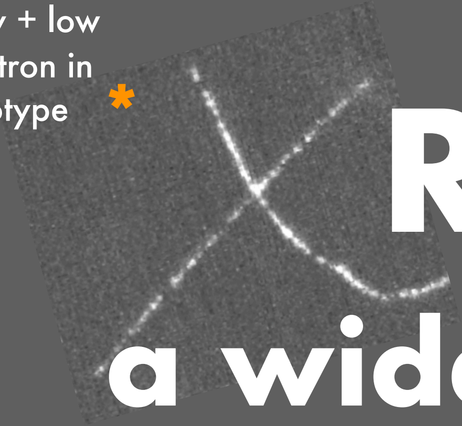
*Cosmic ray + low energy electron in 50 L prototype



Ray CMOS: a wide field of view Xray polarimeter

E. Baracchini, E. Costa, G. Dho, F. Di Giambattista, A. Di Marco, E. Di Marco, D. Marques, G. Mazzitelli, F. Muleri, A. Prajapati, P. Soffitta, S. Torelli

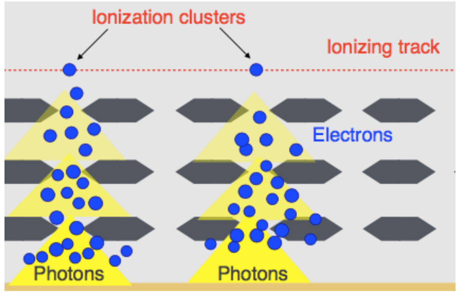
This project has been funded by the Italian Ministry of Education, University and Research through the project PRIN: Progetti di Ricerca di Rilevante Interesse Nazionale "HypeX: High Yield Polarimetry Experiment in X-rays " (Prot. 2020MZ884C)

Outline

- Detector concept
- Large 50 L realisation of detector concept for directional Dark Matter searches
    - Energy response linearity from overground commissioning
    - Low energy electrons directionality from simulation
- Developments for X-ray polarimetry
    - Preliminary results from simulation
    - Preliminary results from calibration with electron tracks

High precision 3D TPC with optical readout via PMT + sCMOS

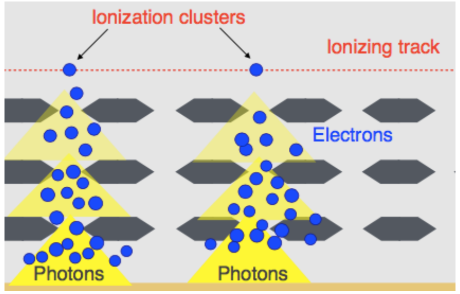
JINST 13 (2018) no.05, P05001



(triple thin) GEM amplification

High precision 3D TPC with optical readout via PMT + sCMOS

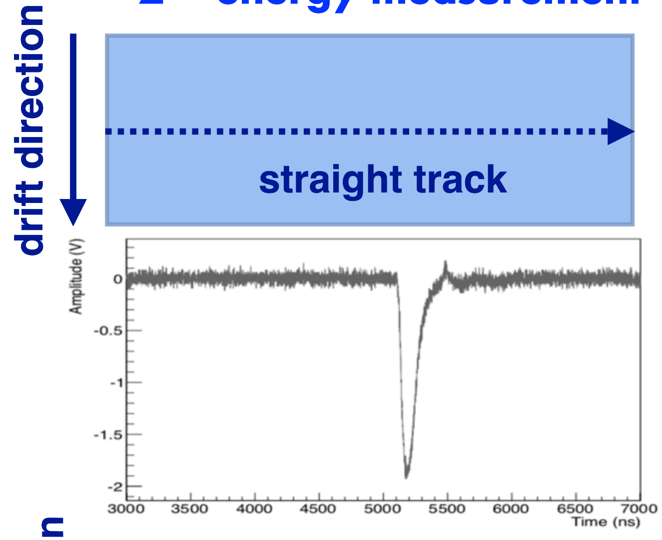
JINST 13 (2018) no.05, P05001

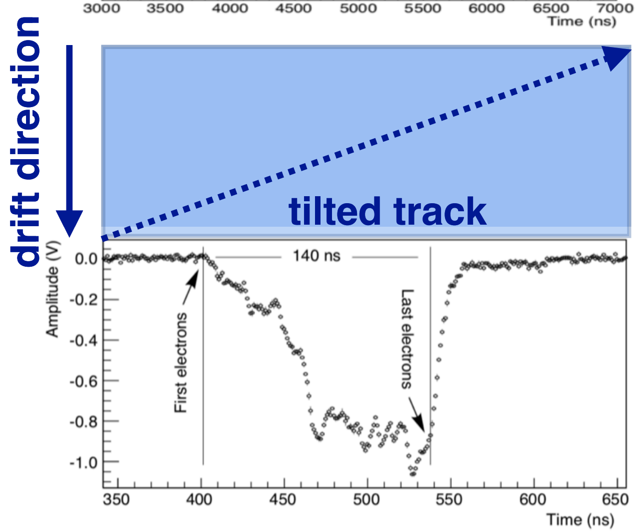


(triple thin) GEM amplification

PMT:

integrated
Z + energy measurement

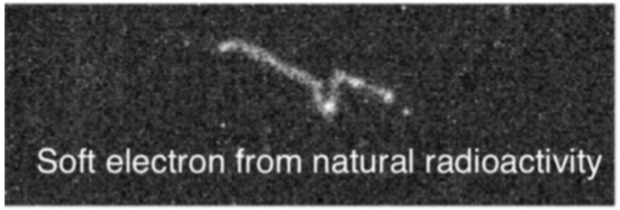


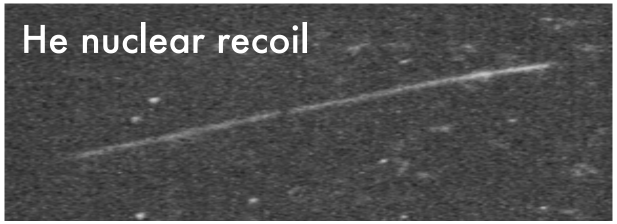


High precision 3D TPC with optical readout via PMT + sCMOS

sCMOS:

high granularity
X-Y + energy measurements

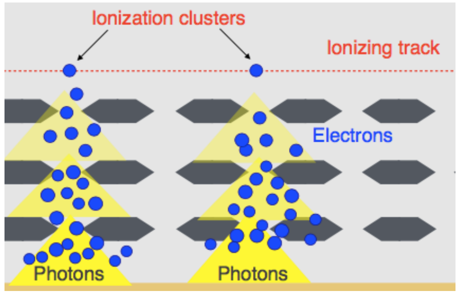




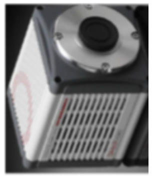
1/3 noise w.r.t. CCDs

- Market pulled
- Single photon sensitivity
- Decoupled from target
- Large areas with proper optics

JINST 13 (2018) no.05, P05001

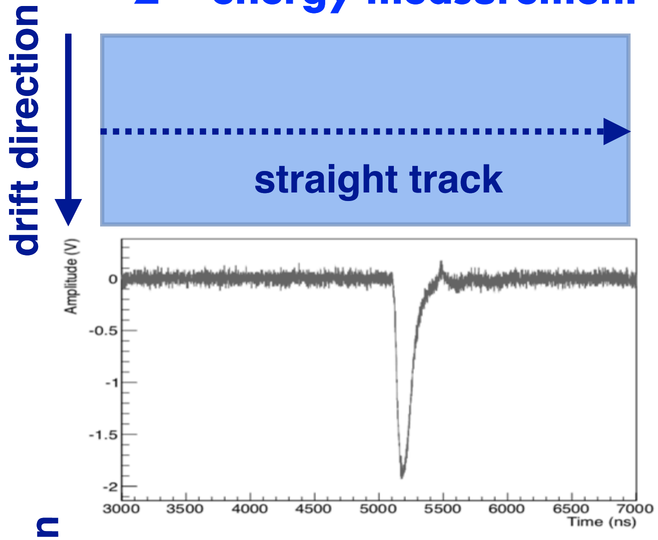


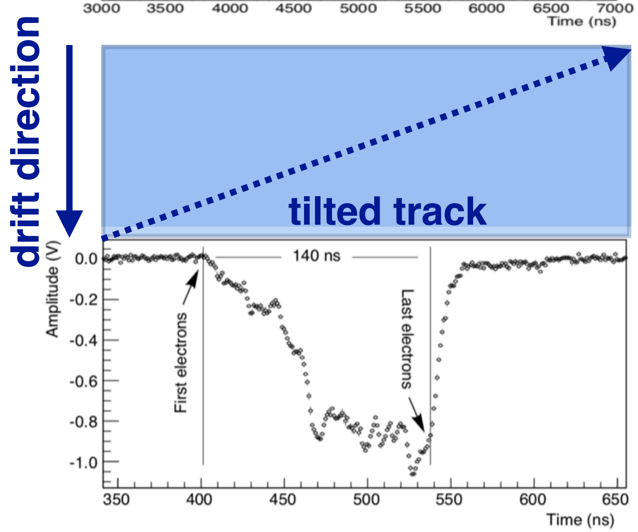
(triple thin) GEM amplification



PMT:

integrated
Z + energy measurement

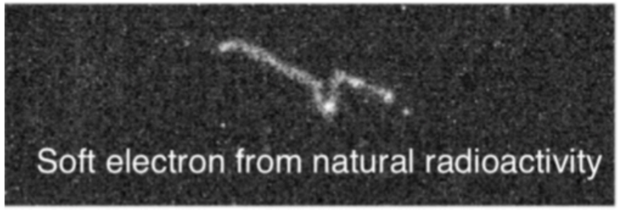


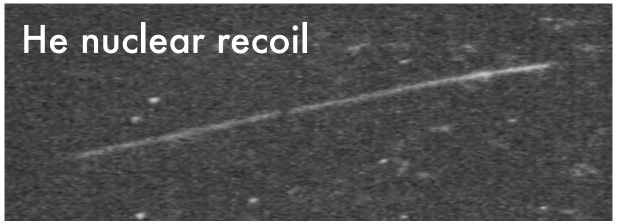


High precision 3D TPC with optical readout via PMT + sCMOS

sCMOS:

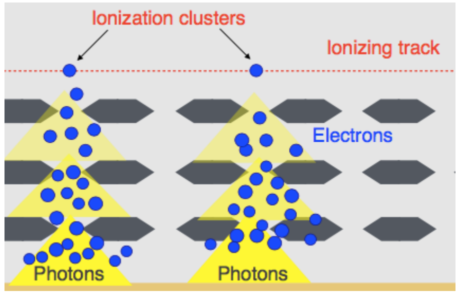
high granularity
X-Y + energy measurements



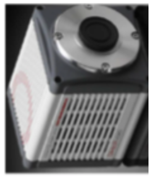


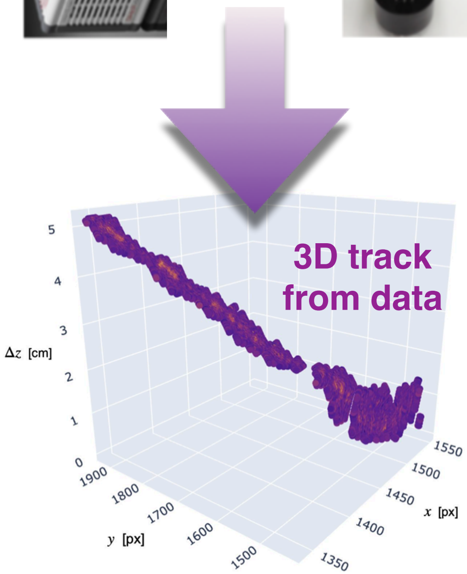
- **1/3 noise w.r.t. CCDs**
- Market pulled
- Single photon sensitivity
- Decoupled from target
- Large areas with proper optics

JINST 13 (2018) no.05, P05001



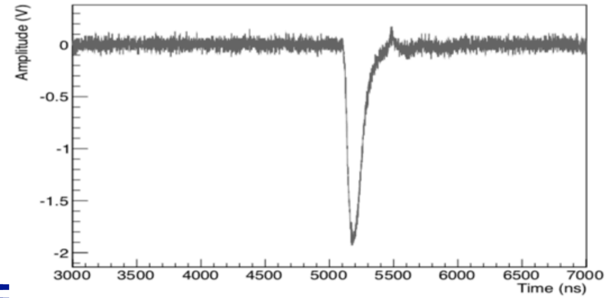
(triple thin) GEM amplification

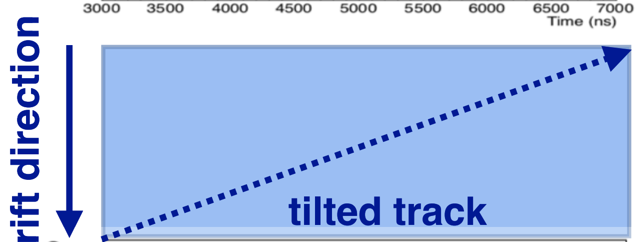


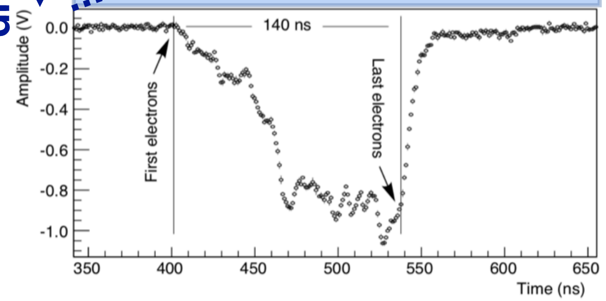


PMT:

integrated
Z + energy measurement







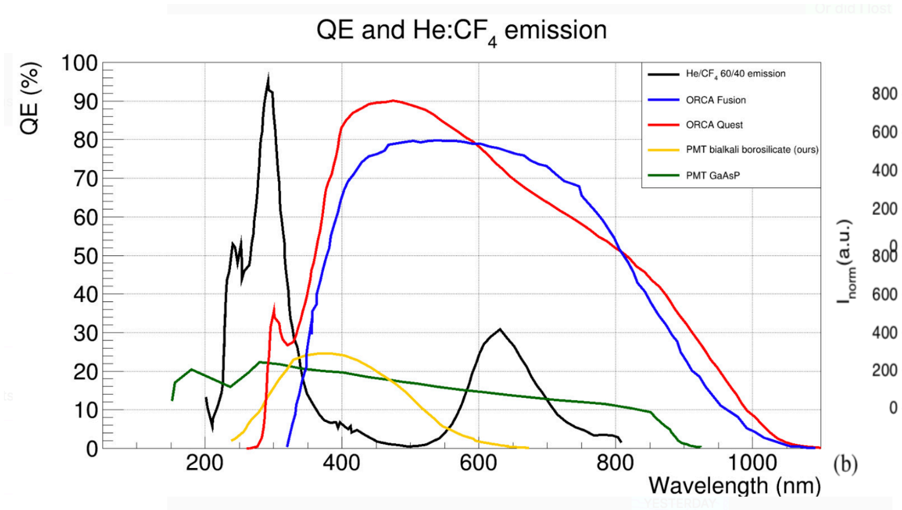
sCMOS characteristics & He/Ar:CF_4 emission spectra

https://www.hamamatsu.com/eu/en/product/cameras/cmos-cameras.html

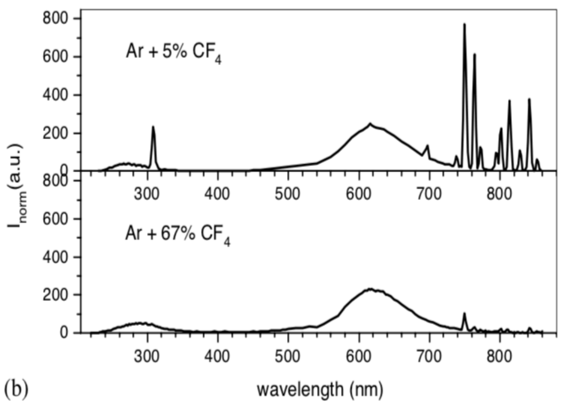


HAMAMATSU	# of pixels	pixel size [um²]	sensor area [cm²]	dynamic range	readout noise (fast scan)	min exposure time (fast)	
Orca Flash	2048 x 2048	6.5 x 6.5	1.33 x 1.33	37000:1	1.4 (1.6) rms	33 (10) us	
Orca Fusion	2304 x 2304	6.5 x 6.5	1.498 x 1.498	21400:1	0.7 (1.4) rms	280 (17) us	Used for the results shown
Orca Quest	4096 x 2304	4.6 x 4.6	1.884 x 1.060	25900:1	0.27 (0.43) rms	200 (7.2) us	Recently purchased

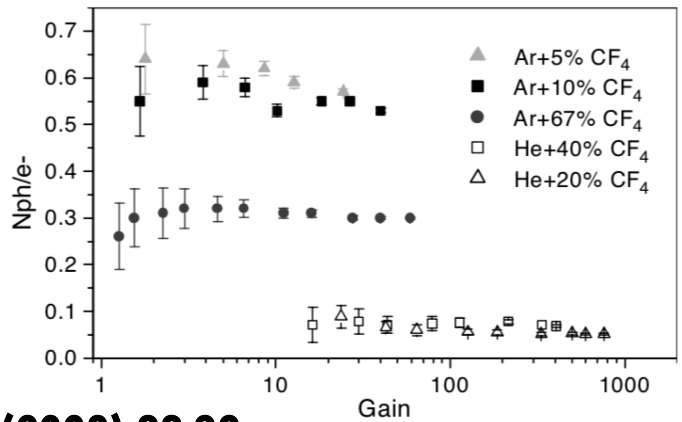
improving performances



Ar:CF_4 spectra



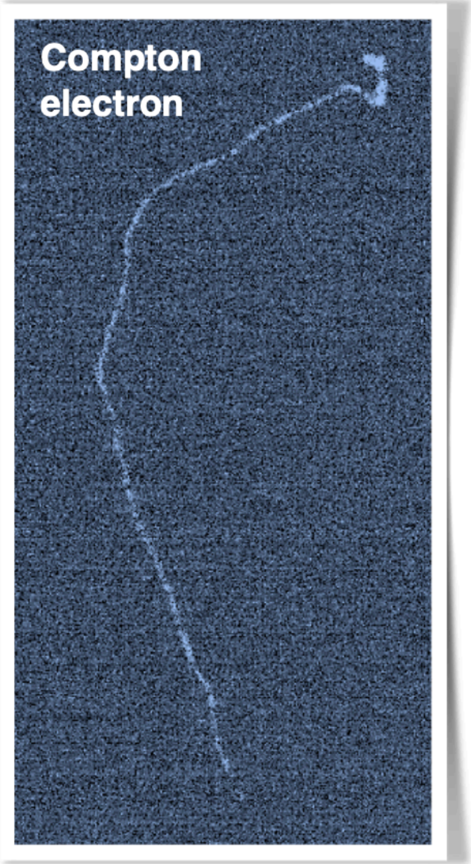
Ar:CF_4 & He:CF_4 photon production

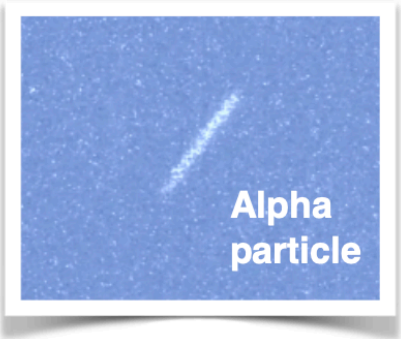


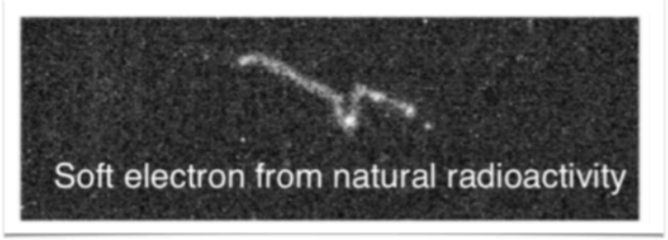
NIM A 504 (2003) 88-92

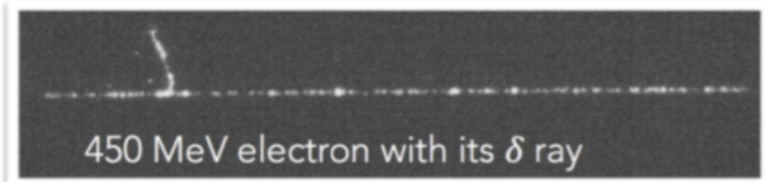
Photographing particle tracks

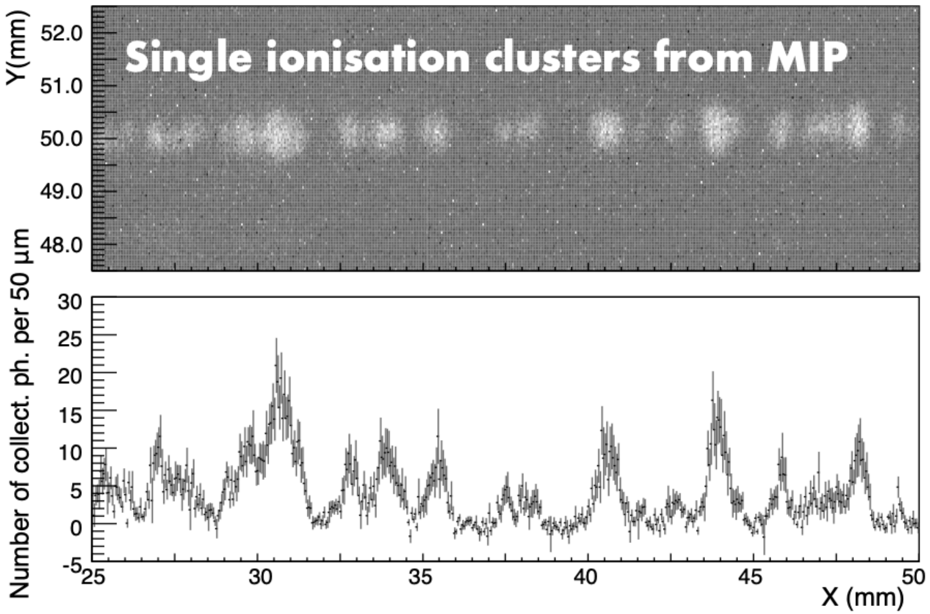
$He:CF_4$ @ 1 atm

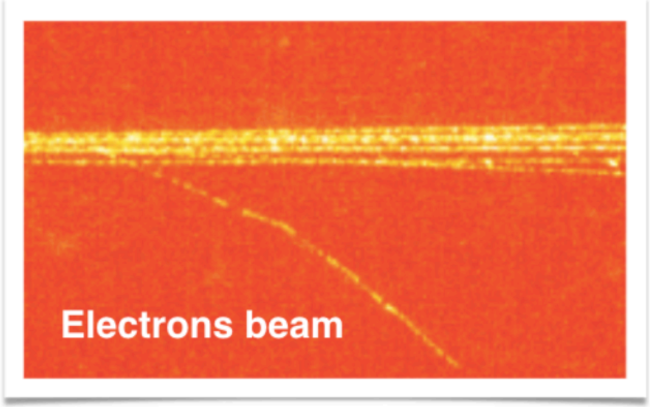


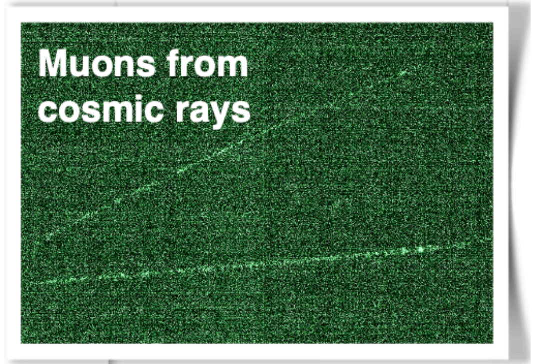


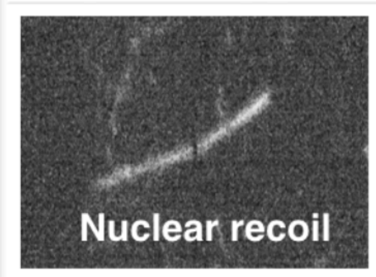












Optical readout features

- **Camera focused on last amplification stage**

Lens de-magnification

$$\delta = \frac{f}{d - f}$$

sCMOS-GEM distance (d)

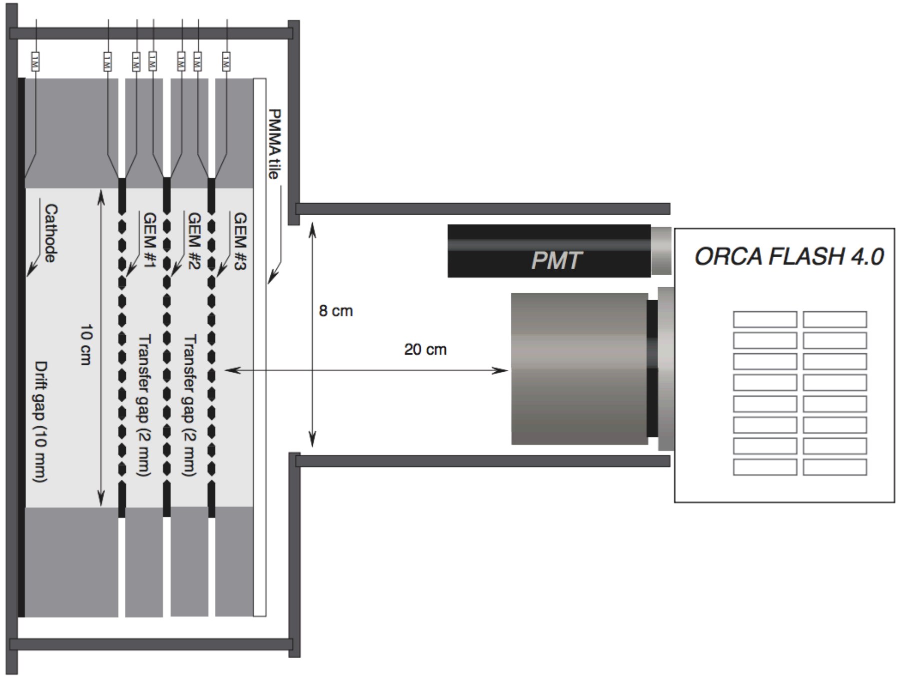
Focal lenght F.L. (f)

sCMOS sensor geometrical acceptance

$$\Omega = \frac{1}{(4(1/\delta + 1) \times a)^2}$$

- **The further the camera, the larger the area it can image**
  - a 36 x 36 cm² area with an effective granularity of 155 x 155 um² (large volume application)
  - a 10 x 10 cm² area with an effective granularity of 41 x 41 um² (small volume application)
- **The further the camera, the lower the light yield detectable**
  - ± 1 x 10^{-4} coverage for large volume application
  - ± 1 x 10^{-3} coverage for large volume application

Camera electronics is integrated, the output is an USB plug



- PMTs **geometrical acceptance:**
  - ➡ critically **depends** on the **position** of the emission on the GEM plane w.r.t. the PMT position
  - ➡ Empirical measured scaling:

$$L_i = \frac{L}{R_i^{\alpha}}$$

Light collected by the PMT #i (L_i)

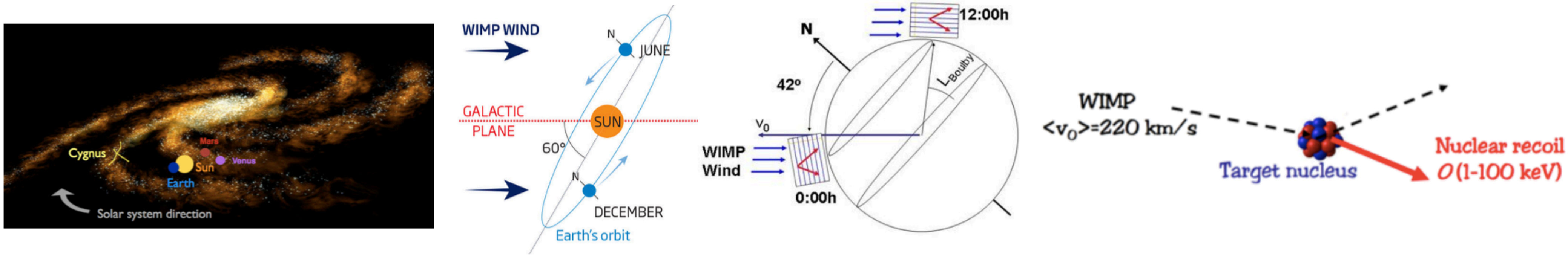
Total light emitted (L)

Distance from the light emission (R_i)

We measured $\alpha \sim 4$

3

The CYGNO/INITIUM project: large realisation of detector concept for underground directional Dark Matter searches



Our Galaxy — Solar system — Earth — Detector target

Requires capability to determine direction of O(keV) nuclear recoil

CYGNO detectors & timeline

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

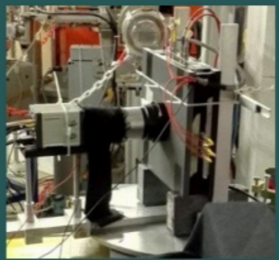
F. D. Amaro et al [CYGNO Collaboration], Instruments, Volume 6, Issue 1

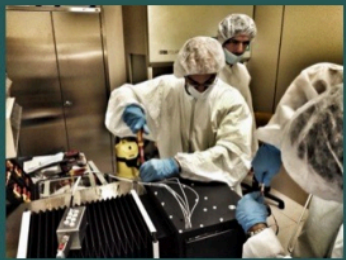
PHASE 0: R&D and prototypes

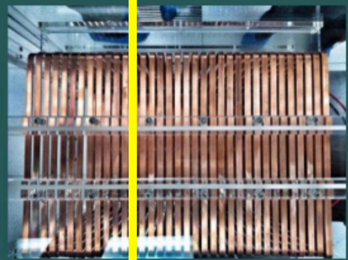
PHASE 1: O(1) m³ Demonstrator

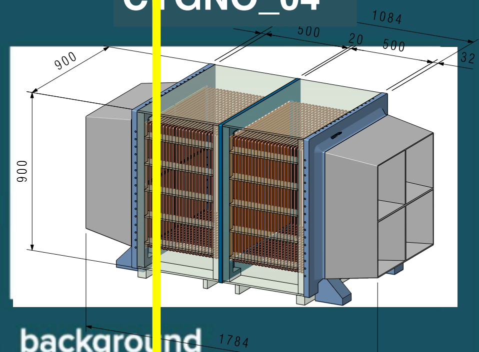
PHASE 2: 30 m³ Experiment

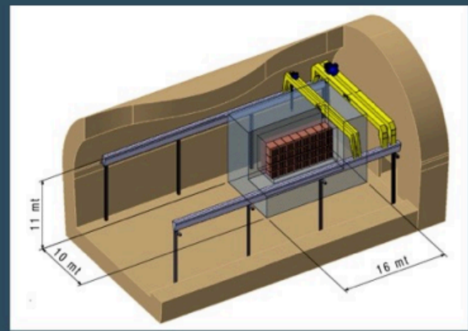
2015/16 ROMA1	2017/18 LNF	2019/22 LNF/LNGS	2023/26 LNF/LNGS	2026.. LNGS
ORANGE	LEMON	LIME	CYGNO_04	CYGNO_30











ORANGE:
- 1 cm drift

LEMON:
- 3D printing
- 20 cm drift

LIME:
- 50 cm drift
- underground tests
- MC validation

CYGNO_04:
- background
- materials test, gas purification
- scalability

CYGNO_30:
- Physics research

Fernando Domingues Amaro [1], Elisabetta Baracchini [2,3], Luigi Benussi [4], Stefano Bianco [4], Cesidio Capoccia [4], Michele Caponero [4,5], Danilo Santos Cardoso [6], Gianluca Cavoto [7,8], André Cortez [2,3], Igor Abritta Costa [9], Rita Joanna da Cruz Roque [1], Emiliano Dané [4], Giorgio Dho [2,3], Flaminia Di Giambattista [2,3], Emanuele Di Marco [7], Giovanni Grilli di Cortona [4], Giulia D'Imperio [7], Francesco Iacoangeli [7], Herman Pessoa Lima Júnior [6], Guilherme Sebastiao Pinheiro Lopes [9], Amaro da Silva Lopes Júnior [9], Giovanni Maccarrone [4], Rui Daniel Passos Mano [1], Michela Marafini [10], Robert Renz Marcelo Gregorio [11], David José Gaspar Marques [2,3], Giovanni Mazzitelli [4], Alasdair Gregor McLean [11], Andrea Messina [7,8], Cristina Maria Bernardes Monteiro [1], Rafael Antunes Nobrega [9], Igor Fonseca Pains [9], Emiliano Paoletti [4], Luciano Passamonti [4], Sandro Pelosi [7], Fabrizio Petrucci [12,13], Stefano Piacentini [7,8], Davide Piccolo [4], Daniele Pierluigi [4], Davide Pinci [7,*], Atul Prajapati [2,3], Francesco Renga [7], Filippo Rosatelli [4], Alessandro Russo [4], Joaquim Marques Ferreira dos Santos [1], Giovanna Saviano [4,14], Neil John Curwen Spooner [11], Roberto Tesauro [4], Sandro Tomassini [4] and Samuele Torelli [2,3]

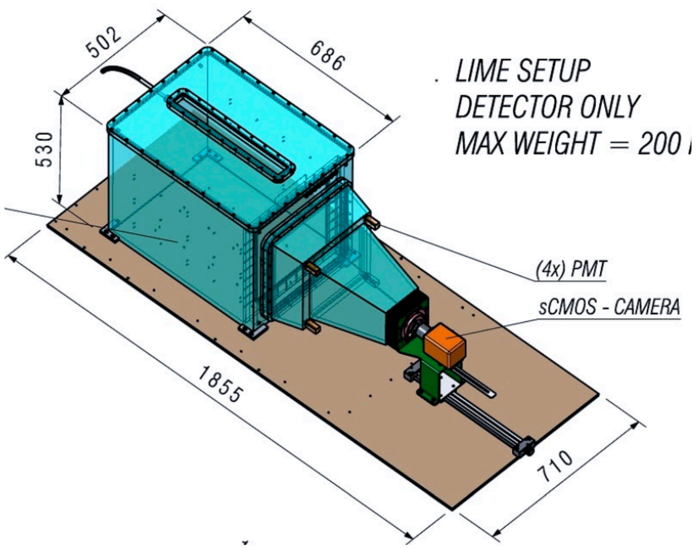
European Research Council
Established by the European Commission

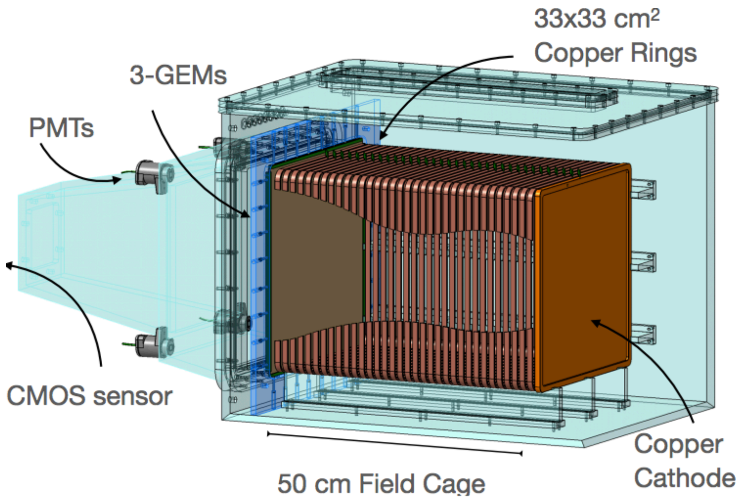
MARIE CURIE ACTIONS

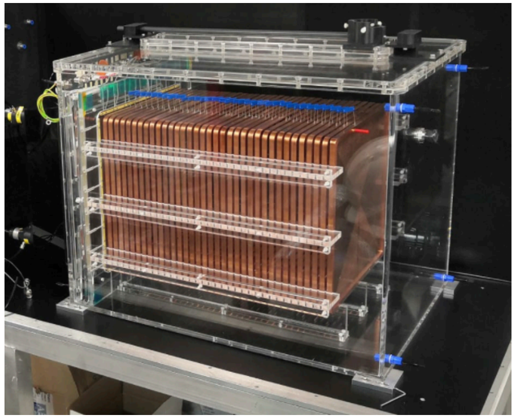
This project has received fundings under the European Union's Horizon 2020 research and innovation programme from the Marie Sklodowska-Curie grant agreement No 657751 and from the European Research Council (ERC) grant agreement No 818744

LIME: Long Imaging ModulE

50 L active volume



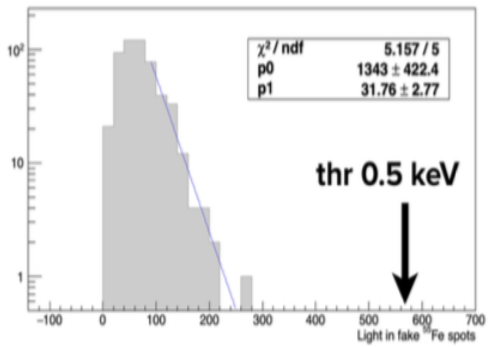




1 sCMOS + 4 PMT + 3 GEMs
33 x 33 cm² readout area
50 cm drift length

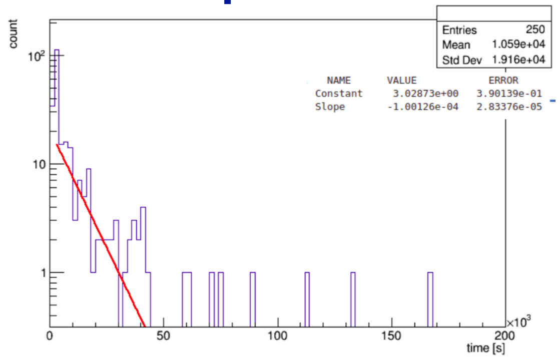
- **1.498 x 1.498 cm² sensor**
- **6.5 x 6.5 um² pixels**
- **2304 x 2304 pixels**
- **Imaging 36 x 36 cm² area**
- **Effective pixel granularity 155 x 155 um²**
- **Sensor geometrical acceptance Ω =1.1 x 10⁻⁴**

1 keV = 1200 photons



sCMOS fake cluster threshold < 0.5 keV$_{ee}$

< 2.7 spikes/hour



Stability

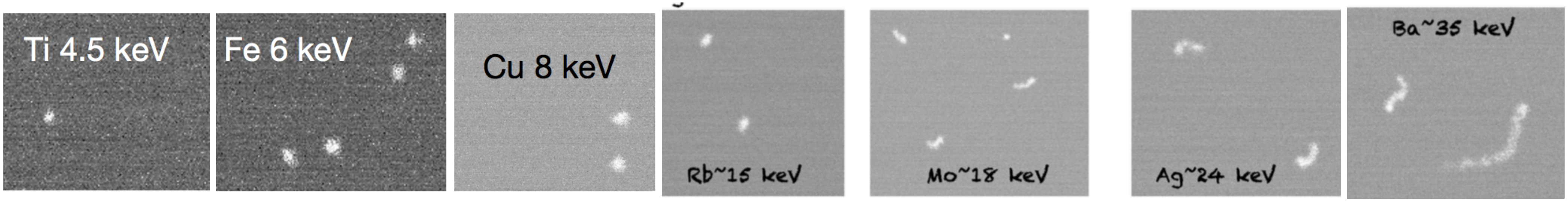
50 L volume (33 x 33 cm² for 50 cm drift)

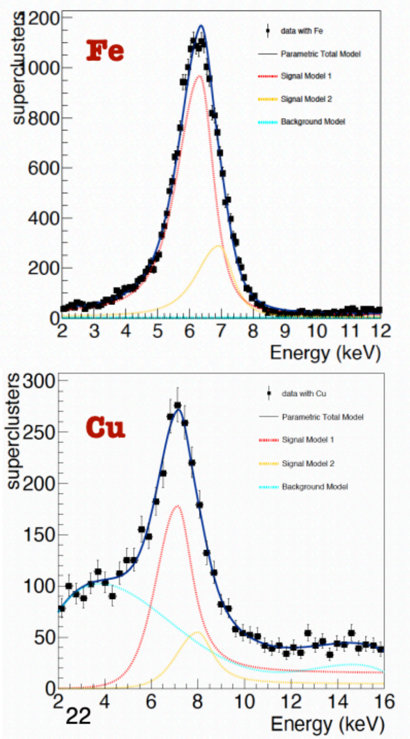
He:CF_4 60:40 1 bar

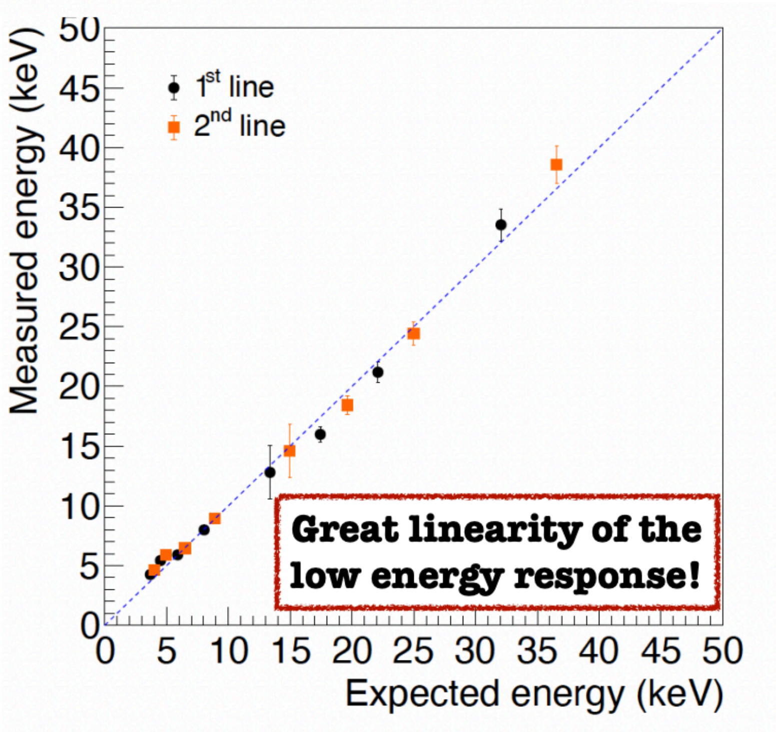
LIME response to low energy Xrays (overground)

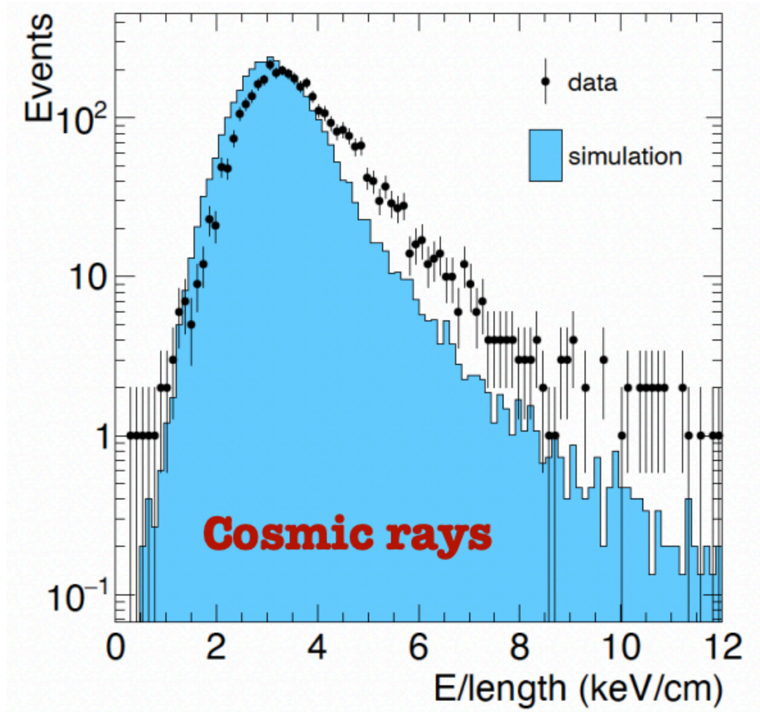
Low energy electrons calibration

arXiv: 2305.06168



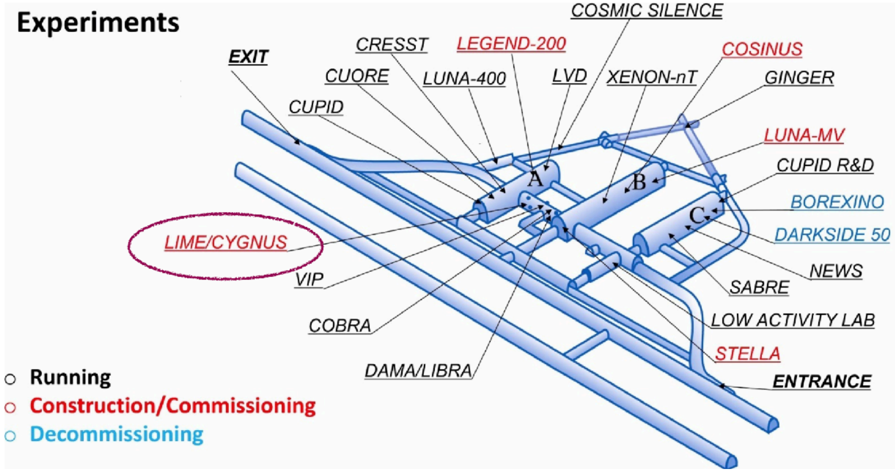




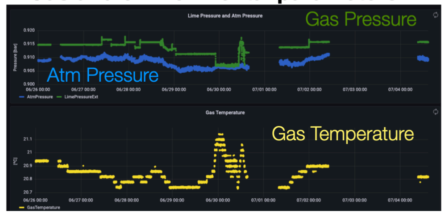


About 15% energy resolution (σ) along the whole volume

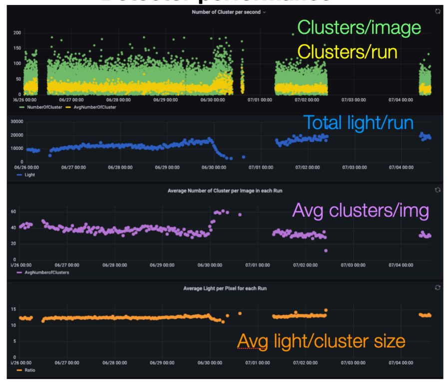
LIME underground installation @ LNGS since May 2022

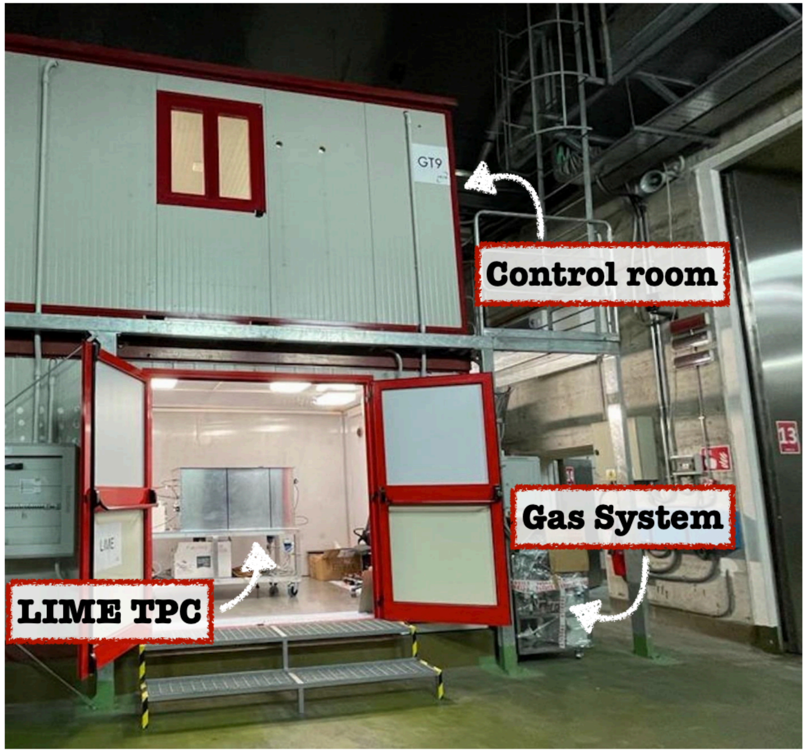


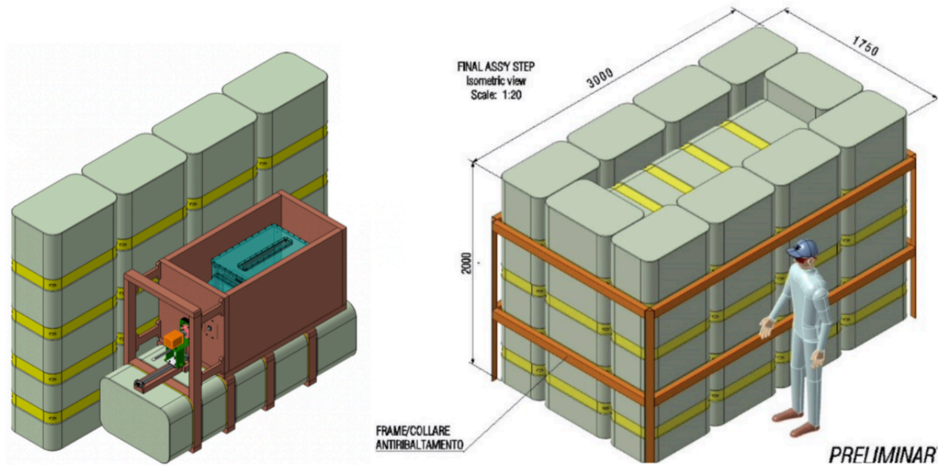
Gas and environmental parameters



Detector performance







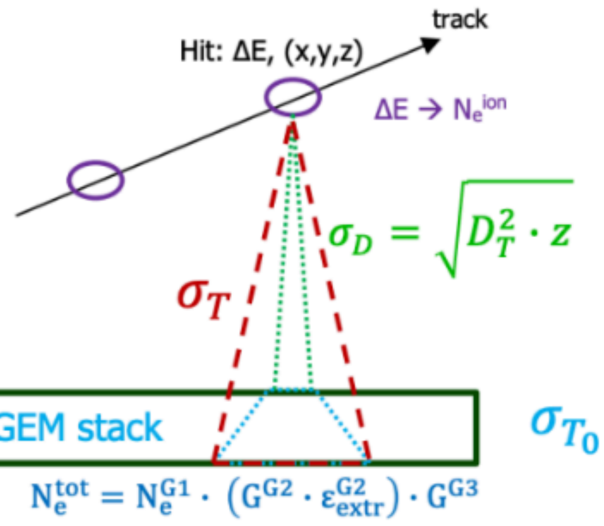
Increasing shielding configuration foreseen
Data already acquired for no shielding & 4 Cu shielding

50 L volume (33 x 33 cm² for 50 cm drift)

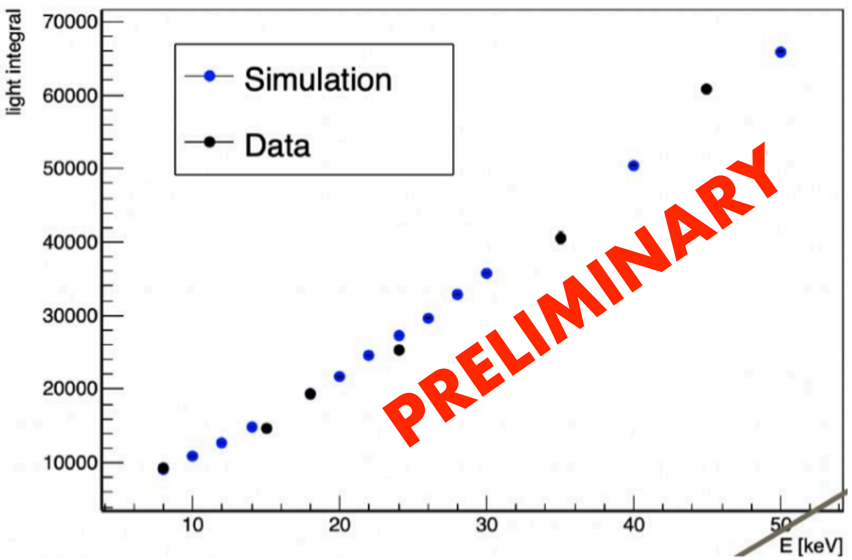
He:CF_4 60:40 1 bar

LIME sCMOS images MC simulation

- Electron tracks generated with GEANT4
- # of primary ionisation electrons extracted from a Poisson distribution with mean $N_e = \Delta E/W_i$ with W_i= 46.2 eV/pair
- Primary ionisation electron diffused longitudinally and transversally along drift following Gaussian distribution with $\sigma_T = \mathrm{sqrt}(\sigma^2_0 + D^2_T\, z)$ with σ_0 & D_T from measurements
- Electron avalanche fluctuation taken into account for the first GEM foil
  - For each ionisation electron *k*, $N^{G1,k}_e$ multiplication electron at first foil extracted from exponential distribution with mean = G_{GEM}
  - Total # of multiplication electron from first foil $N^{G1}_e = \sum_k N^{G1,k}_e$
  - G_{GEM} = 123 from IEEE, Vol. 65, No.1, Jan 2018
- Total electron gain $N^{tot}_e = N^{G1}_e \cdot (G_{GEM})^2$
- Mean total number of photon N^{tot}_γ from Poisson distribution with mean N^{mean}_γ = 0.07 γ/e
- Number of photon hitting the sensor $N_\gamma = N^{tot}_\gamma \cdot \Omega$
- sCMOS sensor noise from real data



data/MC energy response comparison



From S. Torelli PhD thesis work

50 L volume (33 x 33 cm² for 50 cm drift)

Low energy electron directionality on LIME simulated sCMOS images

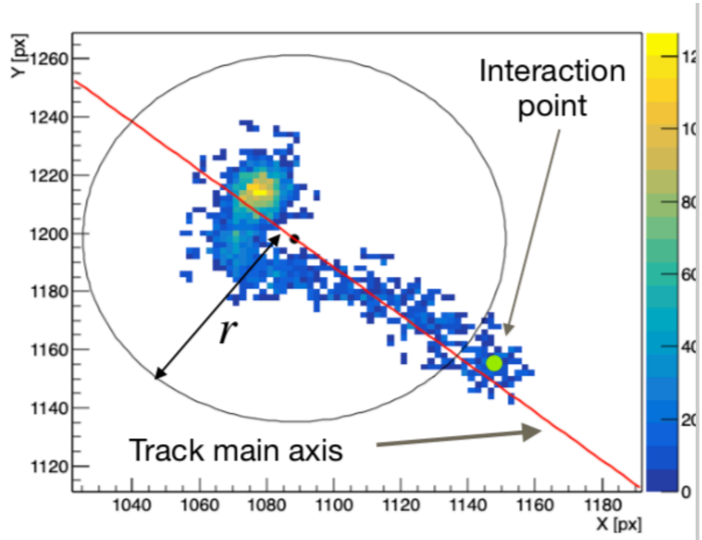
Original goal: feasibility of Solar neutrino measurement with elastic scattering on electrons in CYGNO

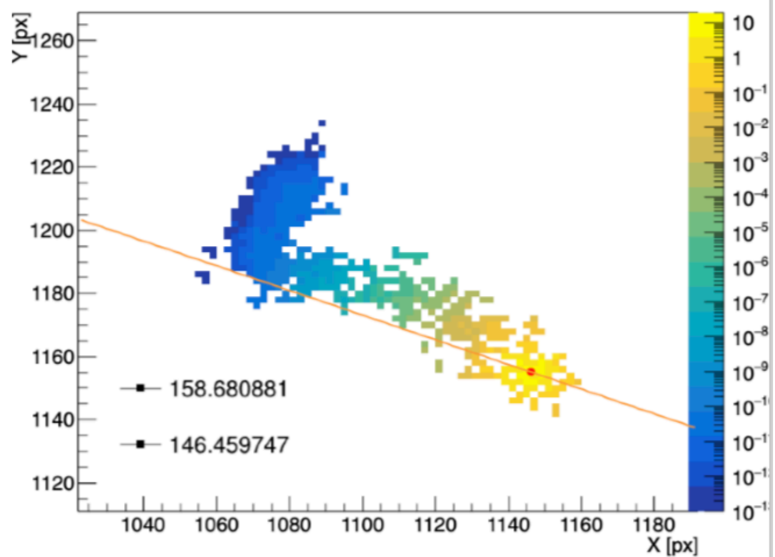
- Algorithm adapted from X-ray polarimetry:

"Measurement of the position resolution of the Gas Pixel Detector"
Nuclear Instruments and Methods in Physics Research Section A, Volume 700, 1 February 2013, Pages 99-105

- First part of the algorithm: search for the beginning of the track with:
  - Skewness
  - Distance of pixels from barycenter (farthest pixels)

- Second part of the algorithm aims to find the direction:
  - Track point intensity rescalad with the distance from the interaction point: $W(d_{ip}) = exp(-d_{ip}/w)$
  - Direction taken as the the main axis of the rescaled track passing from the interaction Point
  - Orientation given following the light in the Pixels





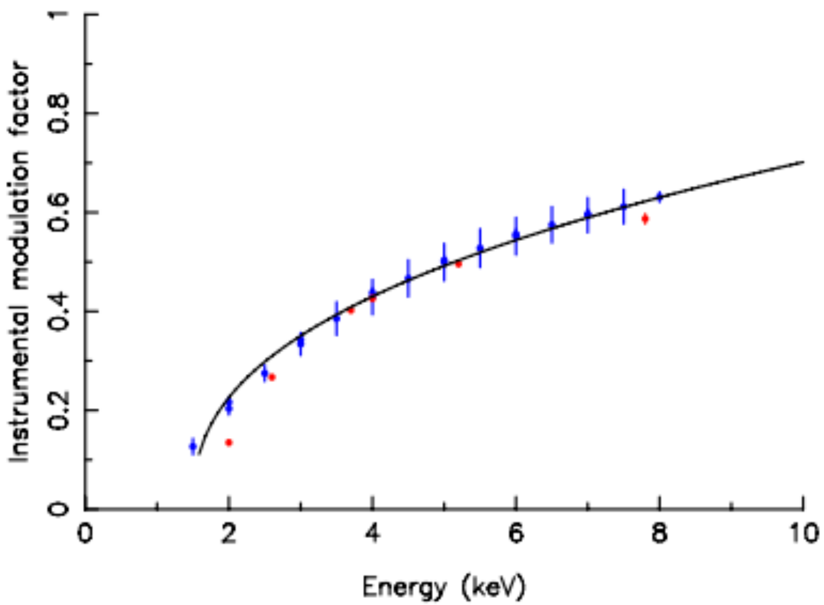
Angular resolution evaluated as difference between real and reconstructed direction

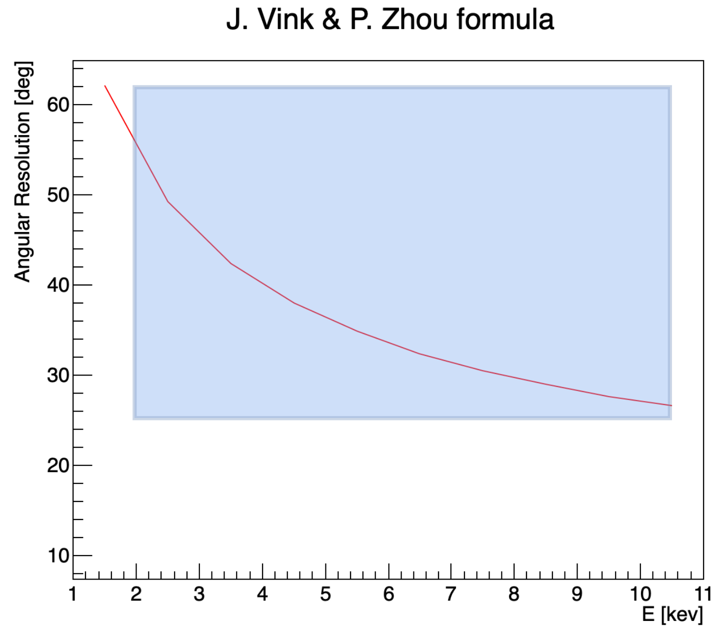
**Please note: for the moment, analysis developed only for sCMOS images, i.e. 2D
PMT information can further improve results**

How to compare angular resolution with modulation factor?

Practical Aspects of X-ray Imaging Polarimetry of Supernova Remnants and Other Extended Sources

J. Vink & P. Zhou, Galaxies 6 (2018) 2, 46





GDP modulation factor for 100% polarised source (not correcting for instrumental effect)
Muleri et al., Nucl. Instrum. Methods Phys. Res. A 2010, 620, 285–293.

Modulation factor from simulating with an angular resolution as in the formula:

IXPE GDP modulation factor correspond to an angular resolution between 54° and 26°

$$\Delta\alpha = 5^o + 35^o\sqrt{\frac{4\text{keV}}{E}}$$

***N.B. paper formula has typo, authors confirms this one**

From S. Torelli PhD thesis work

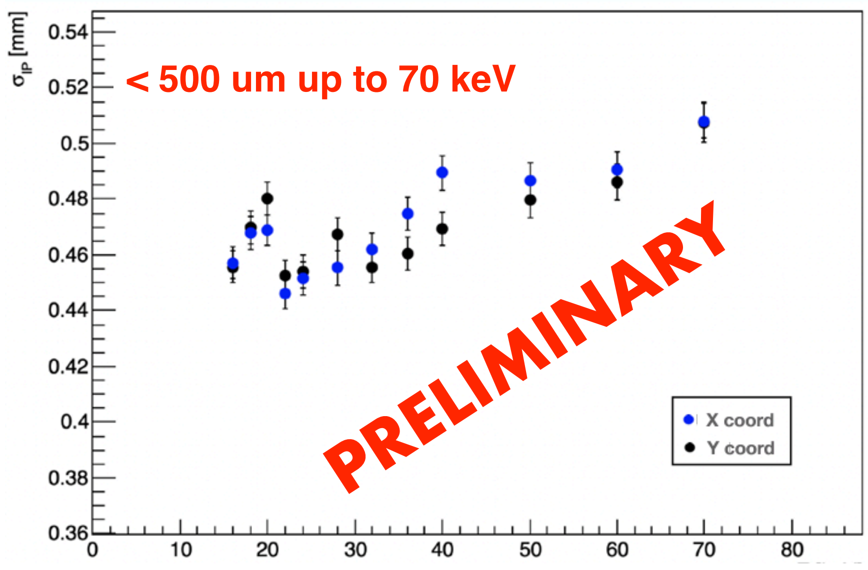
50 L volume (33 x 33 cm^2 for 50 cm drift)

He:CF_4 60:40 1 bar

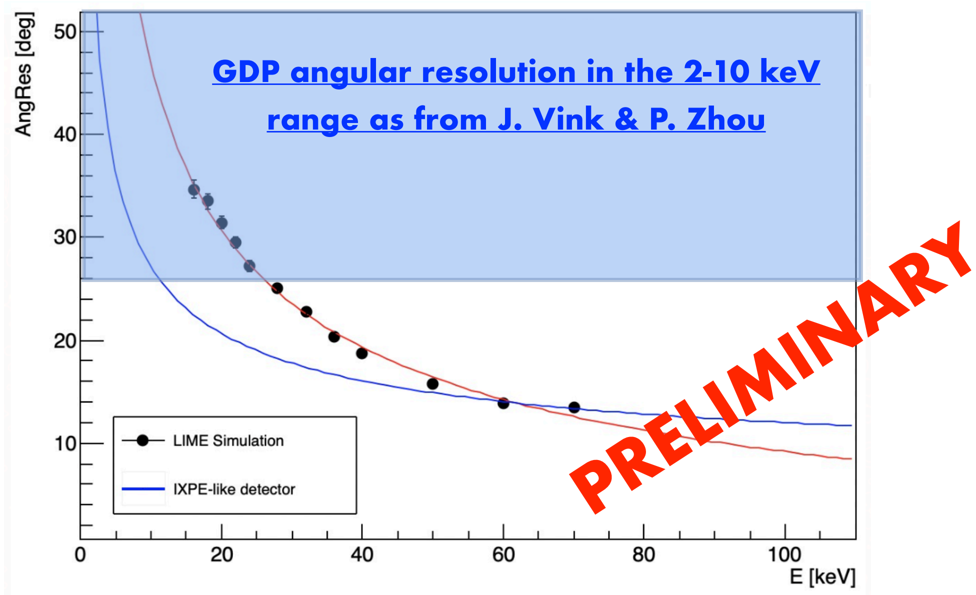
Low energy electron directionality on LIME simulated sCMOS images

Tracks generated with random diffusion and random inclination w.r.t. amplification plane in the whole 50 L volume

Impact point resolution



Angular resolution



In addition, angular & impact point resolution independent from diffusion (i.e. good match of granularity vs drift distance for the gas of choice)

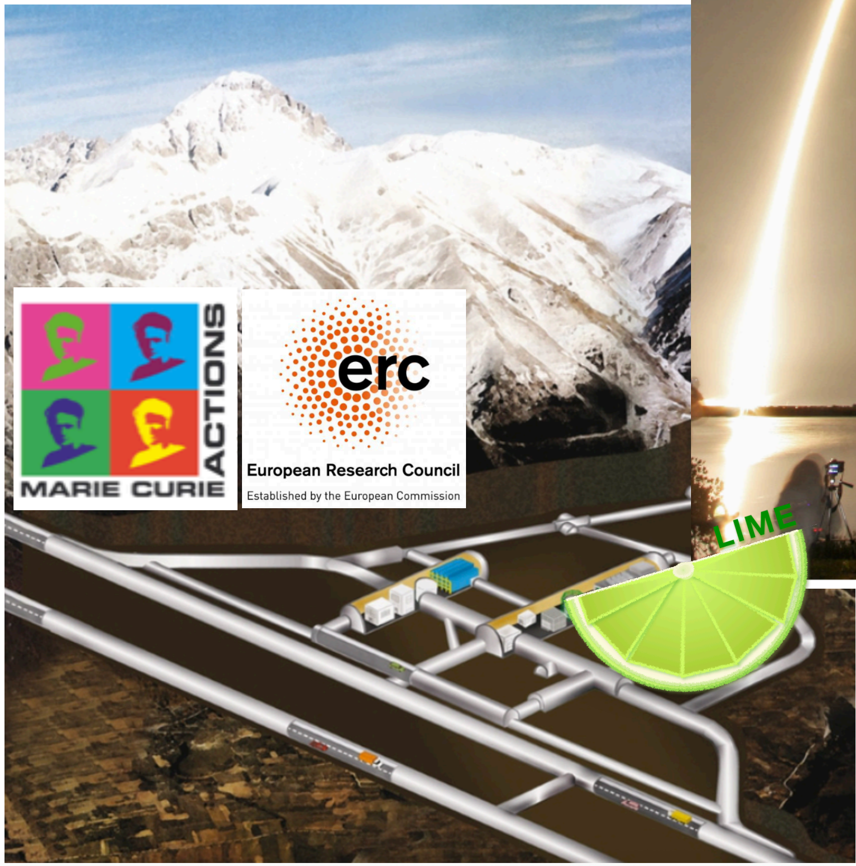
Same angular resolution than GDP > 10 keV, improved for > 30 keV

Expect similar modulation factor in 10-20 keV, improved for > 30 keV

Developments towards x-ray polarimetry

From a LIME underground to a MANGO in space

This project has been funded by the Italian Ministry of Education, University and Research through the project PRIN: Progetti di Ricerca di Rilevante Interesse Nazionale "HypeX: High Yield Polarimetry Experiment in X-rays " (Prot. 2020MZ884C)

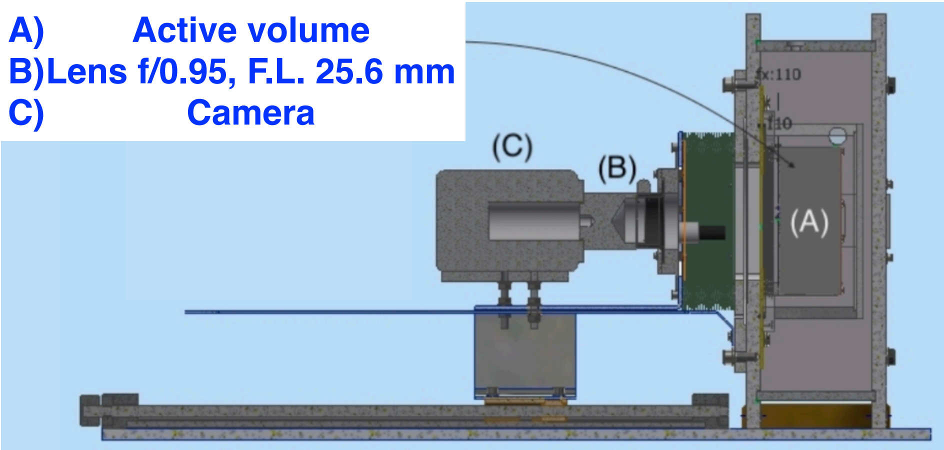


This project has received fundings under the European Union's Horizon 2020 research and innovation programme from the Marie Sklodowska-Curie grant agreement No 657751 and from the European Research Council (ERC) grant agreement No 818744

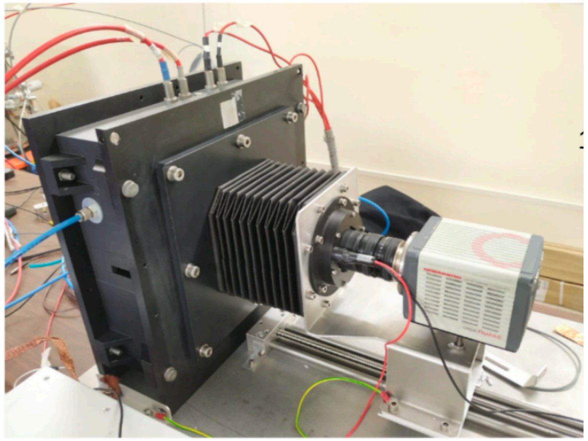
Developments for X-ray polarimetry: the MANGO detector

Goal: x-ray polarimeter with large field of view in the 20-60 keV energy band

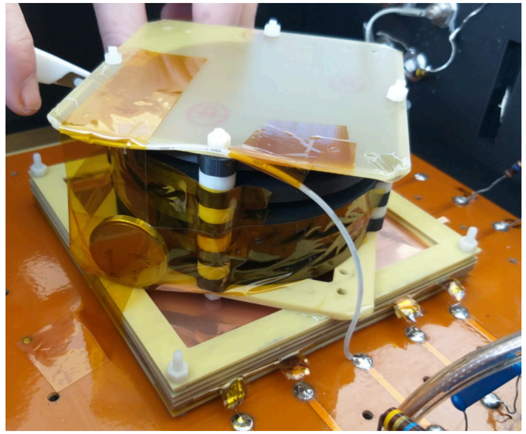
Schematics



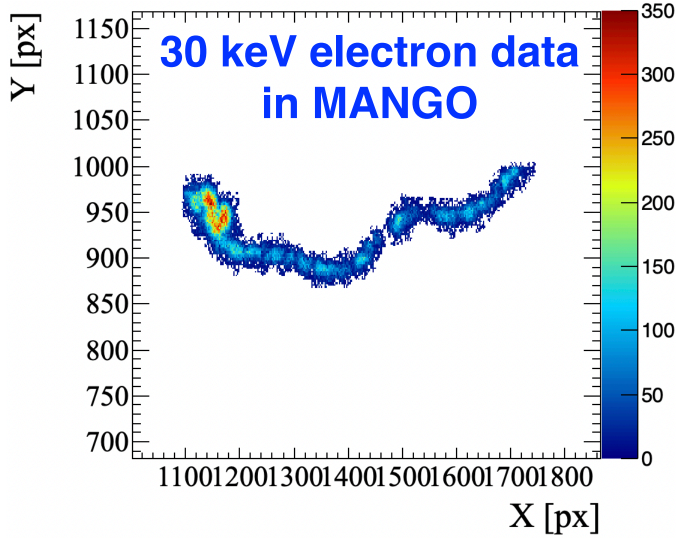
External structure



Internal field cage + GEMs



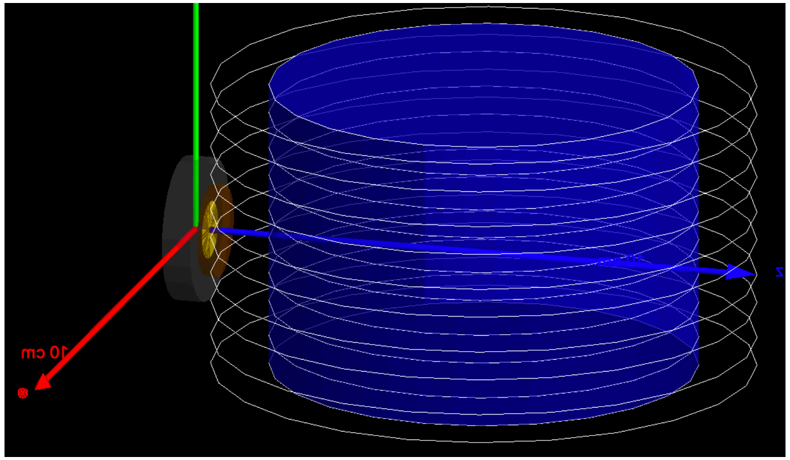
	readout area [cm^2]	drift leght [cm]	active volume [L]	effective pixel size [um^2]	sensor geometrical acceptance	notes
Used for the simulation	11.3 x 11.3	10	1.27	49 x 49	1.1×10^{-3}	square geometry
Used in the data shown	10 x 10	5	0.22	61 x 61	4×10^{-4}	cilindrical volume 3.75 cm internal radius



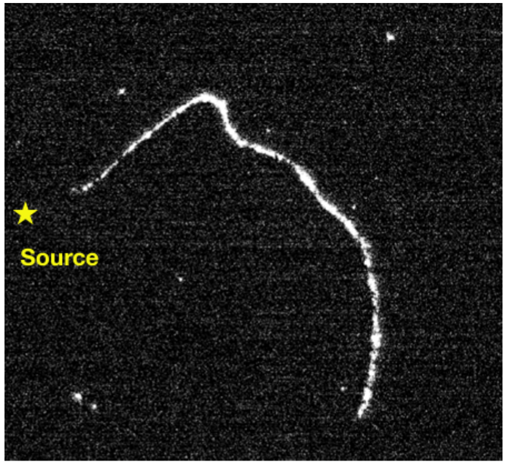
Many thanks to E. Costa, A. Di Marco, S. Fabiani, F. Muleri, P. Soffitta

MANGO setup at IAPS/INAF

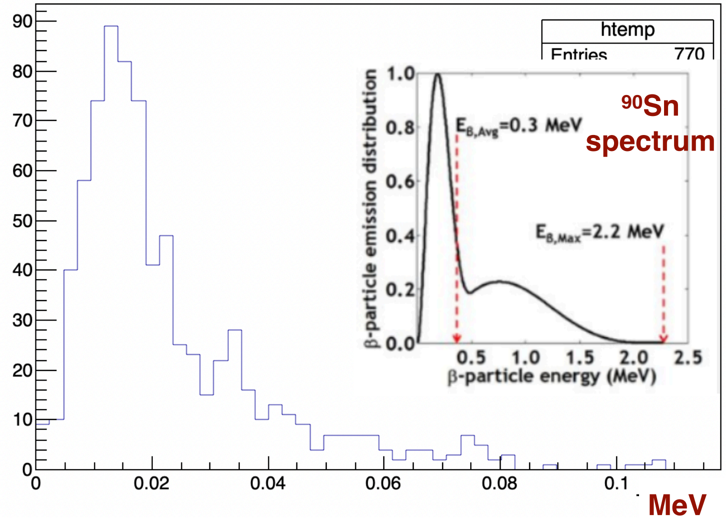
GEANT-4 simulation



MANGO data



Spectrum of contained tracks from simulation



- N.B.: very first preliminary test to demonstrate feasibility of proposal, to be repeated in better optimised conditions
- ^{90}Sn source positioned outside the field cage rings with 2 mm thick collimator with 2000 um hole
  - Initial ± 1 cm of the track outside the sensitive volume
- Thin plexiglass window facing the camera had to be replaced at last minute with a thick 0.5 cm one
  - Forced camera position to a larger distance from the GEM, reducing pixel granularity and solid angle w.r.t. proposal for polarimetry
  - Thick window strongly affected light transparency, further reducing the light yield
  - Forced operation above typical GEM voltages, resulting in saturation of the signal and uncertainty in the energy scale
- GEANT-4 simulation to evaluate efficiency of tracks containment and intrinsic angular spread of detected tracks
  - About 20% of tracks fully contained
  - About 20 degrees intrinsic angular spread
  - Systematics from the uncertainties on the actual source position still to be evaluated

From S. Torelli PhD thesis work

He:CF$_4$ 60:40 1.1 bar

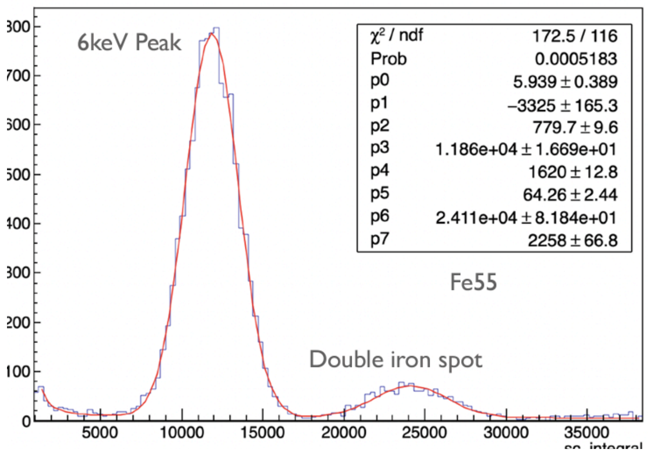
Energy calibration

From S. Torelli PhD thesis work

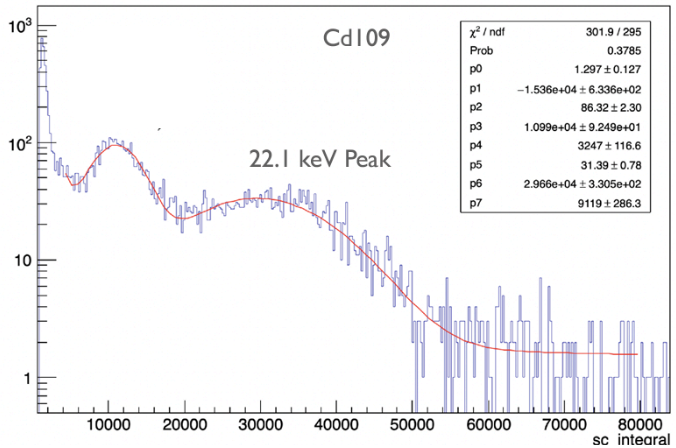
From S. Torelli PhD thesis work

- Preliminary spectra of monochromatic gamma sources for calibration purpose
- Fe55 ad Cd109 used (very intense sources O(MBq))

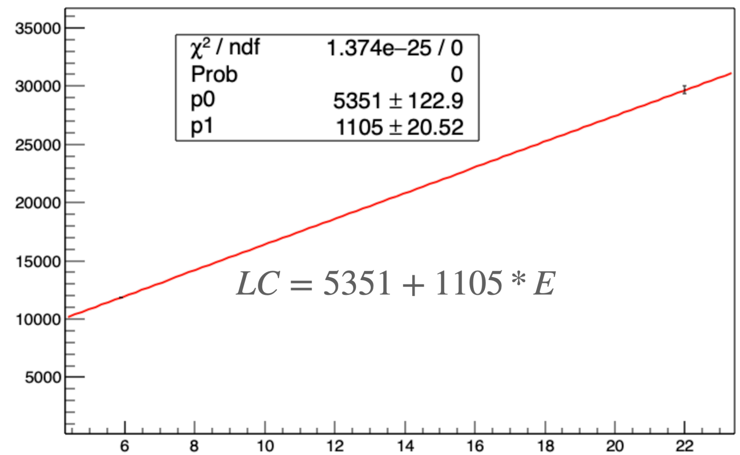
^{55}Fe spectrum



^{109}Cd spectrum



Calibration curve



- 13% energy resolution @ 6 keV, while 30% energy resolution @ 22 keV
- Response of 2010 ph/keV from Fe55 and only 1350 ph/keV from Cd109

clear sign of gain saturation as expected == large uncertainty in the energy scale above 22 keV

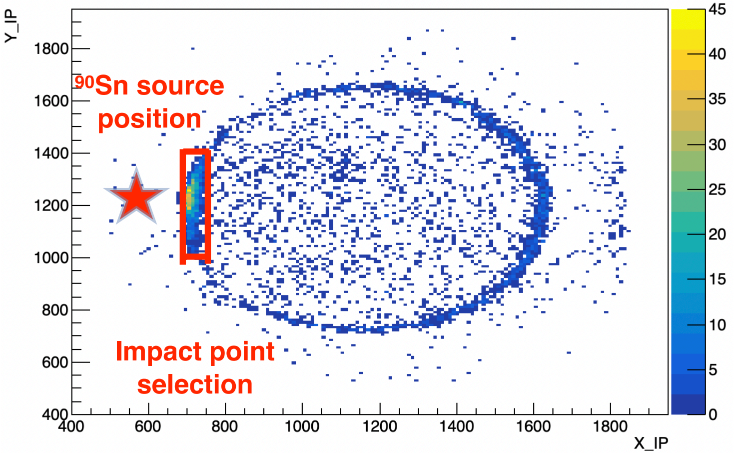
He:CF_4 60:40 1.1 bar

Test performed on 25th May!

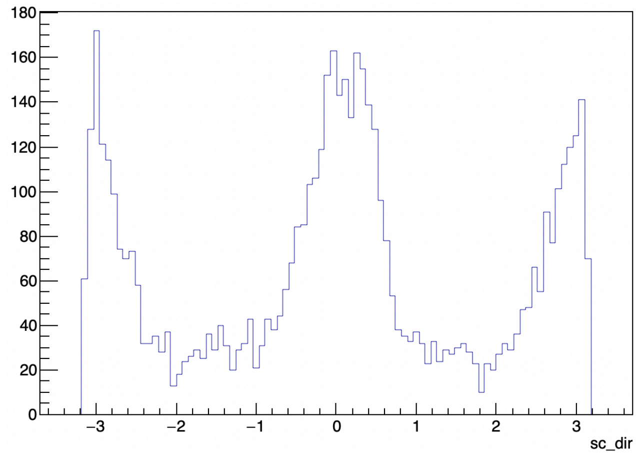
VERY preliminary results

From S. Torelli PhD thesis work

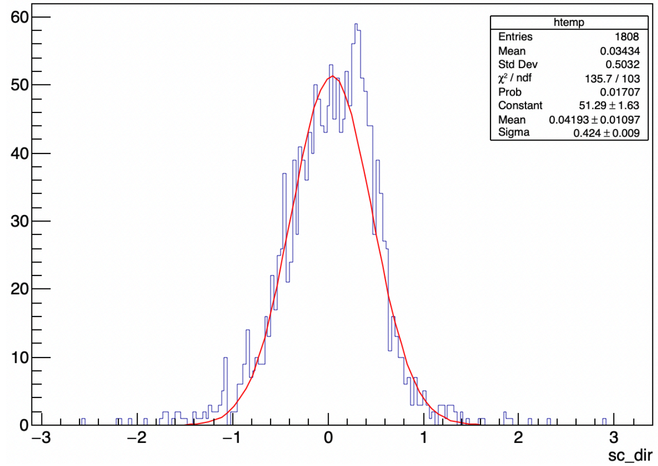
Reconstructed impact point of all tracks



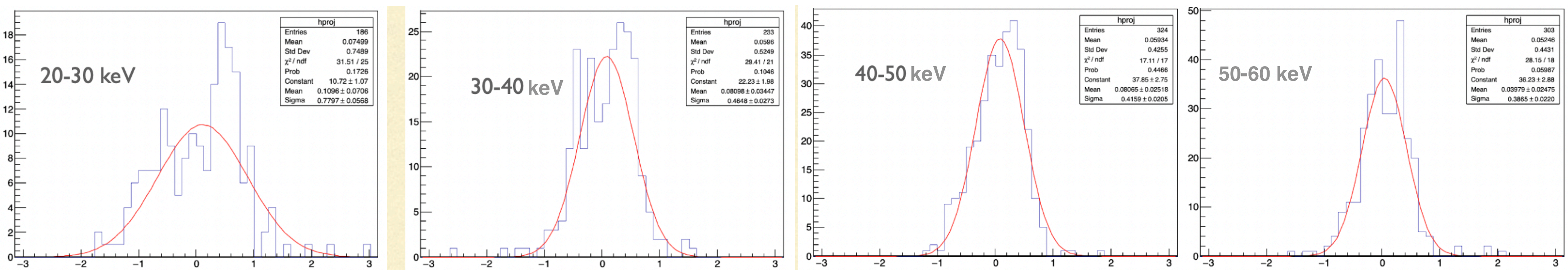
Reconstructed angle of all tracks



Reconstructed angle of tracks with selection on I.P.



Reconstructed angle of tracks with selection on I.P. at different measured energies



....keep in mind uncertainty on energy scale due to saturation

From S. Torelli PhD thesis work

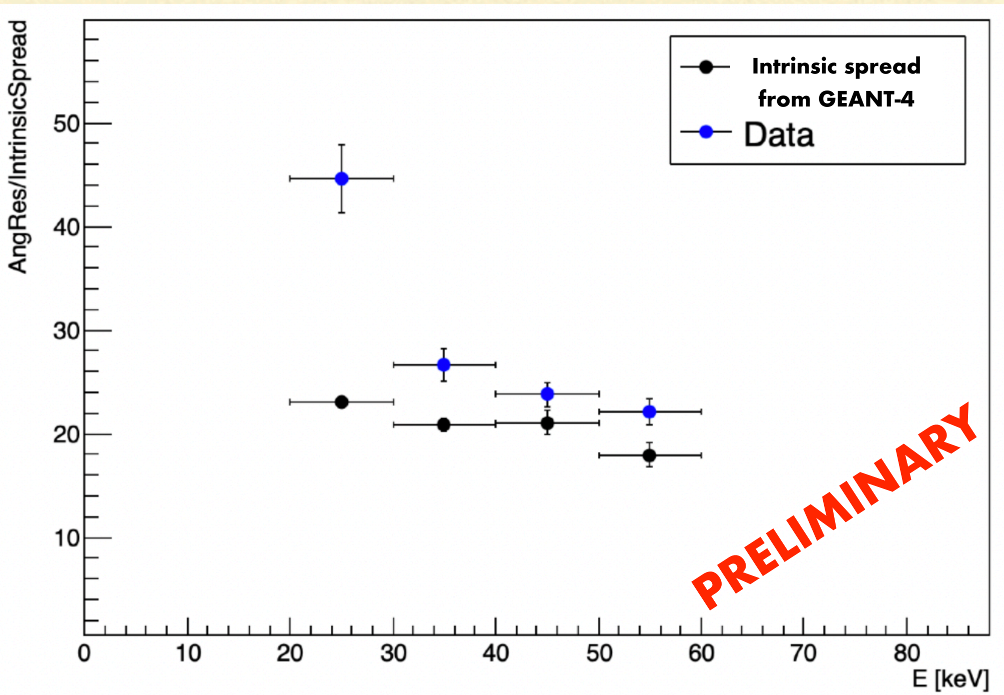
He:CF_4 60:40 1.1 bar

Test performed on 25th May!

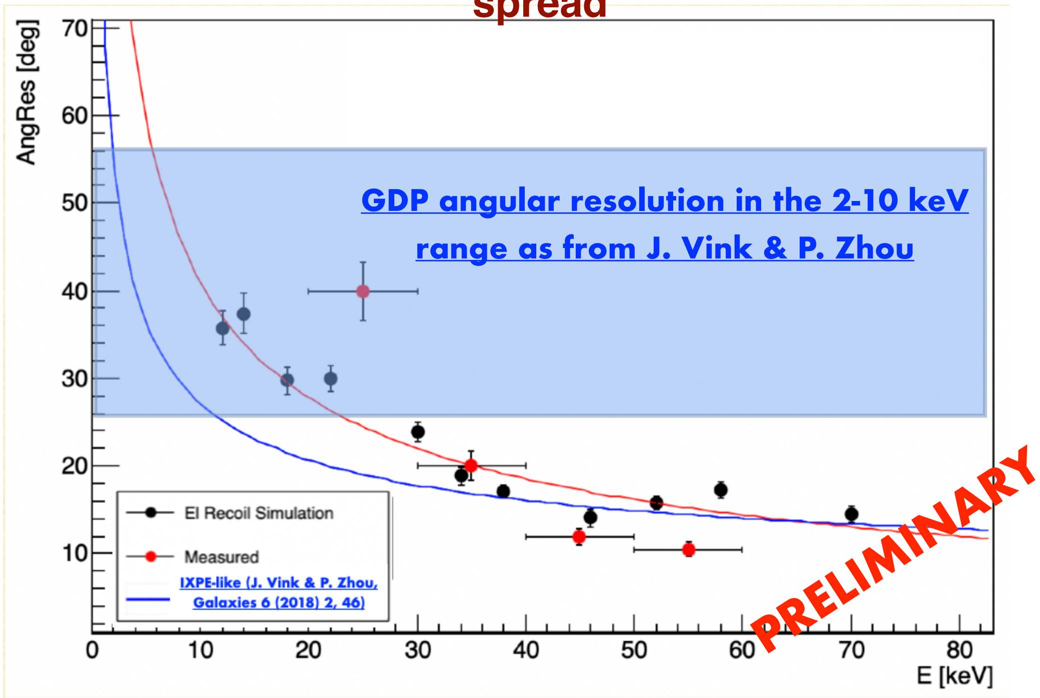
VERY preliminary results

From S. Torelli PhD thesis work

Comparison of intrinsic angular spread from simulation with measured angular distribution



Comparison of angular resolution from simulation with measured angular distribution after subtraction in quadrature of intrinsic angular spread



- Results affected by uncertainty in energy scale due to atypical mode of operation forced by technical reason, that will not happen in the future
- Possible additional collimation effect by field cage rings not yet taken into account
- Still, results and simulation > 5 keV close to (or even better than) GDP performances

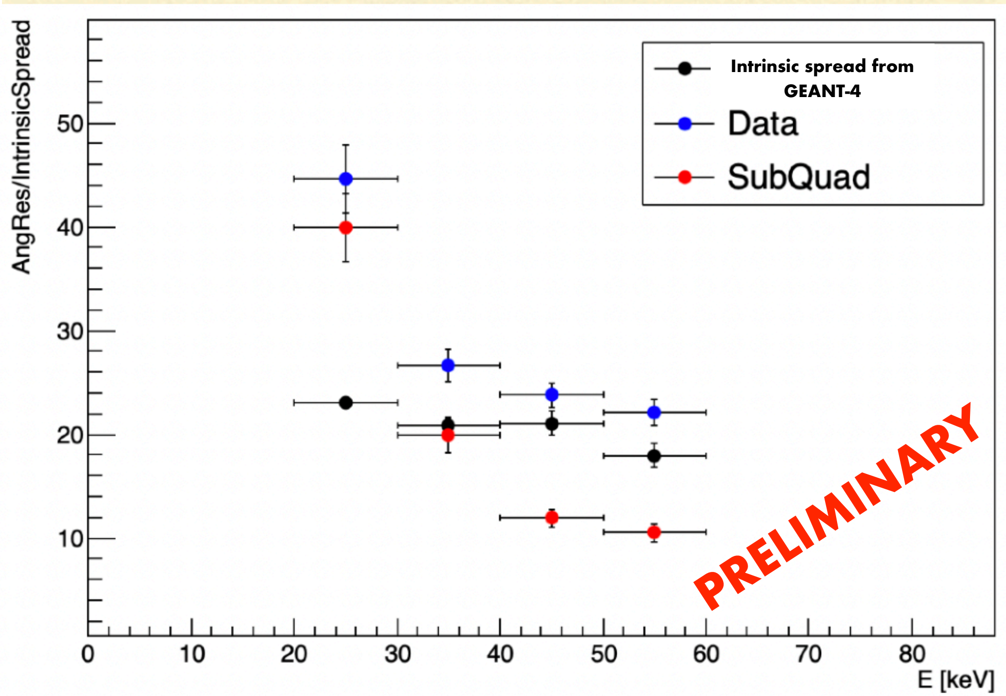
He:CF_4 60:40 1.1 bar

Test performed on 25th May!

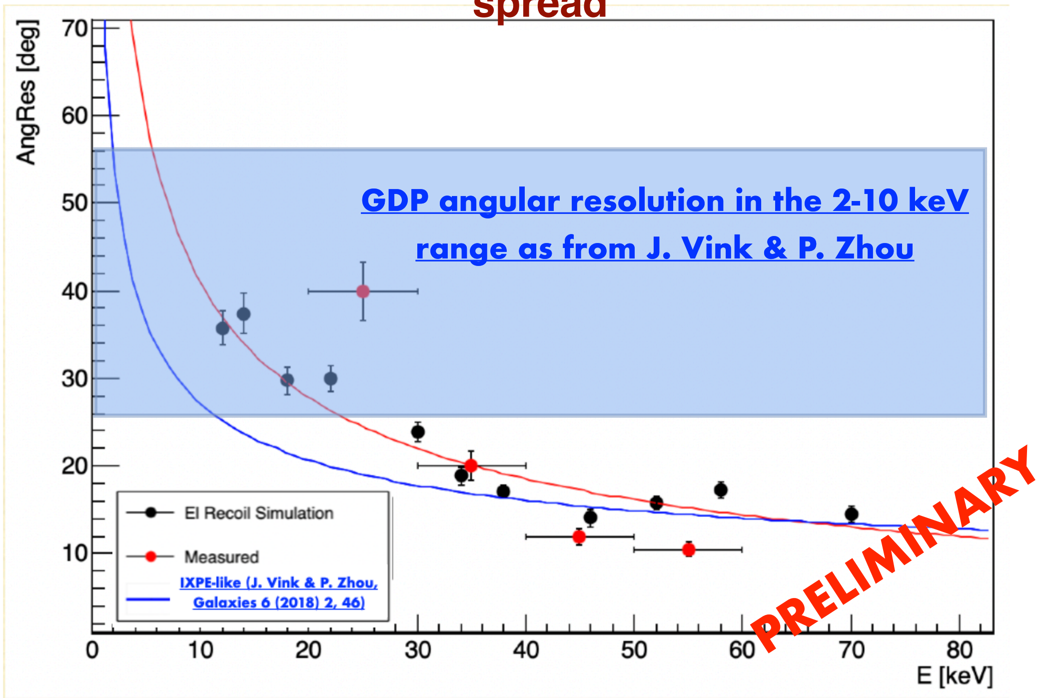
VERY preliminary results

From S. Torelli PhD thesis work

Comparison of intrinsic angular spread from simulation with measured angular distribution



Comparison of angular resolution from simulation with measured angular distribution after subtraction in quadrature of intrinsic angular spread

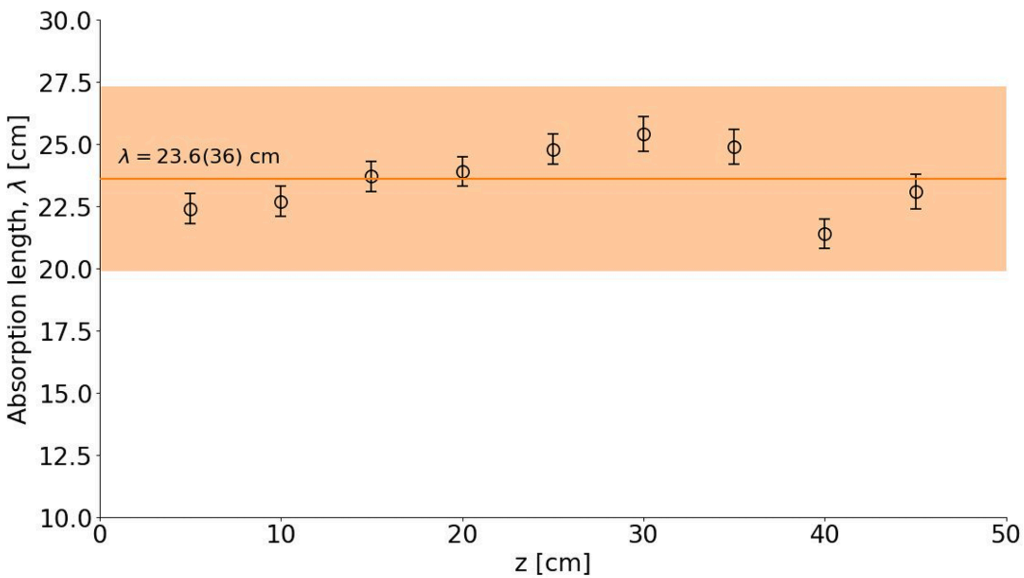


- Results affected by uncertainty in energy scale due to atypical mode of operation forced by technical reason, that will not happen in the future
- Possible additional collimation effect by field cage rings not yet taken into account
- Still, results and simulation > 5 keV close to (or even better than) GDP performances

(rough) X-ray absorption efficiency

Absorption lenght from simulation	6 keV	8 keV	15 kev	18 keV	24 keV	30 keV	40 keV
X-ray absorption lenght [cm] in $He:CF_4$ 60:40 1 bar	20.9	50.1	337.8	565.7	1178.7	1398.2	1946.5
X-ray absorption lenght [cm] in $Ar:CF_4$ 80:20 1 bar	2.15	5.43	34.7	57.1	134.0	254.7	774.1
LIME (MANGO) efficiency with $He:CF_4$	100 (48)%	60 (20)%	9 (3)%	5 (2)%	2.5 (0.8)%	2.1 (0.7)%	1.5 (0.5)%
LIME (MANGO) efficiency with $Ar:CF_4$	100 (100)%	100 (100)%	88 (30)%	53 (18)%	22 (7)%	12 (4)%	4 (1)%

For efficiency calculation, the smallest detector dimensions are assumed:
—30 cm LIME
—10 cm MANGO



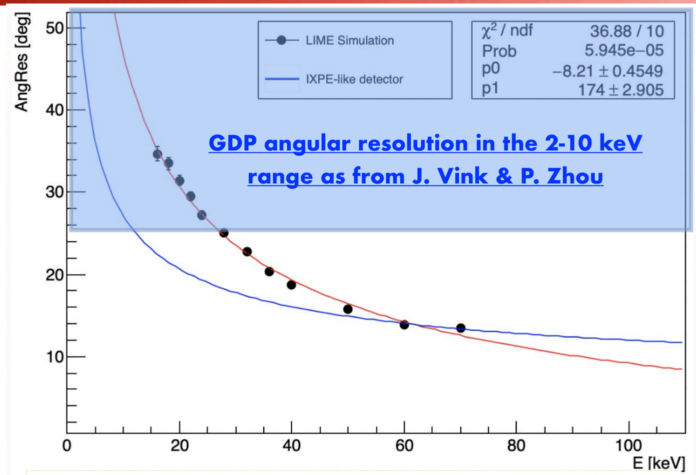
The average absorption length is 23.6(36) cm for ^{55}Fe x-rays in He-40%CF_4

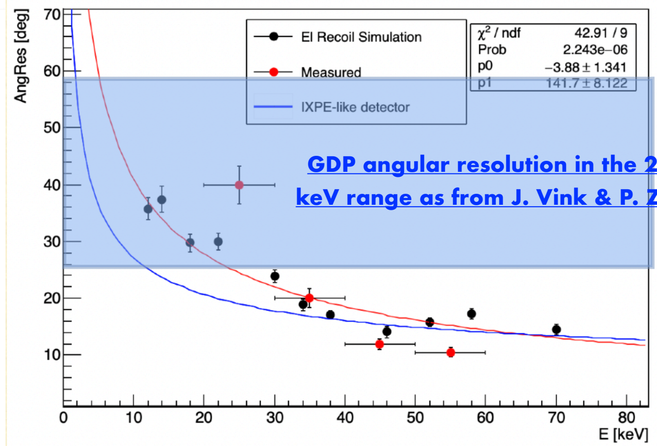
The absorption length does not seem to depend on z.

LIME data confirm simulation

Conclusions & outlook

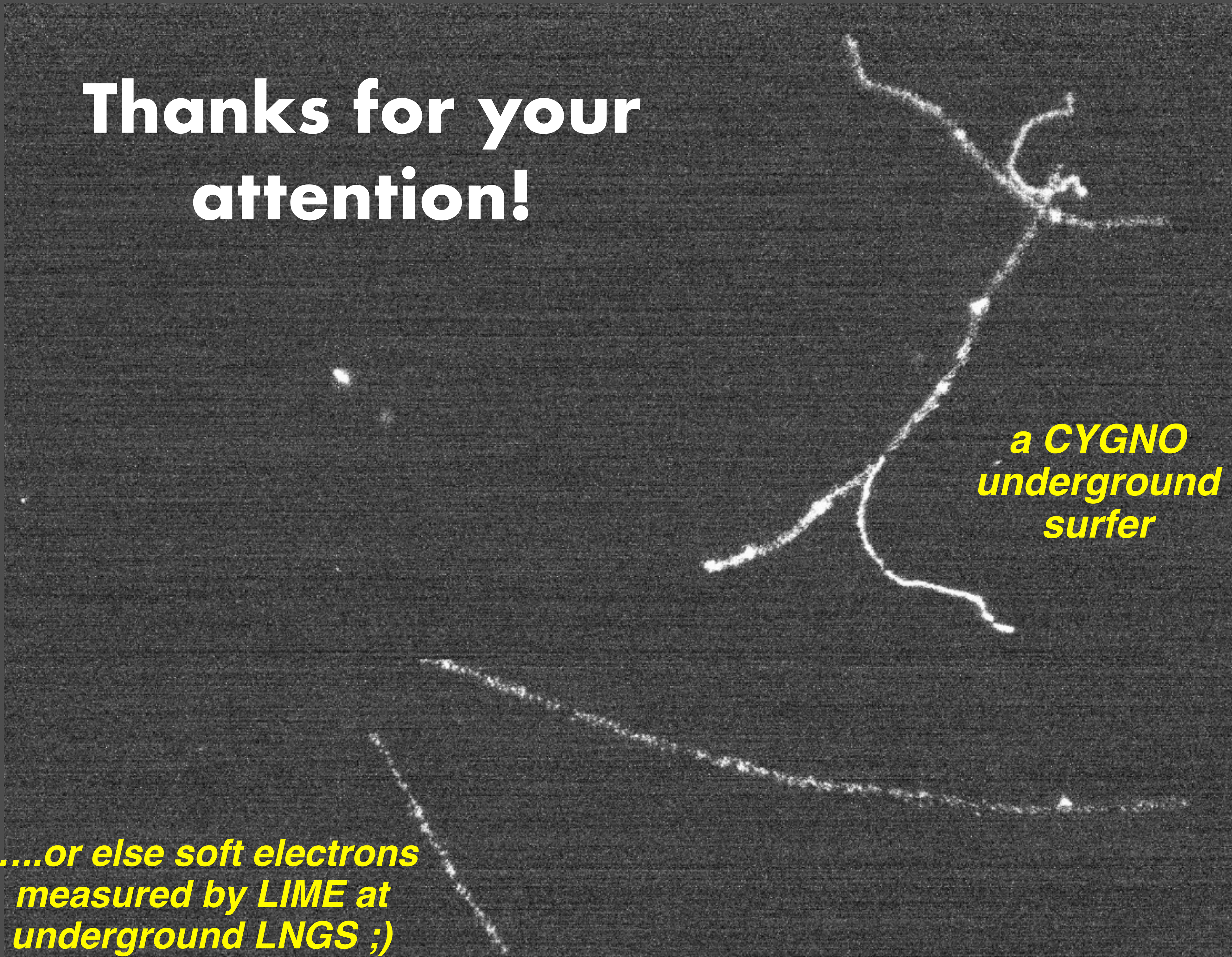
- High precision TPC with optical readout with sCMOS camera appears prosiming technique not only for rare events searches, but also for X-ray polarimetry
- Development and tailoring for X-ray polarimetry only recently started
- Assuming validity of J. Vink & P. Zough formula relating angular resolution to modulation factor:
  - LIME simulation returns performances similar to GDP from 10 keV
  - MANGO simulation returns performances similar to GDP from 5 keV
- Preliminary experimental tests with beta source and MANGO (in an orrible operating condition) are consistent with simulation
- Beta source data acquired also with Ar:CF_4 80:20, data still to be analysed
- Foreseen absorption efficiency (from simulation verified at 5.9 keV with data):
  - 10% at 15 keV with LIME (3% with MANGO) with He:CF_4
  - 12% at 30 keV with LIME (4% with MANGO) with Ar:CF_4
- Project just started, large room for optimisation of:
  - Detector geometry
  - Amplification stage (thin/thick GEMs, Micromegas, MMThickGEM…)
  - Gas mixture/pressure





	6 keV	15 kev	24 keV	30 keV
MANGO eff He:CF_4	48%	3%	0.8%	0.7%
LIME eff He:CF_4	100%	9%	2.5%	2.1%
MANGO eff Ar:CF_4	100%	30%	7%	4%
LIME eff He:CF_4	100%	88%	22%	12%

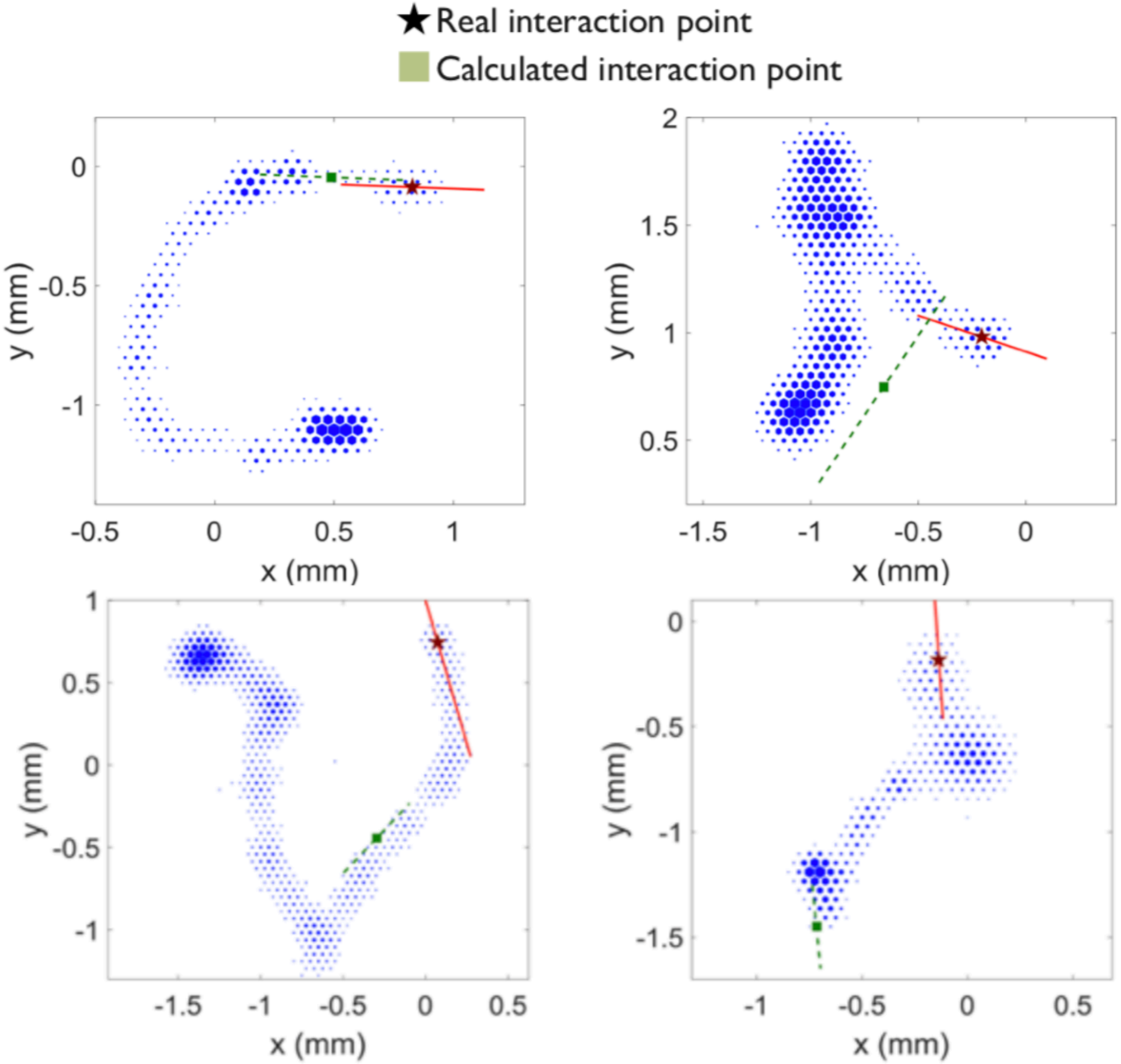
Thanks for your attention!



Backup slides

50 L volume (33 x 33 cm² for 50 cm drift)

When & why algorithm fails



+ when track is perpendicular to the amplification plane

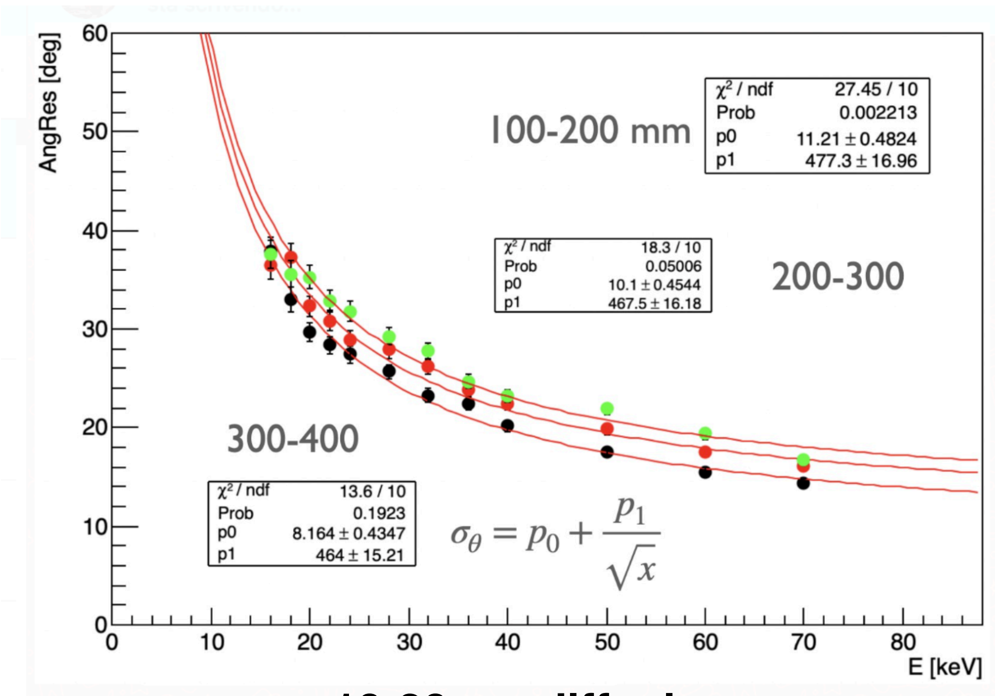
Performances to improve when PMT information is added

From S. Torelli PhD thesis work

From S. Torelli PhD thesis work

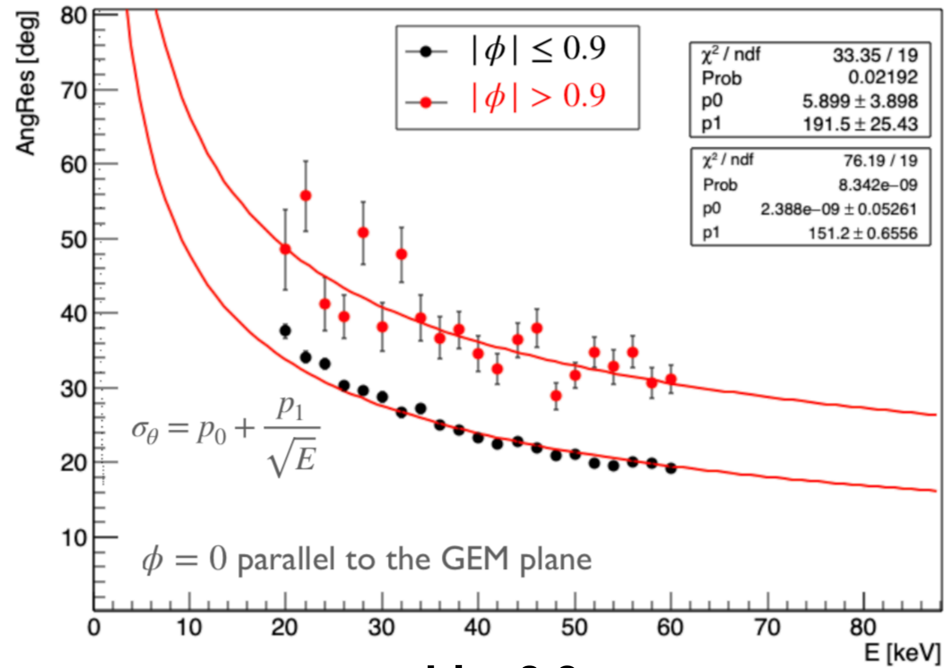
LIME angular resolution dependences

As a function of diffusion



10-20 cm diffusion
20-30 cm diffusion
30-40 cm diffusion

As a function of inclination w.r.t. amplification plane

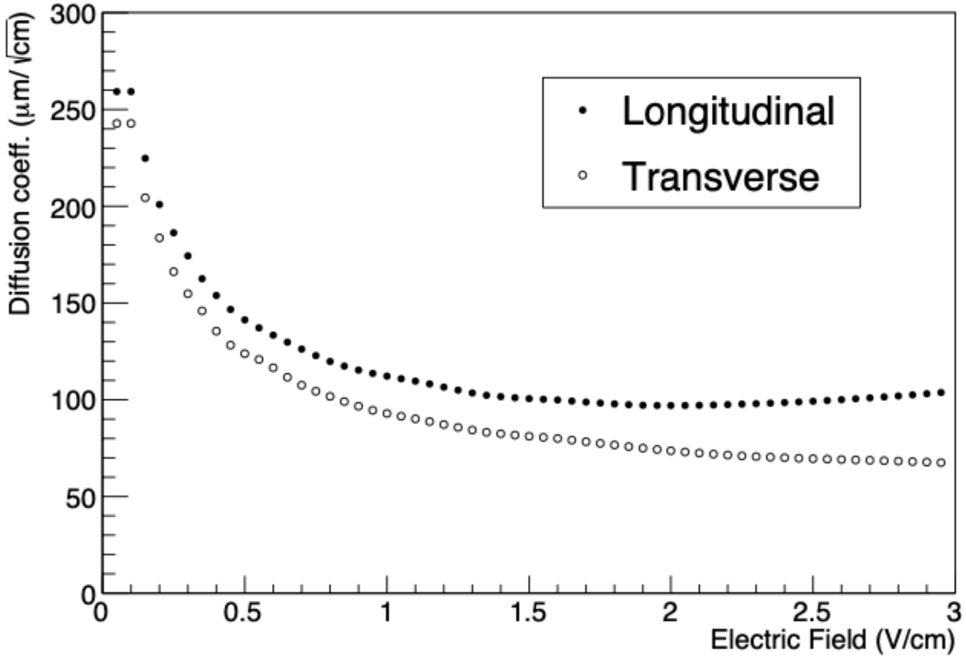


phi < 0.9
phi > 0.9

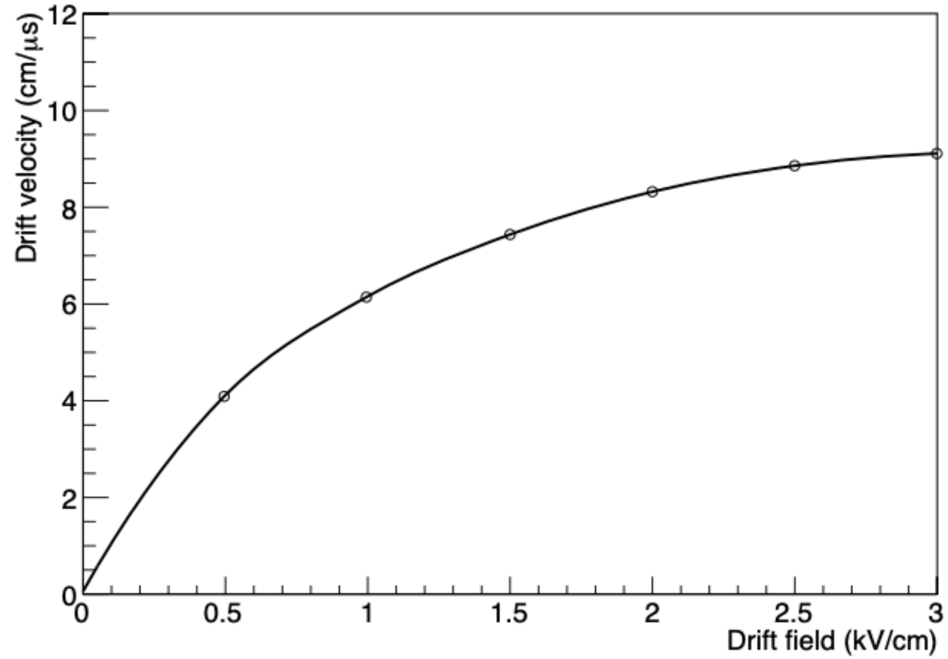
Angular & impact point resolution independent from diffusion
(i.e. good match of granularity vs drift distance for the gas of choice)

He:CF_4 properties

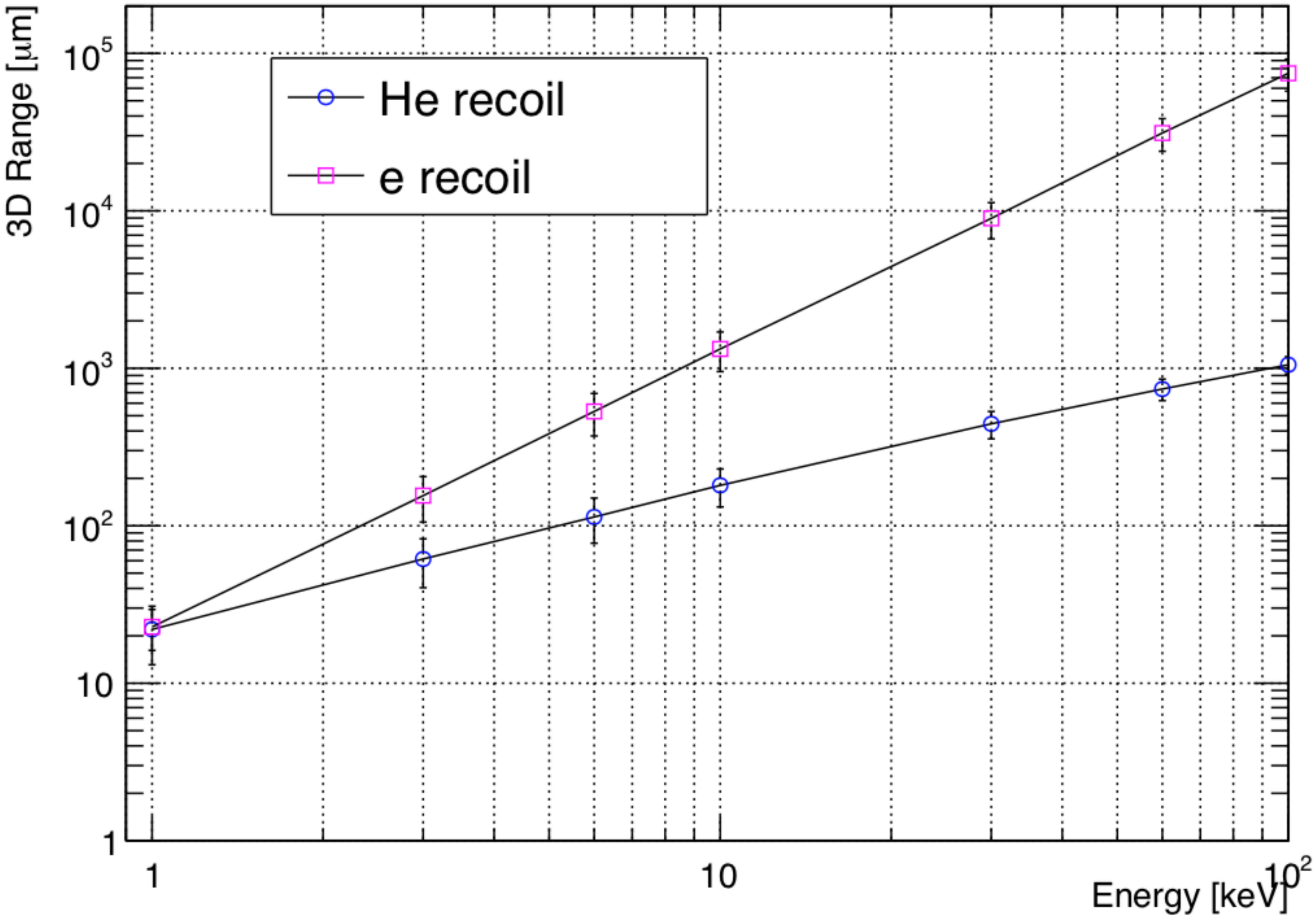
Diffusion during drift



Drift velocity



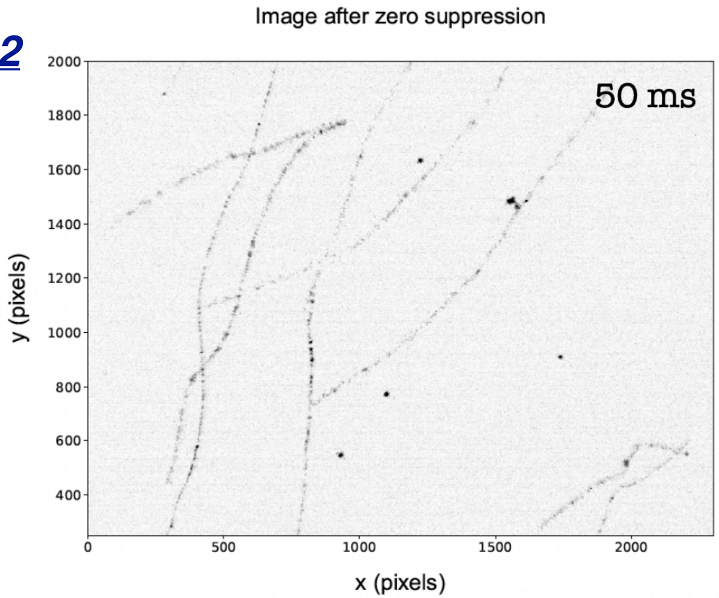
Range in He:CF_4 60:40 @ 1 bar

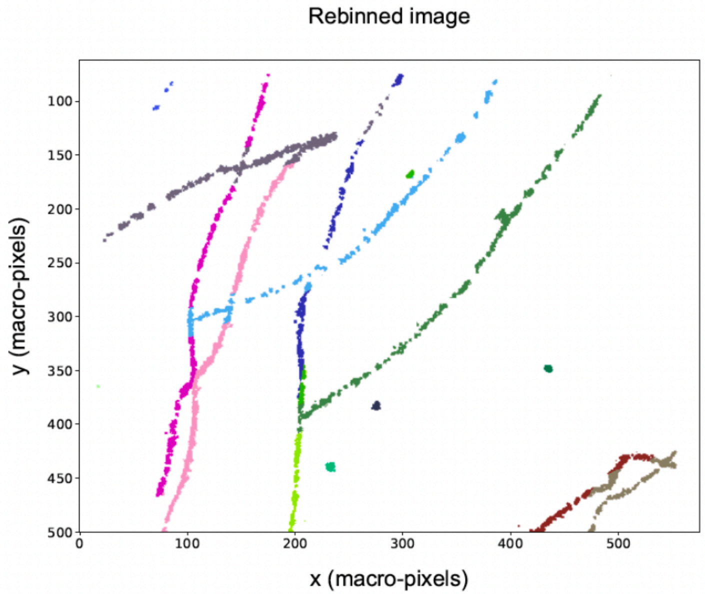


sCMOS pictures reconstruction

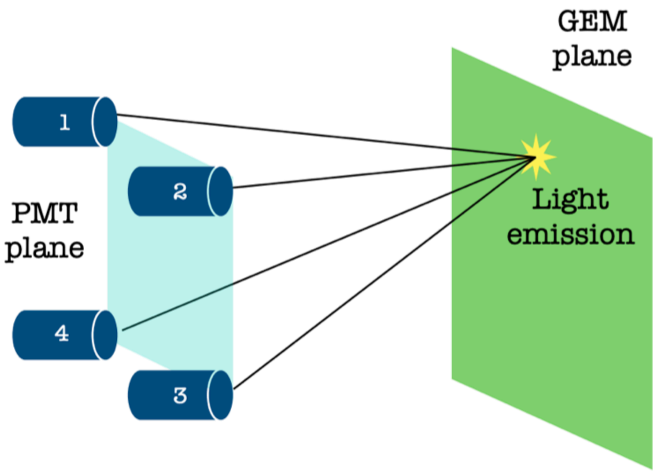
JINST 15 (2020) 12, T12003   *Measur.Sci.Tech. 32 (2021) 2, 025902*

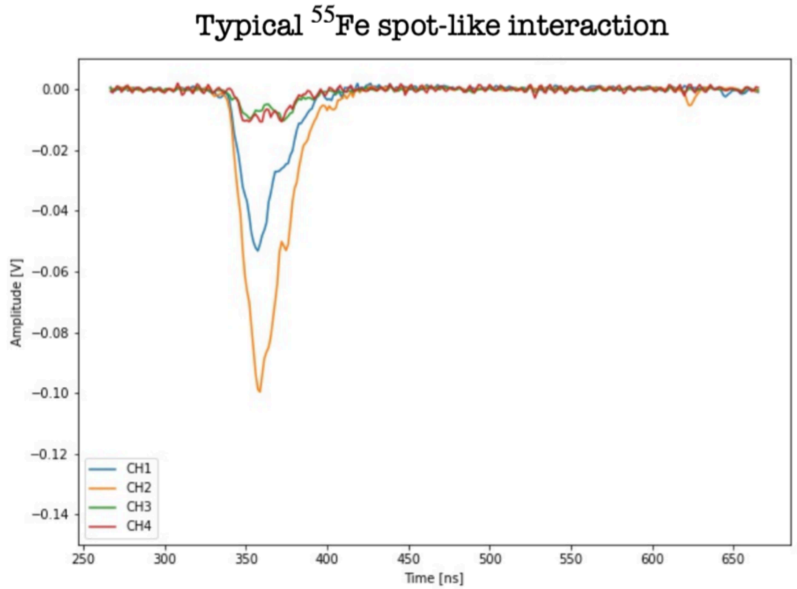
- **Reconstruction** algorithm: **clustering** + **computation of observables** (energy, length, width, etc.)
- **4 steps for clustering:**
  1. zero suppression
  2. optical corrections
  3. super-clustering for long tracks
     ➡ generalization of RANSAC algorithm
     ➡ needed to deal with overlapping tracks
  4. additional clustering step for small deposits
     ➡ based on iDBSCAN algorithm





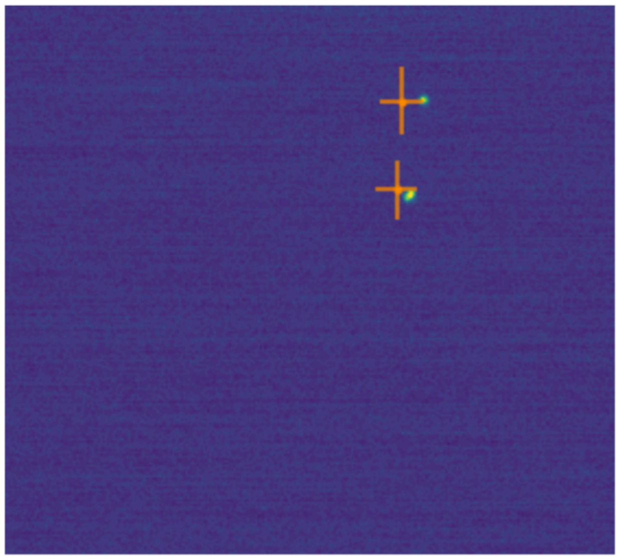
Preliminary results from PMT reconstruction

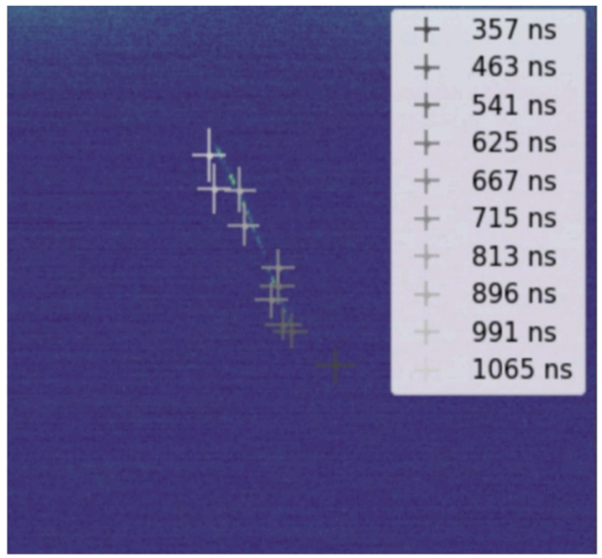




- In principle possible to **associate** single **waveforms** to single **tracks** in the pictures!

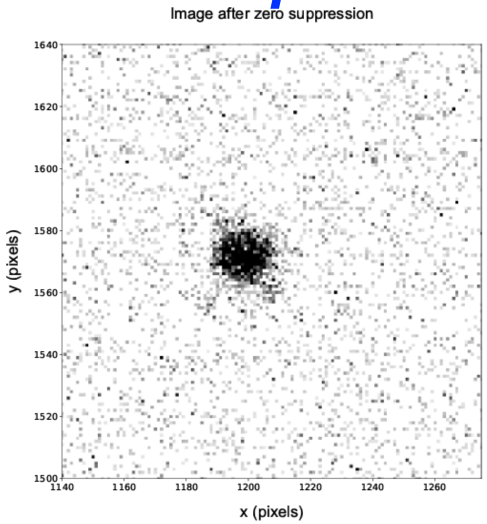
34



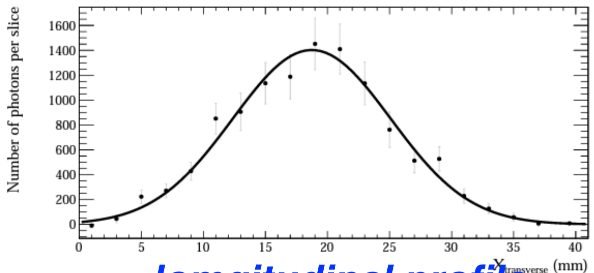


LIME absolute Z coordinate @ 5.9 keV_{ee} from fit to diffusion

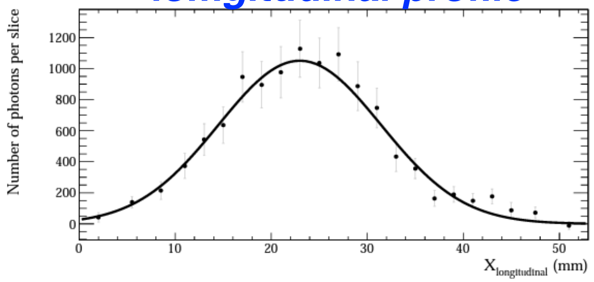
Iron spot



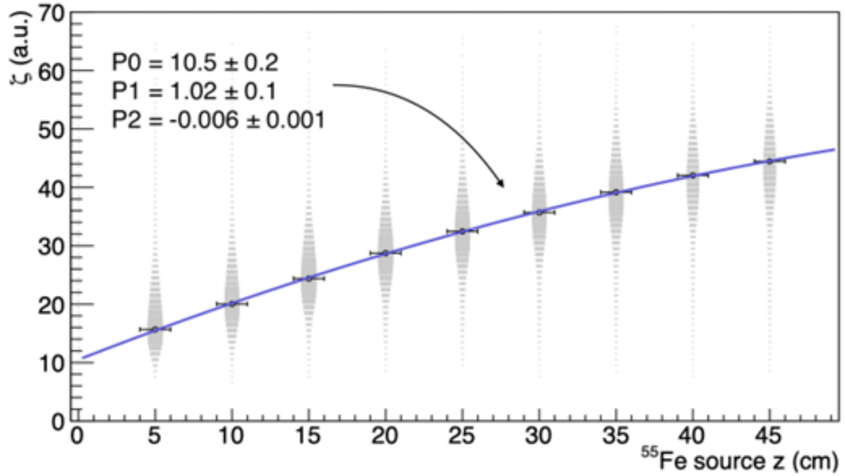
transverse profile



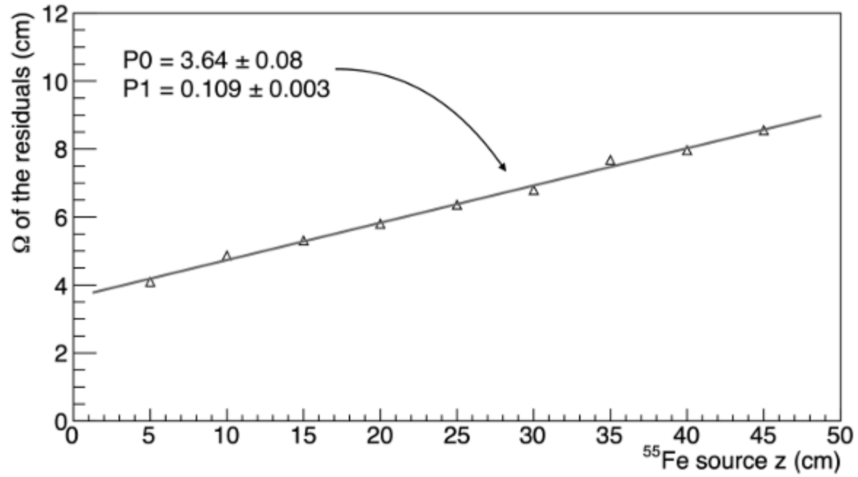
lomgitudinal profile



ζ = sigma of transverse profile x RMS of # pixels inside the spot

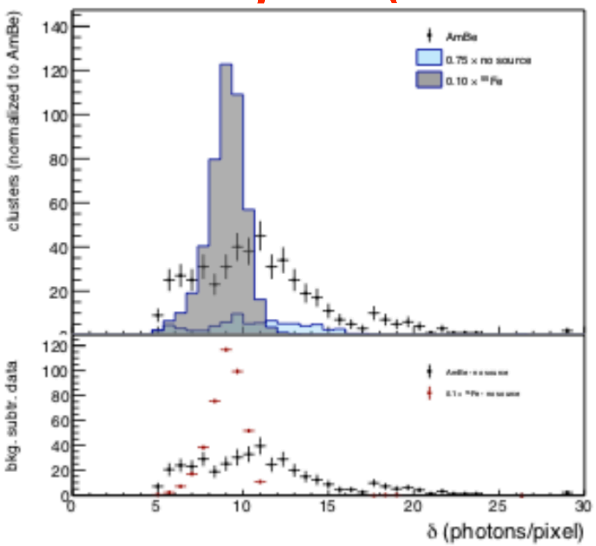


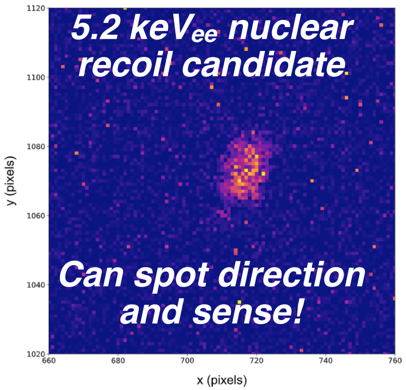
ζ residuals



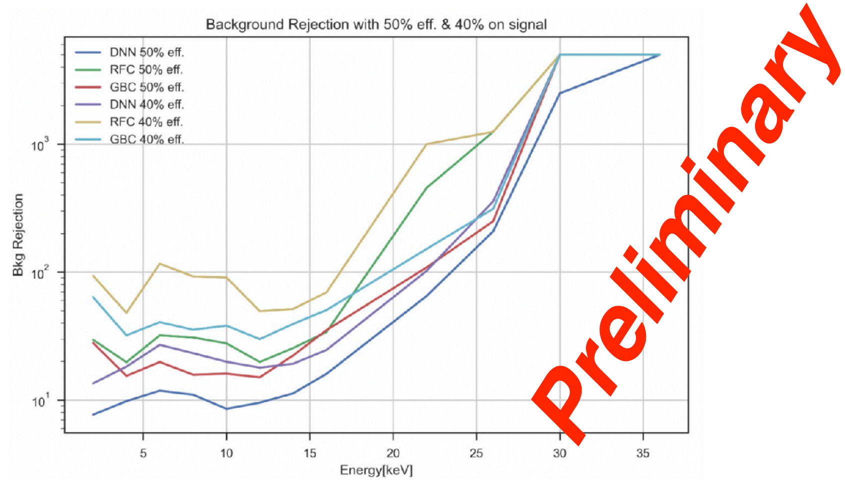
Particle identification

#counts/pixel (i.e dE/dx)





On going work on ML techniques



A. Prajapati PhD Thesis

40% nuclear recoil efficiency for energies < 20 keV$_{ee}$, with 99% ^{55}Fe events rejected

Signal efficiency			Background efficiency		
ε_S^{presel}	ε_S^{δ}	ε_S^{total}	ε_B^{presel}	ε_B^{δ}	ε_B^{total}
0.98	0.51	0.50	0.70	0.050	0.035
0.98	0.41	0.40	0.70	0.012	0.008

Models	Signal Efficiency $[\epsilon^S]\%$	Bkg. Rej. Efficiency $[1-\epsilon^B]\%$
RFC	40	99.1
	50	97.5
GBC	40	98.3
	50	96.5
DNN	40	96.6
	50	93.5

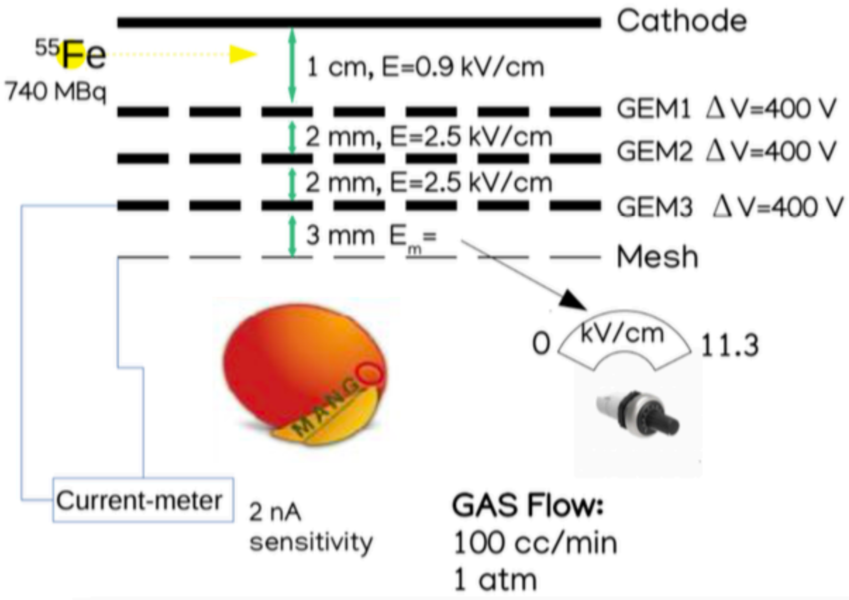
Reconstruction based on custom multiple iteration of IDBSCAN + morphological geodesic active contours (GAC)

Measur.Sci.Tech. 32 (2021) 2, 025902

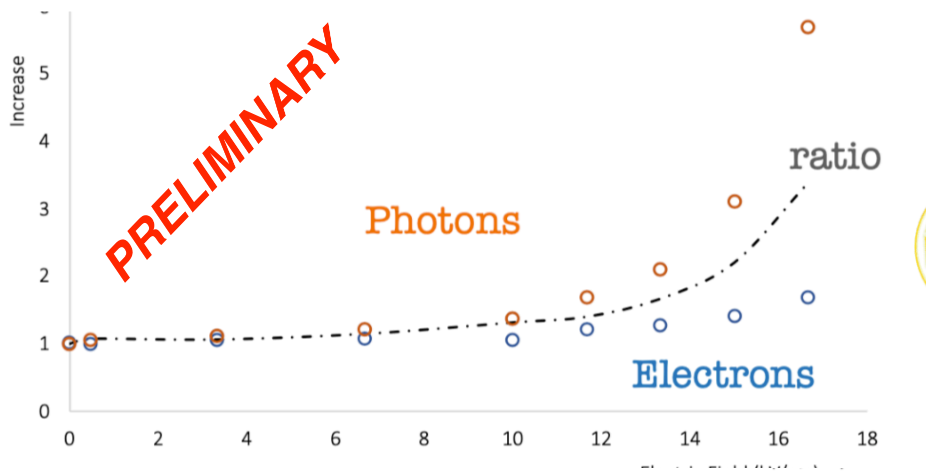
For the full 1-35 keV energy range

CYGNO R&D

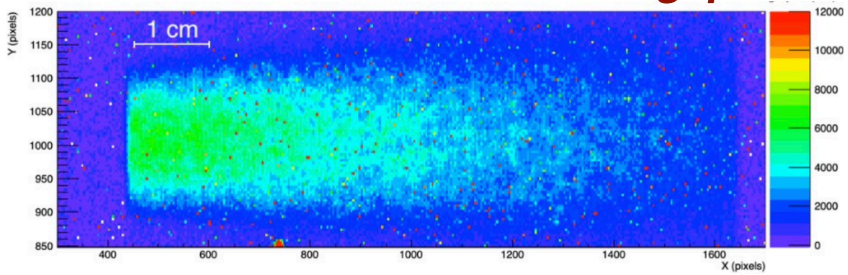
Enhancing the light yield through electroluminescence



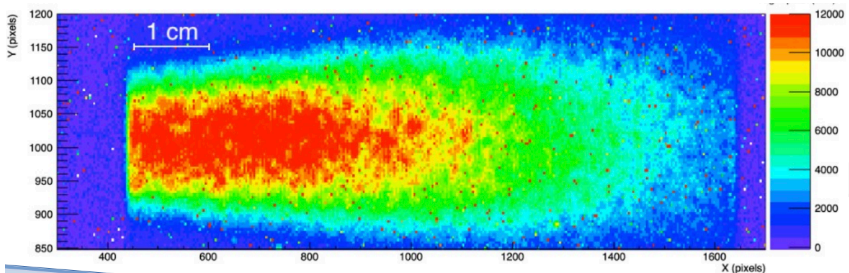
First evidence of electroluminescence in He:CF4 induced by low ionising electrons



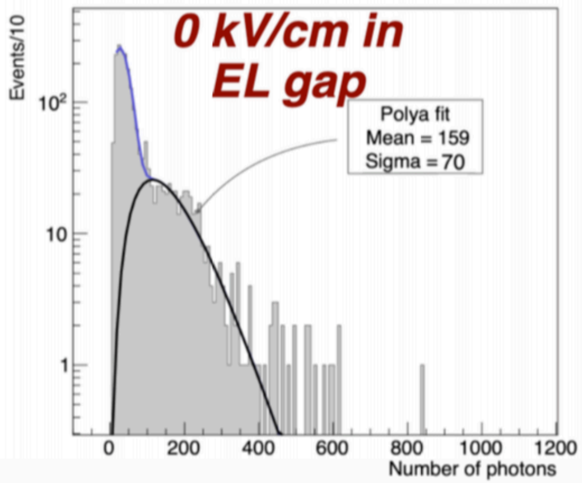
0 kV/cm in EL gap

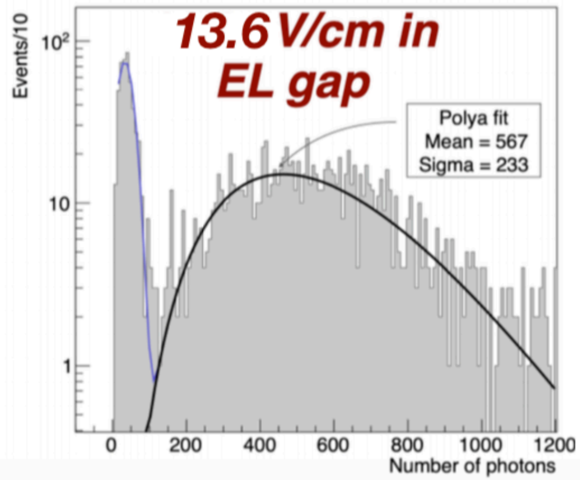


11.3 kV/cm in EL gap



55Fe data

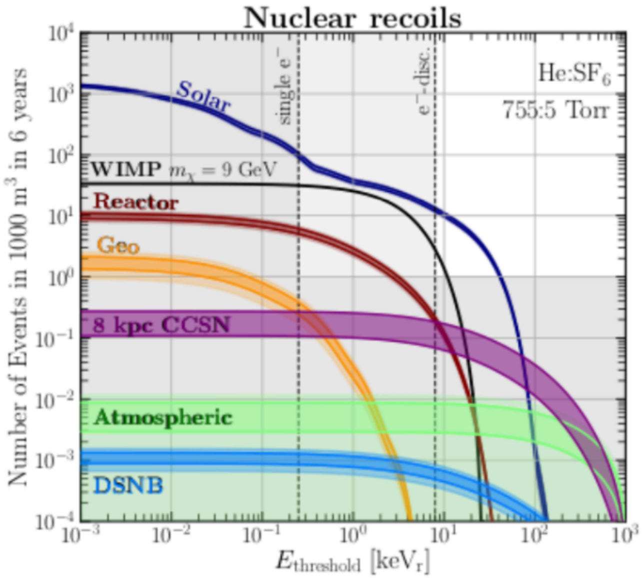




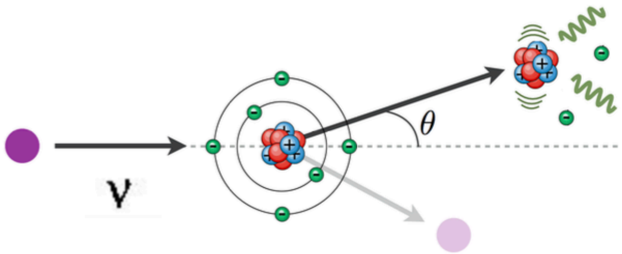
JINST 15 (2020) P08018

Neutrinos & directionality

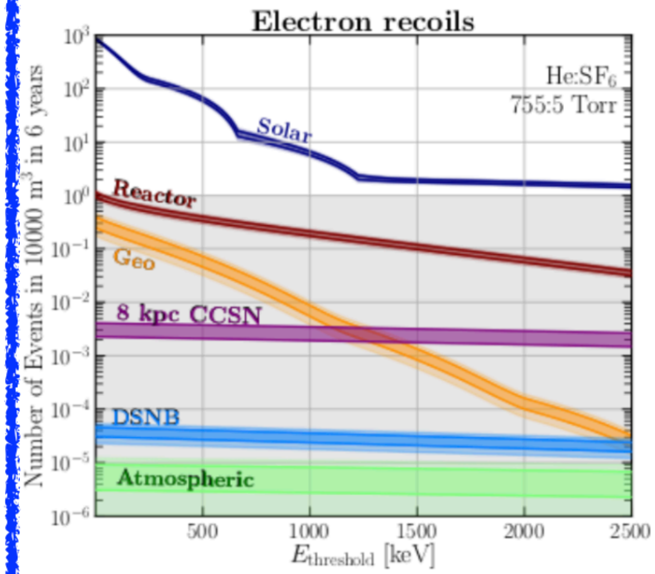
NEW! Physics reach under study



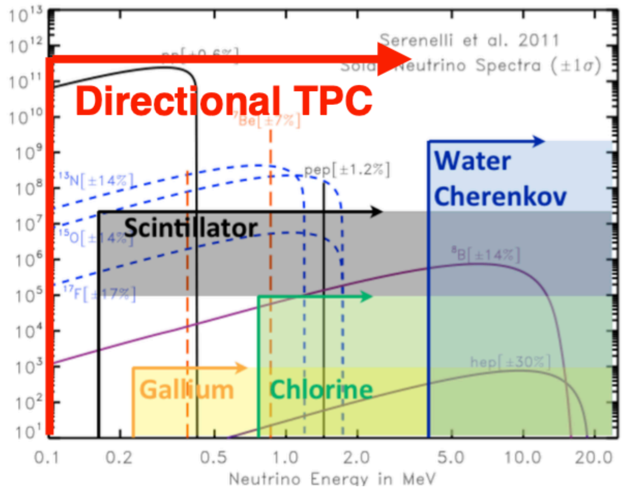
Coherent Neutrino-Nucleus scattering



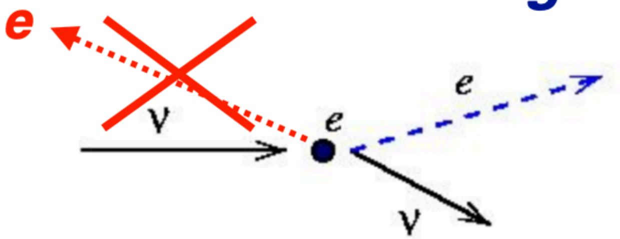
NOTE: only a directional DM detector can distinguish from WIMP signal



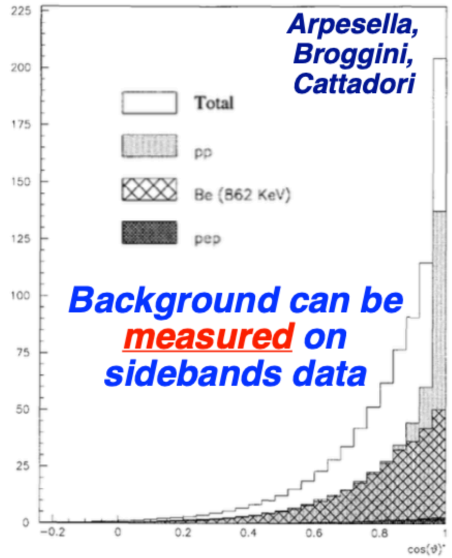
with event by event precise neutrino energy measurement



Elastic Neutrino-Electron scattering



NOTE: only a directional DM detector can distinguish from ER background



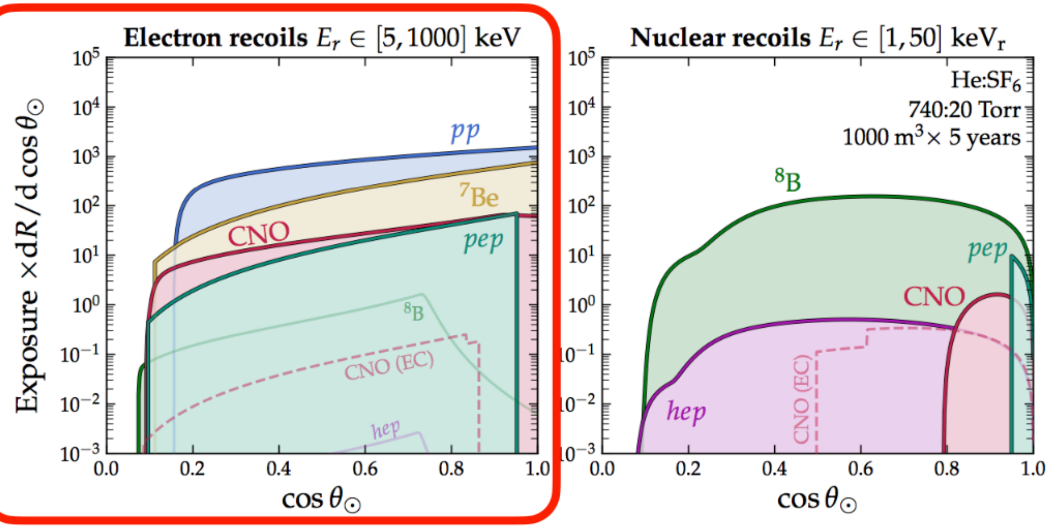
Arpesella, Broggini, Cattadori

Background can be measured on sidebands data

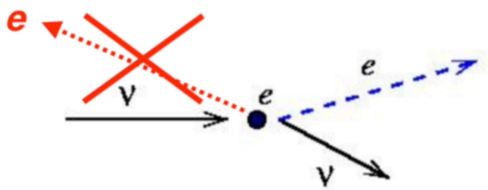
Fig. 4. The events of one year as a function of the reconstructed scattering angle.

Solar neutrinos with elastic scattering on electrons

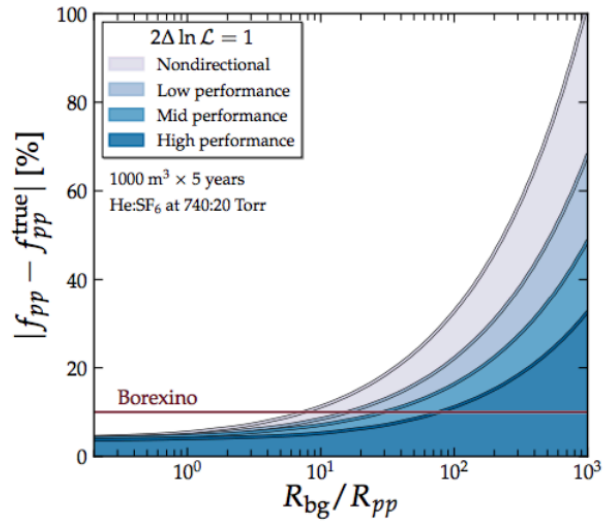
Expected number of ER and NR events as a function of the cosine of the angle away from the Sun



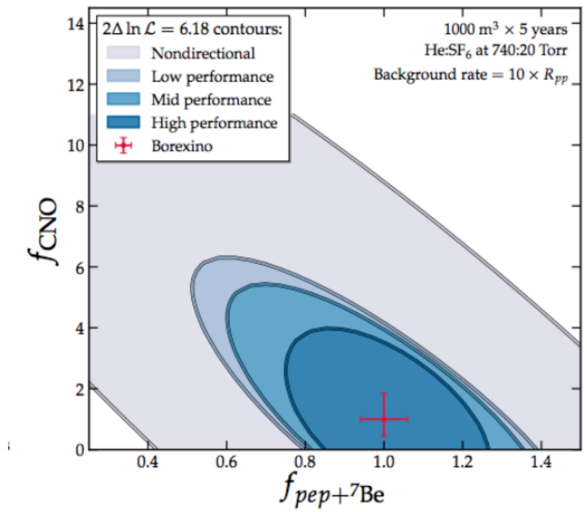
Given the Sun position, recoils in opposite direction are kinematically forbidden



Differently from WIMPs, background can be measured on sidebands data



1 σ sensitivity to pp flux as a function of the total non-neutrino ER background



2 σ sensitivity to combined measurement of the CNO and pep + ^{7}Be pp fluxes, fixing the background rate to 10 times the pp electron recoil rate

- **Electron recoils directionality in CYGNUS enables solar neutrino spectroscopy through neutrino-electron elastic scattering on an event-by-event basis**
  - **An O(10) m^3 ER directional detector could extend Borexino pp measurement to lower energy**
  - **CYGNUS 1 ton could measure the CNO cycle by breaking the degeneracy with pep + ^{7}Be fluxes through directionality**