First results of the ZEPLIN-III dark matter detector

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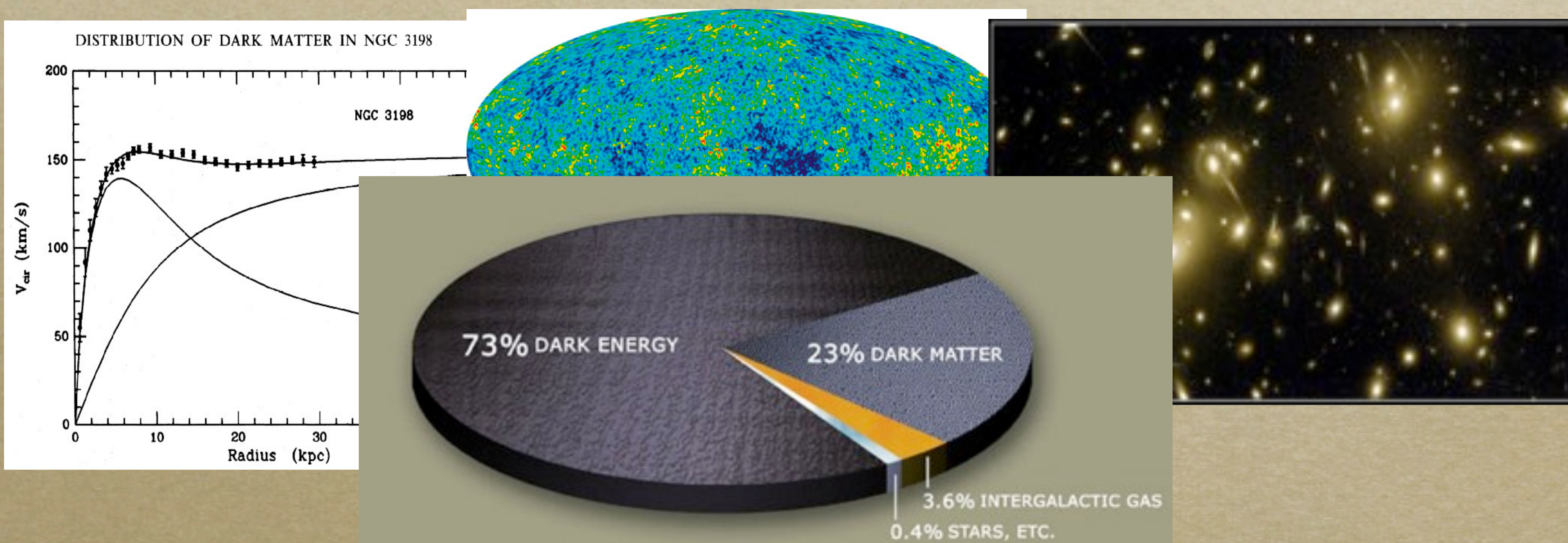
on behalf of the ZEPLIN-III collaboration:

University of Edinburgh, Imperial College London, ITEP-Moscow, LIP-Coimbra, STFC Rutherford Appleton Laboratory

Dark Matter in the Universe

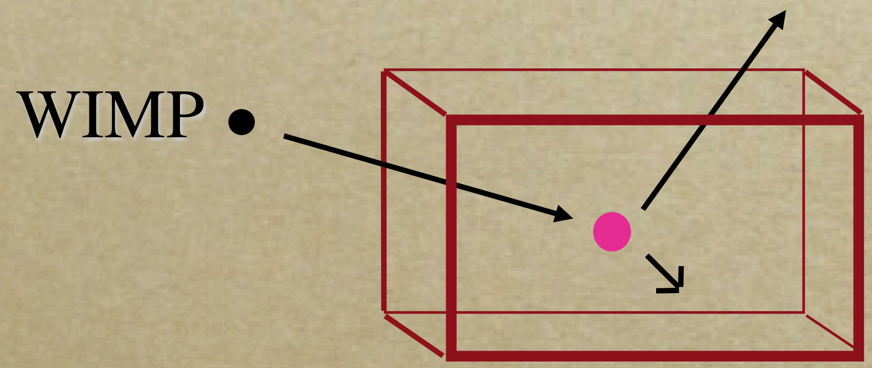
- *Different cosmological observations point to a significant non-baryonic dark matter component.*
  - ➡ *Rotation curves of galaxies, CMB anisotropy, gravitational lensing, etc.*

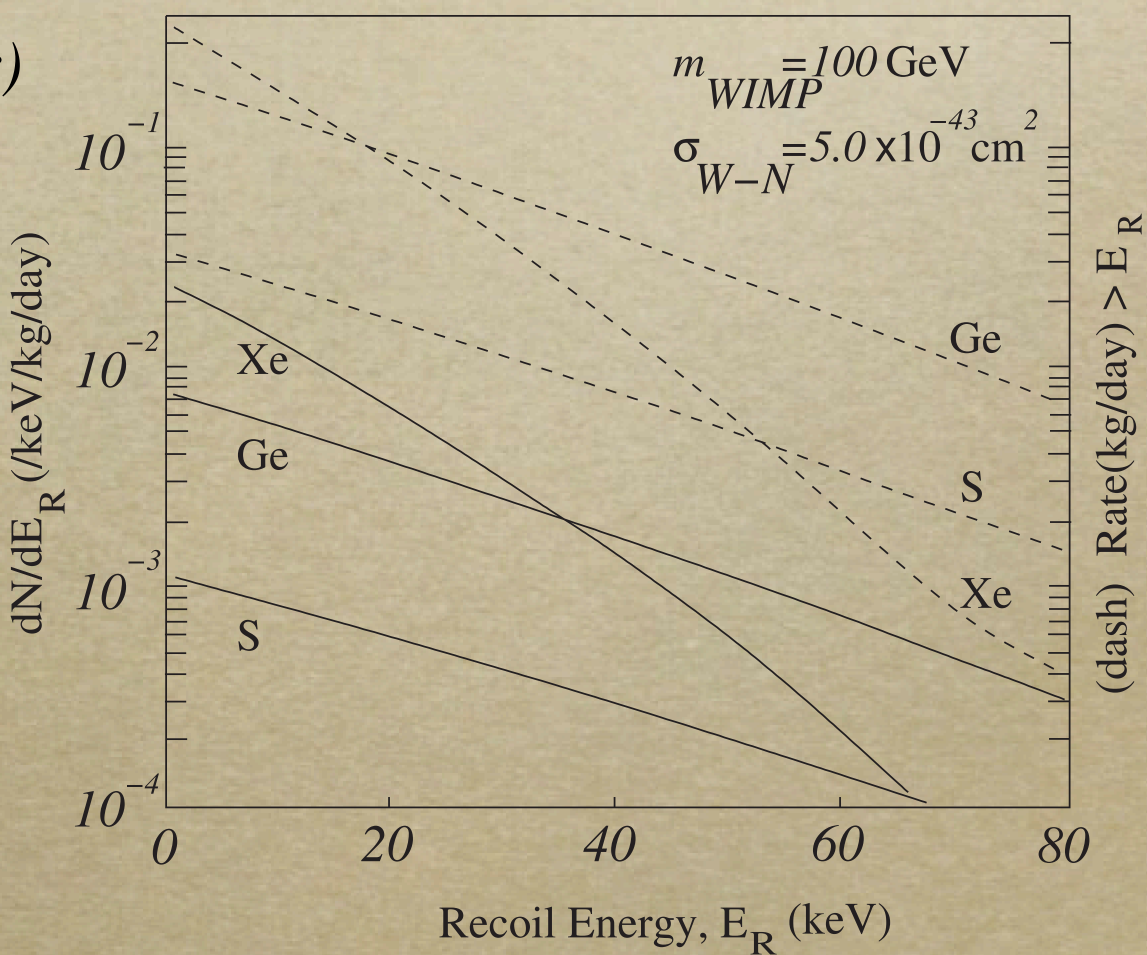


- *WIMPs (Weakly Interacting Massive Particles) - such as the SUSY neutralino - are amongst the best candidates.*
  - ➡ *Mass scale - from **tens** to **hundreds** of GeV*

Direct Detection

- *Look for signals from WIMP interactions with ordinary matter:*
  - *low energy nuclear recoils (< 100 keV)*
  - *very low interaction rates (< 1 event/kg/year)*

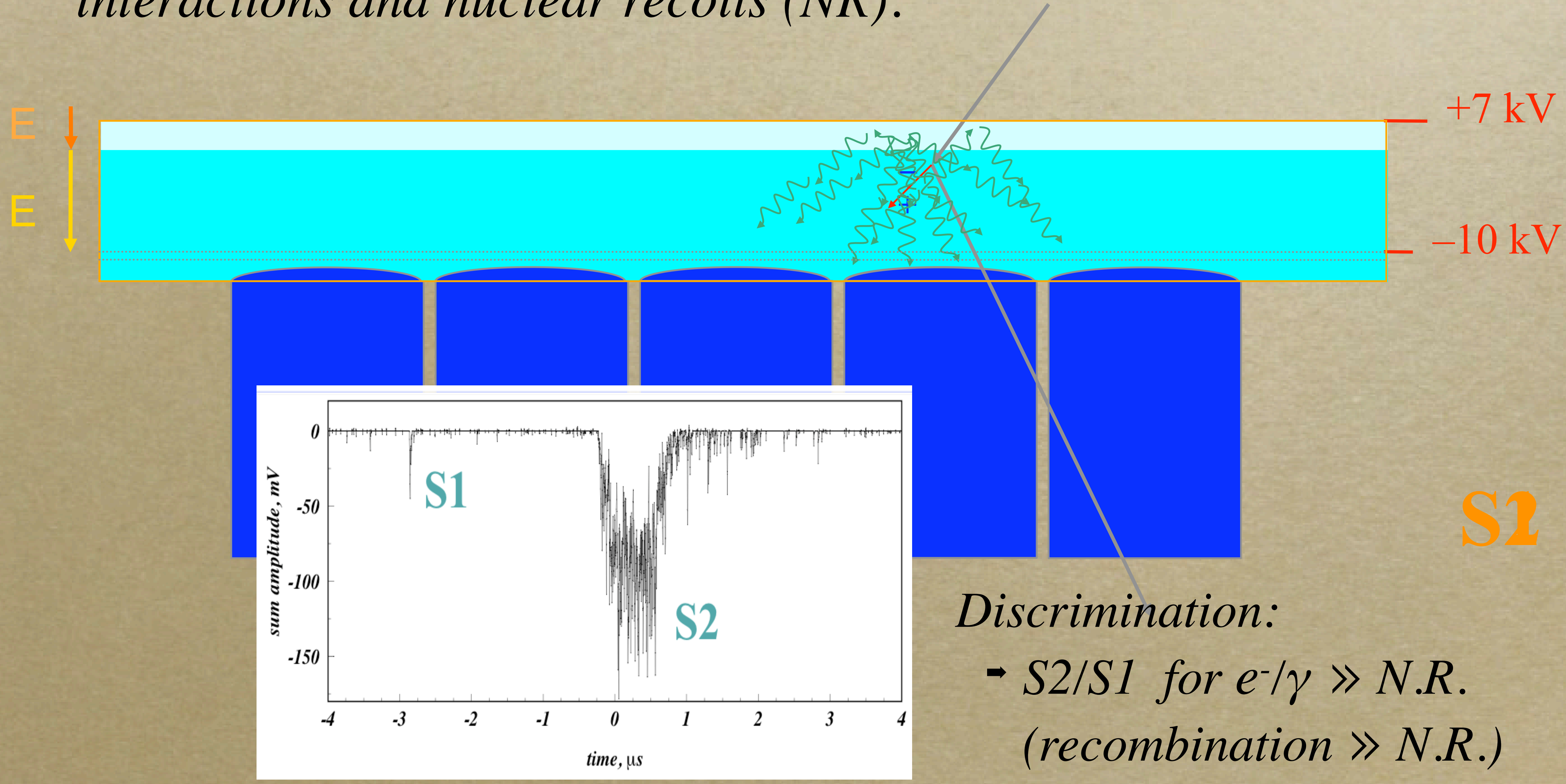




- *So we need detectors…*
  - *with large target masses*
  - *very low threshold*
  - *built from radio-pure materials*
  - *shielded from external radiation*
  - *some discrimination technique between nuclear and e^- recoils*
  - *operate in deep underground laboratories*

Two-phase xenon

- *Interactions in LXe produce scintillation (S1) and ionisation (S2).*
- *The S2/S1 ratio provides the discrimination between e^-/γ interactions and nuclear recoils (NR).*

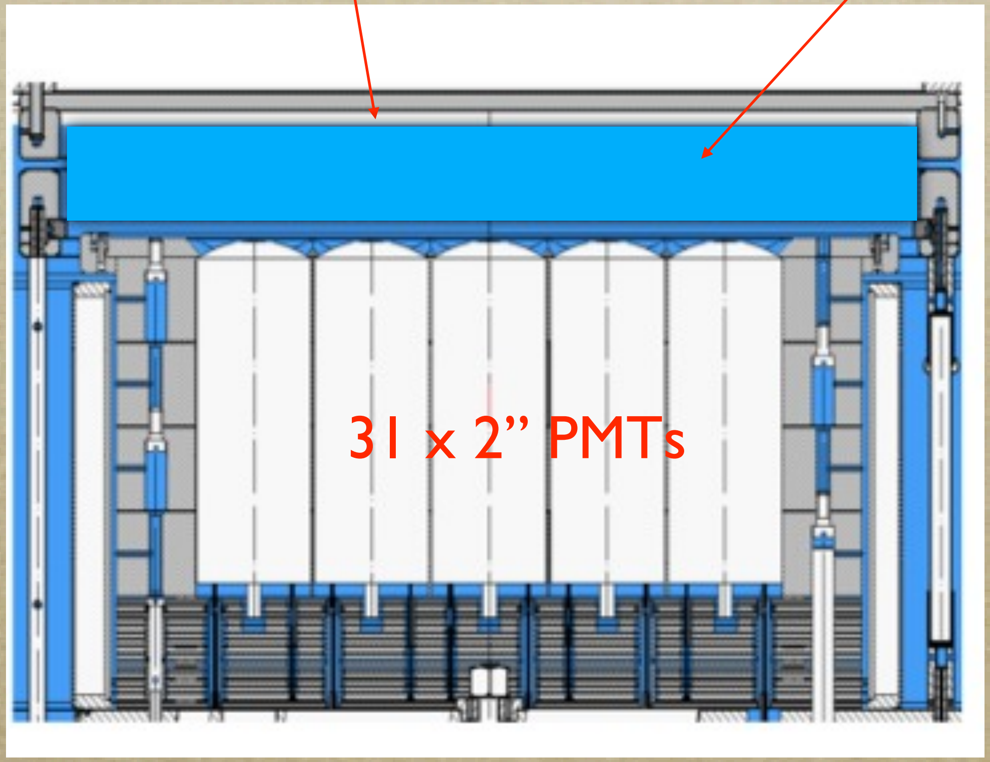


Discrimination:

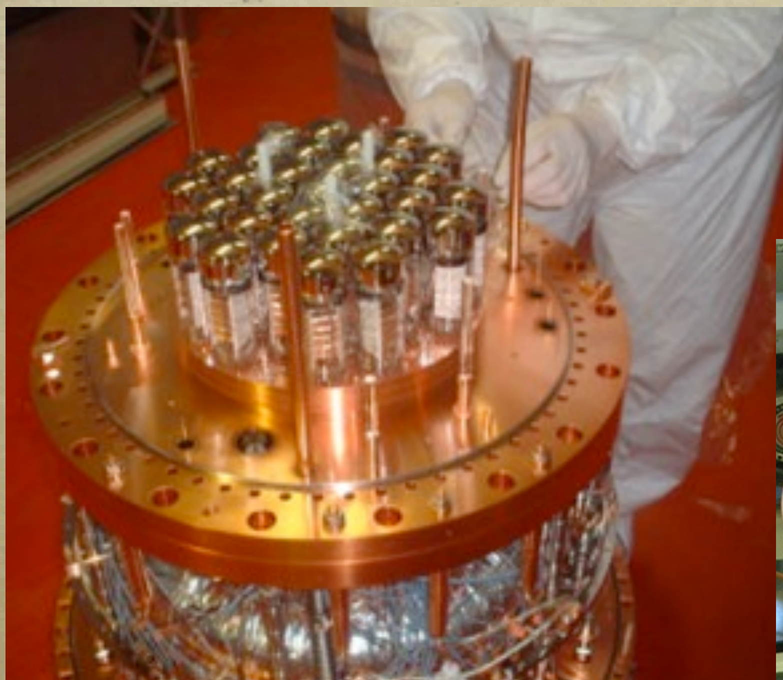
- *S2/S1 for e^-/γ » N.R.*
  (recombination » N.R.)

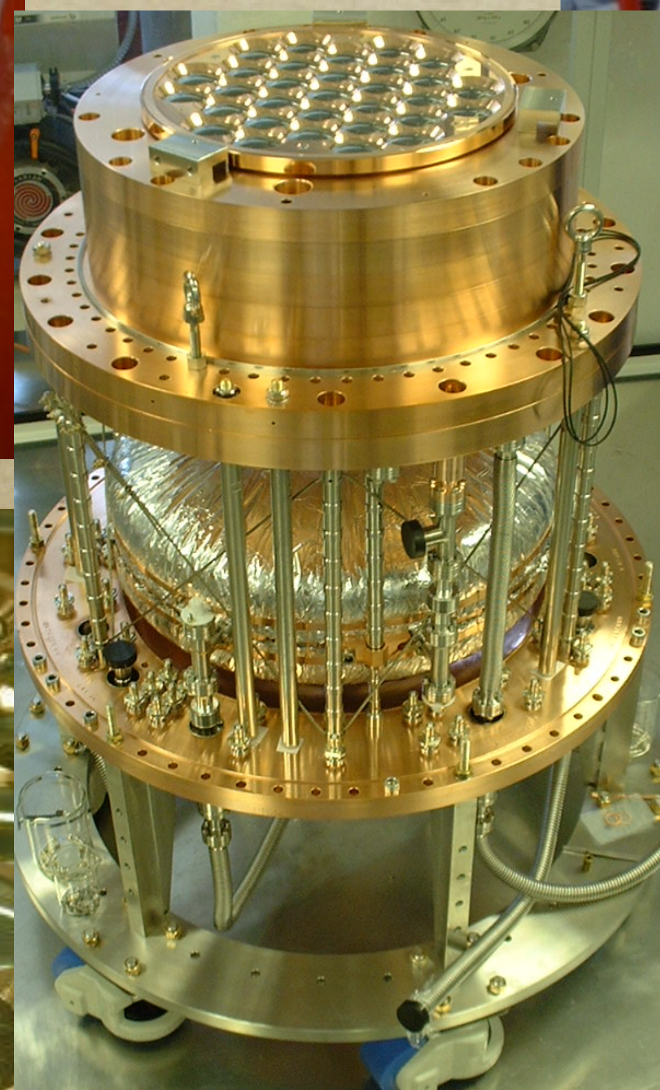
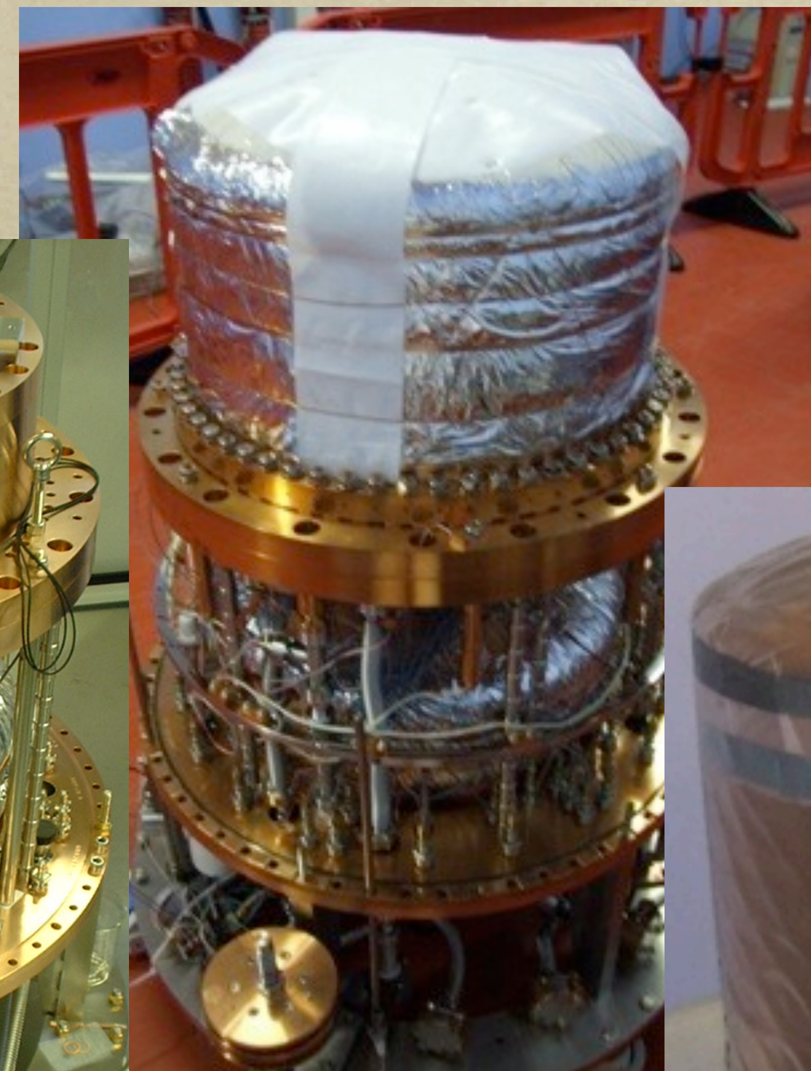
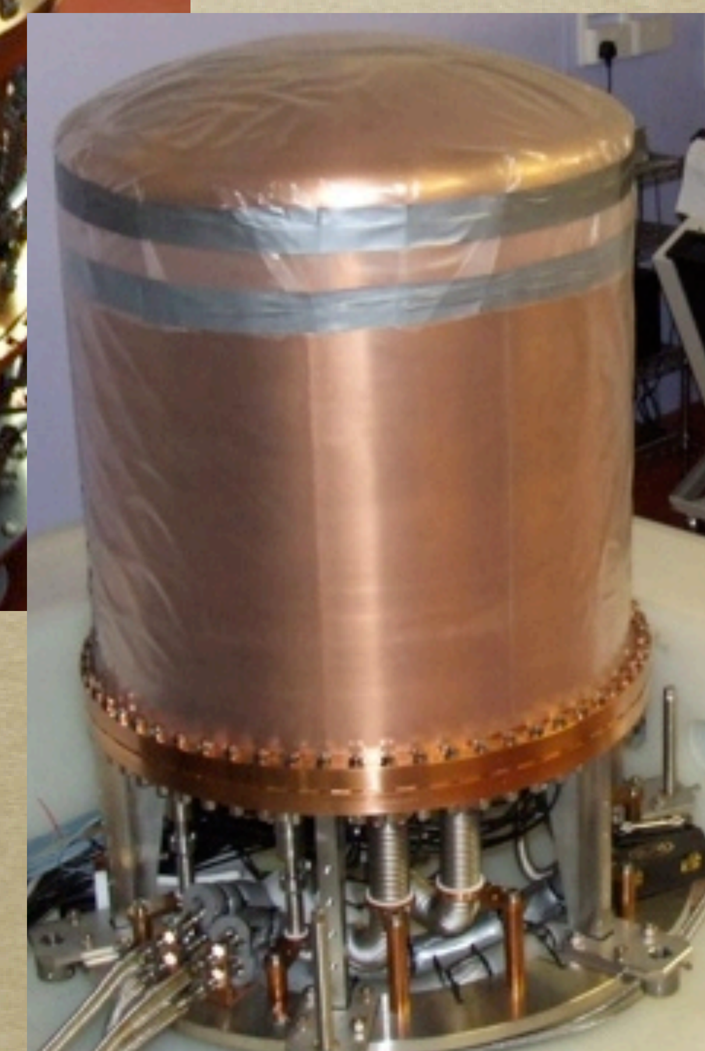
ZEPLIN-III: Design

- *Active volume with 12 kg of low background LXe (40 yr old - low Kr)*
- *Open plan with no surfaces (fiducial volume from position reconstruction)*
- *High field, improved discrimination*
- *Construction in oxygen free Cu (electron beam welded)*
- *31 2" PMTs (QE ~ 30%) in the liquid:*
    - *improved primary light collection*
    - *fine position sensitivity*



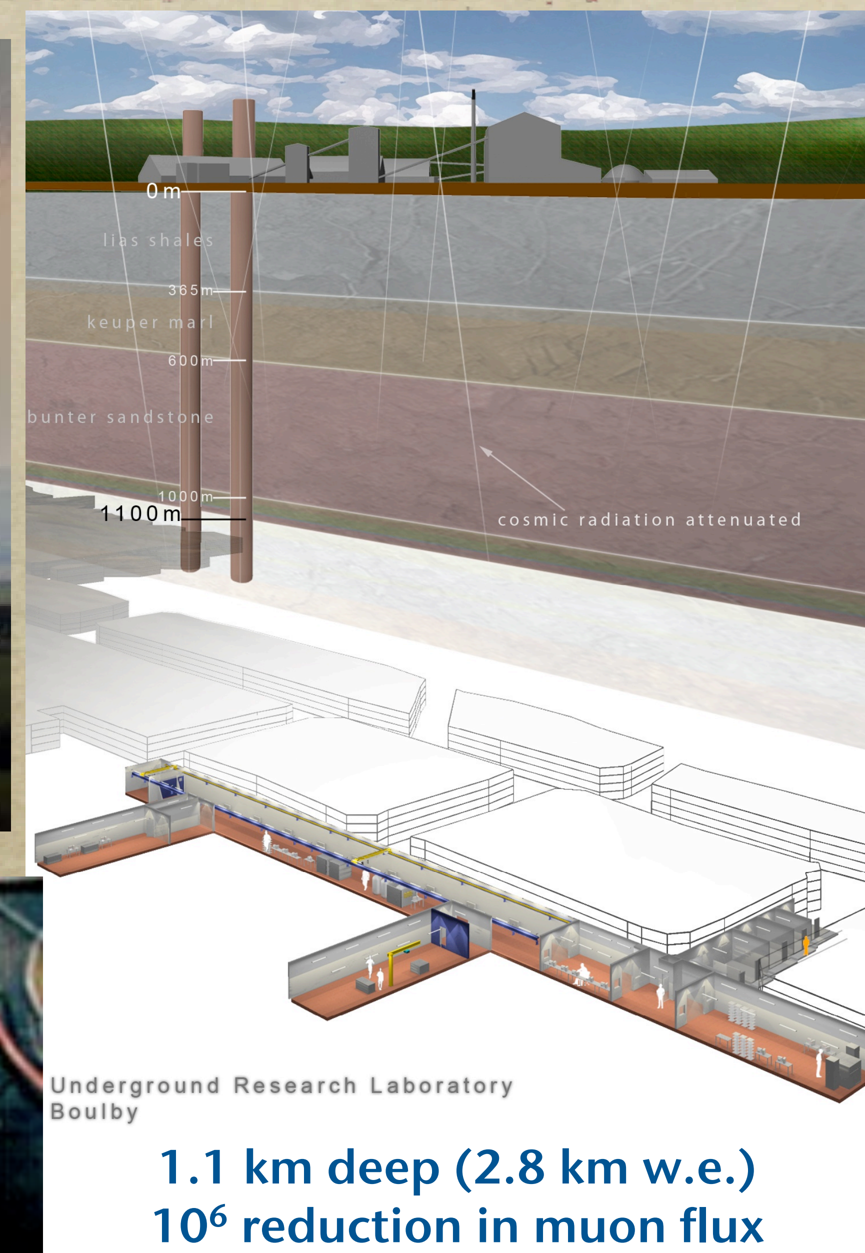
ZEPLIN-III: Assembling



Boulby Underground Lab

- *Located in the NE of England, in a working salt and potash mine*



ZEPLIN-III: Deployment at Boulby

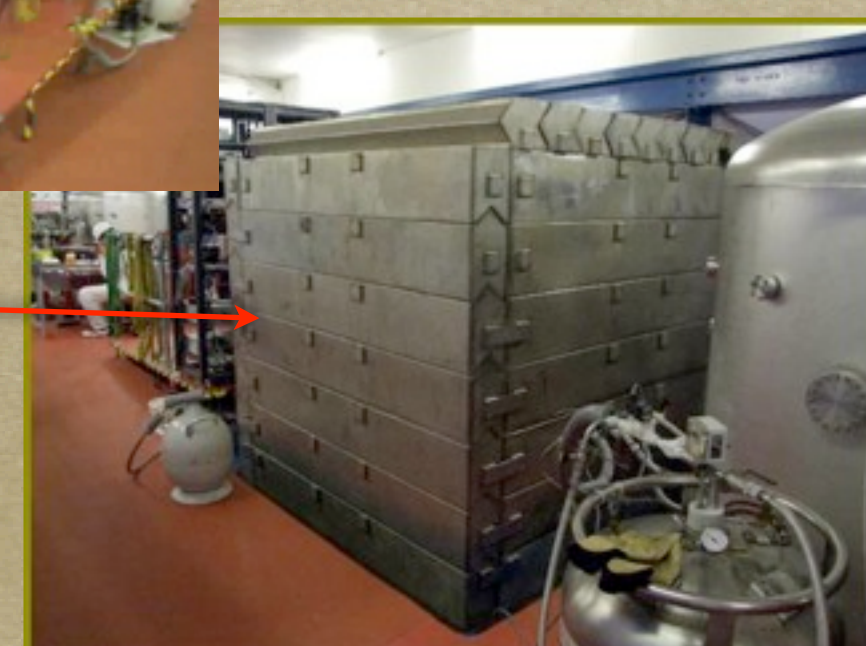
Xenon safety dumps

Detector access points

Vacuum, purification and
re -circulation systems

Data acquisition and
electronic systems

Steel encased 20 cm Pb
gamma ray shielding



30 cm Polypropylene
neutron shielding

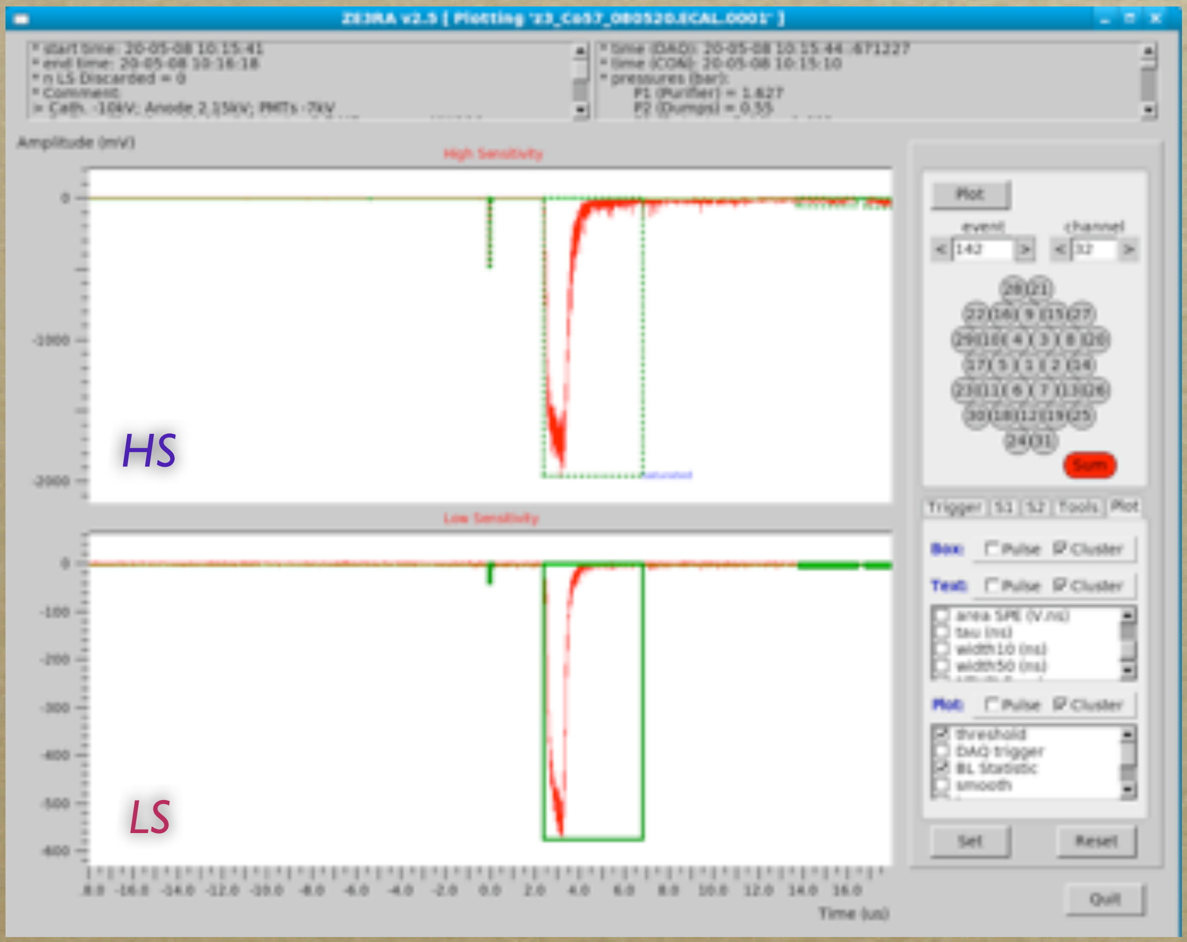
First Science Run

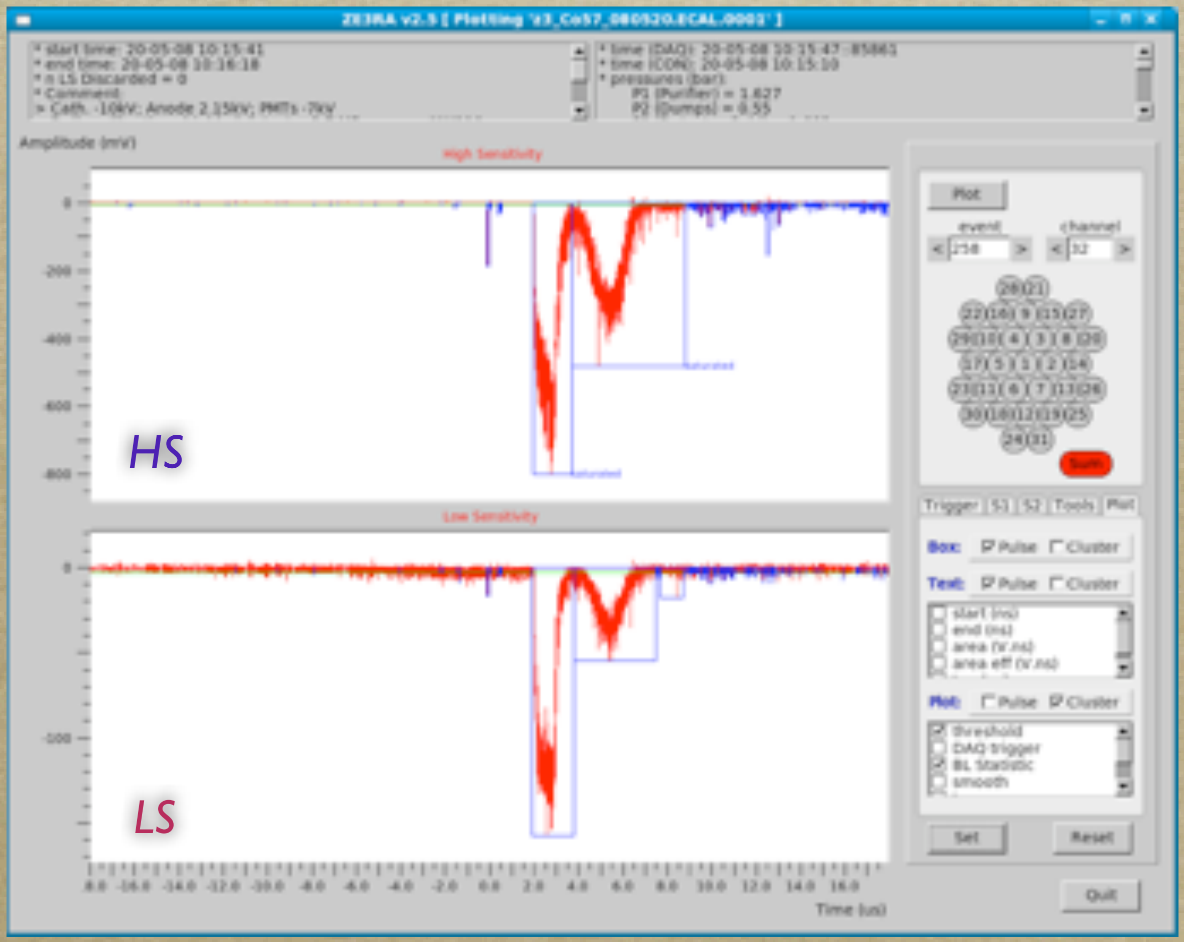
- *83 days @ 84% live time*
- *847 kg.days raw data*
- *Fully shielded*
  (10^5 attenuation for rock γ and n)

- *Daily calibration with ^{57}Co*
- *Two ^{137}Cs calibrations*
  (start and end of run)
- *Two AmBe calibrations*
  (start and end of run, each 5h long)

Data acquisition and processing

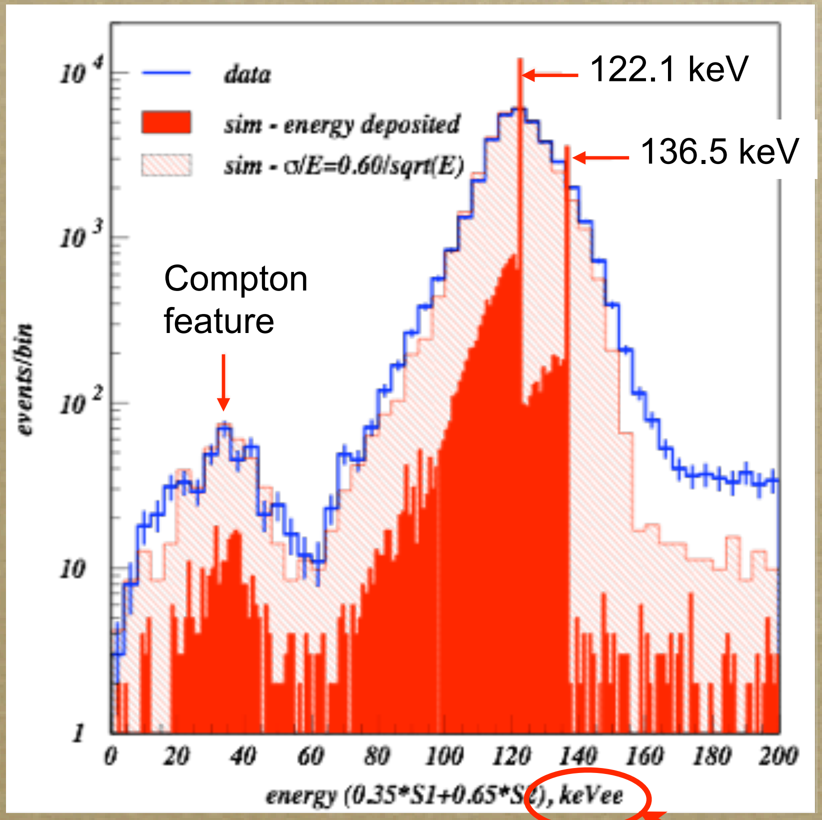
- *62 waveforms acquired in 36 μs timelines*
  (31 PMTs in dual range)
- *Waveforms processed using ZE3RA (ZEPLIN 3 Reduction and Analysis)*

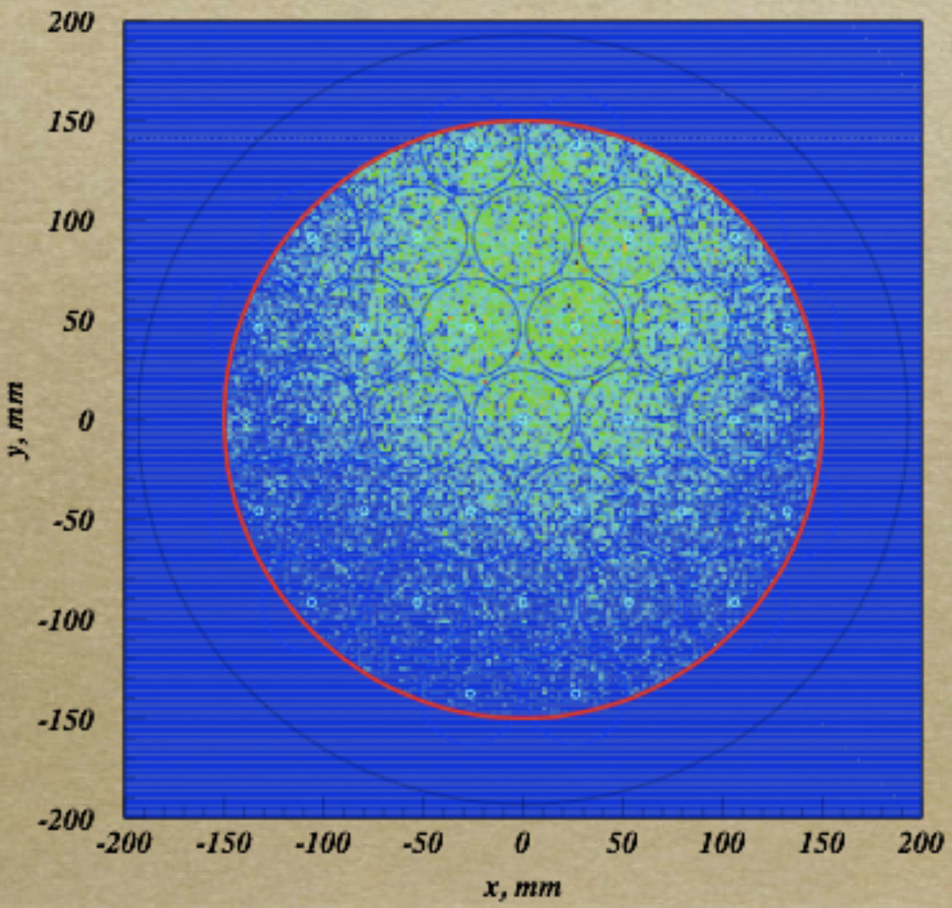




Daily ^{57}Co calibration

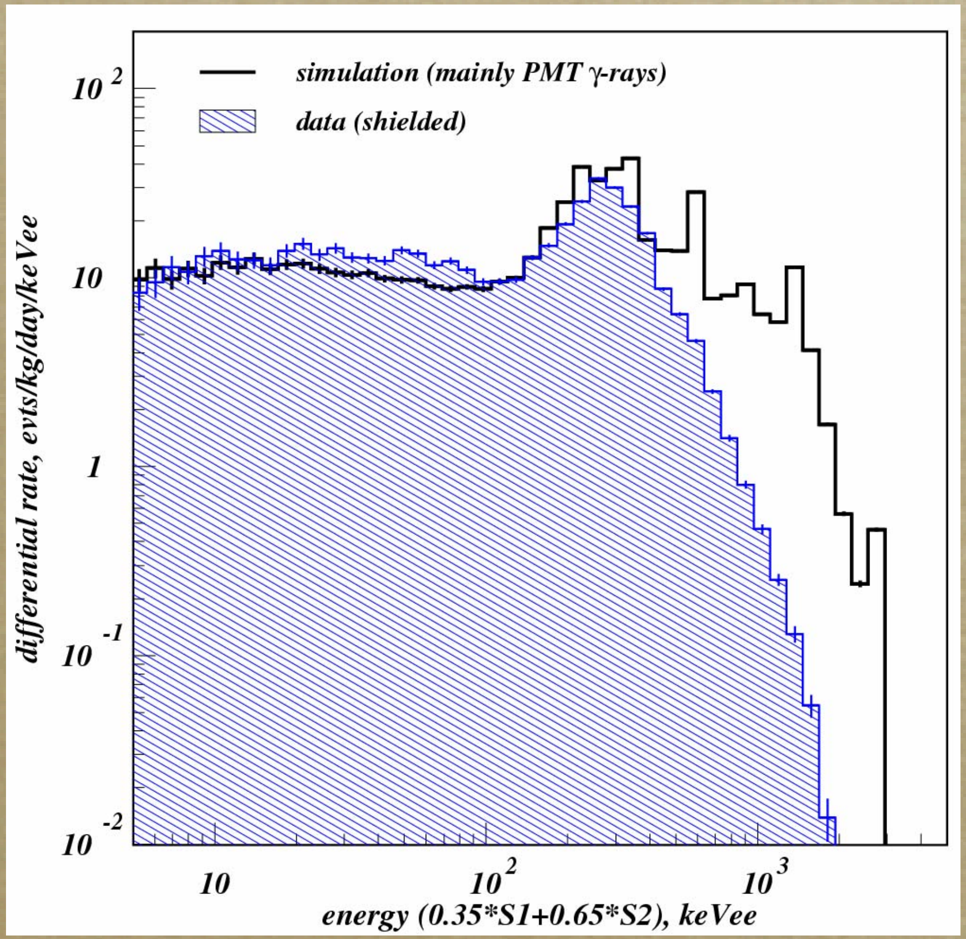
- *Performed daily for stability checks and scintillation response*
- *1.8 pe/keVee @ 3.9 kV/cm (5 pe/keVee @ 0-field)*
- *σ = 5.4% resolution @ 122 keV (using S1-S2 anti-correlation)*
  - *σ = 16.3% if using S1 only, 8.8% if using S2 only*
- *Position reconstruction: (x,y) from LS algorithm (σ ~ a few mm),*
  z from (S2-S1) time difference (σ ~ 0.1 mm)

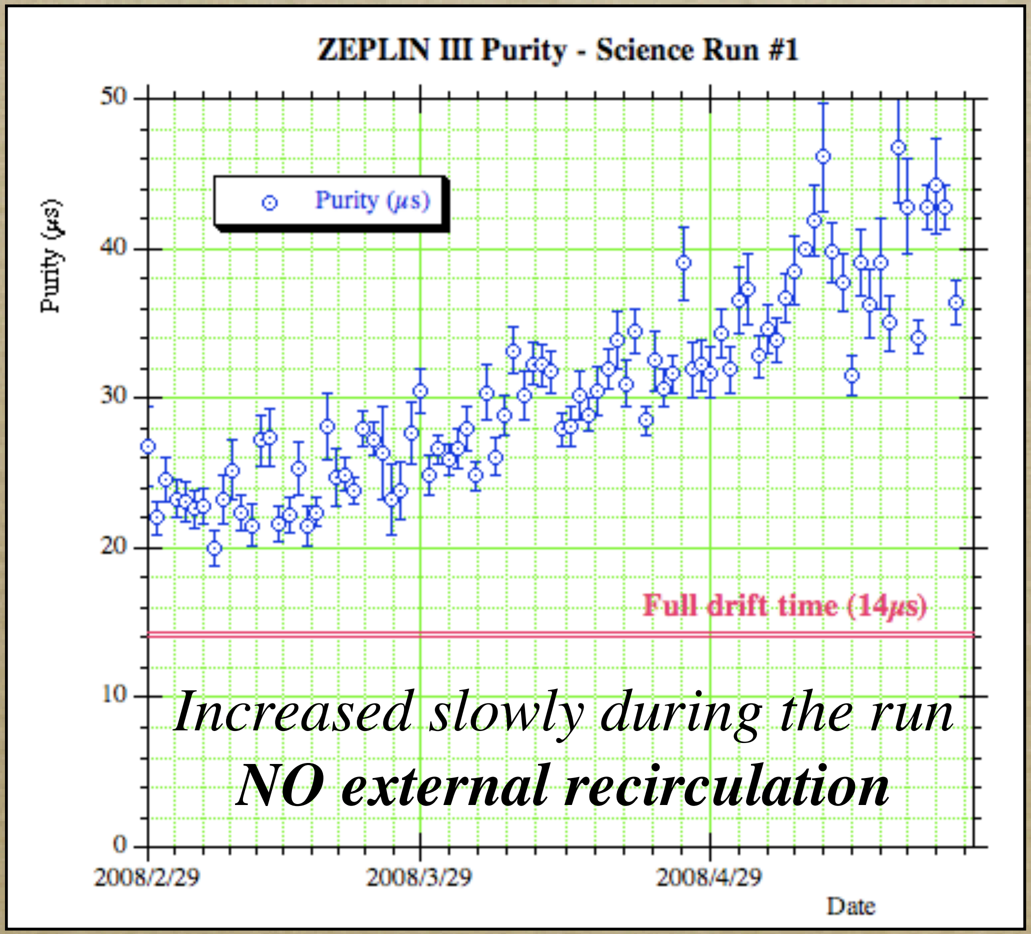




Daily quality checks

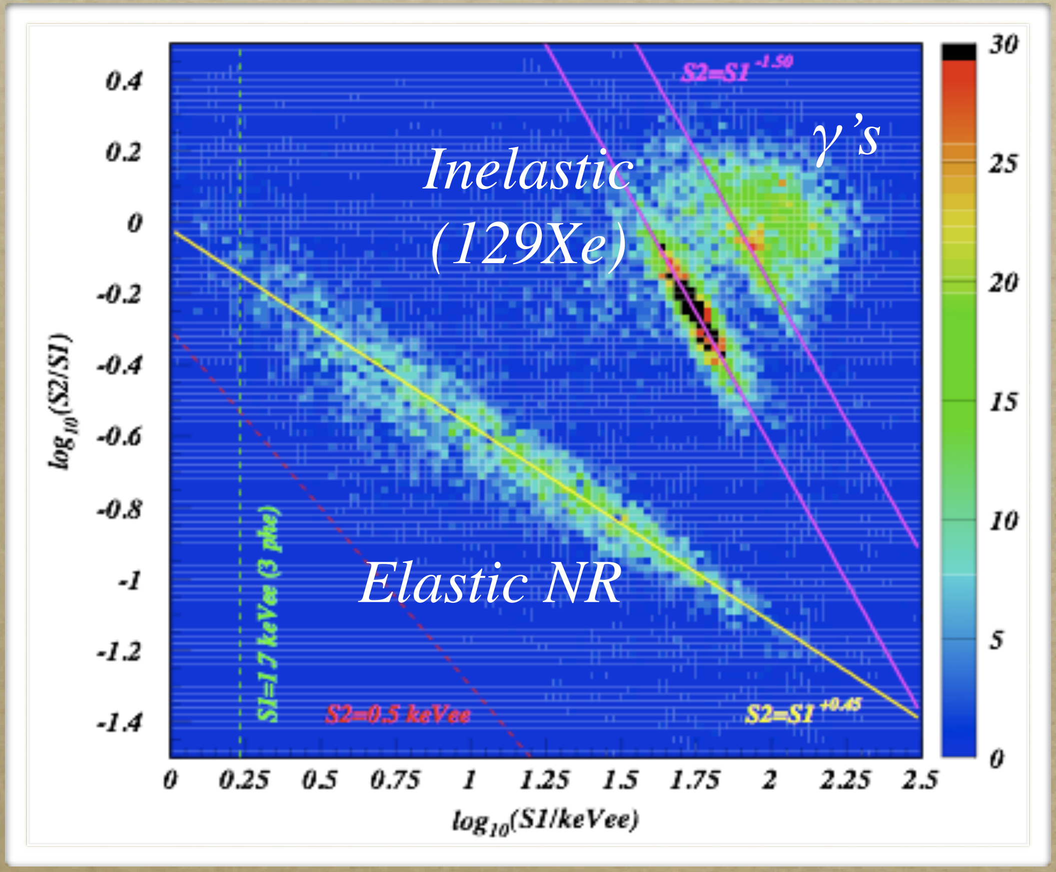
- *Light and ionisation yields*
- *Detector tilt (unstable floor in the lab cave)*
- *Low-energy gamma background*
- *Mean electron lifetime in the liquid (purity)*

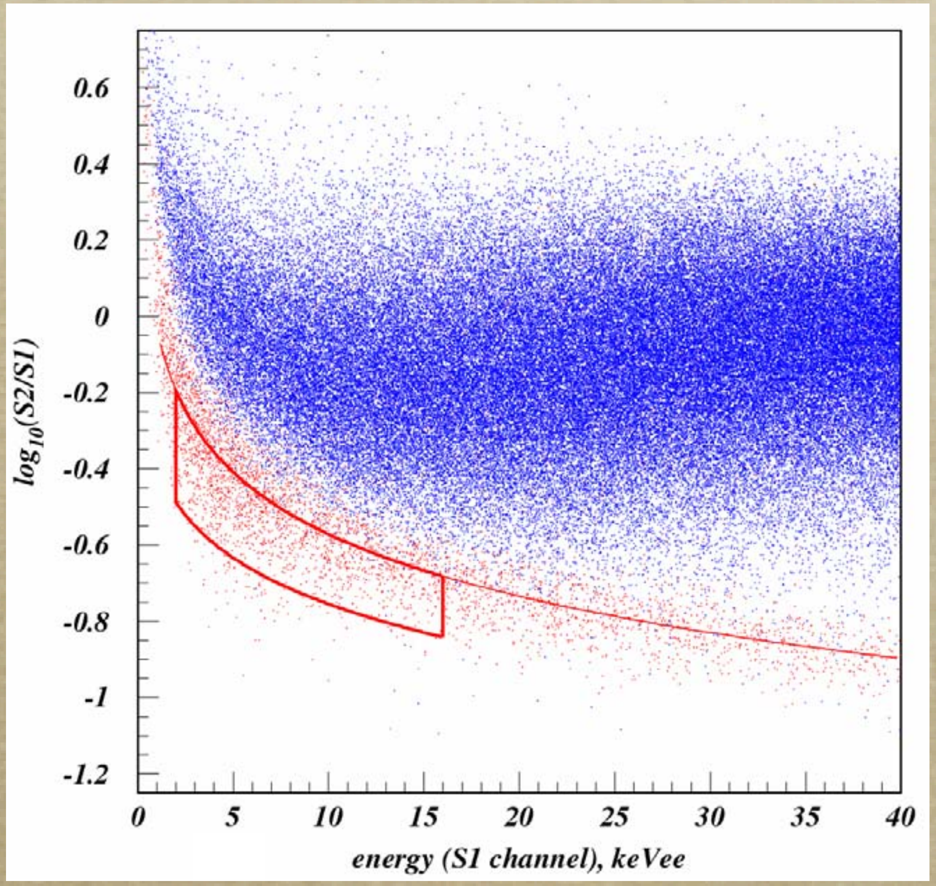




Neutron and Compton calibration

- *Compton scattering from ^{137}Cs γs used to populate the low-energy e^- recoil region.*
- *Neutron calibration with AmBe source to simulate response to WIMPs.*





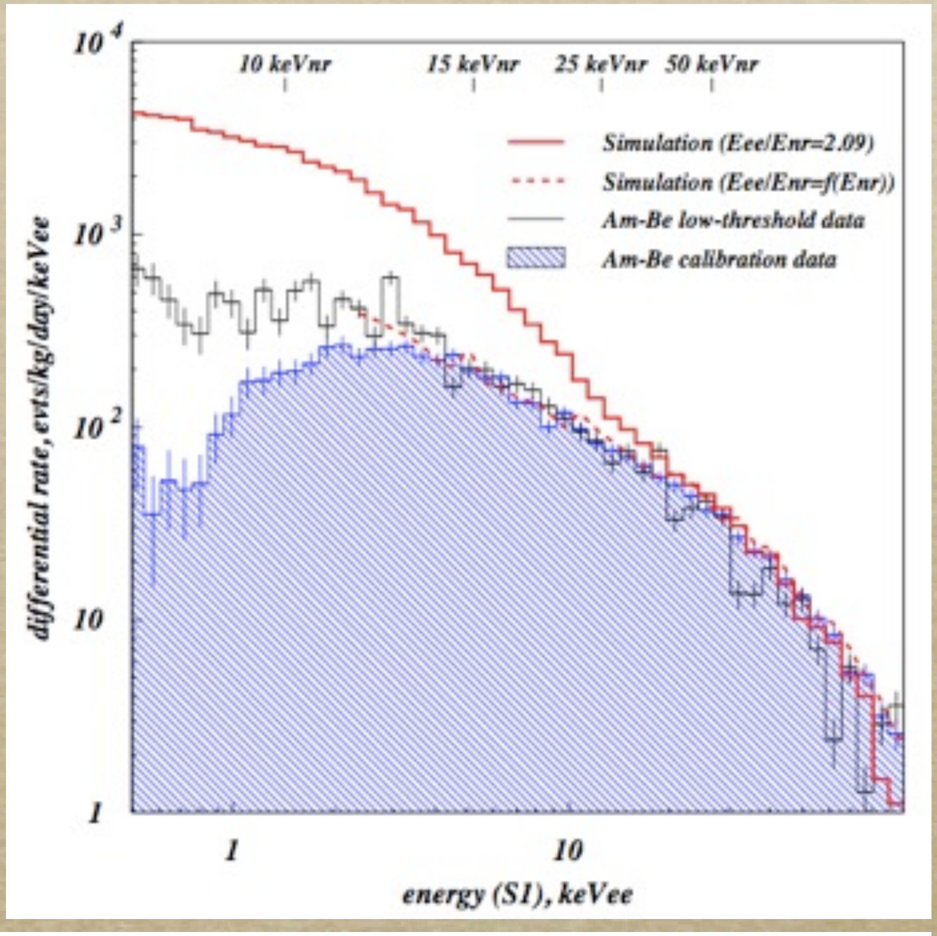
- *WIMP search box: 2 to 16 keVee, μ to μ-2σ of the NR population (~50% of recoils)*
- *1:5000 γ/neutron discrimination at high field*

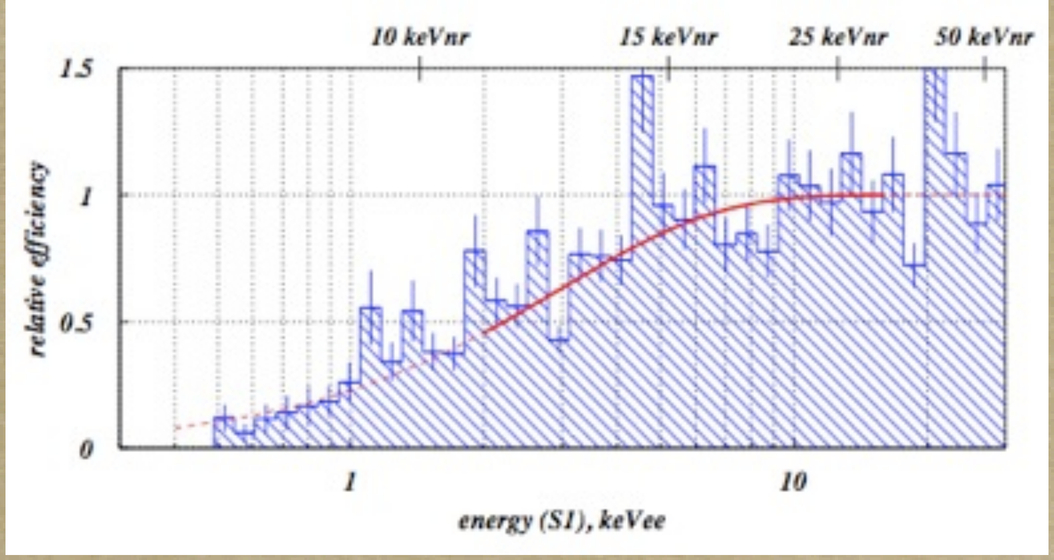
Energy conversion & efficiencies

- *Conversion of energy scale from electron equivalent to nuclear recoil:*

$$E_{nr} = \frac{S1}{L_y}\frac{S_e}{L_{eff}S_n} = E_{ee}\frac{S_e}{L_{eff}S_n}$$

- *Mis-match observed between NR calibration (AmBe) and the GEANT4 simulation.*
- *Efficiencies calculated using a variety of sources* *(data scanning, calculations, hardware tests)*
- *Simulations thoroughly tested* *(model validation and alternative MCs)*
- *Variation of $L_{eff}\times S_n$ with energy below ~6 keVee was determined by matching the simulation to the AmBe spectrum. Recent measurements of L_{eff} also show dip at lower energies.*
- *Effective threshold (3-fold S1 coincidence) at 1.7 keVee*

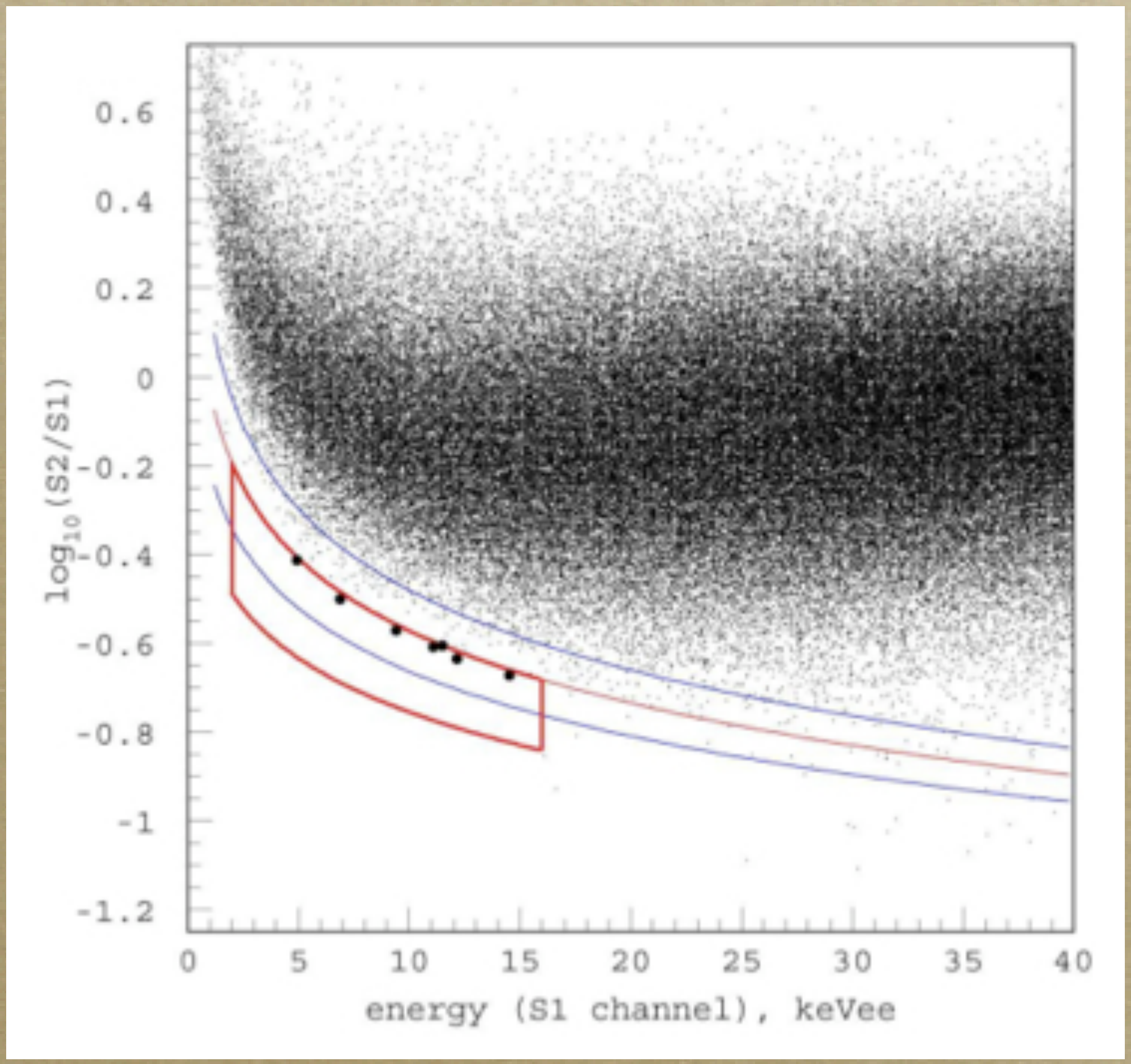


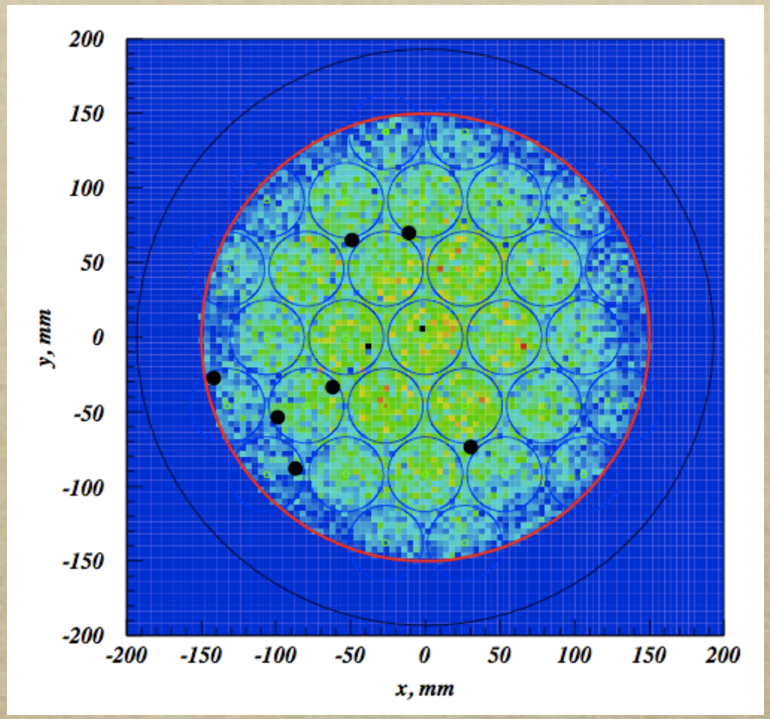


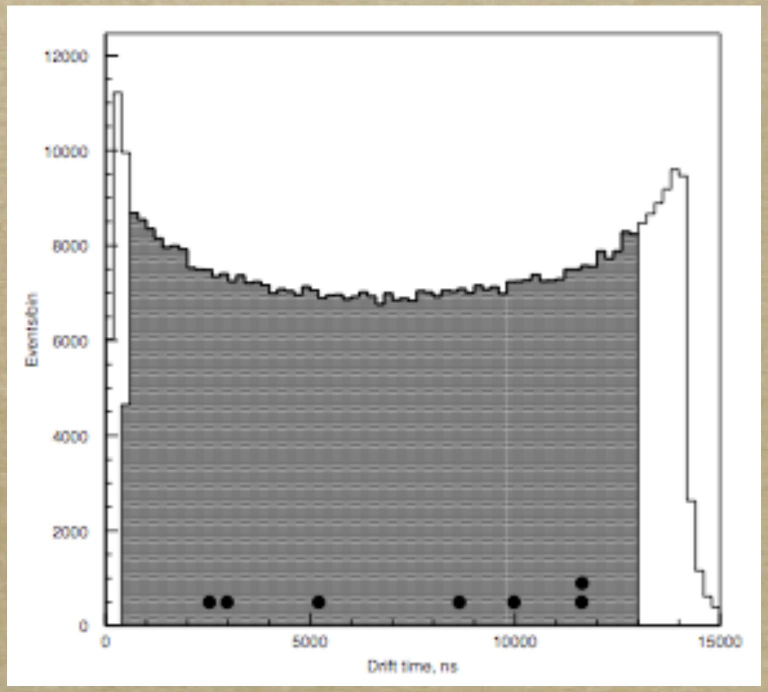
Science data

- *7 events seen in WIMP search box*
- *Equivalent exposure of 126.7 kg.days after all cuts*

  (fiducial volume, DAQ dead time, NR acceptance, analysis cuts, etc.)



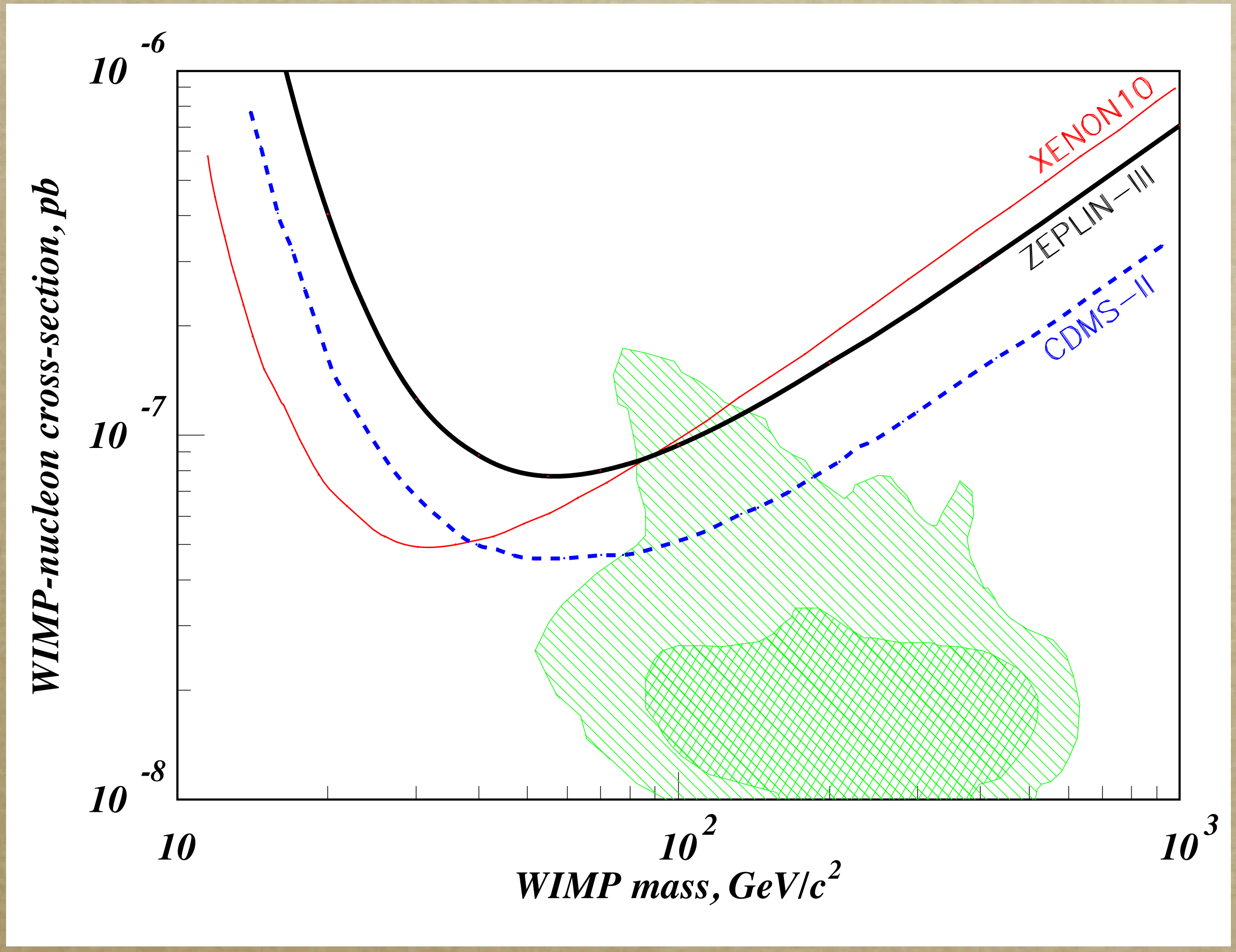




Limits on WIMP cross section

- *90% c.l. upper limit of 3.05 events*
- *Using the 'canonical' halo model:*

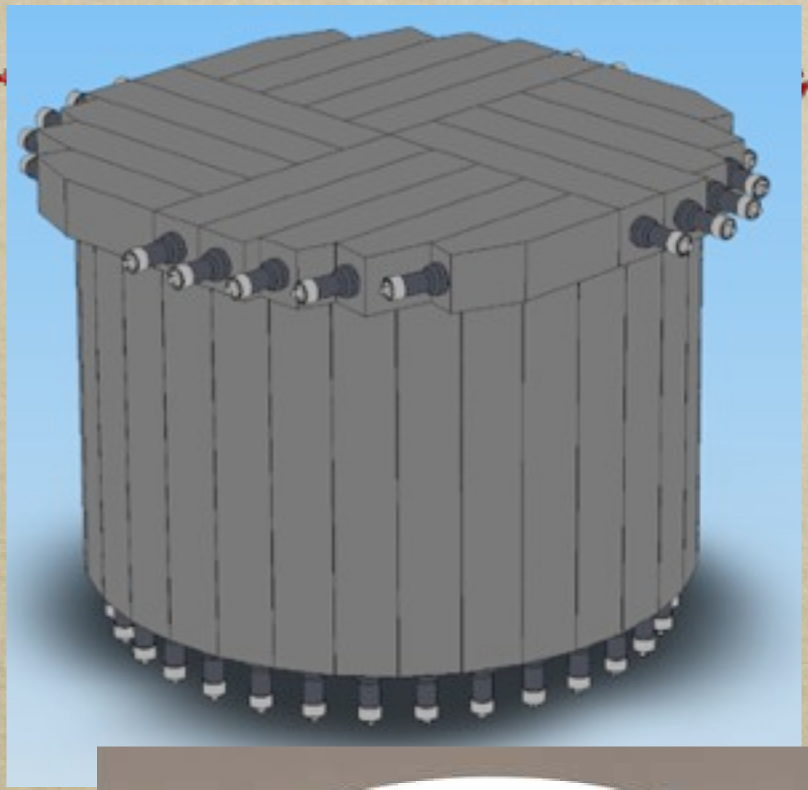
  $\varrho_{DM} = 0.3$ GeV/cm^3; $v_0 = 220$ km/s; $v_{esc} = 600$ km/s; $v_{earth} = 232$ km/s
- *Minimum of 8.1×10^{-8} pb for a WIMP mass of 60 GeV/c^2*

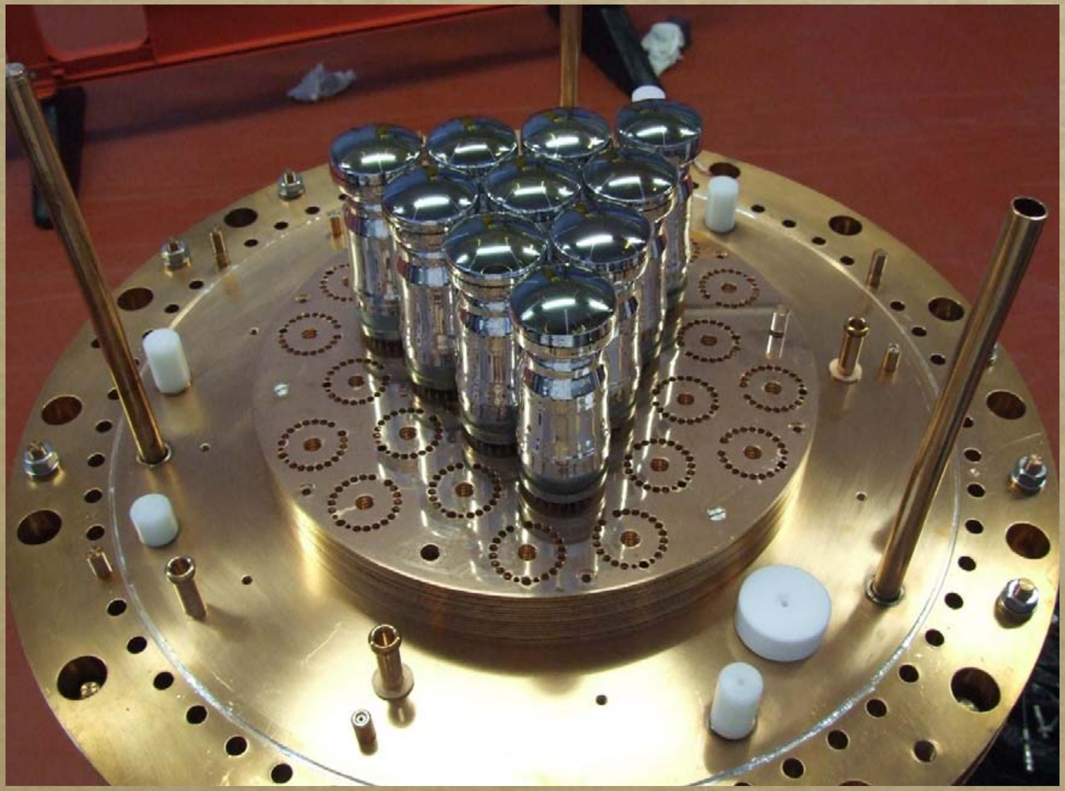


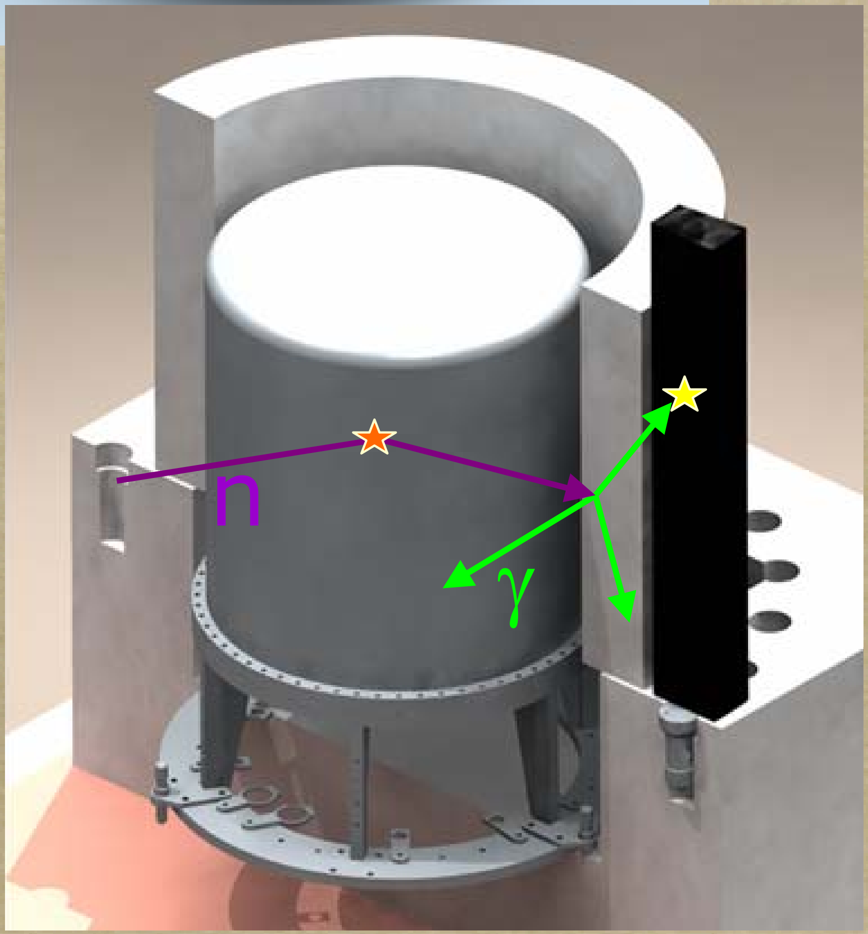
Lebedenko et al., arXiv:0812.1150, PRD (accepted)

Second science run - upgrades

- *Lower background PMTs (×30 lower)*
  (major source of background in FSR)
- *Active veto system*
  (remove neutron and γ events in coincidence)
- *Fully automated daily operations*
  (improved duty cycle)
- *SSR to start next month*

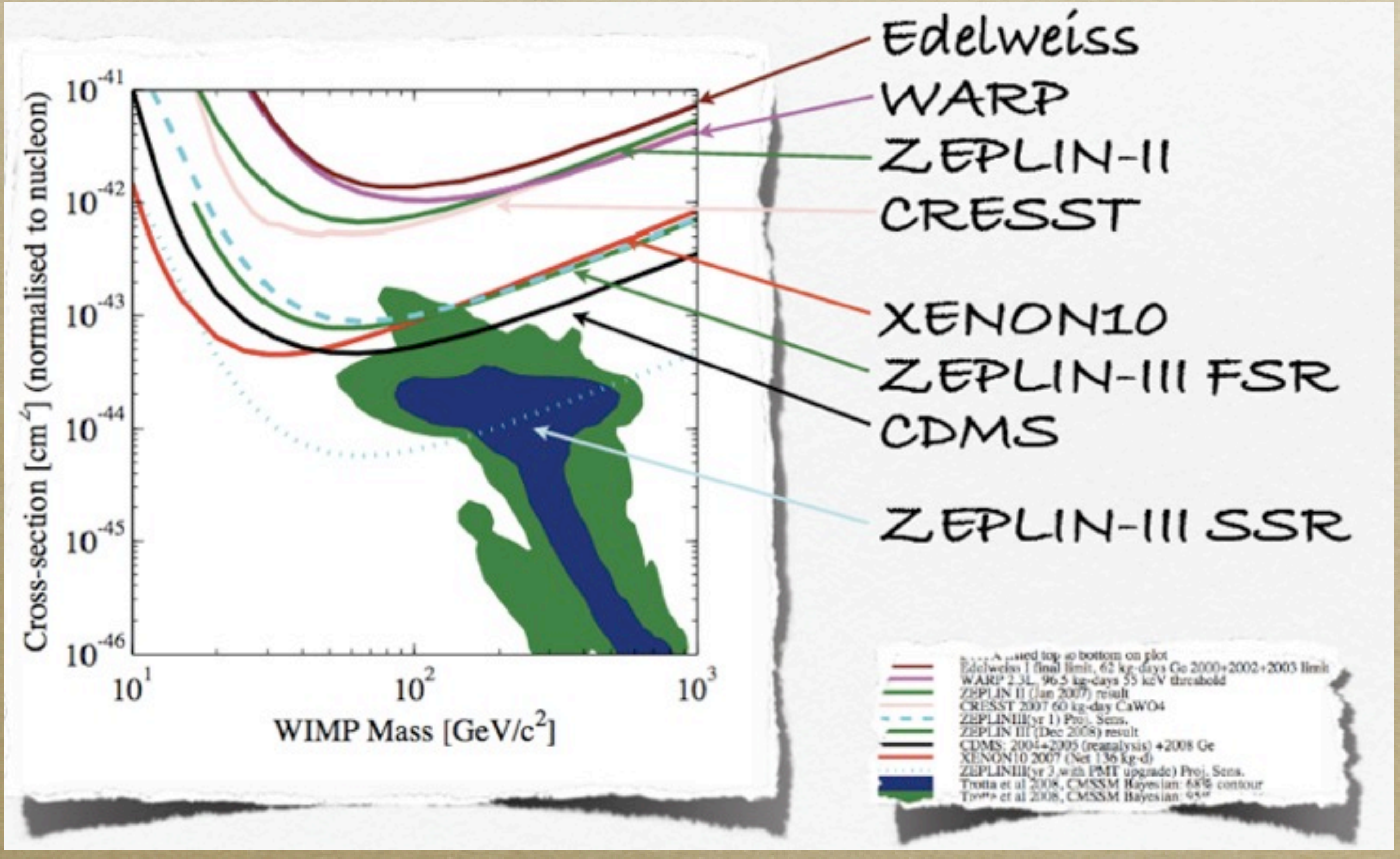






Second science run - sensitivity

- *Improvement in sensitivity by one order of magnitude after 1 year of continuous operation (~10^{-9} pb)*



Summary

- *First science run completed:*
  - *Long term stable operation (at high E-field) demonstrated*
  - *Excellent electron/nuclear recoil discrimination (>1:5000)*
  - *Effective threshold of 1.7 keVee*
  - *World-level sensitivity ($\sigma_{W\text{-}n} = 8.1\times10^{-8}$ pb)*
- *SSR to start very soon with an upgraded detector*
- *Tenfold sensitivity improvement within reach*

In Memoriam

Vadim Nikolaevitch Lebedenko

1939 - 2008

ZEPLIN-III collaboration