Background Simulations for the LUX-ZEPLIN Experiment

Amy Cottle, Fermilab

DPF 2017

Introduction

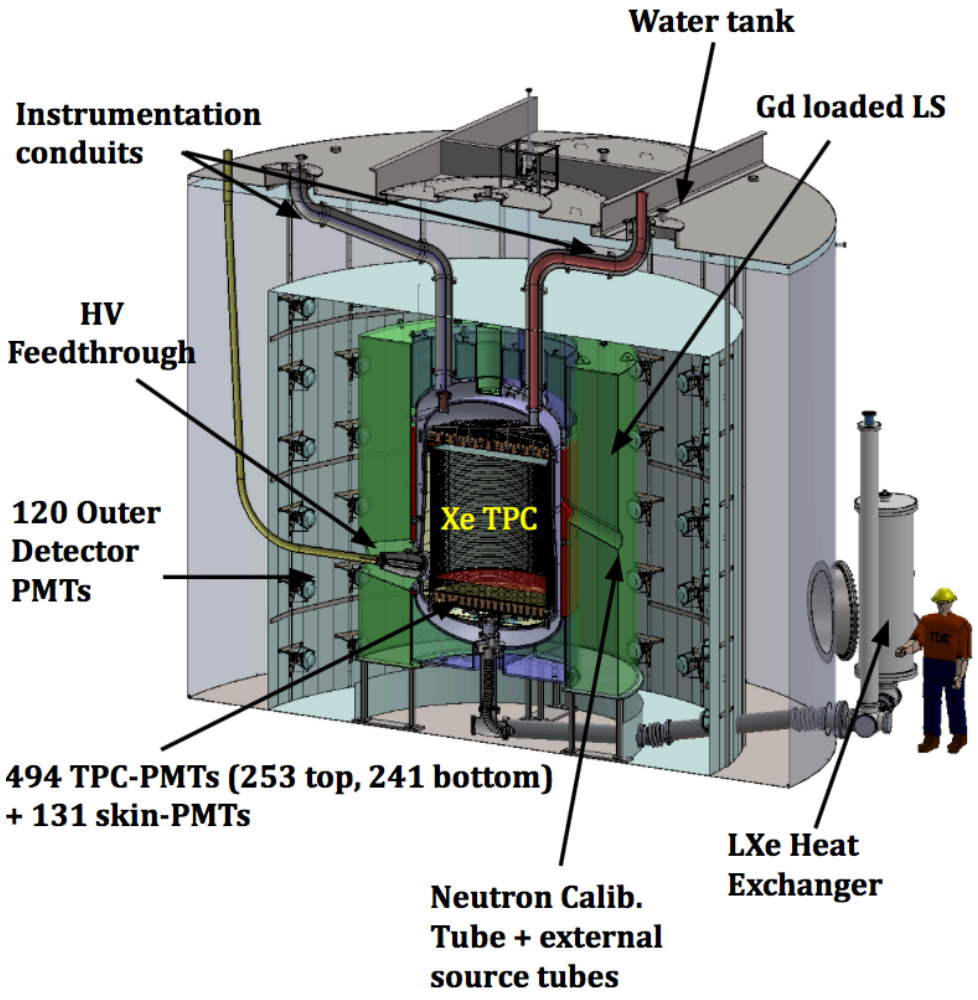
LZ Baseline WIMP Sensitivity: 2.3 x 10^{-48} cm^2 WIMP-nucleon cross section (at 40 GeV/c^2)

Requires unprecedented low background rate

→ <3.7 x 10^{-5} evts/keV/kg/day for ER & NR of <1 count (in 5.6 tonne fiducial volume; 1000 day exposure; from non-astrophysical sources)

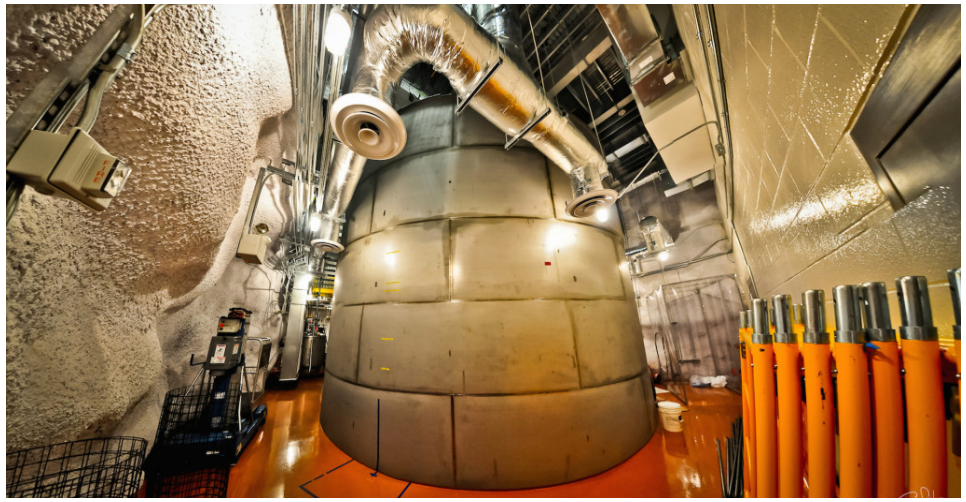
Focus on reducible background

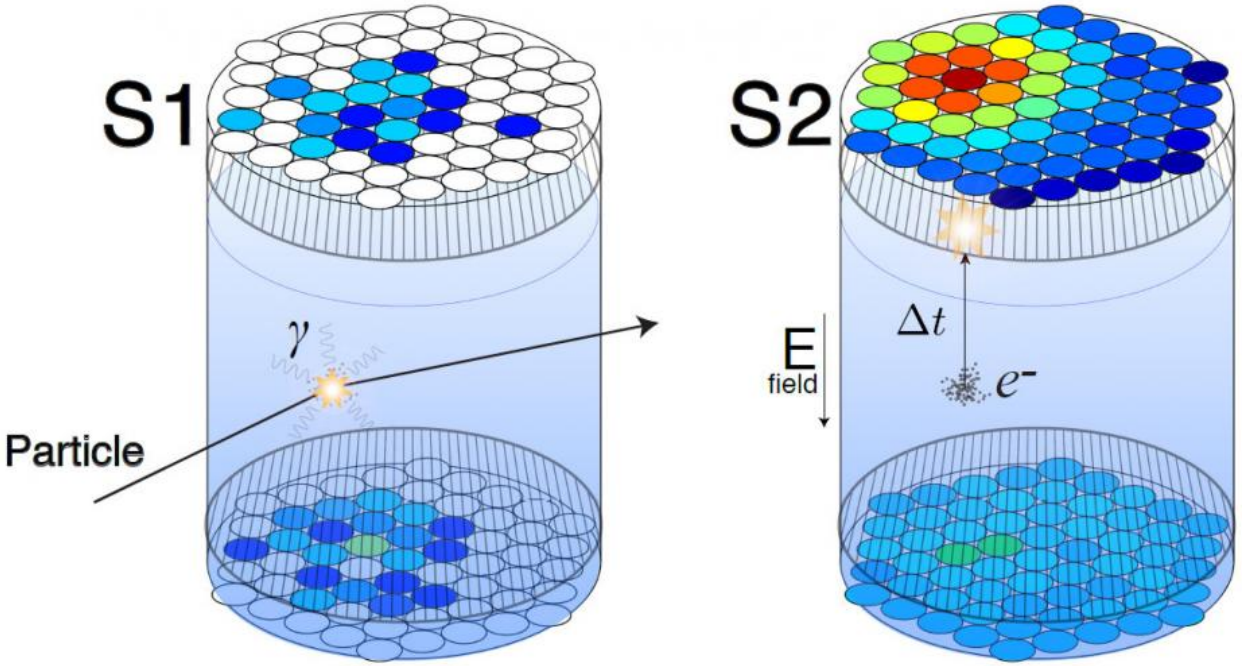
- External (detector components & environment)
- Internal (contamination in TPC Xe)



Fermilab 50 Years of Discovery

Background Suppression





Passive Shielding

- 4850 ft depth at SURF
- Water tank; xenon self-shielding

Active Shielding

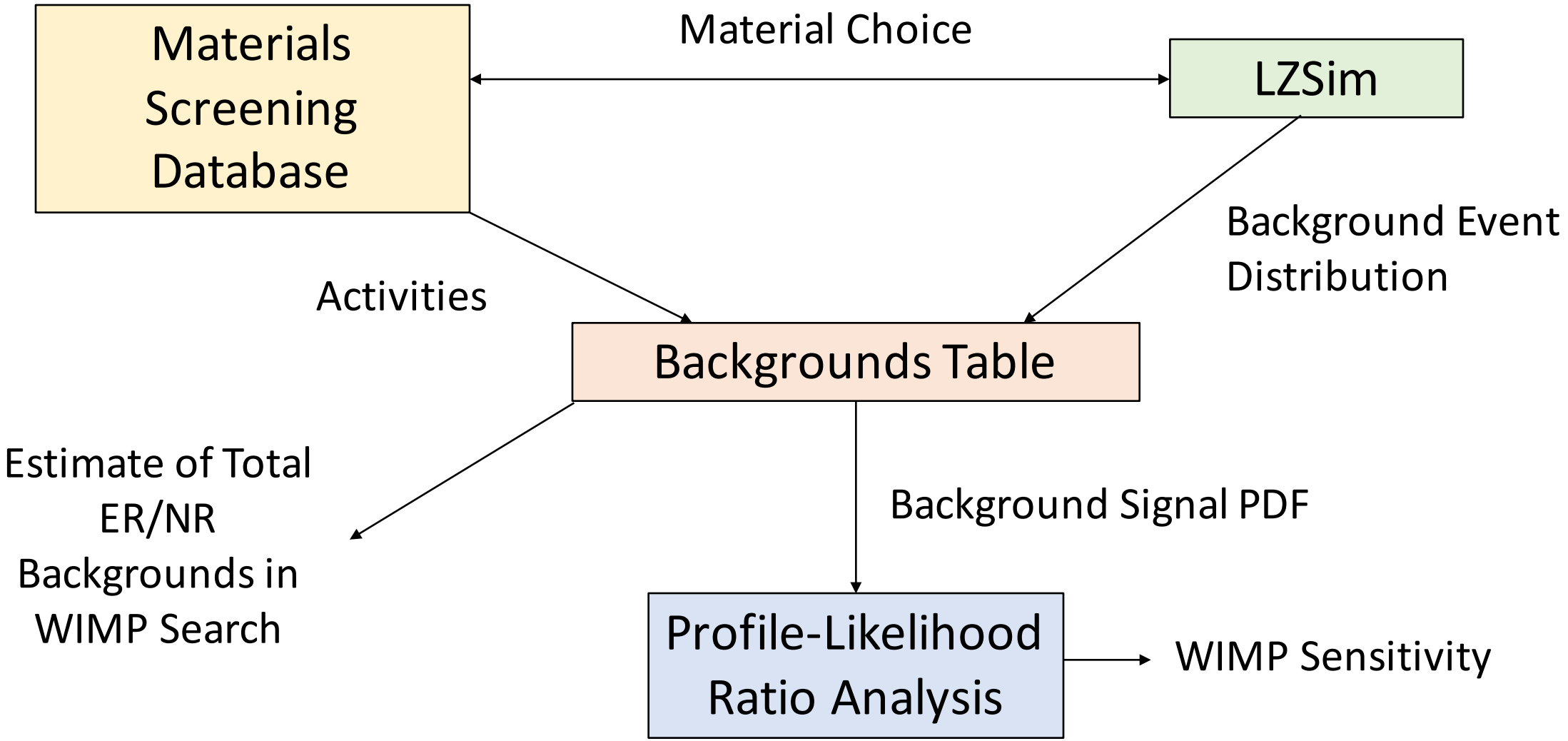
- LXe ‘skin’ & outer liquid scintillator

Material Selection

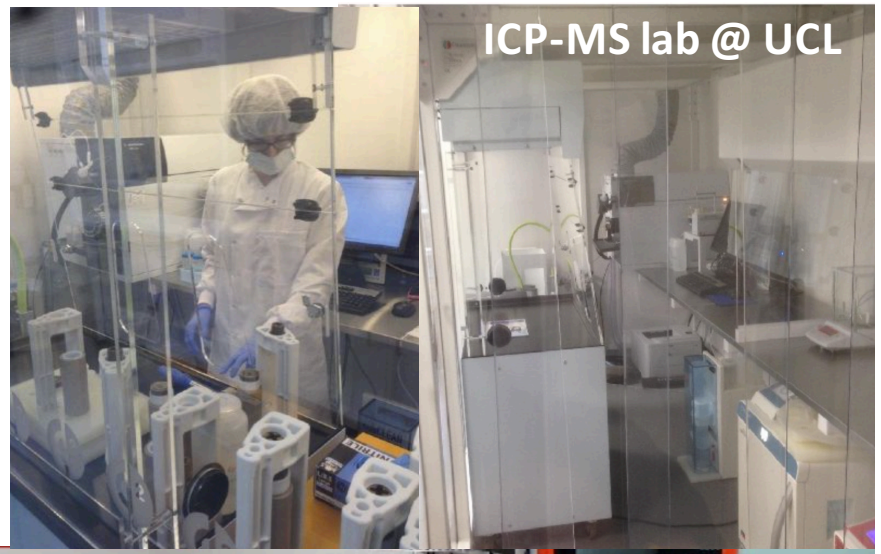
Data Selection

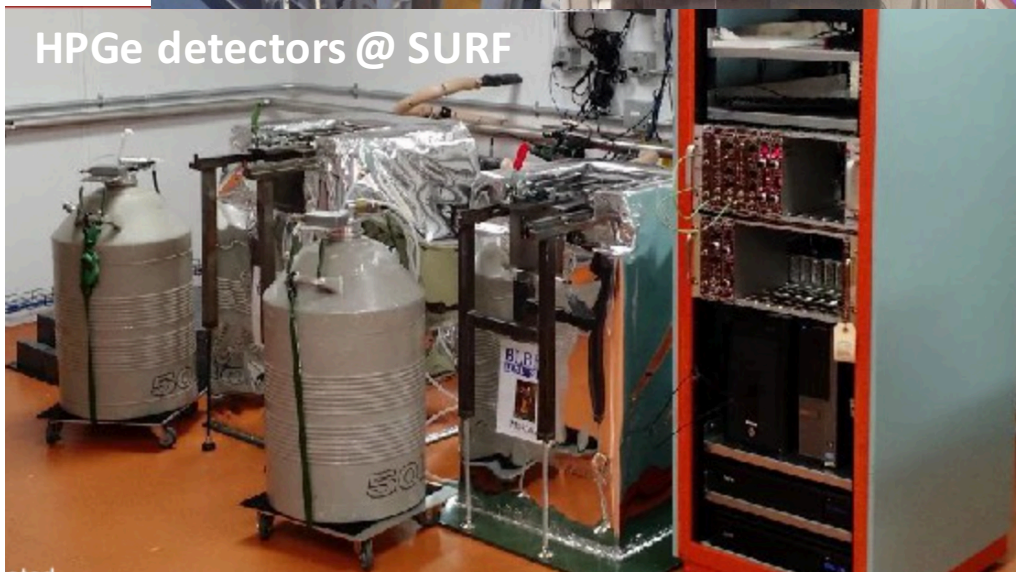
- Position reconstruction
  - Fiducialisation
  - Rejection of multiple scatters
- S2/S1 ratio -> ER discrimination

Backgrounds Model Chain



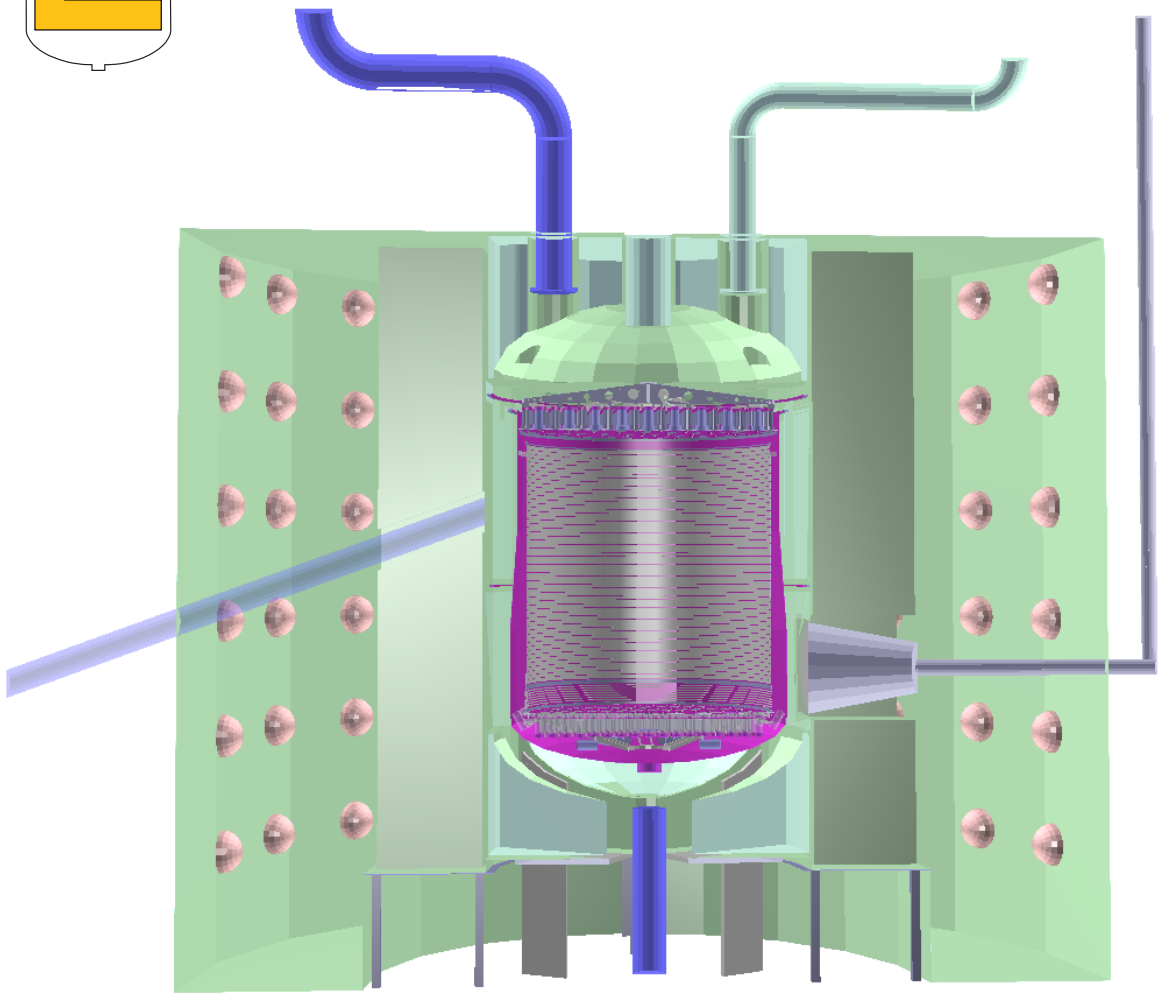
Material Assays





- Control backgrounds from radioactivity in detector
- Select major components s.t. ER rate is no more than ~25 events (<10% of irreducible ν background)
- Complementary assay techniques e.g.
  - γ-ray spectroscopy with HPGe detectors
  - Inductively-Coupled Plasma Mass Spectroscopy (ICP-MS)
- Database of assay results & material compositions
- Feedback from simulations -> max. allowed activity

LZSim



- Geant4-based, component-centric modelling
- CAD drawings, materials -> geometry
- Event generators for background processes
- Version controlled releases

<u>Assessing Background Contributions</u>

- Select component(s) as background sources
- Record energy depositions in Xe and scintillator
- NEST Xe physics package -> expected signal(s)
- *(optional)* Track photons -> detector response

Backgrounds Table

1) Simulate separate background sources

2) Apply analysis cuts to simulation results

WIMP Search Region

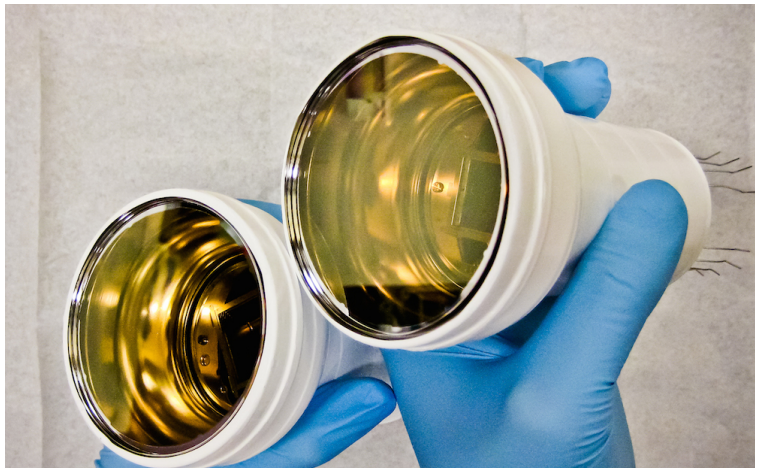
- Single scatters
- 0-20 S1 photons detected (3-fold PMT coincidence)
  - ≈ 1.5-6.5 keV_{ee} (ER) or 6-30 keV_{nr} (NR)
- 5.6 tonne fiducial volume
- No visible energy in veto detectors within set window

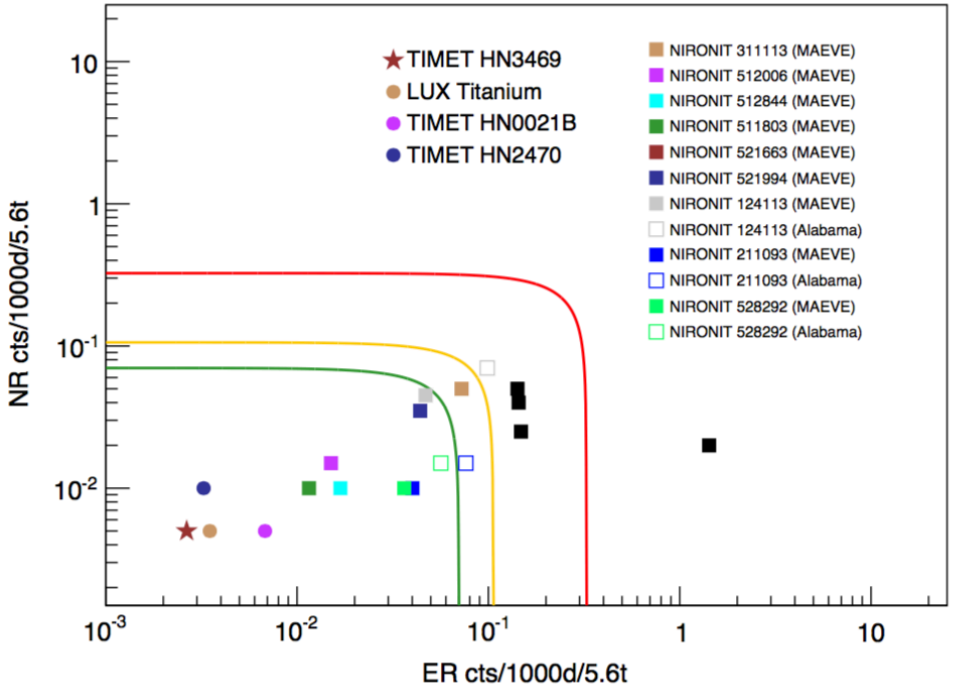
3) Scale by livetime & activities from assays

4) Combine total counts, with ER discrimination

Intrinsic Contamination Backgrounds	ER (cts)	NR (cts) (w/ SF rej.)
PMT Components	3.49	0.027
TPC Components	0.71	0.019
Cryostat Vessel	1.51	0.023
Outer Detector Tanks	0.49	0.001
Subtotal (Detector Components)	**6.20**	**0.070**
222Rn (1.63 μBq/kg)	722	-
220Rn (0.08 μBq/kg)	122	-
natKr (0.015 ppt g/g)	24.5	-
natAr (0.45 ppb g/g)	2.47	-
210Bi (0.1 μBq/kg)	40.0	-
Laboratory and Cosmogenics	4.3	0.06
Fixed Surface Contamination	0.19	0.37
Subtotal (Non-ν counts)	**921**	**0.50**
Physics Backgrounds		
136Xe 2νββ	67	0
Astrophysical ν counts (pp+7Be+13N)	255	0
Astrophysical ν counts (8B)	0	0**
Astrophysical ν counts (Hep)	0	0.21
Astrophysical ν counts (diffuse supernova)	0	0.05
Astrophysical ν counts (atmospheric)	0	0.46
Subtotal (Physics backgrounds)	322	0.72
Total	1,240	1.22
Total (99.5% ER disc., 50% NR efficiency)	6.22	0.61
	6.82	

Material Backgrounds





Gamma/ER Simulations

- ^{40}K, ^{60}Co, ^{238}U, ^{232}Th decay generators
- Chain produced in equilibrium -> single simulation

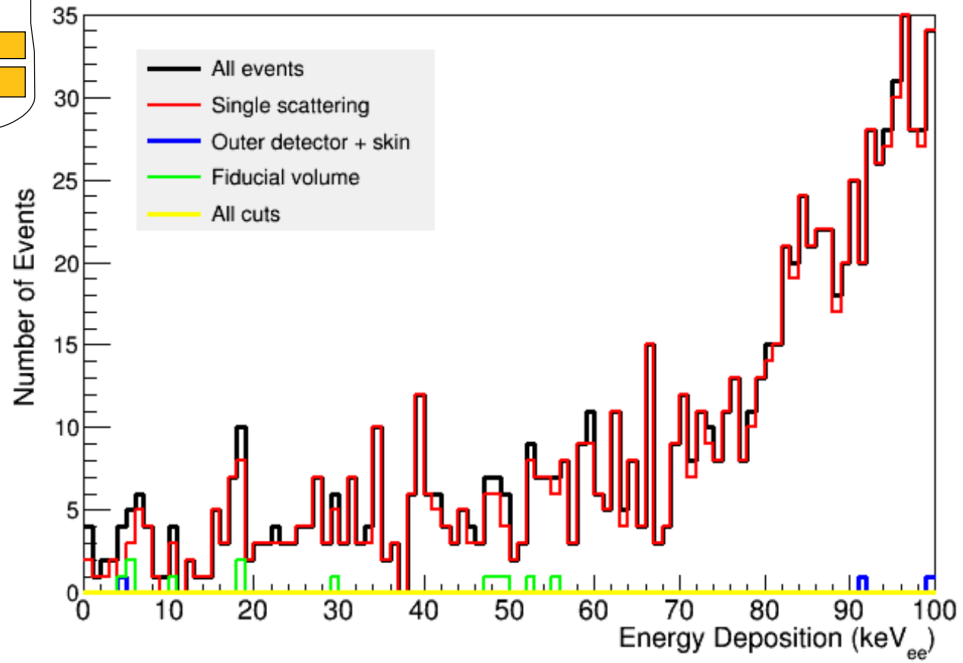
Neutron Simulations

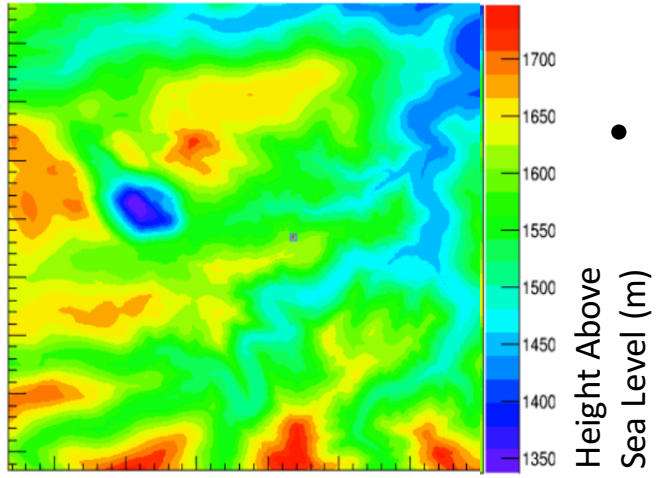
- ^{235}U, ^{238}U and ^{230}Th decay chains
- Yields and spectra from SOURCES-4A

  -> Implemented as generator for (α, n) reactions
- Spontaneous fission –> generator with multiplicity

PMT components dominate -> fiducialisation

Lab & Cosmogenic Backgrounds

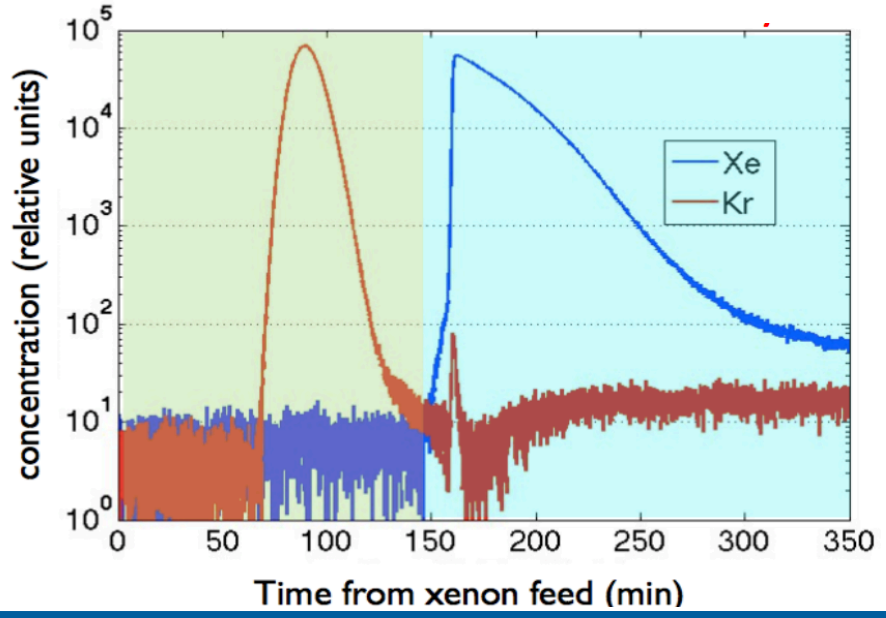




- γs & neutrons from U & Th in cavern walls
  - HPGe detector finds 6.42 ppm Th, 5.95 ppm U
  - Sims -> 4.1 ± 0.8 ER cts (2.6 MeV Th line dominant)
- Muon-induced neutrons
  - Muon flux attenuated by 3 x 10^6 from surface
  - MUSIC & MUSUN -> spectra of underground muons
- Cosmogenic Activation
  - e.g. ^{127}Xe – mitigate by early underground storage

    -> LZSim - 0.11 ER cts, with rate drop underground

Internal Backgrounds



- Intrinsic contamination from Rn, Kr, Ar isotopes

  -> e.g. ^{85}Kr, ^{39}Ar, ^{220}Rn, ^{222}Rn

- Kr, Rn emanation/outgassing measurements

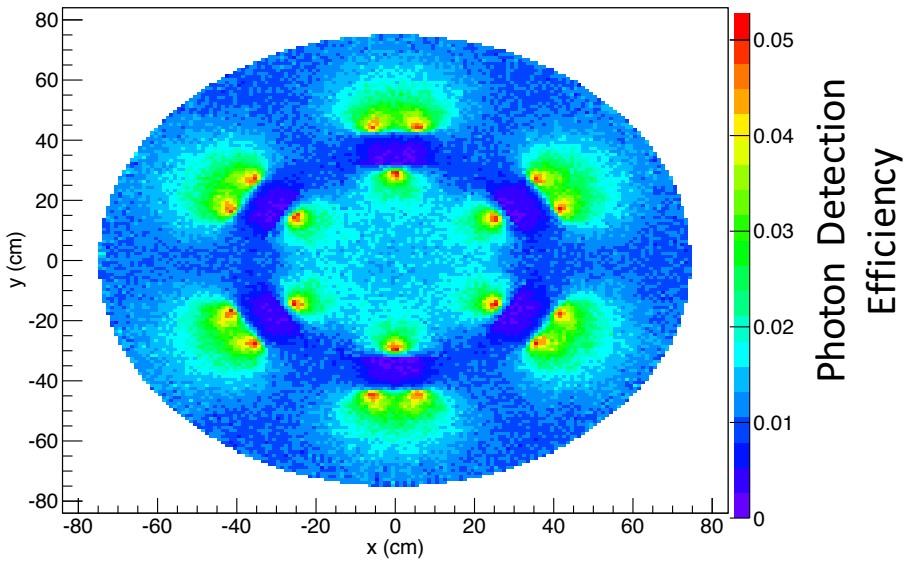
<u>Krypton Removal System</u>

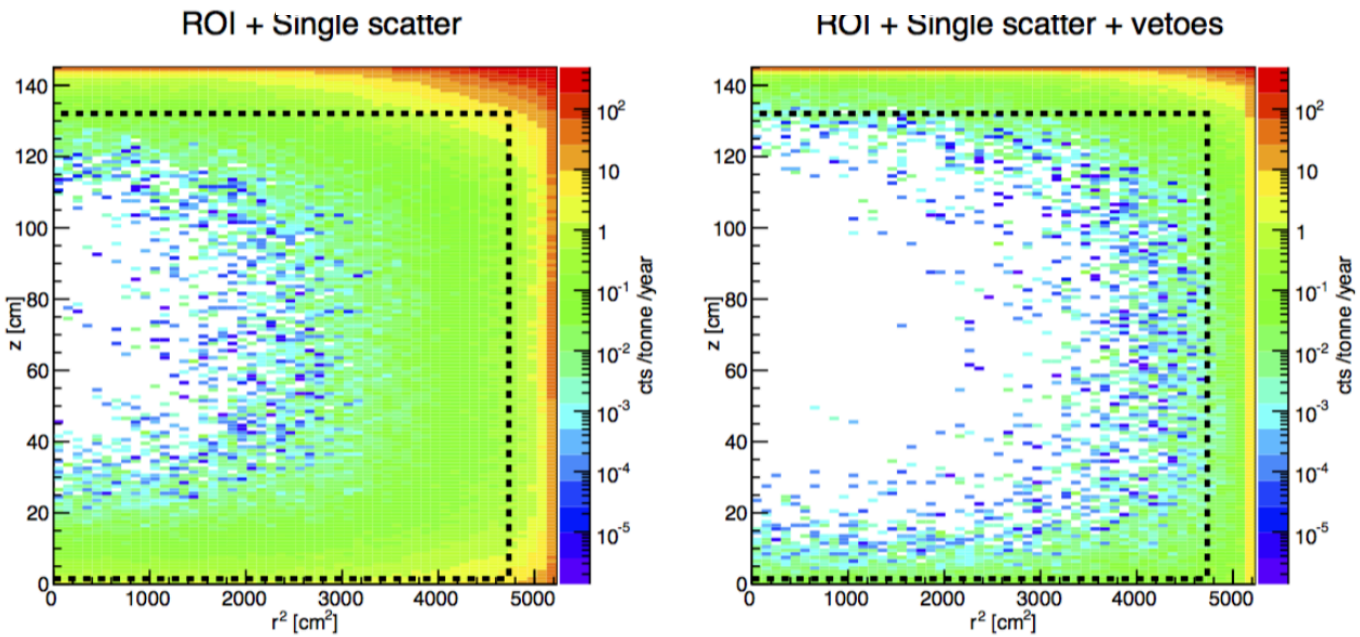
- R&D system met 300 ppq threshold key performance parameter (~10^6 reduction)
- Efficient at removing Ar -> achieve <0.45 ppb ^{nat}Ar

<u>Simulations</u>

Use NEST to model signals, assuming uniform distribution in xenon

Veto Detectors

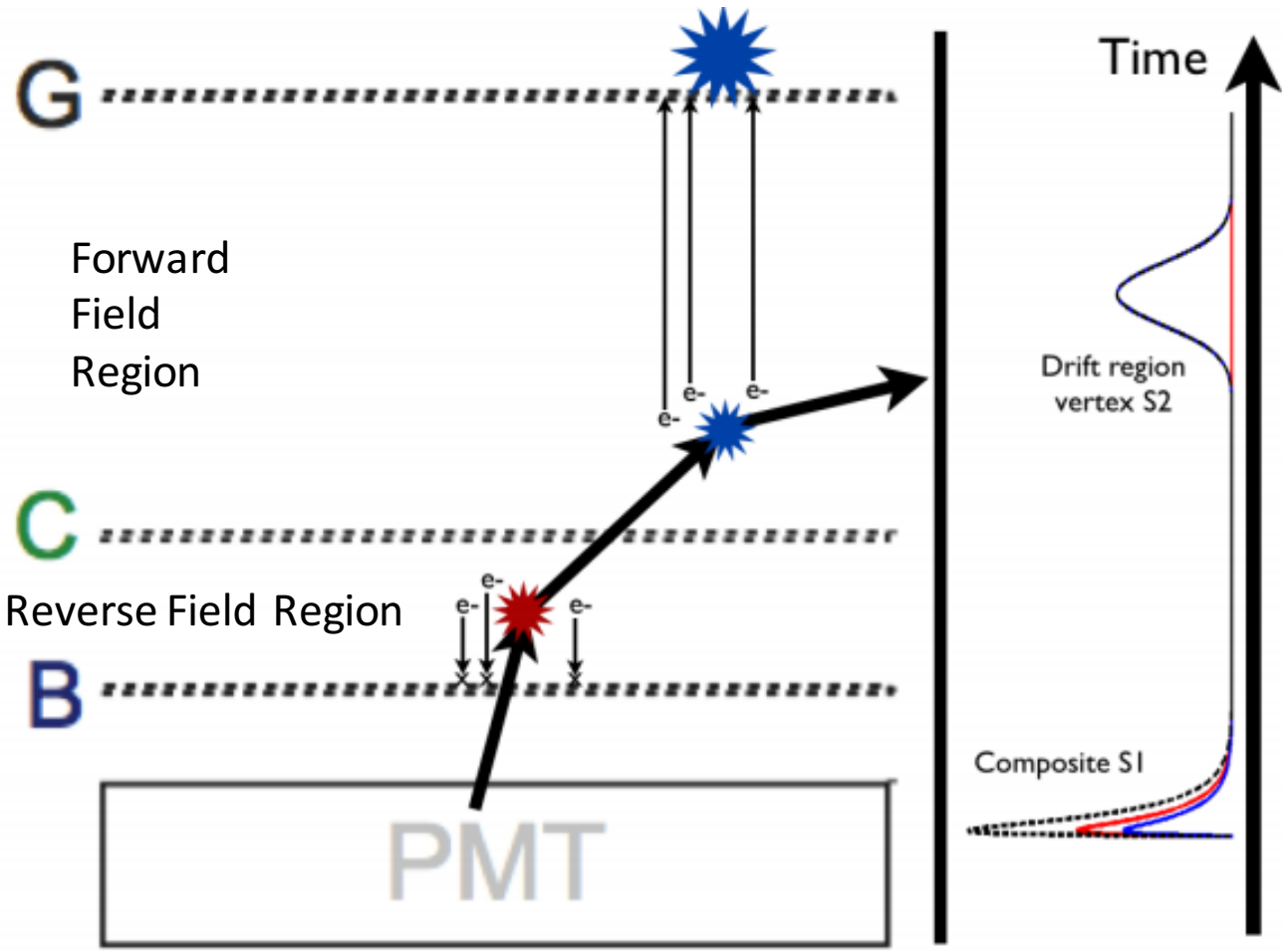




- Anti-coincidence LXe 'Skin' & liquid scintillator outer detector (OD)
- Reject TPC events with depositions >100 keV in Skin & >200 keV in OD
- Simulations to assess veto performance e.g. map of light collection efficiency (fed back into NEST) -> veto inefficiency
- Optimised fiducial mass increases from 3.3 to 5.6 tonnes when vetoes used

Background Studies

Gamma-X Event



Unusual event topologies that can pass cuts

- Gamma-X (2 overlapped S1s, 1 S2)
- $^{131}Xe^{m}$ partial energy deposits
- Wall backgrounds
- S1-S2 random coincidences

  -> esp. Cherenkov 'S1'…

Further studies

- Activation by calibration sources
- Rn dust and plate-out…

Future & Conclusions

- Mature backgrounds model – incremental additions from new assays
- Well-developed simulations chain, with plans for further optimisation
- Scope for investigating backgrounds for non-WIMP searches
- Continued studies to characterise rarer backgrounds

<u>Mock Data Challenge (MDC)</u>

- Currently in MDC1, analysing 30 live days worth of simulated data
- Exercises LZSim + detector response simulation and event processing framework
- Could provide further insight for background studies (incidence; analysis methods)