Sep 15th, 2022
2nd DMNet symposium
Heidelberg, Germany

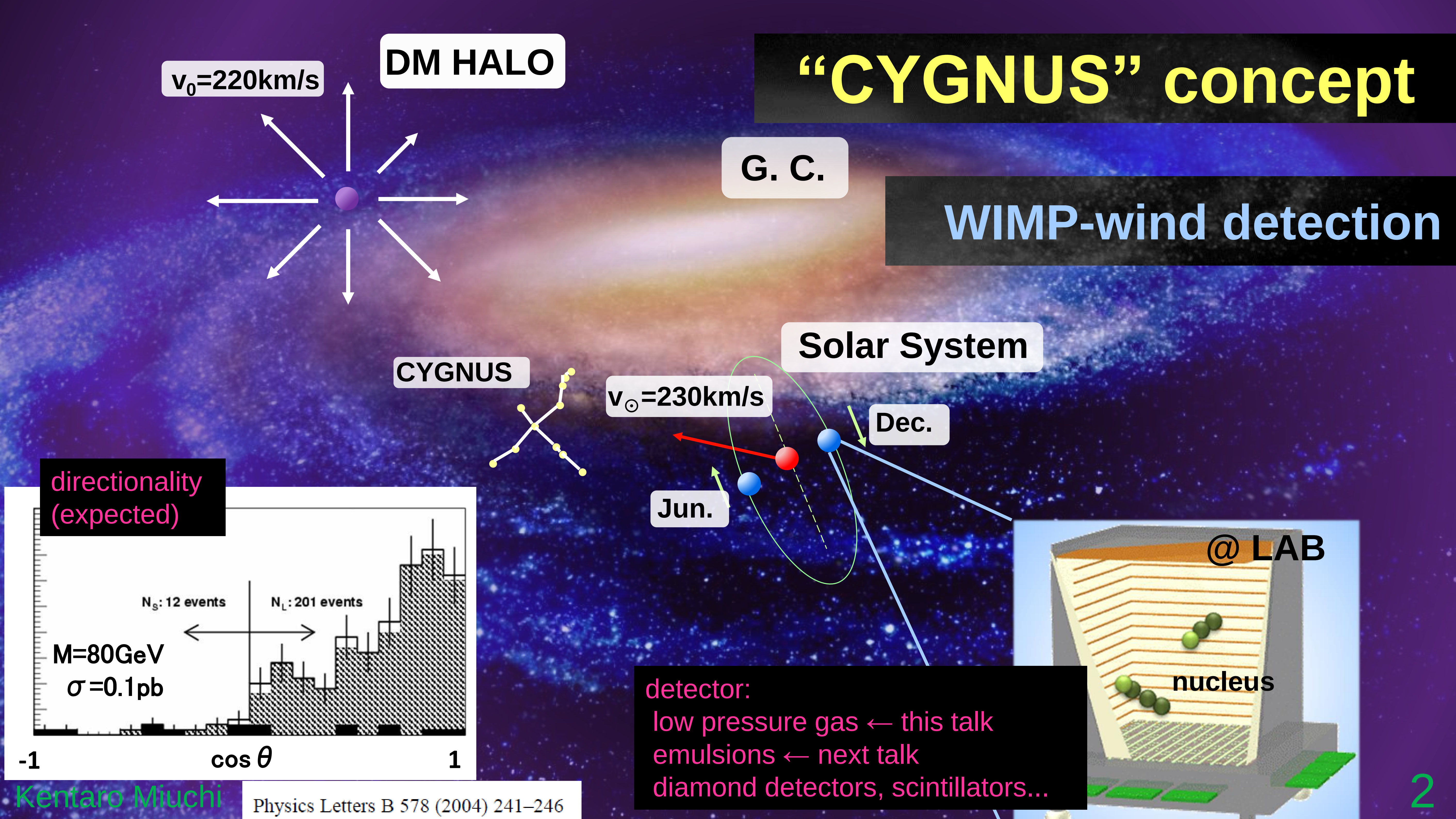
Future Directional DD (gas) and Migdal Detection

Kentaro Miuchi
(Kobe University)

科研費 KAKENHI

DDD:Overview

- DDD:Overview
- DDD:Activities
- Migdal
- Summary



"CYGNUS" concept
WIMP-wind detection
DM HALO
v_0=220km/s
G. C.
Solar System
CYGNUS
$v_\odot$=230km/s
Dec.
Jun.
@ LAB
nucleus
directionality
(expected)
N_S: 12 events
N_L: 201 events
M=80GeV
σ=0.1pb
-1
cos θ
1
Physics Letters B 578 (2004) 241–246
detector:
low pressure gas ← this talk
emulsions ← next talk
diamond detectors, scintillators...
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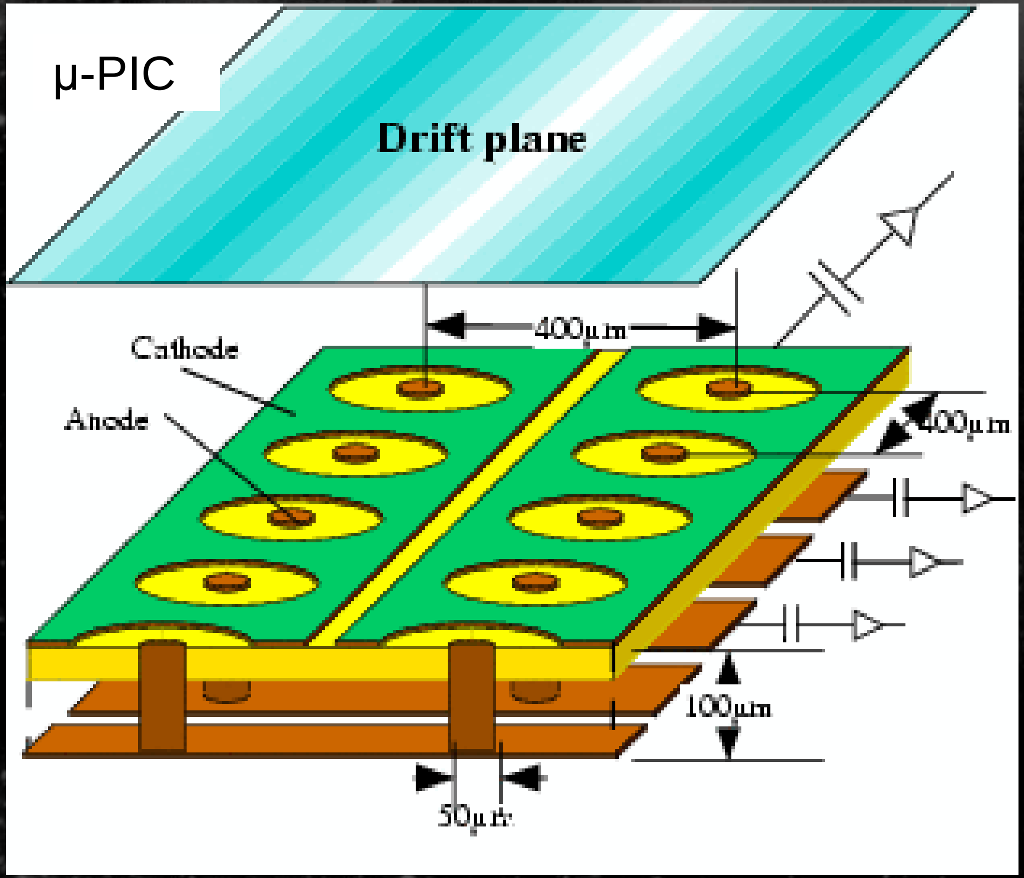
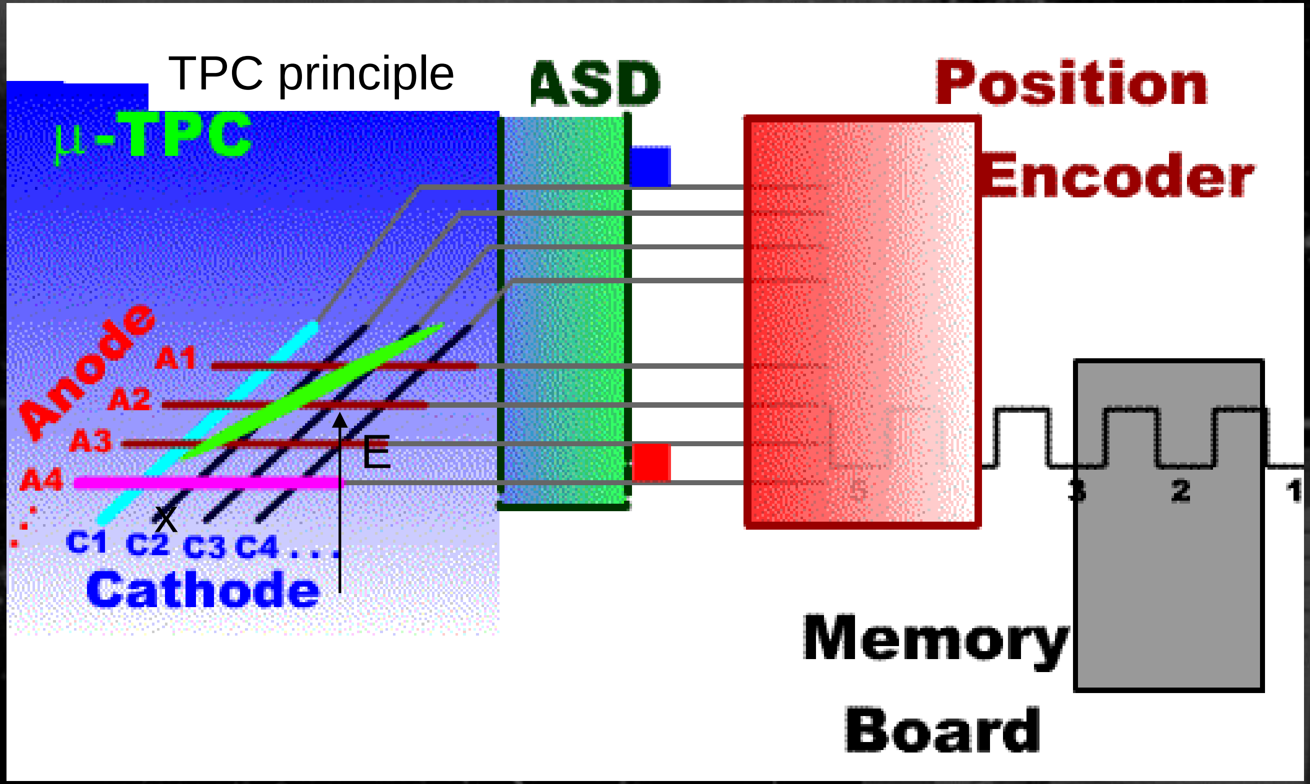
2

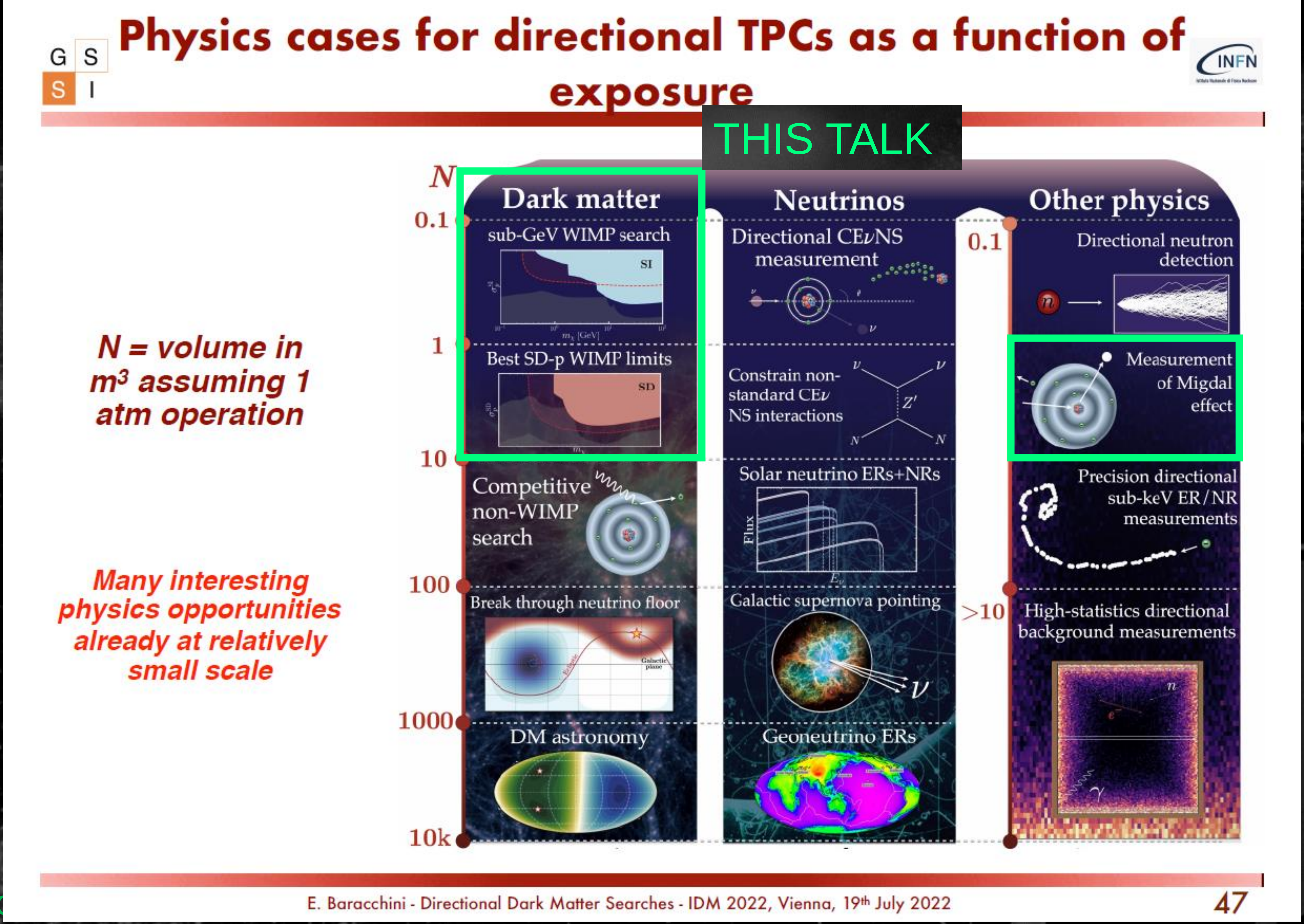
- Key technology: Gaseous Time Projection Chamber
  - 2-dimensional image: Micro Patterned Gaseous Detector (MPGD)
  - timing information: 3rd dimension
  - realtime 3-dimensional tracking

MPGD:
GEM, micromegas, μ-PIC





- drawback: small mass O(kg) / m^3



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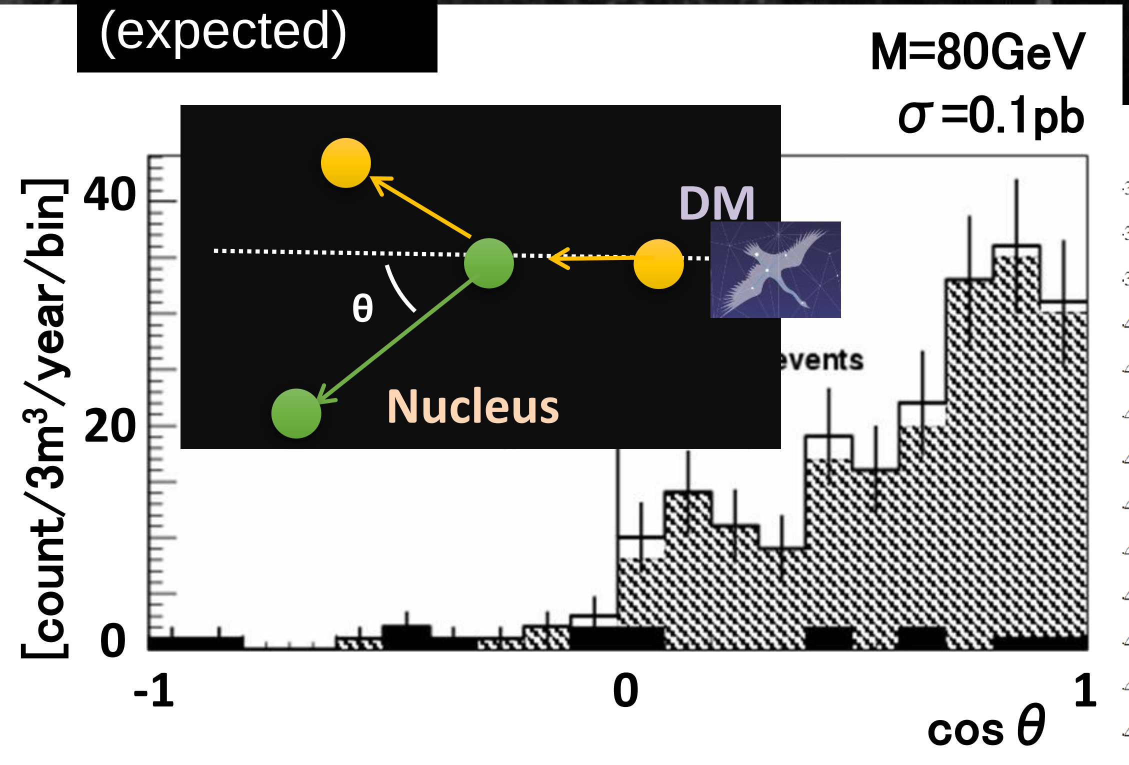
DDD: Activities

- DDD:Overview
- DDD:Activities
- Migdal
- Summary

Directional Detection

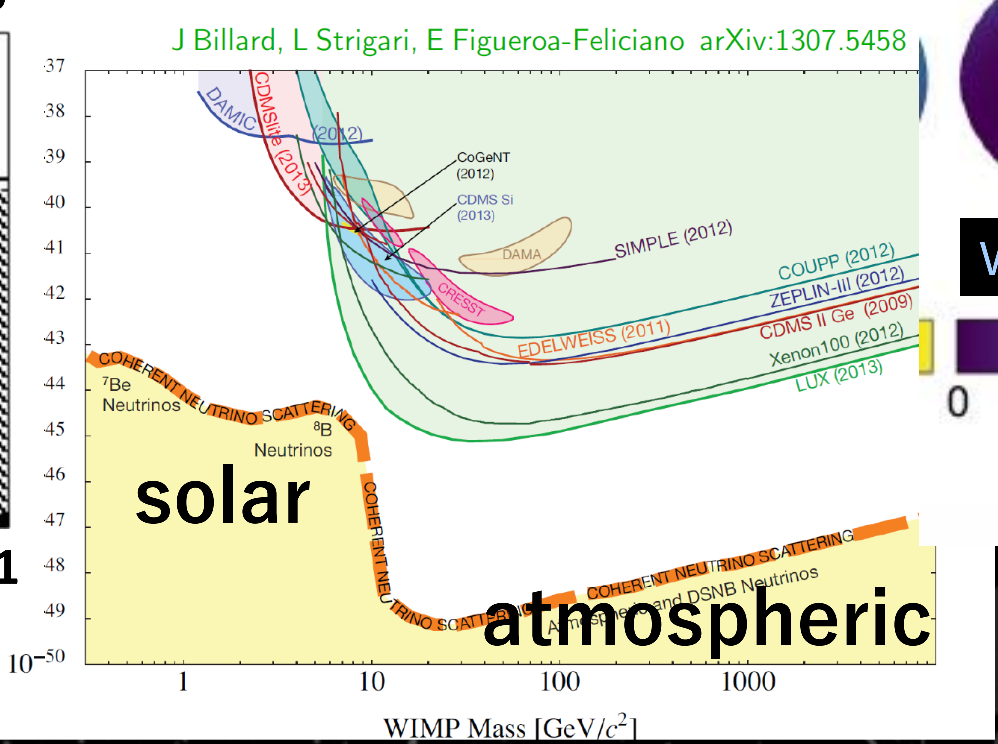
- Clear Discovery
  even with the neutrino BG
  + study the nature of DM after discovery

directionality (expected)

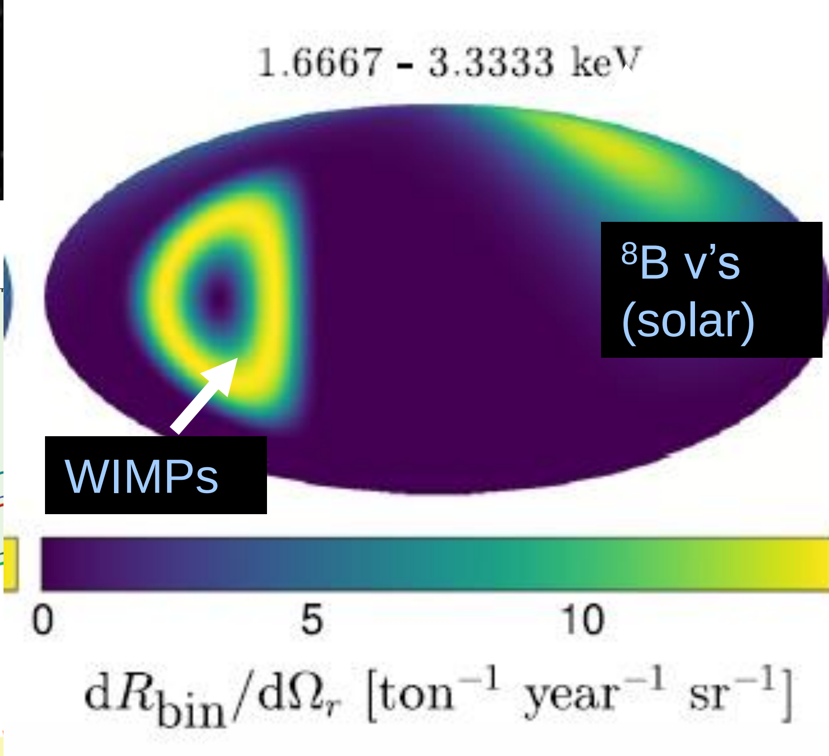


Physics Letters B 578 (2004) 241–246

neutrino floor



w/ neutrino BG (expected)



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

CYGNUS: community

- 7 × bi-annual workshops (2007-)
  - CYGNUS 2017 Xichang, Sichuan, China June 13 - 16, 2017
  - CYGNUS 2015 Occidental College, Los Angeles, California, USA June 2 - 4, 2015.
  - CYGNUS 2013 Toyama, Japan June 10 - 12, 2013.
  - CYGNUS 2011 Aussois, France June 7 - 10, 2011.
  - CYGNUS 2009 Massachusetts Institute of Technology, Cambridge, Massachusetts, USA June 11 - 13, 2009.
  - CYGNUS 2007 Boulby Underground Laboratory, Saltburn-by-the-Sea, Cleveland, UK July 22 - 24, 2007.
- proto-collaboration (2016-)
  - >50 researchers
  - discussion on-going for actual collaboration
- Joint papers

steering committee

E. Baracchini (GSSI)
G. Lane (ANU, Canberra)
K. Miuchi (Kobe)
N. Spooner (Sheffield)
S. Vahsen (Hawaii)

International Journal of Modern Physics A
Vol. 25, No. 1 (2010) 1–51
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THE CASE FOR A
DIRECTIONAL DARK MATTER DETECTOR AND
THE STATUS OF CURRENT EXPERIMENTAL EFFORTS

Readout technologies for directional WIMP Dark Matter detection

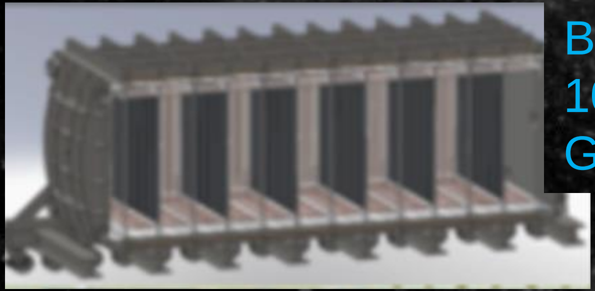
Physics Reports 662 (2016) 1–46

J.B.R. Battat [1,*], I.G. Irastorza [2], A. Aleksandrov
E. Baracchini [6], J. Billard [7,8], G. Bosson [7], O. Bourrion [7], J. Bouvier [7],
A. Buonaura [3,9], K. Burdge [10,11], S. Cebrián [2], P. Colas [12], L. Consiglio [13], T. Dafni [2],
N. D'Ambrosio [13], C. Deaconu [10,14], G. De Lellis [3,9], T. Descombes [7],

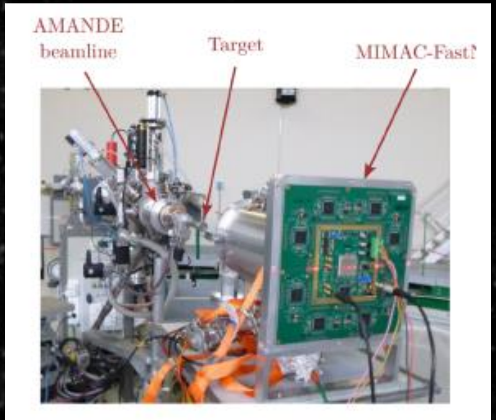
Ke

Gaseous TPC activities

- gaseous TPCs: most-widely studied in the world

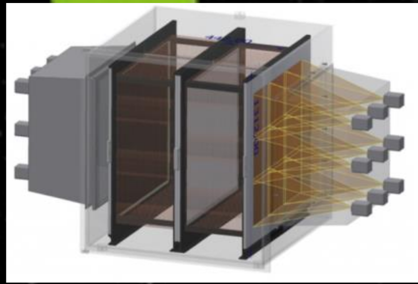


CYGNUS-10
Boulby, UK
$10m^3$ $He:SF_6$
GEM + wire readout



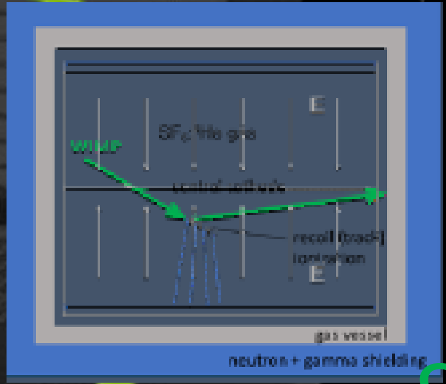
MIMAC
Moderne, France
CF_4+CHF_3
Strip readout

CYGNO-Initium
Gran Sasso, Italy
He CF_4 (SF_6)
sCMOS+PMT readout



NEWAGE/CYGNUS-KM
Kamioka, Japan
SF_6 / CF_4
Strip readout

CYGNUS-HD10
SURF, USA
$He:CF_4:C_4H_{10}$
Strip readout

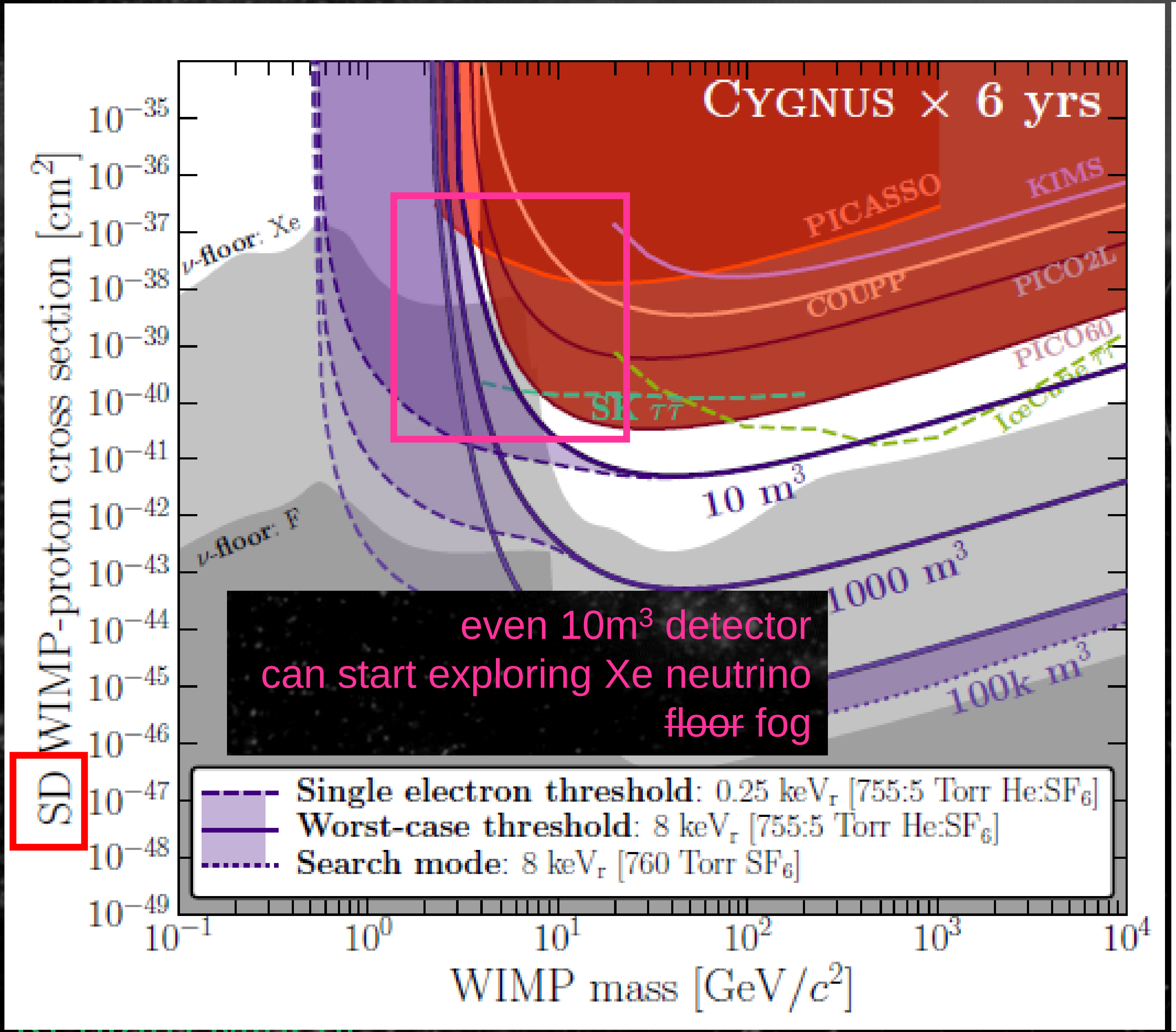


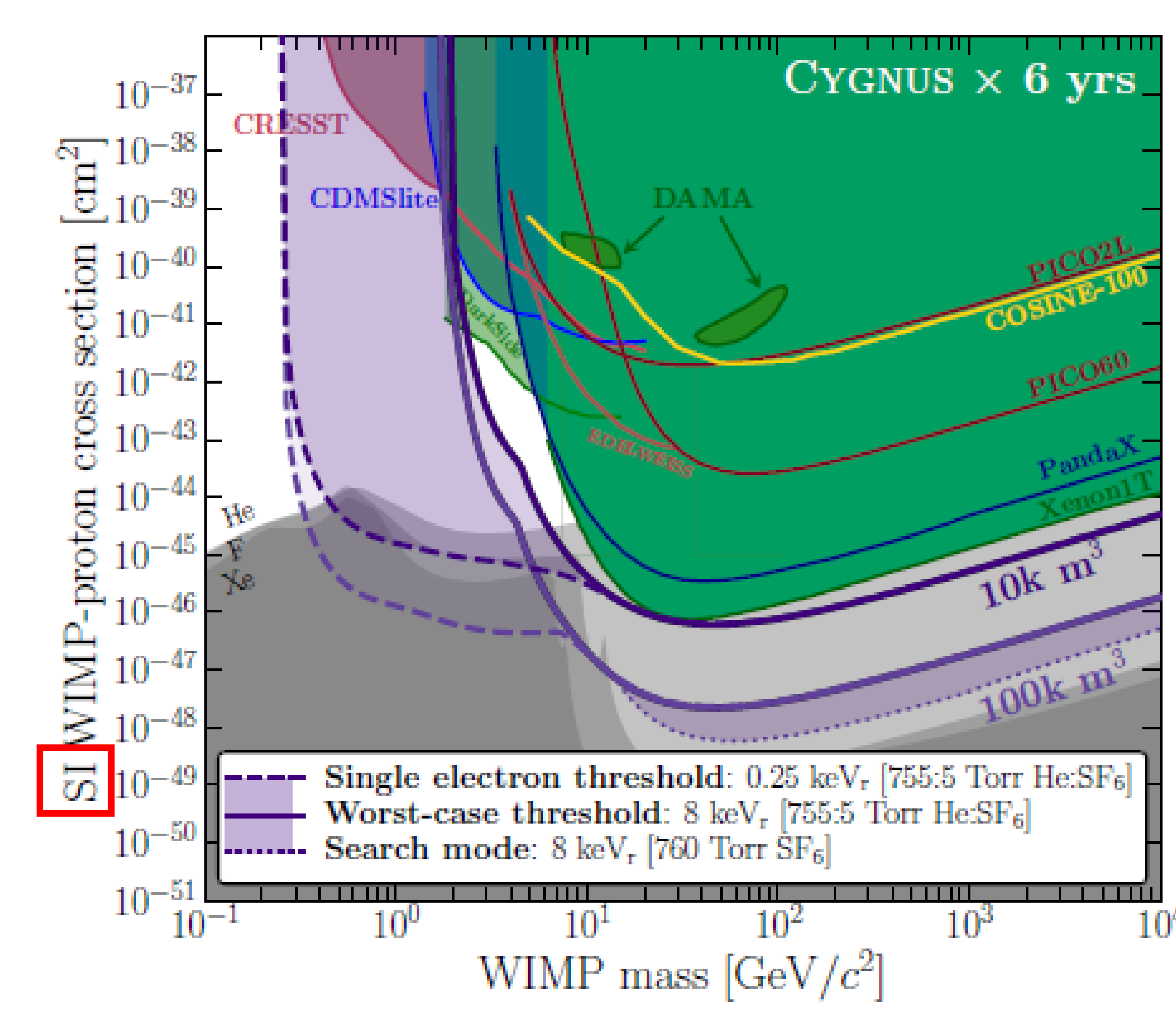
CYGNUS-OZ
Stawell, Australia
R&D leading to 1 m^3
Long-term plan 10 m^3

CYGNUS: physics reaches

- Realistic simulation (strip readout)

arXiv 2008.12587



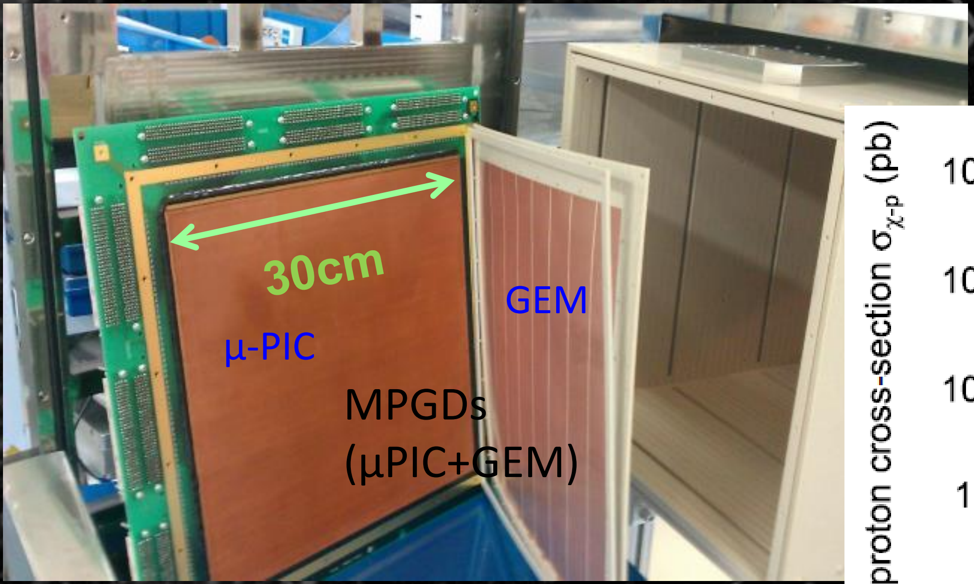


Japanese “CYGNUS” activities

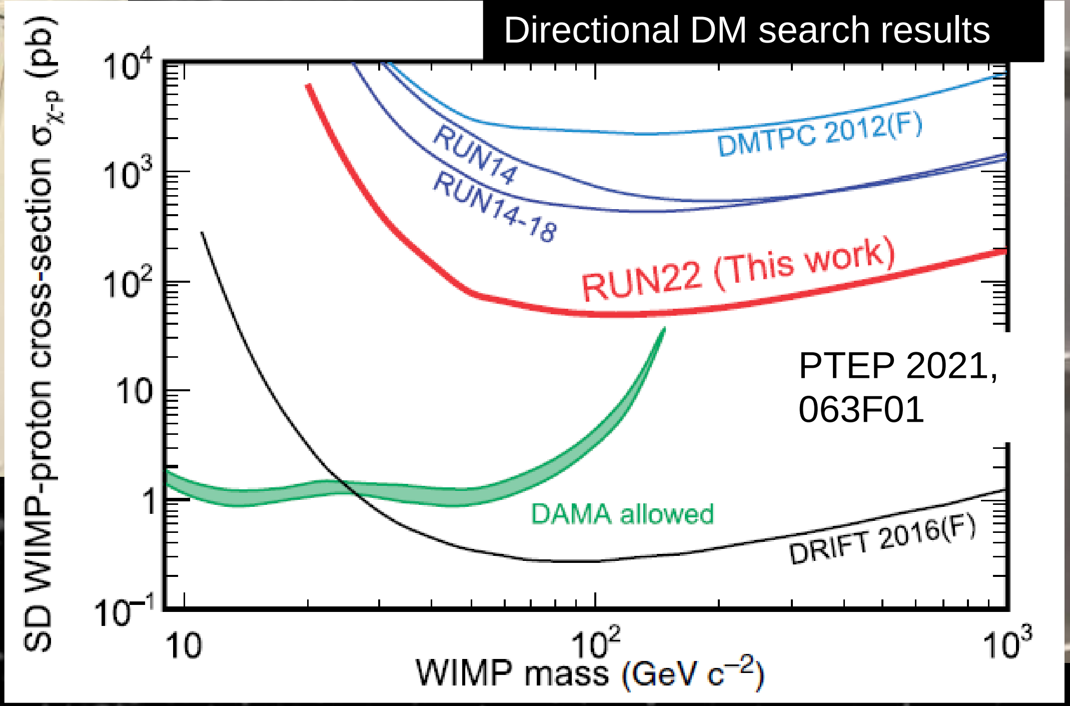
proposal: PLB 578 (2004) 241
first results: PLB 654 (2007) 58
latest results: PTEP 2021 063F01

- pioneered 3d-tracking (direction sensitive) (NEWAGE)
- C/N-1.0 chamber (18 × 30×30 cm^2 detectors)
  - chamber ready

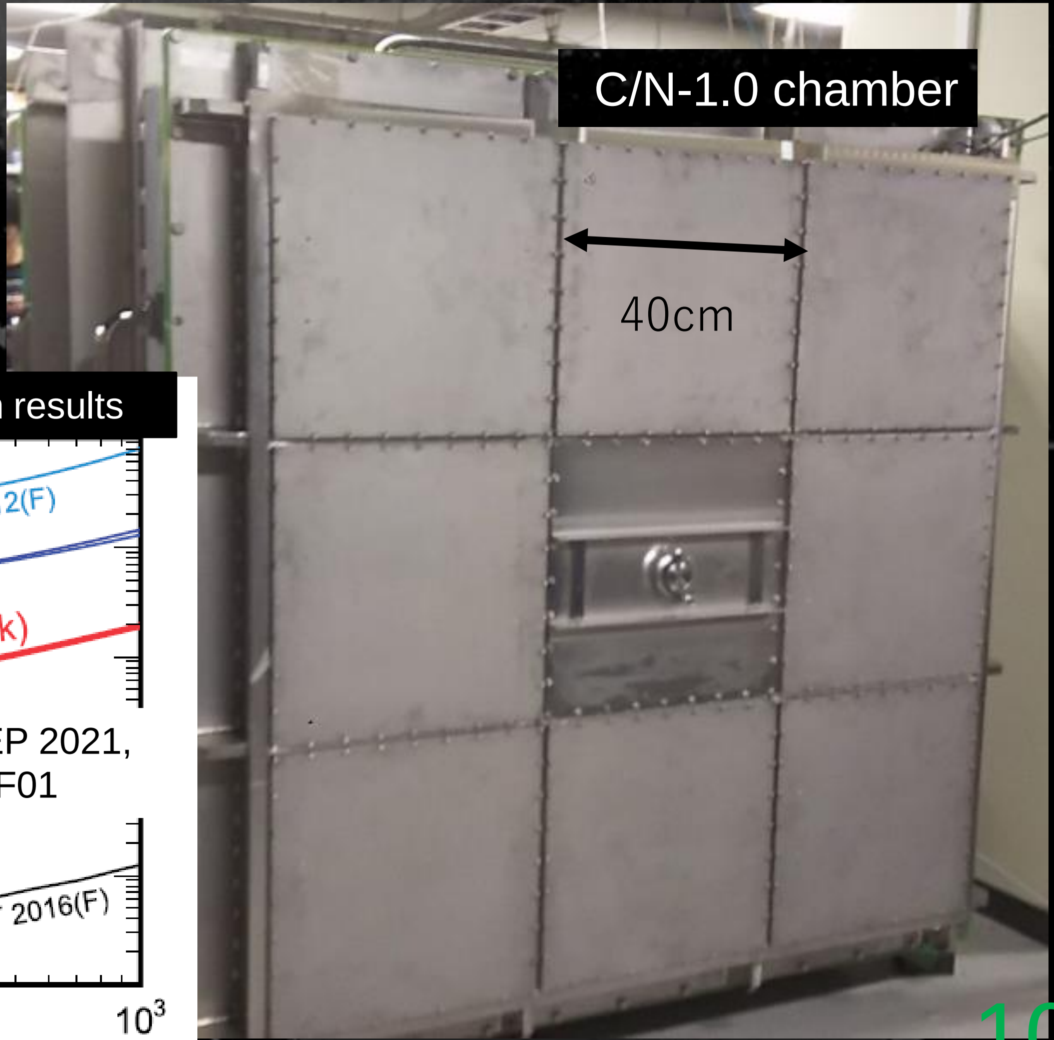
NEWAGE-0.3b”



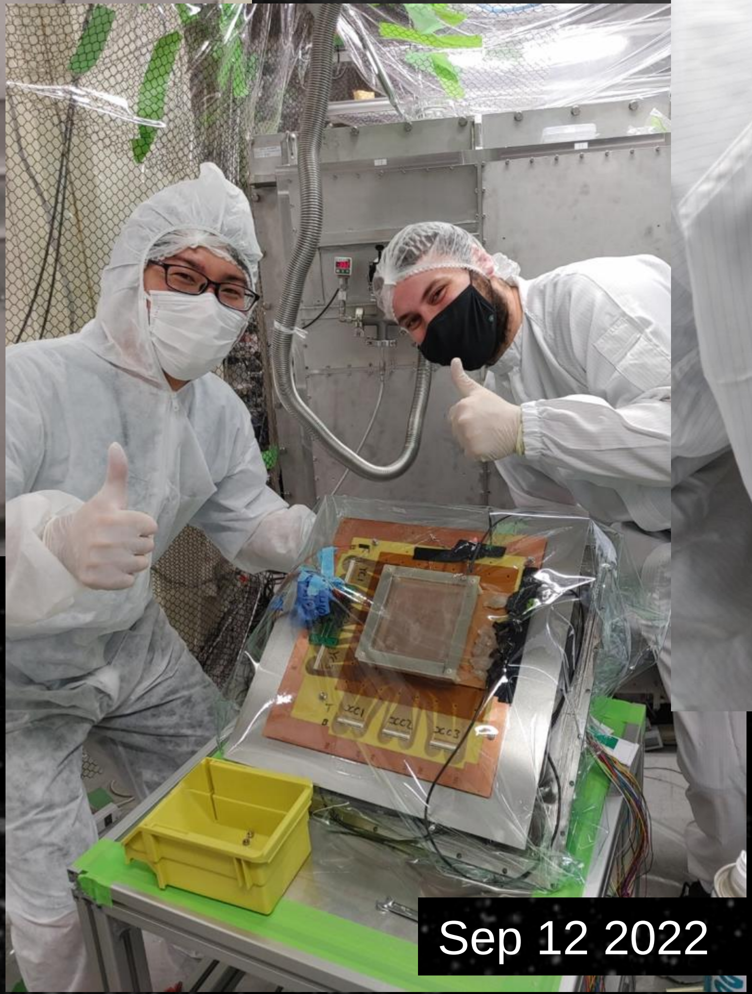
Directional DM search results

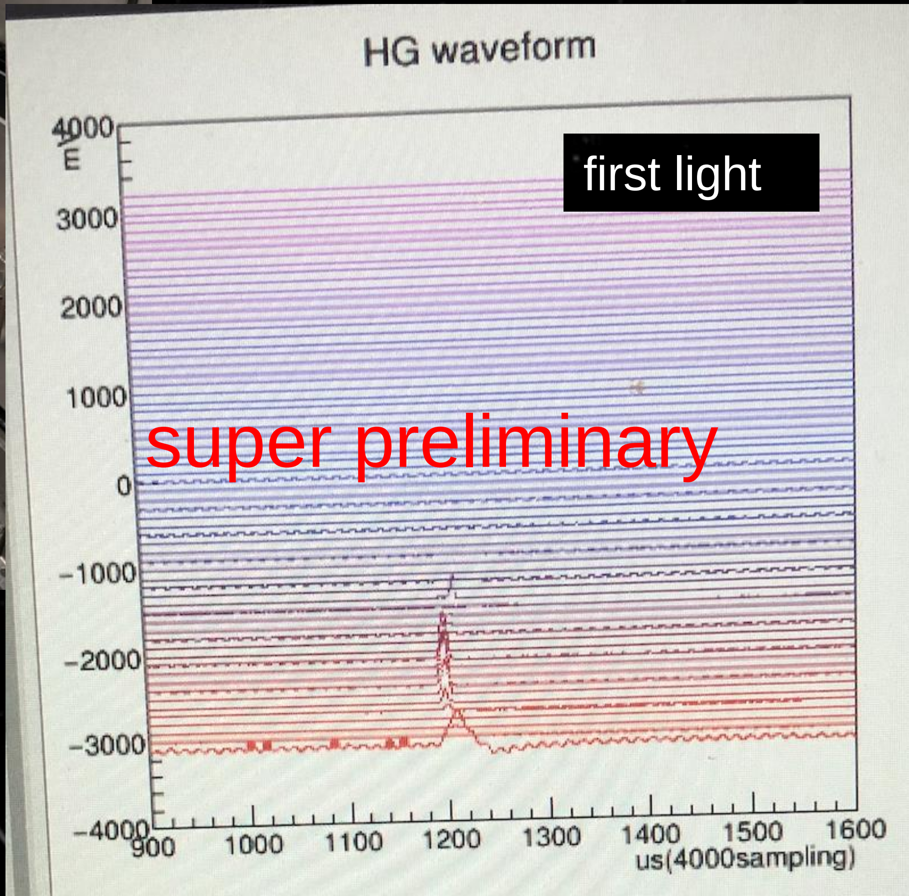


PTEP 2021, 063F01



- Recent C/N-1.0 activities
  - Sheffield (DRIFT) micromegas detector test





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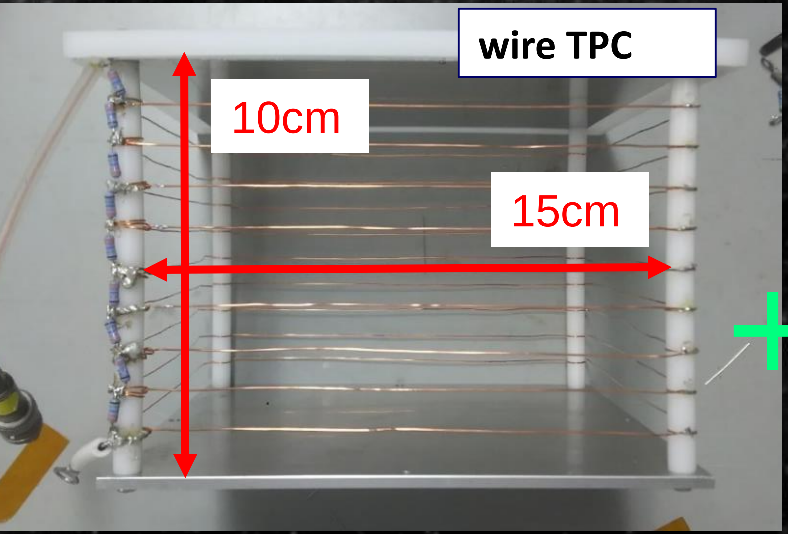
• Resistive Sheet TPC

PTEP 2019 (2019)063H01

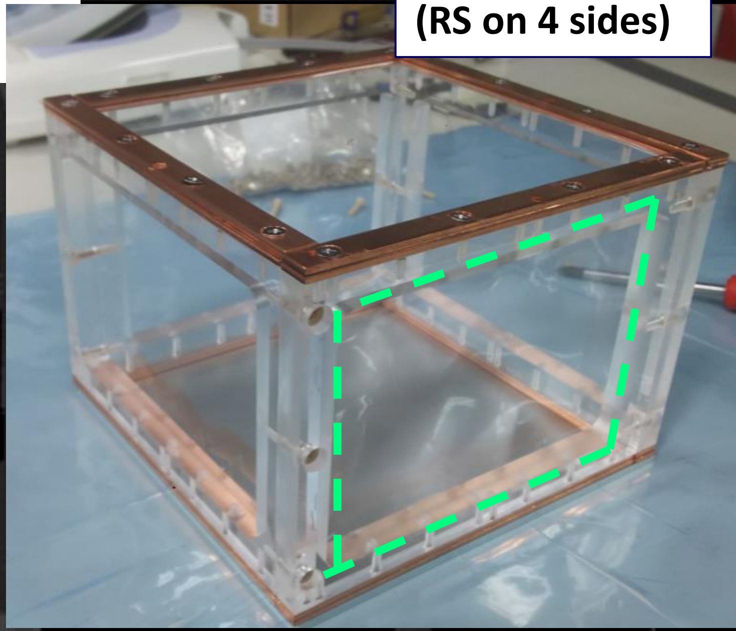
- need electric field to drift electrons
- traditional method: wires, ribbons...
- new approach: resistive sheet
  - easy to assemble
  - radioactive low BG
  - uniform electric field



+

commercially-available
“anti-electric sheet” as cheap starting

carbon sputtered
EVOH sheet (for radon barrier)



RS-TPC
(RS on 4 sides)

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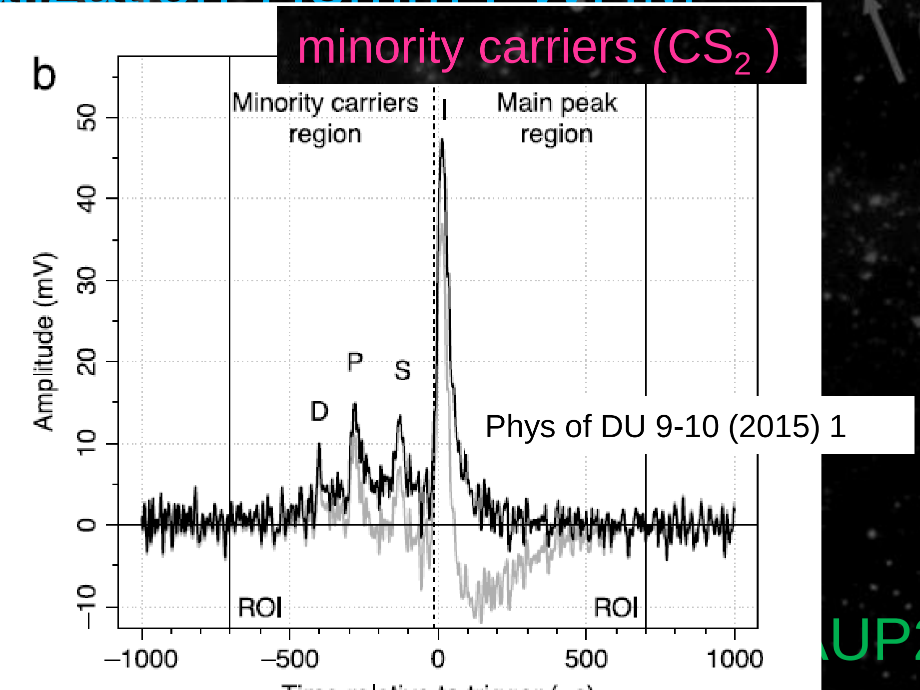
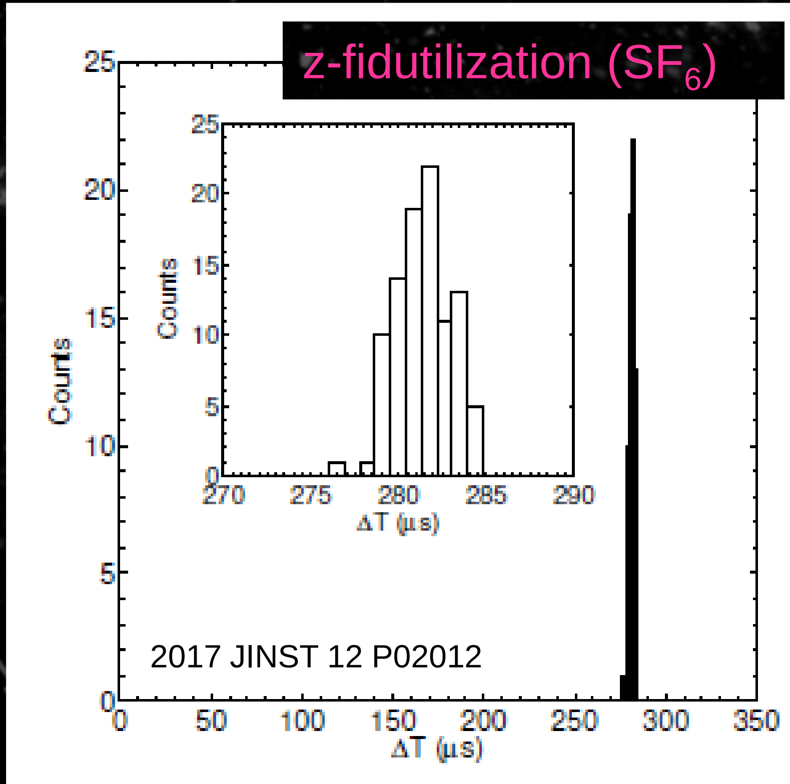
Negative ion TPC Study

- no “S1” signal
- Pioneered by DRIFT group

small diffusion

- Minority carrier discovery (CS_2+O_2, Occidental group)
  - use several ion species with different drift velocities
  - ⇒ z fiducialization possible ⇒LOW BG !
- SF_6 discovery (2015, UNM group).
  - z-fiducialization 7.3mm FWHM



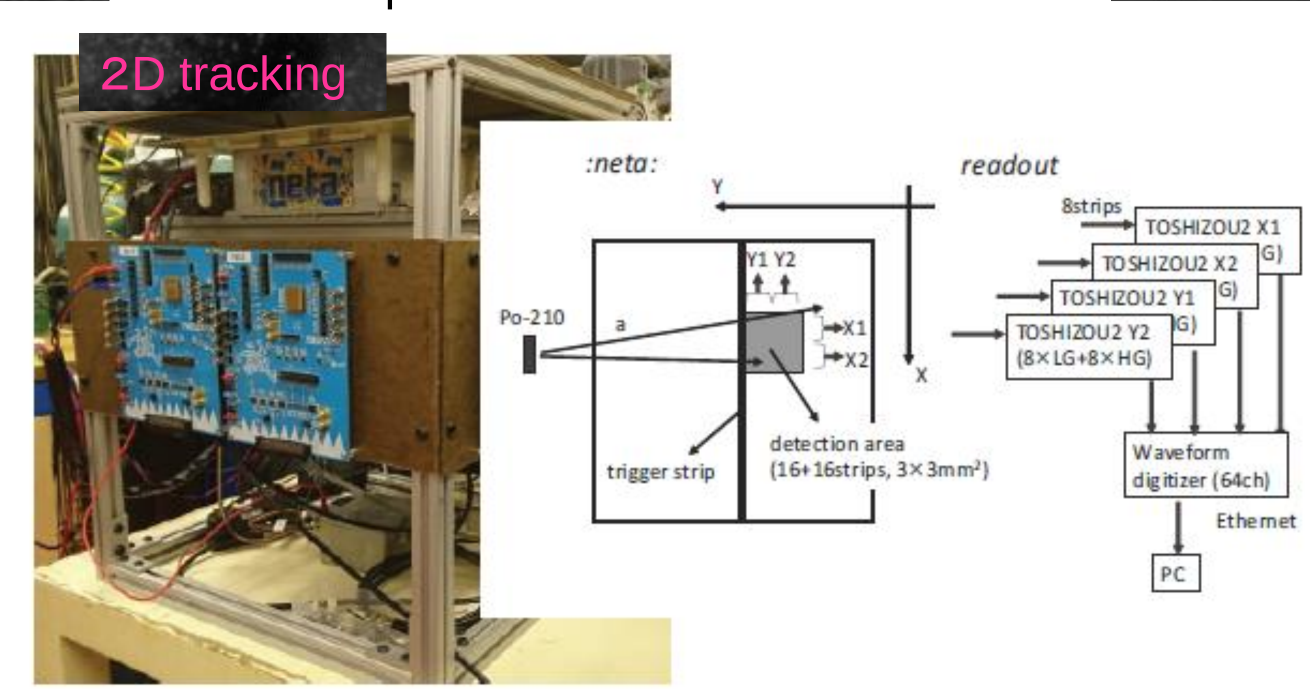


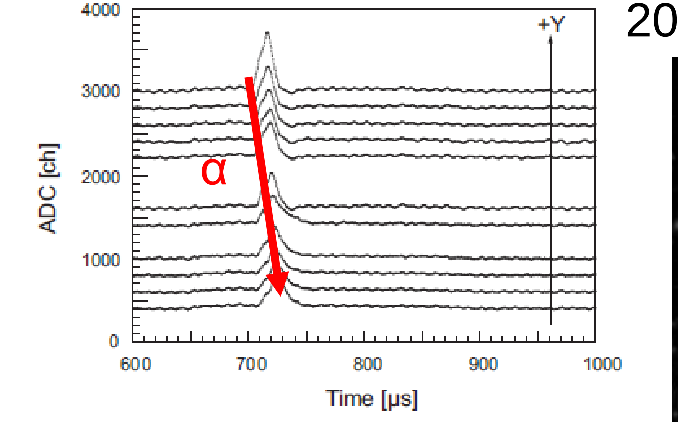
(a) ΔT laser calibration pulses

- to be CYGNUS: Trackings
  - strip readout + ASICs

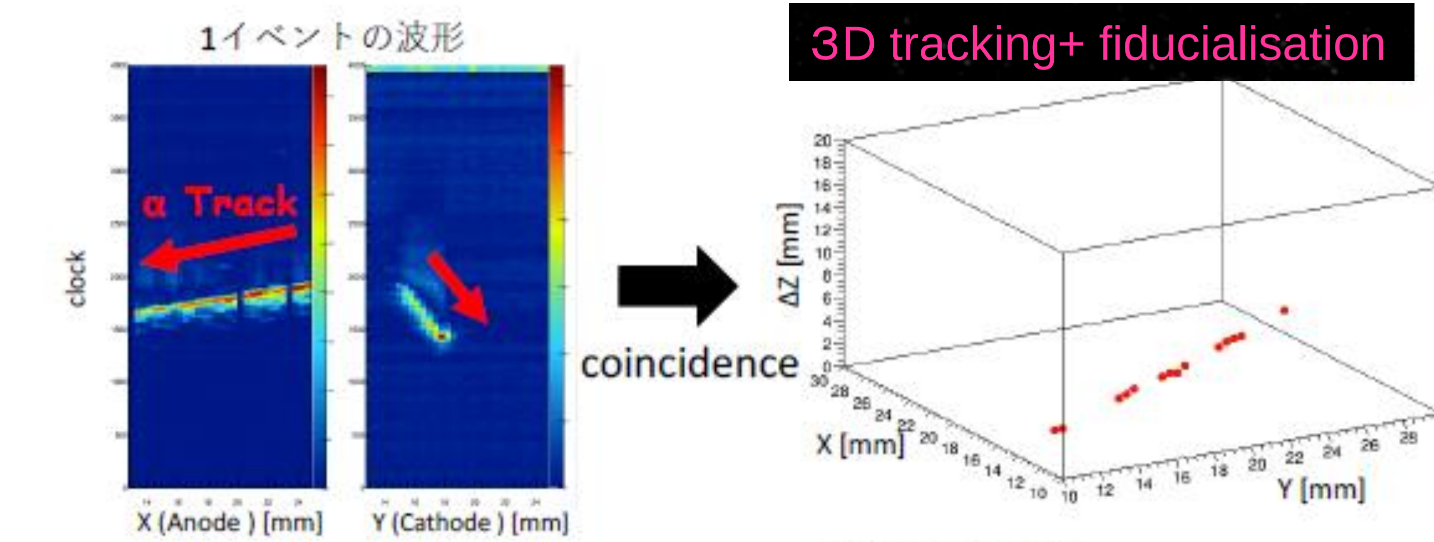
LTARS2016 + Wellesley's micromegas resistive-strip readout

2D tracking

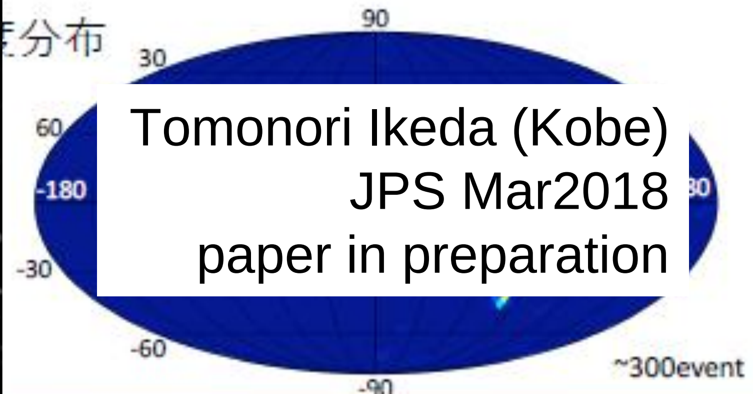




2019 J. Inst. 14 T01008



3D tracking+ fiducialisation



Tomonori Ikeda (Kobe)
JPS Mar2018
paper in preparation

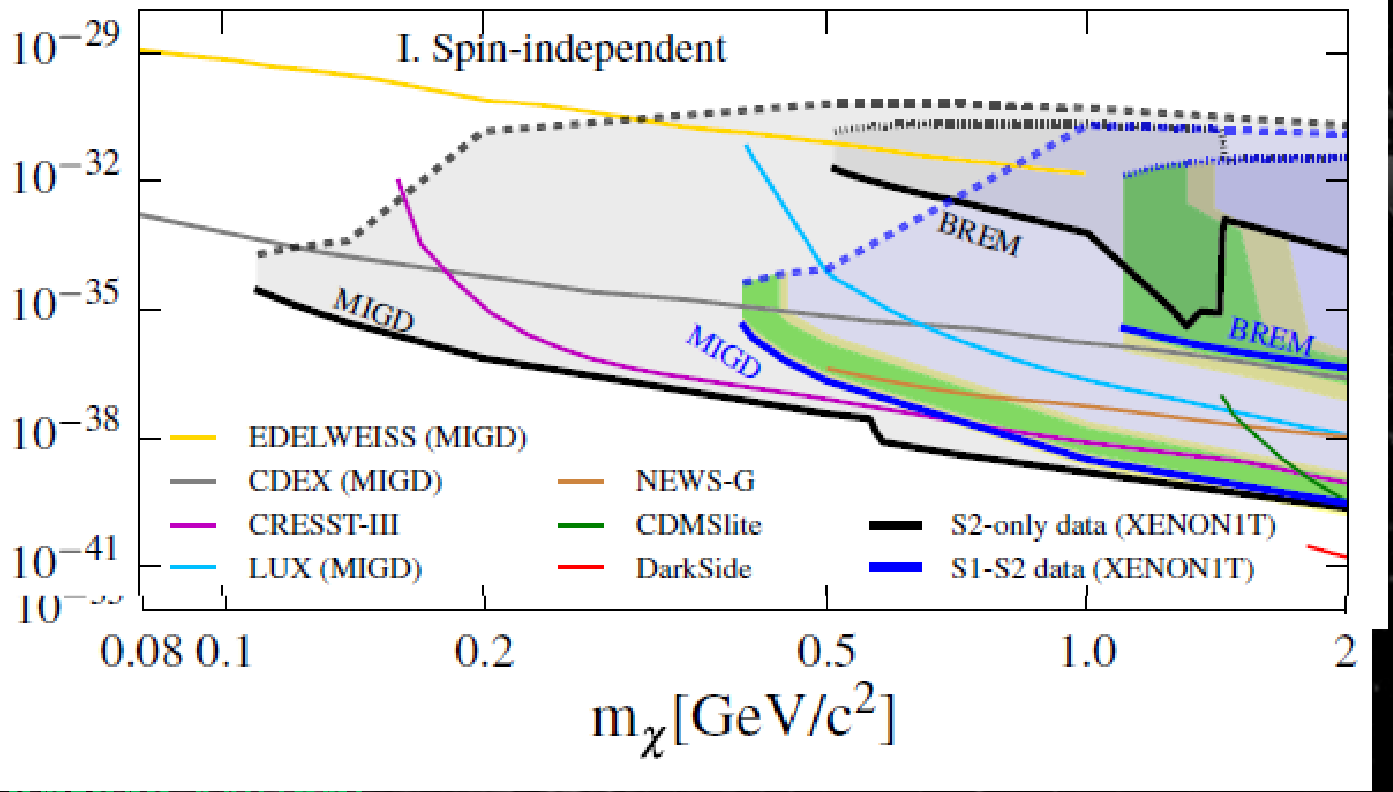
Ke TAU

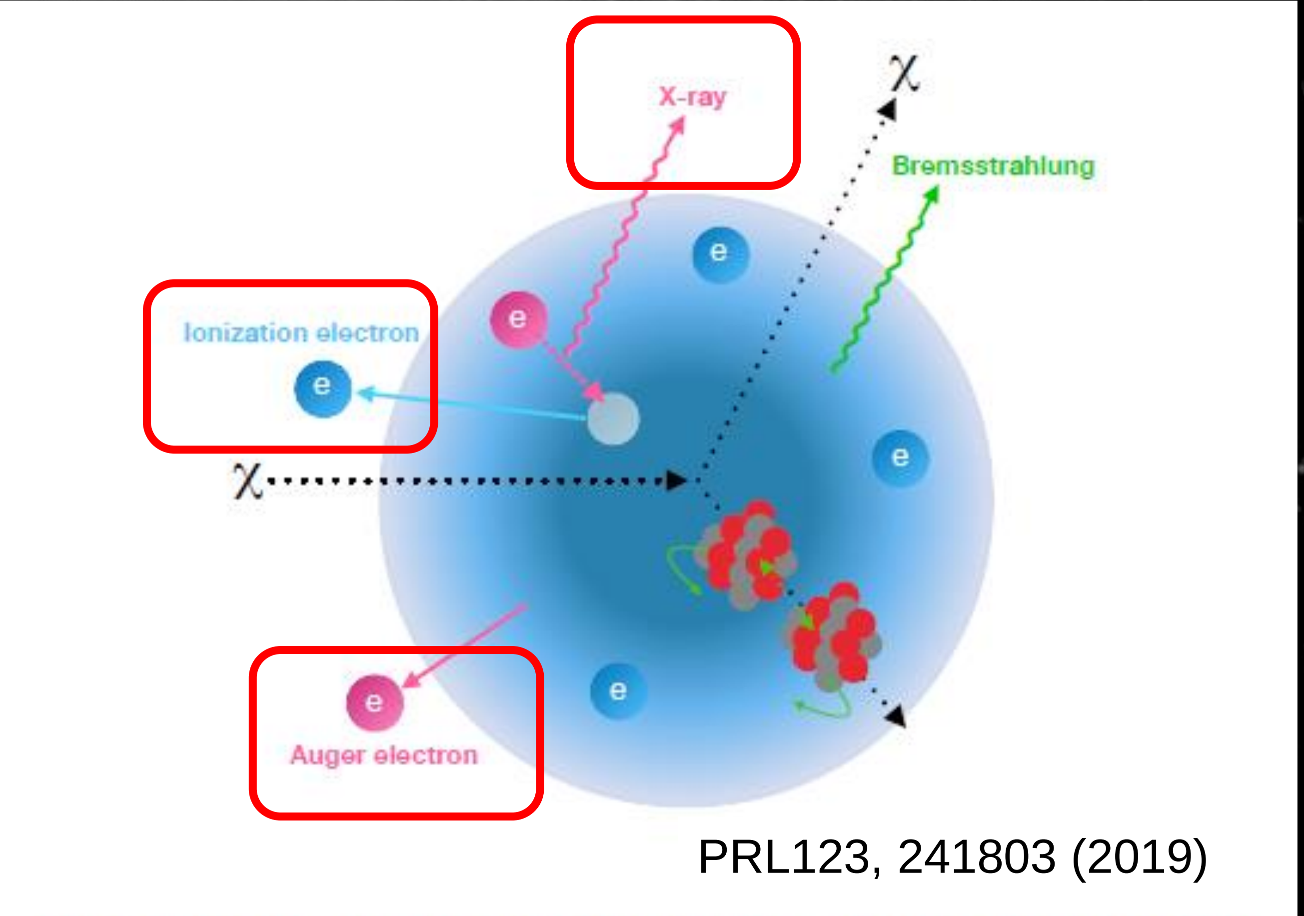
Migdal

Migdal effect associated with nuclear recoil by gaseous detectors

- MIGDAL effect
  - Low mass search with “MIGDAL effect”
  - Ordinary nuclear recoil : ionization along the track
  - Low energy recoil : ionization efficiency is low
    ⇒ cannot be detected
  - Very rare case electrons are emitted

PRL123, 241803 (2019)





PRL123, 241803 (2019)

FIG. 1. Illustration of the ER signal production from BREM (green) and Migdal processes (pink) after elastic scattering between DM (χ) and a xenon nucleus.

Kentaro Miuchi

• Migdal observation proposals by gaseous detectors

MIGDAL
Migdal In Galactic Dark mAtter expLoration

MIRA CLUE

Migdal effect Investigation as RAre event CLUEs

arXiv:2207.08284v1

The MIGDAL experiment:
Measuring a rare atomic process to aid the search for dark matter

H. M. Araújo[a,*], S. N. Balashov[b], J. E. Borg[a], F. M. Brunbauer[c], C. Cazzaniga[d], C. D. Frost[d], F. Garcia[e], A. C. Kaboth[f], M. Kastriotou[d], I. Katsioulas[g], A. Khazov[b], H. Kraus[h], V. A. Kudryavtsev[i], S. Lilley[d], A. Lindote[j], D. Loomba[k], M. I. Lopes[j], E. Lopez Asamar[j,l], P. Luna Dapica[d], P. A. Majewski[b,**], T. Marley[a,b], C. McCabe[m], A. F. Mills[k], M. Nakhostin[a,b], T. Neep[g], F. Neves[j], K. Nikolopoulos[g], E. Oliveri[c], L. Ropelewski[c], E. Tilly[k], V. N. Solovov[j], T. J. Sumner[a], J. Tarrant[n], R. Turnley[d], M. G. D. van der Grinten[b], R. Veenhof[c]

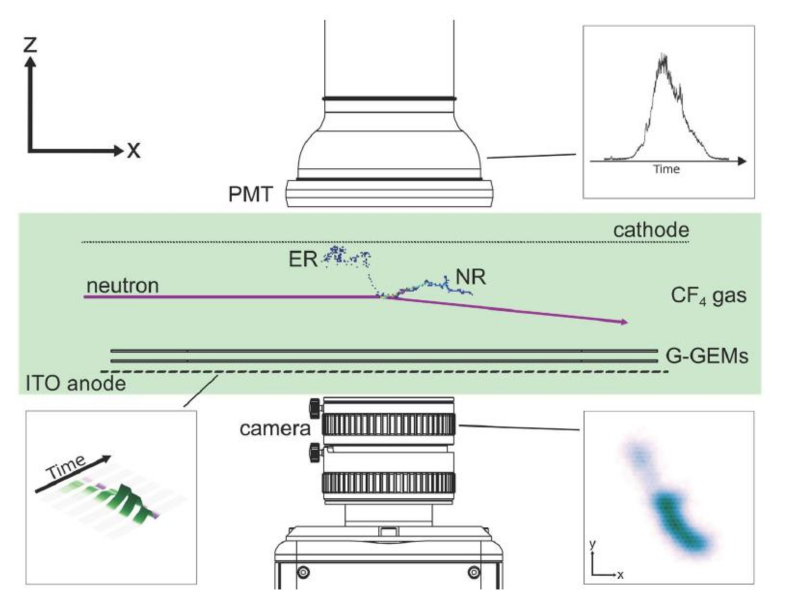
PTEP
Prog. Theor. Exp. Phys. 2021, 013C01 (14 pages)
DOI: 10.1093/ptep/ptaa162

Detection capability of the Migdal effect for argon and xenon nuclei with position-sensitive gaseous detectors

Kiseki D. Nakamura[1,2,*], Kentaro Miuchi[1], Shingo Kazama[3,4], Yutaro Shoji[5], Masahiro Ibe[6,7], and Wakutaka Nakano[8]

- MIGDAL experiment

MIGDAL talk
@IDM2022

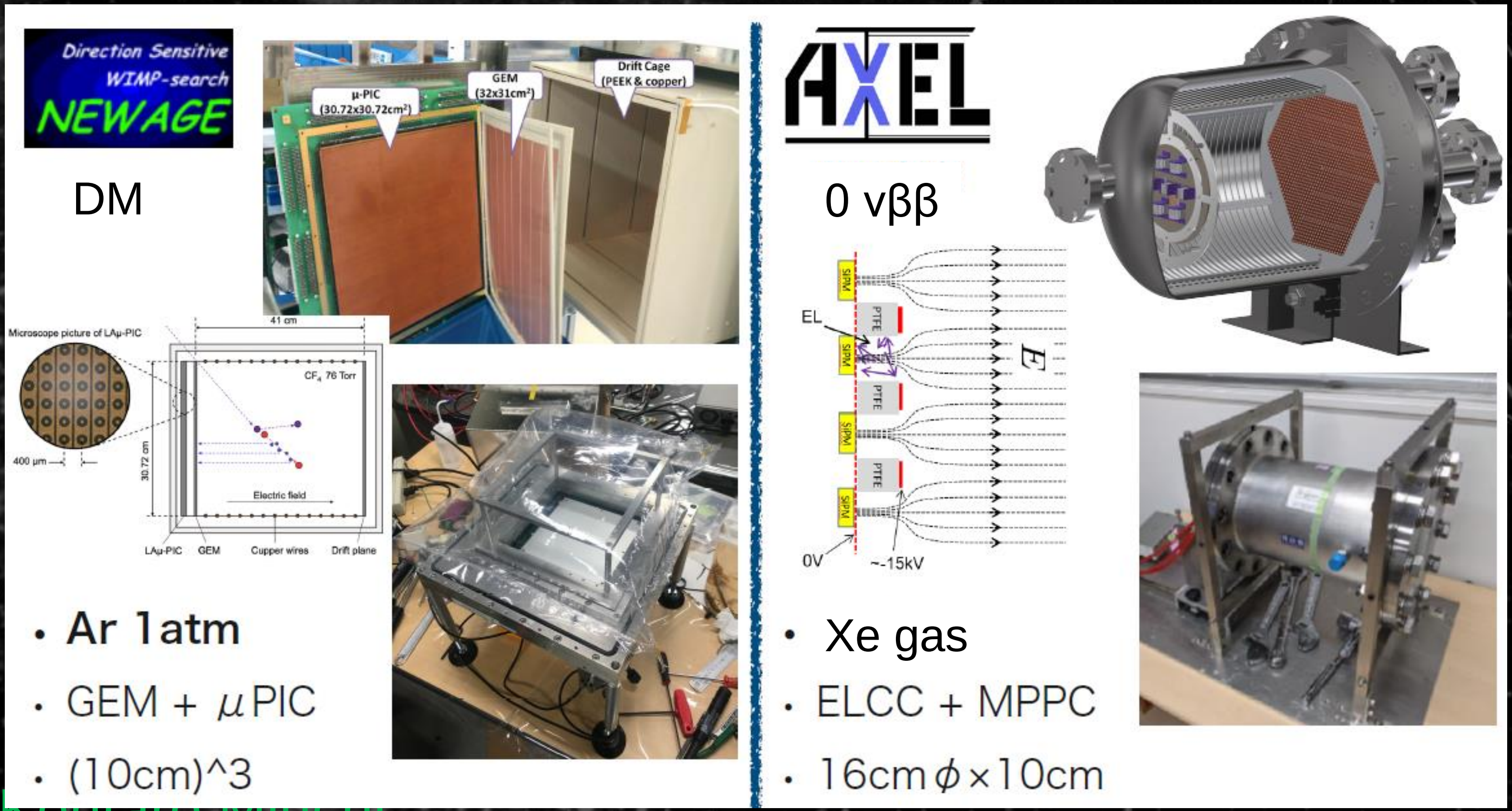


- Low-pressure gas: 50 Torr of CF_4
  - Extended particle tracks
  - Avoid photon interactions
- Optical TPC
  - Imaging: 2x glass-GEMs + camera
  - Ionisation: 120 ITO anode strips
  - Scintillation: photomultiplier tube
- High-yield neutron generators
  - D-D: 2.47 MeV (10^9 n/s)
  - D-T: 14.7 MeV (10^{10} n/s)
  - Defined beam, “clear” through TPC
- Electron and nuclear recoil tracks
  - Migdal: NR+ER tracks, common vertex
  - NR and ER have very different dE/dx
  - 5 keV electron threshold (Fe-55 calibration)

- MIGDAL experiment
  - CF4 gas (50Torr)
  - optical readout for NR+e-track
  - (relatively) high energy neutrons

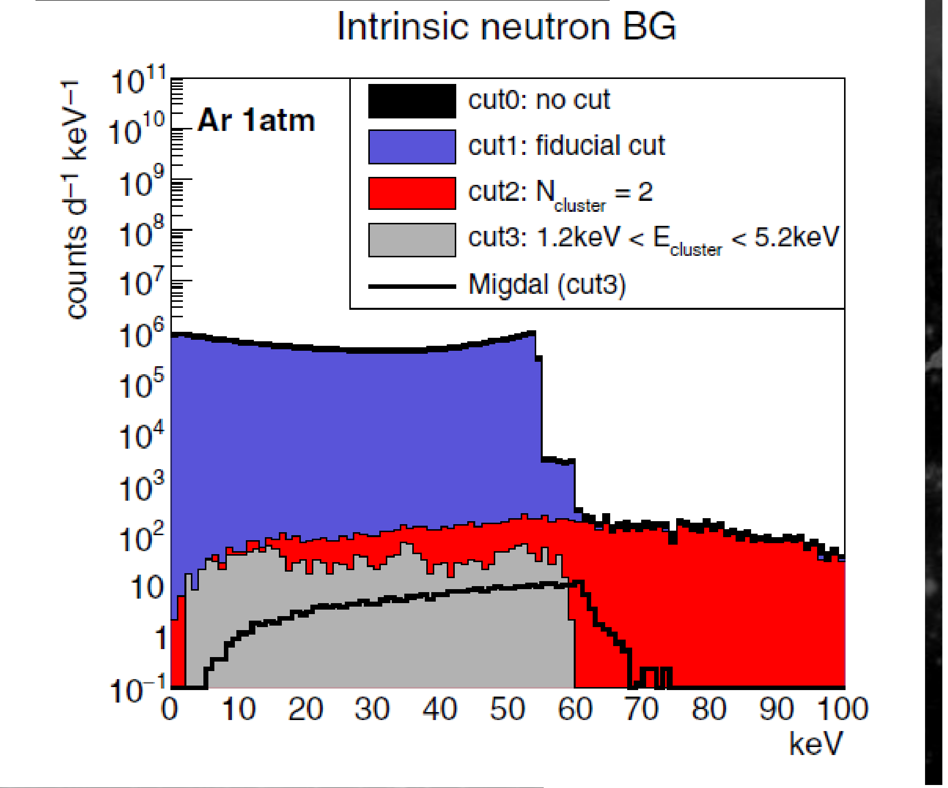
- MIRACLE experiment
  - Ar (1atm) and Xenon (8 atm) gas
    direct interests in DM search
  - start with existing technologies
    less R&D
  - characteristic X-ray channel for 2-cluster detection (as the first step)
    less BG
  - low energy (565keV) neutrons
    less BG

MIRACLUE detectors

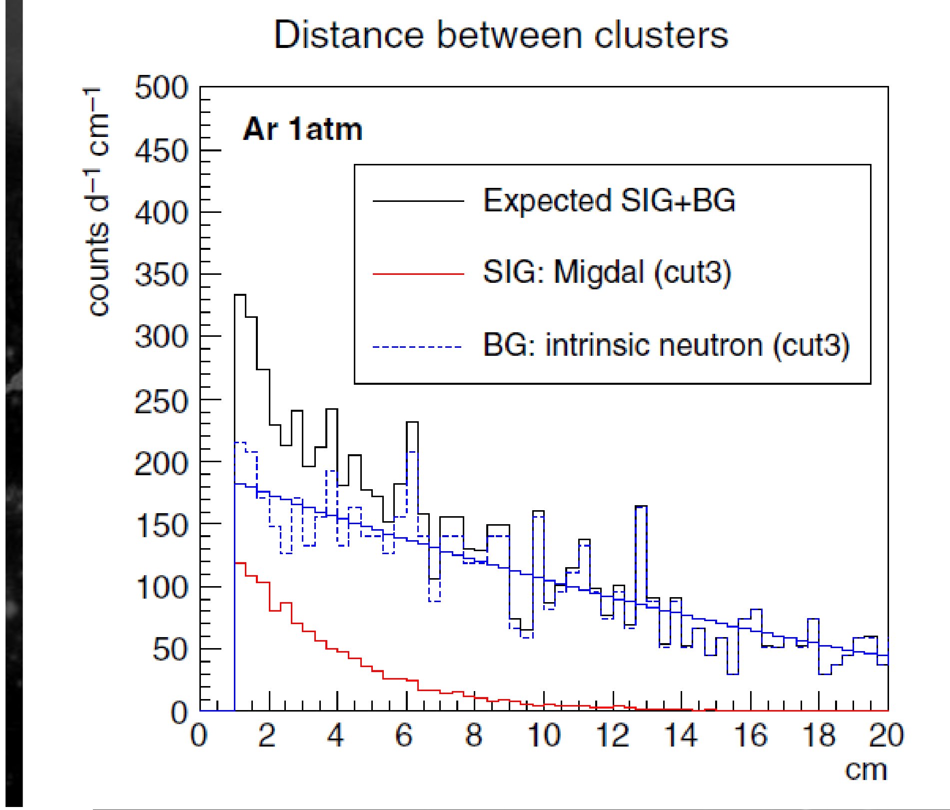


- BG and signal identifications
  - BG reduction is the key to observe Migdal effects

intrinsic neutron BGs
(565keV neutrons)

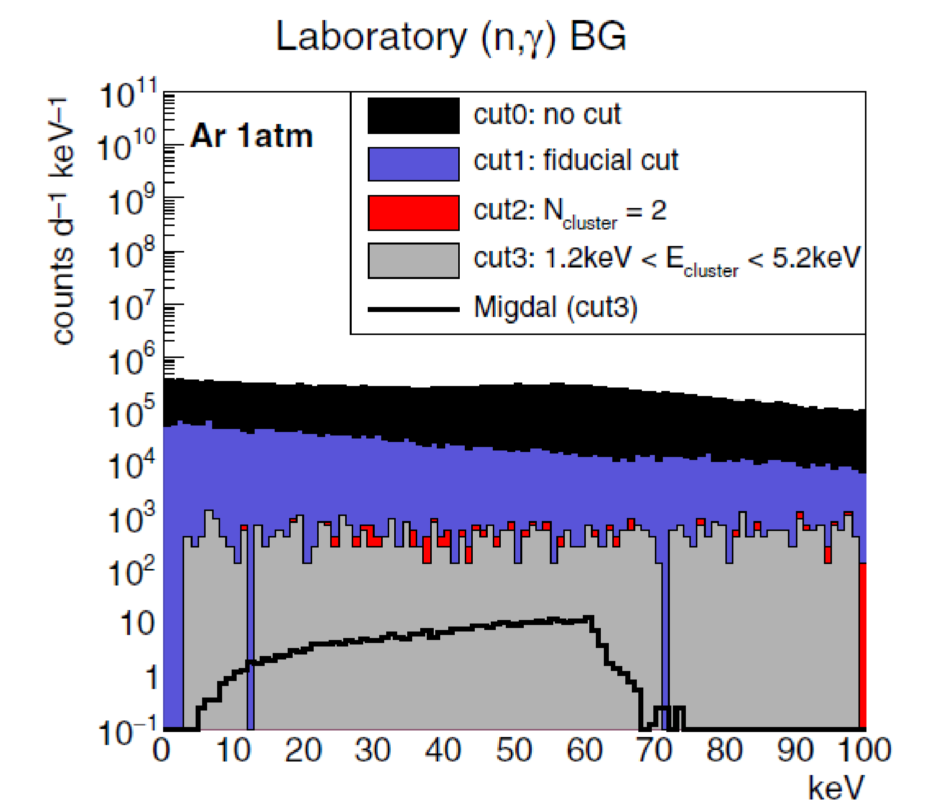


2-cluster distance

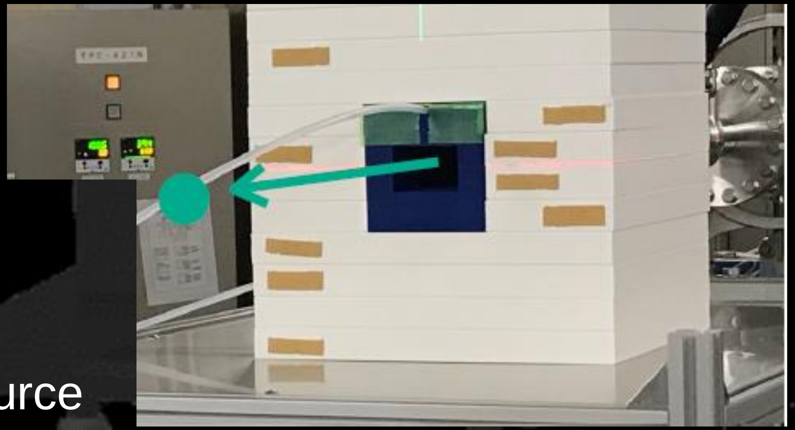


PTEP 2021 013C01

gamma-ray BGs
from lab (avoidable)



LiF loaded polyethylene shieldings
@neutron source

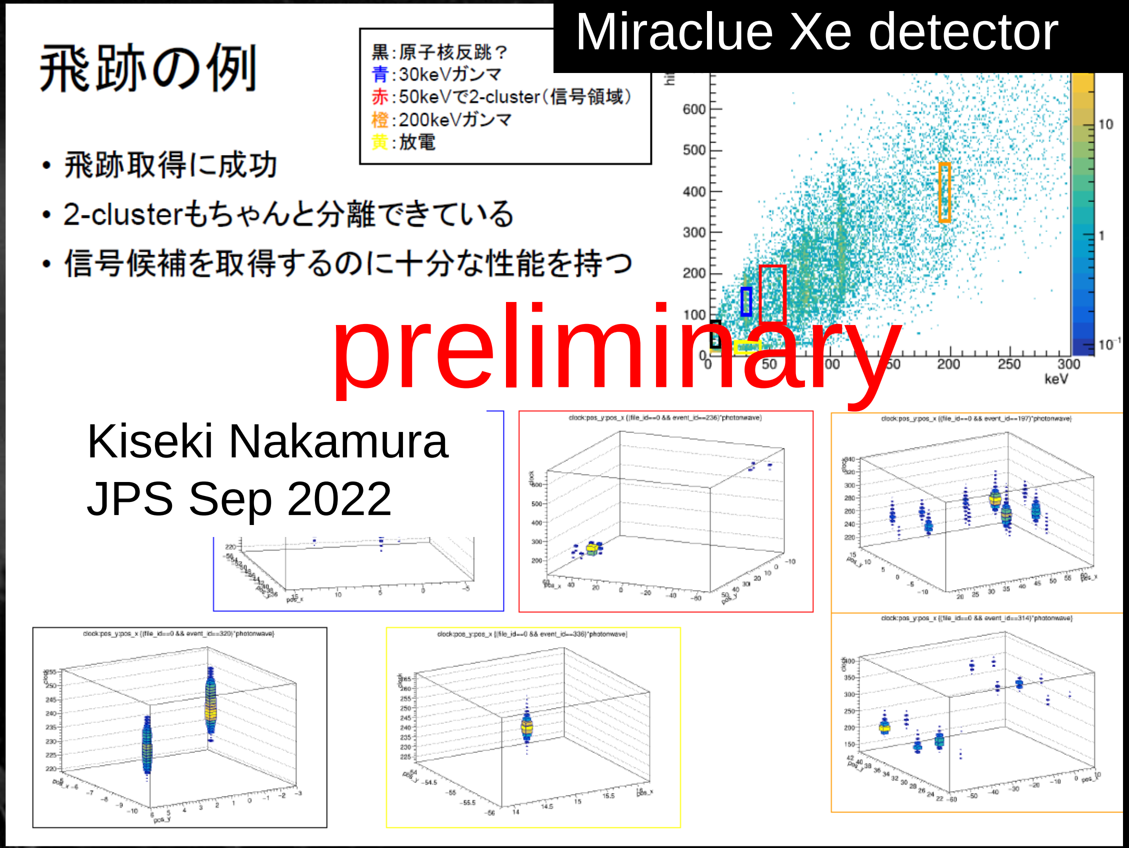


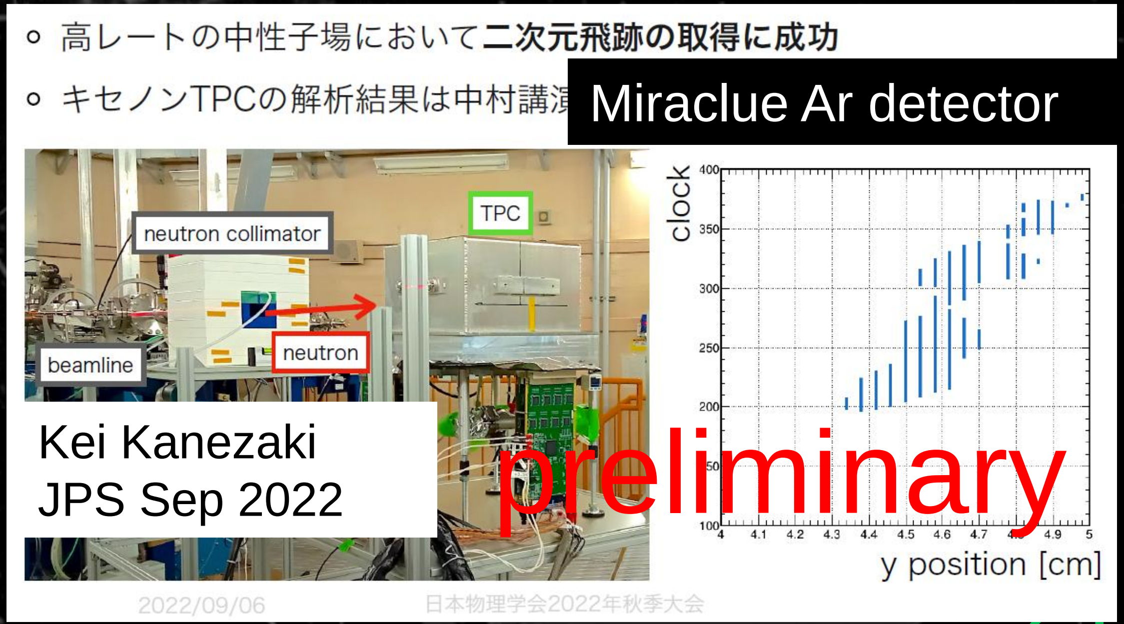
neutron beam
$^{6}Li(p,n)^{7}Be$ @ AIST Japan continuous
565keV
1000 neutrons /cm^2 /sec @ 1m from the source

• MIRACLUE now and future

- 1st beam test: April 2022
  - BG study with scintillators (BGO, CsI) now: comparison with MC
  - Xe, Ar, chamber test
- 2nd beam test: December 2022
  - BG study with real size $(30cm)^3$ Ar chamber

- 2022-2023
  - shielding optimization
  - MIGDAL effect observations





SUMMARY

- Gaseous detectors are powerful tool for
  - directional dark matter search and
  - Migdal effect observations

Thank you, and see you in Japan...