Dark Matter, Deep Mine

Neil Spooner (University of Sheffield and UKDM)

- Dark Matter
- ZEPLIN - Xe towards 1 ton
- DRIFT - directional signal
- Other detectors and results

UKDM =
RAL, Sheffield,
IC, Edinburgh
The Collaboration

[Image showing logos of various universities and institutions]
Composition of the Universe

Contributions to $\Omega$

Total (100%) $\Omega_0 = 1$

- All matter 32%
- Baryons 3%
- Stars 0.5%
- 60-70% still missing
- Non-baryonic dark matter
- Baryonic dark matter
- A dark exotic form of Energy?

Three “dark” problems

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Galaxies and the mystery (~1970s)

- Rotation curves of galaxies

\[ \frac{v_{\text{circ}}^2}{r} = \frac{GM(r)}{r^2} \rightarrow v_{\text{circ}} = \sqrt{\frac{GM(r)}{r}} \]

- Measurement of Doppler shifts in the 21cm emission line of HI in clouds in spiral galaxies (inc Milky Way).

- These showed that the rotation velocity of matter remained constant out to large distances beyond the luminous disc.
Knowing what we don’t known!

We don’t know what constitutes most of the mass in a galaxy

- fundamental problem in physics -

What is this dark matter?
What is its importance in Universe?
> 90% of our galaxy is dark matter gives $\Omega_{\text{halo}} \sim 0.1$

$$\Omega_a = \frac{\rho_a}{\rho_c}$$

LUMINOUS MATTER
actual density (Galactic disk)
mean spherical density
~0.3 GeV cm$^{-3}$

DARK MATTER
mean spherical density

$\Omega = \Omega_{\text{matter}} + \Omega_{\text{dark matter}}$

$\Omega_{\text{dark matter}} \sim 0.1$

$\Omega_{\text{halo}} \sim 0.1$

$\Omega_{\text{halo}} = \Omega_{\text{matter}} + \Omega_{\text{dark matter}}$

distance from galactic centre (cm)

Sun ~30 kpc LMC

HI (layer)
HI (Tangent)
HI (Petrovkaya)
HII (regions)
PNs
Deep space, deeper mystery (~1990s)

Result of gravitational lensing calculations

$\Omega_{\text{cluster}} \sim 0.4$

Tyson et al.
The Universe is flat!
-A relief for theorists?

see D.N. Spergel et al. 2003
# Knowing what we don’t know! with great precision - matter and energy

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy elements</td>
<td>0.03%</td>
</tr>
<tr>
<td>Stars</td>
<td>0.5%</td>
</tr>
<tr>
<td>Neutrinos</td>
<td>0.47%</td>
</tr>
<tr>
<td>Free H and He</td>
<td>3.7%</td>
</tr>
<tr>
<td>Dark matter</td>
<td>24.3%</td>
</tr>
<tr>
<td>Dark energy</td>
<td>71.0%</td>
</tr>
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</table>

If it isn’t dark it doesn’t matter!
The Lack of Baryons

- Big Bang nucleosynthesis places strong limits baryonic matter.

\[ \Omega_b = 0.040 \pm 0.004 \]
Knowing what we don’t know! with great precision

- about 83.7% of the matter in the Universe is something exotic
Dark Matter Candidates

- Black Holes
- Low Mass Stars
- Modified Gravity
- MACHO

UK Dark Matter Collaboration (UKDMC)

Worldwide effort

- WIMP
  Weakly interacting massive particles
  10-1000 GeV

- Light Particles
  (eg axions)
  10^{-5} - 10^{-2} eV

- Tau Neutrino
  Mass 10 - 30 eV

US0703 - all data shown is preliminary
The meek will inherit the Universe (1)

WIMPs are needed by Cosmologists
Non-Baryonic DM: Neutrinos

\[ \Omega_v = \sum_{i=1}^{3} \frac{m_{\nu_i}}{47.1\text{eV}} \]

For \( H_0 = 71\pm7\text{km s}^{-1}\text{Mpc}^{-1} \).

- Neutrinos were the first candidate particles for dark matter (1970s).
- Number density at present \(~300\text{cm}^{-3}\).
- SuperK and SNO results both have evidence for oscillations => rest mass.
- BUT... mass differences small, \( \nu_e \) direct mass small.
- => Neutrino masses all \(~m_{\nu_e}~\text{eV}\).
- Neutrinos cannot contribute more than 30% to the dark matter.

Relativistic particles -> Disagrees with simulated and observed clustering of matter.
The meek will inherit the Universe (2)

**WIMPS are needed by Particle Physicists**

A compelling solution: relic elementary particles left over from the Big Bang

- Symmetry between fermions and bosons
- Each SM particle has a ‘superpartner’ with identical quantum numbers apart from spin
- A stable Lightest Supersymmetric Particle
- Most important SUSY particle for DM is the Neutralino
- If LSP, then an ideal WIMP candidate

\[ \tilde{\chi}^0_i = N_{i1} \tilde{B} + N_{i2} \tilde{W}^3 + N_{i3} \tilde{H}^0_1 + N_{i4} \tilde{H}^0_2 \]

For SUSY to agree with Standard Model: \( 10 GeV < M_\chi < 10^4 GeV \)

Searches for charginos and squarks at LEP and Tevatron: \( M_\chi > 50 GeV \)

CERN - Geneva
WIMPs and Neutralino

Roskowski et. al

General MSSM
WIMPs, WMAP and Neutralino

- Leads to strong constraints on the spin-independent scattering cross-section (also spin-dependent cross-section).

Baer et al. hep-ph/0305191
WIMP Direct Detection

- **Kinematics**

  [Diagram of WIMP kinematics]

  \[
  \frac{dR}{dE_R} = \frac{R_0}{E_0 r} \frac{1}{E_r} e^{-E_R/E_0 r} \\
  \text{kinematic factor} = \frac{4M_D M_T}{(M_D + M_T)^2}
  \]

  - Event rate per unit mass
  - Recoil energy
  - Total event rate (point like nucleus)

  **Expected featureless differential nuclear recoil energy spectrum for stationary detector --> looks like electron background**

  (1) Nuclear recoil discrimination
  (2) Low background
  (3) Need to go underground
WIMP Modulation

diurnal modulation ratio \(1:100\) at \(>50\) GeV

annual modulation few \% change
Detector Technologies

Many techniques investigated since 1982 (20 years)

- **Semiconductor**
  - Ge, Si, GaAs, TIBr...

- **Inorganic Scintillator**
  - NaI(Tl), CsI(Tl), CaF$_2$(Eu)...

- **Organic Scintillator**
  - Stilbene, plastics, liquids...

- **Bolometer**
  - NTD, TES...Ge, Si, LiF, sapphire....

- **S/C granules**

- **Superheated droplets**

- **Noble gases**

- **TPC gases**
  - ........

**Apologies for those techniques and groups left out...**

**Phonon (ionisation-thermal)**

**Xenon (ionisation-scintillation)**

**TPC (directional)**
Edelweiss (Ion-Thermal)

NTD sensor on guard ring electrode

Resolution@ 10 keV 1.3 keV (ion), 1.0 keV (heat)
Edelweiss (Ion-Thermal)
Response to Neutrons and Gammas ($^{252}$Cf source)

- Neutrons
- Gammas

$n/\gamma$ discrimination > 99.9% for $E_r > 15$ keV

$^{71}$Ge($n,n'\gamma$)
Recoil threshold 20 keV
Ionization threshold 3.7 keV

Graph showing ionization/recoil ratio vs. recoil energy for Neutrons and Gammas.
Edelweiss (Ion-Thermal)

EDELWEISS-II
100 lt cryostat for up to 120 detectors: 36 kg Ge

Also
CDMS

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Boulby mine

- Working Potash mine
- Deepest mine in Britain
- 850m to 1.3km deep
Boulby mine

- Roadways & cavern excavated in Potash & Rock salt layer
- Over 40kms of Tunnel dug each year (now >1000kms in total)
Garden shed infrastructure (~1993)
Improving infrastructure (1990s+)

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New labs at Boulby (JIF -2001+)

New Surface facilities
Laboratories, clean room, workshop, loading bay, offices, conference room, showers & mess.
JIF Area Layout

About 1500 m² of underground lab
More possible

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The main hall
The JIF area now

1000m$^2$ of supported lab space available for next generation Dark Matter experiments…
Working underground

- Hard Hat & lamp
- Reflective clothing
- Glasses, gloves & earplugs
- Respirator
- Steel toe shoes
- Sandwiches

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The local economy!

Ellerby Inn

US0703 - all data shown is preliminary
The press!

The Sun

WE PAY £3m TO HUNT INVISIBLE PARTICLES
(...and they may not even exist)

By CHRIS RICHES

SCIENTISTS are spending £3.1m of taxpayers’ cash hunting INVISIBLE particles that may not even exist.

They are searching more than half a mile underground in Yorkshire, at the bottom of one of Europe’s deepest holes, for a WIMP — a Weakly Interacting Massive Particle.

The scientists believe WIMPs are a type of “dark matter” that makes up 23 per cent of the universe.

But not only are they invisible, the scientists admit they may not even exist at all. Their group, called the Bright sparks... experts go to lab

UK Dark Matter Consortium, is being funded by a huge Government grant to keep them ahead of rival projects from America, France and Japan.

The group leader is Sheffield University’s Professor Nell Spooner, who has been searching unsuccessfully for 15 years. He said so far he only knows what is NOT a WIMP.

He said: “You don’t actually see the WIMP, but you see the recoil of whatever it hits. If we are successful this will be one of the great discoveries of our time.”

But he added: “It is still possible though we could be completely wrong.”

Prof Spooner’s latest search is at the bottom of a salt mine in Boltho, North Yorks. His team have built a lab where they can experiment while hidden away from light rays.

It is reached by taking a lift more than half a mile underground — then walking another half-mile through a maze of tunnels.

Astronomers believe dark matter exists merely because many laws of science would fall apart without it.

Particles already known to scientists do not generate enough gravitational force to hold galaxies together.
European Underground Lab Network

Objectives:
- better science co-ordination
- share knowledge of common problems and solutions
- make best use of space available
- exchange of people
- common infrastructure r&d
- EU (e.g. F6) funding

gran Sasso

Frejus

Underground
science

Canfranc

Boulby

LNGS

LSM

LSC

IUS

(Institute for Underground Science - Sheffield)

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European Astroparticle Physics

APPEC (Astroparticle Physics European Coordination)

Framework 6 Integrated Initiative

Networks

- Theory
- Primary Cosmic Rays
- Gravitational Waves
- Dark Matter
- High energy probes
- Low energy neutrinos and double beta

Trans-national access

- Underground Labs LNGS-LSM-LSC-IUS (Boulby)

Joint R&D

- Next generation charge readout
- Advanced photo-detectors
- Thermal noise reduction
- Underground lab infrastructure

20M Euro bid - Community of ~1000

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Recoil discrimination by statistical pulse shape analysis

Double zone refined NaI(Tl) crystal

- Low activity silica light guides & PMT shield
- PMT

Example time constant distributions for new crystal DM72
NAIAD - construction

H2 NAIAD array complete

H1 NAIAD array complete

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New PMT noise cuts

New cuts under development based on PMT tests without NaI
e.g. improved noise and recoil discrimination with no loss of data

Time constant distribution of events in a data run at 6-7 keV for DM74 crystal. The graph on the left side shows the events after asymmetry cuts, as used to set upper limits on WIMPs with the data collected in 2000-2001. The graph on the right side shows same distribution after all new cuts (‘identification’ and ‘pulse shape’) applied. No noise is present after new cuts, while almost all scintillation pulses remain on the graph (compare the number of events in the main peaks).
Predicted sensitivity is based on 100 kg.days exposure using full NaIAD array analysed using new cuts.

However, work is ramping down due to progress on xenon and directional detectors.
DAMA latest

- DAMA - 100 kg of NaI(Tl)
- Annual modulation analysis
- 7 annual cycles analysed so far (latest 3 just released)
- Clear annual modulation signal

![Graphs showing annual modulation analysis](image)
**NaI(Tl) uncertainties**

What about CDMS, EDELWEISS and ZEPLIN I, which do not see WIMPs.....?

**Model uncertainties**

- Halo parameters - $v_0, v_{esc}$, halo structure
- SI, SD, mixed models, inelastic
- Form factors, (size of nucleus) (Helm) (I, Ge, Xe...)
- Quenching factors?
- Unknown systematics
- Non-SUSY candidates?

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**controversy**

- Libra - 250 kg NaI;
- Other NaI/CsI experiments: Canfranc (ANAIS), UKDM (NAIAD), ELEGANT....
DAMA latest

Many different model assumption explored - can push allowed region around

**LEP bound:** depends on GUT assumptions

**Halo:** depends on \( v_0 \) - e.g. low value gives higher mass

**SD contribution:** could push region down

need to look at influence of this on the other new limits

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What else could it be?

Neutron modulation?
- annual neutron modulation at Gran Sasso! (ICARUS note TM/03-01(2003))
- is total DAMA modulating amplitude (~0.02/kg/keV/d) similar to Gran Sasso neutron modulation?
  - DAMA/Gran Sasso n-flux estimate flux used ~0.9 x 10^-7 n/cm^2/s
  - BUT Boulby calculation (with lower U) = 7.3 x 10^-7 (1.9 x 10^-6) n/cm^2/s
- But also DAMA see no modulation above 6 keV (expected for neutrons?)

Noise cut modulation?
- Energy calibration needs to be stable
  - otherwise movement of cut position will change data rate even if total before cut is constant

What about resolution?

UKDMC for DM77
10 kg crystal

DAMA- 10 kg
(INFN/AE-00/10)

Saki et al., 1 cm crystal

UKDM- AstroP. 19(2003)691
Xenon- more sensitive

Ionisation

Electron/nuclear recoil

Excitation

Xe

Xe

Xe

2Xe

2Xe

175nm

Triple

27ns

Singlet

3ns

Xe** + Xe

+Xe

+Xe

Xe

Xe

Xe

3ns

175nm

three discrimination techniques

(1) scintillation pulse shape

---> ZEPLIN I

(2) ionisation-scintillation

- low field-

---> ZEPLIN II

(3) ionisation-scintillation

- high field-

---> ZEPLIN III

single phase Xe

gas

liquid

two phase Xe

liquid

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ZEPLIN I (UKDMC)

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ZEPLIN I Installation

Xenon purifier
Polycold cryogenerator
ZEPLIN I target
ZEPLIN I S3 Fiducial Volume Cut

Trigger condition is set to ‘free-run’

Noise trigger
Single PMT event
Double PMT event
Bulk events
Turret events

Fiducial volume cut

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ZEPLIN I S3 Fiducial Volume

- Light collection simulations allow S3 calculations
- Fiducial volume 3.1kg
  - (excluding turrets + ~1cm below)
ZEPLIN I energy resolution

57 Co Calibration

- 122 keV peak
- 136 keV peak (10%)
- Linear response
  \[ \sigma(E) = 1.24 \sqrt{E} \]
- (57 Co calibration is effective point source)

- 1.5 p.e./keV
- Geant4 Simulation

30 keV X-ray
92 keV recoil e-
106 keV recoil e-

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- Confirmation of background rejection by cuts and Compton veto
- Dual range DAQ

Background (40 dru @ 100keV) implies $^{85}\text{Kr} < 10^{-17}$ atoms/atom (standard Xe used)
Based on lab neutron discrimination (source and ambient)
Efficiencies incorporated, ‘Standard’ DM model, Nuclear physics
Outlook: further underground neutron calibration

Systematic uncertainty from TC ratio calibration - to be confirmed
ZEPLIN II - 30kg two phase design

**collaborators**
- UKDMC, UCLA,
- Mexico City, Texas A&M

- Design based on simple scale-up of UCLA 1 kg test chamber
ZEPLIN II - discrimination r&d

UCLA/Torino/CERN 1 kg Xe test chamber

Electroluminescence signal

90% nuc.rec. <3% elec.rec. @ 10keV

Electron recoil

nuclear recoils

Primary scintillation signal

0 100 200 keV

Gamma (122 KeV) Alpha (5.4 MeV)

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**ZEPLIN II chambers**

- Stainless Steel vacuum chamber
ZEPLIN II dump chambers

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ZEPLIN III - two phase, high field

collaborators: UKDMC + ITEP, Coimbra

High field improvements - enhanced discrimination and lower threshold

1. Better detection of ionisation from nuclear recoils at lower threshold
   --> in ZEPLIN II noise in the S2 channel determines threshold

2. Better extraction of electrons into the gas
   --> potential sub-keV threshold

Other improvements - lower threshold

1. Operation PMTs within the liquid
   --> better light collection

Electrons Yield for LXe

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ZEPLIN III high field

Gas phase

Active volume 6kg

Inverse field region

... 31 PMTs
# Towards a 1 Tonne Detector

## Motivation
- To reach typical predicted minimum cross sections (~$10^{-10}$ pb)

## Implications
- Detector needs recoil discrimination at scaleable cost
- Larger collaborations

## Possibilities
- **GENIUS (HDMS) proposal for 100kg --> 1 tonne**
  - *Intrinsic low background but NO discrimination and expensive (mainly bb)*
- **LIBRA (DAMA) 250 kg under construction**
  - *Annual modulation (what if DAMA region ruled out), PSD not sensitive enough*
- **Cryo-array (CDMS, Edelweiss) ideas for 1 tonne**
  - *Good discrimination but difficult technology and expensive*
- **ZEPLIN-MAX (UKDM) proposal for 1 tonne**
  - *Good discrimination, world expertise, simpler technology(?)*, less expensive
Towards a 1 Tonne Detector

Motivation

- To reach typical predicted minimum cross sections ($\sim 10^{-10}$ pb)
Neutrons, Neutrons, Neutrons, Neutrons (1)

Rock neutrons - simulations

Neutrons generated uniformly through rock and propagated to detector

Primary neutron spectrum assuming 60 ppb U and 130 ppb Th.

Factor of $10^5$ suppression achieved with 30 cm Lead and $\sim$30 g/cm$^2$ CH$_2$

Clear suppression of MeV range neutrons by Lead.

<1 rock event/year possible
(Muons - and how deep is the lab?)

Muon flux measured as $4.09 \pm 0.15 \times 10^{-8} \text{ cm}^{-2}\text{s}^{-1}$

(Rock neutron flux...$7.3 \times 10^{-7} \text{ cm}^{-2}\text{s}^{-1}$) JIF boundary at rock face flux, excludes bouncing neutrons - consistent with DRIFT I....

Corresponding to 2800 m w.e. determined the rock density to be $2.62 \pm 0.03 \text{ g cm}^{-3}$
Neutrons, Neutrons, Neutrons (3)

Detector neutrons - simulations

e.g. neutrons from borosilicate, 10 ppb Th

resulting Xe recoil spectrum in 250 kg (multi+single)

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Neutrons, Neutrons, Neutrons (3)

Detector neutrons - simulations
1 Tonne ZEPLIN-MAX

Conceptual design of a ZEPLIN-MAX module based on a scale-up of the ZEPLIN-I design.

Conceptual design of a ZEPLIN-MAX module based on a scale-up of the ZEPLIN-II design.

Conceptual design of a ZEPLIN-MAX module based on a scale-up of the ZEPLIN-III design.

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Do It without PMTs?

- Significant background problem is neutrons from PMTs
- Solution may be to use charge readout (GEMs, MICROMEGAS)

Conceptual design of a 250 kg module using a charge read-out system.

Possible configuration of four modules installed in passive neutron and gamma shielding, with active muon and Compton/neutron vetos.
Charge readout R&D

Electron recoil pulse observed in two phase prototype detector with Xe:CH₄ (90:10) gas mixture and Amptek A250 charge sensitive pre-amp read-out.

First step - intrinsic ionisation from recoil while Second step - photoelectrons from the photocathode located at the bottom of the chamber by incident primary scintillation photons.

(1) GEMs or (2) MICROMEGAS

Double phase - Xe:CH₄

Typical event
Directional

- How do we know the signal is WIMPs?
Recoil directions

- WIMP velocity distribution in the Earth’s frame is strongly peaked in the direction of the solar motion – A WIMP ‘wind’

- A strong signature tied to sidereal rather than diurnal timescales

- Recoil directions in galactic coordinates is peaked in direction opposite to solar motion
Halo models

- Velocity distribution of dm particles in the halo may be very clumpy
  - Hierarchical?
  - Spherical infall?

E.g. Widrow et al.

CDM halo model showing WIMP clumps?
Beyond discovery - WIMP astrophysics

- N-body simulations showing that WIMP halo may not be simple isothermal and non-rotating

- E.g. smaller subhalos and cold tidal streams of WIMPs

E.g. Osipkov-Merritt anisotropy
Directional detectors

**Organic Scintillators**

DAMA, Sheffield, Tokyo

*results for 48 keV carbon recoils in trans-stilbene (UKDM)*

**Other Solid State**

e.g. multilayer s/c, bolometers (Si - Temple), He (Brown), Mica (Occidental)....

**Gas**

TPC + Magnet (H - Saclay), (Ar/Xe - UCSB)

TPC + -ve ion drift (DRIFT collaboration)
Energy scale of nuclear recoils means recoil ranges very low.

Use a Time Projection Chamber at low pressure (<100 Torr) to extend recoil range to few mm.

Track ionisation drifted to readout plane by high E-field.

Full 3-D reconstruction of track possible by combining a 2-D readout plane with timing information in the drift direction.

-ve Ion Drift with CS₂ (e.g.) idea by Jeff Martoff (Temple)
DRIFT basics

- Potential powerful discrimination based on range

- Potential powerful direction sensitivity

Mean WIMP speed is ~270kms$^{-1}$.
Galactic orbital velocity is ~220kms$^{-1}$.
WIMP wind thus strongly correlated with direction of solar motion.
The recoil flux

- Work out directional recoil flux by assuming elastic scattering.
- Monte Carlo simulation then gives primary WIMP direction and scattering angle.
- Appropriate coordinate transforms then give recoil flux in galactic coordinates.
- Recoil flux anticorrelated with WIMP flux.
- Distribution broader.

US0703 - all data shown is preliminary
• Work out directional recoil flux by assuming elastic scattering.
• Apply appropriate coordinate transforms.
• Monte Carlo then gives primary WIMP direction and scattering angle.
• Recoil flux anticorrelated with WIMP flux - distribution broader.
• The Earth spins once every 24 sidereal hours with respect to the stars so recoil flux thus moves across sky.
• Provided time is known, this can be corrected for.
• But modulation itself is a powerful indicator of a signal.
Identifying a signal

- Helped by having a known reference direction.
- Applying time and coordinate transforms give recoil direction relative to this direction.
- WIMP wind strong => 98.7% of recoils with recoils with $\gamma > 90^\circ$.
- At this level, ~100 events needed to identify signal at >90% confidence in DRIFT I.
- Knowing sense of track only marginally improves ability to identify source direction.
1 ft³ prototype tests (Occidental)

See Snowden-Ifft et al. IDM2000
1 m³ DRIFT I construction

- Vacuum chamber filled with 40 Torr CS₂ gas
- 1 m³ fiducial volume
- Back to back Perspex field cages at 1 kV cm⁻¹
- Two MWPC of 500 x 20 μm SS wires, 2mm pitch
DRIFT I MWPCs

Lower MWPC

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DRIFT I installation

Boulby DRIFT I JIF area
DRIFT I operation and safety

Stable/safe CS$_2$ flow/extraction

Stable/safe HV (20-30 kV)

CS$_2$ flow (24 hrs)

MWPC current (24 hrs)

First full use of new JIF facility - great success

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DAQ and analysis

2 x 500 ch 2Mhz ADC (SLAC)

gamma region

R2

Alphar region 90%

Recoil region

500 NIPs

= 32 keV S recoil

2 mm

Wire 1

Wire 2

Wire 3

Wire 4

\( R2 = \sqrt{\Delta x^2 + \Delta z^2} \)

\( \Delta z \)

\( \Delta x \)
Gammas rejection basics

- Test with 1 ft³ detector at Occidental

Low threshold

High threshold

Low thresh. | High thresh.

Gamma Region

Neutron Region

overlap

\[ \gamma \]

\[ n \]
Gamma rejection in DRIFT I

Example $^{252}$Cf - uncut data

Example on line event analysis
Typical neutron event (S-recoil)
Sample events - alpha

\[ X = (N-1) \times \text{wire spacing} \]
\[ Z = v_{\text{drift}} \times \text{drift time} \]
\[ R^2 = \sqrt{X^2 + Z^2} \]
Sample events

Wide pulses

Alpha

Long track

Narrow

Fe55 Gamma

Short
Veto operation - alpha rejection

- Neutron event - no veto signal
- Horizontal alpha - with veto signal

- Full analysis discrimination cuts under development
- **ALPHA Rejection**: Critical question is cathode alpha rejection
- 3 months DM data being analysed
- Analysis for directional sensitivity underway
- Lower detector noise needs reducing

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Repairs!

US0703 - all data shown is preliminary
Direction sensitivity

About 200 WIMPs needed to identify standard halo CDM with DRIFT I technology

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DRIFT II - design concept (LLNL)

- **Objective**

- **Base-line design**
  - MWPC readout
  - 5 m³, 160 Torr (CH₂Cl₂ if not CS₂)
  - drift cathode readout to get fiducialisation
  - moderate 3d readout (anode, grid and z-drift)
  - limited gamma shielding plus neutron shielding and muon veto

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DRIFT II - grid + HV cathode readout upgrade

- Move from 2d to 3d readout (anode, grid and z-drift)
  - improves directionality
  - improves discrimination (R2 --> R3)

\[ R_2 = \sqrt{\Delta x^2 + \Delta z^2} \]

\[ R_3 = \sqrt{\Delta x^2 + \Delta z^2 + \Delta y^2} \]
DRIFT II - neutron shielding and HV

- DRIFT I unshielded neutron (rock) background dominates (work in progress).
- DRIFT II will need >50cm CH shielding

- But also at 10^-8 pb level muon neutrons become important. So DRIFT II requires at least a 90% efficient muon veto.
- 100 kV feed required
DRIFT III - 30m³

- Duplication of DRIFT II modules
- Gas handling and recirculation upgrade
DRIFT - neutron simulations

All data shown is preliminary

Recalls Produced in CS2 from Neutrons in 4m Rock Salt

All recall in unshielded DRIFT I produced from Geant4 simulation of rock neutrons over 235 days
Rock contamination levels of 50ppb Uranium and 150ppb Thorium
4.06 recalls per day between 20 and 100 keV
5.00 recalls per day between 20 and 200 keV
DRIFT III - other challenges

- Muon/neutron veto (low cost scintillator)
- DAQ (multiplexing)
- Safety (gas and high voltage control)
- Scale mechanics
- Alternative targets
- Alternative readout
DRIFT III - micromegas option

- May allow higher gas pressure
- Easier fabrication (?)

Micromegas basic idea

Y. Giomataris, Saclay etc

Sheffield/RAL tests
5x10 cm device

Tests underway to check potential with -ve ions

Gain (1 atm. He-isobutane)

Energy Spectrum
(V_mesh = 500V)
DRIFT III - micromegas option

Tiled readout array design

Tests underway to check potential with -ve ions

$^{55}\text{Fe}$ spectra

Y. Giomataris, Saclay etc

US0703 - all data shown is preliminary
Tests underway to check potential for operation with two phase xenon and -ve ions (5 cm micromegas)

Results: He, Ar, Xe: isobut; Xe: CH₄; pure CS₂ - first demonstration with -ve ions

^{55}\text{Fe}

spectra

(5.9 keV)
Gas parameters

(1) For any gas at pressure $P$ in parallel electrode-gap $d$ and potential-difference $V$,

$$\text{gain, } M = e^{AP_d(e^{-BP_d/V})}$$  \hspace{1cm} (1)

($A$ & $B$ are gas-dependant parameters)

(2) Pressure, $P_{\text{max}}$ at which gain is a maximum is:

$$P_{\text{max}} = \frac{v}{Bd}$$ \hspace{1cm} (2)

allowing parameter $B$ to be determined.

(3) Rearranging eq. 1 gives:

$$A = \frac{\ln(M_1/M_2)}{P_d(e^{-BP_d/V_1} - e^{-BP_d/V_2})}$$

where $M_1/M_2$ is the ratio of gains at anode voltages $V_1$ and $V_2$ respectively

Ar:isob (80:20), 100 Torr:
B $\sim$ 650 V/cm/Torr
A $\sim$ 50 /cm/Torr
typical gain $\sim$300 @ 400V anode
**SUSY is not the only solution...**

- Although SUSY provides an elegant solution to both the dark matter and SM problems, there are other DM candidates.
- Need CDM to explain structure formation $\Rightarrow$ massive particles with weak scale interactions IF particles produced thermally.

- **Strong CP problem:** Peccei & Quinn proposed existence of a spontaneously broken global U(1) symmetry.
- Leads to a pseudo-Nambu-Goldstone boson, the Axion.
- Although Axion mass small, produced non-thermally.
- Detection scheme relies on conversion to microwave photons in magnetic field.
- Several search experiments underway, but only a small window left...

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L_\theta = \frac{\theta g^2}{32\pi^2} G^a_{\mu\nu} G^{a\mu\nu} \quad \theta = \theta_{QCD} - \theta_{EW}
\]

\[
L_{\alpha\gamma} = -g_\gamma \frac{\alpha a}{\pi f_a} \vec{E} \cdot \vec{B}
\]

\[
m_a = 0.6eV \times \frac{10^7 GeV}{f_a}
\]
Conclusions - Cold Dark Matter is Everywhere