Beam telescope geometry study (II)

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Outline

- Introduction
  summary of previous results
- Telescope geometry
  realistic assumptions, possible configurations
- Results
  configuration choice, expected position resolution
- Conclusions

Introduction

Motivation

The main aims of this study

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

Analytical method

Describes the performance of the telescope including multiple scattering (!!!)

Simplifying assumptions:

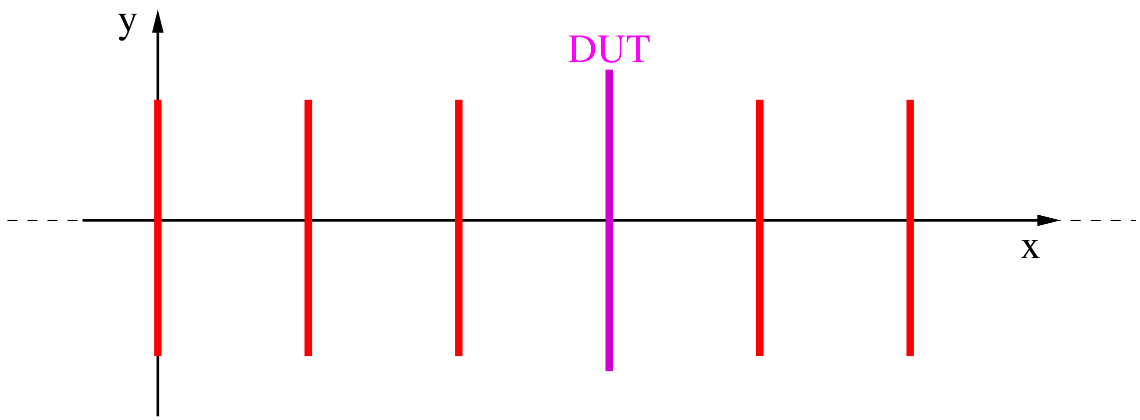
- small scattering angles (Gaussian approximation)
- Gaussian position measurement errors
- perfect alignment
- no additional material (windows, etc.) (could be taken into account)

Analytical approach: track fitting by solving matrix equation

$\Rightarrow$ error on the position reconstructed at DUT given by telescope geometry only

Introduction

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, σ_i, $\Delta\theta_i$) we can look for configuration (plane ordering, values of x_i) resulting in best determination of particle position at DUT

Introduction

Previous results

Error on particle position at DUT, σ_{DUT}, calculated for different telescope set-ups, as a function of d_{min} - minimum distance between two detector planes.

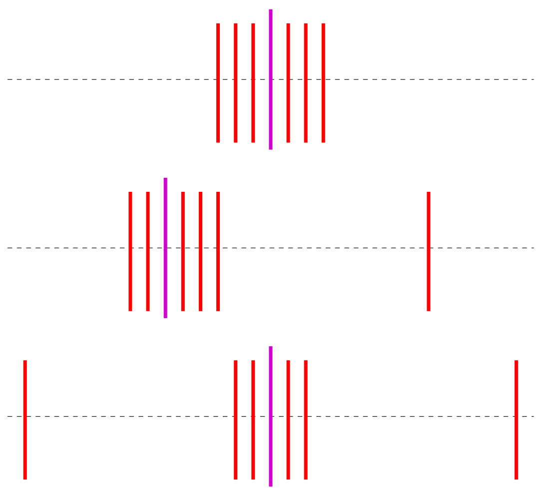
6 GeV e^- beam, 120 μm sensors with 2 μm resolution, DUT thickness of 500 μm

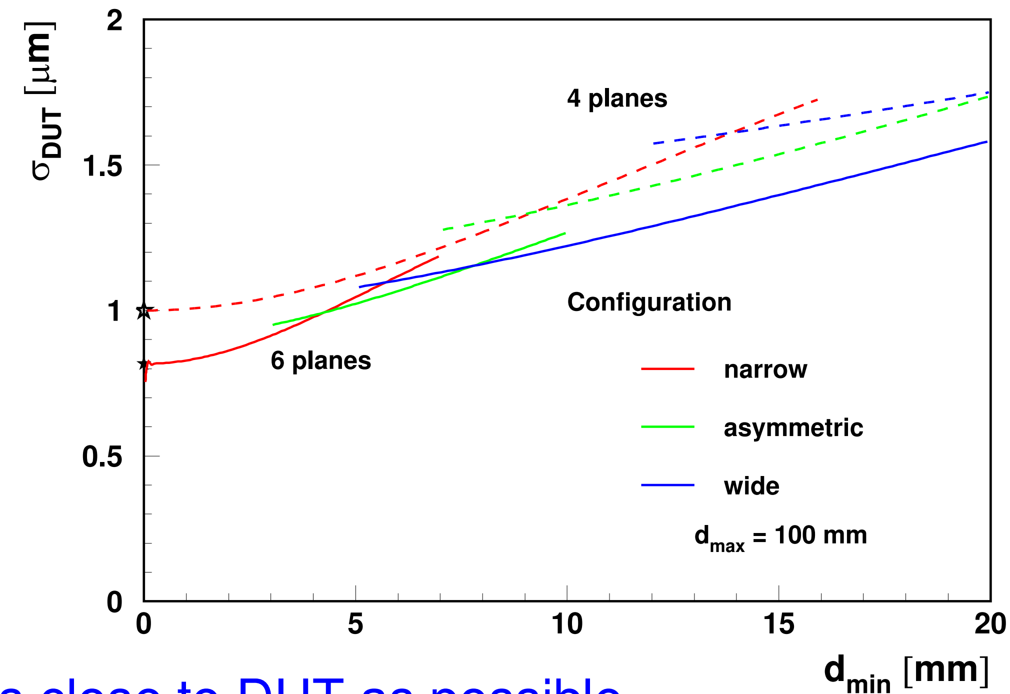
Configurations studied:

Narrow

Asymmetric

Wide





It is essential to place sensor planes as close to DUT as possible.

6 sensor planes always give better position resolution than 4 planes.

For details see: `http://hep.fuw.edu.pl/u/zarnecki/talks/afz_jra1_apr06.pdf`

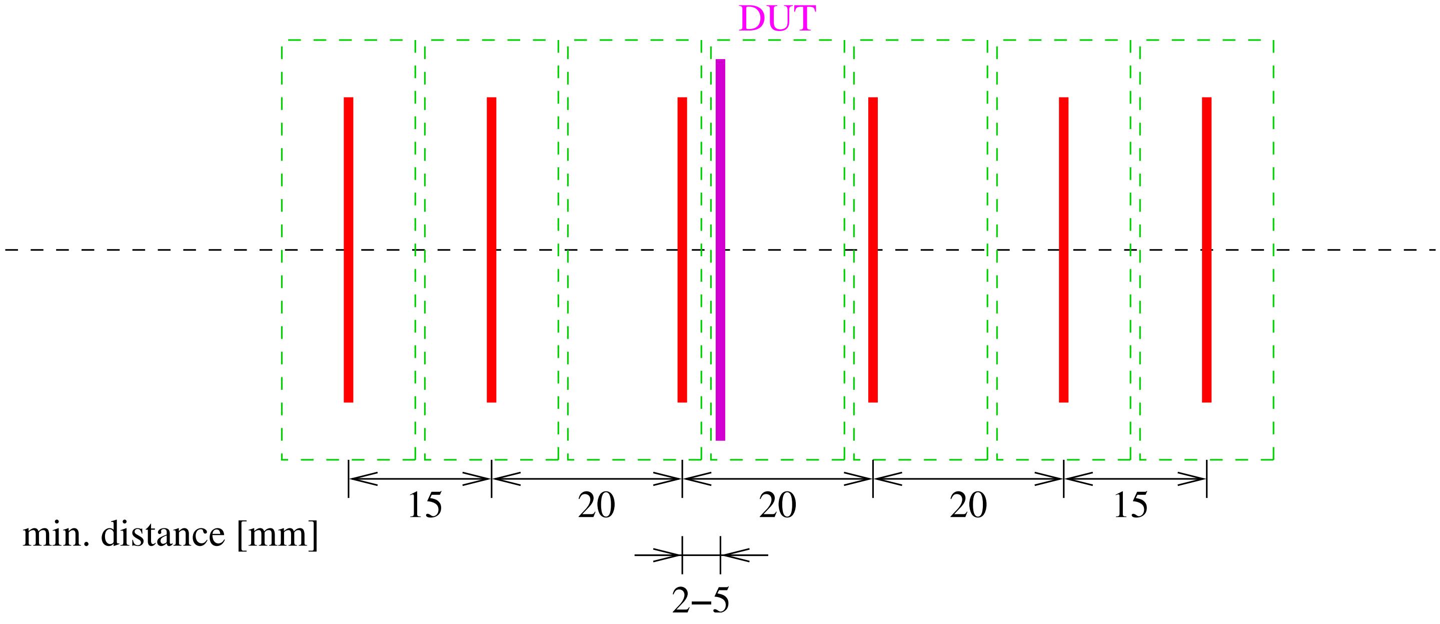
Telescope geometry

Realistic assumptions

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:



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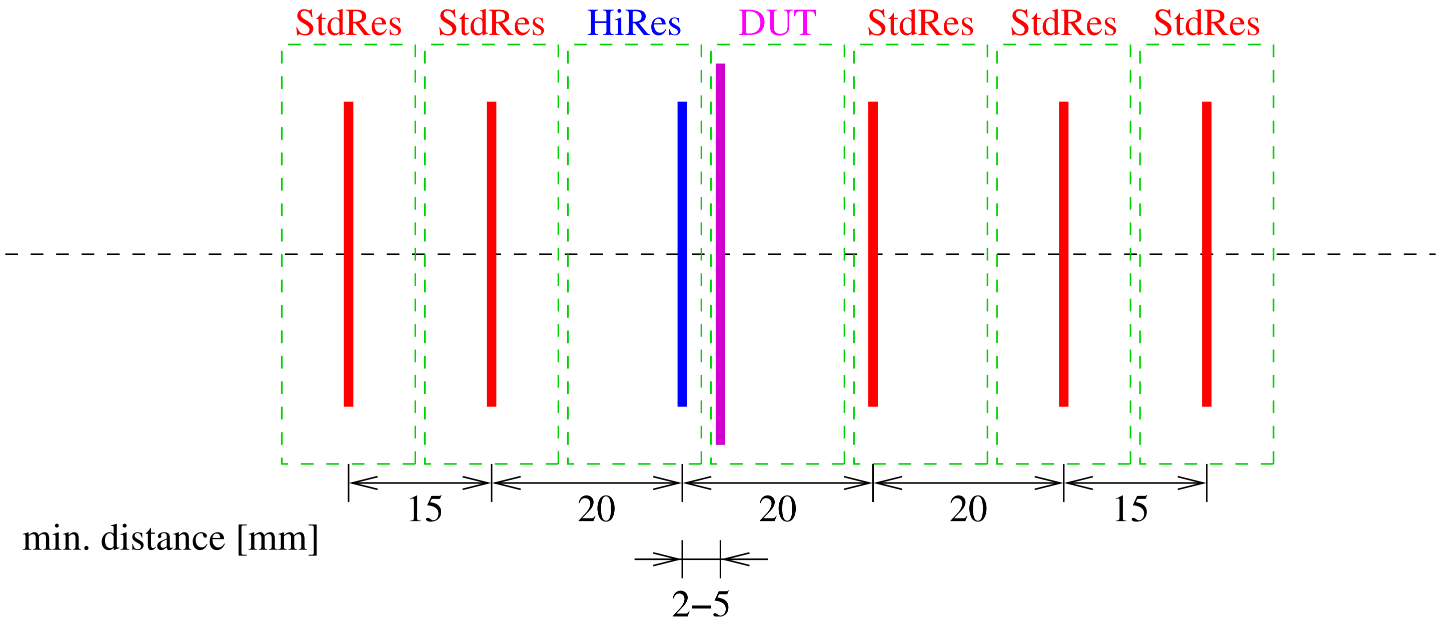

In addition to standard sensor planes with 2 μm resolution we can consider adding one high resolution plane ($\sigma_{HR} \sim 1 \mu m$) in front of DUT

Telescope geometry

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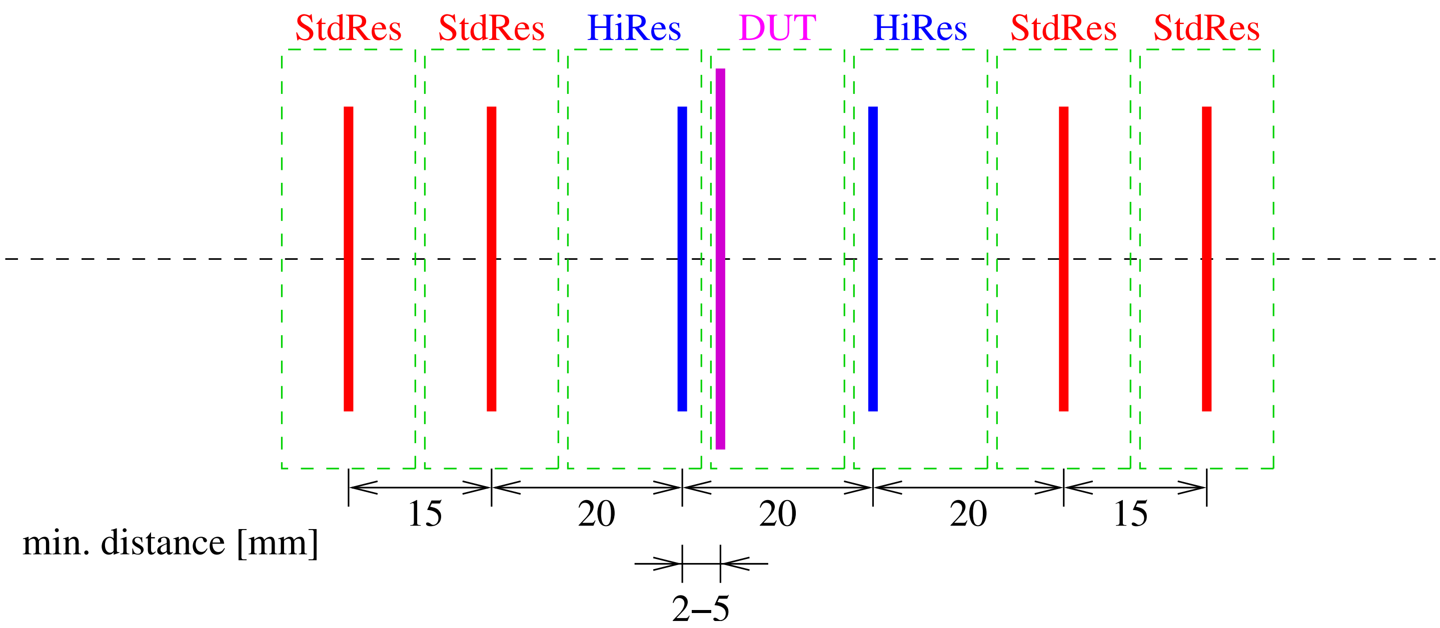


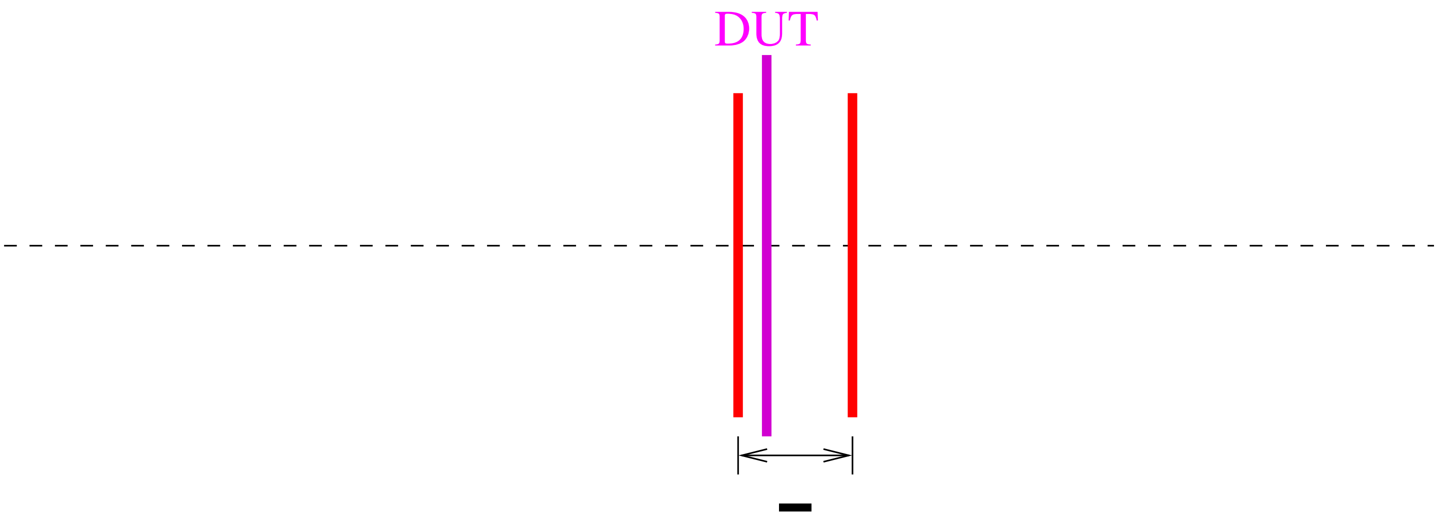
In addition to standard sensor planes with 2 μm resolution we can consider adding one or two high resolution planes ($\sigma_{HR} \sim 1 \mu m$)

Telescope geometry

Configuration description

Labeling scheme introduced to describe considered telescope configurations:

Configuration '–'



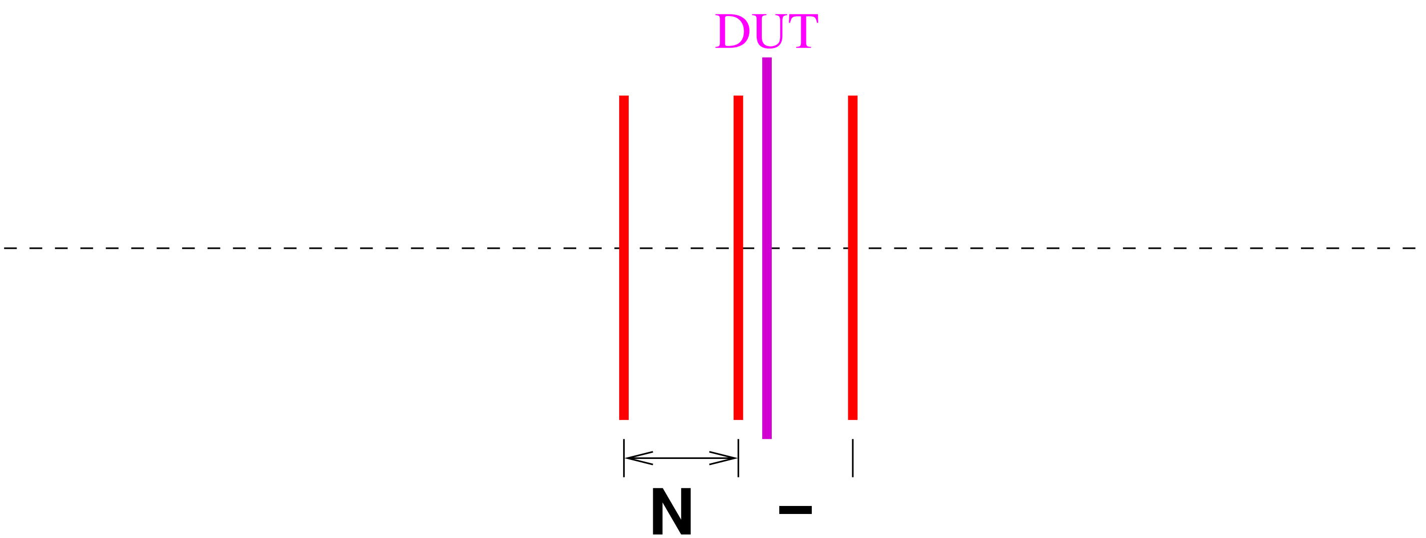
- DUT and two sensor planes close to it: –

Telescope geometry

Configuration description

Labeling scheme introduced to describe considered telescope configurations:

Configuration 'N−'



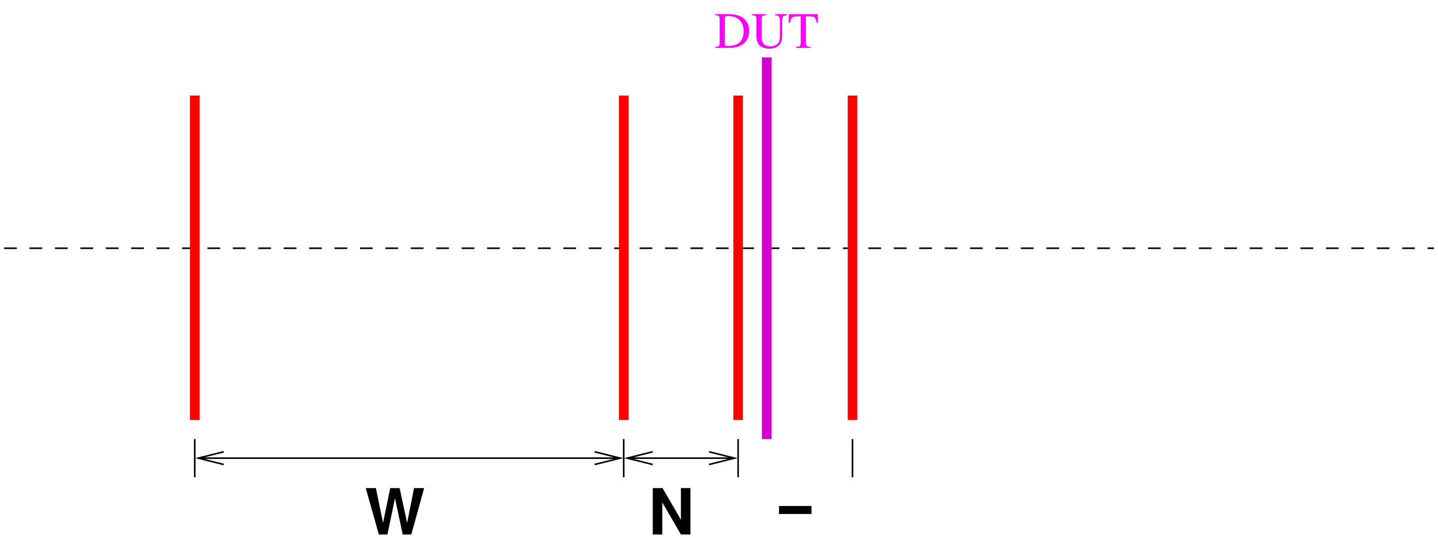
- DUT and two sensor planes close to it: −
- additional plane with narrow gap: N

Telescope geometry

Configuration description

Labeling scheme introduced to describe considered telescope configurations:

Configuration 'WN−'



- DUT and two sensor planes close to it: —
- additional plane with narrow gap: N
- additional plane with wide gap: W

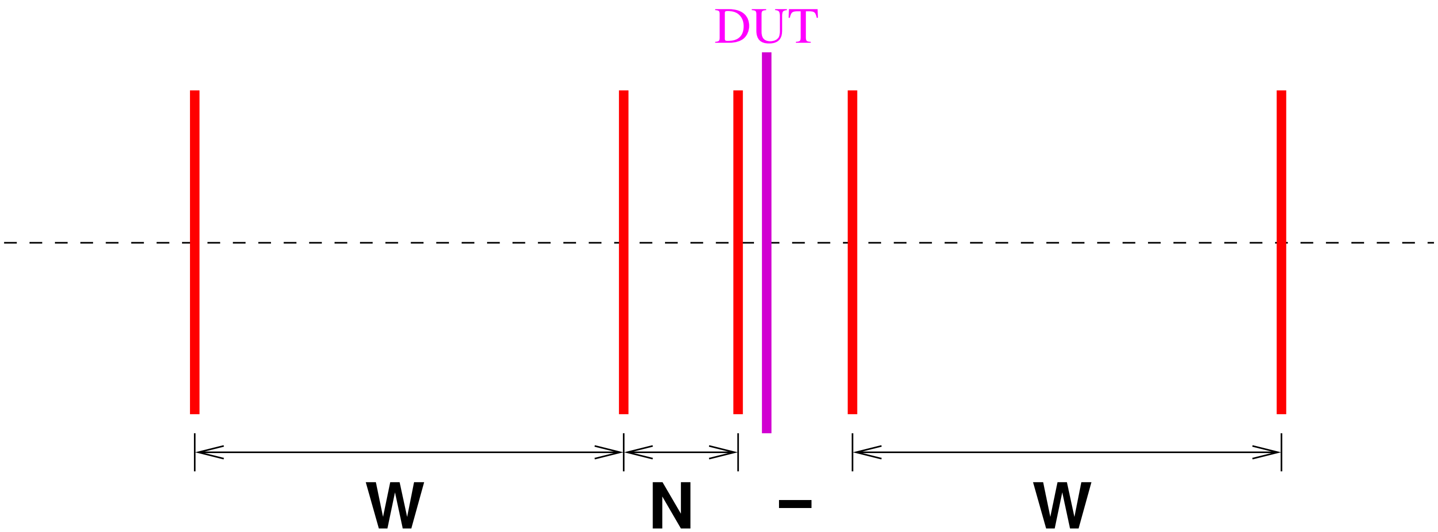
d_{max}=100 mm

Telescope geometry

Configuration description

Labeling scheme introduced to describe considered telescope configurations:

Configuration 'WN–W'



- DUT and two sensor planes close to it: —
- additional plane with narrow gap: N
- additional plane with wide gap: W

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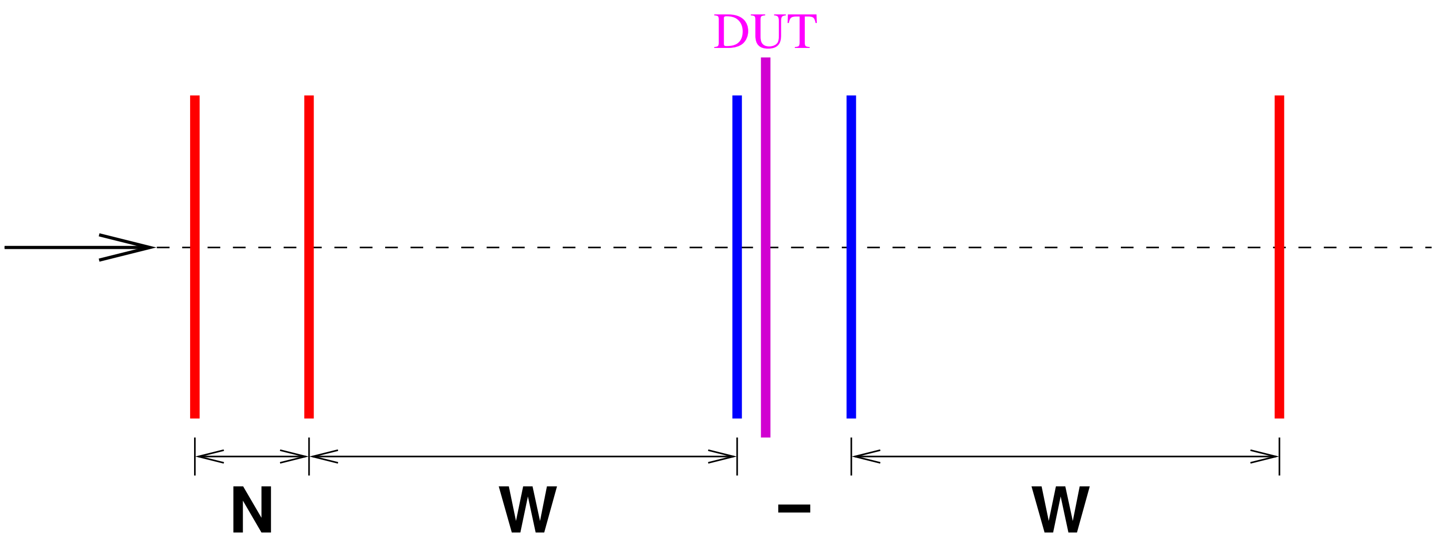
Telescope geometry

Configuration description

Labeling scheme introduced to describe considered telescope configurations:

Configuration 'NW–W'



- DUT and two sensor planes close to it: –
- additional plane with narrow gap: N
- additional plane with wide gap: W
  d_{max}=100 mm

We assume that d_{min} (2 to 5 mm) corresponds to the sensor in front of DUT

General observation: best performance is obtained if

⇒ one high resolution plane is placed in front of DUT (at d_{min} from DUT)

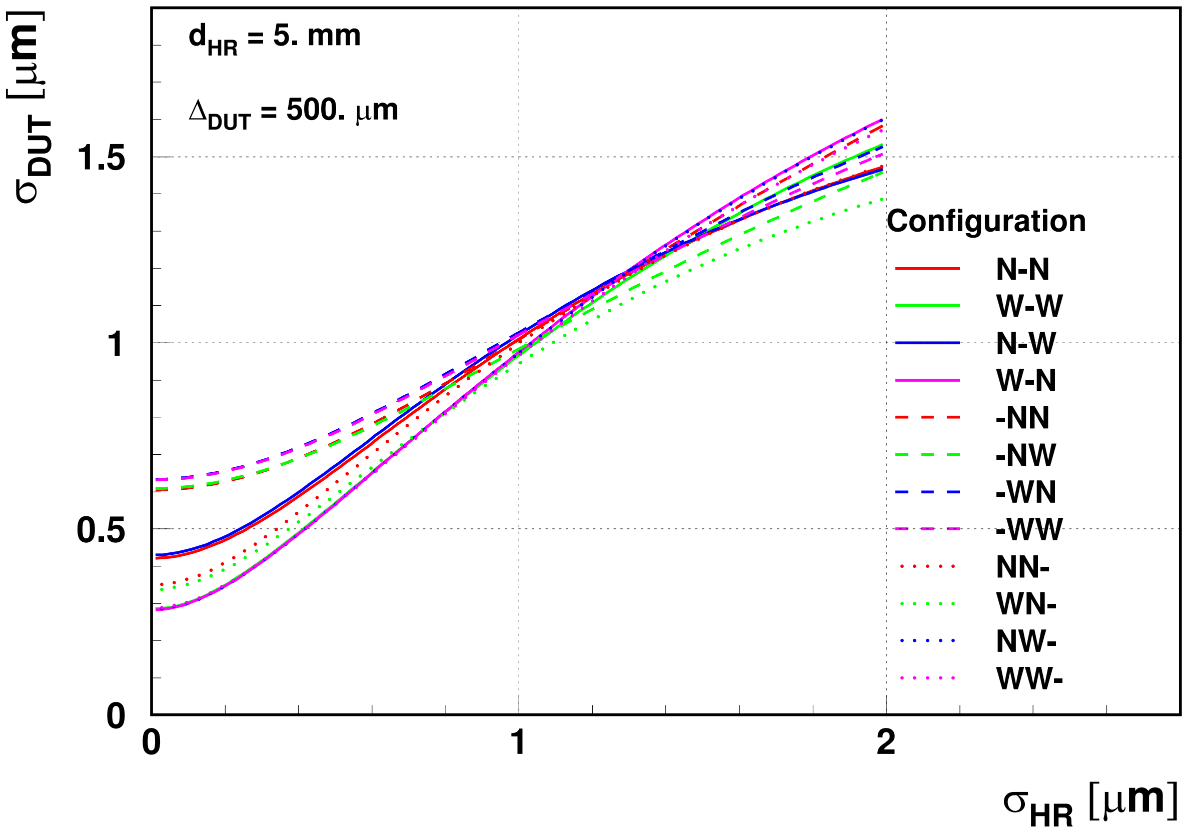
⇒ second high resolution plane usually placed behind DUT

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

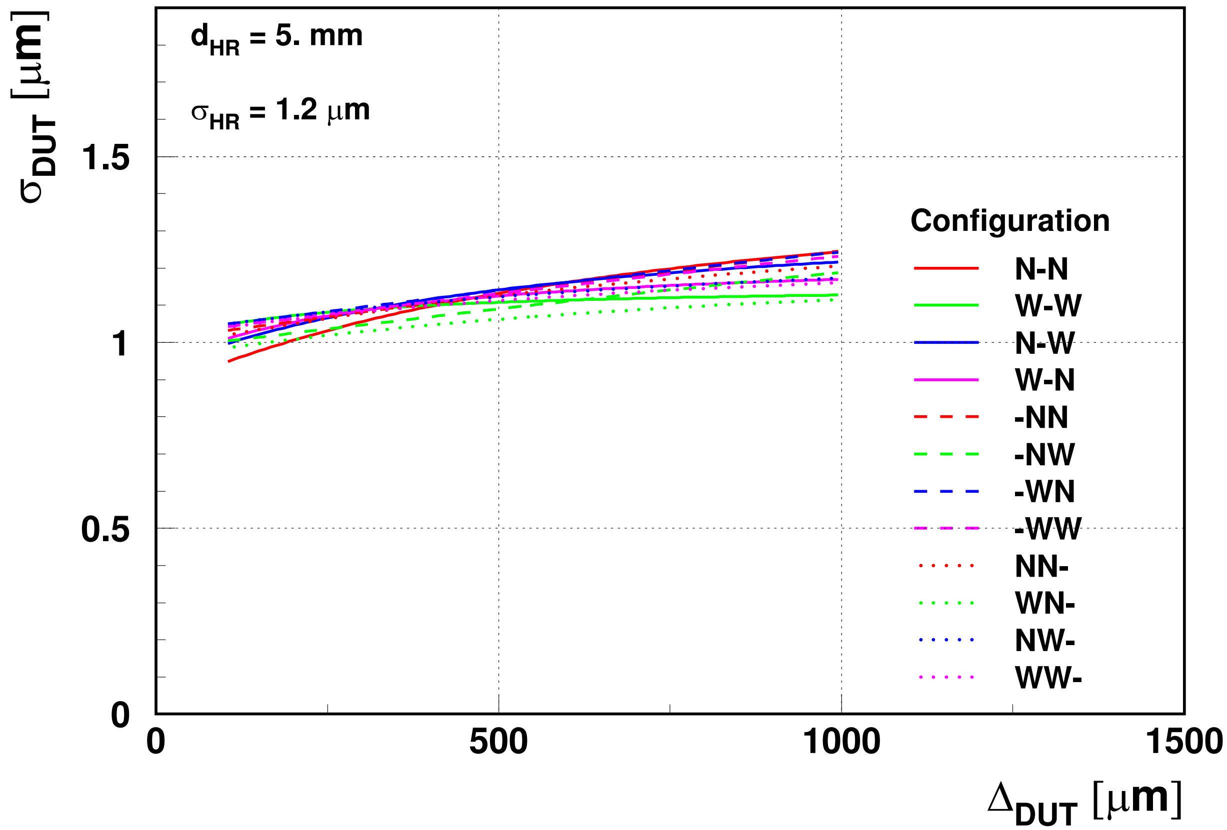


Results

4 (1+3) telescope planes

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 DUT thickness, Δ_{DUT}, for different telescope configurations: 6 GeV e^- beam, HR resolution 1.2 μm

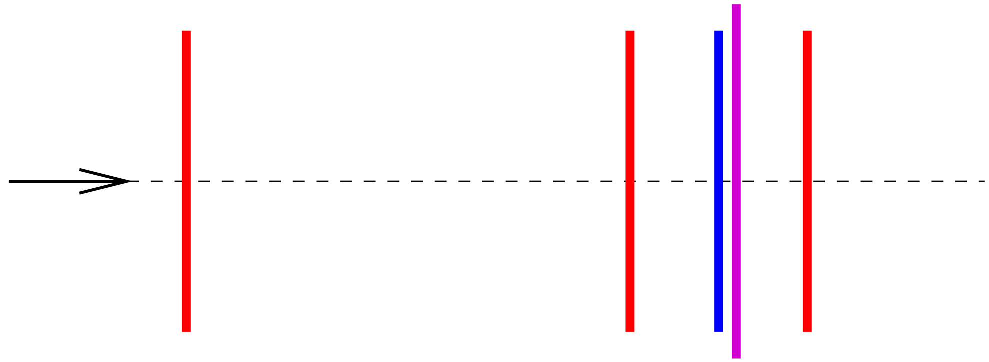


Results

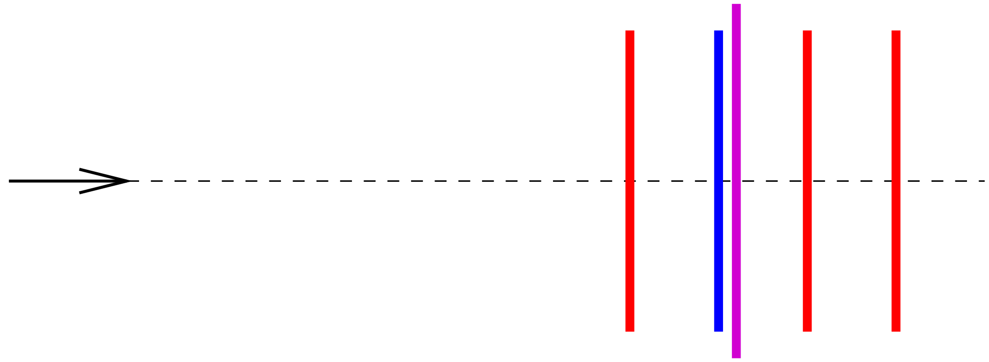
4 (1+3) telescope planes

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

WN– configuration gives best precision for $\Delta_{DUT} \geq 200\mu m$



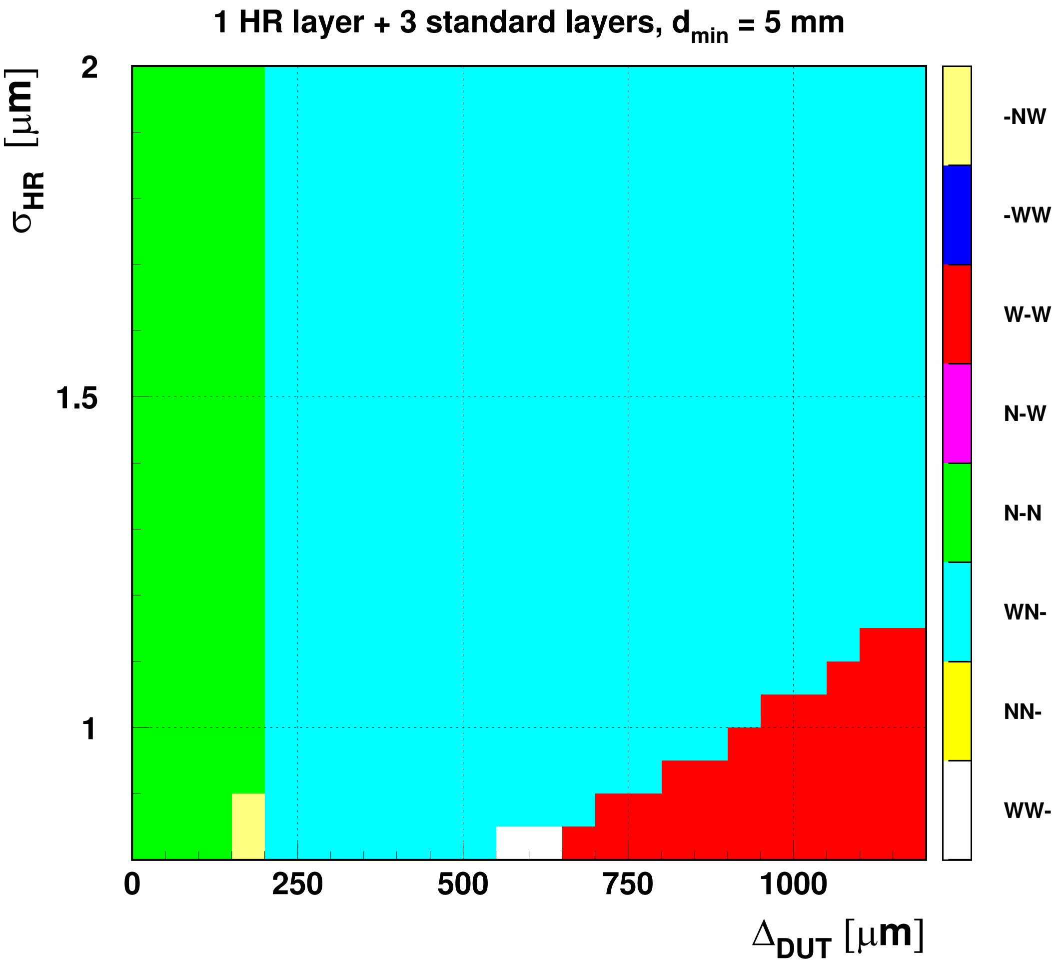
N–N configuration gives best precision for $\Delta_{DUT} \leq 200\mu m$



Results

4 (1+3) telescope planes

Configuration choice as a function of DUT thickness and HR plane resolution:
for minimum distance between HR plane and DUT, $d_{min} = 5$ mm

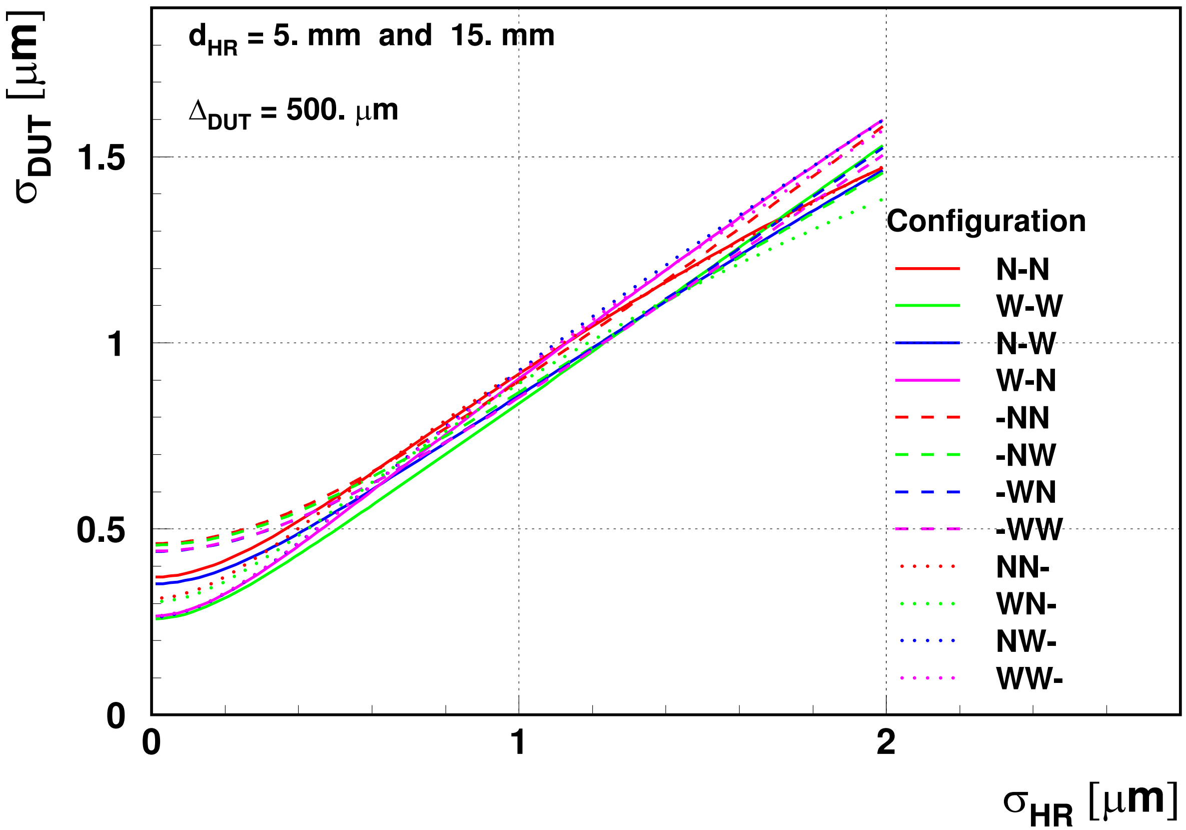


Results

4 (2+2) telescope planes

Two high resolution + two standard planes

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



Results

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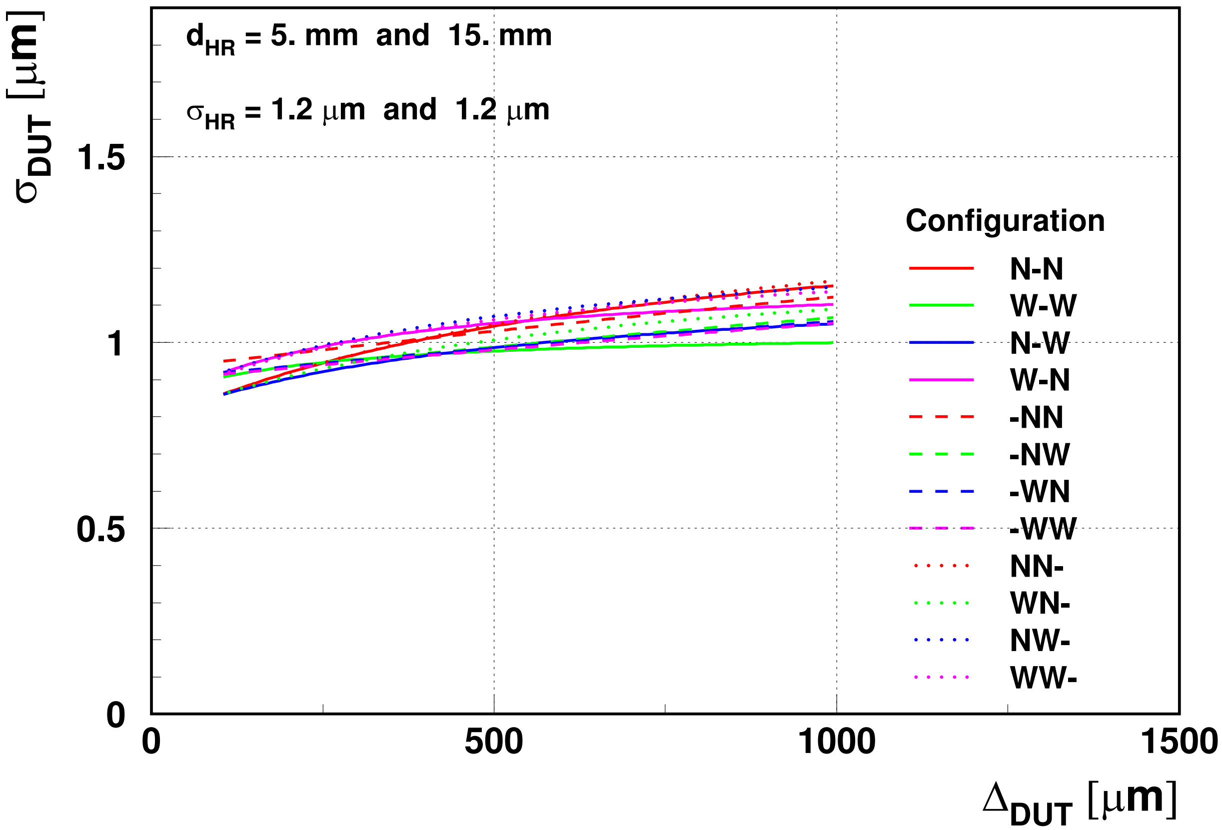
Expected position error at DUT, σ_{DUT}, as a function of the DUT thickness, Δ_{DUT}, for different telescope configurations: 6 GeV e^{-} beam, HR resolution 1.2 μm



Results

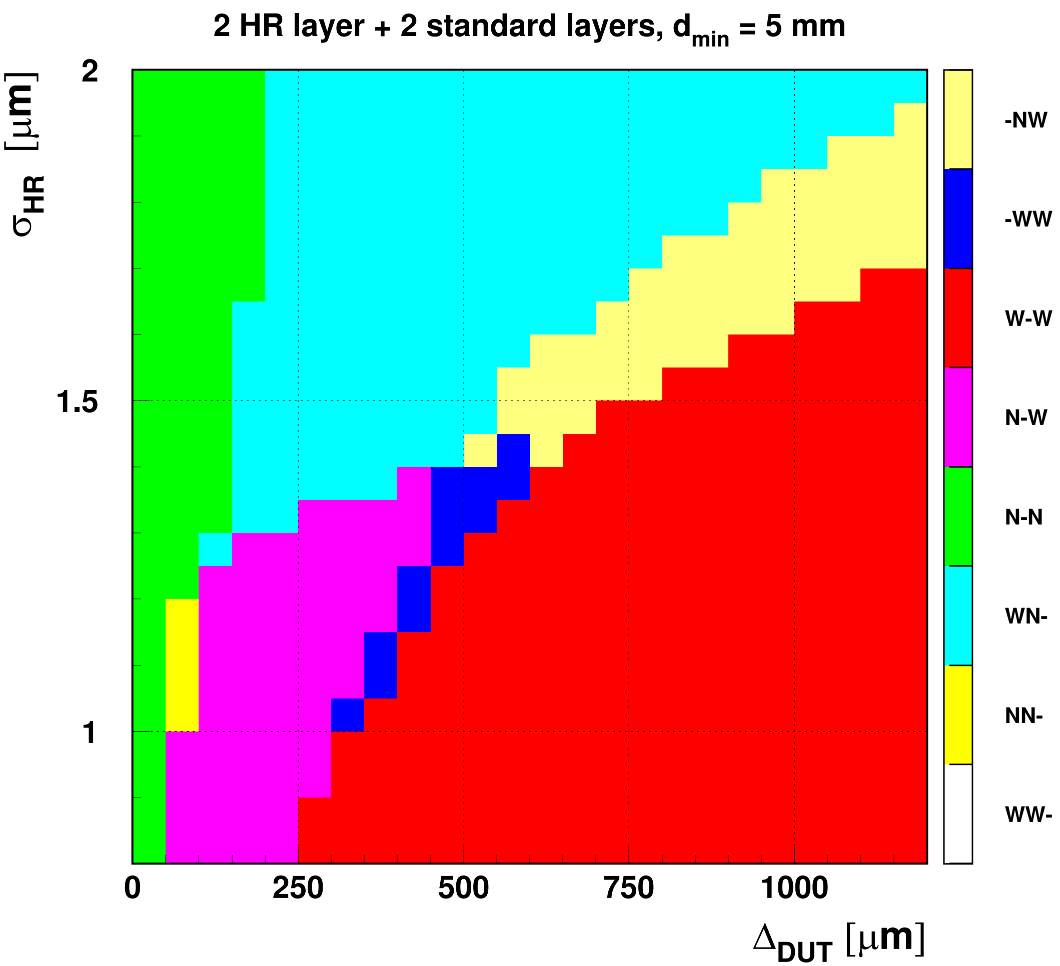
4 (2+2) telescope planes

Two high resolution + two standard planes: more possibilities!

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

$d_{min} = 5$ mm

Assuming second HR plane is always placed behind DUT



Results

4 (2+2) telescope planes

Two high resolution + two standard planes: more possibilities!

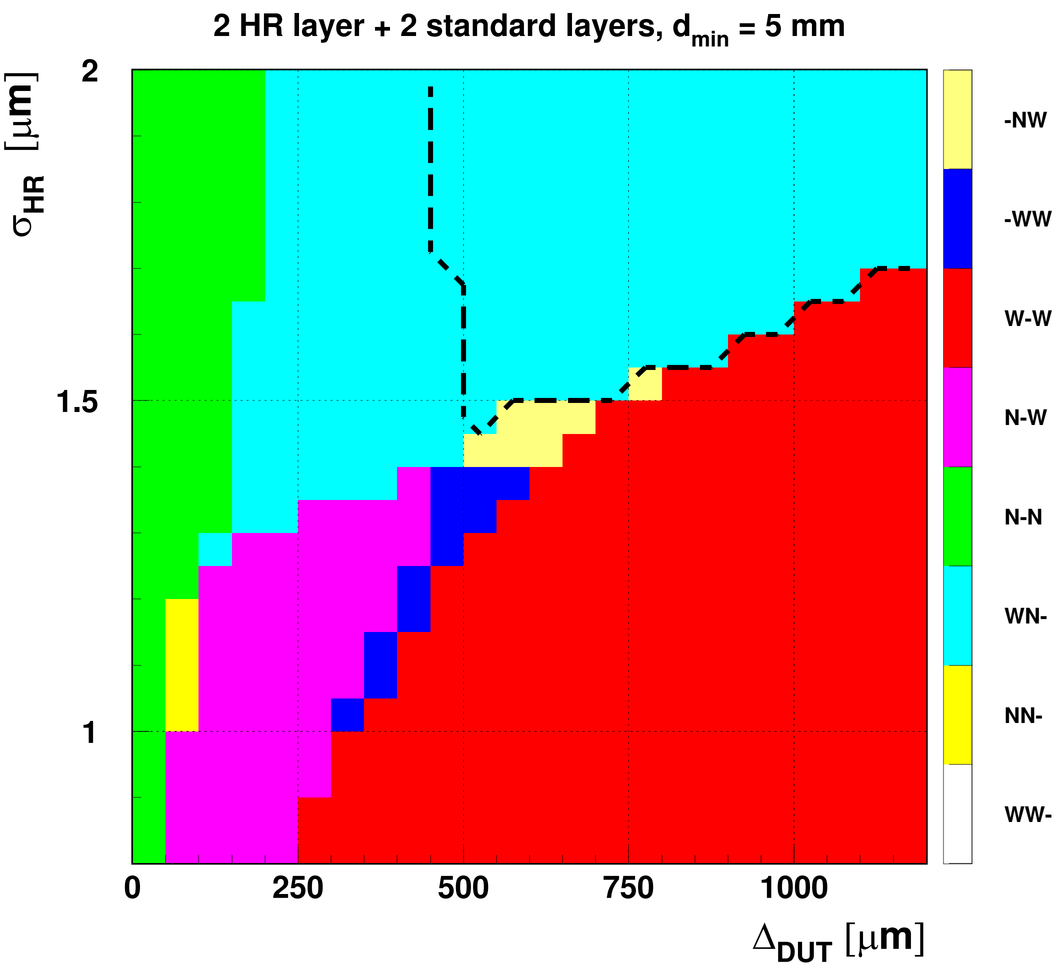
Configuration choice as a function of DUT thickness and HR plane resolution:

$d_{min} = 5$ mm

Above dashed line:

better performance if both HR planes in front of DUT

large σ_{HR} & Δ_{DUT}



Results

4 (2+2) telescope planes

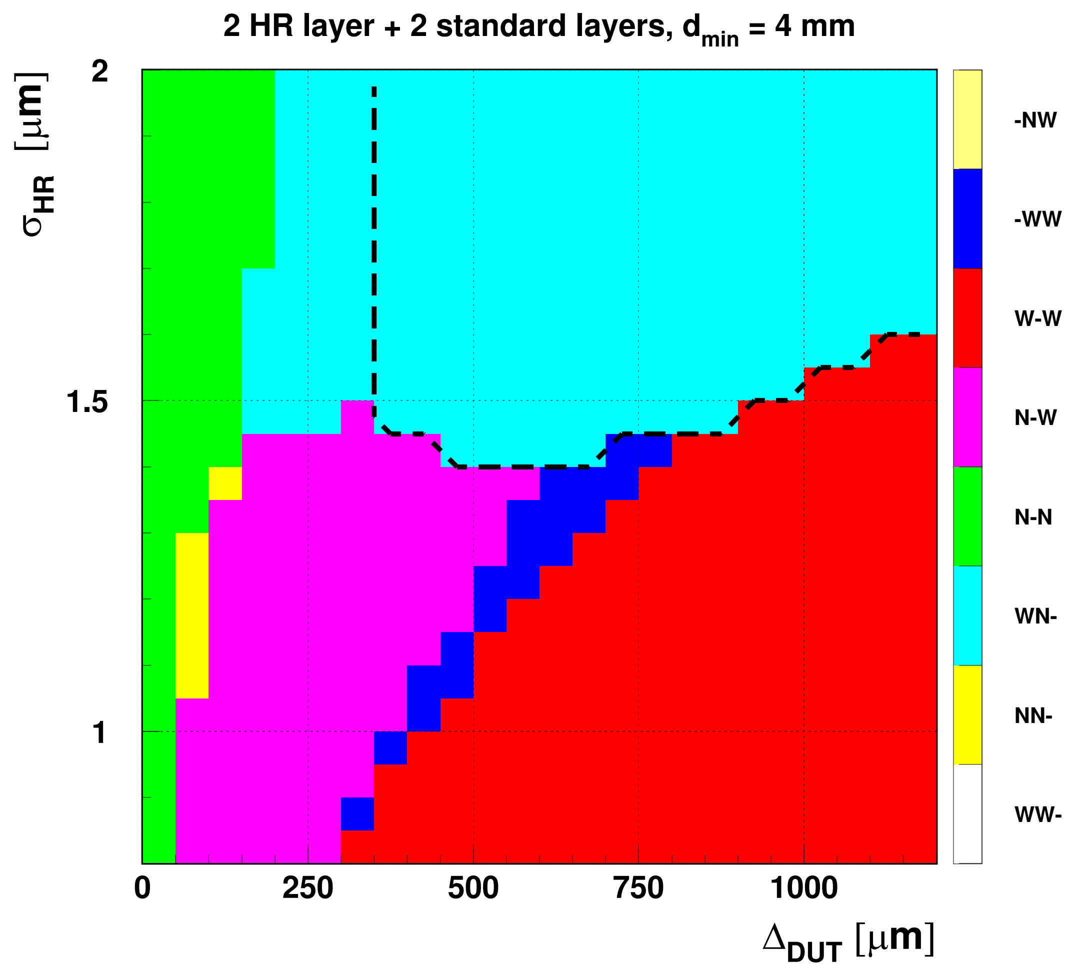
Two high resolution + two standard planes: more possibilities!

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

$d_{min} = 4$ mm

Above dashed line:
both HR planes
in front of DUT

Below dashed line:
second HR plane
behind DUT



Results

4 (2+2) telescope planes

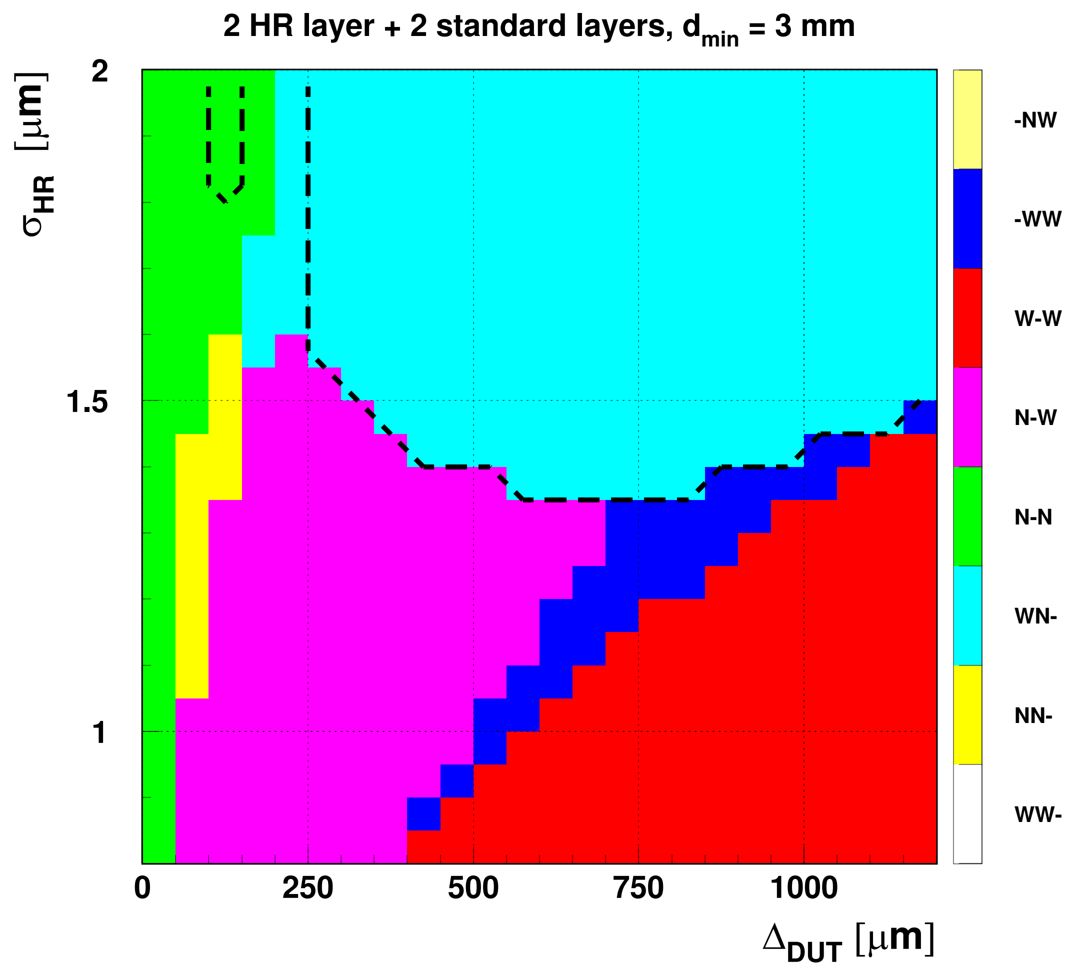
Two high resolution + two standard planes: more possibilities!

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

$d_{min} = 3$ mm

Above dashed line:
both HR planes
in front of DUT

Below dashed line:
second HR plane
behind DUT



Results

4 (2+2) telescope planes

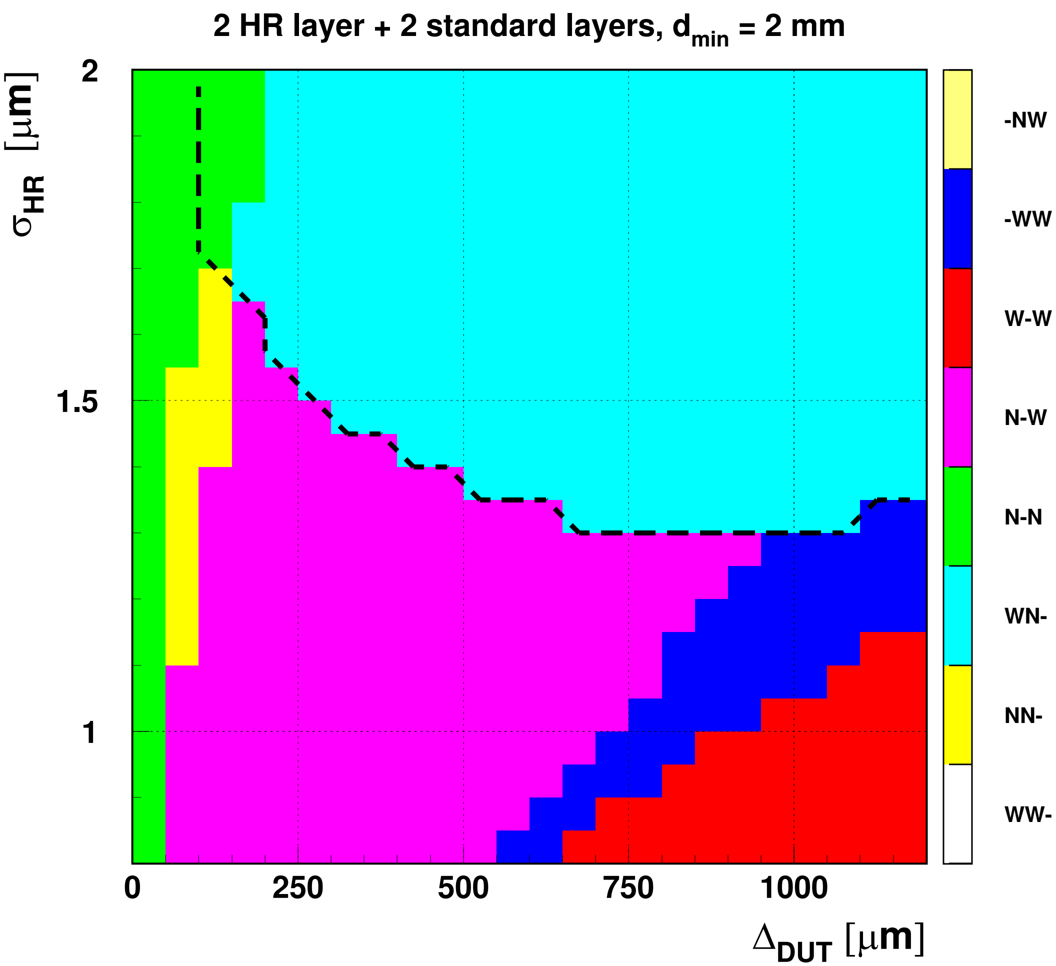
Two high resolution + two standard planes: more possibilities!

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

$d_{min} = 2$ mm

Above dashed line:
both HR planes
in front of DUT

Below dashed line:
second HR plane
behind DUT

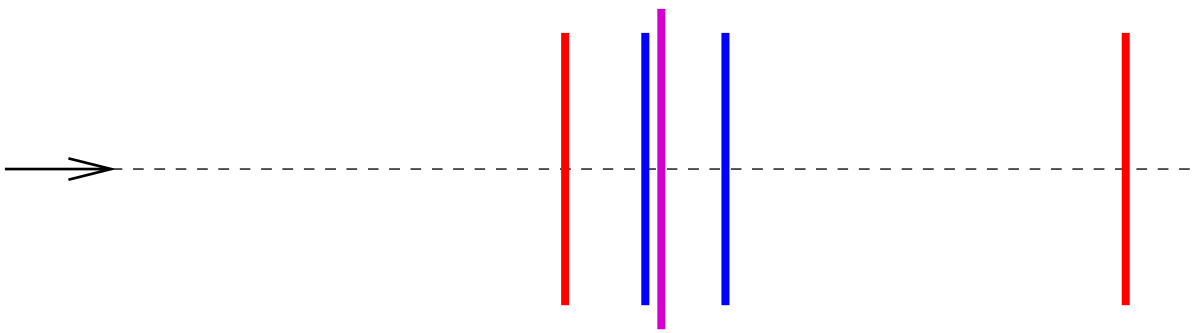


Results

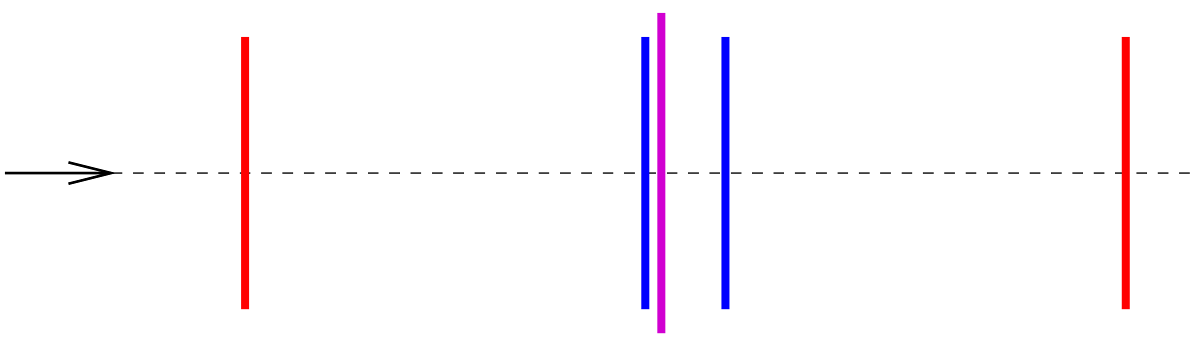
4 (2+2) telescope planes

Assuming HR plane resolution is of the order of 1 μm two configurations contribute most:

N–W configuration gives best precision for thin DUT, small d_{min}



W–W configuration gives best precision for thick DUT, larger d_{min}

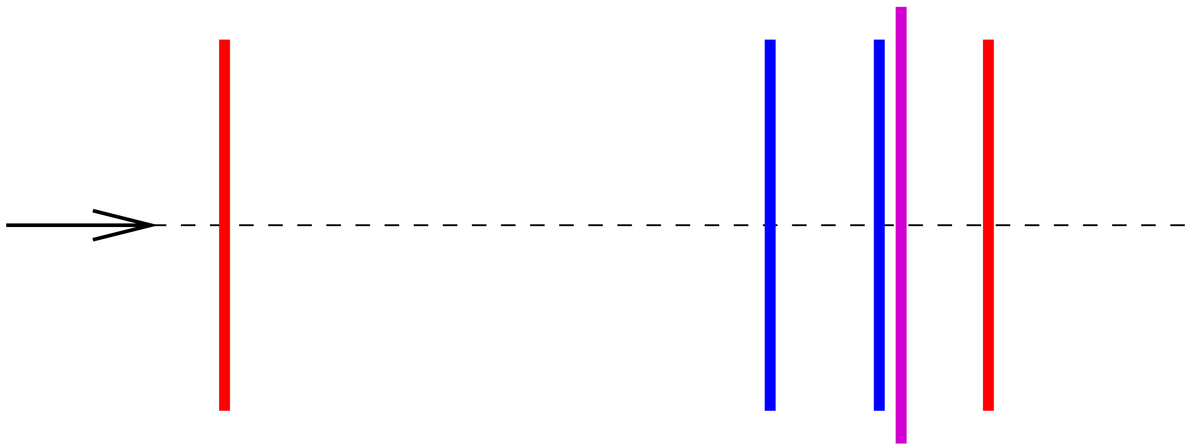


Results

4 (2+2) telescope planes

Assuming HR plane resolution $\sigma_{HR} \geq 1.5\mu m$

best precision for most $\triangle_{DUT}$ values is obtained with **WN–** configuration



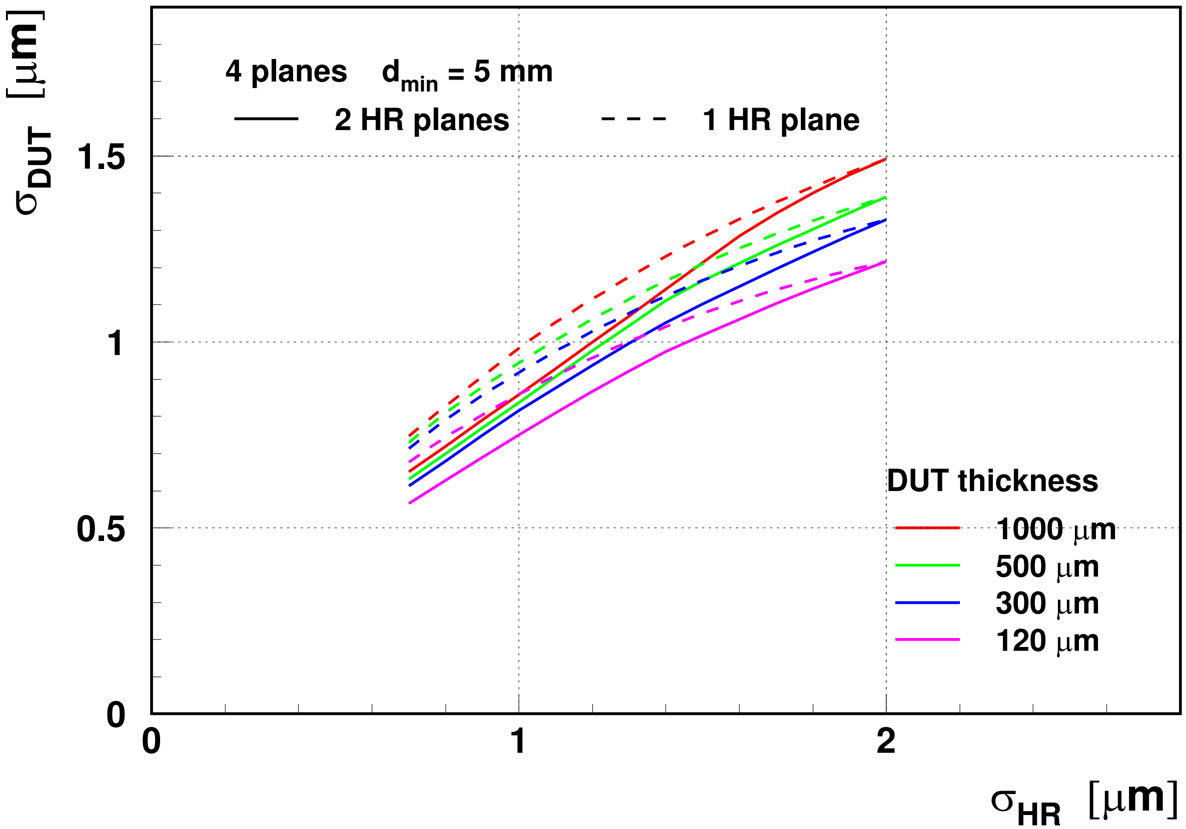
In most cases both HR planes should be placed in front of DUT !

Results

4 telescope planes

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

Expected position error at DUT, σ_{DUT}, as a function of the HR planes resolution, σ_{HR}, for best telescope configurations:



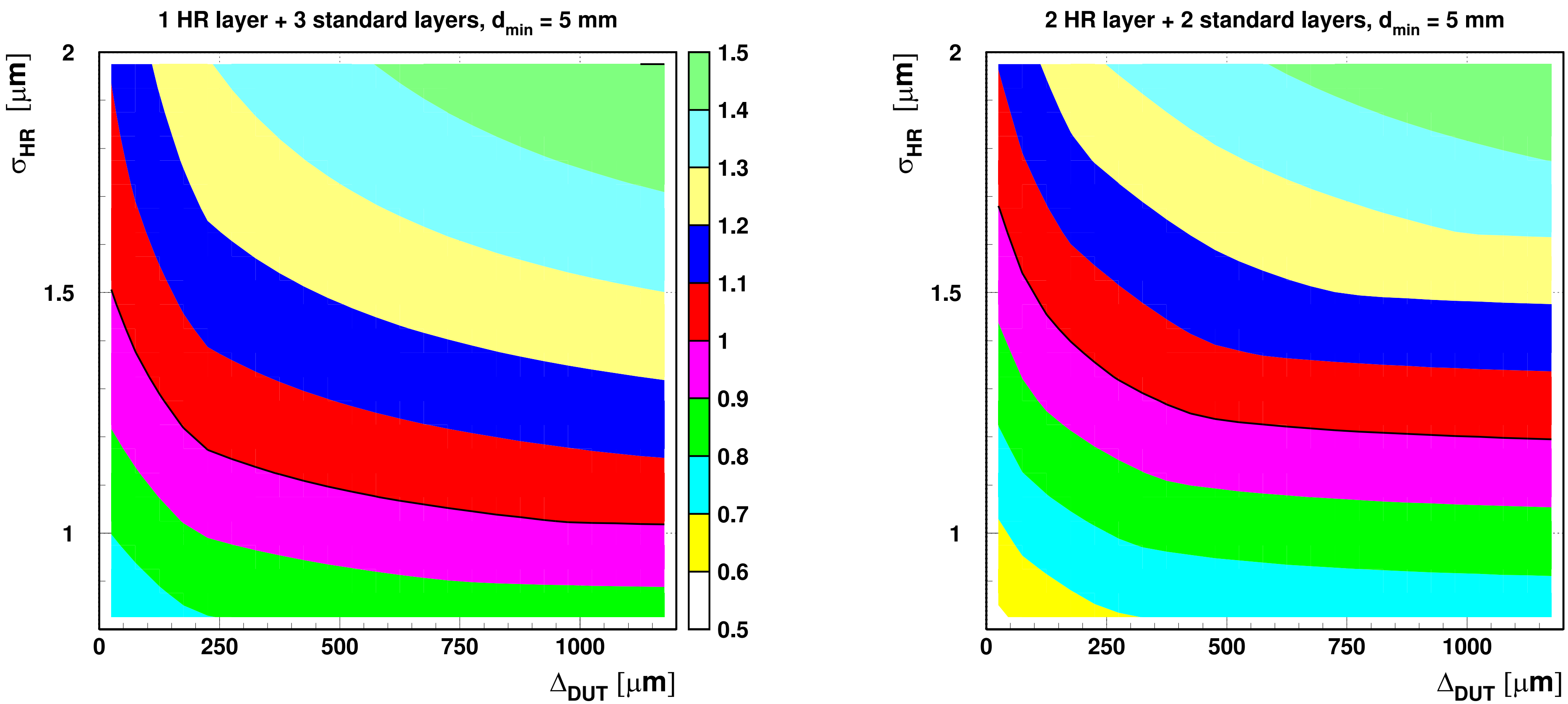
Results

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 | 2 HR planes | d_{min} = 5 mm



Results

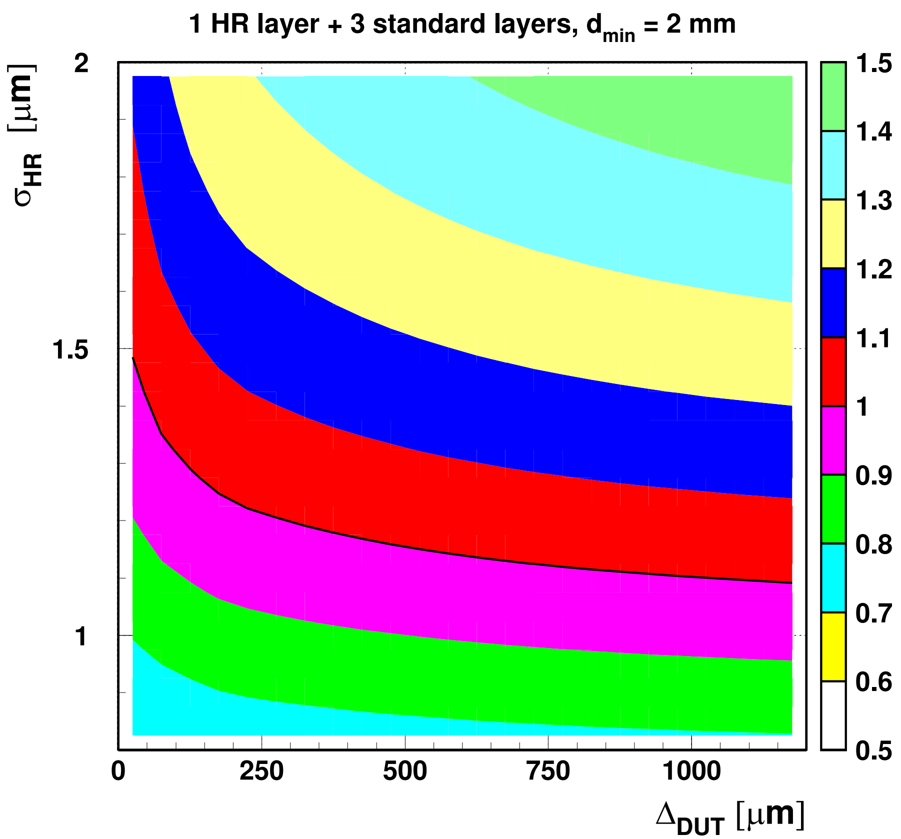
4 telescope planes

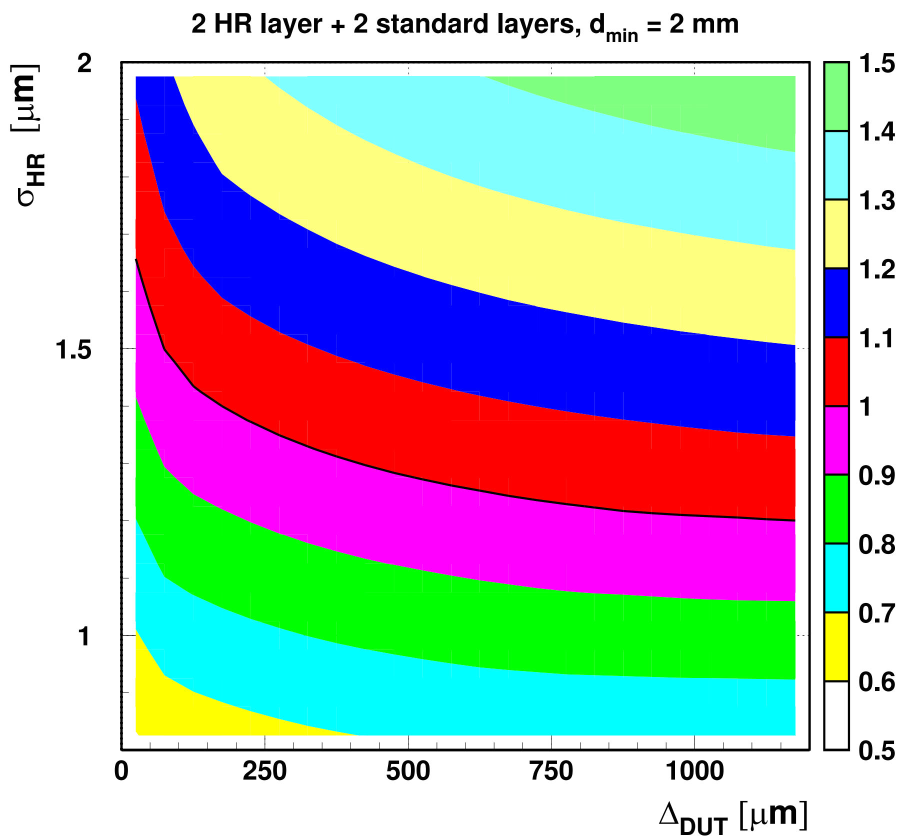
Configuration with two HR planes always gives better precision than with one HR plane.

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

1 HR plane

2 HR planes $\quad$ d_{min} = 2 mm



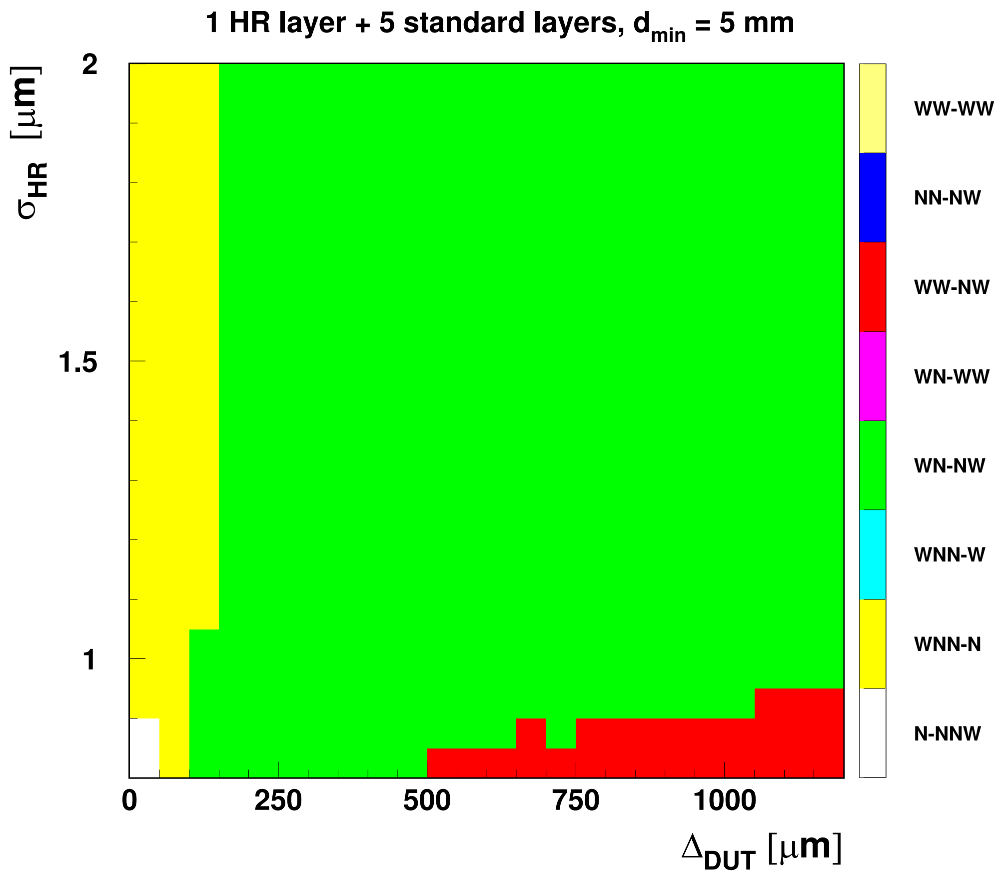


Results

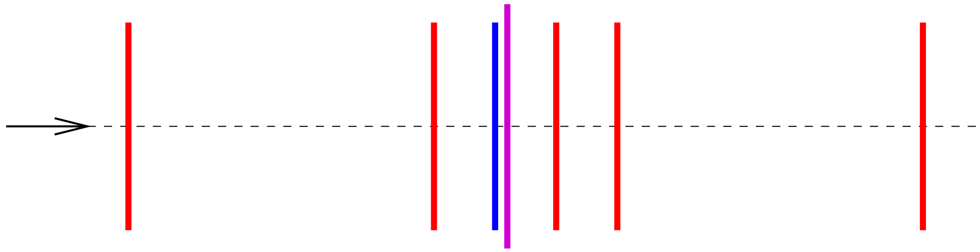
6 (1+5) telescope planes

One high resolution and 5 standard telescope planes

Best configuration as a function of Δ_{DUT} and σ_{HR} ($d_{min} = 5$ mm)



In most of the parameter space the best measurement is obtained with **WN–NW** configuration



Results

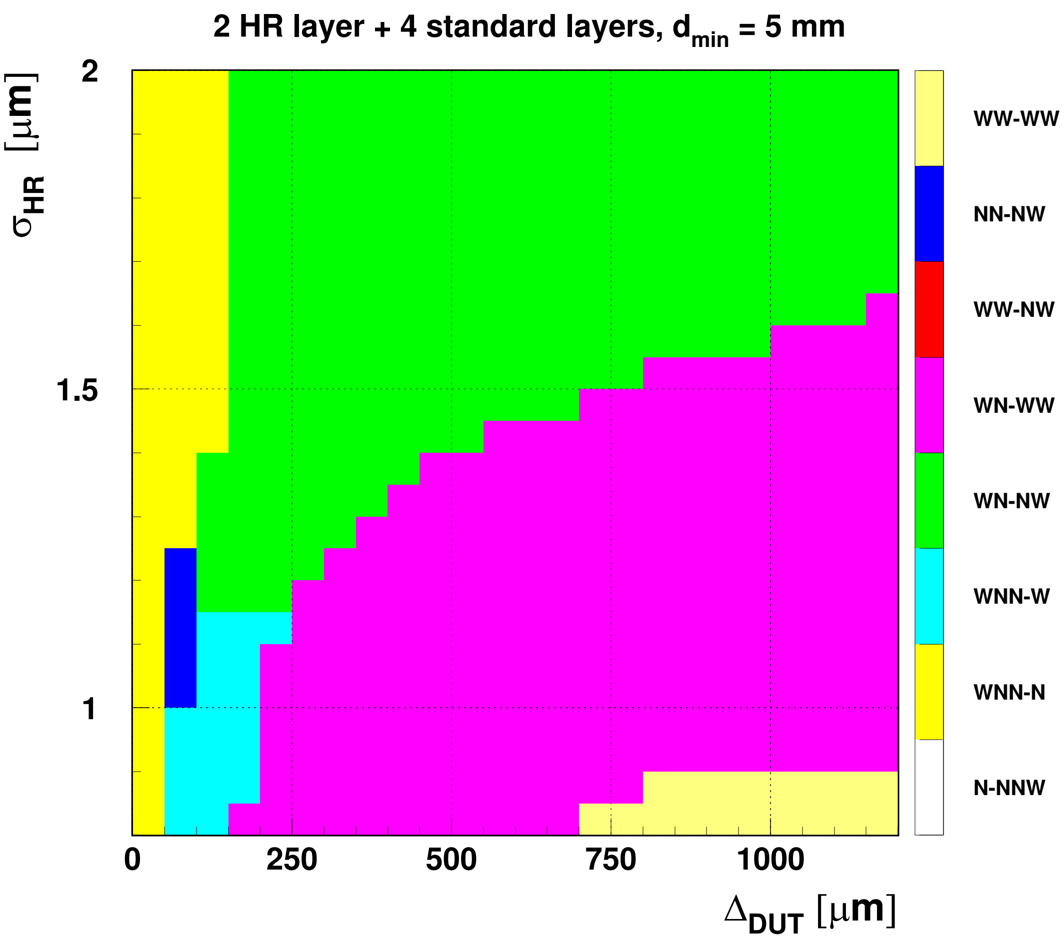
6 (2+4) telescope planes

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



Results

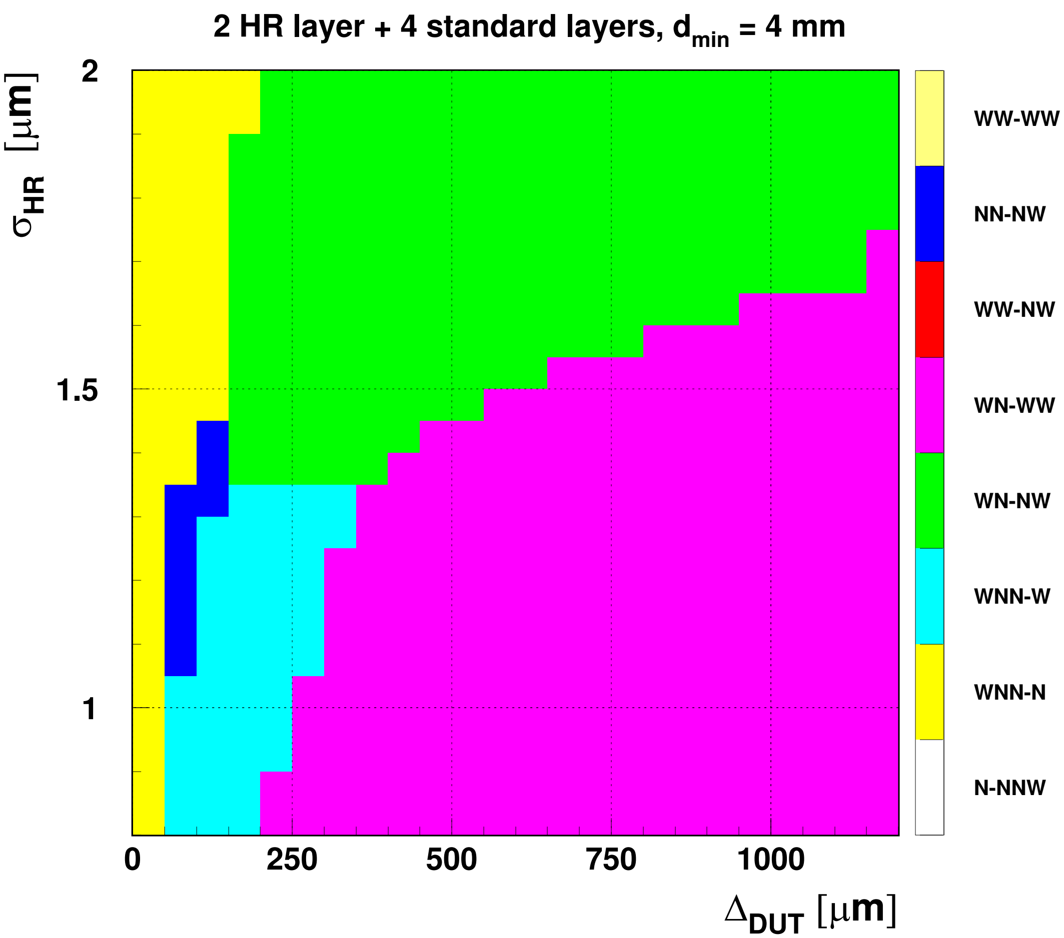
6 (2+4) telescope planes

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

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

$d_{min} = 4$ mm

Best performance with second HR plane always placed behind DUT



Results

6 (2+4) telescope planes

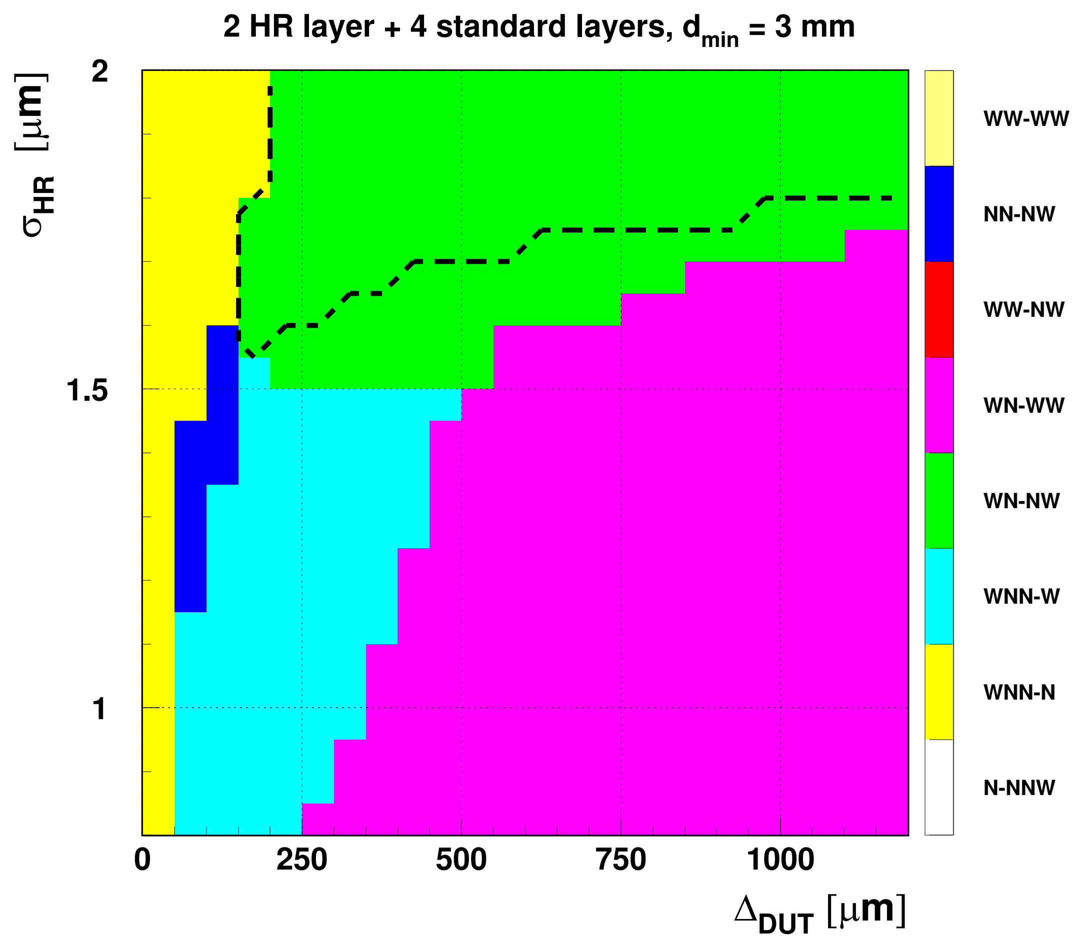
Two high resolution + four standard planes: even more possibilities!

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

$d_{min} = 3$ mm

Above dashed line:
both HR planes
in front of DUT

Below dashed line:
second HR plane
behind DUT



Results

6 (2+4) telescope planes

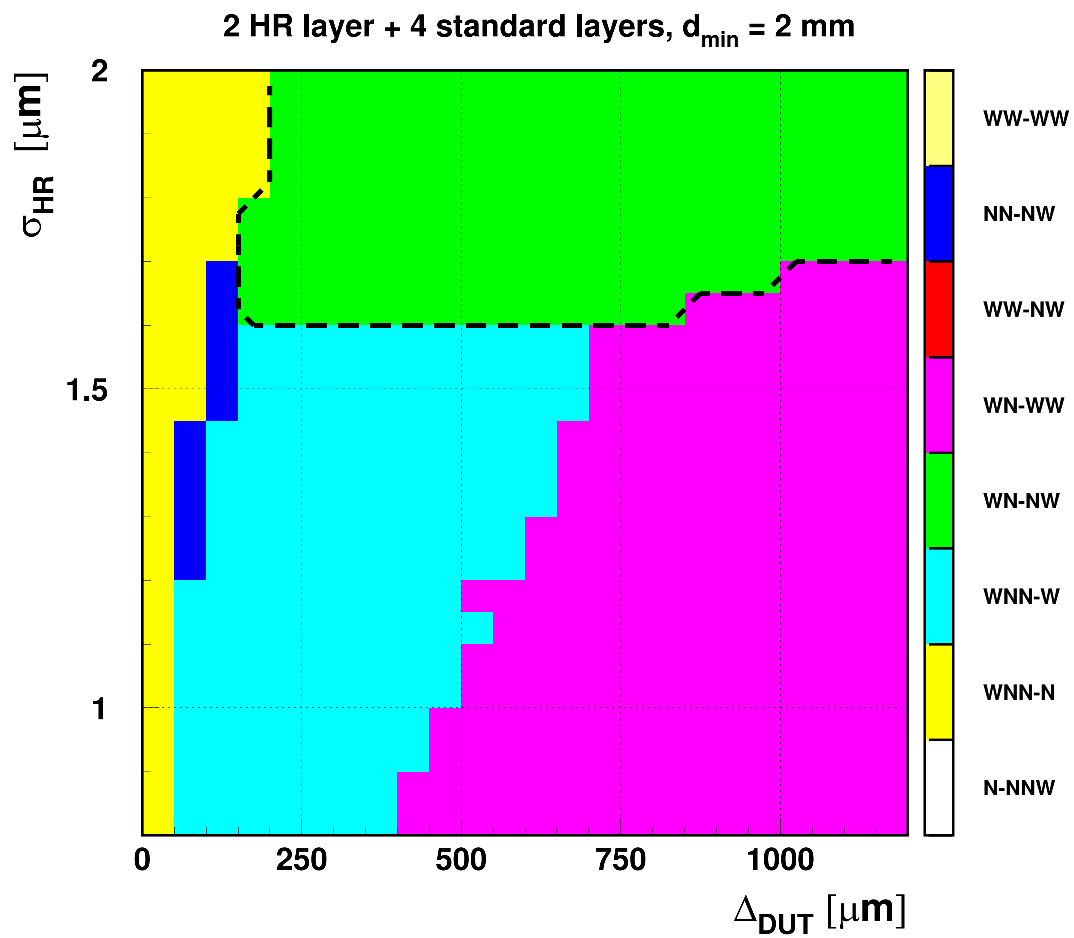
Two high resolution + four standard planes: even more possibilities!

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

$d_{min} = 2$ mm

Above dashed line: both HR planes in front of DUT

Below dashed line: second HR plane behind DUT

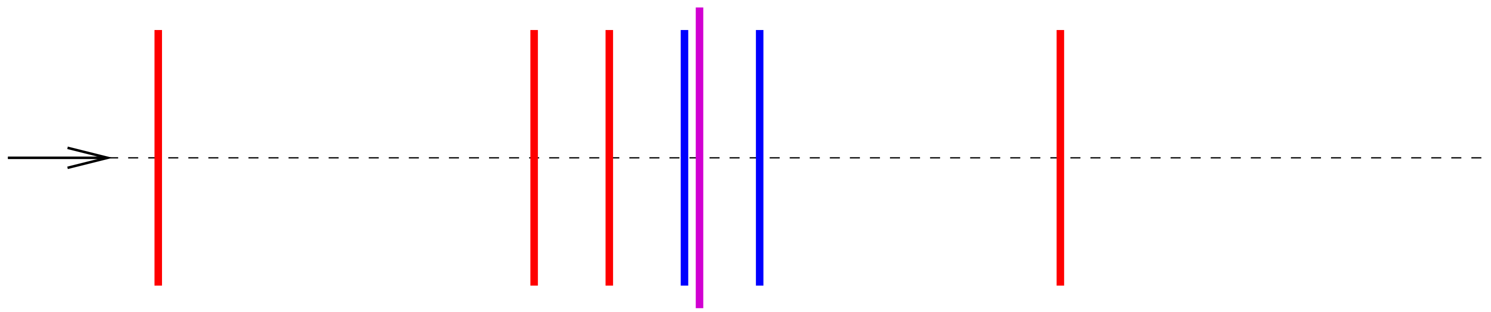


Results

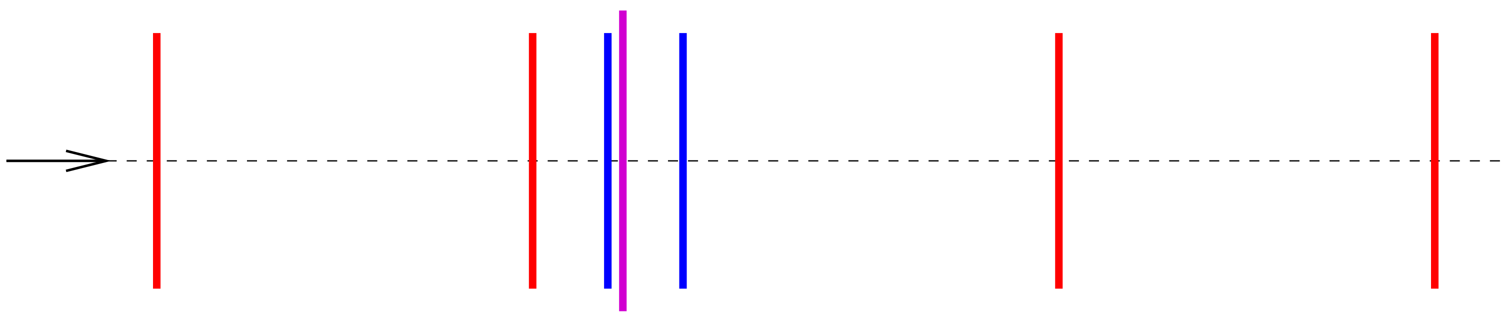
6 (2+4) telescope planes

Assuming HR plane resolution is of the order of 1 μm two configurations contribute most:

WNN–W configuration gives best precision for thin DUT, small d$_{min}$



WN–WW configuration gives best precision for thick DUT, larger d$_{min}$

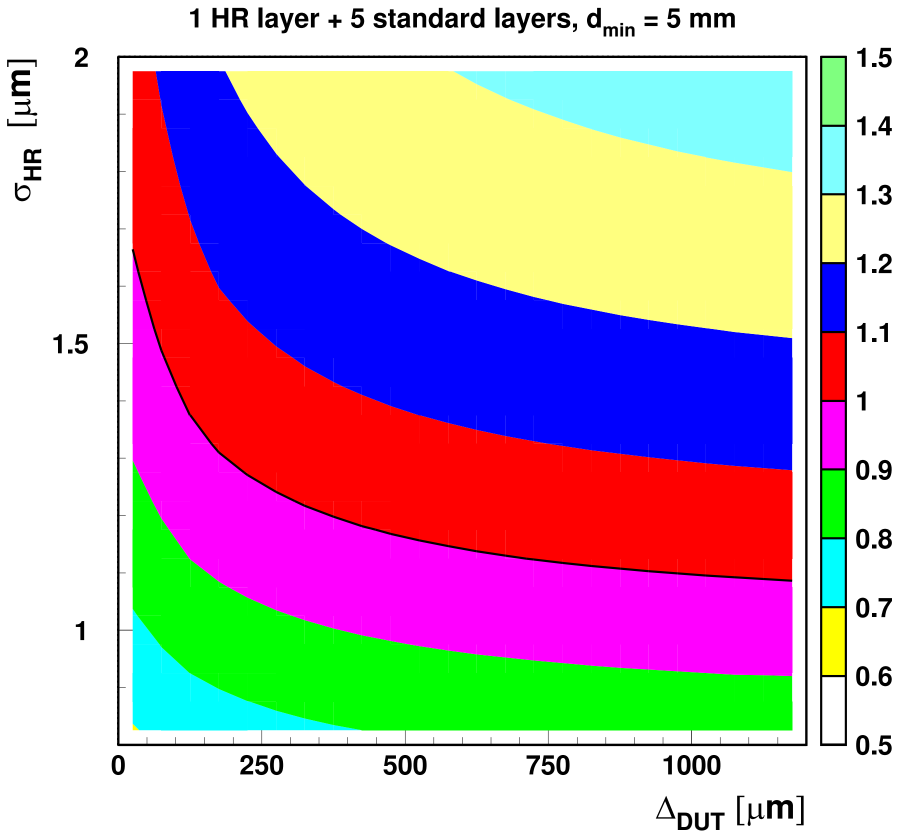


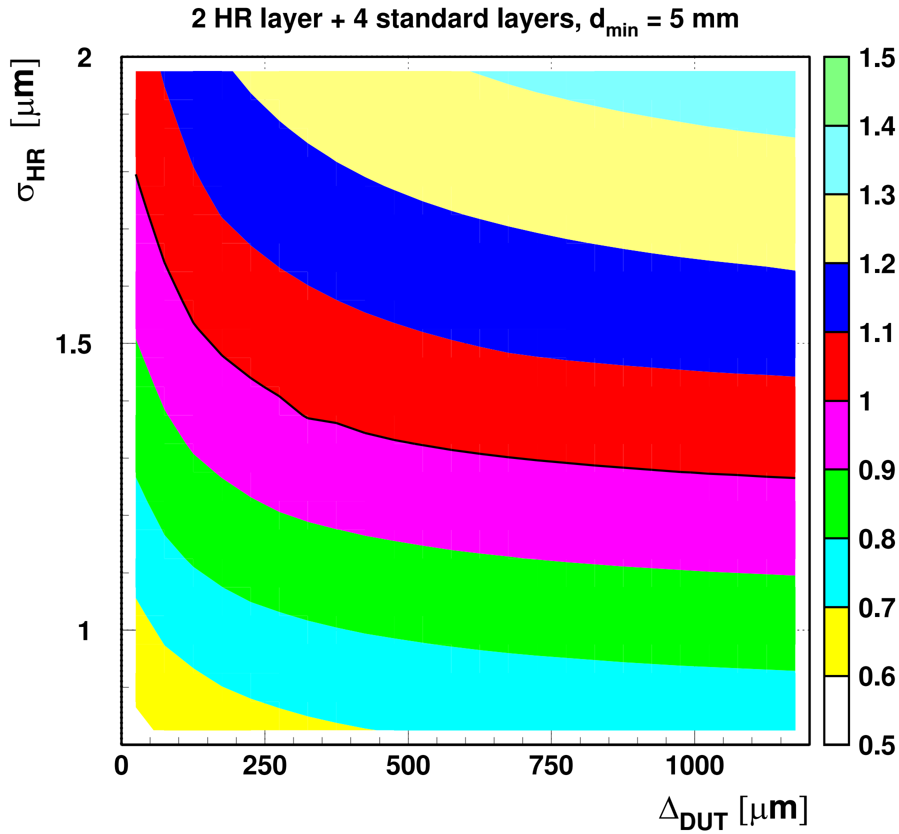
Results

6 telescope planes

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

1 HR plane — 2 HR planes — d_{min}= 5 mm





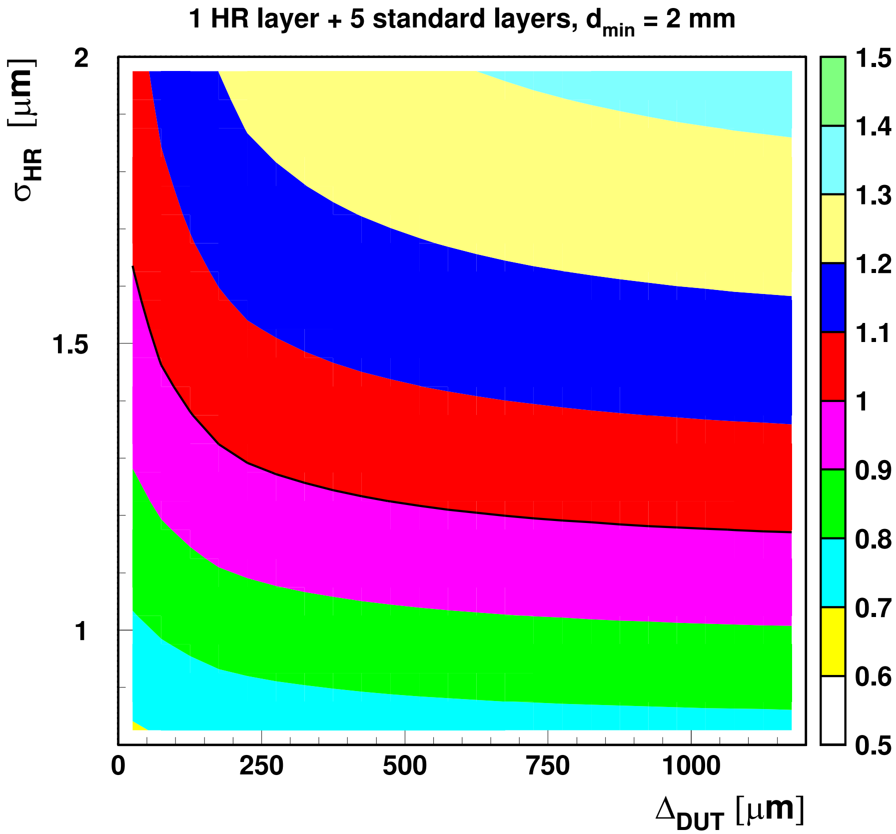
Second HR plane improves position determination precision by $\sim 0.1\ \mu m$

Results

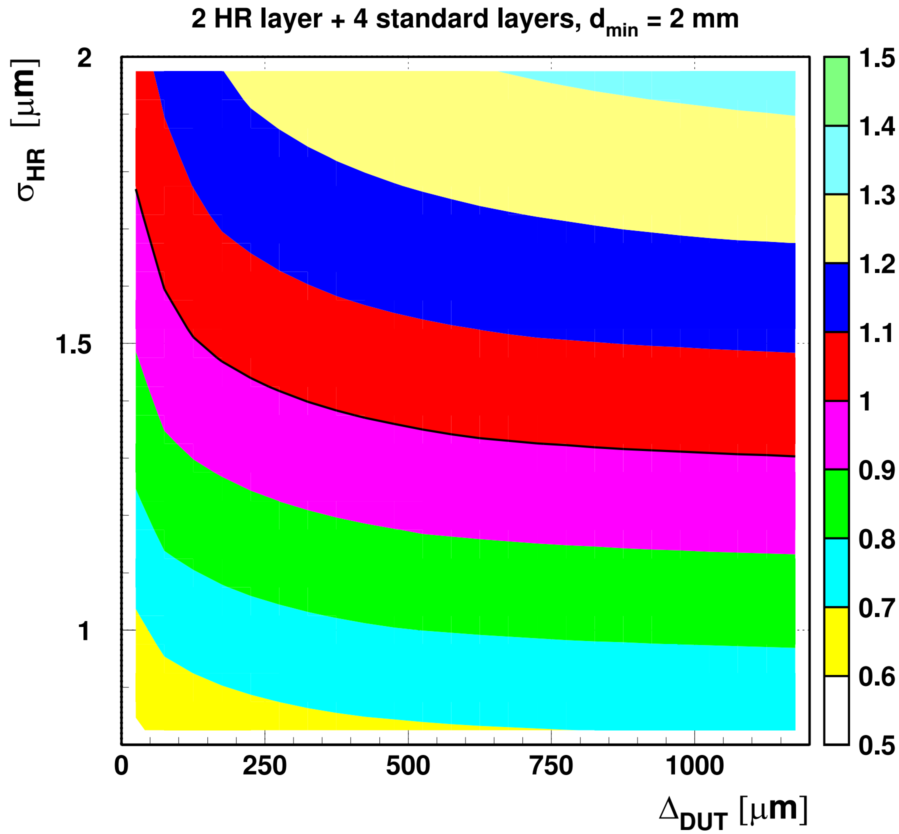
6 telescope planes

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

1 HR plane



2 HR planes d_{min}= 2 mm



Second HR plane improves position determination precision by $\sim 0.1\ \mu m$

Results

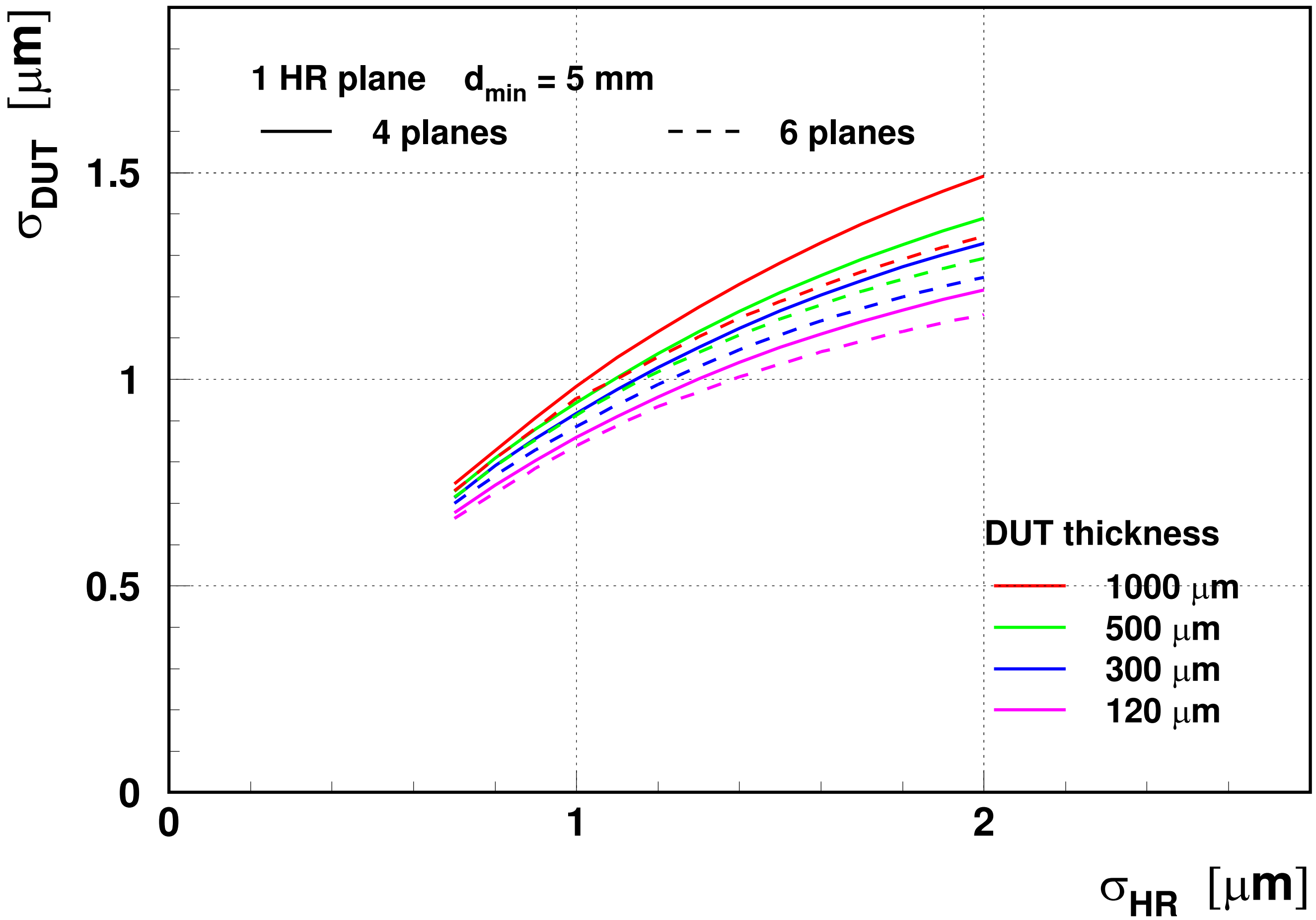
6 vs 4 telescope planes

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

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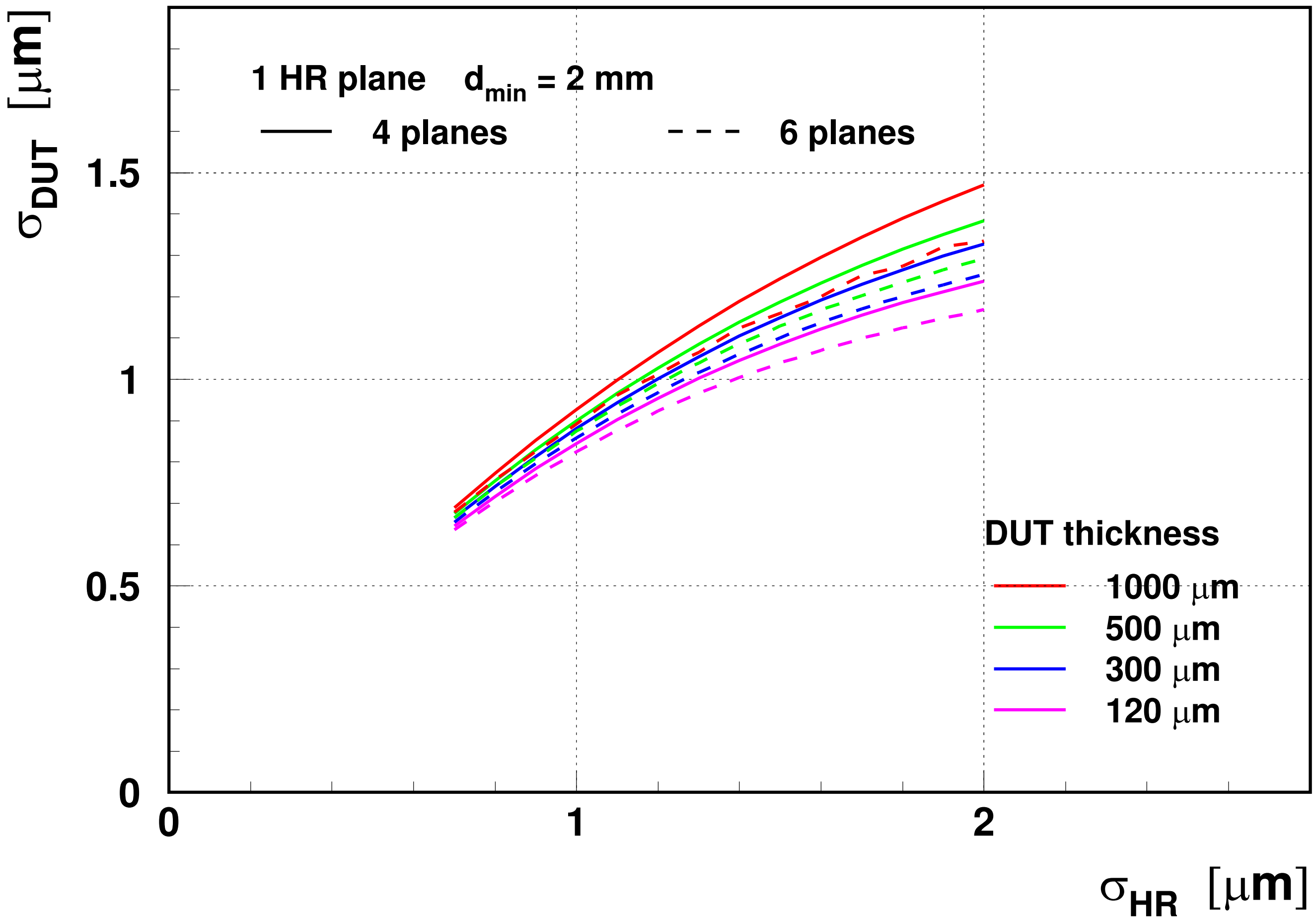
1 HR plane

d_{min}= 2 mm



Results

6 vs 4 telescope planes

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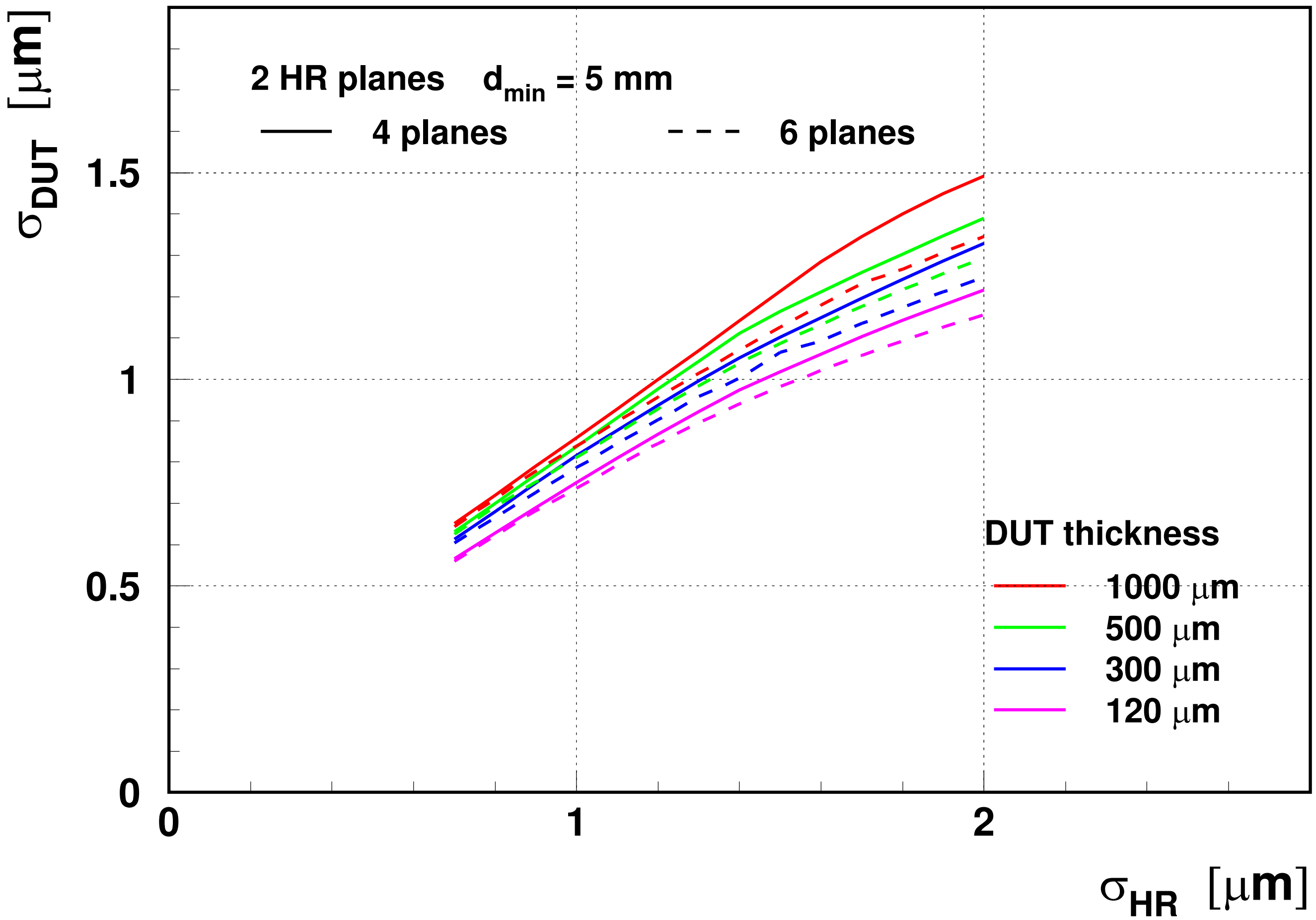
Expected position error at DUT, σ_{DUT}, as a function σ_{HR}

2 HR planes

d_{min}= 5 mm



Results

6 vs 4 telescope planes

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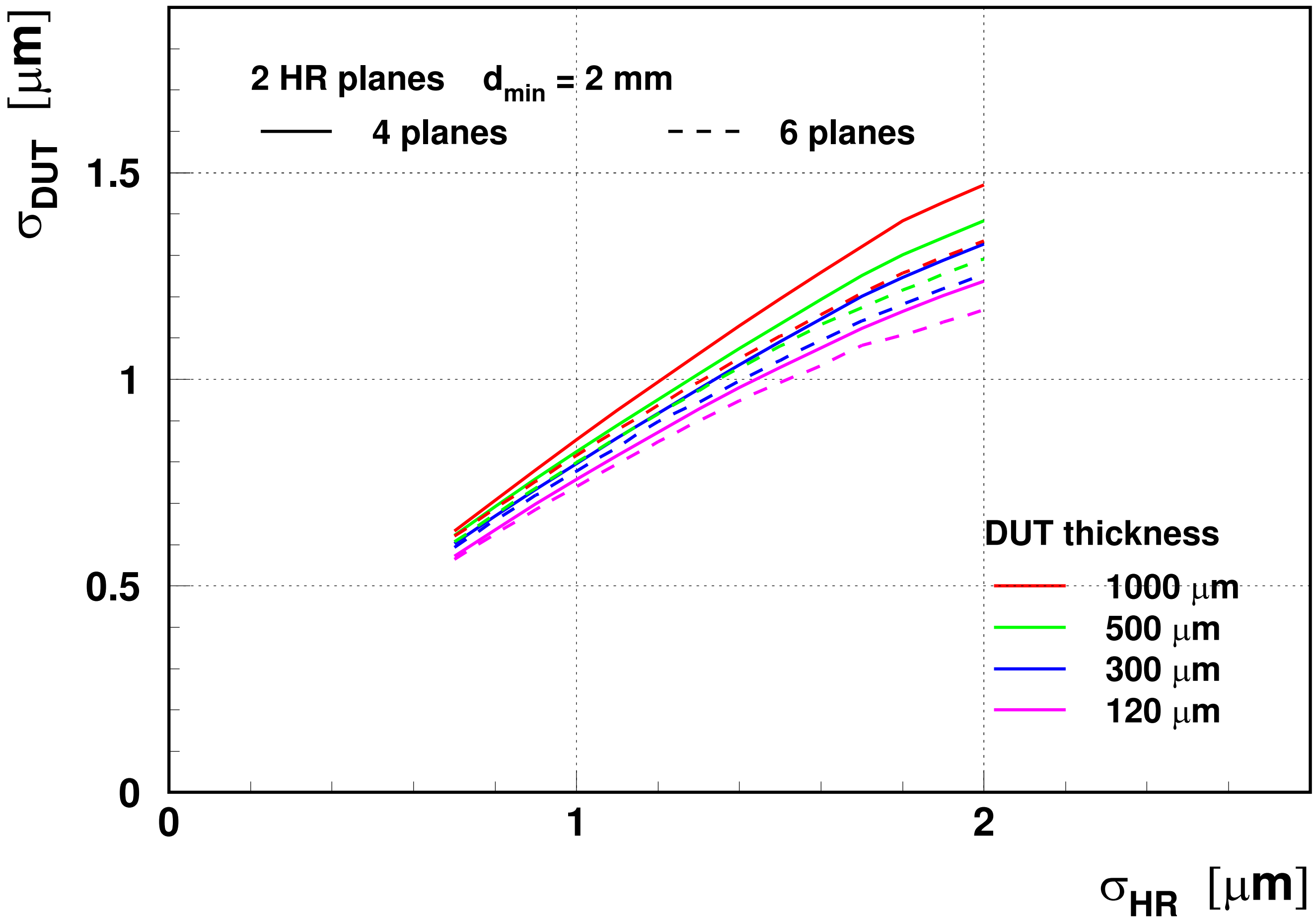
Expected position error at DUT, σ_{DUT}, as a function σ_{HR}

2 HR planes

d_{min}= 2 mm

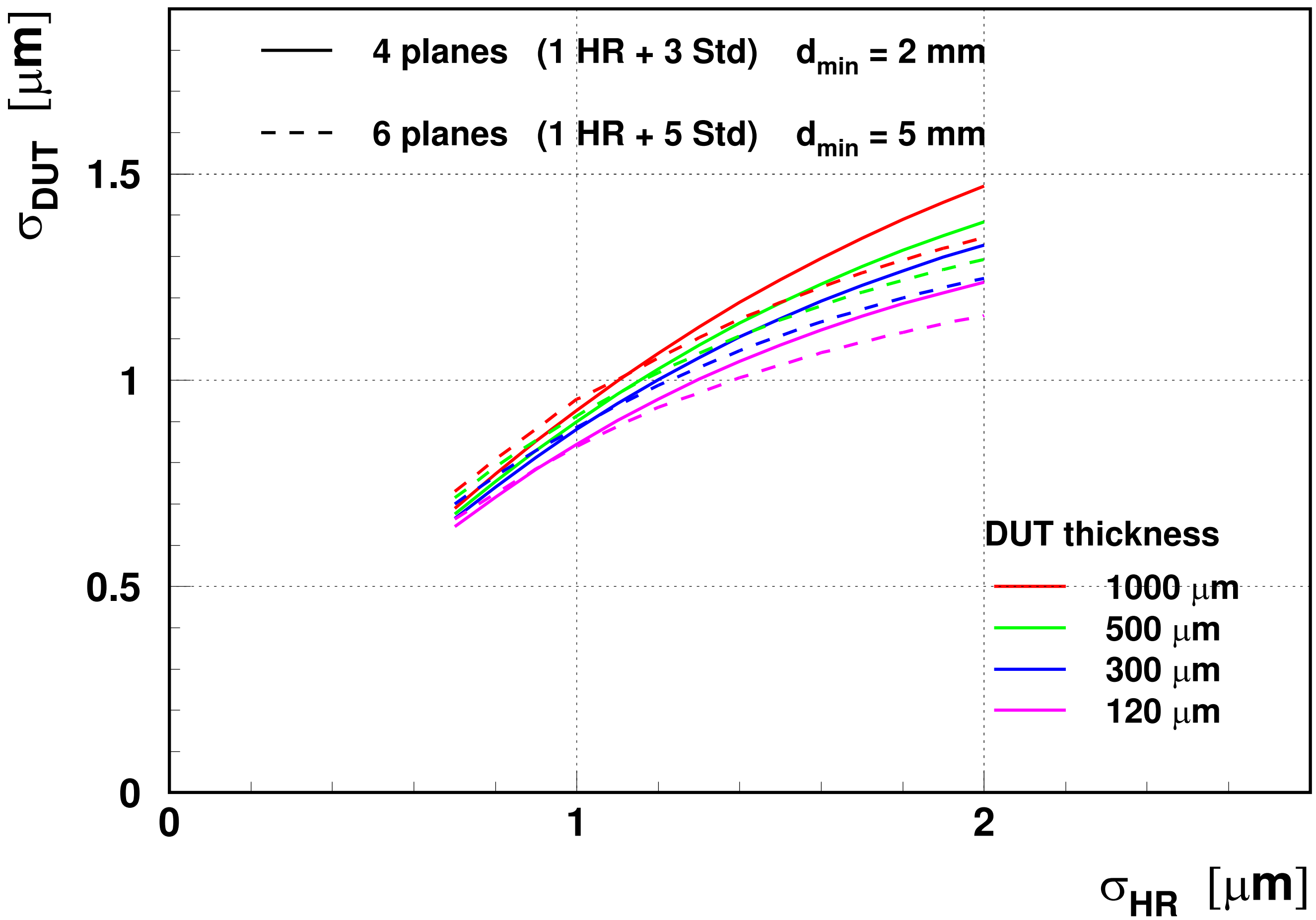


Results

6 vs 4 telescope planes

With one high resolution plane minimizing distance to DUT is crucial.

4 planes with d_{min}= 2 mm equivalent to 6 planes and d_{min}= 5 mm (for $\sigma_{HR} \sim 1 \mu m$)

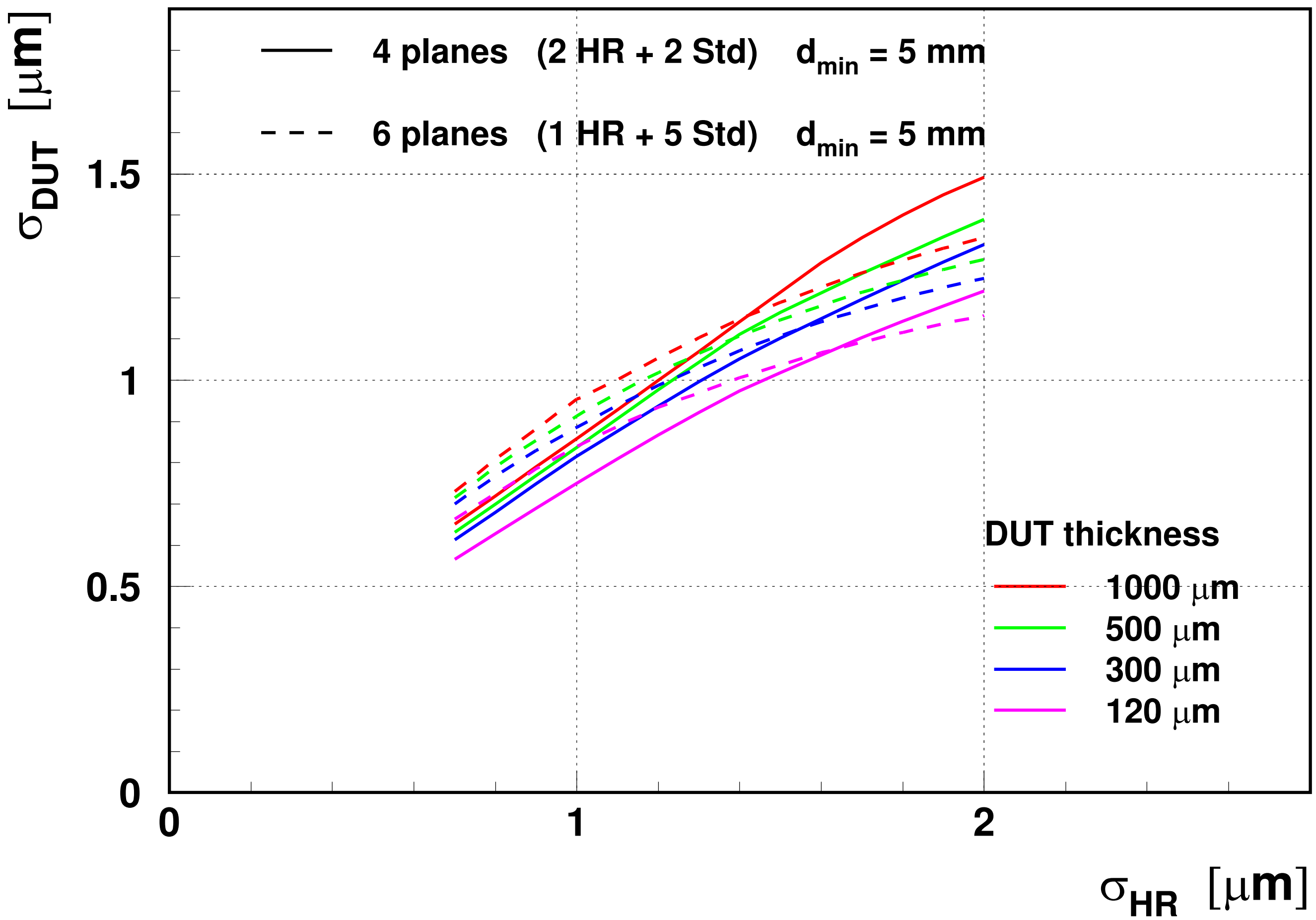


Results

6 vs 4 telescope planes

Second high resolution plane gives significant improvement

4 planes with 2 HR plane are better than 6 planes with 1 HR plane (for $\sigma_{HR} < 1.5\mu m$)



Conclusions

Analytical method used to describe the performance of the telescope with realistic geometry constraints.

The optimum telescope setup is not uniquely defined.

It depends on the number of telescope planes, number of high resolution (HR) planes, position resolution in HR planes, minimum plane–DUT distance and **DUT thickness.**

To achieve error on the reconstructed particle position at DUT of $1\mu m$ at least one high resolution plane is needed (with 6 planes: $\sigma_{HR} \leq 1.2\mu m$)

Significant improvement expected from second HR plane.

If $\sigma_{HR} \sim 1\mu m$ second HR plane should be placed behind DUT.

With one HR plane it is essential to minimize plane–DUT distance (much less for 2 HR planes)

6 sensor planes always give better position resolution than 4 planes