A camera alignment system for the Mu3e experiment

DPG CONFERENCE 2021, DORTMUND

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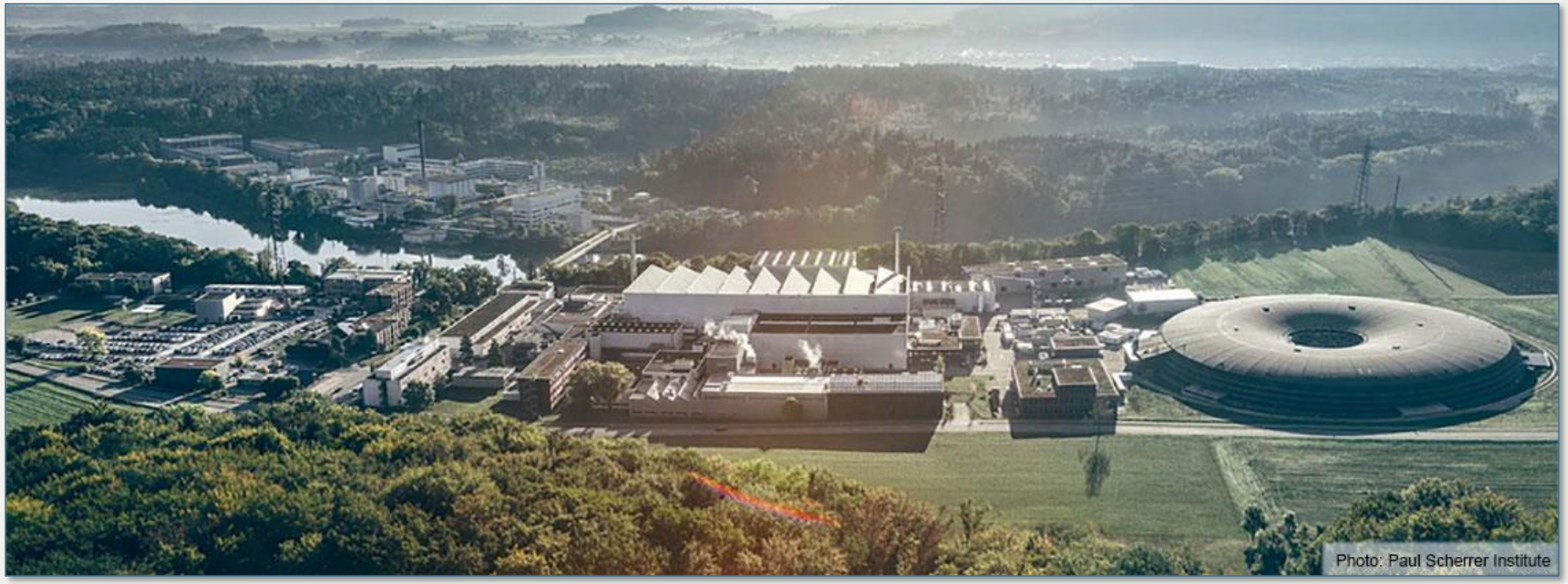
- Location: Villingen, Switzerland
- World's highest intensity proton beam – 2.2 mA at 590 MeV



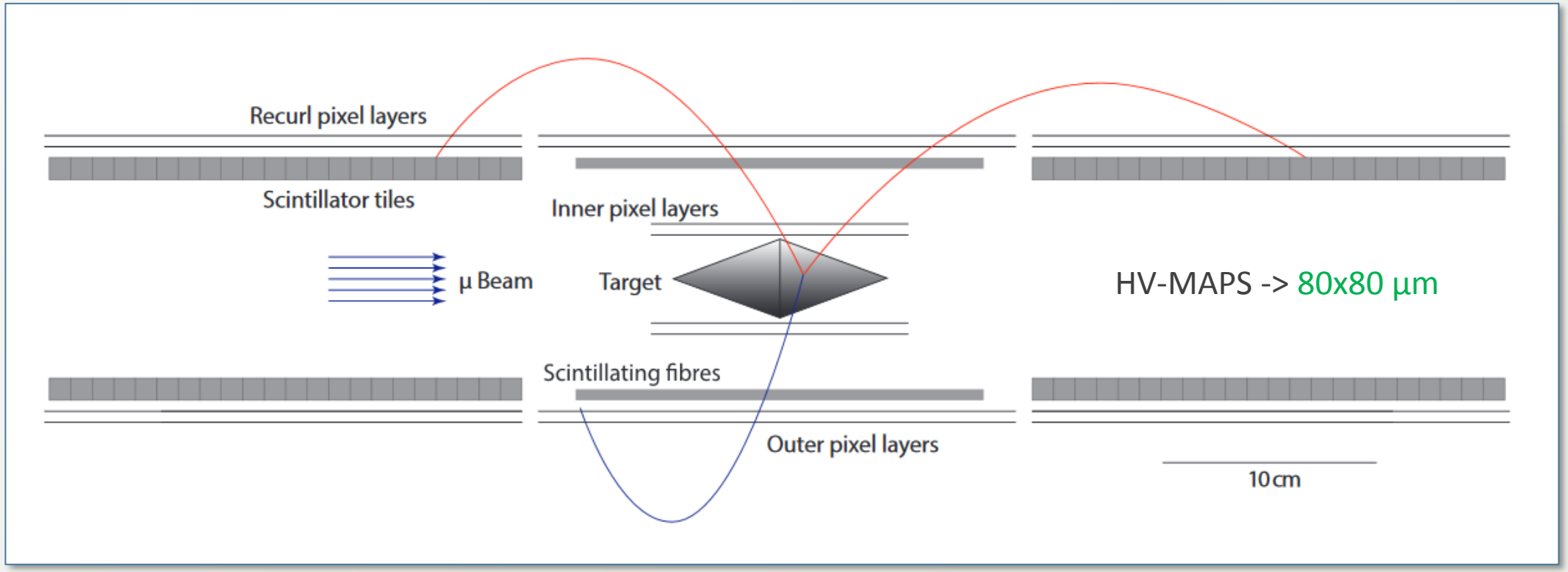
[1]

Mu3e experiment

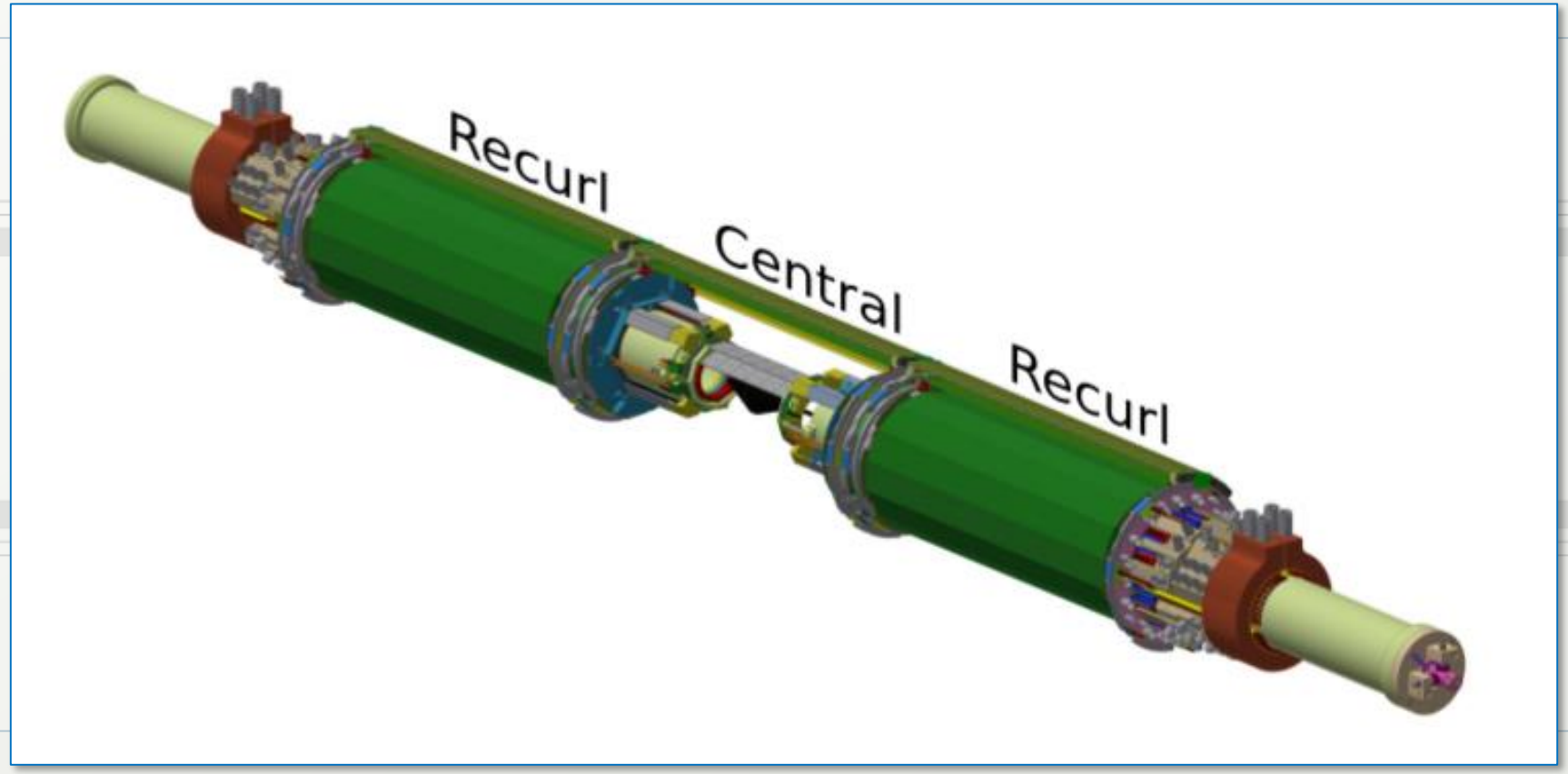
$$\mu^+ \rightarrow e^+e^-e^+$$

- Goal: find or exclude lepton flavor violating (LFV) decay at branching fractions above 10^{-16}
- Why? LF symmetry is a broken one – LFV observed in the neutrino sector
- High sensitivity in terms of branching ratio is expected for $\mu \rightarrow eee$
- Leads to physics beyond the Standard Model

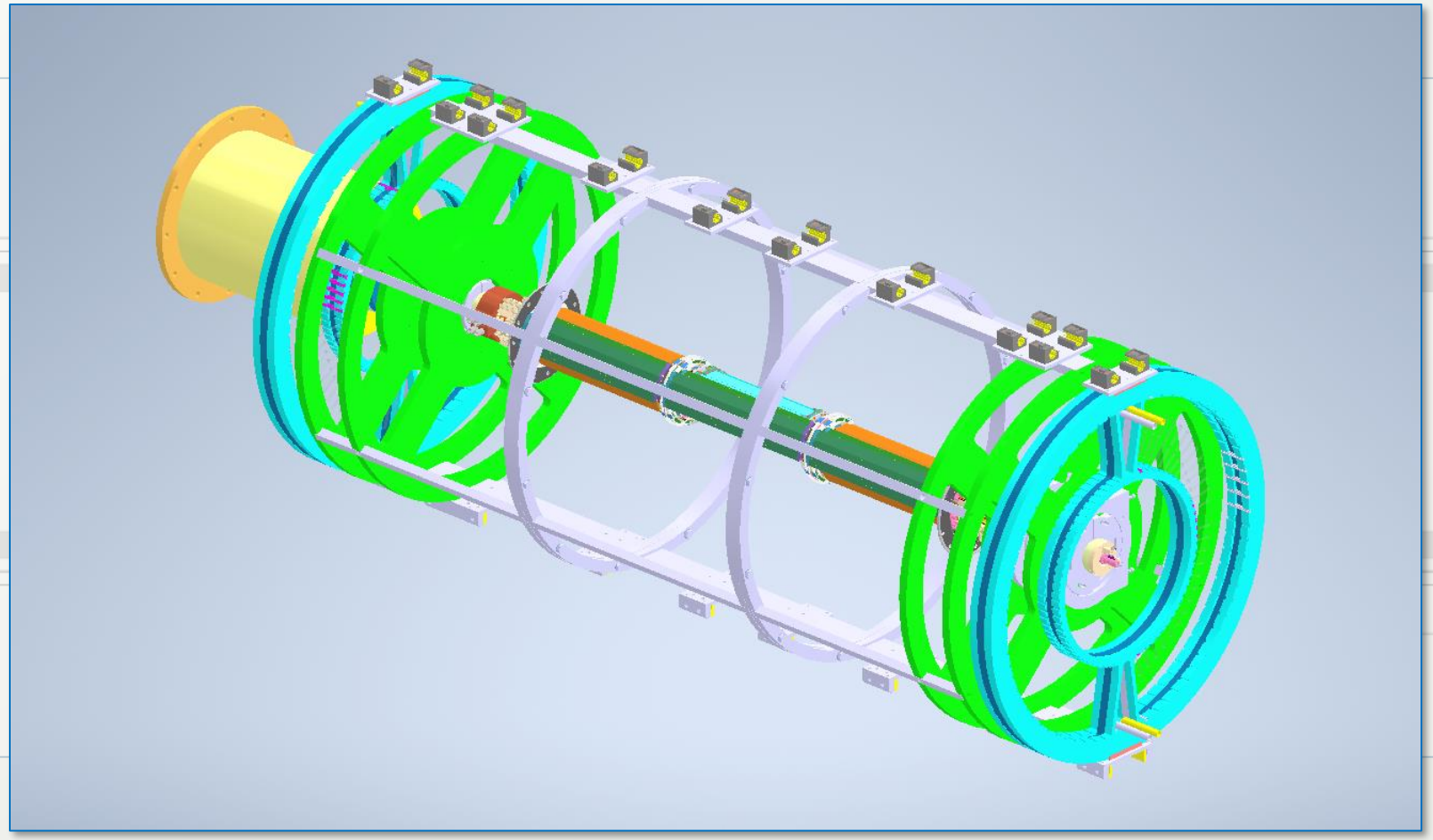
Mu3e experiment



Mu3e experiment



Mu3e experiment



Track based alignment

- Misalignment – huge issue in particle trackers

- Fit individual particle tracks with a model
- Find residuals

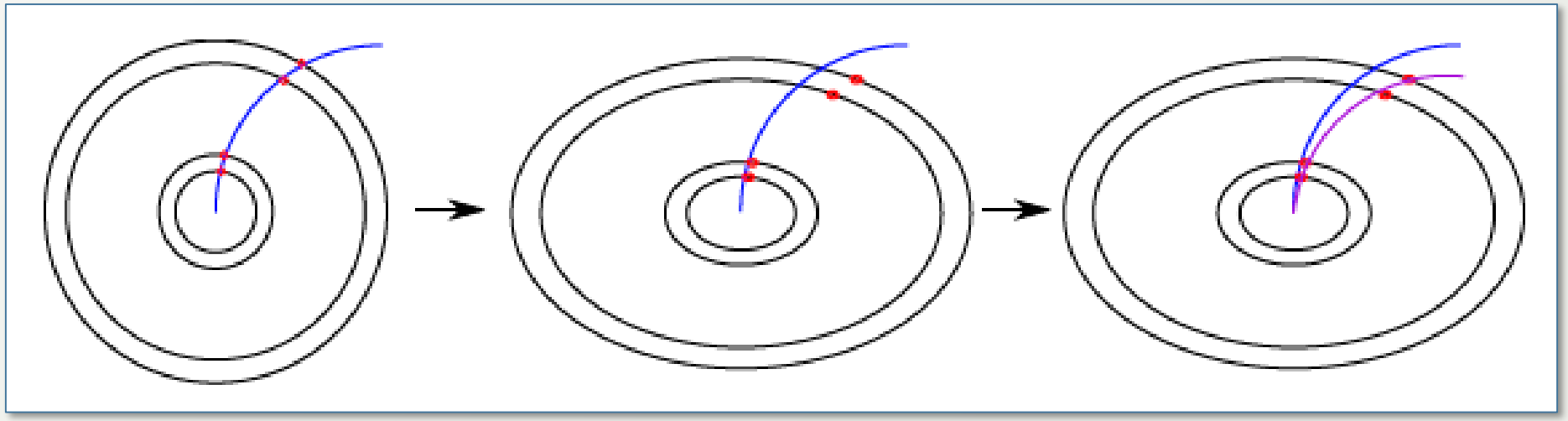
$$r_{ij} = m_{ij} - f(\boldsymbol{q}_j, \boldsymbol{p})$$

- Minimize the χ^2 function to obtain optimal combination of track and global parameters

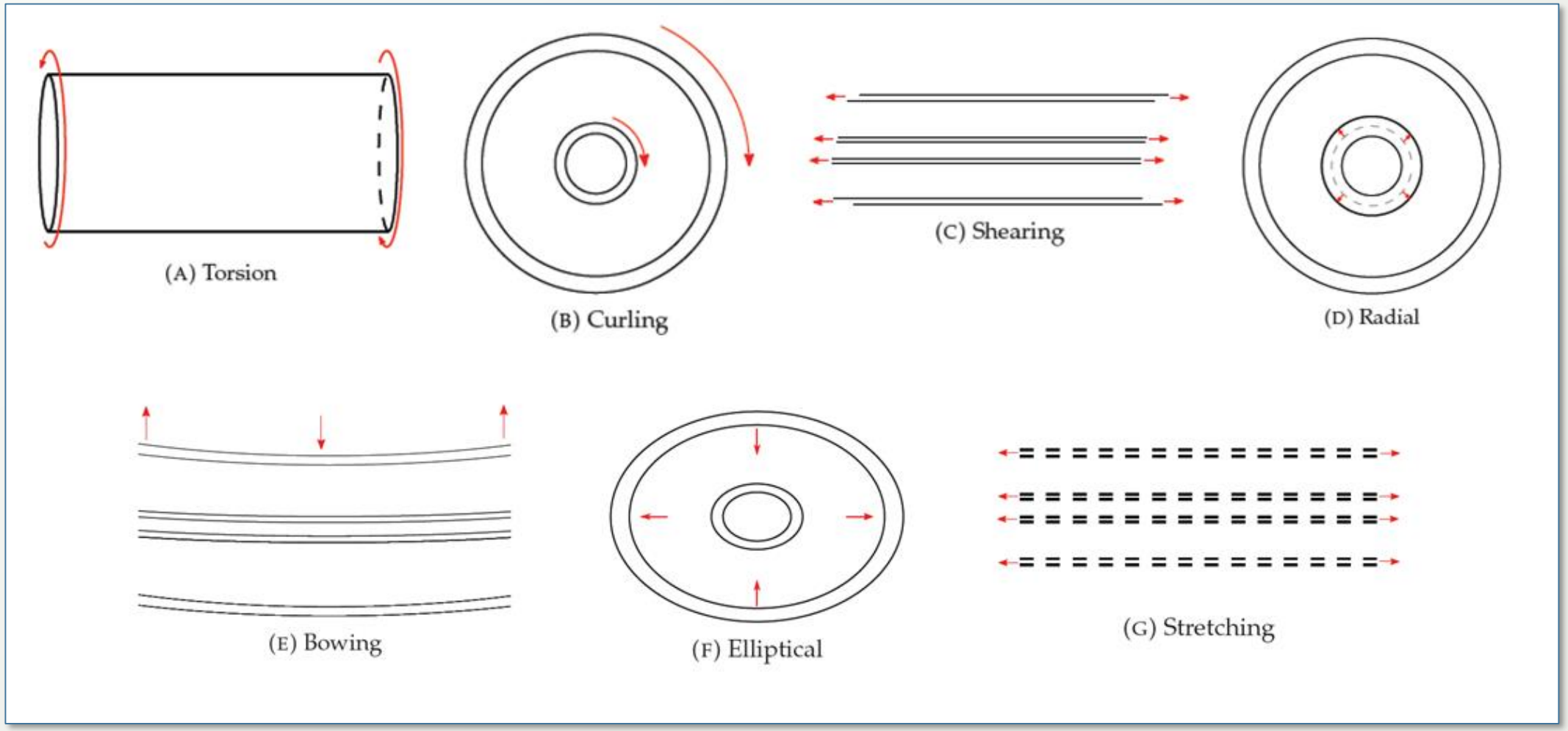
$$\chi^2(q_j, p) = \sum_{j}^{tracks} \sum_{i}^{hits} \left(\frac{r_{ij}}{\sigma_{ij}}\right)^2$$

Weak modes

- Tracker deformation modes that do not influence the χ^2
- **True** track will have a worse χ^2 after deformation, but another track can be reconstructed with the same χ^2 as the original one



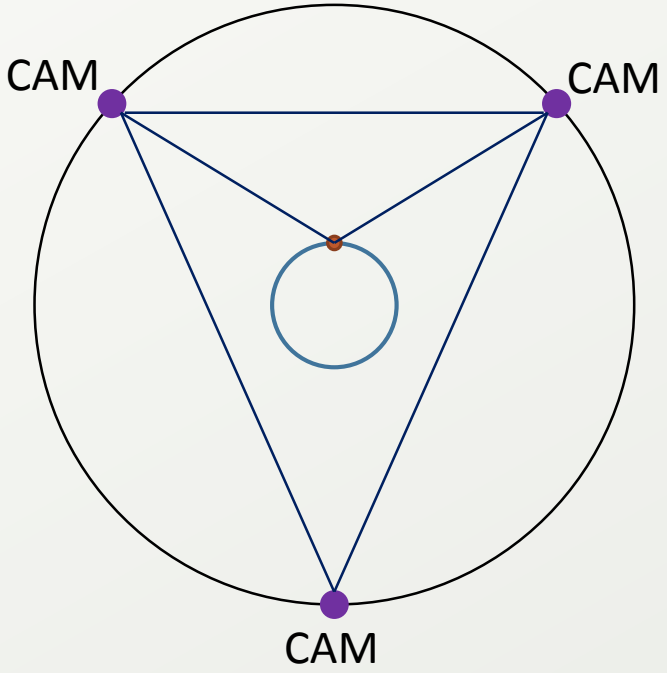
Weak modes

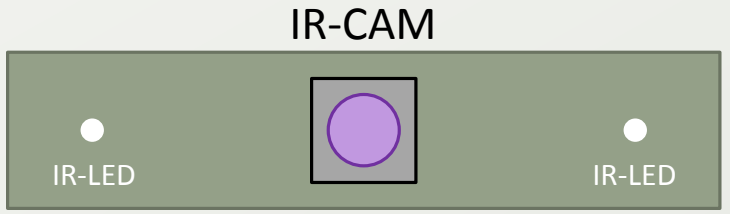

(A) Torsion
(B) Curling
(C) Shearing
(D) Radial
(E) Bowing
(F) Elliptical
(G) Stretching

Solution to weak modes

- Utilizing tracks of different topology than the ones coming from muon decay
  - Cosmic muons
  - Reconstructed tracks from Mott scattering
- High precision detector position measurement with cameras

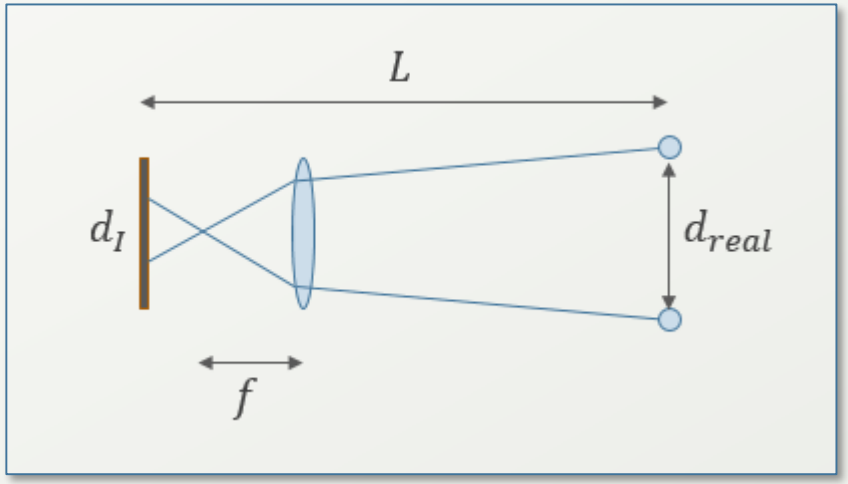
Camera alignment system





Camera alignment system

- Basic geometric optics
- Known distance between two LEDs → distance between the cameras

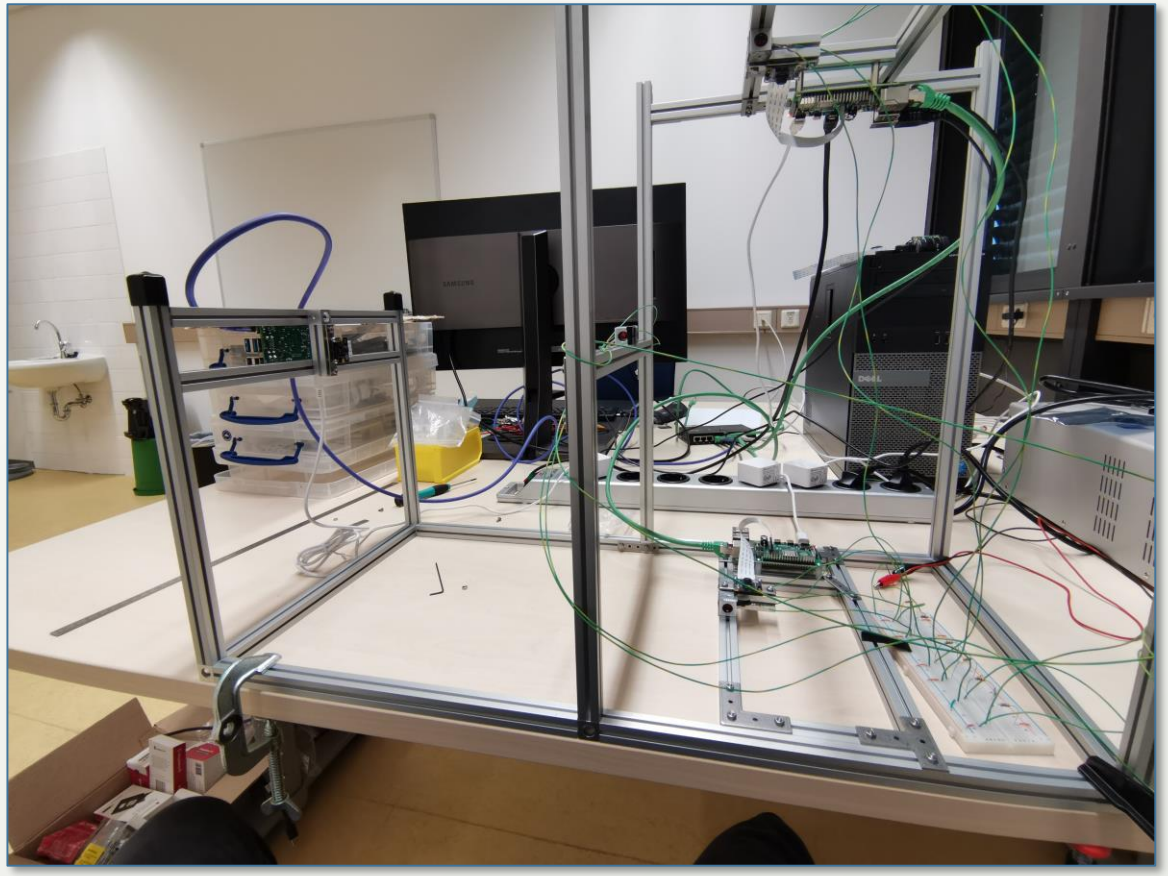


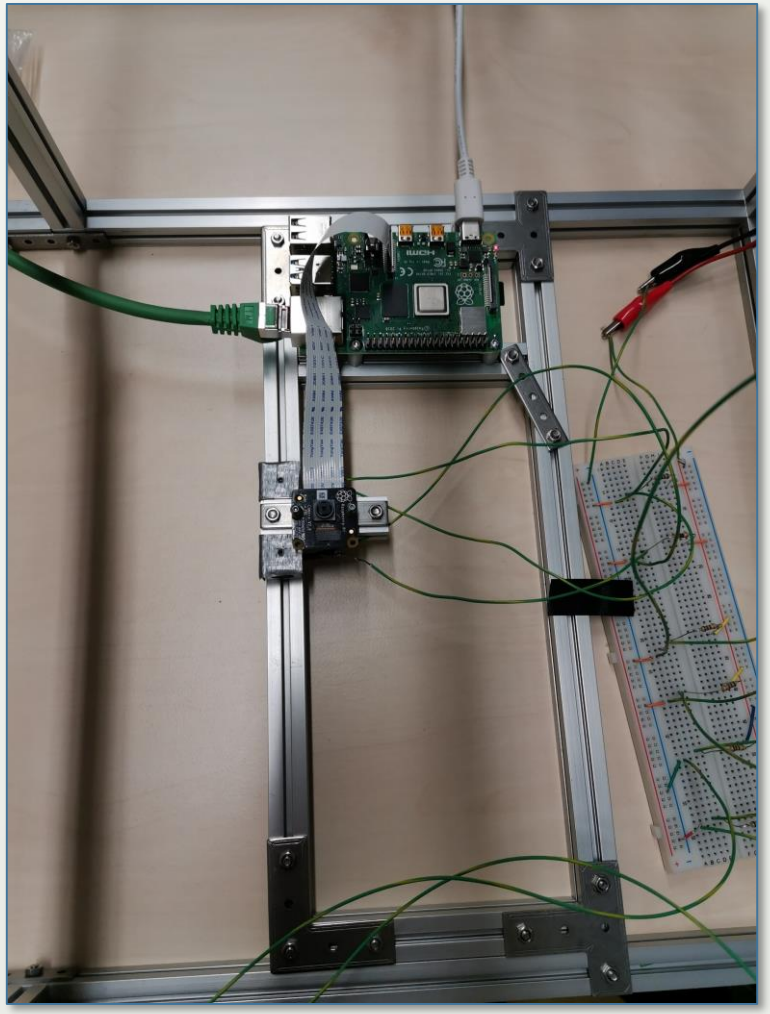
$$\frac{d_I}{d_{real}} = M = \frac{f}{f - L}$$ [5]

- Sub-pixel resolution achievable – very important for micrometer precision

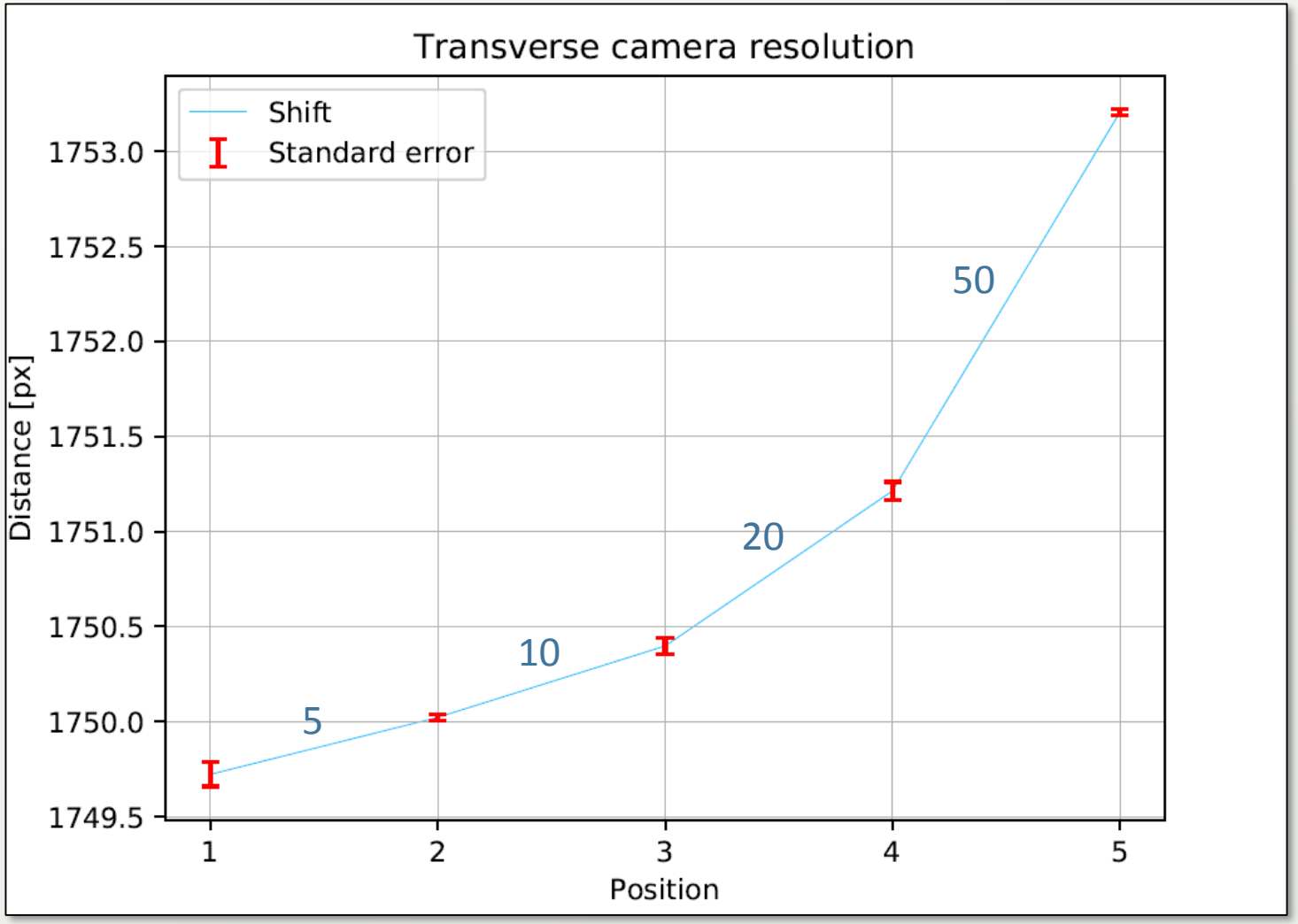
Set-up

- Raspberry Pi and IR-camera ~100e

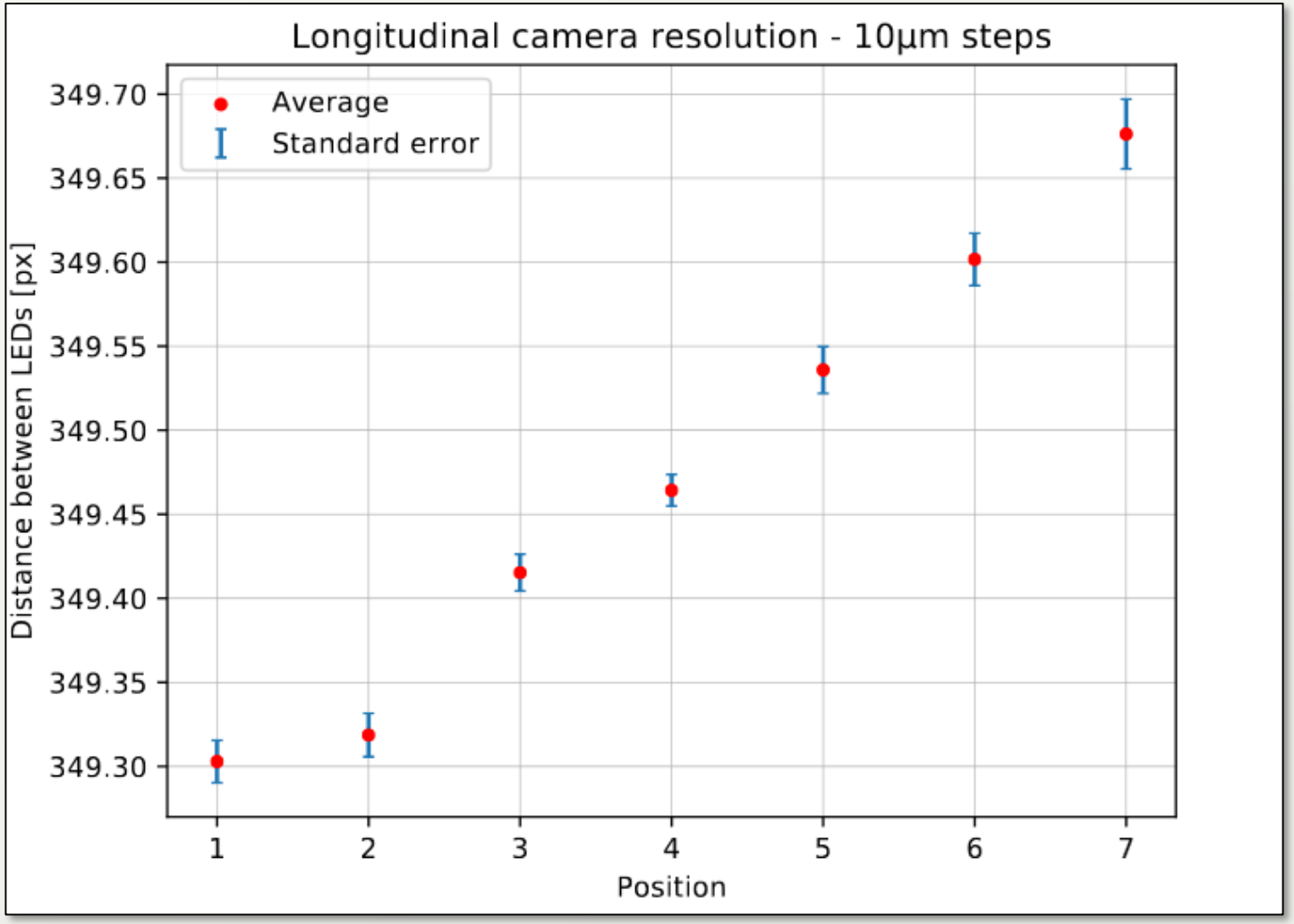




Preliminary results



Preliminary results



Recap and outlook

- PSI and search for a lepton flavor violating decay in the Mu3e experiment

$$\mu^+ \rightarrow e^+ e^- e^+$$

- Track based alignment and weak modes
- Development of a camera alignment system
- Resolution in transverse plane 5 µm, in longitudinal direction 10 µm

References

[1] Paul Scherrer Institute, *https://www.psi.ch/en*

[2] N. Berger, *Particle detectors – Lecture notes*, Johannes Gutenberg University, Mainz, Winter Semester 2019/20

[3] *Technical design of the phase I Mu3e experiment*, arXiv:2009.11690v2, 2021

[4] U. B. Hartenstein, *Track based alignment for the Mu3e pixel detector*, PhD Disertation, Johannes Gutenberg University, Mainz, 2019

[5] G. Cavoto et al., *A photogrammetric method for target monitoring in experiments with particle beams*, arXiv:2010.11576v1, 2020

[6] O. Aflak, *Ray-tracing from scratch in Python*, Medium, 2020