



* He recoils in CYGNO
10 L prototype

Elisabetta Baracchini



DIRECTIONAL DIRECT DARK MATTER SEARCHES



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A. Mills⁷, R. A. Nobrega¹², A. Orlandi², E. Paoletti², L. Passamonti², A. Pelosi³,
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G. Saviano^{2,11}, D. M. Souza¹², N. Spooner⁶, and S. Tomassini²



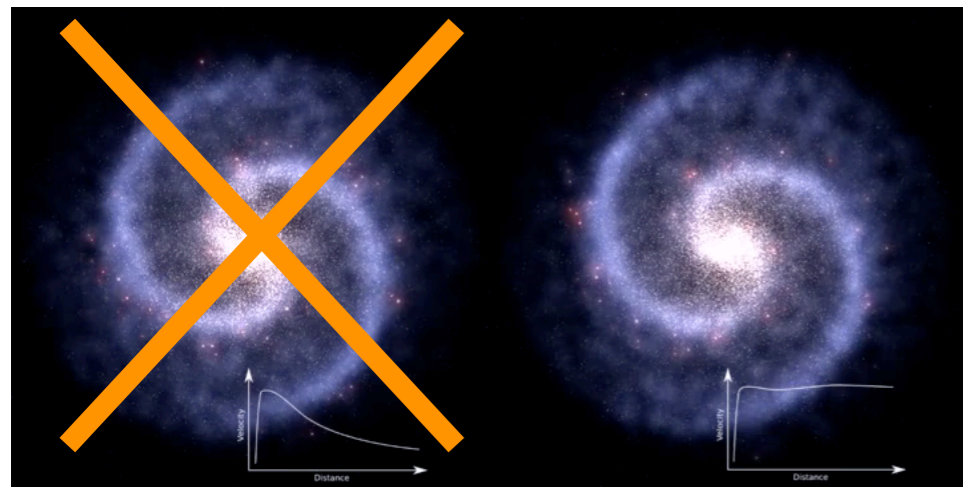
PRIN:
Prot. 2017T54J9J



CYGNON & INTIUM

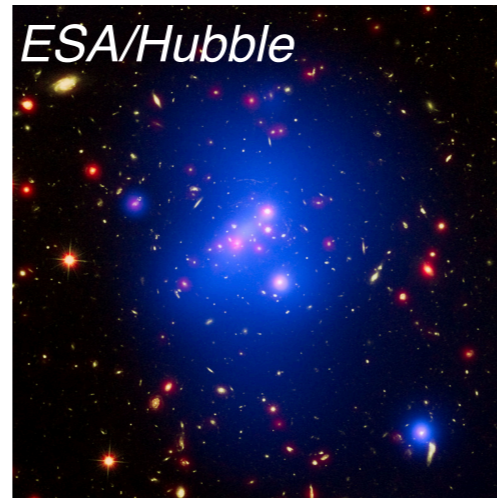
Gravitational DM evidences

“Dark” Matter because it does not interact with light



Galaxy rotation curves

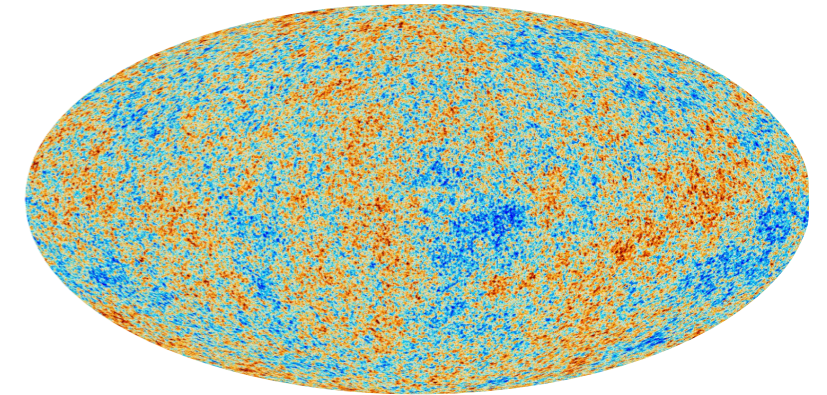
Galaxies motion inside clusters



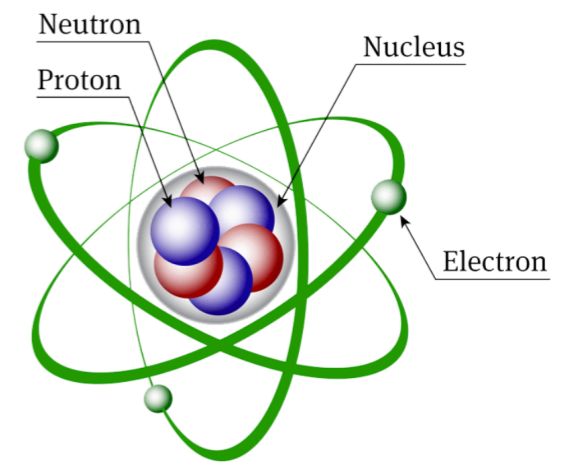
Galactic Collisions



Cosmic Microwave Background



Big Bang Nucleosynthesis



Larger scales explored, older times probed

Cygnus Constellation



Earth



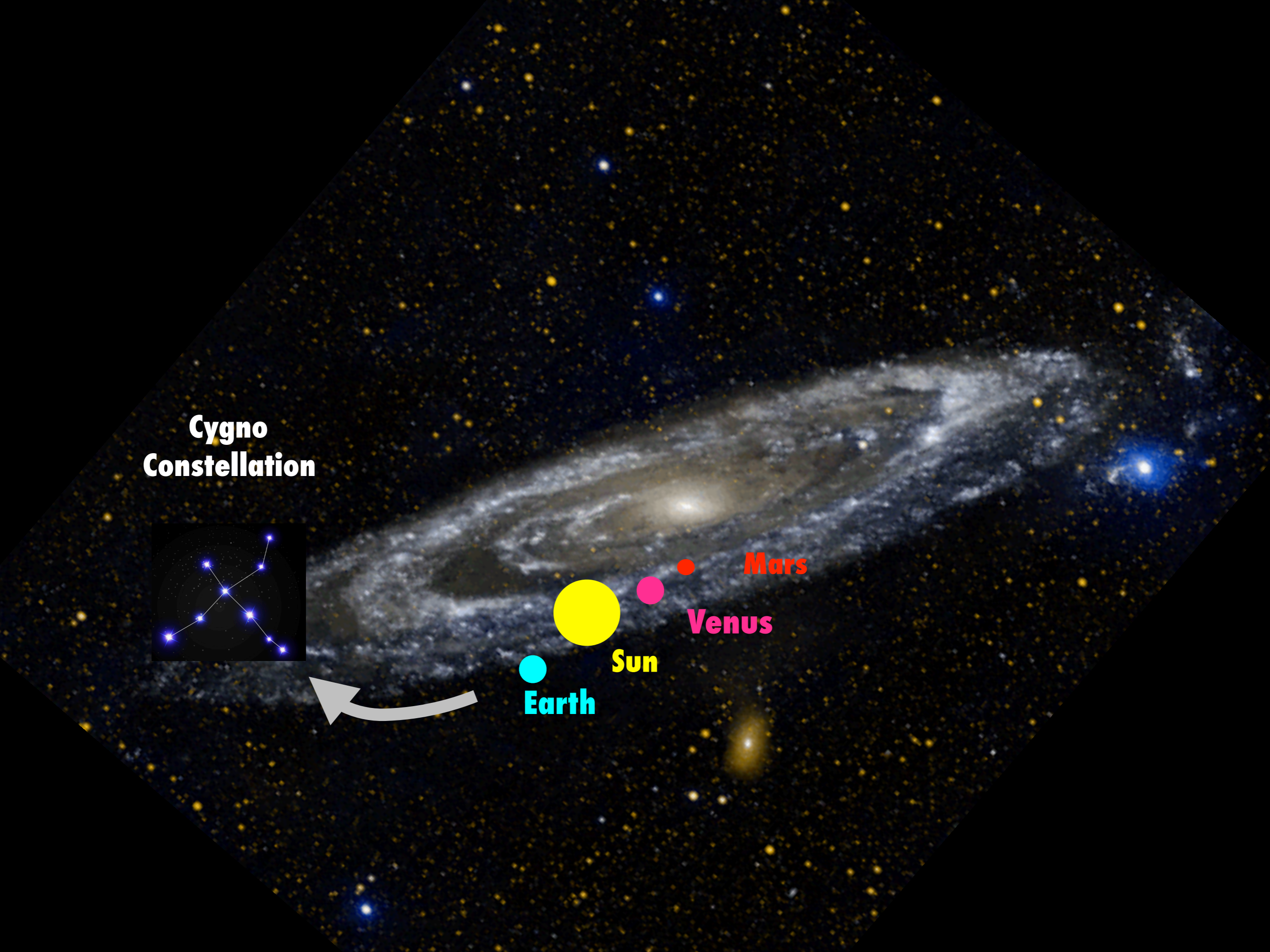
Sun



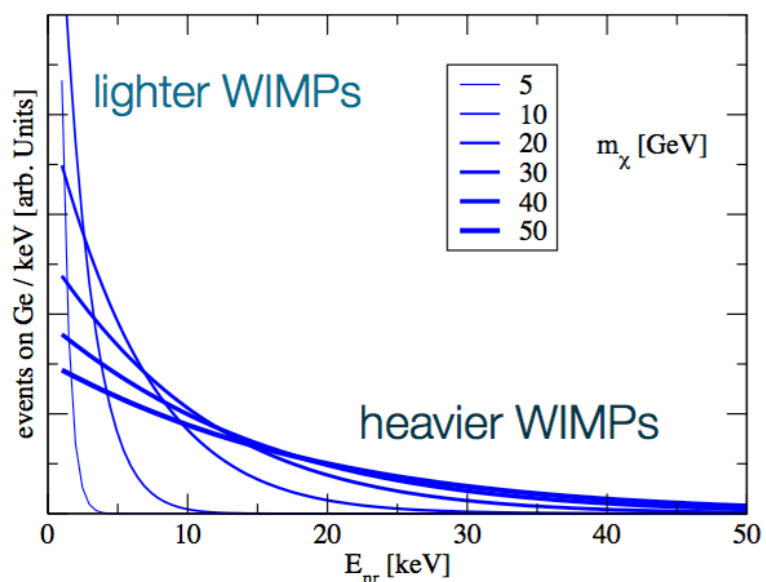
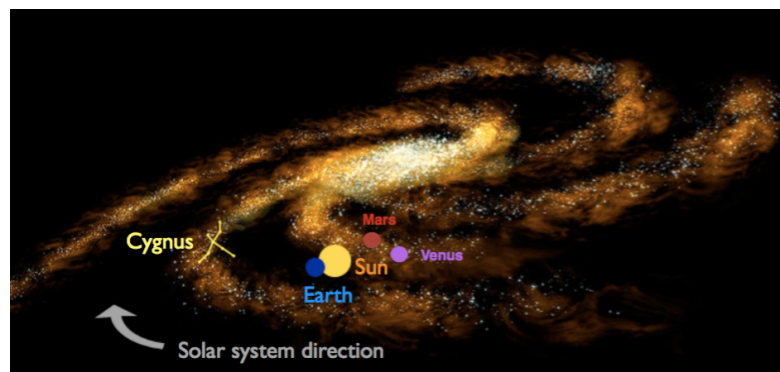
Venus



Mars

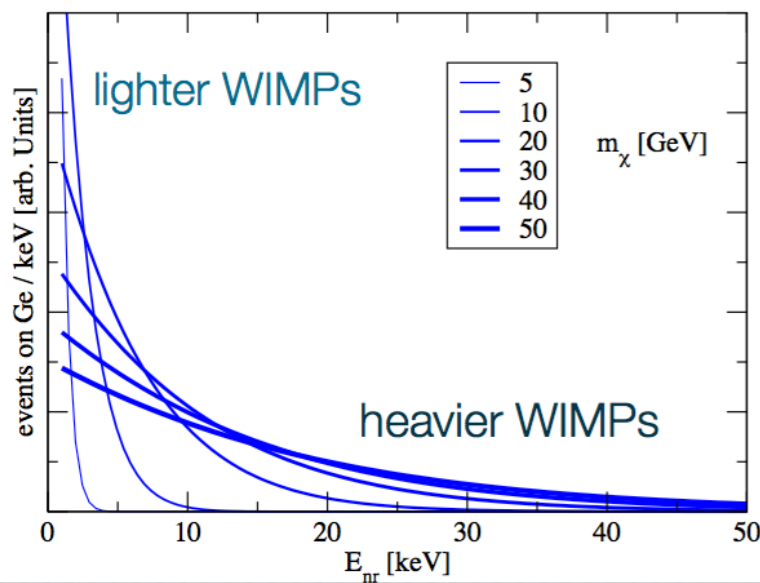
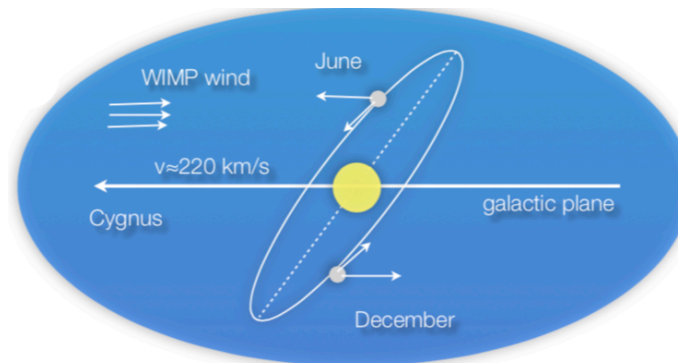
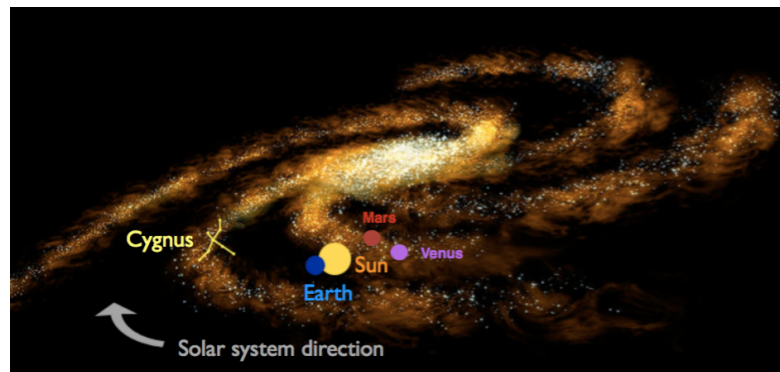


Increasing reliability of any observed signal, increasing difficulty in the experimental technique

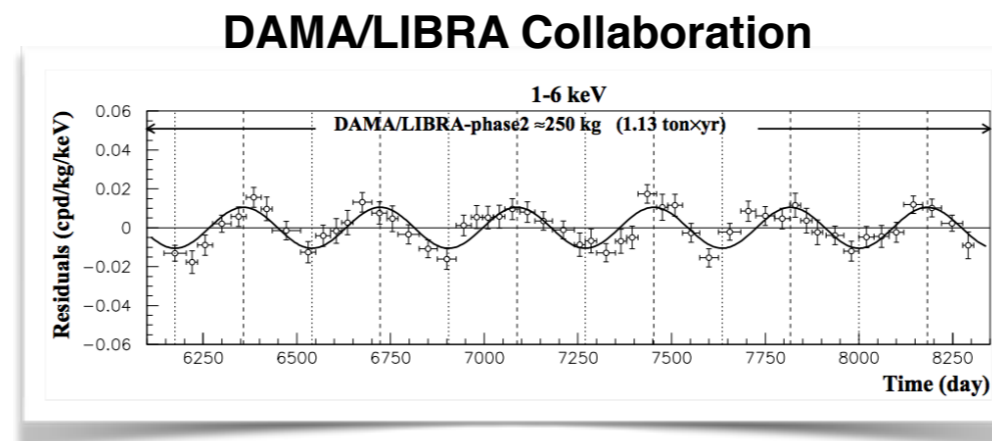


**Energy dependence:
a falling exponential with
no peculiar features**

Increasing reliability of any observed signal, increasing difficulty in the experimental technique



Energy dependence:
a falling exponential with
no peculiar features

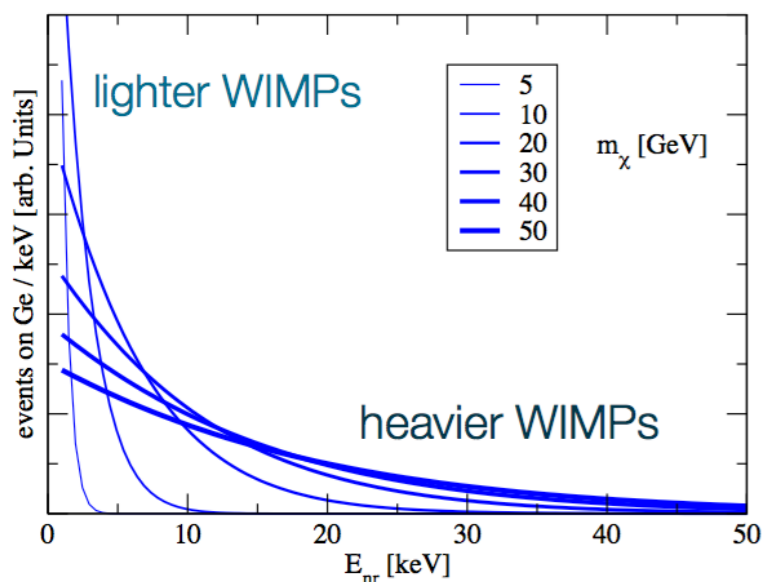
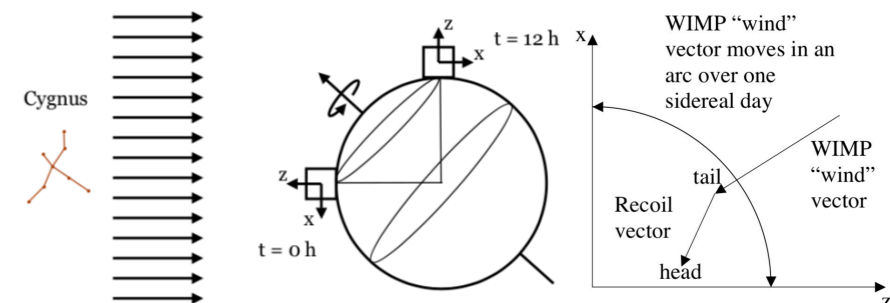
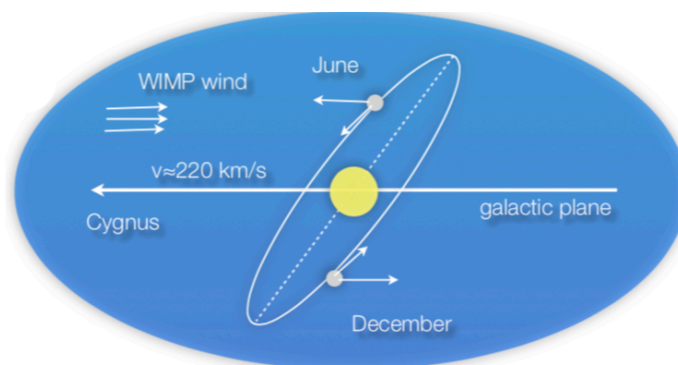
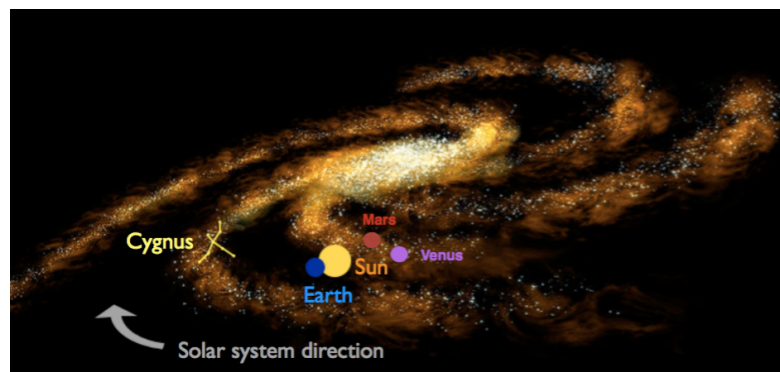


Universe 4 (2018) no.11, 116

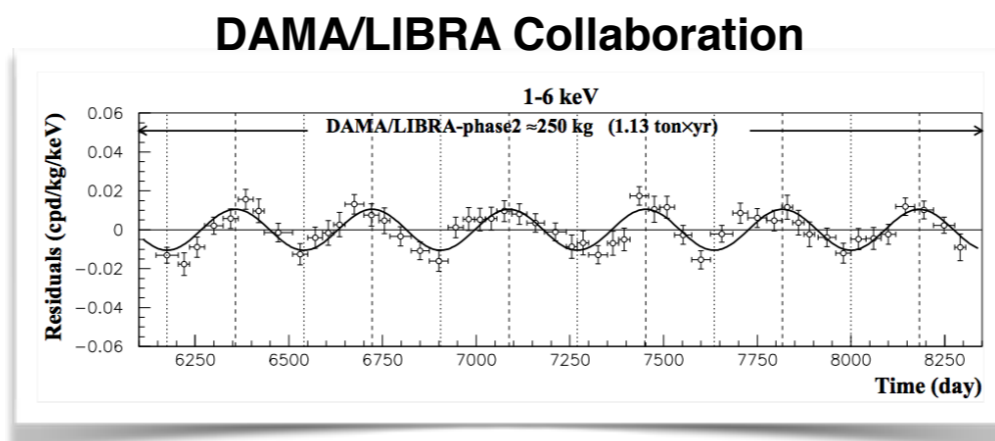
Temporal dependence:
a few % annual modulation

Directionality as key for unambiguous identification of DM

Increasing reliability of any observed signal, increasing difficulty in the experimental technique

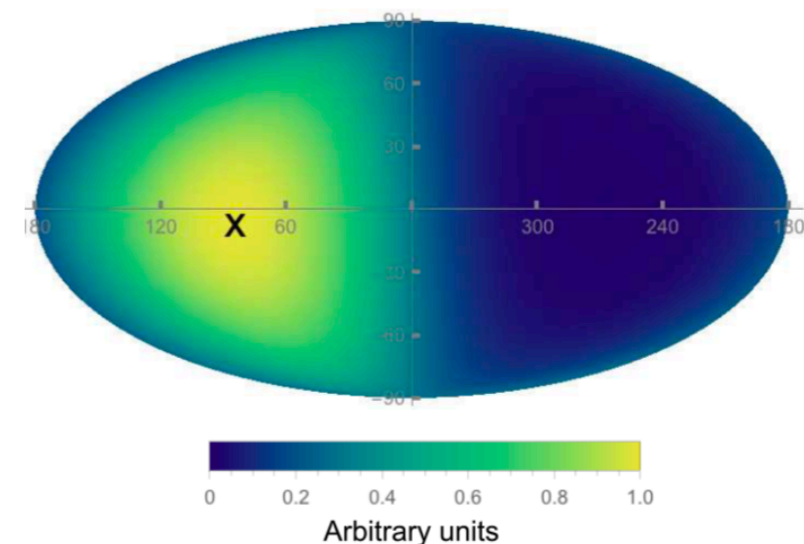


Energy dependence:
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Universe 4 (2018) no.11, 116

Temporal dependence:
a few % annual modulation



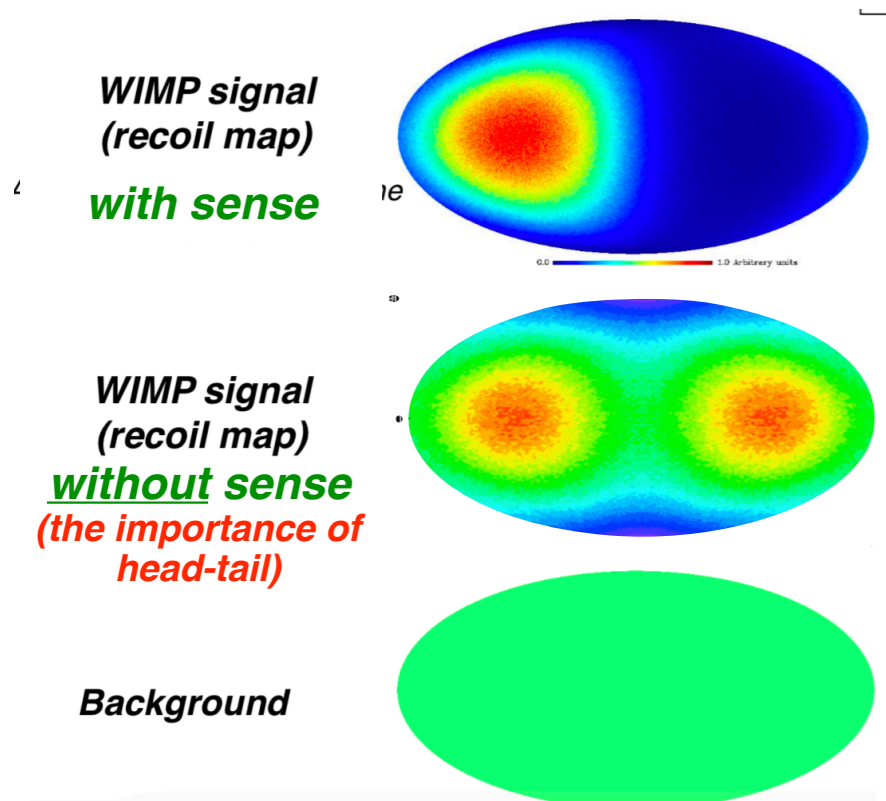
Directional dependence:
an O(1) effect that no background whatsoever can mimic

Directional correlation with an astrophysical source is the only available POSITIVE identification of a DM signal

Directionality as tool for background rejection, neutrino physics and DM astronomy

Capability to reject isotropy down to low threshold, i.e. to fight all backgrounds, including neutral

A. M. Green et. al, Astropart. Phys. 27 (2007) 142



Directional detector can tolerate backgrounds, including neutral

WIMP signal in principle detectable with $O(10)$ 3D events

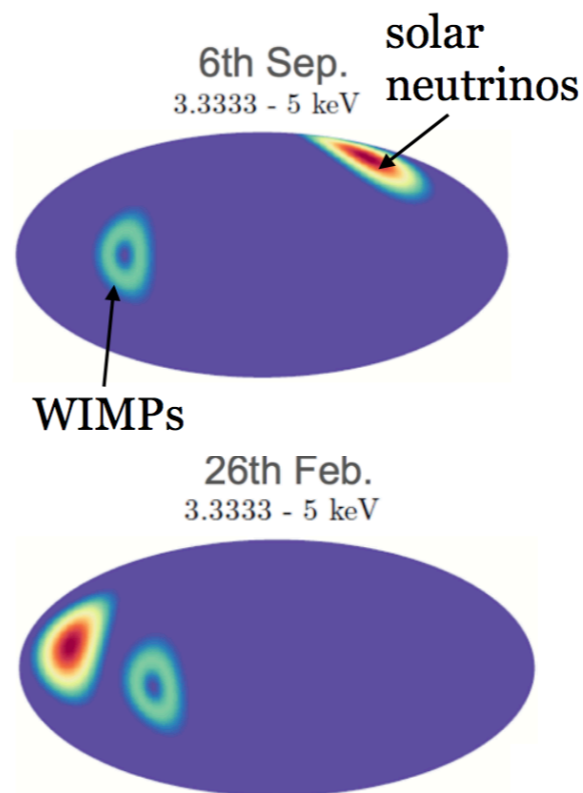
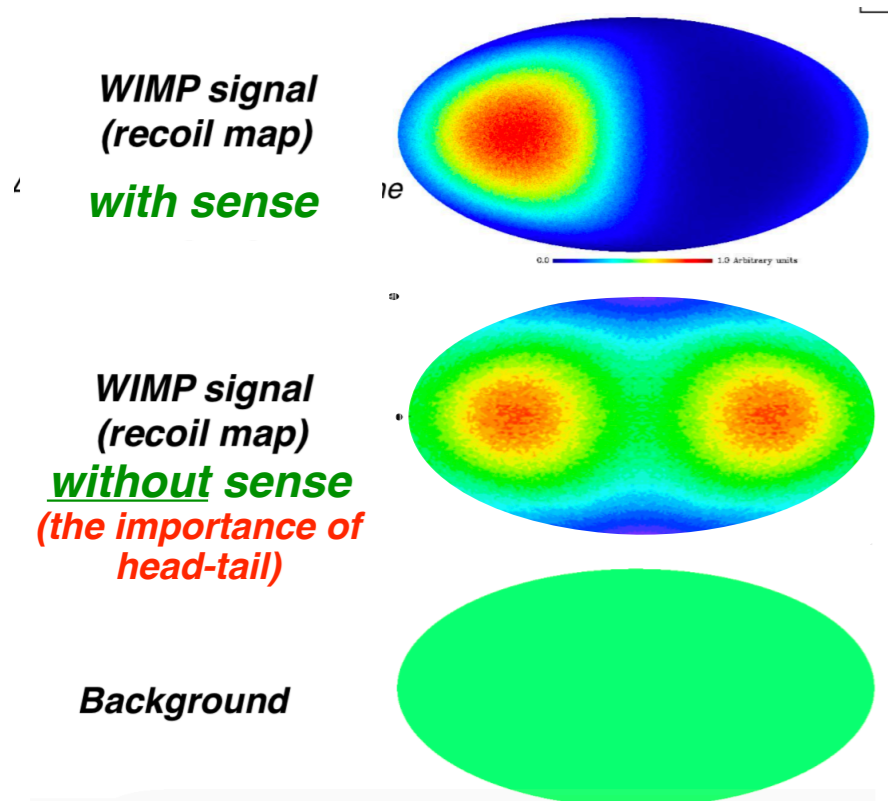
Directionality as tool for background rejection, neutrino physics and DM astronomy

Capability to reject isotropy down to low threshold, i.e. to fight all backgrounds, including neutral

Capability to leap beyond the Neutrino Floor and to do Neutrino physics

A. M. Green et. al, Astropart. Phys. 27 (2007) 142

C. O'Hare et al, Phys. Rev. D 92 063518 (2015)



Directional detector can tolerate backgrounds, including neutral

The Neutrino Floor is an opportunity, not a limit

WIMP signal in principle detectable with $O(10)$ 3D events

Sun neutrinos physics

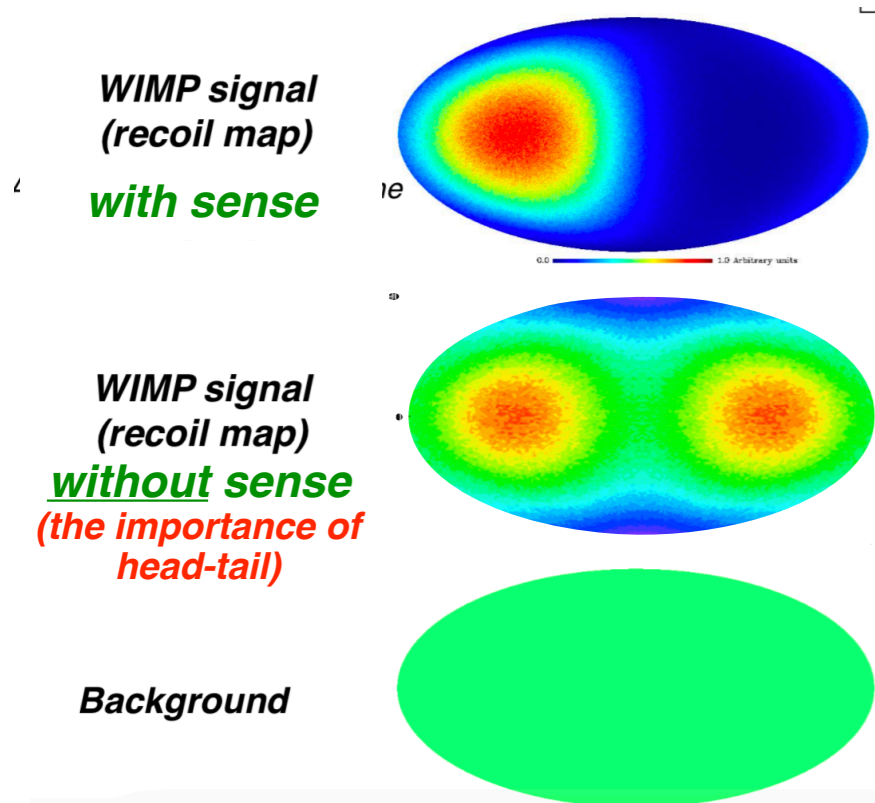
Directionality as tool for background rejection, neutrino physics and DM astronomy

Capability to reject isotropy down to low threshold, i.e. to fight all backgrounds, including neutral

Capability to leap beyond the Neutrino Floor and to do Neutrino physics

Capability to probe DM nature once discovered

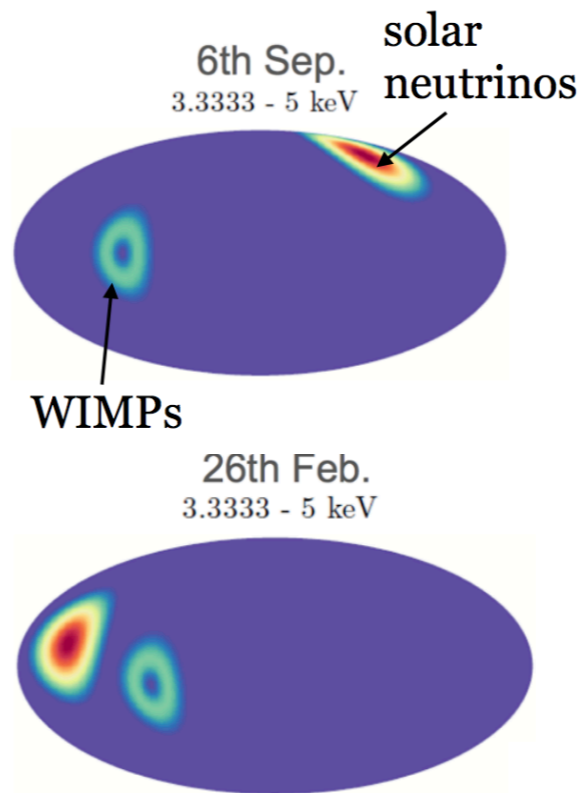
A. M. Green et. al, Astropart. Phys. 27 (2007) 142



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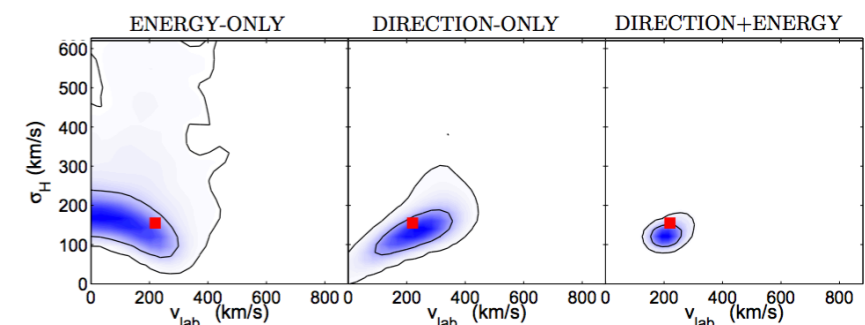
C. O'Hare et al, Phys. Rev. D 92 063518 (2015)



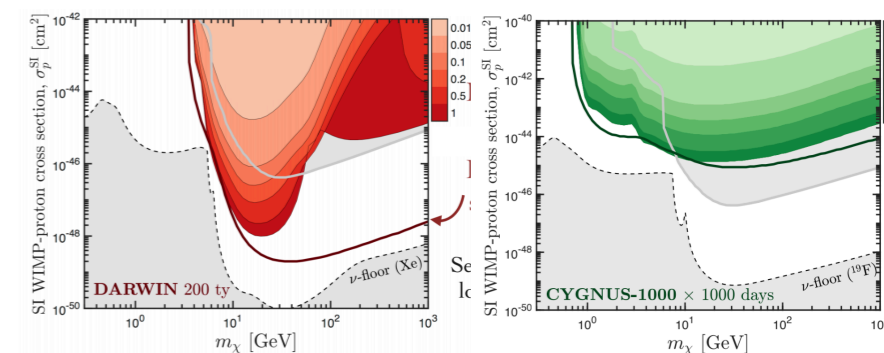
The Neutrino Floor is an opportunity, not a limit

Sun neutrinos physics

F. Mayet et al., Phys. Rept 627 (2016)



Phys.Rev. D98 (2018) no.10, 103006



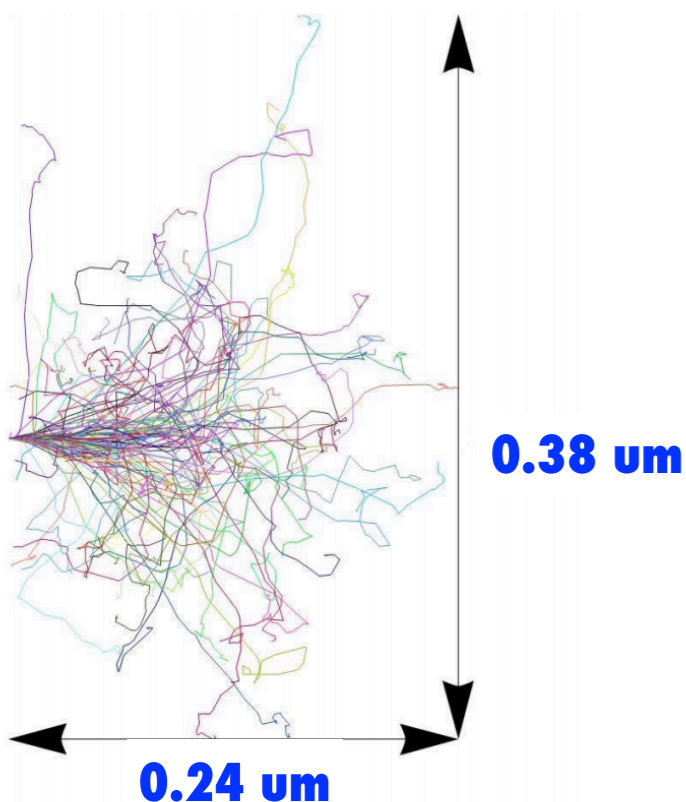
WIMP & halo properties unbiased constrained with a single measurement

DM astronomy & DM interactions

Directionality: how well preserved in nuclear recoils?

Choose your target material & resolution

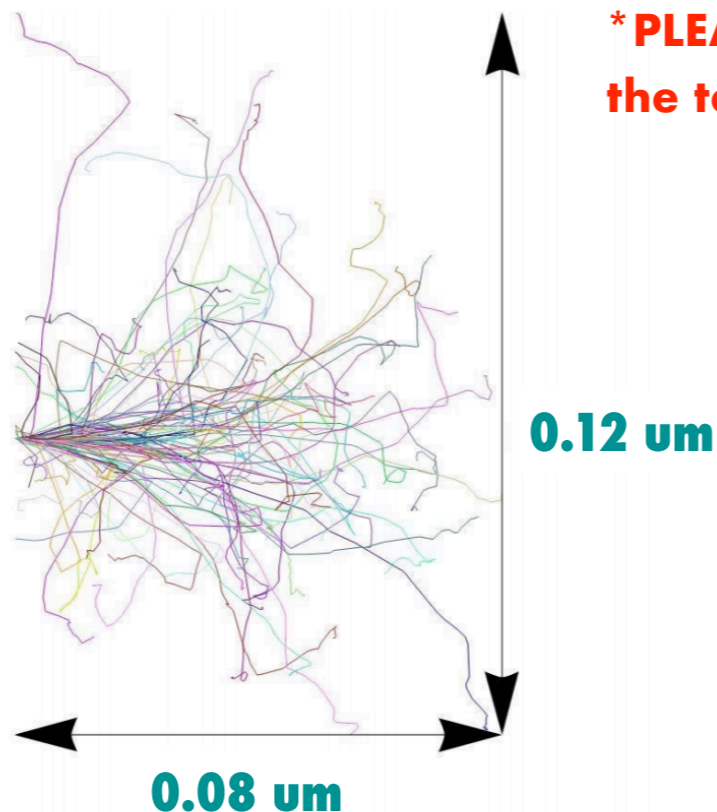
- Emulsion layers



C in Emulsion (22keV)

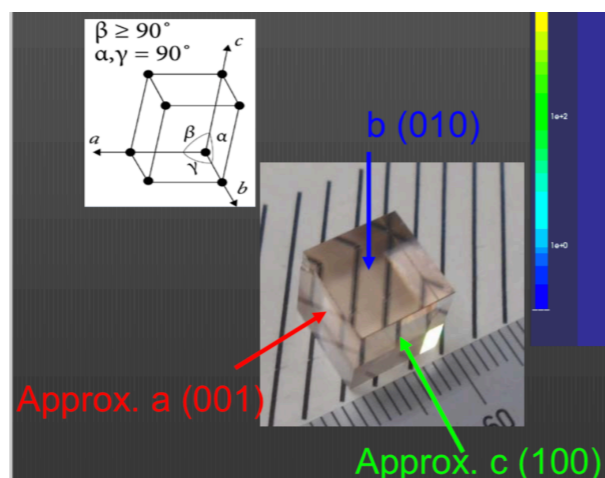
NEWS-DM (emulsions)

- Crystals scintillators



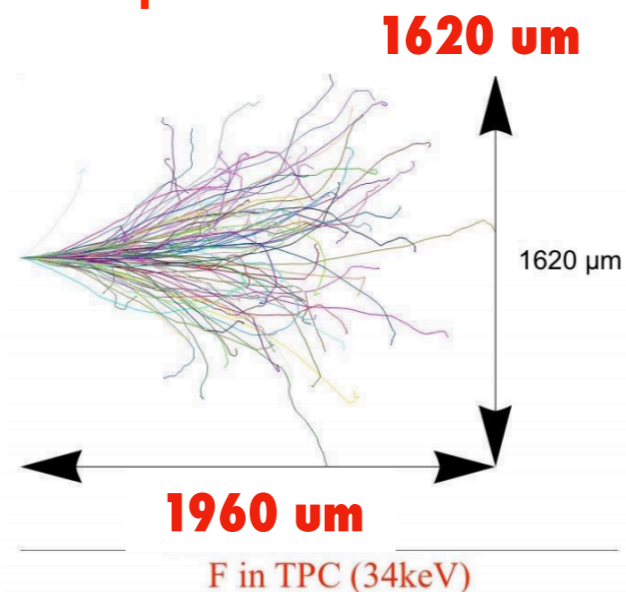
O in Crystal (29keV)

Anisotropic crystals

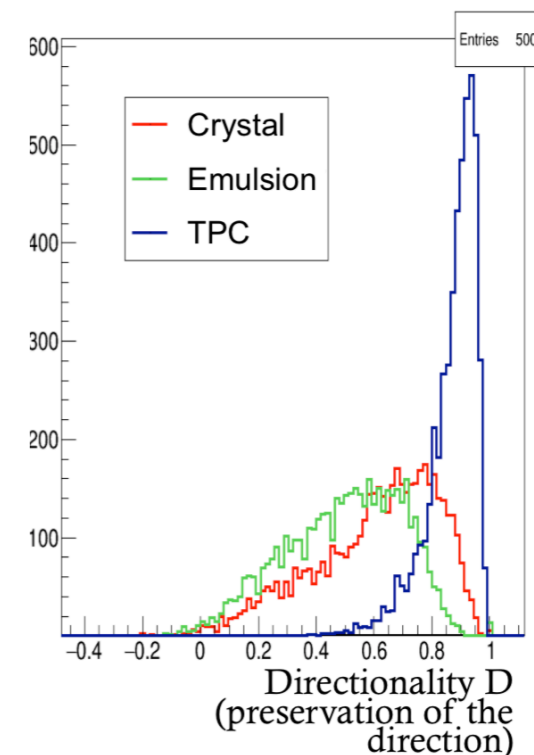


- Low pressure TPCs*

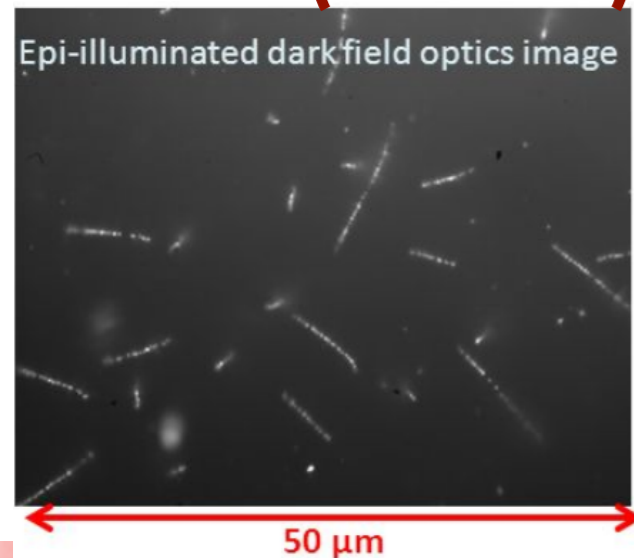
*** PLEASE NOTE: what matter is the target density, not the gas pressure**



From SRIM software simulation

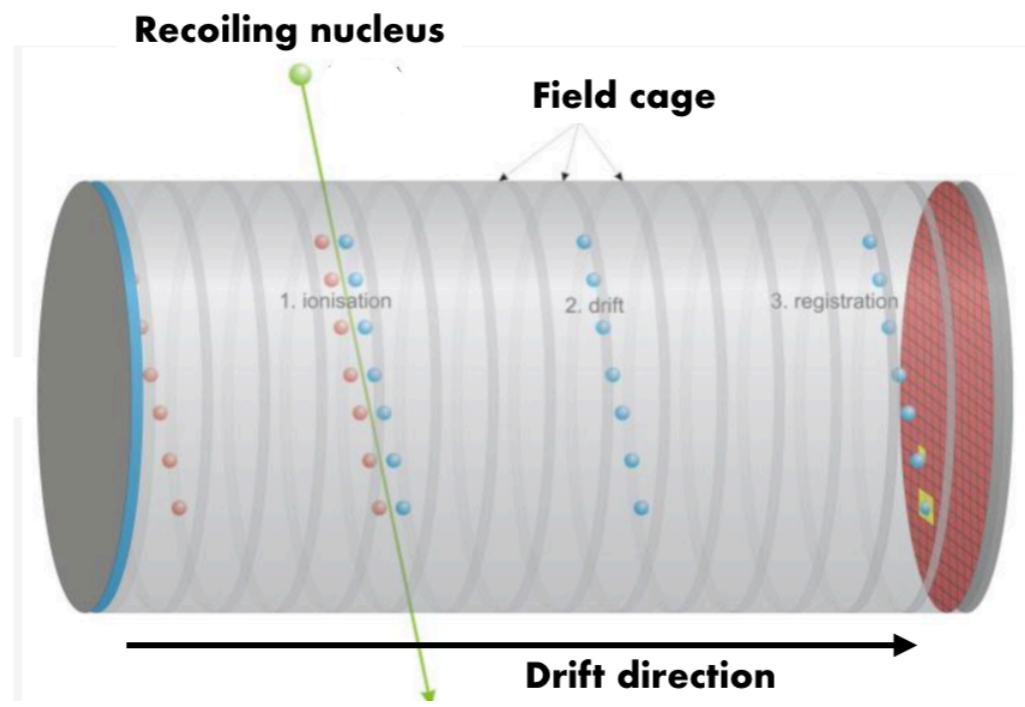
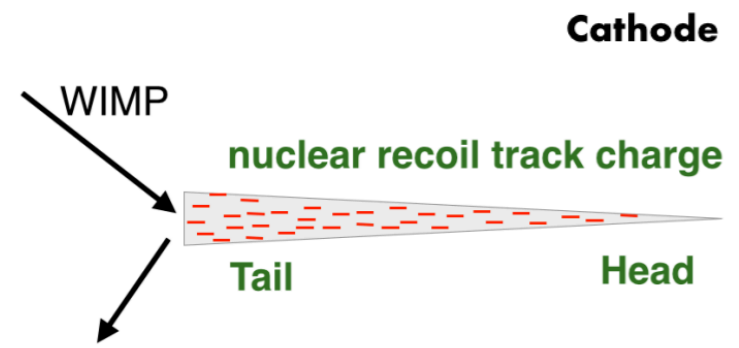


JCAP 1701 (2017) no.01, 027



Gas TPC concept & features

Gaseous Time Projection Chamber, inherently a 3D detector

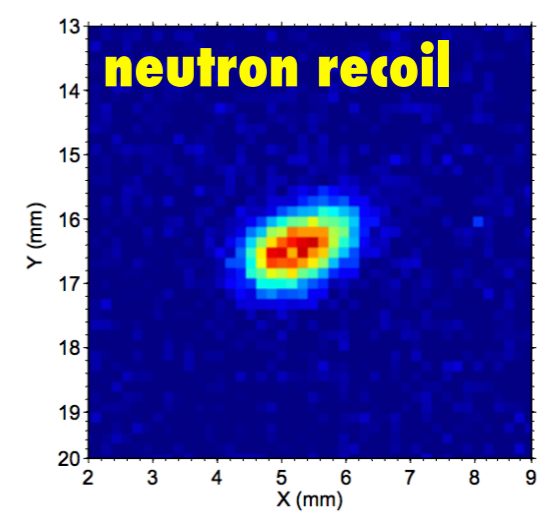
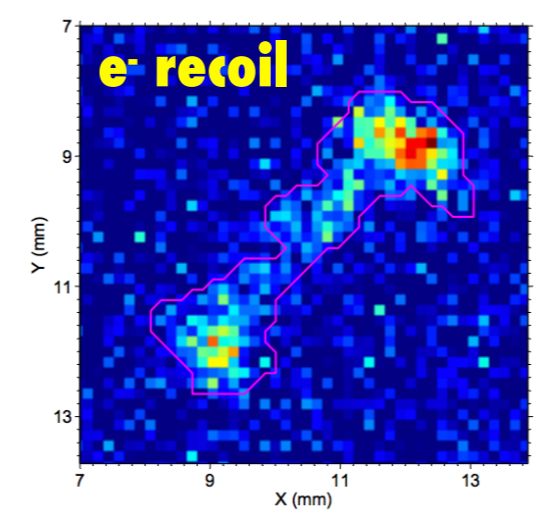
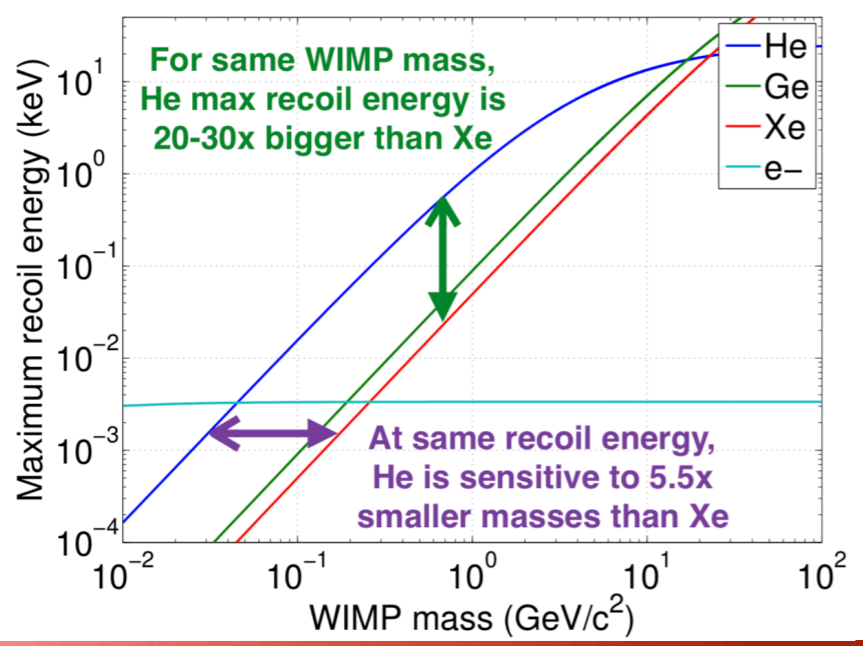


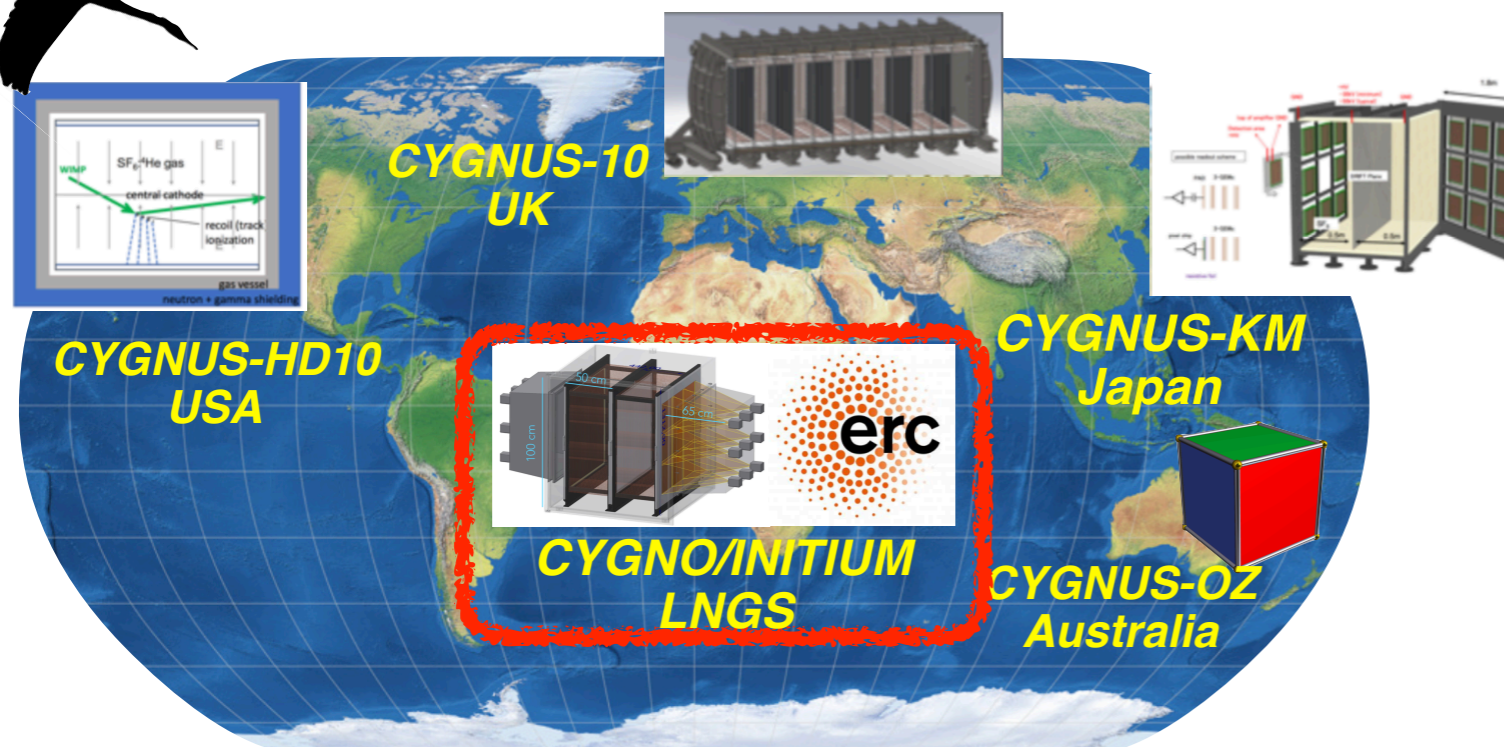
Ionisation signal amplification & readout

- Advantages:
 - Axial Directionality
 - **Head/tail**
 - Background rejection
 - Particle ID
 - 3D fiducialization
- Technologically challenging, but now achievable via multiple technologies

Helium-Fluorine gaseous target for simultaneous Spin Independent & Spin Dependent sensitivity to O(GeV) WIMPs

Energy loss and track topology to efficiently reject background at O(keV) energy threshold

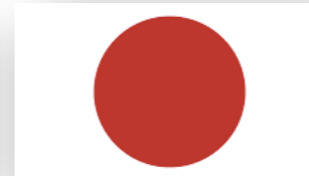
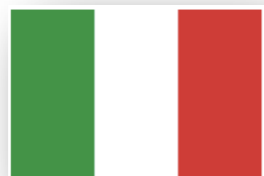




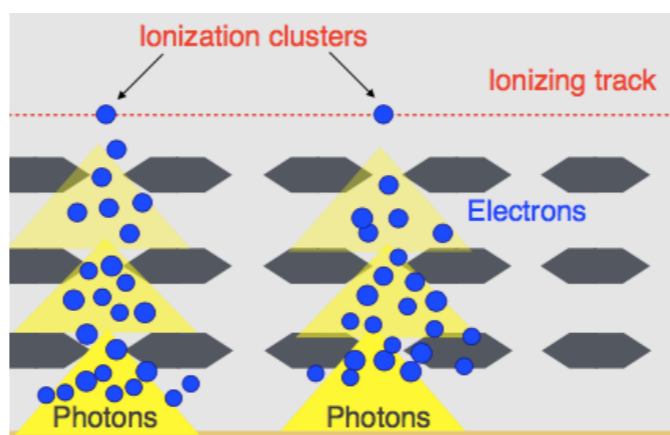
A multi-site Galactic Nuclear Recoil Observatory at the ton-scale to probe Dark Matter below the Neutrino Floor and measure ^8B solar Neutrinos with directionality

- Helium/Fluorine-based gaseous TPC for sensitivity to low mass WIMP region for both SI and SD couplings
- Goal of zero background operation after electron/gamma rejection and fiducialization at $\text{O}(\text{keV})$
- Directional and gamma/electron rejection thresholds at $\text{O}(\text{keV})$

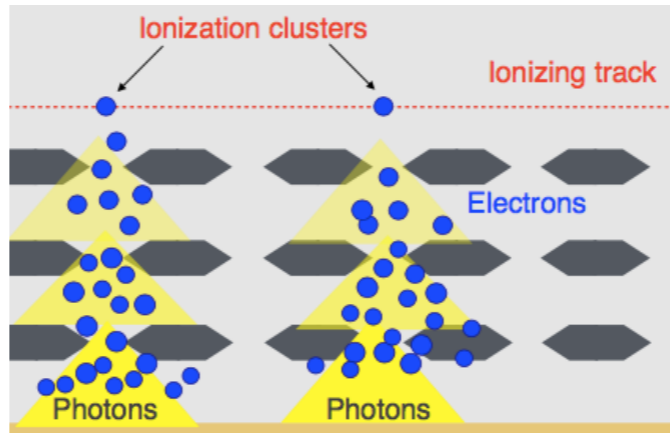
Since fall 2016



GEM amplification

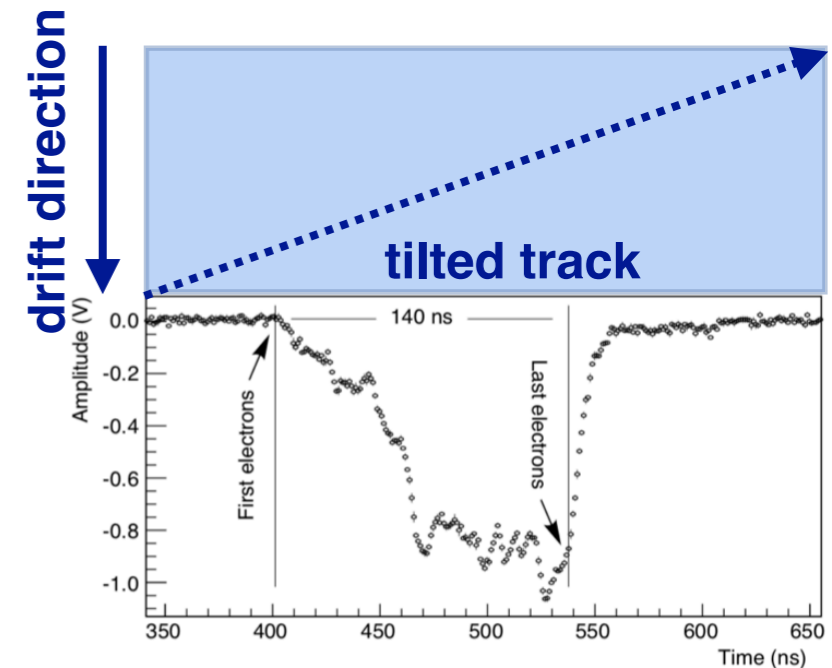
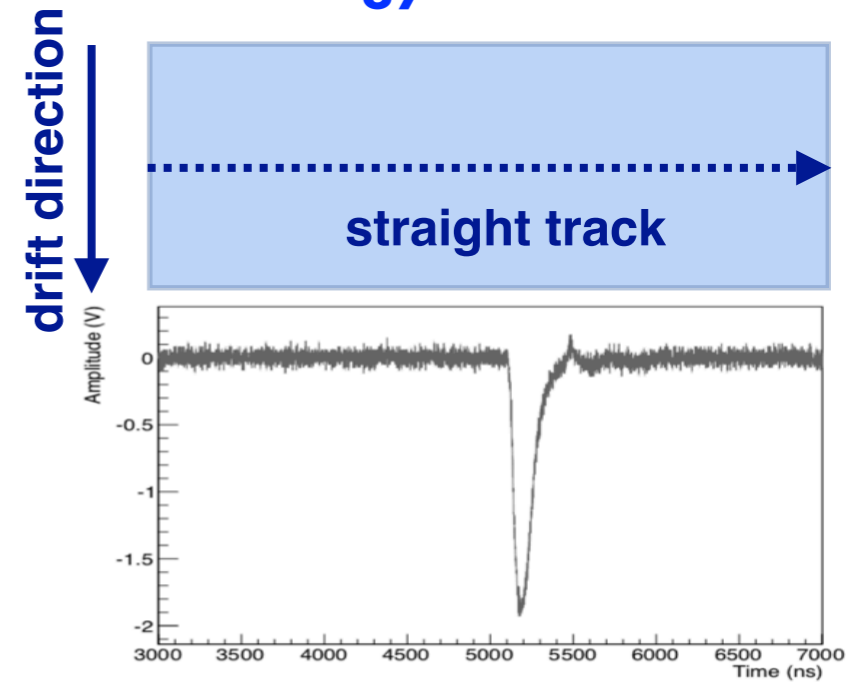


GEM amplification



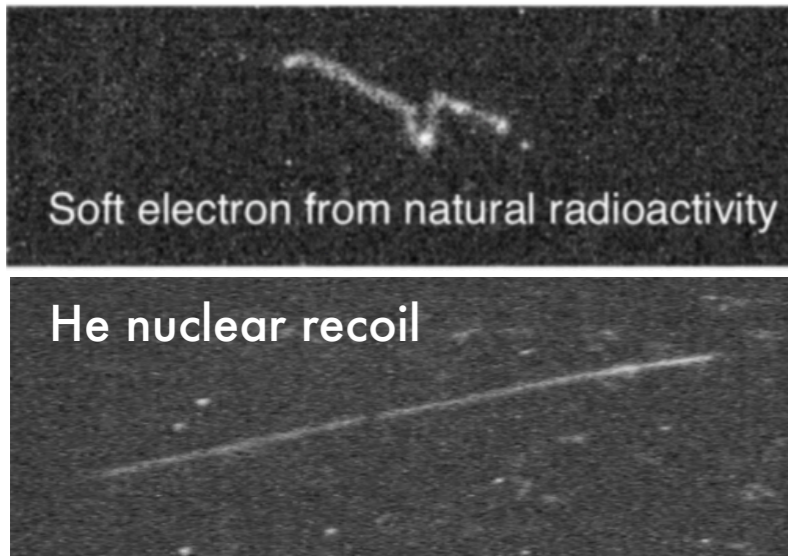
PMT:

integrated
Z + energy measurement



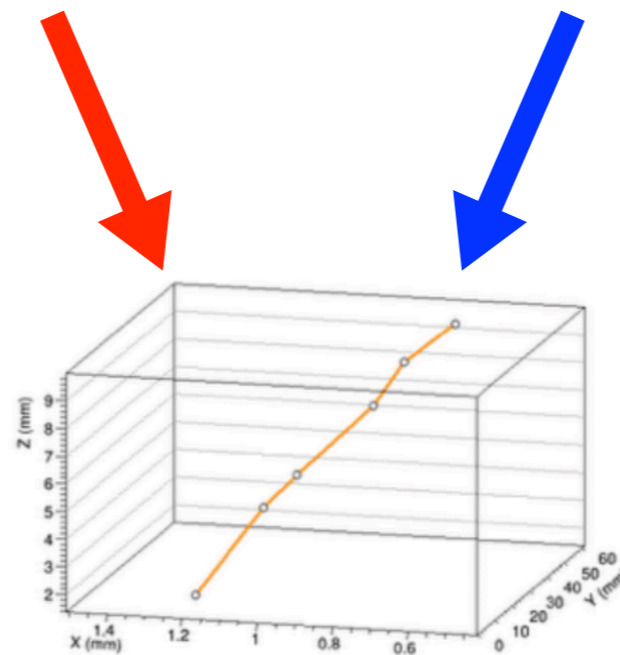
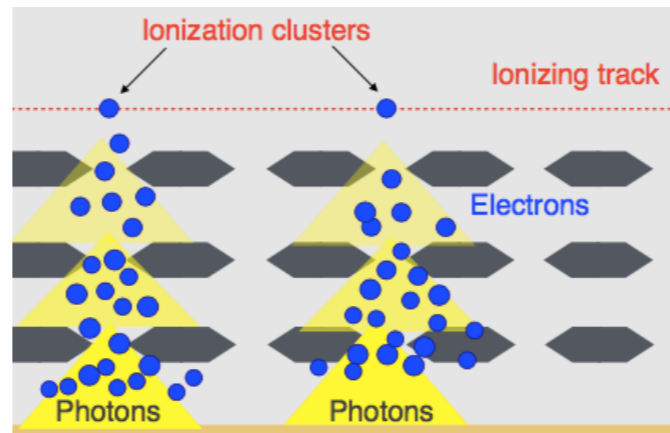
sCMOS:

high granularity
X-Y + energy measurements



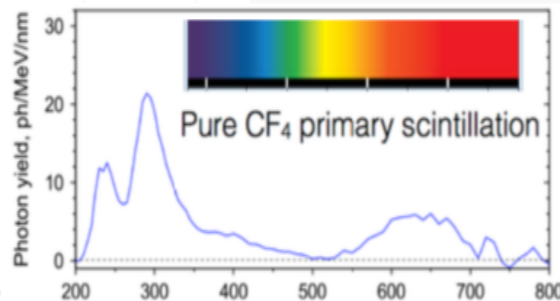
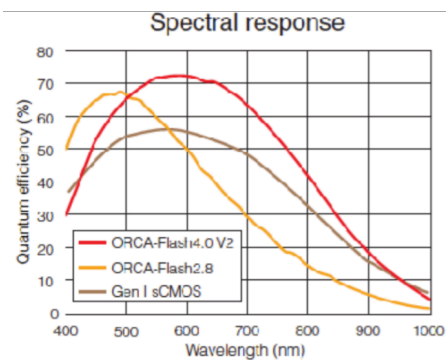
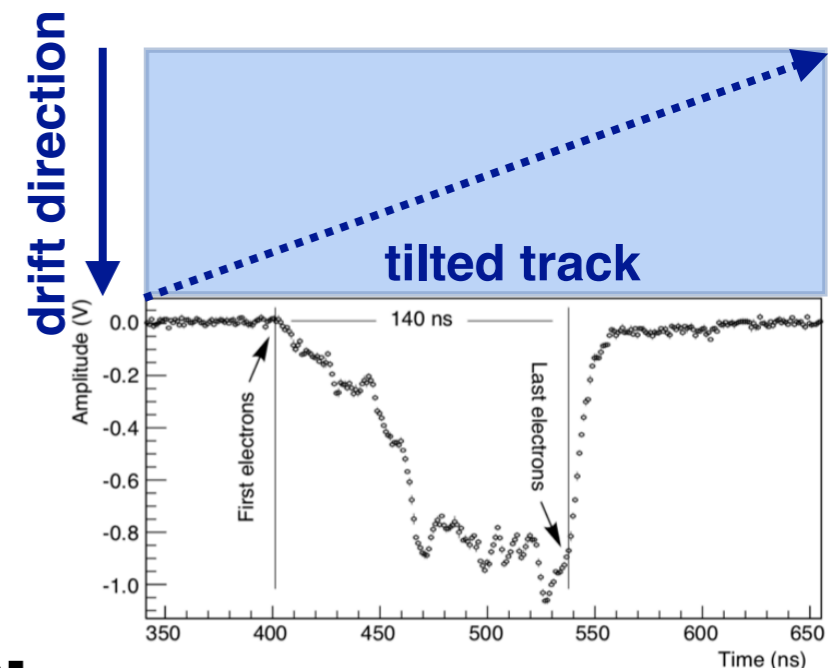
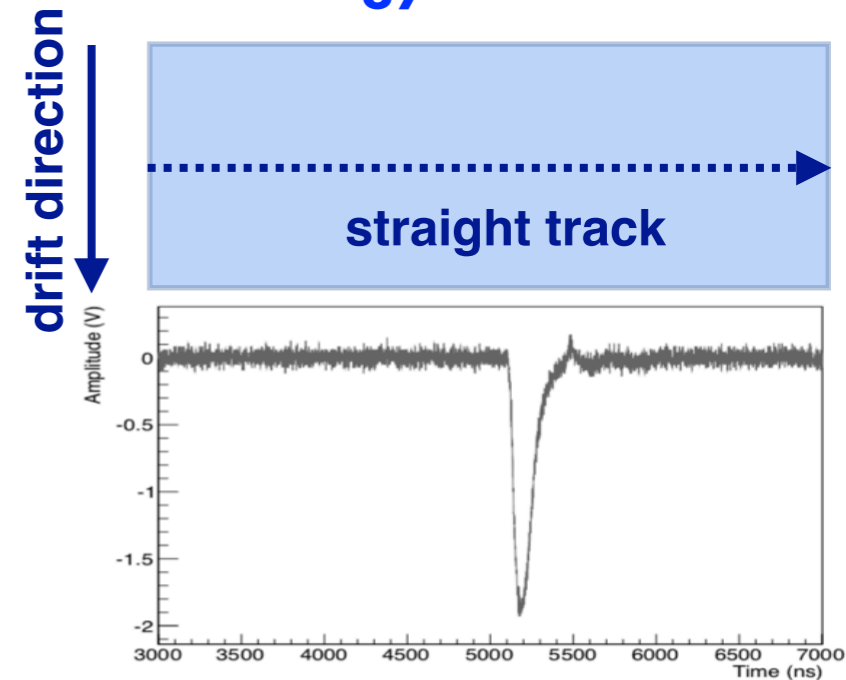
- Market pulled
- Single photon sensitivity
- Decoupled from target
- Large areas with proper optics
- Spectral response matched to CF₄

GEM amplification



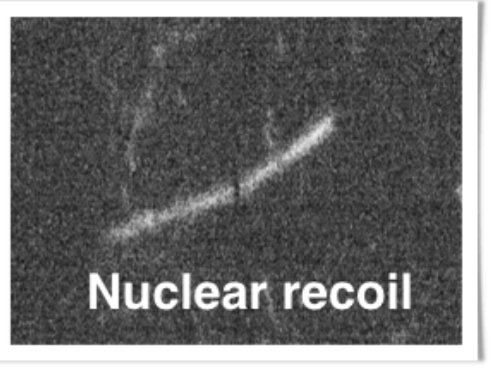
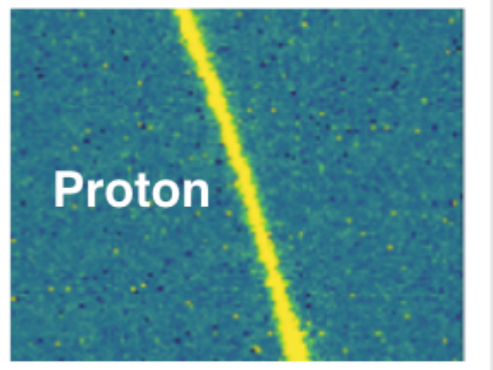
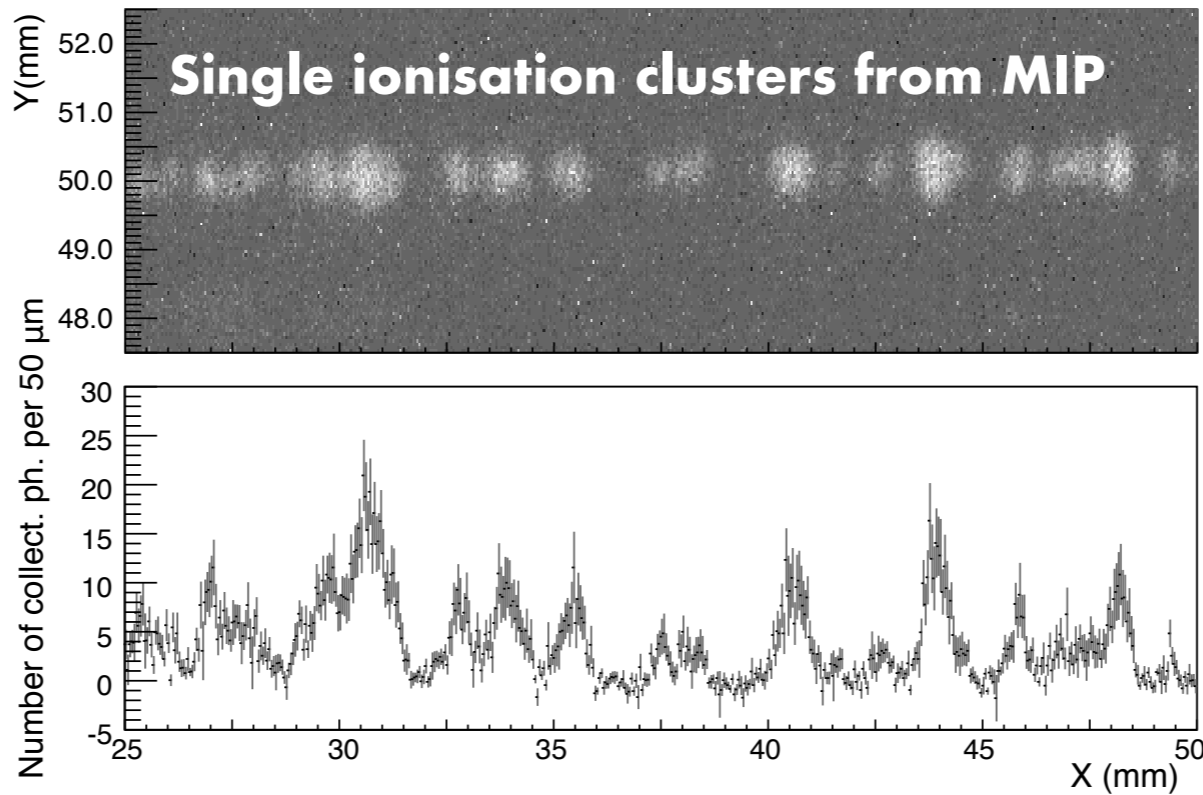
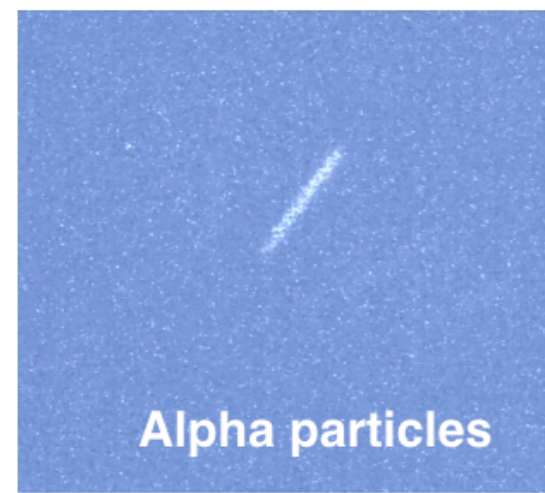
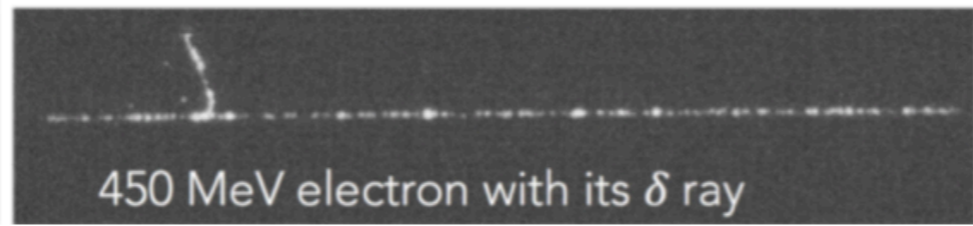
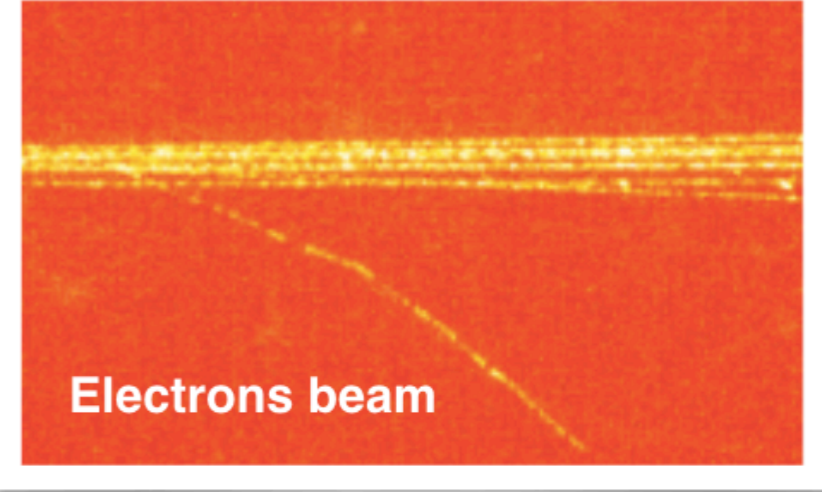
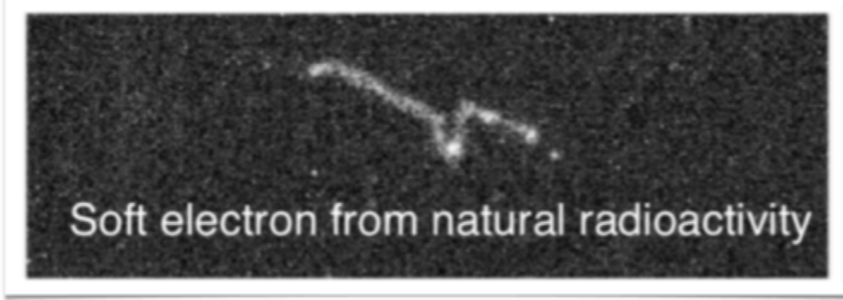
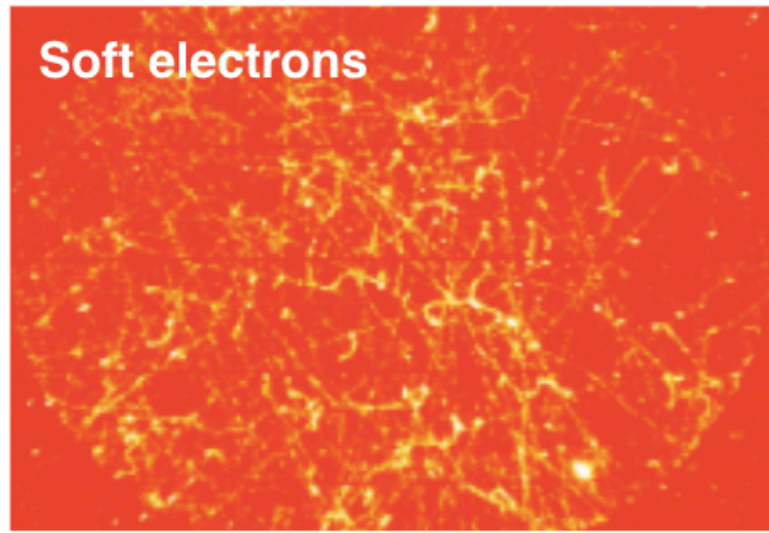
PMT:

integrated
Z + energy measurement



NEW JINST 13 (2018) no.05, P05001

GSSI CYGNO: photographing tracks



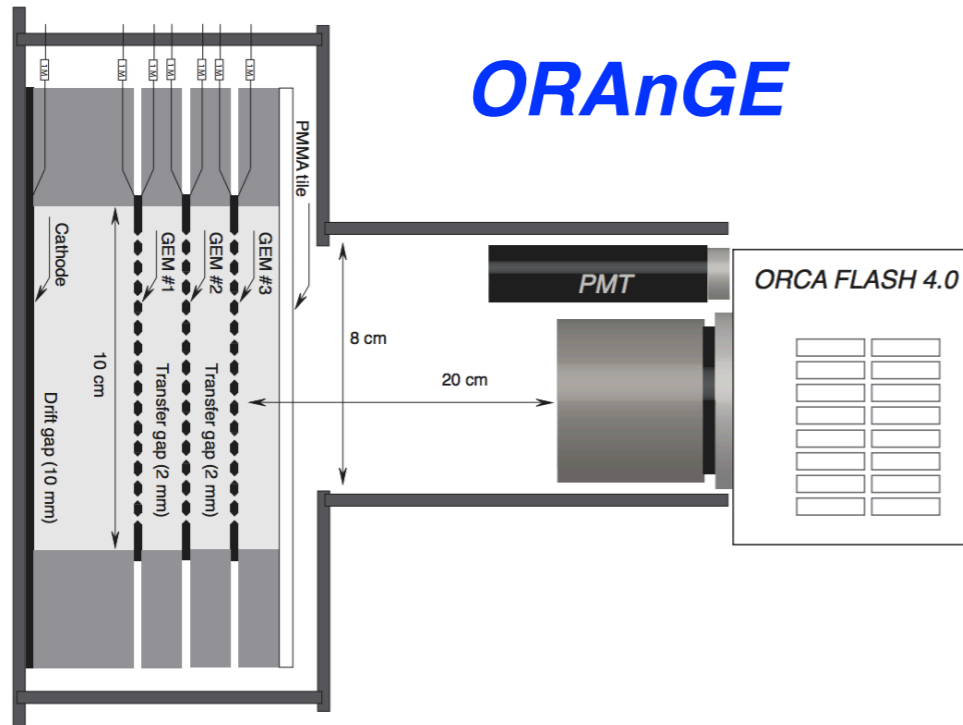
CYGNUS-RD project (2016-2018)

JINST 13 (2018) no.05, P05001

PoS EPS-HEP2017 (2017) 077

10 x 10 x 1 cm³
0.1 Liters

Triple thin GEMs
CMOS & PMT on same side



ORAnGE

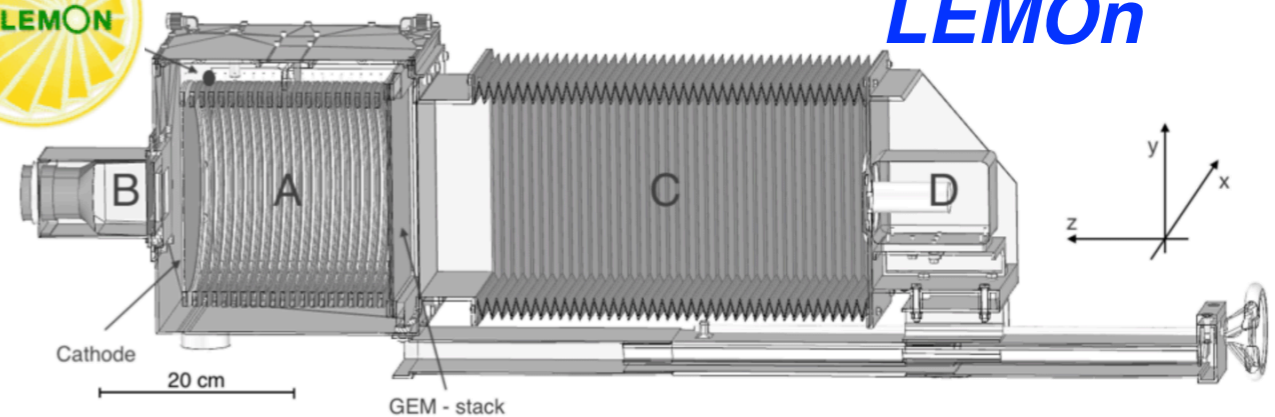
ORANGE: small prototype

Optically ReAdout GEMs

Camera distance ± 18 cm

24 x 20 x 20 cm³
9.6 Liters

Triple thin GEMs
CMOS & PMT on opposite sides



LEMON

- 3D printed gas box
- 3D printed field cage with metallic rings
- semi-transparent cathode (wire mesh)

- (A) Field Cage
- (B) PMT
- (C) Adaptable bellow
- (D) CMOS camera

LEMON: large prototype

Large Elliptical Module Optically readout

Camera distance ± 53 cm

Equipped with a suitable large aperture (f/0.95) and a short focal length (25 mm) lens

JINST 13 (2018) no.05, P05001

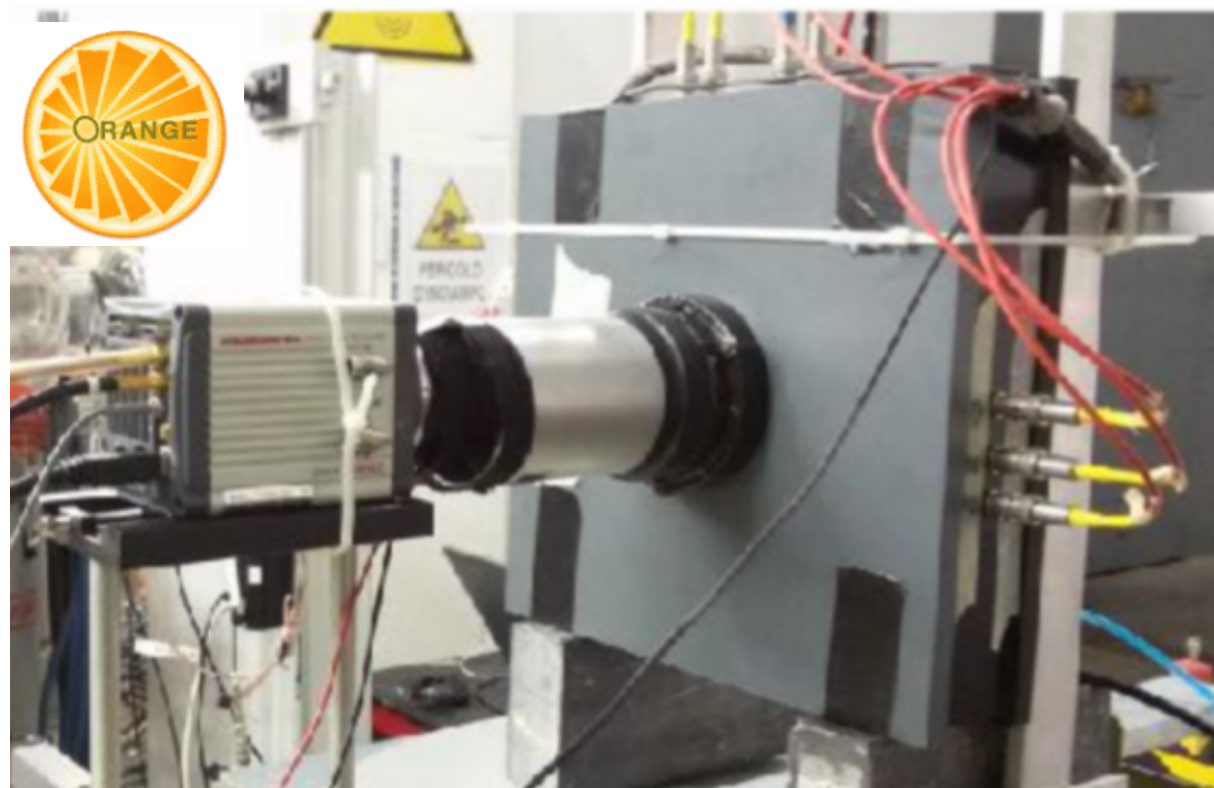
PoS EPS-HEP2017 (2017) 077

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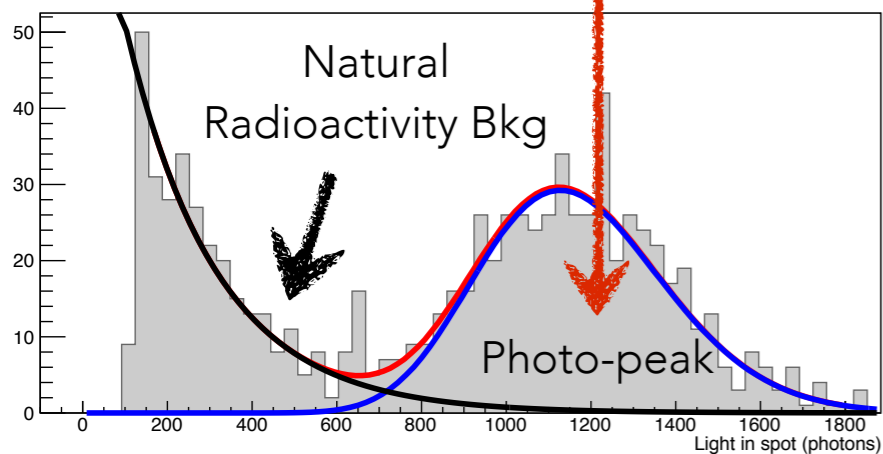
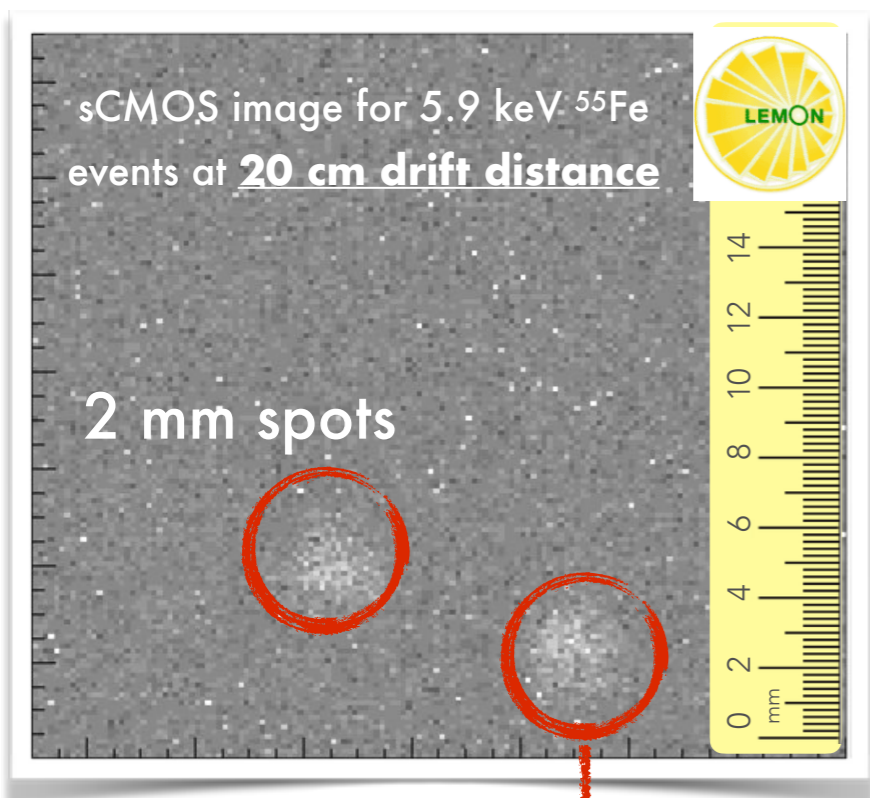
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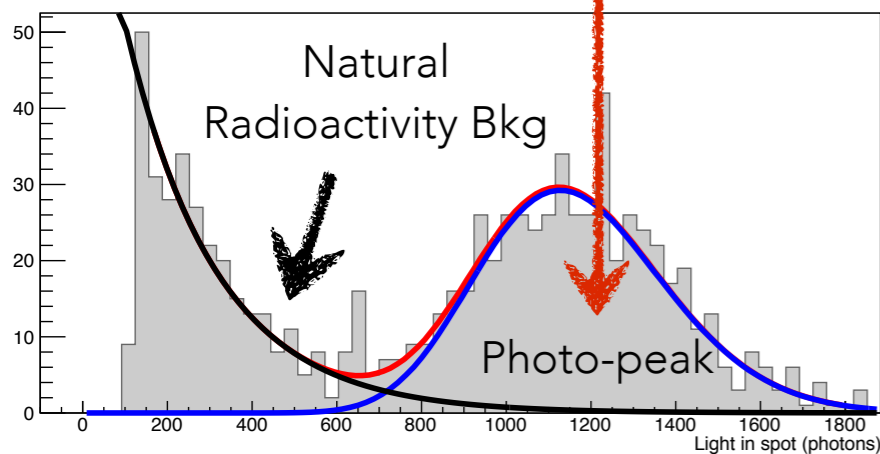
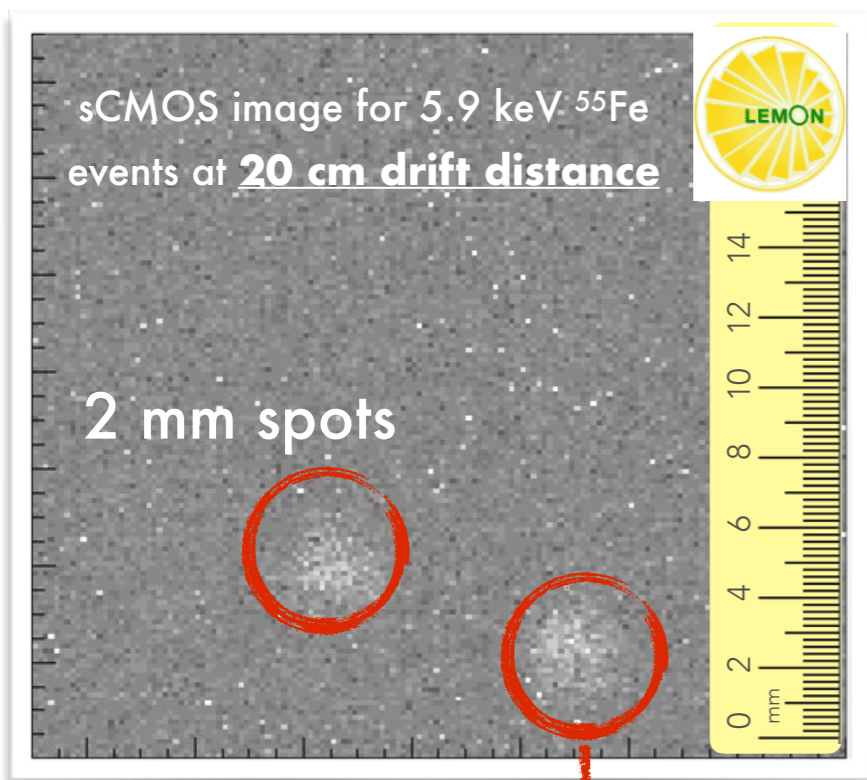
He:CF₄ gas mixture with conventional electron drift

Energy threshold @ about 2 keV_{ee}



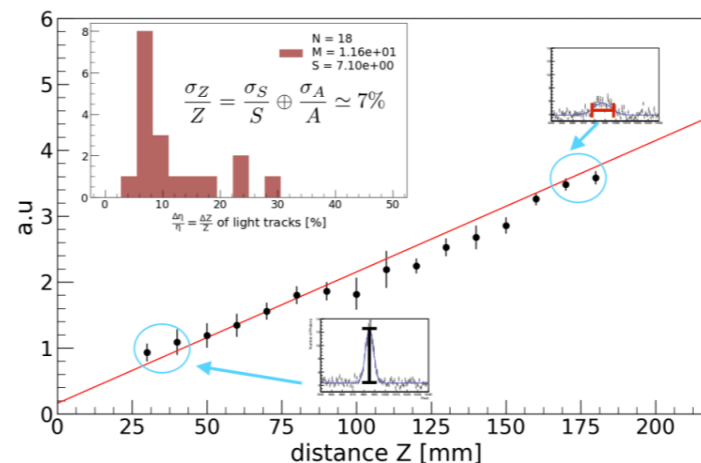
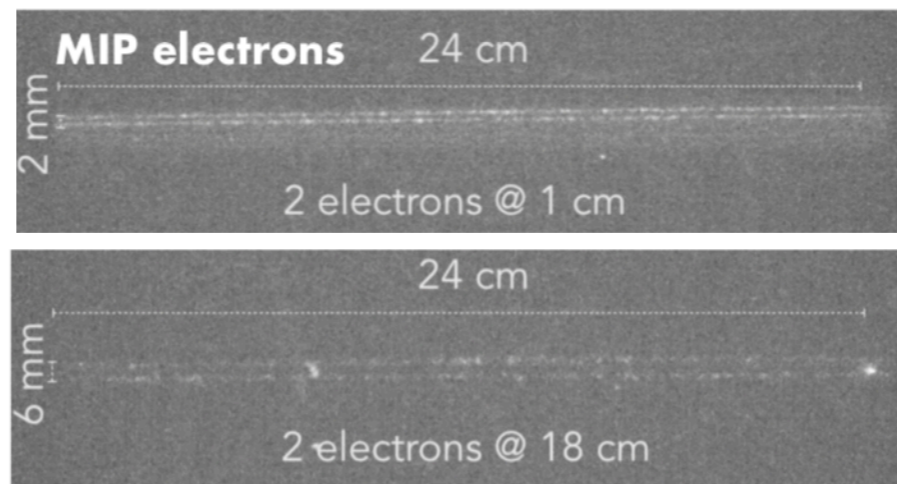
JINST 14 (2019) P07011

Energy threshold @ about 2 keV_{ee}



JINST 14 (2019) P07011

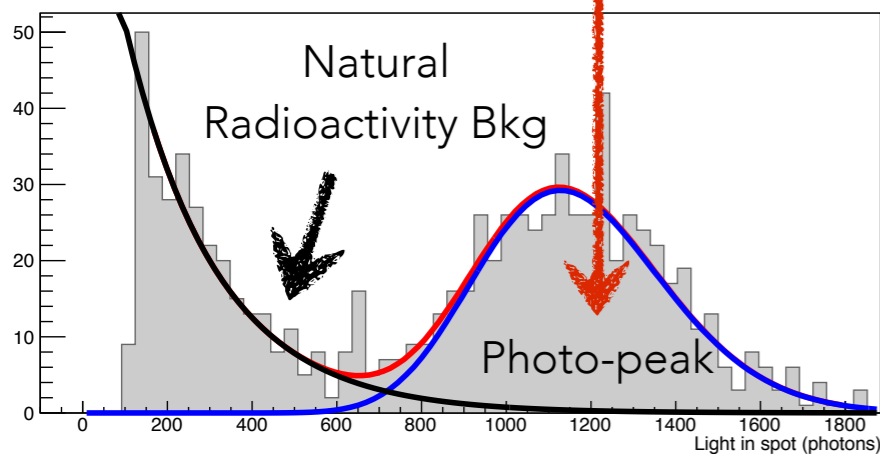
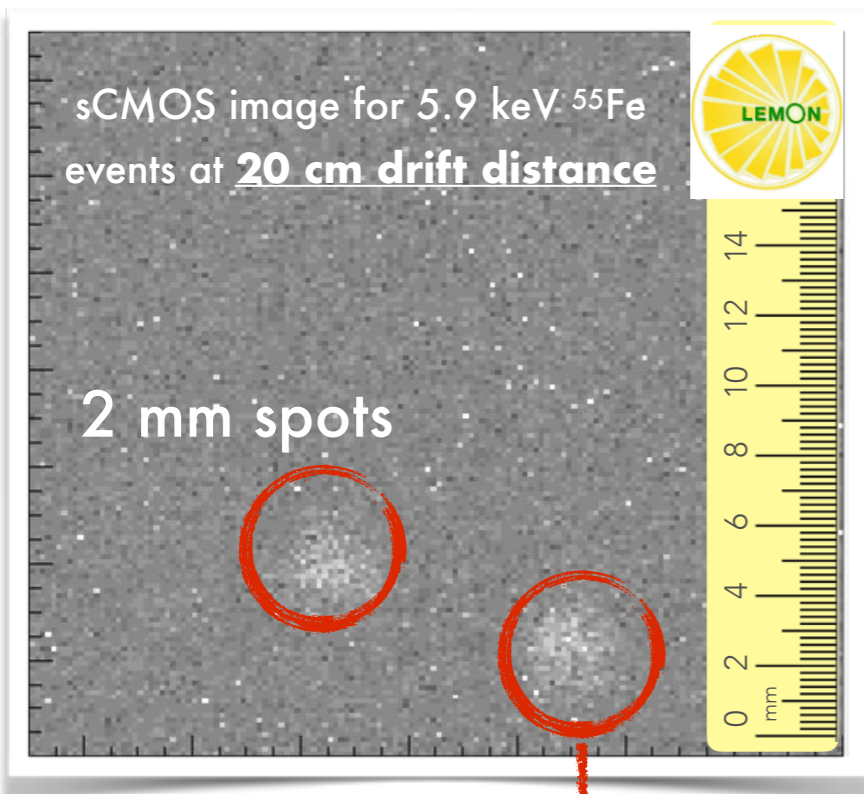
Absolute position determination along drift direction (background reduction through fiducialization)



Light transverse profile of both sCMOS images and PMT waveforms sensitive to absolute Z position via fit to diffusion

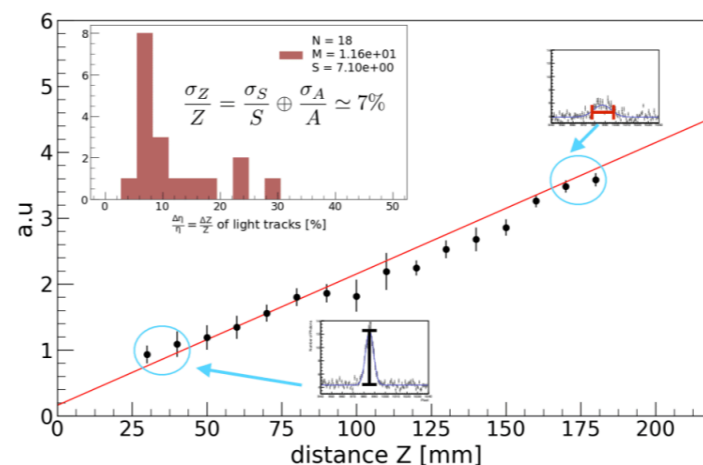
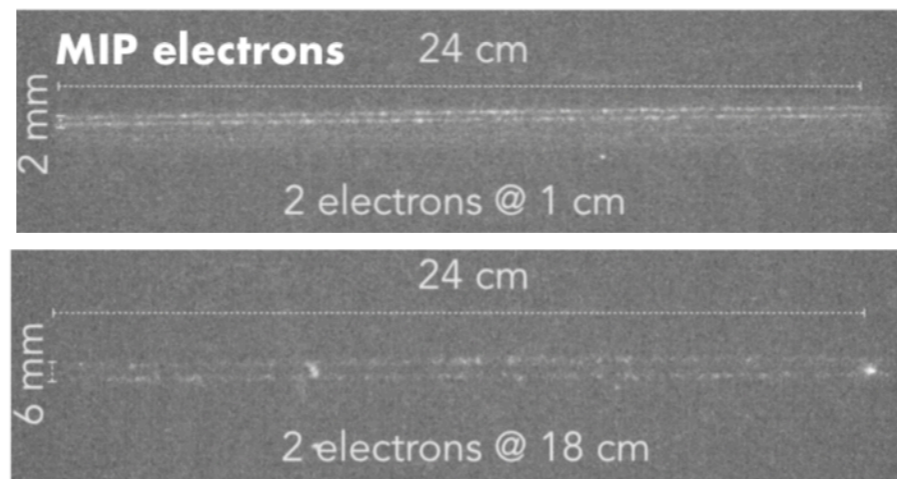
NIM A 936 (2019) 453-455

Energy threshold @ about 2 keV_{ee}



JINST 14 (2019) P07011

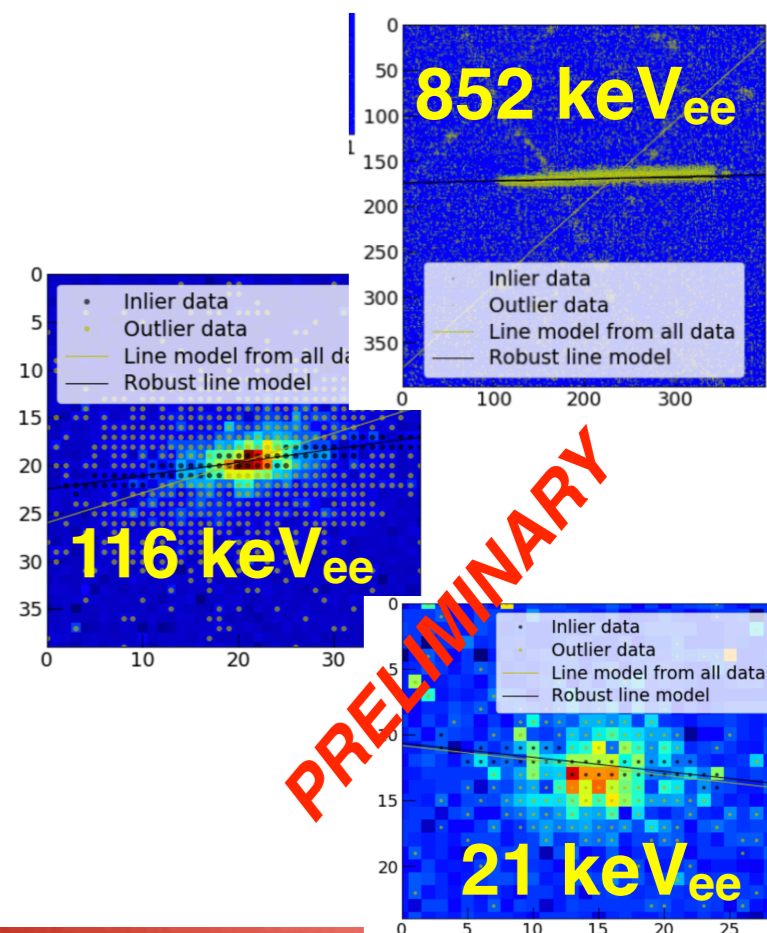
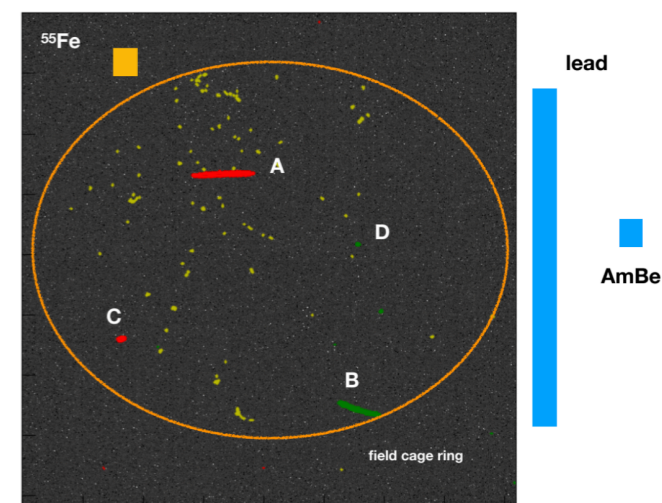
Absolute position determination along drift direction (background reduction through fiducialization)

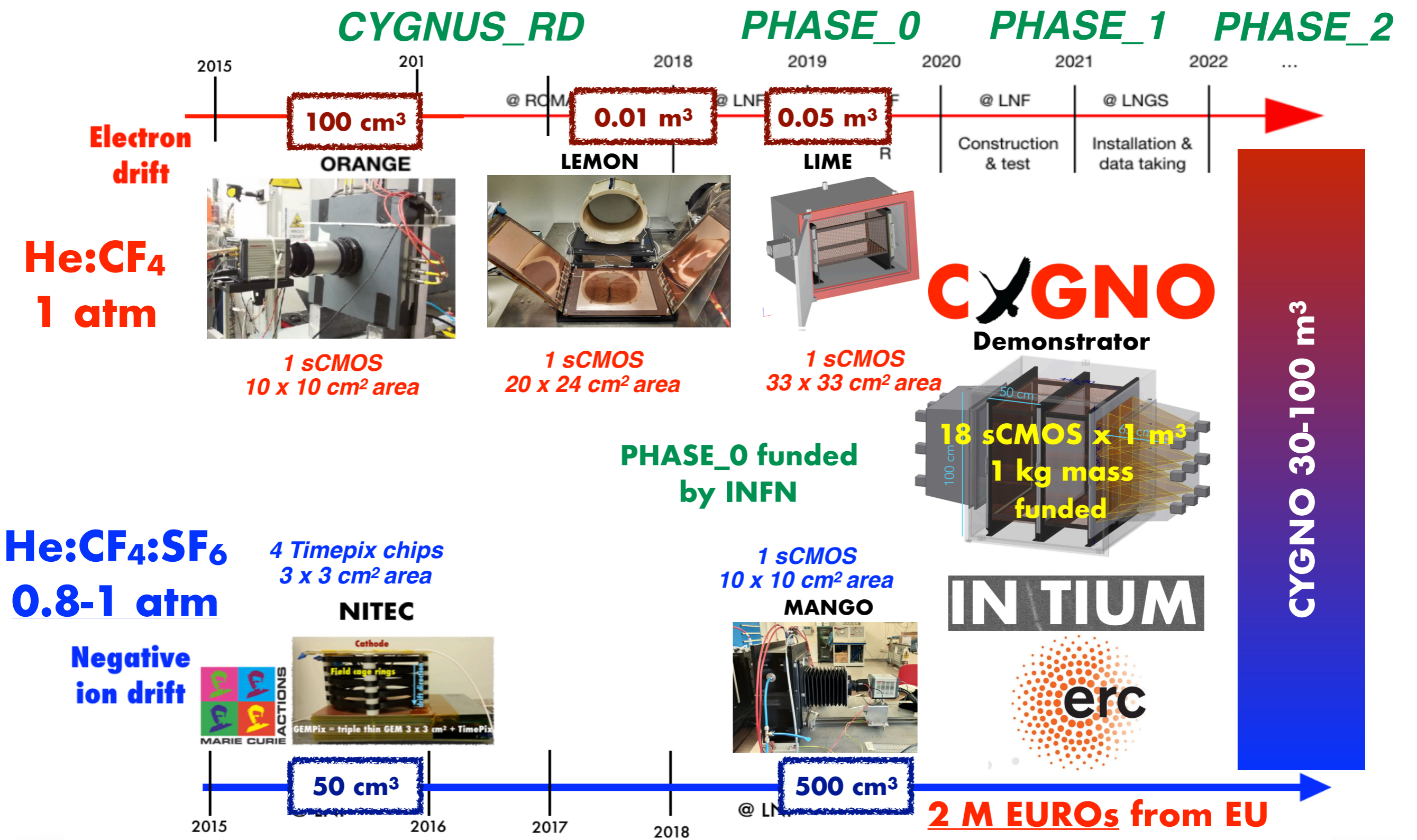


Light transverse profile of both sCMOS images and PMT waveforms sensitive to absolute Z position via fit to diffusion

NIM A 936 (2019) 453-455

Hint of 2D directionality and sense down to very low thresholds!





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PHASE_0: Mango & Lime

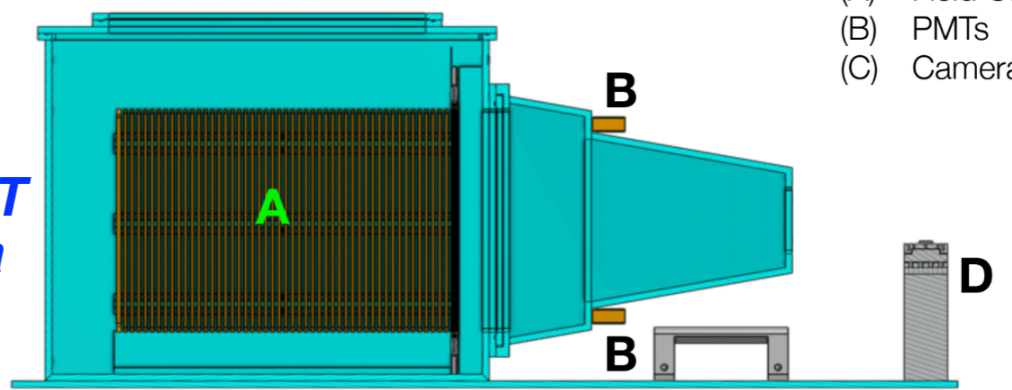


MANGO: a Multipurpose Apparatus for Negative ion studies with GEM Optically readout



LIME: Long Imaging Module

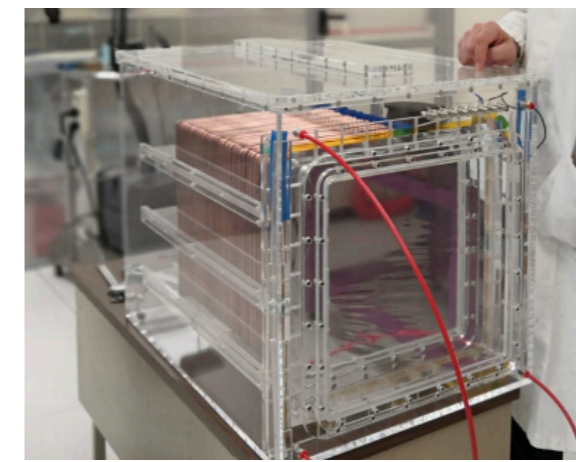
**1 sCMOS + 4 PMT
33 x 33 cm² area
50 cm drift
1/18 of CYGNO**



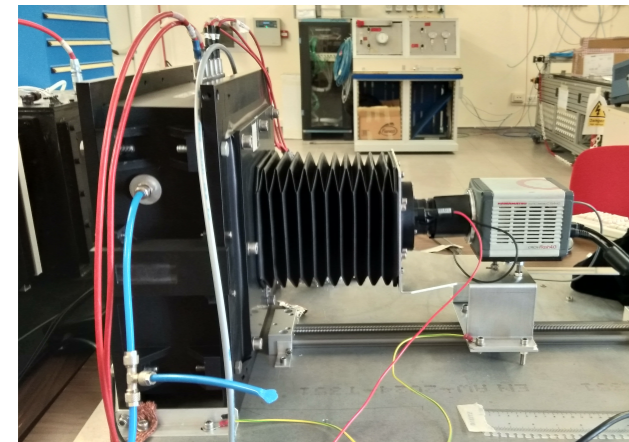
- (A) Field Cage
- (B) PMTs
- (C) Camera stand

- PMMA gas box + copper sheet for EM shielding/gamma shielding/darkening
- Field cage made of copper rings on PMMA supports
 - possibility of testing also DRIFT-like field cage (Kapton foil with copper strips) and **resistive foil**
- 4 PMT for positioning sensitivity with fast readout (center-of-gravity)

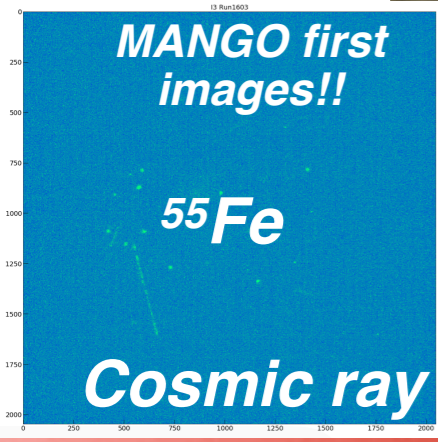
50 L volume



Under preliminary tests @ LNF, to be installed in underground LNGS by end 2020 to asses performance & measure neutron flux

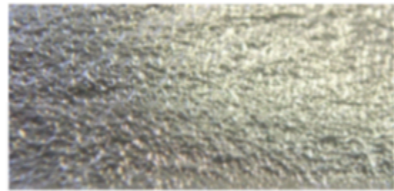


To be soon installed in our new overground LNGS lab in HdM

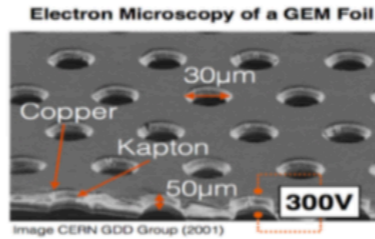


PHASE_1: 1 m³ detector @ LNGS

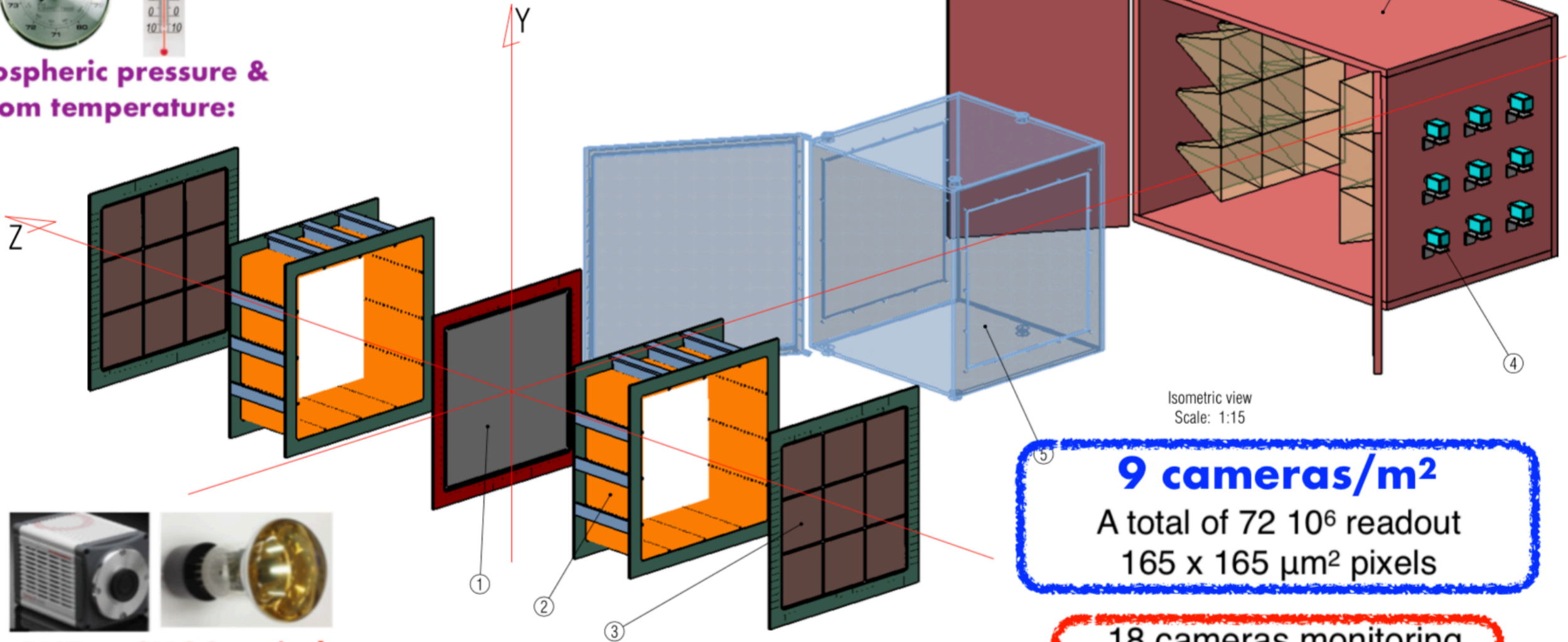
Transparent texturised mylar cathode a'la DRIFT



Gas Electron Multipliers (GEMs) amplification



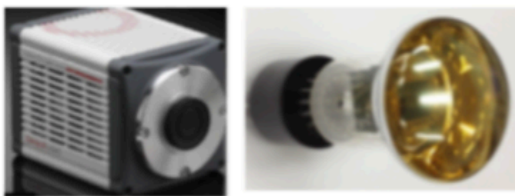
Atmospheric pressure & room temperature:



Isometric view
Scale: 1:15

9 cameras/m²
A total of 72 10⁶ readout
165 x 165 µm² pixels

18 cameras monitoring
330*330 mm each
with **160 µm** resolution



PMT + sCMOS optical readout decoupled from target volume

#socialdetector



<https://web.infn.it/cygnus>

