Alignment of the LMD modules

Anastasia Karavdina

KPH, Uni Mainz

September 5, 2014

Outline

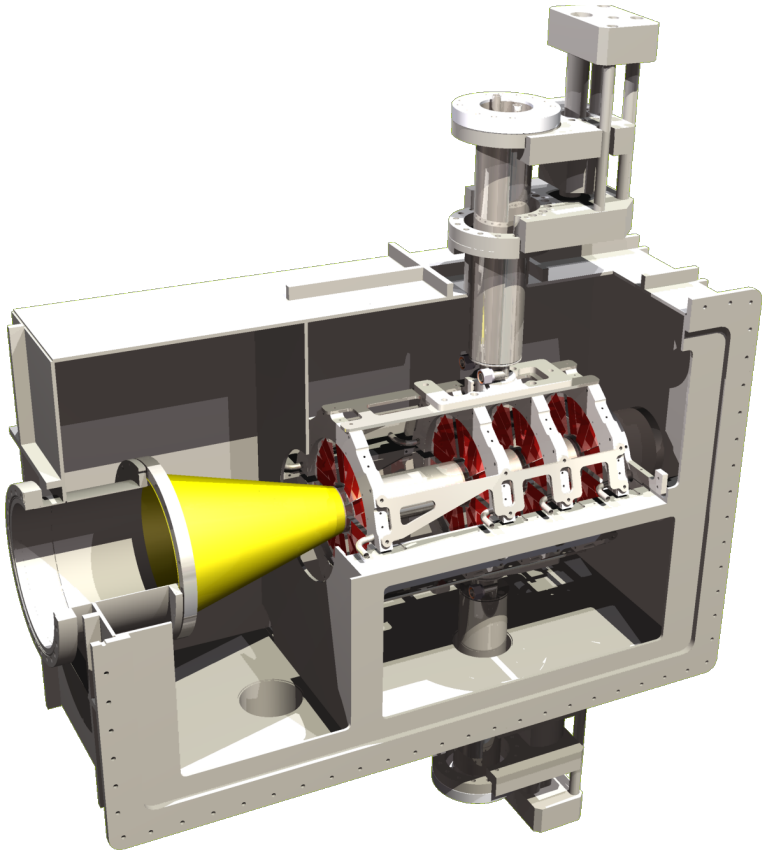
- Why?

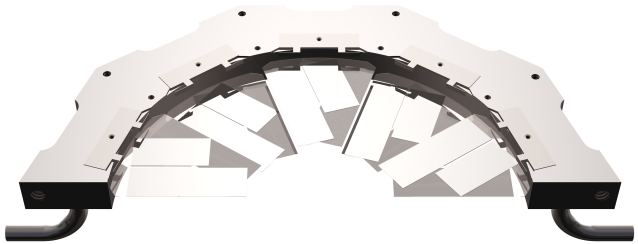
  expected assembling accuracy vs. sensitivity of trk.rec

- How?

  General ideas behind simulation and extraction, the software

- Current results

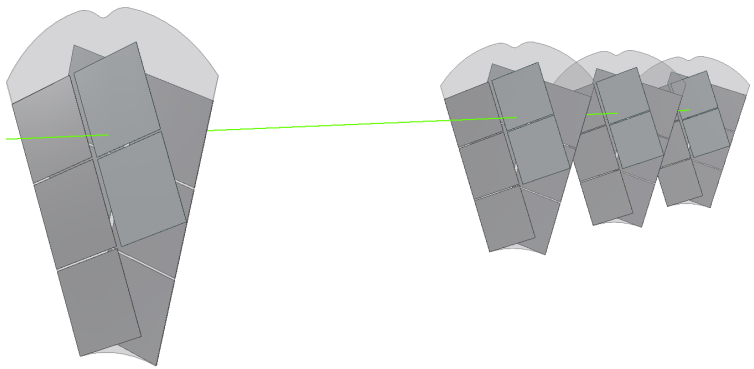




Misalignment variables

6 degrees of freedom:

- 3 translations
  Δ_x, Δ_y, Δ_z
- 3 rotations
  Δ_α, Δ_β, Δ_γ



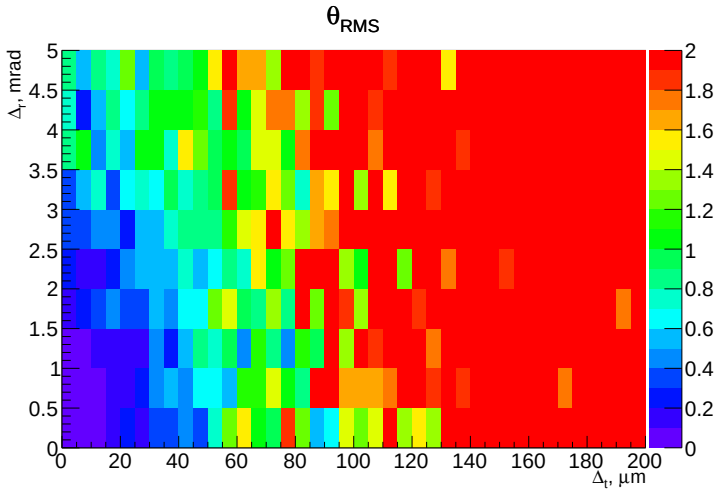
Δ_x, Δ_y, Δ_z, Δ_α, Δ_β, Δ_γ
$\rightarrow$ sampled from Gaussian distribution with
Mean = 0 and σ = Δ_t(translations) or Δ_r(rotations)

Δ_t, Δ_r are misalignment scales

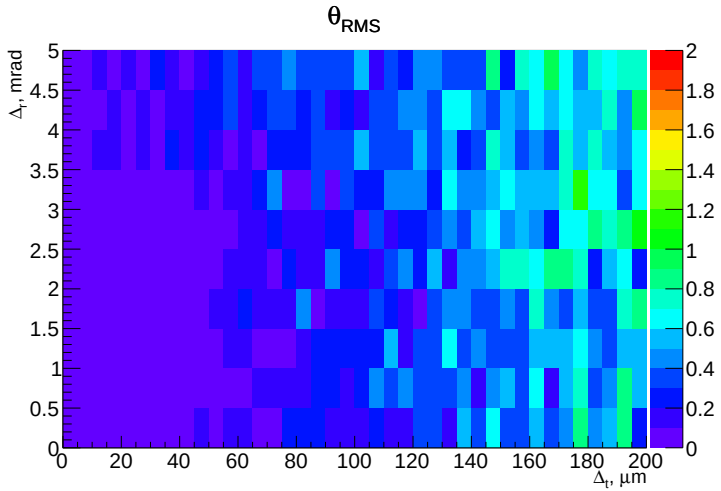
Misalignment effect on track resolution

$$\left|\frac{(Res^{ideal} - Res^{misalign})}{Res^{ideal}}\right|$$

P_{beam} = 15 GeV/c



P_{beam} = 1.5 GeV/c



(arbitrary) limits «resolution worse more than 10%»

Δ_t<15μm, Δ_r<1mrad @ 15 GeV/c

Δ_t<40μm, Δ_r<3.5mrad @ 1.5 GeV/c

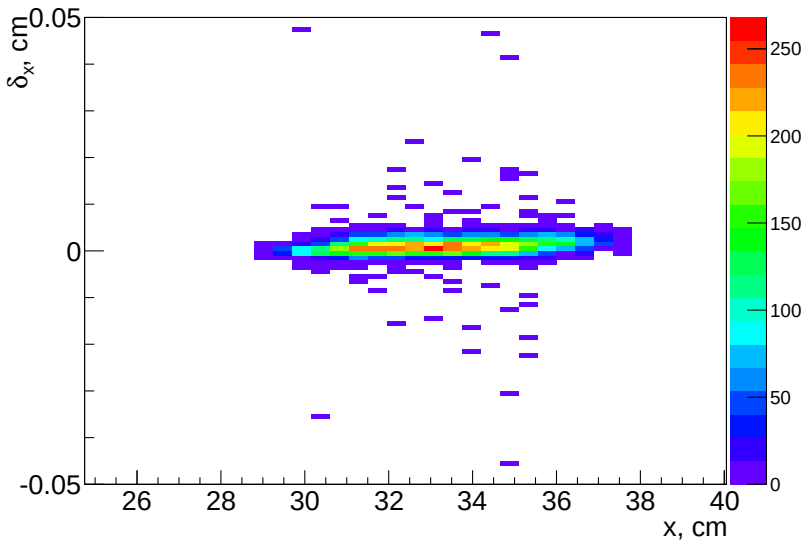
expected assembling accuracy

$\Delta_t \sim$200μm, $\Delta_r \sim$3mrad

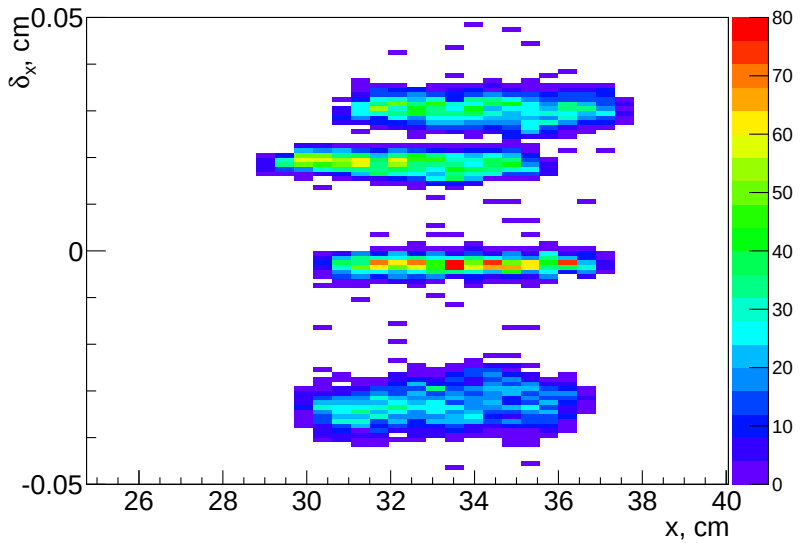
Residuals* as a hint

* difference between hit and reconstructed track

$\Delta_t \sim 0, \Delta_r \sim 0$



$\Delta_t \sim 200, \Delta_r \sim 3$

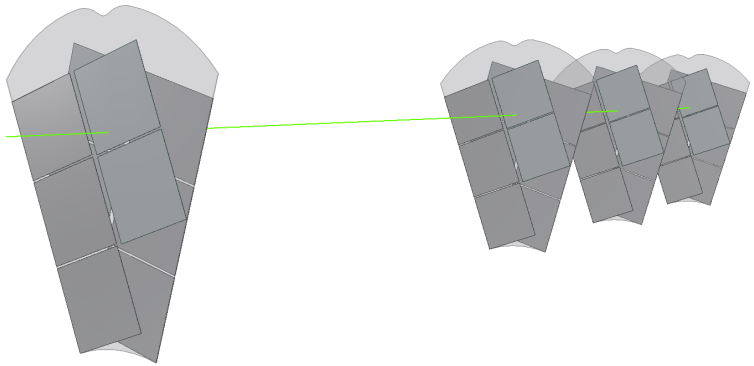


Software alignment

$\rightarrow$ extraction of alignment parameters by help of registered tracks

Alignment algorithm

6 degrees of freedom:



- 3 translations
  Δ_x, Δ_y, Δ_z
- 3 rotations
  Δ_α, Δ_β, Δ_γ

Hit parameterization:

$$\begin{cases} x_{measured} &= x_{trk} + \epsilon_x = a \cdot z + b + \epsilon_x \\ y_{measured} &= y_{trk} + \epsilon_y = c \cdot z + d + \epsilon_y \end{cases}$$

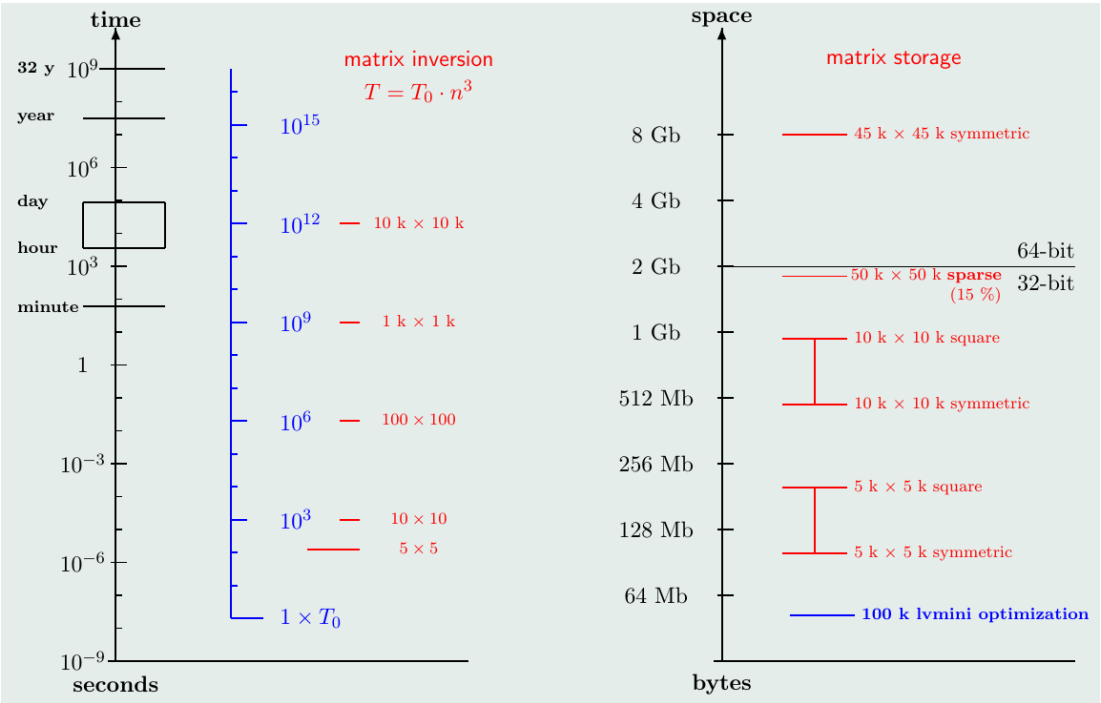
Residuals parameterization:

$$\begin{cases} \epsilon_x &= -\Delta_x + y_{hit} \cdot \Delta_\gamma + a \cdot (\Delta_z + x_{hit} \cdot \Delta_\beta + y_{hit} \cdot \Delta_\alpha) \\ \epsilon_y &= -\Delta_y - x_{hit} \cdot \Delta_\gamma + c \cdot (\Delta_z + x_{hit} \cdot \Delta_\beta + y_{hit} \cdot \Delta_\alpha) \end{cases}$$

- simultaneous fit of tracks and alignment parameters
- alignment of modules in one row (sector)

Millepede vs. standard matrix inversion

Good accuracy = significant number of tracks
number n_{gl} of align.params and n_{loc} of a trk.params for n_{tracks} trks
$\rightarrow$ $n_{TOT} = n_{loc} \cdot n_{tracks} + n_{gl}$



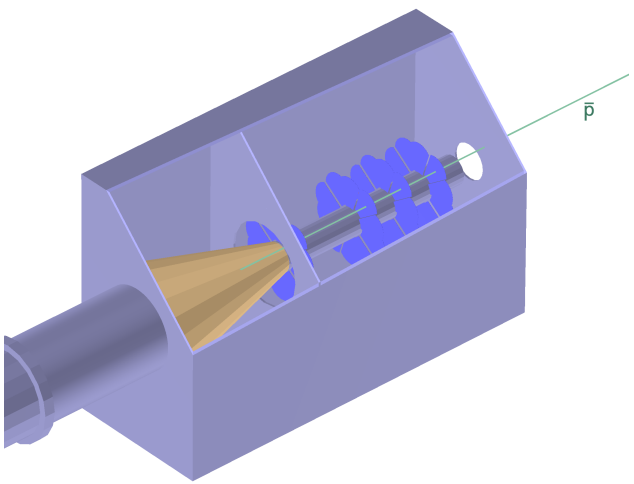
[V. Blobel, 2nd LHC Detector Alignment Workshop (June 2007)]

For $\sim 10^4$ tracks $\rightarrow$ $4 \cdot 10^4 \times 4 \cdot 10^4$ matrix equation

- Standard matrix inversion: $\sim$ 1 day, 8 Gb
- Millepede: $\sim$ 5 sec, 40 Mb (Intel Xeon E5-1603 @2.8 GHz)

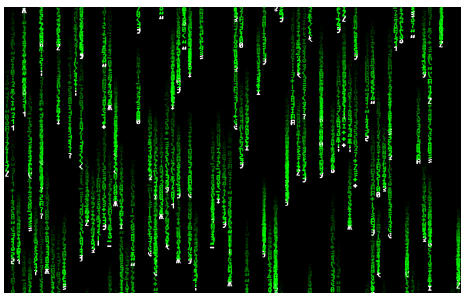
Step I: Hit reconstruction

ROOT geometry



Transformation matrix

(mis)Alignment constants



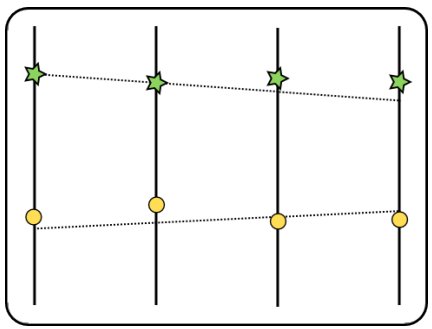
Hit rec

Trans.matrix, Align.consts = ASCII files $\Rightarrow$ to DB

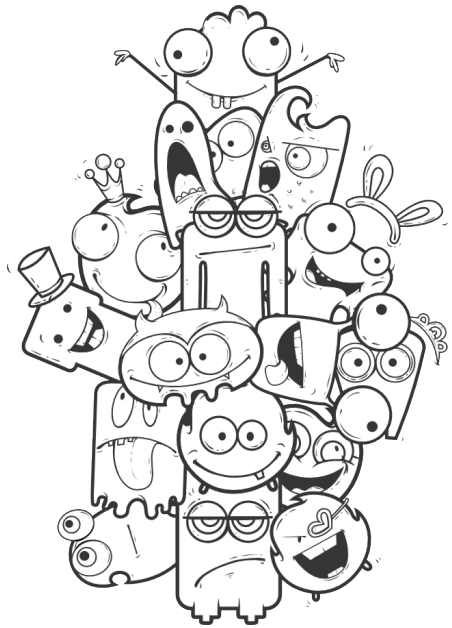
"$\Rightarrow$" means "must be changed to"

Step II: Alignment

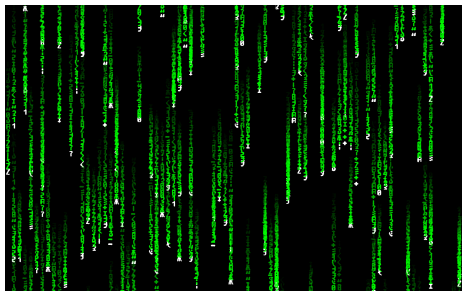
Trks $\rightarrow$ Hits



Alignment



Alignment constants



Alignment = bunch of executables (VELO example)

$\Rightarrow$ Millepede-II. External package since dec13

(currently not compatible with PANDAroot)

Besides being more stable solution, can extend alignment limits

"$\Rightarrow$" means "must be changed to"

How to run tests with LMD

- pandaroot/development/karavdina/myKnossos
  make
- pandaroot/macro/lmd/CMakeLists.txt
  add_subdirectory(LMD_alignment)
  (re)compile PANDAroot: *cmake, make*
- cd pandaroot/macro/lmd/LMD_alignment
  ./runLumiPixelAlignJuly2014
  misalignment → reconstruction → alignment → reconstruction

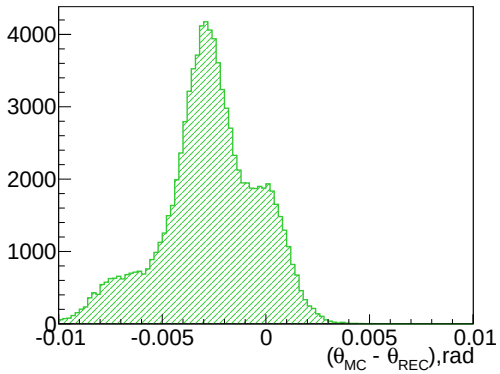
SummaryAlign.C → analysis histograms

Tuning parameters (myKnossos/constantsLMD.h)

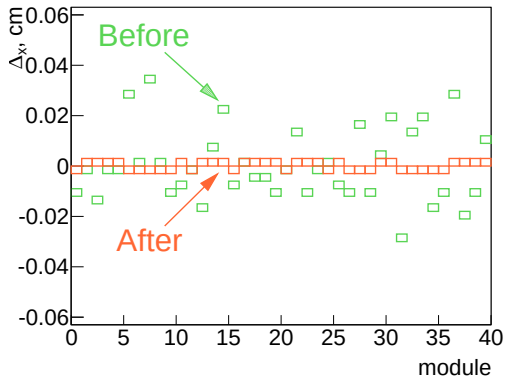
- distance between modules
- free degrees of freedom
- χ^2 cuts
- limits for constrains

Test results

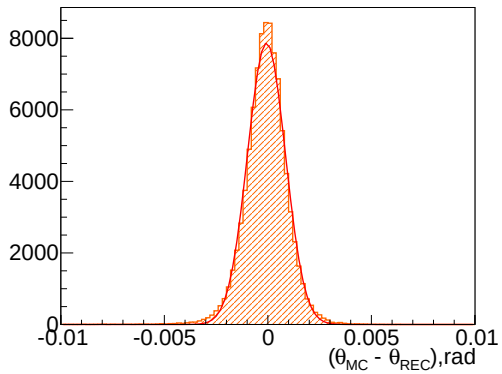
Δ_t ~200μm, Δ_r ~3mrad; P_{beam} 1.5 GeV/c; 10^6 events (BOX generator)



θ resolution "before"



misalignment (Δ_x)

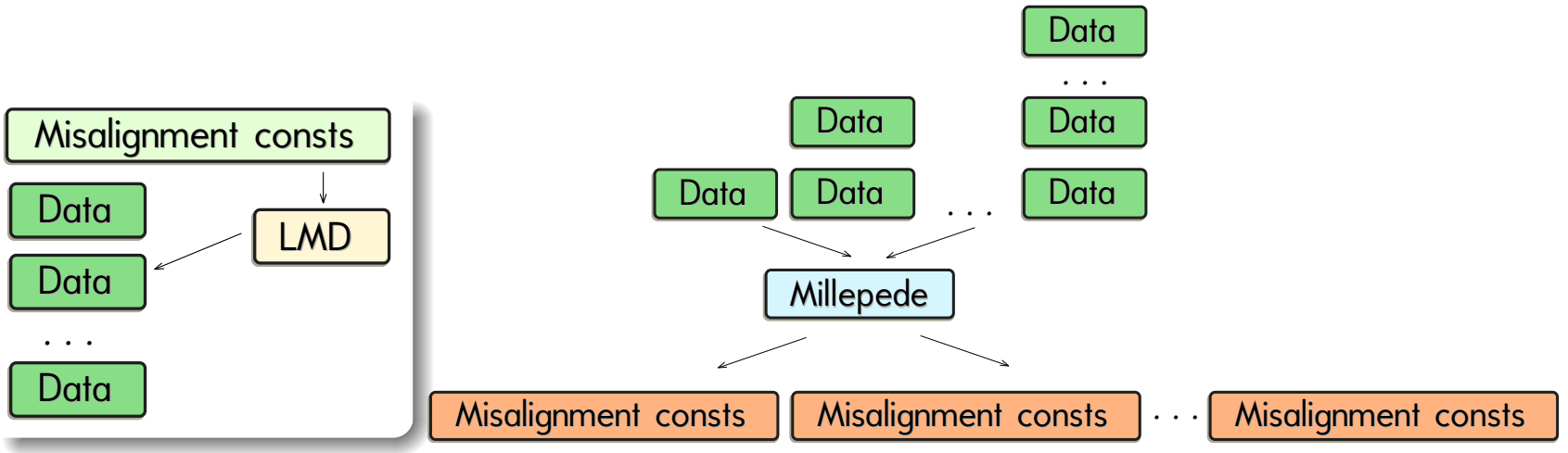


θ resolution "after"

$RMS(\Delta_x)$ = 160 μm $\Rightarrow$ 5 μm
$RMS(\Delta_y)$ = 110 μm $\Rightarrow$ 3 μm
$RMS(\Delta_z)$ = 110 μm $\Rightarrow$ 90 μm
$RMS(\Delta_\alpha)$ = 2.9 mrad $\Rightarrow$ 2.8 mrad
$RMS(\Delta_\beta)$ = 2.9 mrad $\Rightarrow$ 3.1 mrad
$RMS(\Delta_\gamma)$ = 2.7 mrad $\Rightarrow$ 0.3 mrad

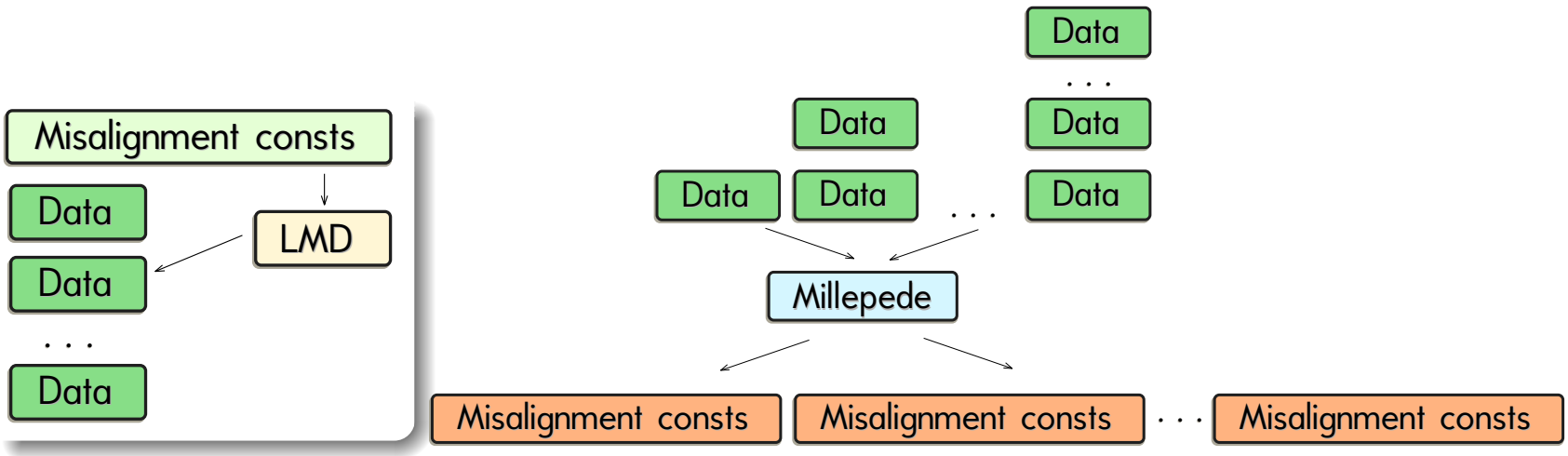
In following results are presented for $RMS(\Delta_t)$ and $RMS(\Delta_r)$

Statistic study (play with Data)

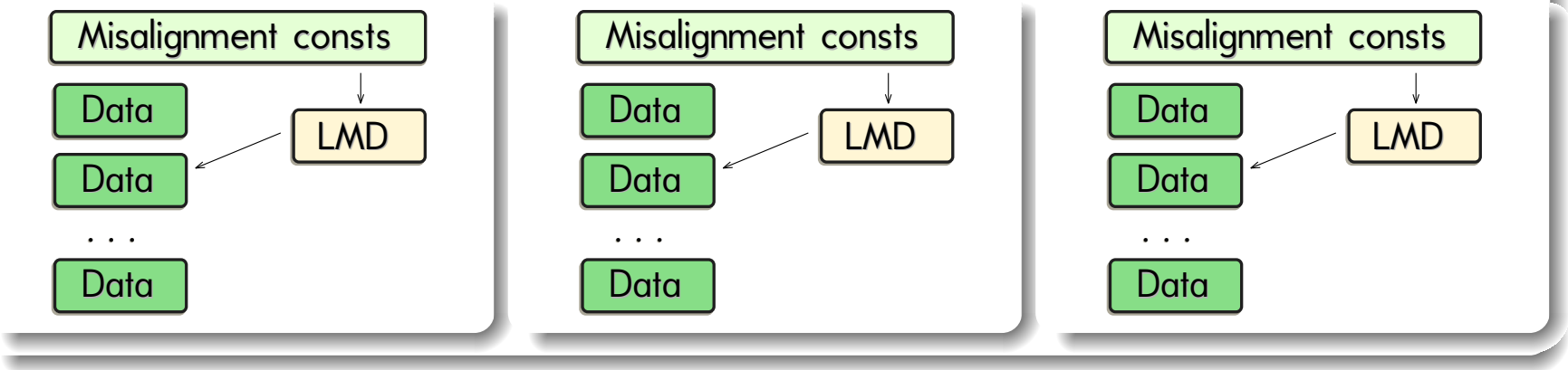


Statistic and systematic study

Statistic study (play with Data)



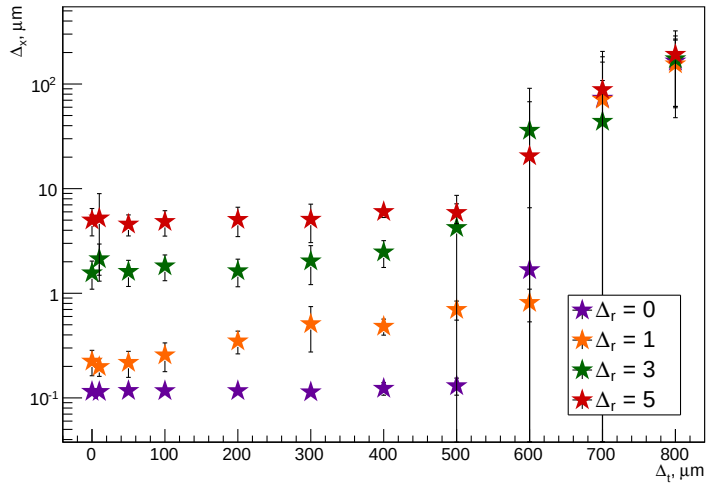
Systematic study (play with Misalign.consts)

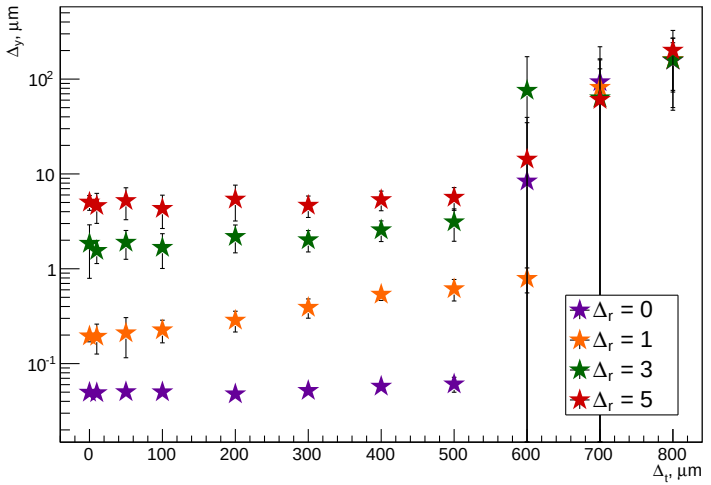


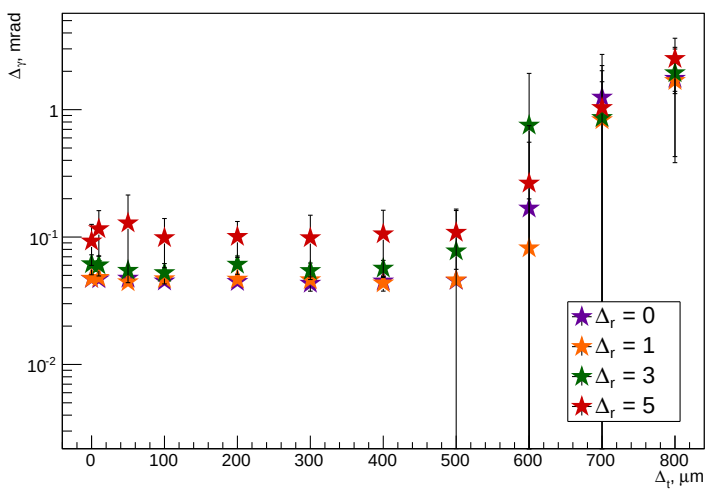
100 Data samples (each with $5 \cdot 10^4$ events); 10 samples with misalign.consts

Accuracy after alignment procedure

P_{beam}=15 GeV/c , BOX ($\theta_{MC} \in$[2,12]mrad); DOF 111111





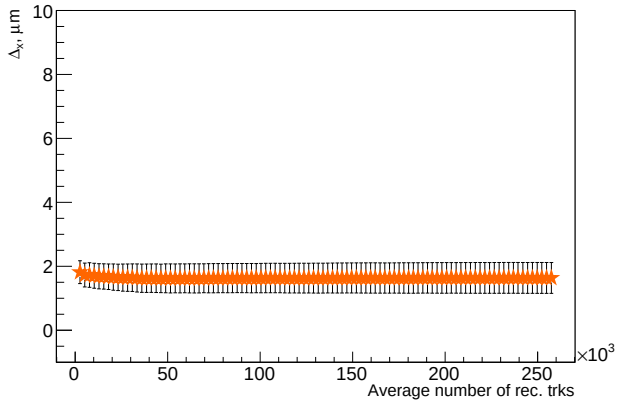


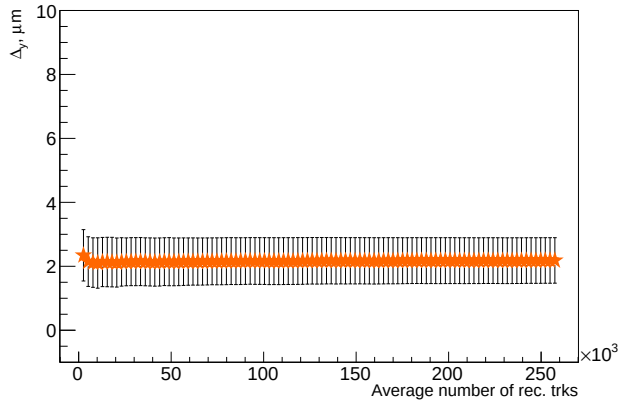
$2.5 \cdot 10^5$ trks/sector

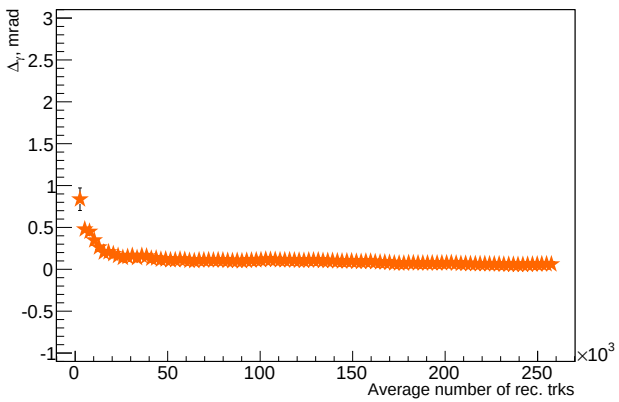
$\Delta_t \leq 10\mu$m, $\Delta_r \leq$ 1mrad
can be reached for
$\Delta_t \leq 500\mu$m and $\Delta_r \leq$ 5mrad

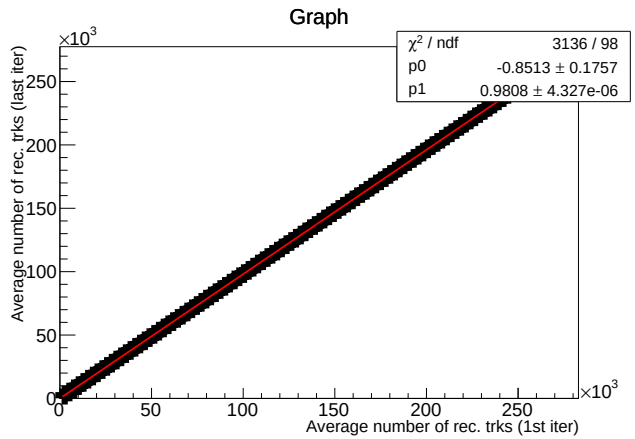
Accuracy after alignment procedure

Δ_t=200μm, Δ_r=3 mrad; P_{beam}=15 GeV/c, BOX ($\theta_{MC} \in$[2,12]mrad); DOF 111111







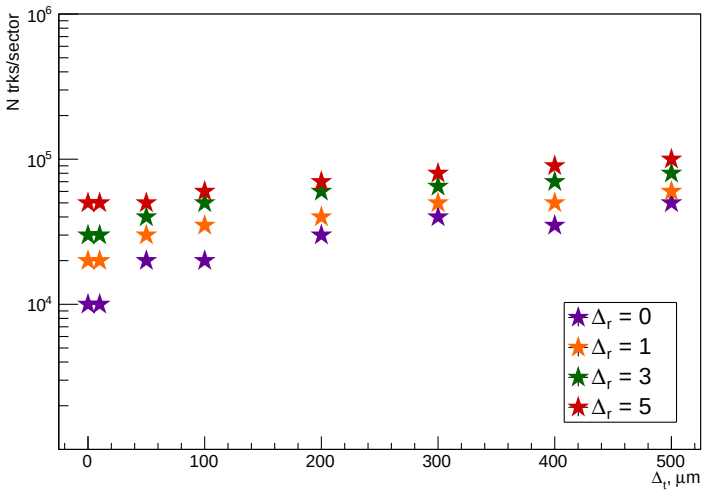


down to $\Delta_t \sim 2\mu$m $\Delta_r \sim 0.1$mrad with $5 \cdot 10^4$trks/sector

$\sim$2% trks rejected during alignment

Required statistic

P_{beam}=15 GeV/c , BOX ($\theta_{MC} \in$[2,12]mrad); DOF 111111



Number of required tracks

10^4 - 10^5 trks/sector

(seconds of data taking)

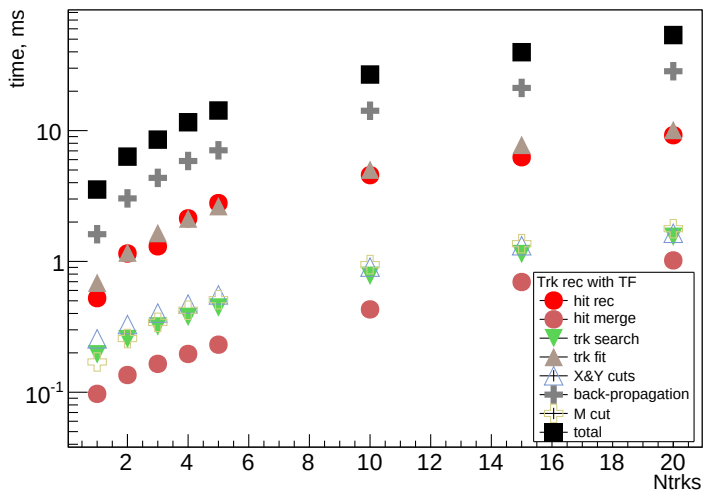
Offline rec.time

Hit rec & Trk search =

2 ms/ev $\rightarrow$ 200 s

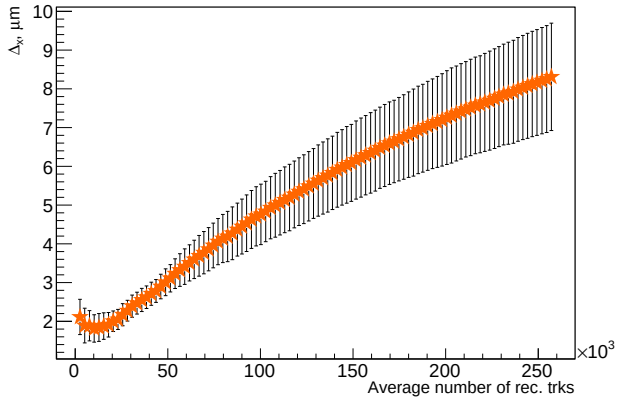
Millipede $\sim$ 70 s

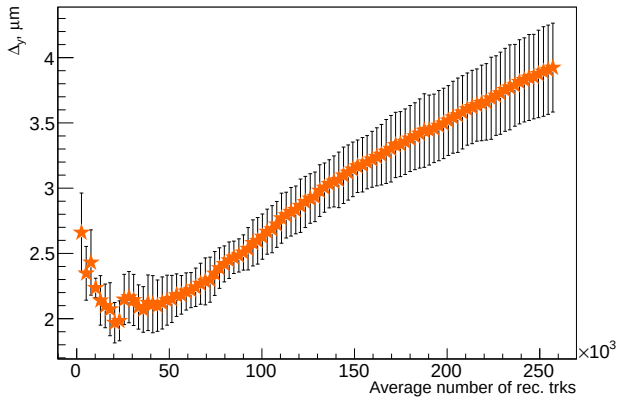
$\Rightarrow$ alignment during 5 min!

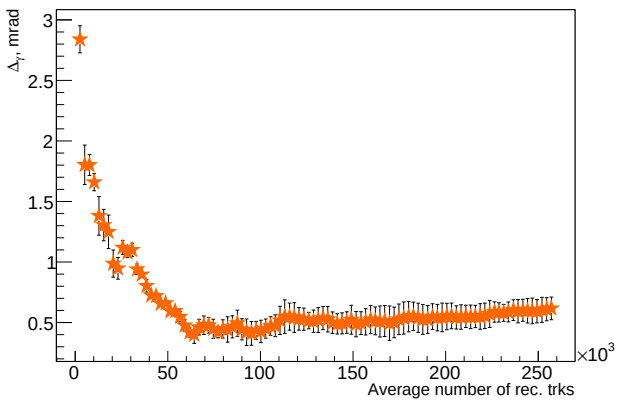


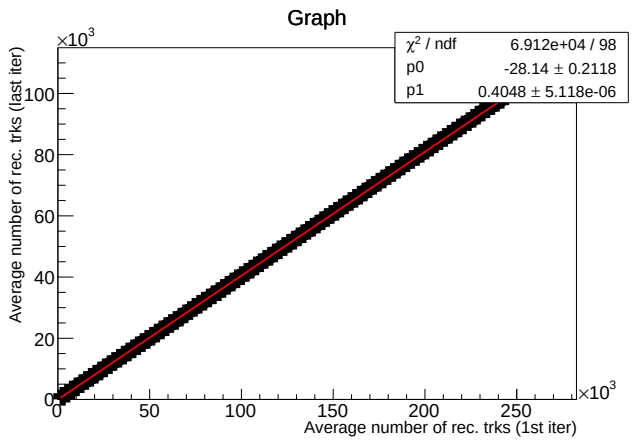
Influence of multiple scattering

Δ_t=200μm, Δ_r=3 mrad; P_{beam}=1.5 GeV/c, BOX ($\theta_{MC} \in$[2,12]mrad); DOF 111111







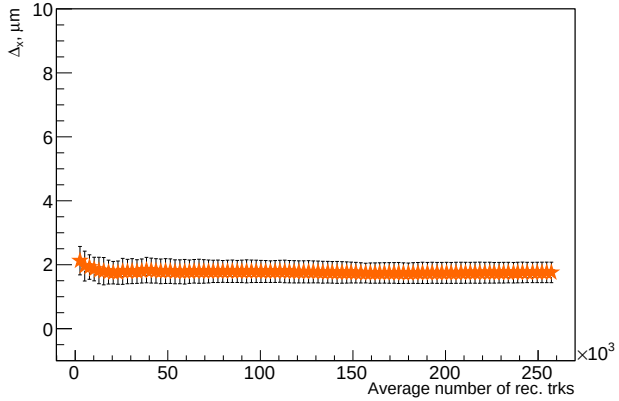


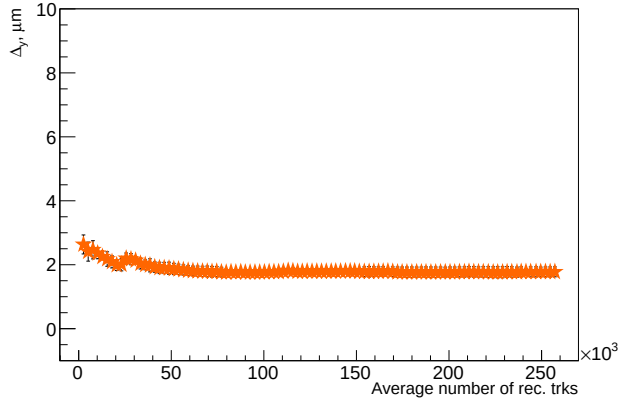
Possible solutions

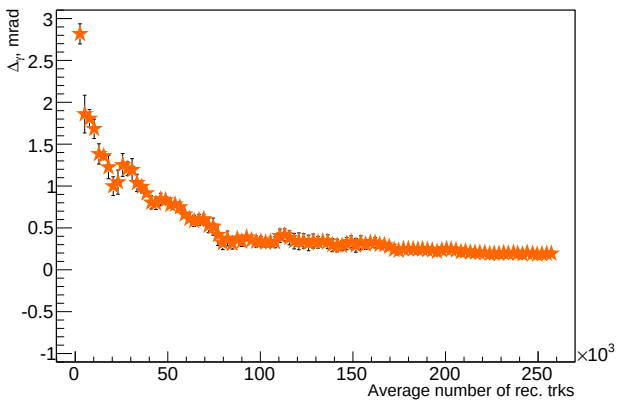
- fix Δ_z, Δ_α, Δ_β d.o.f
- add multiple scattering params in trk model

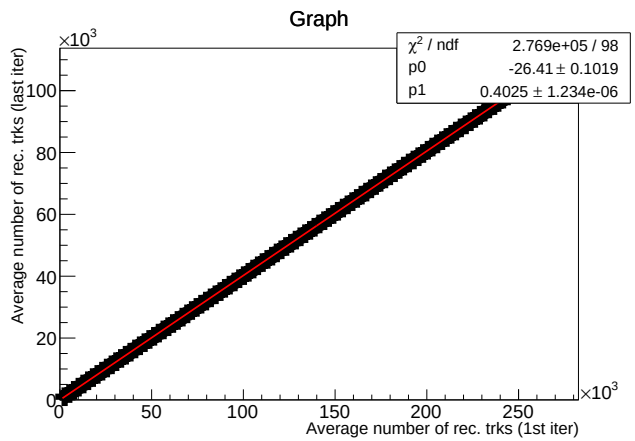
Fixed Δ_z, Δ_α, Δ_β d.o.f

Δ_t=200μm, Δ_r=3 mrad; P_{beam}=1.5 GeV/c, BOX ($\theta_{MC} \in$[2,12]mrad); DOF 110001







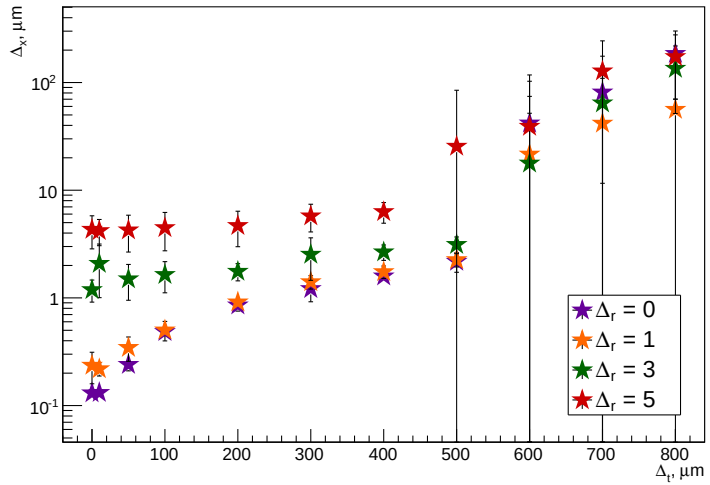


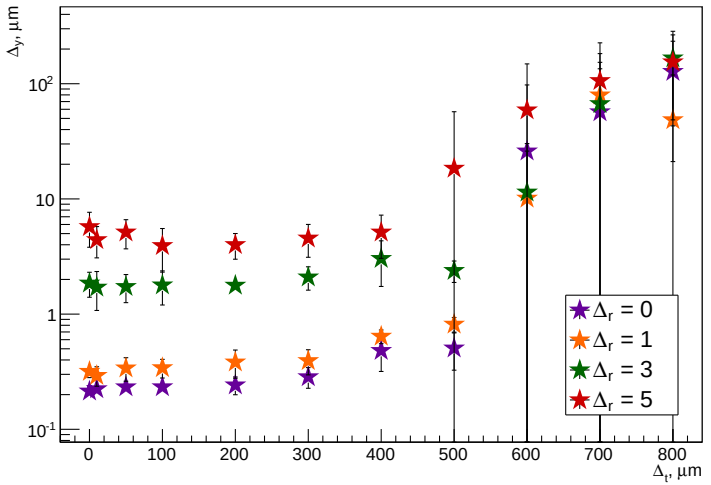
down to $\Delta_t \sim 2\mu$m $\Delta_r \sim 0.1$mrad with 10^5trks/sector

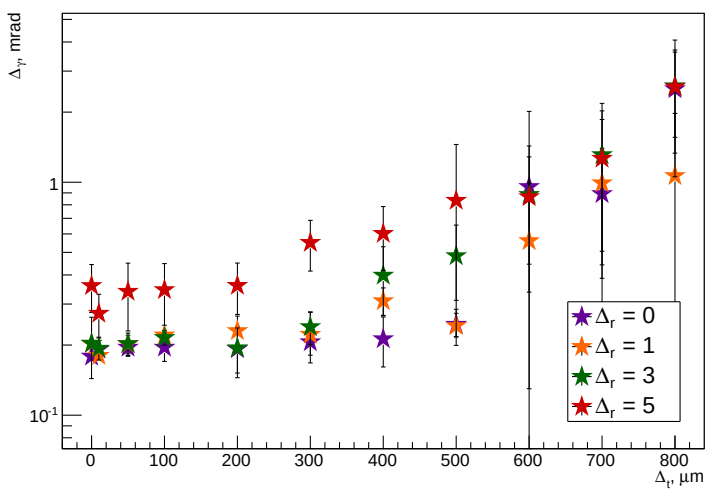
$\sim$60% trks rejected during alignment $\rightarrow$ try change of trk model!

Accuracy after alignment with fixed d.o.f

P_{beam}=1.5 GeV/c, BOX ($\theta_{MC} \in$[2,12]mrad); DOF 110001







$2.5 \cdot 10^5$ trks/sector

$\Delta_t \leq 40\mu$m, $\Delta_r \leq 3.5$mrad can be reached for $\Delta_t \leq 500\mu$m and $\Delta_r \leq 5$mrad

Conclusion

- LMD is sensitive to modules misalignment

  (arbitrary) limits:
  $\Delta_t \sim 15\mu$m, $\Delta_r \sim 1$mrad @ 15 GeV/c
  $\Delta_t \sim 40\mu$m, $\Delta_r \sim 3.5$mrad @ 1.5 GeV/c

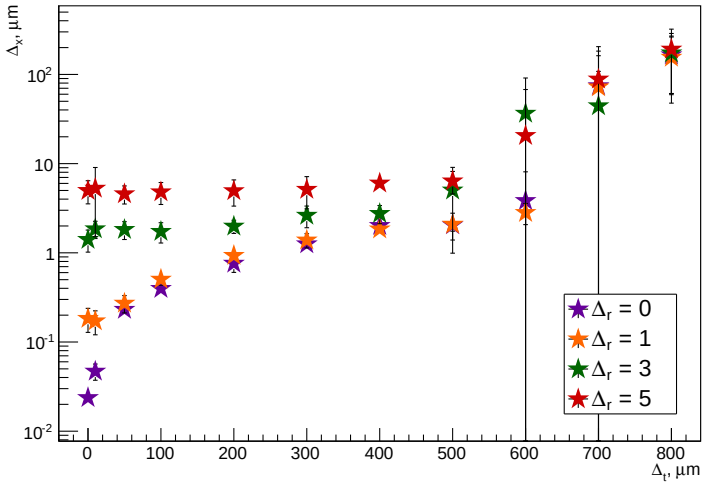
  expected assembling accuracy: $\Delta_t \sim 200\mu$m, $\Delta_r \sim 3$mrad

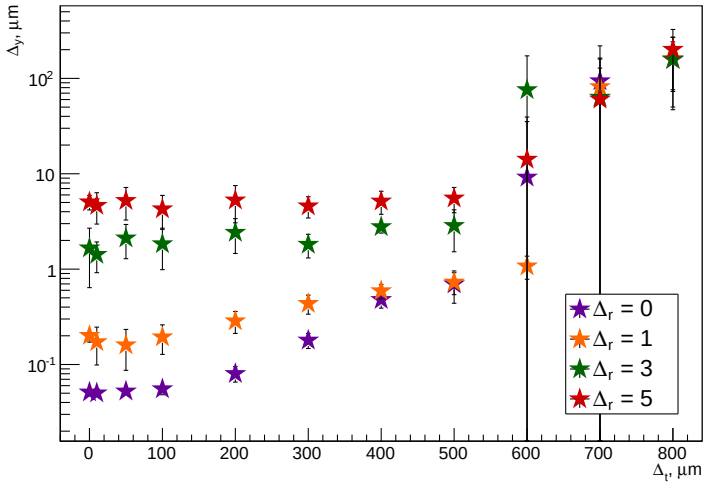
- Software alignment (Millipede) $\Rightarrow$ good results
  $\Delta_t \leq 500\mu$m and $\Delta_r \leq 5$mrad (15 GeV/c, 10^4-10^5 trks/sector)
- Low P_{beam} $\Rightarrow$ large multiple scattering
- By fixing d.o.f
  $\Delta_t \leq 500\mu$m and $\Delta_r \leq 5$mrad (1.5 GeV/c, $2.5 \cdot 10^5$ trks/sector)
  can be aligned

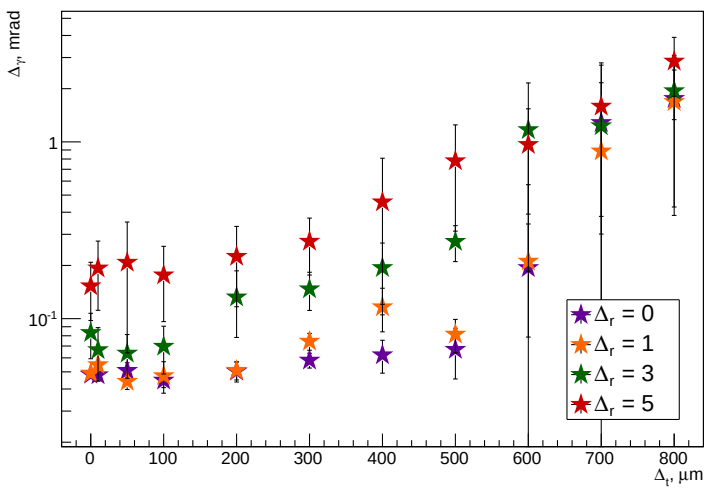
- toy-tool $\Rightarrow$ Millepede II
- I/O $\Rightarrow$ DB
- Studies with high multiplicities, non-uniform signal (DPM), etc

BOX P_{beam}=15 GeV/c

DOF 110001







Cuts in standard trk reconstruction

- $X\&Y$ and M cuts on fitted tracks before or after back propagation
  $\Rightarrow$ Aren't used here since cuts are not valid
- internal Ψ cut in CA (neighbors cells)
  $(1 - \cos\alpha) < \delta\psi_{\max}$
  $\Rightarrow$ Should be extended
  $\delta\psi_{max}(1.5 GeV/c) = 5 \cdot 10^{-6} \rightarrow 10^{-3}$
  $\delta\psi_{max}(15 GeV/c) = 8 \cdot 10^{-7} \rightarrow 10^{-3}$

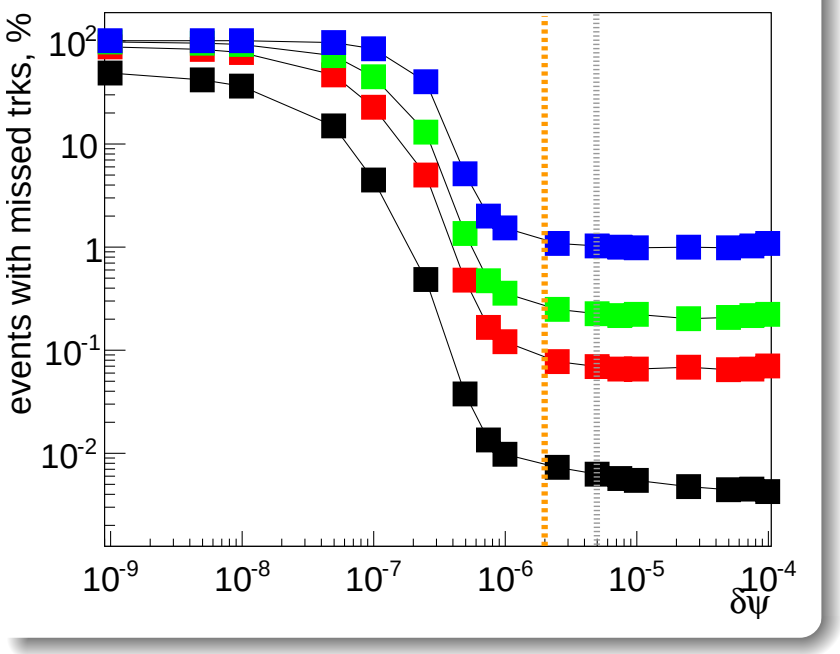
Reminder: How CA cut was chosen?

$(1 - \cos\alpha) < \delta\psi_{\max}$

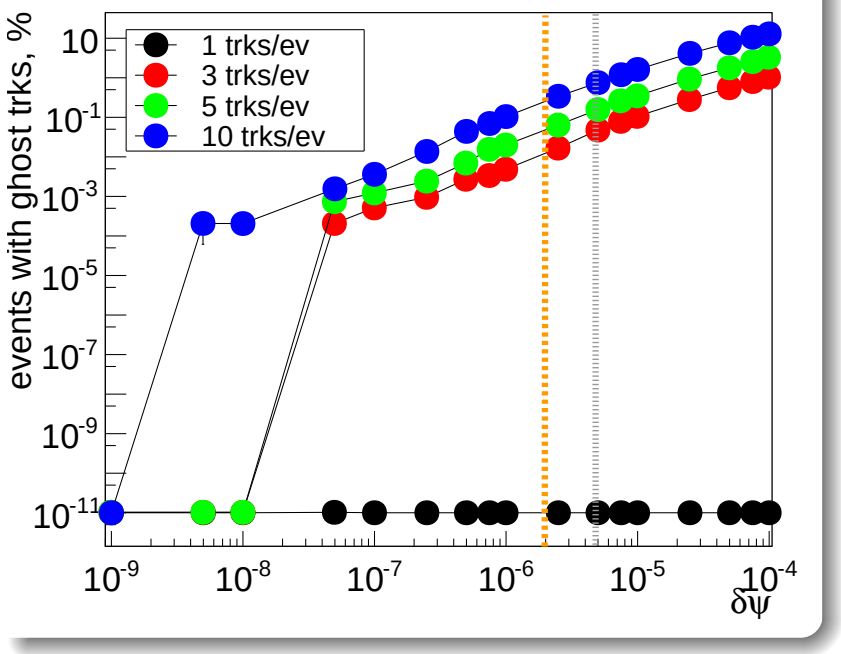
Influence of $\delta\psi_{max}$ on number of missed&ghost tracks @$P_{beam} = 1.5 GeV/c$

(estimated value, chosen value)

Missed trks



Ghost trks

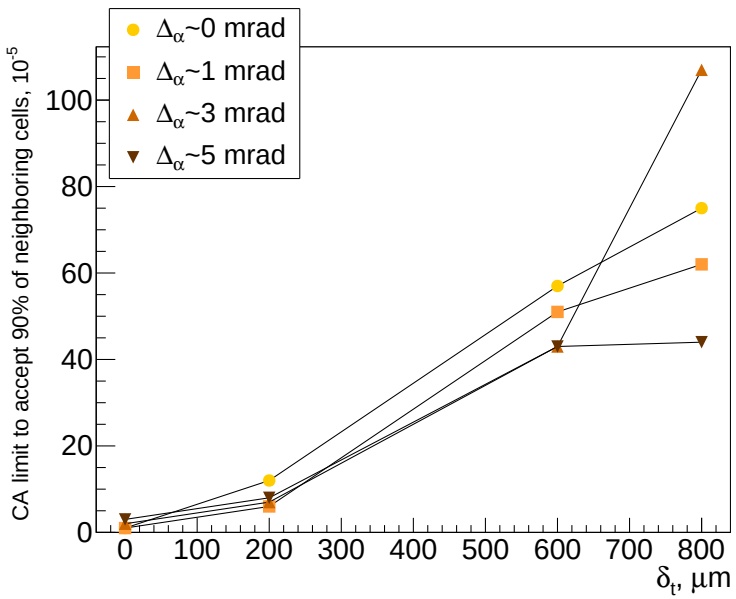


$\delta\psi_{max}(1.5 GeV/c) = 5 \cdot 10^{-6}$, $\delta\psi_{max}(15 GeV/c) = 8 \cdot 10^{-7}$

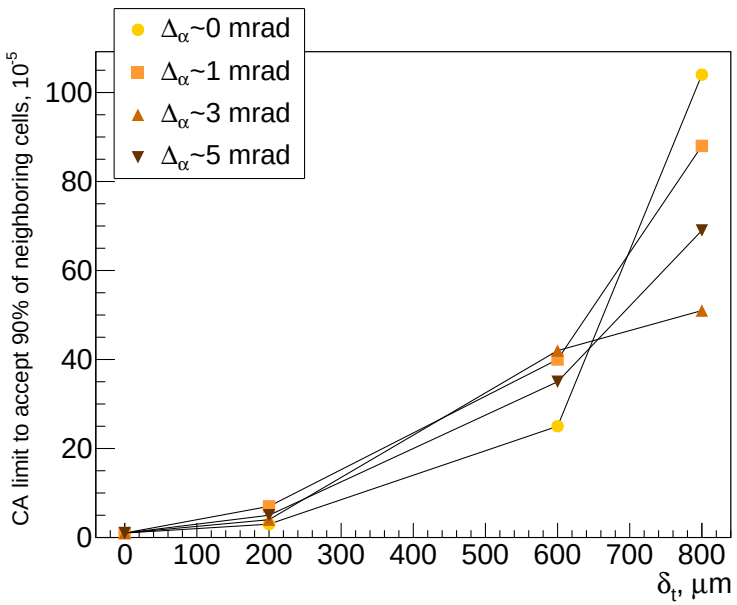
Let's check $(1 - \cos\alpha)$ with misaligned modules

1 trk/ev

1.5 GeV/c



15 GeV/c



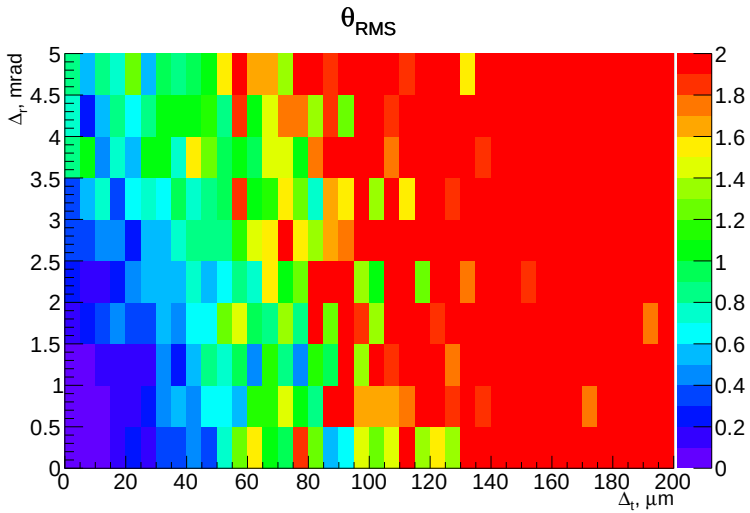
$$\delta\psi_{max}(1.5\,GeV/c) = 5 \cdot 10^{-6} \;\rightarrow\; 10^{-3}$$

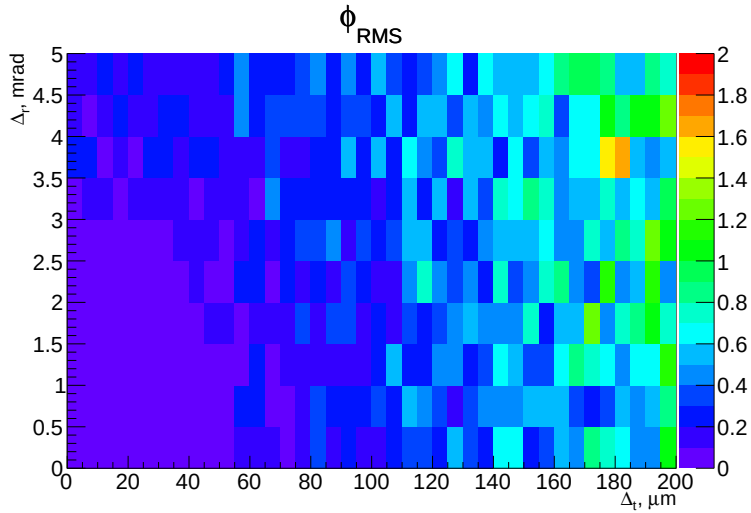
$$\delta\psi_{max}(15\,GeV/c) = 8 \cdot 10^{-7} \;\rightarrow\; 10^{-3}$$

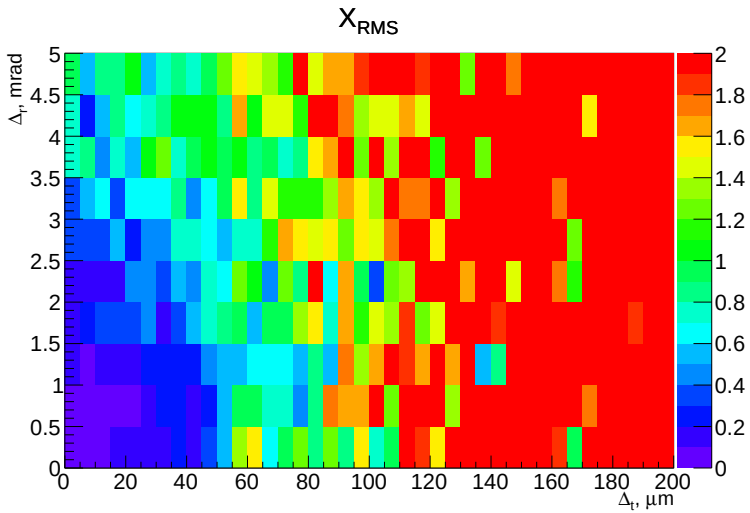
Misalignment effect on track resolution

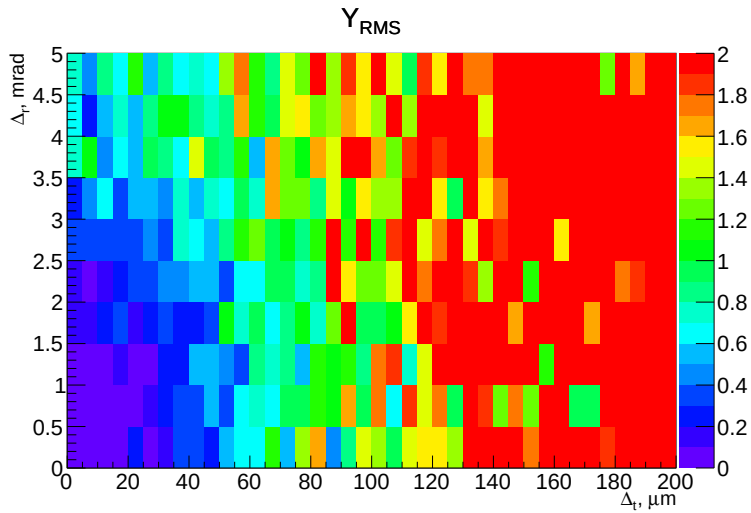
P_{beam} = 15 GeV/c

$$\left| \frac{(Res^{ideal} - Res^{misalign})}{Res^{ideal}} \right|$$









Misalignment effect on track resolution

P_{beam} = 1.5 GeV/c

$$\left| \frac{(Res^{ideal} - Res^{misalign})}{Res^{ideal}} \right|$$