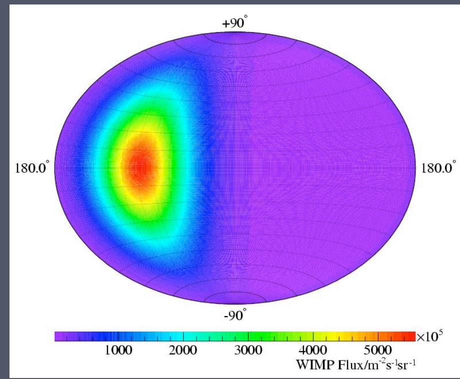
Experimental Techniques to Measure the WIMP Wind Direction



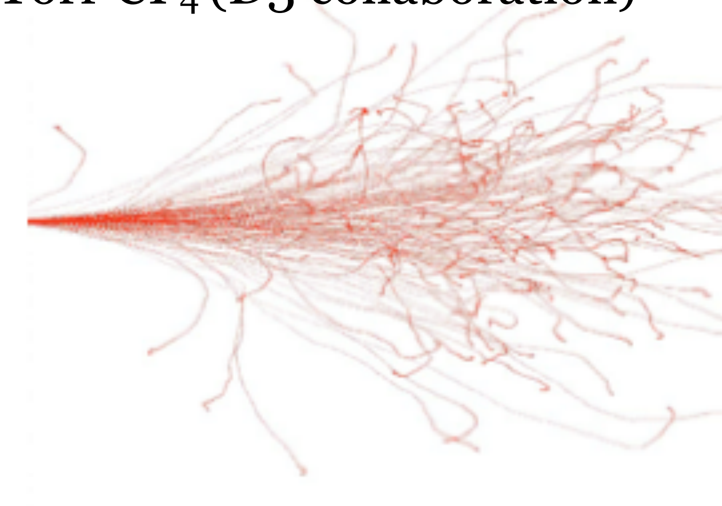
Neil Spooner, University of Sheffield

- Directional Detector Motivation and Basics
- Gas TPCs
- Alternative technologies
- Future - DRIFT-III

What a WIMP does

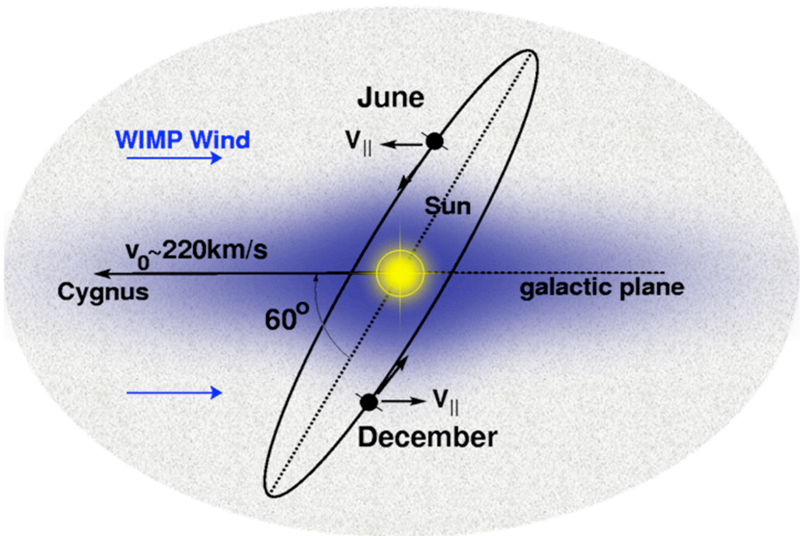
atom

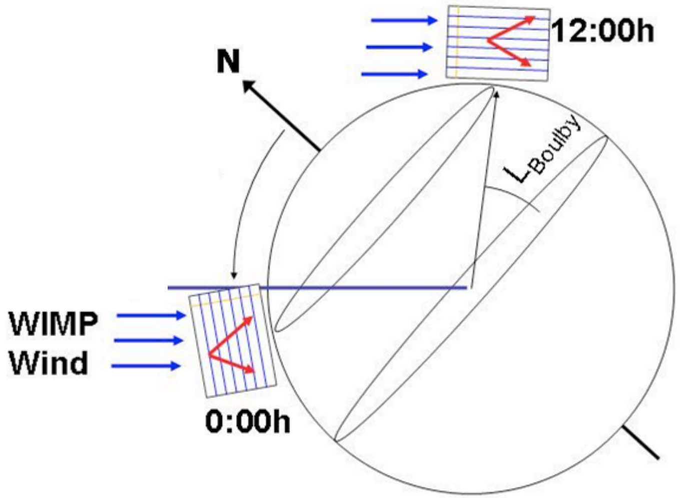
SRIM simulation - 100 keV F recoil
in 75 Torr CF_4 (D3 collaboration)



Galactic Signature

- Motion of the Earth through a static WIMP 'halo' -> Earth is subject to a 'wind' of WIMPs
- of average speed ~220kms^{-1} coming roughly from the direction of the constellation Cygnus.
- The Earths rotation relative to the WIMP wind -> Direction changes by ~90° every 12 hours

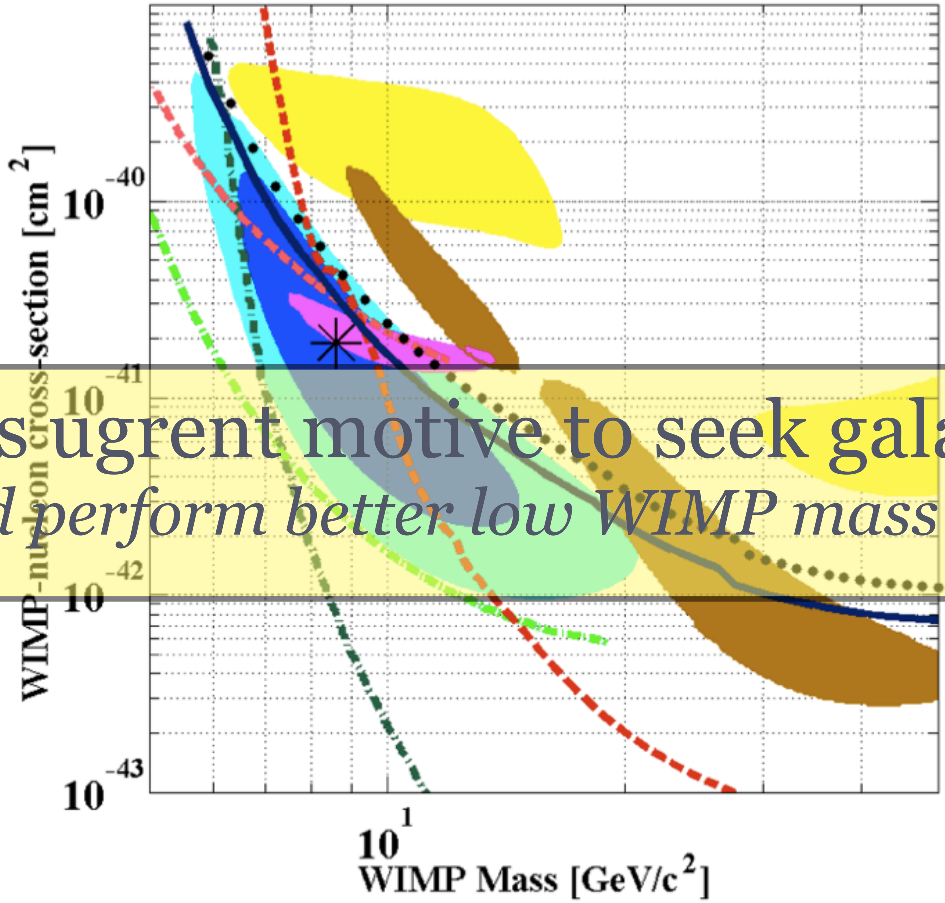




There is a simple, strong, SIGNATURE for WIMP dark matter - that nuclear recoils produced move opposite to our motion in galactic coordinates towards Cygnus. No terrestrial background can mimic this signal.

Confusion in WIMP World

- Currently ~6 direct search experiments see events above expected background - DAMA/LIBRA, CoGENT, CRESST, CDMS/Edelweiss
  and three/four claim detection of WIMP DM



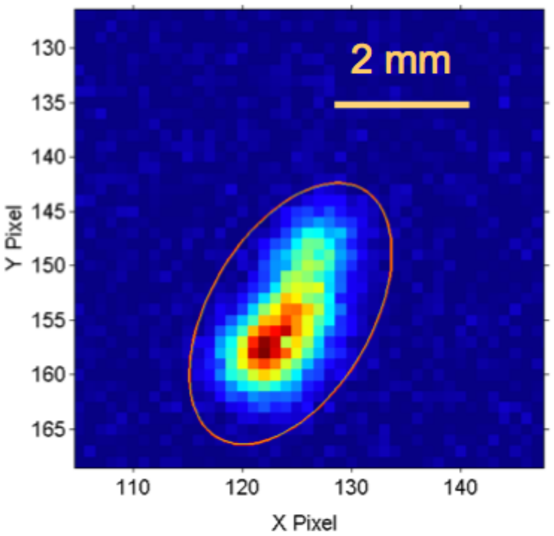
There is ugrent motive to seek galactic signals

and perform better low WIMP mass searches

- Current technologies are bugged by suspect background rejection due to limited particle ID and no clear signal

Power of Recoil Tracking

A gas TPC gives incredible discrimination power by multiple parameters:



- total ionisation
- particle range
- dE/dX topology
- track orientation (axial)
- track sense (head-tail)(vector)

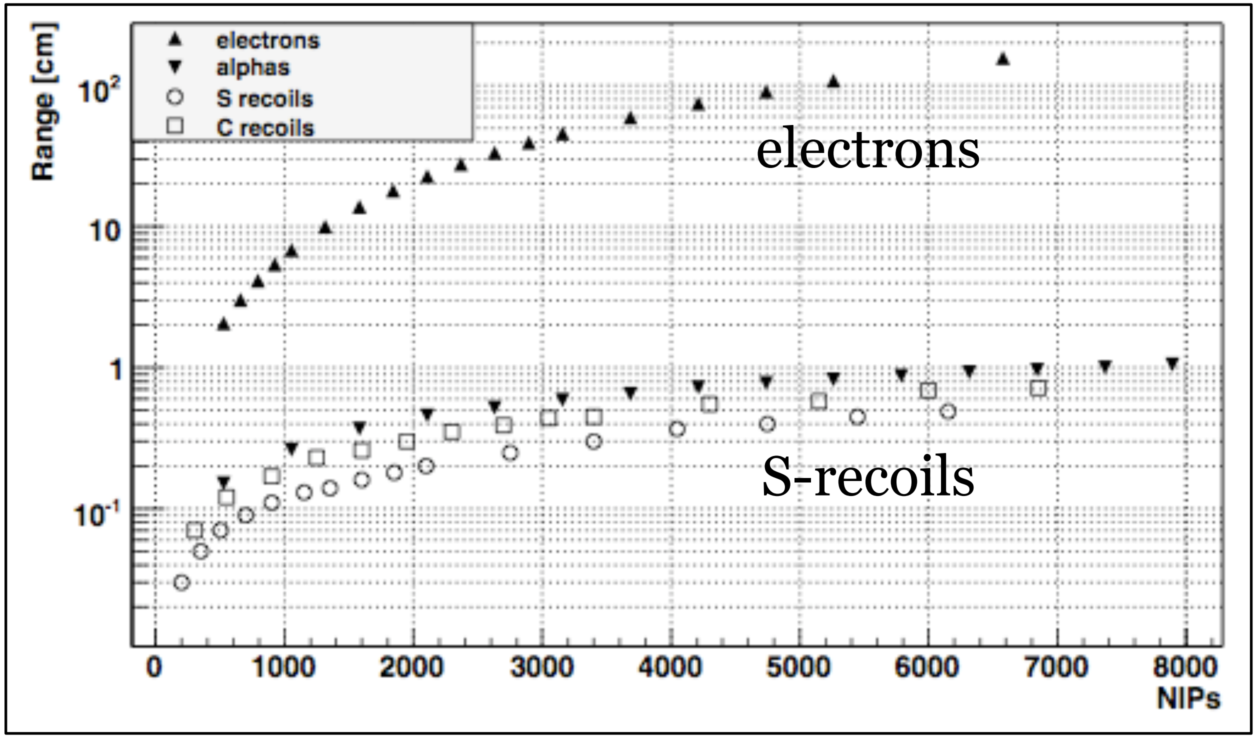
Results from UNM (Dinesh Loomba) operating CCD readout with CS_2

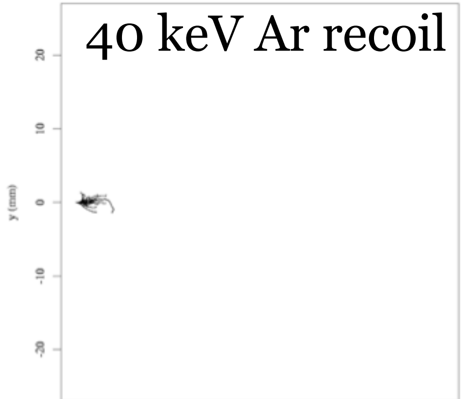
Far more information on events than possible with conventional DM technologies:

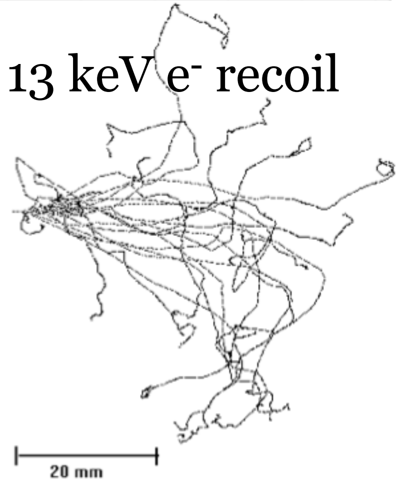
- 3D recoil direction, and sense (head-tail), full particle ID
- A definitive signal, linked to the galaxy, can not be mimicked
- Event by event background rejection, gamma, electron, recoil tracking in space and time (>10^6 gamma rejection)
- Low threshold, <5 keV nuclear recoil feasible
- Many targets possible, C, S, F, Xe… (SD)
- Room temperature operation, relatively known technology

e.g. Range Discrimination

Simulations with 40 Torr CS_2 or in 40 Torr Ar







Key points: it's range discrimination - no doubt
$>10^6$ gamma rejection shown in DRIFT II

S. Burgos et al., Astropart. Phys. 28 (2007) 409

Discovery Strategy

A WIMP search strategy with a directional detector and be divided into three phases which require successively larger numbers of events (and larger exposure):

(1) Search phase (detection of nonzero recoil signal)
(2) Detection of anisotropy
(3) Study of properties of anisotropy

A. Green et al., AstroP 27 (2007) 142; Phys. Rev. D 81, 061301 (2010)

$$f_0(\vec{v}) = \frac{1}{(2\pi/3)^{3/2}\sigma_v^3} \exp\left(\frac{3|\vec{v}|^2}{2\sigma_v^2}\right)$$

Modelling the Milky Way WIMP halo

This leads to a complex optimisation and choice of detector parameters and detector design:

- Full track imaging or asymmetry signal only?
- 1D, 2D or 3D tracking?
- Track sense and head-tail discrimination or not?
- Low energy threshold or not? Low mass WIMP or not?
- Background rejection power
- SI and SD sensitivity, or both
- Scale-up to multi-tonne or not

Is sufficient directional sensitivity possible in a direct WIMP search without ever visualising the nuclear recoil?

Optimising Detectors

Directional signals

e.g. how many WIMPs are needed to get a directional (non-isotropic) signal?:

A. Green et al., AstroP 27 (2007) 142

difference from baseline configuration	N_{90}	N_{95}
none	7	11
$E_T = 0$ keV	13	21
no recoil reconstruction uncertainty	5	9
$E_T = 50$ keV	5	7
$E_T = 100$ keV	3	5
$S/N = 10$	8	14
$S/N = 1$	17	27
$S/N = 0.1$	99	170
3-d axial read-out	81	130
2-d vector read-out in optimal plane, raw angles	18	26
2-d axial read-out in optimal plane, raw angles	1100	1600
2-d vector read-out in optimal plane, reduced angles	12	18
2-d axial read-out in optimal plane, reduced angles	190	270

} upgraded and unrealistic

} assuming perfect angular resolution

A conclusion - head-tail discrimination ("vector") may be more important than 3D reconstruction (however, 3D may be important for background rejection).

Optimising Detectors

A. Green et al.

Axial vs. Vector sensitivity:

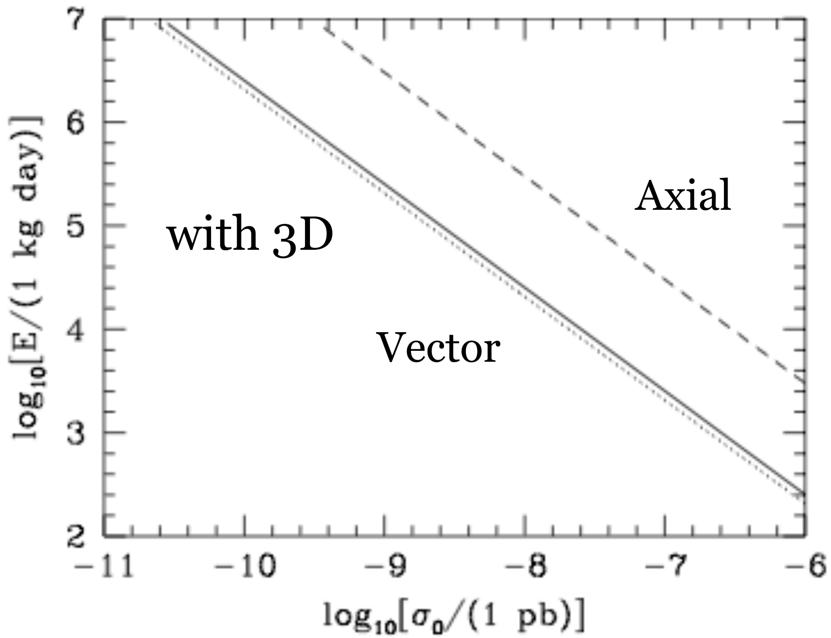


Fig. 6. As Fig. 3. The solid line is for the benchmark configuration (3-d vector read-out, recoil reconstruction uncertainty taken into account). The dotted line is 3-d vector read-out ignoring the uncertainty in the reconstruction of the recoil direction. The dashed line is axial 3-d read-out.

Directional sensitivity vs. energy threshold

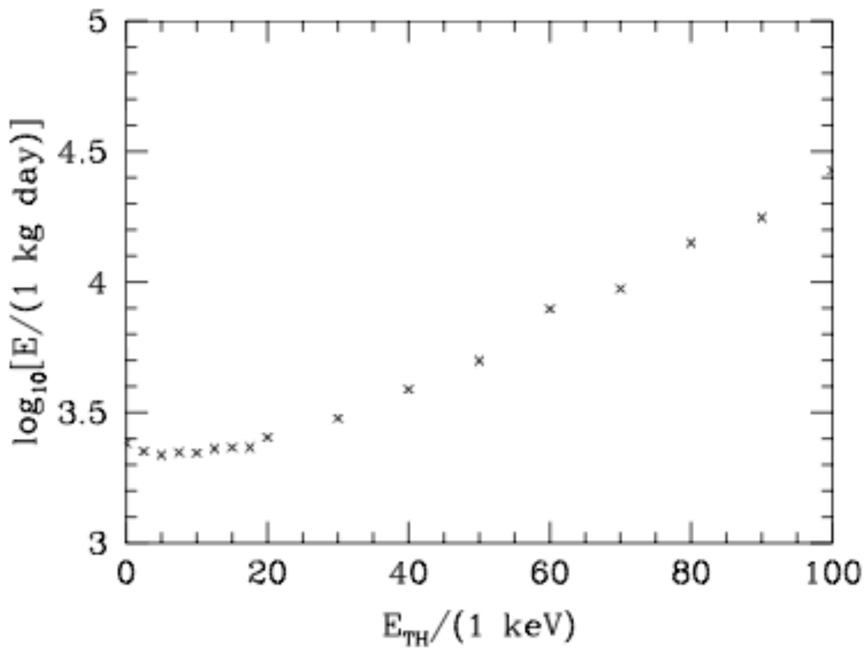


Fig. 4. The exposure required to reject isotropy (and detect a WIMP signal) at 95% confidence in 95% of experiments as a function of energy threshold, for WIMP-proton elastic scattering cross-section $\sigma_0 = 10^{-7}$ pb, assuming a local WIMP density of $\rho = 0.3$ GeV cm^{-3}.

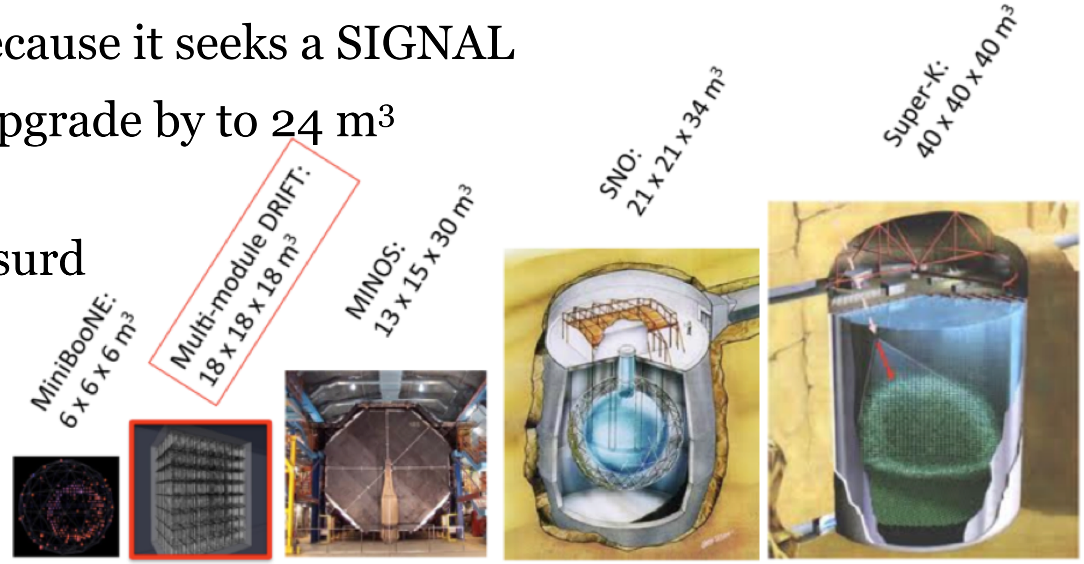
A conclusion - low energy threshold may not be important for directionality (however, it may be important for background rejection).

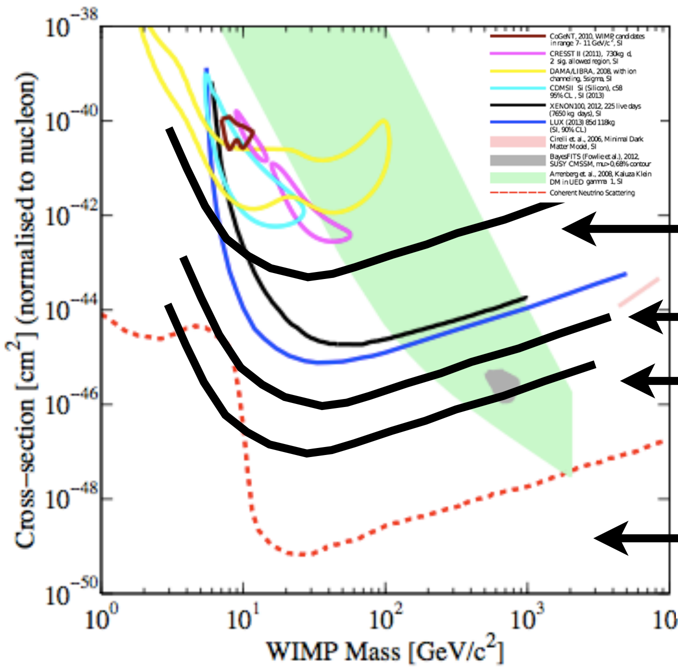
CYGNUS Workshops 2007-2009-2011-2013..

Towards Tonne-Scale?

- The ultimate WIMP experiment because it seeks a SIGNAL
- DRIFT III may be the next step - upgrade by to 24 m³
- Ultimate volumes for TPC directionality are tough but not absurd nor necessarily unaffordable (?)

Existing particle physics detector volumes and equivalent mass of DRIFT gas....





- It's directional so in principle no known background, <u>not even solar neutrinos</u>?

24 m³ with low threshold upgrade

24 tons, SK volume is ~64 tons at 1kg/m³

240 tons

this is a thought experiment - just used scaling here so needs more work

GAS

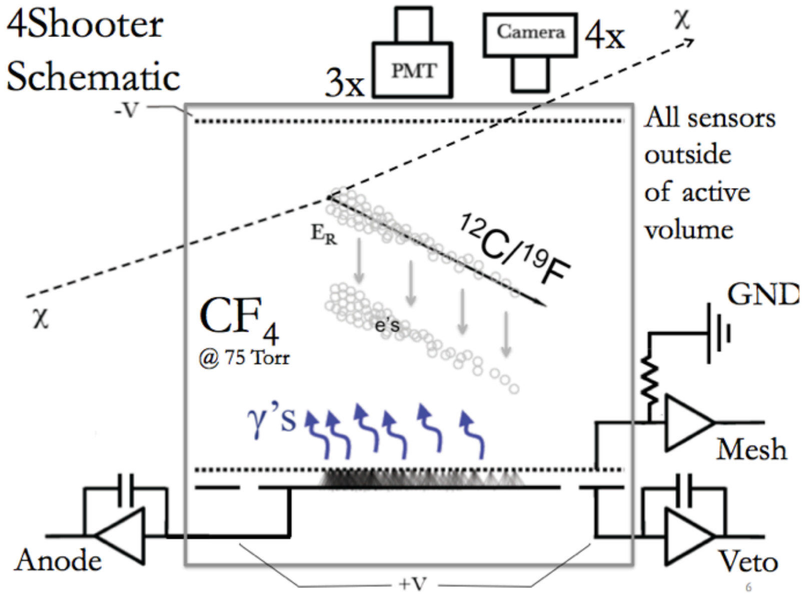
DM-TPC
DRIFT-UNM optical TPC R&D
MIMAC
NEWAGE
D3
DRIFT-II

DM-TPC

DMTPC Collaboration

Brandeis University
A. Dushkin, H. Wellenstein*
Bryn Mawr/Wellesley
T. Ananna, E. Barbosa de Souza, J. Battat*, V. Gregoric, K. Recine,, L. Schaefer
University of Hawaii
I. Jaegle, S. Ross, S. Vahsen*
MIT
H. Choi, C. Deaconu, P. Fisher*, S. Henderson, W. Koch, J. Lopez, H. Tomita
Royal Holloway (UK)
G. Druitt, R. Eggleston, P. Giampa, J. Monroe*

Concept: low pressure CF_4 with charge mesh and CCD optical readout



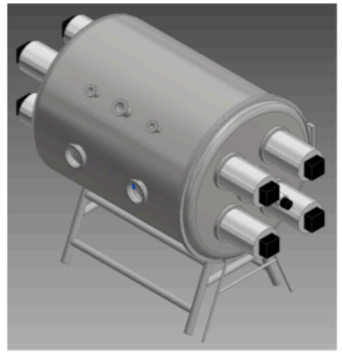
10L

Underground at WIPP

4Shooter (20L)

At MIT

DMTPCino (m^3)



Under development

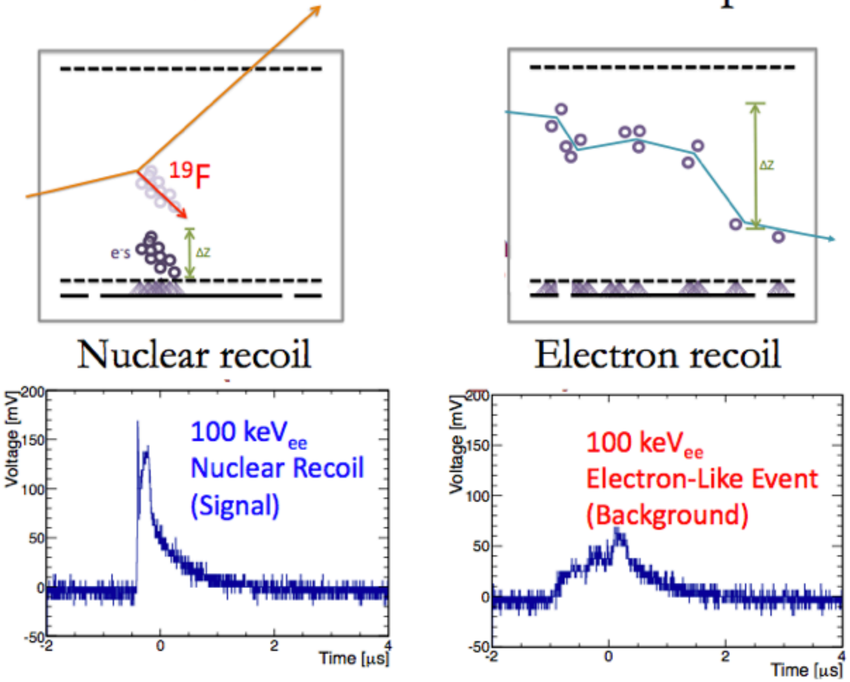
- Avalanche in mesh produces amplification and scintillation
- Primary ionisation encodes track direction via dE/dx profile
- Light and charge readout required for tracking backgrounds
- Light used to reject wrong Range vs. E; charge to reject e^-. CCD artefacts
- No ΔZ from light (for 3D) - R&D to use charge signal for 3D
- No absolute Z or Z fiducialisation

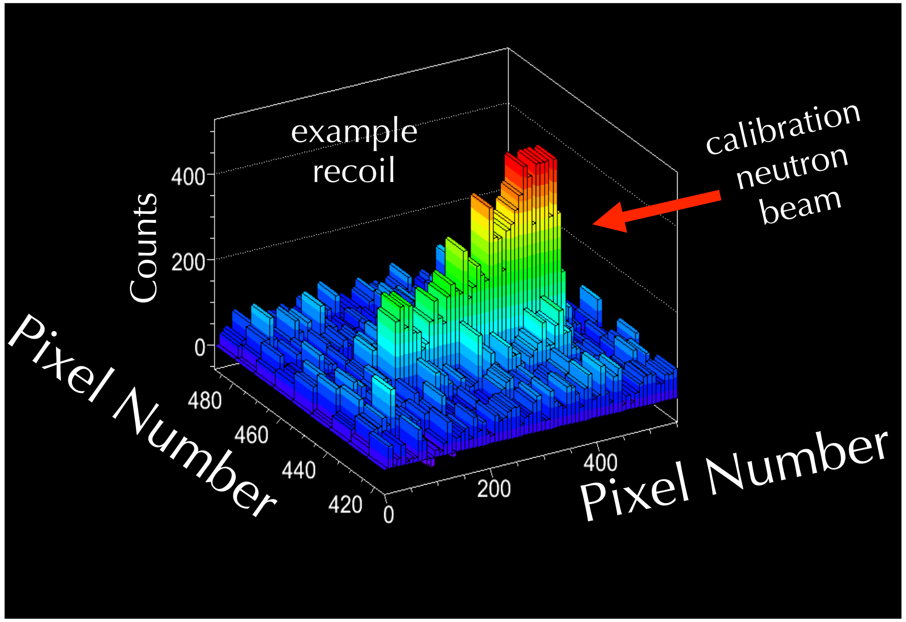
arXiv:1301.5685v2 (2013)

DM-TPC

- Use of charge signal to aid electron rejection
- F-recoils at high energy show head-tail asymmetry

Event discrimination based on mesh pulse shape

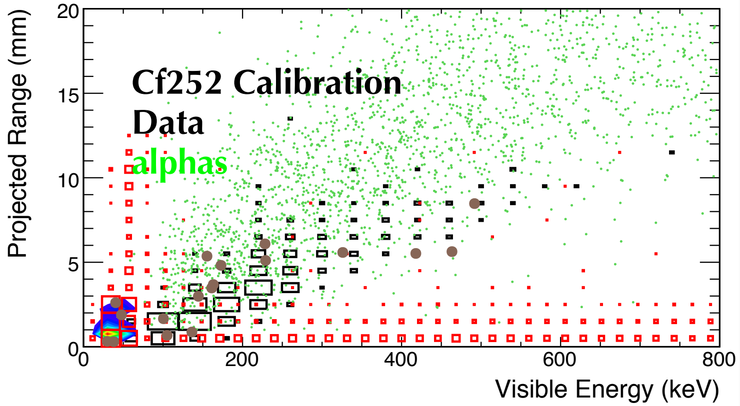


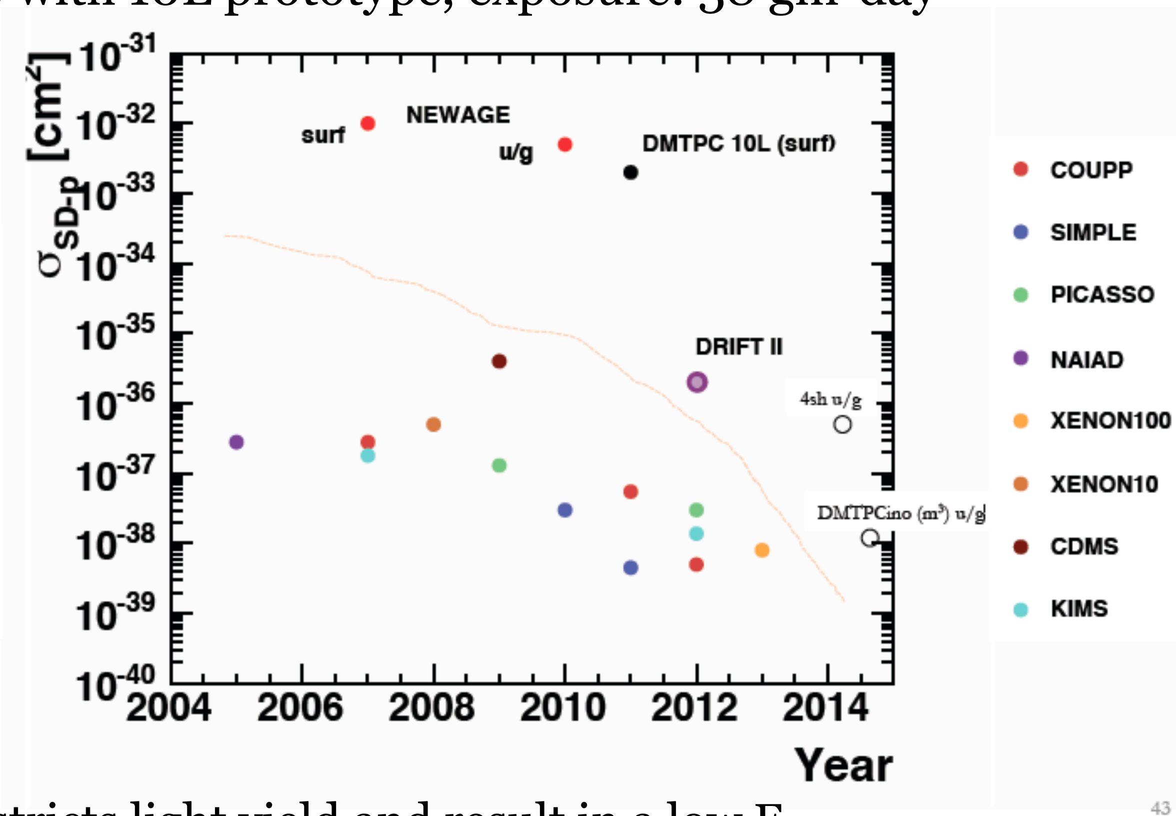


DM-TPC

DMTPC limit at surface (2011) with 10L prototype, exposure: 38 gm-day
CF_4, 80 keV_r E_{th}

S. Ahlen et al., Phys. Lett. B 695 (2011)





Challenges for DM-TPC?:

- Use of mesh and pure CF_4 restricts light yield and result in a low E_{th}
- Fast CF_4 makes makes ΔZ hard to do
- No Z fiducialisation
- Can CCD technology be scaled-up?
- CCD noise: residual bulk images (e.g. from sparks), (2) intermittent hot pixels, (3) noise events, (4) out of time events

DM-TPC

DMTPCino: 1m^3 Detector

- Prototype for very large detector: build many 1 m^3 modules because of diffusion limit.

- Design based on 4-shooter 20L prototype:

(i) multi-camera readout
(ii) low-background materials
(iii) triggering with charge/PMTs

- Detector under construction now - vacuum vessel acceptance test (2 weeks ago), commissioning Fall 2014

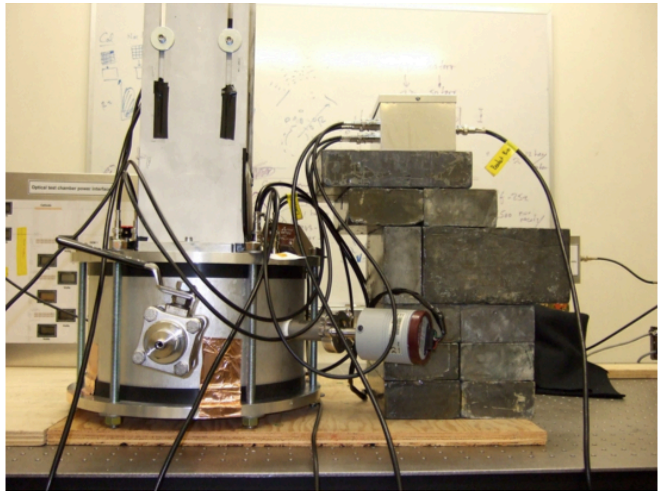
UNM R&D (DRIFT)

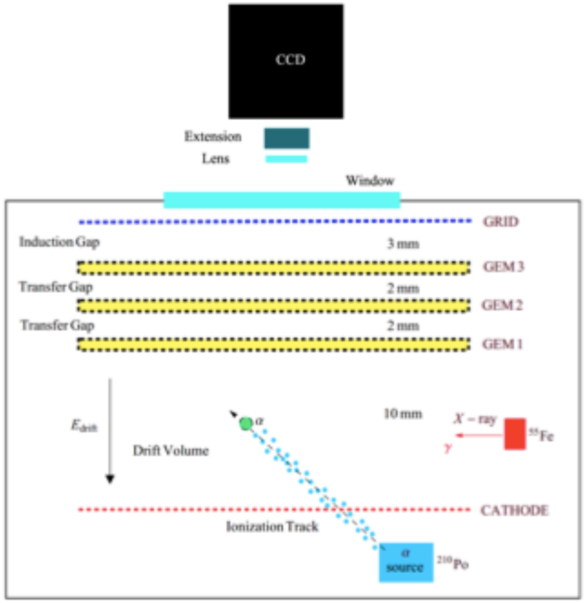
Dinesh Loomba

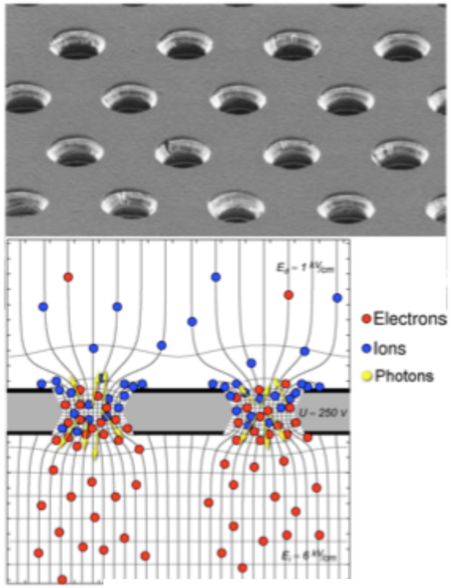
Concept: low pressure CF_4 and CS_2 with ThGEM and CCD optical readout

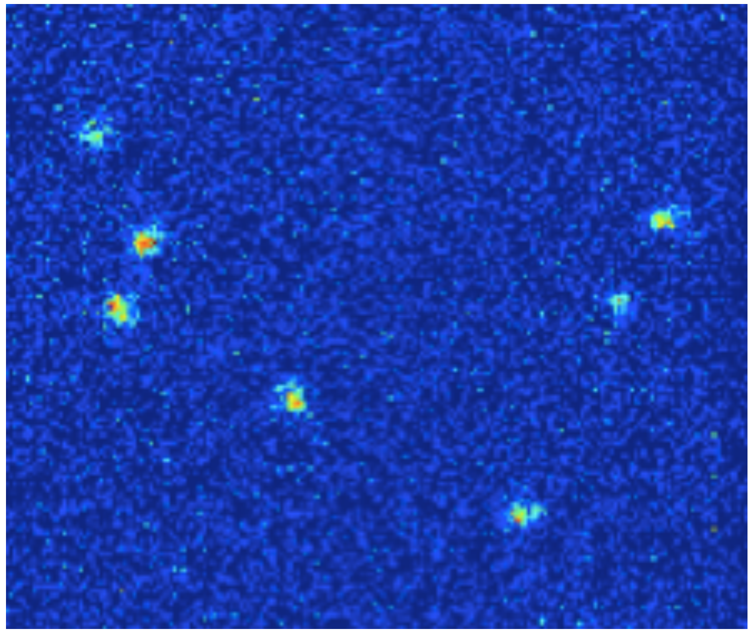
Aim: to explore low energy limit of directionality

- 3 CERN GEMs - very high gains achieved >200,000
- FLI back-illuminated CCD (peak QE ~ 93%, 10 e- rms)



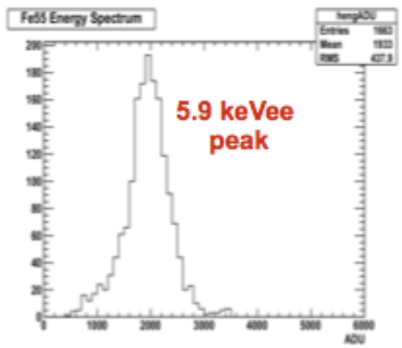






Stunning images of ^{55}Fe electron track, ~400,000 gain,

Nuclear recoil threshold <20 keV_{rec}



UNM R&D (DRIFT)

Powerful background reduction with the GEM and CS_2/CF_4:

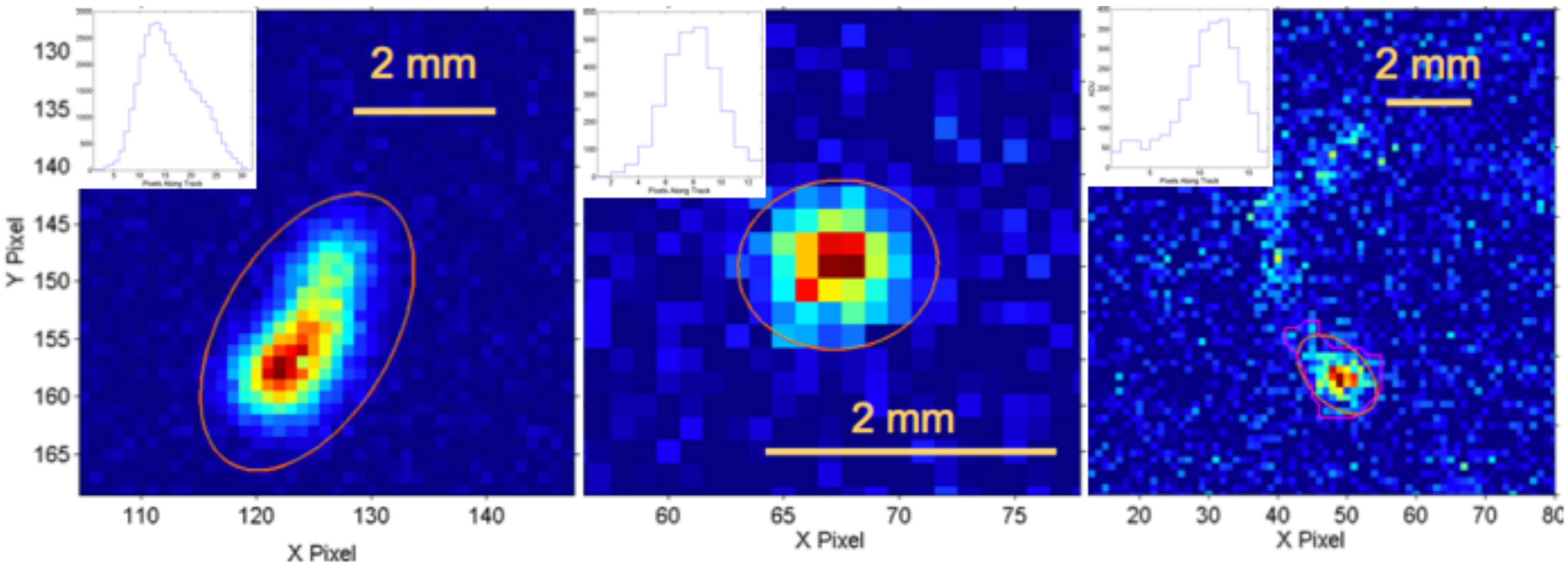
Results reveal how low energy electron tracks look "blobby" so good S/N is essential in CCD technique to separate from low energy recoils.

- Low energy e^- look "blobby" so without low threshold/3D might mimic WIMPs?
- Rejected by topology <5 keV looks feasible but may need xy strip readout

178 keV F recoil

F recoil event of $10\ keV_{ee}$ ($23\ keV_{rec}$) still shows direction

electron recoil ($9.7\ keV_{ee}$)



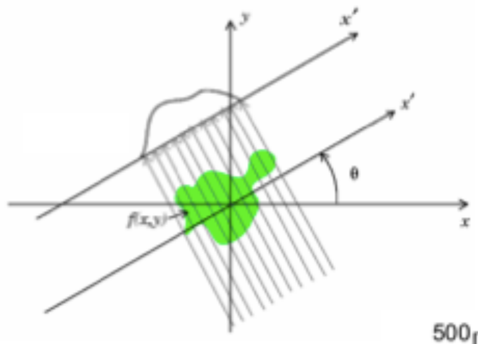
- Latest results show operation down to 13 Torr with CS_2

UNM R&D (DRIFT)

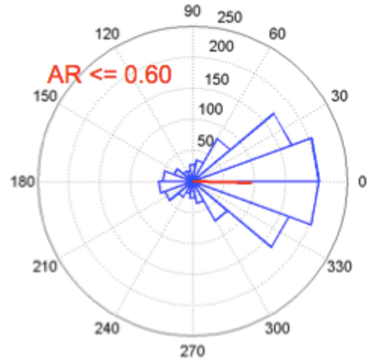
Powerful head-tail and directional discrimination:

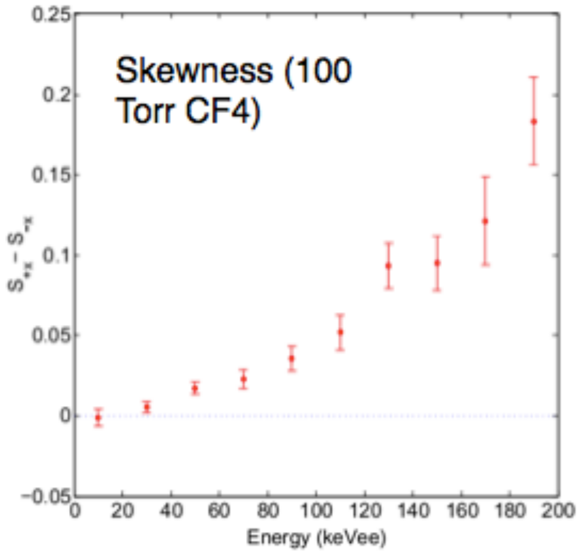
Head-tail measured down to ~55-60 keV_{rec} in 100 Torr CF_4 . Recent results suggest directionality feasible at 10 keV_{rec}, i.e. low mass WIMP directional search nay be feasible

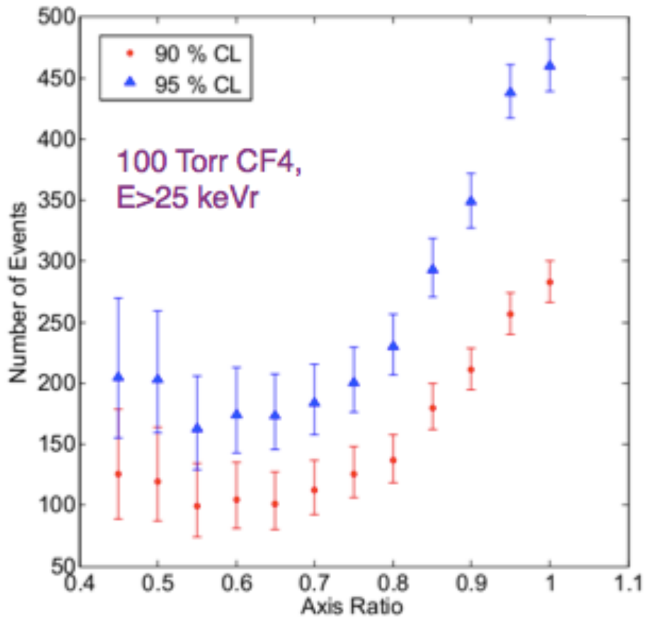
(1) H/T by skewness cut using moments of light distribution



(1) Axial directionality by axis asymmetry cut







Proper choice of AR allows axial directionality with ~100 WIMP events at 25 keV_{rec}

MIMAC

Daniel Santos et al.

LPSC (Grenoble) : J. Lamblin, F. Mayet , D. Santos
J. Billard (Ph.D) (left in July 2012), Q. Riffard (Ph.D) (started in October 2012)

Technical Coordination : O. Guillaudin
- Electronics : G. Bosson, O.Bourrion, J-P. Richer
- Gas detector : O. Guillaudin, A. Pellisier
- Data Acquisition: O. Bourrion
- Mechanical Structure : Ch. Fourel, S. Roudier, M. Marton
- Ion source (quenching) : J-F. Muraz, J. Médard (CDD-1year)

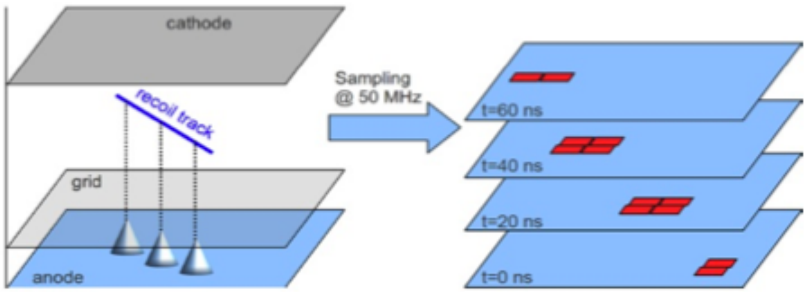
CCPM (Marseille): J. Busto, Ch. Tao, D. Fouchez, J. Brunner (Radon filtering)

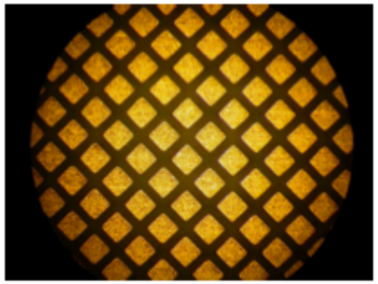
Neutron facility (AMANDE) :
IRSN (Cadarache): L. Lebreton, D. Maire (Ph. D.)

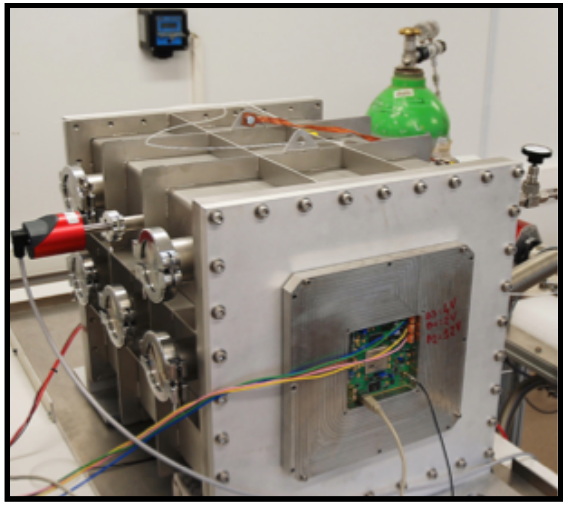
Concept: low pressure CF_4, CHF_3 and H with charge readout via Micromegas + pixel technology

- X and Y coordinates are measured on the pixelated anode
- Z direction by anode sampling at 50 MHz
- The anode is read every 20 ns. The 3D track is reconstructed, from the consecutive number of images defining the event

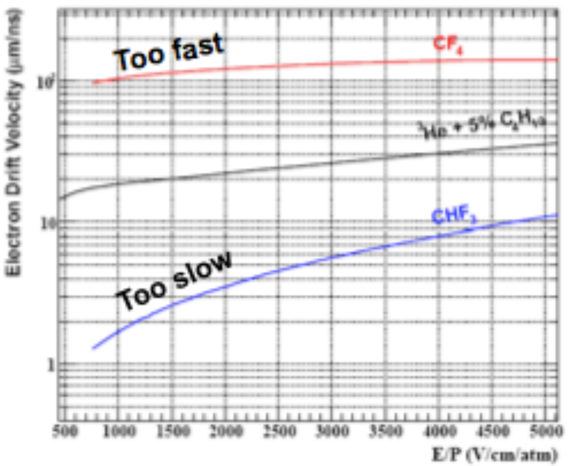
Bi-chamber module 2 x (10.8x10.8x25 cm^3)







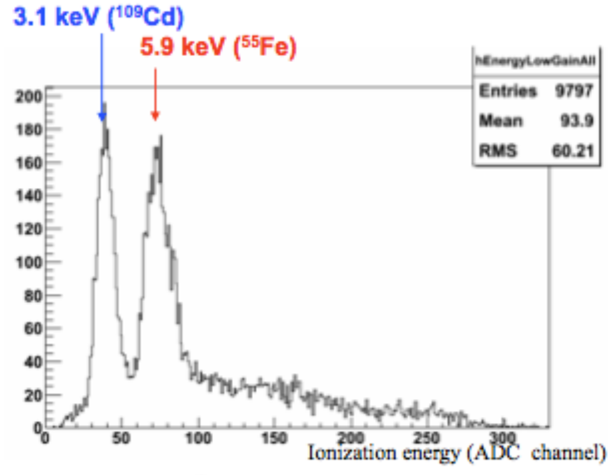
Pixel micromegas from IRFU (Saclay) - 200 µm



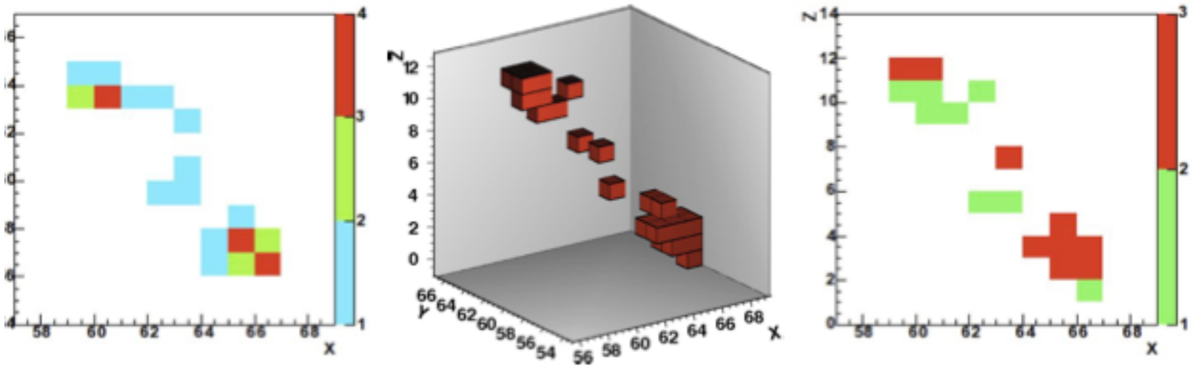
New mixed gas MIMAC target needed to slow drift velocity to match speed of electronics time slicing : CF4 + 30% CHF3

MIMAC

Performance underground at Modane:

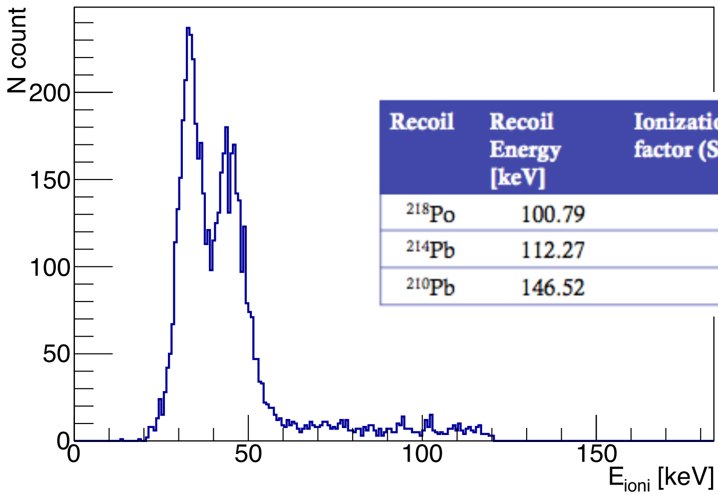


A 5.9 keV electron track in 350 mbar 95% 4He + C4H10



and first operation underground at Modane 2013/14

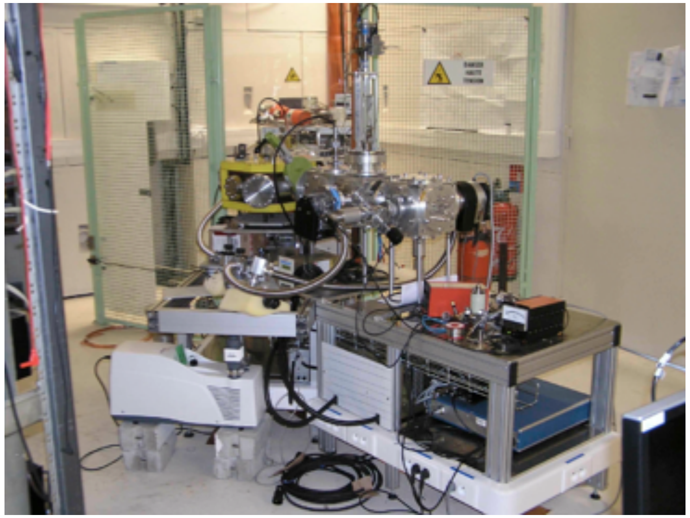
Spectrum of recoil tracks from the ^{222}Rn chain decay, surface events and the alpha particles through the cathode.



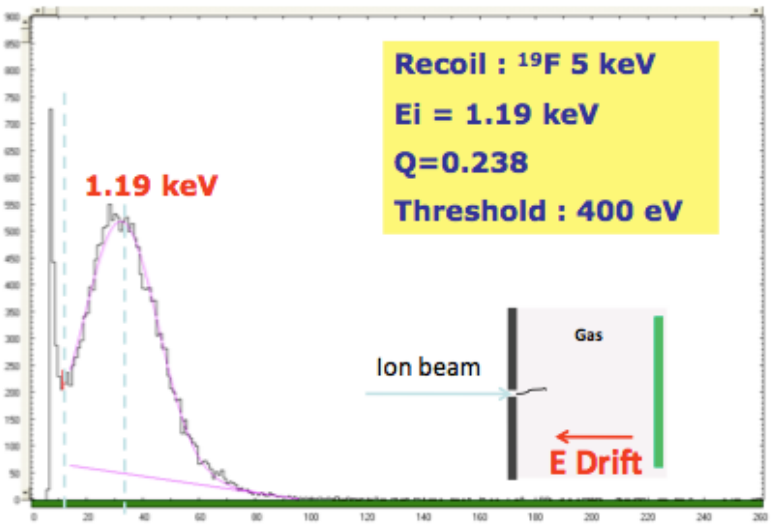
Recoil	Recoil Energy [keV]	Ionization Quenching factor (SRIM) [%]	Ionization Energy (SRIM) [keV]	Ionization Energy measured [keV]
^{218}Po	100.79	37.93	38.23	32
^{214}Pb	112.27	39.10	43.90	34
^{210}Pb	146.52	40.12	58.78	45

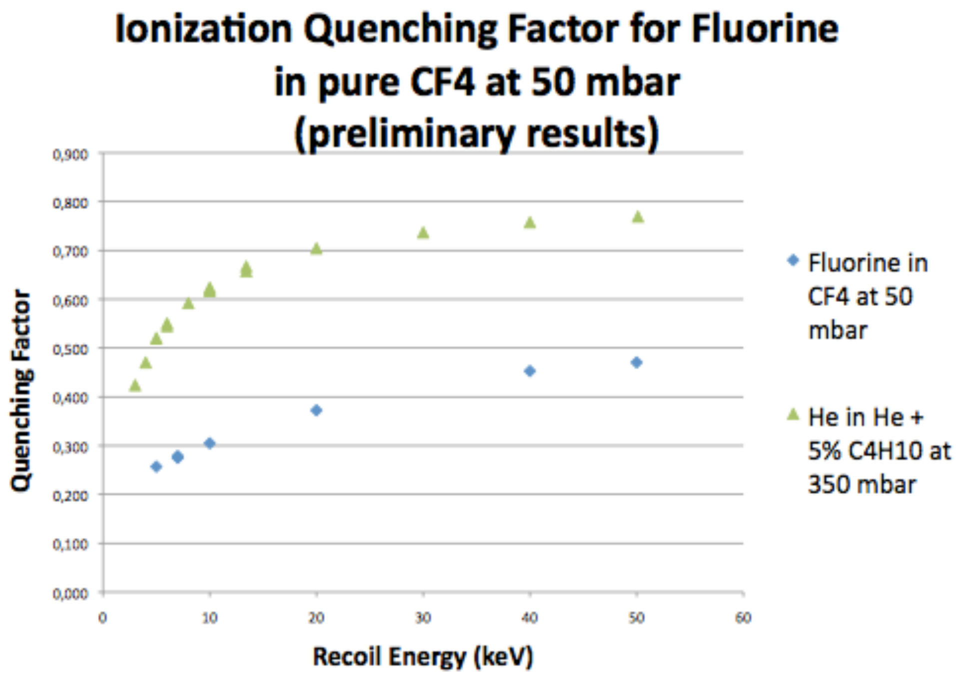
MIMAC

Quench factor measurements:



Ionisation Quenching Measurements with 5keV ^{19}F recoil in 40mbar CF_4 + 16.8mbar CHF_3 + 1.2 mbar Isobutane

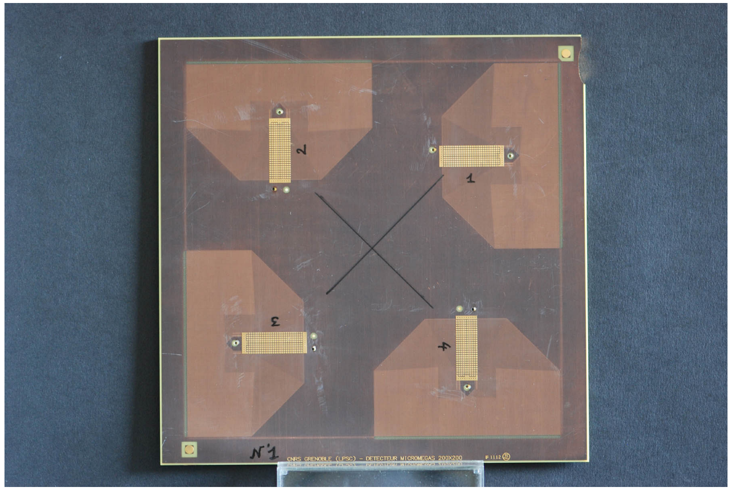


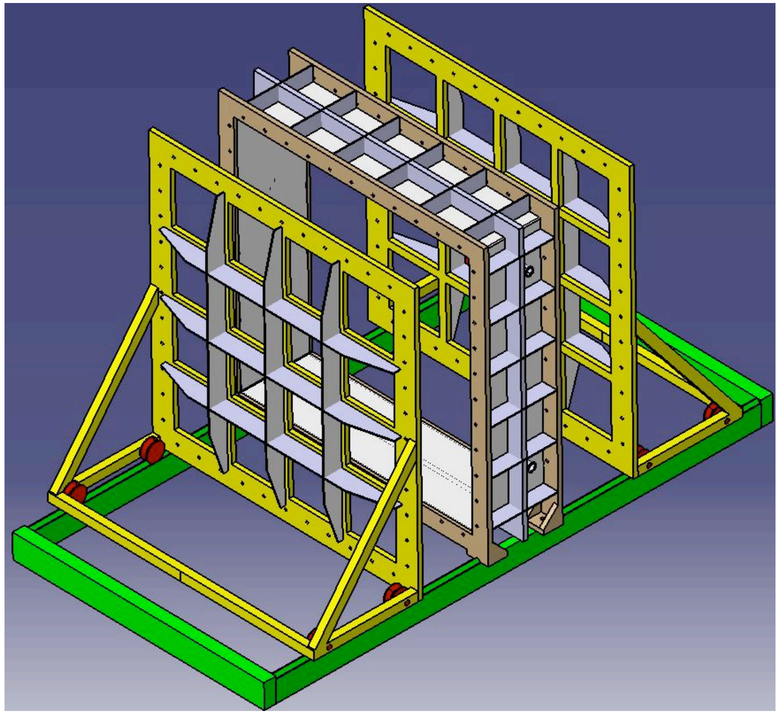


MIMAC

Future: MIMAC – 1m³ = 16 bi-chamber modules (2 x 35 x 35 x 25.5 cm³)

i) New technology anode 35cmx35cm
ii) Stretched thin grid at 500um.
iii) New electronic board
iv) Only one big chamber





New 20cm x 20cm pixel anode (1024 channels)

Challenges for MIMAC?:

- Use of CF_4 requires addition of CHF_3 to slow the gas down to allow z-determination
- No Z fiducialisation
- Can pixilated daq be scaled-up and reasonable cost
- background issues?

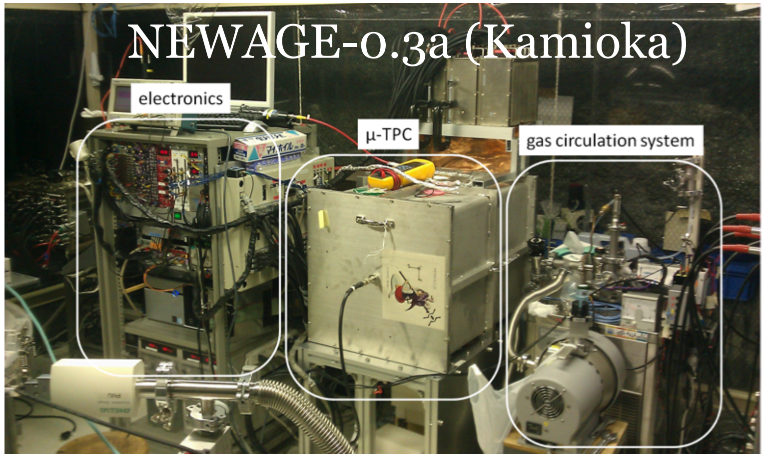
Kentaro Muichi et al.

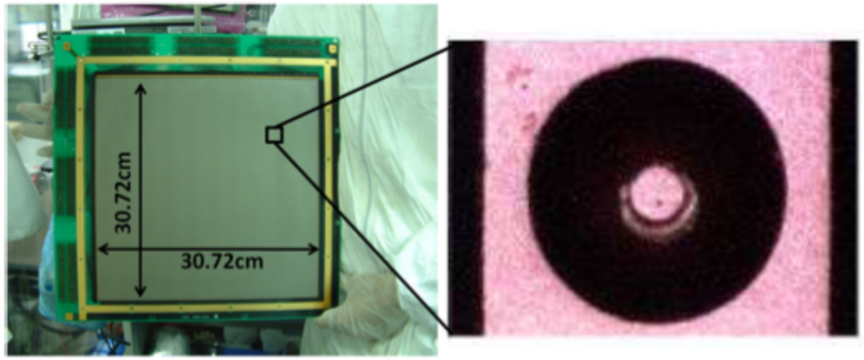
NEWAGE

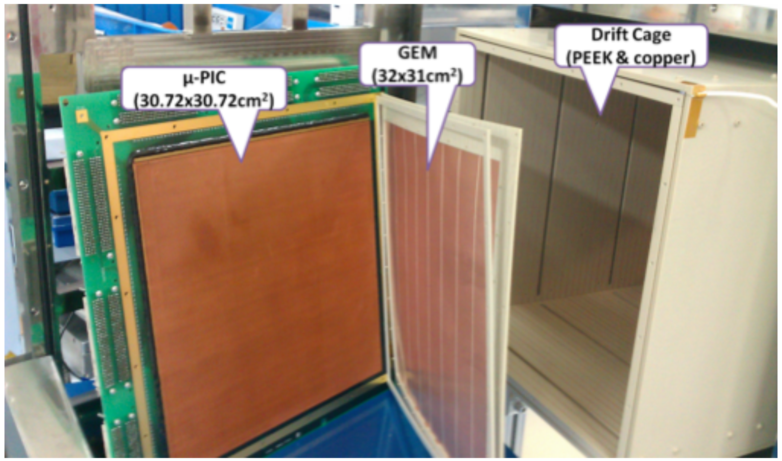
T.Tanimori[1], K.Miuchi[2], K.Kubo[1], T.Mizumoto[1], J.Parker[1], A.Takada[3], H.Nishimura[1], T.Sawano[1], Y.Matsuoka[1], S.Komura[1], Y.Yamaguchi[2], S.Nakaura[2]
(1) Kyoto university department of physics
(2) Kobe university department of physics
(3) Kyoto university RISH

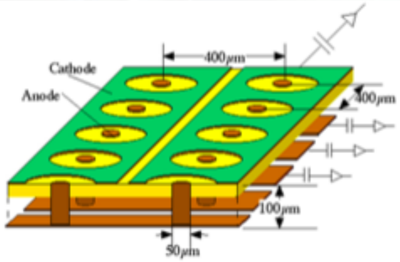
Concept: low pressure CF_4 with charge readout via micro-PIC TPC

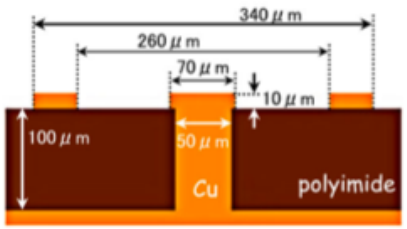
- Three detectors: NEWAGE-0.3a (Kamioka); NEWAGE-0.3b, NEWAGE-0.1 (HT R&D)
- Micro patterned gaseous detectors (MPGDs) 768 × 768 pixels (400 μm) a micro pixel chamber (μ-PIC) which is a two-dimensional fine-pitch imaging device plus a gas electron multiplier (GEM)
- 30 × 30 × 41 cm^3 of detection volume.
- CF4 gas at 0.2 atm
- A gas circulation system with cooled charcoal





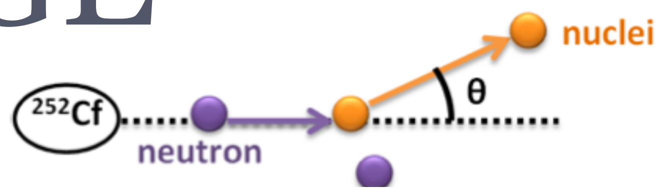




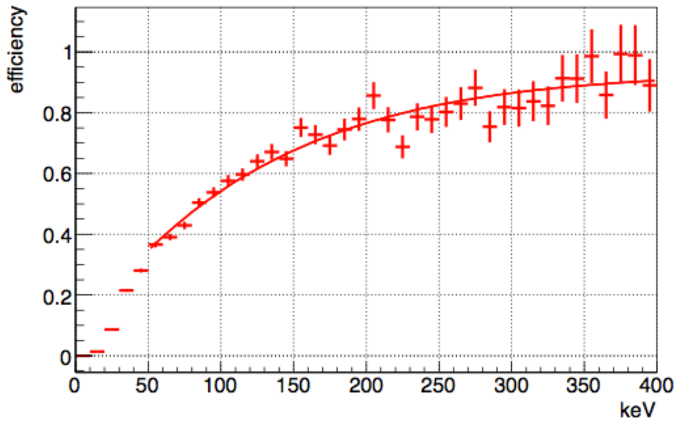


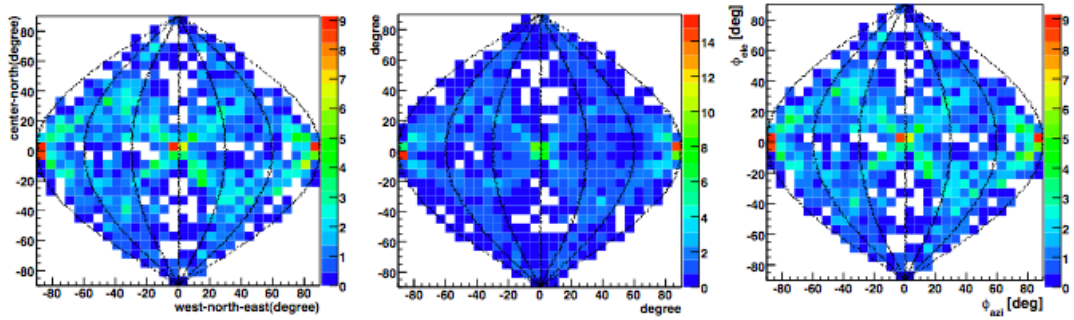
NEWAGE

Performance underground at Kamioka:



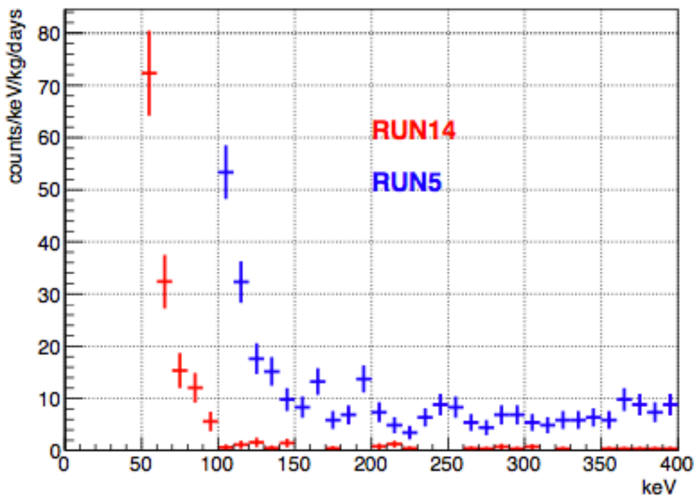
The detection efficiency of nuclear events.



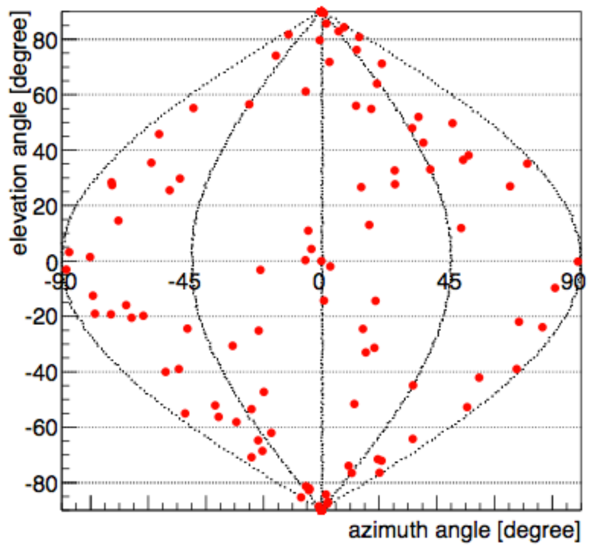


Direction-dependent efficiency - response to isotropic irradiation, 50 – 100 keV, 100 – 200 keV, 200 – 400 keV

Run 14: 0.327 kg · days

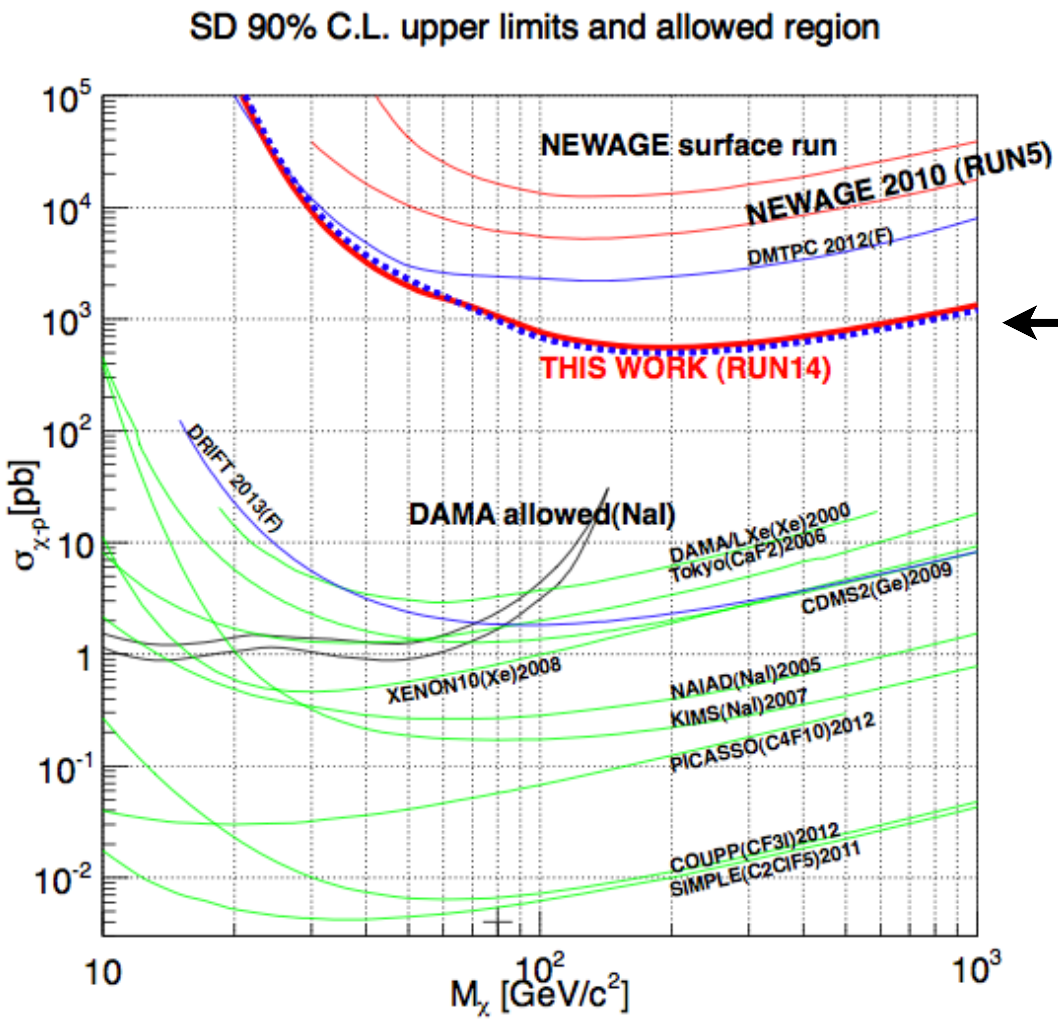


Obtained direction of the nuclear tracks of RUN-14 in the energy range of 50 – 400 keV



NEWAGE

New limits:



← First use of directionality to suppress isotropic backgrounds

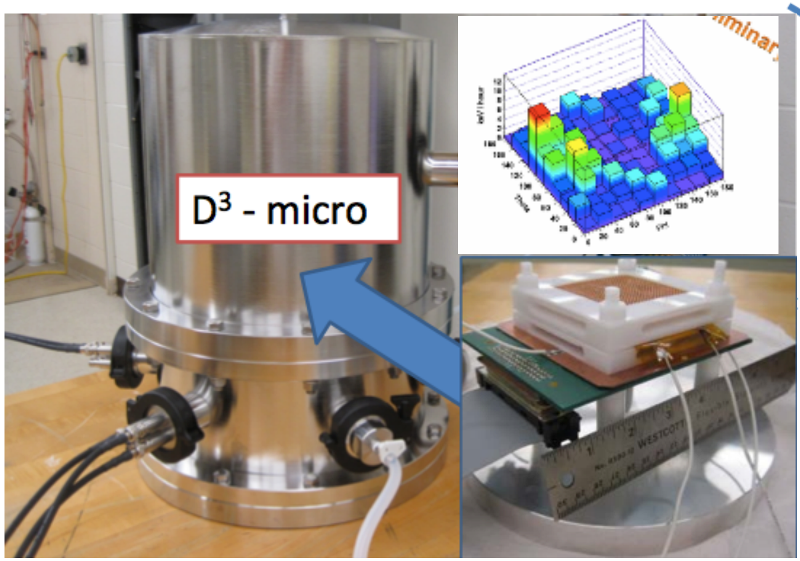
Challenges for NEWAGE?:

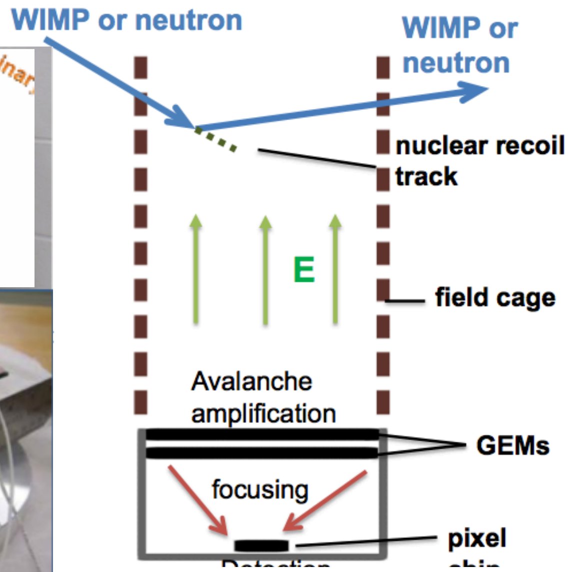
- Background, radon
- Energy threshold
- z-fiducialisation
- DAQ costs

D3

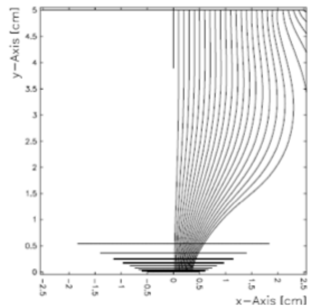
Sven Vahsen et al.
LBNL and U. Hawaii

Concept: low pressure CF_4 with micro-pattern gas detector and charge focussing



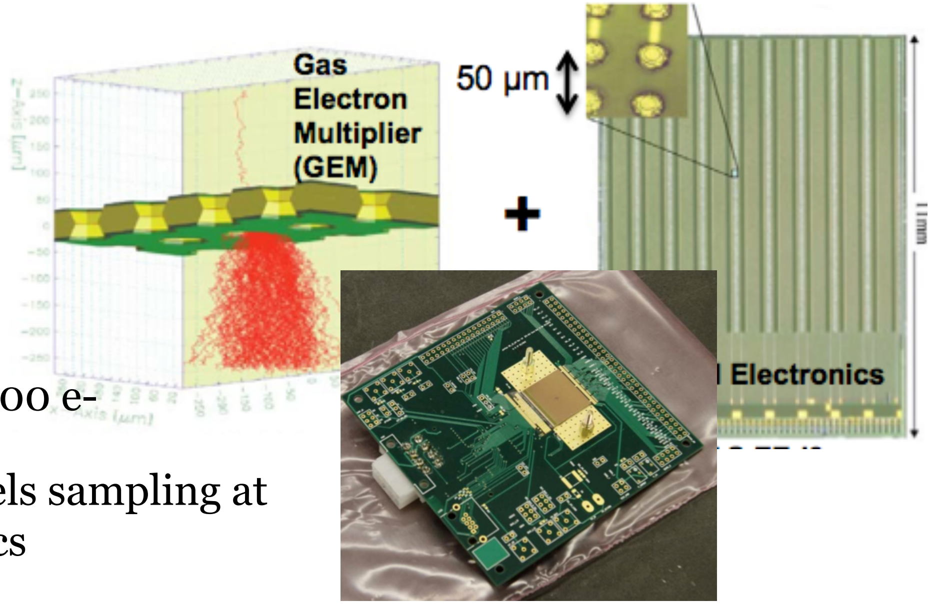


S. Ross et al., “Charge-Focusing Readout of Time Projection Chambers”, proceedings of IEEE NSS 2012



- Charge amplified with GEMs
- Charge amplified with pixel chip
- Charge focusing - potential for significant cost reduction of large detectors

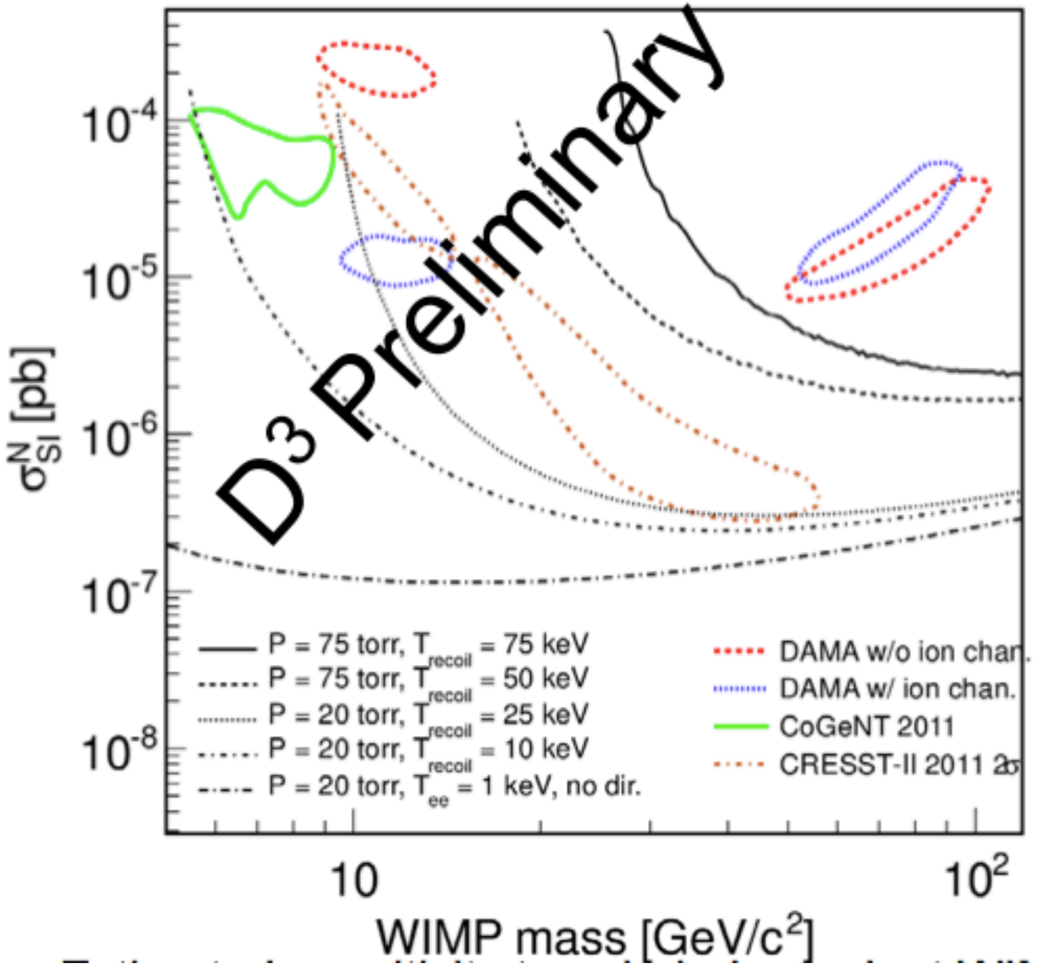
Double layer of GEMs - gain ~20k at 1 atm
pixel electronics - threshold ~2k e-, noise ~100 e-



ATLAS FE-I4 50x400 μm pixels sampling at 40 MHz and ATLAS electronics

D3

D3 predictions for 1 m³:



Typical sensitivity predictions for all the current generation detectors for 1 m³ reach below the "DAMA" regions - assuming zero background.

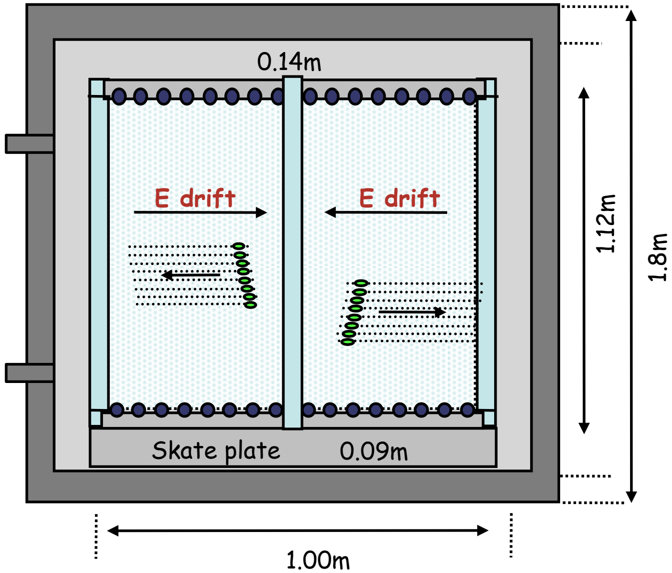
D3 has now joined DRIFT

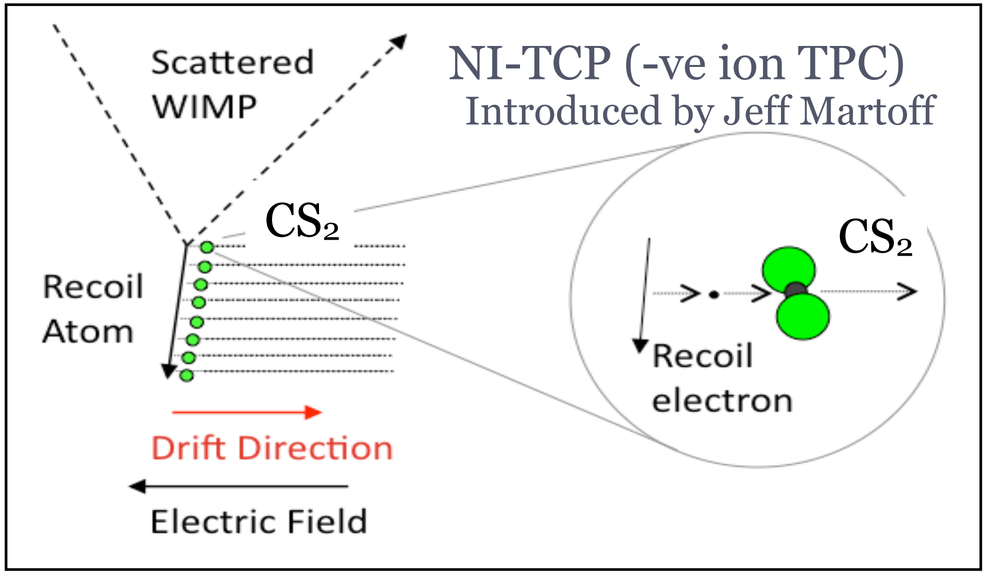
DRIFT - II

Concept: -ve ion CS_2 + CF_4 TPC, MWPC readout, m³ volume, 40 Torr

Directional Recoil Identification From Tracks (DRIFT)

S. Burgos et al., NIM A 584, 114 (2008)

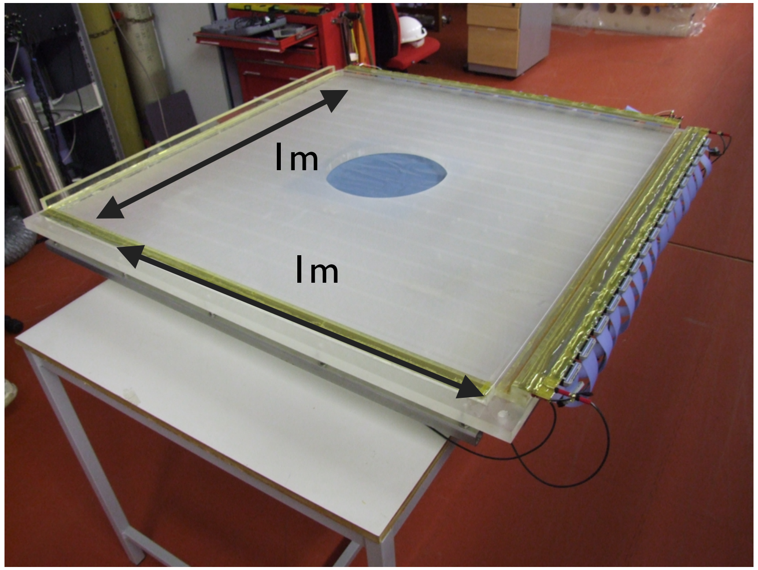


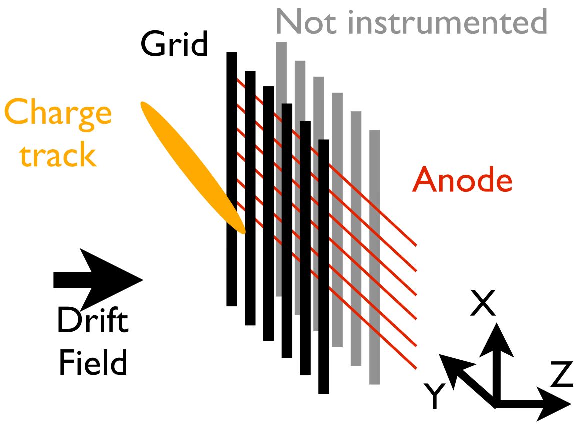


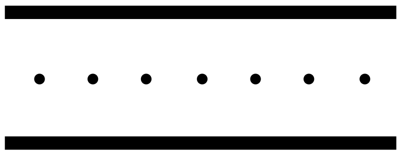
- 1 m³ active volume - back to back MWPCs
- Gas fill 40 Torr CS_2 => 167 g of target gas
- 2 mm pitch anode wires left and right
- Grid wires read out for Δy measurement
- Veto regions around outside
- Central cathode made from 20 μm diameter wires at 2 mm pitch
- Drift field 624 V/cm
- Modular design for modest scale-up

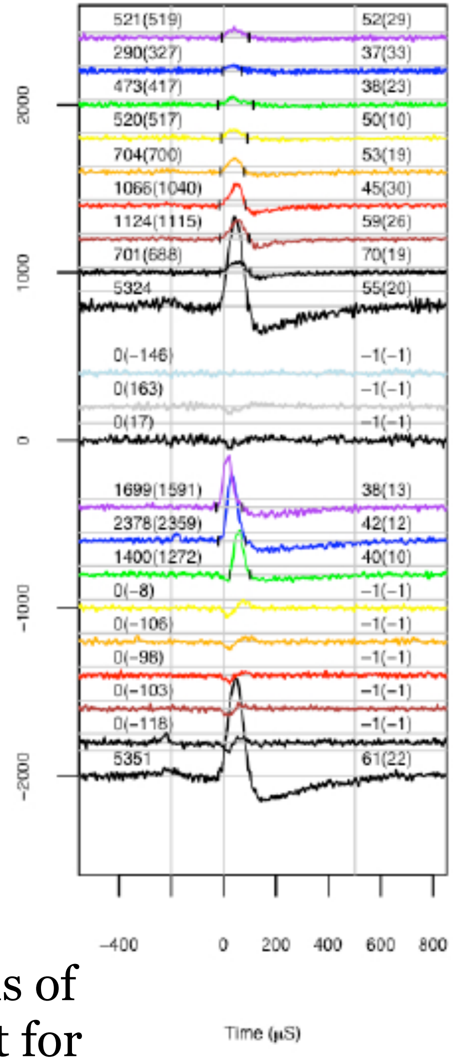
DRIFT - II

MWPC readout:









ΔX: Number of anode wires crossed
ΔY: Progression across grid wires
ΔZ: Drift time between start and end of track

- Anode plane of 512 20μm wires with 2mm pitch
- 2 cathode planes of 512 100μm wires perpendicular to anode plane, 2mm pitch - one of which is read out

Multiplexed to 18 channels of digitised waveform output for 1m² readout plane

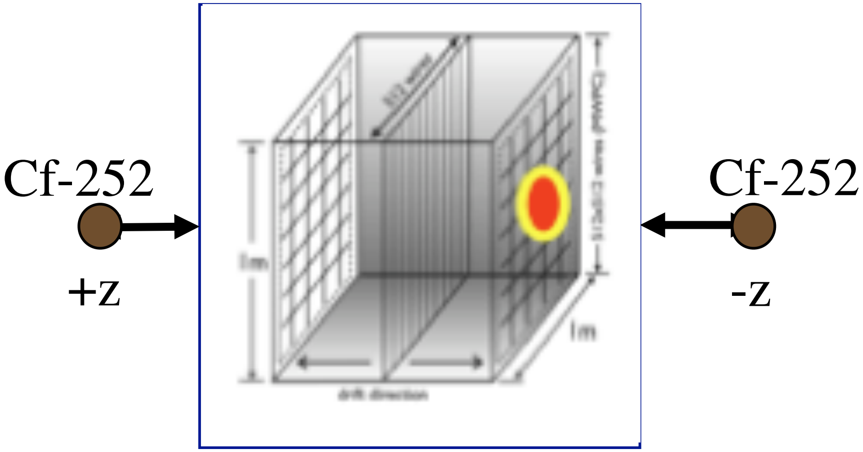
<u>Simple, cheap & scalable</u>

DRIFT - II

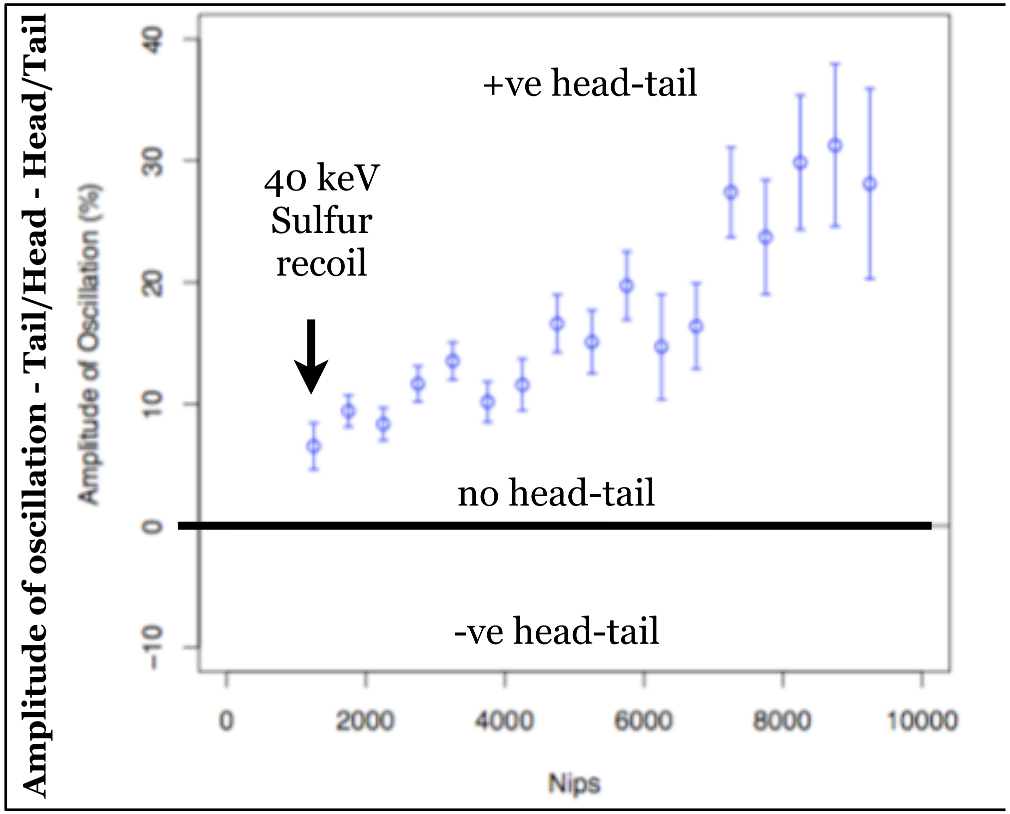
Head-Tail discrimination: First to show HT discrimination (in 1 m³ at low energy)!

Experiment: S. Burgos et al., Astroparticle Physics 31 (2009) 261

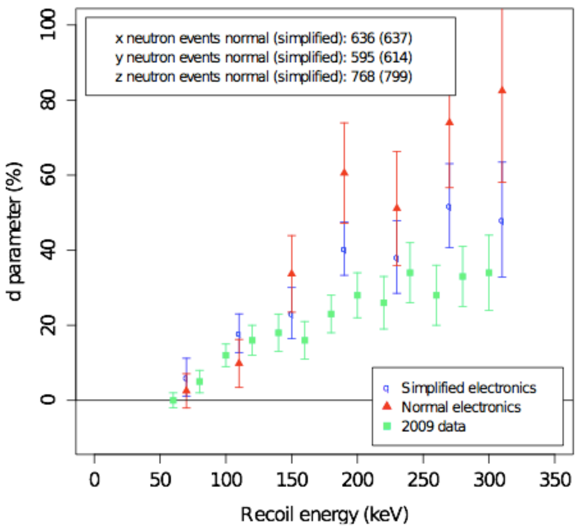
Theory: N.J.C. Spooner (2009) arXiv:0902.4430



Directed neutron runs (DRIFT IIc)



Axial directional discrimination:



- DRIFT uses axial directional discrimination via XZ asymmetry

DRIFT - IId

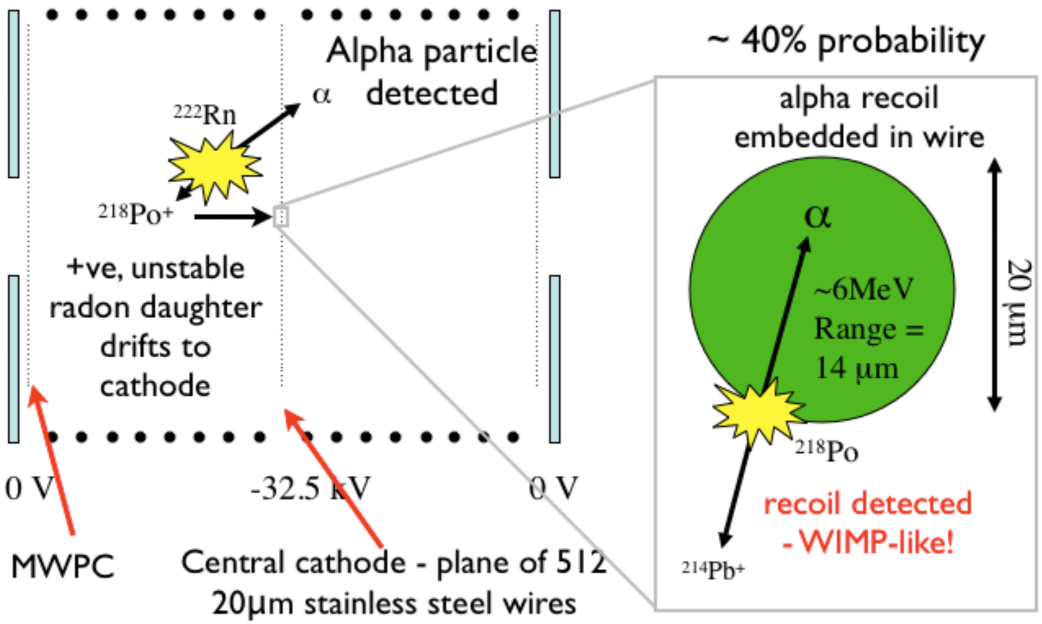
Operation at Boulby with low background:

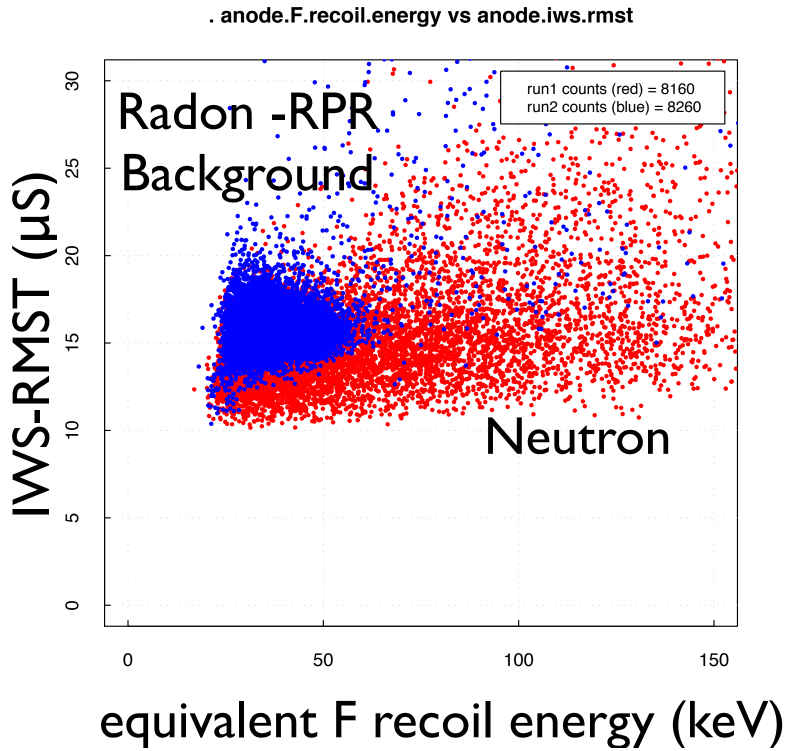
- Lab at depth of 1100m (2800 m.w.e)
- Cosmic ray flux = $4.1\times10^{-8}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$ [M. Robinson et. al, NIM A 511 (2003)]
- Polypropylene pellets of >67cm depth on all sides
- Equivalent to $40\mathrm{g/cm}^2$ solid hydrocarbon passive shielding
- Lead shielding not required due to detector's inherent insensitivity to electron recoil events

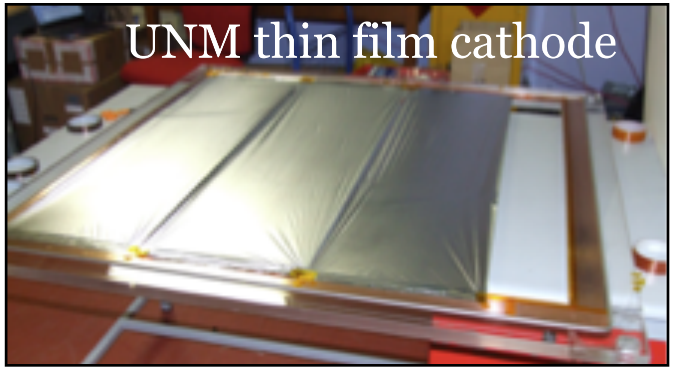
DRIFT - IId

Backgrounds:

- The main background in the DM region is from radon progenies (RPRs)







- Use of ultra-thin (0.9 micron) cathode allows alpha to be "seen" and hence RPR rejection
- Additional Z cuts applied based on diffusion
- Acid etching and selection low Rn materials
- This allowed world leading limits to be set...

DRIFT - IId

Use of multi-panel 0.9μm thick DRIFT cathode

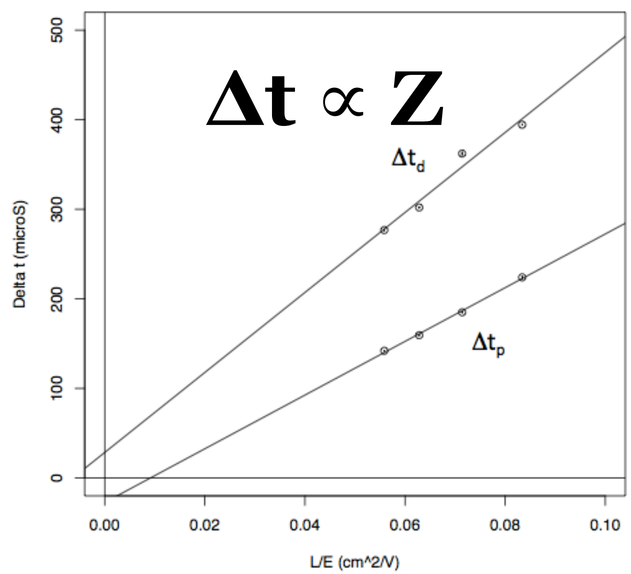
cathode tested at full voltage (32.5kV)

DRIFT - IId

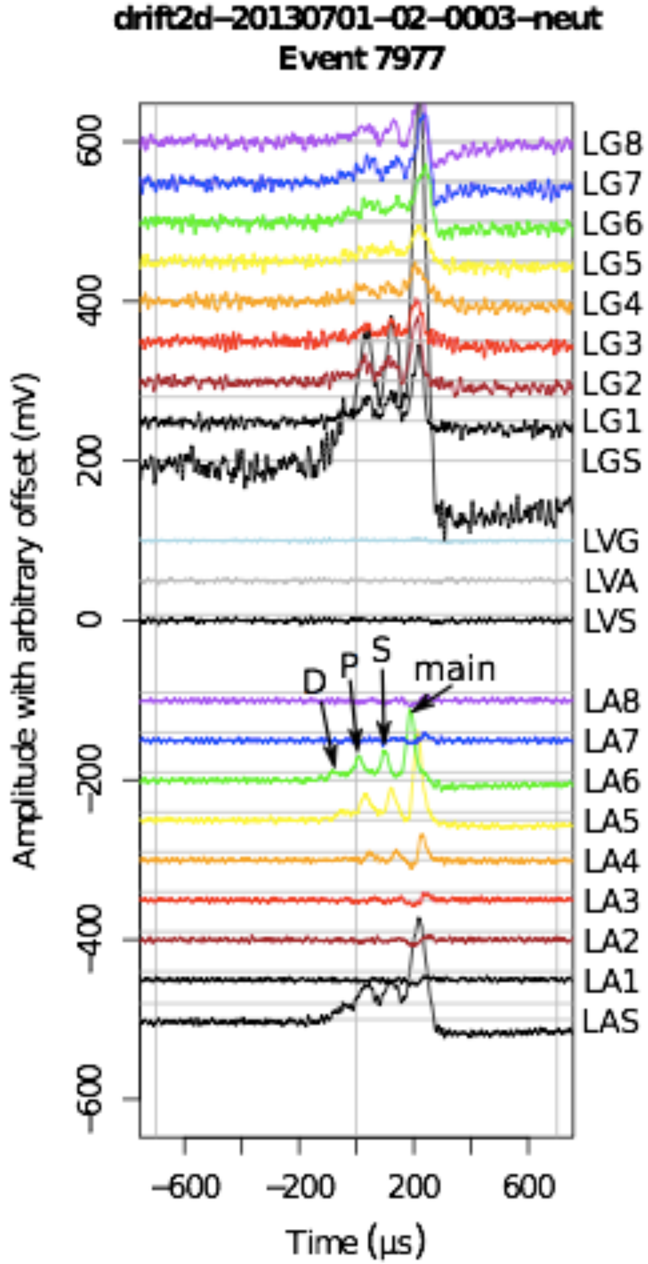
Z Fiducialisation solved:

- A major recent advance has been the discovery of event timing by minority carrier
- Addition of 1% oxygen
- 30 Torr CS_2 + 10 Torr CF_4 + 1 Torr O_2
- Timing between main peak and minotiy peaks gives absolute Z information on events
- This allows rejection of RPR events that originate near the cathode

$$z = (t_m - t_p)\frac{v^m_{drift} v^p_{drift}}{v^m_{drift} - v^p_{drift}}$$



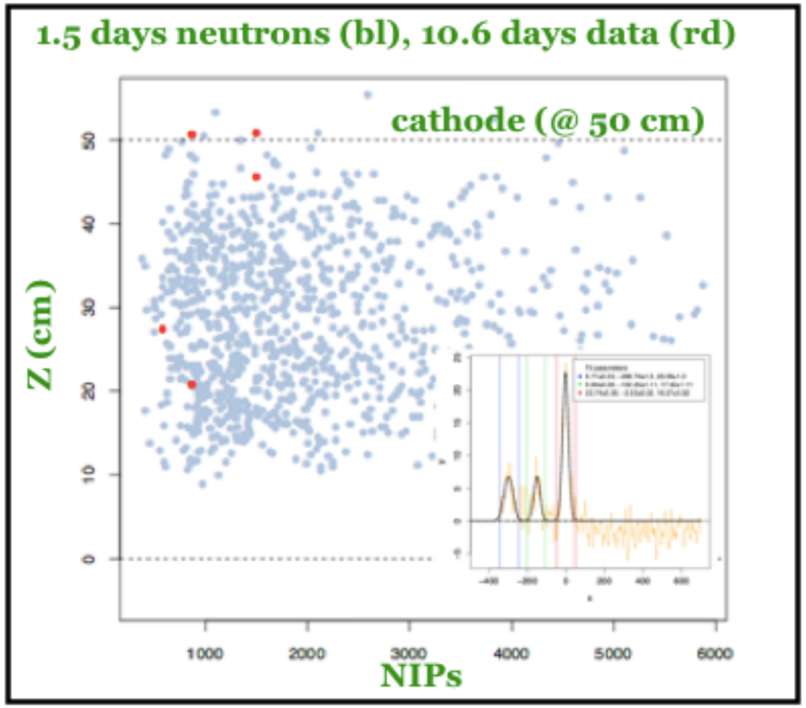
Example event display from minority carrier data. The main peak and the earlier 'S', 'P' and 'D' minority peaks can be seen on LA 3, 4, 5 and 6.

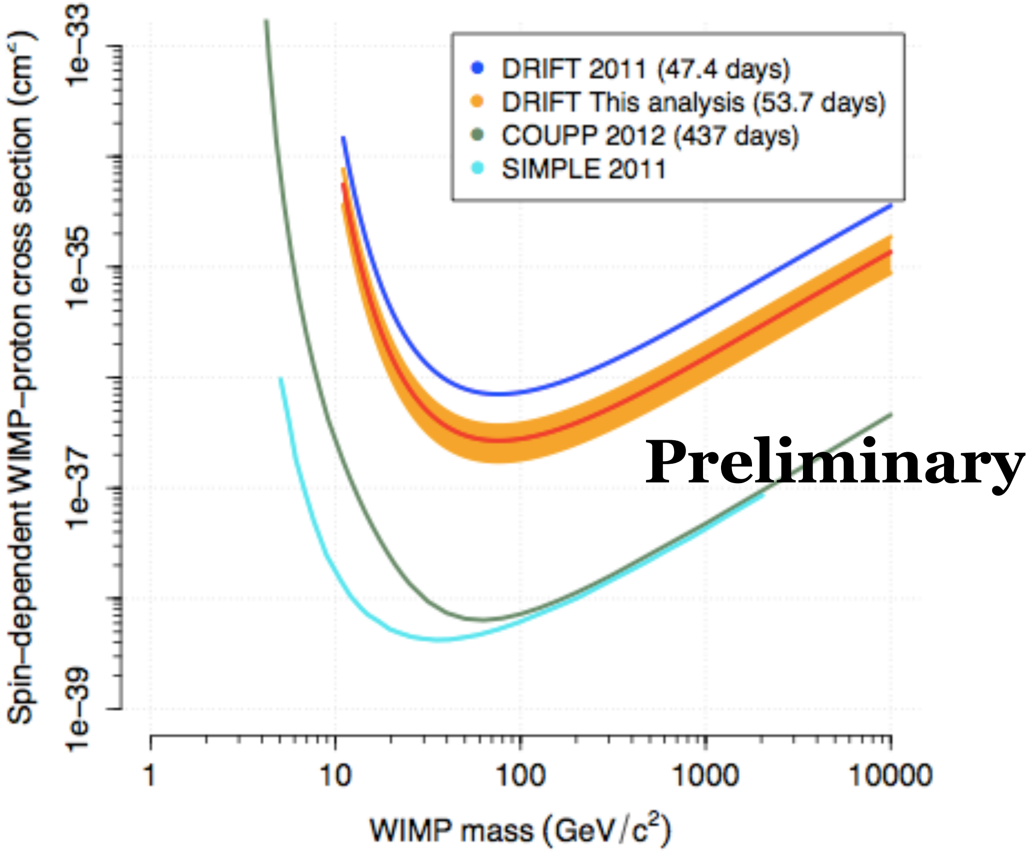


DRIFT - IId

Preliminary new limits from DRIFT:

- Results using an automated minority peak analysis
- Analysis not optimum yet, expect a further ~x10 improvement

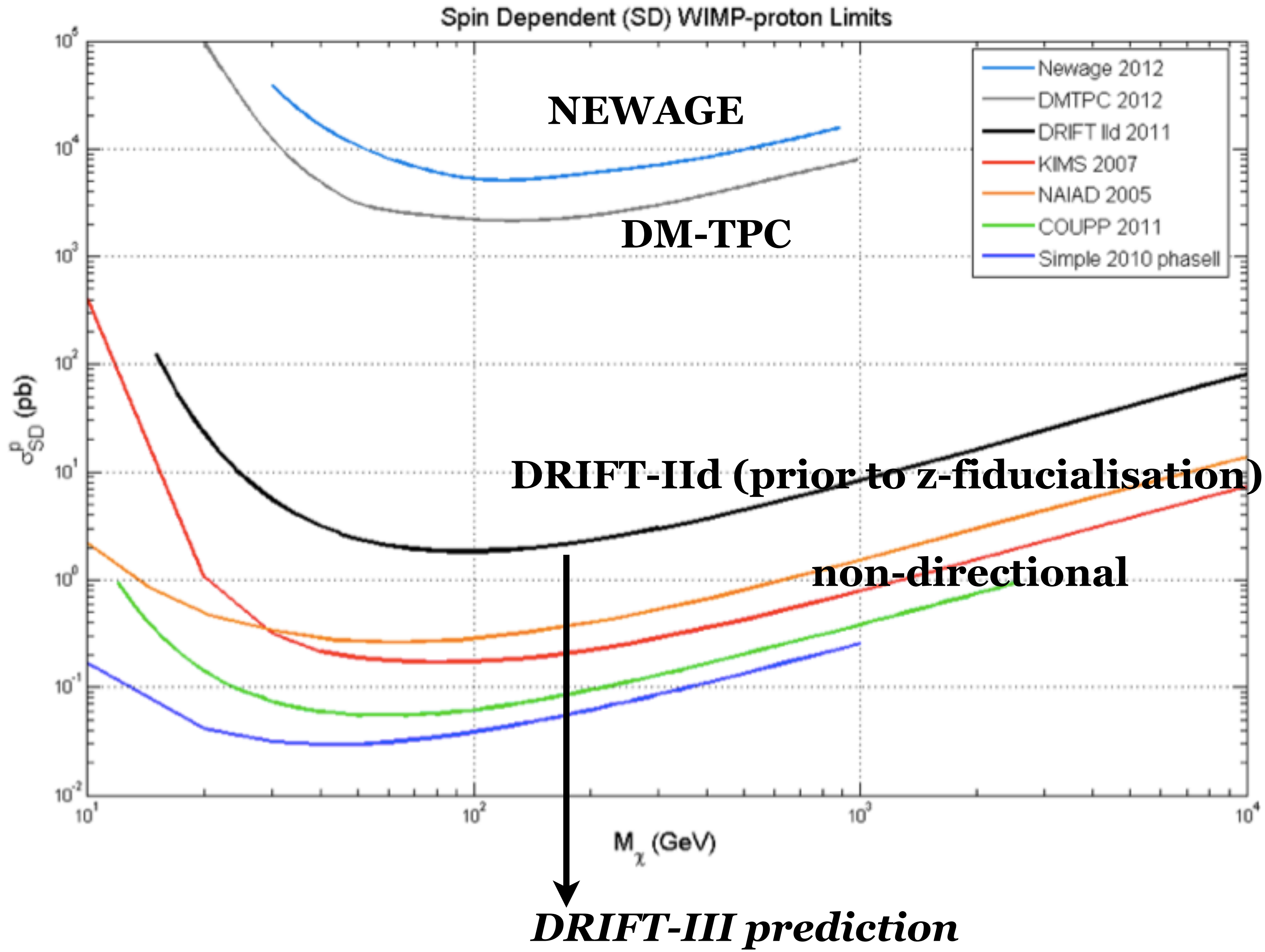




Challenges for DRIFT

- What causes the minority carrier?
- Scale-up to 24 m³

Gas Directional Limits



SOLID?

Between detectors without directionality and gas TPCs with directional sensitivity, a difference of at least three orders of magnitude in active mass exists; how can this gap be confronted?

Can we find a directional technology with higher density?

It would be nice! But a long history of looking has not so far produced much

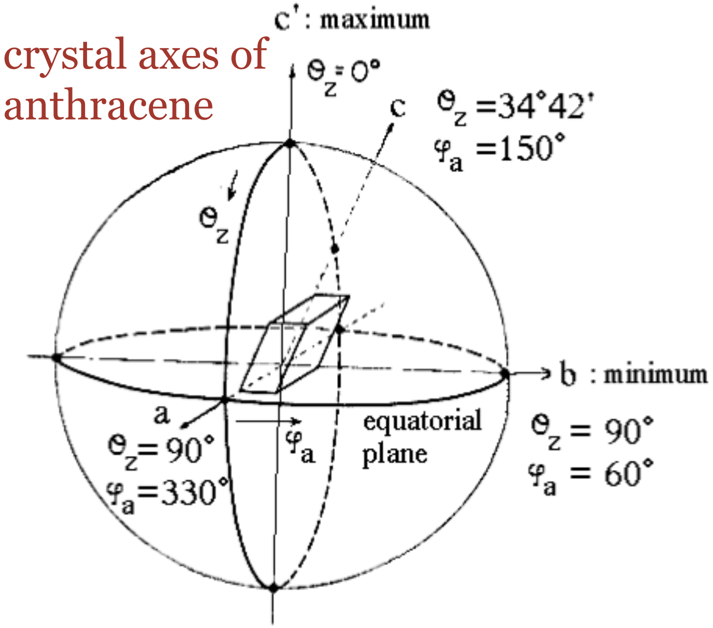
Stilbene
Rotons in Lq He
Phonon focussing
Multilayers....

It is hard...but recent work is progressing...

Anisotropic Scintillators

Concept (1): Anisotropic organic scintillator, anthracene or stilbene where light response p, α, recoil nuclei, ··· depends on direction with respect to the crystal axes:

crystal axes of anthracene



- Groups in UK, Italy and Japan

  Y. Shimizu et al., Nucl. Instr. and Meth. A 496, 347 (2003)

  N.J.C. Spooner et al., IDM (World Scientific 1997), p. 481

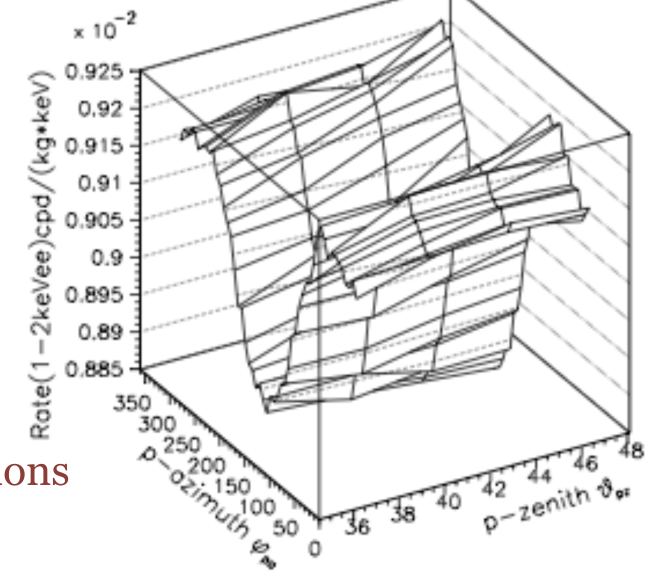
  R. Bernabei et al. Eur. Phys. J. C 28, 203–209 (2003)

- Effect arises from preferred directions of the exciton propagation in the crystal lattice

- e.g. in Anthracene 6.56 MeV alpha impinging along b-axis (a-axis) gives 66% (80%) of the light for direction along the c′-axis

Effectively the quench factor has an angular dependence:

$$q_n(\Omega_{\rm out}) = q_{n,x}\sin\gamma\cos\phi + q_{n,y}\sin\gamma\sin\phi + q_{n,z}\cos\gamma,$$

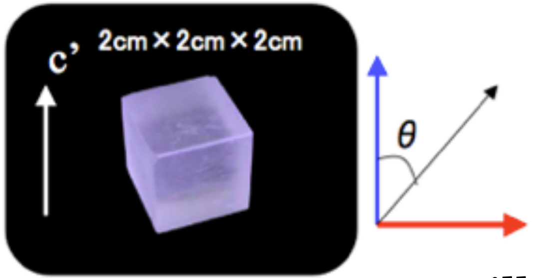


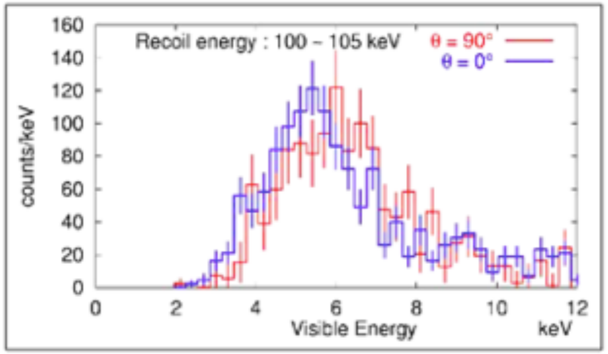
Expected rate at 1–2 keV vs. detector possible velocity directions for 50 GeV WIMP at WIMP–proton cross section $3 \cdot 10^{-6}$ pb

Anisotropic Scintillators

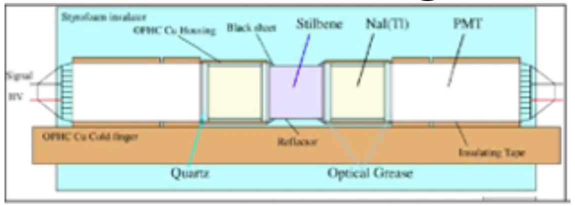
Example work (2003): Hiroyuki Sekiya (Kyoto University) M.Minowa, Y.Shimizu, Y.Inoue, W.Suganuma (University of Tokyo)

Respons to ~100 keV carbon recoils:





116g stilbene crystal + 2 R8778 PMTs

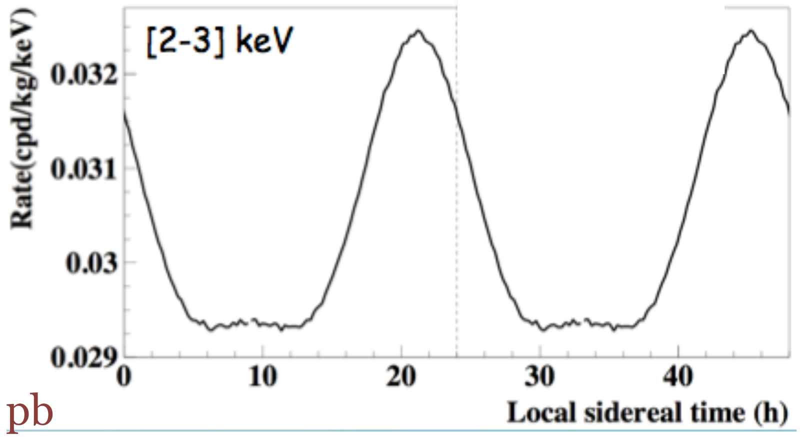


Challenges for directional organics:

- Only carbon is the target (SI)
- Anisotropy is likely <20%
- Low quench factors
- No head-tail
- High backgrounds?
- Small crystals

Alternative example (2013) - $ZnWO_4$: F. Cappella et al., Eur. Phys. J. C 73 (2013) 2276

Both the light output and the pulse shape of ZnWO4 detectors depend on the direction of the impinging particles with respect to the crystal axes - this can provide two independent ways to exploit the directionality approach

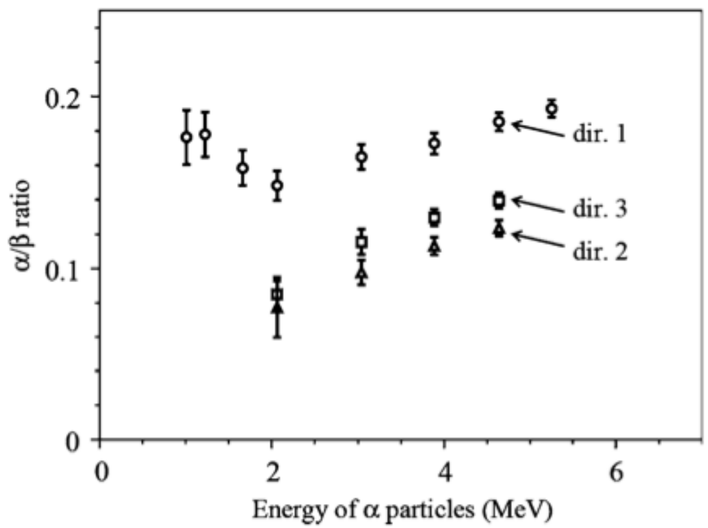


Expected for 10 GeV WIMP–p cross section $3 \cdot 10^{-5}$ pb

ADAMO

Concept: $ZnWO_4$

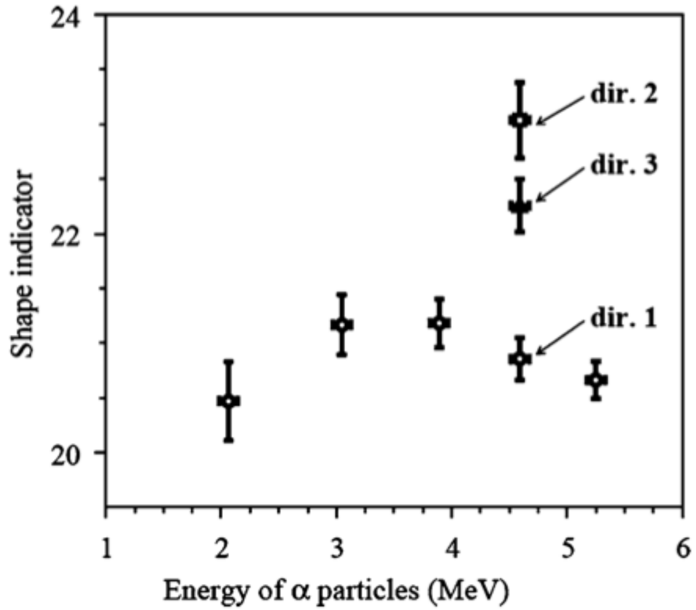
DAMA group - F. Cappella et al., Eur. Phys. J. C 73 (2013) 2276



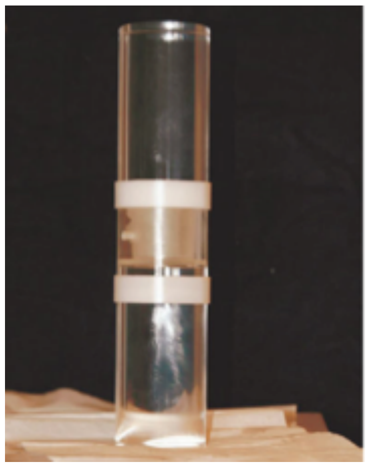
Dependence of α/β ratio on energy of α particles in ZnWO4 - directions perpendicular to (010), (001) and (100) crystal planes (directions 1, 2 and 3, respectively).

Ion	Quenching factor		
	dir. 1	dir. 2	dir. 3
O	0.235	0.159	0.176
Zn	0.084	0.054	0.060
W	0.058	0.037	0.041

QF for O, Zn and W ions with energy 5 keV for different directions in ZnWO4.



Dependence of pulse shape on energy and direction of α particles relatively to (010), (001) and (100) crystal planes.



Prototype now under study

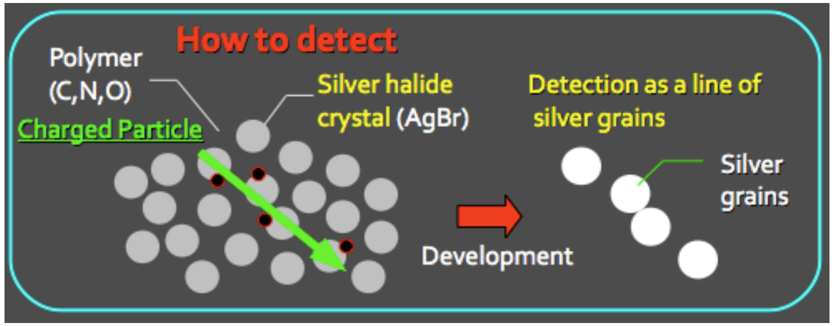
Issues for $ZnWO_4$:

- Check low energy response
- Backgrounds
- No head-tail

Nuclear Emulsion

Nagoya University, OPERA…

Concept (1): Use of emulsion film to give 3D tracking - solid detector (3g/cc), high spatial resolution, low cost, target Ag(46%), Br(34%), C(N,O) (19%)

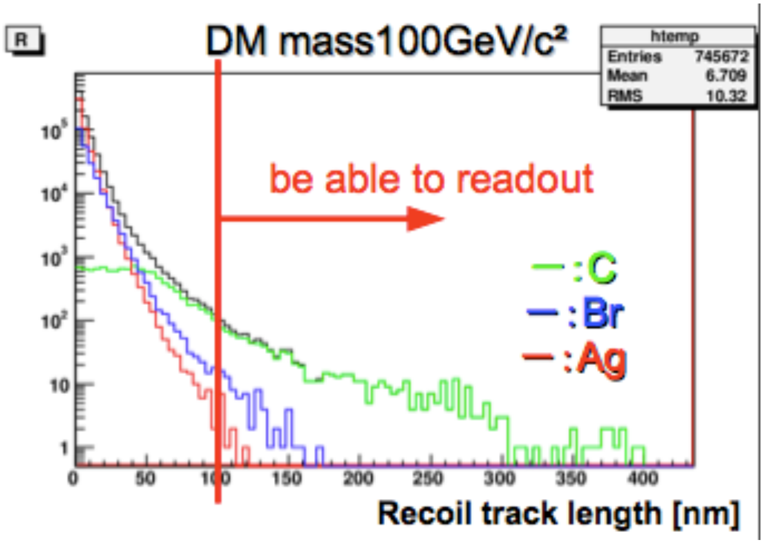


- Track produces line of silver grains

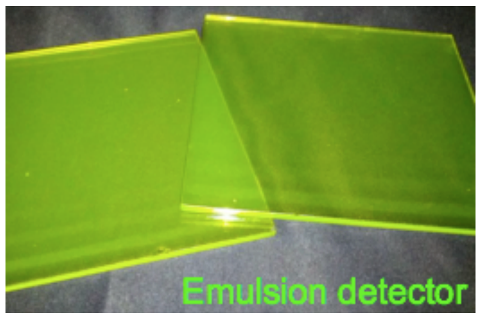
crystal size	45nm
crystal distance	85nm
crystal sensitivity for alpha-ray	>20% (not sensitized)

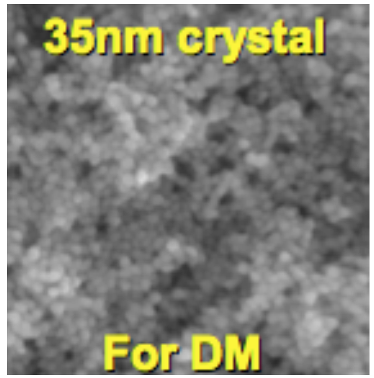
- Challenge is to get: (i) small grains <40nm (OPERA had 200 nm), (ii) closely packed, and (iii) sensitive to low ionisation

- Typical recoils are order 100nm - Ag, Br likely produce tracks too short so need to use C, N, O target



- Progress made to produce stable very fine crystals by using the PVA techniques



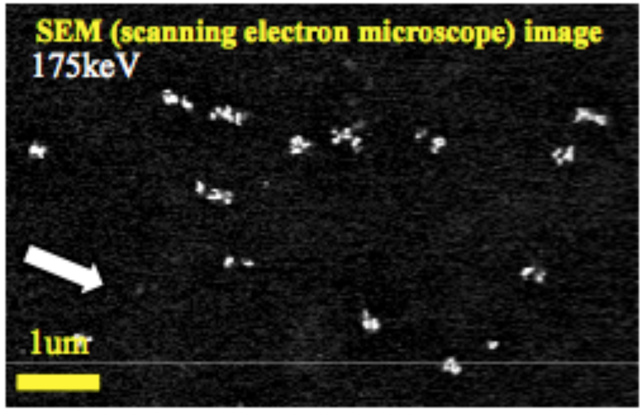


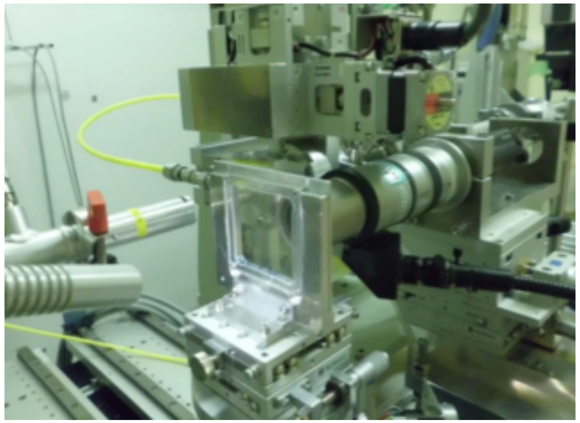
Nuclear Emulsion

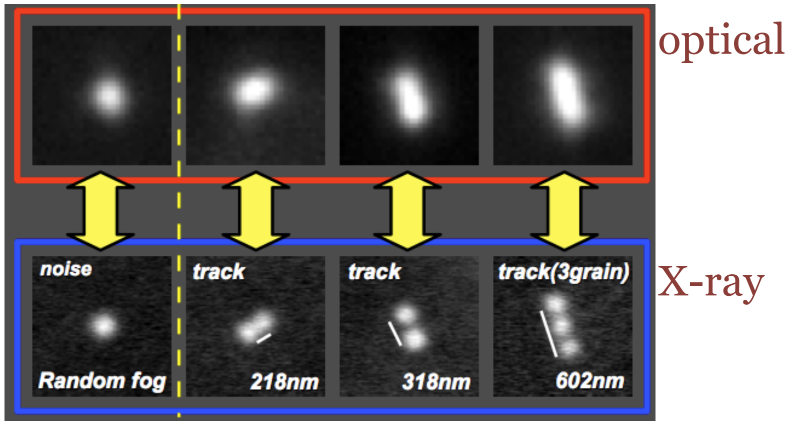
- Progress with carbon recoil tests

  track detection efficiency 175 keV (520nm expected): 80% 80 keV (250nm expected) : 50%
  crystal separation is shorter than carbon tracks

- Scanning process being developed combining optical and x-ray techniques



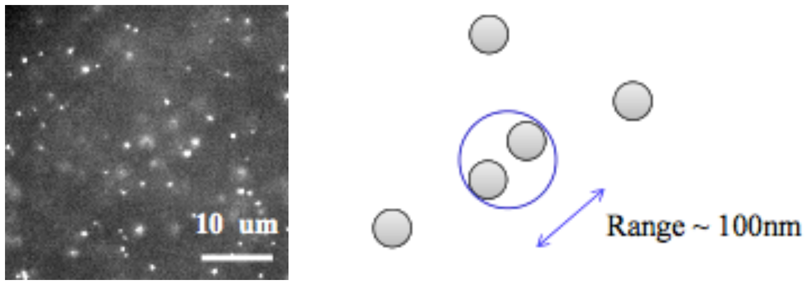




Challenges for directional organics:

- What range threshold can be achieved (100nm)?
- Efficiency of grain production by recoils
- No head-tail?
- Not real time - target rotation?
- Can background grains be reduced?

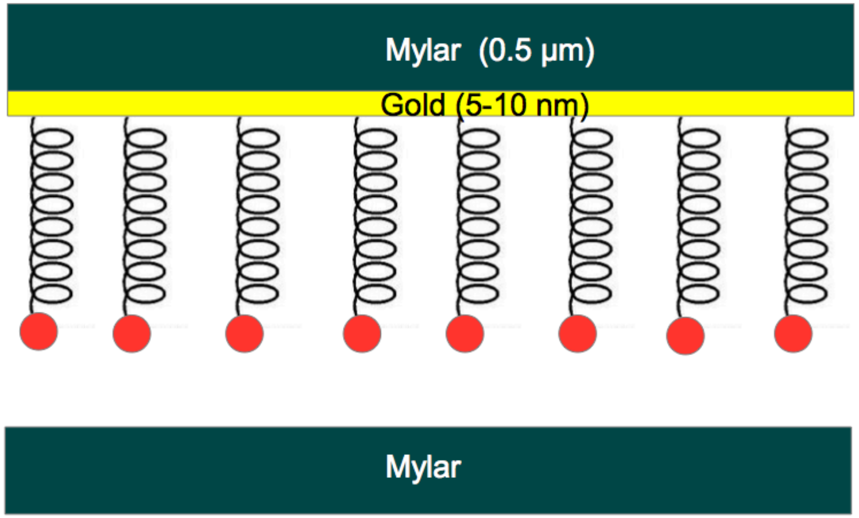
e.g. unexpected silver grains are generated at random, if too close, they become noise tracks

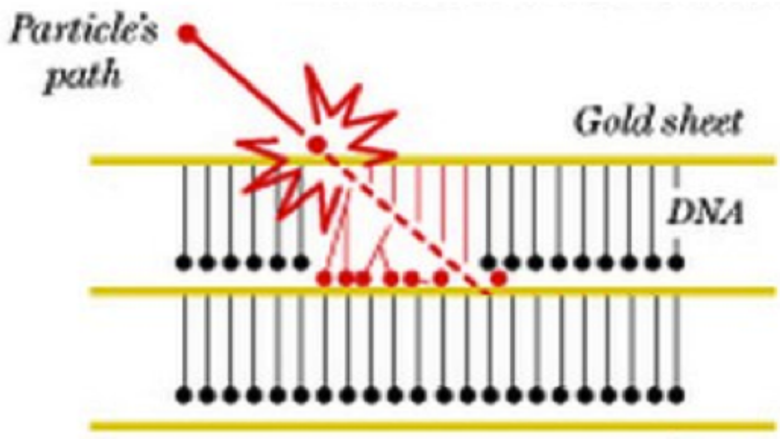


Other Solids - DNA!

A. Drukier, K. Freese, D. Spergel, C. Cantor, G. Church and T. Sano

Concept: Use of DNA sequencing technology as a way of encoding disruption of suspended strands by nuclear recoils.





- Identical units stacked: 5000 such units. On top: 0.5 micron layer of mylar (inactive).
- Next: 5-10 nm layer of gold; WIMP interacts with Au nuclei.
- ssDNA strands: 0.7nm per base when stretched. Strands differ only in "terminus pattern" of say 20- 100 bases at the bottom.

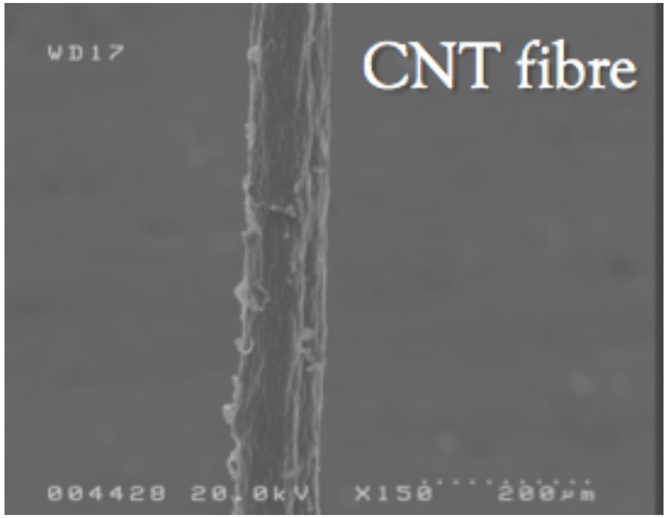
Issues for DNA: Many…

How to keep ssDNA strands straight? Electric or magnetic field (Church)
How to get severed strands to fall down: use electric or magnetic field?
How to scoop the severed ssDNA (e.g. once per hour): use magnetizable rod?
Determine Interaction of ssDNA with heavy Ion (Cross-Section?, singular cut?)
Off-Shelf DNA strands are about 250 bases (l~200nm), want thousand bases (l~μm)

Carbon Nanotubes (CNT)

DAMA group, M. Cirillo

Concept: Use of nano/carbon technology to encode directional fibre-like properties in a detector that can achieve bulk masses



- CNT are thin graphene foils, rolled as tubes with 10-100 nm diameters that can be aligned metallic material can be deposited on them.
- Nucler recoils may be detectable via effect of changing the electrical characteristics induced such as a change of resistivity in CNTs.
- 3 possible nano-devices under study: bare CNT, CNT with standard coating, CNT with superconducting Nb and NbN, all assembled as a grid of oriented bundles.

Challenges for CNT and other fibre technologies:

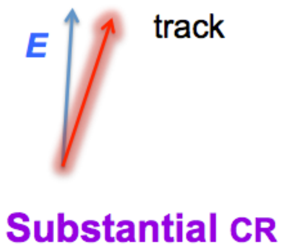
- Need for low cost mass-production with correct encoded properties
- Assembly into bulk detector of ton-scale
- Is there a way to do head-tail discrimination
- Can surface backgrounds be controlled

High-Pressure Xenon

D. Nygren et al.

Concept: Idea to use *columnar recombination* (CR) based on atomic/molecular processes in xenon-TMA. CR may be sensitive to the angle between nuclear recoil direction and drift field E in a gaseous TPC.

A large angle between track and field leads electrons transversely away from the ion column. Recombination signal is small relative to the ionisation signal.



A small angle implies a higher level of recombination as the electrons drift more or less parallel to the ions, encountering many; a recombination signal is relatively large in comparison to the surviving ionization signal.

Key parameter is Onsager radius, $r_O \equiv e^2/\varepsilon E$. r_O is that distance between a positive ion and a free electron for which the potential energy is balanced by E the electron's KE.

- Recoil directionality is obtained by comparison, event-by-event, of the ionisation signal and recombination signal produced *prior* to drifting the track ionisation.
- No visualisation of nuclear recoils necessary
- Use of Fluorescent Penning Molecules may optimise Columnar Recombination
- Optimum xenon density for this concept may be near ten bars

High-Pressure Xenon

Conceptual design: scheme in which all information is collected in the form of optical signals using high-pressure xenon gas electroluminescent (EL) TPC

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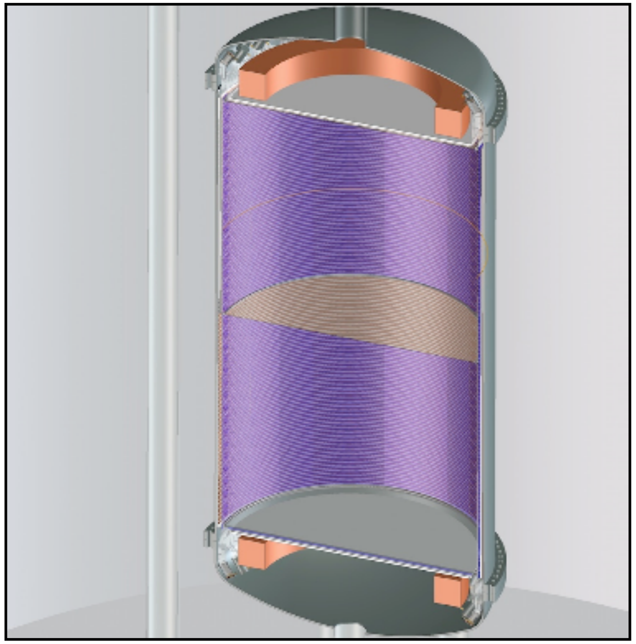


- 10 bars Xe gas TPC with penning additive
- Two drift regions of 2.5m
- WLS 4π for light collection

Directionality is via the ratio of recombination signal "**R**" (UV scintillation) to the surviving ionisation signal "**I**". The challenge is to maximise the detection efficiency of the **R** signal in a detector of interesting scale.

Although unknown at present, a head-tail effect may appear as a difference in **R/I** between the upper and lower halves of the TPC.

Challenges for HPXe:

- No demonstration yet
- The density for optimal Onsager radius may not be matched for directionality
- Optical detection efficiency - does TMA additive work sufficiently, what fraction?
- What electric field is required at given xenon density - is it reasonable?
- No head-tail sensitivity?
- Simulation so far do not show CR exists at the recoil energy

FUTURE

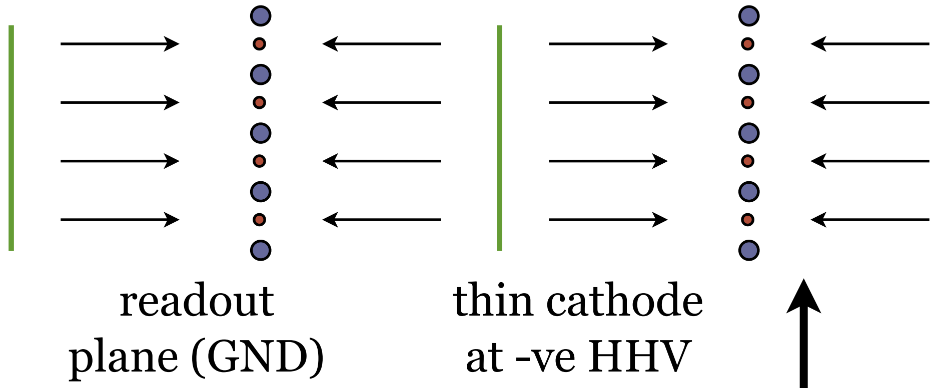
Next step may be DRIFT III

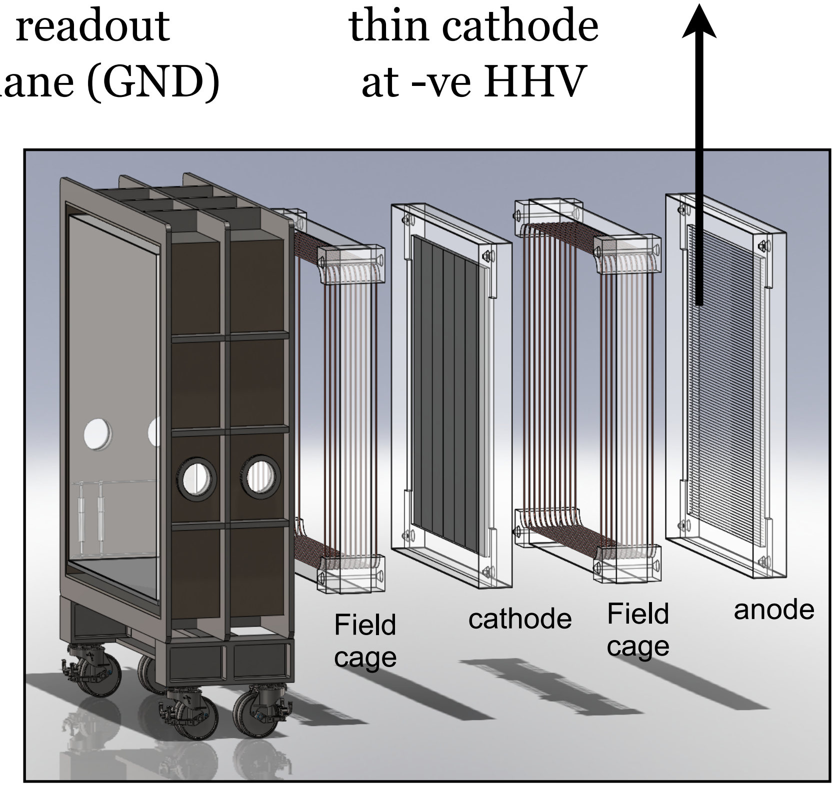
DRIFT III

Readout

Sense plane

- Transparent readout plane to sense two sides (eliminates the mechanical support "strong back")
- 20 µm diameter stainless steel wires on a 2 mm pitch
- X-wires, Y-veto strip
- Alternate grid wires, 1mm pitch
- Head-Tail sensitivity
- 2D readout but with 3D side veto



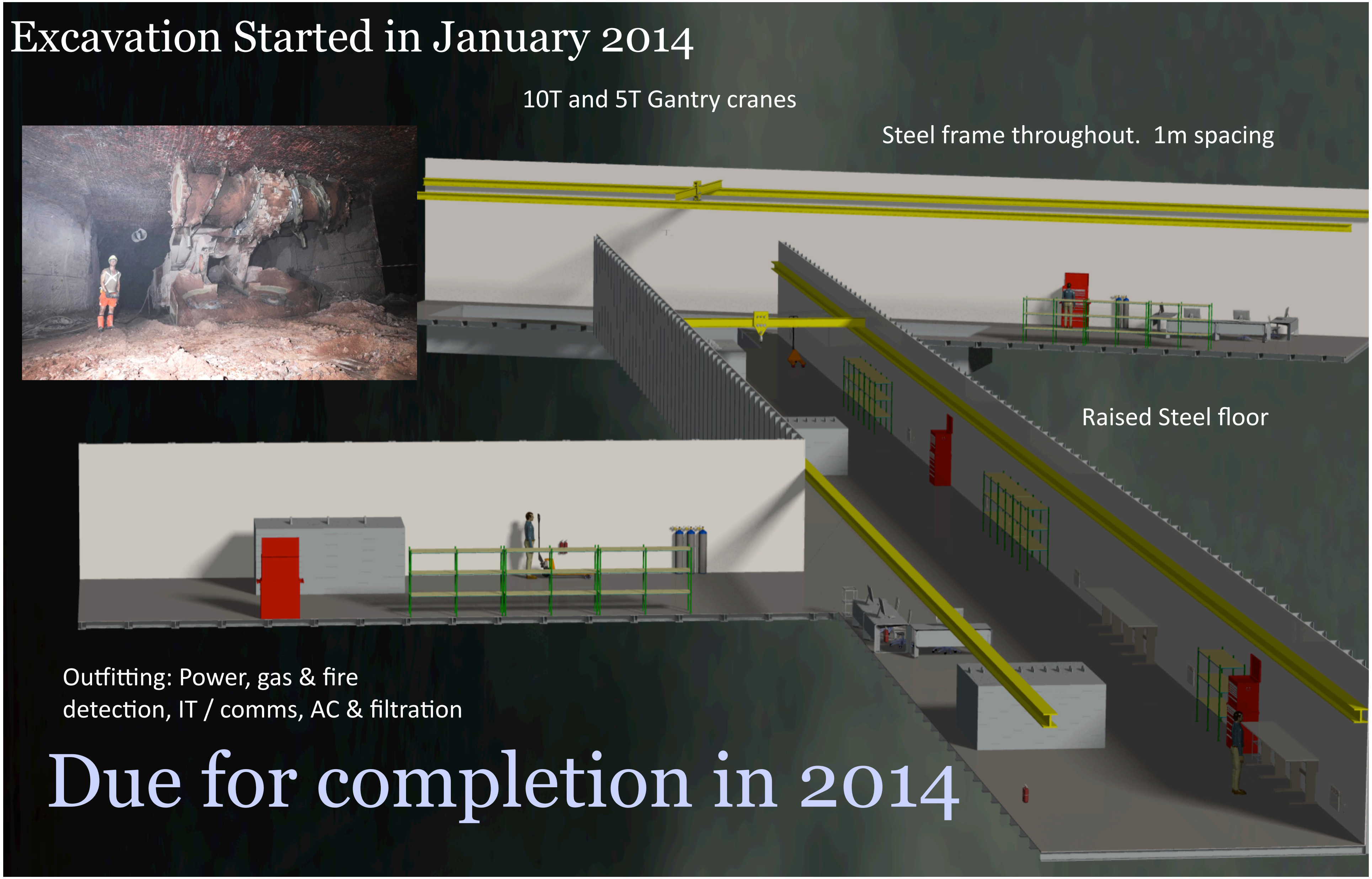


Cathode

- 70 kV with well-engineered field cage and high-voltage system; diffusion (reduced by 40% c.f. DRIFT II)
- Texturised thin film
- Partial segmentation

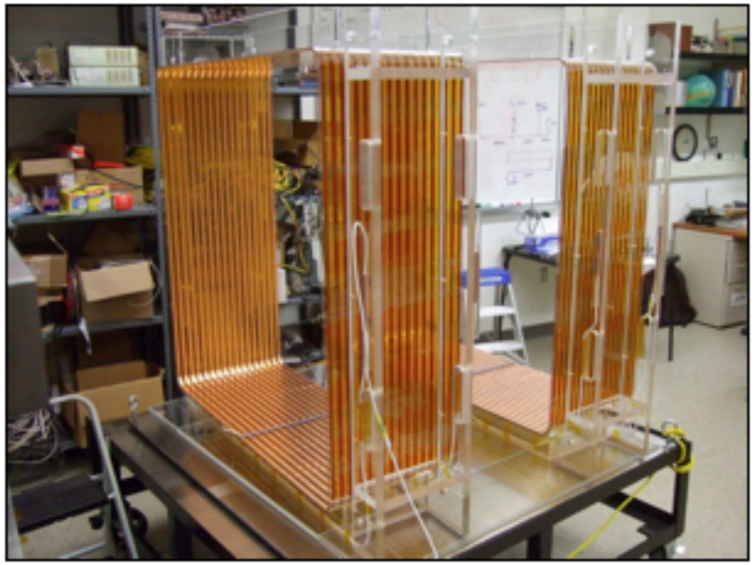
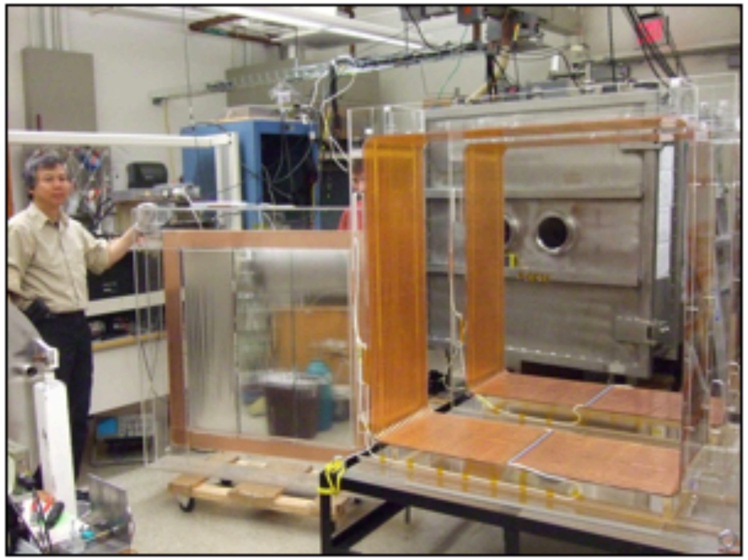
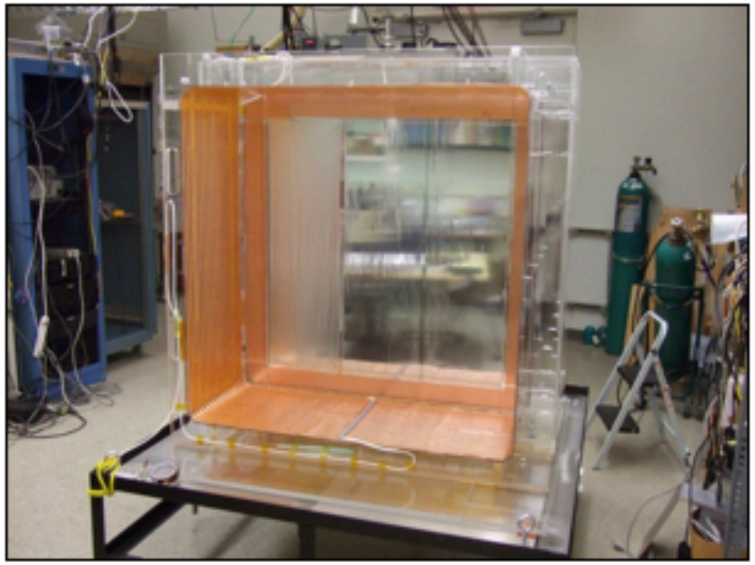
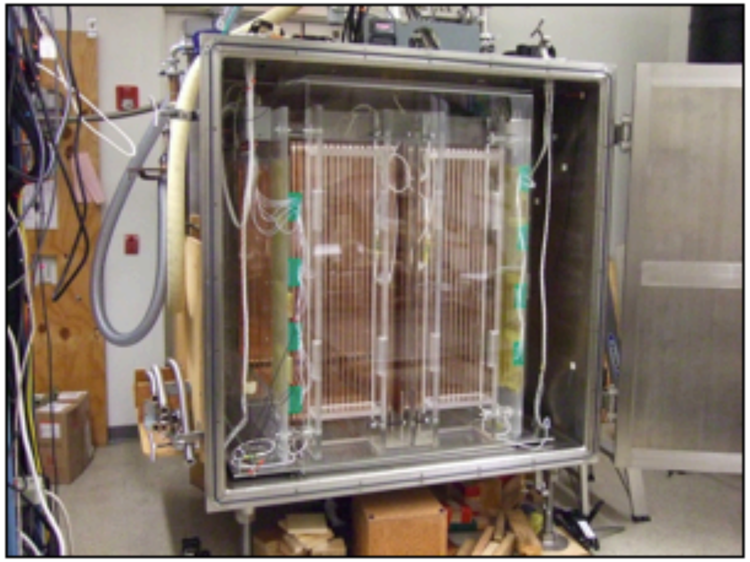
DRIFT III New Boulby Lab

- Large Experiments Cavern (6 x 7 m internal H x W)
- Main Hall (4 x 7 m H x W)



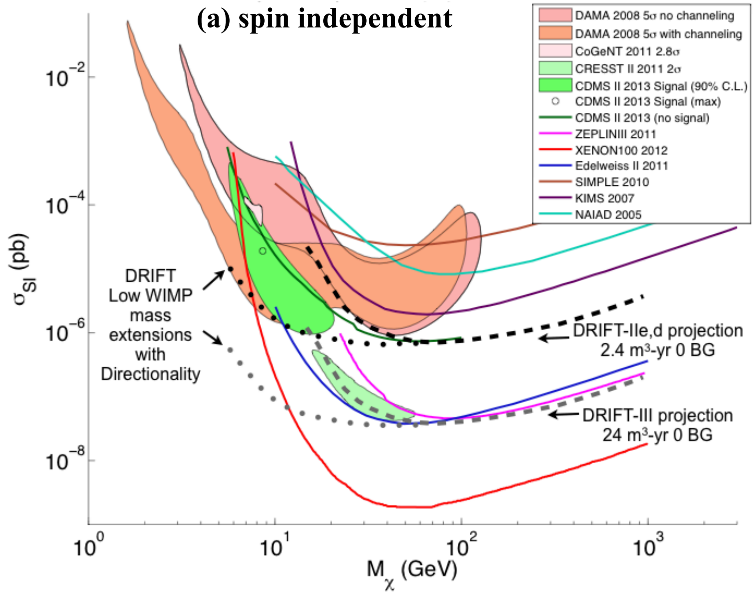
DRIFT IIe

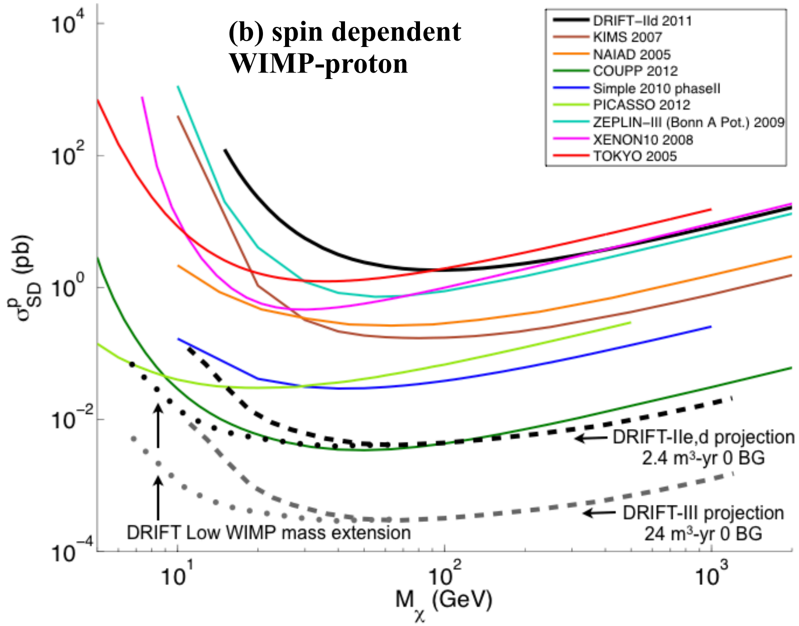
- Will test components of DRIFT-III - installation due in 2014

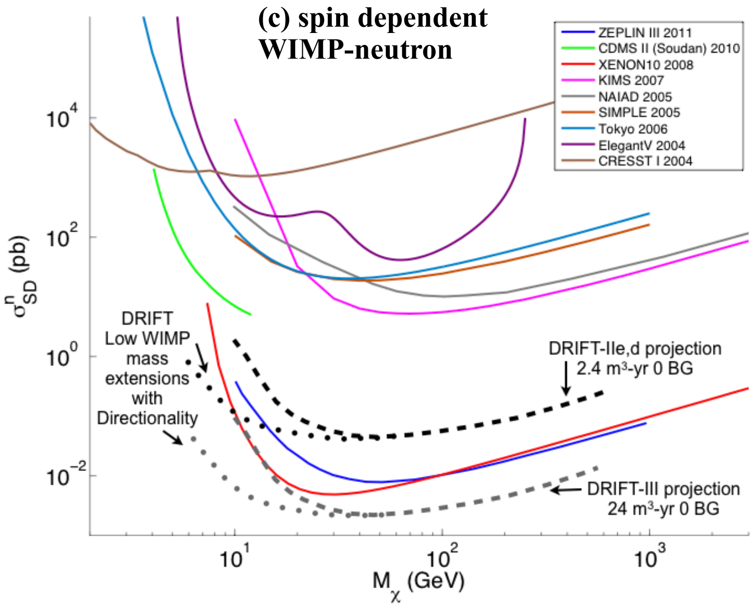





DRIFT III Goals

- Includes low mass WIMP upgrade







Projected limit setting sensitivity of DRIFT-II and DRIFT-III with the upgrades of this PRD for directional capability at reduced threshold for various WIMP-nuclei elastic scattering cross sections in comparison with other experiments (see text for refs): (a) spin independent, (b) spin dependent WIMP-proton and (c) spin dependent WIMP-neutron. The black line in (b) shows the published DRIFT-IId limit. Latest DRIFT-IId sensitivity with fiducialisation and reduced radon is a factor 10-20 lower.

None of the other experiments are directional.

- Apology - not all latest results included yet

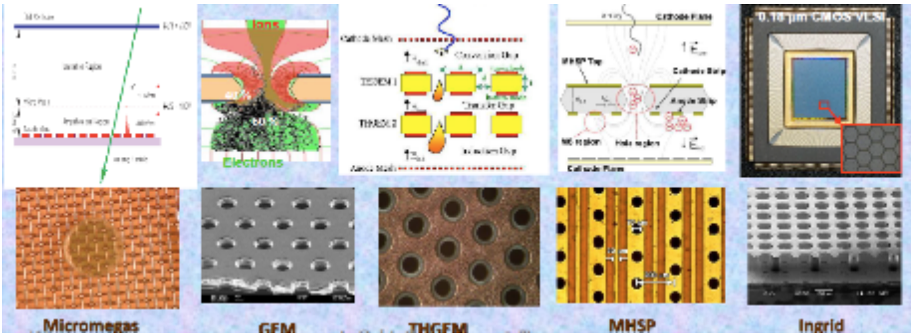
Conclusion

We DO NEED a SIGNAL to discover WIMPs..

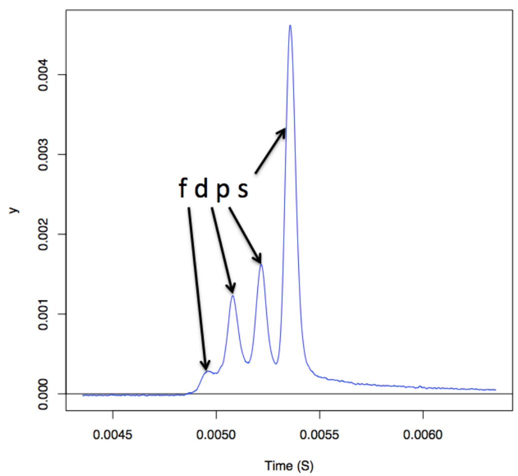
But directional experiments need to compete in the non-directional world

CYGNUS and other directional groups have made huge progress recently. e.g. fiducialisation is vital - the magic gas

Many readout technologies....



30 Torr CS_2 + 10 Torr CF_4 + 1 Torr O_2



..but there are major challenges:

A solid state directional detector remains the Holy Grail

Backup