Limits on WIMP nuclear recoils from ZEPLIN-II data

Vitaly A. Kudryavtsev

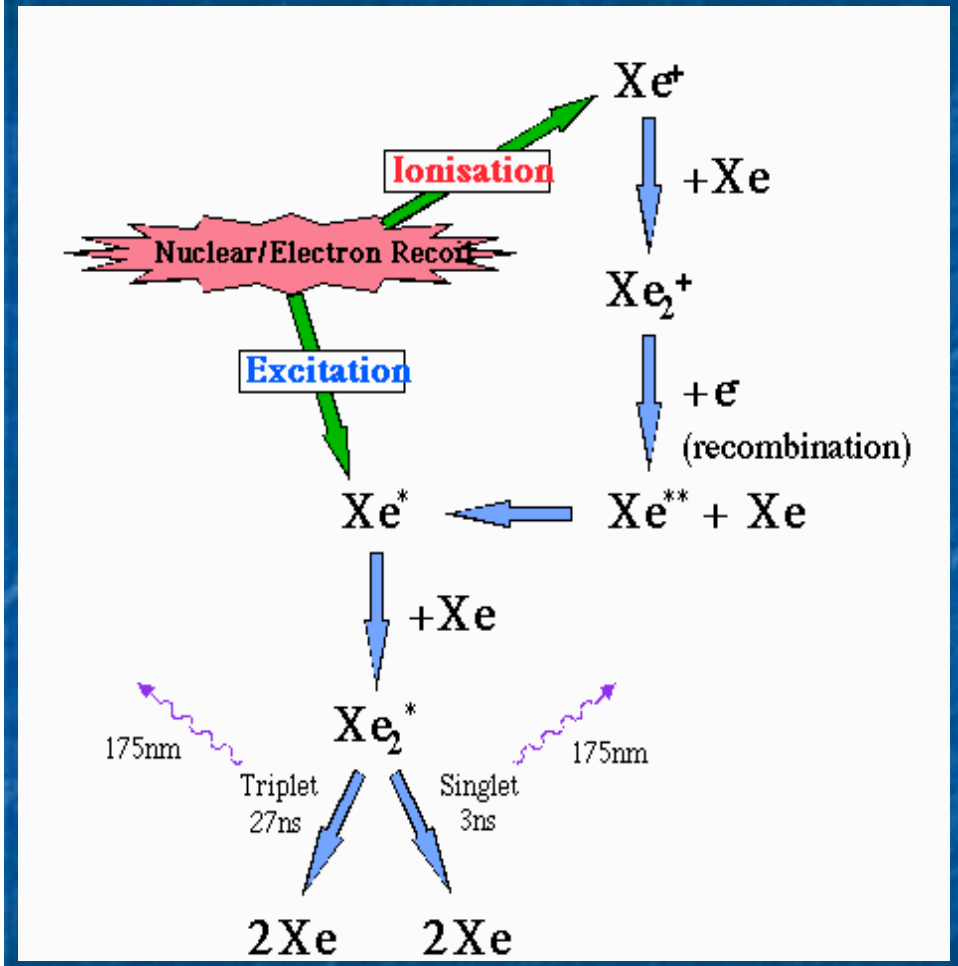
Department of Physics and Astronomy
University of Sheffield

On behalf of
the ZEPLIN-II Collaboration
(University of Edinburgh, Imperial College London, LIP-Coimbra, University of Rochester, STFC - Rutherford Appleton Laboratory, University of Sheffield, Texas A&M University, UCLA)

Outline

- Detection principle.
- ZEPLIN-II detector.
- Event reconstruction.
- Calibrations.
- Data.
- Results.
- Summary.

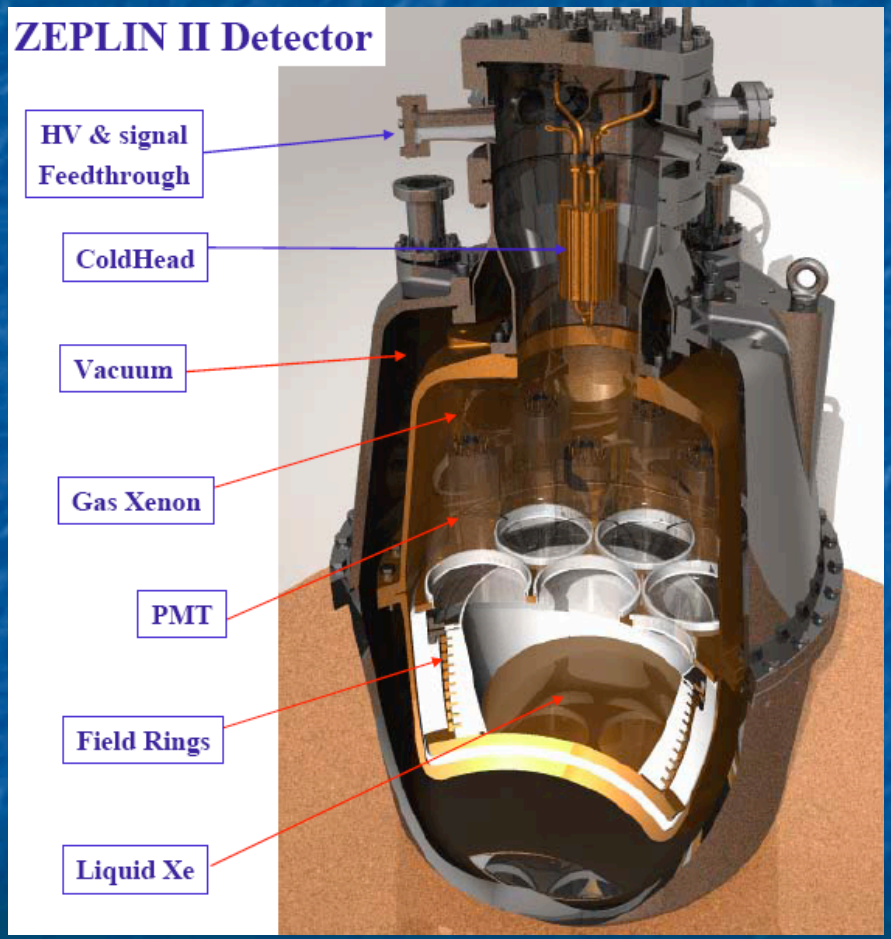
Detection principle



- Excitation
  - production and decay of excited Xe_2^* states: singlet (3 ns - fast component) and triplet (27 ns - slow component) modes -175 nm photons.
  - *dE/dx* -> the ratio of singlet to triplet decays is a few times higher for NR than for ER.
- Ionisation
  - Followed by recombination -> scintillation.
  - Recombination time is smaller for NR than for ER.
  - Electric field suppresses the recombination: the ionisation yield can be directly measured.
  - The ionisation yield is higher for ER than NR (for the same primary scintillation).

ZEPLIN-II detector

Boulby Underground Laboratory, UK; minimal depth 1070 m or 2805 m w.e.



ZEPLIN-II detector

Gd-loaded Paraffin

Cooling and Feed-Through

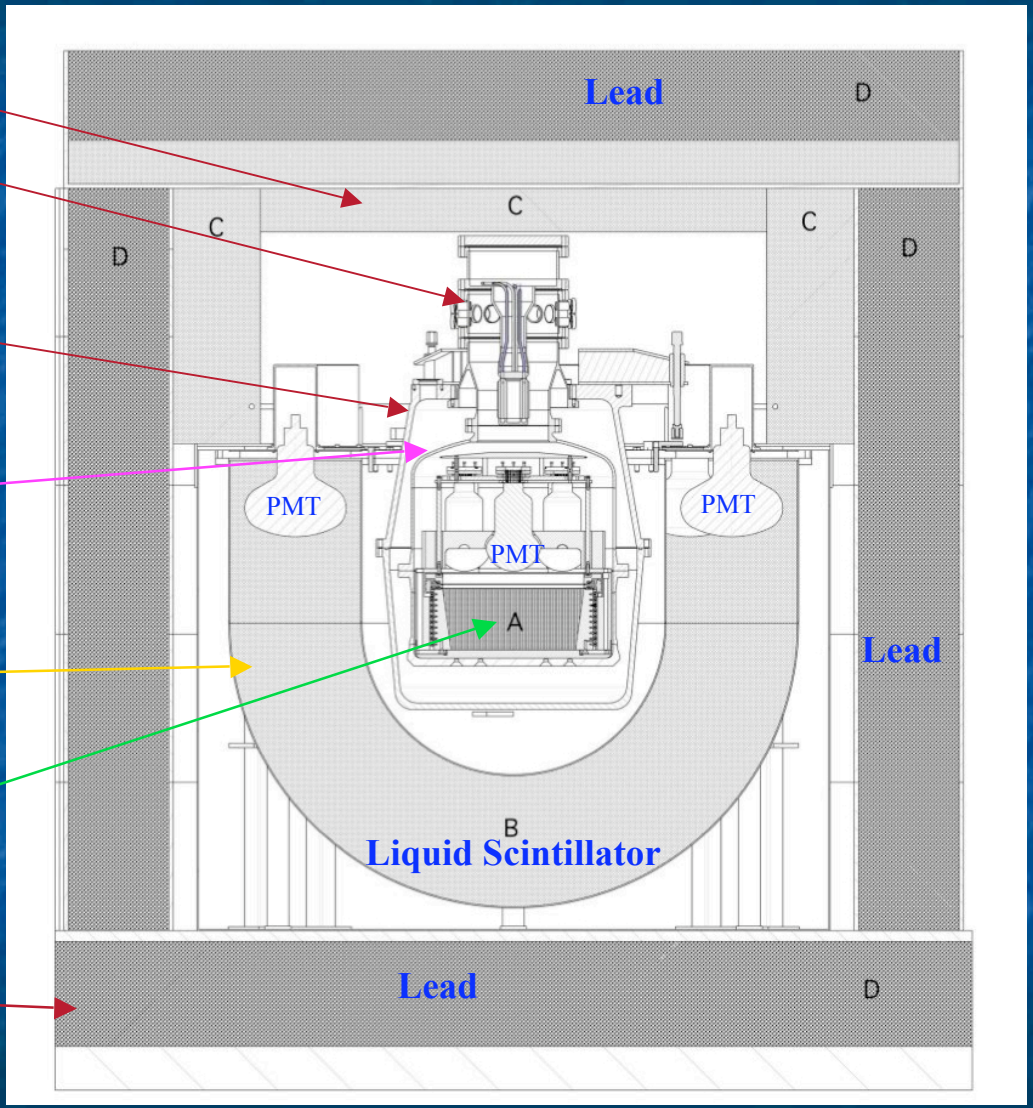
Stainless Steel Vacuum Vessel

50cm diameter Copper Vessel

Active Veto (30cm CH_2)

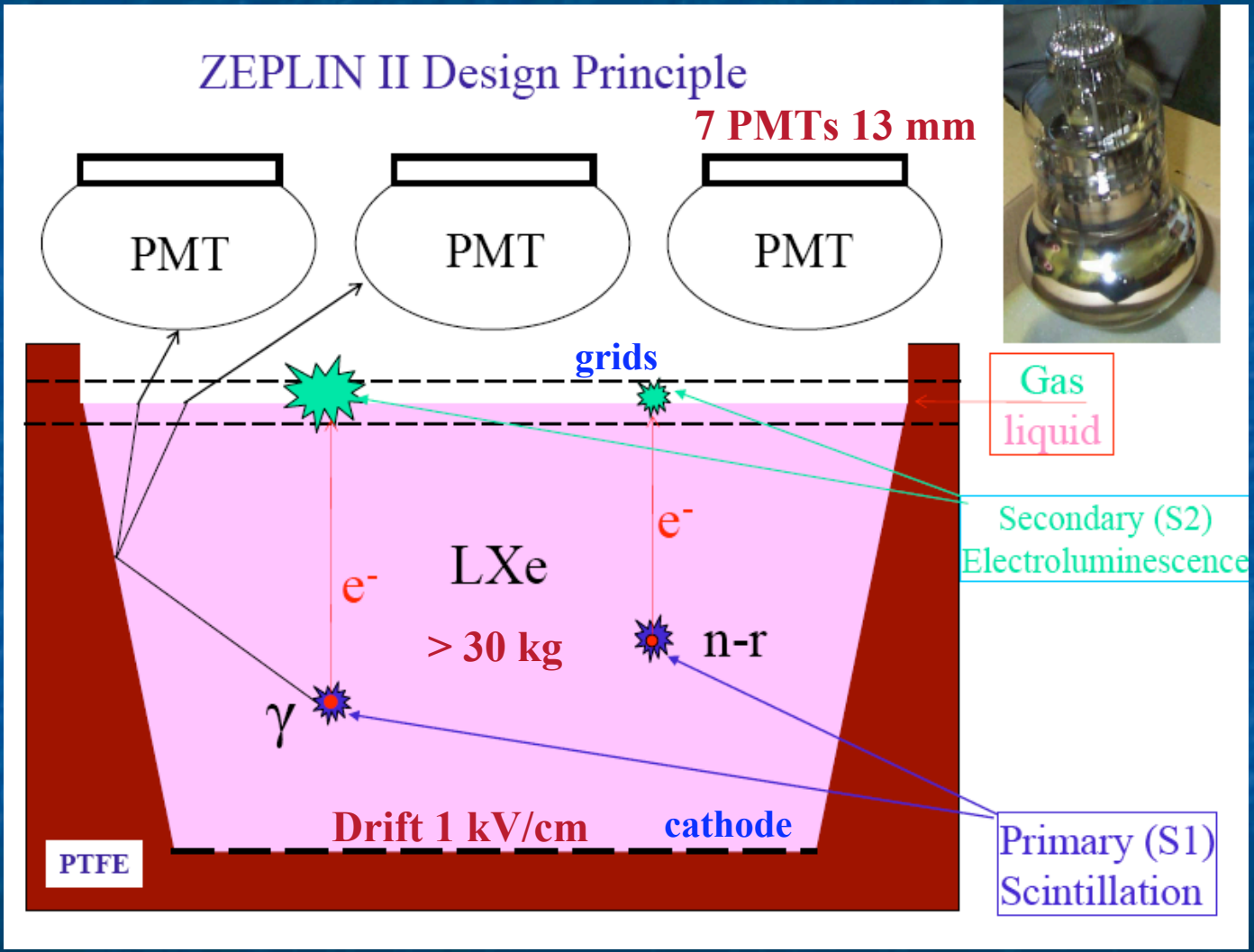
Liquid Xenon (>30 kg) target

Lead Shield (22.5 cm)



ZEPLIN-II detector

Event reconstruction and discrimination



Trigger:

2/5 of a mean photoelectron pulse;

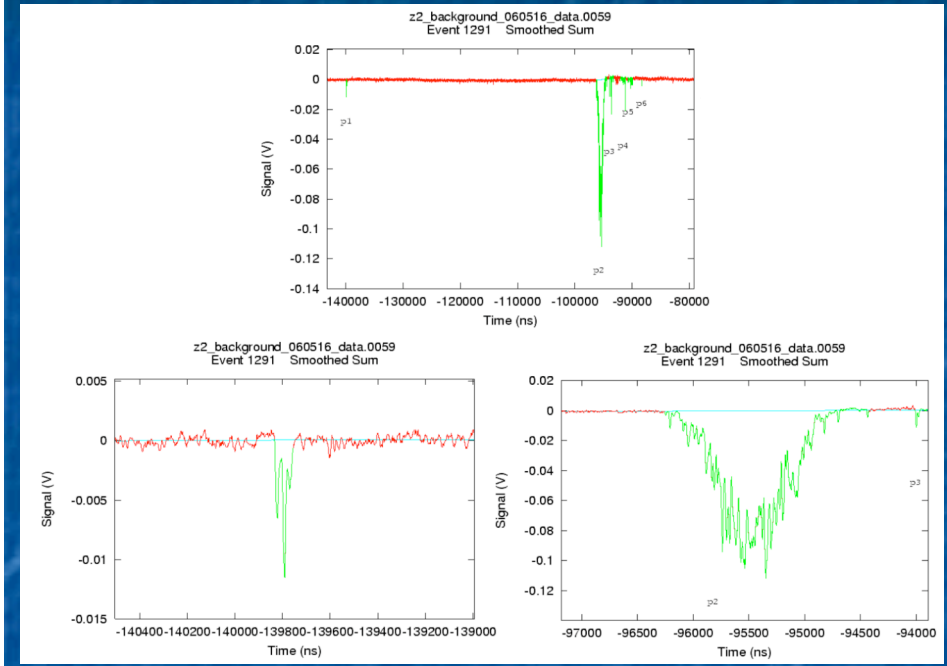
5-fold concidence (at least 5 PMTs);

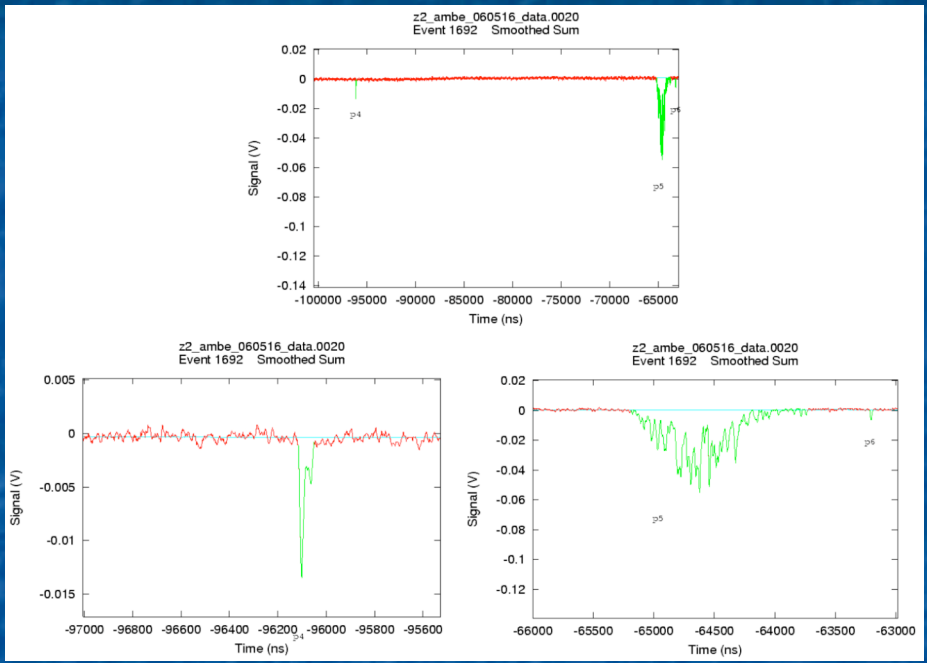
Either primary or secondary;

200 μs digitisation time around the trigger.

Position reconstruction in vertical direction through the delay of S2.

Events





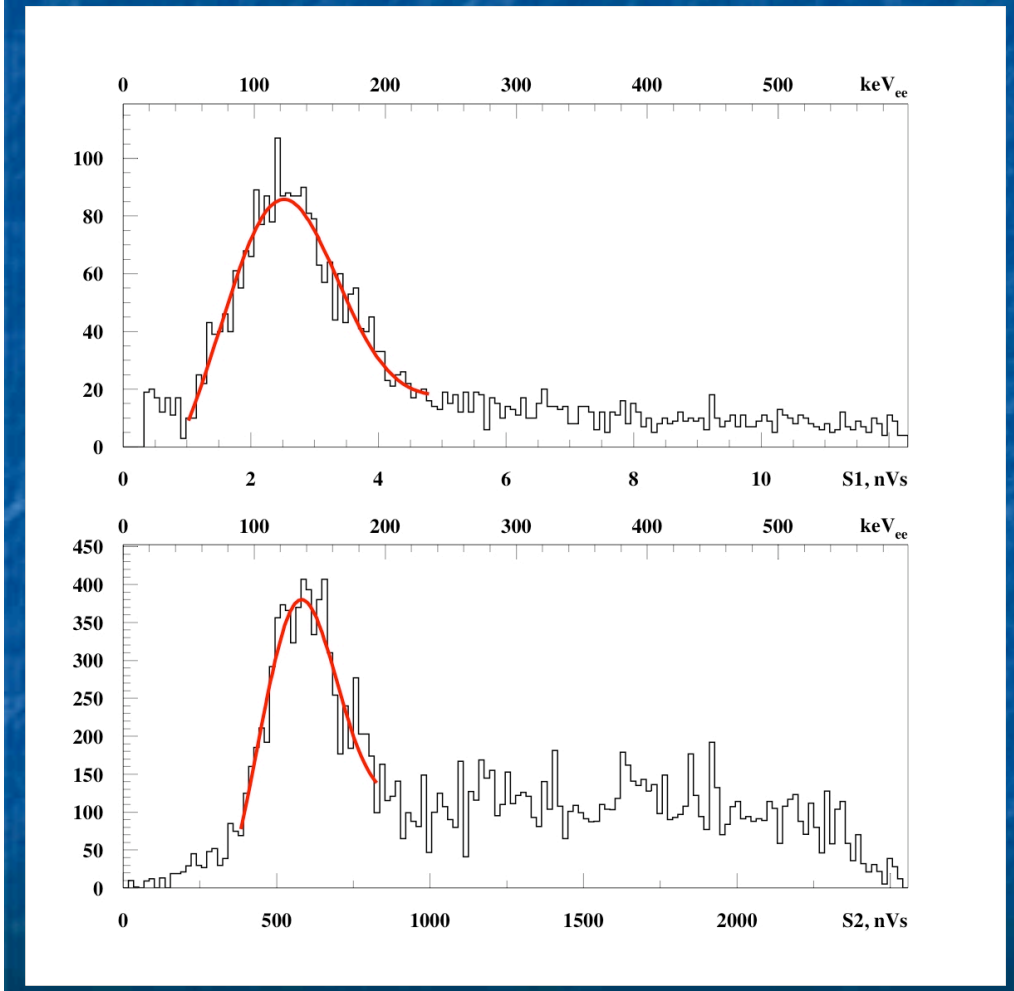
Electron recoil pulse from the dark matter run

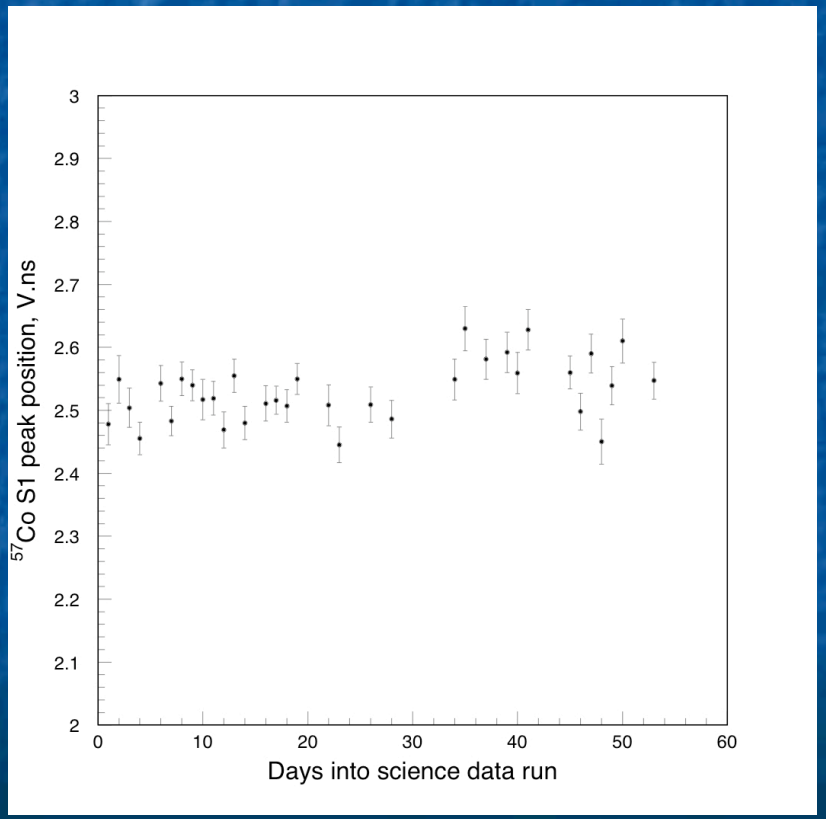
Nuclear recoil pulse from AmBe neutron calibration

S2 is smaller for nuclear recoil event than for electron recoil one.

Calibrations

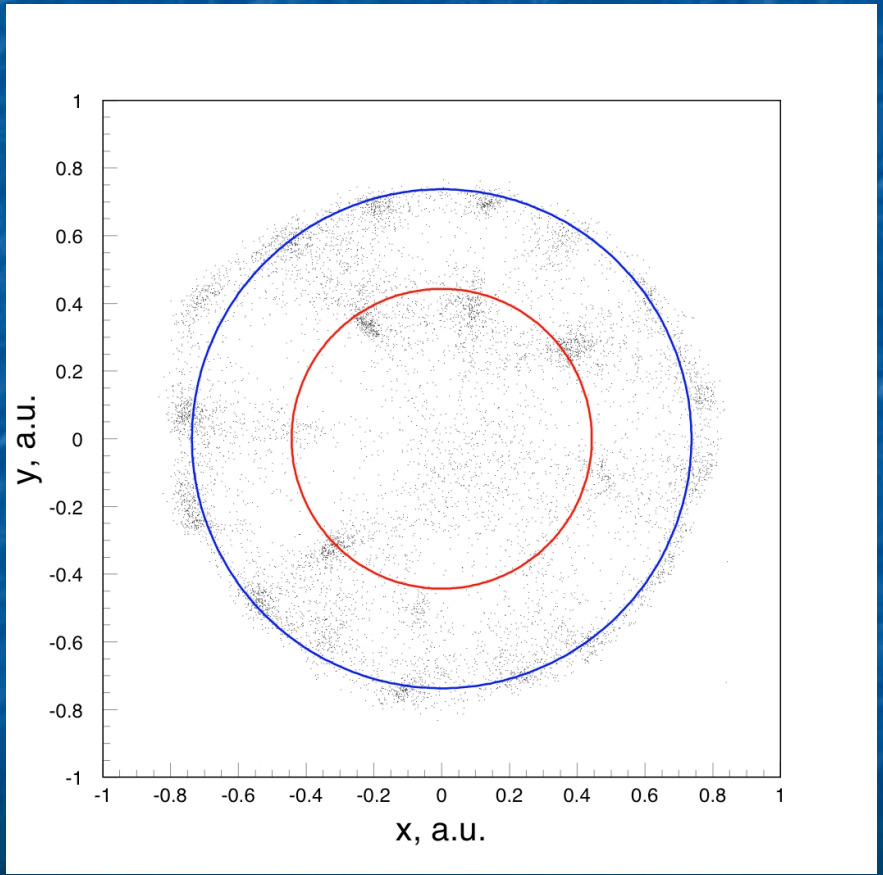
- Energy calibration with ^{57}Co source
- Light yield - 0.55 pe/keV at 1 kV/cm
- 90% electron extraction efficiency
- ~230 photons per extracted electron





Calibrations

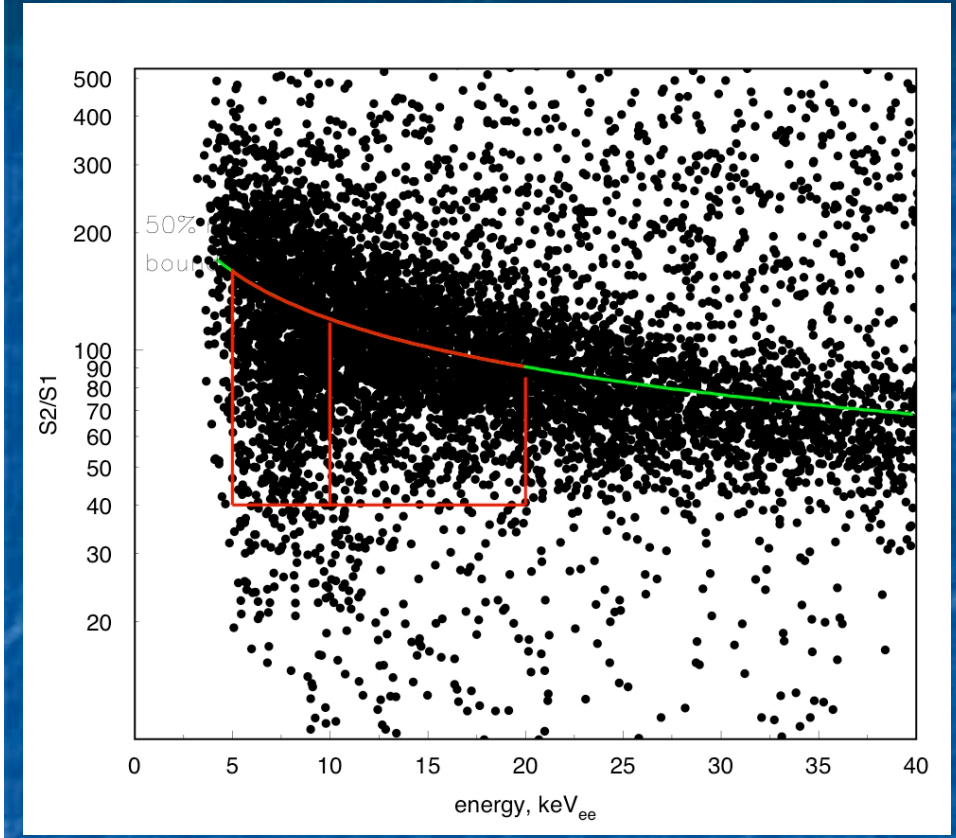
- Relative S2 signals in different PMTs allow position reconstruction in x-y plane.



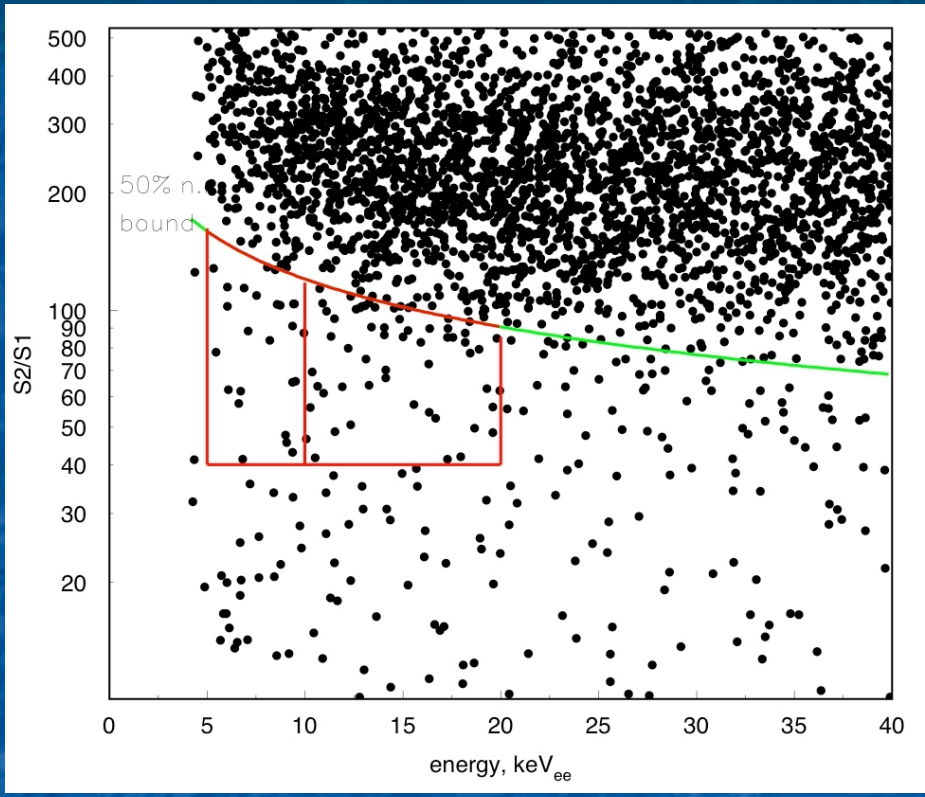
- Calibration of position reconstruction in the horizontal plane using Co-57 source and ‘calibration holes’.
- Events occurring close to the walls at $r > 0.47$ a.u. (associated with radon progeny decays) have been removed from the analysis -> reduction in fiducial mass.

Calibrations

AmBe

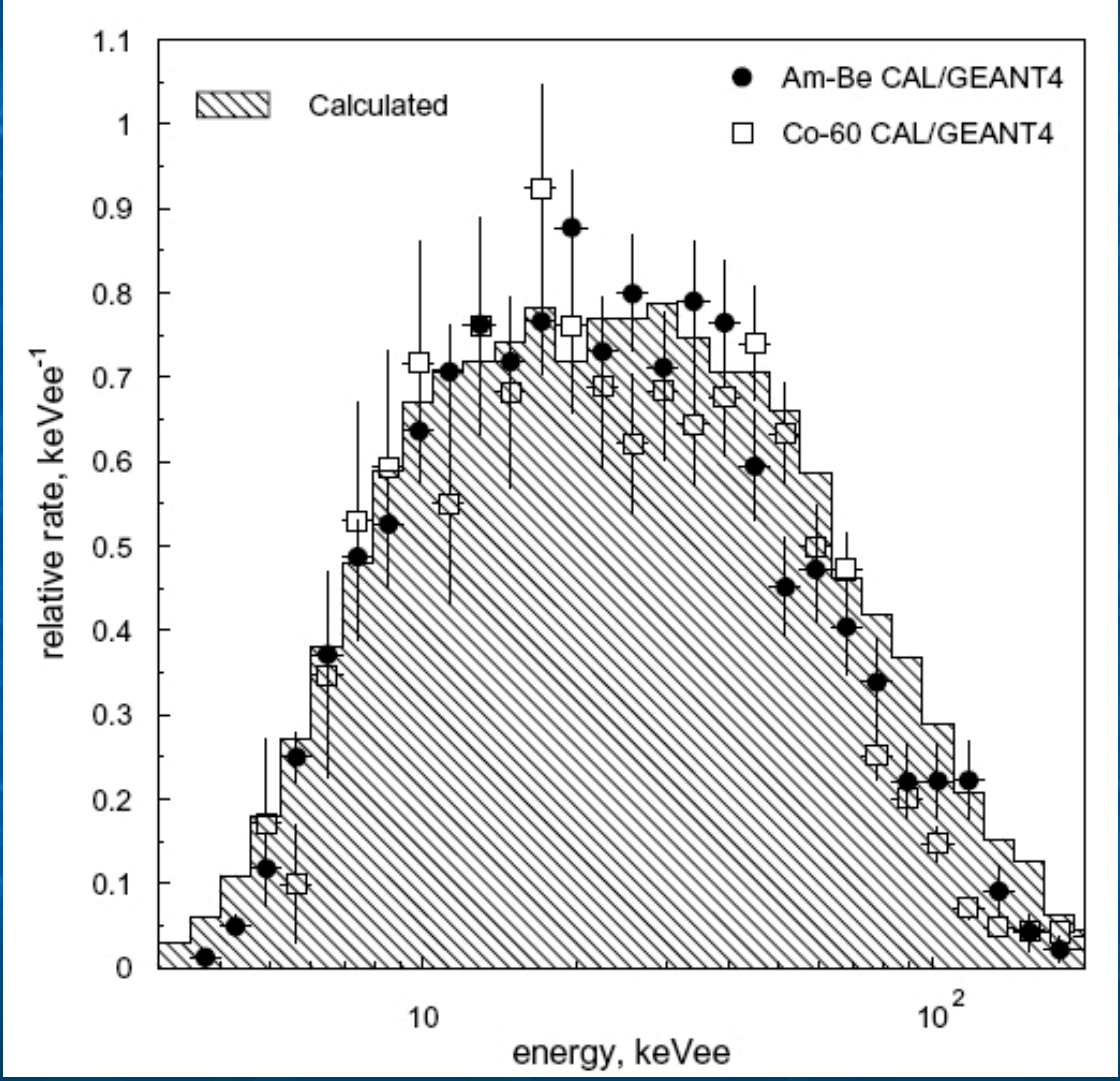


Co-60



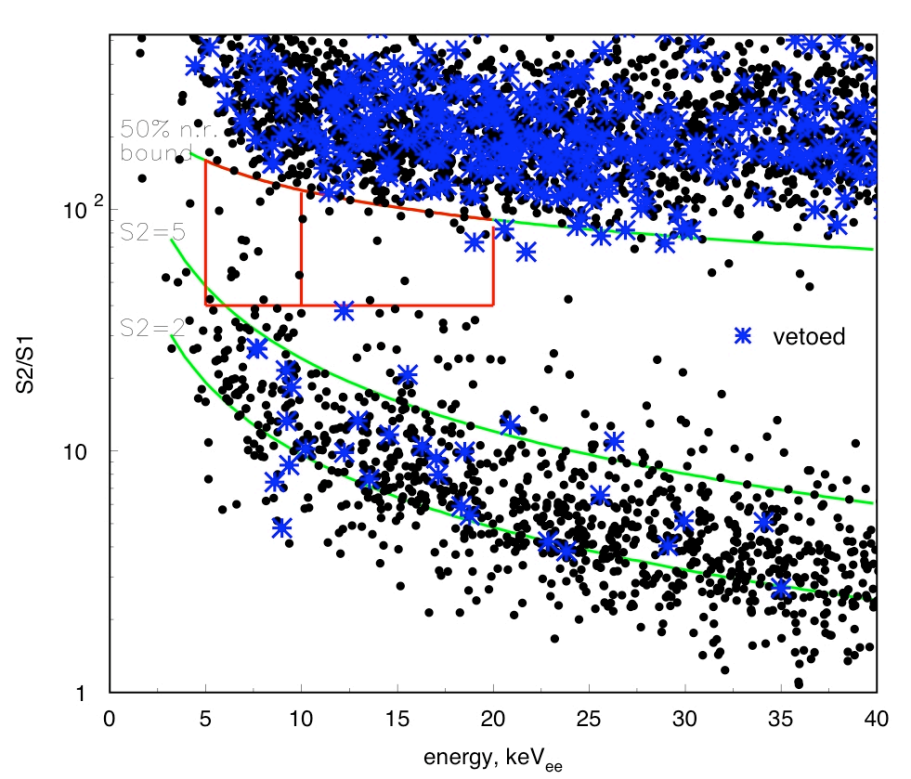
Red box - 50% nuclear recoil acceptance box defined using calibrations and unblind 10% of data; S2/S1 > 40, S1 (energy) = 5 - 20 keV$_{ee}$.
Green curve - centroid for nuclear recoil band.
98.5% discrimination with 50% acceptance of NR at 5-20 keV$_{ee}$.

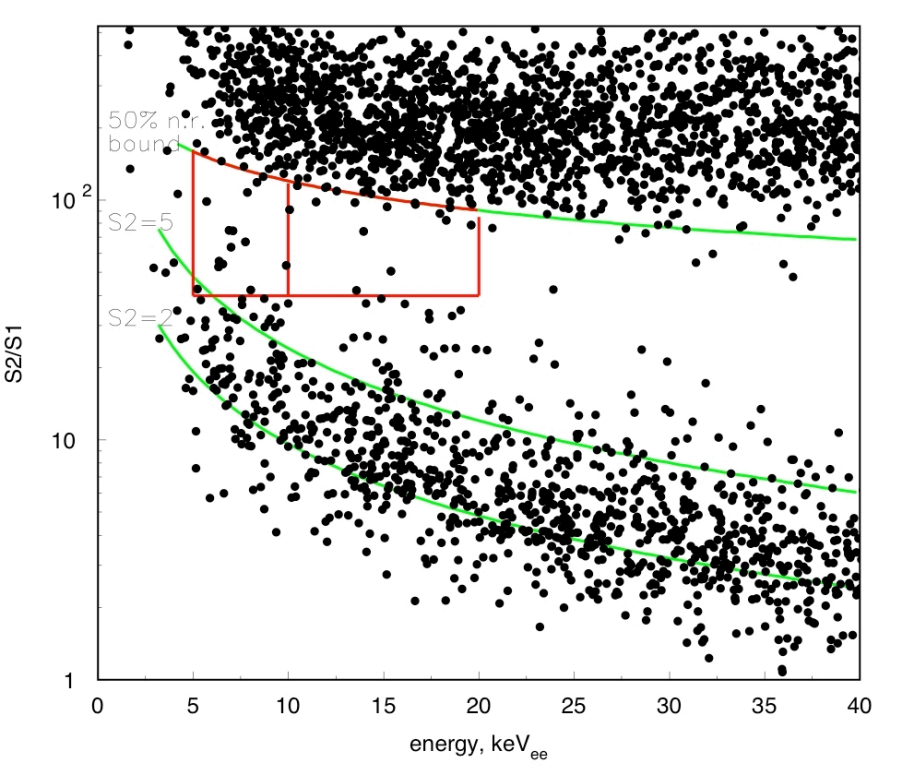
Efficiencies



- Calculated efficiencies:
  - Trigger
  - S2 charge and width
  - X,Y,Z cut -> reduction in fiducial mass
  - Dead time
  - Random coincidences with veto
  - …
- Measured: normalised to the expected spectrum shape from AmBe and Co-60 events.

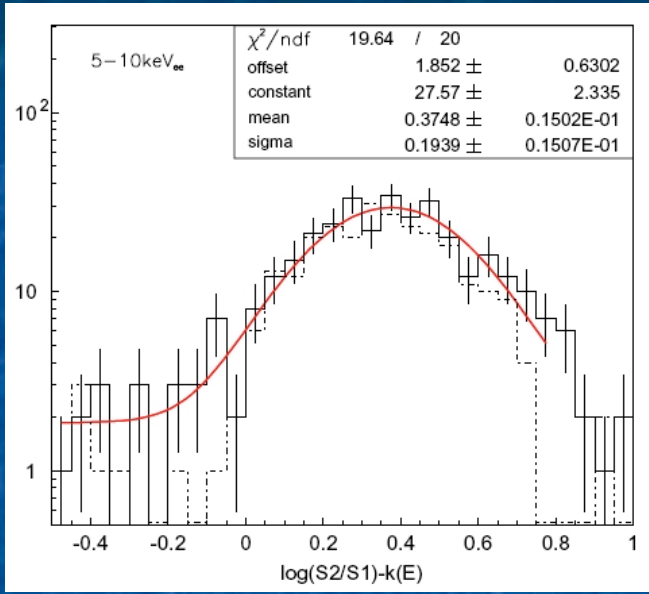
Data

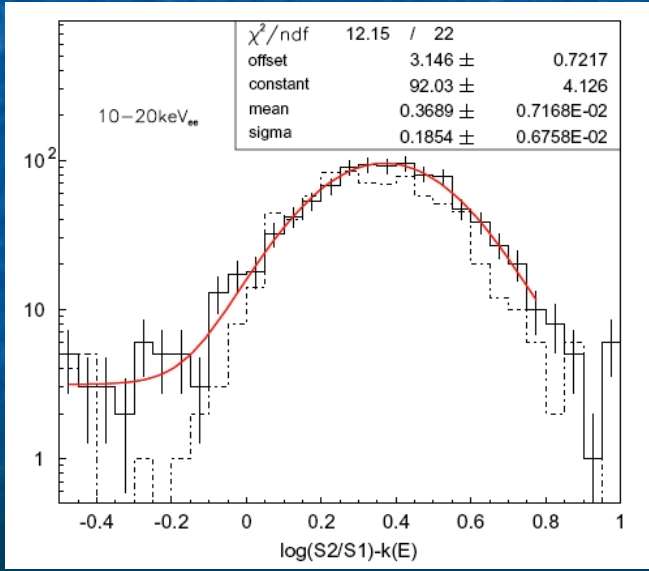




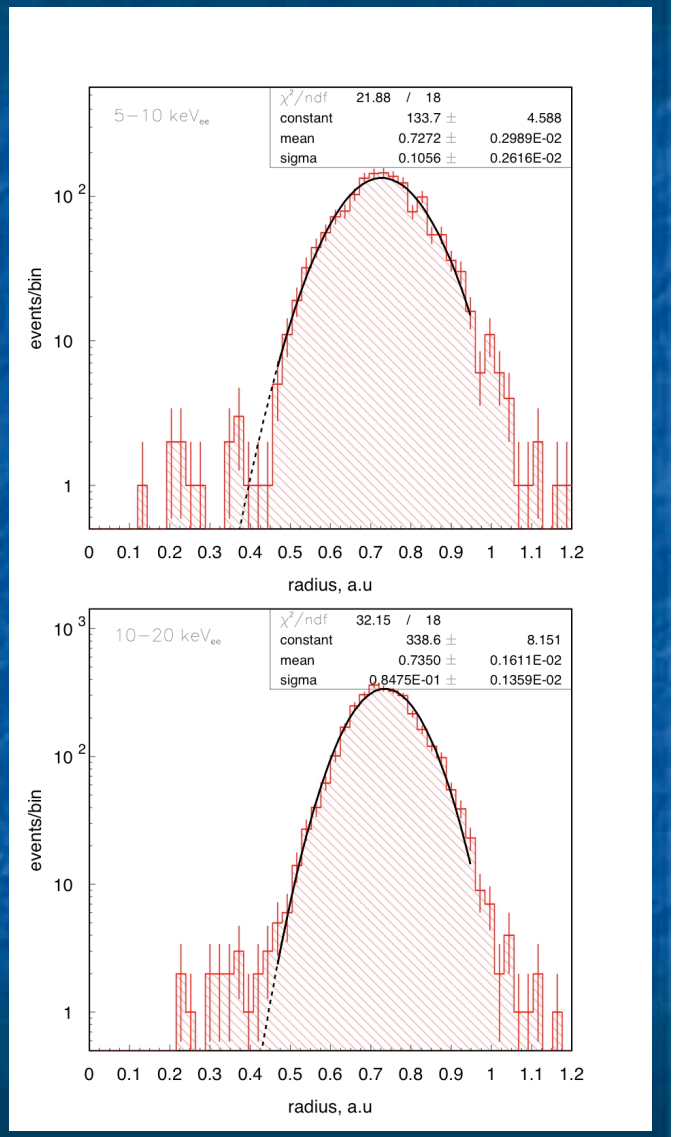
- Data run: 31.2 days, 7.2 kg, 225 kg×days, 29 events observed.
- Blue stars - events in coincidence with veto signals.
- Lower population: radon progeny recoils coming from the walls.

Expectations





- Left - leak of gamma events (^{60}Co and background) into the nuclear recoil acceptance box. Expected number is taken from Gaussian fit.
- Right - nuclear recoil events in the acceptance box without radial cut. Events at small *r* are from the walls but were put in the centre of the detector due to imperfect position reconstruction. Expected number is taken from the extrapolation of the Gaussian fit.



Spin-independent limits

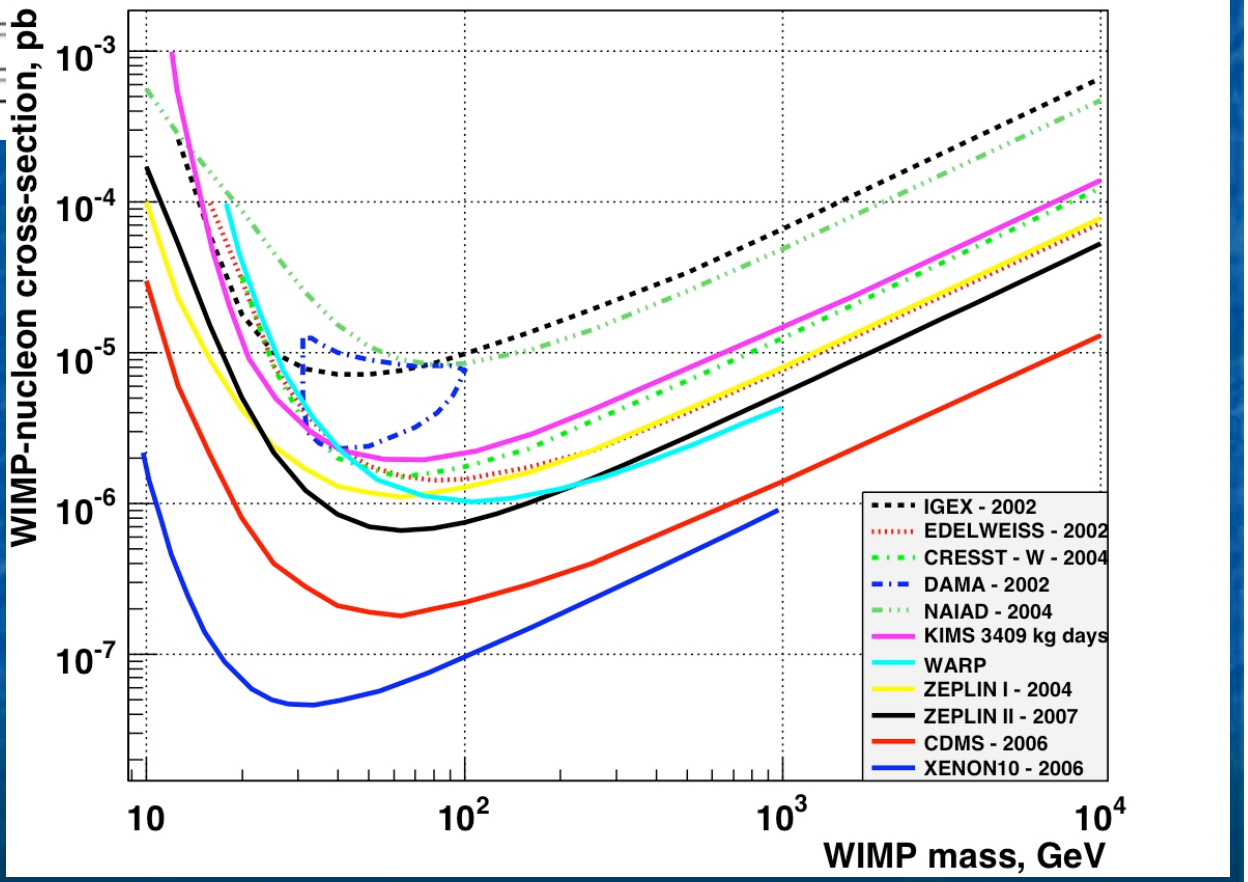
Overall expectation values in the nuclear recoil acceptance window compared to observed counts

Energy range (keV_{ee})	Observed	γ-Ray (^{60}Co) (1)	γ-Ray (data)	Rn-initiated (2)	Total (1 + 2)
5–10	14	4.2 ± 2.4	$5.6 \pm$		
10–20	15	11.9 ± 2.7	$13.0 \pm$		

QF=0.19 -> 0.36 at 1 kV/cm

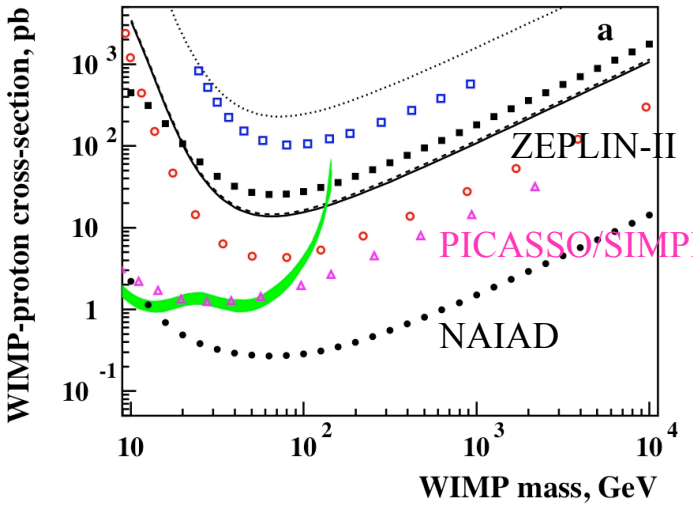
Energy range: 5-20 keV.
29 events observed.
28.6±4.3 expected from two background populations.
Signal consistent with 0.
Upper limit on nuclear recoil rate is 10.4 (90% FC central confidence interval).

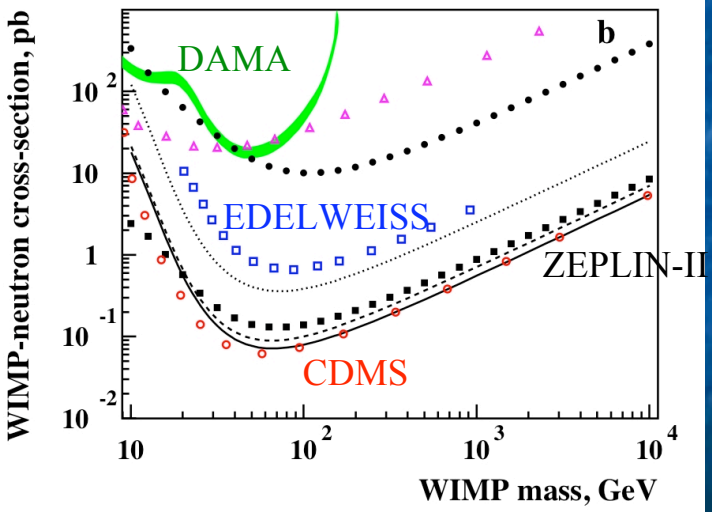
Alner et al. Astroparticle Phys., in press.

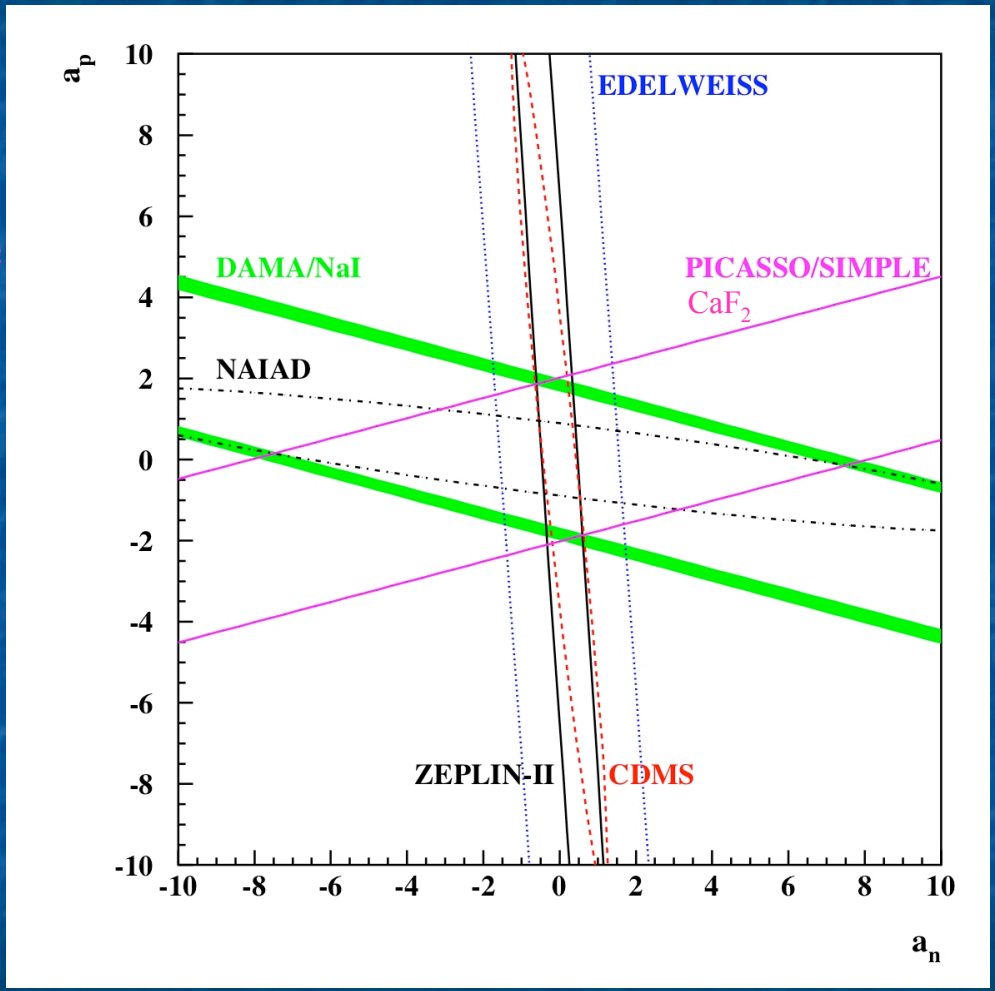


Spin-dependent limits

Also new limits from XENON10 and KIMS







Alner et al. Phys. Lett. B, **653** (2007) 161.

Summary

- First ‘dark matter’ run of the ZEPLIN-II experiment has been carried out.
- 225 kg×days of data have been collected and analysed.
- Two background populations have been identified in the nuclear recoil acceptance box (defined using calibrations and unblind 10% of data): gamma-induced events and nuclear recoils from the walls.
- 29 events have been detected with 28.6±4.3 predicted from the background. WIMP signal is consistent with 0 with an upper limit of 10.4 events (90% central confidence interval).
- Limits on WIMP-nucleon spin-independent interactions: 6.6×10^{-7} pb at the minimum of the curve (65 GeV mass).
- Limits on WIMP-nucleon spin-dependent interactions: 0.07 pb at about 65 GeV.

Thanks to:

- All members of the Collaboration.
- Cleveland Potash Ltd.
- ITEP (Moscow).
- PPARC/STFC (UK).
- CCLRC (UK).
- EPSRC (UK).
- DoE (US).
- NSF (US).
- FCT (Portugal).
- ILIAS (EU).
- Marie-Curie IRG (EU).
- INTAS (EU).