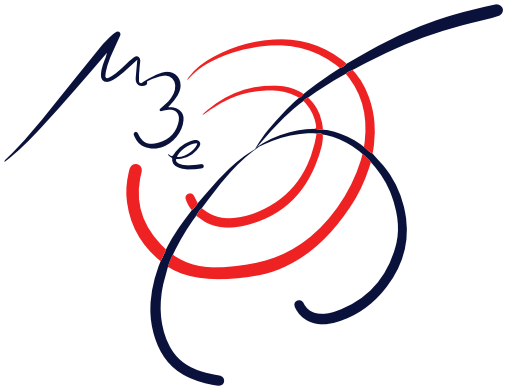
Track-based alignment with cosmic muons



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Cosmics Meeting, April 2020

Track based alignment

- Have to find the positions, orientations, timing offsets and deformations of
  - ~ 3000 pixel sensors
  - ~ 3000 fibres
  - ~ 6000 tiles
- Best done using reconstructed particle tracks and the Millepede II algorithm (V. Blobel & C. Kleinwort)
- Studied extensively for the Mu3e pixels by Uli Hartenstein "Track Based Alignment for the Mu3e Pixel Detector", Ph.D. thesis, Mainz 2019
- Software for misalignment simulation studies and pixel alignment available
- Studies for fibres started at UCL - difficult because of fibre-SiPM mapping

Millepede in a nutshell

- Select a pure sample of particle tracks and fit them (ideally using the general broken lines model)
- Determine the residuals of the fitted track relative to the measurement points
- Define a global χ^2 (Σ (residuals/uncertainty)^2) as a function of both the track parameters and the alignment parameters
- Linearize the problem, determine all relevant Jacobians
- Perform a gigantic matrix inversion (helped by the peculiar matrix structure)
- Repeat if needed (needed fairly often in Mu3e as things are not very linear)

Weak modes

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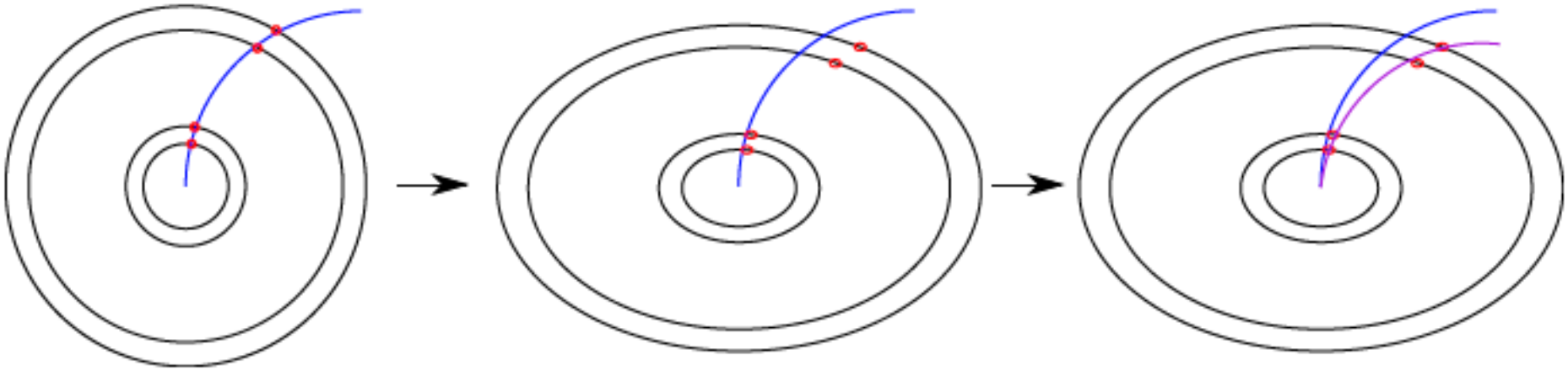
- They cannot be aligned for using tracks only



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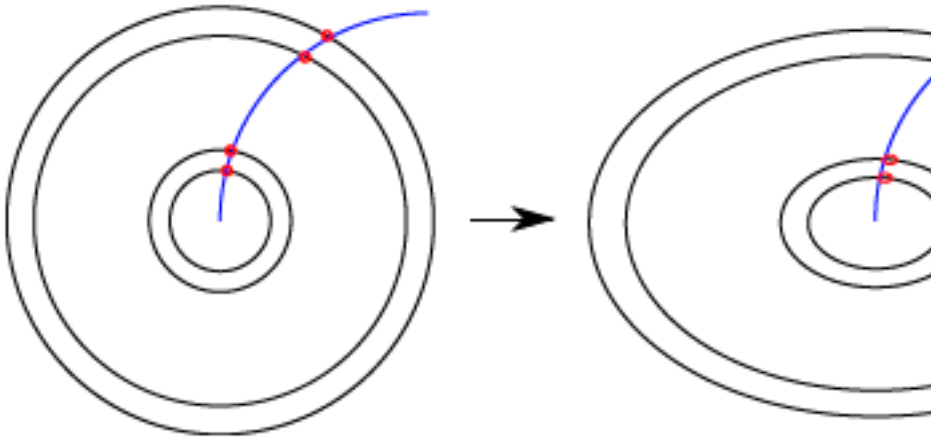

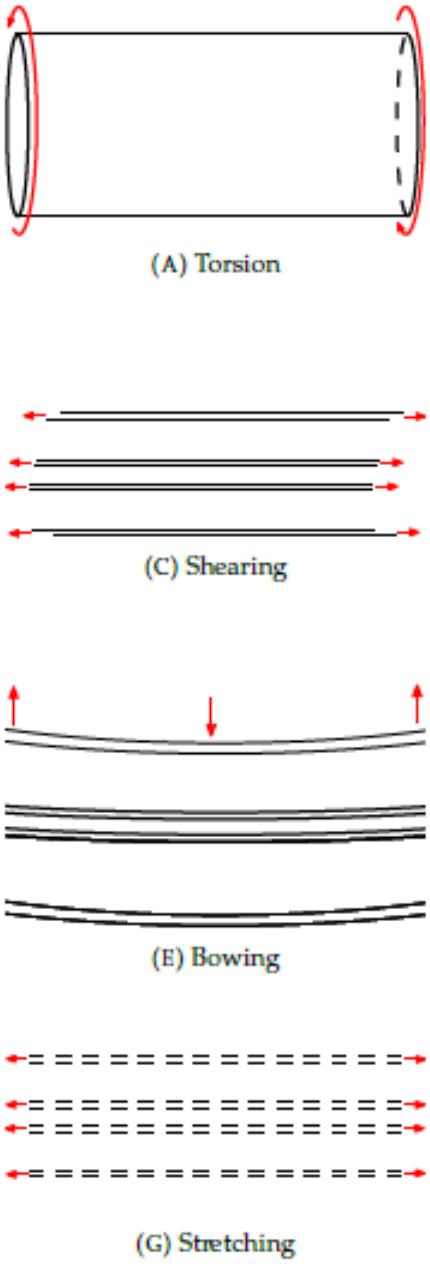

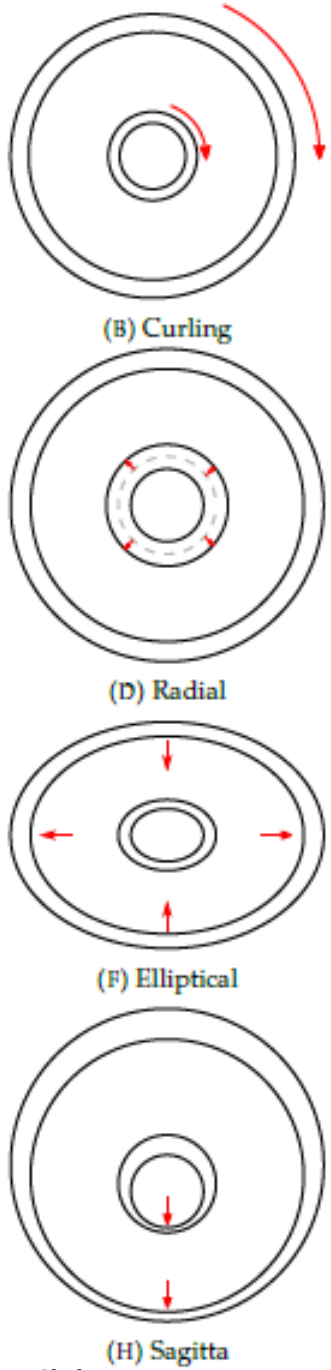

Fighting weak modes

- Use many different track types:
  Michel decays and cosmics and ...
- Use additional constraints
  (the position of the Michel edge does not depend on ϕ - or does it?)
- Use external measurements: Camera alignment system

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Somewhat unpleasant:

- Low rate: A few Hz for the size of Mu3e
- Strong directional dependence: Mostly from above
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Cosmic data taking

- If no beam: easy, pixel noise could be low enough to allow for a simple multiplicity based online selection
(tracking not much harder)

- With beam (and we would like to have this to see movement or better the absence thereof) this is harder

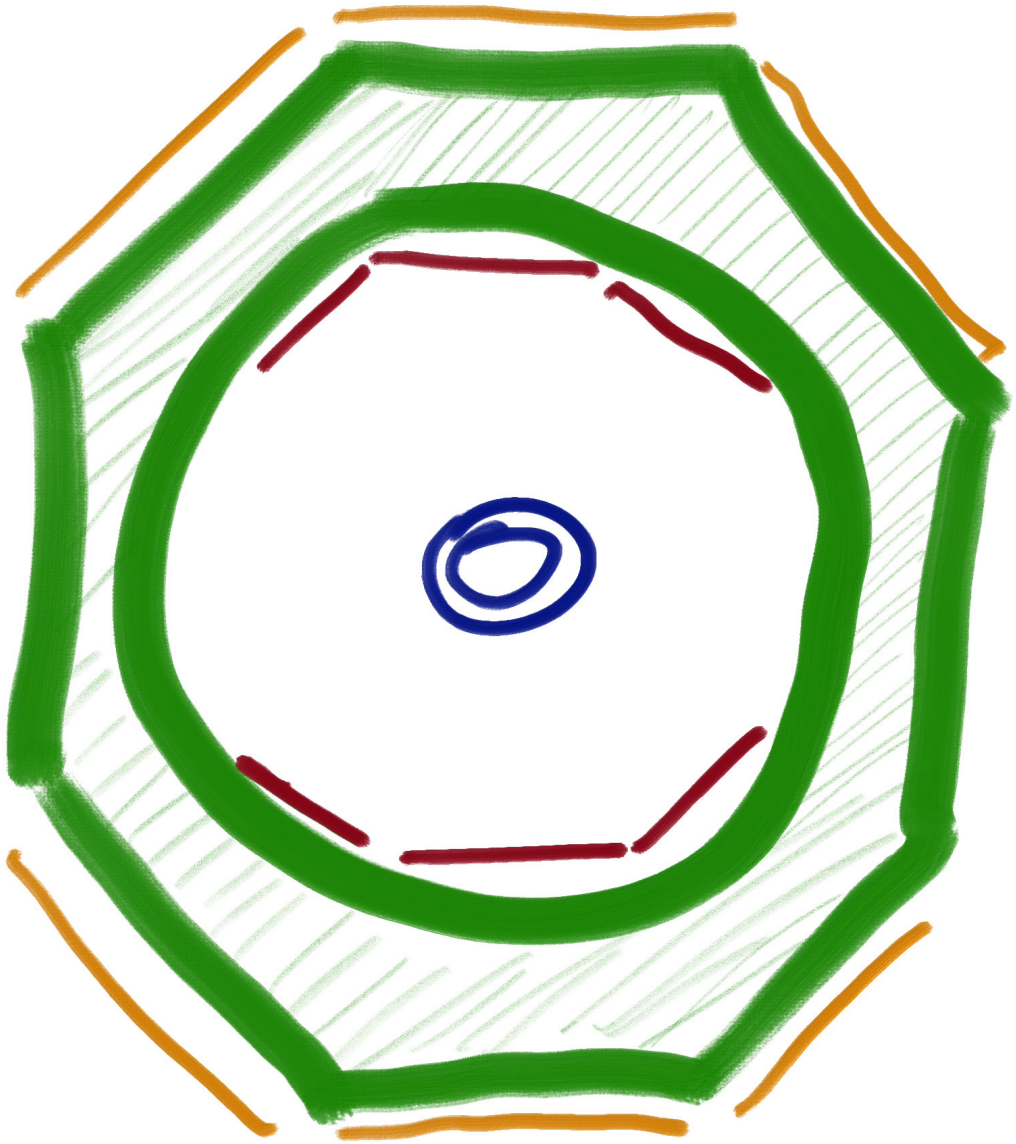
Two options:

- Online cosmic finder
- External trigger

Cosmic trigger

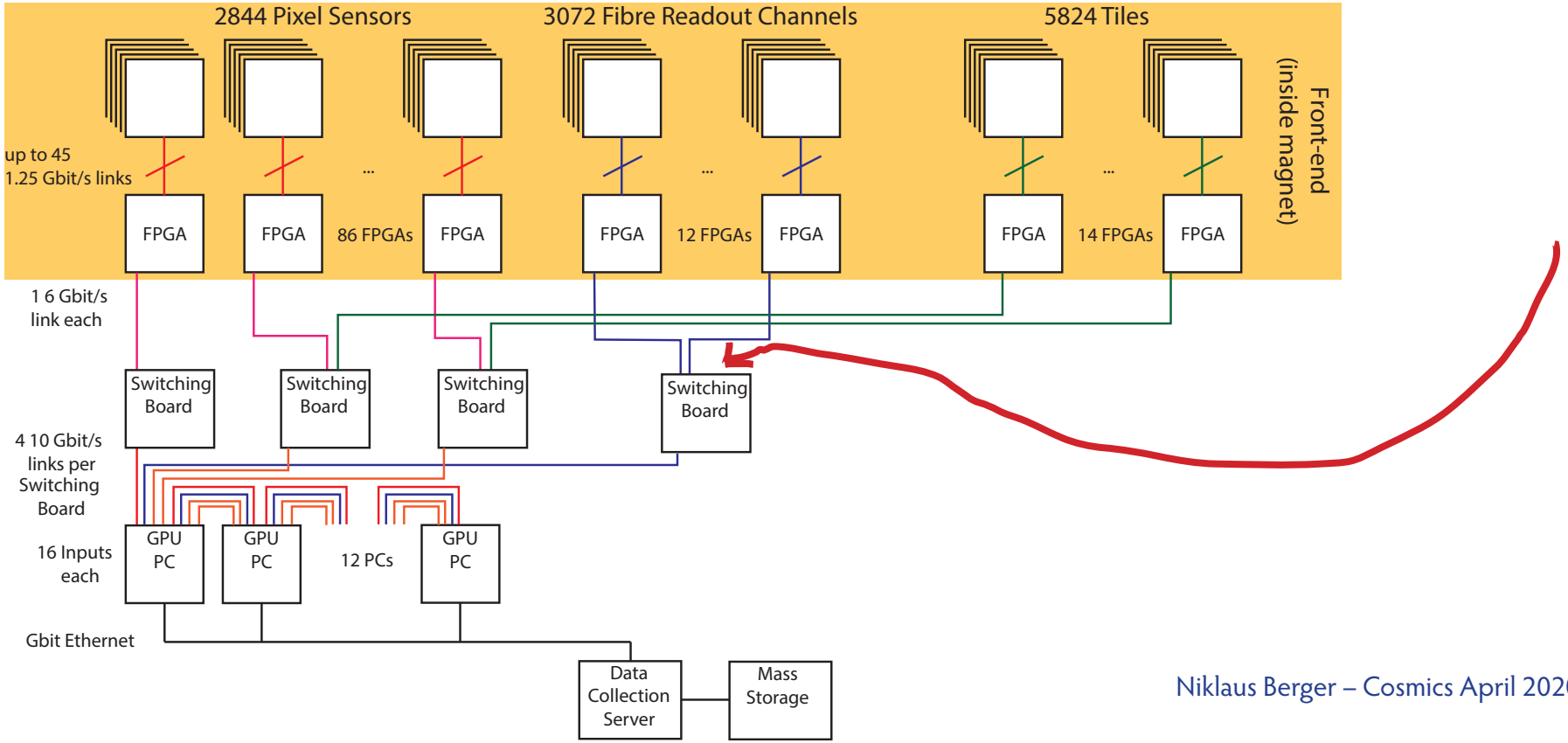
- Scintillator coincidences above/below the detector
- Inside or outside the magnet?
- The usual questions: Mechanics, Cabling, Power etc...

- Version inside magnet was simulated, rates to high



Cosmic trigger

- Not a big issue for the DAQ: Feed discriminated signals from scintillators into an FPGA (connected to clock and reset)
- Determine timestamps of coincidences
- Feed those into the GPU farm either via switching boards or ethernet
- Save events with a cosmic



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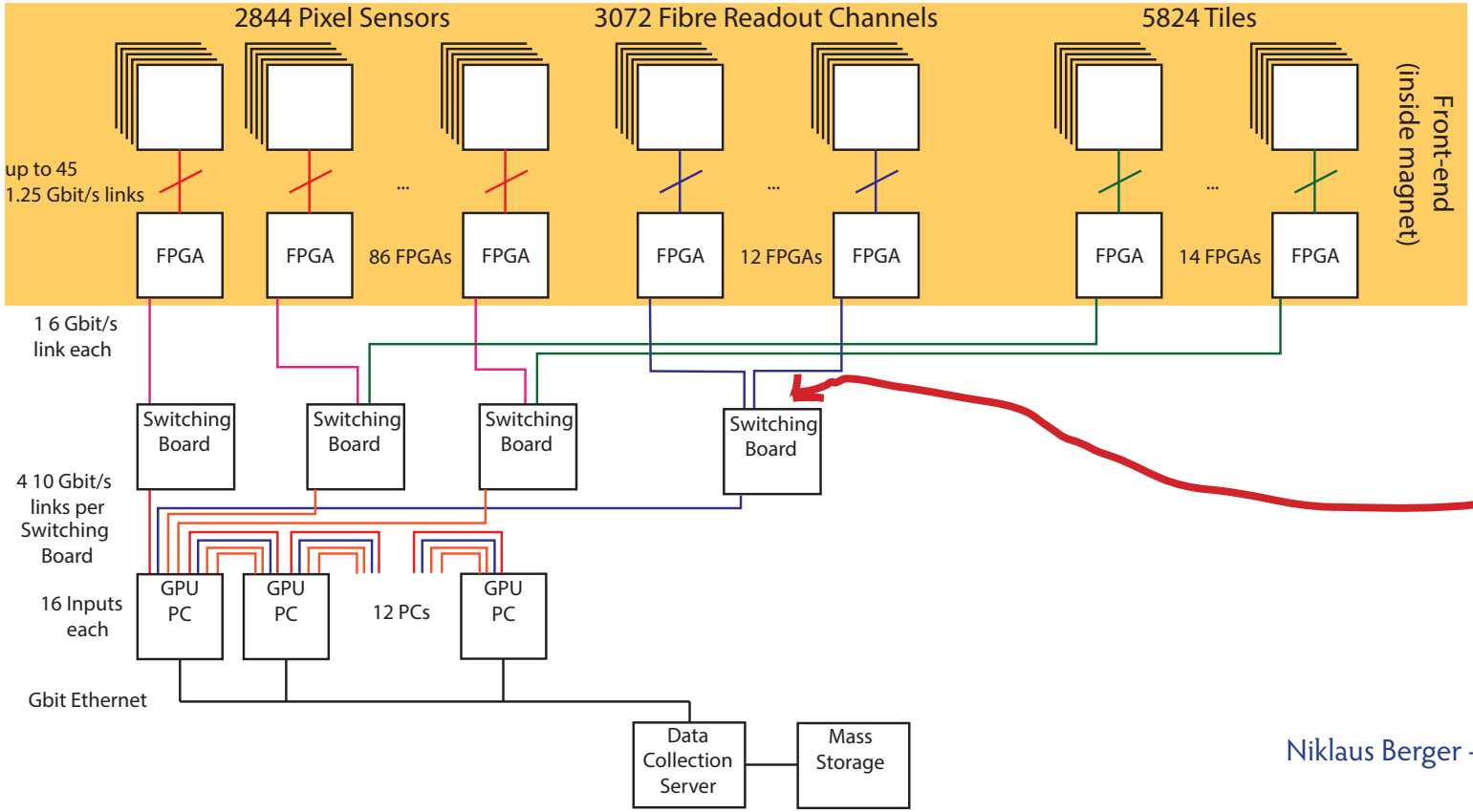

Might also come in handy for other calibrations?

Online cosmic finder

Again two options:

- FPGA based: Maybe this can be done based on pixel chip patterns only
  (Martin)

- Or we have to extend the GPU algorithm:
  How does that fit in our compute budget?
  (Needs preselection)

- Using associative memories either for pre-selection or selection
  (Today)

Online cosmic finder

- Not a big issue for integration to the DAQ: Add additional box(es) at the end of the farm daisy chain
- 16 10 Gbit/s links (4 of which only fibres)
- Maybe some GPU reconstruction, save events via ethernet