[Cold] Dark Matter

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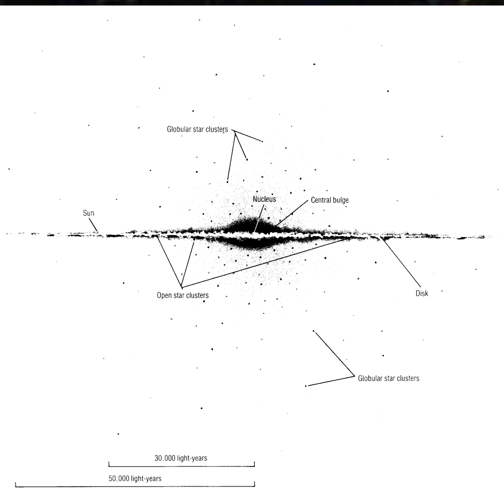
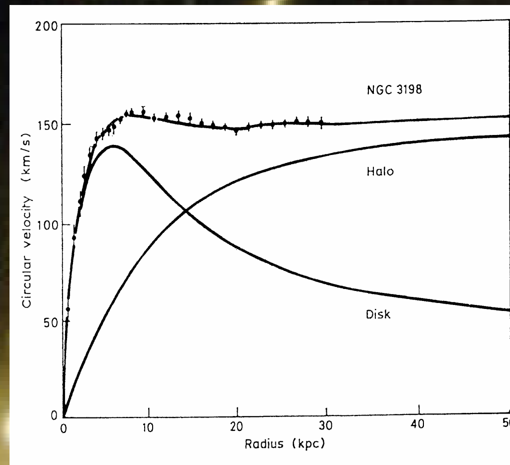
Imperial College London

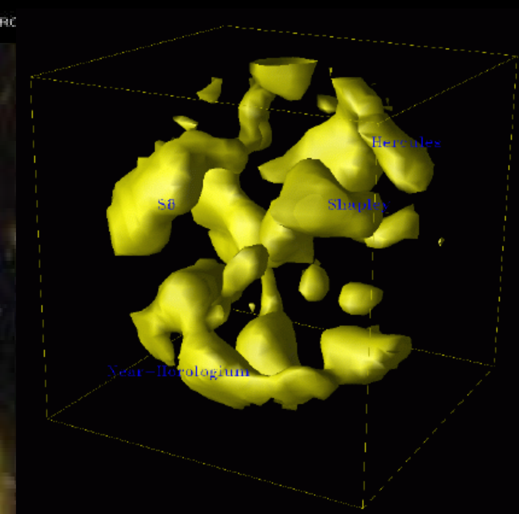
- Evidence for [cold] dark matter
- Galactic candidates
- Neutralino detection requirements
- Underground experiments

Evidence for Dark Matter

Probing Gravitational Potentials

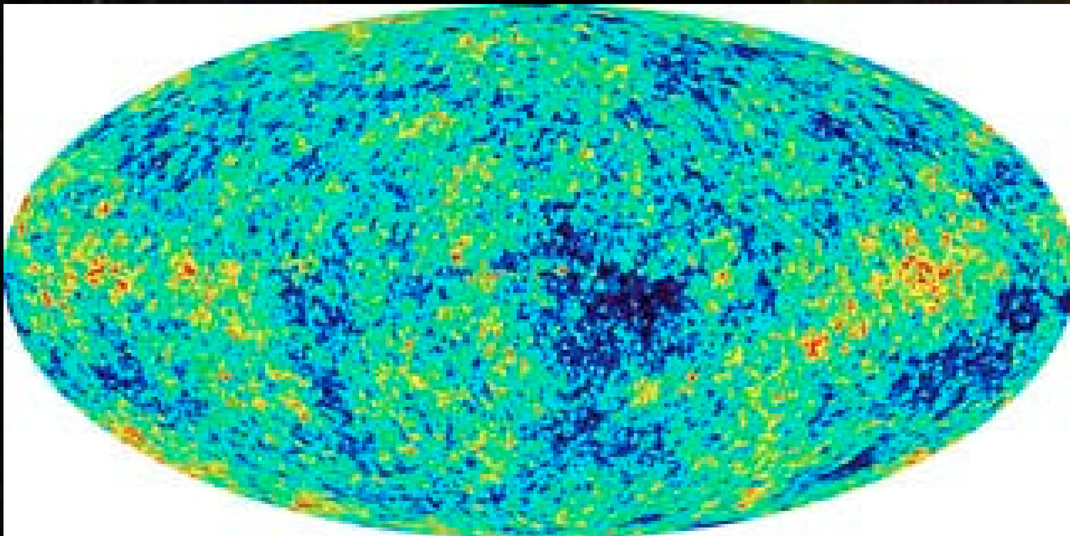


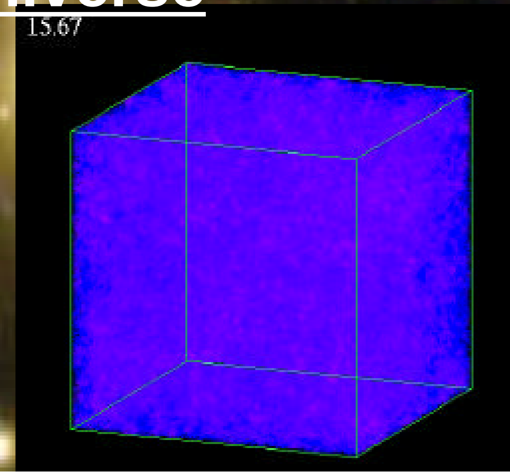


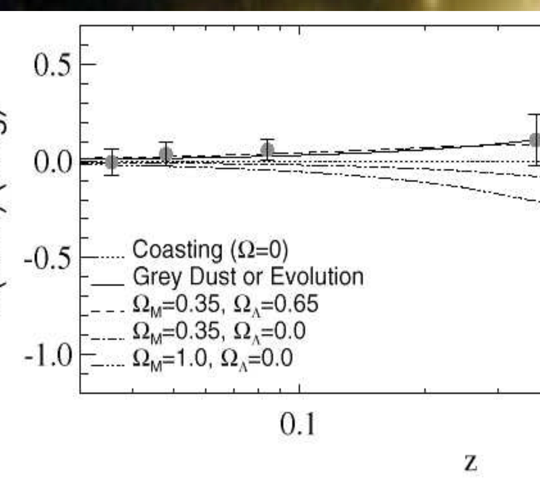


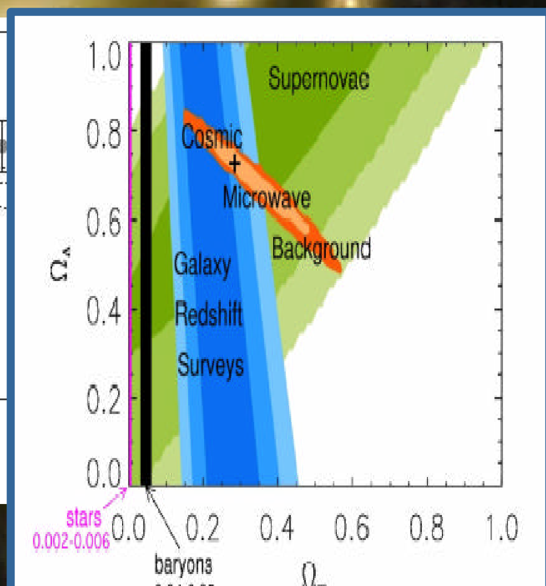
Evidence for Dark Matter

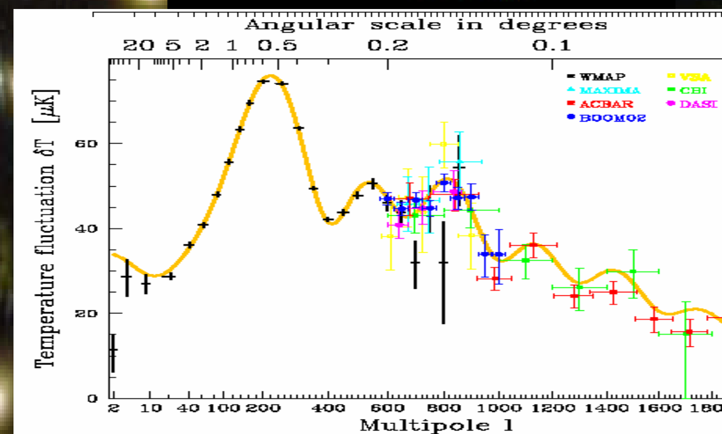
Structure & Evolution of the Universe

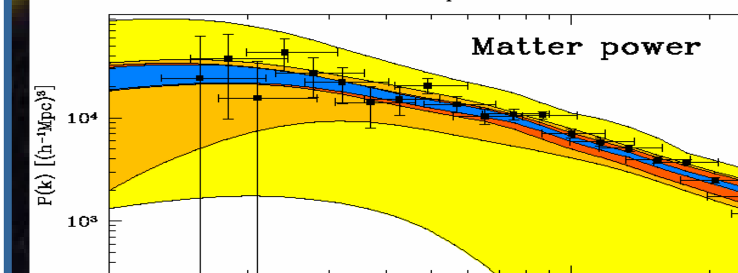


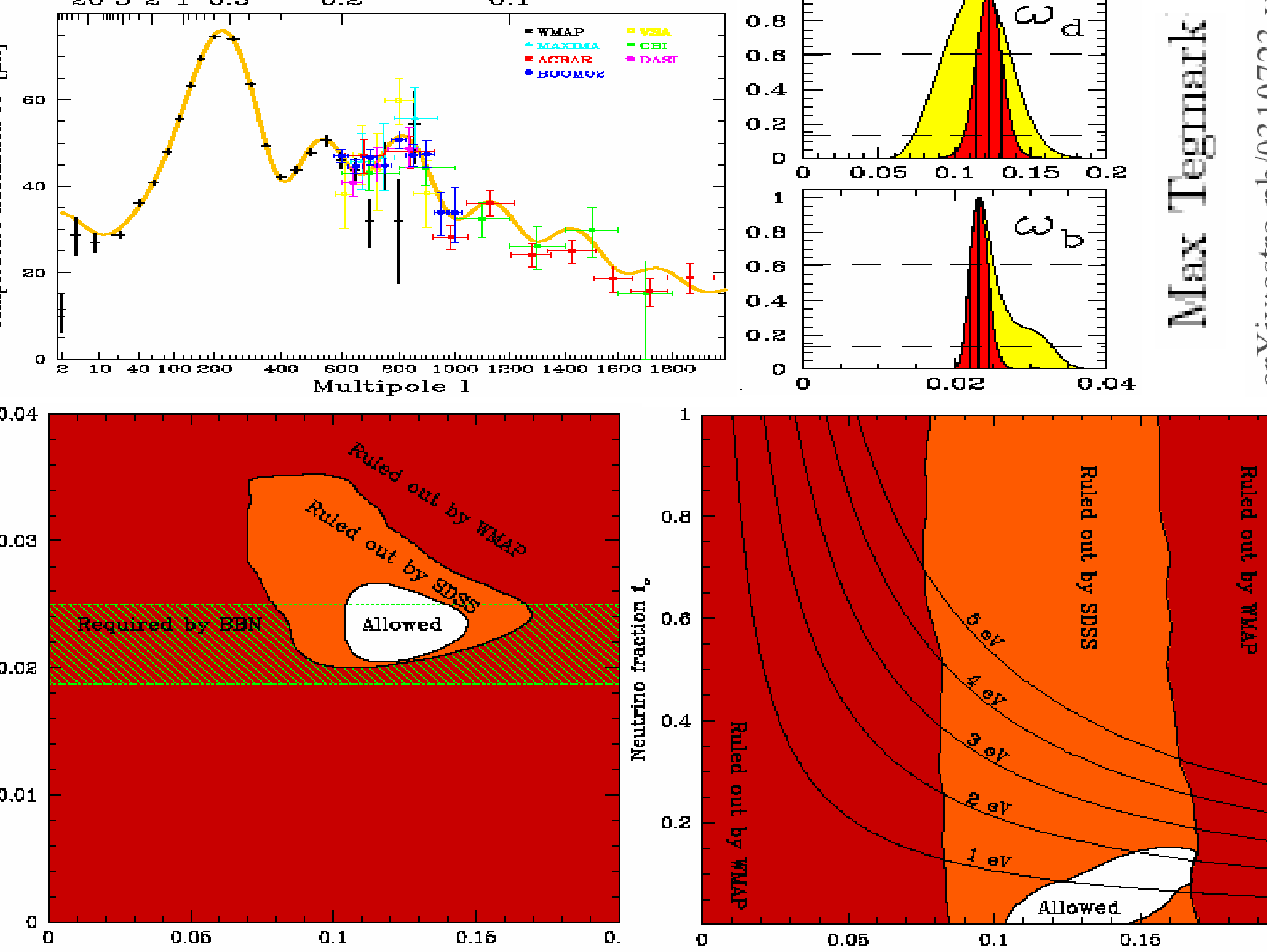










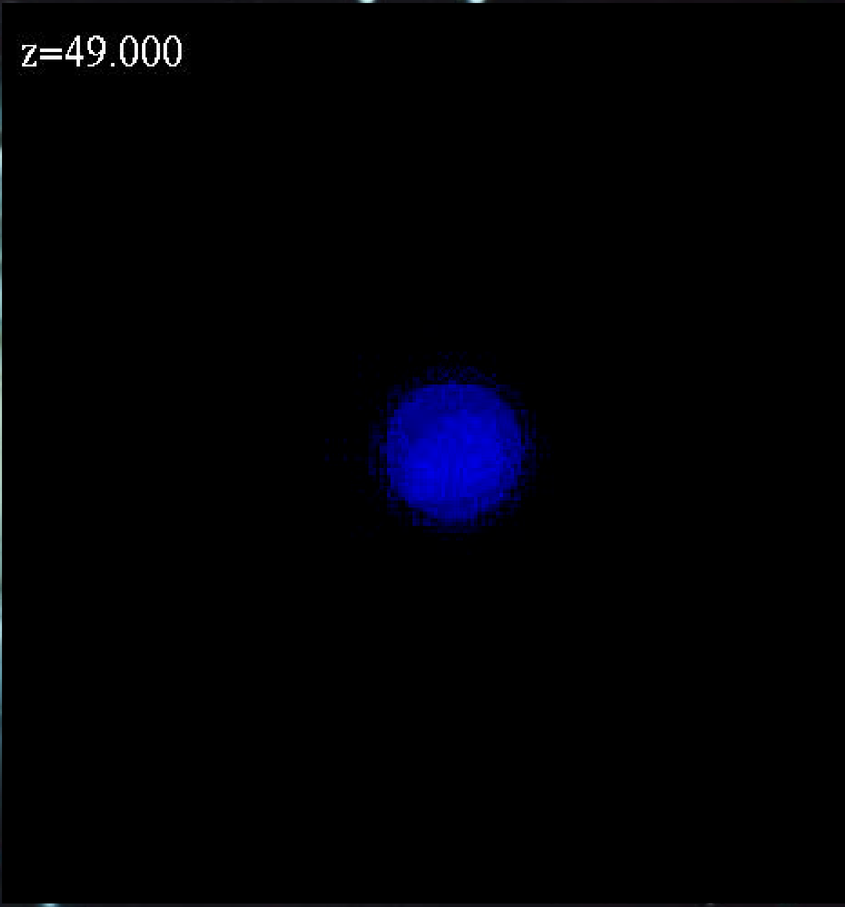


WMAP
MAXIMA
ACBAR
BOOMO2
VSA
CBI
DASI
Multipole l
ω d
ω b
Max Tegmark
Ruled out by WMAP
Ruled out by SDSS
Allowed
Required by BBN
Neutrino fraction f_ν
5 eV
4 eV
3 eV
2 eV
1 eV


Dark Energy
73%
Cold Dark Matter
23%

Galactic DM Candidates

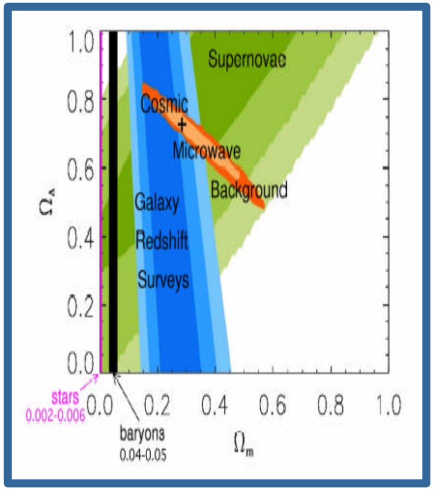
- Dark baryons - primordial nucleosynthesis constraints
- MACHOs - microlensing constraints
- Neutrinos - mass
- Primodial Black Holes
- WIMPS – SUSY Neutralino?
- Axions – strong CP problem?
- Many many others
- Alternative Gravity theories



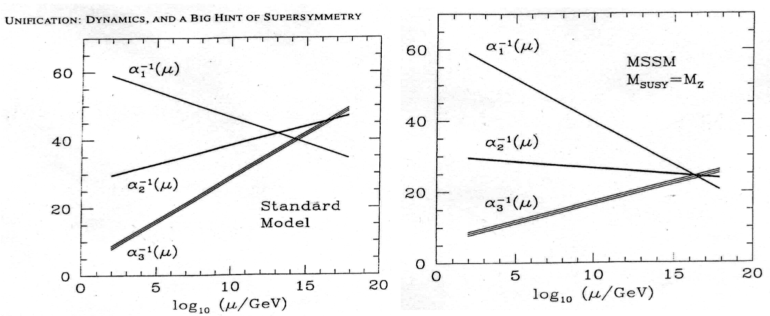
Scientific Motivation

Cold dark matter particle searches are driven by:-

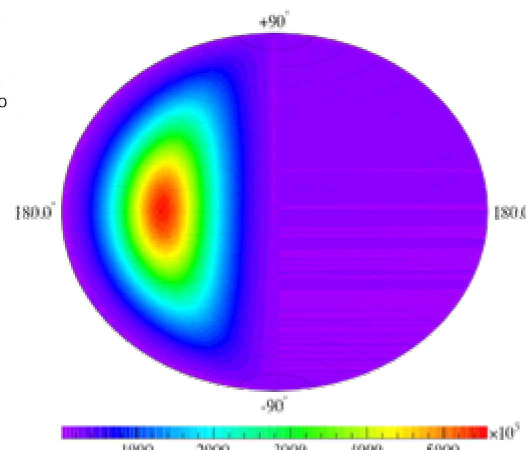
- **Cosmology – is the dark matter that makes up 22% of the Universe in the form of massive particles?**



- **Supersymmetry – are these the particles predicted by supersymmetry?**



- **Galaxy formation and dynamics – how do these particles behave within galaxes?**



Neutralino Detection

- Indirect detection via annihilation products
  - Neutrinos – Antares, Amanda/IceCube
  - Gamma-rays – HESS, GLAST
  - Particles - AMS

- Direct detection from elastic scattering from nuclei.
  - Energy deposit produces phonons, photons and electrons

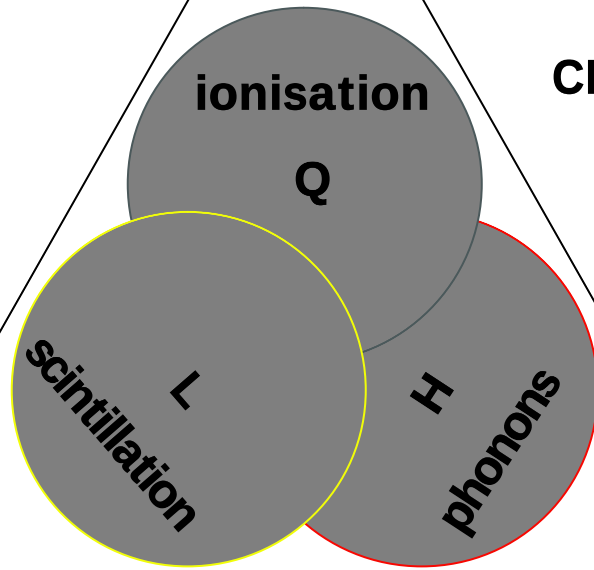
WIMP elastic nuclear recoils deposit < 100keV of energy at a rate 10^{-5} to 1 event/day/kg

IGEX, DRIFTI, II

Þ phonons, photons and charge whose relative proportions and /or characteristics depend on dE/dx Þ particle type

ZEPLIN II, III, MAX, XENON

CDMS, EDELWEISS



NAIAD, ZEPLIN I, DAMA

CRESST I

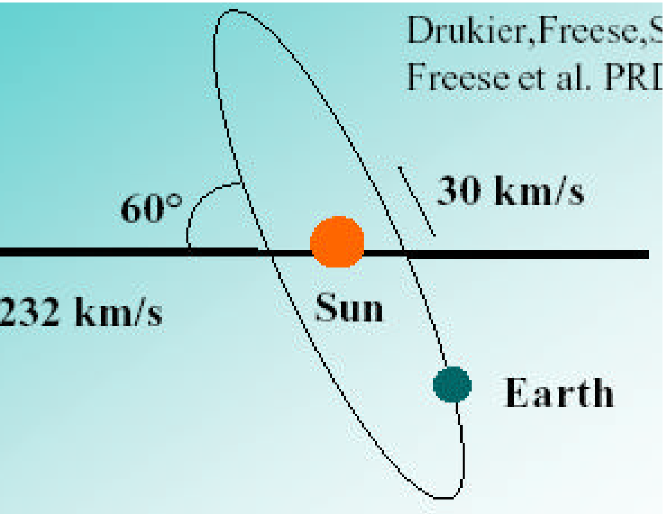
CRESST II, ROSEBUD

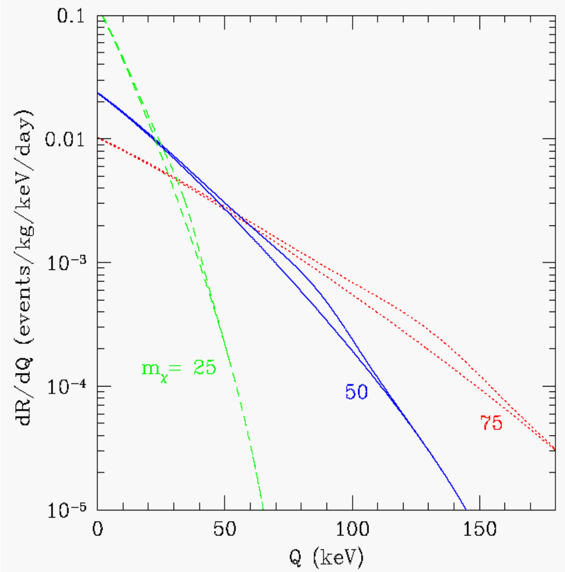
Event-by-event particle identification requires compound information

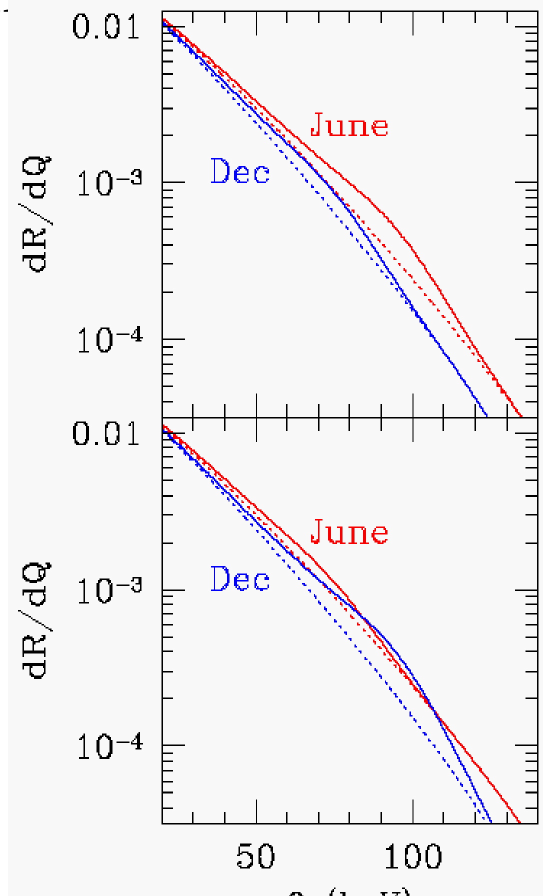
World competition is intense and uses a wid range of complementa techniques

Neutralino signatures

- Characteristic (but featureless) recoil spectrum which depends (rate and spectrum) on target nuclear mass and spin.
- Annual modulation expected in the event rate.
- Annual modulation expected in the spectrum
- Directional modulation on daily basis.
- Directional modulation on yearly basis.
- Site independent signal.







Scintillation Detectors - NaI

DAMA/NaI-1 to -7

107731 kg · d

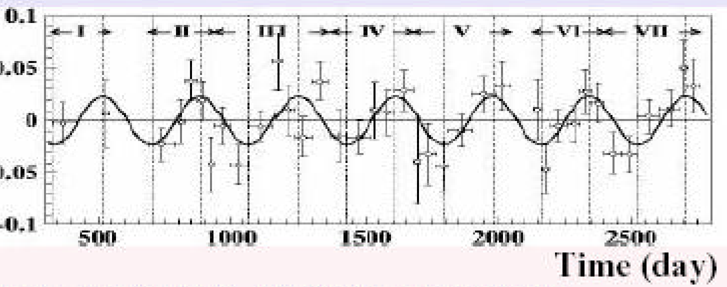
nnual modulation of the rate: the model independent result

Residuals of the rate vs time and energy

Riv. N. Cim. 26 n.1. (2003) 1

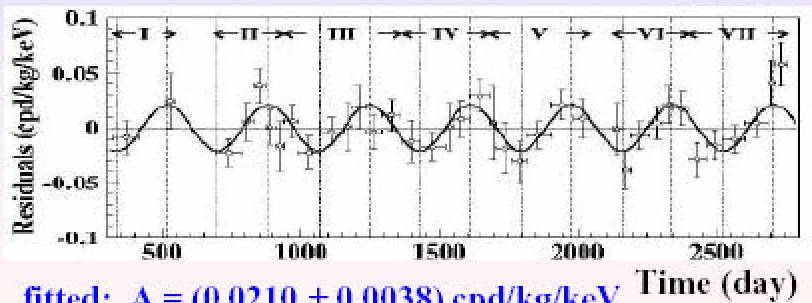
$A\cos[\omega(t-t_0)]$; continuous lines: t_0 = 152.5 d, T = 1.00 y

2-4 keV



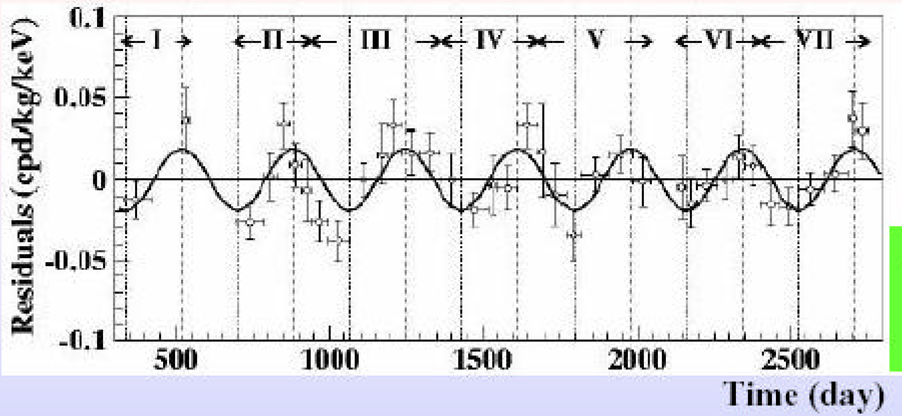
ted: A = (0.0233 ± 0.0047) cpd/kg/keV

2-5 keV



fitted: A = (0.0210 ± 0.0038) cpd/kg/keV

2-6 keV



$P(A=0)=7\cdot10^{-4}$

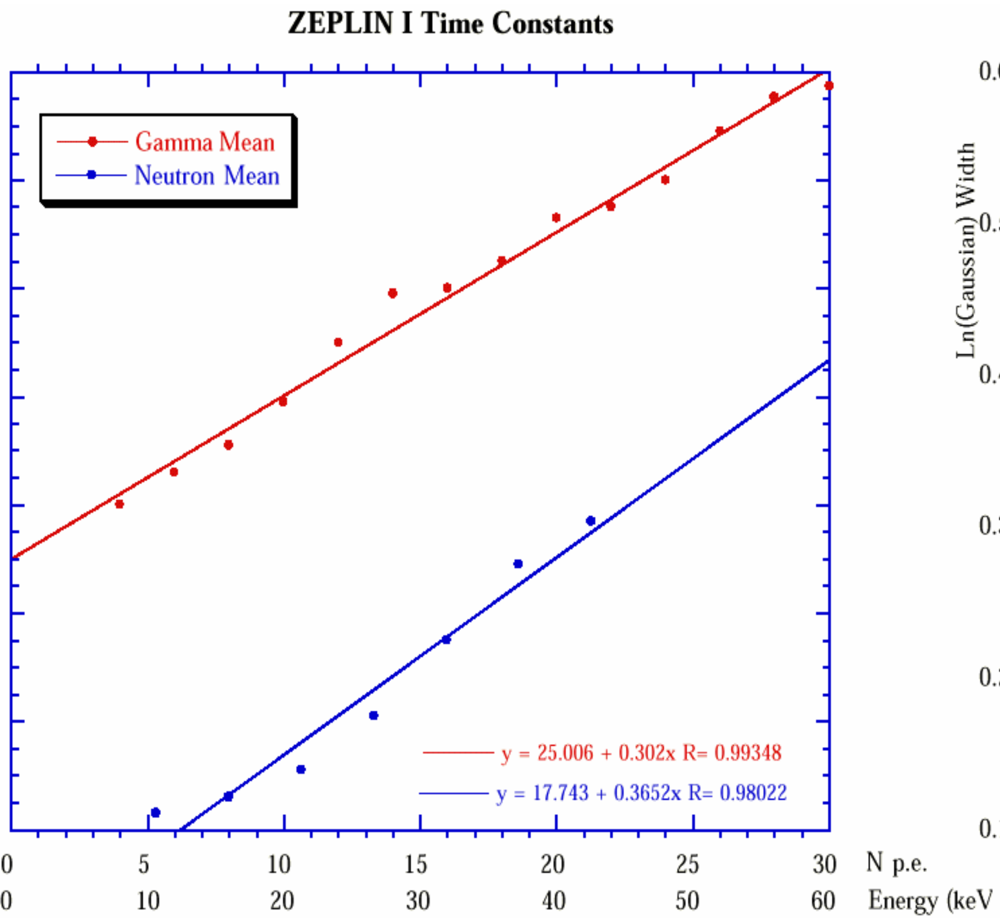
χ^2/dof=71/37

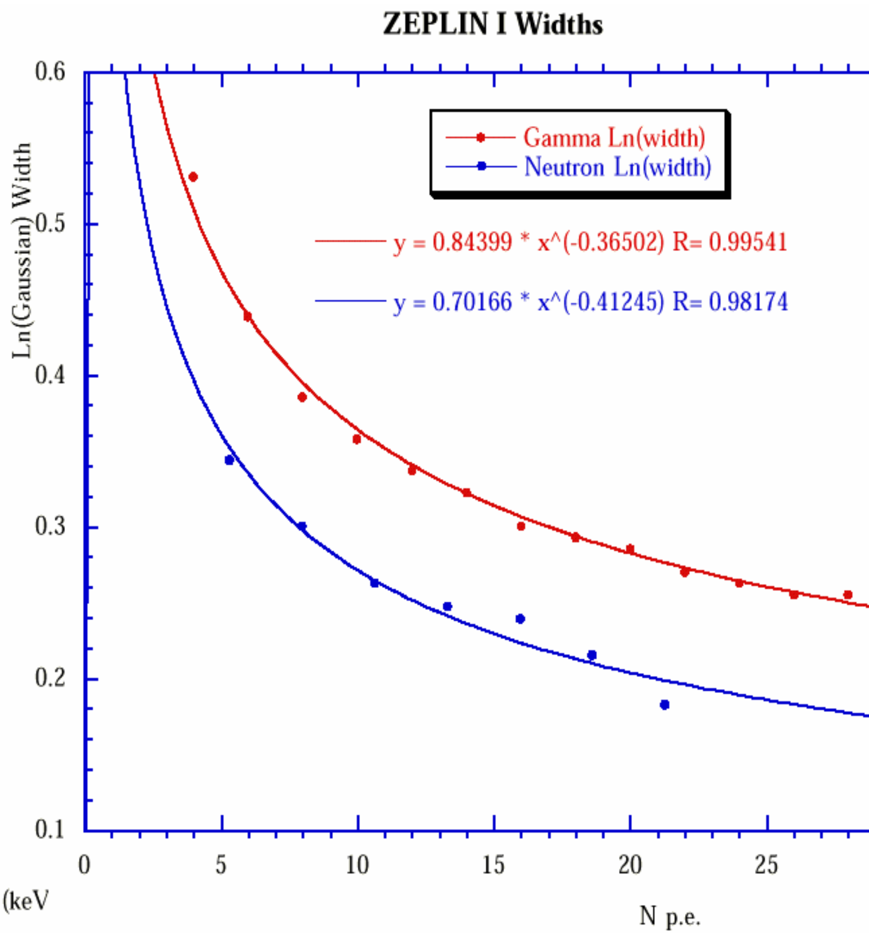
fitted: A = (0.0192 ± 0.0031) cpd/kg/keV

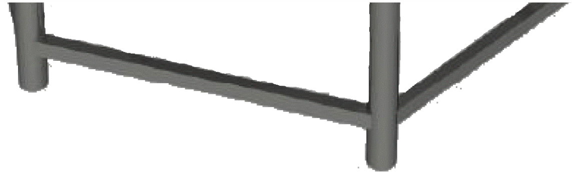
fitted (all parameters free):
A = (0.0200 ± 0.0032) cpd/kg/keV
t_0 = (140 ± 22) d ; T = (1.00 ± 0.01)

The data favor the presence of a modulated behavior with proper features at 6.3σ C.L.

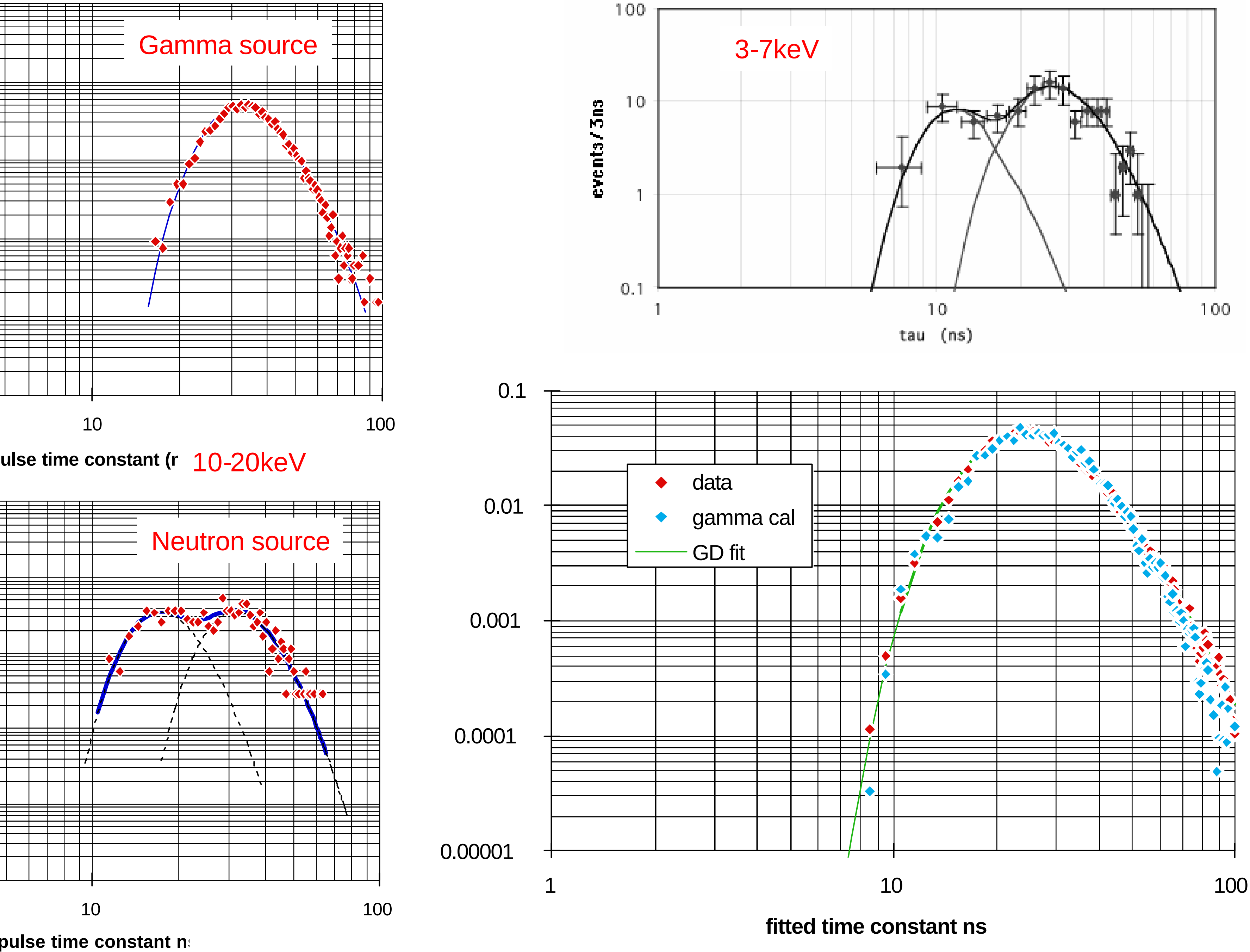
Time Constant Discrimination





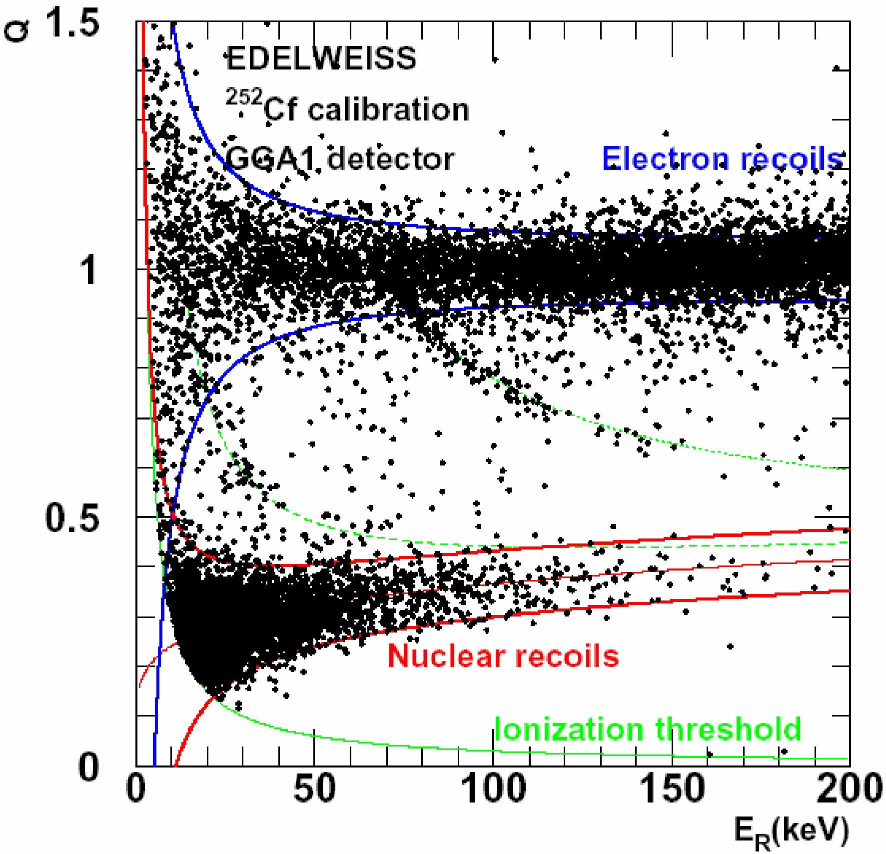


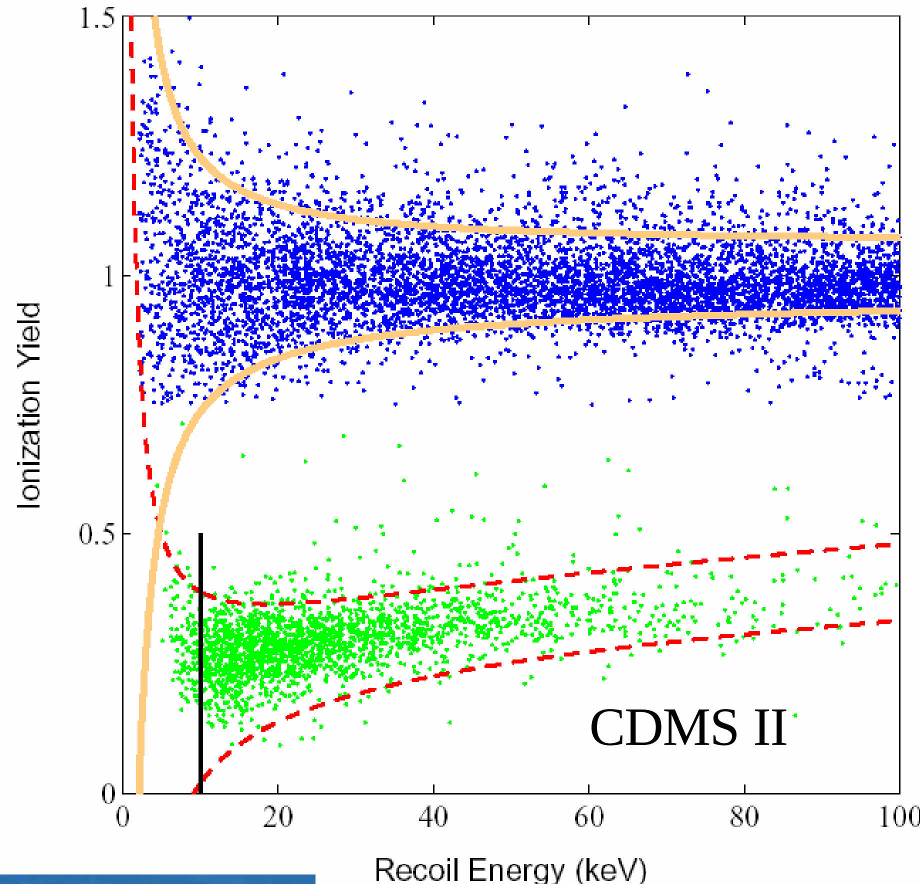
A 6kg detector - ZEPLIN I - has operated at Boulby



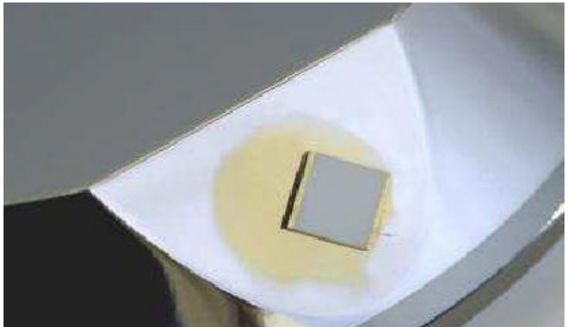
Gamma source
10
100
ulse time constant (r
10-20keV
3-7keV
100
10
1
0.1
events / 3ns
1
10
100
tau (ns)
Neutron source
10
100
pulse time constant n
0.1
0.01
0.001
0.0001
0.00001
data
gamma cal
GD fit
1
10
100
fitted time constant ns

CRYOGENIC DETECTORS

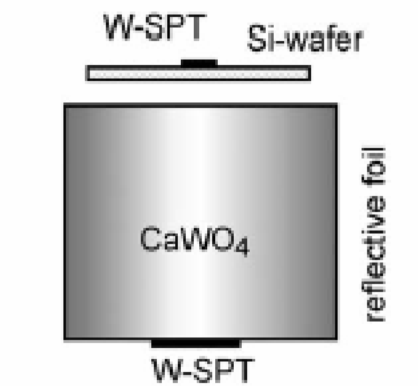




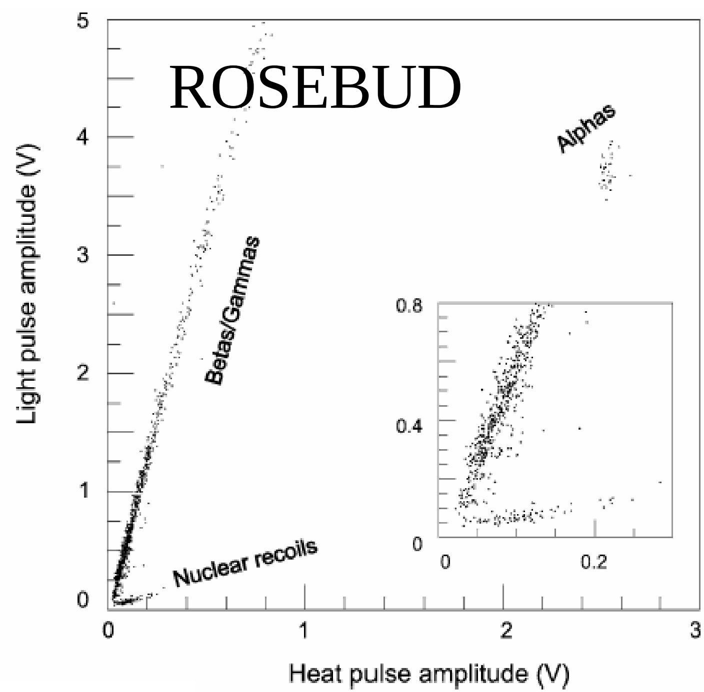
Ionisation + phonons

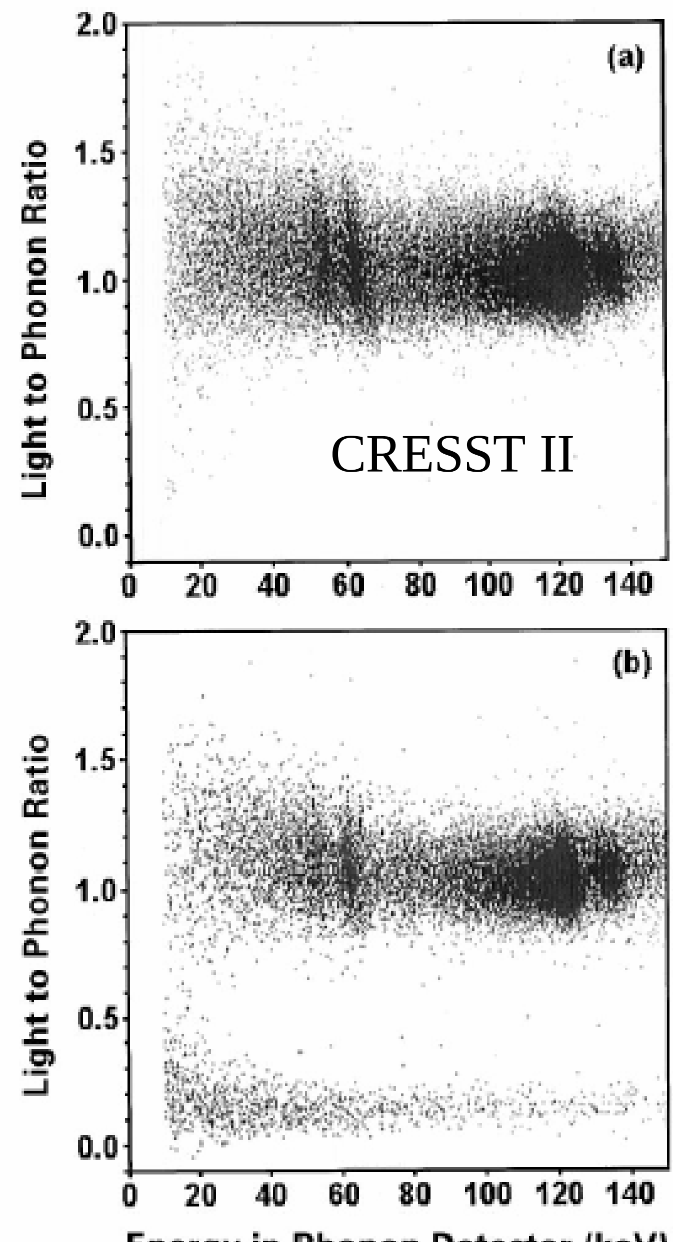


CRYOGENIC DETECTORS



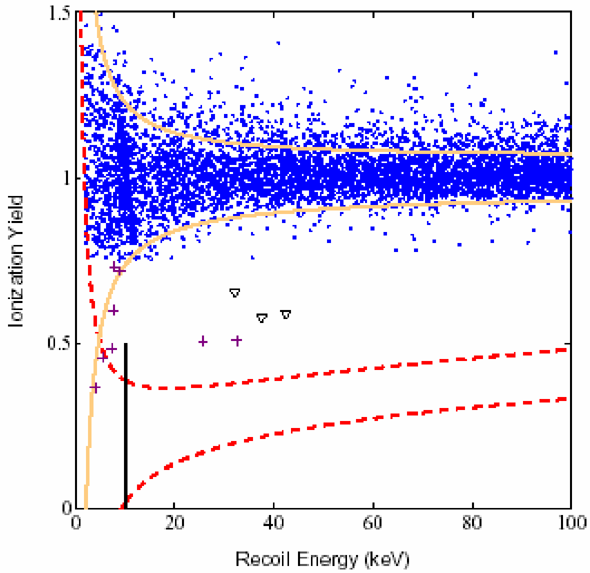
Ionisation + photons



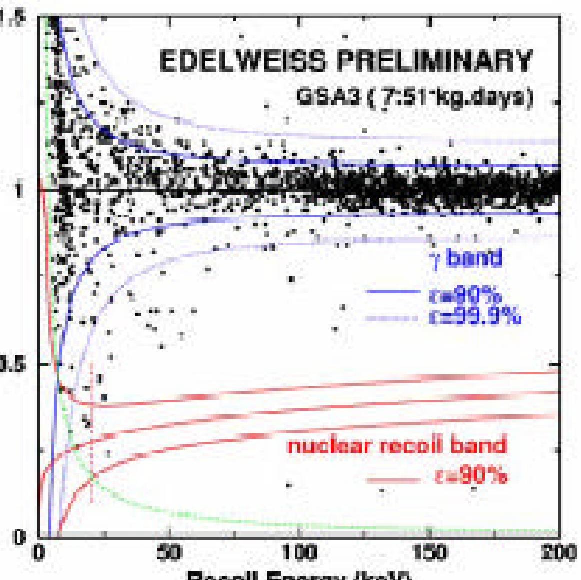


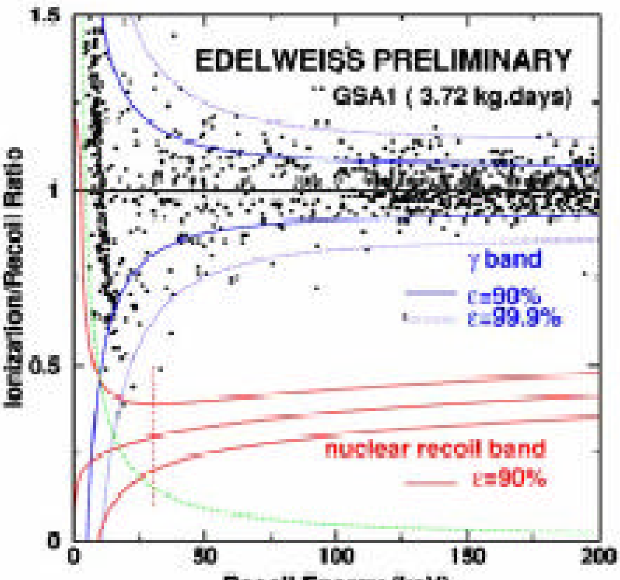
CRYOGENIC DETECTORS

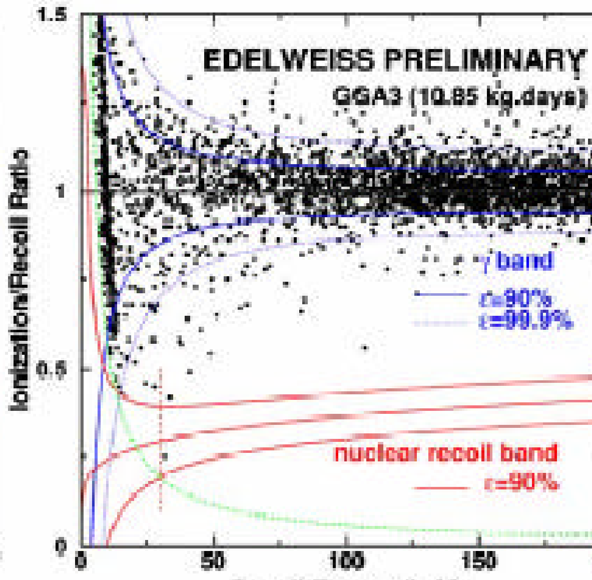
Neutron backgrounds are now, or soon will be, limiting most experiments



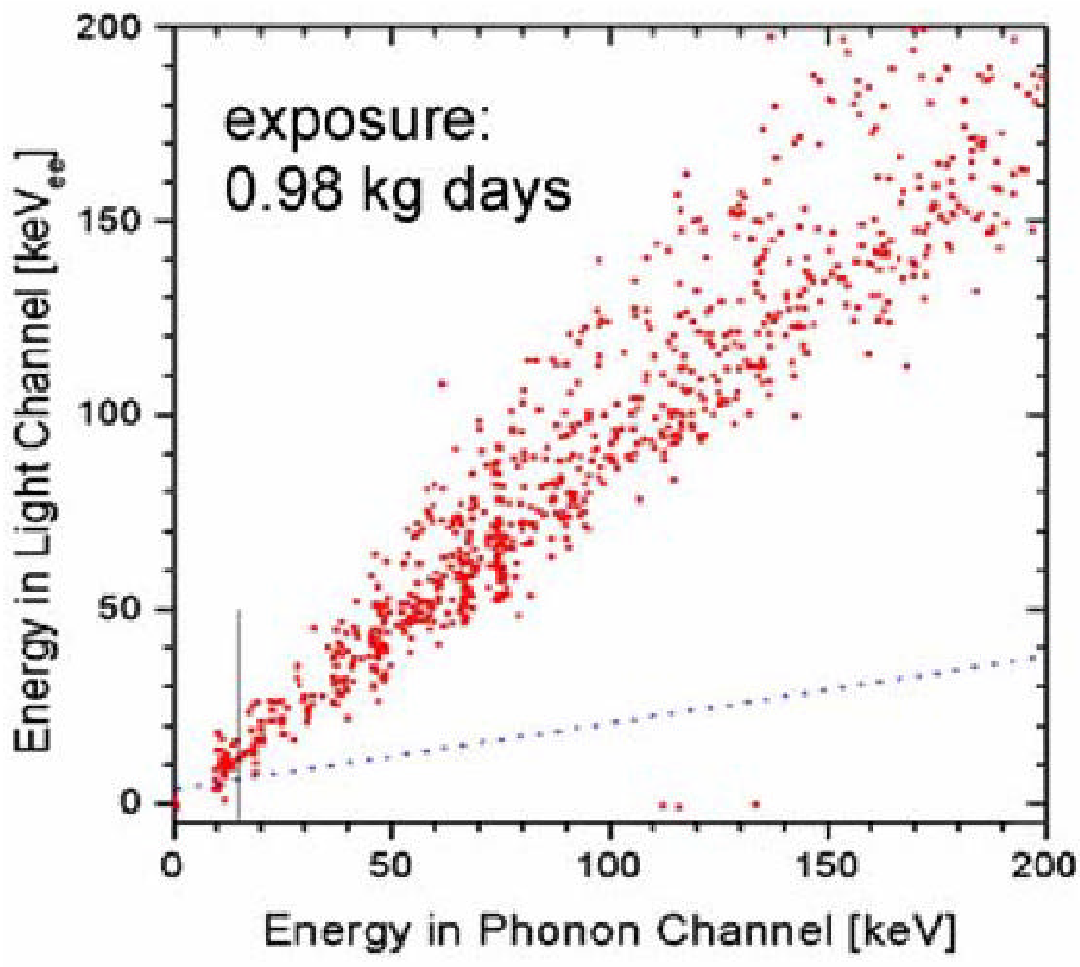
CDMS II - 19.4kg-d Ge







CRYOGENIC DETECTORS



World Status

Comparison between experiments made using a ‘standard’ Galaxy model

• Separated into spin-independent (scalar) cross-sections and spin-dependent (axial) cross-sections and ‘normalised’ to one nucleon

Spin independent

DAMA

IGEX

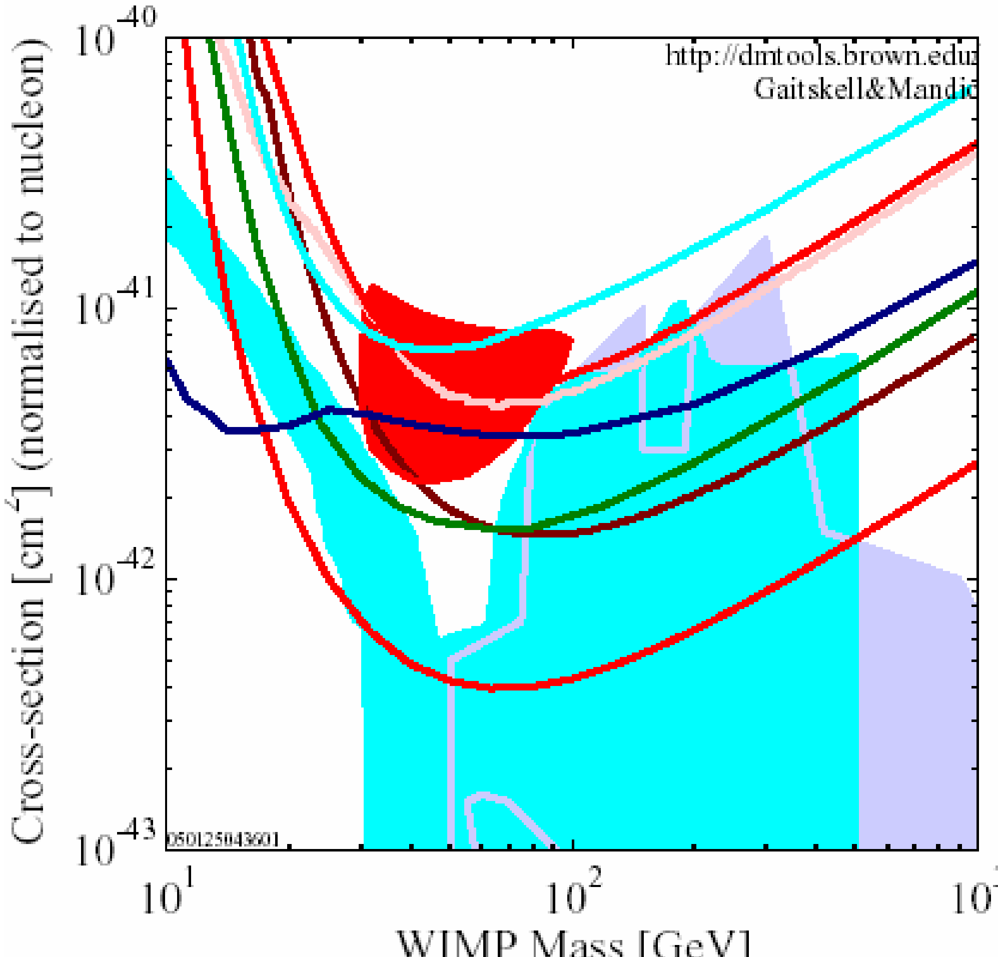
CRESST II

CDMS I

EDELWEISS

ZEPLIN I

CDMS II



Galaxy halo model

- local dark matter density ~ 0.3-0.4 GeV/cm^3
- ~spherical 1/r^2 density distribution
- Truncated Maxwellian velocity distribution
- neutralino mass?
- Earth's spin
- Earth's orbital motion
- Solar system orbital motion

Standard Model

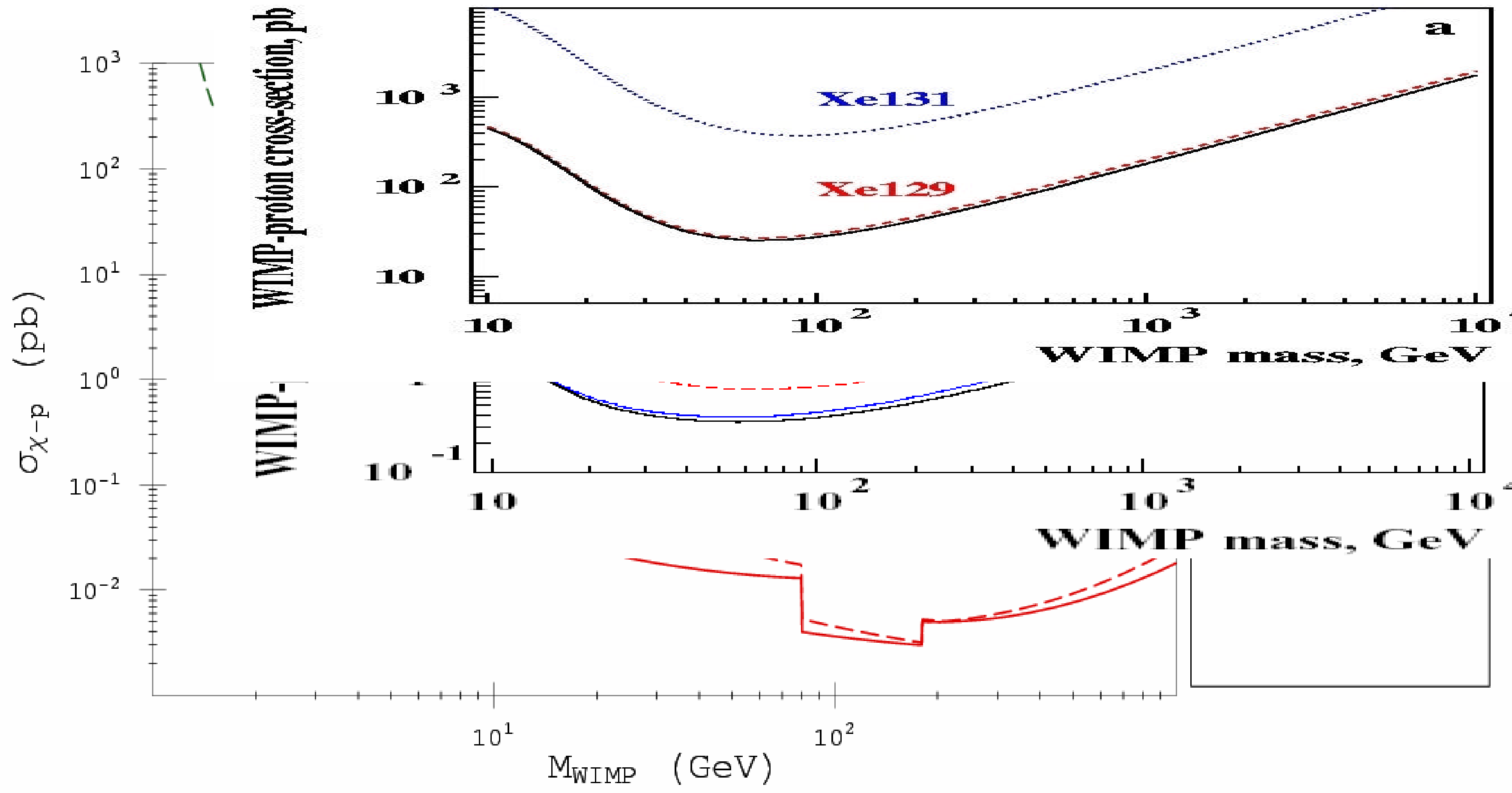
- Non-spherical halo
- Halo rotation
- Galactic in-fall - cusps?
- Bound solar system Earth-crossing component
- clumpy halo
- cluster in-fall
- sub-dominant density

Options

World Status

Spin dependent

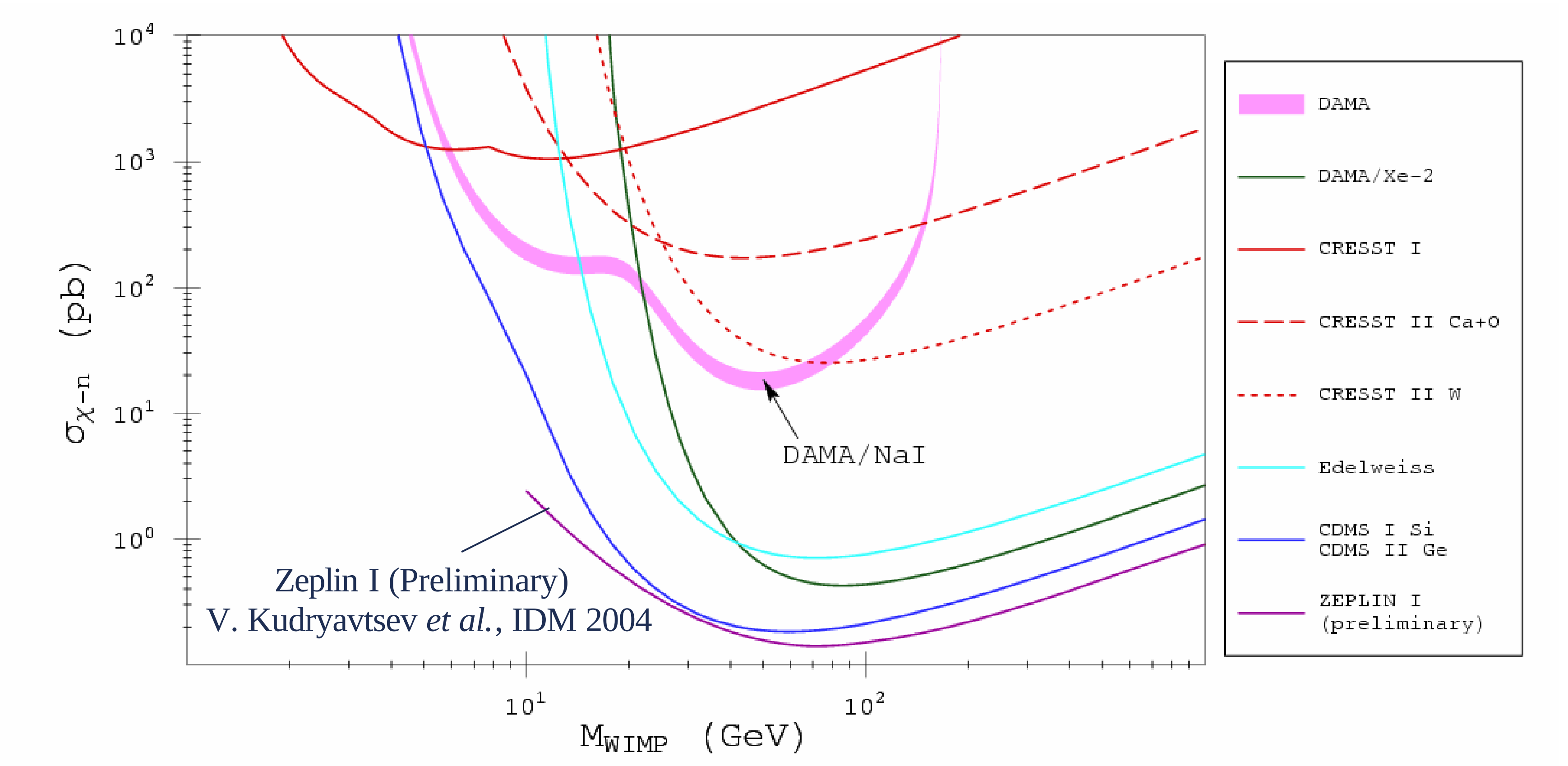
(a) Coupling to unpaired proton



World Status

Spin dependent

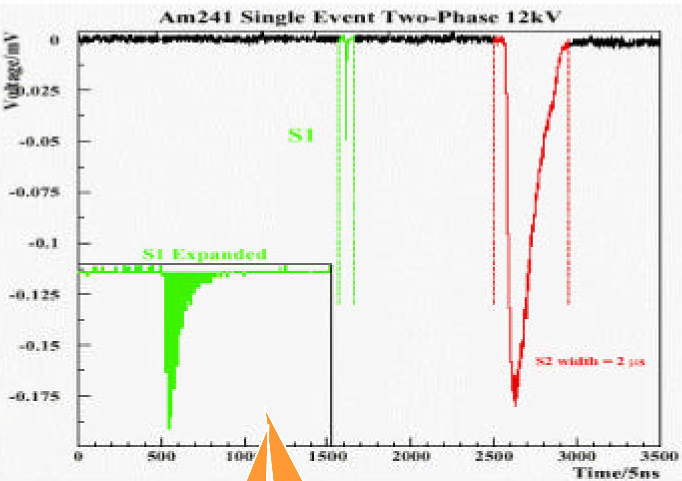
(a) Coupling to unpaired neutron

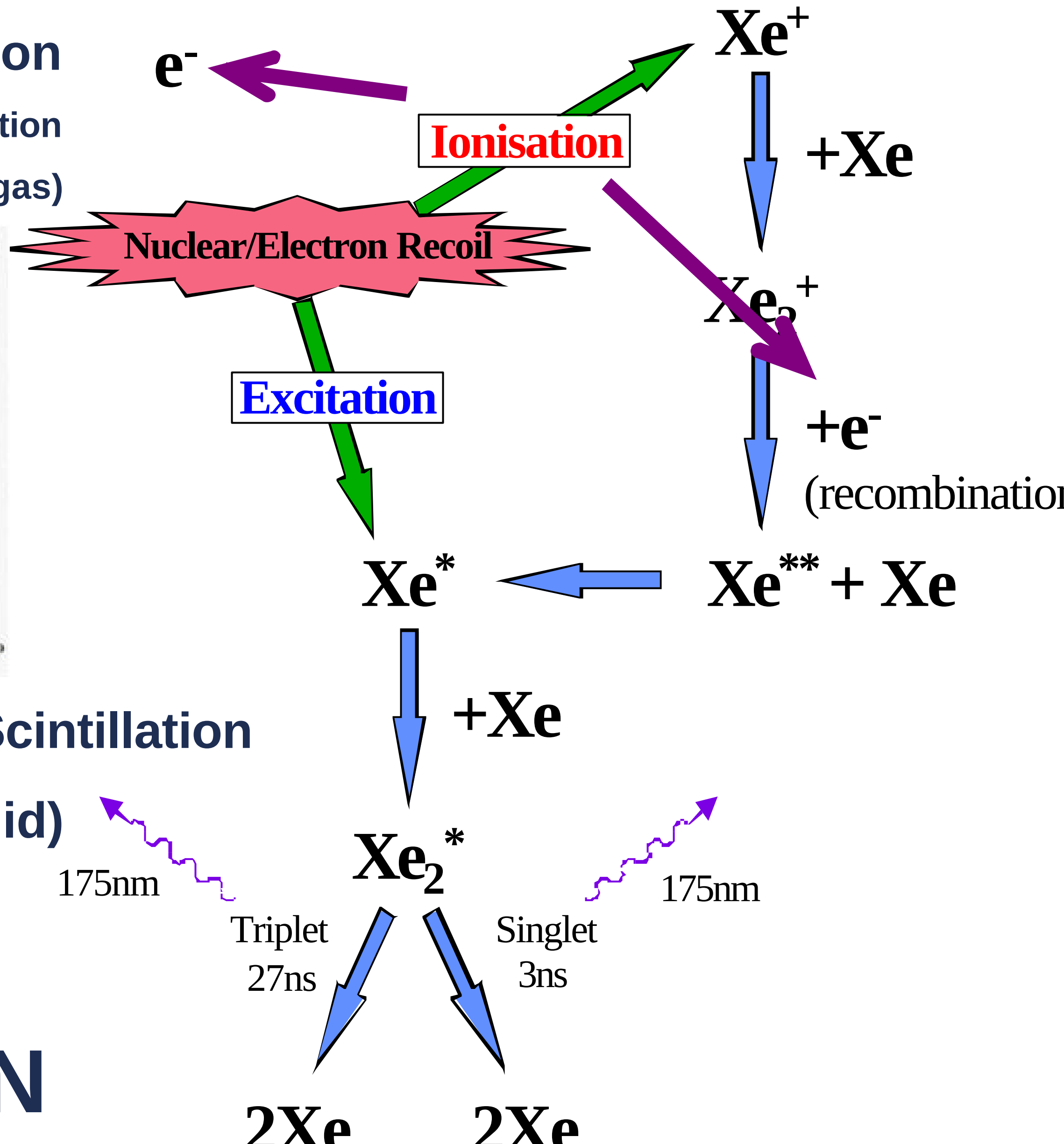


What Next?

Ionisation

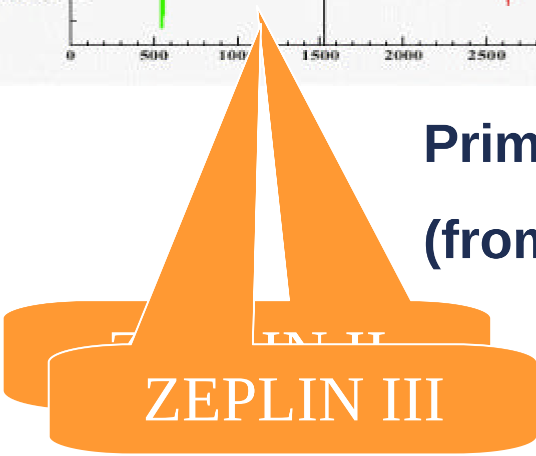
(Secondary scintillation in gas)



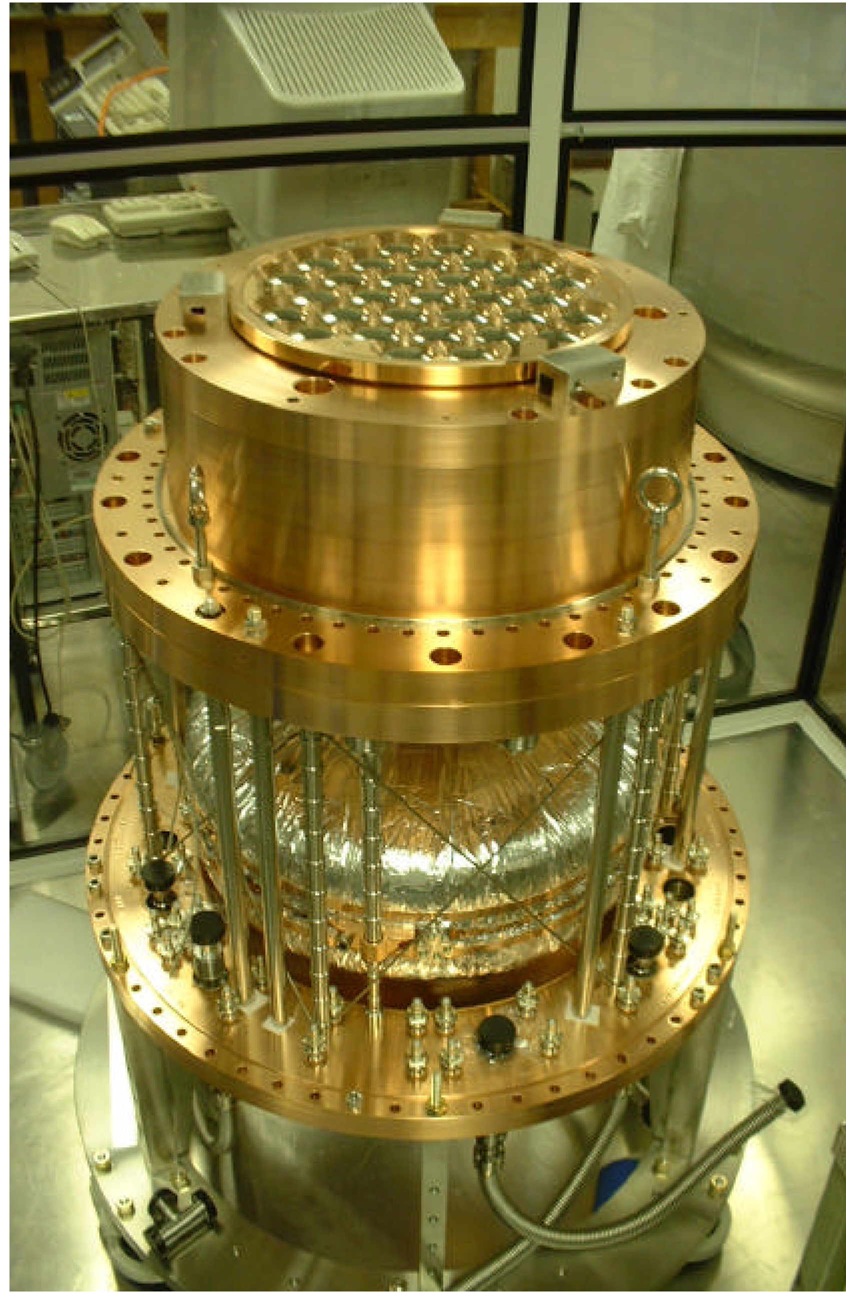


Primary Scintillation

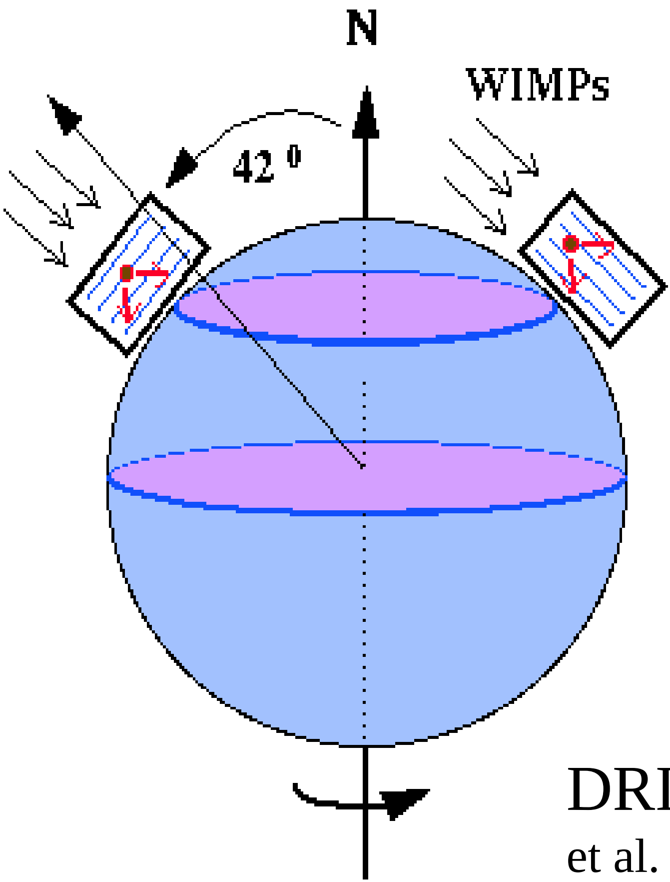
(from liquid)

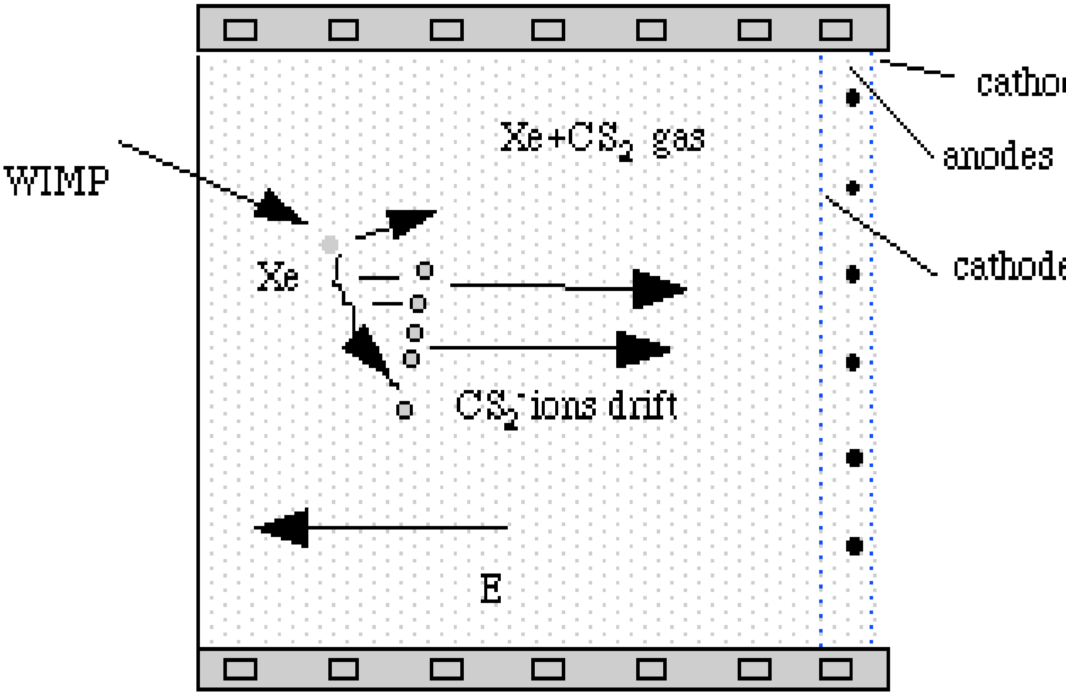


ZEPLIN



DIRECTIONAL DETECTORS





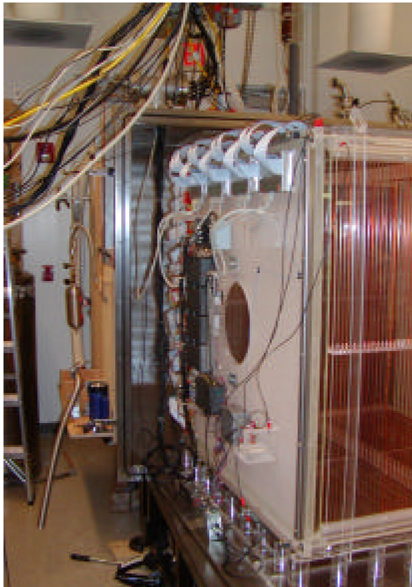
DRIFT I - Martoff et al. 96, Snowden-Ifft et al. 99, Lehner et al. 99

1m³ prototype DRIFT I has been running at Boulby

Current DRIFT Status

- DRIFT I
  - completed its role as a technology demonstrator
  - papers submitted on both the technological achievements and a first dark matter search result.
  - Discrimination against gamma and alpha backgrounds demonstrated.
  - Directionality capability confirmed (high energy).
  - Solutions have been found for all technical problems.
  - Achieved safe and stable operations underground.
  - Established ambient neutron background in Boulby

- DRIFT II
  - First module built, tested and ready to go.



The JIF area - Jan 2005

Now a class <2500 clean room

Stub A

Low Background Lab

Stub B

Store / DRIFT -II Phase B

Air shower

ZEPLIN - II

ZEPLIN - III

DRIFT -II

Materials clean-off

DRIFT-I Lab

Change area

Mess

Gas/fire sensor control

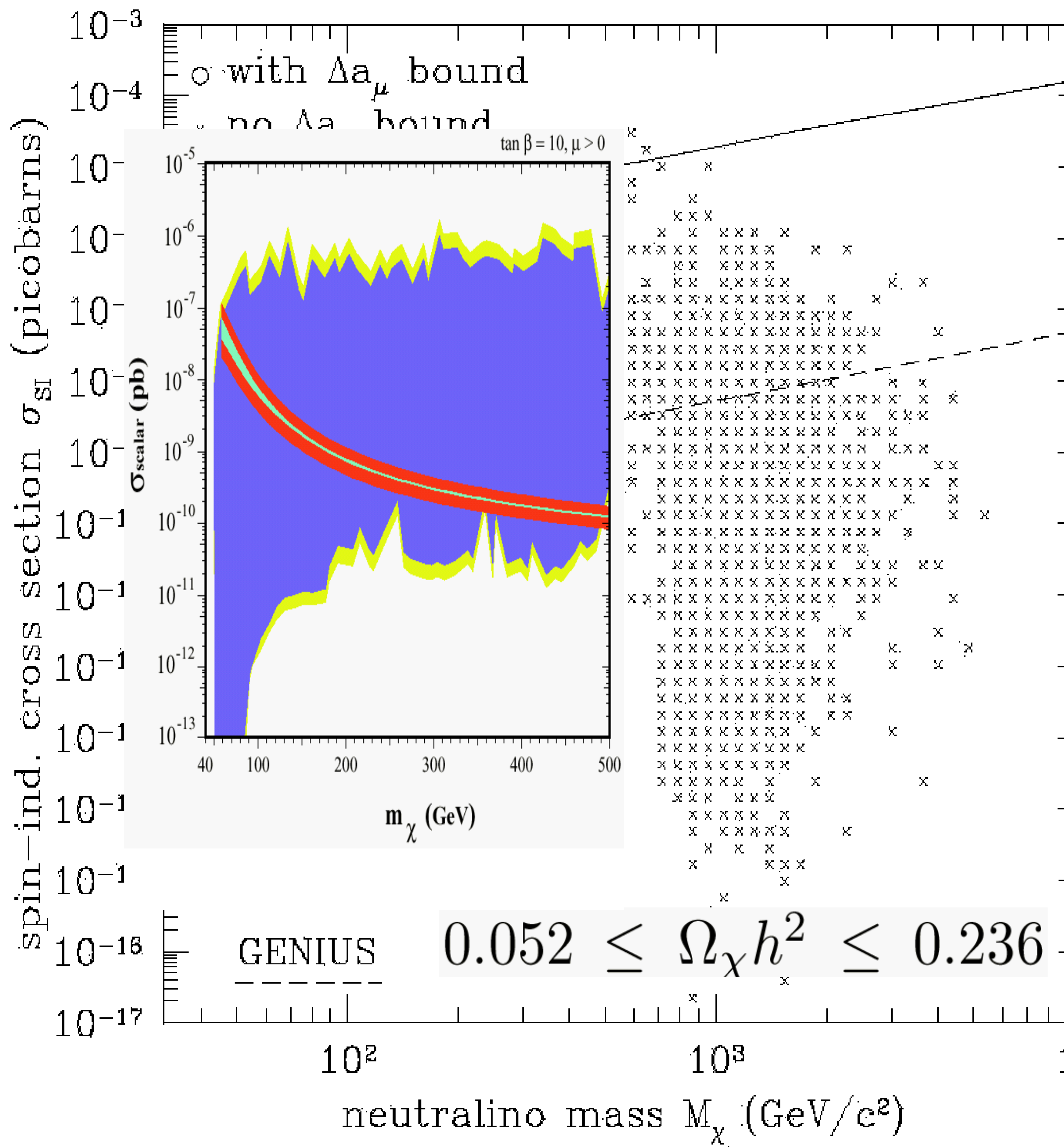
Workshop

Store

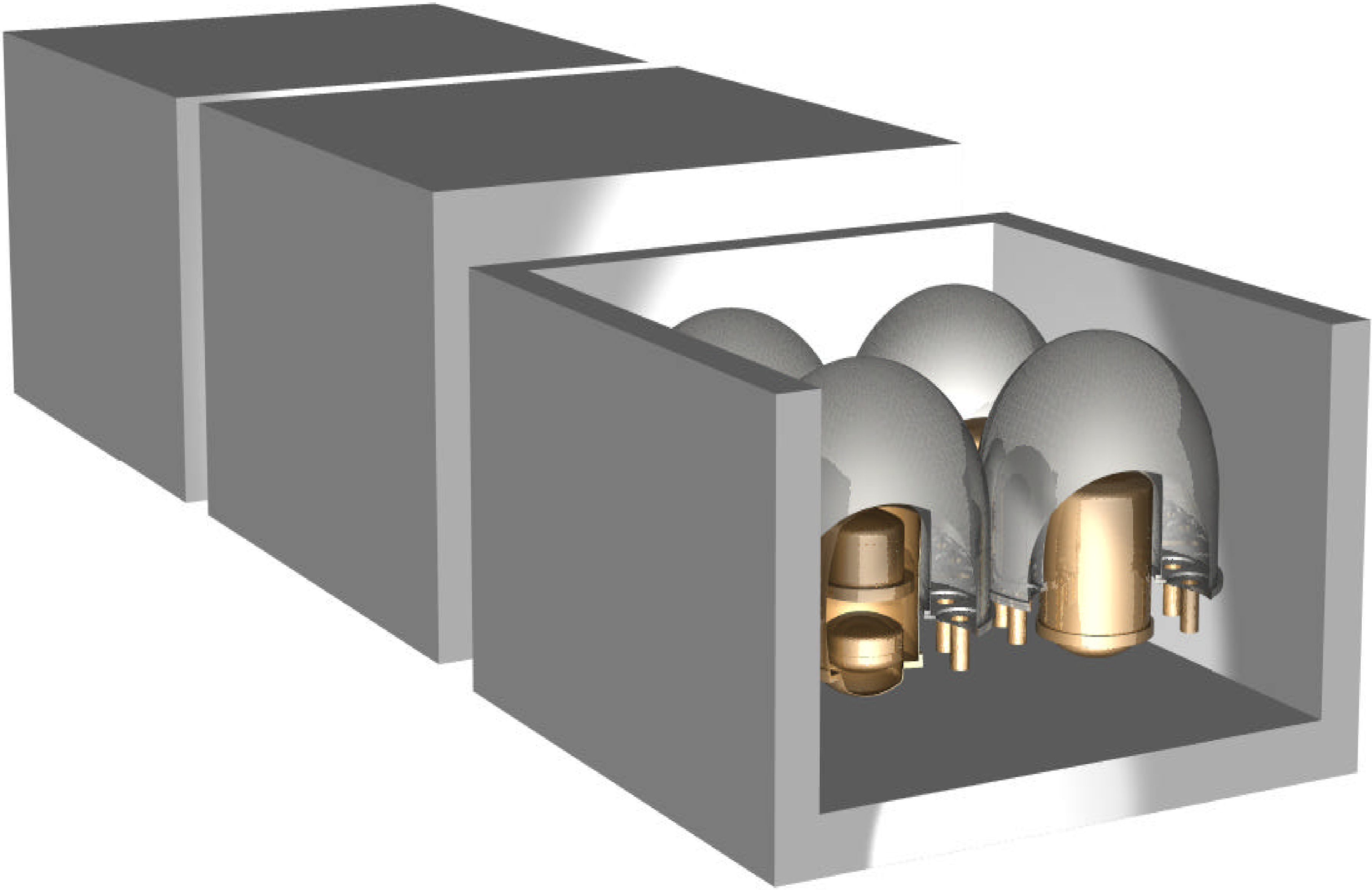
Neutralino cross-sections

- Neutralino model?
- Spin-independent
- Spin-dependent
- Form-factors?
- Spin factors?

10^{-9} pb gives ~1 event/day/ton



Ellis et al. 2001 - hep-ph/0106148



SUMMARY

Spin-independent wimp-nucleon sensitivities in pb

Done
Running
'Modifications/upgrade'
Building
Dreaming

1×10^{-3}	CRESST Sapphire
1×10^{-4}	DRIFT I CS_2
2×10^{-5}	HDMS Ge
2×10^{-5}	UKDMC NaI
2×10^{-5}	UKDMC NaIAD
7×10^{-6}	CANFRANC Ge
4×10^{-6}	CRESST II
3×10^{-6}	CANFRANC Ge
2.5×10^{-6}	CDMS Ge(+Si)
2.5×10^{-6}	DAMA NaI
2×10^{-6}	HDMS Ge
$\sim10^{-6}$	EDELWEISS Ge
10^{-6}	ZEPLIN I Xe
10^{-7}	GENIUS-TF Ge
4×10^{-7}	CDMS II Ge
$>2\times10^{-7}$	COURICINO TeO_2
4×10^{-8}	COURE TeO_2
3×10^{-8}	ZEPLIN II Xe
2.5×10^{-8}	CRESST II $CaWO_4$
1.5×10^{-8}	CDMS II Ge
10^{-8}	EDELWEISS II Ge
10^{-8}	ZEPLIN III Xe
2×10^{-9}	GENIUS Ge
10^{-10}	ZEPLIN MAX Xe

SUMMARY

Spin-dependent wimp-nucleon sensitivities in pb

15	Osaka CaF_2
15	Tokyo LiF
10	SIMPLE F
5	PICASSO
4	DAMA CaF_2
2	UKDMC NaI
1	DAMA NaI
0.4	UKDMC NAIAD
0.15	ZEPLIN I Xe
0.2	SIMPLE F
5×10^{-3}	ZEPLIN II Xe
?	CDMS II Ge
2×10^{-3}	ZEPLIN III Xe
?	GENIUS Ge
10^{-5}	ZEPLIN MAX Xe

Done
Running
'Modifications'
Building
Dreaming