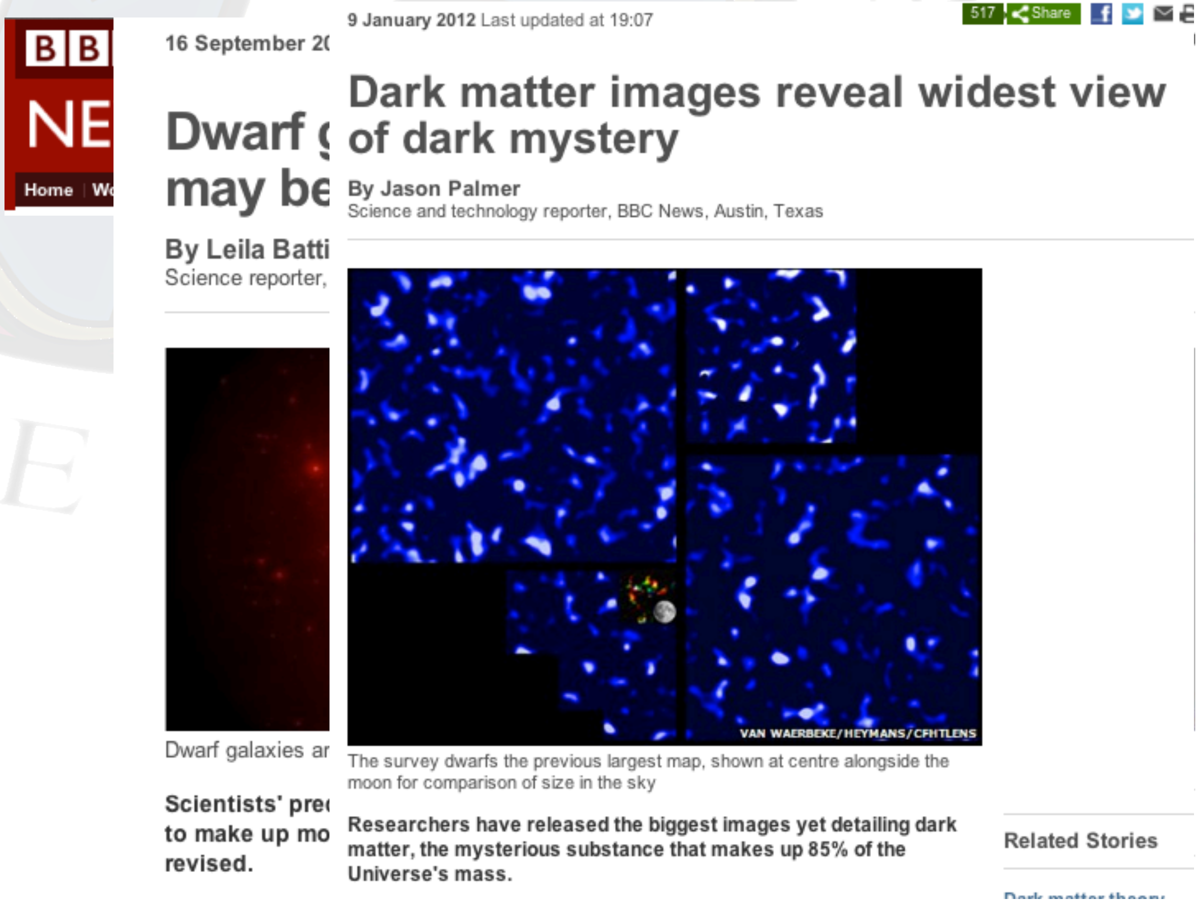
Final Results of the ZEPLIN-III Direct Dark Matter Search

DM in the news...
...easy come, easy go


BBC NEWS
Home | Wo

16 September 20

Dwarf g
may be

By Leila Batti
Science reporter,

Dwarf galaxies ar

Scientists' pre
to make up mo
revised.

9 January 2012 Last updated at 19:07

517 Share

Dark matter images reveal widest view of dark mystery

By Jason Palmer
Science and technology reporter, BBC News, Austin, Texas

The survey dwarfs the previous largest map, shown at centre alongside the moon for comparison of size in the sky

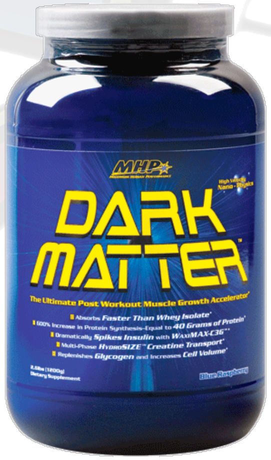
Researchers have released the biggest images yet detailing dark matter, the mysterious substance that makes up 85% of the Universe's mass.

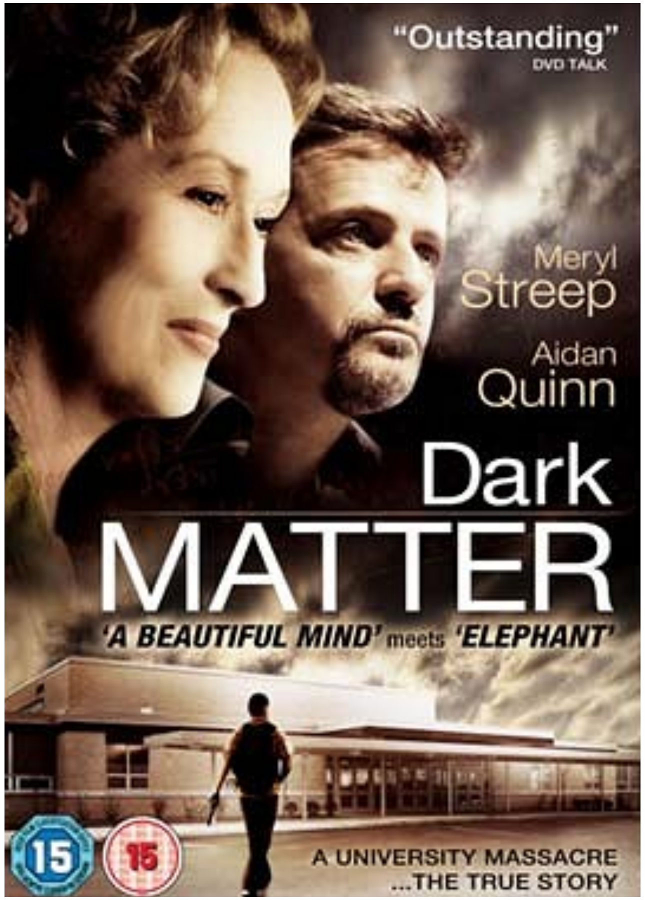
Related Stories

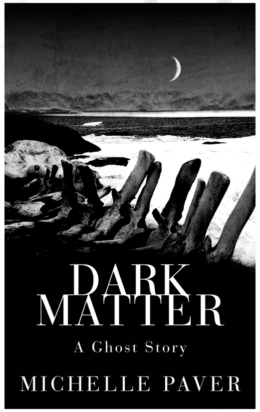
Case for DM
remains very,
strong
(Sorry Carlos!)

See talk of
Carlos Frenk,
same time
same place
next week!

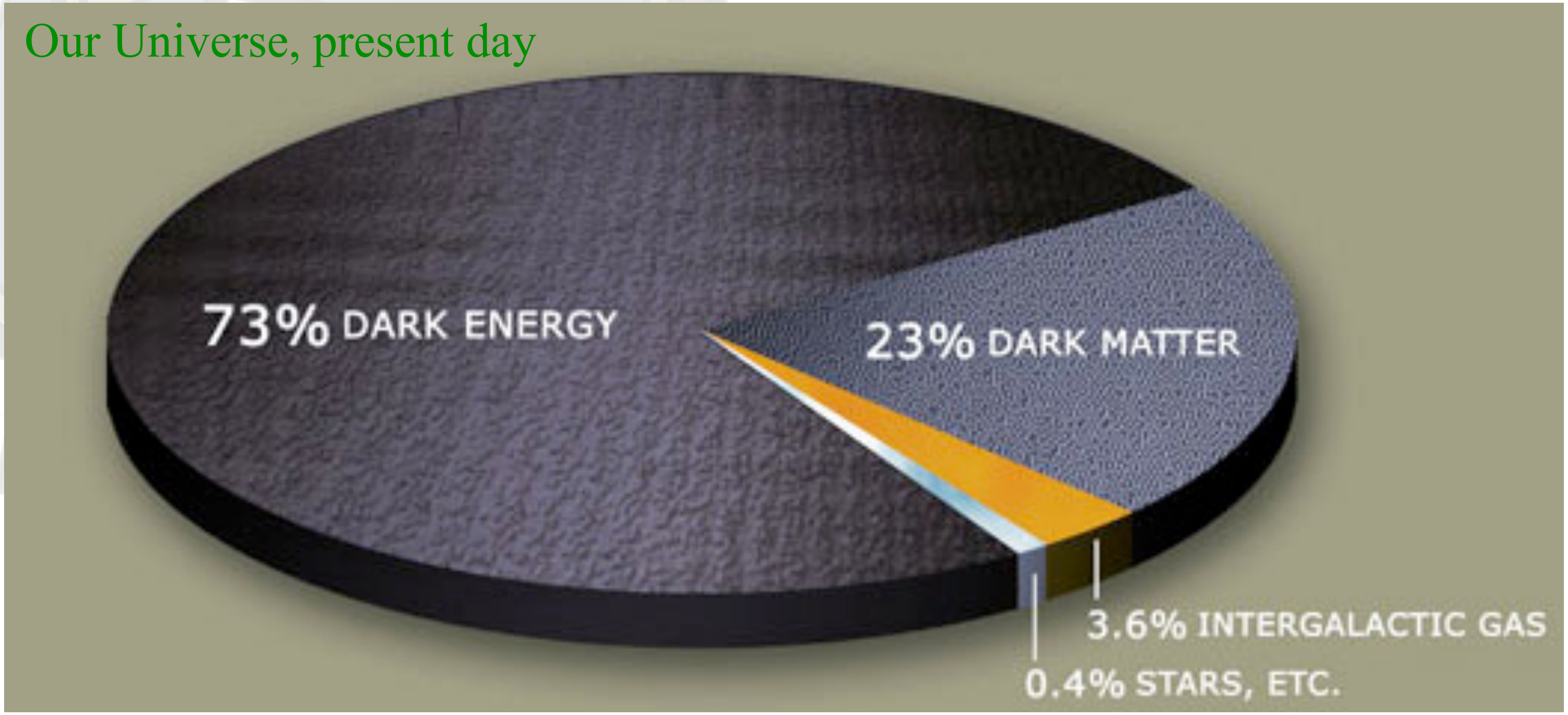
And don't forget DM in a wider public awareness!







For this talk, basic premise...



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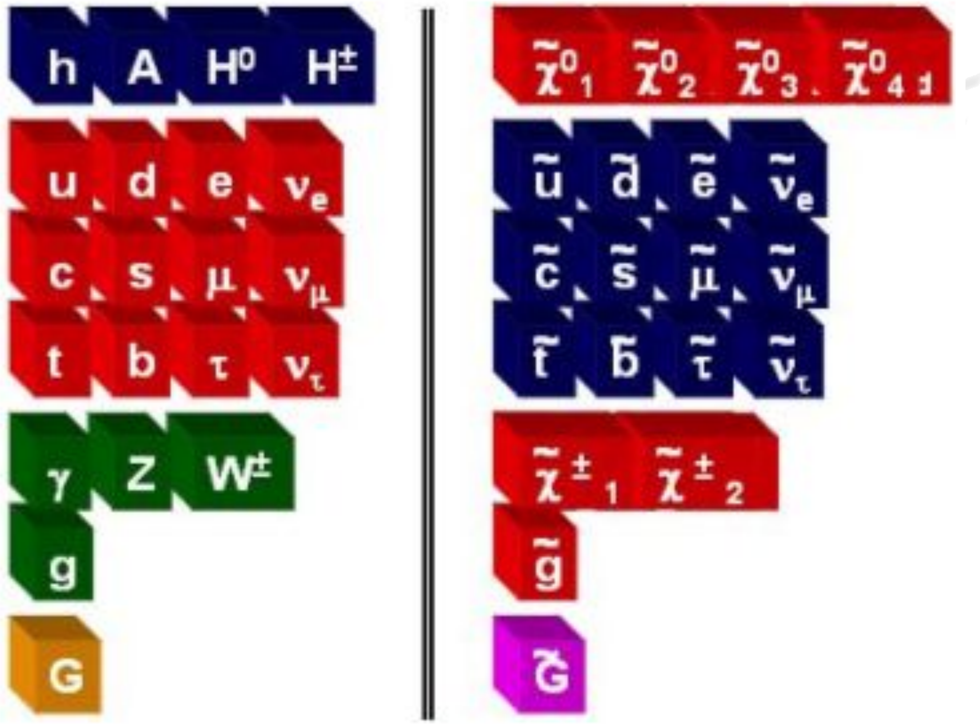


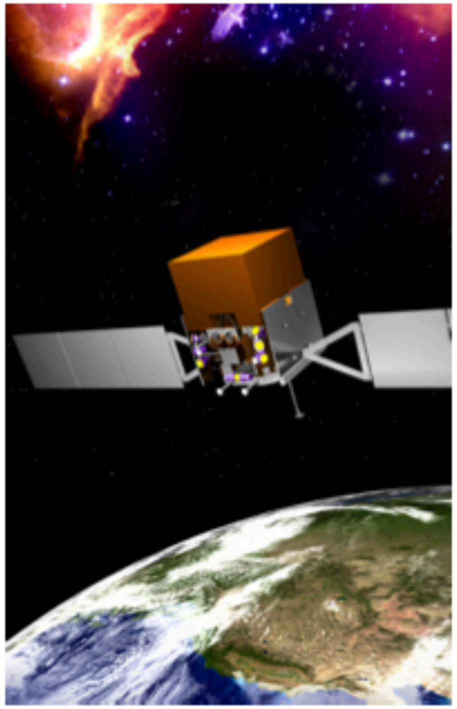
WIMP is the lightest supersymmetric particle ('LSP'), χ, a linear combination of bino, wino and Higgsino fields.

$$\chi = \alpha\tilde{B} + \beta\tilde{W} + \gamma\tilde{H}_1 + \delta\tilde{H}_2$$

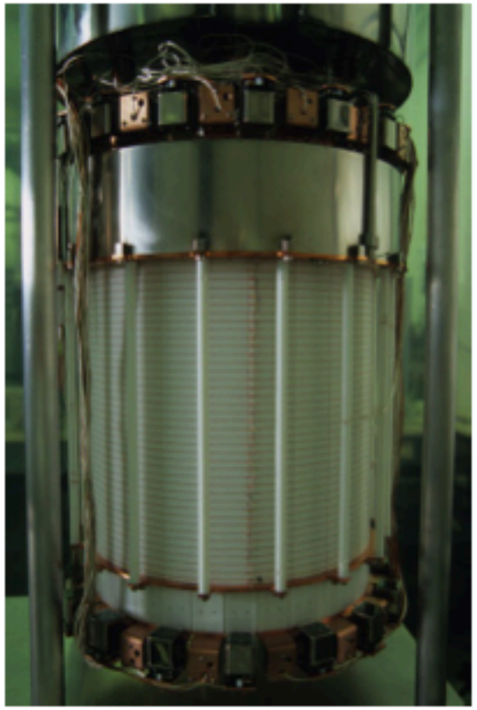
If SUSY is wrong, that doesn't stop galaxies rotating too fast.
Direct DM searches are sensitive to many non-SUSY signals.

How to search for dark matter?

Indirectly



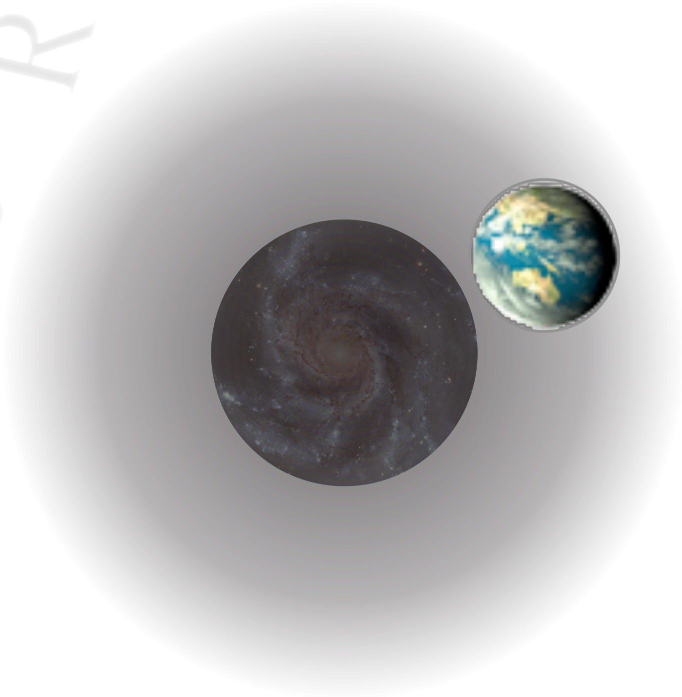
Directly



Collider

For this talk, basic premise...

- Earth should be passing through a halo of weakly interacting massive particles



- We search for the rare collisions of WIMPs with normal matter here on Earth.

How to directly detect dark matter?

In the most simple terms...

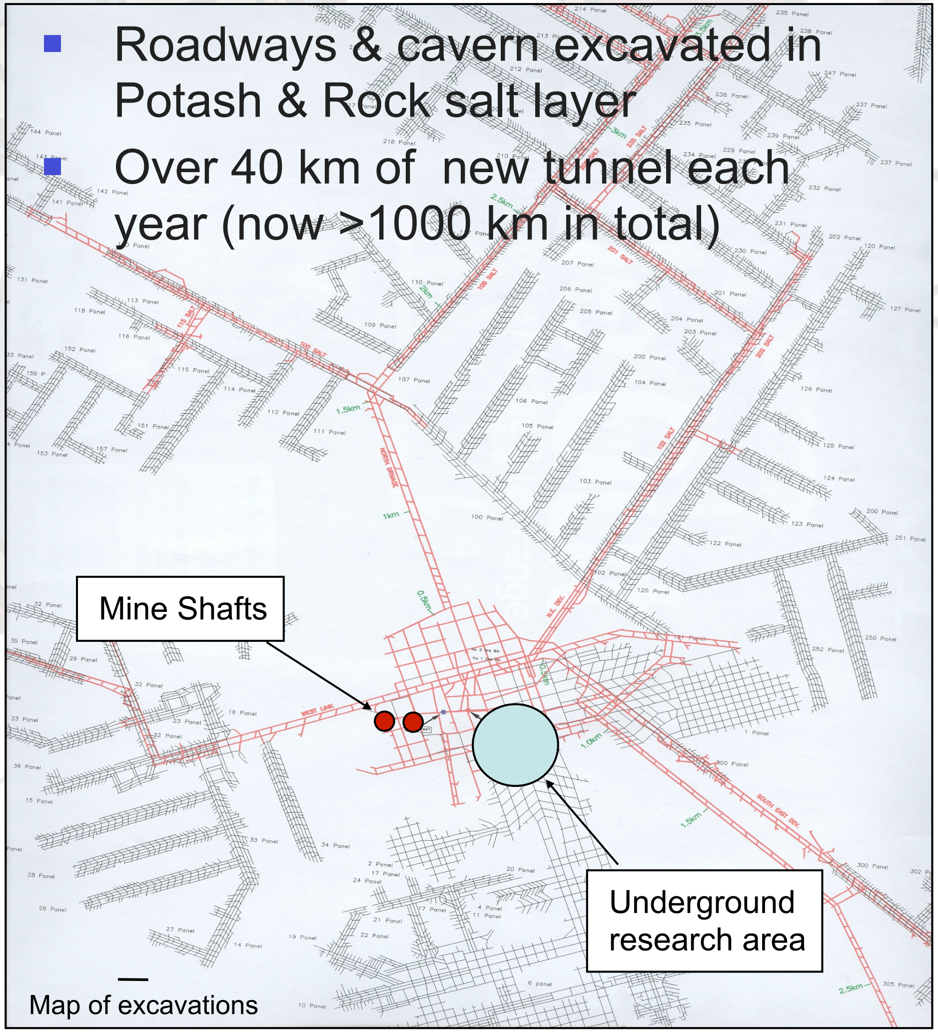
Make a device that should see *nothing*
from normal physics

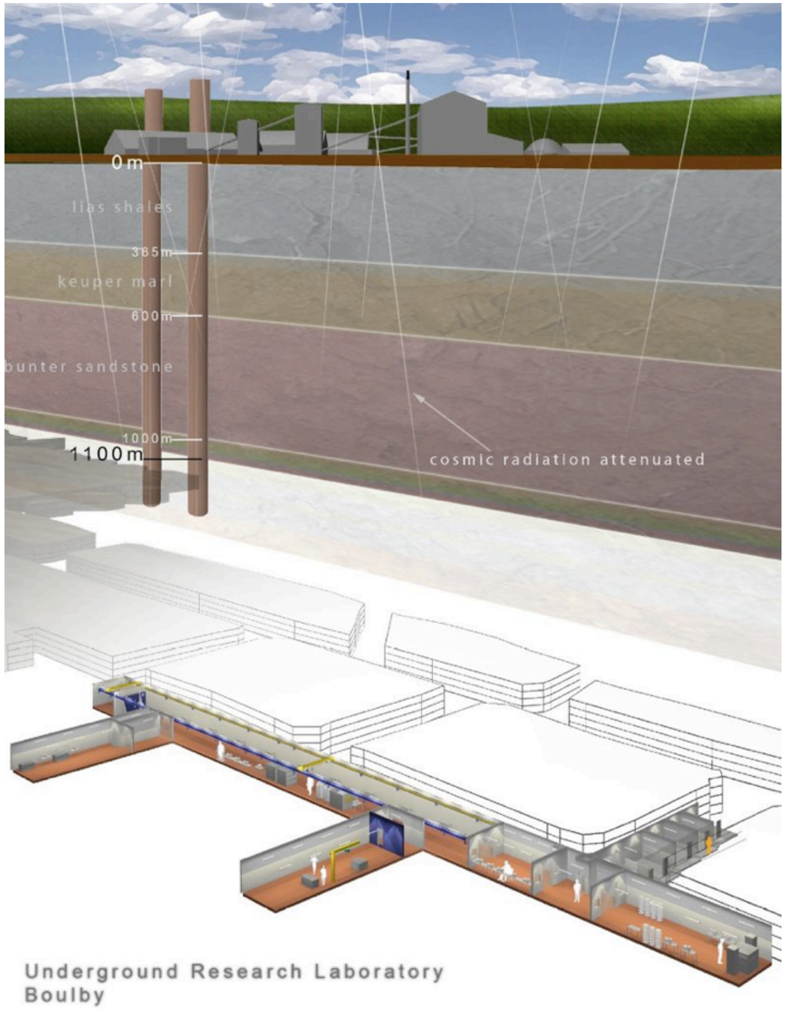
And see if there's anything still there...

WHERE SHALL WE SEARCH?

The Boulby Mine - A very dark place!

- Roadways & cavern excavated in Potash & Rock salt layer
- Over 40 km of new tunnel each year (now >1000 km in total)





The natural radioactive backgrounds <u>greatly</u> reduced

Low background is not easy...

Cosmic Rays
- Muons produced in showers
  - and muon-induced neutron production

Radiological Backgrounds
- From surrounding environment
  - (rock, etc.)

Construction Materials
- Shielding
- Detector interior
- Photo Multiplier Tubes
  - (PMTs)

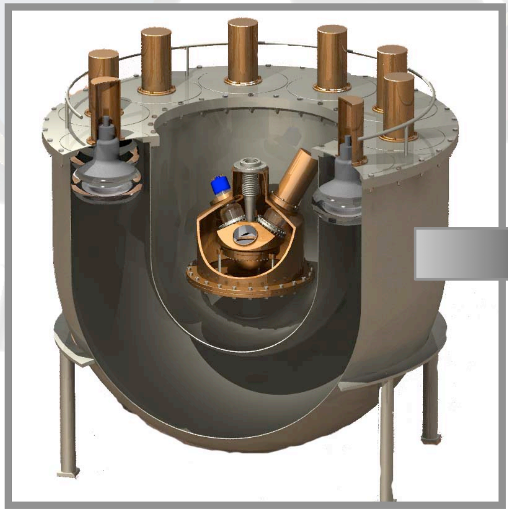
Discrimination between event species, veto detector,…

Low background is not easy...

- <u>Every</u> component is measured for radioactivity (U, Th, K)
- Fission, (α,n), and γ−ray impact of that activity evaluated through full Monte Carlo
- Replacement or redesigns if necessary
- Gamma rays from PMTs limited the first science run
- Second Science Run planned from start

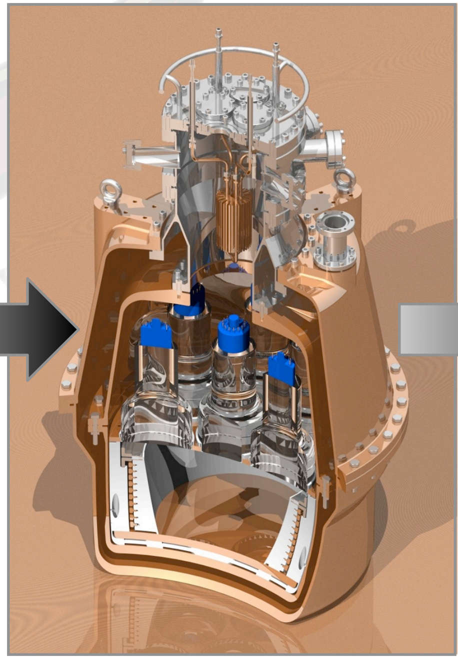
The ZEPLIN Programme

ZEPLIN-I



Single phase

ZEPLIN-II



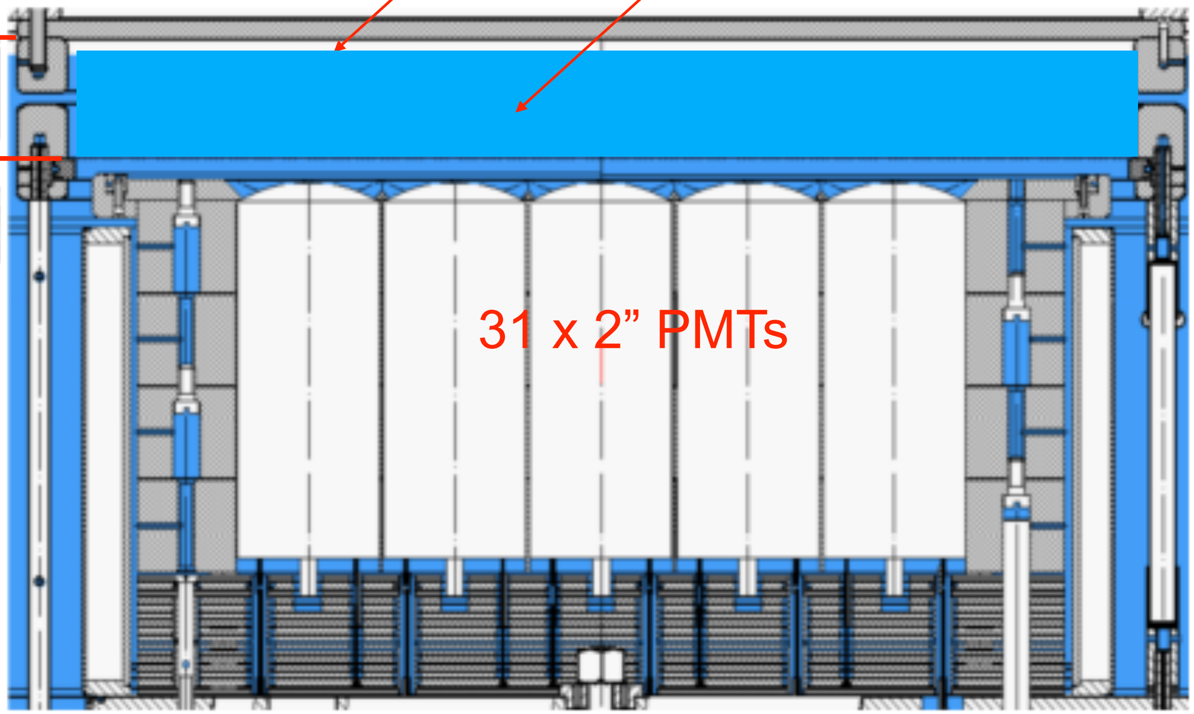
Two phase
Low field

ZEPLIN-III

Two phase, high field, low bkgd

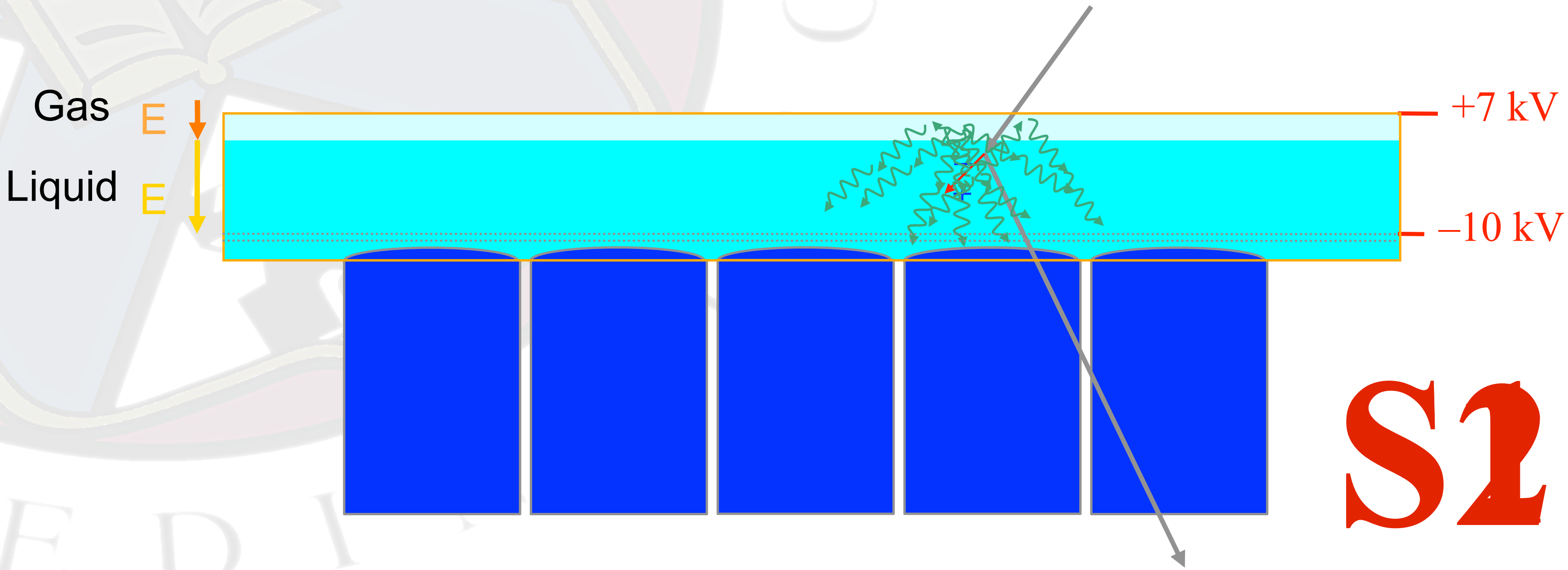
Two-phase Xenon

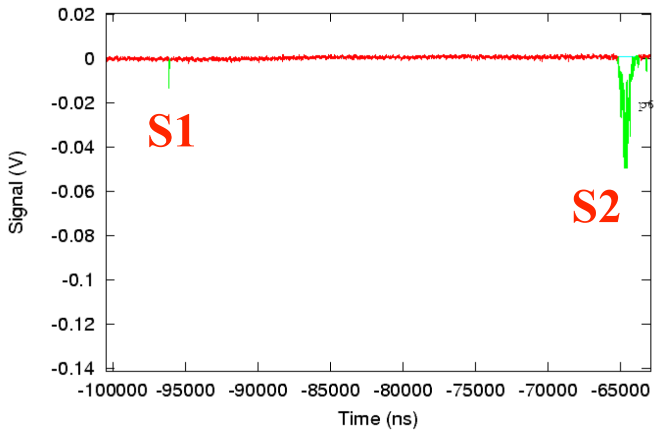
ZEPLIN-III



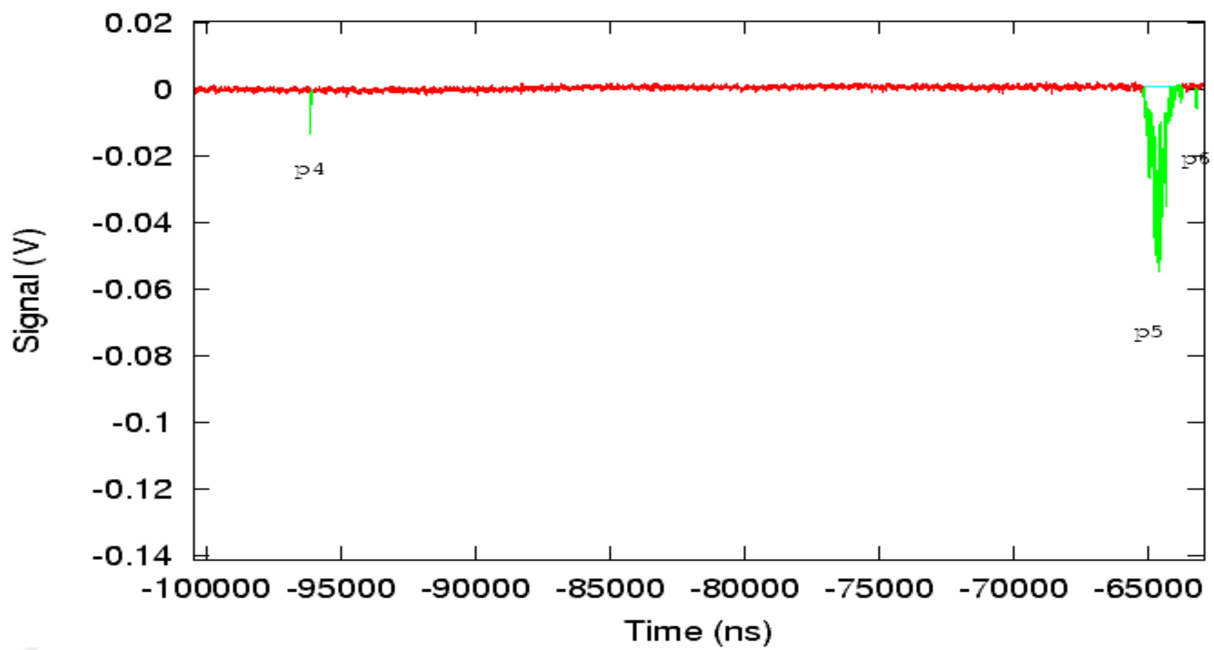
12 kg xenon

Two-phase technique



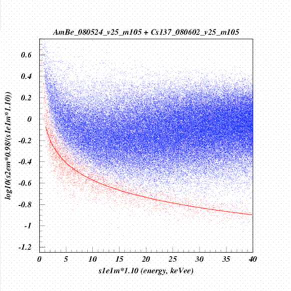


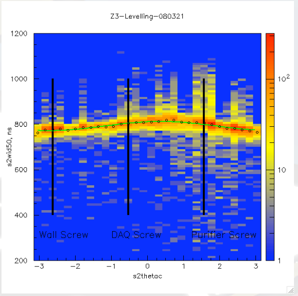
S1 and S2 timelines

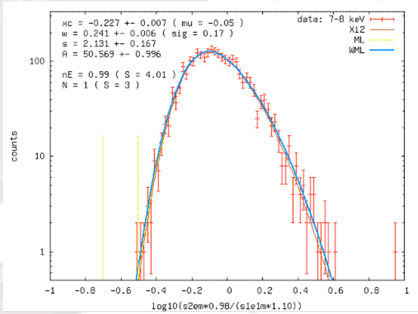


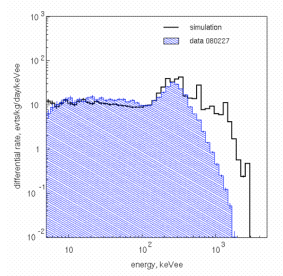
- S1 short
- S2 long
- Time between S1 and S2 gives depth
- Discrimination:
  - S2/S1 ~400 e-/γ
  - S2/S1 <<400 NR

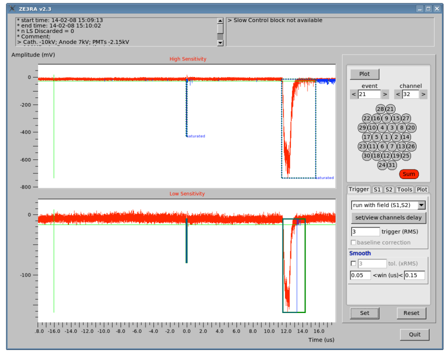
First Science Run: analysis

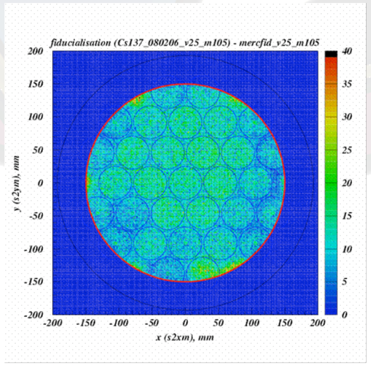


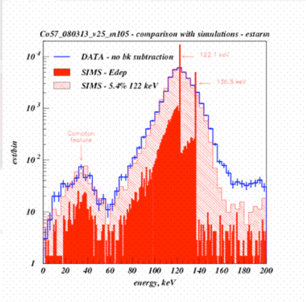


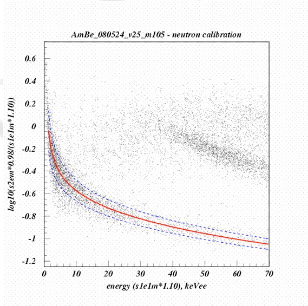


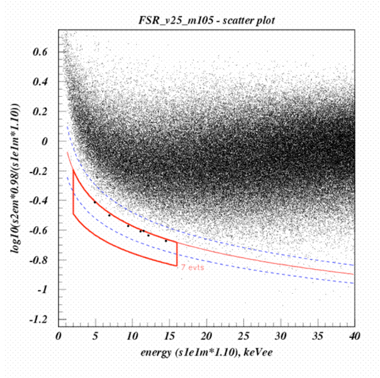


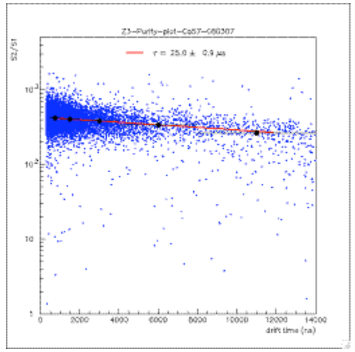


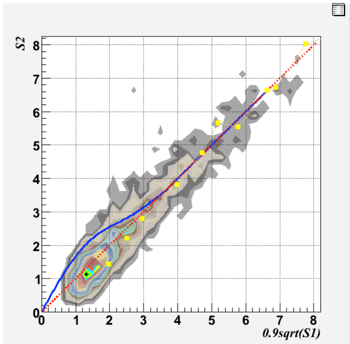


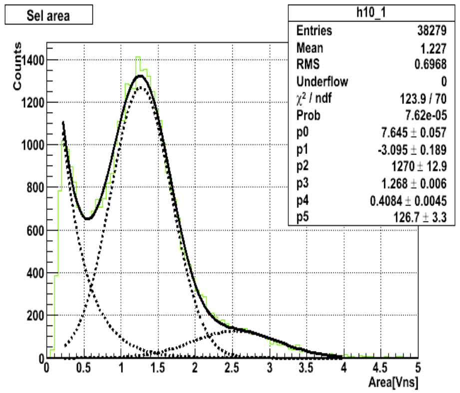


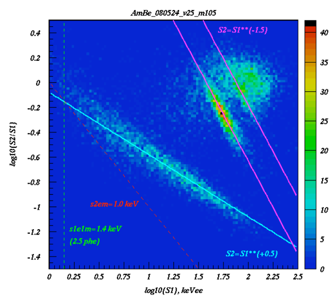


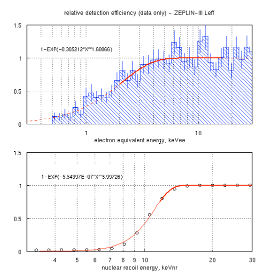












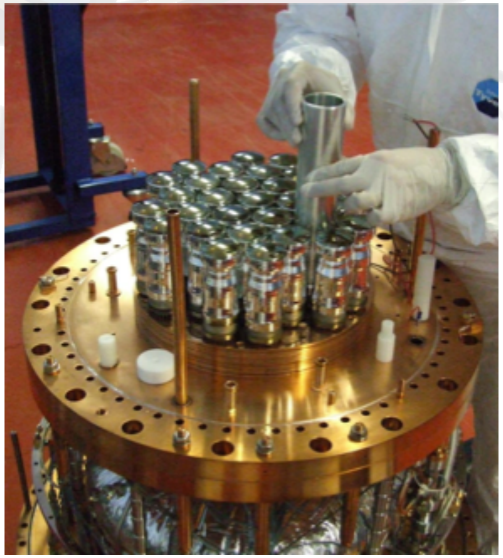
First Science Run

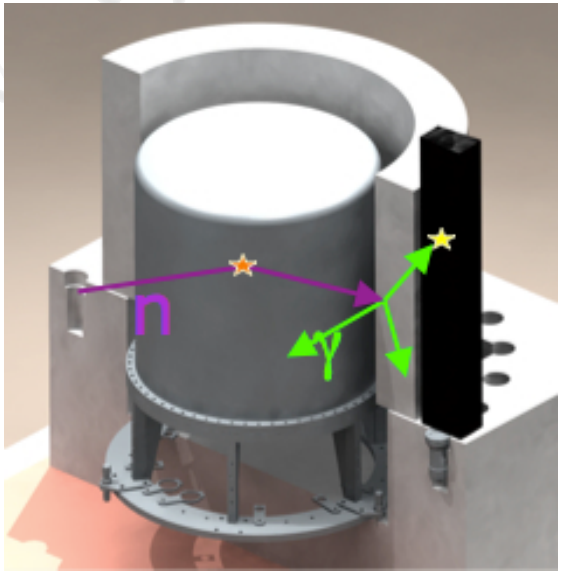
- Primary Science Publications

  - V. N. Lebedenko et al., Phys. Rev. D 80: 052010 (2009)
    Scalar cross-section excluded above 8.1×10^{-8} pb (90% CL) at 60 GeV/c2
  - V. N. Lebedenko et al., Phys. Rev. Lett. 103: 151302 (2009)
    WIMP-neutron cross-section excluded above 1.9×10^{-2} pb (90% CL)
  - Akimov et al., Phys. Lett. B 692: 180 (2010)
    Explanation of DAMA with inelastic DM model ruled out at 87% CL

Phase-II Upgrades

- Commissioned in 2009/10
- New photomultiplier array (greatly reduced background)
- New anti-coincidence veto (background reduction & diagnostic)
- New calibration hardware (reduction of systematics)
- System automation (underground effort, improved stability)

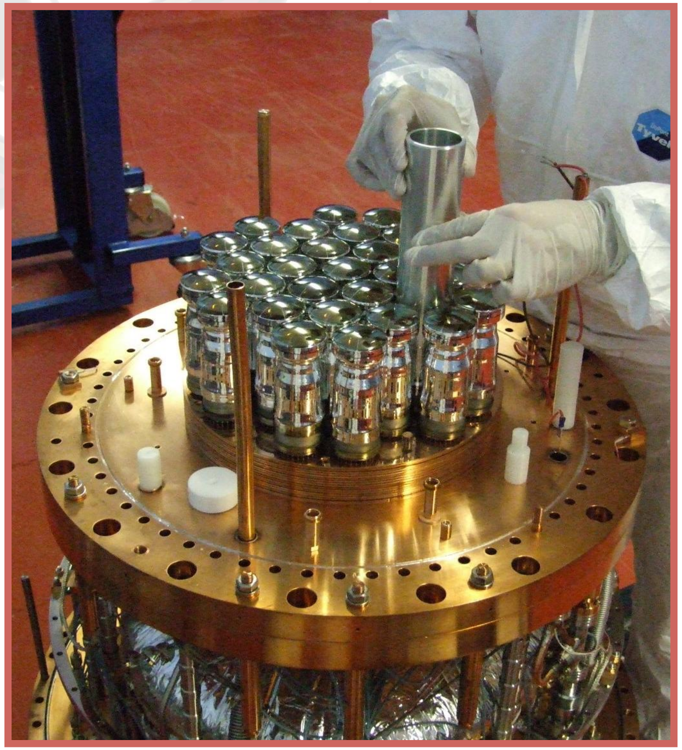




Complete remote operations (duty cycle 96%)

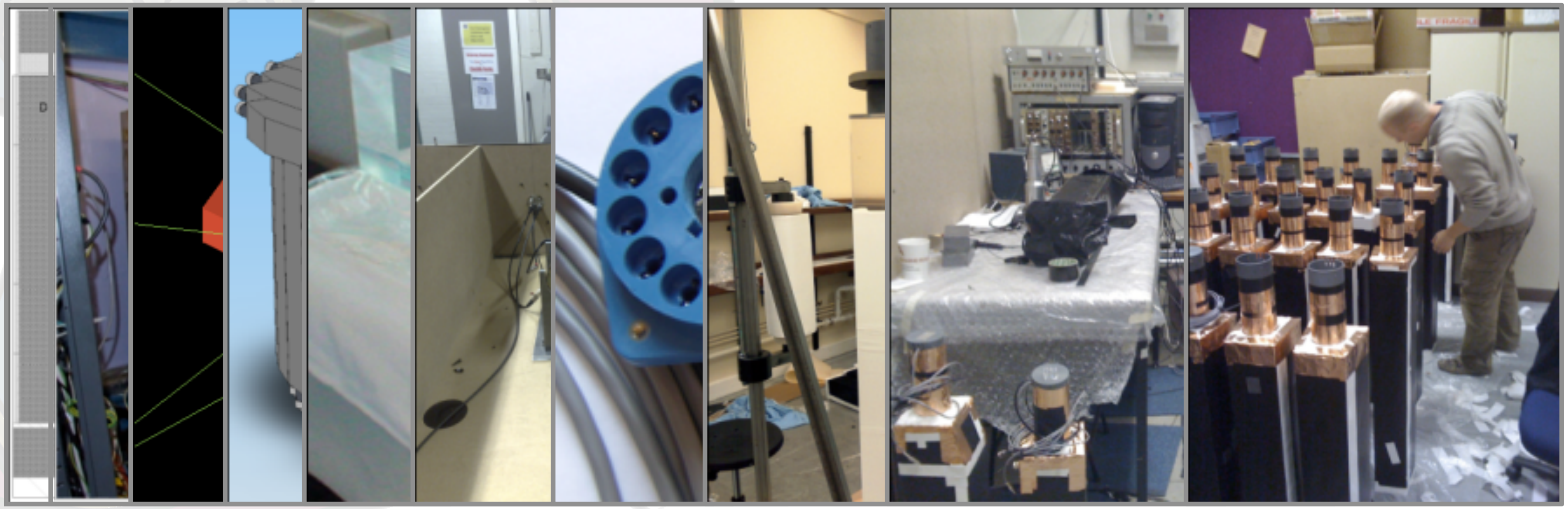
Photomultiplier Upgrade

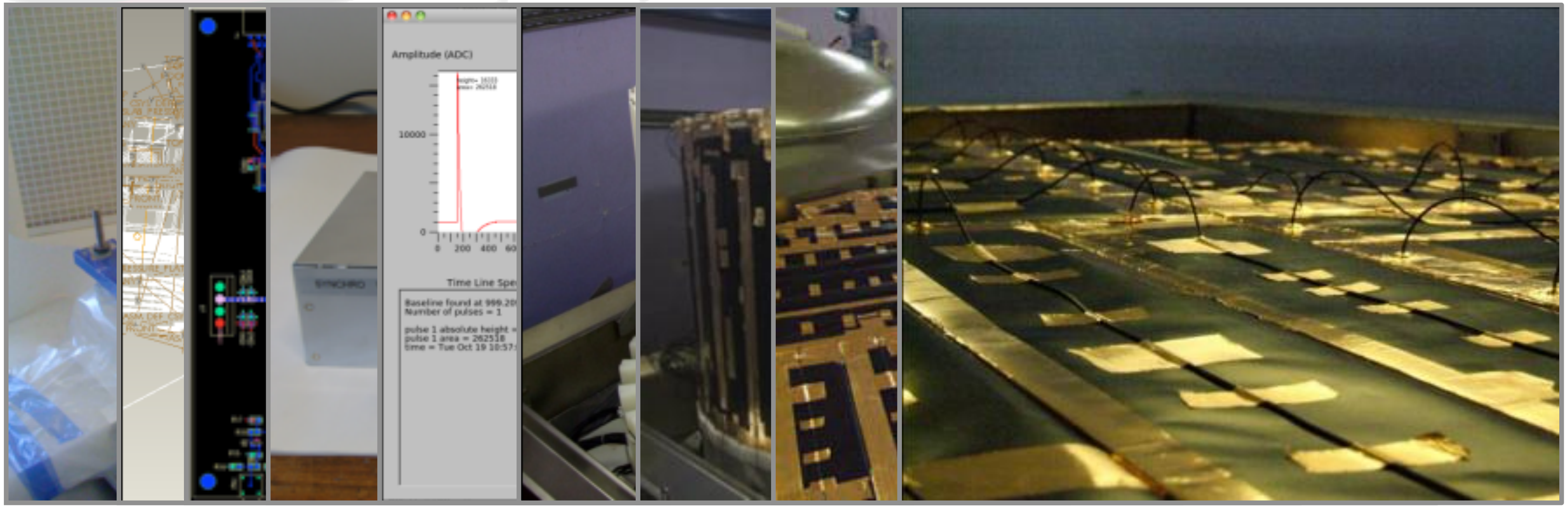
- PMT gamma-rays limited sensitivity of first run by a large factor
- Custom design for ultra low-background tubes, pin-by-pin compatible
- Assembly onto ZEPLIN-III array in early 2010
- Aiming for 30x reduction in radioactivity to <50 mBq/PMT



Retrofitting of Veto

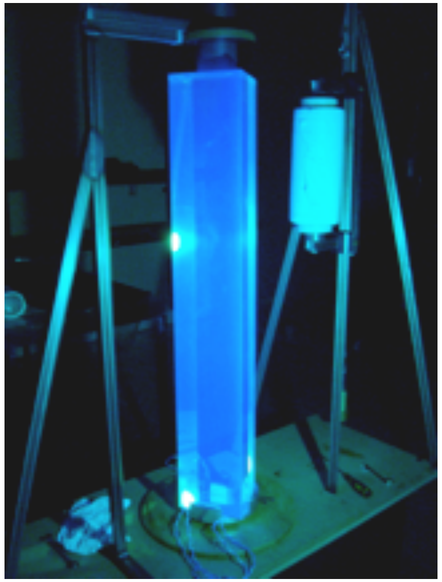
"made in scotland, from girders"

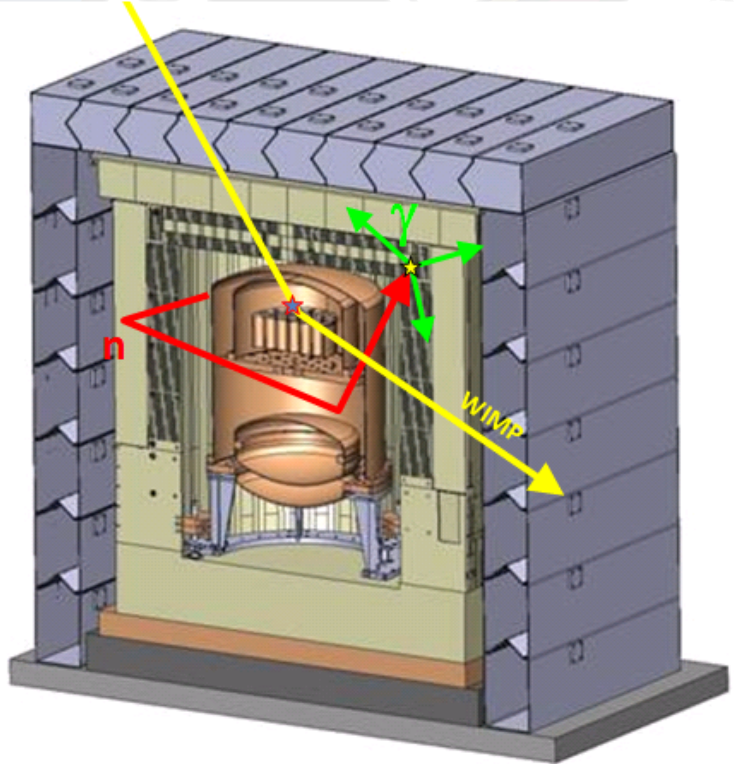


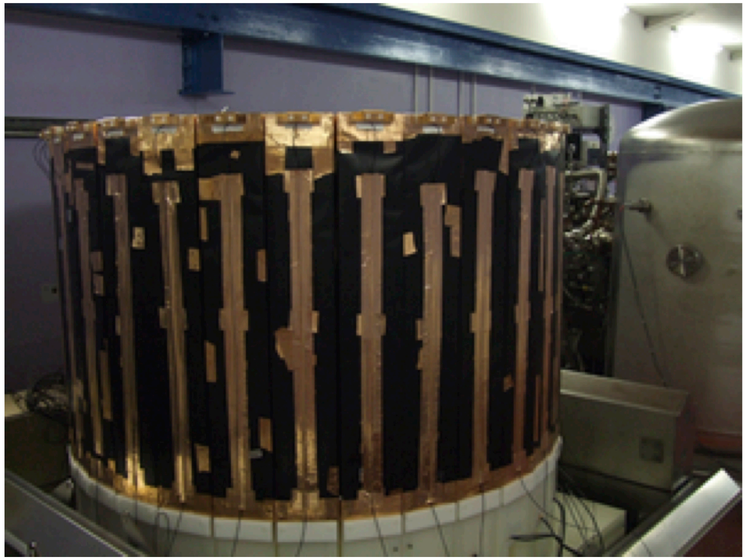


Veto Upgrade

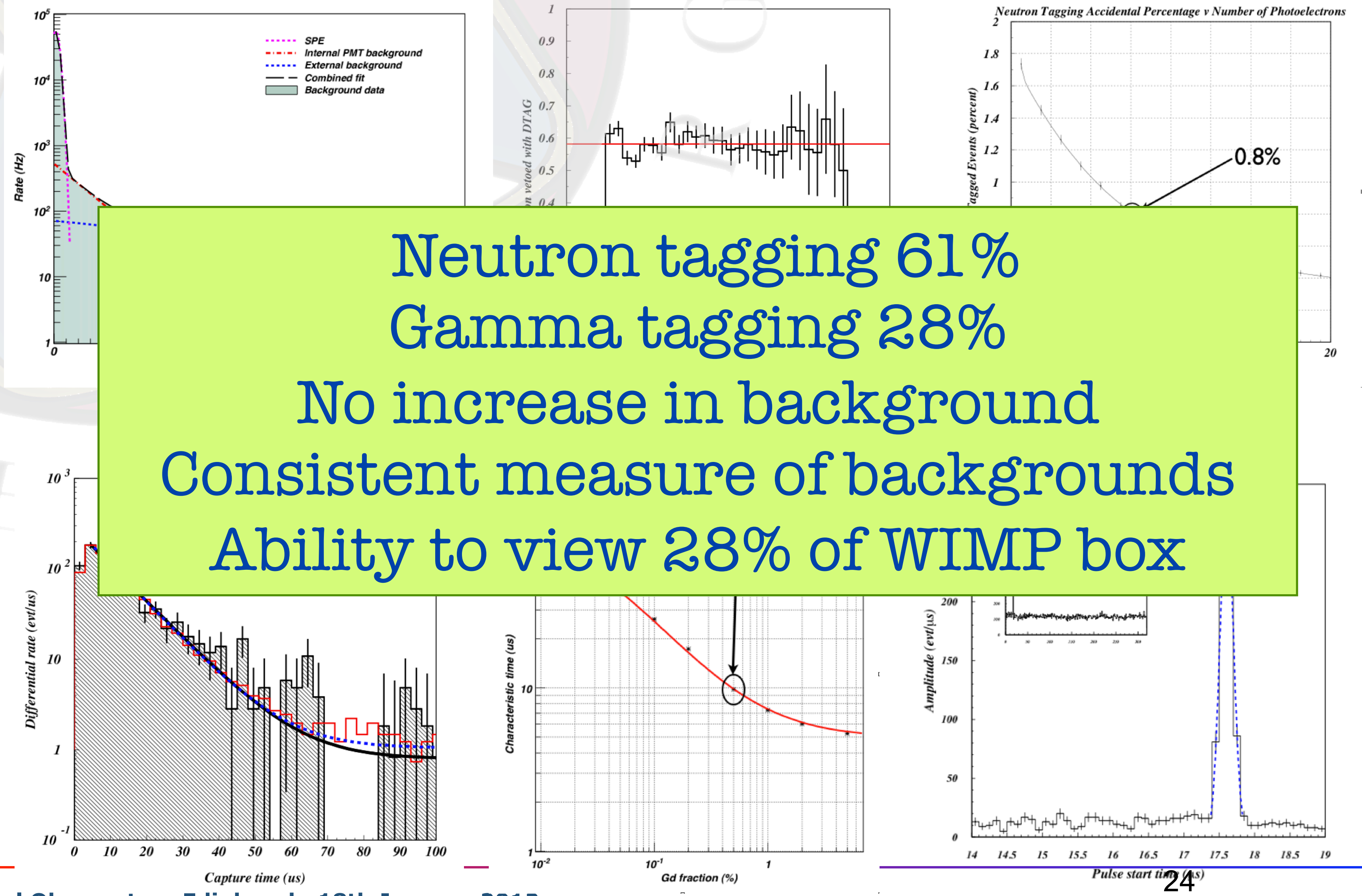
- 1 tonne plastic scintillator in 52 modules (UPS-923A)
- Scintillator 15cm thick, Gd loaded polypropylene 15cm thick
- Dedicated DAq and monitoring system
- Radiation budget very low
- *Design: Astroparticle Physics 34 (2010) 151-163*
- *Performance: Astroparticle Physics 35 (2011) 76-86*
- *Quenching factor: Phys. Rev. C Submitted.*





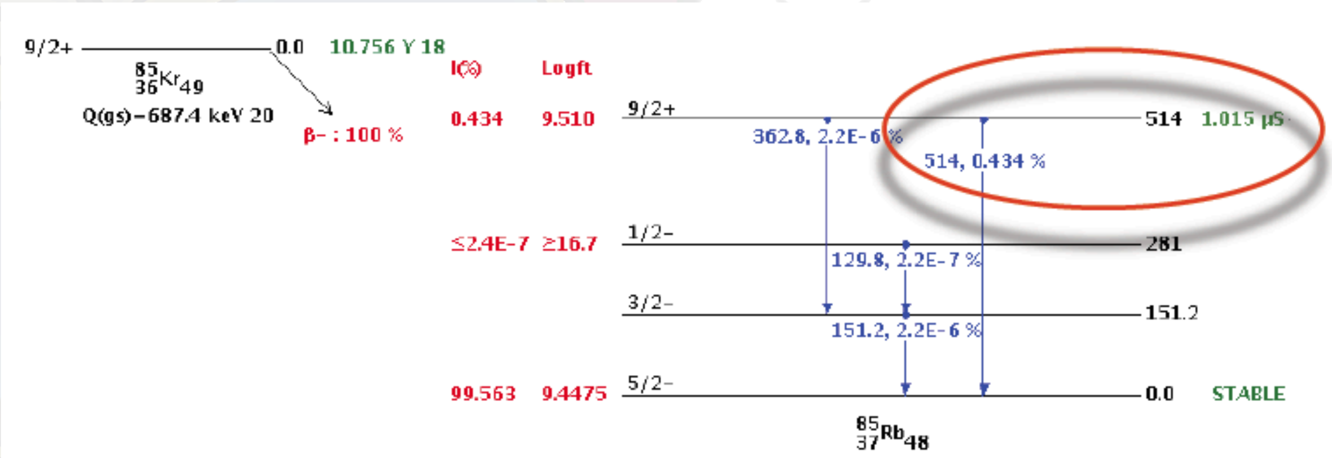


Veto Performance

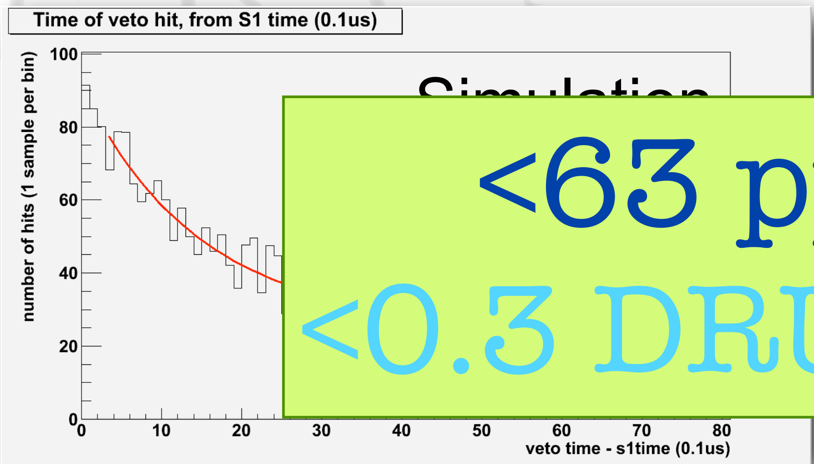


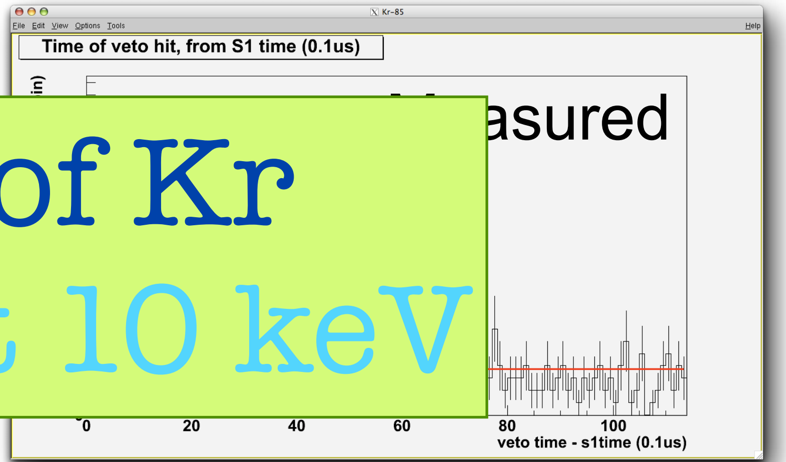
Neutron tagging 61%
Gamma tagging 28%
No increase in background
Consistent measure of backgrounds
Ability to view 28% of WIMP box

^{85}Kr contamination



ΔT=time(β in Z3) - T(γ in Veto)



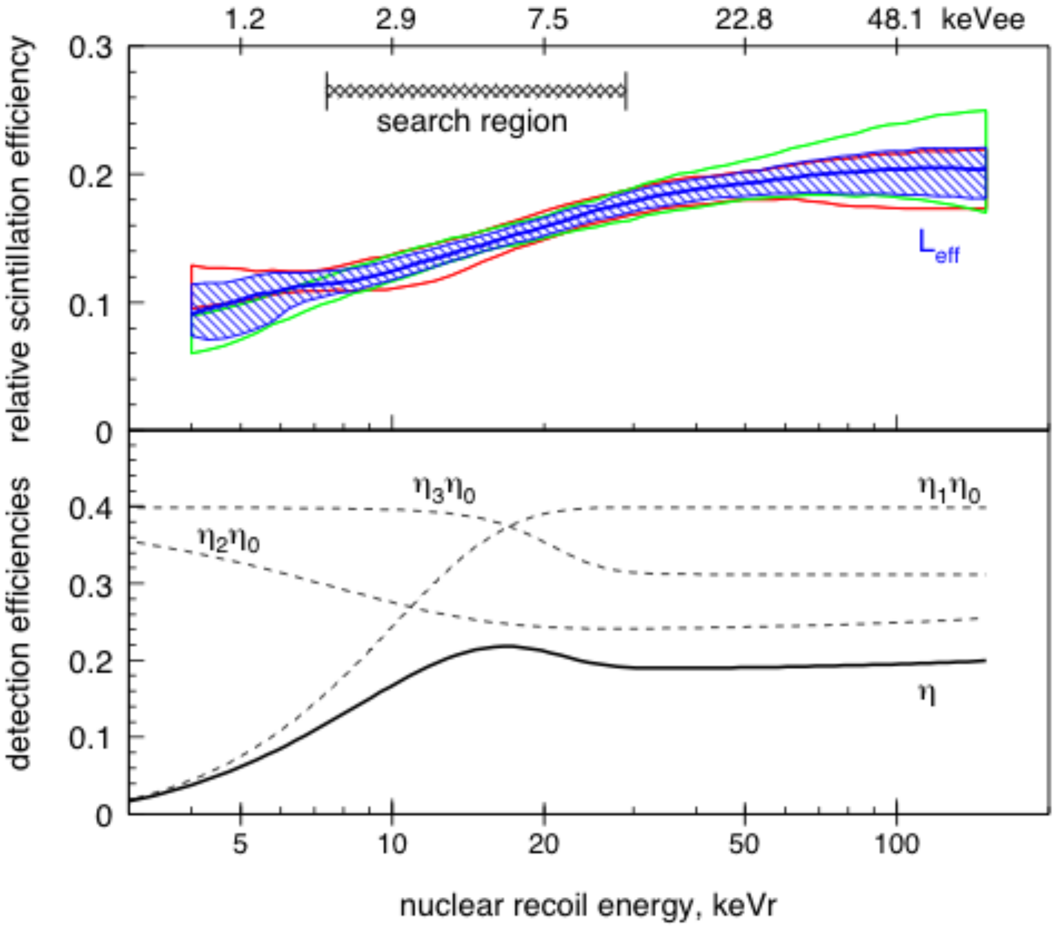


<63 ppb of Kr

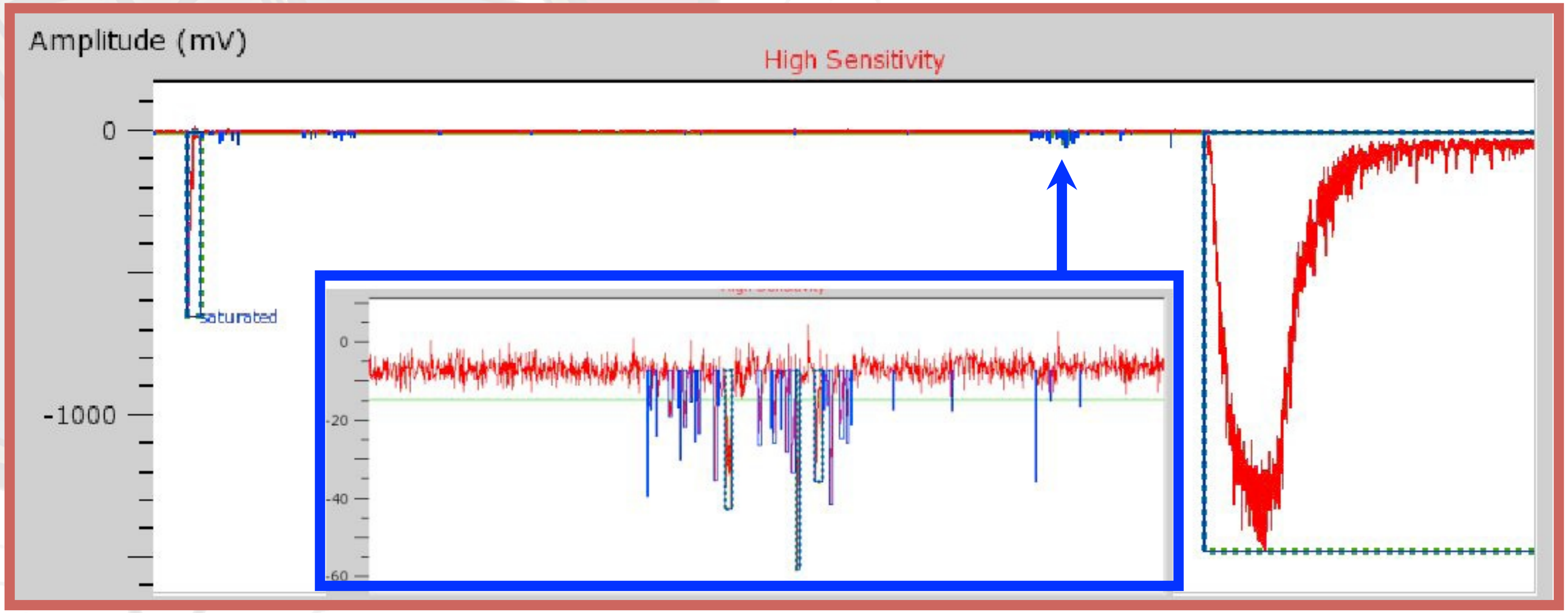
<0.3 DRU at 10 keV

New "L_{eff}" Analysis

- Ratio of light emitted by a nuclear recoil to that of an electron recoil of the same energy
- Key input for analysis
- Response at very low energy important (we have a very low threshold instrument)
- Phys. Lett. B 705 (2011) 471-476



Single Electron Emission

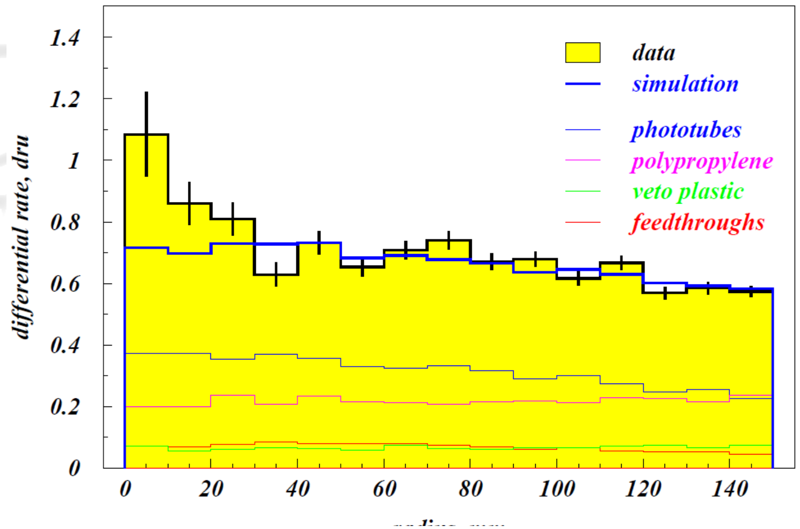


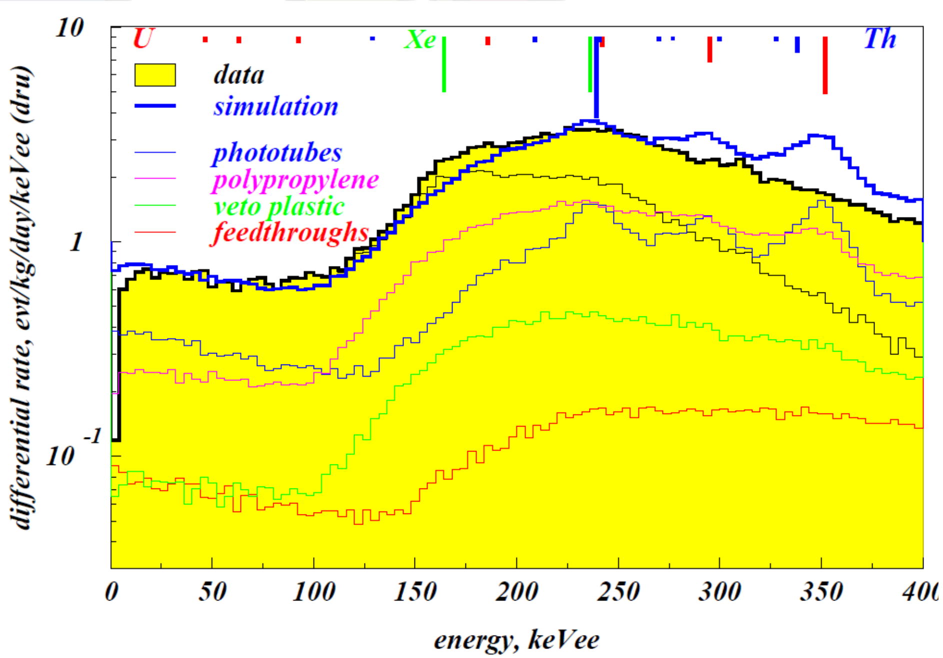
We can see individual electrons being pulled from the liquid surface!

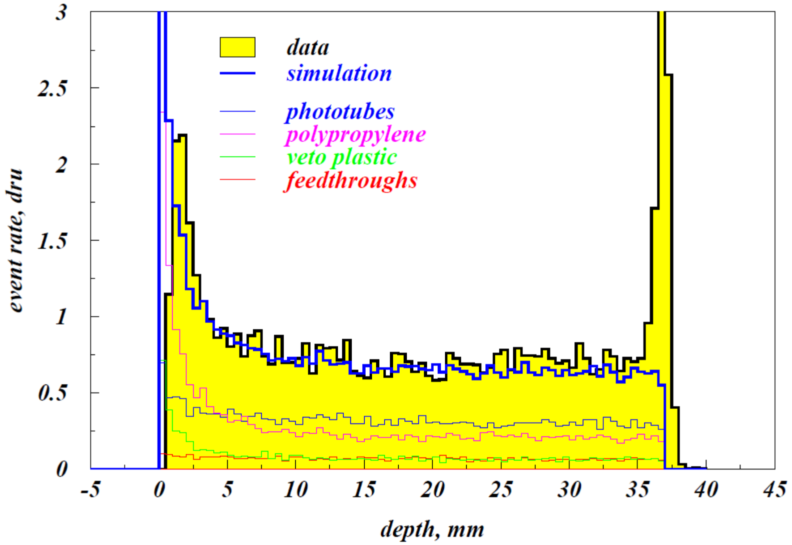
Possible application to detection of coherent neutrino scattering. Submitted to Journal of High Energy Physics.

SSR Electron recoil backgrounds

- 0.75 evt/kg/day/keVee (20x lower than in first run)
- Very good (absolute) agreement of energy and spatial distributions with component-level simulations
- PMT array 35x lower background
- Astroparticle Physics, Accepted

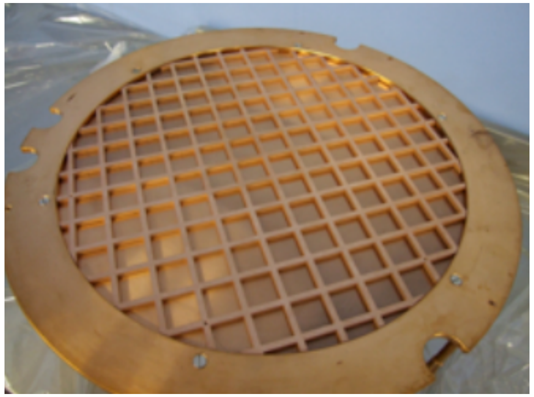


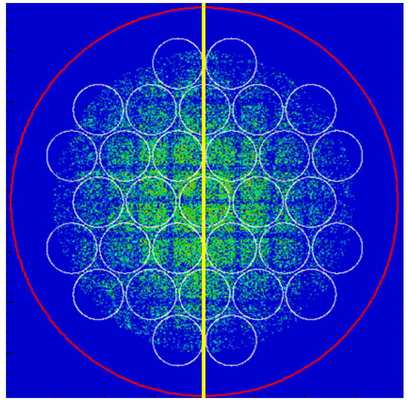


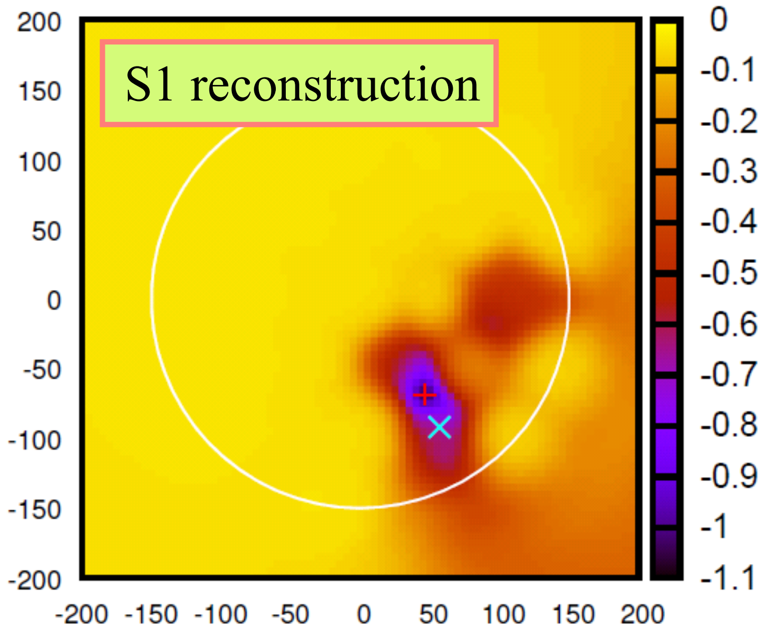


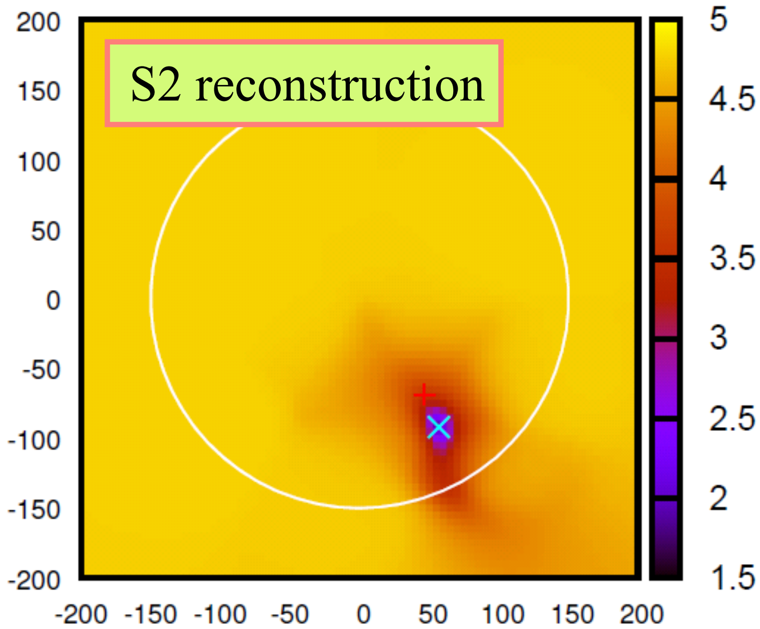
Vertex Reconstruction

- "Phantom Grid"
- dx, dy: 2mm, dz 20μm
- Development of spatial $\chi 2$ maps
- Rejection of Multiple Scatter Single Ionisation ("living dead") events
- JHEP Submitted

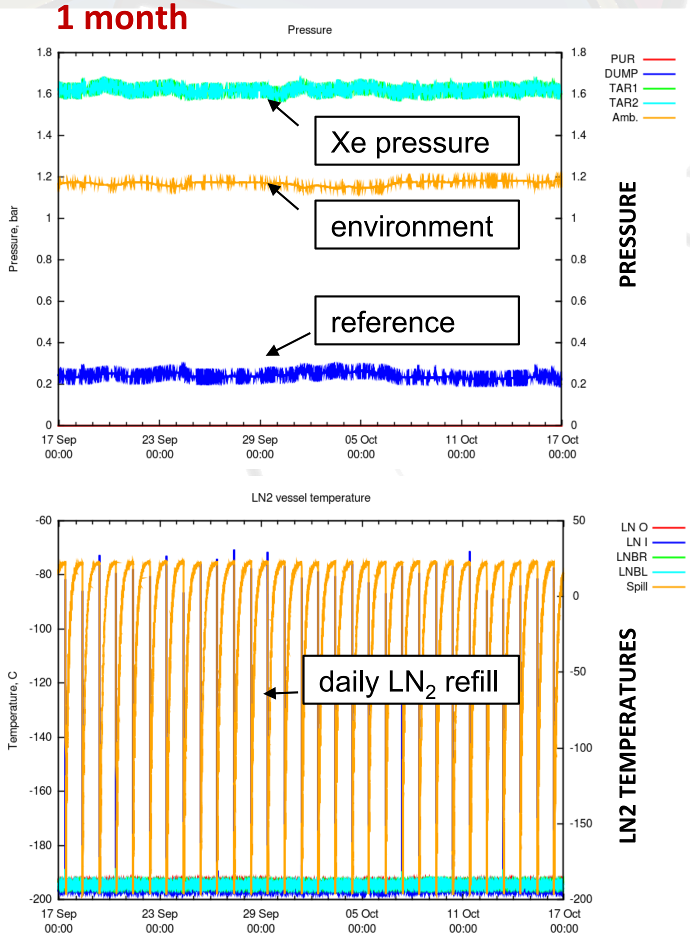


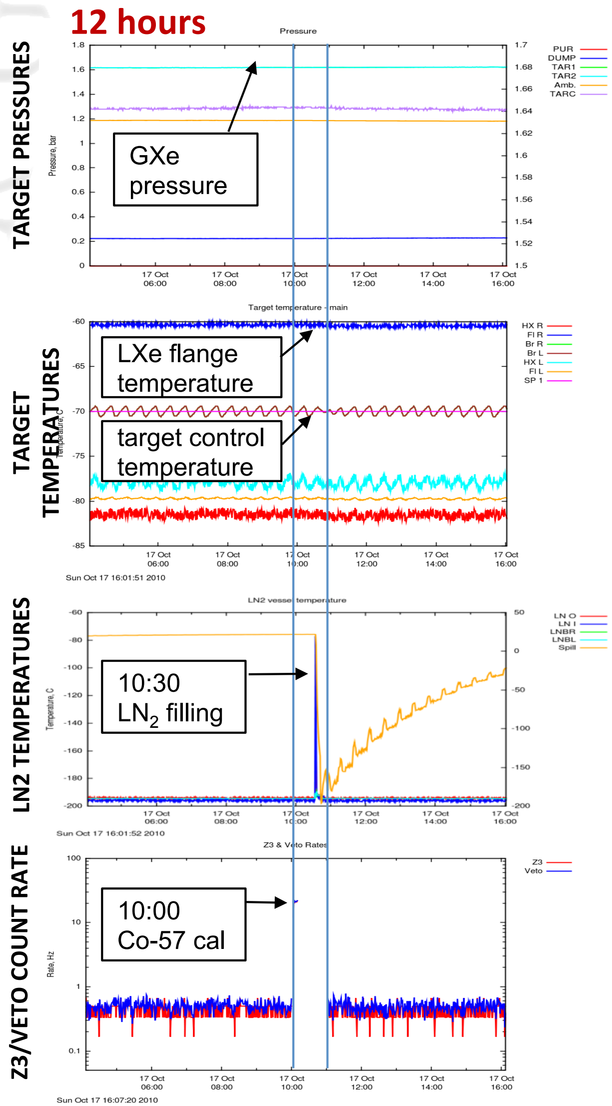




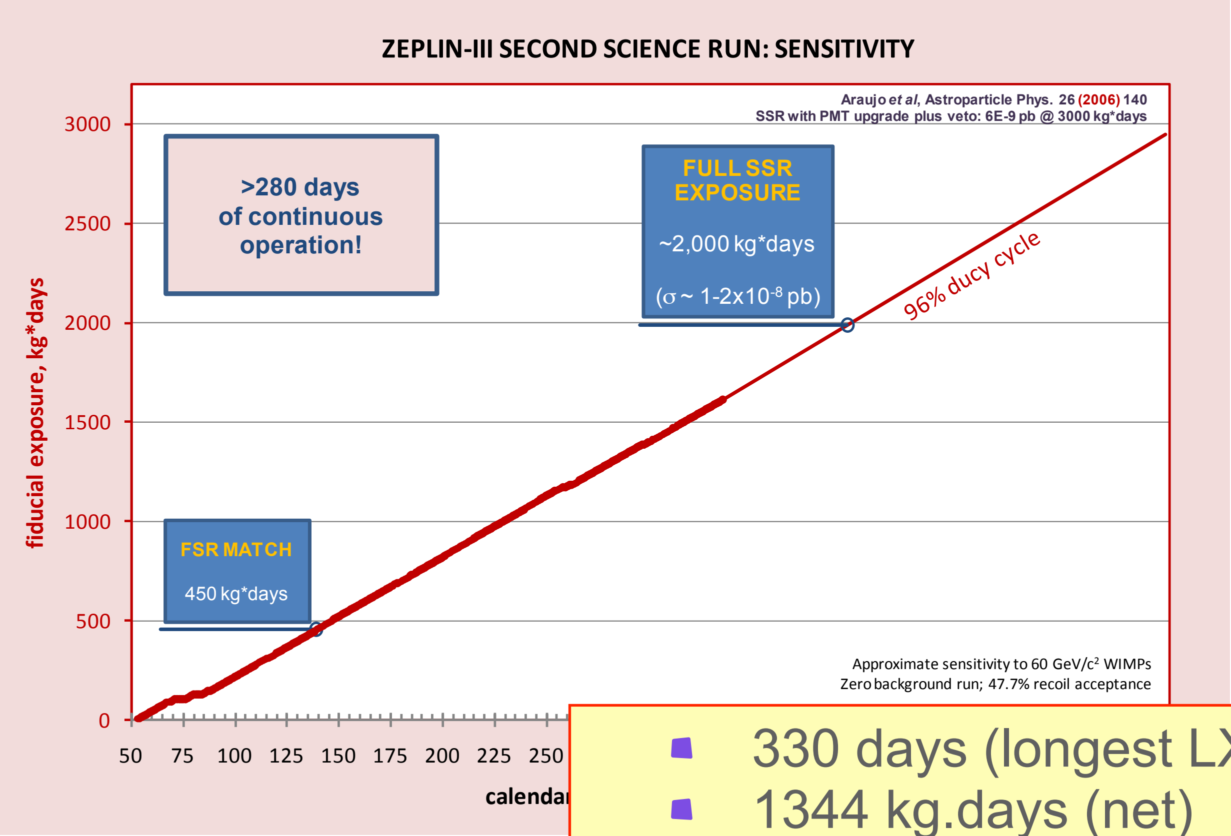


SSR Operations





SSR Operations



- 330 days (longest LXe run ever)
- 1344 kg.days (net)
- Veto worked fabulously
- PMTs achieved background specifications
- PMTs suffered poor performance...

SSR Background Expectations

Material	mass, kg	e-recoil, dru†	ptag	n/year‡	dtag
Krypton-85	12.5	(<0.1)	~0	–	–
Ceramic feedthroughs	0.9	0.08	0.30	1.35	0.58
Photomultipliers	4.2	0.40	0.26	0.74	0.58
Rock (halite)	–	~0	~0	0.53	0.58
Polypropylene shield	1,266	0.25	0.04	0.10	0.58
Scintillator modules	1,057	0.09	~1	0.03	~1
Copperware	~400	(<0.1)	0.10	(<0.15)	0.58
Lead castle	~60,000	0.01	0.54	~0	0.58
Radon-222	(1 m^3?)	0.03	0.19	~0	–
Muon-induced	–	–		~0.3	~1
SSR total		0.86±0.05	0.28	3.05±0.5	0.58
SSR data		0.75±0.05	0.28	n/a	–
(FSR [6]		14.5±0.5	–	(36±18)*	–)

BACKGROUND EXPECTATION IN 1-YEAR DATASET					
NEUTRONS			**E-RECOILS**		
total in 5-50 keVr		**3.05**	rate, evt/kg/day/keV		**0.75**
			total <20 keVee		35588
veto a/c	40%	1.22	veto a/c	72%	25623
duty cycle	90%	1.10	duty cycle	90%	23061
efficiencies	75%	0.82	efficiencies	75%	17296
acceptance	48%	**0.39**	discrimination	1:7,200	**2.4**

Background expectation in 0.9-year dataset, in a/c with veto and realistic signal acceptance:

- 0.4±0.2 neutron scatters
- 9 ± 1 electron recoils

Main challenge is to achieve the same discrimination power as in FSR with new phototubes (poorer optical performance)

ZEPLIN-III

Second Science Run Result Announcement

0 neutrons predicted

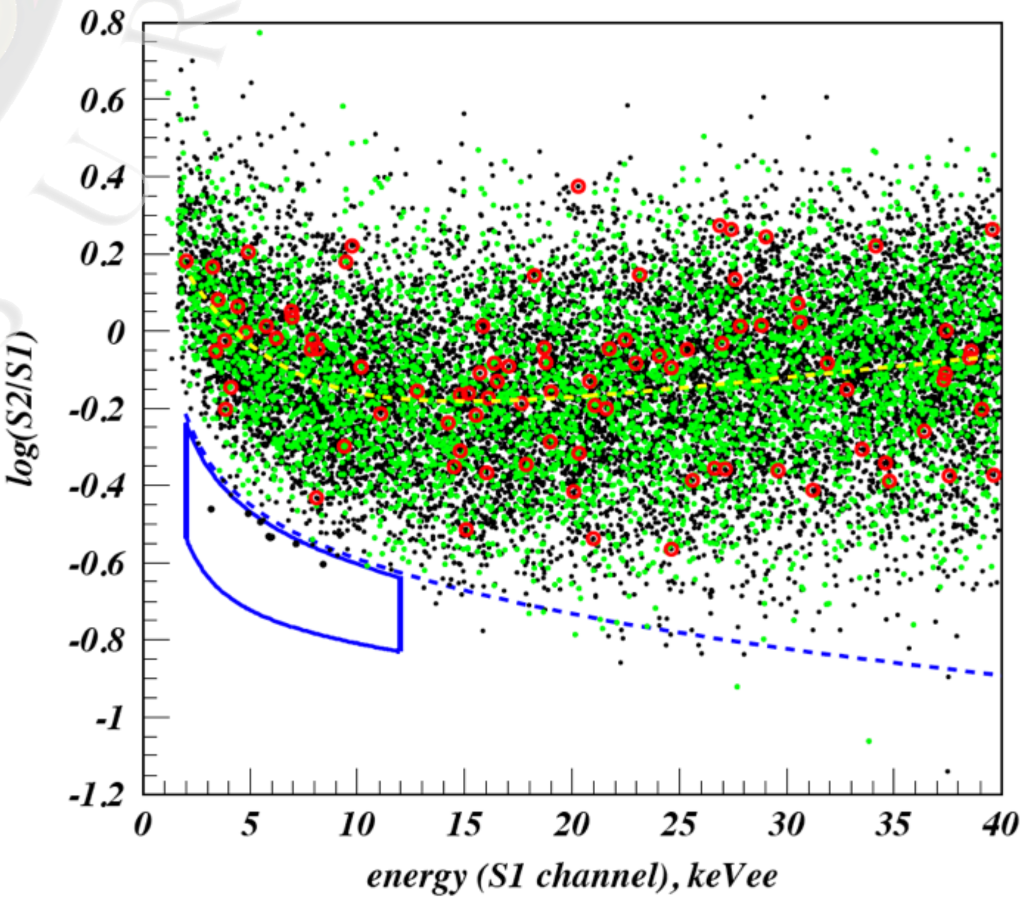
9 gamma rays predicted

...so what did we see?

8 events in box

Consistent with γ background

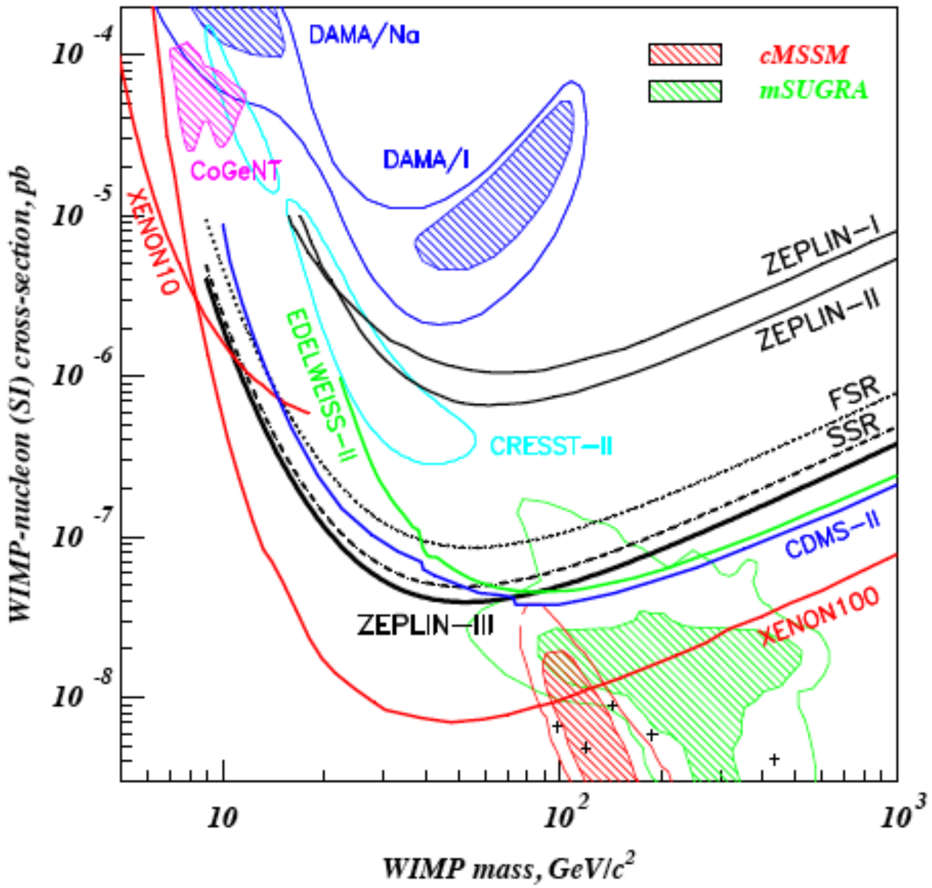
Consistent with zero WIMPs



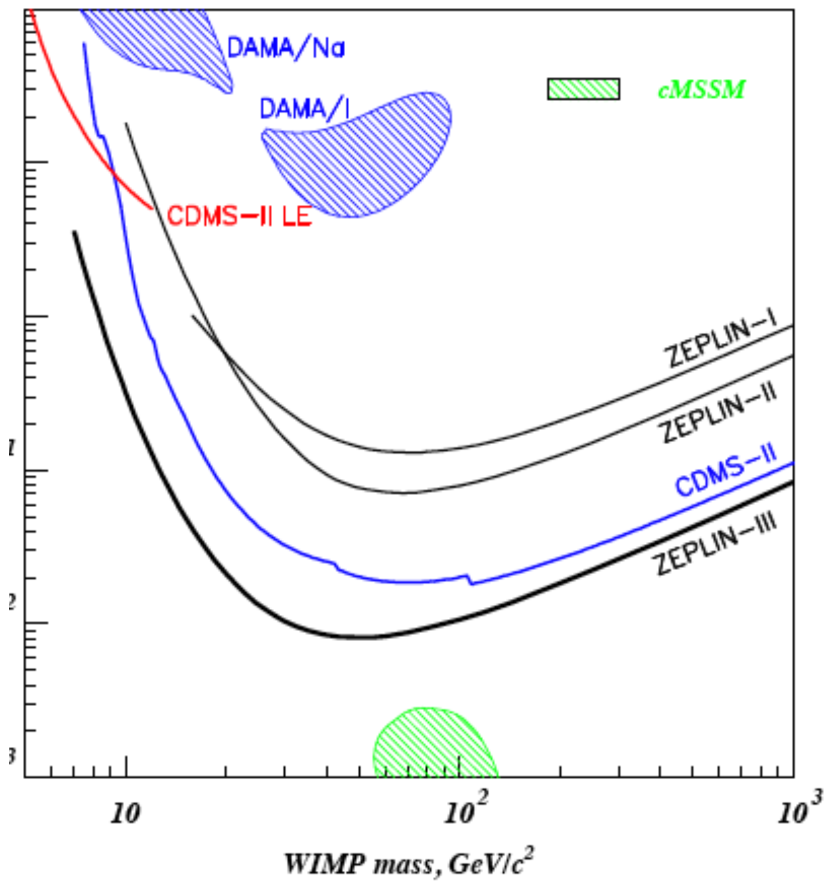
ZEPLIN-III

FINAL RESULTS (FSR + SSR Combined)

PLB Submitted



Second best SI limit



World leading SD limit

ZEPLIN-III 'in numbers'

Since underground deployment in late 2006

2,500 person·days underground effort at Boulby
870 daily entries in electronic log-book
204 internal reports (382 versions) in documents database
203 minuted progress meetings
862 catalogued datasets, 100 TB uncompressed data
12 xenon liquefactions (detector filling)
15,000 litres of liquid nitrogen used underground
Longest uninterrupted operation of a two-phase detector
0 emergency xenon dumps into safety chambers
0 accidents underground (occasional partridge killed on the A174)
6 international collaboration meetings
7 PhD theses (3 more to come)
Many, many cold evenings in Whitby

Extensive list of professional and public outreach activities listed in report

What next?

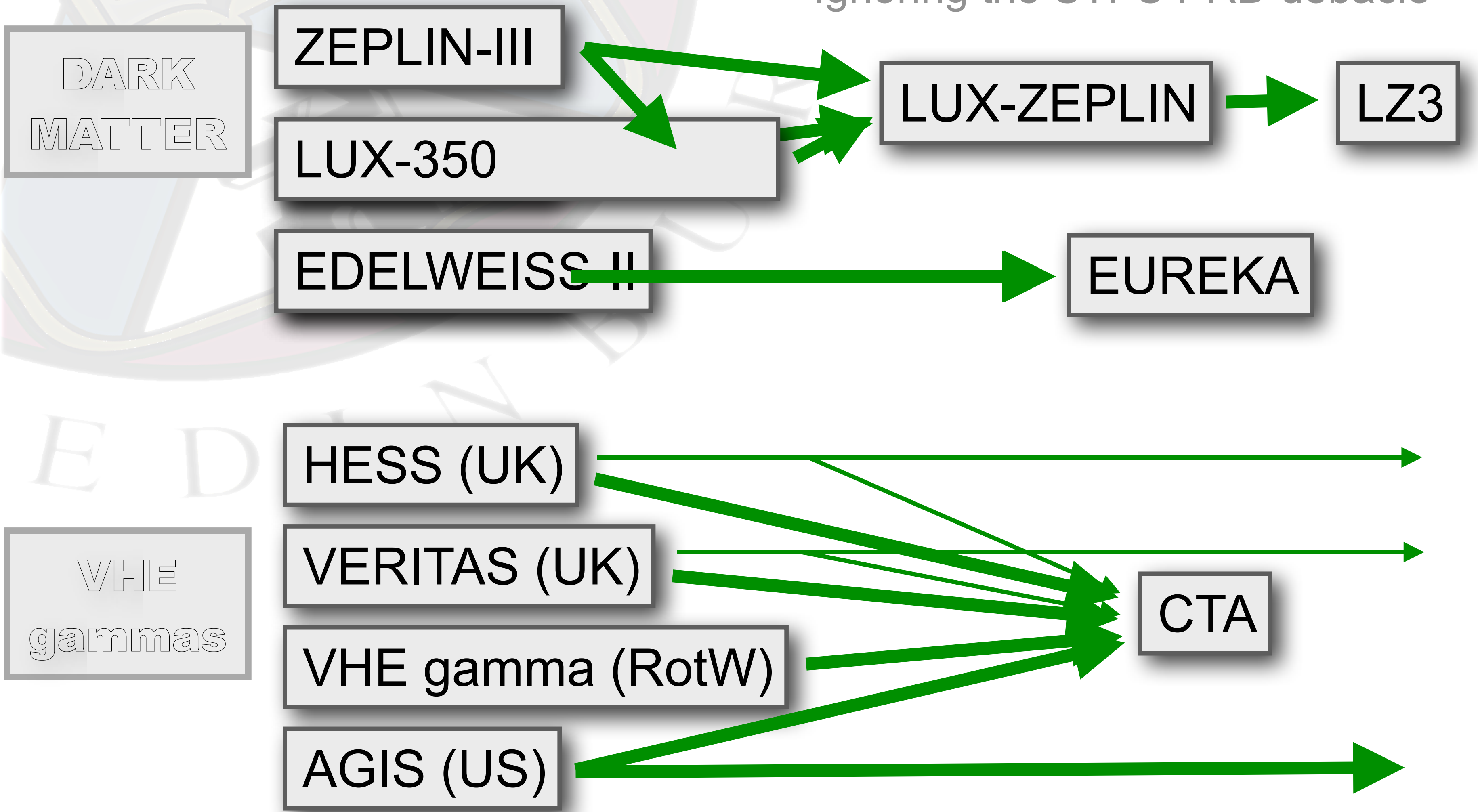
Since last Programmatic review

- STFC recognises PA overly reduced
- ZEPLIN-III extended (till July 2011)
- VHE Gamma Rays: ‘life support’
- Cosmic Rays: ‘hospice’
- Neutrino astrophysics: ‘parasitic’

“Particle Astrophysics Sustainability” funding line introduced

Plans...

Ignoring the STFC PRD debacle



LUX Construction

at the Sanford Surface Facility

LUX Deployment

at the Sanford Surface Facility

April 2011

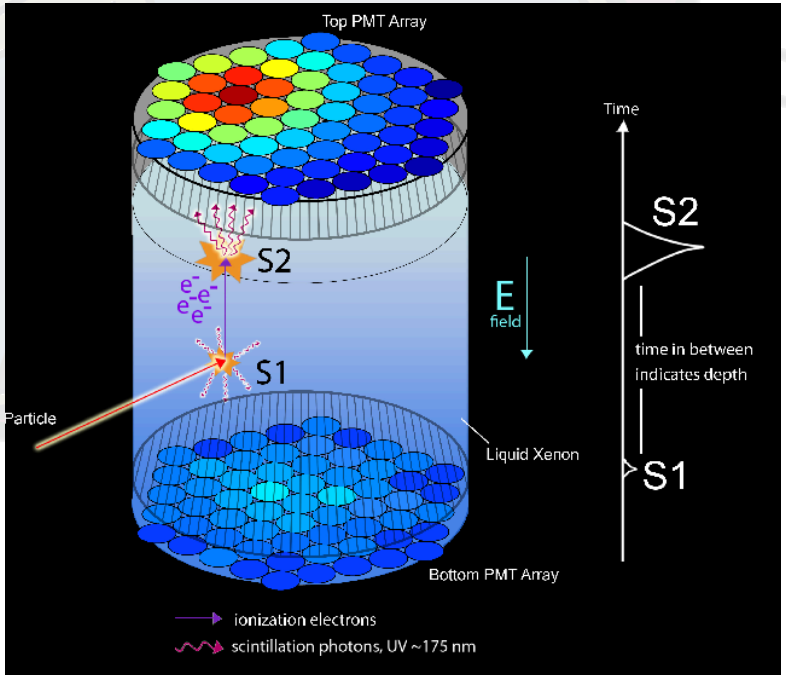


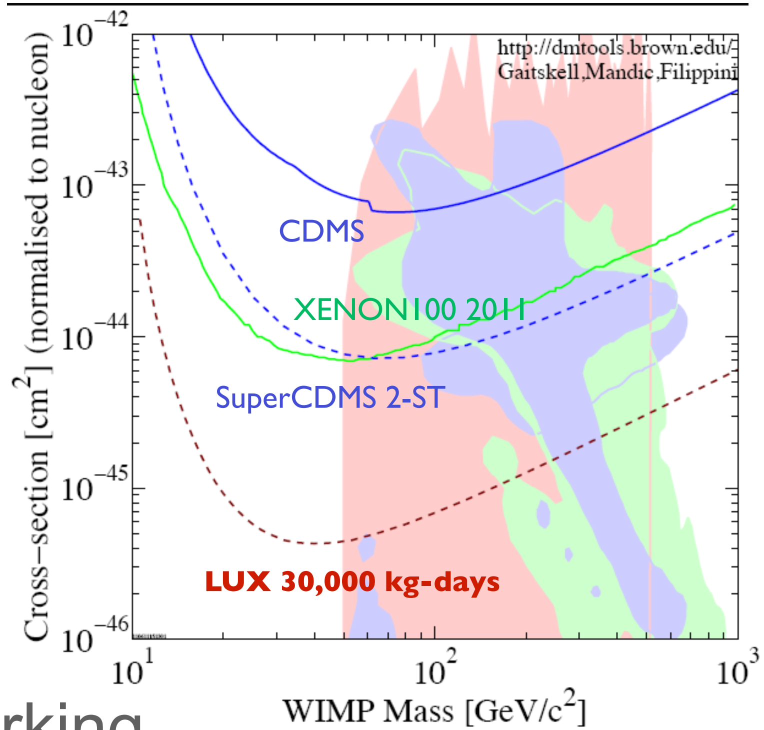

Photo by C. Faham

LUX Detector in Water Tank
Prior to May 2011 Cooldown
Sanford Surface Facility

LUX350

Large Underground Xenon

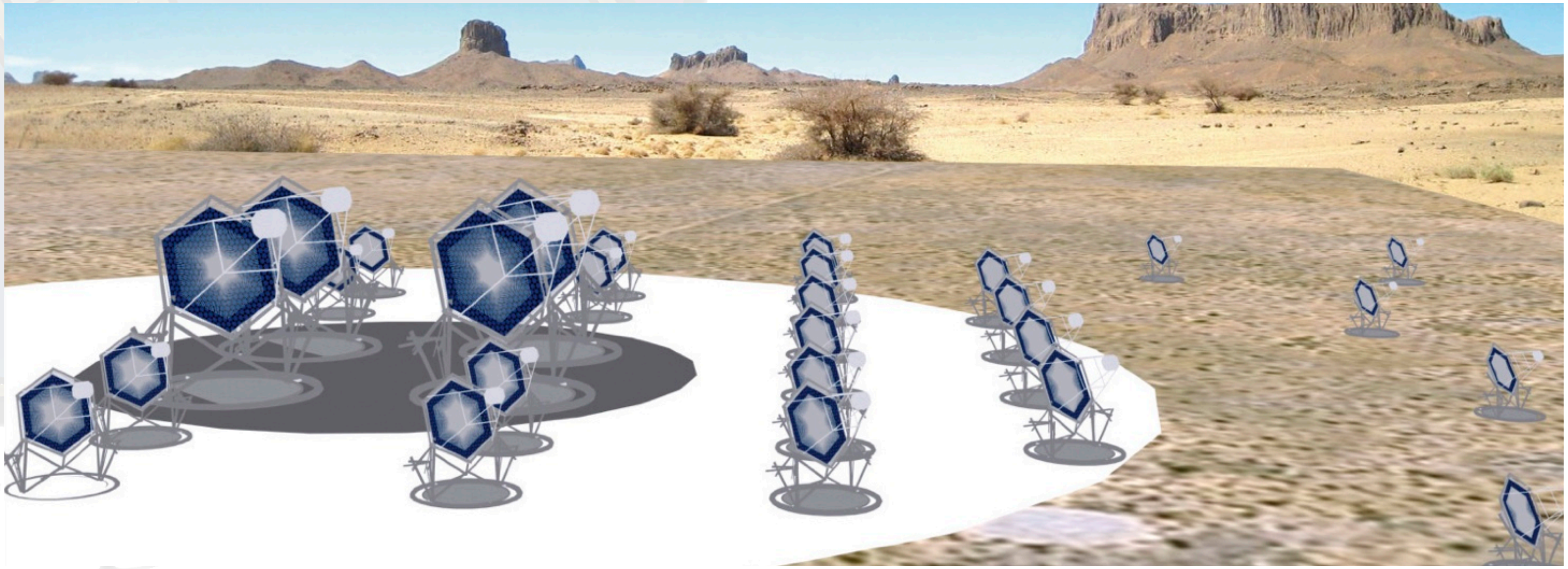




- Fully built, tested and working
- Awaiting deployment at SUSEL
- >15 institutes, >100 scientists

CTA

The Cherenkov Telescope Array



- 10 GeV - 100 TeV: The non-thermal Universe
- 10 x better ‘in every way’
- UK leads Small Sized Telescope: highest energies
- Edinburgh roles: SAPO & minor role in PMT R&D
- Further contributions very welcome

CTA
The Cherenkov Telescope Array

>500 scientists working in >25 countries
180ME project cost

Presently FP7 Preparatory Phase
Construction start ~2015
First light ~2017

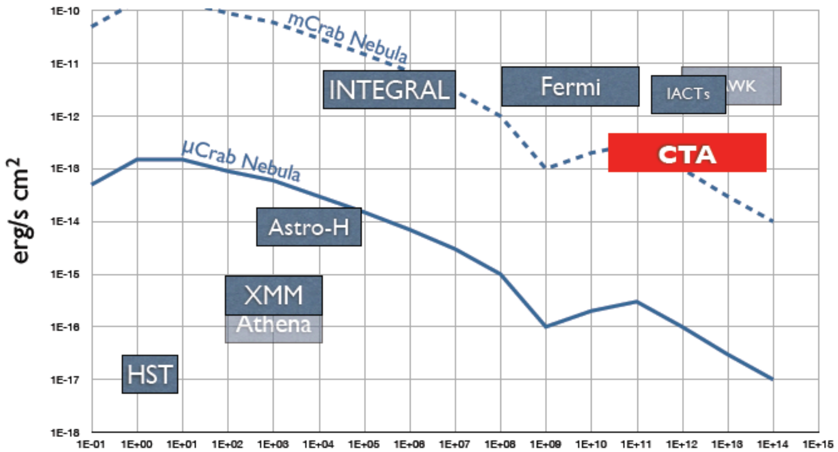
Science Objectives:

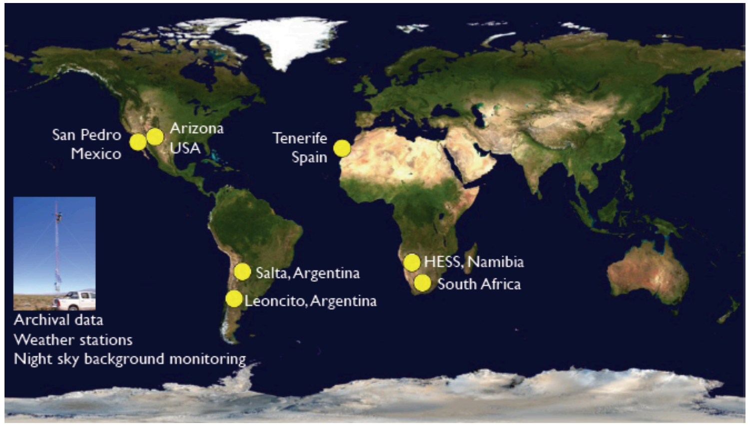
Galactic Gamma-Ray Sources
Supernova Remnants
Pulsar Wind Nebulae
Pulsar Physics
Star-Formation Regions
The Galactic Centre
X-Ray Binaries & Microquasars

Extragalactic Gamma-Ray Sources
Active Galactic Nuclei
Extragalactic Background Light
Gamma-Ray Bursts
Galaxy Clusters

Fundamental Physics
Dark Matter
Quantum Gravity
Charged Cosmic Rays

Optical Interferometry
Optical Images of Stellar Surfaces





Thank You