Galactic Signatures and Directional Detection of Dark Matter Particles - CYGNUS & probing below the neutrino floor

Neil Spooner, University of Sheffield

- **Direct Search Update**
- **Annual Modulation and Directionality**
- **from DM-ICE and DRIFT to COSINE-100 and CYGNUS-TPC**

Thanks to those from whom I have borrowed slides and info

So Galaxies are 90% Dark Matter

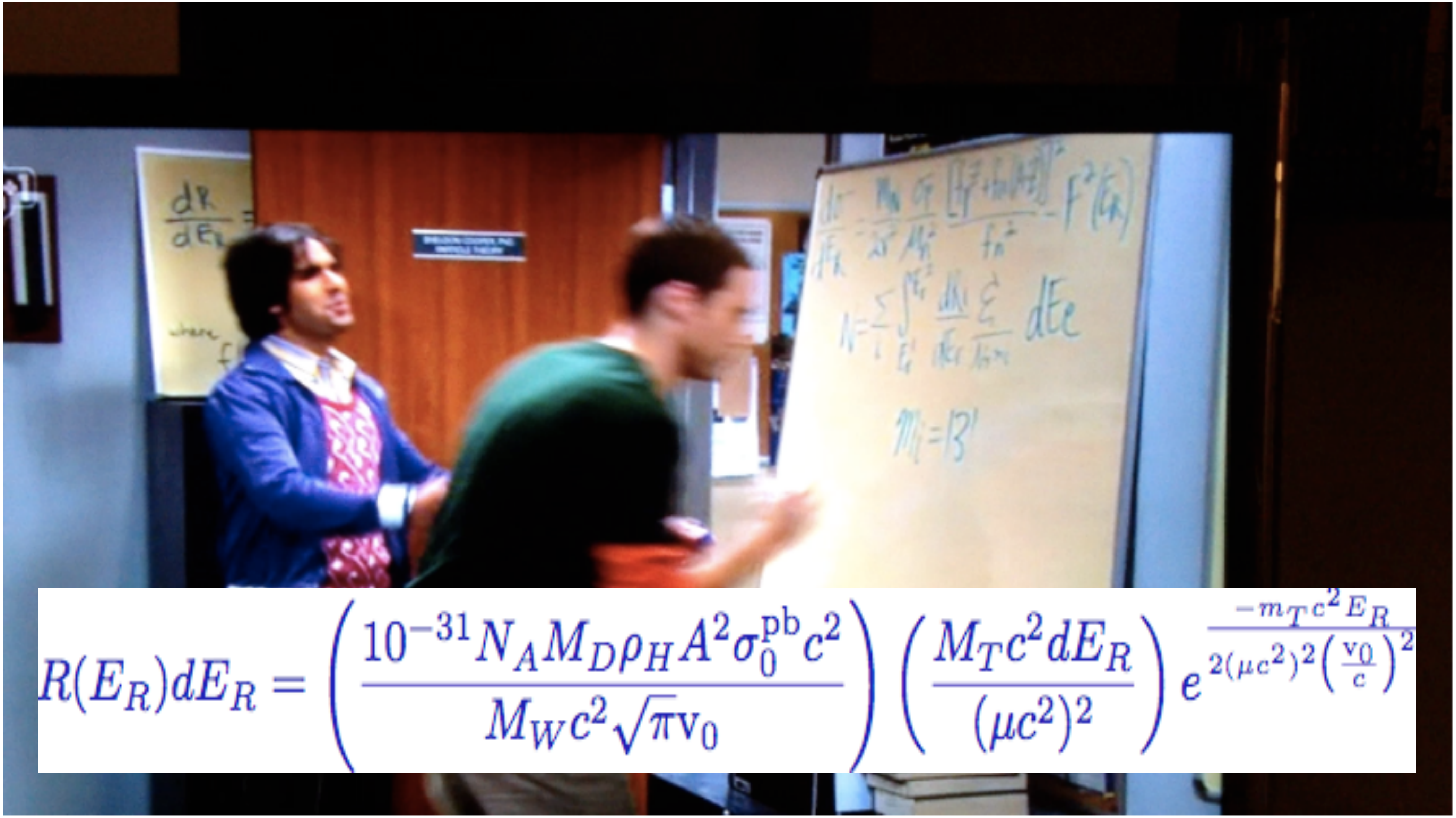
"I can't tell you what's in the dark matter sandwich. No one knows what's in the dark matter sandwich."

WIMPs!

What a WIMP Does

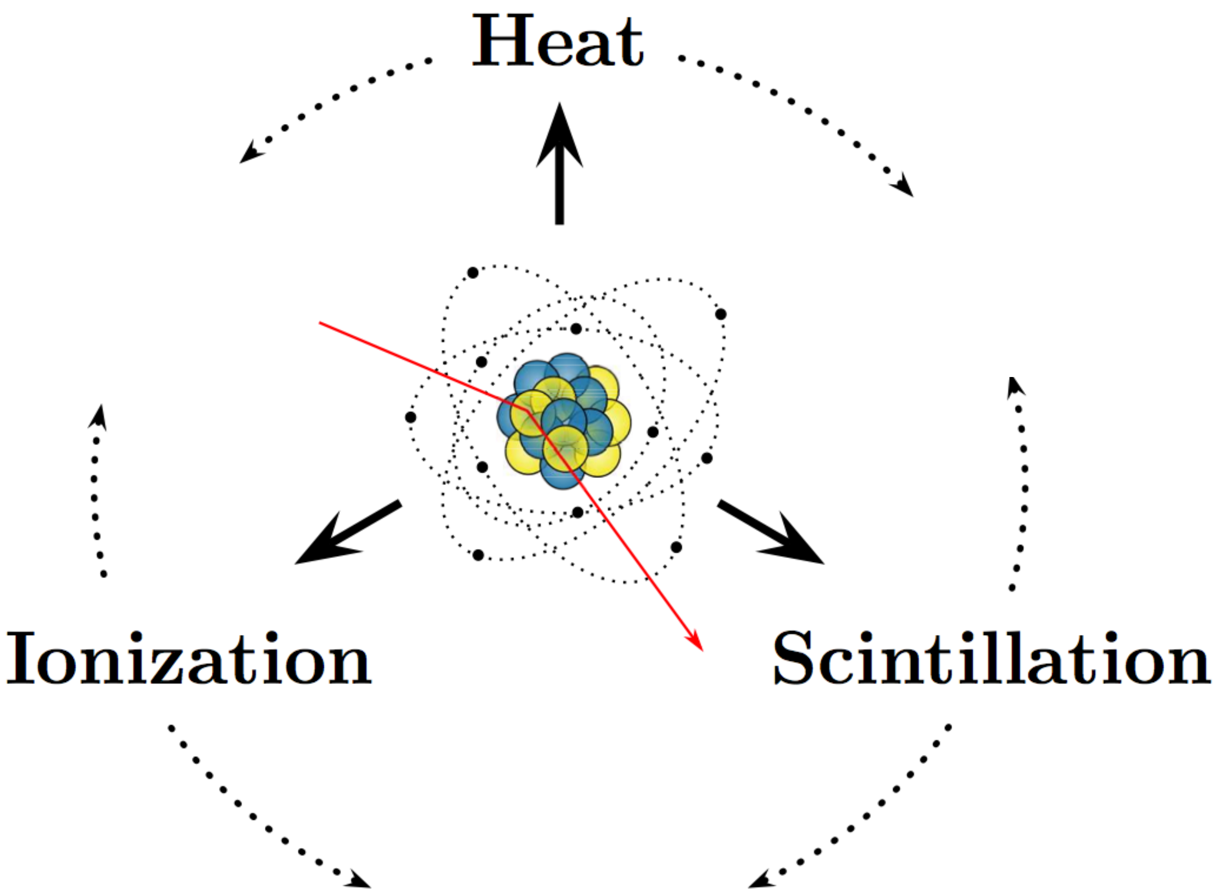
atom

The Recoil Equation



$$R(E_R)dE_R = \left(\frac{10^{-31} N_A M_D \rho_H A^2 \sigma_0^{\mathrm{pb}} c^2}{M_W c^2 \sqrt{\pi} \mathrm{v}_0}\right)\left(\frac{M_T c^2 dE_R}{(\mu c^2)^2}\right) e^{\frac{-m_T c^2 E_R}{2(\mu c^2)^2 \left(\frac{\mathrm{v}_0}{c}\right)^2}}$$

Conventional WIMP Direct Detection



Dealing with backgrounds drives the technology

- Alpha, beta, gamma, neutron, cosmic rays
- U, Th, K….   radon
- Go underground to get away from cosmic rays

~Current WIMP Situation

- ## at High Mass

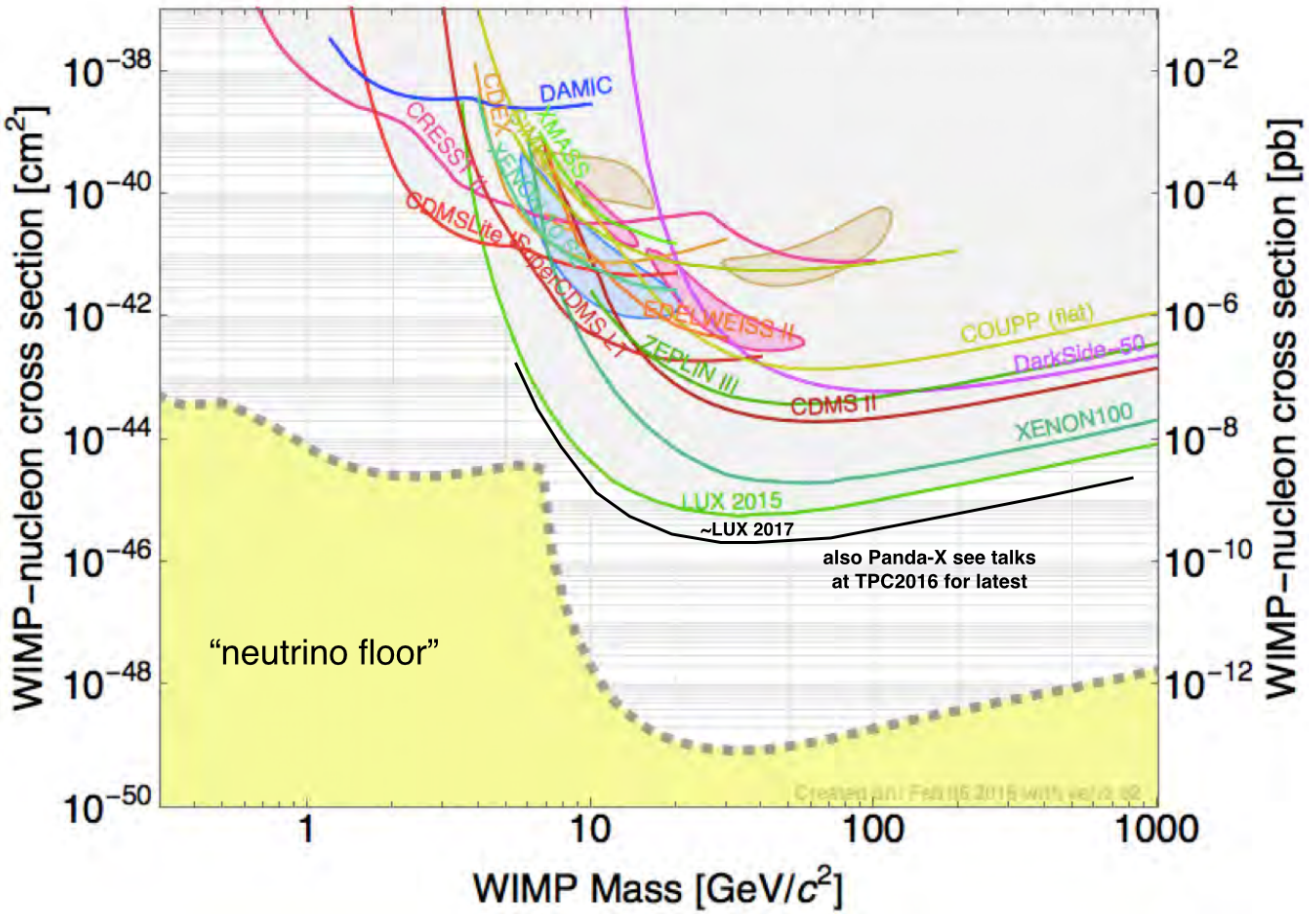
Nothing so far
Consistent with the absence of SUSY@LHC

- ## at Low Mass

Some closed contours, and strong limits

What is going on?

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



Many Recent Technical Advances

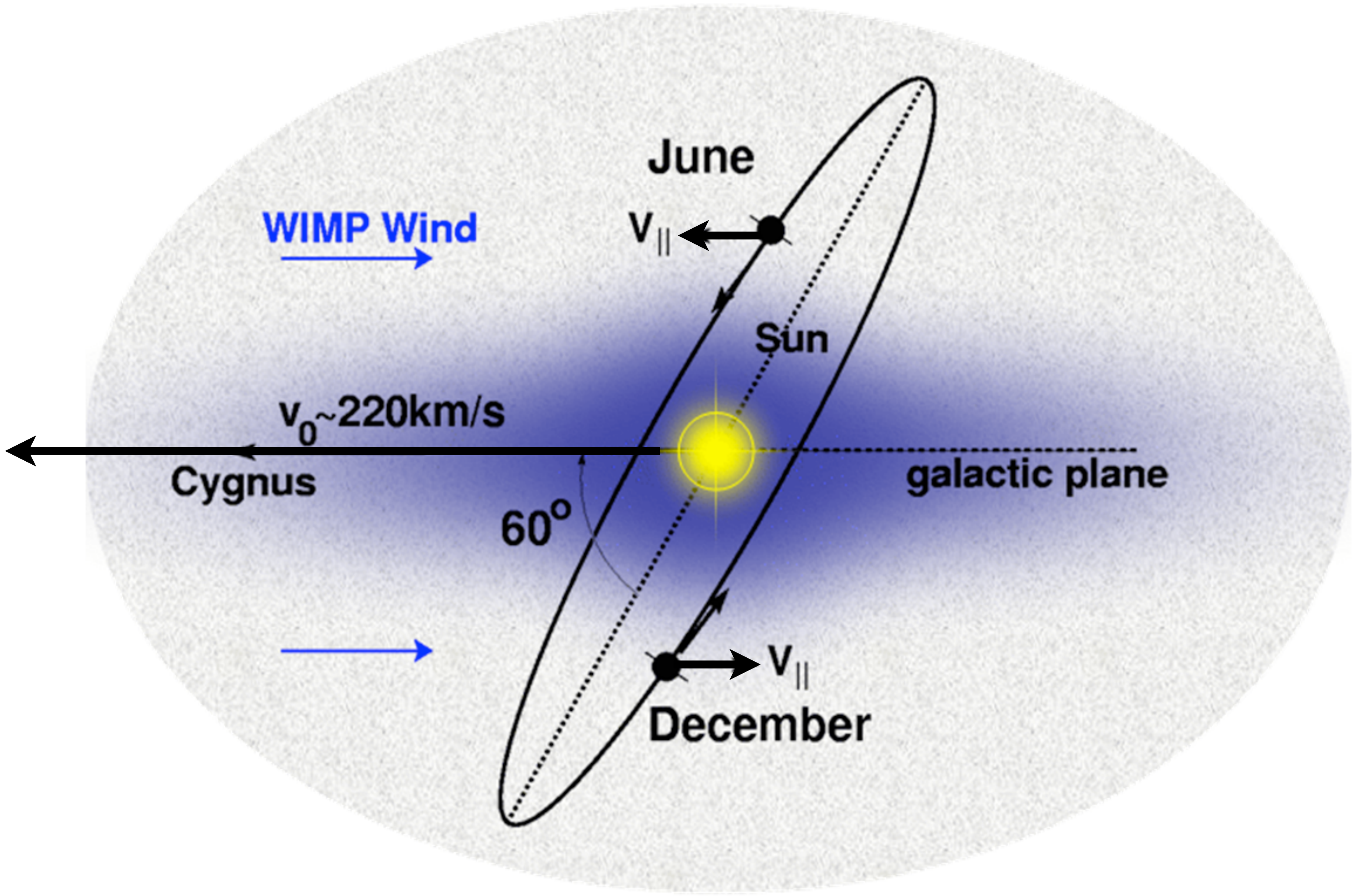
but oh dear, no clear signal?, what to do?:

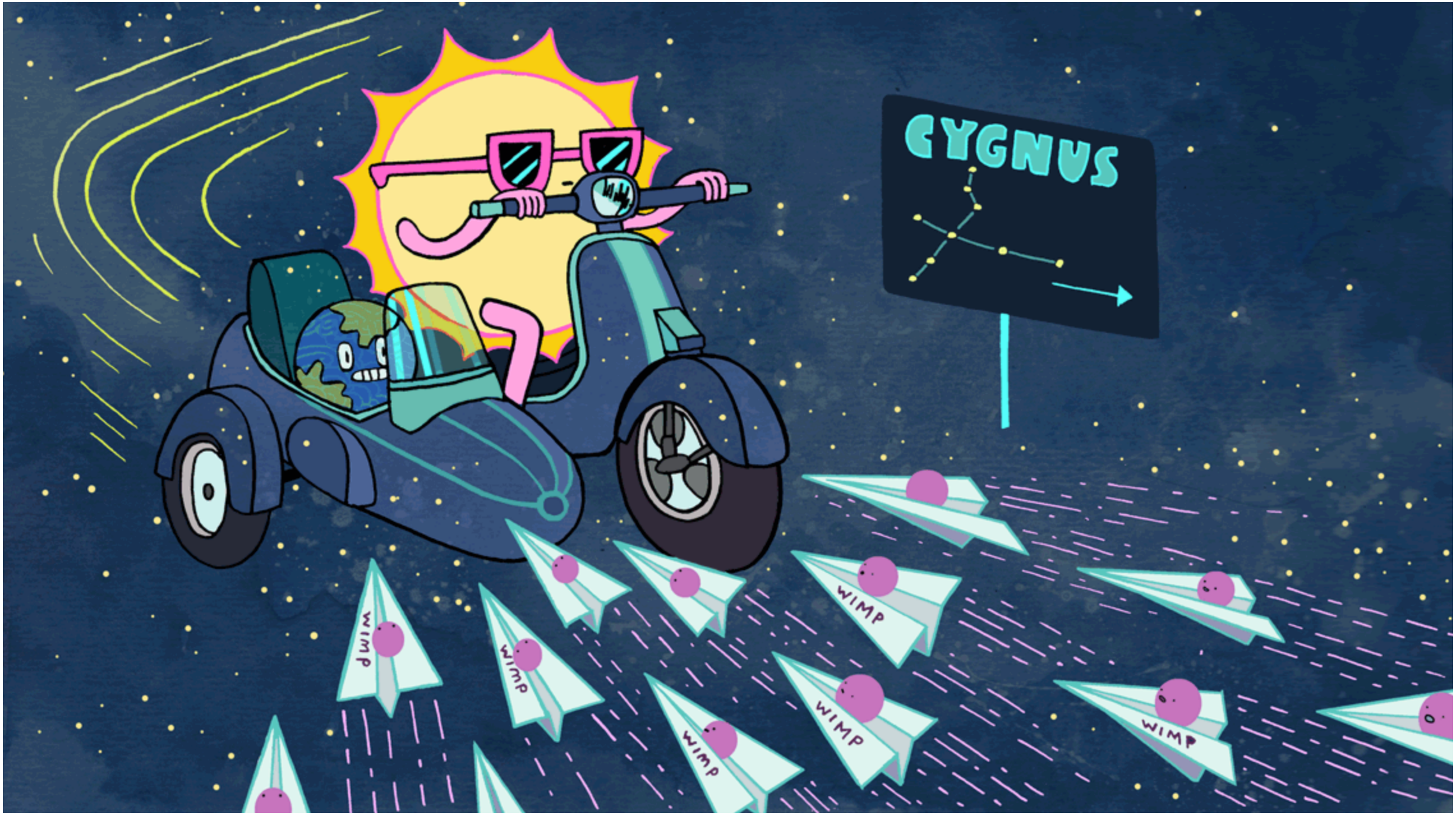
Many Recent Technical Advances

but oh dear, no clear signal?, what to do?:

- try low WIMP mass
- try bigger targets for high WIMP mass
- double check old “signals”
- seek better signal
- try something else!

What could the Signal be for WIMPs?

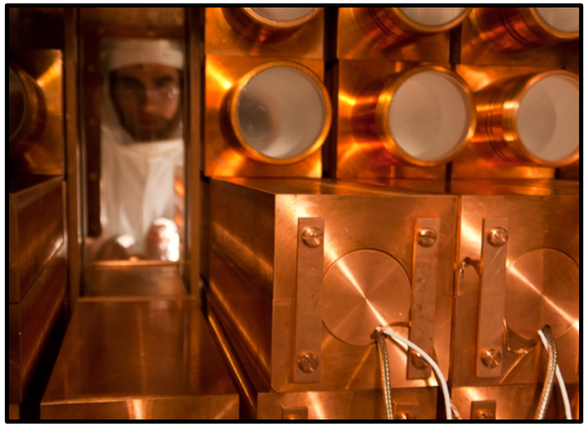


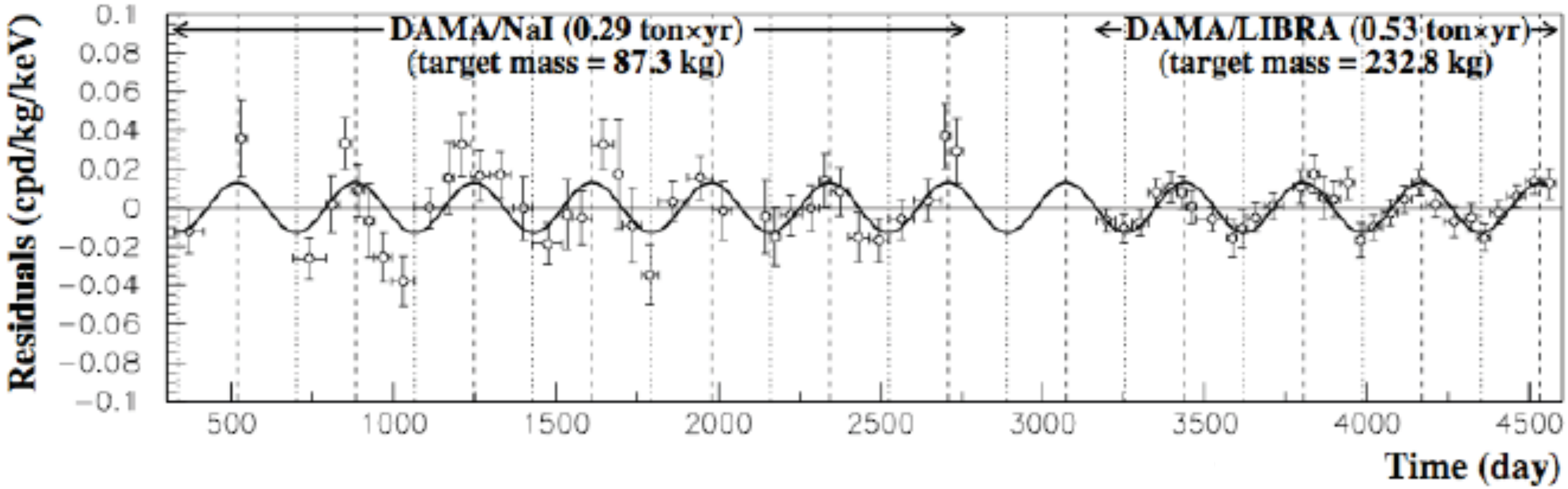


http://www.symmetrymagazine.org/article/wimps-in-the-dark-matter-wind

Annual Modulation

- DAMA/LIBRA collaboration in Italy see an Annual Modulation
- Changed Phototubes to high QE - Results 2017?

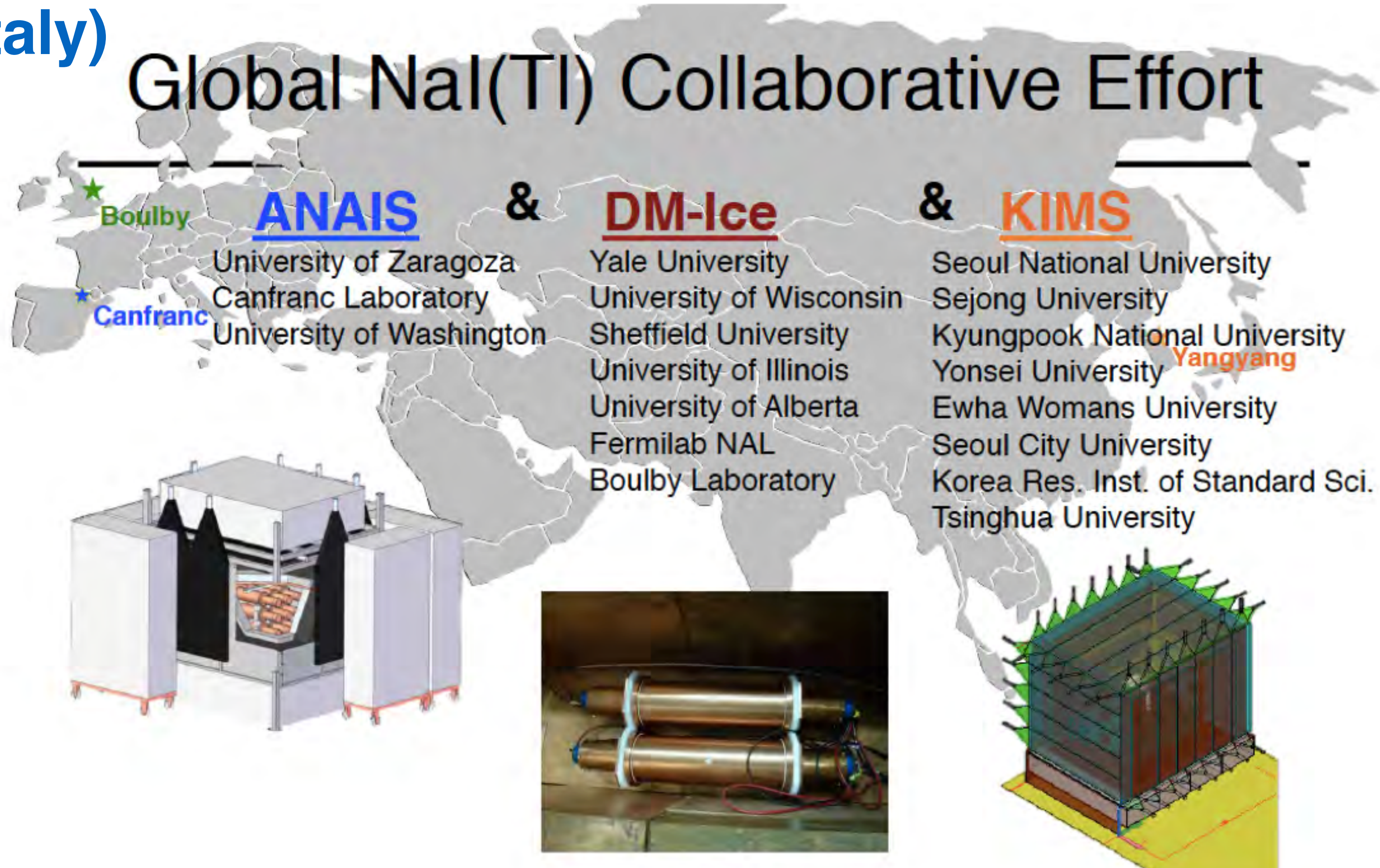




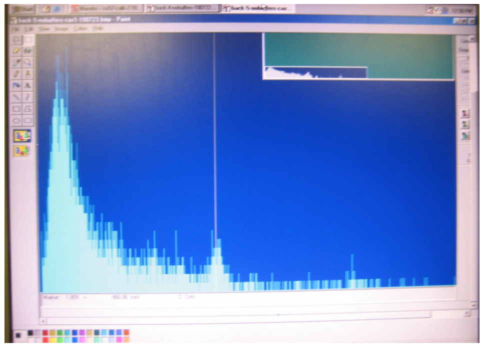
New Annual Modulation

- Renewed global efforts of annual modulation in NaI
  - ANAIS (Spain)
  - DM-ICE (US-UK)
  - KIMS (S. Korea)
  - Sabre (US-Italy)

DM-ICE (US-UK), KIMS (S. Korea) → **COSINE-NaI**



DM-ICE17 Tests at Boulby, UK

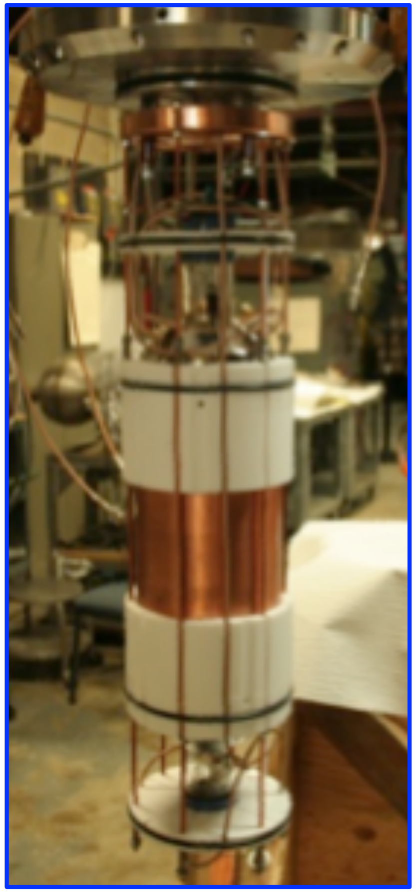


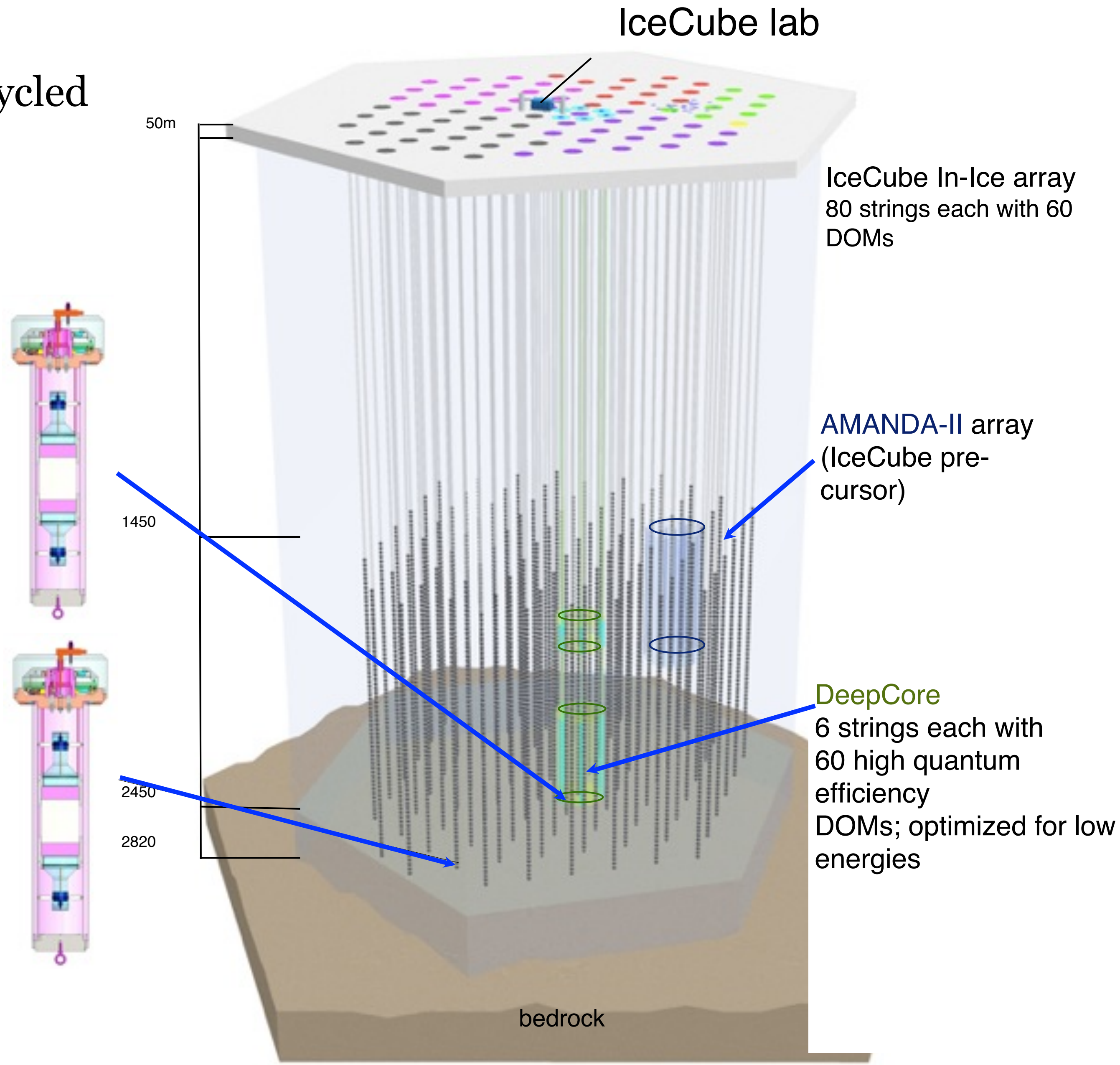
- Two crystals originally used in the NaIAD dark matter experiment

DM-ICE17 Location and Runs

Deployed Dec. 2010

- Two 8.5 kg NaI detectors recycled from the original NAIAD experiment at Boulby
- Operation from Feb. 2011
- Data run from June 2011



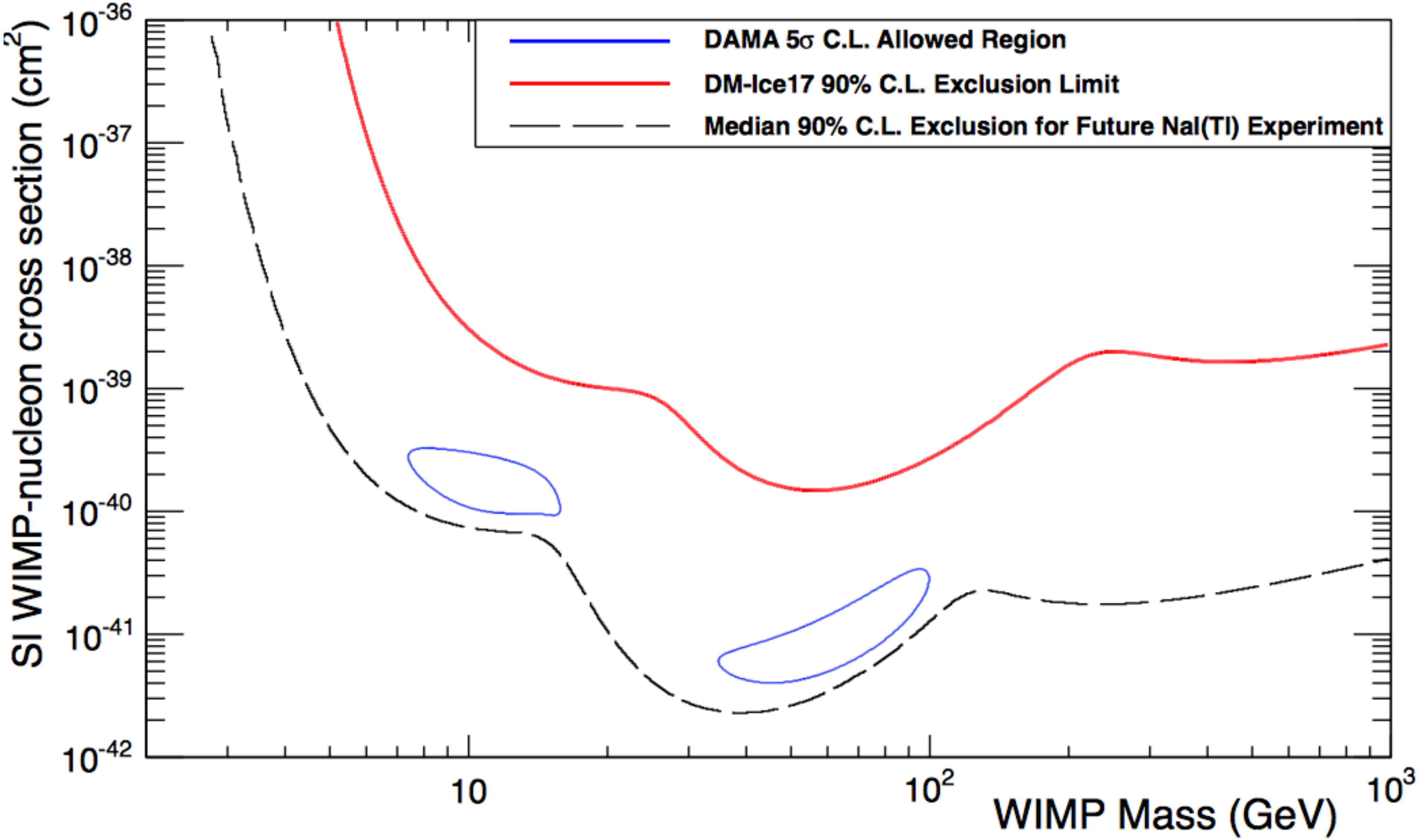


First DM-ICE Result Just Published

- 17 kg, 2.5 km below South Pole

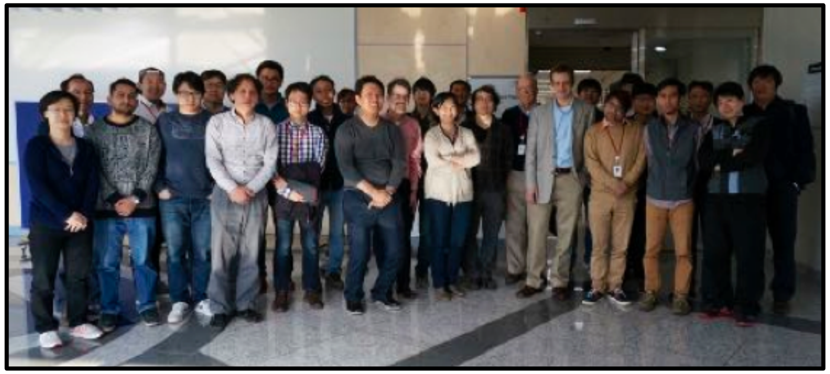
Phys. Rev. D 95, 030001 (2017)

- First southern hemisphere dark matter result

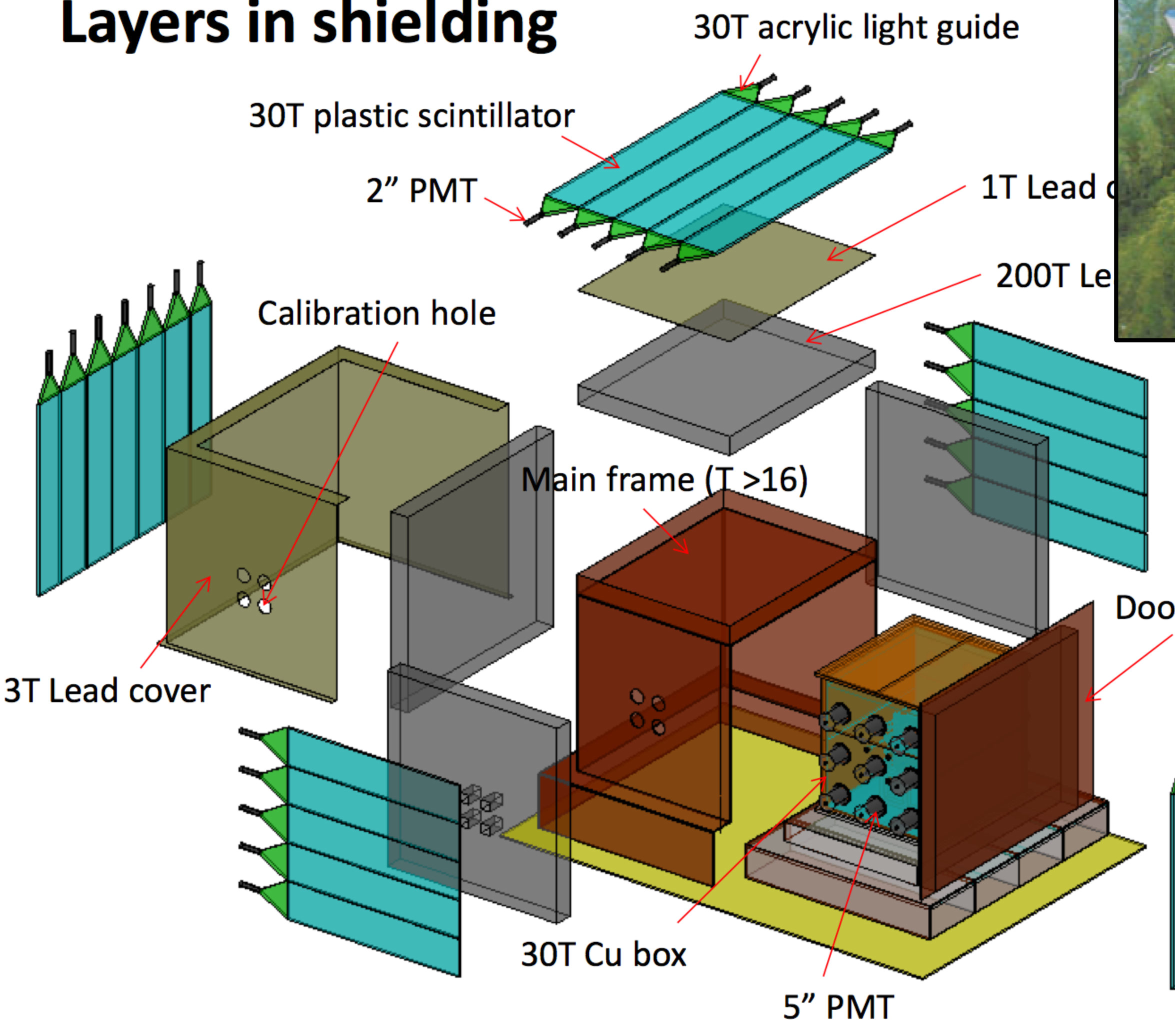


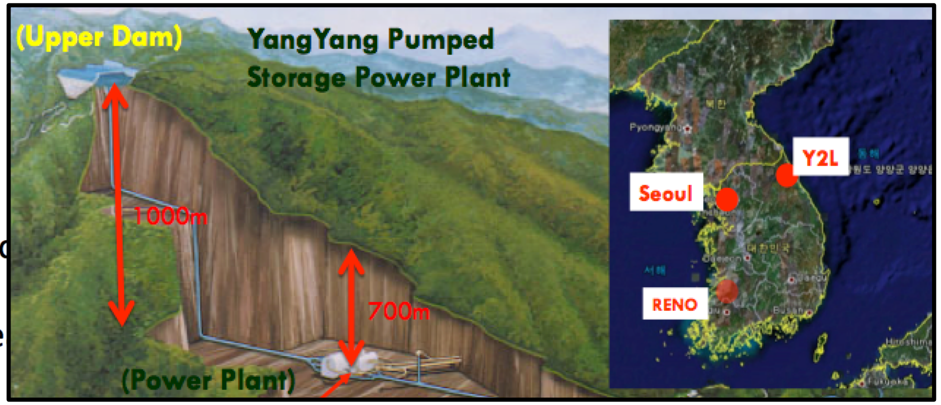
COSINE-100

- Combined DM-ICE/KIMS, YanyYang
- 100 kg data taking since 09/2016
- 14 Institutes

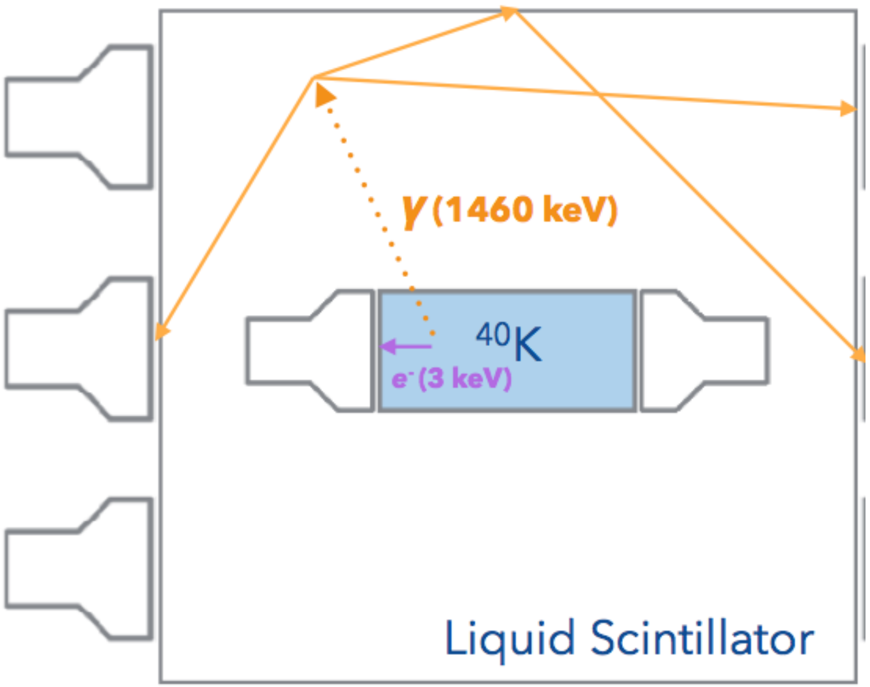


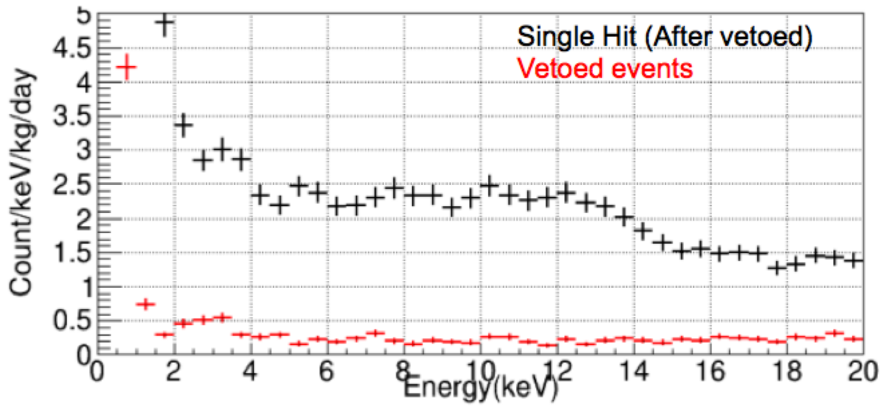
Layers in shielding

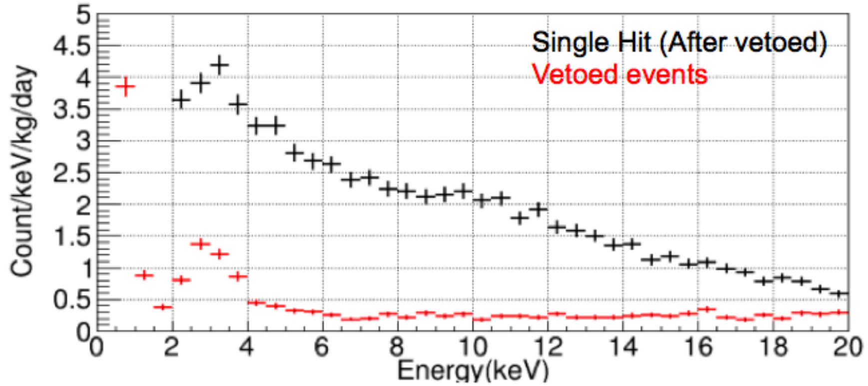




COSINE-100 First Data





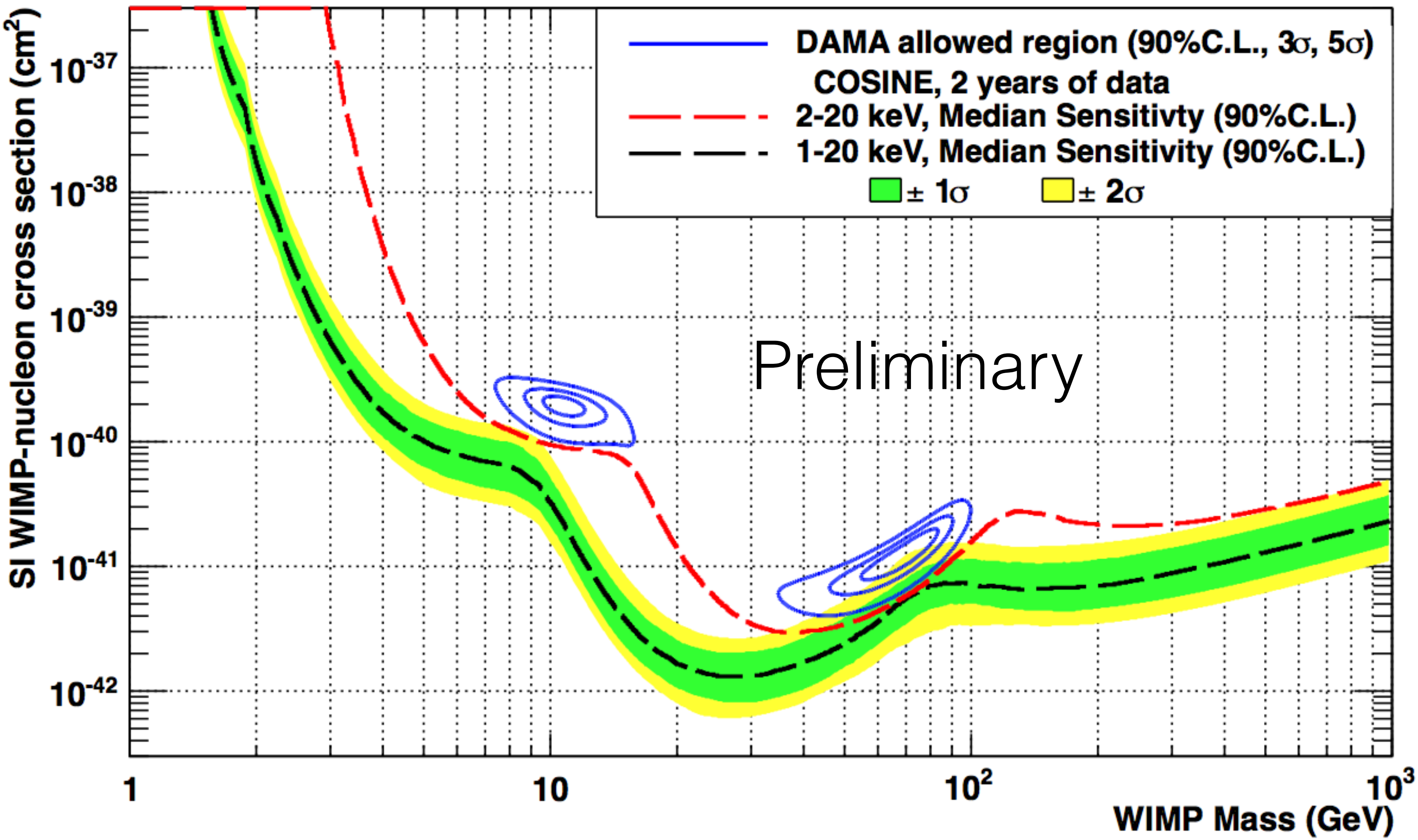


^{40}K Tagging 1460 keV events with LS enables to veto 3 keV background events

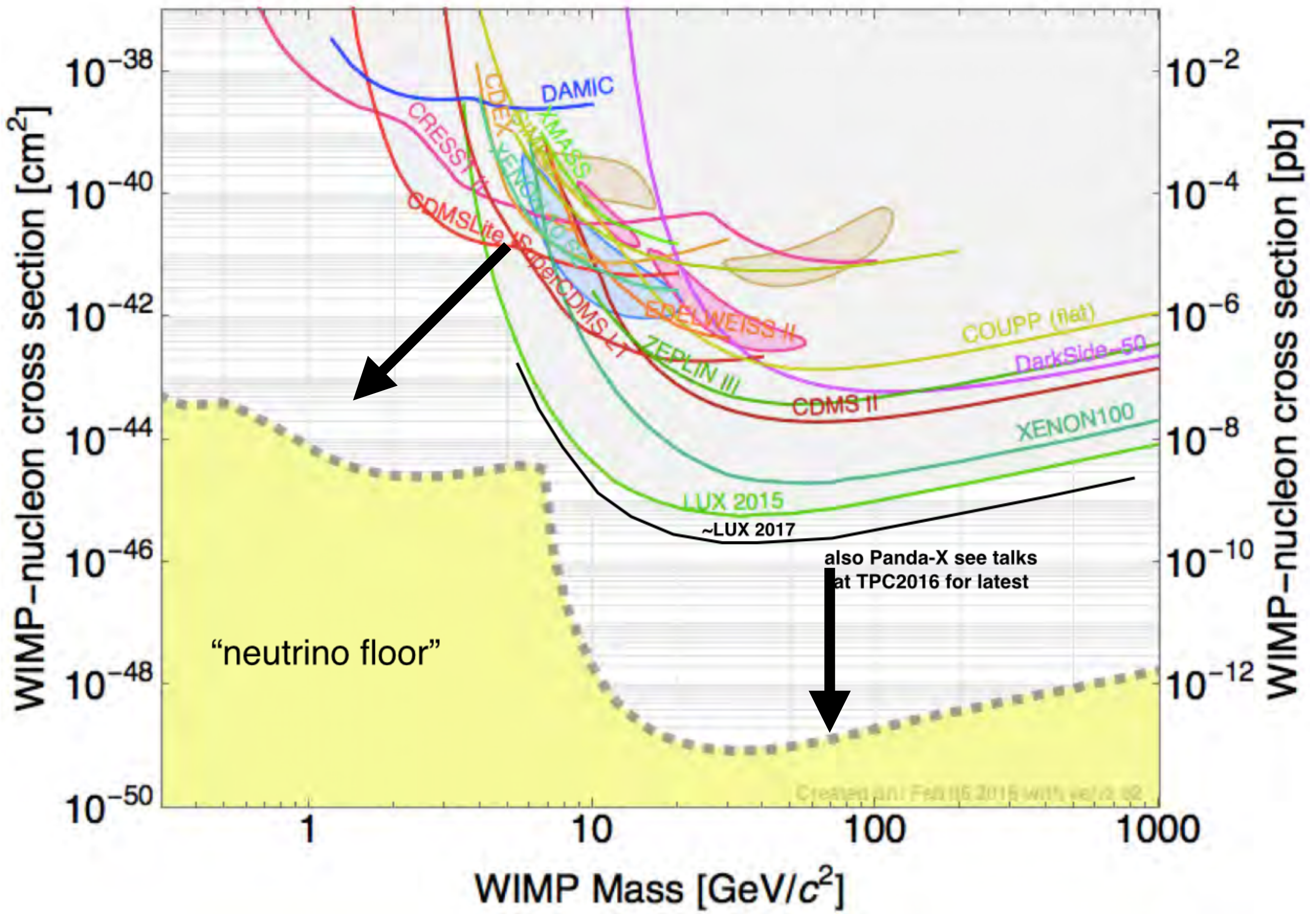
Surface ^{210}Pb is suspected to be the dominant background, followed by ^{40}K internal to crystal

COSINE-100 Projections

- 100 kg, 1 keV threshold, combined DM-ICE/KIMS at YanyYang



Back to Current WIMP Situation



▸ **Mainstream strategy**

1. Improve sensitivity at low mass (lower the threshold): **e.g. CDMS, CRESST, DAMIC.**
2. Improve sensitivity at large mass (increase target mass): **e.g. LZ, Xenon nT…**

XENON 1T Experiment

- 1 tonne dual phase LXe @ Gran Sasso - European/US

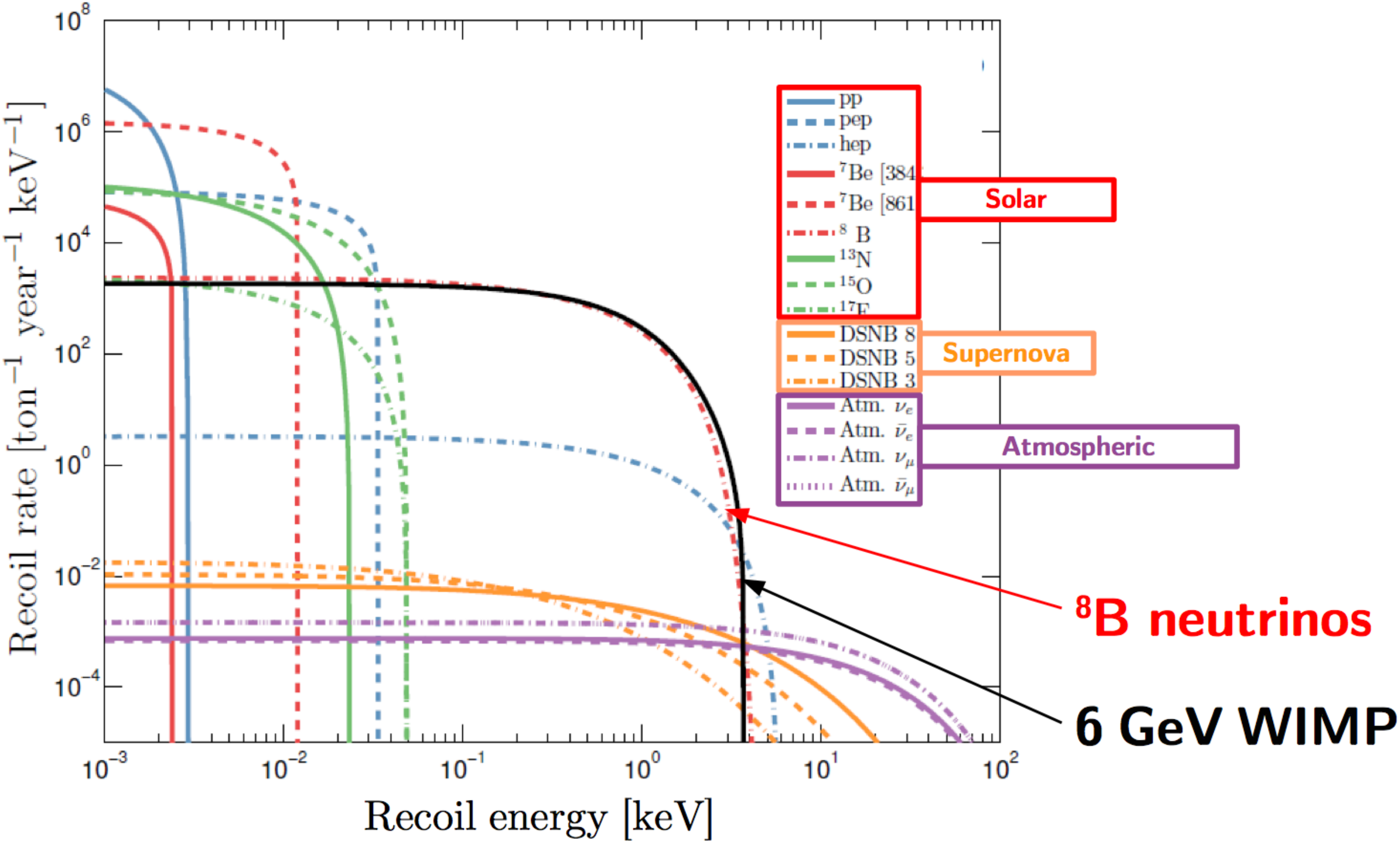
Is there a Better Signal for WIMPs?

Can we get below the neutrino floor?

- Neutrinos may increasingly shape the future of direct detection
- There is some focus on reaching the neutrino floor but this should shift to studying the neutrinos
- Then start to do neutrino/solar physics

Neutrino Coherent Background

Coherent neutrino-nucleus scattering rates on a Xenon target:

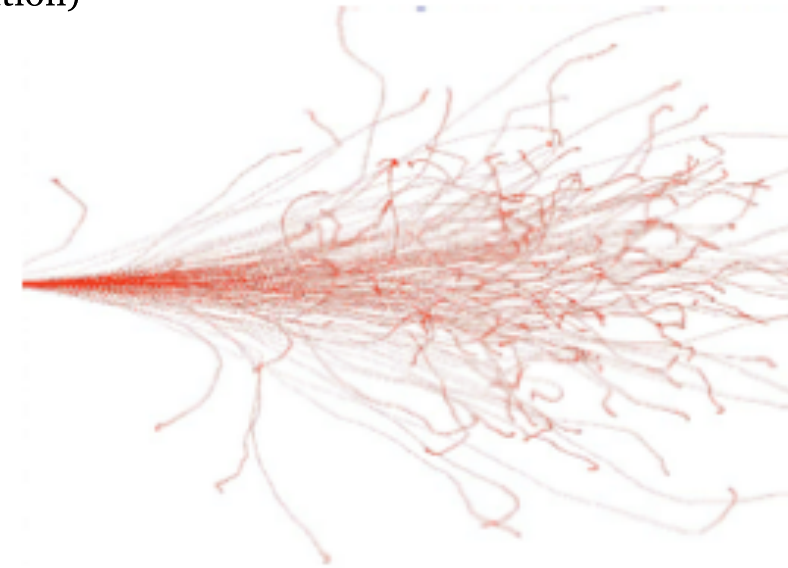


thanks to O'Hare et al.

What a WIMP Does

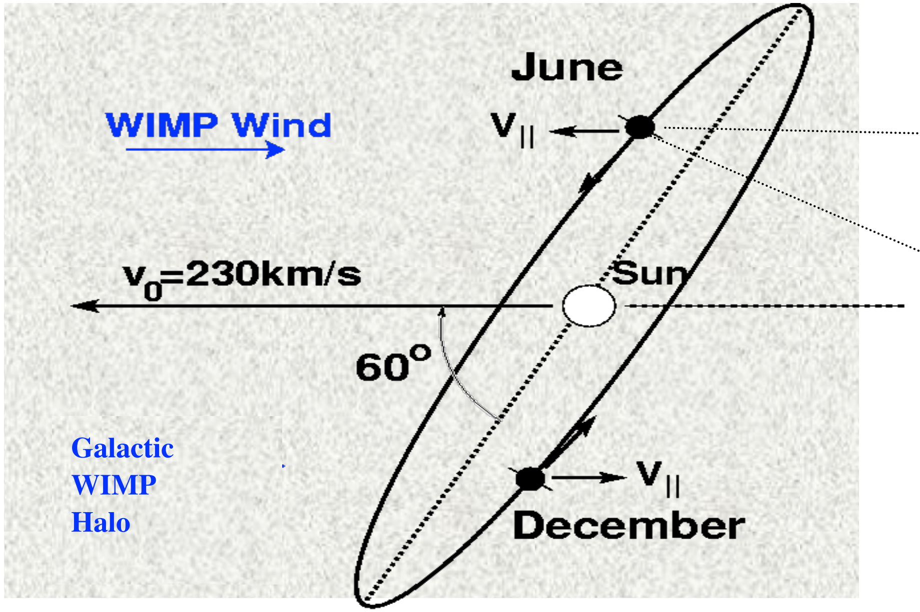
atom

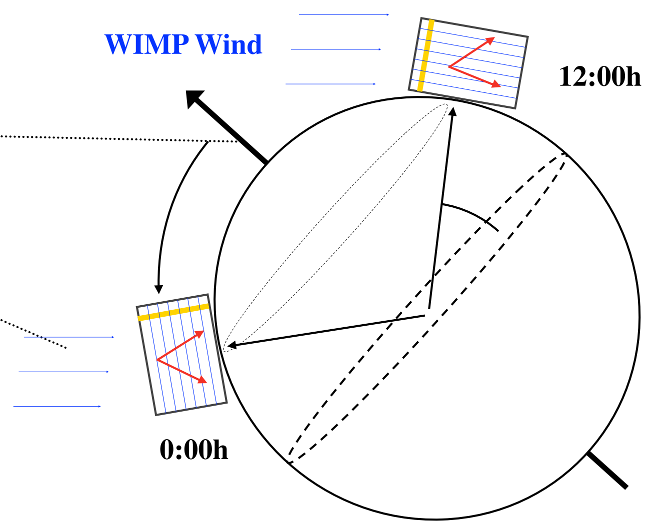
SRIM simulation - 100 keV F recoil in 75 Torr CF_4 (D3 collaboration)



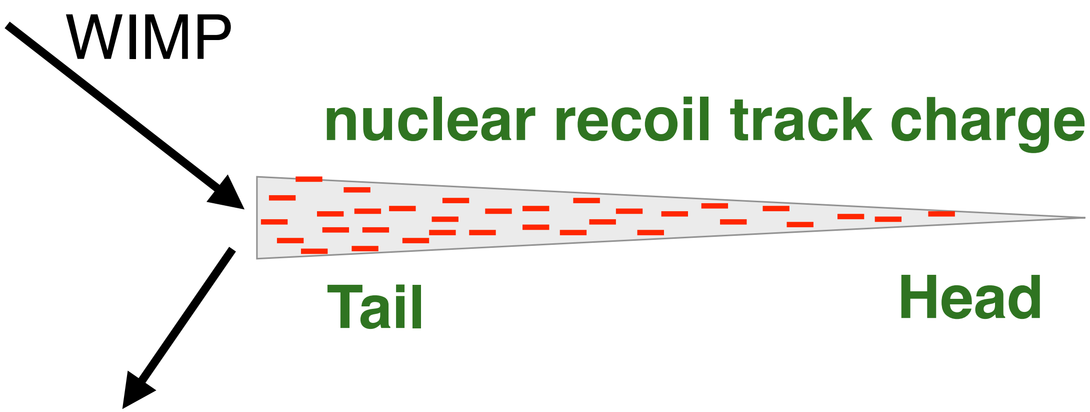
Directionality - A Better WIMP Signal

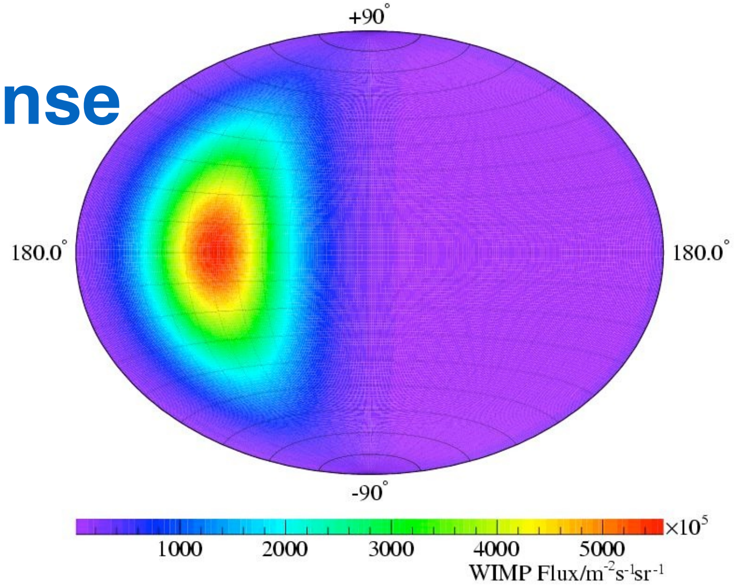
- A directional recoil signal is a very powerful proof
- Lets be prepared!





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





Directional Strategies and CYGNUS

(1) High Density Targets Solid, Liquids

Old work

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

But recent work is progressing...

Anisotropic scintillators,
Emulsions
Columnar recombination in Xe/Ar
Carbon nano-tubes

(2) Low Pressure TPCs

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

CYGNUS

CYGNUS cooperation started in 2007

CYGNUS proto-collaboration formed in 2016

CYGNUS - Agreement

CYGNUS agreement includes Solid and TPC technology

(1) DM below neutrino floor (2) Coherent solar neutrinos

The CYGNUS Galactic Directional Recoil Observatory
Proto-Collaboration Agreement

Now that conventional WIMP dark matter searches are approaching the neutrino floor, there has been a resurgence of interest in the possibility of introducing recoil direction sensitivity into the field. Such directional sensitivity would offer the powerful prospect of reaching below this floor, introducing both the possibility of identifying a clear signature for dark matter particles in the galaxy below this level but also of exploiting observation of coherent neutrino scattering from the Sun and other sources with directional sensitivity. There has also been significant progress recently in development of technology able to record the directional information from nuclear recoils at low energy (sub-100 keV) necessary for these goals. This includes progress on improving the sensitivity of low pressure gas time projection chamber technology but also on novel ideas with higher density targets, such as ultra-fine grain emulsions, scintillation materials, columnar recombination with noble gas targets and concepts using nano-technology. Such world-wide directional expertise, if pooled together and directed at converging on an optimised design, likely at multiple underground sites and different latitudes, could allow creation of a global **Galactic Nuclear Recoil Observatory**. Such a distributed multi-site facility would thus open a new window on the Universe with multiple science goals – the observation of a directional signal from particle dark matter, likely incident on Earth from the direction of the Cygnus constellation, a first means to detect and measure a directional signal due to coherent scattering of non-terrestrial neutrinos including from supernovae and the Sun, correlated with the position of the Sun, and also a novel means to search for exotic new particles including axions.

For several years there has been growing cooperation and exchange between most world groups working on recoil directional technology, including through a series international meetings called CYGNUS. This proto-collaboration agreement now sets the basis for taking this cooperation forward towards formation of a full collaborative experiment to realise construction of a global Galactic Directional Recoil Observatory, which we call the CYGNUS experiment. Signatories to this agreement hence forward agree to work together towards this common goal and to the formation of the CYGNUS collaboration, recognising that cooperation brings mutual benefits to all. Specifically in this regard, we the undersigned, on a best efforts basis, agree to work on the following goals:

(1) to establish the science case for CYGNUS, working with external experts as required
(2) to establish the feasibility and technology choices for CYGNUS, coordinating R&D activities, resources and joint publications as necessary
(3) to form an Institute Board including remit to prepare an organisational structure in readiness for launch of the collaboration
(4) to write an experiment LOI as basis for formation of the collaboration based on (1-3)
(5) to launch the collaboration at an appropriate date to be decided by us

The CYGNUS proto-collaboration will be coordinated by an interim steering group (ISG) with remit to facilitate activities of the proto-collaboration and organise technical meetings. The ISG will guide transition to launch of the collaboration but will be disbanded at that time.

(includes common analysis)
(broad aim - below neutrino floor, high and low mass)

CYGNUS proto-collaboration agreement (Sep. 2016-)
- **50 signatures (as of Nov. 2016)**
- **Steering group**
- **4 working groups, monthly TV meeting**
  - **Engineering WG (N. Spooner)**
  - **Simulation WG (S.Vahsen)**
  - **Neutron WG (E. Baracchini)**
  - **Gas R&D WG (K. Miuchi)**

CYGNUS

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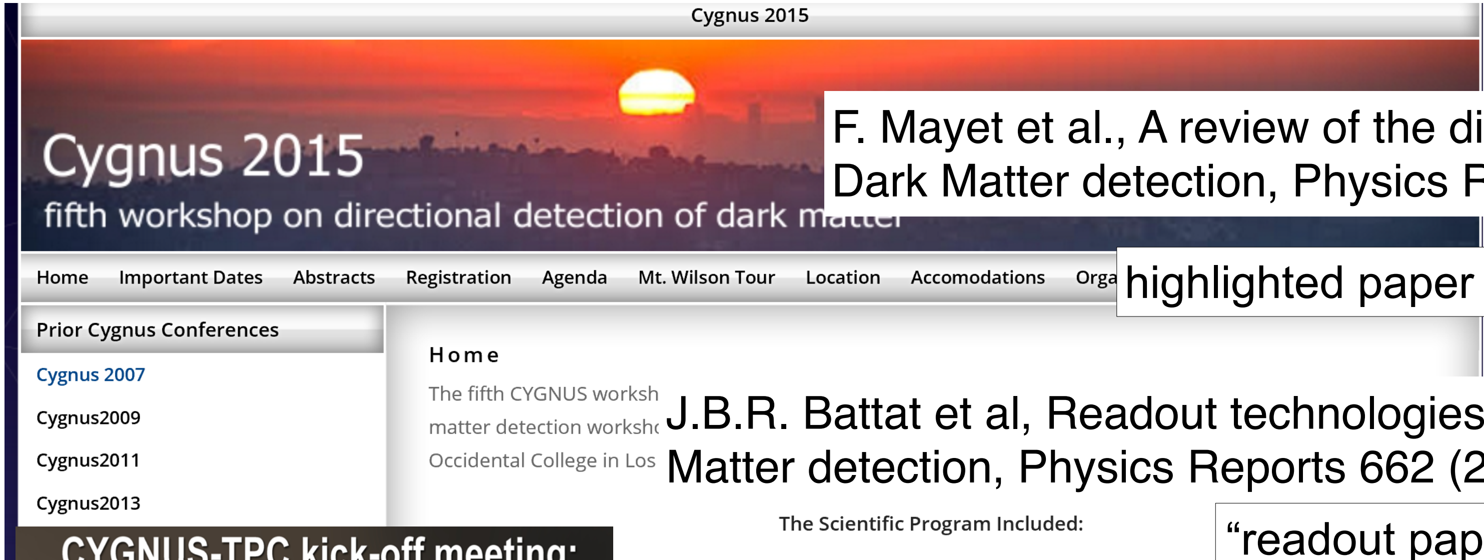
CYGNUS Activities

"CYGNUS" : from workshop to collaboration

- biannual workshop for directional detection of dark mater (2007-)
- two related papers (2010, 2016, 2016), another is ongoing
- proto-collaboration agreement (Sep. 2016-)



F. Mayet et al., A review of the discovery reach of directional Dark Matter detection, Physics Reports 627 (2016) 49

highlighted paper

"physics paper" 16 authors

J.B.R. Battat et al, Readout technologies for directional WIMP Dark Matter detection, Physics Reports 662 (2016) 46

"readout paper" 93 authors

Physics Reports 662 (2016) 1–46

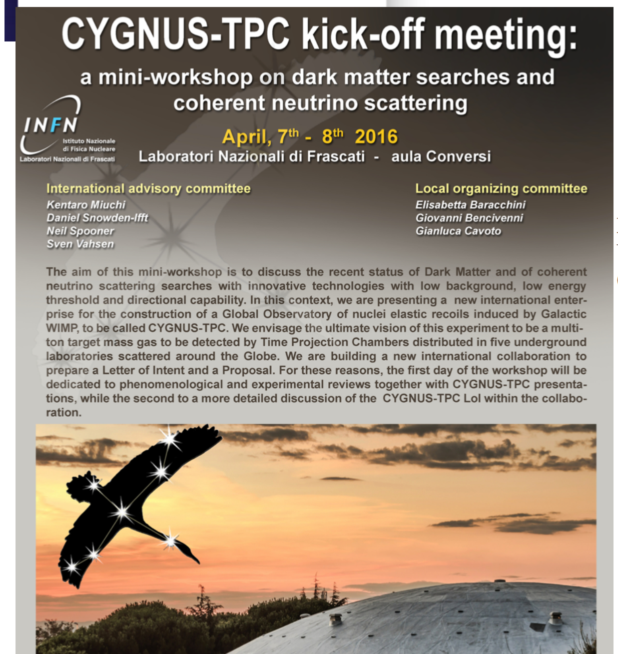
Contents lists available at ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physr

ELSEVIER

Readout technologies for directional WIMP Dark M detection



International Journal of Modern Physics A
Vol. 25, No. 1 (2010) 1–51
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"white paper" 112 authors

Physics Reports

homepage: www.elsevier.com/locate/physrep

THE CASE FOR A
DIRECTIONAL DARK MATTER DETECTOR AND
THE STATUS OF CURRENT EXPERIMENTAL EFFORTS

Readout technologies for directional WIMP Dark Matter detection

CYGNUS - Multiple Sites

Directionality benefit from multiple sites at different latitude

CYGNUS @ LNGS

→ NEWS (Emulsions)
UNDER (TPCs)

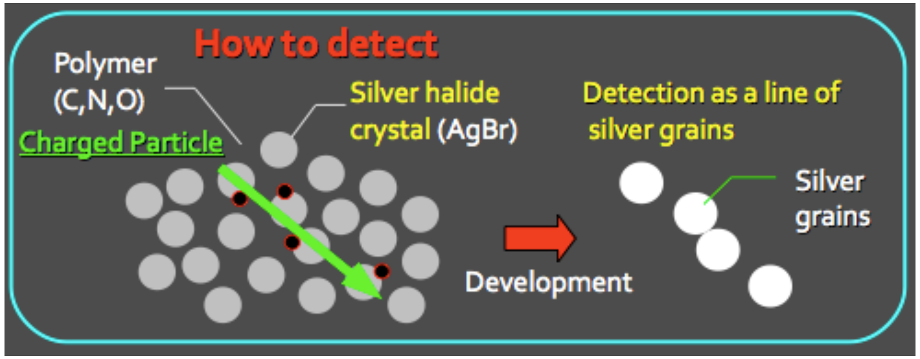
new lab funded in Australia

Nuclear Emulsions - NEWS

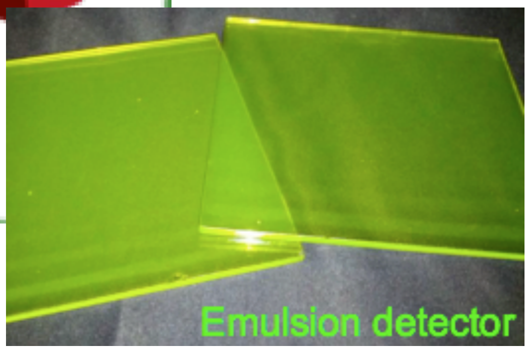
Giovanni de Lellis (Napoli) and Nagoya University, OPERA...

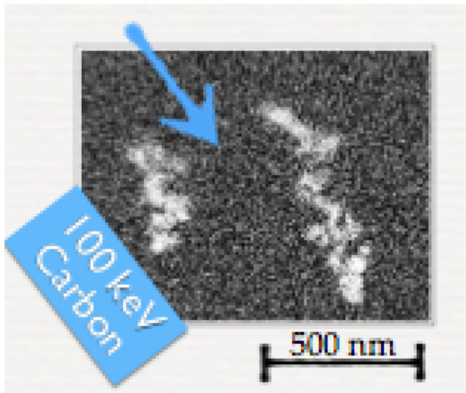
Concept: Use of emulsion film to give 3D tracking
- Track produces line of silver grains

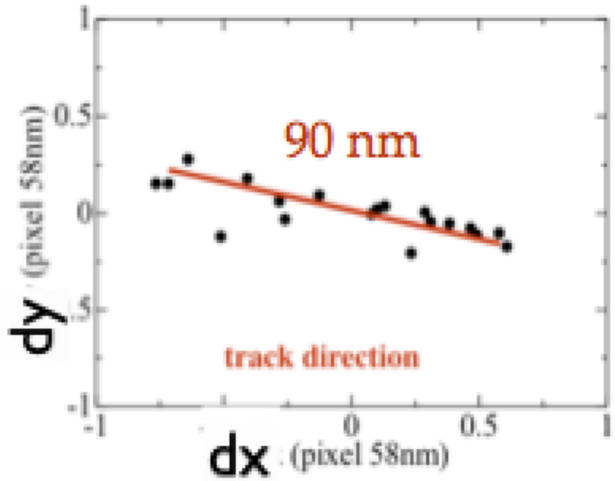
Solid (3g/cc), high spatial resolution, low cost, target Ag(46%), Br(34%), C(N,O) (19%)



- 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







- Application of resonant light scattering greatly improves position sensitivity, towards 10nm

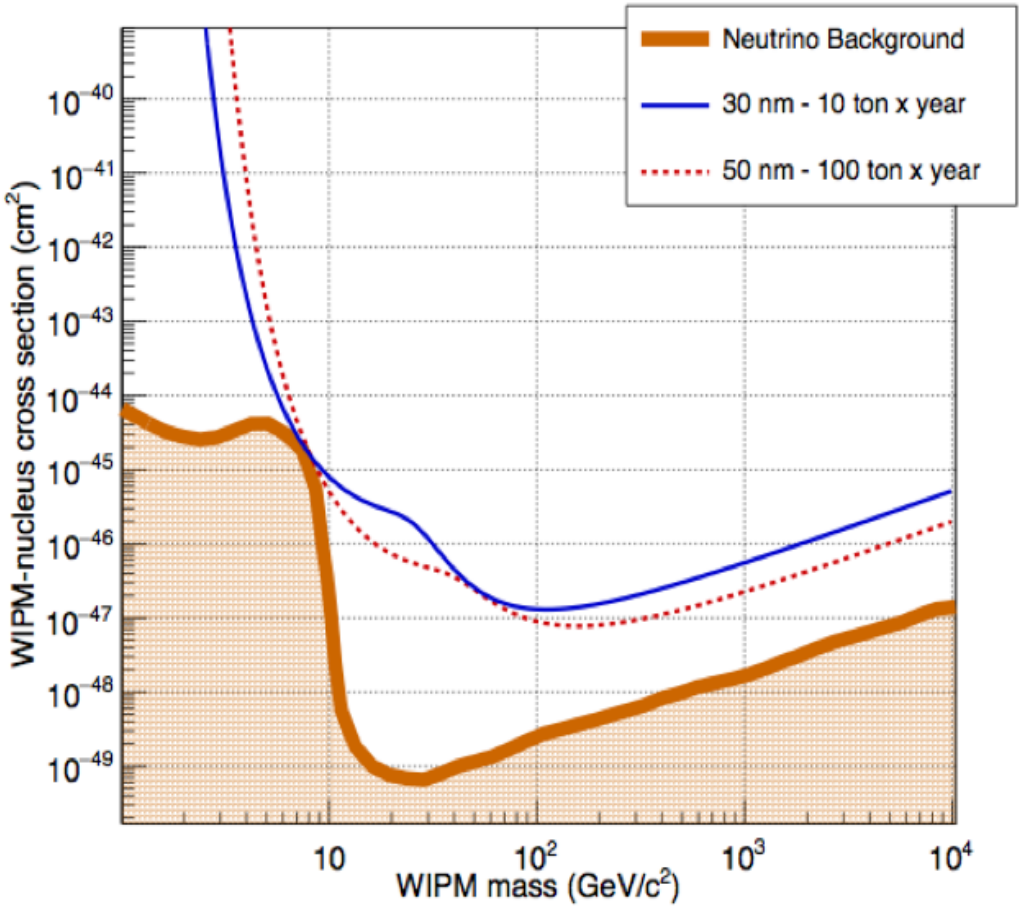
▸ **R&D funded towards 1kg experiment**

Nuclear Emulsions - NEWS

▸ **R&D tests at LNGS**

Test sensitivity and backgrounds with 10g target

- **Aim**: measure the detectable background from environmental and intrinsic sources and validate estimates from simulations
- Confirmation of a negligible background will pave the way for the construction of a pilot experiment with an exposure on the kg year scale
- Pilot experiment will act as a demonstrator to further extend the mass range



▸ **Eventual sensitivity complementary to TPCs**

Higher mass WIMPs

Spin Independent

Power of TPC Directionality

- **Only TPCs have the advantage of accessing head-tail information and sensitivity to the start of the recoil track**

- Head-Tail Sensitivity
- Axial Sensitivity
- Recoil/electron discrimination <5 keV_{recoil}

Power of TPC Directionality

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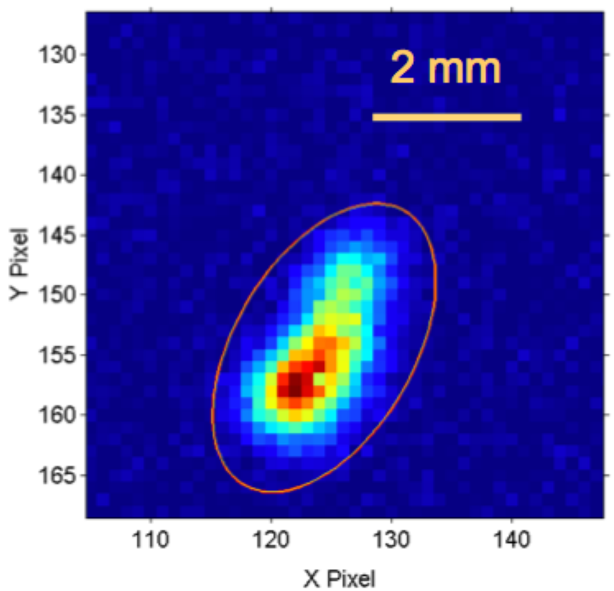
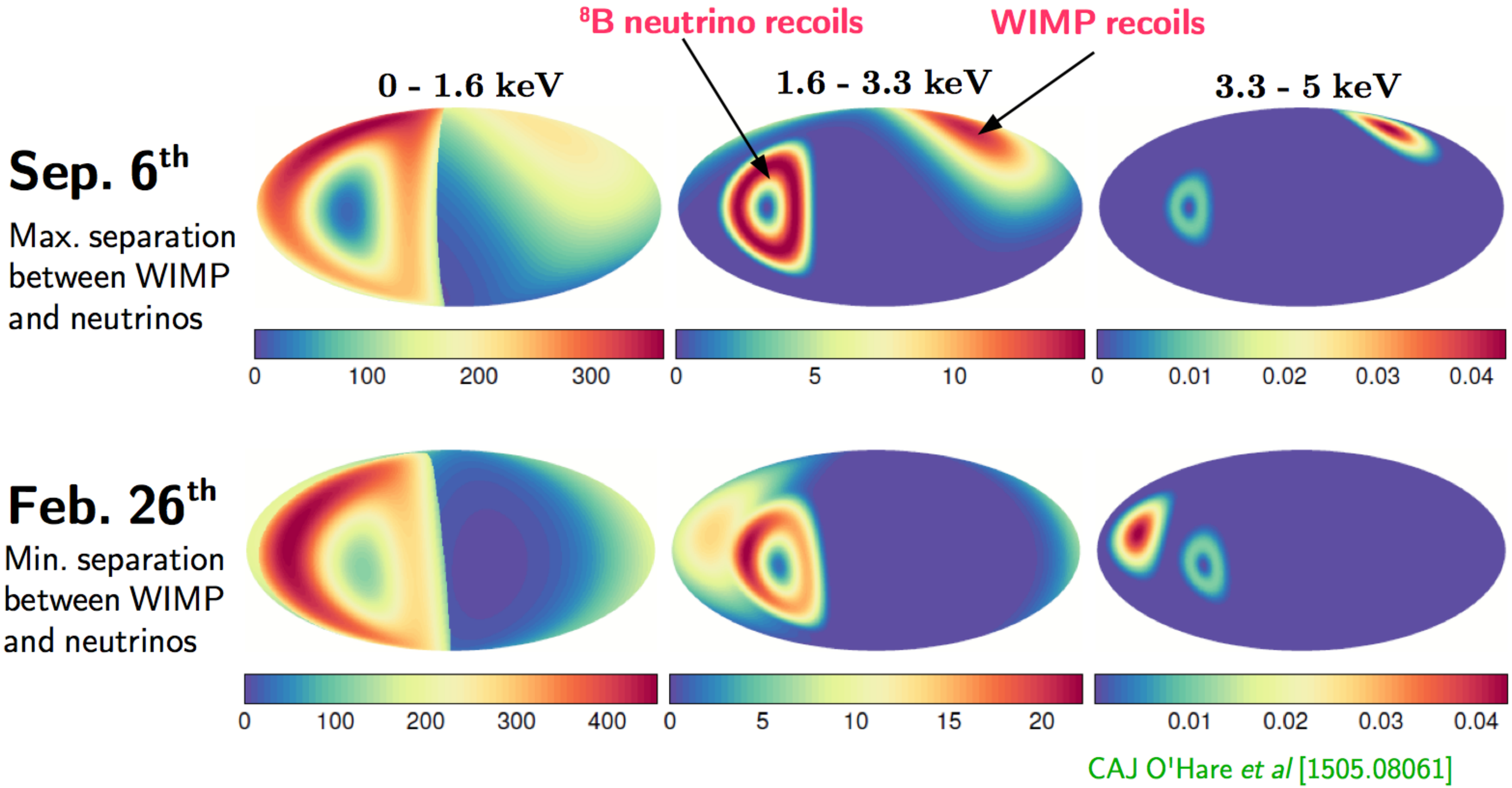


Example high energy F recoil in optical TPC (D. Loomba et al.)

- **How many WIMPs to get a directional (non-isotropic) signal?**

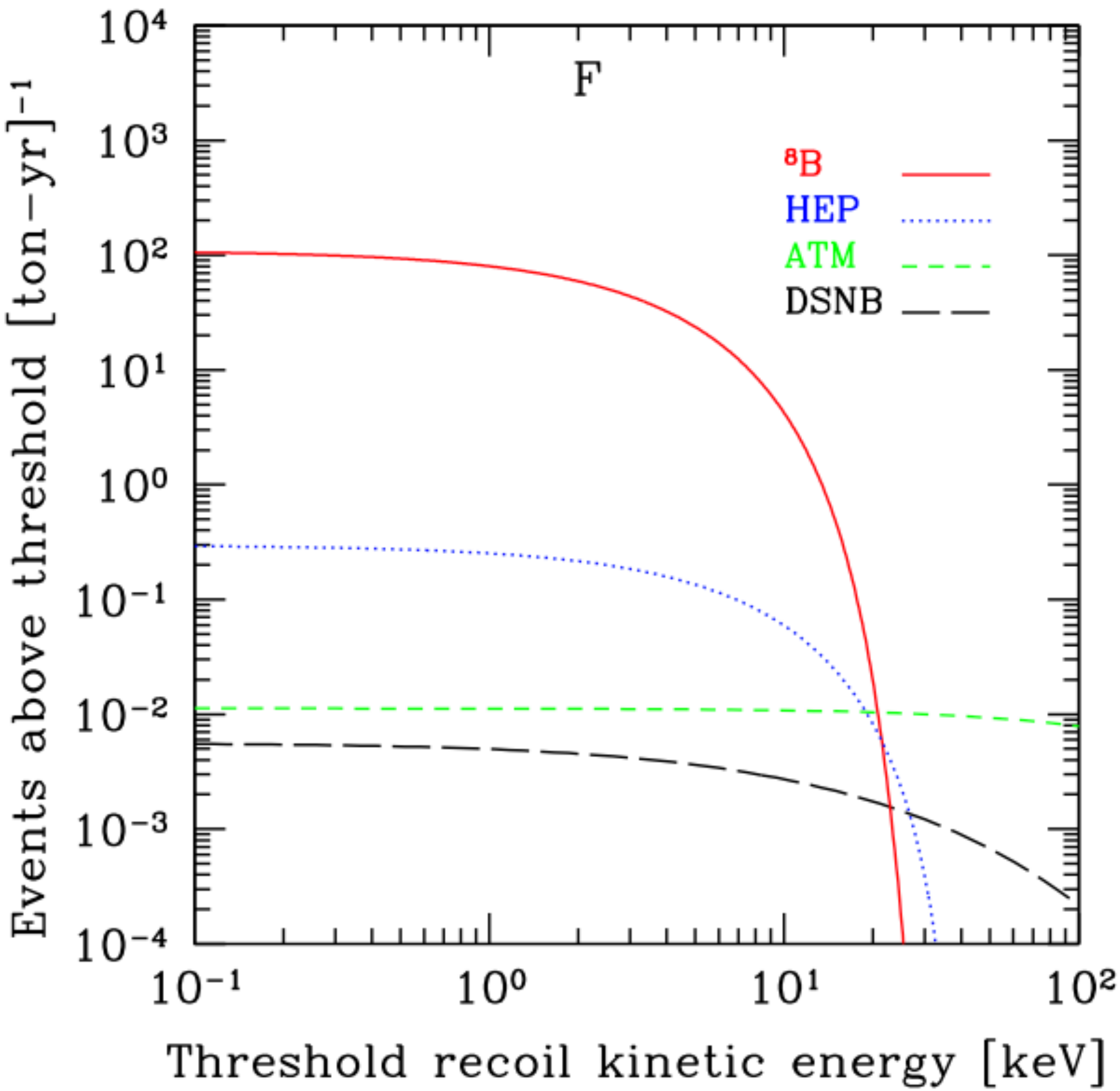
Power of Directionality - Solar Neutrinos

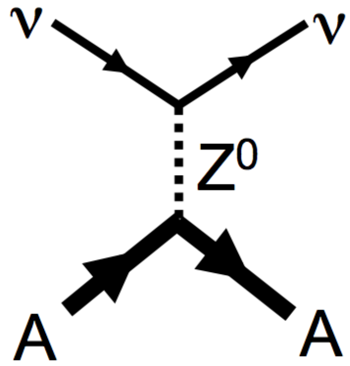
- Sun does not coincide with peak WIMP direction at any time
- It should be possible to distinguish the two signals at any time



Neutrino Coherent Rates, Fluorine

Louis E. Strigari arXiv: 0903.3630v2



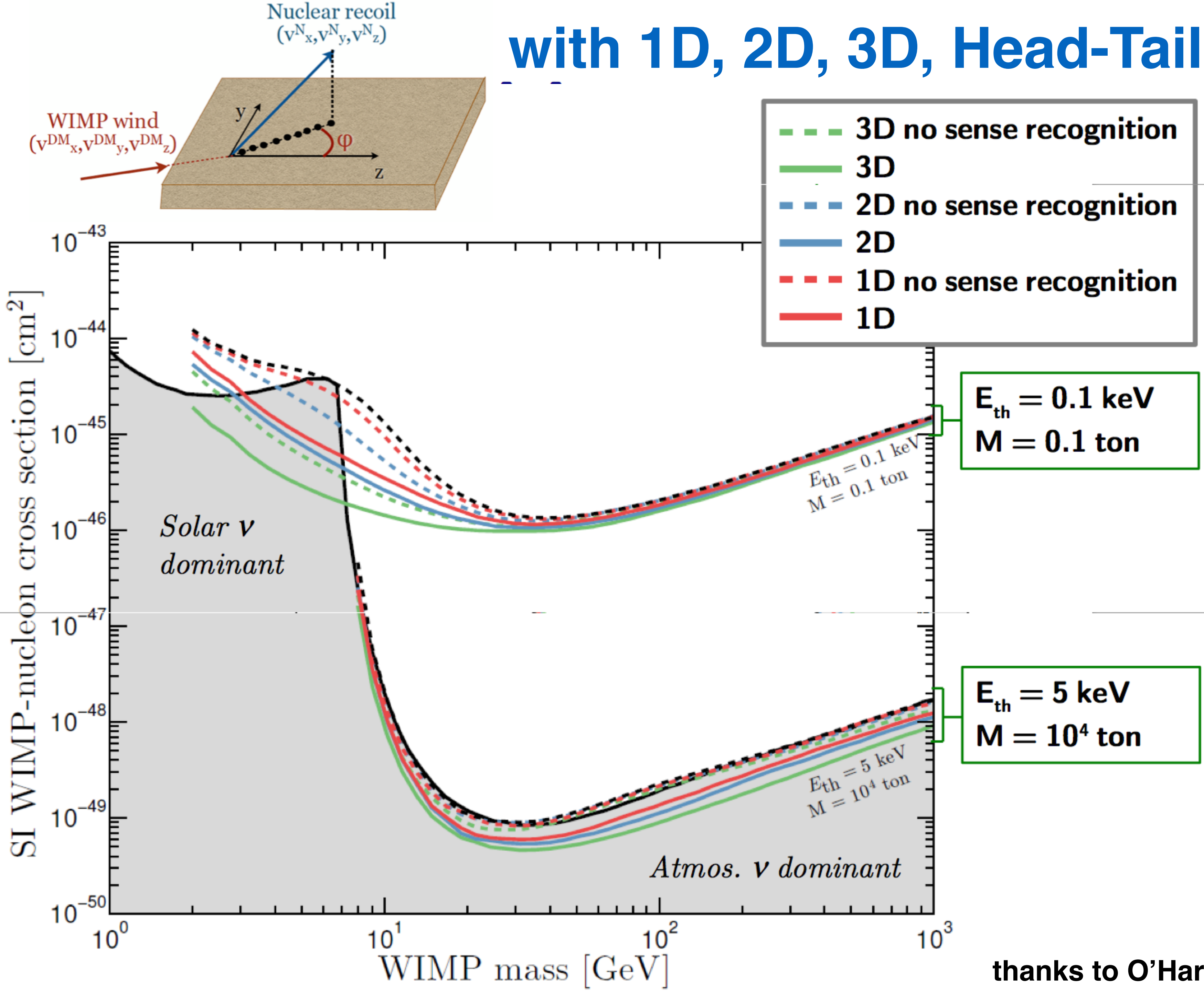


1keV$_{rec}$ threshold —> ~70 events per ton year

10m^3 SF_6 at 200 torr for 3 years operation yields 4 neutrinos.

Below the Neutrino Floor

with 1D, 2D, 3D, Head-Tail



thanks to O'Hare et al.

Technology Optimisation

3D ⟷ **1D with head-tail**

3D

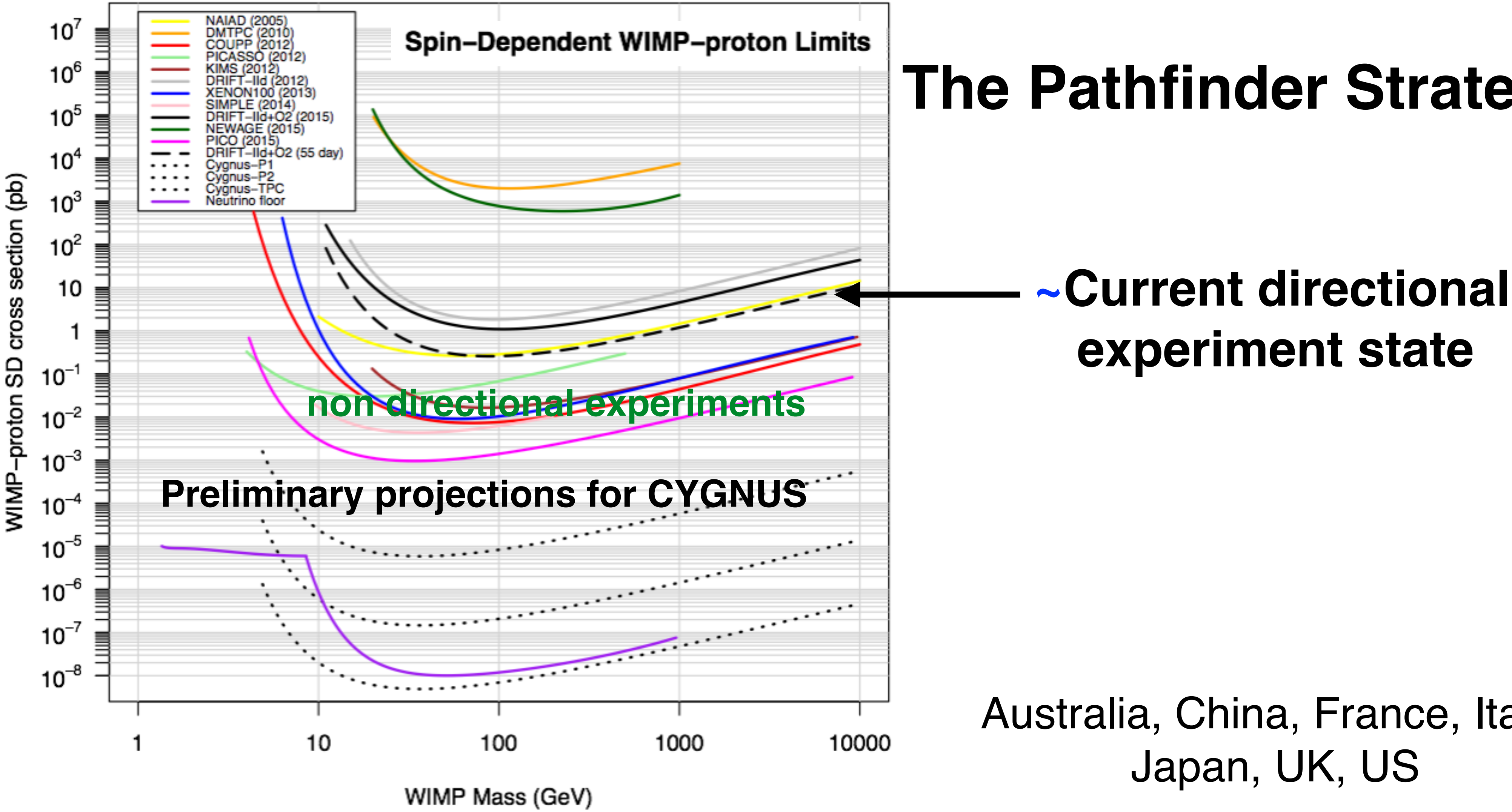
- better directionality
- higher cost
- higher background

1D with head-tail

- lower cost
- lower background

CYGNUS-TPC Baseline Concepts/Aim

- 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



The Pathfinder Strategy

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

CYGNUS-TPC Baseline Concepts/Aim

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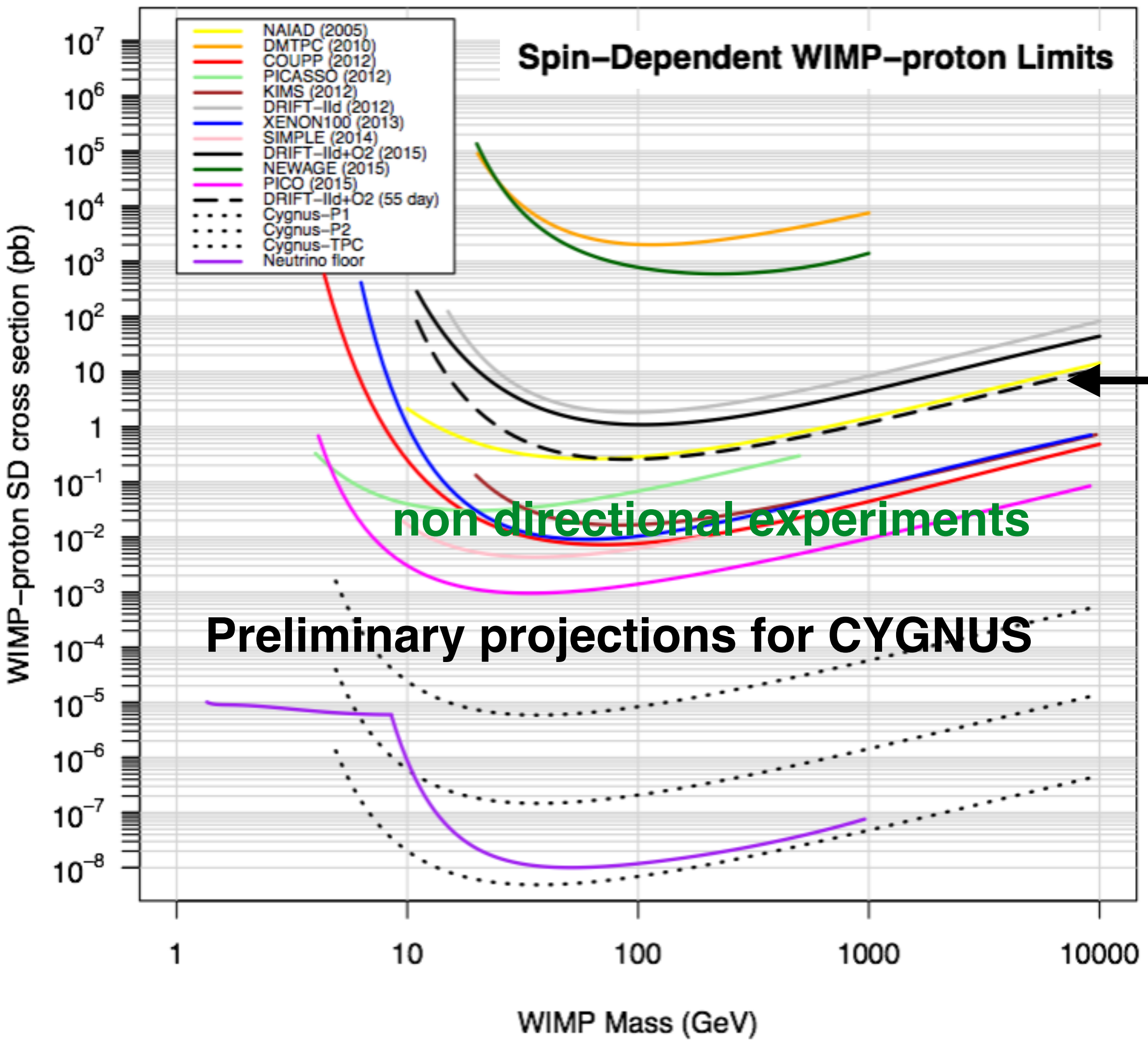


The Pathfinder Strategy

~Current directional experiment state

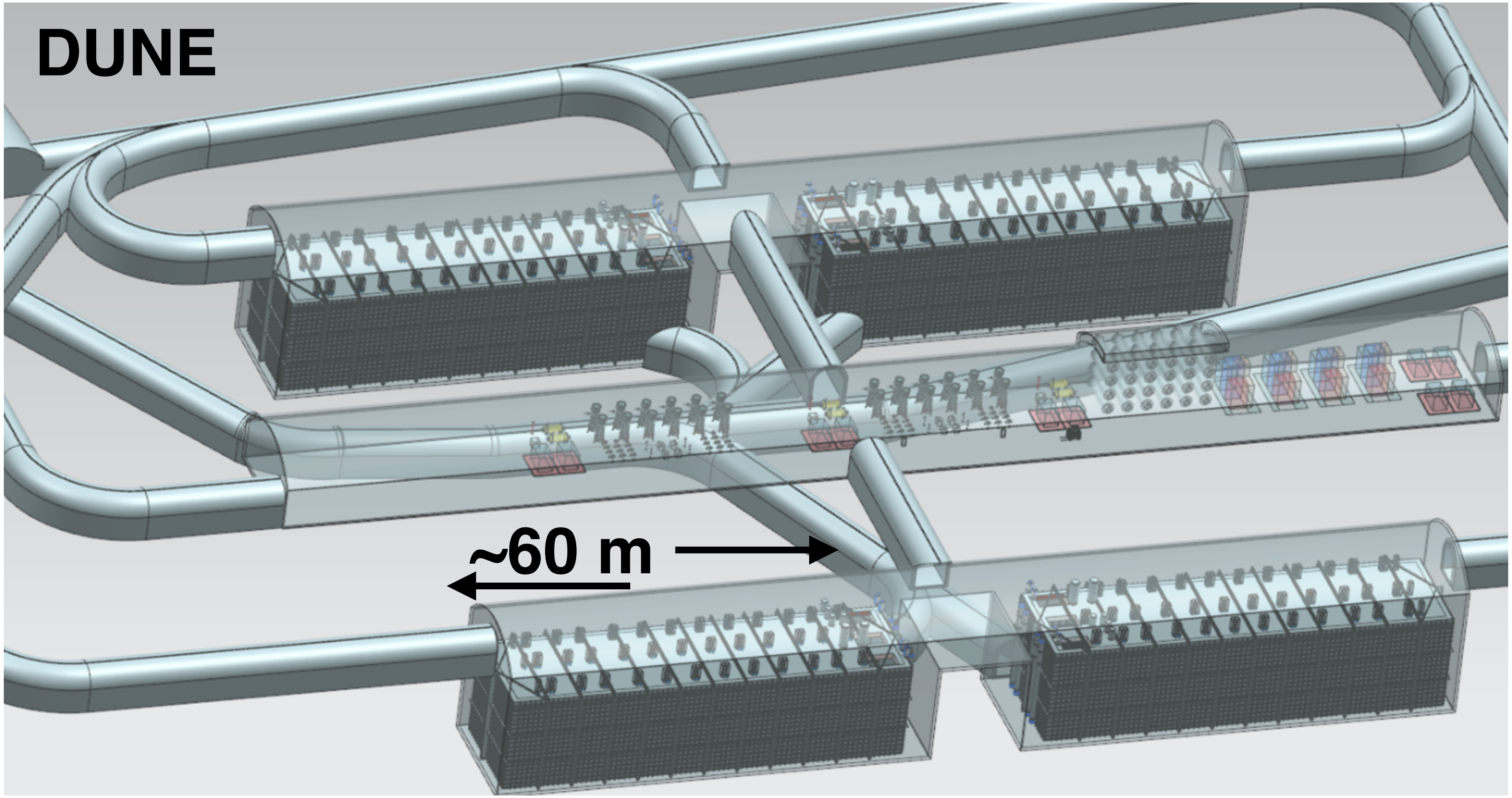
CYGNUS - Pathfinder 1

CYGNUS - Pathfinder 2

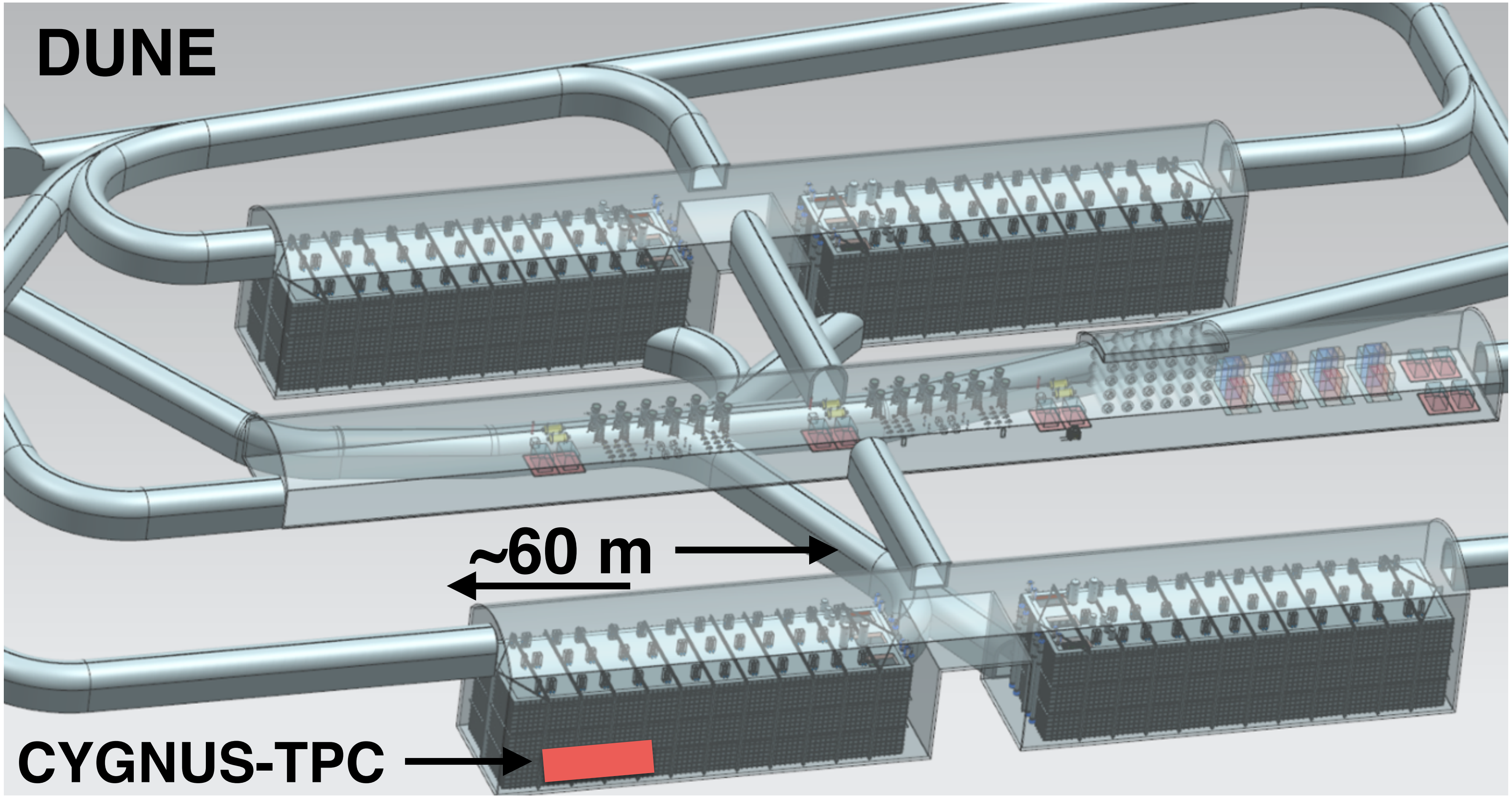
CYGNUS - TPC

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

How Not to be Afraid of Larger TPCs



How Not to be Afraid of Larger TPCs



- Size is ~ 100th scale of proposed DUNE liquid argon TPC
- But would also be spread on multiple sites

CYGNUS NOW

Stage 1 Vision

(1) CYGNUS-TPC-South (10 m3 vessel….readout 1)
(2) CYGNUS-TPC-North (10 m3 vessel….readout 2)
(3) R&D at 1 m3 (CYGNUS-Japan, DRIFT…

North - Boulby, LNGS, Kamioka?
South - Stawell?

CYGNUS NOW

Stage 1 Vision

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(3) R&D at 1 m3 (CYGNUS-Japan, DRIFT…

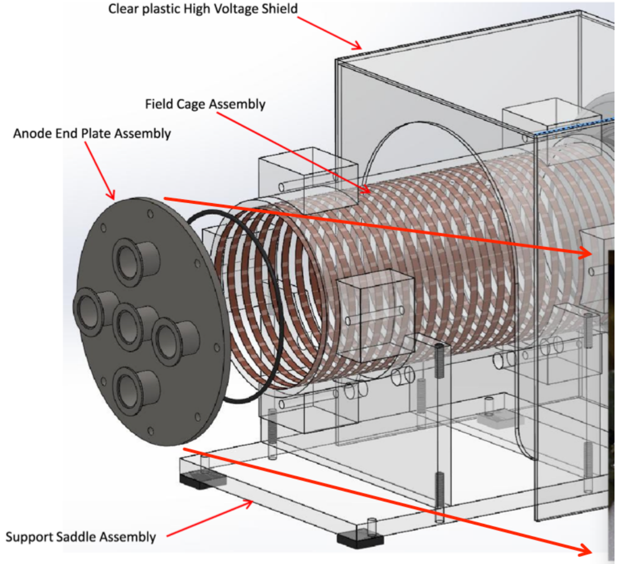
North - Boulby, LNGS, Kamioka?
South - Stawell?

CYGNUS-TPC Optimisation - key issues

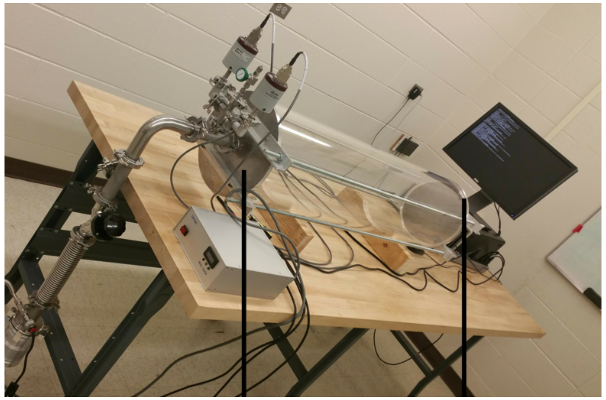
- What directional capability is optimal - 1D, 2D, 3D + HT vs cost?
- What directional sensitivity can there be <20 keV_{recoil}?
- Can we use multiple underground sites
- What gas - can SF_6 work well enough for fiducialisation?
- Can zero background be achieved (particularly neutrons)?

New Studies - Funded Activity

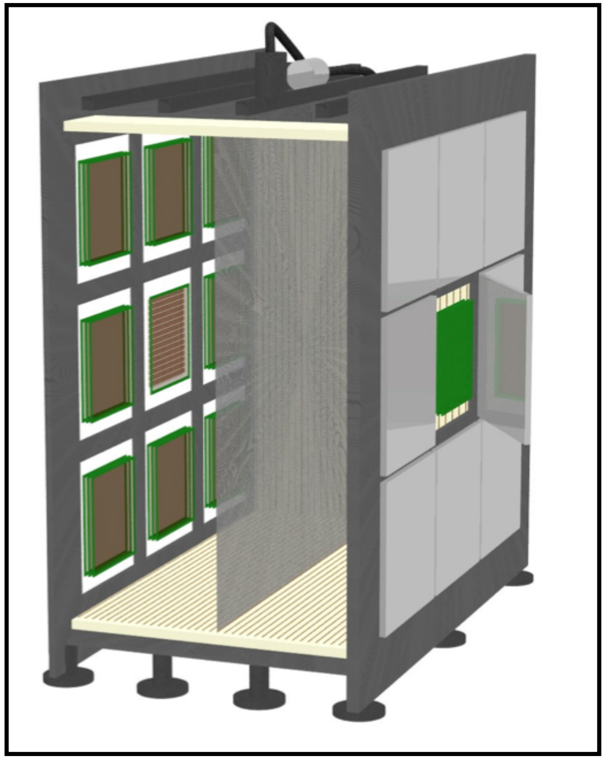
UNM acrylic (USA)



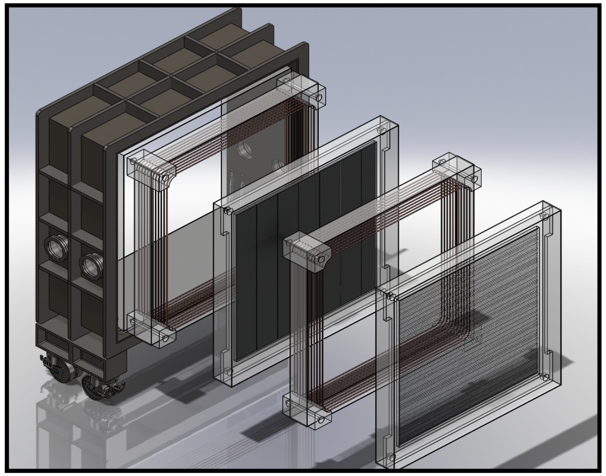
Hawaii D3 (USA)

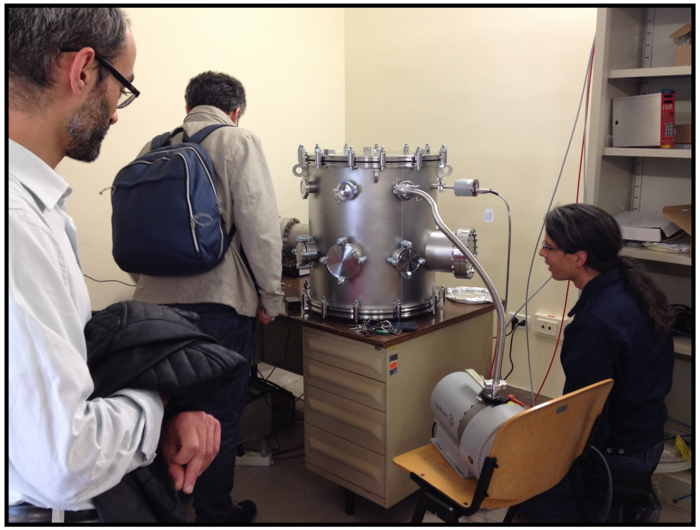


1 m3 CYGNUS test vessel (Japan) →

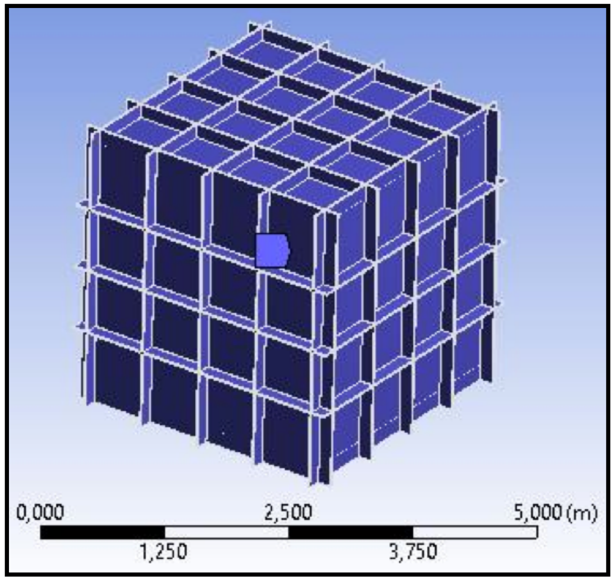


10 m³ designs (US, UK)





SF_6 R&D, Frascati, (Italy)

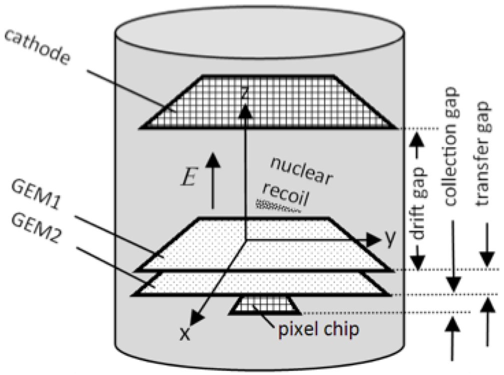


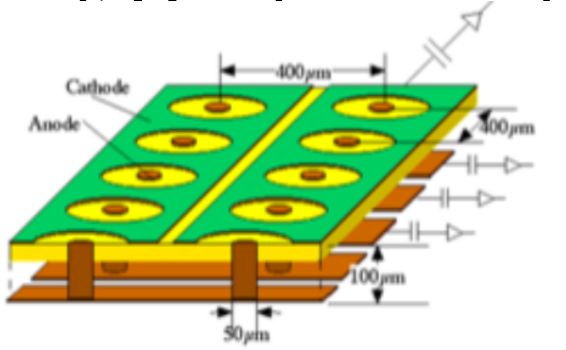
10 m³ vessels (Australia)

What Directional TPC Technology?

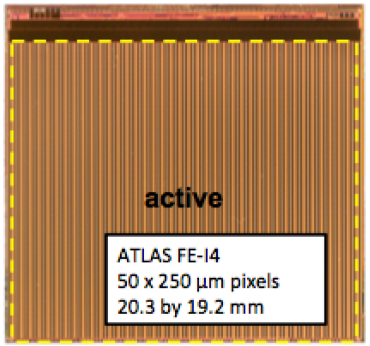
"high definition - 3D"

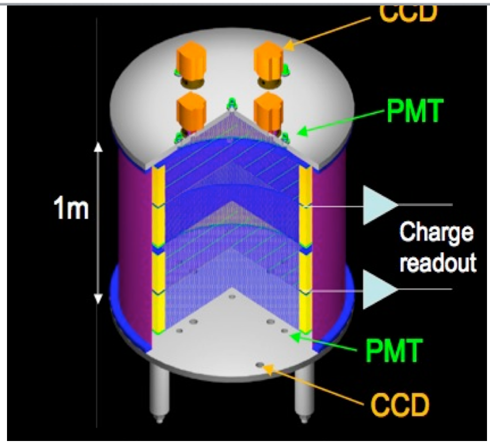
Pixel (D3), CCD (DM-TPC), Micromegas (MIMAC), µpic (NEWAGE)

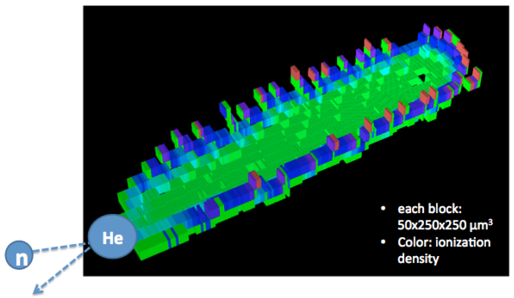


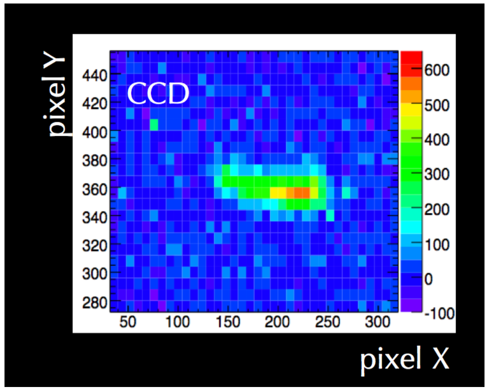


Pixel chip:



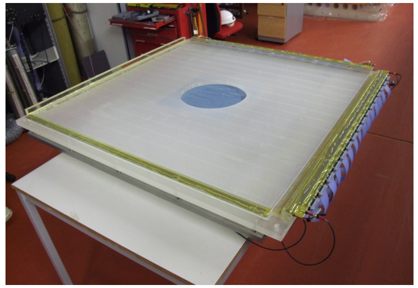


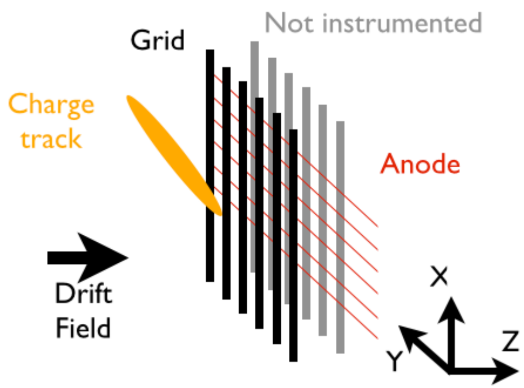


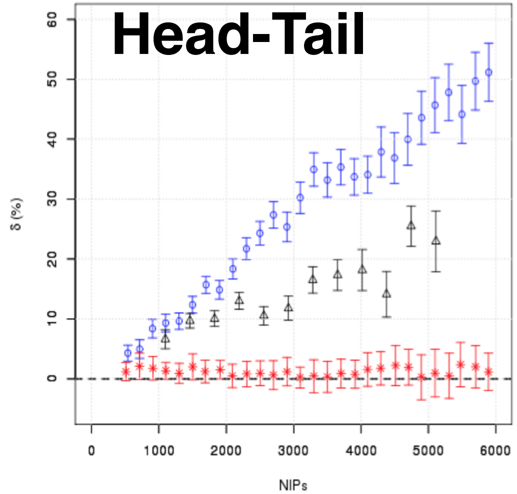


"low definition ~ 1.5D"

MWPC wires (DRIFT)



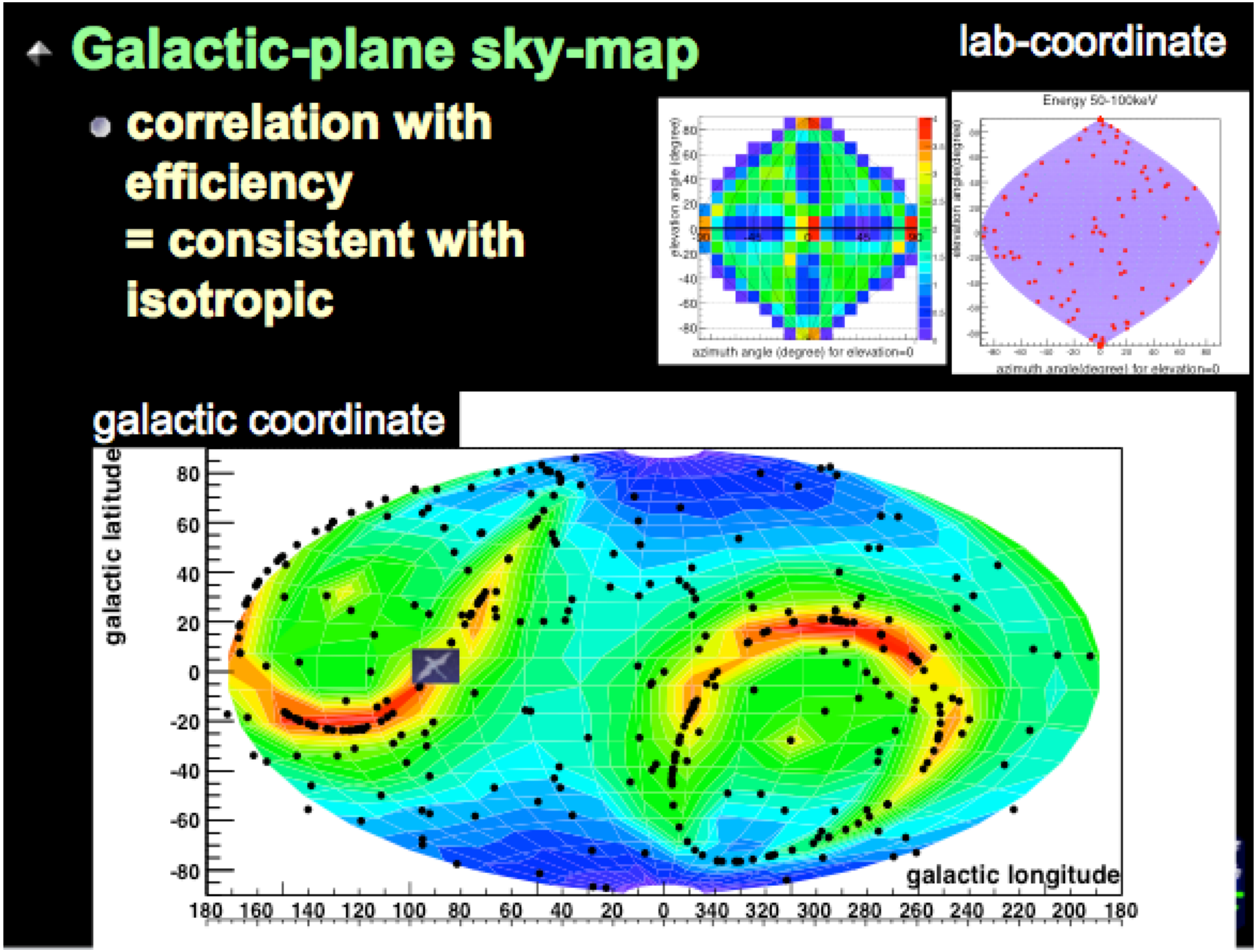




NEWAGE Experiment (Japan)

K. Muichi et al.

- **First demonstration in use of 3D to produce sky maps**



CYGNUS Next Paper

- **Next CYGNUS paper underway will address issue of cost-benefit of readout options**

Feasibility of a Nuclear Recoil Observatory with Directional Sensitivity to WIMPs and Solar Neutrinos

Contents

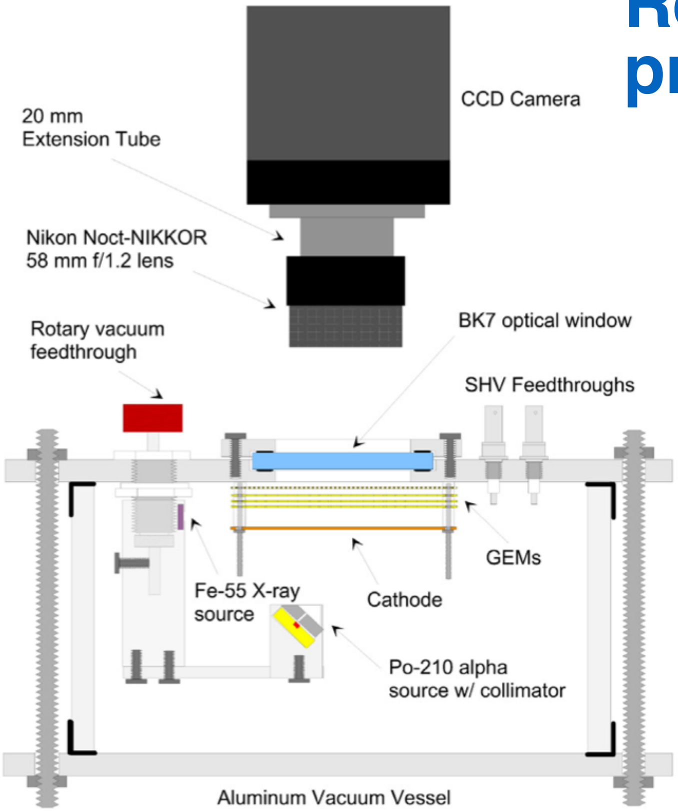
Sven Vahsen (Hawaii) is coordinating

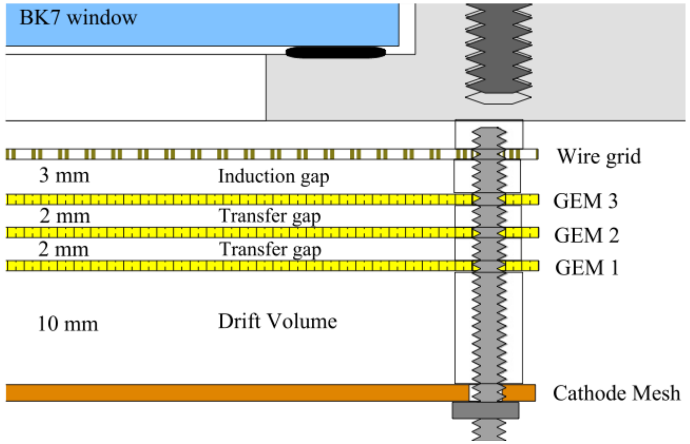
Low Energy Directionality Seen (UNM)

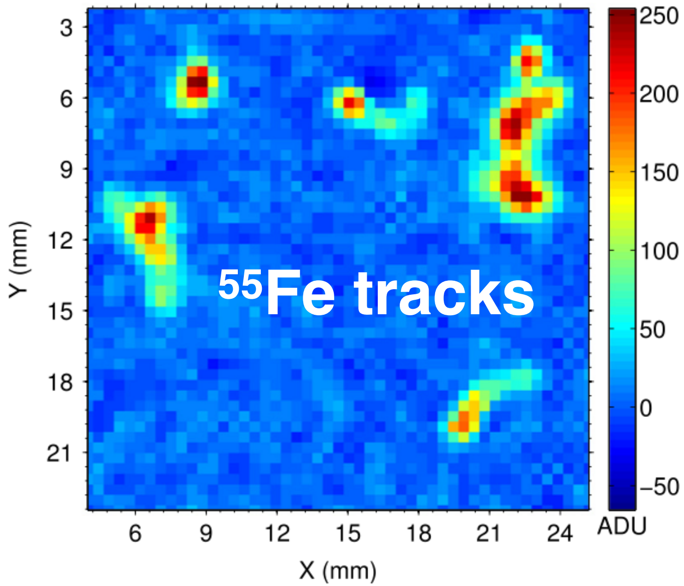
D. Loomba et al.,

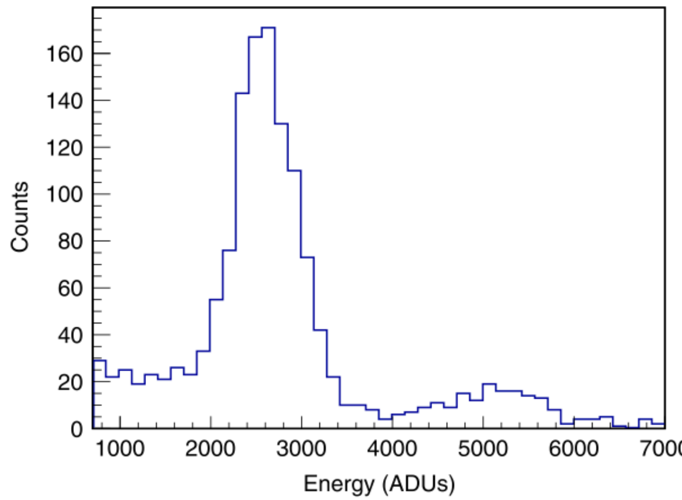
Recoil Directionality R&D is now probing <20 keV region

- CCD + triple GEM optical readout
- e.g. ^{55}Fe tracks resolved
- see upcoming papers by UNM

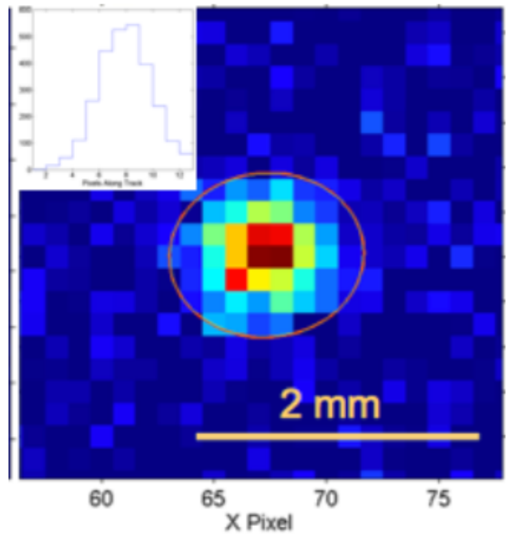








F recoil event of 10 keV_{ee} (23 keV_{rec}) still shows direction

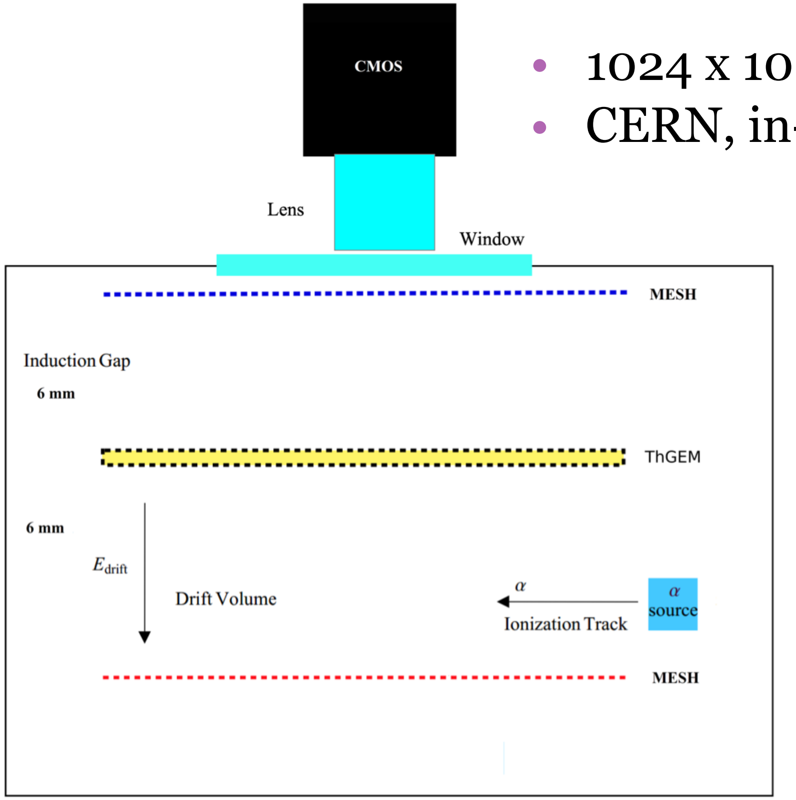


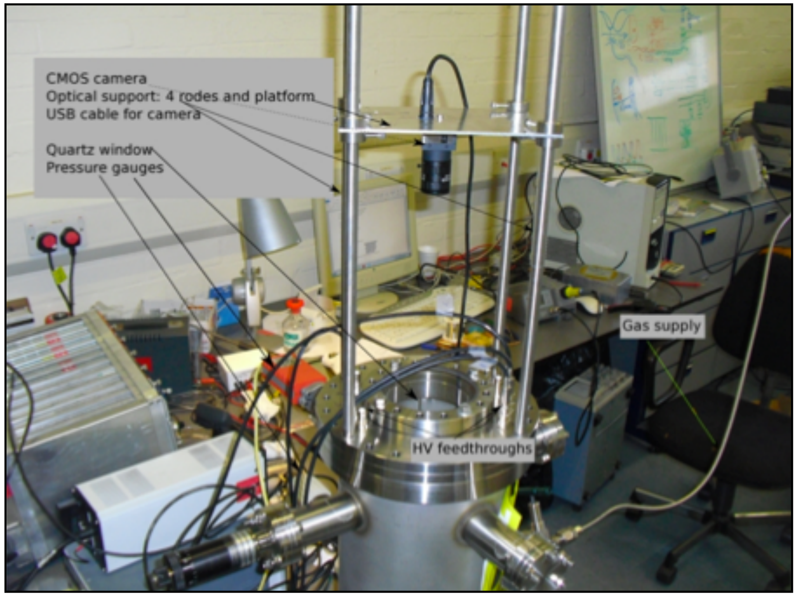
Sheffield R&D - CCD + Thick GEMs

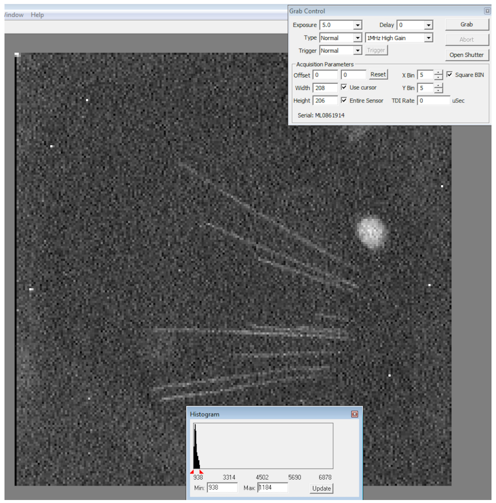
Concept: low pressure **CF_4 and SF_6 with Thick GEMs and CCD** readout

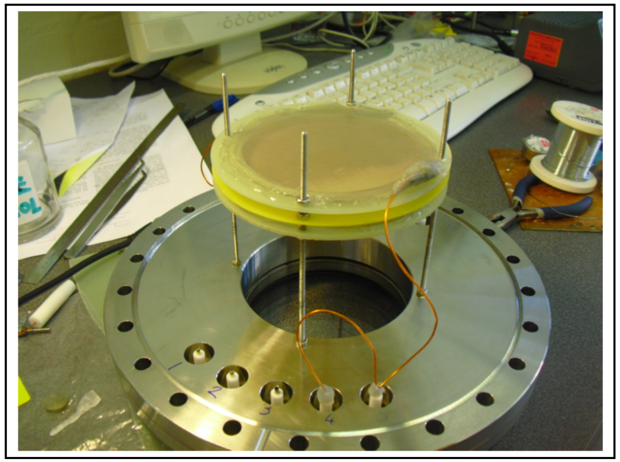
N. Spooner et al.,

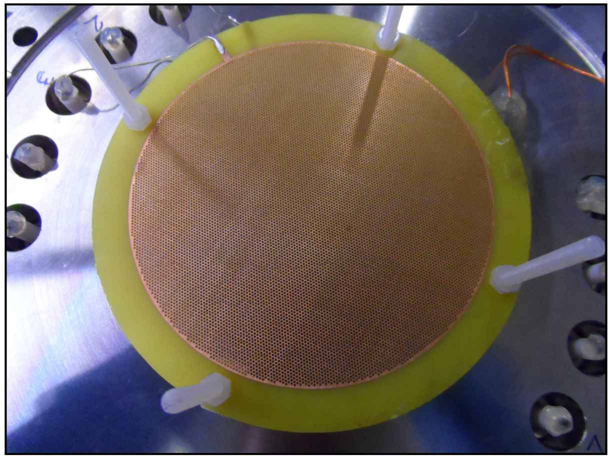
- 1024 x 1024, 24µm microline ML1001E camera
- CERN, in-house and AWE design Thick GEMs







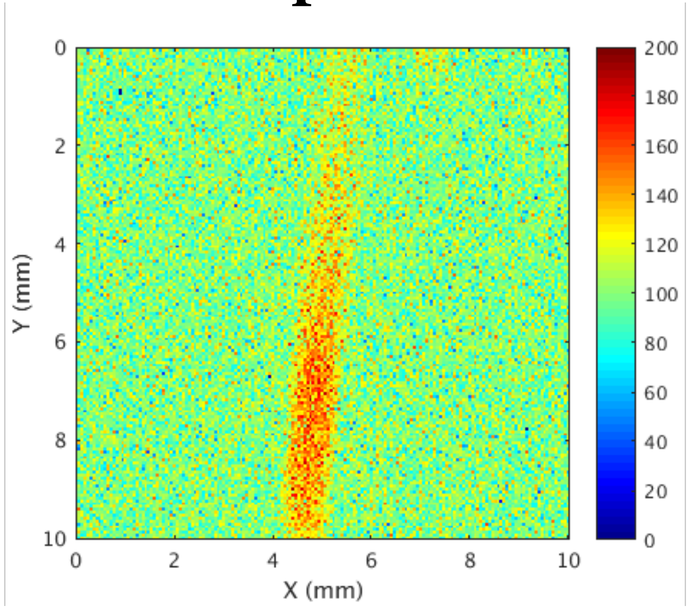




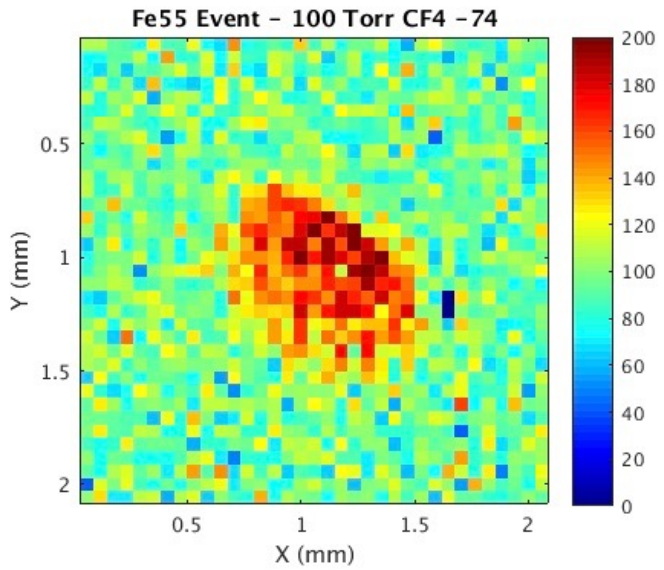
Sheffield R&D - CCD + Thick GEMs

Track images with 100 Torr CF_4 with Thick GEMs and CCD readout

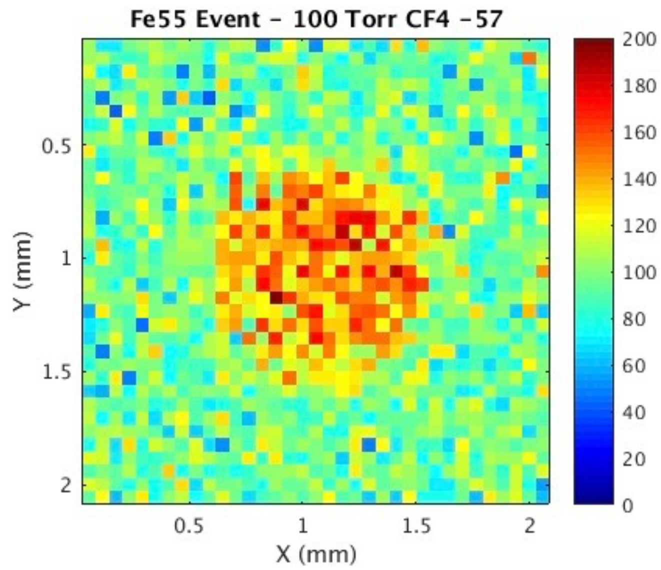
Alpha



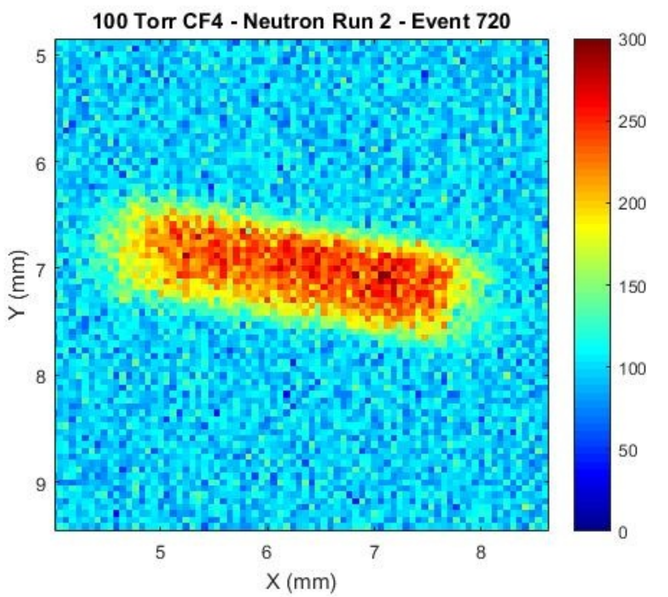
^{55}Fe 5.9 keV e^-



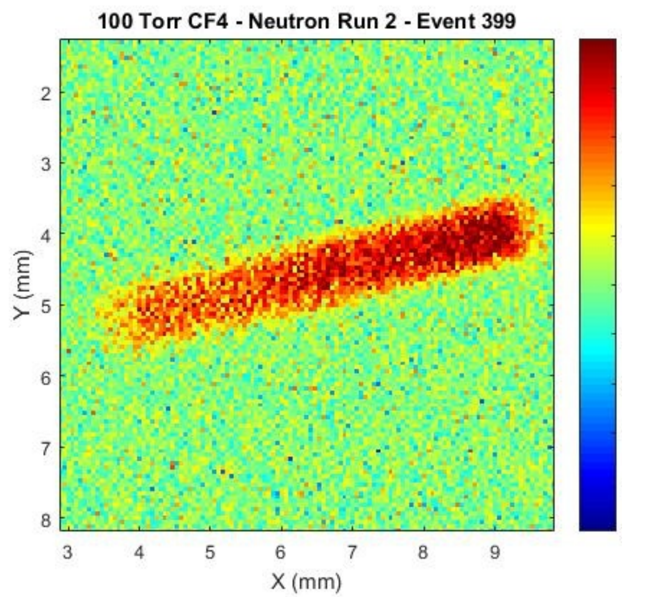
^{55}Fe 5.9 keV e^-



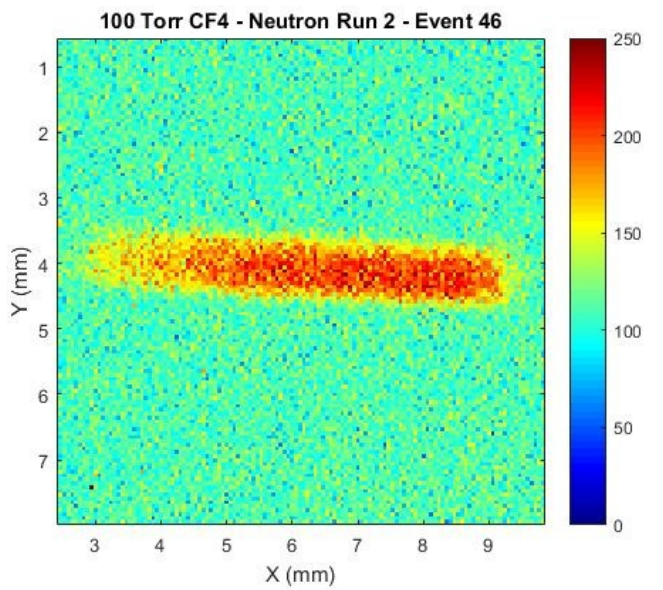
nuclear recoil



nuclear recoil



nuclear recoil



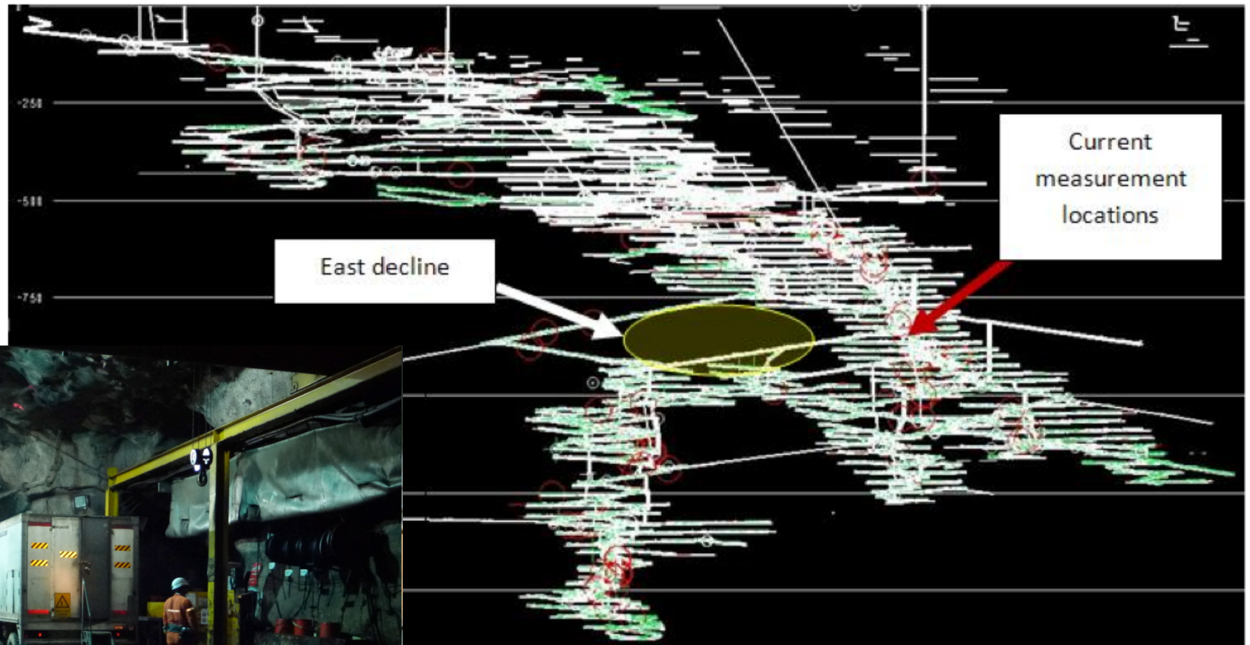
New Site Infrastructure

Stawell, Australia new site

- **New site funded by Australian government - 1 km depth**

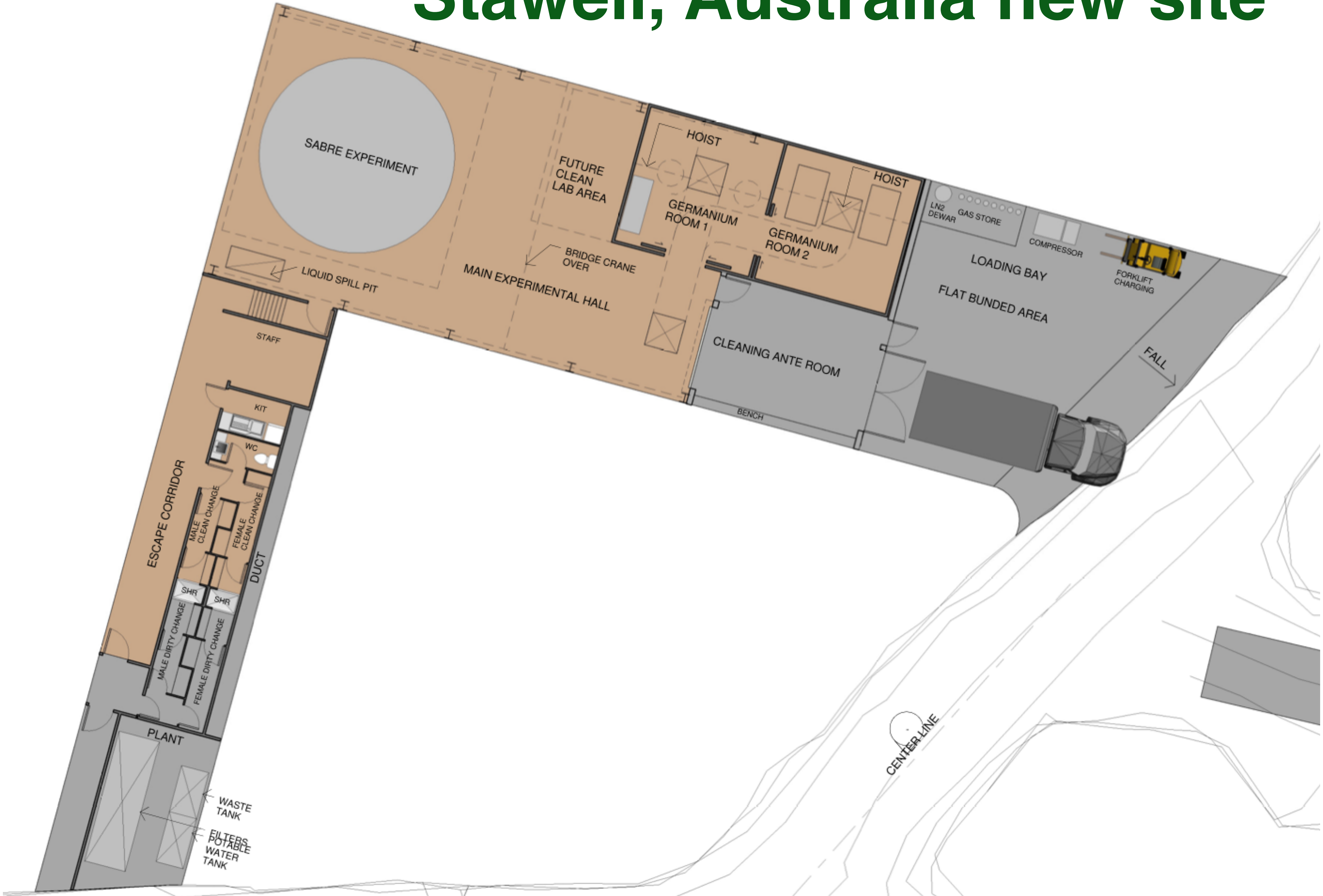
Stawell gold mine ~240 km west of Melbourne,
could be the first underground laboratory in the Southern hemisphere.

Decline mine, 1.6 km deep, with many caverns.
All sites served with electricity, optical fibre, reached by car/truck.



New Site Infrastructure

Stawell, Australia new site

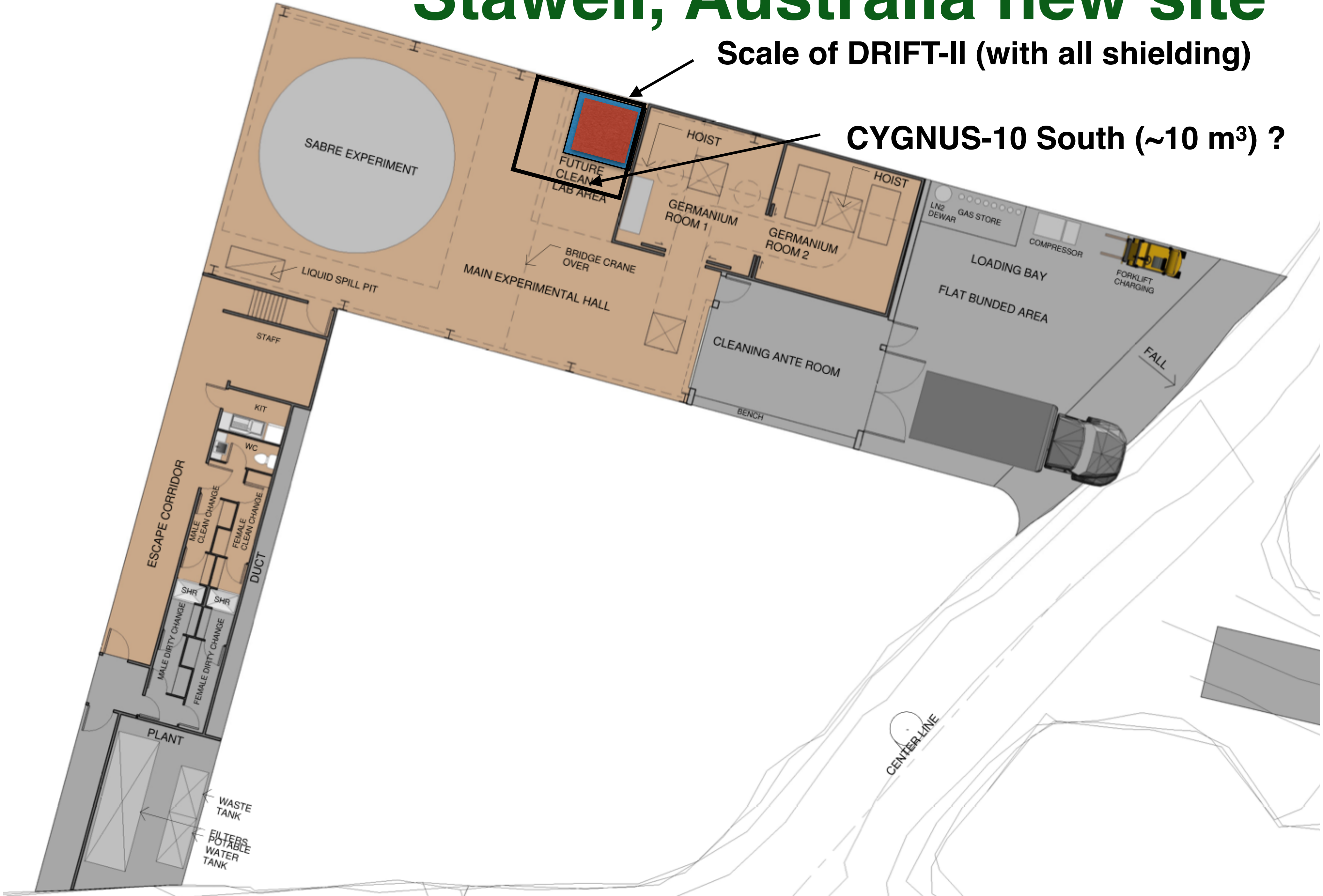


New Site Infrastructure

Stawell, Australia new site

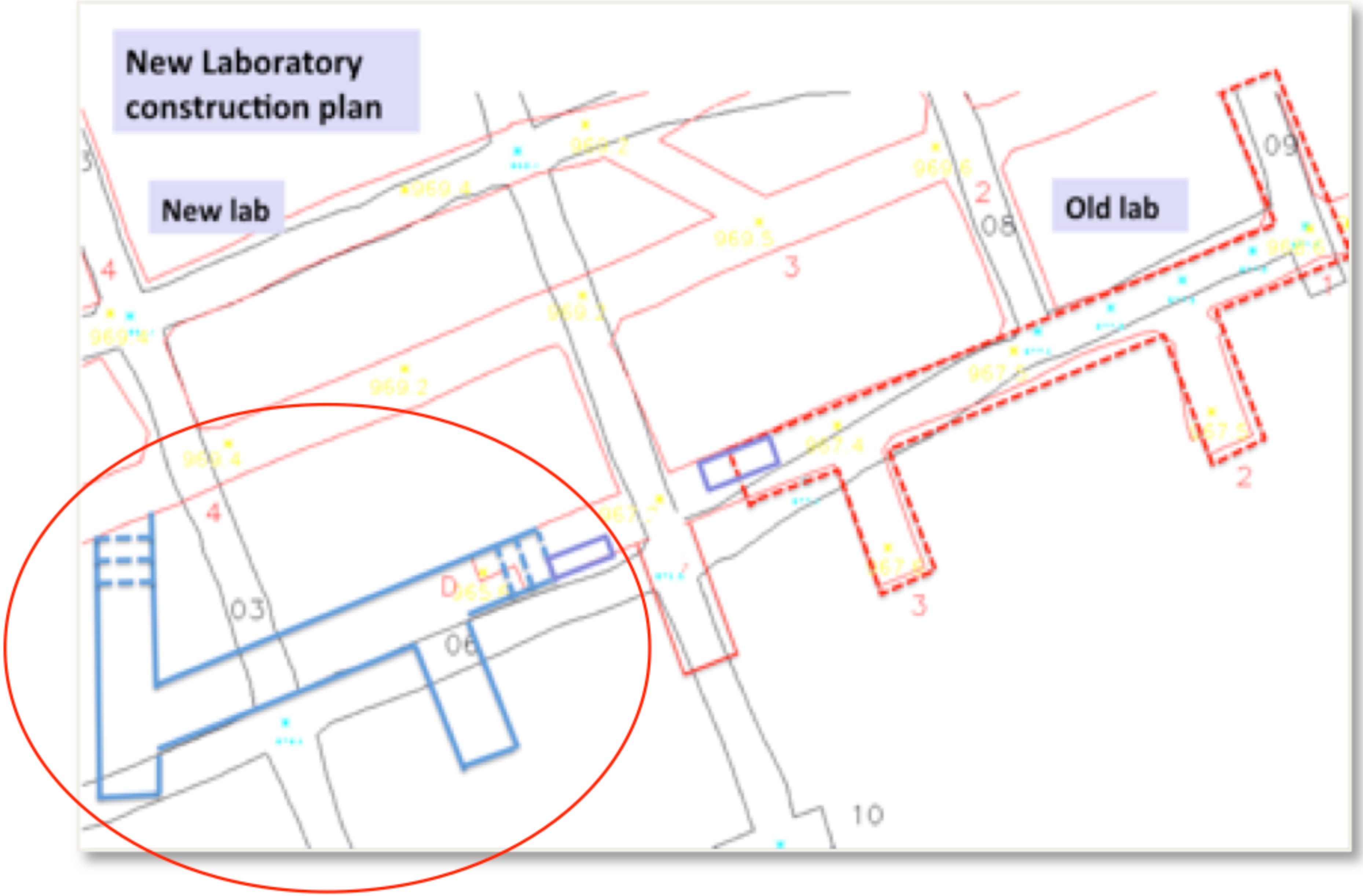
Scale of DRIFT-II (with all shielding)

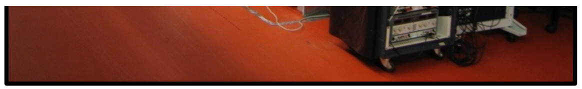
CYGNUS-10 South (~10 m³) ?



New Site Infrastructure

Boulby Laboratory, UK



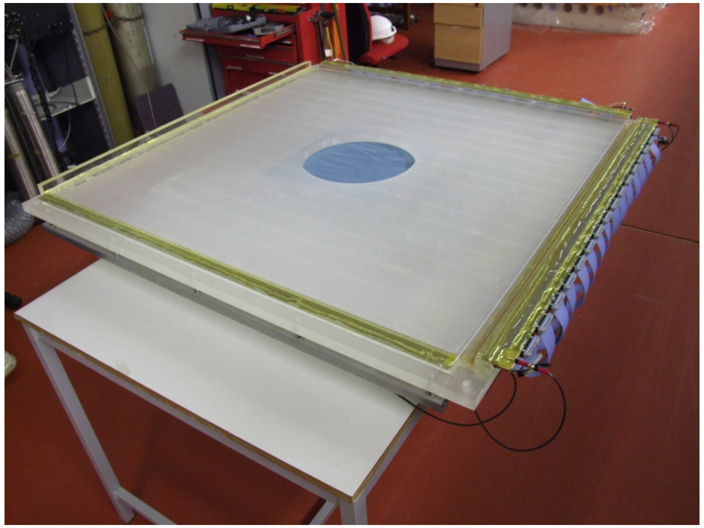


Underground Research Laboratory
Boulby

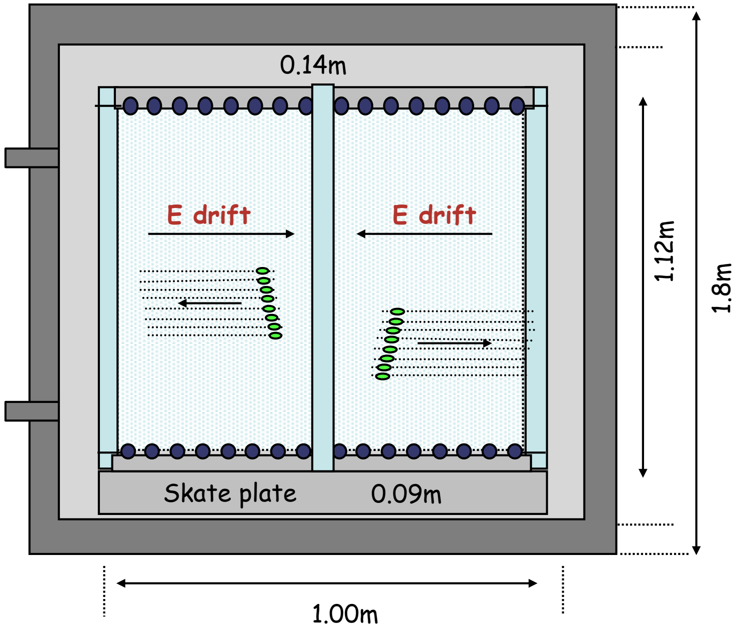
CYGNUS site at New Boulby Lab, UK

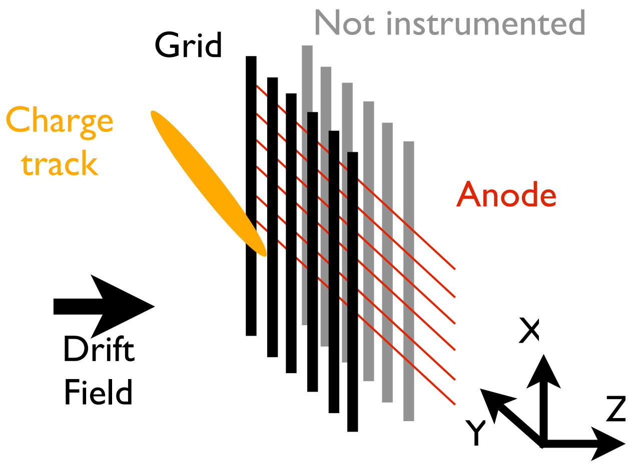
DRIFT IId & DRIFT IIe at Boulby

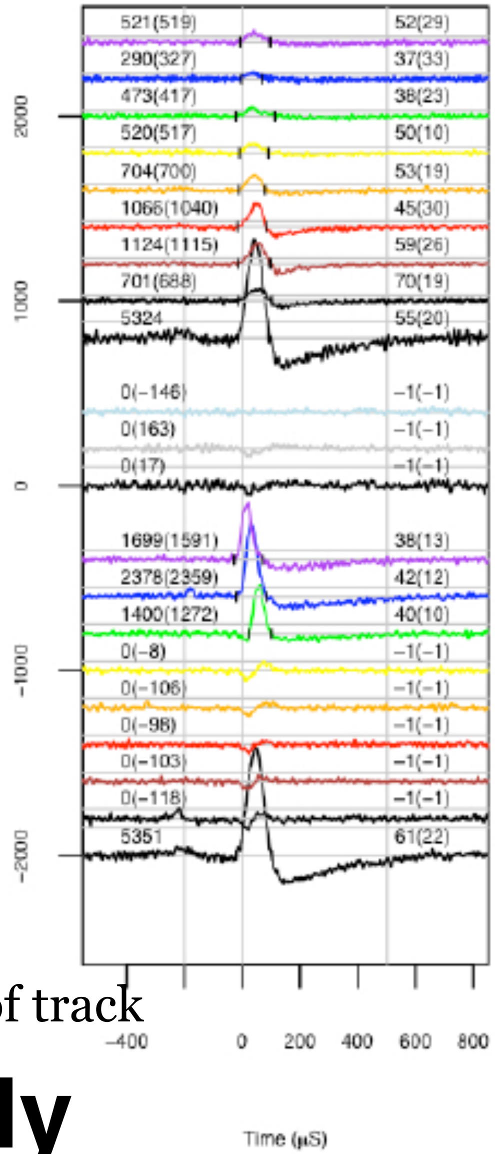
DRIFT is Pioneer (US-UK) at Boulby



DRIFT IIa, b, c, d, e



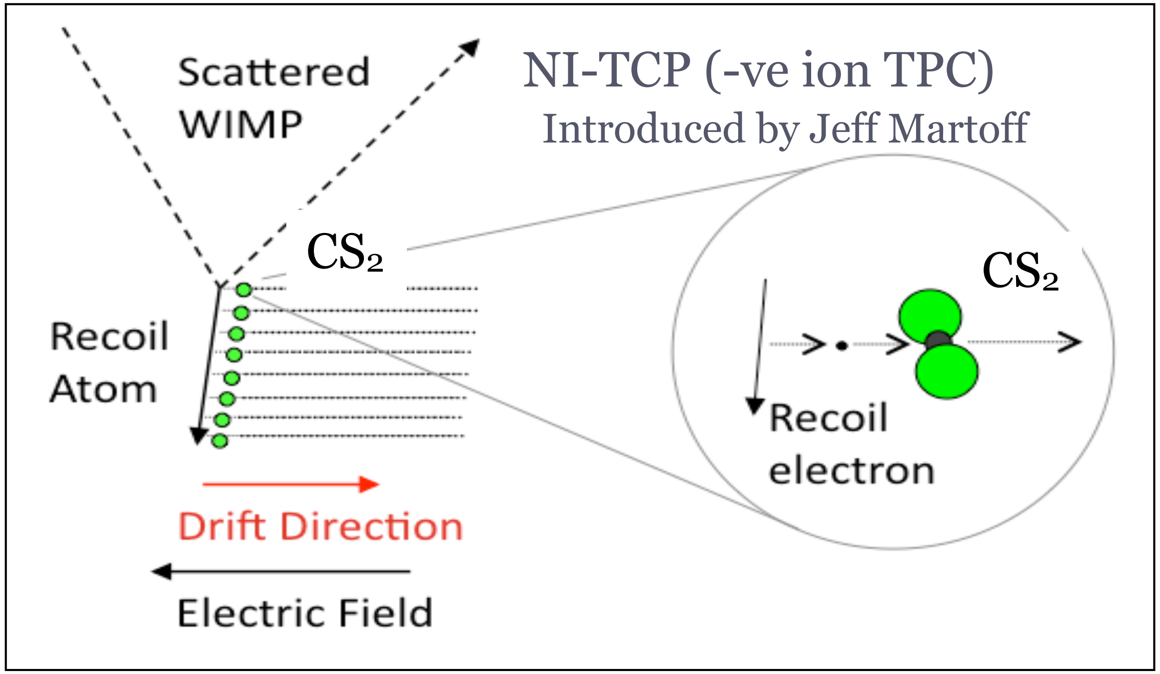




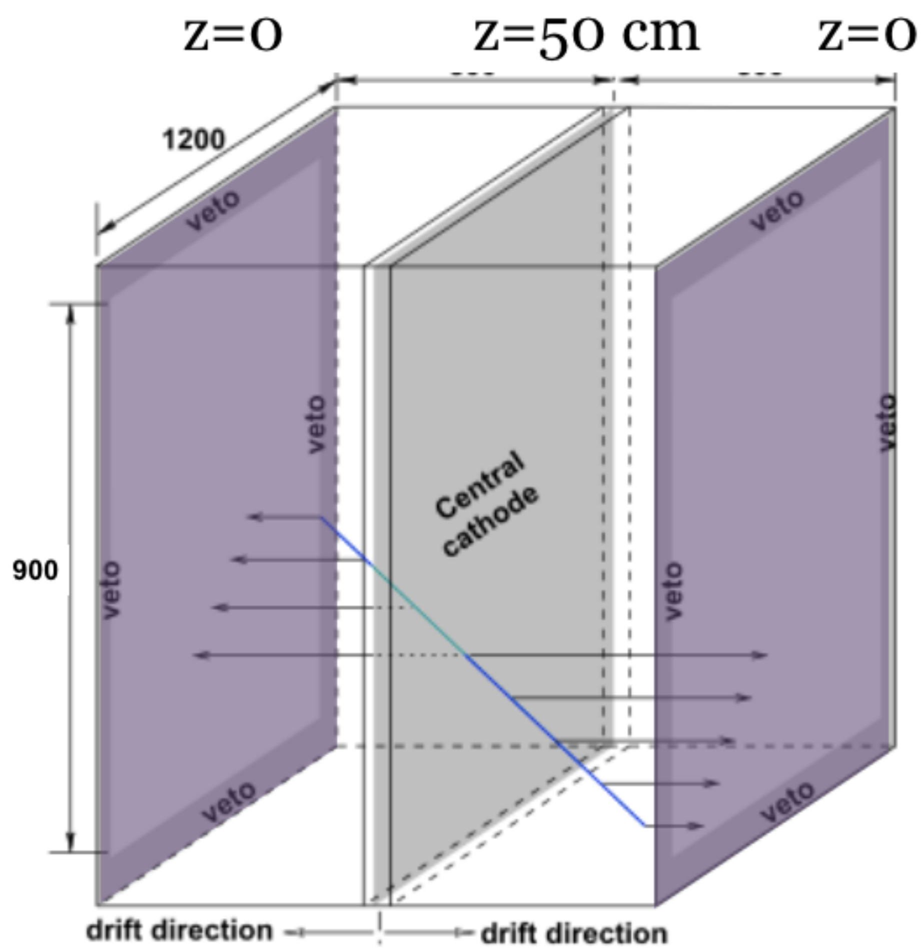
ΔX: Number of anode wires crossed
ΔY: Progression across grid wires
ΔZ: Drift time between start and end of track

Significant advances recently

Negative Ion Drift

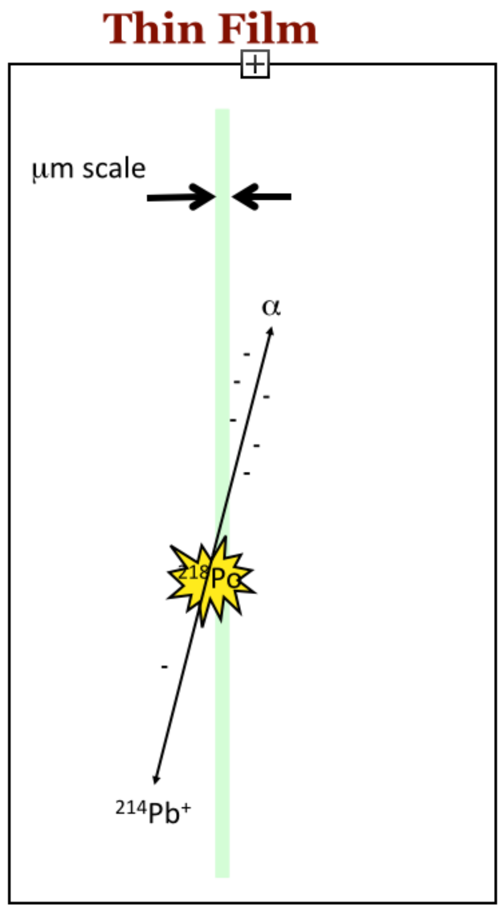


Towards Zero Background
Radon Progeny Recoils

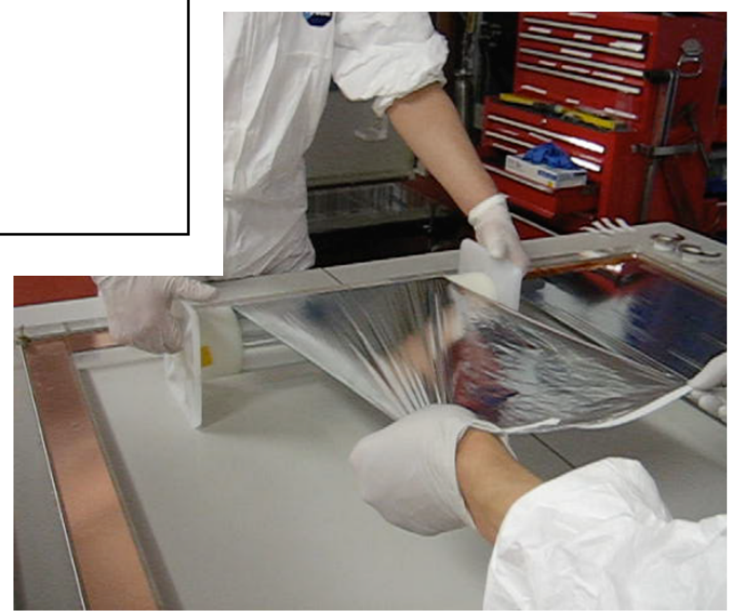


Left MWPC Cathode -32kV ight MWPC

x

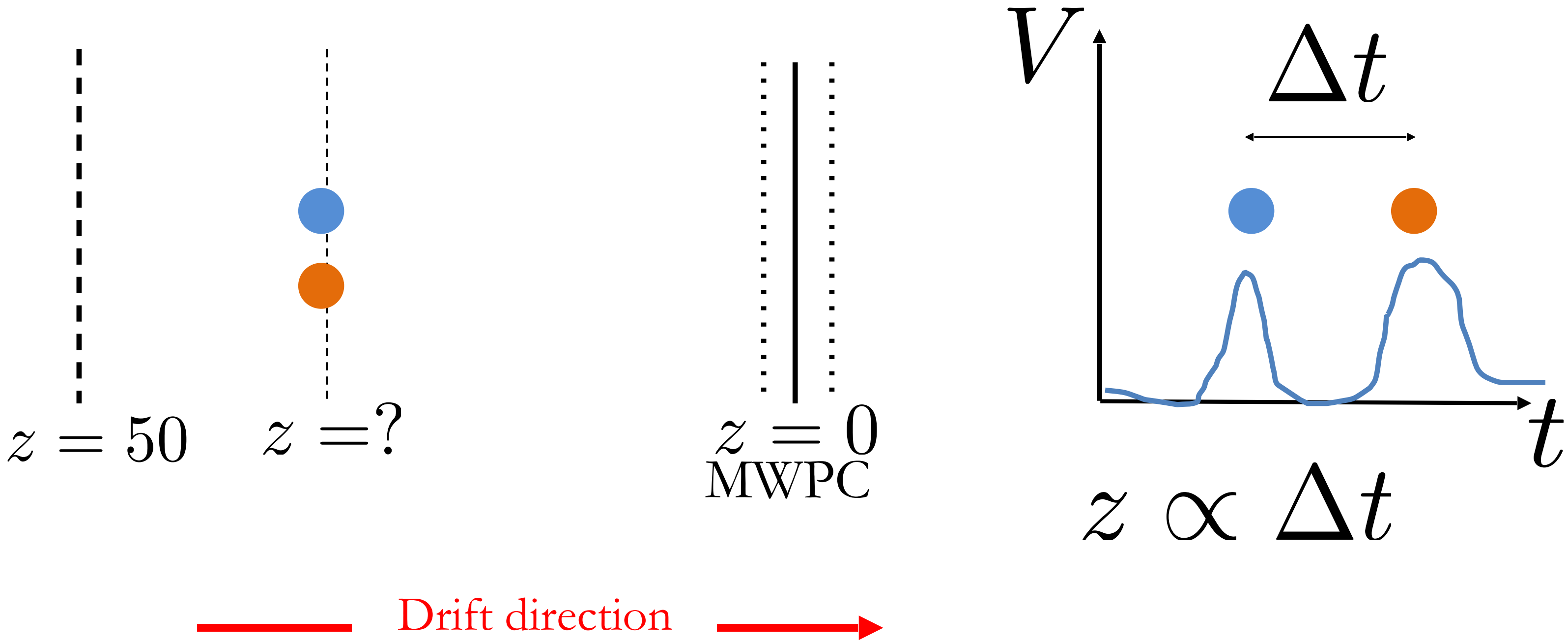


- 0.9µm textured thin cathode reduces radon events



z-Fiducialization Breakthrough

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



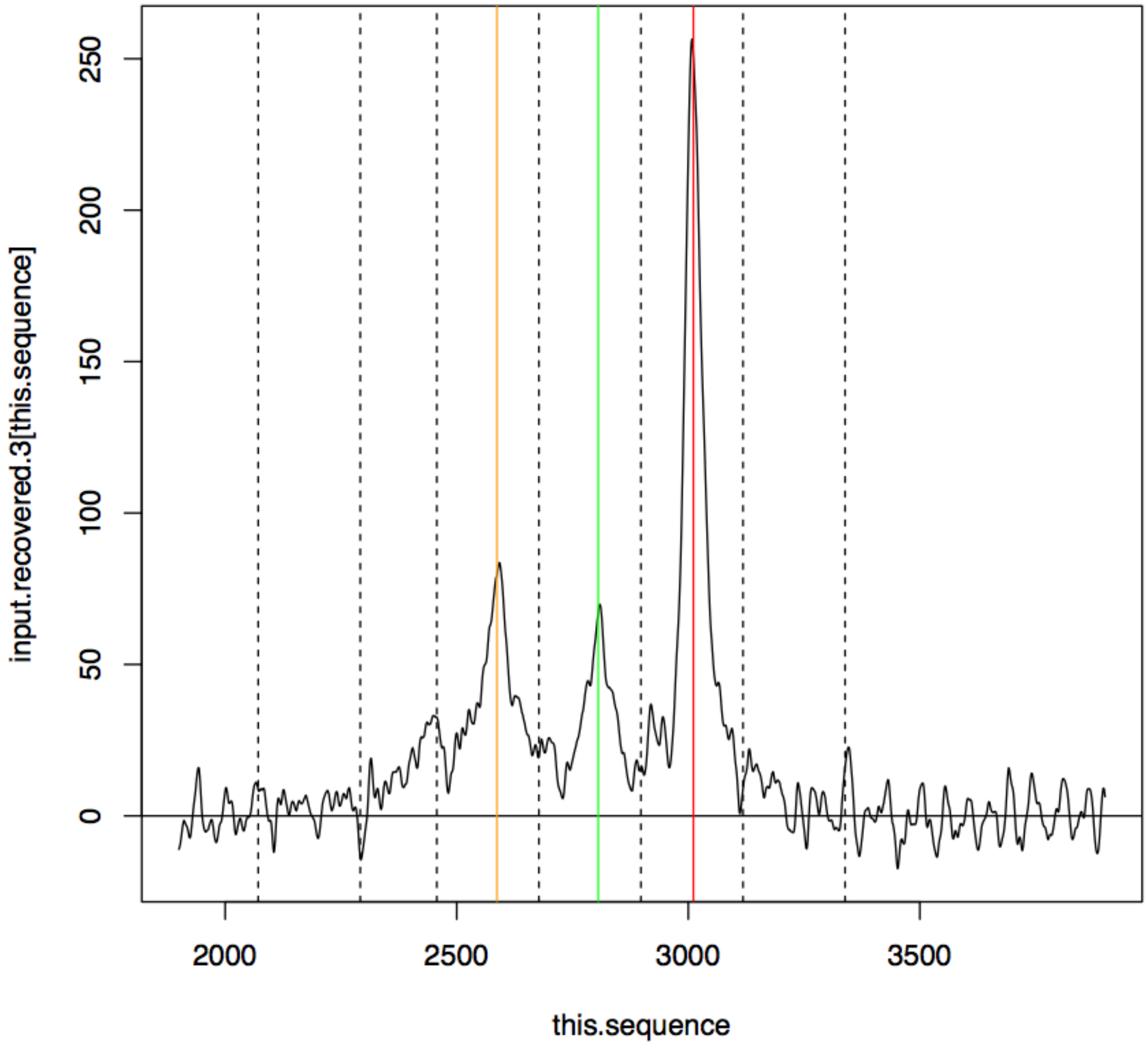
Proportionality constant can be measured for various gas mixtures, or calibrated in-situ.

thanks to D. Snowden-Ifft

z-Fiducialization

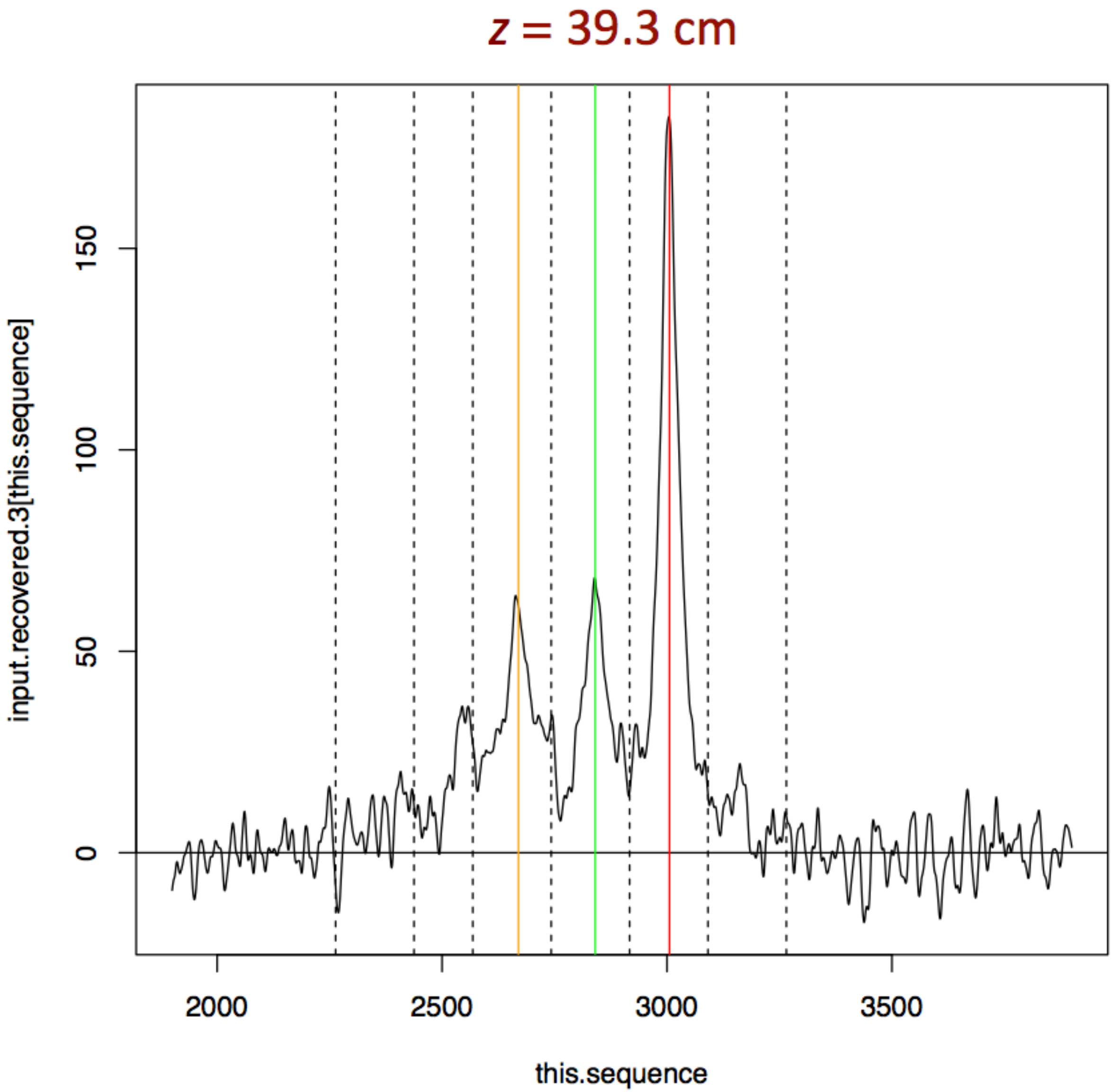
Examples

z = 49.7 cm



z-Fiducialization

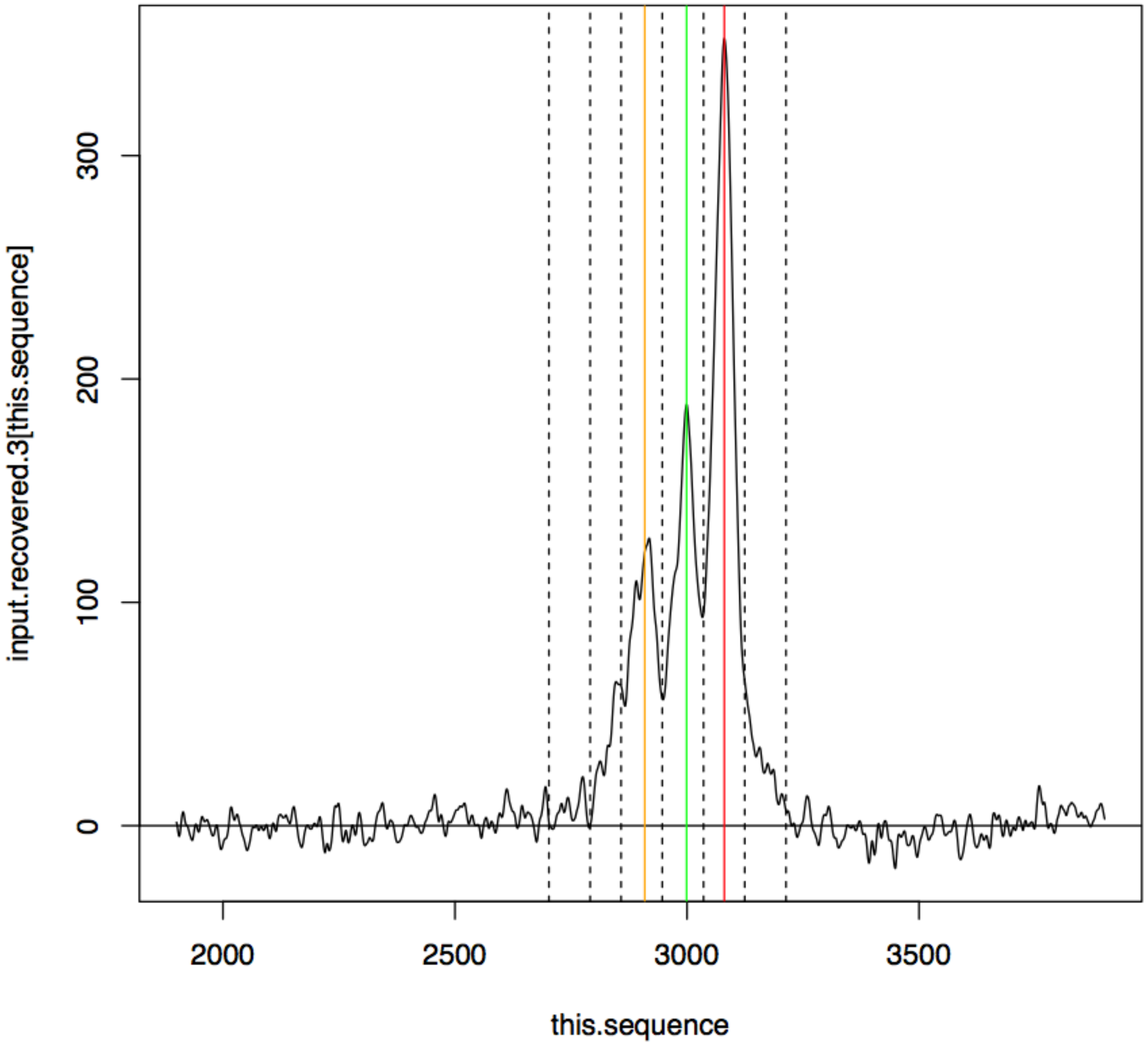
Examples



z-Fiducialization

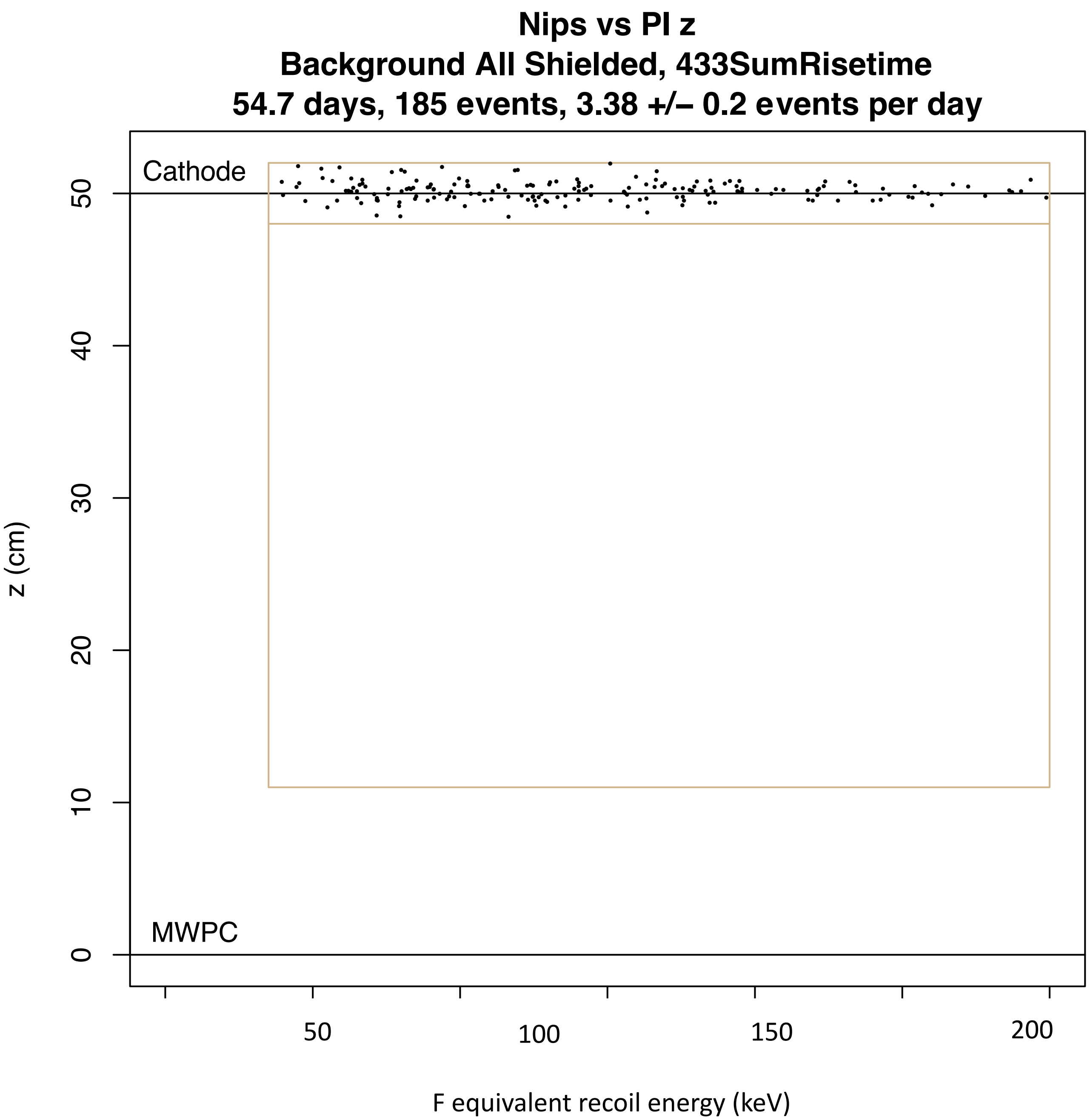
Examples

$z = 20.1$ cm



DRIFT WIMP Analysis

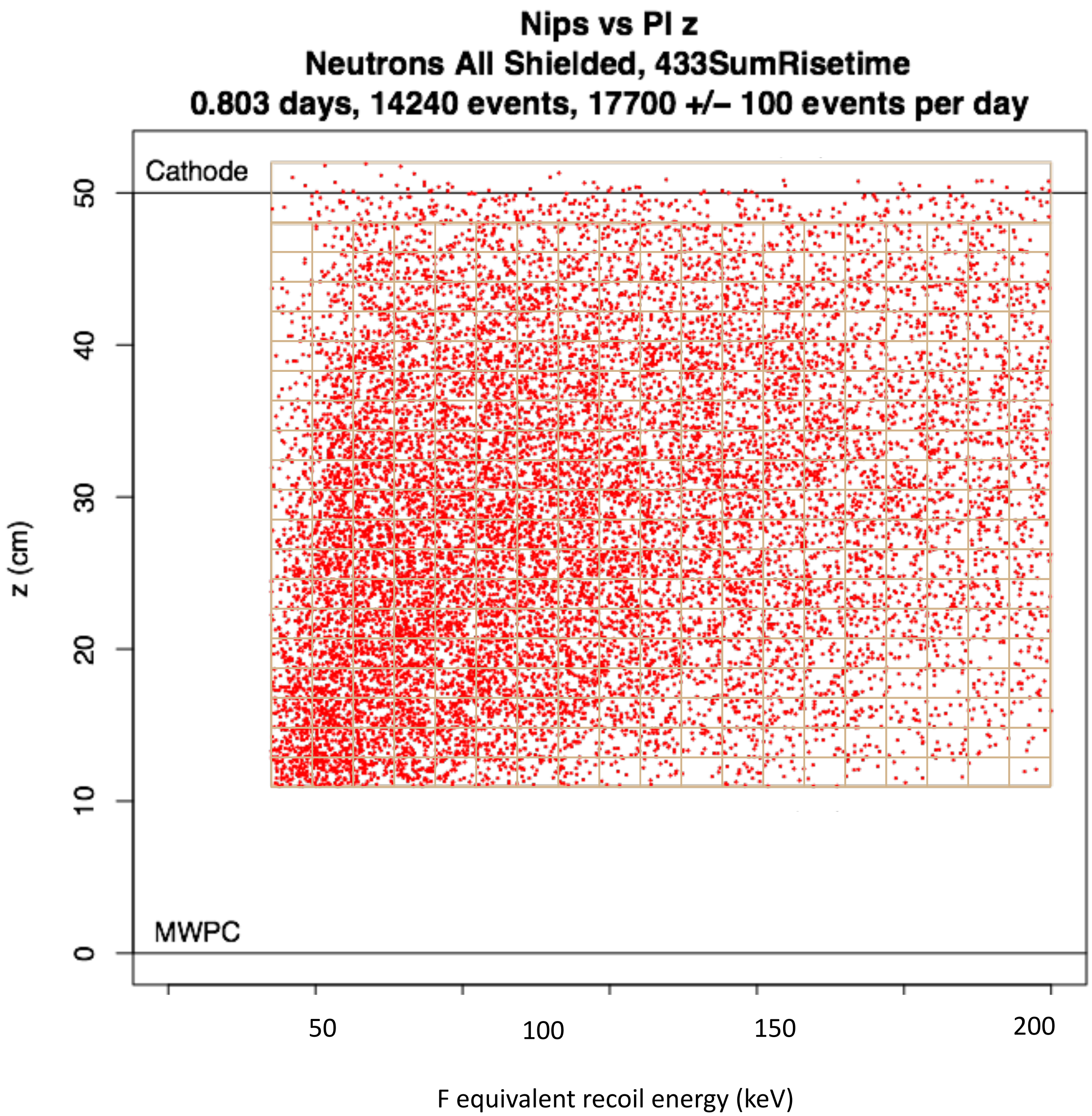
Shielded 30-10-1 CS_2-CF_4-O_2 Data



- **54.7 days of data analyzed**
- **185 events found but as expected all were located at 50 cm away from the detector, i.e. on the central cathode.**
- **Define a background-free fiducial region.**
- **In order to interpret this as a limit need to calibrate the detector…**

DRIFT WIMP Analysis

Cf-252 Neutron Calibration Data



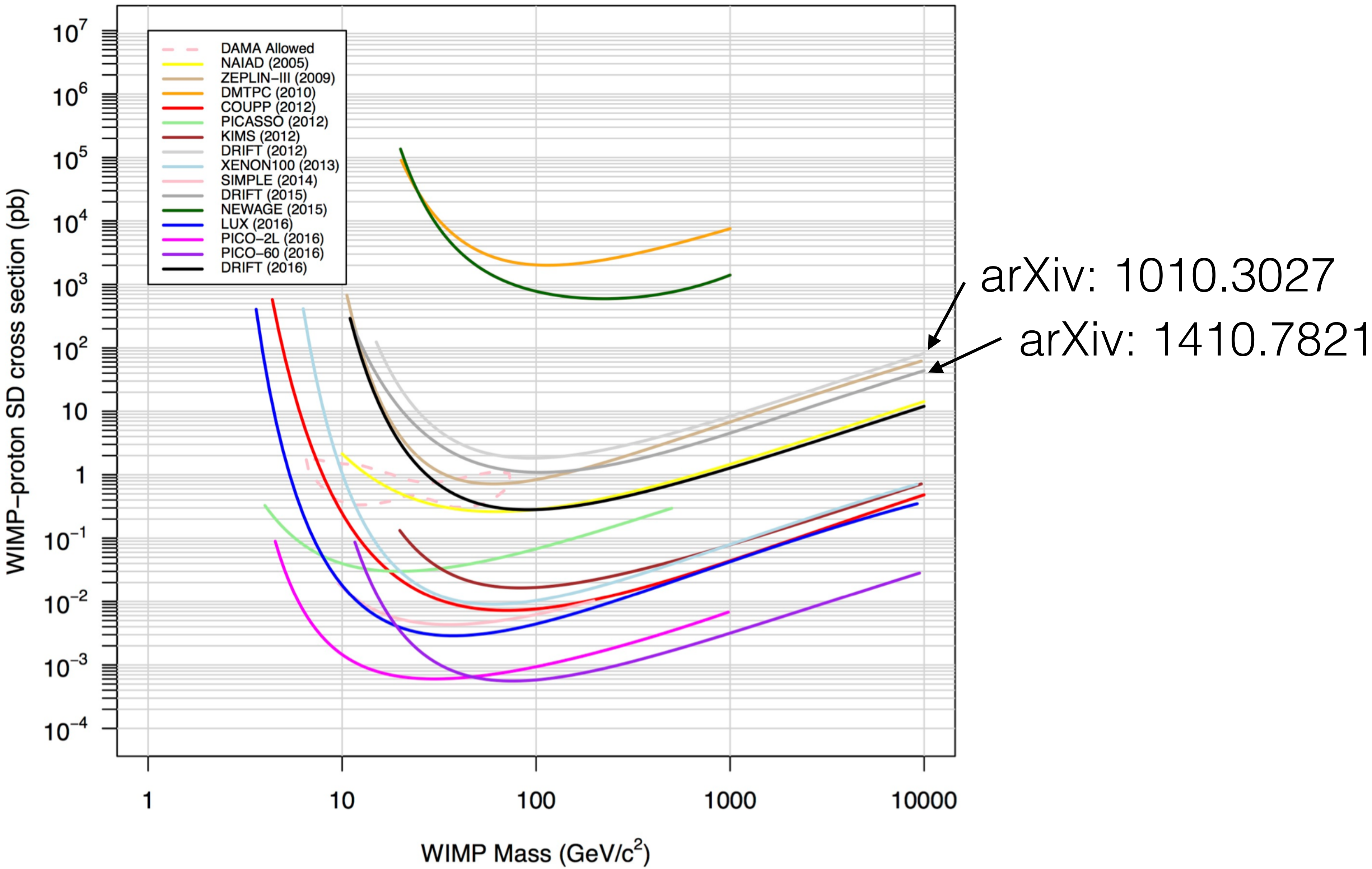
- **Exposed the detector to a CF-252 neutron source**
- **As expected the neutrons distributed themselves more or less uniformly in *z* within the fiducial region**
- **Since neither the distribution in *z* nor *NIPs* (ionization) is truly uniform need to do this carefully…**

- **Did the same for the experimental data.**

New Result (zero background)

New result (CAASTRO2017) including reduced threshold analysis

First result in "DAMA Region" with directional sensitivity"



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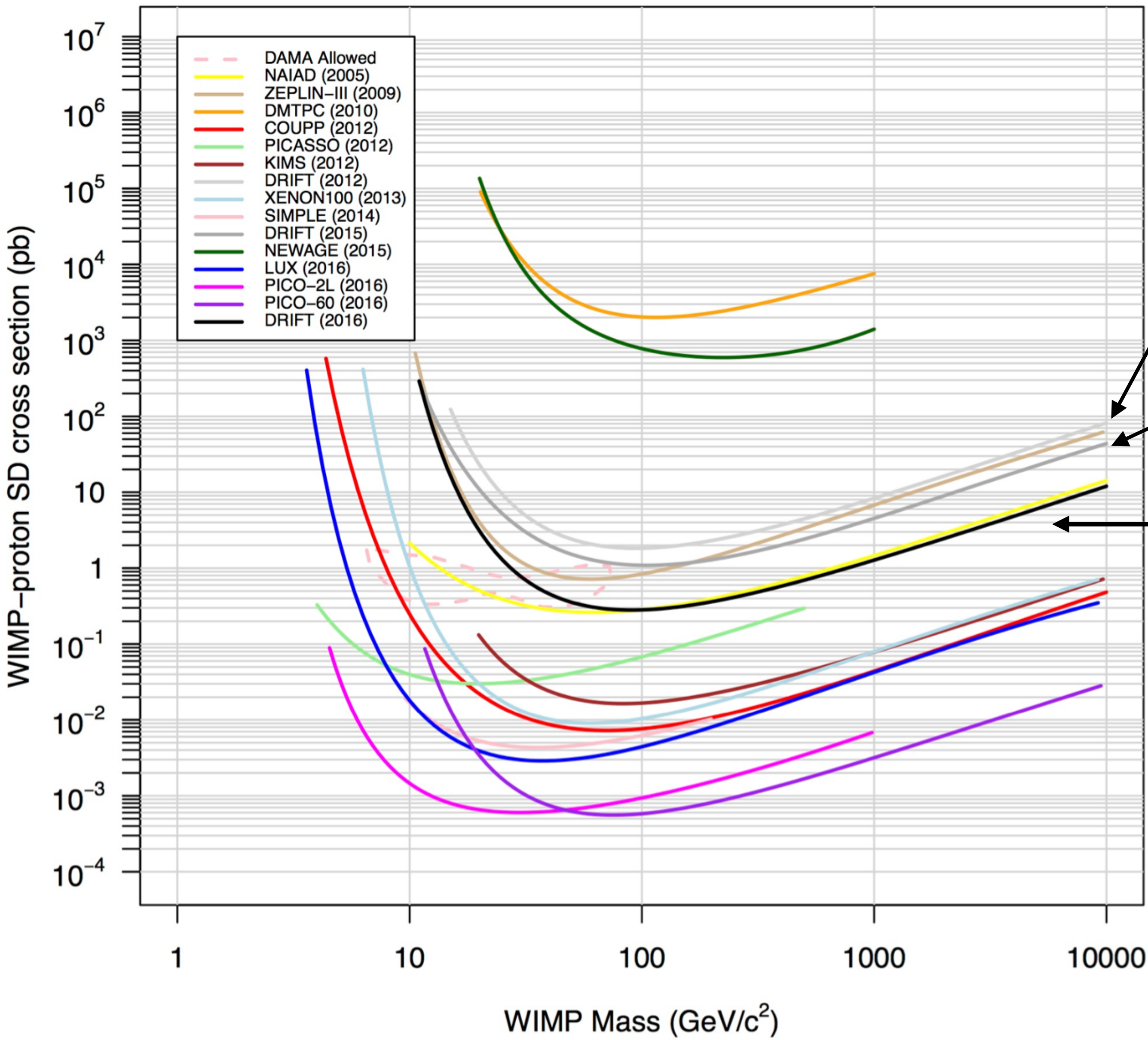


arXiv: 1010.3027

arXiv: 1410.7821

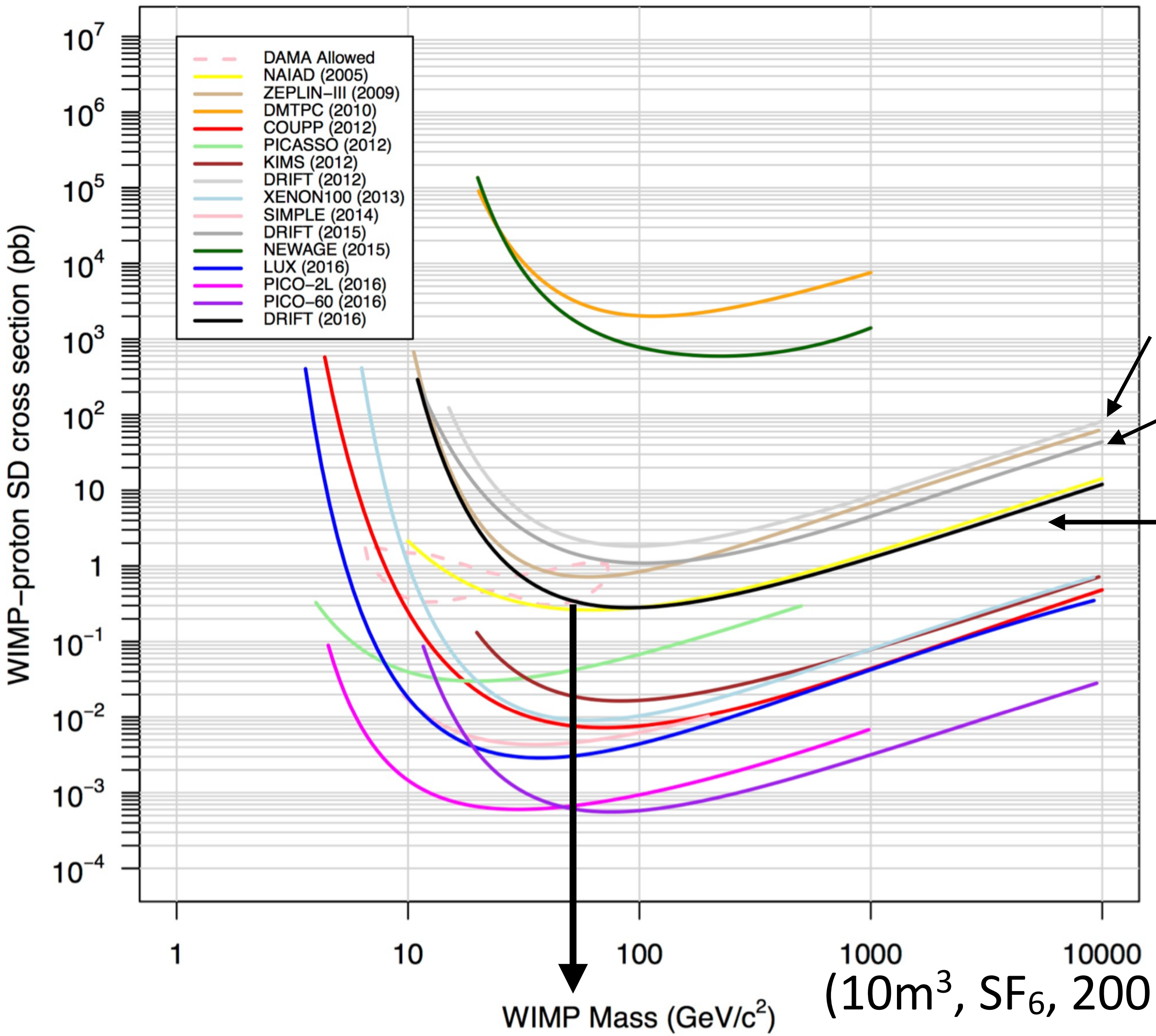
arXiv: 1701.00171

(31 gram F, 40 Torr, ~50 days, zero background)

New Result (zero background)

New result (CAASTRO2017) including reduced threshold analysis

First result in "DAMA Region" with directional sensitivity"



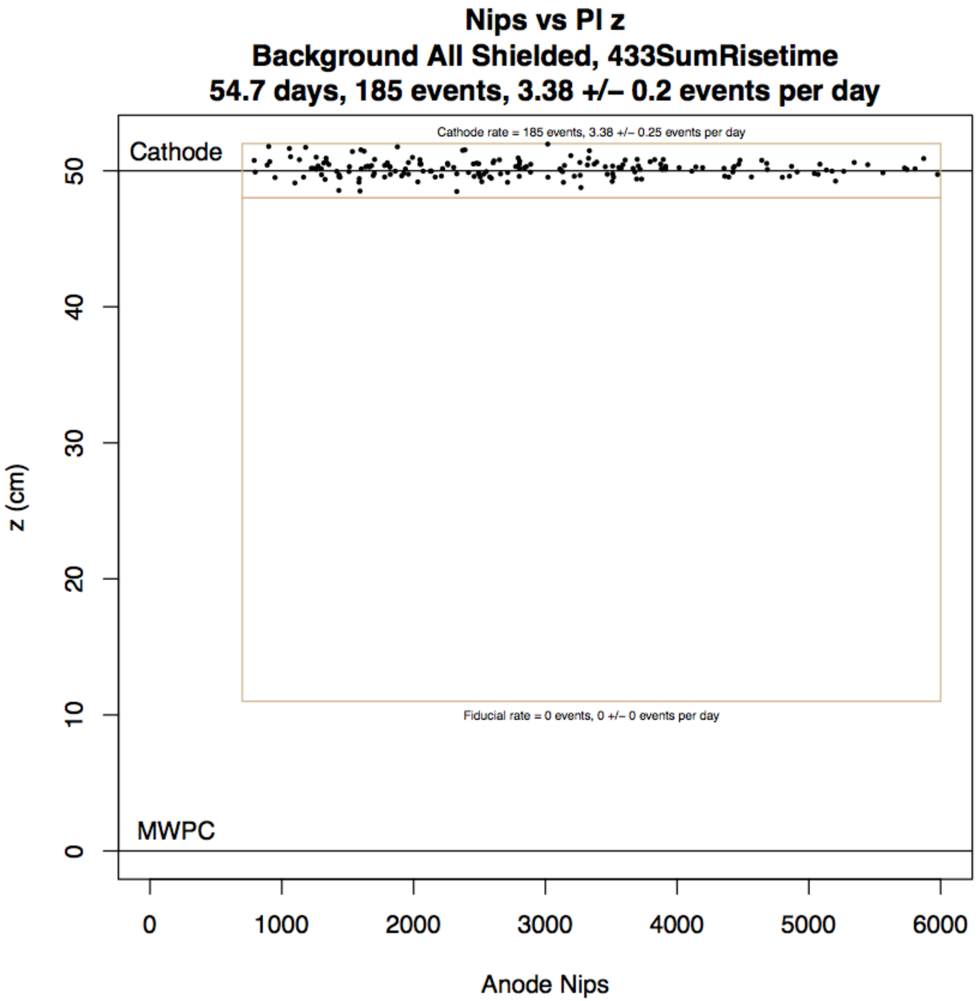
(31 gram F, 40 Torr, ~50 days, zero background)

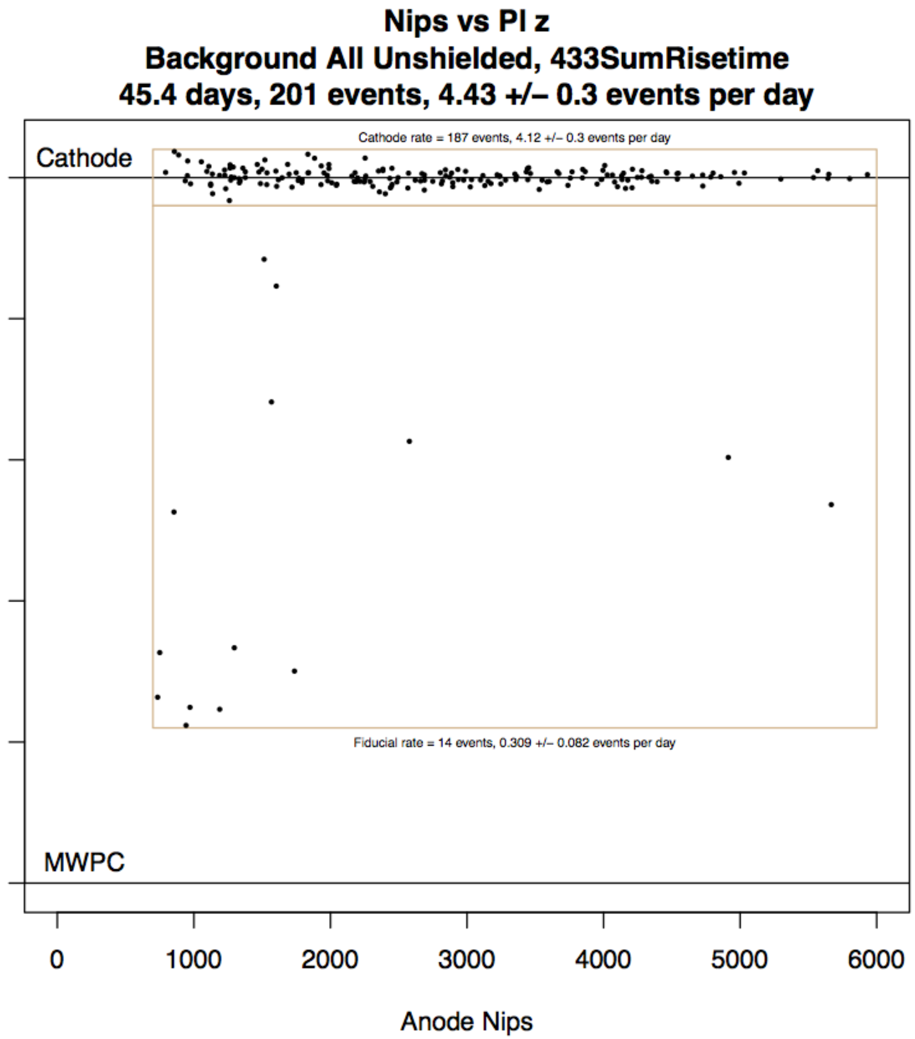
(10m^3, SF_6, 200 Torr, 3 years days, zero background)

Rock Fast Neutron Test

Neutron Background & Directionality

- 54.7 day shielded run - no events seen
- 45.4 day unshielded run - see 14 fast rock neutrons



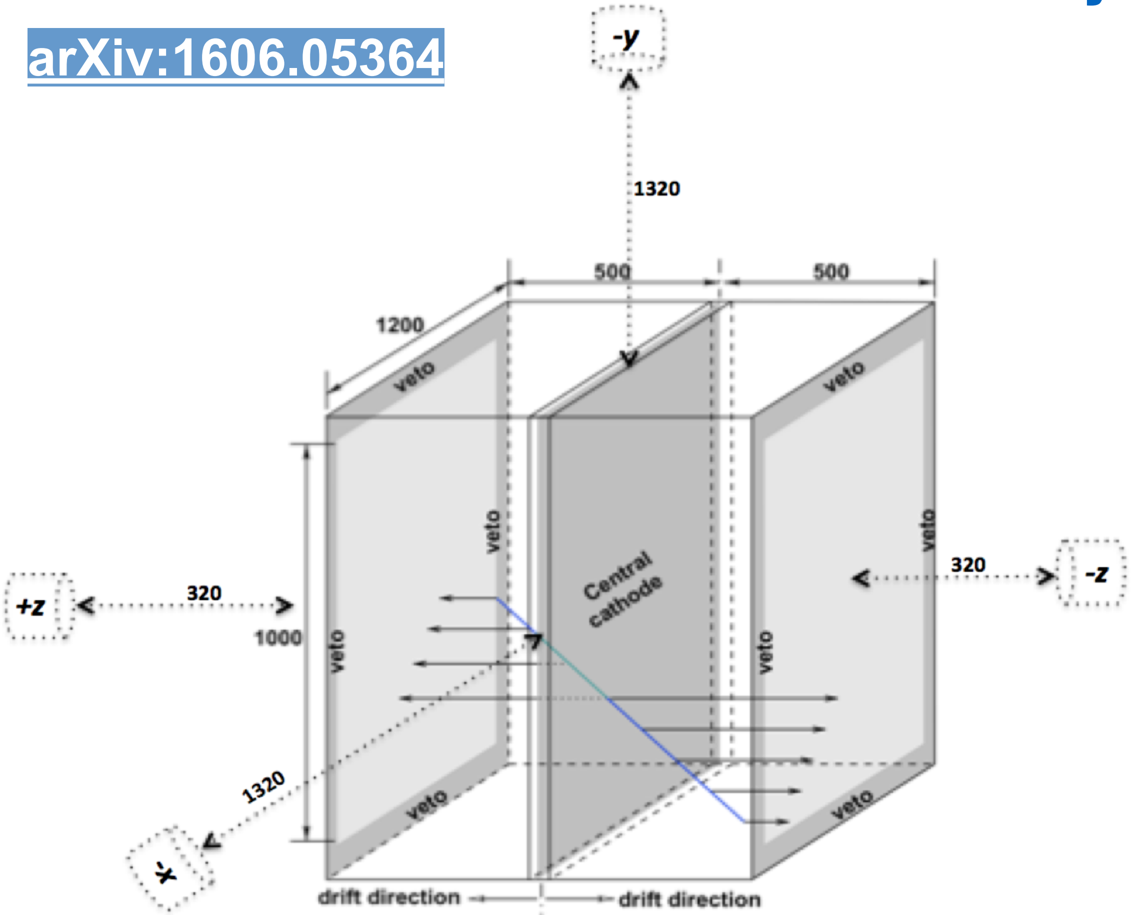


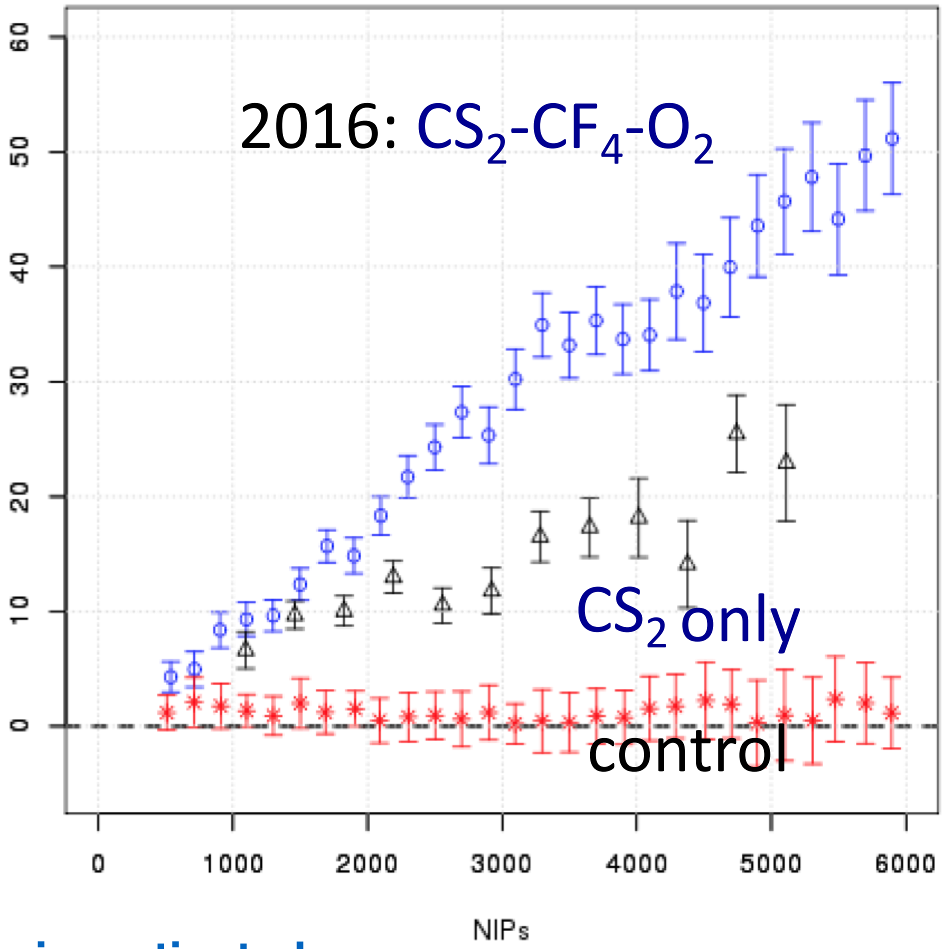
- Consistent with Boulby neutron flux of 7 x 10^{-7} n/cm^2/s
- So TPC is a powerful fast neutron monitor

Head-Tail Directionality Maintained

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

arXiv:1606.05364





- **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.**

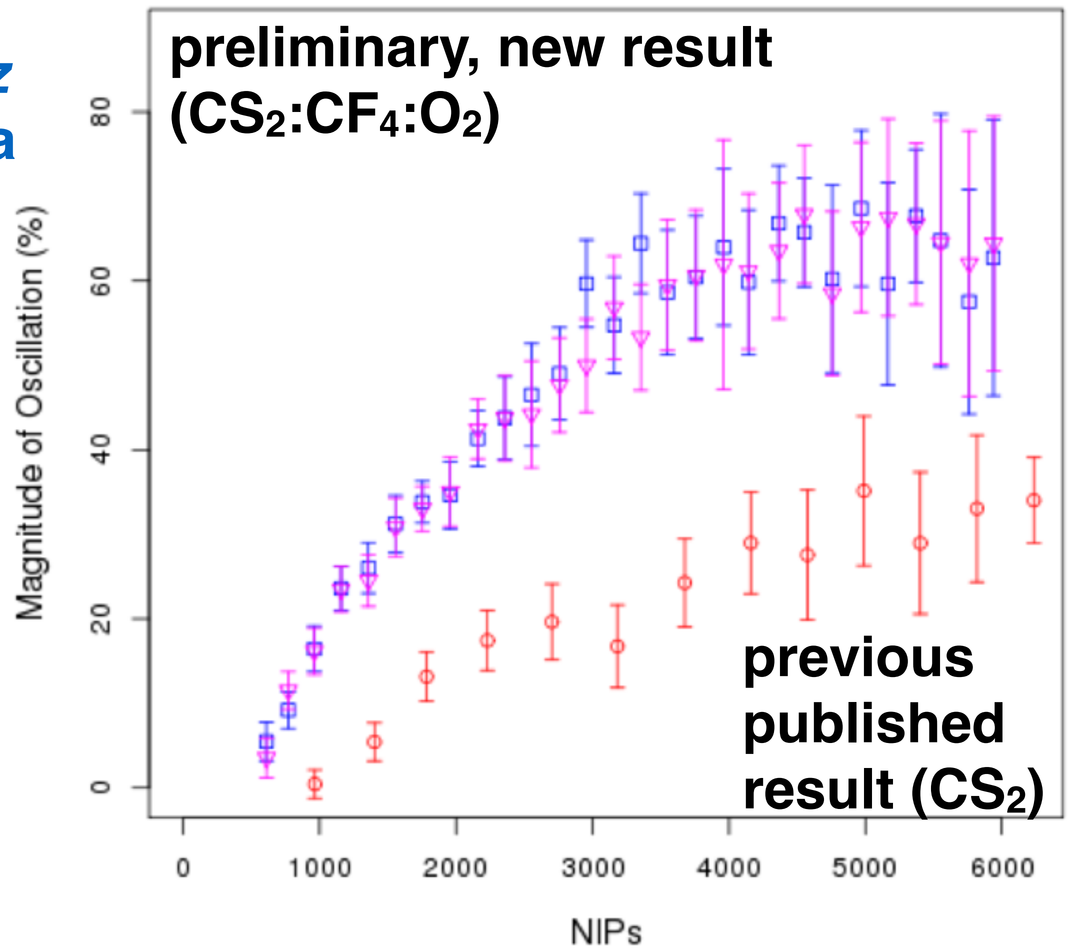
Axial Directionality also Maintained

- **Axial Directional sensitivity with z-fiducialisation**

Magnitude of "oscillation" as neutron source is moved from +*z* to *x* and from *z* to *x* (A_{ozx} %) as a function of nuclear recoil NIPs equivalent energy:

$$\overline{\frac{\Delta z}{\Delta x}} = \frac{\sum_{a=1}^{n}\left(\frac{\Delta z_a}{\Delta x_a}\right)}{n}$$

$$A_{o_{zx}} = \left(\frac{\overline{\frac{\Delta z}{\Delta x_z}} - \overline{\frac{\Delta z}{\Delta x_x}}}{\frac{1}{2}\left(\overline{\frac{\Delta z}{\Delta x_z}} + \overline{\frac{\Delta z}{\Delta x_x}}\right)}\right)100$$



(blue) this analysis average values in bins of 200 NIPs interval square points for +*z* to *x* oscillation, (pink) triangular points from *z* to *x* oscillation. Red circle points are results obtained with only ^{32}S recoil tracks.

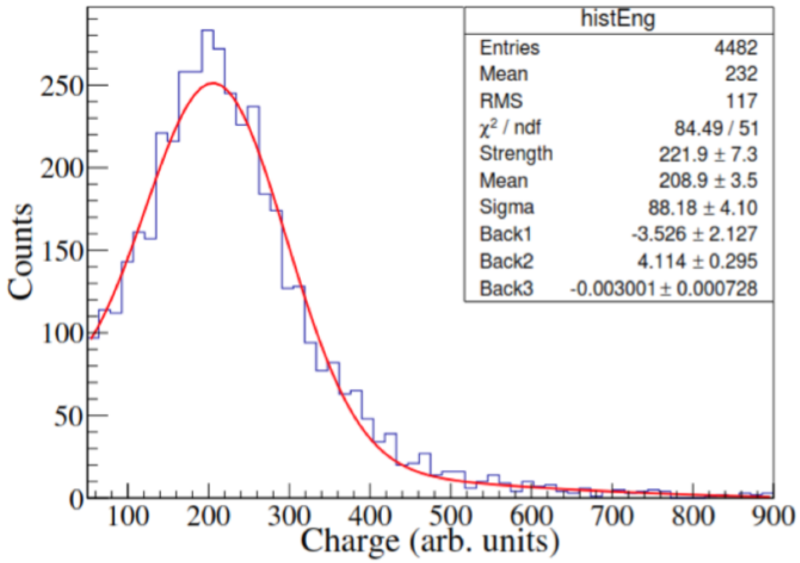
SF_6 Breakthrough at UNM

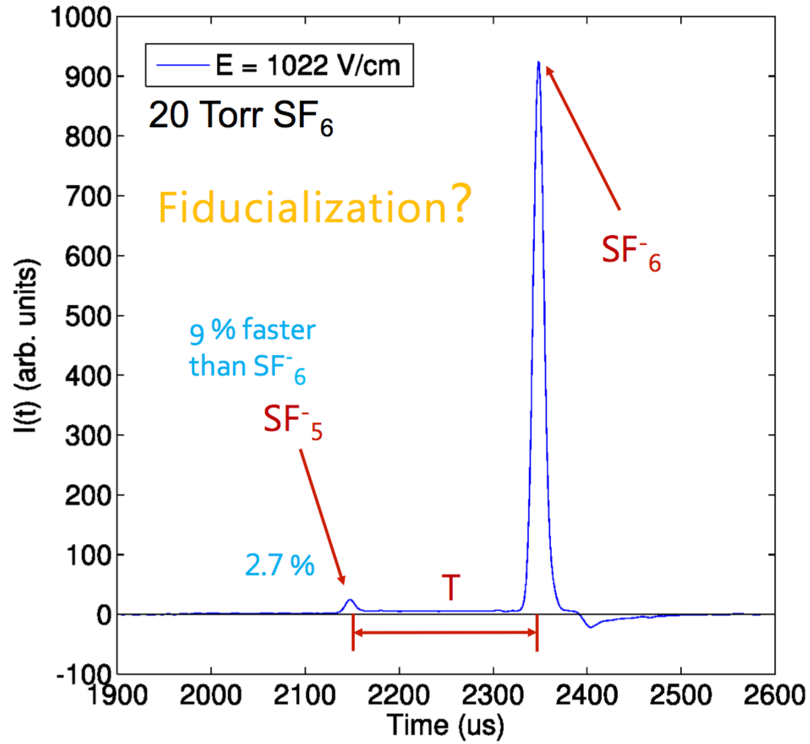
-ve ion with minority carrier and increased target mass

N. Phan, University of New Mexico

- **Replacement for CS_2**
- **First demonstration of SF_6 as -ve on gas (with GEMs)**
- **Potential for x5 more mass, with fiducialisation?**
- **This has been a revelation**

  - ^{55}Fe spectrum in 40 Torr SF_6 with 0.4mm GEM
  - Gain curves up to x3000
  - z-fidusialization with SF_5^- shown (20 Torr)





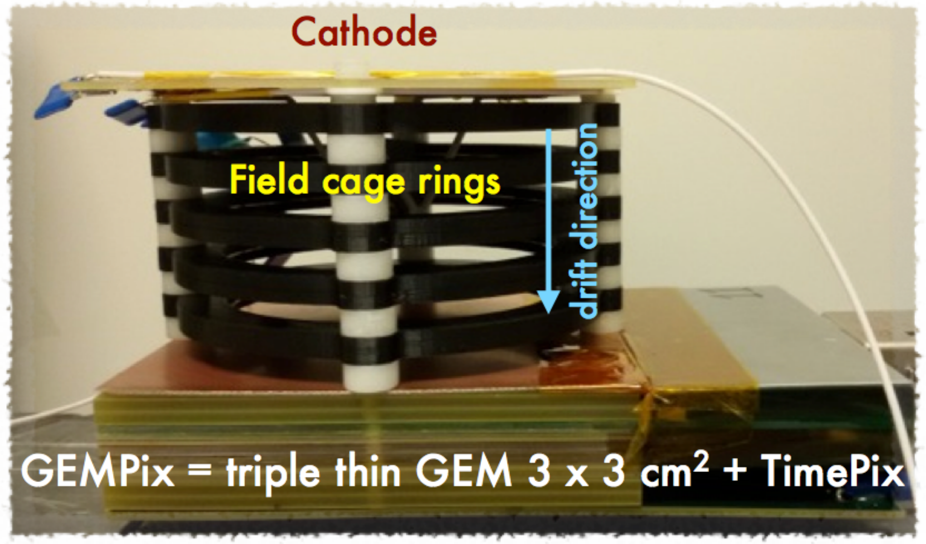
- **Activity now in many groups**
- **Frascati, Kobe, UNM, Sheffield**

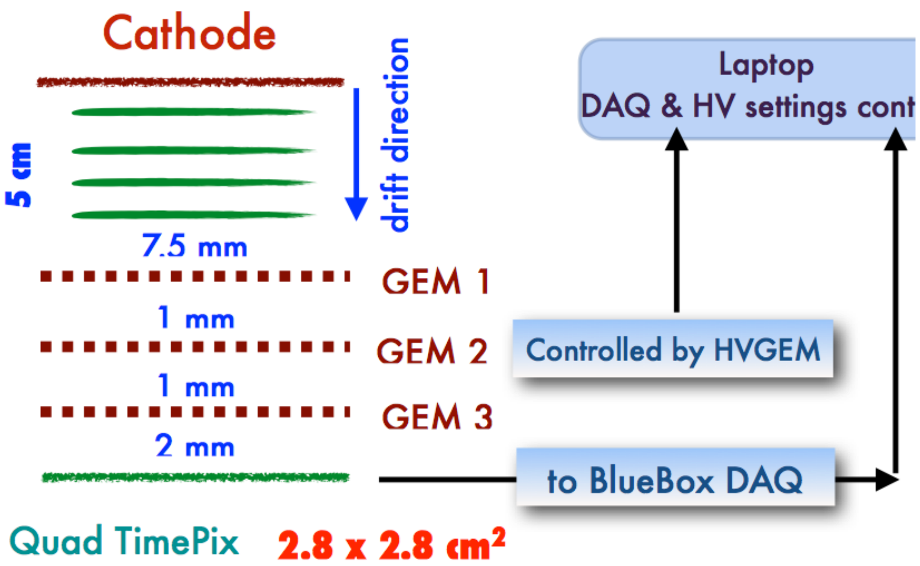
NITEC at Frascati

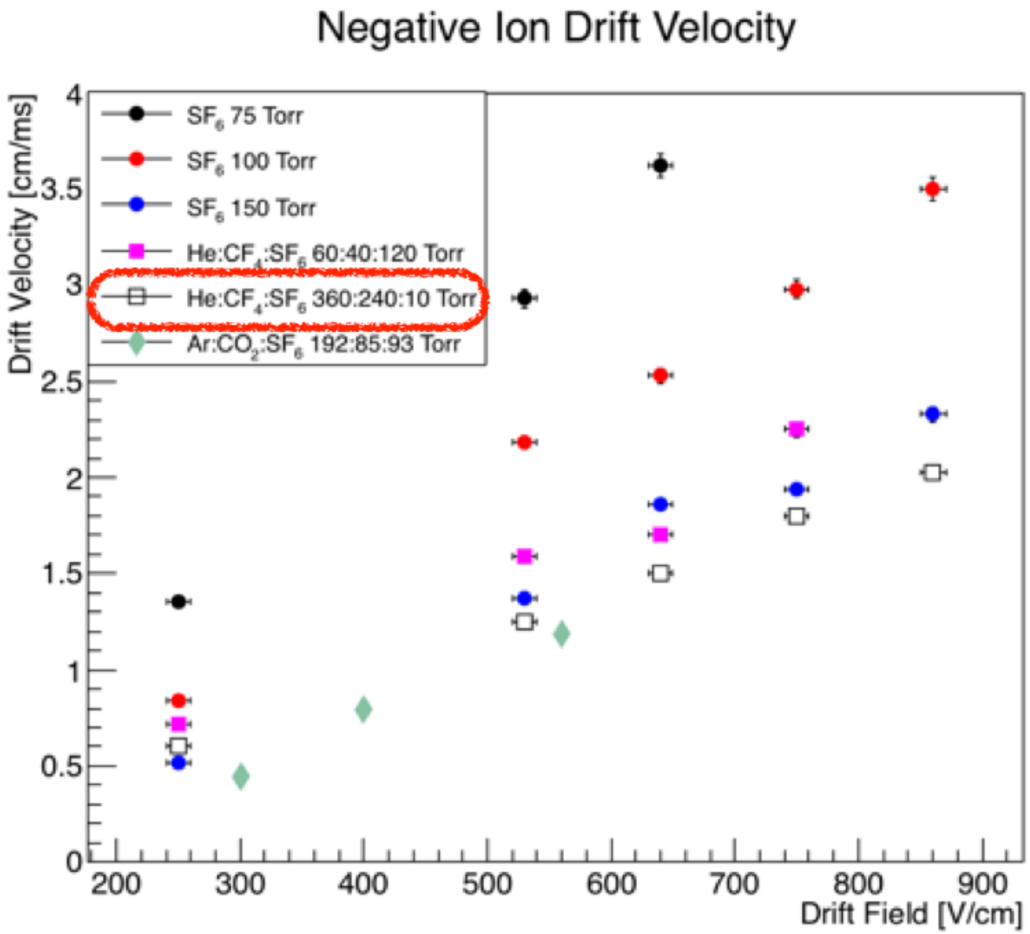
E. Baracchini

Demonstration of SF_6 with He and high gain

- Replacement for CS_2







- Pure SF_6 gains up to 6000 so far (Sheffield)

UNDER Project Proposal at LNGS

- Application to measure/monitor fast neutron flux at LNGS
- Improve on reliability of old measurements

Current Neutron Measurements at LNGS

Fast neutrons

Liquid scintillator | BF_3 | ^3He | ^3He

E interval (MeV)	Fast Neutron Flux ($10^{-6}cm^{-2}s^{-1}$) Ref. [5]	Ref. [6]	Ref. [2]	Ref. [1]	Ref. [7]	Ref. [8]
0.1 – 1			0.54±0.01			
1 – 2.5		0.14±0.12	(0.53±0.08)			
2.5 – 3		0.13±0.04	0.27±0.14			
3 – 5			(0.18±0.04)			2.56±0.27
5 – 10		0.15±0.04	0.05±0.01 (0.04±0.01)	3.0±0.8	0.09±0.06	
10 – 15	0.78±0.3	$(0.4\pm0.4)\cdot10^{-3}$	$(0.6\pm0.2)\cdot10^{-3}$ $((0.7\pm0.2)\cdot10^{-3})$			
15 – 25	UL		$(0.5\pm0.3)\cdot10^{-6}$ $((0.1\pm0.3)\cdot10^{-6})$		UL	

Measurement of fast neutron flux are more than 20 years old!

Thermal neutrons

^3He | BF_3 | ^3He | ^3He

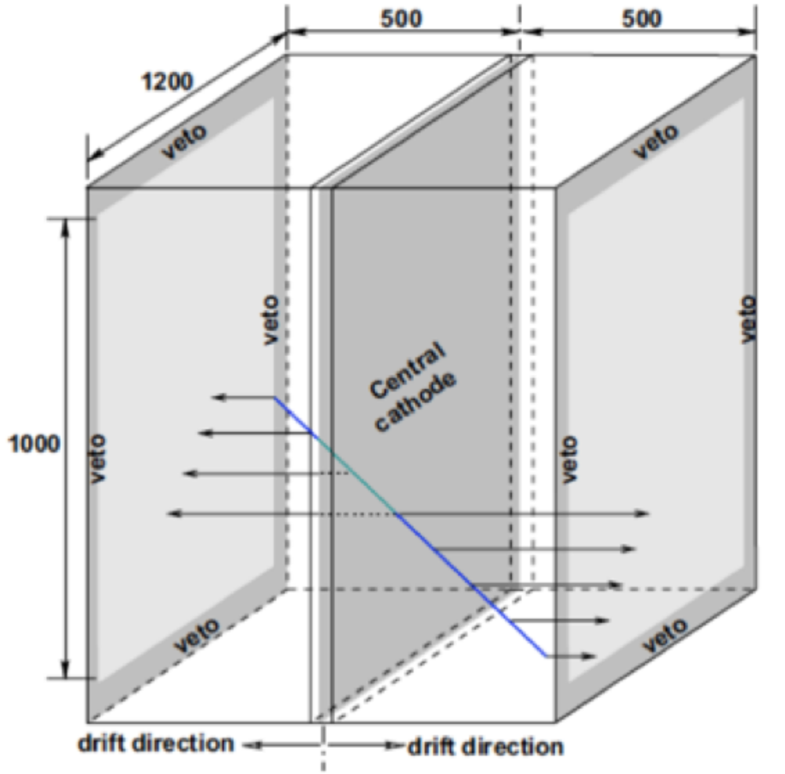
E interval (eV)	Thermal Neutron Flux ($10^{-6}cm^{-2}s^{-1}$) Ref. [1]	Ref. [2]	Ref. [3]	Ref. [4]
0 - 0.05	5.3 ± 0.9	1.08 ± 0.02 (1.07 ± 0.05)	0.54 ± 0.13	0.32 ± 0.09
0.05 - 1000		1.84 ± 0.20 (1.99 ± 0.05)		

[1] Bellotti 1985
[2] Belli 1989
[3] Debicki 2009
[4] Best 2015
[5] Aleksan 1989
[6] Arneodo 1999
[7] Cribier 1995
[8] Rindi 1988

- Both fast and thermal measurements vary widely

UNDER Project at LNGS

- Two 50 cm back-to-back **Negative Ion TPC** with **triple thin GEMs** amplification for a one-year measurement in Hall B to check for seasonal variation
- **He:^{3}He:SF_6** gas mixture (atmospheric pressure)
- Fast neutron flux measurement **with zero background** through usual nuclear recoil technique (as demonstrated by DRIFT)



$$n + {}^3He \longrightarrow p + {}^3H + 764keV$$

Proton 573 keV

Tritium 191 keV

- Thermal neutron flux measurement through ^{3}He capture
- Fiducialization through minority carriers
- CYGNUS-TPC demonstrator

UNDER Project Strategy

- (1) High yield, no directionality He:^{3}He:SF_6 659:1:100 Torr
- (2) If inconsistencies are found, lower partial SF_6 content to investigate observed flux with directionality down to low threshold He:^{3}He:SF_6 749:1:10 Torr

He:^{3}He:SF_6	Rock neutrons rate	Concrete neutrons rate	Recoils due to fast neutron/month
659:1:100	2.93×10^{-5}	3.6×10^{-3}	9330
749:1:10	$< 8.22 \times 10^{-5}$	3.1×10^{-4}	800

(Preliminary)

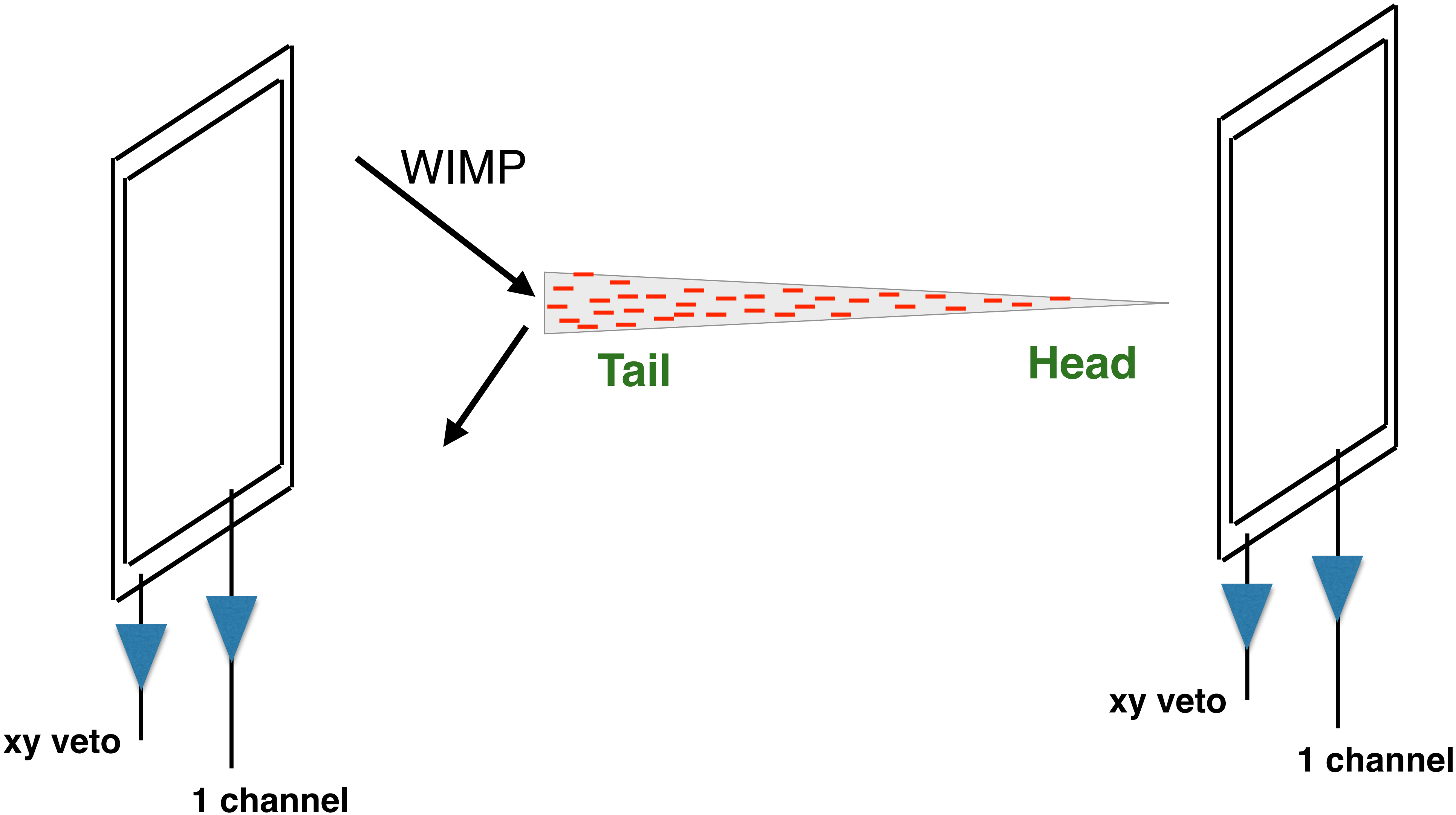
- From the simulation developed for the DRIFT measurement @ Boulby (SOURCES + GEANT4)
- Assume same performance as DRIFT with CS_2:CF_4:O_2 30:10:1 Torr (including fiducialization). ,Rate includes fiducial cuts and 30 keV energy threshold (as in DRIFT)

Is a Simpler "1D-HT" Readout Possible?

CYGNUS R&D activity at Boulby

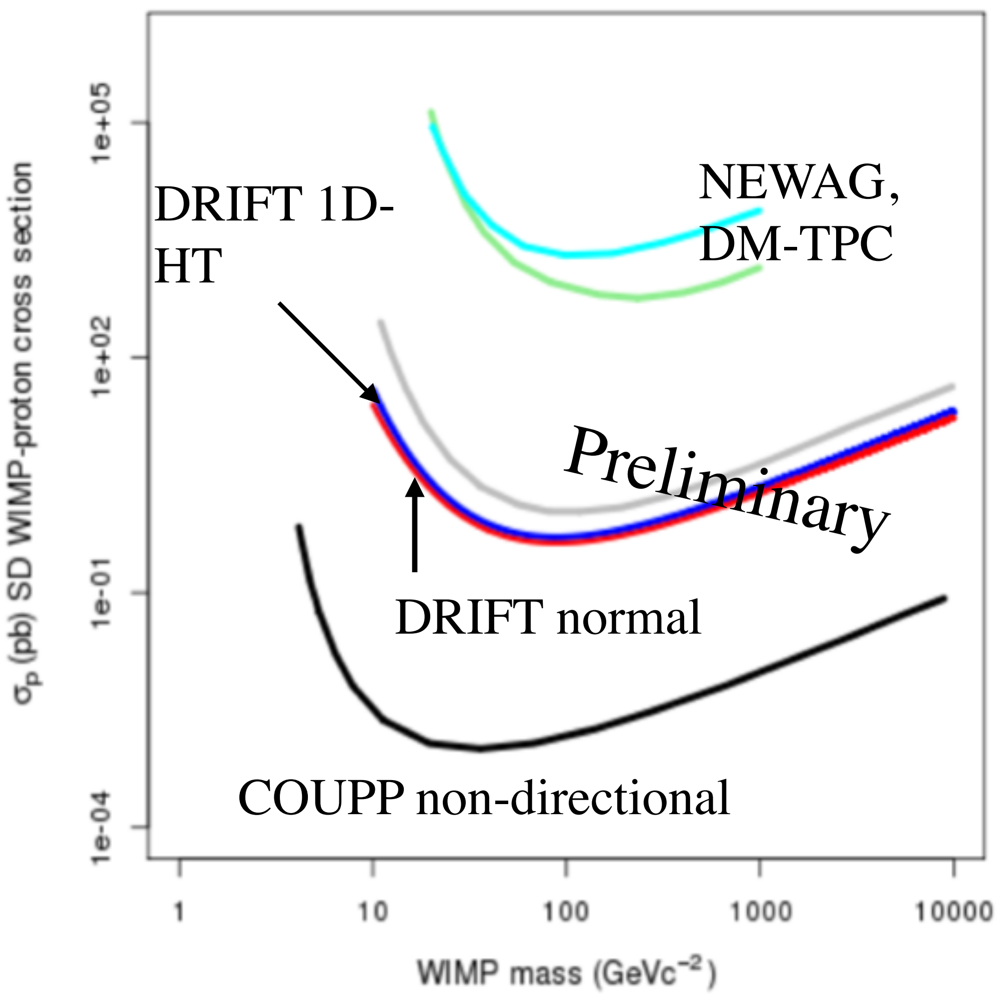
N. Spooner, University of Sheffield

- **What is the simplest possible readout that might just work?**



"1D-HT" Test using DRIFT Data

- experiment with DRIFT-IId xy information switched off, just z and head-tail data analysed, like a 1 x 1m single channel.

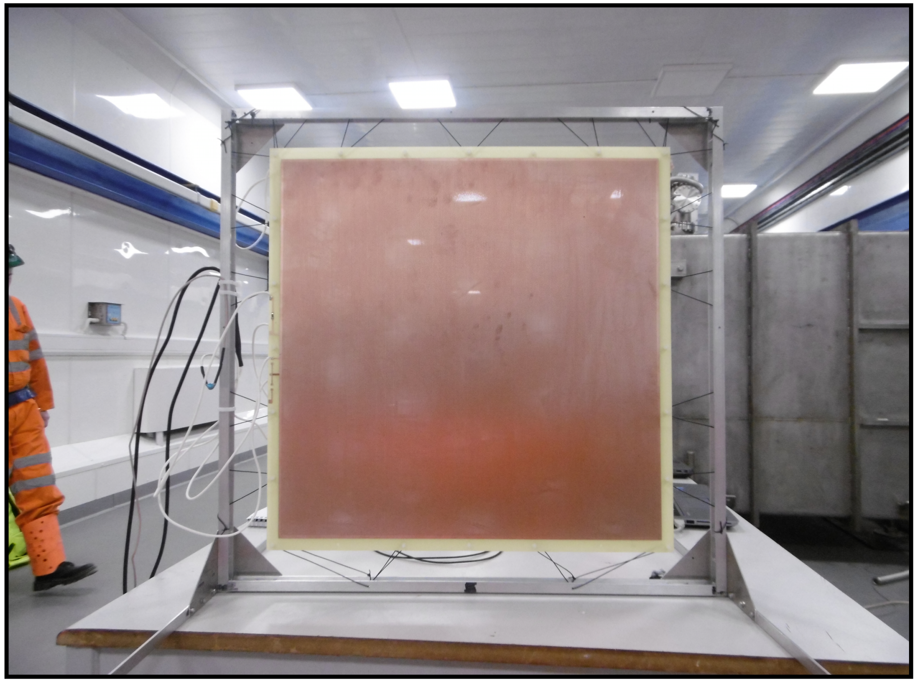


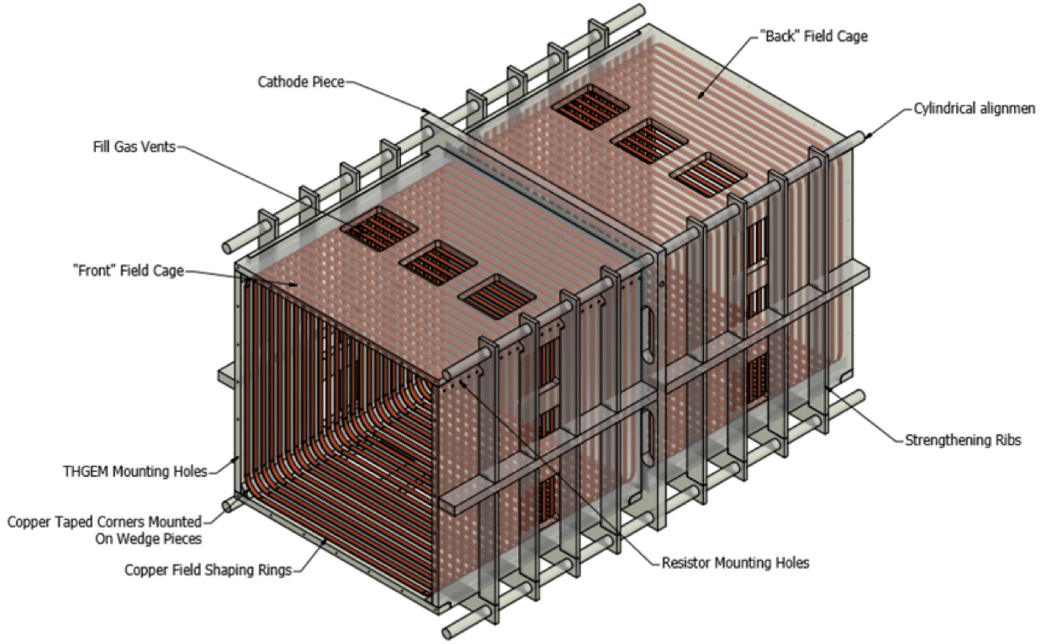
Paper in preparation

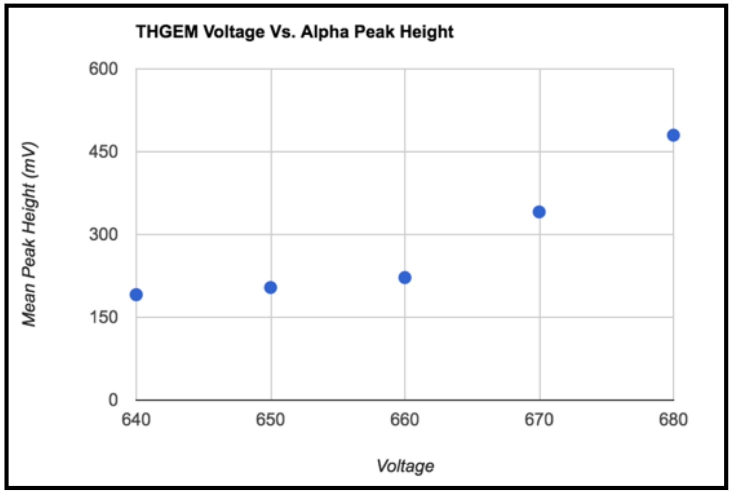
Simpler "1D-HT" Readout Concept

N. Spooner, University of Sheffield

- **ThGEM 0.4mm hole dia., pitch 1mm, first data from alpha interactions - 2cm drift gap, 300 V/cm. 100 Torr CF_4**



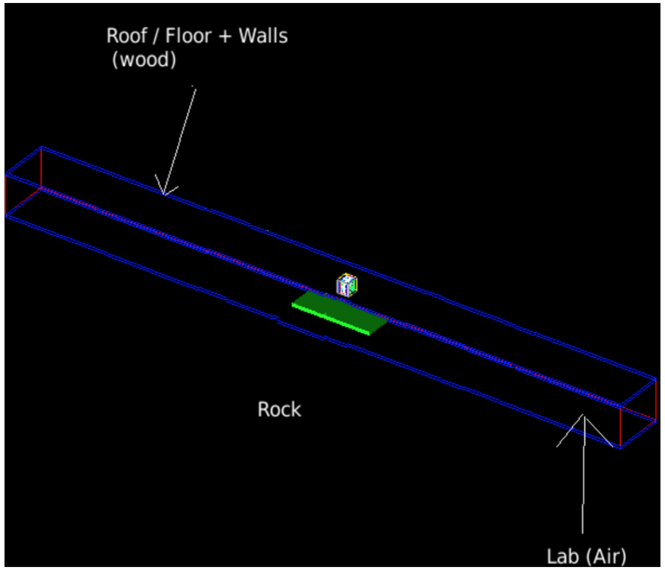


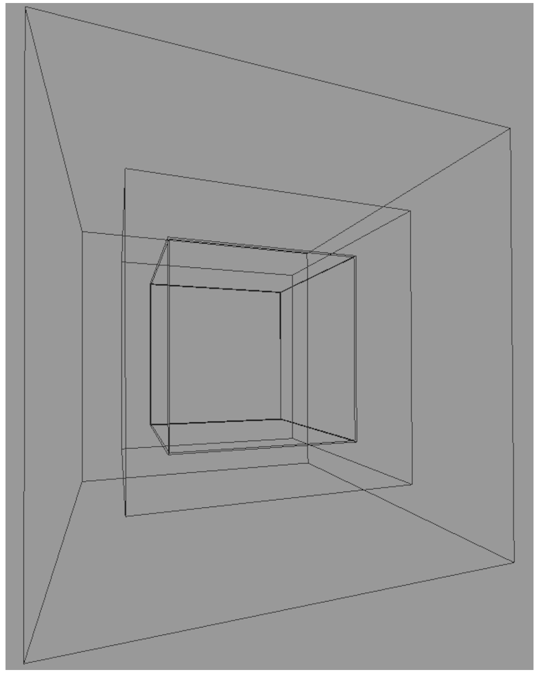


TPC Vessels & Neutron Backgrounds

- Neutron backgrounds in a 10 x 10 x 10m TPC required to achieve < 1 neutron in 3 years operation

- GEANT4 simulations
  - Rock neutrons
  - Muon neutrons
  - Internal neutrons
  - Vessel types: steel, acrylic, steel + internal plastic shield
  - e.g. steel vessel 100 tons, acrylic vessel 20cm thick





Highlight results

- Steel has typically x10^3-10^4 times too much U/Th
- "SNO/DEAP" acrylic (~ 39 microBq/kg Th = 9.6 x 10^{-3}ppb), is suitable
- Steel plus ~50 cm internal acrylic shield, is suitable
- Ceramic components - maximum allowed total mass ~30-50g

CYGNUS-10 Proposal for Boulby

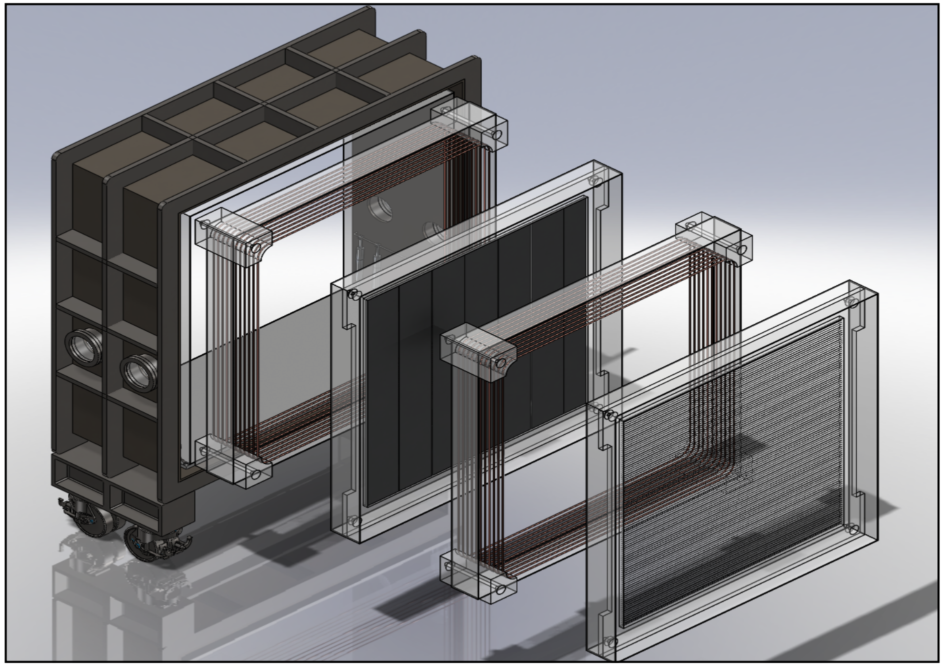
- 10 m^3 vessel, 75 cm poly neutron shield, simple veto
- Two modes of operation:

  (1) High pressure

  (200 Torr SF_6 : 500 Torr He)

  13 kg F, 1 kg He

  (2) Low pressure, directional
  (40 Torr SF_6)



- Science

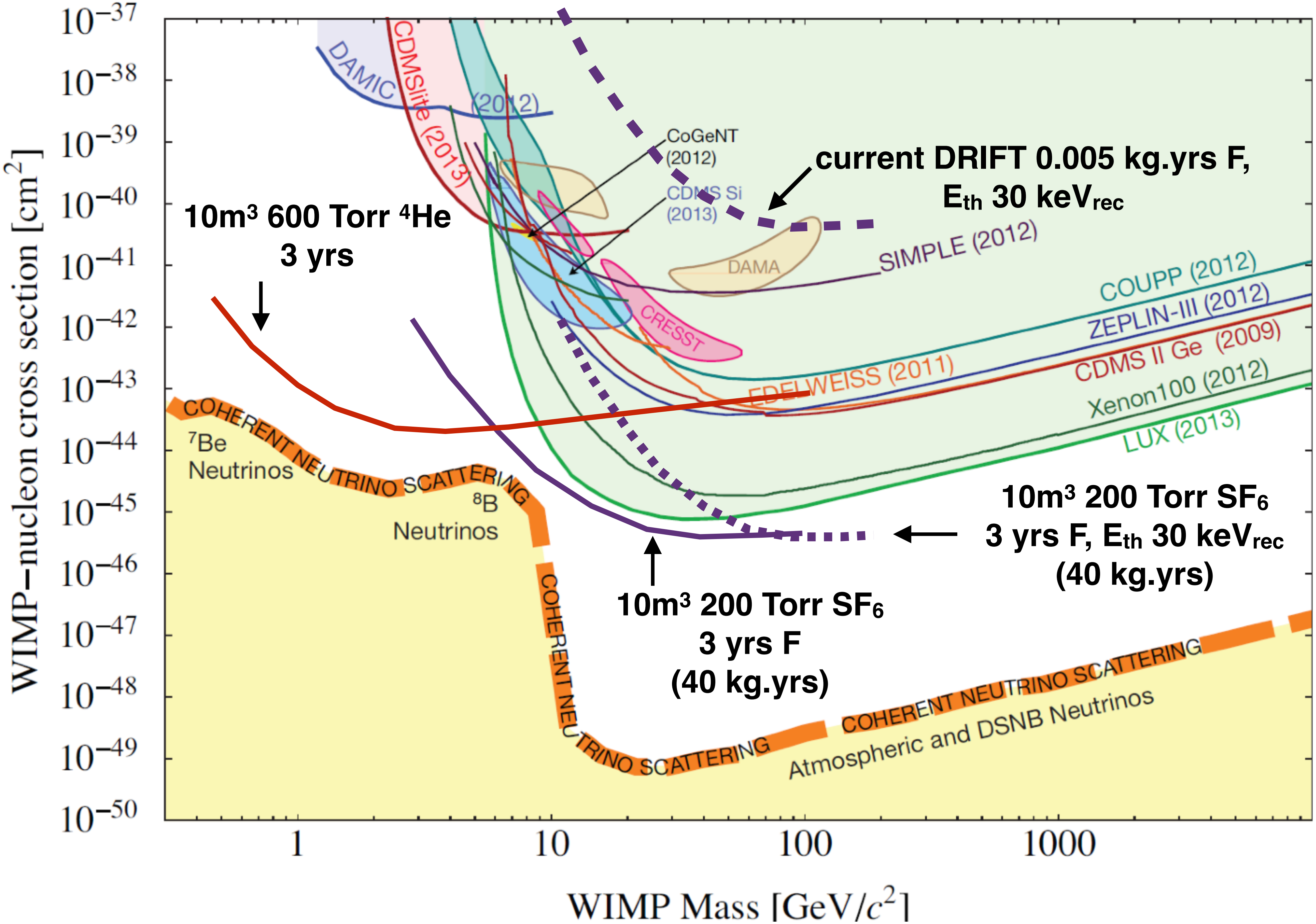
(1) directional sensitivity at 1 x 10^{-4} pb in high mass SD WIMP (~50 GeV), x 2000 below DAMA

(2) non-directional at 2 x 10^{-5} pb in high mass SD WIMP regime (~50 GeV), x 10000 below DAMA

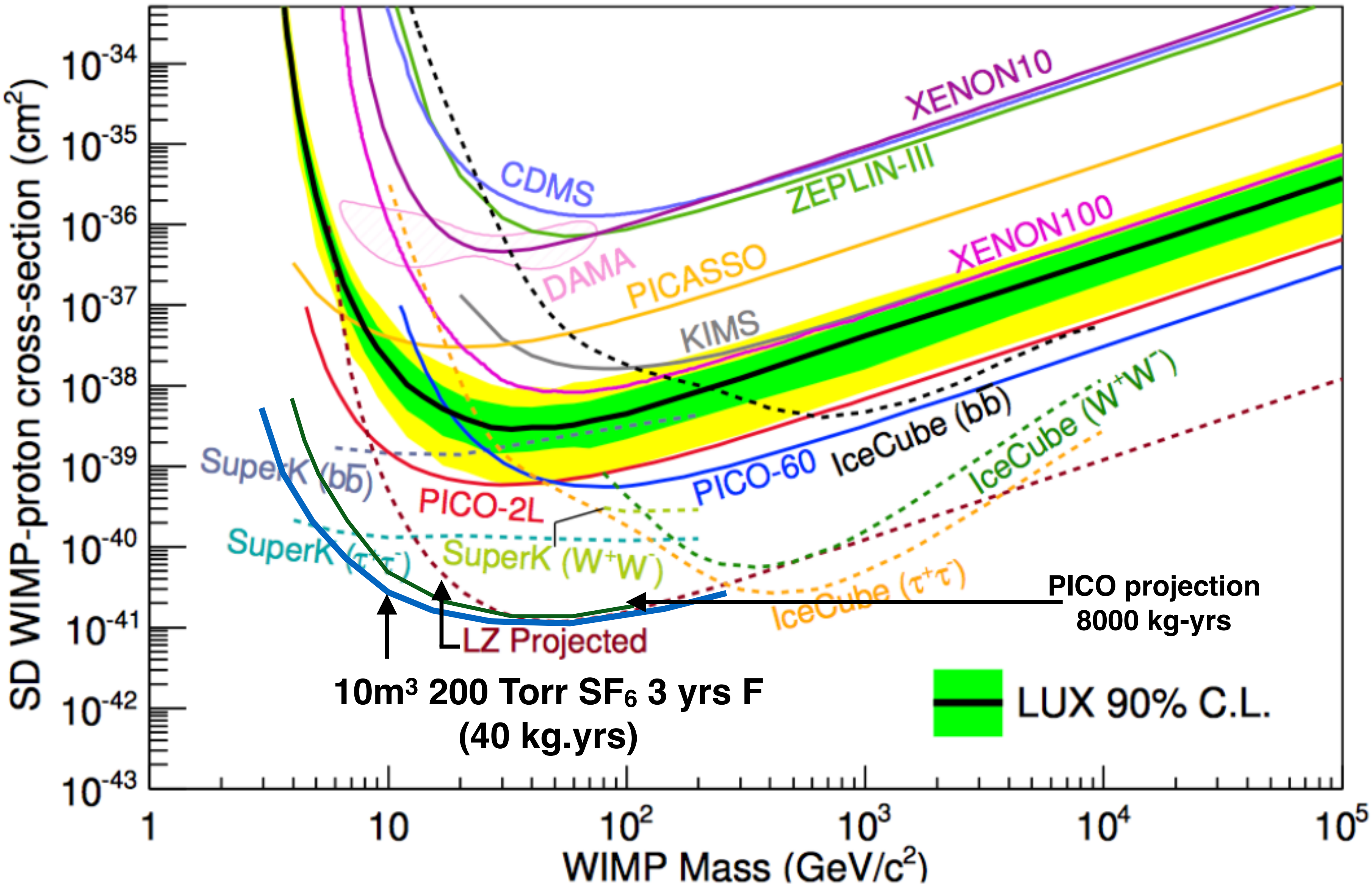
(3) for 10 GeV region sensitivity at 10^{-6} Pb SI

(4) 4 ^8B neutrinos detected with direction sensitivity on

SI Sensitivity for 10m³ SF6:He



SD Sensitivity for 10m³ SF6:He



Conclusion

Idea of a Global Galactic Recoil Observatory

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

Significant progress made recently

(1) Low energy directionality, (2) fiducialisation, (3) SF_6, (4) new lab..

Proto-collaboration underway and growing

Please join in!

CYGNUS Astrophysics and Neutrino Workshop

Jan 30th - Feb 2nd 2017
Melbourne, Australia

CYGNUS2017 Full Workshop

Jun 13th - Jun 15th 2017
Jinping, China