ZEPLIN III
Two-Phase Xenon WIMP Detector

Preliminary Results from the First Science Run

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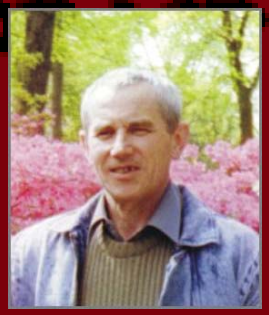
ITEP-Moscow (Russia), LIP-Coimbra (Portugal)
STFC Rutherford Appleton Laboratory (UK)

In Memoriam

Vadim Nikolaevitch Lebedenko

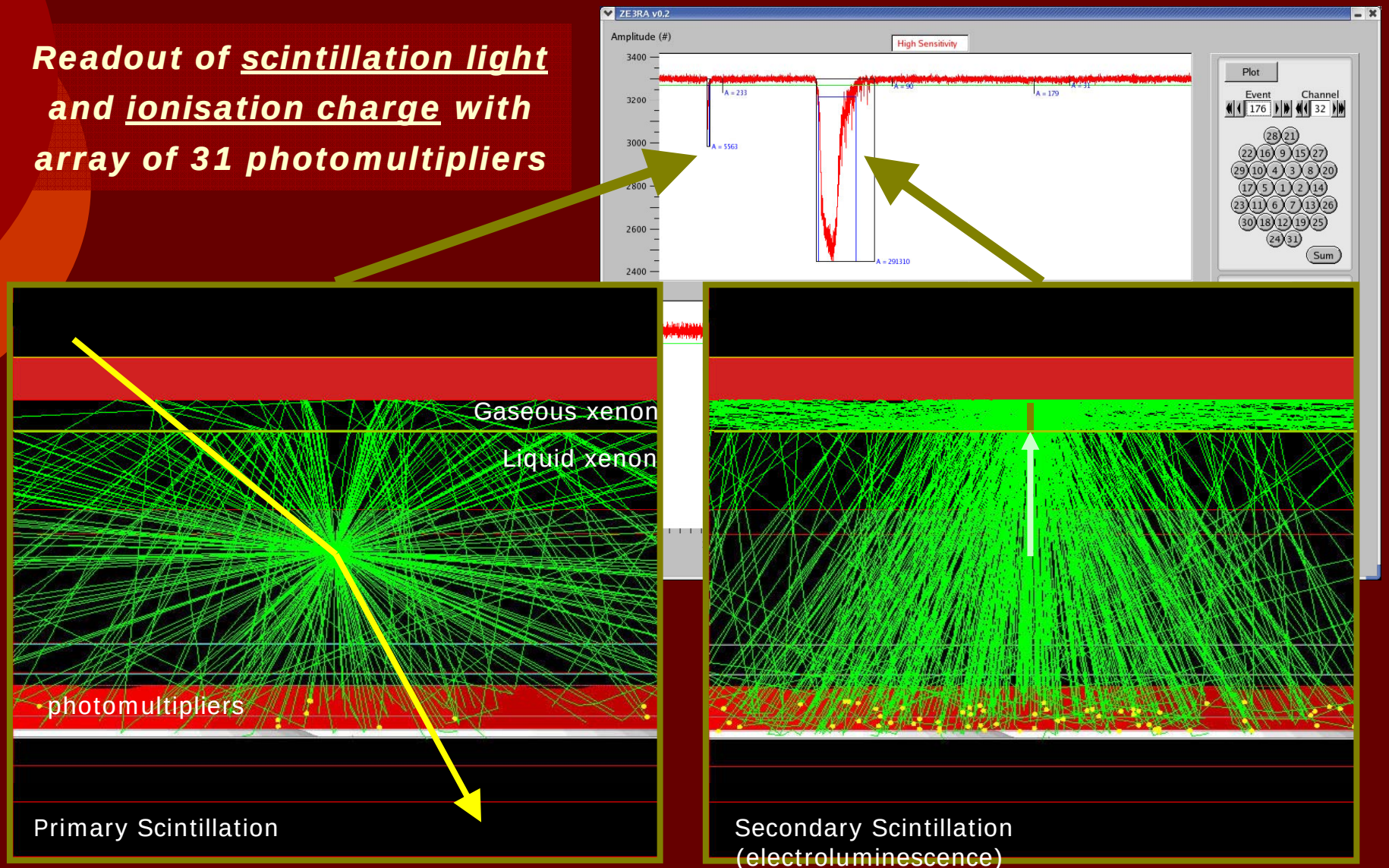
1939 – 2008



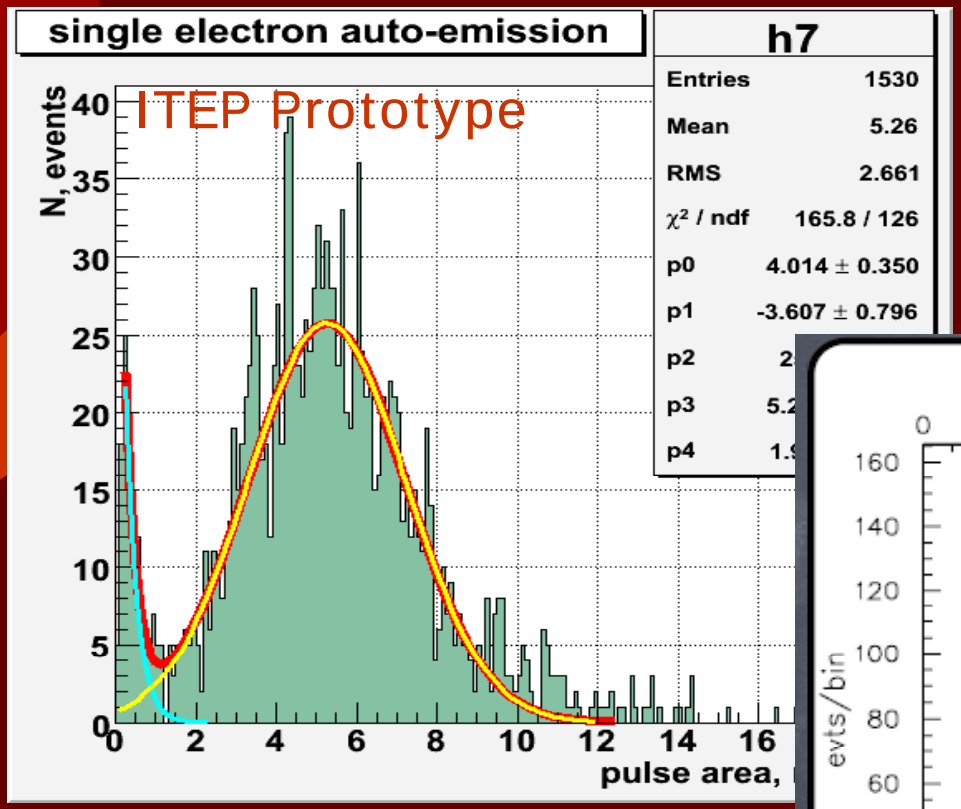
PSD-2008, 1-5 September 2008, University of Glasgow, UK

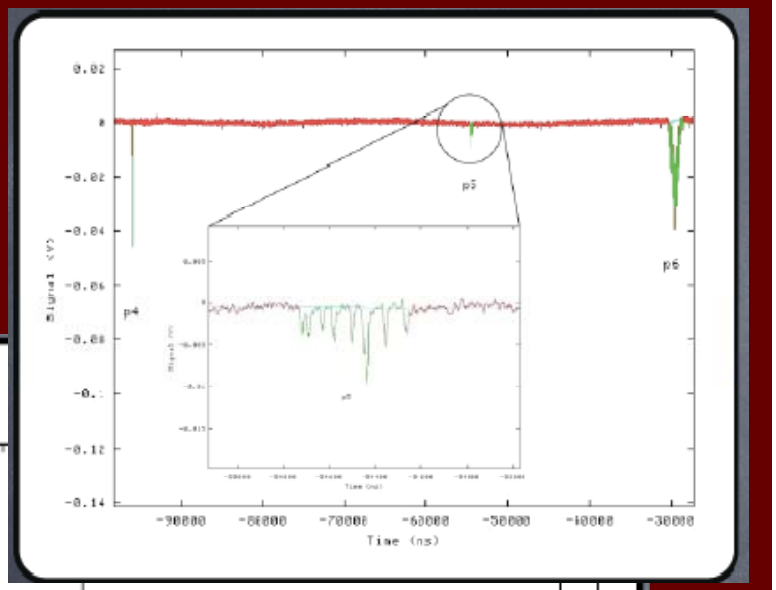
ZEPLIN-III Operation Principle

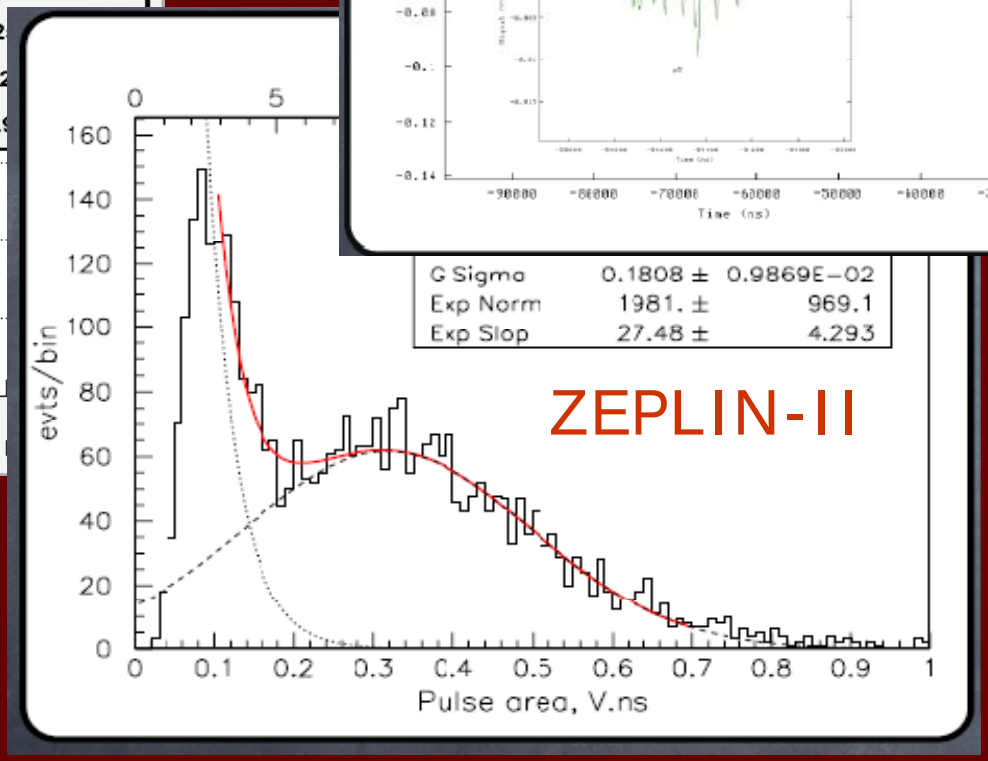
Readout of scintillation light and ionisation charge with array of 31 photomultipliers



Single Electron Detection!





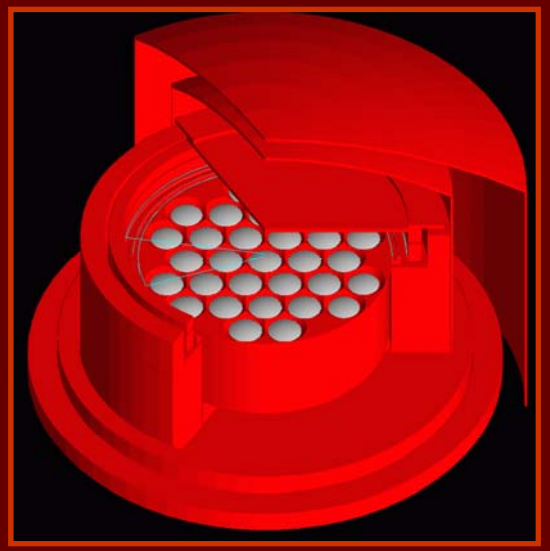


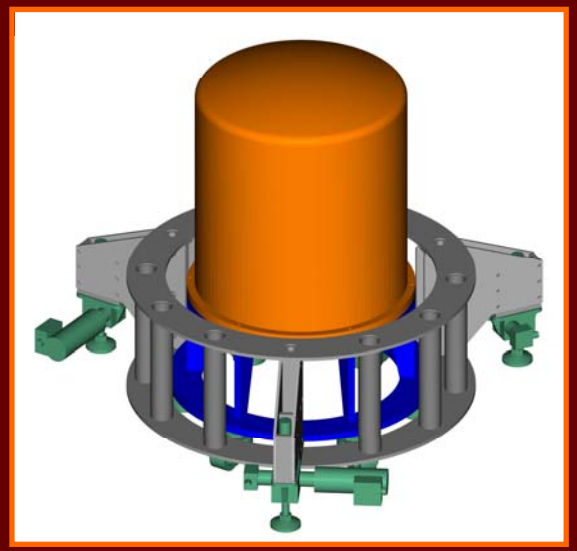
Single ionisation electrons extracted from >kg LXe target!

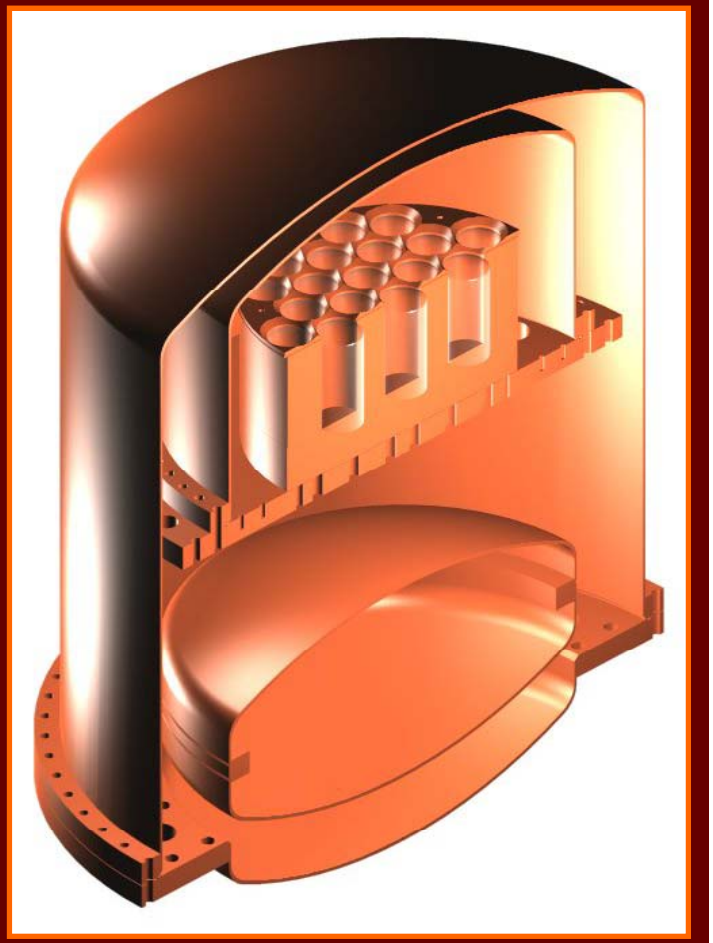
Edwards *et al.*, arXiv:0708.0768

ZEPLIN III: High-Field, 2-Phase Xenon

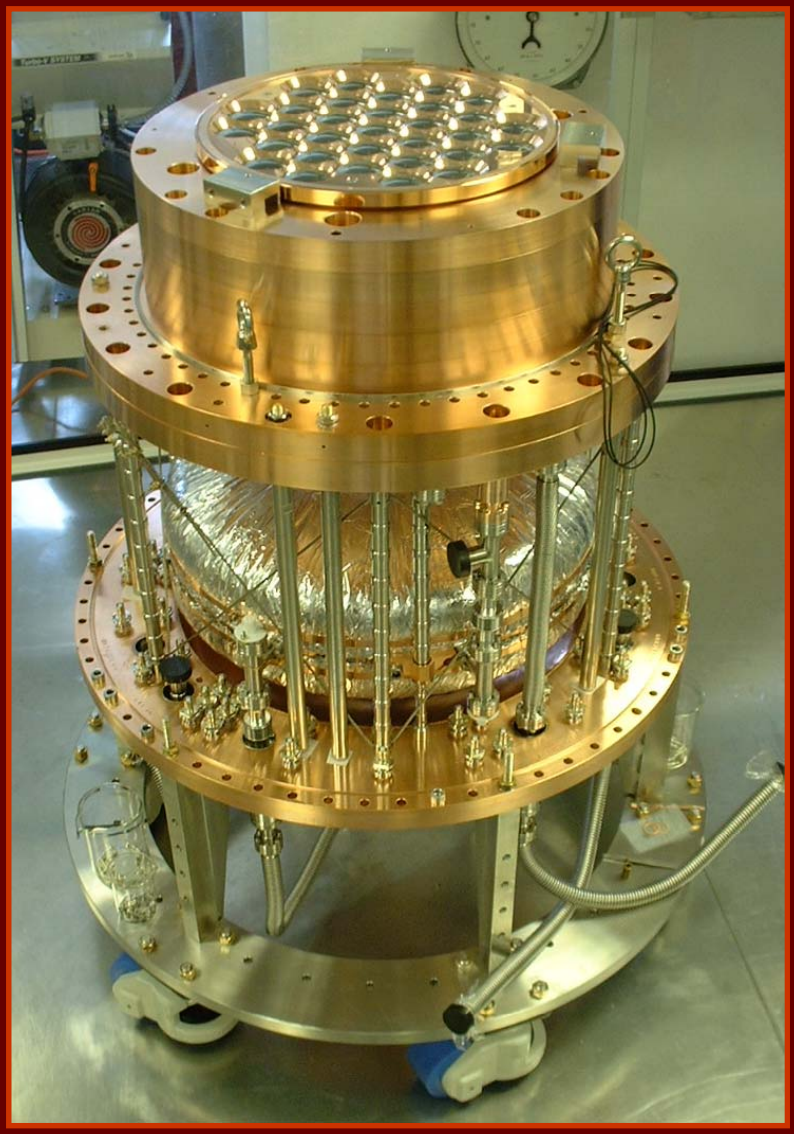
- ***Good light collection for scintillation***
  - ***Slab geometry (35 mm drift height, D/h~10)***
  - ***Photomultipliers immersed in the liquid***
- ***Better discrimination***
  - ***'Open plan' target, no extraction grids***
  - ***High field operation (3-5 kV/cm)***
  - ***Precision 3D position reconstruction***
- ***Low background construction***
  - ***Copper construction, low background Xe***





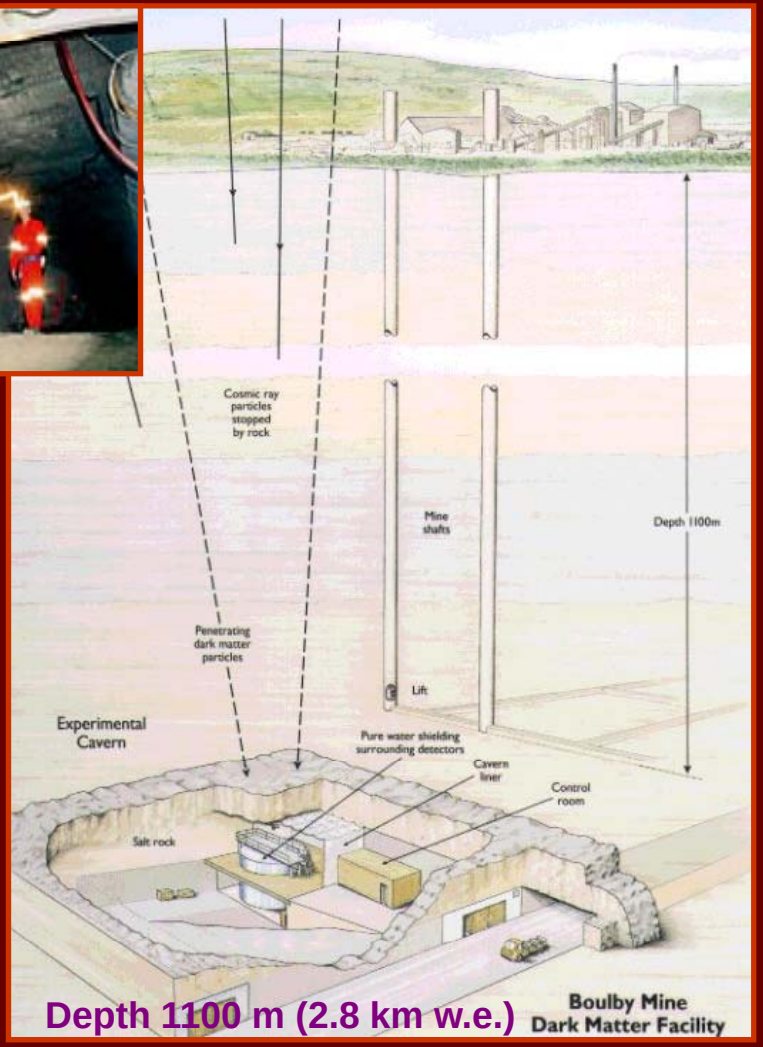


ZEPLIN III: Entrails



Boulby Underground Laboratory

We're all in the gutter, but some of us are looking underground...



Shielding: completed mid Feb 2008

- Neutron shield – 30 cm hydrocarbon
- Gamma shield – 20 cm boxed lead

First Science Run – parameters

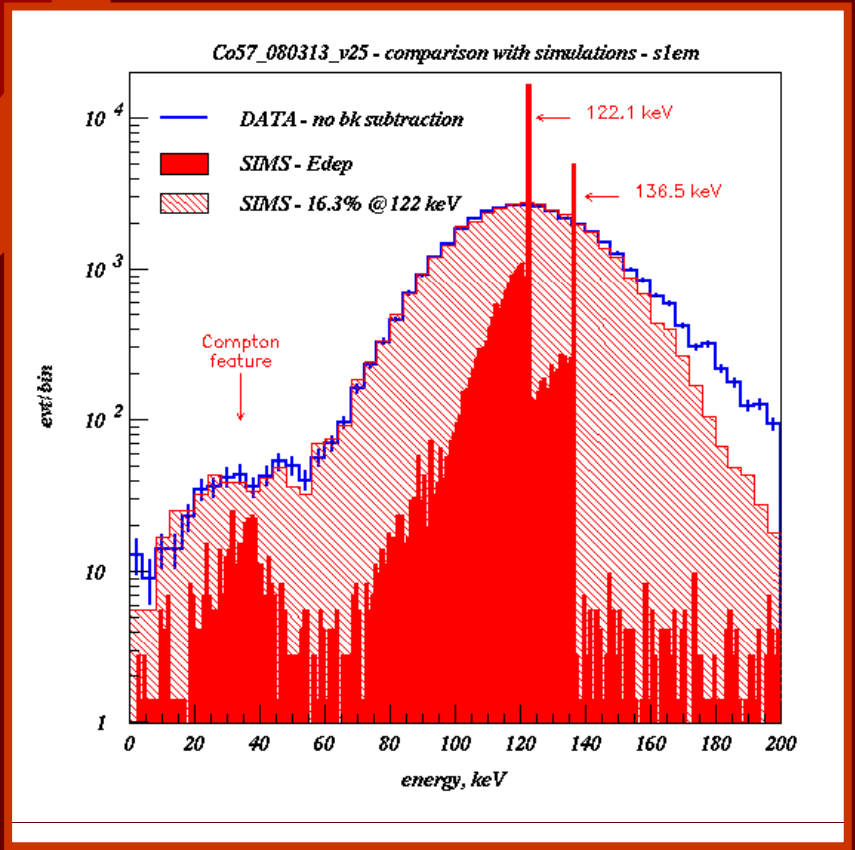
- **Transport from lab at IC and recommissioning u/g during 2007**
- **Commissioning stage completed mid-Feb 2008**
  - All systems ready: gas handling, cooling, shielding, external levelling, DAQ, slow control, calibration delivery, data pipeline, …
- **Required electron lifetime achieved (>20 us)**
  - Purification in gas phase through external getters
  - No degradation once in target (construction with xenon-friendly materials)
- **Operational parameters defined**
  - 4 kV/cm in LXe, 8 kV/cm in GXe (17 kV between electrodes)
  - 4 mm gas gap, 1.6 bar operating pressure
  - S1 light yield ~2.5 phe/keV @4 kV/cm (v. preliminary!)
  - S2 light yield ~11 phe/electron @4 kV/cm (v. preliminary!)
- **Very stable operation for nearly 5 months!**
  - LN2 consumption: <20 litres/day as per thermal design
  - Stable pressure (temperature) throughout
  - Occasional (Poissonian) trips of PMT power supply
  - No anode/cathode trips during entire science run!

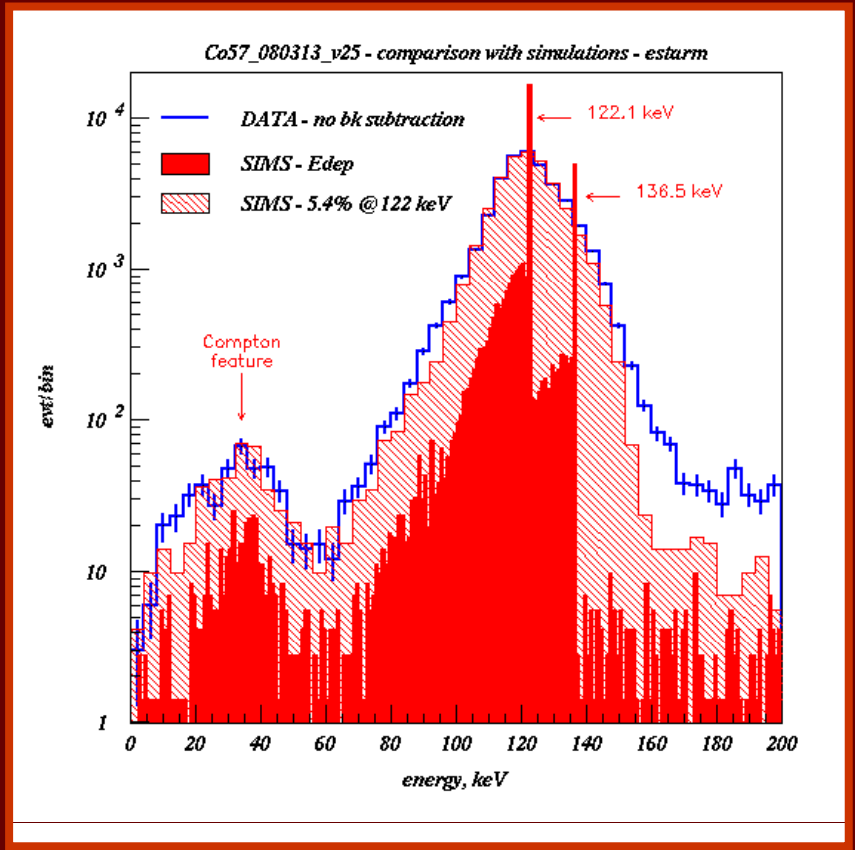
First Science Run – dataset

- **Early calibrations (Am-Be, Cs-137, Co-57, Co-60, …)**
  - Confirm performance, optimise operation parameters
- **First Science Run (shielded) begins 27 Feb 2008**
- **Daily calibration with Co-57 gamma-rays**
  - S1 & S2 stability, electron lifetime, levelling
- **Daily data dip-test (10%)**
  - Quality monitoring, electron-recoil background, analysis tuning
  - Thrown out from blind analysis
- **Science Run ends 20 May 2008**
  - 84 days at 84% duty cycle, 27 TB raw “dark” data
  - 800 kg*days raw exposure (12 kg LXe)
  - 400 kg*days fiducial exposure (6.6 kg LXe)
  - 120 kg*days efficiency-corrected exposure
- **Final calibration runs**
  - Extended neutron (Am-Be) calibration (4.9 hours)
  - Extended gamma (Cs-137) calibration (122 hours, volume ~ dark data)
  - Engineering & Physics runs (a couple of weeks)

Co-57 Calibration

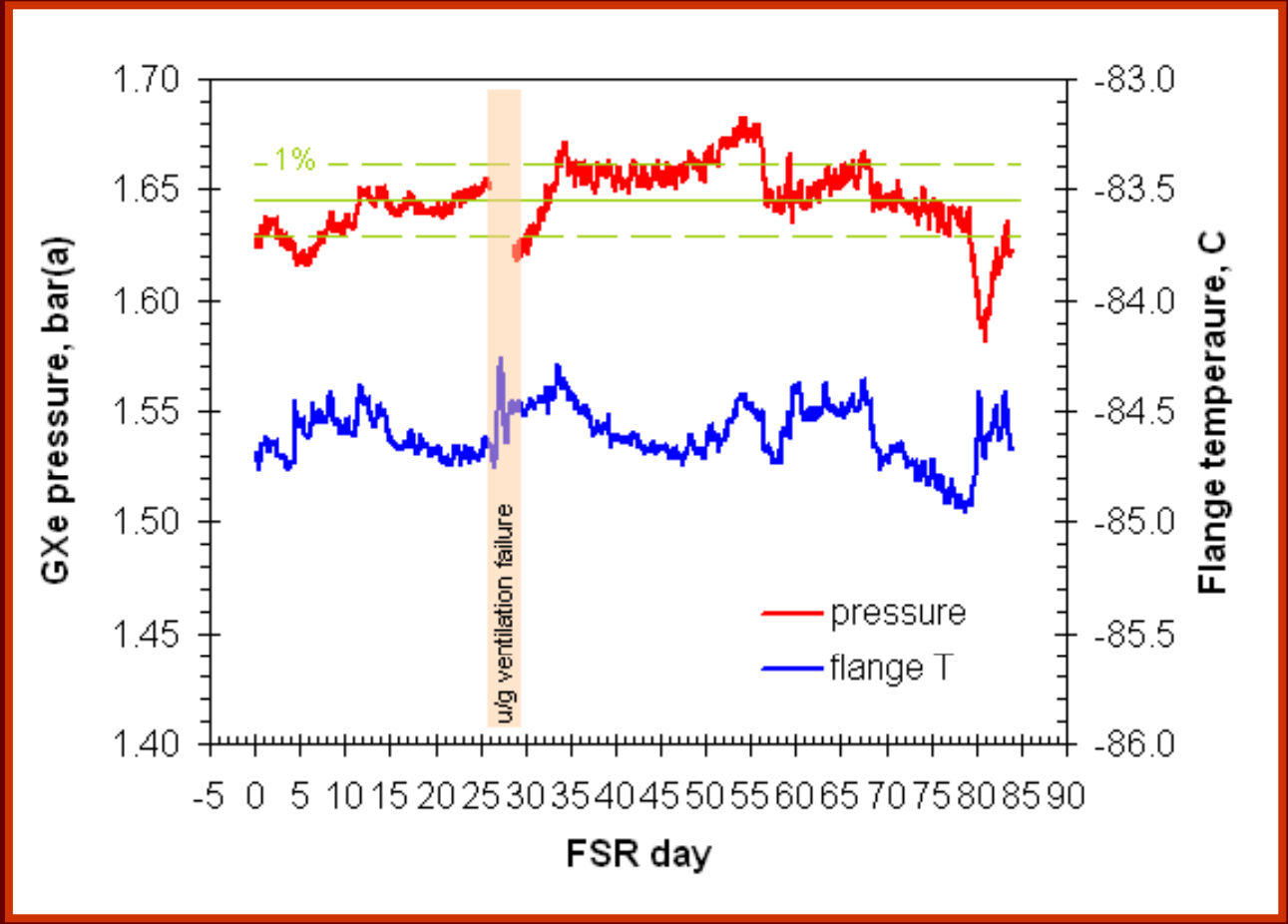
- Calibration is well understood – including predicted low-energy Compton feature!
- Excellent energy resolution by exploiting S1-S2 anti-correlation (σ=5.4% @122keV)





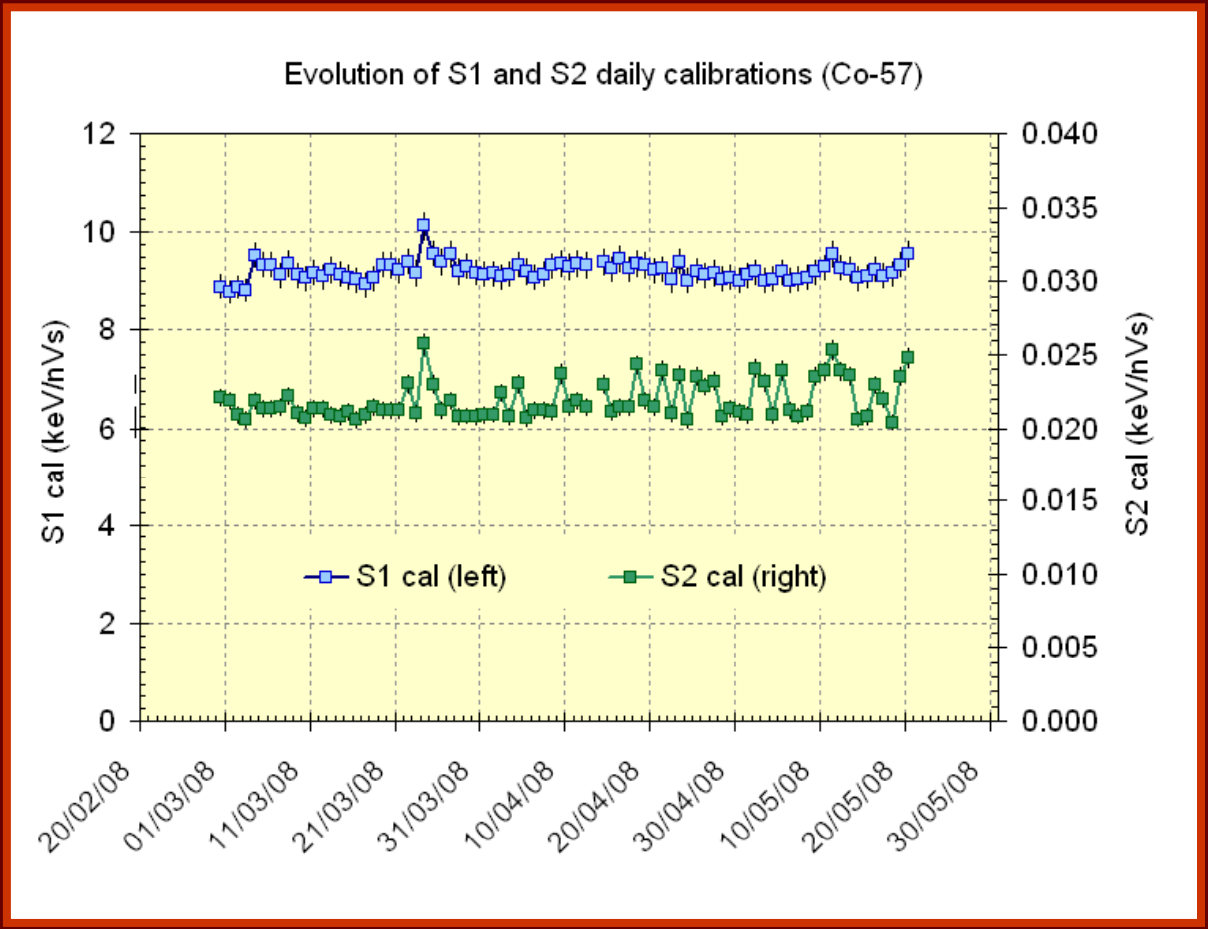
Thermal stability

- Good thermal stability and low LN2 consumption (<20 litres/day)
- 4 days excluded from FSR due to failure of u/g ventilation (TOO HOT!)



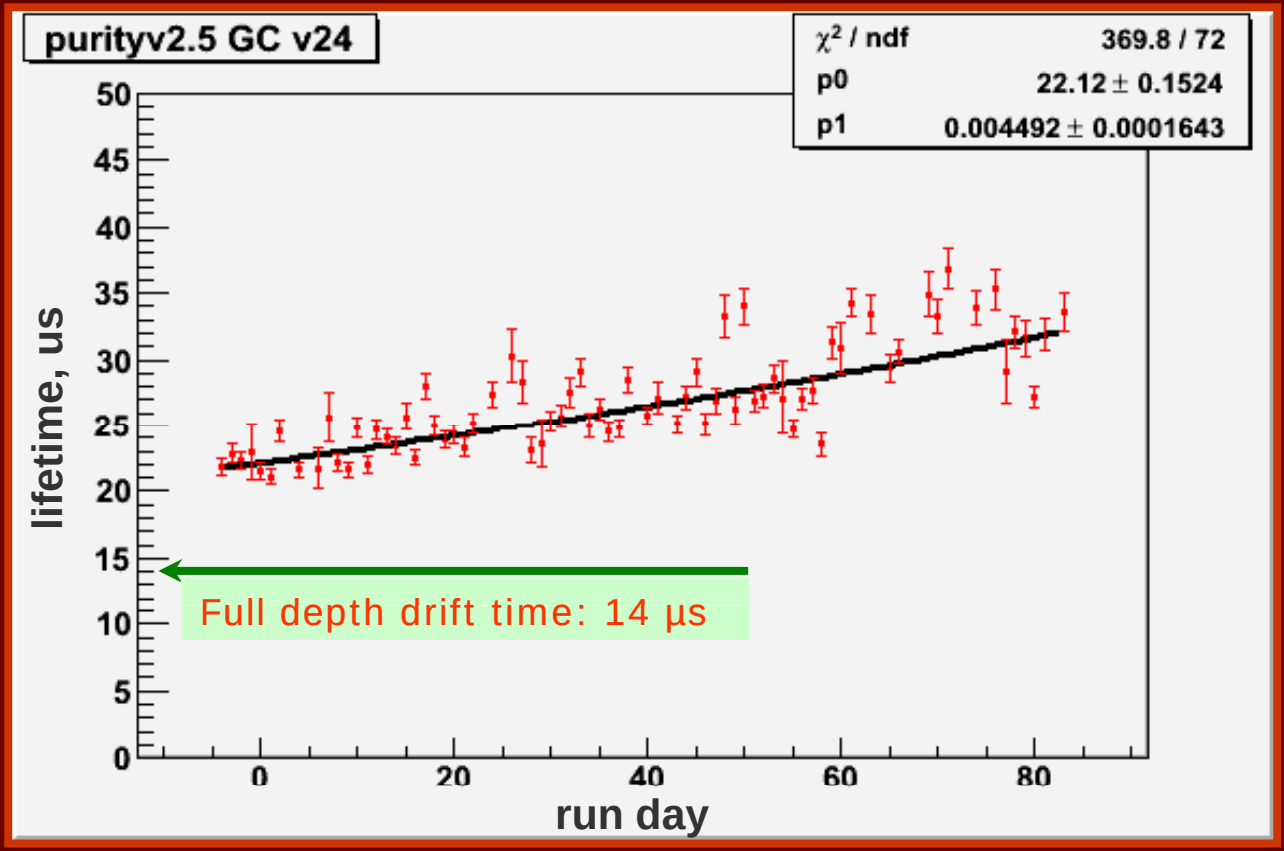
Stable S1 and S2 response

- Scintillation and ionisation channels remain stable throughout run



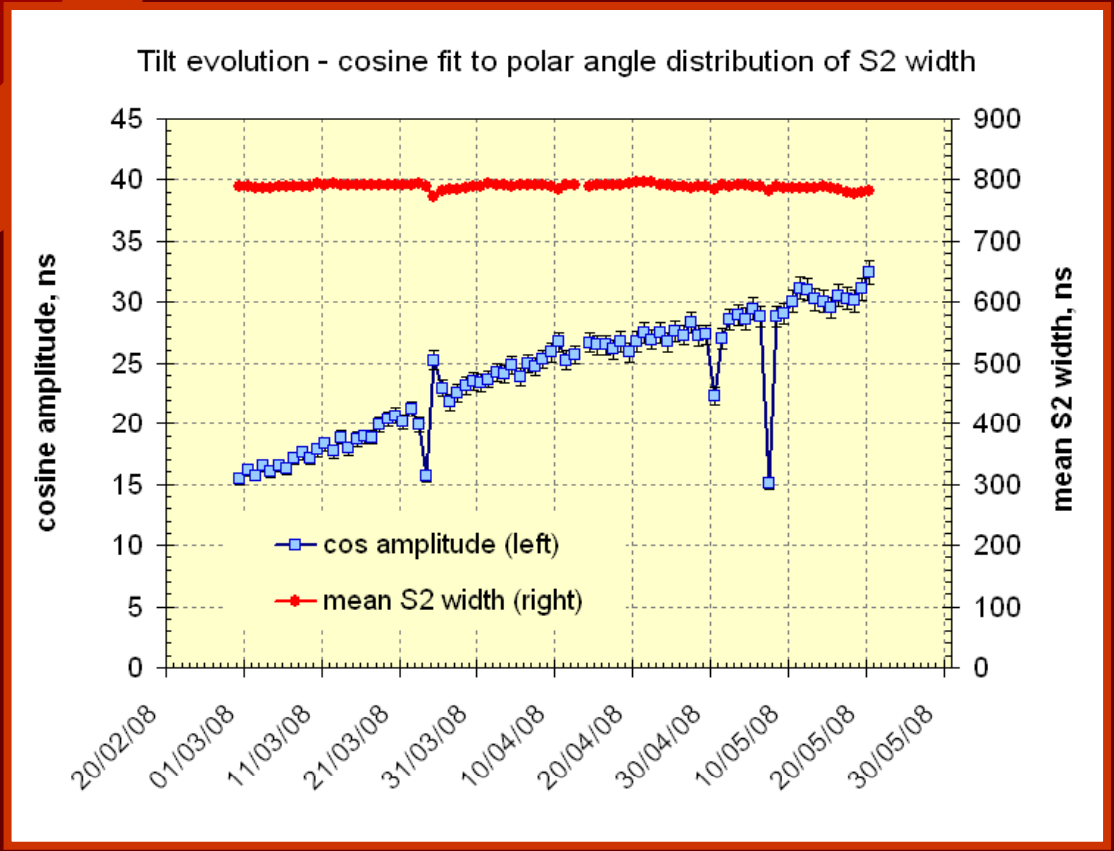
Free electron lifetime in liquid xenon

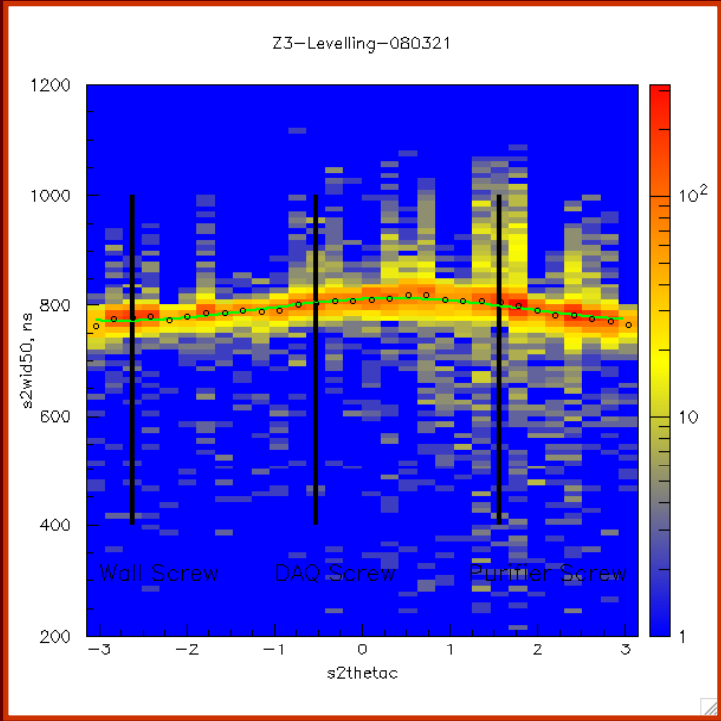
- First purification achieved ~20 us at high field (no degradation in target)
- (note that there is strong field dependence: low-field value >100 us!)
- This increased slowly during the run – with NO external recirculation!



Detector tilt & liquid level

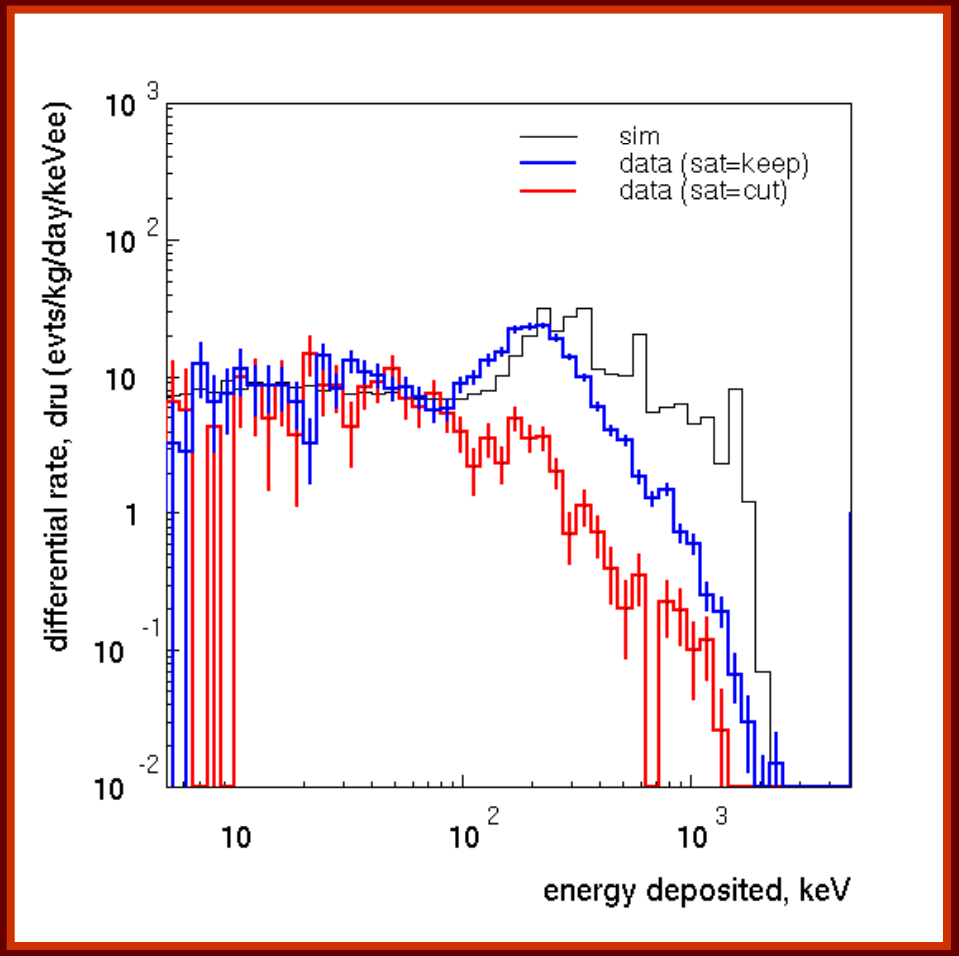
- Rock movement tilted detector by ~1 mrad during the run
- Decided not to level during run – few % effect on S2 pulse area





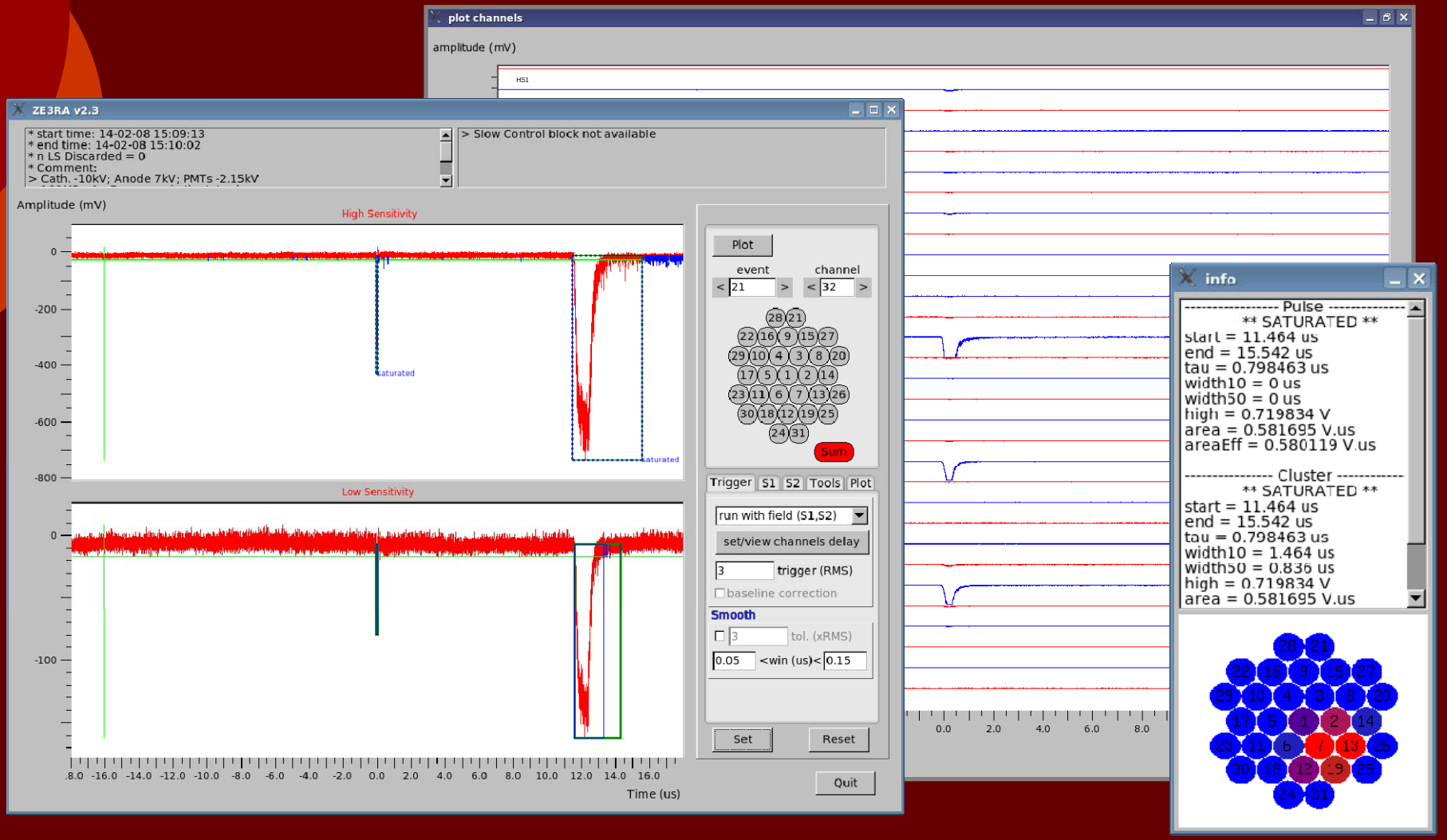
Low-energy gamma background

- 10 DRU – excellent agreement with MC prediction from PMT array!



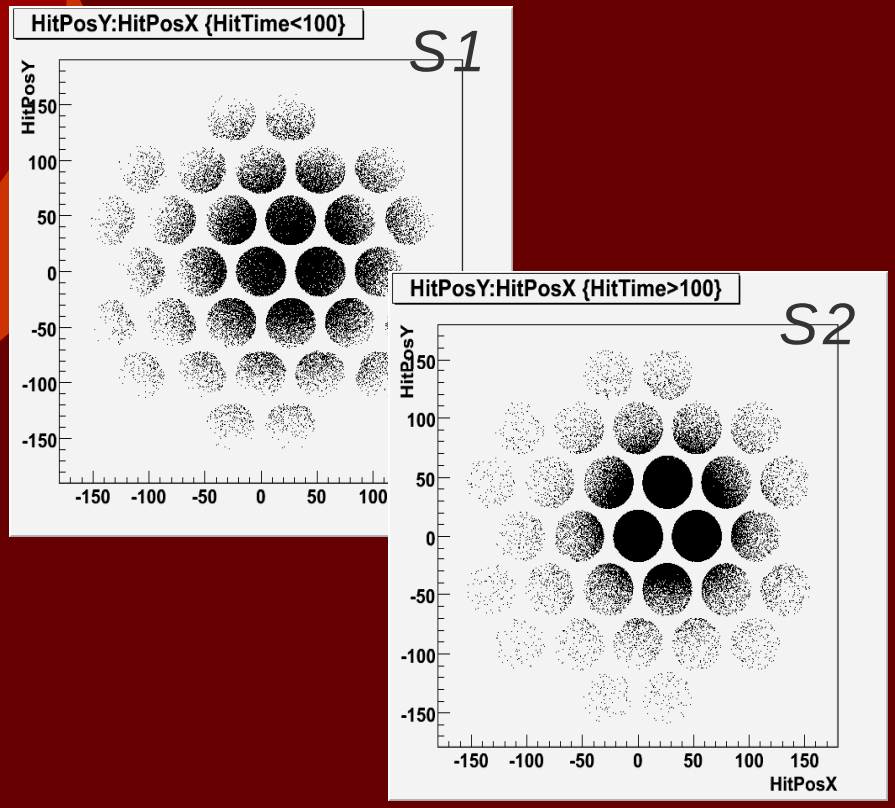
Data Processing

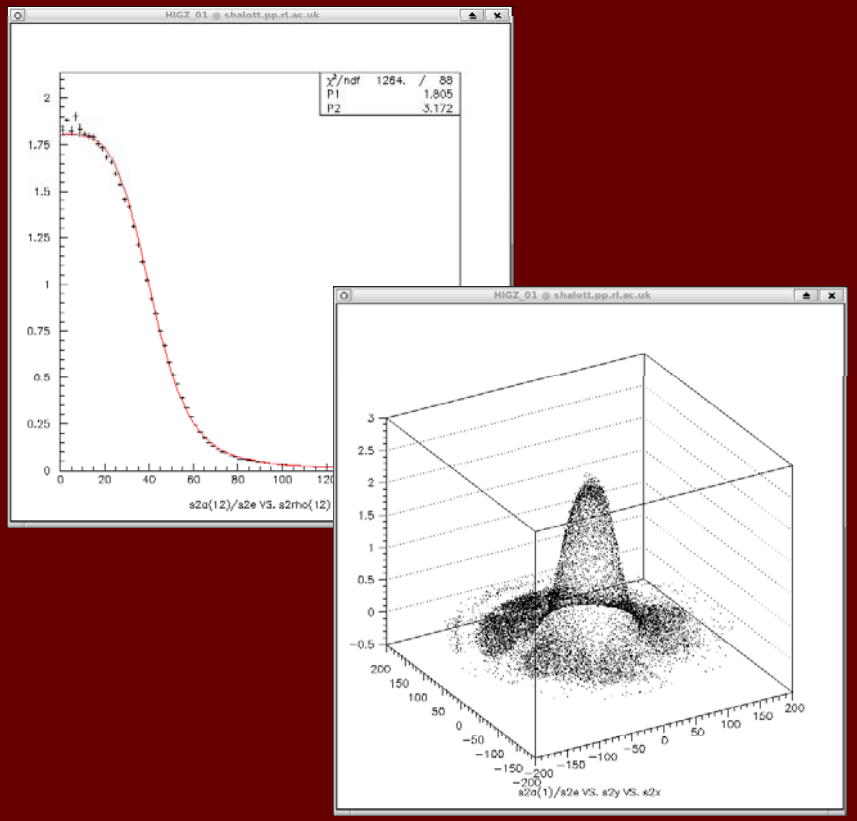
- Pulse finding and event display: ZE3RA (ZEplin 3 Reduction & Analysis)



Position Reconstruction

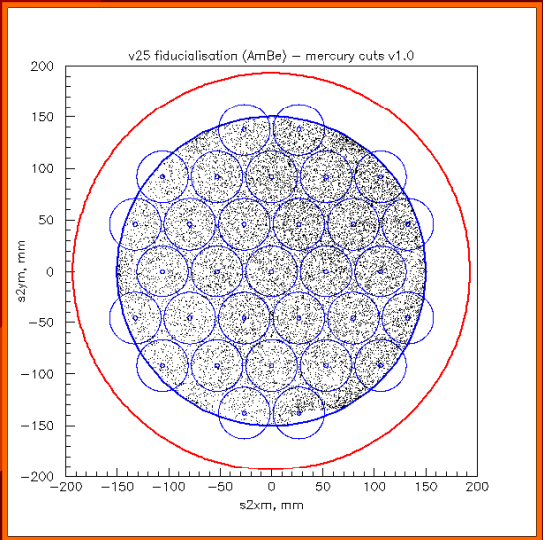
- Mote Carlo Template Algorithm
- Fit to PMT Light Collection Profile

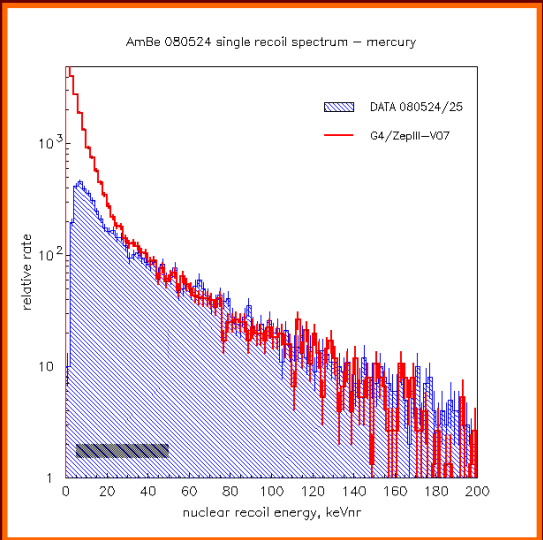




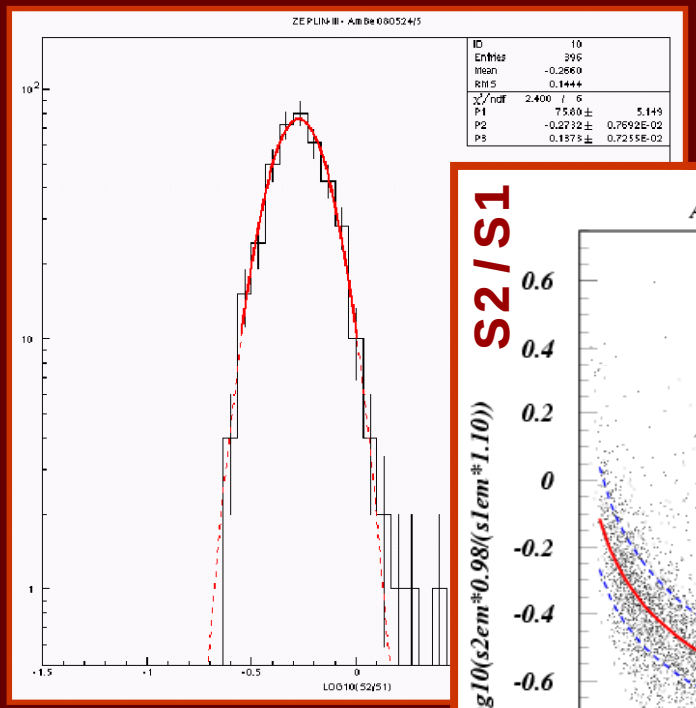
- Both algorithms are able to reconstruct S2 out to 150 mm radius
- S2 reconstructions should achieve a few mm FWHM at 122 keV
- “Phantom grid” being installed above top mirror to help reconstruction

Neutron Calibration (Am-Be)

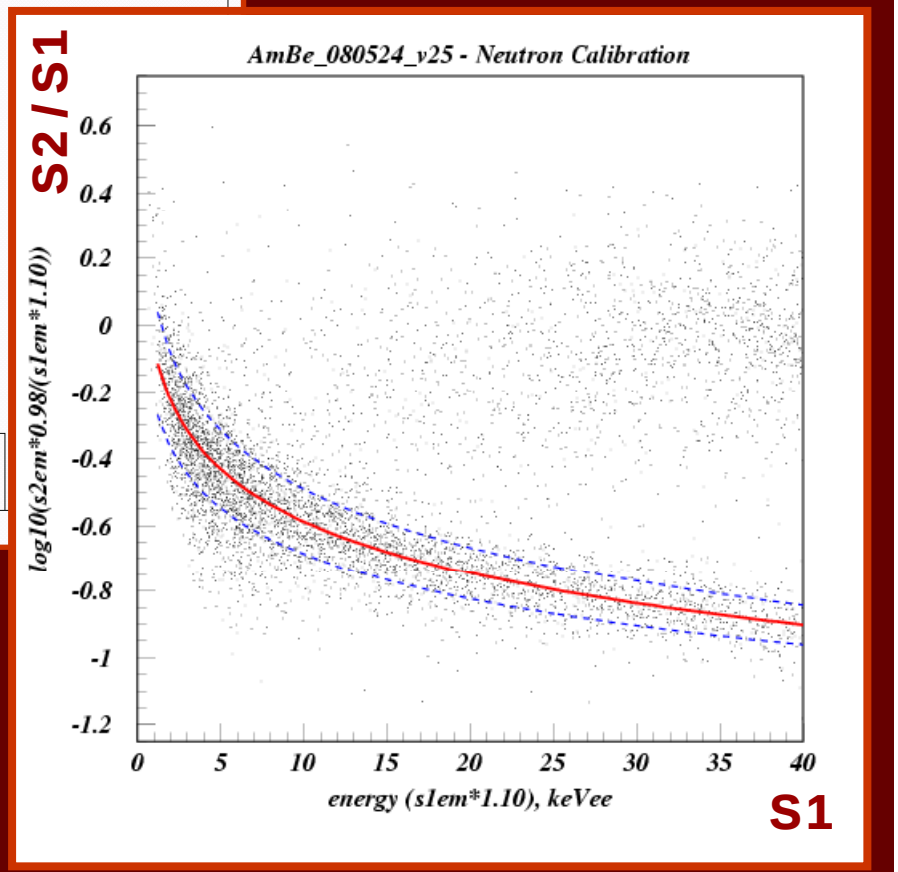




- Characterisation of elastic recoils in S2/S1 parameter

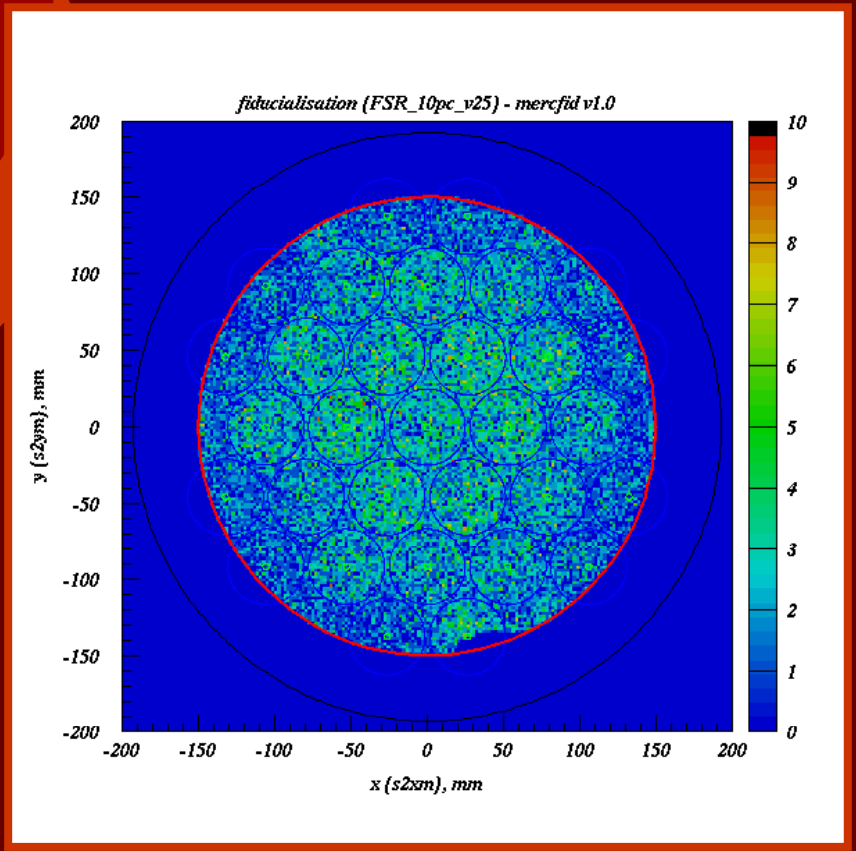


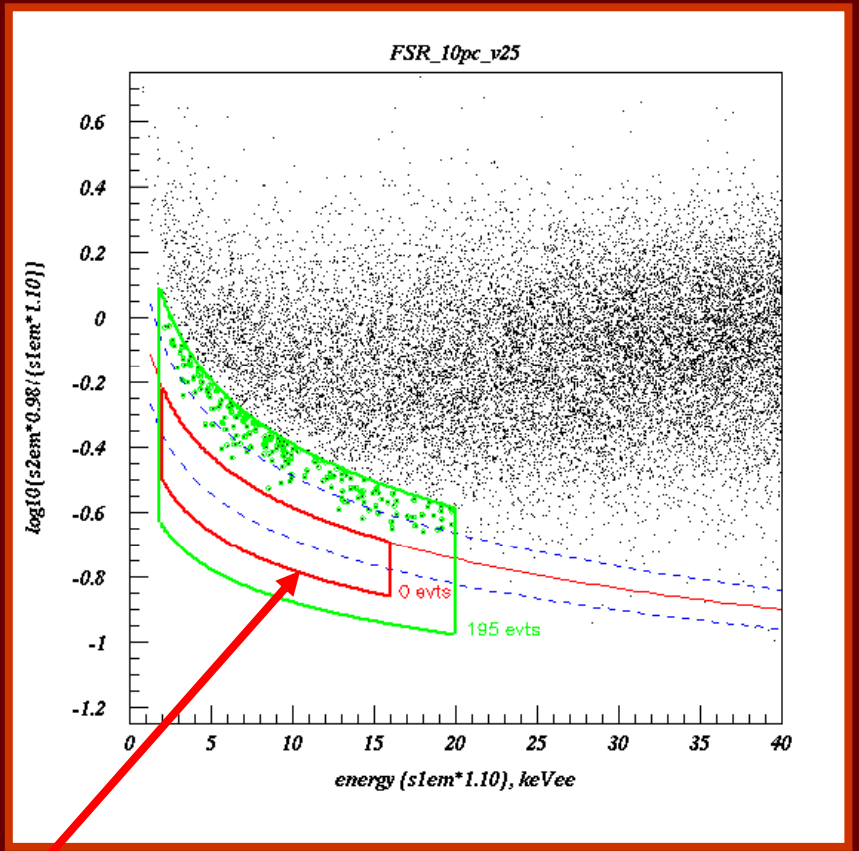
AmBe



Science Data – 10% open sample

- For detector characterisation and development of analysis

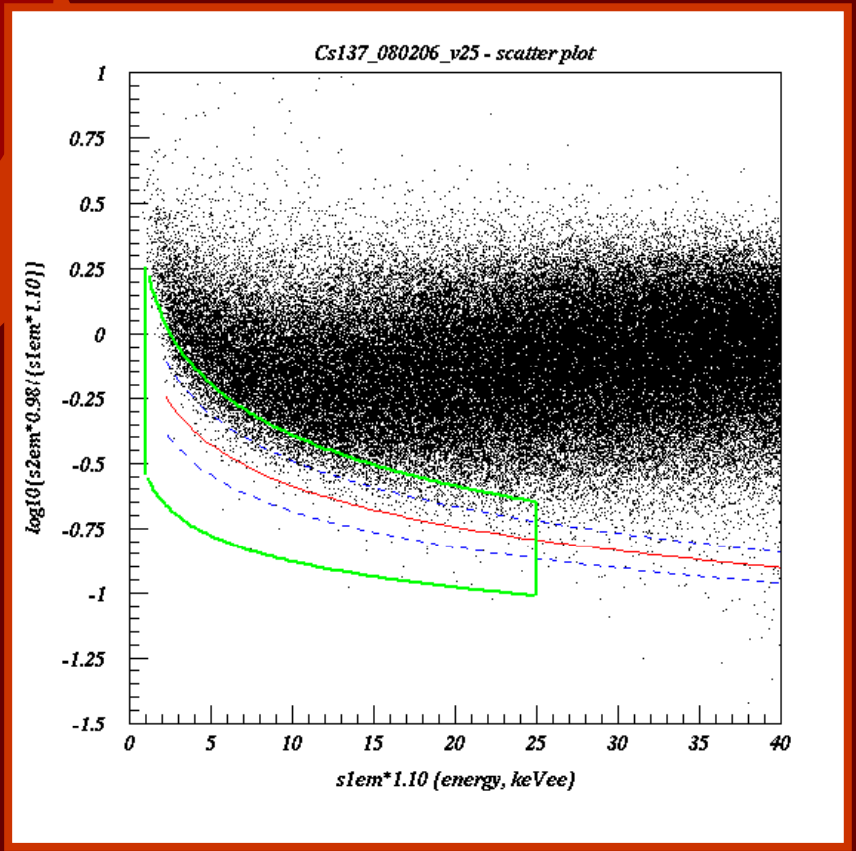




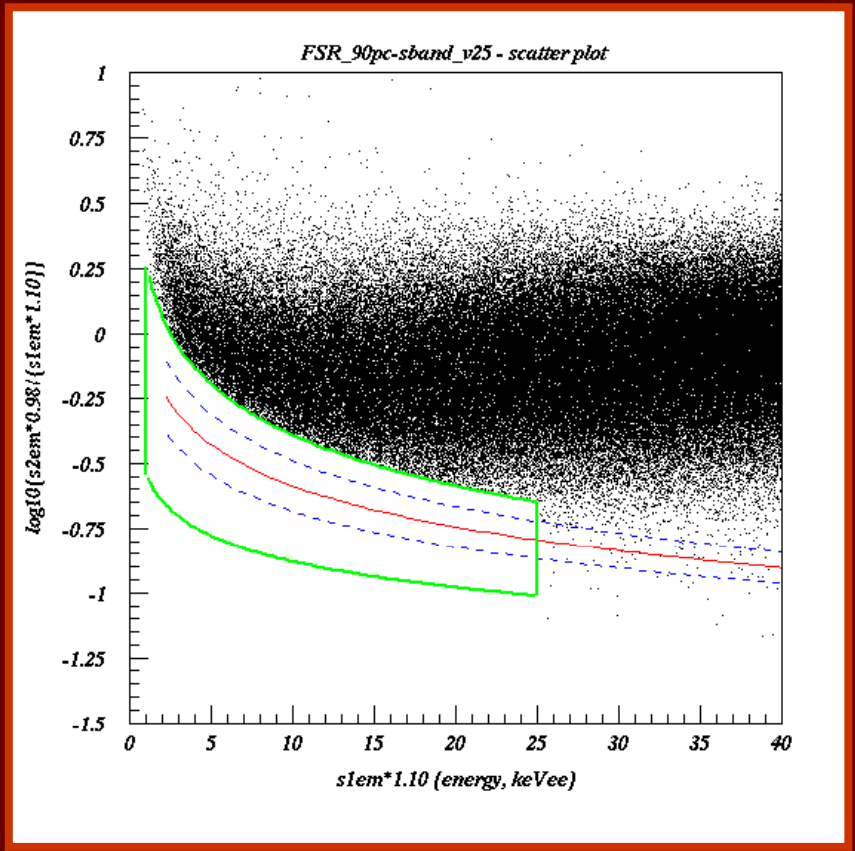
acceptance region (2-16 keVee, m-2σ < S2/S1 < m)

Science Data – sideband analysis (90%)

- Comparison between Cs-137 and 90% (blinded) datasets



Cs137

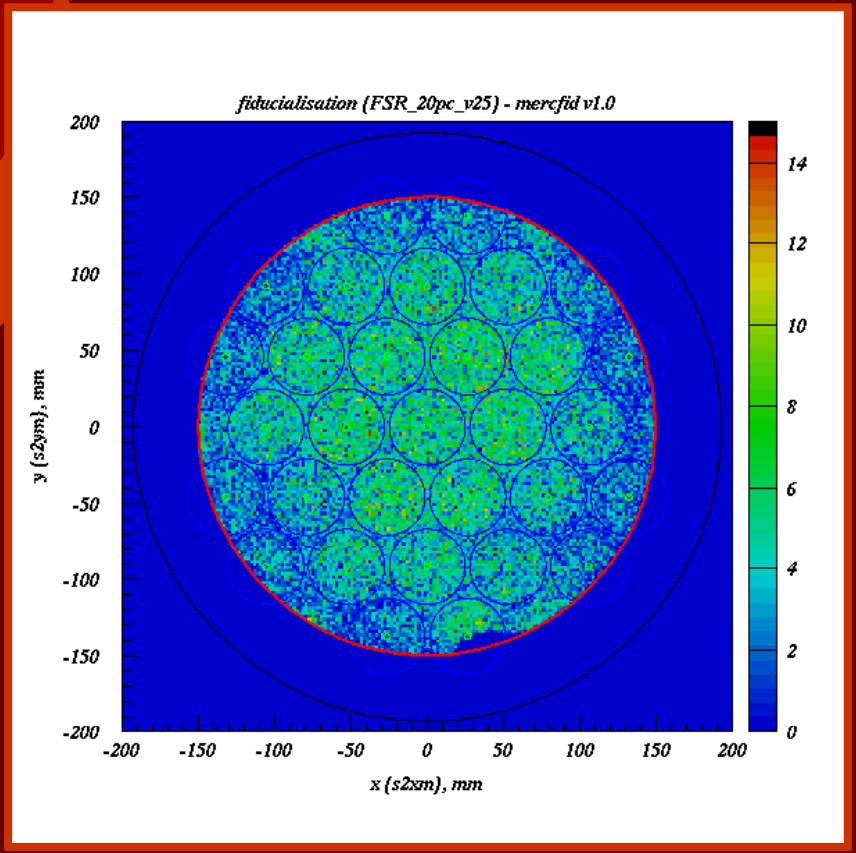


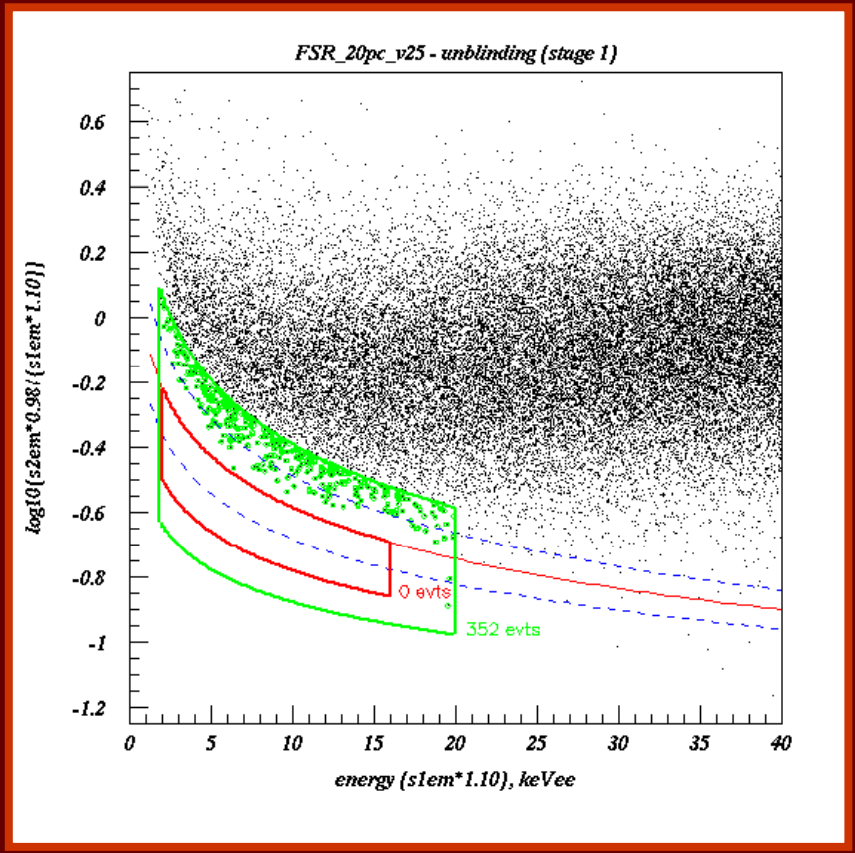
data

sideband analysis region (1-25 keVee, m-3σ < S2/S1 < m+2σ)

Science Data – 20% un-blinded

- Staged un-blinding to confirm prediction of gamma leakage





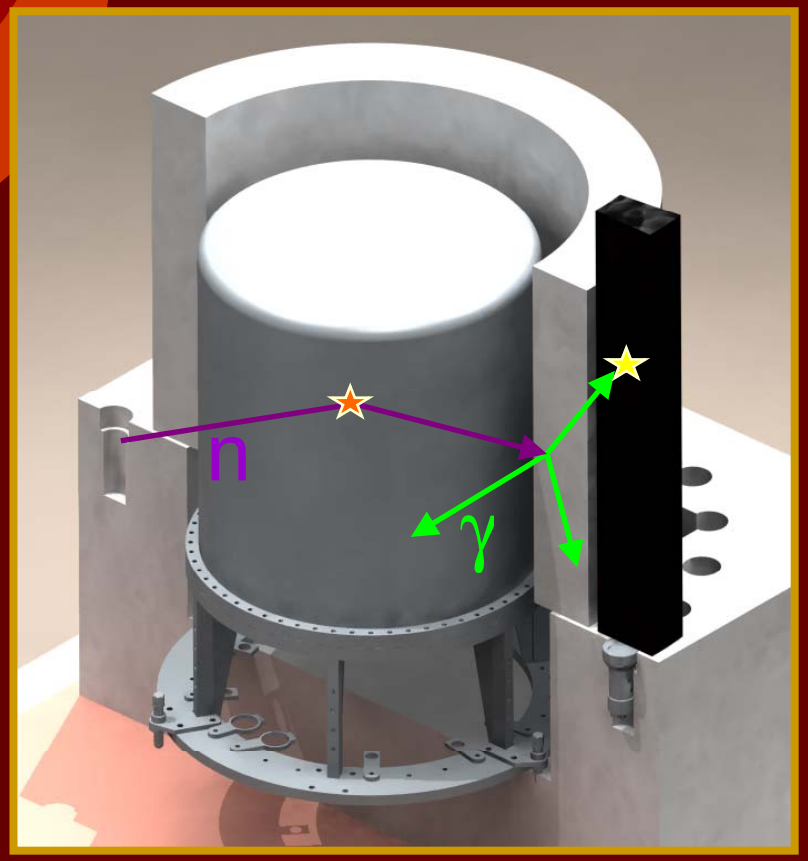
…but found 0 events in acceptance box! However, we DO expect some in full dataset: ~1 neutron, some gammas, possibly WIMPs…

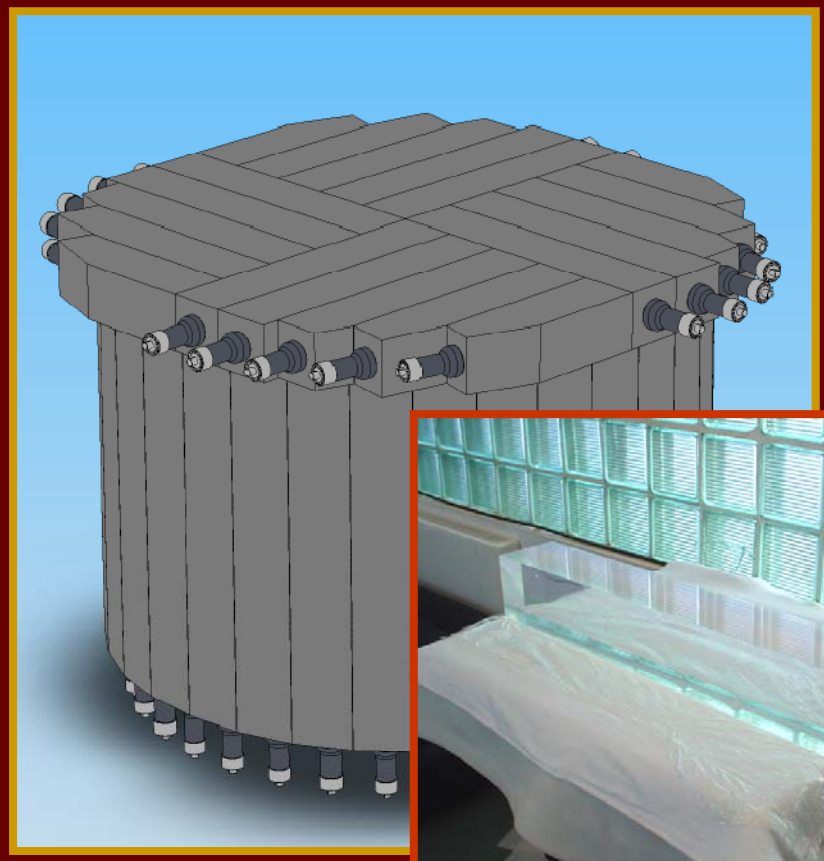
Science Data – summary

- Demonstrated long-term operation of two-phase xenon detector
- Achieved operation at high electric field (4 kV/cm)
- Excellent electron/nuclear recoil discrimination (~1:10,000)
- Gamma background (PMT dominated) is well understood
- Cs-137 calibration is poor predictor for tails of gamma distribution in dark data (different directionality). This biases the prediction of double-scatters in active-plus-dead regions ("living-dead" events) – which is delaying the final stage in the analysis
- Nonetheless we expect a competitive WIMP result very soon!

Phase II – Integration with Veto

- An important tool for both neutron rejection as well as diagnostics!
- Inner Gd-loaded hydrocarbon surrounded by plastic scintillator veto
- Delayed coincidence detection of capture gammas from Gd and H
- Assembly making excellent progress

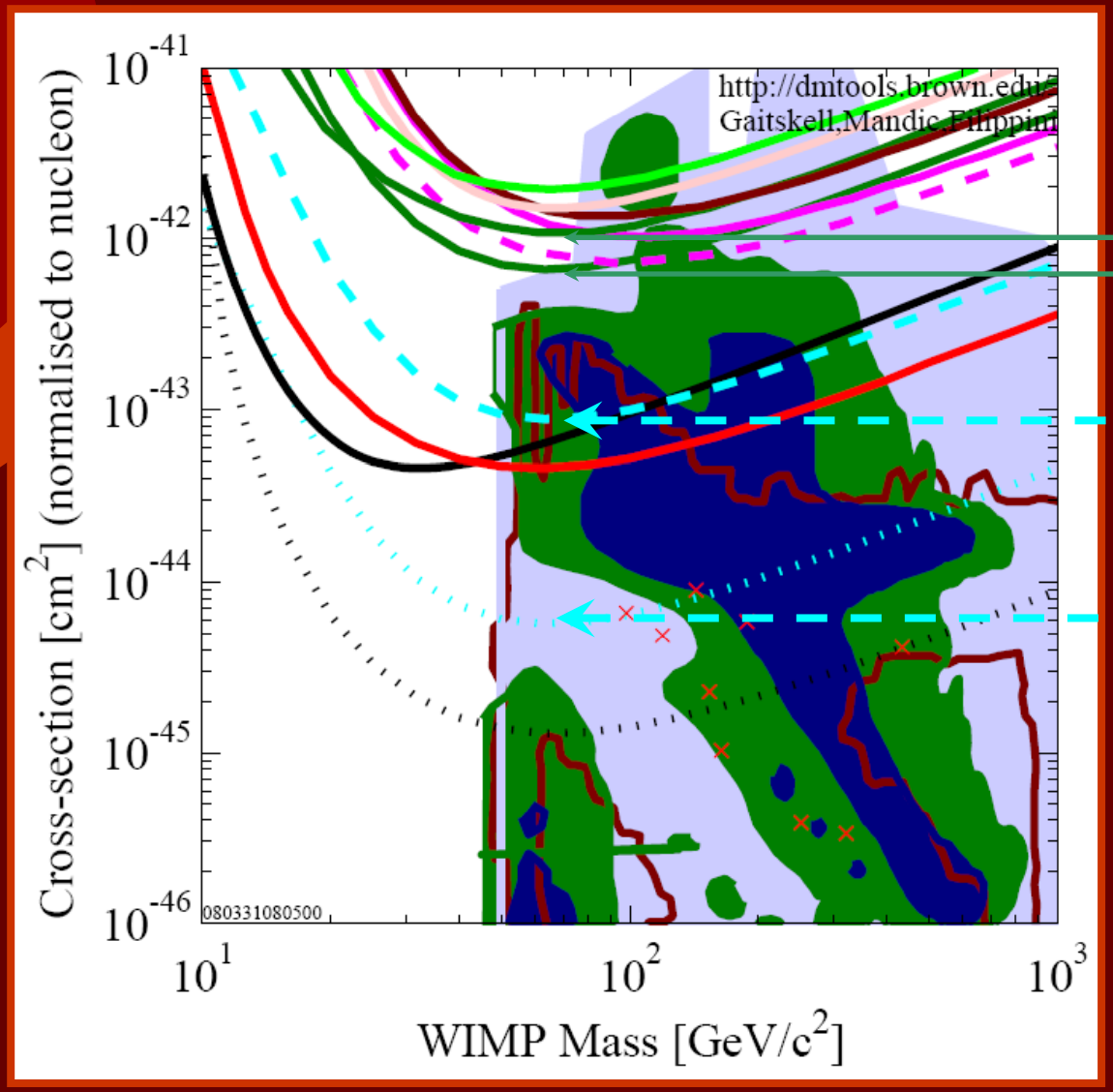




Phase II – PMT Upgrade

- Existing PMTs limit sensitivity of first run (gammas & neutrons)
- Custom design for ultra low-background tubes, pin-by-pin compatible
- Factor ~30 improvement in gamma-ray activity expected

Predicted sensitivity



ZEPLIN-I

ZEPLIN-II

PHASE I SHORT RUN

PHASE II UPGRADED LONG RUN

(unrevised 2006 prediction)

Araújo *et al*, Astroparticle Phys. **26**:140-153, 2006