Boulby Dark Matter Searches:

The Current Experimental Status

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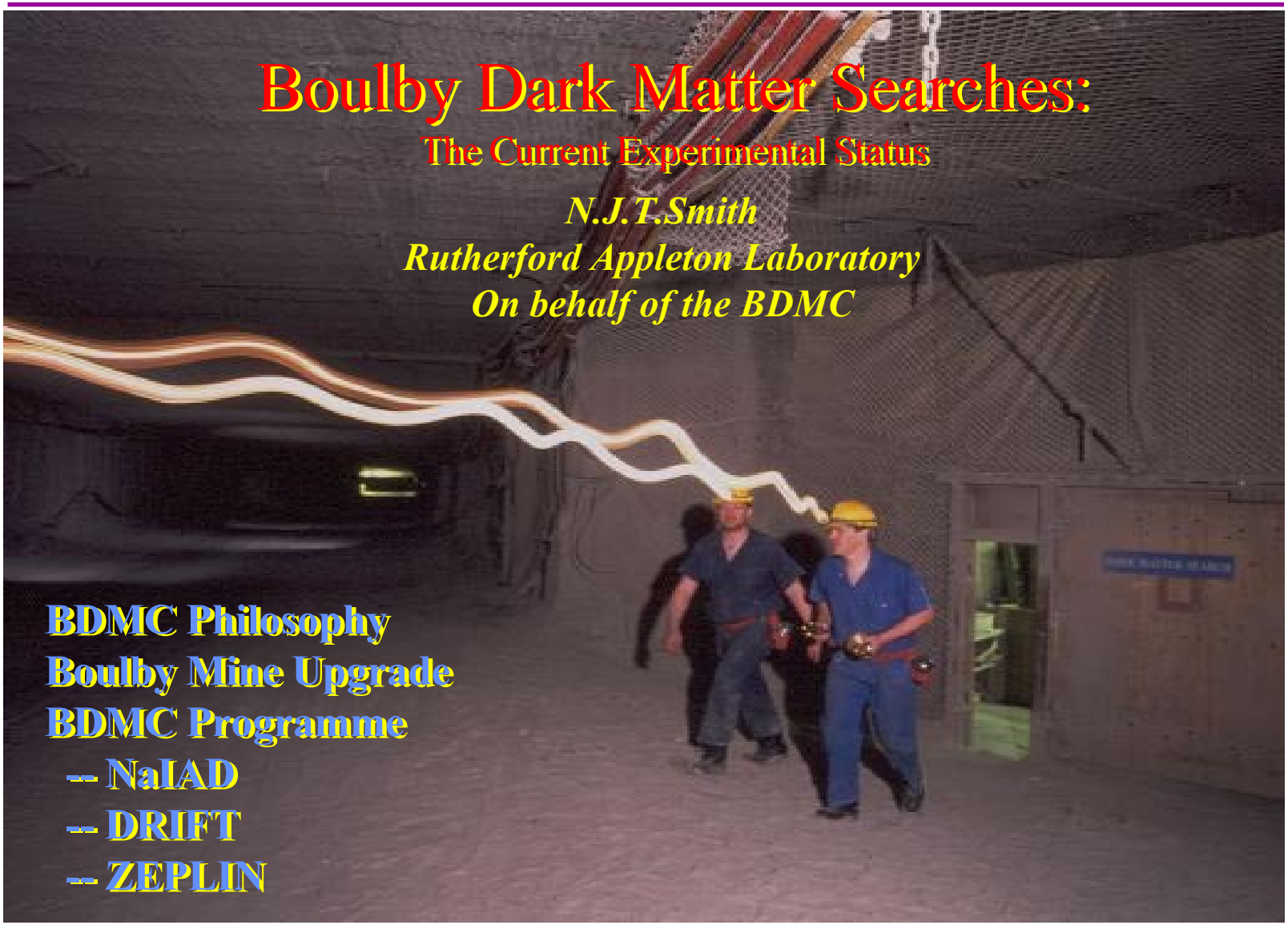
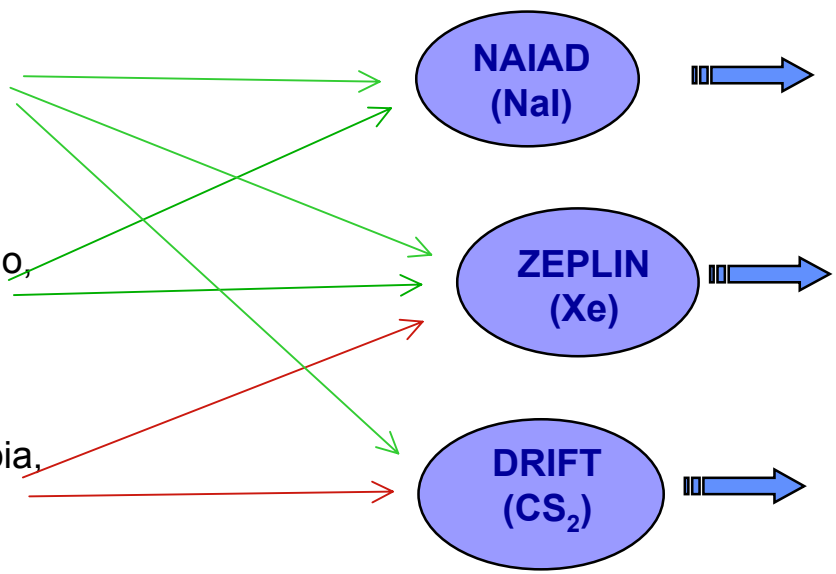
On behalf of the BDMC



BDMC Philosophy
Boulby Mine Upgrade
BDMC Programme
- **NaIAD**
- **DRIFT**
- **ZEPLIN**

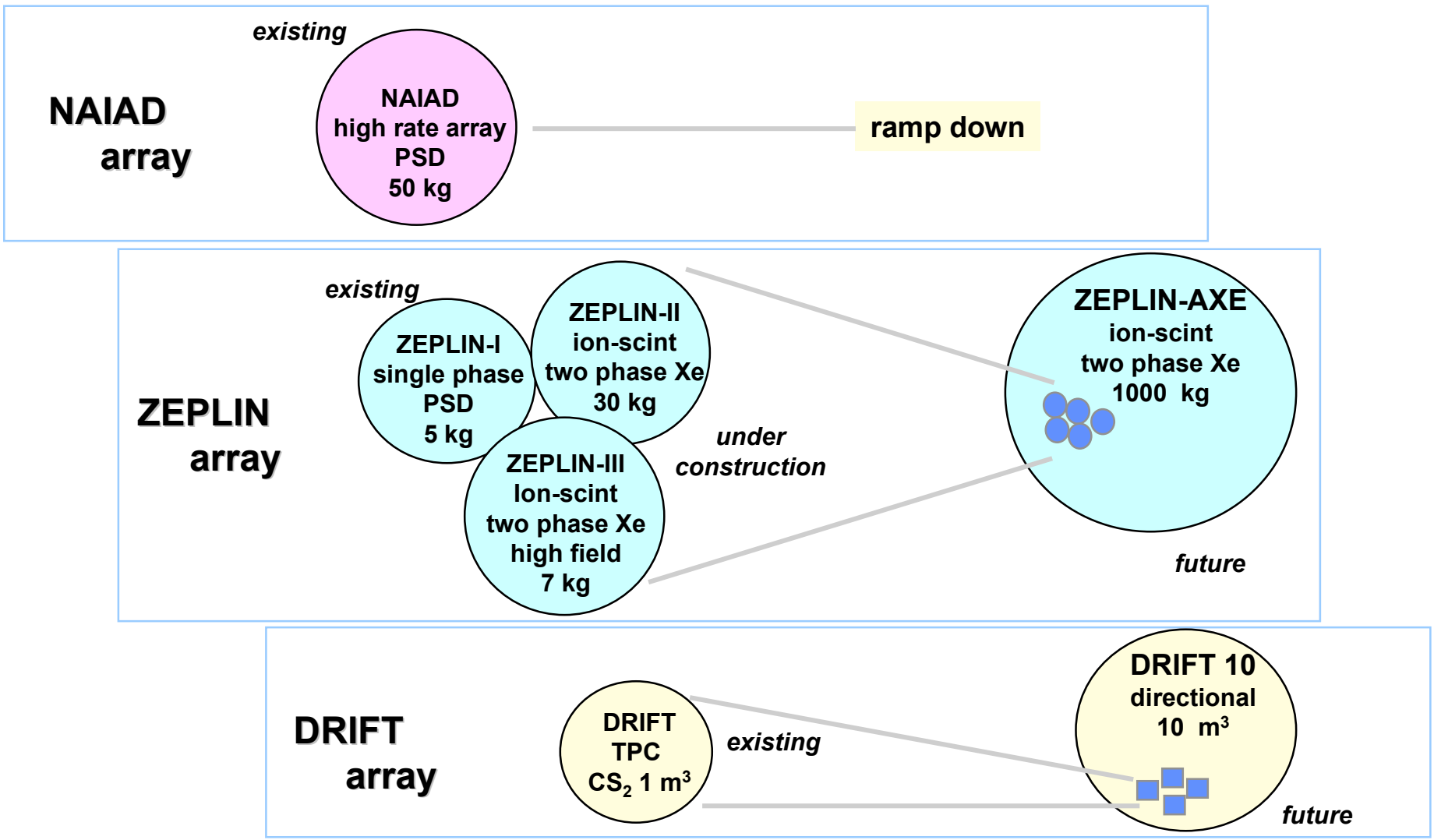
BDMC Philosophy

Groups	Experiments	Purpose
UK: ICSTM, RAL, Sheffield, *Edinburgh*	NAIAD (NaI)	***Exploration of DAMA Ann. Mod. result in similar target material Using PSD***
Europe: Saclay, Torino, ITEP, Coimbra	ZEPLIN (Xe)	***Discriminating, high mass, low threshold target for tonne scale detectors. PSD and ion/scint***
USA: UCLA, Columbia, Temple, Occidental, LLNL	DRIFT (CS_2)	***Directional TPC detector for recoil correlation. Additional targets possible***

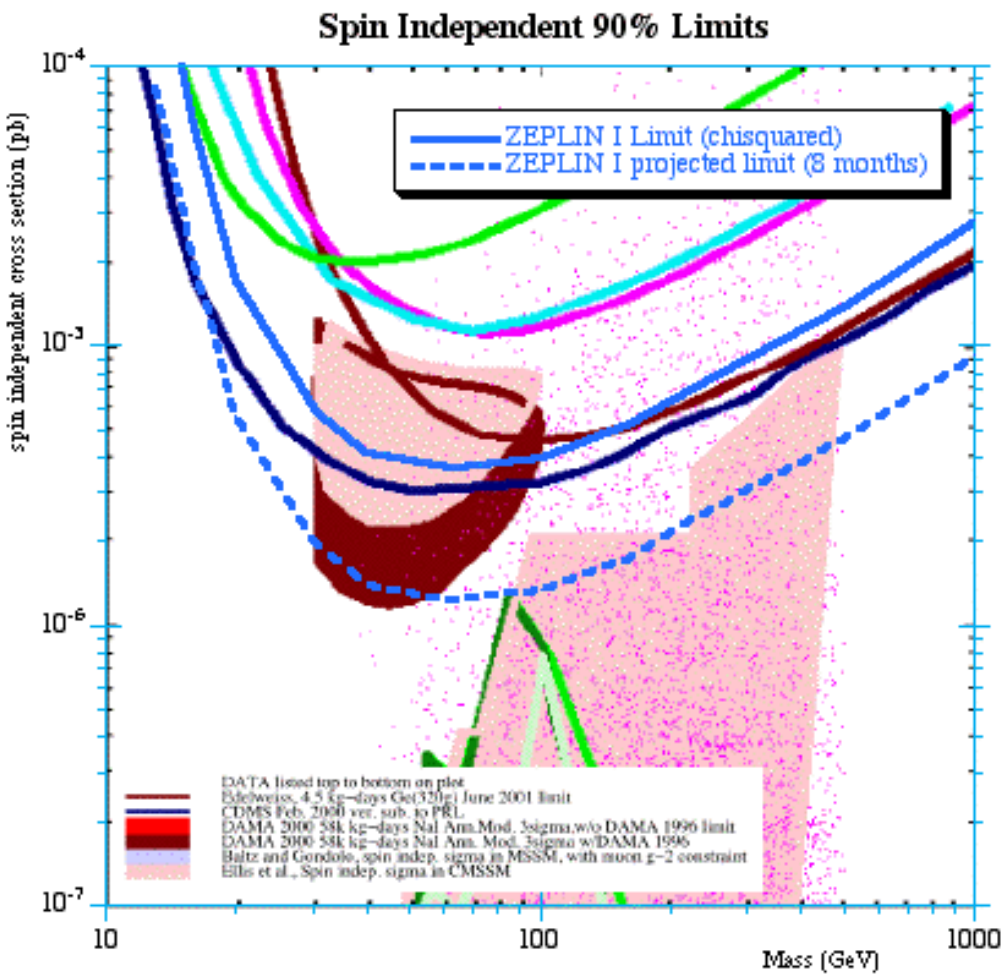


Three complementary techniques

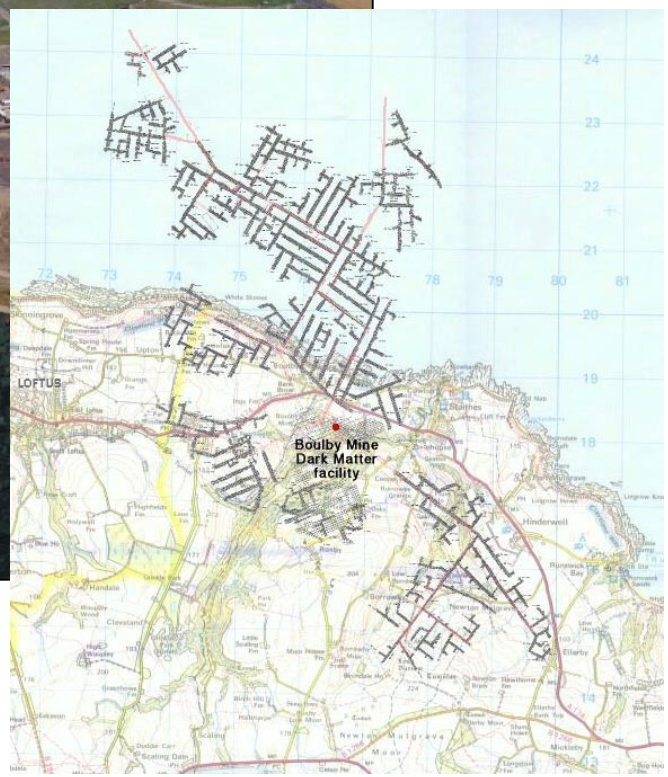
BDMC Programme



ZEPLIN I Prelim. Limits

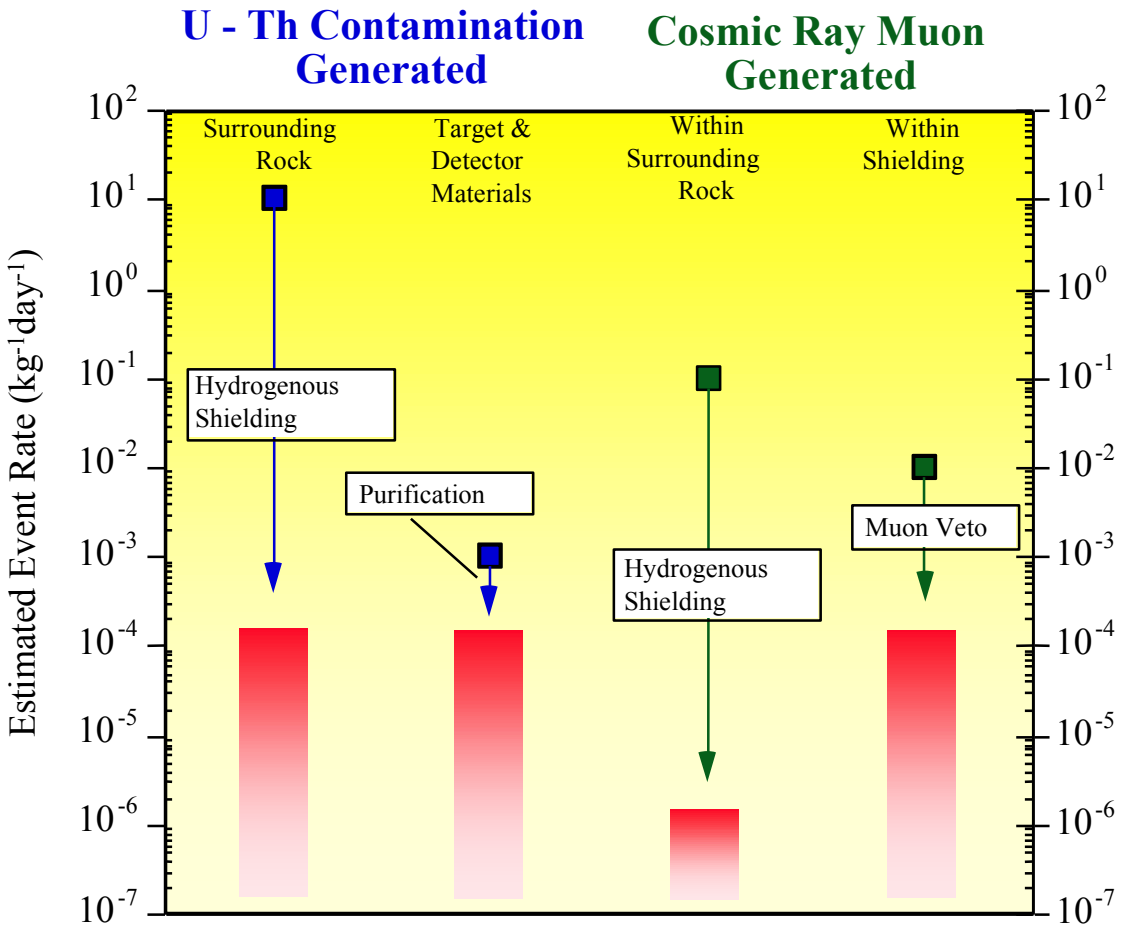


Boulby Mine



Neutron Backgrounds

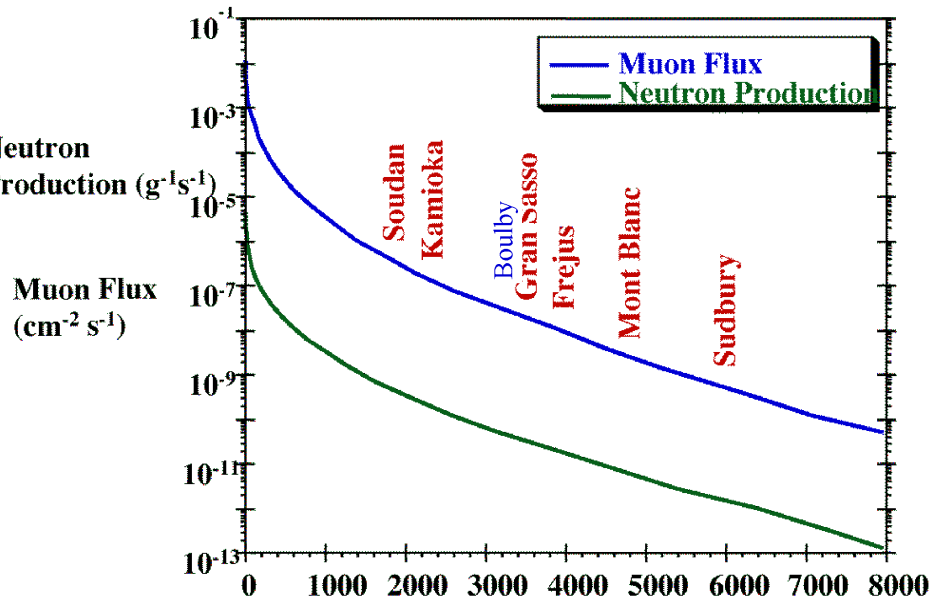
- U and Th contamination
  - **alpha interactions and fission (10^{-5} of γ flux)**
- Cosmic ray muons
  - **spallation and evaporation**



Gamma Backgrounds

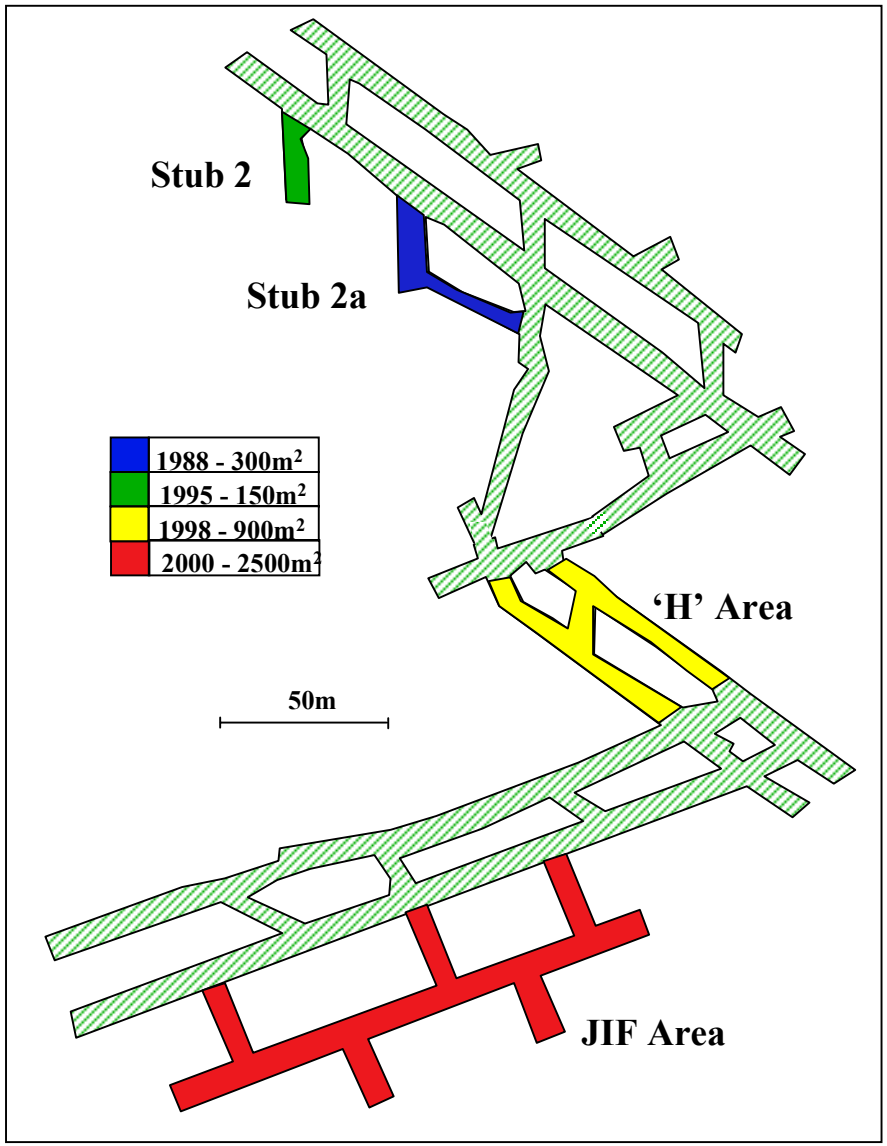
- Cavern radioisotope impurities
  - **Halite intrinsically low U/Th levels**

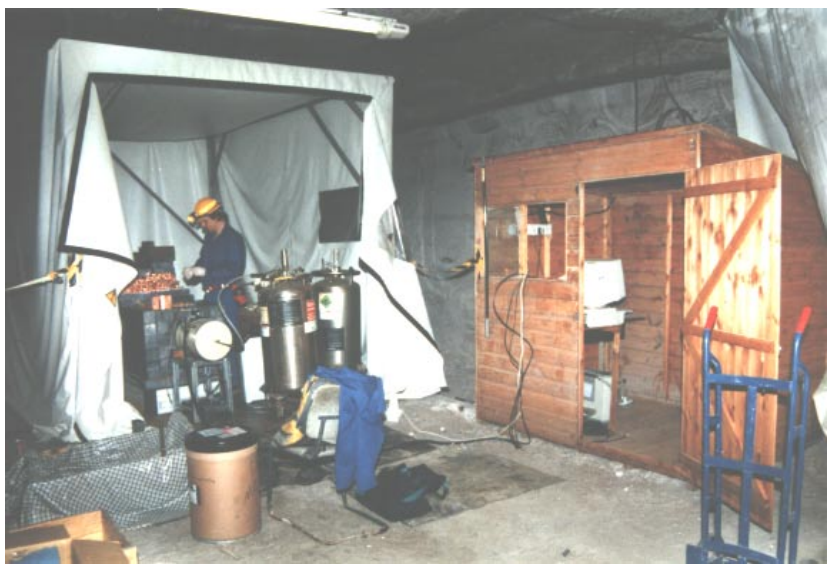
	Radioisotope impurity in rock			Depth (wme)
	U (ppb)	K (ppm)	Th (ppb)	
Boulby	10	750	100	3300
Gran Sasso	500	160	65	3800
Sudbury	1200	1150	3300	6200
Soudan	100	1200	250	2200



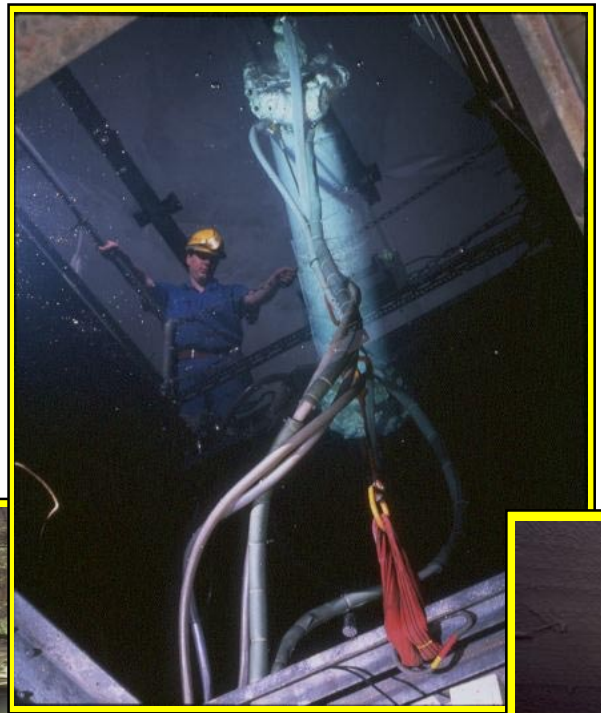
- Radon levels measured ~5 Bqm^{-3}
- NaI Detector total event rates
  - **Unshielded: >2e5 $kg^{-1}day^{-1}$**
  - **Shielded: 6e3 $kg^{-1}day^{-1}$**

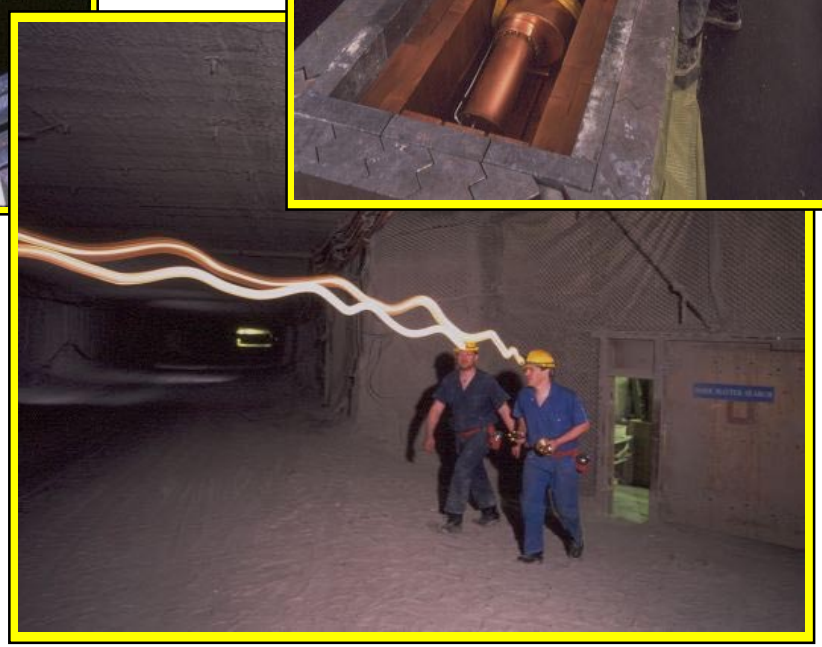
Laboratory Locations



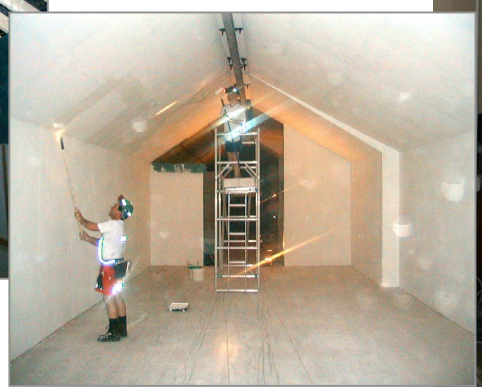


Boulby Potash Mine





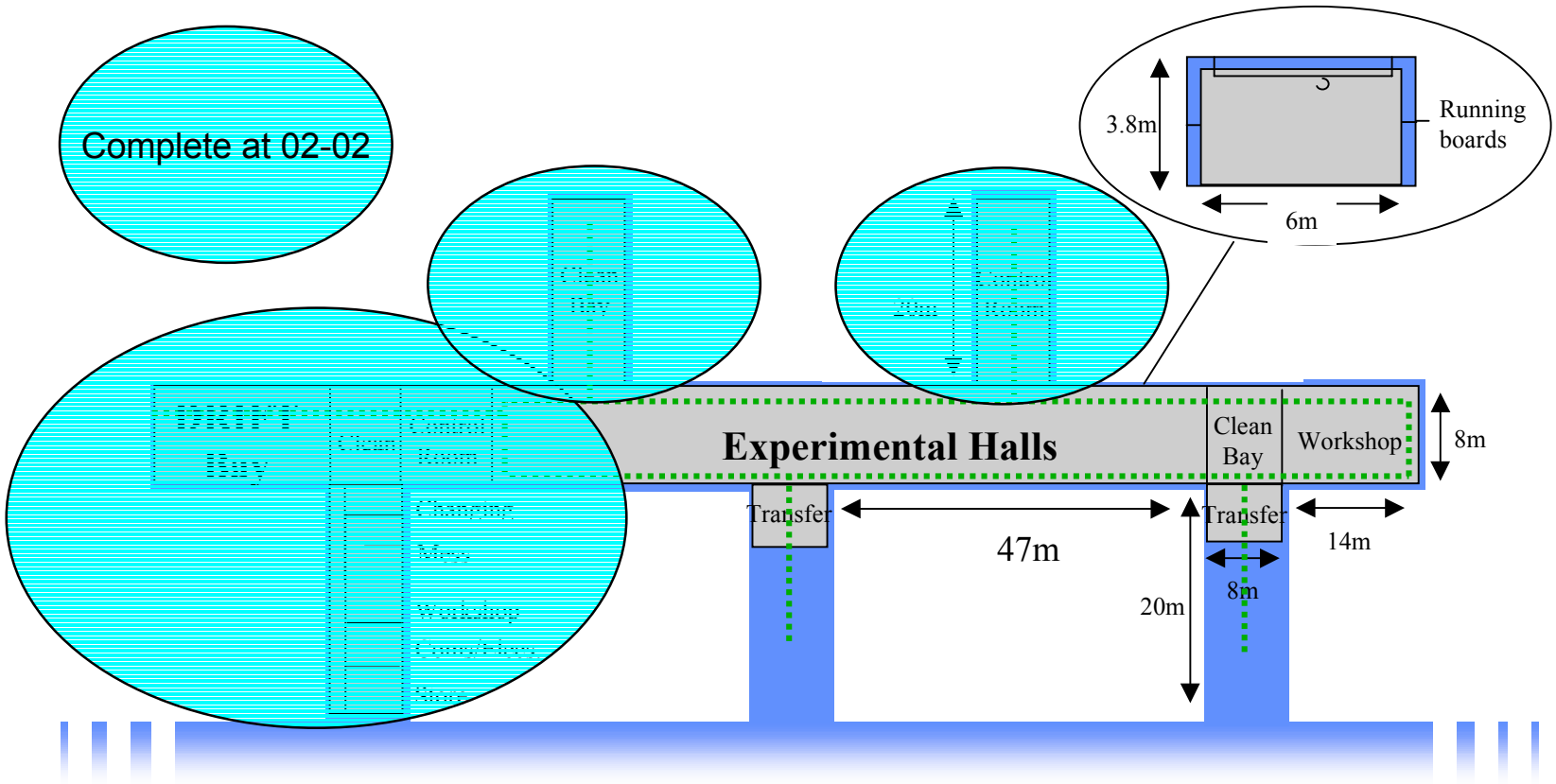
JIF Expansion



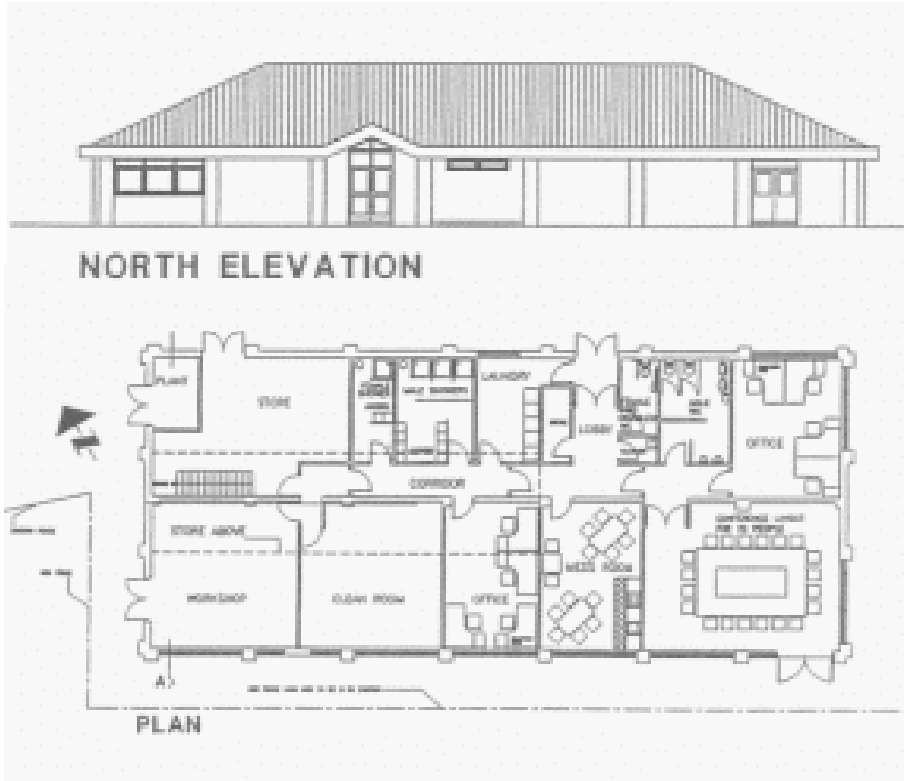
- £2M JIF Award
- Surface facilities
  - **Workshop, offices, etc.**
- Underground facilities
  - **New clean area, upgrade existing**

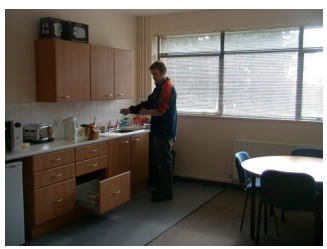
JIF Expansion

~1500m² new lab space



JIF Expansion





New Surface facilities

Completed Fall 2001

Laboratories, clean room, workshop, loading bay, offices, conference room, showers & mess.

How to find WIMPs

- Fit expected (exponential) recoil distribution curve to observed spectrum

event rate per unit mass

total event rate (point like nucleus)

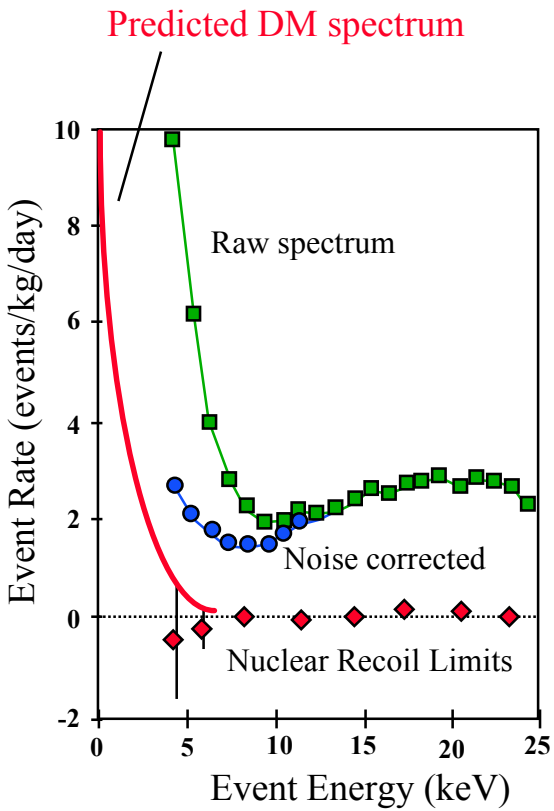
$$\frac{dR}{dE_R} = \frac{R_o}{E_o r} e^{-E_R/E_o r}$$

recoil energy

incident energy

kinematic factor $= 4M_D M_T/(M_D + M_T)^2$

- Remembering....
  - Earths velocity
  - Galactic Escape velocity
  - Nuclear Form factor
  - Spin factor
  - Nuclear fraction
  - Resolution
  - Trigger Efficiency



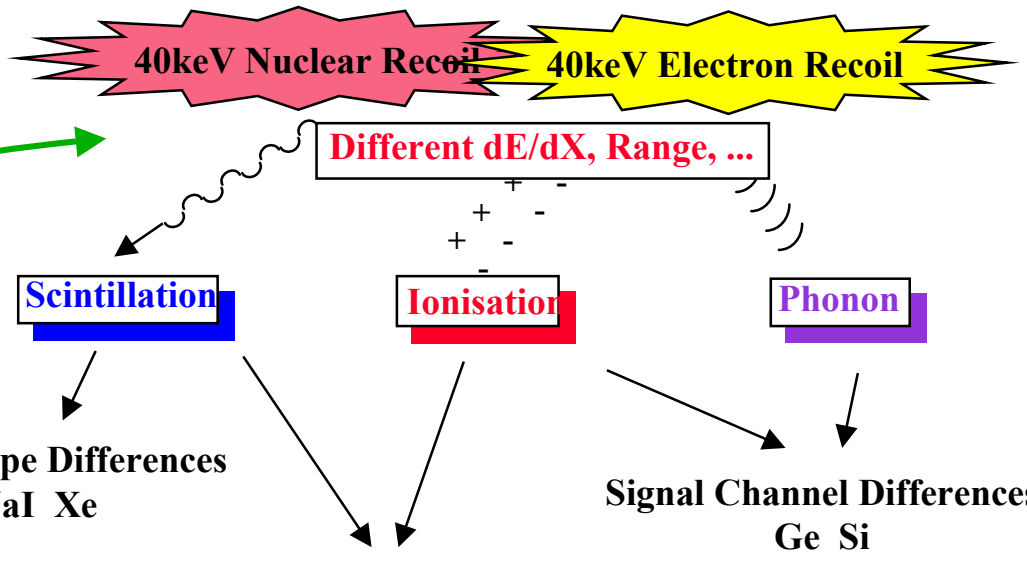
Eg 1996 NaI Spectrum

Signal Identification

- Underlying spectrum

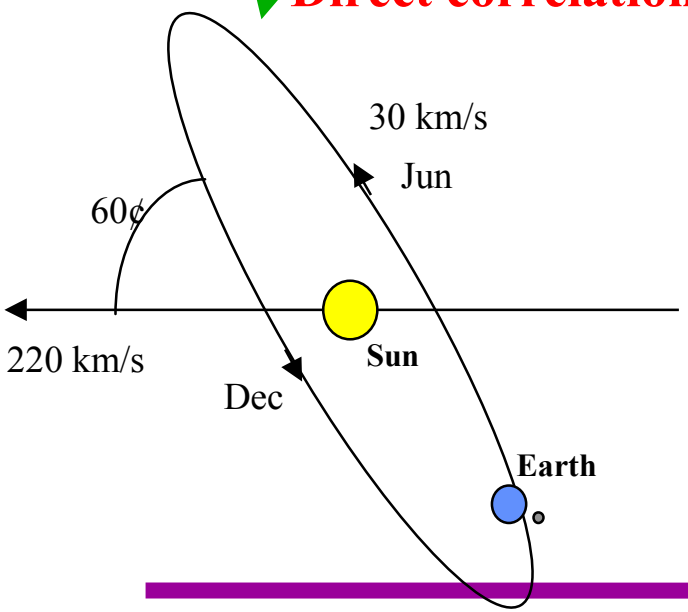
$$\frac{dR}{dE_R} = \frac{R_0}{E_0 r} \exp\left(-\frac{E_R}{E_0 r}\right)$$

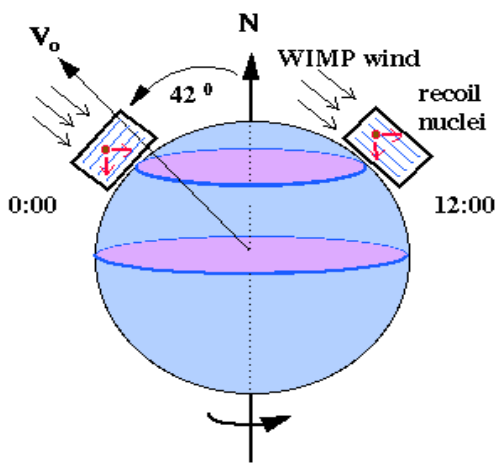
- Nuclear recoil disrimination
- Directional signal



Annual modulation

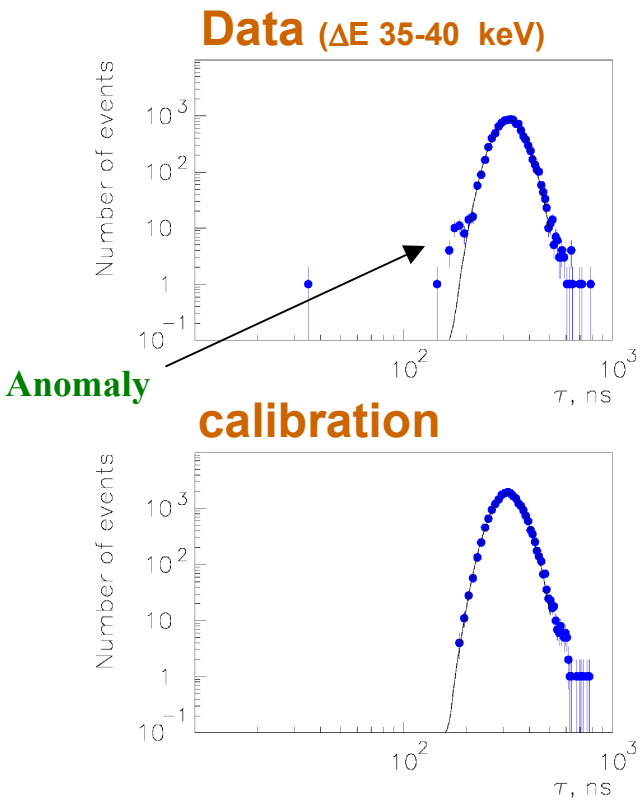
Direct correlation



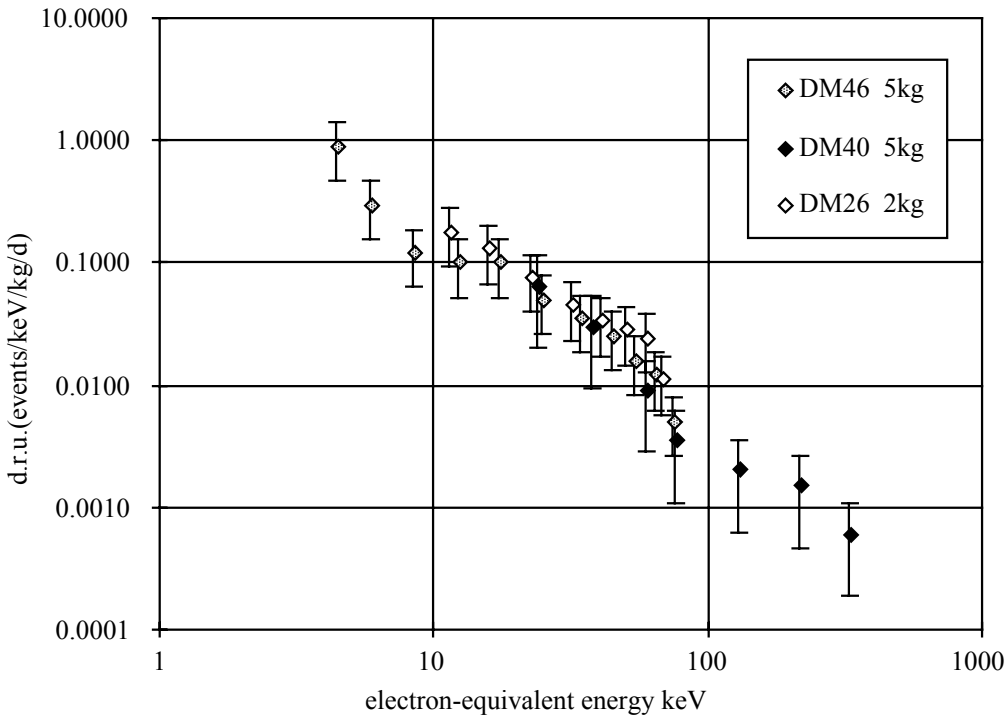


NaI Anomalous Events (1998)

- Following improvement in DM46 (5 kg) - discovery of fast events



Example τ histogram for DM46 showing anomalous events

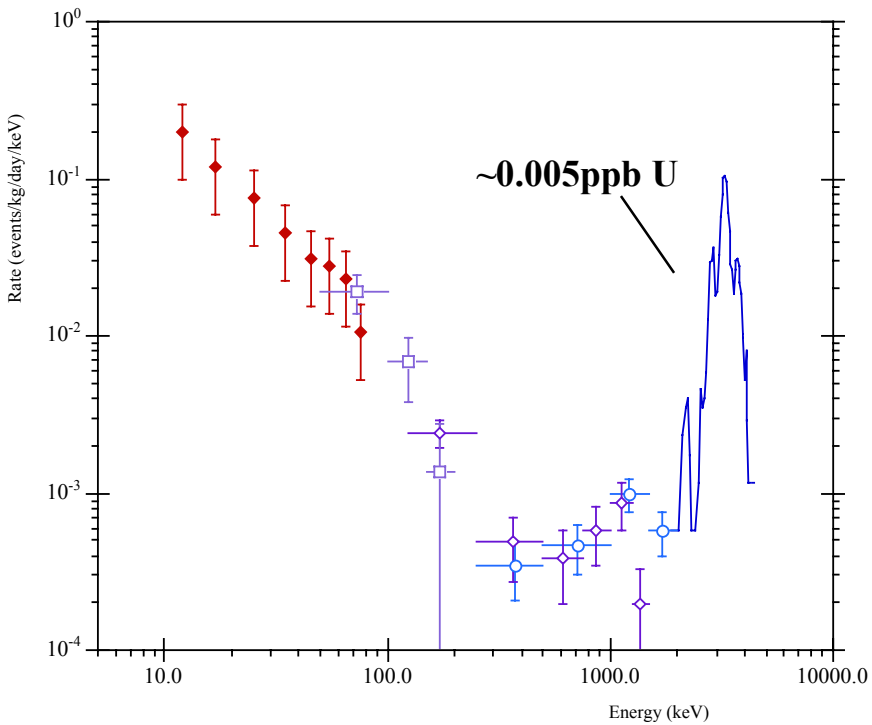


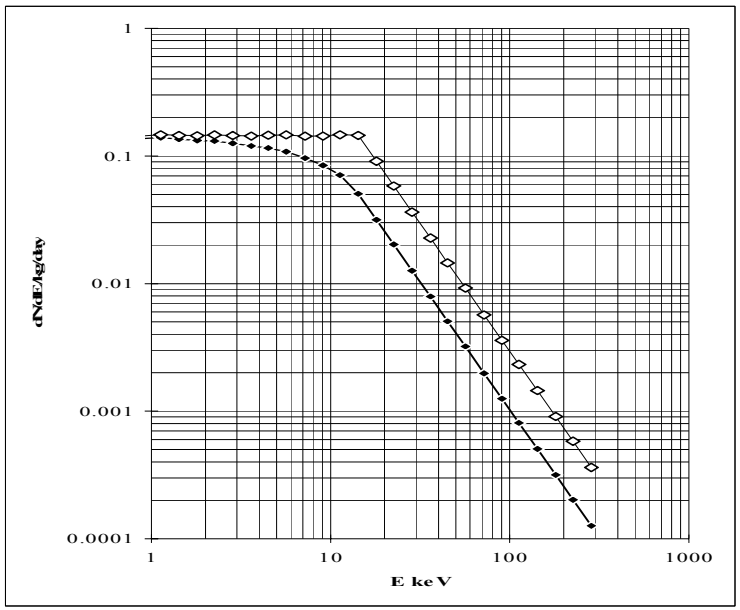
Typical fast event energy distributions in various crystals of different geometry

Many tests performed on different crystals/configurations

Outgoing Surface Alphas?

- **$^{222}Rn \rightarrow {}^{218}Po + \alpha$;**
- **$^{218}Po \rightarrow {}^{214}Pb + \alpha$;**
- $^{214}Pb \rightarrow {}^{214}Bi + \beta + \nu\ (+\gamma)$;
- $^{214}Bi \rightarrow {}^{214}Po + \beta + \nu\ (+\gamma)$;
- **$^{214}Po \rightarrow {}^{210}Pb + \alpha$;**
- ***$^{210}Pb \rightarrow {}^{210}Bi + \beta + \nu\ (+\gamma)$;***
- $^{210}Bi \rightarrow {}^{210}Po + \beta + \nu\ (+\gamma)$;
- **$^{210}Po \rightarrow {}^{206}Pb + \alpha$;**

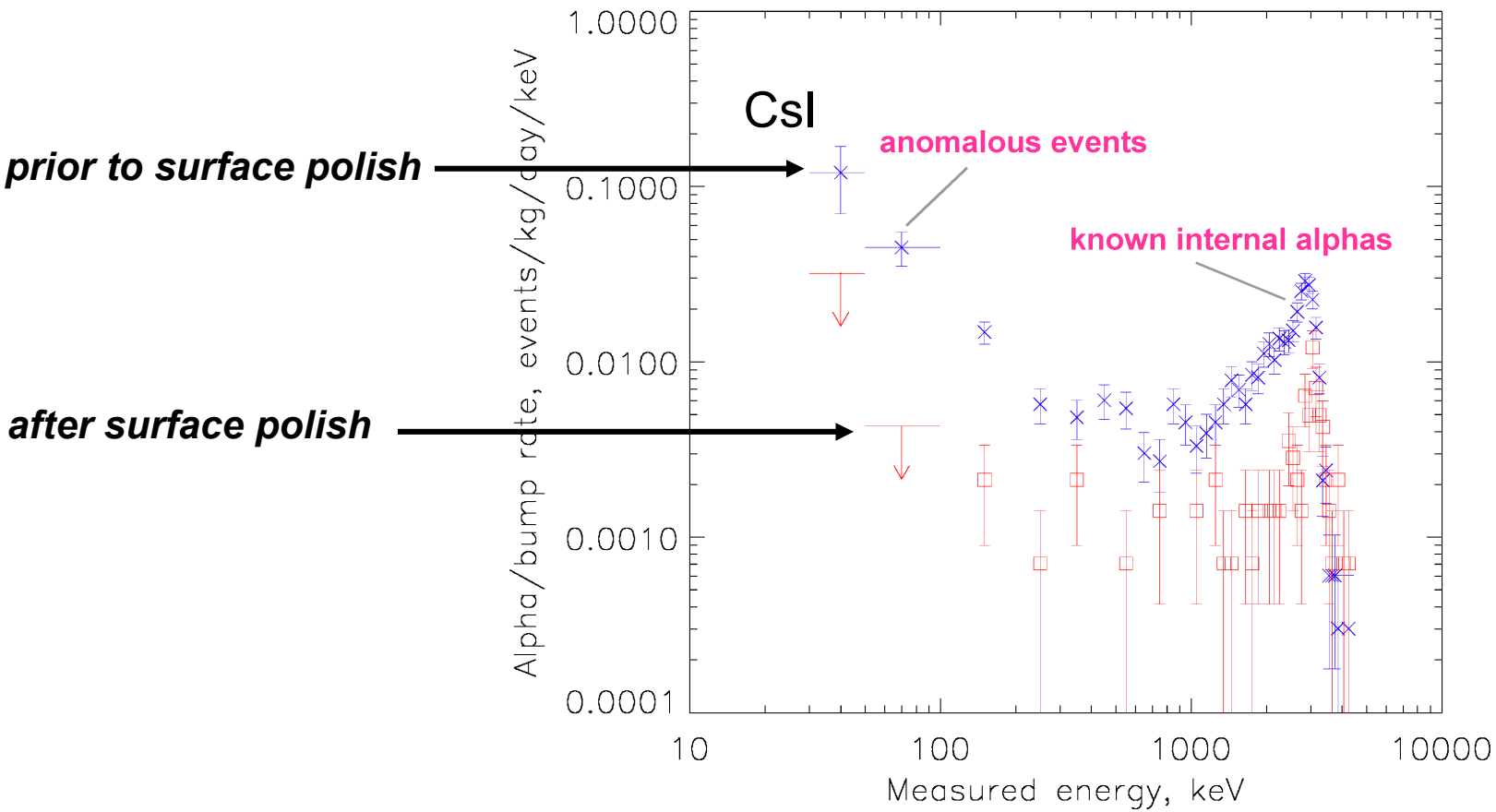




- Outgoing α events
  - **Radon implantation?**
  - **Surface contamination?**
- Requires high exposure

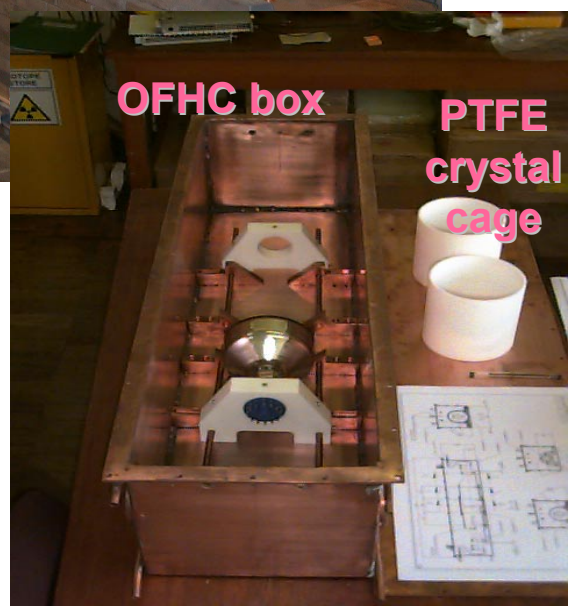
Identification of the events

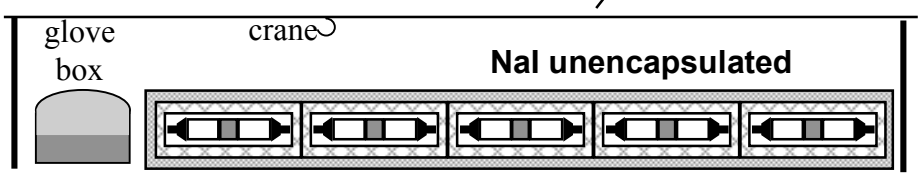
- Surface effect confirmed with CsI - easier to use unencapsulated than NaI



NAIAD - unencapsulated array

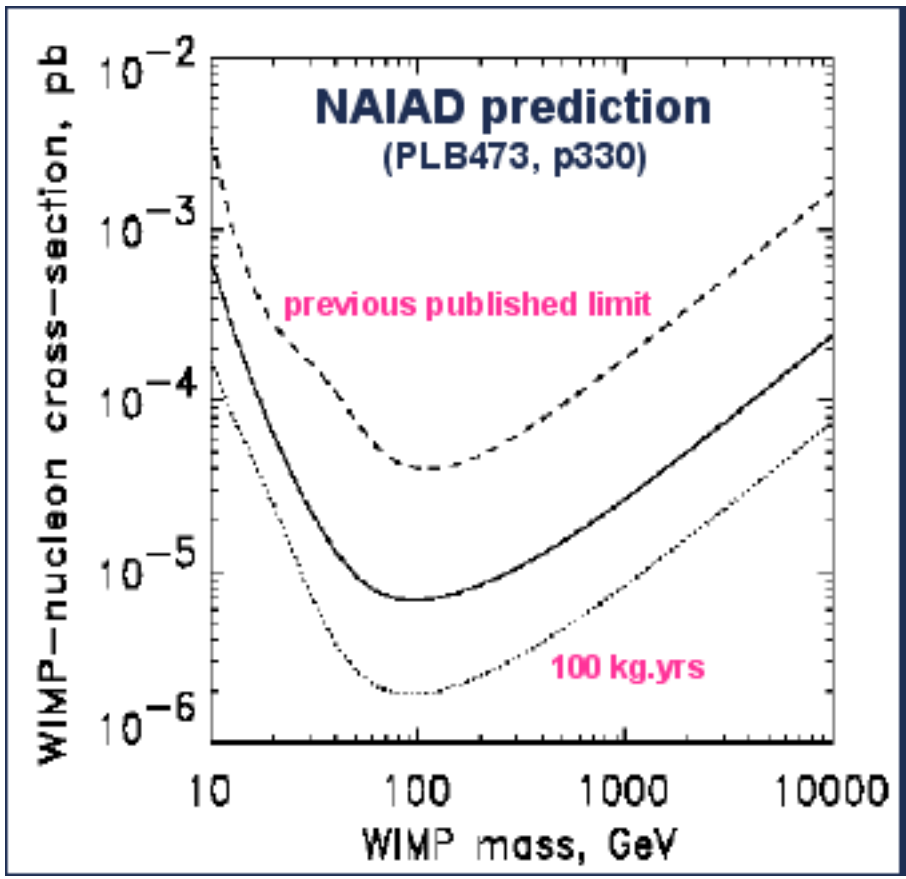
- 40-50 kg Unencapsulated surface controlled NaI
- 10 kg Saclay crystal
- Lead/copper/wax shielding
- Dry N_2 environment
- 8 castles, temperature stable <0.1C
- Acquiris PCI high rate DAQ
  - **8 bit ADC**
  - **Slow control**
- PSD
  - $\tau_n / \tau_\gamma = 0.75$
- Auto calibration
  - **CCAL daily (5hours)**
  - **ECAL weekly**
- 6-9 p.e./keV yield

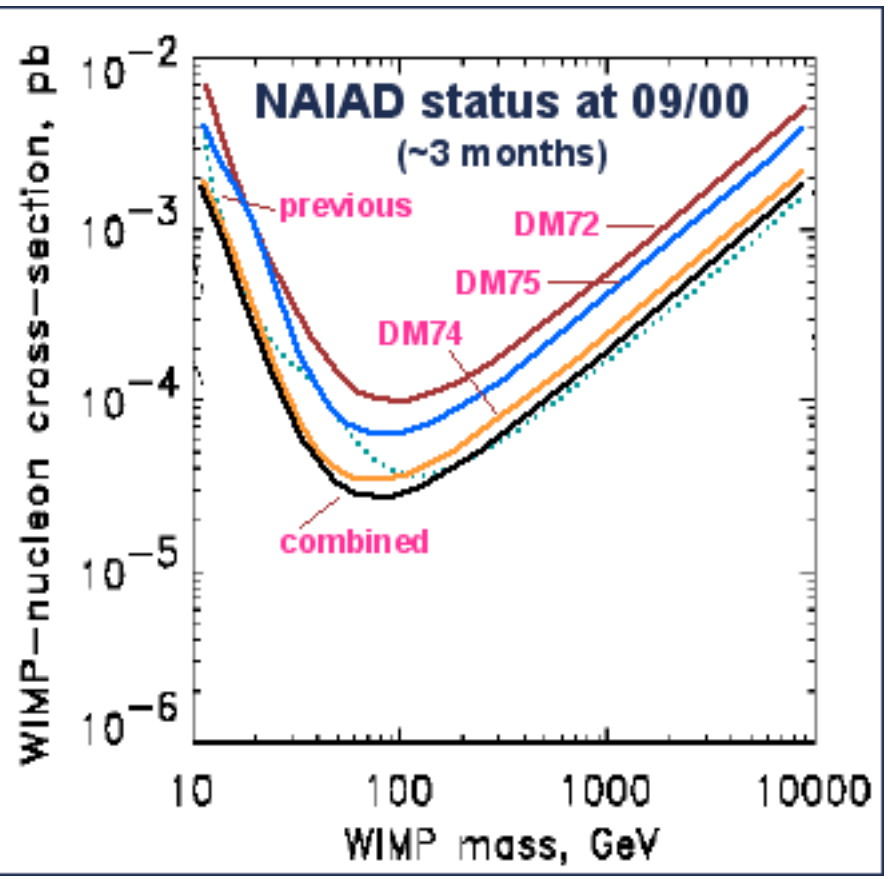




NAIAD Preliminary Results

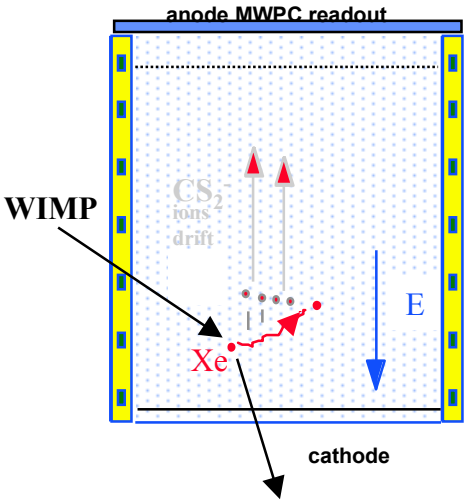
- Last published result PLB473
- Now down to ~10^{-5}pb
- All crystals now installed and running

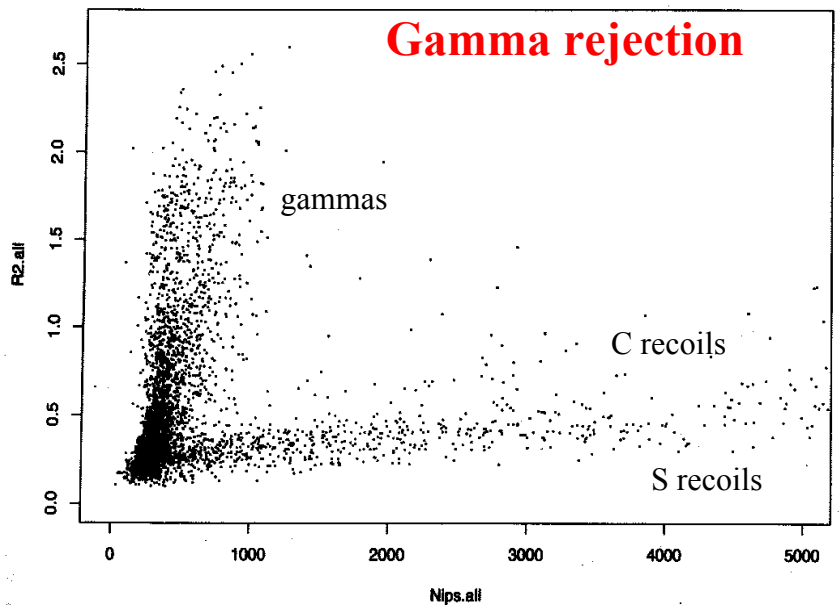


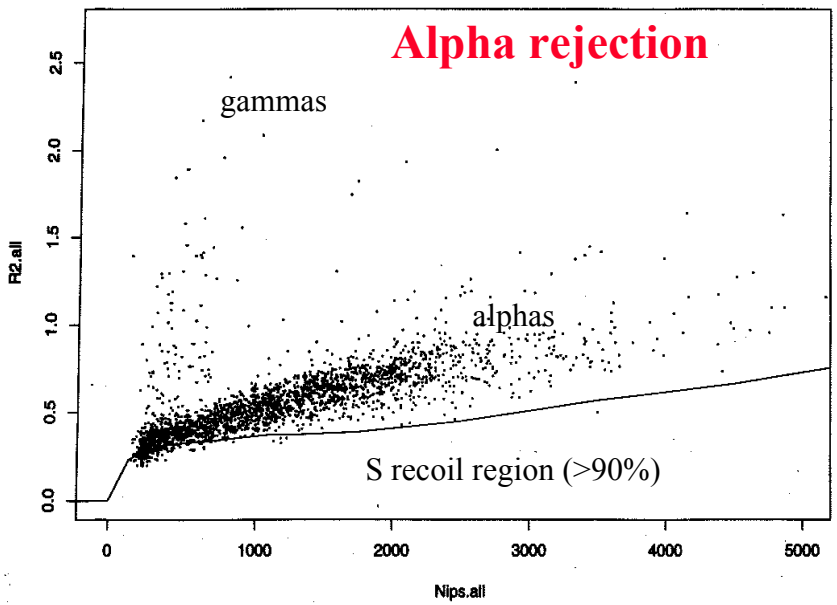


DRIFT TPC

- DRIFT: low pressure gaseous TPC
  - **Recoil direction correlation**
  - **Electronegative CS_2 minimises diffusion**
  - **No magnet required (good for mines)**
- 1 foot cube detector
  - **99.9% gamma rejection @ 6keV**
  - **95% alpha rejection (from wires)**





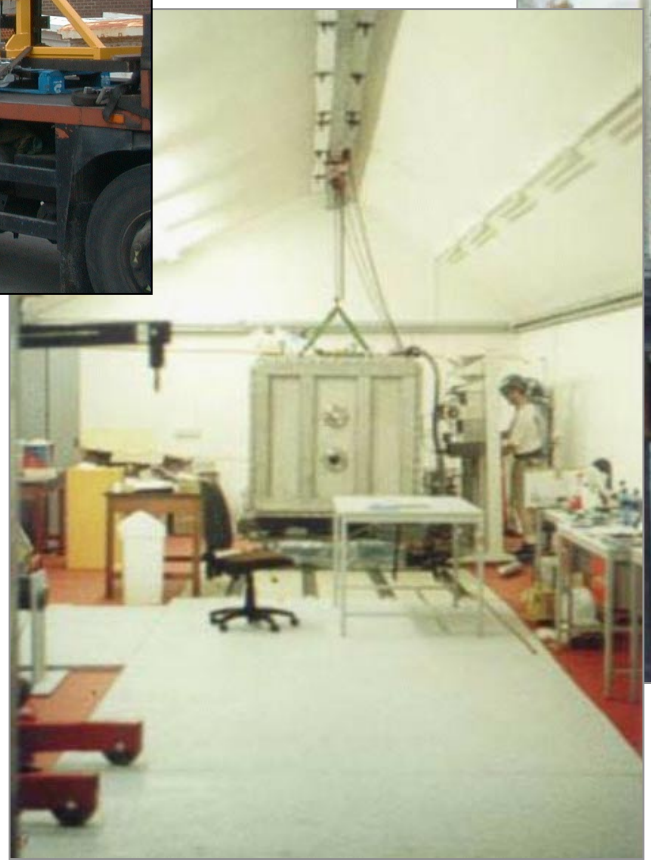


DRIFT I Design

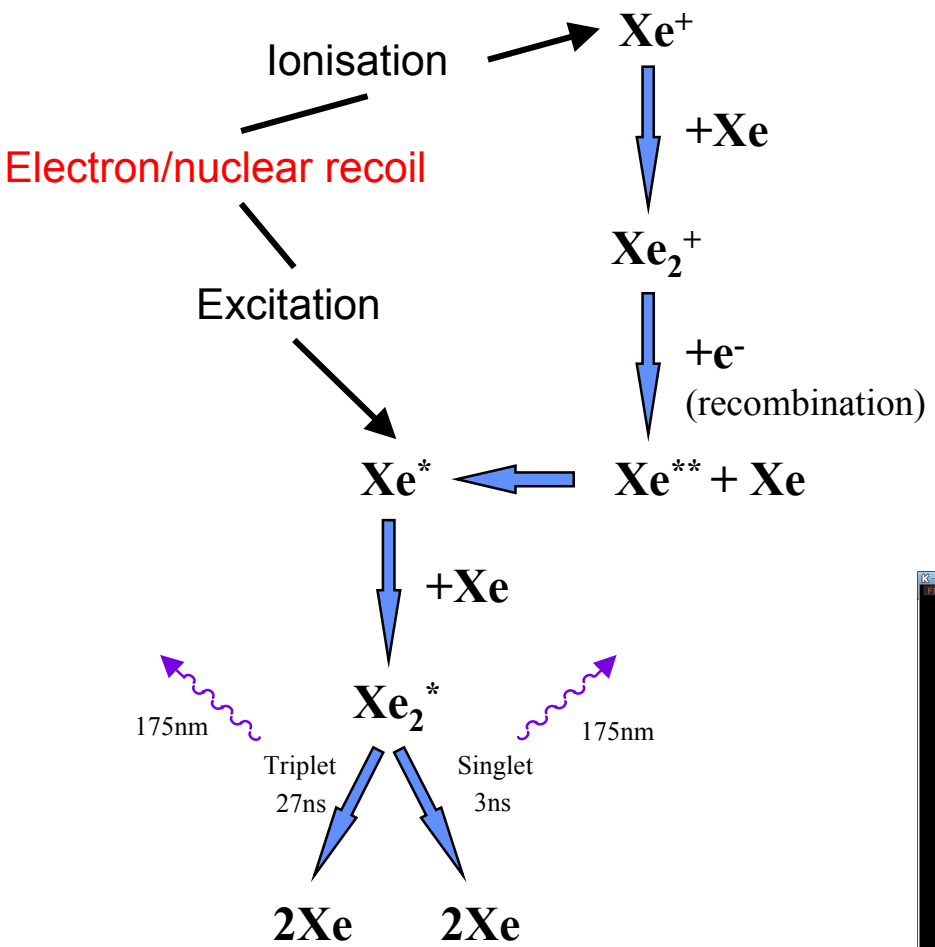
- DRIFT 1m^3 module now operational
  - **200μm wire chamber 2cm pitch**
  - **20μm MWPC readout 2mm pitch**
- CS_2 at 40 Torr: 200g target
- Currently un-shielded for background studies
  - **Ambient neutrons observed**
- Shielding under construction
- Expected backgrounds:

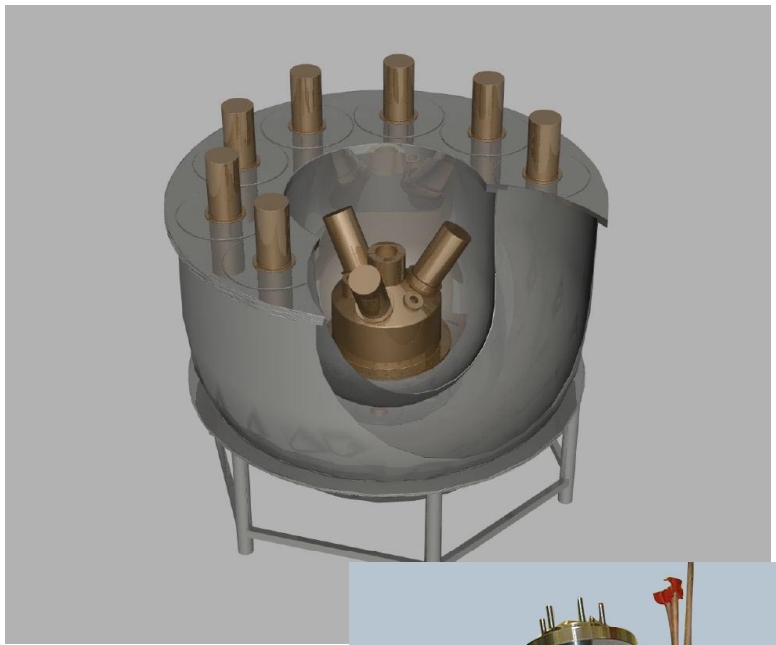
Background Source (per year)	Chamber rate (No shield)	Raw rate (12 cm Pb shield)	Raw rate (12 cm Pb + 3mm Cu shield)	With alpha and electron cuts (90% acceptance of nuclear recoils)
Internal surface X-rays	2.60E+07	6.10E+04	5.40E+04	1.59
Internal surface betas	2.40E+06	2.40E+06	6.10E+04	1.82
Grid wire alphas	1500.00	1500.00	1500.00	0.04
Cathode wire alphas	300.00	300.00	300.00	1.53
Neutrons	50.00	50.00	50.00	0.25
	0.03	0.03	0.03	0.03
Total	2.84E+07	2.46E+06	1.17E+05	5.26

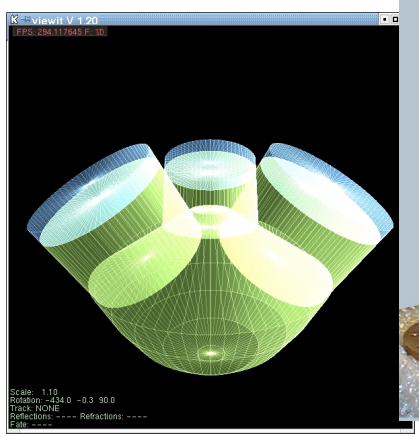
DRIFT Installation



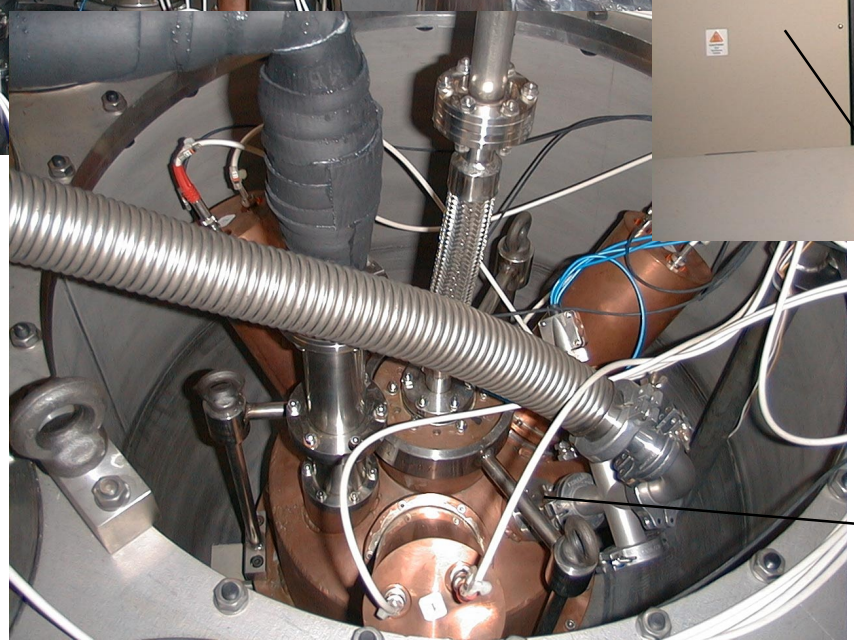
ZEPLIN I


Ionisation
Electron/nuclear recoil
Excitation
Xe+
+Xe
Xe2+
+e-
(recombination)
Xe**
+ Xe
Xe*
+Xe
Xe2*
175nm
175nm
Triplet
27ns
Singlet
3ns
2Xe
2Xe





ZEPLIN I Installation



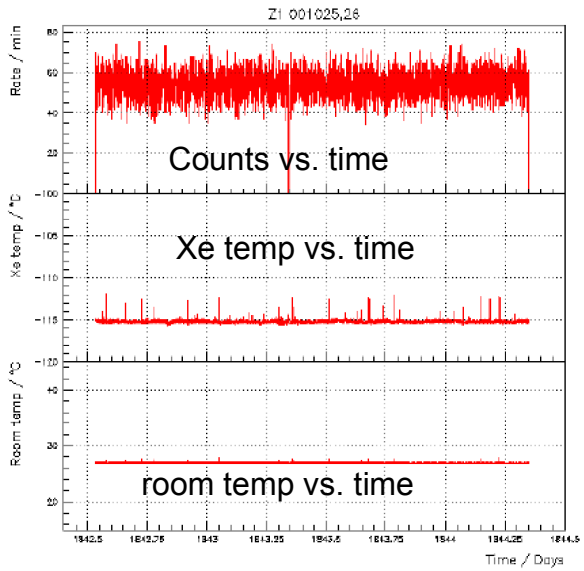
Xenon recovery system

Xenon purifier

Polycold cryogenerator

ZEPLIN I target

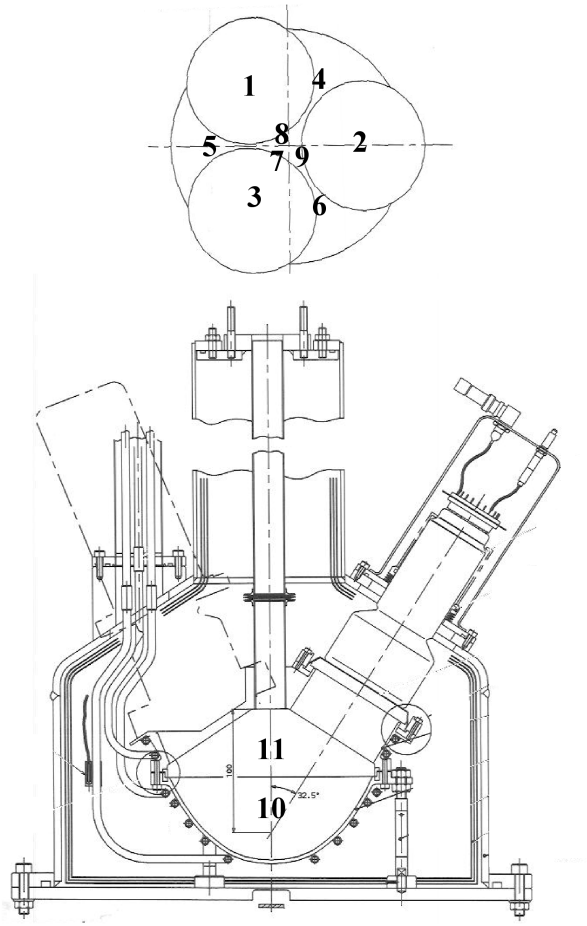
ZEPLIN I Underground

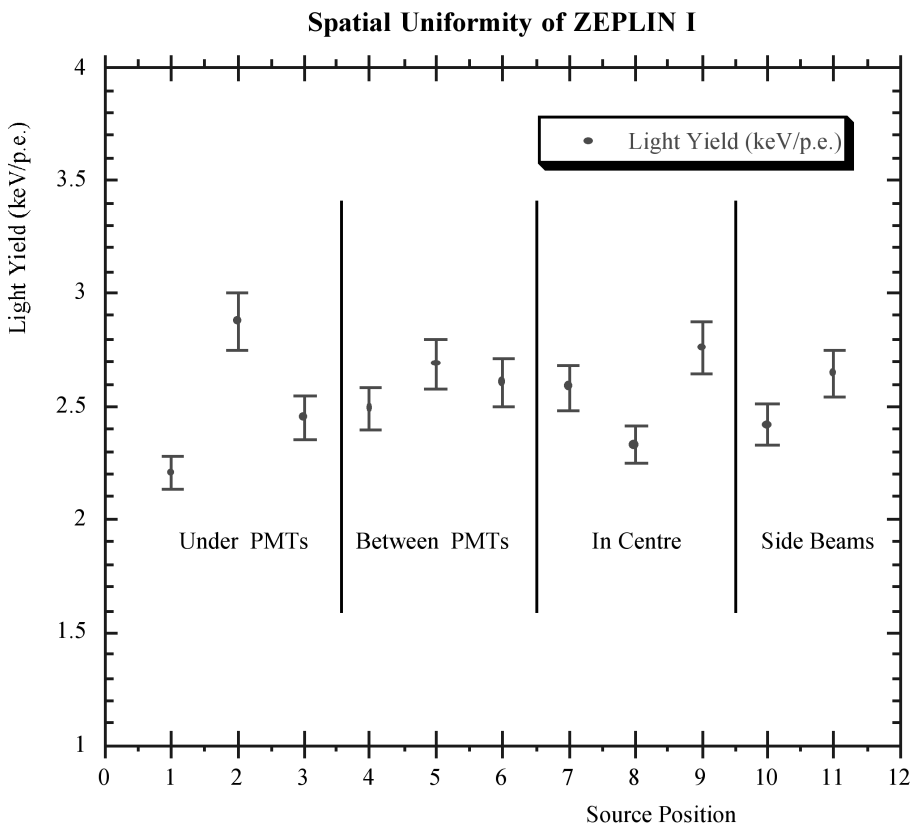


Stable operation demonstrated

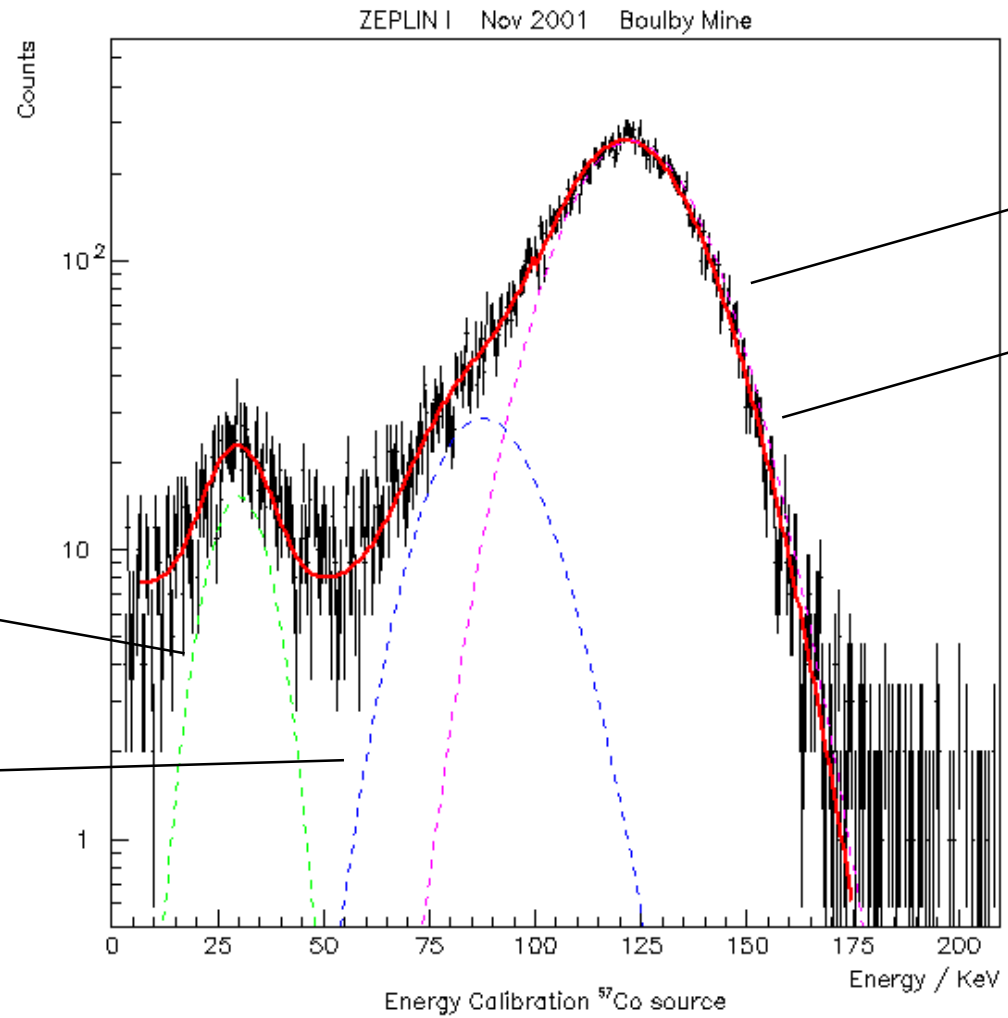
ZEPLIN I Performance

- SpatialUniformity
  - ^{137}Cs Source, collimated beam





ZEPLIN I Energy Calibration



122 keV peak

136 keV peak (10%)

30 keV X-ray

90 keV recoil e-

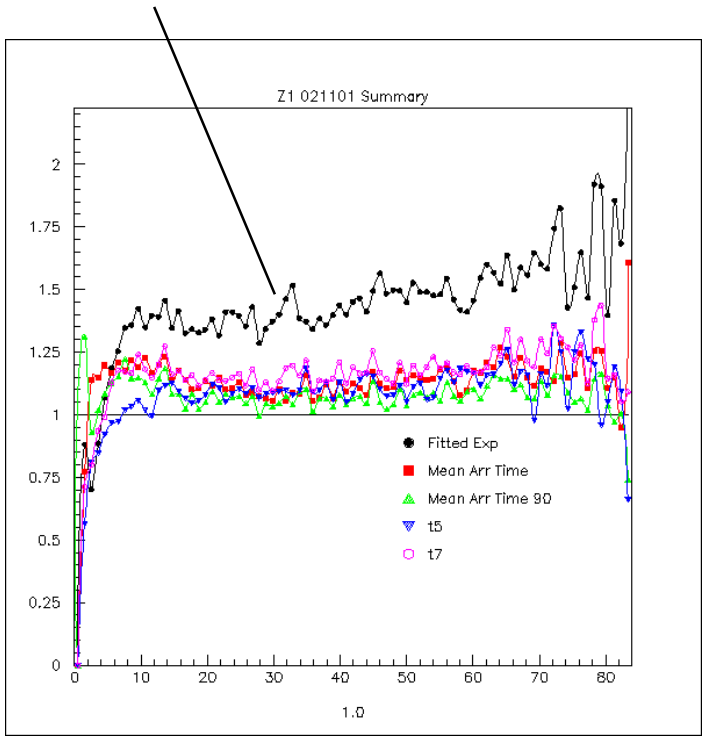
Linear response
1.5 p.e./keV
Resolution

$$\sigma(E) = 1.24\sqrt{E}$$

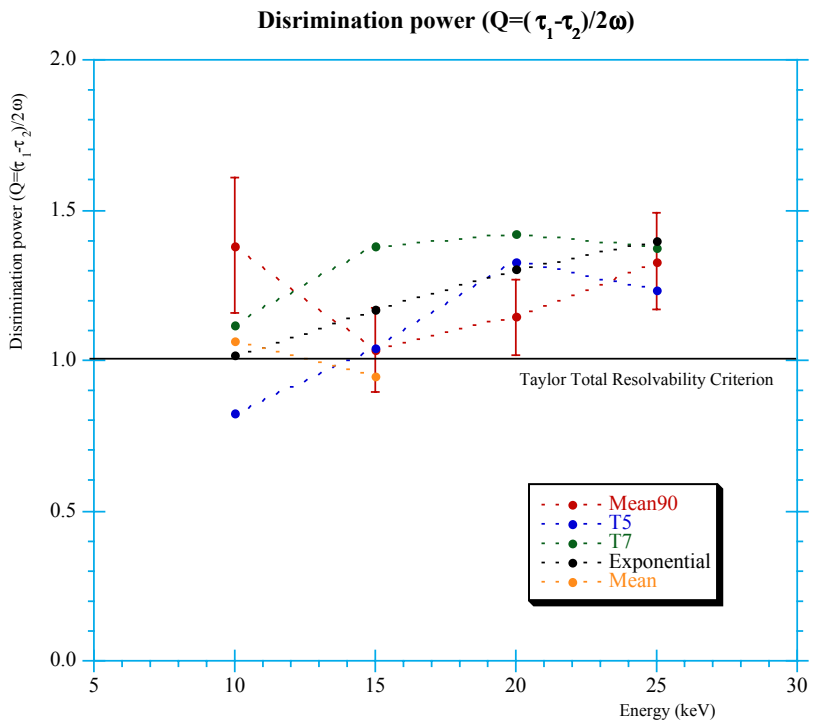
ZEPLIN I Analysis

- Different techniques applied to assess widths and discrimination power
  - **General agreement for model independent fits**

Fitted single exponential (not expected Xe pulse shape)

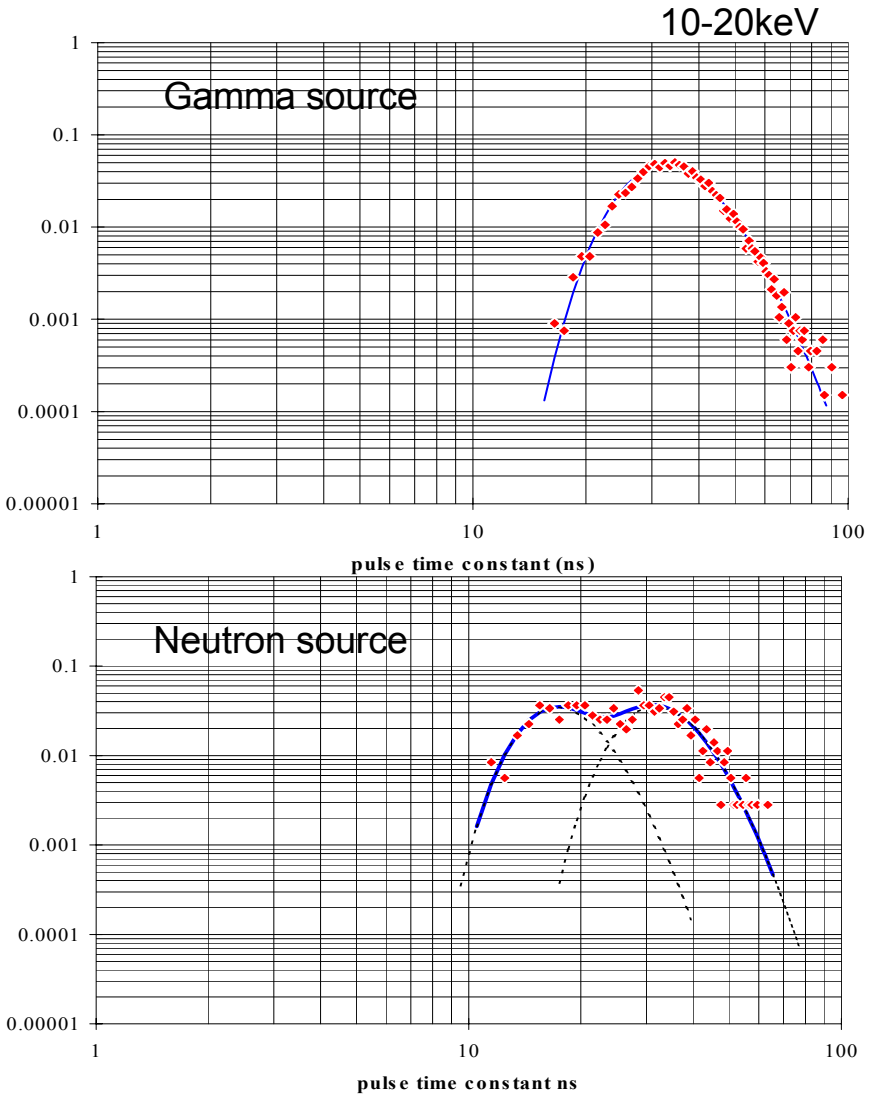


Widths of τ distbn. Normalised to □$N_{p.e.}$

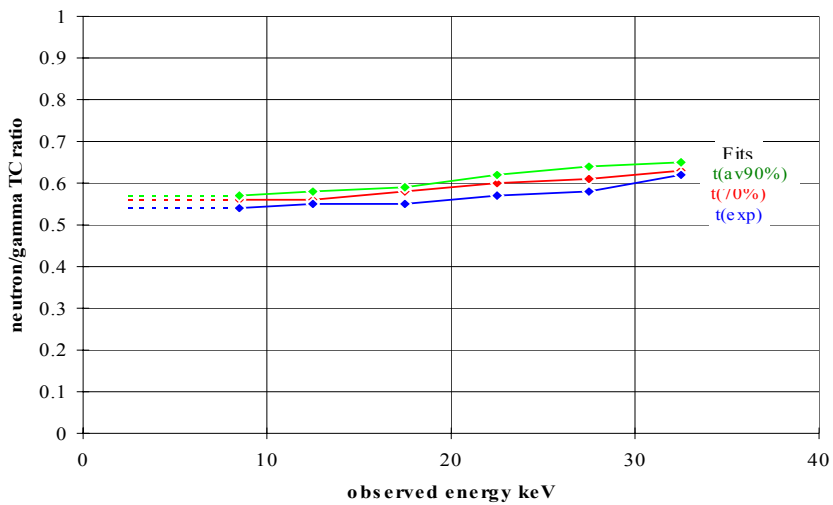


Discrimination power

ZEPLIN I Discrimination

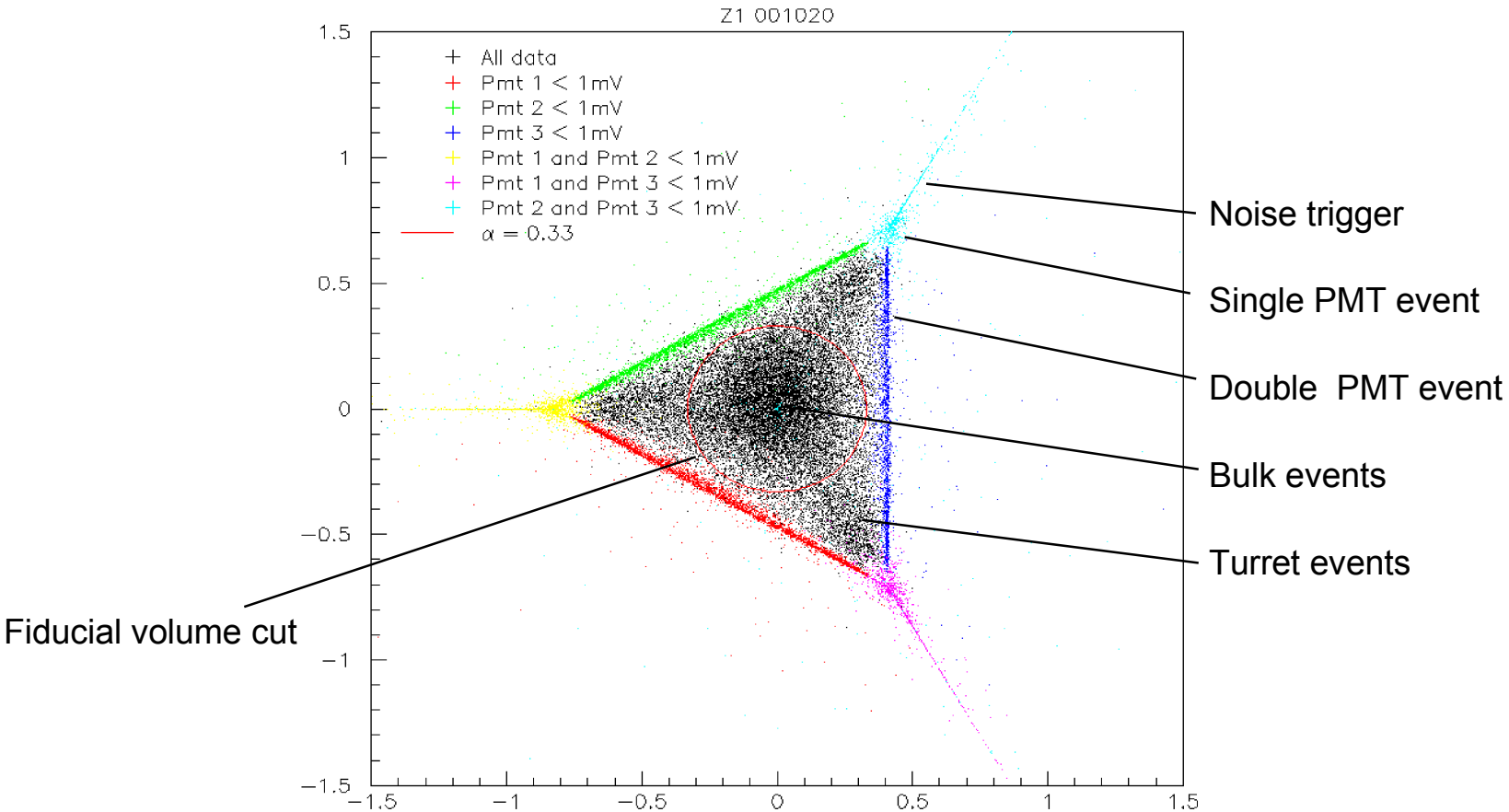


- Using different fitting techniques
  - **Single exponential fit**
  - **Mean, mean to90%, median**
- Fitted ‘gamma’ density function in $1/\tau$
- Lab calibrations data to 7keV
- Assume flat for last E bin
  - **Long u/g run planned**
  - **Effect minimal in analysis**



S3 Fiducial volume cut

- Project normalised amplitudes PMT1,2,3 onto plane - S3

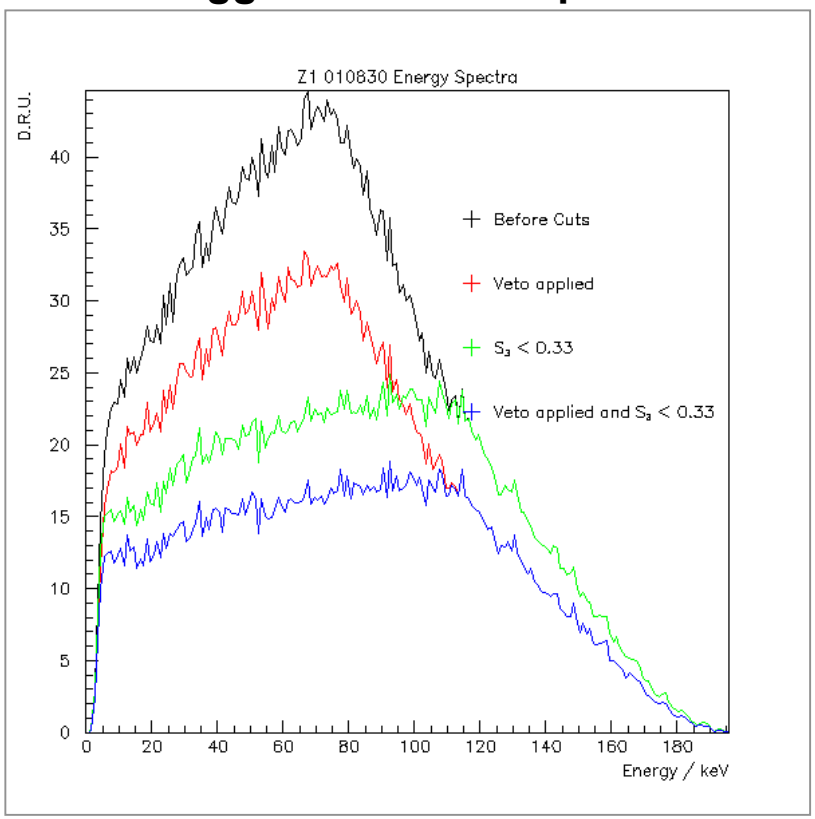


Trigger condition is set to ‘free-run’

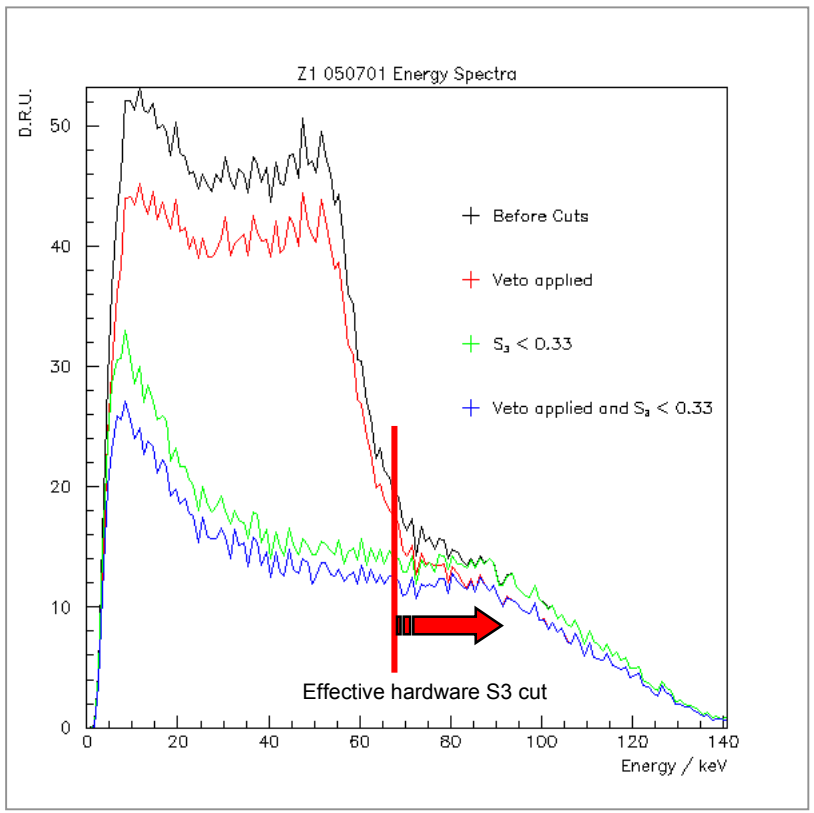
ZEPLIN I Veto cuts

- Confirmation of background rejection by fiducial cuts and Compton veto rejection

Trigger 3 PMTs at 1 pe



Trigger 2 PMTs of 3 at 1 pe

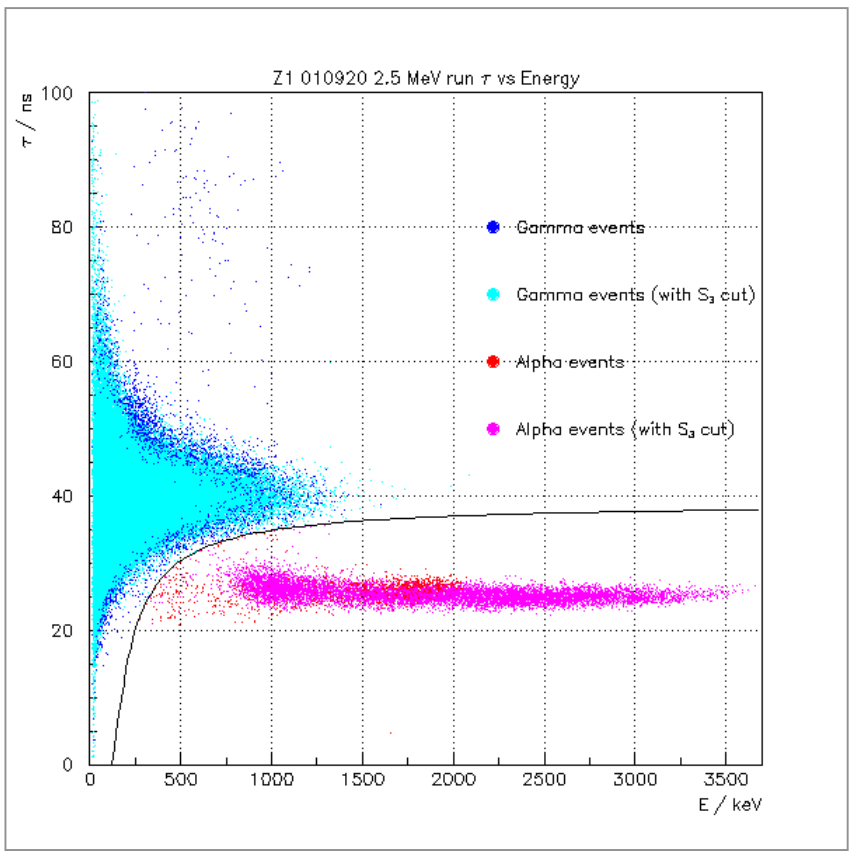


- Background implies $^{85}Kr < 10^{-17}$ atoms/atom (standard Xe used)

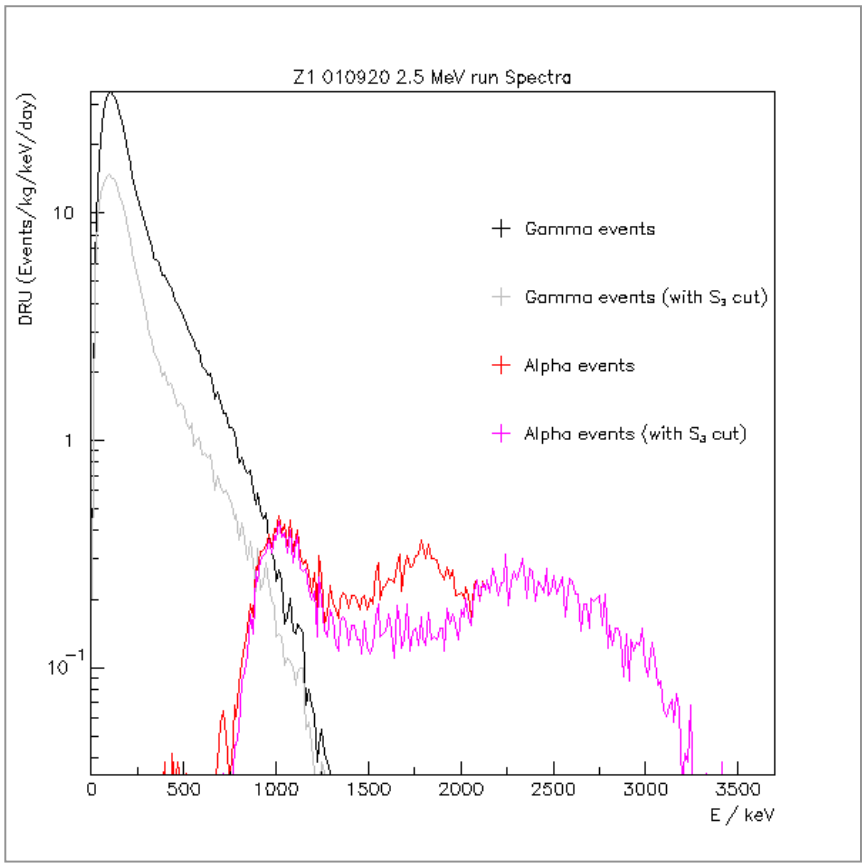
ZEPLIN I alpha counting

- Study alpha contamination in Xenon - limits on U/Th MC underway

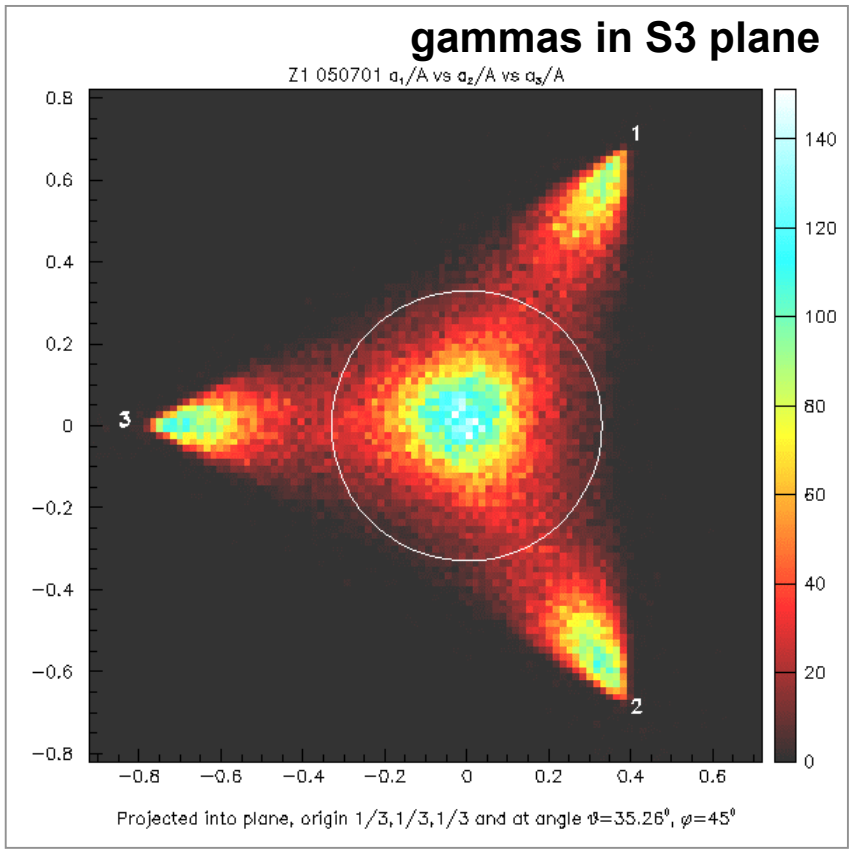
tau vs. energy

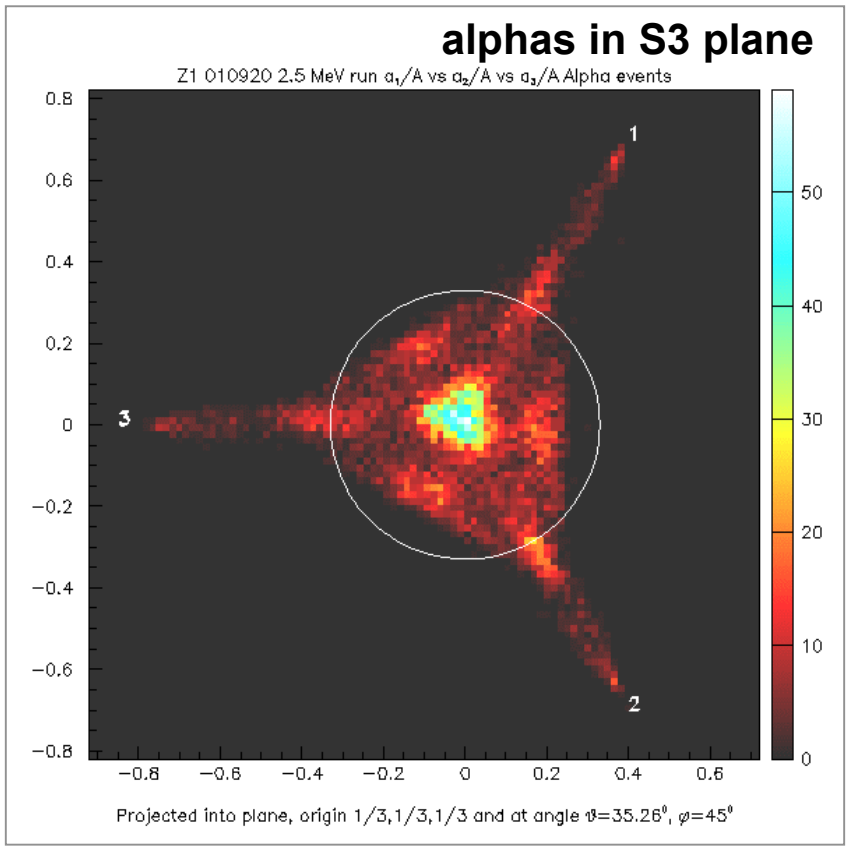


gamma and alpha spectra



ZEPLIN I S3 fiducial cuts (alphas)

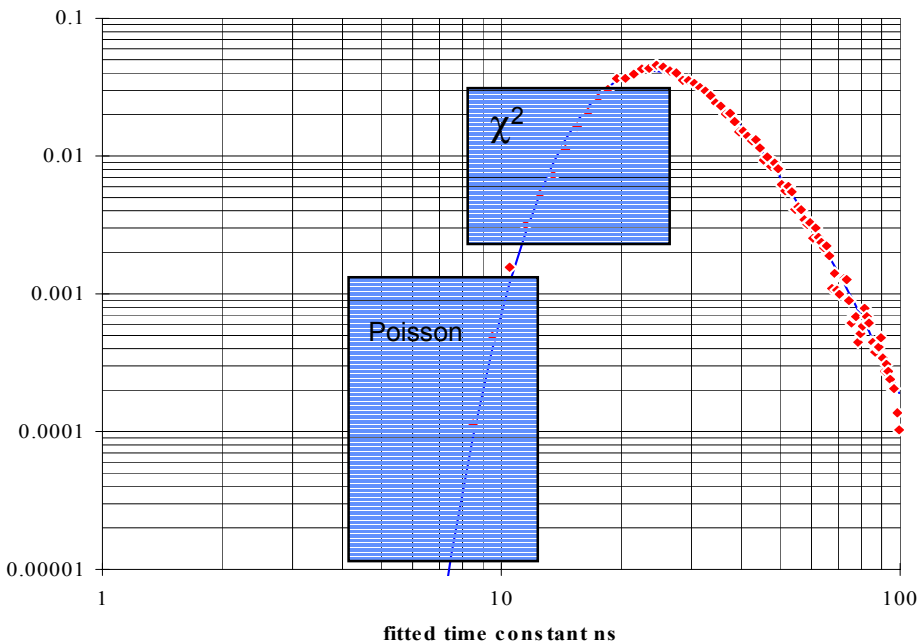


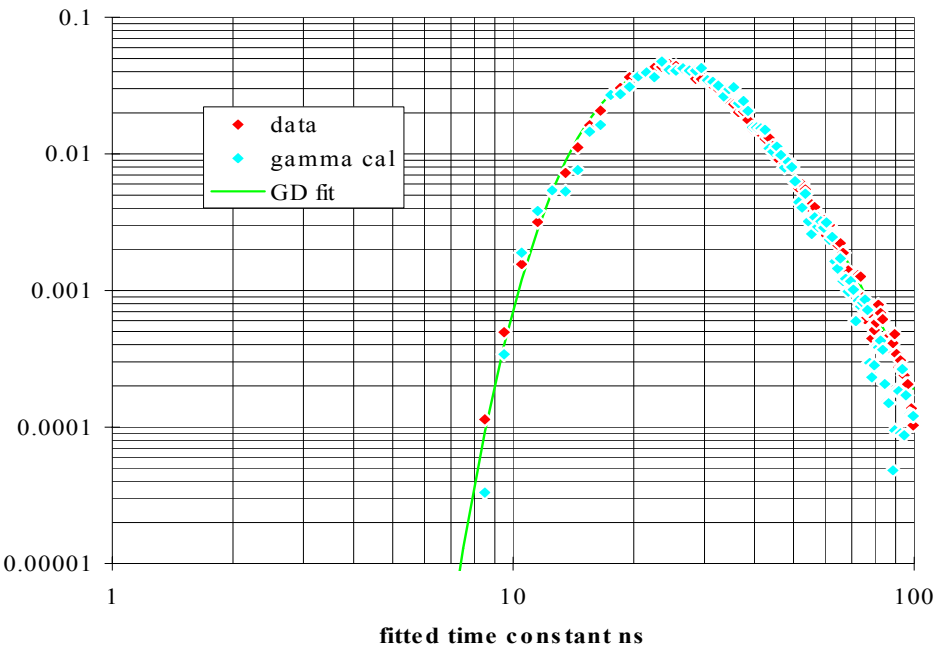


- Information about alpha contamination location available?
  - **PTFE favoured, rather than windows/seals**
- Gamma contamination from PMTs rejected in turrets

ZEPLIN I Nov 2001 Data Run

- 27 day livetime, 90kg.days data
- Gamma calibration data from contemporaneous veto events
- 'Gamma' density fit (actually in 1/τ) as guide: smooth slope
- Analysis:chisquared signal region, poisson tail, ML underway

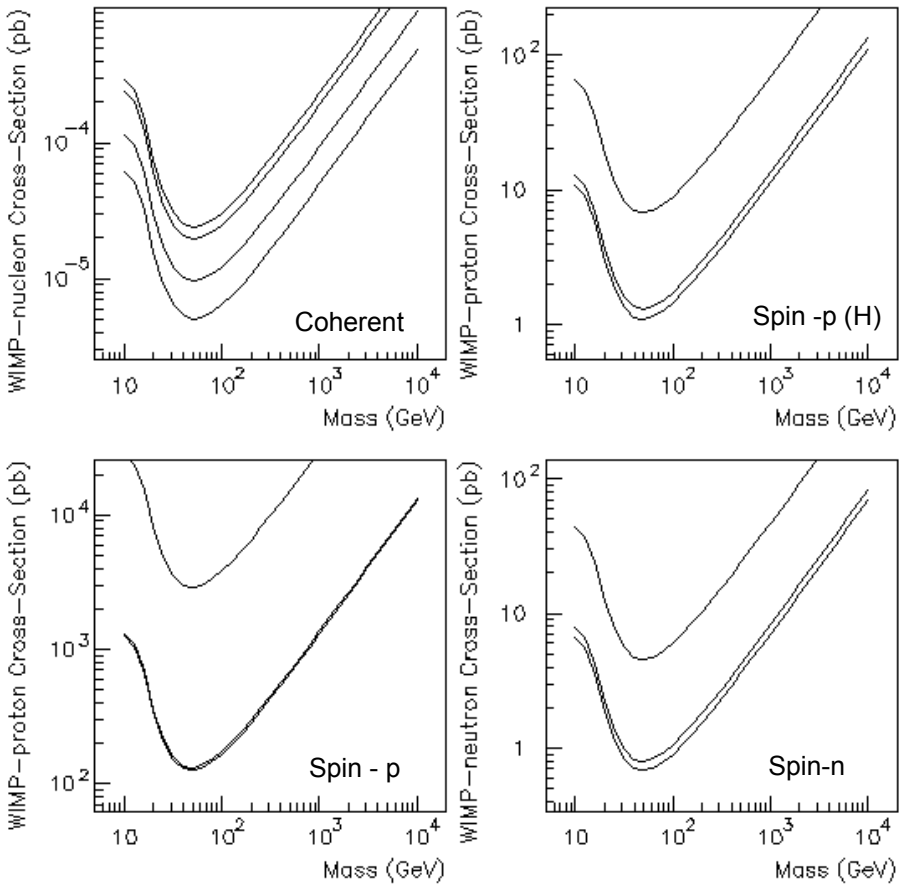




ZEPLIN I limit

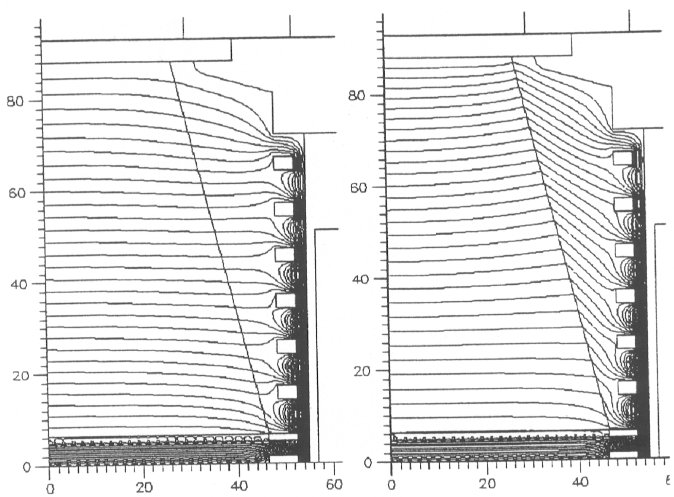
- Chisquared analysis
  - **Conservative**
- Based on measured lab neutron discrimination
  - **Effect of extrapolation for last E bin minimal**
  - **To be re-done underground**
- Poisson trigger efficiency analytically included
- S3 volume efficiency cut at low E to be Monte Carlo'd
  - **Conservative assumption fed in from spectrum**
- Standard DM assumptions
- Spin - as per Tovey et al.

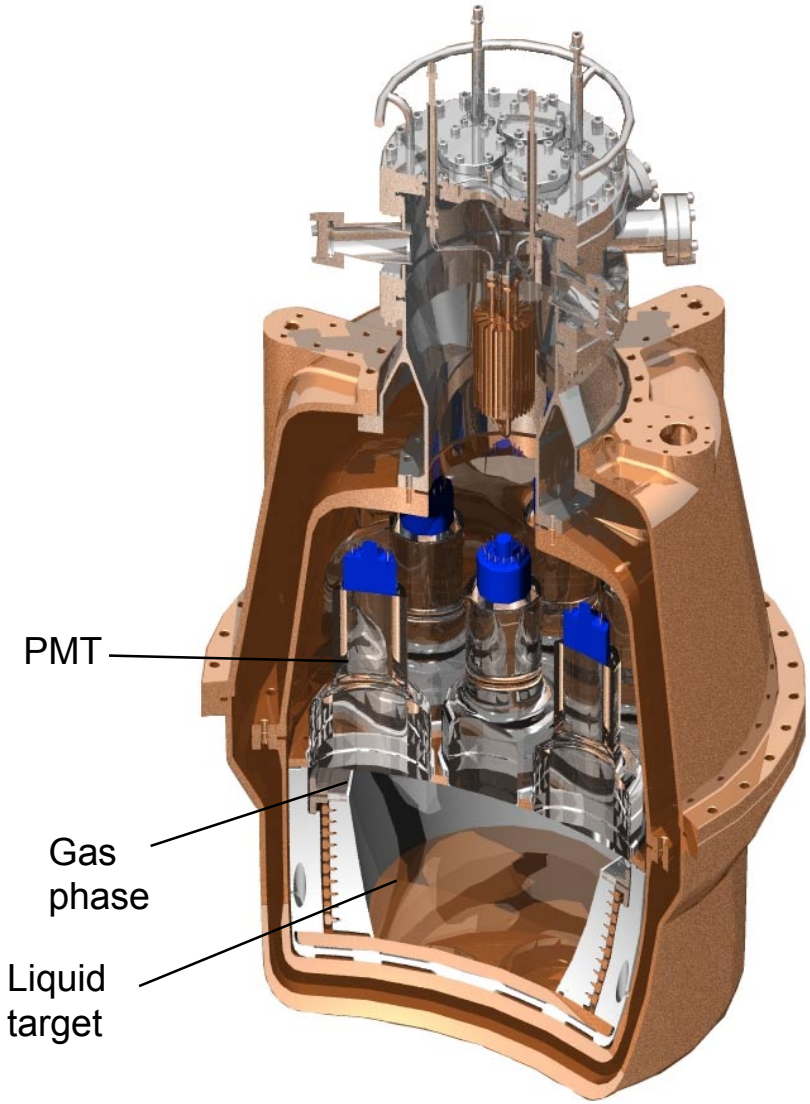
Preliminary



ZEPLIN II

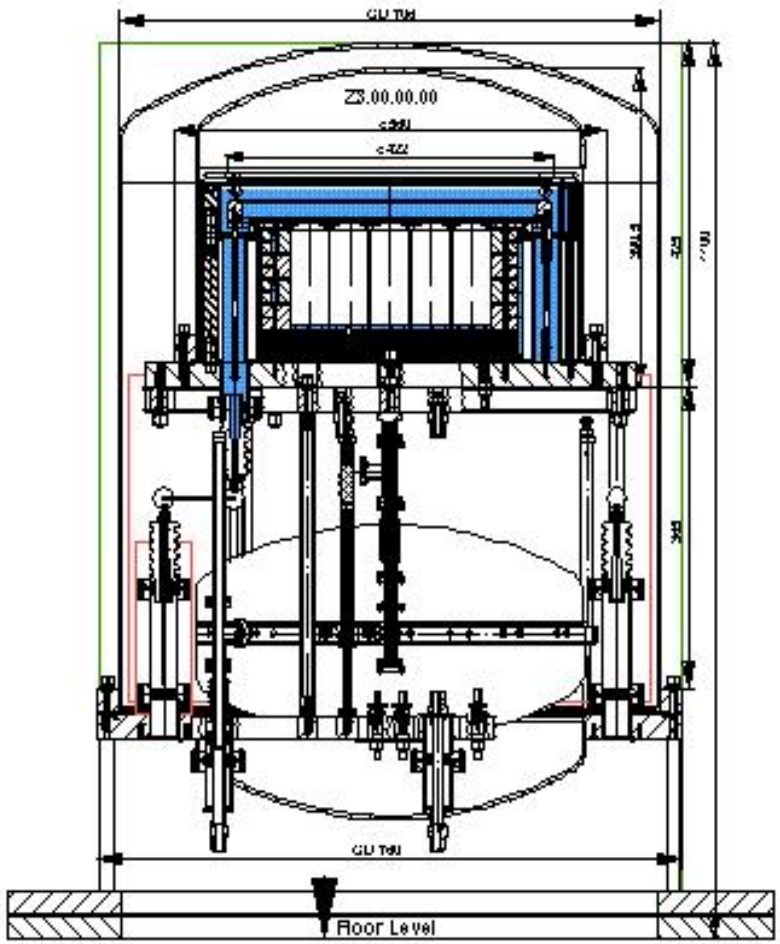
- 2 phase detector, 7x 5” PMT
  - **Scintillation for S1**
- E-field to extract ionisation
  - **Electroluminescence for S2**
  - **Nuclear recoil negligible S2**
- 30kg target under construction
- Deploy summer 2002
- PTFE Liner
  - **Define E-field (no dead zones)**





ZEPLIN III Design

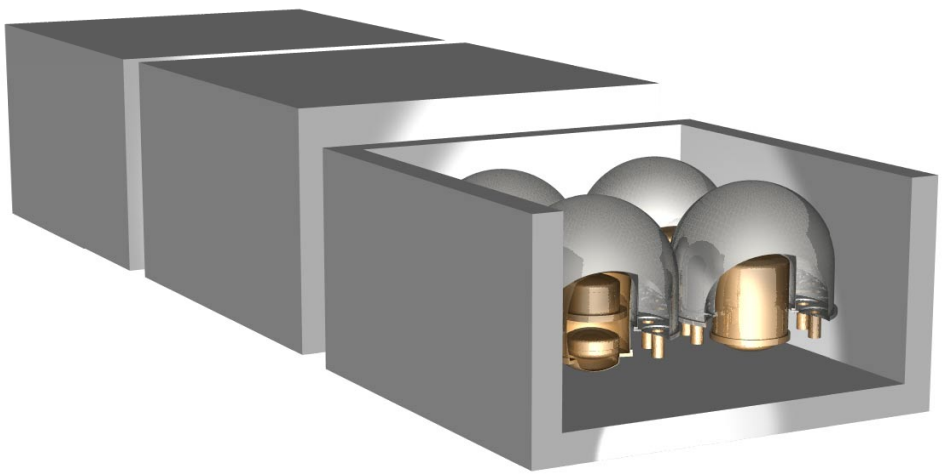
- 2 phase detector, 31x 2” PMT
- High E-field to extract ionisation from nuclear recoils
  - **Nuclear recoil S1 and S2**
- 7kg target under construction
- Deploy fall 2002
- Jaime’s talk to follow

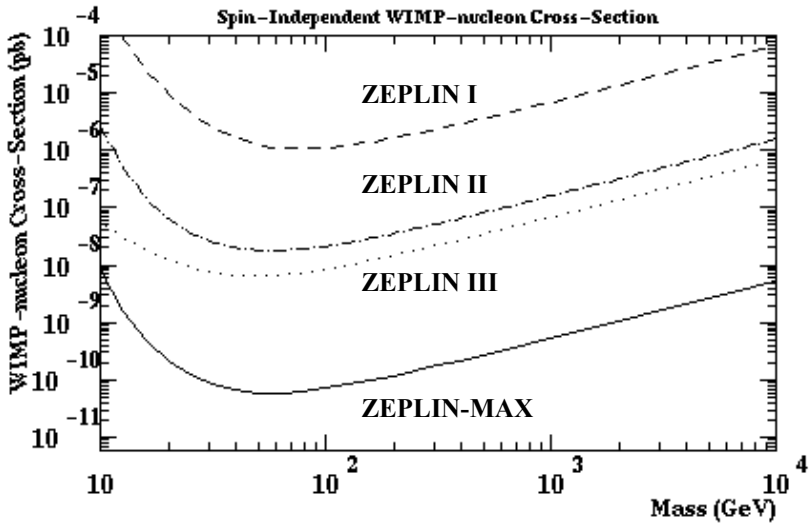


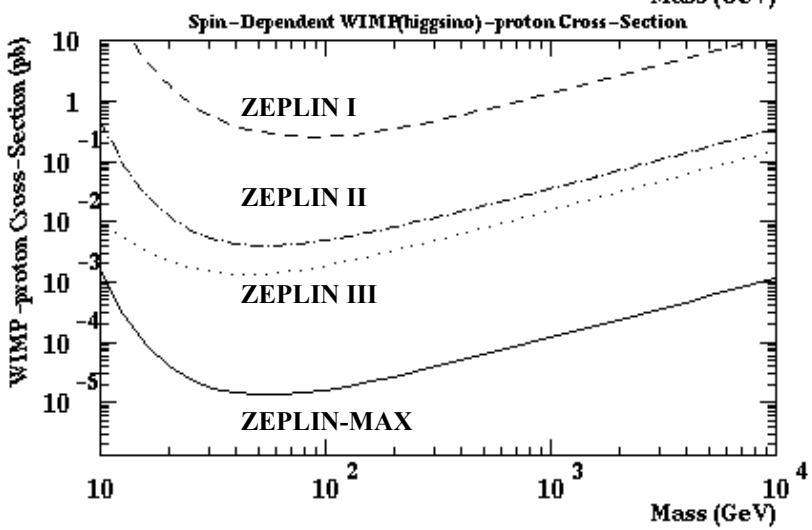
ZEPLIN Sensitivities

- Assumptions
  - 1 year data
  - No signal
- ZEPLIN-MAX (IV)
  - 1 tonne two phase target

ZEPLIN-MAX Conceptual (or all in one)



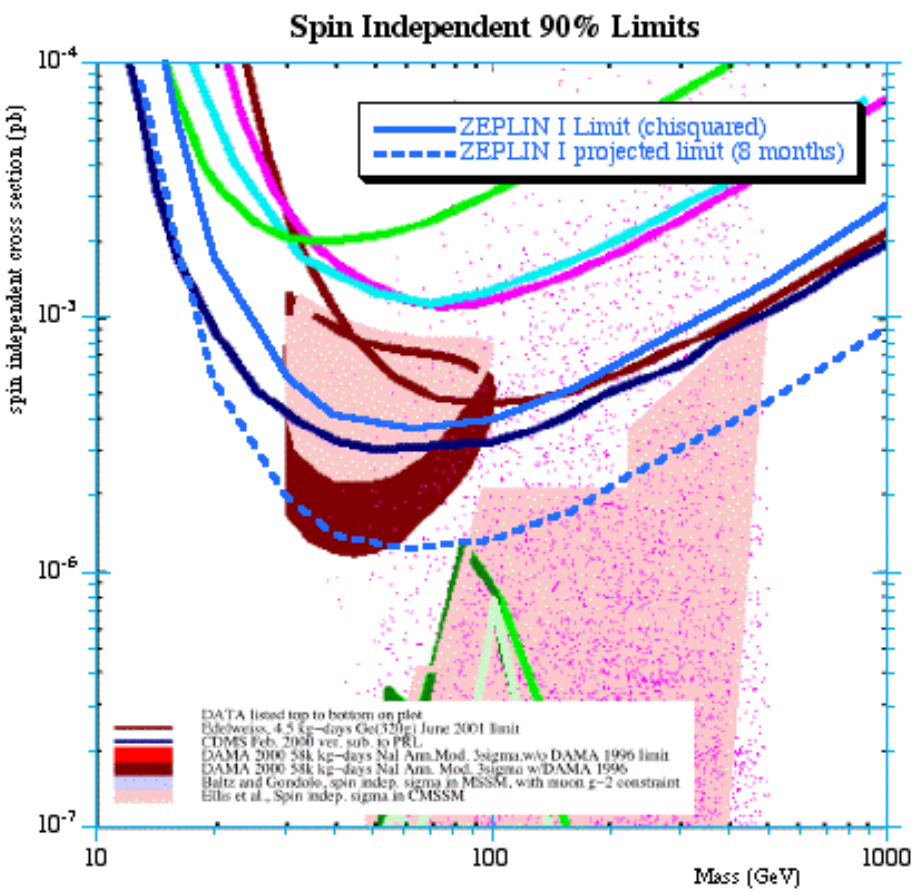




Summary

- Boulby Facility
  - Surface building complete
  - Underground labs Aug 2002
- NaIAD
  - Investigate DAMA ann. Mod. Region
  - Surface events controllable
  - 50kg array operational
  - ~10^{-5}pb limit
- DRIFT
  - Directional detector
  - 1m^3 CS_2 200g target operational
  - Background neutron runs
  - Shielding installation underway
- ZEPLIN
  - ZEPLIN I operational
    - New limits for UKDMC
    - Operational test for Xe systems
    - Analysis refinement on-going
    - S3 volume efficiency simulations on-going
  - ZEPLIN II/III
    - Construction underway
    - Other talks (D.Cline, J.Dawson)
  - ZEPLIN-MAX (IV)
    - Amalgam of technologies and expertise

http://cdms.berkeley.edu/limitplots/
Gaitskell, Mandic



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