Track Based Alignment of the Mu3e Detector

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for the Mu3e Collaboration

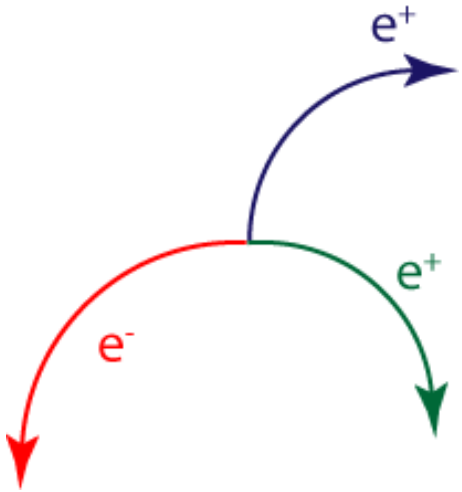
DPG-Früjahrstagung 03.03.16

1. The Mu3e Experiment
2. The Detector
3. Misalignment Studies
4. Alignment Strategy

The Mu3e Experiment

Goal

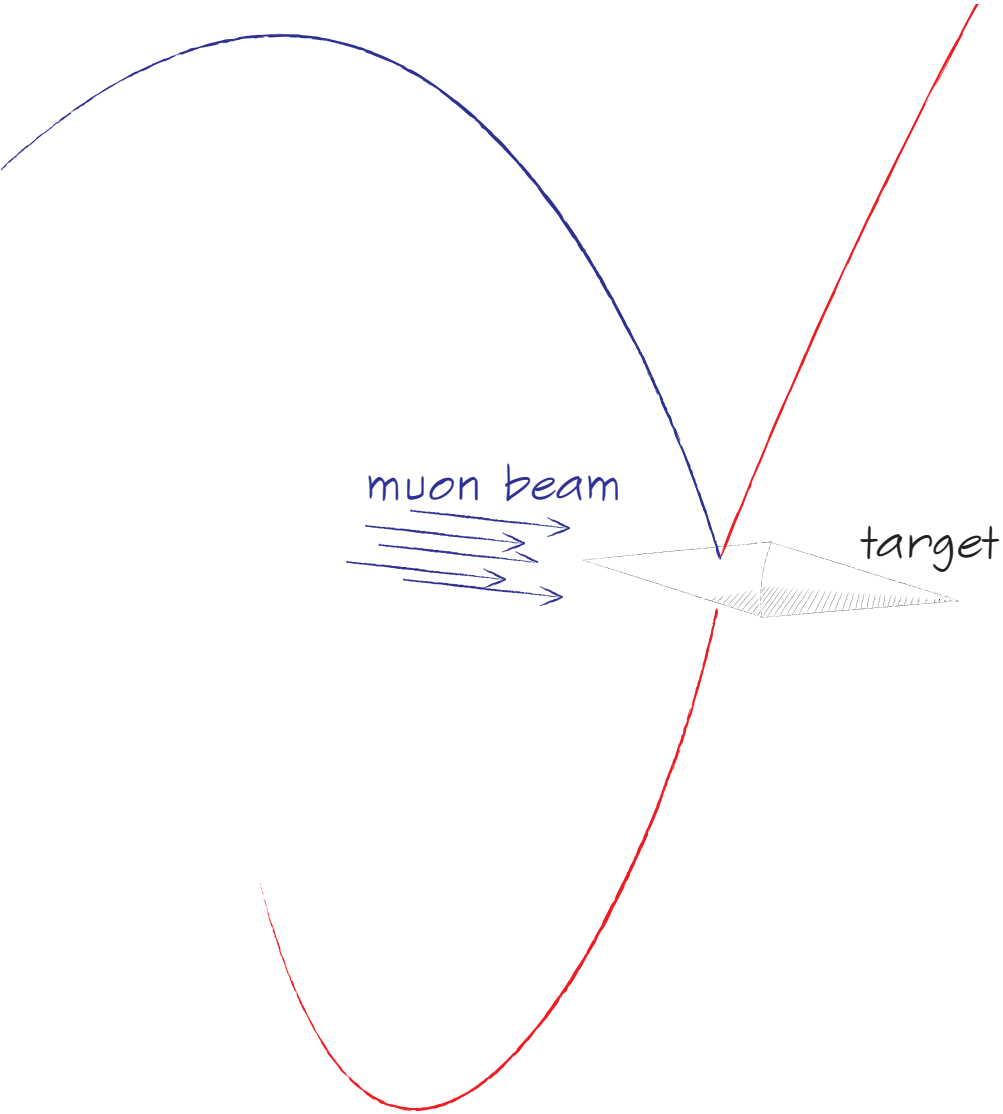
Observe
$\mu^+ \to e^+ e^- e^+$ if $\mathcal{BR} > 10^{-16}$
or
exclude a $\mathcal{BR}$ of $> 10^{-16}$ with CL=90%



Motivation

- in SM suppressed by $\mathcal{BR} < 10^{-54}$
  - new physics?!
- current status (SINDRUM 1988): $\mathcal{BR} < 10^{-12}$

Building the Detector



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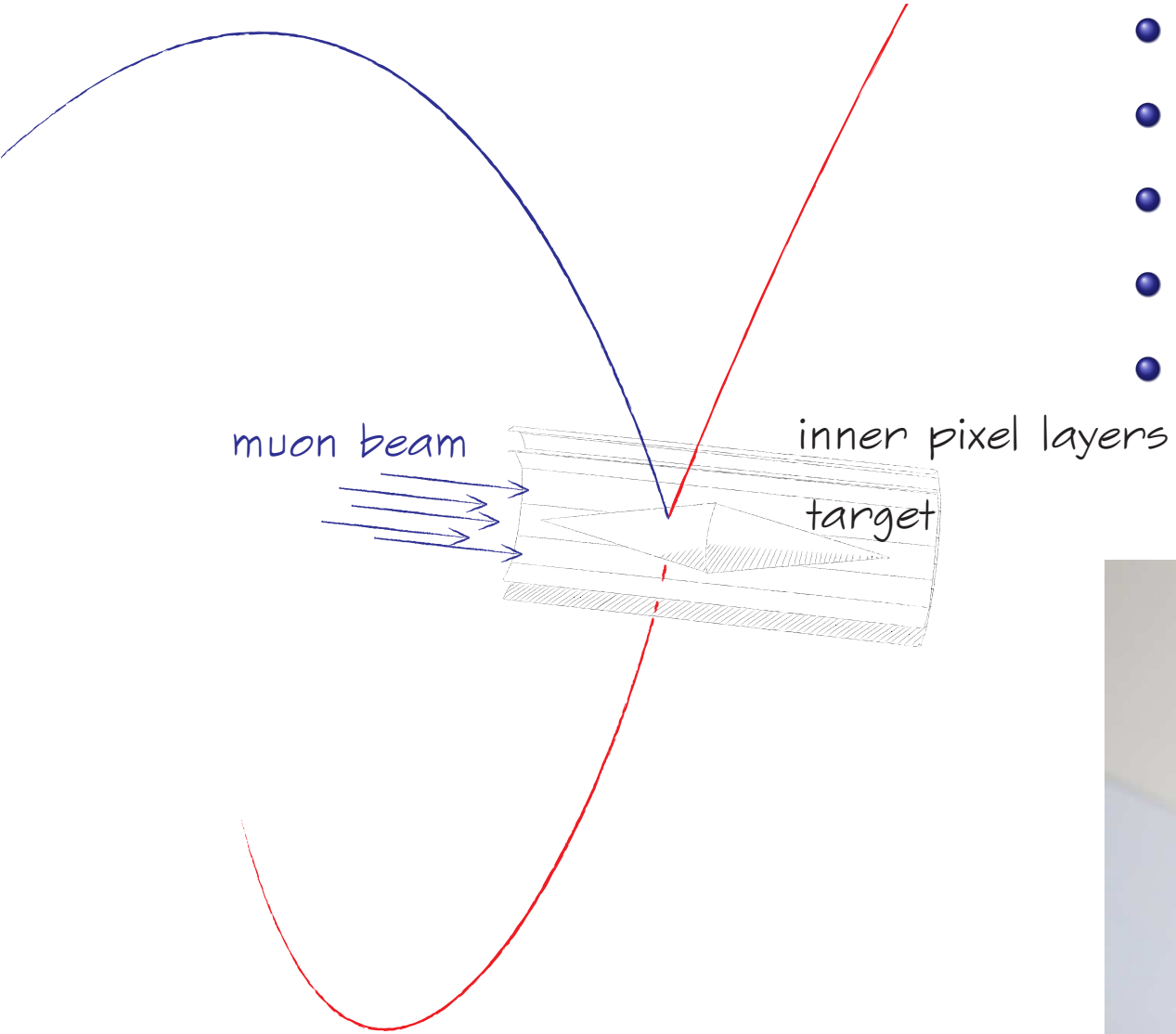
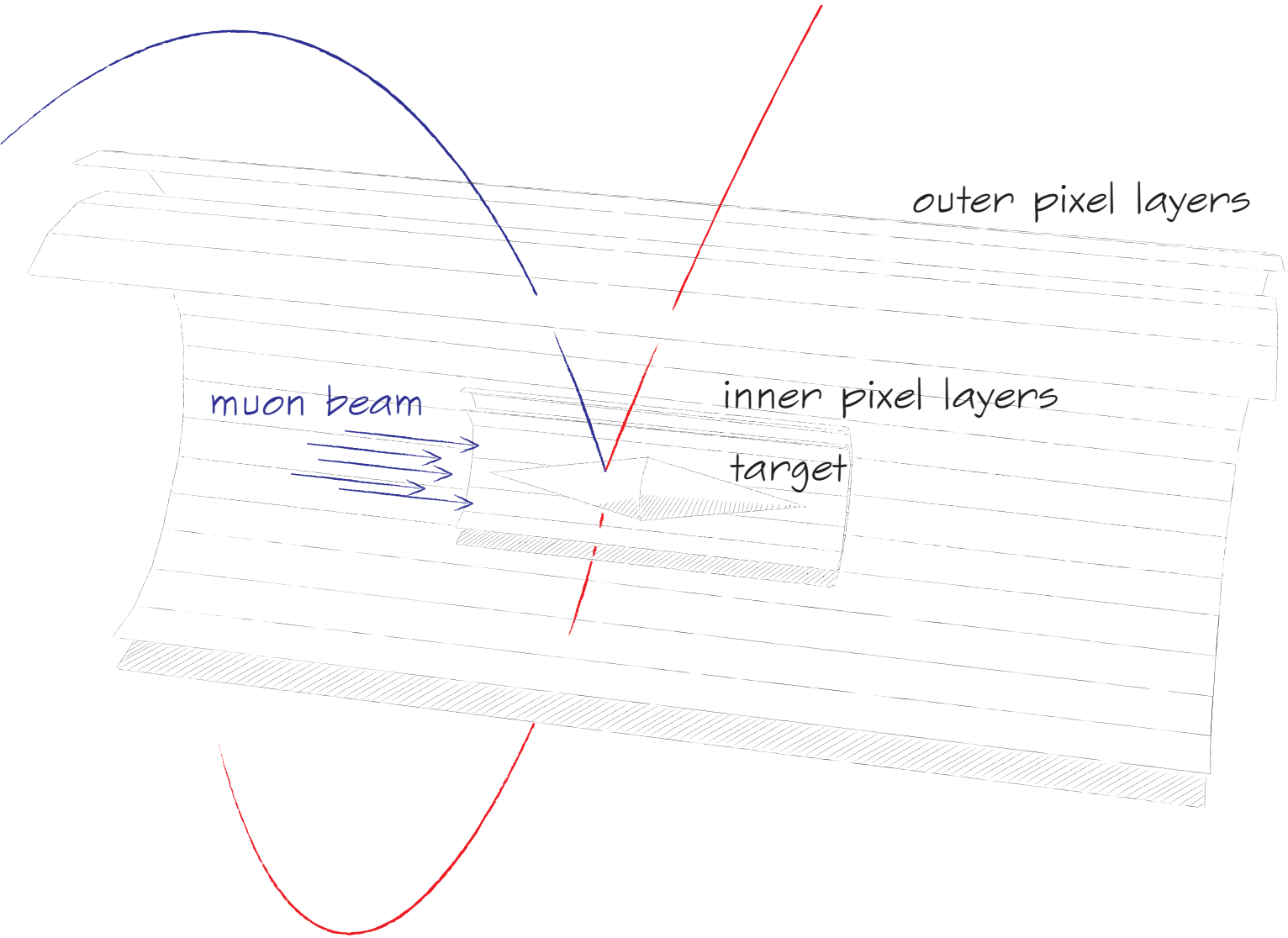
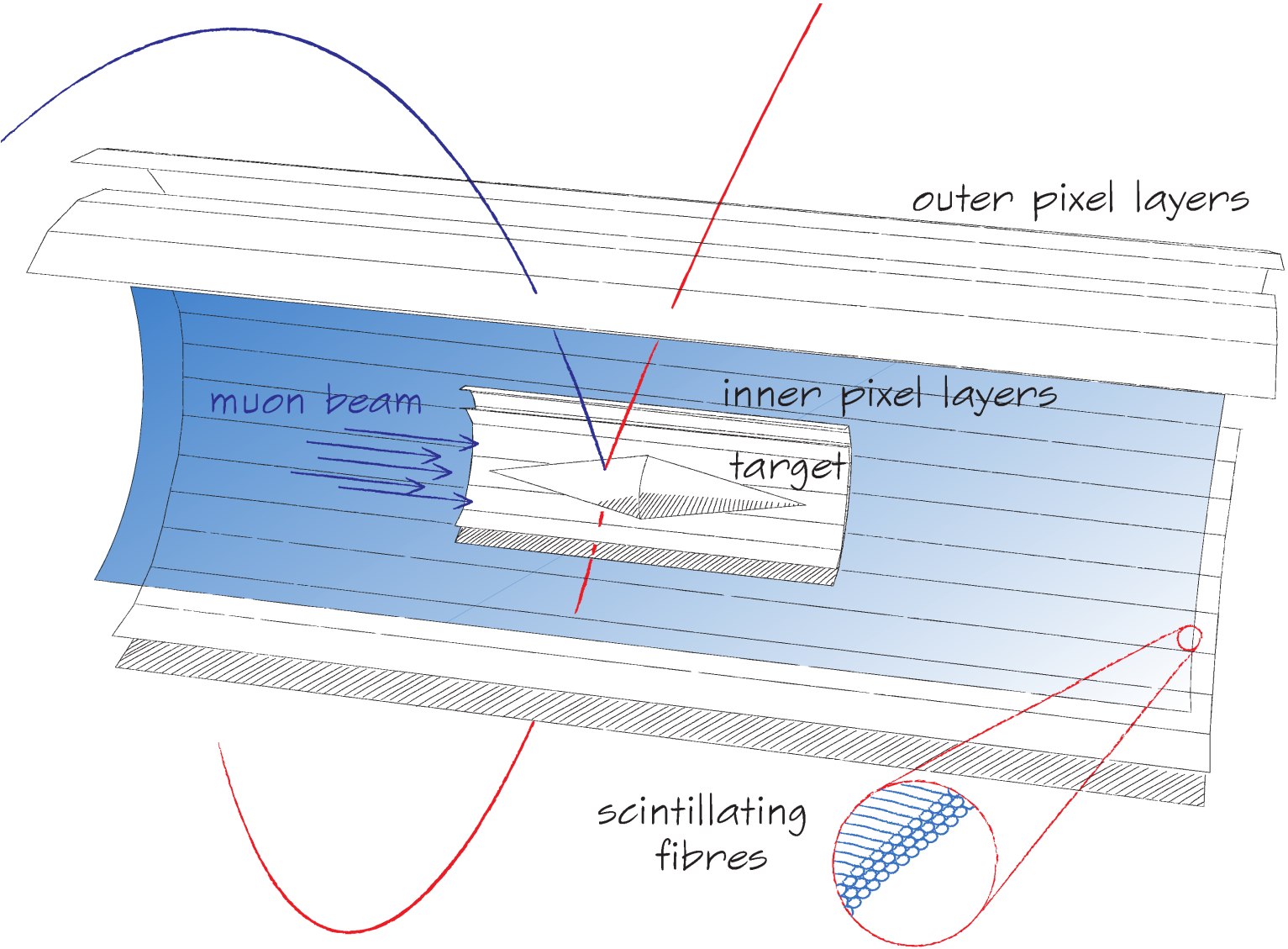


- HV-MAPS
- pixel size $= 80\mu m$
- mount to $2x2cm^2$ *sensors*
- thinned to $50\mu m$
- Kapton as support structure

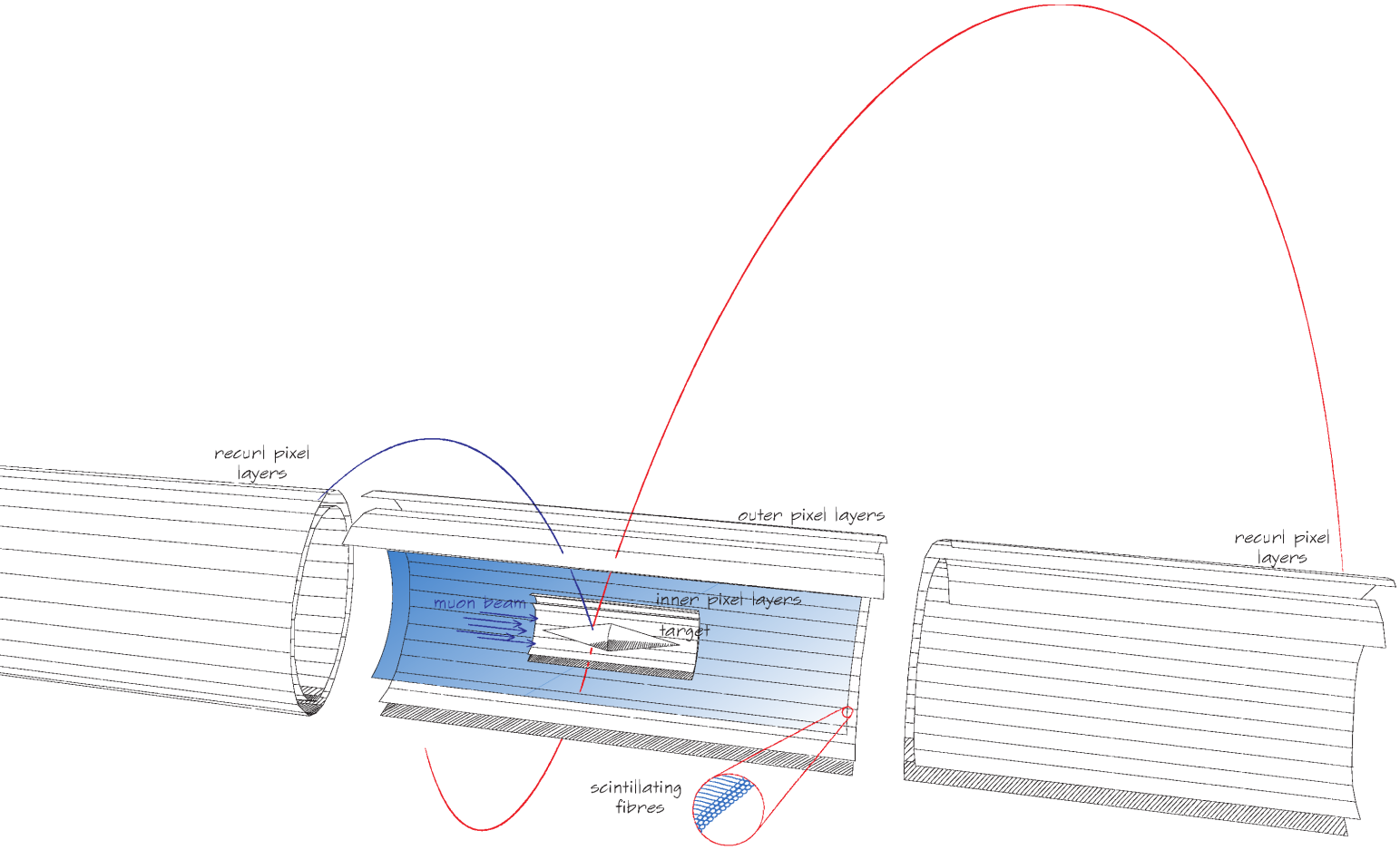
Building the Detector



Building the Detector



Building the Detector



Building the Detector

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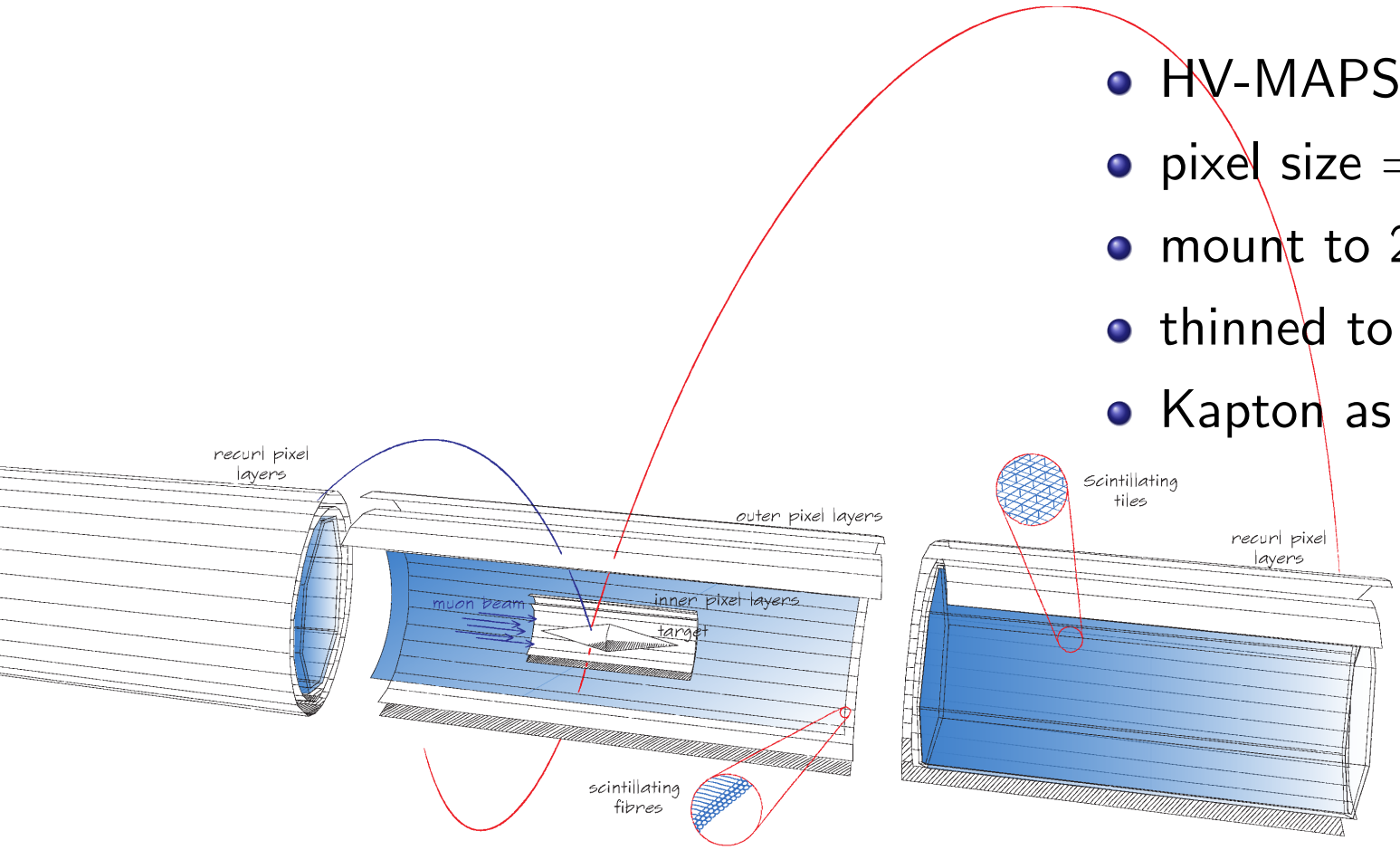
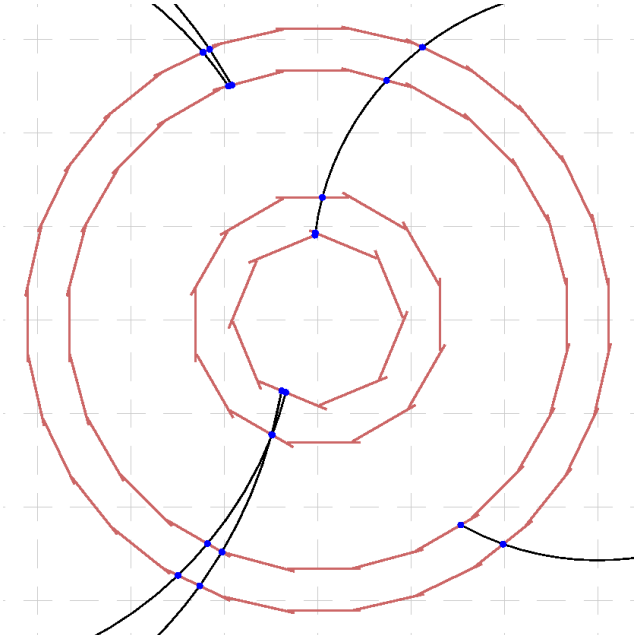


impossible to have sufficient alignment after construction!

Misalignment

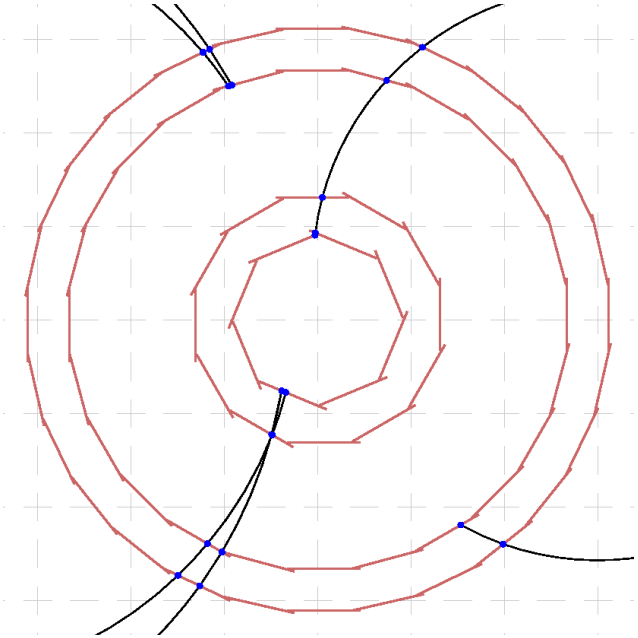
xy-view of the silicon sensors



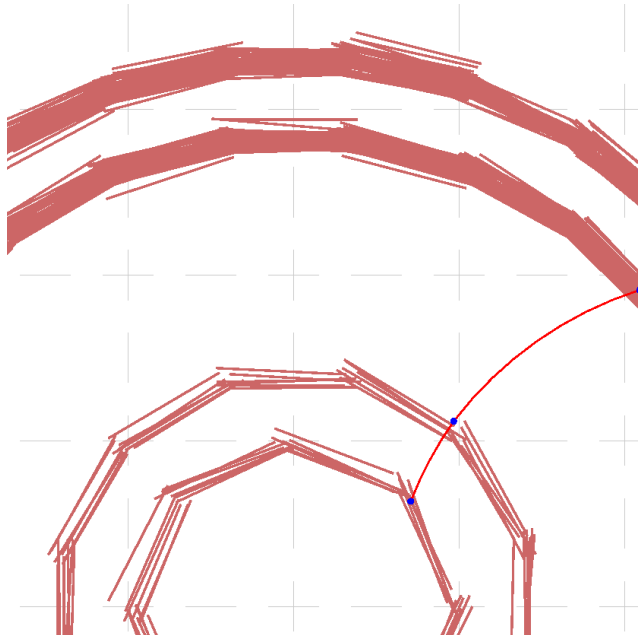
- perfect alignment

Misalignment

xy-view of the silicon sensors

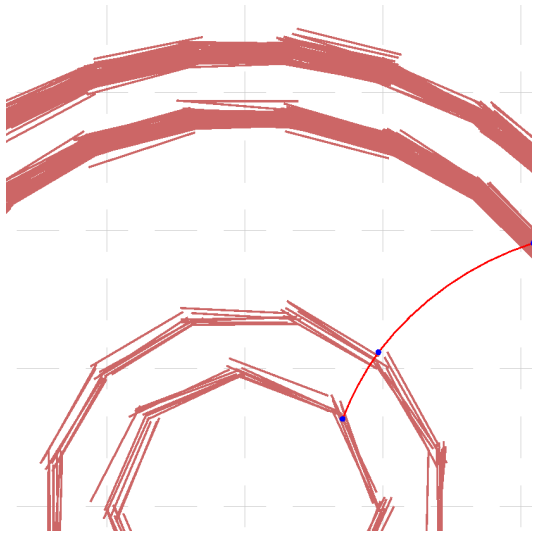


- perfect alignment



- misaligned sensors

Misalignment Studies



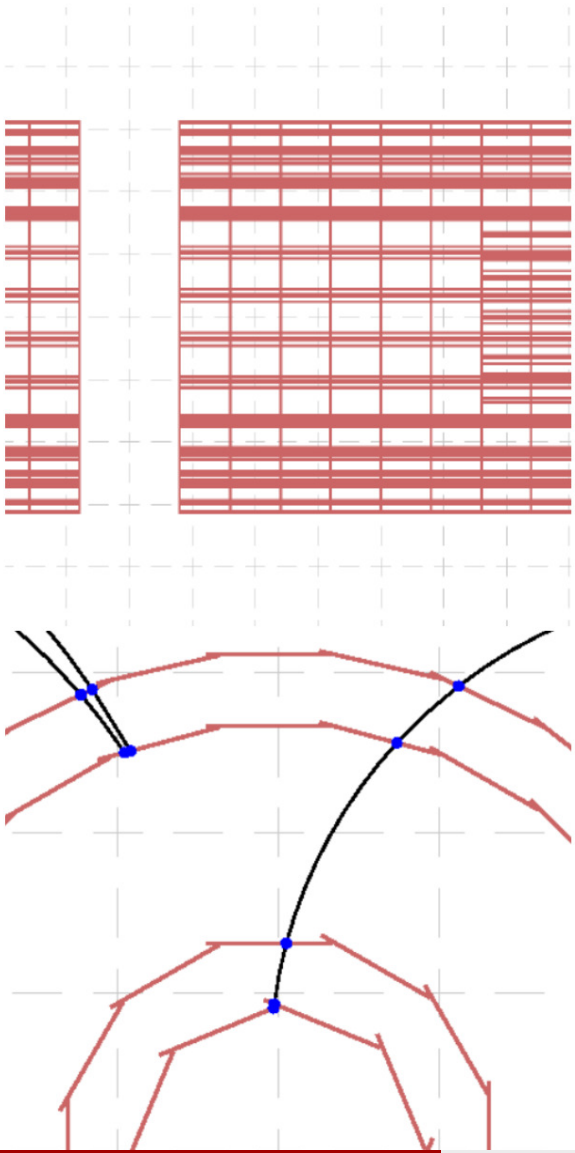
- what does that mean?

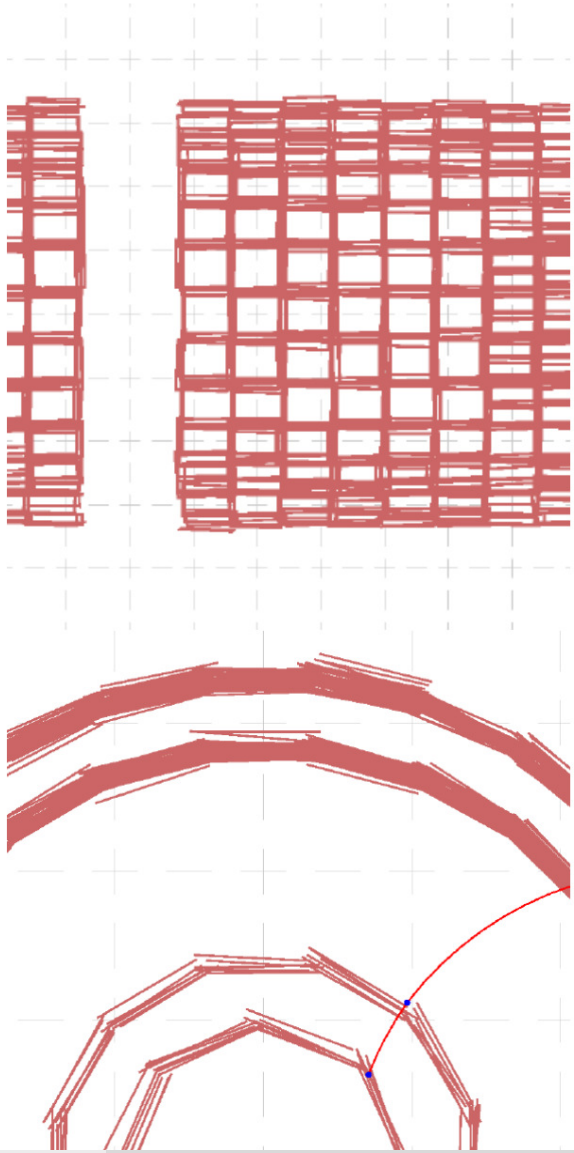
  $\rightarrow$ need for alignment algorithm
- for track based alignment tracks are needed!

  $\rightarrow$ despite of misalignment reconstruction possible?
- how well aligned to be able to align?

Misalignment Studies

Produce Misalignment in a Simulated Detector





Misalignment Studies

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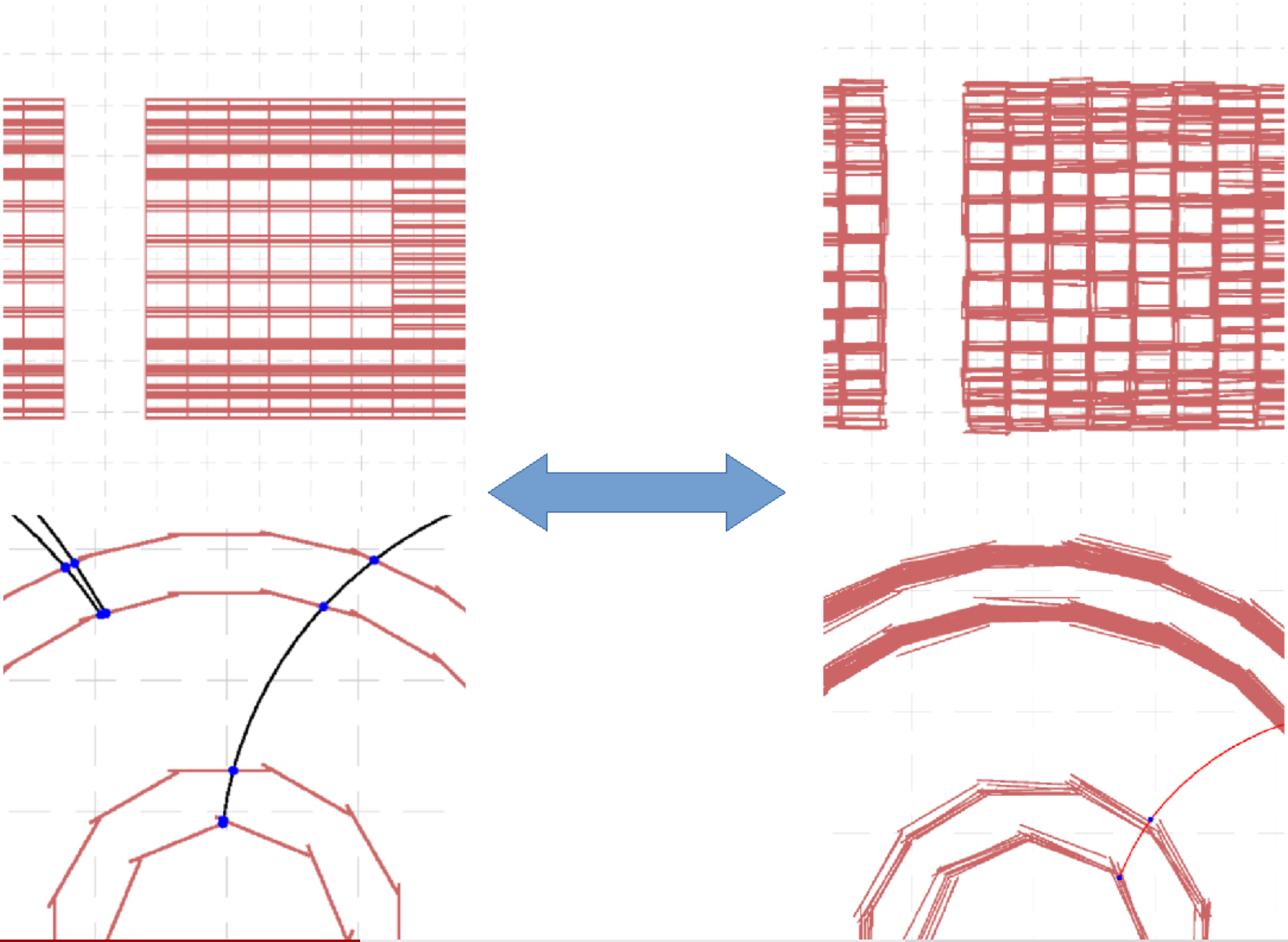
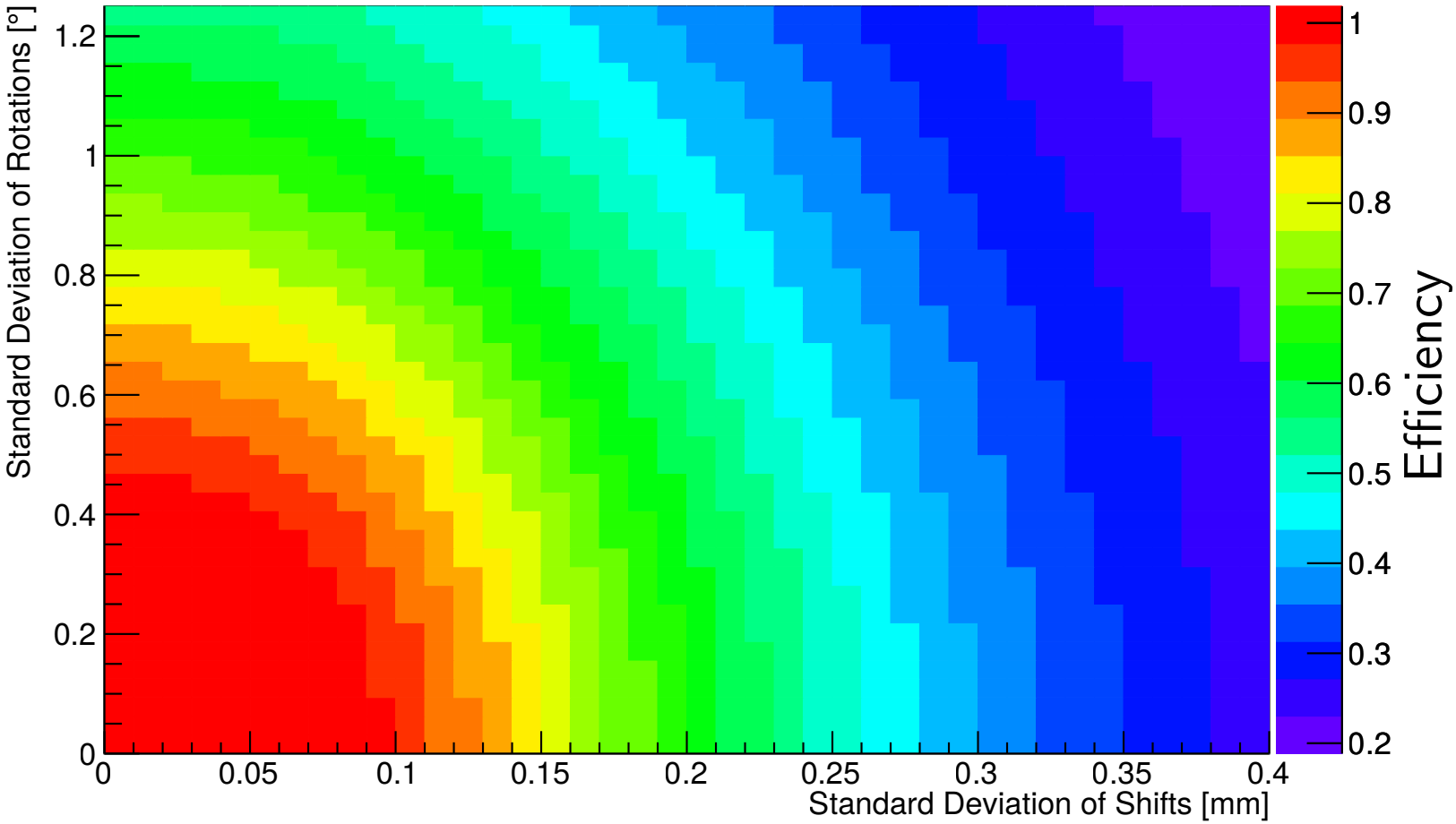


Momentum Reconstruction Efficiency

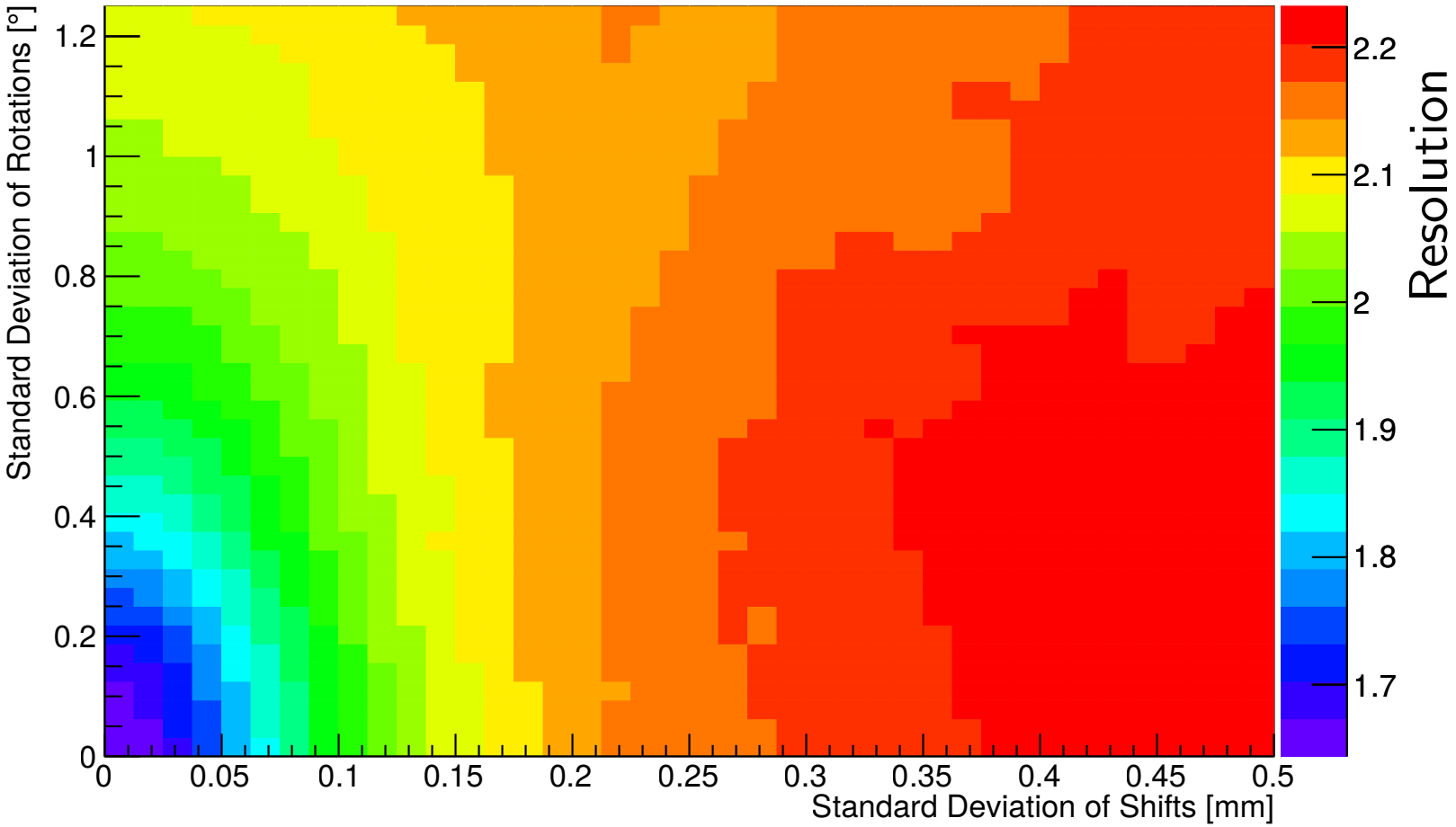
For Misalignment of Individual Sensors



- normalised to the efficiency of a perfectly aligned detector
- efficiency plateau

Momentum Reconstruction Resolution

For Misalignment of Individual Sensors



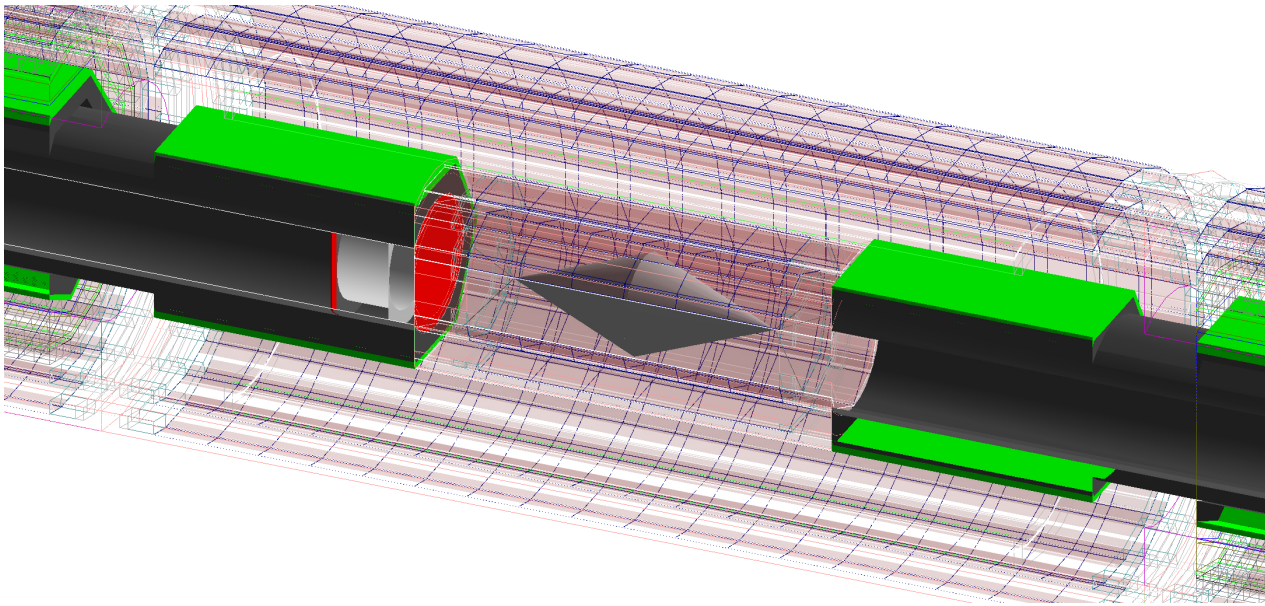
- momentum resolution from RMS of $p_{rec} - p_{MC}$
- for random sensor shifts & rotations in MeV/c

Used Software

- after construction:
  - $\sigma_{position} \leq 80 \mu m$
  - $\sigma_{orientation} \leq 0.3°$

  track based alignment

Used Software



- after construction:
  - $\sigma_{position} \leq 80\mu m$
  - $\sigma_{orientation} \leq 0.3°$

  track based alignment
- Mu3e software package
- General Broken Lines (V. Blobel, C. Kleinwort, arXiv:1201.4320v1)
- Millepede-II (V. Blobel, C. Kleinwort, arXiv:1103.3909v1)

General Broken Lines Fit

An Advanced Track Fitting Method

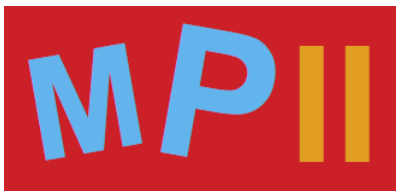
- multiple scattering & energy loss $\rightarrow$ more advanced track models
- track refit (seeding needed!)
  $\rightarrow$ complete covariance matrix of all parameters
  $\rightarrow$ track based alignment with Millepede-II
- computing time of $\mathcal{O}(n)$
  by exploiting sparsity of matrix (n = number of measurements)

V. Blobel, C. Kleinwort,
arXiv:1201.4320v1

Millepede-II

Least Squares Fits with a Large Number of Parameters

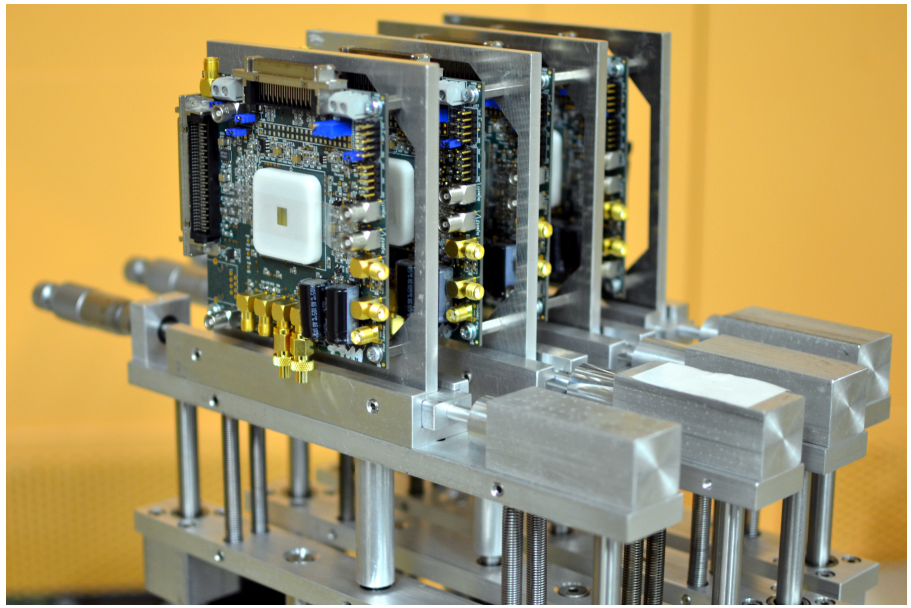
- fit track & alignment parameters simultaneously
  $\rightarrow$ very large minimisation problem!
- solve irrespectively of track parameters
  $\rightarrow$ reduced to a $n \times n$ matrix equation
  (n =number of alignment parameters)
- reasonable computing time
  even for up to 100,000 alignment parameters



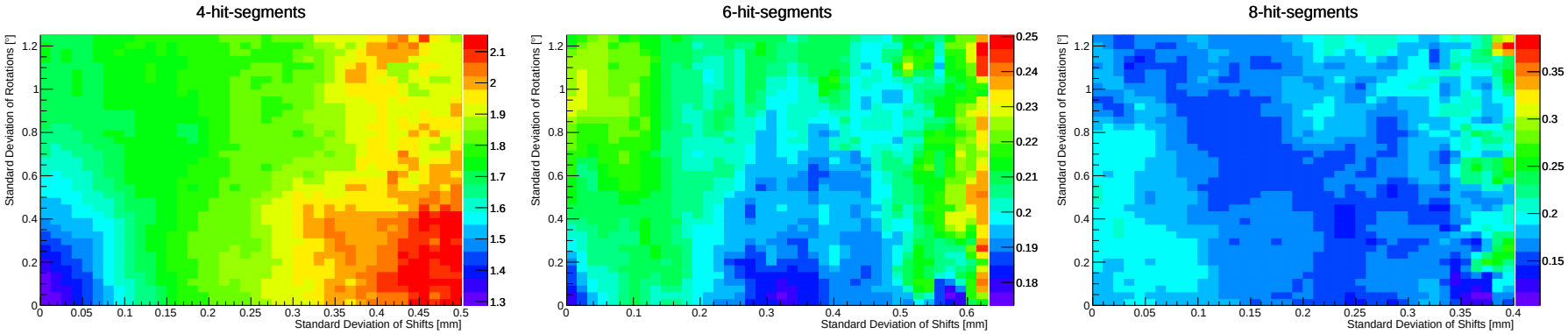
V. Blobel, C. Kleinwort,
arXiv:1103.3909v1

Current Status & Outlook

- misalignment Studies ✓
- basic software ✓
- improvements & bug fixing
- use telescope to practice use of MP-II (March '16)
- blinded tests of alignment software

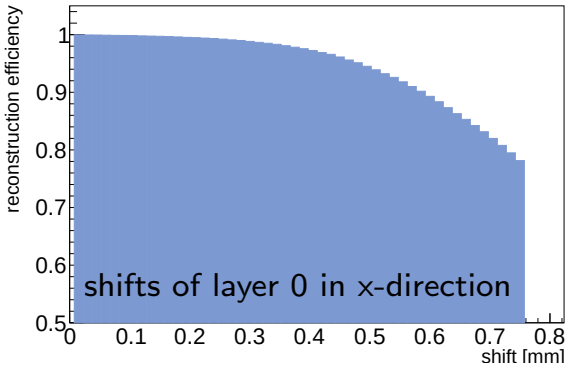


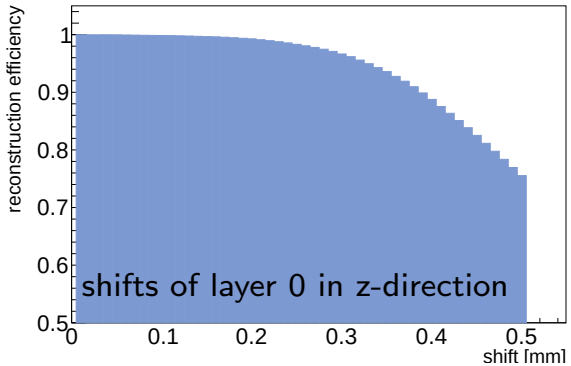
Misalignment Studies - Momentum Resolution Sigma

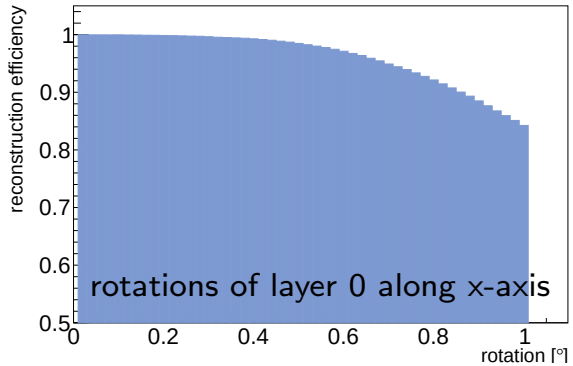


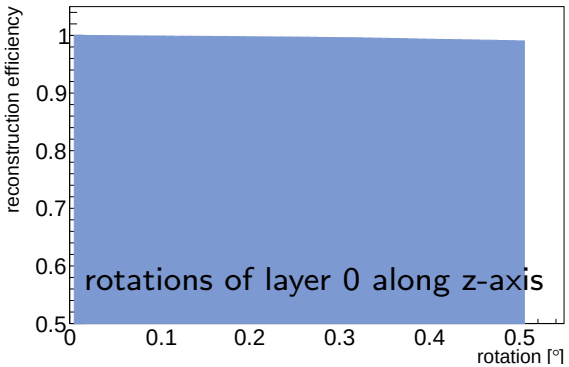
- sigma of gaussian fit to the core of the momentum resolution distribution (single sensors) in MeV/c

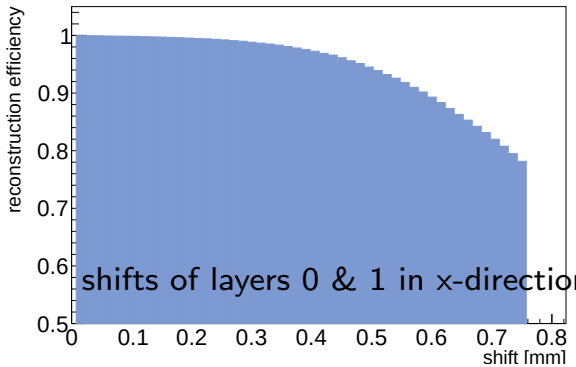
Misalignment Studies - Momentum Reconstruction Efficiency (4-hit segments)

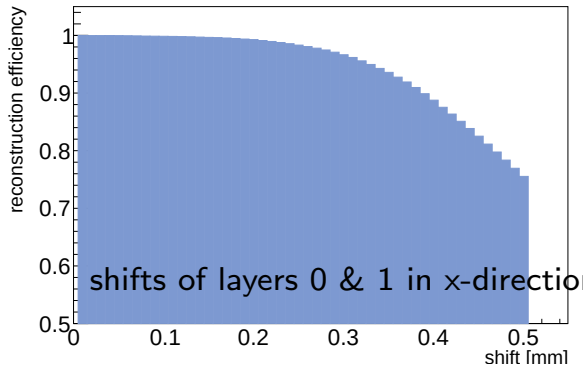


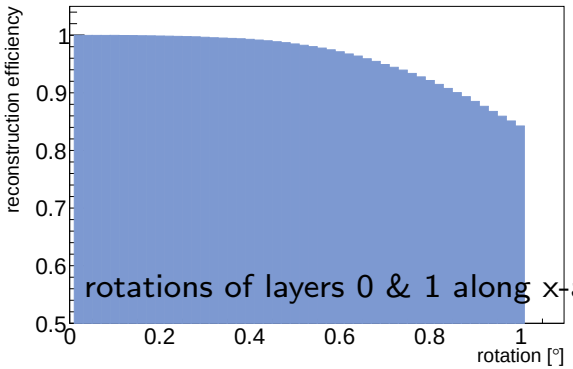


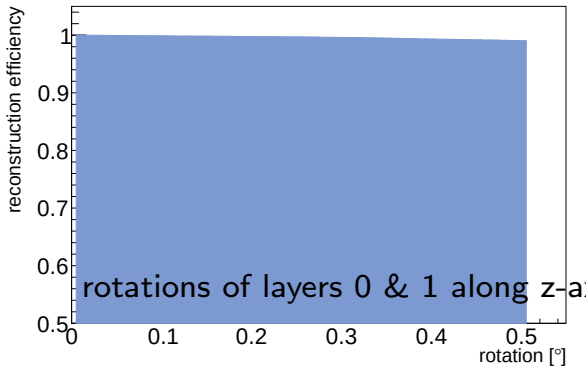






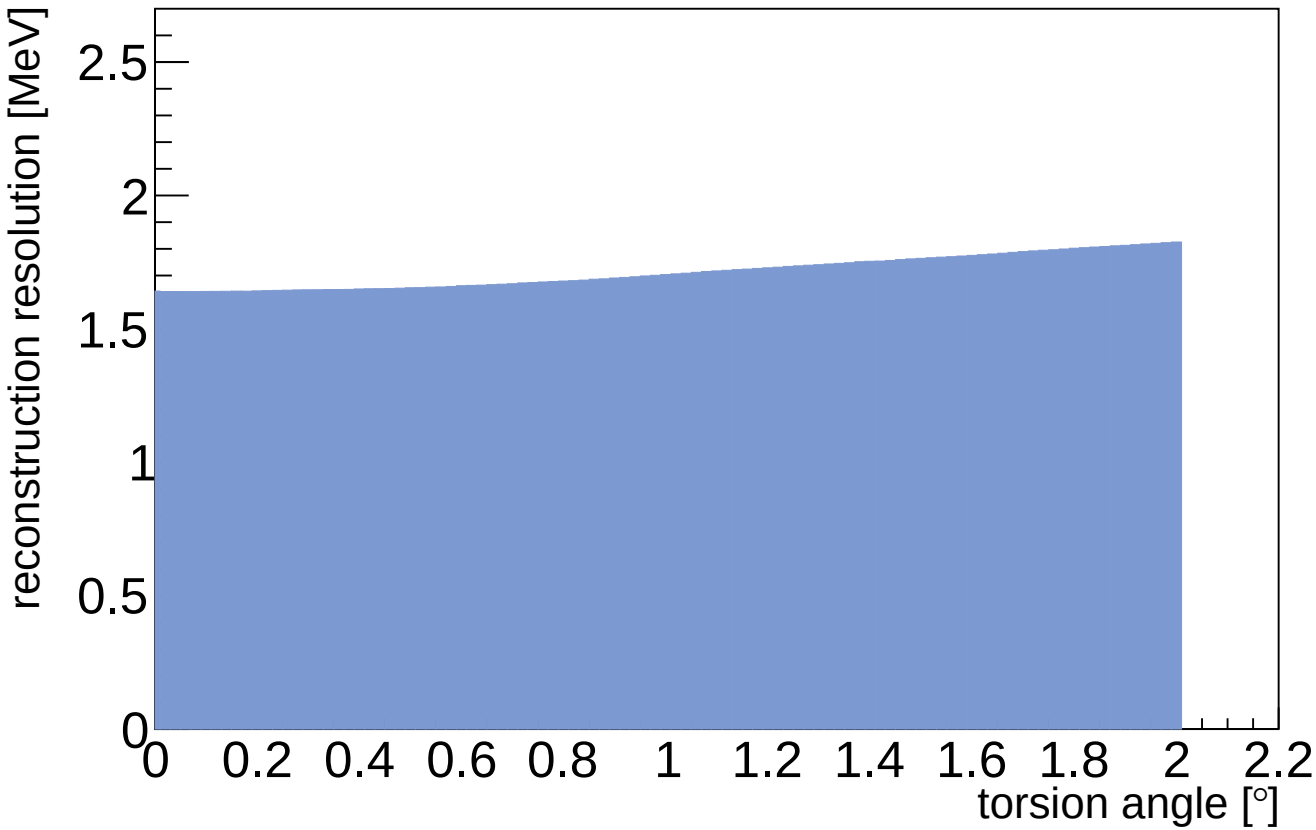






Momentum Reconstruction Resolution

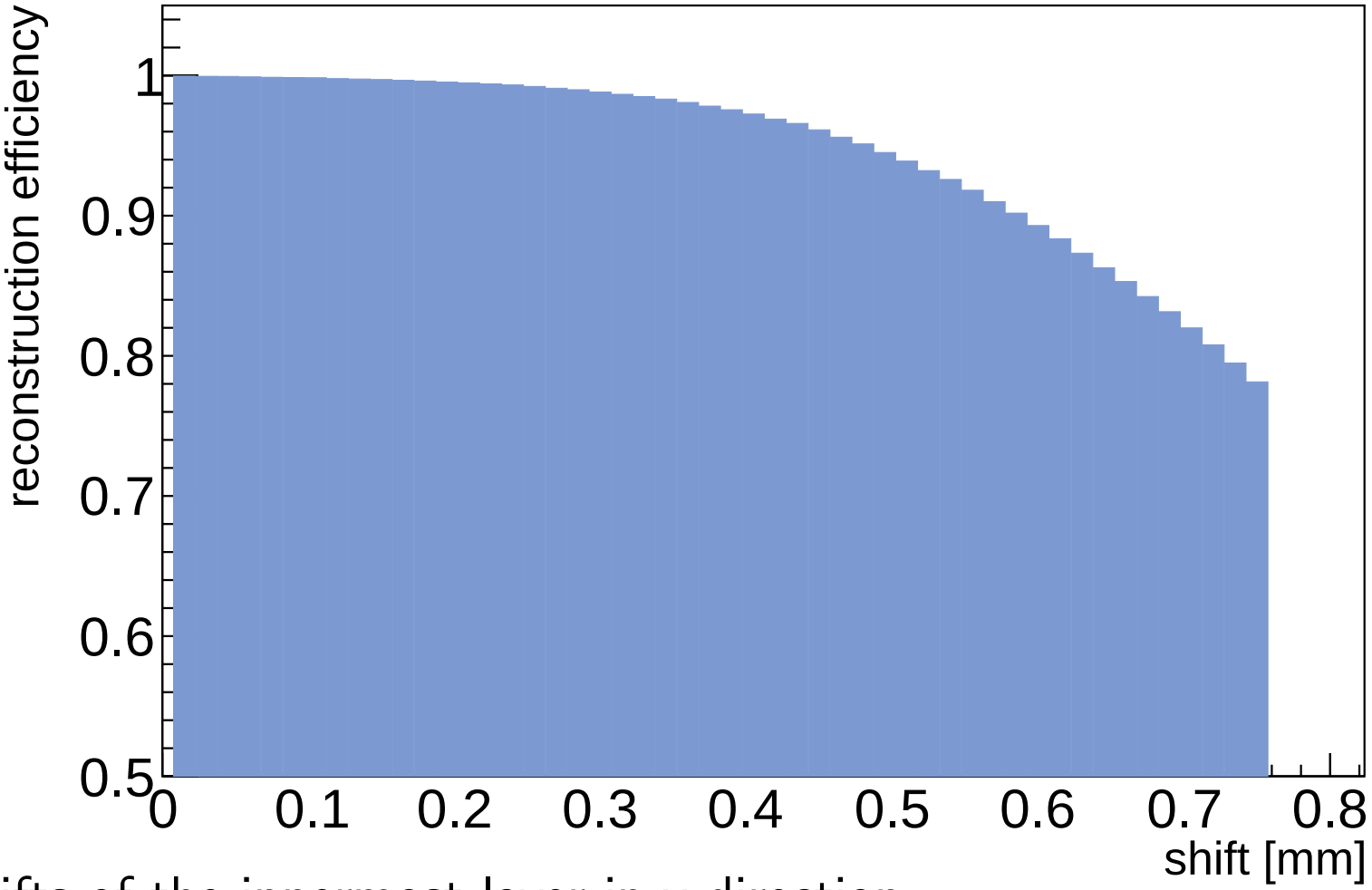
For Torsion of the Whole Detector



- torsion of the whole detector
- maximum rotation angle of each detector end (total: 4°)
- fairly insensitive to torsion

Momentum Reconstruction Efficiency

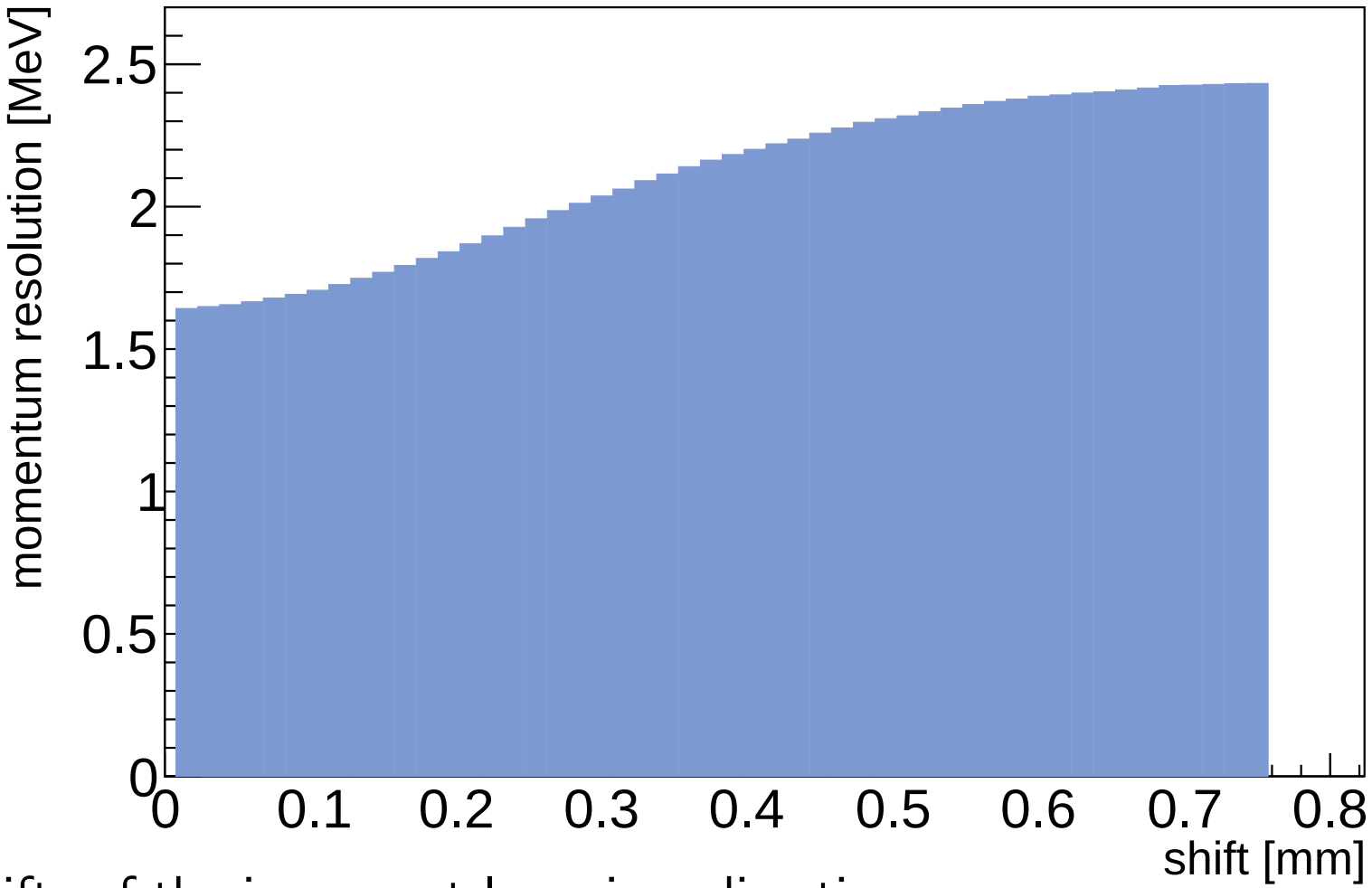
For Misalignment of Whole Detector Layers



- shifts of the innermost layer in x-direction

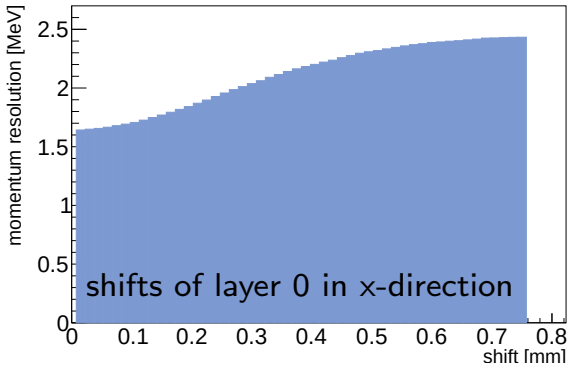
Momentum Reconstruction Resolution

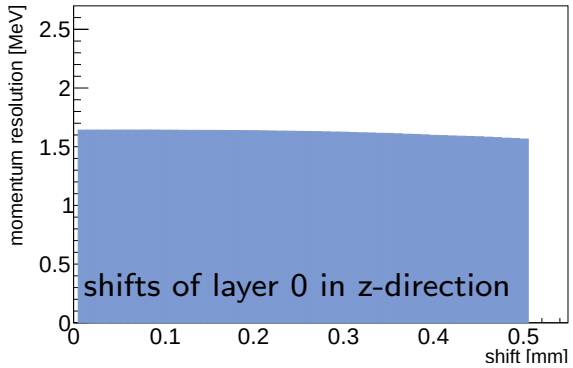
For Misalignment of Whole Detector Layers

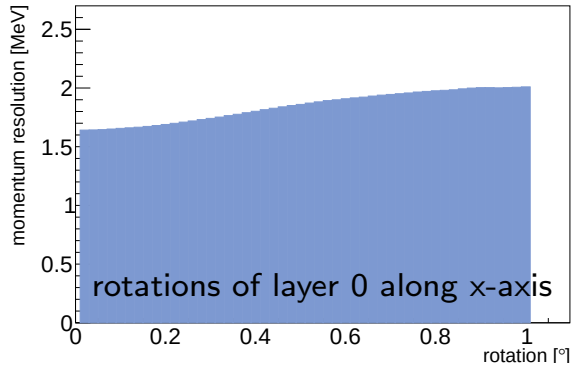


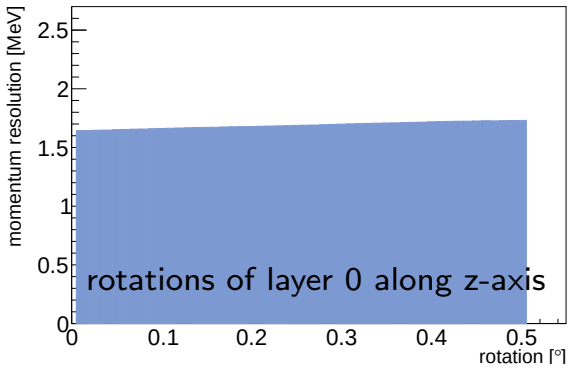
- shifts of the innermost layer in x-direction

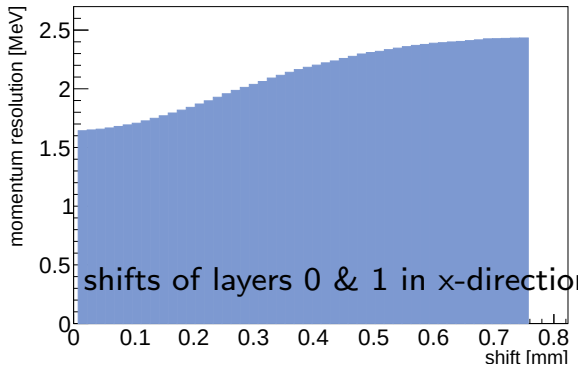
Misalignment Studies - Momentum Resolution RMS (4-hit segments)

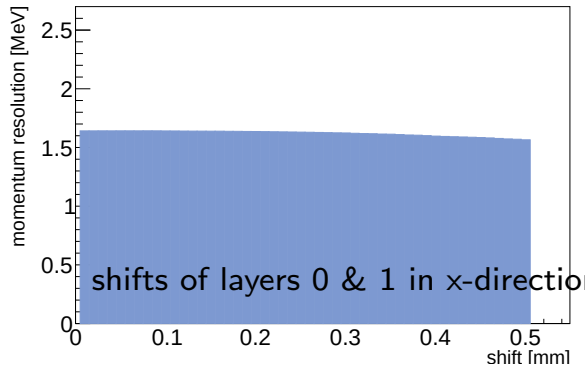


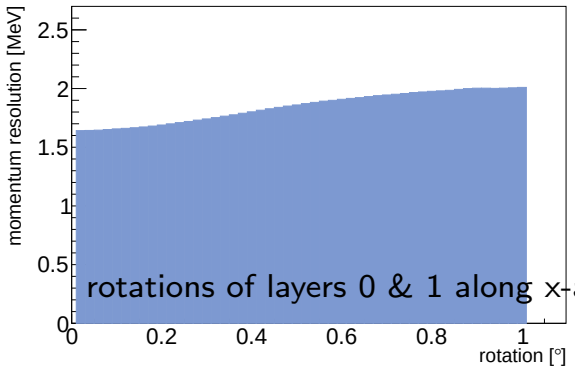


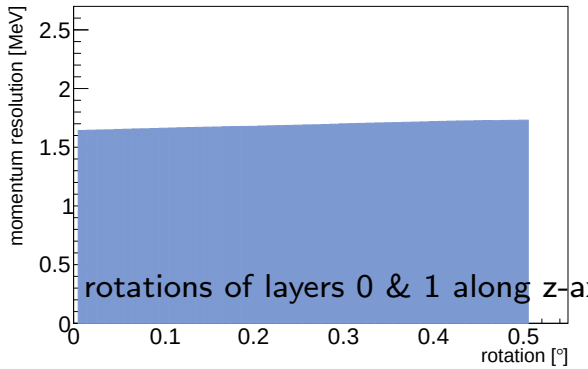


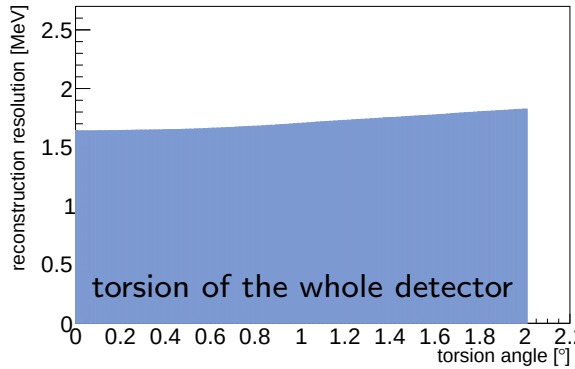






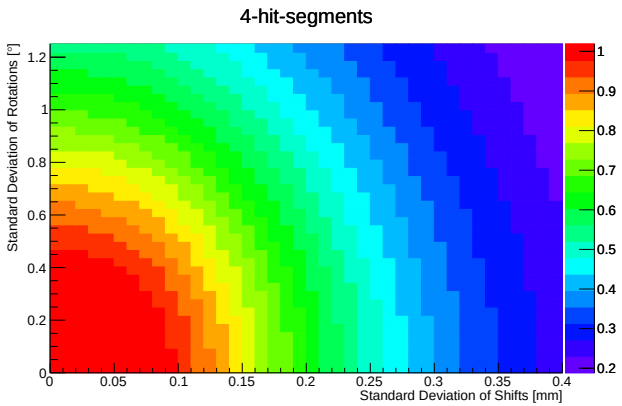


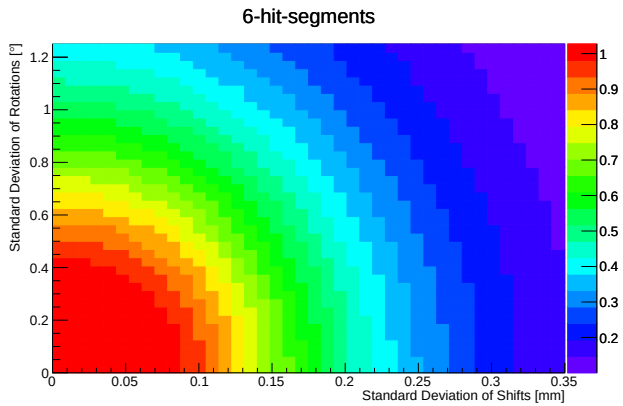


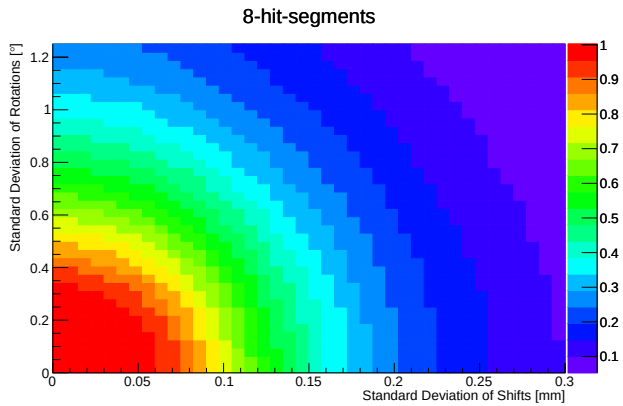


Momentum Reconstruction Efficiency

For Individual Sensors

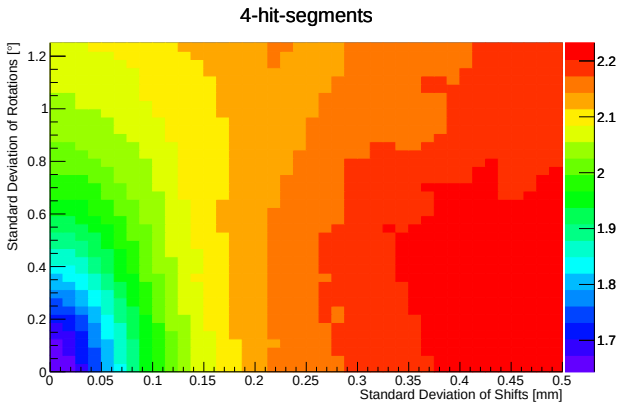


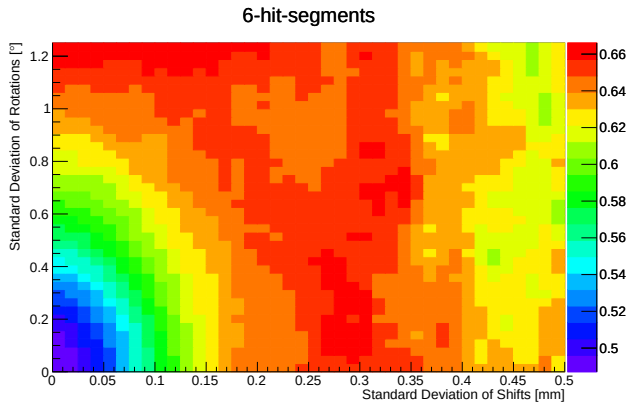


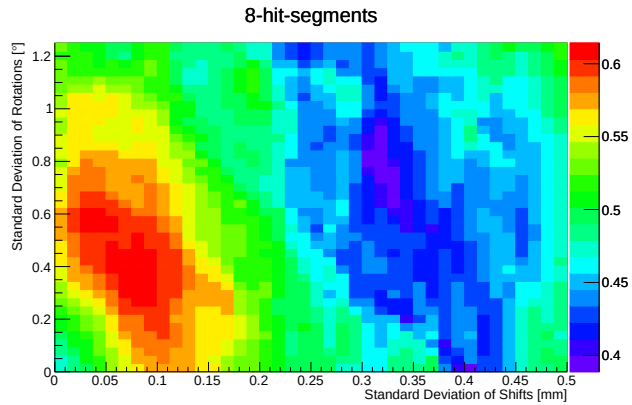


Momentum Resolution

For Individual Sensors

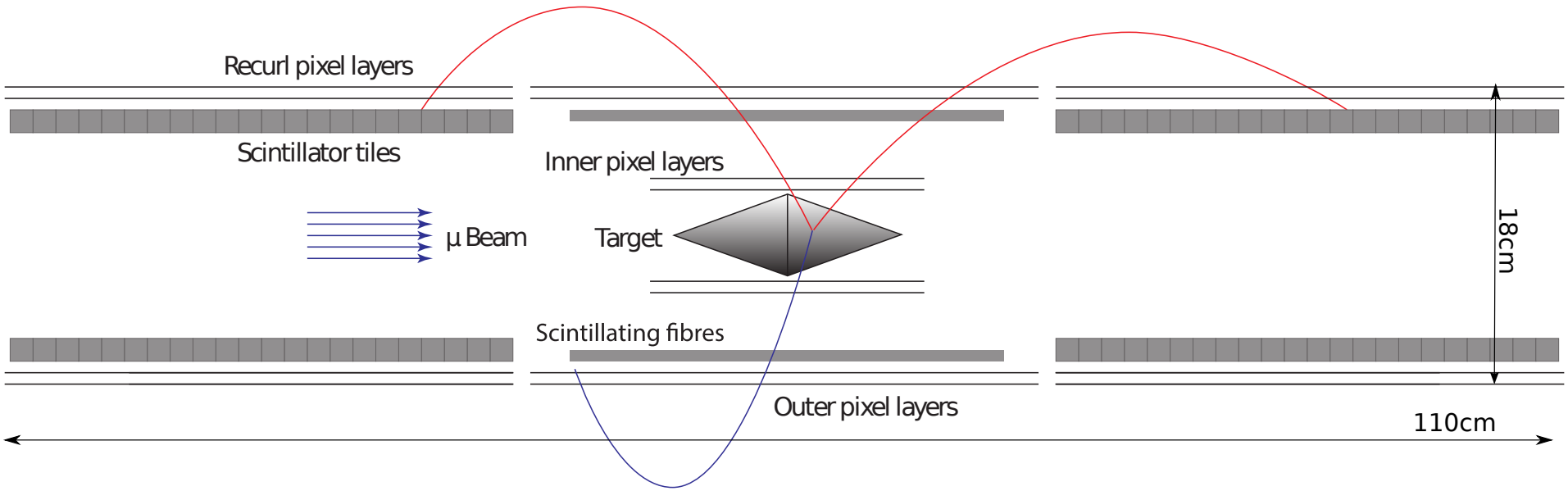






The Detector

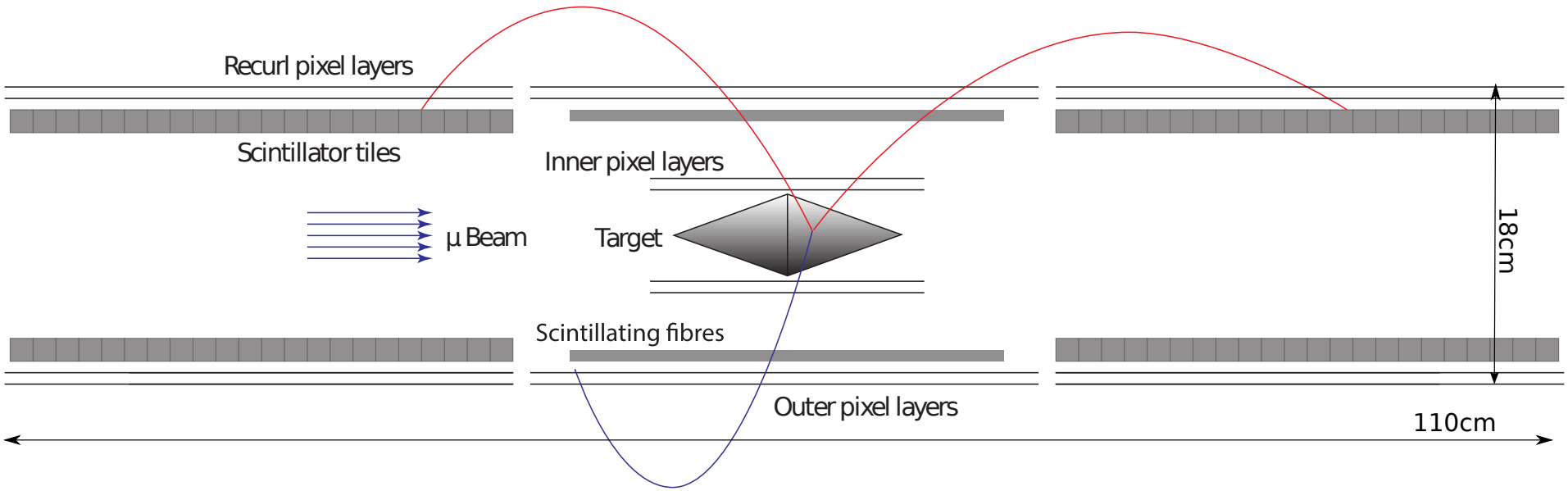
Baseline Design



- barrel detector
  - two double layers of silicon sensors
  - scintillating fibre tracker & scintillating tiles (timing)

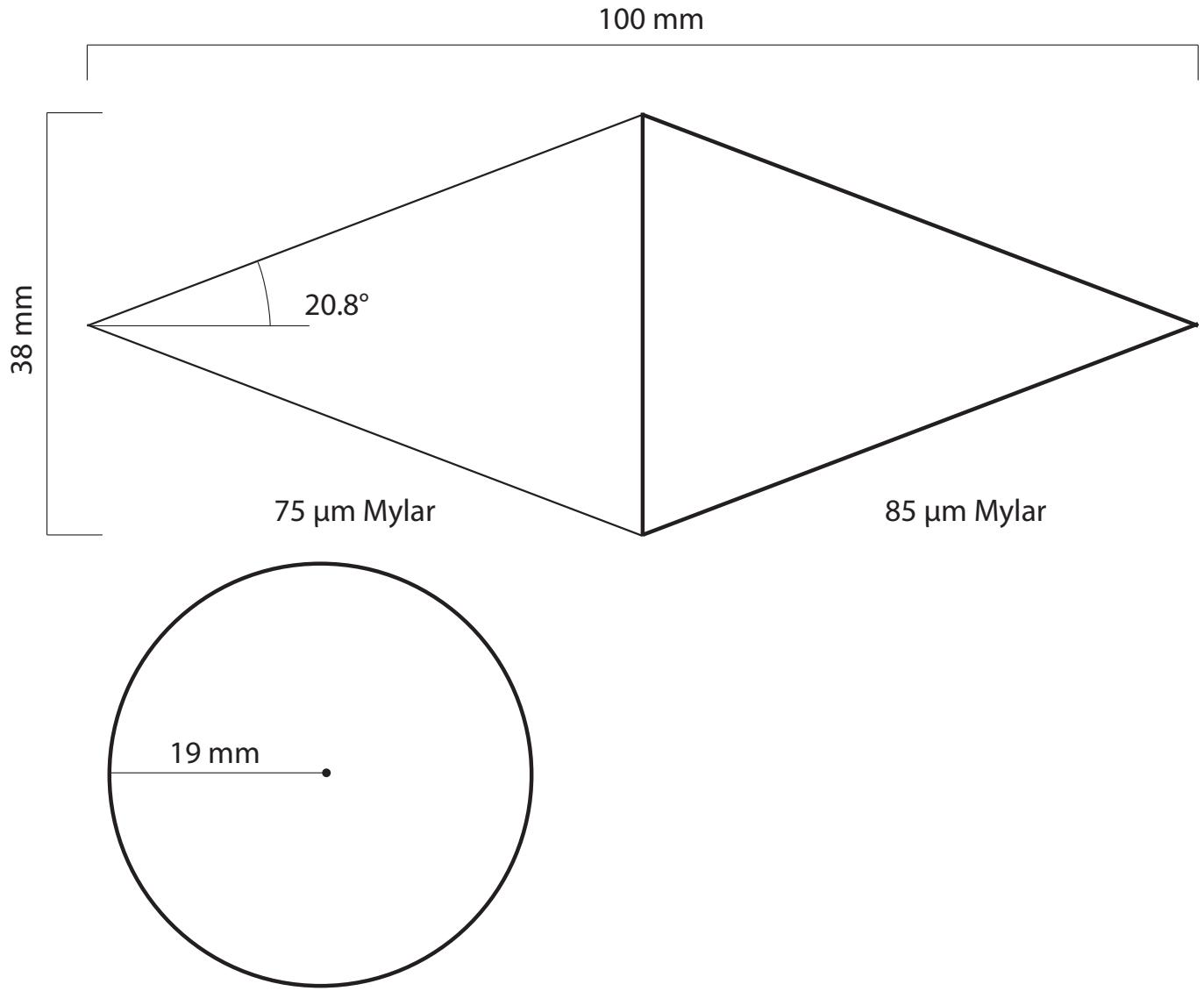
The Detector

Baseline Design



- barrel detector
  - two double layers of silicon sensors
  - scintillating fibre tracker & scintillating tiles (timing)
- hollow double cone target
- use re-curlers
  - allow precise momentum measurements

The Target



The Phases of the Mu3e Detector