4D Particle Tracking with LGAD Strip Sensors and the DOGMA Readout System

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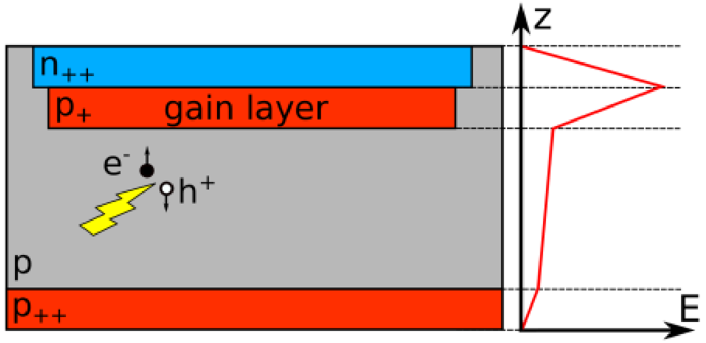
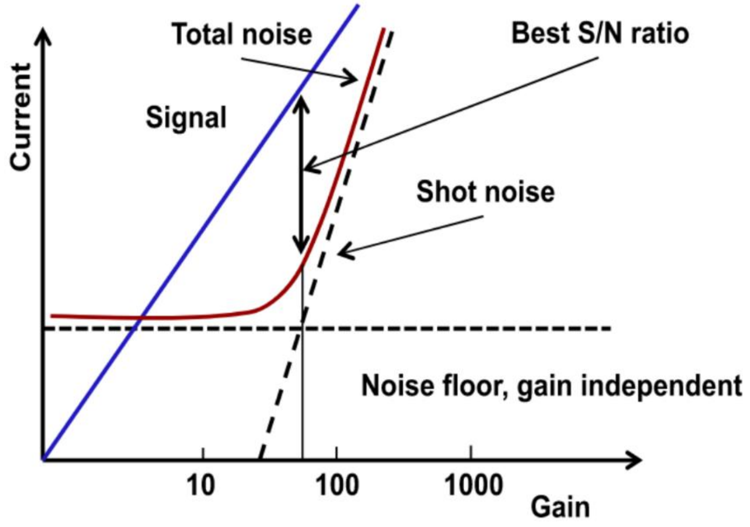
Low Gain Avalanche Diode Detectors (LGADs)

- Thin silicon detectors optimized for timing performance
  - high electric field in gain layer (> 300 kV/cm)
    - intrinsic signal amplification
    - large signals with short rise times (< 1 ns)



- Bulk gain optimization
  - high gain also amplifies noise
    - shot noise rises faster than signal
    - leads to signal fluctuations (jitter)
    - deteriorates timing performance
  - LGADs are operated at relatively low gain (G ≈ 10-30)



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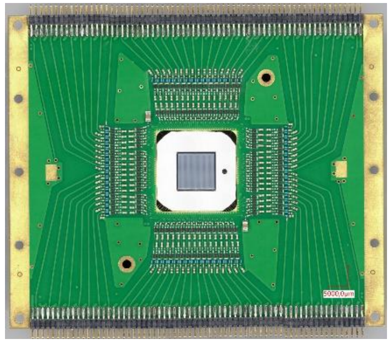
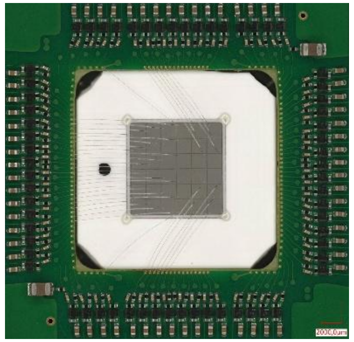
Front-end electronics

- Amplification based strategy
- GSI amplification board for LGAD/diamond
  - 128 channels
  - AC coupled
  - Single- or double-sided readout
  - 60 ps for MIPs
  - < 30 ps for C ions
  - Voltage gain: 400

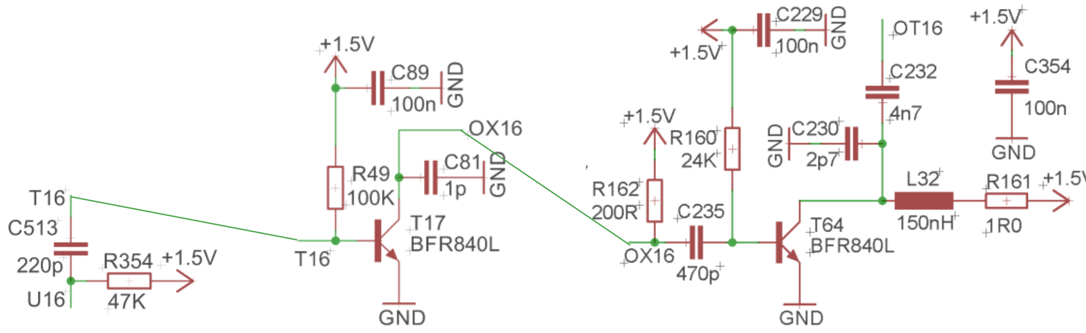


128-channel readout board



Pad diamond sensor

Strip LGAD sensor



AC coupling Stage 1 Stage 2

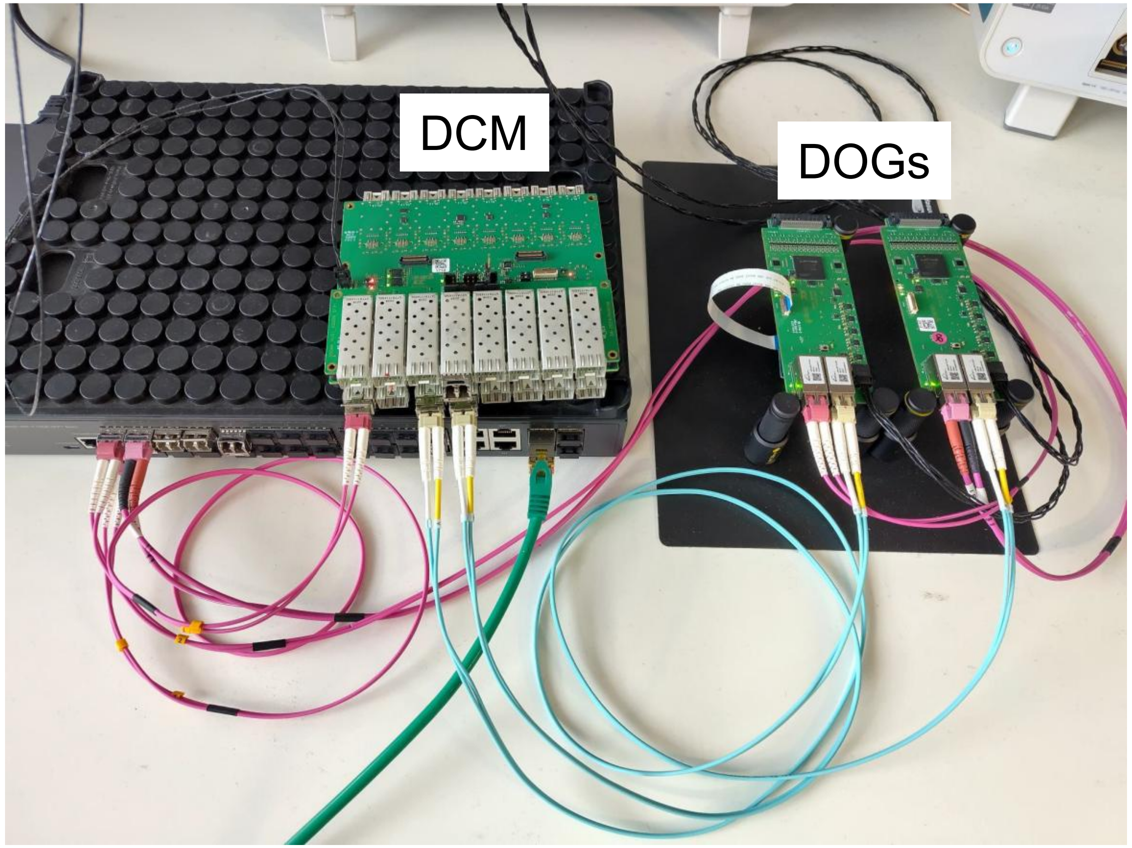
DOGMA Readout Framework

- Best effort DAQ paradigm
- Automatic fast reintegration after reboot
  - Higher reliability and fault tolerance
  - Enables use of commercial and cheap FPGAs
- Optical data transmission and < 10 ps RMS clock
  - No GND issues due to galvanic isolation
  - Scaleable
- Arbitrary system size due to no handshake latency
- Ethernet protocol for easy and cheap upgrades
- Keep it Small and Simple
  - Easy to maintain for small teams

DOGMA Readout Implementation

- Dogma Control Module
  - Communication with DOGs
  - Trigger and clock distribution
  - Add-ons for more ports possible
- DiRICH5d2 modules
  - 32 channel readout
- 1 GbE connection to switch
- 10 GbE data to servers
- Switches can be added

→ Used during beam time



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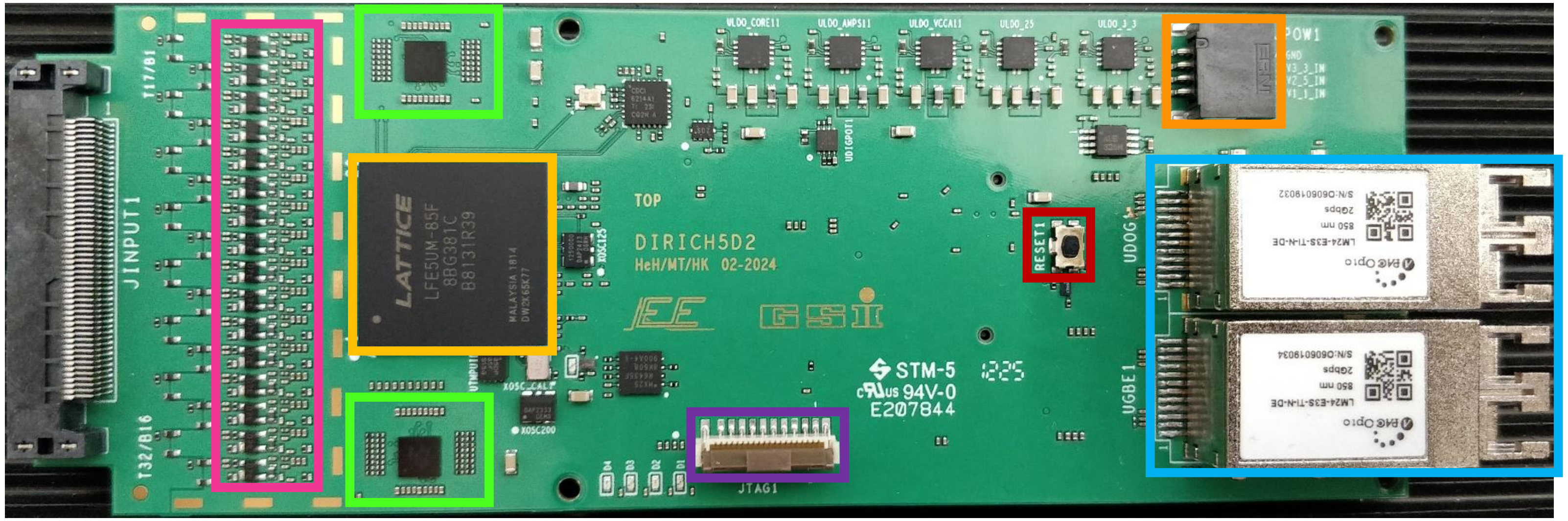
DOGMA Readout Electronics

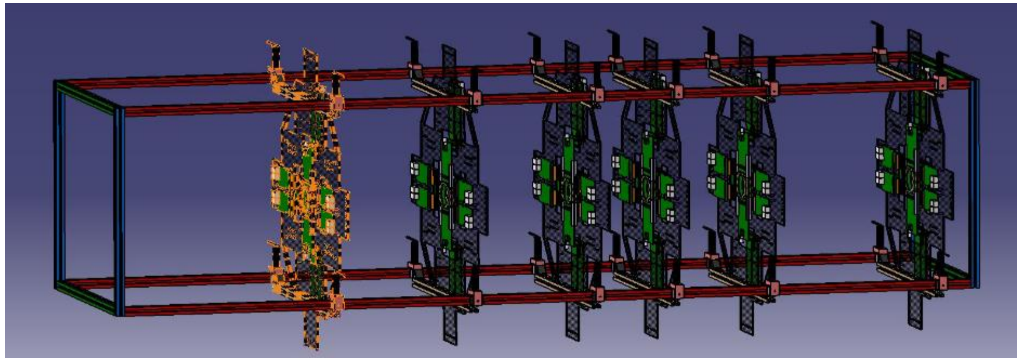
- Pre-amplifier
- Main FPGA
  - Discriminator, TDC, DAQ, ethernet, slow control, etc.
- Satellite/threshold FPGA
- JTAG connector
- Physical reset button
- Power connector
- SFF optical ports
  - DCM and switch labelled



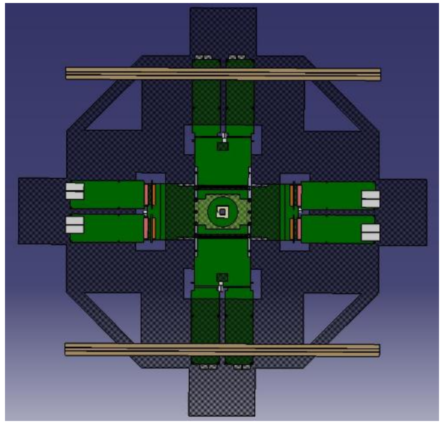
4D Tracking iCT Setup

→ Talk by F. Ulrich-Pur at 12:30

- 2 m long frame to fix modules
- PCBs fixed to plexiglass pane
- 6 layers with 2 X-Y-tracking LGADs each
- 45 channels per LGAD, 540 channels total
- Mouse placed between layers 2 and 3
- 90 cm ToF path between layers 4 and 5



CAD model of setup, distances not adjusted



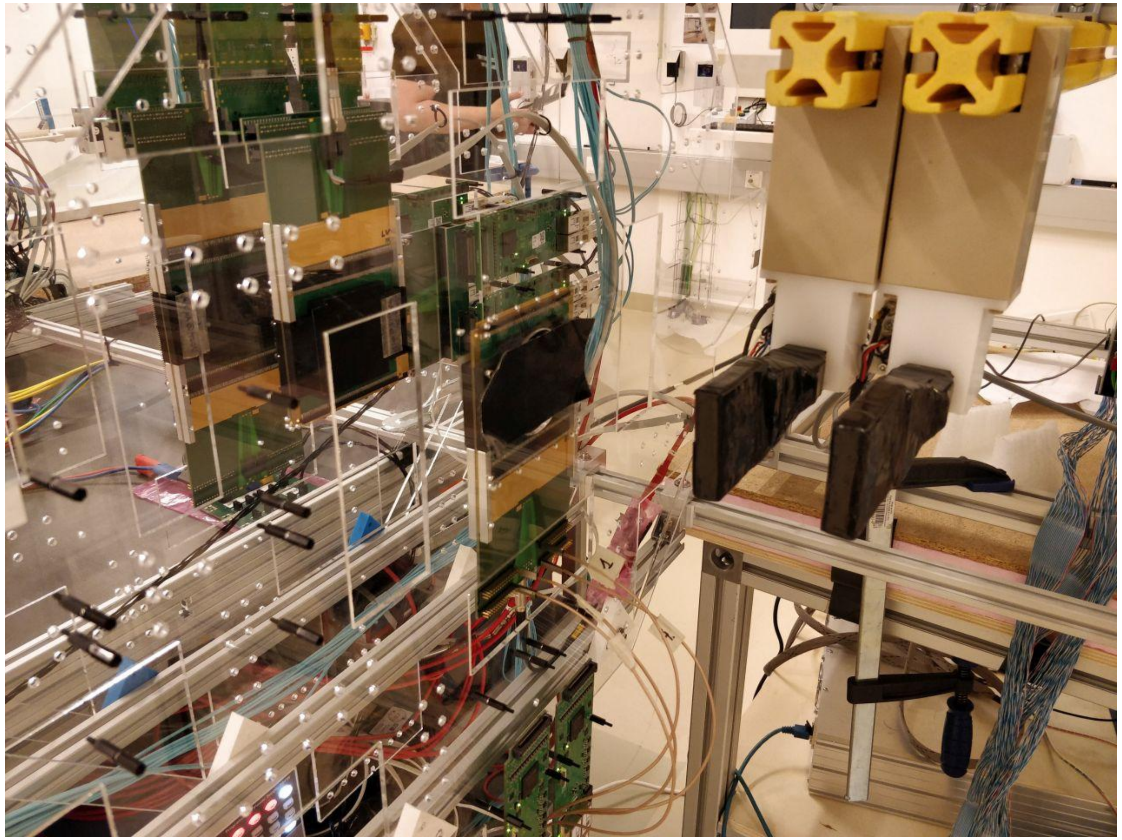
CAD model of one layer

Laser alignment

CBM T_0 Performance Study

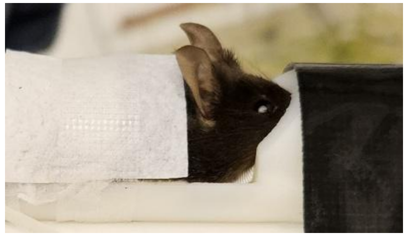
→ Talk by M. Kis / J. Pietraszko tomorrow at 10:30

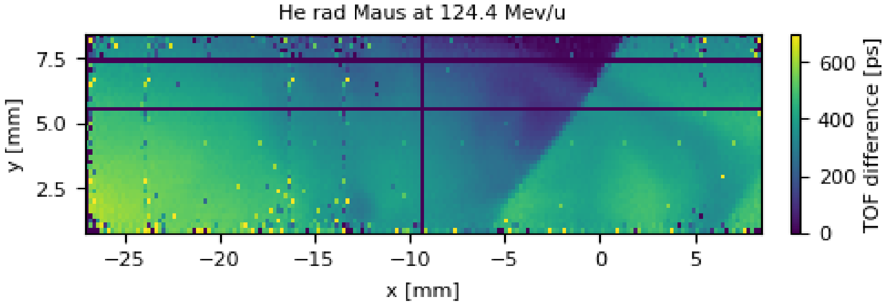
- Diamond layer placed behind iCT setup
- Read-out connected after scope analysis
- Single-sided 6 x 6 pad sensor with aluminium metallization
- Efficiency analysis at different beam energies

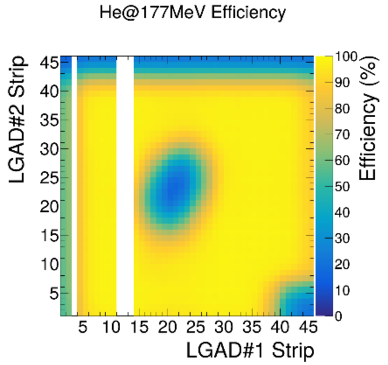


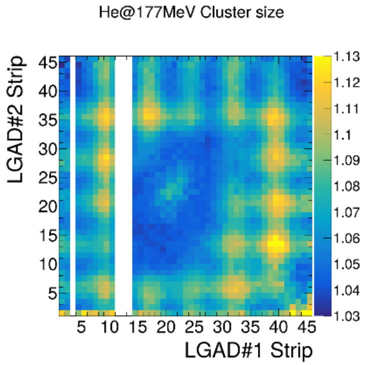
4D Setup Performance

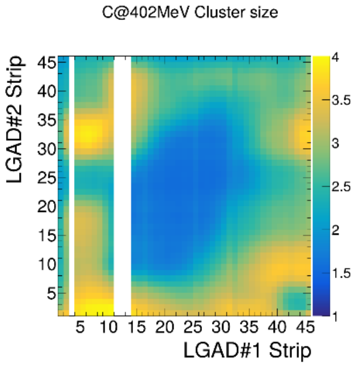
- Full analysis chain
  - Time over threshold normalization
  - Time walk correction
  - Cluster identification
- Best timing performance so far
  - 60 ps for 800 MeV protons
- Tomography of sacrificed mouse
  - 4D tracking algorithms currently WIP
- Methods for diamond study developed
- DAQ issues encountered
  - Lower DAQ rate
  - SEU data corruption







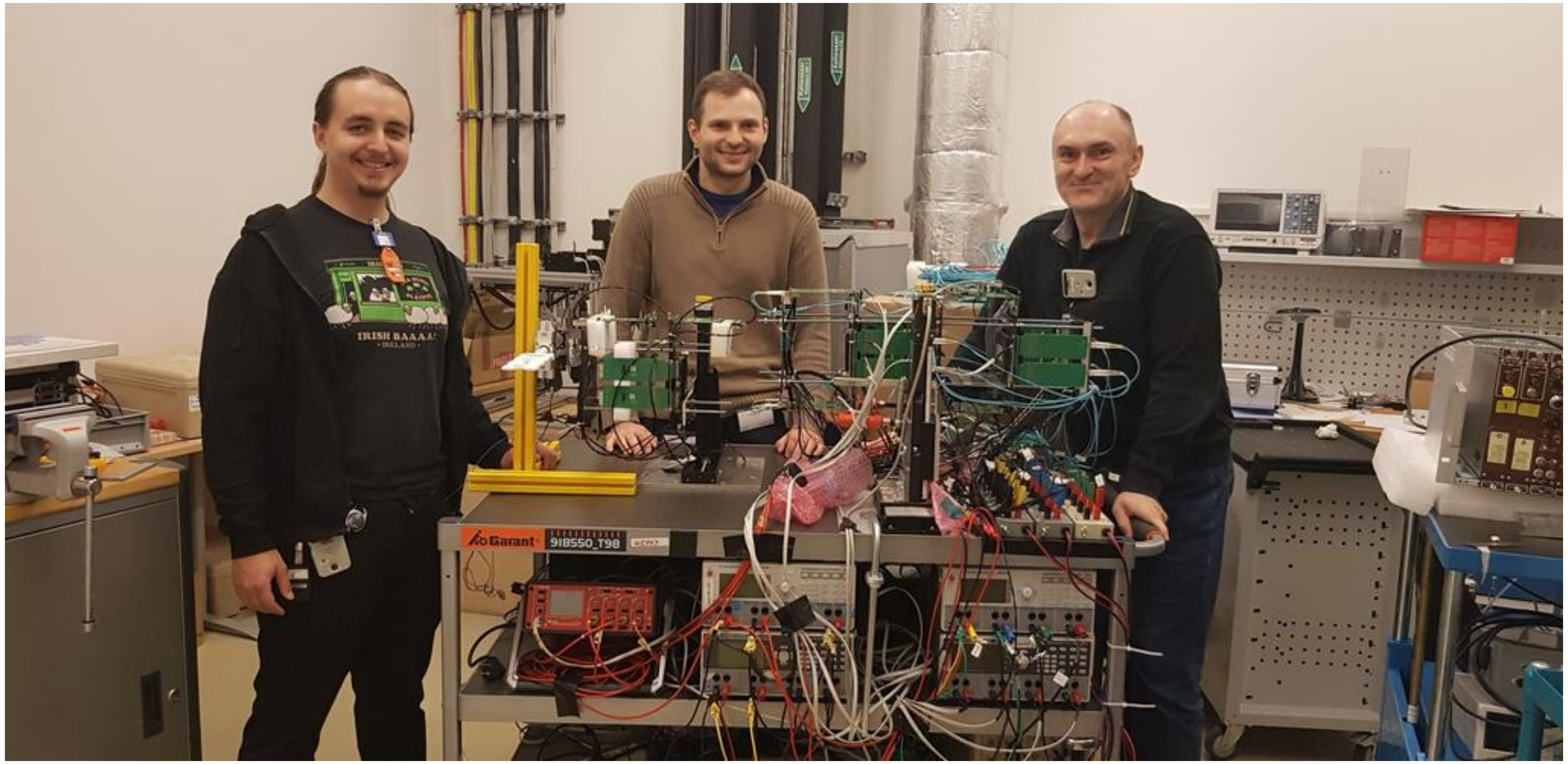




Outlook

- Two beam times at MedAustron in Dec./Jan.
  - Live mouse radiography
  - Diamond irradiation level study
- Cold box construction to demonstrate < 50 ps with MIPS
- Setup for laser driven beam at ELI-NP
  - Vacuum operation
  - Shielding concerns
- DOGMA improvements
  - DAQ rate investigation
  - SEU prevention

Thank you for your attention!



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References

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2. The DOGMA DAQ System. dogma.gsi.de
3. Ulrich-Pur, F. et al. (2022). "Feasibility study of a proton CT system based on 4D-tracking and residual energy determination via time-of-flight". In: *Physics in Medicine & Biology*. ISSN: 0031-9155, 1361-6560. DOI: 10.1088/1361-6560/ac628b
4. Johnson, Robert P (2017). "Review of medical radiography and tomography with proton beams". In: *Reports on Progress in Physics* 81.1, p. 016701. ISSN: 0034-4885, 1361-6633. DOI: 10.1088/1361-6633/aa8b1d
5. Ulrich-Pur, F. et al. (2023). "First experimental time-of-flight-based proton radiography using low gain avalanche diodes". In: *Physics in Medicine & Biology.* DOI: 10.1088/1361-6560/ad3326