The (noble) liquid route to dark matter detection

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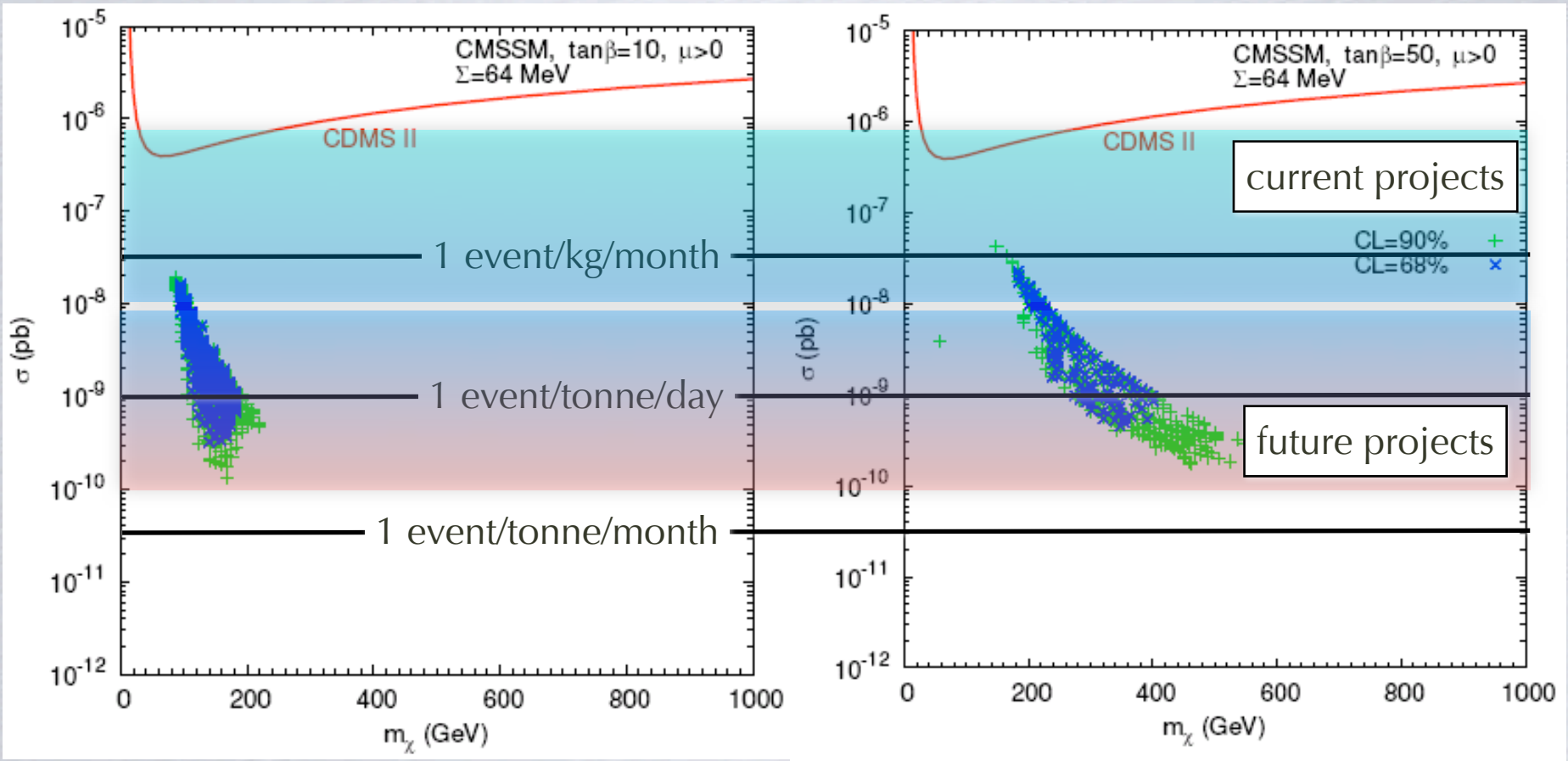
STFC Rutherford Appleton Laboratory

RAL 1957 2007
Celebrating 50 years of world class science

Where are we going?

Ellis et al hep-th/0502001



CMSSM Example

- Required sensitivity is ~10^{-7} - 10^{-10} pb
  - may not need to go all the way for discovery...

What are the challenges?

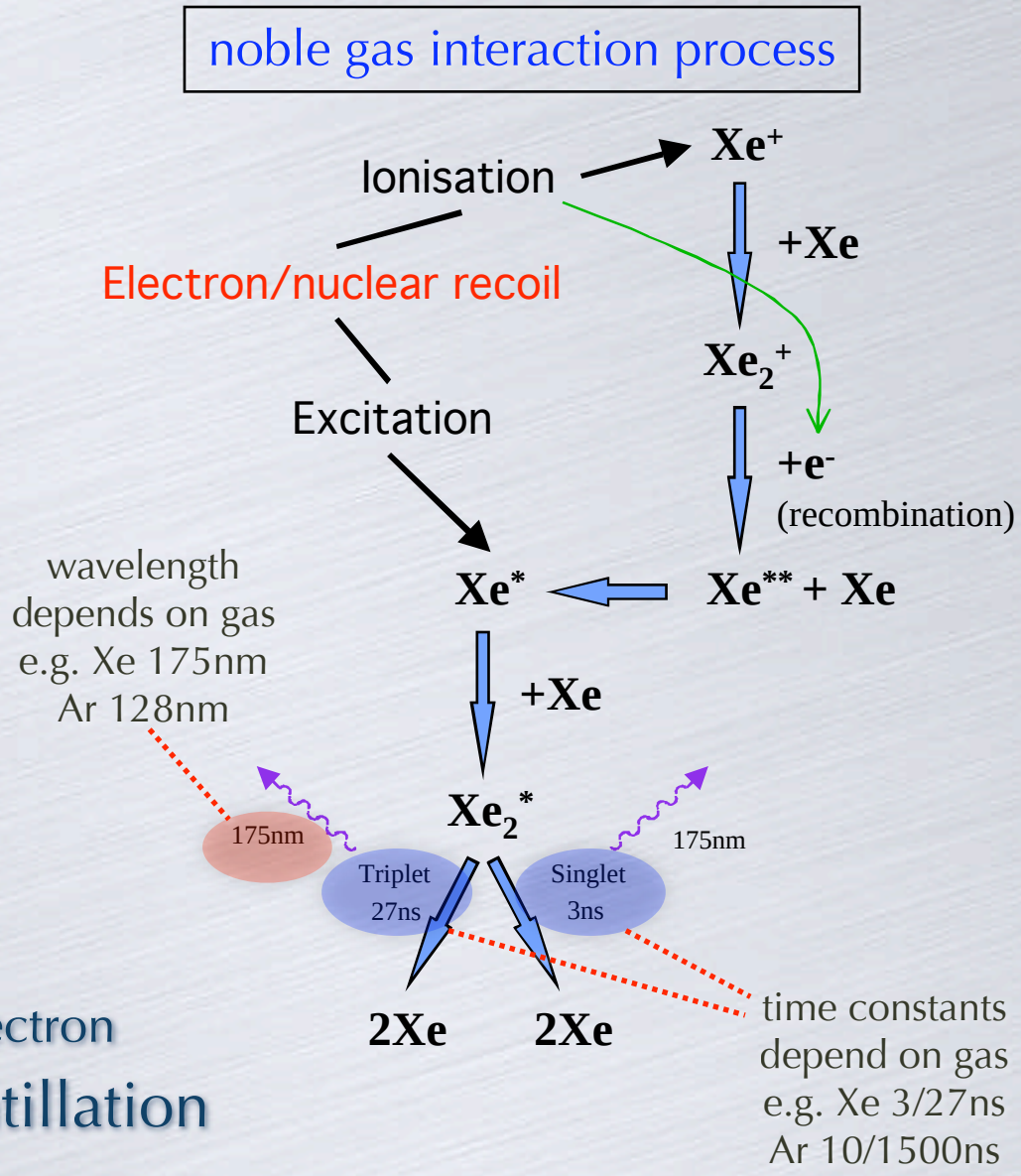
- To cover lower reaches of parameter space:
  - Event rate is small, energy deposited is small
- Large scale detectors
  - target masses of tonne scale to provide count rate
- Low (keV) energy threshold for nuclear recoils
- Low background, especially neutrons
  - intrinsic activity from detector
  - external activity from surroundings
- Good background rejection
  - (α), β, γ rejection
  - control/rejection of surface events
  - position sensitivity, segmentation, fiducialisation / self shielding

How noble in reason

- Why use liquid nobles?
  - Reasonable/good discrimination power
    - scintillation & scintillation/ionisation
  - Single electron extraction / high light yield
  - Excellent prospects for large scale detectors
    - cheap and dense
  - Easily purified... and re-purified
    - Good (potential) control on surfaces
  - Excellent self shielding capability
  - Excellent self vetoing capability
  - Good position reconstruction (two phase detectors)
  - Potential for A^2 WIMP-neutron comparison

(Liquid) Noble Gas detectors

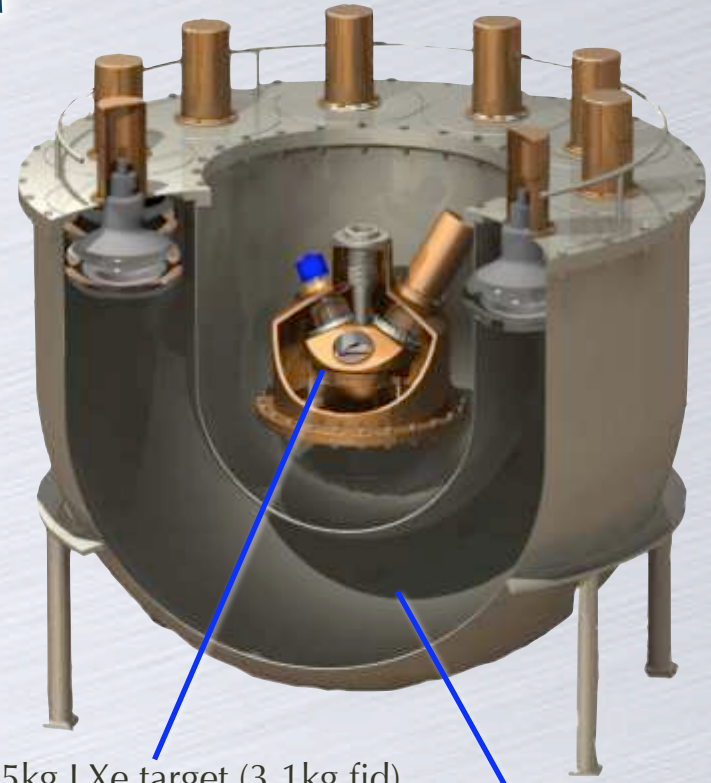
Gas	Single phase	Double phase
Xenon	ZEPLIN I, XMASS	ZEPLIN, XENON, XMASS
Argon	DEAP, CLEAN	WARP, ArDM
Neon	CLEAN	SIGN



- Single phase - scintillation
  - recombination occurs
  - singlet/triplet ratio 10:1 nuclear:electron
- Double phase - ionisation/scintillation

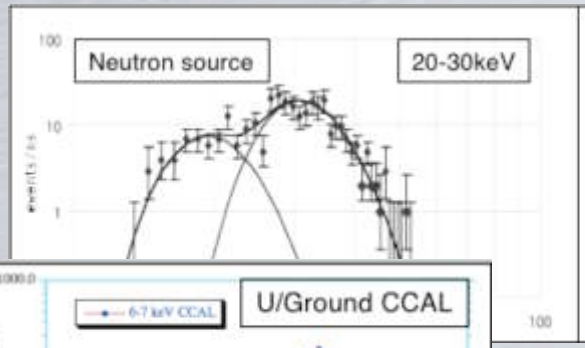
ZEPLIN I

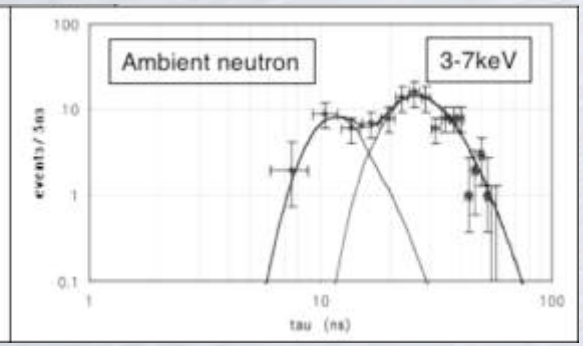
- Single phase Xe detector
- Test for u/ground ops
- 5kg target volume
- PSD only on scintillation
- 91 day livetime, 290kg.days data
- Limit on xsection set: 1.6 x 10^{-6}pb

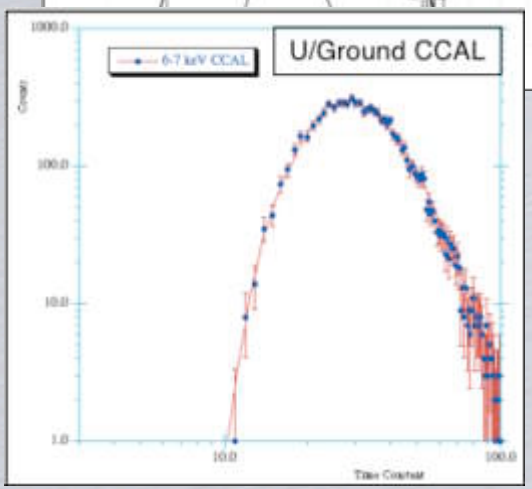


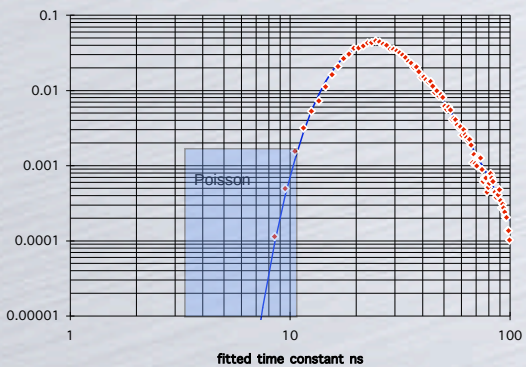
5kg LXe target (3.1kg fid)
3 PMTs
Cu construction
Polycold cryogen cooling

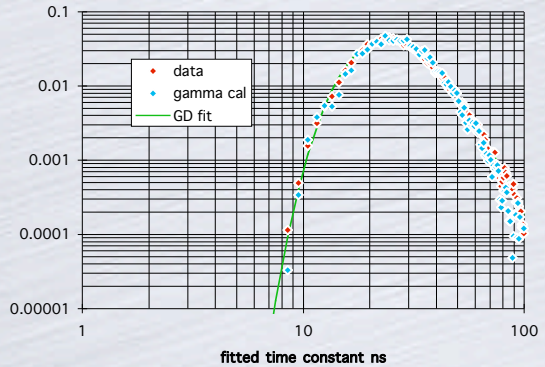
1 tonne Compton veto
PMT background tag
Gamma calibration
Neutron monitor







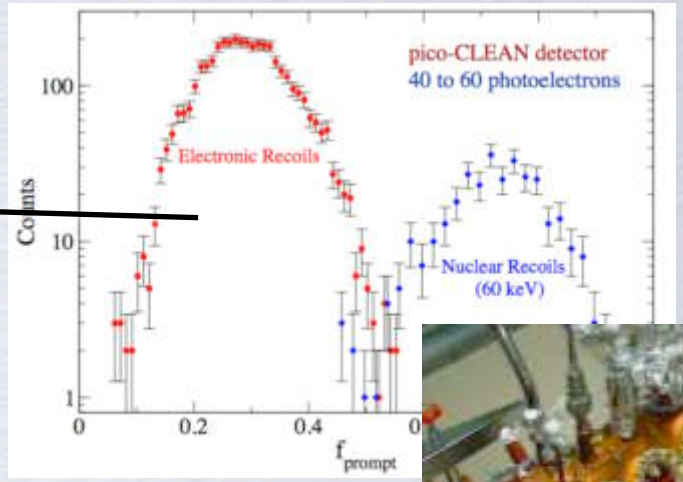


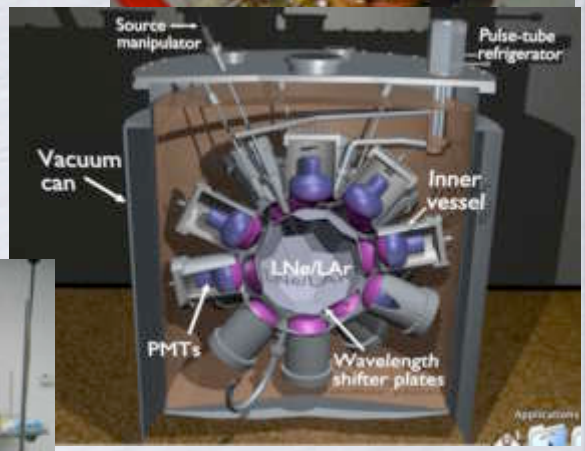


Science & Technology Facilities Council

XMASS / CLEAN / DEAP

- Single phase Xe/Ar/Ne
  - p-p solar neutrino objective as well as DM
  - single phase discrimination demonstrated
  - self-shielding, low background
  - position sensitivity from PMT hits
- XMASS (Xe)
  - 10kg two phase target operated
  - 100 kg single phase prototype operated (800kg now funded)
- CLEAN (Ar/Ne)
  - pico(200g)/micro(4kg) completed
  - quenching factor tests underway
  - mini(100kg) under construction. deployment underground 2008
- DEAP - 10nkg(Ar)
  - DEAP-0: high light yield (6p.e./keV)
  - low threshold, low background
  - neutron discrimination demonstrated
  - DEAP-1 under construction





(Liquid) Noble Gas detectors

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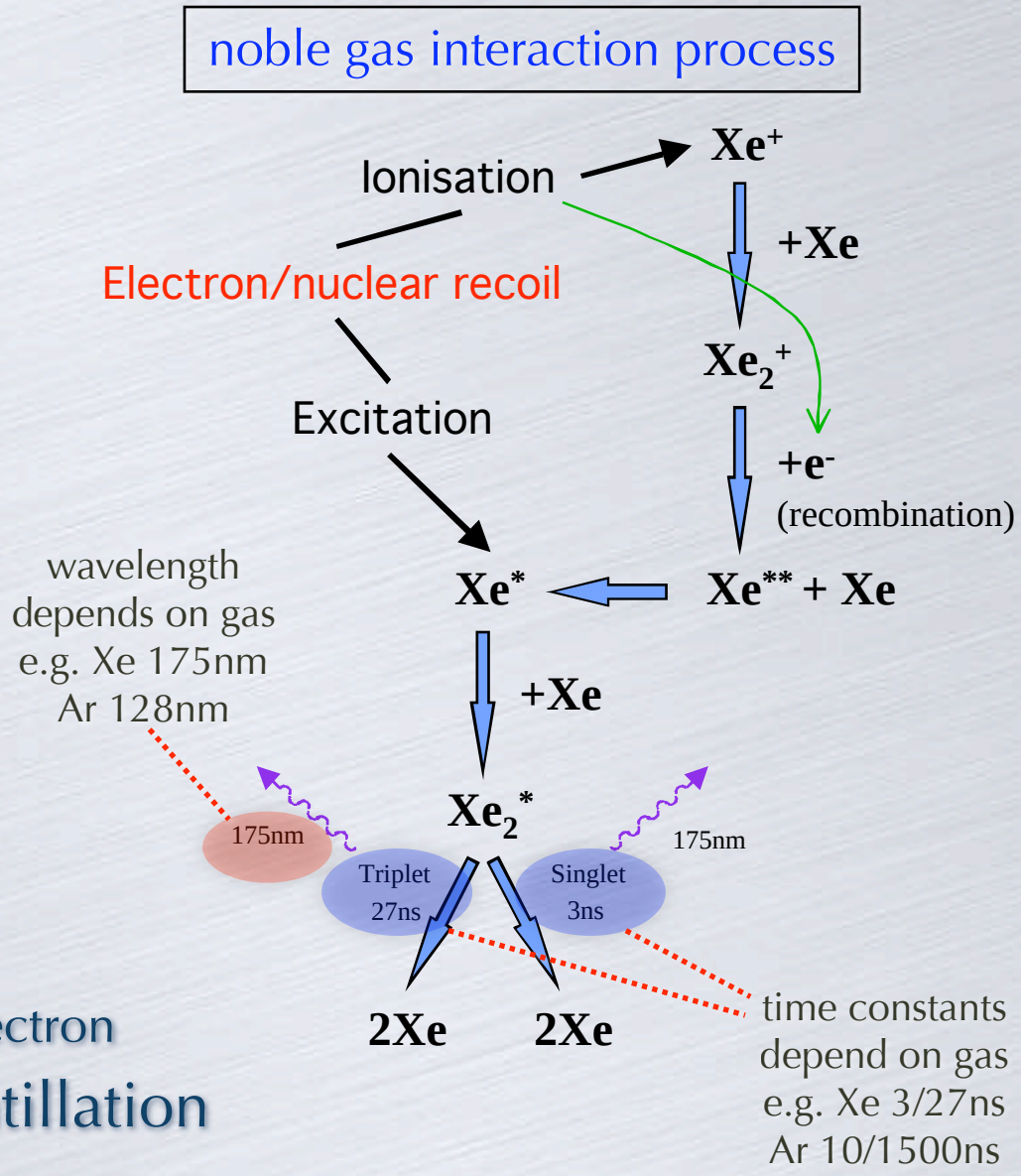
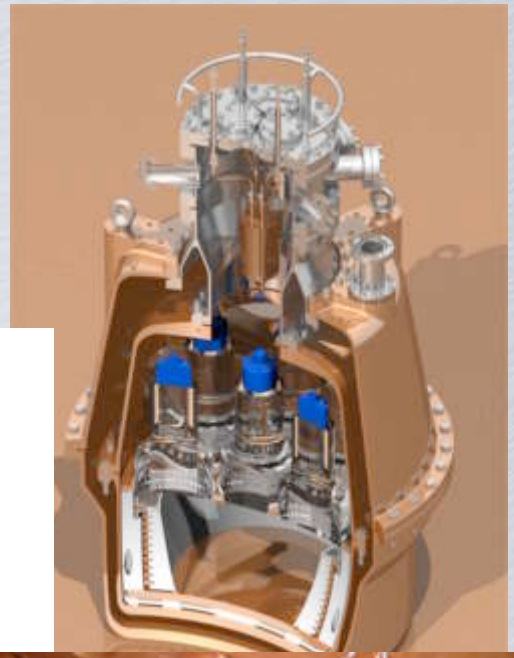
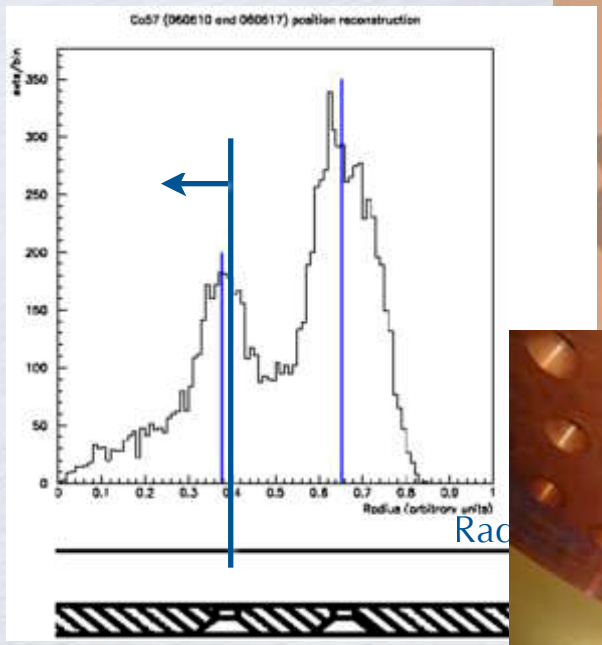


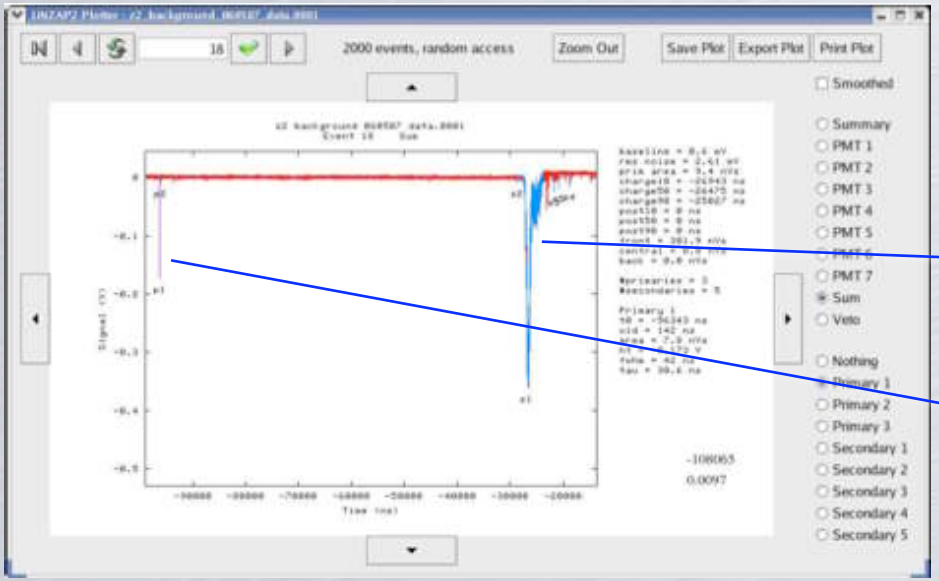
- Single phase - scintillation
  - recombination occurs
  - singlet/triplet ratio 10:1 nuclear:electron
- Double phase - ionisation/scintillation

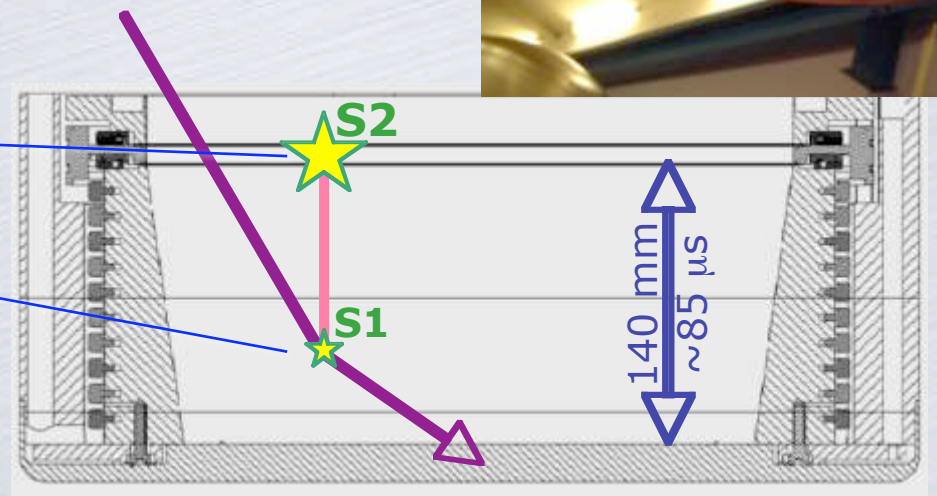
ZEPLIN II

- First science run complete
  - 30kg target mass
  - PTFE volume definition
  - 7 PMTs in gas phase
  - 0.55 p.e./keV (with field)
  - Spatial resolution ~1cm
  - Fiducial volume 7.2kg

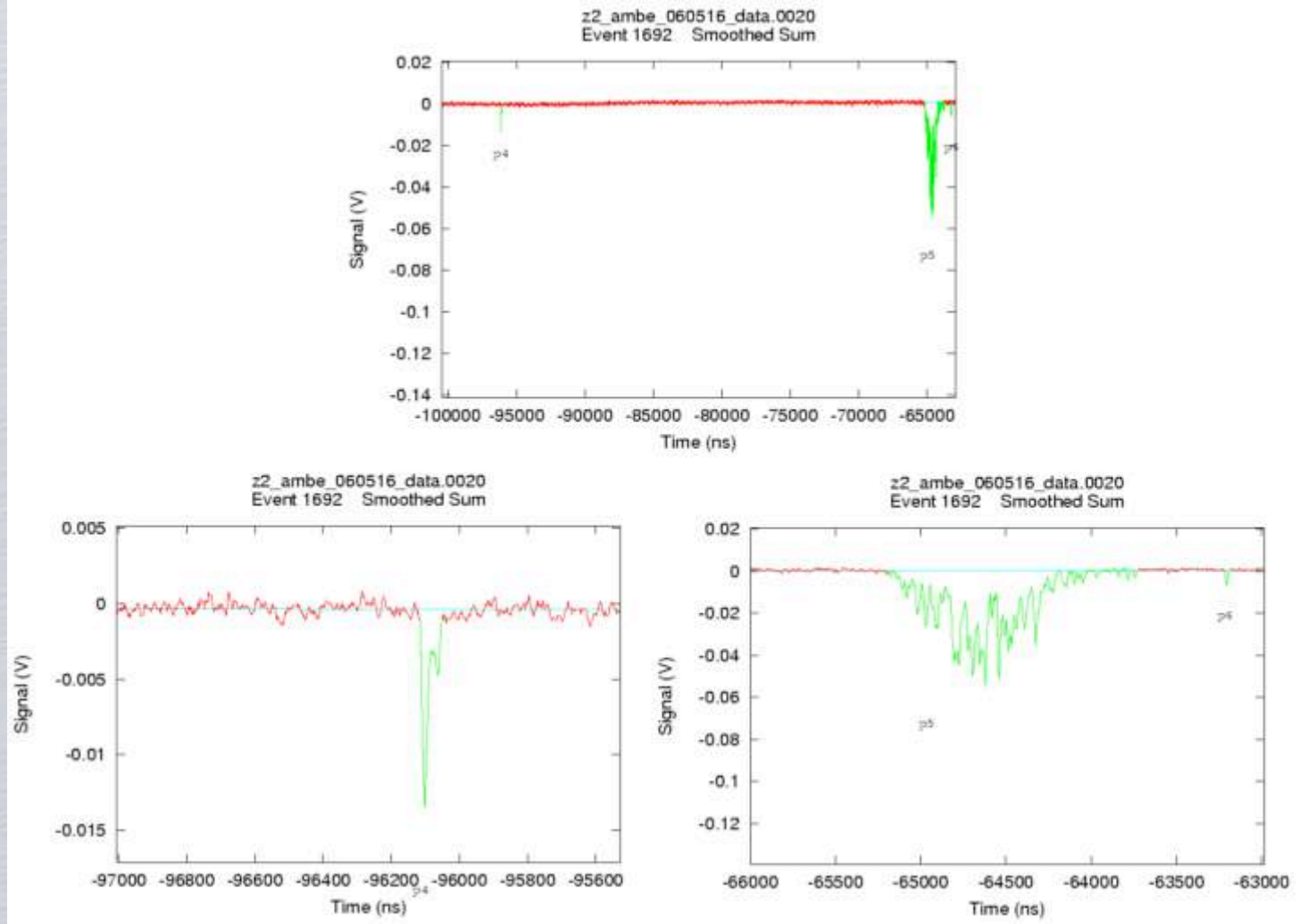






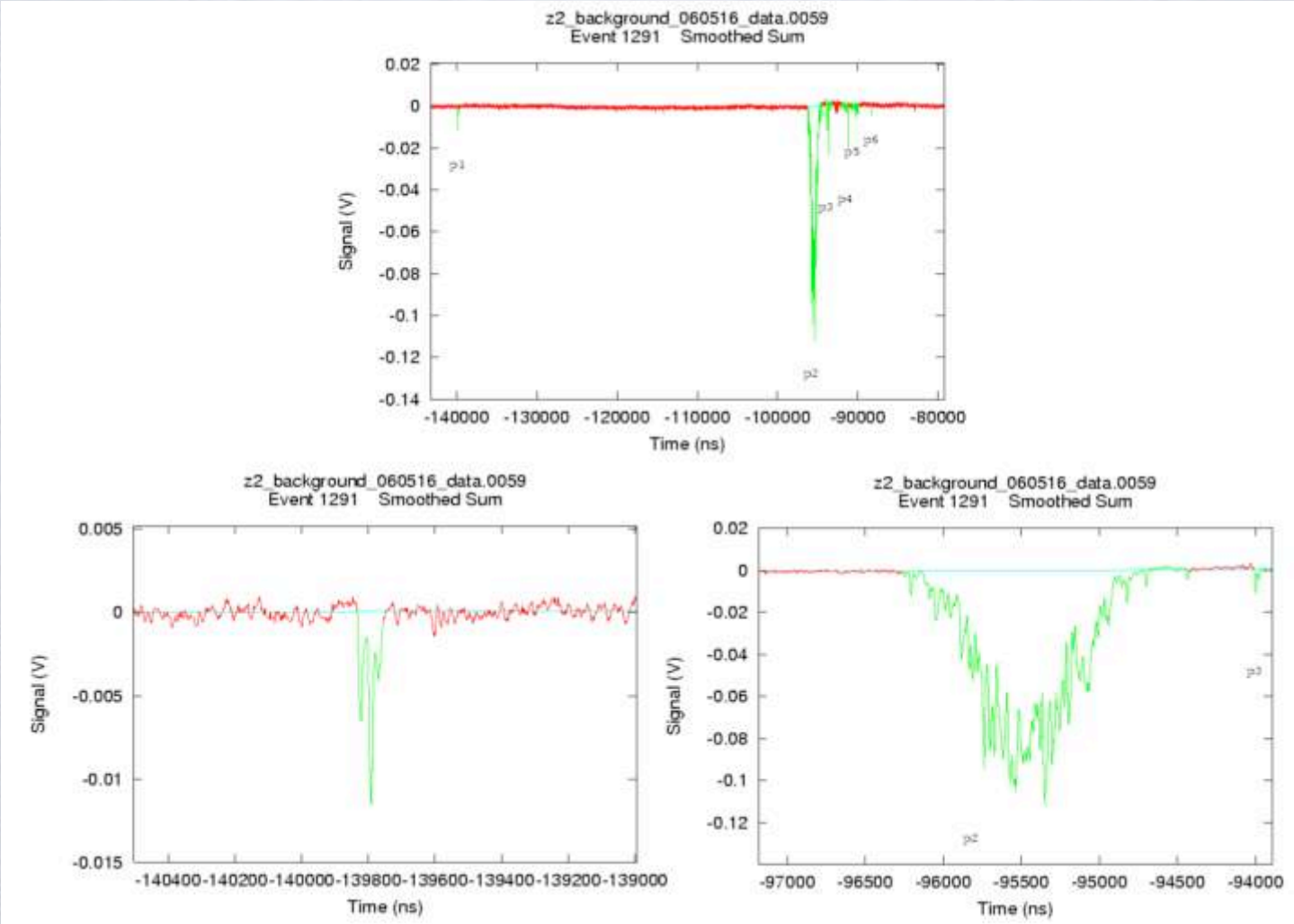


Neutron/Gamma pulses



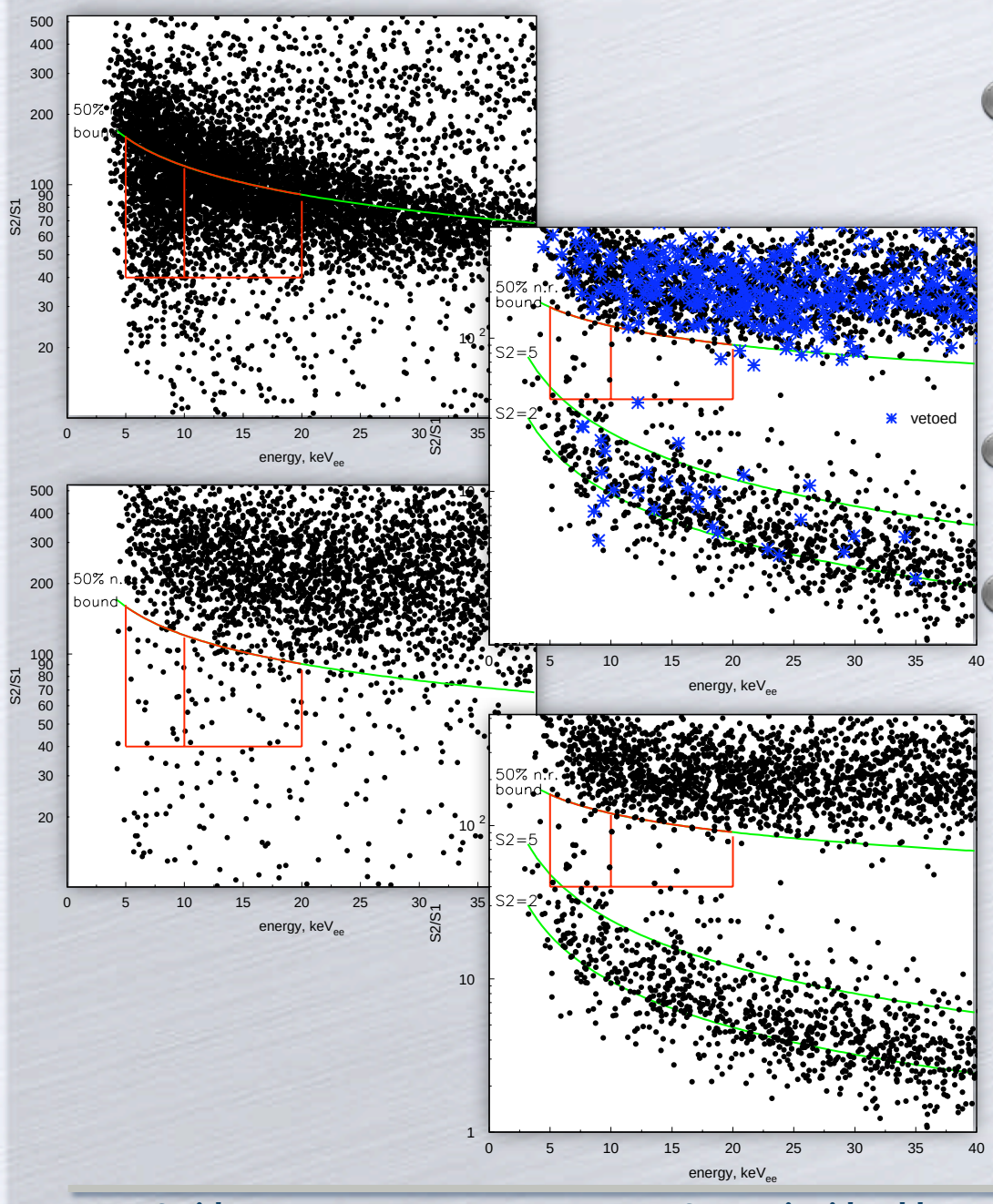
Neutron pulse

Neutron/Gamma pulses



Gamma pulse

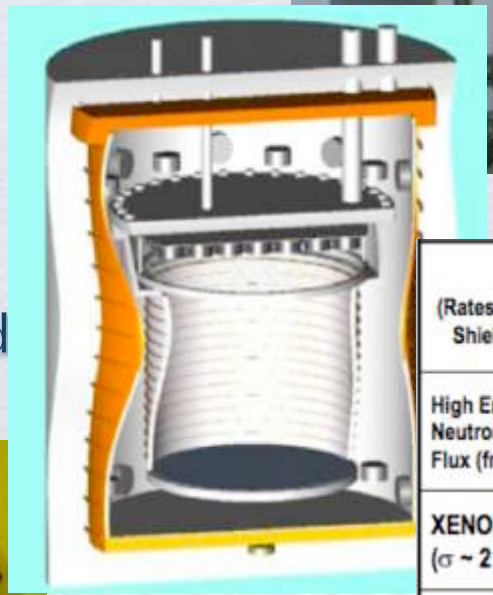
ZEPLIN II Results

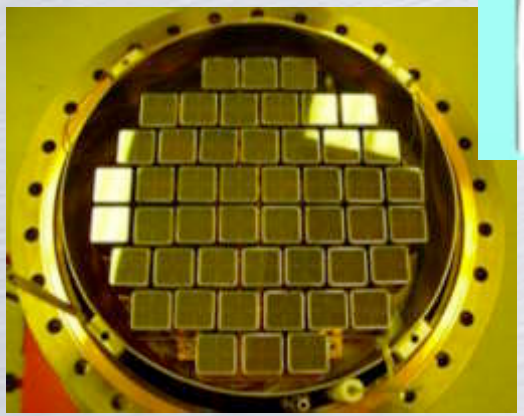


- AmBe (upper) & Co-60 (lower)
  - Used to define acceptance window
  - 50% n.r. acceptance shown
  - Uniform population across plots
    - high rate coincidences
- 98.5% γ discrimination at 50% n.r. acceptance
- Data runs veto top plot
  - Second population seen
  - Due to radon-progeny events on walls
  - Acceptance window as before
  - 29 events seen, 28.6±4.3 expected
  - 10.4 n.r 90%c.l. upper limit -> 6.6e-7pb

XENON

- XENON 10
  - 22kg target mass, 15kg active
  - 89 low b/g 1″ PMTs in liquid and gas phase
    - 48 in gas, 41 in liquid
    - ~mm position reconstruction in x,y
  - Deployment at LNGS
  - Pulse tube cooling
- XENON 100
  - 100kg target mass
  - background assessments completed

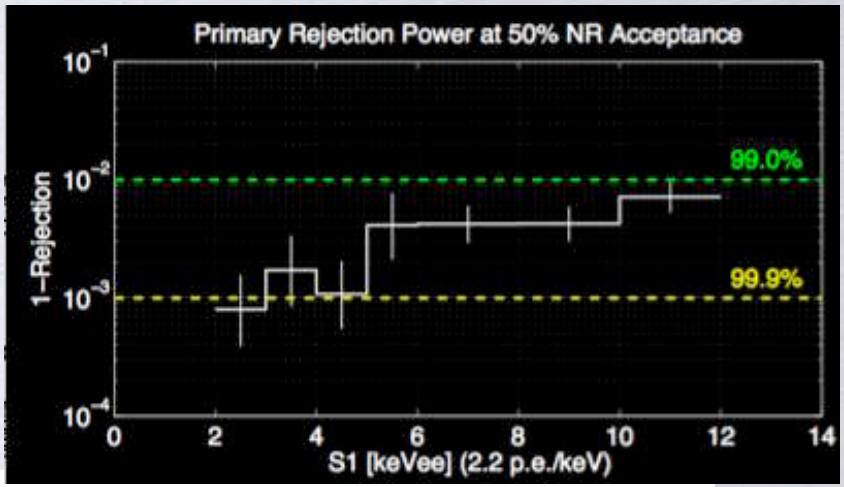


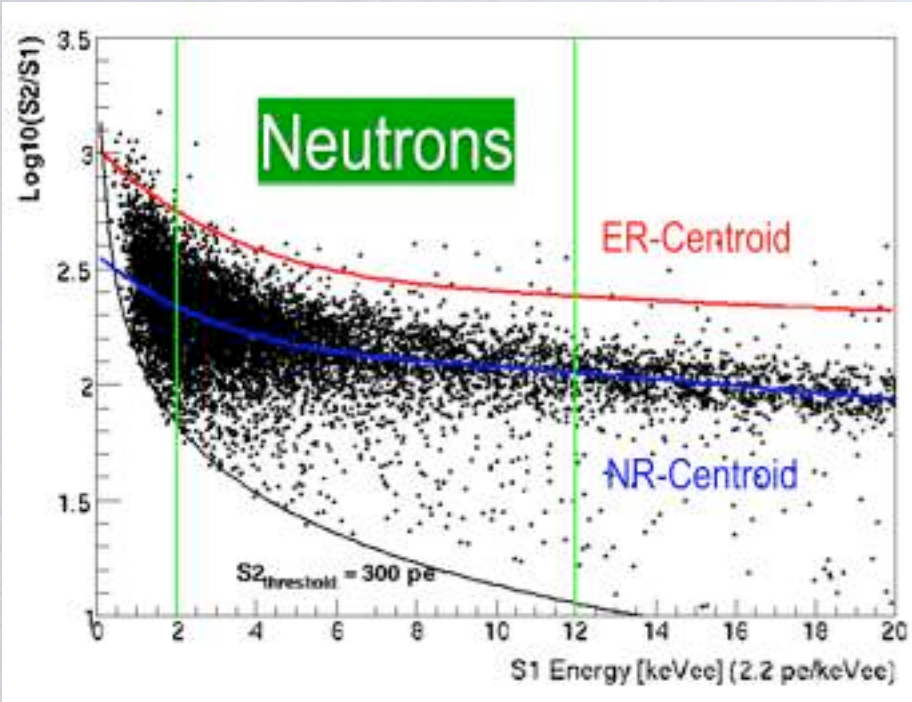


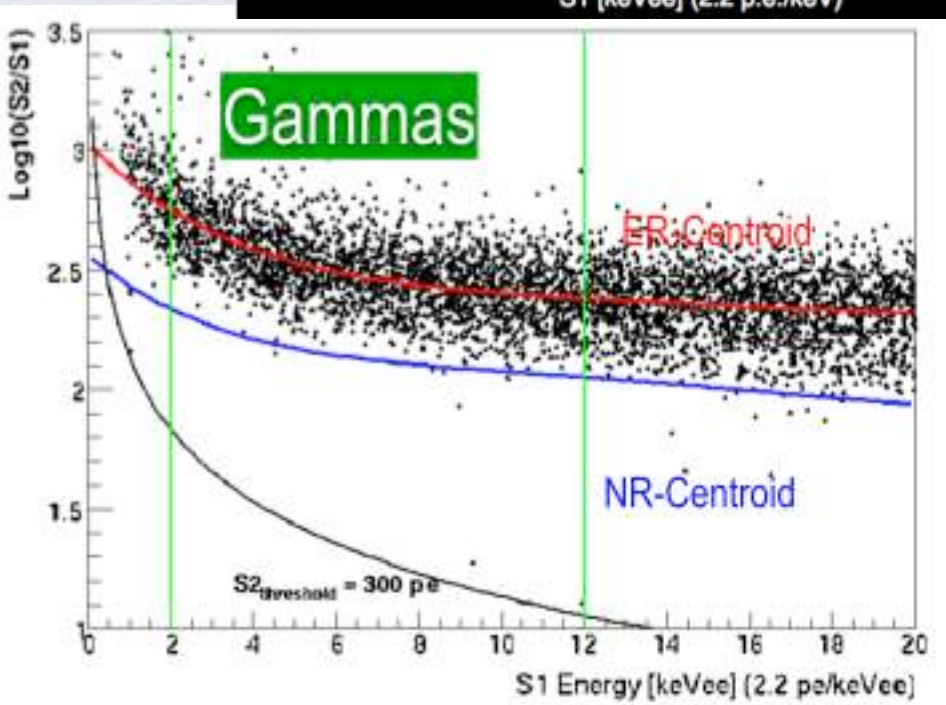
Goal (Rates for Current Shield Design)	DM NR Signal Rate Xe @ 16 keVr	Soudan 2.0 kmwe	Gran Sasso 3.0 kmwe	Home-stake 4.3 kmwe
High Energy Neutron Relative Flux (from muons)		x1	X1/6	x1/30
XENON10 ($\sigma \sim 2\ 10^{-44}$ cm^2)	400 dru	x 20	x 120	x 600
XENON100 ($\sigma \sim 2\ 10^{-45}$ cm^2)	40 dru	x 2	x 12	x 60
XENON1T ($\sigma \sim 2\ 10^{-46}$ cm^2)	4 dru	x 0.2	x 1	x 6

Discrimination power

- 2.2 p.e./keV$_{ee}$
- 99.5% discrimination at 50% acceptance
- improved discrimination (99.9%) below 5keV$_{ee}$

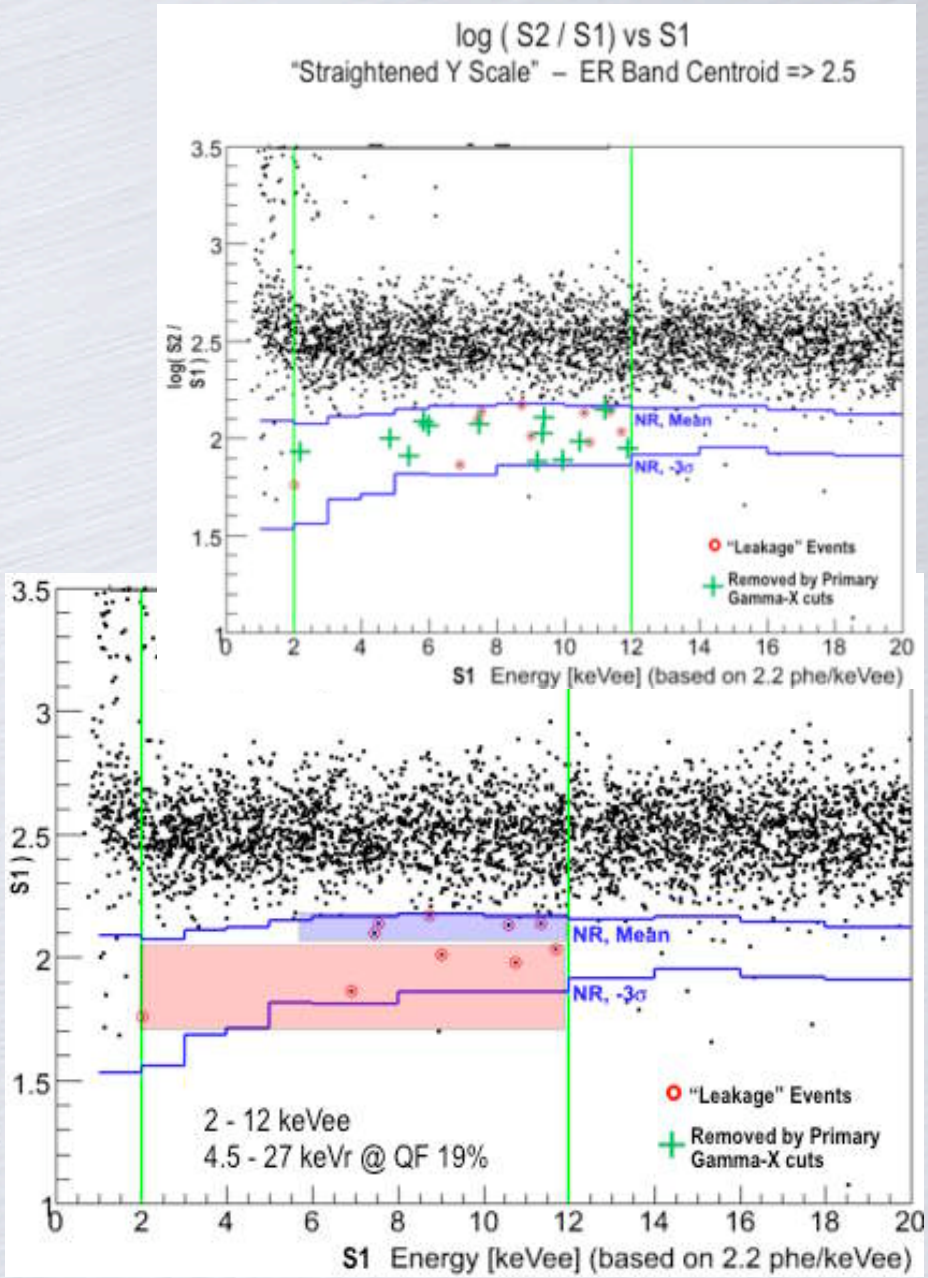






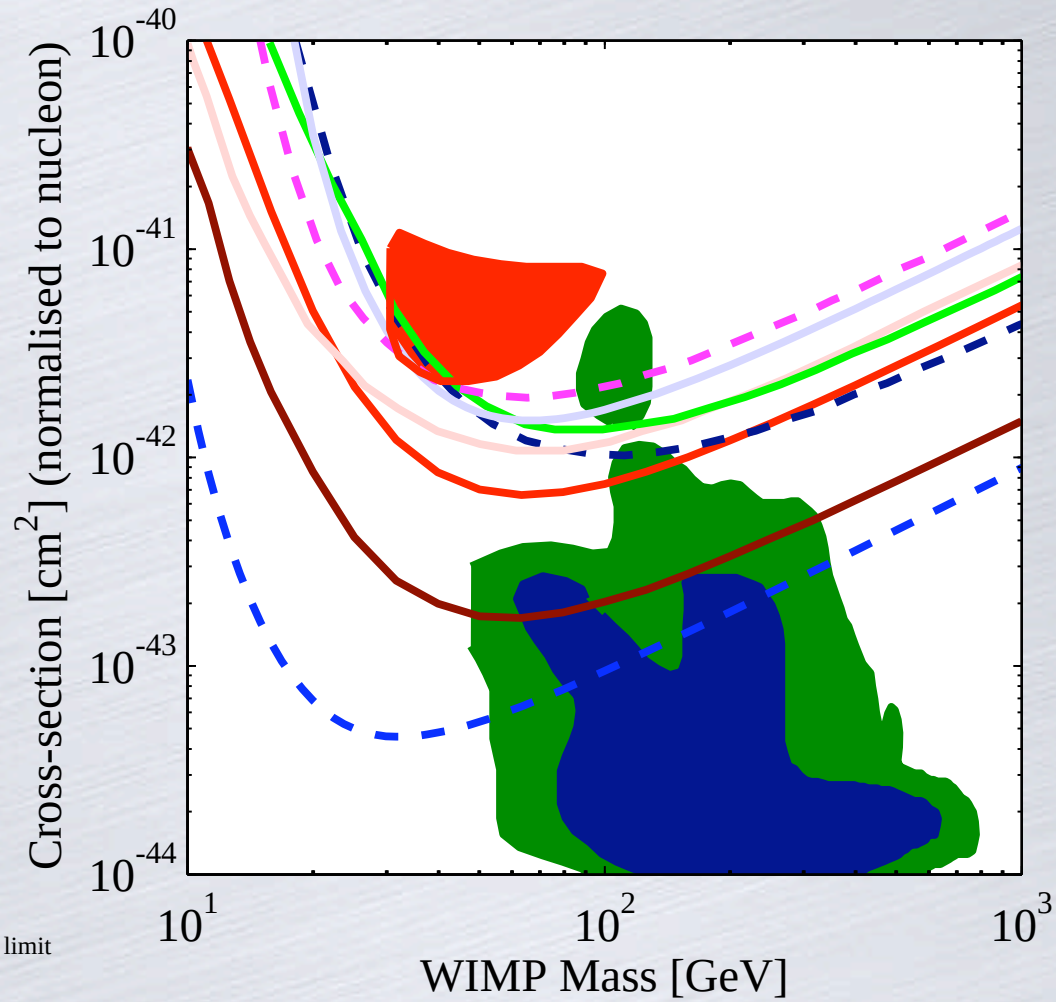
XENON Results

- Blind analysis on 58.6 days
- Acceptance window
  - 50% n.r., 2-12 keV
- 23 events in n.r. window
- 13 events removed by 'gamma-X' cut
- 10 events after all cuts
- 6.8 expected from gamma leakage events
- Yellin maximal gap analysis
  - minimum 4.5e-8 pb



Where are we now?

- 'Canonical' halo model
- Spin independent interaction
- normalised to nucleon

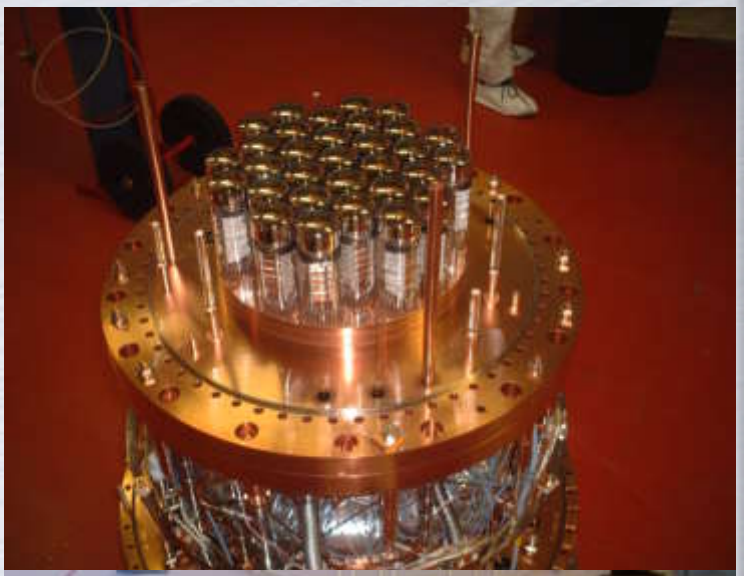


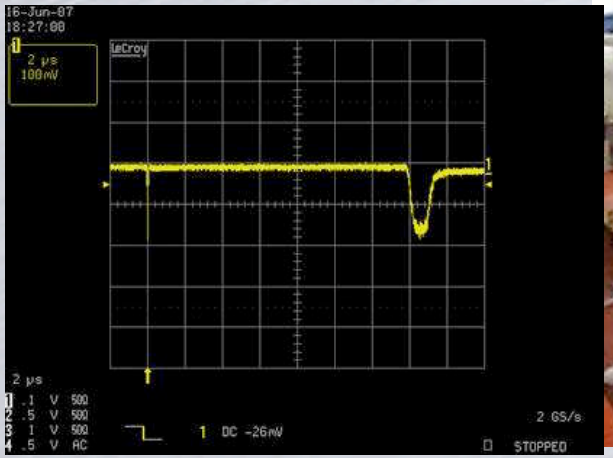
DATA listed top to bottom on plot
DAMA 2000 58k kg-days NaI Ann.Mod. 3sigma,w/o DAMA 1996 limit
KIMS 2007 - 3409 kg-days CsI
CRESST 2004 10.7 kg-day CaWO4
Edelweiss I final limit, 62 kg-days Ge 2000+2002+2003 limit
ZEPLIN I First Limit (2005)
WARP 2.3L, 96.5 kg-days 55 keV threshold
ZEPLIN II (Jan 2007) result
CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
XENON10 2007 (Net 136 kg-d)
Ruiz de Austri/Trotta/Roszkowski 2007, CMSSM Markov Chain Monte Carlos (1
Ruiz de Austri/Trotta/Roszkowski 2007, CMSSM Markov Chain Monte Carlos (1
x x x Ellis et. al Theory region post-LEP benchmark points

http://dmtools.berkeley.edu/limitplots/ Gaitskell/Mandic

ZEPLIN III

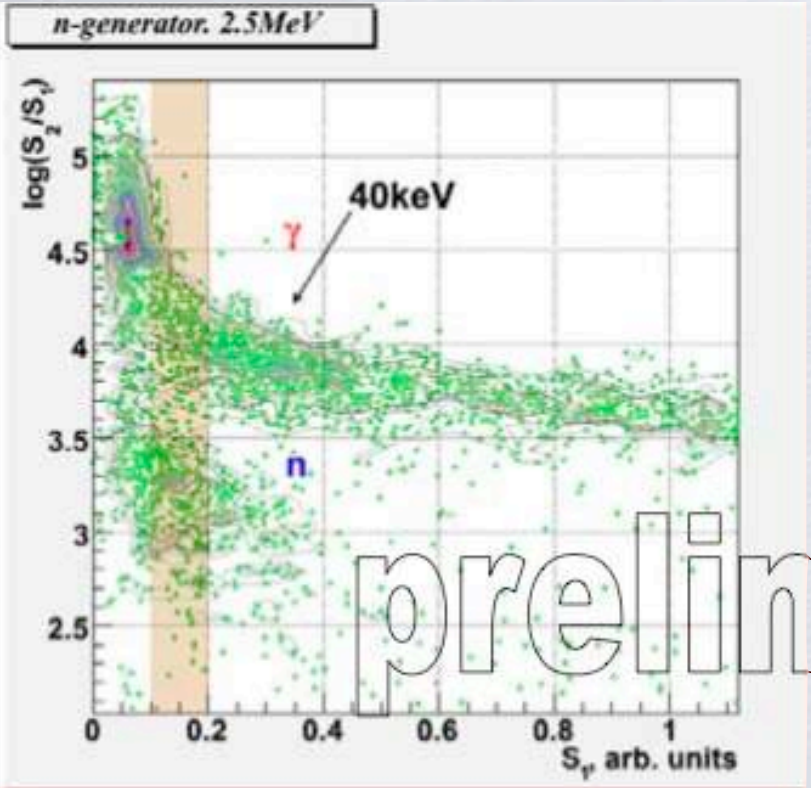
- 8kg fiducial mass
- PMTs in liquid to improve light collection
- 3.5 cm drift depth – higher E-field
- 0.5 cm electroluminescent gap
- 31 small PMTs for fine position sensitivity
- open plan – no surfaces - reduced feedback
- Lower-background PMTs available
- Copper construction
- Low-background xenon

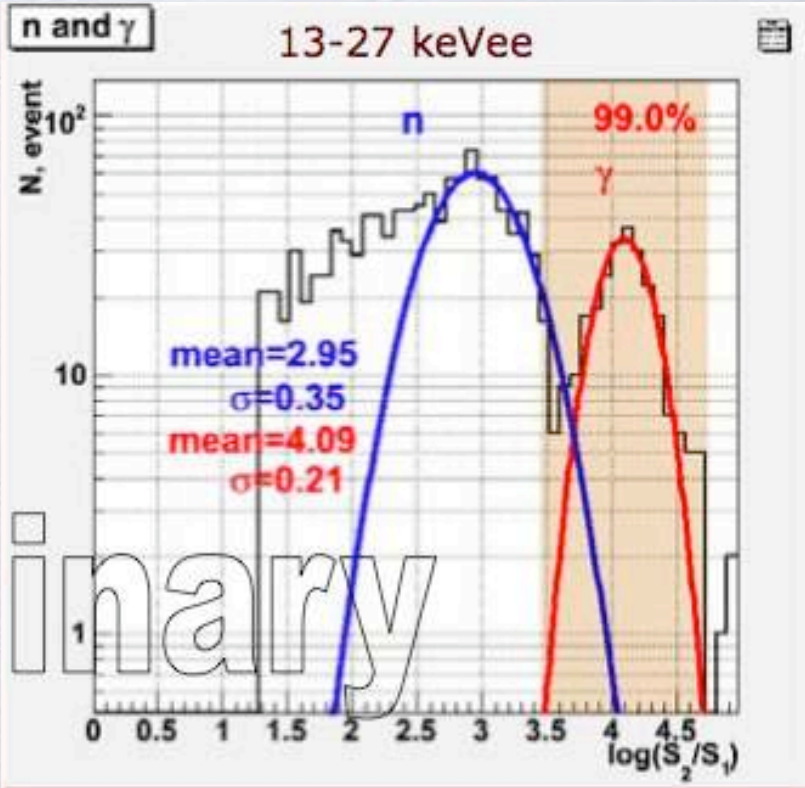




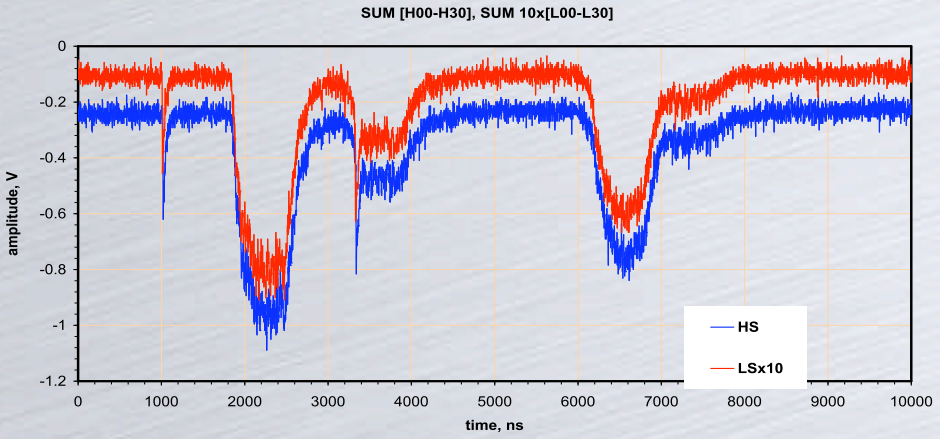
High field operation

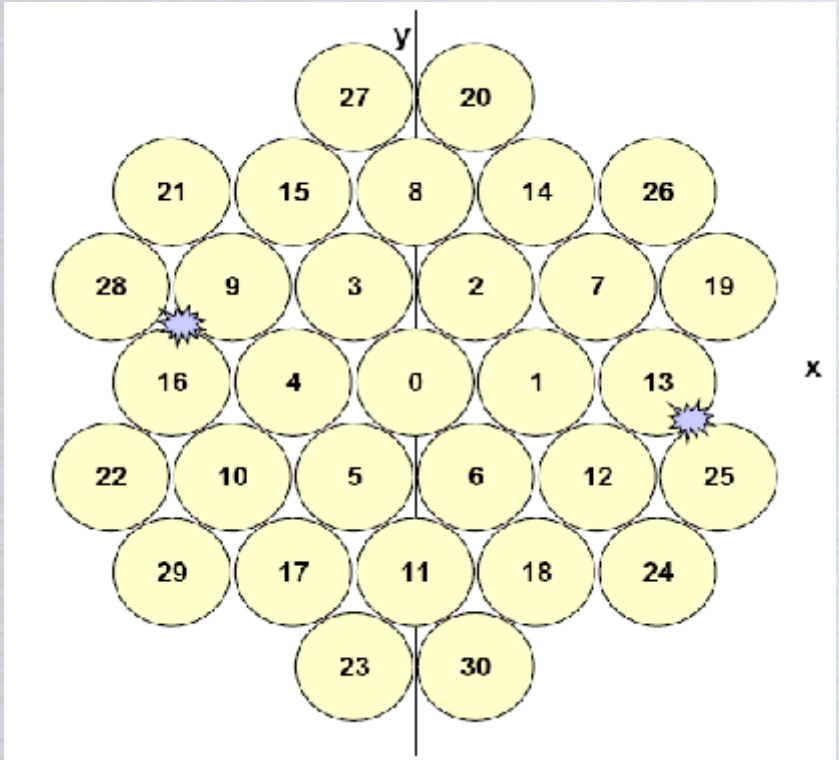
- ITEP Test chamber (7 PMTs, Z-III configuration)
- Operation at 4.5 kV/cm
- Excellent discrimination observed
- Full analysis underway
- Significant implications for future design

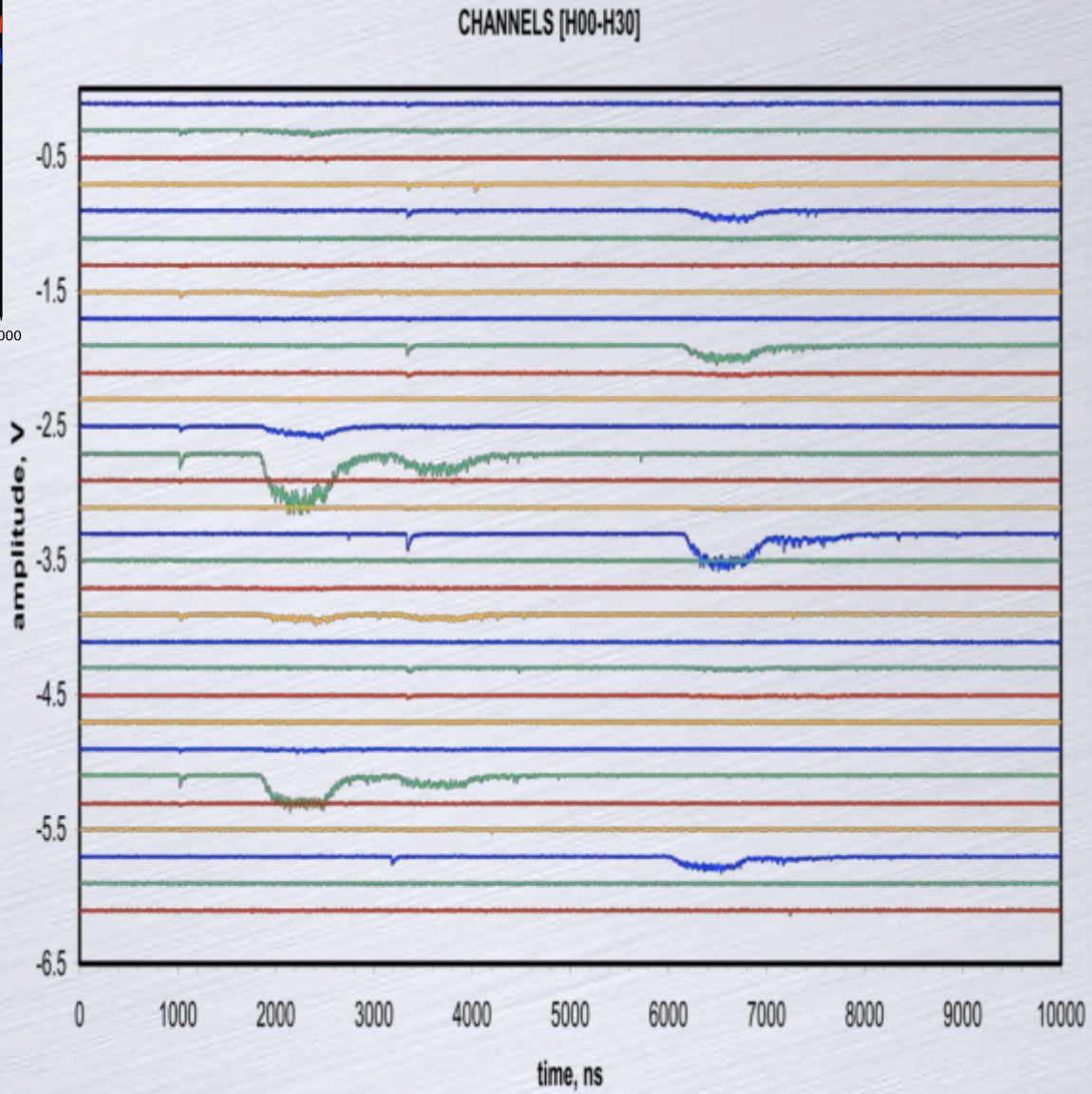




ZIII Position reconstruction

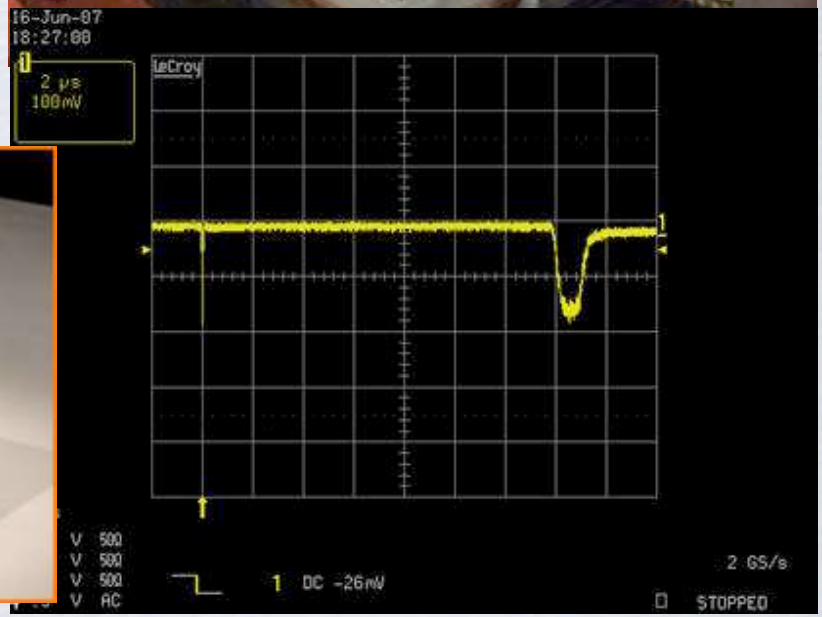


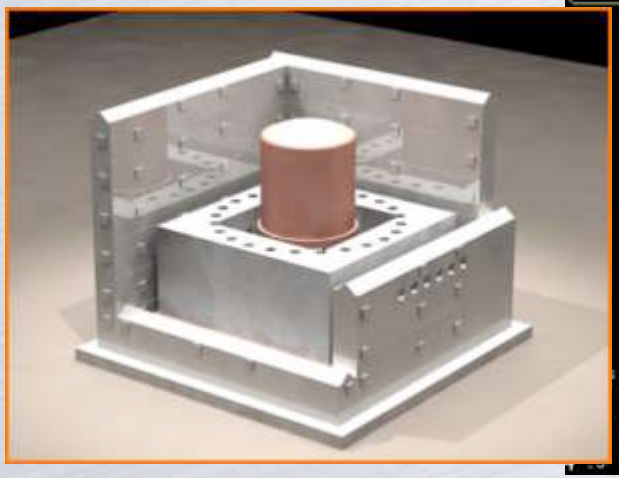




"First dark" pulses

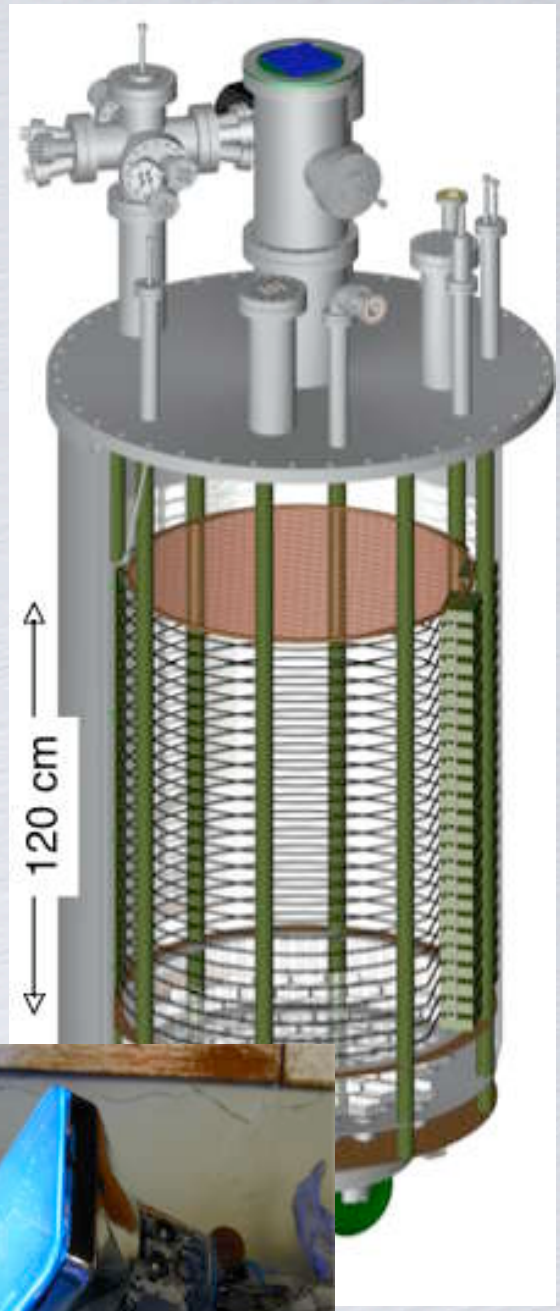
- Neutron shielding in place
- Full gas system operation
- Full PMT/DAQ operations
- Slow control operations
- Commissioning underway
- Expected full operations in the new year
- Veto + lower background PMT upgrades in construction



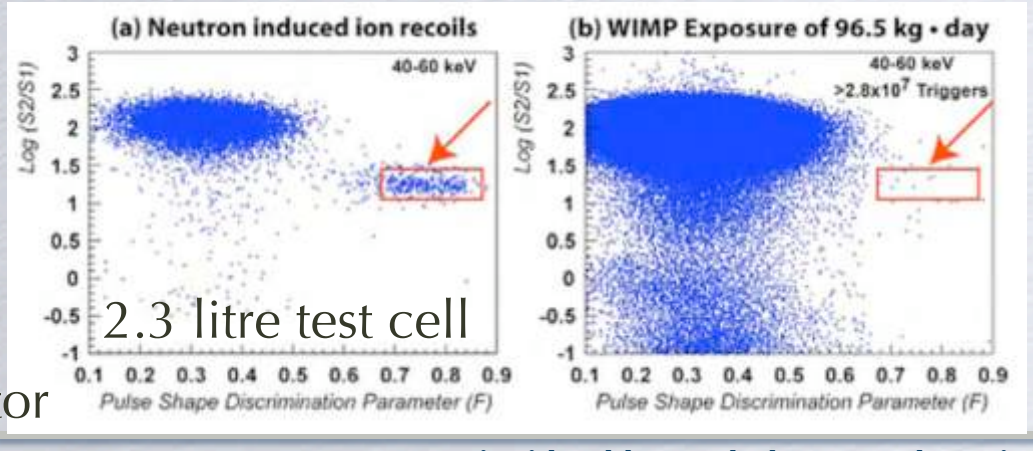


WARP / ArDM

- Two phase LAr detectors
- WARP
  - Dual discrimination (S2/S1 + PSD)
  - Results posted from 2.3l test cell
  - PMT (with TPB λ shifter)
- ArDM
  - 1 tonne prototype in construction
  - Thick - LEM for charge 500μm holes, 800μm pitch
  - PMTs (with λ shifter) for light (30%)



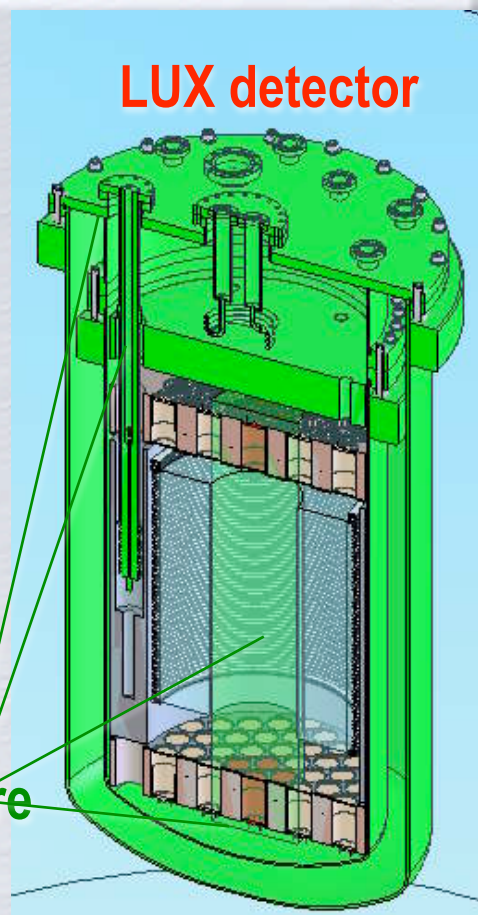
100 litre detector

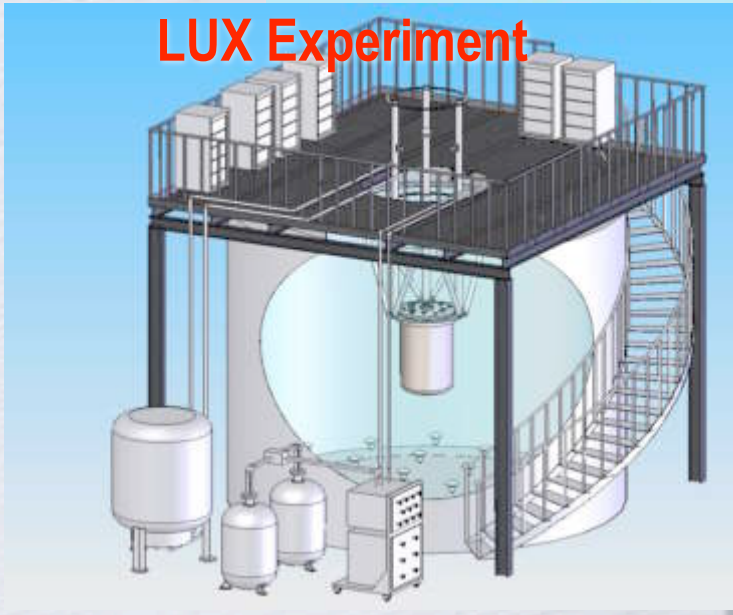


2.3 litre test cell

ELIXIR/LUX

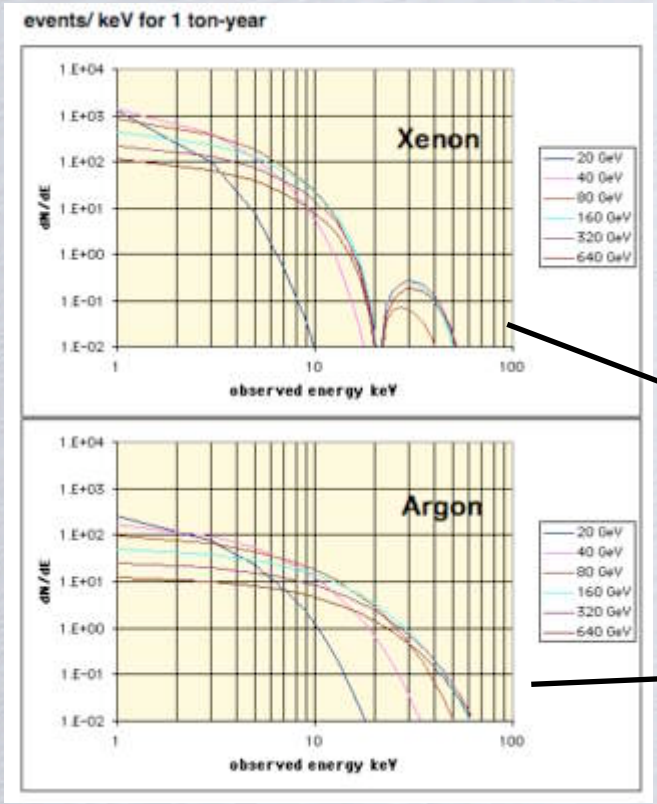
- ELIXIR
  - FP7 Design study for tonne scale xenon detectors
  - all EU xenon groups involved (ZEPLIN, XENON10)
- LUX: 300 kg Xe TPC with 100 kg fiducial
  - XENON10 (part) + US ZEPLIN + SuperK/SNO
  - 3D-imaging TPC eliminates surface activity, defines fiducial
- Backgrounds:
  - Internal: strong self-shielding of PMT activity
    - $\gamma/\beta < 7\times10^{-4}$ /keVee/kg/day, from PMTs (Hamamatsu R8778 or R8520).
    - Neutrons (α,n) & fission subdominant
  - External: large water shield with muon veto.
    - Very effective for cavern γ+n, and HE n from muons
    - Very low gamma backgrounds with achievable purity.
- LUXcore: Final engineering for large-scale det.
- Clear route to tonne scale detectors
  - Caveat: high field discrimination

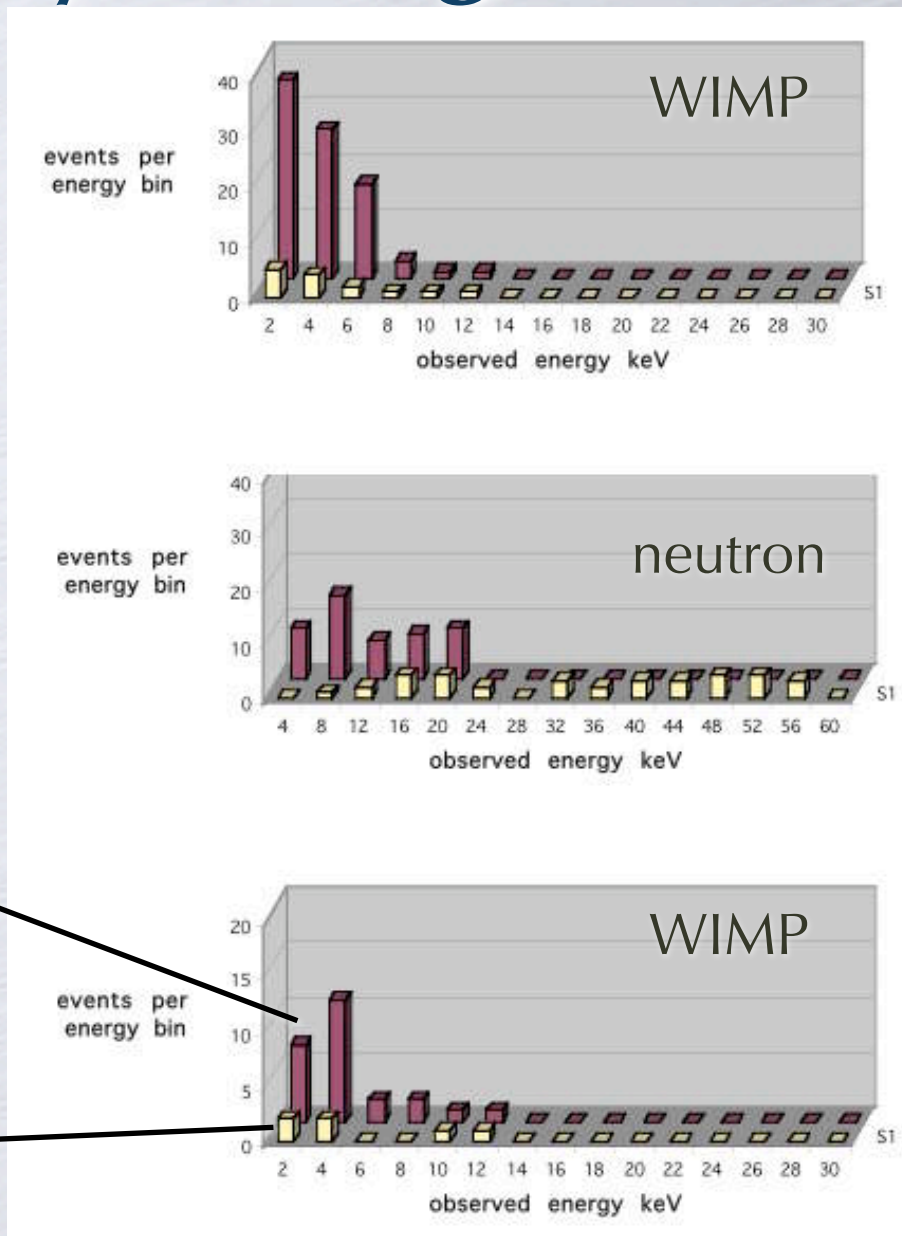




Complementarity of targets

- Comparison of rates in LXe and LAr detectors
- Shows effect of A^2 and form factor





Liquid noble gas detectors

- Noble gas DM detectors address many aspects required for next generation detectors
  - Large scale targets possible
  - High purity targets
  - Surface and volume contaminant control
  - Self-shielding and fiducialisation
- Noble '(r)evolution' underway
  - ZEPLIN-II posted leading EU sensitivity curve
  - XENON sensitivity (in review) leading sensitivity curve
- Future plans well advanced
  - Strategy dependent on high field performance
  - Detailed R&D of low energy response underway