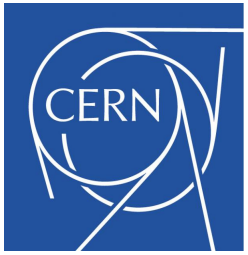

GEMPix @ CNAO
Geant4 simulation and measurements

Adele Rimoldi on behalf of

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1) INFN Section of Pavia, 2) University Pavia, 3) CERN, 4)INFN Section of Frascati, 5) CNAO Center

Consuntivo Scientifico RDH & IRPT, Roma 01/02/17

Outline

- GEMPix detector for hadrontherapy
- GEMPix layout
- CNAO measurements: experimental setup and first results
- GEANT4 simulation
- Conclusions and future developments

A possible detector for hadrontherapy (I)

Fundamental Requirements

High rate capability and Radiation hardness → High fluxes (10^8 particles/s) of carbon ions, protons, oxygen

Good spatial resolution → Beam diagnostic for daily quality controls and dosimetric measurements of treatment plans.

Good candidate → GEMPix detector – a Timepix based GEM detector

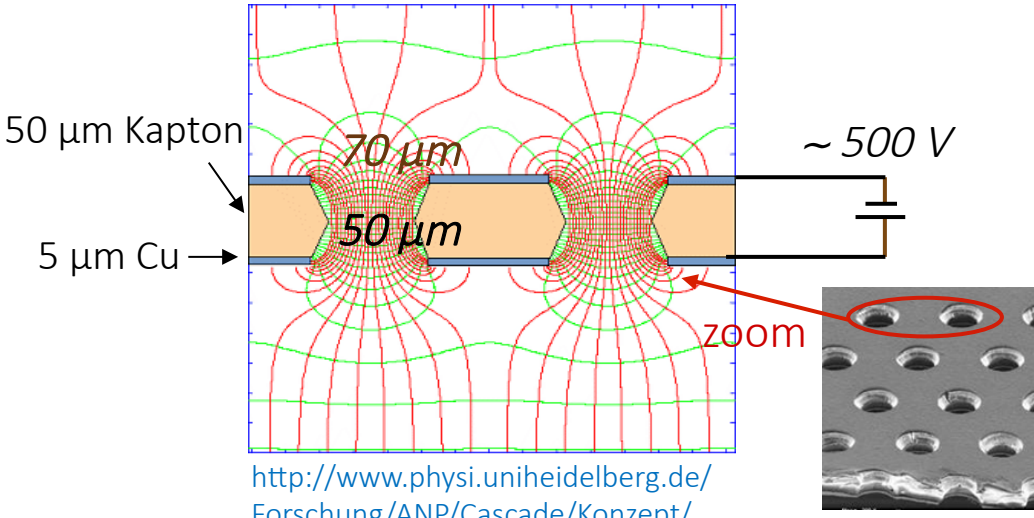
Already used for: Radioactive waste/ Microdosimetry/ Radiotherapy / Radom monitoring @ CERN *(http://ardent.web.cern.ch/ardent/ardent.php?link=publications)*

A possible detector for hadrontherapy (II)

t is a GEM detector?

M foil → Kapton sheet (50 µm thick) metallized at both sides (5 µm of Cu) with 70 µm holes etched inside

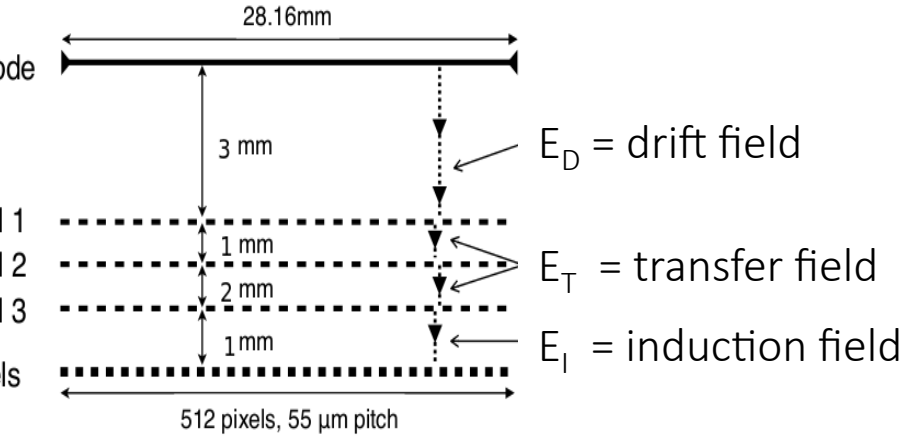
ctrical field ~100 kV/cm inside the holes
localised electron avalanche



http://www.physi.uniheidelberg.de/Forschung/ANP/Cascade/Konzept/

Image CERN Group (20

does the GEMPix work ?



Primary particle interaction in the Drift gap

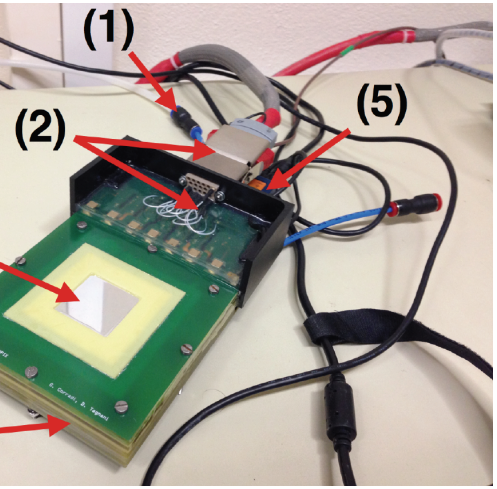
↓

Electrons multiplication: up to 40 output electrons for eac electron in. Three GEM foils give gains up to 10^5 → *f*(gas)

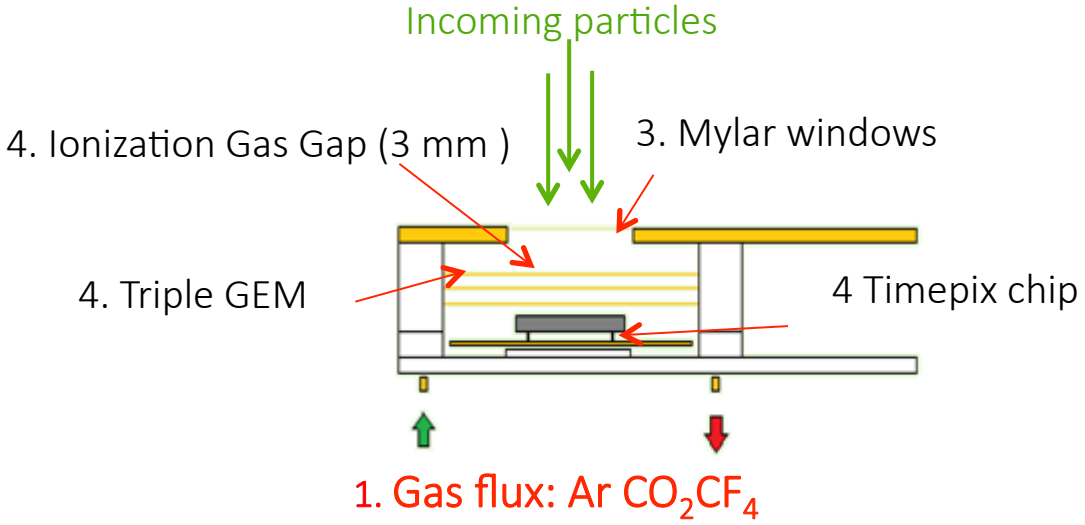
↓

Readout: electrons are collected by the Timepix chip

GEMPix: detector and readout system



onntector / 5. **Timepix Readout**



Layout

Developed by ARDENT pr
(CERN – INFN).

Read by *4 naked Timepix c*

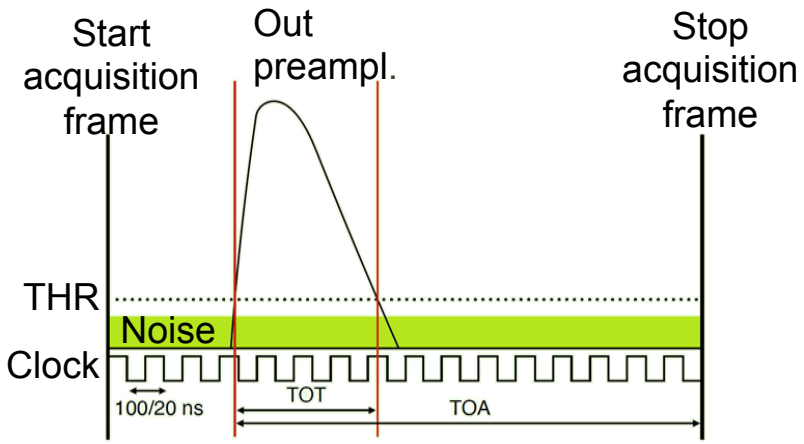
Active area → 9 cm²

out System

n pixel can measure the deposited
rge and count the single particle.

ection threshold around 1000
trons (noise ~ 100 electrons)

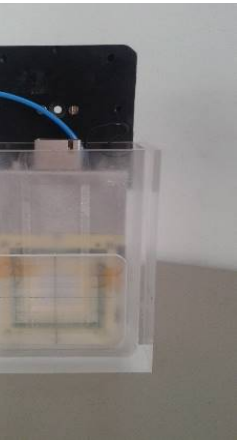
dout configuration with 4 chip
2x512) → 2.6 x 10^5 pixels

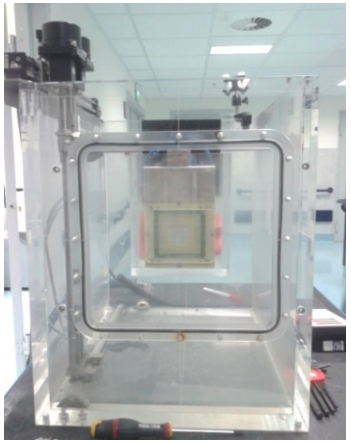


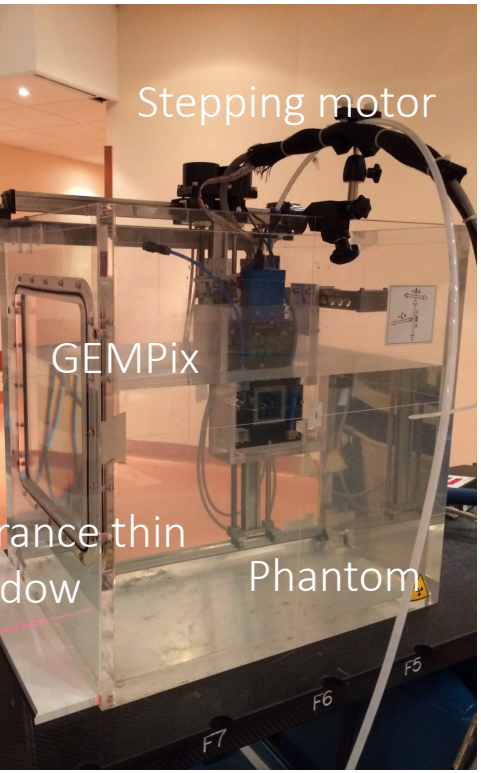
TOA -> Time Of Arrival (3D single tra
reconstruction)
TOT -> Time Over Threshold (Charg
dE/dX)

→ TOA and TOT clock up to 100 MH
stable at 50 MHz

GEMPix: *experimental setup at CNAO*





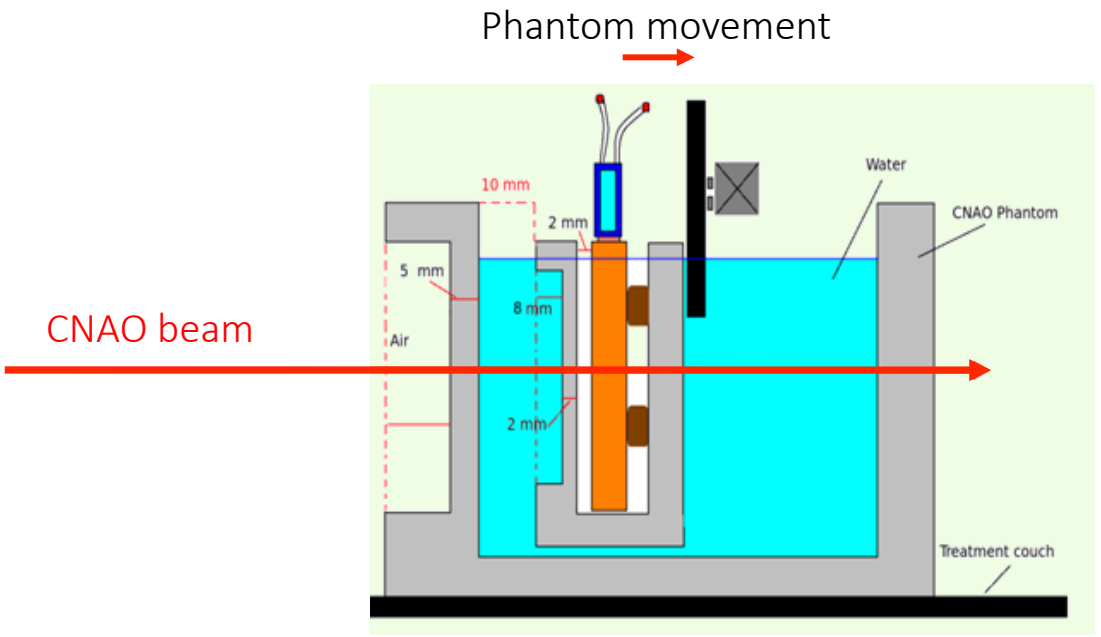


Particles type: carbon ions (single beam spot and scanned field)

Beam Energy: 3.9 GeV and 3.4 GeV

Particles per *spill*: 8 x10^5

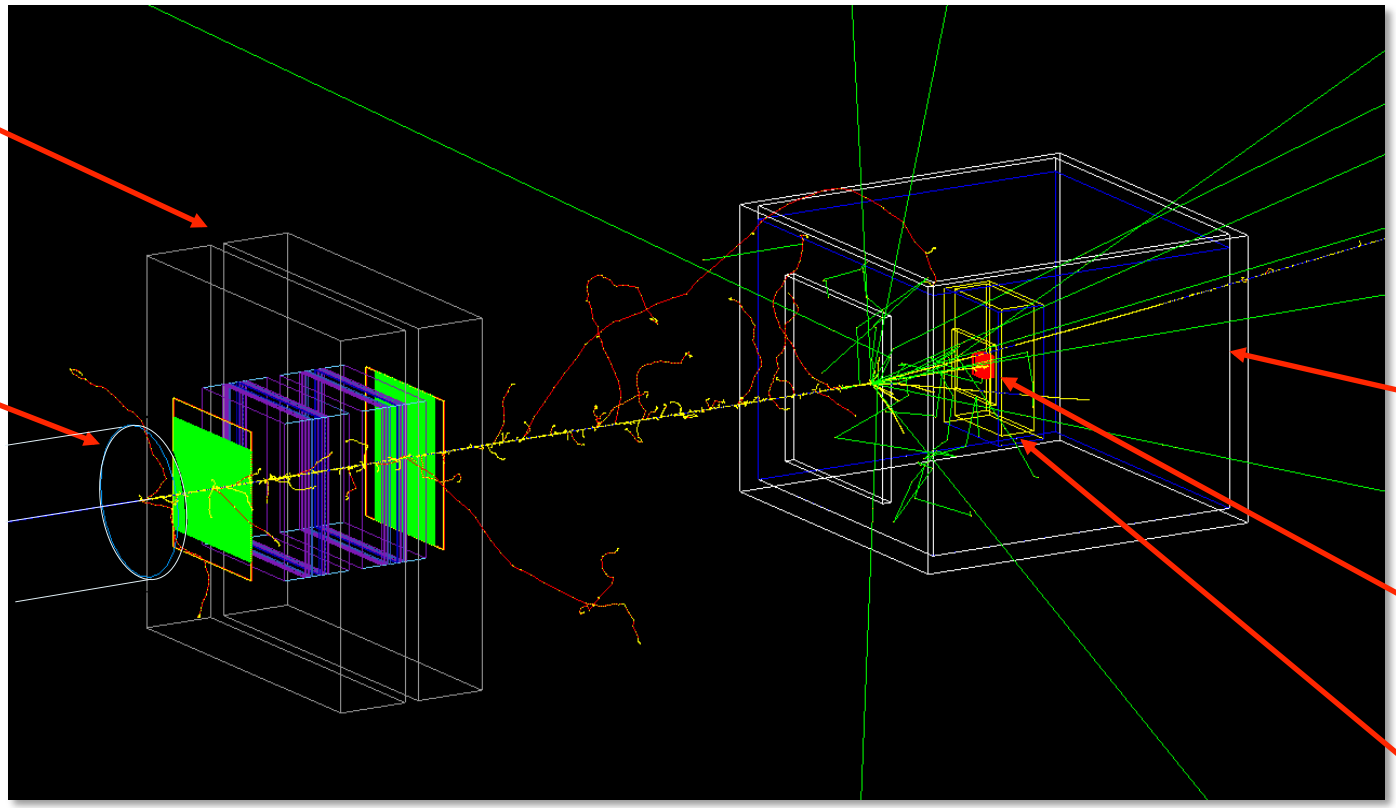
Measurements: *Linearity, homogeneity and energy measurements* at different water depths



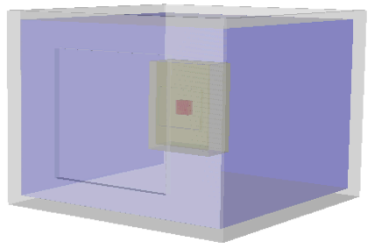
Motorized 3D wat
phantom

GEANT4 simulation: *experimental setup*

The CNAO extraction beamline and the experimental setup are fully simulated



3D view
phantom + GEMPix



All the layers of the GEMPix active area are simulated with the corresponding materials

Geant4 simulation parameters

elease version: **Geant4 10.0 patch 03**

hysics Lists (for Carbon Ions): G4EMStandardPhysics_option4, G4RadioactiveDecayPhysi

4IonBinaryCascadePhysics, G4EmExtraPhysics, G4HadronElasticPhysicsHP,

4StoppingPhysics, G4EmPenelopePhysics, G4NeutronTrackingCut,

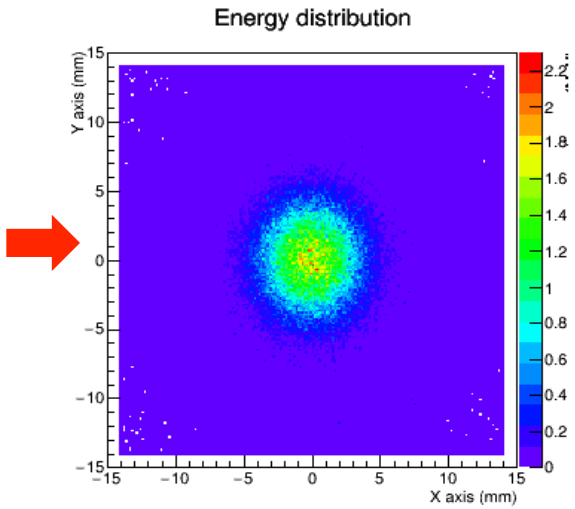
4HadronPhysicsQGSP_BIC_HP

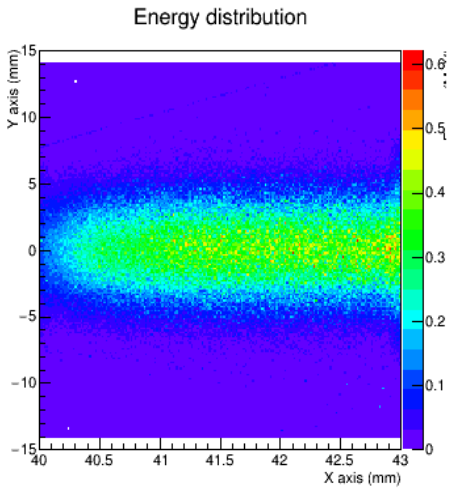
arallel geometries for scoring purposes (3D mesh) and sensitive detectors

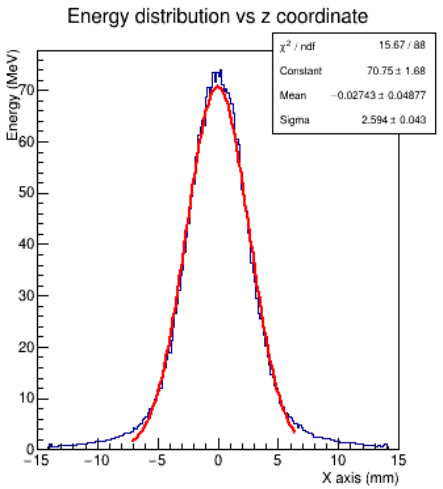
ingle spot and scanned beam irradiation methods implemented

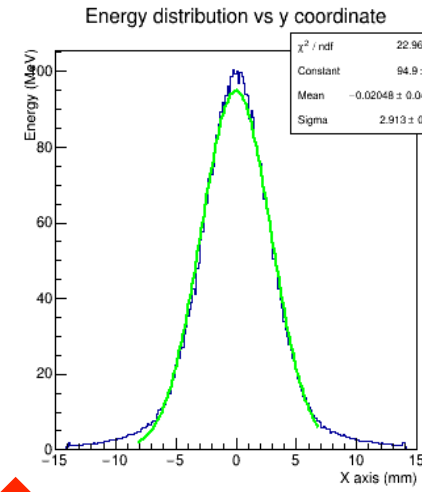
GEANT4 Simulation: *Lateral Profiles*

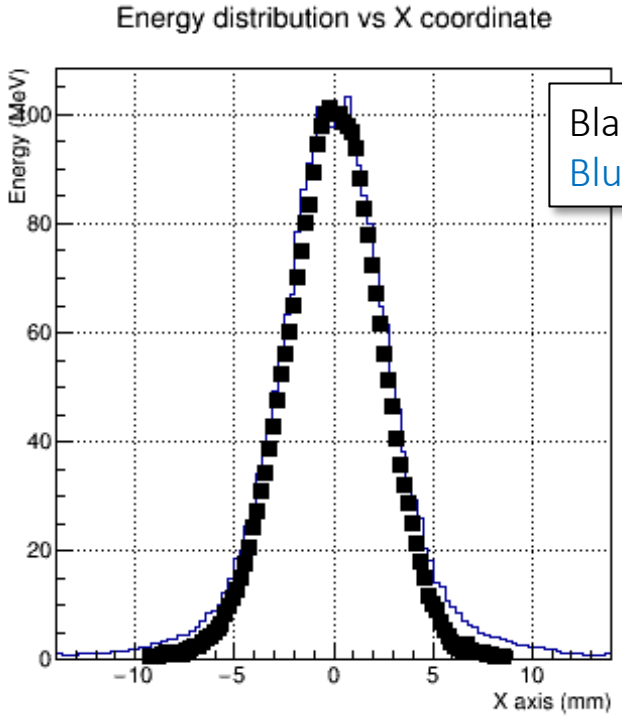
n ion beams:
nsversal and
udinal view











Black dots: EBT3 film
Blue line: Geant4 simulation

Beam vertical (y) and lateral (z) profile.

Lateral profile of the energy deposited by 3.9 GeV carbon ions bear

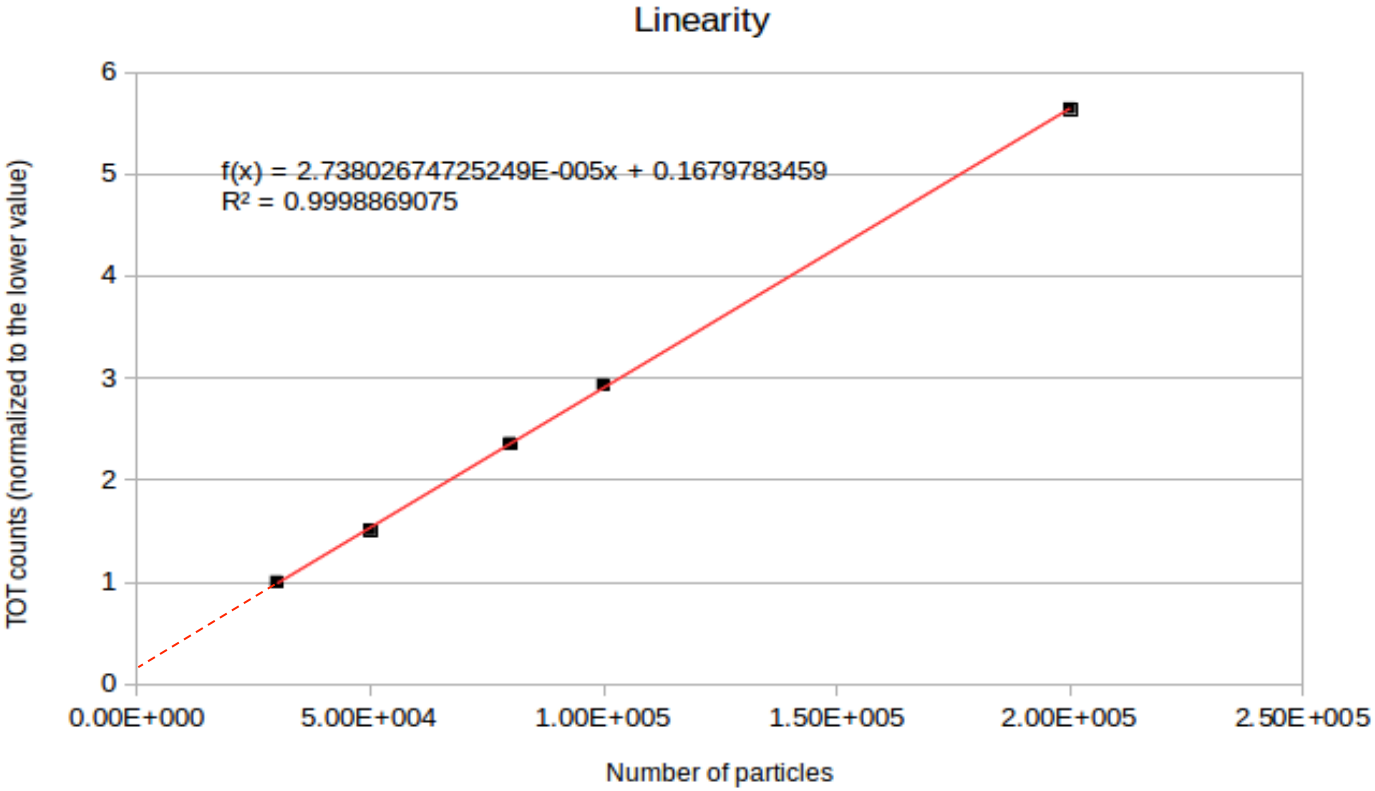
spot along the beam axis (x) within the 3 mm *drift gap*

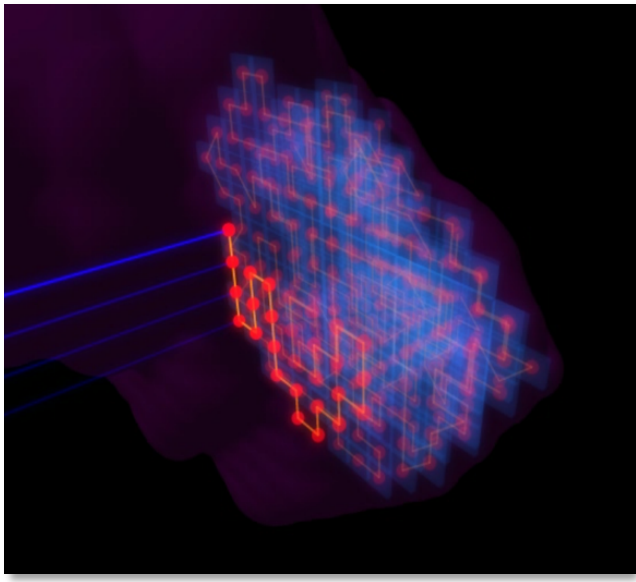
Cross-check with CNAO data from EBT3 radiochromic films

CNAO measurements: *linearity*

Irradiation method: 60x60 mm^2 **scanned field** - 3.4 GeV carbon ions

5 fluxes: $3x10^4$ - $5x10^4$ - $8x10^4$ - 10^5 - $2x10^5$ total particles delivered



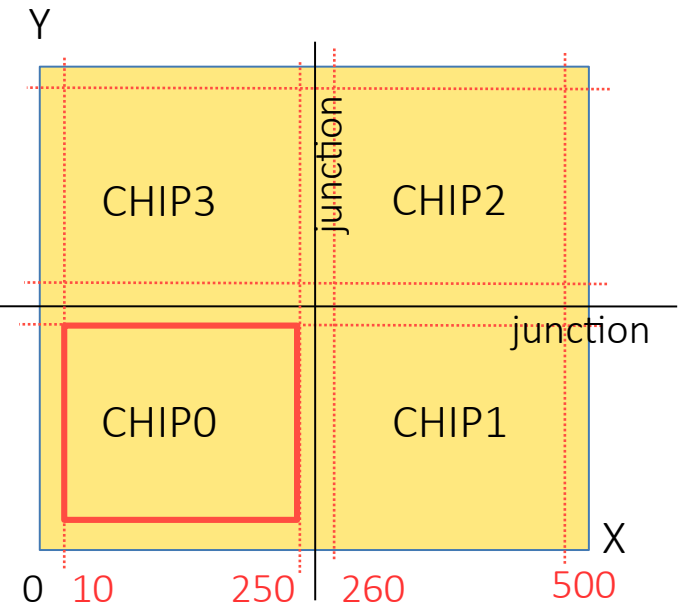


Active scanning

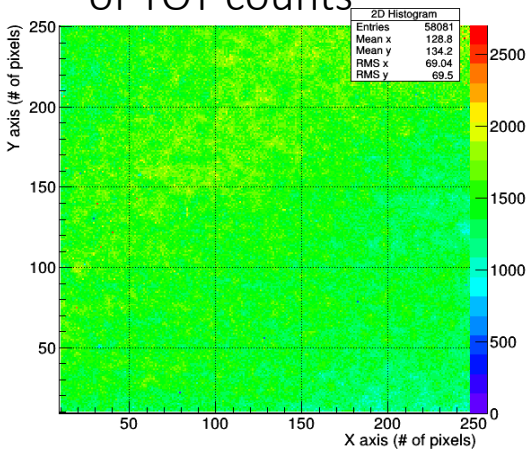
The scanned field dimensions allow to neglect side effects by including all the detector's sensitive area

CNAO measurements: *homogeneity*

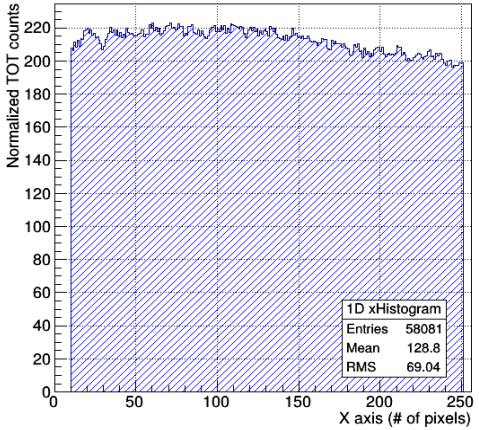
PRELIMINARY RESU



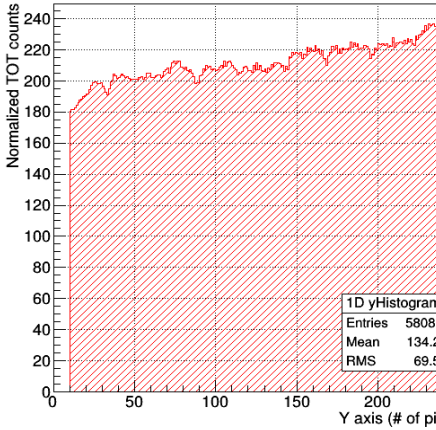
2D histogram of TOT counts



X projection (from pixel 0 to pixel 250)



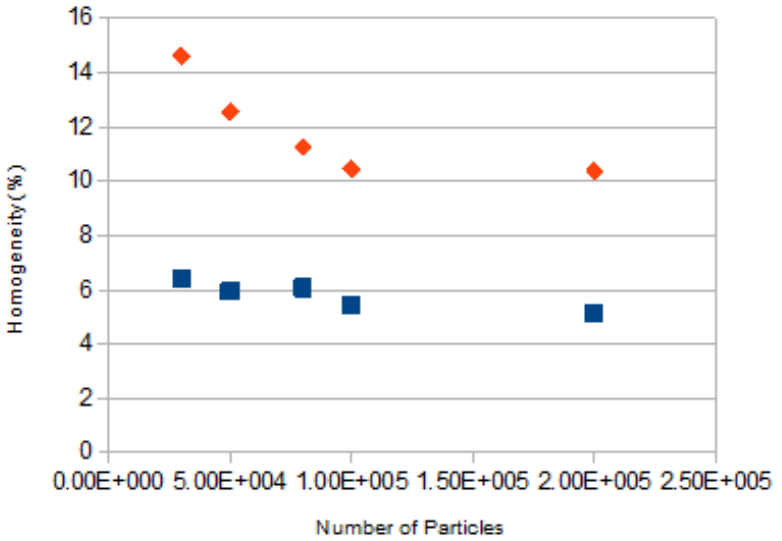
Y projection (from pixel 0 to pixel 25



SINGLE CHIP homogeneity:

I(%) = (Max Count-Min Count)*100/(Max Count+Min Count)

Homogeneity CHIP0

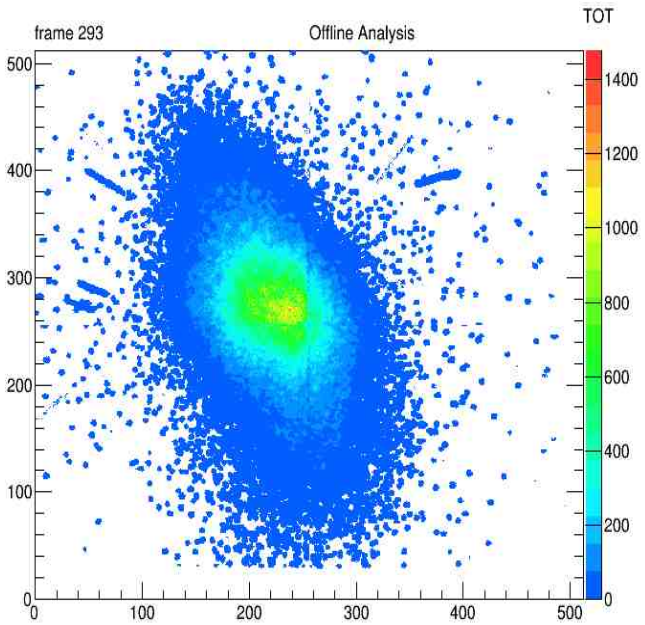


CNAO measurements: *Bragg Peak (I)*

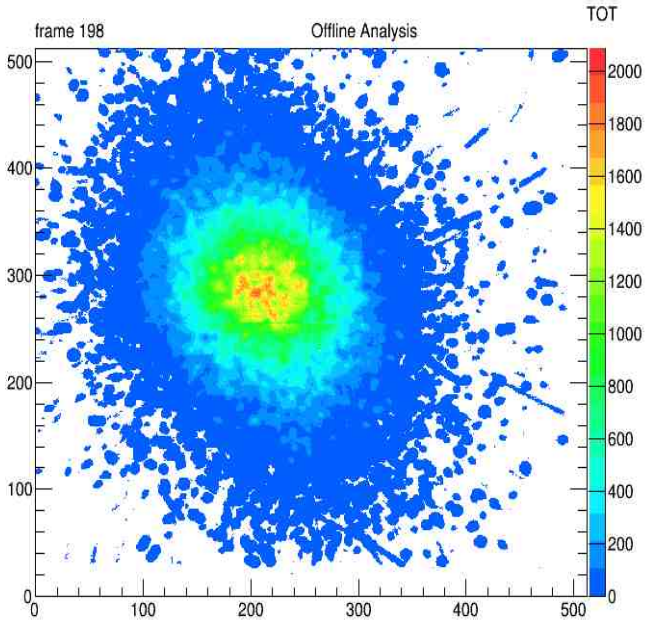
PRELIMINARY RESU

2D histograms of TOT counts obtained with 3.9 GeV carbon ions beam spot as a function of the GEMPix position in water

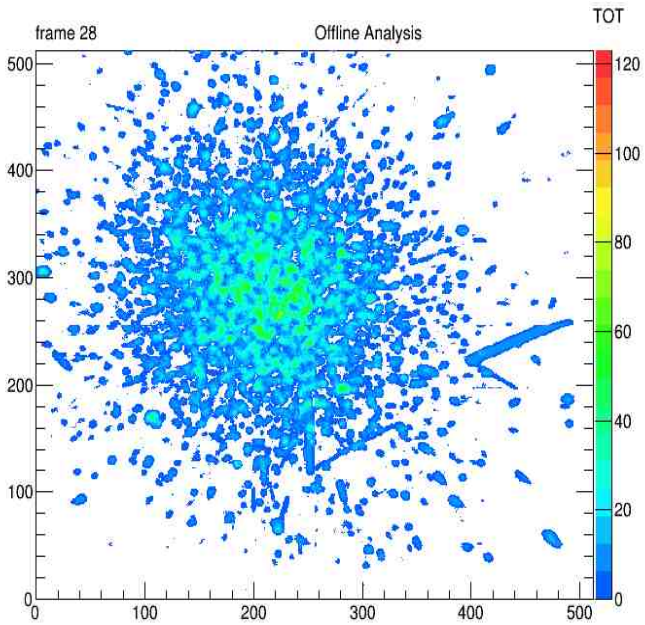
Plateau



Peak



Tail

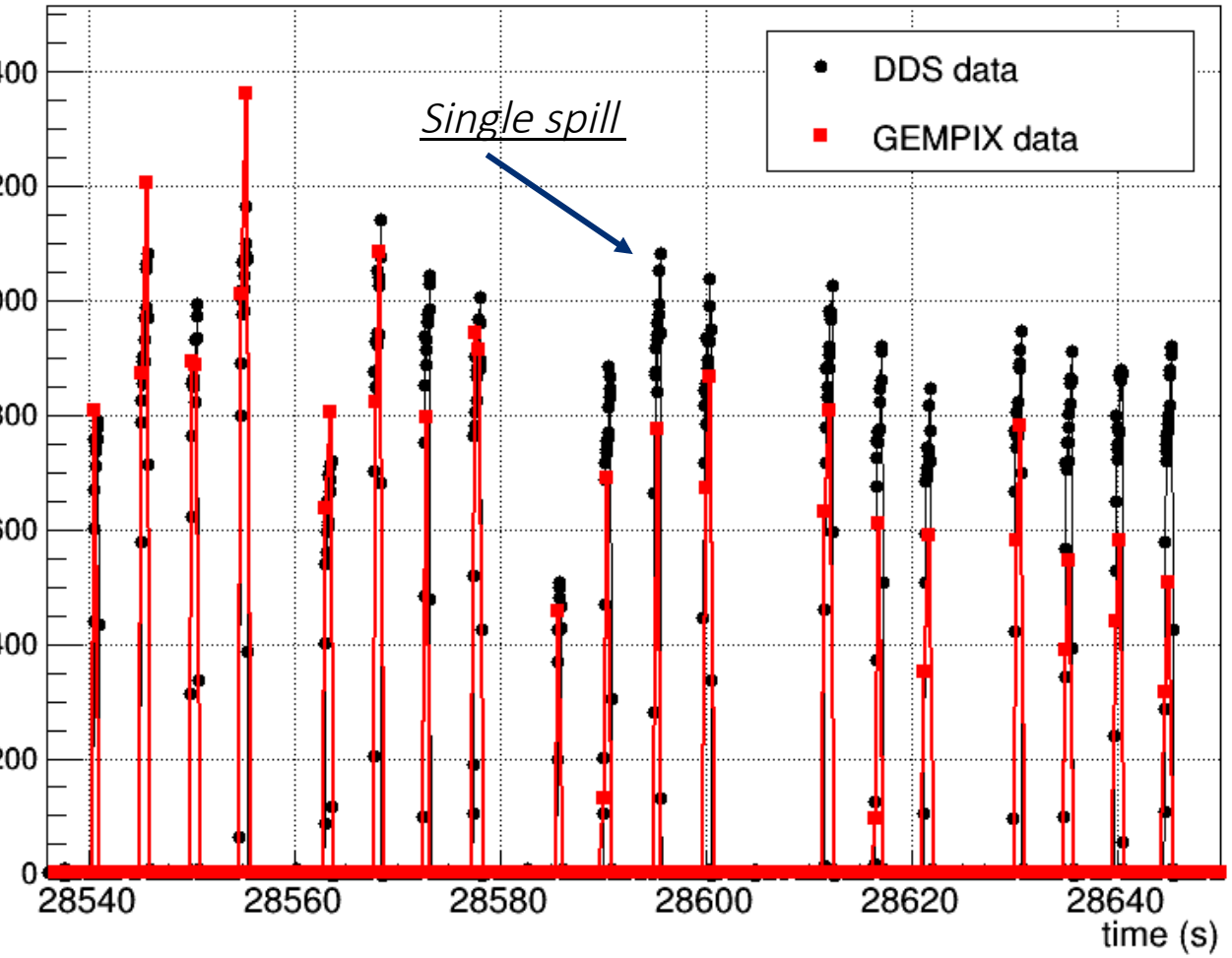


Further studies are currently ongoing to determine the origin of lateral clusters.

CNAO measurements: *Bragg Peak (II)*

PRELIMINARY RESU

Beam time/space evolution



3.4 GeV carbon ions beam

DDS (Dose Delivery Sistem)

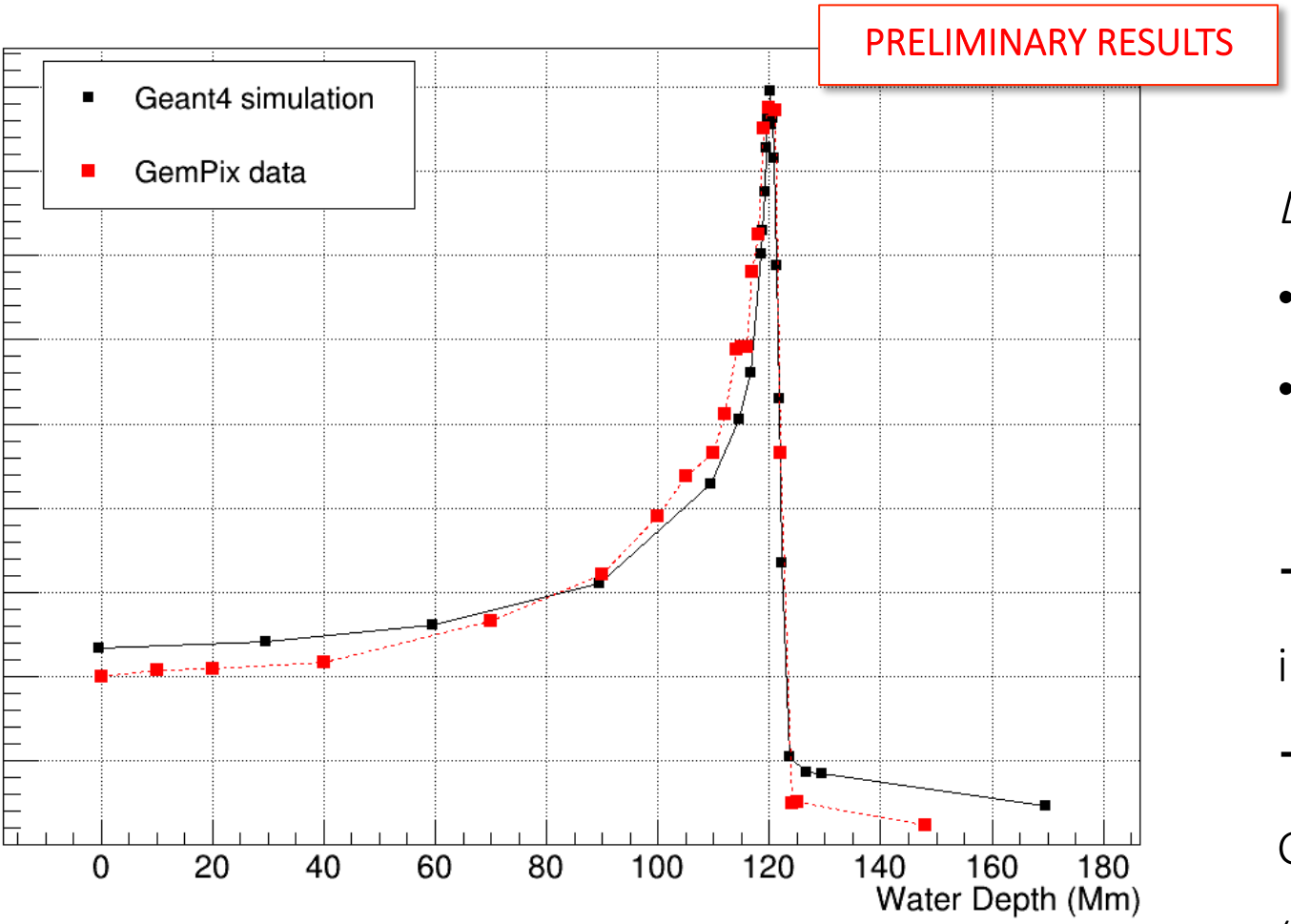
↓

CNAO beam control system

(Ionization and pixels chambers)

Med Phys. 2015 Jan;42(1):263-75. doi: 10.1118/1.4903

CNAO measurements: *Bragg Peak (II)*



The curves are normalized at the peak

3.4 GeV carbon ions beam

Deposited dose underestimated:

- Plateau region
- Fragmentation tail

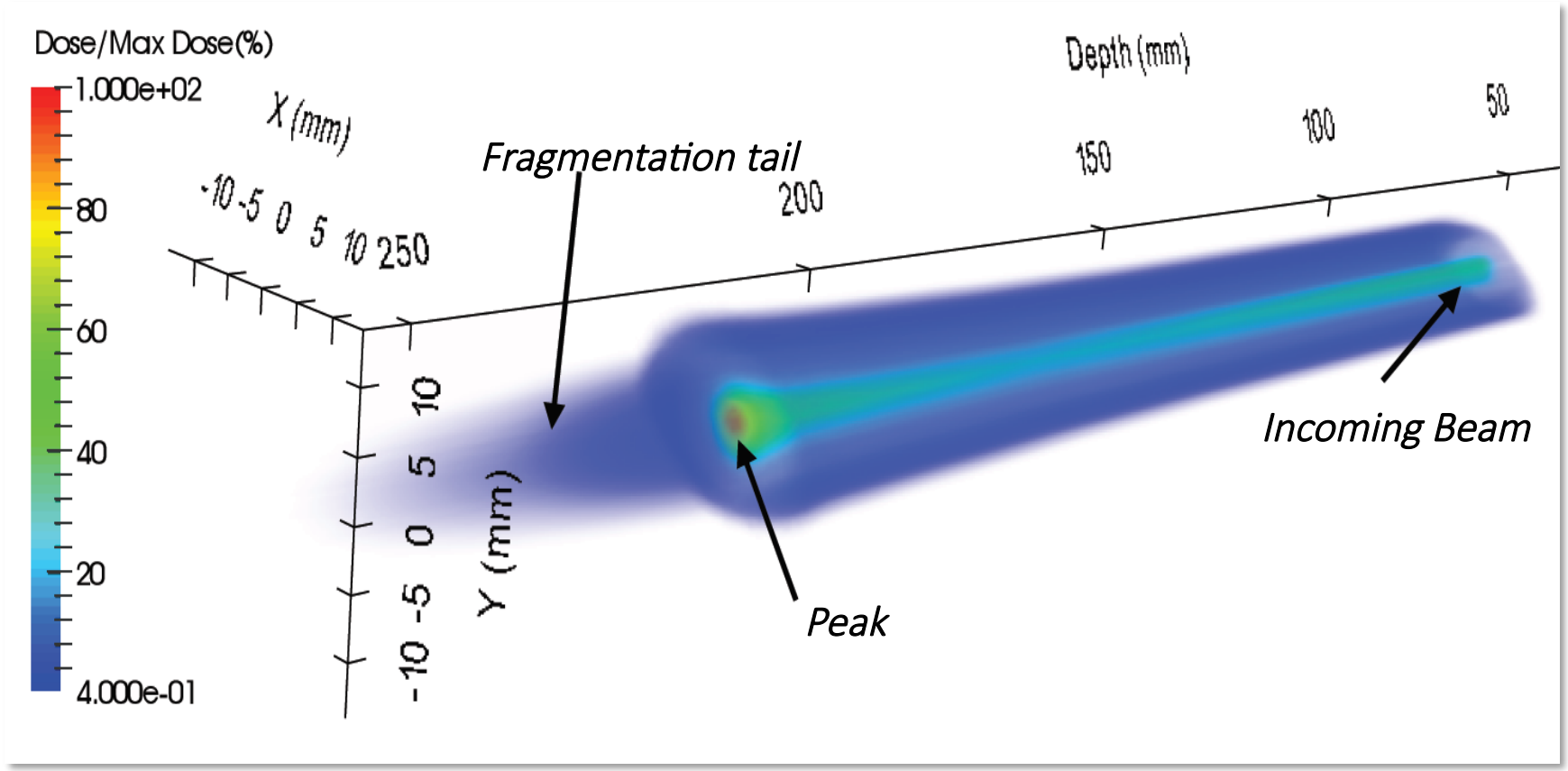
→ Ongoing studies on physics lists and interaction processes in Geant4.

→ Further characterization tests of the GEMPix detector with carbon ion beams (different clock, gain, gas …)

CNAO measurements: *Bragg Peak (III)*

PRELIMINARY RESU

3D reconstruction 3.9 GeV carbon ions Bragg peak in water



Conclusions

mplete simulation of the CNAO extraction beamline, GEMPix detector and experimental setup

ear response as a function of particle flux

ite good homogeneity response → study of edge/junction effects

od agreement between data and simulation

rther experimental measurements have been done at CNAO and are being analysed

Future developments

More detailed simulation → electric field of GEM layers

Advanced simulation study of secondary particle distrubution in water and in the GEMPix

Study of the Bragg curve for different GEMPix setting parameters (gain, acquisition clock)

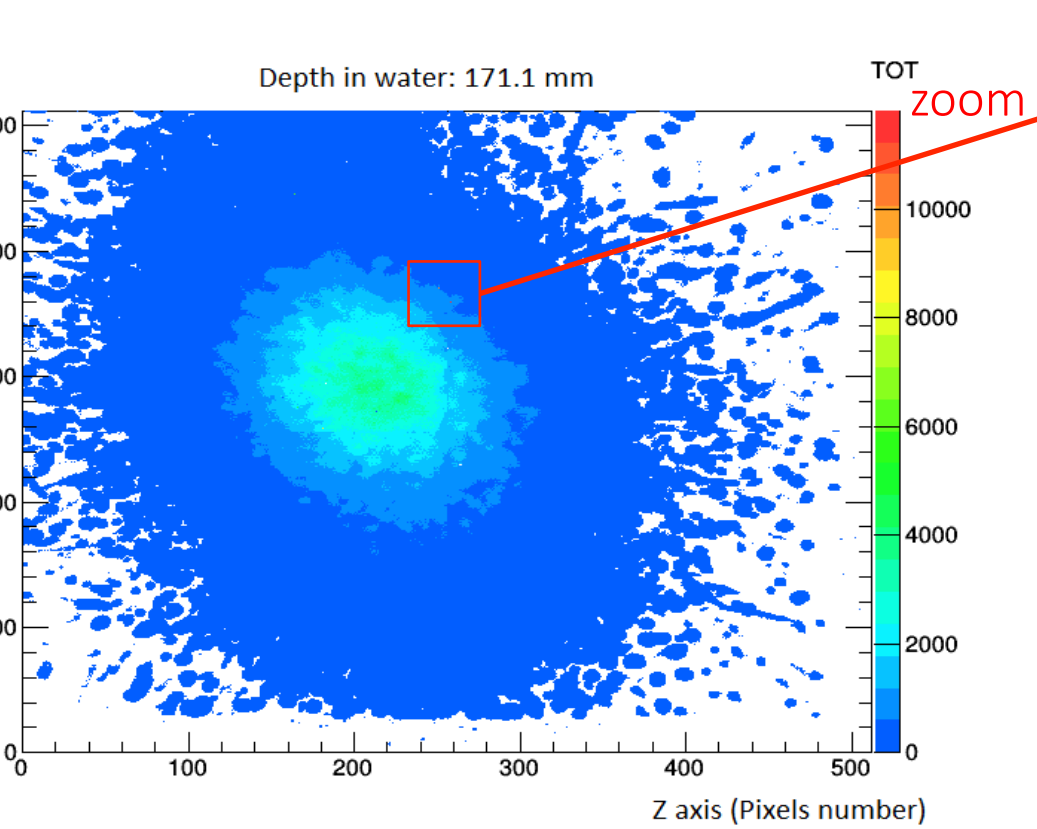
Continuous monitoring of pressure and temperature inside the detector during the measurements

mplementation of a better trigger system between GEMPix and DDS CNAO system

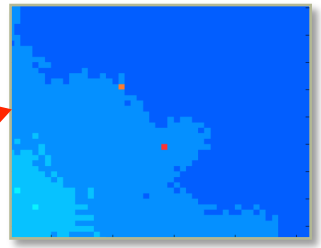
New measurements at CNAO Centre


Backup
Ctrl

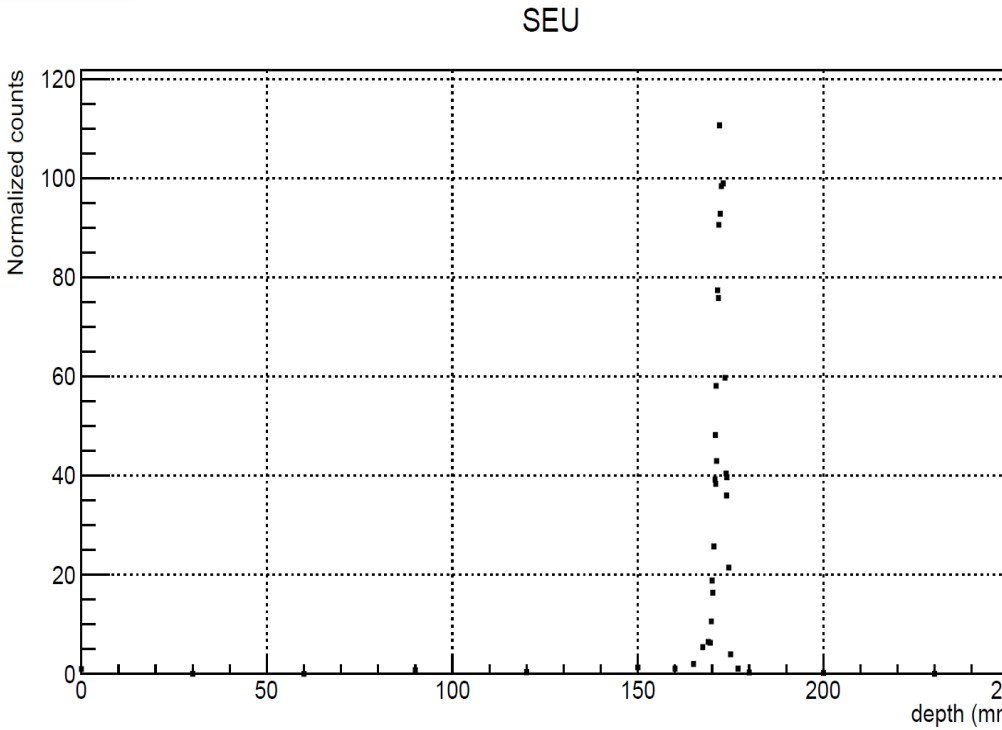
GEMPix and SEU *(Single Event Upset)*



zoom



SEU events above (red) and below (orange) the TOT saturation level (110

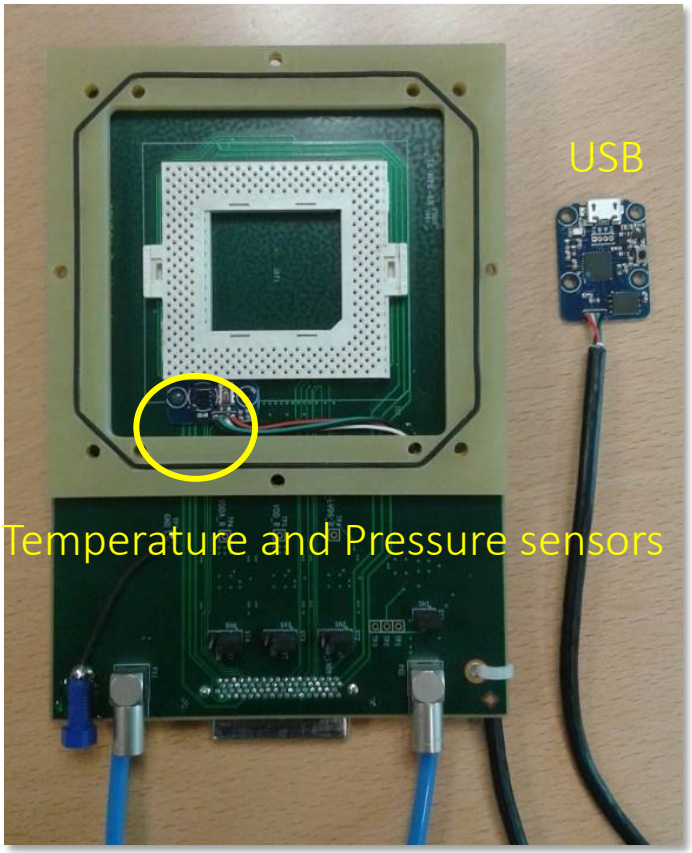


SEU is a function of water depth

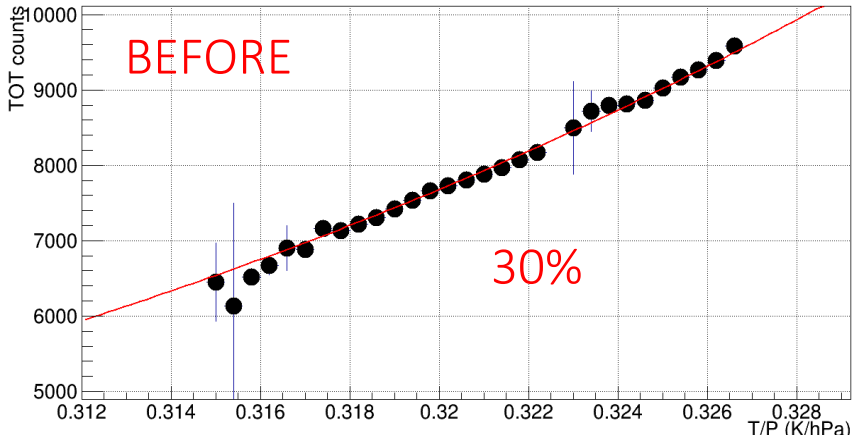
Maximum value of SEU at the Bragg peak → maximum dose release

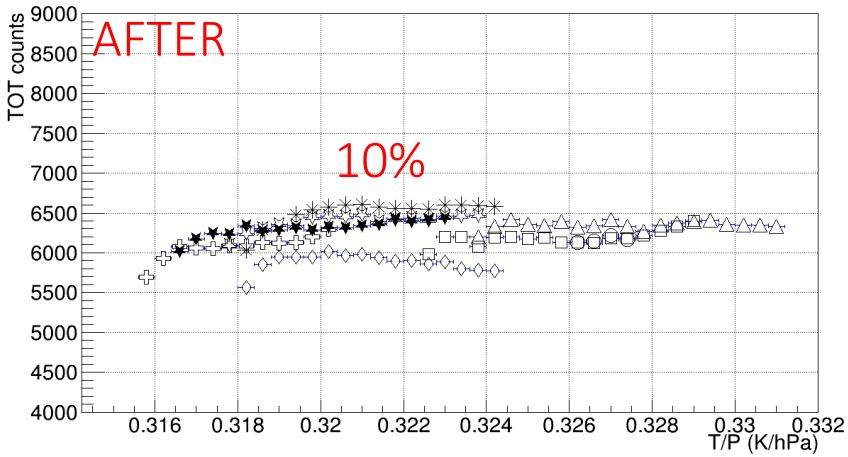
Energy calibration and T/P correction

The temperature and the pressure measured inside the detector allow the realtime HV correction to obtain gain stability



Online
HV correctic



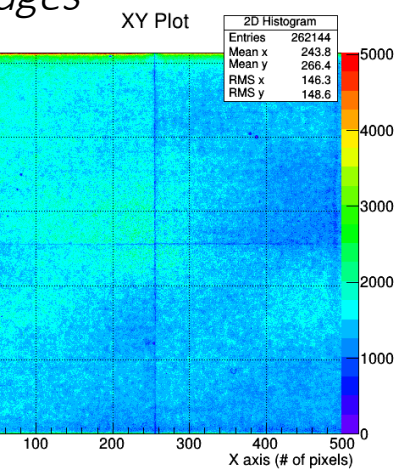


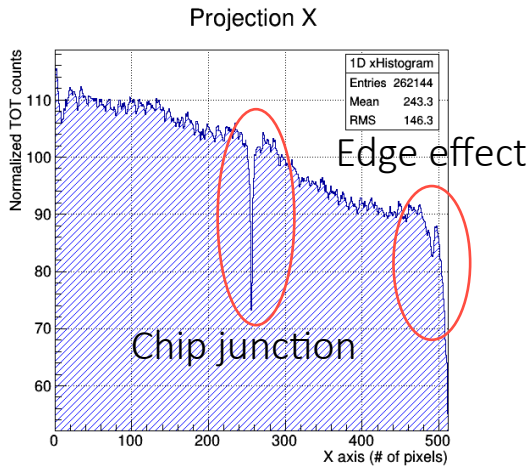
CNAO measurements: *homogeneity (I)*

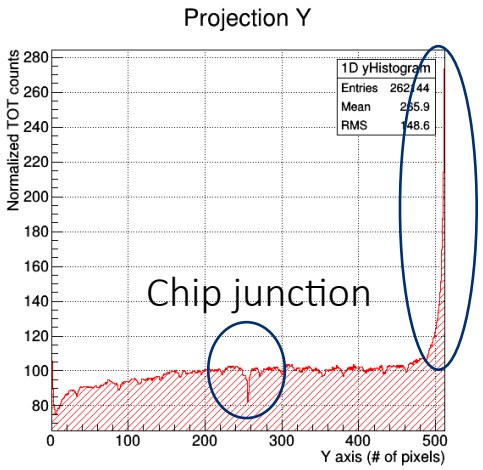
PRELIMINARY RESU

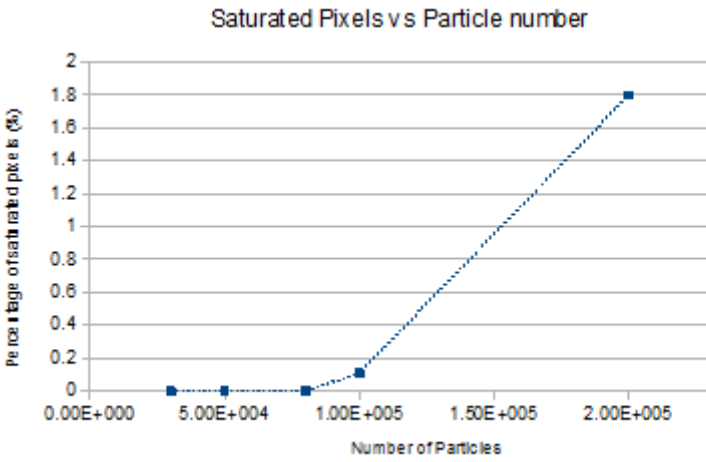
60 mm^2 carbon ions scanned field (3x10^4 total particles delivered)

dges

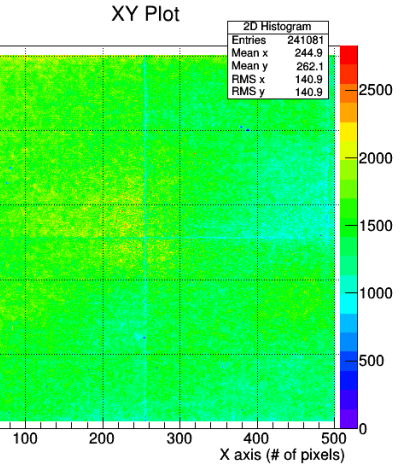


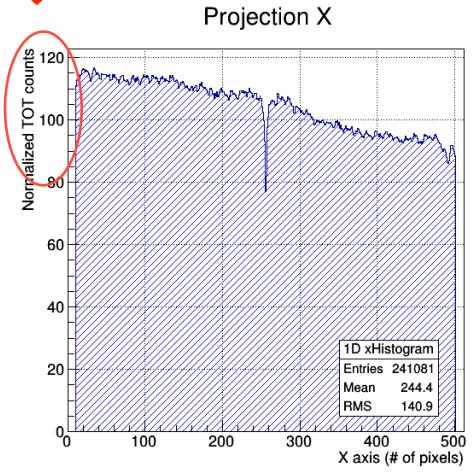


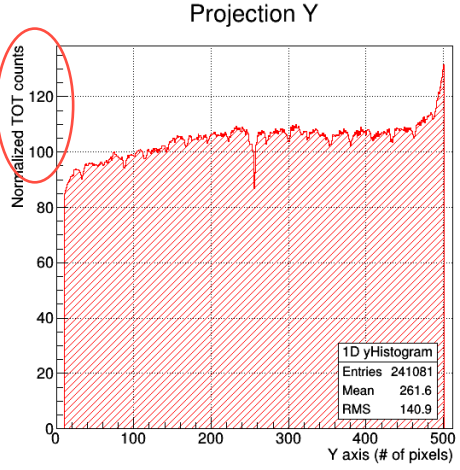




ut edges







Edge effects → 2% of satura
pixels at higher particle flux