The Camera Alignment System for the Mu3e Experiment

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abstract

The Mu3e experiment under construction at the Paul Scherrer Institute, Switzerland, aims to search for the lepton flavour violating decay of a muon into one electron and two positrons with an ultimate sensitivity of one in 10^{16} muon decays. The Mu3e detector consists of High-Voltage Monolithic Active Pixel Sensors (HV-MAPS) for an accurate track and vertex reconstruction complemented with scintillating tiles and fibres for precise timing measurements. The individual subdetector systems are placed in the 1m diameter bore of a 1T superconducting magnet.

In order to achieve the high sensitivity goal, special attention must be paid to the exact alignment of the detector elements. Misalignment may occur not only due to the construction or integration of the different detector parts but may also be caused by environmental influences during the operation of the experiment. To reduce the effects of misalignment and to achieve the best possible momentum resolution, a track-based alignment program is used. With the help of this tool, however, certain deformations of the detector that produce the same track quality, the so-called weak modes, cannot be resolved. To compensate for this, an optical system based on 18 camera modules is also being developed. In combination with high contrast optical fiducials, the cameras determine their positions among each other and to the different detector elements. At the moment several combinations of camera settings and different fiducials are being tested in order to achieve a sufficient precision to fulfil the experimental objectives.

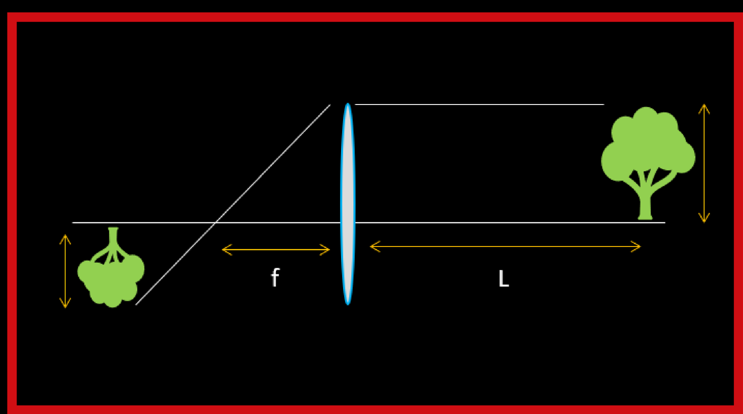
the basic principle

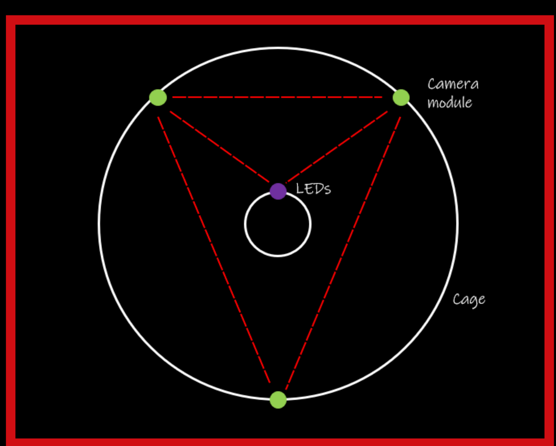
- Underlying principle: **magnification formula**

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

- connects the actual size of the observed object with its size on the image plane and the distance between
- If the size of the observed object and the focal length of the camera is known the distance can be determined:

$$L = f\left(1 - \frac{d_{real}}{d_I}\right)$$



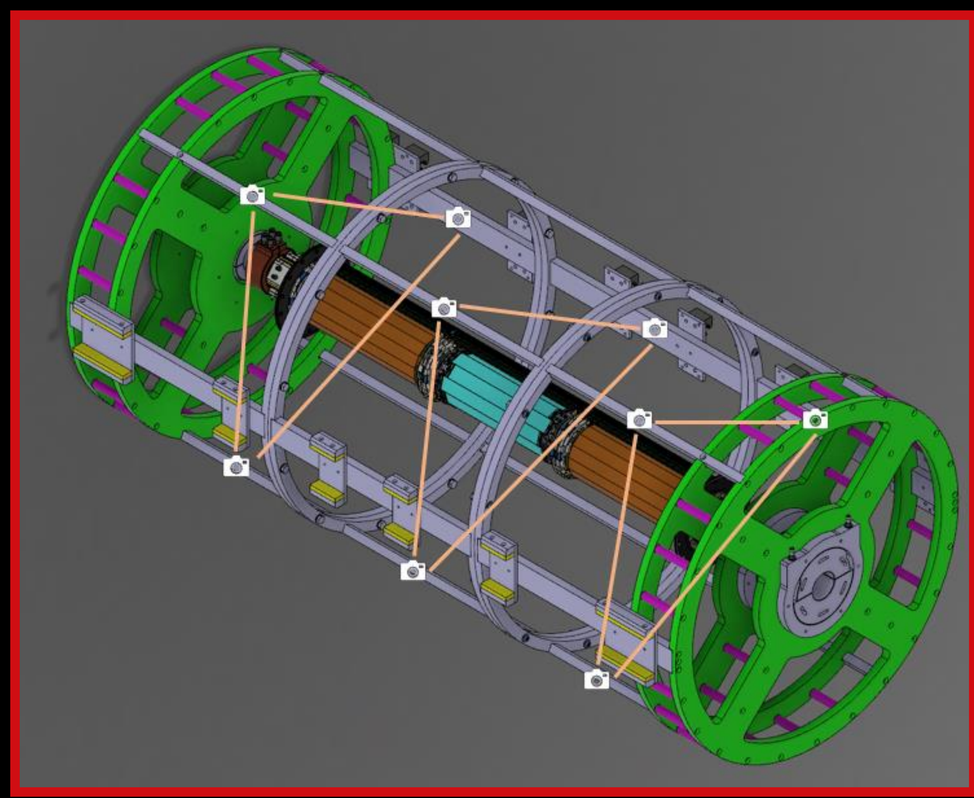


- One measurement setup consist of 3 camera modules
- One central camera and two modules with LEDs
- The distance between the LEDs represent the size of the object d_{reel} in the magnification formular

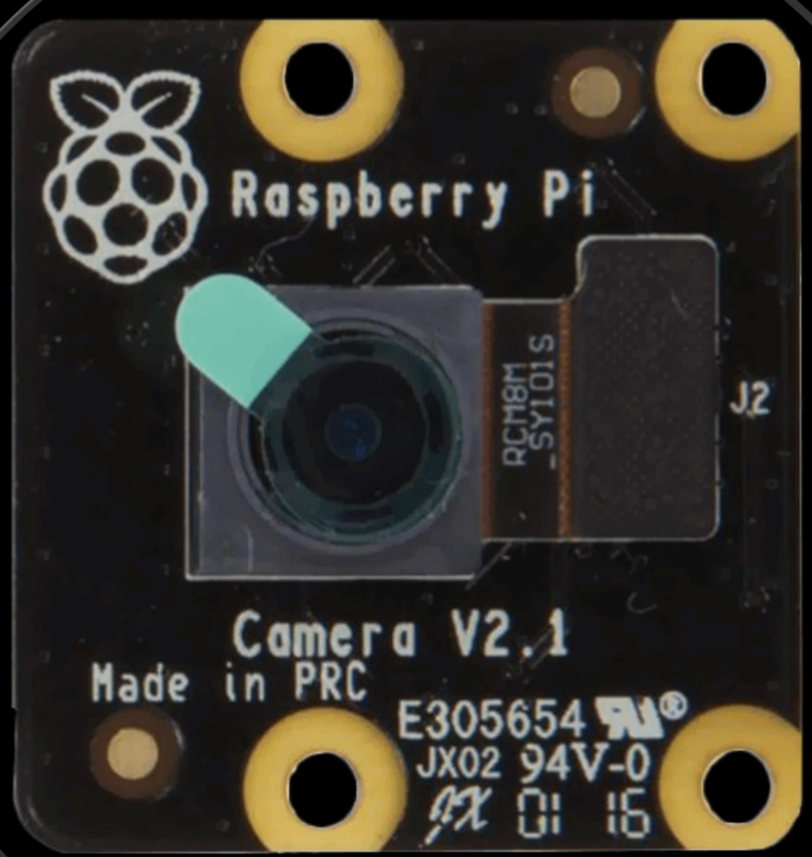
- There will be high contrast optical fiducial connected to the detector (LEDs in first place)
- The distances between all the objects in the setup can be measured
- Precise determination of detector position

camera module & setup

- The Mu3e detector can be divided into three segments
- Each segment will have fiducial at each end
- The camera angle is wide enough to cover the whole segment
- Per segment we will have 2 measurement setups
- This means 6 cameras per segment and 18 cameras in total to cover the whole detector

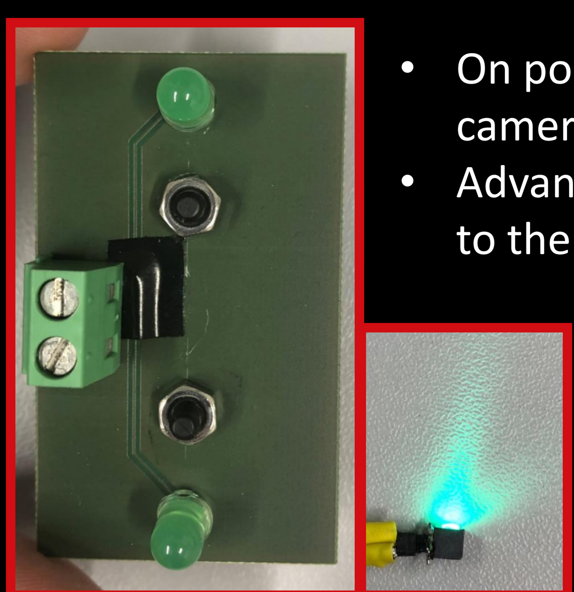


- The camera module is based on the Raspberry Pi v2 camera
- The camera itself will be integrated in the PCB with the LEDs in the final experiment



the fiducials

- On the detector side we need high contrast optical fiducials
- With a program we then find the centre of gravity of this point
- Advantage: you still can measure precisely even if the object is out of focus



- On possibility is to use LEDs like at the camera modules
- Advantage: LEDs provide a very high contrast to their surroundings
- Disadvantage: the space in this area is very limited; mounting them and laying cables is very difficult; the risk to damage the detector is high

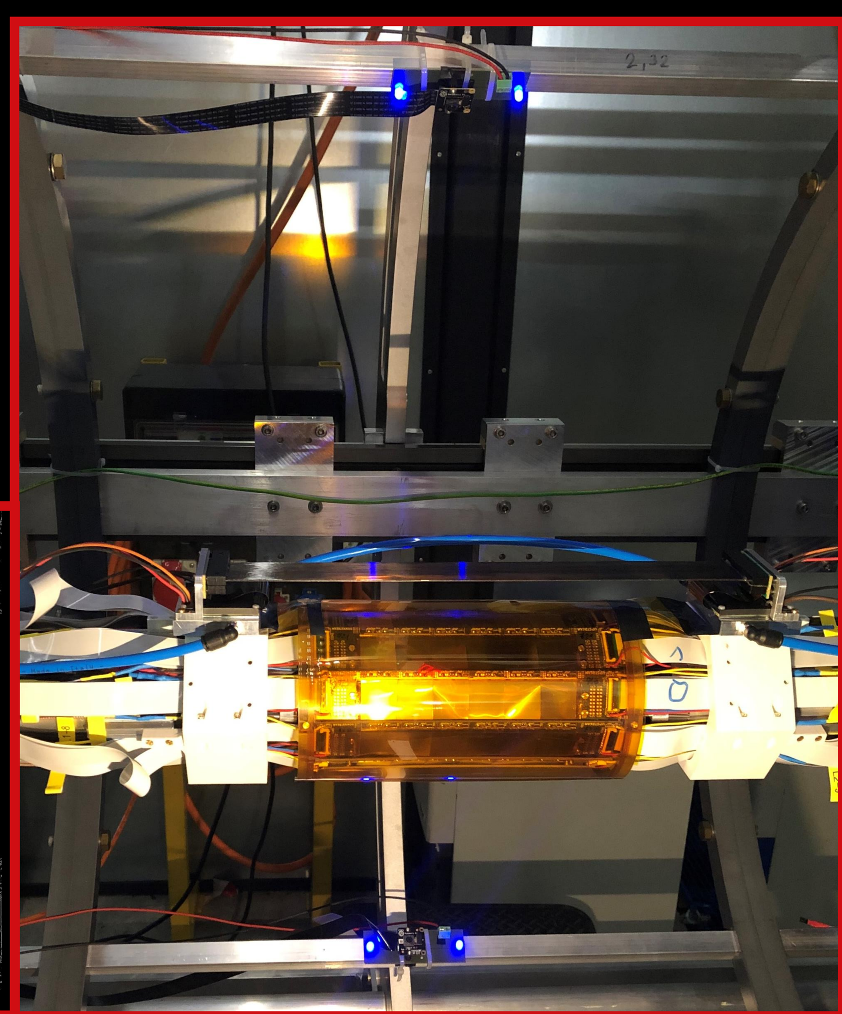
- A non electrical solution is to use so called tooling balls
- They have a reflecting area and can be lightened by the camera modules

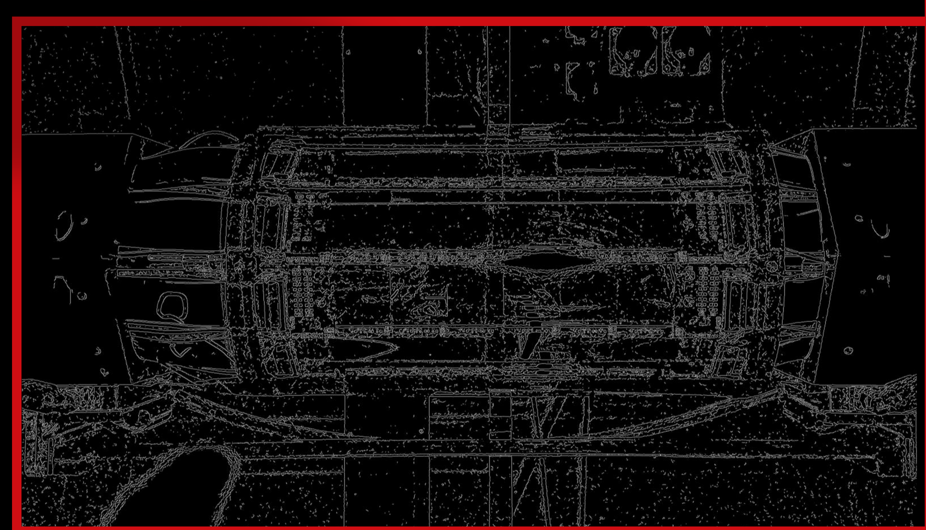
Disadvantage: they are too big for the available space

- Currently a tape with retro reflective tape is tested
- They deliver a very good contrast
- The mounting is easy and space efficient
- There are still a few issues to be investigated regarding durability

integration & first tests

First integration in May 2022





- In parallel the option to use the detector as a fiducial and to use pattern recognition to determine the distance was tested

- This option could then be used as a addition to the optical fiducial system

www.psi.ch/mu3e