NEWAGE

神戸大学
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2017年6月25日

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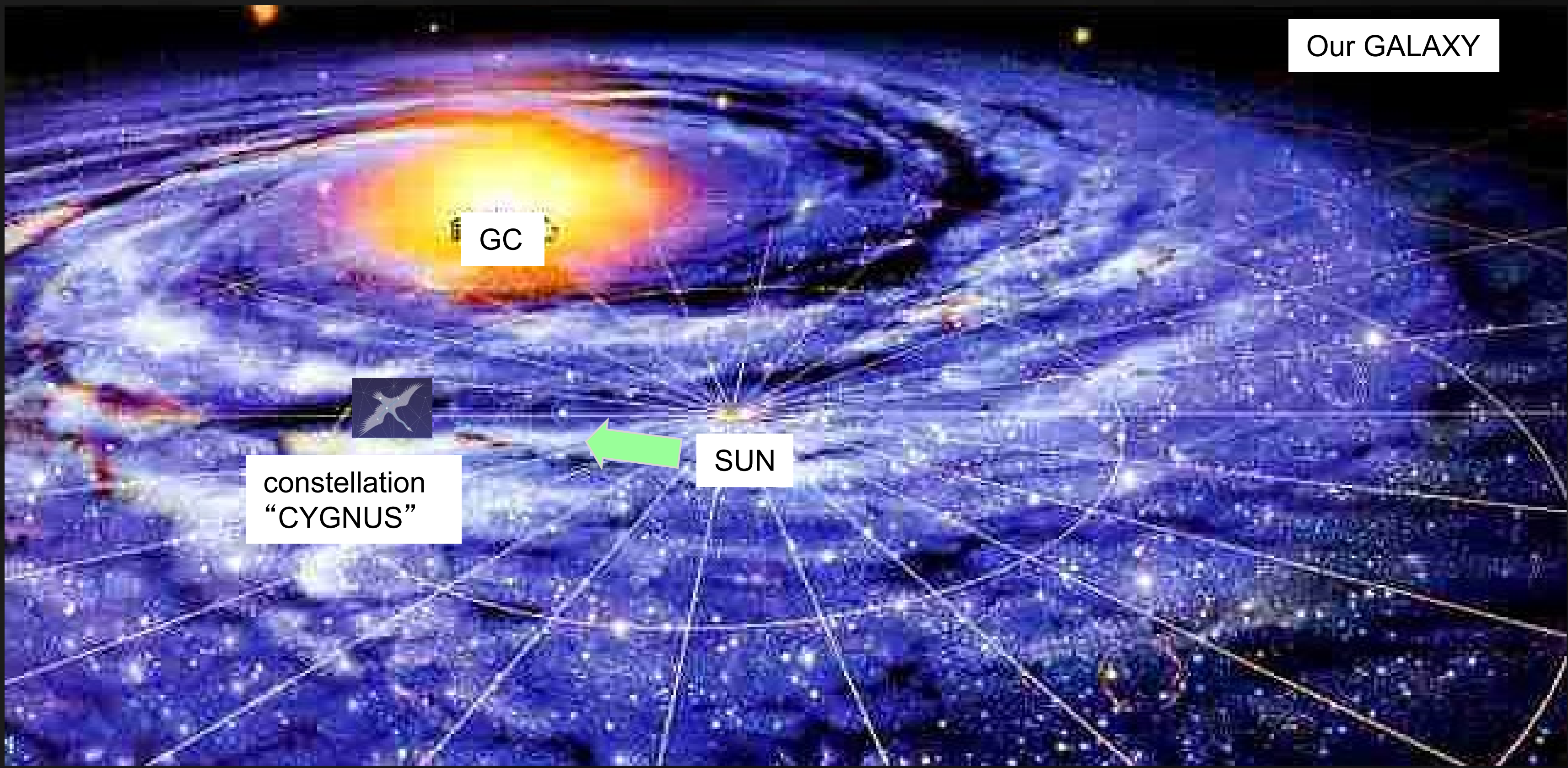
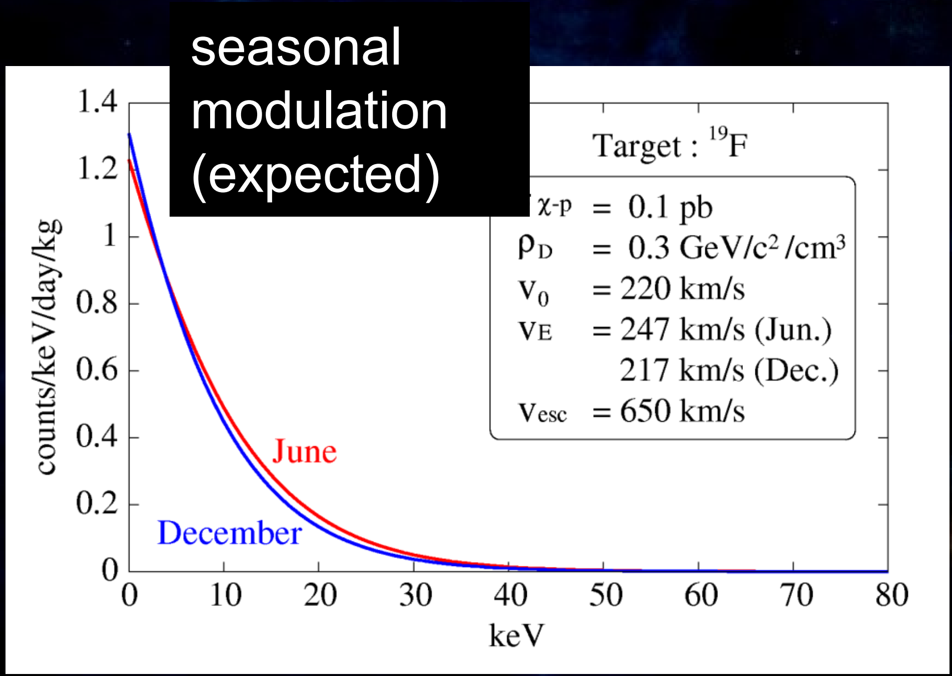
物理

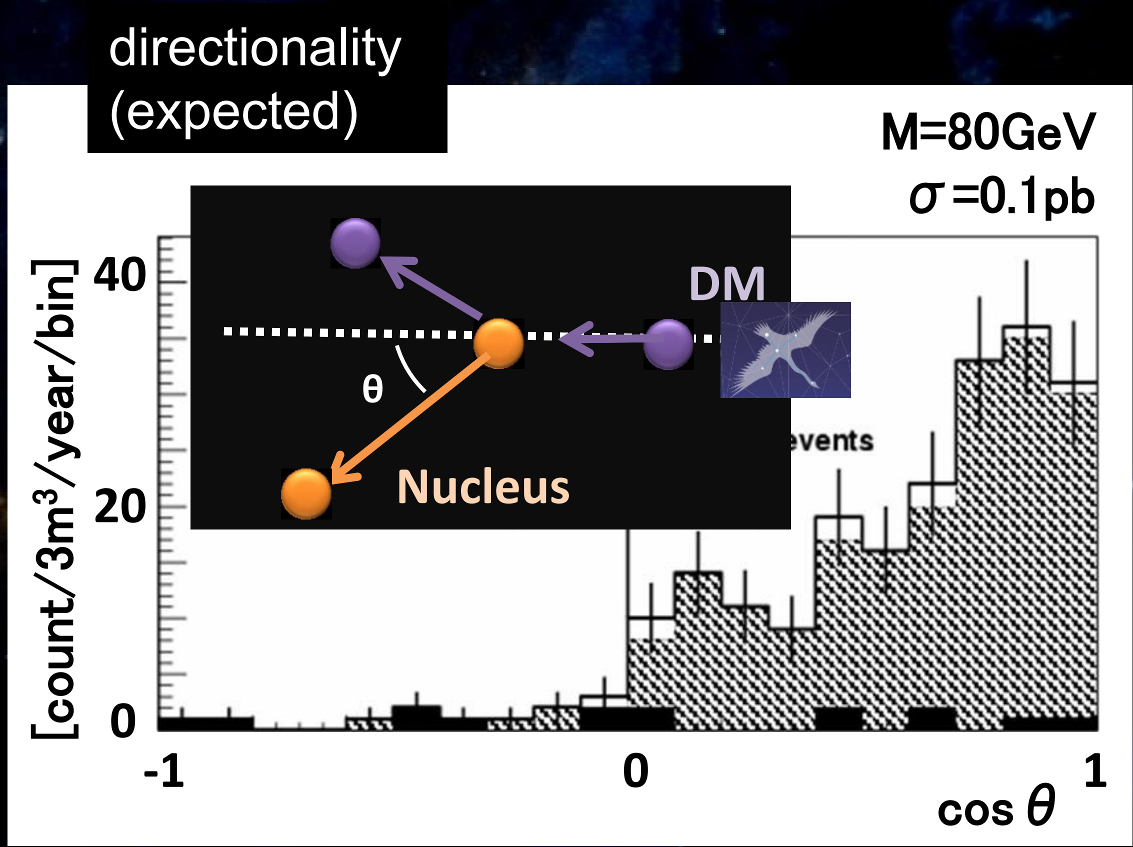
方向に感度を持つ暗黒物質直接探索



はくちょう座からのWIMPの風

"CYGNUS" concept





Clear Discovery

+ study the nature of DM after discovery

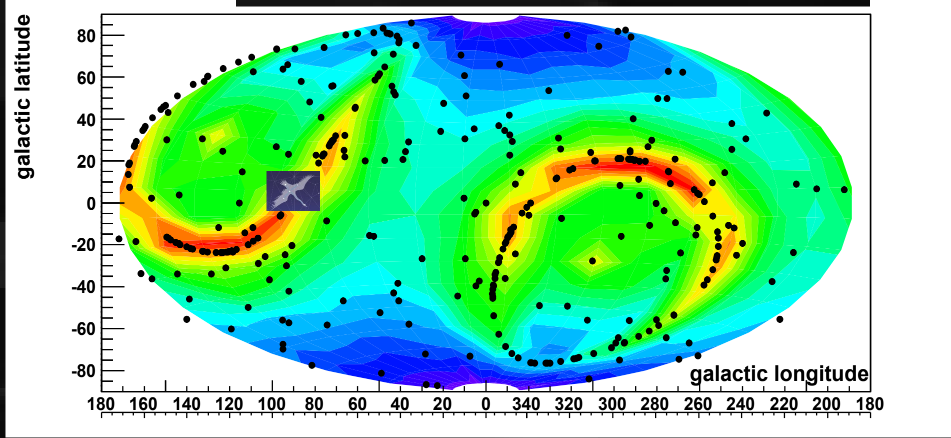
NEWAGE

NEWAGEのこれまで

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

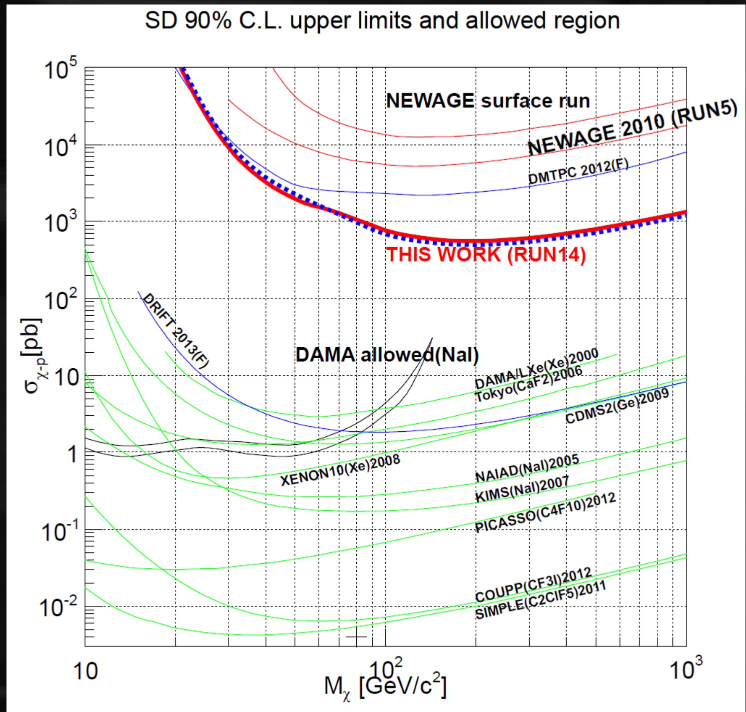
PLB654 (2007) 58

- 2007年-地下実験室Bでの観測
- Underground results

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

- Phase for “low BG & large mass”

PTEP (2015) 043F01s

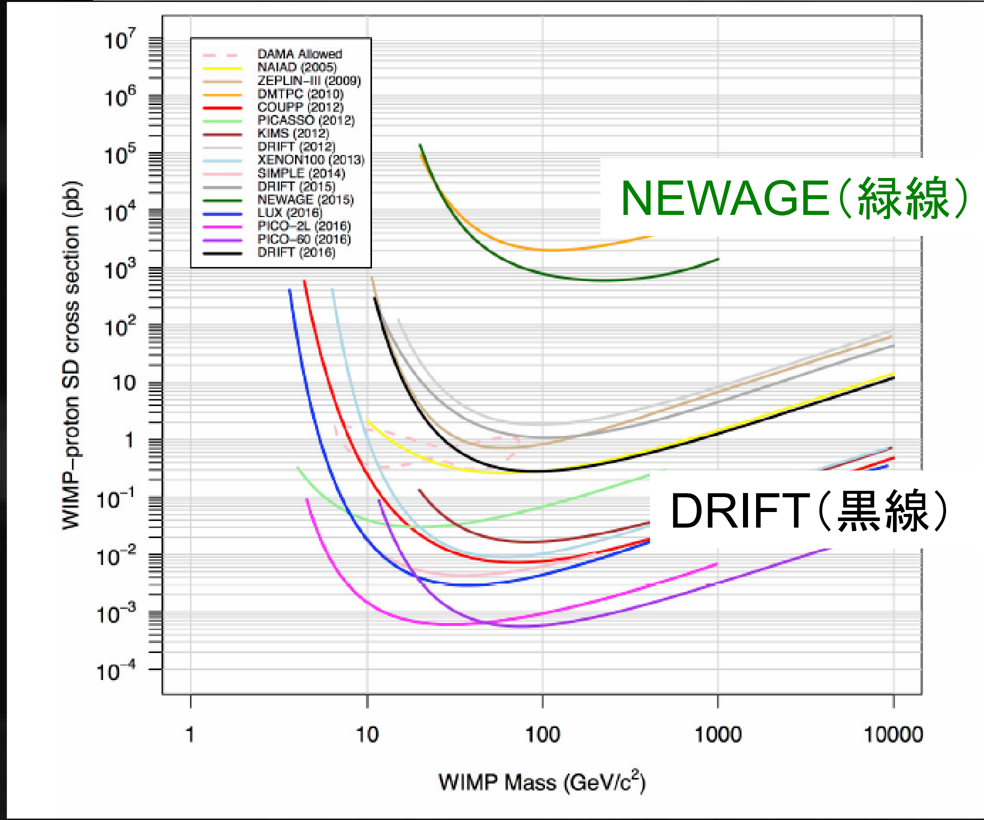


NEWAGE strategy since its new ages

世界情勢

- DRIFT（英・米）　Astropart. Phys. 91 (2017) 65
  - MWPC
  - directionは捨ててBG低減　SDのリミットを追求。
    0.28pb@100GeV ガスで最良
  - 米・ヨーロッパでそれぞれ
    大型化の申請準備中。（”CYGNUS”）
- MIMAC（仏）
  - MPGDで飛跡検出に注力
  - 地下測定は行っているがBGやDMに関する結果は出ず。
- DMTPC（米・英）
  - CCD　開店休業
- D3（米）
  - ピクセルチップ　小型機でのR&D
- NITEC
  - ピクセルチップ　小型機でのR&D
- NEWSdm（日・伊）　中氏
  - 原子核乾板
  - グランサッソでBG測定開始
- 関谷結晶　関谷氏

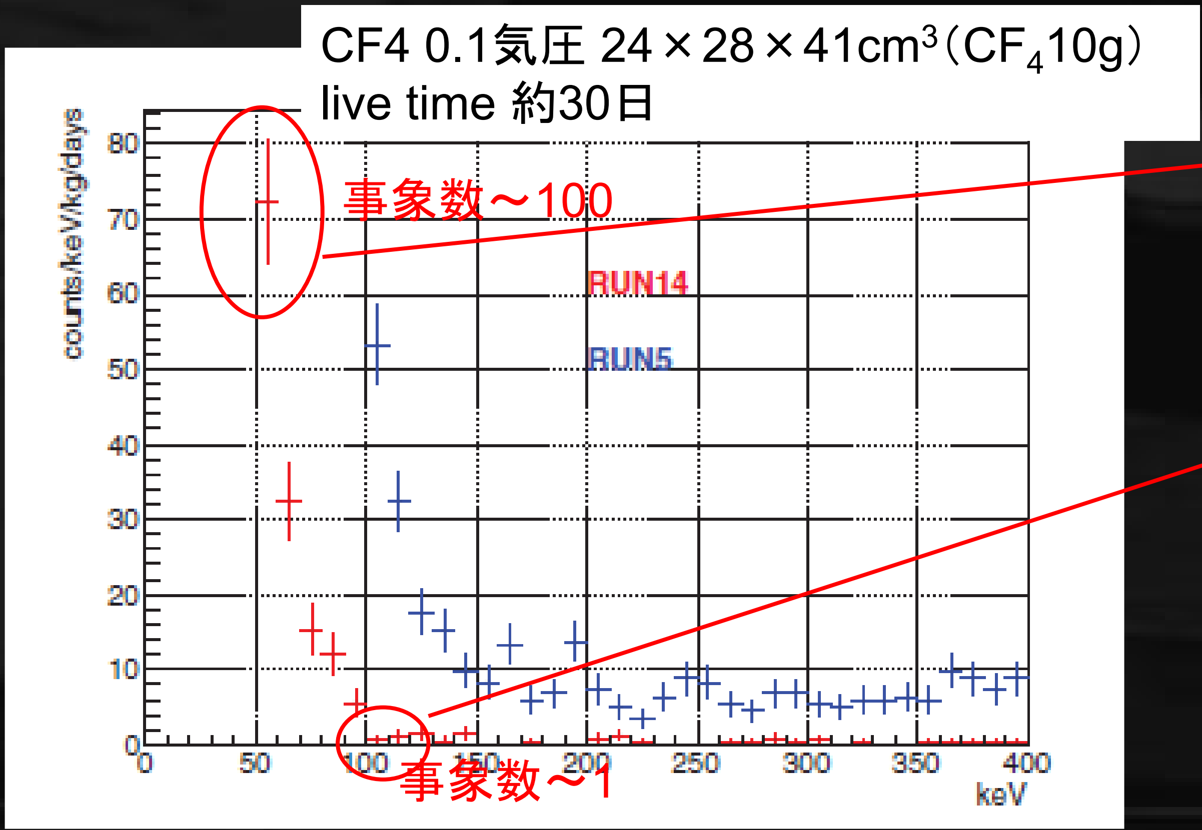
Low Threshold Results and Limits from the DRIFT Directional Dark Matter Detector

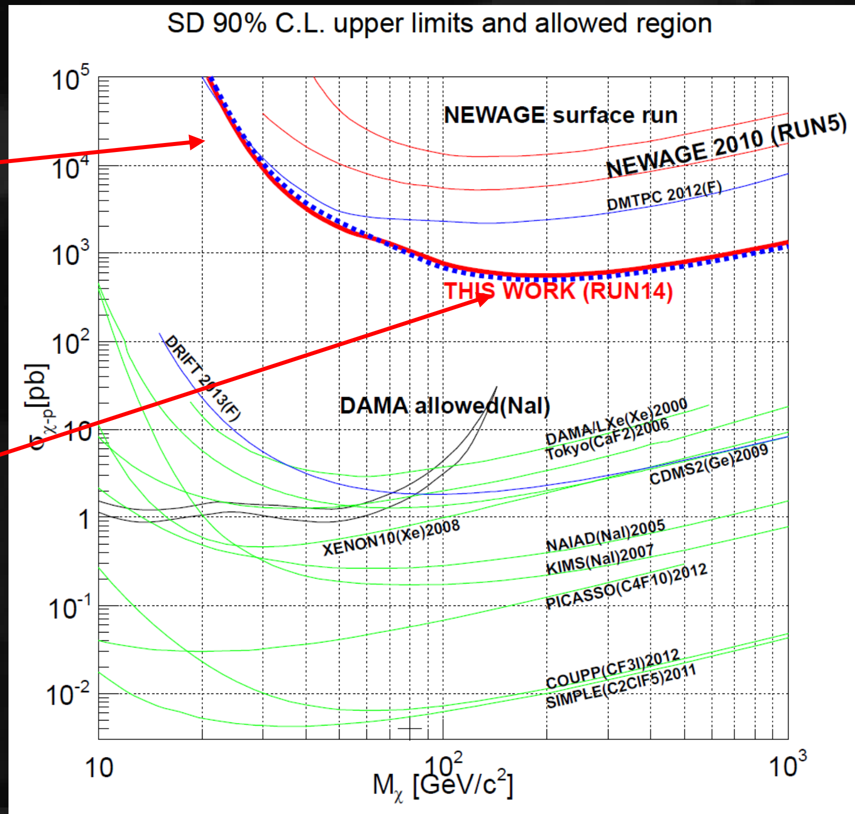


NEWAGEの現状　500pb

- 数10GeV以下：BGリミット
  - ⇒ 低BG化　低α μ-PIC、z-fiducialization
- 数10GeV以上：統計リミット
  - ⇒ 大型化　大型チェンバー

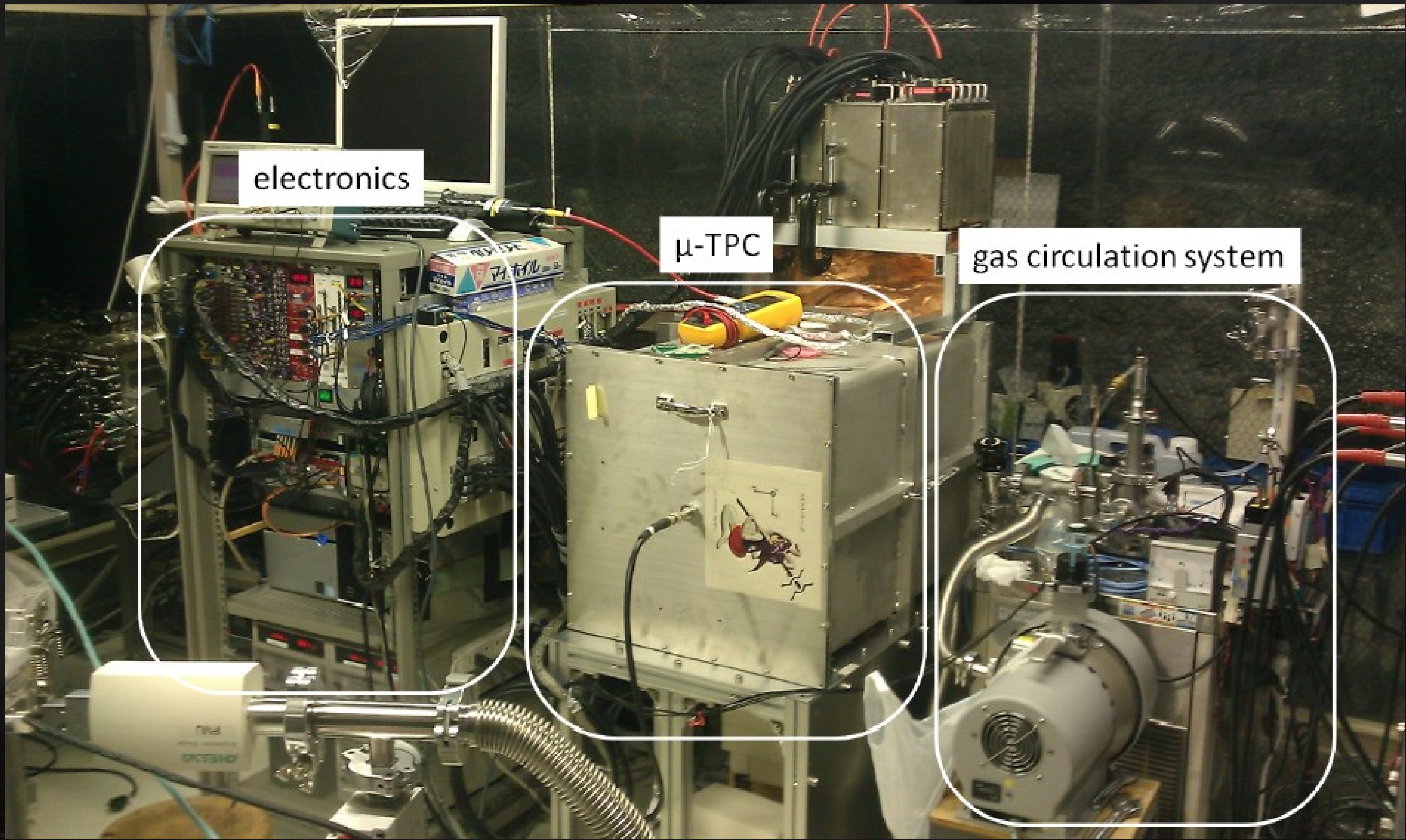
PTEP (2015) 043F01s





NEWAGE detector

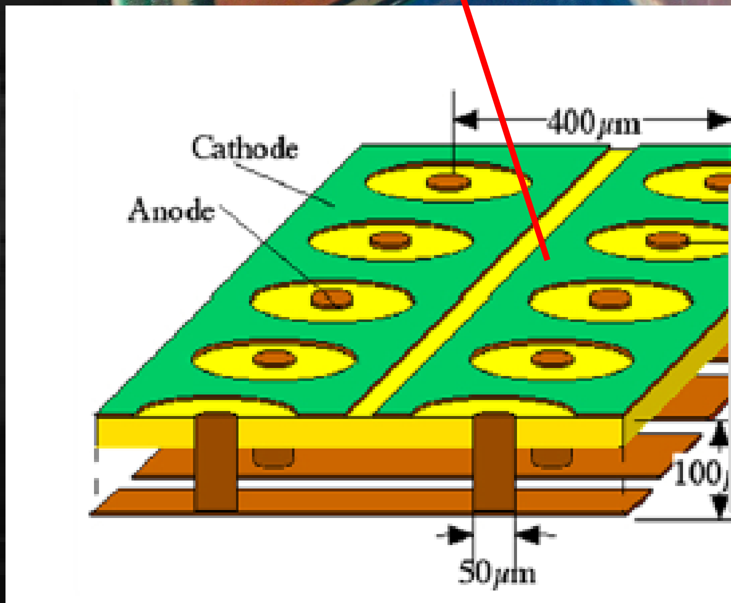
- NEWAGE-0.3b'
- Detection Volume: 31×31×41cm^3
- Gas: CF_4 at 0.1atm (50keVee threshold)
- Gas circulation system with cooled charcoal



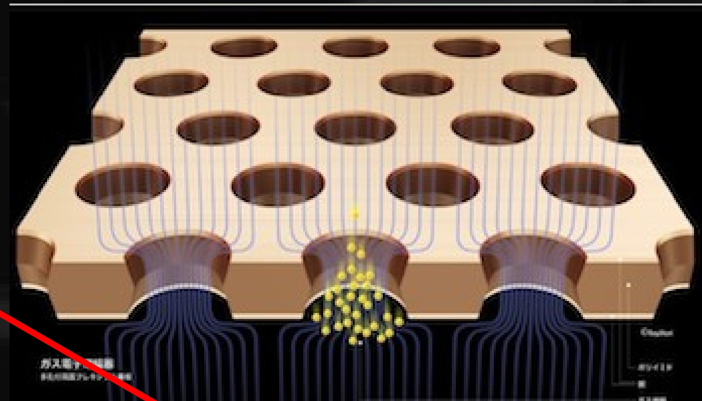
NEWAGE-0.3b' inside view

Detection Volume: 30×30×41cm^3

Field cage
Drift length: 41cm
PEEK + copper wires



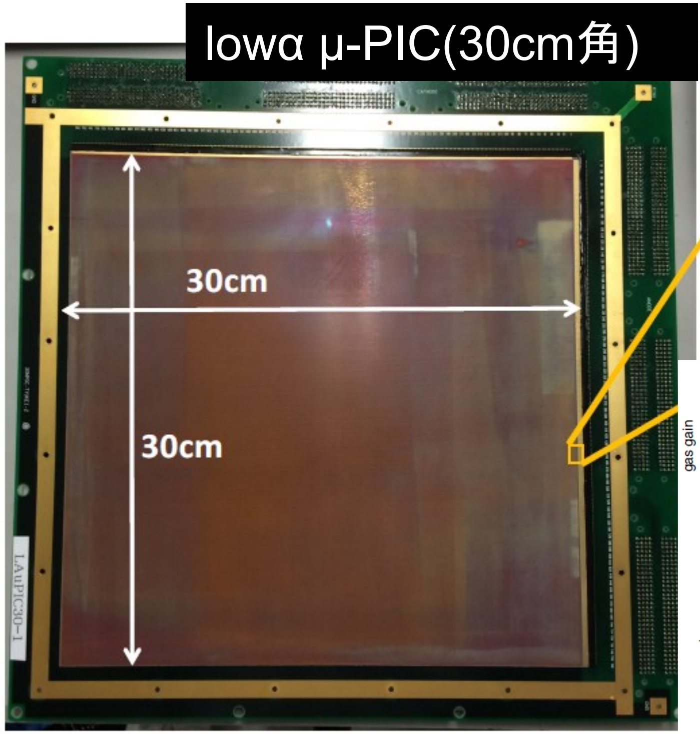
μ-PIC(Micro-pixel chamber)
- 31×31cm^2
- pitch : 400μm
- gain : ~1000
- made by DNP, Japan



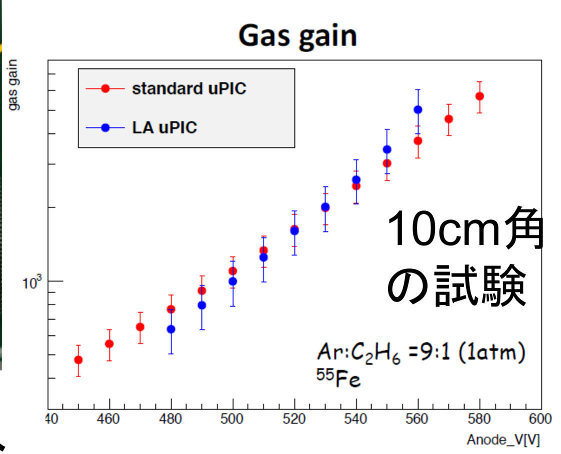
GEM
- 31×32 cm^2
- 8-segmented
- hole pitch : 140μm
- hole diameter: 70μm
- insulator : LCP 100μm
- gain : ~5
- made by Scienergy, Japan

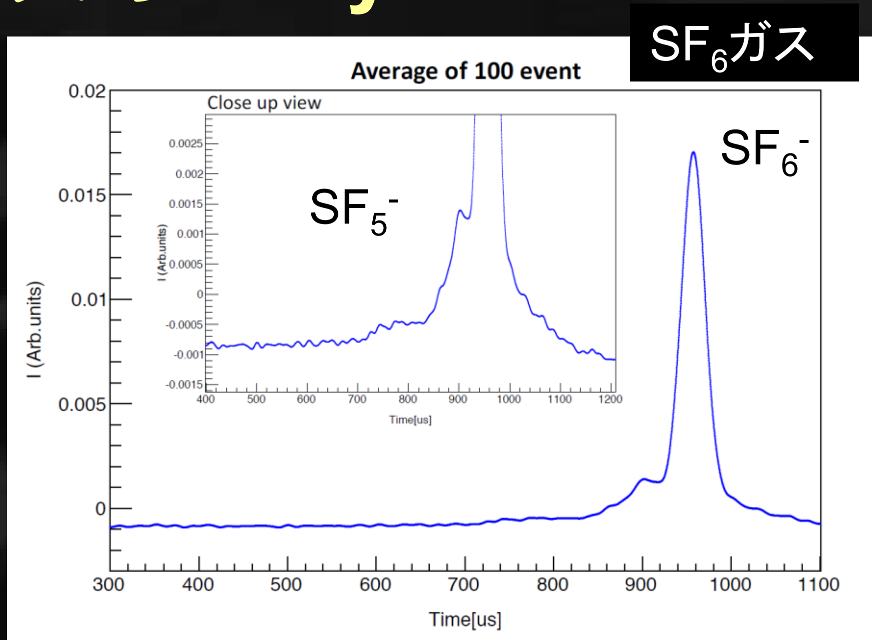
低BG化

- 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

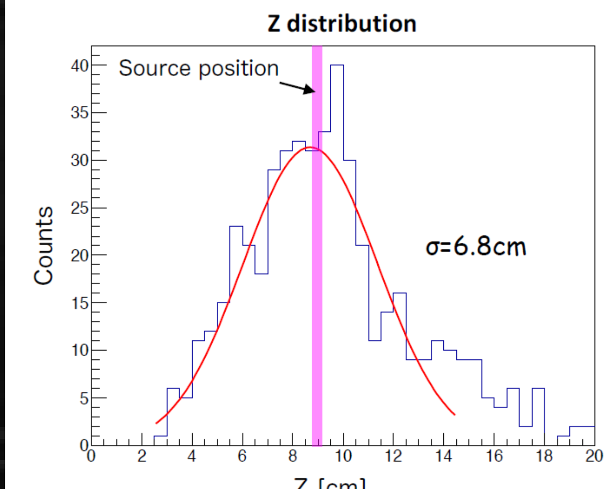


8月に地下実験へ投入





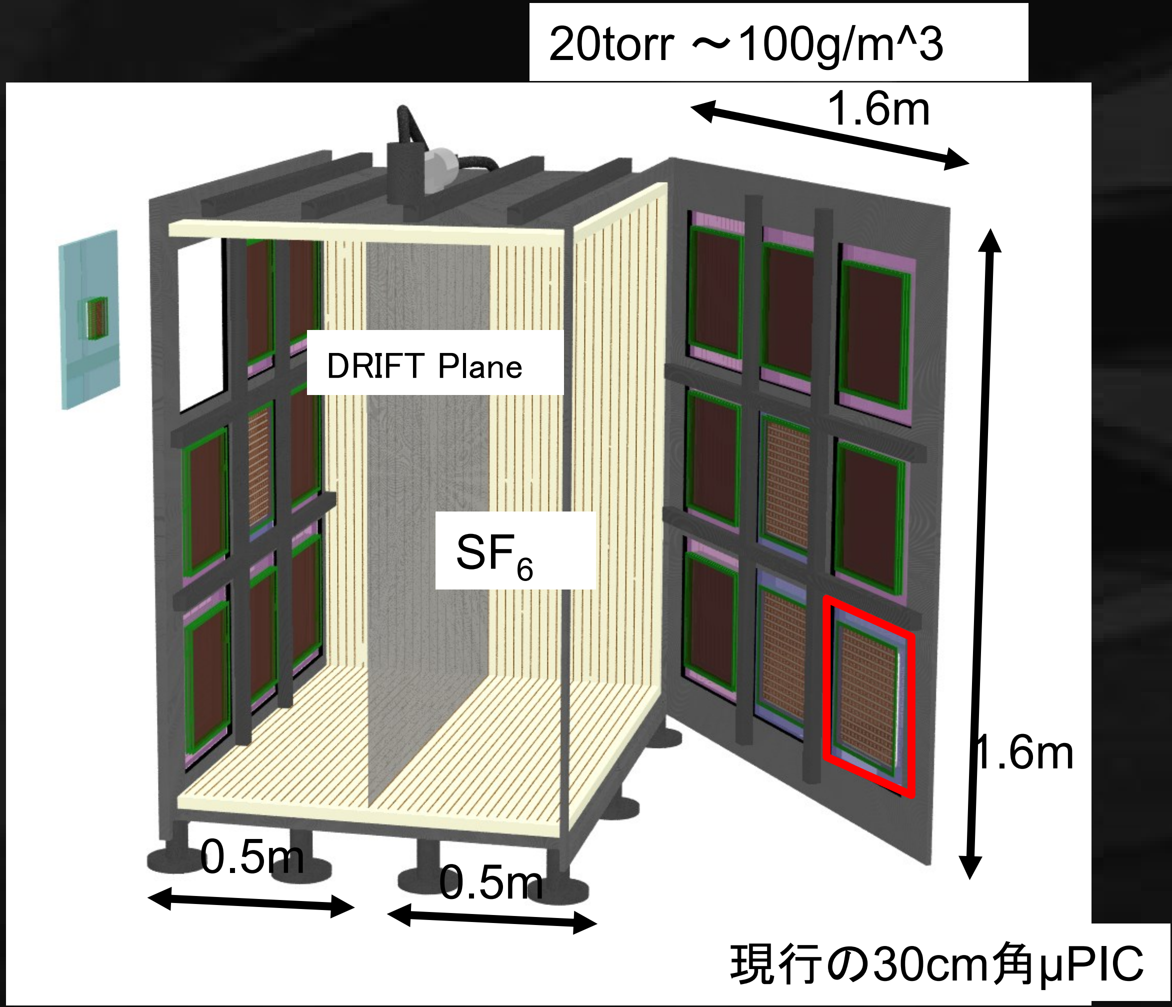
ドリフト速度の違い → Zの絶対値測定



- それぞれ2桁のBG削減

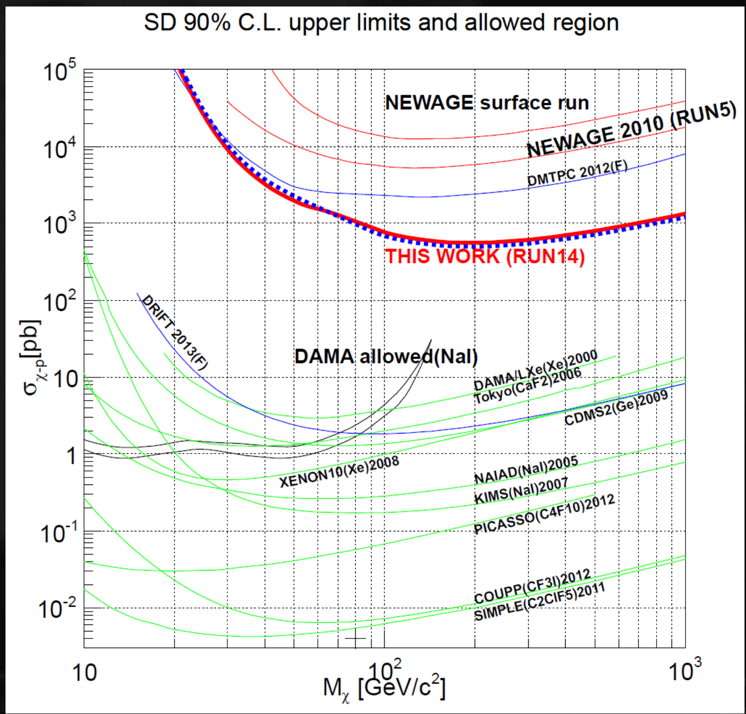
大型化

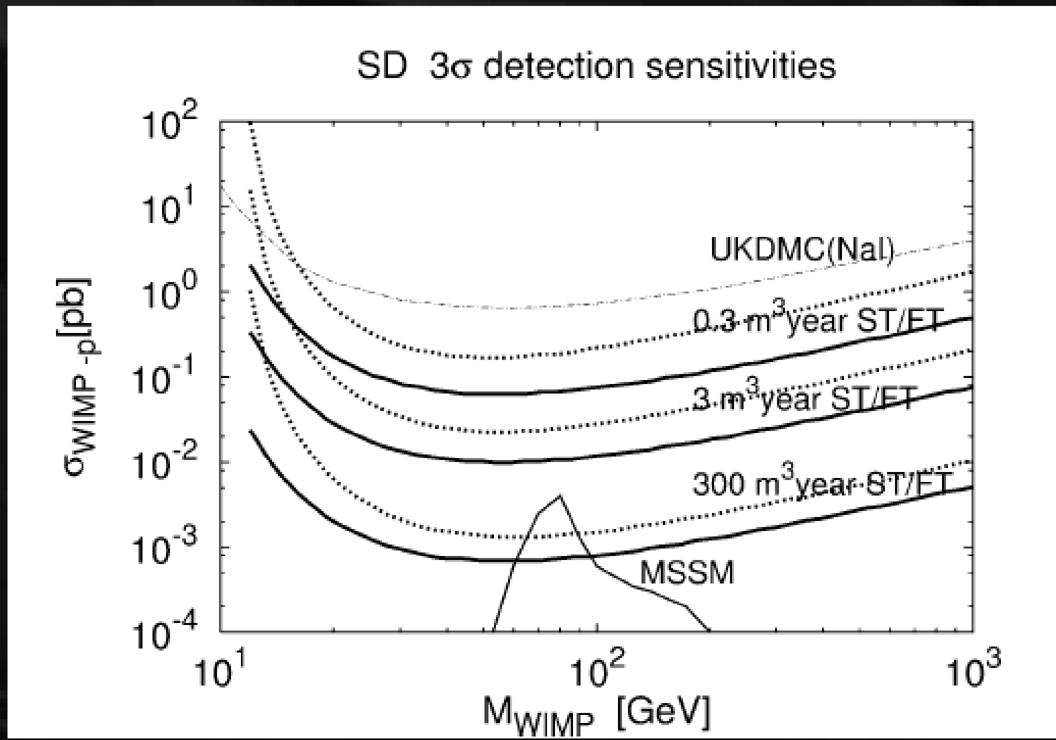
- 現状：30×30×40cm3　→　大型チェンバー製作中
- まずは　2×(30×30×50cm³)で開始



NEWAGEの戦略　マイルストーン

- 現状　500pb
  ←　100dru@ 50keV$_{ee}$ 30日×0.03m^3
- ①　DAMA領域（10pb）　5年程度で
  ←1dru@ 50keV$_{ee}$ 100日×1m^3
- ②　ガス最良（0.1pb）
  ←　1e-2dru@20keV$_{ee}$ 300日×10m^3
- ③　SD最良、SUSY（1e-3 pb）国際協力
  ←　1e-4 dru@10keV$_{ee}$ 1000日×100m^3

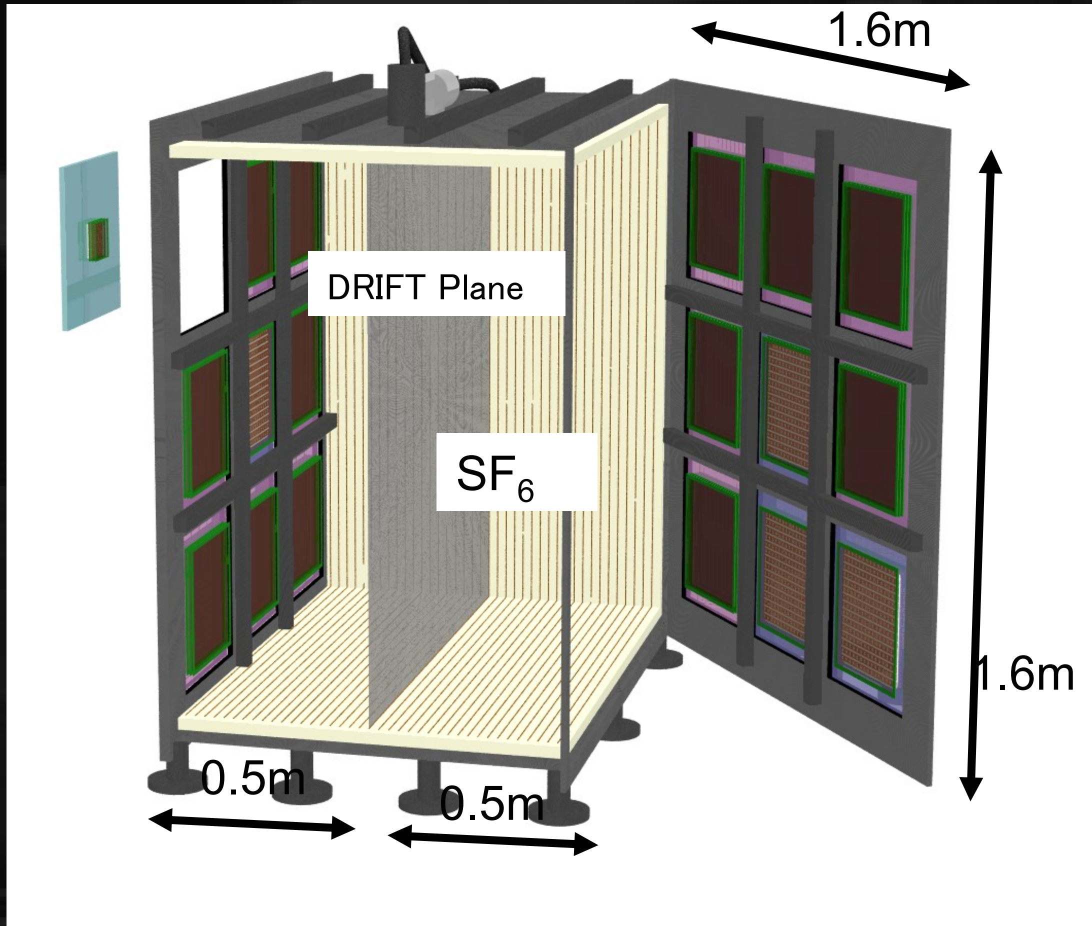




国際競争力・協力

- CYGNUS proto-collaboration
  - steering committee（N.Spooner (英　実質的牽引), K,Miuchi, S.Vahsen(米), E.Baraccini(伊), E. Barbario(豪) ）
  - DRIFT　→　CYGNUS Large detector で予算申請
  - NEWAGE　→　CYGNUS/NEWAGE チェンバー
  - CYGNUS部分（CYGNUS-KM Observatory）：他グループのモジュール受け入れ。
  - NEWAGE部分：μ-PICでこれまでの延長を
  - （本音）できるところまではオリジナルでがんばりたい。
  - （目論見）既成事実で神岡主導で大型検出器を稼働させたい

CYGNUS/NEWAGE vessel
20torr ～100g/m^3



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

　　　　→　proto-collaboration

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

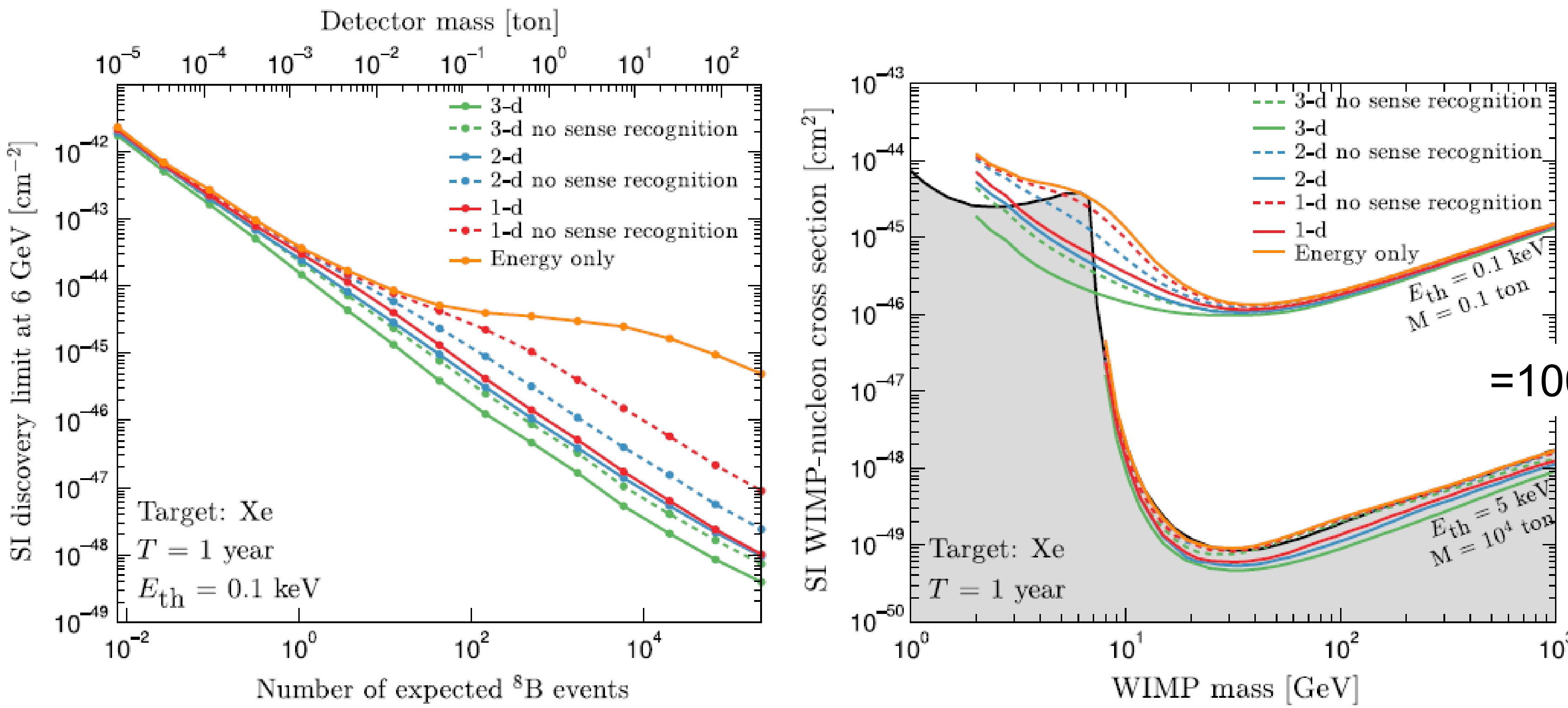
Signatures

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50名（うち日本人 約20名）

国際協力をリードして
実現したいはなし



=1000m^3

Fig. 9. Left: evolution of the discovery limit for a 6 GeV WIMP as a function of Xenon detector mass. The exposure time was fixed at $T = 1$ year and the energy threshold was 0.1 keV. The limits shown are for each read-out strategy, 1d (red), 2d (blue) and 3d (green) in cases both with (solid lines) and without (dashed lines) sense recognition, the limit made by the same detector with no directional information is shown in orange. Right: the discovery limit as a function of WIMP mass for the same read-out strategies as the left panel but with fixed detector set-up. The upper set of limits are for a low threshold-low mass detector (0.1 keV, 0.1 ton) and the lower set of limits for a high threshold-high mass detector (5 keV, 10^4 ton). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Source: The shaded region shows the neutrino floor from Ref. [10] and the Figures are taken from Ref. [190].

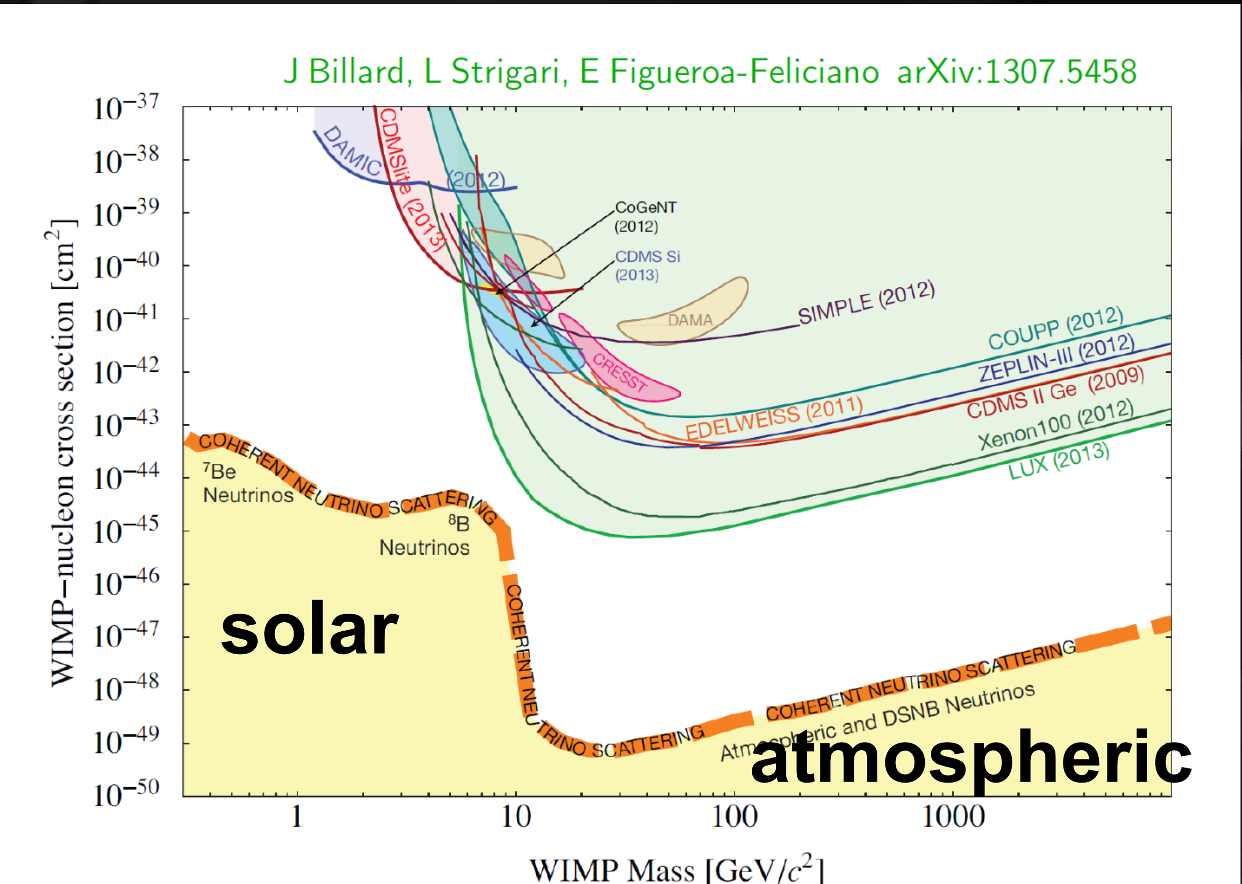
参考①　SF_6 20torr ～100g/m^3

参考②　LAB-C水タンク　800m^3

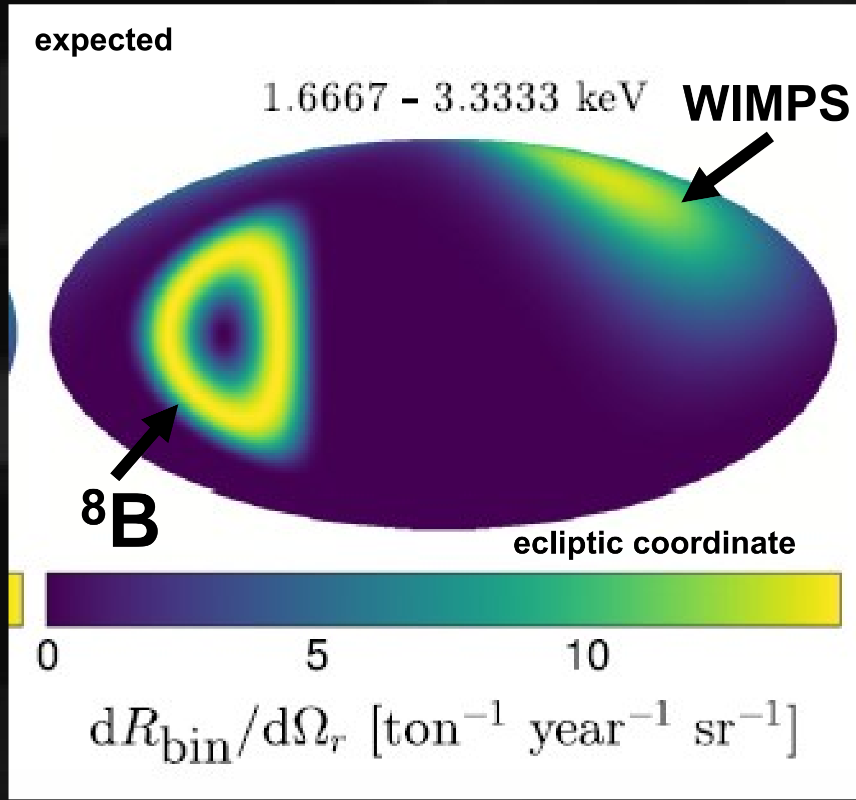
参考③　SK　50000m^3

“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

ニュートリノ-原子核　コヒーレント散乱

Why Measure Coherent ν-Nucleus Scattering?

- A high-σ, neutral current detector would be a clean way to search for sterile ν's

  A. Drukier & L. Stodolsky, PRD 30 (84) 2295

- The development of a coherent neutrino scattering detection capability provides perhaps the best way to explore any sterile neutrino sector that could be uncovered with ongoing experiments.

  A. J. Anderson et al., PRD 86 013004 (2012)

- Coherent σ proportional to Q_W^2. A precision test of σ is a sensitive test of new physics above the weak scale. M_{top} and M_{higgs} are known → Remaining theoretical uncertainties ~0.2%

  L. M. Krauss, PLB 269, 407

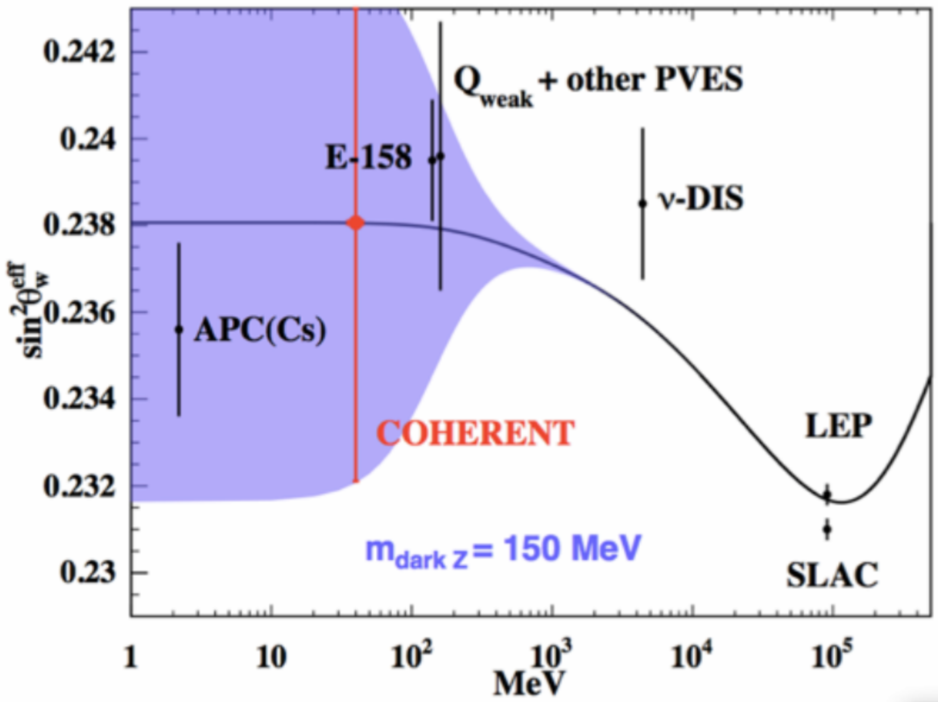
$$\sigma_{coh} \sim \frac{G_f^2 E^2}{4\pi}(Z(4\ sin^2\theta_w - 1) + N)^2$$

- Neutrino Magnetic Moments

  A. C. Dodd, et al., PLB 266 (91), 434

- Measuring the neutron distribution functions (Form Factors)

  K. Patton, et al., PRC 86, 024216



P. Barbeau @ IDM 2016

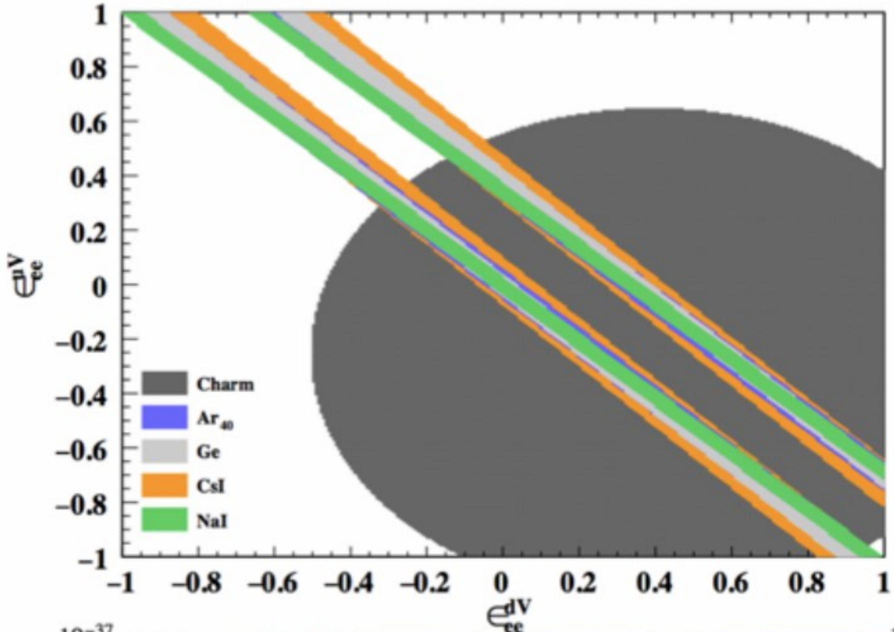
Why Measure Coherent $\boldsymbol{\nu}$-Nucleus Scattering?

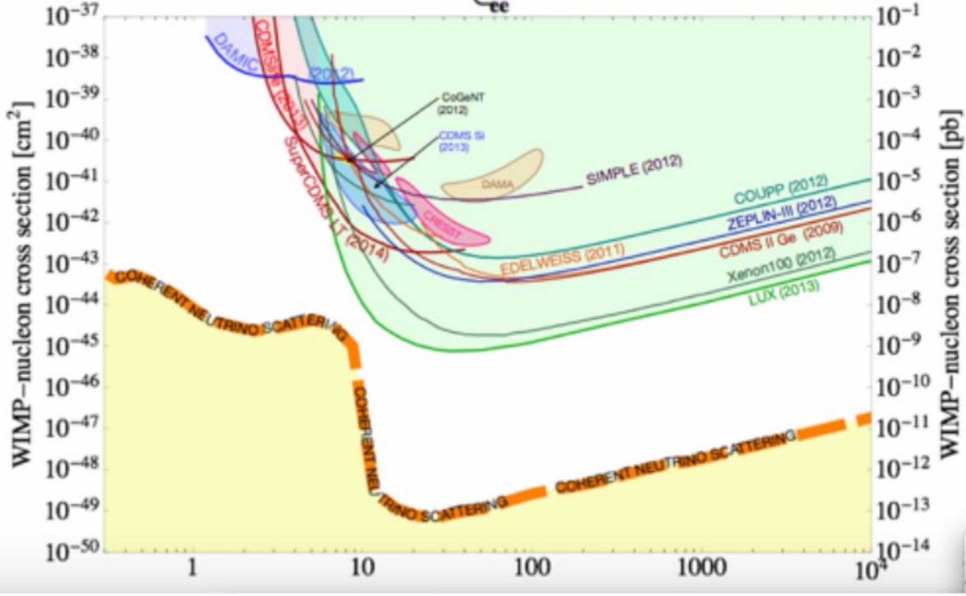
- Largest σ in Supernovae dynamics. We should measure it to validate the models
  J.R. Wilson, PRL 32 (74) 849

- By measuring the relative rates on several nuclear targets we dramatically extend the sensitivity of searches for Non-Standard $\boldsymbol{\nu}$ Interactions. **K. Scholberg, Phys.Rev.D73:033005,2006**
  J. Barranco et al., JHEP0512:021,2005

- NSI Relevance for DUNE & LBL CP violation.
  Mehedi Masud, Poonam, Mehta, arXiv: 1603.01380

- CEvNS is an irreducible background from WIMP searches, and should be measured in order to validate background models and detector responses.



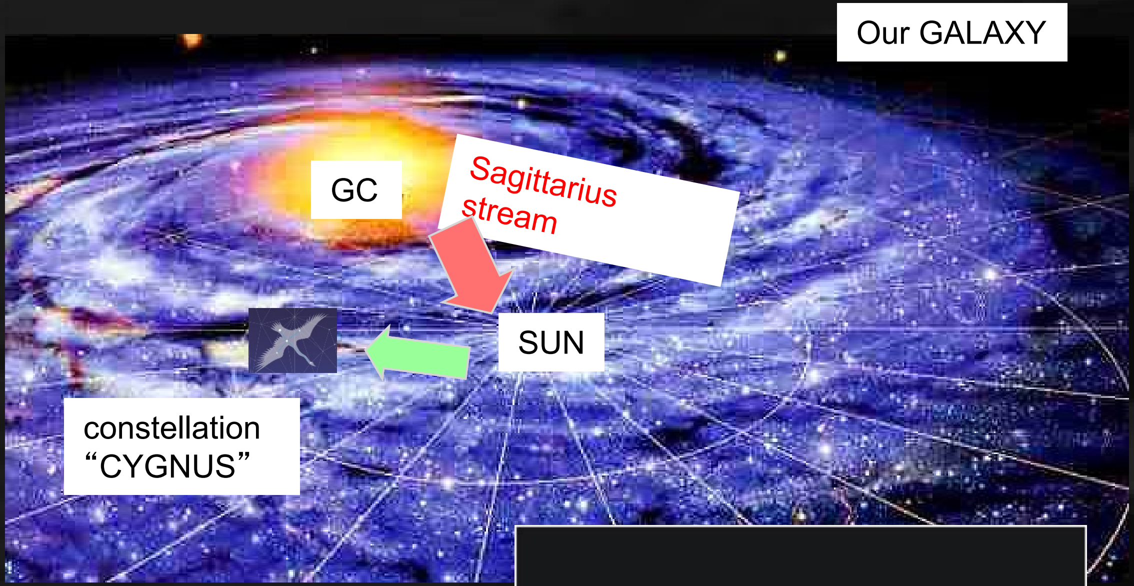


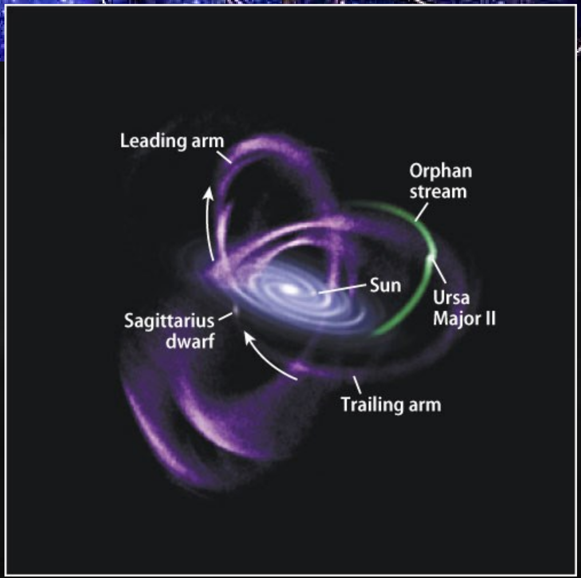
P. Barbeau @ IDM 2016

“CYGNUS” physics after discovery

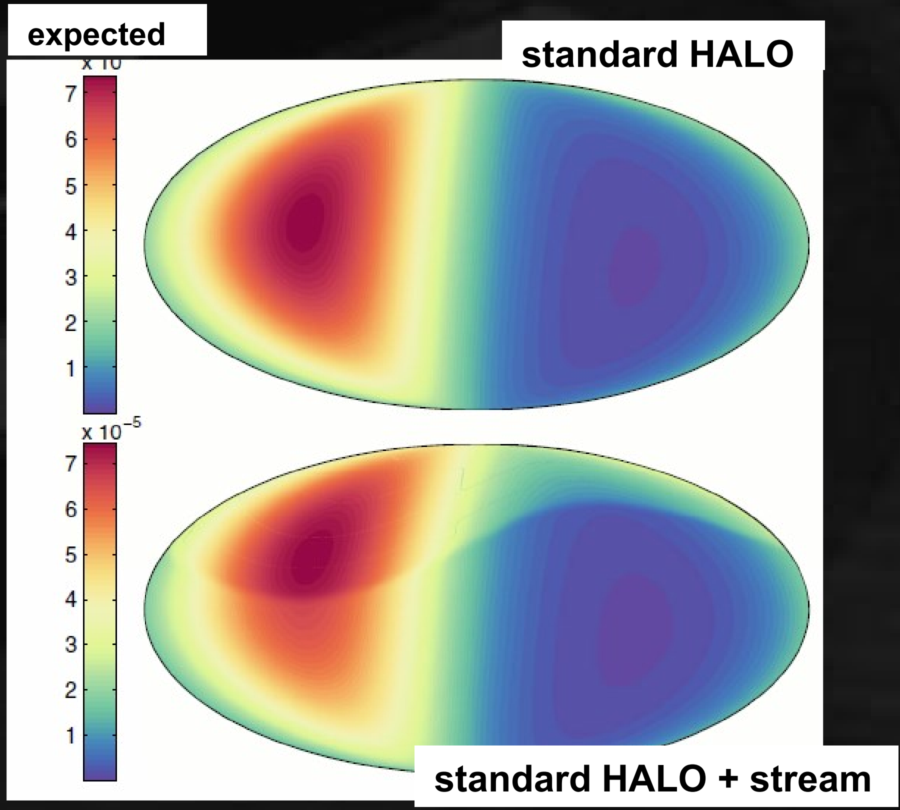
Test the DM motion

ex. Sagittarius stream





PHYSICAL REVIEW D 90, 123511 (2014)



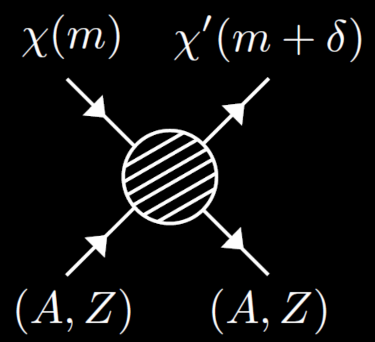
- streams, halo model…

"CYGNUS" physics after discovery

Inverted dipole and beyond

Paolo Gondolo
University of Utah

Inelastic dark matter



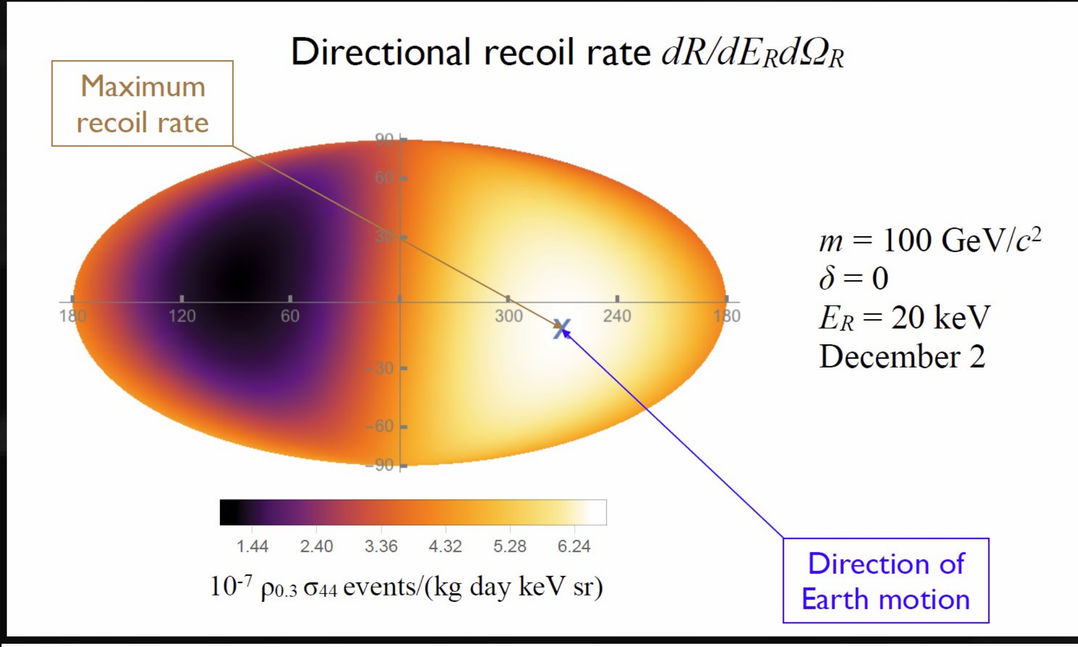
There are two dark matter species very close in mass, and they can scatter one into the other.

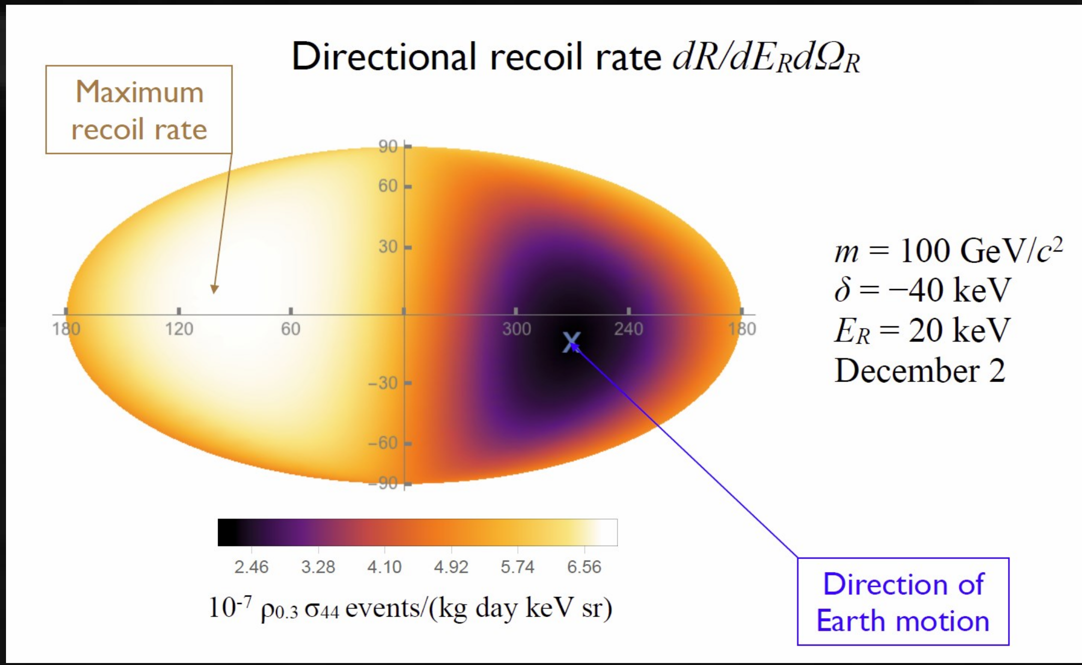
Mass splitting δ up to tens of keV.

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

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

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



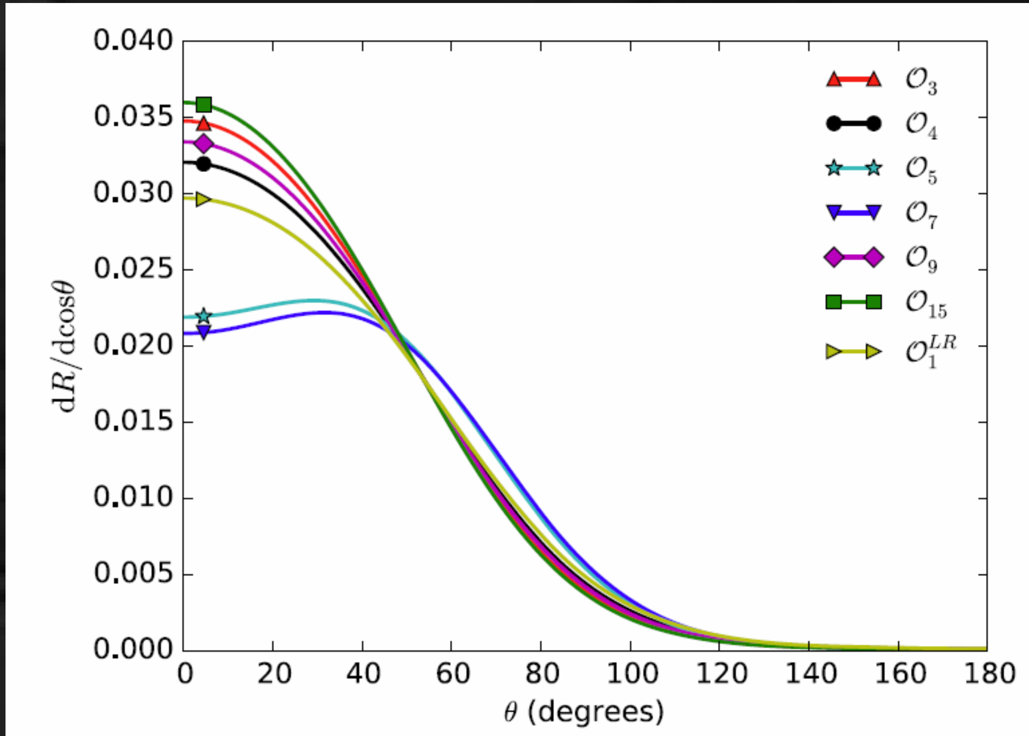


- 質量の異なるDM同士の遷移

“CYGNUS” physics after discovery

- **Test the interaction by scattering angle**

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



SI SD

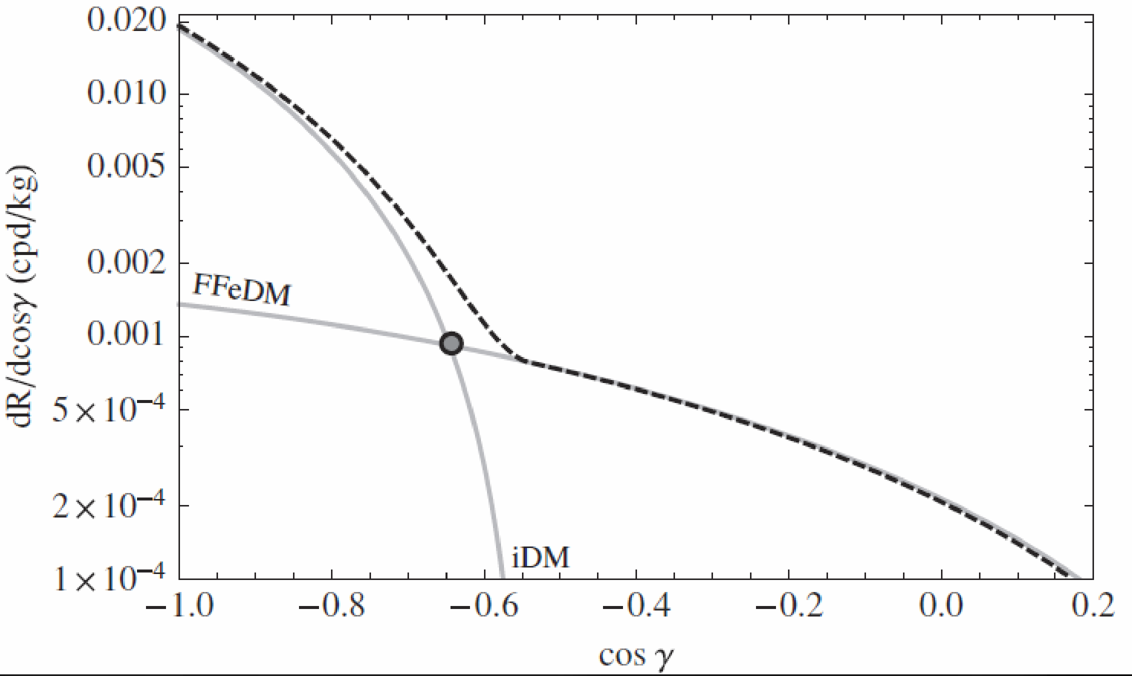
$$\text{Proportional to} \begin{cases} 1 & : \mathcal{O}_1, \mathcal{O}_4, \\ v_\perp^2 & : \mathcal{O}_7, \mathcal{O}_8, \\ q^2 & : \mathcal{O}_9, \mathcal{O}_{10}, \mathcal{O}_{11}, \mathcal{O}_{12}, \\ v_\perp^2 q^2 & : \mathcal{O}_5, \mathcal{O}_{13}, \mathcal{O}_{14}, \\ q^4 & : \mathcal{O}_3, \mathcal{O}_6,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

- **some operators are distinguishable**

“CYGNUS” physics after discovery

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

PHYSICAL REVIEW D **81**, 096005 (2010)



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

まとめ

- **NEWAGE**：方向に感度という特色を出して感度向上中

- （本音）**NEWAGE**としての発見
- （必要とあらば）将来の国際協力をリードすべく既成事実