A High-Granularity Digital Tracking Calorimeter Optimized for Proton CT

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on behalf of Bergen proton CT collaboration
(full collaboration list)

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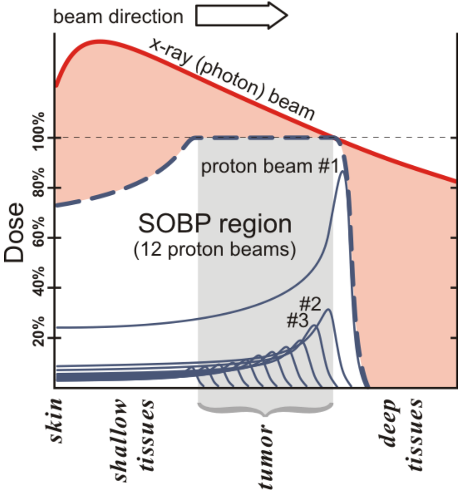
Advantages of proton therapy

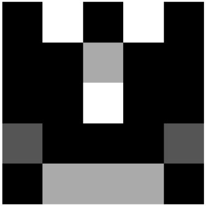
- Original idea by Wilson in 1946
- Widespread in the last 20 years
- More advantageous dose distribution due to Bragg-peak
  $\Rightarrow$ less side effect



Relative stopping power distribution

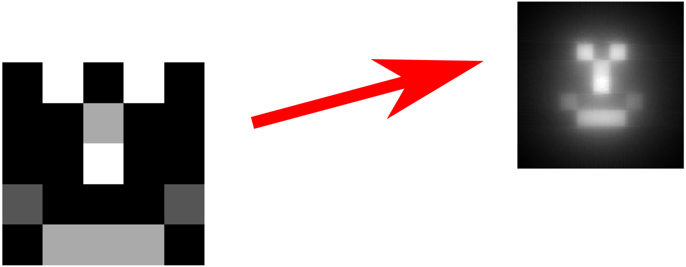
Patient

Image

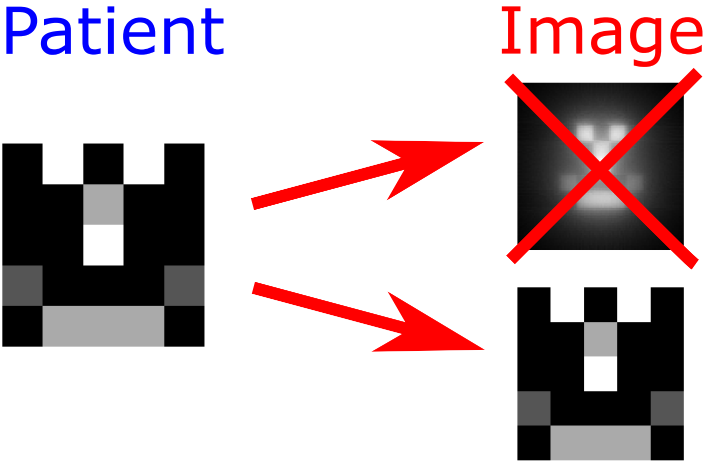


Relative stopping power distribution

Patient Image



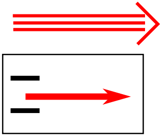
Relative stopping power distribution



Bergen pCT Collaboration

General design
of the digital tracking calorimeter

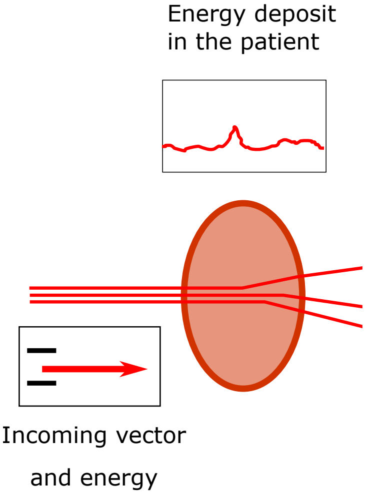
General pCT concept



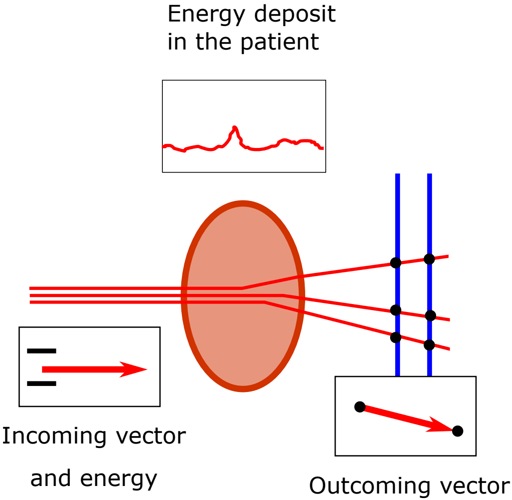
Incoming vector

and energy

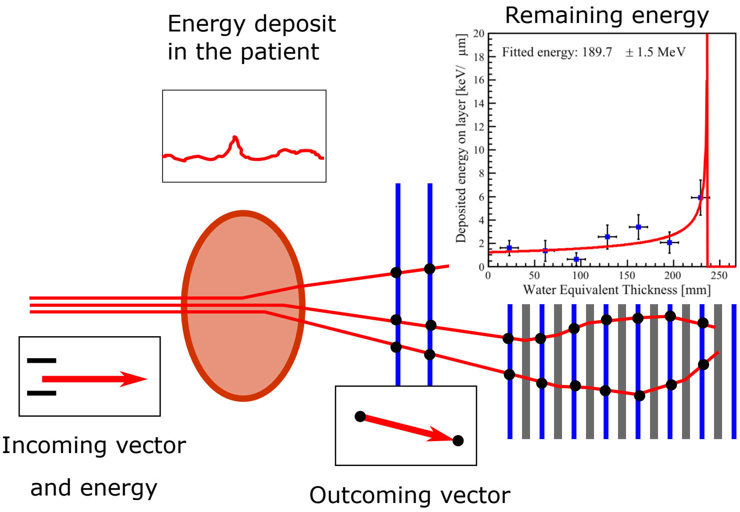
General pCT concept



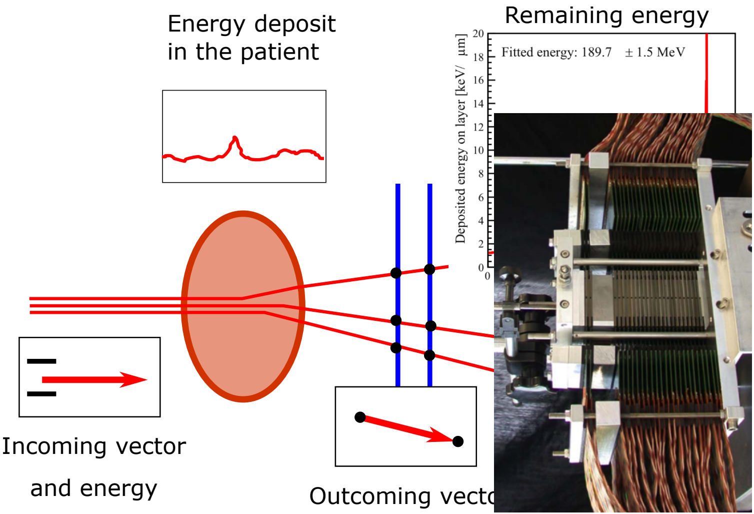
General pCT concept



General pCT concept

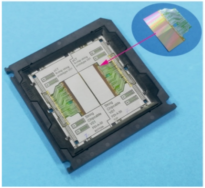


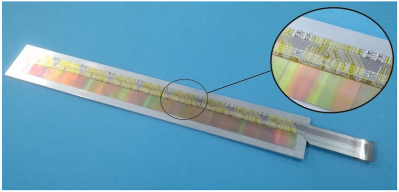
General pCT concept



General pCT concept – Tracker layers

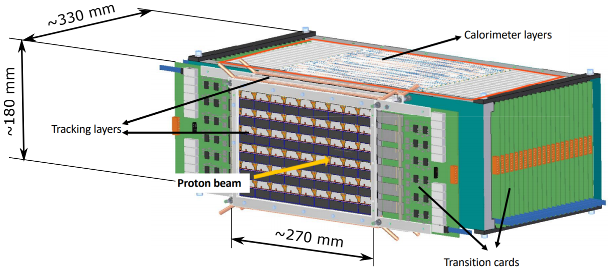
- **10^7 proton/s** and 5μs frame time must be handled
  $\Rightarrow$ ALPIDE silicon pixel detector developed by ALICE, CERN
- Trigger less readout architecture $\Rightarrow$ fixed frame time
- **Accurate** path reconstruction
  $\Rightarrow$ carbon-composite support layer
  $\Rightarrow$ 50 mm between the tracker layers
- **Radiation** must not damage nor critically interfere with the operation of the detector
- **Minimize the noise and uncertainties**





General pCT concept – Calorimeter layers

- **Tracker detectors in calorimeter layers**
  ⇒ fast and use the same readout electronics
- **Absorber** and support layer with **minimal scatering**
  ⇒ Aluminum: low scattering and good support material
- To avoid oscillation error 3.5 mm absorber thickness
- 41 absorber layer to stop a 230 MeV/u proton beam



Clinically-oriented investigations & results

(Test beam setup and clinical Monte Carlo studies)

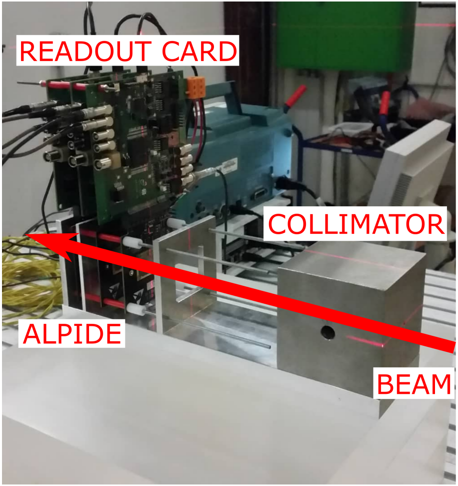
Test beam setup

Parameters:

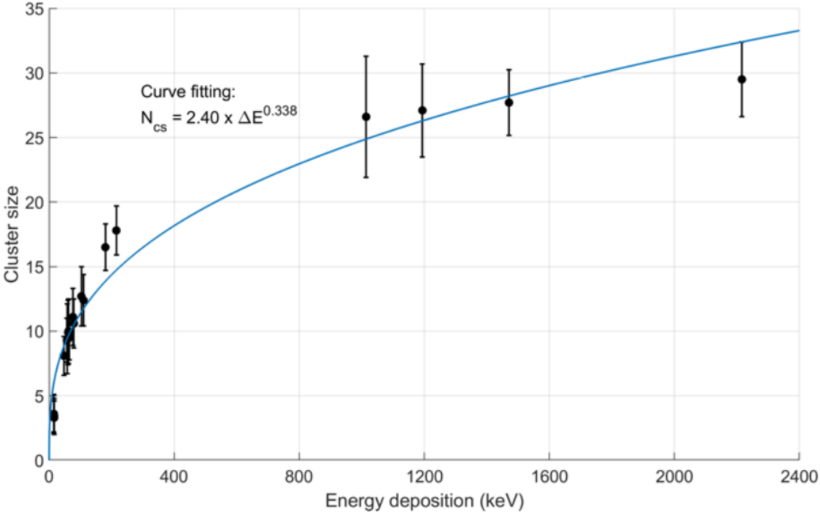
- Energies 50-220 MeV/u
- Particle rate 15-145 kHz
- Beams: p, α^{2+}, c^{6+}

Measurements:

- Cluster evolution
- Cluster size – energy deposit
- Tracking efficiency
- Cluster size – different cluster occupancy
- Discriminate different type of particles



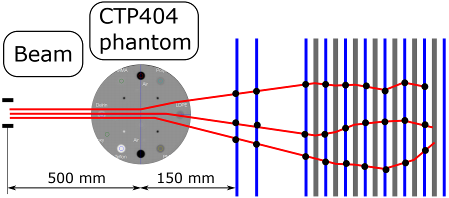
Cluster size and the deposited energy



Monte Carlo model

Geant4 for physics

Geant4 Application for Tomographic Emission (GATE) v8.2.
- Designed for easier build of medical detector models
- QBBC_EMZ physics builder list



Detector model:
- homogenous layers
- accurate thickness

Readout:
- hit position and
- deposited energy

Monte Carlo model

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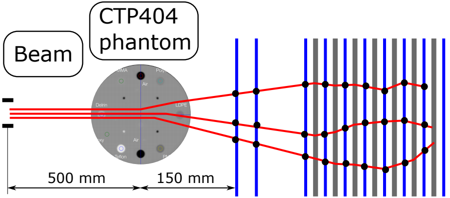

Detector model:
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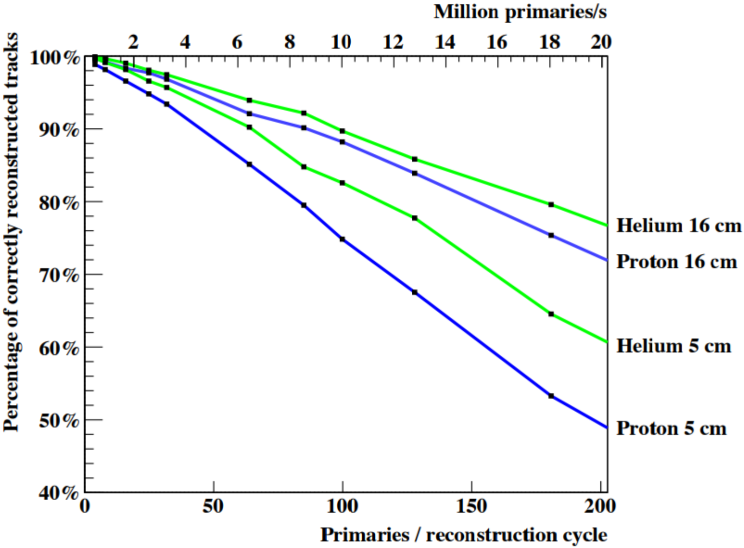
- accurate thickness

Readout:
- hit position and
- deposited energy

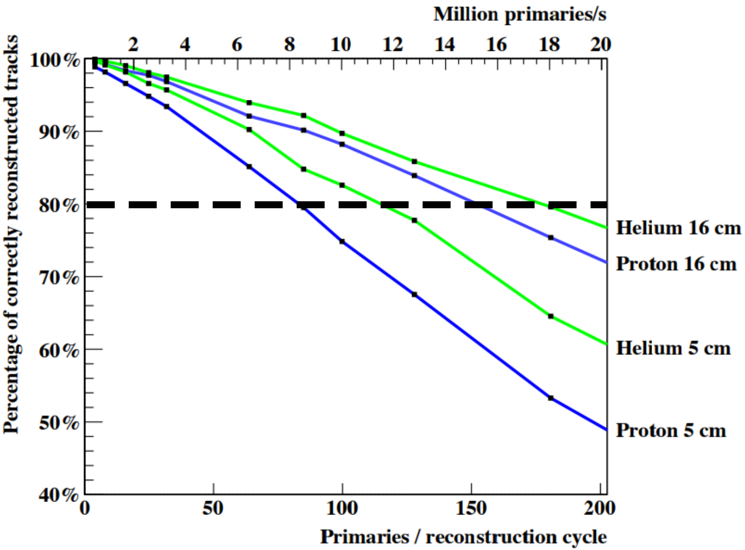
Cluster modelling based on readout data

Reconstruction of the phantom from taken data

Rate of correctly reconstructed tracks



Rate of correctly reconstructed tracks



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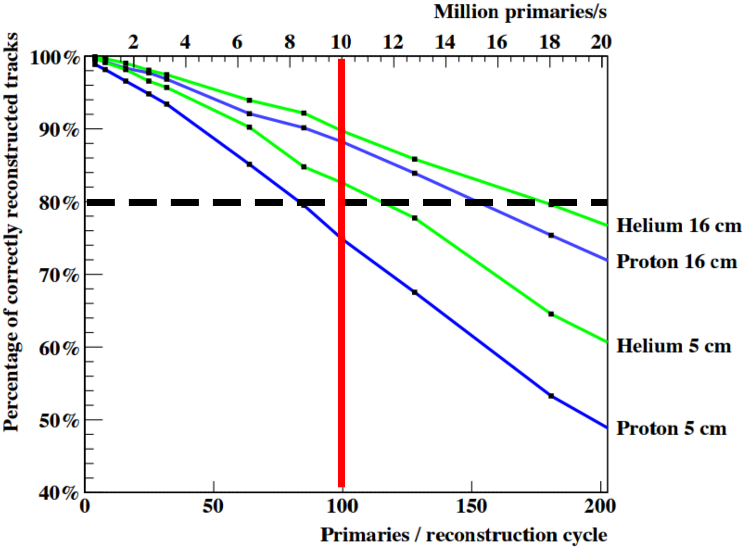
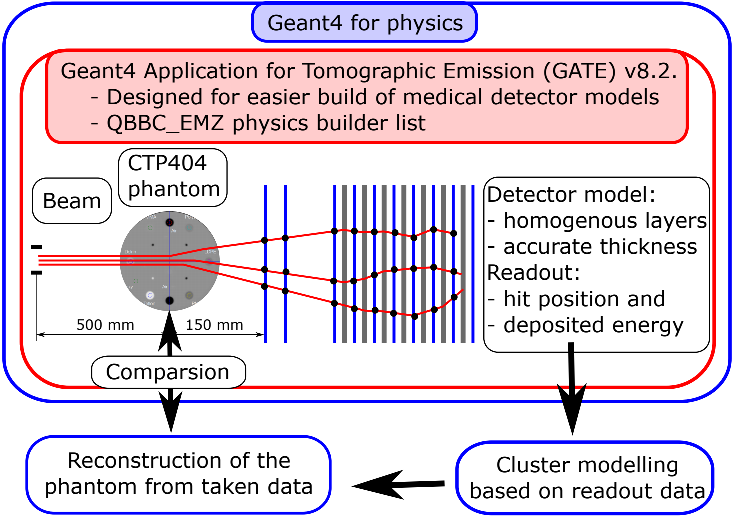
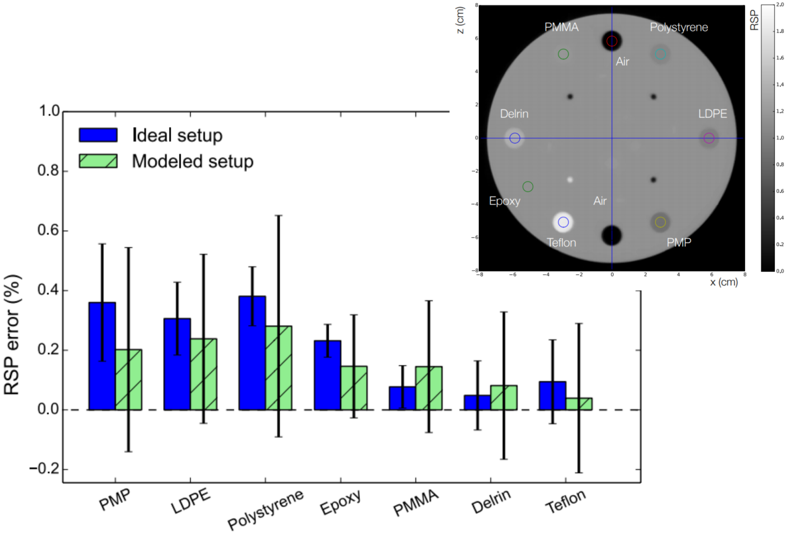


Monte Carlo model

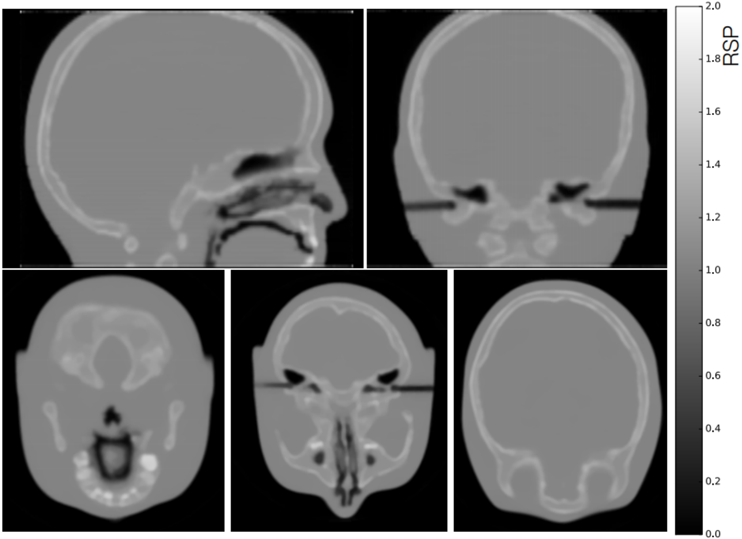


MC – Error of the Relative Stopping Power

CTP404 phantom: seven materials for RSP error investigations



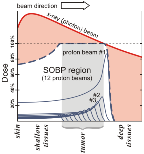
MC head imaging



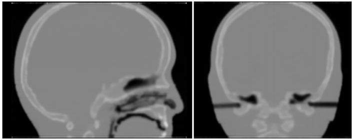
Summary and outlook

Summary – Accuracy and performance

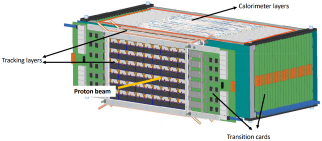
- **Accurate relative stopping power:** 0.4% (MC simulation) $<$ required 1%



- **10^7 proton/s** (MC simulation)
  $\Rightarrow$ pCT image in less than a minute
  $\Rightarrow$ maybe clinical testing will be possible



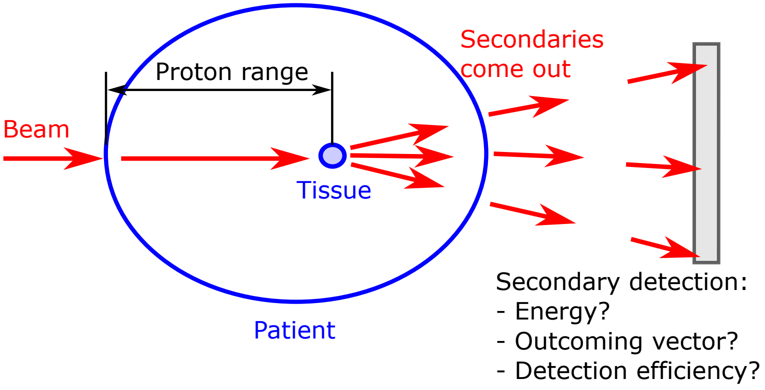
- **Clear image**
- Free of artifacts



- **Under construction**, tests within 2 years
- Ongoing component tests

Outlook – In vivo dosimetry

Goal: measuring the proton range



Thank you for your attention!

Members of the Bergen pCT collaboration: University of Bergen, Norway; Helse Bergen, Norway; Western Norway University of Applied Science, Bergen, Norway; Wigner Research Center for Physics, Budapest, Hungary; DKFZ Heidelberg, Germany; Heidelberg Ion-Beam Therapy Center (HIT), Germany; Utrecht University, The Netherlands; RPE LTU, Kharkiv, Ukraine; Suranaree University of Technology, Nakhon Ratchasima, Thailand; China Three Gorges University, Yichang, China; University of Applied Sciences Worms, Germany; University of Oslo, Norway; Eötvös Loránd University, Budapest, Hungary

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Backup slides

Imaging for the treatment plan of a proton therapy

- Hounsfield Unit (HU): linear attenuation coefficients in a scale which assigns 0 to water and -1000 to air
- Relative Stopping Power (RSP):
  the stopping power compared with water
- RSP map is necessary for treatment planning
- Nowadays:
  X-ray CT $\rightarrow$ measures HU unit $\rightarrow$ RSP distribution
  1.7-11% RSP error $\Rightarrow$ bigger safety zone
  $\Rightarrow$ less advantages proton Therapy
- More accurate option:
  Proton CT $\rightarrow$ direct measurement of RSP distribution
  0.5-1% RSP error $\Rightarrow$ reduced safety zone
  $\Rightarrow$ more advantages proton Therapy

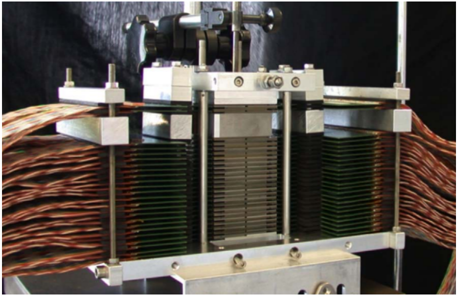
Previous prototype of the group – Concept

Sandwich structure:

- MIMOSA23 sensors
  (developed in ALICE-FoCal)
  2 kHz readout speed
- 3.3 mm tungsten absorber

Layer length: 32 mm WET
WET: Water Equivalent Thickness
Originally designed for other purpose
$\Rightarrow$ 24 layers but just 7 useful
$38.5 \cdot 38.3$ mm^2 sensitive area
New prototype:

- MIMOSA23 $\rightarrow$ ALPIDE
- Optimized absorber



Previous prototype of the group – Results

- 4% range resolution
  caused by the too thick absorber
  goal is 1% for prototype pCTs
- 1 MHz effective proton frequency
  high end of the prototype pCTs