Telescope Precision Studies

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Status report

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- Analysis method
- Main Results
- Conclusions and Plans

Introduction

Motivation

The main aims of this study

- understand the position measurement in the telescope
- optimize the performance by suggesting the best plane setup

Approach

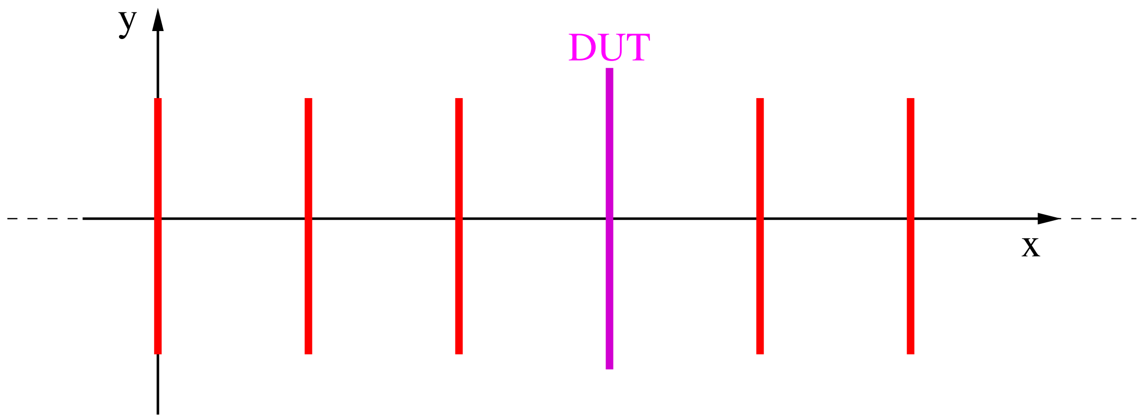
Use analytical method for track fitting including multiple scattering (!!!)

Simplifying assumptions:

- small scattering angles (Gaussian approximation)
- Gaussian position measurement errors
- perfect alignment (could be taken into account !)
- no additional material (windows, etc.) (could be taken into account as well !)

Analysis method

Geometry description



Geometry can be specified by giving:

- N - number of detector planes (including DUT)
- x_i - position of each plane $(i = 1 \ldots N)$
- σ_i - position resolution in each plane $(i \neq i_{DUT})$
- $\Delta\theta_i$ - average scattering angle in each plane

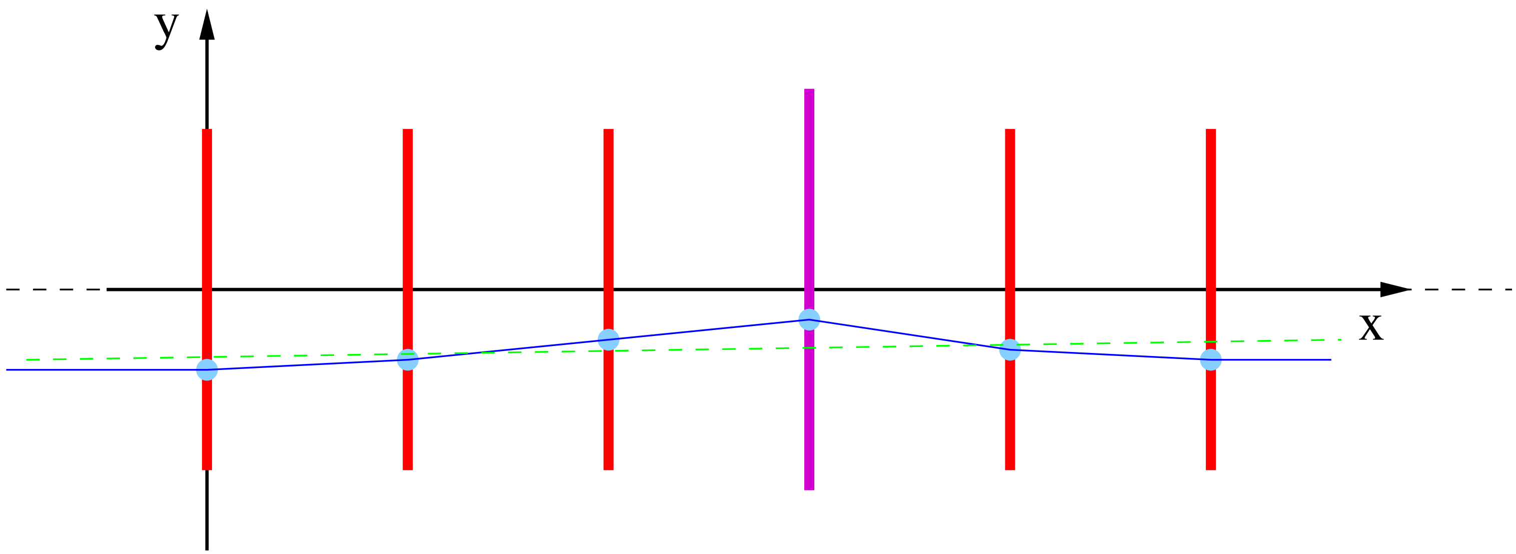
For given telescope parameters $(N,\ \sigma_i,\ \Delta\theta_i\ )$ we can look for configuration (plane ordering, values of x_i) resulting in best determination of particle position at DUT

Analysis method

Multiple scattering

Distances between planes $\sim O(10\ mm)$ + scattering angles $\sim O(0.1\ mrad)$

$\Rightarrow$ track displacement due to scattering $\sim O(1\ \mu m)$ (for beam energy of few GeV)



Displacement comparable with position resolution $(1 - 2\ \mu m)$!

$\Rightarrow$ significantly influences the measurement, can not be neglected !

Straight line fit is not sufficient...

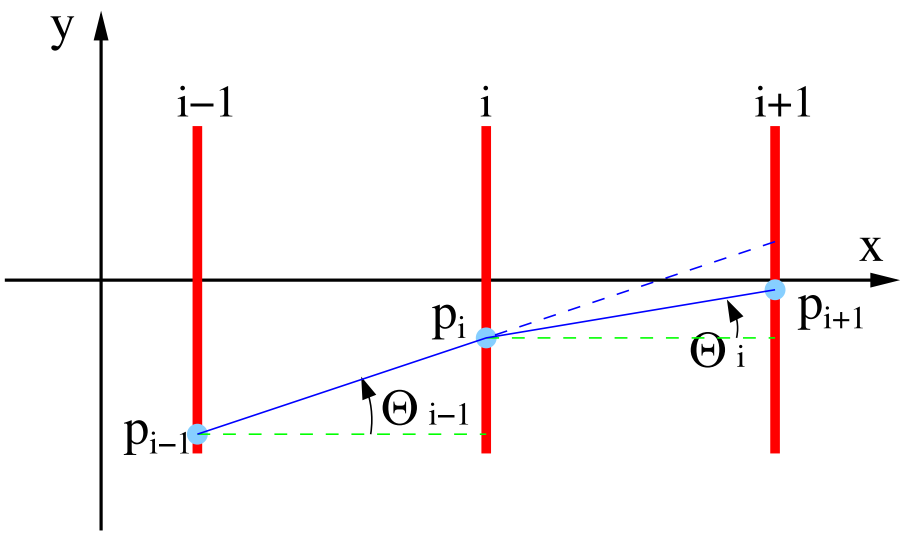
Analysis method

Track fitting

We want to determine track positions in each plane (including DUT), i.e. N parameters $(p_i,\ i = 1 \ldots N)$, from $N-1$ measured positions in telescope planes $(y_i,\ i \neq i_{DUT})$.

However, we can use constraints on multiple scattering!

Contribution of plane i to χ^2 of the fit



position measurement — multiple scattering

$$\Delta\chi_i^2 = \left(\frac{y_i - p_i}{\sigma_i}\right)^2 + \left(\frac{\Theta_i - \Theta_{i-1}}{\Delta\Theta_i}\right)^2$$

where: $$\Theta_i = \frac{p_{i+1} - p_i}{x_{i+1} - x_i}$$

Both terms present for planes $i \neq 1, i_{DUT}, N$,
first term missing for DUT, second for first and last plane

χ^2 minimum can be found by solving the matrix equation.

As a by-product we get also an error on the position reconstructed at DUT.

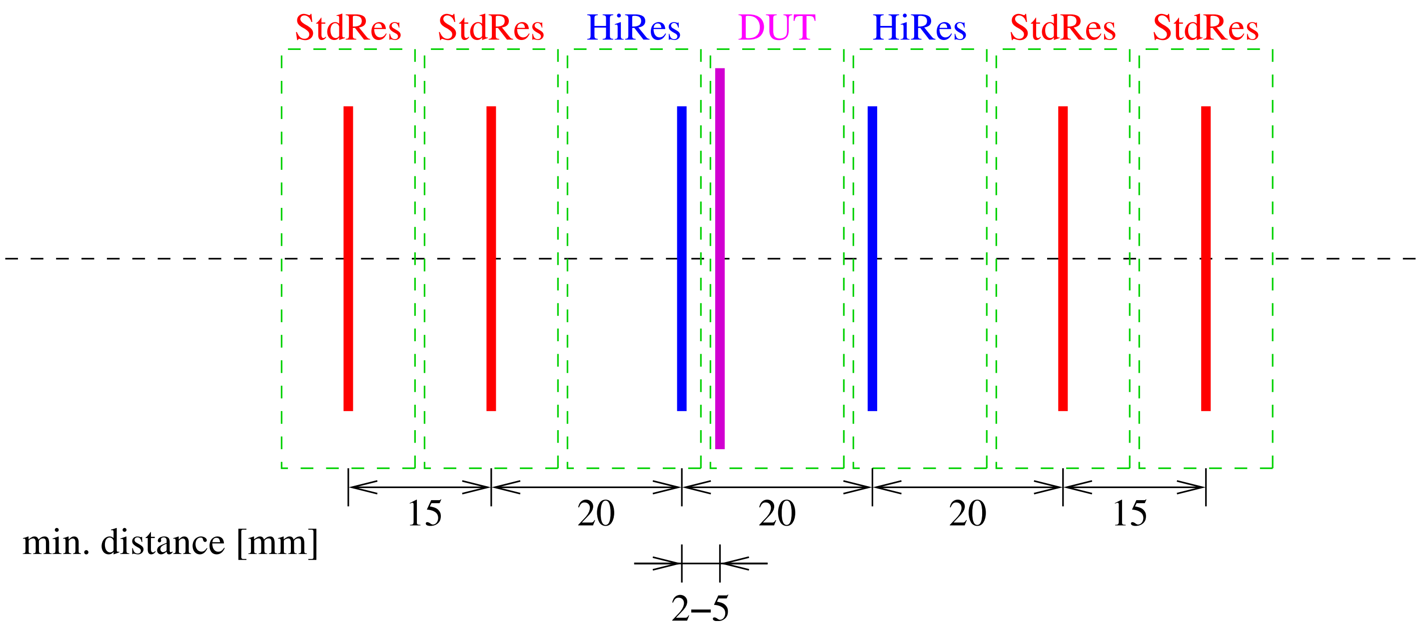
Analysis method

Realistic telescope geometry

thanks to W.Dulinski

The minimum distance between DUT and **one** of the telescope planes, d_{min}, is 5 mm (easy, realistic) or even 2 mm (hard, optimistic).

However, other distances can not be smaller than 15 or 20 mm:



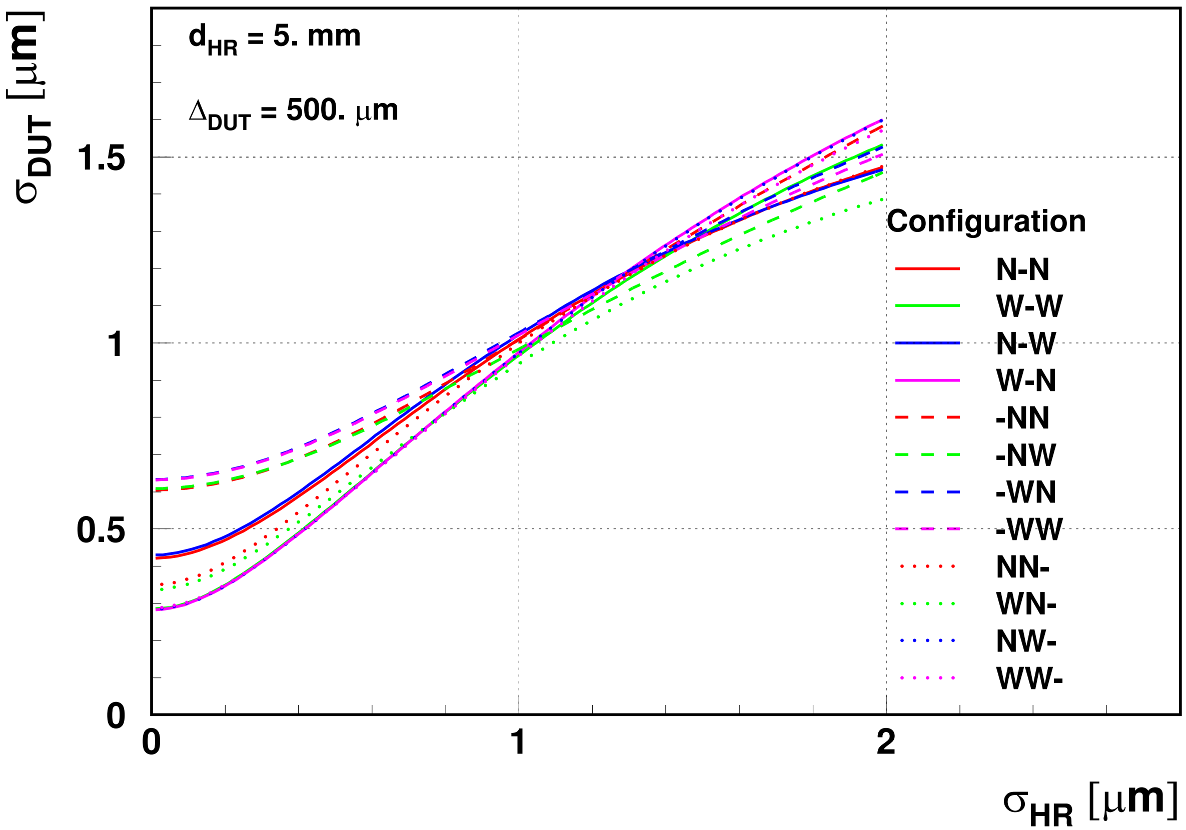
In addition to standard sensor planes with 2 μm resolution we can consider adding one or two high resolution planes ($\sigma_{HR} \sim 1\mu m$)

Results

4 (1+3) telescope planes

Simplest case: 1 high resolution (HR) and 3 standard sensor planes (120 μm each)

Expected position error at DUT, σ_{DUT}, as a function of the HR plane resolution, σ_{HR}, for different telescope configurations: 6 GeV e^{-} beam, DUT thickness of 500 μm

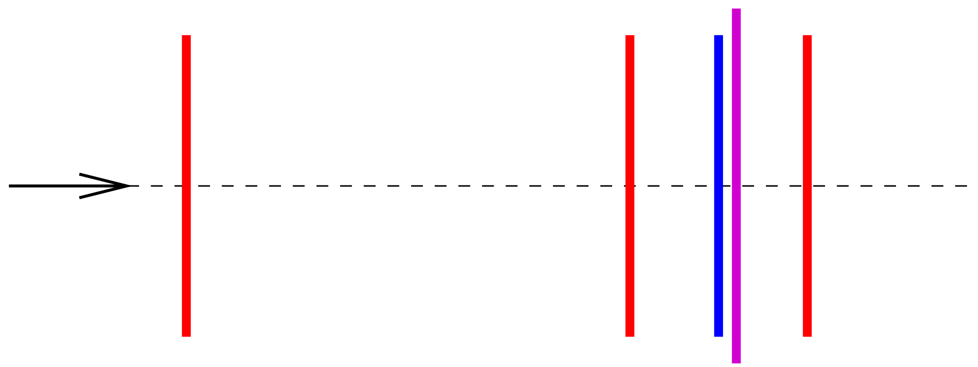


Results

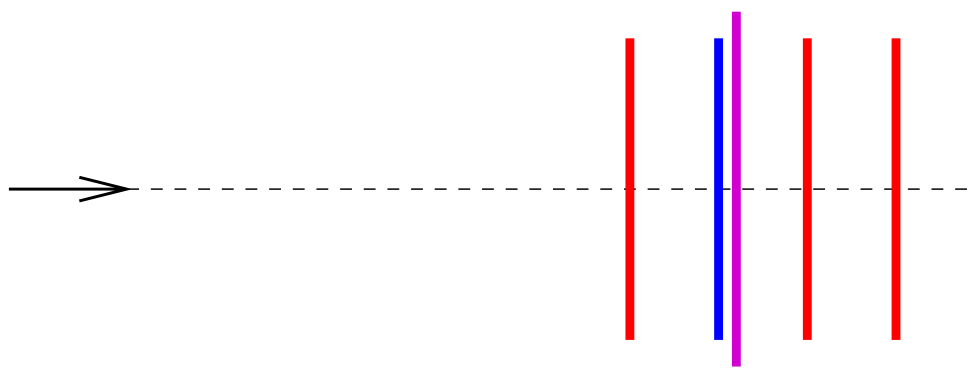
4 (1+3) telescope planes   6 GeV e^- beam

Assuming HR plane resolution is not better than 1 μm and DUT is thiner than 1 mm:

Best precision for thick DUT, $\Delta_{DUT} \geq 200\mu m$, is obtained for **WN–** configuration



N–N configuration gives best precision for very thin DUT, $\Delta_{DUT} \leq 200\mu m$



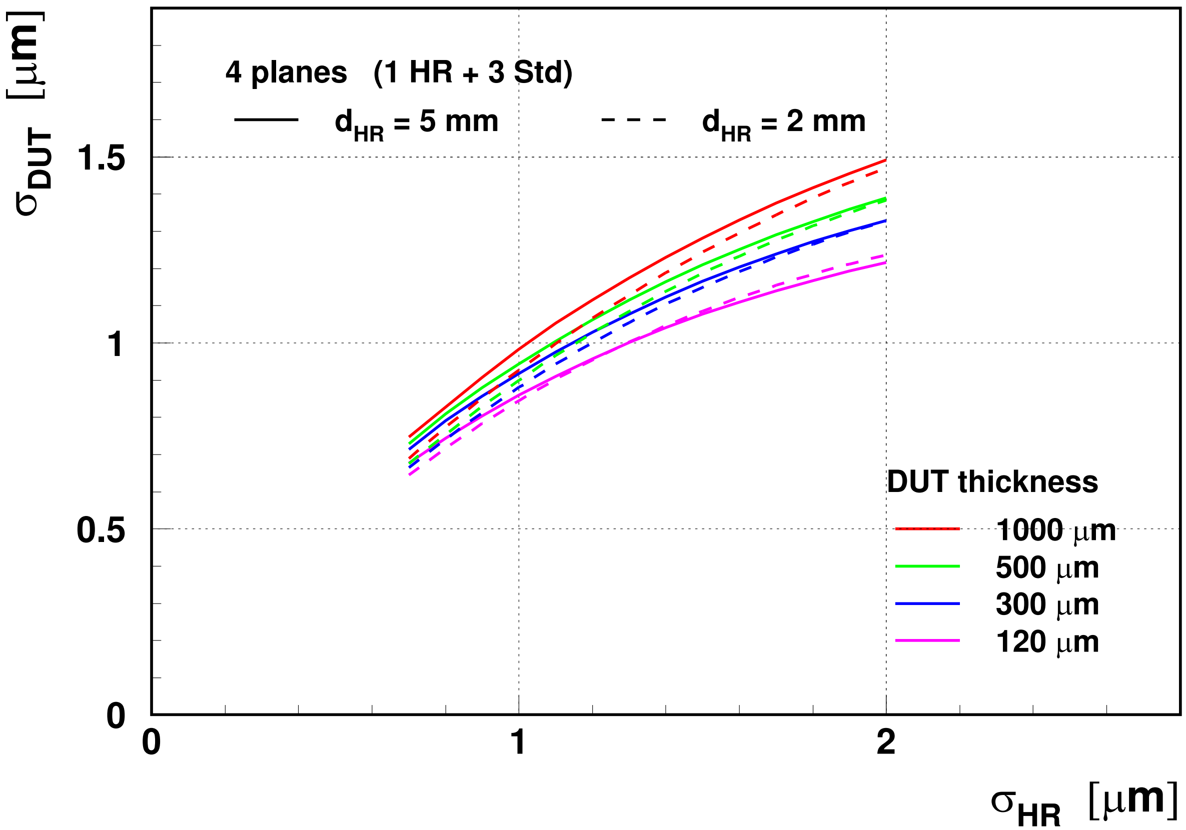
not to scale !

Results

4 (1+3) telescope planes   6 GeV e^- beam

High resolution plane should be put as close to DUT as possible.   (for $\sigma_{HR} \sim 1\mu m$)

Expected position error at DUT, σ_{DUT}, as a function of the HR plane resolution, σ_{HR}, for optimum telescope configuration:



Results

4 (2+2) telescope planes

Two high resolution + two standard planes: more possibilities!

Configuration choice as a function of DUT thickness and HR plane resolution:

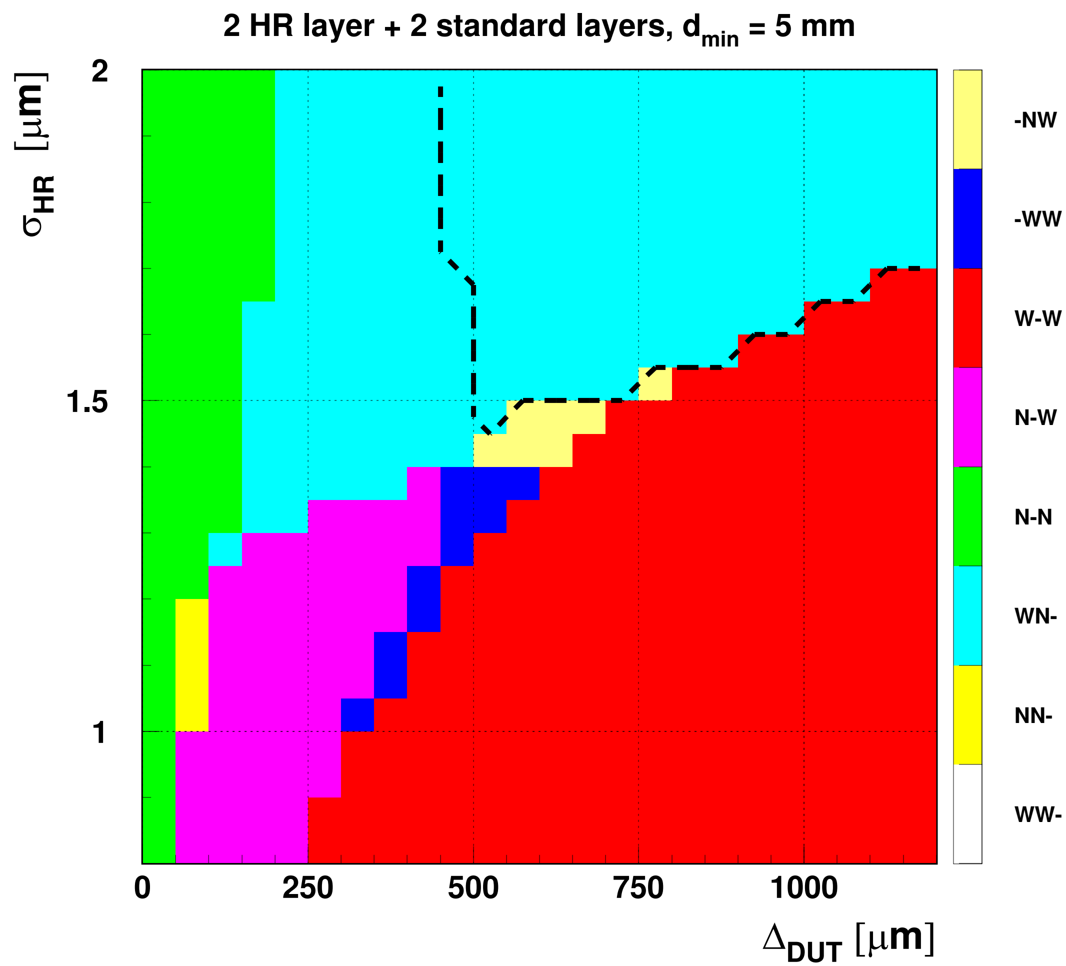
$d_{min} = 5$ mm

Above dashed line:

better performance if both HR planes in front of DUT

large σ_{HR} & Δ_{DUT}

6 GeV e^- beam

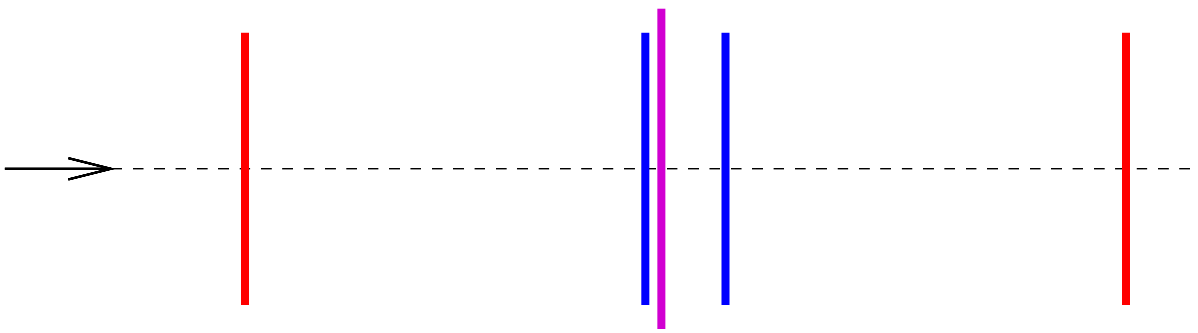


Results

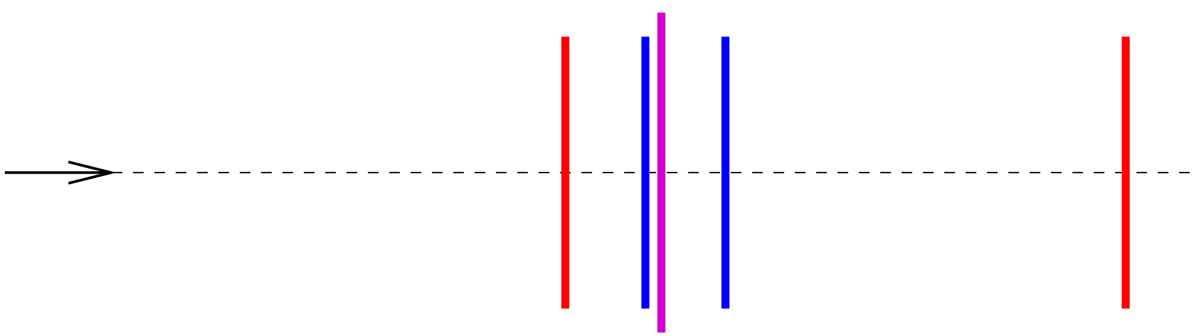
4 (2+2) telescope planes   6 GeV e^- beam

Assuming HR plane resolution is of the order of 1 μm:

W–W configuration gives best precision for thick DUT



N–W configuration gives best precision for thin DUT, or smaller d_{HR}



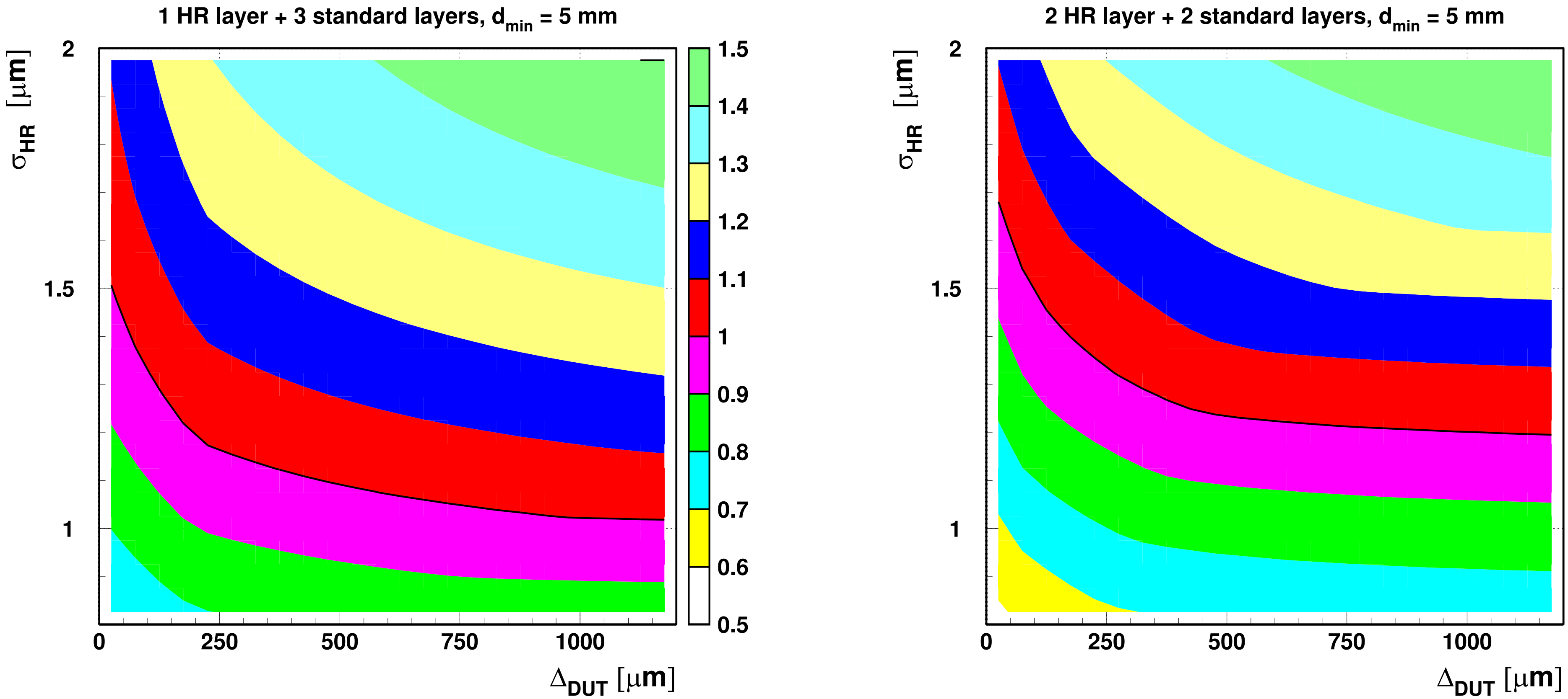
Results

4 telescope planes

Configuration with two HR planes always gives better precision than with one HR plane.

Expected statistical precision of position reconstruction at DUT [μm]:

1 HR plane   6 GeV e^- beam   2 HR planes d_{min} = 5 mm



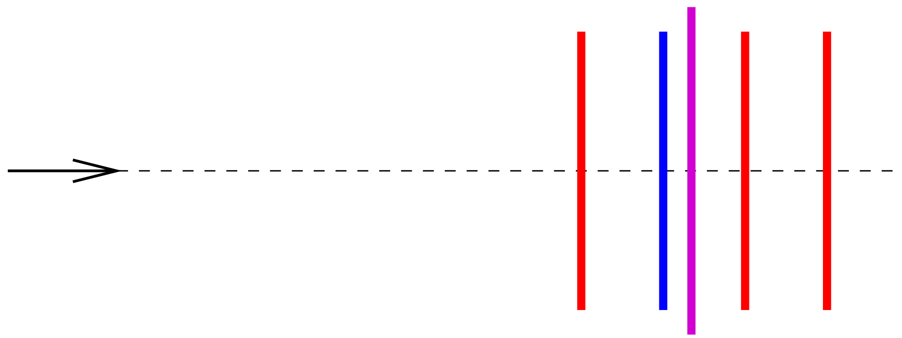
Results

4 telescope planes   100 GeV π^- beam

Multiple scattering much smaller, much less important!

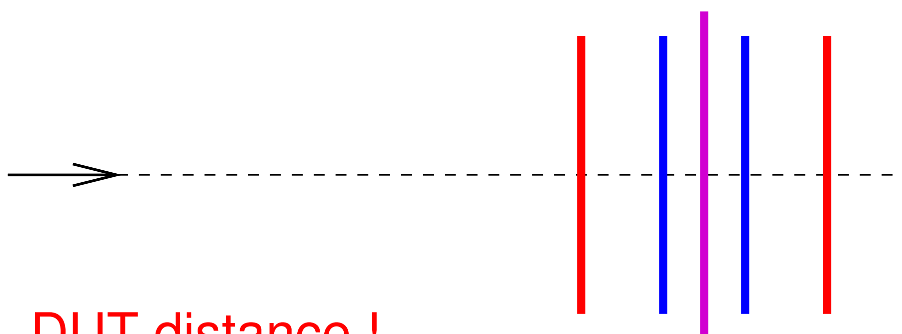
Best precision obtained for detector planes put close to each other (N–N configuration)

With one HR plane DUT should be placed in $\sim \frac{1}{3}$ of the distance between sensors



assuming $\sigma_{HR} \sim 1 \mu m$

With two HR planes DUT should be placed in the middle between HR planes.



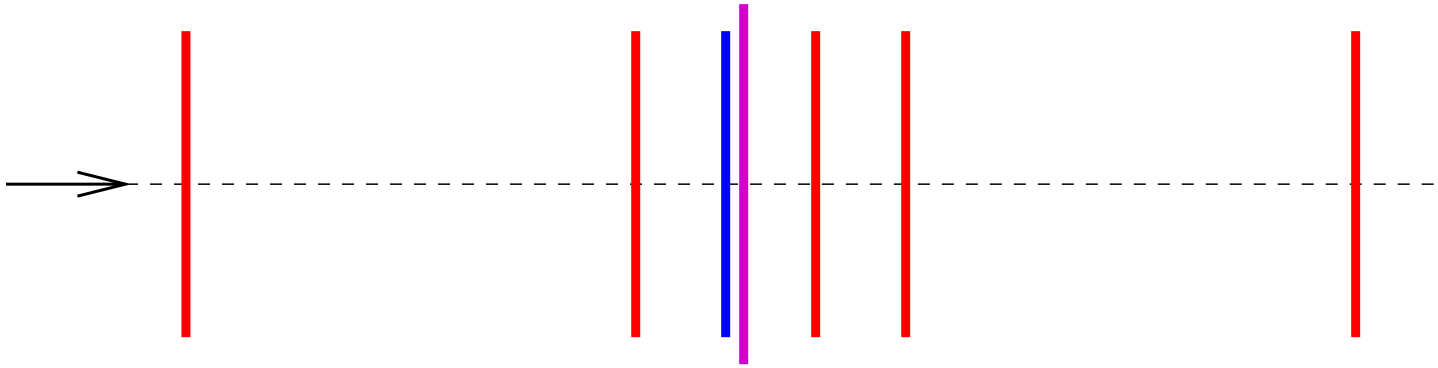
No need to minimize HR–DUT distance !

Results

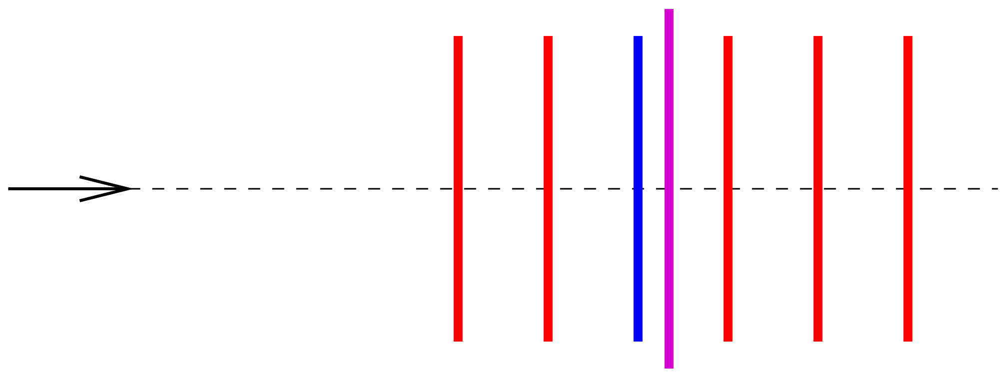
6 (1+5) telescope planes

One high resolution and 5 standard telescope planes

For low energy beam (eg. 6 GeV e^-) best measurement in **WN–NW** configuration



For high energy beam (eg. 100 GeV π^-) best measurement in **NN–NN** configuration



Results

6 (2+4) telescope planes

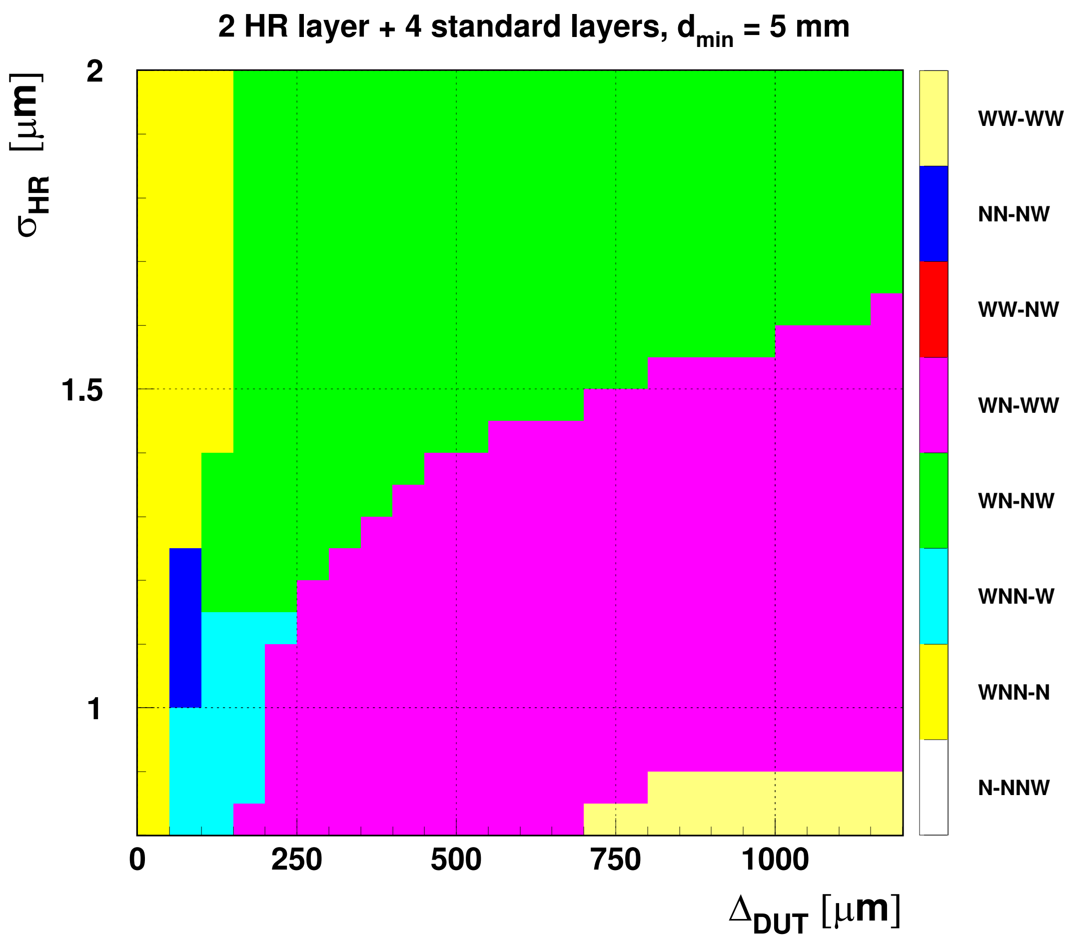
Two high resolution + four standard planes: even more possibilities!

Configuration choice as a function of DUT thickness and HR plane resolution:

$d_{min} = 5$ mm

Best performance with second HR plane always placed behind DUT

6 GeV e^- beam

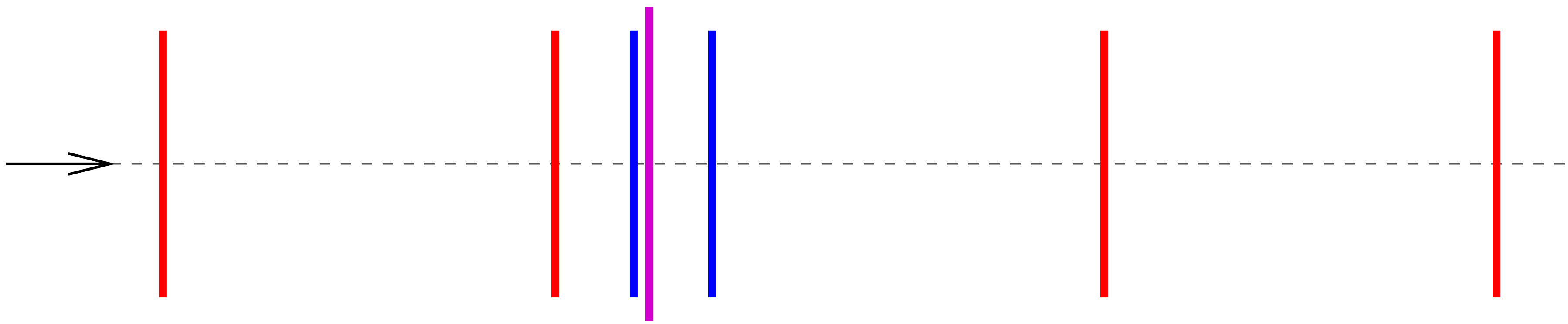


Results

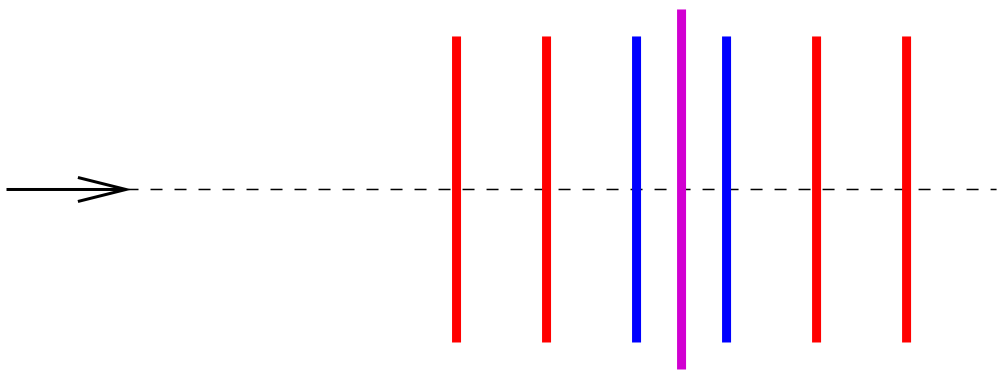
6 (2+4) telescope planes

Assuming HR plane resolution is of the order of 1 μm, $d_{min} = 5mm$

For low energy beam (eg. 6 GeV e^-) best measurement in **WN–WW** configuration (except for very thin DUT)



For high energy beam (eg. 100 GeV π^-) best measurement in **NN–NN** configuration



Results

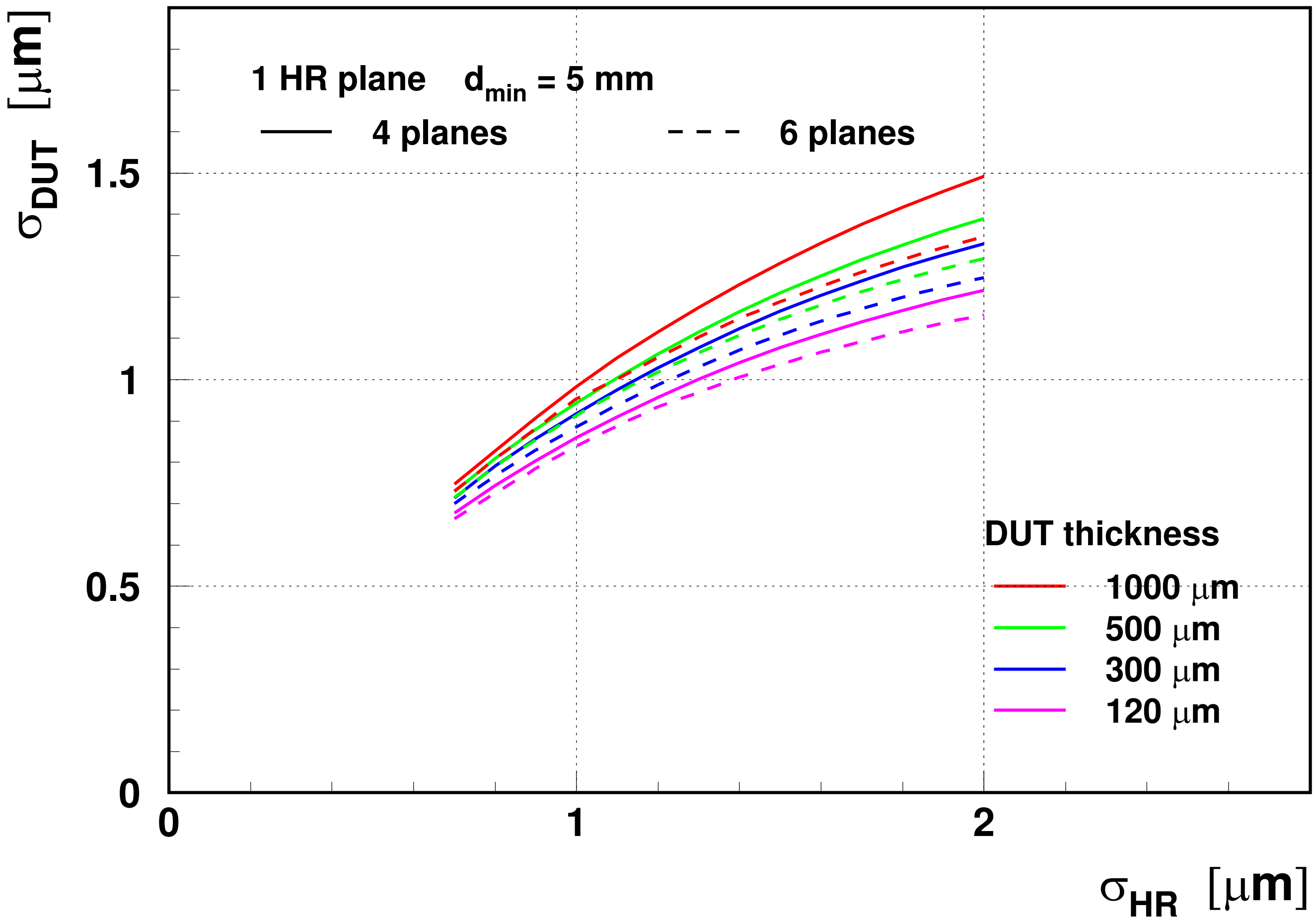
6 vs 4 telescope planes

Configuration with 6 planes planes always gives better precision than 4 planes.

Expected position error at DUT, σ_{DUT}, as a function σ_{HR}

1 HR plane

d_{min}= 5 mm



Results

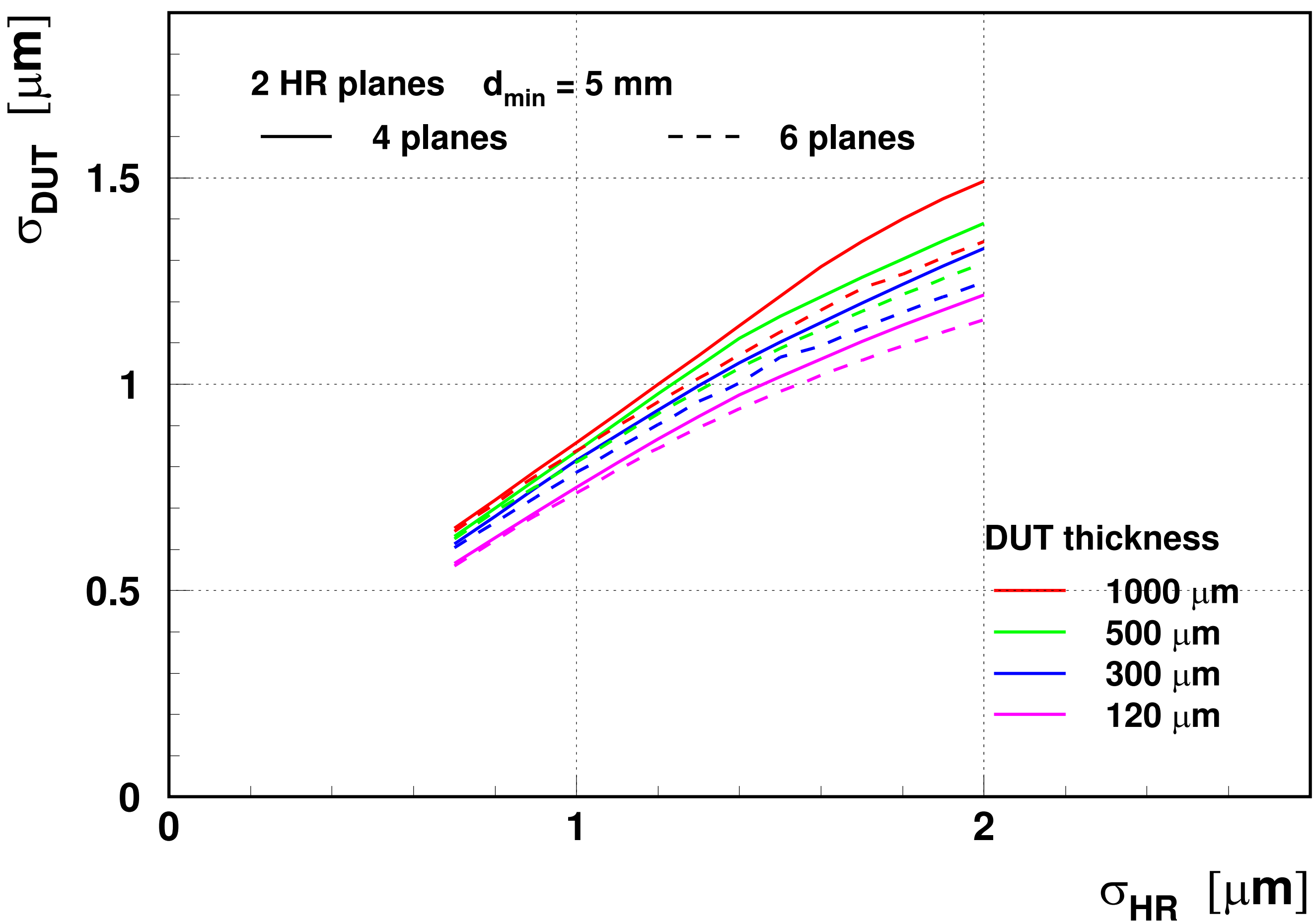
6 vs 4 telescope planes

Configuration with 6 planes planes always gives better precision than 4 planes.

Expected position error at DUT, σ_{DUT}, as a function σ_{HR}

2 HR planes

d_{min}= 5 mm



Conclusions and Plans

- Analytical method used to describe the performance of the telescope with realistic geometry constraints.
- The optimum telescope setup is not uniquely defined
  $\Rightarrow$ few configurations, for different telescope parameters, suggested.
- To achieve error on the reconstructed particle position at DUT of 1μm at least one high resolution plane is needed
- Significant improvement expected from second HR plane.
- 6 sensor planes always give better position resolution than 4 planes

Our current aim is to confirm obtained results with GEANT 4 simulation, we hope to have first results for EUDET annual meeting.

For detailed description of the analysis and current results see:
http://hep.fuw.edu.pl/u/zarnecki/talks/afz_jra1_apr06.pdf
http://hep.fuw.edu.pl/u/zarnecki/talks/afz_jra1_jul06.pdf