Review on Direction-Sensitive Direct Dark Matter Search with gaseous detectors

Kentaro Miuchi
KOBE University

July 27th 2018
IDM 2018

Contents

科研費 KAKENHI
JSPS 二国間事業
「ガス飛跡検出器を用いた暗黒物質探索実験」

Related talks

Friday morning: Plenary

Review on directional direct dark matter search with gaseous detectors — *Prof. Kentaro Miuchi*
117, MacMillian 08:30 - 08:50

CYGNUS - a multi-latitude directional WIMP experiment — *Prof. Neil Spooner*
117, MacMillian 08:50 - 09:10

Directional Search for Dark Matter Using Nuclear Emulsion — *Prof. Atsuhiro Umemoto*
117, MacMillian 09:10 - 09:30

Monday morning: Plenary

Dark matter in disequilibrium and its implications for direct detection
117, MacMillian
Dr Lina Necib
09:40 - 10:05

Monday afternoon: Parallel

The PTOLEMY-G experiment for light dark matter direct det... — *Dr Alfredo Davide Ferella*

Friday afternoon: Parallel

Directional Dark Matter search with optical readouts and the CYGNO p... — *Elisabetta Baracchini*

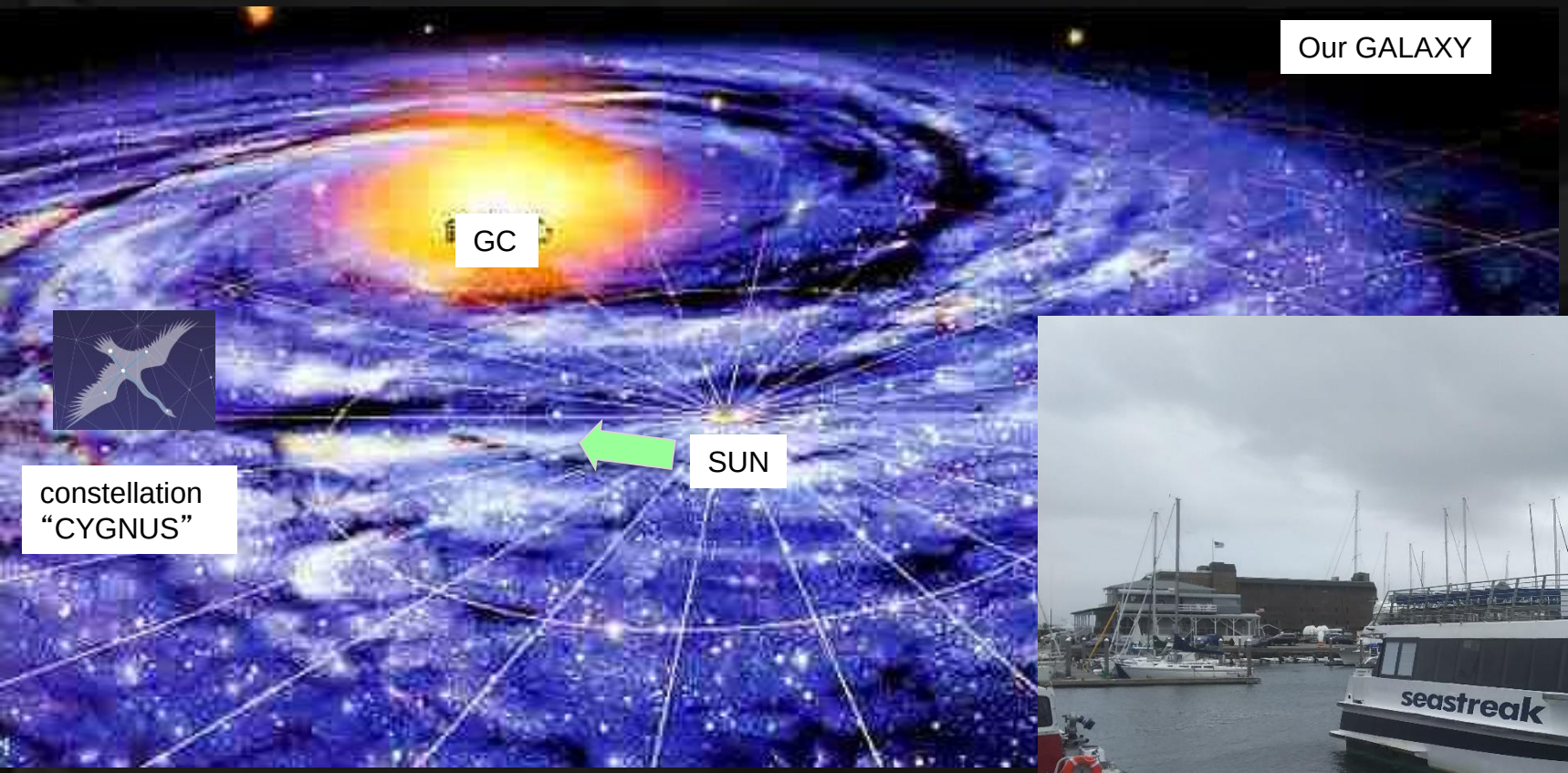
NEWS-G Light dark matter searches with a Spherical Proportional Counter — *Ioannis Katsioulas*

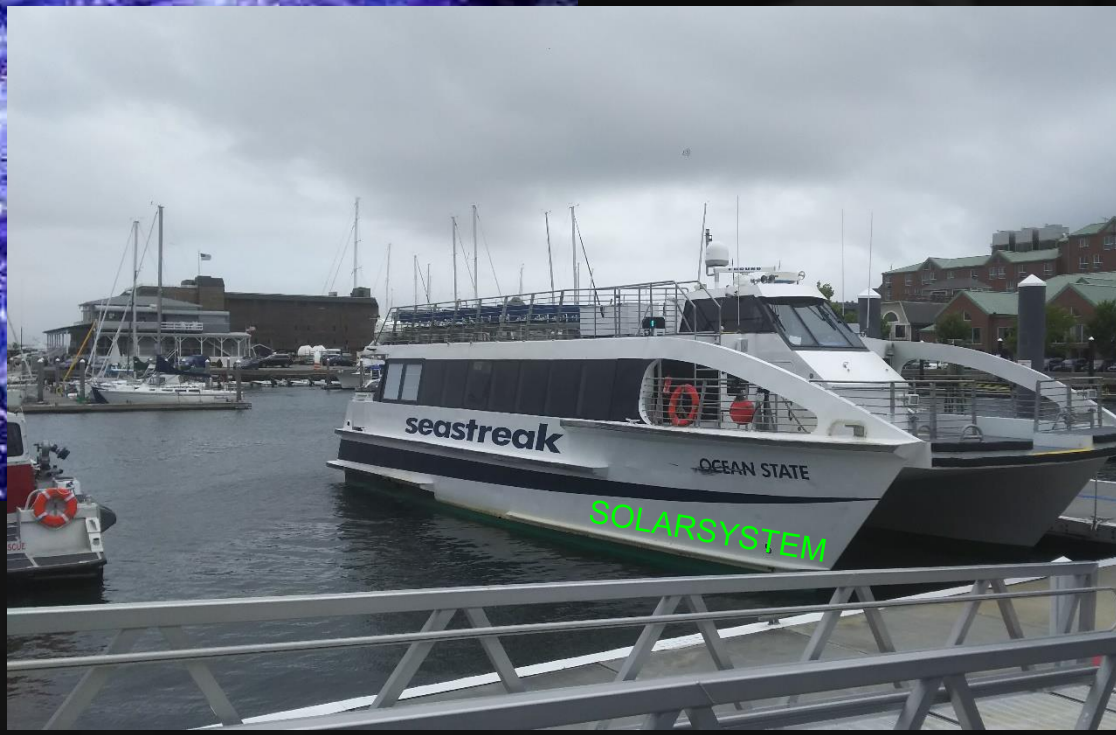
Status of the TREX-DM experiment at the Canfranc Underground Laboratory — *Susana Cebrian*

NEWAGE — *Prof. Kentaro Miuchi*
117, MacMillian 15:20 - 15:40

Introduction

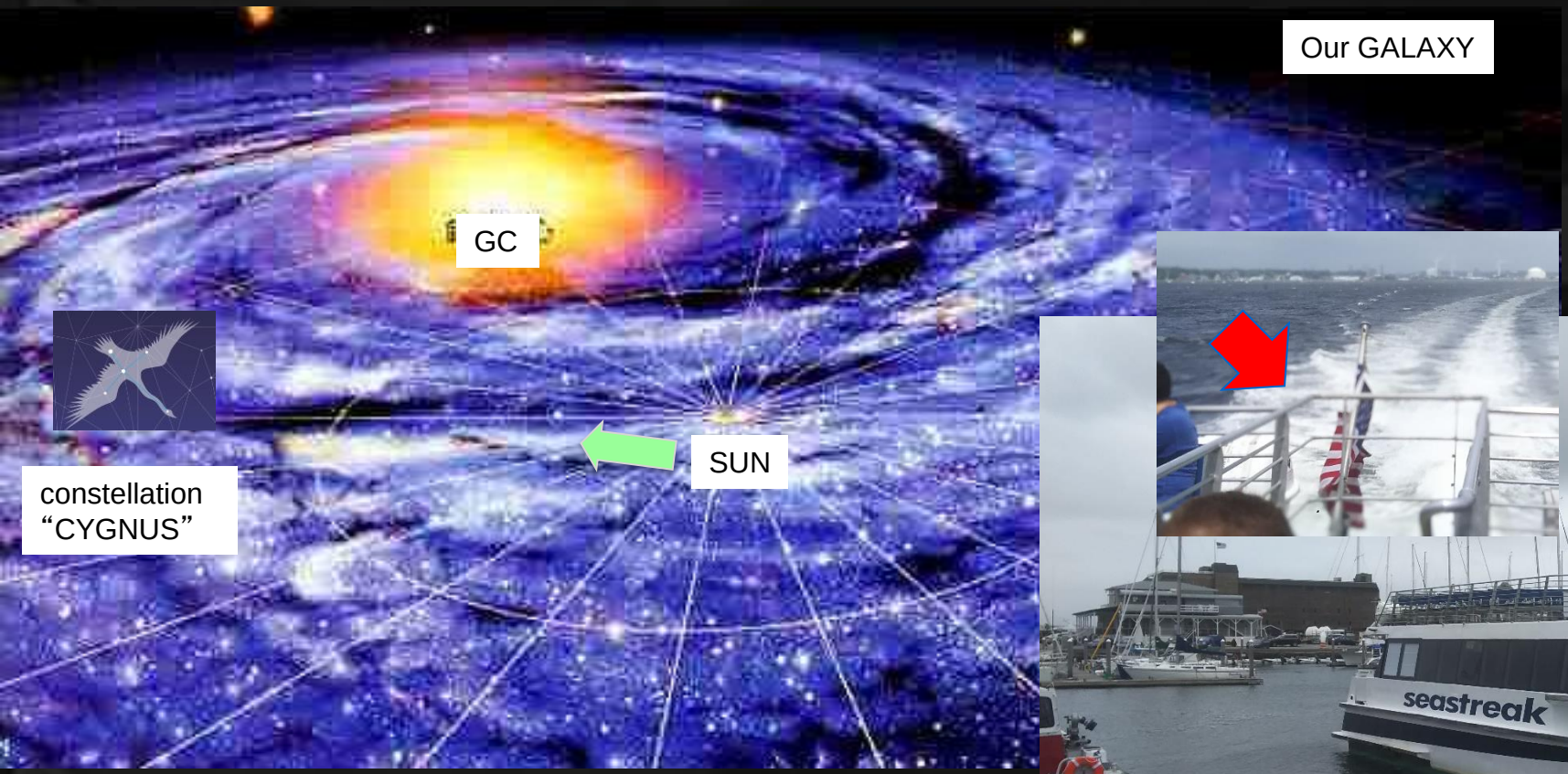
Direction-Sensitive Dark Matter Search concept “CYGNUS”





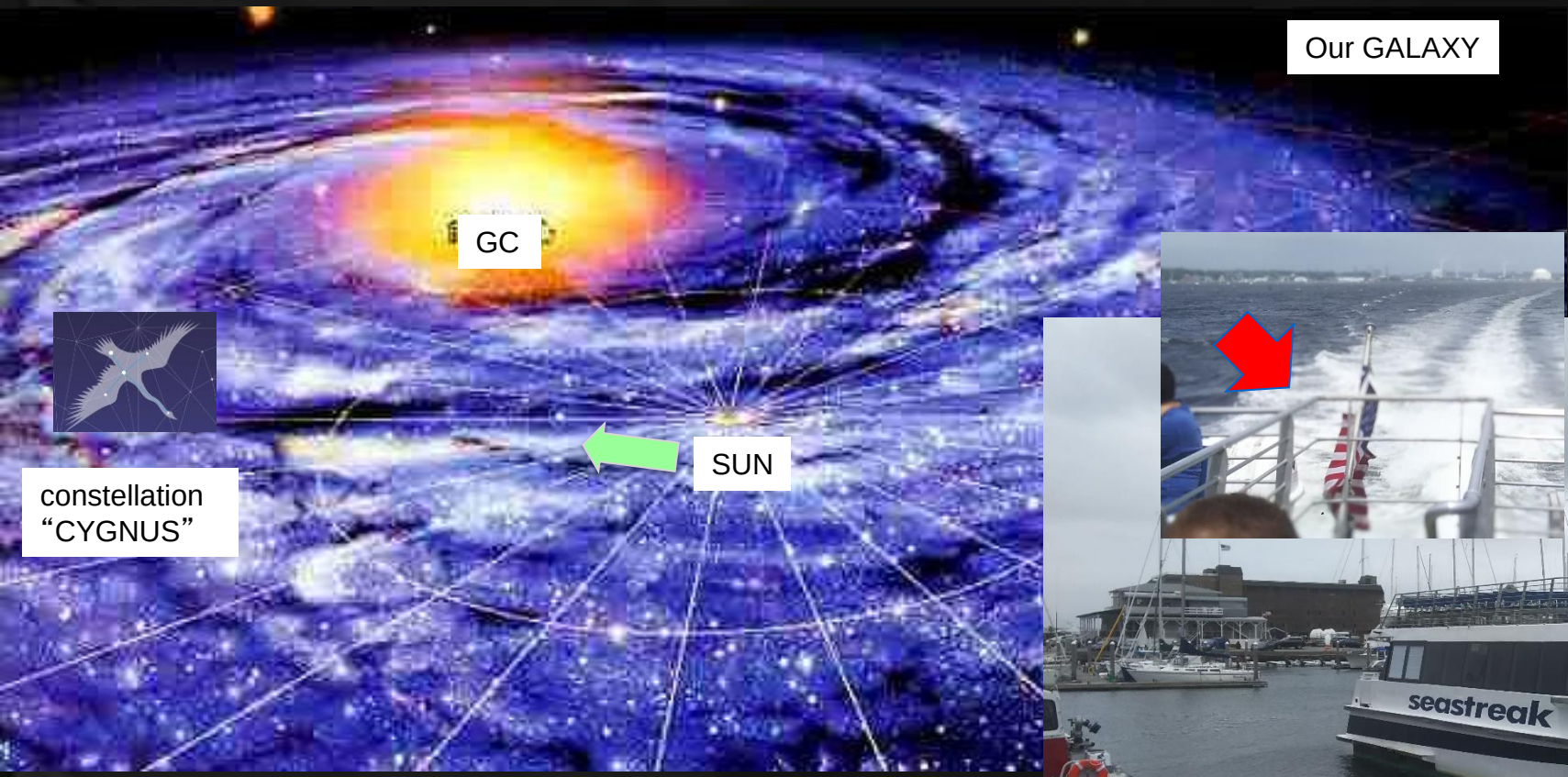
WIMP-WIND from “CYGNUS”

Direction-Sensitive Dark Matter Search concept “CYGNUS”



WIMP-WIND from “CYGNUS”

Direction-Sensitive Dark Matter Search concept “CYGNUS”



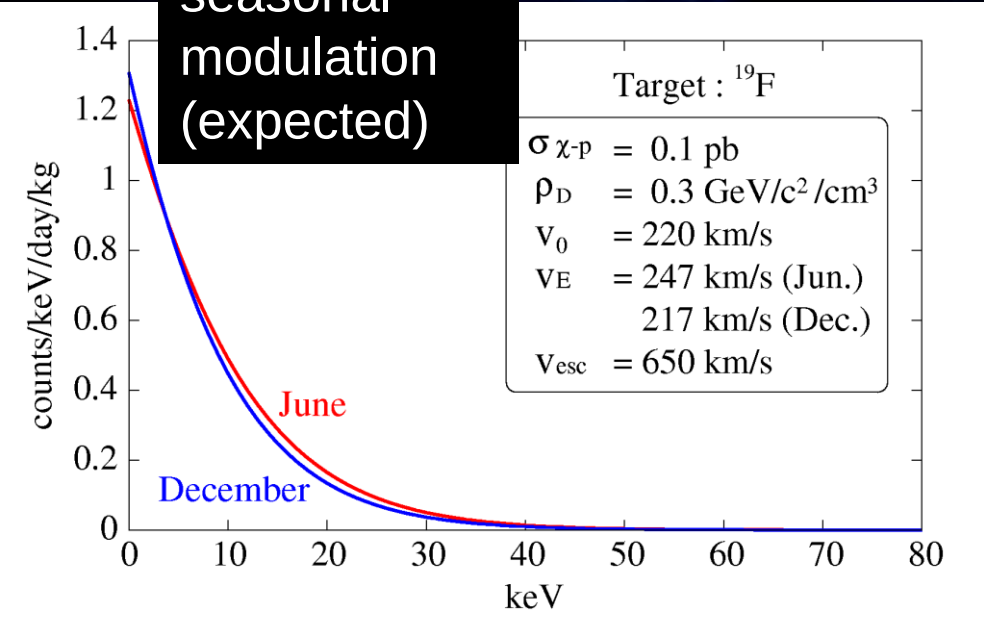
Our GALAXY

WIMP-WIND from “CYGNUS”

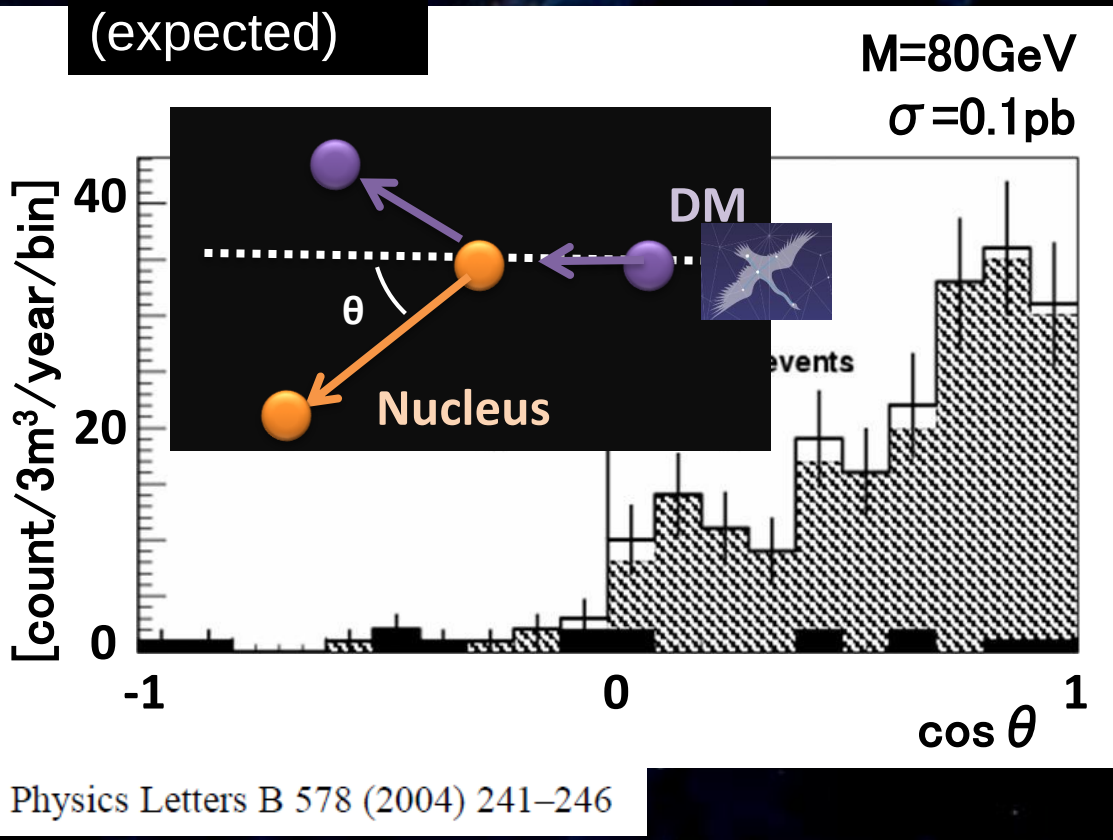
Science

Directional Detection

seasonal modulation (expected)



directionality (expected)

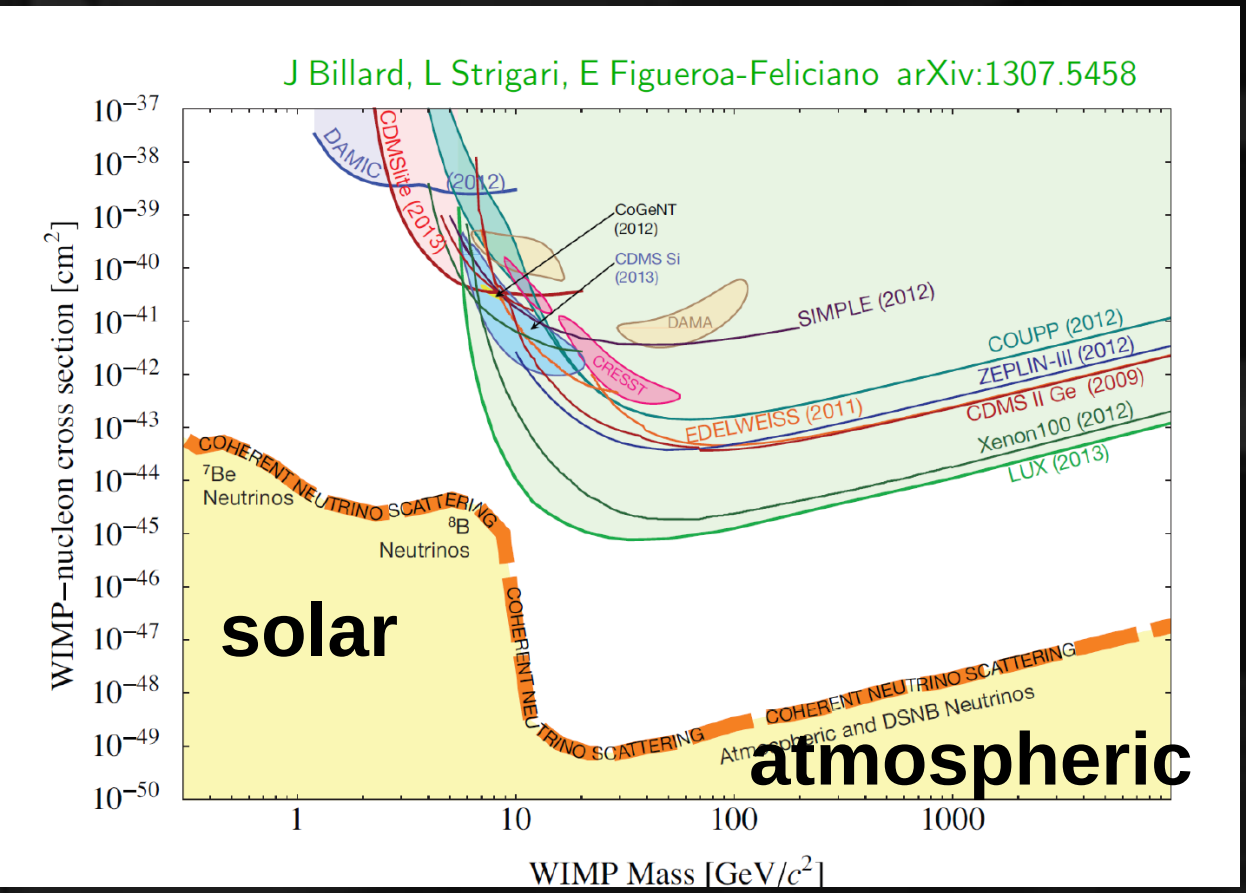


Physics Letters B 578 (2004) 241–246

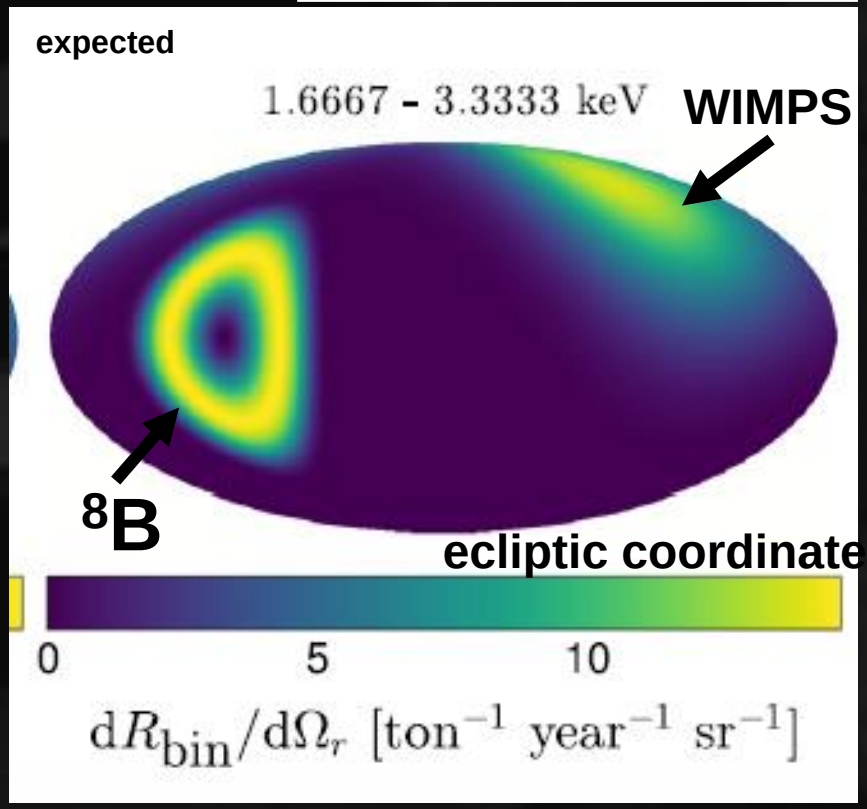
Clear Discovery
+ study the nature of DM after discovery

Toward discovery

- Potential to search beyond the “neutrino floor”



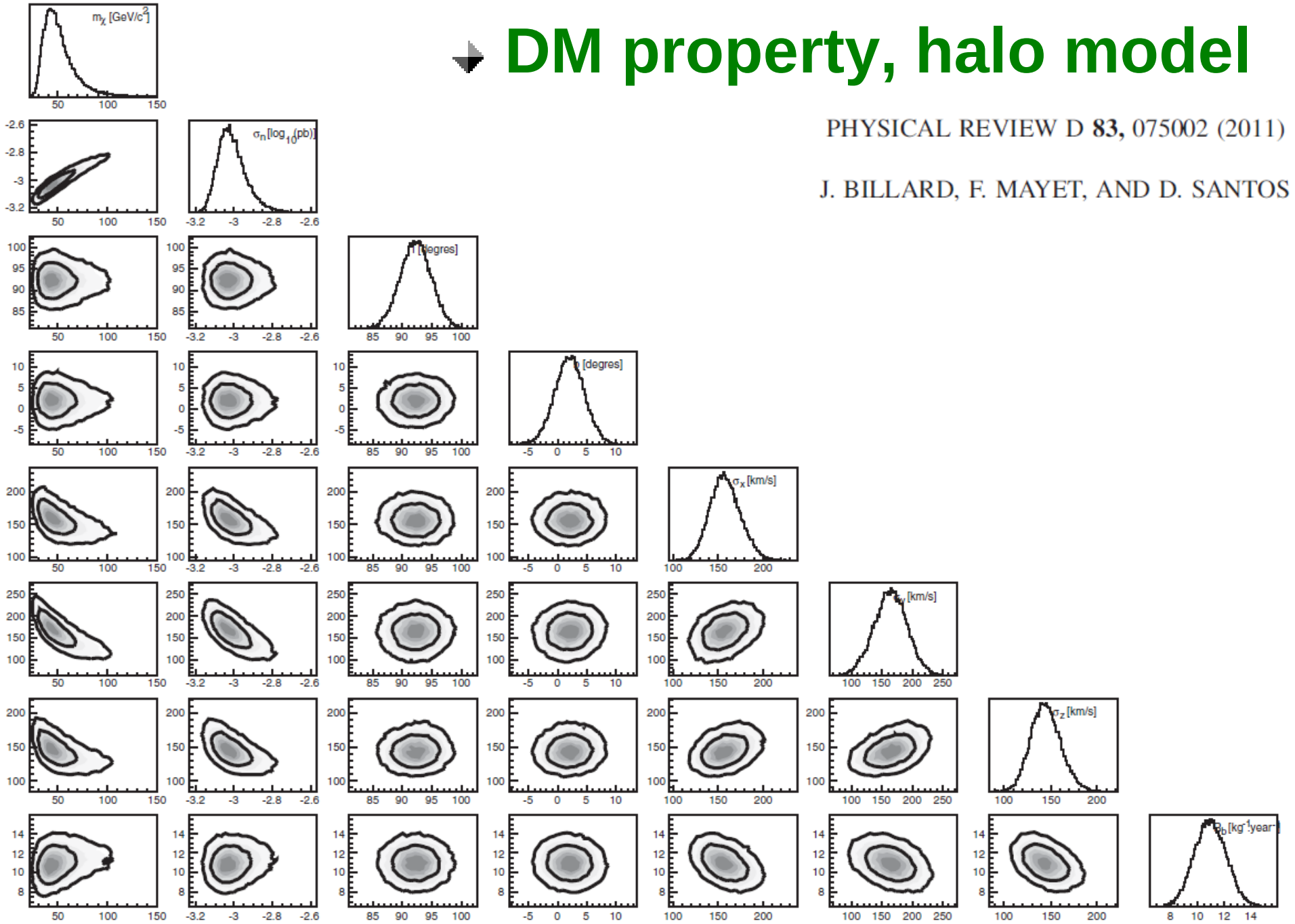
F. Mayet et al. / Physics Reports 627 (2016) 1–49



- clearly distinguishable

Physics after discovery

- **DM property, halo model**



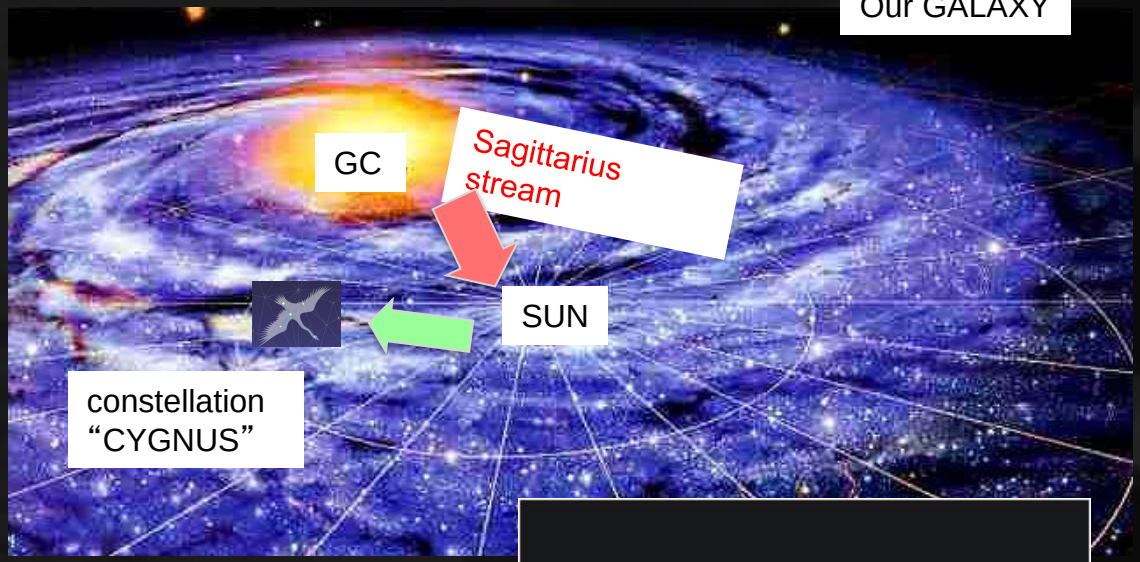
PHYSICAL REVIEW D **83,** 075002 (2011)

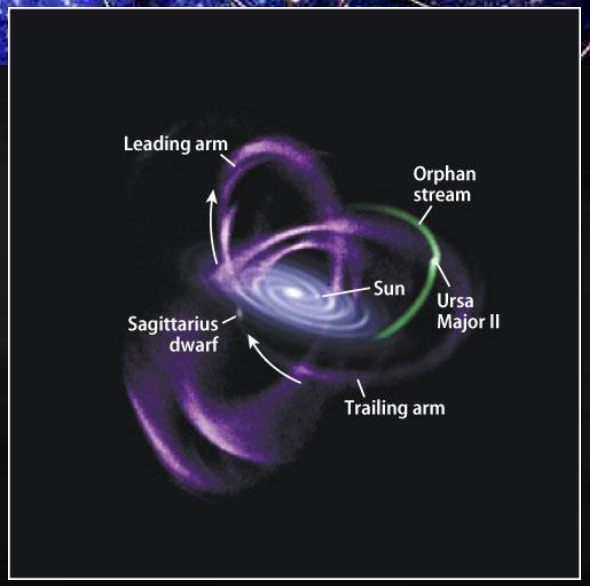
J. BILLARD, F. MAYET, AND D. SANTOS

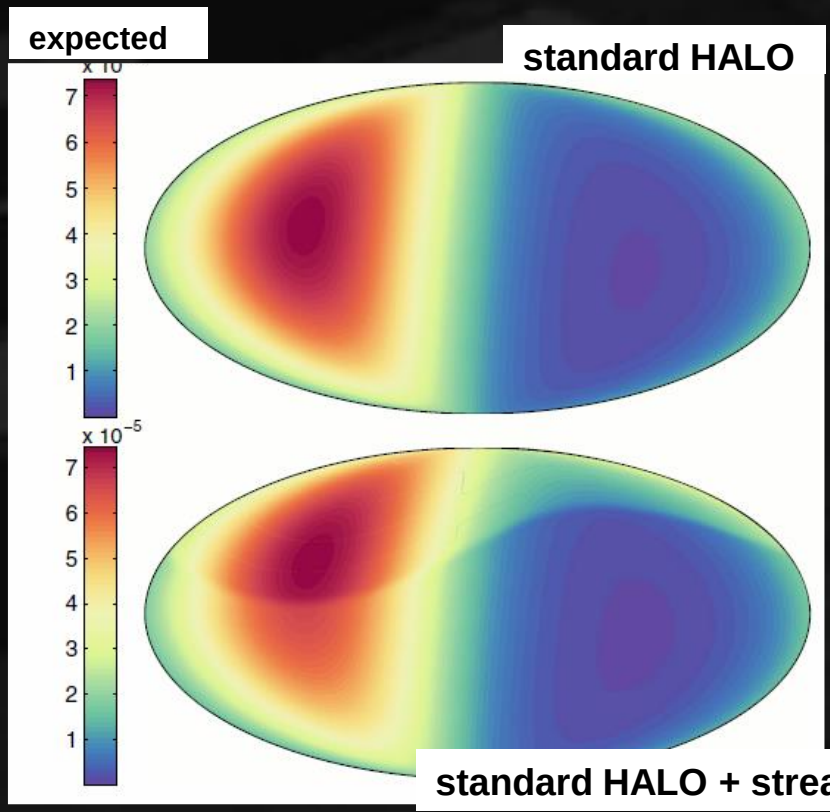
Physics after discovery

- **Astrophysics**
  - **Sagittarius stream**

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







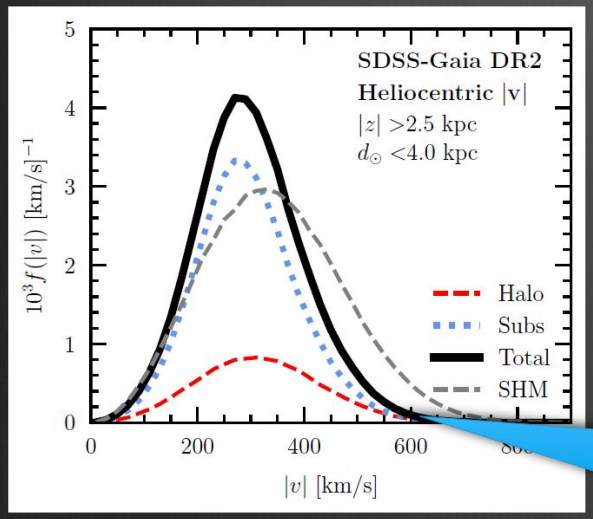
galactic coordinate

- **streams, debris…**

Physics after discovery

- **Astrophysics**
  - **Dibris**

New Velocity Distribution!



Can be found in a github repository near you
https://linoush.github.io/DM_Velocity_Distribution/

Link in paper arXiv:1807.02519.

Final distribution dominated by the substructure, and very different from the assumed Maxwell Boltzmann distribution

Lina Necib, Caltech 31 7/23/18

Dark Matter in Disequilibrium, and Implications for Direct Detection

Lina Necib, Caltech

Based on

Necib, Lisanti, Belokurov, arXiv:1807.02519

ib, Lisanti, Garisson Kimmel, Sanderson, Wetzel, Hopkins, arXiv:1808.XXXXX

Herzog-Arbeitman, Lisanti, Madau, Necib PRL 120(2018) no.4, 041102

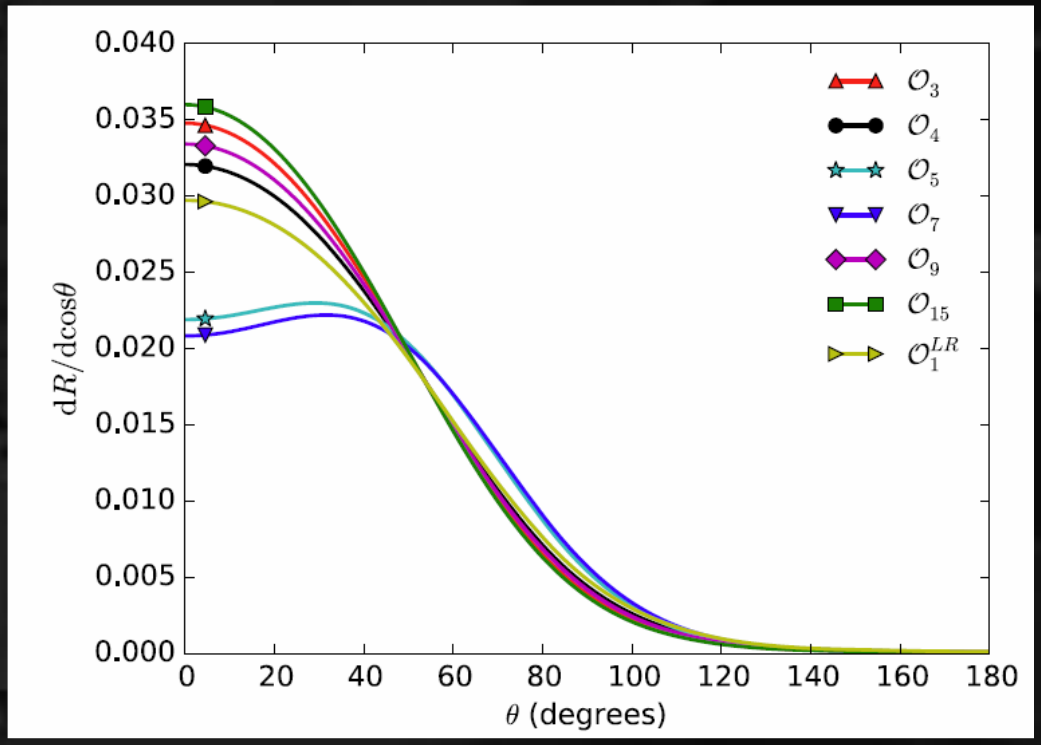
Herzog-Arbeitman, Lisanti, Necib, JCAP 1804 no. 4, 052

- **can be studied by directional information!**

Physics after discovery

- **Particle physics①**
  - **Test the interaction by scattering angle**

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



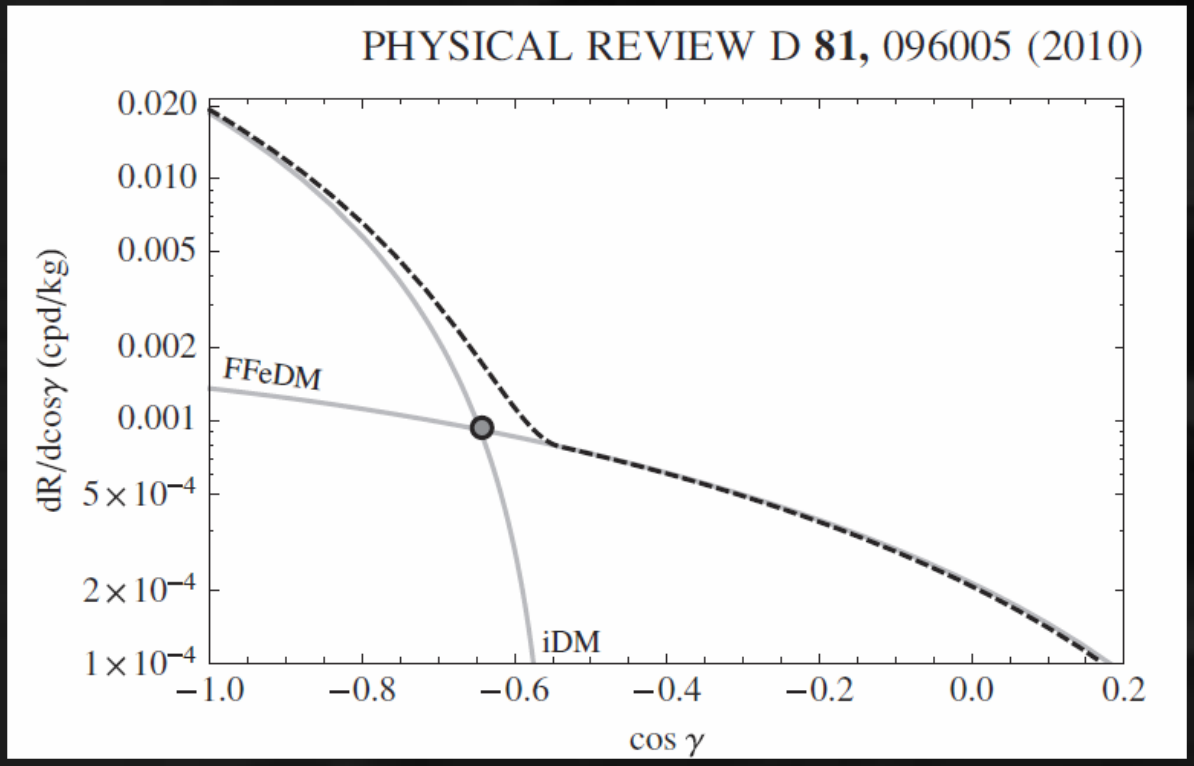
SI SD

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

- **some operators are distinguishable**

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

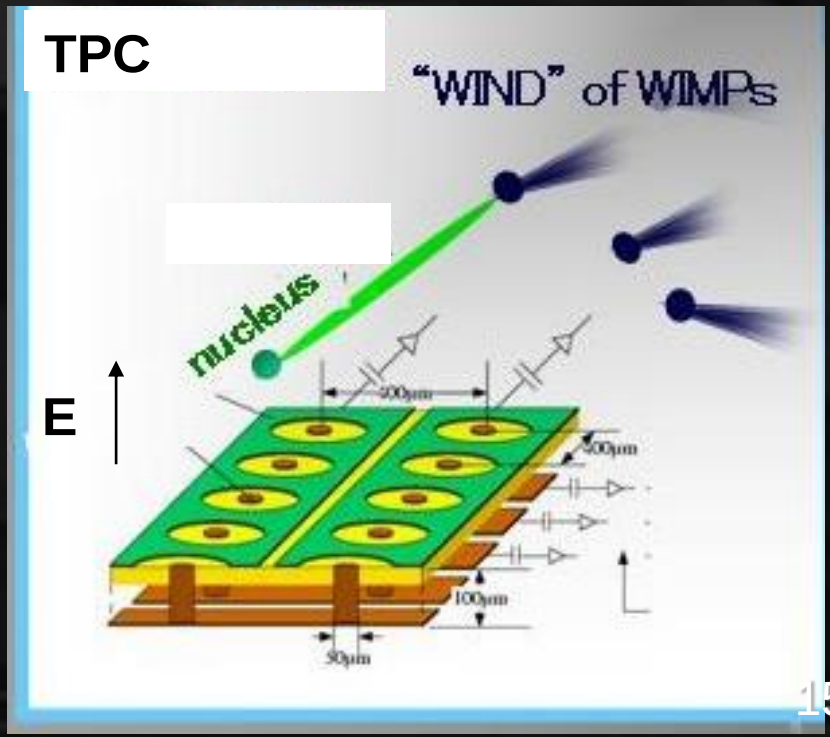
Recoil nuclear track detection < 100keV

challenge: short track

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

Typical approach:
low pressure gas TPC
(time projection chamber)

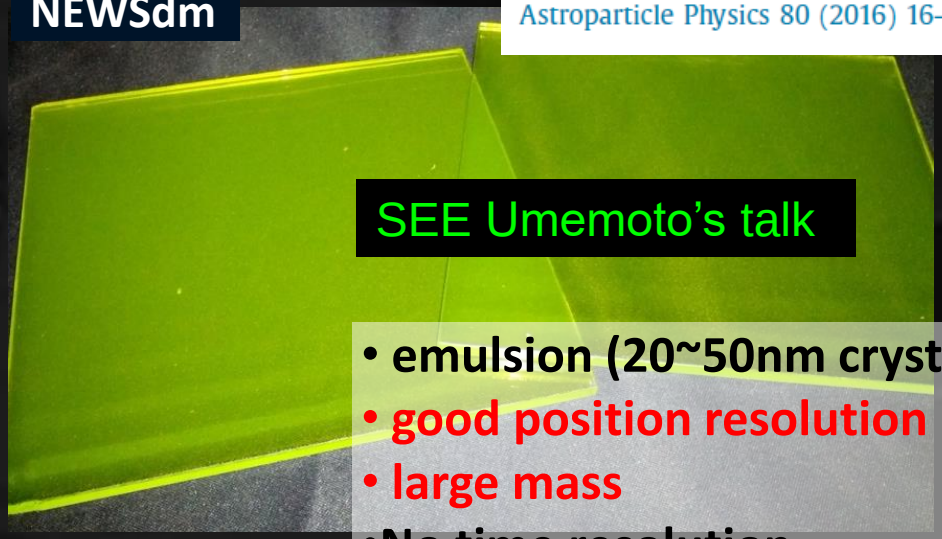
2D readout + timing
→ 3D tracking



NonTPC

NEWSdm

Astroparticle Physics 80 (2016) 16–21

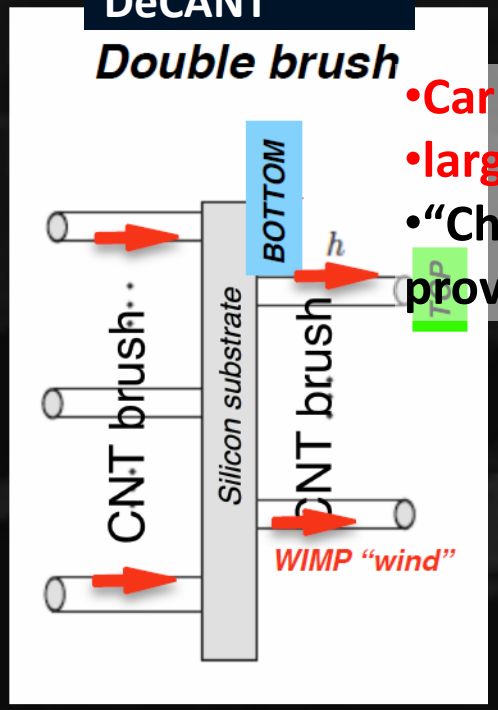


SEE Umemoto's talk

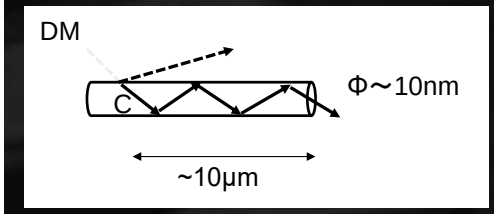
- emulsion (20~50nm crystal)
- good position resolution
- large mass
- No time resolution

DeCANT

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



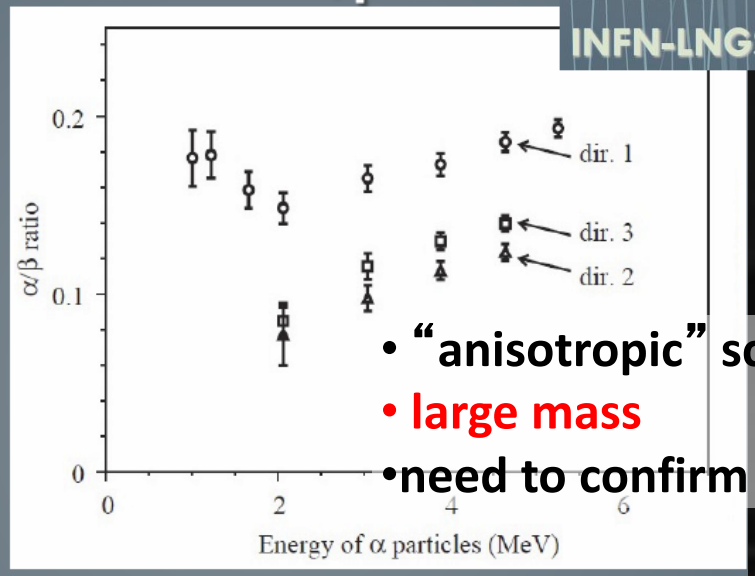
- Carbon nano tube
- large mass
- "Channeling" needs to be proven



$ZnWO_4$ [Italy, Japan]

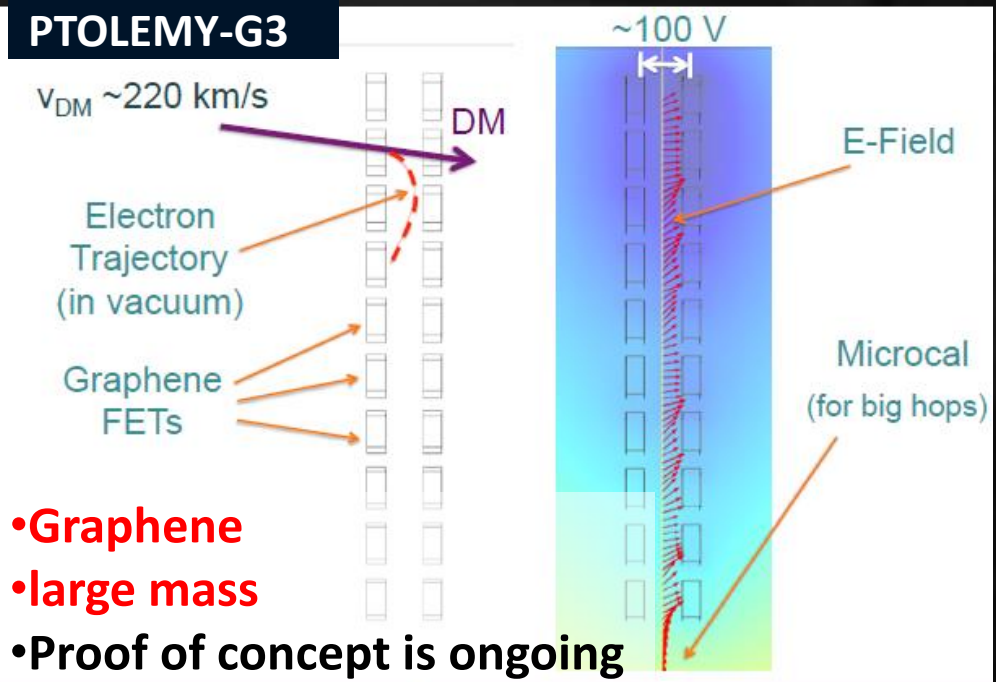
α/β ratio

R. Cerulli
INFN-LNGS



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

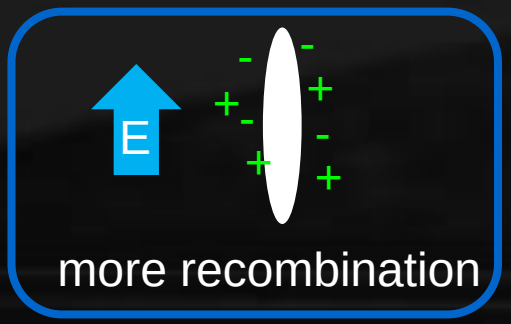
PTOLEMY-G3



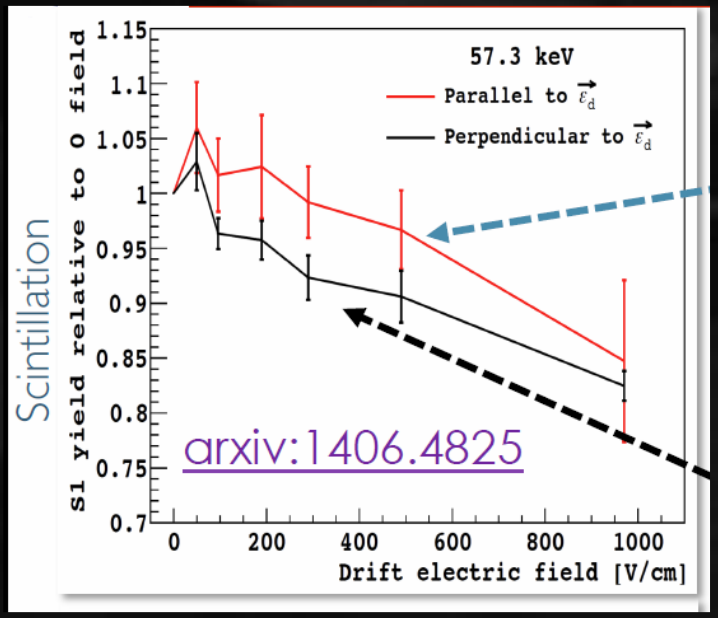
- Graphene
- large mass
- Proof of concept is ongoing

Columnar recombination

- **proposed by D. Nygren in 2013**
  - **recombination (light yield) depends on the track direction**
  - **directionality not very strong**
  - **large mass**

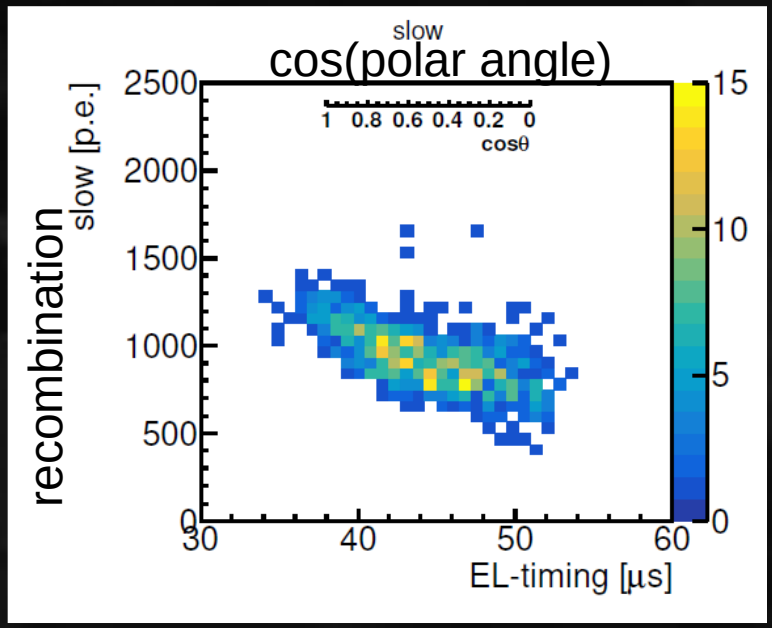


Liq Ar



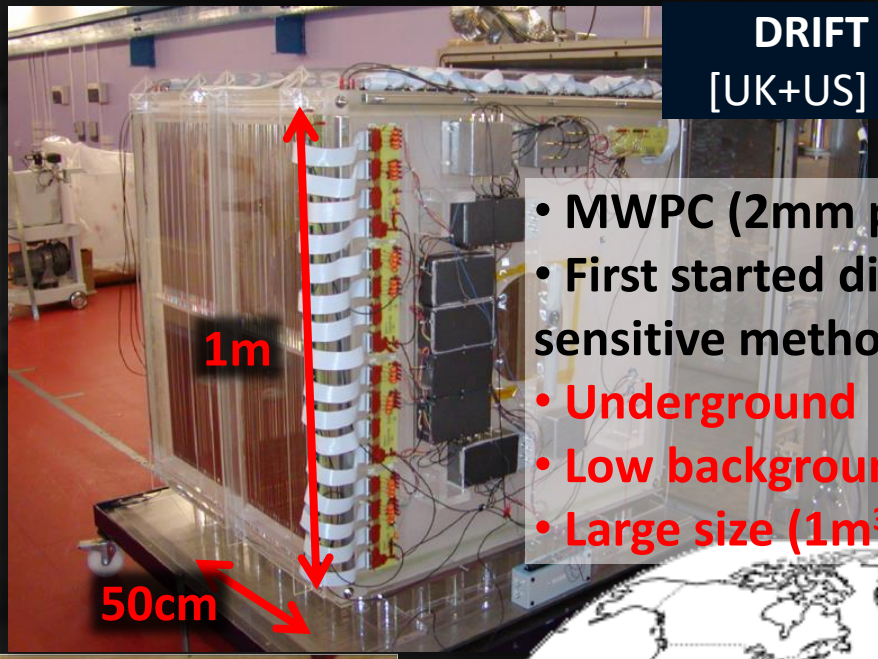
PHYSICAL REVIEW D **91,** 092007 (2015)

high pressure Xe gas



JINST 13(2018)P07015
1803.00752

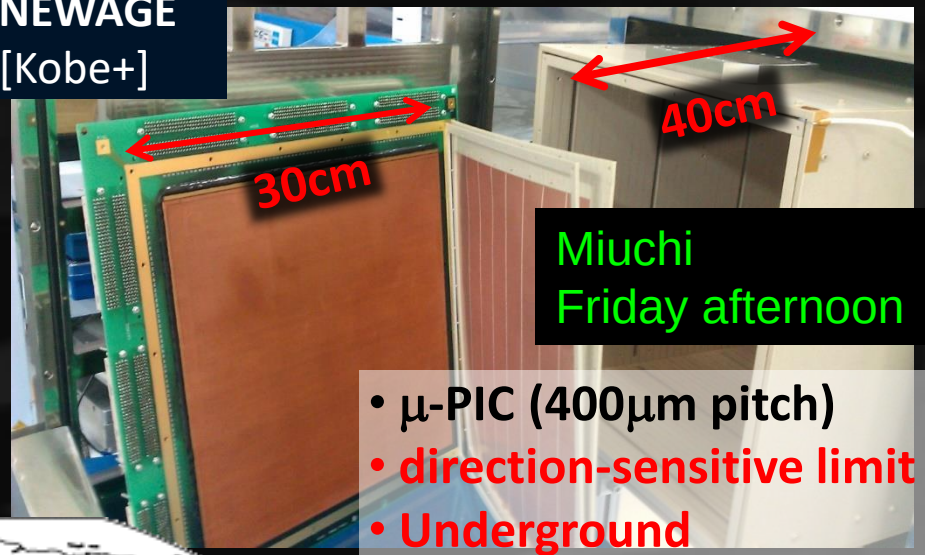
low pressure gas TPCs



DRIFT
[UK+US]

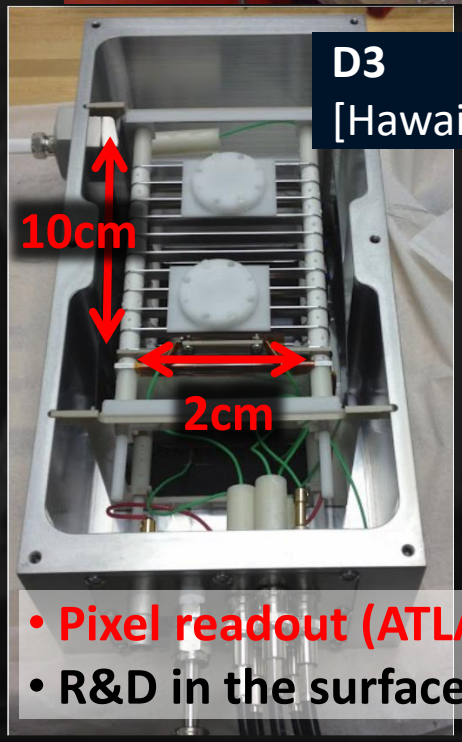
- MWPC (2mm pitch)
- First started direction-sensitive method
- Underground
- Low background
- Large size (1m³)

NEWAGE
[Kobe+]



Miuchi
Friday afternoon

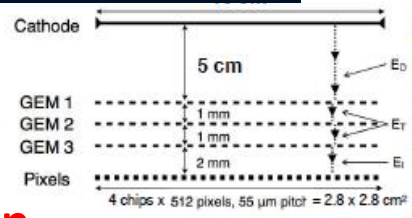
- μ-PIC (400μm pitch)
- direction-sensitive limit
- Underground



D3
[Hawaii]

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

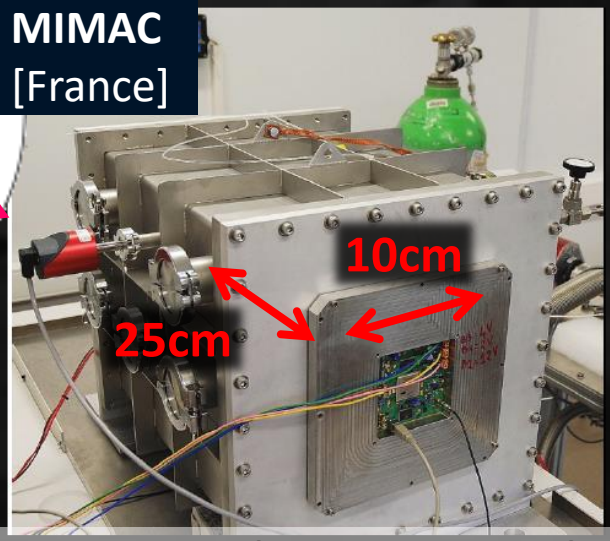
NITEC/CYGNO
[Italy]



- pixel/optical

Baracchini
Friday afternoon

MIMAC
[France]



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

DRIFT: the pioneer

- 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

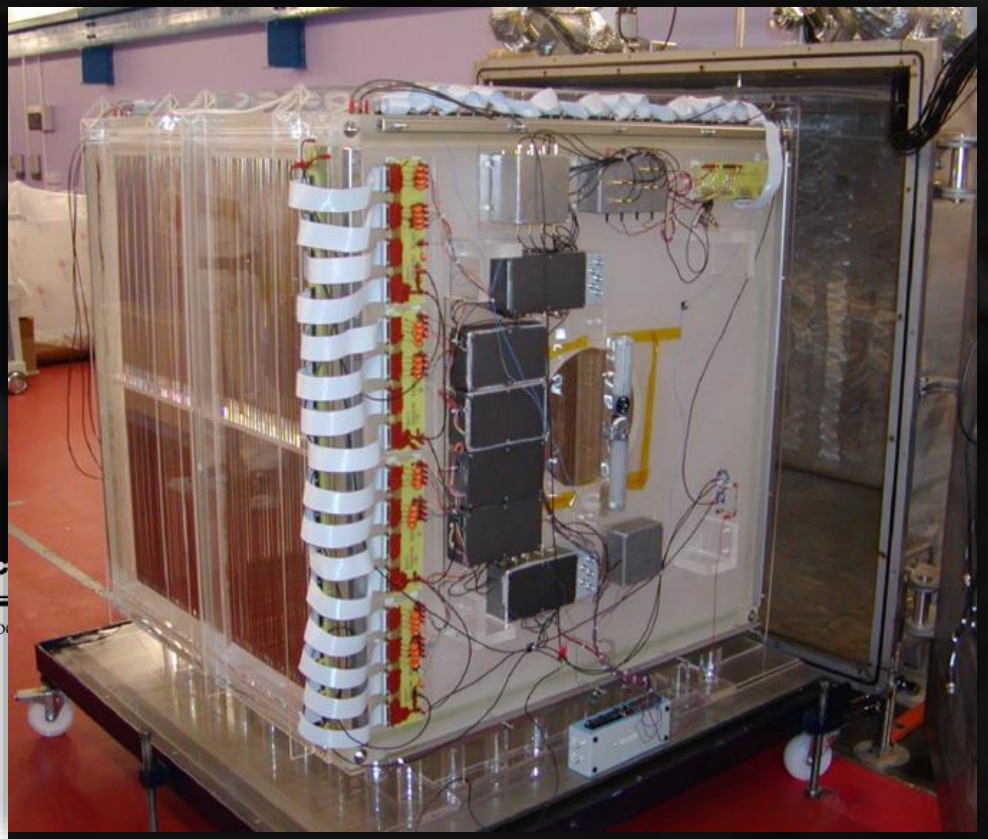
R Nuclear Instruments and Methods in Physics Research A 498 (2003) 155–164 RESEARC Section A
www.elsevier.com/lo

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



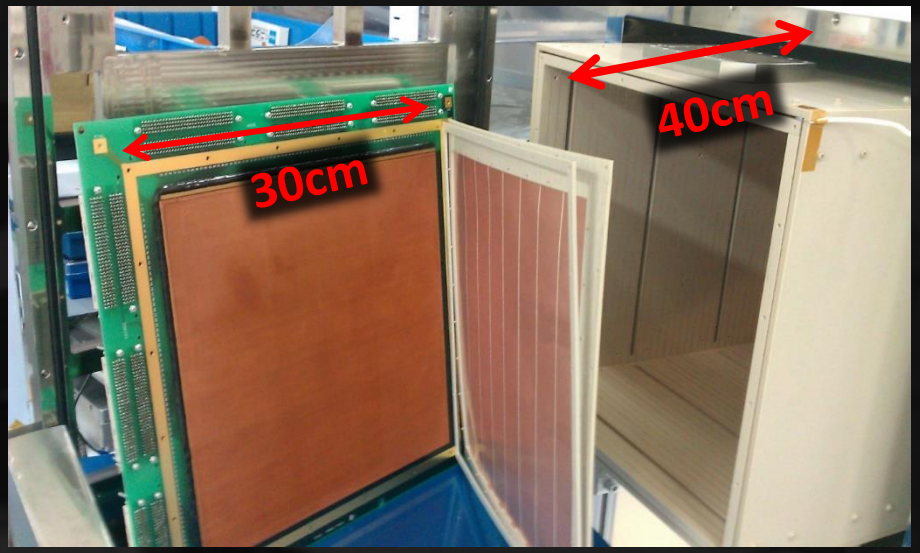
- 2mm pitch multi-wire proportional chamber
- not very direction-sensitive

NEWAGE: 3D-tracking

SEE Miuchi's talk
Friday afternoon

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

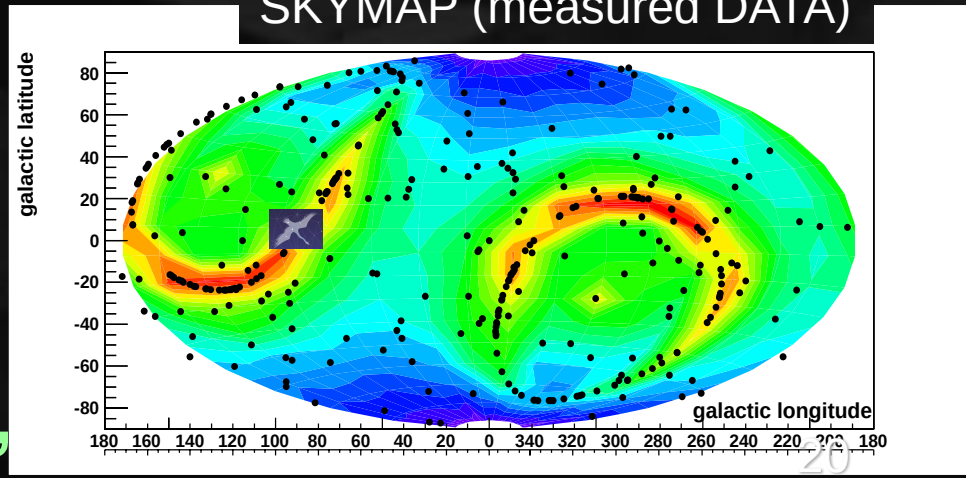


- Proposal PLB 578 (2004) 241
- First direction-sensitive limits

  PLB654 (2007) 58
- Underground results

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

SKYMAP (measured DATA)



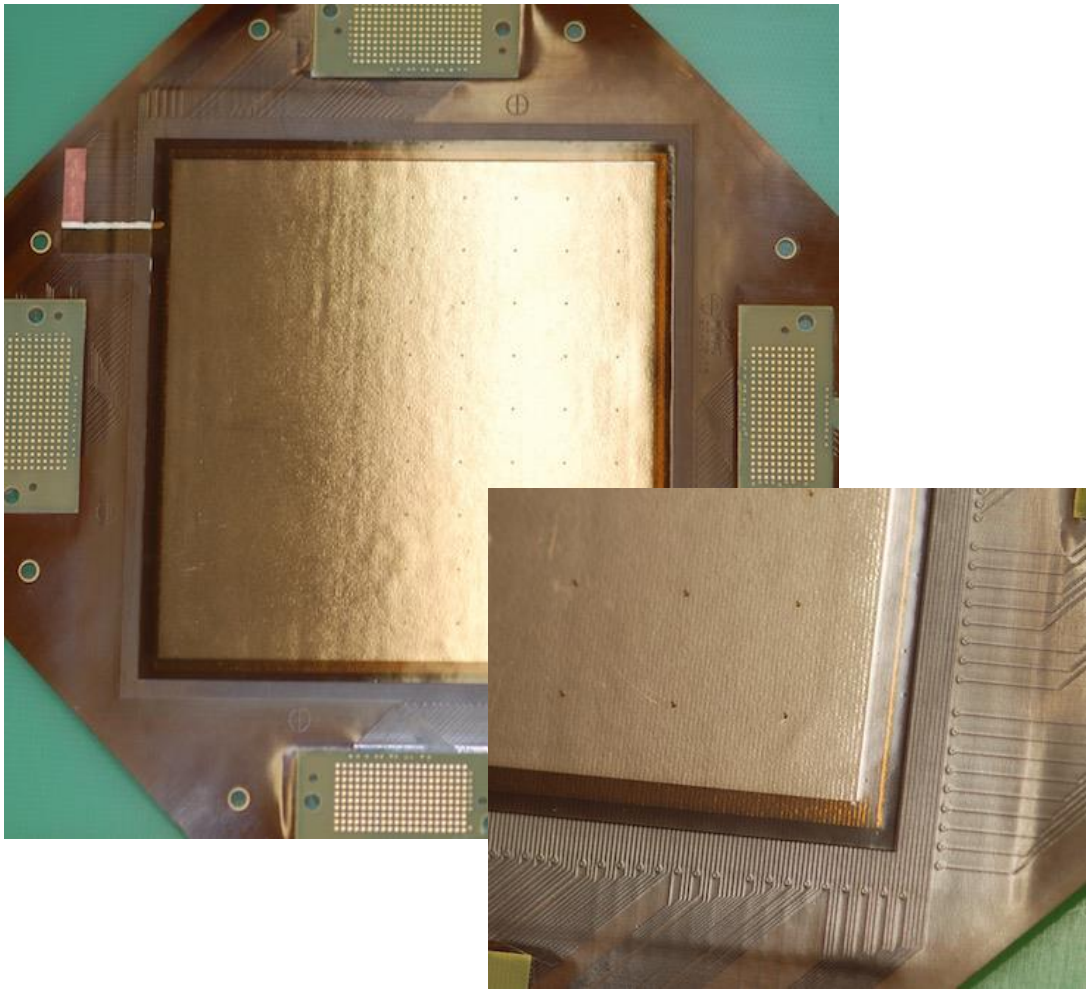
MIMAC (MIcro-tpc MAtrix of Chambers) for Directional Dark Matter Detection

LPSC (Grenoble) : D. Santos, F.Naraghi , N. Sauzet (CDD)
-Technical Coordination, Gas circulation and detectors : **O. Guillaudin**
- Electronics : **G. Bosson, J. Bouvier, J.L. Bouly, L.Gallin-Martel, F. Rarbi**
- Data Acquisition: **T. Descombes**
- Mechanical Structure : **J. Giraud**
- COMIMAC (quenching) **: J-F. Muraz**

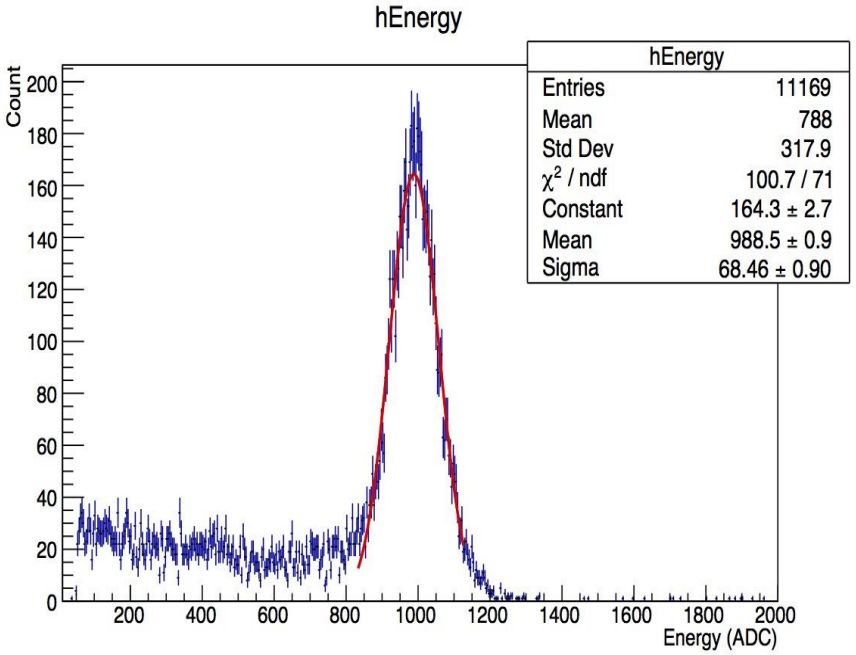
IRFU (Saclay): P. Colas, E. Ferrer-Ribas, I. Giomataris
CCPM (Marseille): J. Busto, D. Fouchez, C. Tao
Tsinghua University (Beijing-China): C. Tao, I. Moric (post-doc), Y. Tao (Ph.D)
Prototype hosted in **IHEP (Beijing-China)**: **ZhiminWang , Changgen Yang**

Neutron facility (AMANDE) :
IRSN (Cadarache): V. Lacoste, B. Tampon (Ph. D.)

New MIMAC low background detector



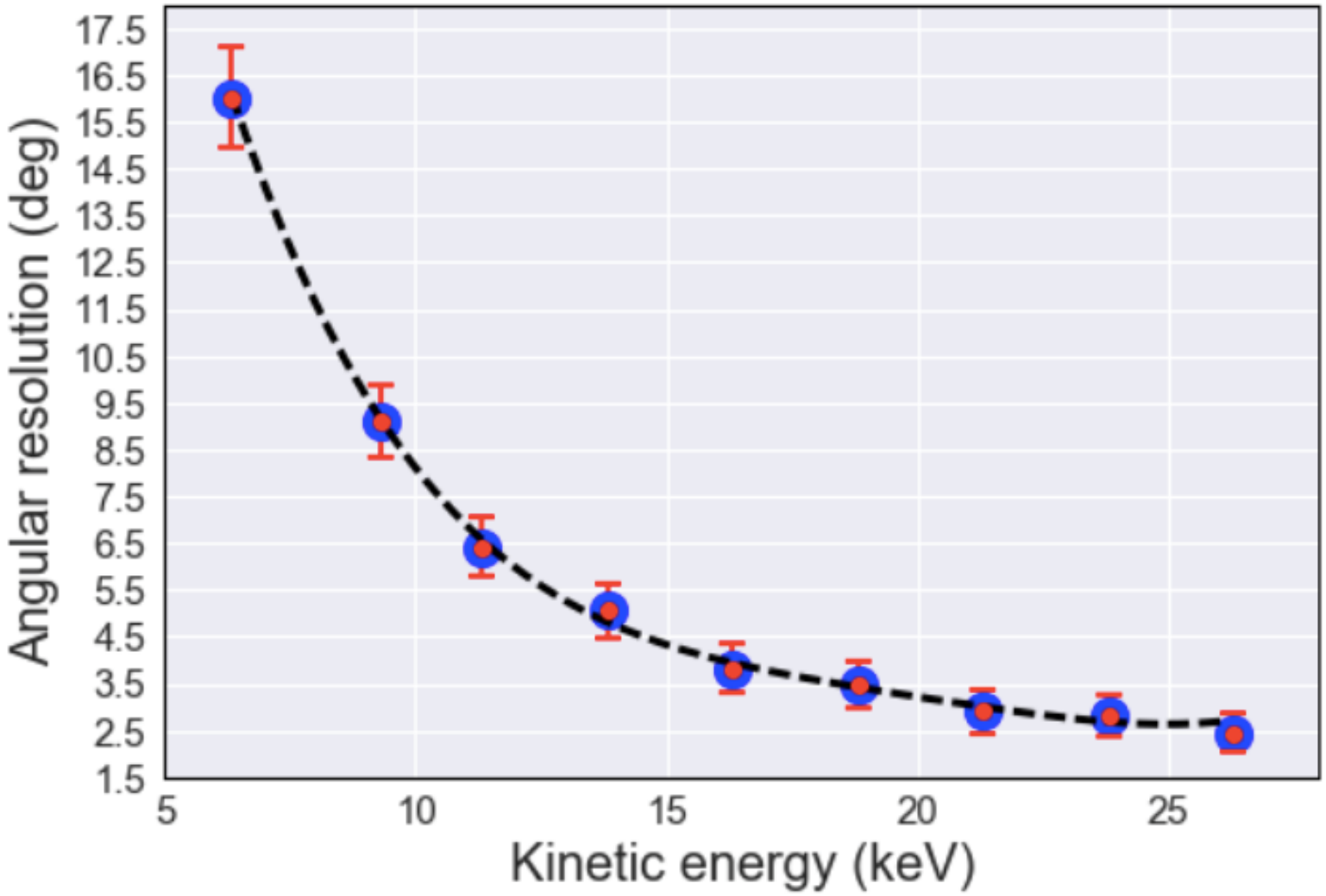
Kapton micromegas readout



Gaz : MIMAC 50 mbar
HT grille : -560 V
Drift field : -150 V/cm

16,3 % FWHM (6 keV)
Gain ~25 000
Energy threshold <1 keV

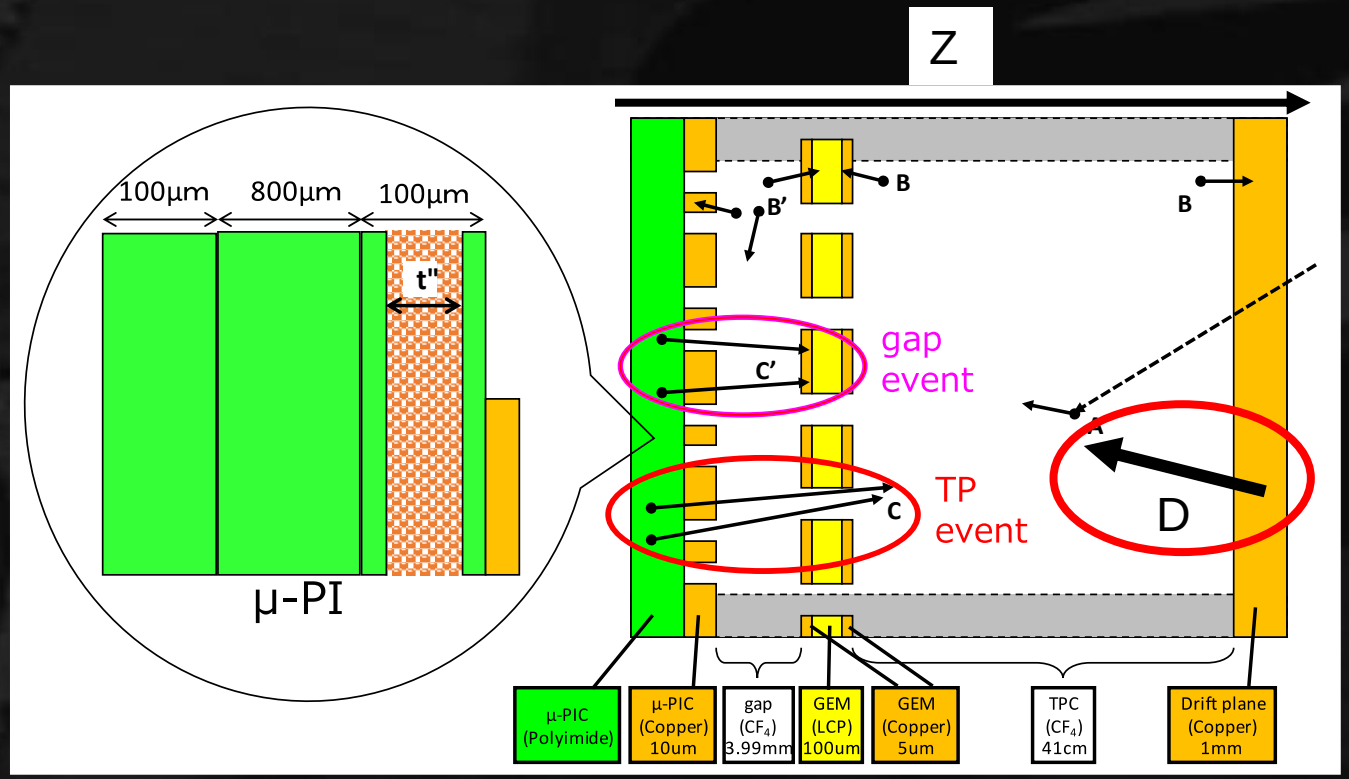
Angular resolution measured with COMIMAC
(^{19}F ions at known kinetic energies)
(I. Moric, Y. Tao et al. 2018)



Recent Activities

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

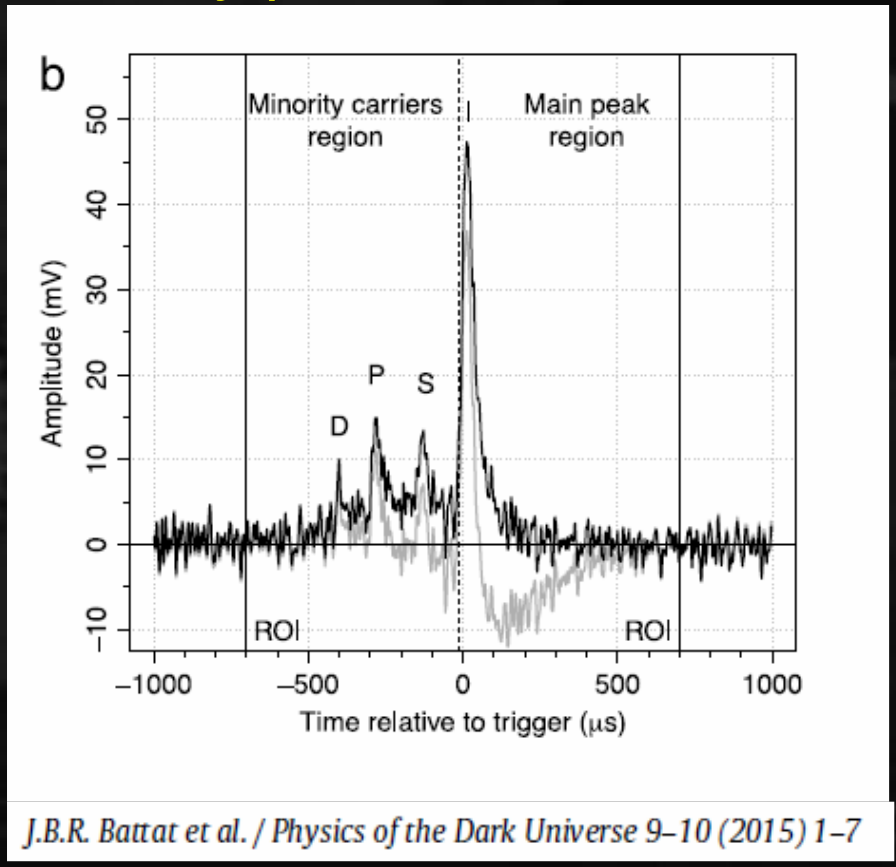


serious background:
- readout plane
- cathode (drift) plane

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



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

2nd breakthrough (2015)

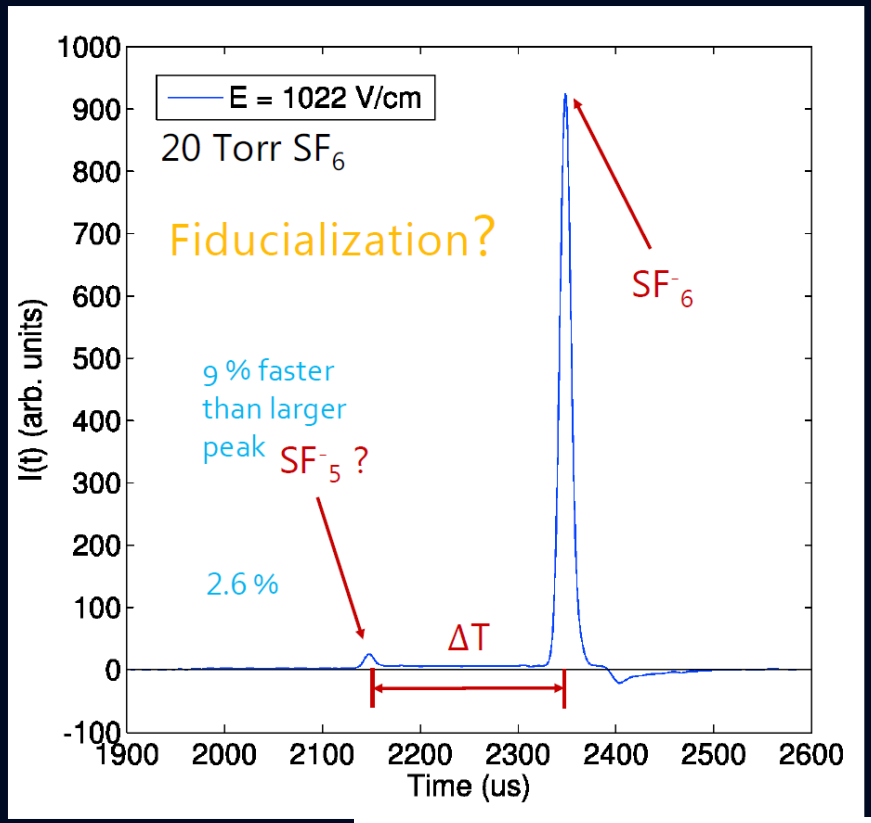
- **SF_6 gas** （NEW MEXICO group）
  - **SF_6 : famous insulator gas (safe gas)**
    → found to have minority carriers

THE UNIVERSITY of NEW MEXICO

First Studies of SF_6 in a TPC

NGUYEN PHAN, ERIC LEE
UNIVERSITY OF NEW MEXICO

2017 JINST 12 P02012



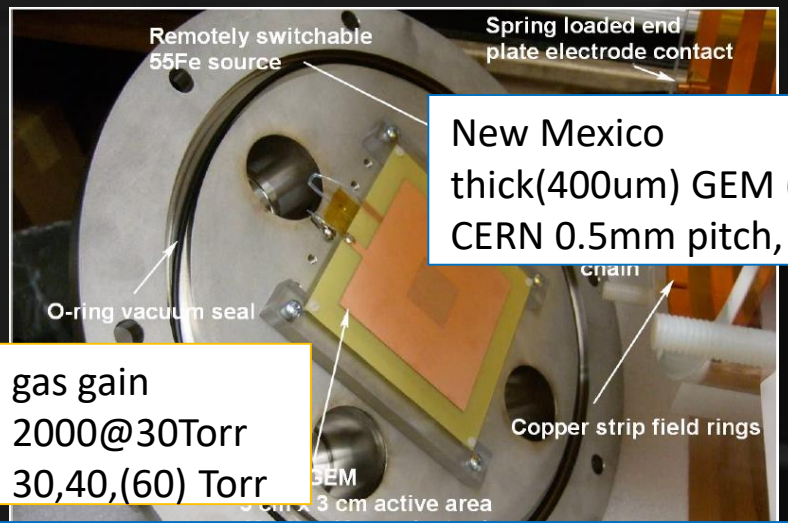
averaged waveform

minority carrier is really minor

Direction Sensitive WIMP search NEWAGE

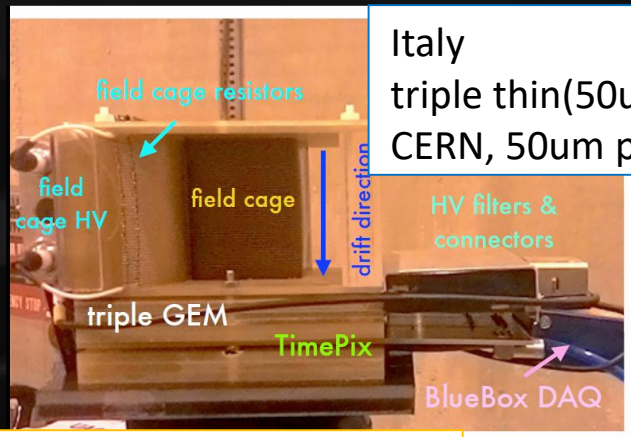
World-wide SF_6 activities (convener: Miuchi)

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

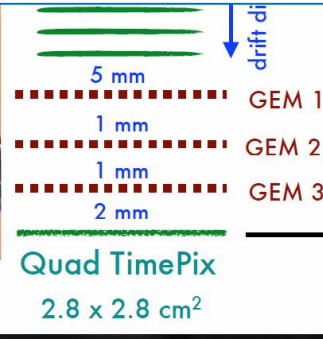


New Mexico
thick(400um) GEM ($3 \times 3cm^2$)
CERN 0.5mm pitch, Φ0.3mm

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

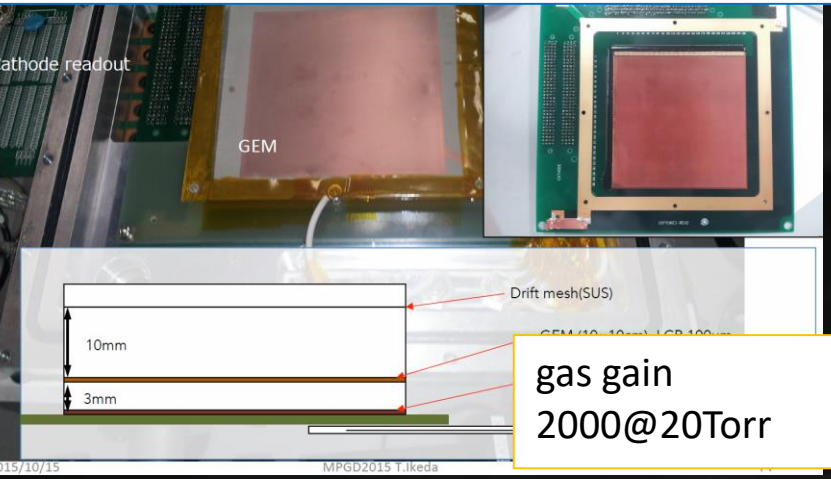


Italy
triple thin(50um) GEM ($3 \times 3cm^2$)
CERN, 50um pitch, Φ30um



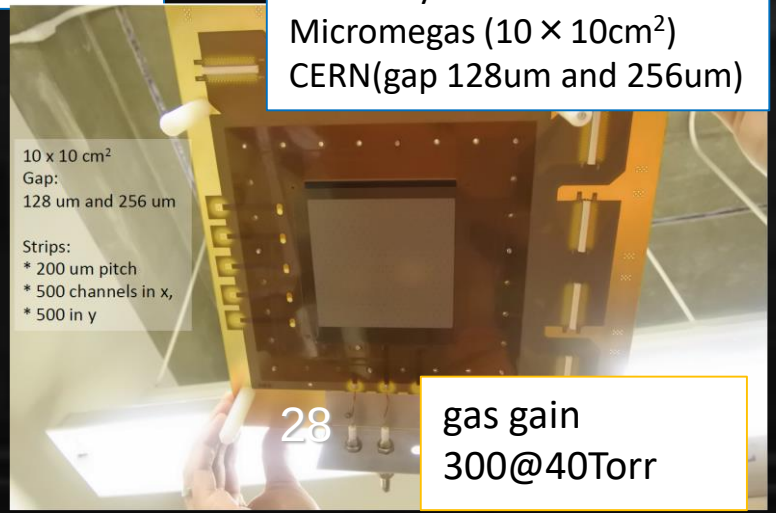
gas gain
5000@ 175Torr, 2000@370Torr

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



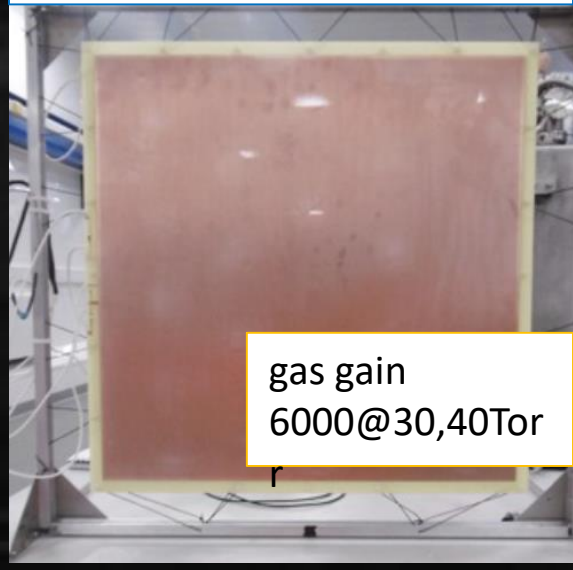
gas gain
2000@20Torr

Wellesley
Micromegas ($10 \times 10cm^2$)
CERN(gap 128um and 256um)



gas gain
300@40Torr

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



gas gain
6000@30,40Tor
r

SUMMARY

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