The ZEPLIN Liquid Xenon programme

N.J.T. Smith
For the Boulby Dark Matter Collaboration
Edinburgh, ICL, RAL, Sheffield,
UCLA, Texas A&M, Torino, Mexico, Coimbra, ITEP

Intro to DM detectors
Boulby mine
ZEPLIN programme
DM Requirements
Principles of WIMP Detection

- A detector needs both interaction and observable
- Interact: coherent elastic scatter from target nuclei
  - $v = 300\text{km/s}$
  - $M = 200\text{GeV}$
  - 40keV Nuclear Recoil

- Observe: nucleus recoil energy
  - Ionisation: free charge released
  - Thermal: phonons created
  - Scintillation: light pulse
Where to find WIMPs

- Accelerators
  - SUSY searches
- Indirect detection
  - Halo (decay products)
  - Halo (gamma line)
  - Sun/Earth.GC □
- Direct detection
  - Elastic recoil

1 event /kg/day
1 event /kg/week

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

- **WIMP recoil signal is:**
  - Low rate (1 - $10^{-5}$ events/kg/day)
  - Small energy (1-100keV actual: observed is less)
  - Similar exponential spectrum to background (PMT, □ etc.)

- **Detection technique must be:**
  - Low background (best in Ge bolometers: 0.1 events/kg/keV/day)
    - Gamma, beta: from U/Th/Co/Pb/etc radio-impurities
    - Neutron: from U/Th radio-impurities and c.r. □ spallation
  - Low threshold (best in Ge bolometers: 100s eV)
    - To minimise form factor, maximise spectrum
  - Discriminating (best in Xe, Ge, TPC)
    - Difference between WIMPs/n and □□, directionality of signal
  - Large mass (best in Xe, NaI, TeO$_4$)
    - To see low rate signals
  - Different mass/spin target, or multiple targets
    - Explore different interactions/mass ranges
JIF Expansion

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

Ionisation

Electron/nuclear recoil

Excitation

Xe

Xe** + Xe

2Xe

2Xe

Xe**

Xe

Xe**

Xe+ + Xe

+e- (recombination)

175nm

175nm

175nm

Triplet 27ns

Singlet 3ns

Xe

Xe*

Xe2*

Xe2+ + Xe
ZEPLIN I Installation

Xenon recovery system
Xenon purifier
Polycold cryogenerator
ZEPLIN I target
ZEPLIN I Underground

‘Gold’ Runs:
Nov 2001 – 25 days
June 2002 – 50 days
+~ 45 days lower light yield
• Using different fitting techniques
  – Exp, Mean, mean to 90%, median
• Fitted ‘gamma’ density function in 1/\[\text{t}\]
• Lab calibrations data to 7 keV
• Surface ambient neutrons to 4 keV
• Project normalised amplitudes PMT1,2,3 onto plane - S3

Trigger condition is set to ‘free-run’
ZEPLIN I ‘Gold’ Data Run

- 75 day livetime, 230kg.days data
- Gamma calibration data from contemporaneous veto events
- ‘Gamma’ density fit (actually in $1/\tau$) as guide: smooth slope
- Analysis: chi-squared signal region, poisson tail
• Based on lab neutron discrimination (source and ambient)
  – To be re-done underground
• Efficiencies incorporated
  – Poisson trigger efficiency (analytically)
  – Light collection response matrix
  – S3 volume efficiency
  – Compton veto
  – Dead-time
• ‘Standard’ DM model
• Nuclear physics
  – Quenching
  – Form factor

![Diagram showing WIMP-Nucleon cross section pb vs Mass GeV]

ZEPLIN I limit

Zeplin I limit
Two phase discrimination

Electron/nuclear recoil

Excitation

Ionisation

Xe* + Xe

Xe** + Xe

Xe2*

Xe2+

+Xe

+e− (recombination)

2Xe

2Xe

175nm

Triplet 27ns

Singlet 3ns

175nm

Xe

Xe

Xe

Xe

Xe

19-09-02
• 1kg Prototype
• Alpha calibration

Depth Information
For given drift fields

Relative size gives discrimination
Nuclear recoils from neutrons
• 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 2002/3
• Study for 1 tonne
  – Long drifts
  – Large mass
  – Field definition
  – Use of PTFE
• 2 phase detector, 31x 2” PMT
• High E-field to extract ionisation from nuclear recoils
  – Nuclear recoil S1 and S2
• 7kg target under construction
• Study for 1 tonne
  – Low threshold
  – High light yield
  – Fiducialisation, imaging
1 tonne detector

• ZEPLIN MAX (IV) detector
  – 1 tonne active volume
  – Target sensitivity $10^{-10}$pb
  – Input from ZEPLIN I operational experience
  – ZEPLIN II/III progenitors for design info

• Issues
  – Operational mode
  – Readout technology (U/Th background)
  – Background suppression
    • active muon/neutron veto
    • passive shielding
    • detector design
    • purity requirement
  – Systematics!?
Future ZEPLIN programme

• ZEPLIN I
  – Full CH shielding + neutron checks
  – Low Kr Xenon + more data
  – ML analysis

• ZEPLIN II/III
  – Commissioning 2002/3
  – Progenitors for two phase
  – Xenon purity requirements
  – Background assessments
  – Efficiencies

• ZEPLIN-MAX (IV)
  – 1 tonne mass
  – Multiple isotope target
    • WIMP interaction info
    • Double beta/positron decay
• **UKDMC programme baseline (NaIAD, DRIFT, ZEPLIN)**
  – PPARC resourced - rolling grant, PIPPS, EU
  – Capital: £500k/yr, Manpower: ~24 FTE
  – JIF Infrastructure upgrade £2M over three years

• **Current ZEPLIN Programme**
  – UKDMC current baseline £300k/yr capital, ~14 FTE
  – UCLA/TAM/MC (NSF/DOE) $200k/yr operational

• **Requirement for ZEPLIN MAX**
  – £6M capital construction
  – ~18 FTE manpower
  – Infrastructure support £250k/yr
  – £200k/yr operational
  – ~12 FTE operational/exploitation

£1 = $1.5
Neutron shielding

U - Th Contamination Generated ($10^{-5}$ of flux)

Cosmic Ray Muon Generated

Estimated Event Rate (kg$^{-1}$day$^{-1}$)

Zeplin I
90% limit
Expected n

Need to get here
\(\text{\#} + \text{n} \) background reduction

- External U/Th/K gamma backgrounds (10^6 /kg/day)
  - High purity shielding
- Internal U/Th/K gamma/beta backgrounds (10^3 /kg/day)
  - Purity of detector materials - readout options (PMT replacement)
  - Detector design
  - Discrimination
- External U/Th/\(\text{\#}\) neutron backgrounds (10 /kg/day)
  - CH shielding against U/Th - more needed for \(\text{\#}(\text{\#},\text{n})\)
  - Active neutron veto (with Gd tagging?)
  - Go deeper
- Internal U/Th/\(\text{\#}\) neutron backgrounds (0.01 /kg/day)
  - Purity of detector materials - readout options (PMT replacement)
  - Detector design
  - Active neutron veto (with Gd tagging?)
  - Muon veto and/or go deeper
What’s the objective?
- Reduce backgrounds (shielding, vetos, depth)
- Ease of operation (access, operational, technical, exploitation)

What do we need / would we like?
- Access and convenience
  - deployment, location
  - installation support
  - size of caverns - 100m² for 1 tonne
- Services and support
  - low background counting facilities
  - low energy simulation support
  - cryogenics, power, ventilation, air-con
  - data management, networking, security
  - operational support
- Passive shielding
  - gamma
  - neutron
  - depth
  - materials storage
- Active vetos
  - muon and neutron