ILC Main Linac Alignment Simulations using Conventional Techniques and Development of Alignment Model

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GEODESY

Introduction

- Presentation in two sections

- Section 1.
  - ILC Main Linac Alignment Simulations using Conventional Techniques

- Section 2.
  - Simple mis-alignment model for the ILC

Section 1

ILC Main Linac Alignment Simulations using Conventional Techniques

Introduction

- Aim Of the Work :
  - Look at how well the ILC Main Linac can be aligned using conventional measurement techniques and software

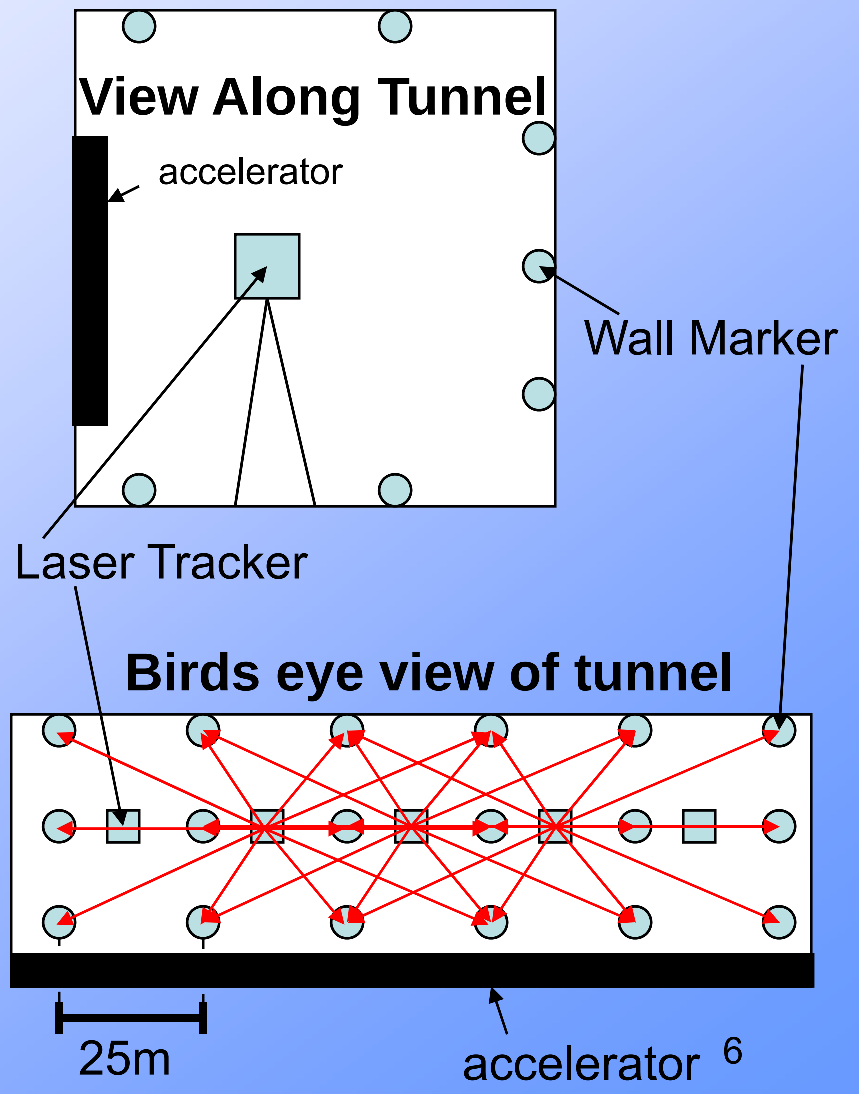
- There are many Conventional Methods for accelerator alignment. The method used in this talk is as follows.
  - Measurement of a network of reference markers using an instrument such as a laser tracker
  - Measurements of a small number of Primary Reference Markers (PRM) using, for example GPS transferred from the surface.
  - Combining all measurements in a linearised mathematical model to determine network marker positions
  - Using adjusted network to align Main Linac
  - Using Dispersion Matched Steering (DMS) to adjust correctors to minimise emittance

Outline

- Network layout
- Network adjustment using PANDA
- Network adjustment simulations without PRM
- Accelerator mis-alignment
- DMS Simulations without PRM
- Introduction of PRMs using GPS
- GPS network adjustment simulations
- GPS DMS simulations
- Future work

Network Layout

- Rings of 7 markers placed every 25m
  - Would like every 10m but current adjustment software not capable
- Network is Measured by a Laser Tracker
  - Laser tracker is placed between marker rings
  - measures 2 rings up and down the tunnel
  - statistical measurement Errors
    - Distance : 0.1mm+0.5ppm
    - Azimuth : 0.3 mgon (4.7 µrad)
    - Zenith : 0.3 mgon (4.7 µrad)
    - Errors estimated by experienced surveyors and laser tracker operators from DESY
  - ignoring all systematic errors from refraction in tunnel air (top hotter than bottom)



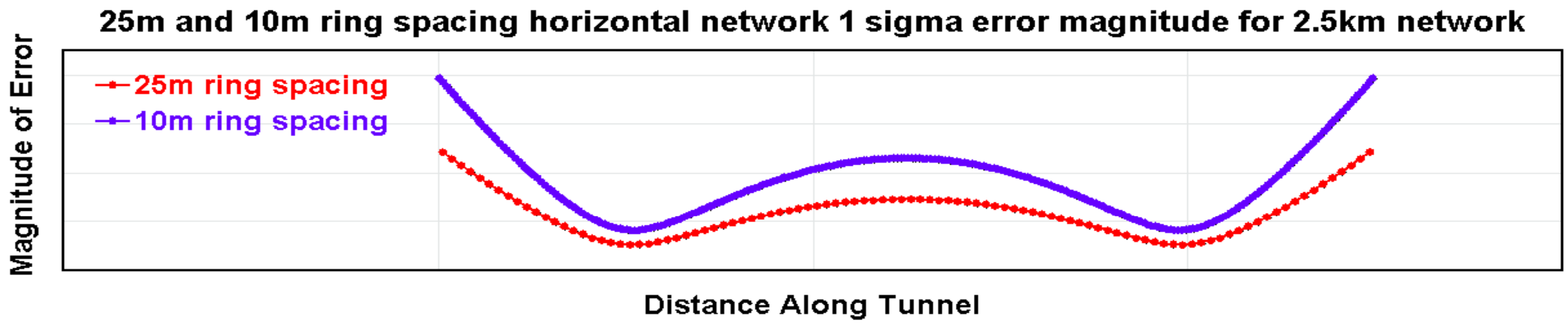
Network Adjustment using PANDA

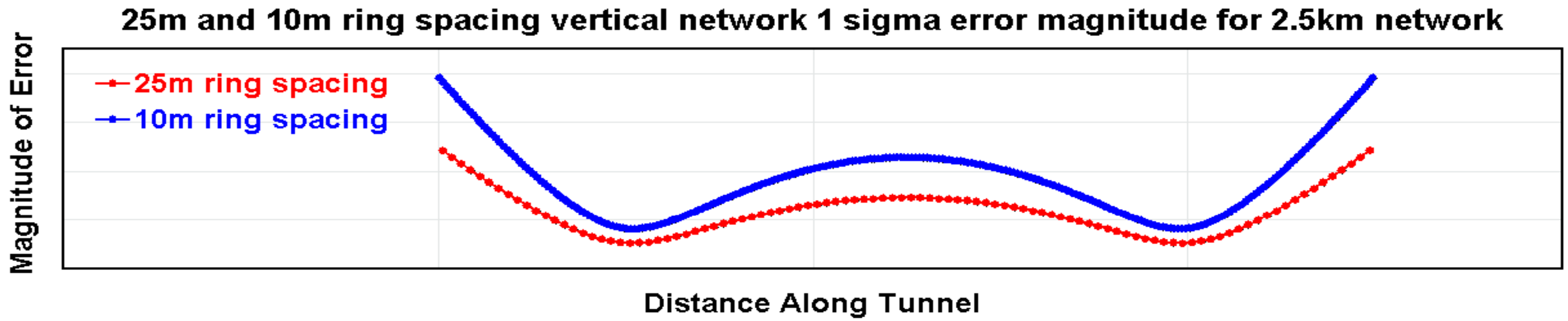
- PANDA is a software package which can design, optimize, adjust (solve for positions) and assess 3D networks
- It is the commercial package used by the DESY geodesy group to adjust their networks
- The network described above is simulated using JAVA code, along with the required laser tracker measurements.
- Simulated measurements are fed into PANDA to produce the adjusted reference network
- Adjusted reference network is used to align the accelerator
- Currently a memory problem in PANDA
  - Cannot add enough positions and measurements to simulate whole ILC tunnel with 10m network spacing
  - Using 25m spacing for these simulations

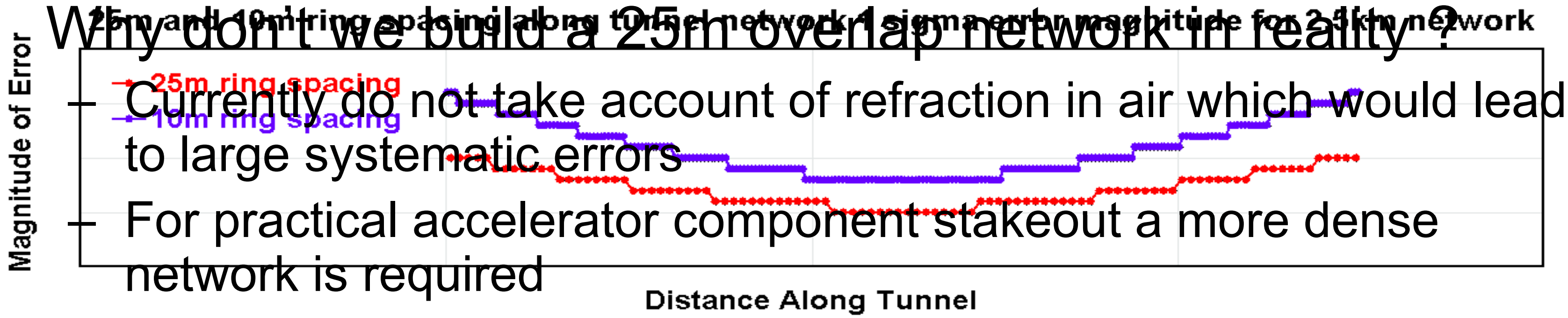
Comparison of 10m and 25m network

- What does this mean for the simulations
  - The laser tracker measurements have errors
    - fixed term of 0.1mm and
    - term scaling with distance 0.5ppm
  - The laser tracker measurement errors will be
    - 10m spacing network the maximum distance measured is ~15m ± 0.1075mm
    - 25m spacing network the maximum distance measured is ~37.5m ± 0.1188mm
    - Measured distance has more than doubled but error has not
  - So a 25m overlap network will have smaller errors than a 10m overlap network.
  - We have verified this is in a short tunnel section (next slide)

Comparison of 10m and 25m network



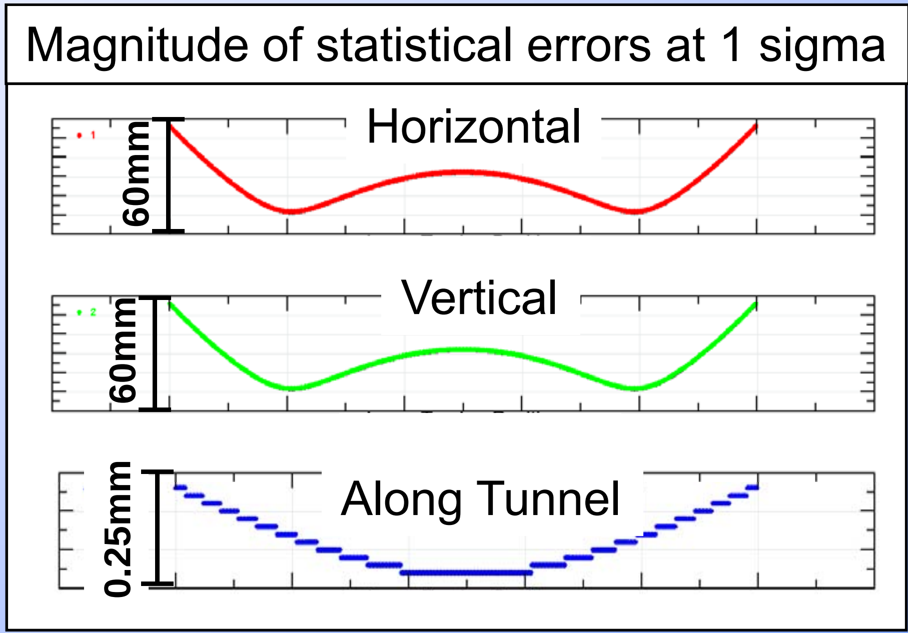


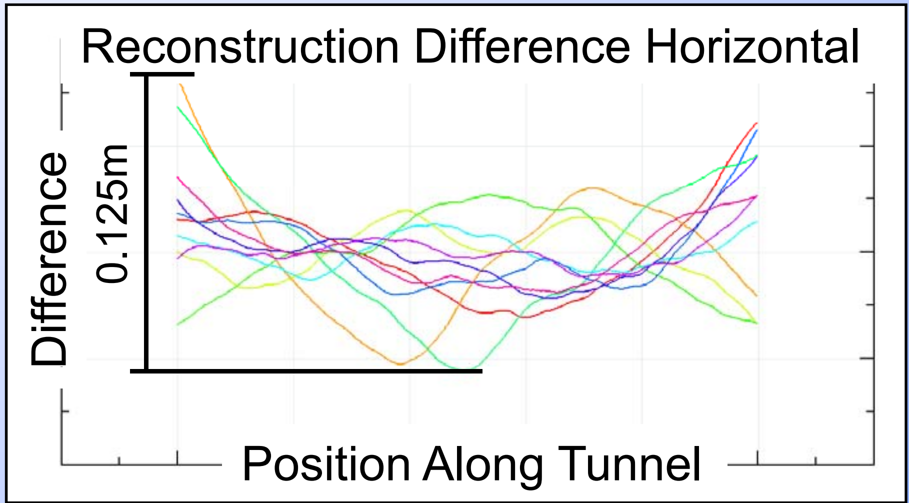


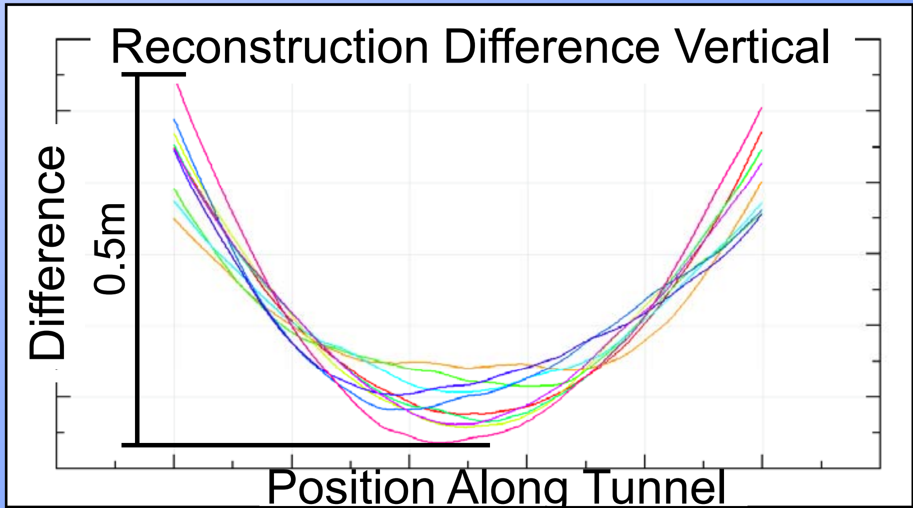
- Why don't we build a 25m overlap network in reality ?
  - Currently do not take account of refraction in air which would lead to large systematic errors
  - For practical accelerator component stakeout a more dense network is required

Network Simulation

- Vertical and horizontal errors computed by PANDA are very similar (as expected from network geometry)
- 10 Reference Networks were simulated in JAVA:
  - length 12.5km with
  - 25m network ring spacing
- And adjusted in PANDA
- Problem with vertical adjustment is under investigation

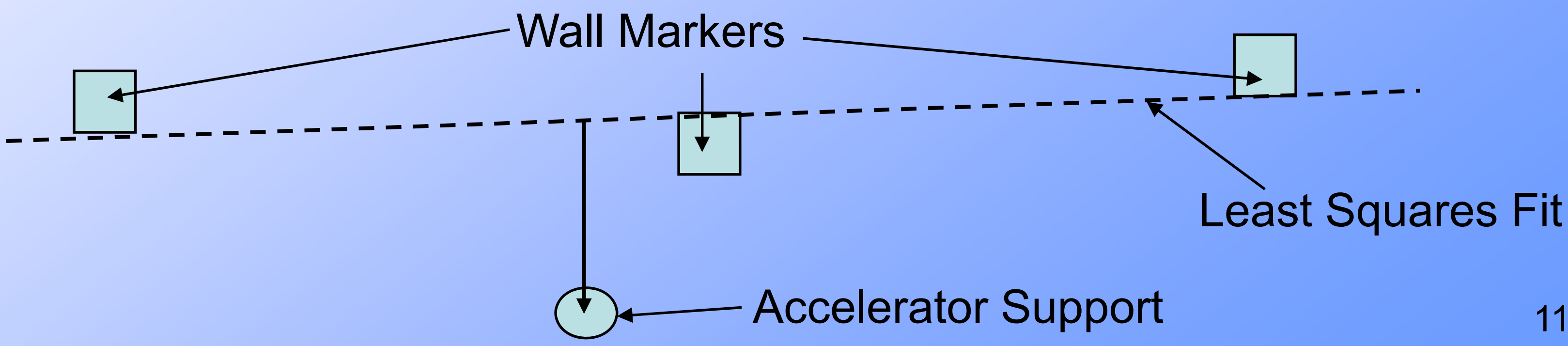






Main Linac Mis-alignment

- Main Linac is mis-aligned by moving the accelerator structure supports from their nominal positions to follow the shape of the adjusted network
- The mis-alignment is calculated by:
  - finding the closest 3 middle wall marker positions to the support
  - fitting a straight line through the wall marker adjusted positions
  - Using the fitted straight line to determine the required support position
  - Note: this doesn't reflect how stakeout is done in practice



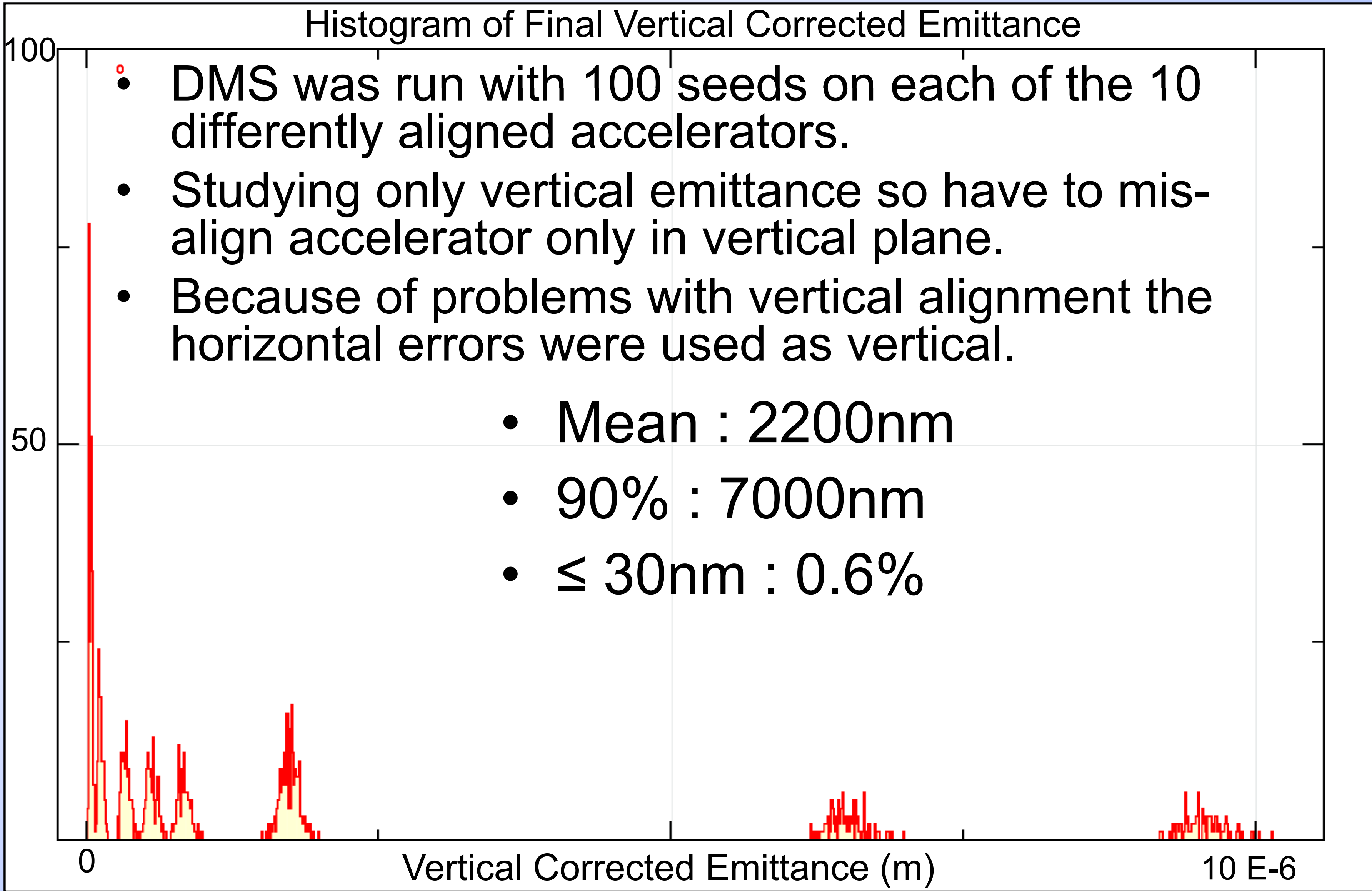
Simulation of DMS using Merlin

- DMS simulations using Merlin (a C++ based library for particle tracking)

- The Merlin based ILCDFS package
  - Is performing the tracking through the curved main linac (positron side)
  - It has implementation of the Beam Based Alignment method based on Dispersion Matched Steering

- Dispersion Matched Steering (DMS)
  - Attempts to locally correct the dispersion caused by alignment errors in magnets and other accelerator components.
  - Adjusts correctors to bring dispersion to its nominal value and preserve the emittance along the Main Linac (ML)
  - Parameters used here
    - Starting emittance 20nm
    - A nominal beam starting energy 15GeV → 250Gev at exit
    - Initial energy of test beam is 20% of nominal beam
    - Constant gradient adjustment of -20%

DMS Results



- DMS was run with 100 seeds on each of the 10 differently aligned accelerators.
- Studying only vertical emittance so have to mis-align accelerator only in vertical plane.
- Because of problems with vertical alignment the horizontal errors were used as vertical.

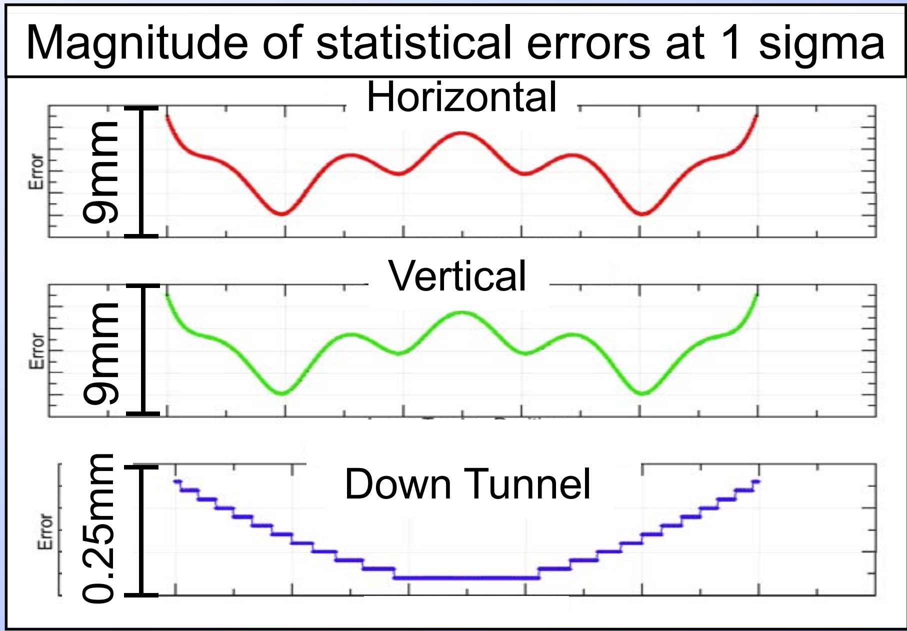
- Mean : 2200nm
- 90% : 7000nm
- ≤ 30nm : 0.6%

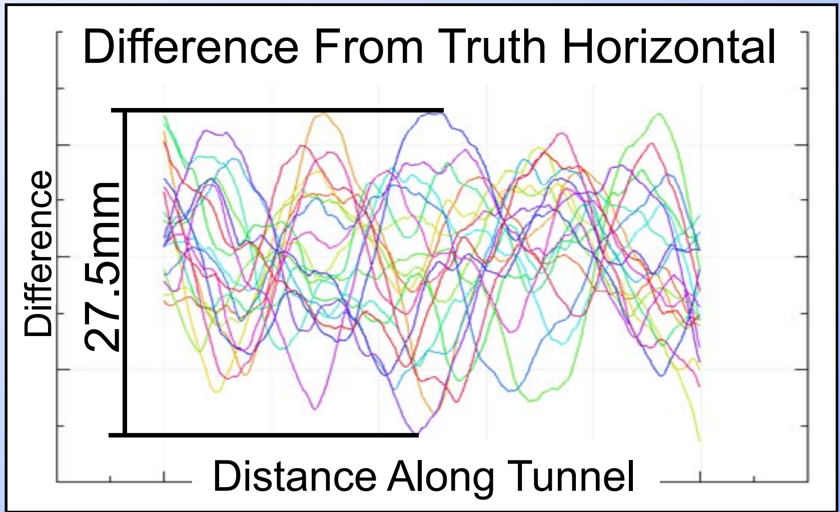
Introduction of Primary Reference Markers (PRM) using GPS

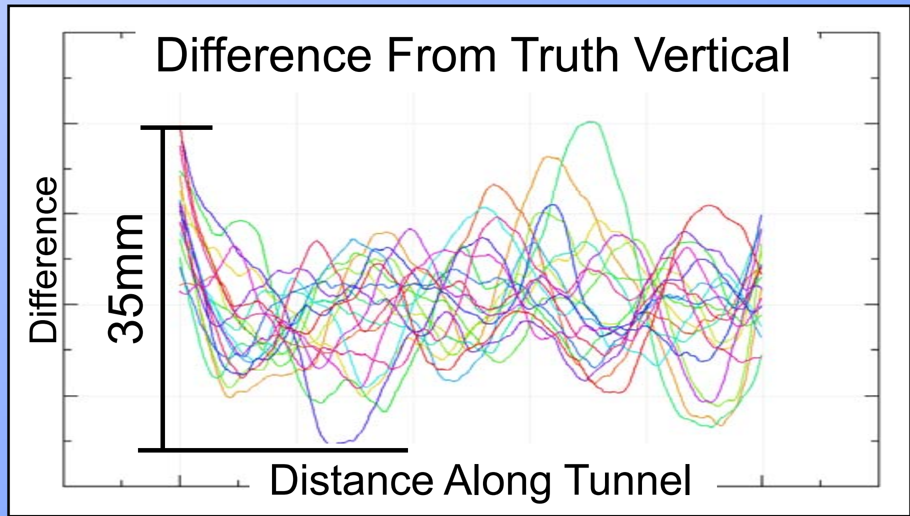
- Primary Reference markers introduced every 2.5km
- They are a primary measurement of a marker already in the network
- Could be measured by GPS on the surface and transferred underground via access shafts.
- Surface-to-tunnel transfer is not simulated here explicitly
- Only assume an effective position accuracy in tunnel
- Appears in PANDA as a baseline measurement (vector difference between points)
  - Currently using a simple diagonal covariance matrix for PRM errors in tunnel
  - Assuming standard deviation error of 10mm in all directions

Network Simulations with PRM

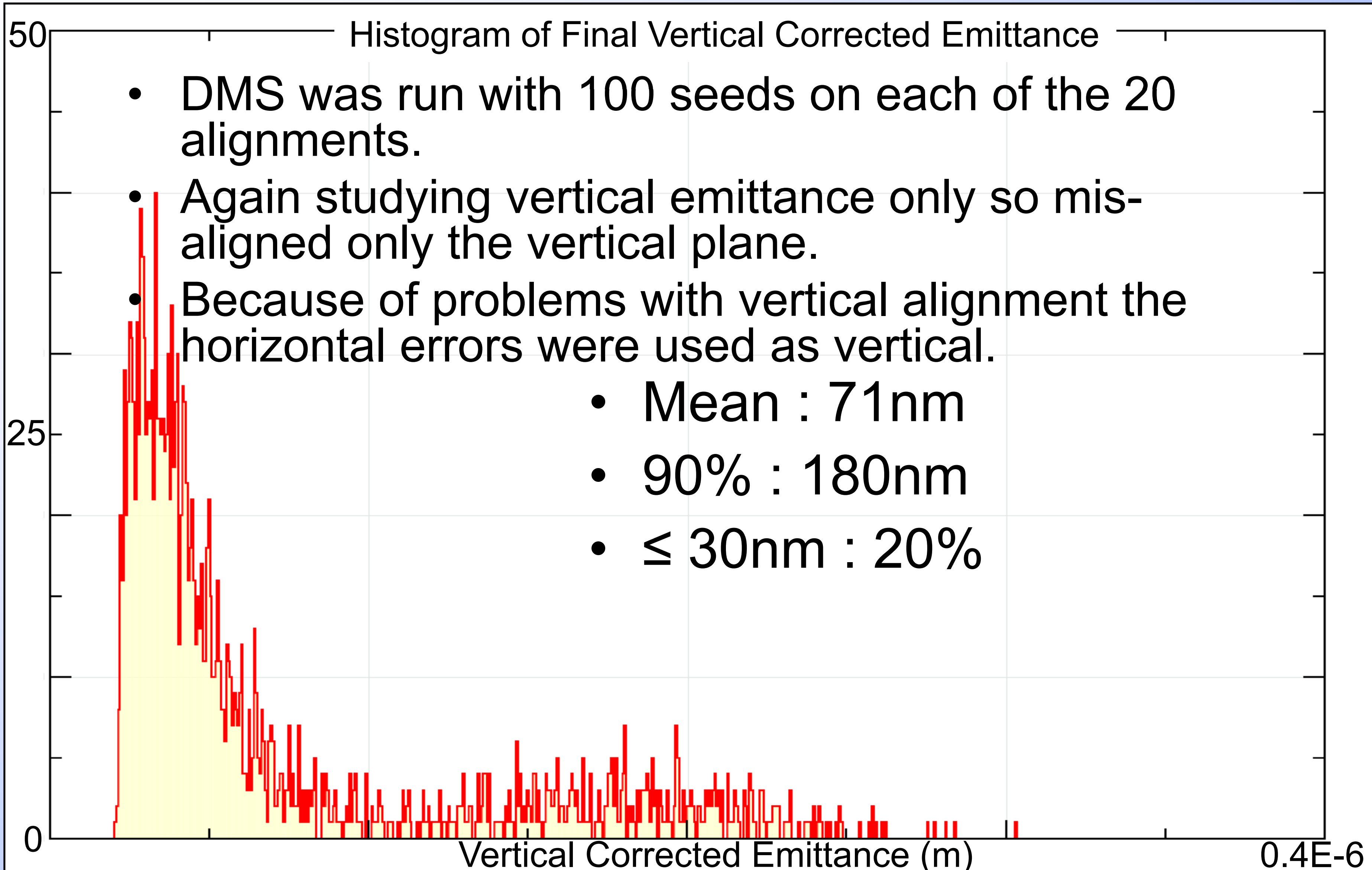
- Use PANDA to calculate error propagation through network
- Looks plausible
- 20 Reference Networks were simulated in JAVA
  - Length 12.5km
  - Including GPS every 2.5km
- and adjusted using PANDA
- Problem with vertical adjustment under investigation at DESY and by authors of PANDA







GPS DMS Simulations



- DMS was run with 100 seeds on each of the 20 alignments.
- Again studying vertical emittance only so mis-aligned only the vertical plane.
- Because of problems with vertical alignment the horizontal errors were used as vertical.

- Mean : 71nm
- 90% : 180nm
- ≤ 30nm : 20%

Future Work

- Re-run network simulations with PANDA at 10m interval spacing when it has been fixed
- Simulate stake out process
- Simulate transfer of GPS co-ordinates into tunnel
- Improve PRM covariance matrix
- Confirm PRM network adjustment using different software
- Confirm DFS using different code

Summary

- Without primary reference markers it would be impossible to achieve the required emittance
- Although optimistic assumptions for network and PRM errors were used …
- …the emittance improves insufficiently with primary reference markers:
  - only 20% are in spec (below 30nm)
  - 90% value is 180nm (6 times too large)
- More work is required to prove the adjusted network is correct
- Emittance results need to be confirmed with a different code

Section 2

Simple mis-alignment model for the ILC

Introduction

- There has been work on the development of a simplified alignment model which can be used by LET community to mis-align the ILC for beam dynamics simulations.
- Model uses a pseudo random walk from one PRM to the next
- The PRM are used to correct the random walk

The Present Model

- Random walk (y) parameterized as:

$$\theta_{j,n+1} = \theta_{j,n} + a_\theta + \Delta\theta_{syst}$$

$$y_{0,j,n+1} = y_{0,j,n} + a_y + l_{step}\,\theta_{j,n} + \Delta y_{syst}$$

$$y_{0,j,0} = y_{p,j}$$

$$0 \le n \le N_{rfpt}$$

- Errors (stat. and sys.):

$$\sigma_{y,n,stat.} = \sqrt{l_{step}^2 a_\theta^2 \frac{n(n+1)(2n+1)}{6} + a_y^2 \frac{n(n+1)}{2}}$$

$$\sigma_{y,n,syst.} = l_{step}\Delta\theta_{systematic}\, n\frac{(n+1)}{2} + n\Delta y_{systematic}$$

- Correction (yc): Error weighted average fit (parabolic)

$$y_{j,n} = y_{0,j,n} + \left(y_{0,j,N} - \frac{y_{P,j+1}/\sigma_{y-primary}^2 + y_{0,j,N}/\sigma_{y-0,j,n}^2}{\sigma_{y-primary}^2 + \sigma_{y-0,j,n}^2} \right)\left(s_j(0,n)/s_j(0,N)\right)^2$$

Parameter values
Based on LiCAS Train
a_θ = 55.4E-9
$\Delta\theta_{syst}$ = -260E-9
ay = 5E-6
Δy = -5.3E-6
$\sigma_{y\text{-}primary}$ = 10mm

Systematics dominate
The LiCAS Train

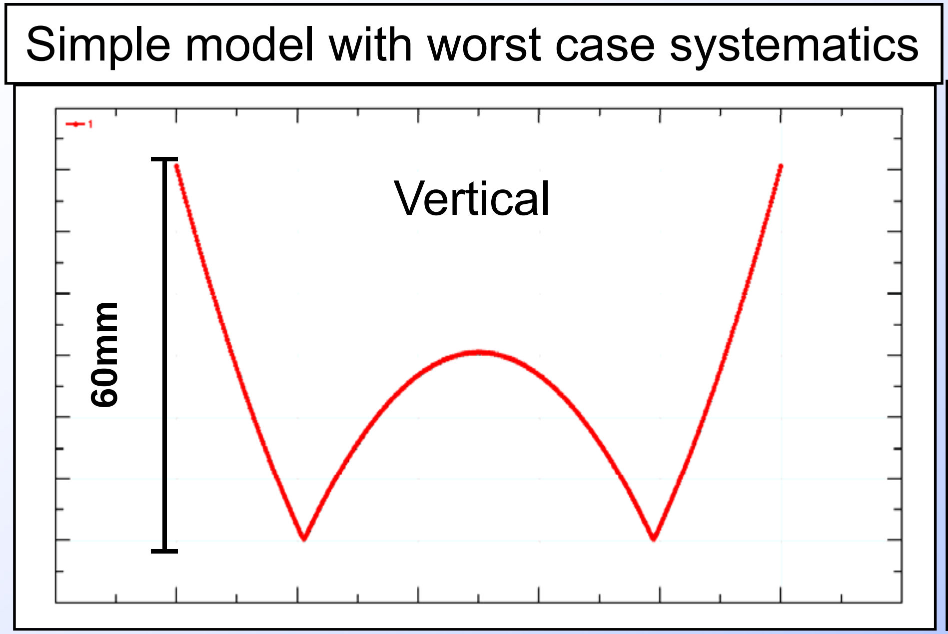
DMS simulation with simple mis-alignment model

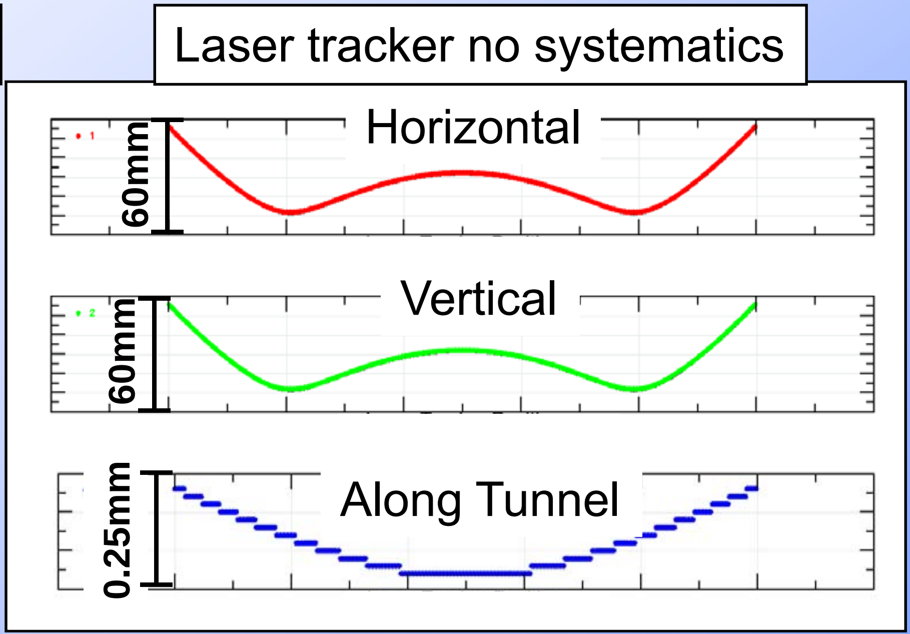
- Freddy and Kiyoshi used the above model as input to DMS simulations
- Simulations seems to show no problem with emittance
- Freddy used 2mm vertical PRM error ➔ too optimistic. 10mm is more realistic
- And there are more problems with the model …

Error Curves Without PRM

- Without PRM survey is a random walk down tunnel
- Determine the error propagation plots for the simple model:
  - Simulate 2000 random walks with systematic error parameters varied at worst case range
  - Note: Statistical errors negligible compared to systematic
  - Fit straight line to each random walk
  - Compute residuals for each random walk
  - Plot standard deviation at each point over all runs
- Compare to PANDA’s error propagation for laser tracker method

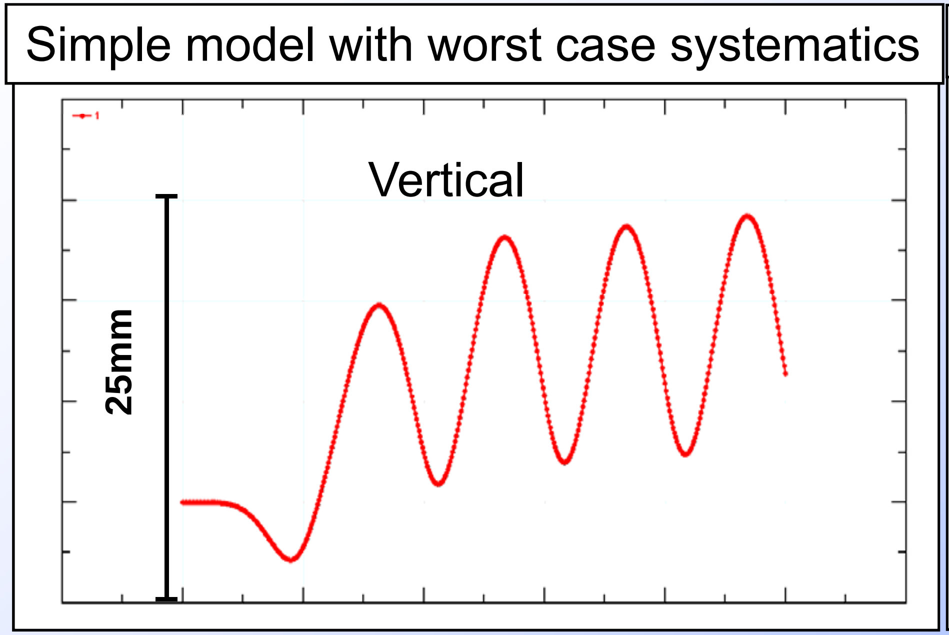
Error Curves No PRM

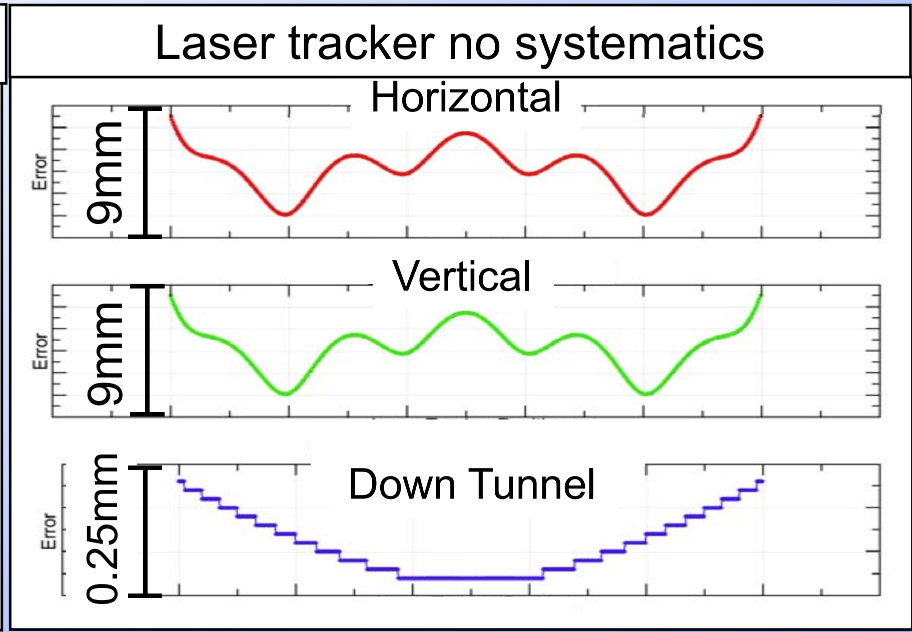




- Form and magnitude of both errors are similar
- Simple model has sharper turns compared to laser tracker because systematic dominated

Error curves with PRM





- Error shape expected to be similar
- Cleary different
- Asymmetry in errors of simple model with PRM
- Model’s errors becomes larger than expected

Why does it not work

- Errors on the random walk are defined to be 0 error at the start
- Errors on PRM are random around a arbitrary straight line
- Cannot compare these two directly
- Need new model

How To Improve the model

- More work is required to be able to generate reference networks for LET simulation
- Possible methods for improving may be:
- 1) Improve the exiting simple model
  - random walk down entire tunnel
  - Fit straight line
  - Randomly generate PRM around fit line
  - Combine “in a way” which produces realistic adjusted networks
    - Not clear how to do this yet

How To Improve the model

- 2) Simplified Linear algebra model for LiCAS type train
  - Represent each train stop as a set of baseline measurements
  - add PRM baseline measurements
  - Use network adjustment software (eg PANDA) to produce a large number of network simulations
  - Simulations can be distributed to beam dynamics simulations community

How To Improve the model

- 3) Full linear algebra model of LiCAS train
  - Develop a full linear algebra model for a LiCAS train
  - add PRM baseline measurements
  - Use model to produce a large number of networks
  - Simulations can be distributed to beam dynamics simulations community
  - Very Difficult to achieve this in short term

Summary

- Currently no model exists which can generate a realistic representation of an ILC reference network
- Our current assumption, that there is no problems with alignment is flawed
- Need to re-run DMS studies with a realistic adjusted network

Conclusions

- Conventional Methods without PRM will not be suitable for ILC alignment
- Conventional Methods with PRM don't appear to be good enough to align, but more work is required to verify
- Current simplified Mis-alignment model is flawed
- Need new simplified alignment model

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