Discussion of IOP PA group

PA community meeting

Prep for FP7?
relation to ILIAS FP6

FP6 - ParticleAstro - ILIAS

4th November 2002

1. Research on Primary Cosmic Rays (NW)
2. Gravitational Wave Research (NW)
3. Direct Dark Matter Detection (NW)
4. Search for Axions (NW)
5. Low-energy neutrinos (NW)
6. Search for double beta decay (NW)
7. Deep underground laboratories (NW)
8. High energy probes of the cosmos (NW)
9. Astroparticle Physics theory (NW)
10. Advanved photon detectors (JRA)
11. Radio & acoustic particle detectors (JRA)
12. Thermal noise in GW detectors (JRA)
13. Double beta European observatory (JRA)
14. Charge readout devices (JRA)
15. Low background techniques (JRA)
16. Transnational access to deep labs (TA)
17. Cubic Kilometer neutrino telescope (DS)
18. High altitude Cerenkov telescope (DS)
19. Dark matter detector large array (DS)
20. Upgrade to Canfranc (CNI)
21. Upgrade to Boulby (CNI)

14th April 2003

1. Deep underground laboratories (NW)
2. Direct Dark Matter Detection (NW)
3. Low-energy neutrinos (NW)
4. Search for double beta decay (NW)
5. High energy probes of the cosmos (NW)
6. Primary particles in space (NW)
7. Gravitational Wave antennas (NW)
8. Astroparticle Physics theory (NW)
9. Transnational access to deep labs (TA)
10. Low background techniques (JRA)
11. Advanced TPC tracking (JRA)
12. Double beta European observatory (JRA)
13. Advanved photon detectors (JRA)
14. Radio and acoustic particle detectors (JRA)
15. Thermal noise in GW detectors (JRA)

1st April 2004

1. Deep underground laboratories (NW)
2. Direct Dark Matter Detection (NW)
3. Search for double beta decay (NW)
4. Gravitational Wave antennas (NW)
5. Astroparticle Physics theory (NW)
6. Transnational access to deep labs (TA)
7. Low background techniques (JRA)
8. Double beta European observatory (JRA)
9. Thermal noise in GW detectors (JRA)

funded at ~€10M

The ILIAS Project

- **Three key science areas**
- **One key infrastructre**

GRAVITATIONAL WAVES
Gravitational Wave antennas (N5)
Thermal noise in GW detectors (JRA3)

NEUTRINOS - ββ DECAY
Search for double beta decay (N4)
Double beta European observatory (JRA2)

DARK MATTER
Direct dark matter detection (N3)

THEORY
Astroparticle Physics theory (N6)

Gran Sasso - Canfranc - Frejus - Boulby
Transnational access to deep labs (TA1)
Deep underground laboratories (N2)
Low background techniques (JRA1)

The Future of WIMP Dark Matter Detection

The Sun - Wed 30th April 2003

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

By CHRIS RICHES

SCIENTISTS are spending £3.1million 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 make up 95 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 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 Professor Neil 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."

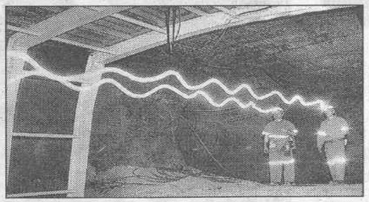
But he added: "It is still possible though we could be completely wrong."

Prof Spooner's latest search is at the bottom of a salt mine in Boulby, 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.



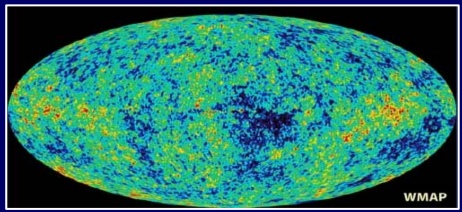
Bright sparks . . . experts go to lab

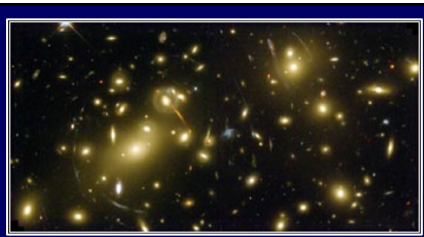
Mysterious . . how WIMP may look

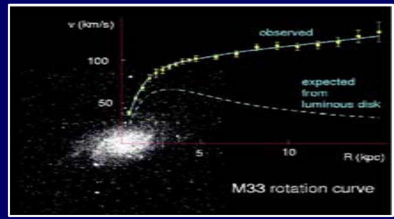
Neil Spooner (Sheffield)

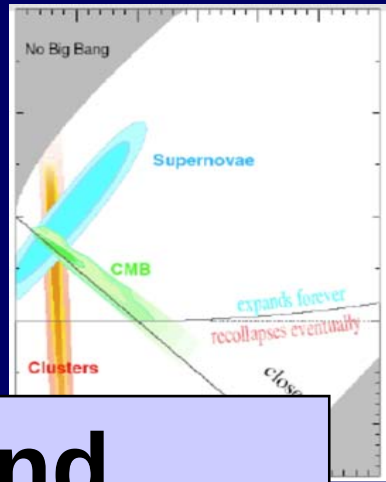
How to pay more and what you might get!

MOTIVATION!









Contributions to Ω

Total (100%) $\Omega_0 = 1$

Three “dark” problems and >95% of the Universe is still unidentified

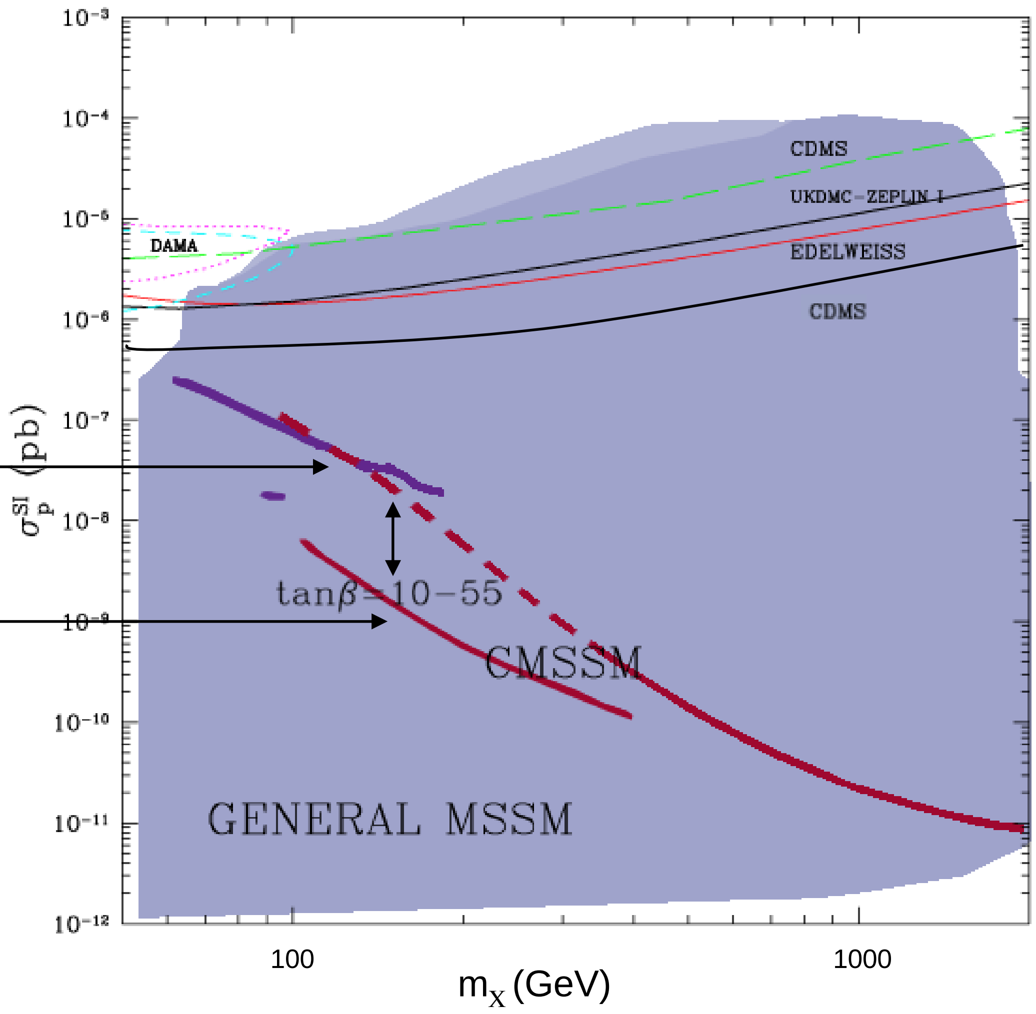
73% still missing

Neutralino - MSSM

Broad region if GUT constraints lifted

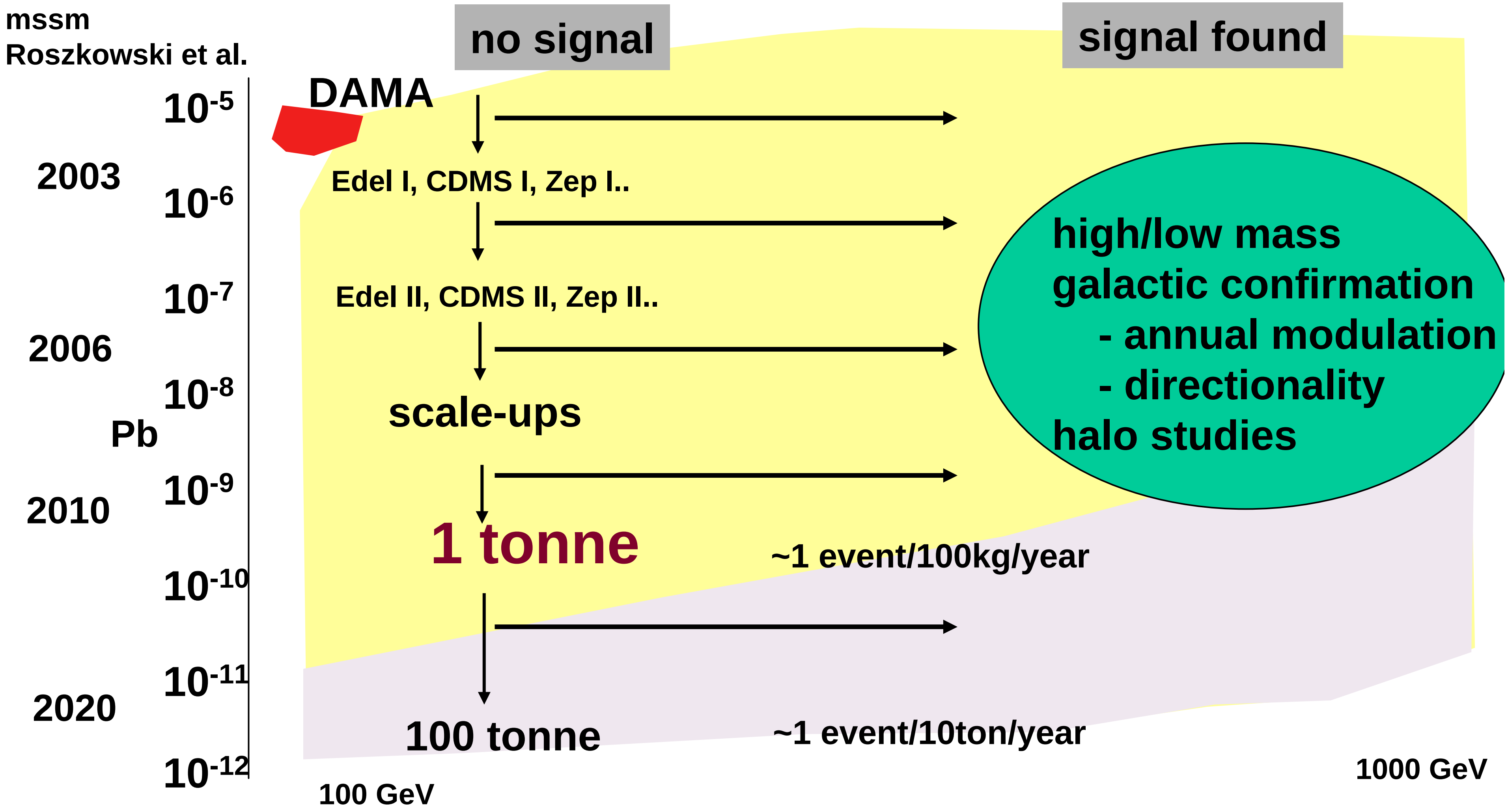
With grand unified theories allowed region collapses

Narrow allowed bands from WMAP (Ωh^2) + collider + GUT



L. Roszkowski et al.

Strategy flow chart/matrix



barriers? • technology barriers (manufacturability/reliability)
• background barrier • site barriers (depth & volume) • cost

Signal, what signal?

- technology

scintillators
semiconductors
s/c grains

ion-thermal
xenon
directional/gas

point 1

must have gamma rejection solved (>10^5), because neutrons will become main problem

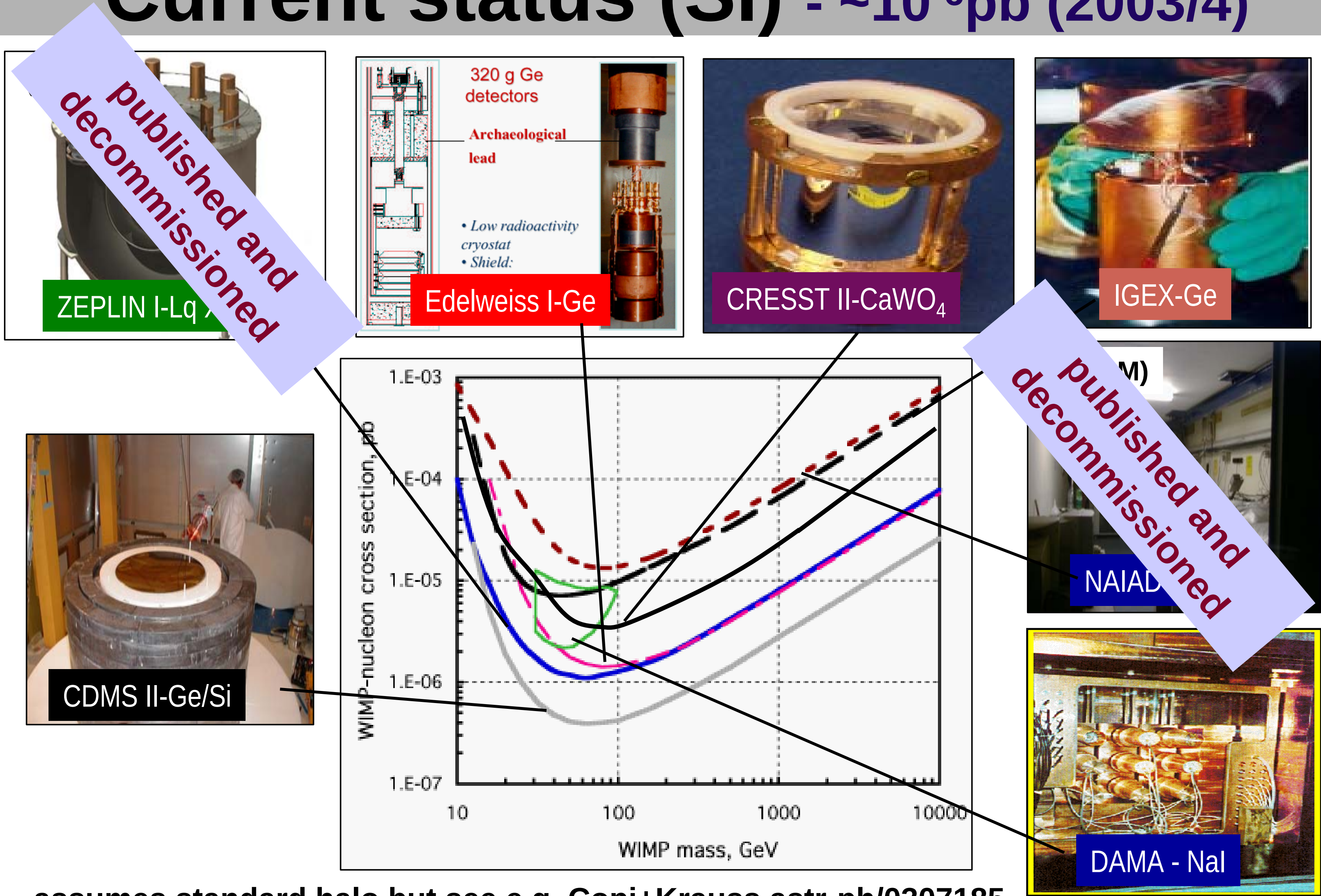
point 2

two targets/detectors is good

point 3

a directional signal is good show that events are galactic

Current status (SI) - ~10^{-6}pb (2003/4)



assumes standard halo but see e.g. Copi+Krauss astr-ph/0307185

WHAT'S NEXT
(path of no detection)

10^{-7}-10^{-8}pb (2005/6)	in construction
10^{-8}-10^{-10}pb (2008/11)	needs 1 tonne (~zero background)

How?

event rates

100 events in 1 tonne, 90% cl --> ~ 10^{-9} pb
need to achieve backgrounds <10-100 ev/yr

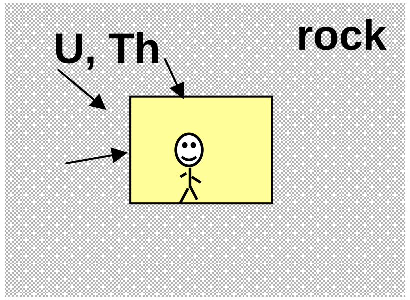
10^{-12}pb (2015)	needs 100 tonnes (~zero background)

WIMP physics at lowest cross sections

can it be done?

neutrons are critical

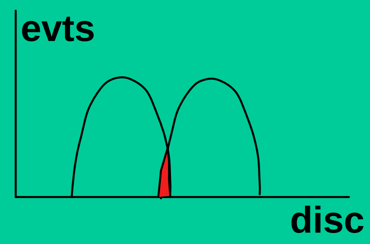
Rock neutrons



rule of thumb: rock gamma rate = 10^6 x neutron rate

once γ discrimination ~x10^{5-6} then neutrons are the main concern

detectors are already close to this



Muon neutrons

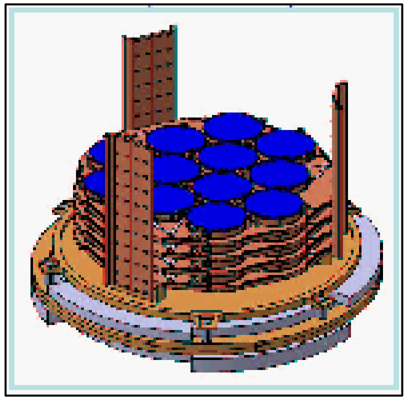
Detector neutrons

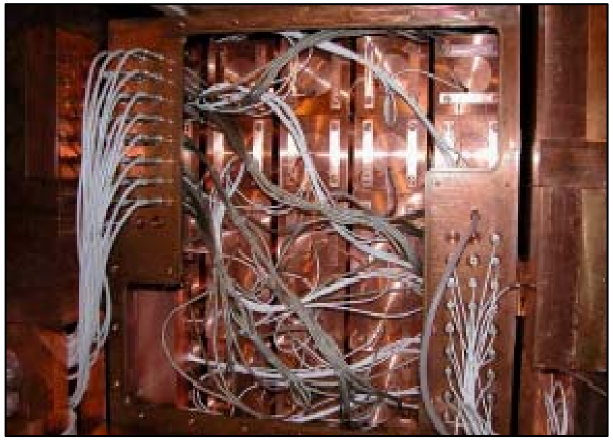
In construction - 10^{-7}-10^{-8}pb (2005/6)

Edelweiss II

100 lt cryostat for up to 120 detectors (36 kg Ge)

(21 x 320 g) 2004





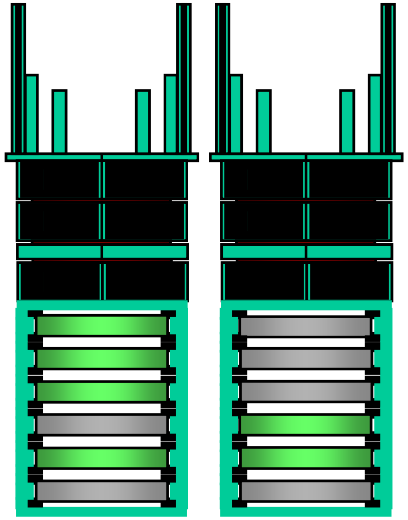
LIBRA - NaI (DAMA)

(250 kg-annual modulation)

CDMS II

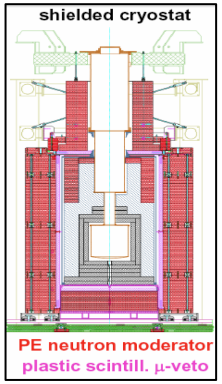
more towers

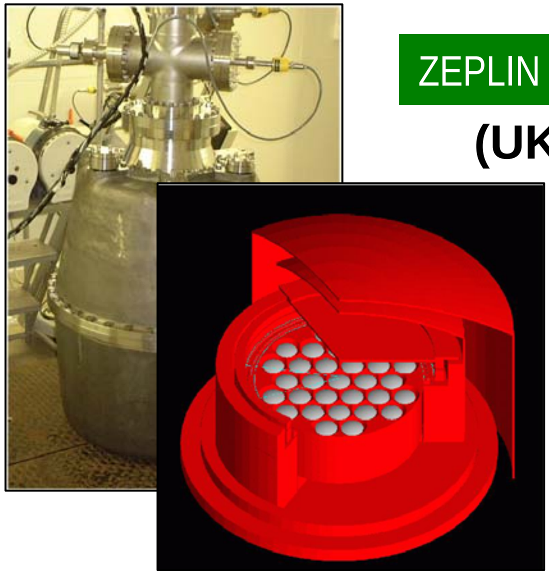
(4.5 kg Ge, 1.2 kg Si)



CRESST

Scale-up to 10 kg planned





ZEPLIN II and III

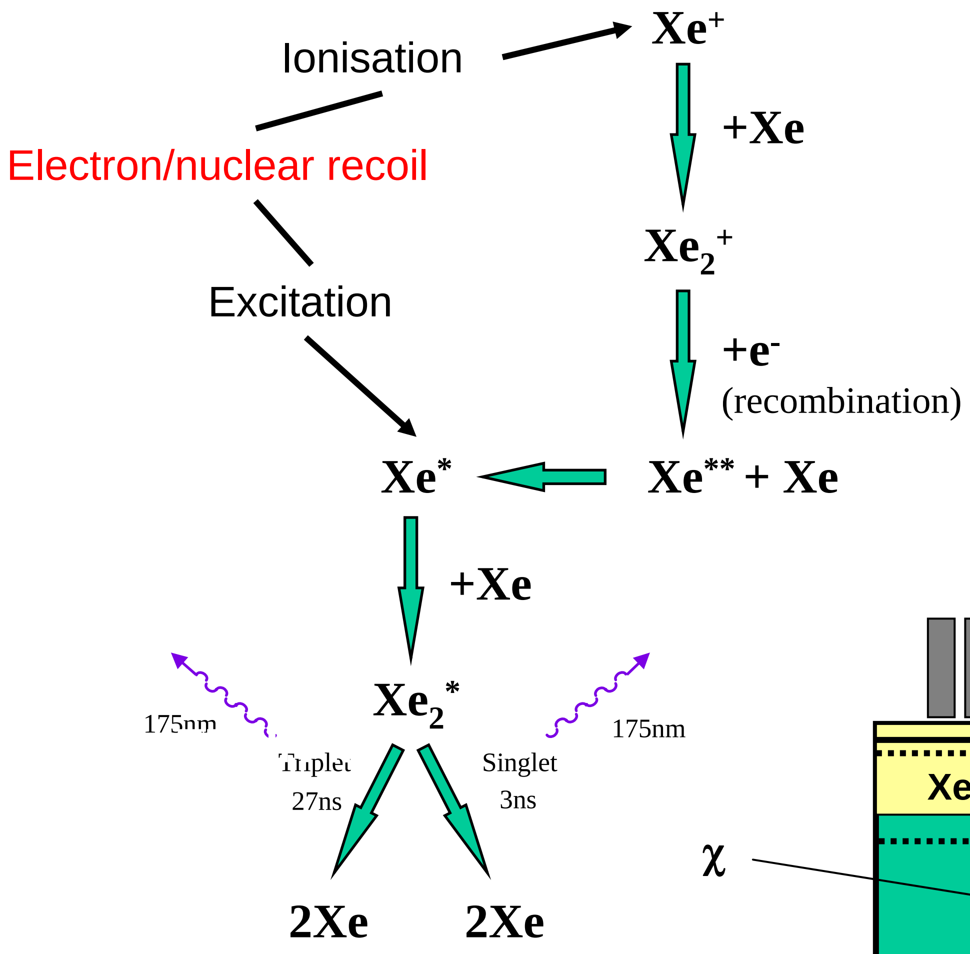
(UKDM)

two-phase xenon

(6-30 kg)

Apologies for those techniques and groups left out...

Xenon Basics

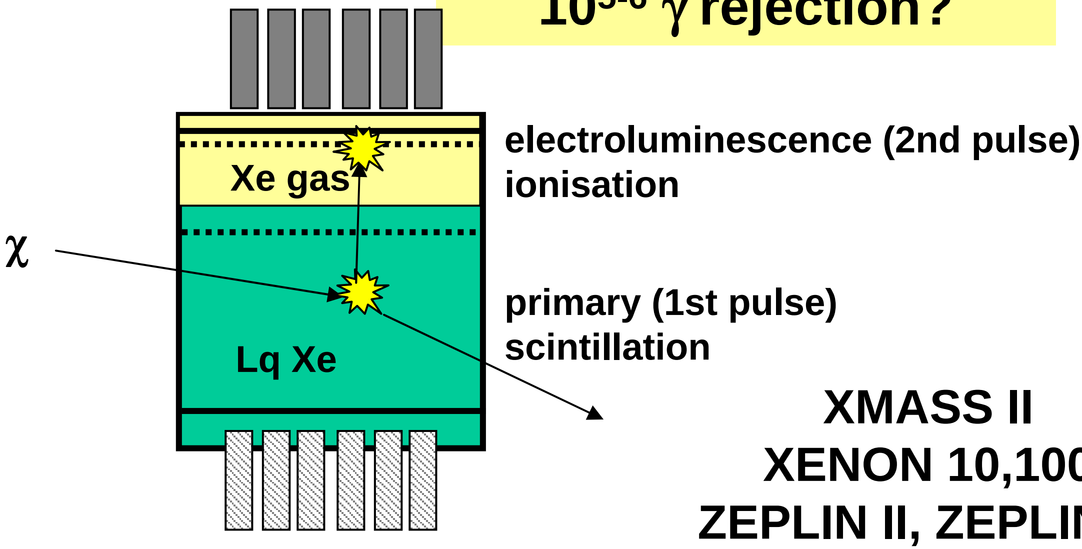


(1) Single Phase Experiments

DAMA Xe
ZEPLIN I (PSD)
XMASS I (no PSD)

(2) Double Phase

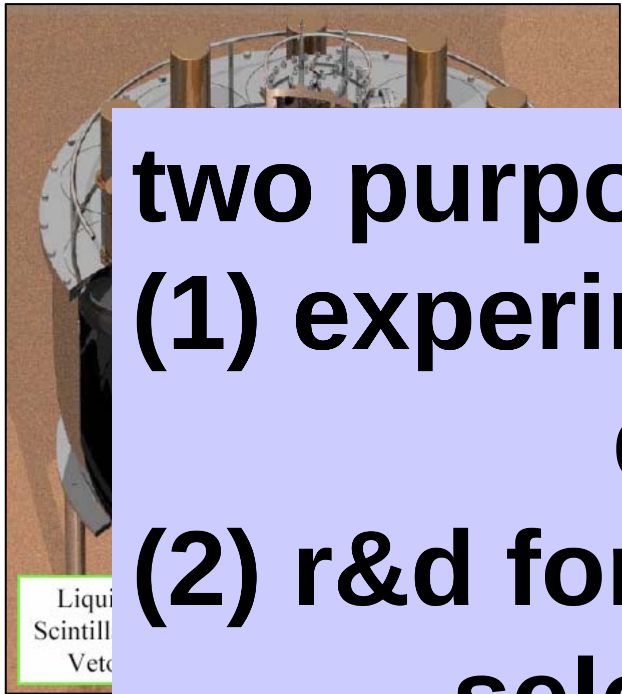
should give necessary $10^{5\text{-}6}$ γ rejection?

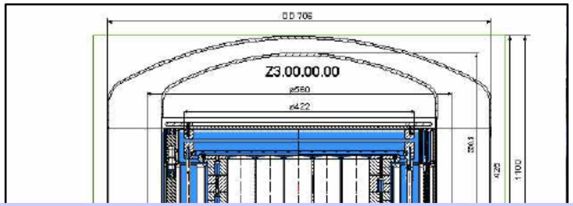


XMASS II
XENON 10,100
ZEPLIN II, ZEPLIN III

Xe - two phase for Boulby

ZEPLIN-II **30 kg design based on scale-up of UCLA 1 kg test chamber**





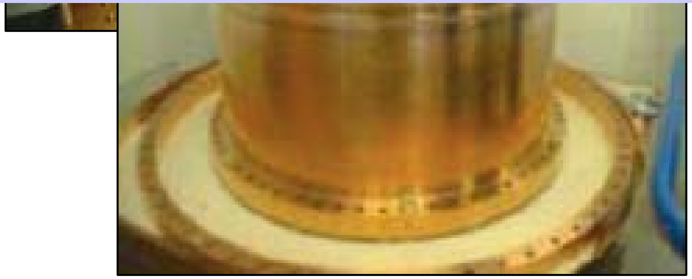
ZEPLIN-III

6 kg high field

two purposes:

(1) experiments to reach ~10^{-8}pb discovery?

(2) r&d for 1 tonne design select optimum technology



UKDMC + UCLA, Texas A&M, ITEP

Towards 1 Tonne Detectors

Main Issues

- **gamma rejection solved?, neutron reduction?, scaleable?, reasonable cost?**

Possibilities

- **GENIUS (HDMS) proposal for 100kg --> 1 tonne ?**

Intrinsic low background but NO discrimination and expensive (mainly bb)

- **LIBRA (DAMA) 250 kg now running**

Annual modulation (what if DAMA region ruled out), PSD not sensitive enough

- **Cryo-array ("SDMS", Edelweiss) ideas for 1 tonne**

Good discrimination but difficult technology and expensive

- **ZEPLIN-MAX/IV proposal for 1 tonne**

Good discrimination, simpler but less proven technology?, less expensive?

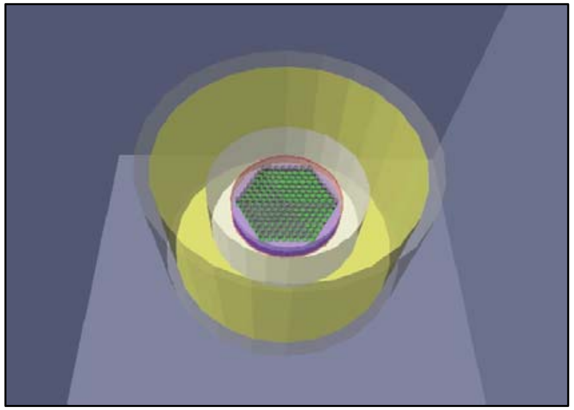
- **XMASS 1 tonne (needs 10 tonnes) ?**

Intrinsic low background but NO discrimination and expensive (mainly bb)

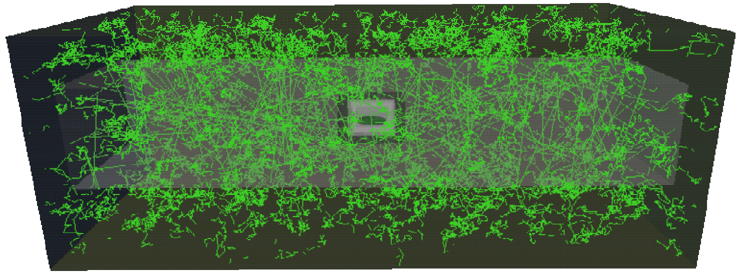
Are neutrons ok at 1 tonne?

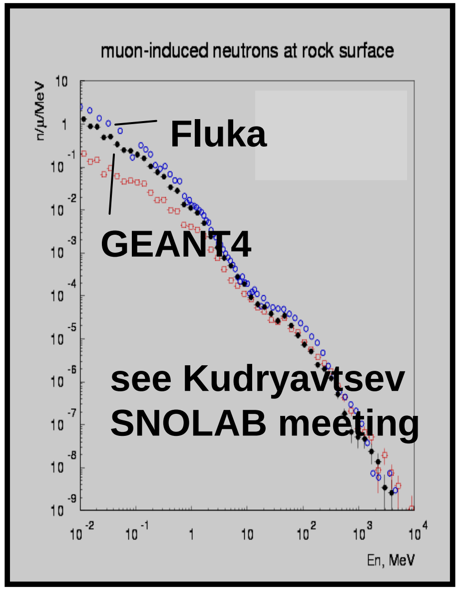
neutron simulations for Large Scale Xenon

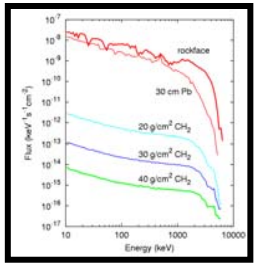
M. J. Carson *et al.* Astrop. Phys. 21 (2004) 667

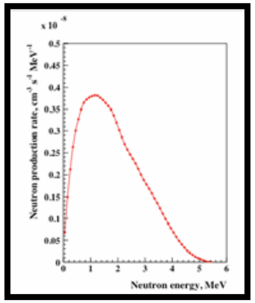


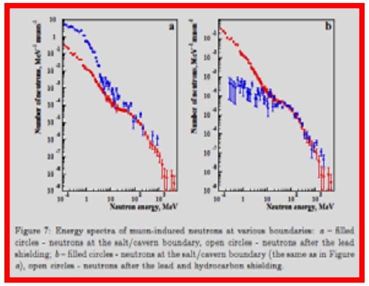
GEANT4
SOURCES
FLUKA











Rock neutrons

Muon neutrons

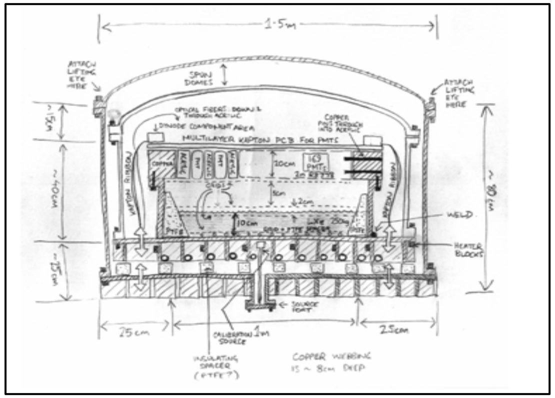
Detector neutrons

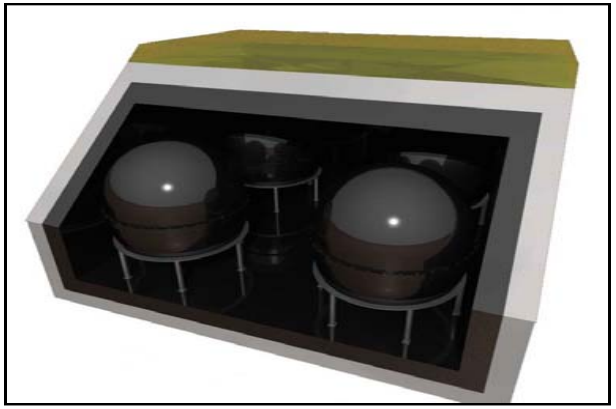
YES

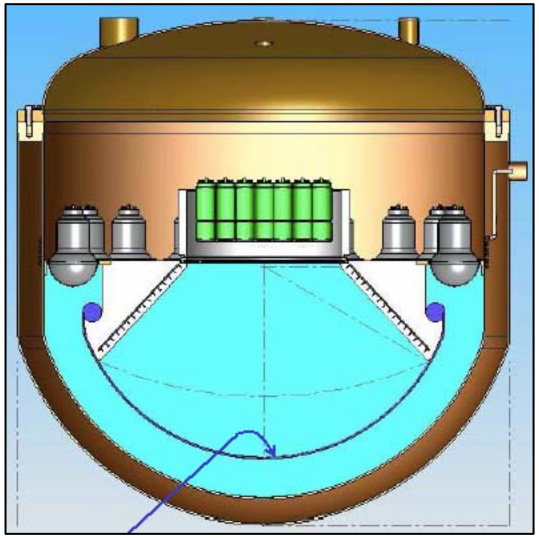
$10^{-9/10}$ pb is possible with xenon with current technology

1 tonne xenon design

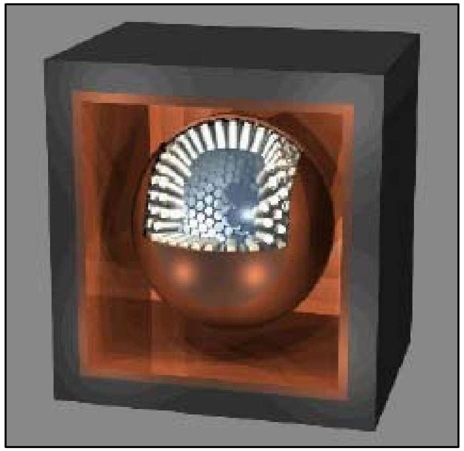
ZEPLIN-MAX/IV | UKDM, UCLA et al | **Two-phase modular**



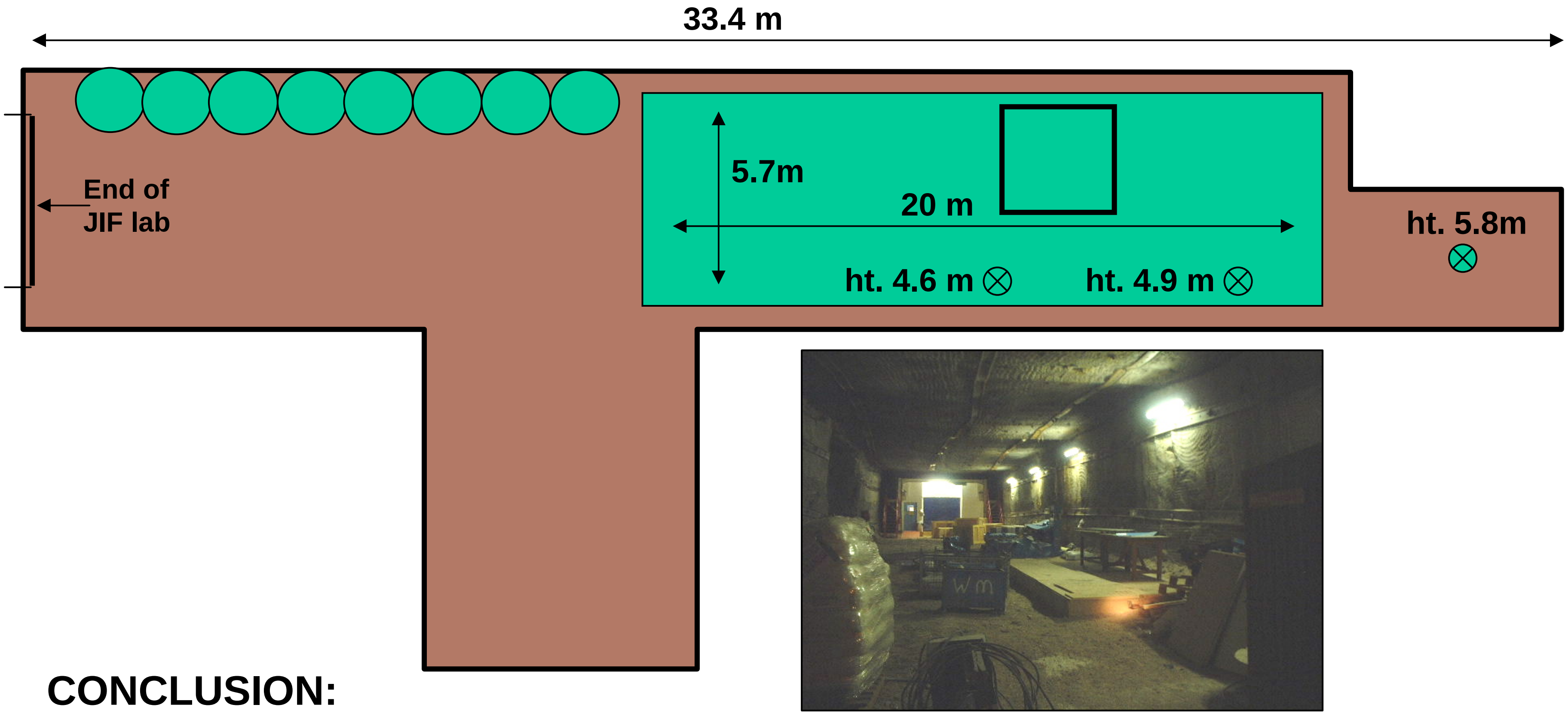




XMASS | Japan | **1-10 ton single phase xenon**

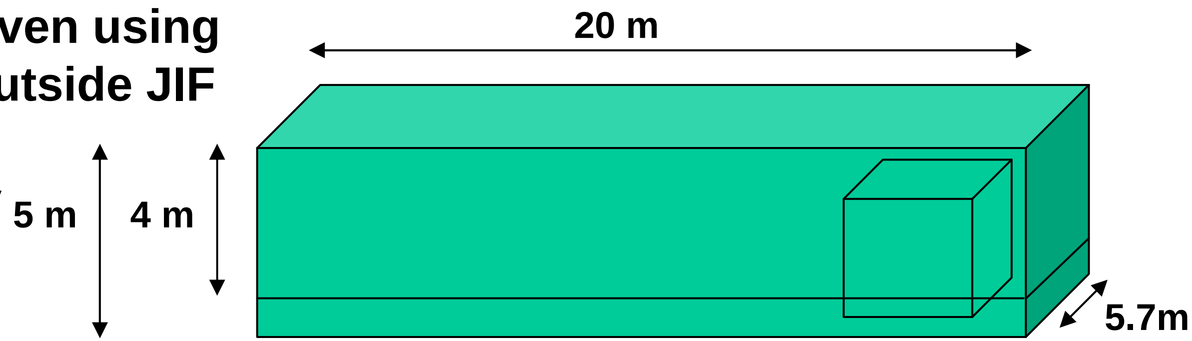


1 tonne xenon at Boulby (UK)



CONCLUSION:
can do it at Boulby even using our existing space outside JIF

new space at Boulby would be better



What about 10-100 tonnes? 10^{-10}-10^{-12}pb

more neutron issues

Carson et al (submitted)

10 - 100 Tonnes	Rock	Muon	Detector (~1.5 tonnes inside shielding - 1 tonne modules)
10^{-10}pb (1 unit) 1-5	40 g/cm^2 CH_2		
(100 units) 0.01-0.005 ct/yr/ton			

conclusion:

multiple small units (100s kg) probably unsuited for reaching below around $10^{-9/10}$ pb

(1) must remove PMTs - go for bulk charge readout
(2) go for larger single detectors with a fiducial cut

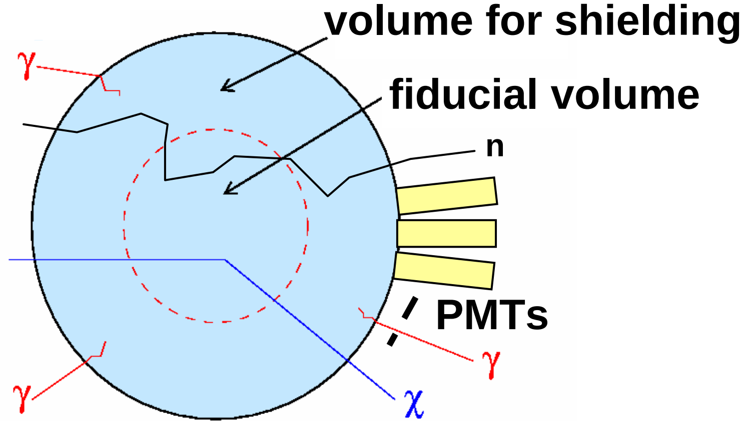
Higher internal purity or fiducial cut

Note: (1) neutron absorption length in LXe (or Ge) ~10m
--> so passive LXe neutron shield no good

(2) but neutron MFP in LXe (or Ge) ~15cm
--> so can use detection to define fiducial volume

LSXe: option 1

large single phase liquid Xe with fiducial cut
- NO γ discrimination -



30cm outer volume should suppress neutrons by ~x10 (60cm by x100...) but needs position sensitivity to define two regions (e.g. 1 cm)

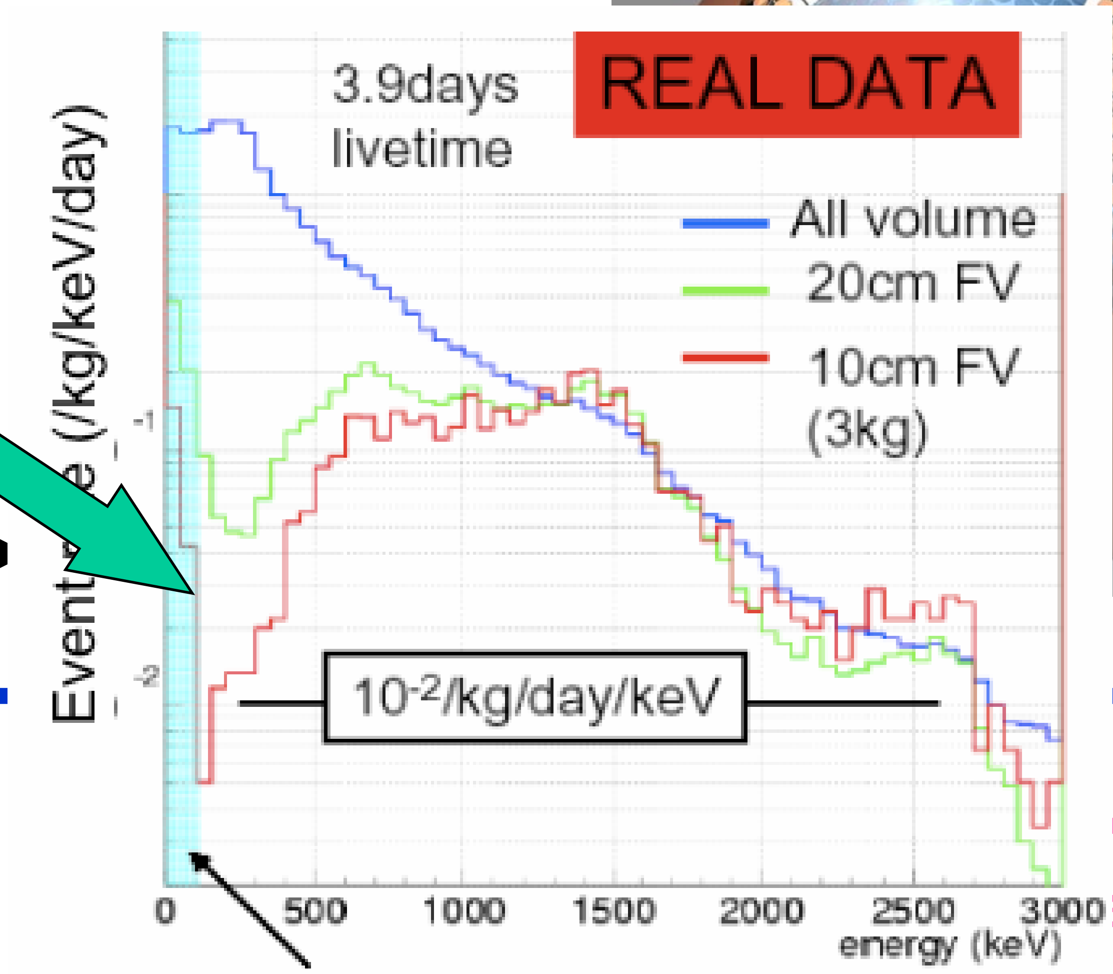
i.e. like XMASS...

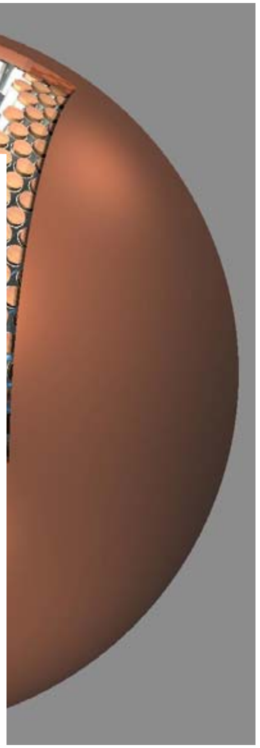
Make single phase Xe big - XMASS

100kg Prototype

～30cm

800kg detector





R&D

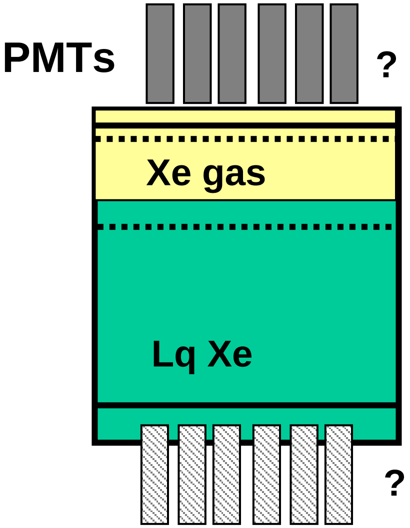
Now

etector

(solar neutrino, ββ …)

option 2 - ZEPLIN/XENON route

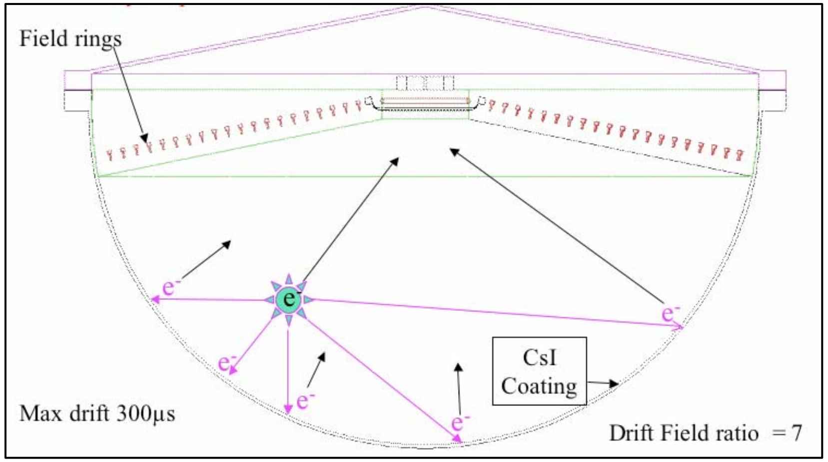
LSXe: option 2

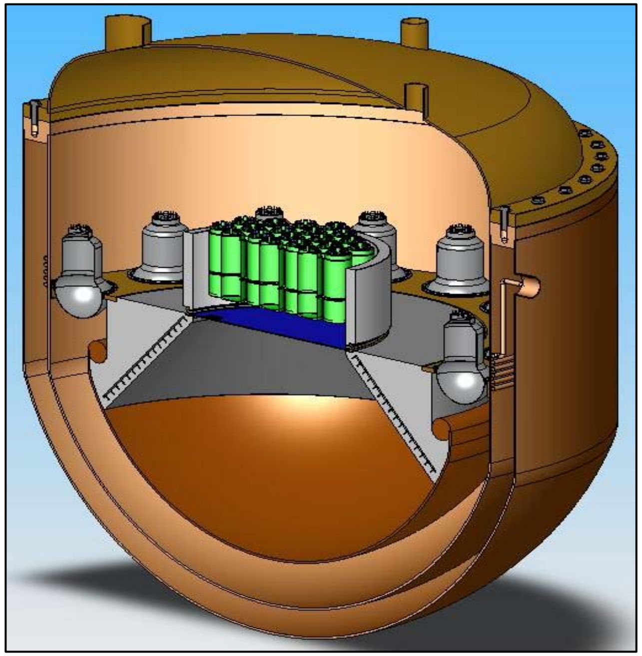


large double phase liquid Xe with fiducial cut
- WITH γ discrimination -

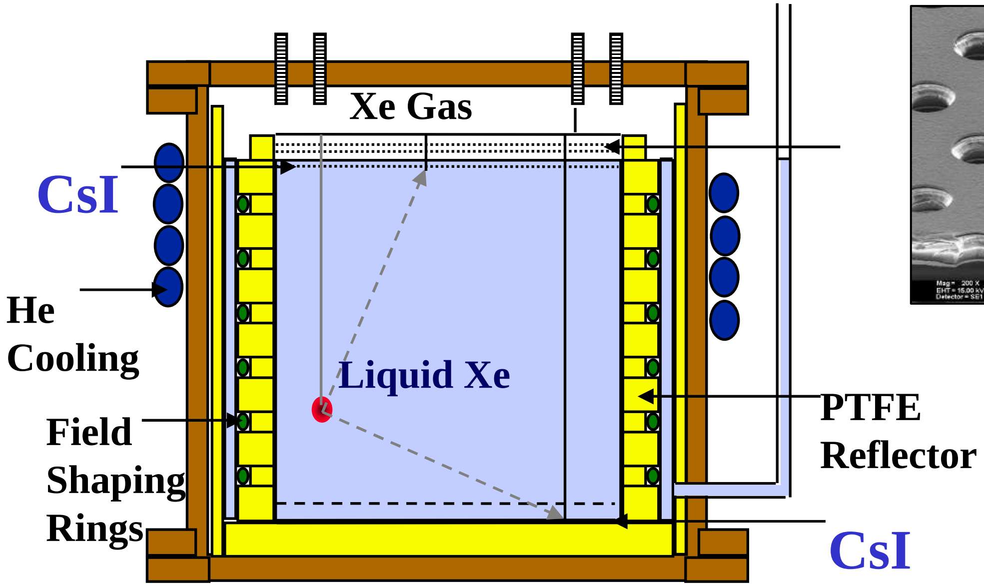
-has gamma discrimination
-but difficult geometry to create fiducial cut
-probably need charge extraction from the recoil

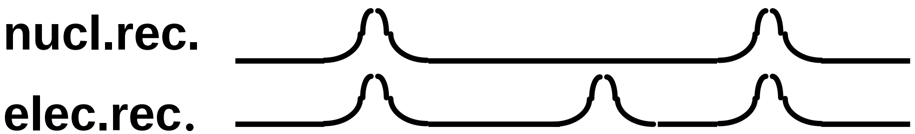
e.g. Wang et al.





charge readout technology

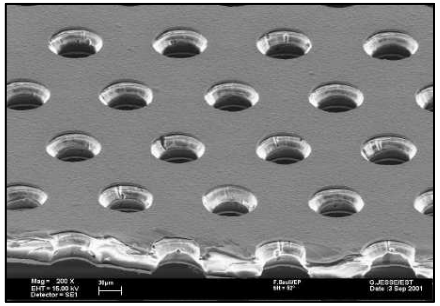


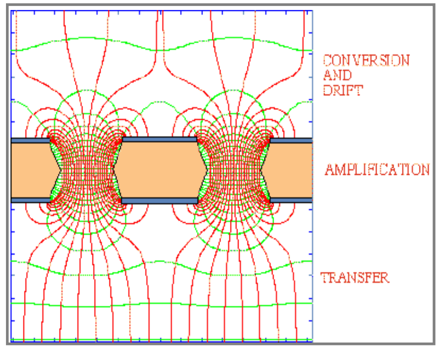


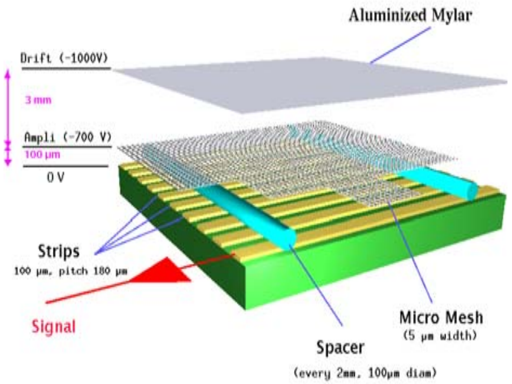
CsI photocathodes in LXe: E.Aprile, NIMA 338 (1994), 328; NIMA 343 (1994), 121.

GEM phototubes in noble gases:http://gdd.web.cern.ch/GDD/A.Buzulutskov, NIMA, 443 (2000), 164.

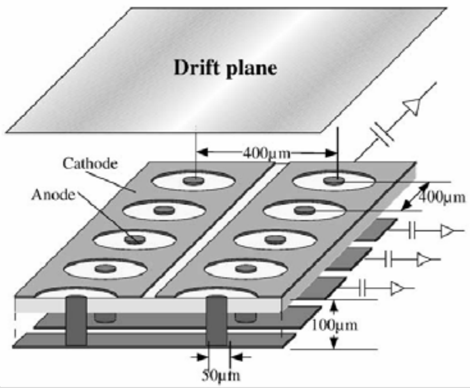
GEM (Sauli, CERN)





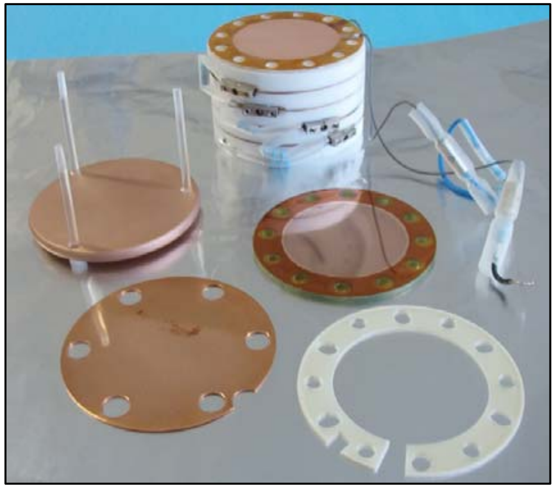


Micromegas (Giomataris, Saclay)



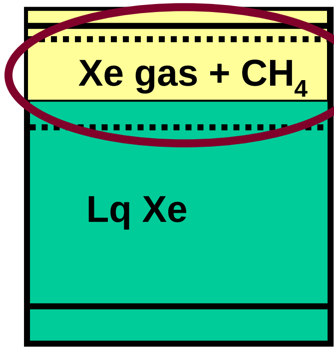
Micropixel devices (Kobe, Tokyo, Kyoto, KEK)

It works!



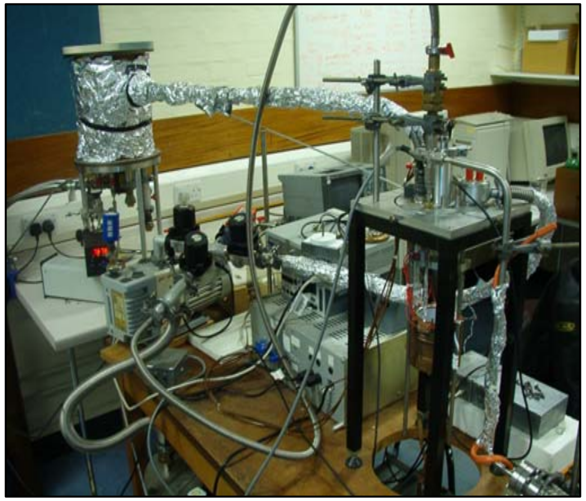
see P.K. Lightfoot talk at Paris TPC meeting Dec 04

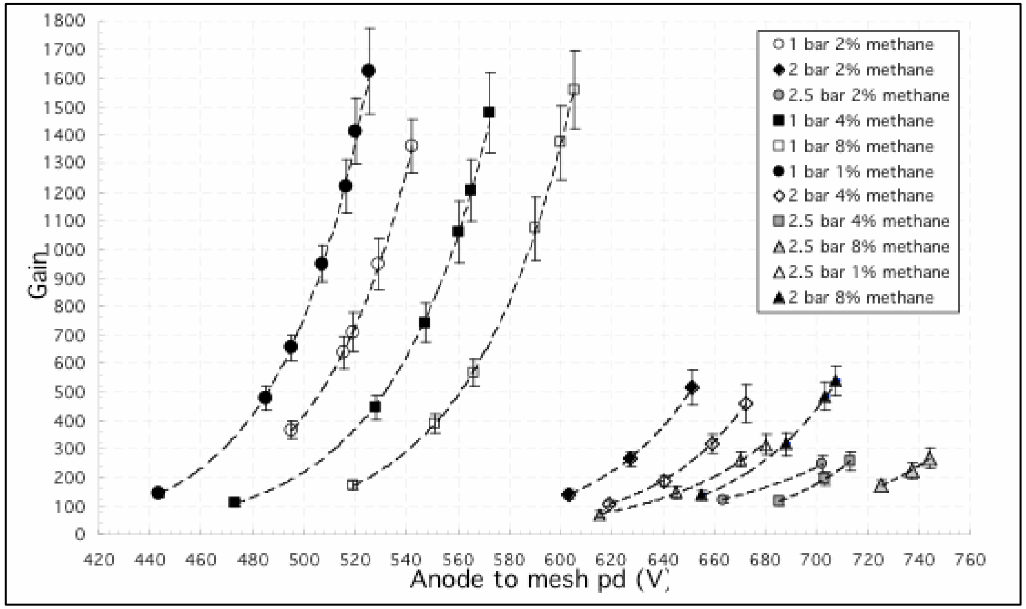
quite well understood now (Sheffield group):



conclusion with Micromegas

(1) CH_4 quench in two-phase ok
(2) CH_4 % can be optimised
(3) micromegas gain at 1.8-2.0 bar ok
(4) hole size/pitch can be optimised
(5) drift field can be optimized



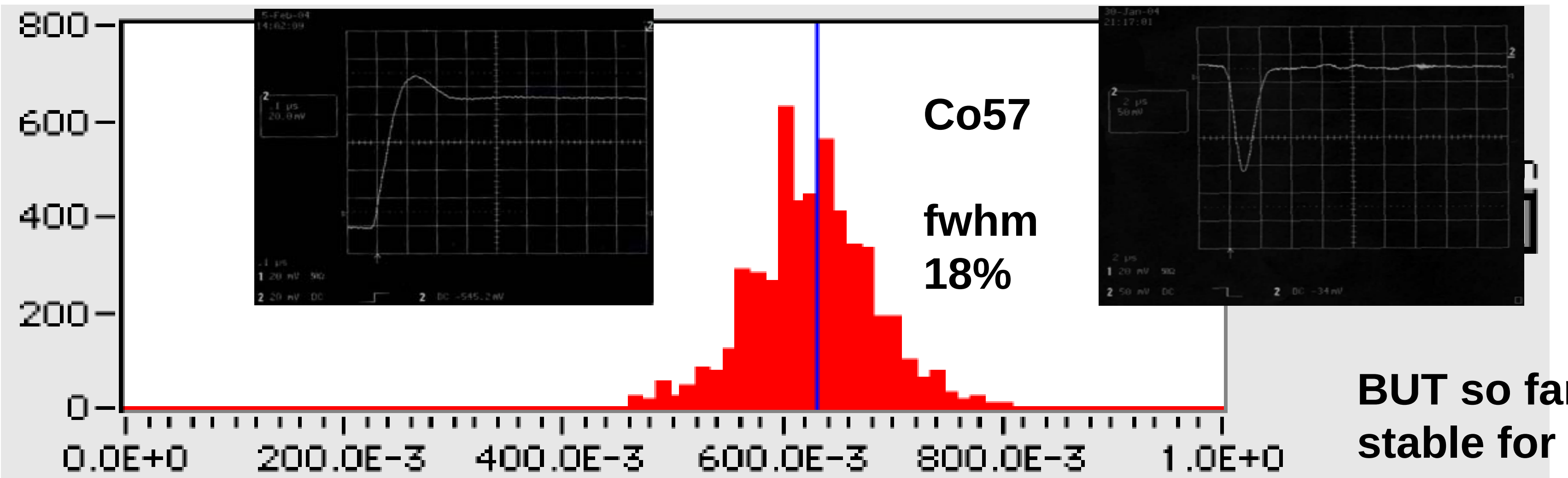


First two-phase Xe by charge

TPC Workshop, Paris 2004 P.K.lightfoot, University of Sheffield

Set point of -102°C
Anode to mesh pd of 650V
External Co57 source positioned under the cathode

Typical output from A250 charge amplifier



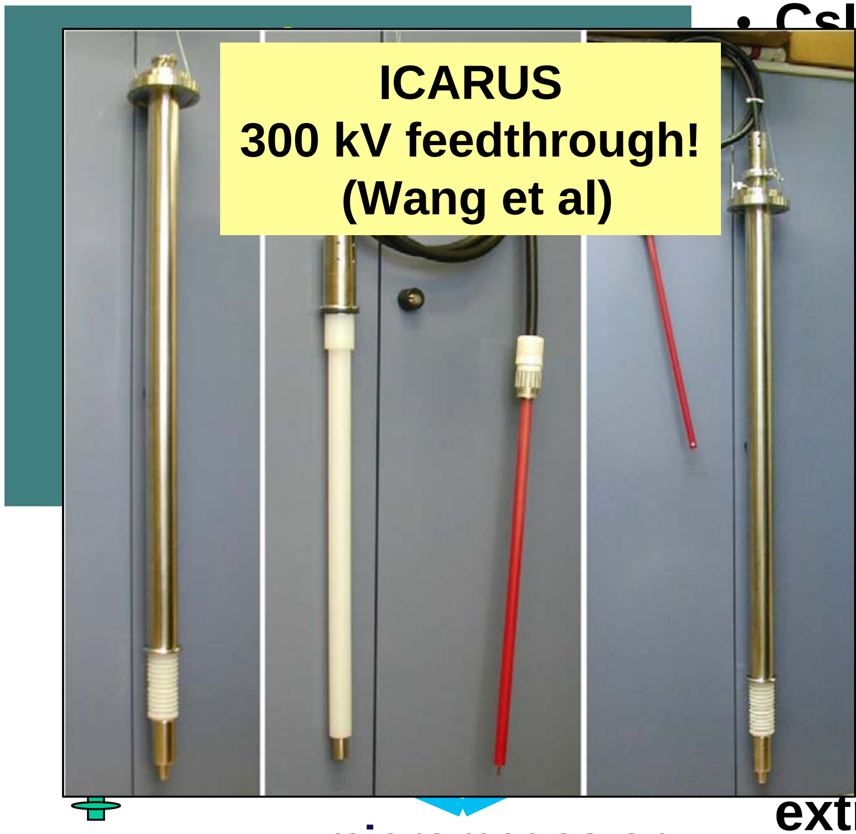
mV gain is x 1323

BUT so far stable for 20 min

Dream 10^{-12}pb LSXe Experiment

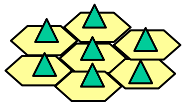
thanks to Hanguo Wang, Yannis Geomataris for discussions

plot stolen from NOSTOS (Giomataris) [gas TPC]



HV feed with shaping rings

micromegas or nano-tip readout



Features

- CsI photocathode over entire sphere
  …er surface makes use of known good
  …c
  …s … et al.
  … t
  …-
  …a… megas
  …V
  …u… of
  …rge distribution
  …h efficiency means no need to extract recoil ionisation (better if can)
- Recoil discrimination (unlike XMASS)

NOSTOS spherical gas TPC

Giomataris - Saclay

Dream 100KTonne Lq Ar

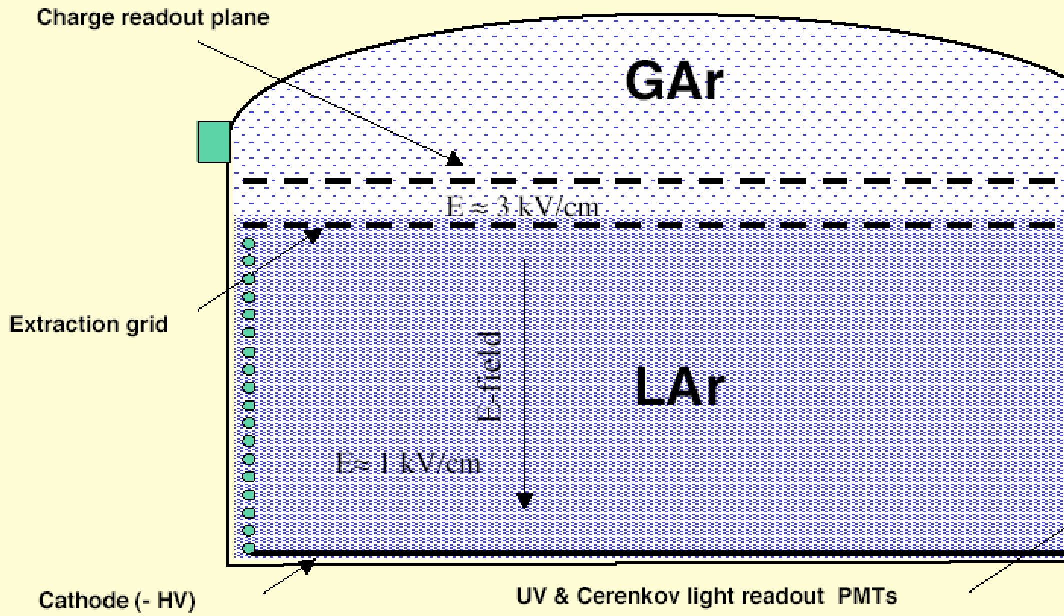
A. Rubbia et al.

(proton decay, SN, ʋ osc..)

possible alternative for Dark Matter if ^{39}Ar can be removed (?)

Single detector: charge imaging, scintillation, Cerenkov light

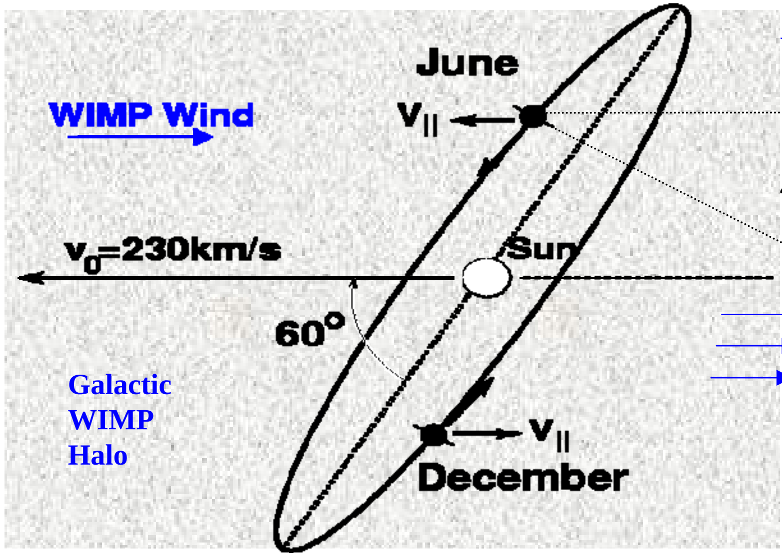
Dewar	$\phi \approx$ 70 m, height $\approx$ 20 m, perlite insulated, heat input $\approx$ 5 W/m^2
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m^3, ratio area/volume $\approx$ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc $\phi \approx$70 m located in gas phase above liquid phase
Charge readout electronics	100000 channels, 100 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 1000 immersed 8" PMTs with WLS
Visible light readout	Yes (Cerenkov light), 27000 immersed 8" PMTs of 20% coverage, single γ counting capability

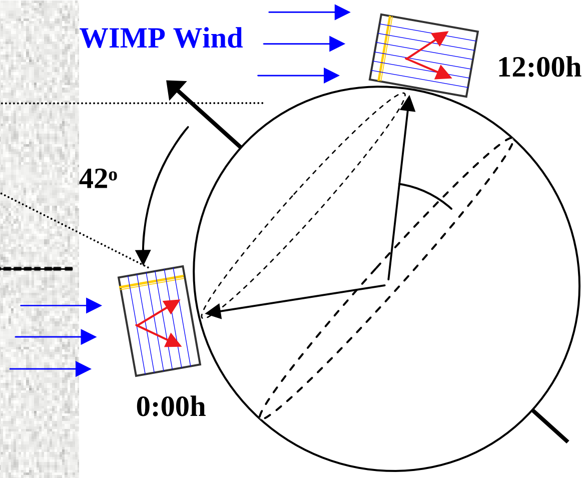


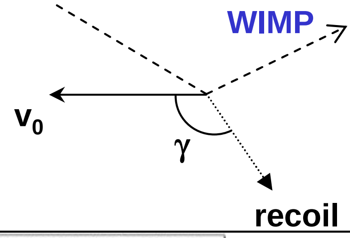
A SIGNAL!
but can it be true?
but is it galactic?

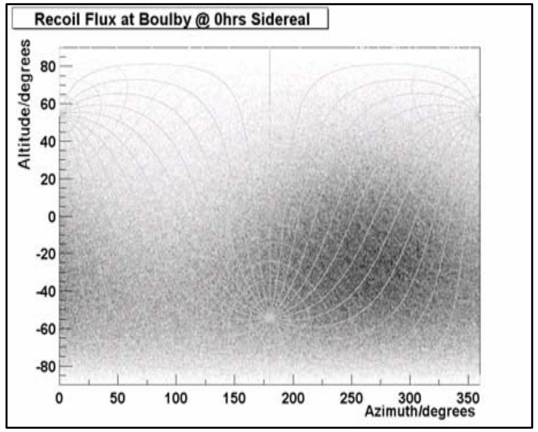
Paths from Detection

Direction sensitive detectors









(1) Achieve WIMP recoil signal --> requires usual >10^6 γ rejection

-technology could also achieve first detection
-neutron suppression via sidereal modulation

(2) Confirm galactic origin - forward-back recoil direction correlation with velocity through halo

(3) Determine which WIMP halo model is correct

WIMP astrophysics

Death of the Standard Model?

Models: many structures

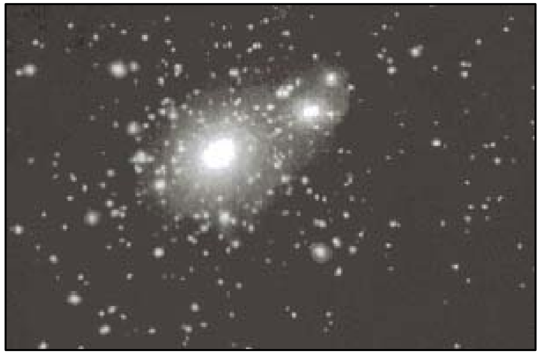
- velocity space anisotropy
- bulk rotation
- substructure, clumps
- ultra-small scale clumps
- triaxality, logarithmic ellipsoidal
- oblate vs. prolate
- late accreted sub-halos
- sub-structure on sub-pc scales
- spikes and caustics

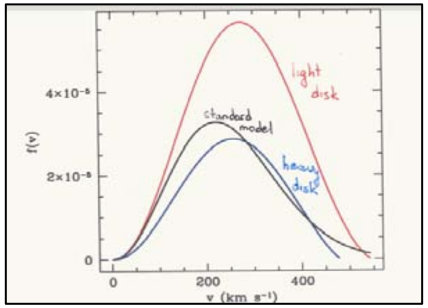
Evidence:

- rotation curves
- local kinematics, Oort constants,
- tracers: satellites
  (PNs, globular clusters, halo stars)
- IR maps

New satellite missions

Clumps **Moore et al.....**





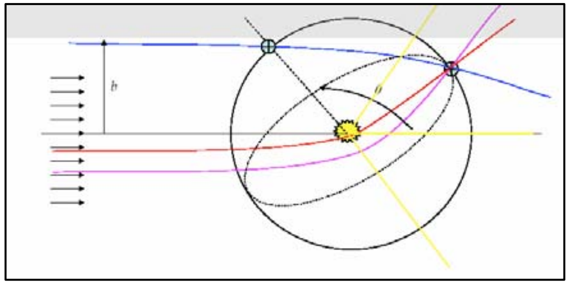
Multicomponents

Stiff , Widrow et al..
Helmi et al, Evans et al...

Tidal disruption streams - Sagittarius

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

K. Johnston et al, Sackett & Merrifield reviews
Freese, Gondolo et al.



Sun's influence

Fu-sin Ling et al.
Sikivie, Wick et al

Low pressure TPC

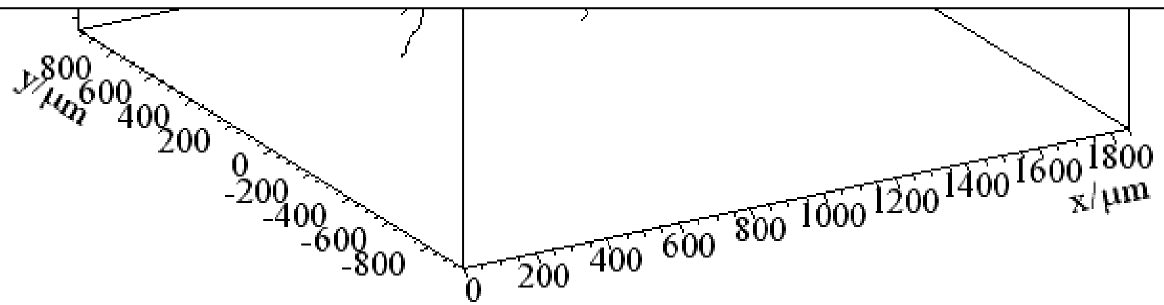
Simulated events

SRIM 40 keV S recoils in 40Torr Cs_2

the DRIFT Collaboration

(UKDM) Imperial College, RAL, Sheffield, Edinburgh, Occidental College, Temple, University of New Mexico*, Boston University*, Thessaloniki(+), Darmstadt(+)

*new, +new for KK axions

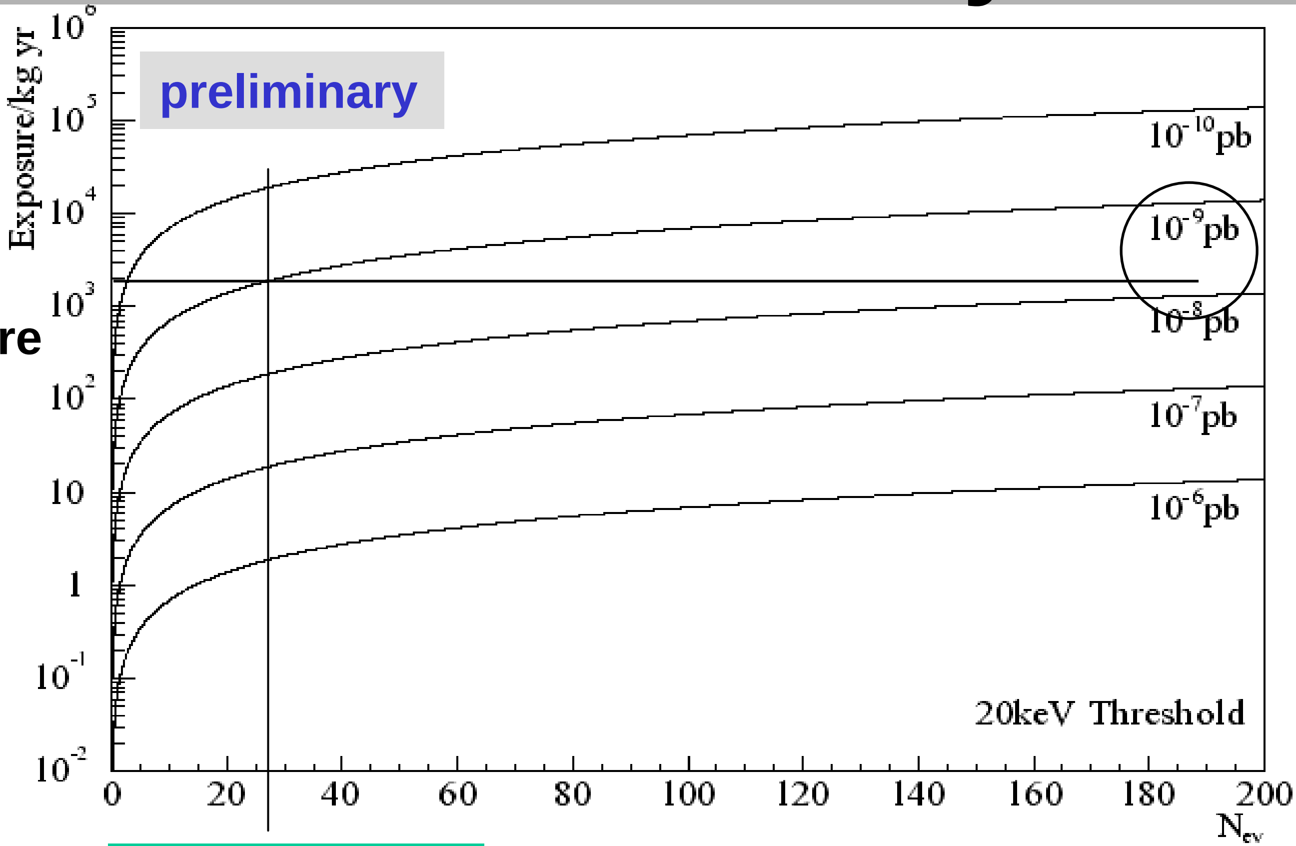


of similar energy is off scale (sketch)

negative ion drift with CS_2 idea by Jeff Martoff (Temple)

Directional sensitivity - 10^{-6} - 10^{-10}pb

Exposure



Number of detected WIMPS needed

perfect PSD with straggling

DRIFT II type

DRIFT I type with no sense

Triaxial | **M-B** | **Osipkov-Merritt**

Morgan et al. (UKDM)

Sensitivity Note - DRIFT II

This technology also good as a non-directional search experiment

- **add 50% Xe**
- **increase pressure by x4**
- **throw away directionality but retain gamma discrimination**
- **RESULT: full DRIFT II @ 160 Torr, 50:50 CS_2:Xe**

could reach 10^{-9} pb (zero backgound)

DRIFT Programme - DRIFT I

DRIFT I: 2002/4 technology r&d

(UKDMC, Temple University, Occidental College)

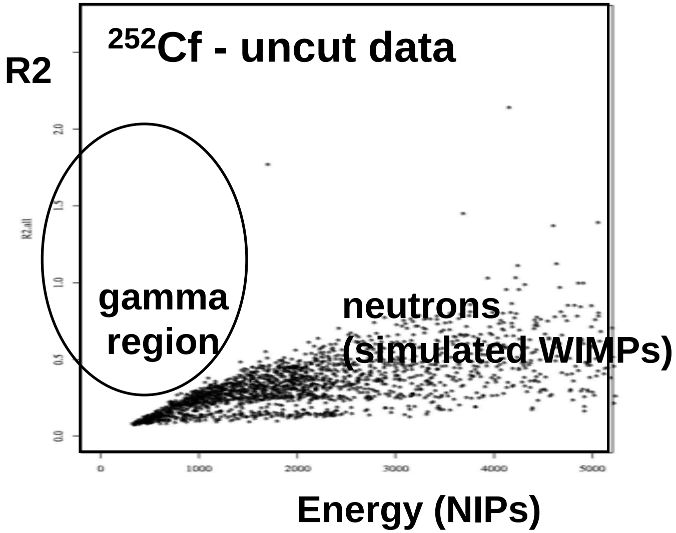
- $1m^3$ Dual Negative Ion DRIFT TPC

Technology achieves γ rejection ($<10^{-5/6}$)
No need for Pb shielding in DRIFT I

[Alner et al. - NIM A 535/3 p644]

DRIFT-I @ Boulby

DRIFT-I @ Boulby
with CH shield

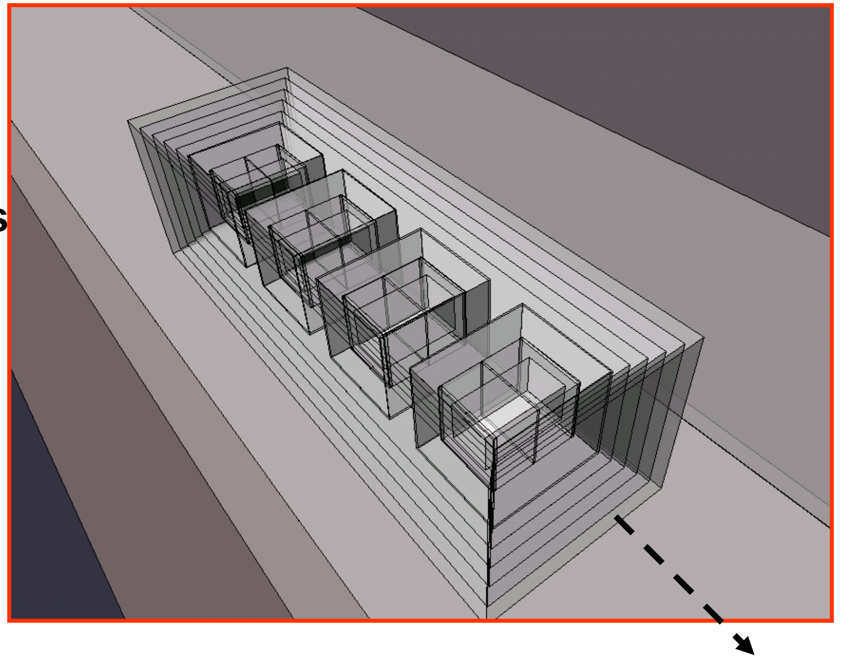


DRIFT Programme - DRIFT II

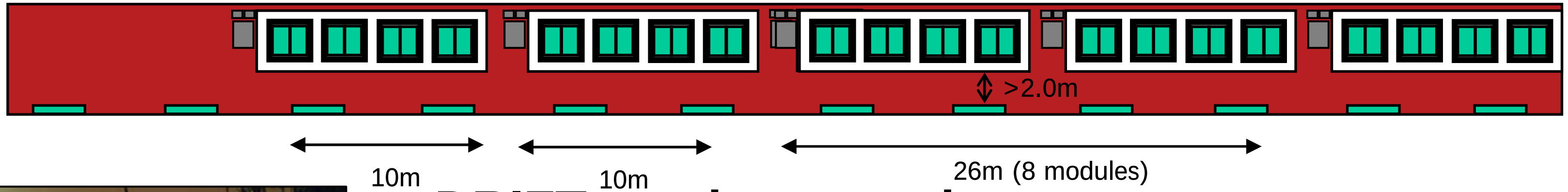
DRIFT II: 2005/6 first directional array (5-10 modules)

first steps to cheap multi-modules

- x 20 improvement in sensitivity of D-I
- Modular… n (3-4) × $1m^3$ fiducial vol, NITPCs
- Back-to-back drift vols & dual MWPC readout
- Vertical planes, Warp adjust strongback MWPCs
- 3d reconstruction (anode, grid and z-drift) (resolution: Δx = 2mm, Δy = 0.1mm, Δz = 0.1mm)
- Lower noise DAQ (few keV S-recoil threshold)
- Improved vessel design ($<10^{-5}$ T.L.s^{-1}) .
- Improved gas system (various pressure & gas mixtures)



Could it be scaled up? - DRIFT III+

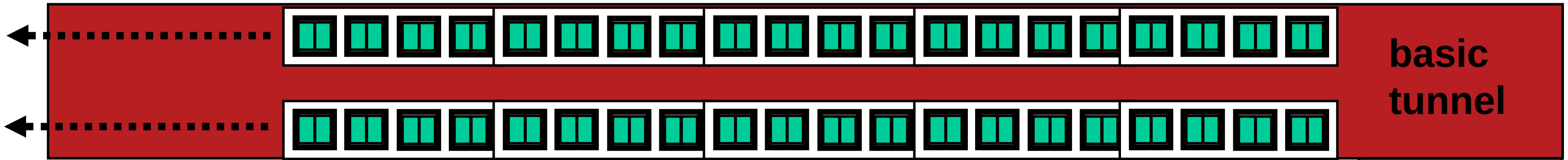


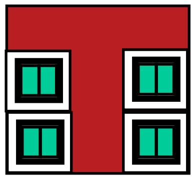
DRIFT needs space, but modules can be cheap

like Auger!

many but cheap modules

no gamma shielding
no cryogenics
no complex underground structure
no complex servicing
no expensive target materials
no big down time on power outages



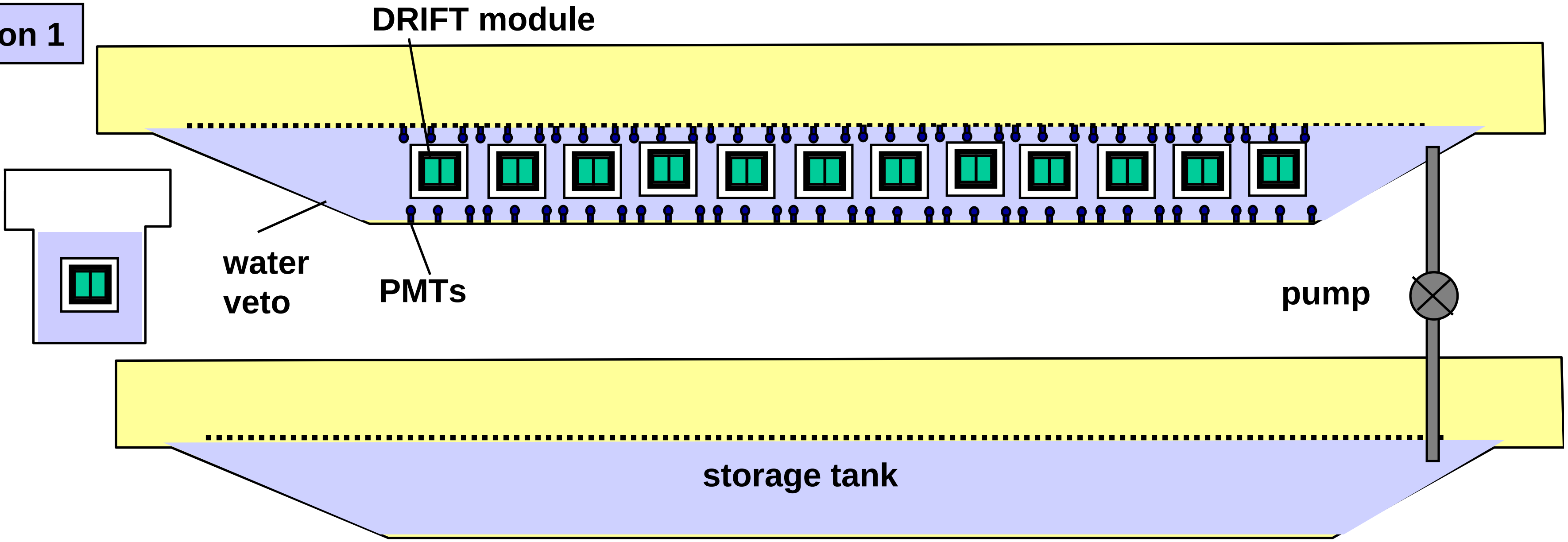


plan view

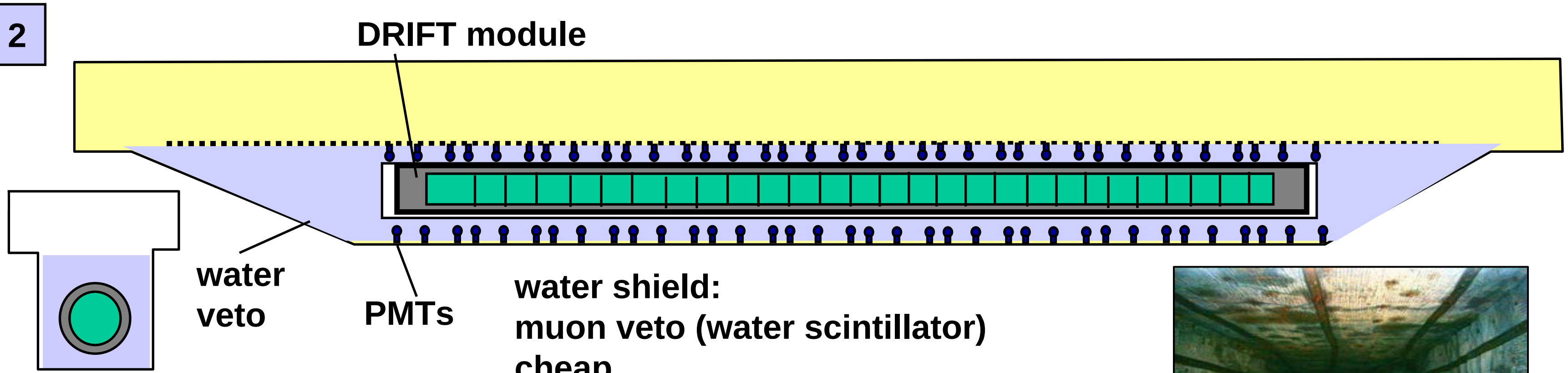
e.g. DRIFT III - 100-500 kg?

DRIFT III+ - how to scale-up

Option 1



Option 2

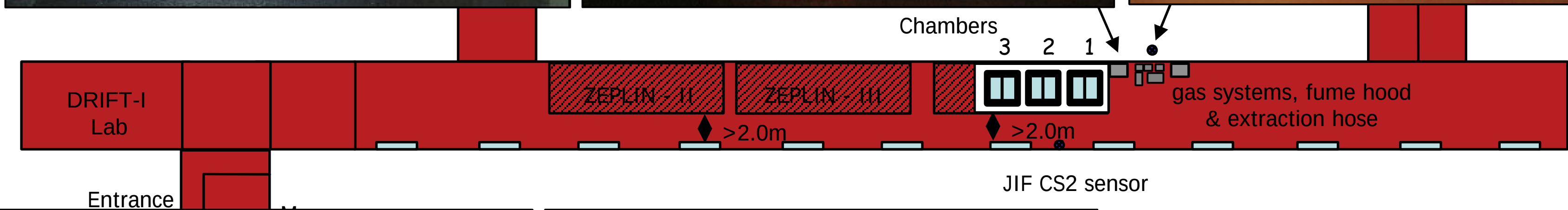


water shield:
muon veto (water scintillator)
cheap
safe for CS2
quick installation and removal (pump)
RF shielding

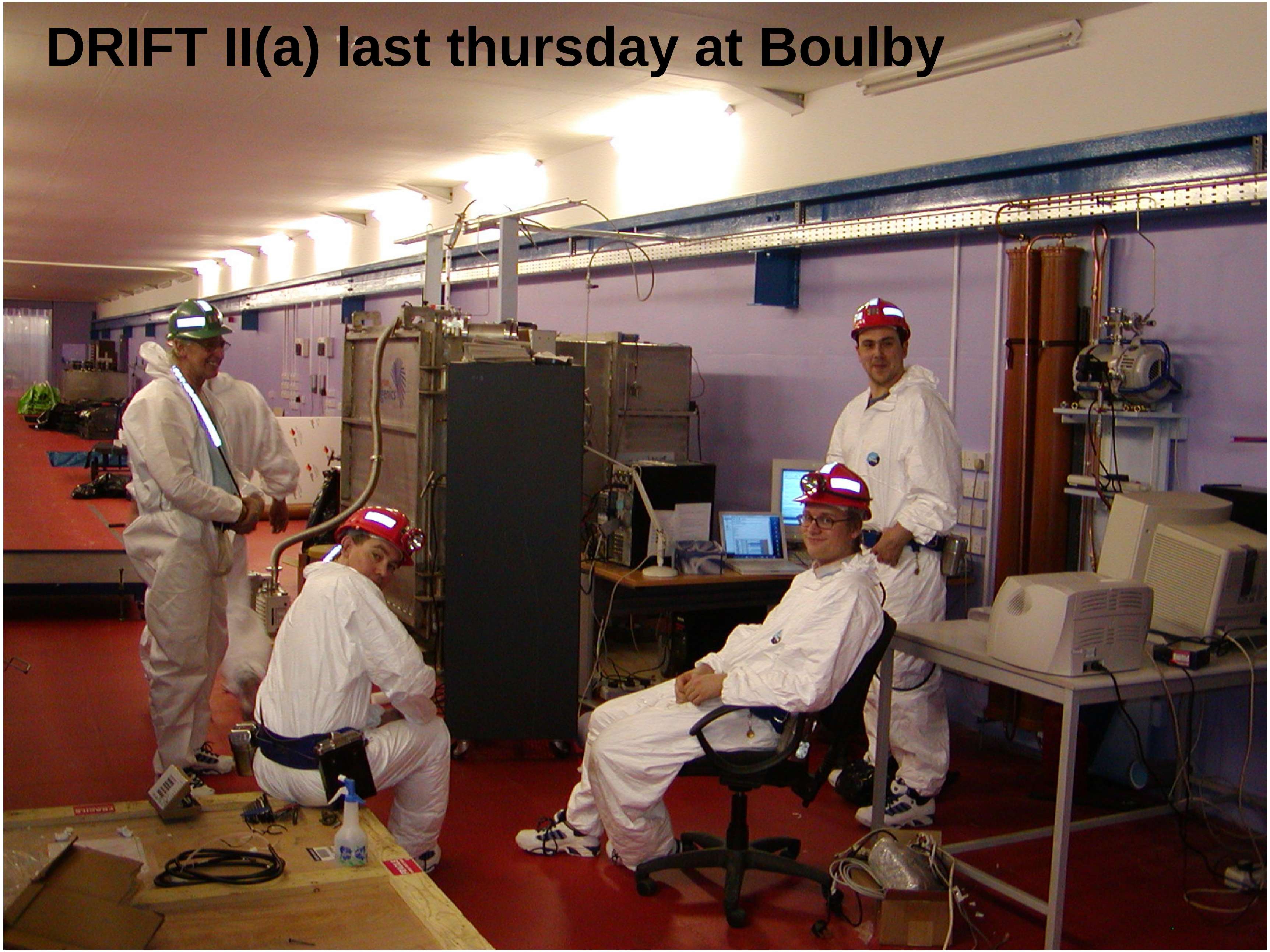
www.nationalpoolwholesalers.com

DRIFT II - construction

DRIFT II (A) installation



DRIFT II(a) last thursday at Boulby

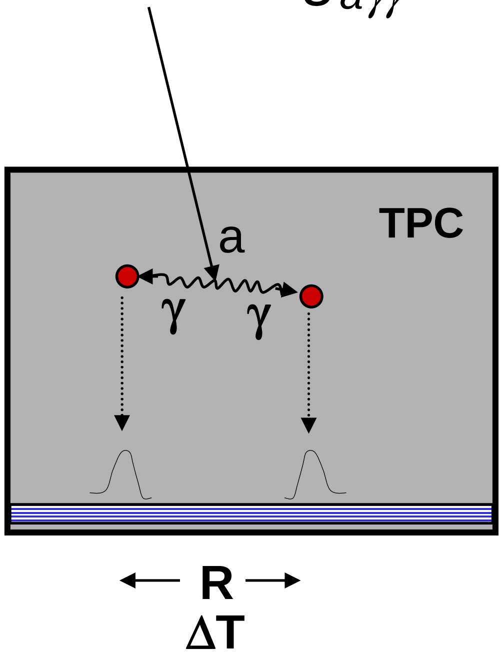


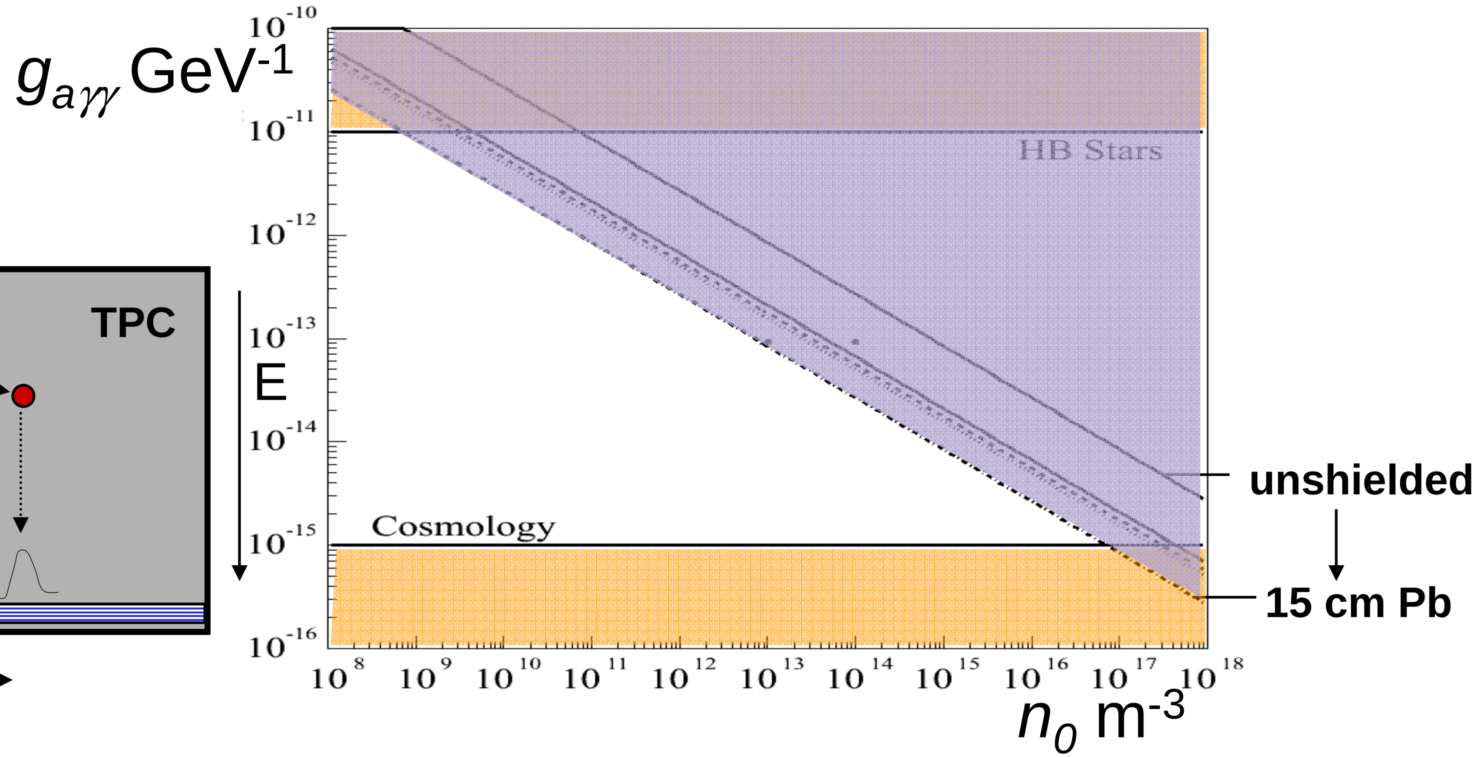
Kaluza-Klein axions

BASIC LIMIT - Add Pb shielding until vessel background dominates (10 cm for 1 ppb)

B. Morgan, N. Spooner, D. Hoffmann, K. Zioutas (paper accepted in Astrop. Phys)

[1 m^3yr, CS_2, 160 Torr, a_{mass} 6-20 keV, 1 ppbU/Th in vessel]



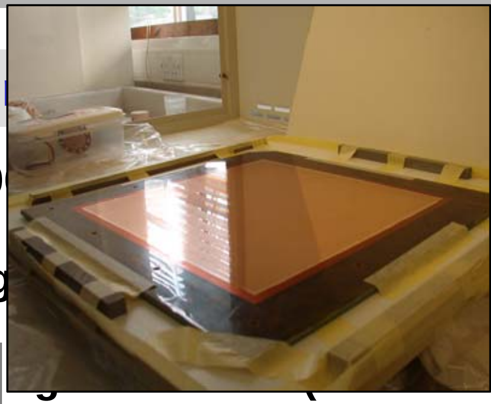


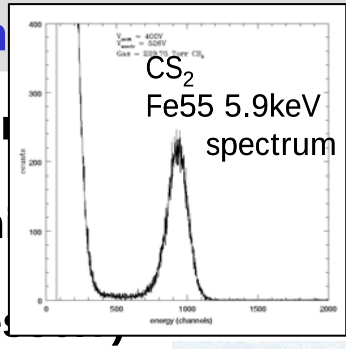
LSP, LKP, KK axion and directional

The Ultimate Dream Detector?

halo sensitivity at 10^{-12}pb (2020+?..)

Basic numbers for wo

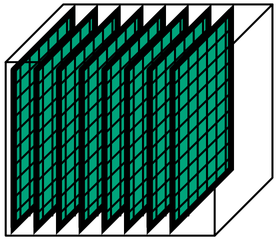




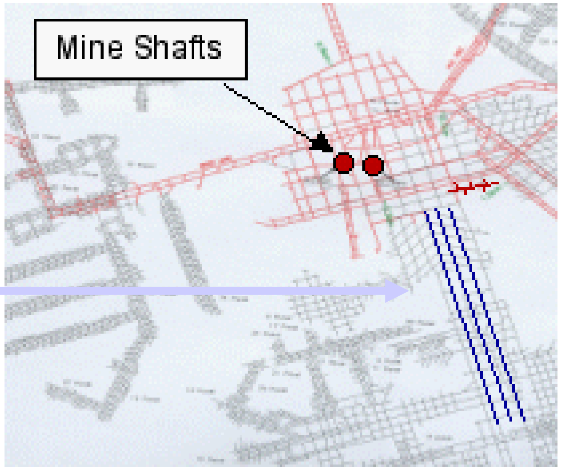
Exposure, Mass 10 … n.yr (halo confirmation)

Depth >4000 mwe (ig … ns via isotropy)

(if) Gas technology



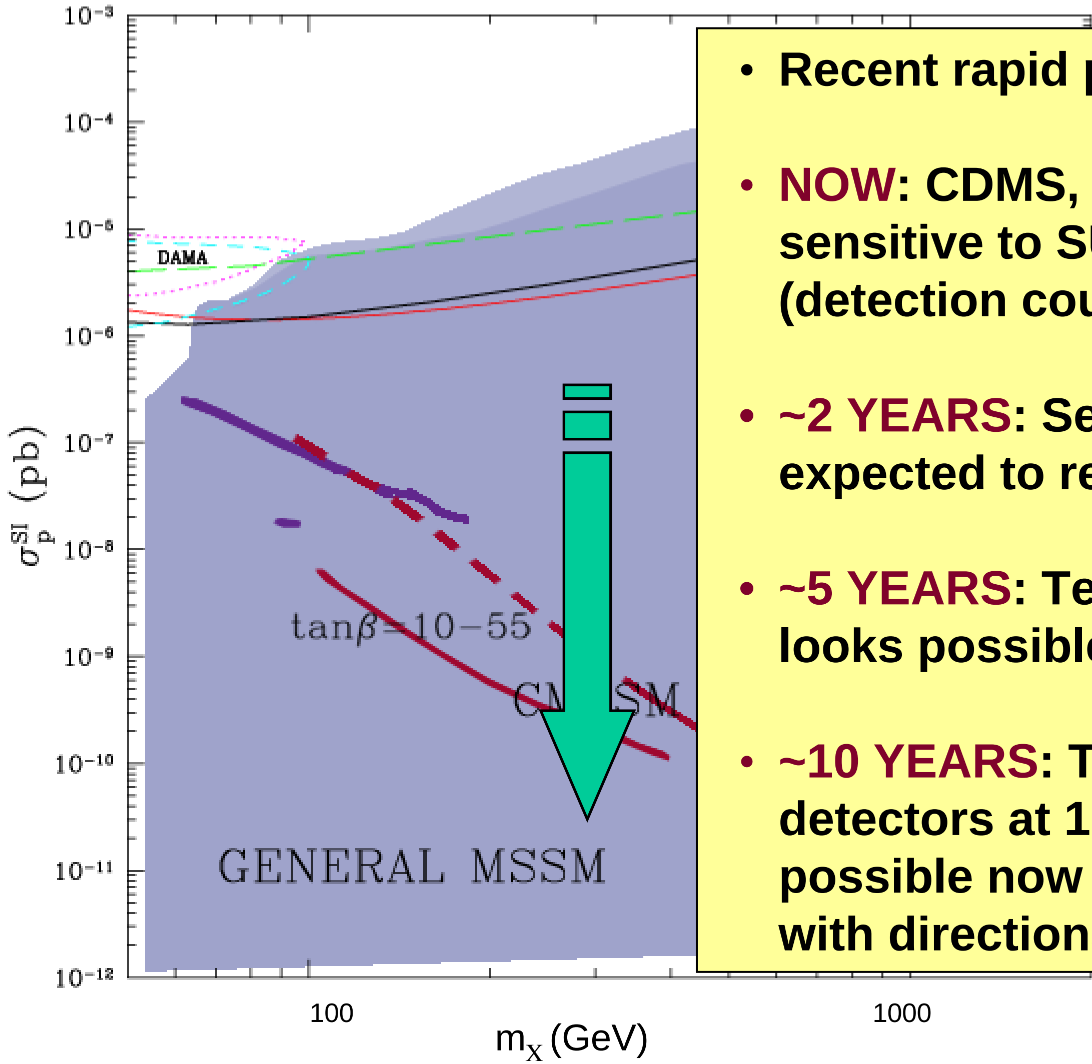
50 µm track µmgas readout (interpolation)
3 kg/m³ target
1cm readout plane spacing (2d/3d)
diffusion subtraction



Caverns 3 caverns of 2km x 10m x 5m

Low background components ok: Lucite, Cu, Kapton

Messages to take home



- **Recent rapid progress**
- **NOW: CDMS, Edelweiss, ZEPLIN… sensitive to SUSY models - $10^{-6/7}$ pb (detection could be very soon)**
- **~2 YEARS: Several experiments expected to reach to 10^{-8} pb**
- **~5 YEARS: Technology for 10^{-10}pb (1 ton) looks possible particularly with Xenon**
- **~10 YEARS: Technology for directional detectors at 10^{-10}pb (1 ton) also looks possible now - it's important to be ready with directionality**

Earth-mass dark matter halos

QuickTime™ and a
YUV420 codec decompressor
are needed to see this picture.

Earth-mass dark-matter halos as the first structures in the early Universe

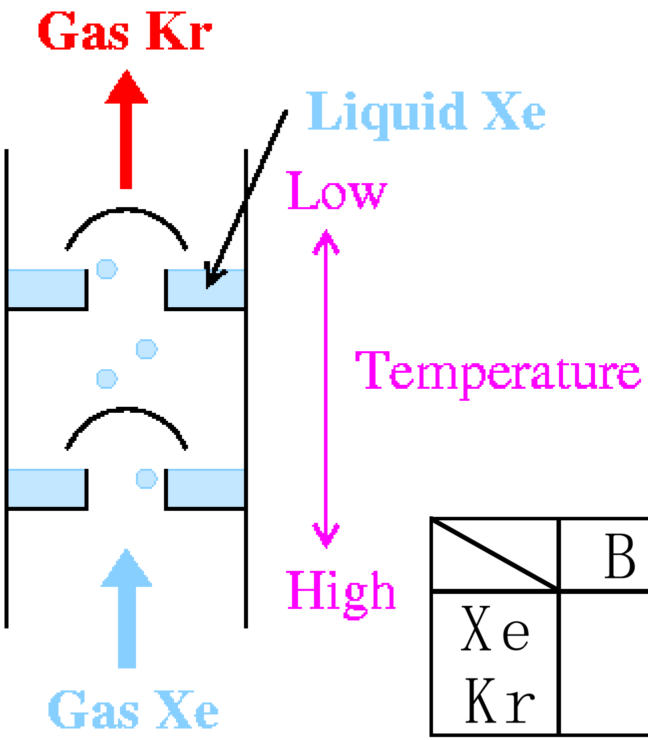
J. Diemand, B. Moore & J. Stadel
Nature 433, 389-391 (2005) &
astro-ph/0501589

Simulation of the formation of a Galaxy Cluster by Juerg Diemand, Joakim Stadel, Ben Moore (University of Zurich) on the zBox Supercomputer at the University of Zurich.

Purification of Xenon

XMASS: success in reduction of Kr concentration in Xe from 310[ppb] to < 5[ppb] with one cycle (~1/100)

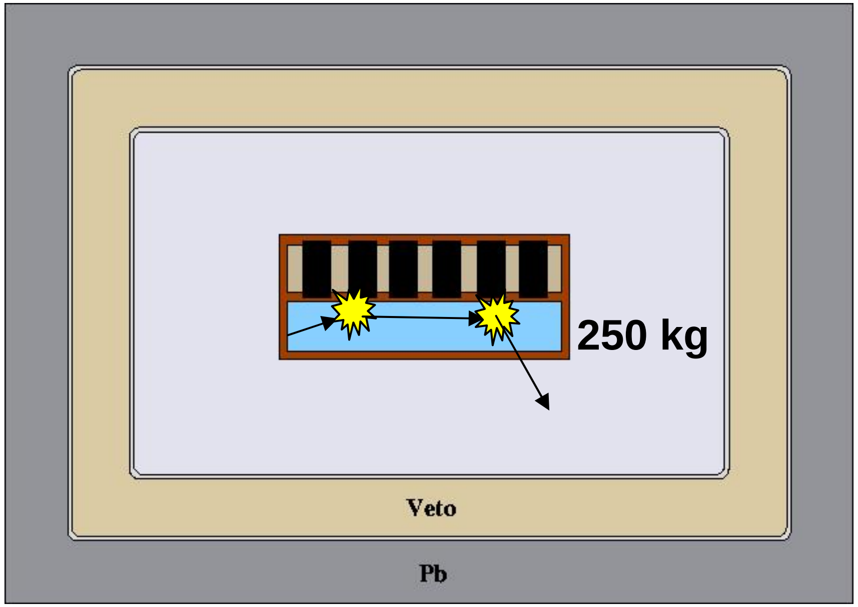
Moriyama et al.



	Boiling point
Xe	165K
Kr	120K

An active neutron veto?

(1) internal neutron vetoing



(a) 80% of recoils are single hit (E_{rec} >10 keV)

(b) lower if threshold of total is 10 keV but can see all individual hits below 10 keV

Assumptions (Xe and Ge):

target is pure and external n shielded

(fission fragments seen, no alpha-n)

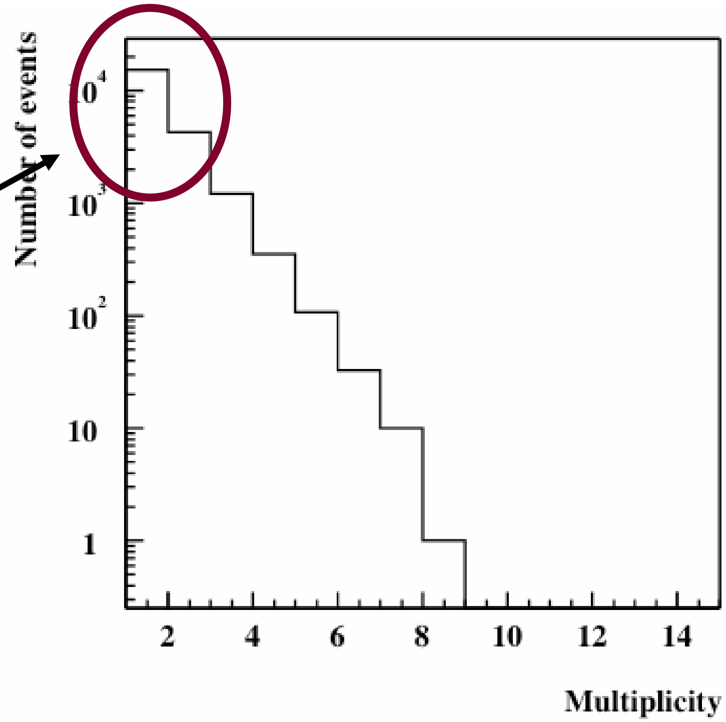
Internal detector neutrons dominate

(e.g.veto vessel, Xe vessel, PMT)

(Cu 0.02 ppb, PMTs 4 ppb)

perfect position sensitivity

(1cm ok ZIII type for z)



How many WIMPs to see the halo

Generic optimum DRIFT detector

[B. Morgan, A. Green, N. Spooner - Astro-ph/040804]

Model for realistic (advanced) detectors

- **40 Torr CS_2**
- **1 $kVcm^{-1}$ drift field**
- **200 mm resolution**
- **10 cm drift**
- ***SRIM2003 - recoil scattering and diffusion***

Vectorial Statistics:

Axial Statistics:

Recoil directions estimated as principal axis ±r of *moment analysis of pixel signals*.

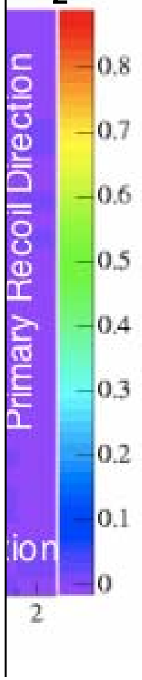
Recoil sense known(unknown): ***10-20(***
isotropy at 95% confidence in 95% of exp

primary limitations*: **(1) recoil scattering and***
(2) head-tail

40 keV S recoil in 40 Torr CS_2

Halo Model	N_{iso} for $(R_c, A_c) = (0.90, 0.90)$						
	Vectorial Statistics				Axial Statistics		
	$\mathcal{W}^*$	$\mathcal{A}$	$\mathcal{F}$	$\langle\cos\theta\rangle$	$\mathcal{B}^*$	$\mathcal{G}$	$\langle\lvert\cos\theta\rvert\rangle$
1	12	12	13	7	167	168	104
2	12	12	12	7	112	114	73
3	14	14	15	8	156	157	121
4	12	12	13	7	148	150	96
5	15	15	15	8	215	215	150
6	11	11	11	6	67	68	47
7	14	14	14	8	89	88	74
8	13	13	13	7	176	177	112
9	15	15	16	9	264	265	188
10	15	15	15	8	278	281	194
11	12	12	12	7	126	128	81
12	16	16	17	9	233	234	210
	N_{iso} for $(R_c, A_c) = (0.95, 0.95)$						
1	18	18	19	11	235	235	131
1 (no)	16	16	17	9	128	129	65
6	16	16	16	10	96	96	59
7	19	20	20	12	125	126	94
8	18	18	19	11	248	249	142
9	21	21	22	3	376	379	237
10	21	21	21	12	395	399	244
11	17	17	17	10	180	180	102
12	20	20	20	15	326	327	276

predictions for TPC-type detector with 200 μm resolution



Lightest Kaluza-Klein Particle (LSP)

Can look at other WIMP candidates

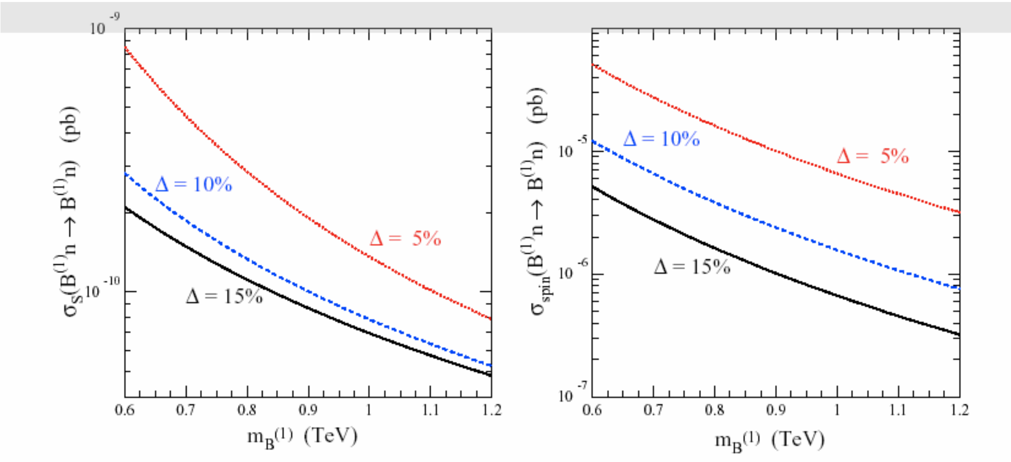
Alternative (or supplement) is Extra Dimension theory

e.g. Servant et al. ANL-HEP-PR-02-054, ANL-HEP-PR-02-032,Cheng CERN-TH/2002-157

Stable Kaluza-Klein modes of ordinary standard model particles allowed to propagate in one or more compact extra dimensions

LKP (Lightest Particle)

Applies as generic Bosonic Dark Matter candidate

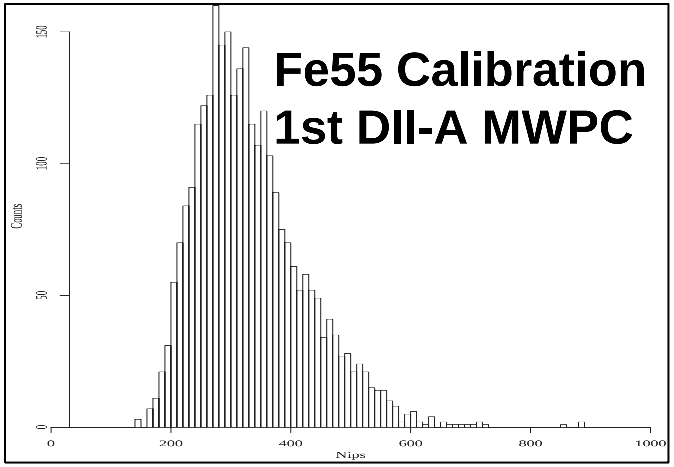


- **Assumes a Higgs mass of 120 GeV**
- **Higher Higgs mass lowers the cross section (x10 for 300 GeV)**
- **Greater $B^{(1)}$, $q^{(1)}$ degeneracy increases cross section**

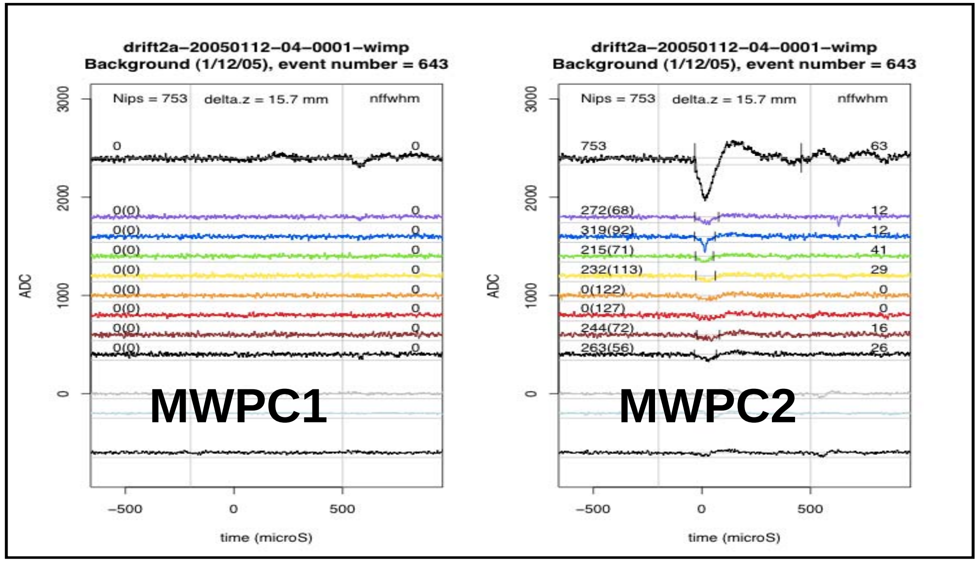
Typical values KK $\sigma_{p,n}^{scalar} \sim 10^{-10}\,pb$ ______ $\sigma_{p,n}^{spin} \sim 10^{-6}\,pb$

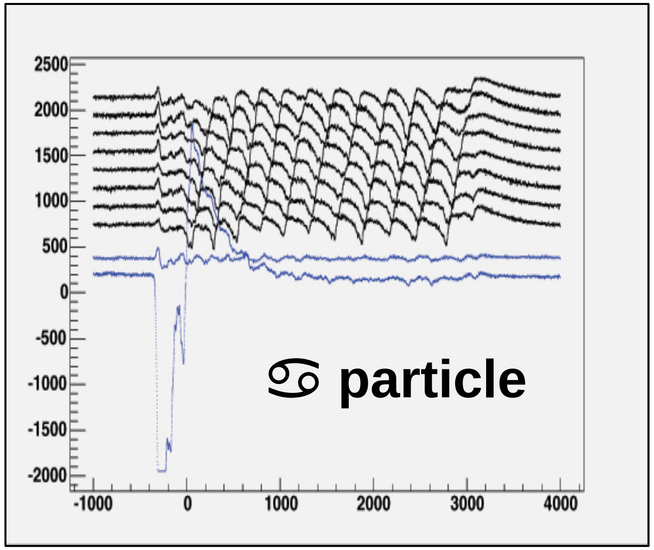
Typical values neutralinos $\sigma_{p,n}^{scalar} \sim 10^{-12} - 10^{-6}\,pb$ _____ $\sigma_{p,n}^{spin} \sim 10^{-9} - 10^{-6}\,pb$

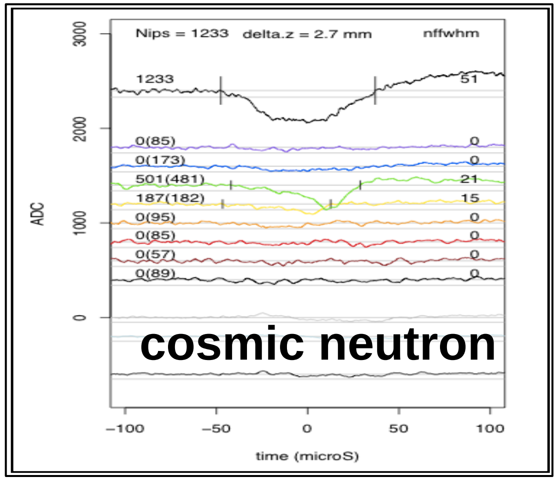
DRIFT II(a) - First test data (surface)

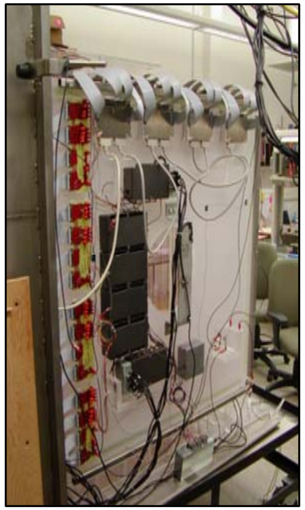


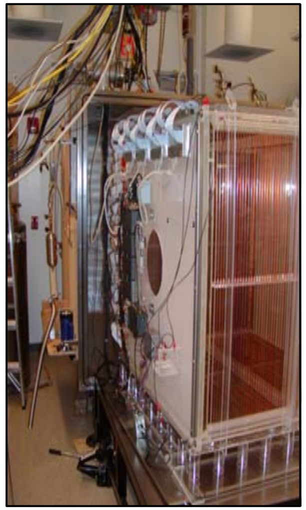
Raw Data







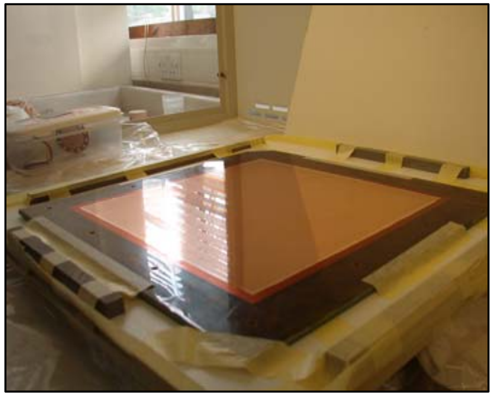


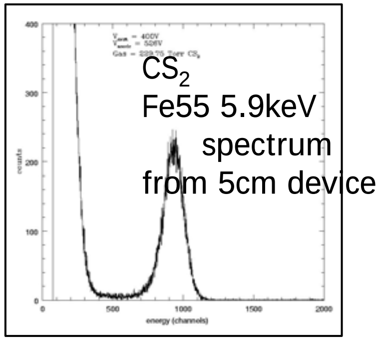


Better PSD for higher pressure

DRIFT III (US-UK)

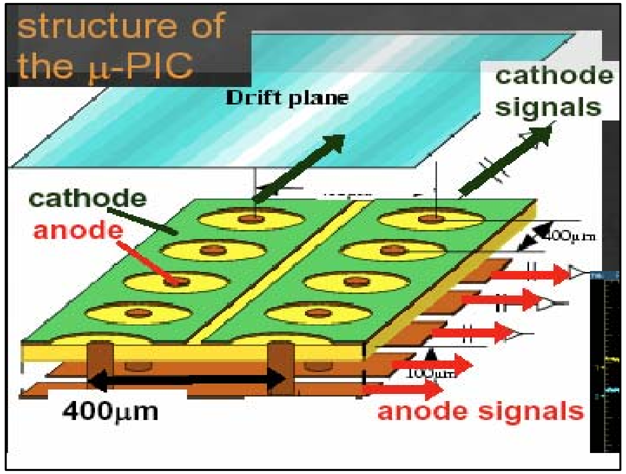
- GEMs,Micromegas
- 25 x 25cm trials

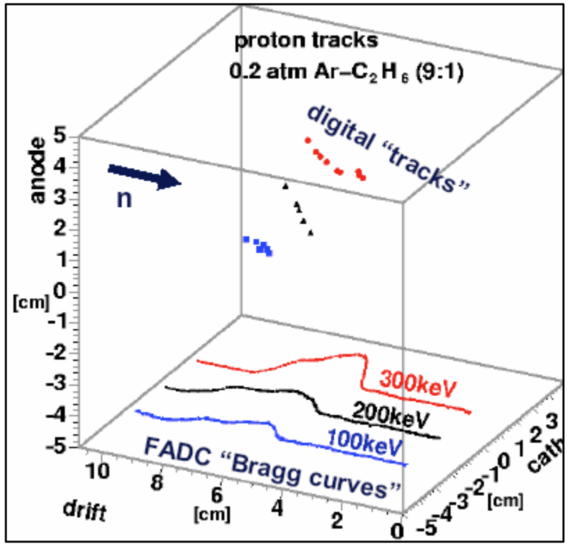




NEWAGE (Japan)

- micro-PIC (micro pixel chamber)
- 120 micron 2-D position readout
- 30 x 30 cm under development





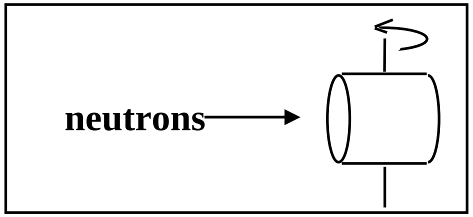
Ultimate aim - HEAD-TAIL discrimination --> x10 better halo identification

Directional technology ideas

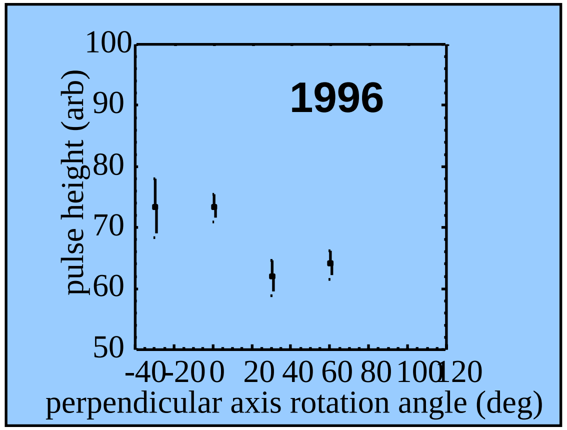
Organic Scintillators

DAMA, Sheffield,

Tokyo/Kyoto (Japan) **new**



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



Other Solid State

multilayer s/c and scintillators (Sheffield), bolometers (Stanford), Si (Temple), He (Brown), Mica (Occidental)….

Gas

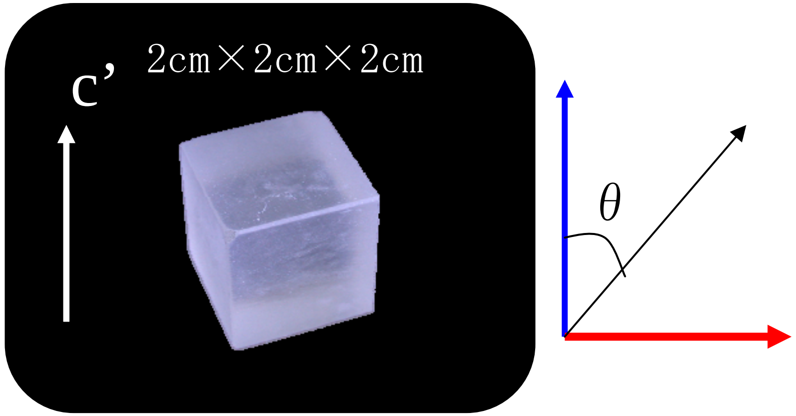
Saclay, UCSD, Temple, Occidental, UKDMC

(UKDMC + Occidental College, University of New Mexico, Boston University) → **DRIFT (US/UK)**

NEWAGE (Japan) **new**

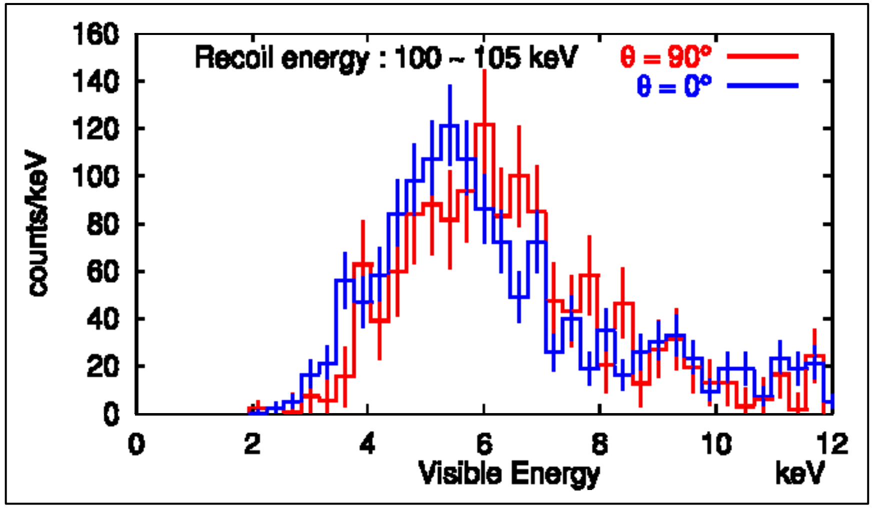
Organic Scintillator (Japan)

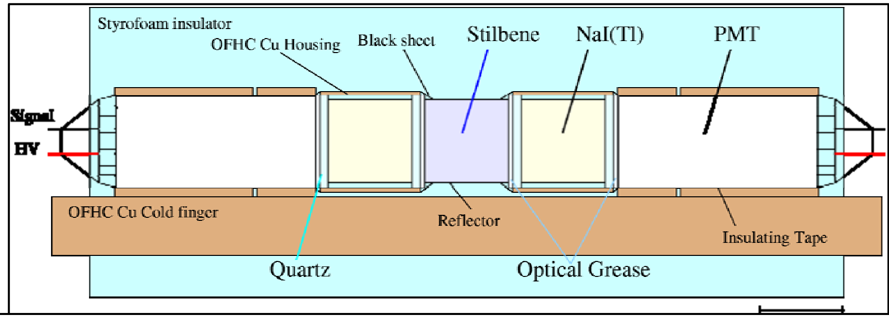
Hiroyuki Sekiya (Kyoto University) M.Minowa, Y.Shimizu, Y.Inoue, W.Suganuma (University of Tokyo)



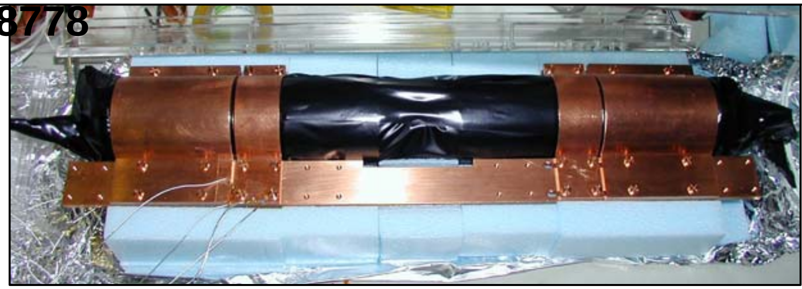
- **small level of directionality (~7%)**
- **poor targets - stilbene (H, C)**
- **high background**
- **.......**

Response to ～100 keV carbon recoil





116g stilbene crystal - 2 low BG PMT R8778



Directional sensitivity - 10^{-6} - 10^{-10}pb

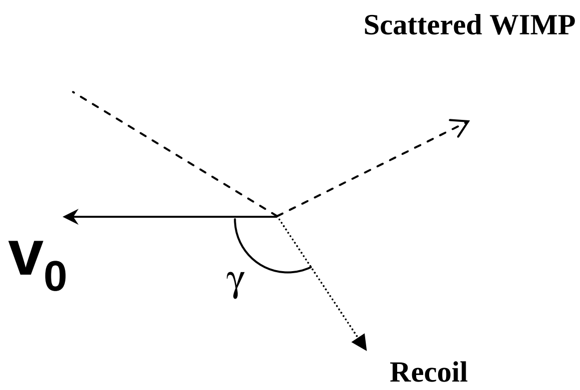
three modes

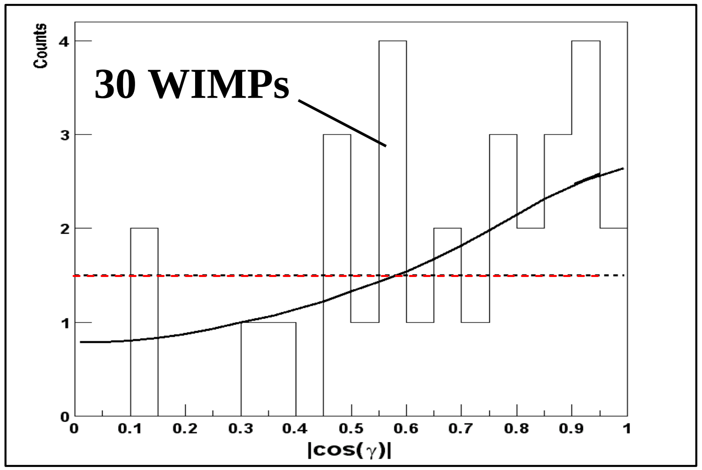
(1) Sensitivity to detection of WIMPs (like other detectors)

e.g. assume bkg = 1/year --> 3 events (90% cl discovery); 4 ev (95%)..
0/year --> 2.44 upper limit (=3 events)

(2) Sensitivity to direction of WIMPs

best case: standard halo model, perfect PSD detector
forward-back asymmetry >1:100 >50 GeV





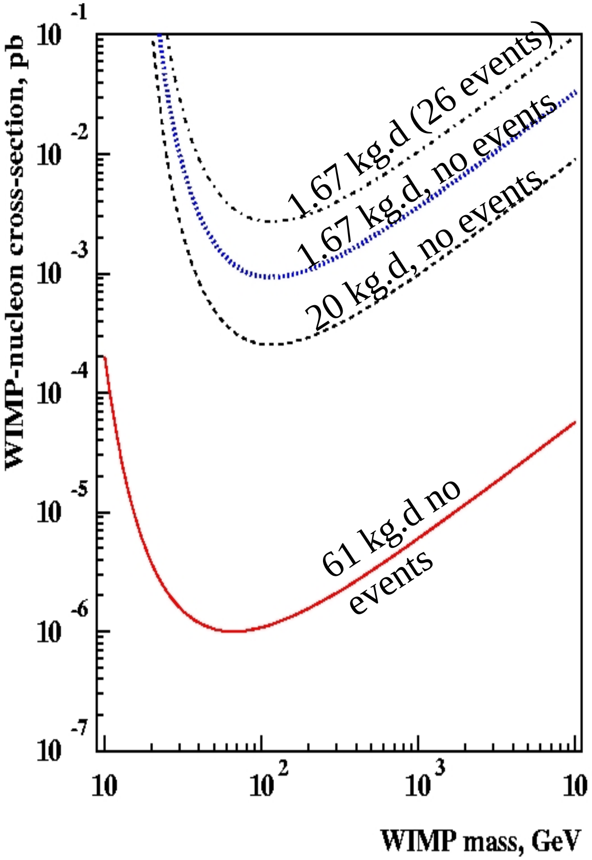
Monte Carlo --> 10s WIMPs needed to establish signal is directional
i.e. at least 10 times more statistics

(3) Sensitivity to halo models

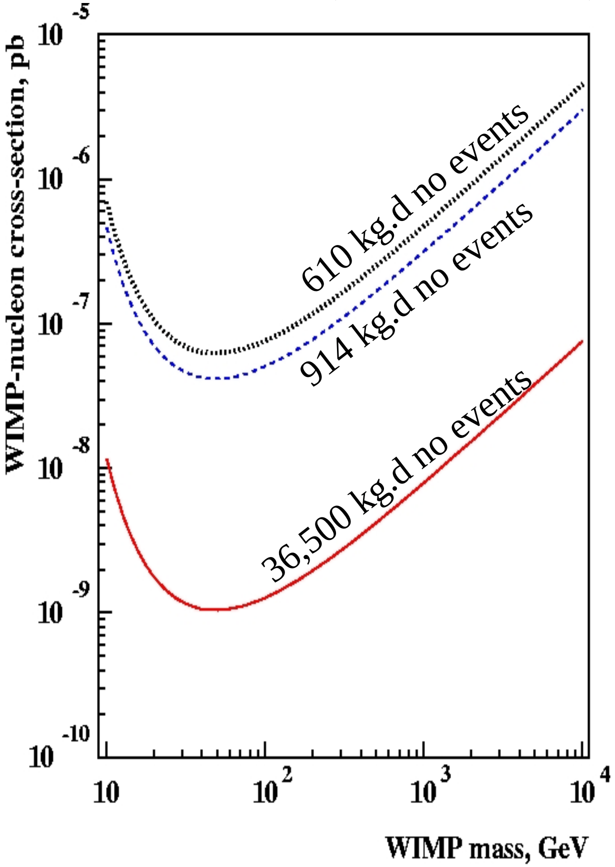
Limits and sensitivity

(preliminary)

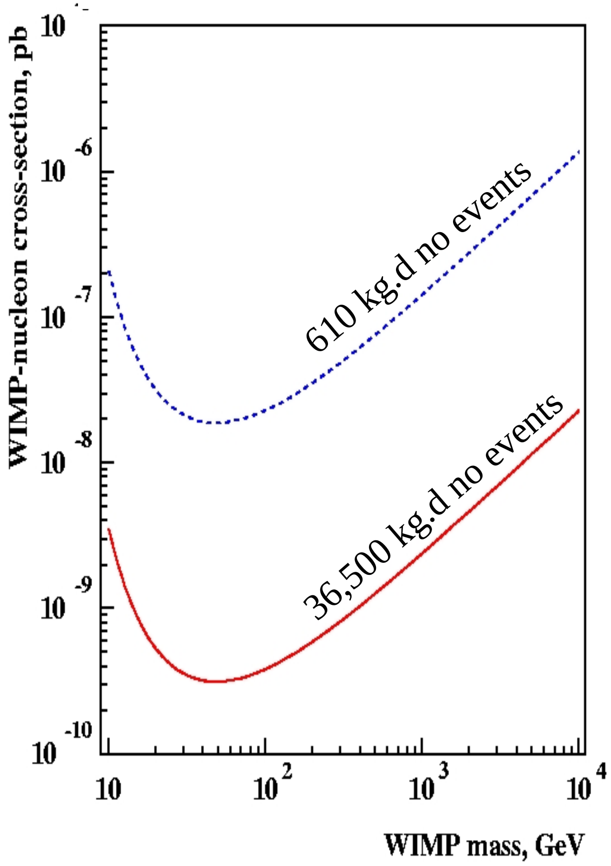
D-I (20 keV



D-II & D-III (10 keV thresh.)



D-II & D-III (50:50 Xe:CS_2)
10 keV thresh.



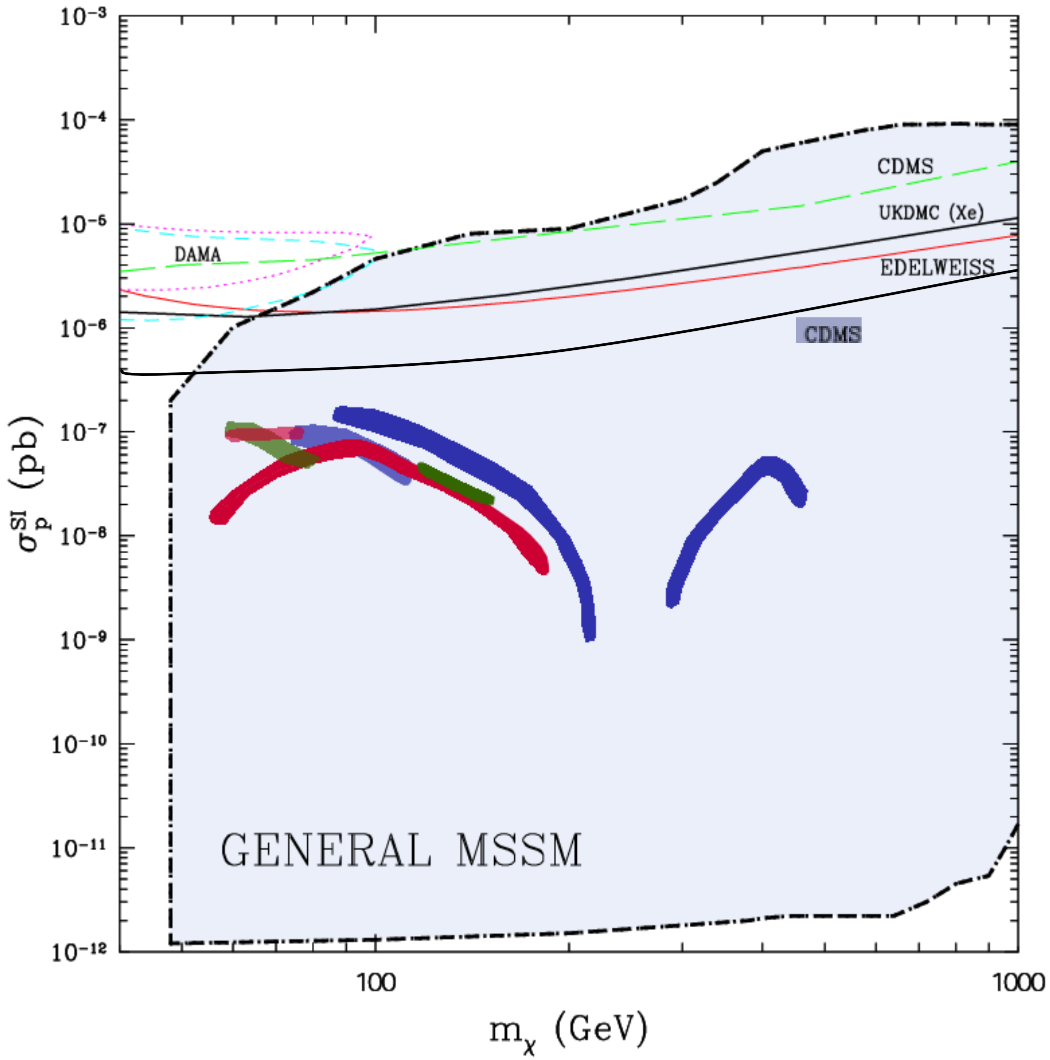
MSSM SUSY SO(10) GUT

Realistic SUSY SO(10) GUT (S. Raby et al.)

Bands allowed by collider limits

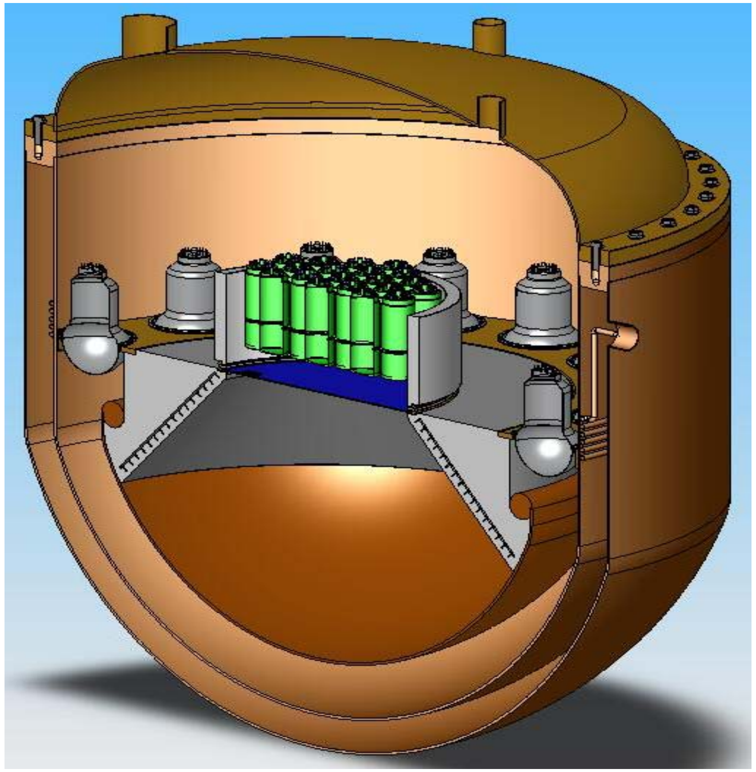
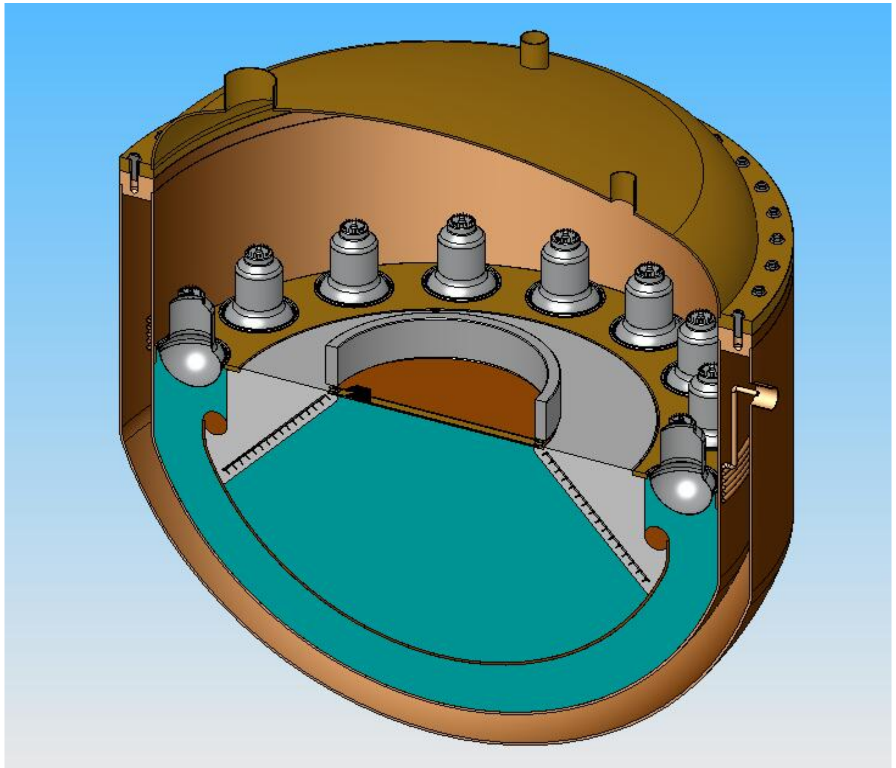
Experimentalists conclusion:

worth a bet!



(Dermisek, Raby, Roszkowski, Ruiz JHEP (2003))

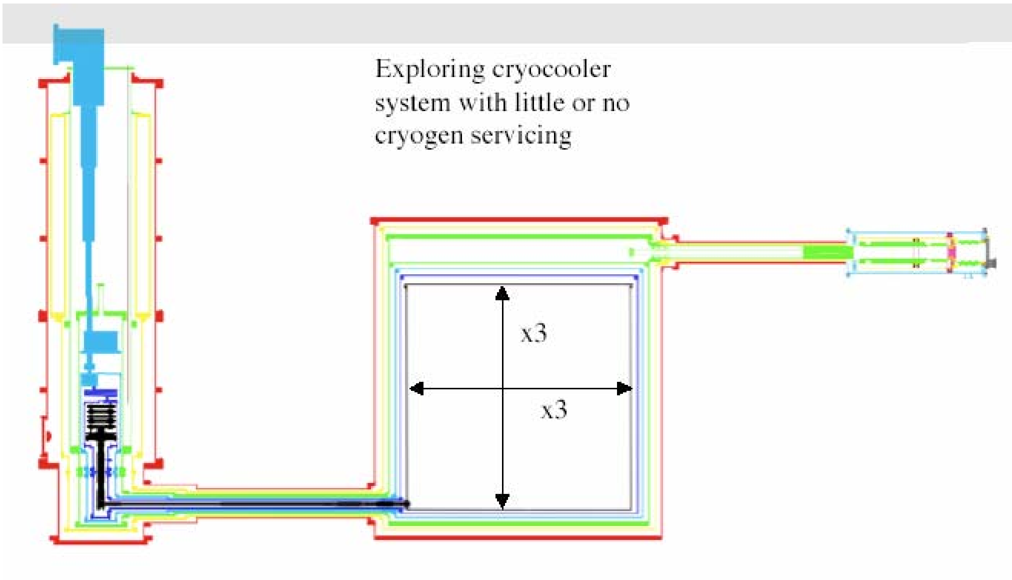
Replace PMTs with charge readout

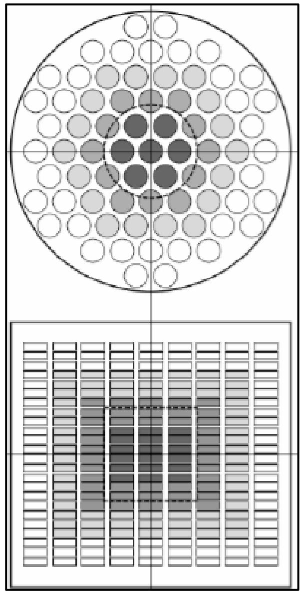
 

But could we go back to gain in the liquid (Peskov et al)?
for 50 μm gap micromegas only needs ~5000V

Example 1 tonne Ge/Si - “SDMS”

- **Ideas from CDMS collaboration**





A: Development Project - Soudan (2008)
B: SNOlab, run 25 kg (2011)
C: Advanced detectors 150 kg-1000Kg (2018)
very expensive - needs larger collaboration

DRIFT vision

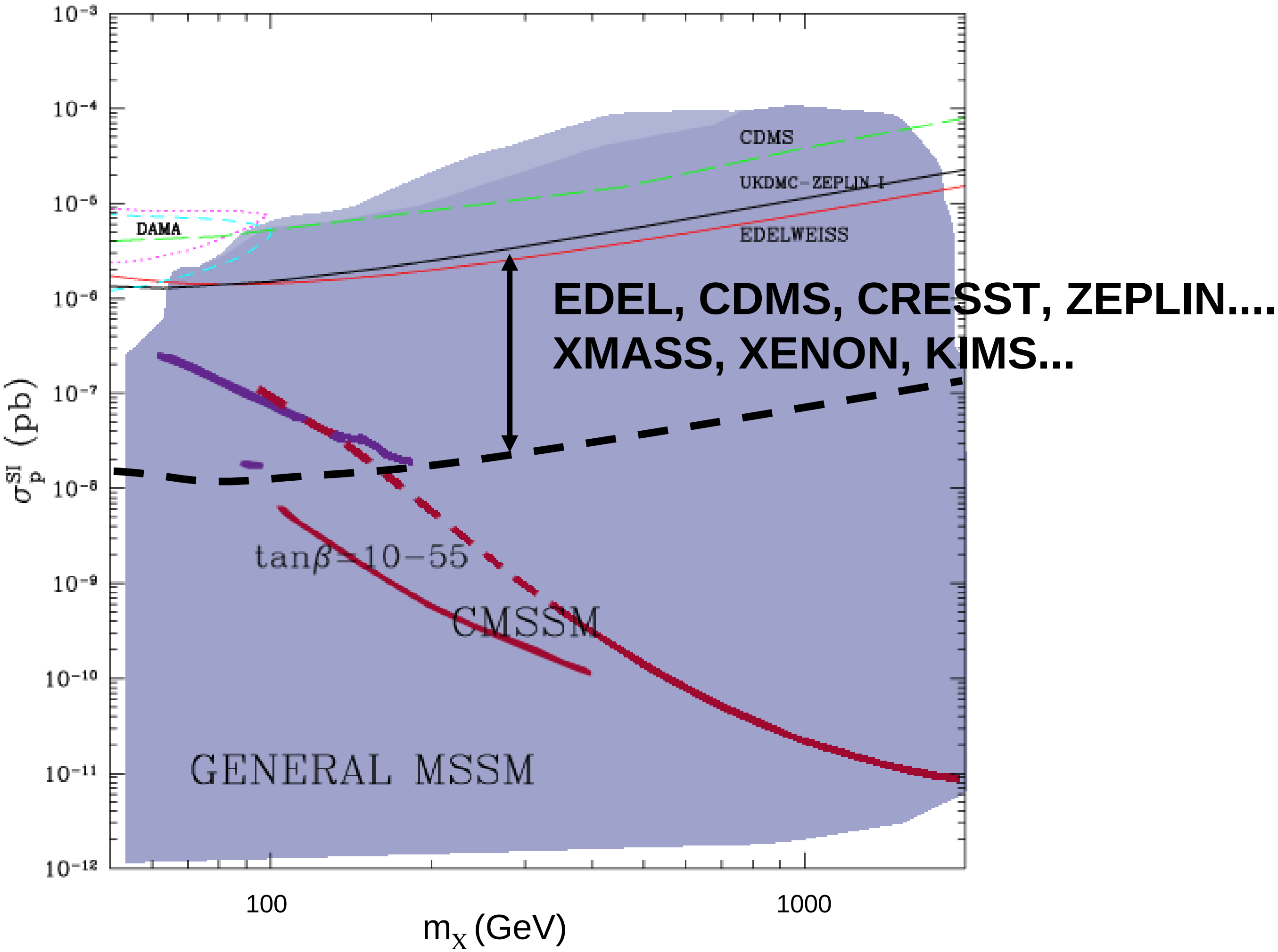
A directional signal - definitive **<u>SEE</u> THE WIMP HALO!**

DRIFT technology - needs space, but:

no cryogenics needed
no complex underground infrastructure
no complex servicing
no expensive target materials
no major problems (down time) with power outages
no levelling

modules potentially cheap (20K/Kg?)

Next 2-3 years = x100



An active neutron veto?

(2) external Gd neutron veto

Assumptions (Xe and Ge):

target is pure and external n shielded

(fission fragments seen, no alpha-n)

Internal detector neutrons dominate

VETO conclusion:

for small units (100s kg) an internal+external neutron veto may achieve only x6 improvement in neutron background (at high cost)

(1) better to spend cash on lower intrinsic internal background

(2) and/or larger detectors with a fiducial cut

(detection of gammas from neutron capture)

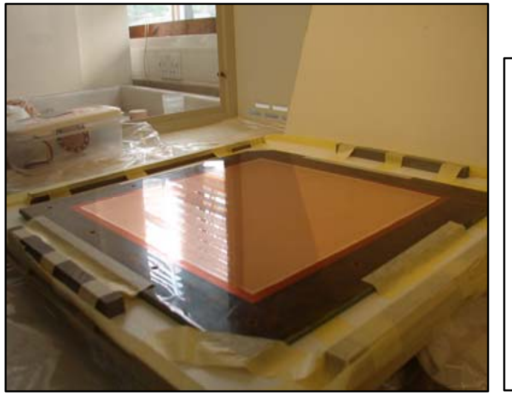
conclusion

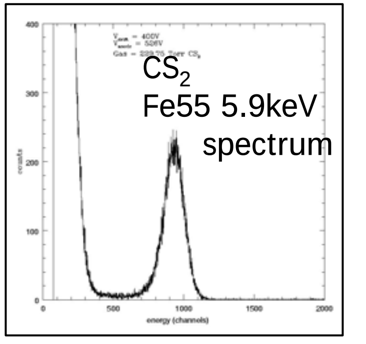
probably poor solution because only 70% rejection but have to add material, which itself must be very low background

Better PSD for higher pressure?

DRIFT III (US-UK)

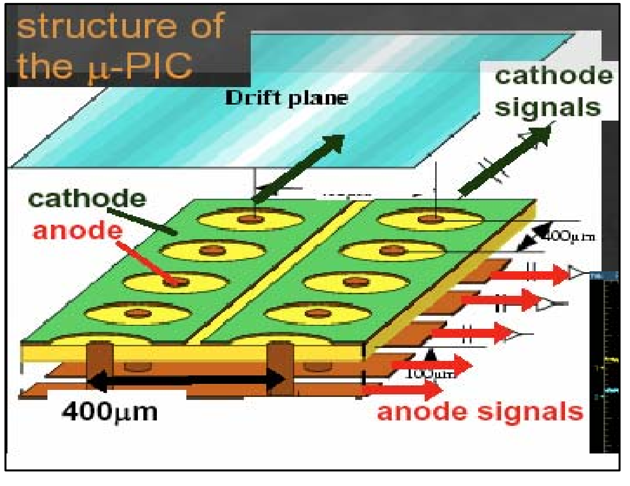
- GEMs,Micromegas
- 25 x 25cm trials

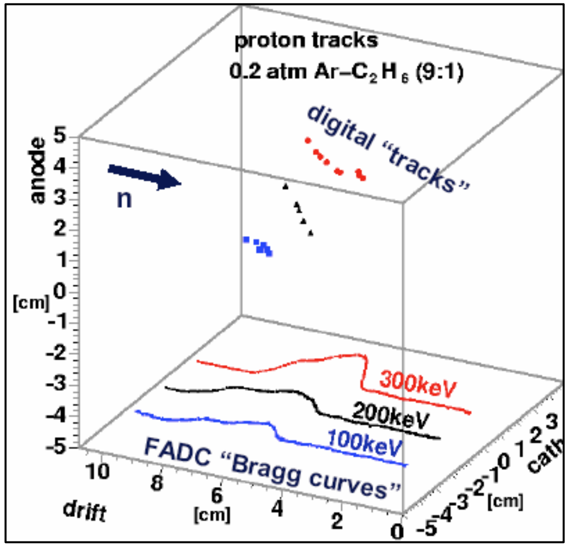




NEWAGE (Japan)

- micro-PIC (micro pixel chamber)
- 120 micron 2-D position readout
- 30 x 30 cm under development



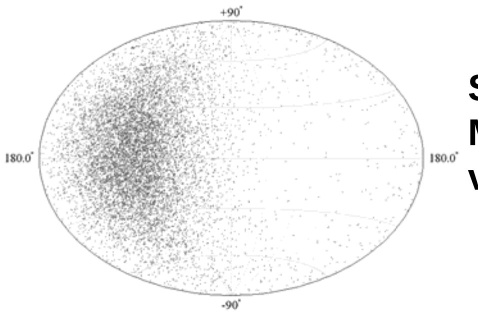


Ultimate aim - HEAD-TAIL discrimination --> x10 better halo identification

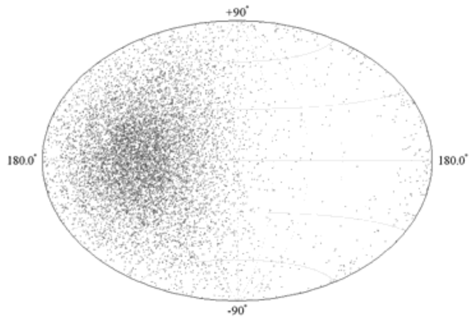
Ultimate goal - WIMP astrophysics

WIMP flux inputs for example halo models

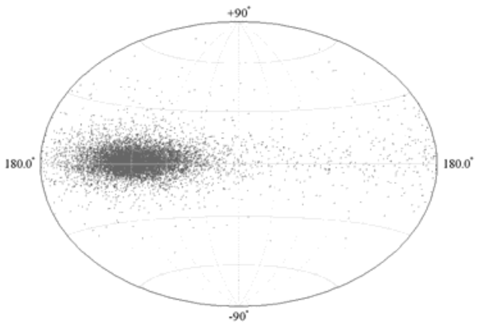
- assume all S (32GeV) recoils with 100GeV WIMPs.



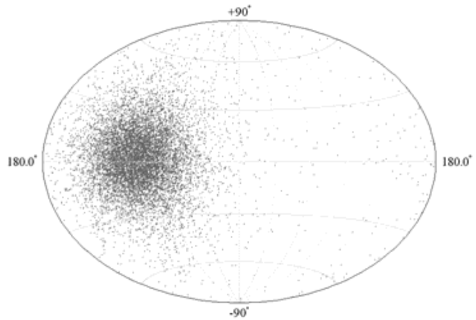
Standard Maxwellian halo, v_0=220kms^{-1}.



N-body simulations also suggest mild radial orbit bias.



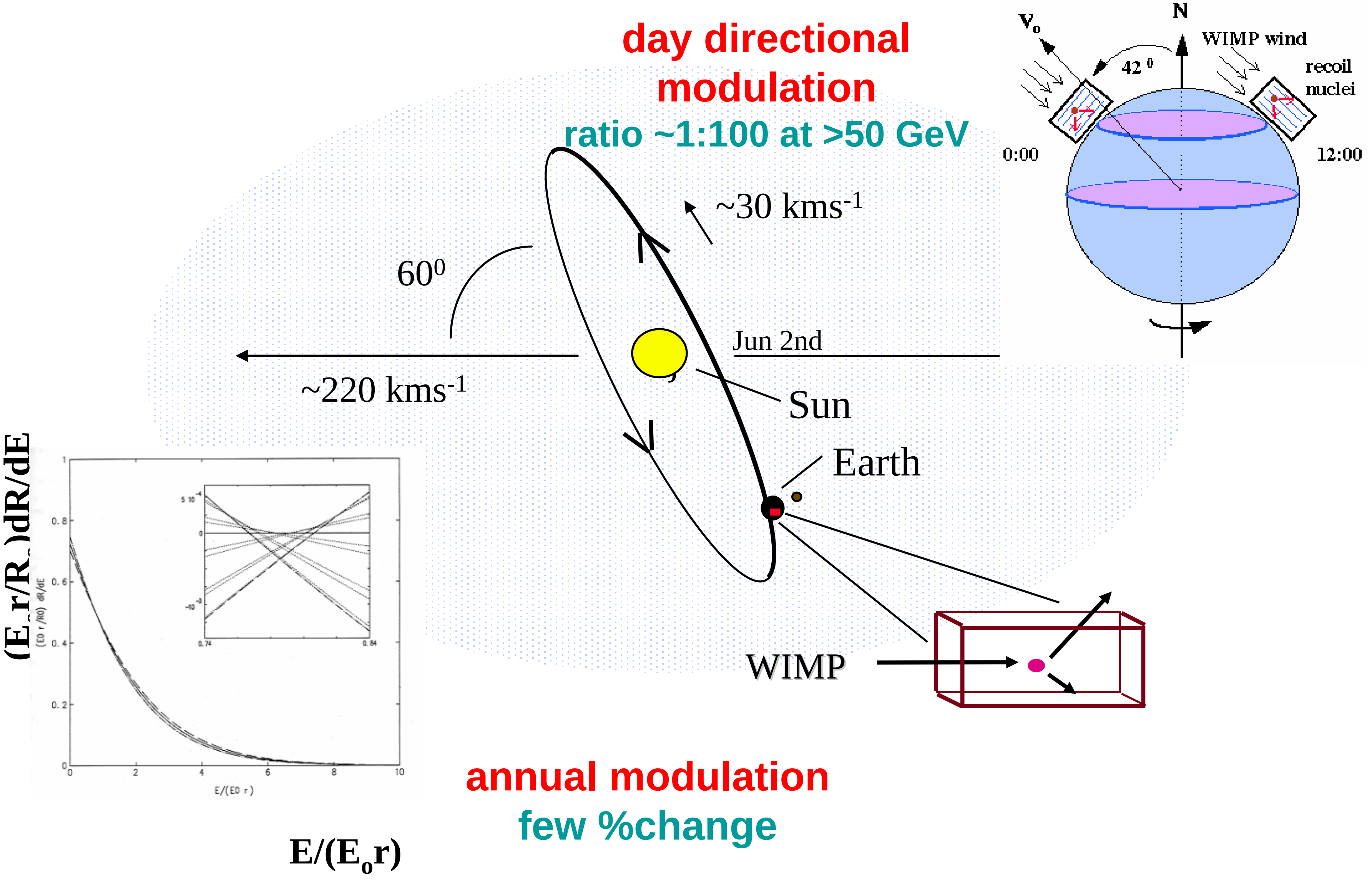
Triaxial - rather extreme case: p=0.72, q=0.7



Triaxial halo with p=0.9, q=0.8.

To see this needs improved technology - i.e. better PSD, larger scale

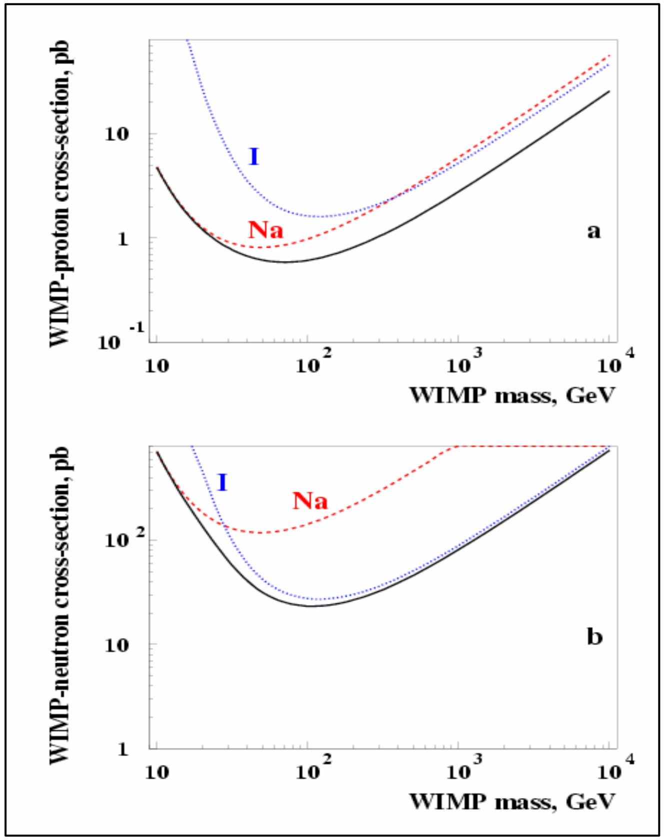
Direct Searches - Signals



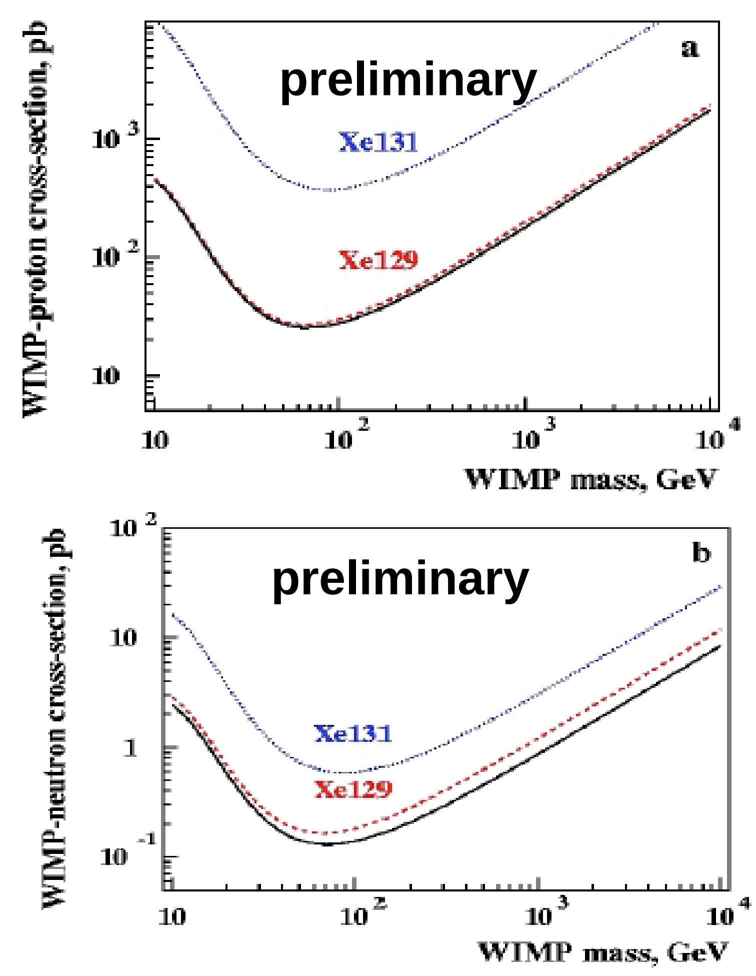
Current status (SD) (2003/4)

NAIAD - NaI

- Data from first 4 (non-optimal) crystals
- 3800 kg.day, pulse shape analysis
- Higgsino



ZEPLIN I - Xe



-Astro-P 19 (2003) 691, see also F. Giuliani et al. Spin/form factors - Ressell and Dean Phys. Rev. C56 (1997) method Tovey et al. Phys. Lett. B 488 (2000) 17

WIMP experiment summary

LABORATORY	EXPERIMENT	TECHNIQUE
Bern (Switzerland)	ORPHEUS	(SSD) Tin Superconducting Superheated Detector
Boulby (UK)	NAIAD	NaI scintillator (50-60 kg)
	ZEPLIN I	Liquid Xe scintillator (4 kg)
	ZEPLIN II/III	Liquid-Gas Xe (scintillation/ionisation) (6-30 kg)
	…N Max	Liquid-Gas Xe1 ton detector (under development)
	…T I/II	Low pressure CS_2 TPC $1m^3$
		Ge ionisation detector (2.1 kg)
	…ON	Ge detector in construction (4x7x2 kg)
	…S	NaI scintillators (110 kg)
	…BUD	$CaWO_4$ and BGO scintillating bolometers (50-200 g)
	…eiss	Ge thermal/ionisation detectors (n x 320 g)
		Ge ionisation detector (2.7 kg)
		…e ionisation in 0.2 kg Ge well
		… in Ln…
		…scint…
		…int…
		…X…
		…tillat…
		…$_2O_3$ 0.2…
	…ST-II	$CaWO_4$ scintillating bolometers (0.6-9.9 kg)
	…ICINO	TeO_2 thermal detectors (41 kg)
	…E	1000x760 g TeO_2 (under development)
		Large mass liquid Xe (R&D)
	…LE	(SDD) Superheated Droplet Detectors (Freon)
	…-II	5 kg Ge +1 kg Si thermal/ionisation detectors
	…-I	1 kg Ge +0.2 kg Si thermal/ionisation detectors
	…SSO	(SDD) Superheated Droplet Detectors (Freon)
	…ANTS V	Massive NaI scintillators (670 kg)
	ELEGANTS VI	CaF_2 scintillators

- **Semiconductor**
  Ge, Si, GaAs, TlBr….
- **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**

……..

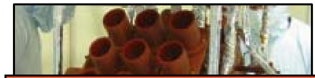
Phonon (ionisation-thermal)

Xenon (ionisation-scintillation)

TPC (directional)

Apologies for those techniques and groups left out...

XMASS route



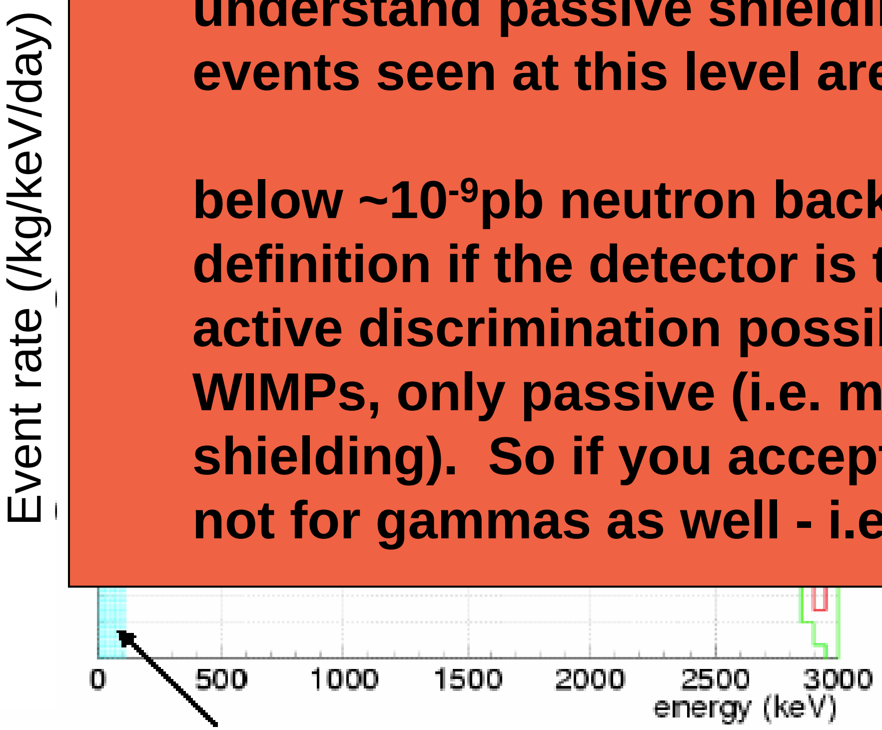
3 Kg fiducial volume

SUGGESTS POSSIBLE SHIFT in WHOLE PHILOSOPHY of WIMP DETECTION?

above ~10^{-9}pb we emphasize active gamma discrimination as a means of identifying WIMPs because we think we understand passive shielding of neutrons to be sure any events seen at this level are not neutrons.

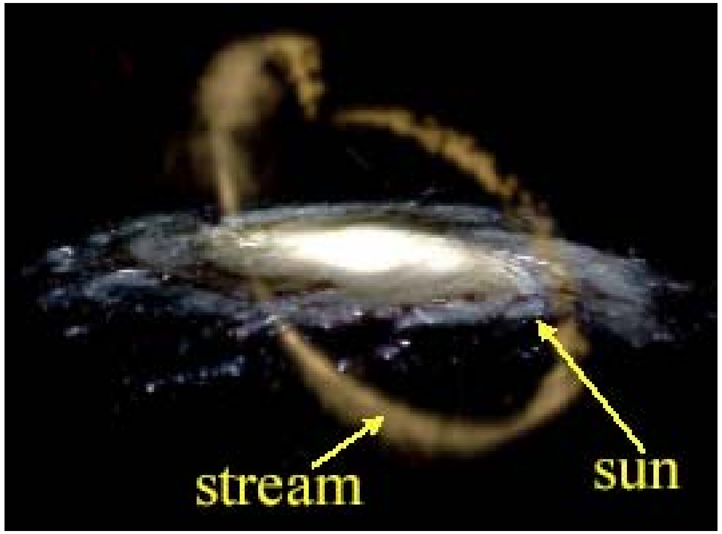
below ~10^{-9}pb neutron background has to dominate (by definition if the detector is to be any use). But there is no active discrimination possible between neutrons and WIMPs, only passive (i.e. material purity and passive shielding). So if you accept passive shielding here, why not for gammas as well - i.e. forget recoil discrimination

s



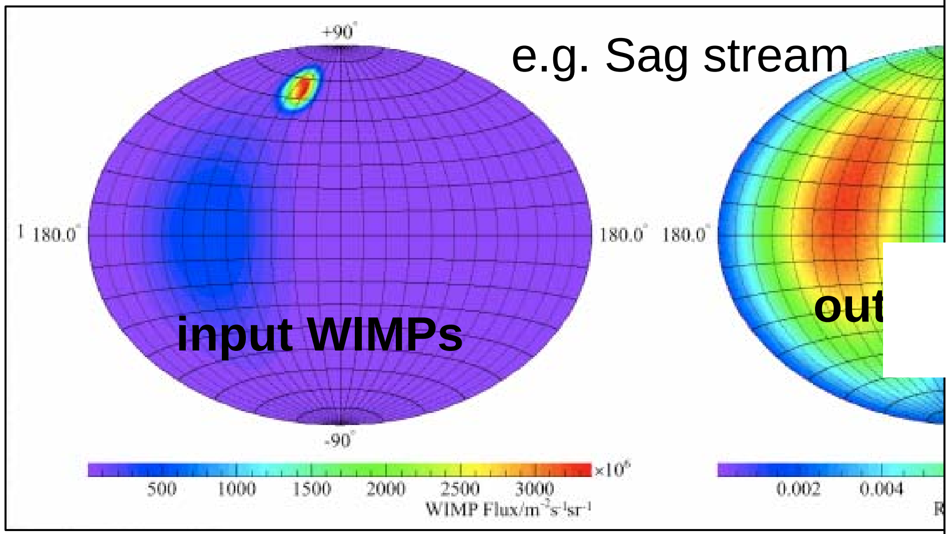
BUT is light collection sufficient for position sensitivity?

Aim - See the galactic WIMP halo



how many WIMP events are needed?

Halo Model	N_{iso} for $(R_c, A_c) = (0.90, 0.90)$						
	Vectorial Statistics				Axial Statistics		
	$\mathcal{W}^*$	$\mathcal{A}$	$\mathcal{F}$	$\langle\cos\theta\rangle$	$\mathcal{B}^*$	$\mathcal{G}$	$\langle\lvert\cos\theta\rvert\rangle$
1	12	12	13	7	167	168	104
2	12	12	12	7	112	114	73
3	14	14	15	8	156	157	[illegible]
4	12	12	13	7	148	150	96
5	15	15	15	[illegible]	215	215	[illegible]
6	11	11	11	6	67	68	47
7	14	14	14	8	89	88	74
8	13	13	13	7	176	177	112
9	15	15	16	9	264	265	188
10	15	15	15	8	278	281	194
11	12	12	12	7	126	128	81
12	16	16	17	9	233	234	210
	N_{iso} for $(R_c, A_c) = (0.95, 0.95)$						
1	18	18	19	11	235	235	131
1 (no)	16	16	17	9	128	129	65
6	16	16	16	10	96	96	59
7	19	20	20	12	125	126	94
8	18	18	19	11	248	249	142
9	21	21	22				237
10	21	21	21				244
11	17	17	17				102
12	20	20	20	15	326	327	276

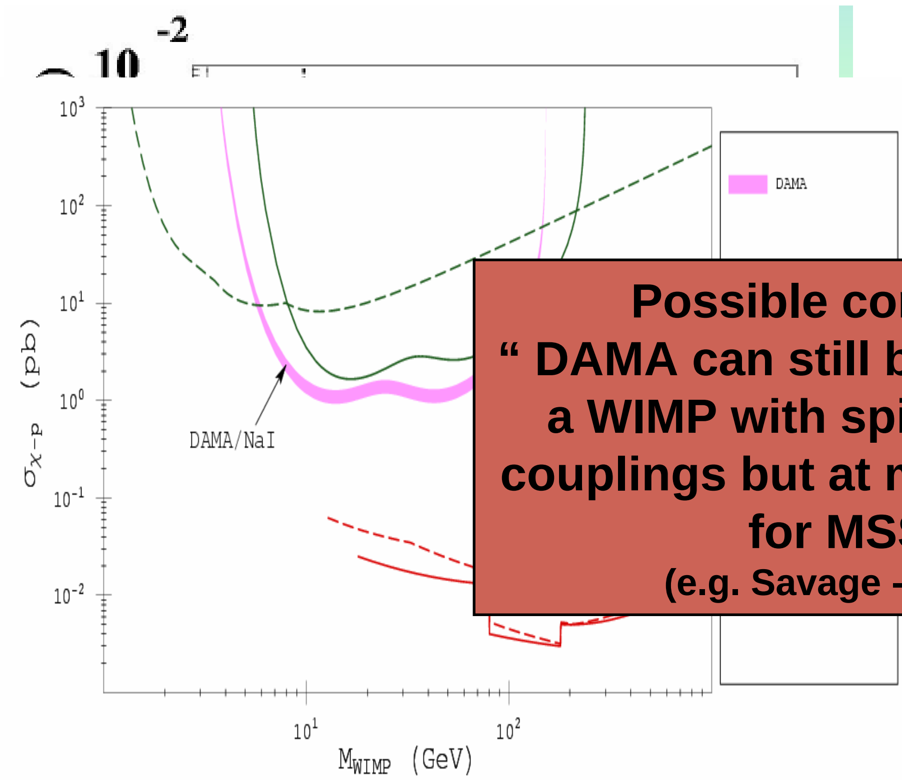


predictions for TPC-type detector
with 200 μm resolution

B. Morgan
A. Green

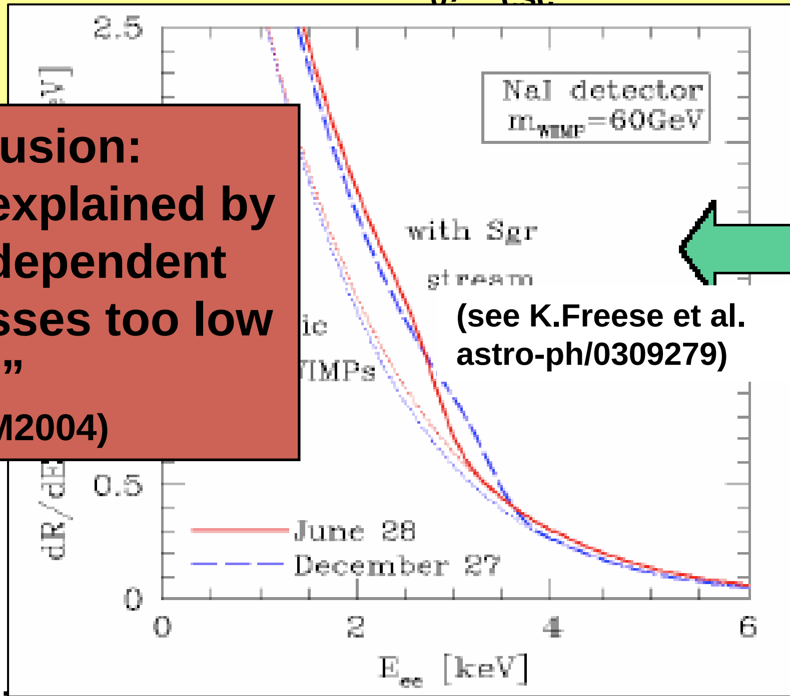
Possibility 1 - wiggle room? e.g:

Many different model assumption explored - can push allowed region around



Model uncertainties

Halo structure - v_0, v_{esc}



(see K.Freese et al. astro-ph/0309279)

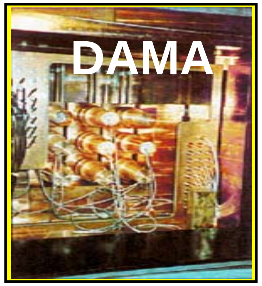
Possible conclusion:
" DAMA can still be explained by a WIMP with spin dependent couplings but at masses too low for MSSM"
(e.g. Savage - IDM2004)

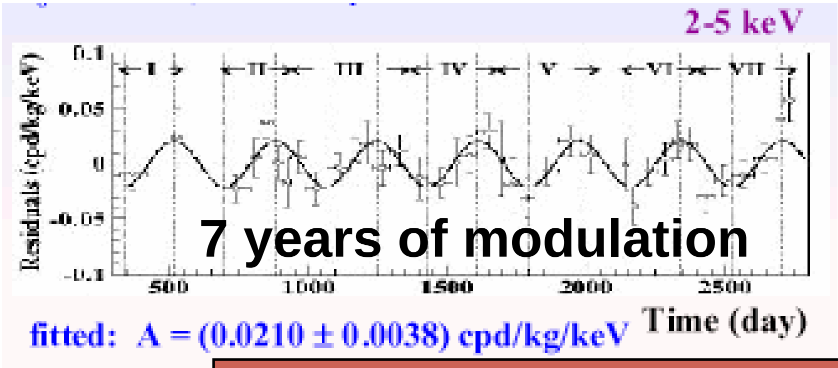
a steep spectrum but SD would give flatter spectrum
- I and Na comparable (no A^2 dominance) -

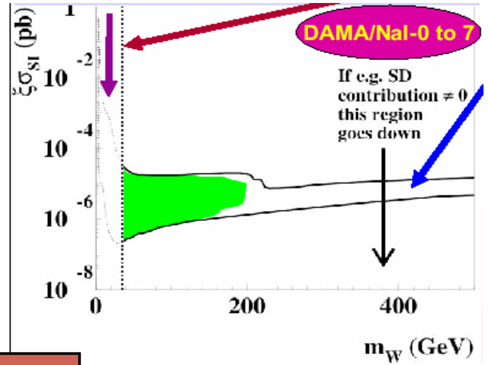
5-6 0.03+/-0.01

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

Paths from detection - 10^{-6}pb (now-2005)







point 1 Any wiggle ... el I, CDMS I, Zep I.?

- if pure SI - very diff ... ep spectrum but SD
- component of SD a ... d give flatter spectrum
  ... d Na comparable
  ... A^2 dominance)-

Possible conclusion:
" DAMA can still be explained by a WIMP with spin dependent couplings but at masses too low for MSSM"
(Chris Savage)

point 2 What if correct?

- Alternative NaI experiments?
- More annual modulation - Libra (250 kg) underway (1 Ton NaI next)
- ⟹ progress to directional confirmation now.......

[NB: at DAMA WIMP rate ~3kg.yr pure recoil data is enough see annual modulation]