

RAL Particle Physics Master Class

The search for WIMPs in the U.K.



The evidence for Dark Matter

Potential candidates for Dark Matter (WIMPs)

The UK programme and current results

What is an Observatory?

- Out of this World: HST
- The World's Coldest: Antarctica



Or Is It....?

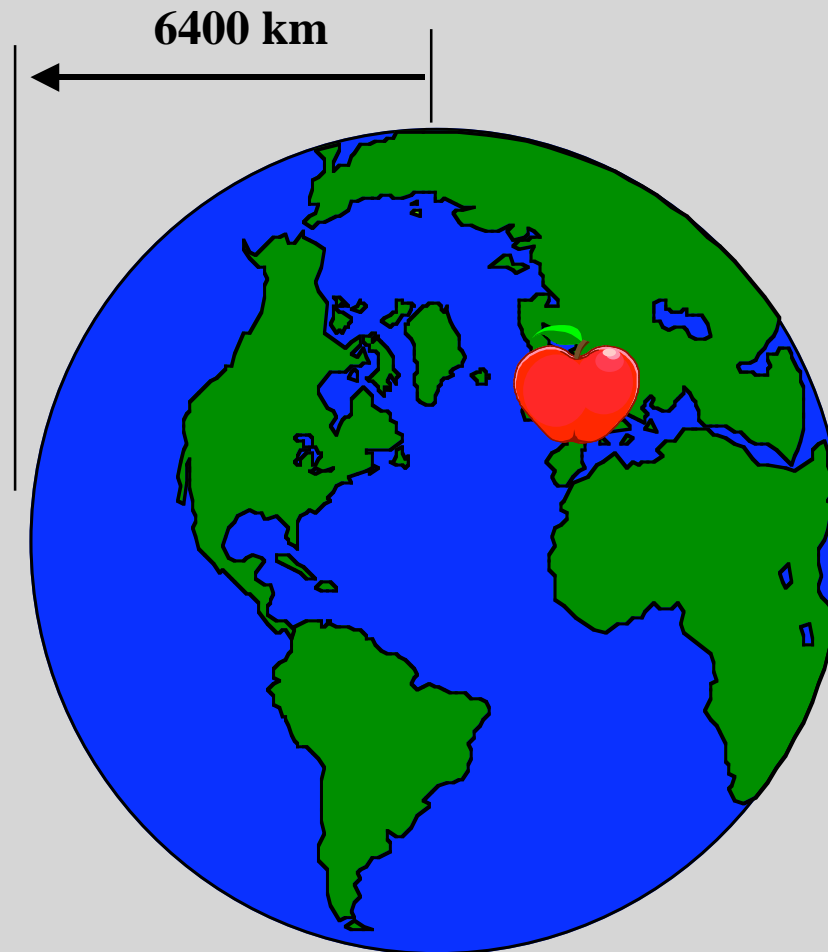
- Britain's Highest:
Ben Nevis



- Britain's Deepest:
Boulby Mine

Weighing the Earth

- Use the law of gravity in this laboratory



Testing for 'Missing' Mass

- Newton's law of gravity: $F = \frac{Gm_a m_E}{r_E^2} \longrightarrow a = \frac{Gm_E}{r_E^2}$

- Dynamics: $s = ut + \frac{1}{2}at^2$

- Earth's mass by gravity:

$$m_E = \frac{2r_E^2 s}{Gt^2} = \frac{2 \times 6.4e^{6^2} \times [\dots 5 \dots]}{6.7e^{-11} \times [\dots 1 \dots]^2}$$

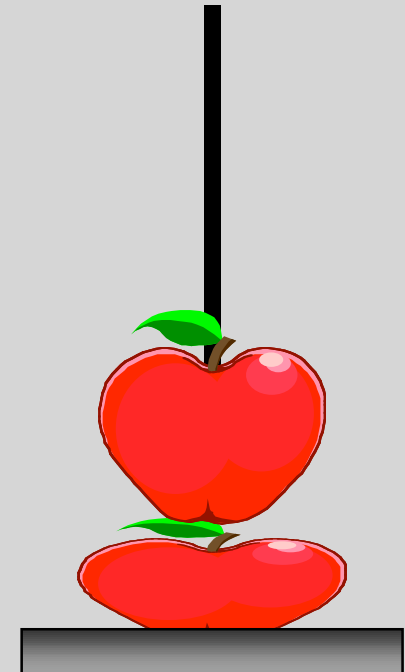
$$m_E = \dots 6.0 \times 10^{24} \text{ kg}$$

- Earth's mass by weighing:

$$m_E = \frac{4}{3} \pi r_E^3 \rho_E$$

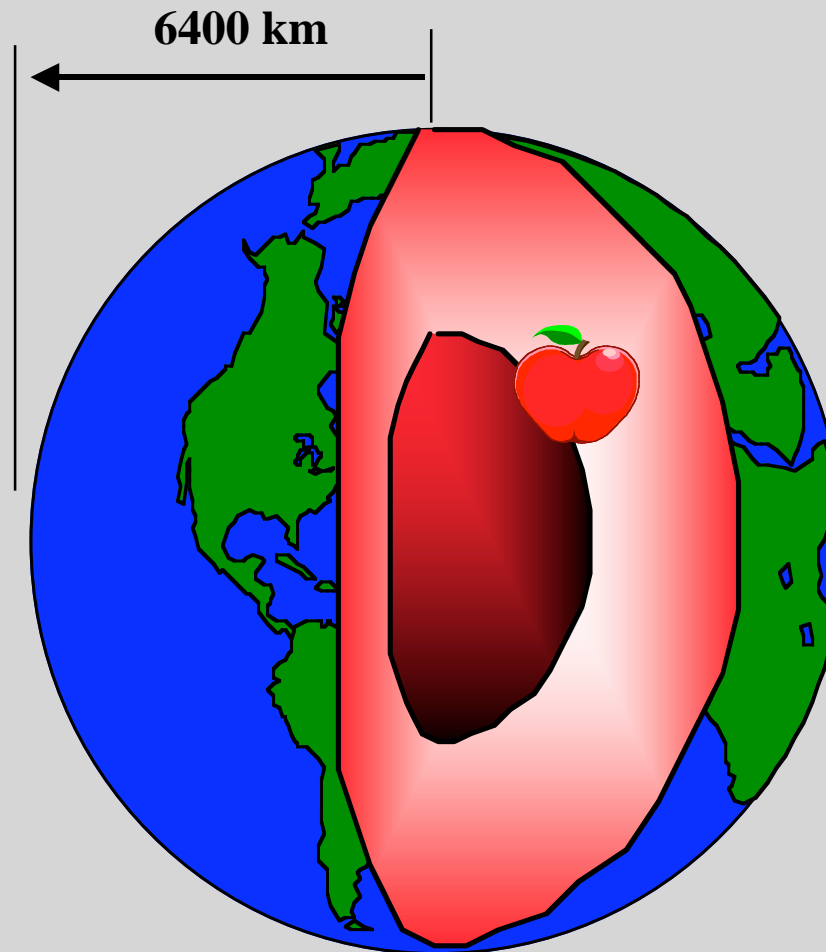
$$m_E = \frac{4}{3} \pi \times 6.4e^{6^3} \times [\dots 2.4 \dots]$$

$$m_E = \dots 2.6 \times 10^{24} \text{ kg}$$



The Earth's 'Missing' Mass

- Heavy metal core increases mean density of planet

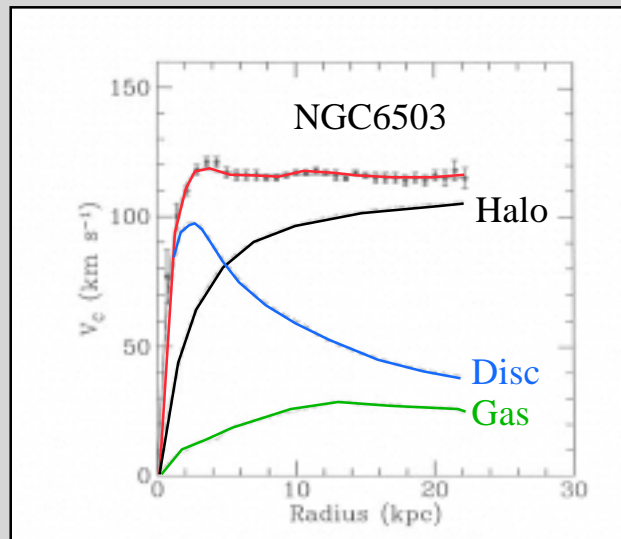


Weighing a Galaxy

- Scale 10kPc (30 000 light years)
- Uses Doppler shift of light from star in spiral galaxy to give velocity (red shift)
- Expect velocity to fall off with distance from centre
 - **...but it doesn't**
- $\rho_{\text{dm}} \sim 0.3 \text{ GeV/cc}$

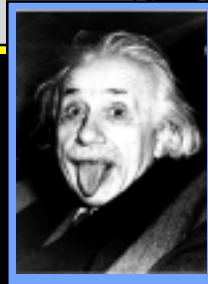
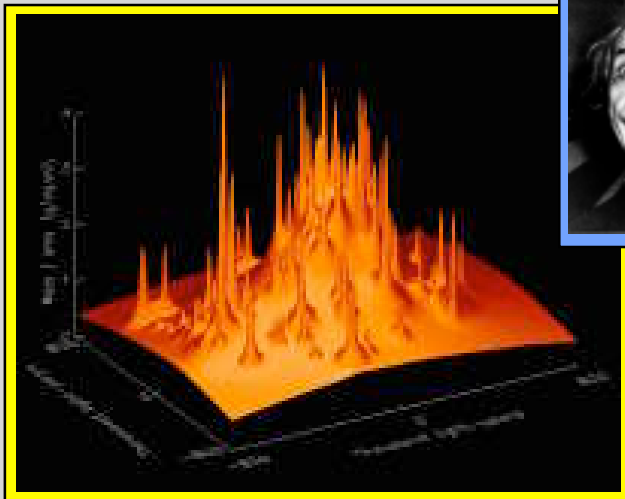
$$M_{\text{tot}}(r) = \frac{v_c^2 r}{G_N}$$

$$v_c^2 = G_N \frac{M_{\text{vis}}}{r}$$



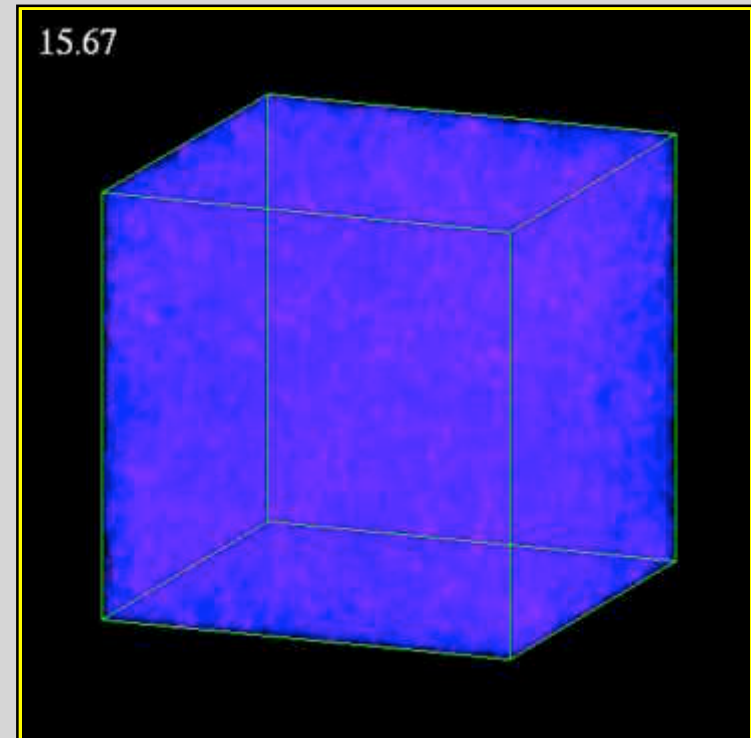
Weighing Galaxy Clusters

- Scale 1 Mpc
(3 000 000 light years)
- Use gravitational lensing of quasars or galaxies by galaxy clusters.



How Massive is the Universe?

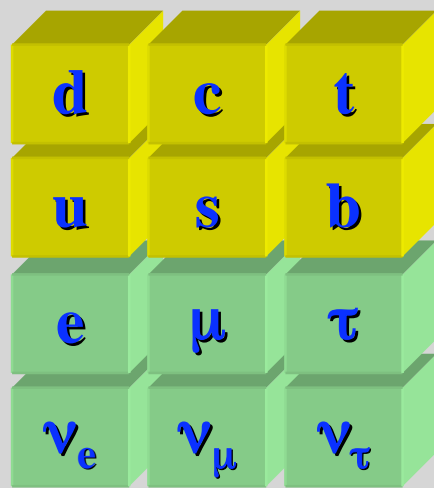
- Describe with a cosmological mass density called Ω_{total}
 - $\Omega_m (\Omega_{\text{cdm}} + \Omega_{\text{hdm}} + \Omega_b) + \Omega_\lambda + \Omega_\kappa$
- $\Omega_\lambda > 0$: Universe ‘open’: Big Chill
 - This is the way the World ends,
Not with a bang but with a whimper. (T.S.Eliot)
- $\Omega_\lambda < 0$: Universe ‘closed’: Big Crunch
 - Some say the world will end in fire, some
say in ice. From what I've tasted of
desire, I hold with those who favor fire.
(R. Frost)
- Best scenario $\Omega_{\text{total}} = 1$,
 $\Omega_\lambda \approx 0.7$, $\Omega_b \approx 0.04$
 $\Omega_{\text{cdm}} \approx 0.3$, $\Omega_{\text{hdm}} \approx 0.03$
- Big Bang inflationary theory
requires $\Omega_{\text{total}} = 1$ exactly



Lucas and CDM



PP: Standard Model



Quarks

Baryons: qqq
(fermions)

Hadrons

Mesons: $q\bar{q}$
(bosons)

- Building blocks: elementary fermions

Leptons

Force

Boson

Strength

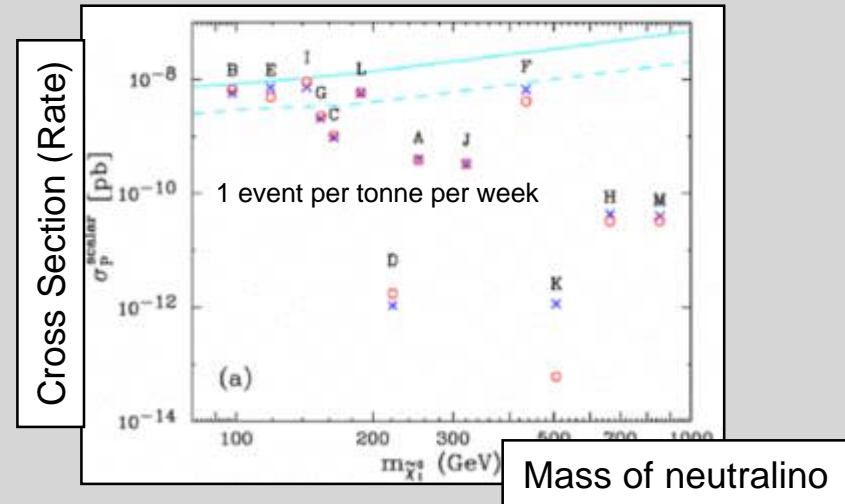
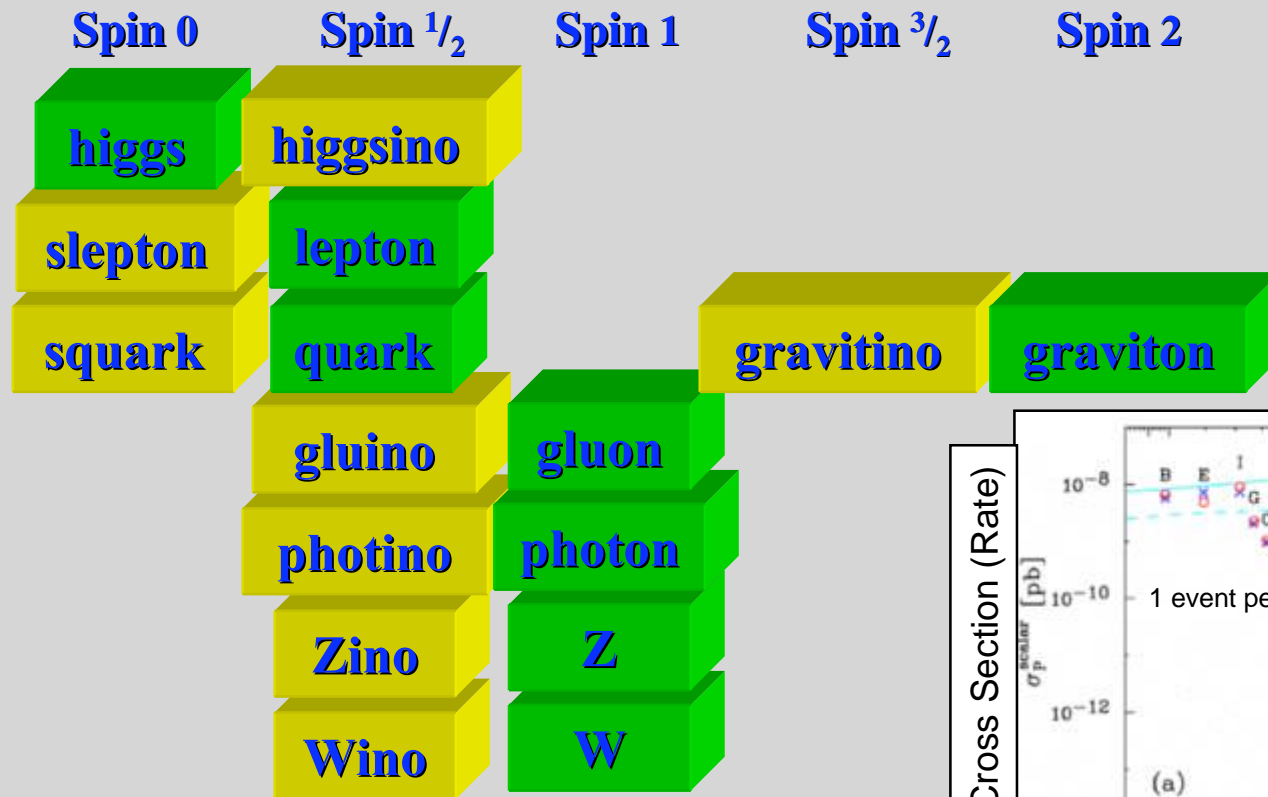


“Normal Matter”

- Forces: exchange bosons

Force	Boson	Strength
Gravitation	graviton	10^{-39}
Weak	W, Z	10^{-5}
Electromagnetic	photon	10^{-2}
Strong (colour)	gluon	1
Strong (nuclear)	mesons	

Supersymmetry



- Four neutralinos

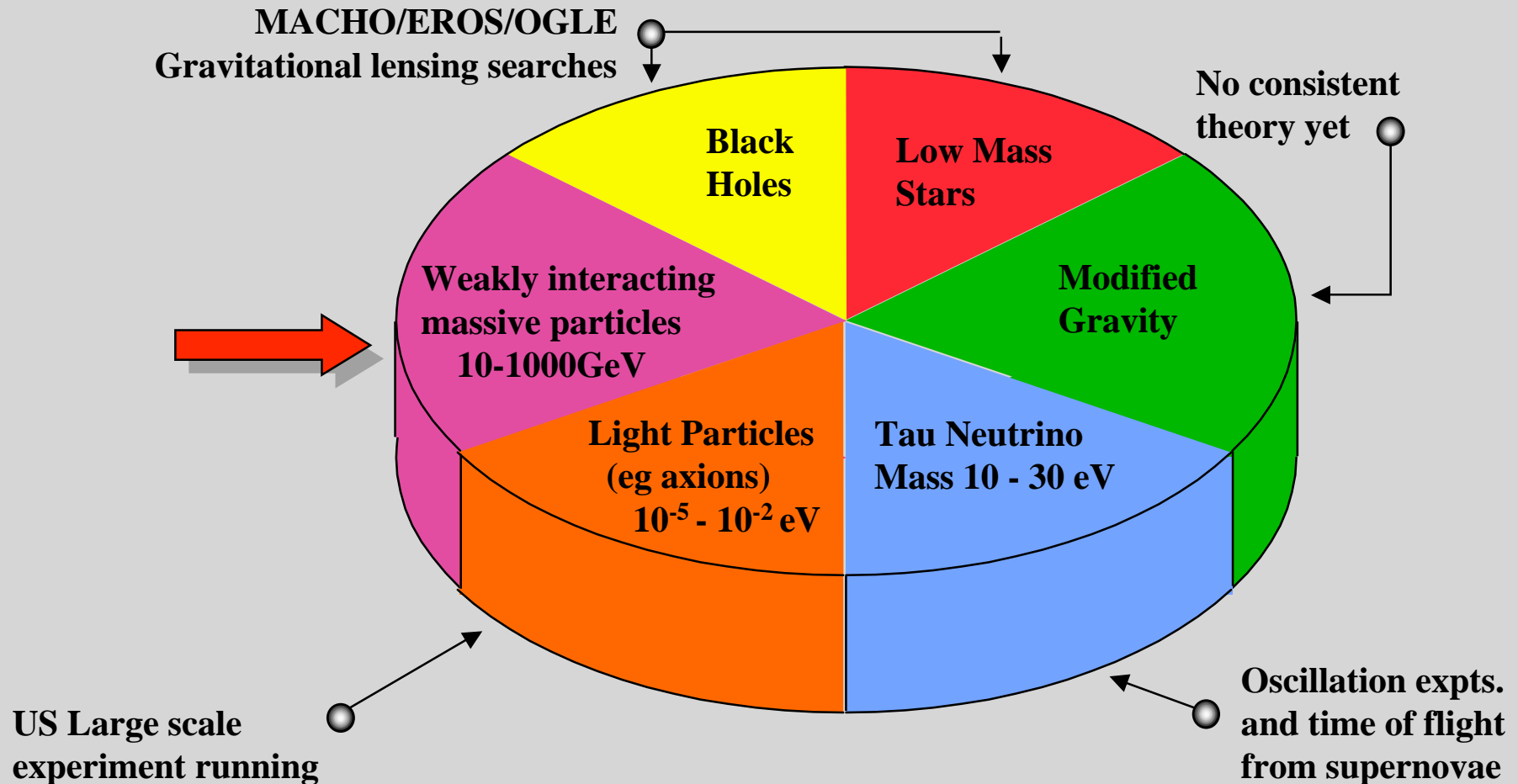
- χ , lightest SUSY particle (LSP)
- $34 \text{ GeV} < m_\chi < 300 \text{ TeV}$ (expt.)
- $10^{-12} \text{ pb} < \sigma_\chi < 10^{-8} \text{ pb}$ (theory)

- Connects particles and forces

- Fermions have sfermion partners
- Bosons have bosino partners

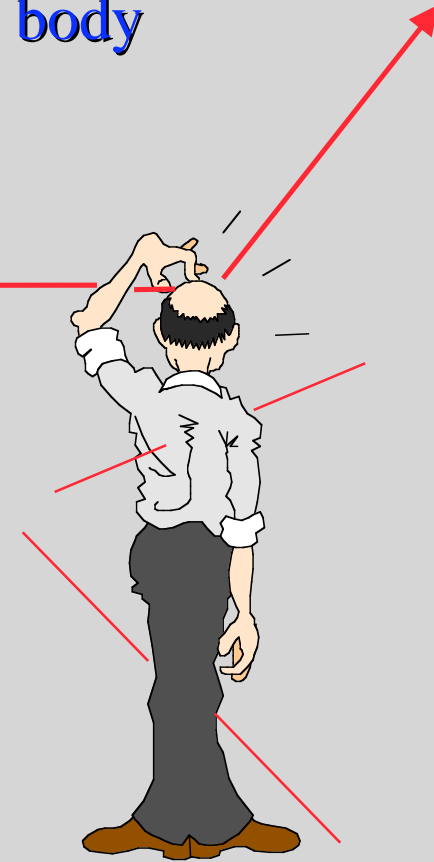
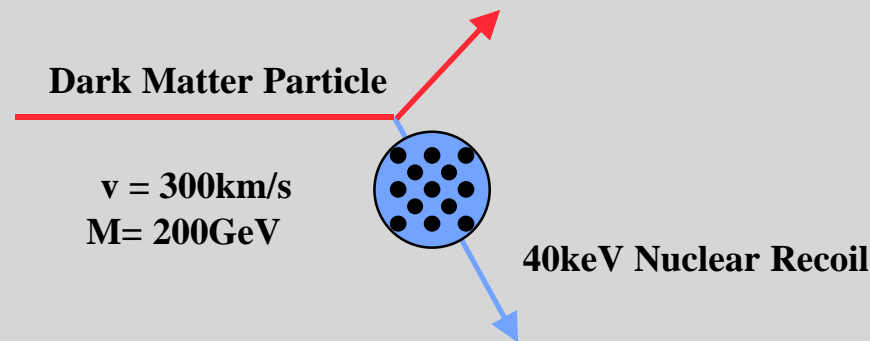
Dark Matter Candidate Review

- Hybrid Solution for cosmology: $\Omega = \Omega_b + \Omega_{\text{CDM}} + \Omega_\lambda$
0.04 0.3 0.7



Principles of WIMP Detection I

- 1,000,000,000 WIMPs pass through every body each second
- Travelling at 1,000,000 km/hr
- 0.01 - 1 will hit nuclei in the body each day
- This causes the whole nucleus to recoil (coherently)



Principle of WIMP Detection II

- Recoiling nucleus releases energy



- Ionisation: free electric charge released
- Thermal: phonons created
- Scintillation: light pulse
 - **The best detectors use a combination of all three, or differences within a process to tell the difference between WIMPs and background events**
- UK project concentrates on scintillation and ionisation detectors (NaI, liquid Xe, CS₂)

Background Signals

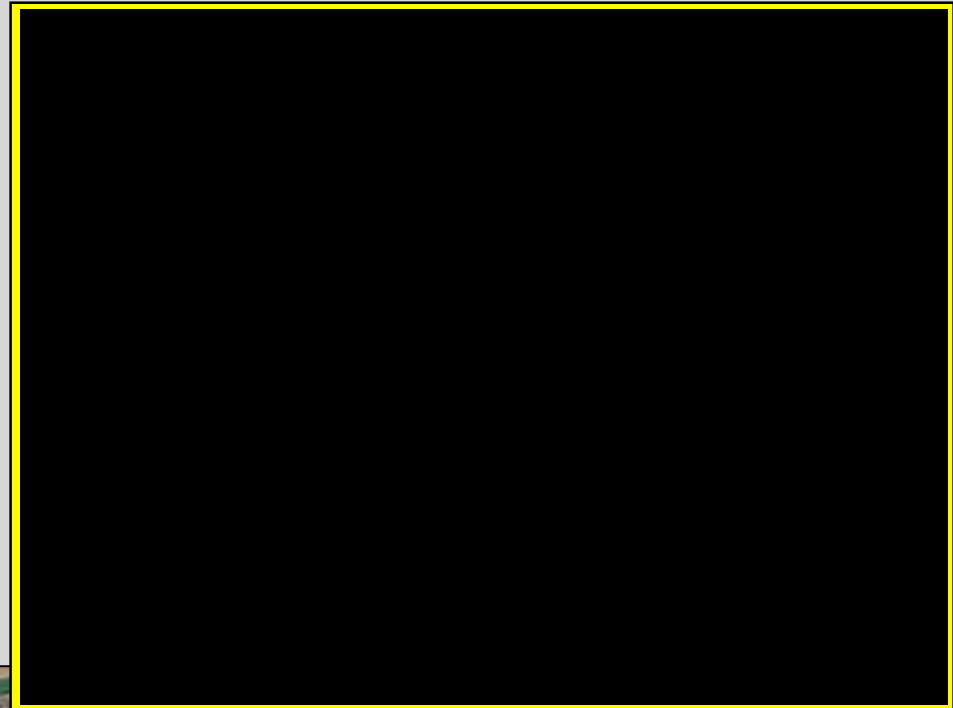
- Not as simple as all that
- For each DM event there are millions of events from other sources



Background Source	Solution
neutrons from cosmic ray muons (1,000/day)	Go deep underground
Gamma rays from surroundings (1,000,000/day)	Shielding of detector High purity Pb/Cu
Gamma rays from photomultipliers (100,000/day)	Low background materials
Beta rays from materials (300/day)	High purity target design
Gamma rays from Radon decay (100/day)	Clean room construction

Boulby Potash Mine

- Working salt mine
- Easily modified structure



Tango Man



Early Infrastructure

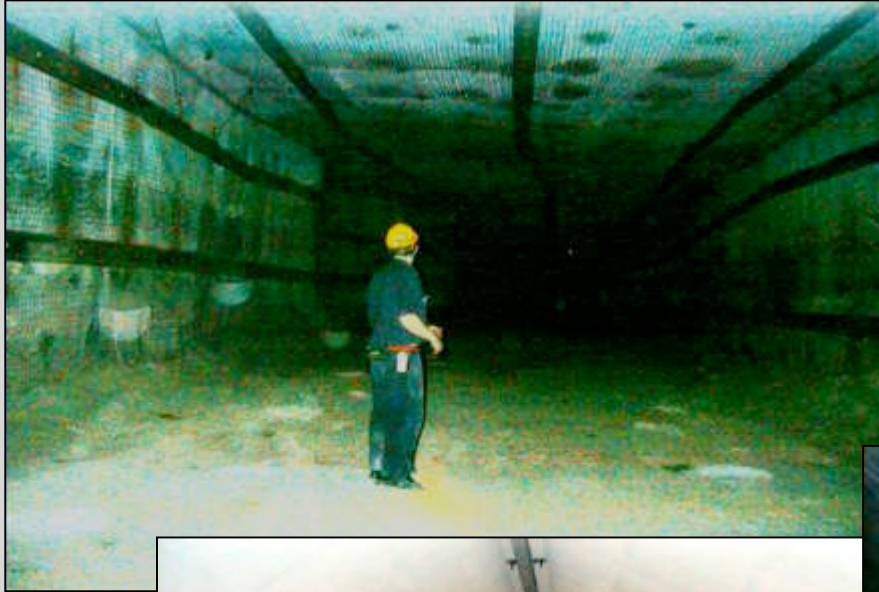


New Facilities

- Surface facilities
 - Workshop, offices, etc.
- Underground facilities
 - New clean area, upgrade existing
- Opened April '03 by Lord Sainsbury
 - With a place in the Sun



Building a world class laboratory

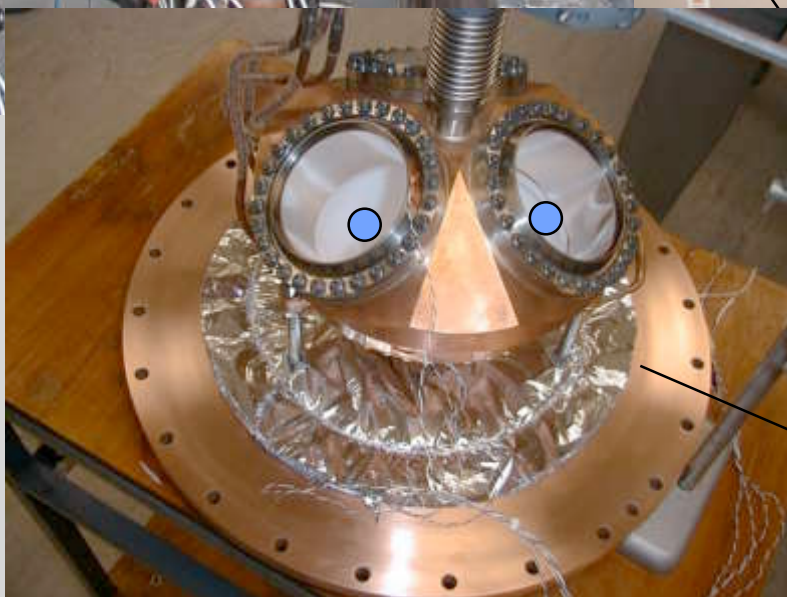


Direct Detection - Experiments

Site	Experiment	Technique	Target	Status
Baksan (Russia)	IGEX	Ionisation	3kg Ge	Operational
Bern (Switzerland)	ORPHEUS	SSD	0.5kg Sn	Operational
Boulby (UK)	NaI	Scintillator	5kg NaI	Completed
	NaIAD	Scintillator	50kg NaI	Operational
	ZEPLIN I	Scintillator	3kg Lxe	Operational
	ZEPLIN II/III	Scintillator/Ionisation	30kg/7kg Xe	Construction
	ZEPLIN-MAX	Scintillator/Ionisation	1000kg Xe	Planned
	DRIFT-I	TPC	0.2kg CS ₂	Operational
DRIFT-II	TPC	3kg CS ₂	Planned	
Canfranc (Spain)	COSME	Ionisation	0.2kg Ge	Completed
	IGEX	Ionisation	2.1kg Ge	Operational
	ANAIS	Scintillator	107kg NaI	Construction
	ROSEBUD	Thermal	Al ₂ O ₃ , Ge, CaWO ₄	Operational
Frejus (France)	Saclay-NaI	Scintillation	10kg NaI	Completed
	EDELWEISS I	Thermal/Ionisation	0.07kg Ge	Completed
	EDELWEISS II	Thermal/Ionisation	1.3 kg Ge	Operational
Gran Sasso (Italy)	Hdlberg/Mscw	Ionisation	2.7kg Ge	Completed
	HDMS	Ionisation	0.2kg Ge	Operational
	Genius	Ionisation	100kg Ge	Planned
	DAMA	Scintillation	100kg NaI	Operational
	LIBRA	Scintillation	250kg NaI	Construction
	Xenon	Scintillation	6kg Xe	Operational
	CRESST-I	Thermal	1kg Al ₂ O ₃	Operational
	CRESST-II	Thermal/Scintillation	10kg CaWO ₄	Construction
	CUORICINO	Thermal	40kg TeO ₂	Construction
CUORE	Thermal	760kg TeO ₂	Planned	
Otto-Cosmo (Japan)	Elegants V	Scintillation	NaI	Operational
	Elegants VI	Scintillation	750kg CaF ₂	Operational
Rustrel (France)	SIMPLE	SDD	1g Freon	Operational
Stanford (USA)	CDMS-1	Thermal/Ionisation	0.1kg Si, 1kg Ge	Completed
Soudan (USA)	CDMS-II	Thermal/Ionisation	1kg Si, 7 kg Ge	Construction
	CryoArray	Thermal/Ionisation	1000 kg	Planned
SNO (Canada)	PICASSO	SDD	1g Freon	Operational

Apologies to the rest.....

ZEPLIN I Installation

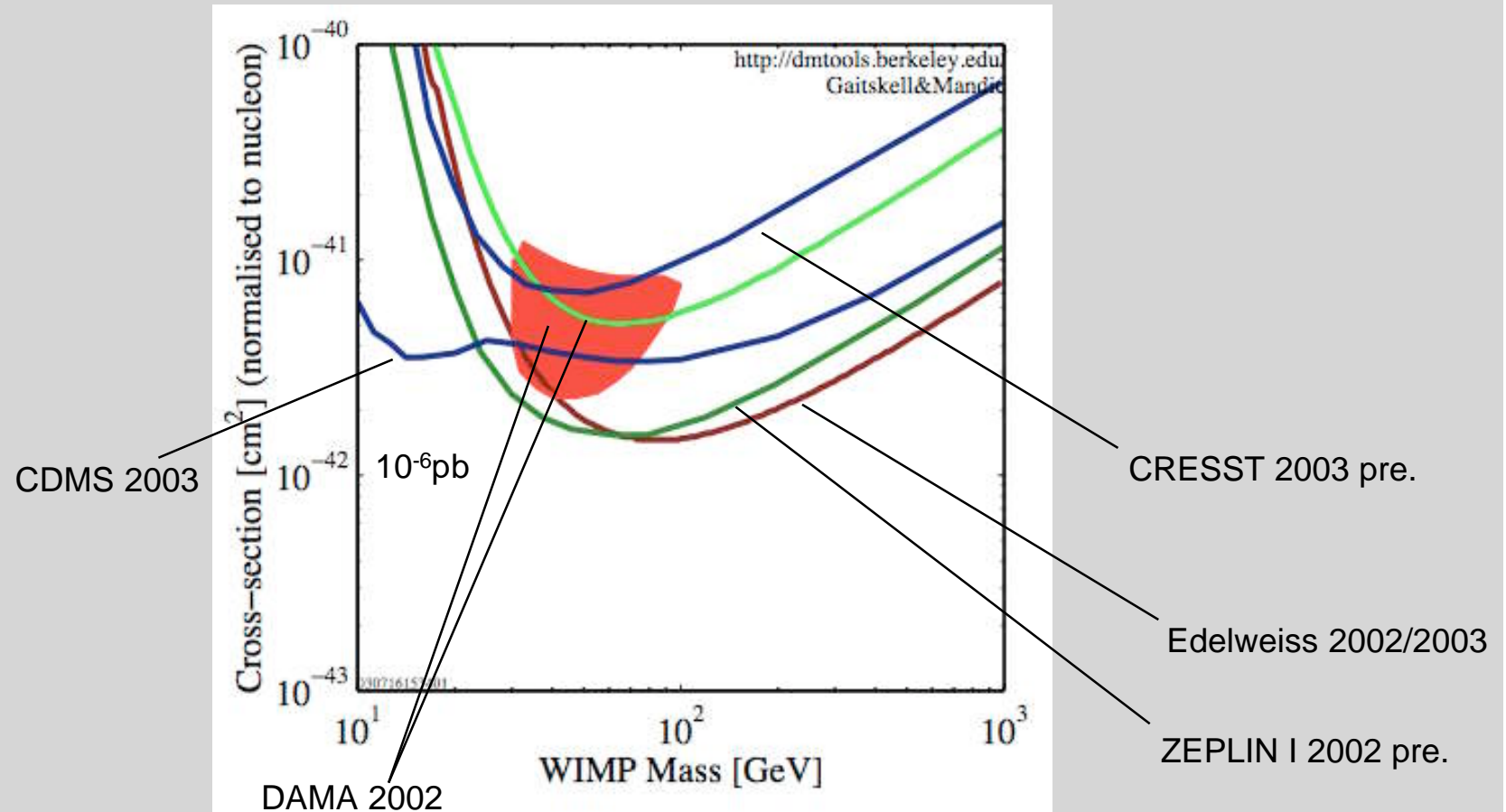


Xenon recovery system
Xenon purifier
Polycold cryogenerator
ZEPLIN I target

World results at present

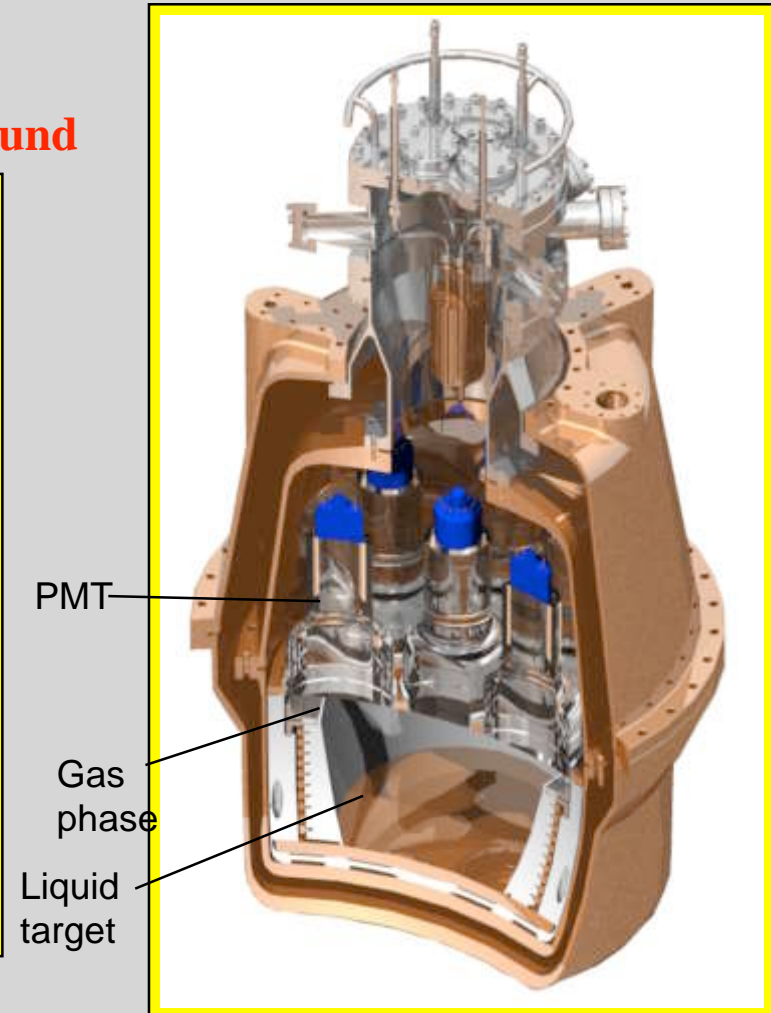
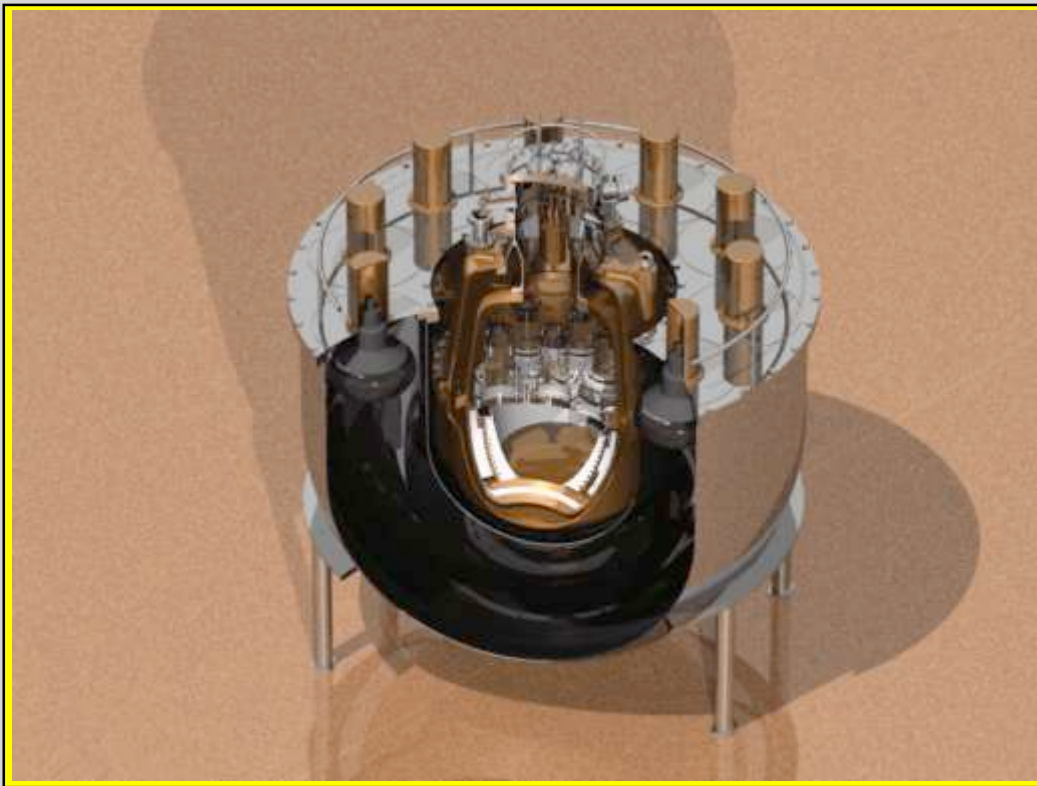
$10^{-6}\text{pb} \sim 1 \text{ event/kg/day}$

Scalar interaction cross section (WIMP-nucleon)



Future Detectors

- ZEPLIN II/III: 10-40kg two phase discrimination in Xenon
 - **Primary scintillation**
 - **Electroluminescence in high-E field**
 - **Better discrimination against background**



The Search for WIMPs

- Missing mass in Galaxy
 - 30% of Universe is matter
 - 90% of this is non-baryonic
 - Particle Physics expects.....
- WIMPS
 - Current sensitivities $\sim 10^{-6}\text{pb}$
 - Planned upgrades $\sim 10^{-8}\text{pb}$
 - Future (5 years) 1 tonne $\sim 10^{-10}\text{pb}$
- Theoretical expectation $10^{-7}\text{pb} - 10^{-10}\text{pb}$
- Ultimately link the very large and the very small