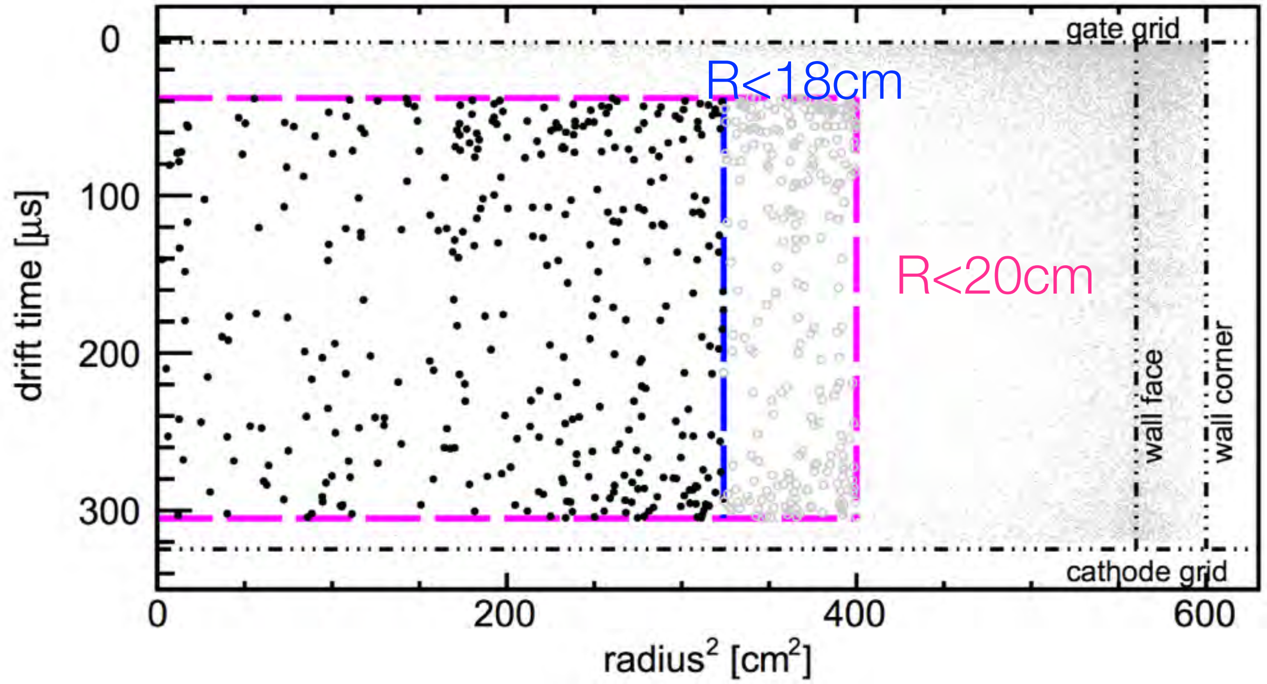


Run 3 vs Run 3 Reanalysis



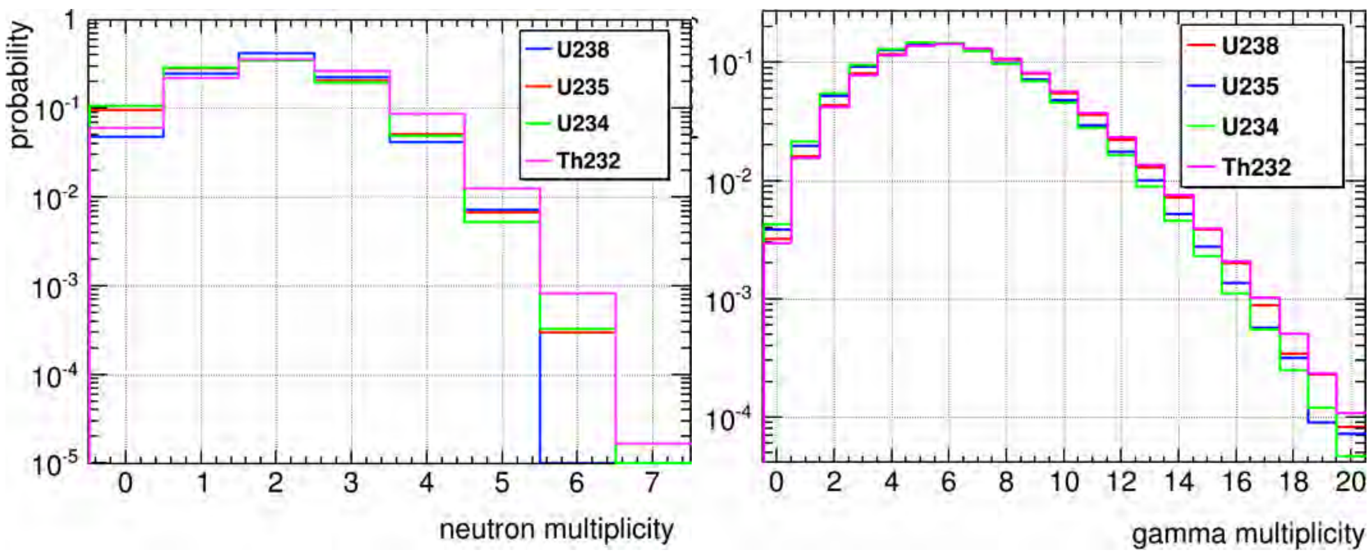


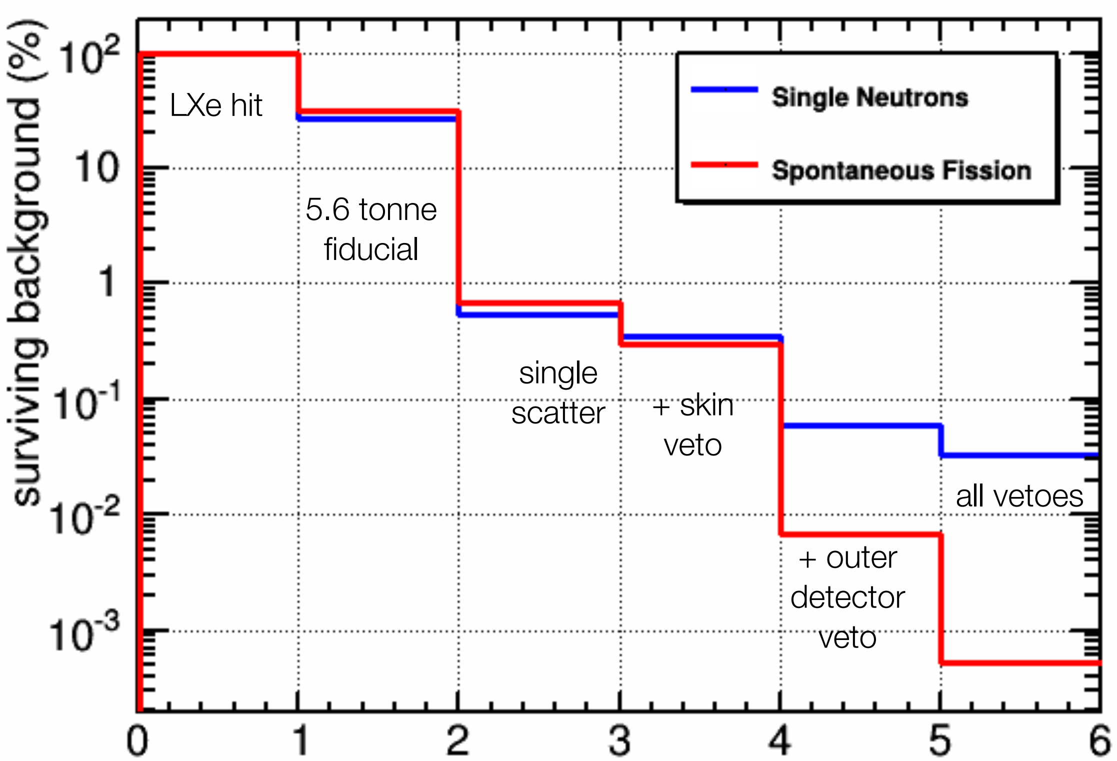


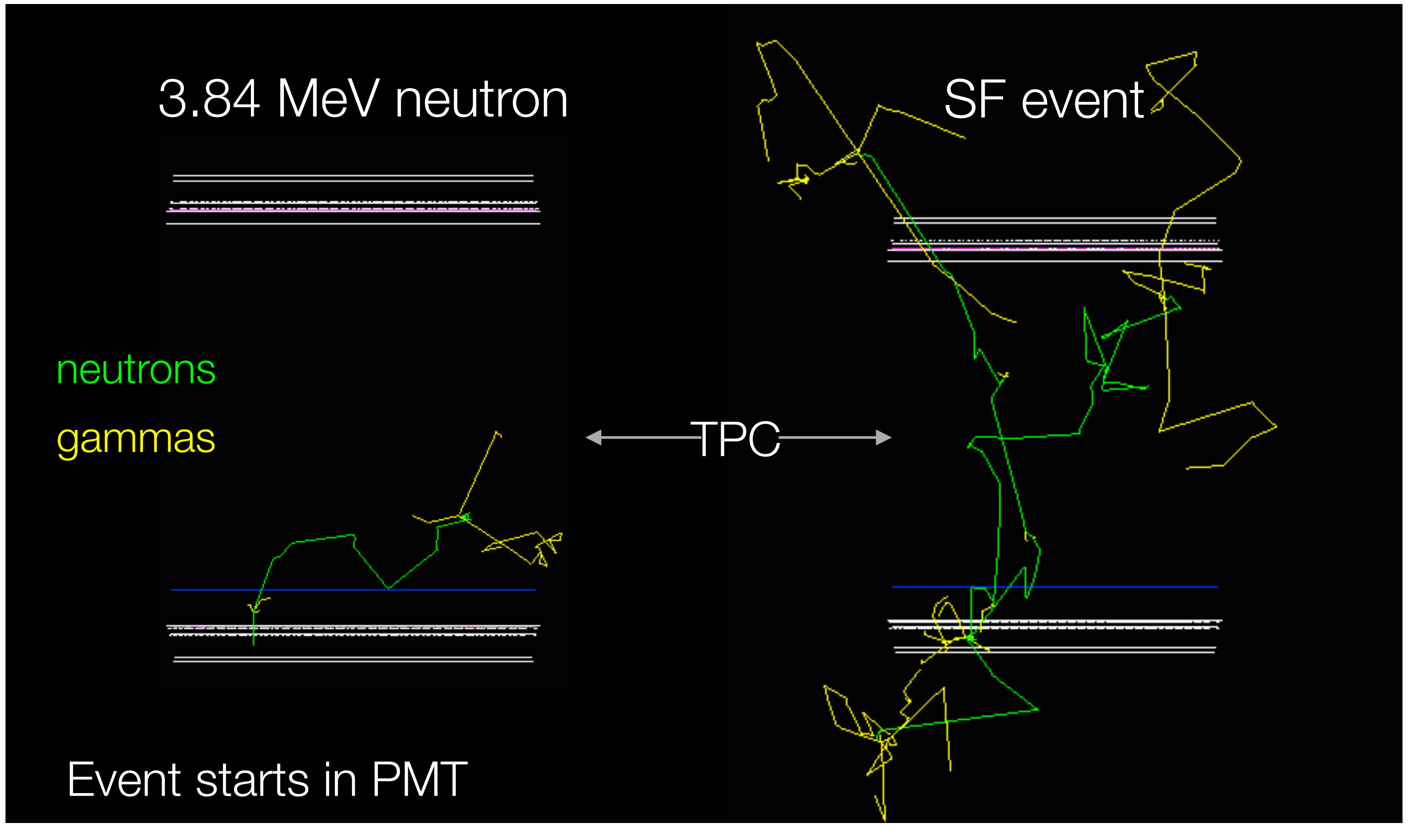


Spontaneous Fission

- S.F. can be a dominant background source in some materials
- Aim: determine if multiplicity of neutrons and gammas allows better rejection
- Development of Geant4 SF generator for LZSim
- Scintillator veto has big impact on rejection ability - ~50-100x better for S.F.
- S.F. rejection good enough to remove it from background estimates







LZ Backgrounds Table

Intrinsic Contamination Backgrounds	Mass	U-early	U-late	Th-early	Th-late	^{60}Co	^{40}K	n/yr	ER	NR
	(kg)	(mBq/kg)							(cts)	(cts)
Upper PMT structure	40.2	1.45	0.10	0.25	0.21	0.00	0.50	3.96	0.01	0.002
Lower PMT structure	64.1	0.85	0.06	0.15	0.12	0.00	0.33	5.49	0.01	0.003
R11410 3" PMTs	93.7	67.1	2.68	2.01	2.01	3.86	62.1	372.5	1.24	0.203
R11410 PMT bases	2.7	525.	74.6	29.1	29.1	3.60	109.	76.7	0.17	0.033
R8520 Skin 1" PMTs	4.2	60.5	5.19	4.75	4.75	24.2	333.	11.4	0.09	0.002
R8520 Skin PMT bases	0.9	513.	58.3	24.2	24.2	3.91	108.	23.3	0.06	0.003
PMT cabling	85.5	29.8	1.47	3.31	3.15	0.65	33.14	89.5	0.92	0.008
TPC PTFE	343.	0.02	0.02	0.01	0.01	0.00	0.10	24.1	0.17	0.007
Grid wires	0.33	1.20	0.27	0.33	0.49	1.60	0.40	0.02	0.01	0.000
Grid holders	69.6	1.60	0.09	0.28	0.23	0.00	0.54	6.92	0.02	0.003
Field-shaping rings	262.	5.89	1.81	1.13	1.08	0.00	1.83	32.2	1.22	0.004
TPC sensors	0.90	8.76	7.28	1.37	1.37	0.20	5.39	0.72	0.08	0.000
TPC thermometers	0.70	332.	329.	136.	136.	4.90	658.	85.2	3.67	0.010
Xe recirc. tubing	5.2	0.02	0.02	0.01	0.007	0.00	0.10	0.37	0.00	0.000
HV conduits – cables	138.	1.80	2.00	0.40	0.60	1.40	1.20	15.6	0.72	0.001
HX and PMT conduits	200.	1.05	0.21	0.27	0.38	1.18	0.60	11.9	0.41	0.000
Cryostat vessel	2.14E3	1.60	0.09	0.28	0.23	0.00	0.54	213.	0.86	0.019
Cryostat seals	4.5	102.	102.	34.0	34.0	7.27	22.6	40.3	0.79	0.001
Cryostat insulation	23.8	18.9	18.9	3.45	3.45	1.97	51.7	85.2	0.92	0.003
Cryostat Teflon liner	70.7	0.02	0.02	0.01	0.01	0.00	0.10	4.97	0.00	0.000
Outer detector tanks	4.00E3	0.15	0.37	0.02	0.06	0.04	4.32	101.	0.14	0.0002
Liquid scintillator	2.08E4	0.01	0.01	0.01	0.01	0.00	0.00	22.9	0.00	0.00
Outer detector PMTs	122.	1.50E3	1.50E3	1.07E3	1.07E3	0.00	3.90E3	2.09E4	0.08	0.022
OD PMT supports	620.	1.20	0.27	0.33	0.49	1.60	0.40	37.0	0.25	0.00
^{222}Rn (0.67 mBq)									23.2	-
^{220}Rn (0.07 mBq)									4.68	-
^{nat}Kr (0.015 ppt g/g)									24.5	-
^{nat}Ar (0.45 ppb g/g)									2.47	-
Subtotal (Non-ν counts)									**66.7**	**0.33**
Physics Backgrounds										
^{136}Xe 2νββF									53.8	0
Astrophysical ν counts (pp+^{7}Be)									271	0
Astrophysical ν counts (^{8}B)									0	0
Astrophysical ν counts (Hep)									0	0.002
Astrophysical ν counts (diffuse supernova)									0	0.113
Astrophysical ν counts (atmospheric)									0	0.385
Total									**392**	**0.83**
Total (with 99.5% ER discrimination, 50% NR efficiency)									**1.96**	**0.41**
Sum of ER and NR in LZ for 1,000 days, 5.6-tonne FV, with all analysis cuts									**2.37**	