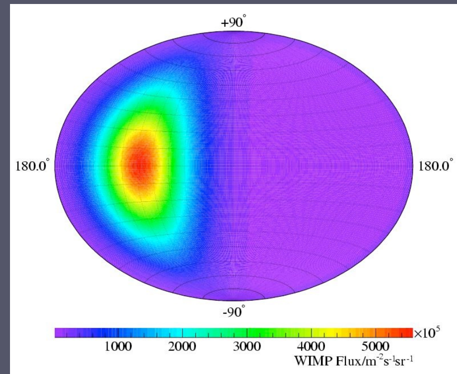
Review of Dark Matter Directional Detection



Neil Spooner, University of Sheffield

- **Motivation for Directional Detection of WIMPs**
- **High Density Directional Detector Ideas**
- **Directionality with Gas Detectors**
- **CYGNUS and Coherent Neutrino Detection**

Thanks to those from whom I have borrowed slides and info

Sorry not to cover all experiments

~Current Situation

- **at High Mass**

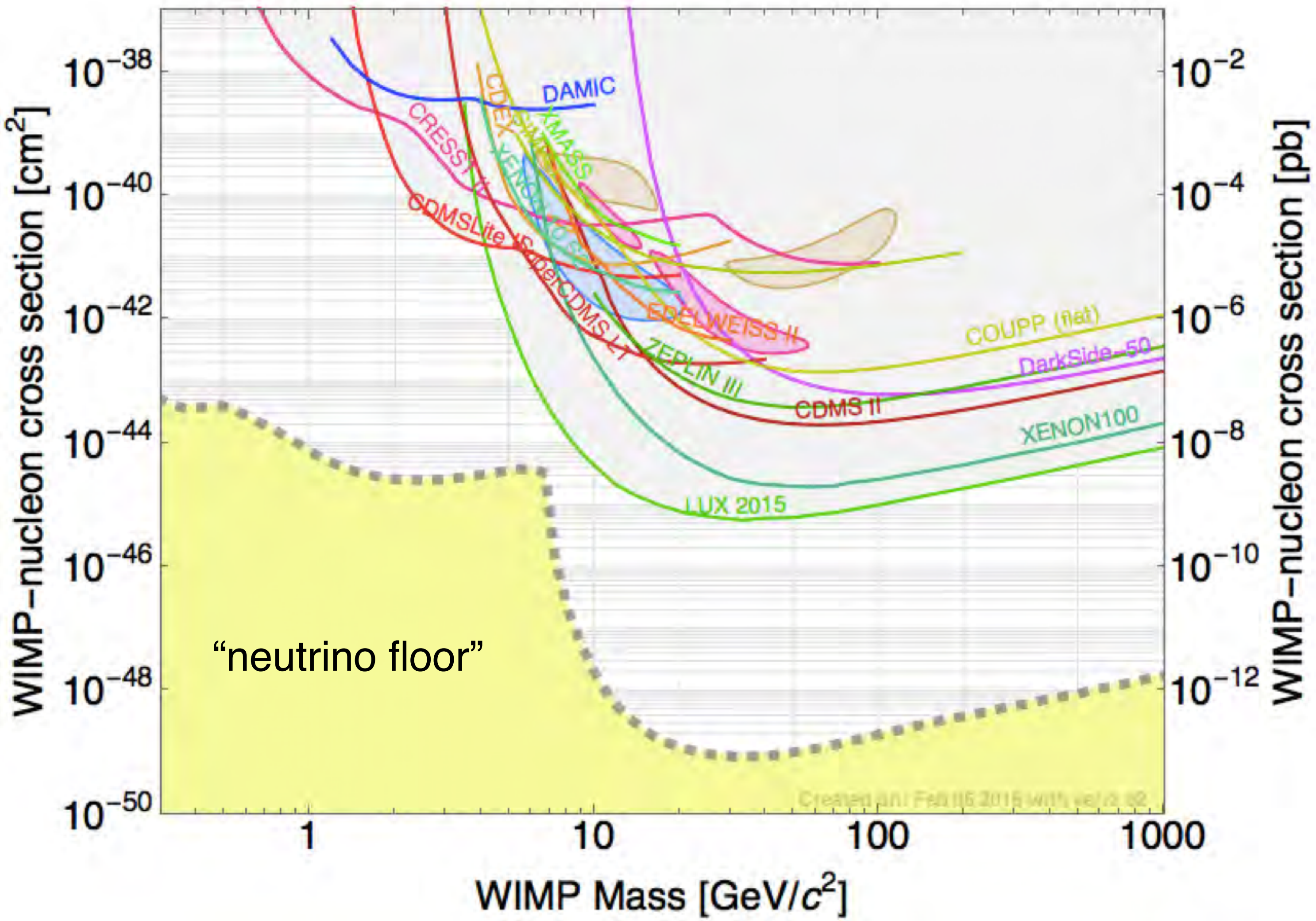
Nothing so far
Consistent with the absence of SUSY@LHC

- **at Low Mass**

Some closed contours, and strong limits

What is going on?

- **Are the closed regions a hint or just unreliable calibration**

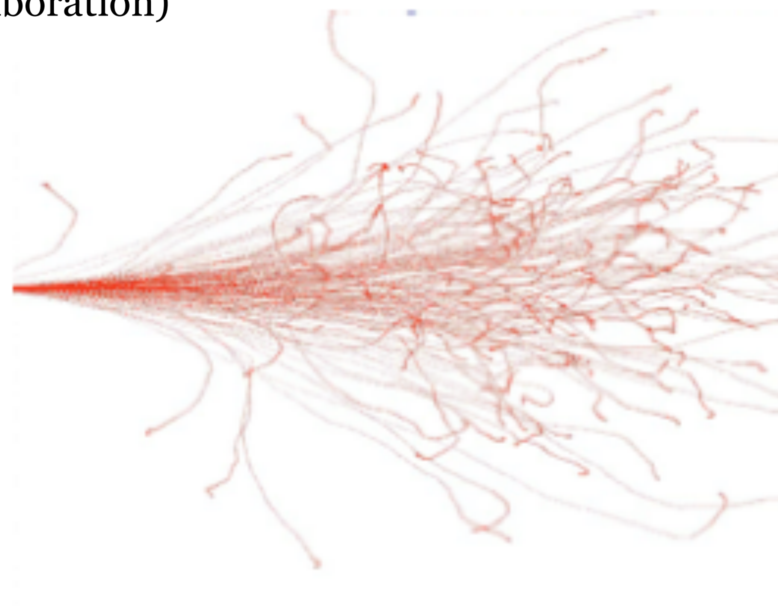


What to do? - seek a better signal..

What a WIMP Does

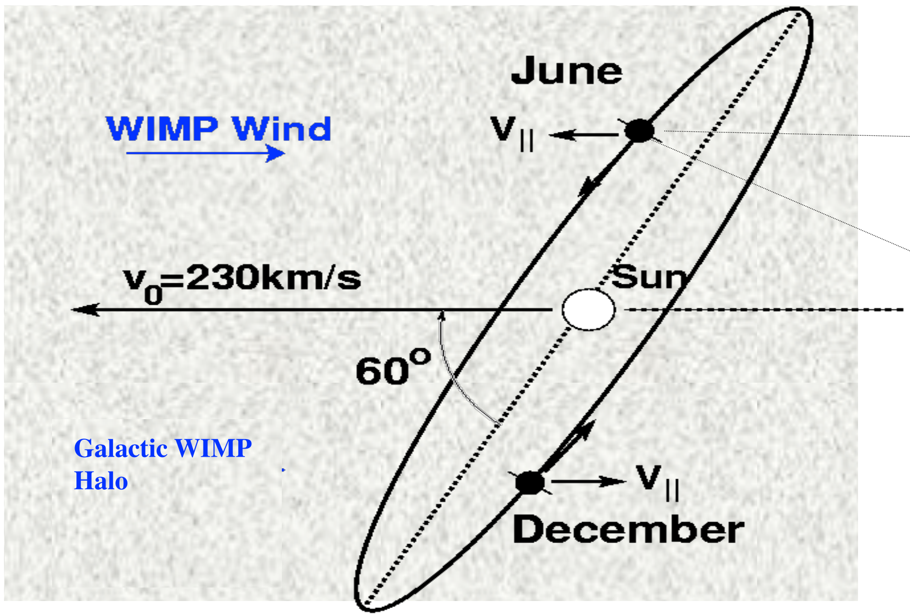
atom

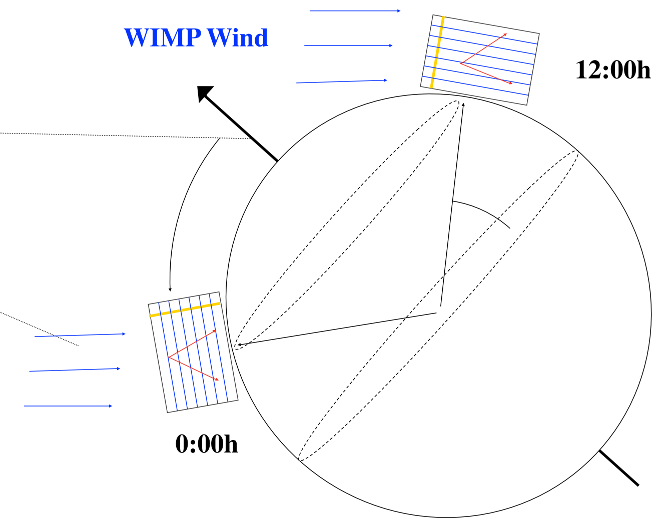
SRIM simulation - 100 keV F recoil in 75 Torr CF_4
(D3 collaboration)



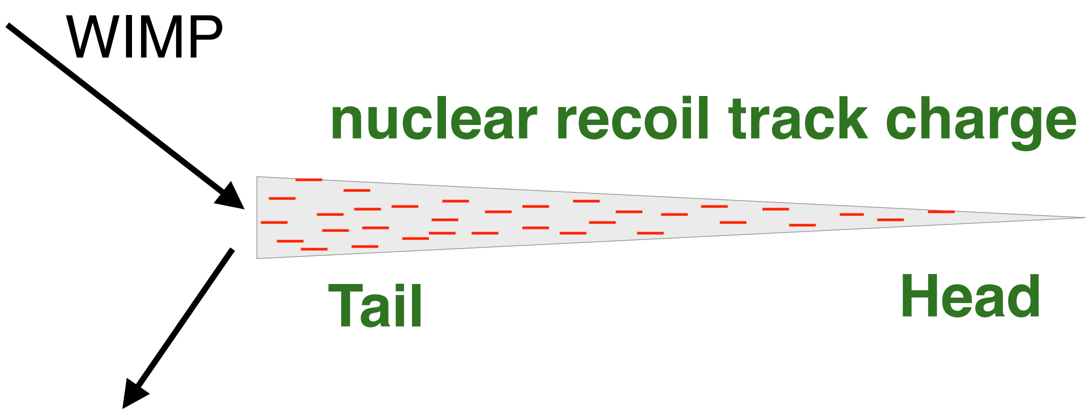
A Better Signal for WIMPs

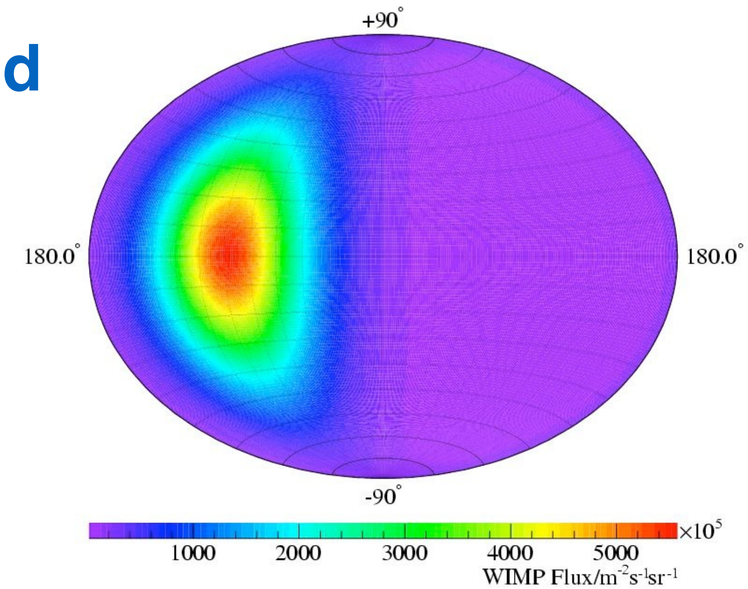
- A directional recoil signal is a very powerful proof
- Lets be prepared!





- Measure the nuclear recoil track itself and determine the head from the tail

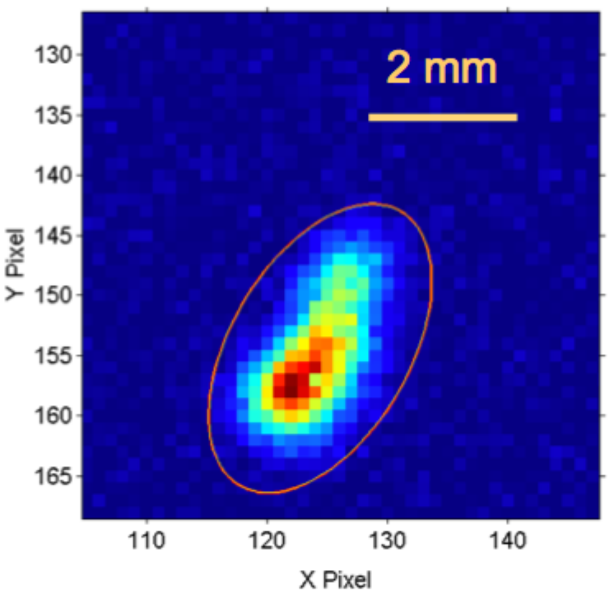




Power of Directionality

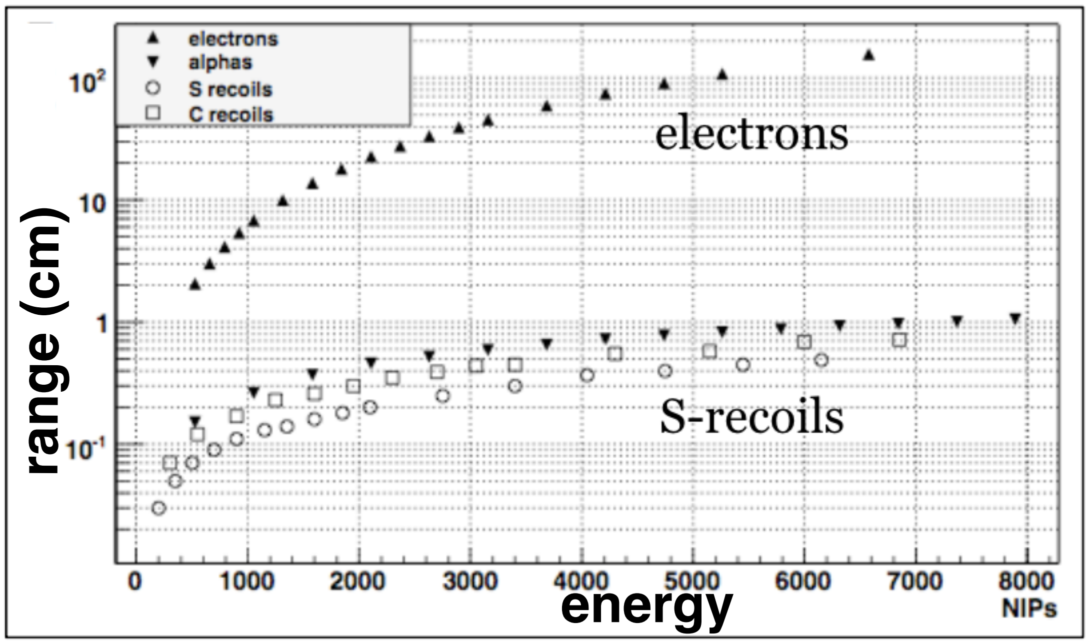
(at least in a gas TPC)

- Strong particle identification from topology



Example high energy F recoil in optical TPC (D. Loomba et al.)

- Total ionisation
- Particle range
- dE/dX topology
- Track orientation (axial)
- Track sense (head-tail)(vector)



Track range vs. Energy simulations with 40 Torr CS_2

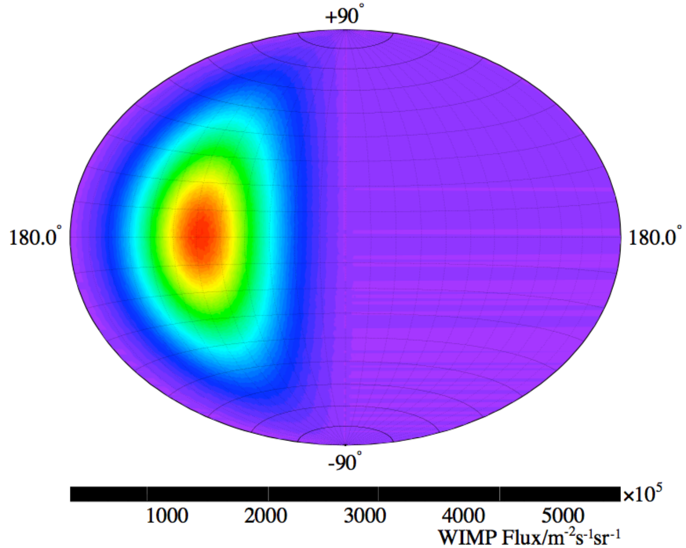
S. Burgos et al., Astropart. Phys. 28 (2007) 409

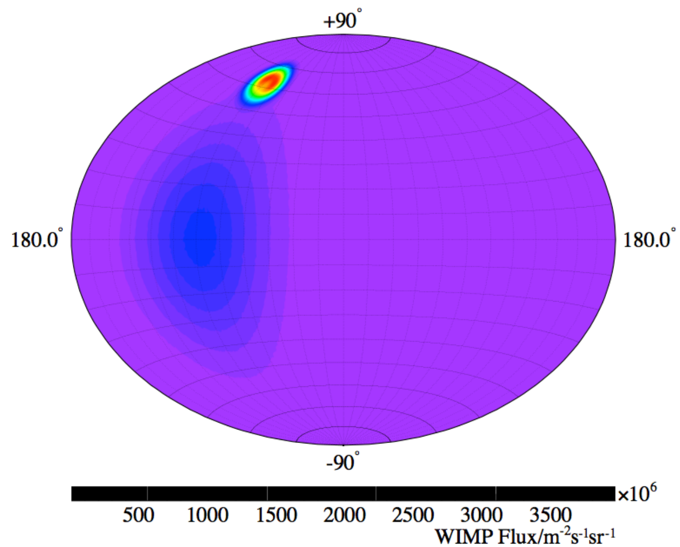
Power of Directionality

- Potential for WIMP “Astronomy”

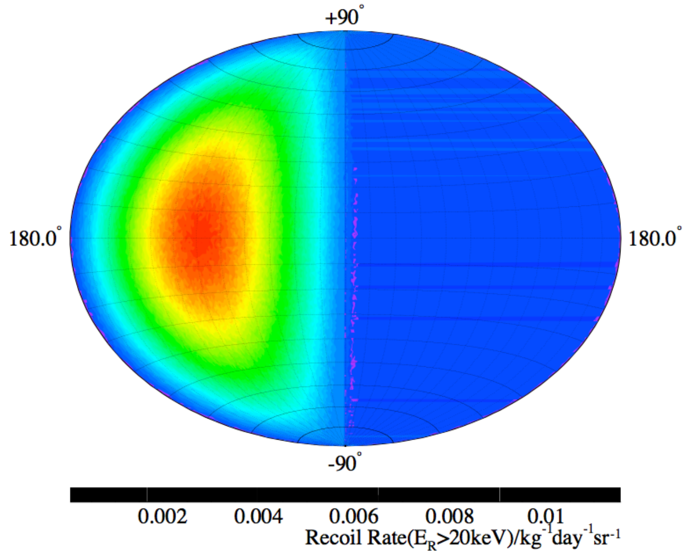
Standard Halo | **With Sagittarius Stream**

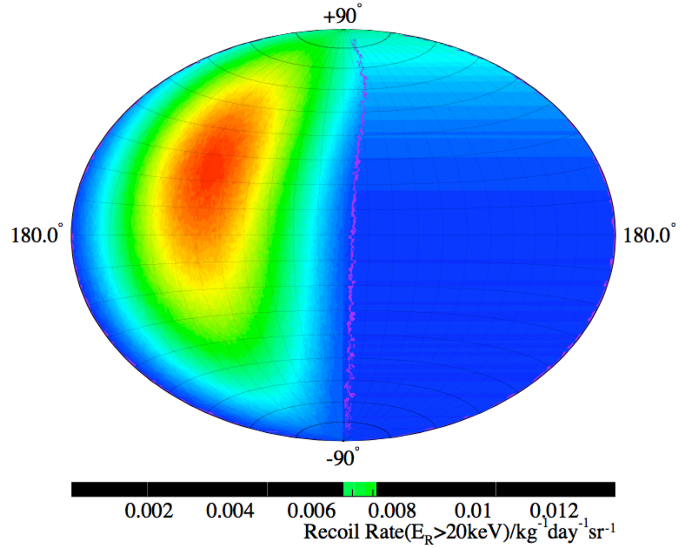
WIMP flux





S recoil flux

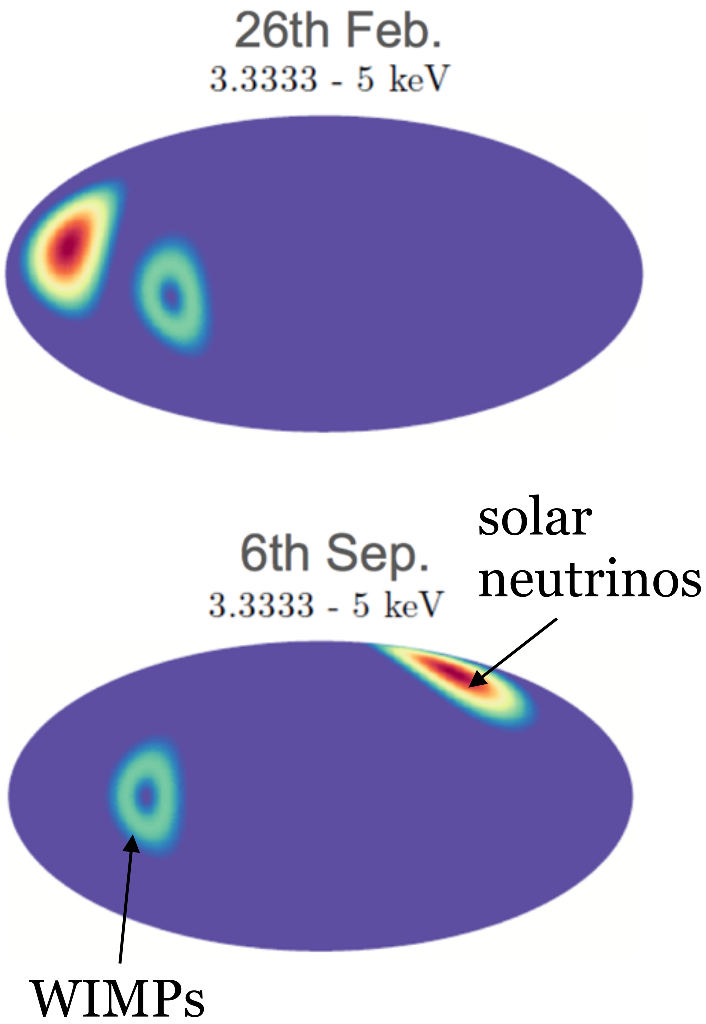


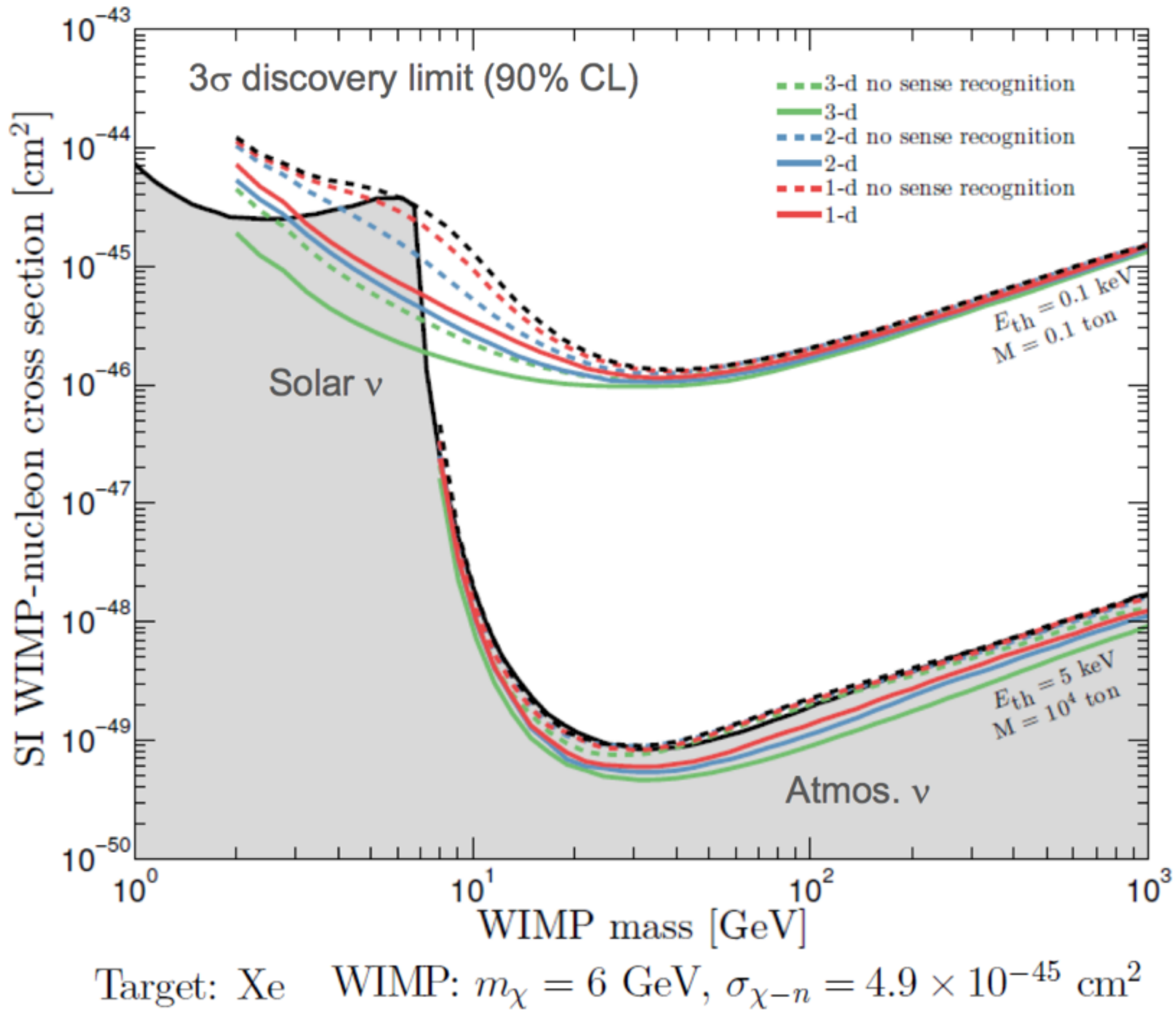


simulations by Ben Morgan (Sheffield)

Power of Directionality

- Potential to go beyond the “neutrino floor”





- position of Sun never coincides with Cygnus

e.g. C.J.G. O’Hare 1505.0806

Optimising Directional Detectors

- **How many WIMPs to get a directional (non-isotropic) signal?:**
- Example simulations with perfect angular resolution

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

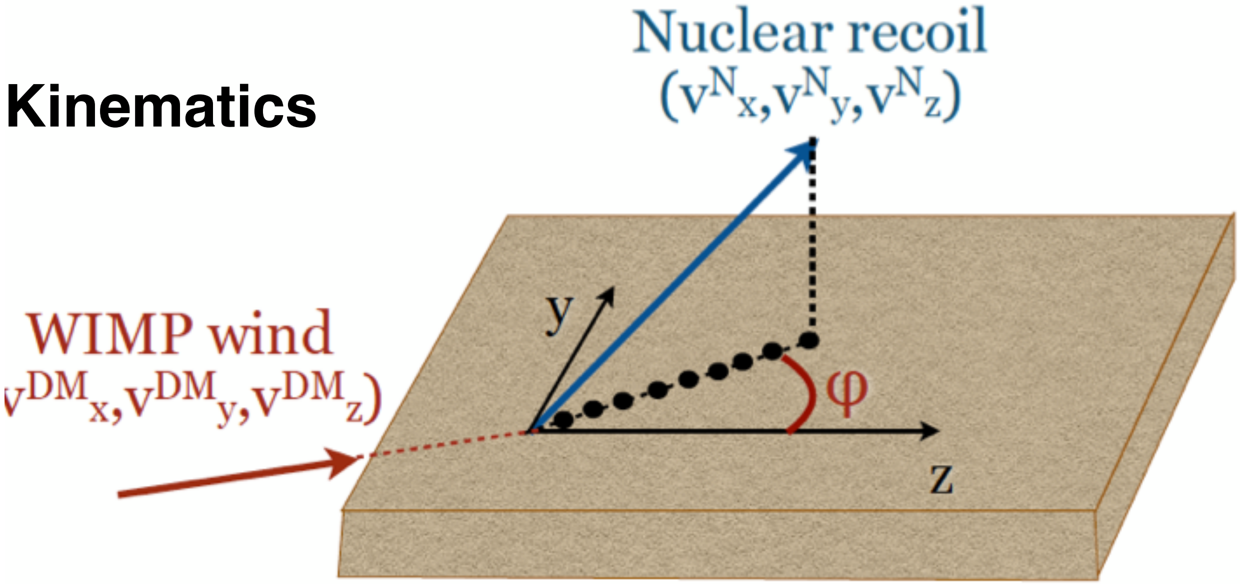
difference from baseline configuration	N_{90}	N_{95}
none	7	11
$E_T = 0$ keV	13	21
no recoil reconstruction uncertainty	5	9
$E_T = 50$ keV	5	7
$E_T = 100$ keV	3	5
$S/N = 10$	8	14
$S/N = 1$	17	27
$S/N = 0.1$	99	170
3-d axial read-out	81	130
2-d vector read-out in optimal plane, raw angles	18	26
2-d axial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

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

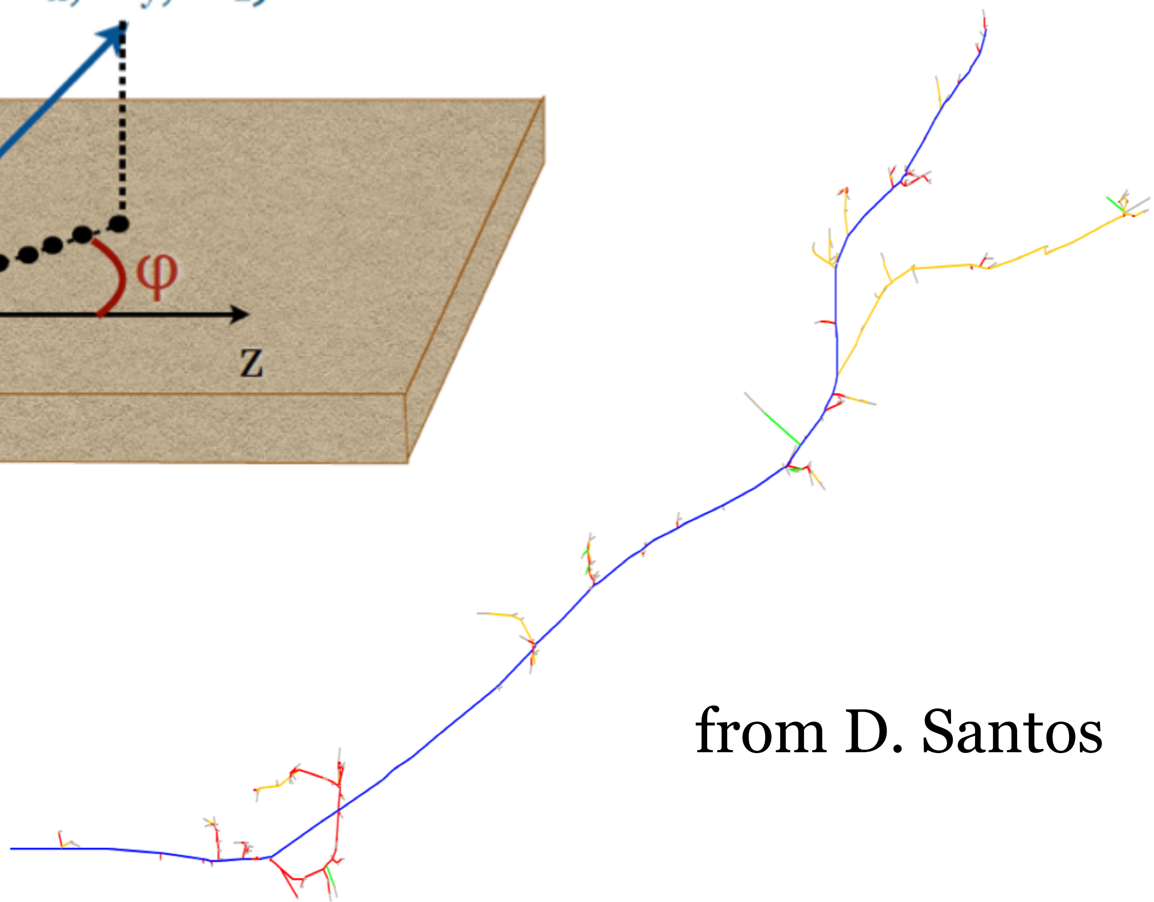
Directionality and Straggling

- **In practice straggling reduces directional sensitivity.**

Kinematics



Straggling



from D. Santos

- The start of the track may have most of the directional information

Discovery Strategy with Directionality

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

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

Modelling the Milky Way WIMP halo

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

Leads to a complex optimisation of detector parameters and design:

- 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

High Density Targets
Solid, Liquid…

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

Old work

Stilbene

Rotons in Lq He

Phonon focussing

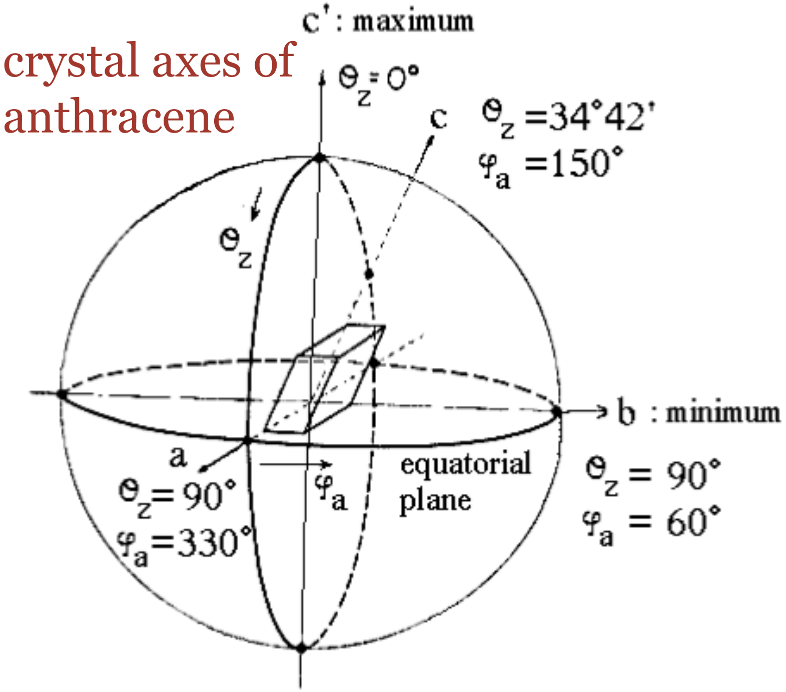
Multilayers....

But recent work is progressing...

Anisotropic Scintillators

Concept (1): **Anisotropic organic scintillator, anthracene, stilbene** 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)

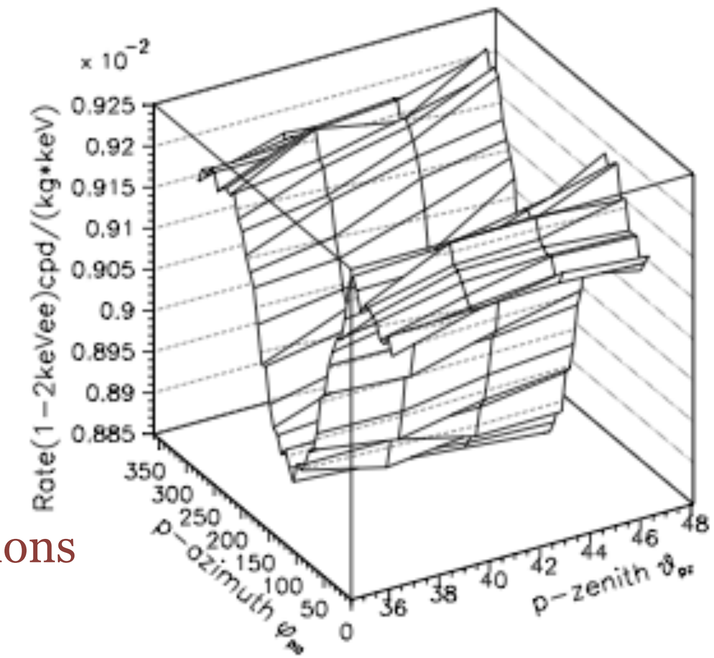
N.J.C. Spooner et al., IDM (World Scientific 1997) 481

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

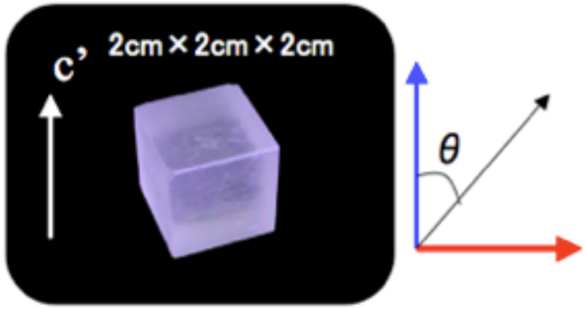
Anisotropic Scintillators

Concept: Anisotropic scintillation in organics

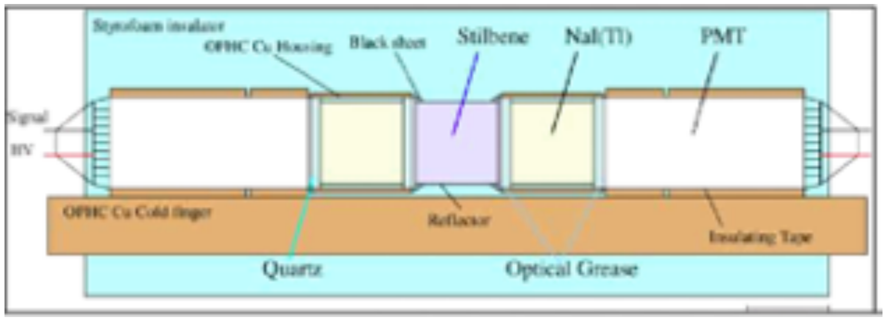
Example work (2003):

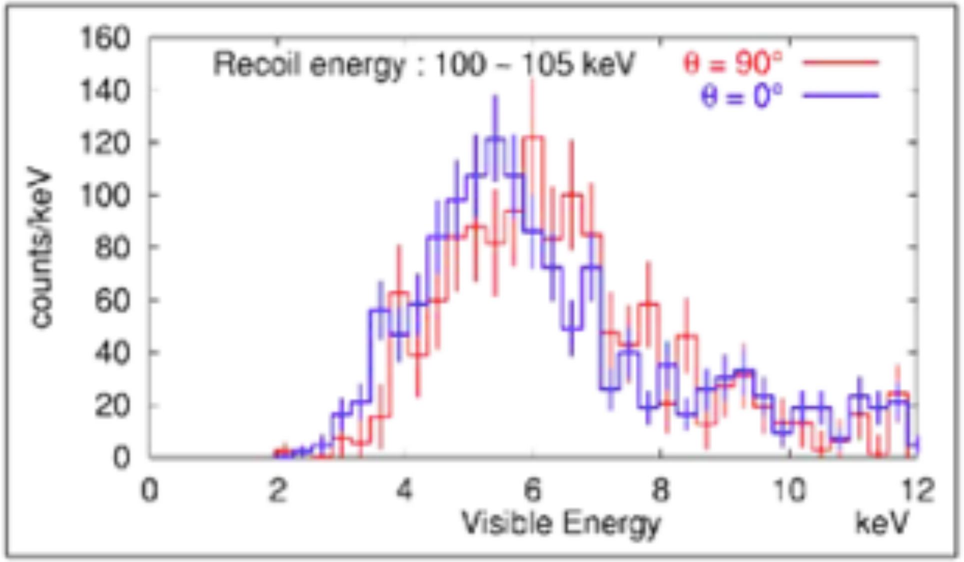
Hiroyuki Sekiya (Kyoto University) M.Minowa, Y.Shimizu, Y.Inoue, W.Suganuma (University of Tokyo)

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

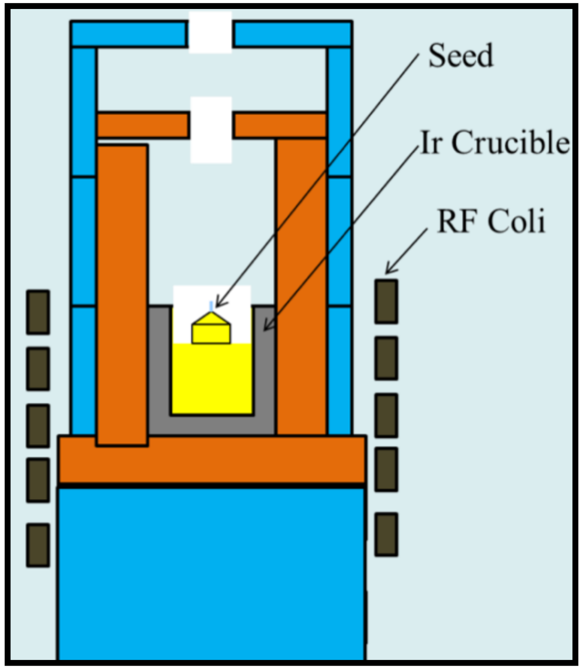
$ZnWO_4$ - Japan

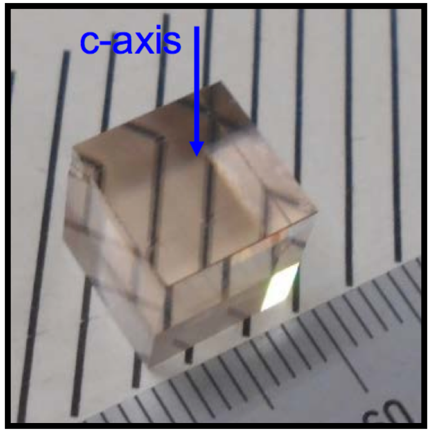
Concept: Anisotropic scintillation in $ZnWO_4$ **Sekiya group**

Hiroyuki Sekiya
Kamioka Observatory, ICRR, University of Tokyo
Shunsuke Kurosawa, Akira Yoshikawa
Research Lab. on Advanced Crystal Engineering, IMR, Tohoku University

~40% anisotropic response for α particles was observed with this 9 x 9 x 9 mm sample.

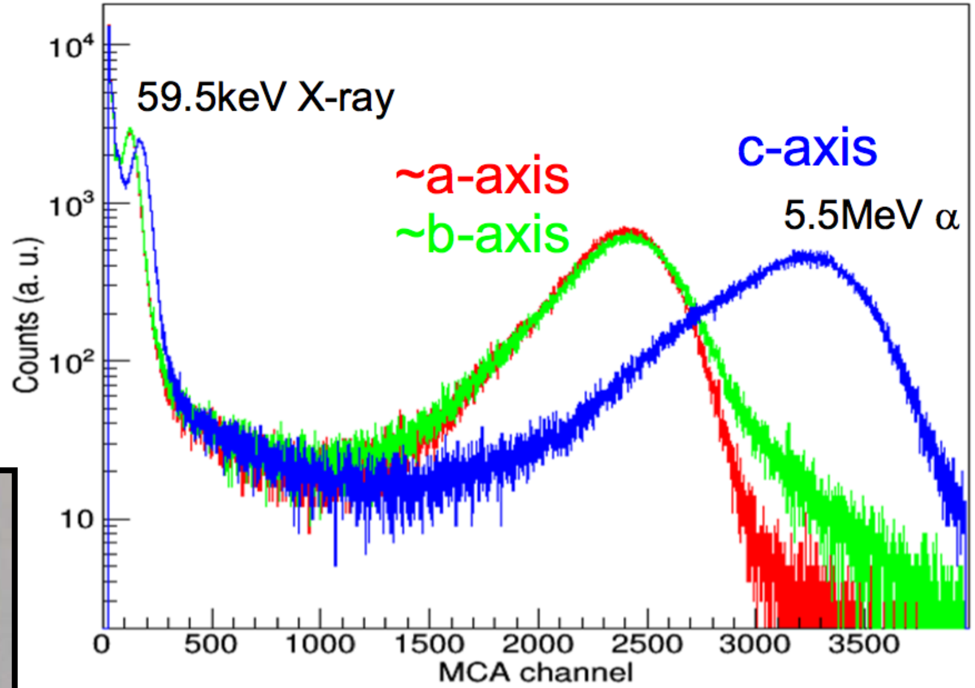
Similar response for X-ray was also observed. This was not expected…Systematics? True effect?Crystal dependence





9mm x 9mm x 9mm

Make larger crystals with Czochralski process

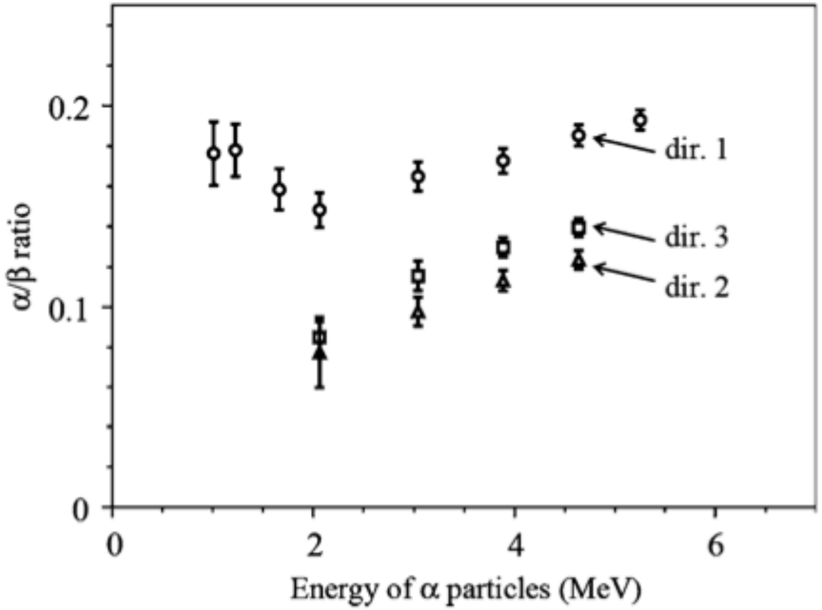


Issues for $ZnWO_4$:

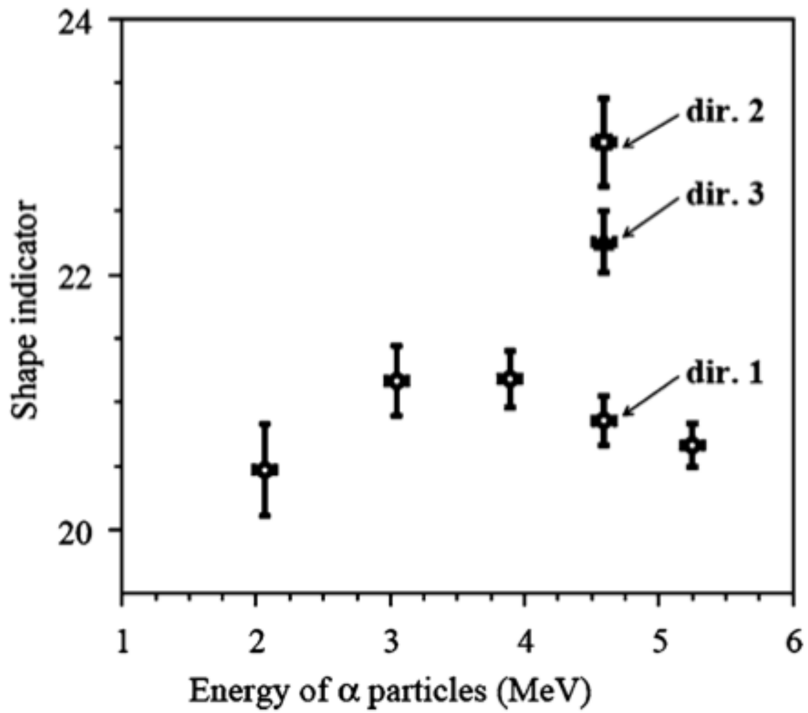
- Check low energy response
- Backgrounds
- No head-tail

$ZnWO_4$ - ADAMO

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

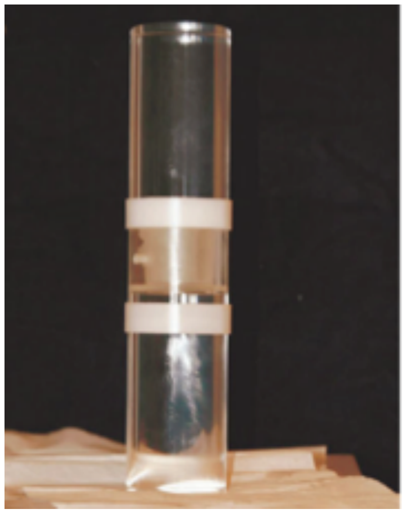


Dependence of α/β ratio on α particle energy of in directions perpendicular to (010), (001) and (100) crystal planes (directions 1, 2 and 3, respectively).



QF for O, Zn and W ions with energy 5 keV for different directions in $ZnWO_4$.

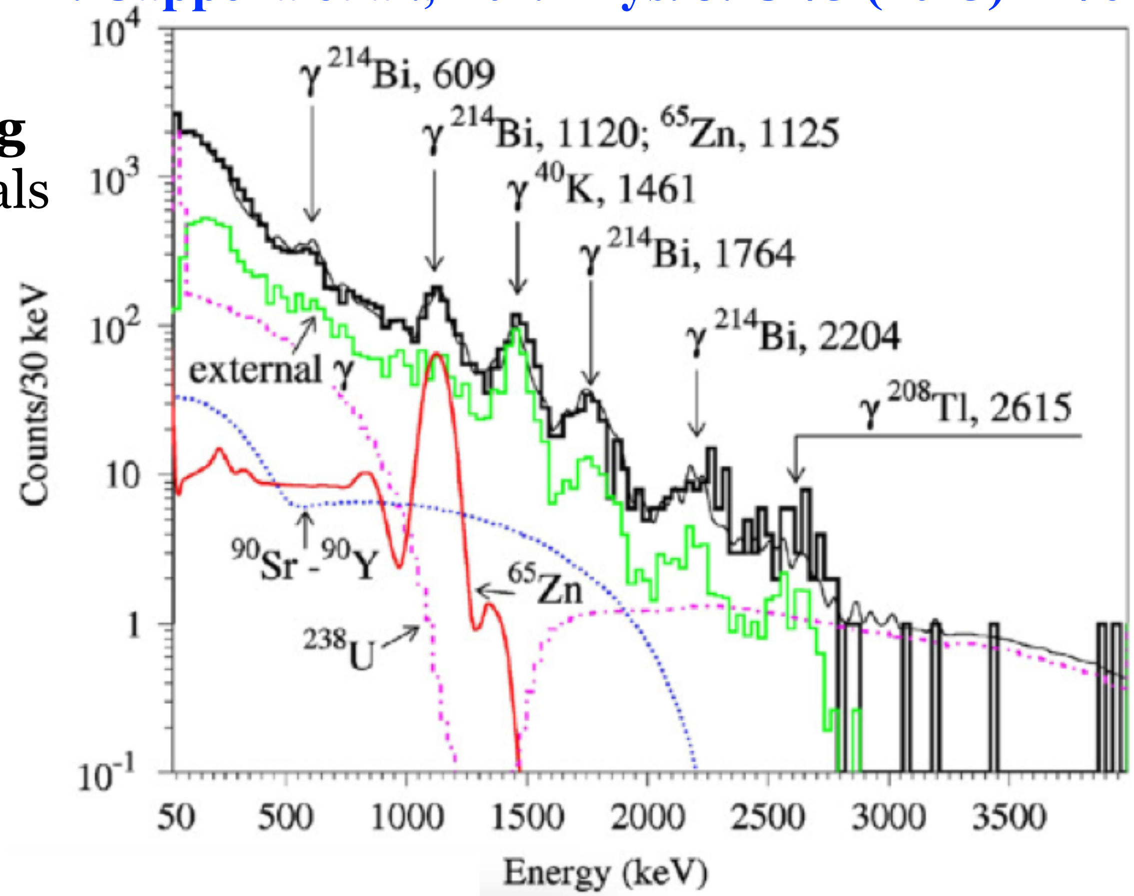
Ion	Quenching factor		
	dir. 1	dir. 2	dir. 3
O	0.235	0.159	0.176
Zn	0.084	0.054	0.060
W	0.058	0.037	0.041



Prototype now under study

$ZnWO_4$ - ADAMO

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



Various crystals with mass **0.1 - 0.7 kg** realised by exploiting different materials and techniques

Low background measurements in the DAMA/RD set-up at LNGS

The measured radioactivity of $ZnWO_4$ approaches that of specially developed low background NaI(Tl)

Future $ZnWO_4$ crystals with higher radiopurity expected

Issues for $ZnWO_4$:

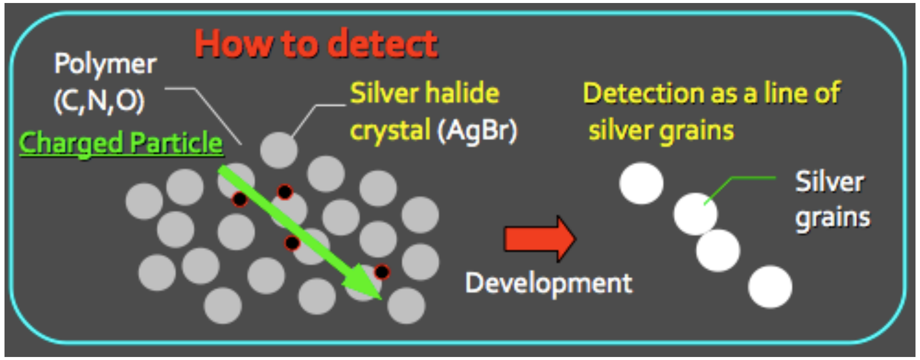
- Check of low energy recoil response needed
- Backgrounds
- No head-tail

Nuclear Emulsions - NEWS

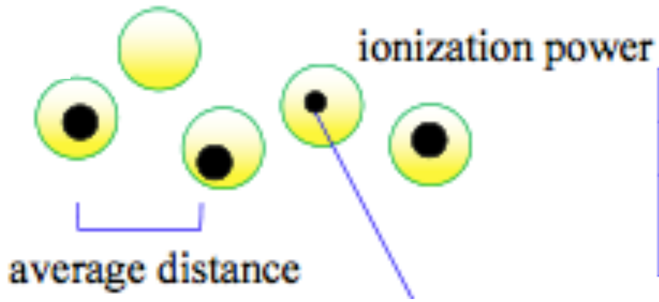
Giovanni de Lellis (Napoli) and Nagoya University, OPERA...

Concept: Use of emulsion film to give 3D tracking

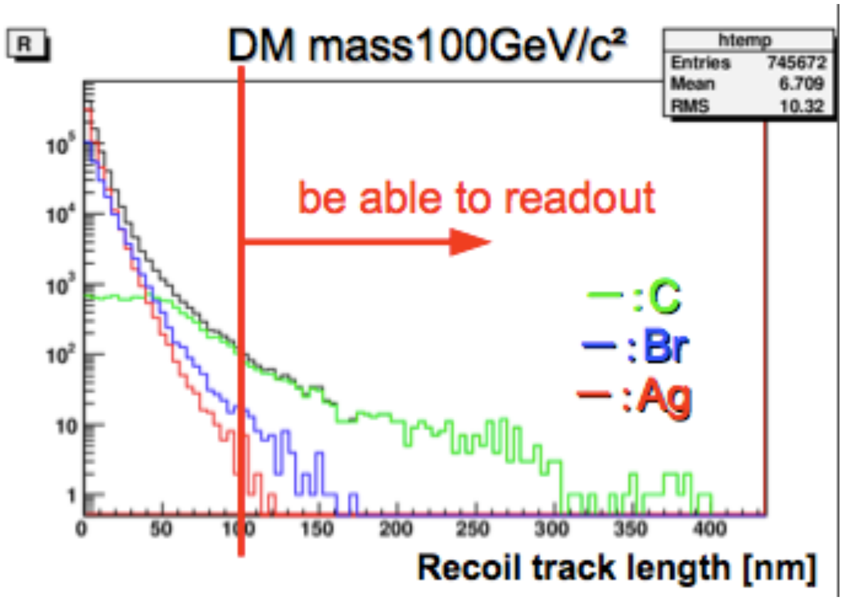
Solid (3g/cc), high spatial resolution, low cost, target Ag(46%), Br(34%), C(N,O) (19%)



- Track produces line of silver grains

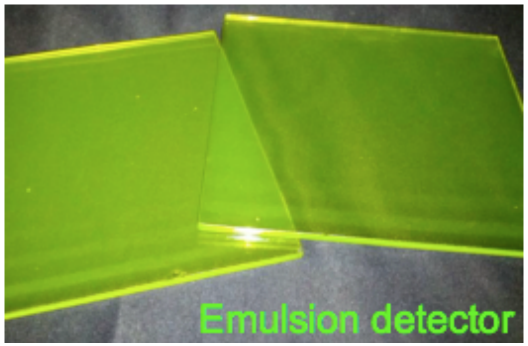


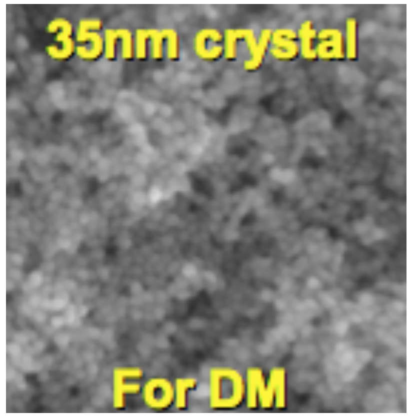
crystal size	45nm
crystal distance	85nm
crystal sensitivity for alpha-ray	>20% (not sensitized)



- 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





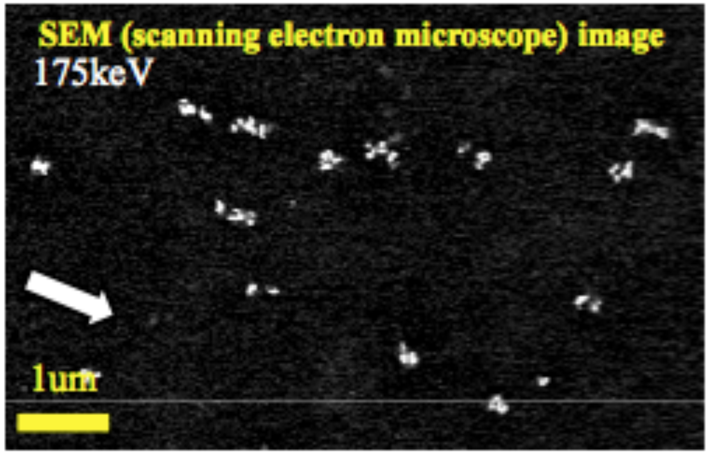
- Progress made to produce stable very fine crystals by using the PVA techniques

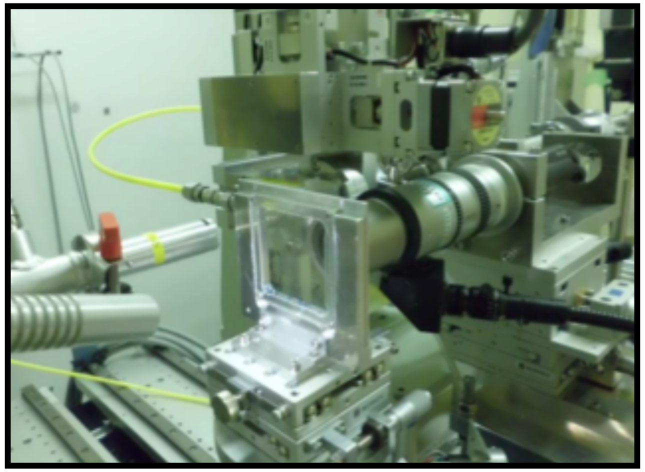
Nuclear Emulsions - NEWS

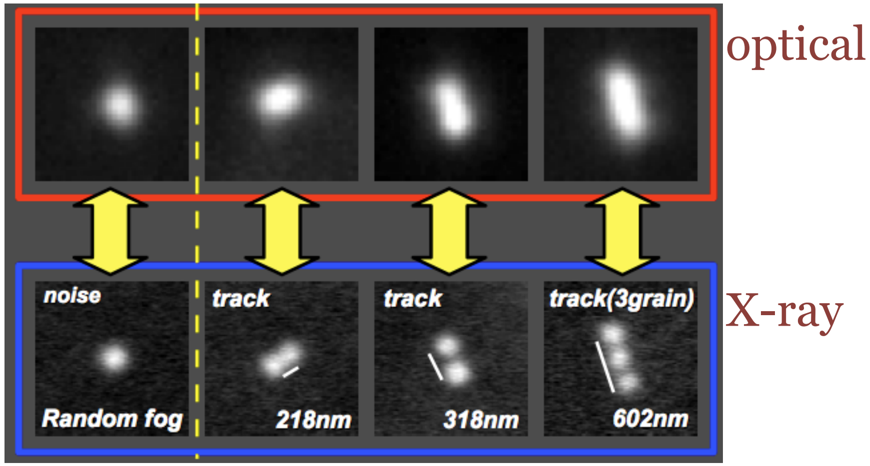
Giovanni de Lellis (Napoli) and Nagoya University, OPERA...

- 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



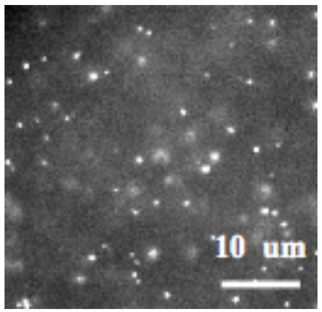


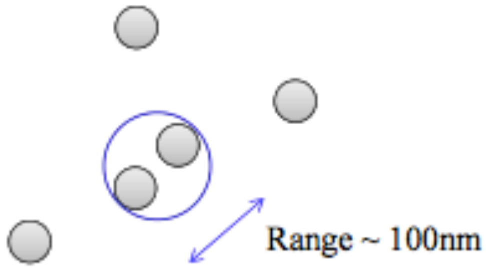


Challenges for directional organics:

- 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



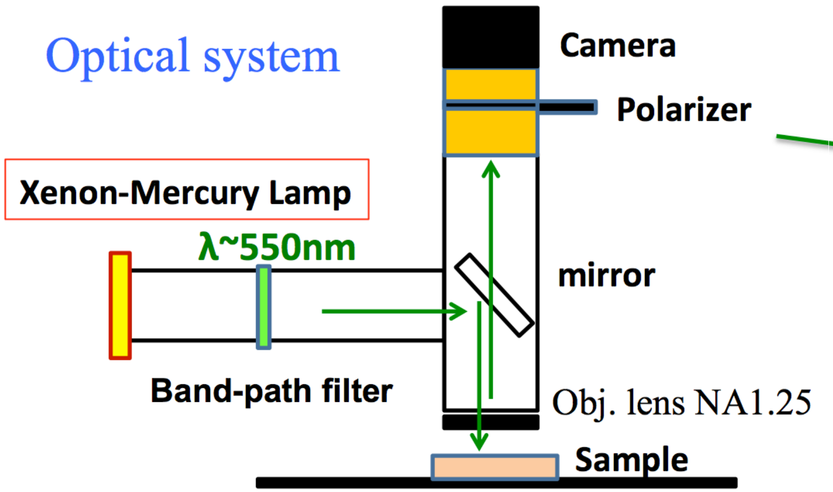


Nuclear Emulsions - NEWS

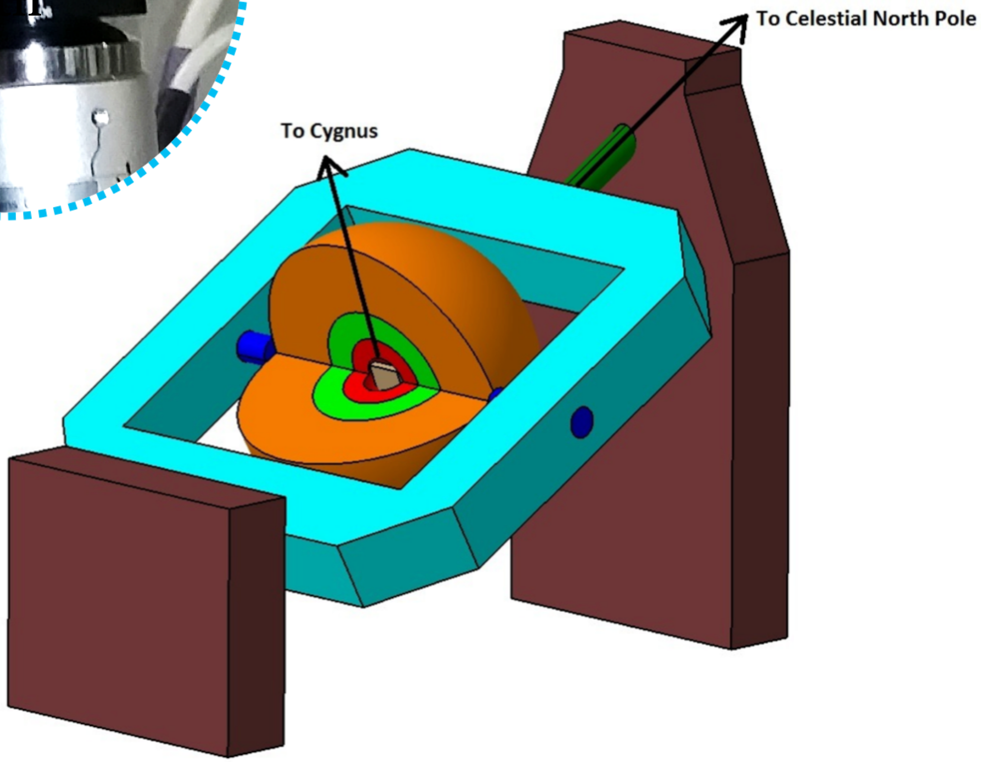
Giovanni de Lellis (Napoli) and Nagoya University, OPERA...

- **Preparing Technical Design Report for a pilot experiment at kg-year scale.**
- Automatising the use of polarised light for unprecedented position resolution (10 nm)

Optical system

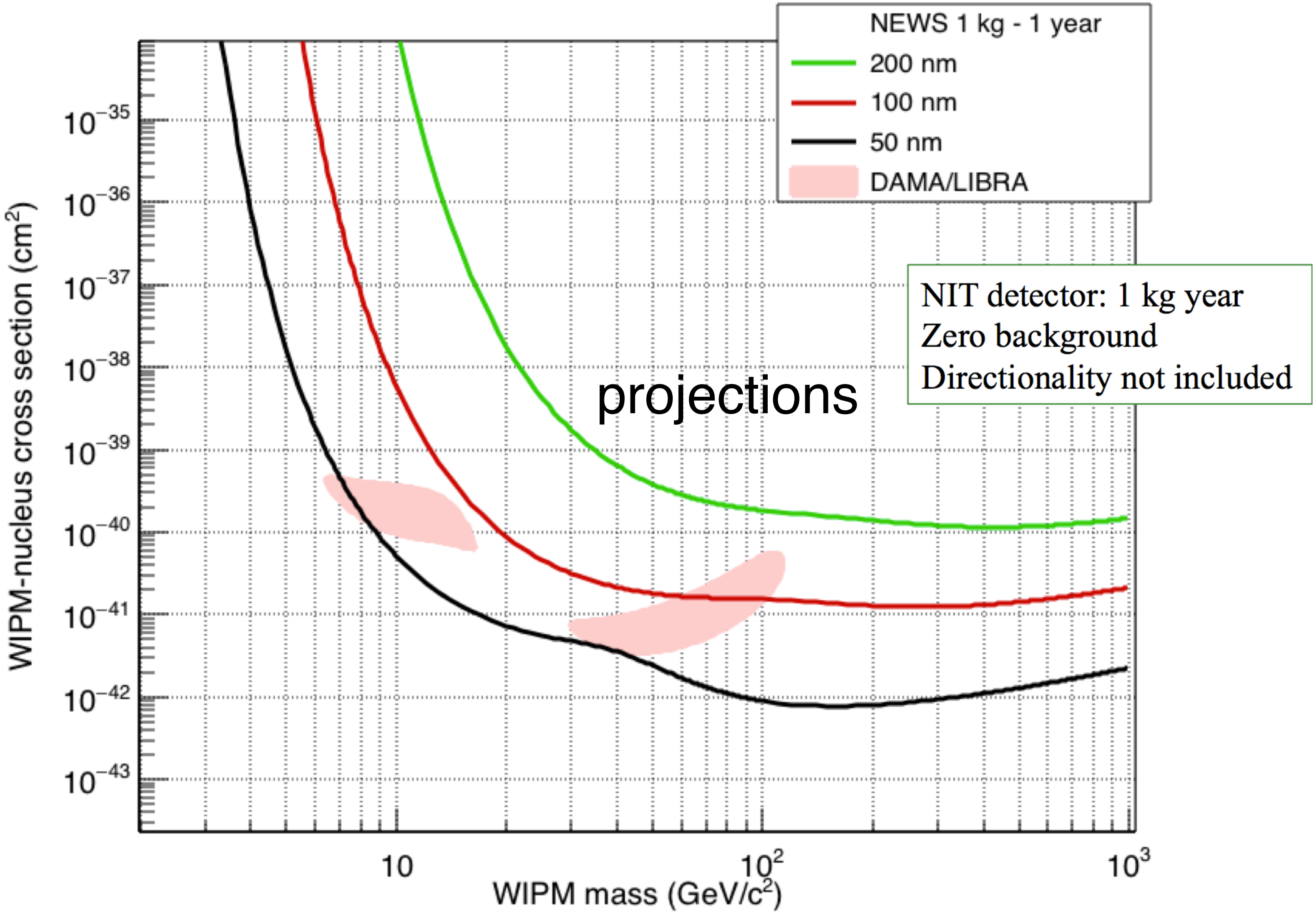


- Designing telescope mount



Nuclear Emulsions - NEWS

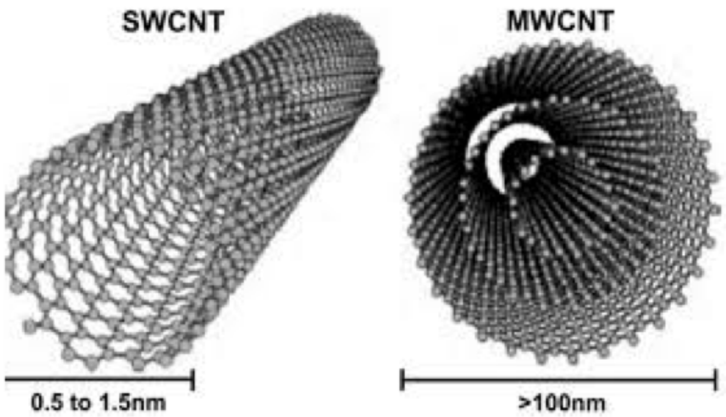
Giovanni de Lellis (Napoli) and Nagoya University, OPERA...

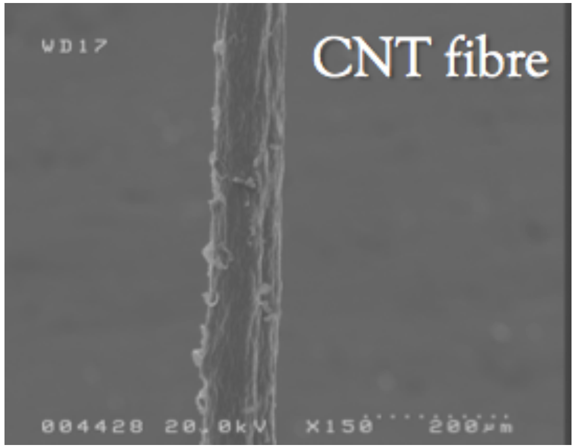


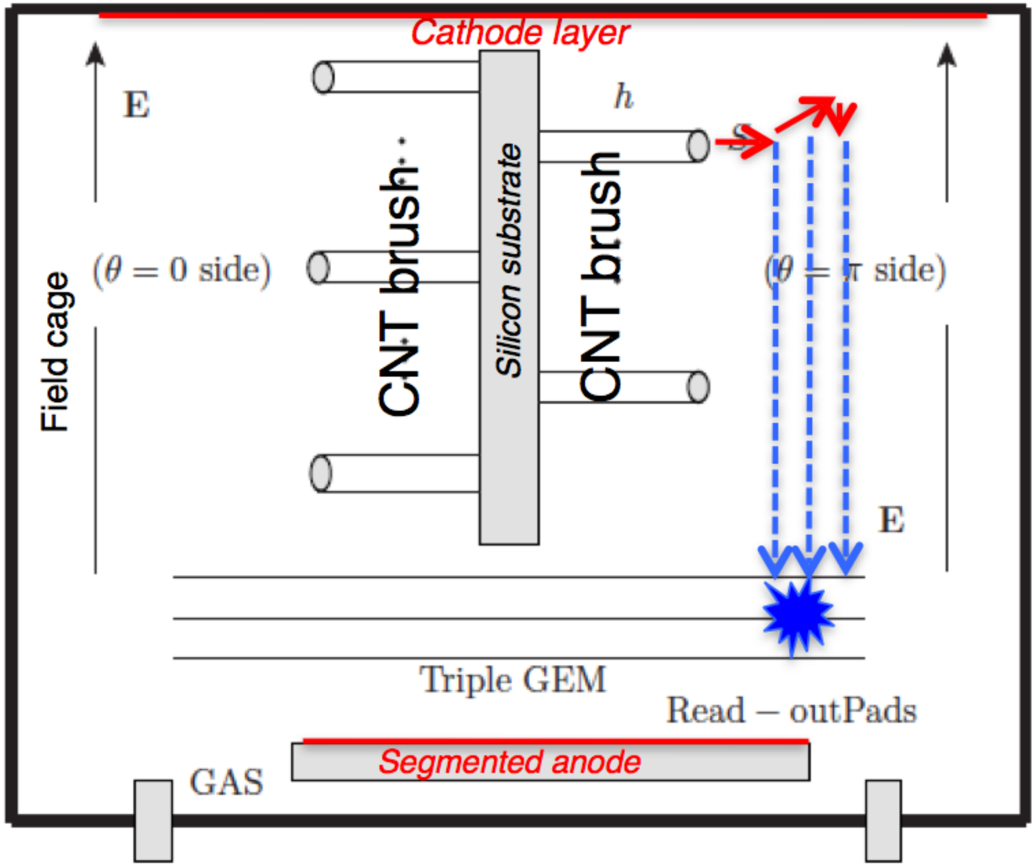
Carbon Nanotubes (CNT)

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

Gianluco Cavoto at al. (Rome)







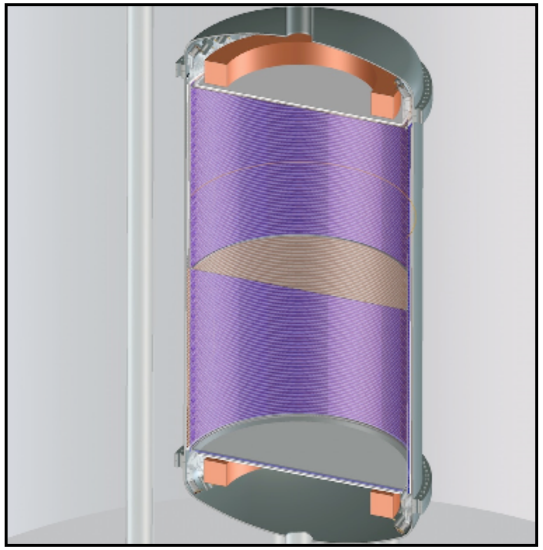
Challenges for CNT and other fibre technologies:

- 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

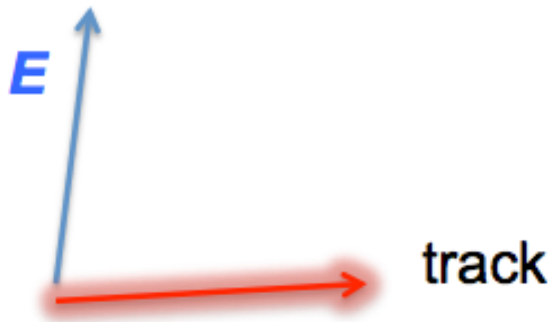
CR in High Pressure Xe gas

D. Nygren et al.,

Concept: Idea of ***columnar recombination* (CR)** based on atomic/molecular processes in Xe-TMA. CR is sensitive to the angle between recoil direction E-field.



A large angle between track and E-field may mean small recombination signal.



~No CR

A small angle may imply a higher level of recombination

Substantial CR

Challenges for CR:

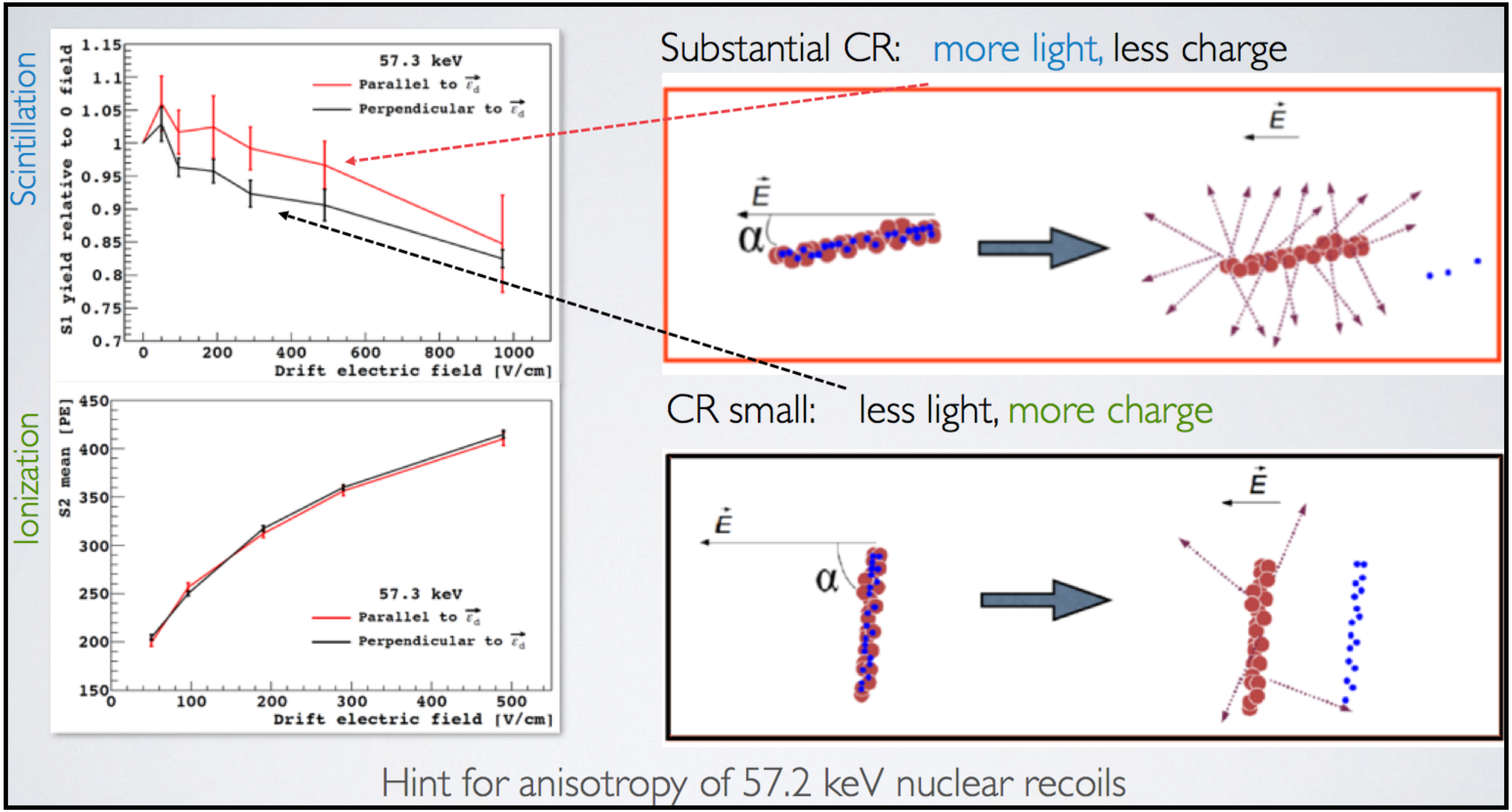
- No demonstration yet
- The density for optimal Onsager radius may not be matched for directionality
- Optical detection efficiency - does TMA additive work sufficiently, what fraction?
- What electric field is required at given xenon density - is it reasonable?
- No head-tail sensitivity?
- Simulation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

RED - CR in Liquid Argon

G. Fiorillo et al., Università degli Studi di Napoli "Federico II" & INFN-NA

Concept: can idea of *columnar recombination* (CR) work in Liquid Argon?

- Tests by the DarkSide dark matter collaboration underway
- Evidence is not clear yet



Low Density Targets the gas TPC

DRIFT
DM-TPC
MIMAC
NEWAGE
D3
Italy R&D
Australia R&D
others..

CYGNUS- TPC

(1) DM below neutrino floor

(2) Coherent solar neutrinos

DRIFT is Pioneer (US-UK)

Directional Recoil Identification From Tracks (DRIFT)

Sheffield University
Neil Spooner – PI
Matt Robinson
Dan Walker
Stephen Sadler
Sam Tefler
Andrew Scarff
Anthony Ezeribe
Leonid Yuriev
Trevor Gamble

Occidental College
Dan Snowden-Ifft - PI
Jean-Luc Gauvreau
Chuck Oravec
Alex Lumnah
Chongmo Tang

Colorado State University
John Harton – PI
Jeff Brack
Dave Warner
Alexei Dorofeev
Fred Shuckman II
Ryan Held

University of New Mexico
Dinesh Loomba - PI
Michael Gold – PI
John Matthews - PI
Eric Lee
Eric Miller
Nguyen Phan
Randy Lafler

The University of Edinburgh
Alex Murphy – PI

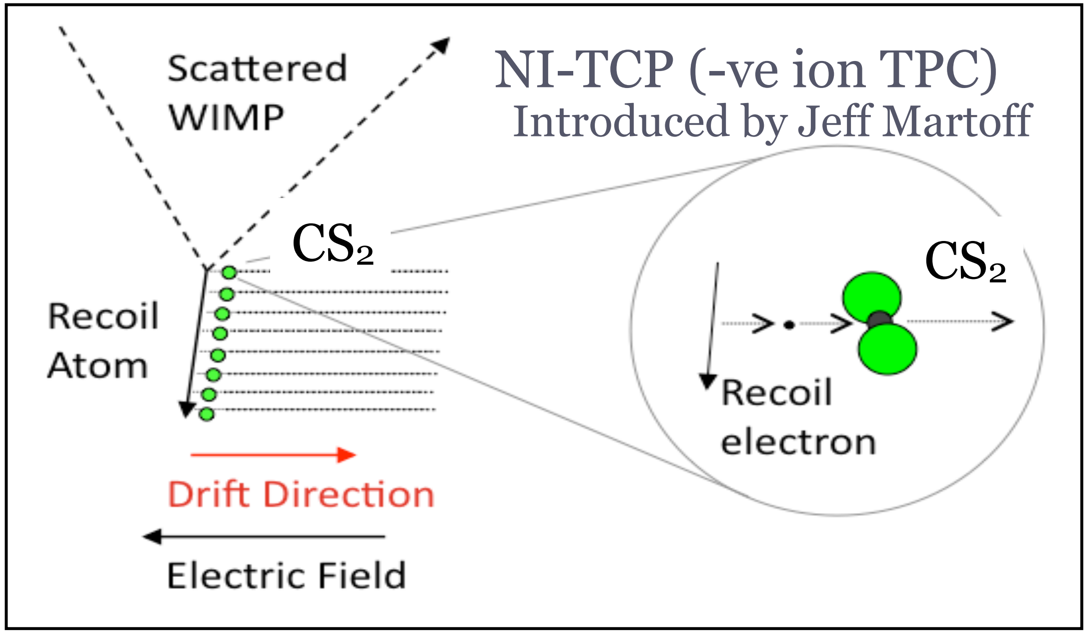
Wellesley College
James Battat – PI
NEW!

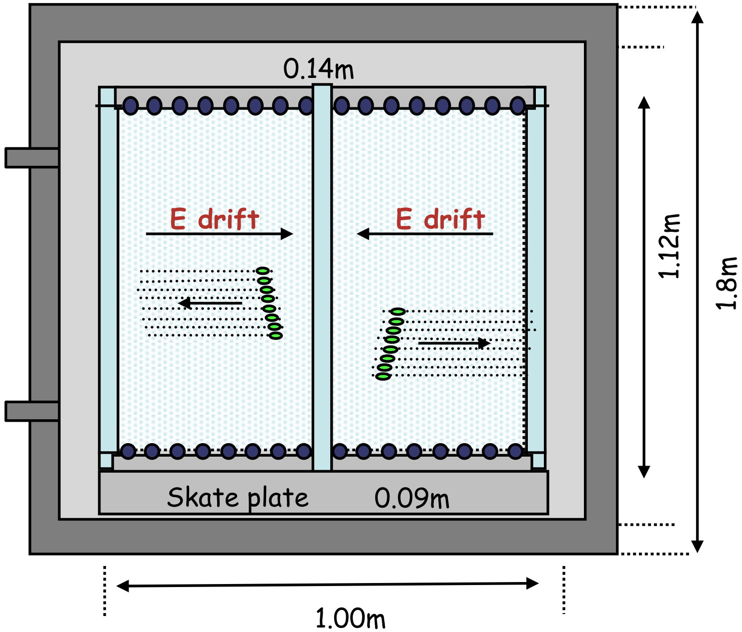
University of Hawaii
Sven Vahsen – PI
NEW!

Boulby Mine
Sean Paling – PI
Emma Meehan
Louise Yeoman

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

Concept: -ve ion CS_2 + CF_4 TPC, MWPC readout, 1 m^3, 40 Torr



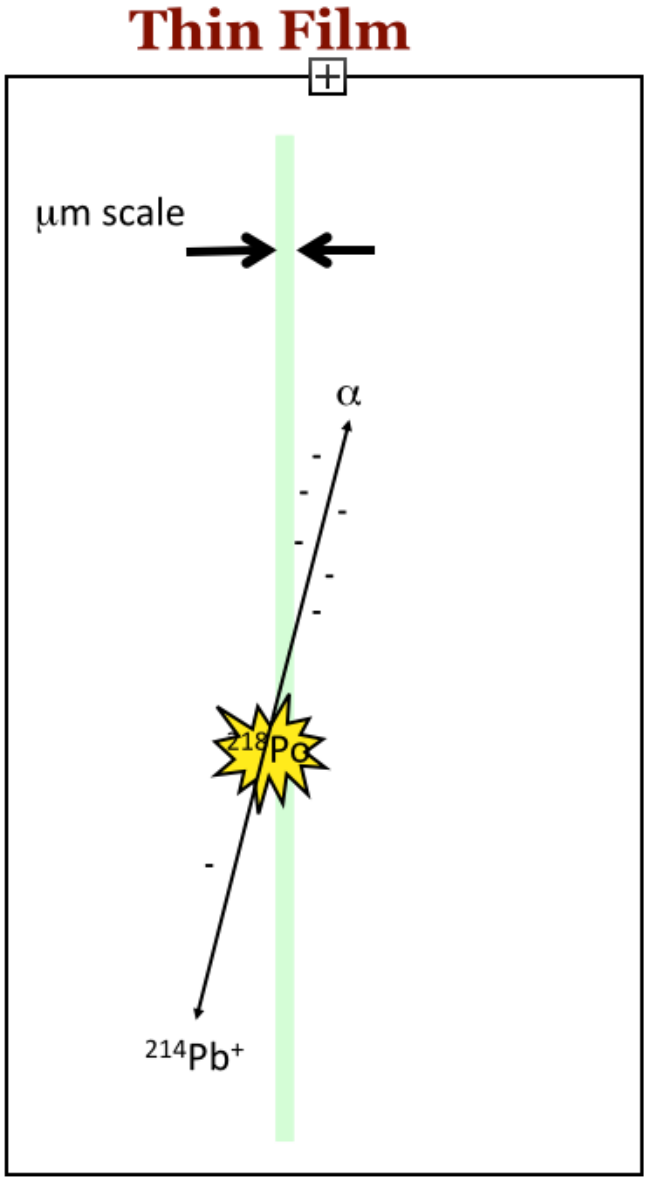


Significant advances recently

- Z- fiducialisation using minority carriers, -ve ion CS_2:CF_4:O_2
- Good head-tail sensitivity with this mixture
- Use of SF_6 -ve ion drift - improved target mass

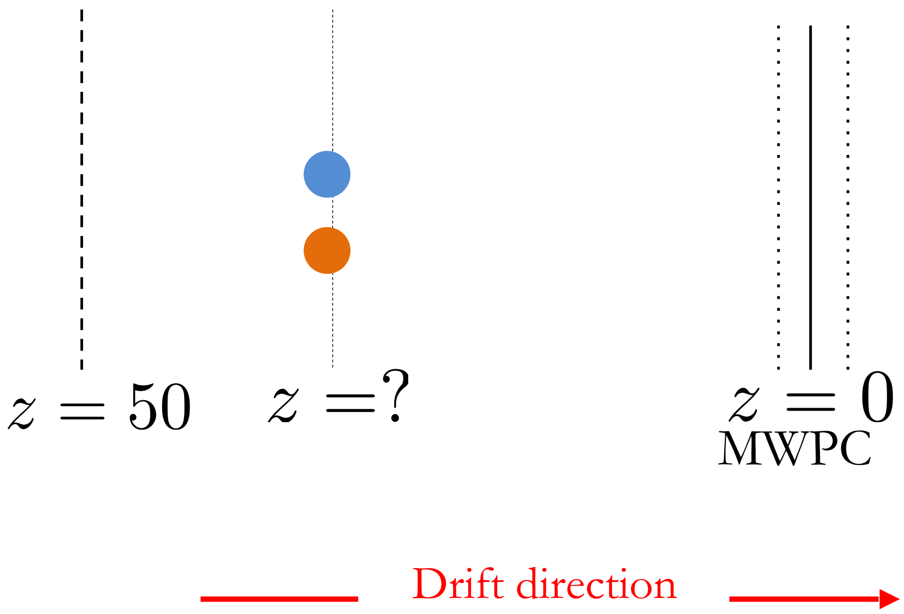
Ultra-thin Cathode

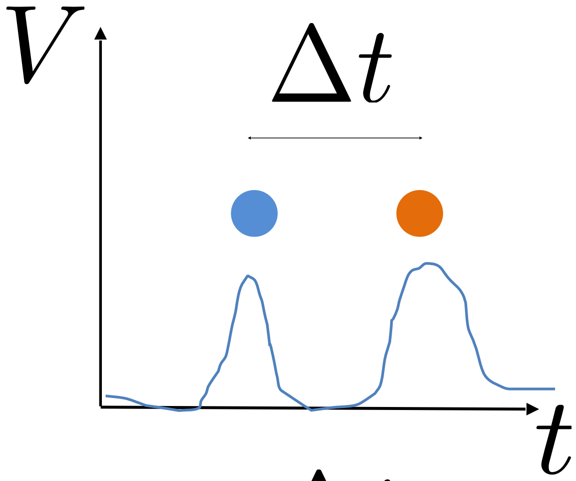
- Use of 0.9μm thick cathode



z-Fiducialization

- Discovery of minority carrier gas mixtures CS_2:CF_4:O2
- Use of different drift speeds of carriers





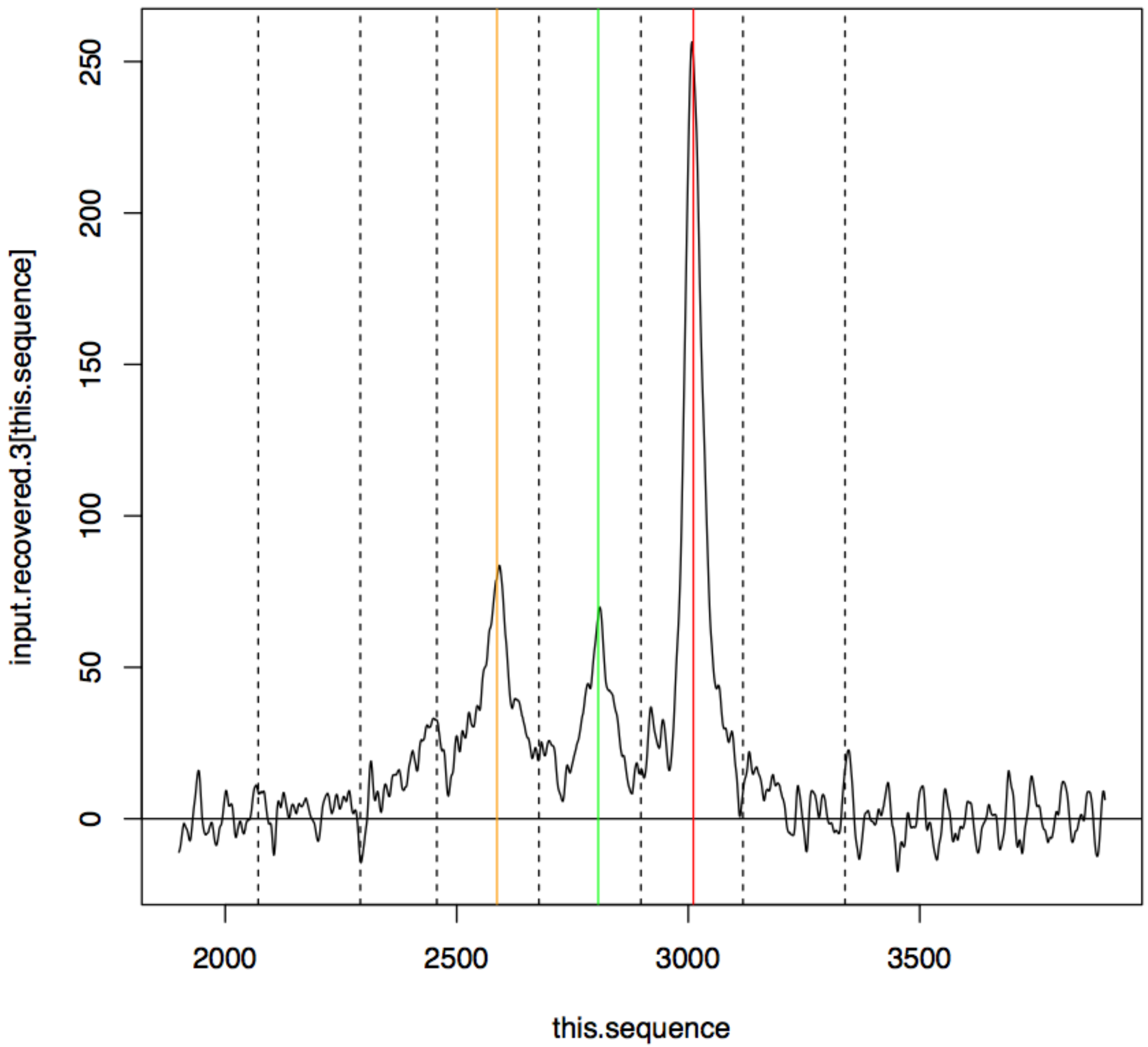
$z \propto \Delta t$

Proportionality constant can be measured for various gas mixtures, or calibrated in-situ.

z-Fiducialization

Examples

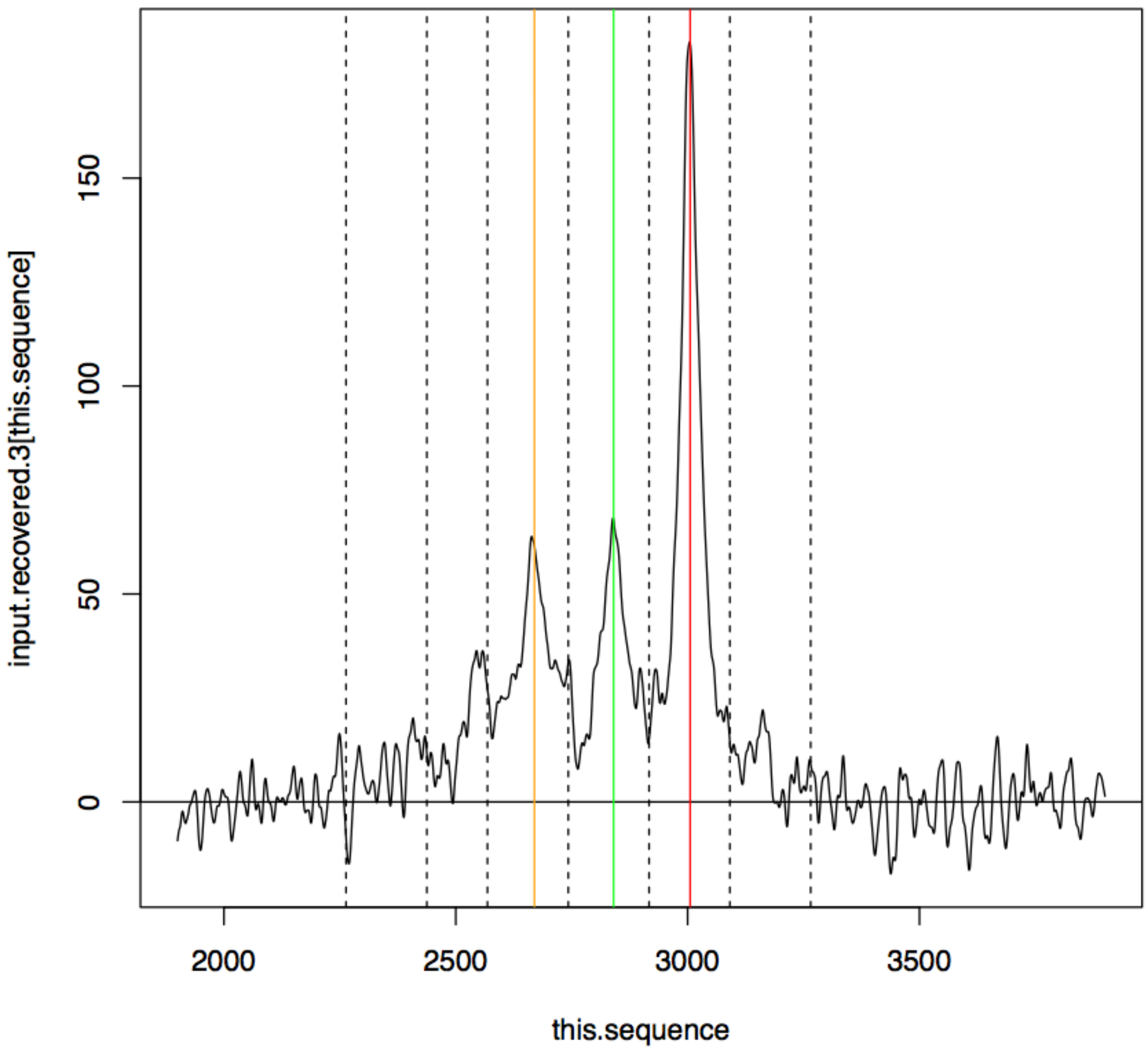
z = 49.7 cm



z-Fiducialization

Examples

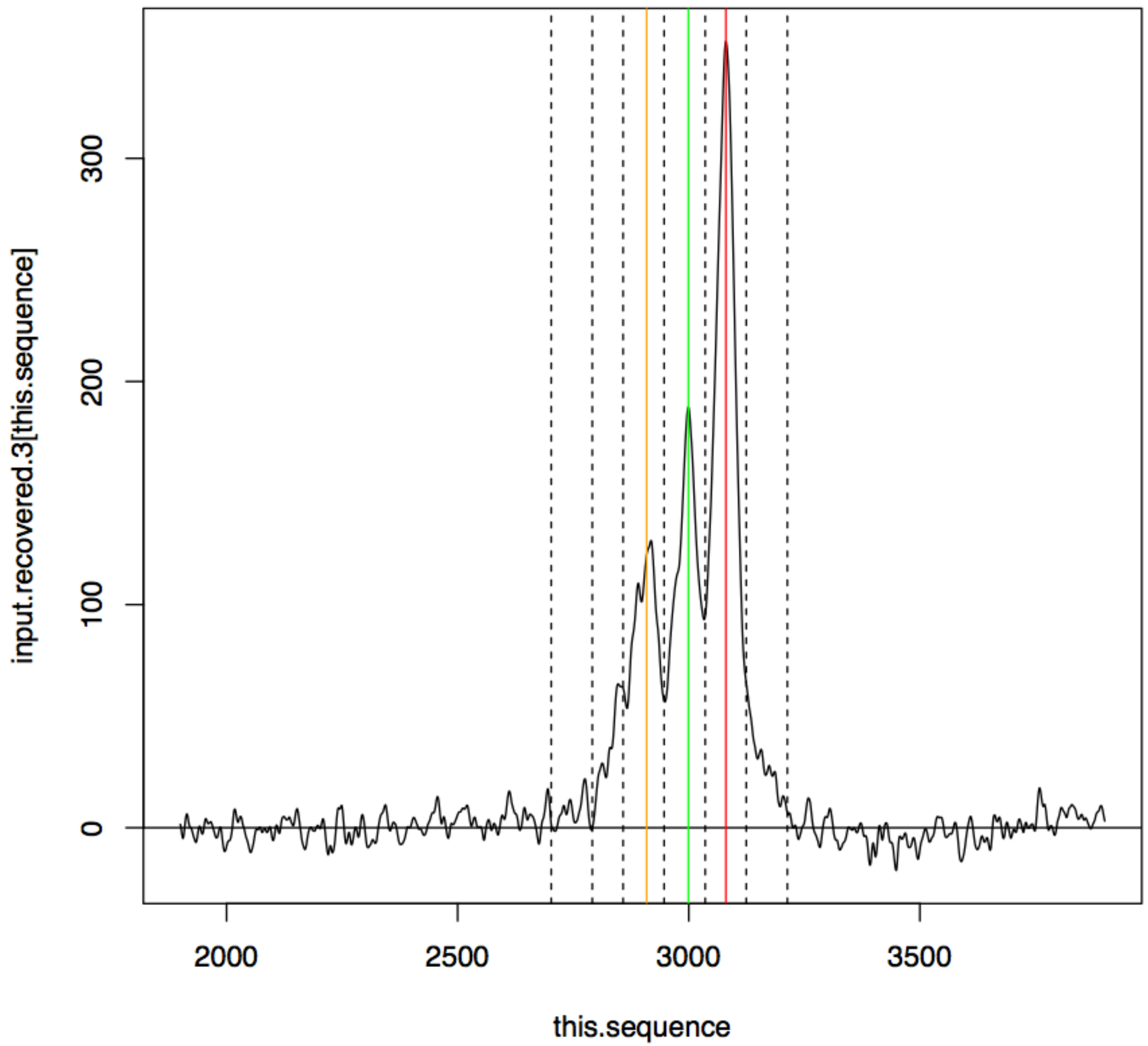
$z = 39.3$ cm



z-Fiducialization

Examples

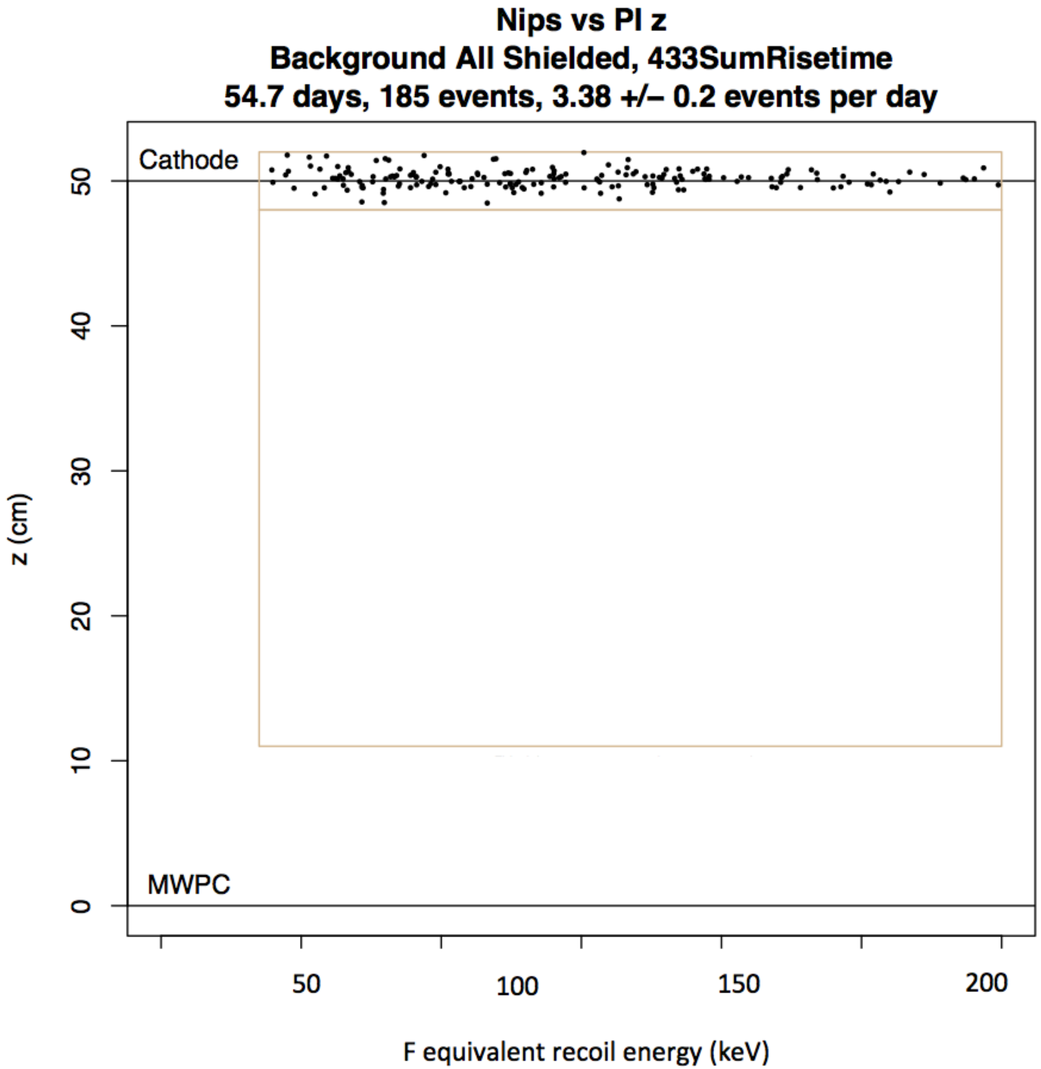
$z = 20.1$ cm



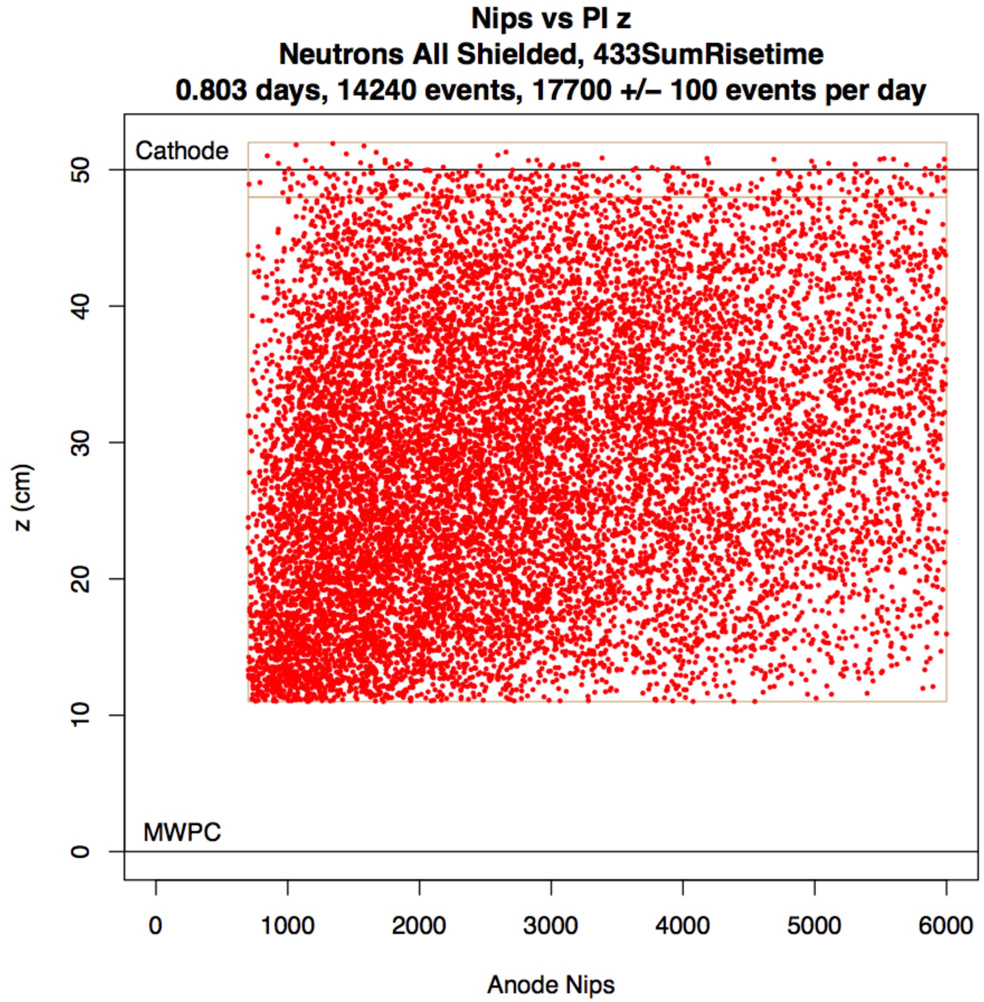
DRIFT - 3D Fiducial with Head-Tail

- **DRIFT-IId now runs zero background, only volume limited**

Shielded 30-10-1 CS_2-CF_4-O_2 Data

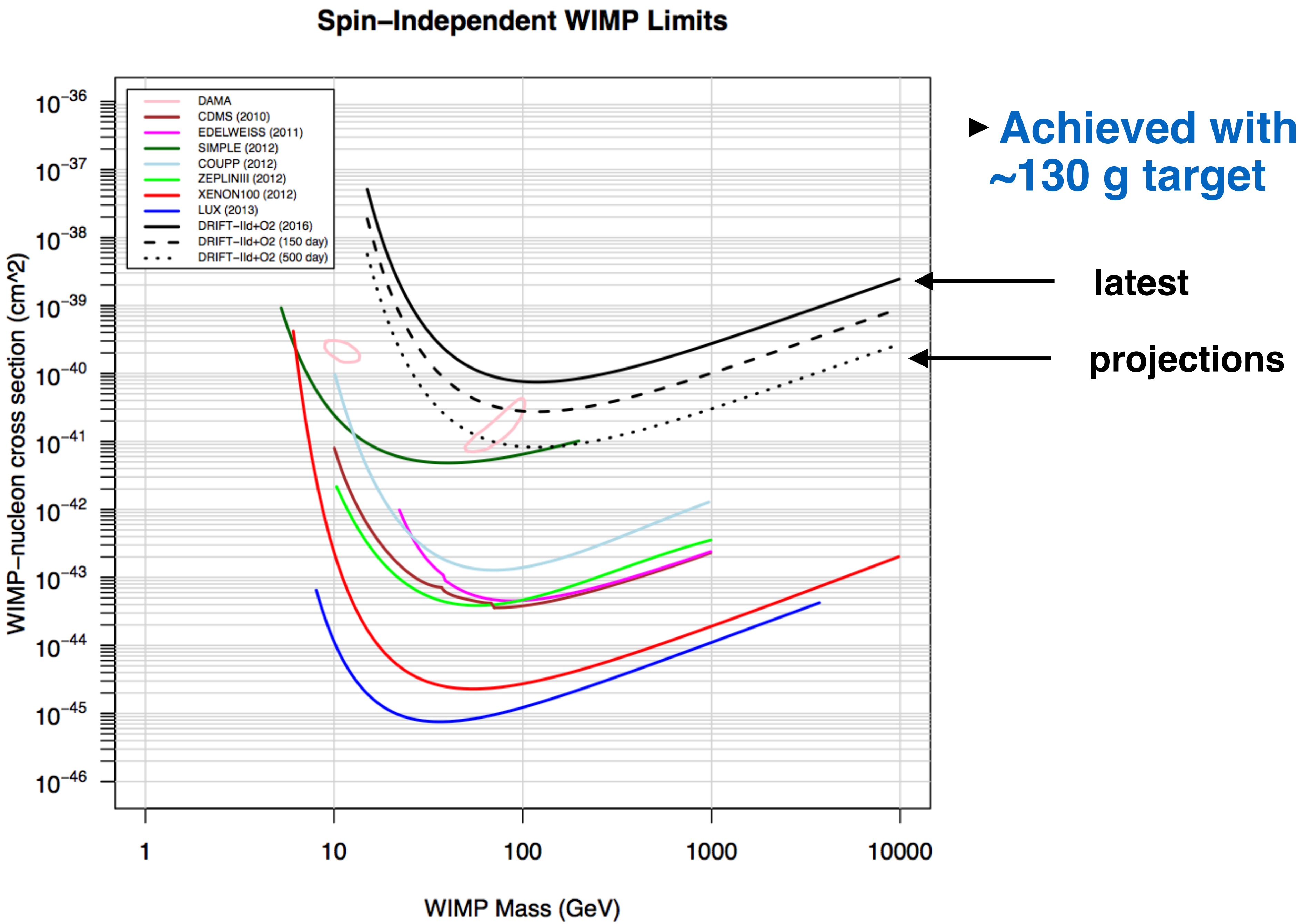


Cf-252 Neutron Calibration Data



DRIFT-II - 3D Fiducial with Head-Tail

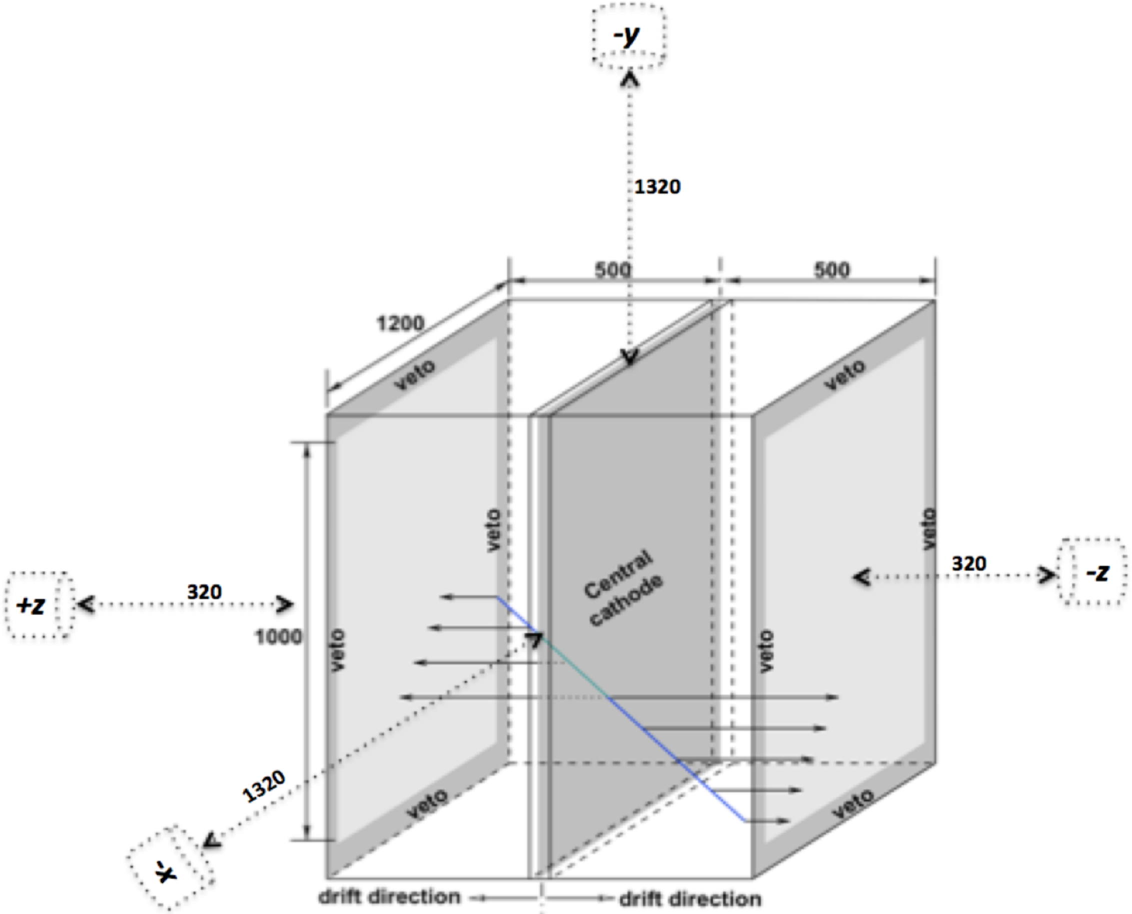
- Towards ruling out DAMA - with Directionality

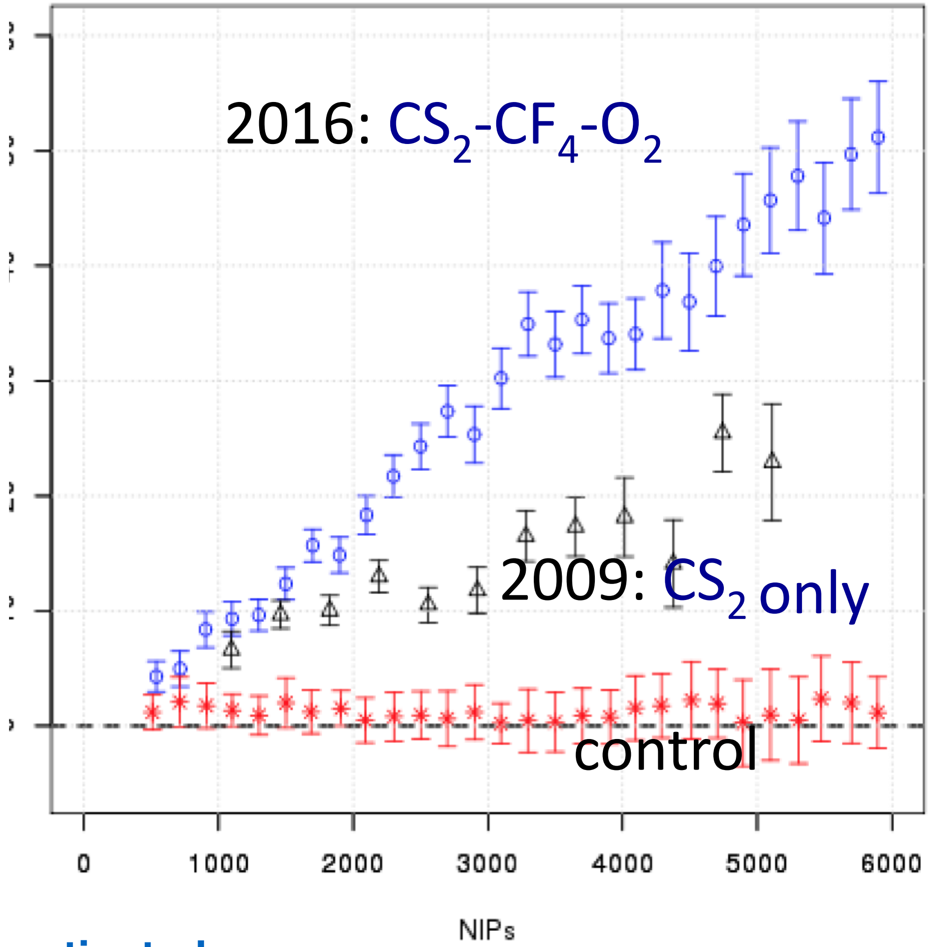


- Achieved with ~130 g target

Head-Tail Directional Analysis

▸ **Directional Head-Tail sensitivity with z-fiducialisation**



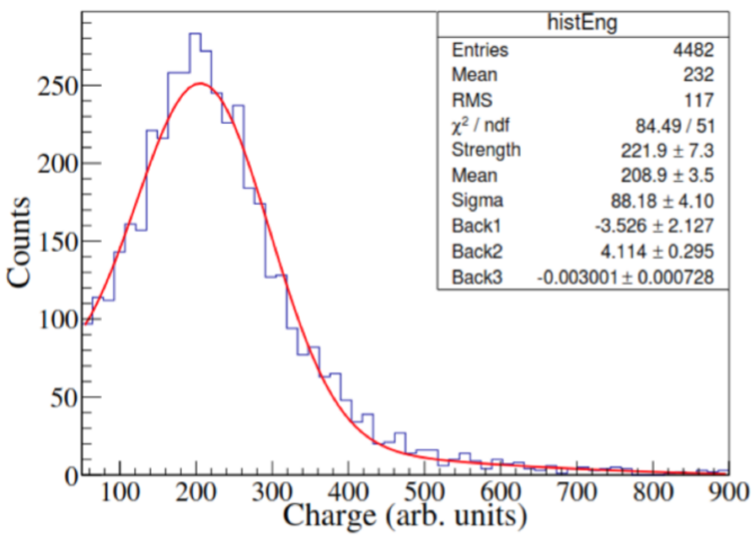


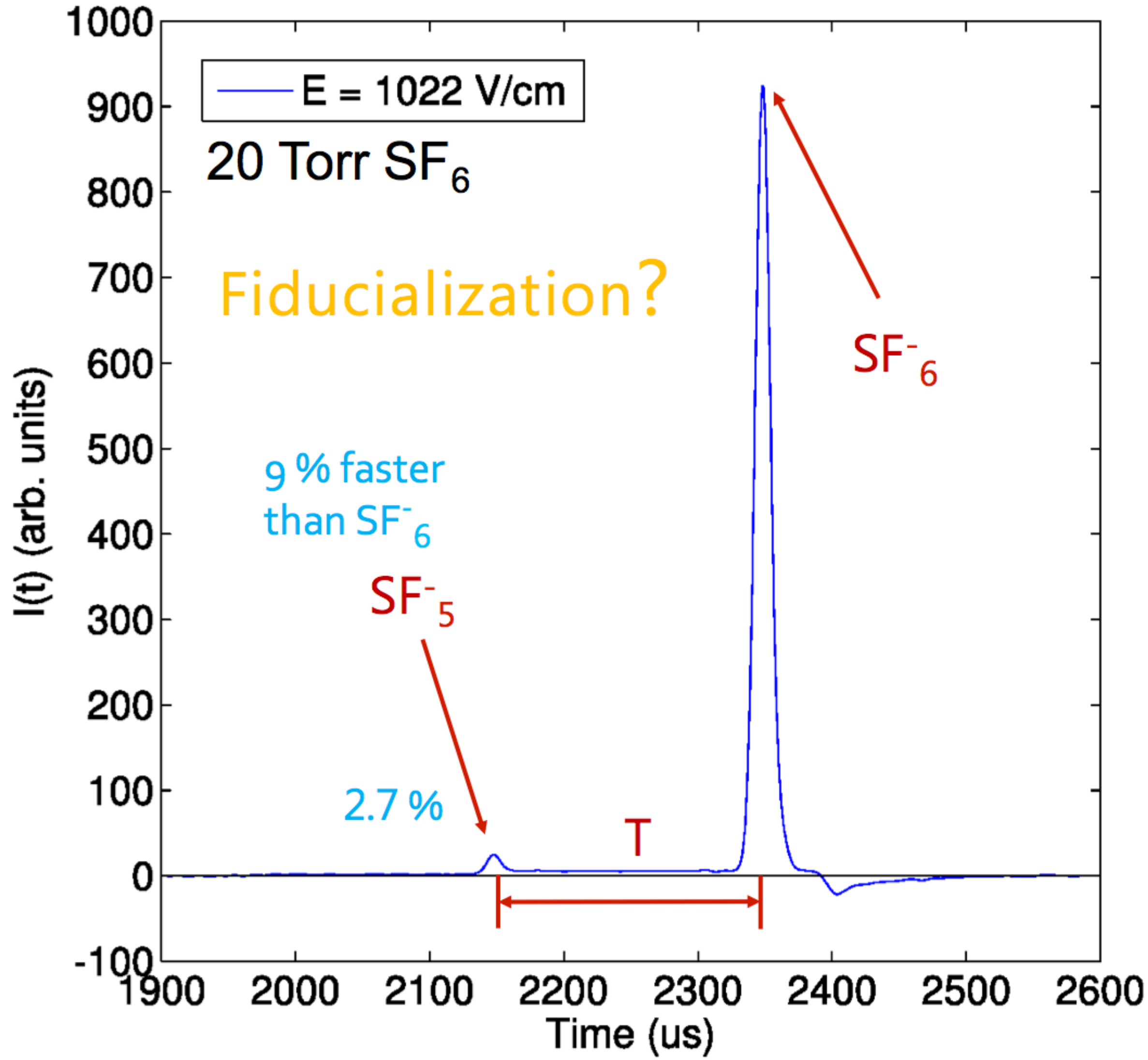
- **DRIFT sensitivity to HT in the new gas mode was investigated.**
- **Method of extracting the HT parameter from Astropart. Phy., 31 (2009) 261.**
- **Analyzed 7 days of directed source neutron data.**
- **Event by event measurement of the HT parameter was done using η_1 to η_2 ratio.**
- **Can now study HT *z*, thanks to fiducialization.**

New SF_6 Breakthrough

N. Phan, University of New Mexico

- First demonstration of SF_6 as a -ve gas (with GEMs)
  - ^{55}Fe spectrum in 40 Torr SF_6 with 0.4mm GEM
  - Gain curves up to 2.5 x 10^4
  - z-fidusialization with SF_5^- shown (20 Torr, laser events)





MIMAC

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

D. Santos et al.,

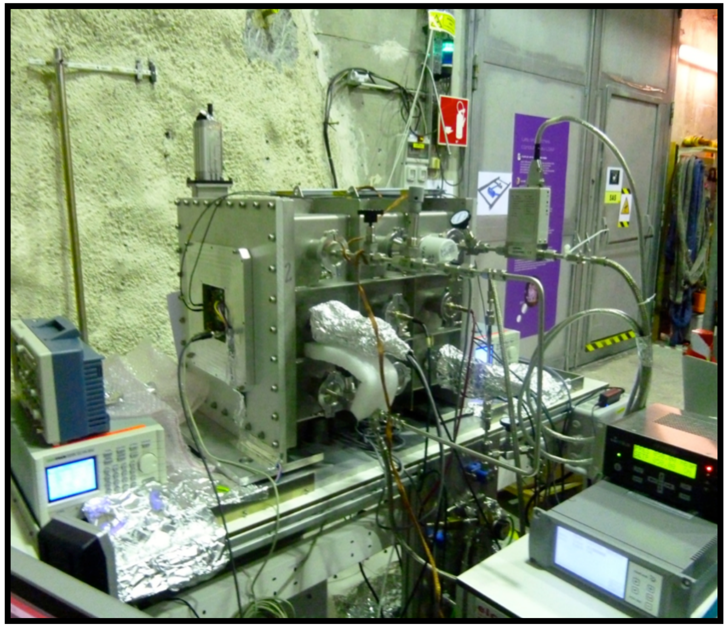
LPSC (Grenoble) : J. Lamblin, F. Mayet , D. Santos
J. Billard (Ph.D) (left in July 2012), Q. Riffard (Ph.D) (started in October 2012)

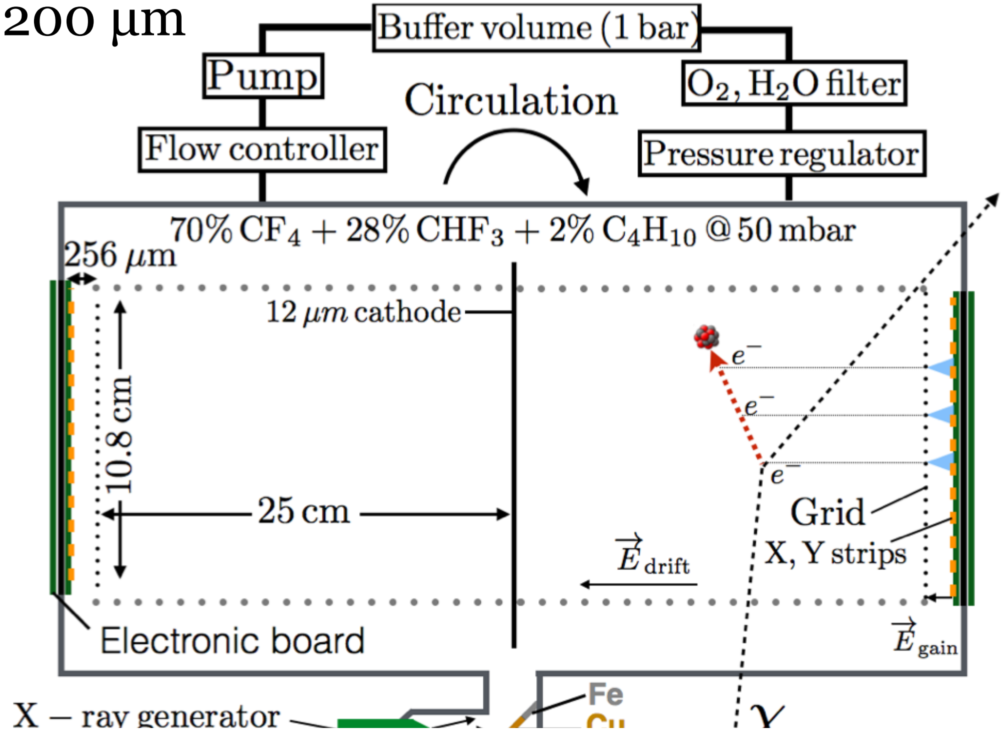
Technical Coordination : O. Guillaudin
- Electronics : G. Bosson, O.Bourrion, J-P. Richer
- Gas detector : O. Guillaudin, A. Pellisier
- Data Acquisition: O. Bourrion
- Mechanical Structure : Ch. Fourel, S. Roudier, M. Marton
- Ion source (quenching) : J-F. Muraz, J. Médard (CDD-1year)

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

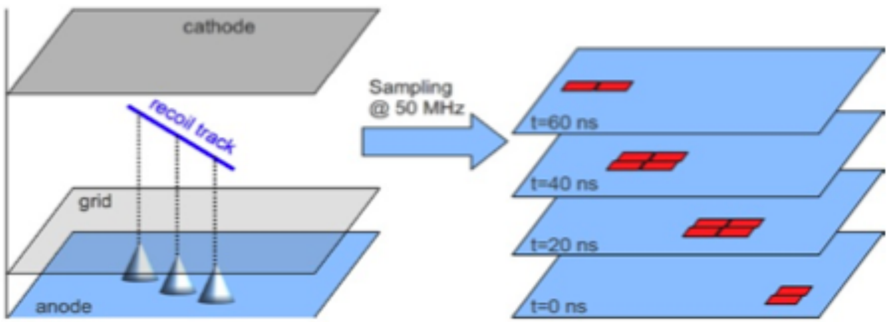
Neutron facility (AMANDE) :
IRSN (Cadarache): L. Lebreton, D. Maire (Ph. D.)

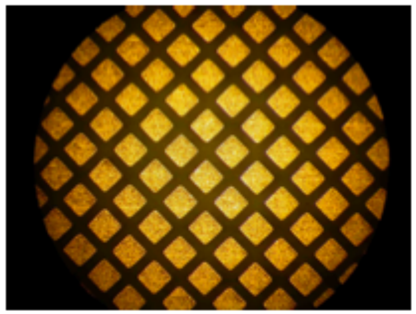
- X and Y measured on the pixelated anode, Z direction by anode sampling at 50 MHz
- CF4 + 30% CHF3 needed to slow drift velocity to match speed of time slicing :
- Pixel micromegas from IRFU (Saclay) - 200 µm





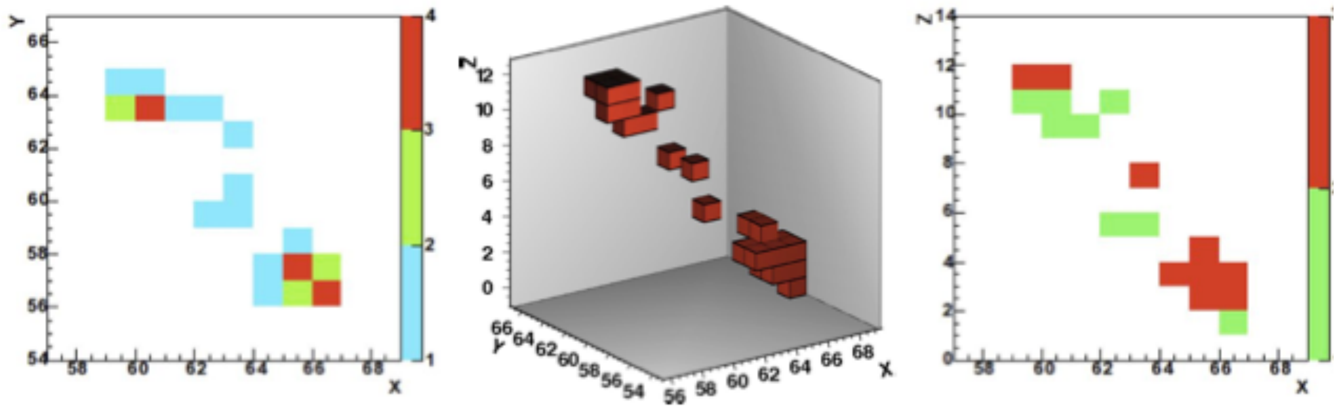
- The anode is read every 20 ns. The 3D track is reconstructed, from the consecutive number of images defining the event

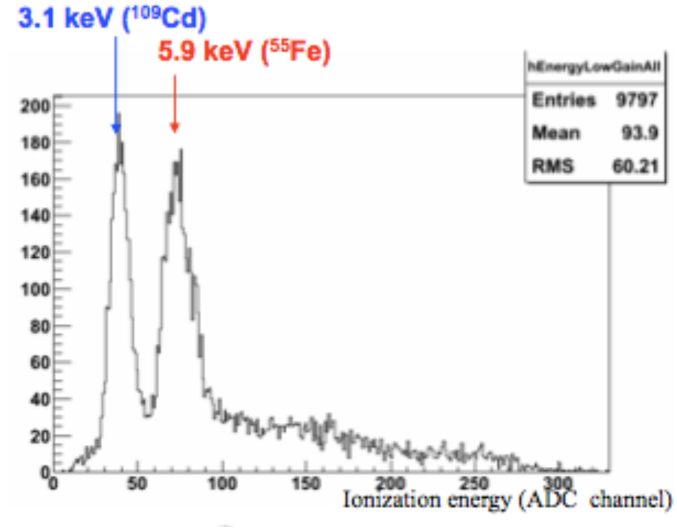




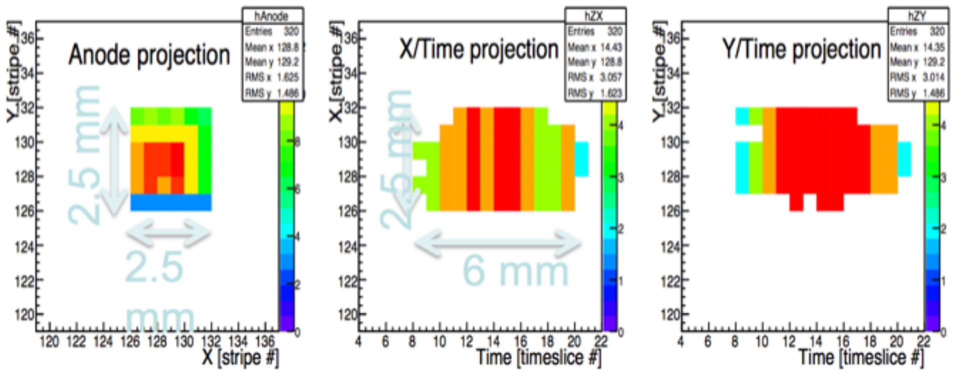
MIMAC

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





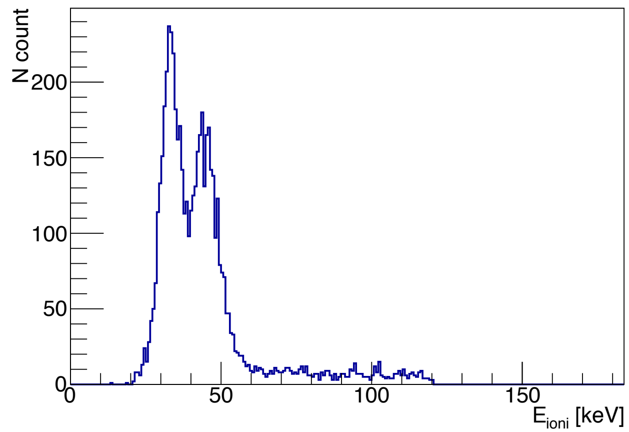
A 25 keVrec (~9 keV_{ee})
Fluorine recoil



First operation underground at Modane

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

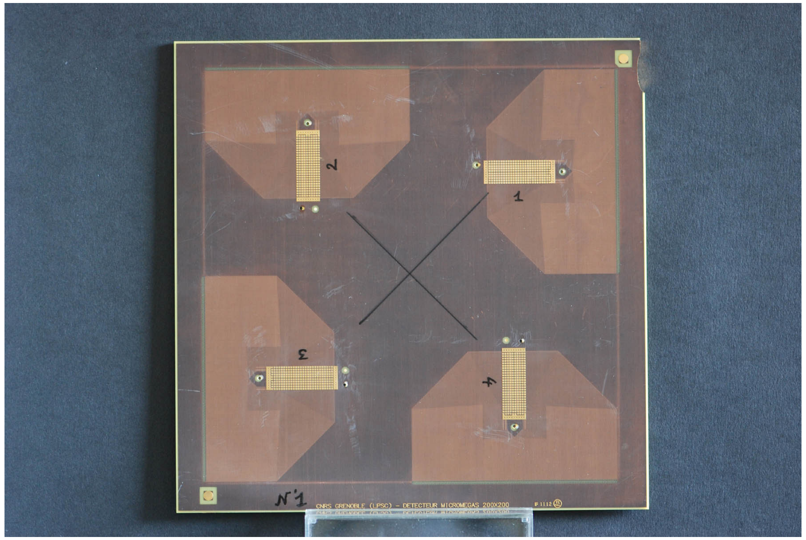
Recoil	Recoil Energy [keV]	Ionization Quenching factor (SRIM) [%]	Ionization Energy (SRIM) [keV]	Ionization Energy measured [keV]
^{218}Po	100.79	37.93	38.23	32
^{214}Pb	112.27	39.10	43.90	34
^{210}Pb	146.52	40.12	58.78	45

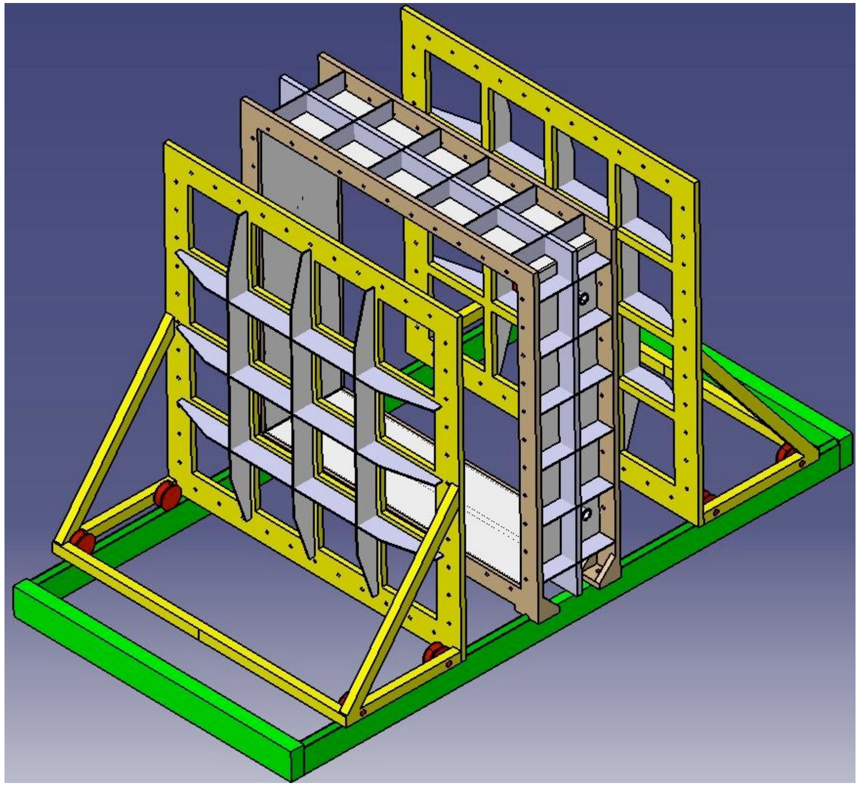


MIMAC

Future: MIMAC – 1m^3 = 16 bi-chamber modules (2 x 35 x 35 x 25.5 cm^3)

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?

NEWAGE

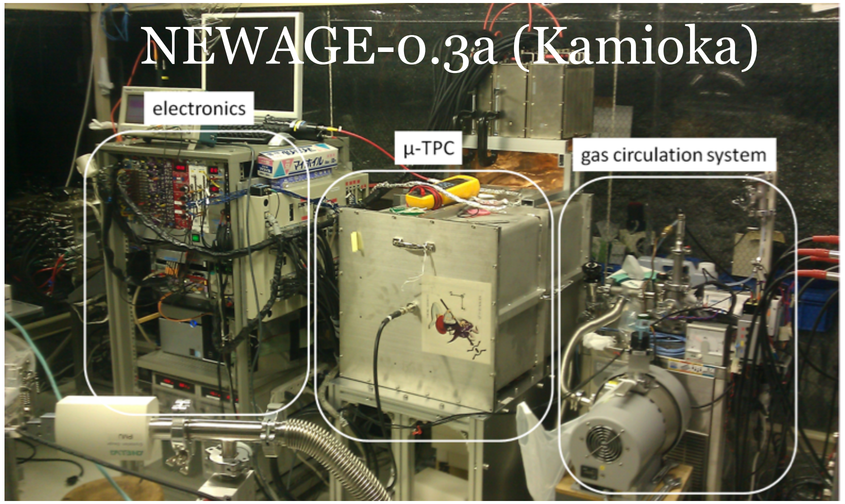
Kentaro Muichi et al.

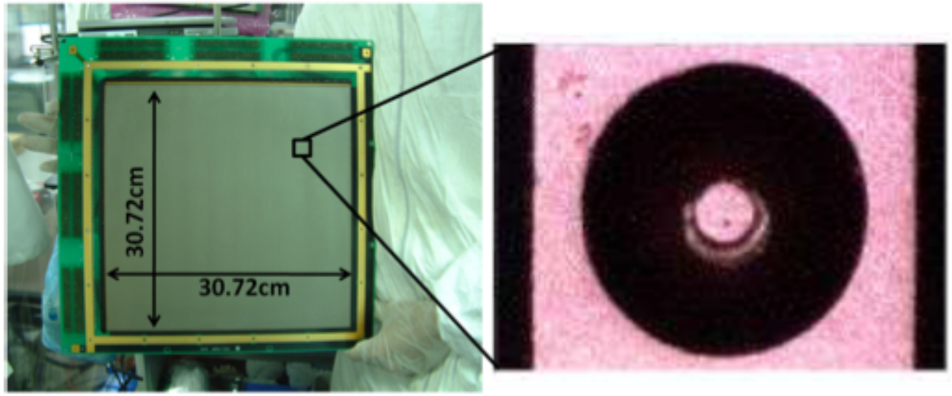
T.Tanimori[1], K.Miuchi[2], K.Kubo[1], T.Mizumoto[1], J.Parker[1], A.Takada[3], H.Nishimura[1], T.Sawano[1], Y.Matsuoka[1], S.Komura[1], Y.Yamaguchi[2], S.Nakaura[2]

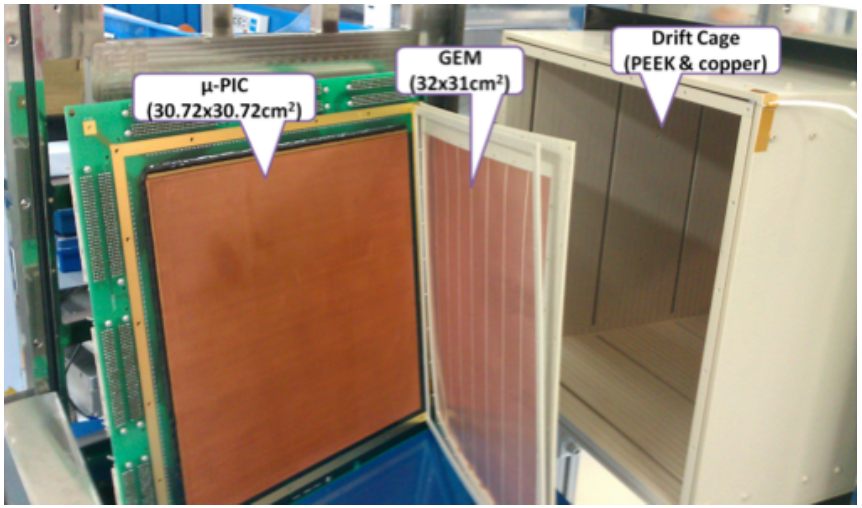
(1) Kyoto university department of physics
(2) Kobe university department of physics
(3) Kyoto university RISH

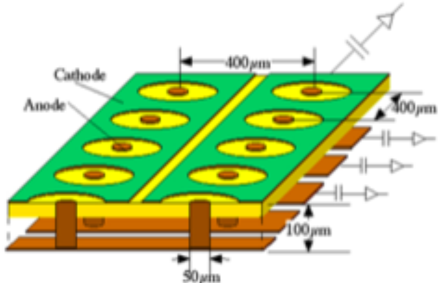
Concept: low pressure **CF_4 with charge readout via micro-PIC TPC, also SF_6**

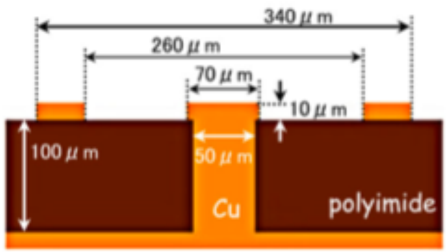
- Three detectors: NEWAGE-0.3a (Kamioka); NEWAGE-0.3b, NEWAGE-0.1 (HT R&D)
- Micro patterned gaseous detectors (MPGDs) 768 × 768 pixels (400 μm) a micro pixel chamber (μ-PIC) which is a two-dimensional fine-pitch imaging device plus a gas electron multiplier (GEM)
- 30 × 30 × 41 cm^3 of detection volume.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





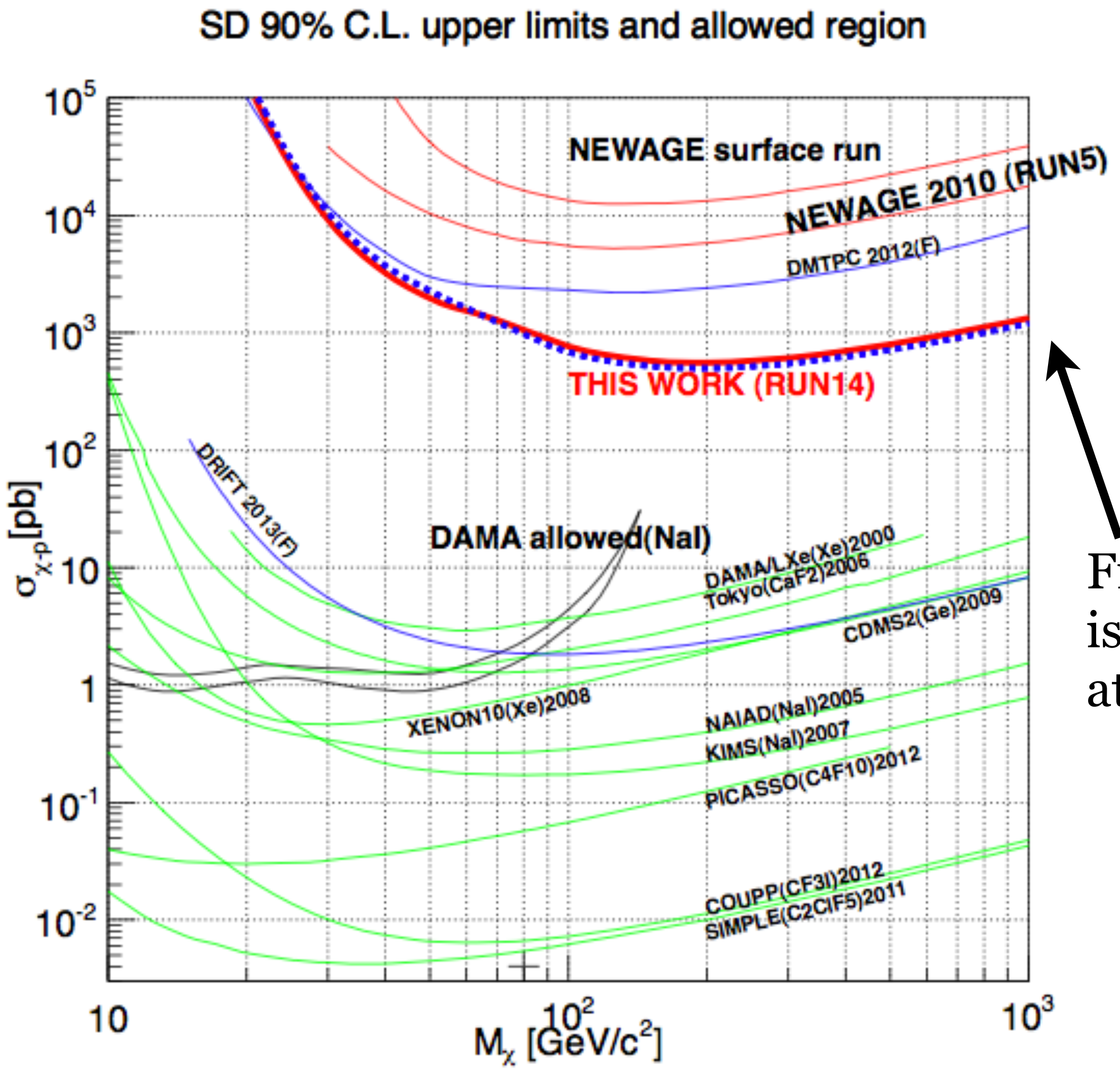


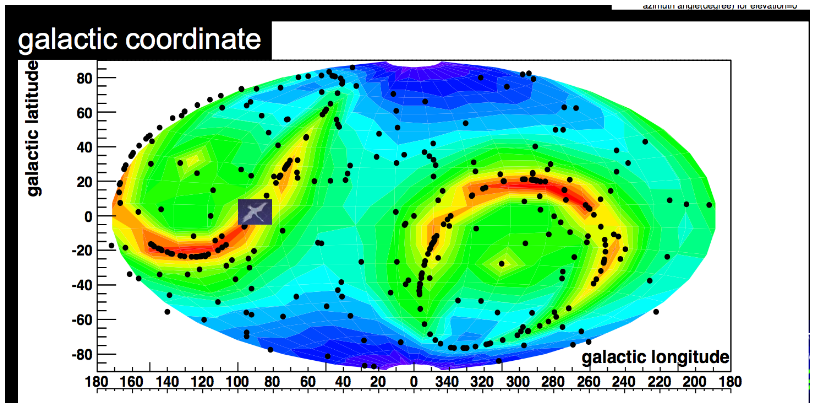




NEWAGE

New limits:





First use of directionality to suppress isotropic backgrounds. Obtained limit at 557 pb @ 200GeV

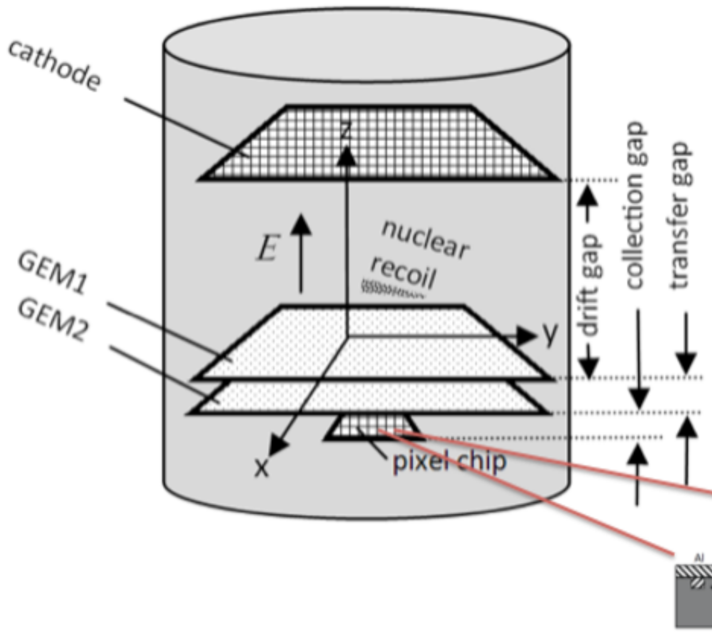
Challenges for NEWAGE?:

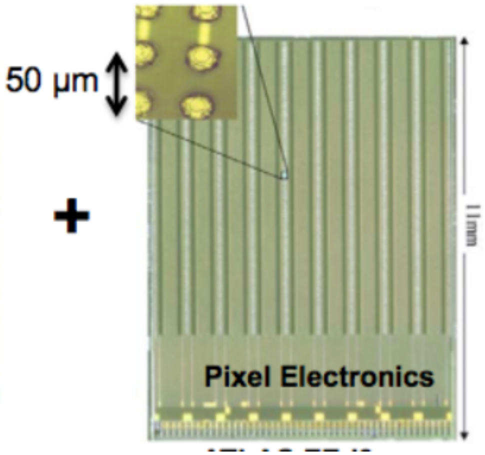
- Background, radon
- Energy threshold
- z-fiducialisation
- DAQ costs

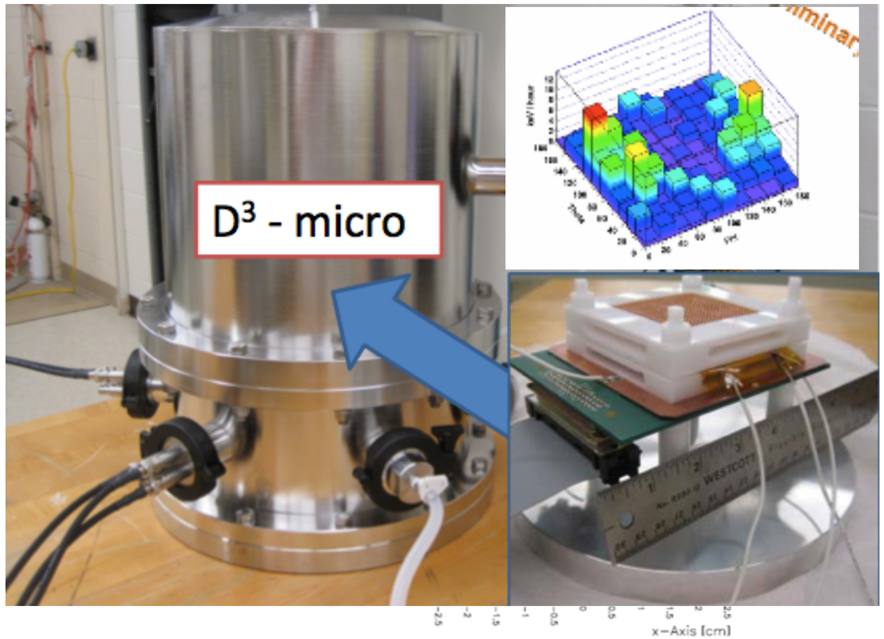
D3

Sven Vahsen et al. LBNL and U. Hawaii

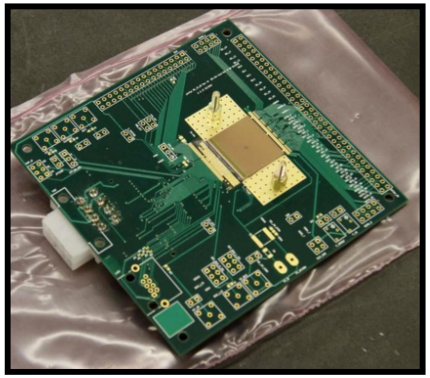
Concept: low pressure CF_4 with micro-pattern gas detector and charge focussing



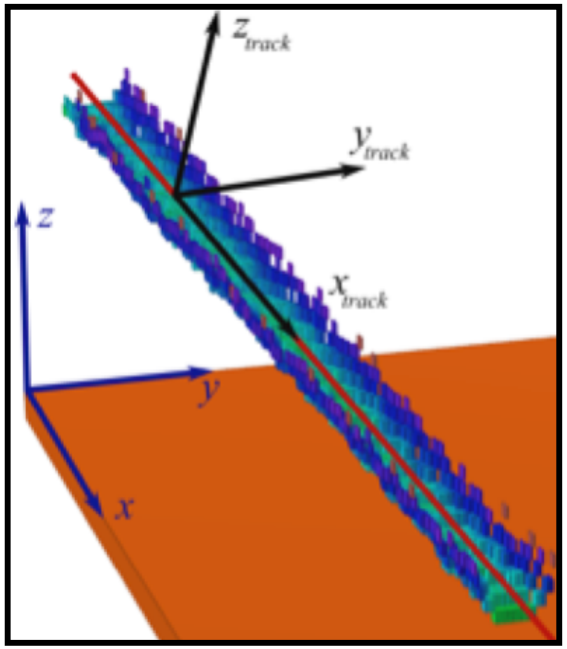




- Charge amplified with double GEM - gain ~20k at 1 atm
- **Readout - ATLAS FE-I4 50x400 µm pixel** chip, 40 MHz
- Charge focusing for cost reduction of large detectors



- Measurement of charge-profile (not width) of track, enables accurate measurement of transverse diffusion
- obtain absolute position in drift direction ("absolute z")



DM-TPC

Concept: low pressure **CF_4 - charge mesh + CCD**

arXiv:1301.5685v2 (2013)

DMTPC Collaboration

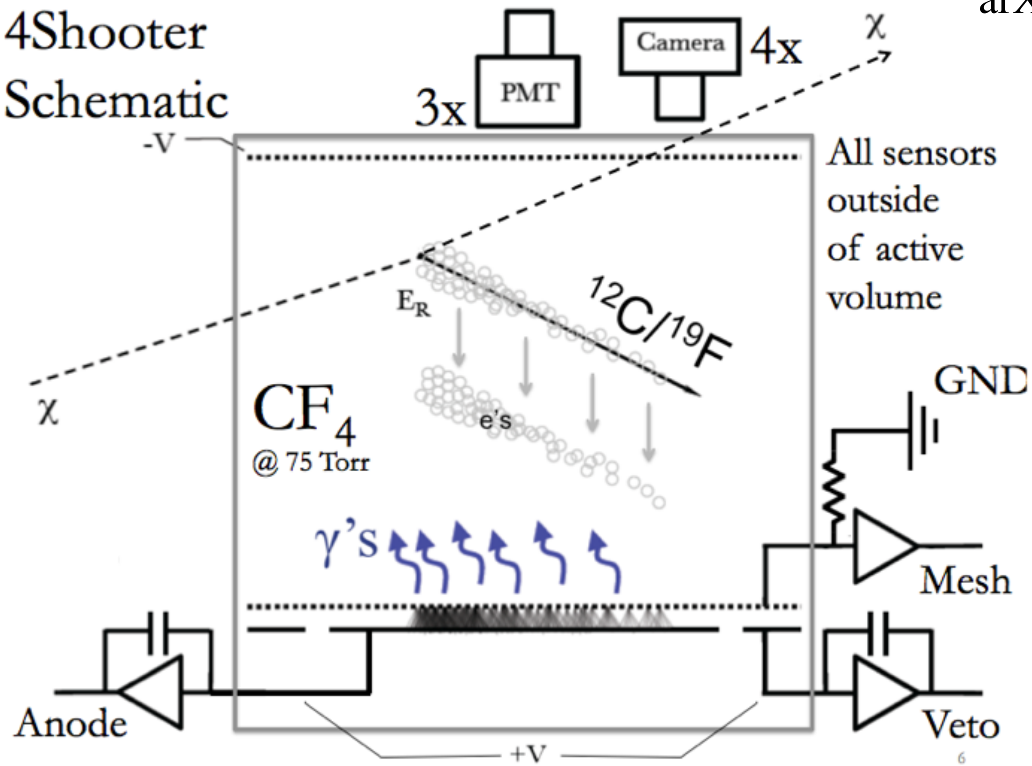
Brandeis University
A. Dushkin, H. Wellenstein*

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)
leston, P. Giampa, J. Monroe*



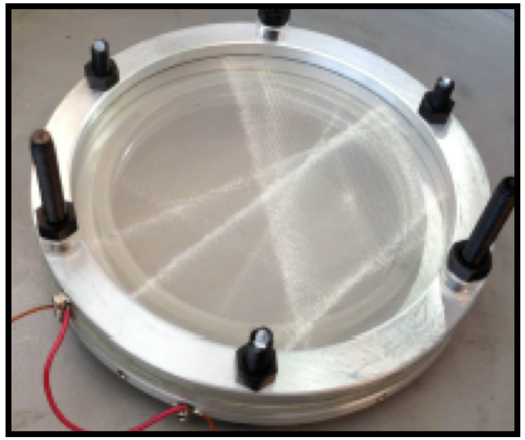
10L

Underground at WIPP

4Shooter (20L)

At MIT

- 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 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

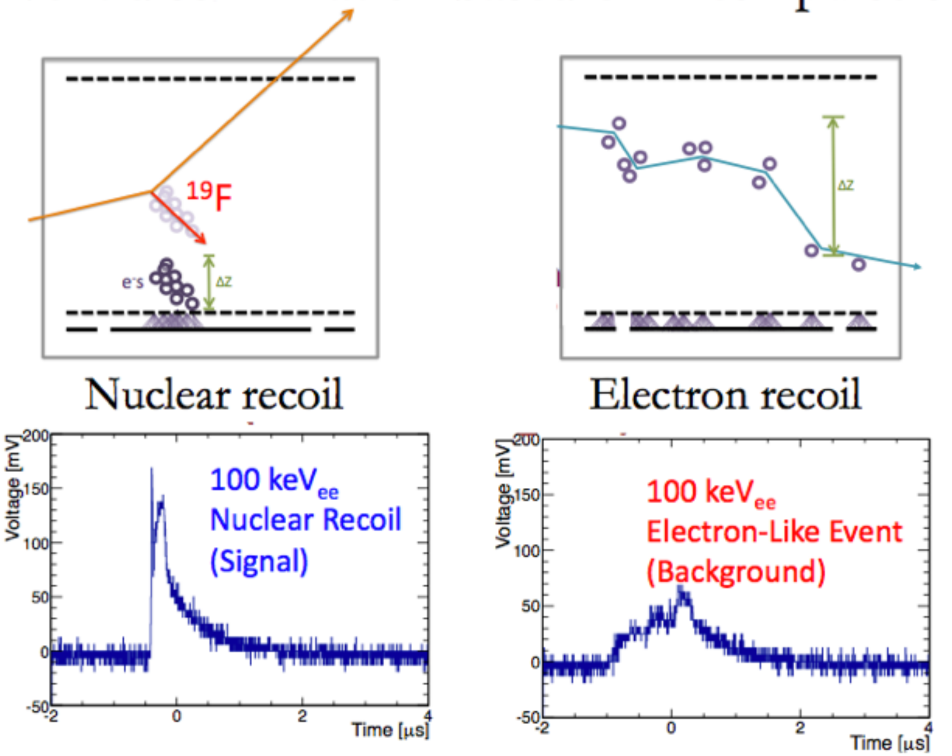


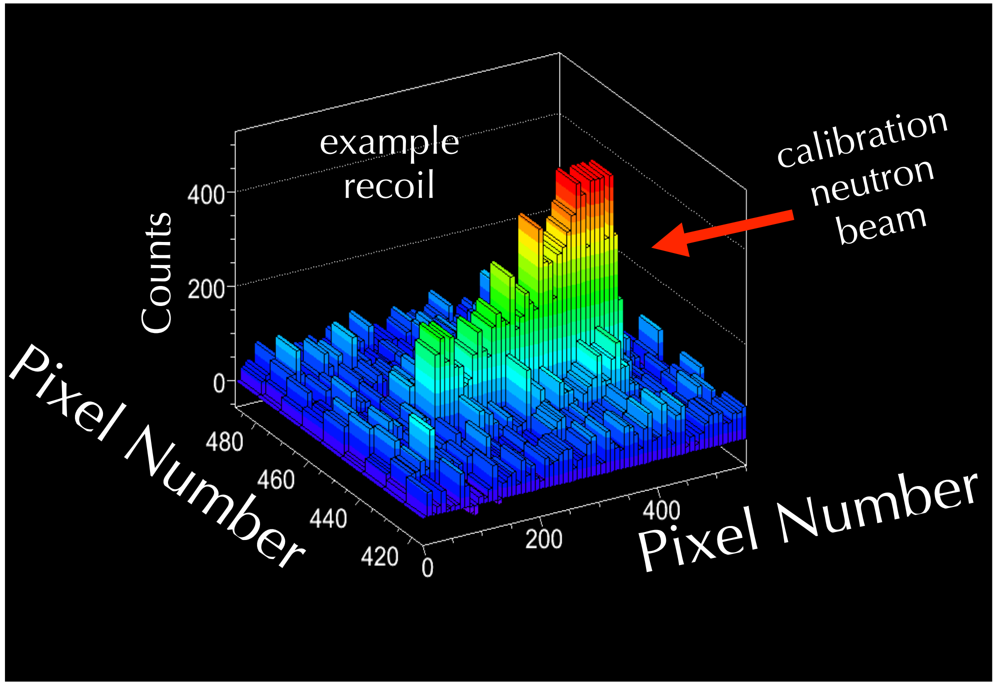
DM-TPC

Concept: low pressure **CF_4 - charge mesh + CCD readout**

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

Event discrimination based on mesh pulse shape

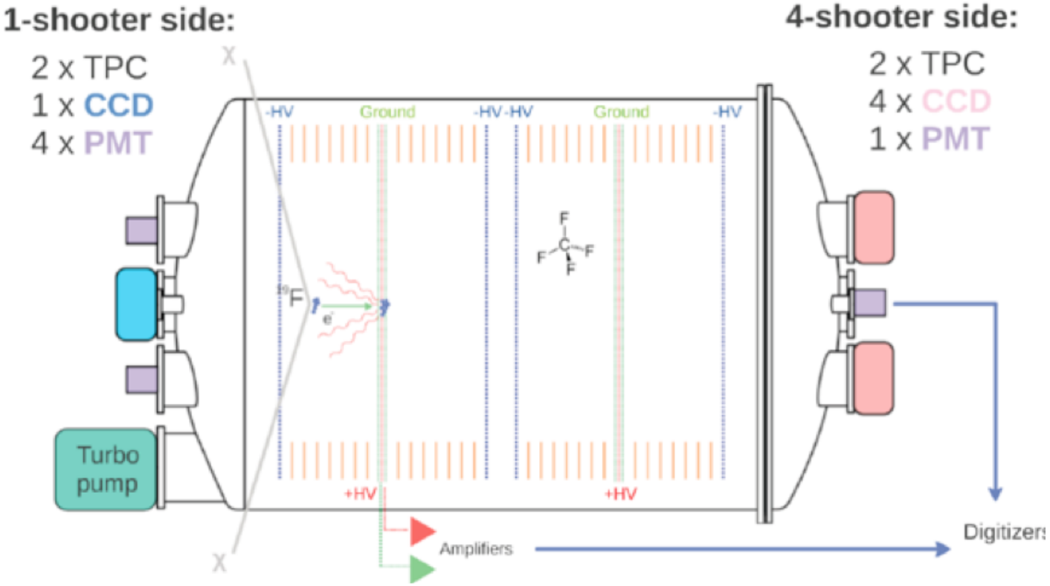




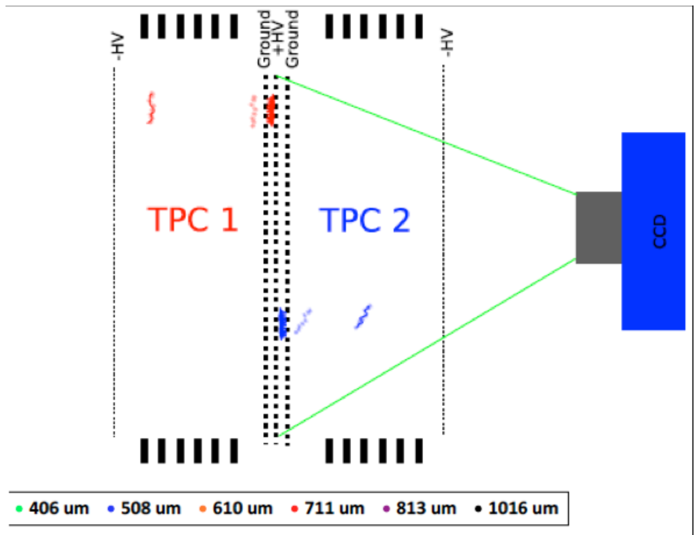
DM-TPC

m³ prototype for very large detector:

goal: achieve similar or better S:N per pixel,
for 35⁰ resolution at 50 keVr in 1m3 module, and
R&D: 1 camera+lens/side (~0.005$/channel now)



triple mesh amplification: one camera images 2x 25 cm drift regions



Challenges for DM-TPC?:

- Use of mesh and pure CF_4 restricts light yield
- Fast CF_4 makes makes ΔZ hard to do
- How to do 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

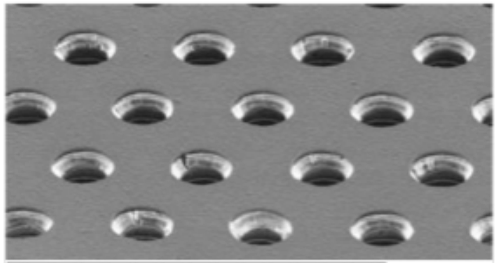
UNM R&D - CCD + Thin GEMs

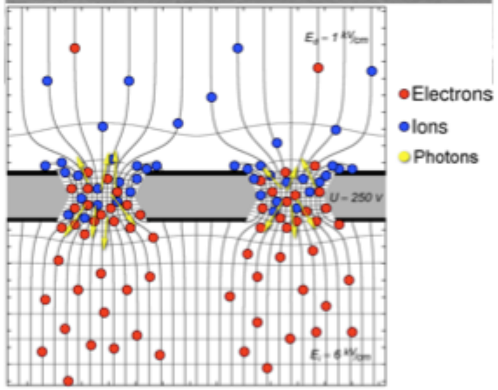
D. Loomba et al.,

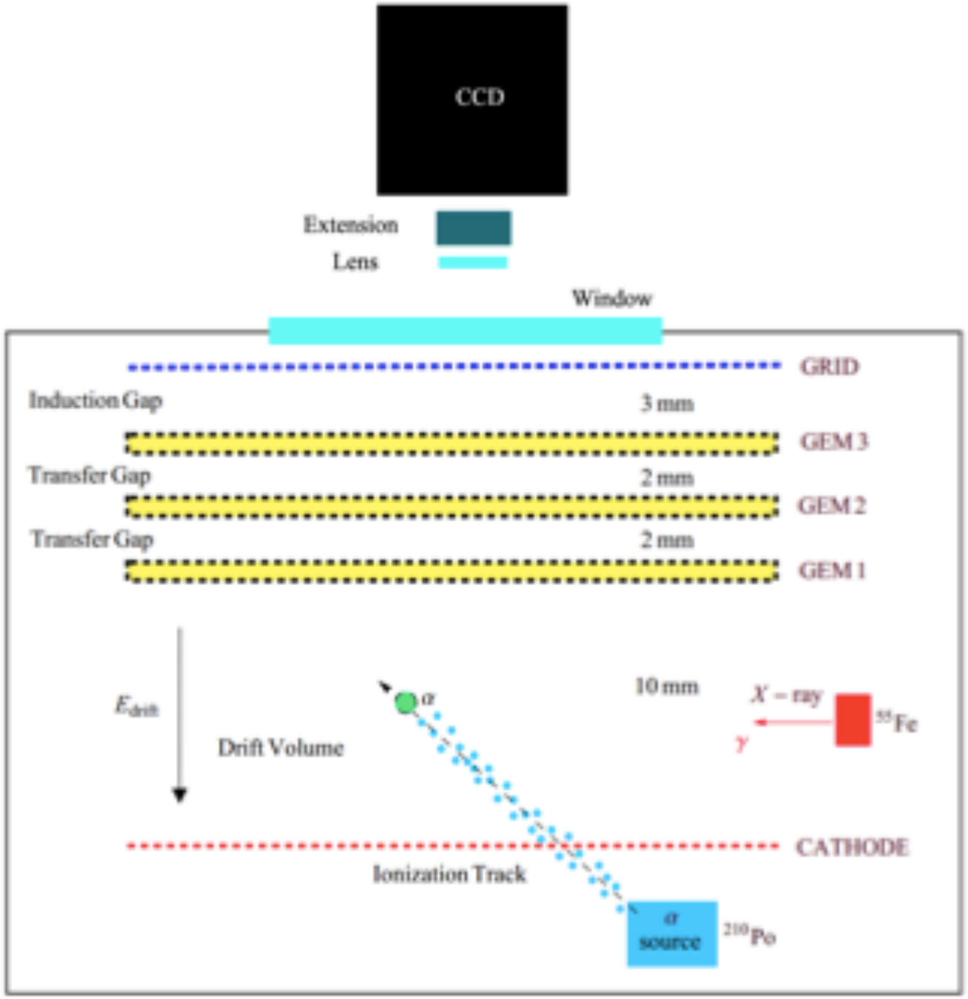
Concept: low pressure **CF_4 and CS_2 with Thin GEMs and CCD** optical readout

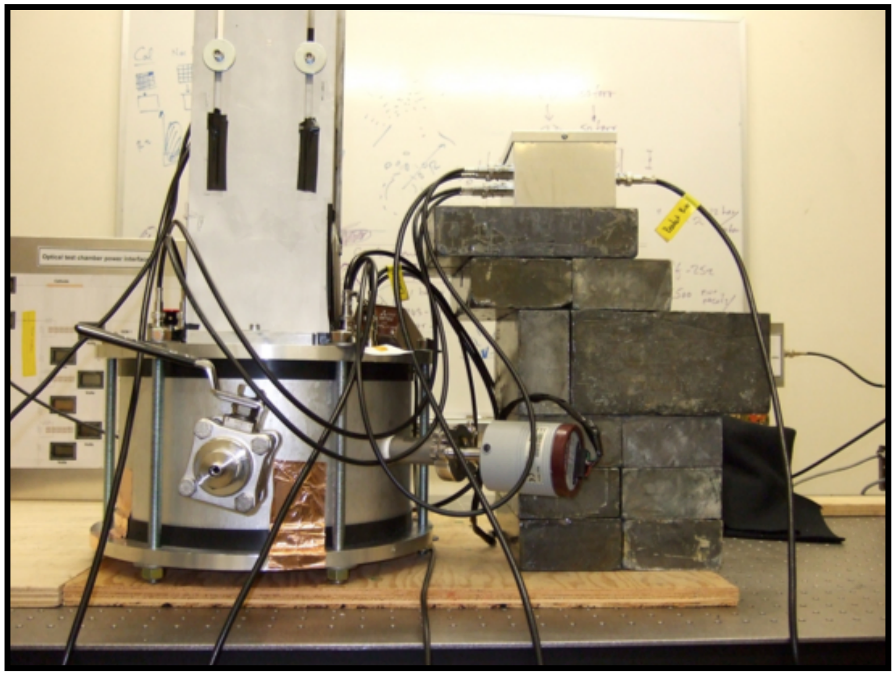
Aim: to explore low energy limit of directionality

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









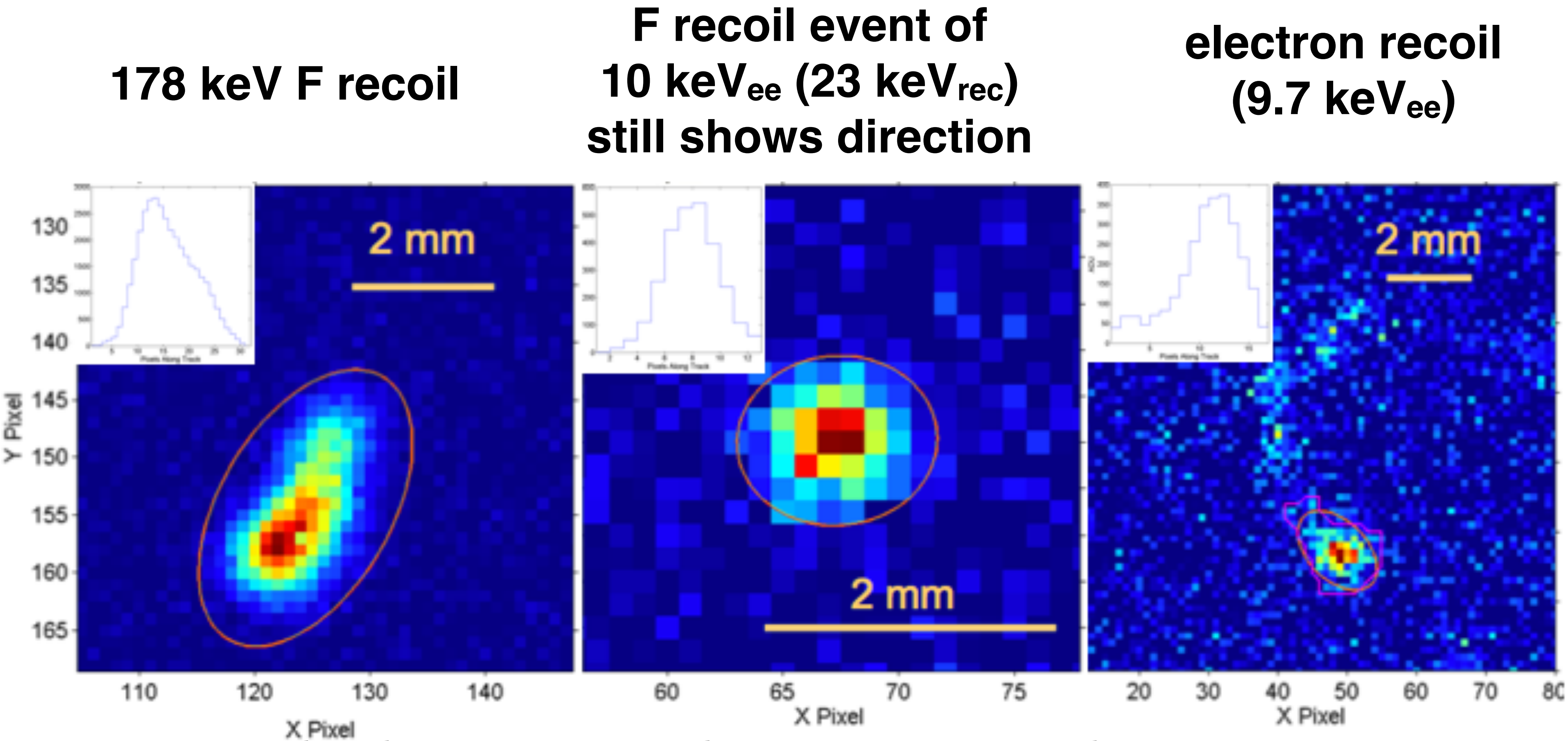
UNM R&D - CCD + Thin GEMs

D. Loomba et al.,

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

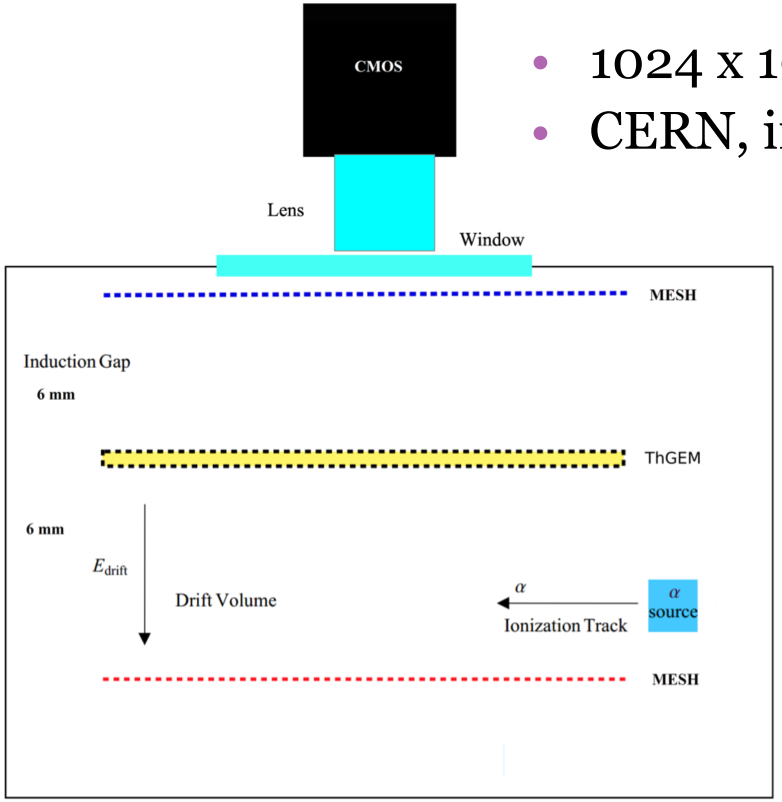


- Latest results show operation down to 13 Torr with CS_2

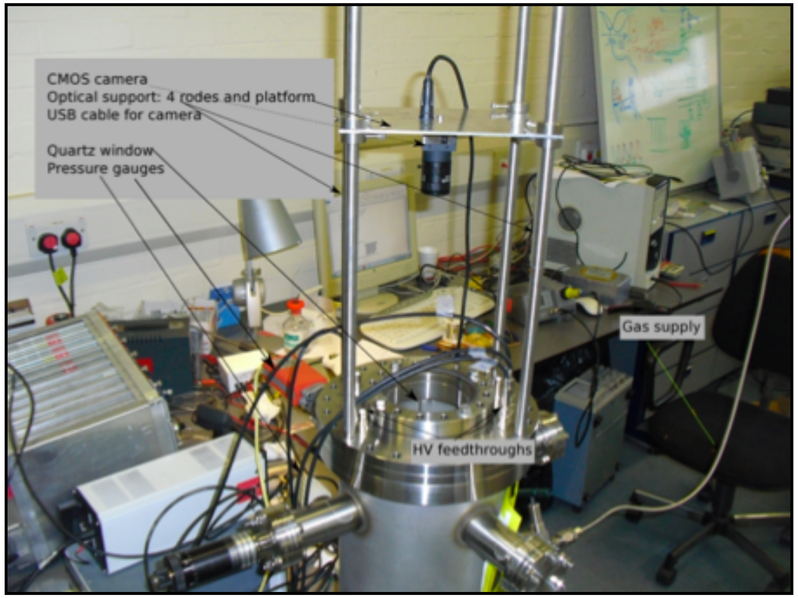
Sheffield R&D - CCD + Thick GEMs

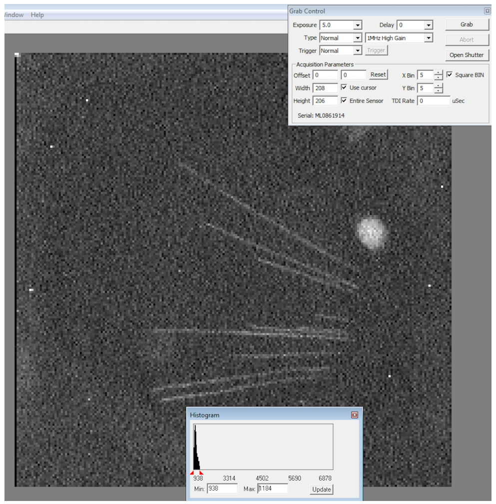
Concept: low pressure **CF_4 and SF_6 with Thick GEMs and CCD** readout

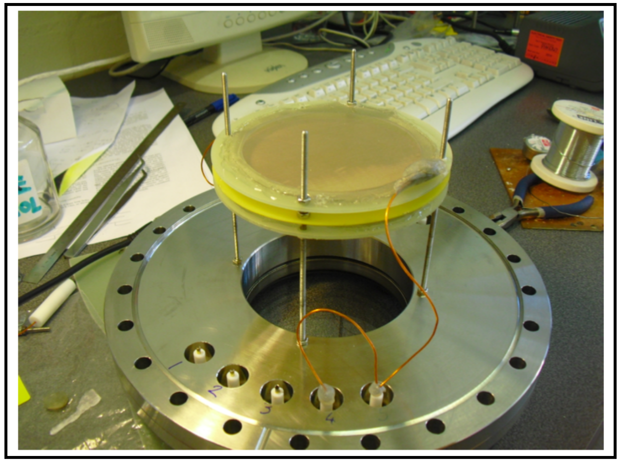
N. Spooner et al.,

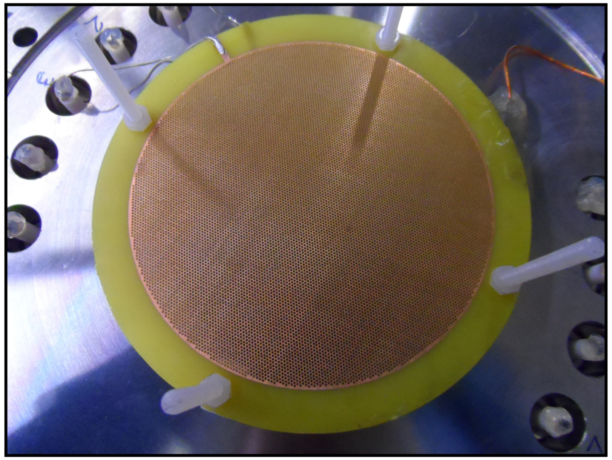


- 1024 x 1024, 24μm microline ML1001E camera
- CERN, in-house and AWE design Thick GEMs









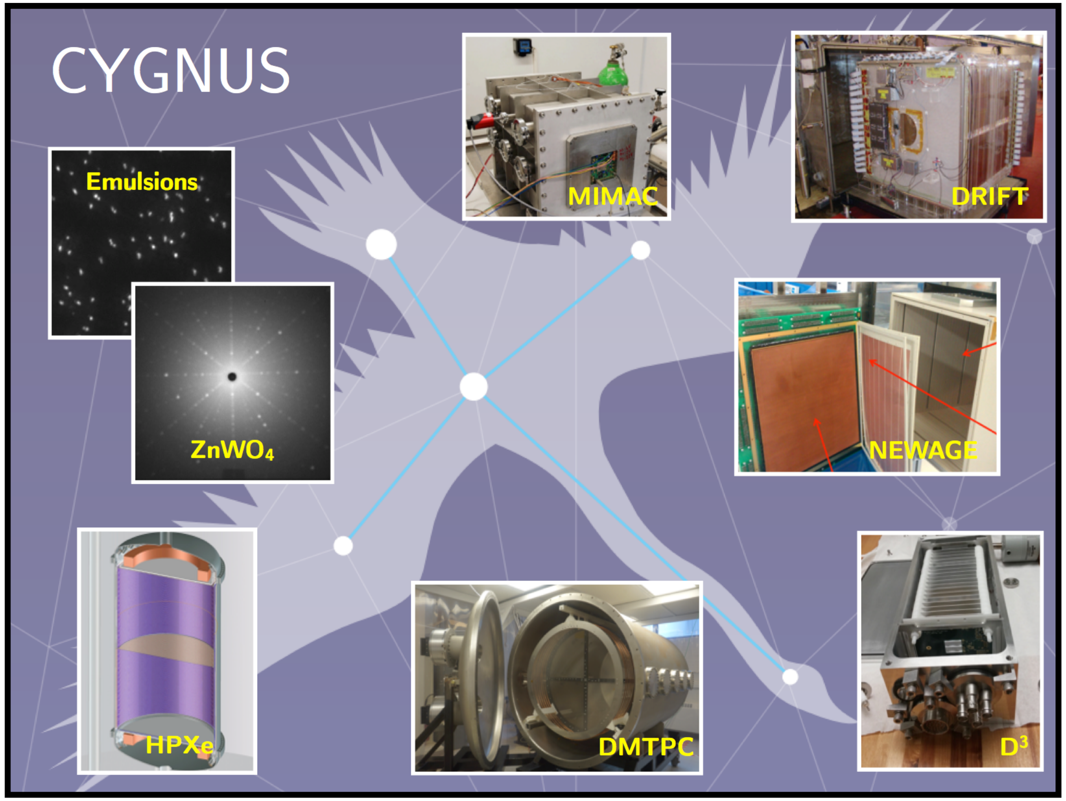
CYGNUS Collaboration - Ton scale

- **From workshops to collaboration**

2007 Boulby, UK
2009 MIT, US
2011 Modane, France
2013 Toyama, Japan
2015 Occidental, US

- Meet challenge of scale-up
- Optimise techniques

Australia, China, France, Italy, Japan, UK, US…



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CYGNUS-TPC

What Directional TPC Technology?

“high definition - 3D”

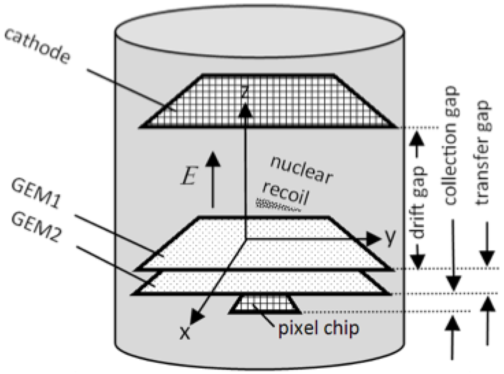
e.g. D3 - pixel **e.g. DM-TPC - CCD**

small volume R&D

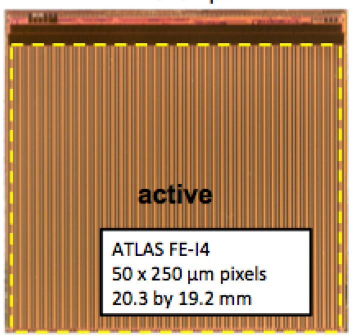
“low definition ~ 1.5D”

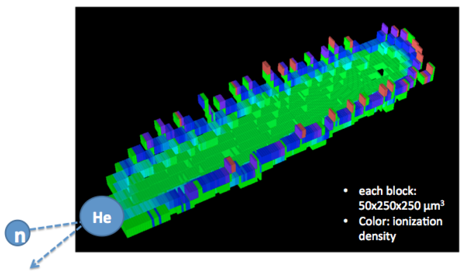
e.g. DRIFT - wires

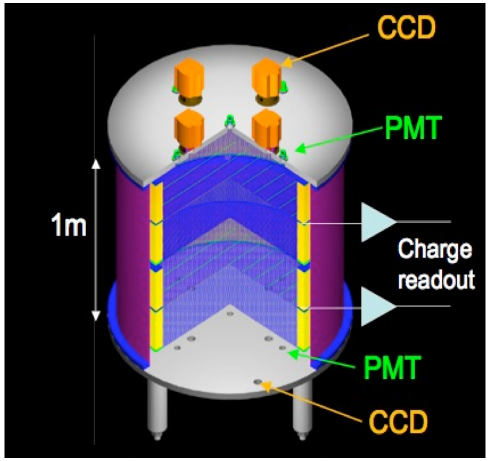
larger volume R&D, low background

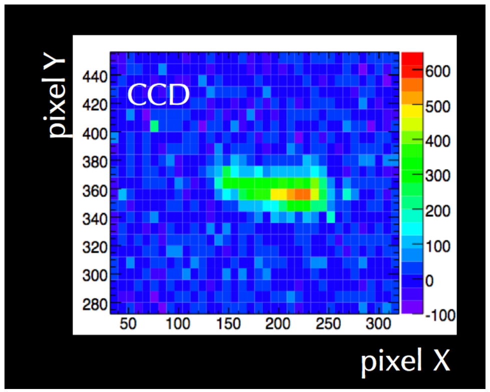


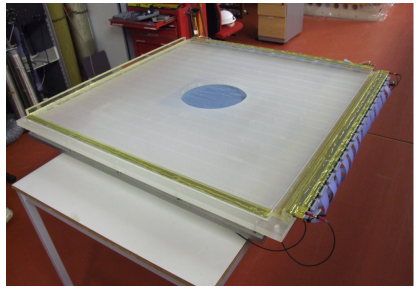
Pixel chip:

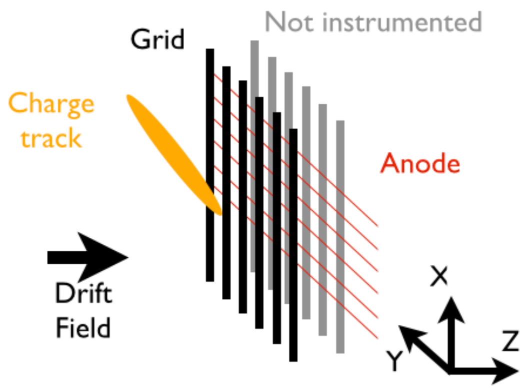


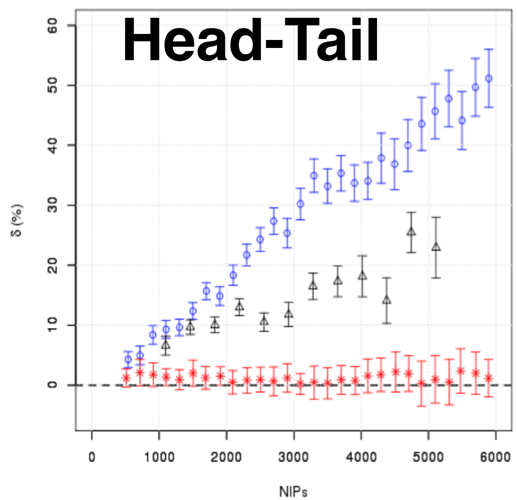






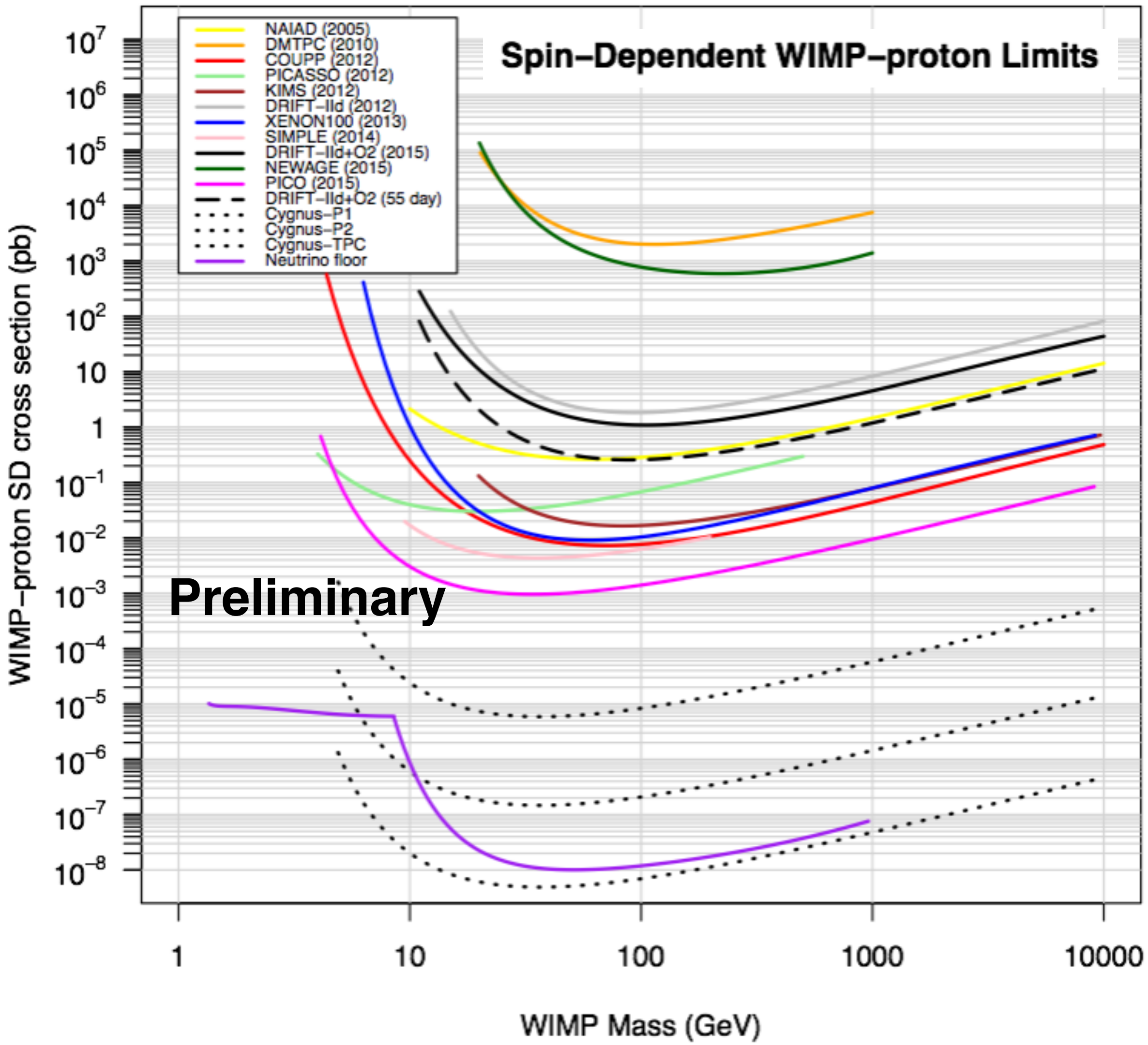






CYGNUS-TPC Global Concept

- SF_6 target (~x5 more F per volume than current)
- Fiducialisation, -ve ion drift, head-tail sensitivity
- Multi-tonne, multi-underground site,
- Staged programme - low WIMP mass, high WIMP mass



Australia, China, France, Italy, Japan, UK, US

~Current state

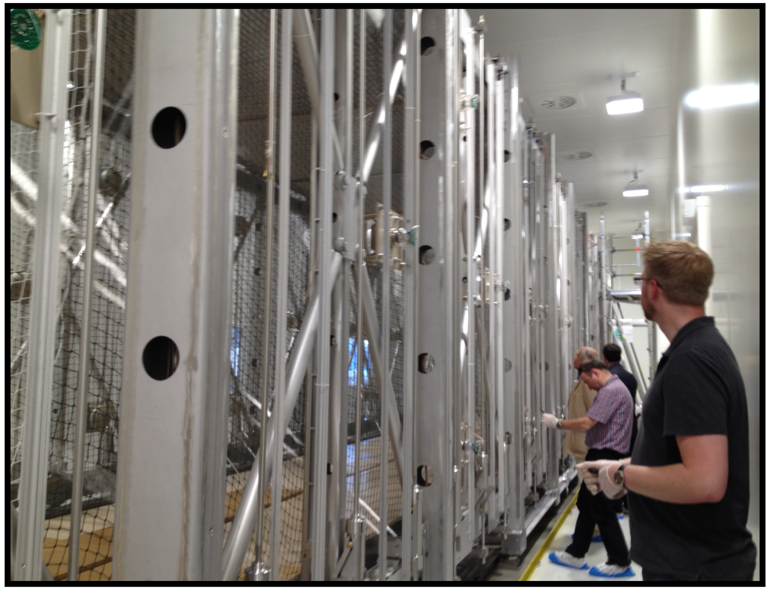
CYGNUS - Pathfinder 1

CYGNUS - Pathfinder 2

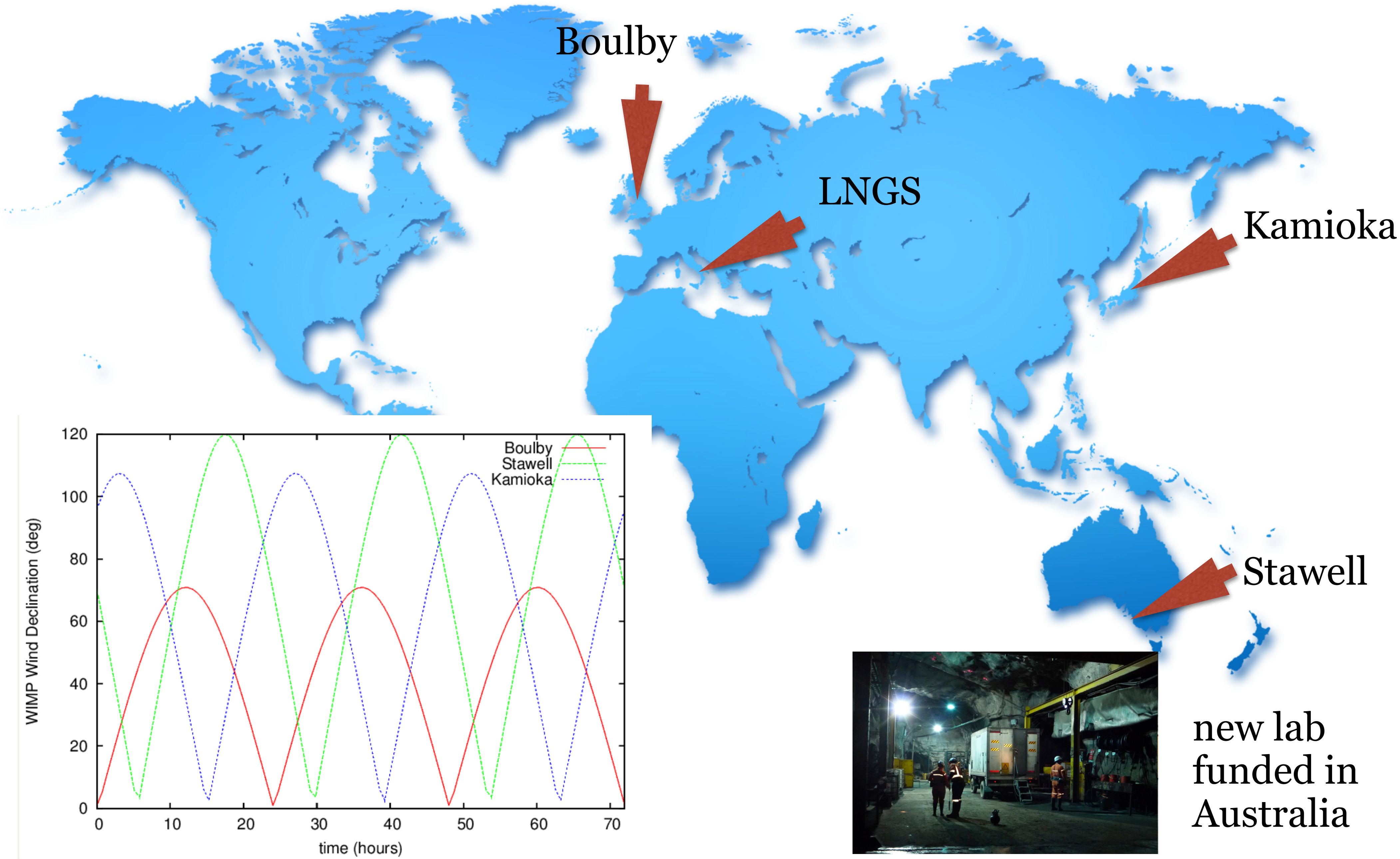
CYGNUS - TPC

How Not to be Afraid of Large TPCs

- Example - something the size of ICARUS (used for LAr)
- Size: 2 x ~18 x 3 x 3 m, central cathode, 1.5m drift
- Would contain ~ 0.5 Tonne Fluorine (SF_6) @ 200 Torr
- Size is ~ 100th scale of proposed DUNE liquid argon TPC



CYGNUS-TPC - Multiple Sites



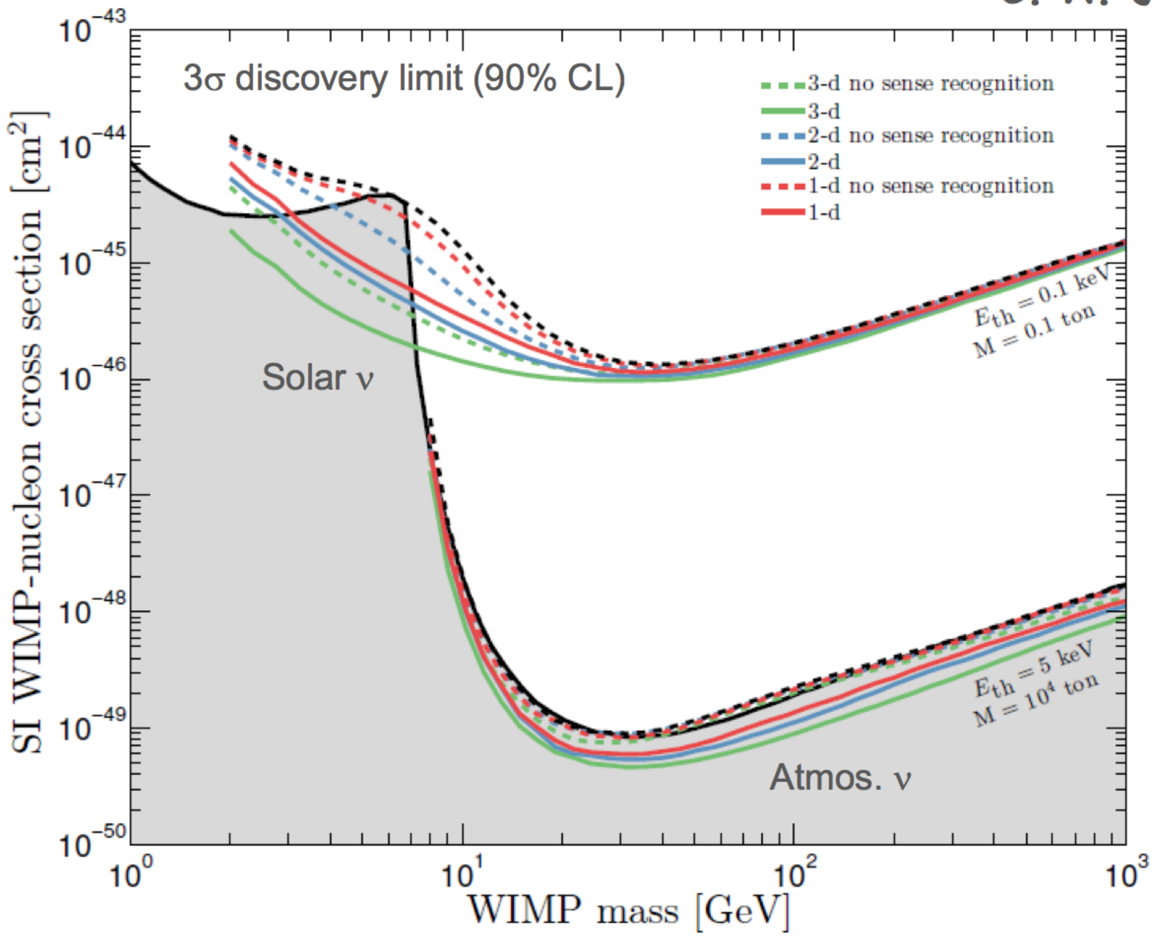
new lab funded in Australia

CYGNUS R&D at New Boulby Lab

CYGNUS R&D at New Boulby Lab

Coherent Neutrino Scattering in Directional DM Detector

C. A. J. O'Hare *et al.*, 1505,0806



Conclusion:

Directional detection allows to *dig* the ν floor :

→ by several orders of magnitude at low WIMP mass(<10 GeV),

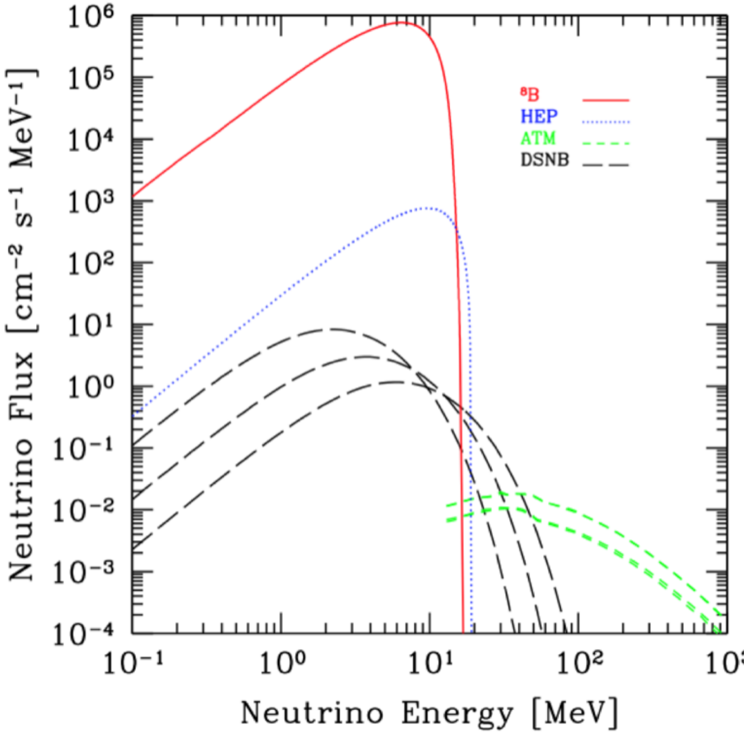
even 3d without sense recognition, or 1d with sense recognition

→ By a factor of a few at high WIMP mass (100 GeV)

Coherent Neutrino Scattering ^8B

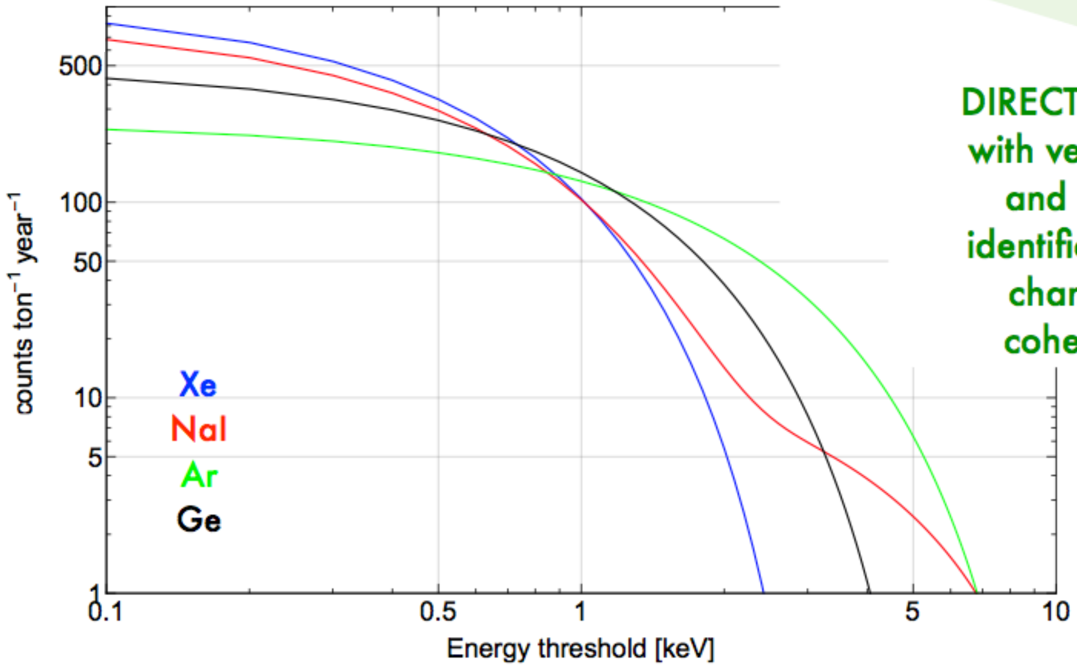
▸ **Potential directional coherent neutrino detection from the Sun**

M. Biassoni et al.,



- Solar neutrinos from ^8B are and interesting source
- Neutrino coherent scattering never observed
- Observation is a result by itself
- Can give insights into nuclear physics
- Measure of SN neutrino emission temperature

~1000 events with zero threshold
~100 events with 1keV threshold
strong directional signature



DIRECTIONAL detectors with very low threshold and nuclear recoil identification = first real chance to observe coherent scattering

Conclusion

We want to build a Global Galactic Recoil Observatory

(1) Dark Matter Directionality (2) Coherent Astrophysical Neutrino

Trying to develop in WIMP “telescope” is fascinating and challenging…

It will be needed to determine a definitive detection of WIMP dark matter

It is not harder than non-directional, it’s different

It needs more minds….and a global effort

Join CYGNUS

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- To know more —> IDM2016
- Sheffield, 18-22 July
- mini-CYGNUS, 23rd July