HSE
Occupational Health & Safety
and Environmental Protection unit

# A Large Area GEMPix detector for treatment plan verification in hadron therapy

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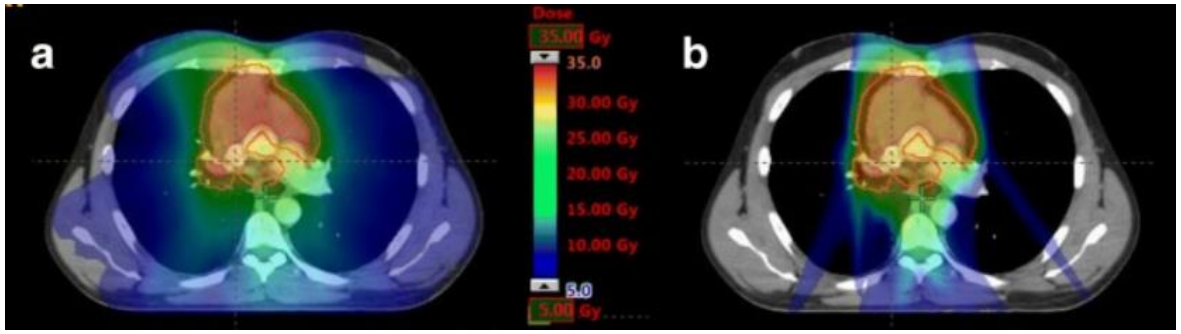
HSE-RP-SP

# Outline

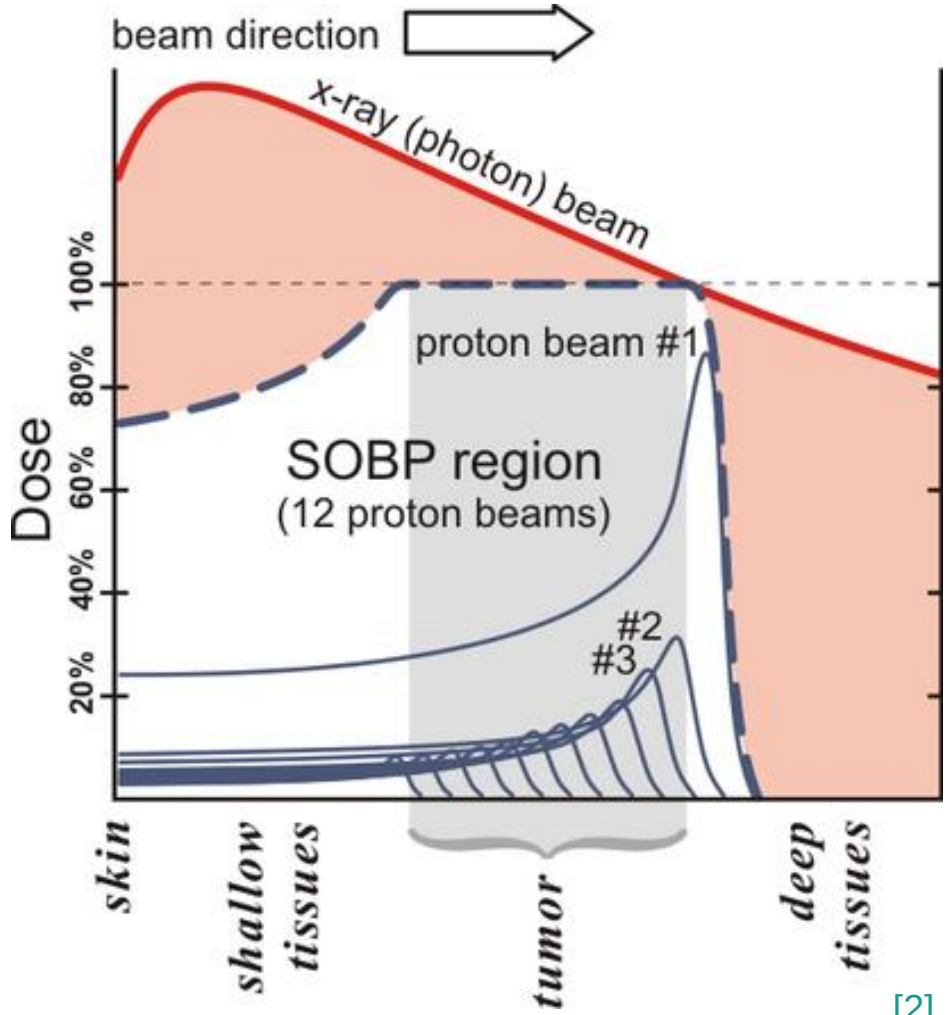
- Motivation
- The GEMPix Detector
- A larger area GEMPix (LaGEMPix) detector
- Preliminary results
- Conclusions & Outlook

# Hadron Therapy & Quality Assurance

- Hadron therapy: Well-defined region of energy deposition
- 2D images with better spatial resolution than ion chambers
- Quality Assurance (QA): check range, spread of Bragg peak, treatment plan verification
- QA: typical dose uncertainty O(1%)




a) Photon beam b) Proton beam [1]



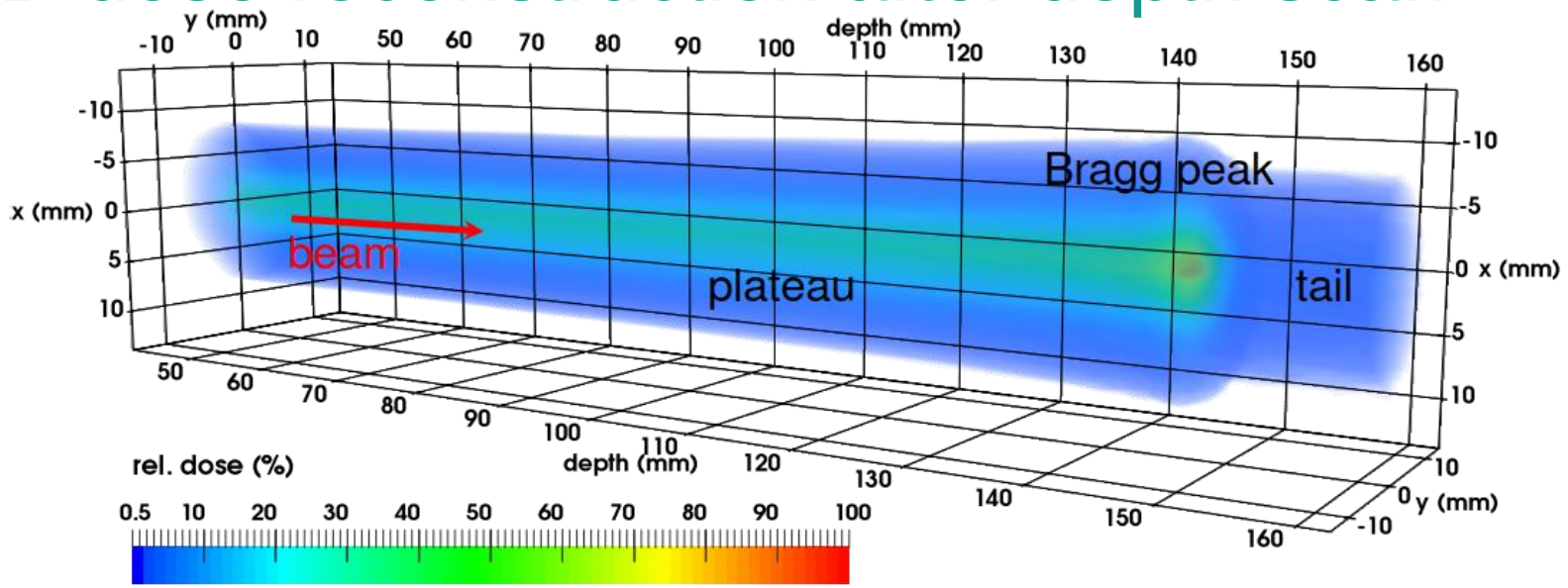

[2]

# Measurements at CNAO

**active area: 2.8 cm x 2.8 cm!**

## *3D energy deposition by $^{12}C$ ion beam*

### 3D dose reconstruction after depth scan



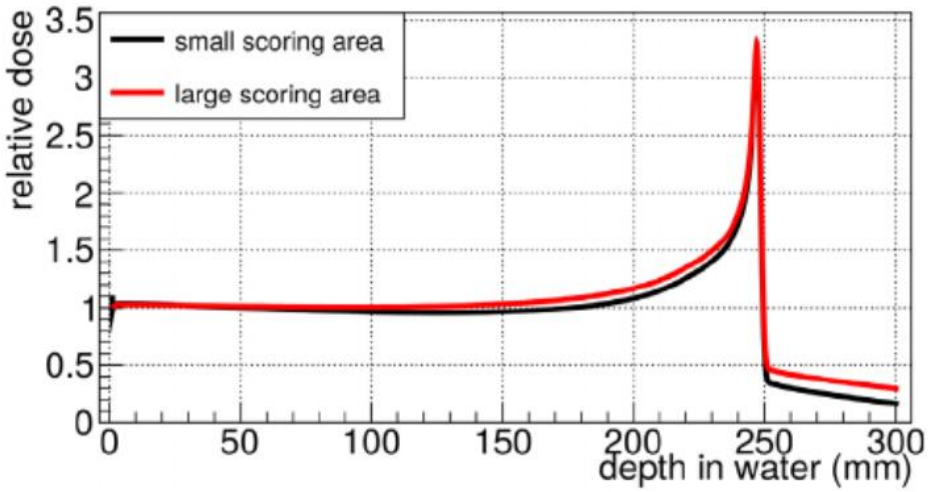

Papers on proof-of-concept:

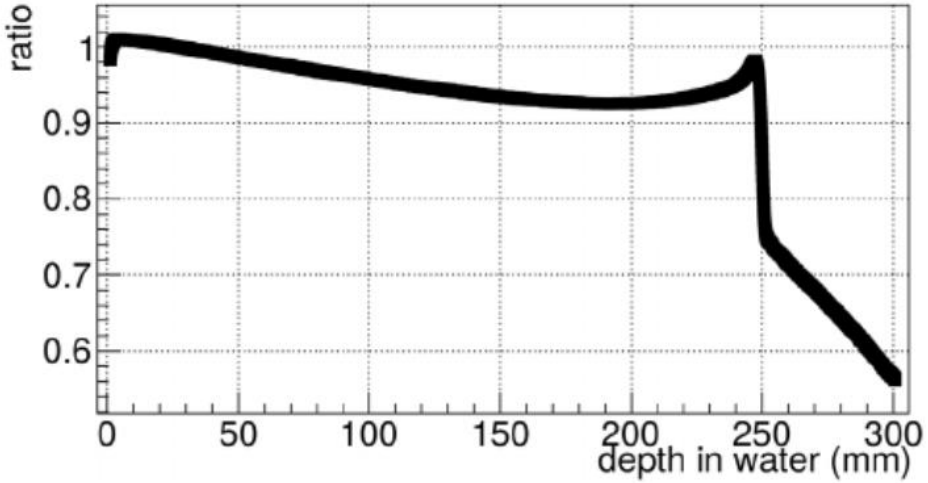
J. Leidner et al. **3D energy deposition measurements with the GEMPix detector in a water phantom for hadron therapy.** JINST. 2018.

J. Leidner et al. **A GEMPix-based integrated system for measurements of 3D dose distributions in water for carbon ion scanning beam radiotherapy.** Med. Phys. 2020.

# Why a Large Area GEMPix?

- **Underestimation** of the dose of a pencil beam in the GEMPix:
  - The beam is spread out with increasing depth in water
  - It is especially evident in the tail!
- Larger detector area of 20 cm x 20 cm needed to:
  - **cover typical maximum** radiation field size for scanned beams
  - avoid **losses** due to beam spread out
- On-going work focused on **larger sensitive area readout:**
  - Large area GEMs already exist
  - Check new readout possibilities



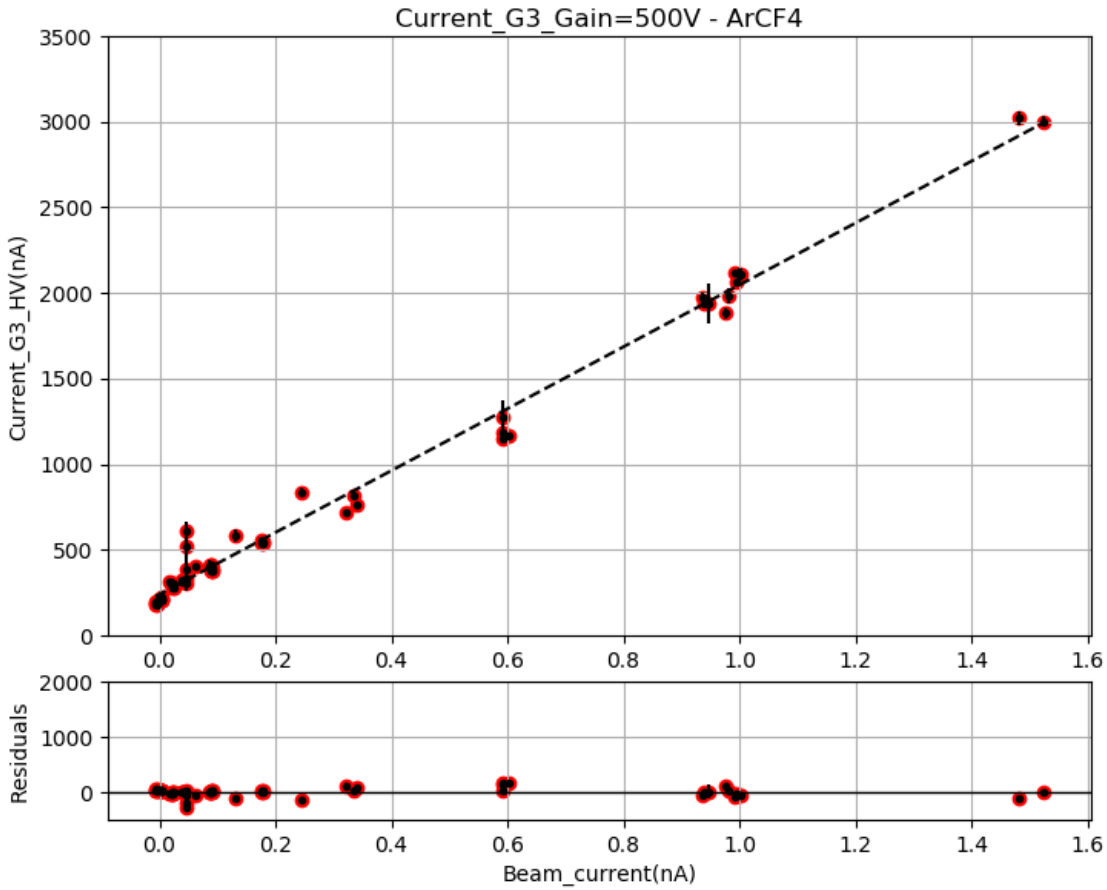

Small area: 2.8 × 2.8 cm$^2$ (the area of the GEMPix)
Large area: 50 × 50 cm$^2$

FLUKA simulation for CNAO clinical carbon pencil beam

# Triple-GEM

## → The IBA 18-MeV cyclotron at Bern

- Test the behaviour at high proton flux of the recently built **Triple-GEM detector:**
  - 10*10 $cm^2$
- Perform **current scans:**
  - Typical range used in hadrontherapy:
    - [$10^9$ ;$10^{10}$] protons/s
  - Range used at Bern:
    - [$10^7$;$10^{10}$] protons/s
    - [$10^{-2}$;$10^0$] nA




**Successful measurements with currents up to 1.5 nA**

# Readout options

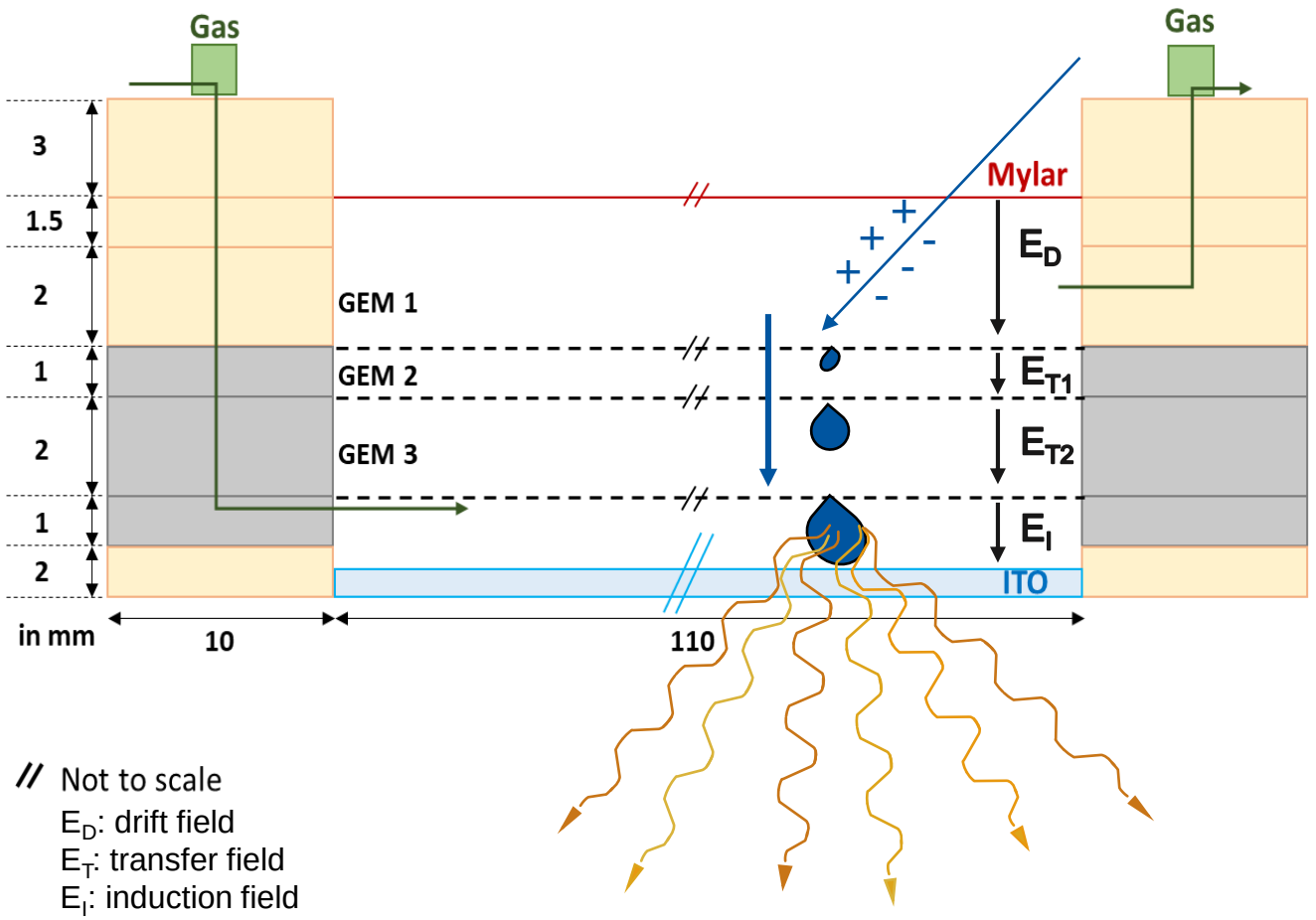
## → Different readouts

- **Charge** readout

  relies on collecting electrons from the avalanche in the GEMs.

- **Optical** readout

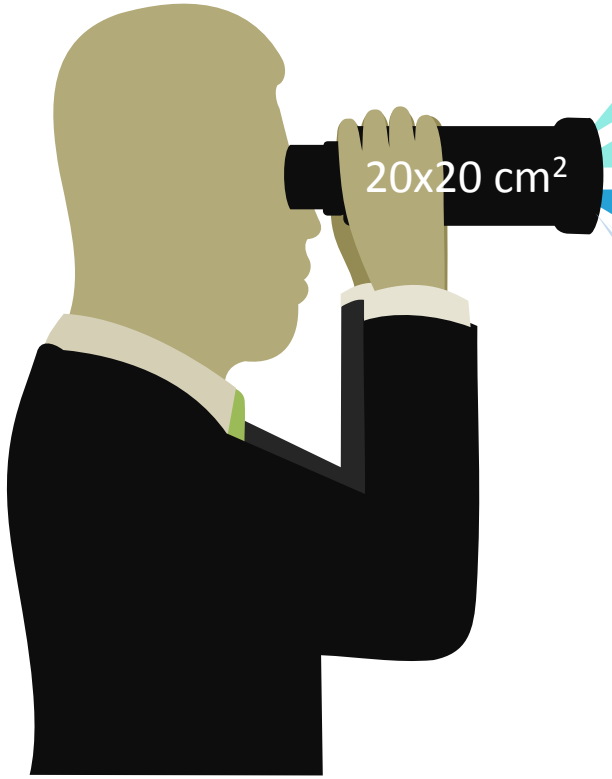
  relies on detecting photons emitted during the electron avalanche multiplication processes, which can be achieved when specific gas like $ArCF_4$ mixtures are used.

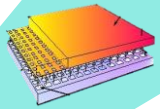


# Readout Options

Gas Electron Multipliers (GEM's) +
**Pixelated Read-out**

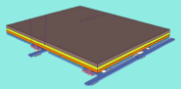
Charge readout
or
Optical readout?



**01 Timepix or Timepix3**

Well-known system
Good performance
Cost
Difficult to increase area



**02 TFT (Thin Film Transistor)**

Printed on any size
Couple to Triple GEM (to be studied)
Radiation hardness (to be studied)

**03 TFT + OPD (Organic Photodiode)**

Printed on any size
Easy to couple to Triple-GEM
Radiation hardness (to be studied)

**04 CCD/CMOS Camera**

High resolution
Complexity of set-up

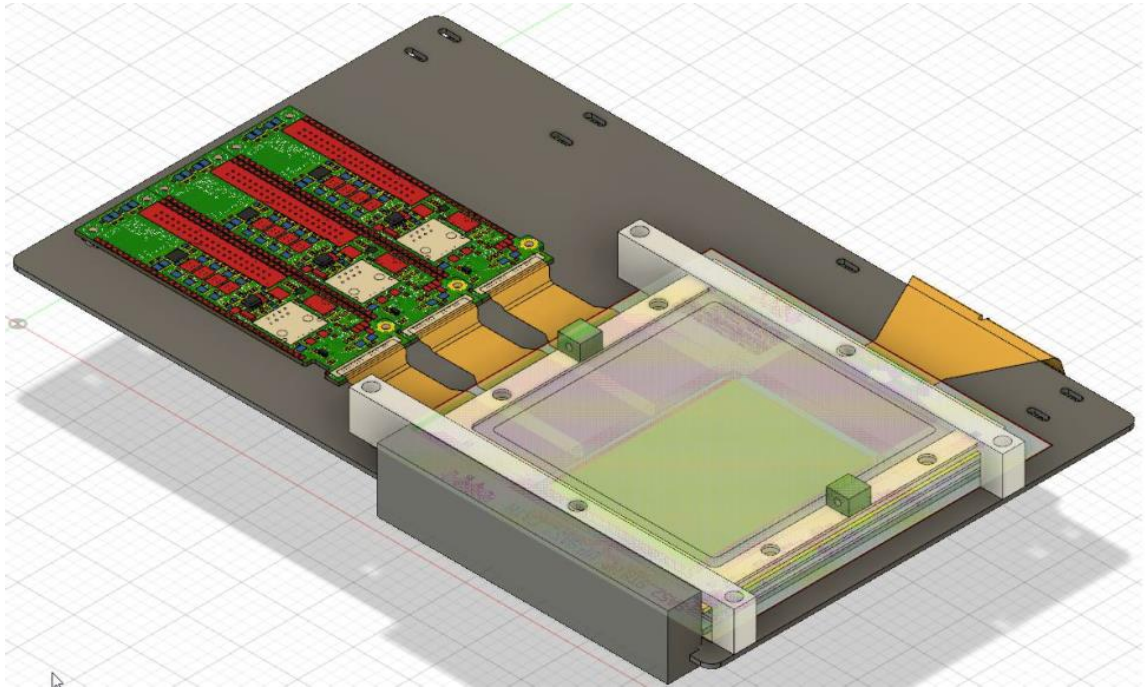
**05 Light sensitive Timepix 3**

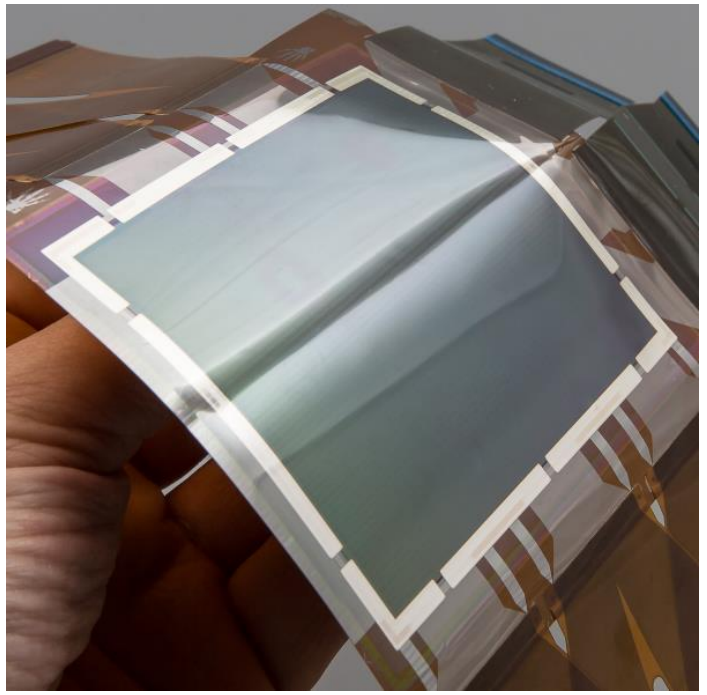
MAPF Funding

ATTRACT funding project

# Matrix TFT+OPD

Organic photodiodes coated on an organic TFT backplane



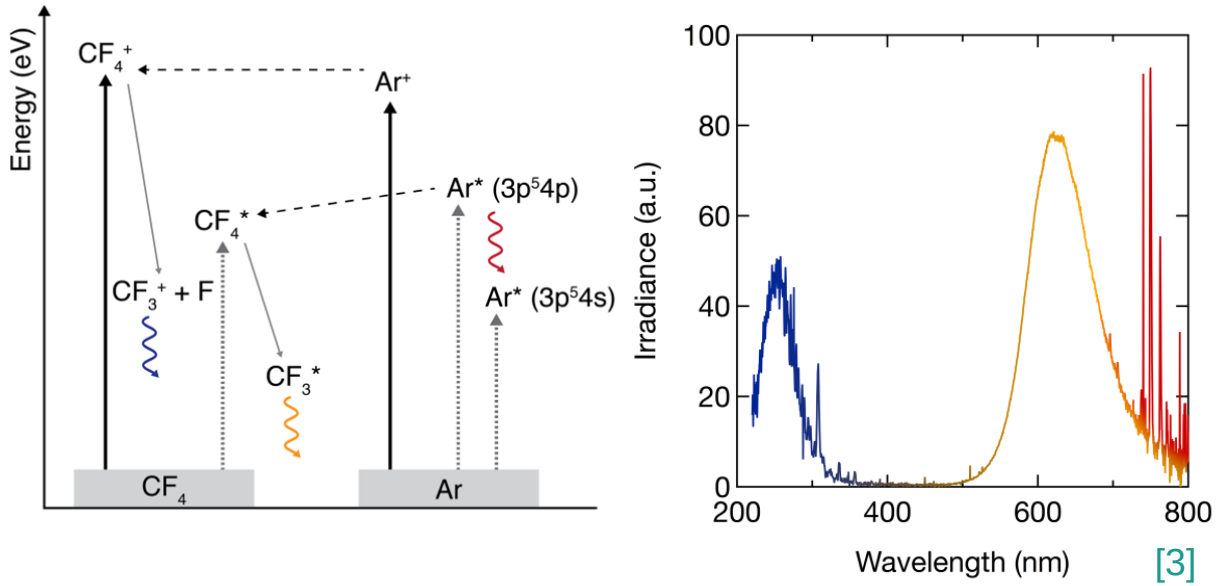


**This project has received funding from the CERN Medical Applications Project Forum and the ATTRACT project funded by the EC under Grant Agreement 777222.**

# Scintillation of Ar:$CF_4$ mixtures

## → Emission spectrum

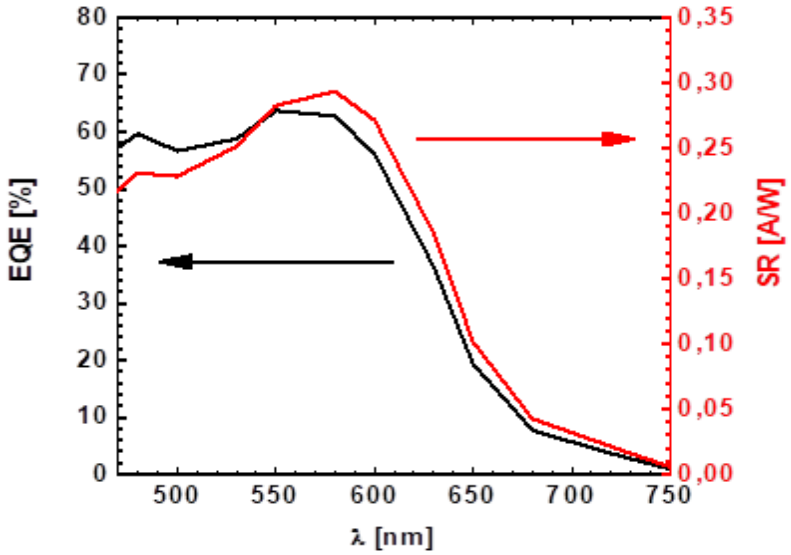
Secondary scintillation spectra of Ar:CF4 gas mixture




[3]

## → Acceptance spectrum

EQE spectrum of the current OPD




**Match with readout acceptance spectrum**

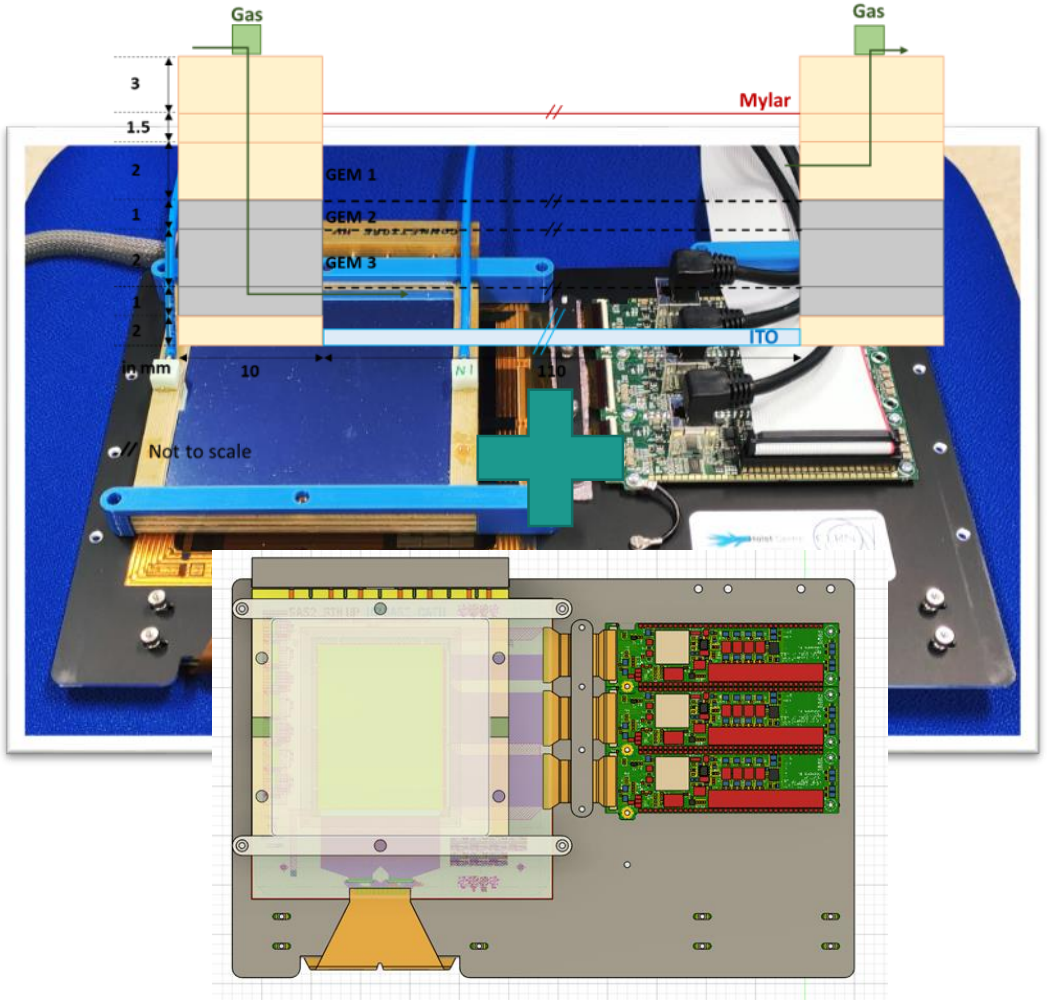
# The LaGEMPix Detector
# Matrix TFT+OPD

1. **Development of the first prototype**:
   - Triple-GEM @ CERN
     - 10x10 $cm^2$
   - Imager sensor @ TNO
     - 60 x 80 $mm^2$
     - pixels of 126 x 126 $\mu m^2$

**Increase of 6x active area!**

2. The first LaGEMPix detector has been **successfully** assembled.

3. First tests of the LaGEMPix prototype were performed in the CERN Calibration Laboratory of Radiation Protection Group.

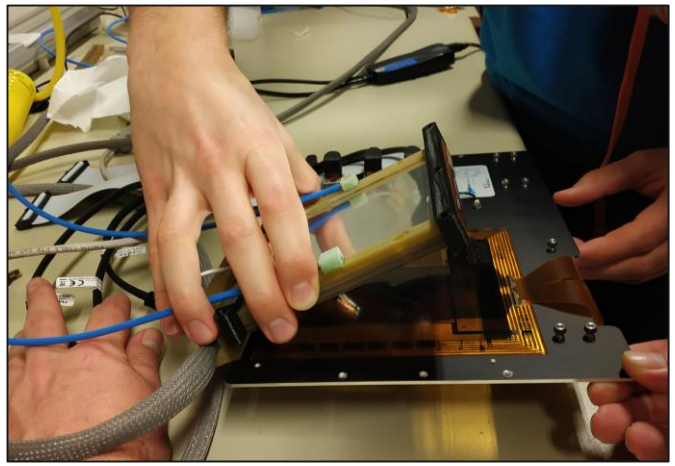


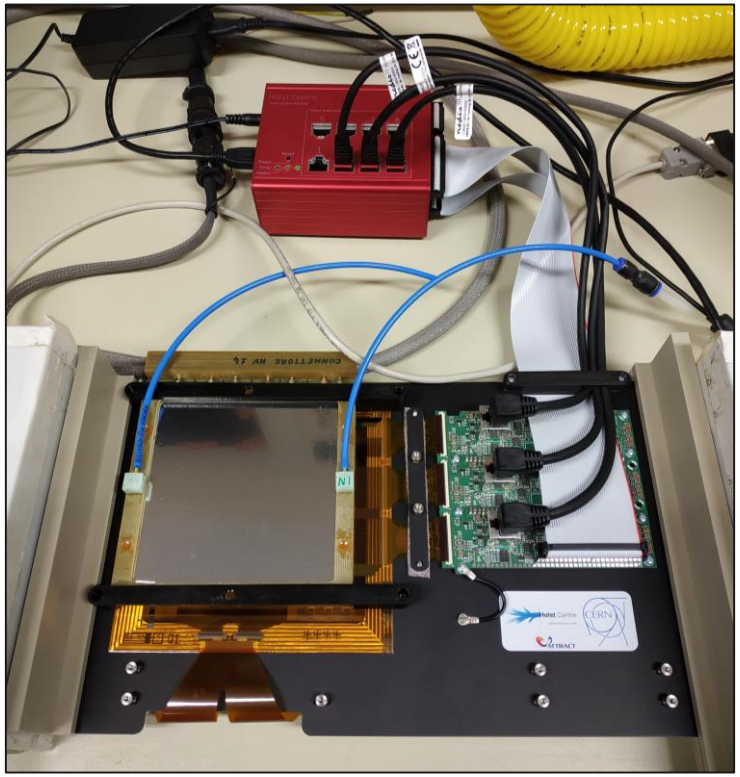
# The LaGEMPix Detector
# First prototype

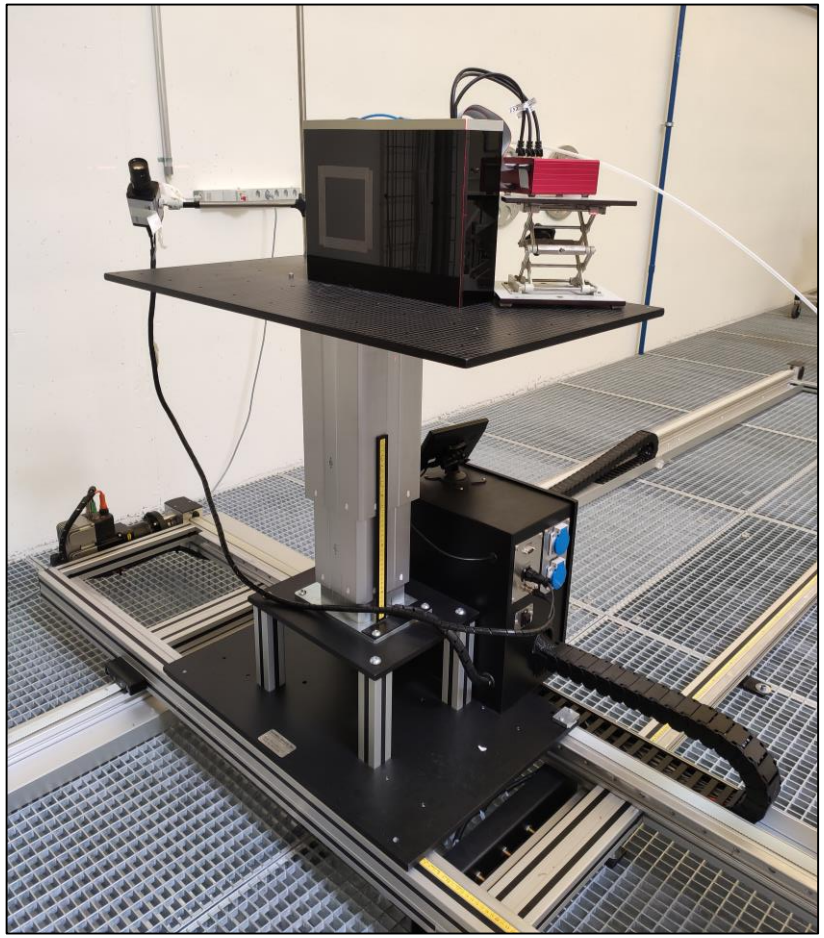
→ **Merging**

- Triple-GEM @ CERN
- Imager sensor @ TNO

Wider area (60x80 mm$^2$)

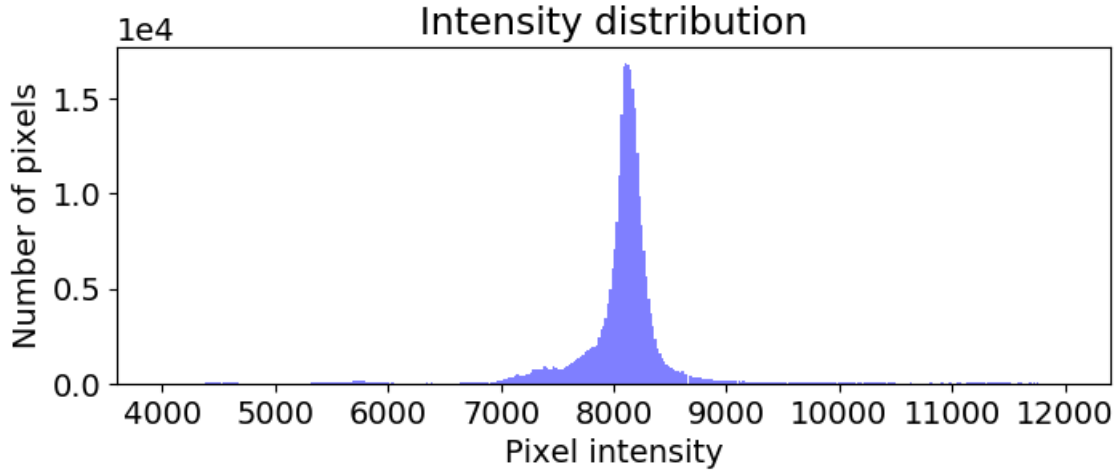


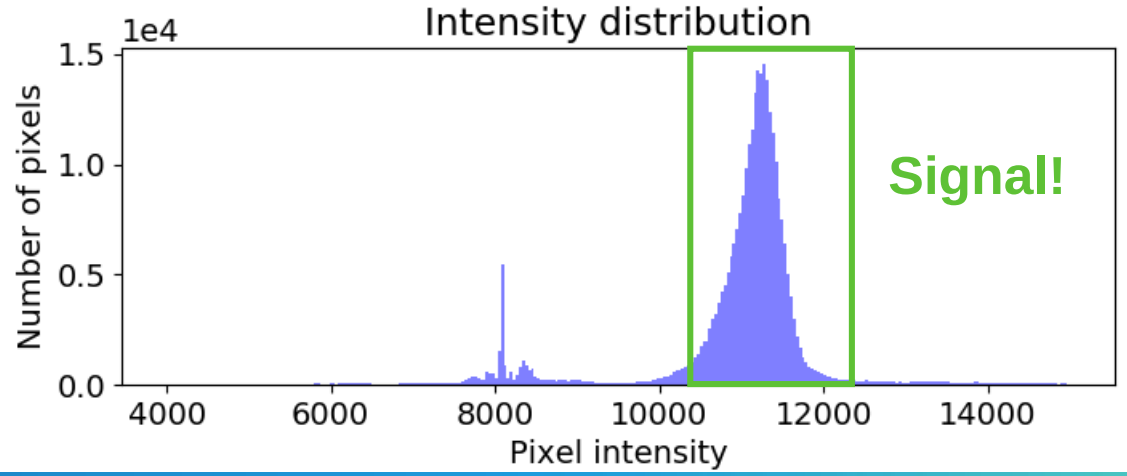




# First test of the merged detector

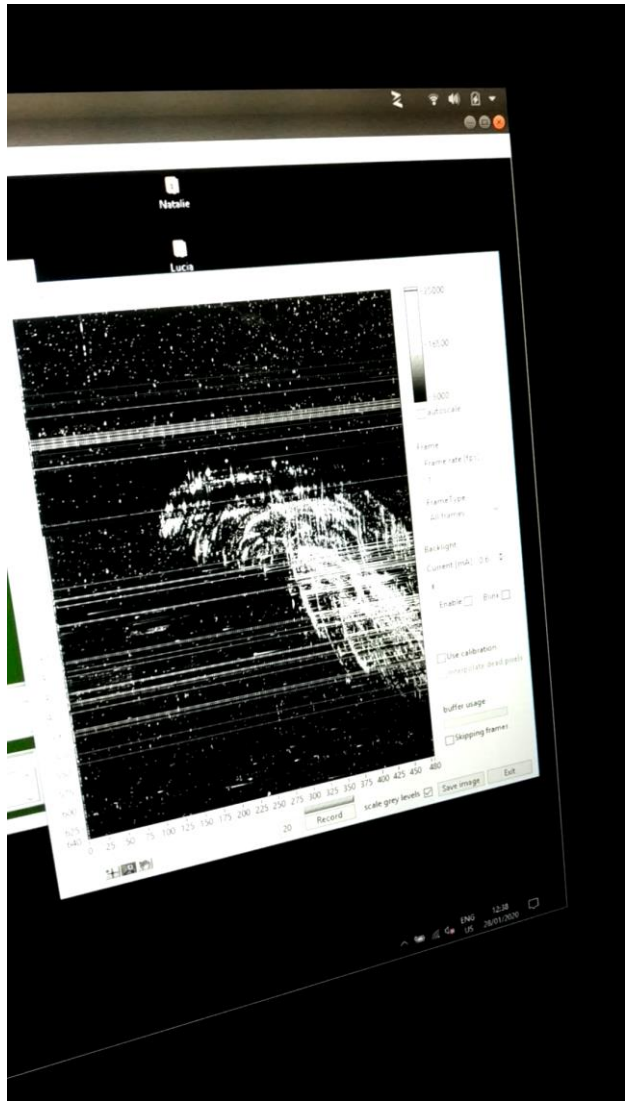
→ Calibration Laboratory of the RP




No radioactive source

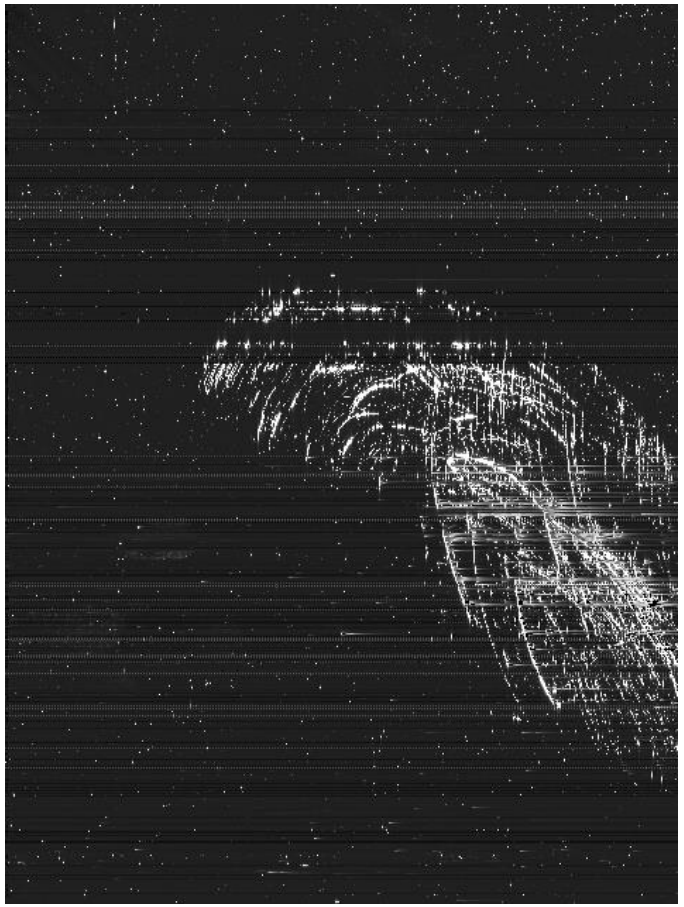
3 TBq
137-Cs source
γ –rays:
0.6617 MeV



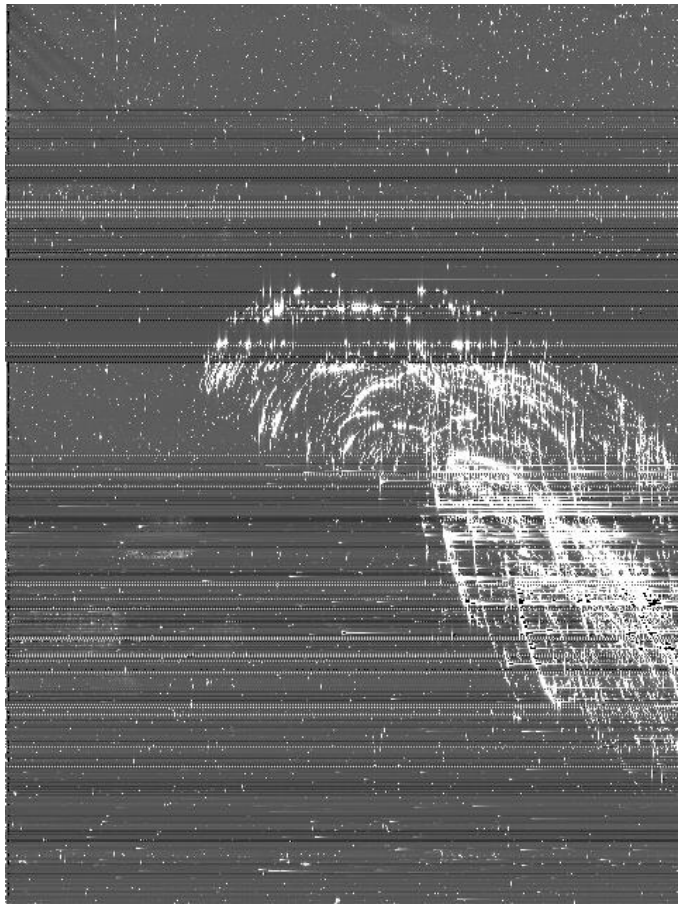
First functional test

# First test of the merged detector

→ Calibration Laboratory of the RP



No radioactive source



3 TBq
137-Cs source
γ –rays:
0.6617 MeV

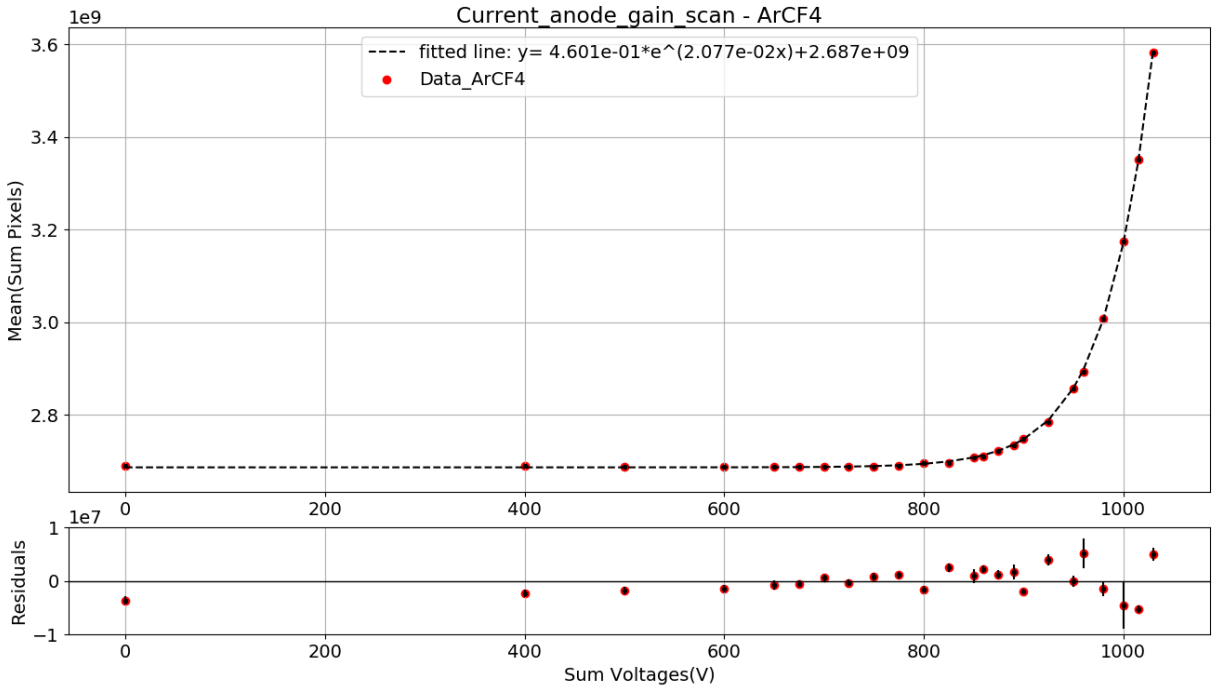
## The LaGEMPix Detector

# Characterization optical signal

3 TBq
137-Cs source
γ –rays:
0.6617 MeV

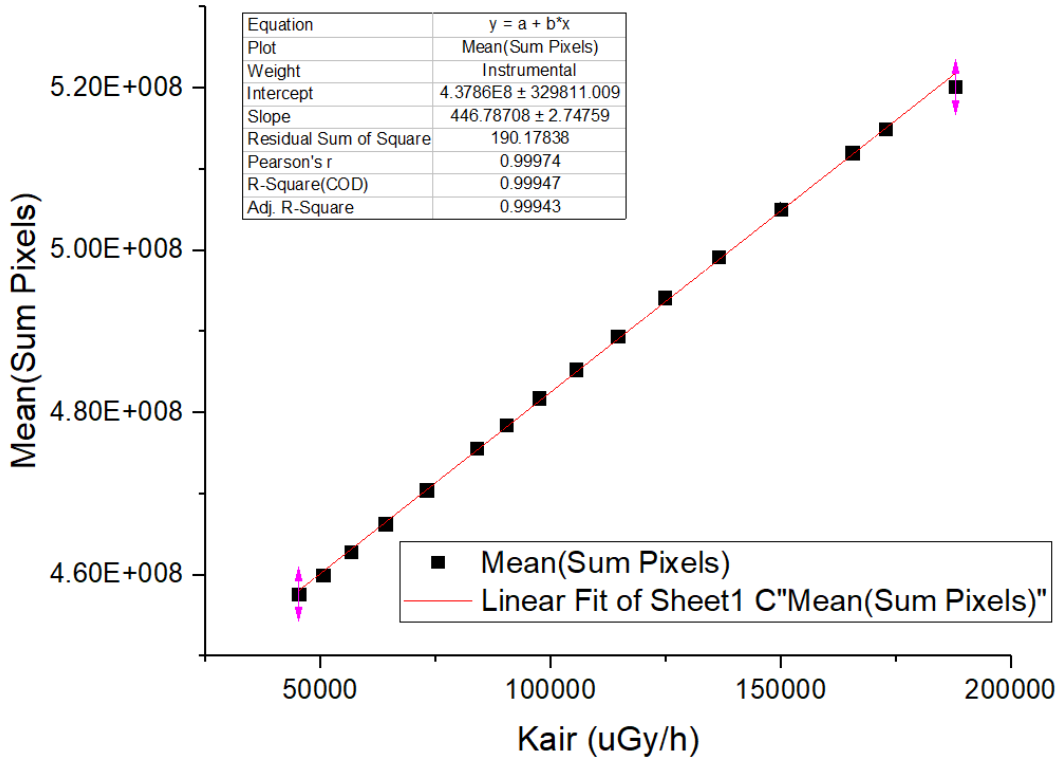
→ **Calibration Laboratory of the RP**

### Gain scan




**Exponential behavior!**
**Same behavior measured with electrons.**

### Dose scan




**Linearity with dose!**

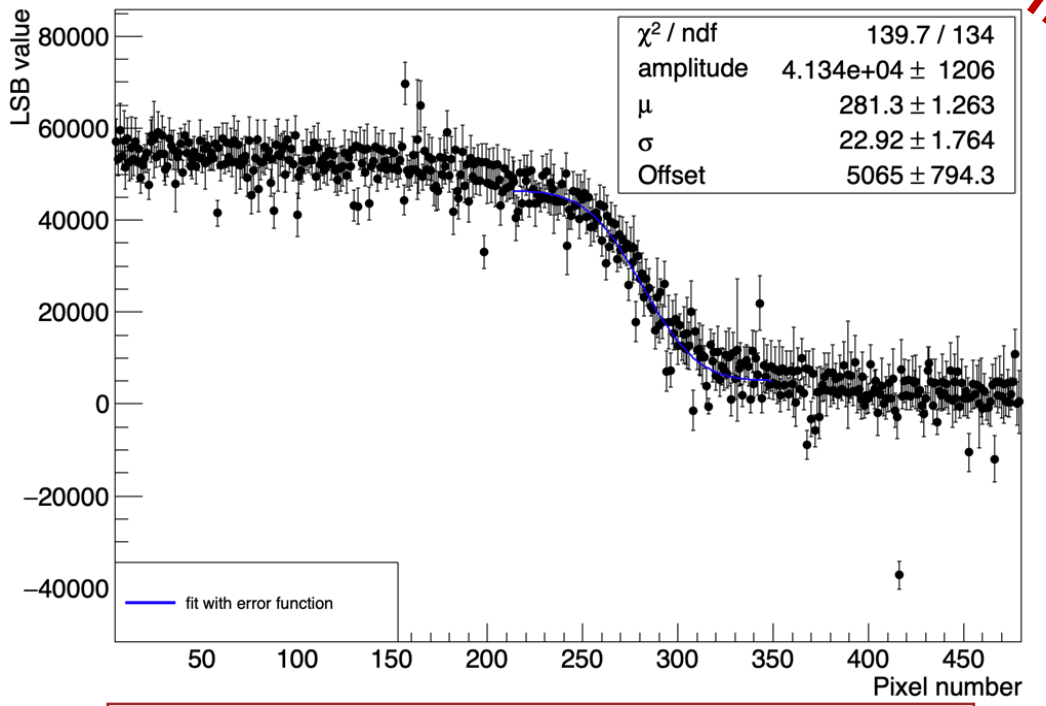
# The LaGEMPix Detector
# Spatial resolution


X-Ray generator 30 kV

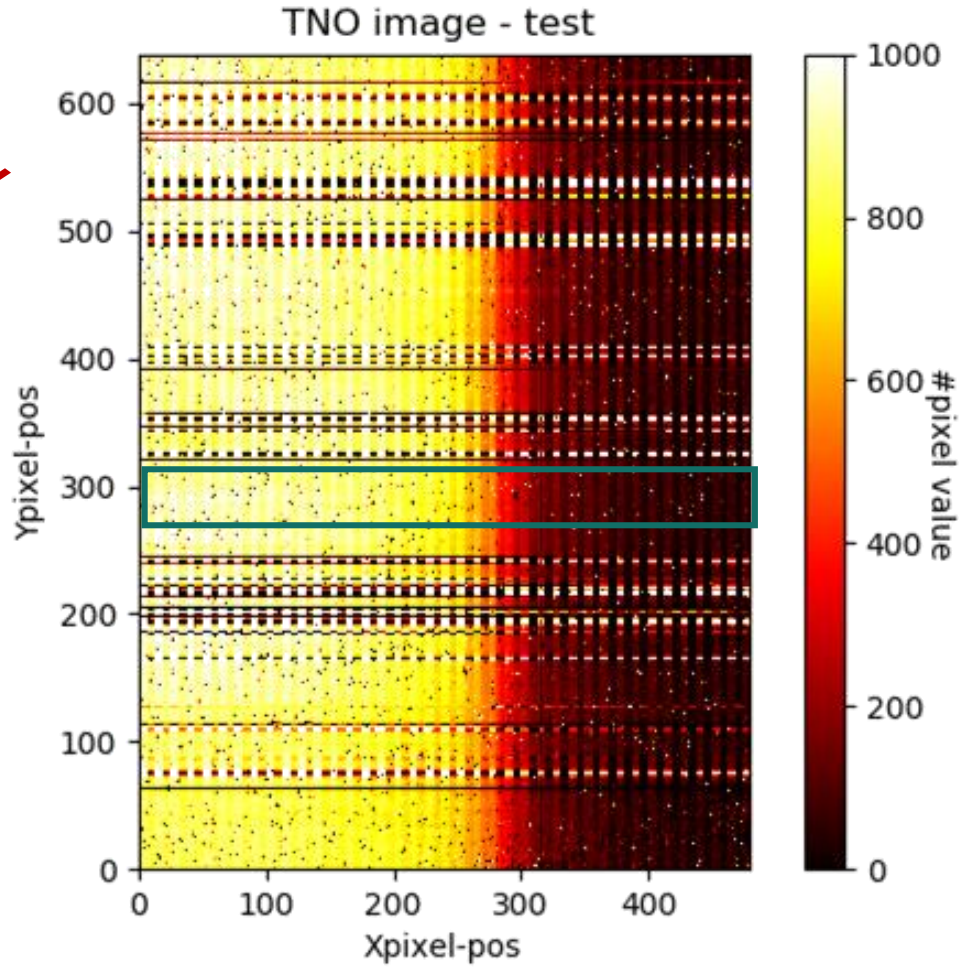
→ **Edge response to rise from 10% to 90%**

- Block of lead in front of the detector

Preliminary




Error function fit to the experimental data
σ = 2.89 +- 0.22 mm
10-90% rise distance = 7.5 mm

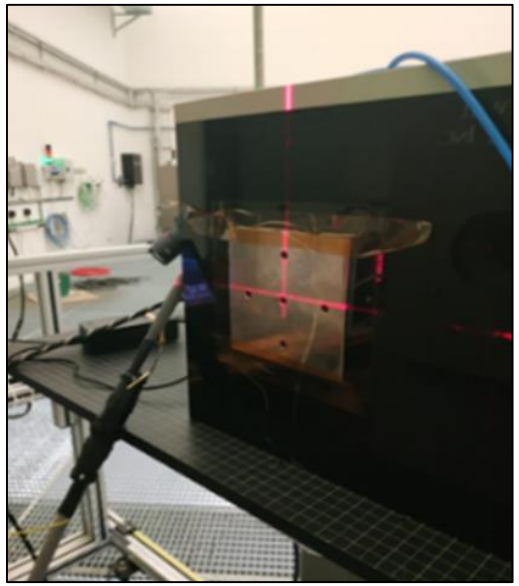


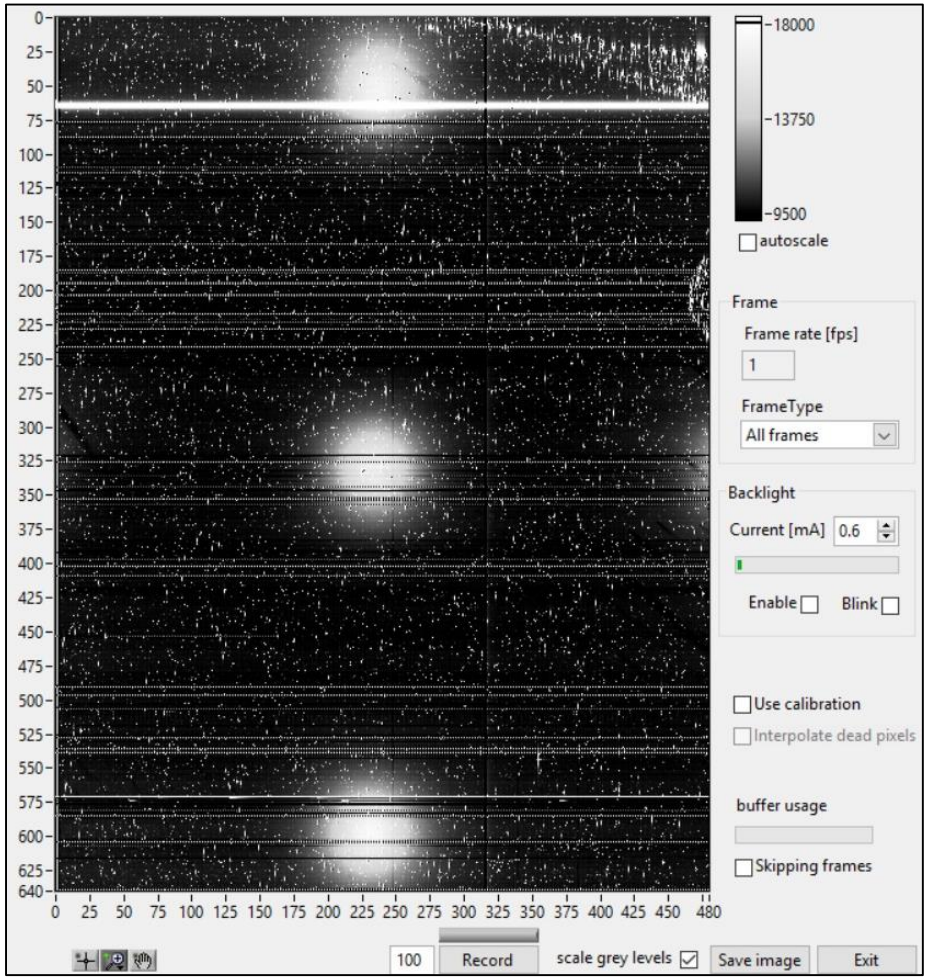
# The LaGEMPix Detector
# Spatial resolution

X-Ray generator 30 kV

## → Calibration Laboratory of the RP

- Copper plate in front of the detector
  - 6 mm Ø holes
  - Thickness 1 mm
  - Absorption X-Rays ~ 99.4% @ 30 keV



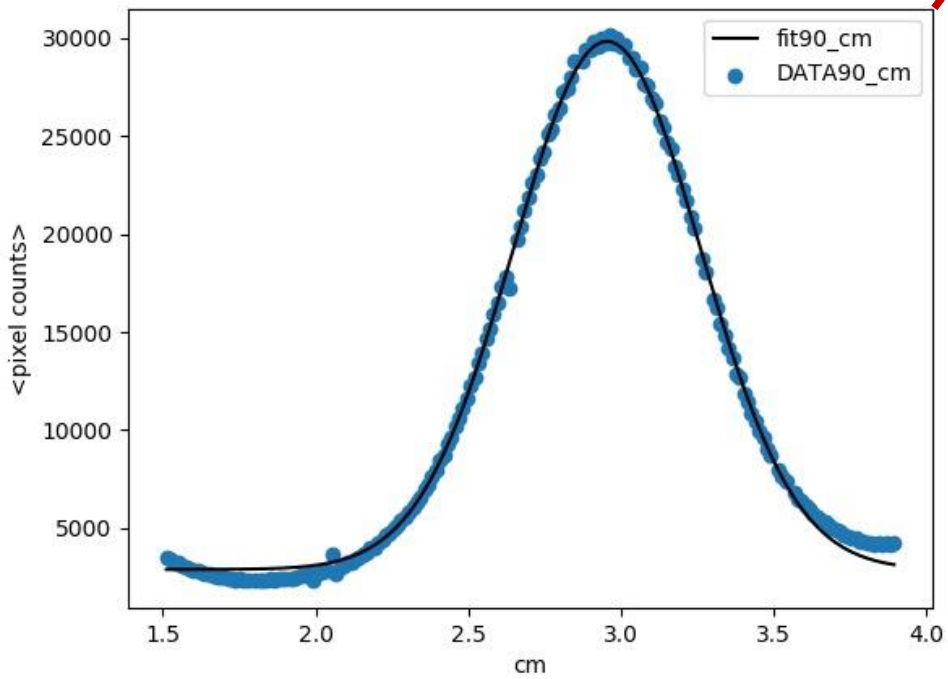


# The LaGEMPix Detector
# Spatial resolution

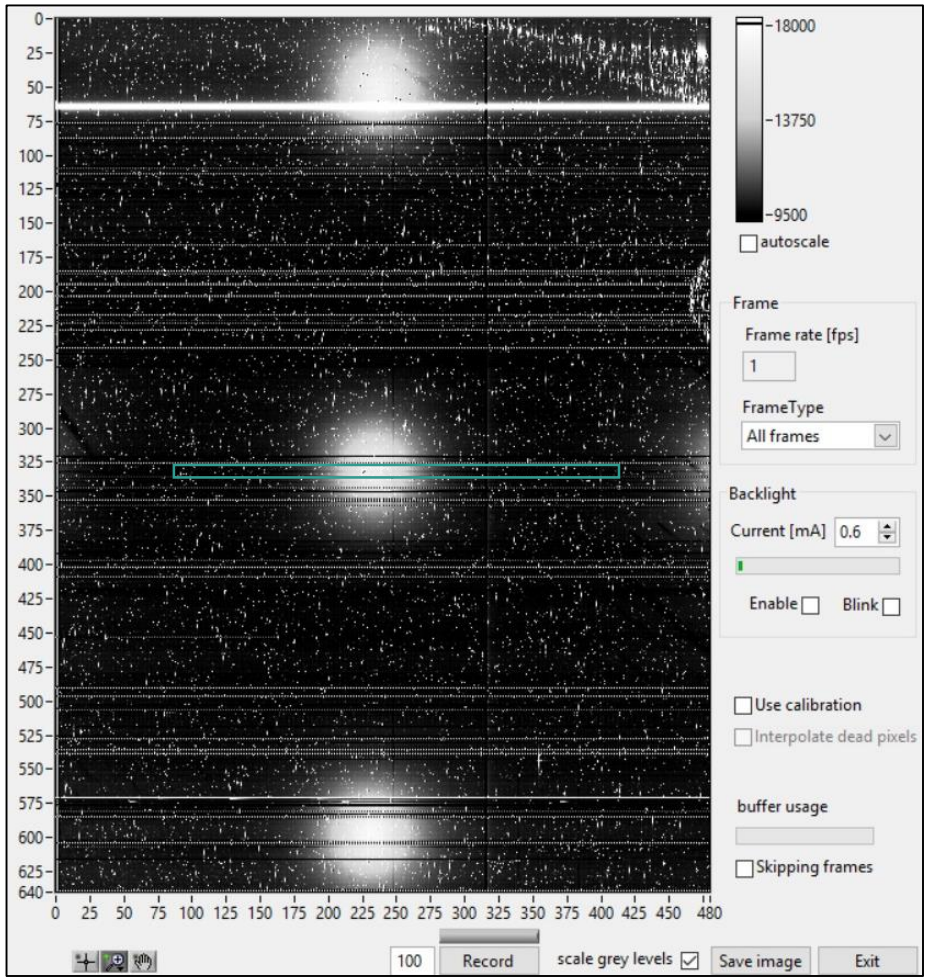
X-Ray generator 30 kV

→ Calibration Laboratory of the RP

Preliminary




Gaussian fit to the experimental data
FWHM ≃ 7.1 mm (errors < 4%)

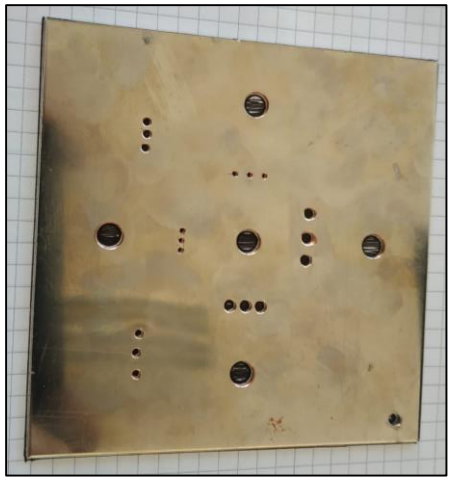


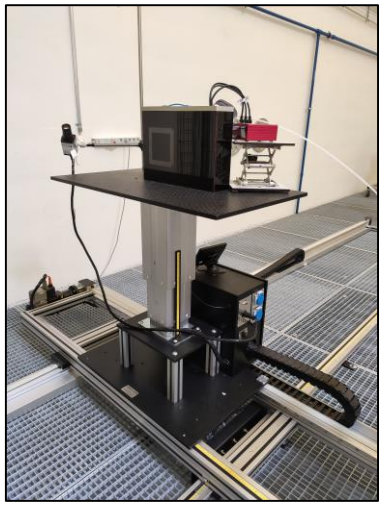
# Spatial resolution

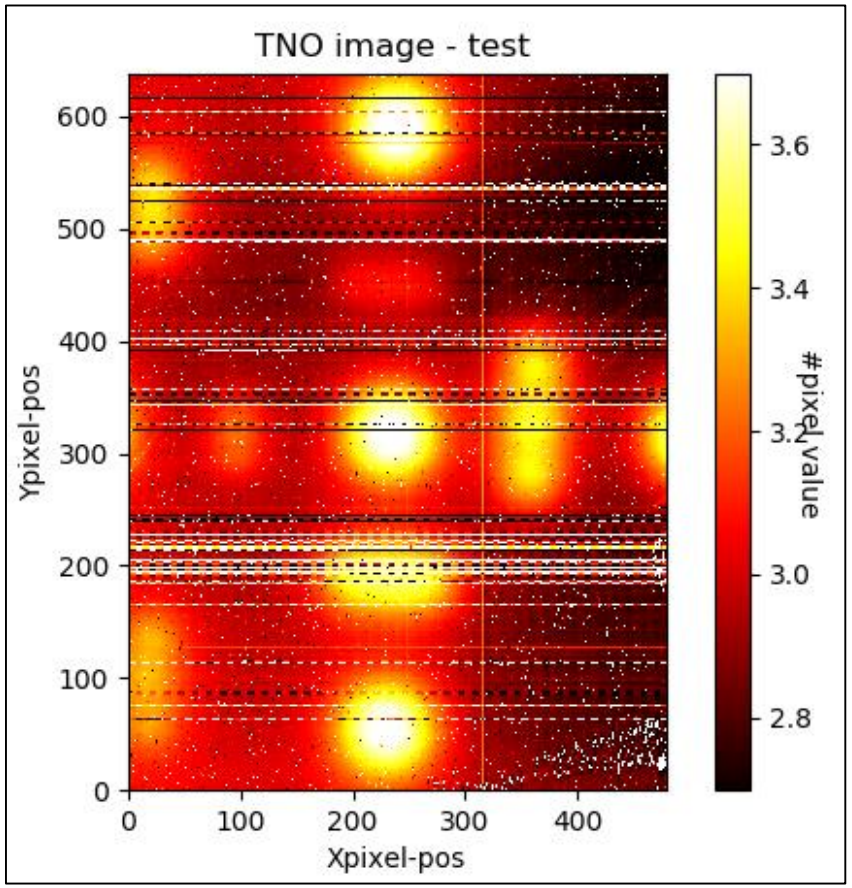
X-Ray generator 30 kV

## → Calibration Laboratory of the RP

- Copper plate in front of the detector
  - 3 mm holes – space between holes 3 mm
  - Absorption X-Rays ~ 99.4%





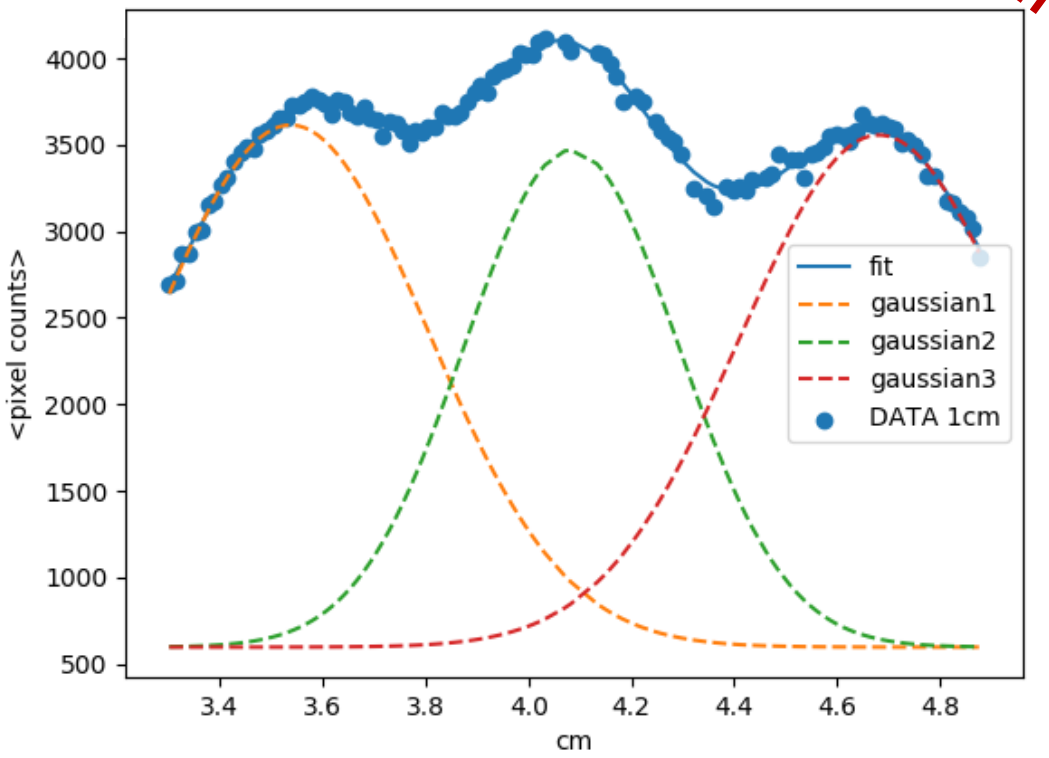


# The LaGEMPix Detector
# Spatial resolution

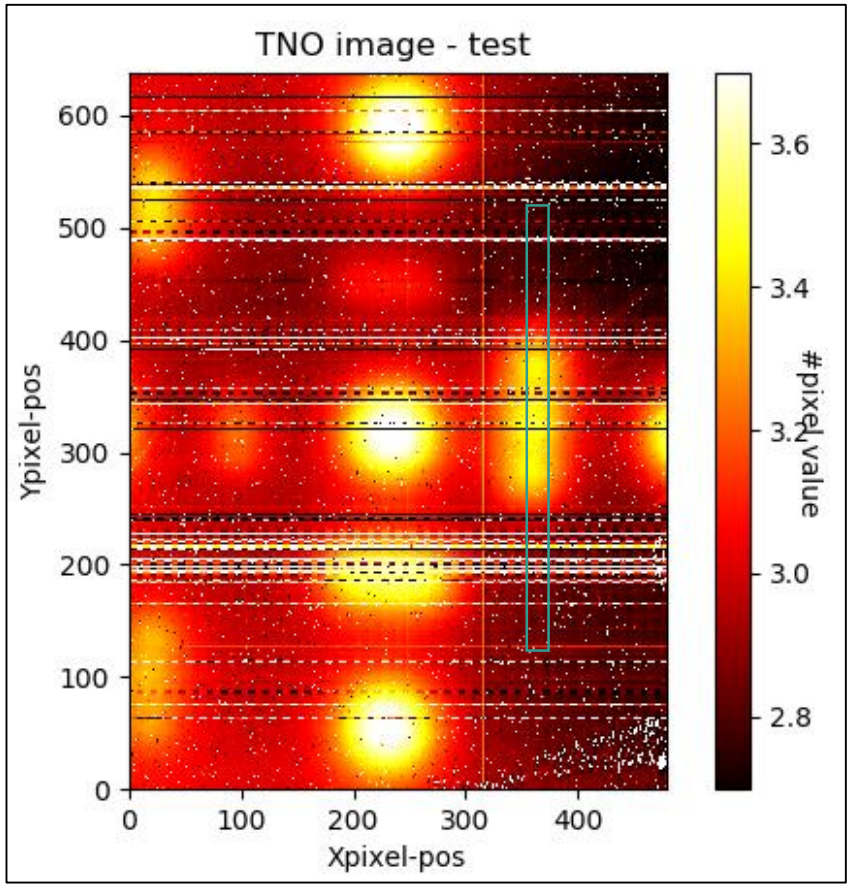
X-Ray generator 30 kV

→ Calibration Laboratory of the RP

Preliminary



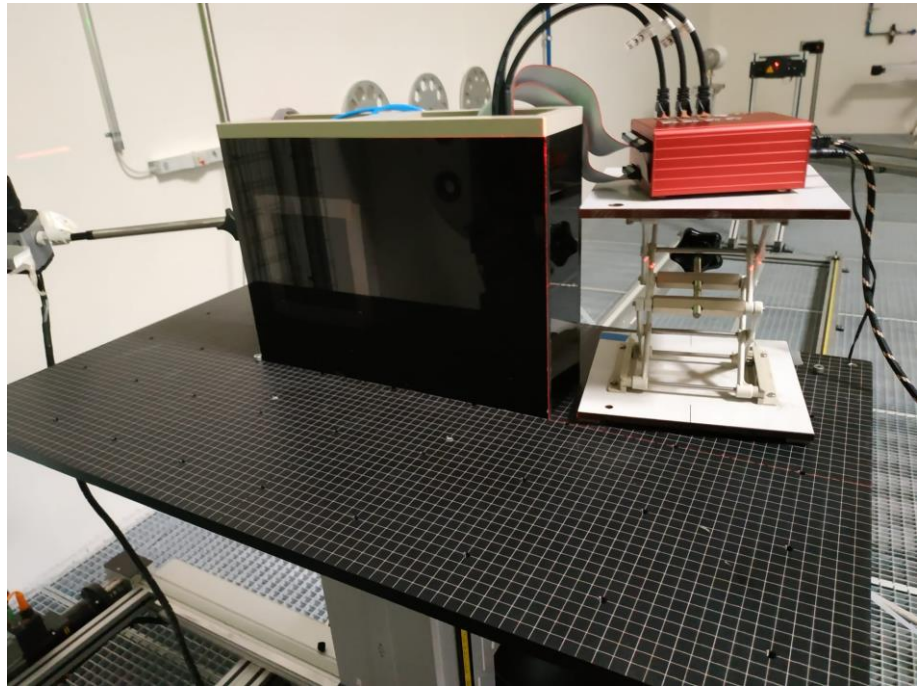

Triple-Gaussian fit to the experimental data
FWHM ≃ 5.2 mm (errors < 10%)



# Summary

## Organic photodiodes coated on an organic TFT backplane

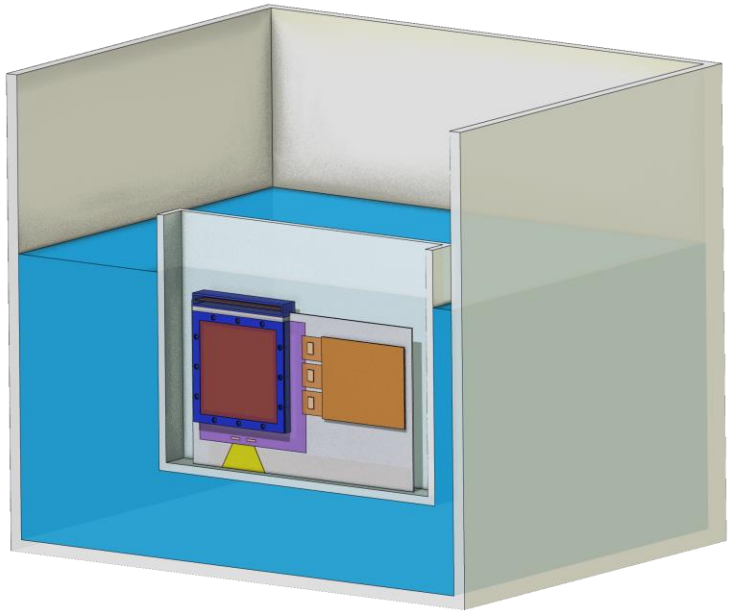
- Various tests on the large area GEMs in terms of their response curve in a proton beam **performed** at the 18-MeV cyclotron at Bern
- Read-out system (6x8 $cm^2$) fabricated by Holst Center
- First tests with the readout coupled to GEMs **are being performed** at the Calibration Laboratory
- Radiation hardness tests with the readout matrix **scheduled**
- Design and production of the experimental set-up system to perform measurements with the LaGEMPix detector in a water phantom **under study**

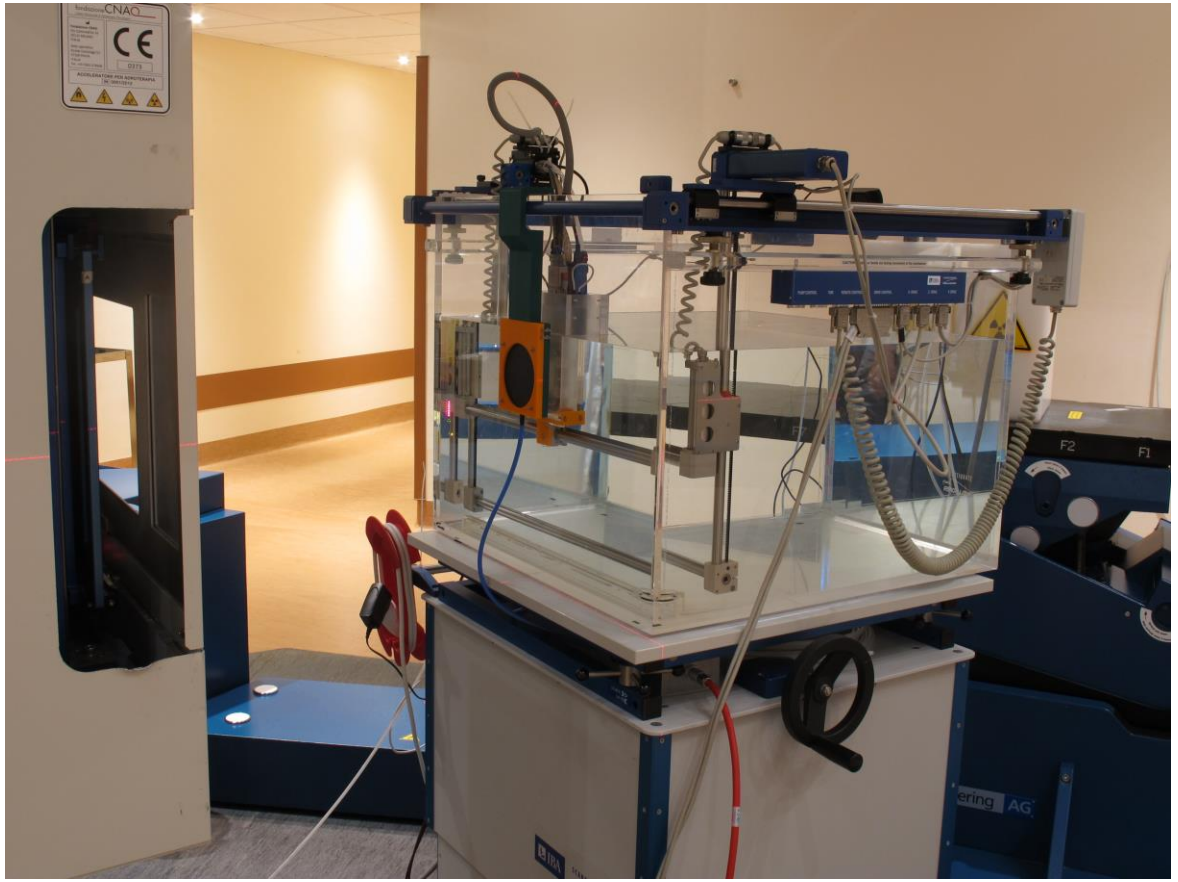


# Next steps

## CNAO Measurements

- Perform depth scans with the LaGEMPix inside the water phantom
- Ionization chamber for normalization to beam intensity
- FLUKA simulation of full setup





# Conclusions & Outlook

- **GEMPix** (active area of 2.8 x 2.8 $cm^2$) in water phantom is able to provide 2D images, Bragg curves and 3D energy deposition of carbon ion beam
- **Larger sensitive area** of 20 x 20 $cm^2$ needed to cover typical maximum radiation field size and to avoid losses due to beam spread out
- On-going work focused on **larger sensitive area readout**
  - Large area GEMs already exist
  - Check new readout possibilities

**Feasibility of optical readout**

- LaGEMPix in collaboration with TNO (6.0 x 8.0 $cm^2$)
  - Characterization of the detector
  - Evaluation of the spatial resolution on-going
- Light sensitive Timepix3

**Charge readout**

- Matrix 4x4 or 5x5 Timepix chips – very detailed pencil beam
- Matrix TFT

https://vimeo.com/404604175

# Muito obrigada!
# Thank you!

This project has received funding from the CERN Medical Applications Project Forum and the ATTRACT project funded by the EC under Grant Agreement 777222.


www.cern.ch


# References


- [1] C. Baues (2018): “Proton versus photon deep inspiration breath hold technique in patients with hodgkin lymphoma and mediastinal radiation”
- [2] Wikipedia, adapted from W. P. Levin (2005): "Proton beam therapy"
- [3] E. Seravalli (2008): “ A Scintillating GEM Detector for 2D Dose Imaging in Hadron Therapy”
- [4] S., Steven W. (1997): The Scientist and Engineer’s Guide to Digital Signal Processing”