Direction-Sensitive Direct Dark Matter Search

Kentaro Miuchi

KOBE University

Nov 14th 2017

Topical workshop on DARK MATTER

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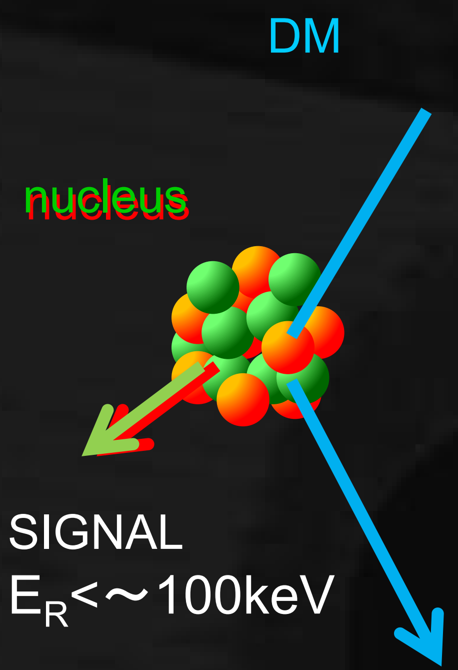
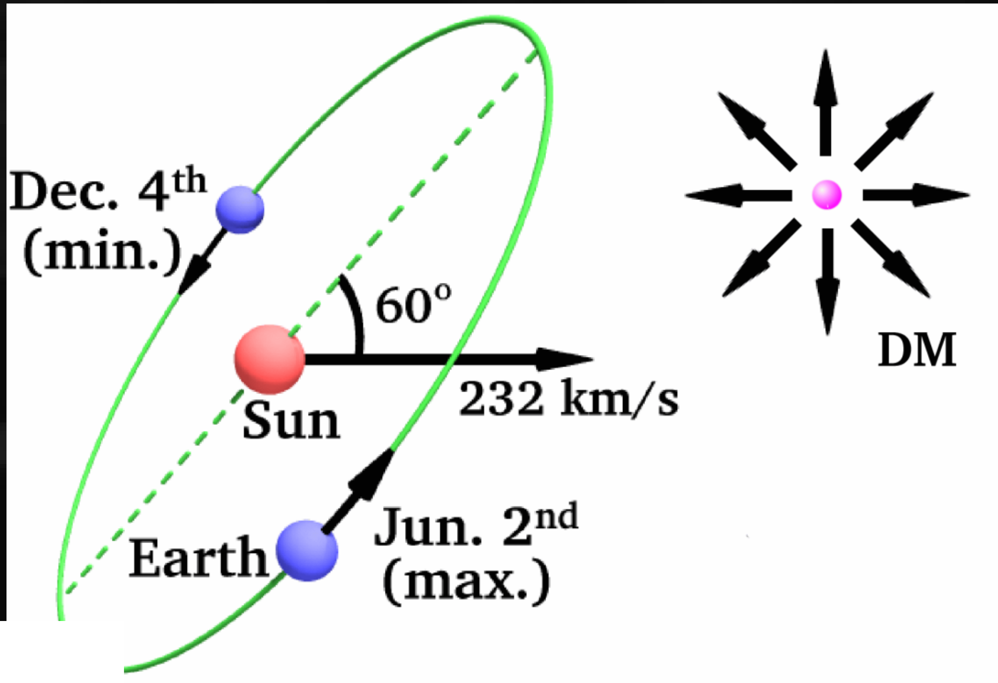
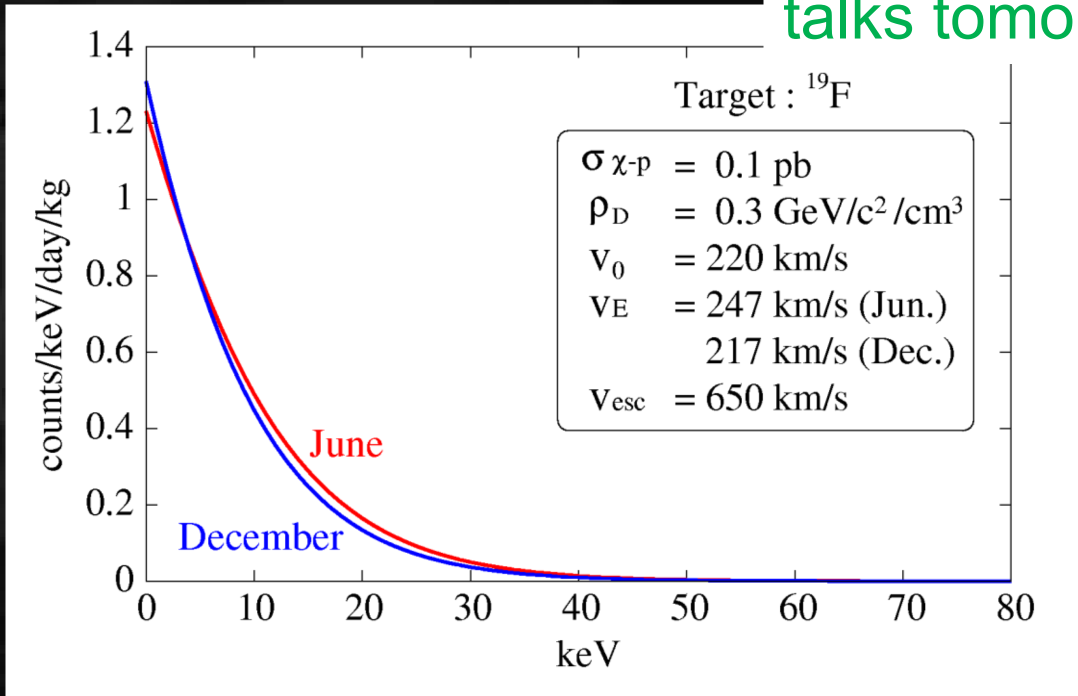
Introduction

DM direct detection







“mainstream”
talks tomorrow

expected direct DM signals

- ① observed * events
- ② energy spectrum
- ③ seasonal modulation
- ④ material dependence
- ⑤ direction-sensitive

"original" literatures: late 1980s

PHYSICAL REVIEW D
PARTICLES AND FIELDS

THIRD SERIES, VOLUME 37, NUMBER 6 — 15 MARCH 1988

Motion of the Earth and the detection of weakly interacting massive particles

David N. Spergel*
Institute for Advanced Study, Princeton, New Jersey 08540
(Received 21 September 1987)

$$\frac{dR}{dE\,d\cos\gamma} = \frac{\rho_0\sigma_0}{\sqrt{\pi}}\frac{(m_x+m_n)^2}{2m_x^3 m_n v_{\rm halo}} \times \exp\left[\frac{-[(v_E+v_\odot)\cos\gamma - v_{\rm min}]^2}{v_{\rm halo}^2}\right]. \qquad (7)$$

Detection of Dark Matter Using Low Pressure Gas Detectors (TPC's)

G. Masek, K. Buckland, M. Mojaver
Physics Department, University of California, San Diego 92093

G. Masek, K. Buckland, M. Mojaver, in: E.B. Norman (Ed.), Proceedings of the Workshop on Particle Astrophysics, World Scientific, Singapore, 1989, p. 41.

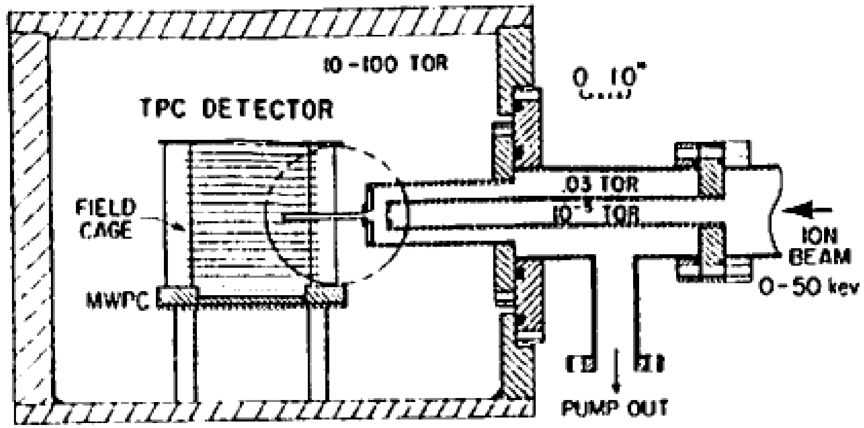


Fig. 2: Set up for observing low energy (kev) ion tracks. The circled region is the locaton of the differential pumping holes.

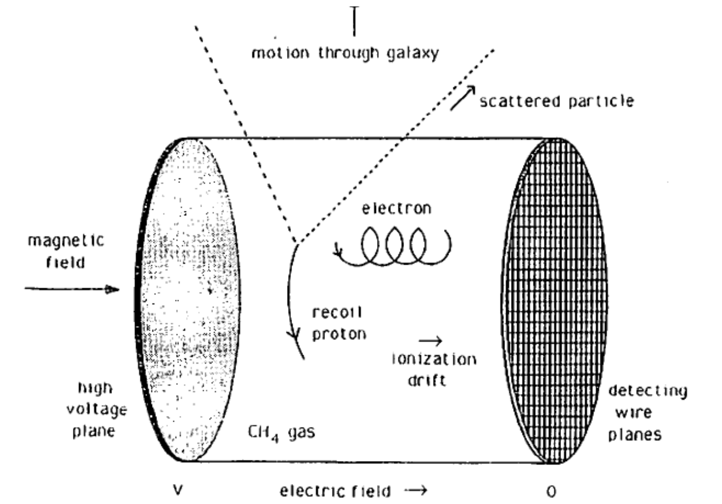
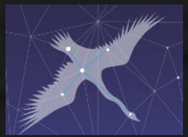


Fig. 13.1. Directional detection scheme proposed by Rich and Spiro [13.7] utilizing low pressure gas in a TPC geometry.

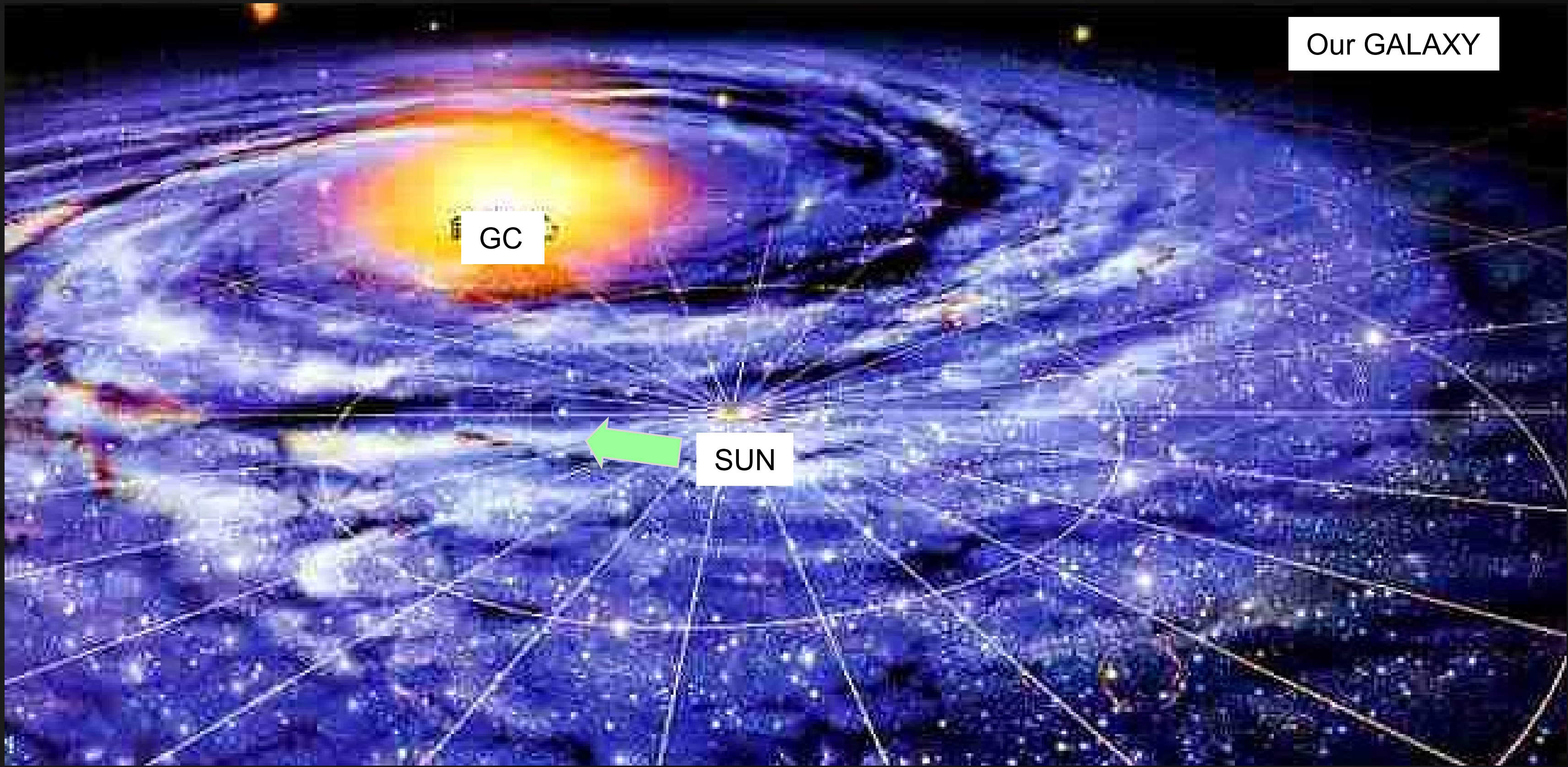
30 years later, many up-to-date detectors are begin developed

Science

Direction-Sensitive Dark Matter Search concept "CYGNUS"



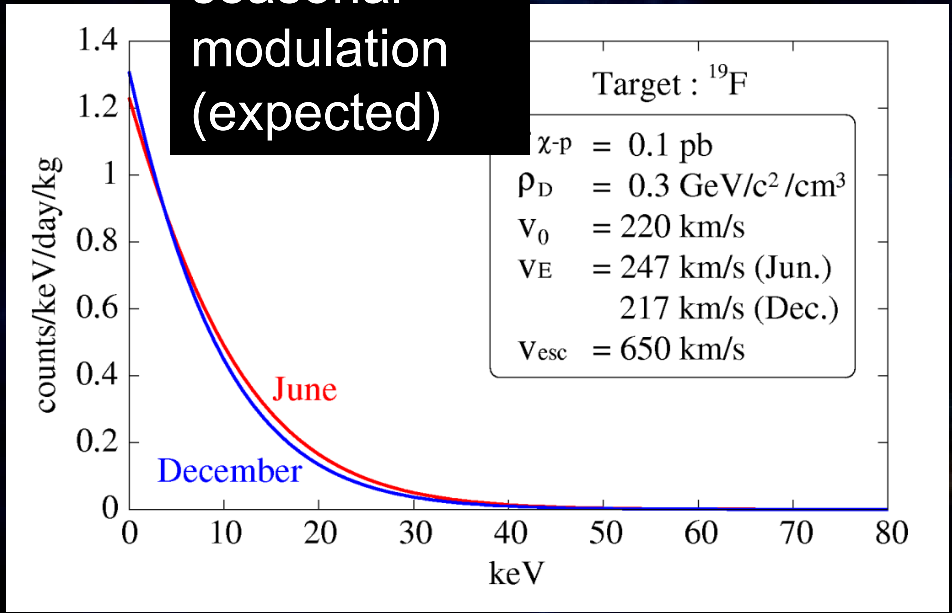
constellation "CYGNUS"



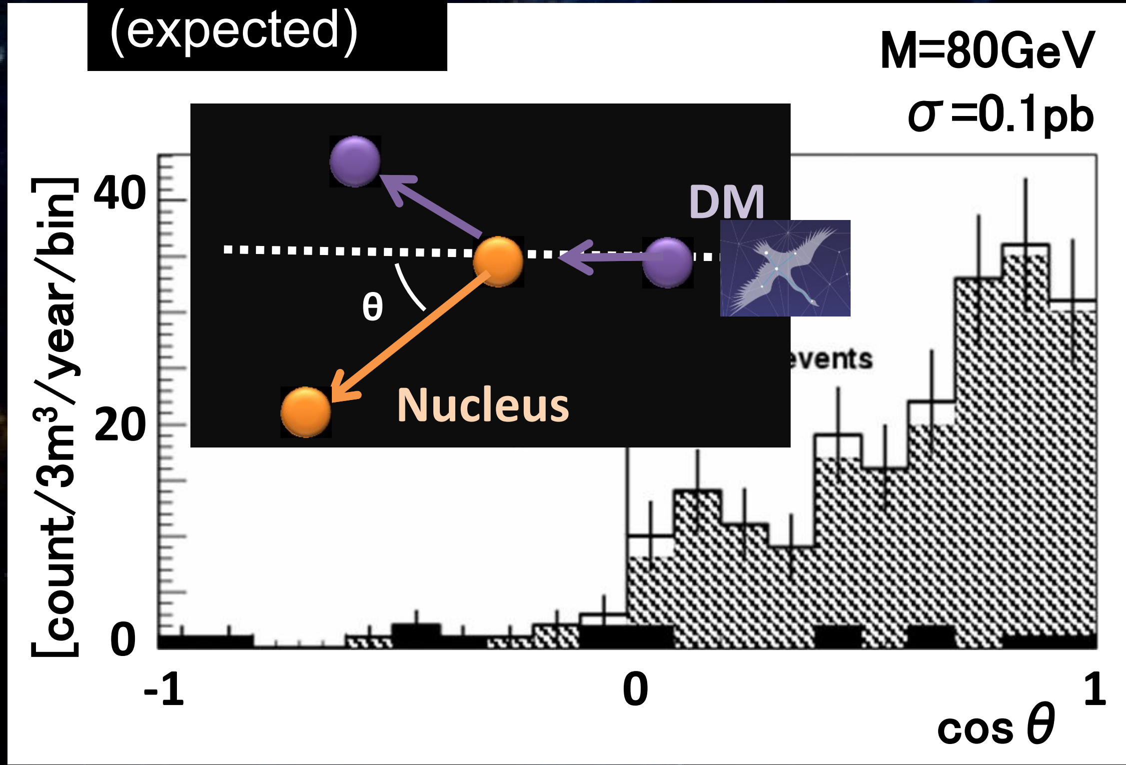
WIMP-WIND from "CYGNUS"

"CYGNUS" concept

seasonal modulation (expected)



directionality (expected)



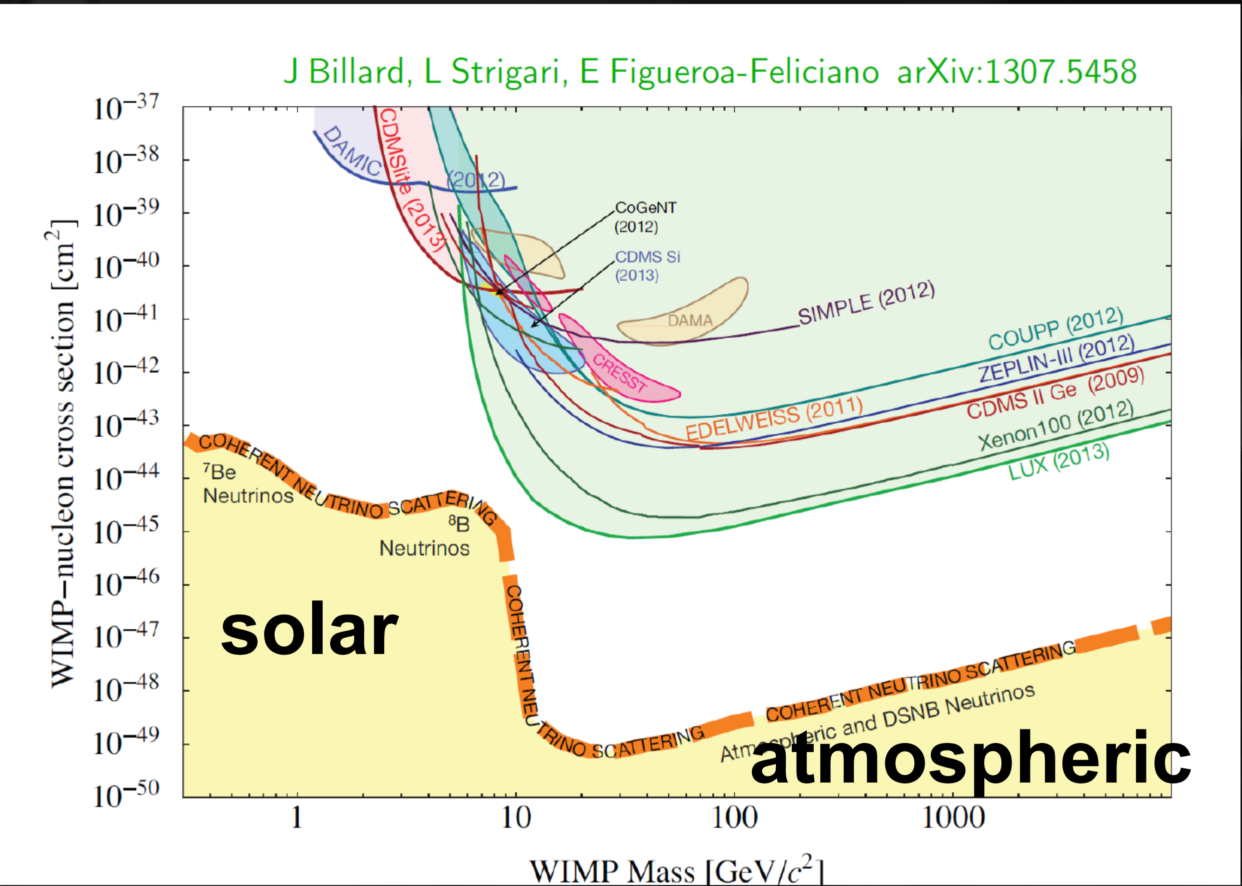
Clear Discovery

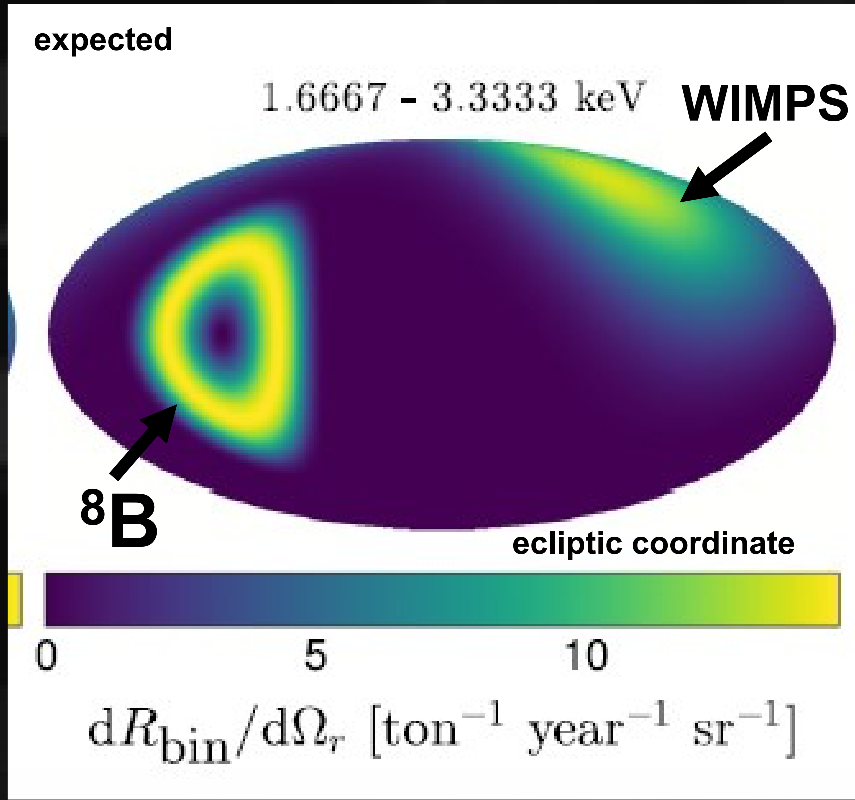
+ study the nature of DM after discovery

"CYGNUS" physics towards discovery

- Potential to search beyond the "neutrino floor"†

F. Mayet et al. / Physics Reports 627 (2016) 1–49





- clearly distinguishable

† neutrino-nucleus coherent scatteri
really exists!

“CYGNUS” physics after discovery

Astrophysics ①

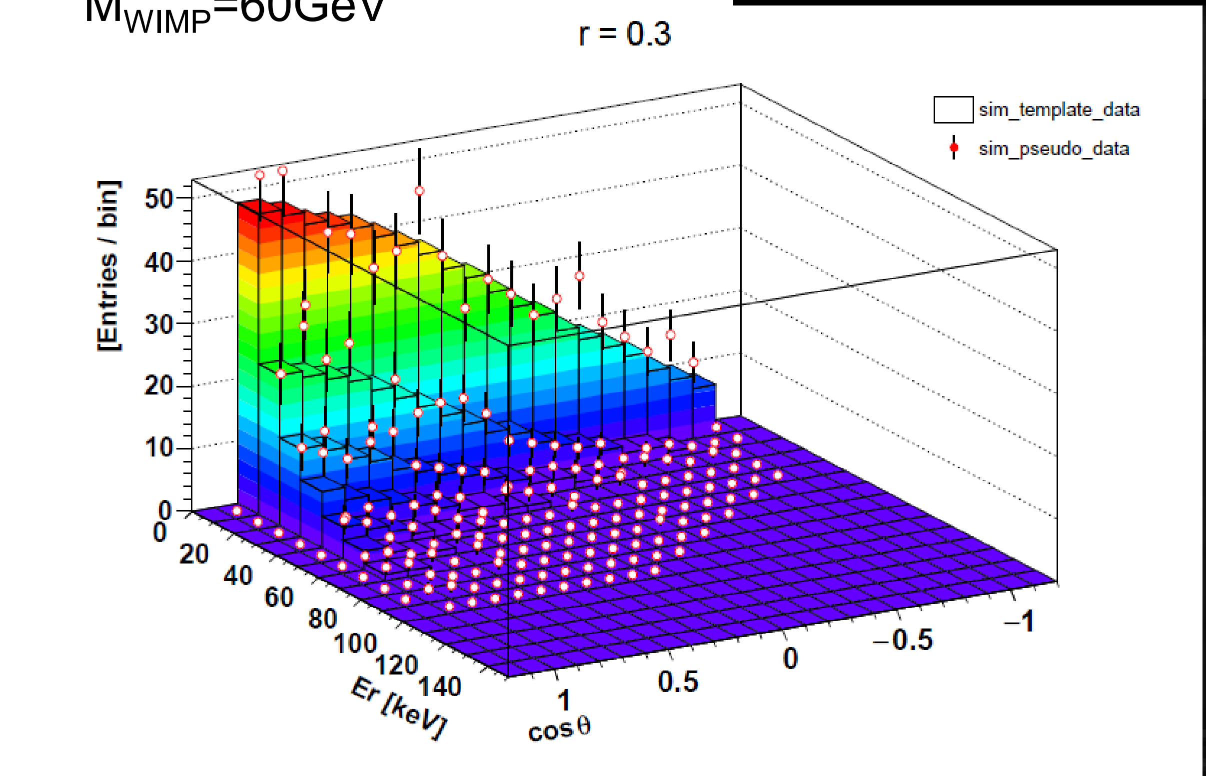
- standard halo (1-r) + co-rotating halo (r)

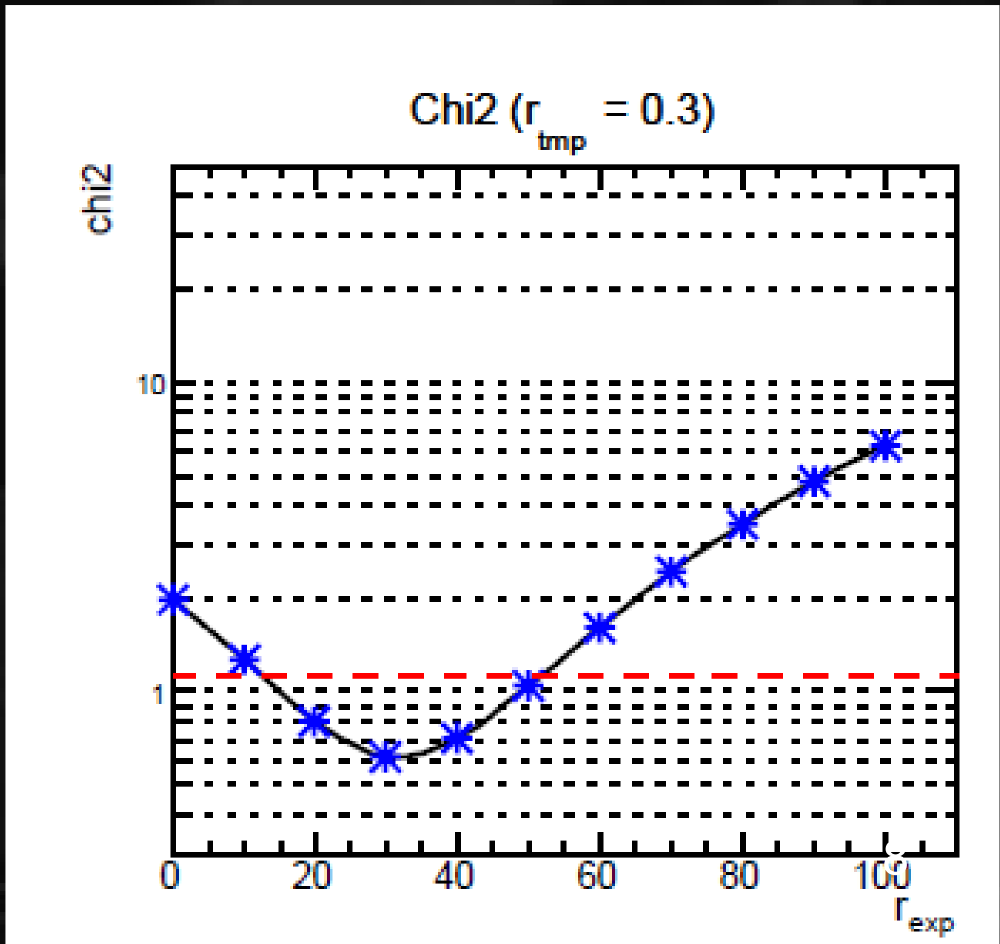
arXiv:1707.05523v1

Discrimination of anisotropy in dark matter velocity distribution with directional detectors

Keiko I. Nagao*, Ryota Yakabe†, Tatsuhiro Naka‡, Kentaro Miuchi§

standard “spectrum” in AD era

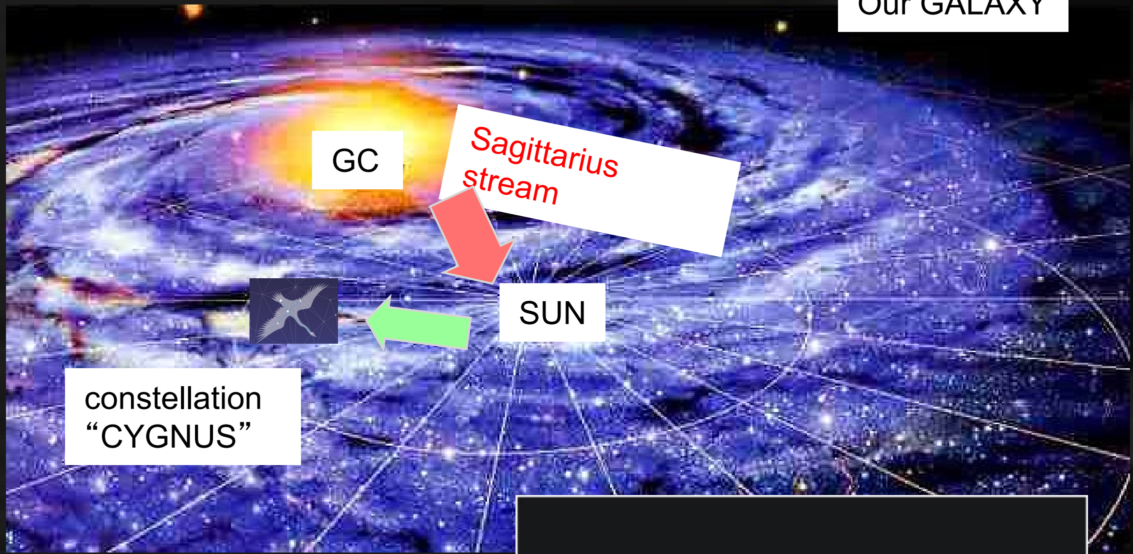


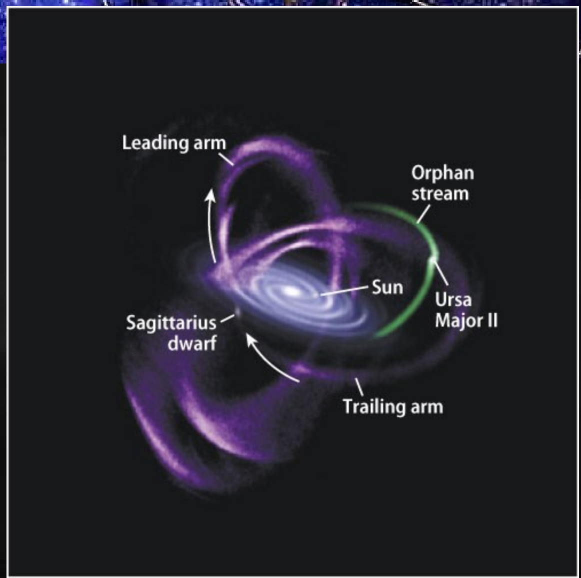


“CYGNUS” physics after discovery

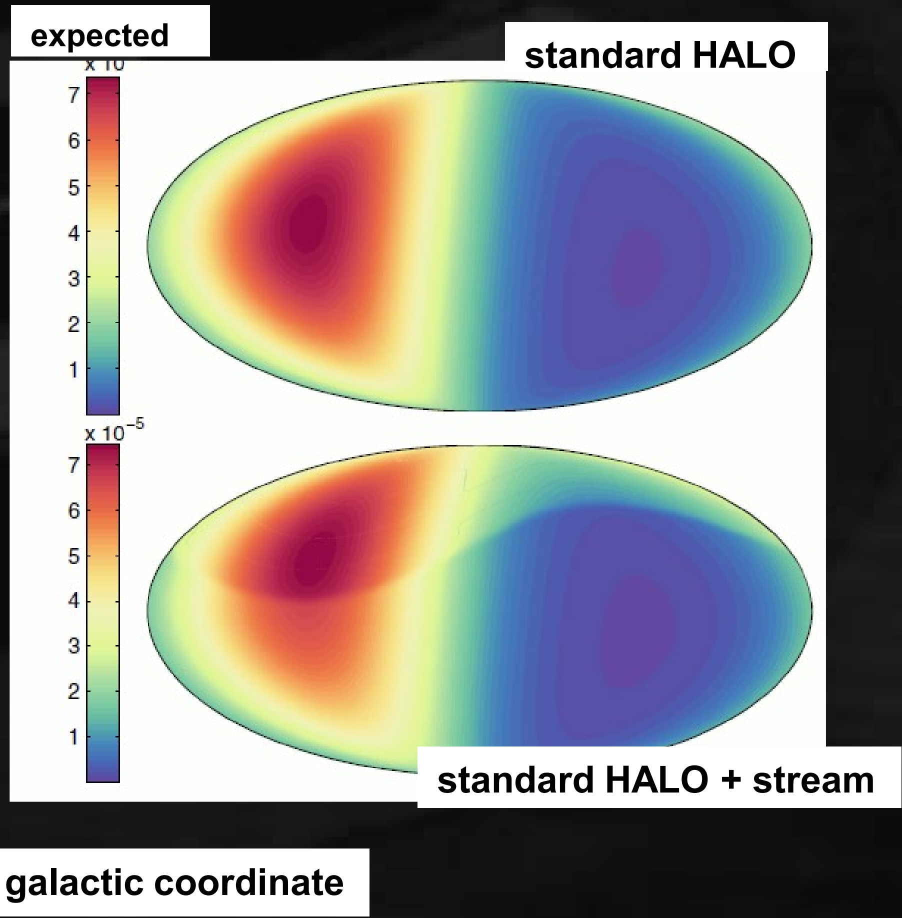
Astrophysics②

- ex. Sagittarius stream





PHYSICAL REVIEW D **90**, 123511 (2014)



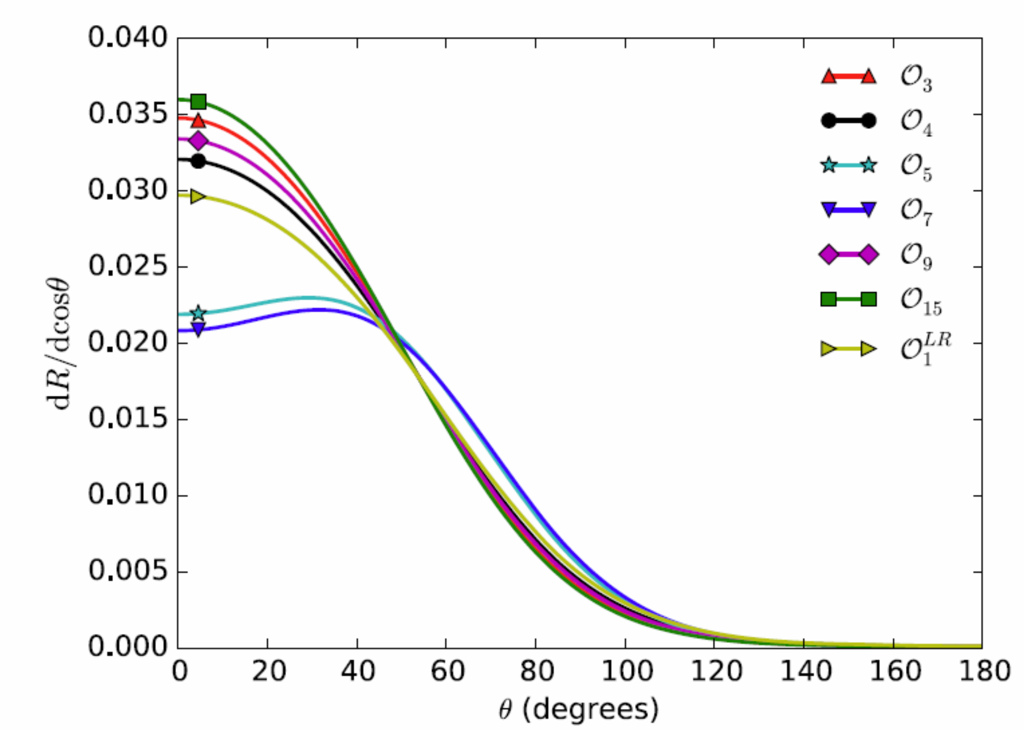
- streams, halo model…

“CYGNUS” physics after discovery

Particle physics①

- Test the interaction by scattering angle

PHYSICAL REVIEW D **92**, 023513 (2015)



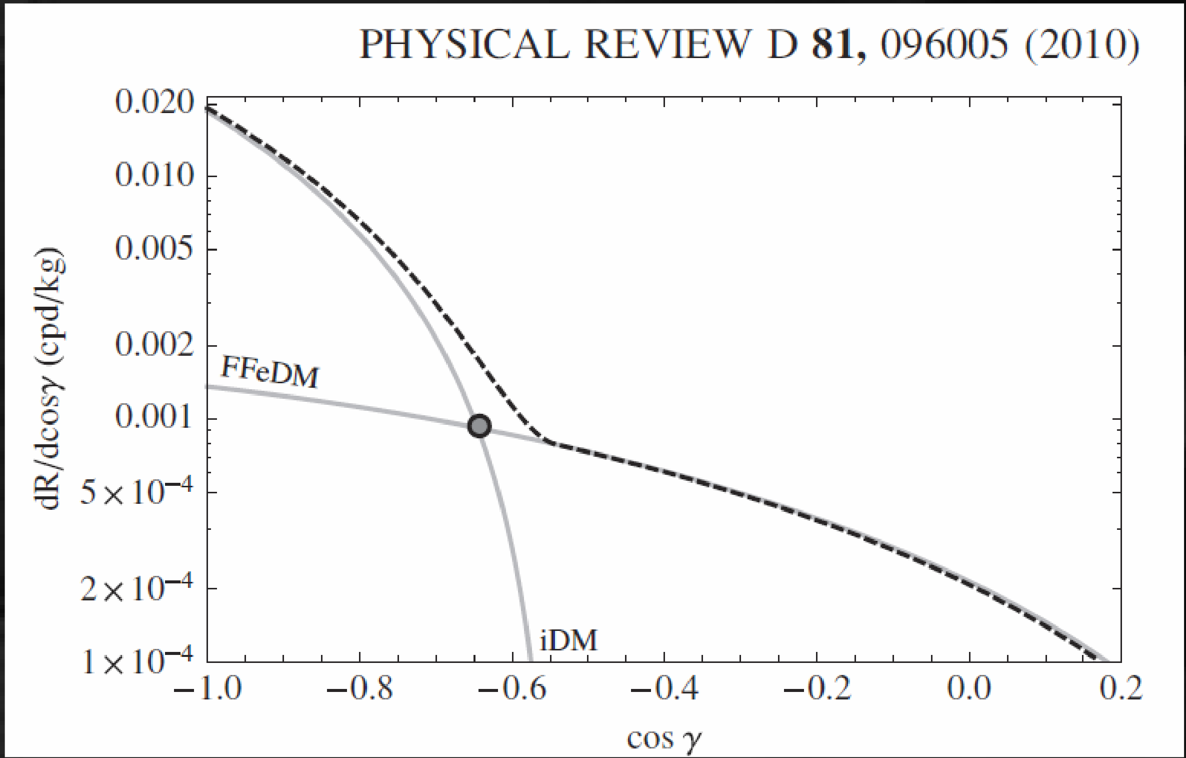
SI **SD**

$$\text{Proportional to} \begin{cases} 1 & : \mathcal{O}_1, \mathcal{O}_4, \\ v_\perp^2 & : \mathcal{O}_7, \mathcal{O}_8, \\ q^2 & : \mathcal{O}_9, \mathcal{O}_{10}, \mathcal{O}_{11}, \mathcal{O}_{12}, \\ v_\perp^2 q^2 & : \mathcal{O}_5, \mathcal{O}_{13}, \mathcal{O}_{14}, \\ q^4 & : \mathcal{O}_3, \mathcal{O}_6, \\ q^4(q^2 + v_\perp^2) & : \mathcal{O}_{15}, \\ q^{-4} & : \mathcal{O}_1^{\mathrm{LR}}. \end{cases}$$

- some operators are distinguishable

"CYGNUS" physics after discovery

- **Particle physics②**
  - **inelastic scattering**



- **iDM (inelastic scatterings dark matter) and normal darkmatter (FFeDM** (form factor elastic dark matter)) **show different angular DISTRIBUTION**

Experiments

Experimental concept

Recoil nuclear track detection < 100keV

challenge: short track

a few mm in low pressure gas

a few 100 nm in solid

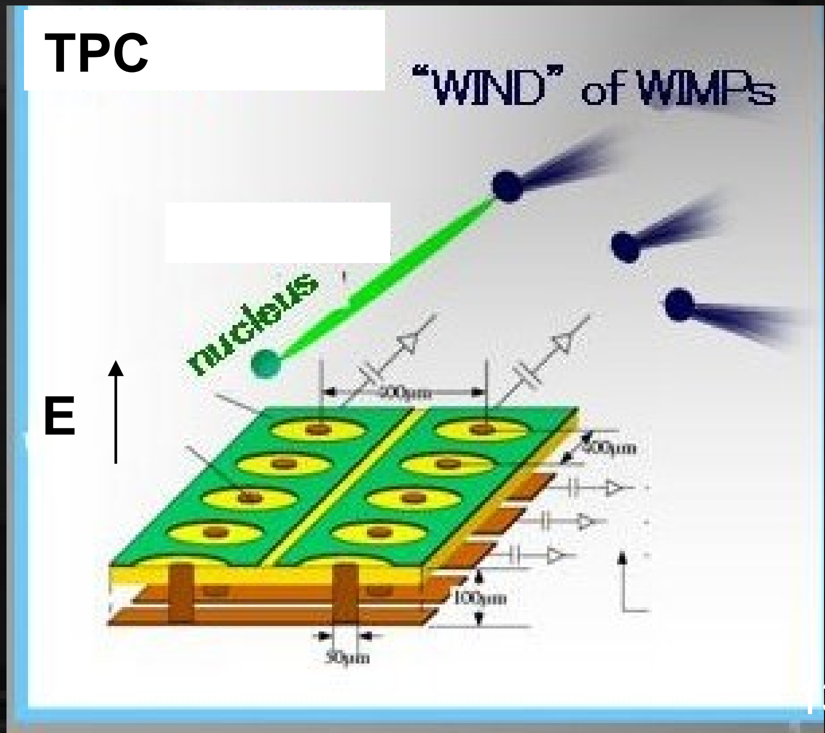
Most typical "CYNGUS":

low pressure gas TPC

(time projection chamber)

2D readout + timing

→ 3D tracking



Cygnus, nonTPC

NEWSdm
[Japan+Italy]

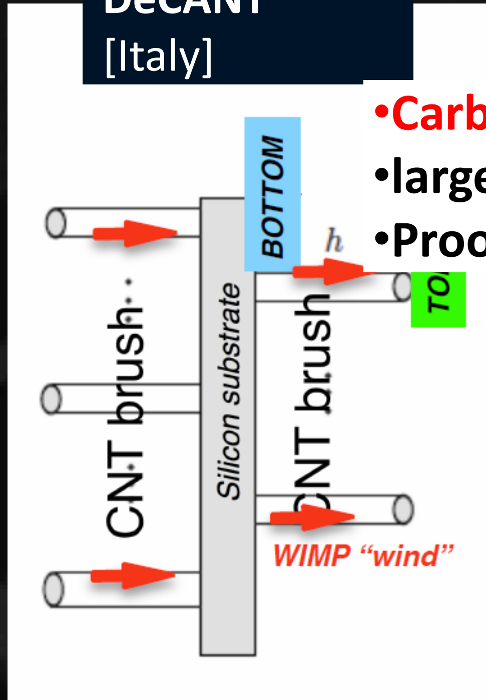
Astroparticle Physics 80 (2016) 16–21

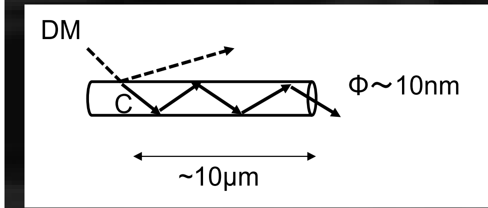
- emulsion (20~50nm crystal)
- good position resolution
- large mass
- No time resolution

DeCANT
[Italy]

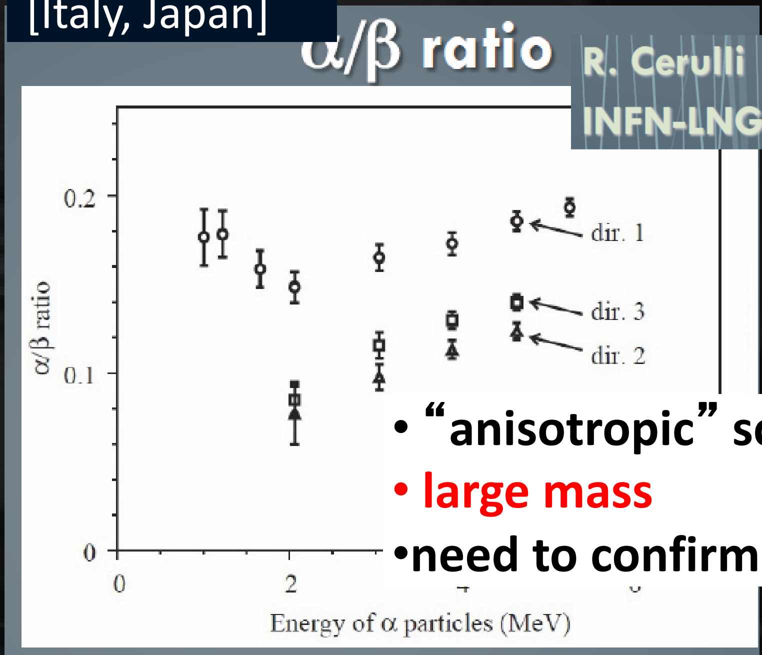
Physics of the Dark Universe 9–10 (2015) 24–30

- Carbon nano tube
- large mass
- Proof of concept is ongoing





$ZnWO_4$
[Italy, Japan]

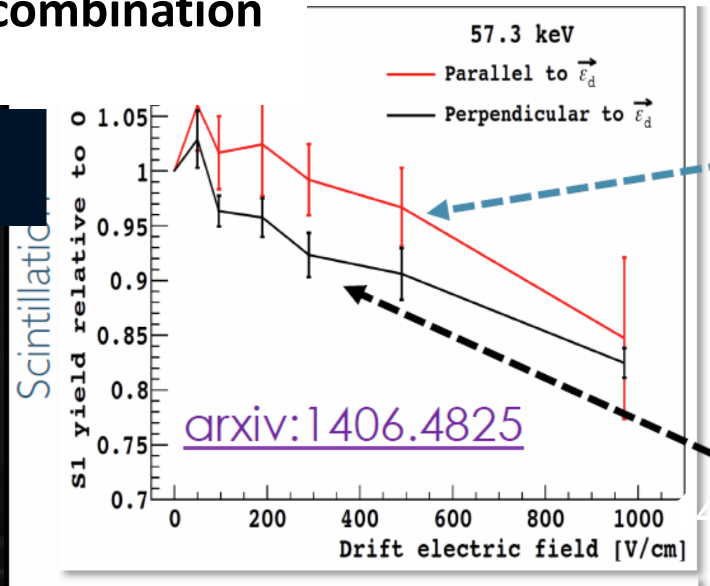


- "anisotropic" scintillator
- large mass
- need to confirm in low energy

- columnar recombination
- large mass

Liq Ar
[Italy, Japan]

PHYSICAL REVIEW D **91**, 092007 (2015)



DRIFT: pioneer of "CYGNUS" concept

- **early 2000s ~**
  - large TPC
  - low BG study

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 463 (2001) 142–148

RESEARCH Section A

www.elsevier.nl/locate/nima

Measurement of carbon disulfide anion diffusion in a TPC

Tohru Ohnuki[a,*], Daniel P. Snowden-Ifft[a], C. Jeff Martoff[b]

[a] Department of Physics, Occidental College, 1600 Campus Road, Los Angeles, CA 90041-3314, USA

[b] Department of Physics, Temple University, 1900 N. 13th Street, Philadelphia, PA 19122-6082, USA

Received 15 May 2000; received in revised form 13 November 2000; accepted 14 November 2000

Nuclear Instruments and Methods in Physics Research A 498 (2003) 155–164

RESEARCH Section A

www.elsevier.com/lo

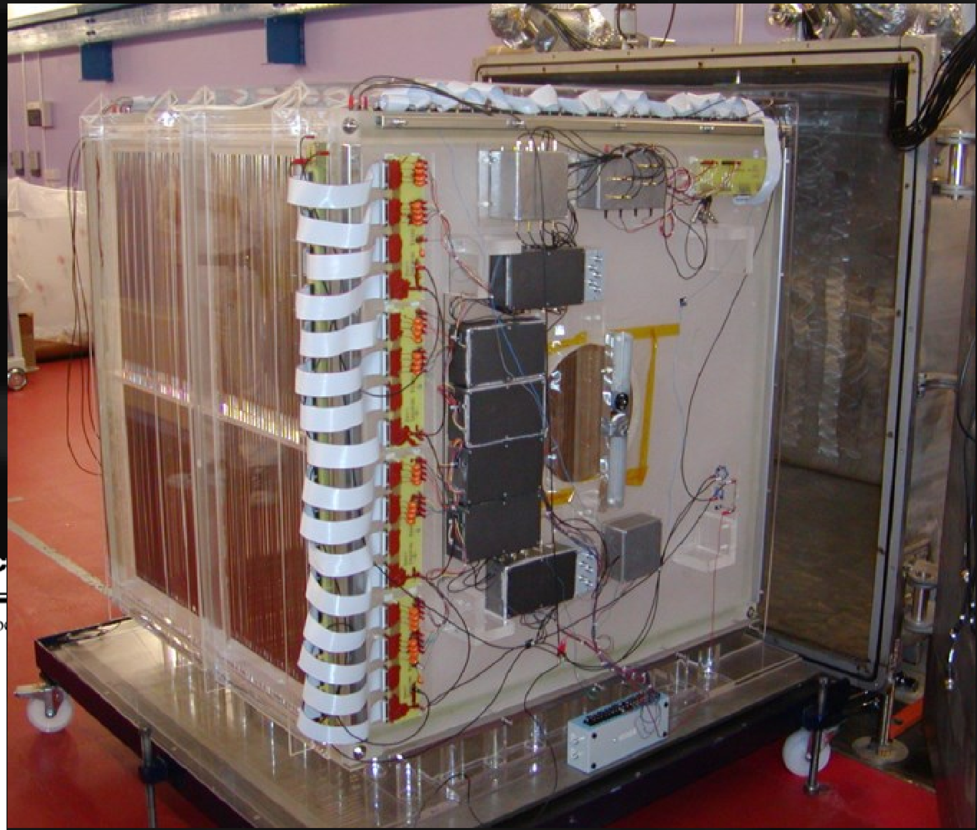
Neutron recoils in the DRIFT detector

D.P. Snowden-Ifft[a,b,*], T. Ohnuki[a,b], E.S. Rykoff[a,b], C.J. Martoff[a,b]

[a] Physics Department, Occidental College, 1600 Campus Road, Los Angeles, CA 90041, USA

[b] Barton Hall, Temple University, 1900 N. 13th St., Philadelphia, PA 19122-6082, USA

Received 5 July 2002; received in revised form 11 October 2002; accepted 27 November 2002

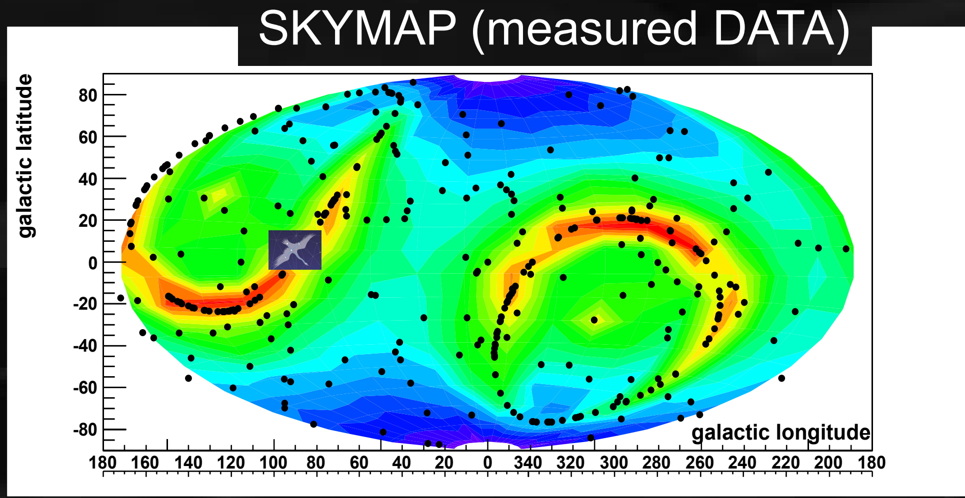


- 2mm pitch multi-wire proportional chamber
- not very direction-sensitive

NEWAGE: always direction-sensitive

New general WIMP search with an Advanced Gaseous tracker Experiment

- μ-PIC(MPGD) based TPC
  - 3-D tracks SKYMAP
- CF_4 gas for SD search



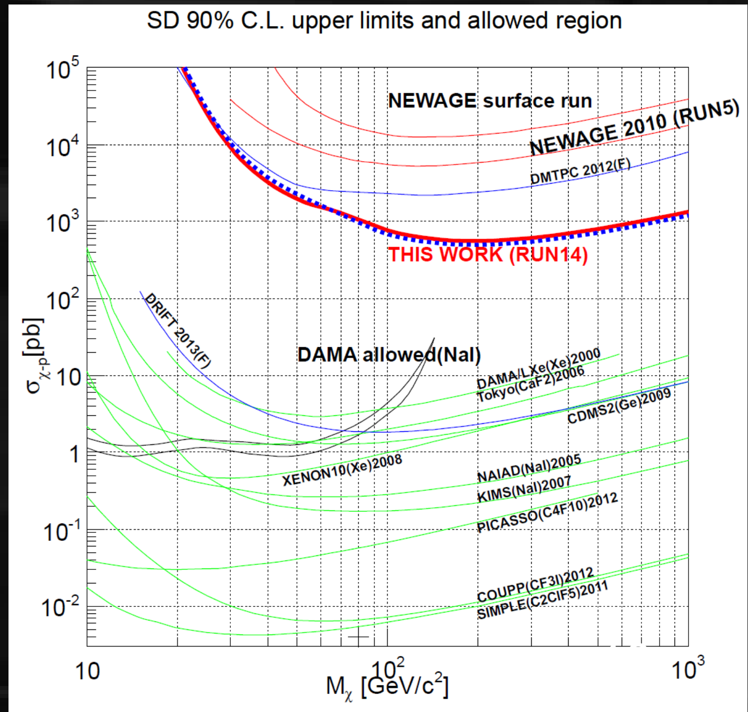
- Proposal PLB 578 (2004) 241
- First direction-sensitive limits

  PLB654 (2007) 58

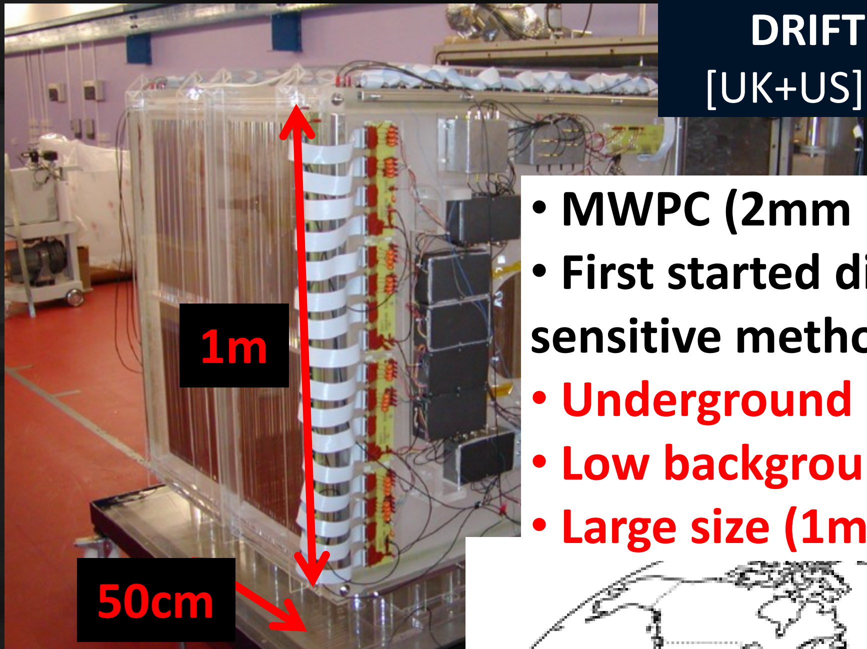
- Underground results

  PLB686 (2010) 11, PTEP (2015) 043F01s

- Phase for “low BG detector”

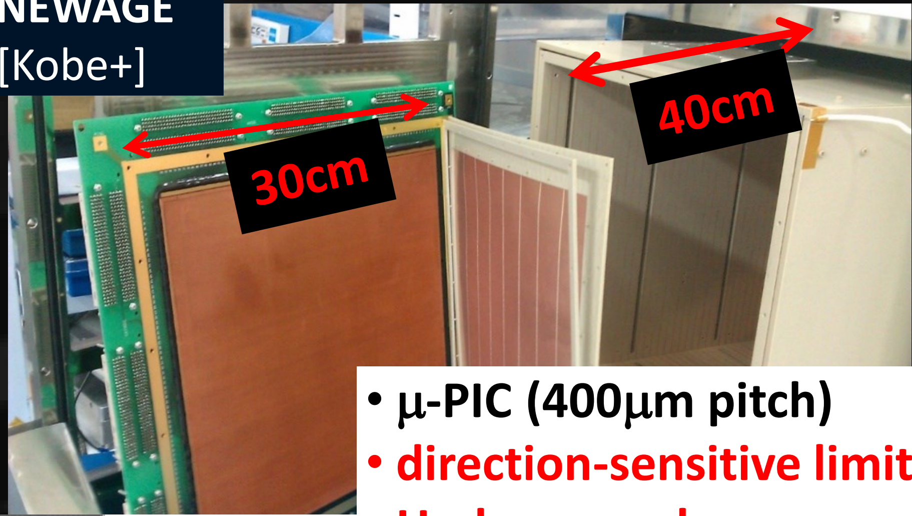


Cygnus, gas TPCs



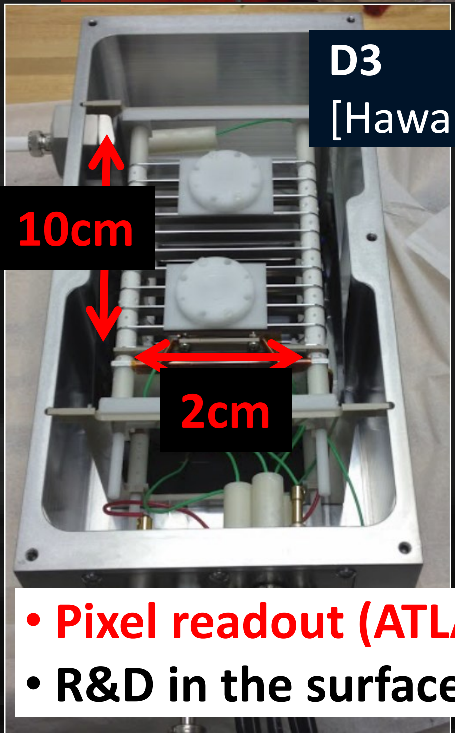
DRIFT
[UK+US]

- MWPC (2mm pitch)
- First started direction-sensitive method
- Underground
- Low background
- Large size ($1m^3$)



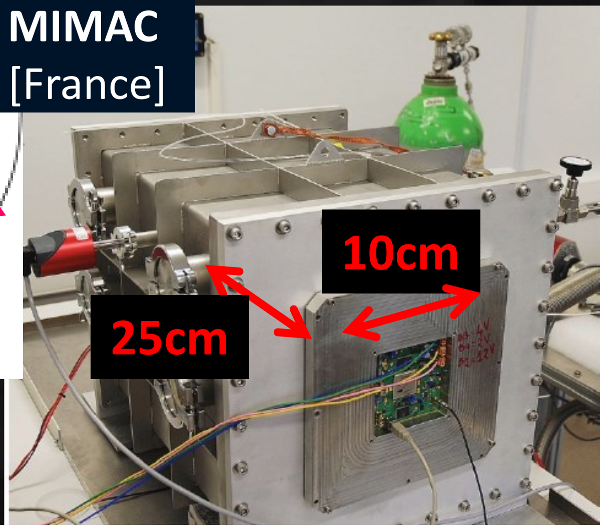
NEWAGE
[Kobe+]

- μ-PIC (400μm pitch)
- direction-sensitive limit
- Underground



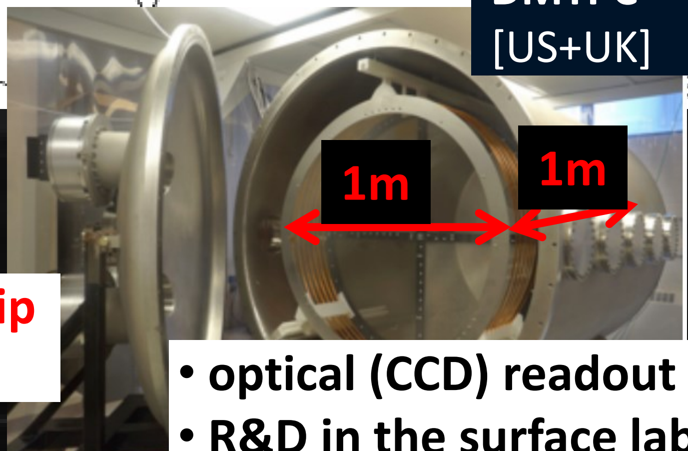
D3
[Hawaii]

- Pixel readout (ATLAS FE-I4) chip
- R&D in the surface lab



MIMAC
[France]

- Micromegas (~400μm pitch)
- quenching factor measurement



DMTPC
[US+UK]

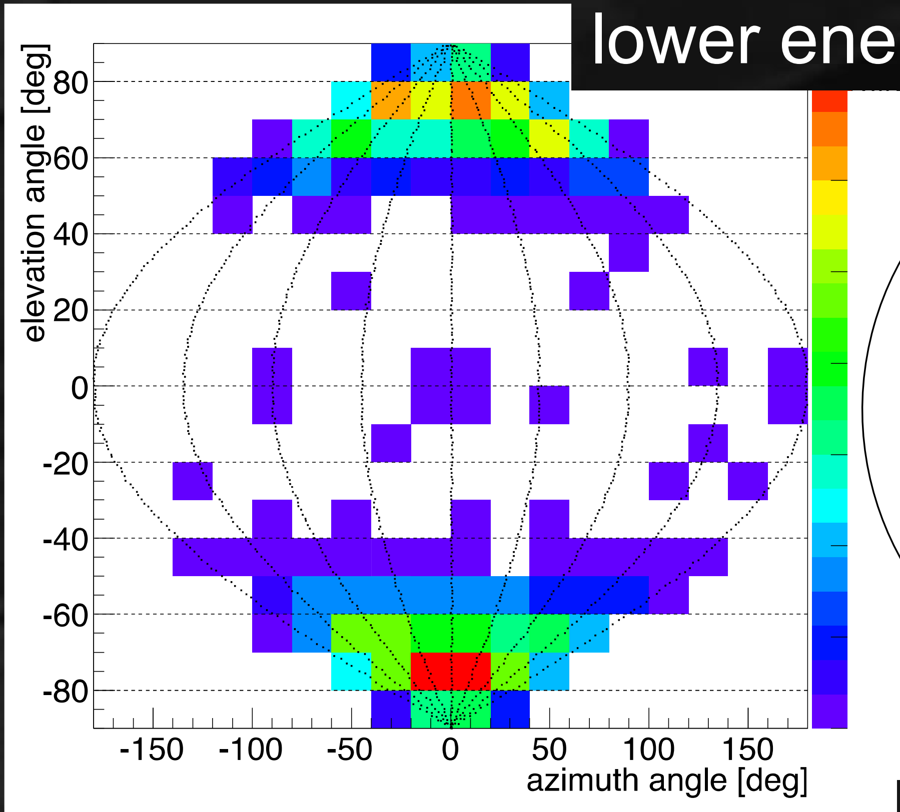
- optical (CCD) readout
- R&D in the surface lab

Technologies
State-of-theArt

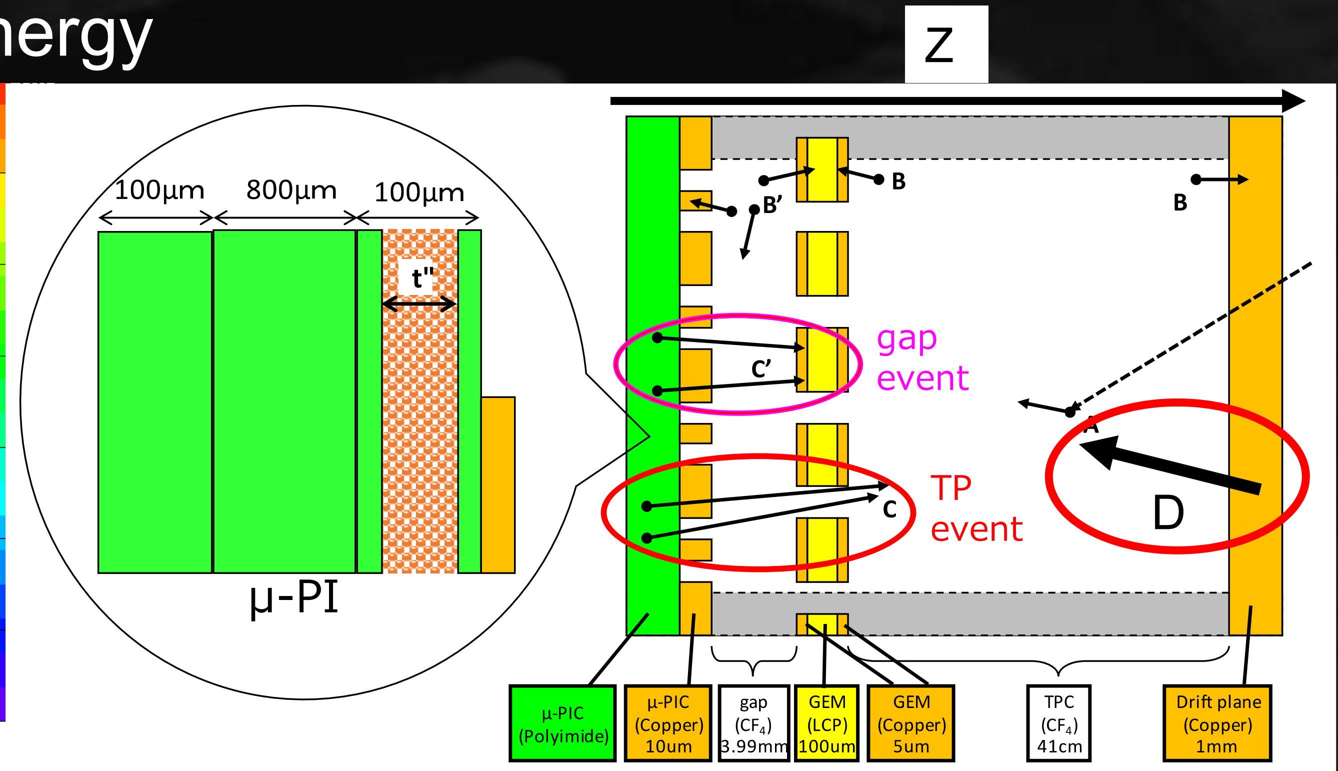
Main Background

- **From directional analysis: C and D below**

  SKYMAP @ detector coordinate



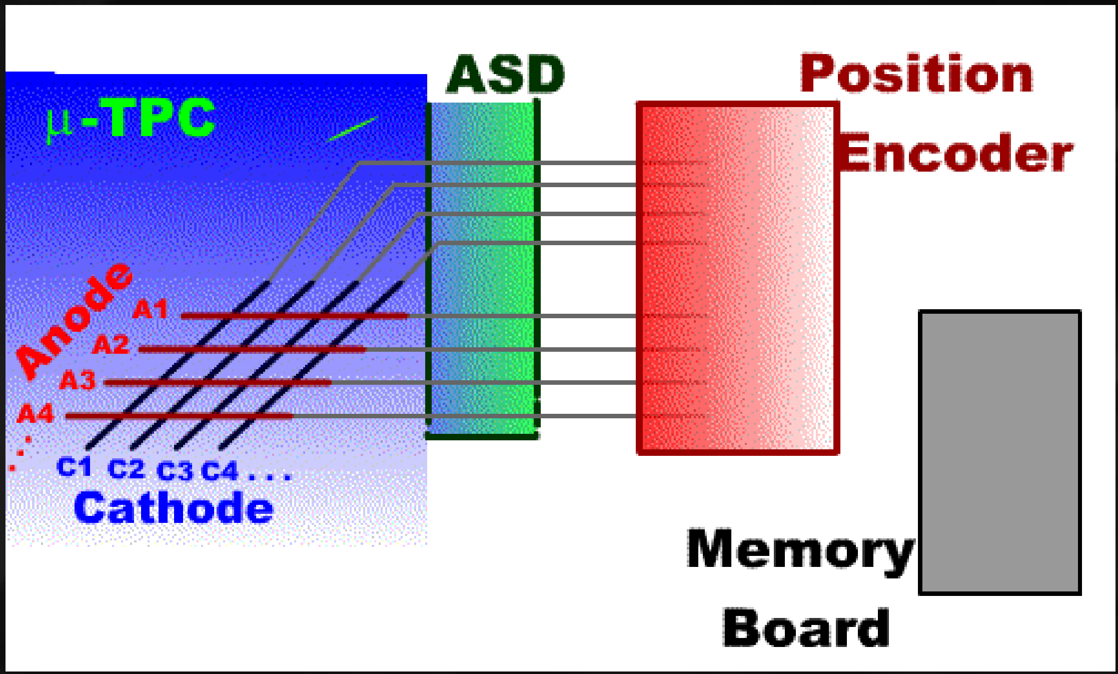
lower energy



- **reason: absolute “Z” position cannot be measured…**

absolute Z position…

- for 2-phase xenon detector: trigger timing (t_0) is given from S_1
- for self-triggering TPC: t_0 cannot be detected
  → Z-fudicialization is not possible

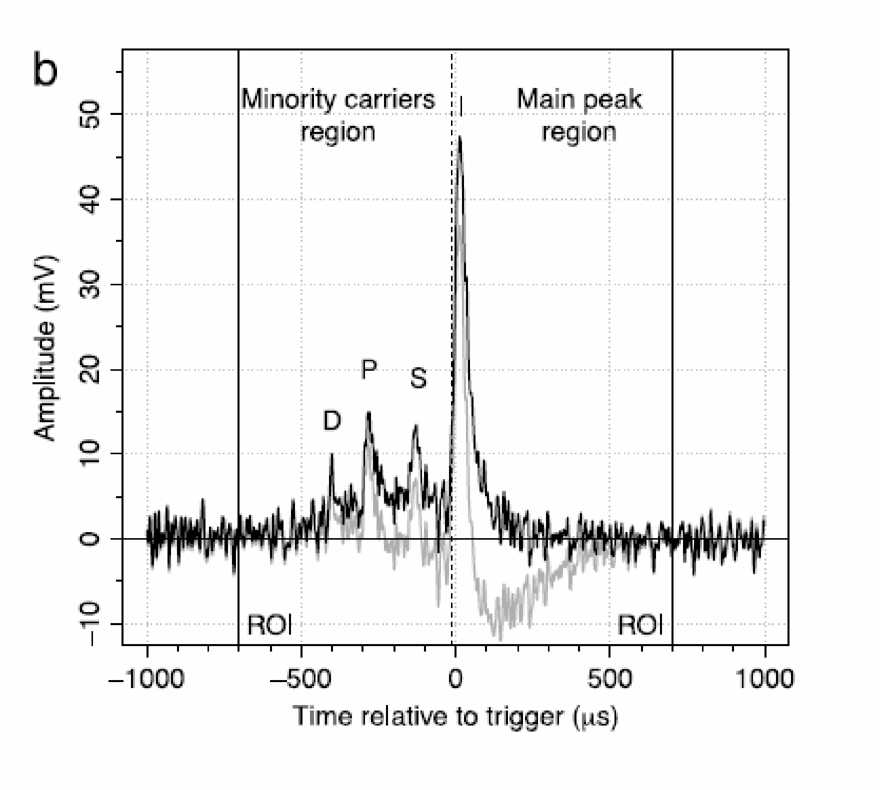


Direction Sensitive WIMP-search NEWAGE

breakthrough for “z” detection

- minority peaks “discovery” （Occidental college group）
- O_2 addition to CS_2+CF_4 gas
  - CS_2 : used as negative ion gas for small diffusion
  - CF_4 : added as dark matter target
  - O_2 : accidentally mixed

minority peaks



J.B.R. Battat et al. / Physics of the Dark Universe 9–10 (2015) 1–7

several species of ions with different velocities

$$z = (t_a - t_b)\frac{v_a v_b}{(v_b - v_a)}$$

z-fidutialzation realized at last!

but… CS_2 gas is toxic, volatile, flammable

Direction Sensitive WIMP-search NEWAGE

2^{nd} breakthrough (2015)

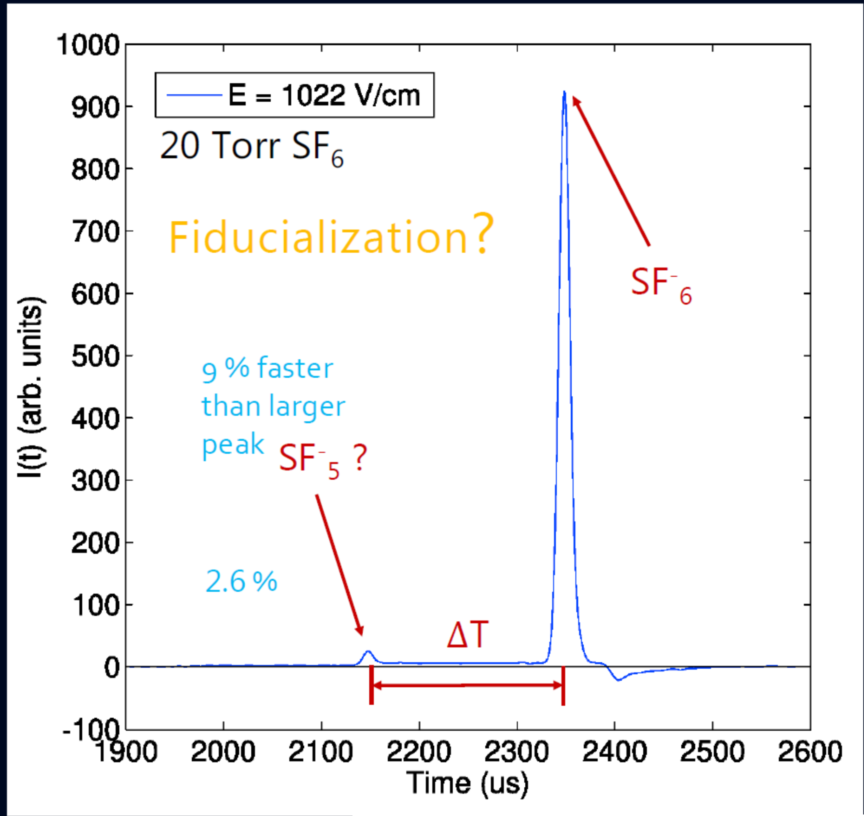
SF_6 gas (NEW MEXICO group)

- SF_6 : famous insulator gas (safe gas)
  → found to have minority carriers

First Studies of SF_6 in a TPC

NGUYEN PHAN, ERIC LEE
UNIVERSITY OF NEW MEXICO

2017 JINST 12 P02012



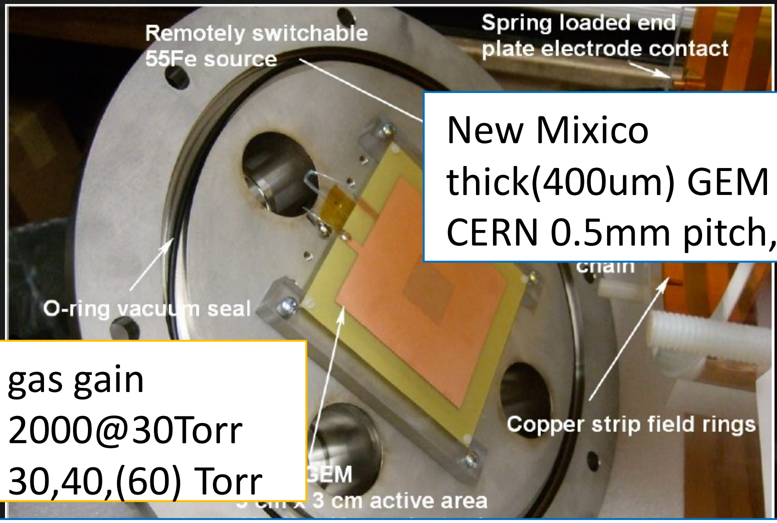
averaged waveform

minority carrier is really minor

Direction Sensitive WIMP search NEWAGE

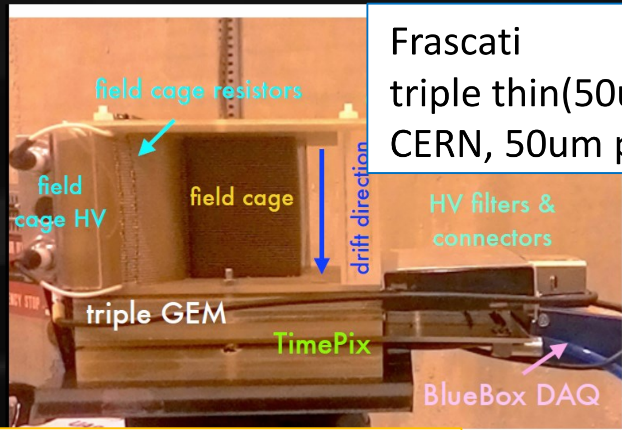
World-wide SF_6 activities

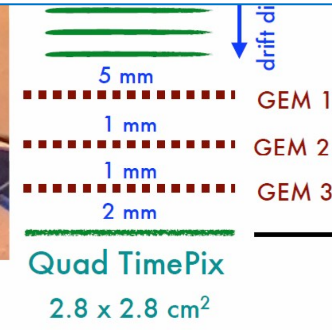
- **Wide varieties of MPGD(micro patterned gaseous detectors)**
- **very active, new comers are welcome!**



New Mixico
thick(400um) GEM (3 × 3cm^2)
CERN 0.5mm pitch, Φ0.3mm

gas gain
2000@30Torr
30,40,(60) Torr

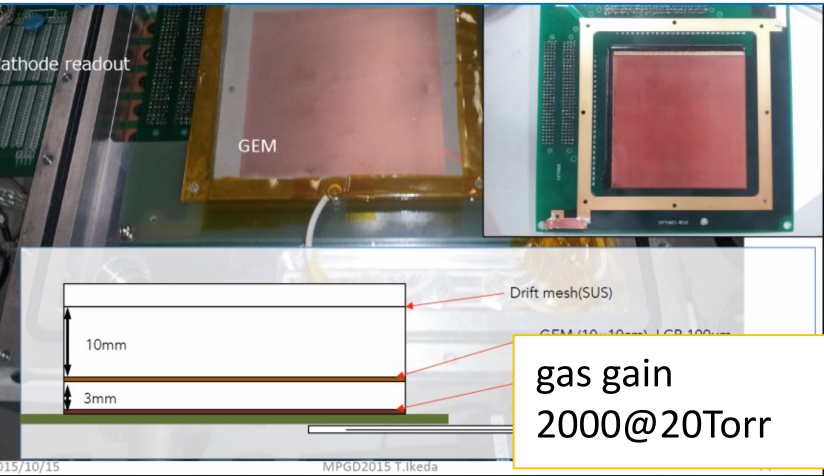




Frascati
triple thin(50um) GEM (3 × 3cm^2
CERN, 50um pitch, Φ30um

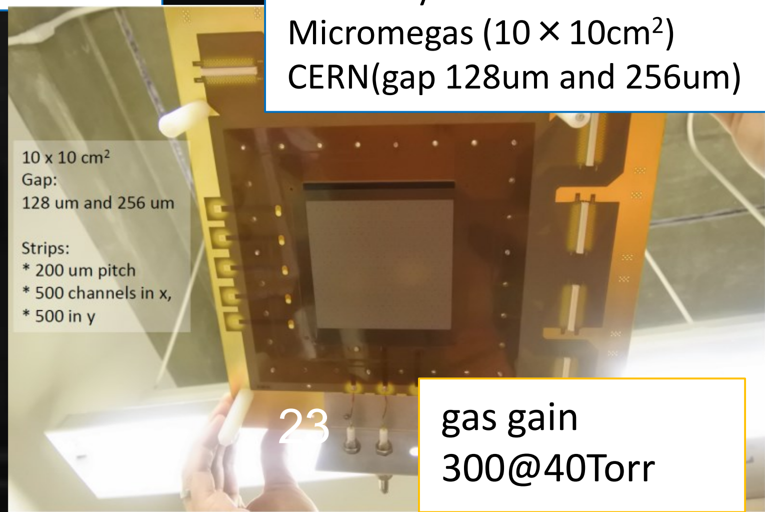
gas gain
5000@ 175Torr, 2000@370Torr

Kobe
thin(100um) GEM (10 × 10cm^2) Scienergy, 140um pitch, Φ70um
+ μ-PIC(10 × 10cm^2) DNP, 400um pitch strip readout
triple thin (100um) GEM Scienergy, 140um pitch, Φ70um



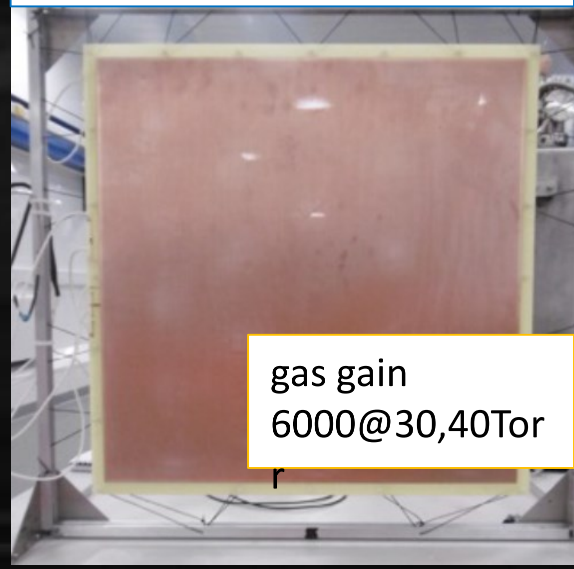
gas gain
2000@20Torr

Wellesley
Micromegas (10 × 10cm^2)
CERN(gap 128um and 256um)



gas gain
300@40Torr

Sheffield
thick(400um) GEM(50 × 50cm^2)
UK , 0.5 um pith Φ0.3um



gas gain
6000@30,40Tor
r

“CYGNUS” concept to collaboration

2007 ～ biannual workshop

- 2007 Boulby,UK
- 2009 Boston, USA
- 2011 Aussois, France
- 2013 Toyama, Japan
- 2015 LA, USA
- 2017 Xichang, China

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

2016 Sep –
proto-collaboration
4 WGs

Signatures

We the undersigned agree to work together on the CYGNUS programme, noting that this does not automatically imply participation in the CYGNUS collaboration when that is formed:

Person	Signature	Affiliation	Email	Date
Neil Spooner		University of Sheffield	n.spooner@sheffield.ac.uk	9th Sept 2016
Sven Vahsen		University of Hawaii	sevahsen@hawaii.edu	9th Sept 2016
Kentaro Miuchi		Kobe University	miuchi@phys.sci.kobe-u.ac.jp	12th Sept 2016
Giovanni De Lellis		University of Naples	Giovanni.de.Lellis@cern.ch	21st Sept 2016
Hiroyuki Sekiya		University of Tokyo	sekiya@icrr.u-tokyo.ac.jp	12th Sept 2016
Tatsuhiro Naka		Nagoya	naka@flab.phys.na	12th

- 50 researches signed so far.

CYGNUS-KM vessel: modular approach

low BG gas chamber with 40 × 40cm^2 windows
chamber ready, will be in Kamioka late 2018
your detectors are welcome!

CYGNUS-Kamioka vessel

AXIONs

- gas detectors are useful for decay-search (volume matters) → KK axion

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Available online at www.sciencedirect.com
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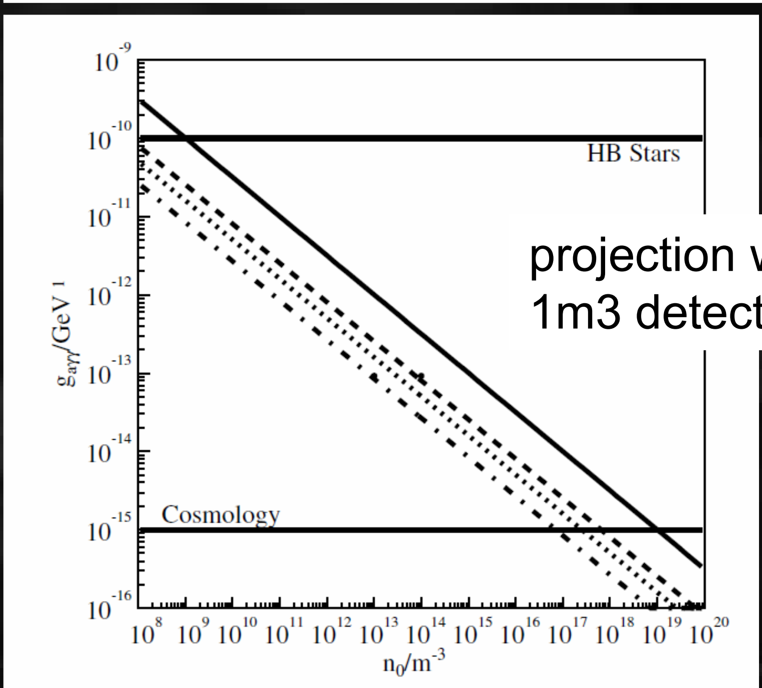
Astroparticle Physics 23 (2005) 287–302
Astroparticle Physics
www.elsevier.com/locate/astropart

Searches for solar Kaluza–Klein axions with gas TPCs

B. Morgan [a,*,1], N.J.C. Spooner [a,*], M.S. Armel-Funkhouser [d], D.H.H. Hoffmann [b], J. Jacoby [c], D.P. Snowden-Ifft [d], K. Zioutas [b,e,f]



- first experimental limit (not by gas detector, though)

PTEP Progress of Theoretical and Experimental Physics

1707.08995

Issues ▾ Subject ▾ Submit ▾ Alerts About ▾ All Progress

Volume 2017, Issue 10
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Article Contents

Search for solar Kaluza–Klein axions by annual modulation with the XMASS-I detector

XMASS Collaboration, N Oka, K Abe, K Hiraide, K Ichimura, Y Kishimoto, K Kobayashi, M Kobayashi, S Moriyama, M Nakahata ... Show more
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SUMMARY

- Direction sensitive dark-matter search
  - For the discovery and further investigation
  - Gas TPC and other detectors
  - R&Ds are actively ongoing