Review of Direction-Sensitive Direct Dark Matter Search

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DarkOn 2017

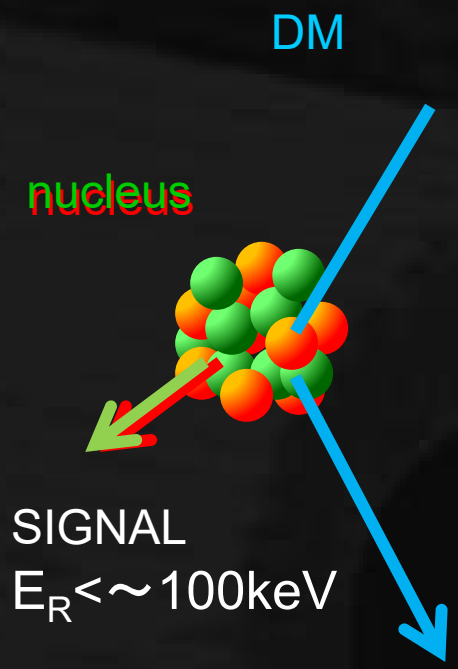
Contents

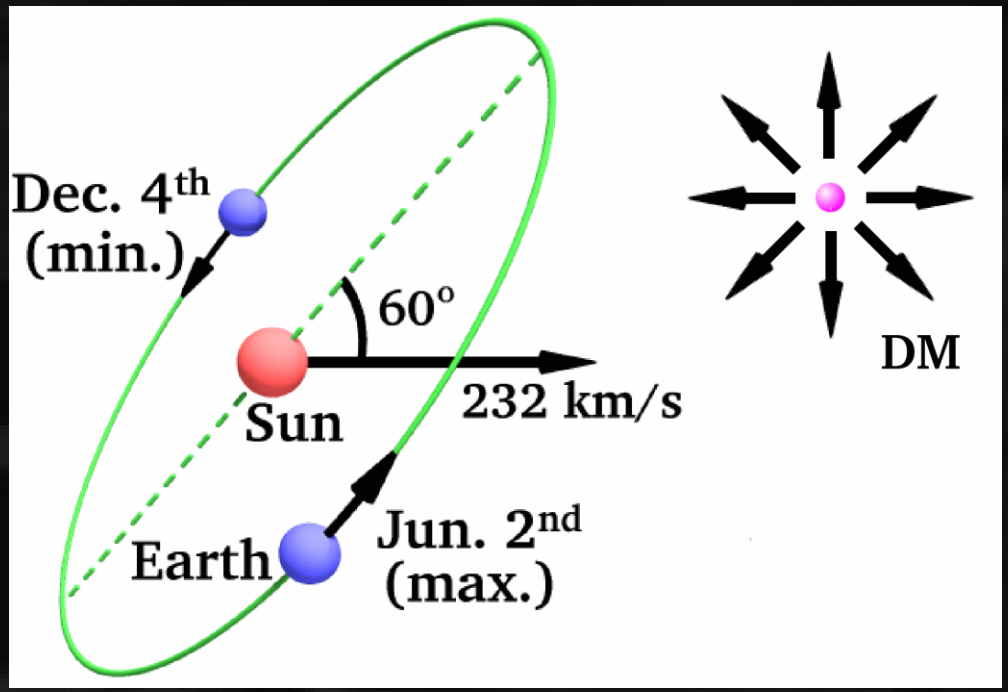
Dark Matter Direct detection
Physics
Experiments

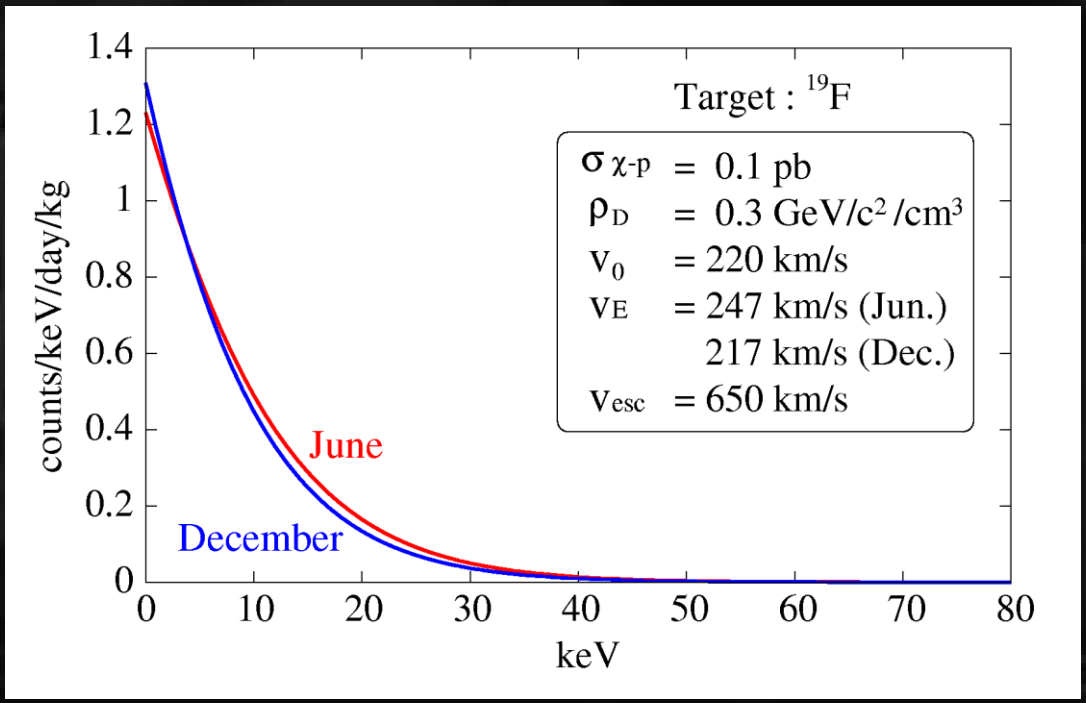
科研費 KAKENHI

Direction-Sensitive WIMP-search NEWAGE

DM direct detection







expected direct DM signals

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

アイディアは1980年代から

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

[11] J. Rich, M. Spiro, Saclay preprint DPhPE 88-04 (1988);
G. Gerbier, J. Rich, M. Spiro, C. Tao, in: E.B. Norman (Ed.)
Proceedings of the Workshop on Particle Astrophysics, Worl
Scientific, Singapore, 1989, p. 43.
[12] G. Masek, K. Buckland, M. Mojaver, in: E.B. Norman (Ed.)
Proceedings of the Workshop on Particle Astrophysics, Worl
Scientific, Singapore, 1989, p. 41.

R&Dは1990年代から

VOLUME 73, NUMBER 8 PHYSICAL REVIEW LETTERS 22 AUGUST 1994

Low Pressure Gaseous Detector for Particle Dark Matter

K. N. Buckland, M. J. Lehner, G. E. Masek, and M. Mojaver
Physics Department, University of California at San Diego, La Jolla, California 92093
(Received 22 March 1994; revised manuscript received 29 June 1994)

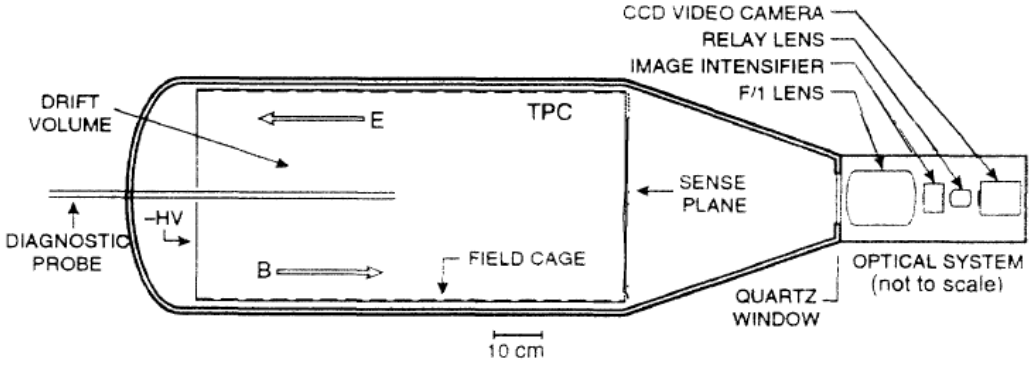


FIG. 1. A schematic view of the low pressure TPC and optical system.

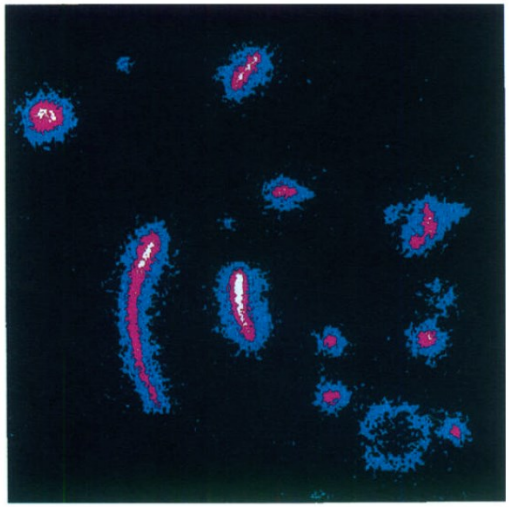
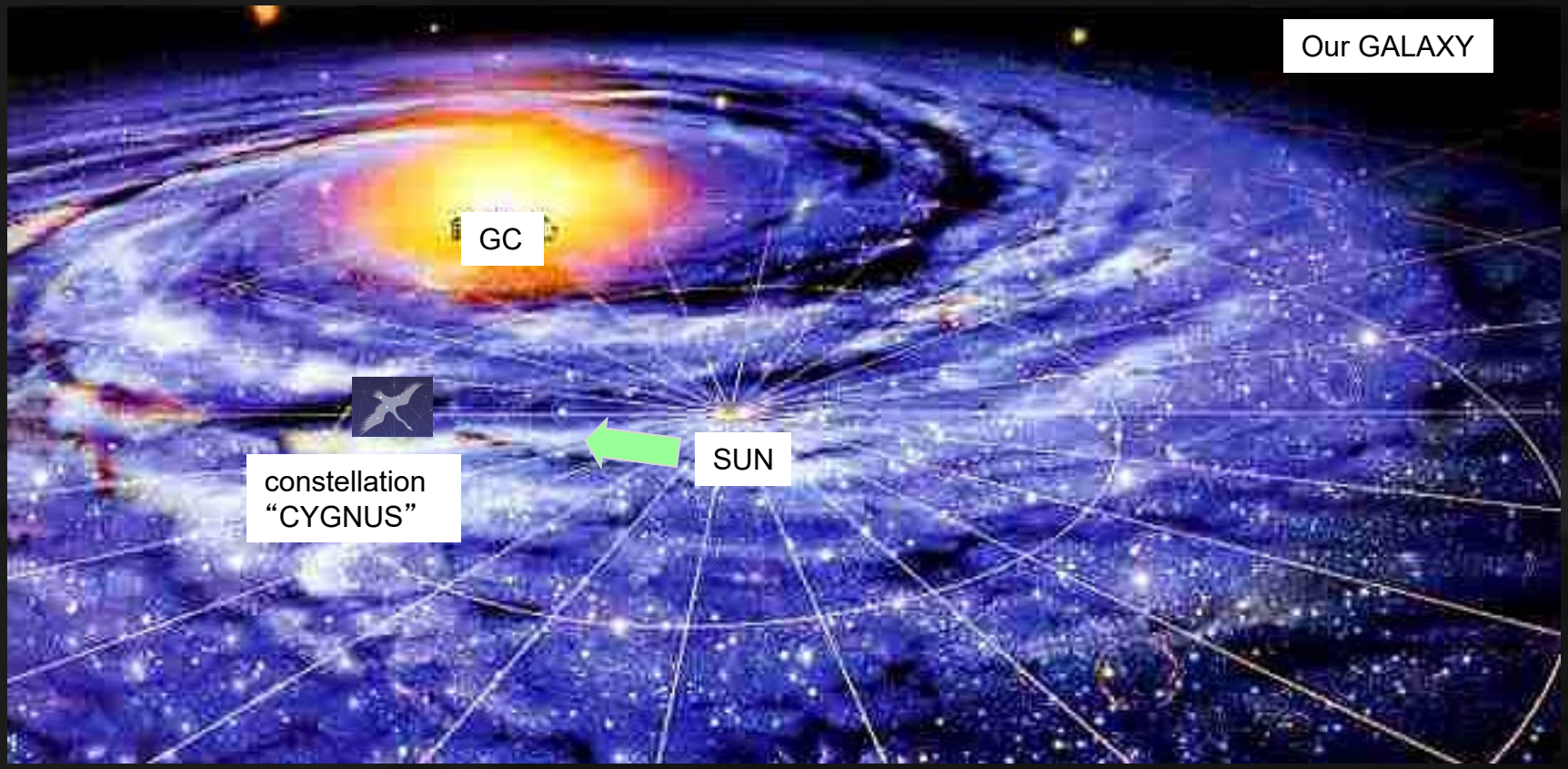


FIG. 2. A false color CCD image resulting from a ^{252}Cf neutron source. The colors black, blue, red, and white represent the order of increasing light intensity levels. The area displayed represents a 25 cm by 25 cm section of the detector plane. See the text for a description of image features.

Physics cases

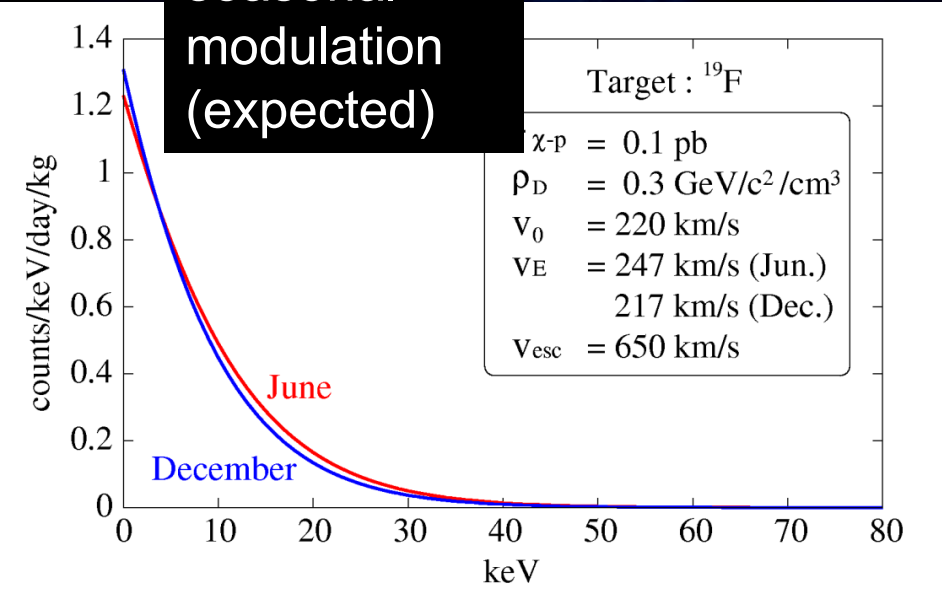
Direction-Sensitive Dark Matter Search concept “CYGNUS”



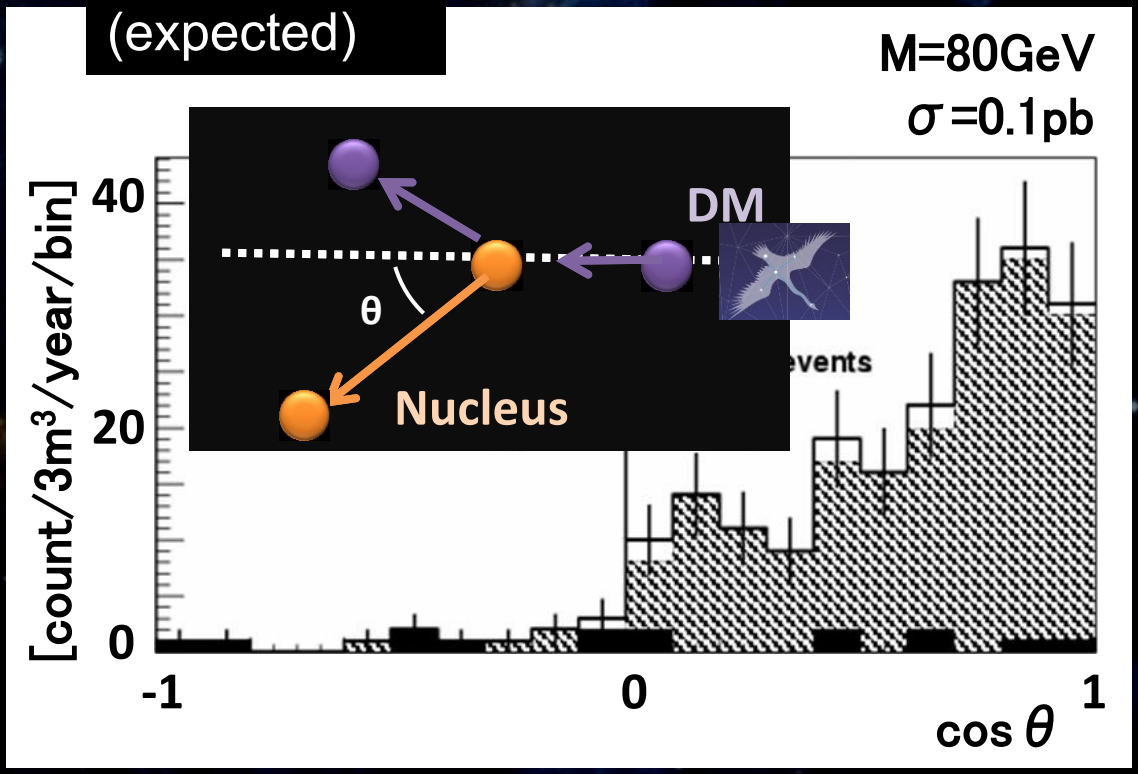
WIMP-WIND from “CYGNUS”

“CYGNUS” concept

seasonal modulation (expected)



directionality (expected)

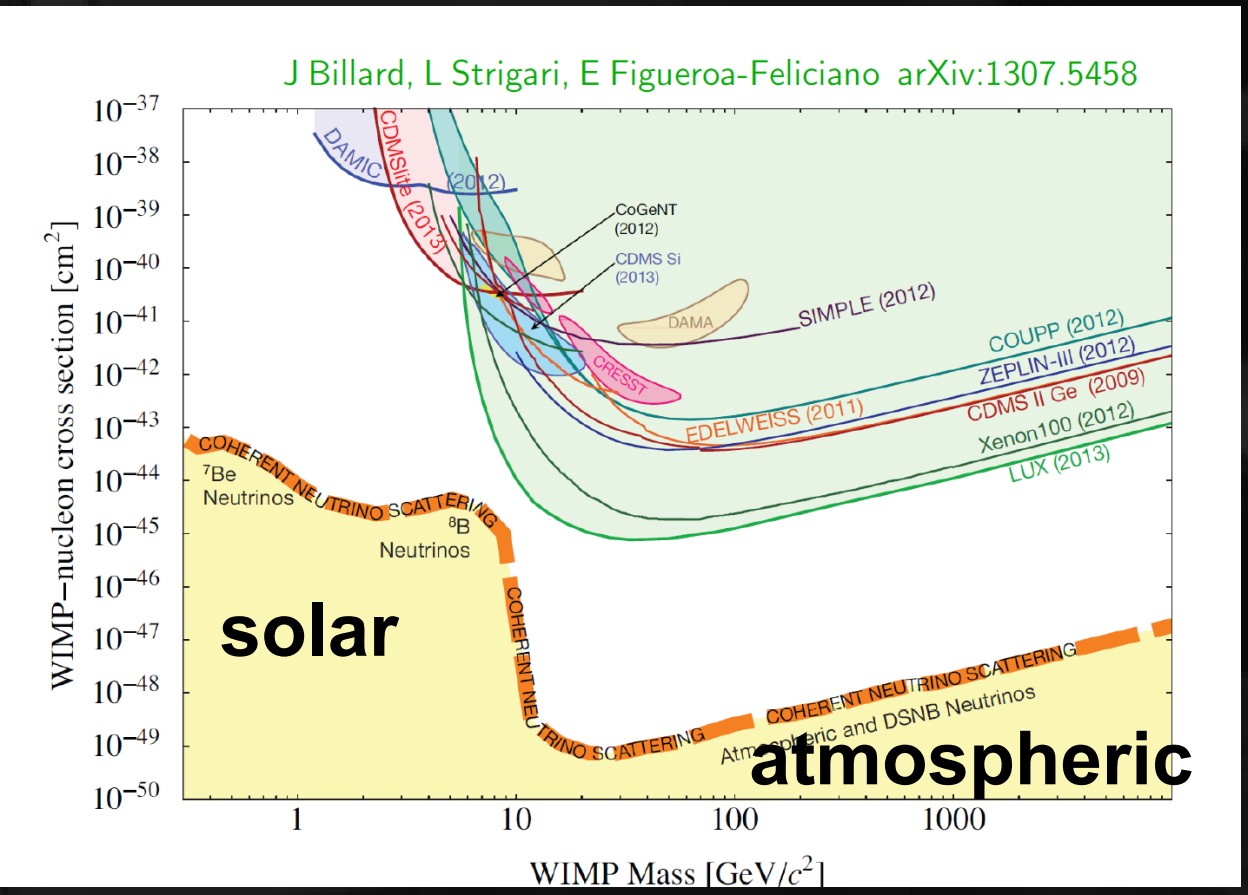


Clear Discovery

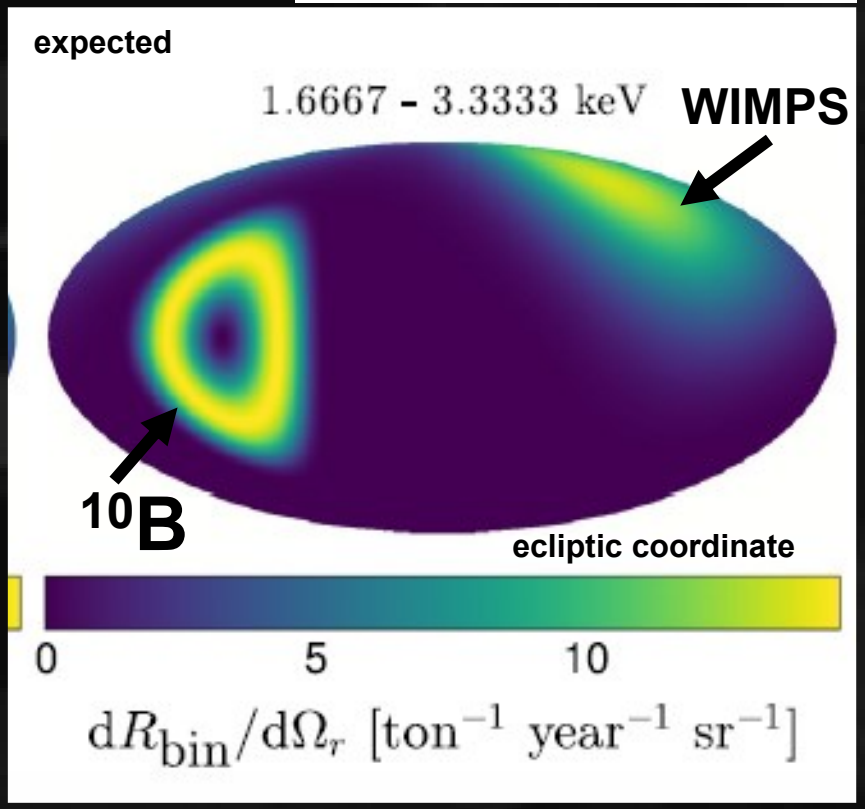
+ study the nature of DM after discovery

“CYGNUS” physics towards discovery

- **Potential to search beyond the “neutrino floor”†**



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



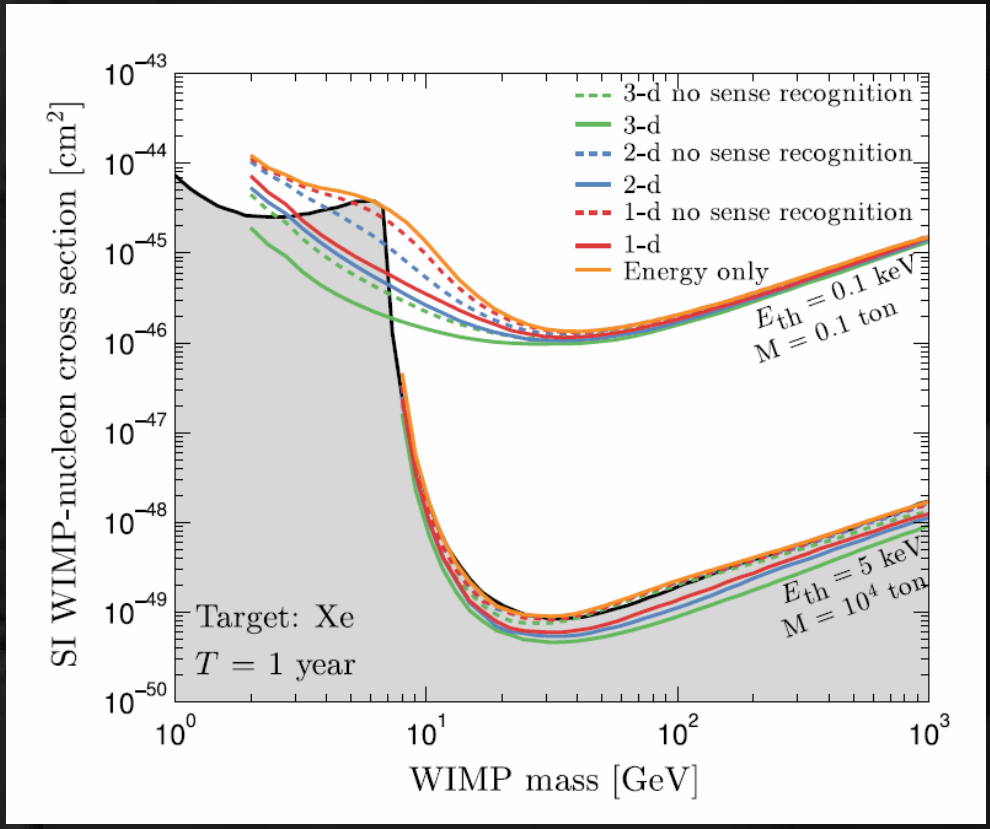
- **clearly distinguishable**

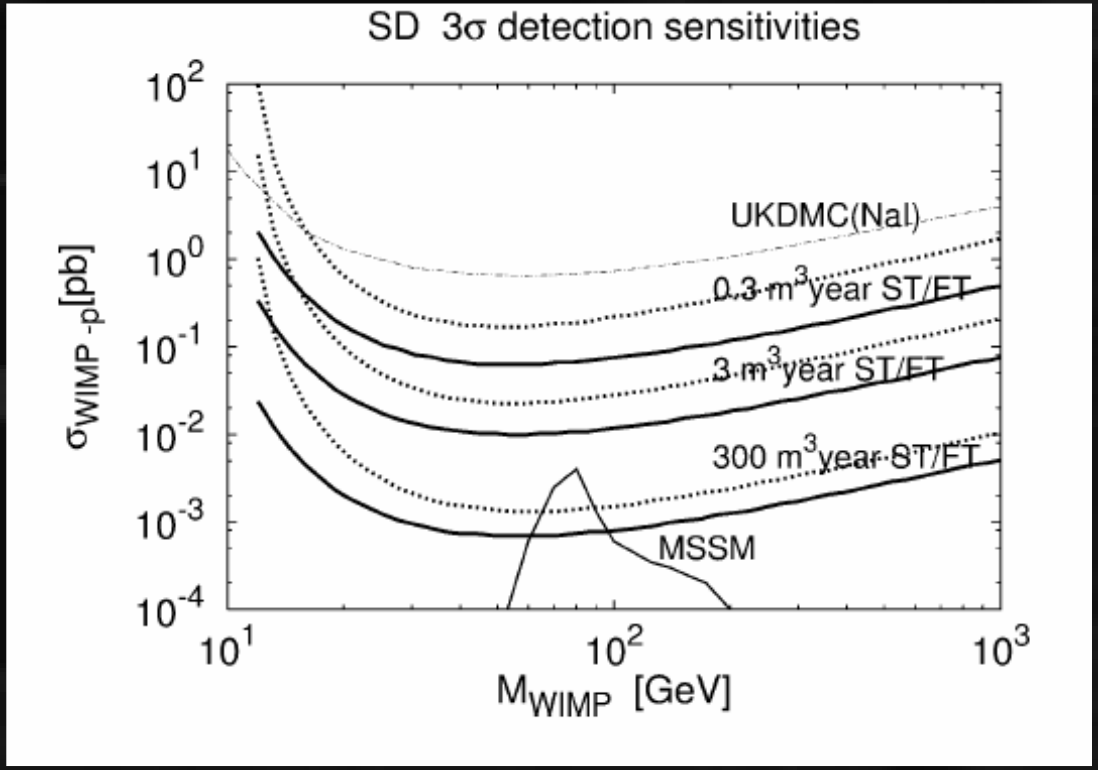
† neutrino-nucleus coherent scattering

Size and Physics Reach

Physics Reports 627 (2016) 1–49

T. Tanimori et al. / Physics Letters B 578 (2004) 241–246

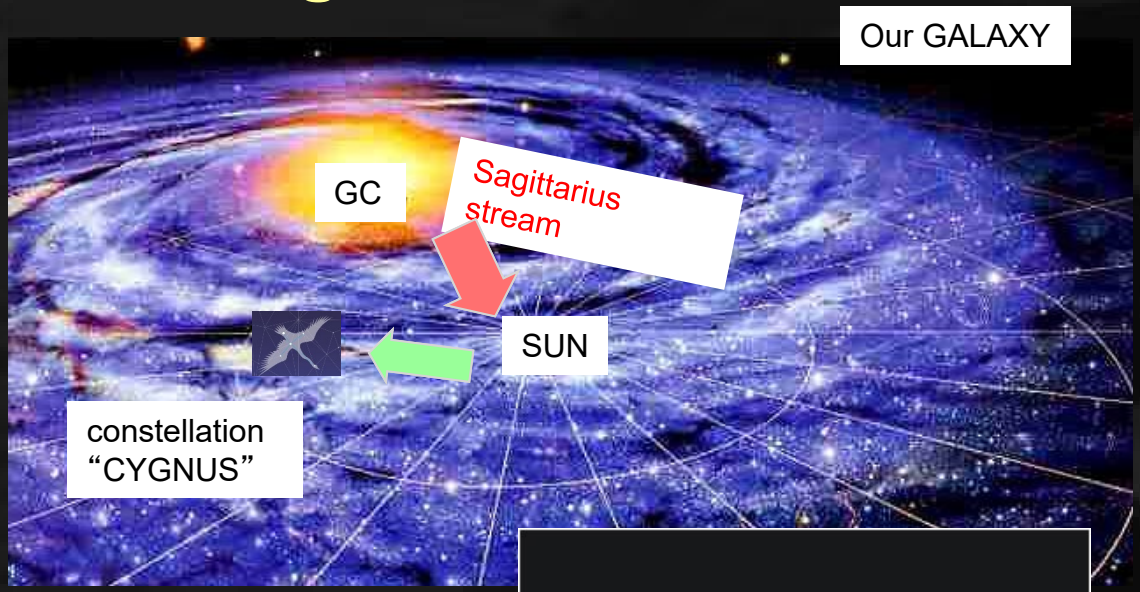


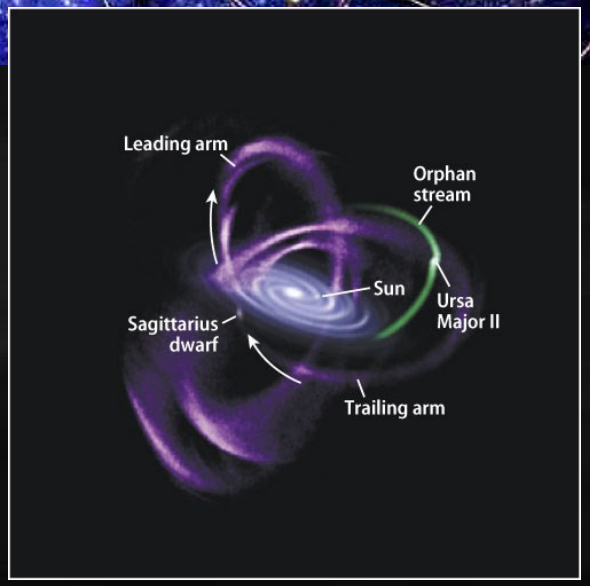


- オーダー　1m^3 ～ 0.1kg 程度
- 方向感度での必要事象数　10～100事象

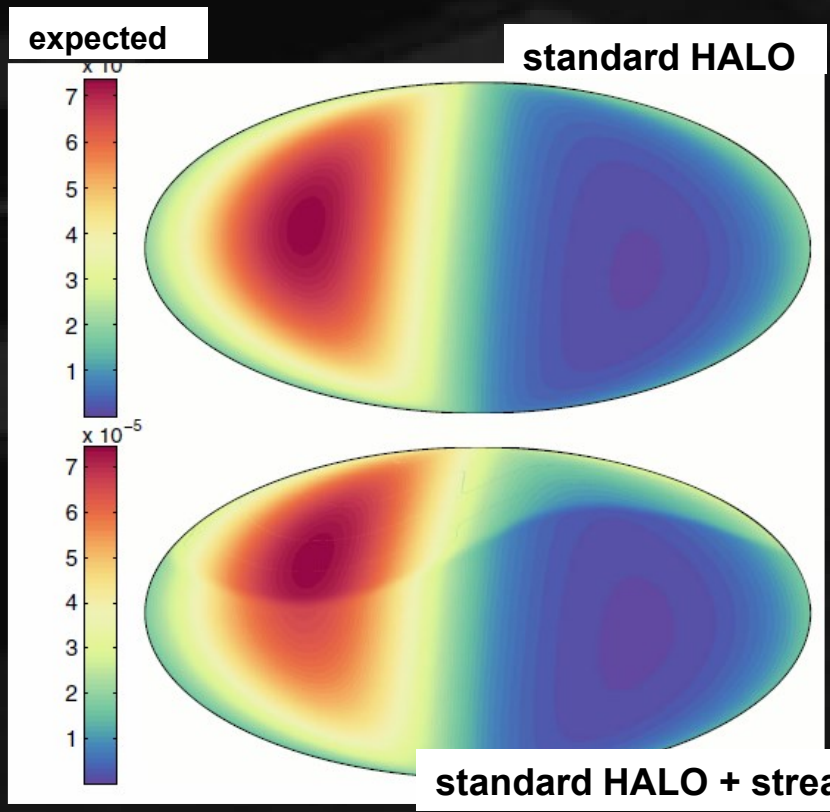
“CYGNUS” physics after discovery

- **Test the DM motion**
  - **ex. Sagittarius stream**





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



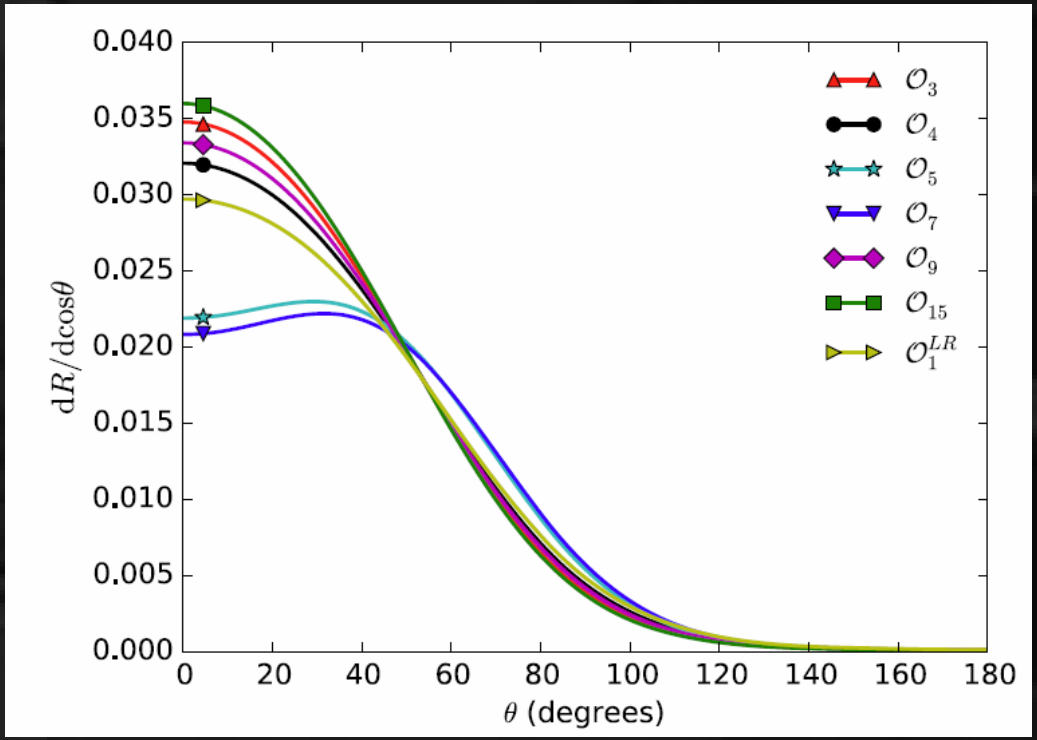
galactic coordinate

- **streams, halo model…**

“CYGNUS” physics after discovery

- **Test the interaction by scattering angle**

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



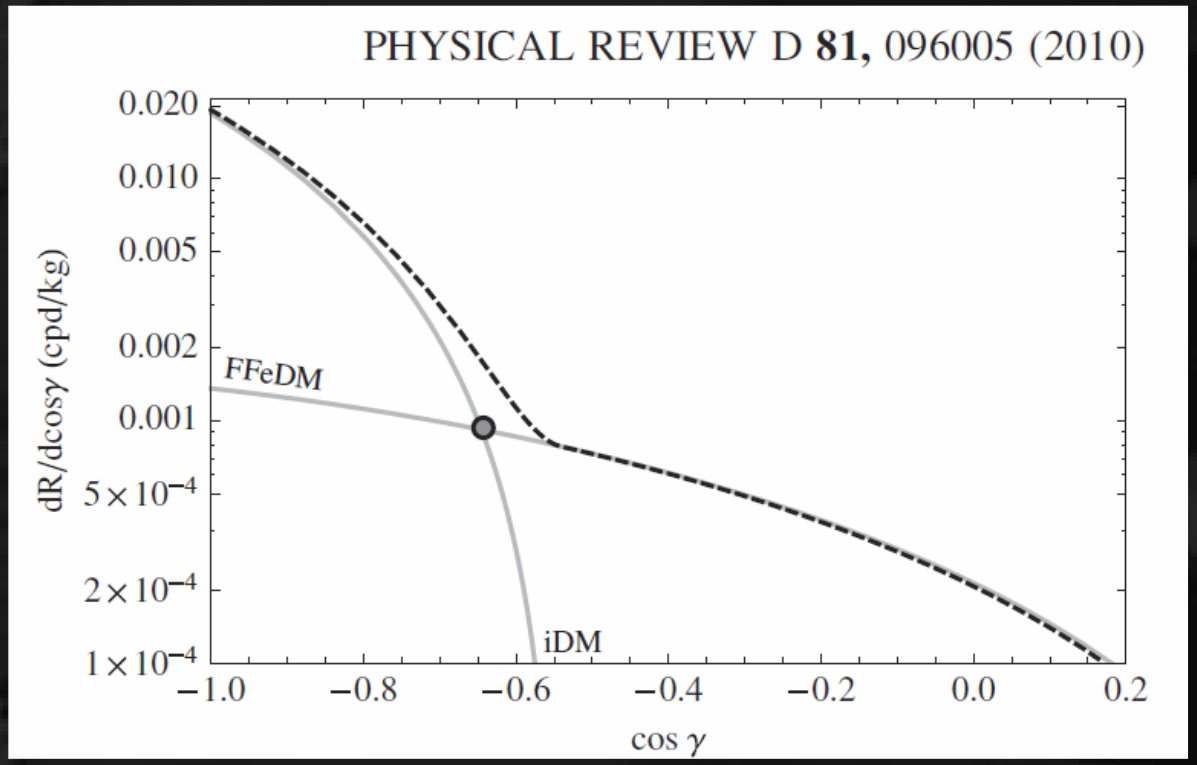
SI SD

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

- **some operators are distinguishable**

“CYGNUS” physics after discovery

- **Test the interaction by scattering angle ②**



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

Experimental Status

Experimental concept

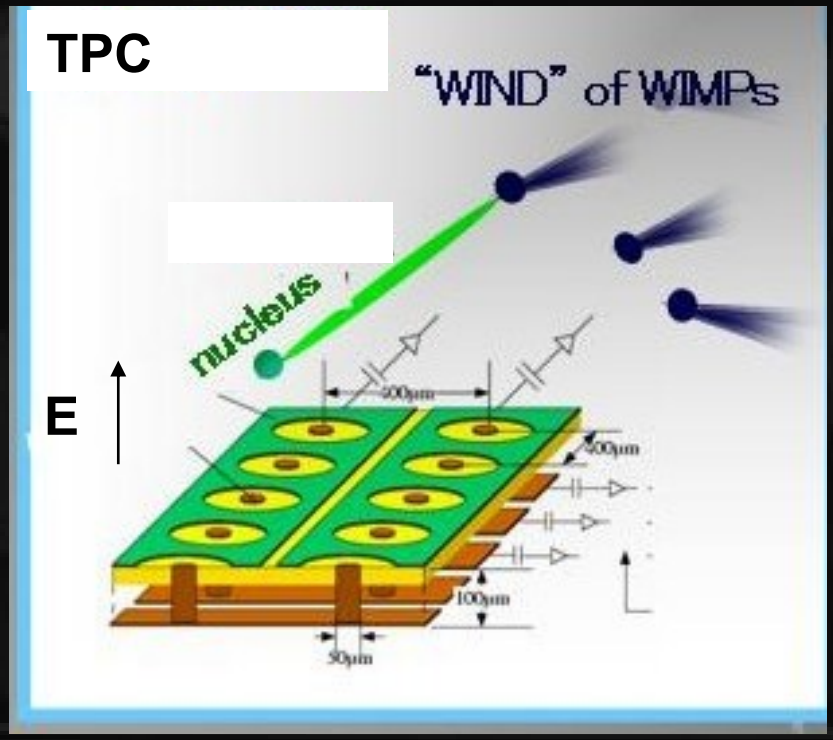
Recoil nuclear track detection < 100keV

challenge: short track

a few mm in low pressure gas
a few 100 nm in solid

Most typical “CYNGUS”: low pressure gas TPC

2D readout + timing
→ 3D tracking



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

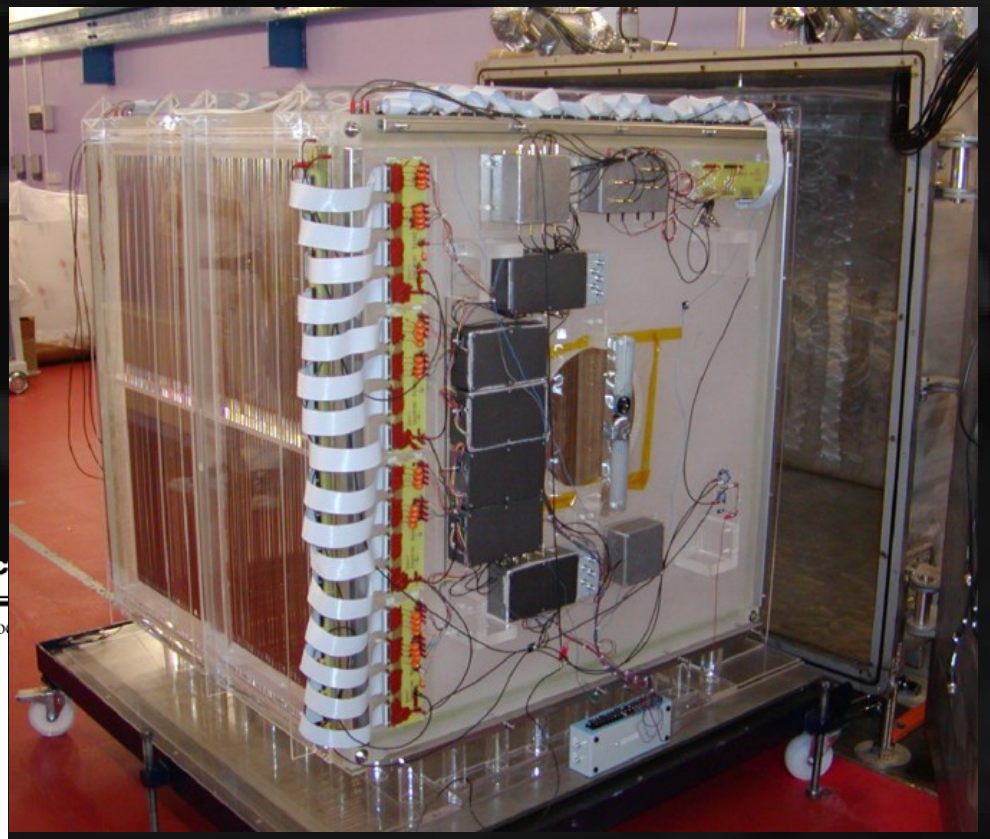
R Nuclear Instruments and Methods in Physics Research A 498 (2003) 155–164
RESEARC Section A
www.elsevier.com/lo

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]

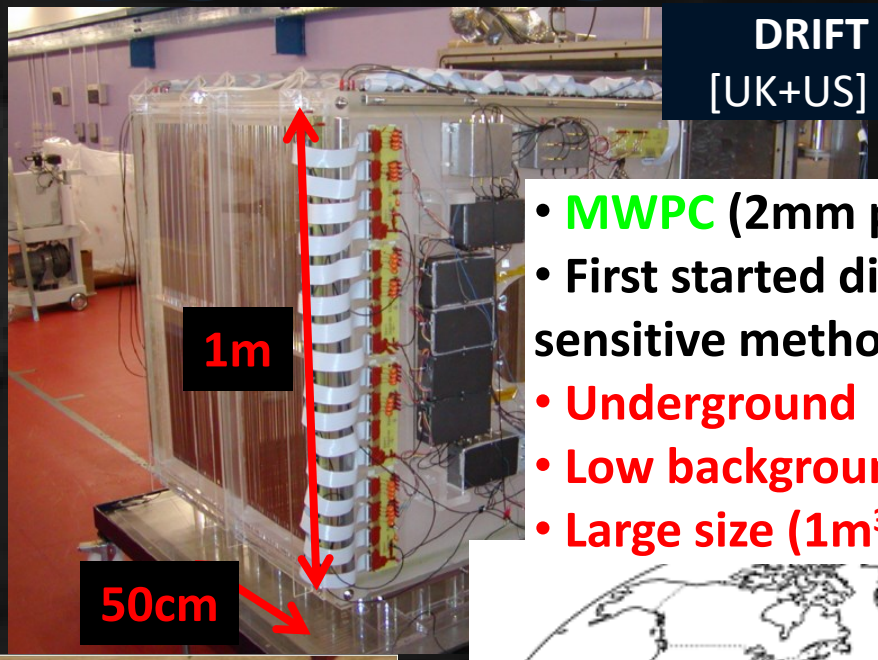
[a] *Physics Department, Occidental College, 1600 Campus Road, Los Angeles, CA 90041, USA*
[b] *Barton Hall, Temple University, 1900 N. 13th St., Philadelphia, PA 19122-6082, USA*

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



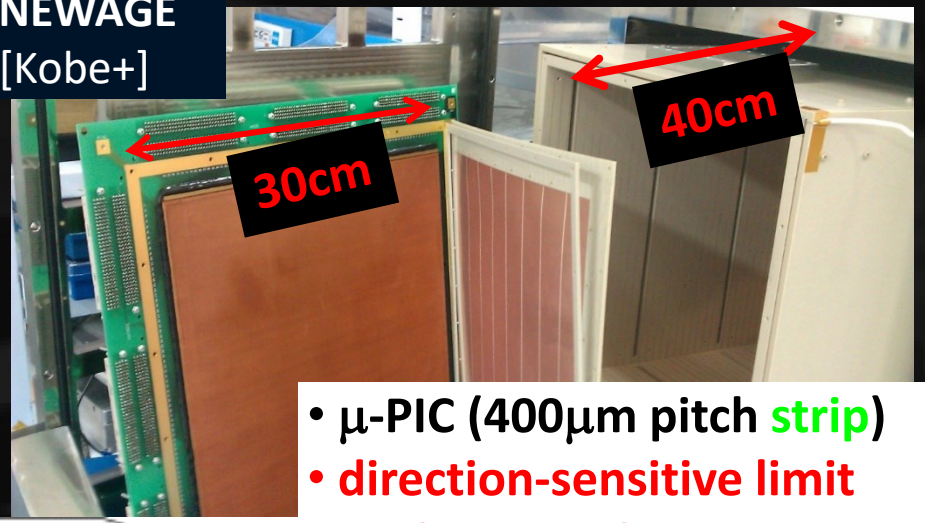
- 2mm pitch multi-wire proportional chamber
- not very direction-sensitive

Cygnus, gas TPCs



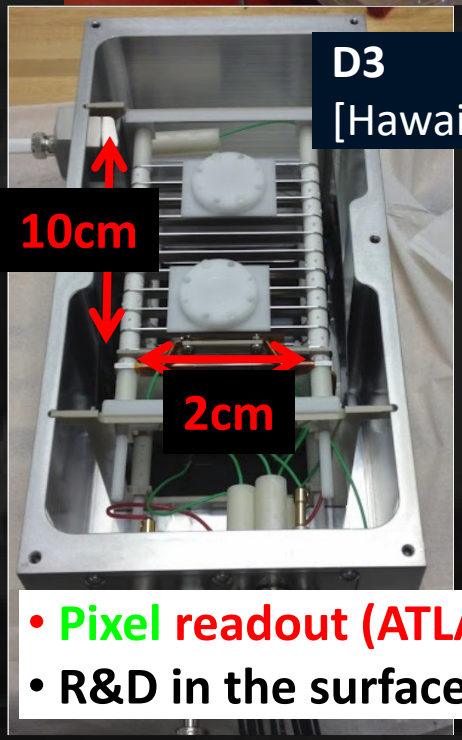
DRIFT
[UK+US]

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



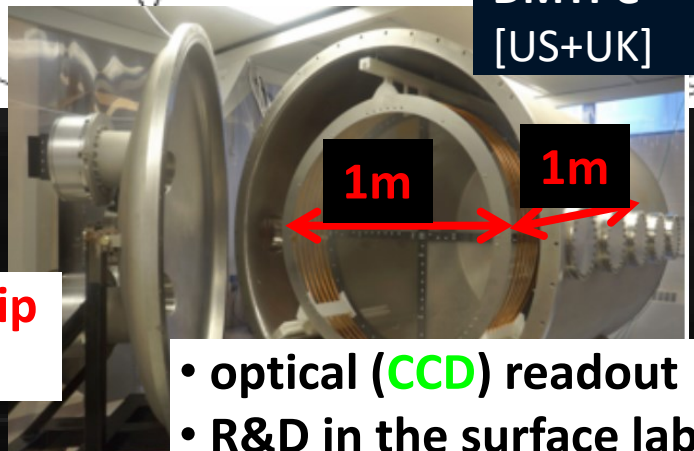
NEWAGE
[Kobe+]

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



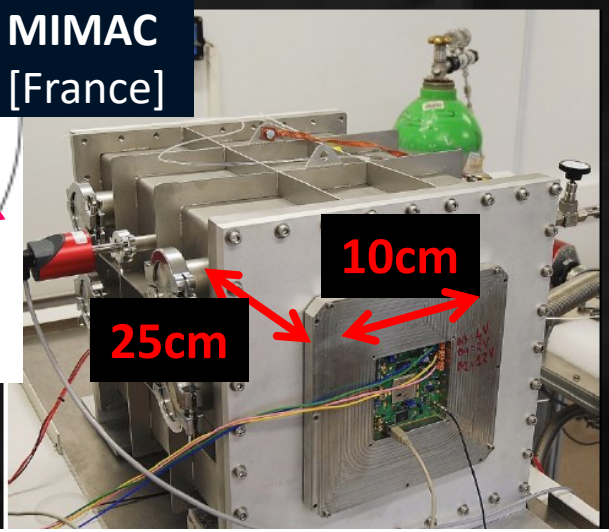
D3
[Hawaii]

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



DMTPC
[US+UK]

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



MIMAC
[France]

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

- 議論：
  - gas: asymmetryは大きいが信号数は少ない

    → 固体や液体で何とかならない?

Cygnus, others

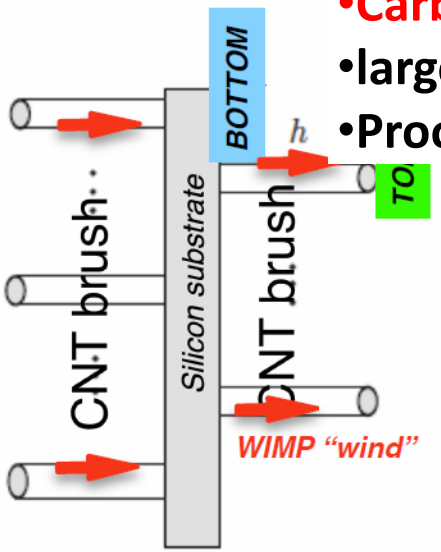
Gianluca Cavoto INFN Roma
IDM 2016
18th 22nd July 2016
The University of Sheffield

NEWSdm
[Japan+Italy]

中

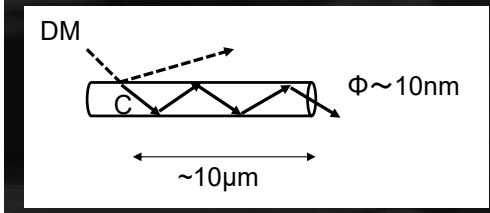
- emulsion (20~50nm crystal)
- good position resolution
- large mass
- No time resolution

DeCANT
[Italy]



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

身内?

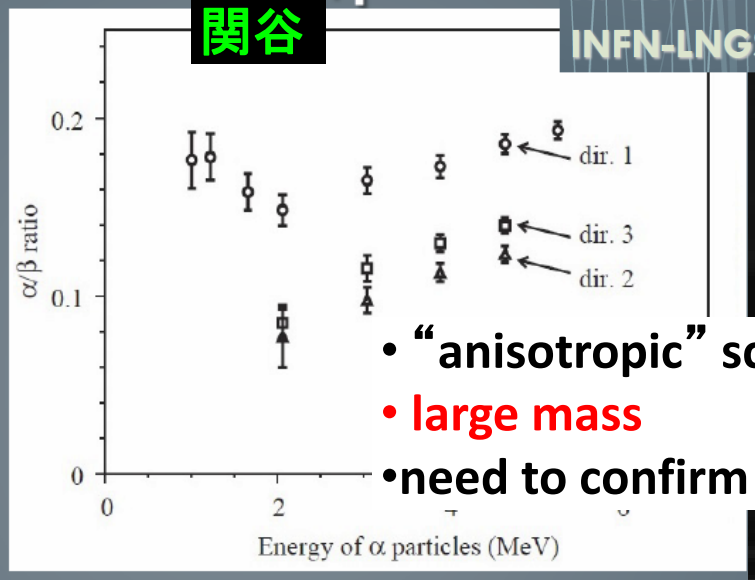


$ZnWO_4$
[Italy, Japan]

α/β ratio

R. Cerulli
INFN-LNGS

関谷

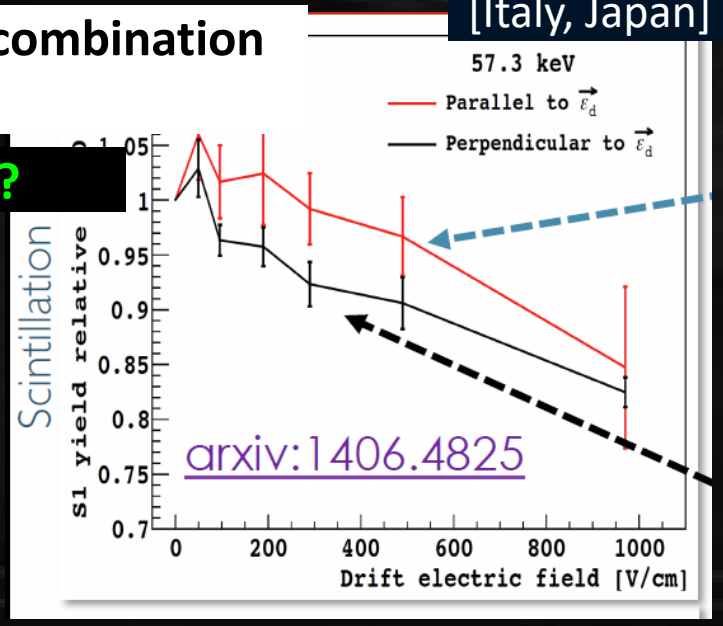


- "anisotropic" scintillator
- large mass
- need to confirm in low energy

Liq Ar
[Italy, Japan]

- columnar recombination
- large mass

中村、早稲田?



“CYGNUS”
concept to collaboration

2007 ～ biannual workshop

2007 Boulby

2009 Boston

2011 Aussois

2013 Toyama

2015 LA

2017

for 10th aniversary

2016 co-working meetings

Jan Boulby

Apr Roma

July Sheffield

2016 Sep –

proto-collaboration

4 WGs

NEWAGE/CYGNUS-Kamioka test chamber

CYGNUS proto-collaboration

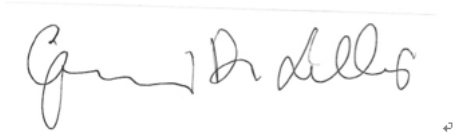
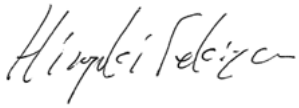
- 将来的に大きな検出器が必要　←　意見一致
- 時期については様々な見解　→　お友達契約

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

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

- 約40名（うち日本人 22名）

- **CYGNUS activities**
  - steering committee (Spooner(英), Miuchi(日), Vahsen(米), Baracchini(伊), Barberio(豪))
  - WGs' chairs (occasional TV meetings)
    - gas(Miuchi)
      simulation(Vahsen)
      vessel(Spooner)
      BG(Baracchini)

SUMMARY

- Direction sensitive dark-matter search
  - Discovery and further investigation
  - Many small size R&Ds are actively ongoing