# Recent results from the UK Dark Matter Search at Boulby Mine.

**Nigel Smith**
**Rutherford Appleton Laboratory**
**on behalf of the**
**UK Dark Matter Collaboration**
**(Imperial College, Sheffield, RAL)**

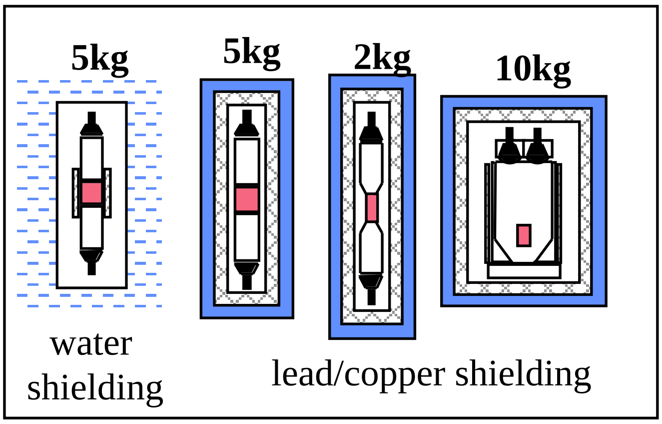
- NaI scintillation detectors
- UKDMC NaI results
- Comparison to other experiments
- Future directions

# NaI as a WIMP detector

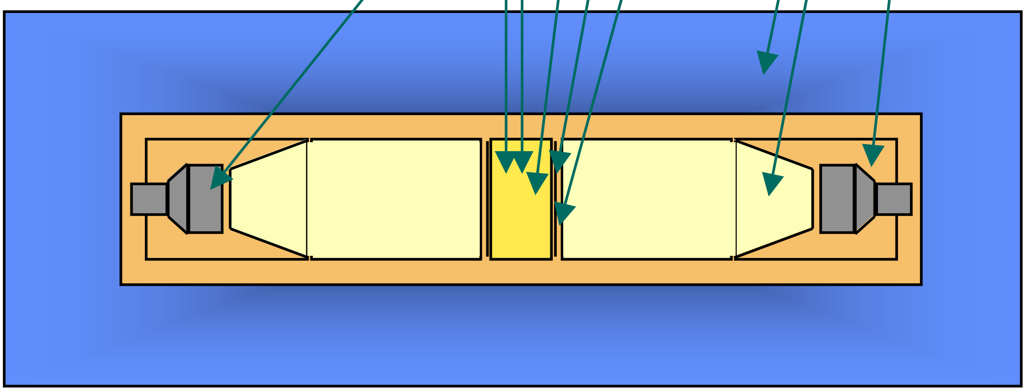
- Full pulse shape discrimination
  - **Noise control (PMT events)**
  - **Event information**
  - **Electron recoil rejection**
- Spin sensitivity (SI and SD)
- Two targets -> good mass coverage
- Form factors provide potential structure
- Low threshold ~1keV
  - **No microphonics**
- Known recoil efficiencies
- Radio-purification possible
- High mass detectors (100 kgs) possible

# The UKDMC NaI array

- Existing array

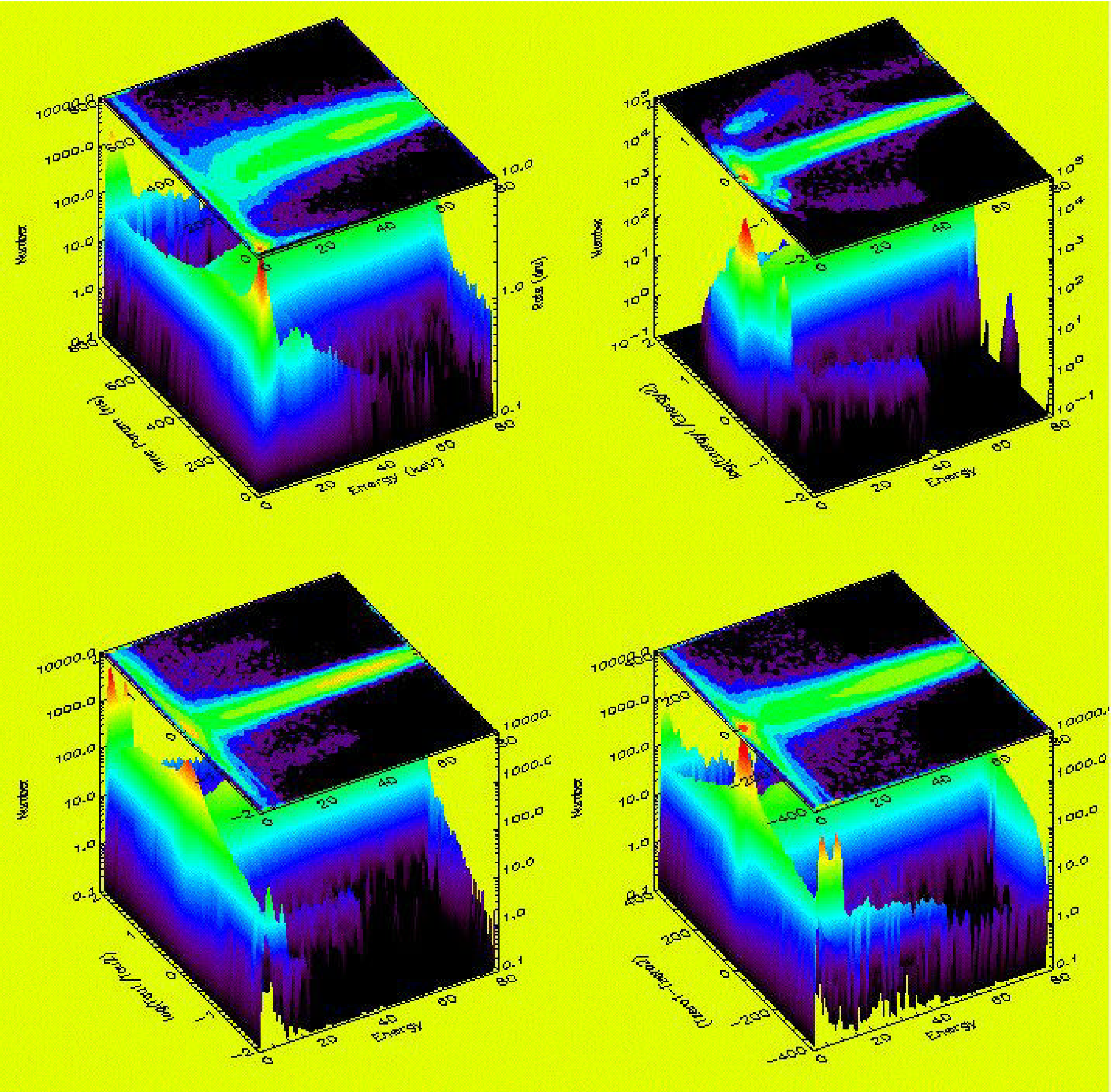



- Detector Arrangement
  - low activity copper PMT shields and containers
  - Low activity silica light guides & PMT shield
  - 3m low activity/high purity water shielding
  - Low activity selected optical grease
  - Pre-selected windows/adhesive
  - Double zone refined crystal
  - NaI powder preselected
  - PTFE wrapped crystal
  - EMI9265A PMT



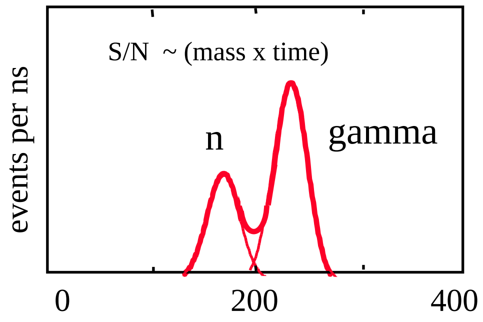
# Noise rejection plots

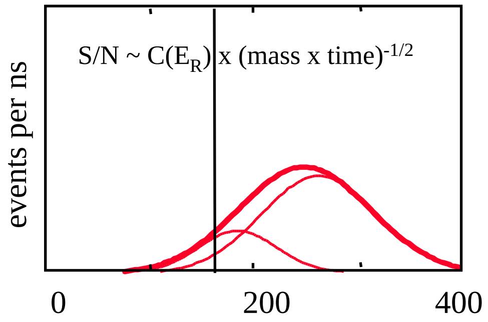
- Ratio between PMTs of
  - **Energy observed, risetime, start time**
- Chisquare of pulse fits



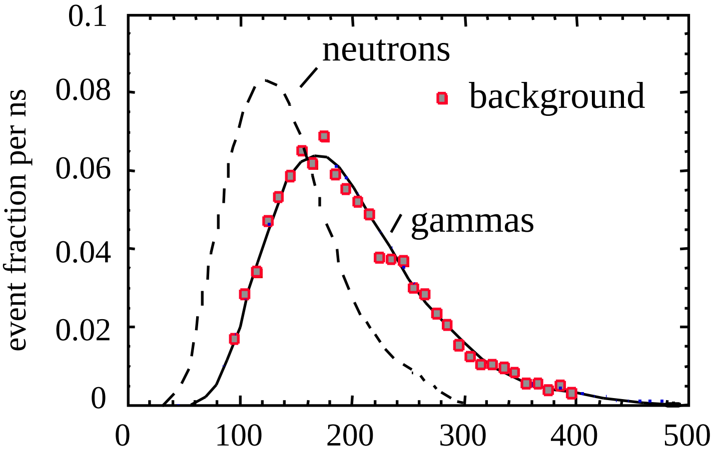
# NaI analysis

- High E (>MeV) event by event discrimination
- Low E statistical discrimination



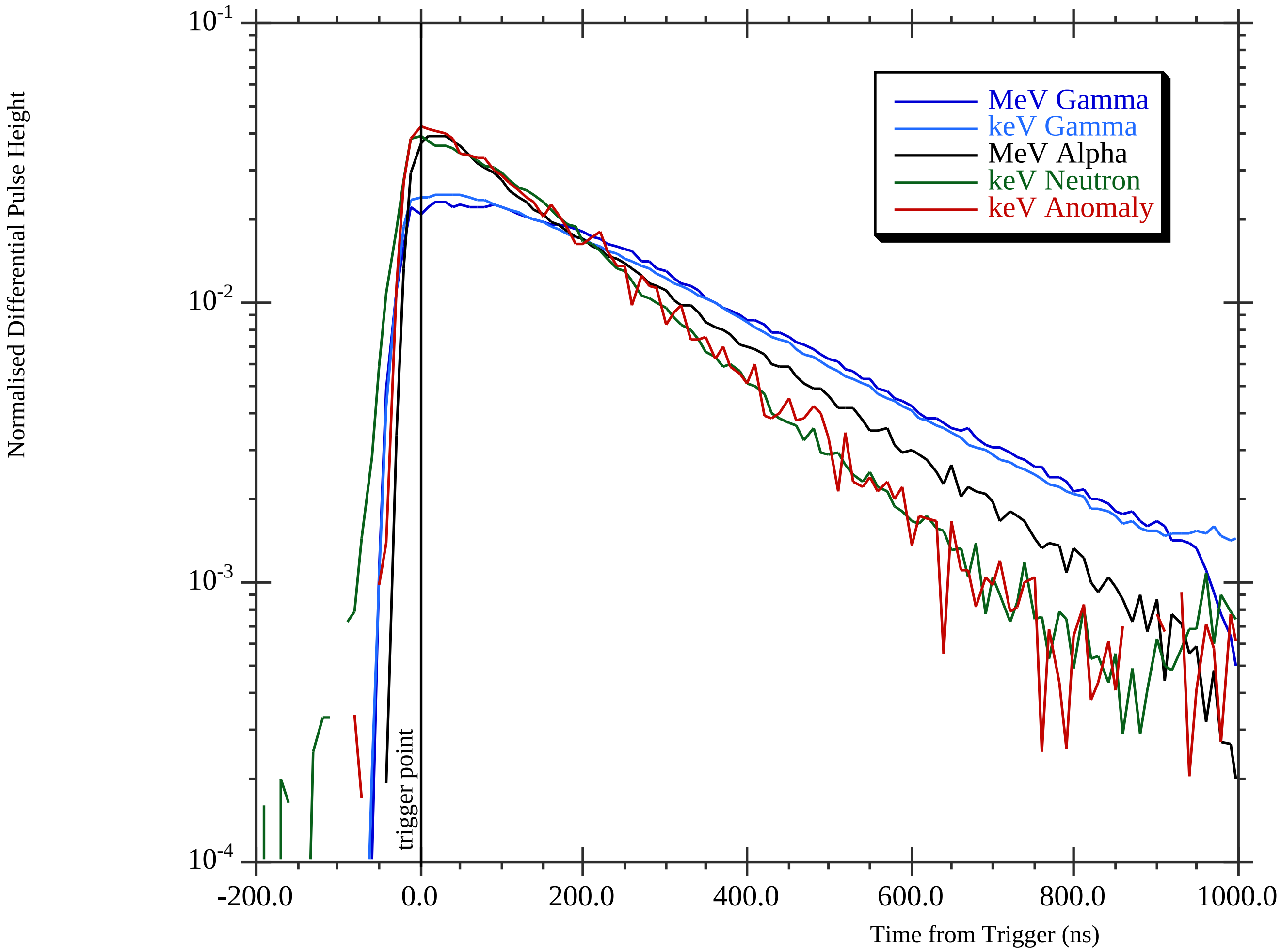

- Time constant distribution - log Gaussian




$$\frac{dN}{d\tau} = \frac{1}{(2\pi)^{1/2}} \frac{1}{\tau \ln w} e^{-\frac{(\ln\tau - \ln\tau_0)^2}{2(\ln w)^{-2}}} \qquad \text{error in } \tau_0 : \ \Delta\tau_0 = \frac{\tau_0 \ln w}{\sqrt{N}}$$

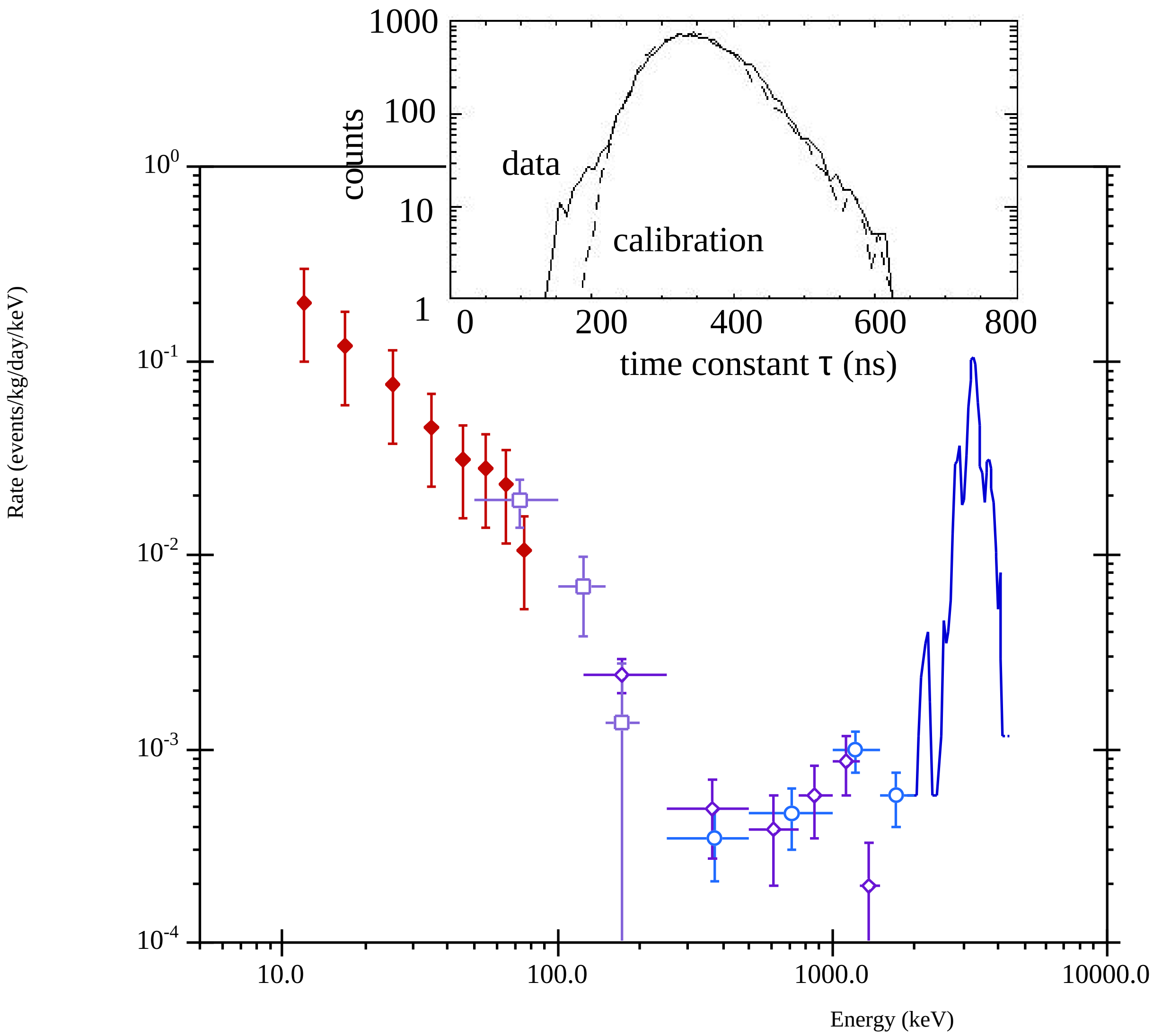
# UKDMC anomalous events

- Pulse shapes
  - Clear distinction between electron and nuclear recoils
  - Anomaly is nuclear recoil type

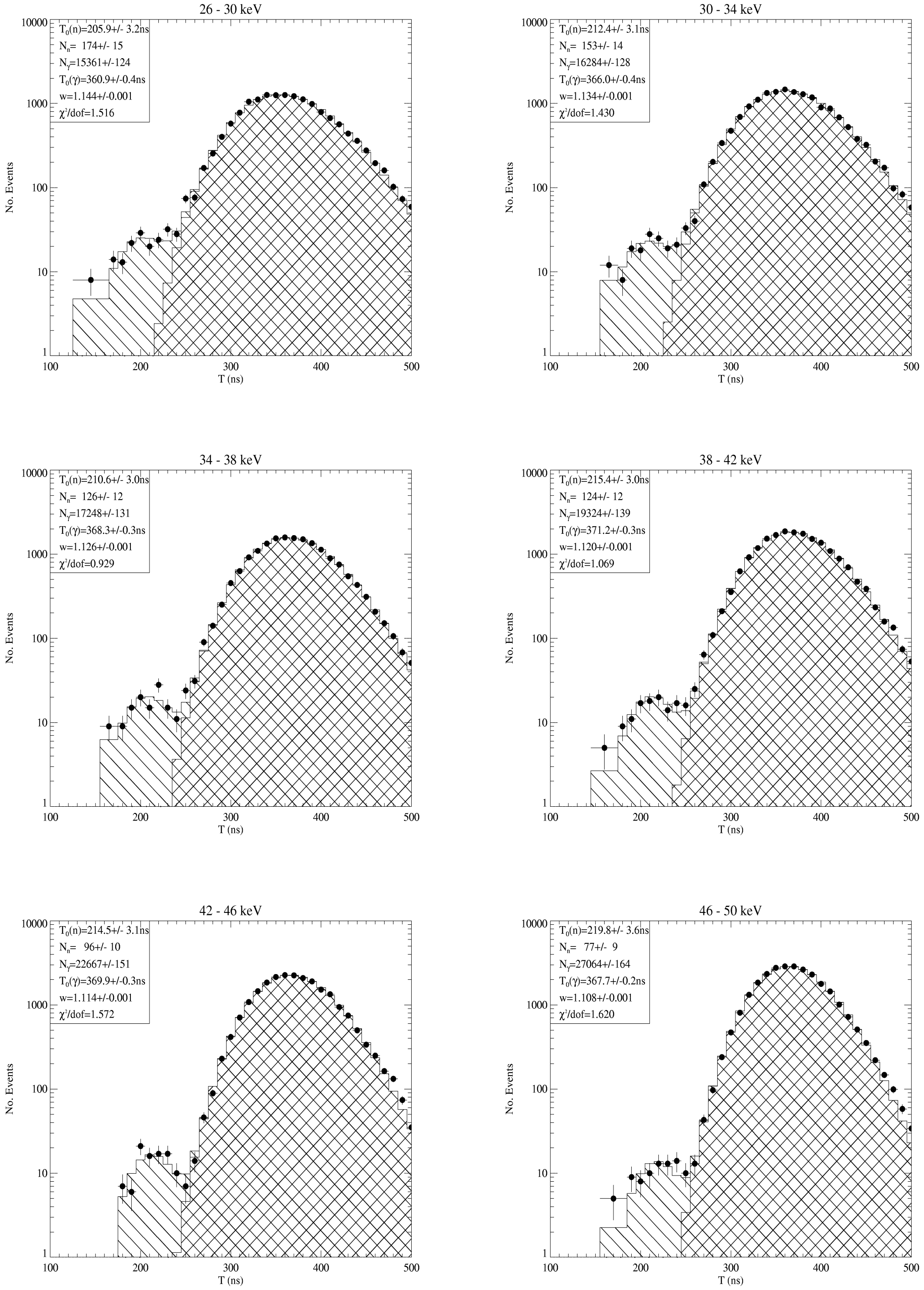


# UKDMC anomalous events

- High energy alphas clearer visible
- Anomaly energy spectrum
  - **10% of alpha rate at high energies**
  - **Too high for expected alpha tail**



# DM46 τ distributions



# What are these events?

- Possibilities excluded so far

1. neutron background --> NO (shielding)

2. low energy alphas from photodisintegration --> NO (cross section too low)

3. low energy tail to internal high energy alpha events --> NO (rate too high)

4. surface alphas ---> NO (test completed)

5. surface betas ---> NO (test completed)

6. surface x-rays ---> NO (test completed)

5. Tl distrib. problem --> NO (unless a very well defined region)

6. gamma calibration problem --> NO (not seen with Comptons)

7. break in temperature gradient in NaI --> NO (cooling control)

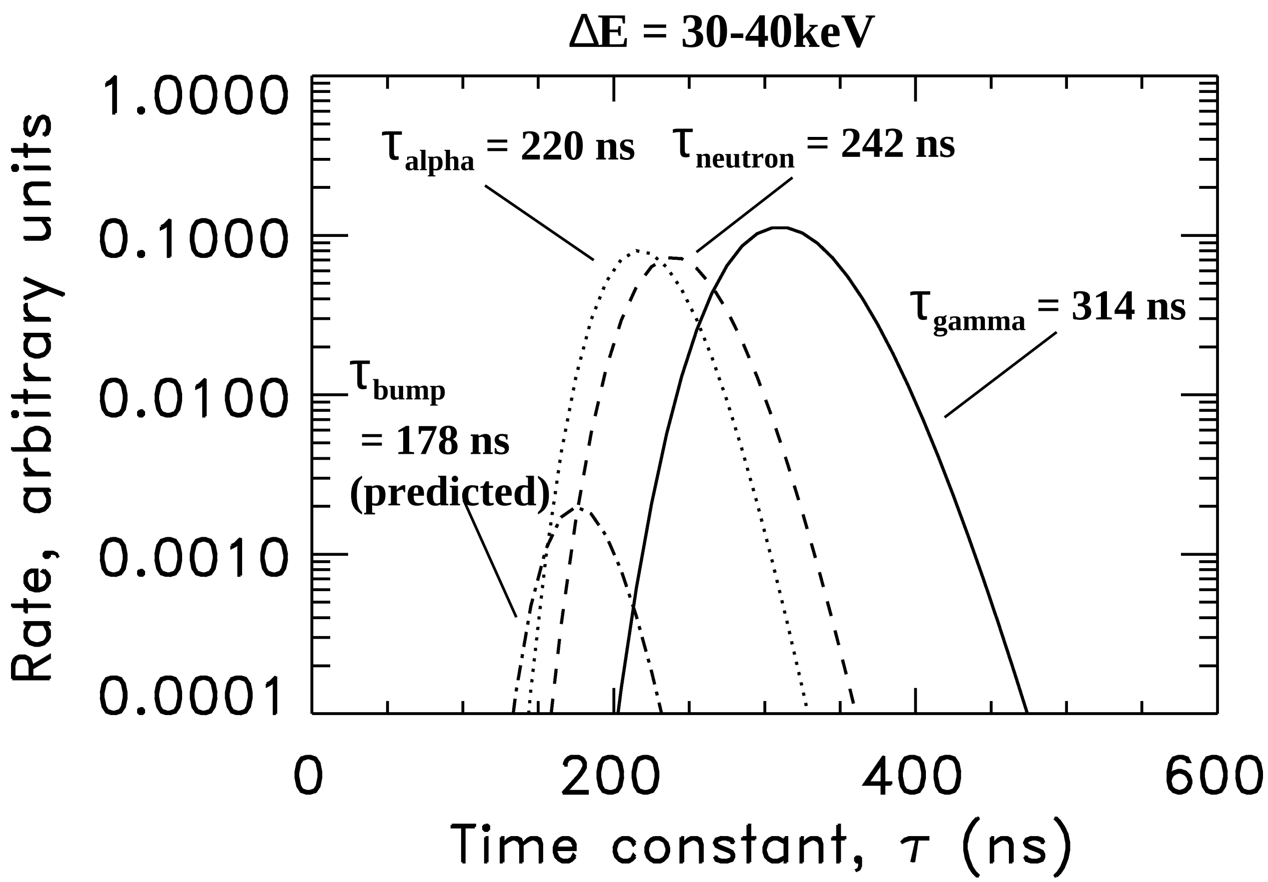
8. unusual PMT events --> NO (noise well studied)

9. daq or analysis artefact --> NO (many techniques used)

10. fission products --> NO (gamma rate too low)

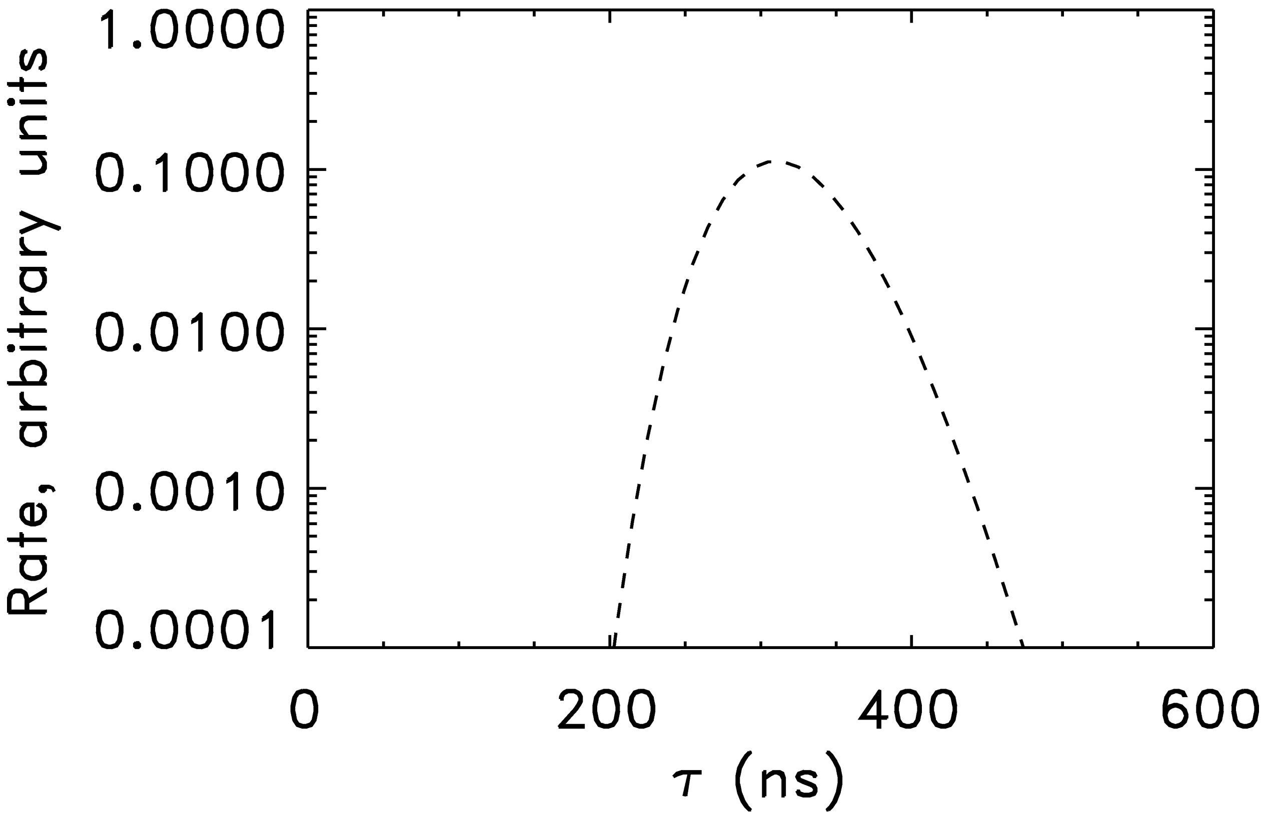
# Example surface alpha tests

- Alphas from source -> degraded
- Curves are fits to τ distributions.
  - Errors 2-5ns
  - Temperature stable to 0.1˚C



# Example surface beta tests

- Betas from source
- Un-encapsulated crystal



# What are these events…?

- Other possibilities not excluded

1. **outgoing alphas with Brem?**
2. **unknown scintillation relaxation events**
3. **unknown lattice events**
4. **WIMPs...**

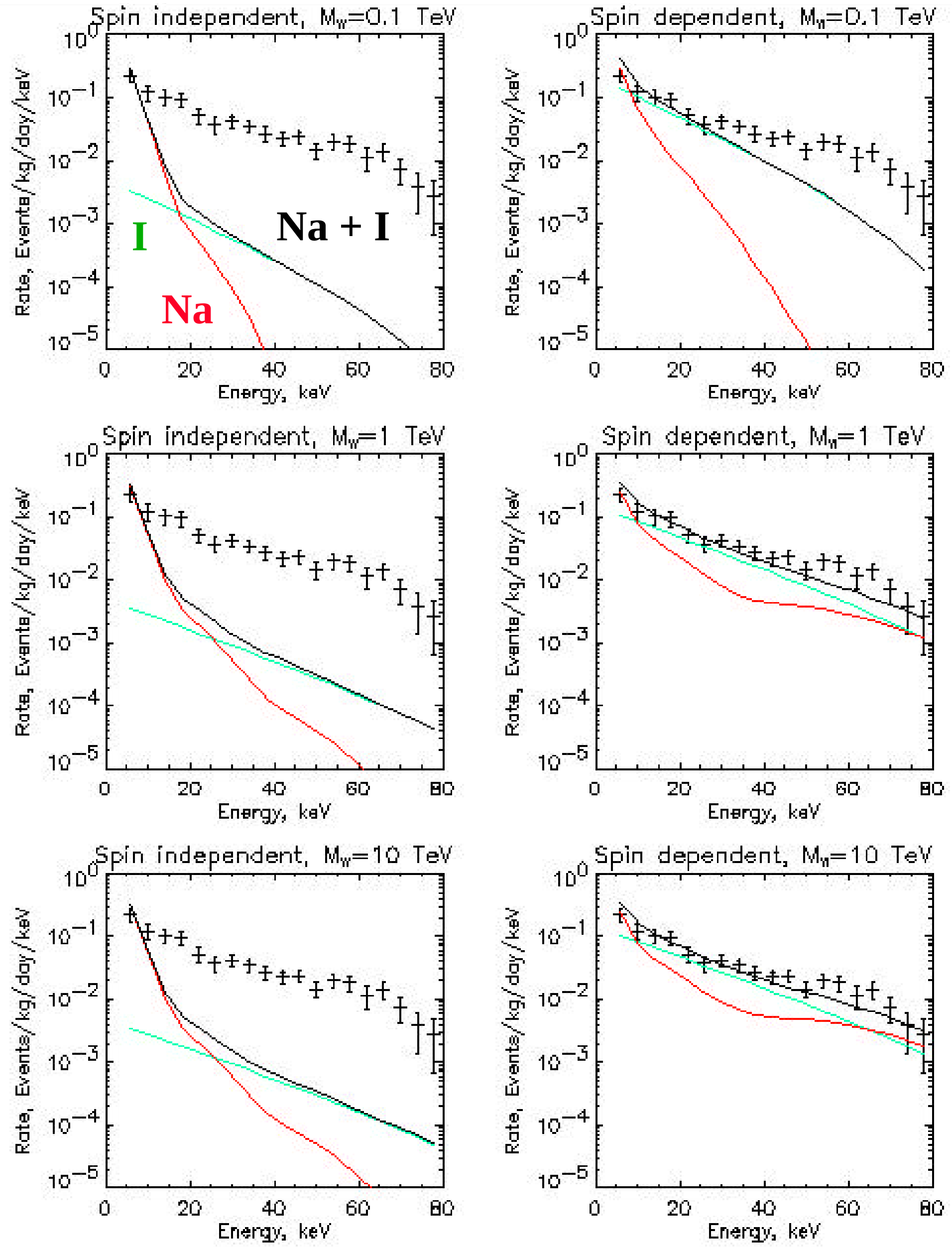
BUT how to get $\tau_{bump} < \tau_{neutron}$ ?

**neutron induced recoils vs. WIMP induced recoils?**

1. **$\tau_{Na} < \tau_{I}$ --> NO (n-beam test)**
2. **Neutron scattering increases $\tau_{neutron}$ --> NO (MC test)**
3. **Tl distribution problem --> NO (would be smooth)**
4. **phosphorescence in NaI during neutron calibration?**
5. **Brem or inelastic gammas in neutron calibration**
6. **something missed in the WIMP-nucleon interaction --> ?**

# Fitting WIMPs to anomaly

- Na and I sum fits with $v_0$ = 350 kms$^{-1}$, $v_{esc}$ = 800 kms$^{-1}$
  - **Not surprising for a falling spectrum?**



# Signal/Limit Calculations

- Many parameters involved in cross section calculations
  - Form factors
  - Spin factors
  - Normalisation by $A^2$ or $(A-Z)^2$
  - Detector resolution
  - Trigger efficiency
  - Halo model & velocities
- Better to plot $(R_0/r)$
- All assumptions must be stated for comparison

• **UKDMC limits (present and future) assume:**

$Q_{Na} = 0.275$, $Q_I = 0.086$,

$V_o = 230\ kms^{-1}$, $V_{esc} = 600\ kms^{-1}$, $V_{Earth} = 244\ kms^{-1}$, $\rho_{halo} = 0.4\ GeVcm^{-3}$

normalisation by $(A-Z)^2$

• **DAMA limits assume (?):**

$Q_{Na} = 0.3$, $Q_I = 0.09$,

$V_o = 220\ kms^{-1}$, $V_{esc} = 650\ kms^{-1}$, $V_{Earth} = 234\ kms^{-1}$, $\rho_{halo}.=0.3\ GeVcm^{-3}$

normalisation by $(A)^2$

# DAMA annual modulation

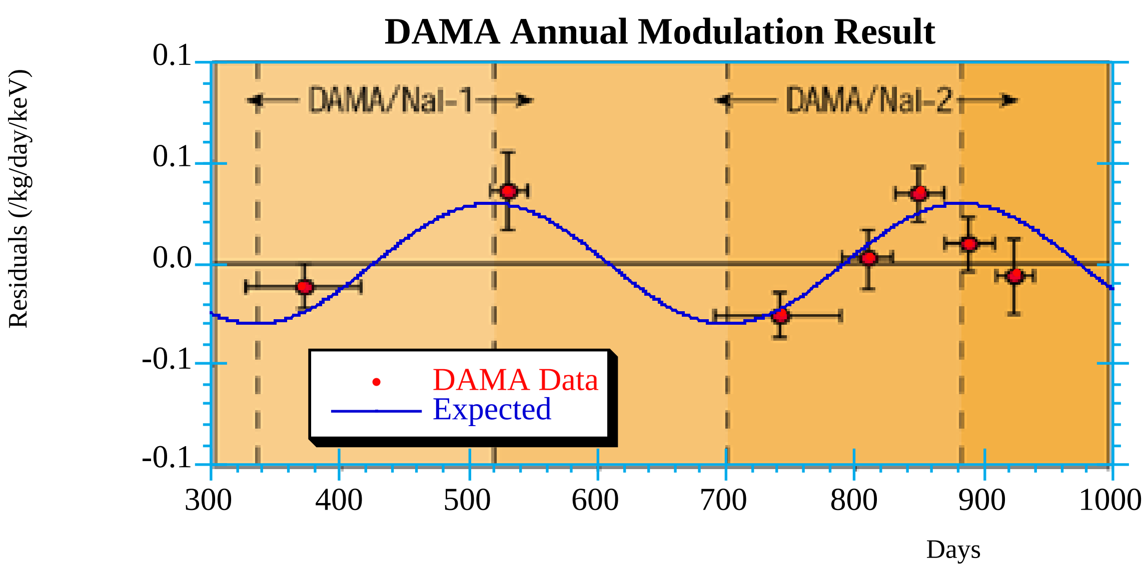
INFN AE-98-20

- 9 x 9.7kg crystals. 1 dead
- High energy (>90keV) no modulation, rate has distribution with σ = 0.1%
- MACRO data -> μ modulation $<10^{-4}\ d^{-1}kg^{-1}$
- 7 out 8 crystals fall within statistics of modulated signal

$$N_{ijk} = M_j \Delta t_i \Delta E \varepsilon_{jk} (b_{jk} + S_{0,k} + S_{m,k} \cos\omega(t_i - t_0))$$

$i$ − *day*
$j$ − *energy*
$k$ − *crystal*

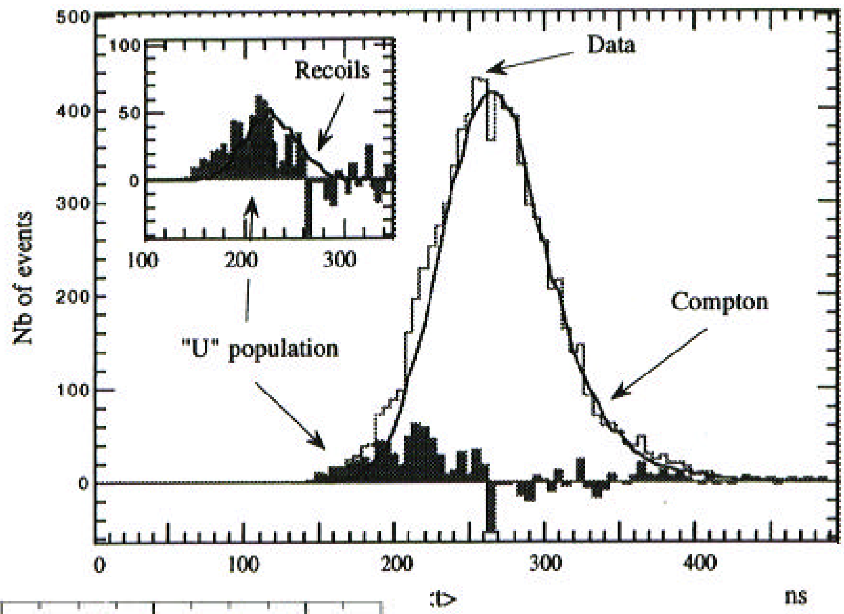
| Energy (keV) | S0 | Sm |
|---|---|---|
| 2-3 | 0.54 | 0.018 |
| 3-4 | 0.23 | 0.012 |
| 4-5 | 0.09 | 0.006 |
| 5-6 | 0.04 | 0.003 |

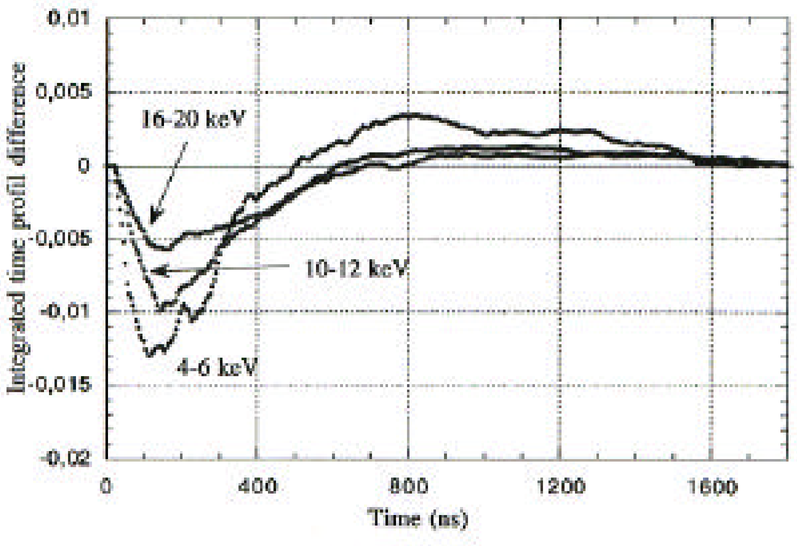


# Saclay - NaI with PSD

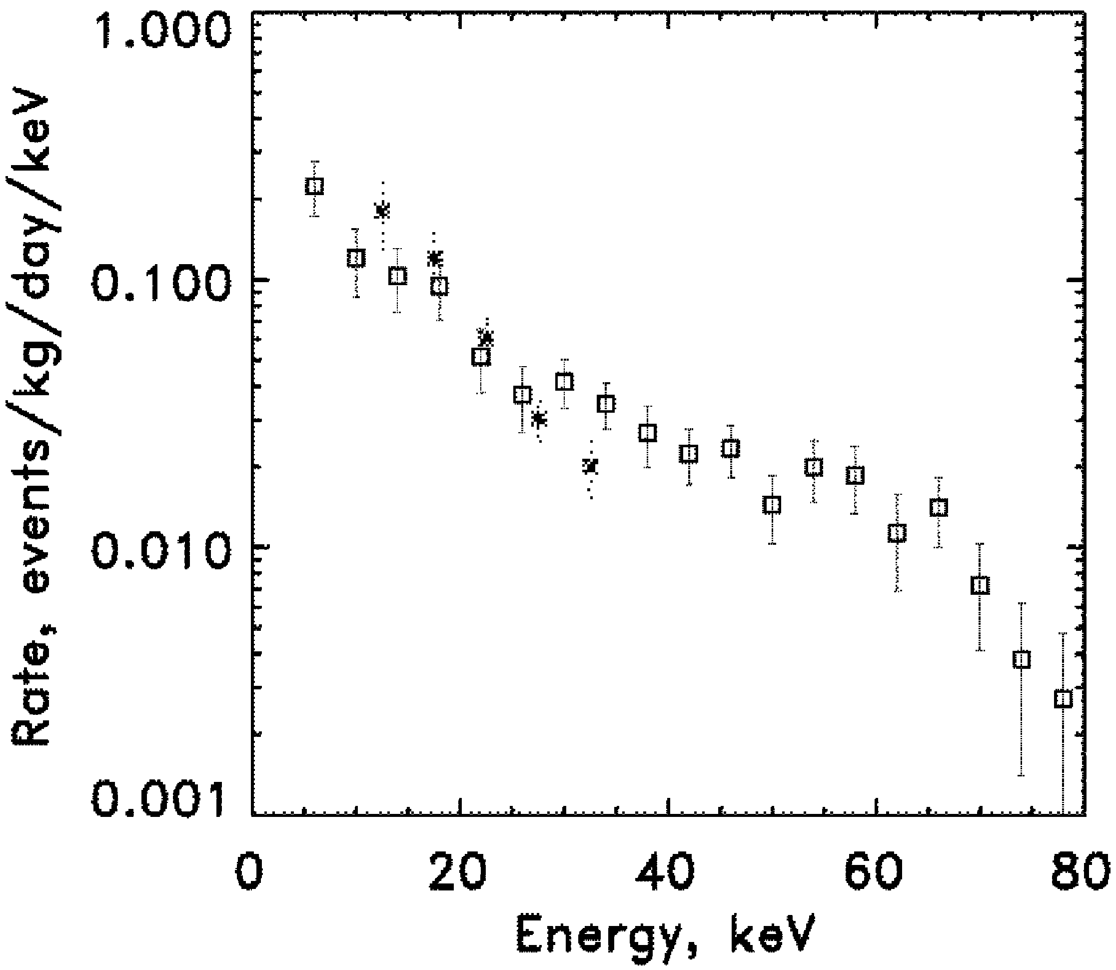
Astro. Phys. 11/3 287 1999

- Saclay/LPCC/IPN Lyon - Modane site
- 2 x 9.7kg ex-BPRS crystals
- 805 kg.days 2 ev/kg/keV/day @ 5keV
- Population fast risetime events - not α,β,γ,x-ray



# Saclay ‘U’ events




**Note on UKDMC vs. Saclay**

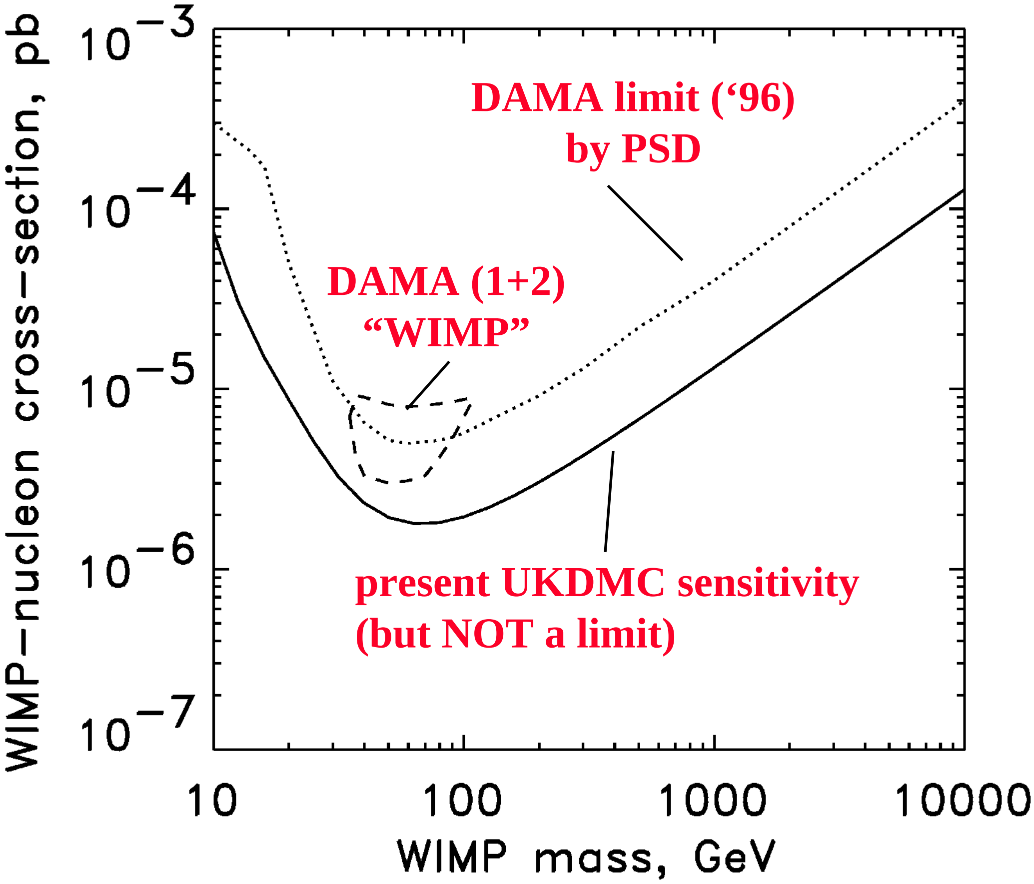
**different crystal manufacture, shielding, analysis, electronics, underground site, crystal mass and shape.... yet spectrum similar**

**Note on Saclay vs. DAMA**

**they use the SAME crystals ---> thus DAMA mave have these un-identified “bump” events in their data**

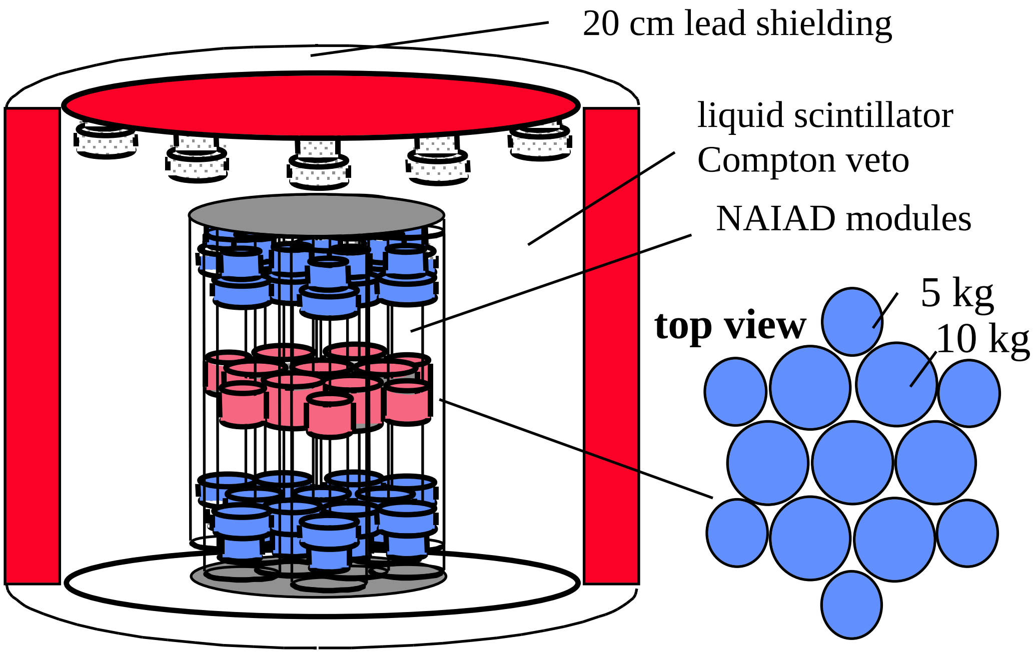
# UKDMC sensitivity and DAMA results

- UKDMC sensitivity recalculated to compare with DAMA

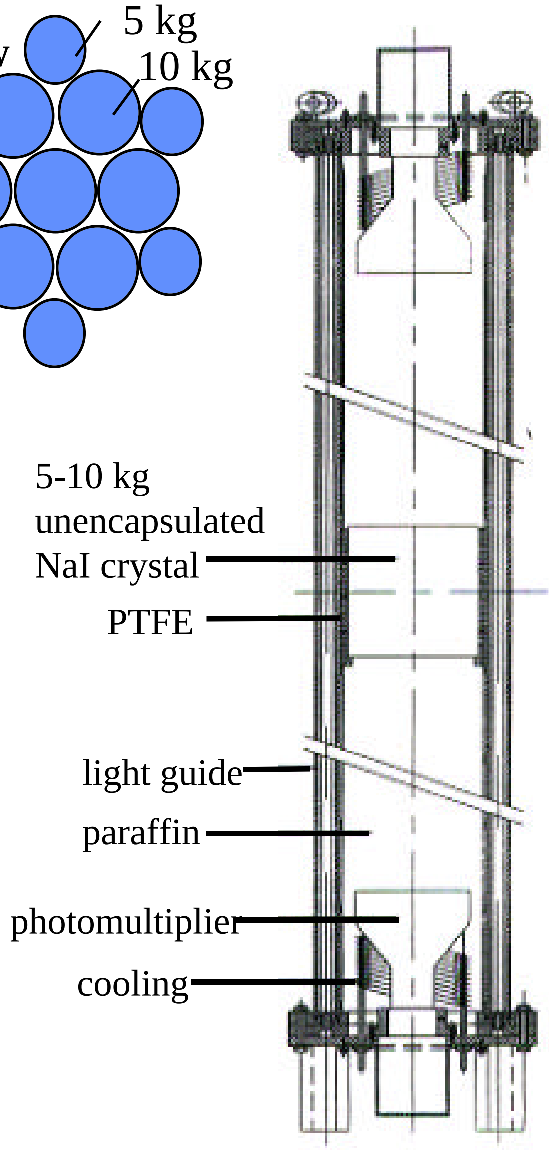



DAMA limits assume (?):
$Q_{Na}$ = 0.3, $Q_I$ =0.09,
$V_o$ = 220 kms$^{-1}$, $V_{esc}$ = 650 kms$^{-1}$, $V_{Earth}$ = 234 kms$^{-1}$, $\rho_{halo}$.=0.3 GeVcm$^{-3}$
normalisation by $(A)^2$

# Future UKDMC detectors

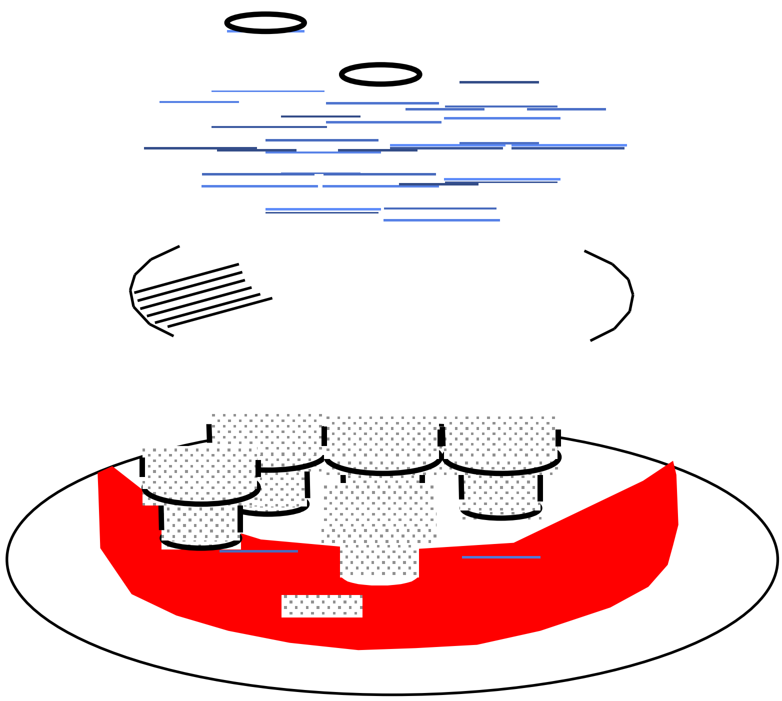



- NaI 100kg Array
  - **High light yield**
  - **Good discrimination**
  - **Un-encaps crystals**
  - **Paraffin shield**
  - **Compton veto?**



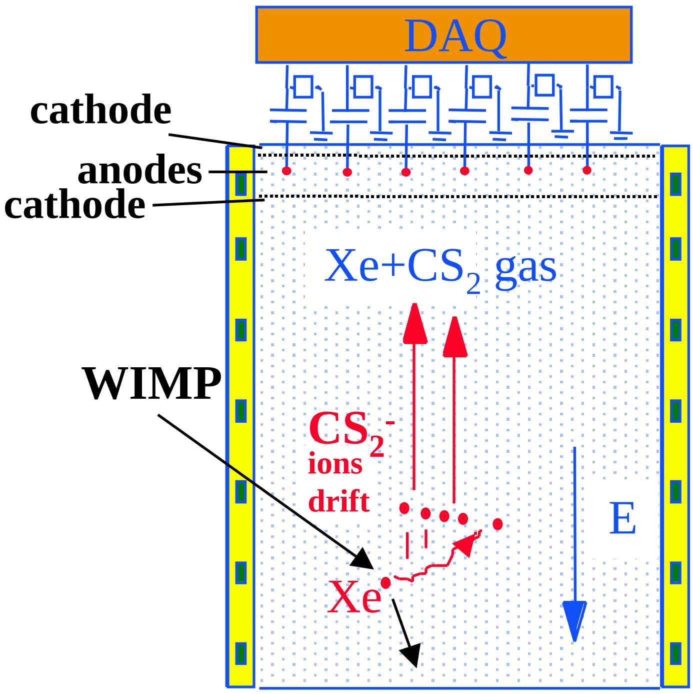
# Future UKDMC detectors

- Liquid xenon ionisation/scintillation
  - >x10 discrimination over NaI
  - Discrimination below 10keV confirmed

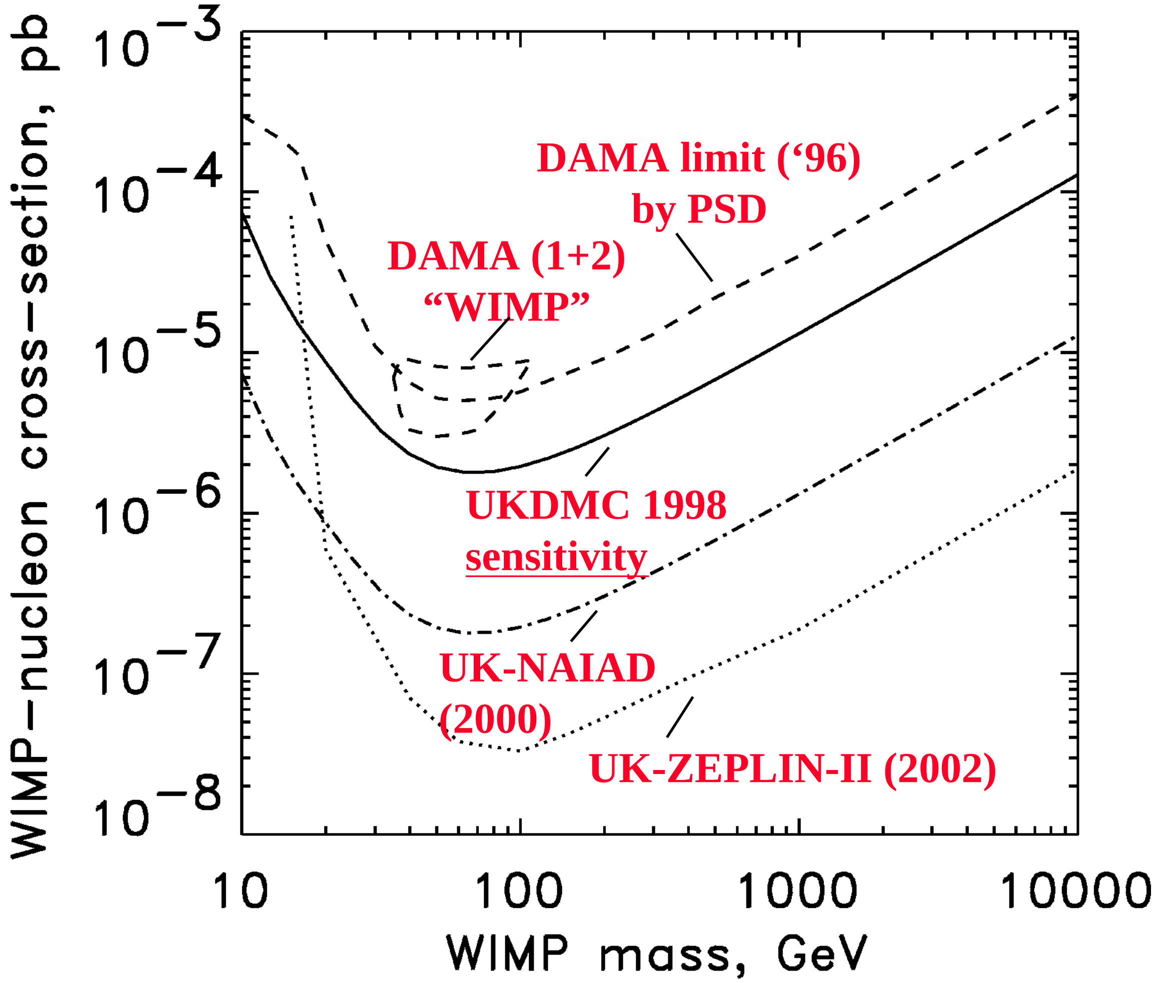


# Future UKDMC detectors

- Gaseous Xenon TPC
  - With Temple/Occidental/UCSD/Surrey
  - Use -ve ion drift to remove large magnets
- Correlate tracks to Earth's motion
  - 4:1 forward/back ratio
  - Dependent on recoil energy



# Expected sensitivities




**UKDMC-NAIAD: Na + I, 100 kg NAIAD unencapsulated detector**

**ZEPLIN II (UKDMC+UCLA, Torino, ITEP): Xe 2-phase, 80 kg-years**

Plots assume: $Q_{Na}$ = 0.3, $Q_I$ =0.09,$Q_{Xe}$ =0.50
$V_o$ = 220 $kms^{-1}$, $V_{esc}$ = 650 $kms^{-1}$, $V_{Earth}$ = 234 $kms^{-1}$, $\rho_{halo}$.=0.3 $GeVcm^{-3}$
normalisation by $(A)^2$, latest form factors

# Conclusions

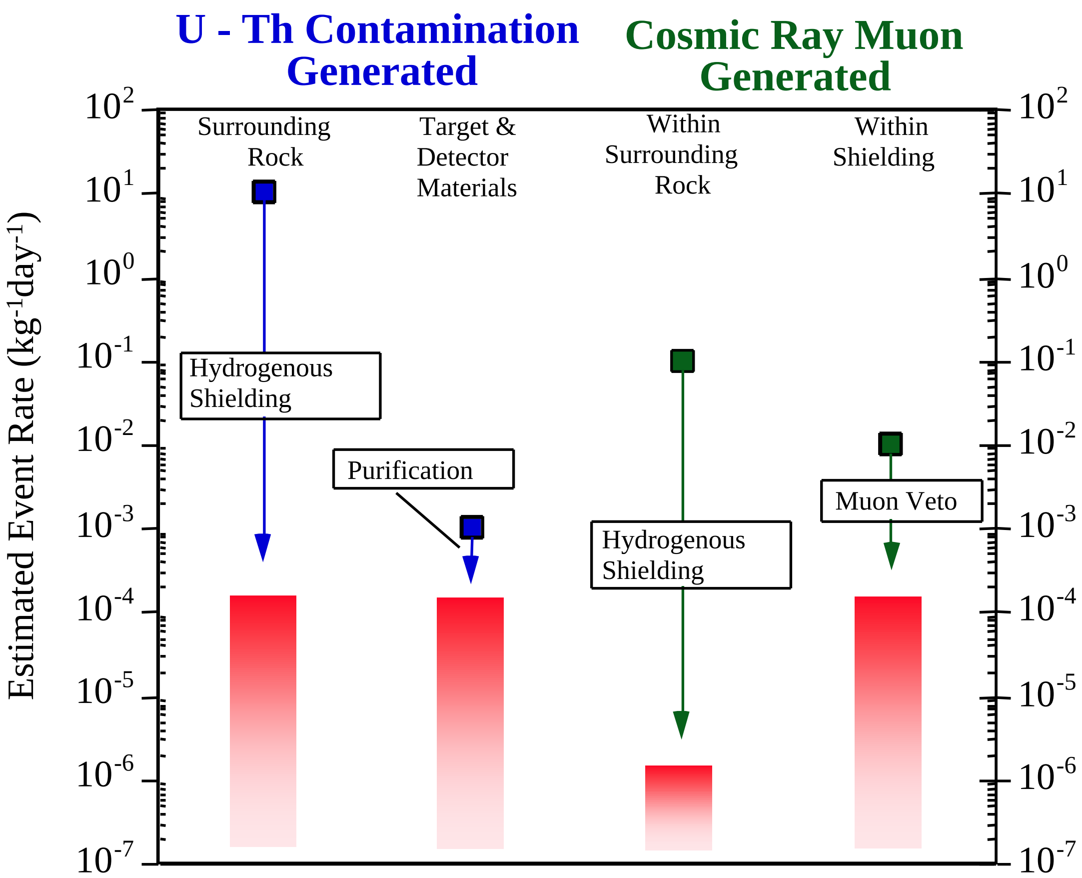
- Population of ‘anomalous’ events seen in UKDMC NaI detectors
  - Faster than gammas and neutrons
  - Source still unknown
    - Not $\gamma$, $\beta$, incoming $\alpha$s
- Confirmed in several crystals
  - Including Saclay crystals
  - Different manufacture/configuration
- Prevents new limits being set
  - Sensitivity only
- DAMA observe annual modulation at low energies setting target for DM expts.
- Future systems using NaI and Xe to explore this region

# Boulby Potash Mine

- Working potash / rock salt mine
- Easily modified cavern structure

# Neutron Backgrounds

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



# Gamma Backgrounds

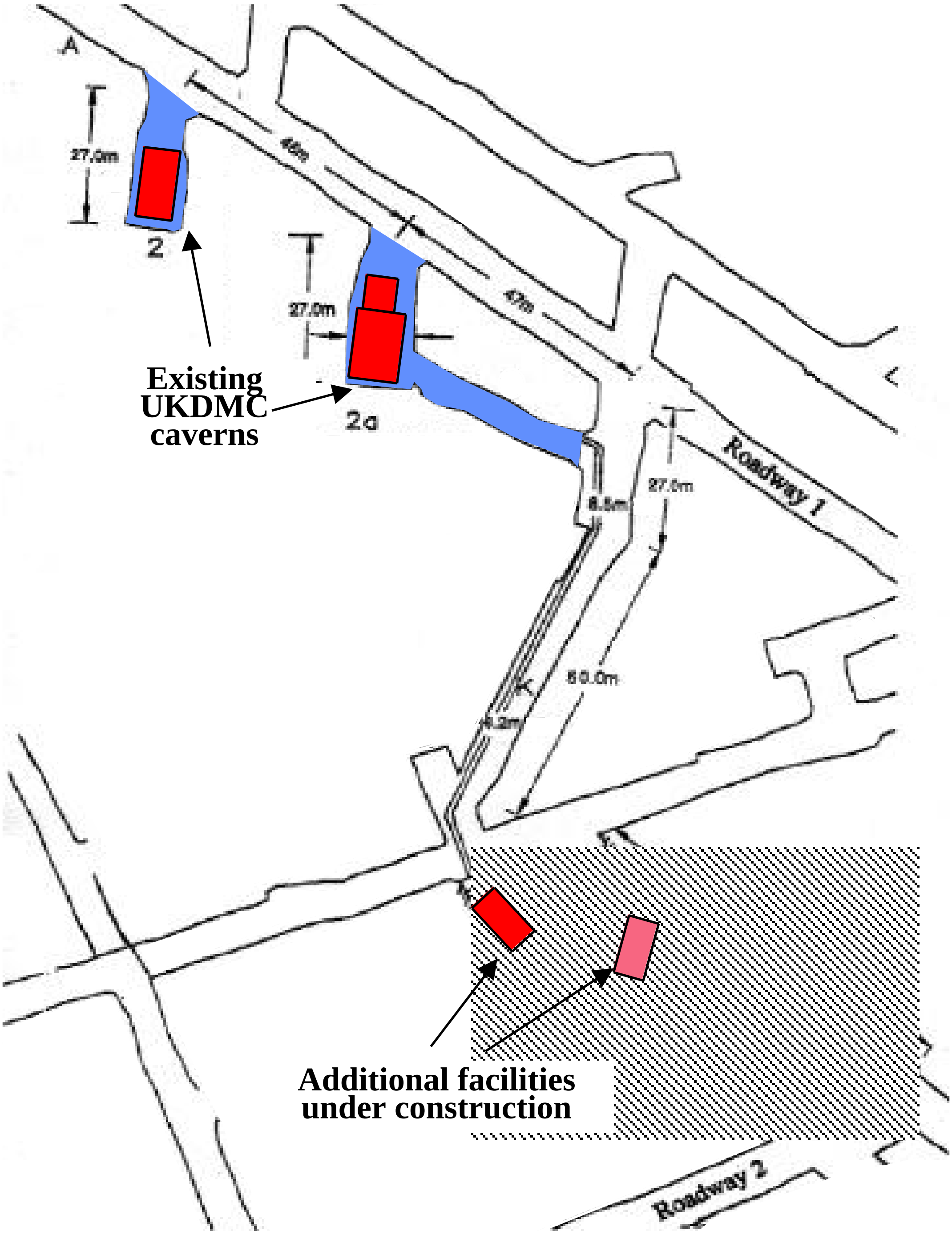
- Cavern radioisotope impurities
  - **Halite intrinsically low U/Th levels**

| | Boulby | Gran Sasso | Soudan |
|---|---|---|---|
| U(ppb) | 10 | 500 | 100 |
| Th(ppb) | 100 | 60 | 200 |
| K(ppm) | 750 | 100 | 1000 |

- Low radon levels comparable to Gran Sasso
  - **~5 $Bqm^{-3}$**

- NaI Detector total event rates
  - **Unshielded: >2e5 $kg^{-1}day^{-1}$**
  - **Shielded: 6e3 $kg^{-1}day^{-1}$**

# UKDMC Caverns



# UKDMC Cavern

# Lead/Copper Castle Area