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Gran Sasso Science Institute & INFN

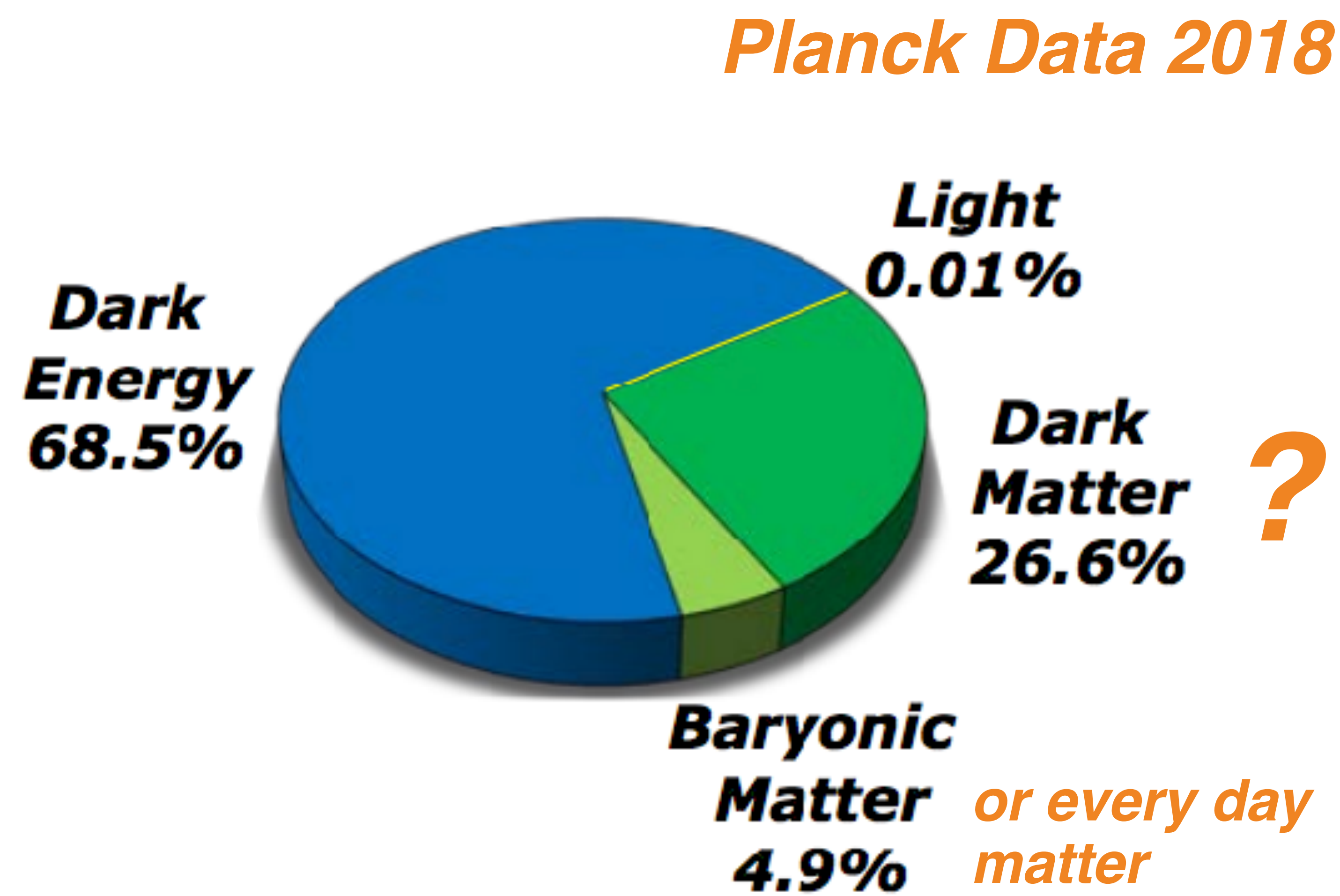
CYGNO & INITIUM

Directional Dark Matter searches with optical readout

E. Baracchini[1], R. Bedogni[2], F. Bellini[3], L. Benussi[2], S. Bianco[2], L. Bignell[4], G. Cavoto[3], E. Di Marco[5], C. Eldridge[6], A. Ezeribe[6], R. Gargana[2], T. Gamble[6], R. Gregorio[6], G. Lane[4], D. Loomba[7], W. Lynch[6], G. Maccarrone[2], M. Marafini[8], G. Mazzitelli[2], A. Messina[3], A. Mills[7], K. Miuchi[10], F. Petrucci[11], D. Piccolo[2], D. Pinci[5], N. Phan[7], F. Renga[5], N. Spooner[6], T. Thorpe[9], S. Tomassini[2], and S. Vahsen[9]

On behalf of the CYGNO collaboration

It's a Dark Universe



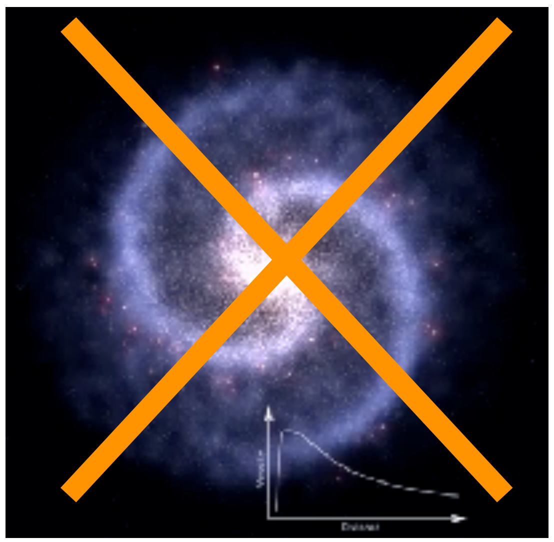
Dark Matter holds it together

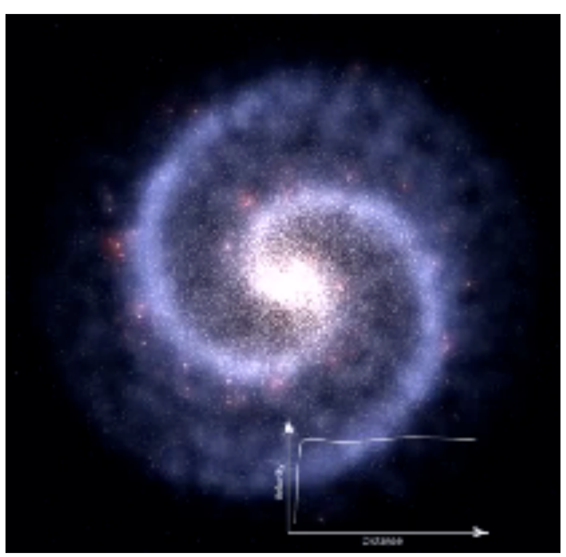
Dark Energy determines its destiny

Gravitational DM evidences

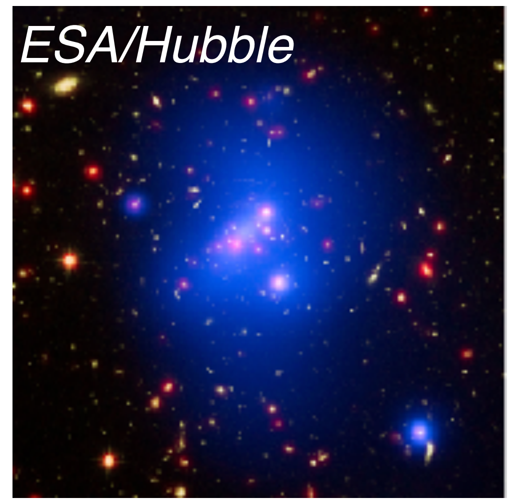
"Dark" Matter because it does not interact with light

Galaxy rotation curves

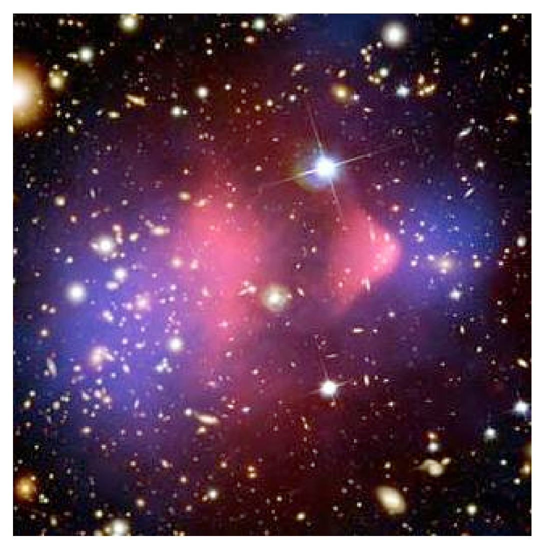




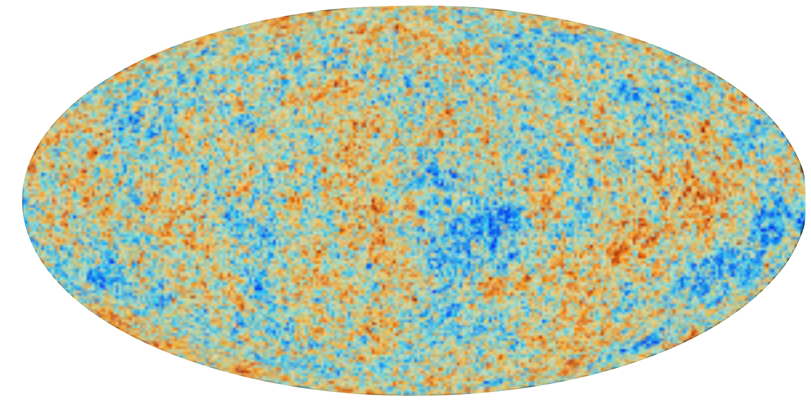
Galaxies motion inside clusters



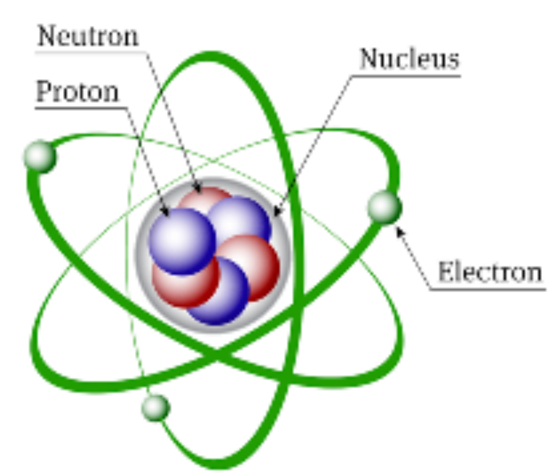
Galactic Collisions



Cosmic Microwave Background

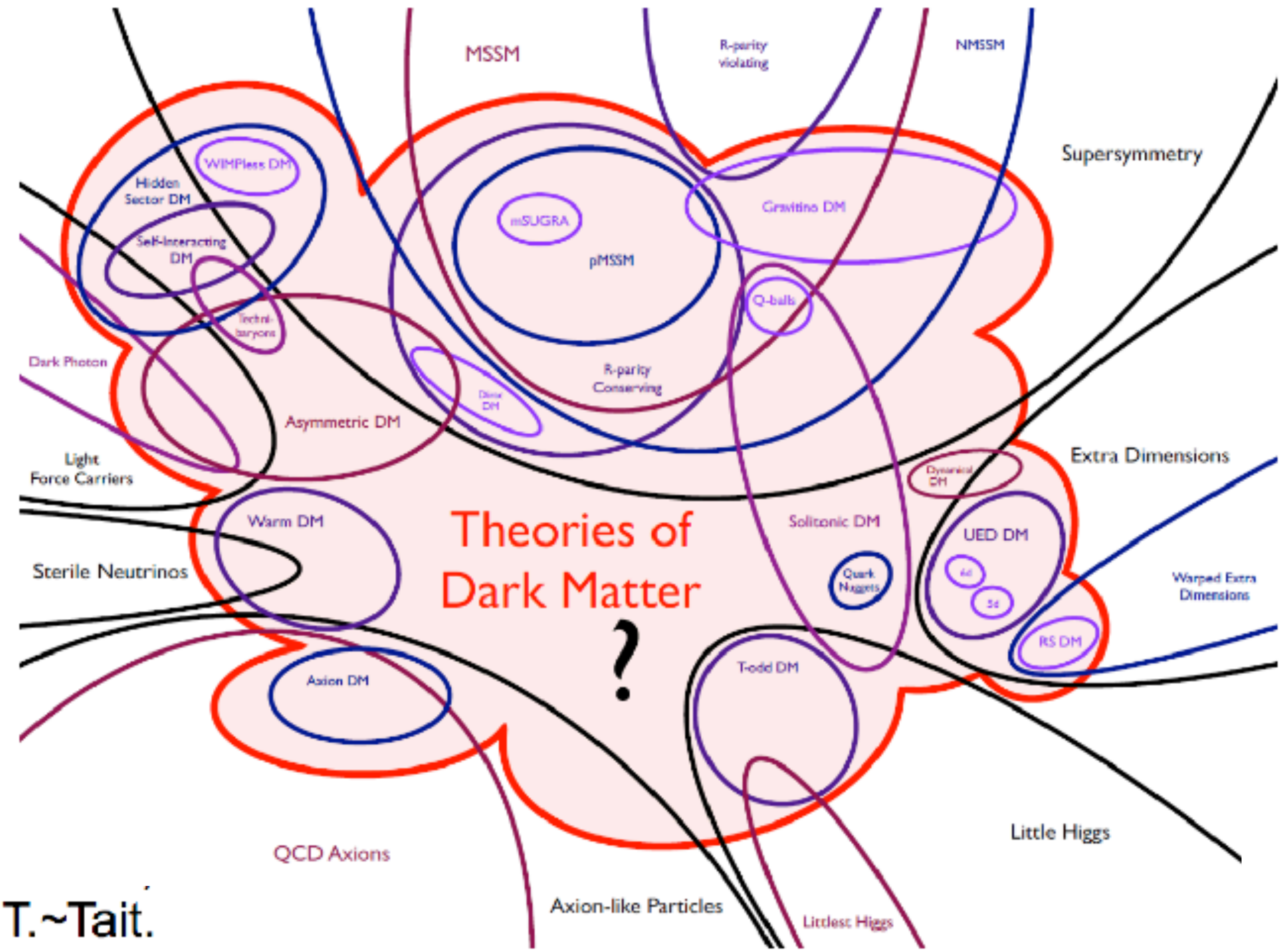


Big Bang Nucleosynthesis



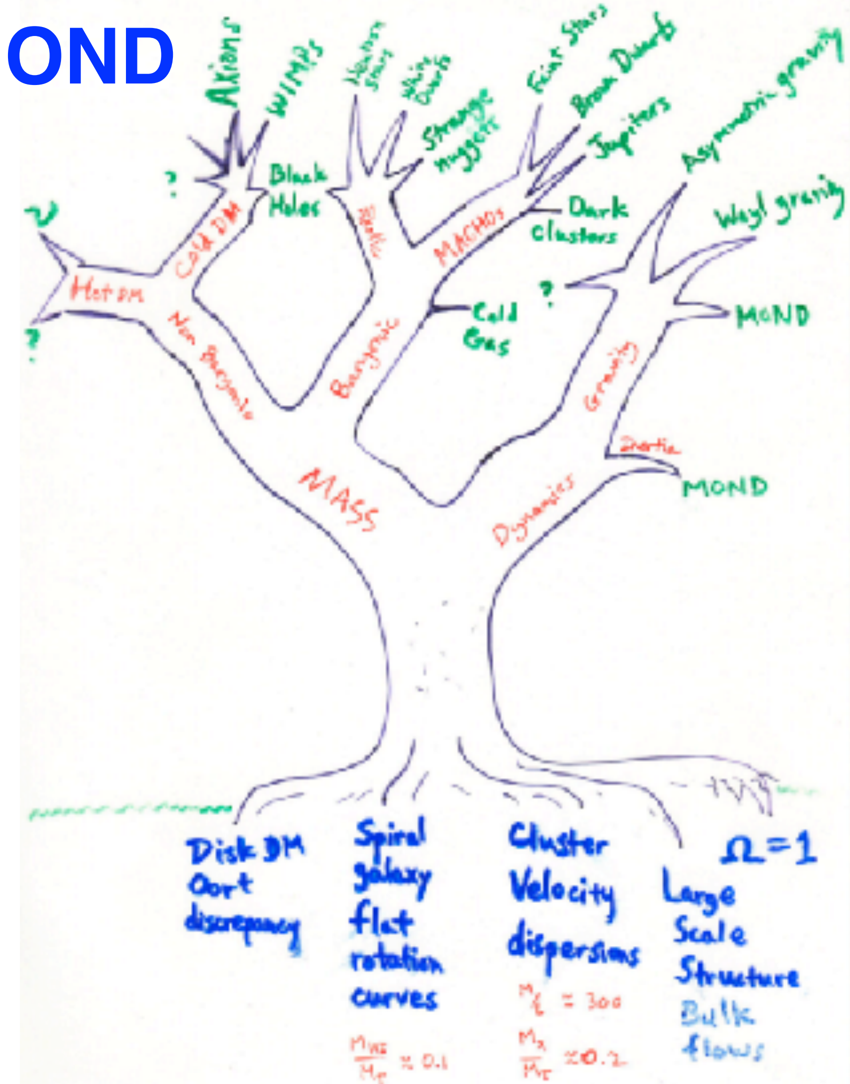
Larger scales explored, older times probed

DM candidates zoo

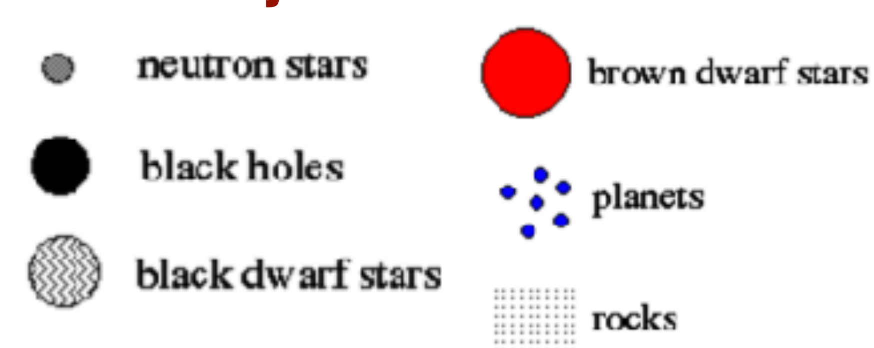


T.~Tait.

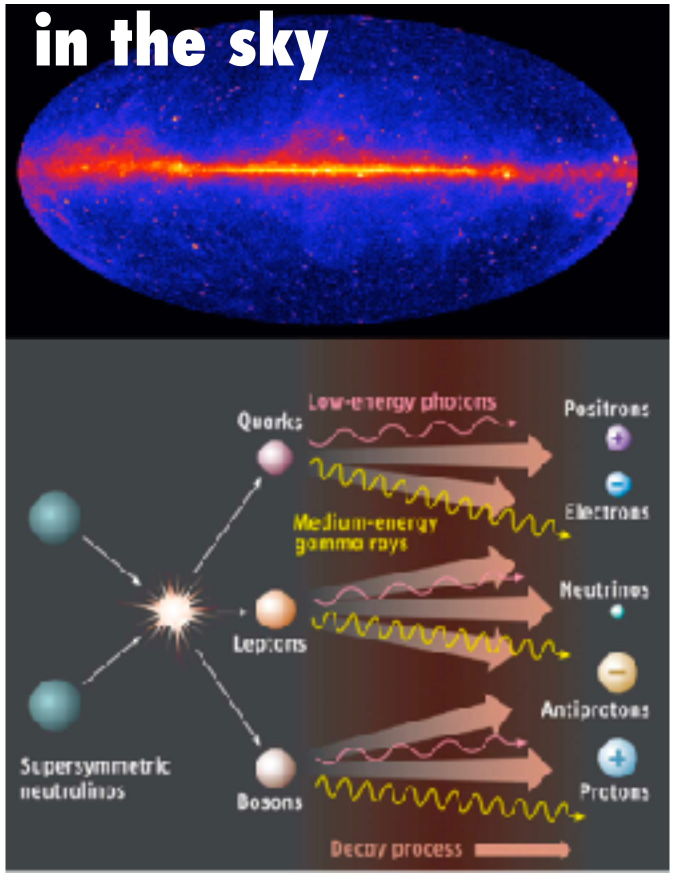
MOND



Other objects:

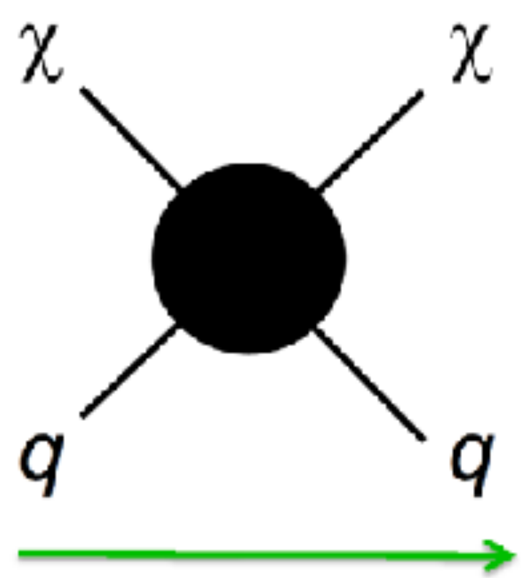


WIMP DM searches



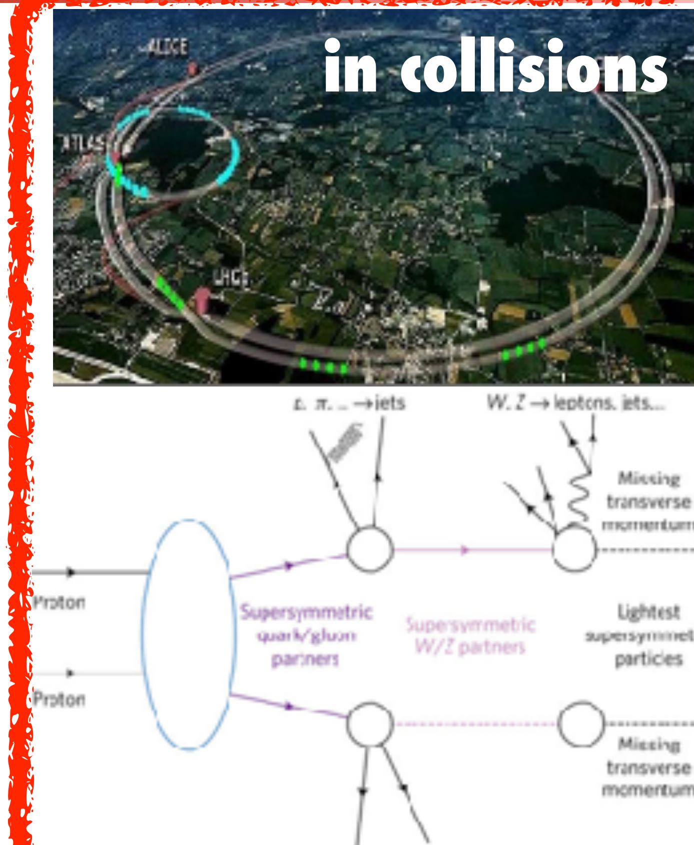
$\chi\chi \rightarrow e^+e^-, p\bar{p}$

Efficient annihilation now
(Indirect detection)

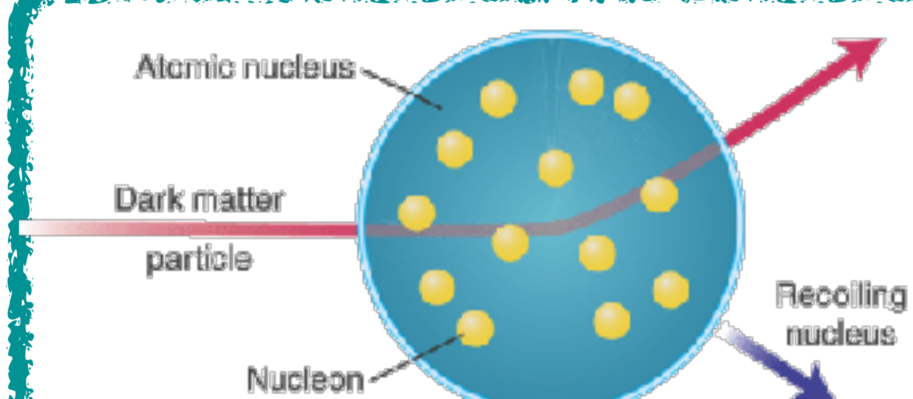


Efficient scattering now
(Direct detection)

Efficient production now
(Particle colliders)

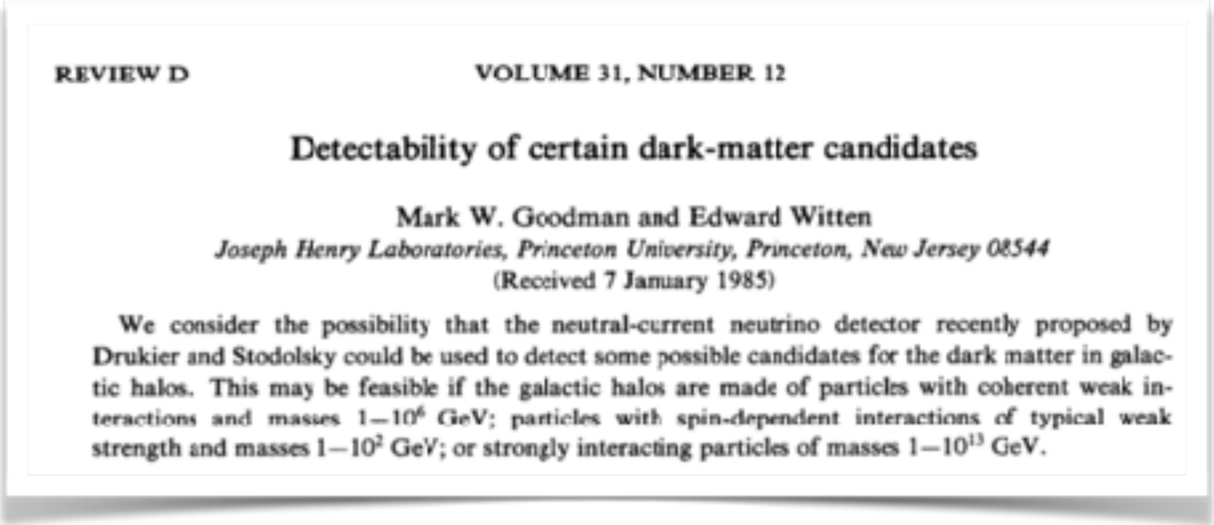


$p + p \rightarrow \chi + \text{a lot}$



$\chi N \rightarrow \chi N$

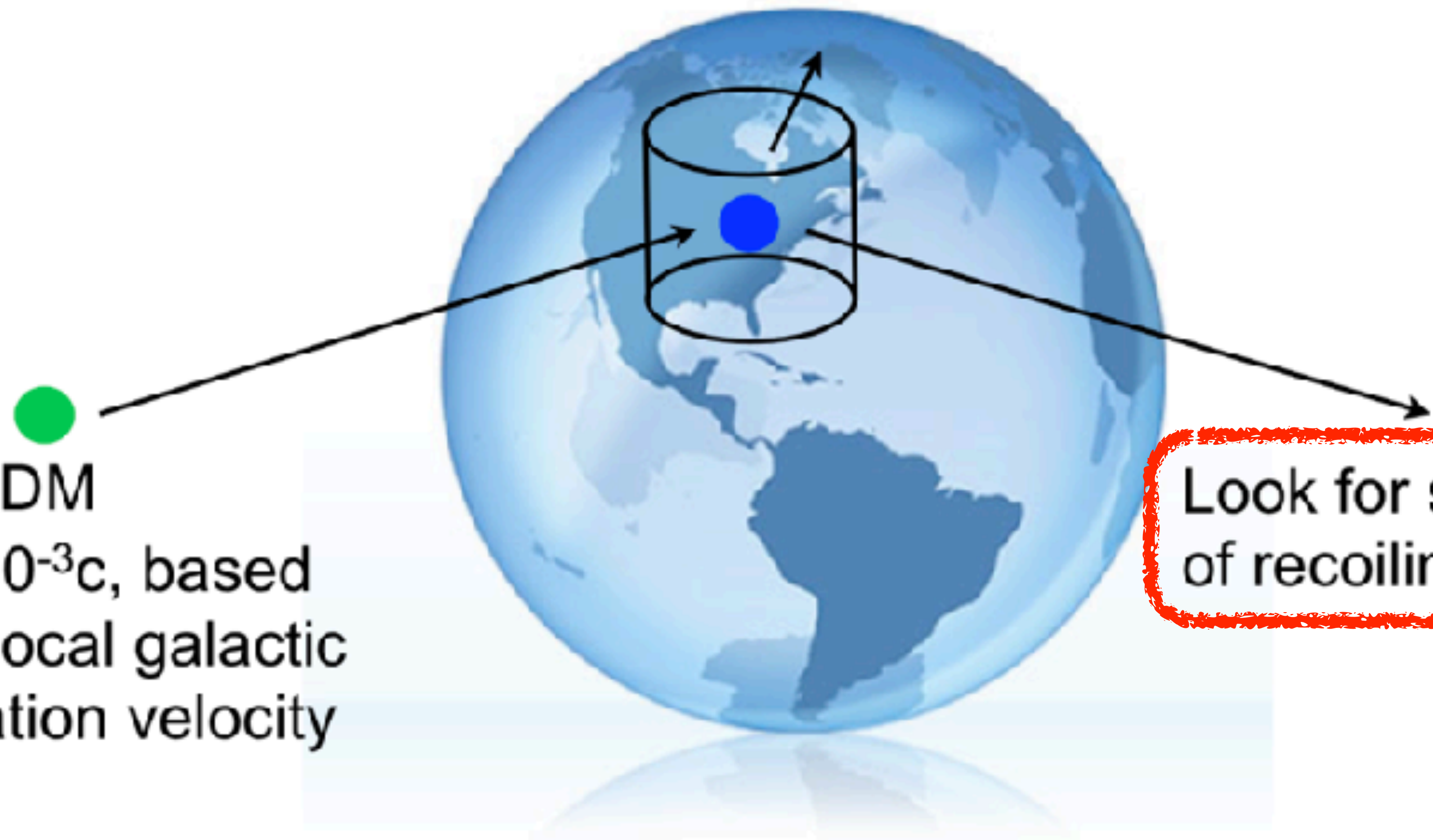
How to detect something invisible?


REVIEW D VOLUME 31, NUMBER 12

Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

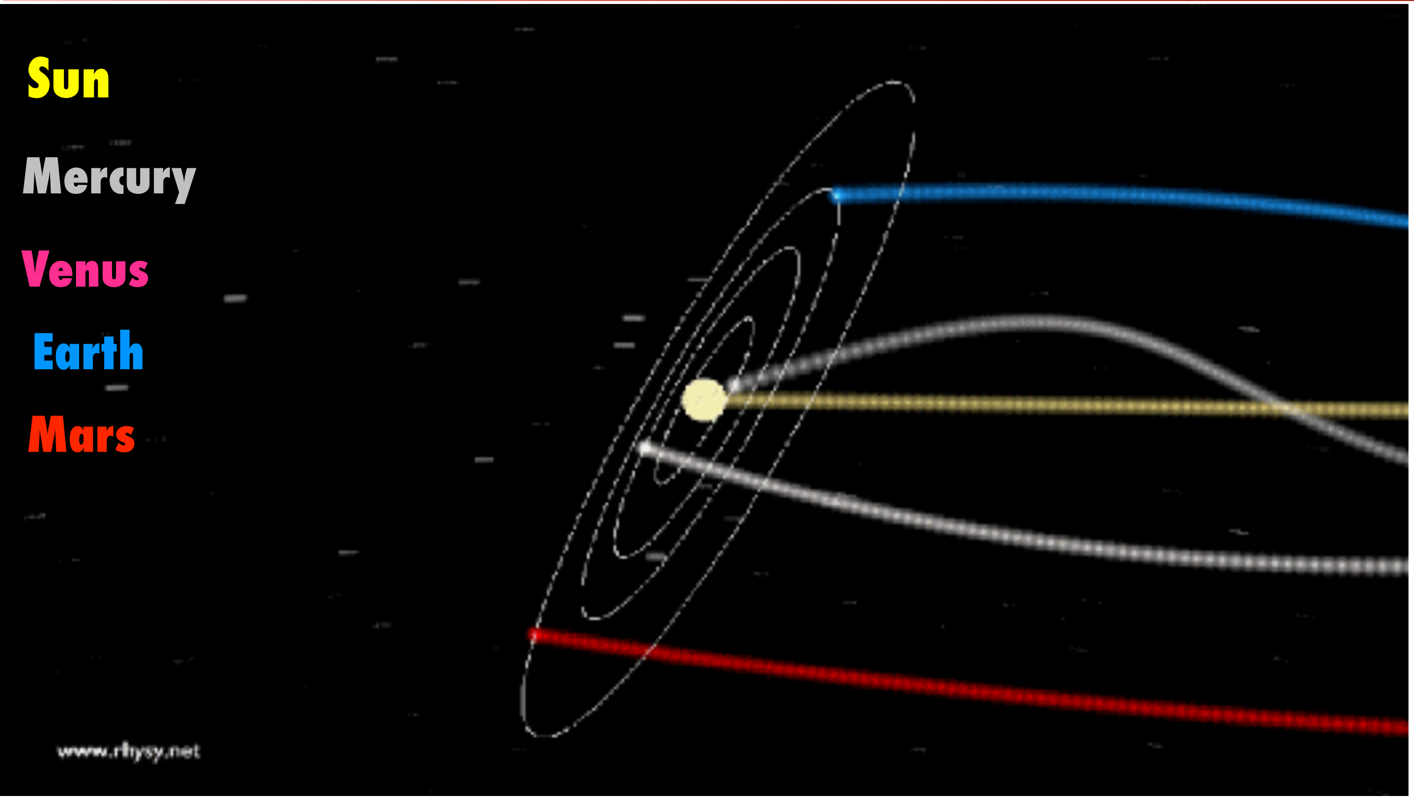


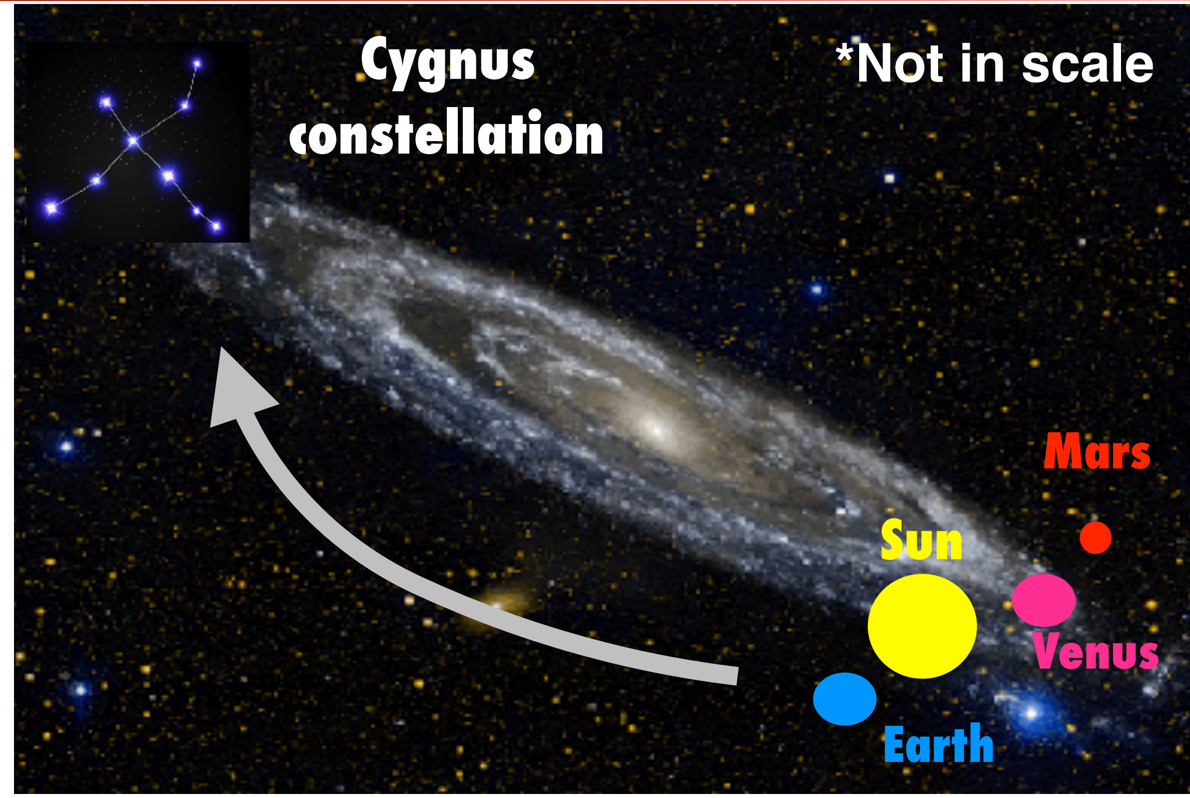
DM
$v \sim 10^{-3}c$, based on local galactic rotation velocity

Look for signature of recoiling nucleus

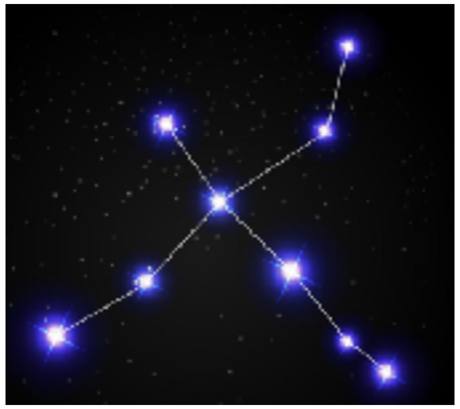
Travelling through space

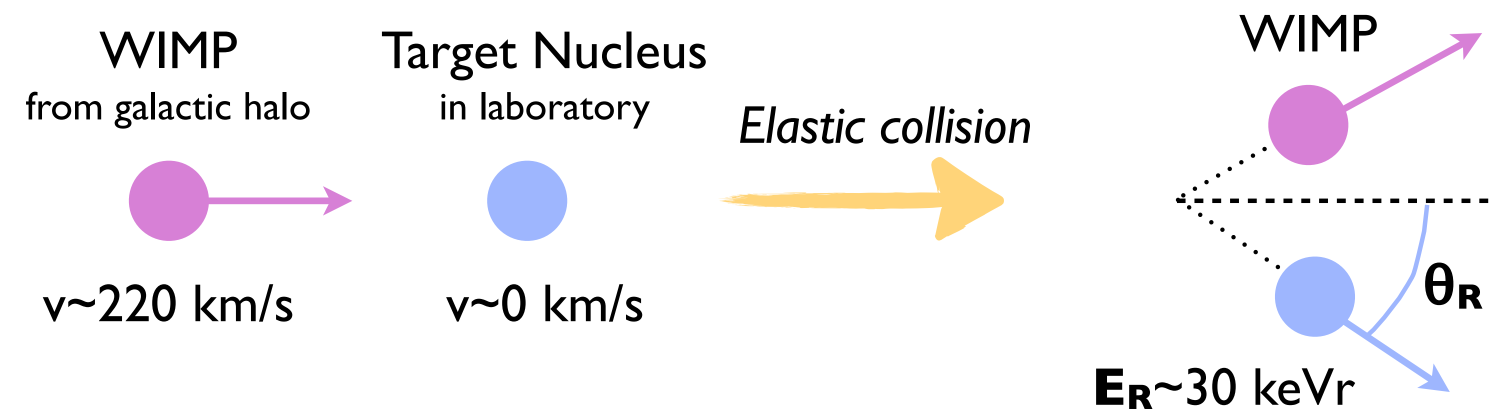
GSSI





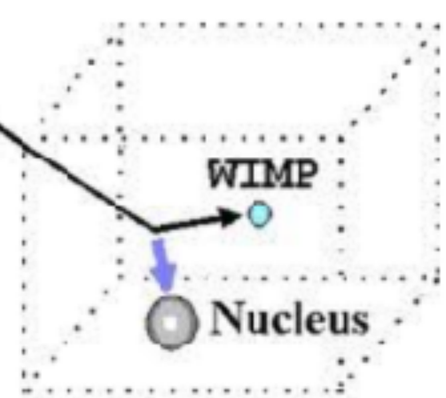
Non-relativistic collision

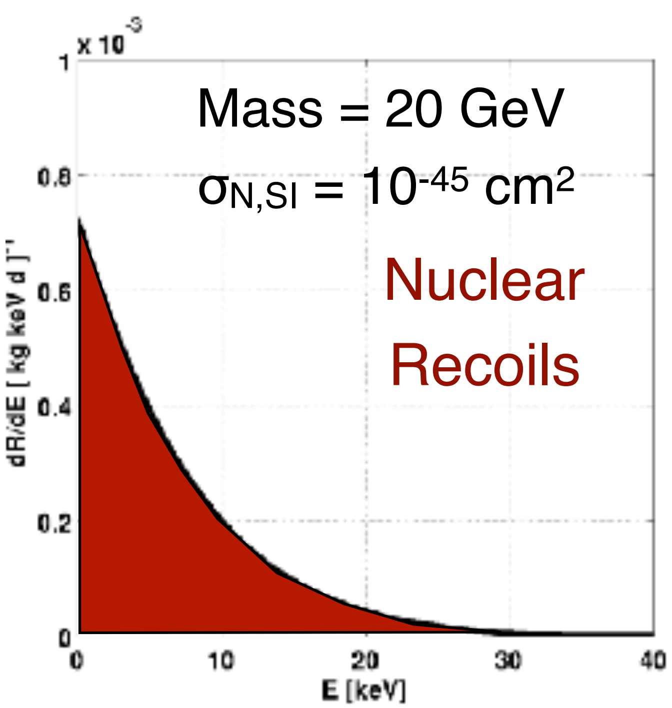




Recoiling nuclei (partially) retain WIMP direction

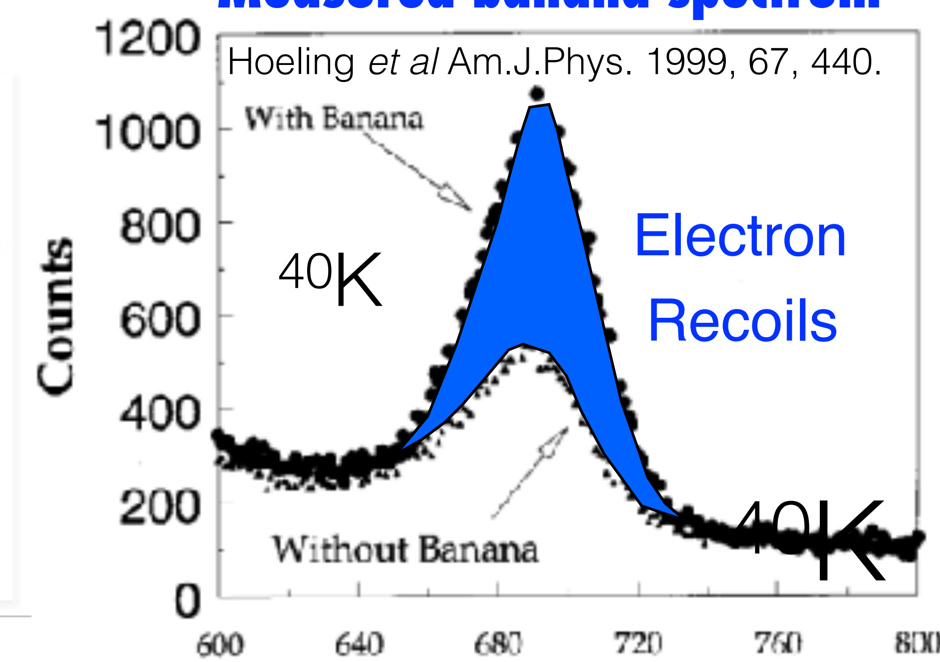
$$R \sim 0.13 \frac{\text{events}}{\text{kg year}} \left[\frac{A}{100} \times \frac{\sigma_{WN}}{10^{-38}\ \text{cm}^2} \times \frac{\langle v \rangle}{220\ \text{km s}^{-1}} \times \frac{\rho_0}{0.3\ \text{GeV cm}^{-3}} \right]$$





~1 events/kg/year

Measured banana spectrum

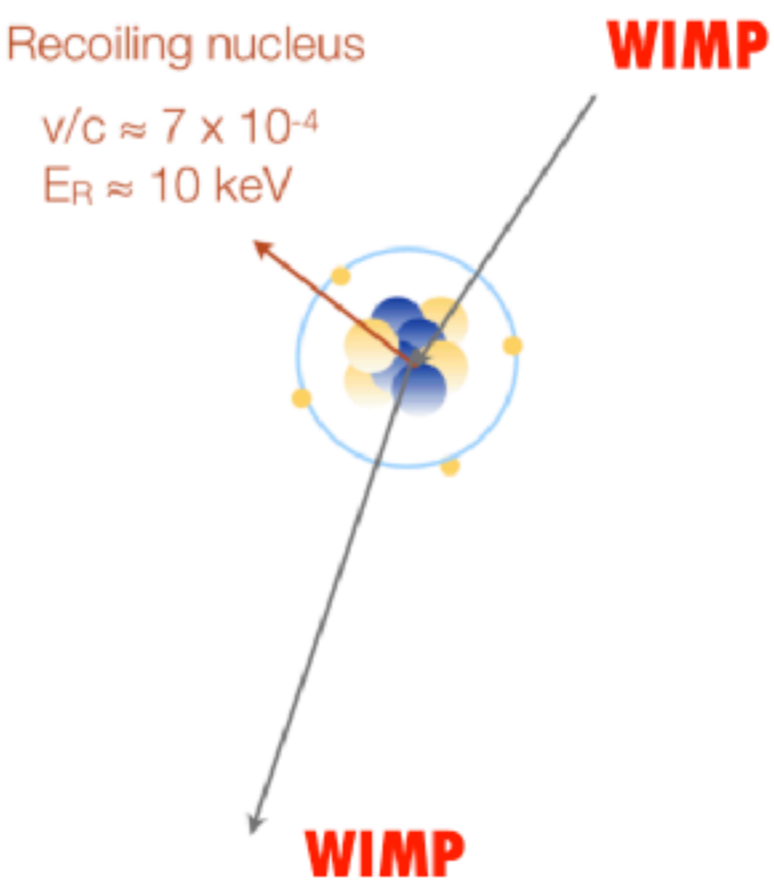


~100 events/kg/s

Interaction rate is extremely low & backgrounds extremely high

Direct DM searches signal & backgrounds

Signal

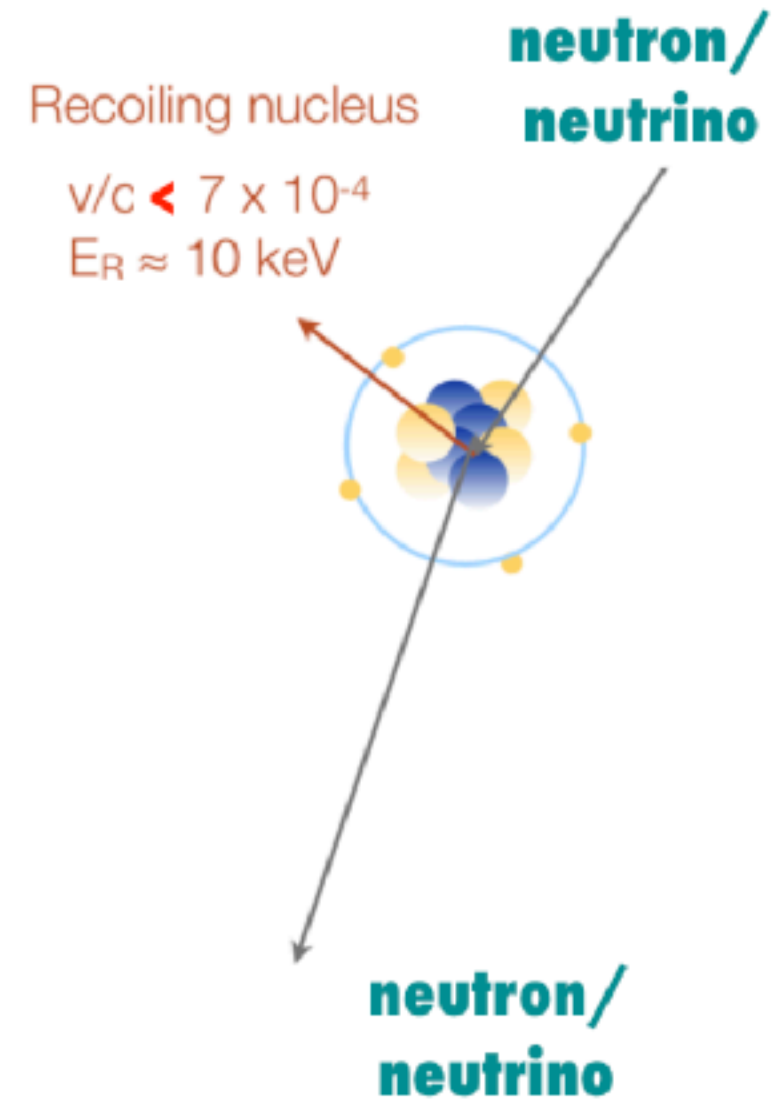


Dense energy deposition

Electromagnetic background

Sparse energy deposition

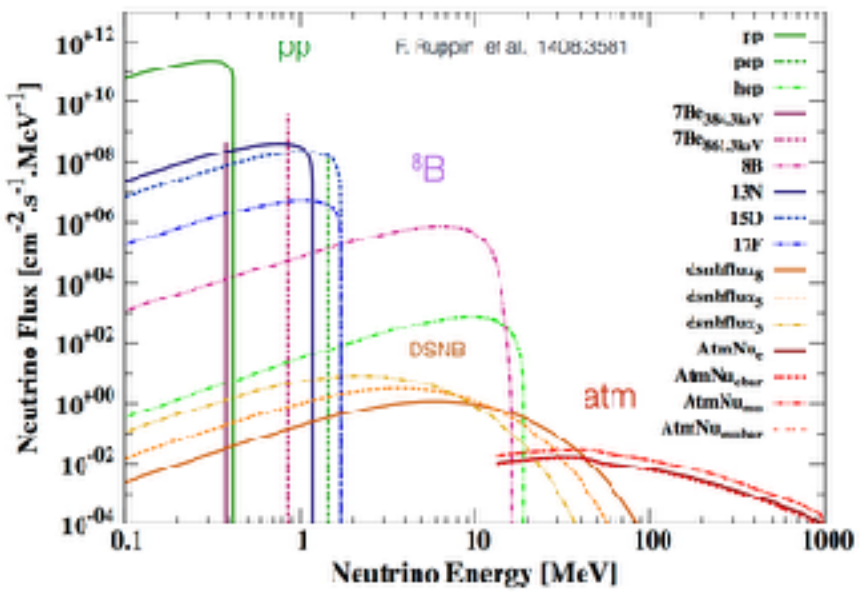
Neutral background



Dense energy deposition

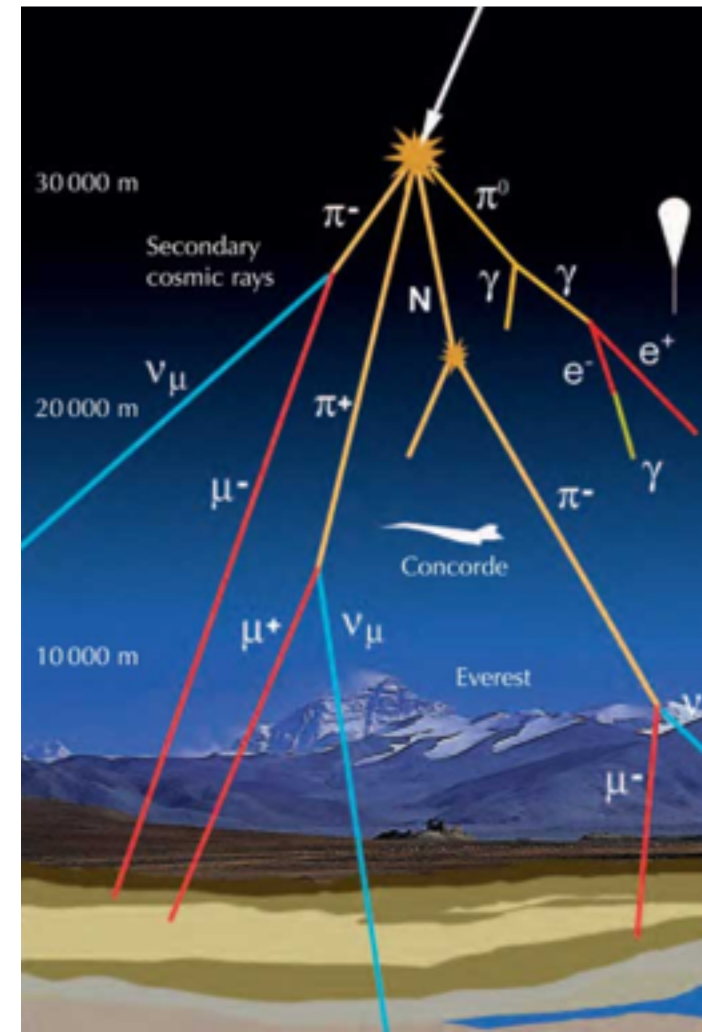
Direct DM searches backgrounds

Neutrinos from Sun, atmospheric and diffuse supernovae

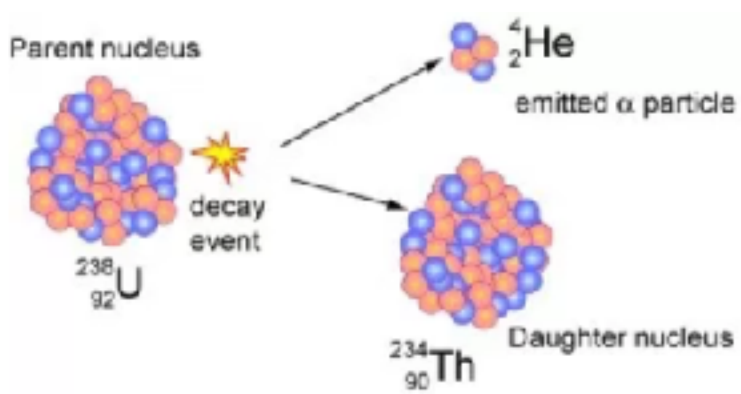


Dark Matter

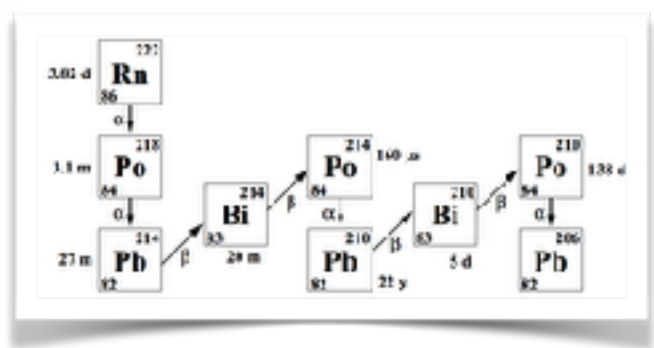
Cosmic rays & cosmogenic activation of detector materials



Natural radioactivity from ^{238}U, ^{232}Th, ^{222}Rn, ^{40}K…

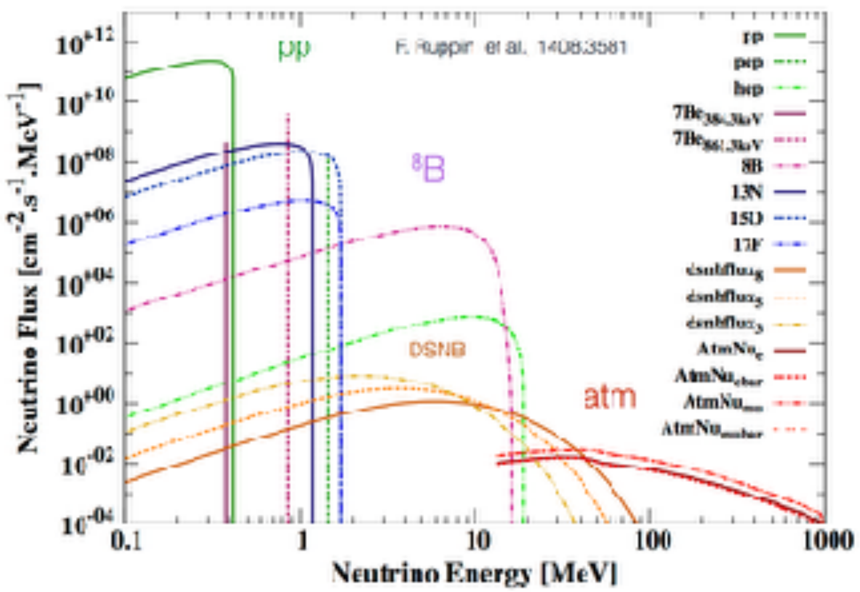


Rn progeny recoils on detectors surfaces



Direct DM searches backgrounds

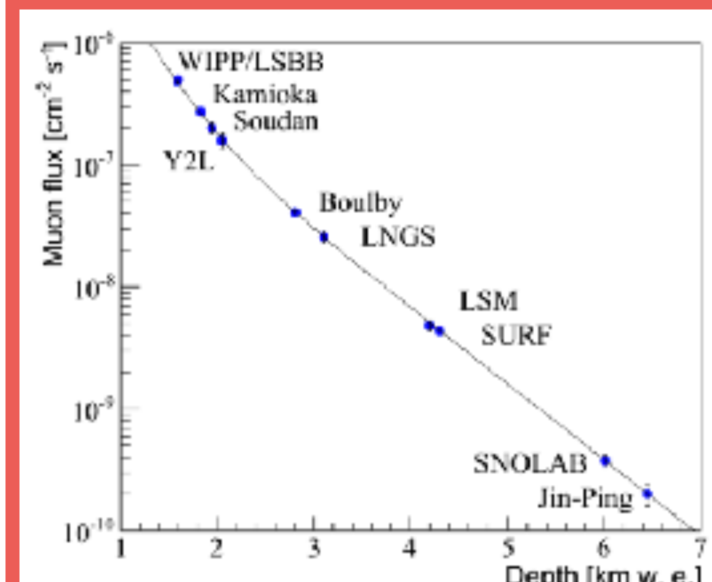
Neutrinos from Sun, atmospheric and diffuse supernovae



Dark Matter

Cosmic rays & cosmogenic activation of detector materials

Go underground + active/passive shielding + active recoil/e⁻ discrimination <u>(not available to all exp.)</u>



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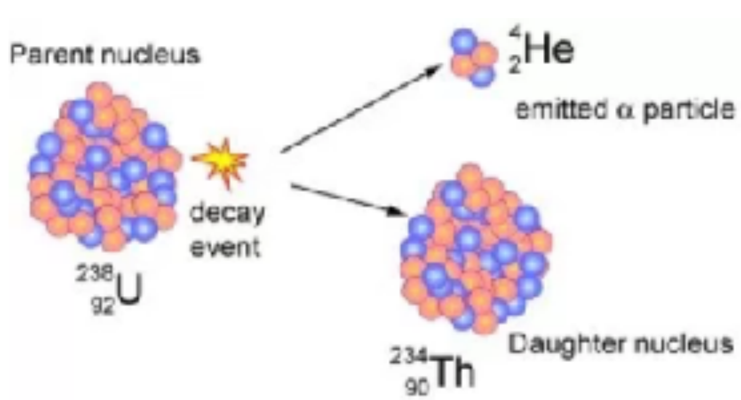

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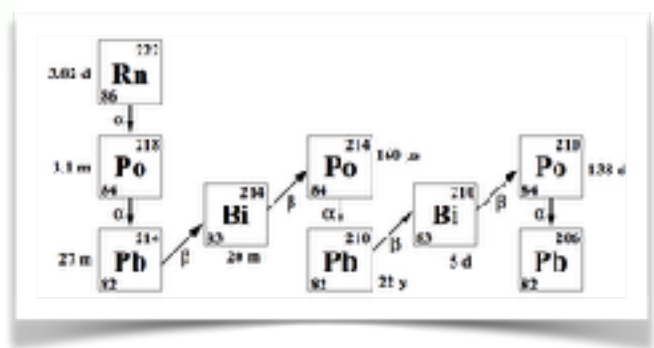

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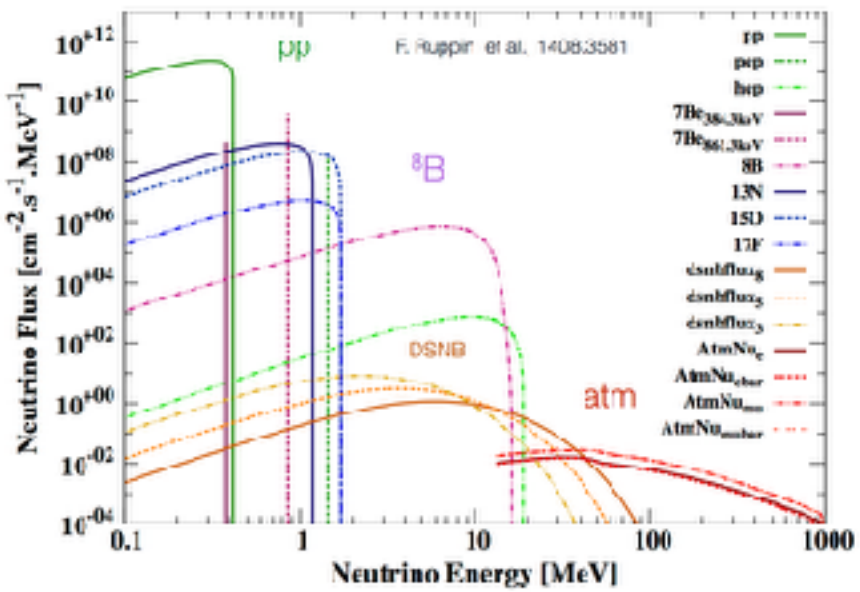
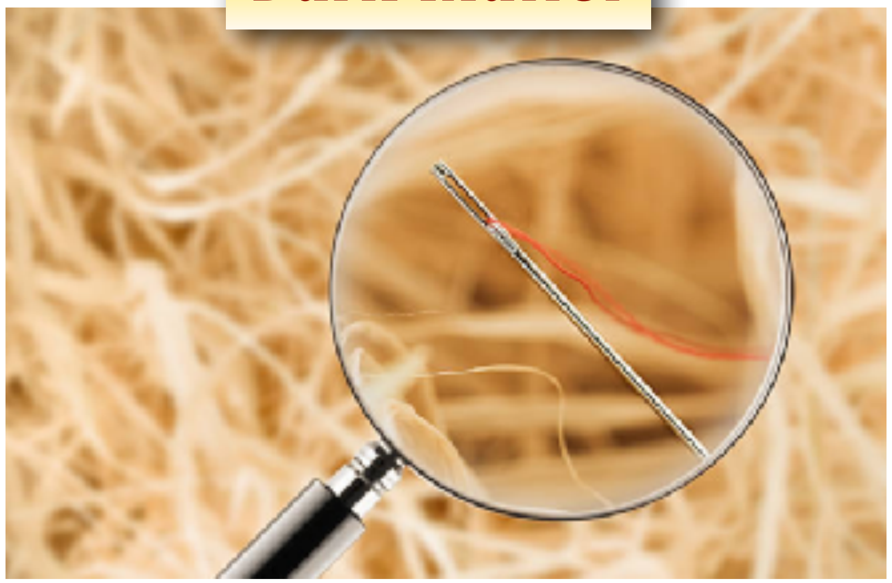


Dark Matter



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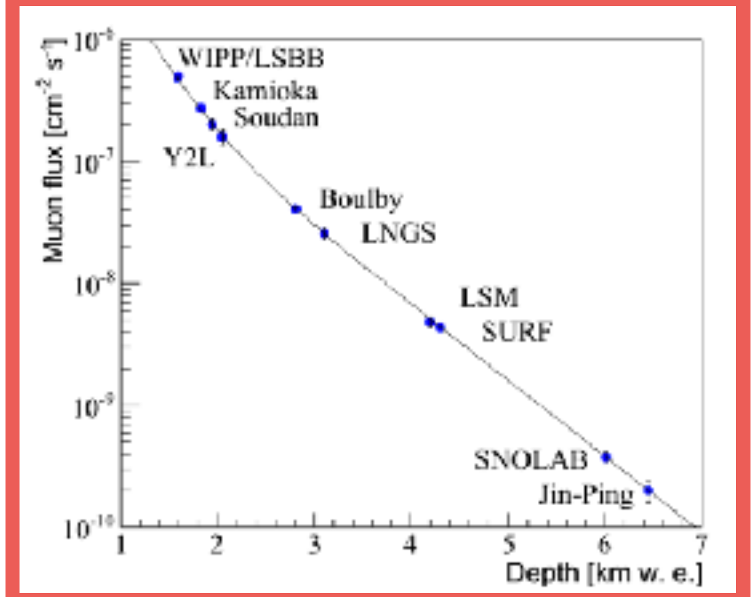

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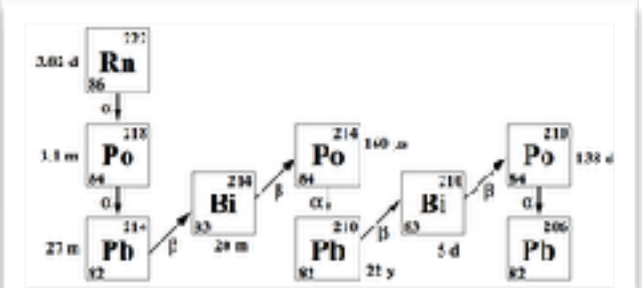

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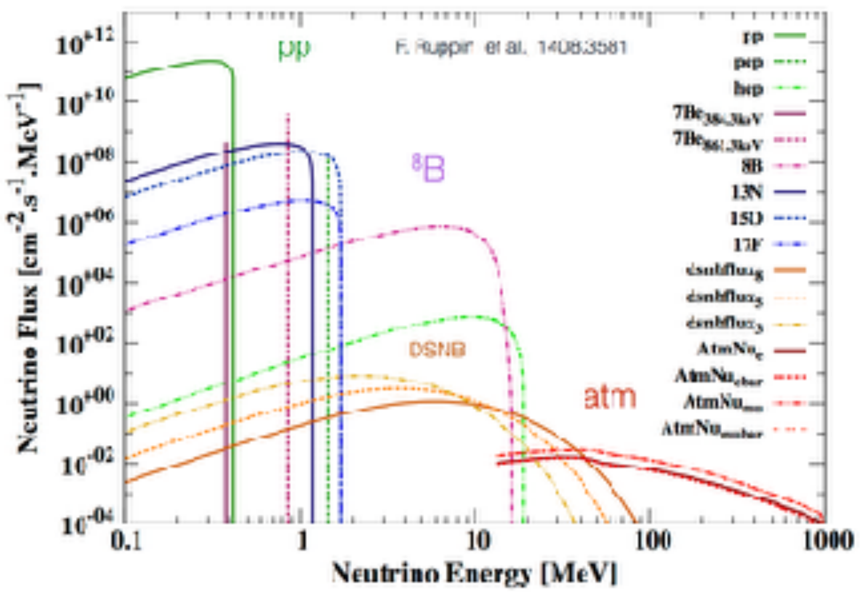

Dark Matter

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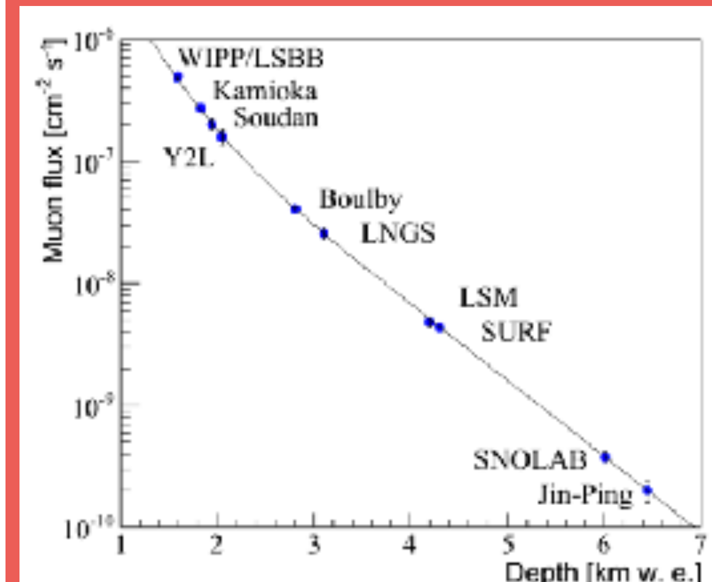


Natural radioactivity from ^{238}U, ^{232}Th, ^{222}Rn, ^{40}K…

Material selection & screening + active recoil/e⁻ discrimination <u>(not available to all exp.)</u>

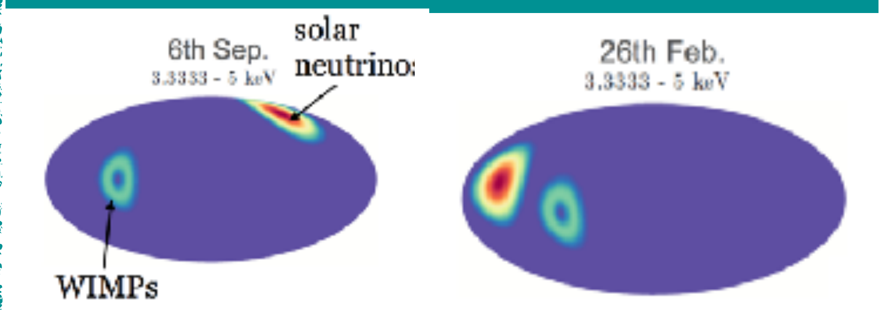
Rn progeny recoils on detectors surfaces

Measure 3D position of your event: "fiducialization" <u>(not available to all exp.)</u>

Direct DM searches backgrounds

Neutrinos from Sun, atmospheric and diffuse supernovae

Only if you can measure track direction (i.e. correlate with the source), only for Solar Neutrinos



Dark Matter

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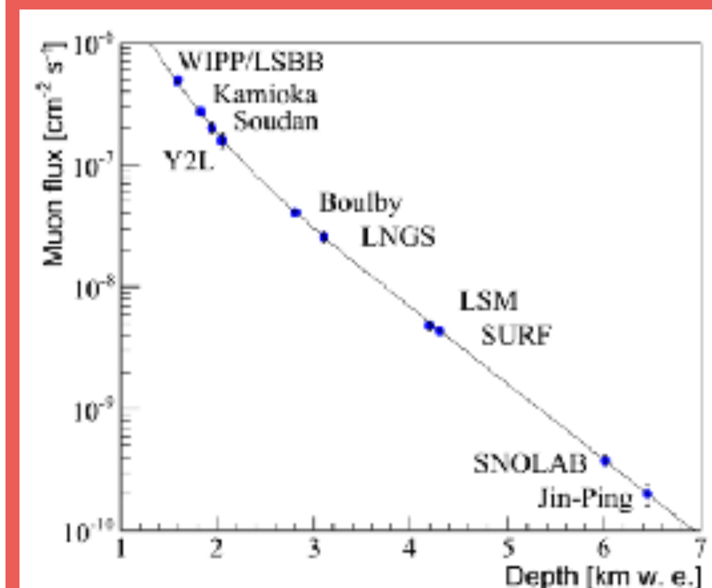

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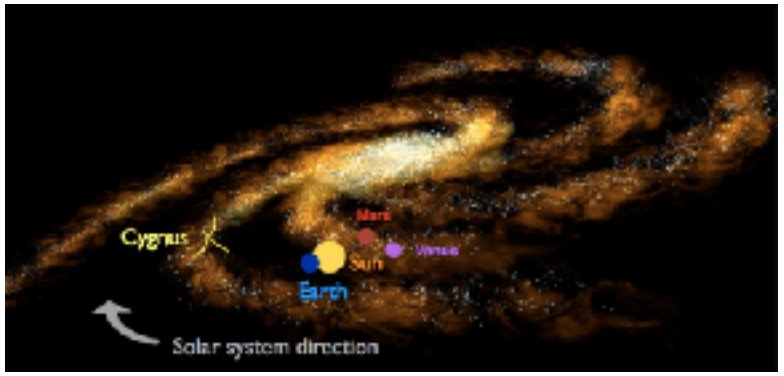
Material selection & screening + active recoil/e- discrimination
<u>(not available to all exp.)</u>

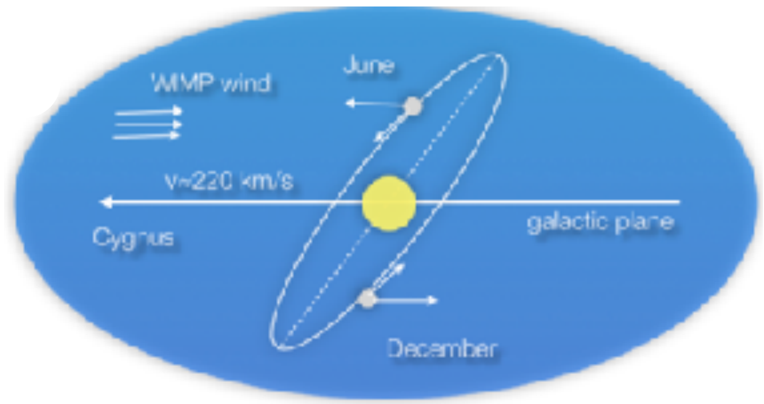
Rn progeny recoils on detectors surfaces

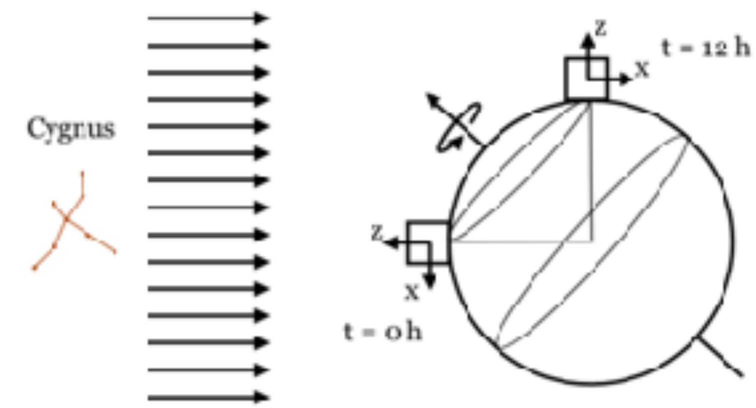
Measure 3D position of your event: "fiducialization"
<u>(not available to all exp.)</u>

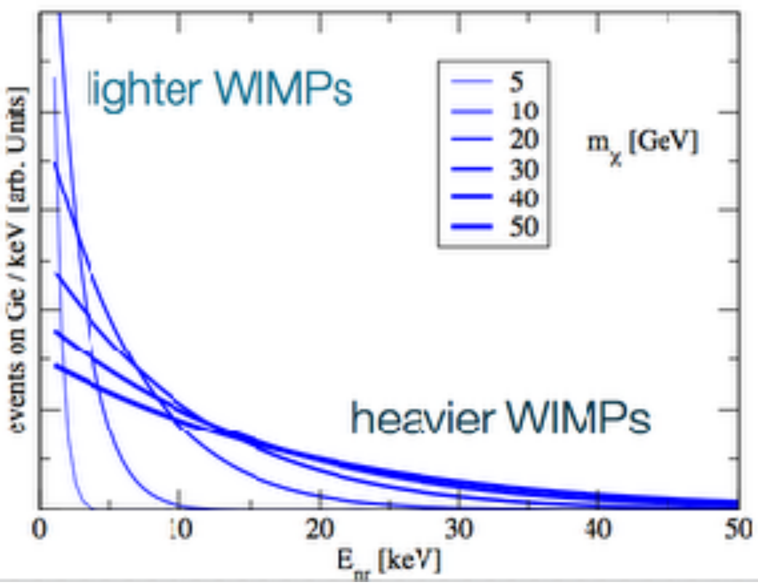
Direct Dark Matter search signal

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

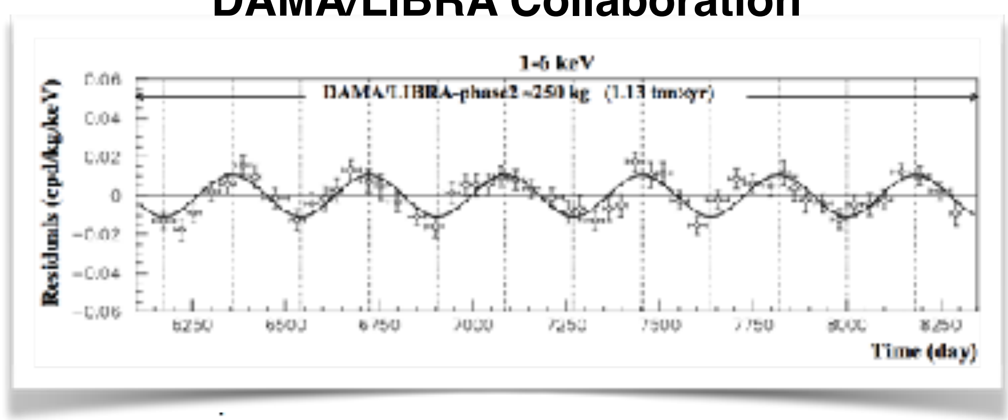




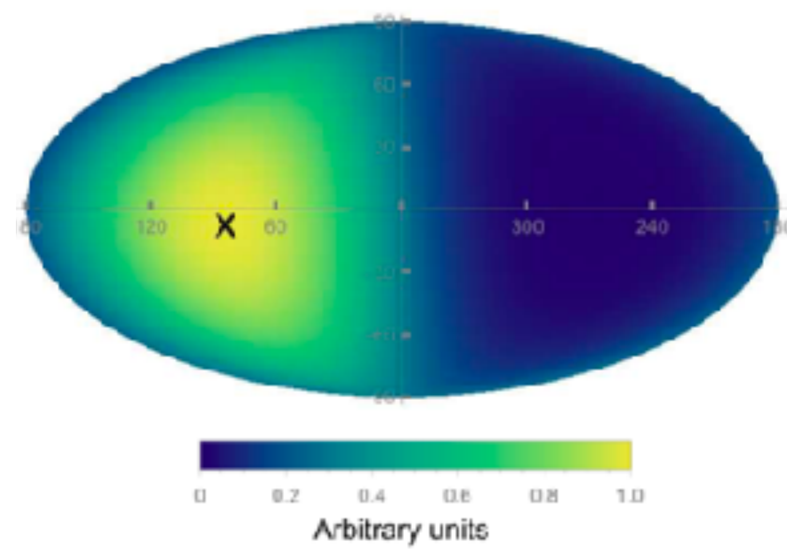




DAMA/LIBRA Collaboration



Universe 4 (2018) no.11, 116



Energy dependence:
a falling exponential with
no peculiar features

What most of experiments measure

Temporal dependence:
a few % annual modulation

Directional dependence:
an O(100) forward/backward asymmetry that no background whatsoever can mimic

Directional DM searches features

The only approach able to unambiguously and positively identify a DM signal

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

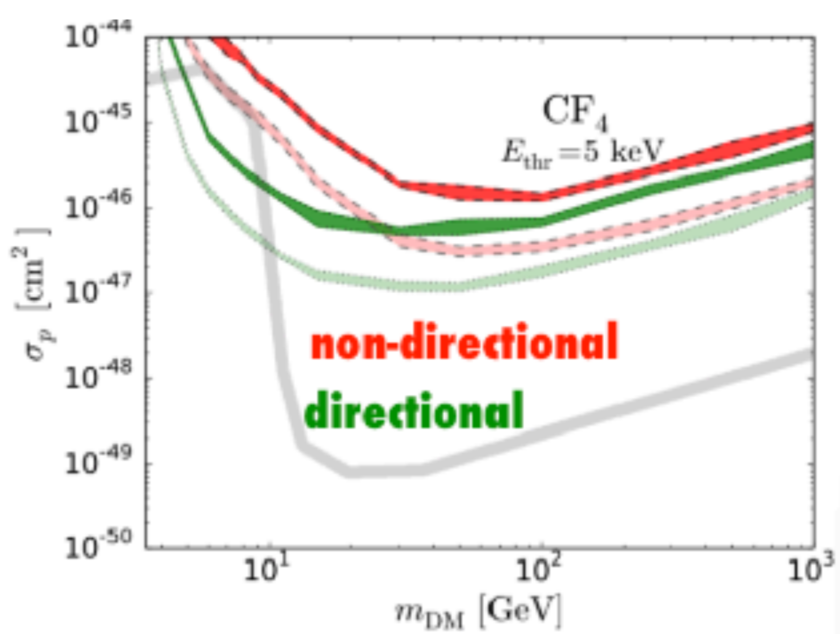
Capability to leap beyond the Neutrino Floor and to do Neutrino physics

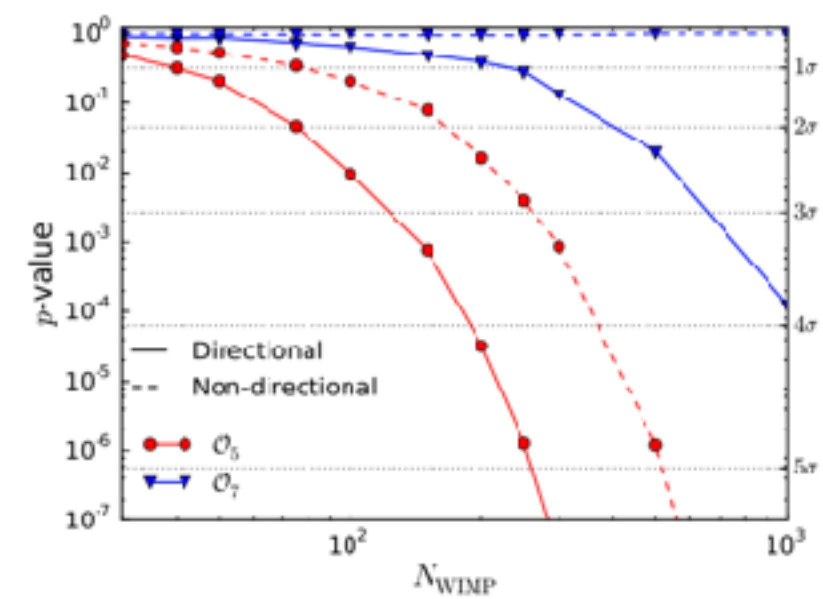
P. Grothaus, et al, Phys. Rev. D 90 (2014) no.5

Capability to probe DM nature once discovered

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

difference from baseline configuration	N_{90}	N_{95}
none	7	11
$E_{TH} = 0$ keV	13	21
no recoil reconstruction uncertainty	5	9
$E_{TH} = 50$ keV	5	7
$E_{TH} = 100$ keV	3	5
$S/N = 10$	8	14
$S/N = 1$	17	27
$S/N = 0.1$	99	170
3-d axial read-out	81	130
2-d vector read-out in optimal plane, raw angles	18	26
2-d axial read-out in optimal plane, raw angles	1100	1600
2-d vector read-out in optimal plane, reduced angles	12	18
2-d axial read-out in optimal plane, reduced angles	190	270





WIMP signal in principle detectable with order 10 events

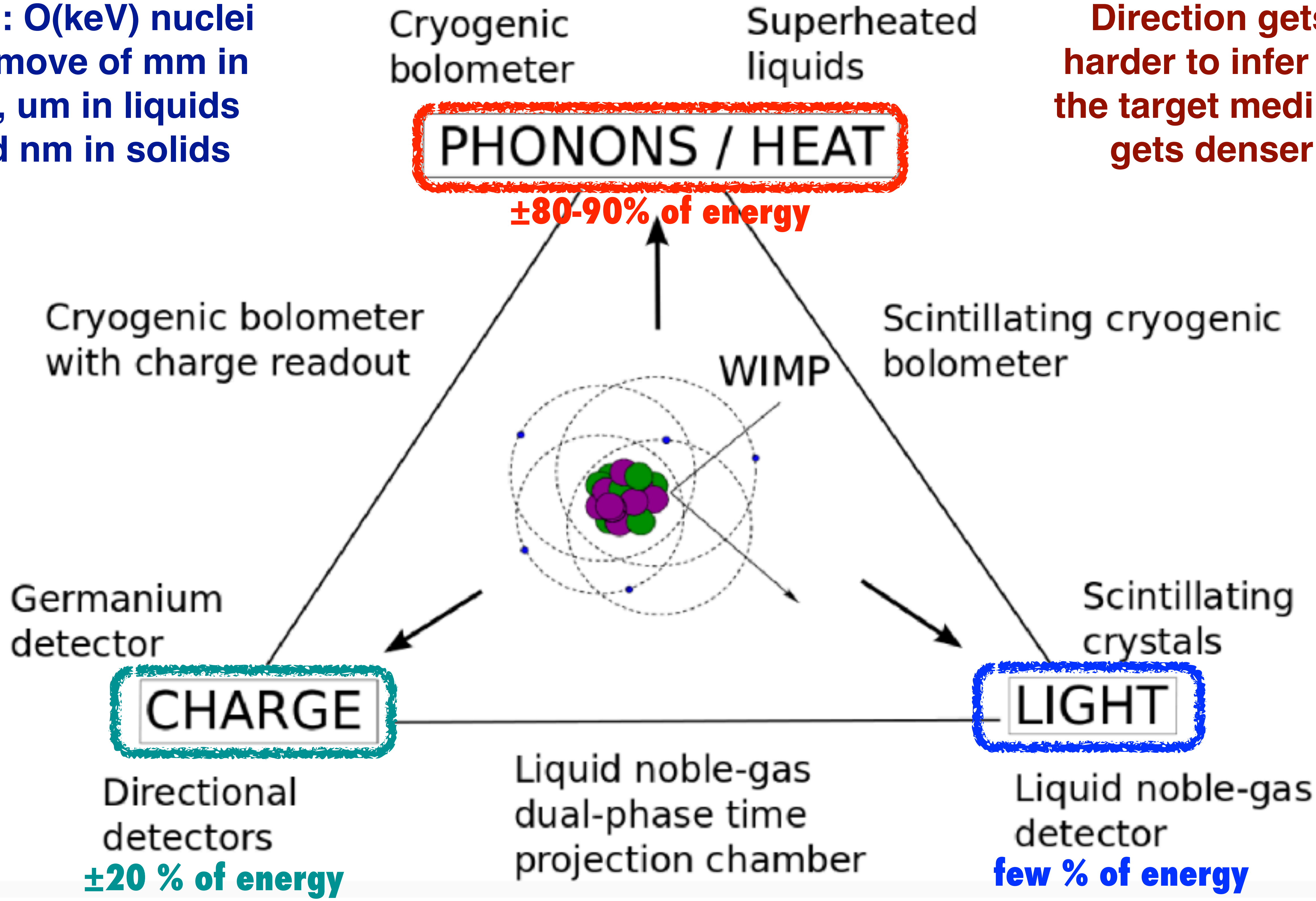
Sun neutrinos physics through CNNS

DM astronomy & DM interactions

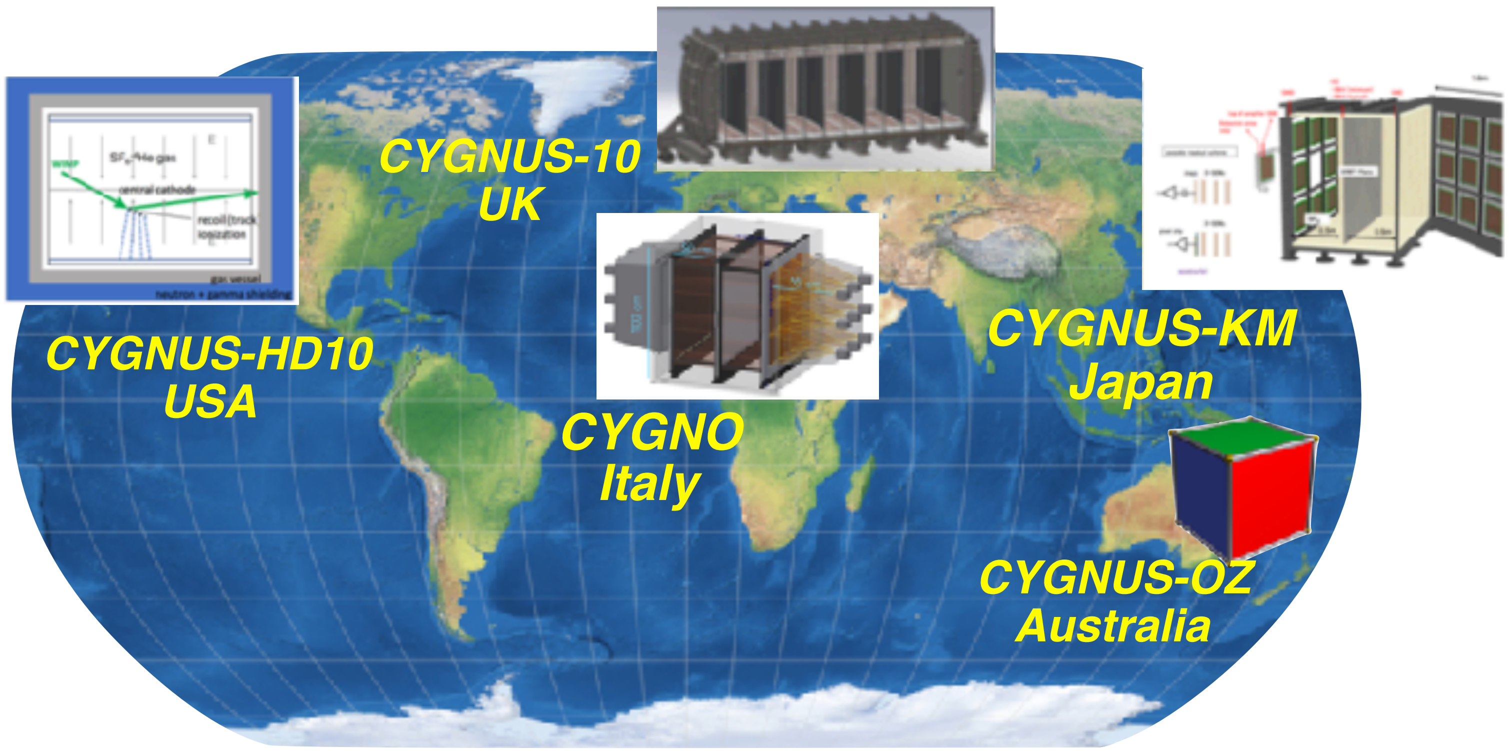
Experimental techniques

Note: O(keV) nuclei will move of mm in gas, um in liquids and nm in solids

Direction gets harder to infer as the target medium gets denser



CYGNUS-TPC vision



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

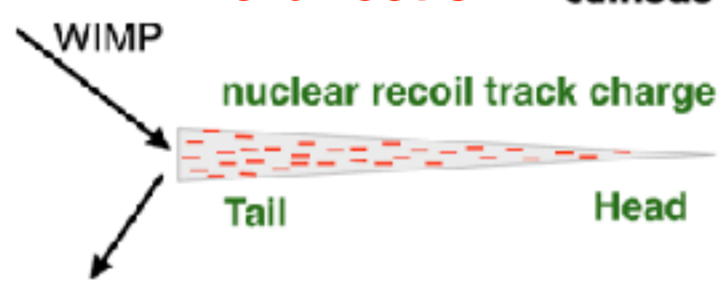
Since fall 2016

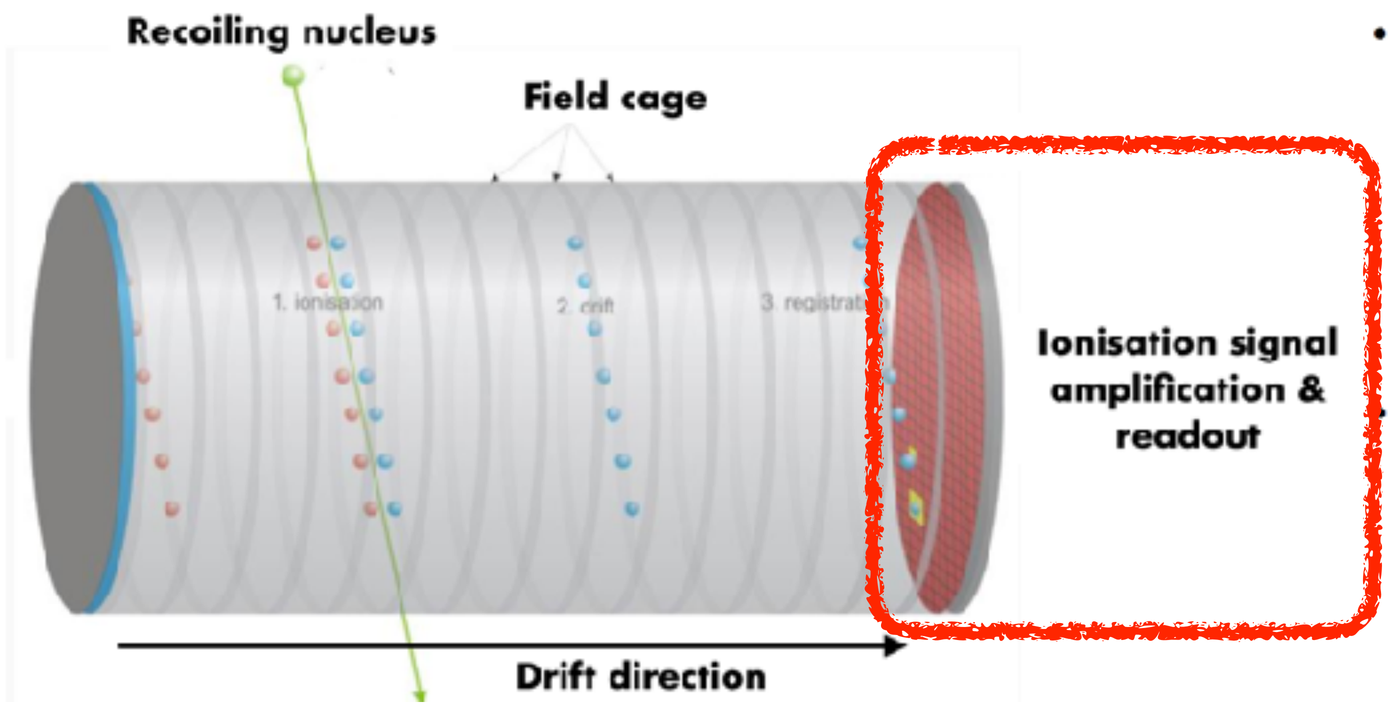
- **Helium/Fluorine-based gaseous TPC for sensitivity to low mass WIMP region for both SI and SD couplings**
- **Goal of zero background operation after electron/gamma rejection and fiducialization at O(keV)**
- **Directional and gamma/electron rejection thresholds at O(keV)**

Gas TPC concept & features

Gaseous Time Projection Chamber, inherently a 3D detector

Sensitive to track sense & direction





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

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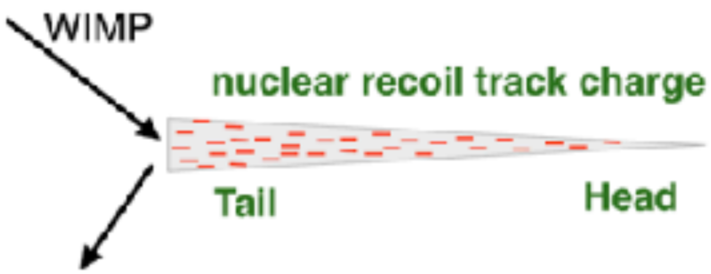

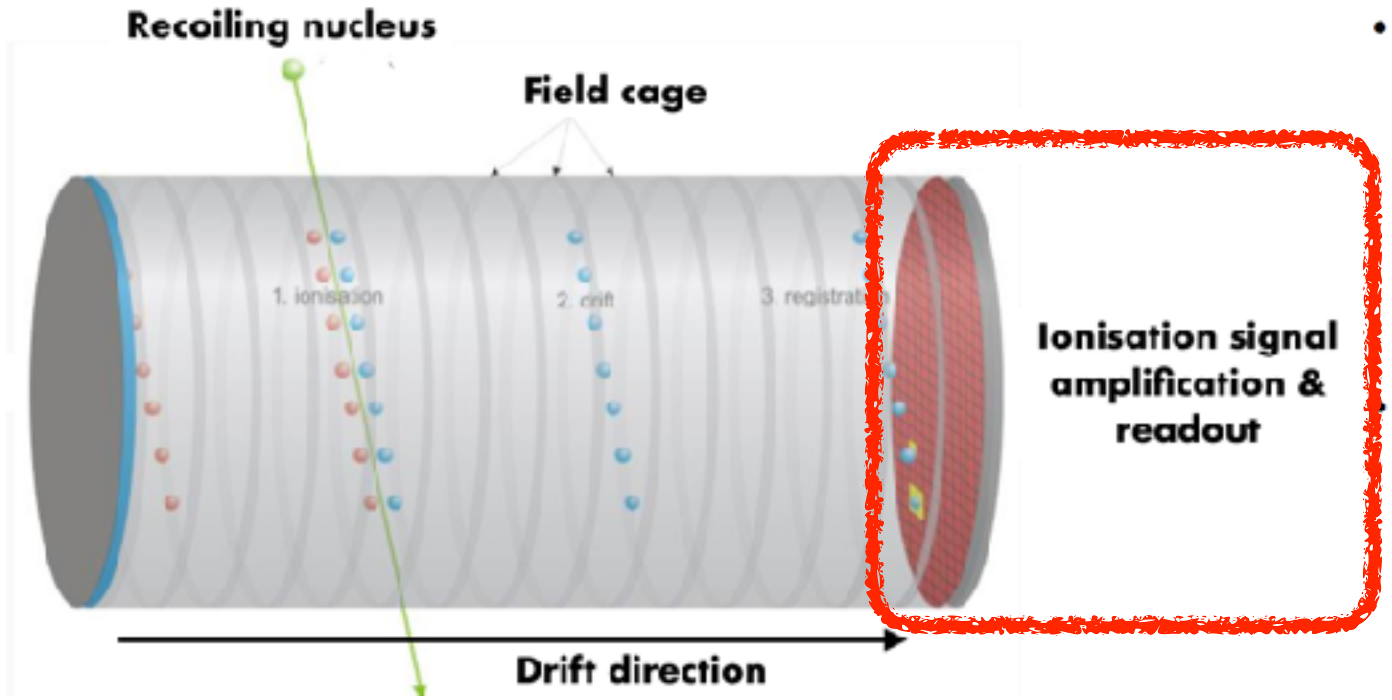

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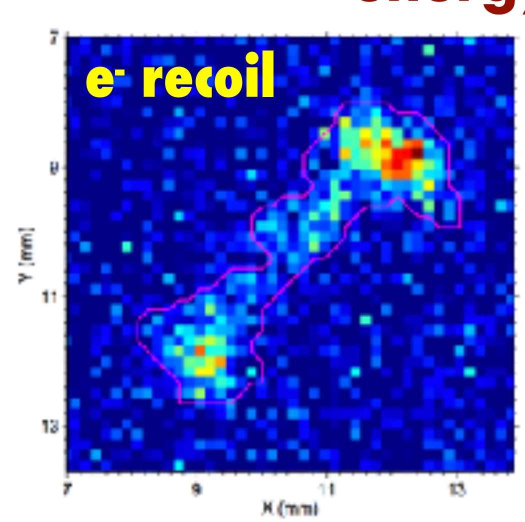
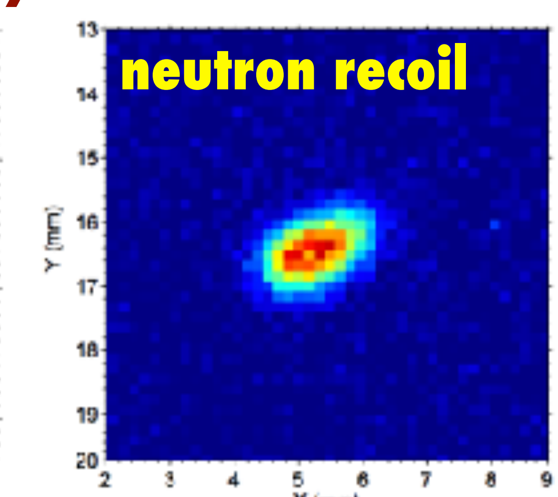
- Technologically challenging, but now achievable via multiple technologies

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



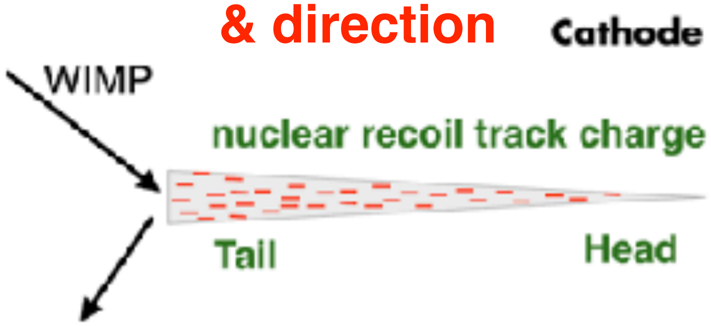


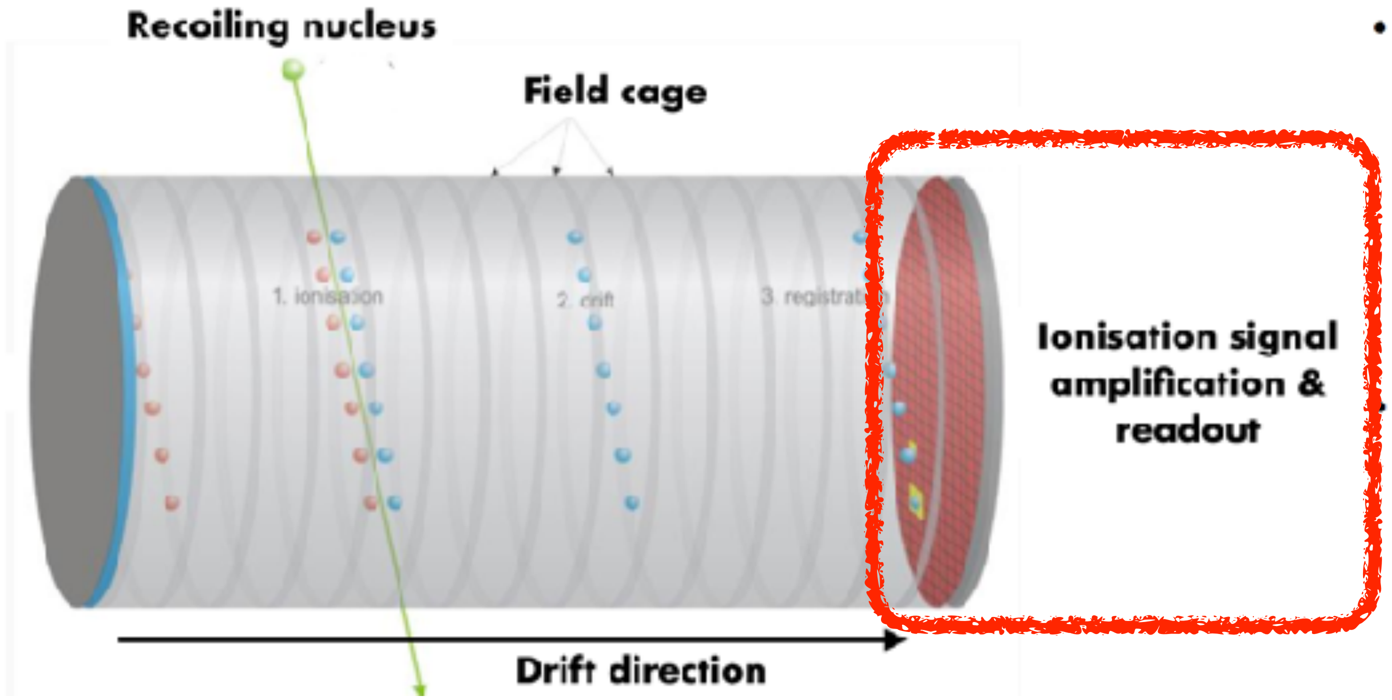
Sparse energy deposition | **Dense energy deposition**

Gas TPC concept & features

Gaseous Time Projection Chamber, inherently a 3D detector

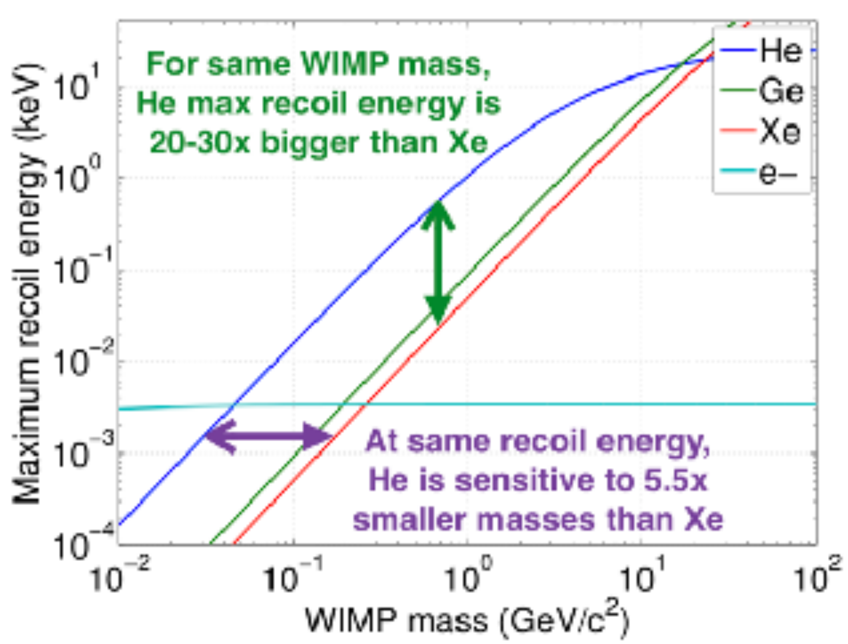
Sensitive to track sense & direction



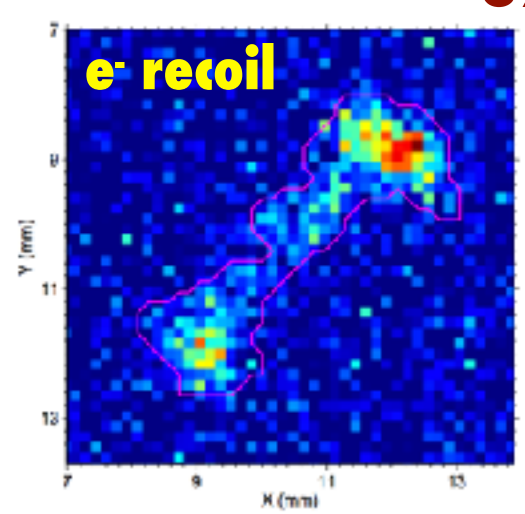


- Advantages:
  - Axial Directionality
  - **Head/tail**
  - Background rejection
  - Particle ID
  - 3D fiducialization
- Technologically challenging, but now achievable via multiple technologies

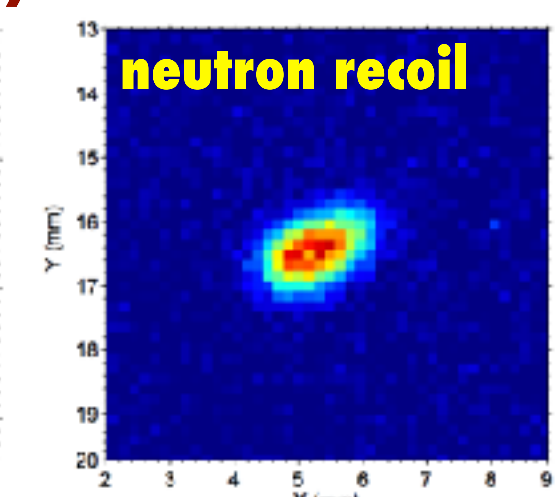
Helium-Fluorine gaseous target for simultaneous Spin Independent & Spin Dependent sensitivity to O(GeV) WIMPs



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



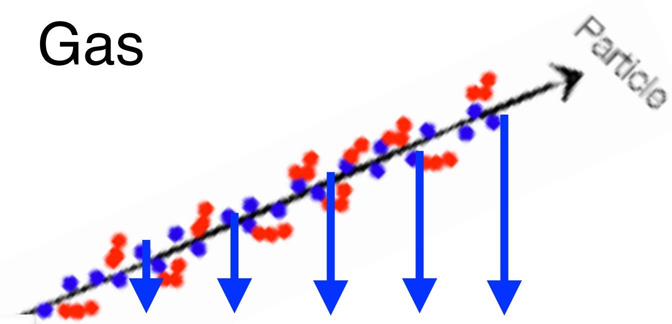
Sparse energy deposition



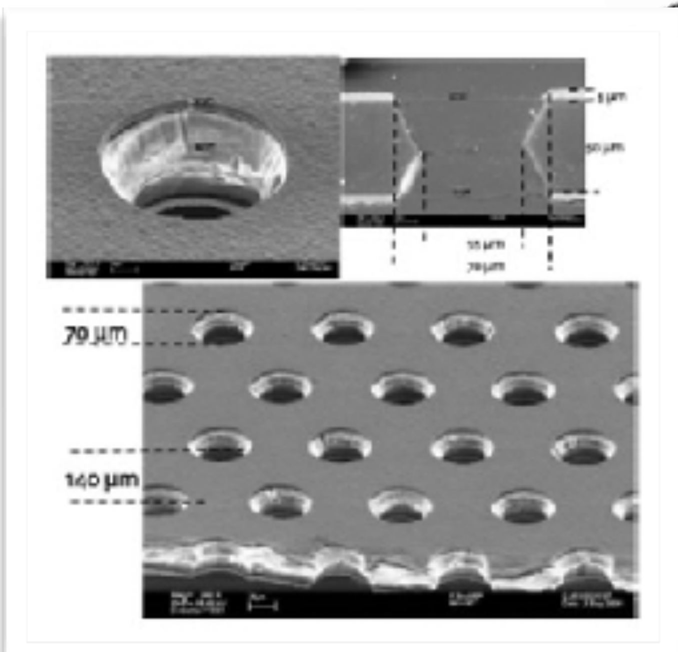
Dense energy deposition

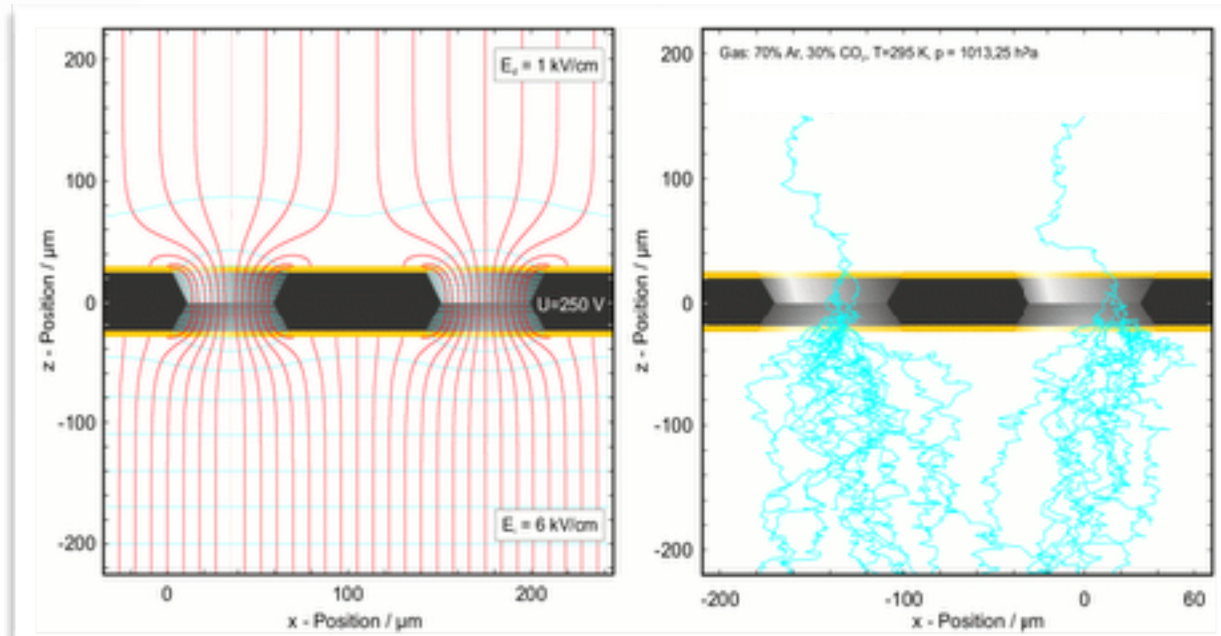
CYGNO's change of paradigm: go for the light

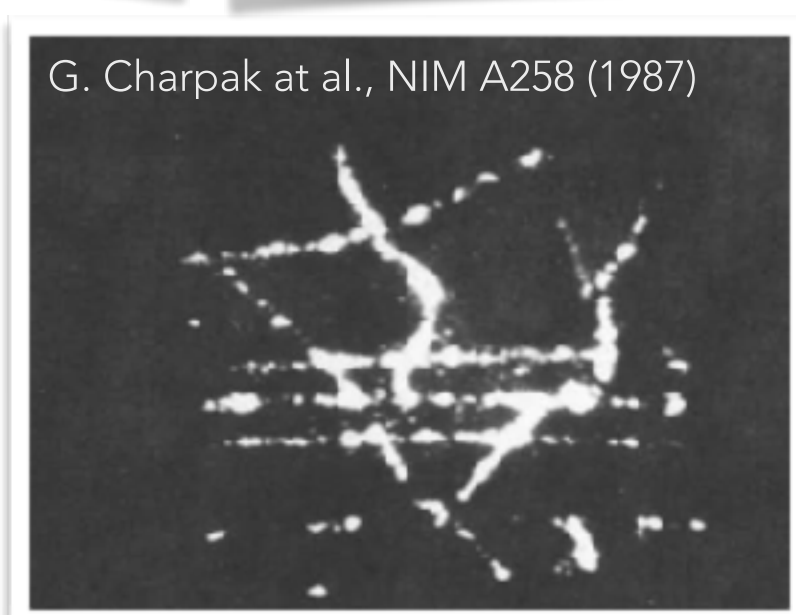
...instead of the more commonly detected electric charge



Gas Electron Multipliers (GEMs)



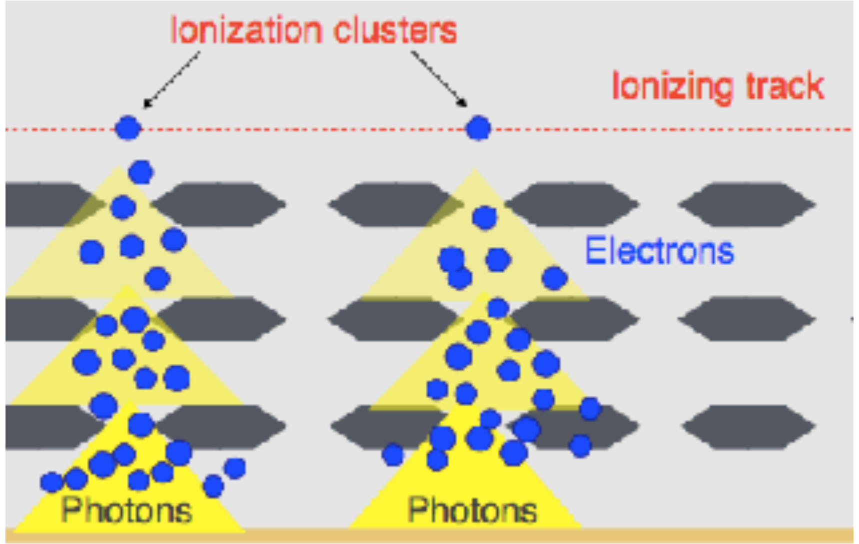


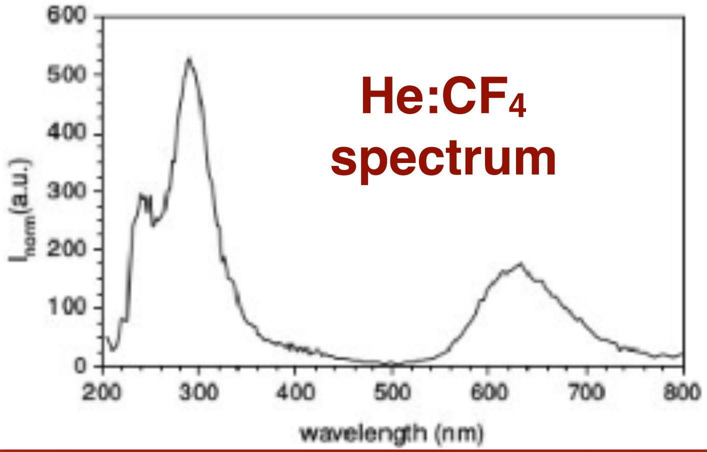


In the amplification process, photons are produced together with electrons

CYGNO amplification & readout

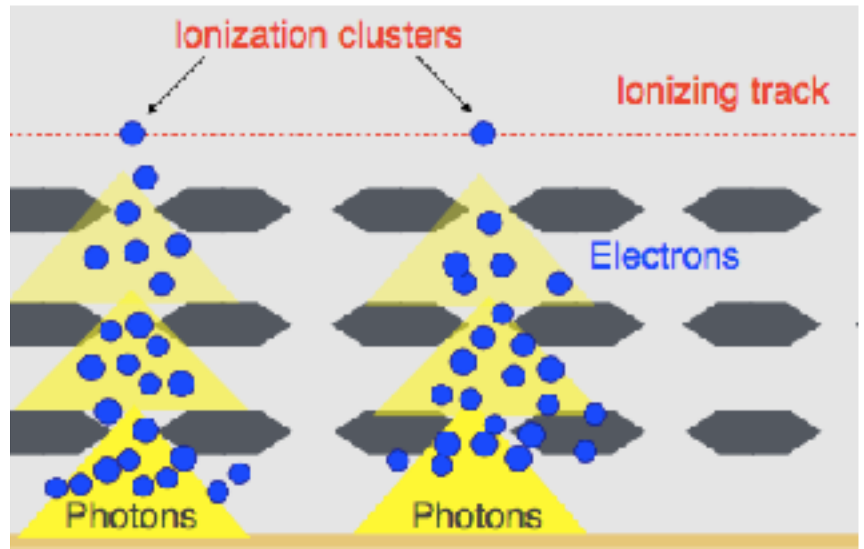
GEM amplification





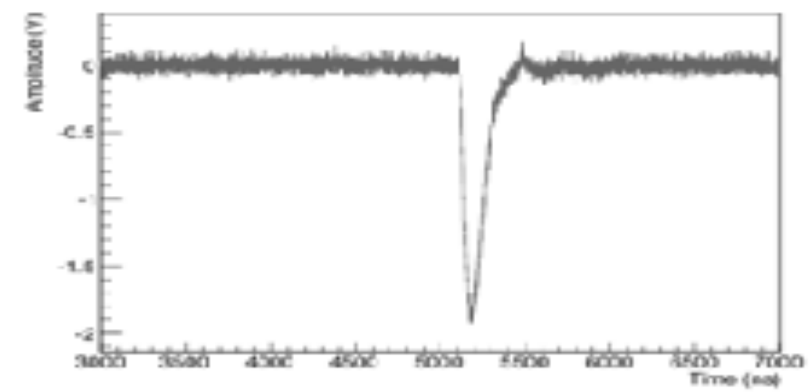
CYGNO amplification & readout

GEM amplification

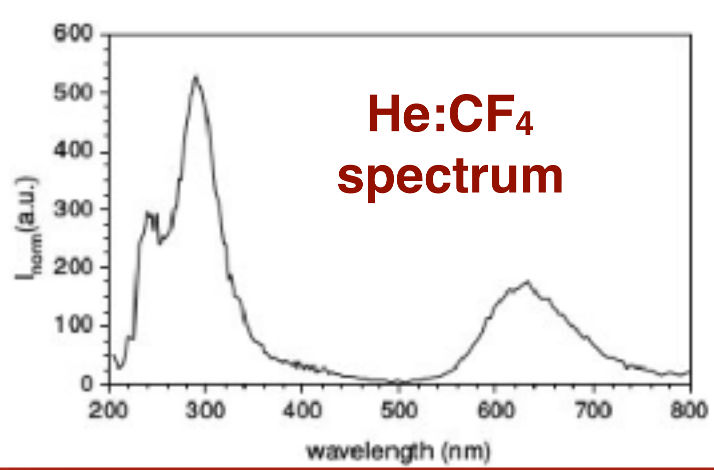


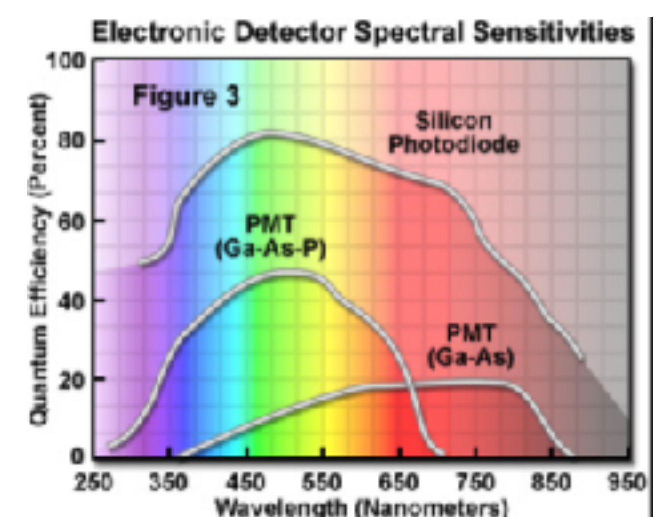
PMT:

fast, integrated
Z + energy measurement



Single photon sensitivity
Widely used in particle physics and DM searches

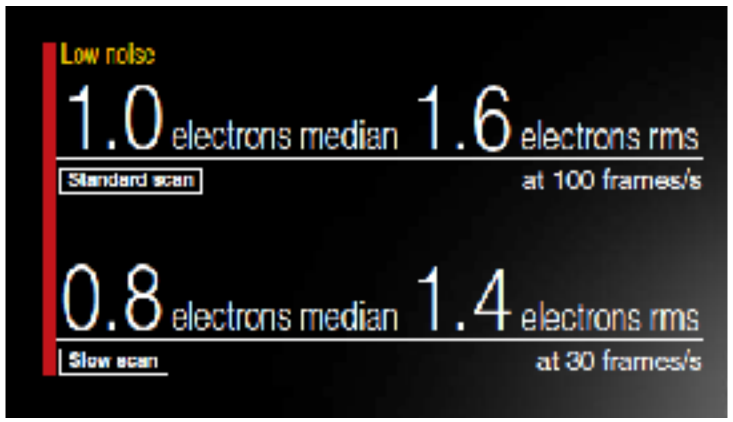




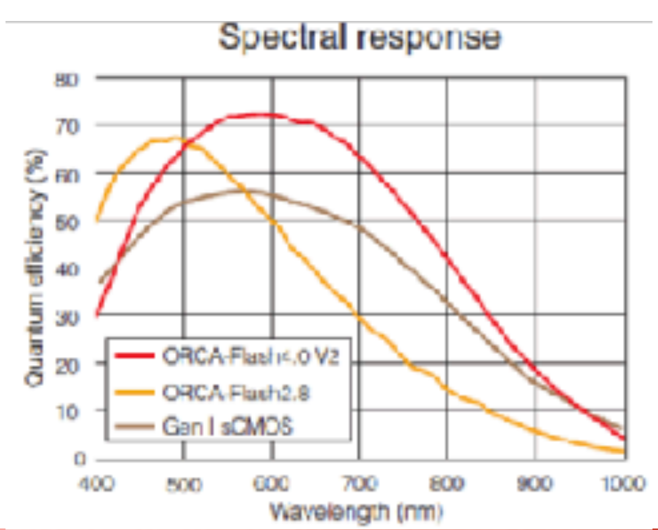
CYGNO amplification & readout

sCMOS:

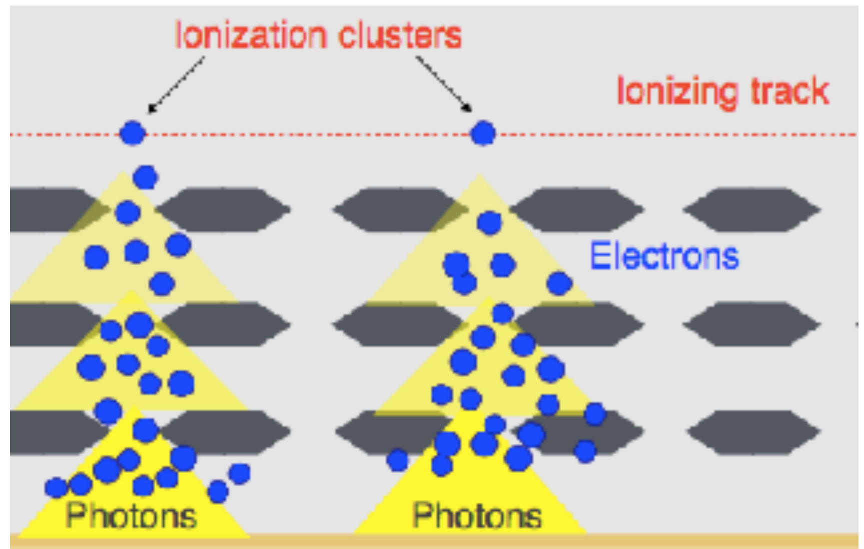
slow, high granularity
X-Y + energy measurements

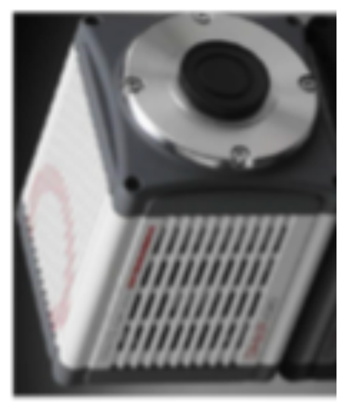


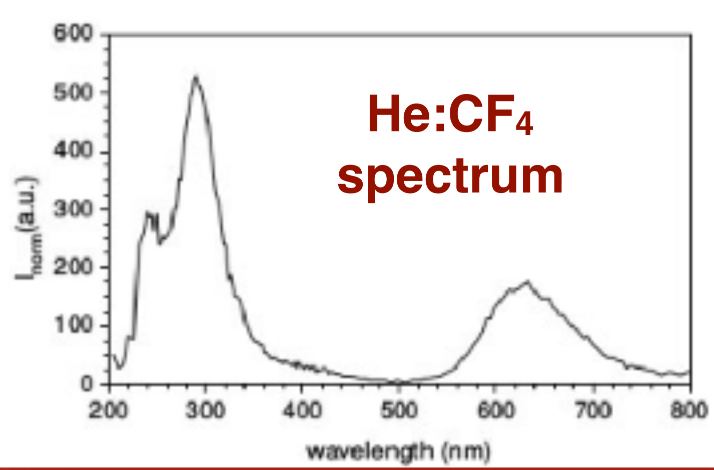
- **Market pulled**
- **Single photon sensitivity**
- **Decoupled from target**
- **Large areas with proper optics**
- **Spectral response matched to CF_4**



GEM amplification

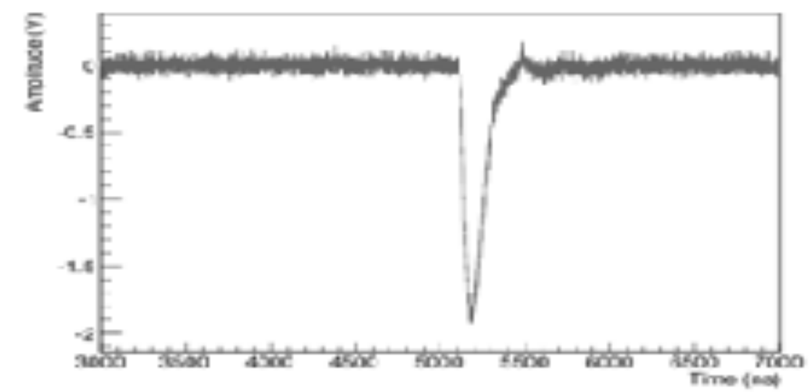




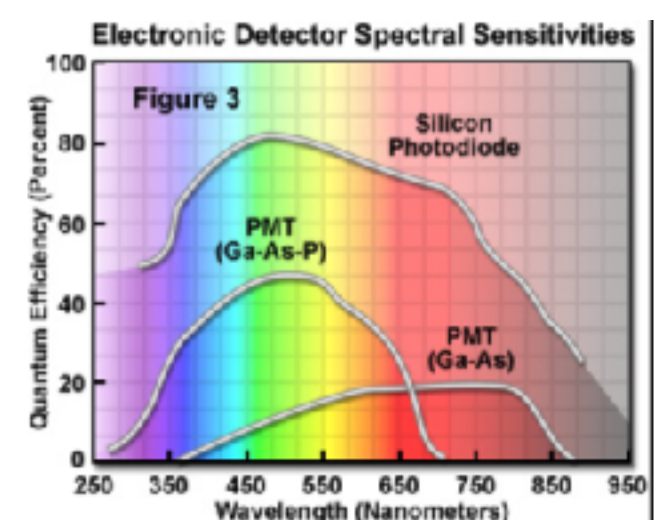


PMT:

fast, integrated
Z + energy measurement

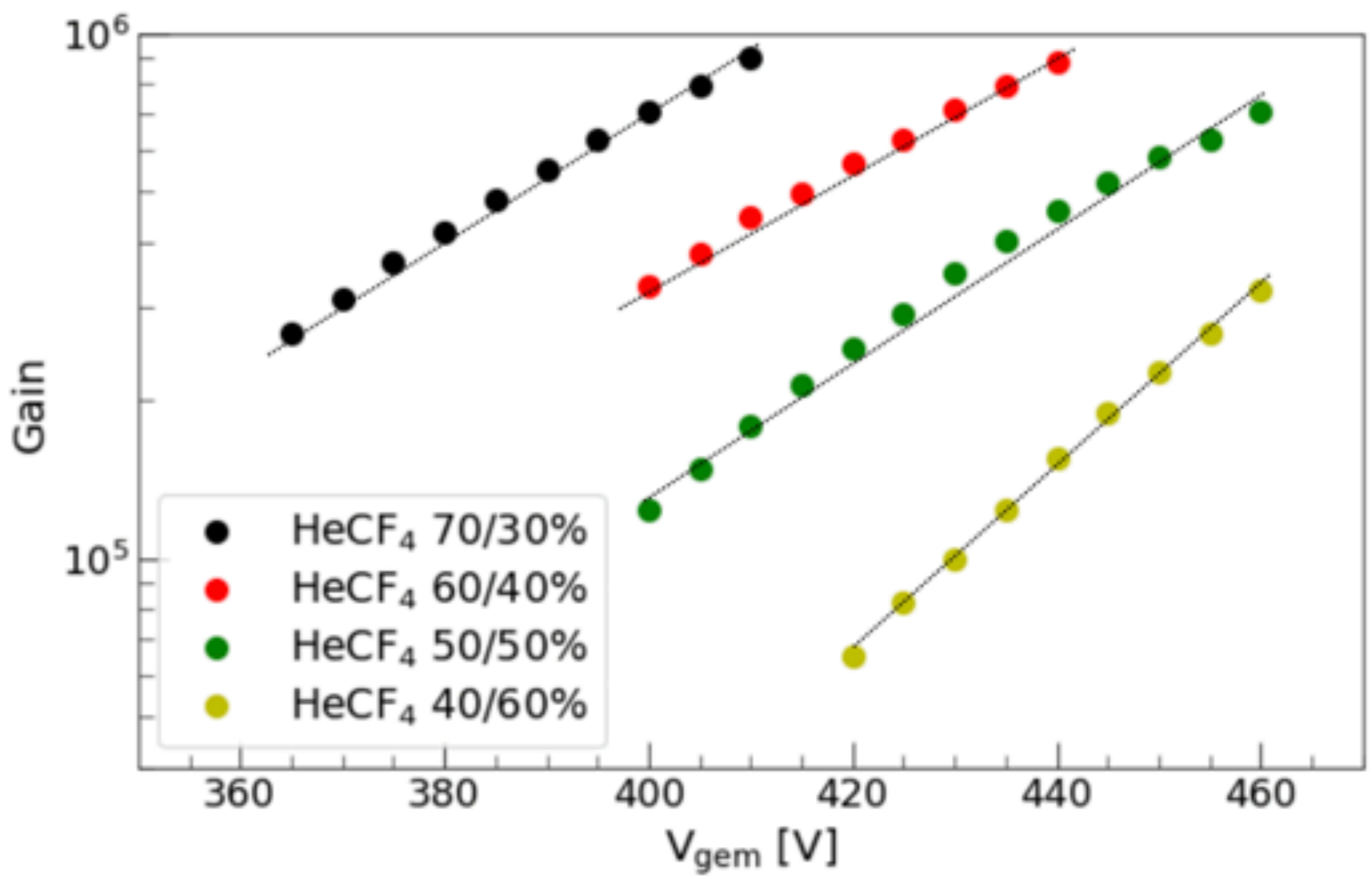


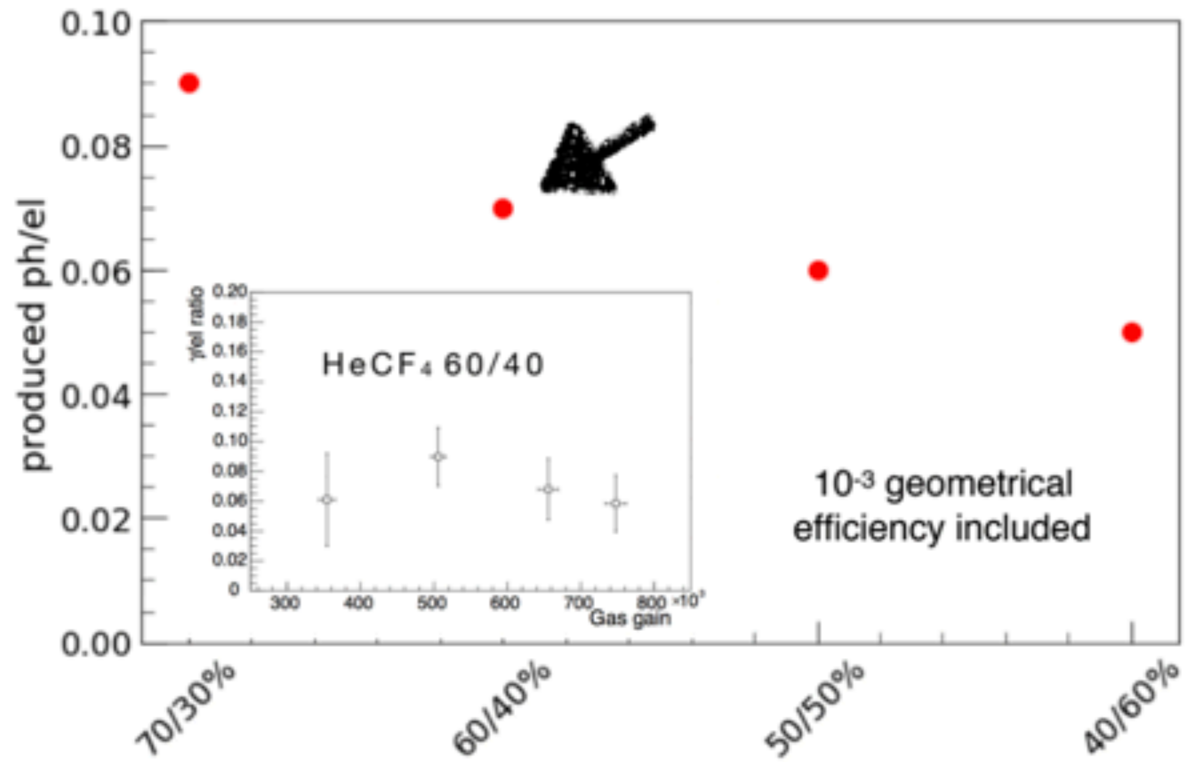
Single photon sensitivity
Widely used in particle physics and DM searches



CYGNO gas mixture

$HeCF_4$ Gain and photons efficiency



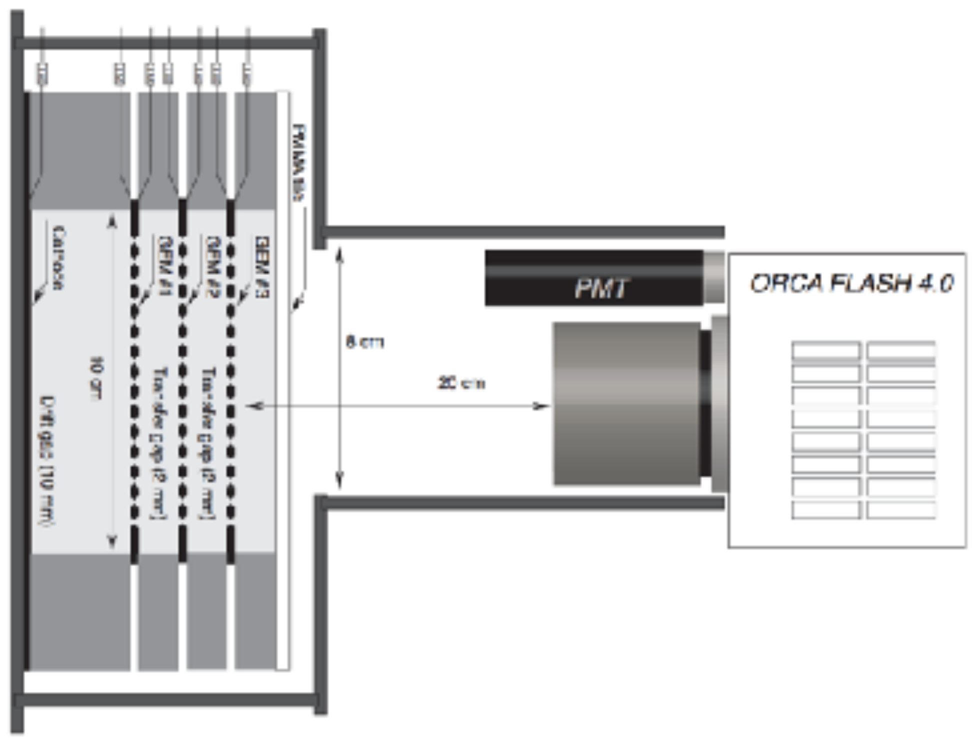


about 0.07 photons produced by secondary electron in the GEM shower

CYGNUS-RD project (2016-2018)

JINST 13 (2018) no.05, P05001

10 x 10 x 1 cm^3
0.1 Liters
Triple thin GEMs
CMOS & PMT on same side



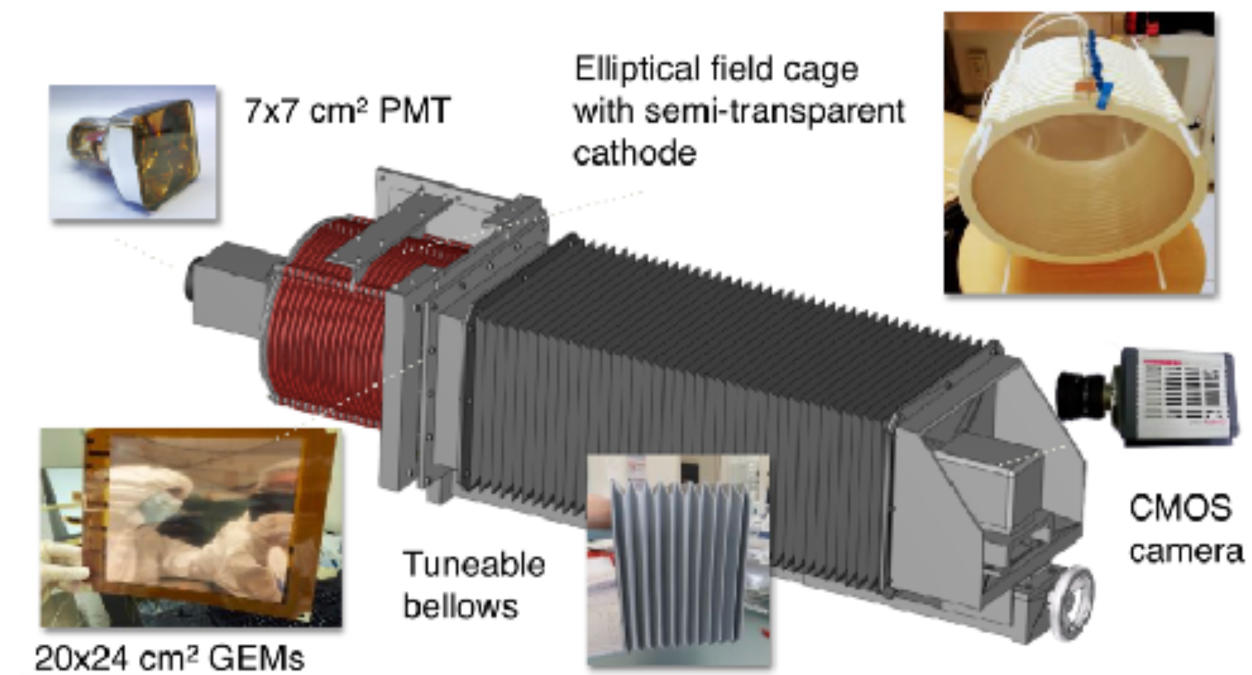
ORANGE: small prototype

Optically **R**e**A**dout **GE**ms

Camera distance ± 18 cm

PoS EPS-HEP2017 (2017) 077

24 x 20 x 20 cm^3
9.6 Liters
Triple thin GEMs
CMOS & PMT on opposite sides



LEMOn: large prototype

Large **E**lliptical **M**odule **O**ptically readout

Camera distance ± 53 cm

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

CYGNUS-RD project (2016-2018)

JINST 13 (2018) no.05, P05001

10 x 10 x 1 cm³
0.1 Liters
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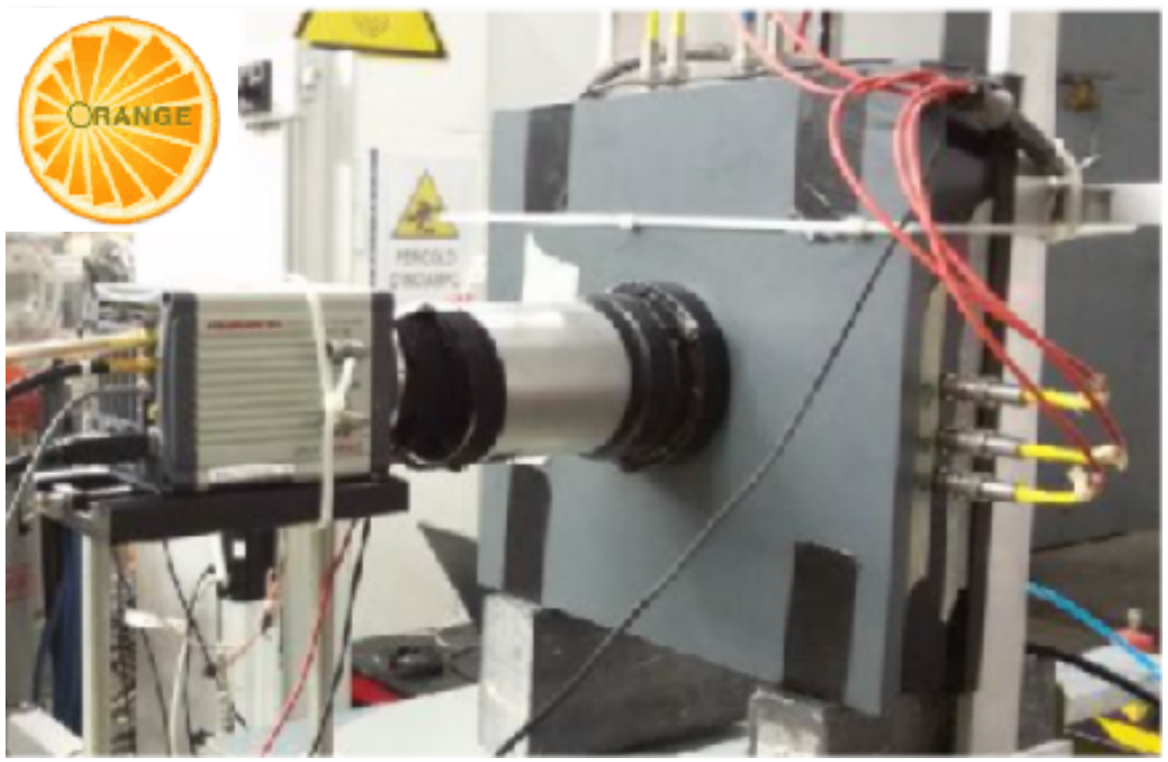


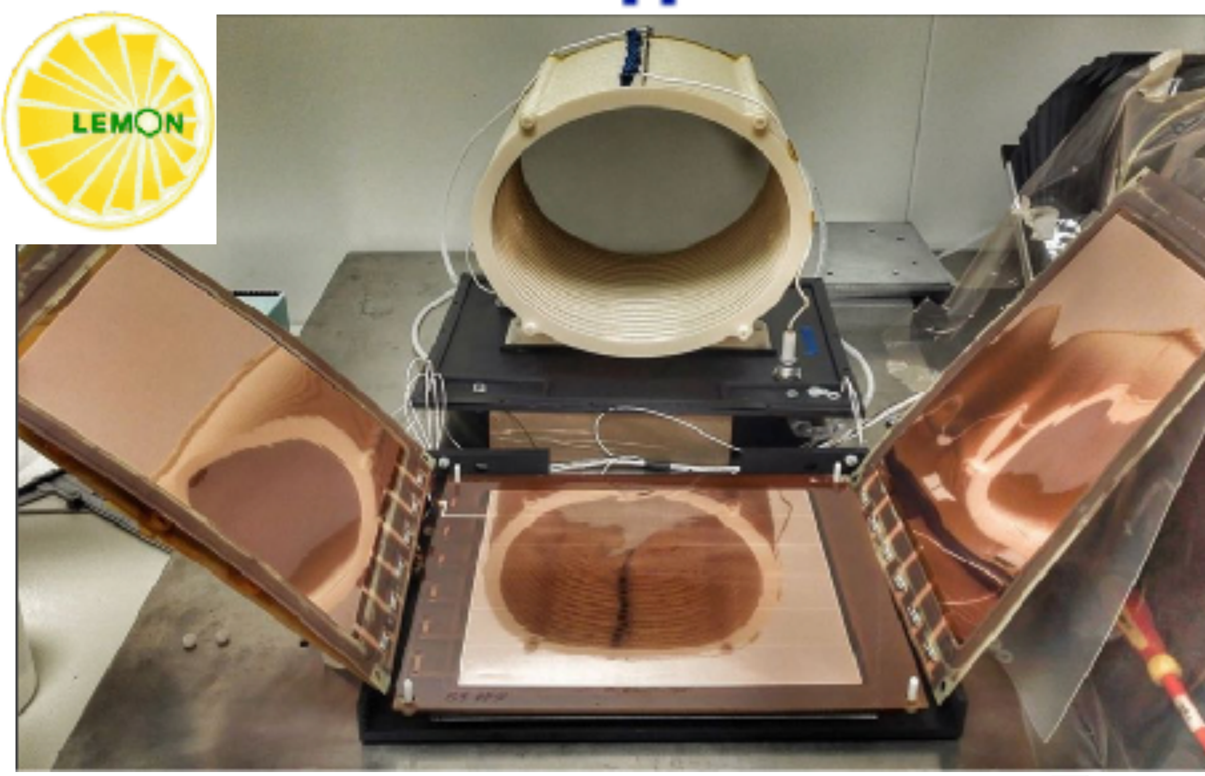
ORANGE: small prototype

Optically **ReA**dout **GE**ms

Camera distance ± 18 cm

PoS EPS-HEP2017 (2017) 077

24 x 20 x 20 cm³
9.6 Liters
Triple thin GEMs
CMOS & PMT on opposite sides



LEMOn: large prototype

Large **E**lliptical **M**odule **O**ptically readout

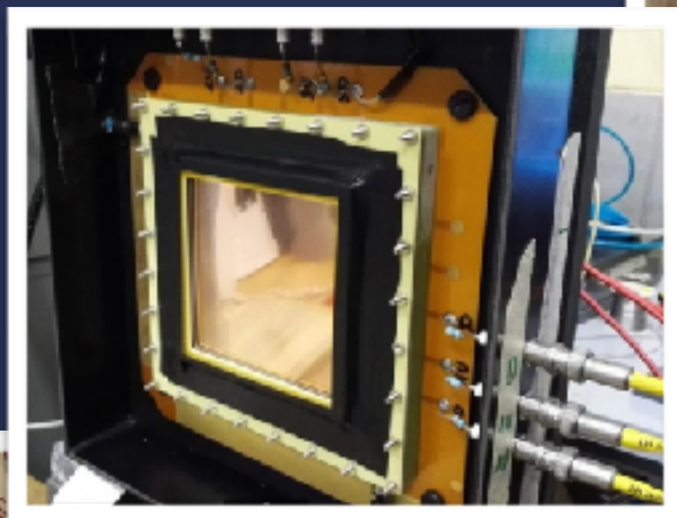
Camera distance ± 53 cm

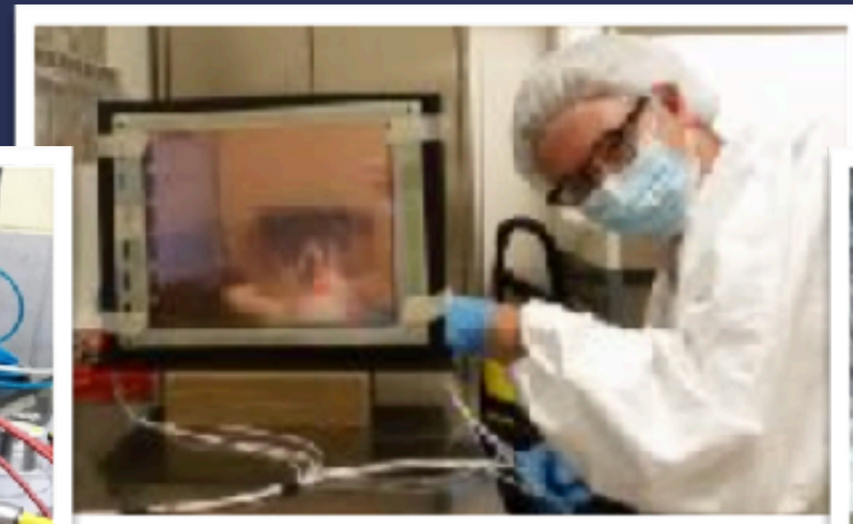
Equipped with a suitable large aperture (f/0.95) and a short focal length (25 mm) lens

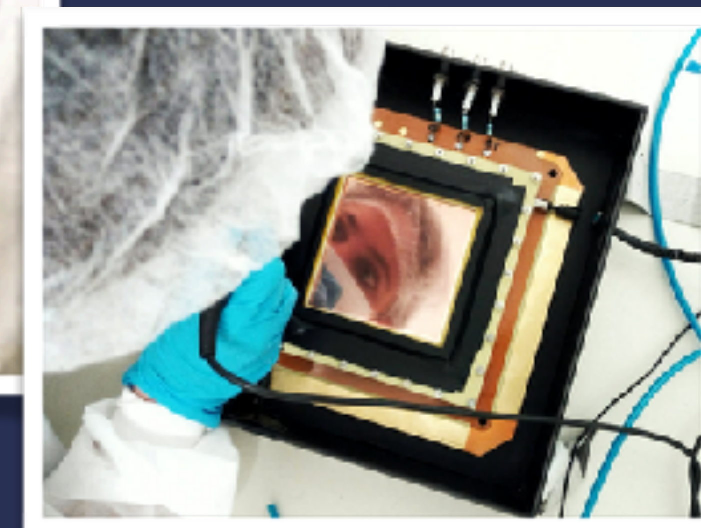
#socialdetector

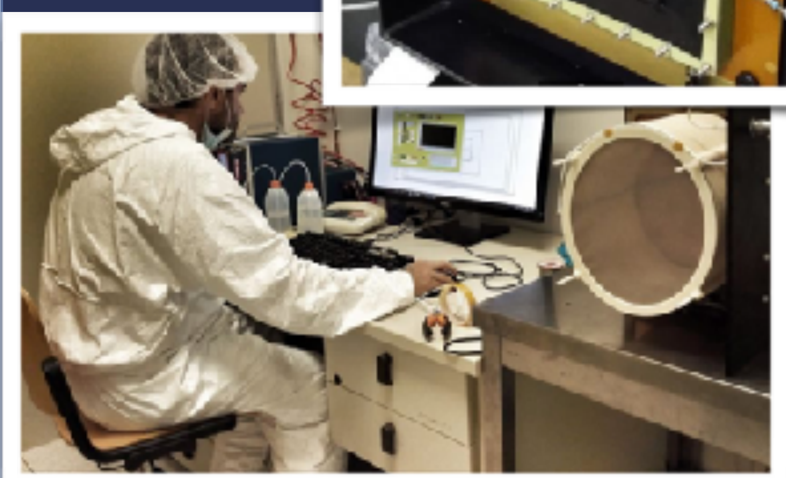
#socialdetector #infn

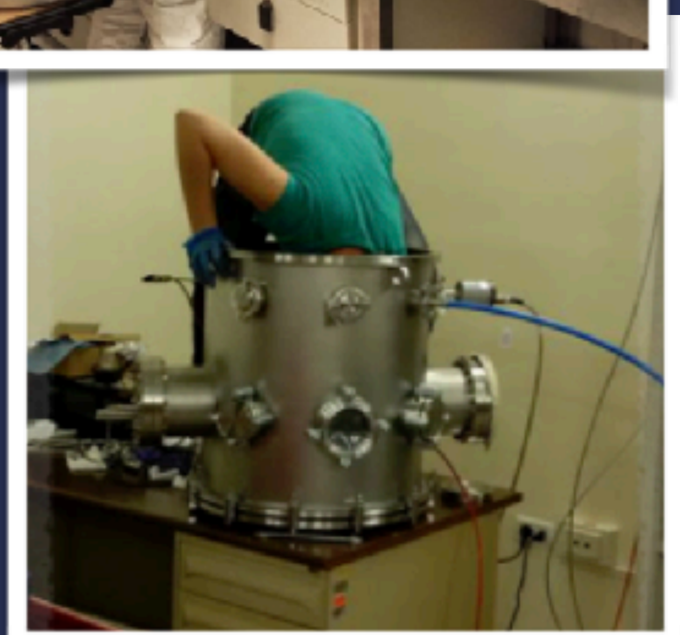
https://web.infn.it/cygnus

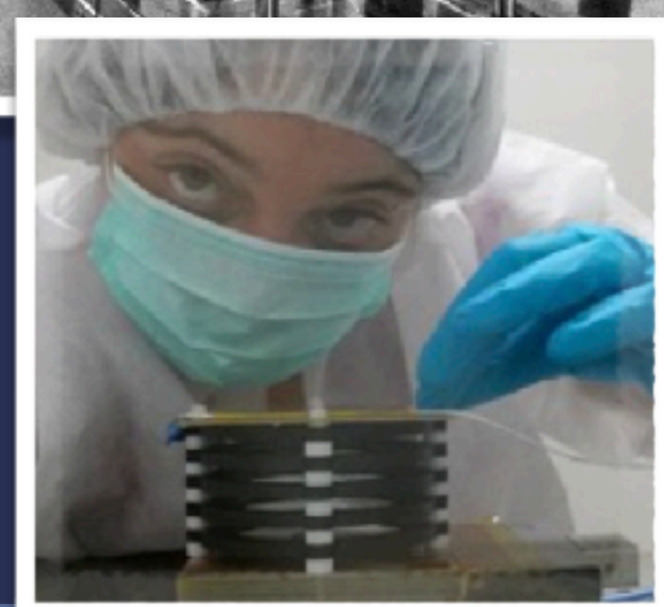




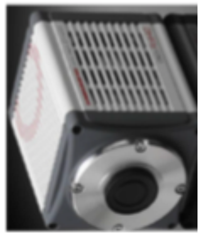


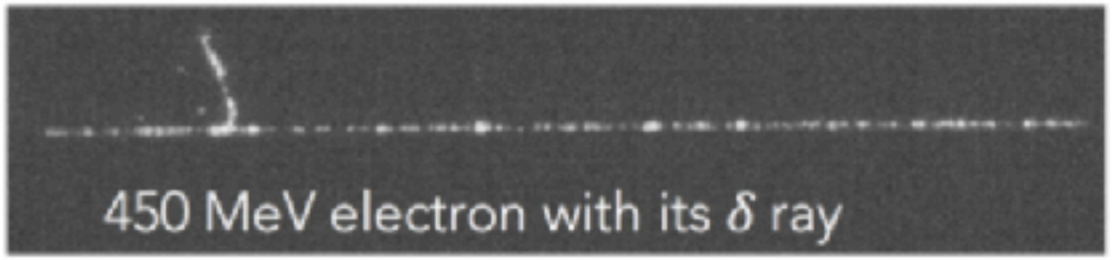


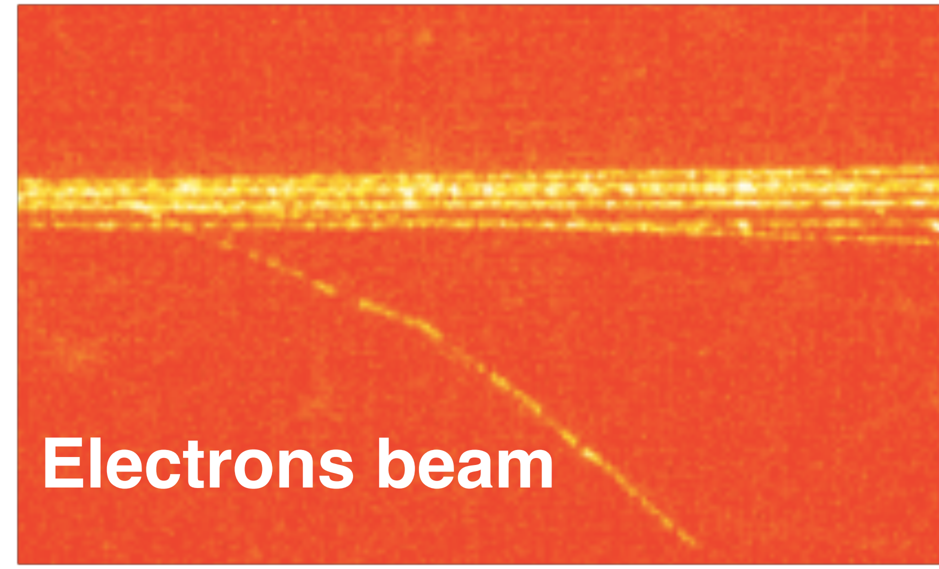


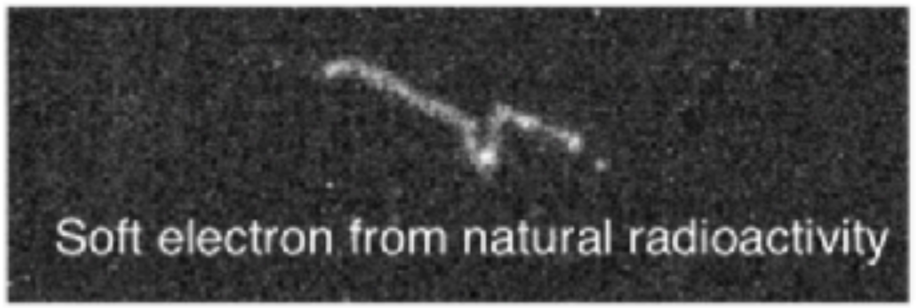


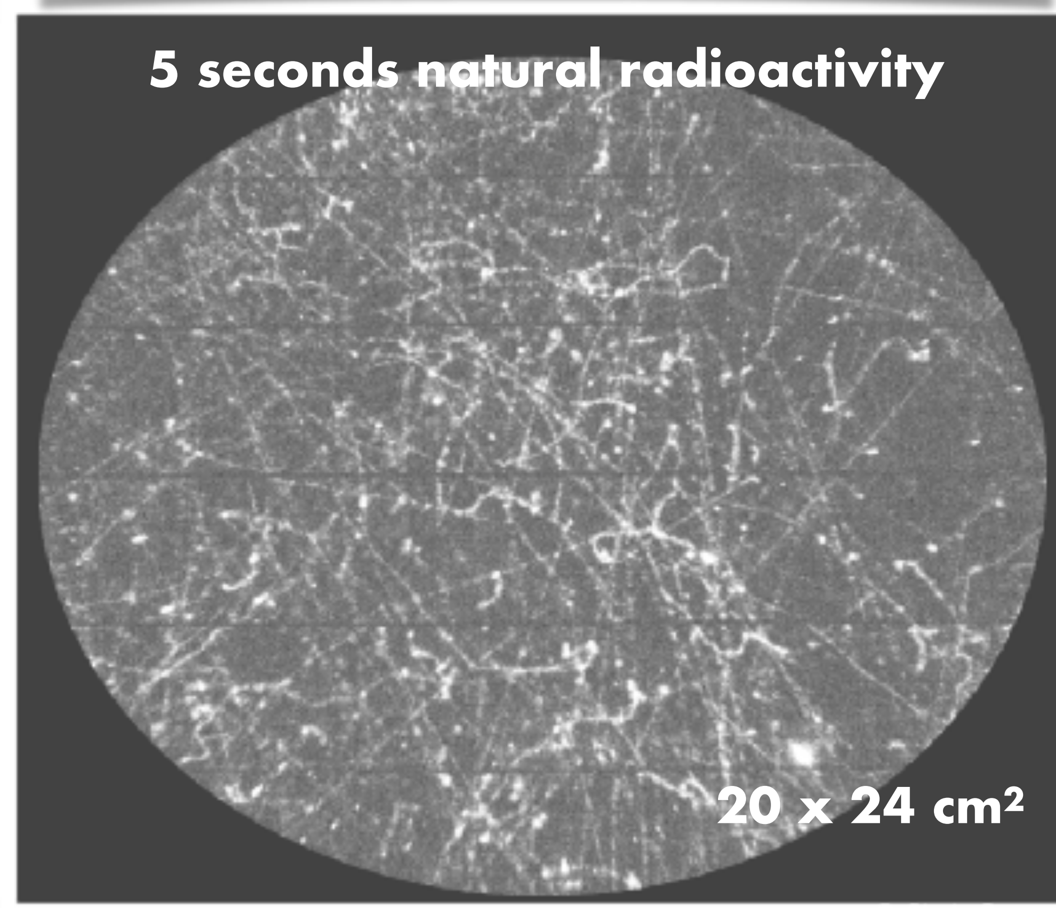
sCMOS: photographing 2D tracks

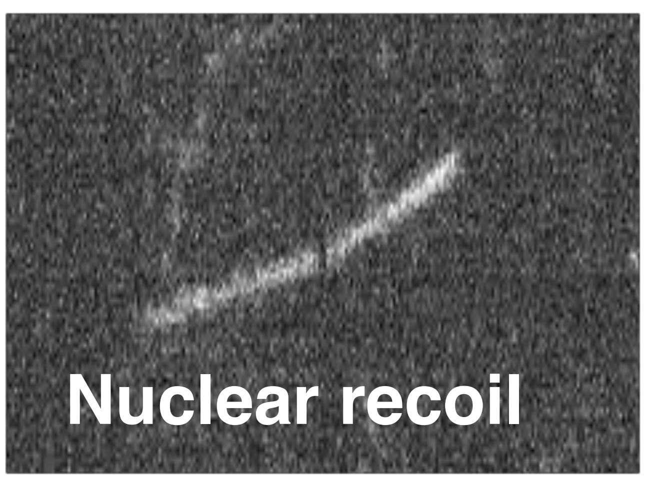


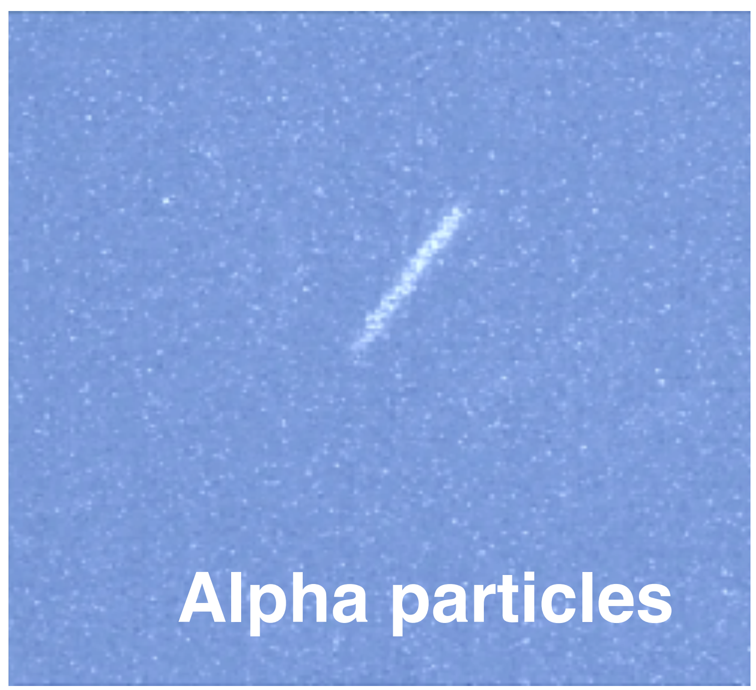






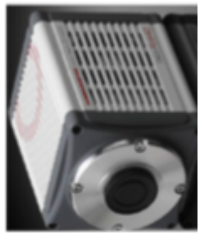


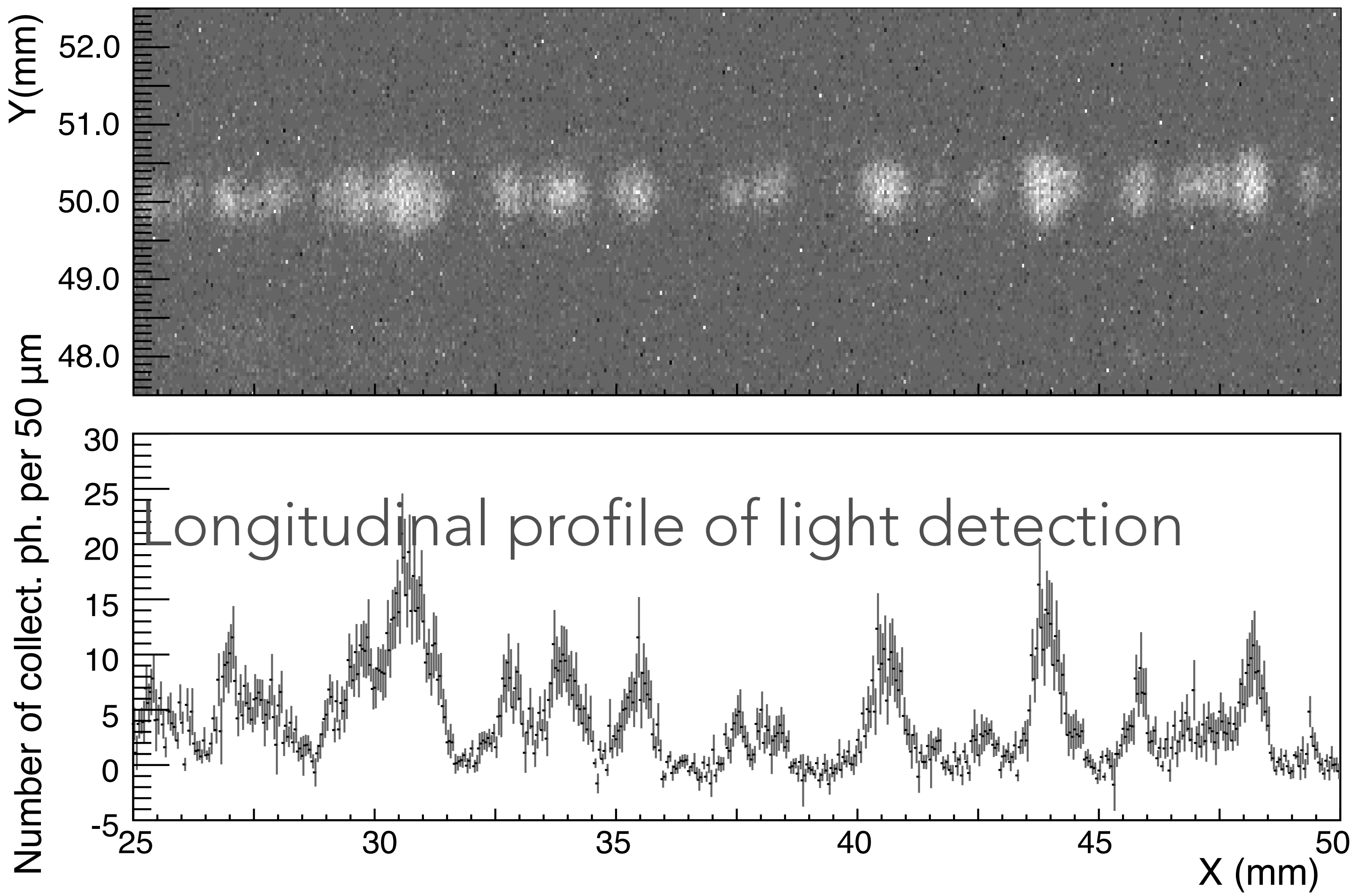


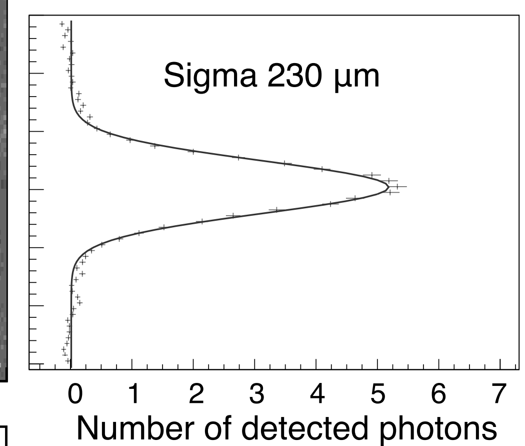


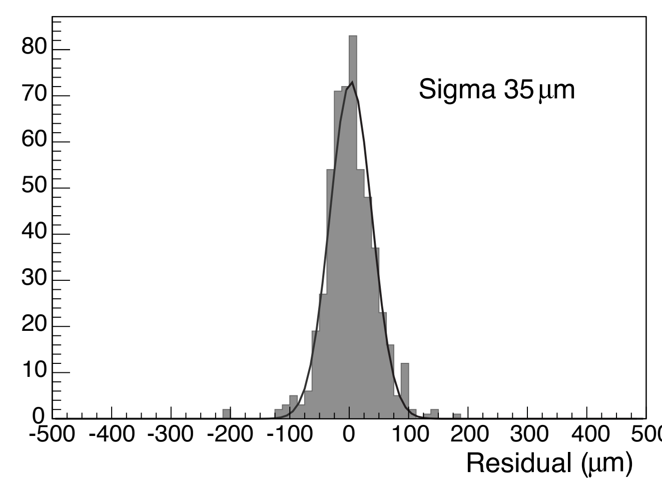
Particle identification capabilities, hence background rejection, clearly visible

ORANGE: sCMOS 2D tracking performances (XY)



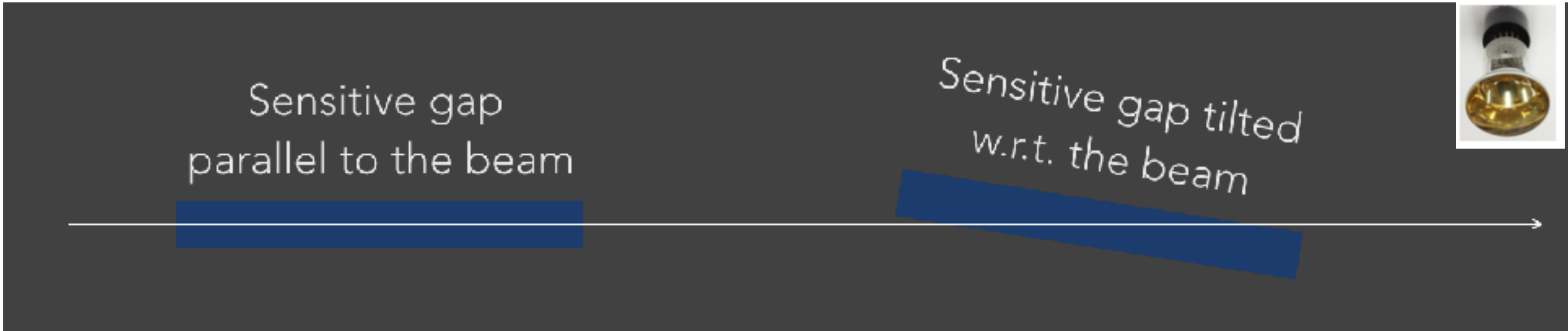


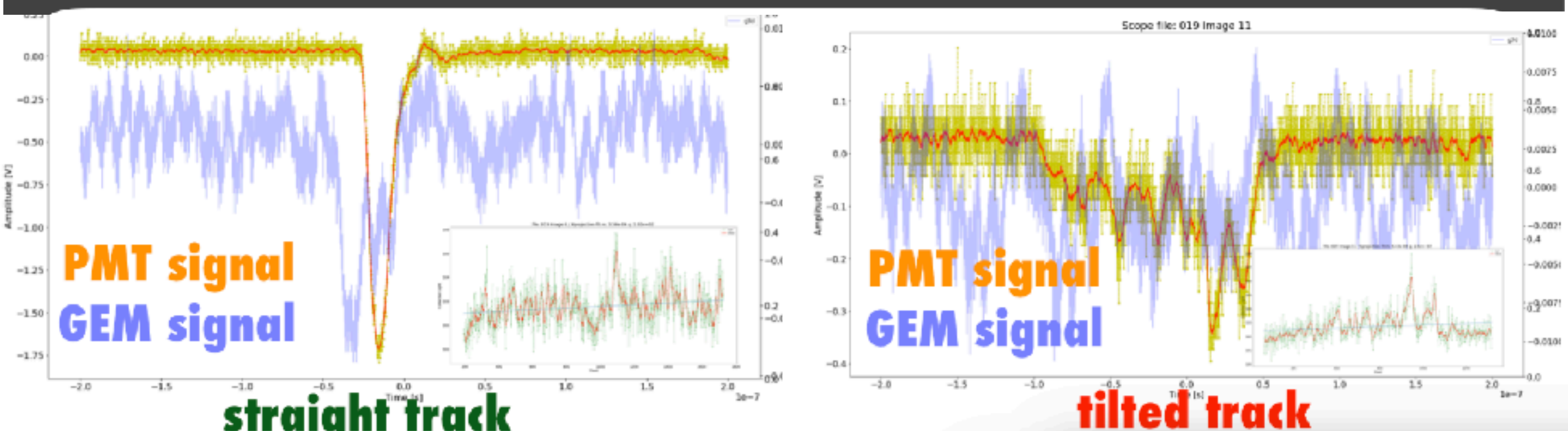




About 330 detected photons per track millimetre (for V_{GEM} = 440V), i.e. 230 eV released in gas (from Garfield).

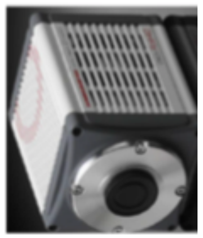
PMT: fast sensing of track orientation (Δz)





1 cm in 140 ns => drift velocity 7.2 cm/μs in agreement with Garfield expectation of 7.3 cm/μs.

Optical 3D track reconstruction



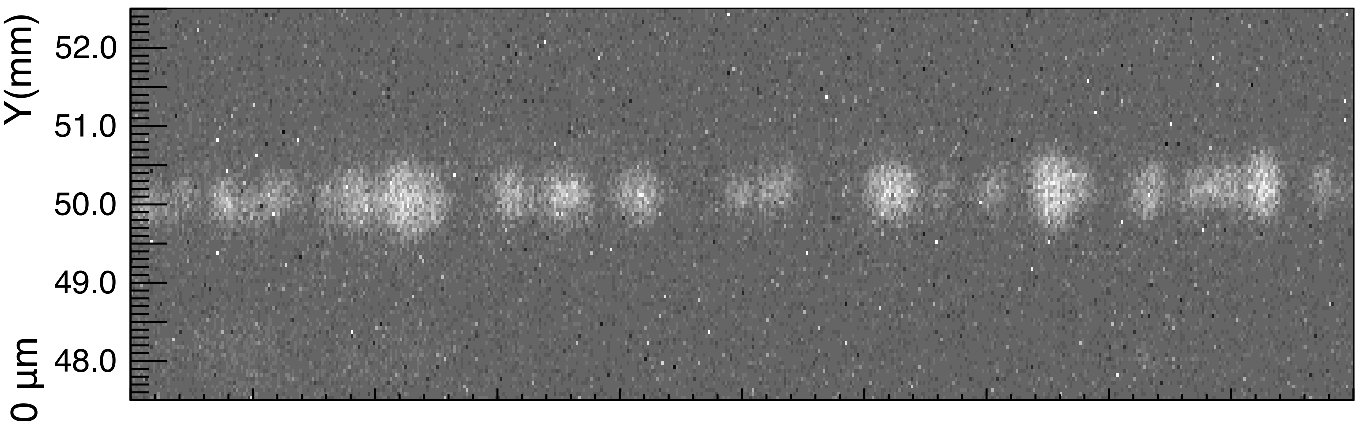
sCMOS:

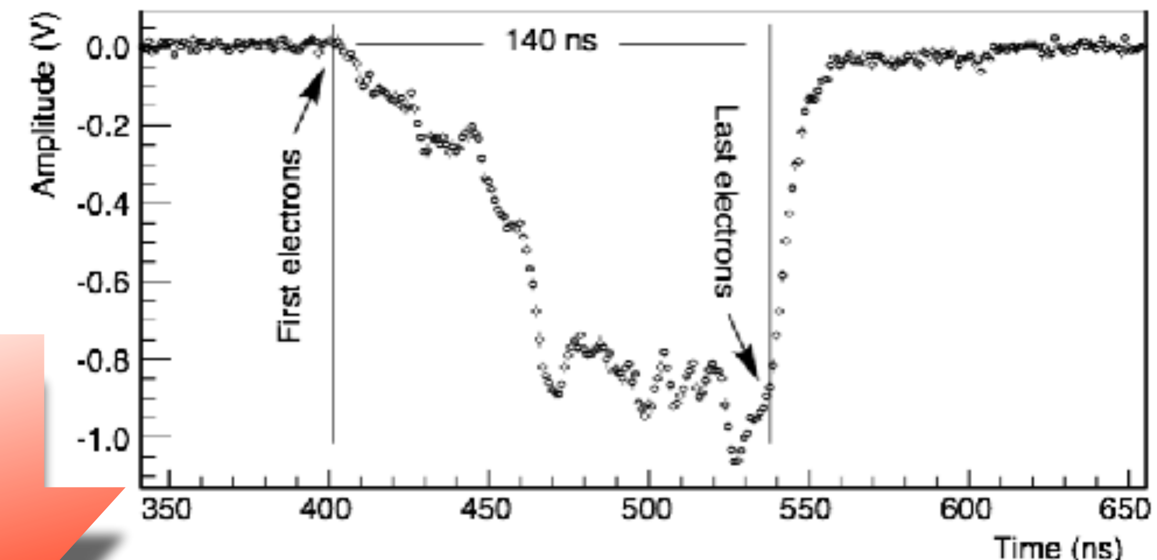
slow, high granularity
X-Y + energy measurements

JINST 13 (2018) no.05, P05001

PMT:

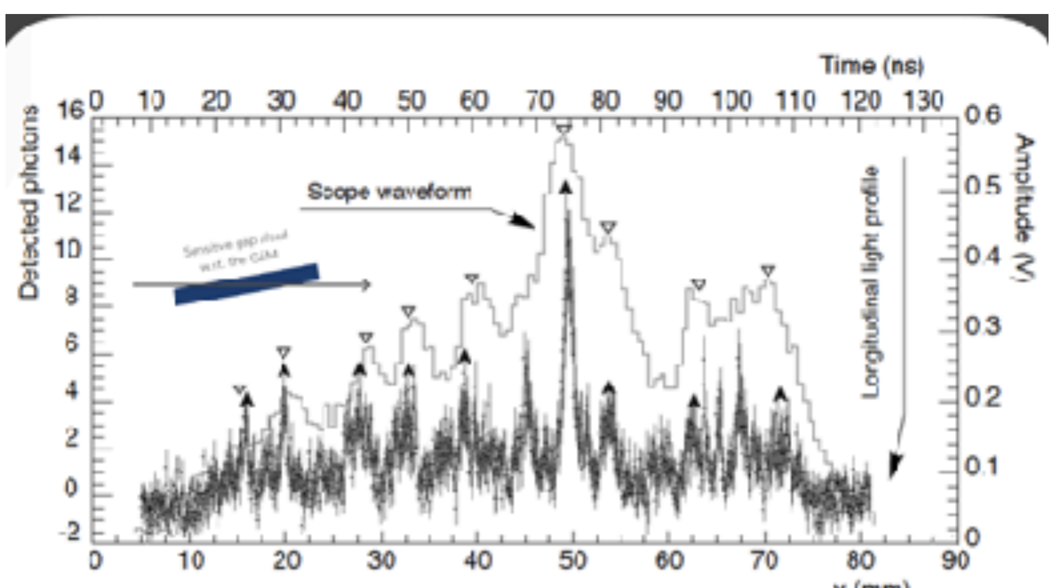
fast, integrated
ΔZ + energy measurement

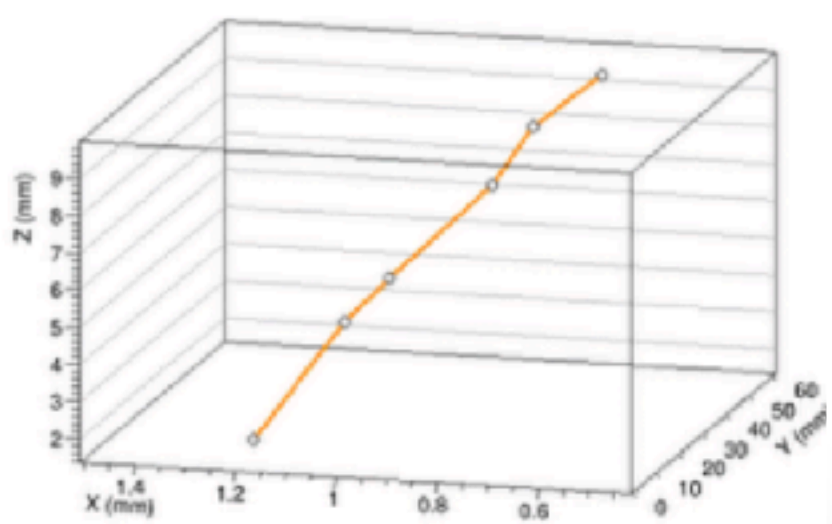


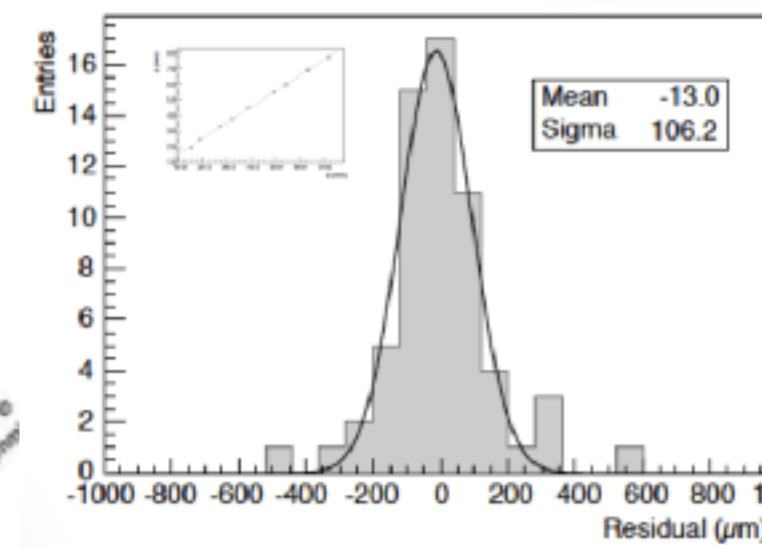


Light profile superimposed to PMT waveform: allow to identify clusters position

O(100) um relative Z resolution from PMT



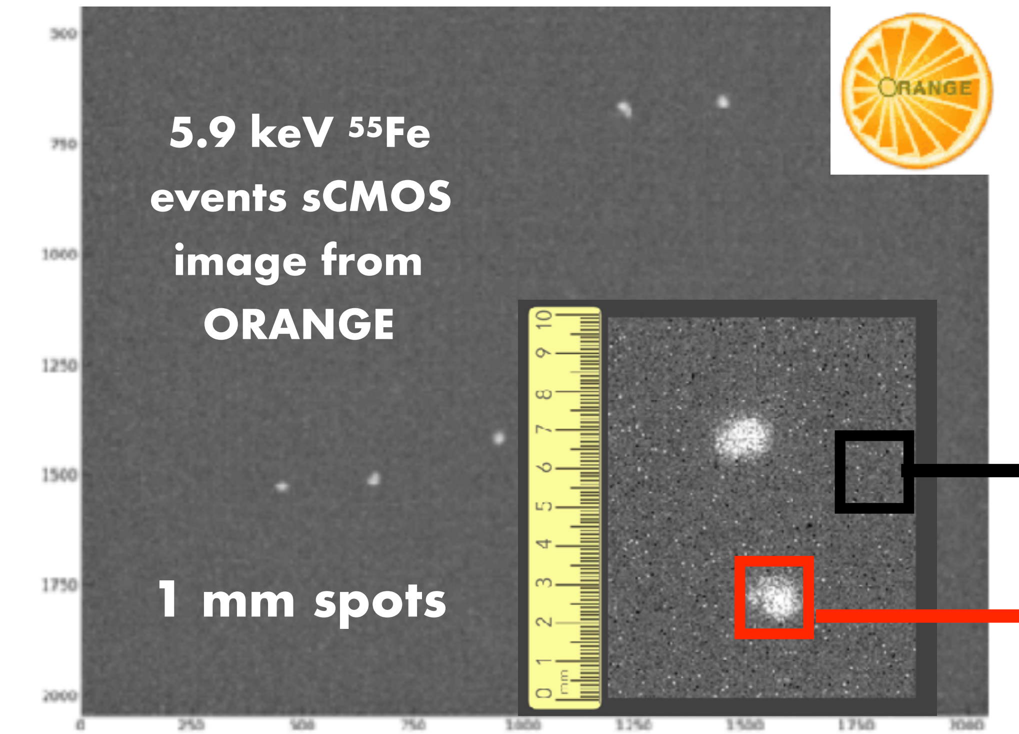


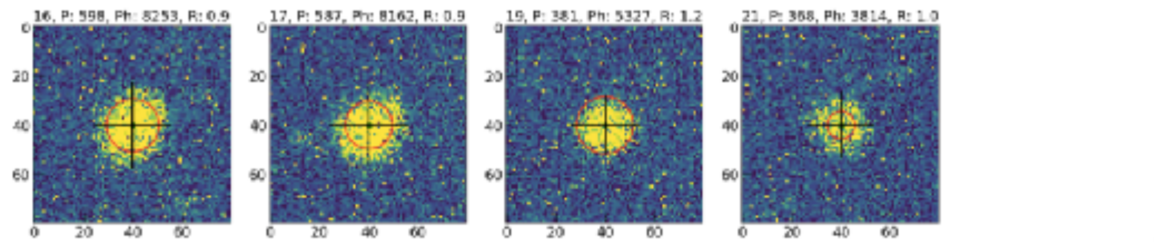


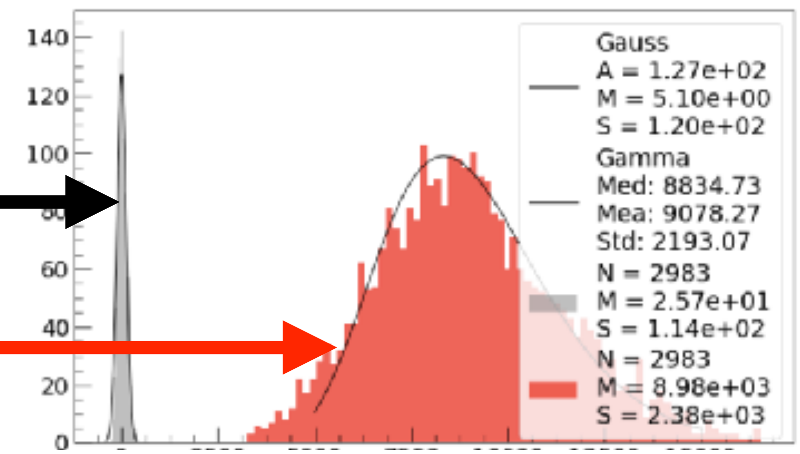
O(100) um 3D tracking with high quality particle identification (PID)

Energy threshold: response to ^{55}Fe 5.9 keV

threshold at ± 1 keV in both prototype





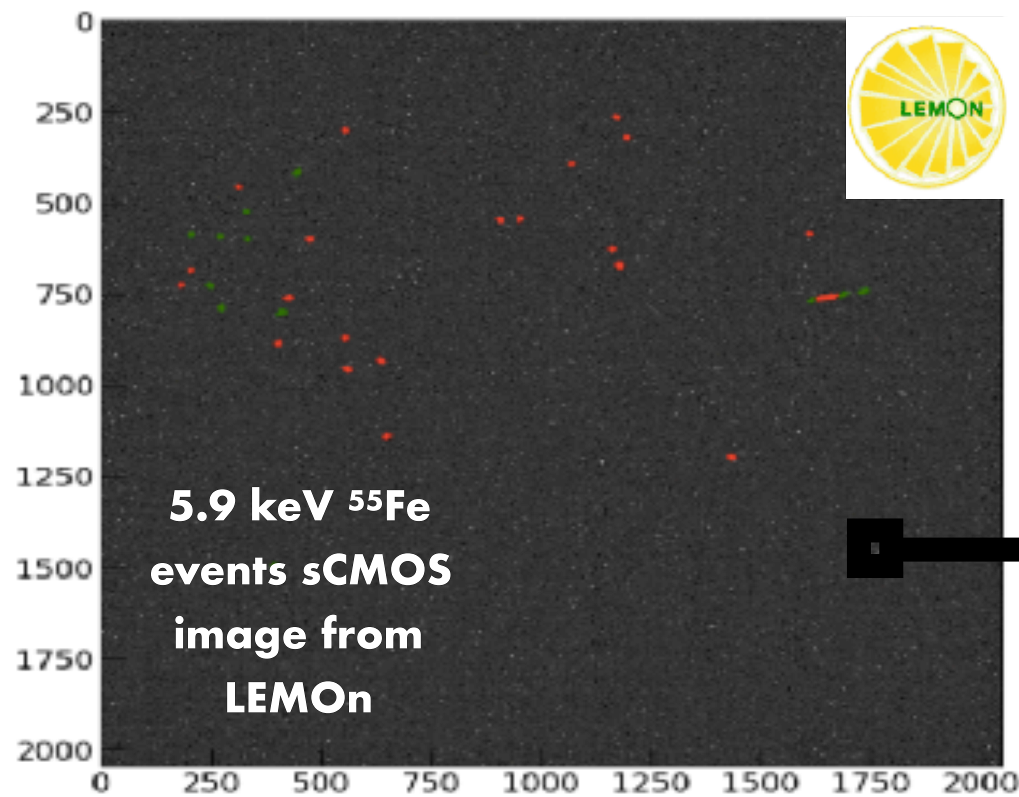


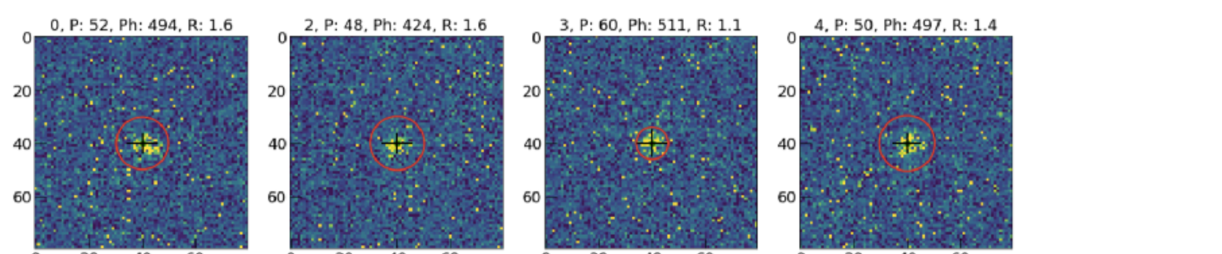
9078 ph / 5900 eV
—> **1.5 ph/eV**.

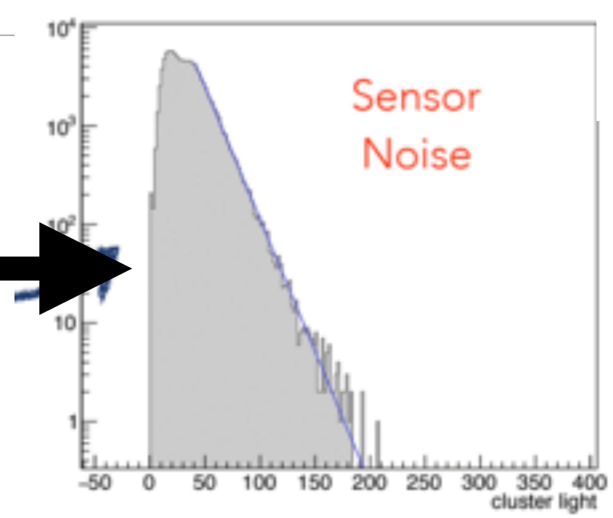
pedestal jitter 120 ph
@ 5 sigma **600 ph**
—> 600/1.5 —> **Th = 400 eV**

(pedestal based on data averaged with the Fe source in the detector)

Energy resolution ~ **24%** ~ **1.5 keV**





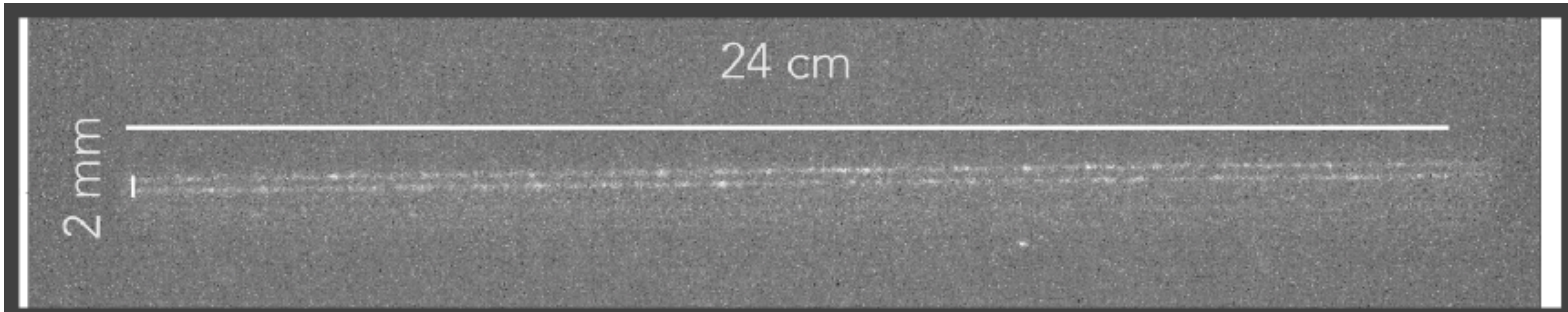


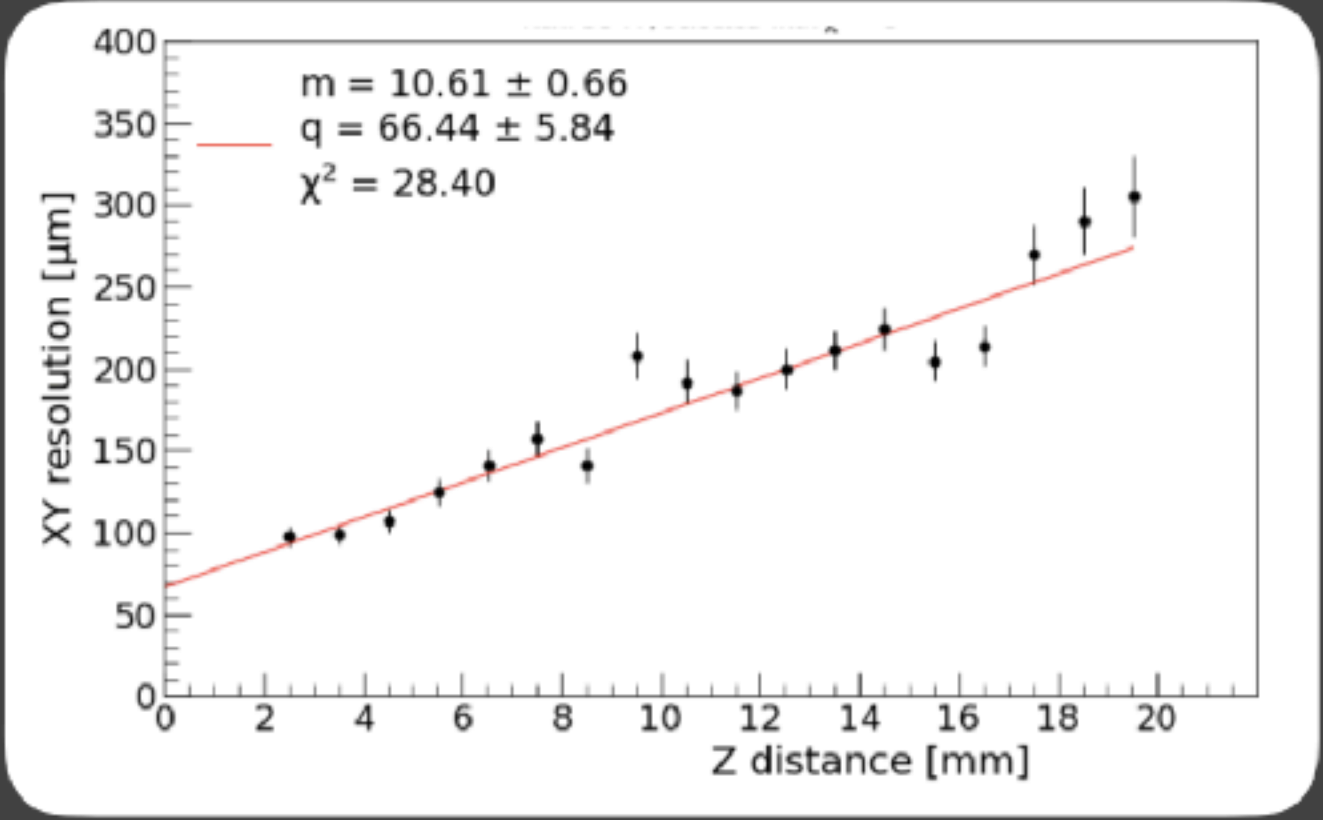
1 photon detected every 5 eV

Exponential distribution for noise (slope ~ 16 photons).

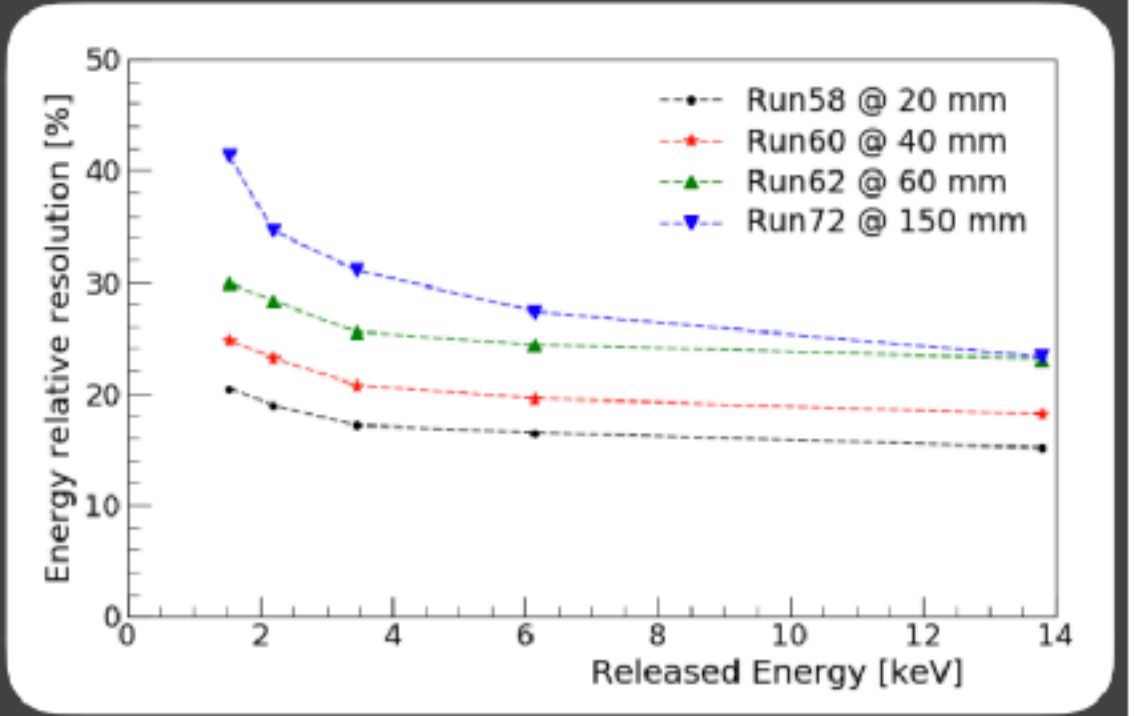
With 400 ph. threshold (2 keV) :
fake rate 10 events/year per sCMOS sensor

LEMOn tracking performances





Energy resolution was studied at different depths (Z).

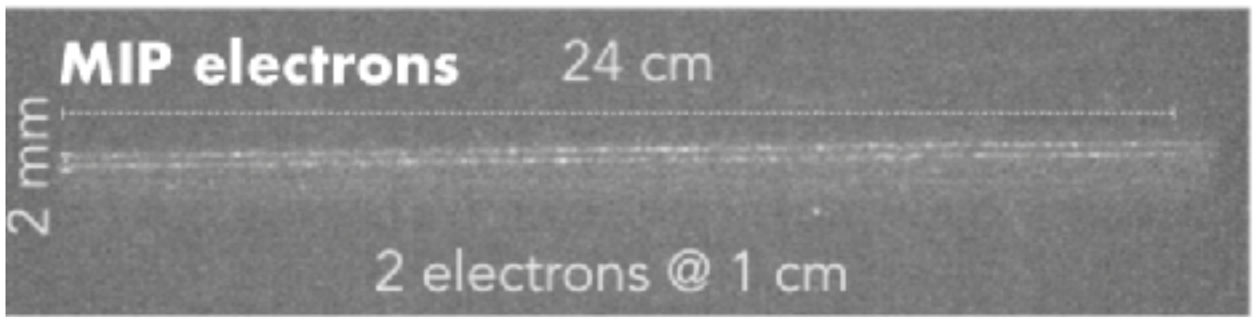


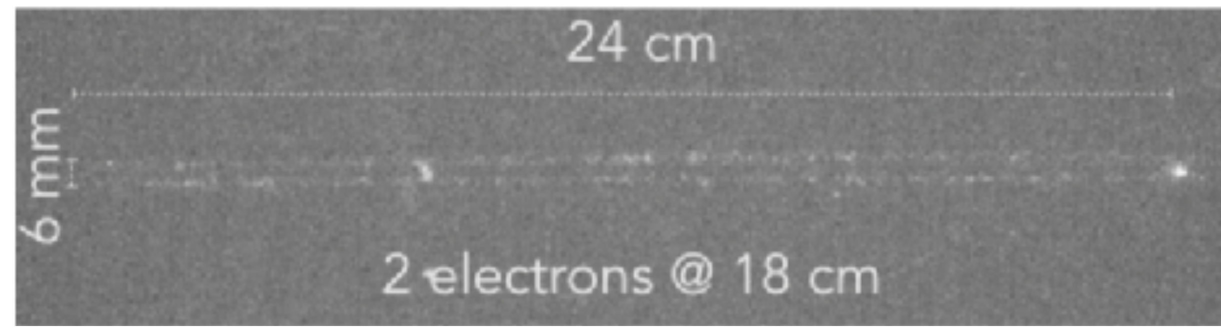
In the few keV region a relative resolution of 20%-30% is achieved

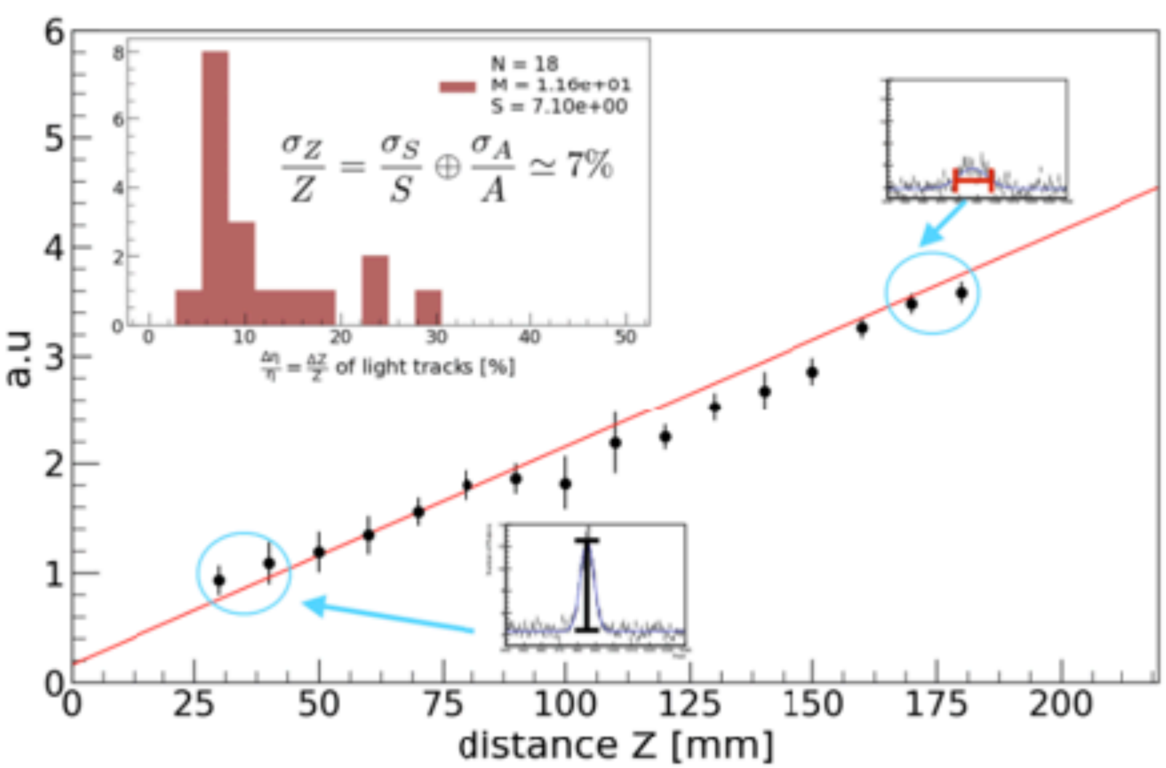
Fiducialization in the drift direction exploiting diffusion

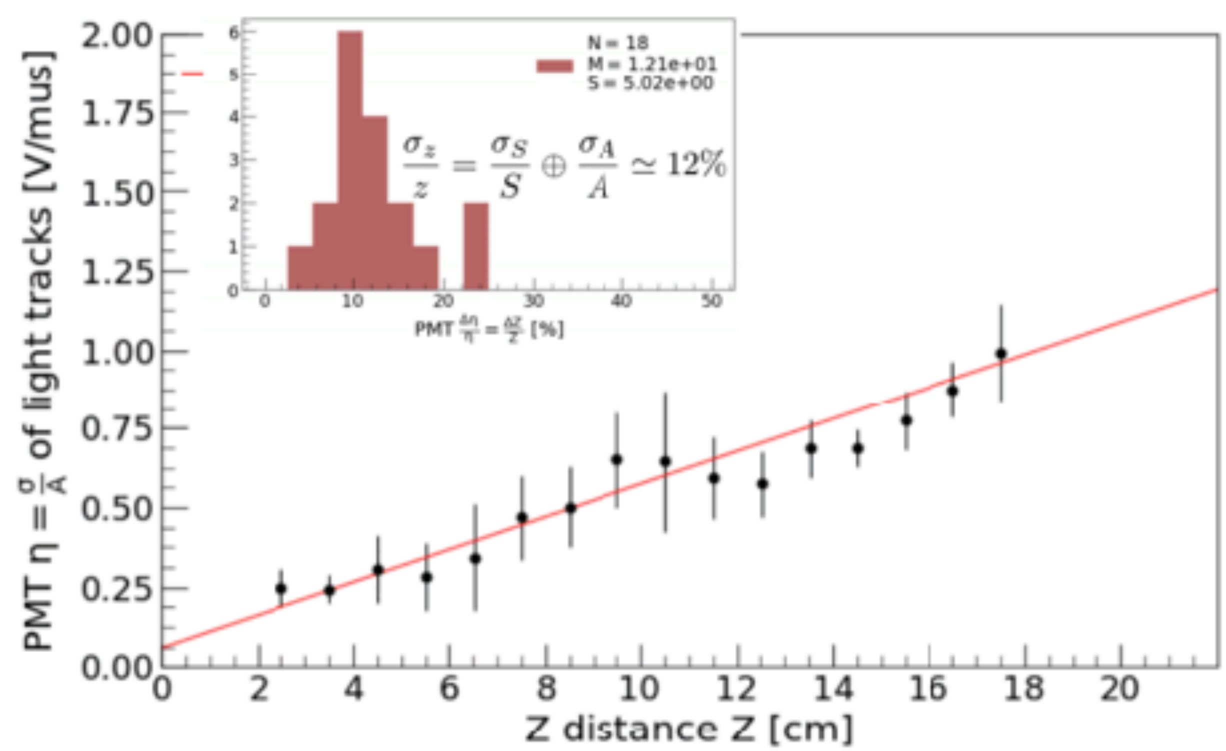
or else, suppression of RPRs (i.e. surface) backgrounds

The high readout granularity and position resolution allows to to measure coordinate along drift direction fitting for the diffusion





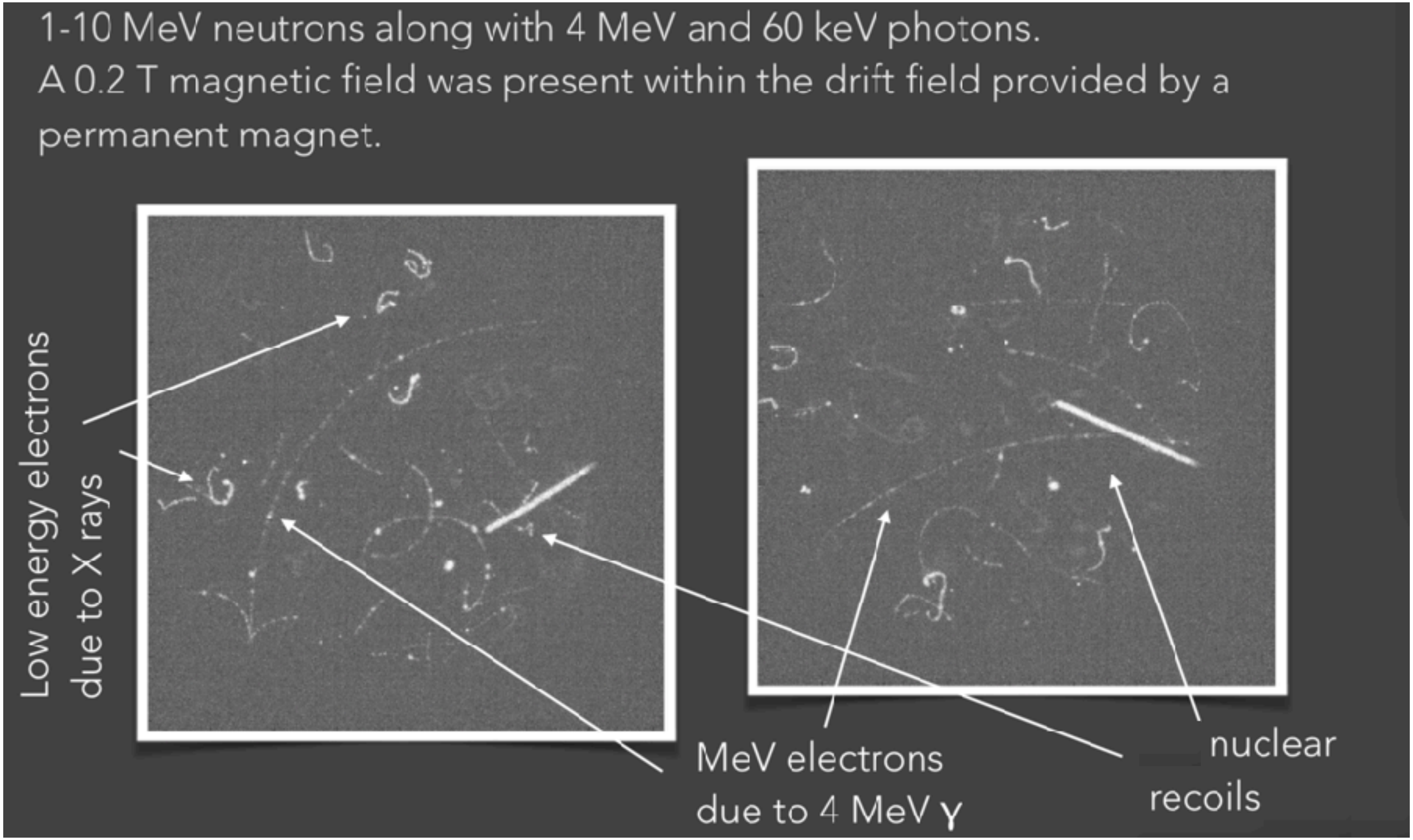




Light transverse profile (sCMOS) and PMT waveform:
larger width and lower amplitude from z farther from the anode

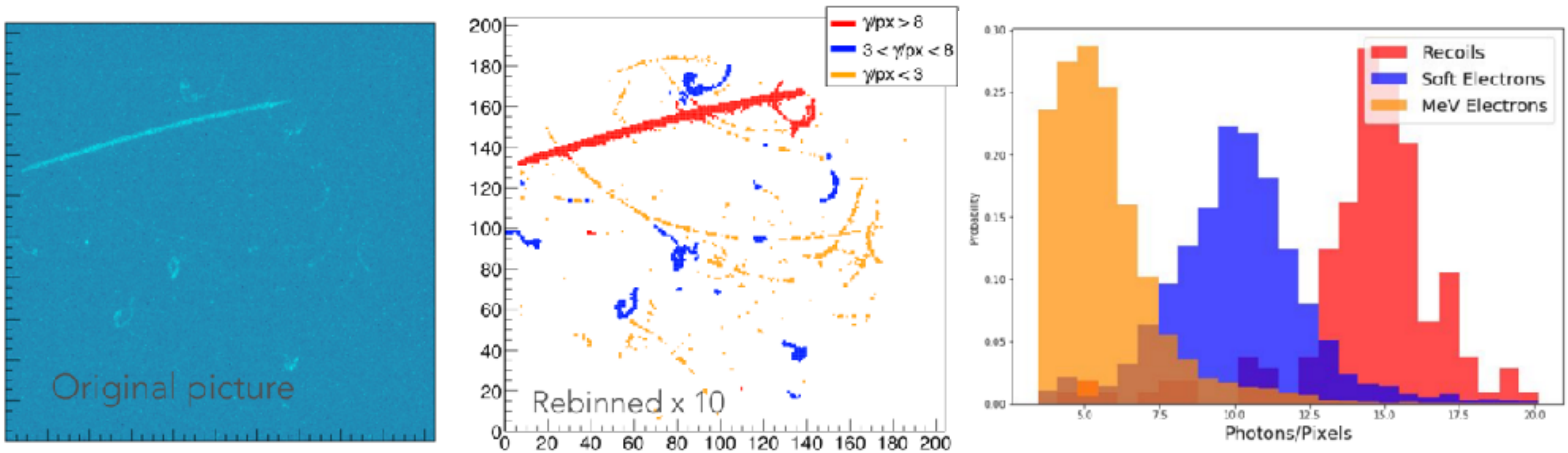
ORANGE: response to AmBe neutrons & PID

or else, small prototype response to WIMP-like (i.e. neutrons) scattering & capability to distinguish them from backgrounds



ORANGE: response to AmBe neutrons & PID

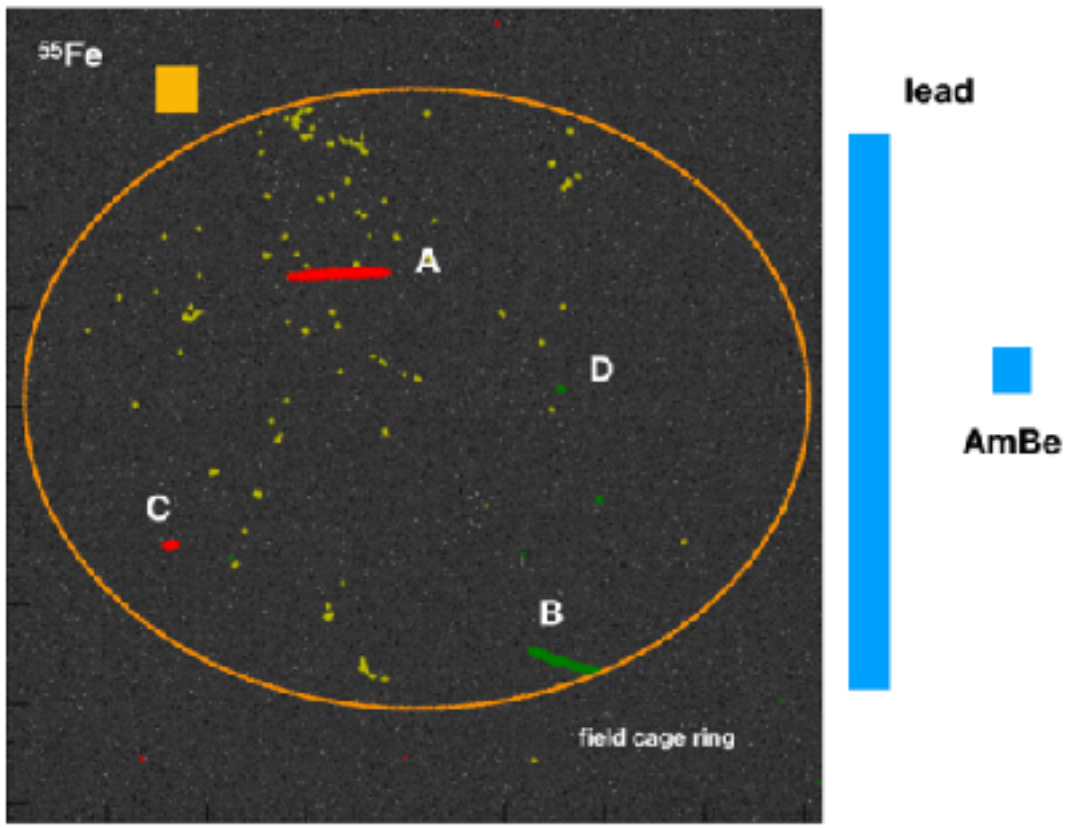
Nuclear recoils clearly distinguishable from #photons/pixel (i.e. ionisation density)

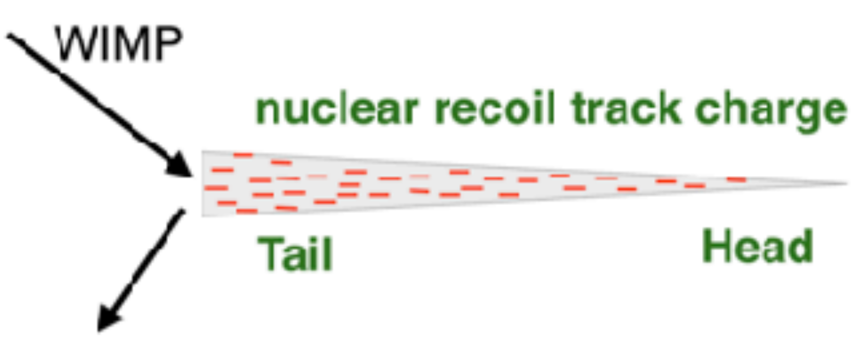


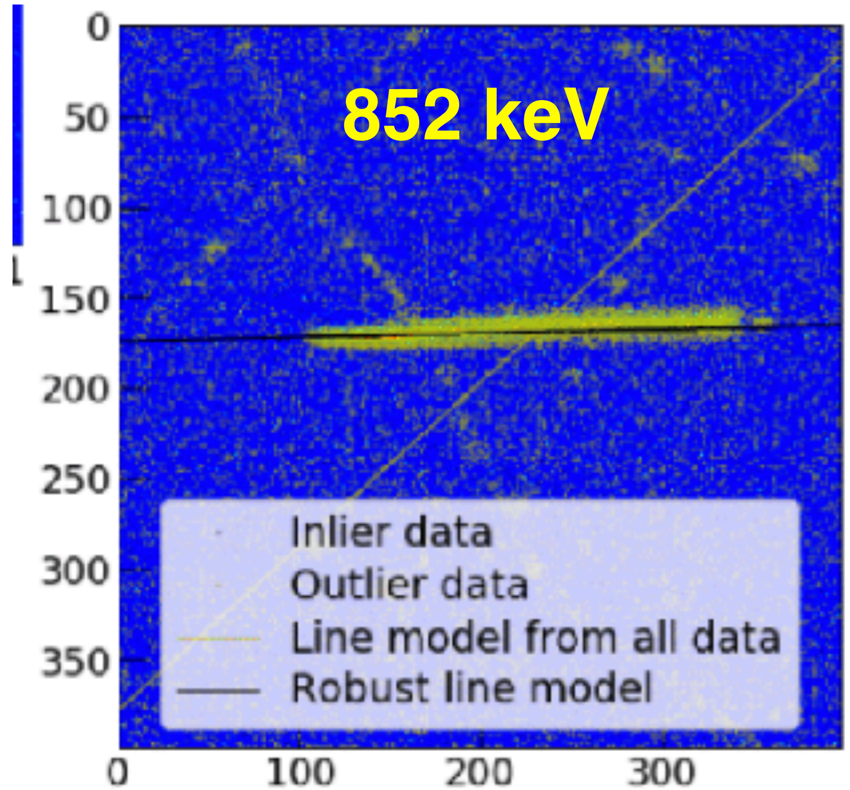
Please note: only ionisation density used. PID can be complement and largely improved combining it with track topology and track length vs energy

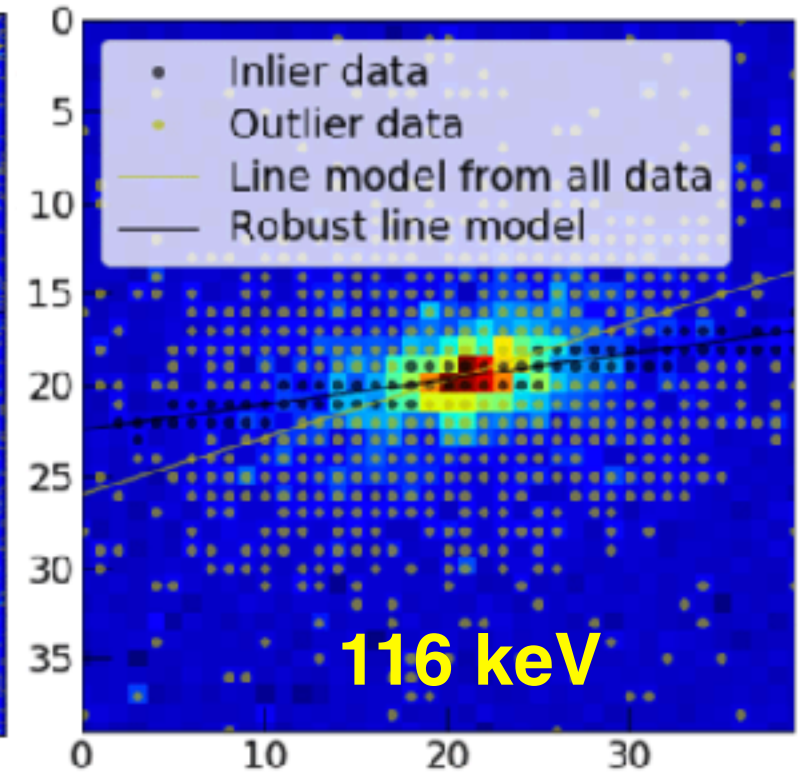
LEMOn: nuclear recoils from AmBe with directionality

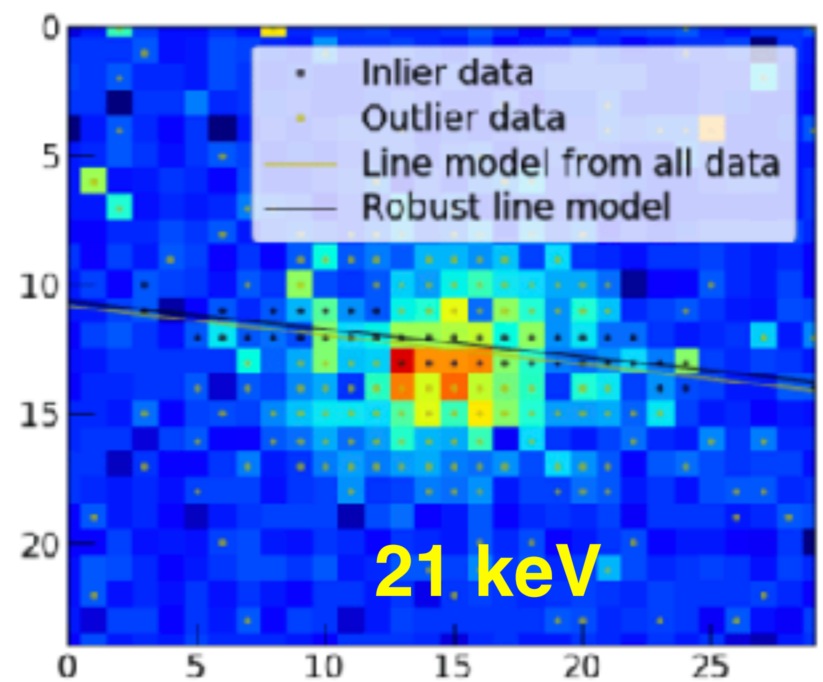
Hint of directionality down to low thresholds!

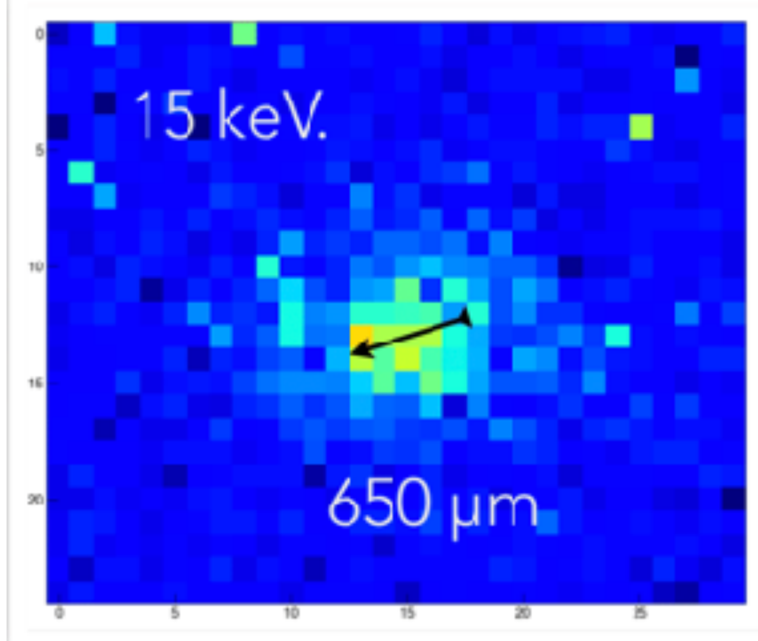








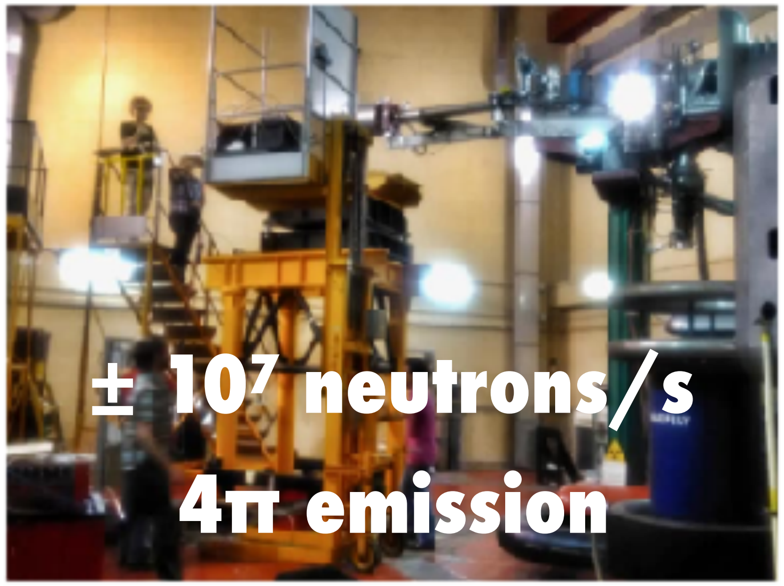


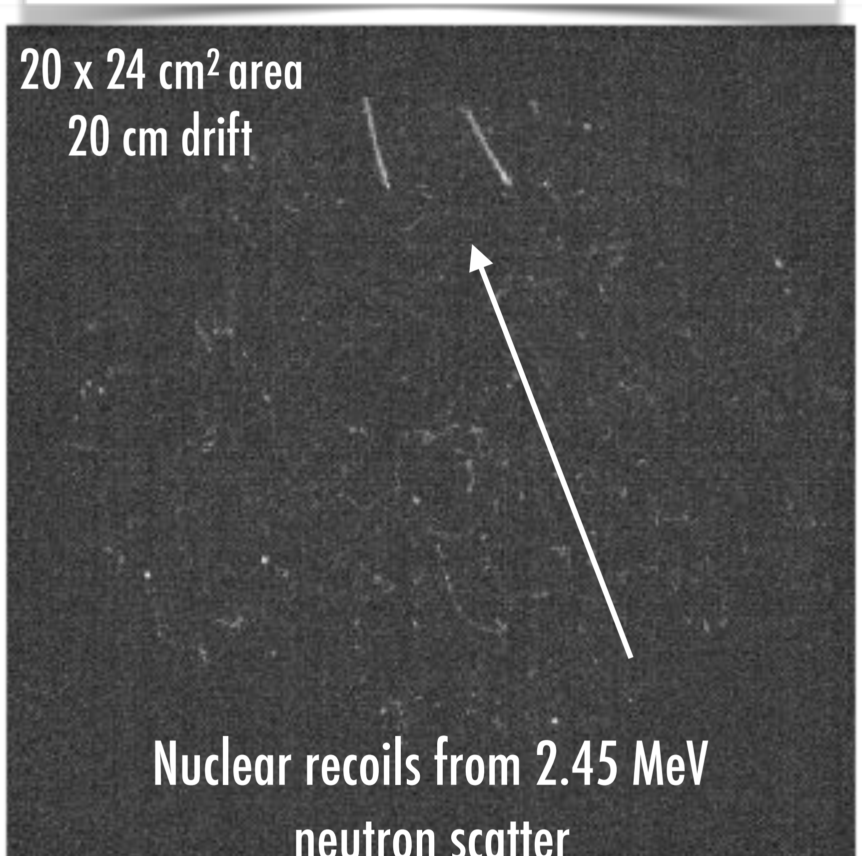


http://www.fusione.enea.it/LABORATORIES/Tec/FNG.html.en

2.45 MeV neutrons test @ FNG

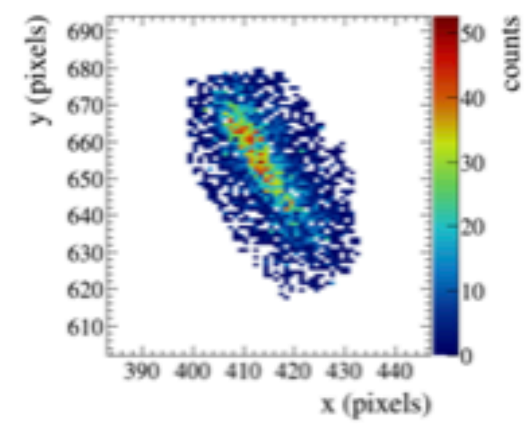
D(d,n)3He fusion reaction. 2.5-MeV neutron





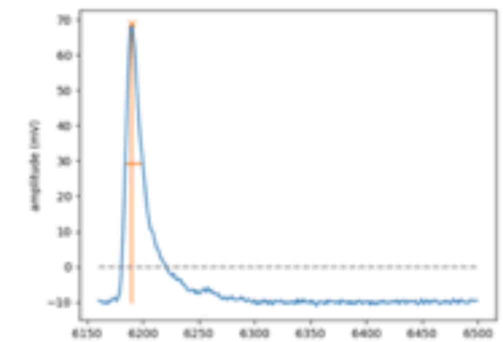
sCMOS

pic_run00060_ev142_cluster2.png

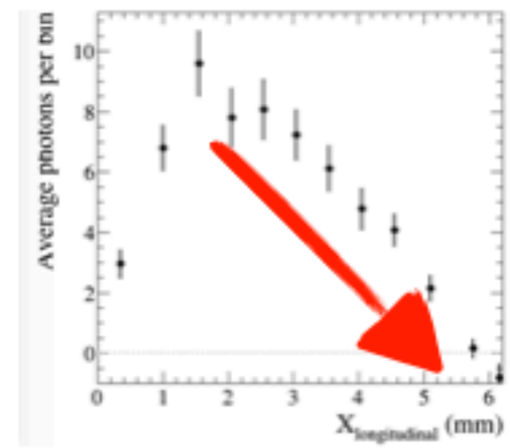


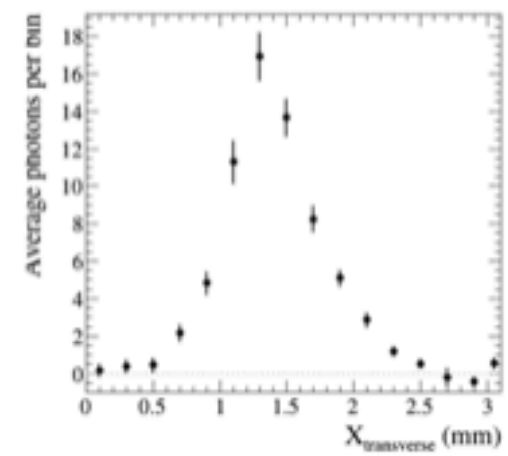
PMT

wfm_run00060_ev142.png



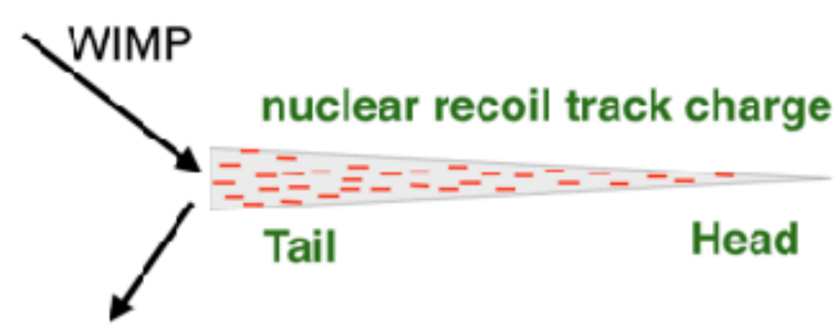
pic_run00060_ev142_snake2_-latprofile.png





longitudinal profile
track sense!

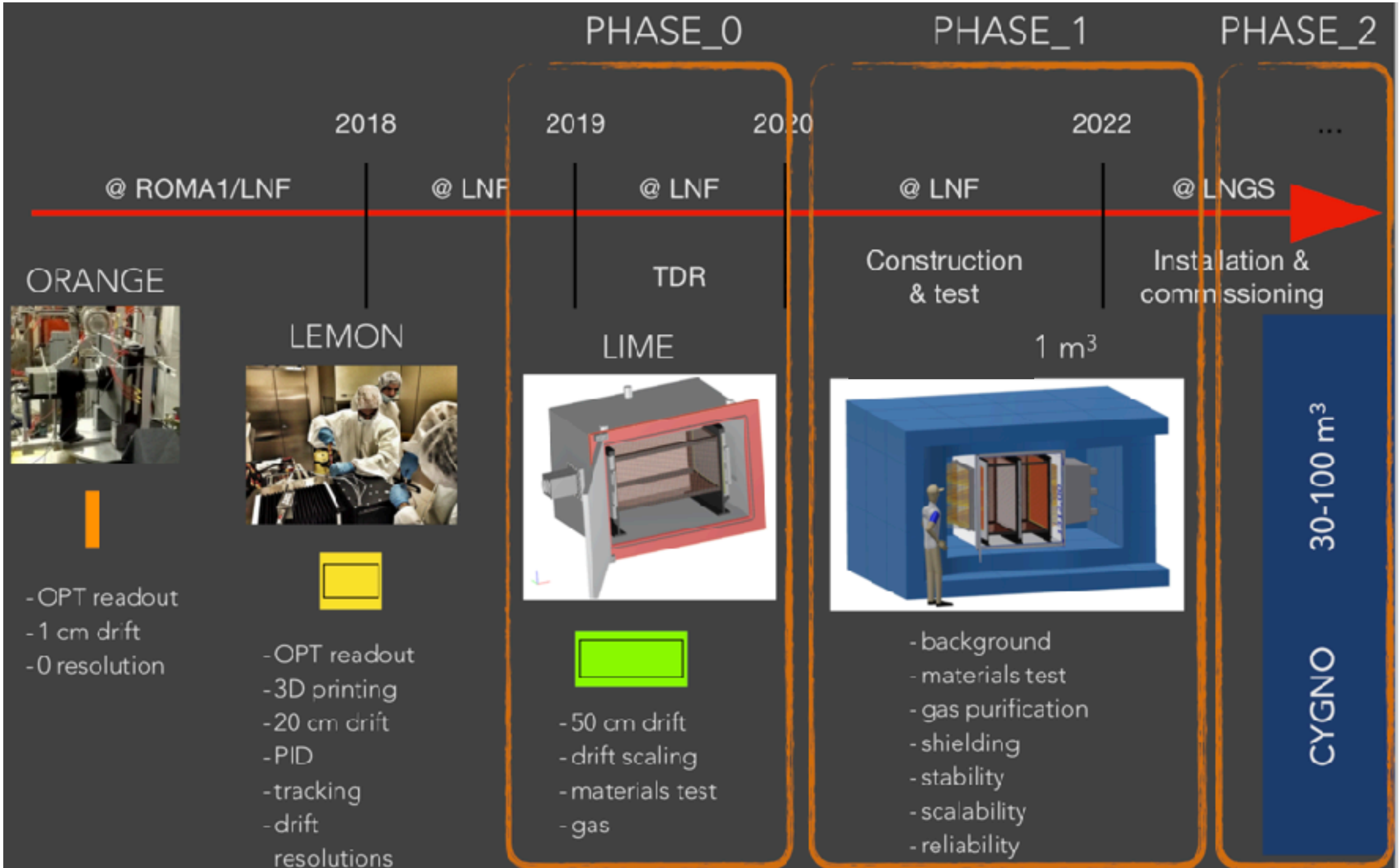
lateral profile



CYGNO

A CYGNus tpc module with Optical readout

CYGNO roadmap towards 30-100 m^3



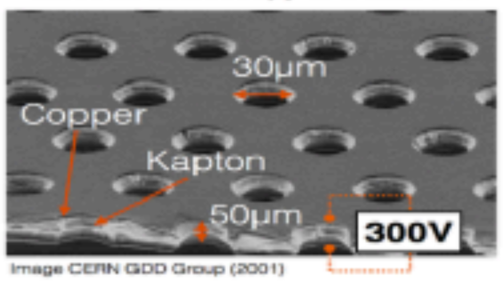
PHASE_0 funded by INFN in September 2018

PHASE_1: detector concept

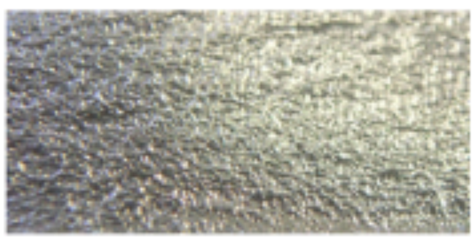
GSSI

Gas Electron Multipliers (GEMs) amplification

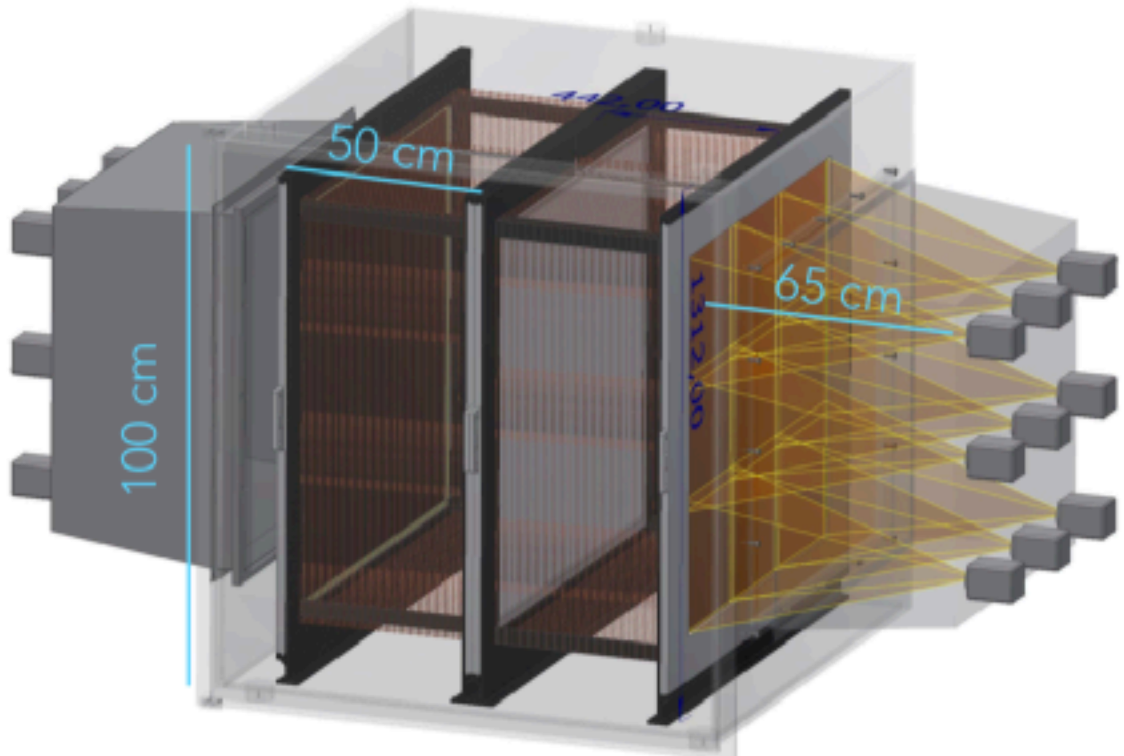
Electron Microscopy of a GEM Foil

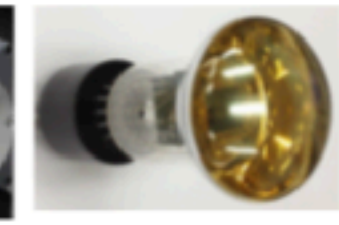


Transparent texturised mylar cathode a'la DRIFT



*gammas & neutrons shielding not shown but present





PMT + sCMOS optical readout decoupled from target volume

Atmospheric pressure & room temperature: minimal infrastructure

Year	Rich. (k€)
(CSN5) 2018	29
(TDR) 2019	89
2020	237
2021	284
2022	83
Tot (20-22)	604

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

A total of 72 10^6 readout 165 x 165 μm^2 pixels

Active contribution from several CYGNUS-TPC members

PHASE_1 very preliminary background budget

GEMs: Kapton + Cu, radioactivity measured @ LNGS

~3.7 x 10^4 gamma/year between 1-100 keV
~2.6 x 10^3 gamma/year between 1-10 keV
~0.04 neutron recoils/year

Low radioactivity PMTs, far & outside gas volume

Feedthroughs & services

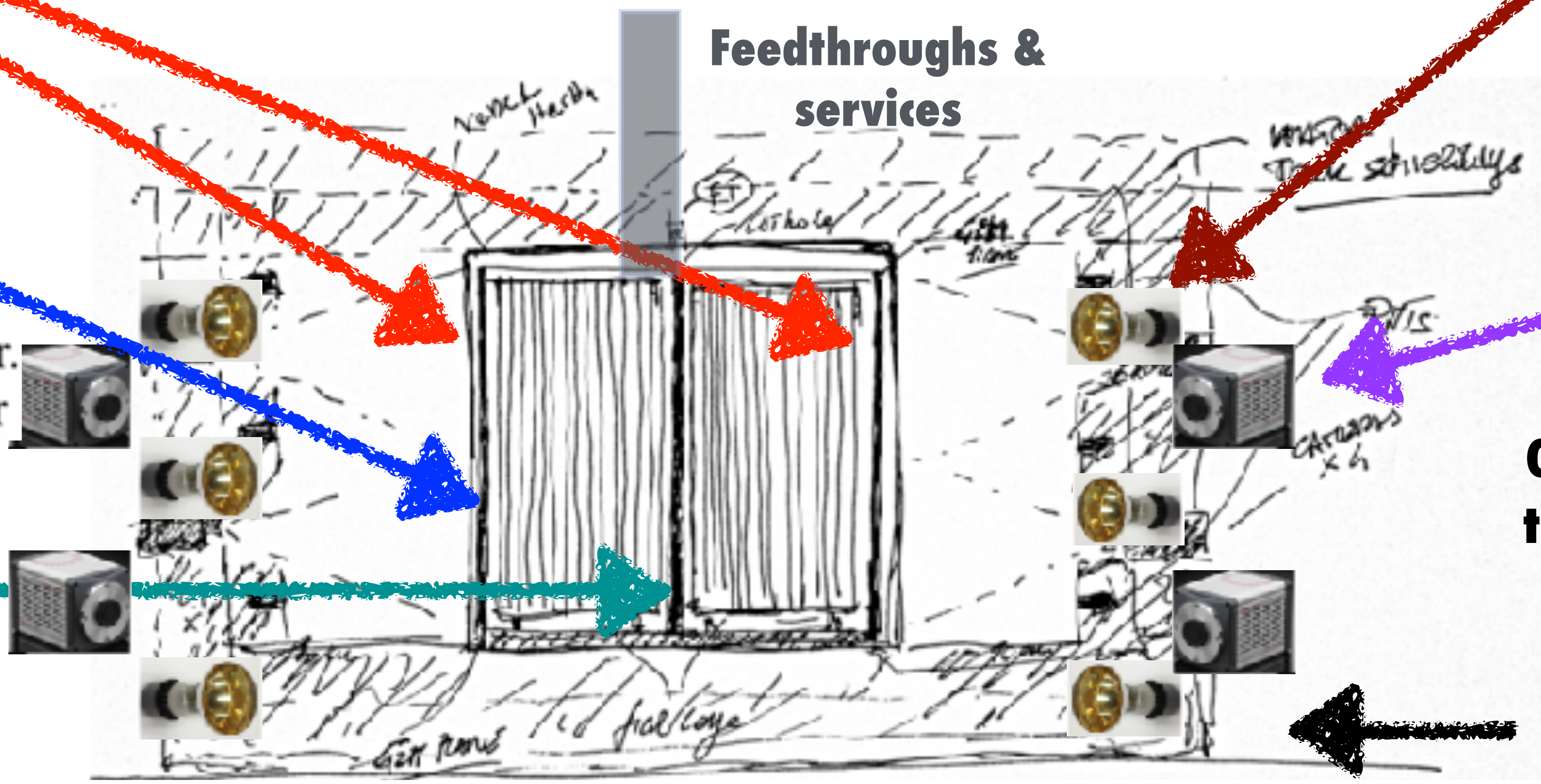
Field cage, Acrylic + Cu, low radioactivity

~1 x 10^2 electron recoils/year
~1 x 10^{-6} neutron recoils/year

Cameras: radioactivity measured @ LNGS, can be partially shielded

Transparent texturised mylar cathode a'la DRIFT

Gas vessel: do not need to keep vacuum, i.e. not necessary steel, low radioactivity materials under evaluation



Full simulation on going with sCMOS camera & GEMs activities recently measured @ LNGS

Preliminary background budget

Component	Material	n bkg [cts/yr]	γ bkg [cts/yr]
Environment (after shield.)	Rock, concrete	1×10^{-3}	0.01
Ex. shielding	H_2O, Steel, Cu, Veto	1×10^{-3}	1×10^{2}
In. shielding + field cage	Acrylic, Cu	1×10^{-6}	1×10^{2}
GEMs	Kapton, Cu	4×10^{-2}	3×10^{3}
Cathode (after fid.)	Mylar	1×10^{-6}	2×10^{2}
Vessel	Steel or plastic?	1 bar == thin vessel	
PMTs	Glass, electronics	>50 cm from gas volume	
sCMOS	Si, electronics	>50 cm from gas volume	

ERC Consolidator Grant

PHASE_1 is funded as a synergy to the INITIUM project

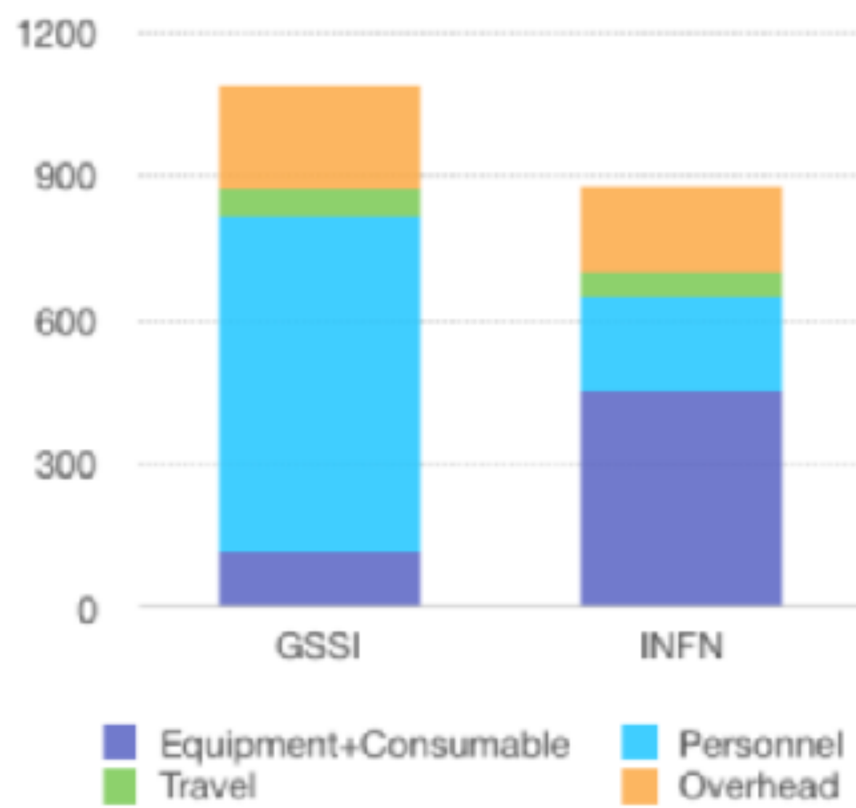
December 2018

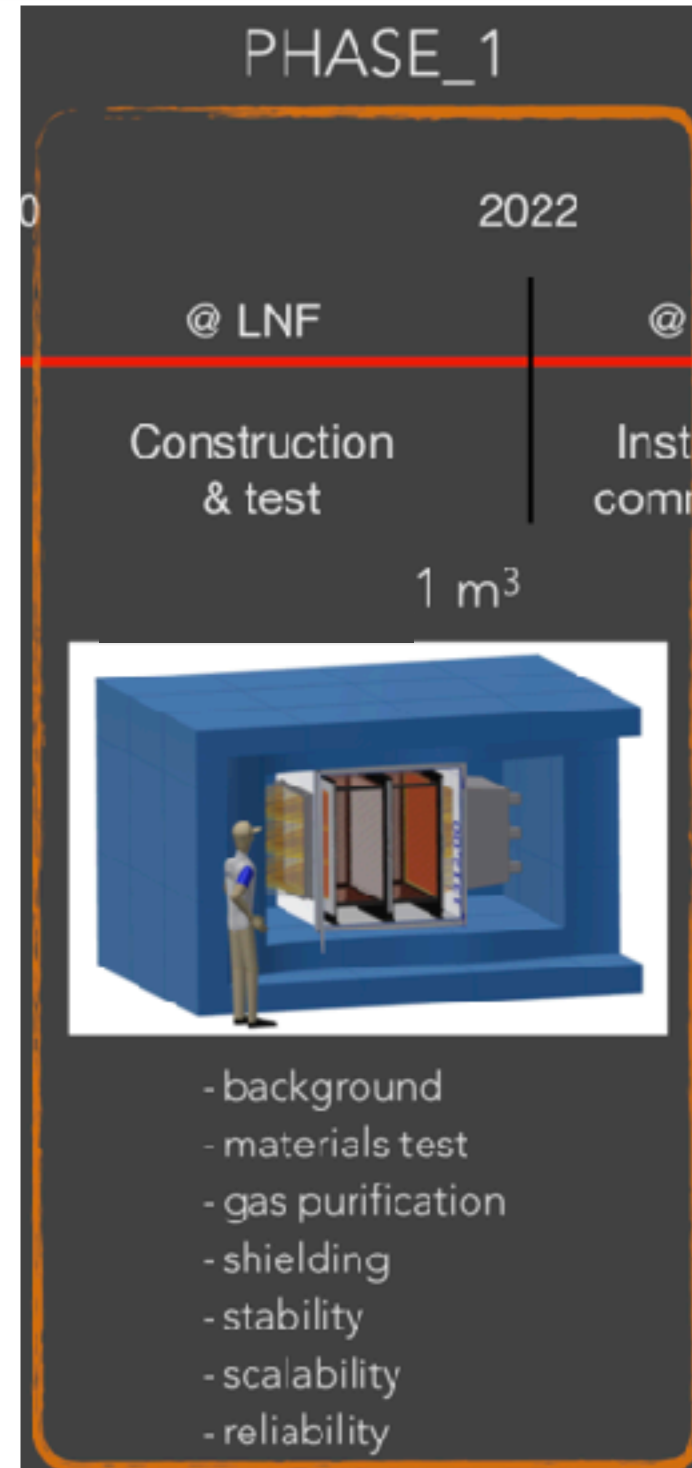
European Research Council

Supporting top researchers from anywhere in the world

INITIUM innovation: atmospheric pressure negative ion He gas mixture with 3D optical readout demonstrator towards the development of 100-1000 m^3 directional DM detector

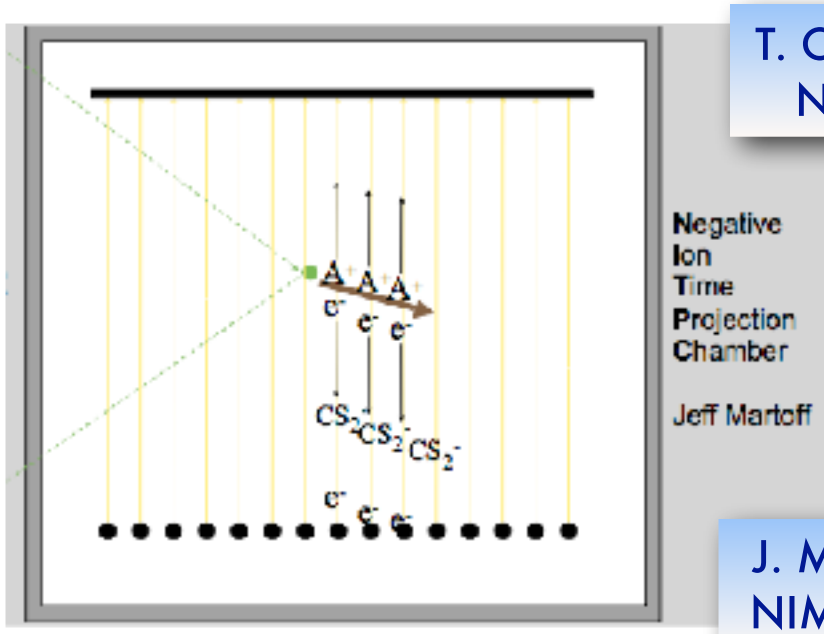
Total budget ± 2 MEUROs





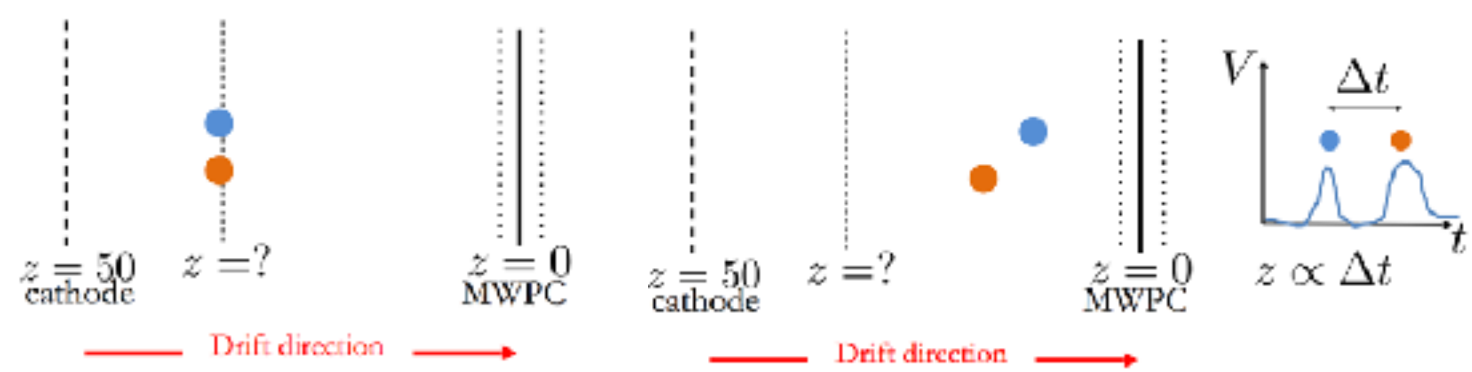
Negative ion drift concept

Reduced diffusion, improved tracking & additional means of fiducialization

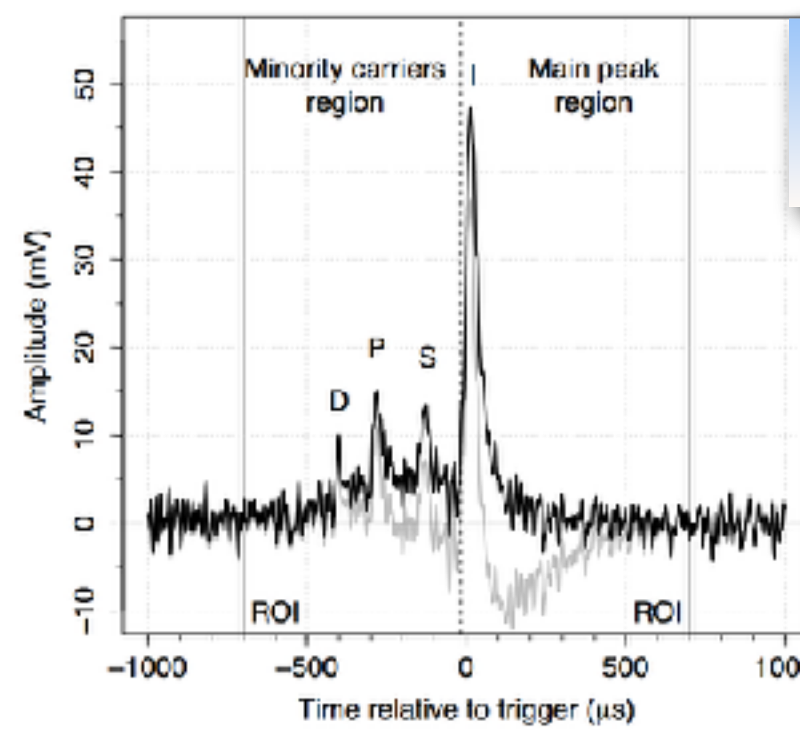


T. Ohnuki et al., NIM A 463

J. Martoff et al., NIM A 440 355



$$z = (t_m - t_p)\frac{v^m_{drift} v^p_{drift}}{v^m_{drift} - v^p_{drift}}$$



D. Snowden-Ifft, Rev. Sci. Instrum. 85 (2014) 013303

DRIFT

- Primary ionization electrons are captured by the electronegative gas molecules at tens of um
- Anions drift to the anode acting as the effective image carrier instead of the electrons
- At the amplification stage, anions are stripped of the additional electron and common electron avalanche is generated
- This effectively reduces both longitudinal and transverse diffusion to thermal limit

$$\sigma = \sqrt{\frac{2kTL}{eE}} = 0.7\,\mathrm{mm}\left(\frac{T}{300\,\mathrm{K}}\right)^{1/2}\left(\frac{580\,\mathrm{V/cm}}{E}\right)^{1/2}\left(\frac{L}{50\,\mathrm{cm}}\right)^{1/2}$$

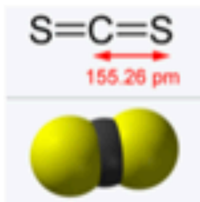
low diffusion increases active volume per readout area

SF_6: a new non-toxic player in the negative ion game

GSSI

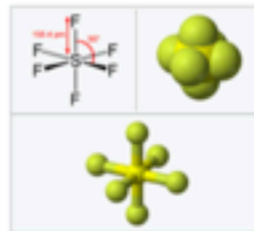
Known since 2000

CS_2



TOXIC

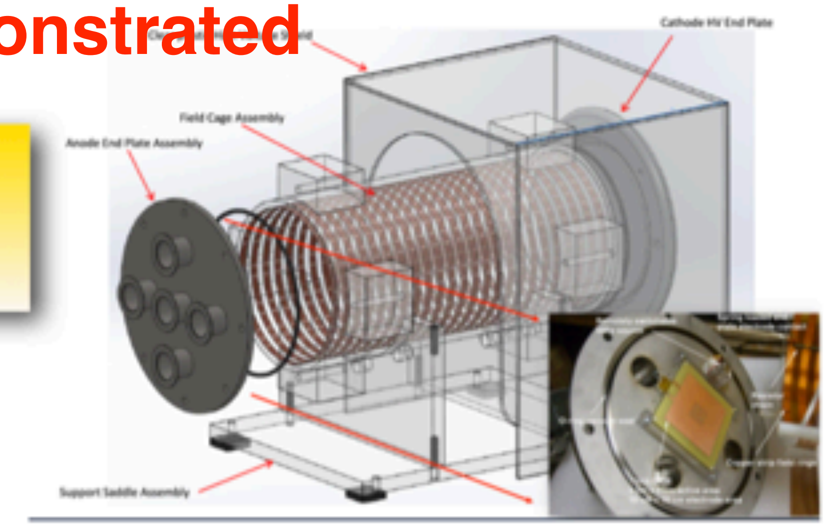
SF_6



Safer, easier to handle

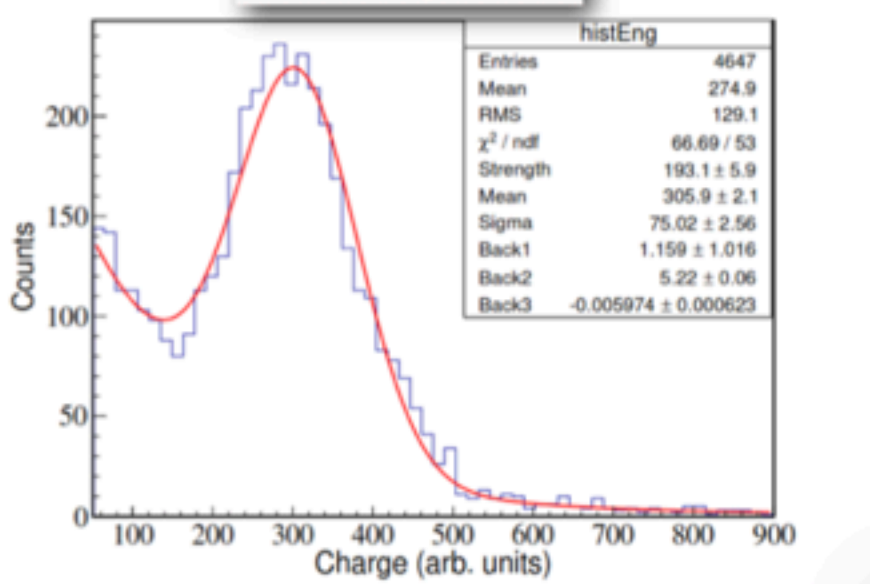
Only low pressure (10-100 Torr) operation demonstrated

N.S.Phan et al, JINST 12 (2017) no. 02, P02012



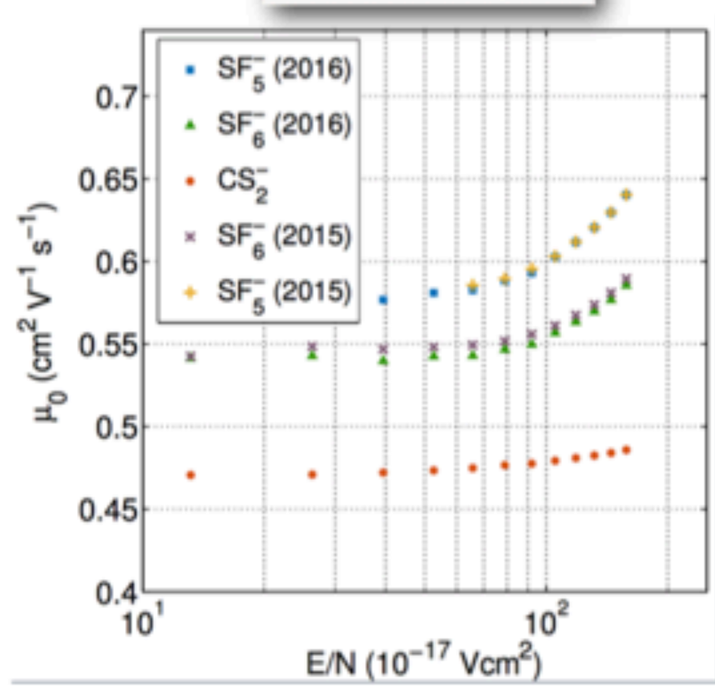
First evidence for SF_6 negative ion operation in July 2015

Gas gain

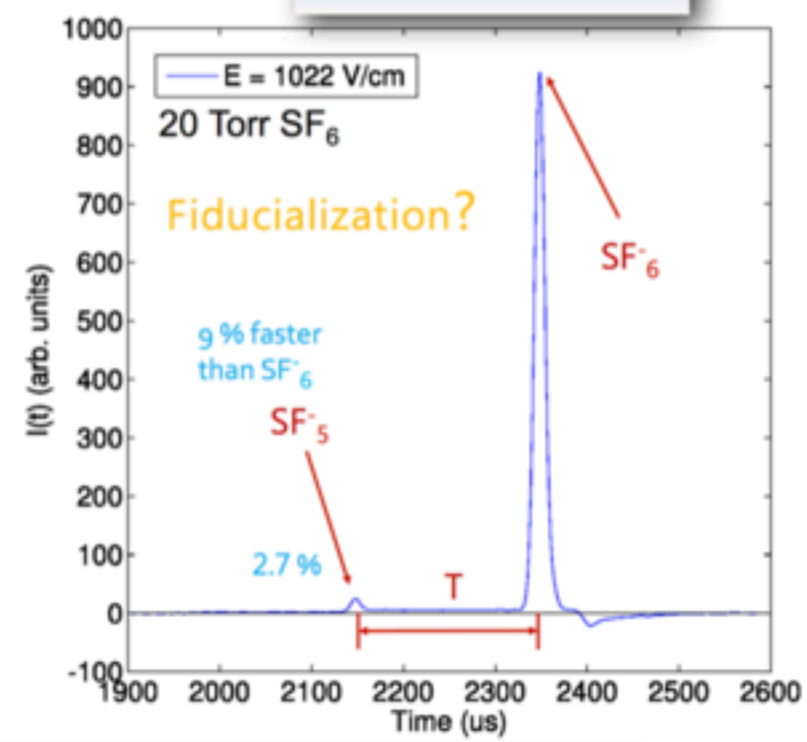


(a) ^{55}Fe energy spectrum in 30 Torr SF_6 using 0.4 mm THGEM

Mobility



Fiducialization

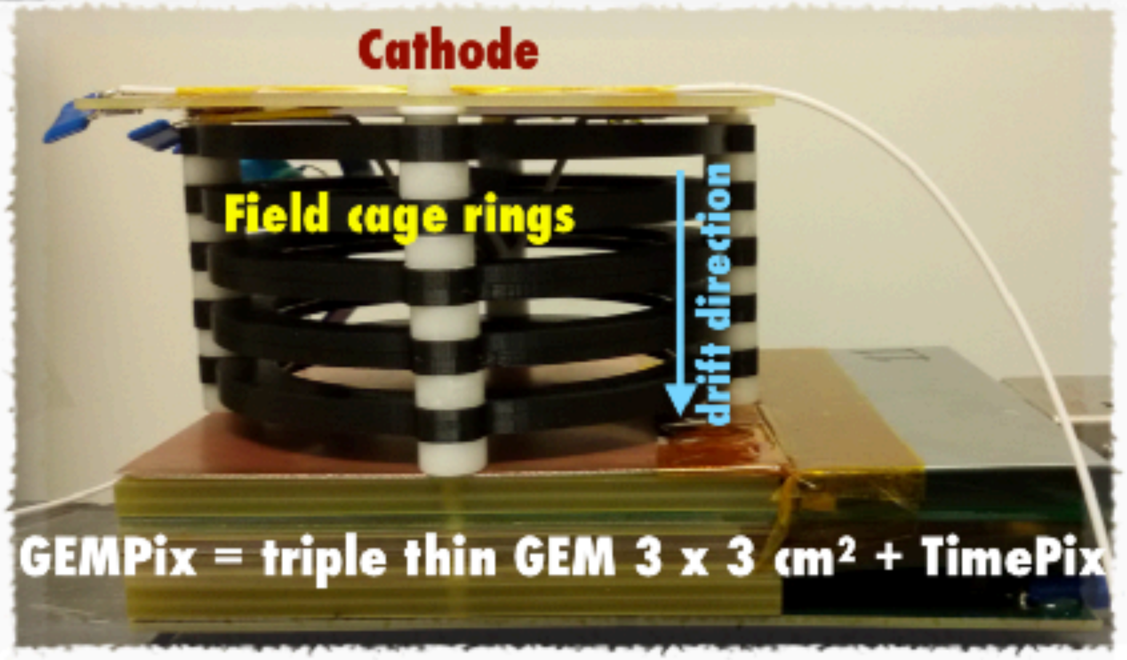


Discovered by CYGNO & INITIUM University of New Mexico collaborators

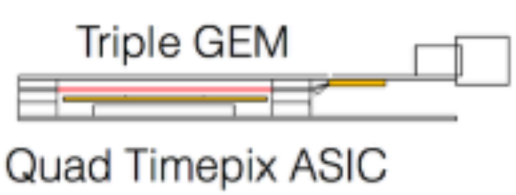
NITEC: a Negative Ion Time Expansion Chamber (2015-2016)

This project has been funded by the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 657751

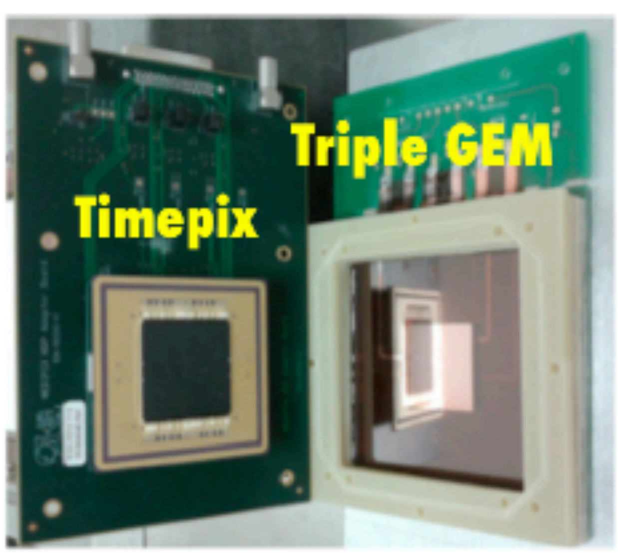
Charge pixel readout with negative ion drift



Field cage: rings support structure (in black in the picture) manufactured with 3D printer at LNF



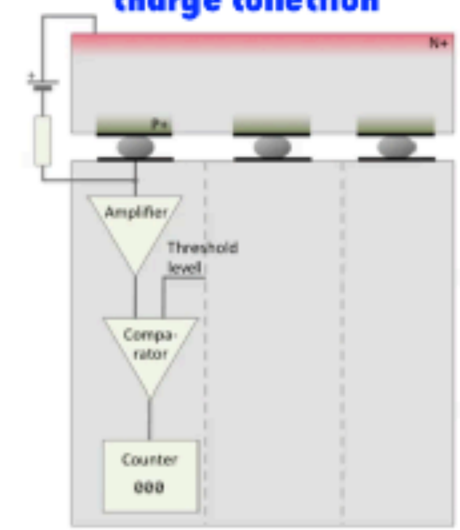
Developed at LNF in collaboration with CERN

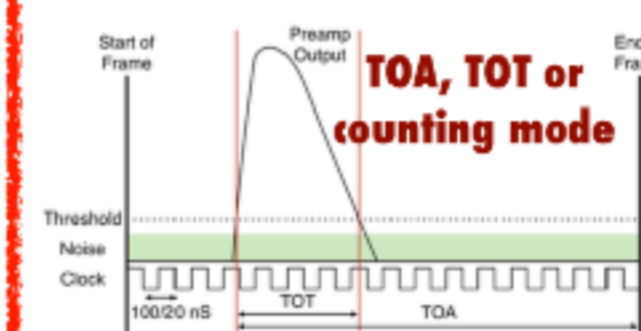


Timepix

55 x 55 um² pixels

No silicon in our TimePix, just charge collection





Adjustable clk from 50 kHz to 100 MHz SUITABLE for both electron and negative ion drift

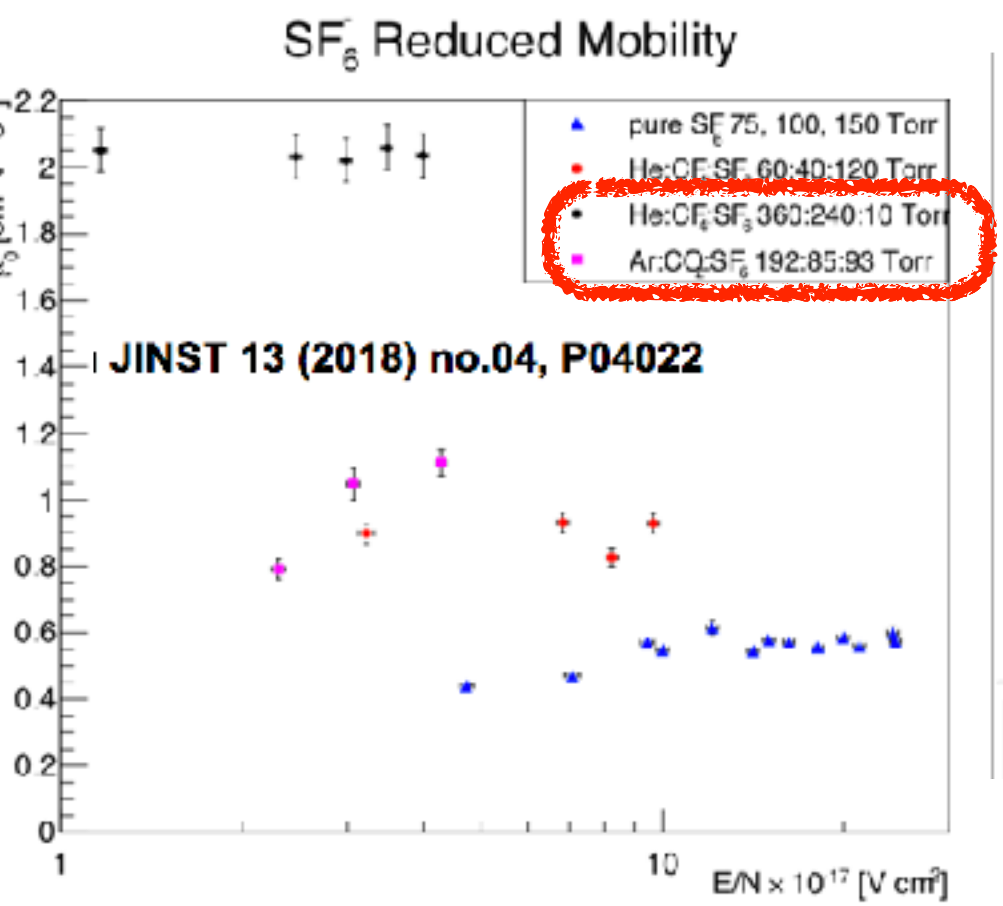
G S
S I

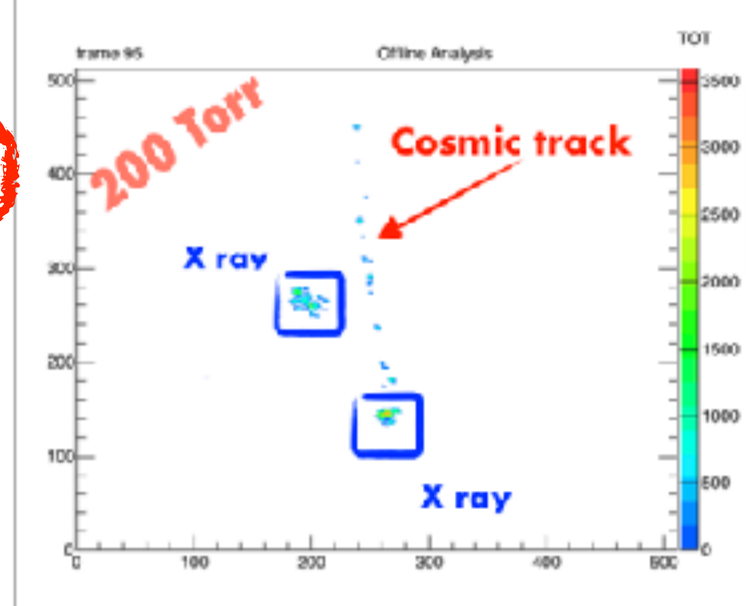
NITEC: a Negative Ion Time Expansion Chamber (2015-2016)

MARIE CURIE ACTIONS

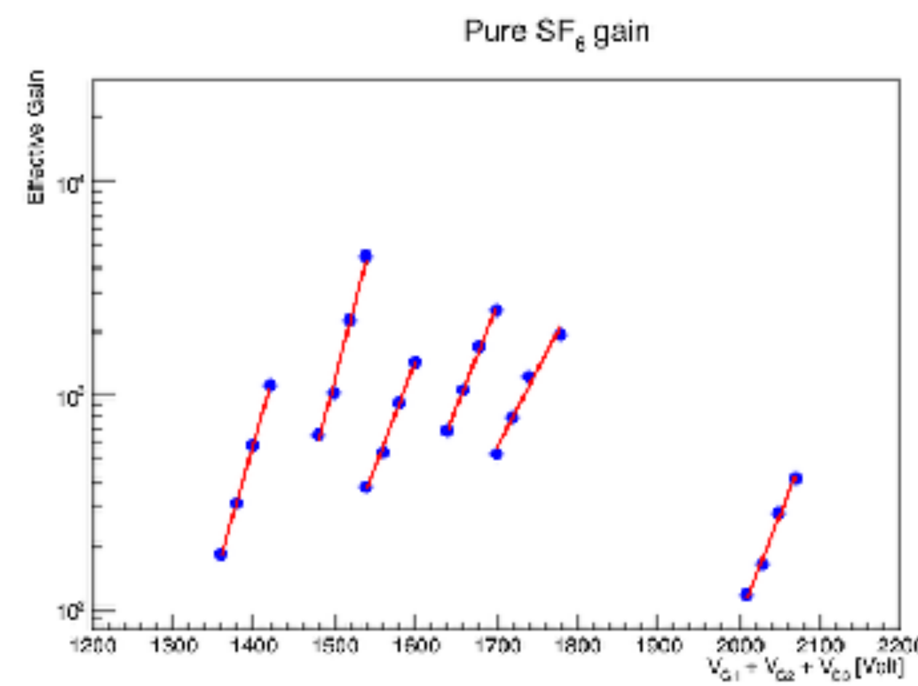
This project has been funded by the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 657751

First ever negative ion operation at nearly atmospheric pressure with SF_6





a NITEC event a 200 Torr of pure SF_6



Opened the doors for a realistic development of negative ion TPC at 1 bar with SF_6

INITIUM gas mixture

±80% He

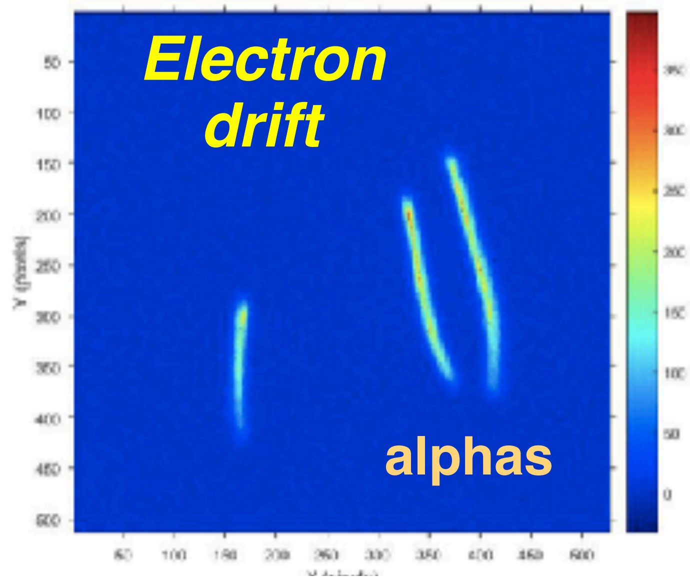
- Kinematic match to O(GeV) WIMPs
- Longer tracks at low energies
- Low density

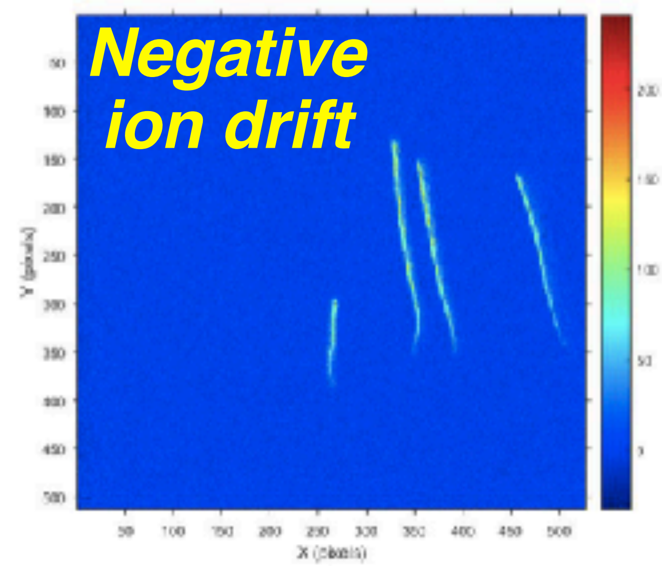
±19% CF_4

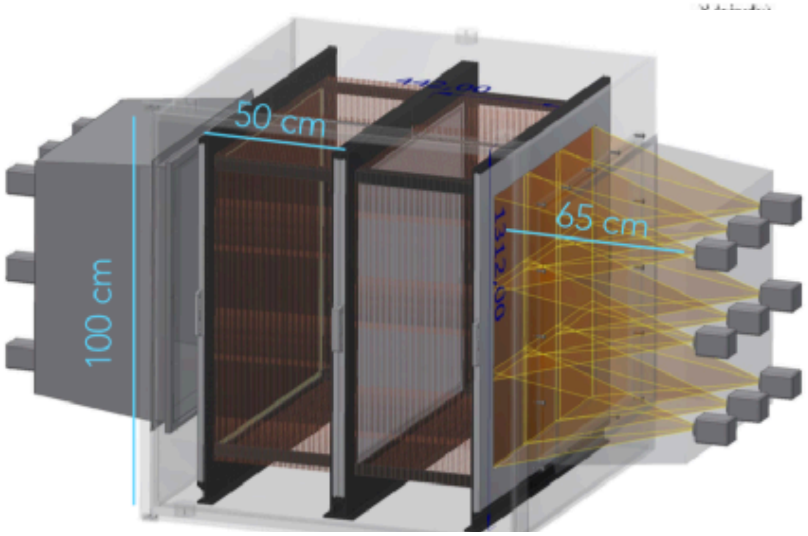
- Quencher with high light yield
- Spectrum matched to sCMOS
- Fluorine for SD sensitivity

±1% SF_6

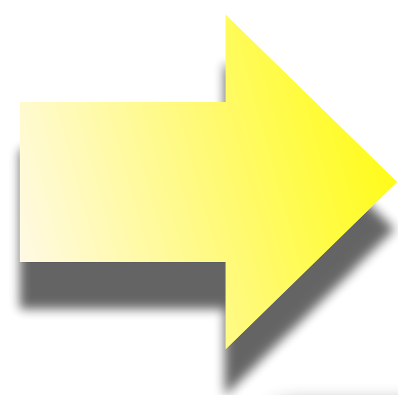
- Induce negative ion drift (NID)
- NID reduce x 20 diffusion
- NID provides fiducialization







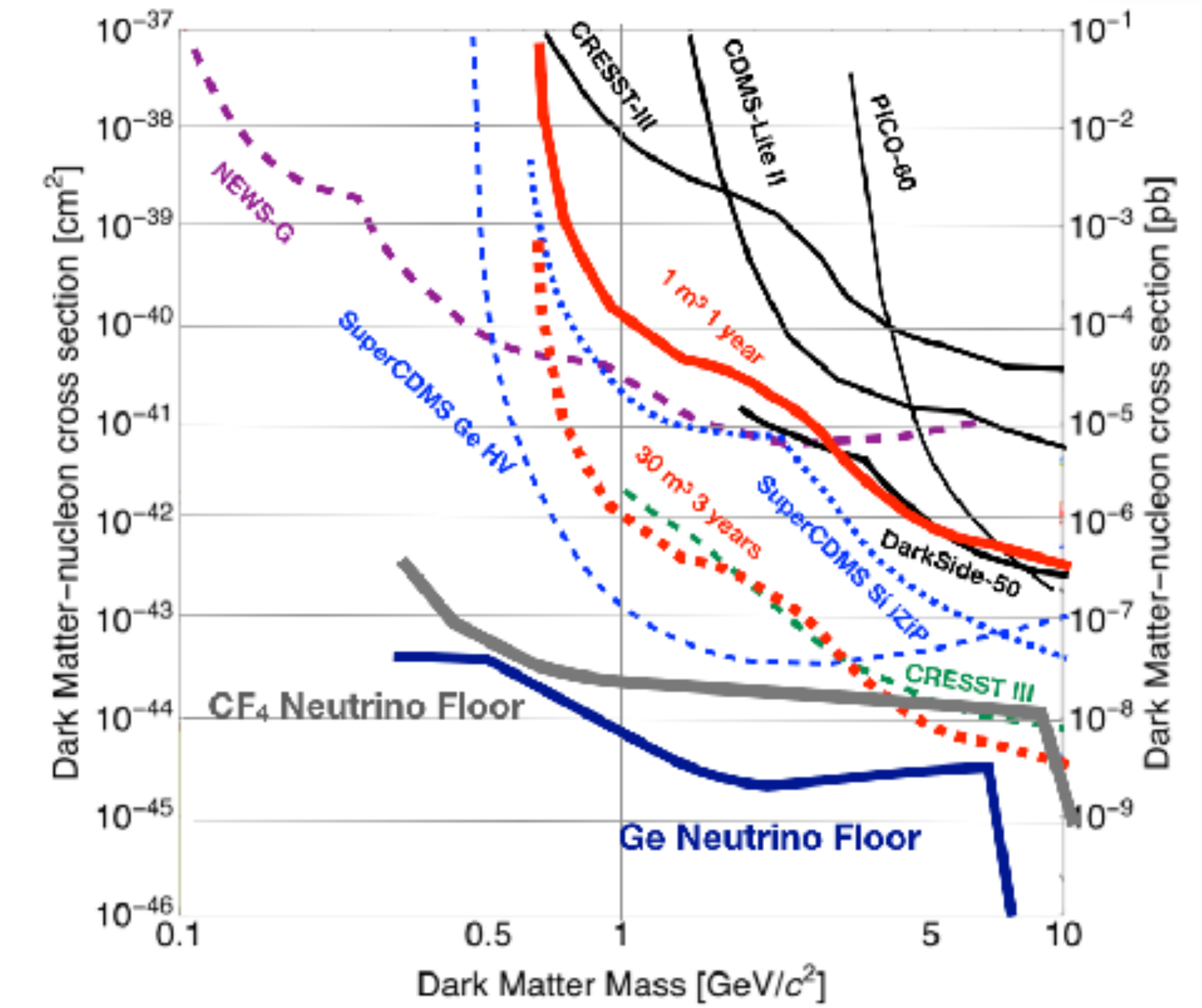
He:CF_4:SF_6 1 kg mass, 1 m^3 volume

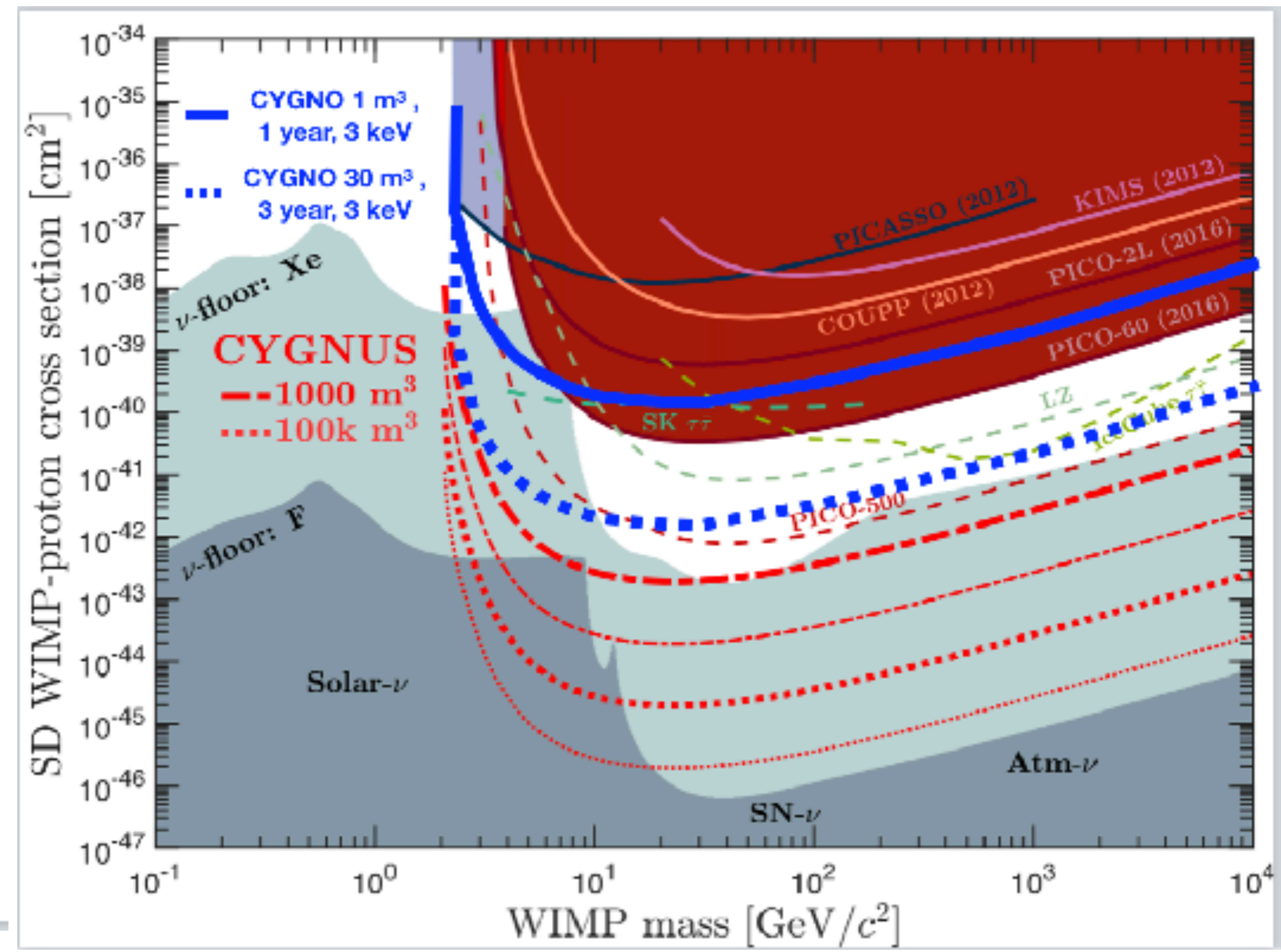


Increased active volume per unit area with same or improved performances

CYGNO prospects sensitivity at low WIMP masses

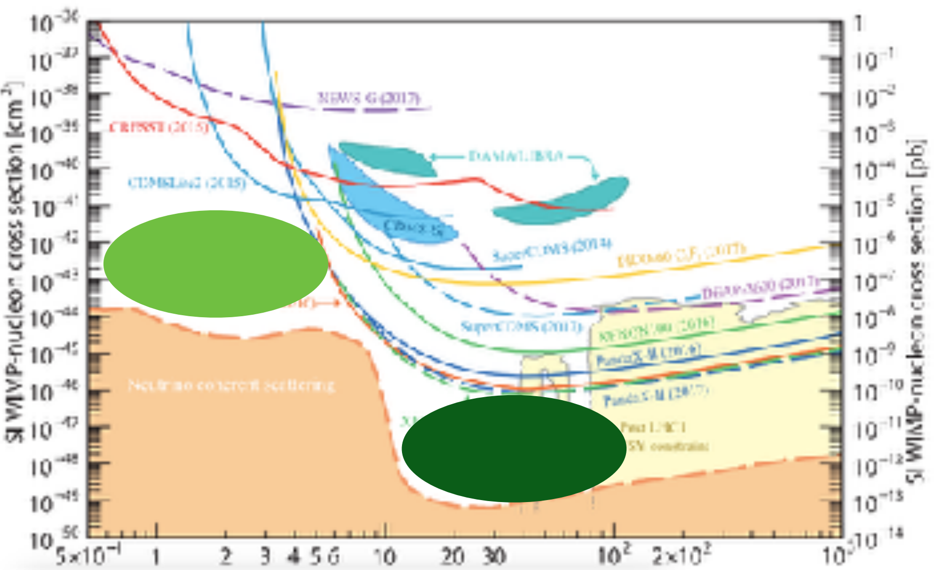
GSSI





Zero background assumed

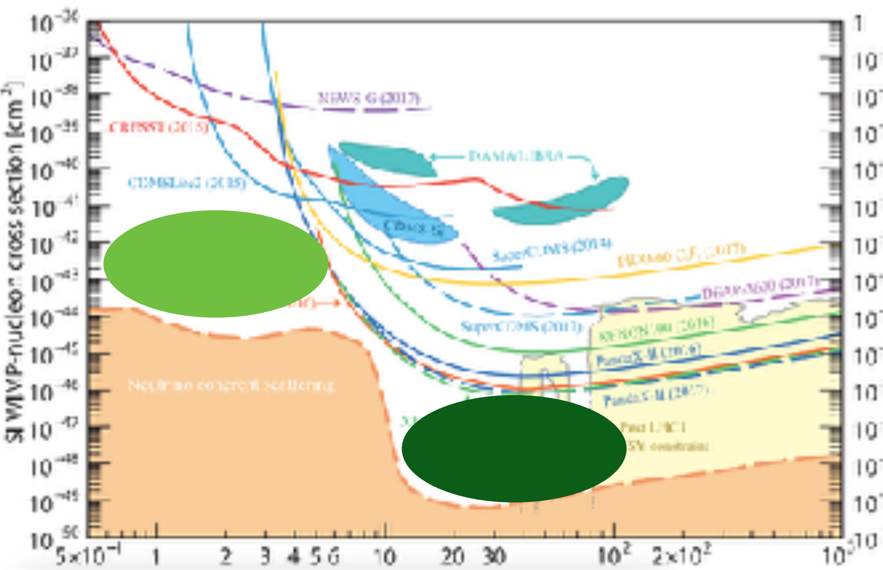
Direct DM search future

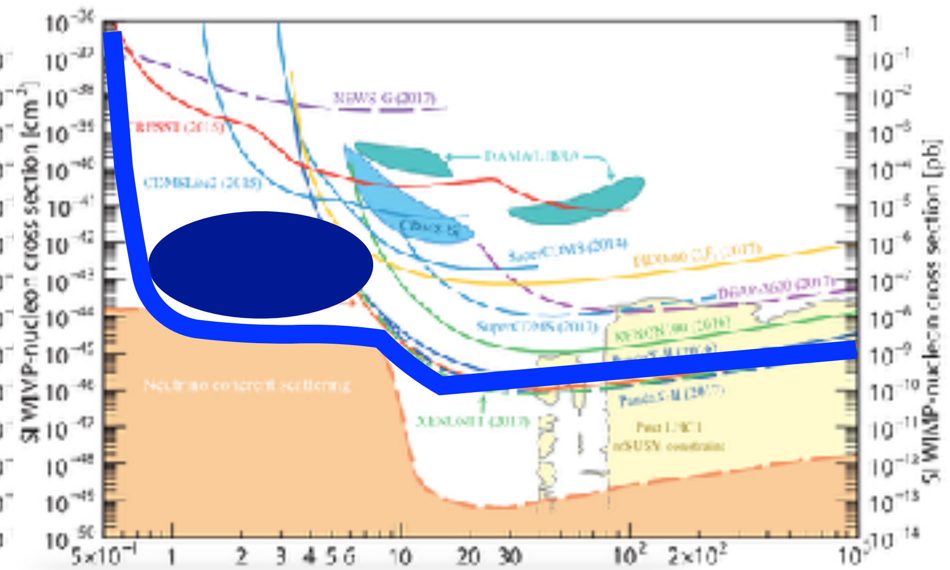


DM is observed:
only a directional experiment can perform DM astronomy

Direct DM search future

NOTE: this is already happening



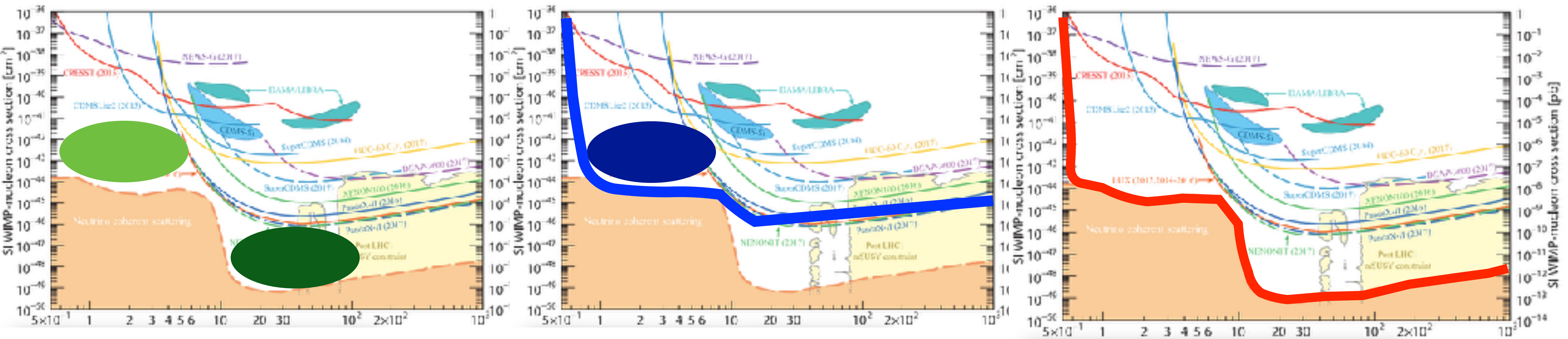


DM is observed:
only a directional experiment can perform DM astronomy

Incompatible results:
only a directional experiment can test the galactic origin of the observed signal

Direct DM search future

NOTE: this is already happening



DM is observed: only a directional experiment can perform DM astronomy

Incompatible results: only a directional experiment can test the galactic origin of the observed signal

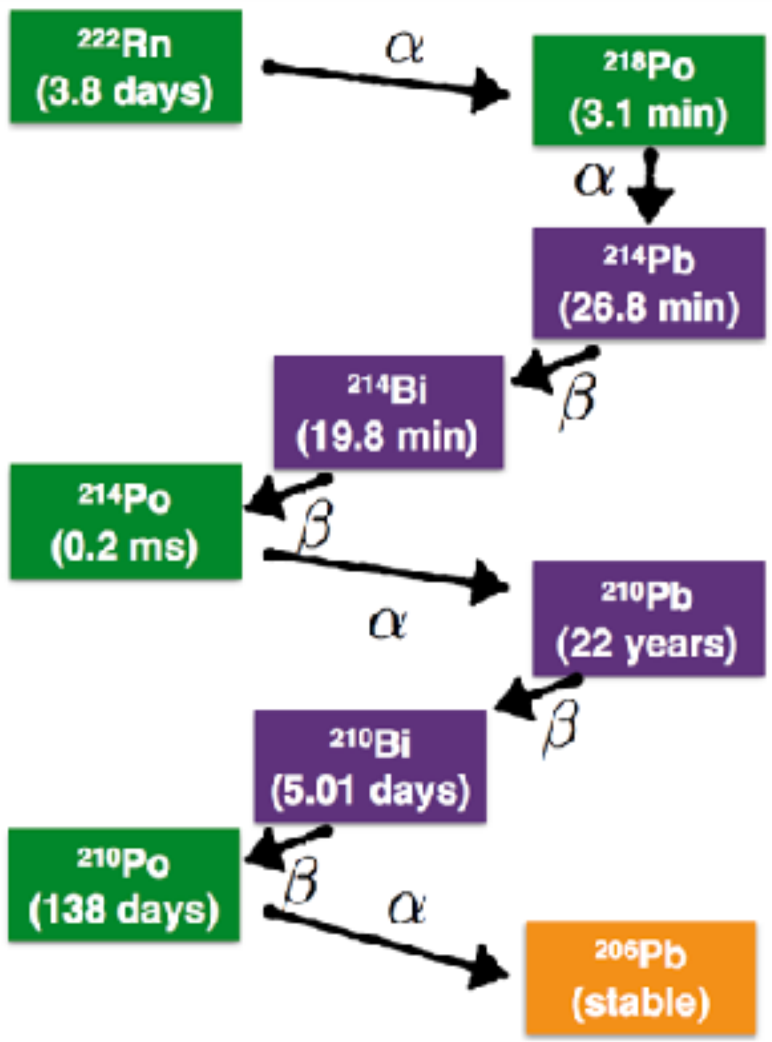
DM is excluded to the Neutrino Floor: only a directional experiment can continue DM searches and study neutrinos

Stay tuned for CYGNO birth!

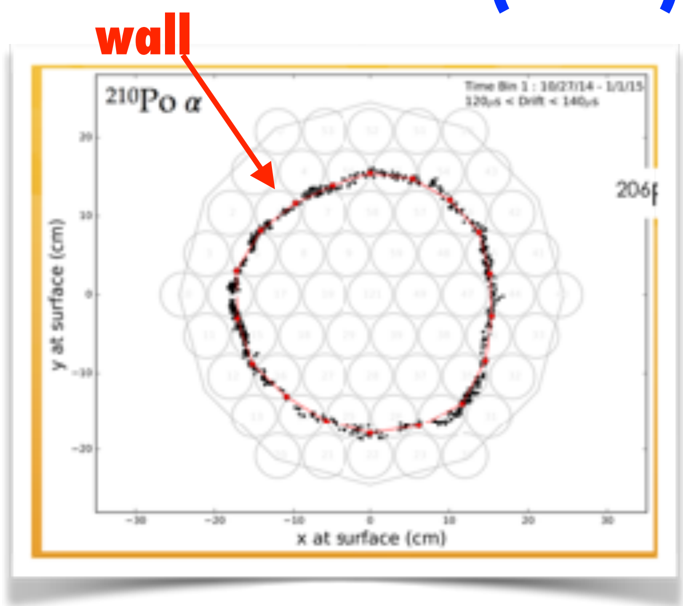
https://web.infn.it/cygnus/

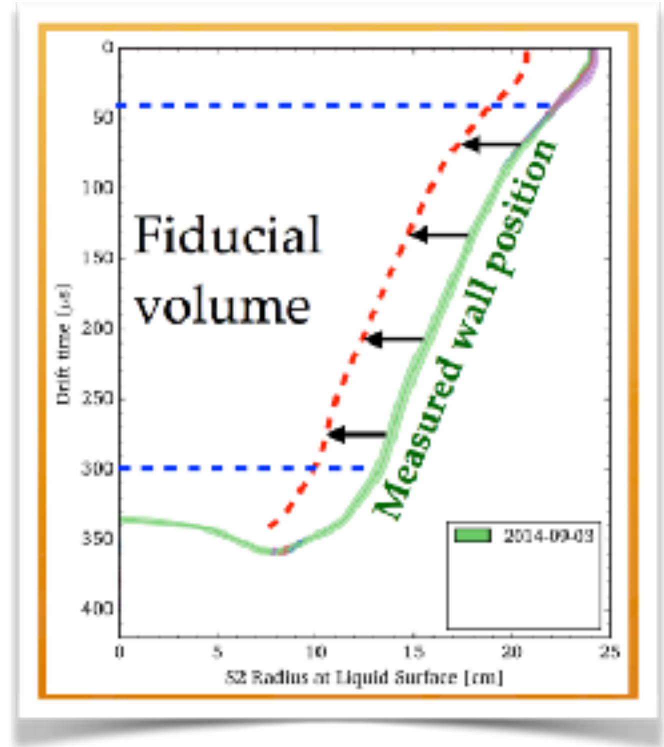
Backup slides

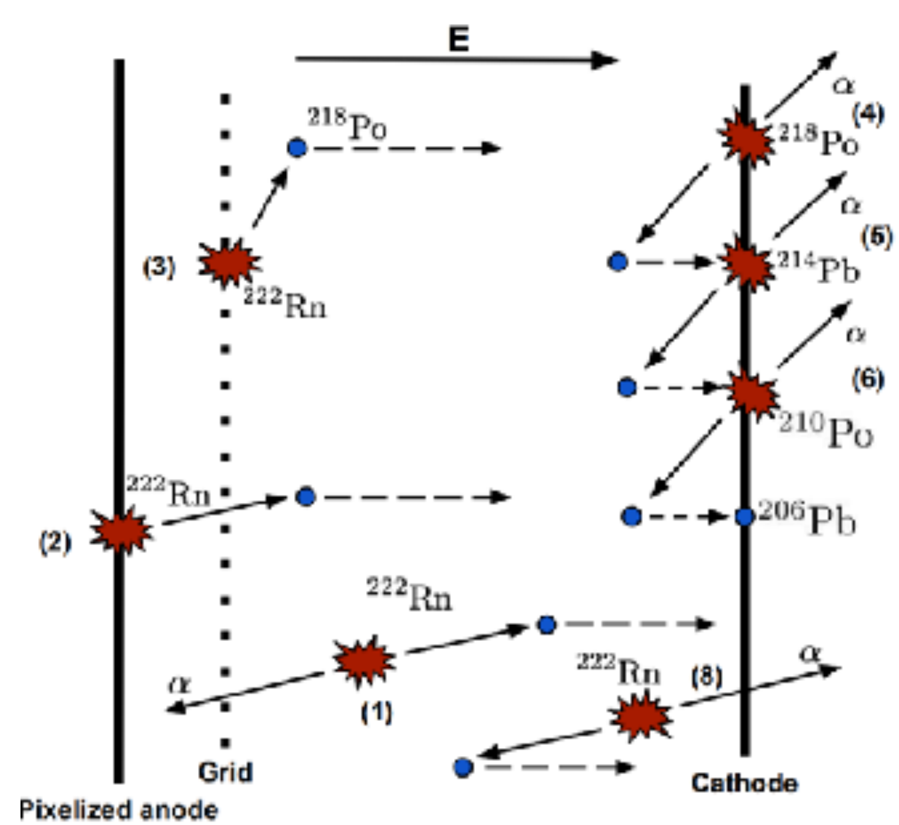
Radon Progeny Recoils



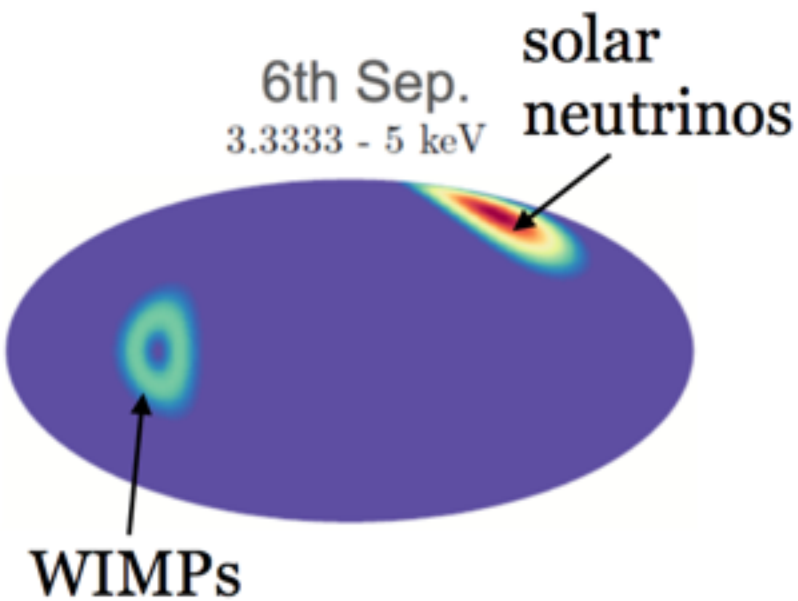
LUX (2014)

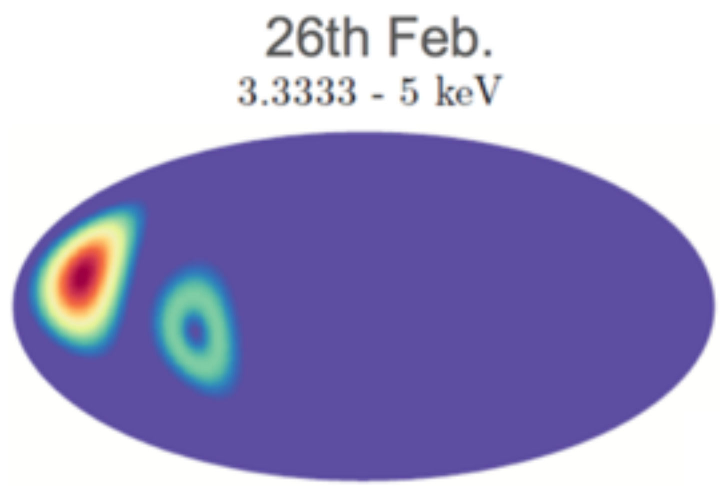






WIMP Sun neutrinos background

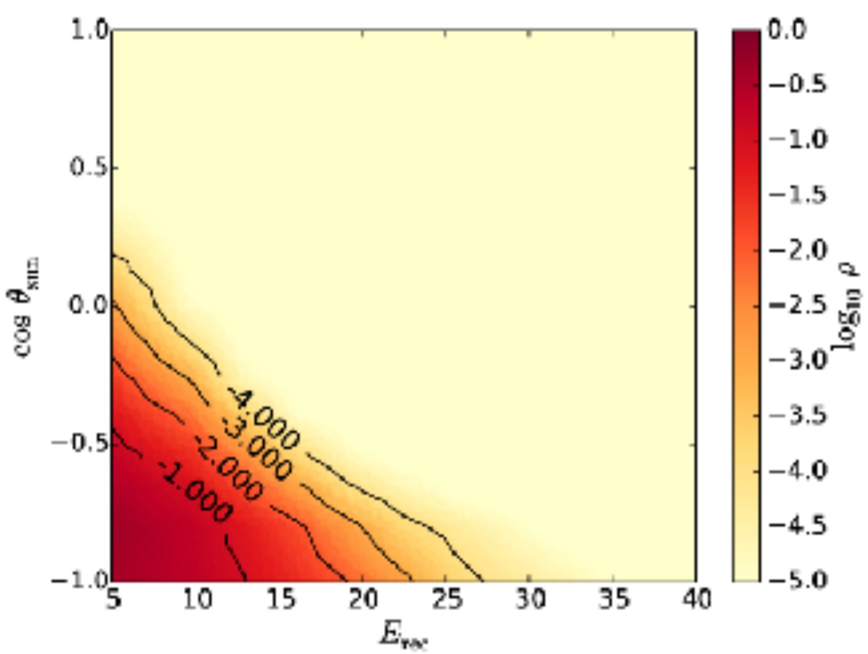




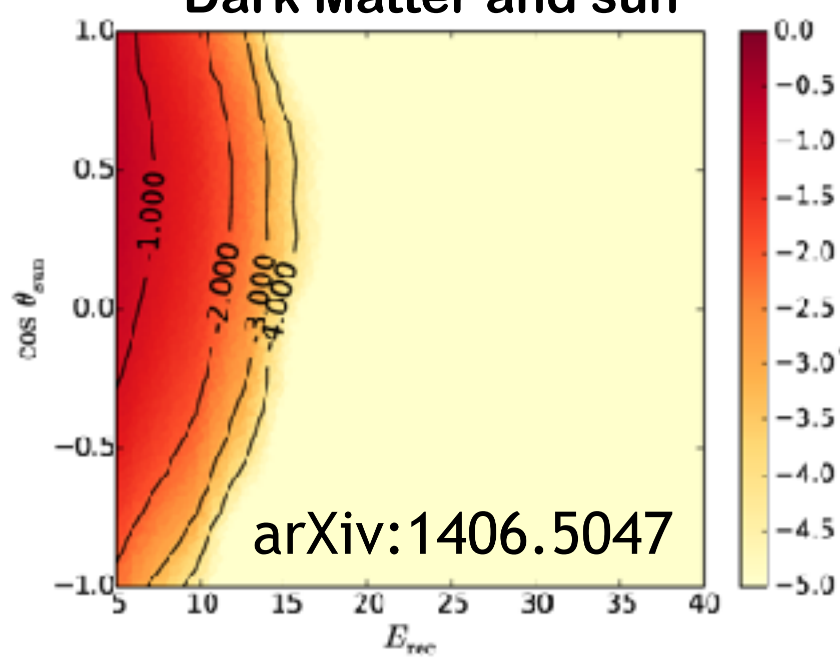
The Sun is never superimposed to the WIMP incoming direction during its yearly revolution

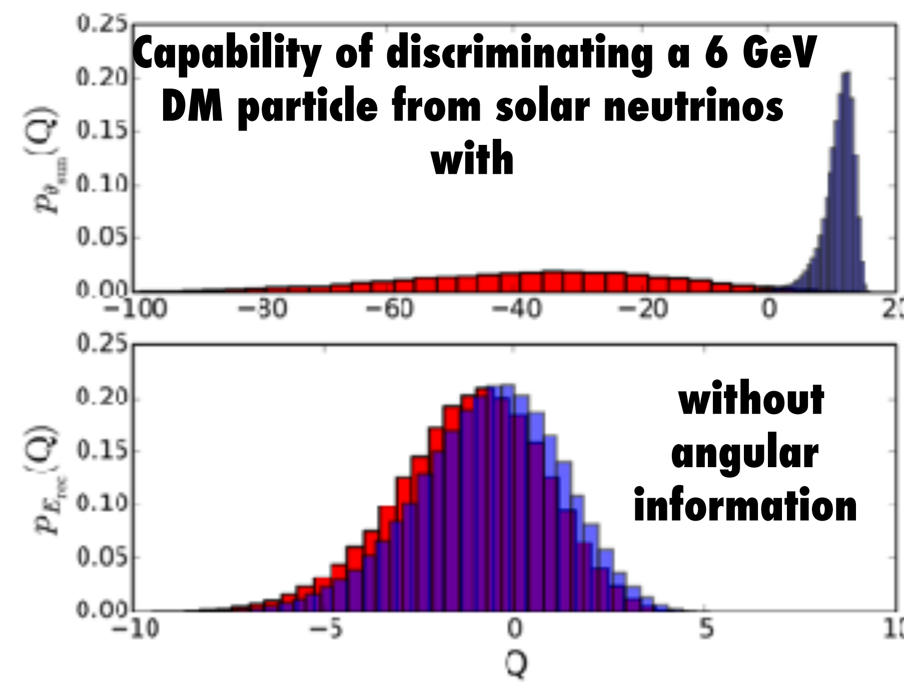
Clear directional signature for neutrinos from the Sun

angle between recoil from Solar neutrino and sun



angle between recoil from Dark Matter and sun





Signal + background

Background