# The single sided digital tracking calorimeter designed and developed by the Bergen pCT group

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*on behalf of the*
Bergen pCT collaboration

# The Bergen pCT collaboration

# The project: build a new pCT scanner

**Institutions**

- University of Bergen, Norway
- Helse Bergen, Norway
- Western Norway University of Applied Science, Bergen, Norway
- Wigner Institute Budapest, Hungary
- DKFZ Heidelberg, Germany
- Utrecht University, The Netherlands
- 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

**Financing**

- 5 years (2017-2021)

**Status**

- Finishing the optimization of the design
- Start mass-production of the sensor chips
- Sensor characterization
- MC simulations to investigate image reconstruction accuracy

**The Norwegian government has decided to build two particle therapy facilities (Oslo, Bergen) to be operational by 2022**

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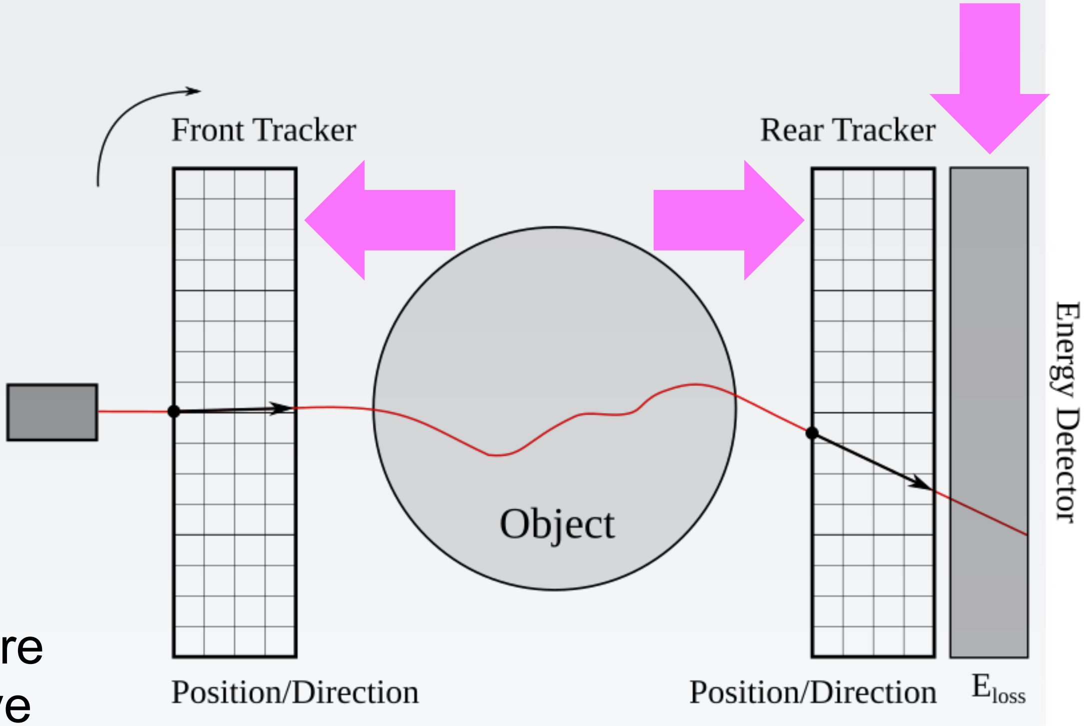
# The pCT imaging concept

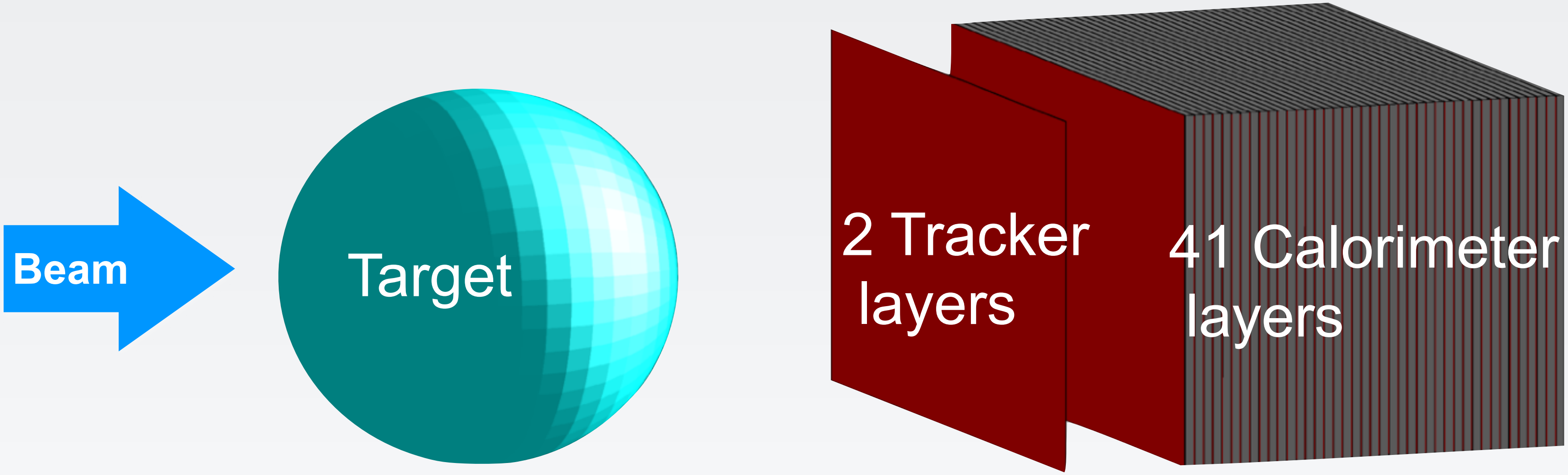
Trajectory and residual energy of each **single particle history** crossing an object from different directions

- **Tracker system:**
  entrance and exit points
- **Energy detector:**
  residual energy
- Residual Energy into
  water equivalent path length (**WEPL**)
- WEPL and path information are used to reconstruct the relative stopping power (**RSP**) of each voxel in the target through reconstruction algorithms



# pCT at Bergen

Same technology for tracking and energy detector:
High-granularity Digital Tracking Calorimeter - DTC



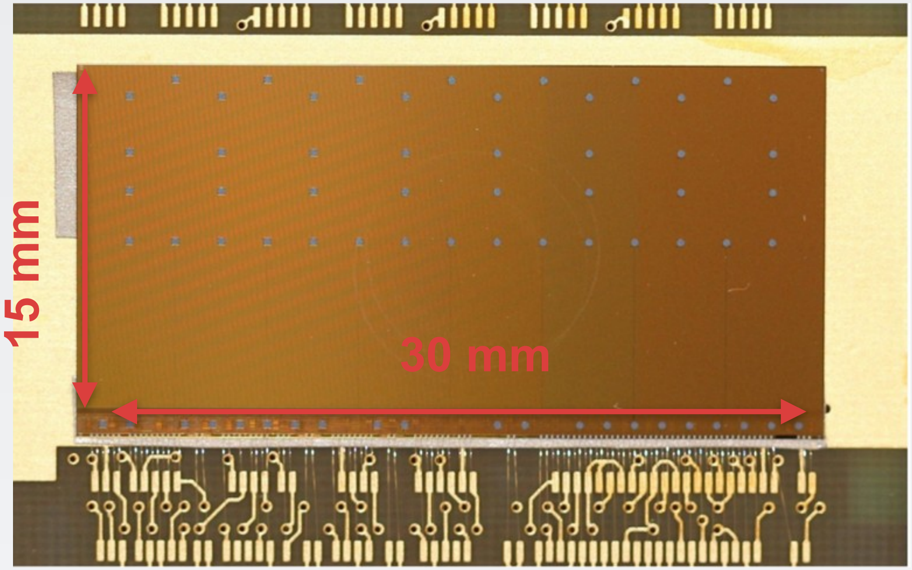
**No Front Tracker**
assuming direction and position from TPS information

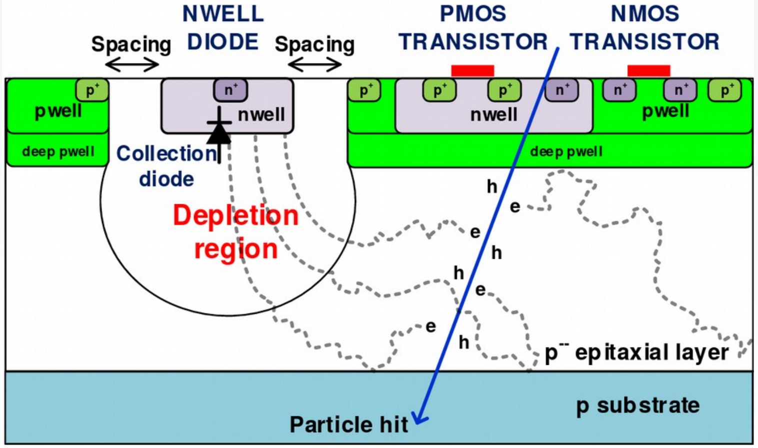
Measure particles exit position and direction

Track particles to find range

# The ALPIDE chip

- The ALPIDE pixel sensor is a CMOS Monolithic Active Pixel Sensor (MAPS)
- Chip size: 30 mm x 15 mm
- Chip thickness: 50 μm or 100 μm
- 1024 x 512 pixels
- Pixel size: ~ 29 x 29 $\mu m^2$
- Integration time: ~4 μs
- On-chip data reduction

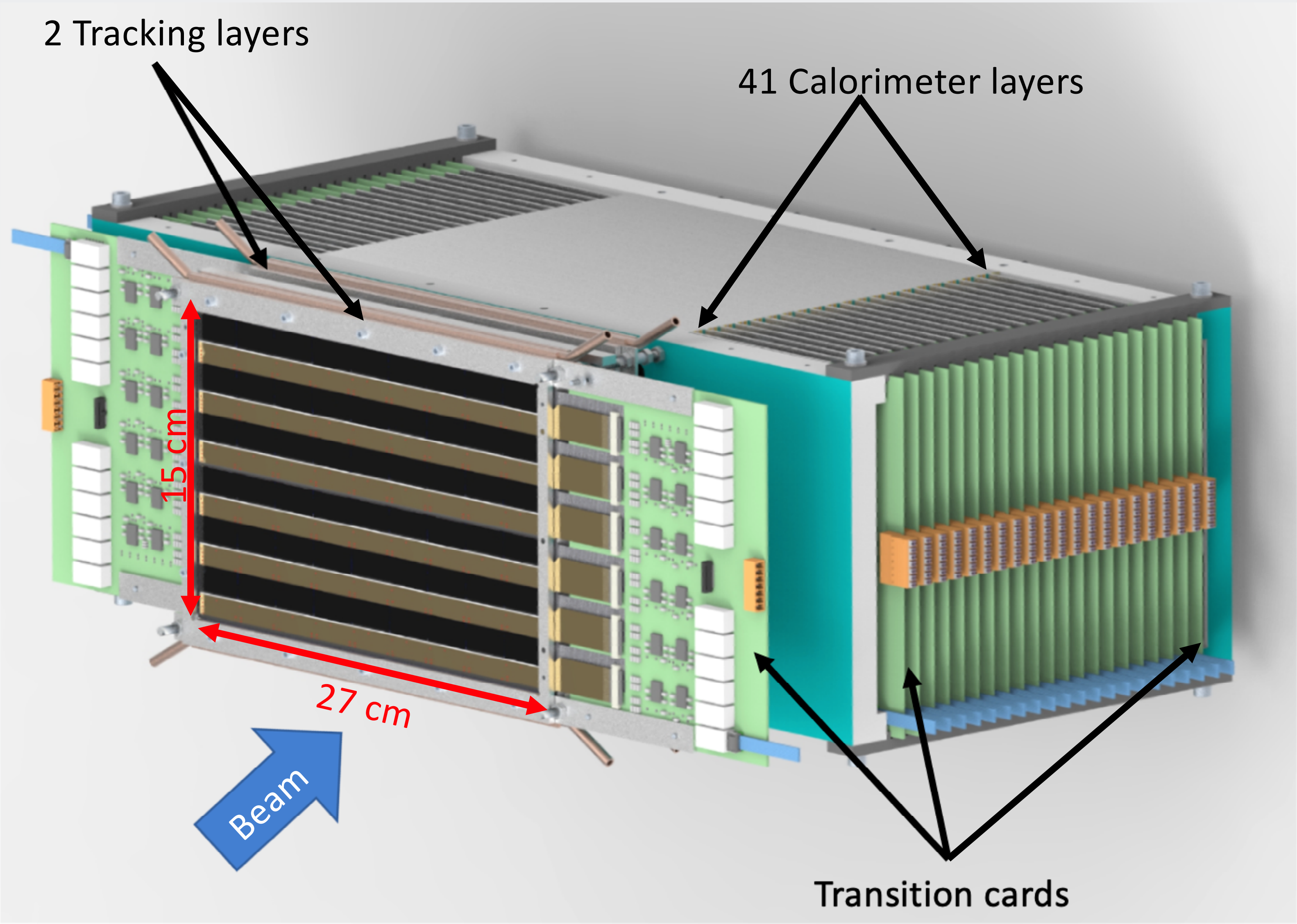




The ALPIDE high-granularity allows to disentangle and reconstruct a large number of concurrent proton tracks

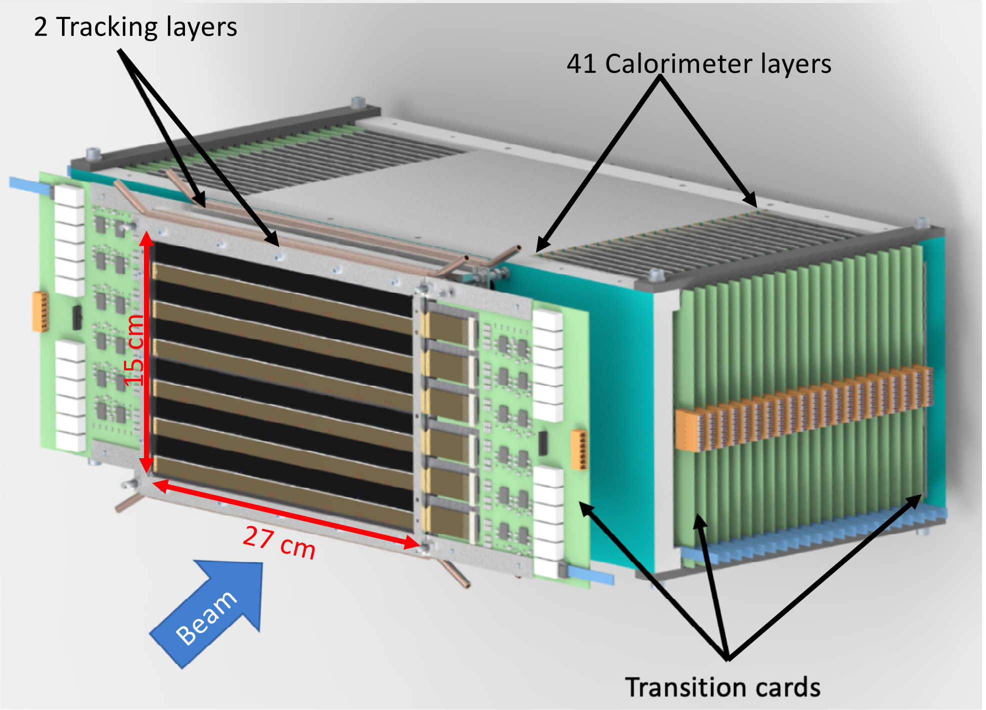
Design team:
CCNU Wuhan, CERN Geneva, YONSEI Seoul, INFN Cagliari, INFN Torino, IPHC Strasbourg, IRFU Saclay, NIKHEF Amsterdam

# Current design of the prototype



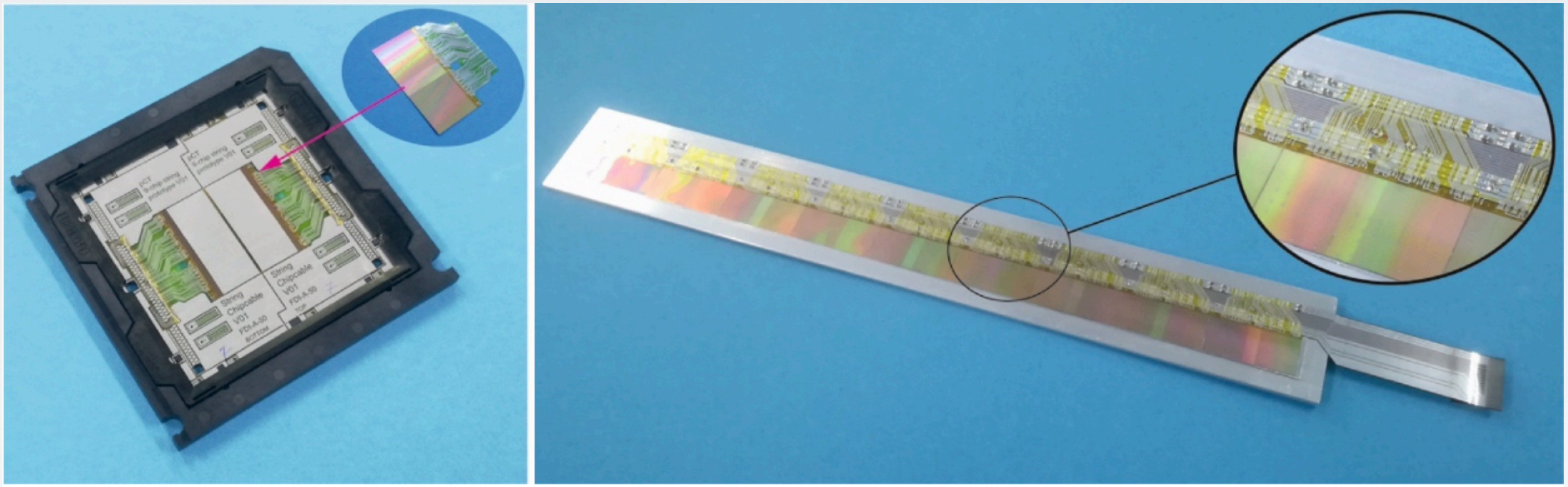
# Current design of the prototype

- The calorimeter is multi-layer structure made of ALPIDE-aluminum sandwiches
- Al (3.5 mm) works as absorber (1.5 mm thick) and carrier (2 × 1.0 mm thick)
- 41 aluminum absorber layers needed to stop a 230 MeV proton beam
- The area of the sensitive part of each layer is 15 cm × 27 cm
- The detector will track the traversing particles and assign an energy difference or water equivalent path length (WEPL) to each single crossing proton with an uncertainty of ~ 1%



Tracker and Calorimeter layers have the same structure, except:
- no absorber in the trackers
- a thin (~200 μm) Carbon-epoxy sheet functions as carrier
- the ALPIDE is 50 μm (not 100 μm) thick

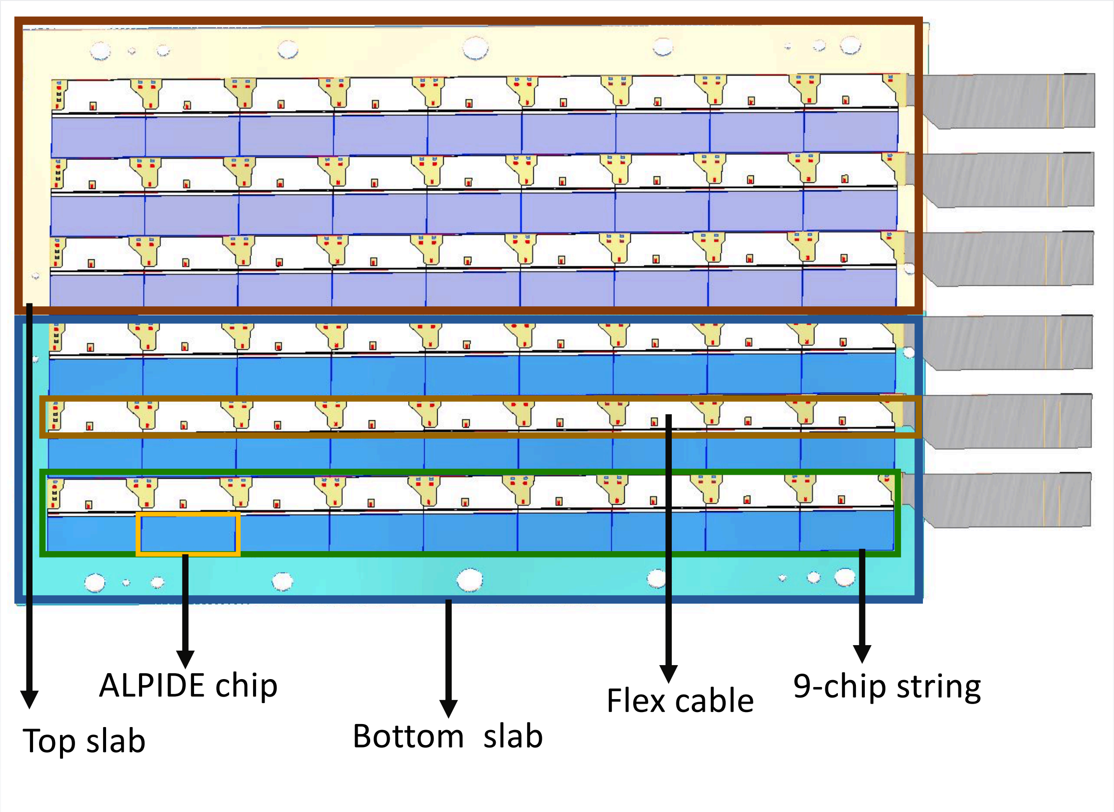
# Design of layer



- The ALPIDE chip is mounted on a flex cable
- 9 ALPIDEs mounted on flex cable (*string)*

# Design of layer

- Three strings are subsequently glued on a carrier, called a slab
- Two types of slabs: T-slab and B-slab together make a **half layer**



The trackers will have a whole slab, not two half slabs, made of carbon-epoxy

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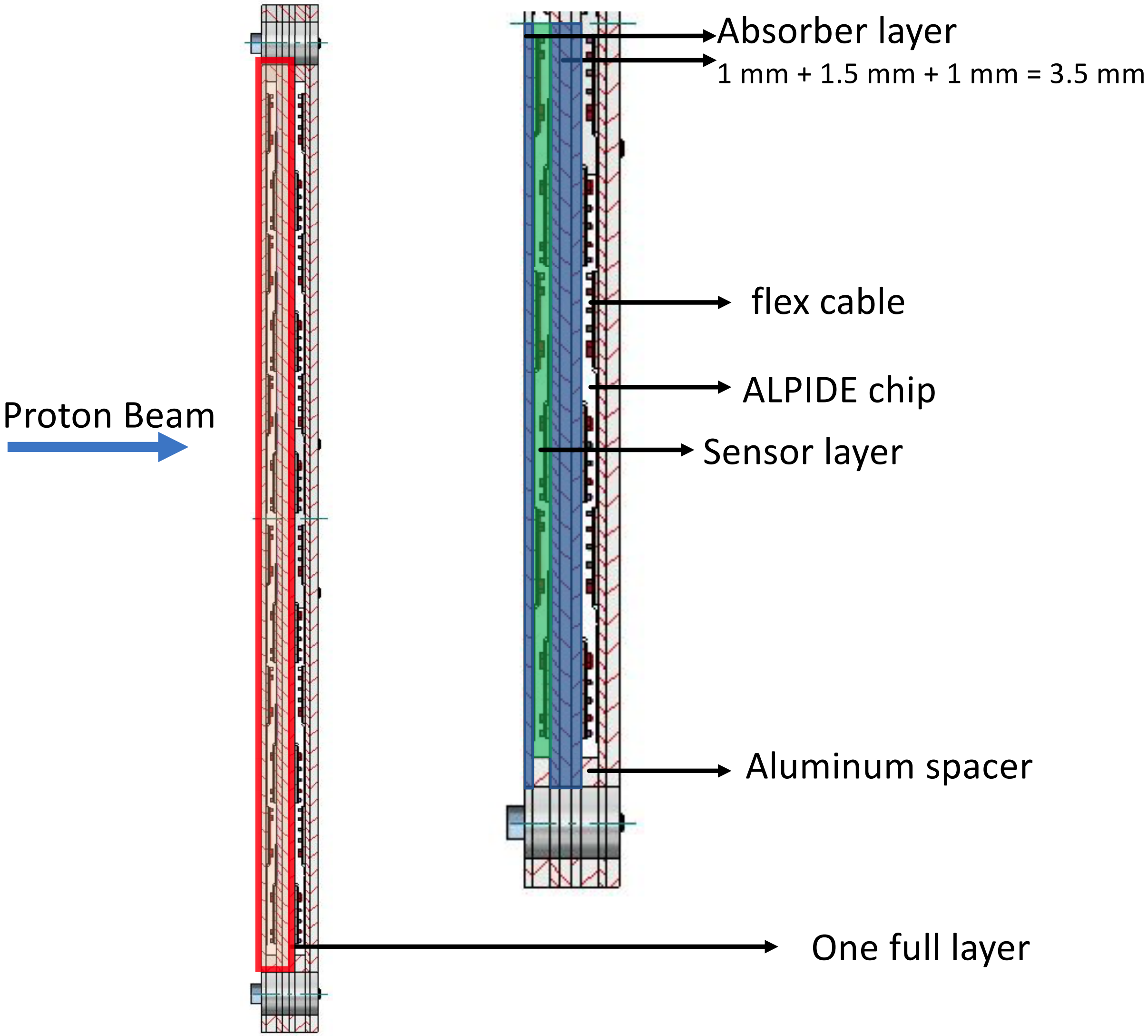
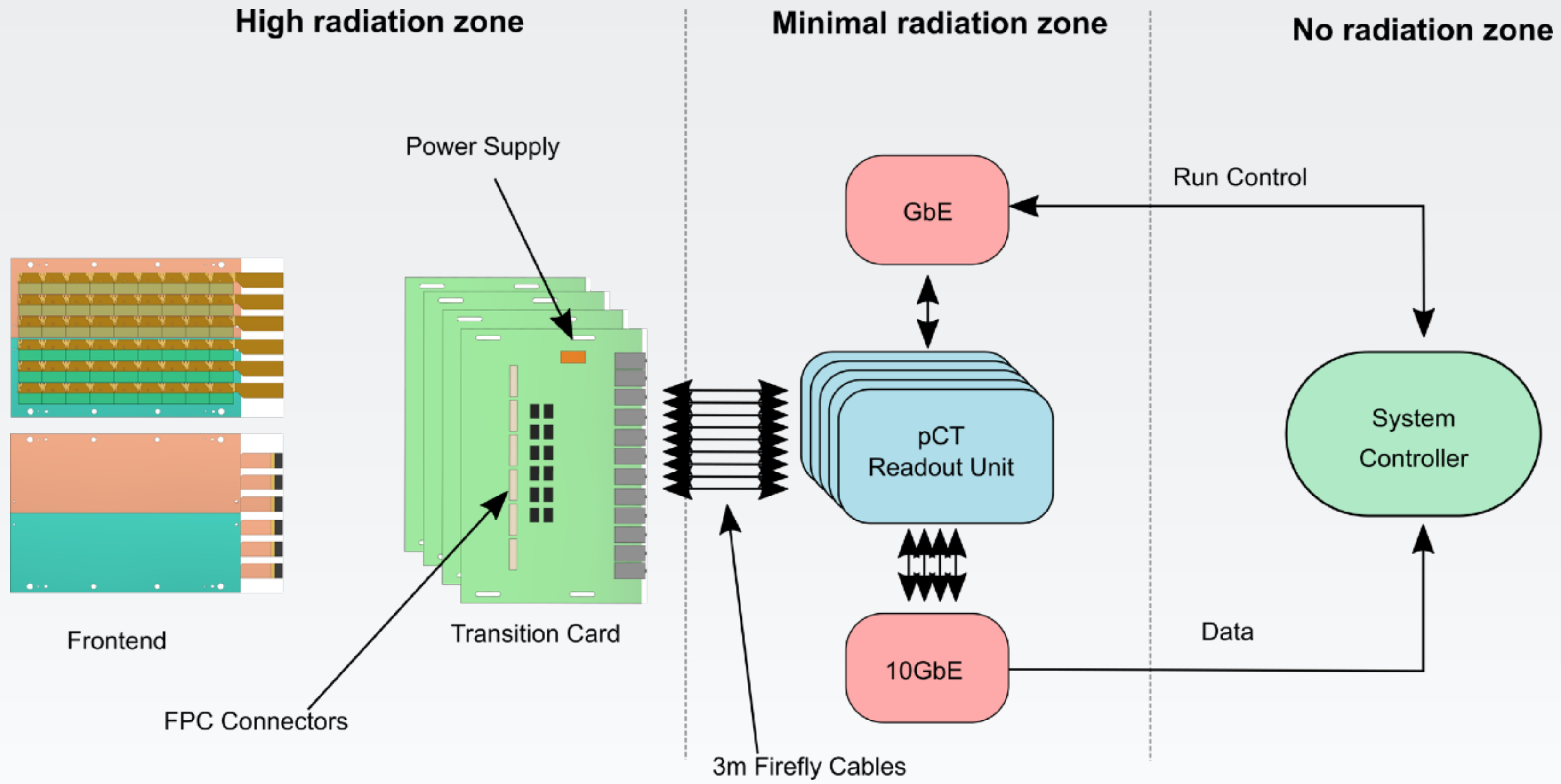
# Current design of the prototype

- One full layer is made of 2 half layers with alternated positions of ALPIDEs
- The two halves of the layer are then stacked with the ALPIDEs facing each other and with an air-gap of 2 mm



# Electronics design

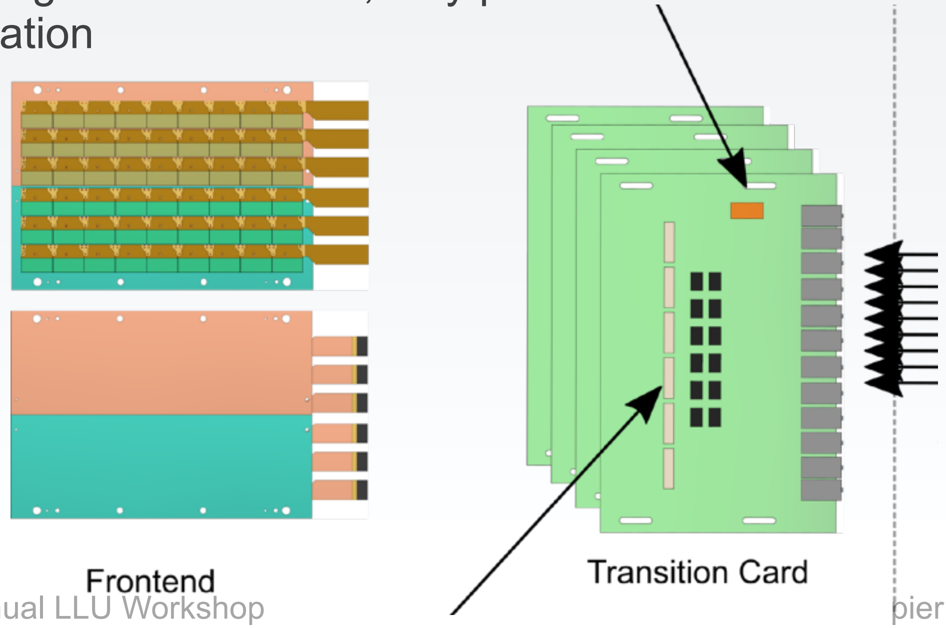
The pCT data acquisition (DAQ) and run-control (RC)



- Frontend electronics
- Transition card (TC)
- pCT readout unit (pRU)

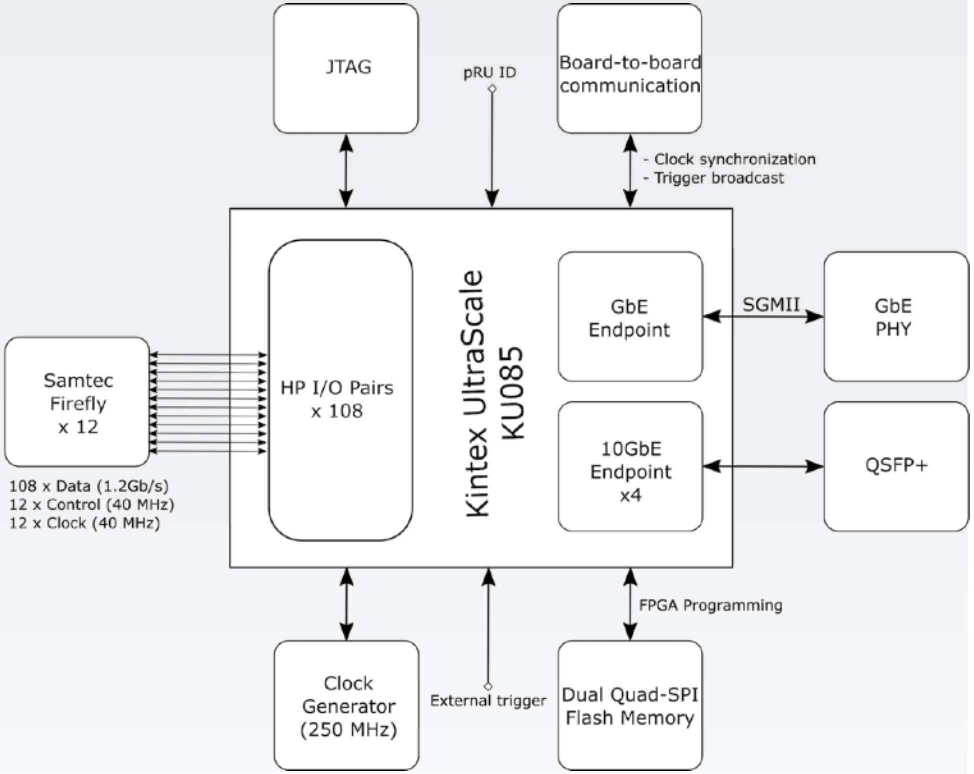
# Frontend electronics

- Each layer in the detector is electrically identical and is composed of 108 sensor ALPIDE chips
- Nine chips are mounted together on a string where clock and slow control signals are shared
- The ALPIDEs are bonded to thin, flexible printed circuits (**FPC**) of aluminum and polyimide (Pi) called *flex*
- A transition card (TC) is used as an intermediate medium between the frontend electronics and the readout electronics for each layer
- The cards also deliver stable power to the sensors
- As the TC is placed in a high-radiation area, only pre-tested radiation hard components are used for power regulation



# Readout unit for pCT

- The pRU is based on a Xilinx Kintex Ultrascale FPGA
- The FPGAs provide high enough bandwidth to handle the 108 data links
- The pRUs are placed together in a crate that supplies power and allows for board-to-board communication and synchronization
- Trigger-less readout architecture designed to continuously capture data with minimal integration time over a short period of time
- With these features, a capture rate of 10 µs with a gap of roughly 250 ns for only few seconds will provide enough data for a single 2D-image



# Monte Carlo simulation - general setup

- GATE version 8.2 with Geant4 version 10.5.1
- Representation of the DTC sandwich structure accounting for the full material budget of the DTC
- This model was used to simulate and reconstruct proton radiographs (pRad) and full pCT scans with different phantoms
- Physics builder list QBBC_EMZ activated for the simulations, as recommended by the GATE Radiation Therapy and Dosimetry working group

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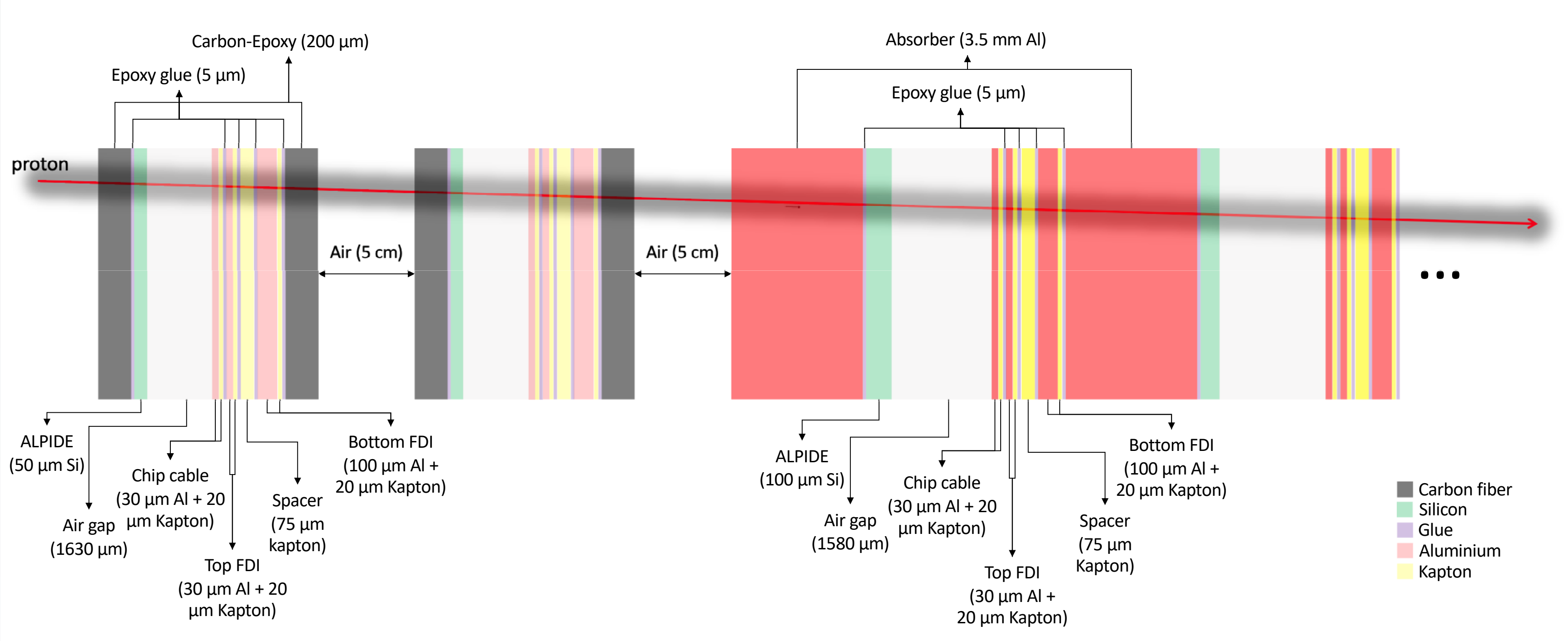
# Monte Carlo simulation - DTC model



- The MC model has exactly the same materials and material budget as the planned detector
- All the detector components were approximated as slabs with different thicknesses to eliminate the intended overlapping structures and subsequent calibration

# Conclusions

- Thanks to high-granularity and high speed readout high intensity beams can be handled by the DTC
- The final version of the ALPIDE strings are being bonded and will be ready to be tested soon
- The full DTC should be finished presumably in two years

➡ The DTC could be positioned downstream of the patient during the treatment with a carbon-helium mixed beam

➡ Placing the detector beside the treated patient at an opportune angle, secondary radiation (e.g., gamma, neutron) originating from the Bragg peak area could be tracked for *in situ* range verification

➡ Machine learning investigation to analyze secondary radiation originating from the Bragg peak and possibly to improve track reconstruction

# Thanks to all our collaborators

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Hochschule
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University of Applied Sciences

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# Removing the front tracker pair; investigations and observations (Monte Carlo)

By Jarle Rambo Sølie


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