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Position sensitive detectors in proton therapy: online monitoring of the beam position

12th PSD conference

September 13th, 2021

Outline

Quick introduction to proton therapy

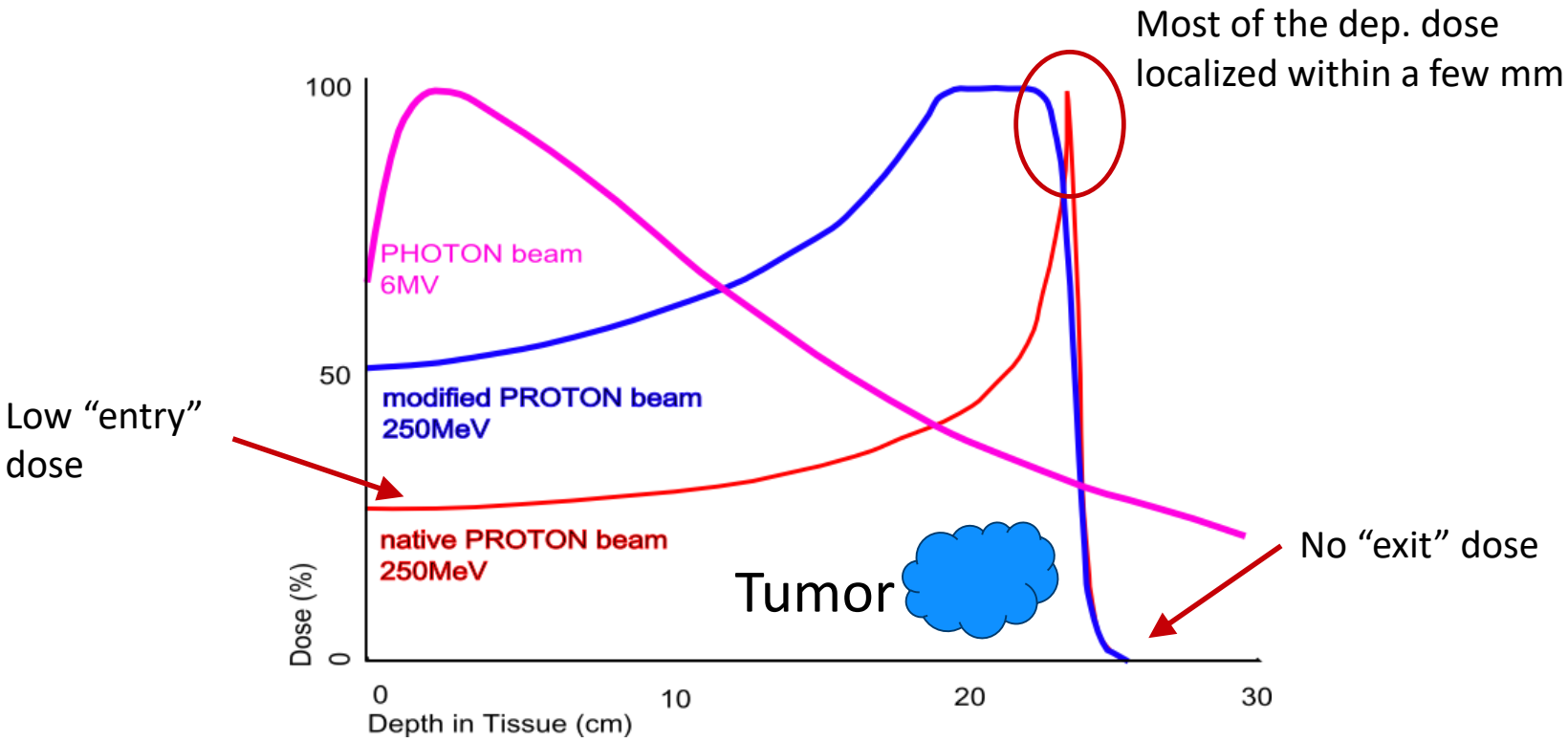
A strip chamber for online-position monitoring

Challenges of a detector upgrade

Summary

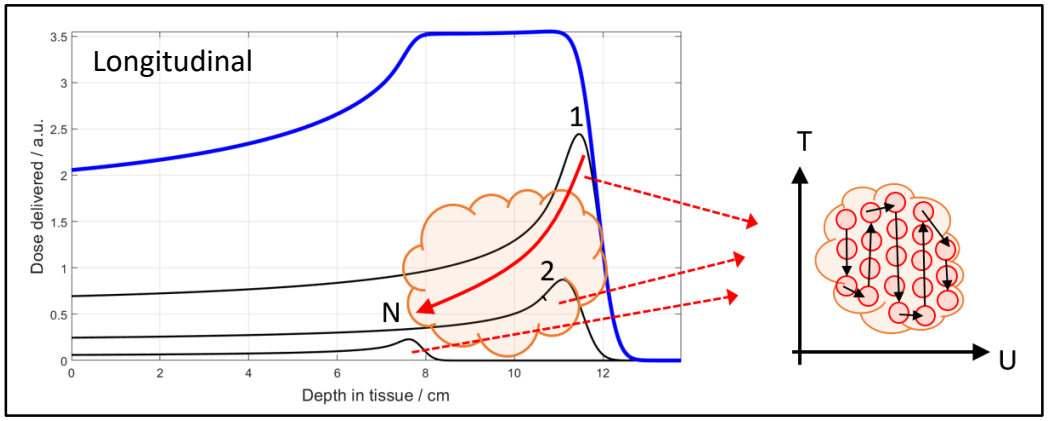
Proton therapy

- Irradiation of tumors inside a human body with a particle beam.
- Deposited dose as function of depth in tissue:
  - Exponential for photons and electrons
  - Bragg peak for protons ($dE/dx \propto 1/v^2$)



Spot scanning technique and requirements

- Spot wise application of beam (Gaussian shape)
  - S (depth in tissue / beam energy) → U, T



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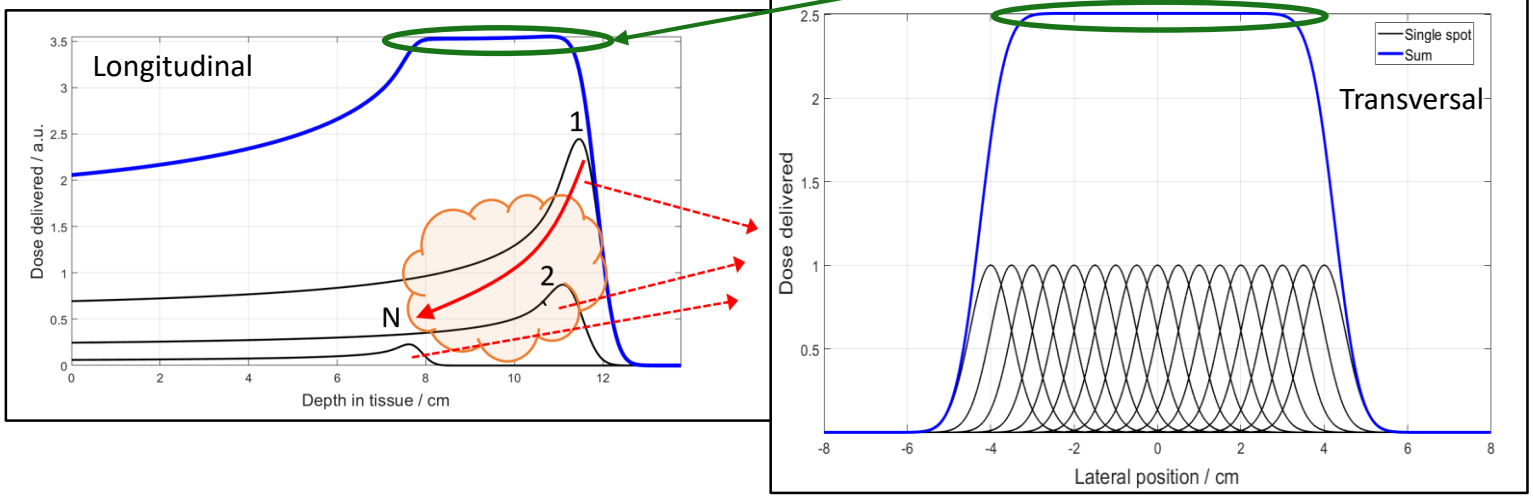

- Aim: dose inhomogeneity < 1 %

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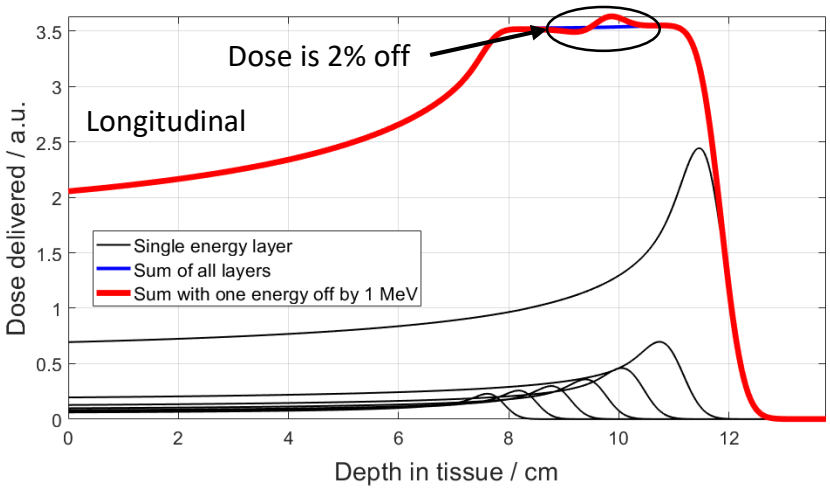

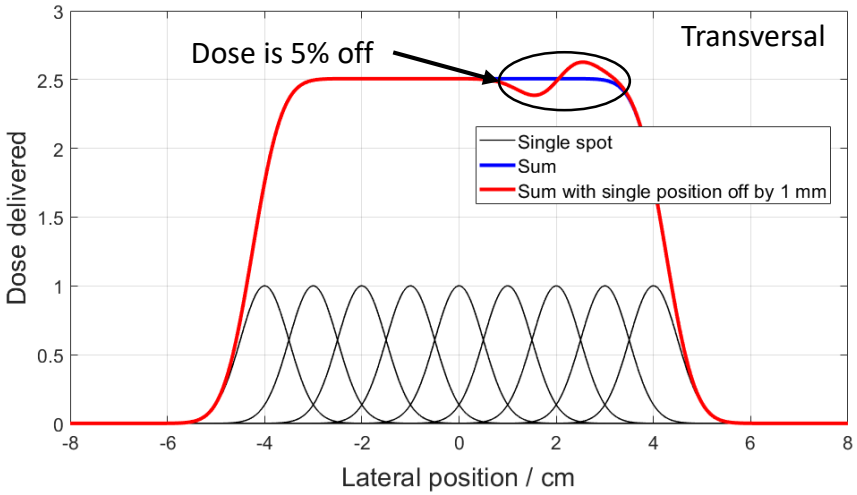

- Aim: dose inhomogeneity < 1 %
  - What does that mean for the beam positioning accuracy?
  - Longitudinal beam position has to be of the order of millimeters
  - Lateral beam pos. better than < 1 mm (control: sweeper dipole magnets)

- Lateral position measurement DURING beam application to patient!
  - Highly dynamic beam movement (milliseconds!)

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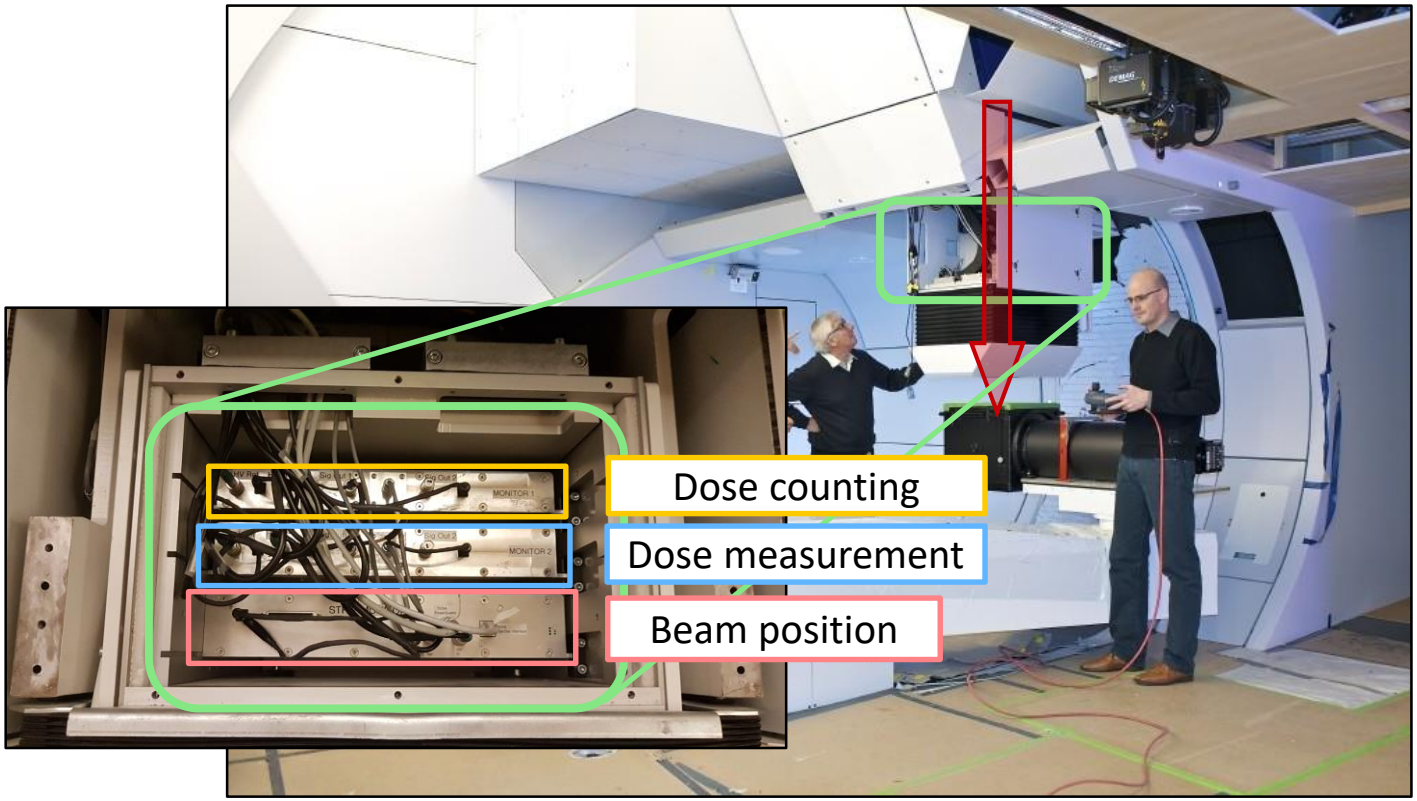
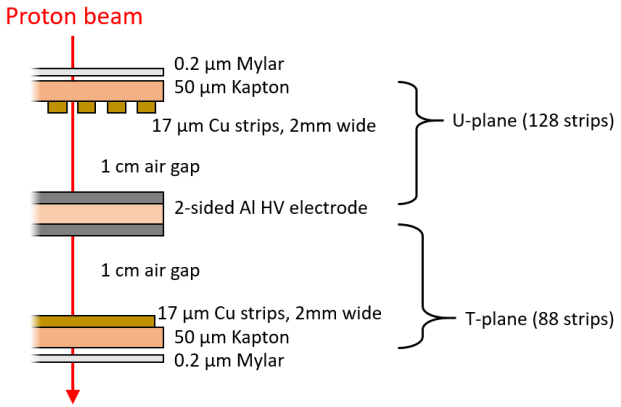
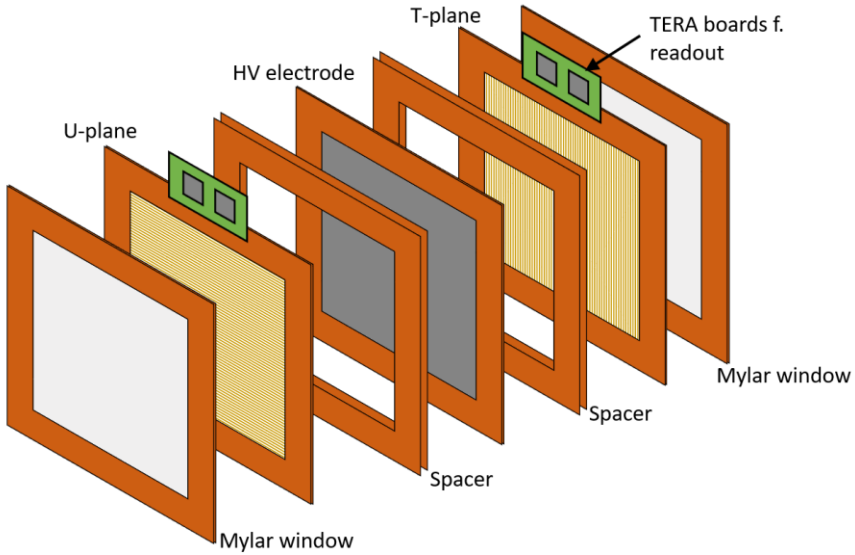
Device for position measurement in-situ



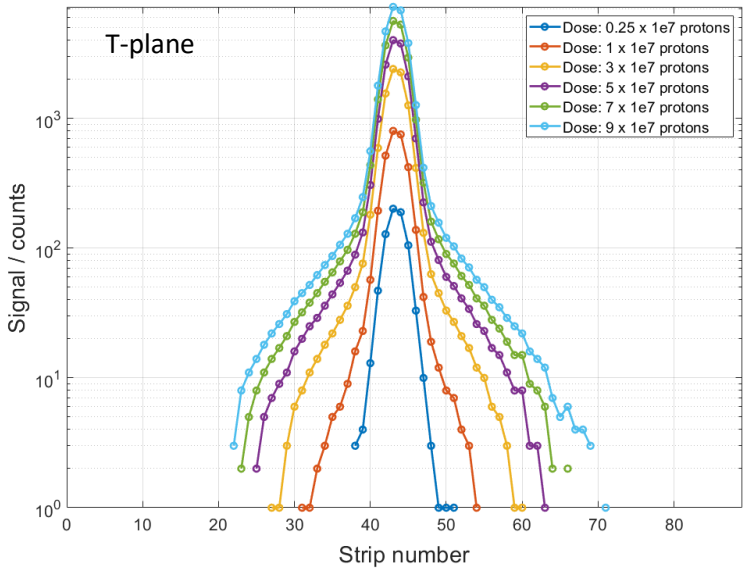
- Design parameters:
  - Thin (material in beam / minimize multiple scattering)
  - Robust (radiation)
  - Low maintenance/easy access (maintenance)
  - Last beam line element (closest beam “representation” before isocentre)
  - Movable (Gantry rotation, nozzle extension)

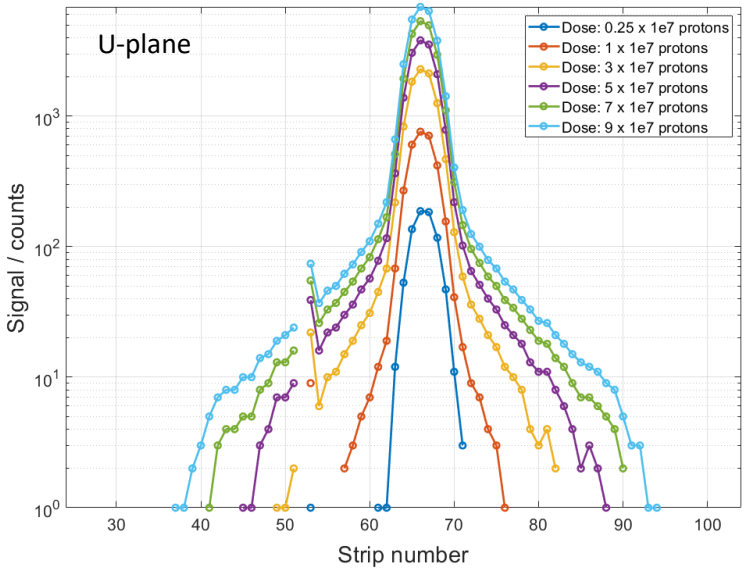
Nozzle strip chamber





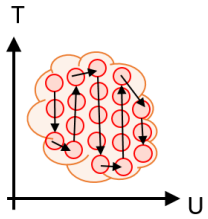
- Readout via TERA board (collab. w Uni Torino)
  - CFC functionality, 128 channels (= 64 channel per chip), 16 bit counter
  - Quantum of Charge: -100 fC, integrated readout

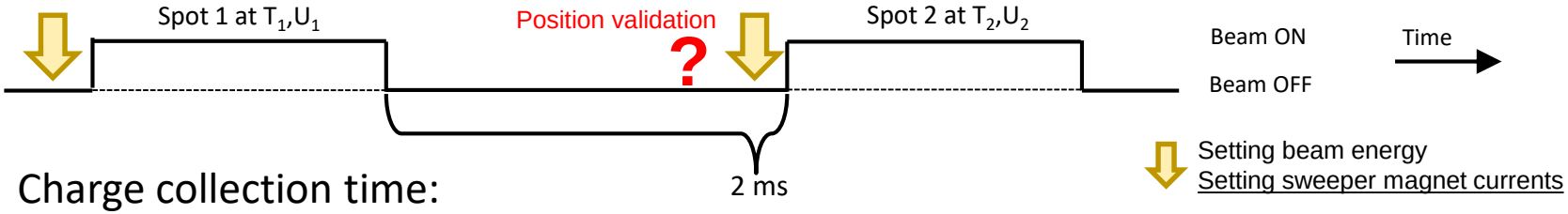




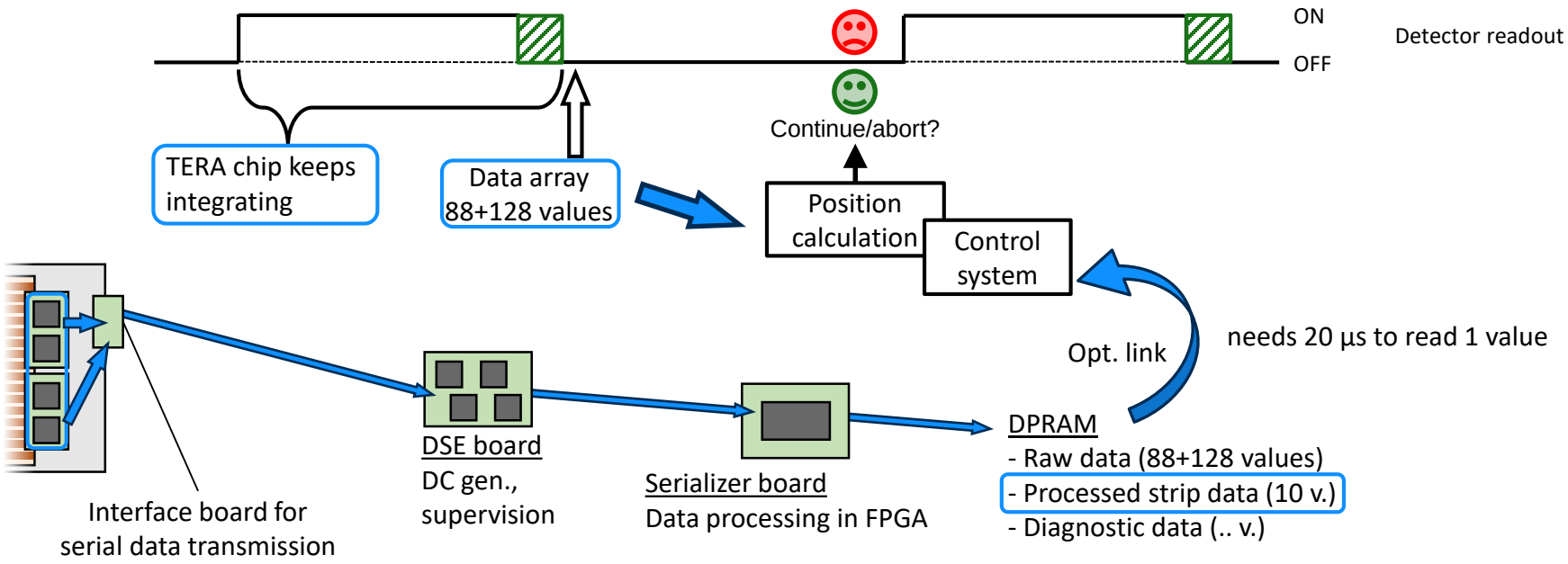
Signal readout and processing

- Spot-wise application of beam





- Charge collection time:
  - U = -1800 V, d = 1 cm → t ≈ 0.4 ms



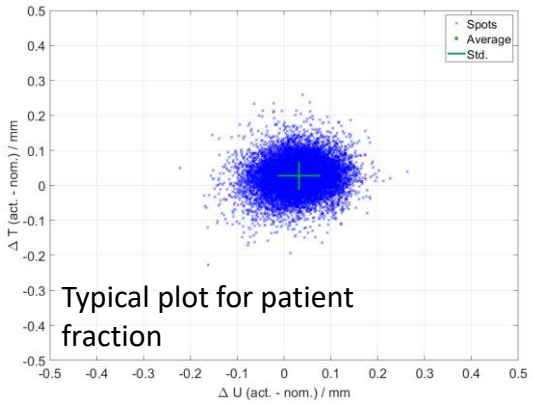
Position validation

- Position calculation:

Gaussian fit	Centre-of-gravity
+ Robust to noise + Good results even if partial profile visible (beam at detector edged) + Precise position calculation - Computation time	- Bad results even if partial profile visible - Threshold (> 1/32 of max.) - Noise sensitive (spikes) + Computation time + FW implementation

- Actually two positions needed: actual (measured) and nominal (planned)
  - Interrupt treatment if difference > 1.5 mm

- Performance throughout the years:



Typical plot for patient fraction

- Strip chamber not touched since 2013 (= commissioning)
- Monitored: position, RMS, area (of beam profile)

- No. of fractions to patients (since 2015): ~ 9300
  - Position violations detected: 62

- Tight QA program and close monitoring of HW parameters

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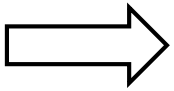
Never touch a running system?

- Strip chamber detector not touched since its commissioning (8 years)!

- Motivating an upgrade
  - Limited functionality: no sampling readout, no online gain control (FLASH effect)

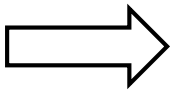
Conventional:
Dose rate < 1 Gy/s
Beam current < 0.5 nA



FLASH:
Dose rate > 1400 Gy/s
Beam currents > 700 nA

  - Availability: discontinued product series, limited stock.

TERA:
- 64 channels per chip
- Sensitivity: -100 fC/count
- 16 bit resolution
- $$$
- discontinued



ADAS:
- 128 channels per chip
- Sensitivity: 0.04 fC/count
- 24 bit resolution
- $
- available (*analog devices*)

- Challenges & opportunities:
  - Integration of a commercial part into a highly customized system
  - Sufficient testing in the lab (performance & utility)
  - Implementation: “touch” running patient operations

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Conclusion:

- Proton therapy needs a reliable position sensitive detector!

- Successful and low maintenance online beam position measurement is possible, because …
  … foil design: minimal beam disruption (multiple scattering, energy)
  … data processing: position determination BEFORE control system
  … electronics: only necessary electronics (rad. hard) close to detector, sensitive parts are far away

Outlook:

- Position measurement concept will remain as it is
- Moderate updates necessary:
  – Treatment optimization (dead time), FLASH dose rates (= extremely high currents)