方向に感度を持った暗黒物質直接探索実験

神戸大学
身内賢太朗

Contents

イントロ
物理
実験

2017年10月3日
宇宙観測と地上実験から探る
ダークマター研究の現状と展望

科研費
KAKENHI

Direction-Sensitive
WIMP-search
NEWAGE

イントロ

身内JPS2017秋シンポジウム

身内賢太朗
2013年秋学会シンポジウム

日本の戦略

CRCでは、現在検討中の将来計画についての検討を行い、研究者のコンセンサスを形成するためにタウンミーティングを開催してゆきます。
＊なお、本タウンミーティングは、専門の研究者を対象としており、一般市民向けの講演会ではありません。

これからの開催

NEW!**2017年度CRC将来計画タウンミーティング (通算第12回)**

日時：2017年6月24日(土), 25日(日)
場所：東京大学 総合研究棟6F大会議室 (柏キャンパス)
（交通案内 柏アクセスマップ）
案内文・プログラム

ダークマターの懇談会

2017年1月27，28日
於：神戸大学梅田インテリジェントラボラトリ

18トーク（含レビュー）

Information

- 趣旨
- 場所
- 参加登録
- 締め切りなど
- プログラム
- 世話人
- 連絡先

趣旨

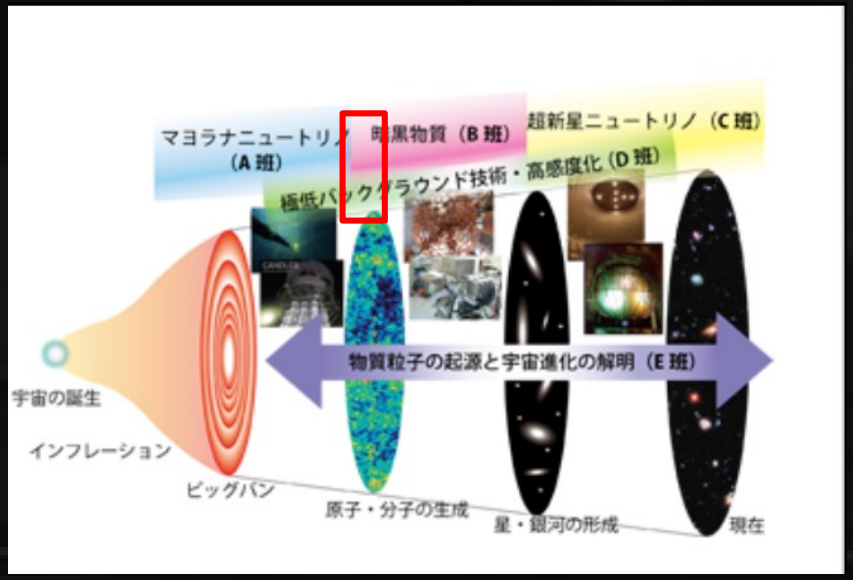
世界的に感度向上が加速している暗黒物質の直接探索について、国内の暗黒物質探索についてこれまでを振り返り、将来（10年、20年くらい）について議論することを目的とします。その際に各プロジェクトのこれからの戦略を示していただき、議論を行い戦略の向上の可能性を探りたいと考えております。

研究会形態

講演は世話人からの依頼を基本とし、単なる技術的な進捗報告ではなく、世話人からある程度お願いする内容（物理や戦略など）に基づいた報告としたいと思います。それらを踏まえて、議論の時間も十分とる予定です。当事者間での厳しい議論を行うため、関係者に優先して連絡、登録を予定しております。

宇宙の歴史をひもとく地下素粒子原子核研究

文部科学省研究費補助金　新学術領域　領域番号2603（平成26年～30年度）



直接探索実験

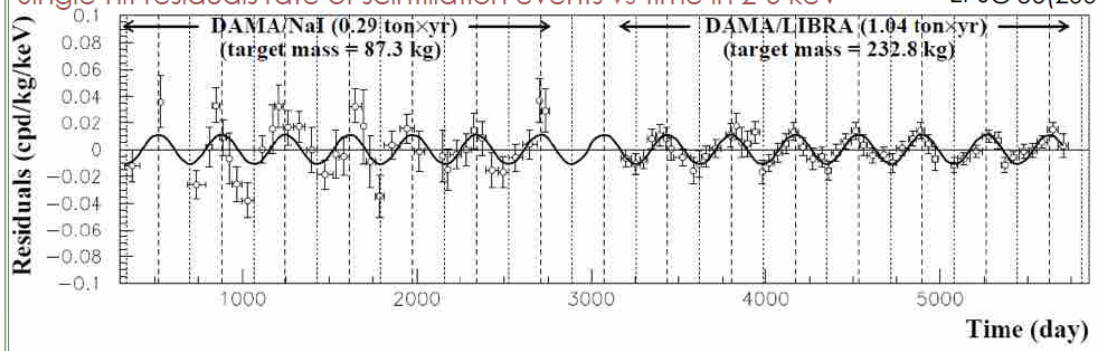
DAMA実験

Model Independent Annual Modulation Result

DAMA/NaI + DAMA/LIBRA-phase1 Total exposure: 487526 kg×day = **1.33 ton×yr**

Single-hit residuals rate of scintillation events *vs* time in 2-6 keV

EPJC 56(2008)333, EPJC 67(2010)39, EPJC 73(2013)2648



continuous line: t_0 = 152.5 d, T =1.0 y

A=(0.0110±0.0012) cpd/kg/keV

χ^2/dof = 70.4/86 9.2 σ C.L.

Absence of modulation? No

χ^2/dof=154/87 P(A=0) = 1.3×10^{-5}

Fit with all the parameters free:

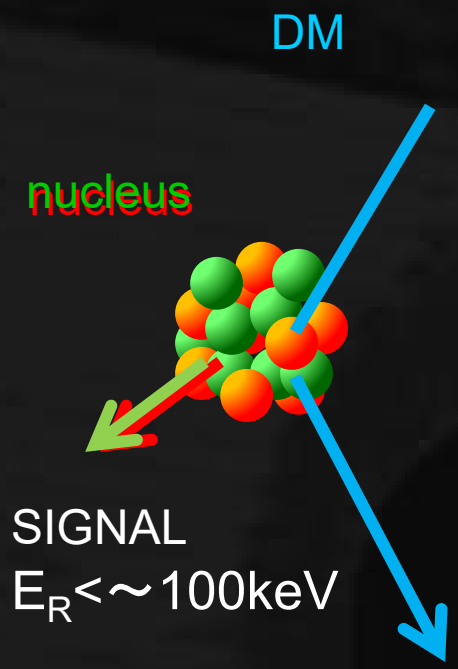
A = (0.0112 ± 0.0012) cpd/kg/keV

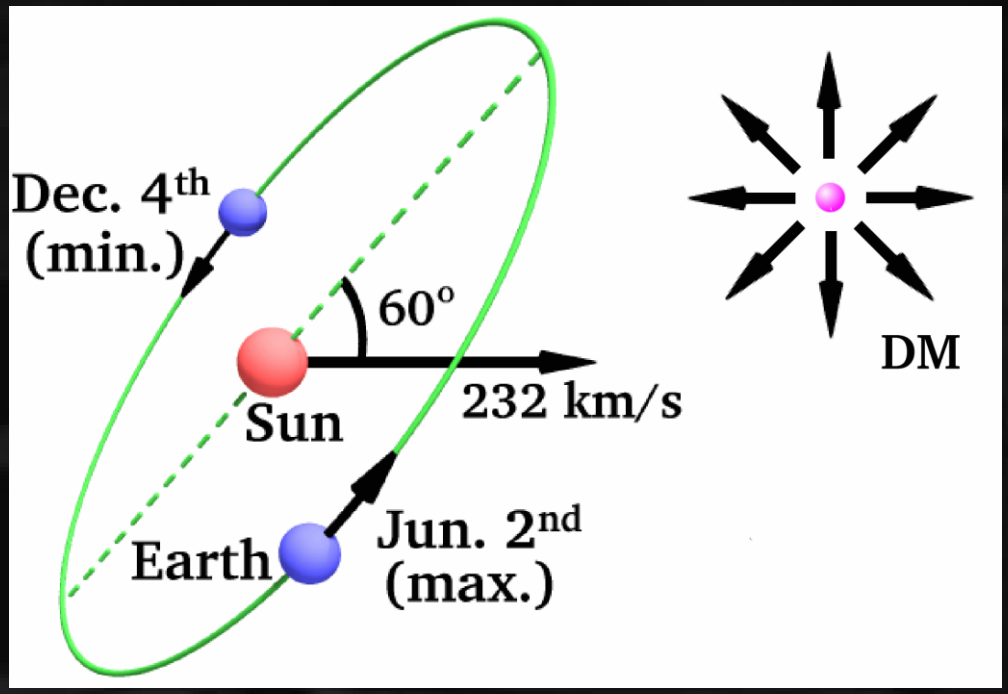
t_0 = (144±7) d - T = (0.998±0.002) y

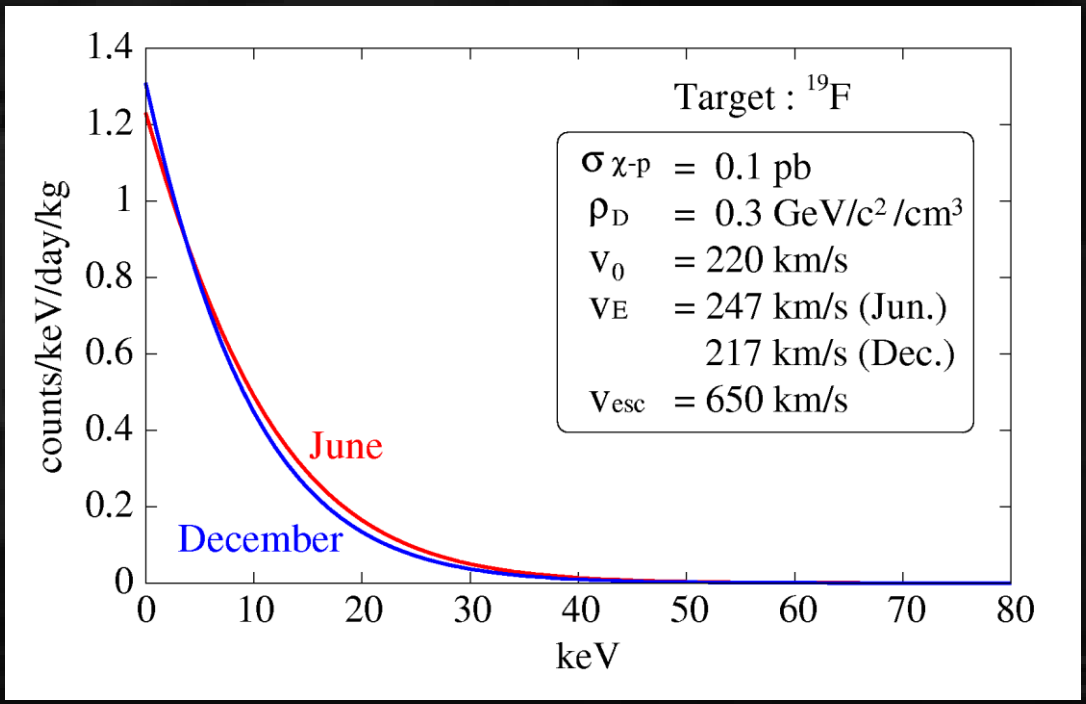
over 9σ (by 14yrs of measurement)

⇒ 発見には至らず。。。

DM direct detection



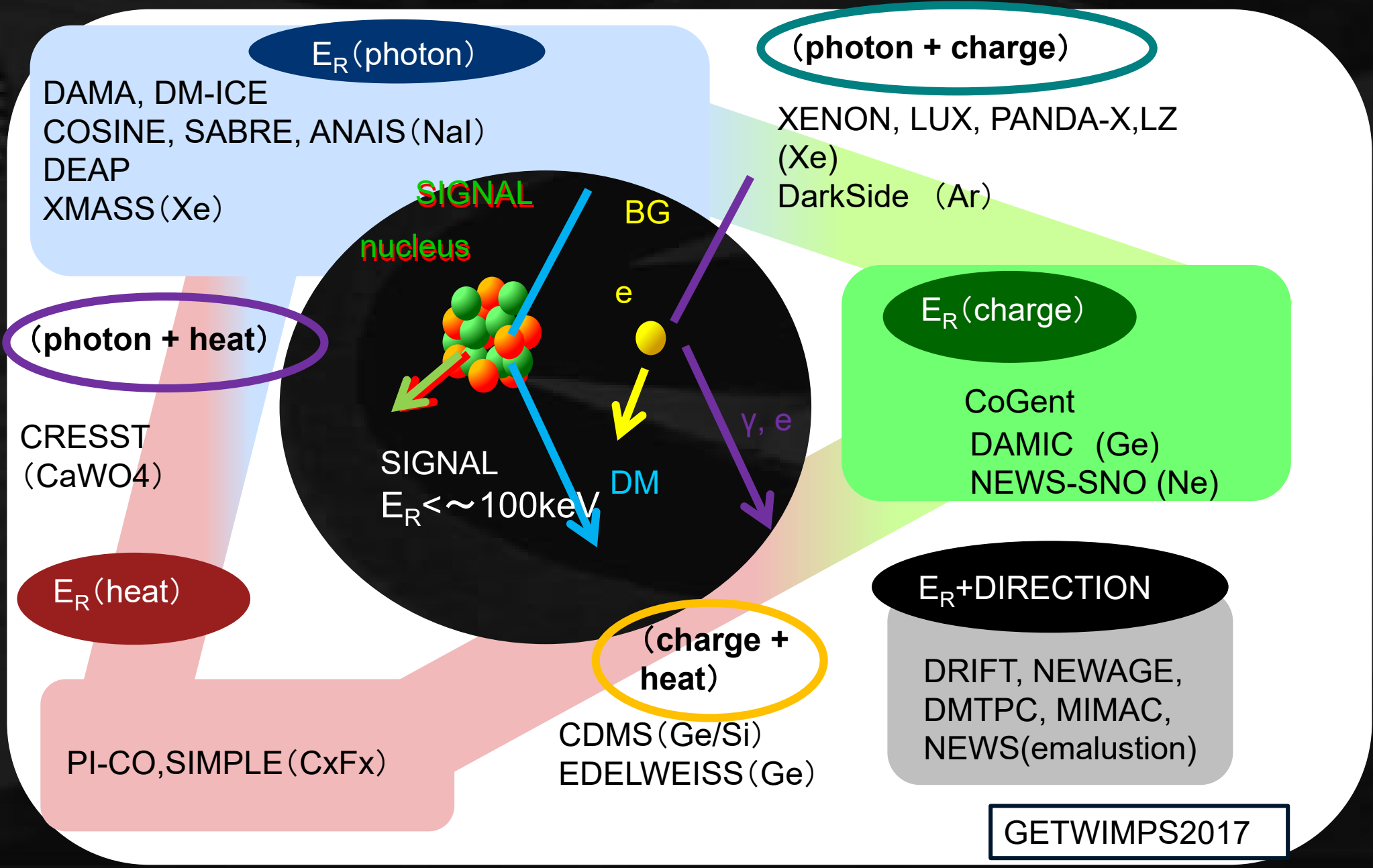




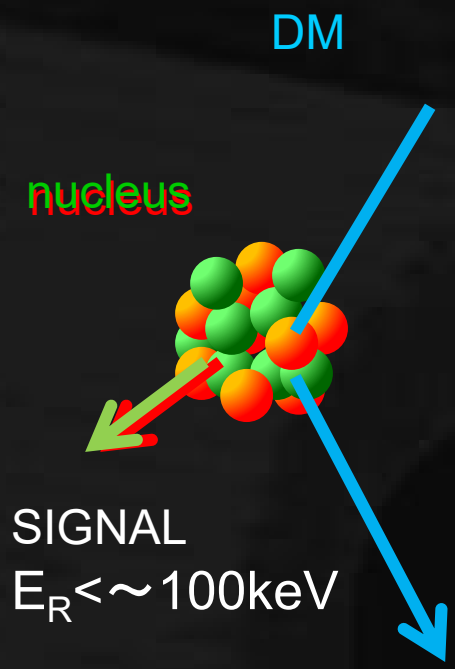
expected direct DM signals

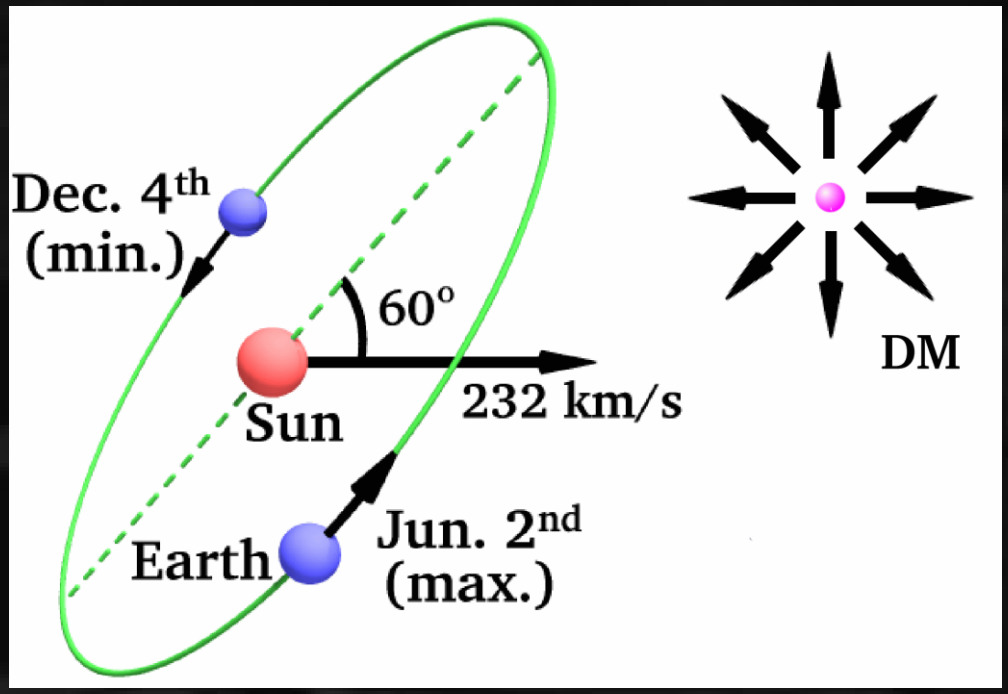
- ① observed * events
- ② energy spectrum
- ③ seasonal modulation
- ④ material dependence
- ⑤ direction-sensitive

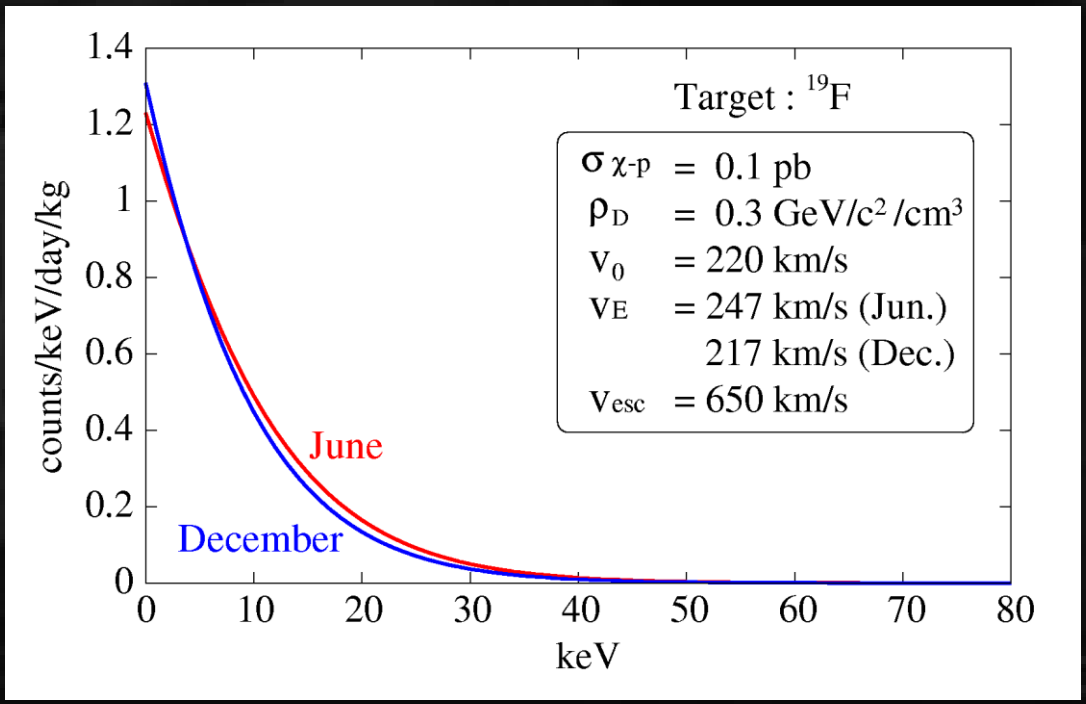
E_Rの捉え方


E_R（photon）
DAMA, DM-ICE
COSINE, SABRE, ANAIS（NaI）
DEAP
XMASS（Xe）
（photon + charge）
XENON, LUX, PANDA-X,LZ
(Xe)
DarkSide （Ar）
SIGNAL
nucleus
BG
e
γ, e
DM
SIGNAL
E_R<～100keV
（photon + heat）
CRESST
（CaWO4）
E_R（charge）
CoGent
DAMIC （Ge)
NEWS-SNO (Ne)
E_R（heat）
（charge + heat）
CDMS（Ge/Si）
EDELWEISS（Ge）
E_R+DIRECTION
DRIFT, NEWAGE,
DMTPC, MIMAC,
NEWS(emalustion)
PI-CO,SIMPLE（CxFx）
GETWIMPS2017

DM direct detection



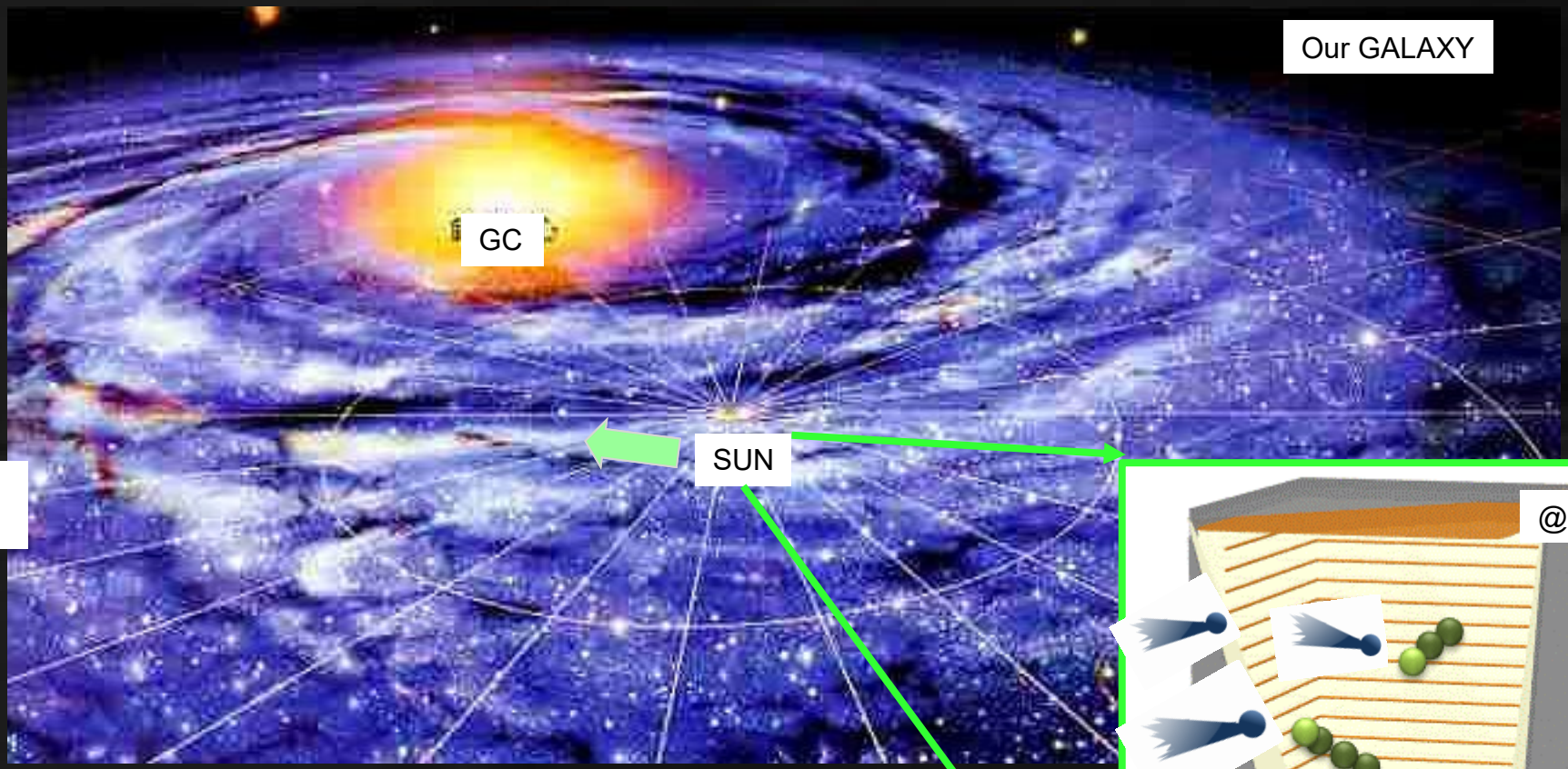


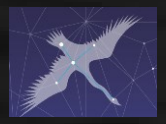


expected direct DM signals

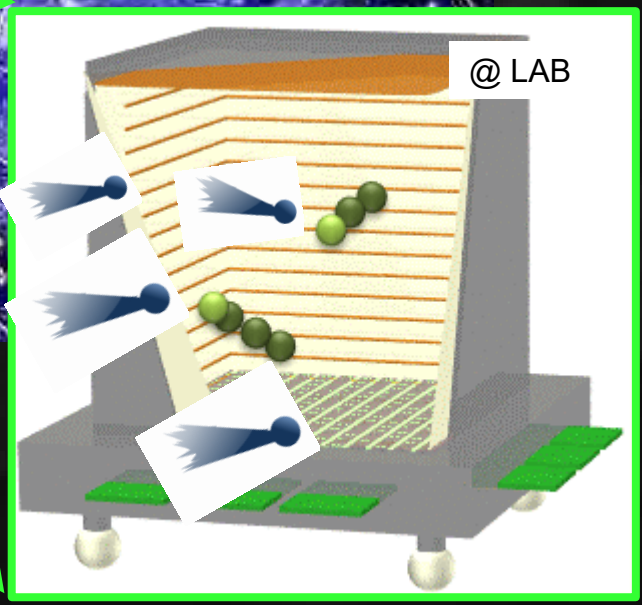
- ① observed * events
- ② energy spectrum
- ③ seasonal modulation
- ④ material dependence
- ⑤ direction-sensitive

Direction-Sensitive Dark Matter Search concept “CYGNUS”





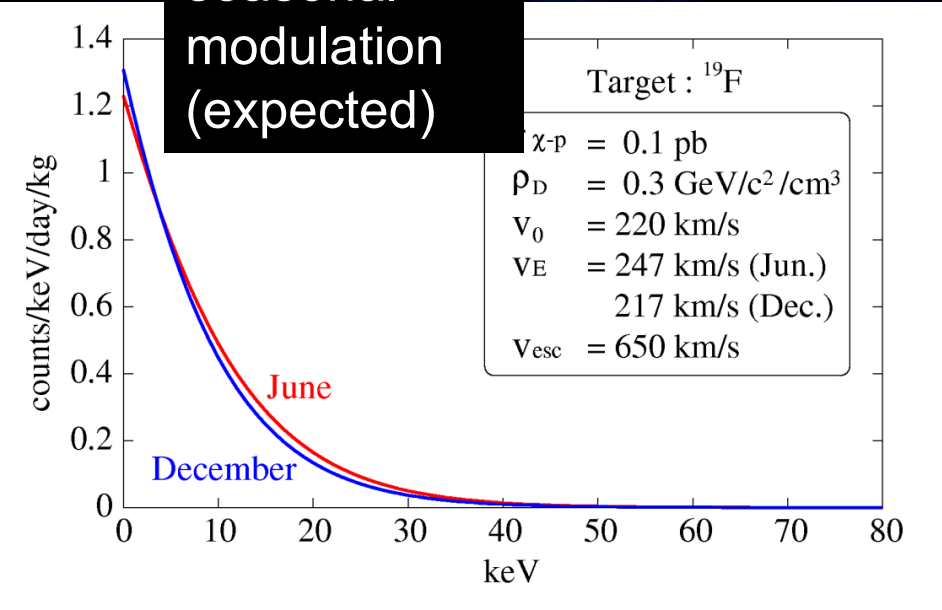
constellation “CYGNUS”



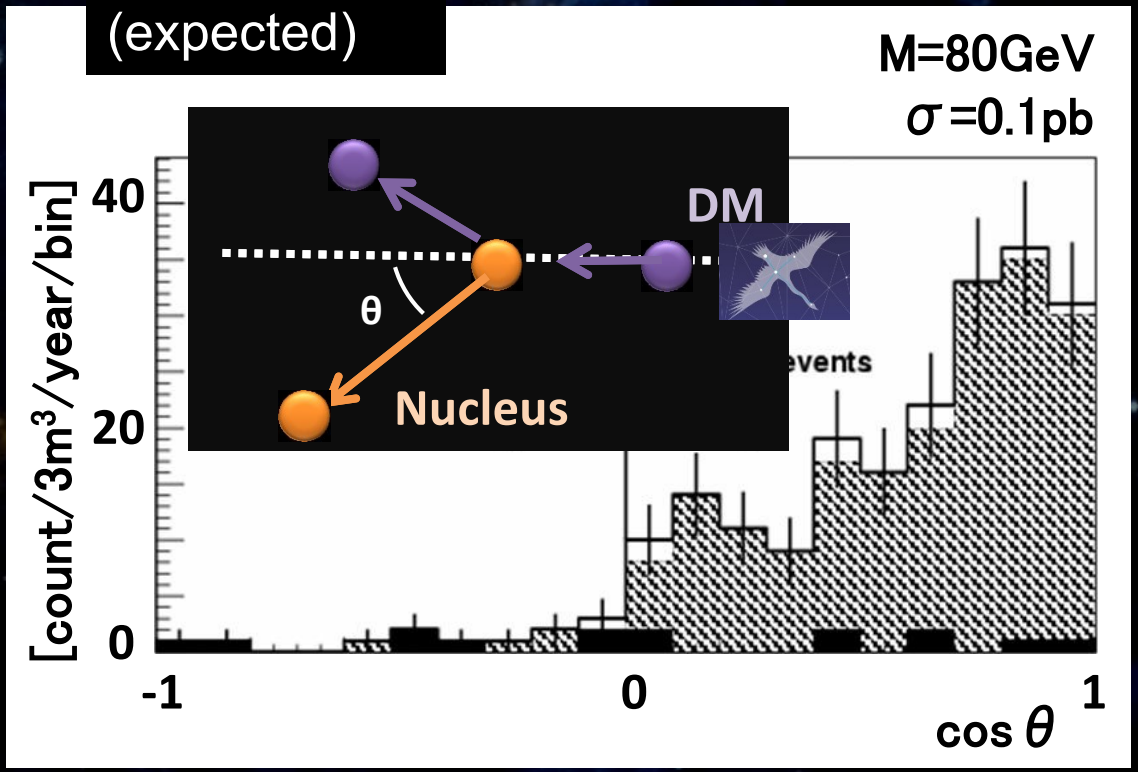
WIMP-WIND from “CYGNUS”

“CYGNUS” concept

seasonal modulation (expected)



directionality (expected)



Clear Discovery

+ study the nature of DM after discovery

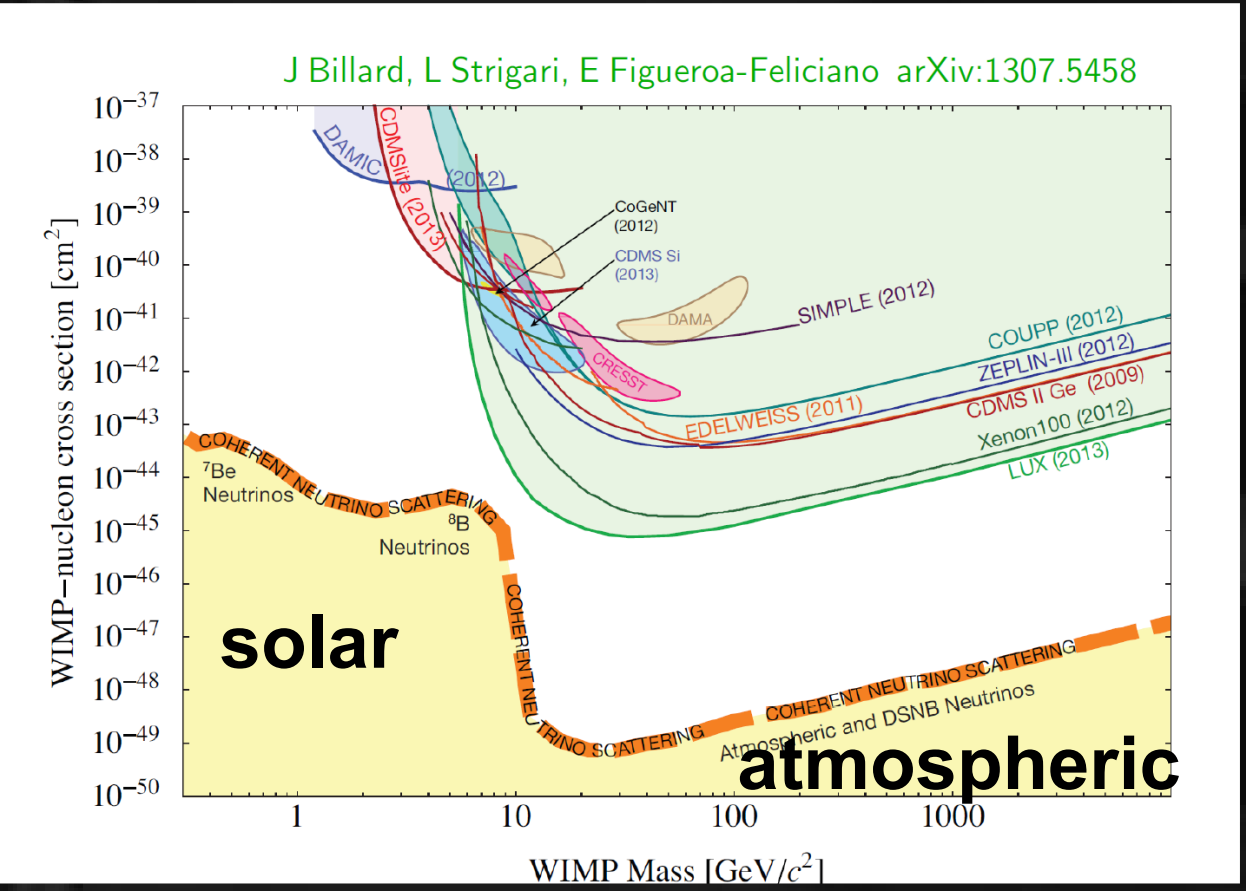
物理

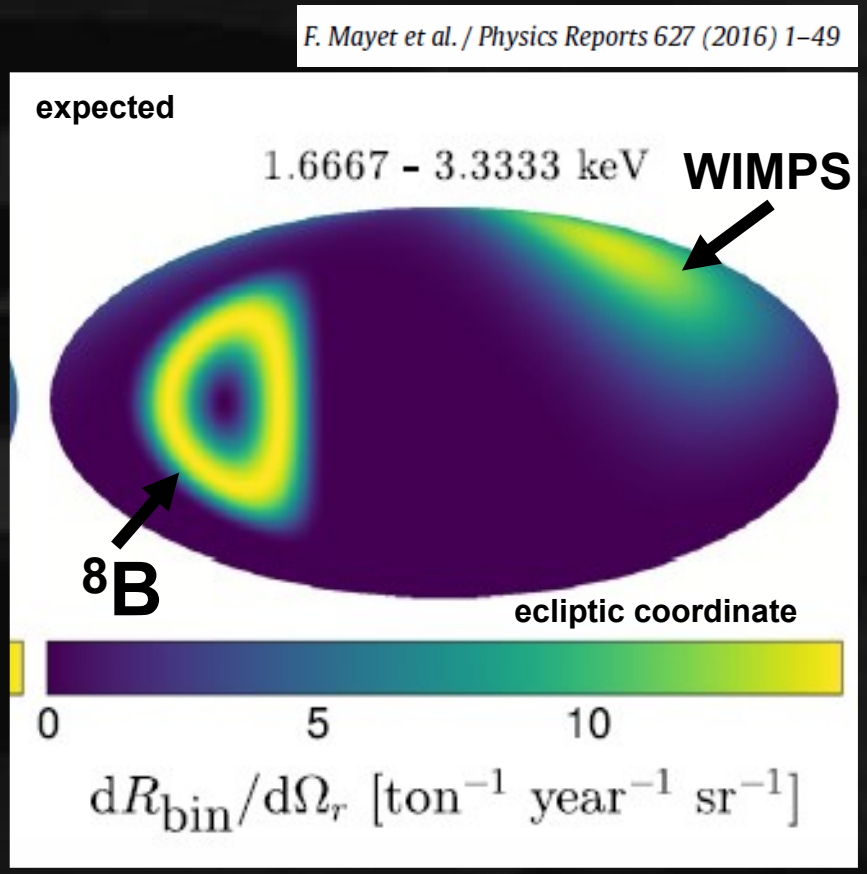
検出まで

検出後：　宇宙物理　素粒子物理

検出まで

- 「ニュートリノフロア†」を超えた探索が原理的に可能





Science REPORTS

Cite as: D. Akimov *et al.*, *Science* 10.1126/science.aao0990 (2017).

Observation of coherent elastic neutrino-nucleus scattering

- **clearly distinguishable**

† ニュートリノ-原子核コヒーレント散乱
2017年ビーム試験で初観測

検出後：宇宙物理

- **Test the halo model**
  - **standard halo (1-r) + co-rotating halo (r)**

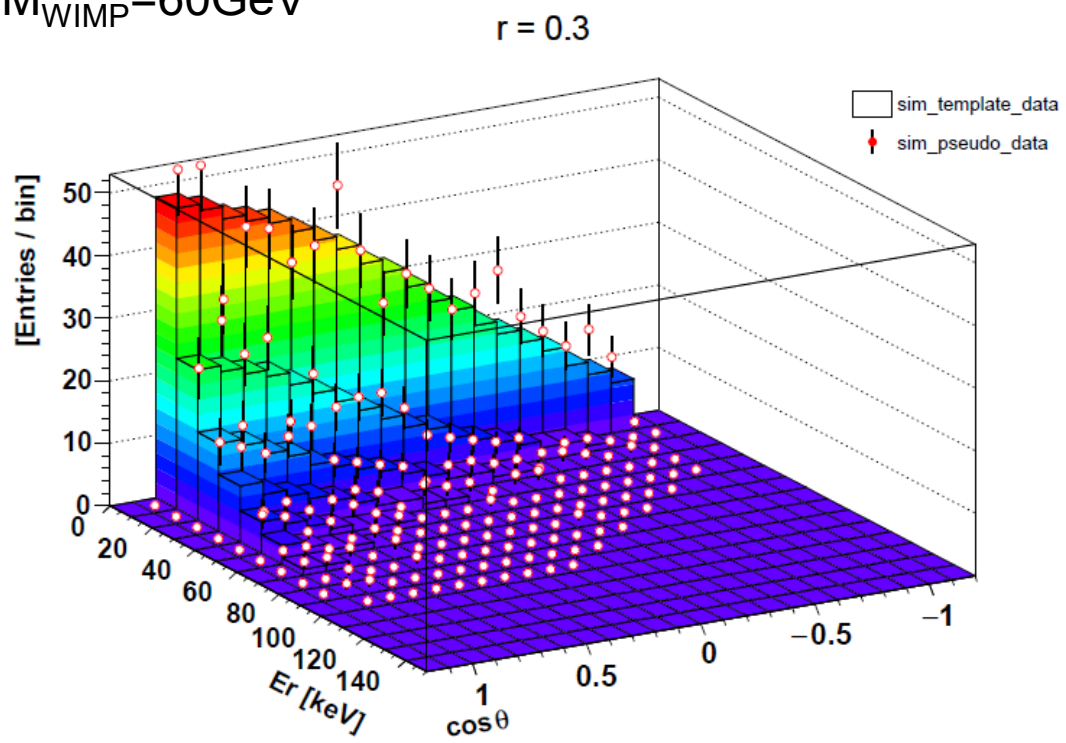
arXiv:1707.05523v1

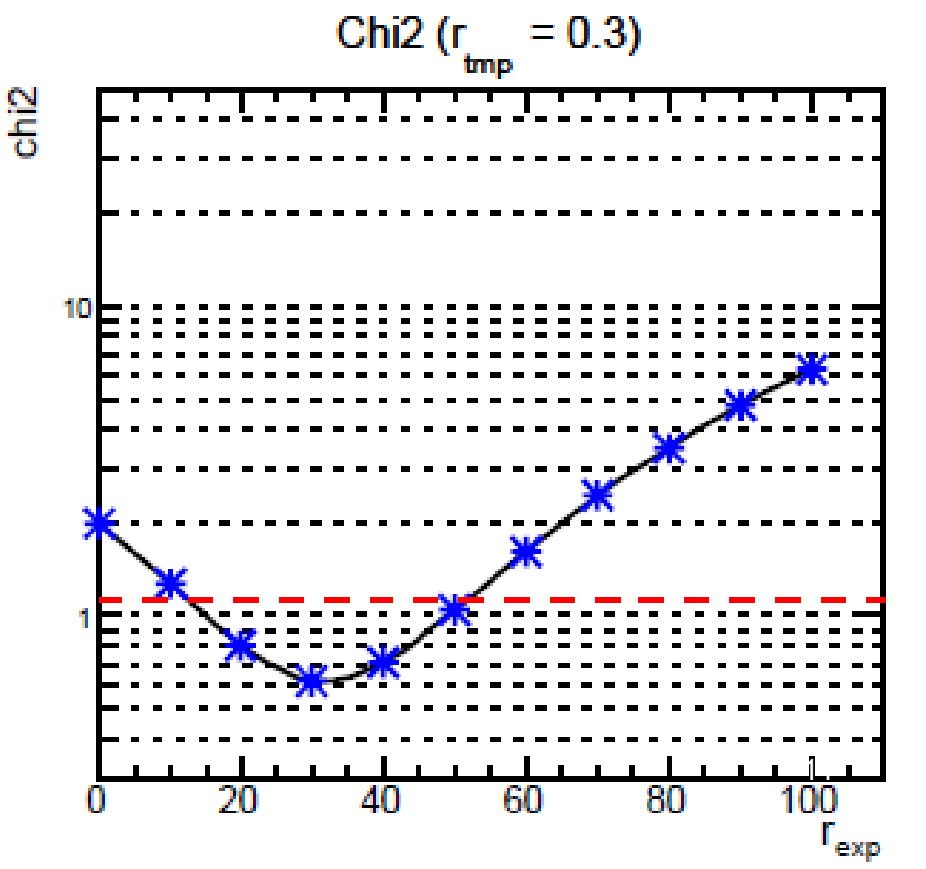
Discrimination of anisotropy in dark matter velocity distribution with directional detectors

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

target: F
M_{WIMP}=60GeV

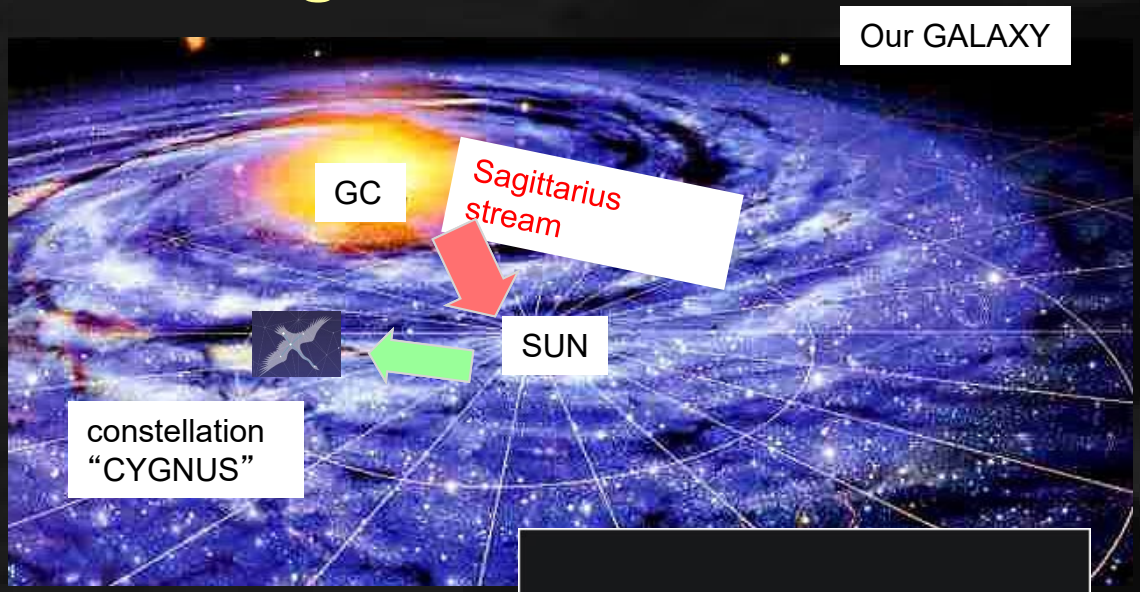
standard “spectrum” in AD era

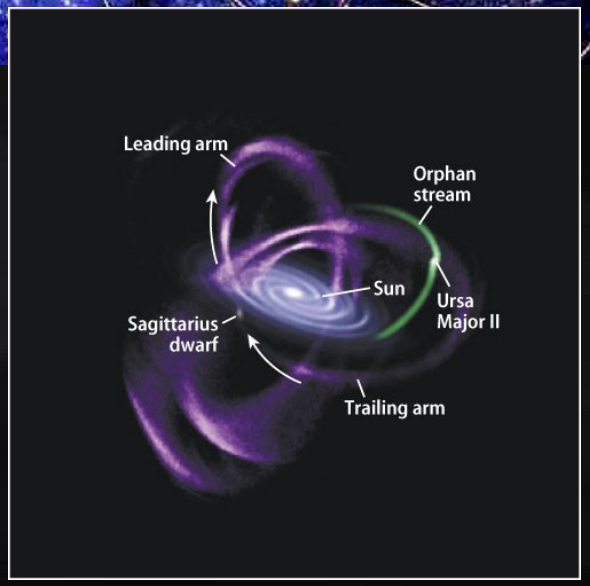




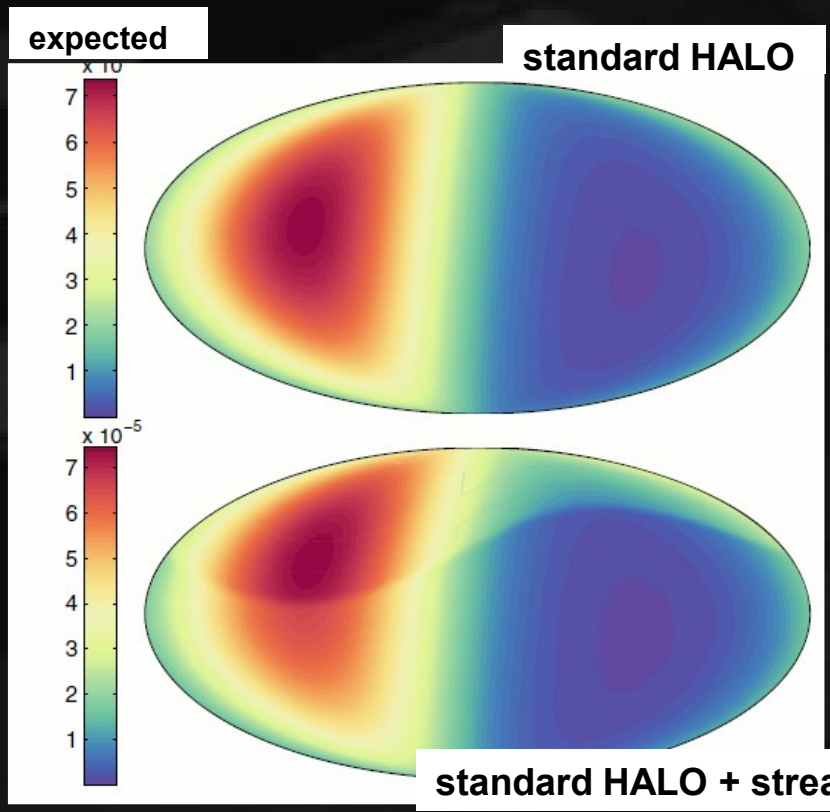
検出後：宇宙物理

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





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



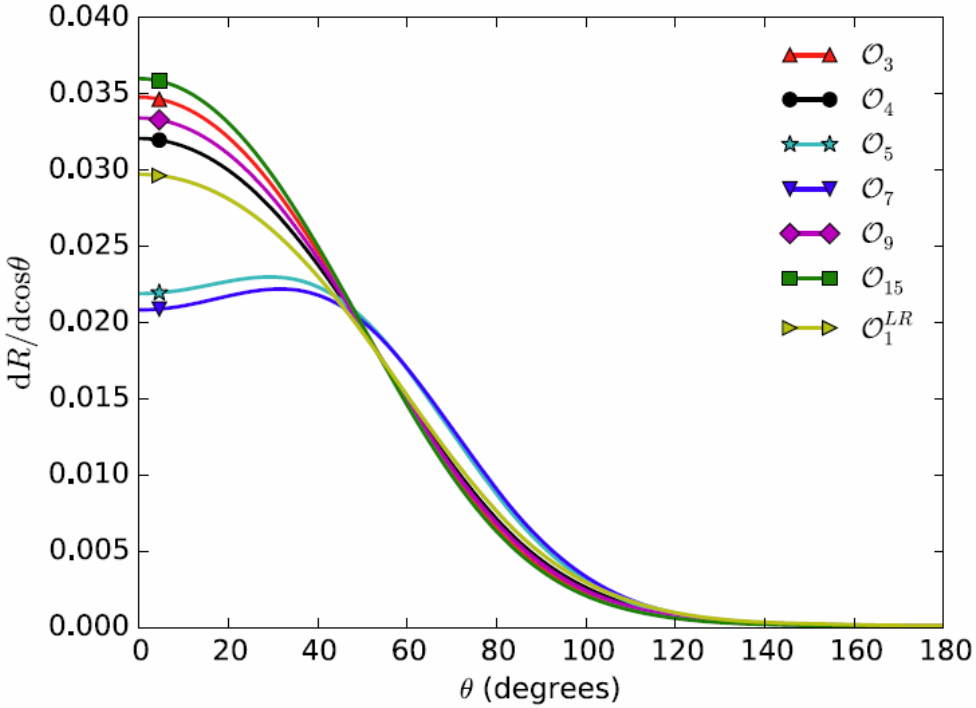
galactic coordinate

- **streams, halo model…**

検出後：素粒子物理

- **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**

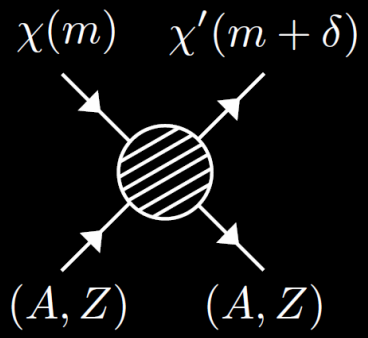
検出後：素粒子物理

Inverted dipole and beyond

Paolo Gondolo

University of Utah

Inelastic dark matter



There are two dark matter species very close in mass, and they can scatter one into the other.

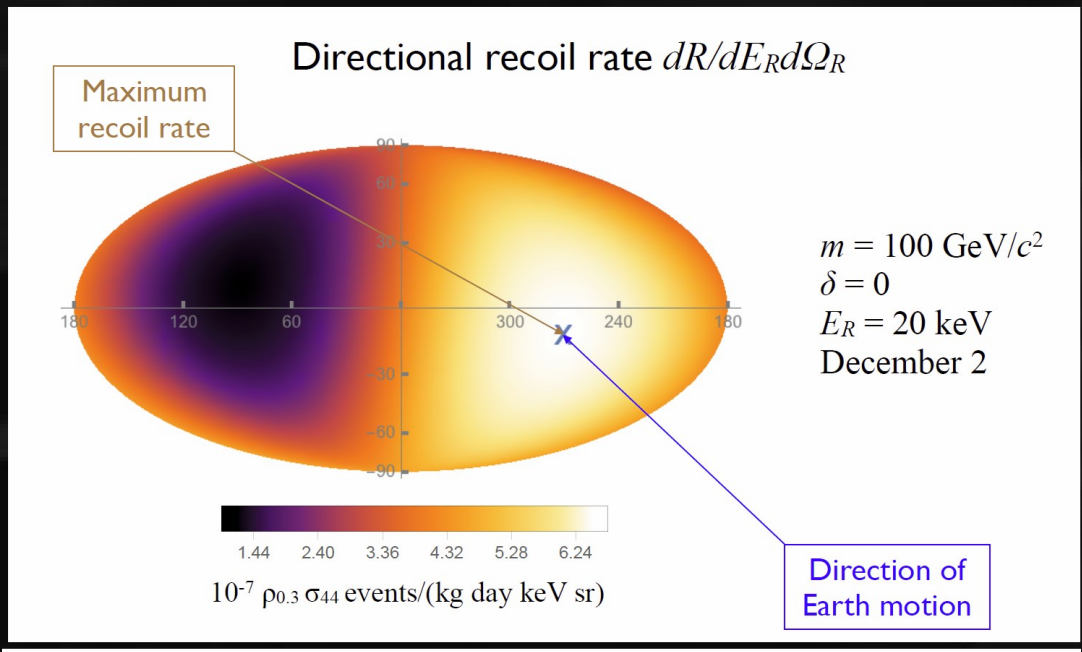
Mass splitting δ up to tens of keV.

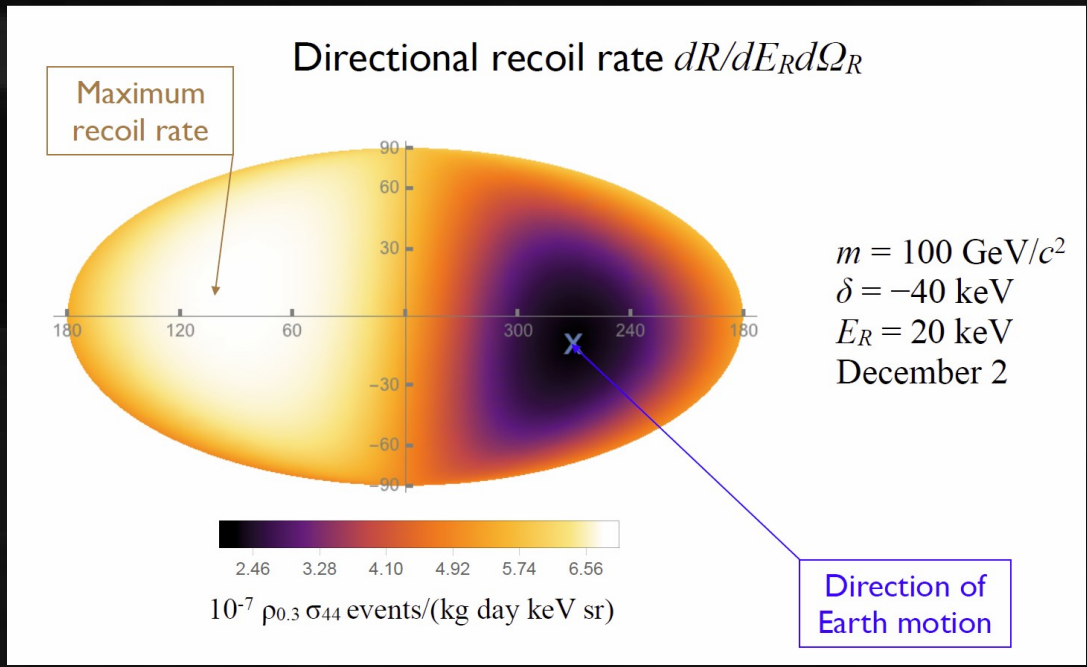
$$\delta = m_{\text{out}} - m_{\text{in}}$$

$\delta > 0$ endothermic
(outgoing WIMP has less kinetic energy than incoming WIMP)

$\delta < 0$ exothermic
(outgoing WIMP has more kinetic energy than incoming WIMP)

- 質量の異なるDM同士の遷移





実験

原理

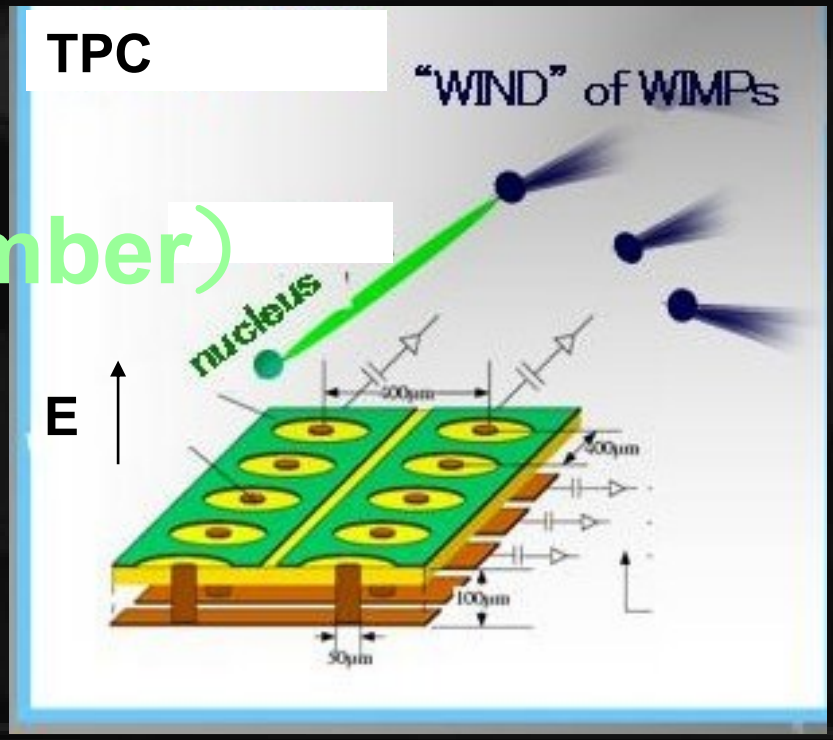
Recoil nuclear track detection < 100keV

challenge: short track

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

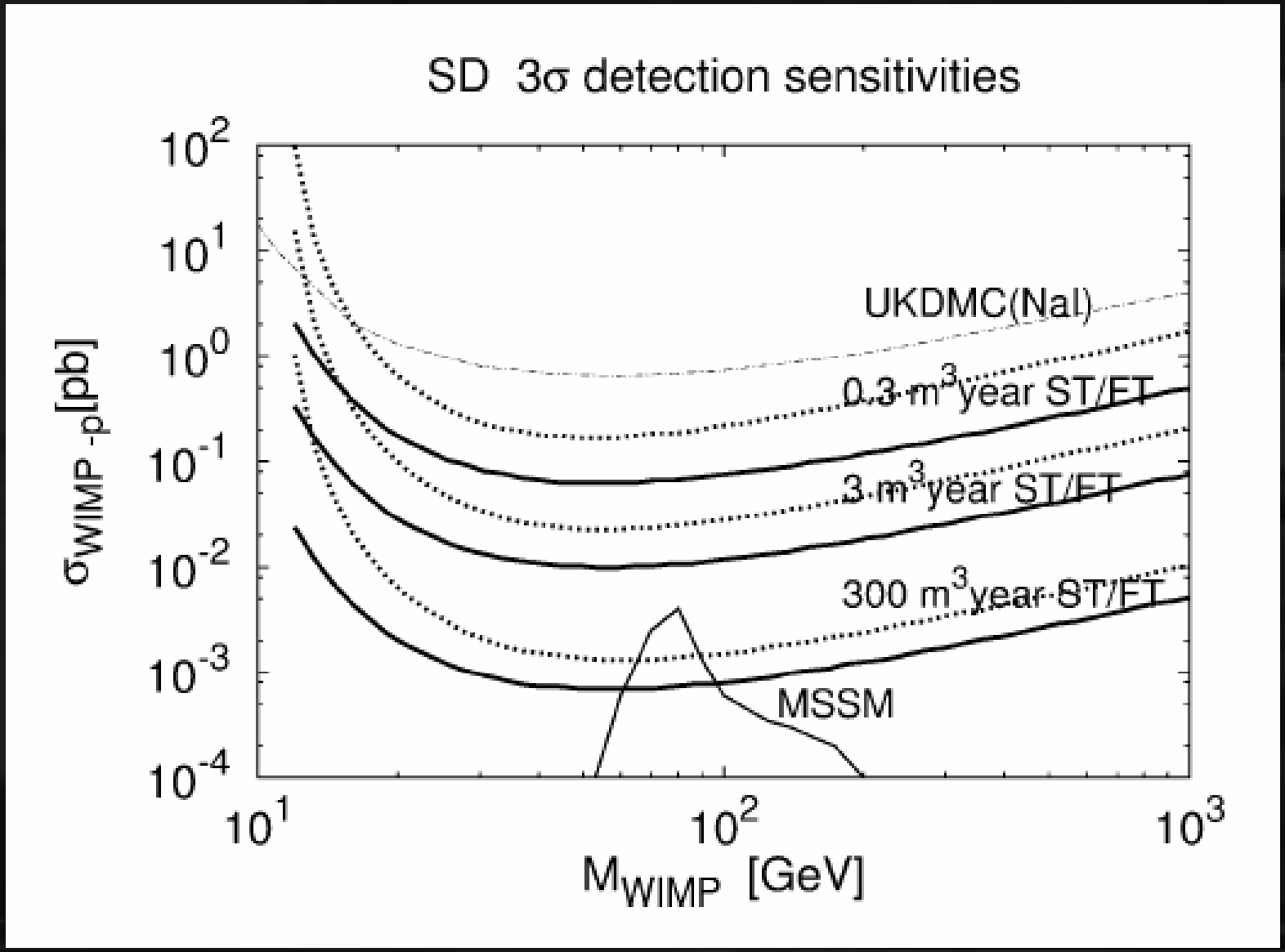
Most typical "CYNGUS":
low pressure gas TPC
（time projection chamber）

2D readout + timing
→ 3D tracking



ガスTPC：大型検出器

Physics Letters B 578 (2004) 241–246



DRIFT: パイオニア

- 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

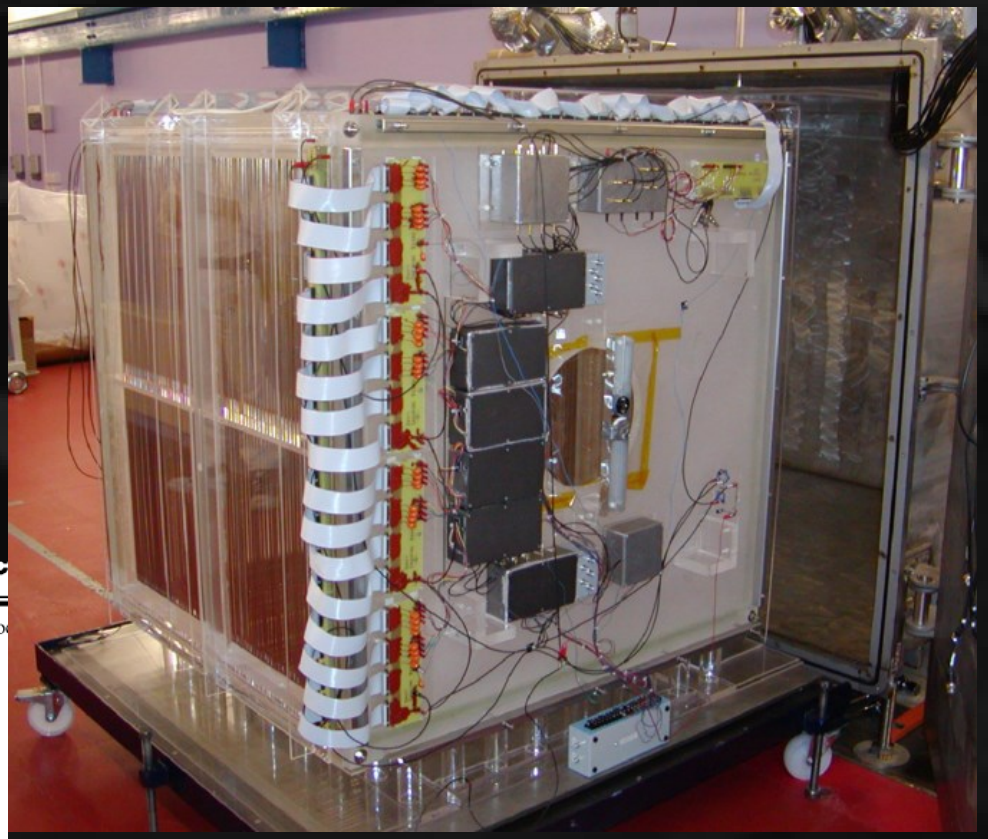
R Nuclear Instruments and Methods in Physics Research A 498 (2003) 155–164
RESEARC Section A
www.elsevier.com/lo

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



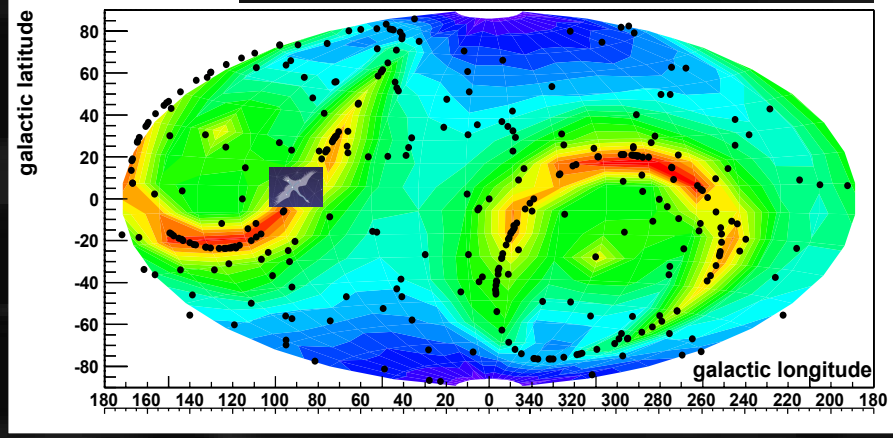
- 2mm pitch multi-wire proportional chamber
- not very direction-sensitive

NEWAGE（PI 身内）：方向感度を追求

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

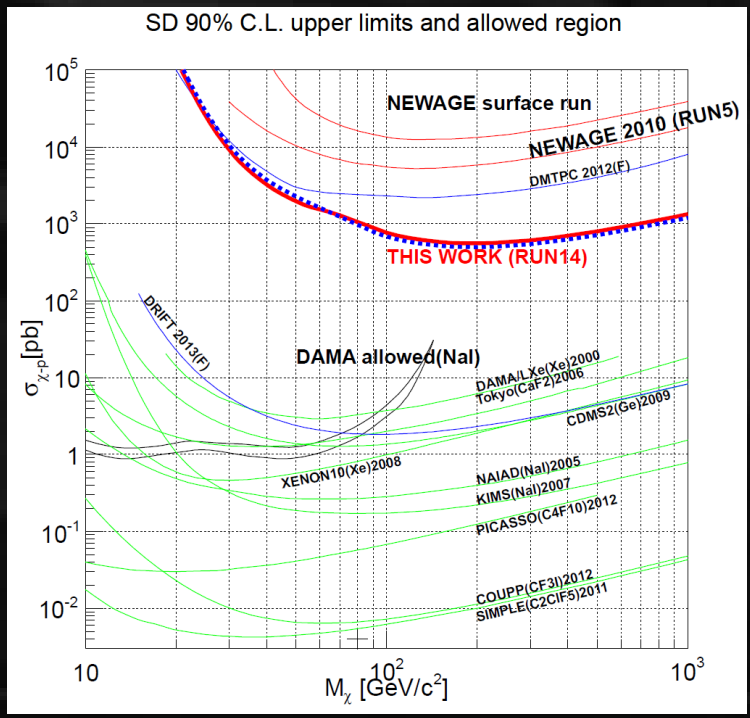
SKYMAP (measured DATA)



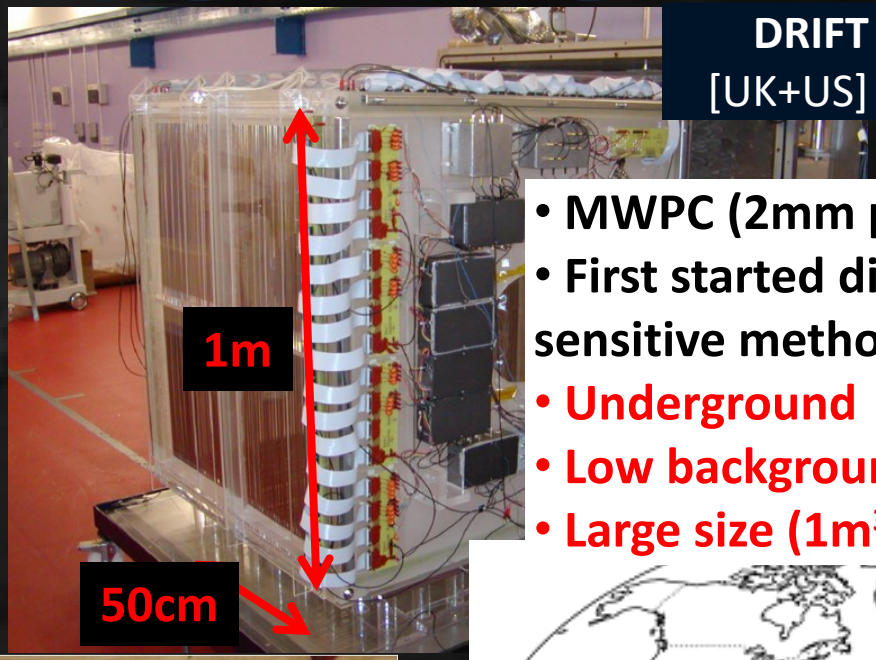
- Proposal PLB 578 (2004) 241
- First direction-sensitive limits

  PLB654 (2007) 58
- Underground results

  PLB686 (2010) 11, PTEP (2015) 043F01s
- Phase for “low BG detector”

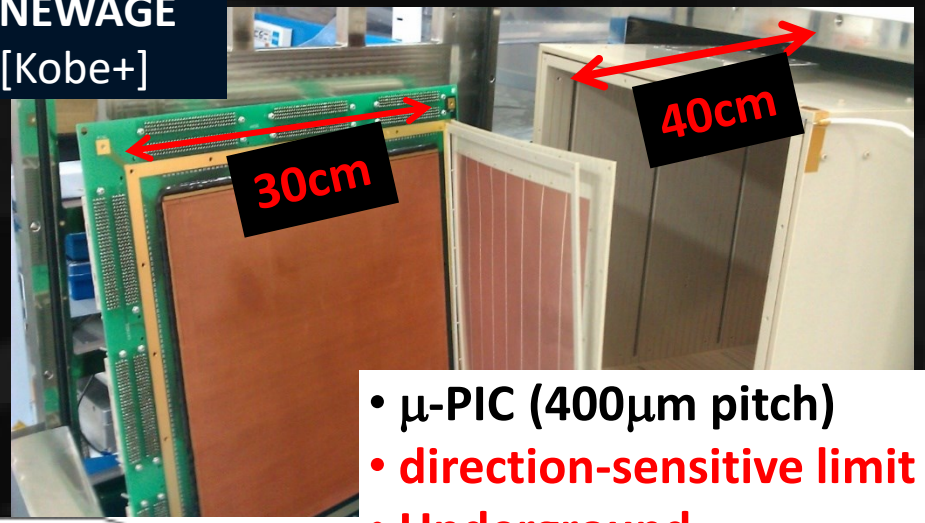


Cygnus, gas TPCs



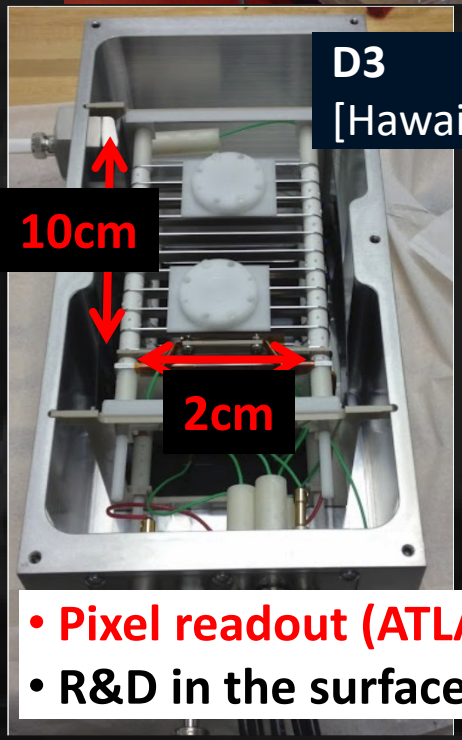
DRIFT
[UK+US]

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



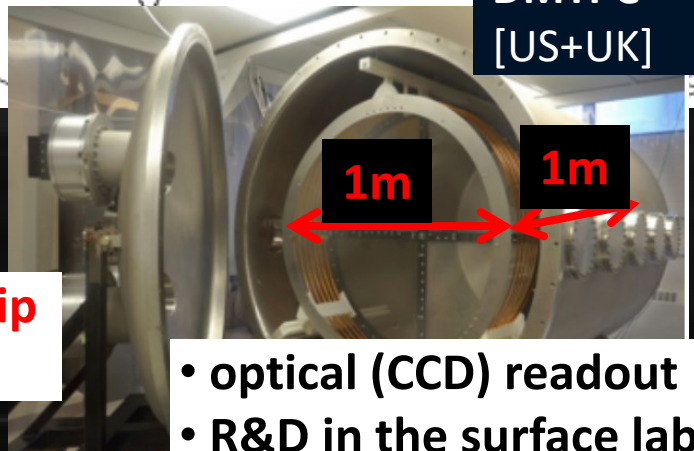
NEWAGE
[Kobe+]

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



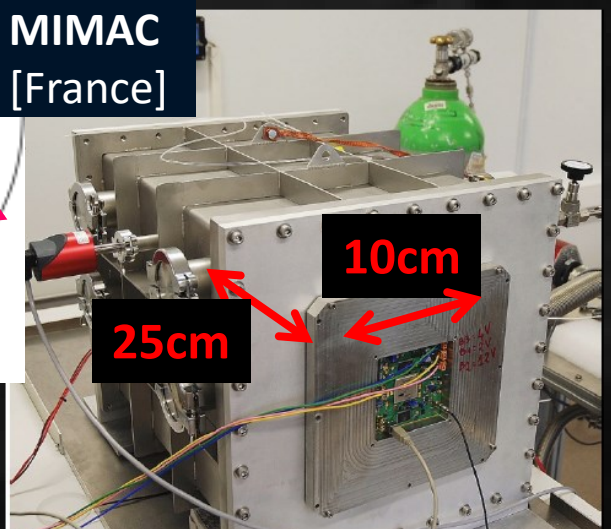
D3
[Hawaii]

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



DMTPC
[US+UK]

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



MIMAC
[France]

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

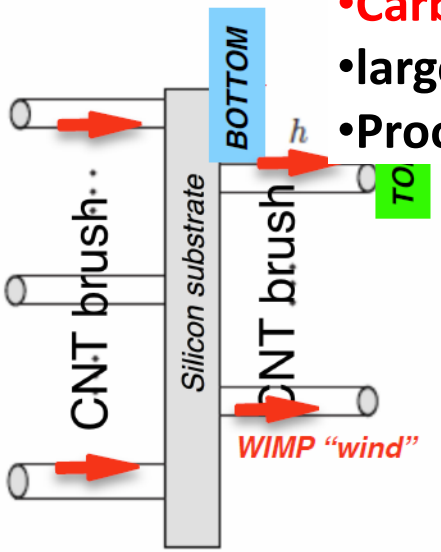
Cygnus, others

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

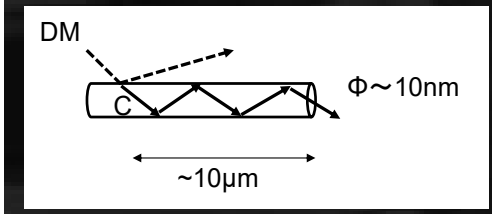
NEWSdm
[Japan+Italy]

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

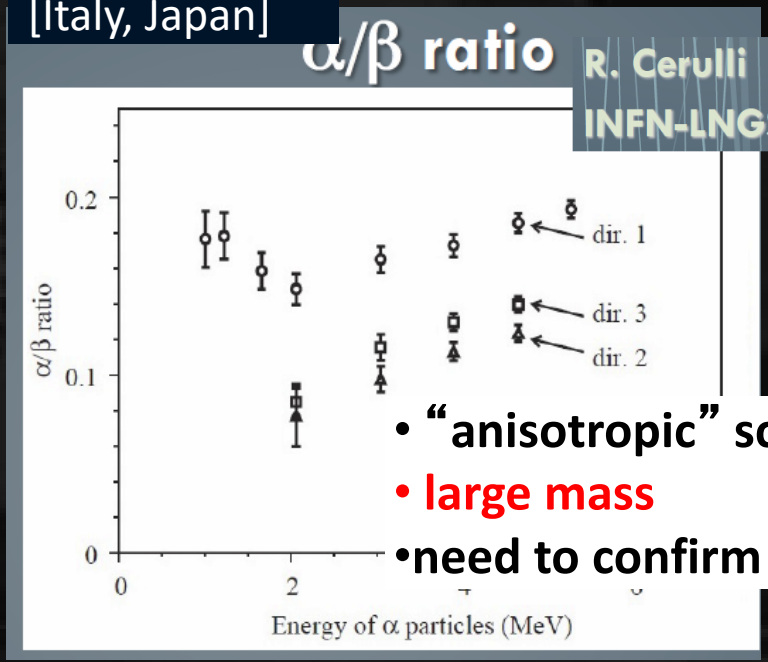
DeCANT
[Italy]



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



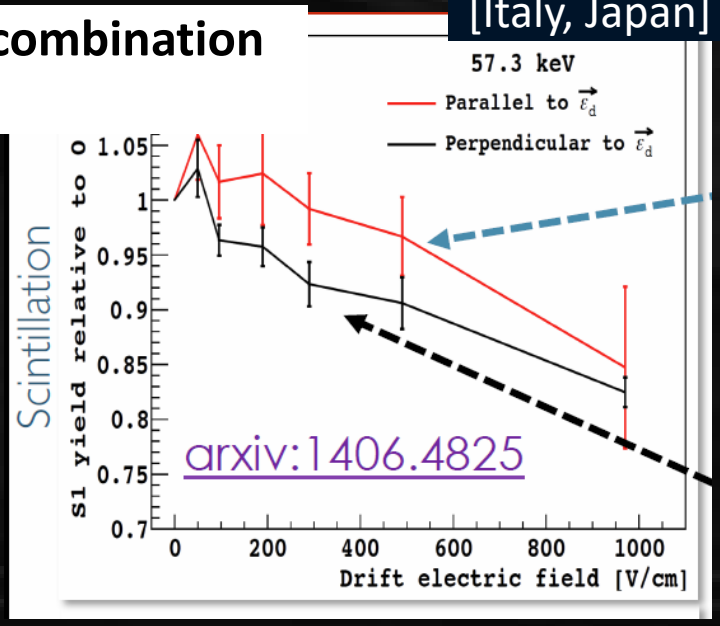
$ZnWO_4$
[Italy, Japan]



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

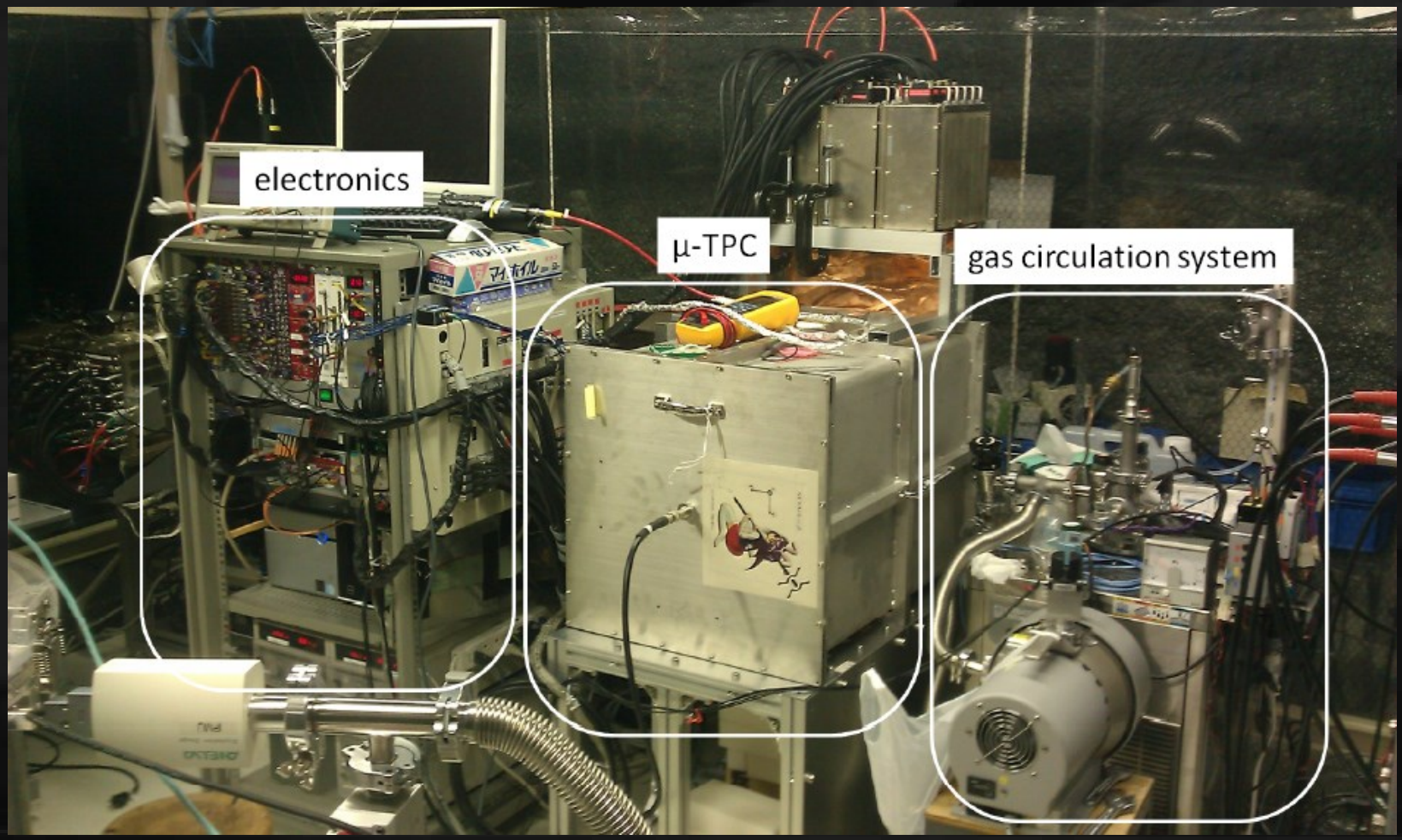
Liq Ar
[Italy, Japan]

- columnar recombination
- large mass



NEWAGE detector

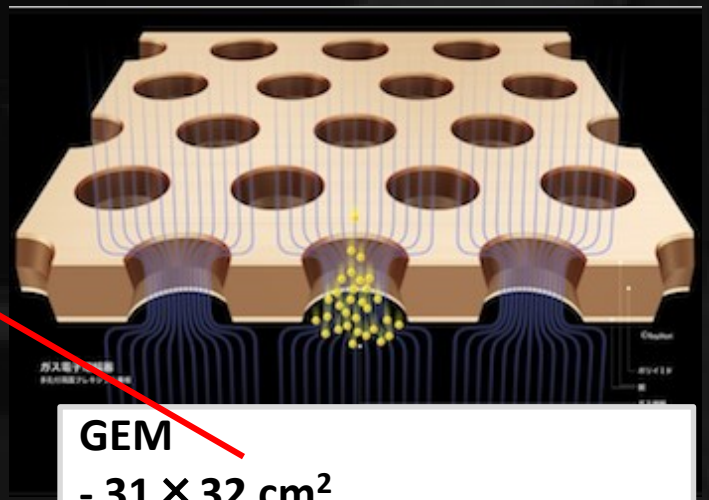
- NEWAGE-0.3b'
- Detection Volume: 31×31×41cm^3
- Gas: CF4 at 0.1atm (50keVee threshold)
- Gas circulation system with cooled charcoal



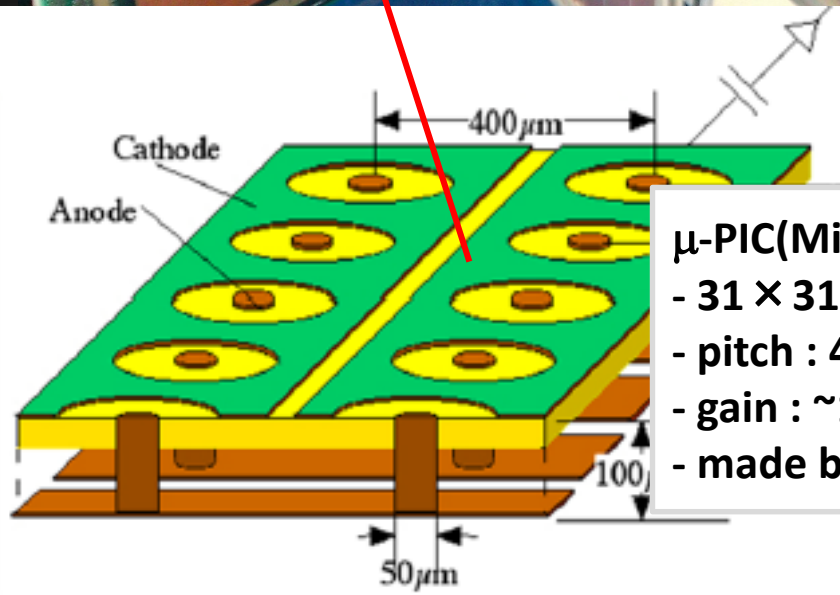
NEWAGE-0.3b' inside view

Detection Volume: 30×30×41cm^3

Field cage
Drift length: 41cm
PEEK + copper wires



GEM
- 31 × 32 cm^2
- 8-segmented
- hole pitch : 140μm
- hole diameter: 70μm
- insulator : LCP 100μm
- gain : ~5
- made by Scienergy, Japan

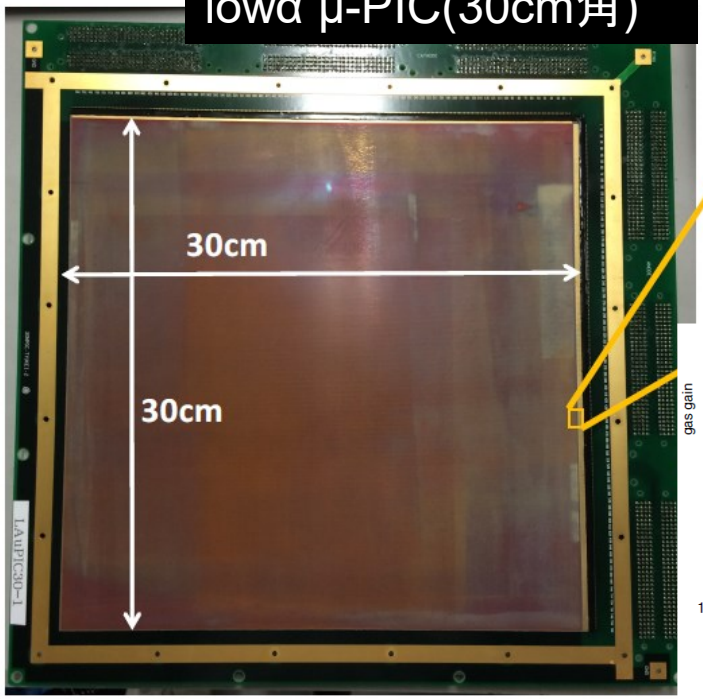


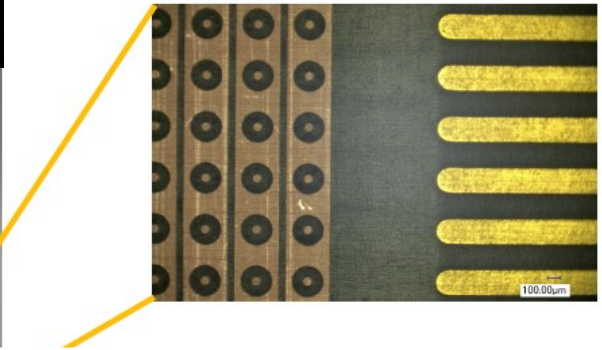
μ-PIC(Micro-pixel chamber)
- 31 × 31cm^2
- pitch : 400μm
- gain : ~1000
- made by DNP, Japan

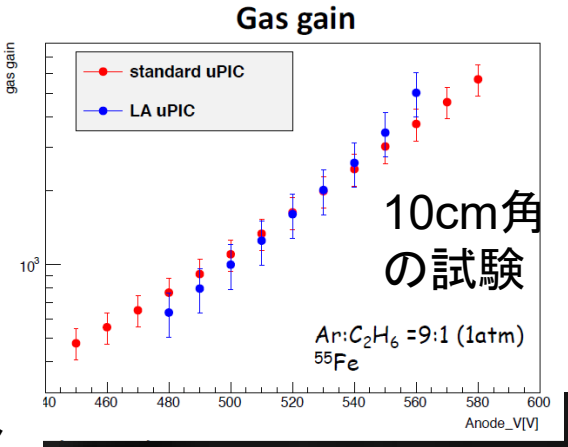
低BG化

- 低α μ-PIC：α線レベル×1/100のμ-PIC完成
- Z方向のfiducialization：SF_6ガスのstudy

lowα μ-PIC(30cm角)

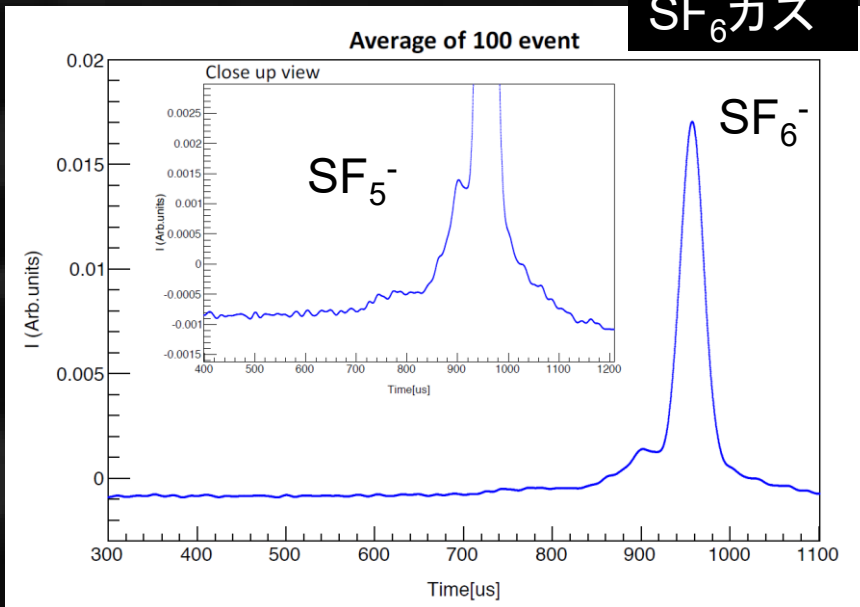




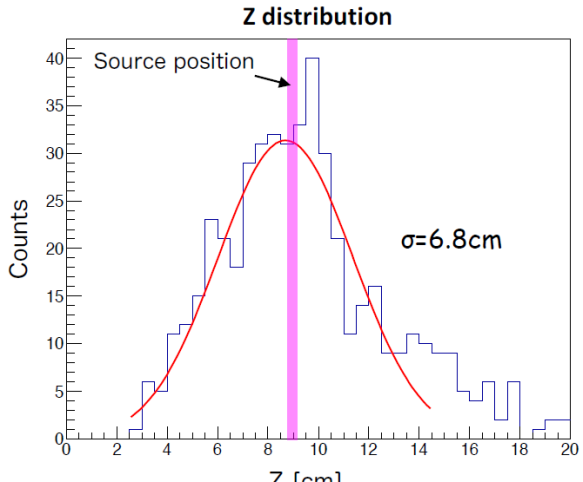


8月に地下実験へ投入

SF_6ガス



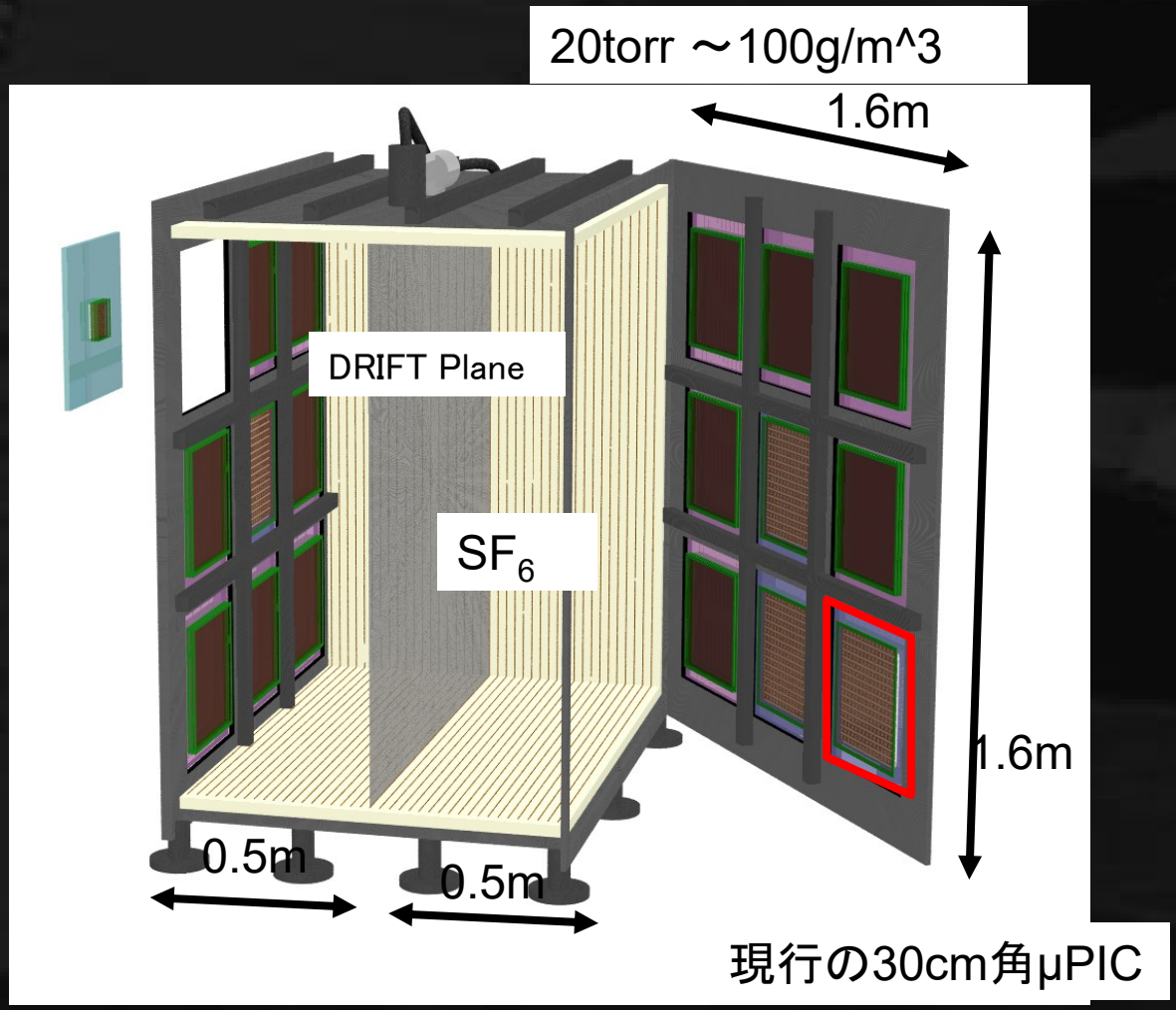
ドリフト速度の違い → Zの絶対値測定



- それぞれ2桁のBG削減

NEWAGE 大型化

- 現状：30×30×40cm3　→　大型チェンバー製作中
- まずは　2×(30×30×50cm^3)で開始



- 18個ある窓に違った検出器を設置可能
- observatoryとして国内外の研究者に提供予定

まとめ

- 方向に感度を持つ直接探索
  - 確実な発見　→　宇宙物理　素粒子物理
- ガスTPC、原子核乾板　など