ILC Main Linac Alignment Simulations

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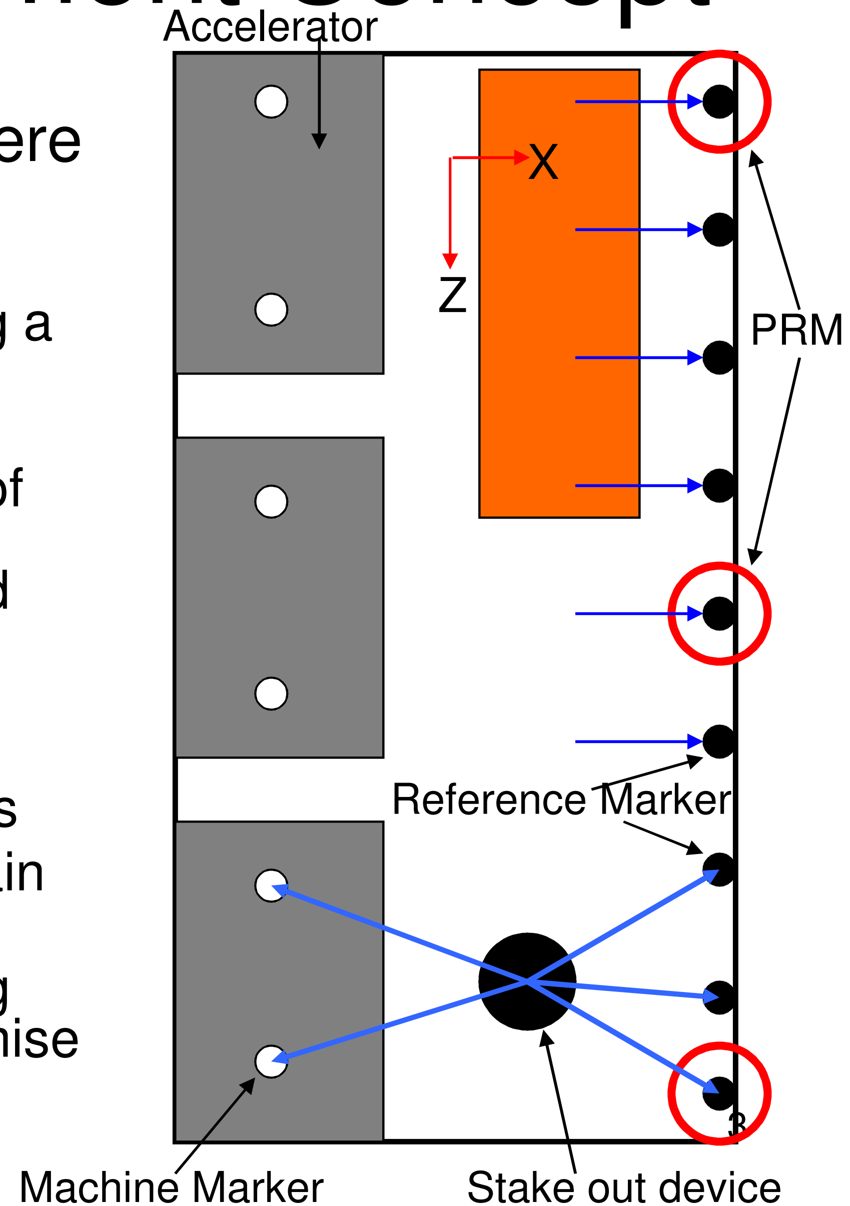
Introduction

- Alignment Concept
- Latest results using PANDA for conventional alignment simulations
  - RTML and Main Linac Matching
  - Results
- The Simplified Network Simulation Model
  - Status
  - Comparison to PANDA results
- Summary

Accelerator Alignment Concept

- Many possible ways to Align an Accelerator, the concept used here is:
  - Over lapping measurements of a network of reference markers using a device such as a laser tracker or a LiCAS RTRS
  - 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

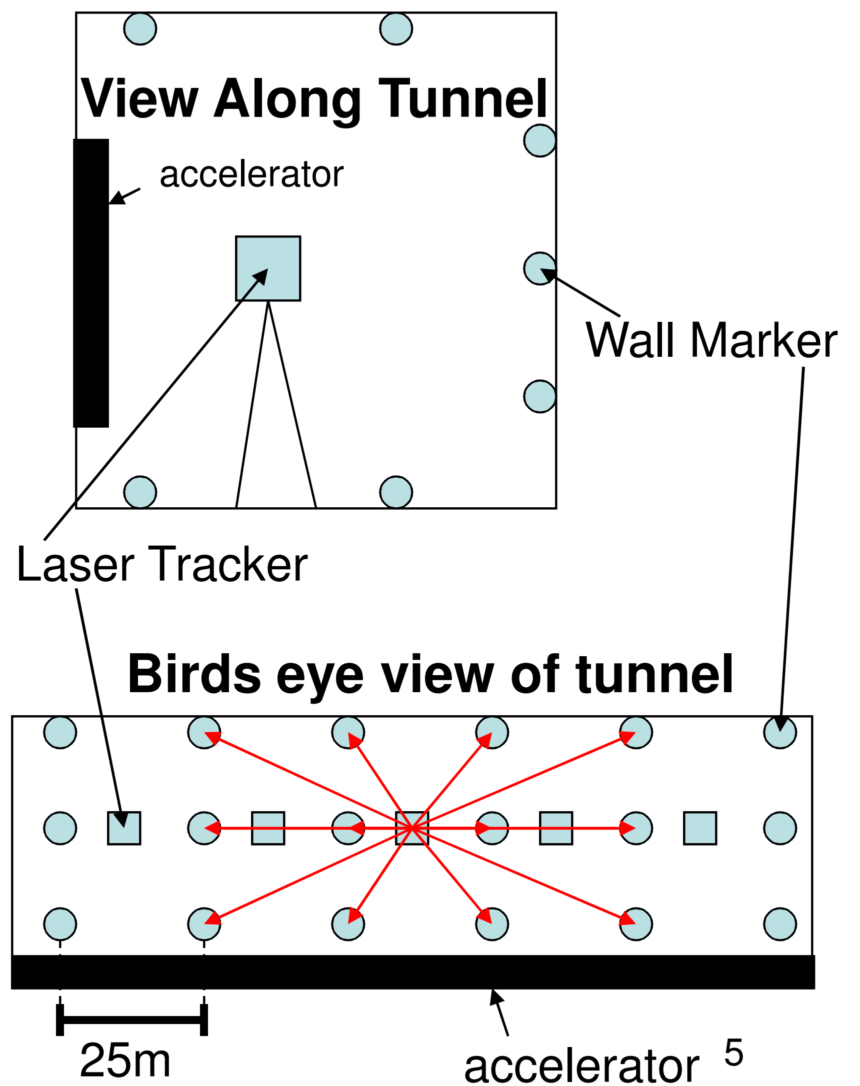


PANDA

- 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
- Analysis data from conventional measurement devices such as laser tracker and tacheometers.
- Simulated measurements can be fed into PANDA to produce simulated adjusted reference network
- Adjusted reference network is used to align the accelerator

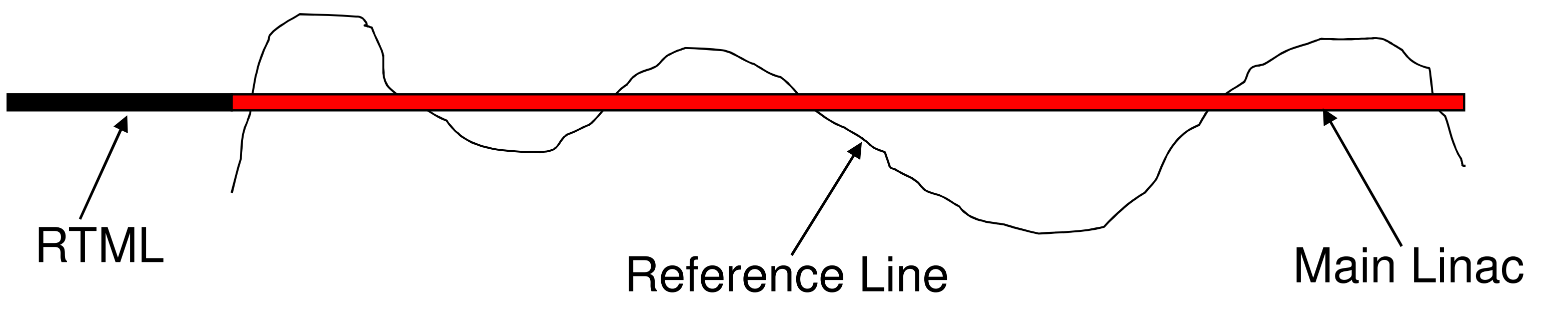
Network Measurement Using a Laser Tracker

- Rings of 7 markers placed every 25m
- 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)
- PRMs every 2500 m simulated with an error of 10mm



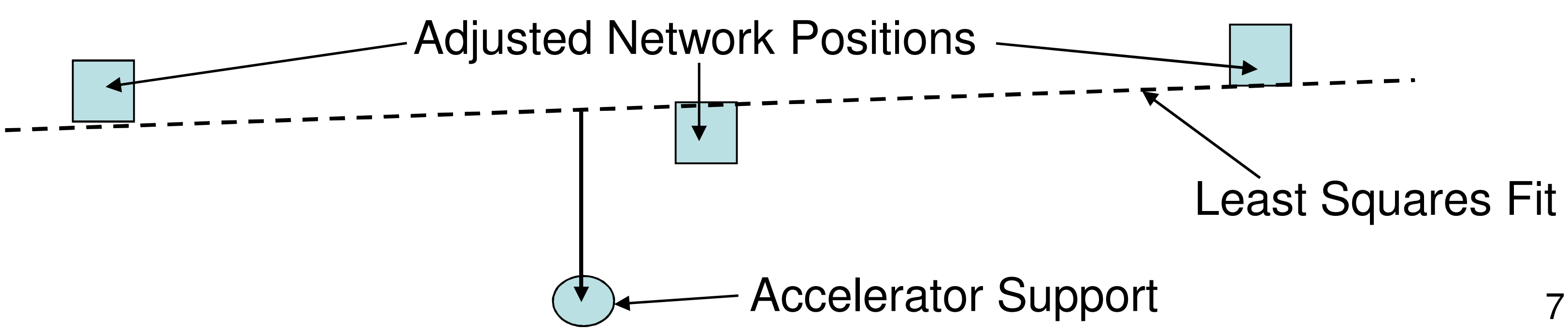
Main Linac Misalignment

- Simulations output adjusted network positions
- Adjusted networks give offset at RTML and main linac (ML) join
- In practice RTML and the ML are surveyed at the same time
- The connection should be smooth
- Approximate by shifting the adjusted network positions so that the start of the ML matches with the RTML.



Main Linac Misalignment

- Main Linac is misaligned by moving the accelerator structure supports from their nominal positions to follow the shape of the adjusted network
- The misalignment is calculated by:
  - finding the closest three adjusted network positions to the support
  - fitting a straight line through the adjusted positions
  - Using the fitted straight line to determine the required support shift
  - 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)

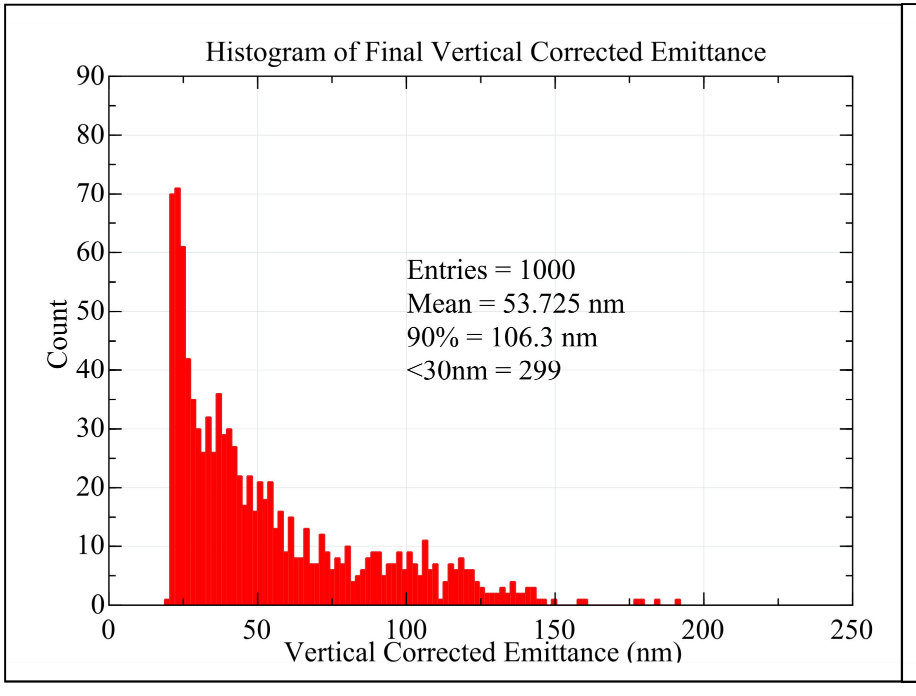
- The Merlin based ILCDFS package
  - Is performing the tracking through the curved main linac (positron side)
  - It has implementation of the Beam Based Alignment method based on Dispersion Matched Steering

- 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%

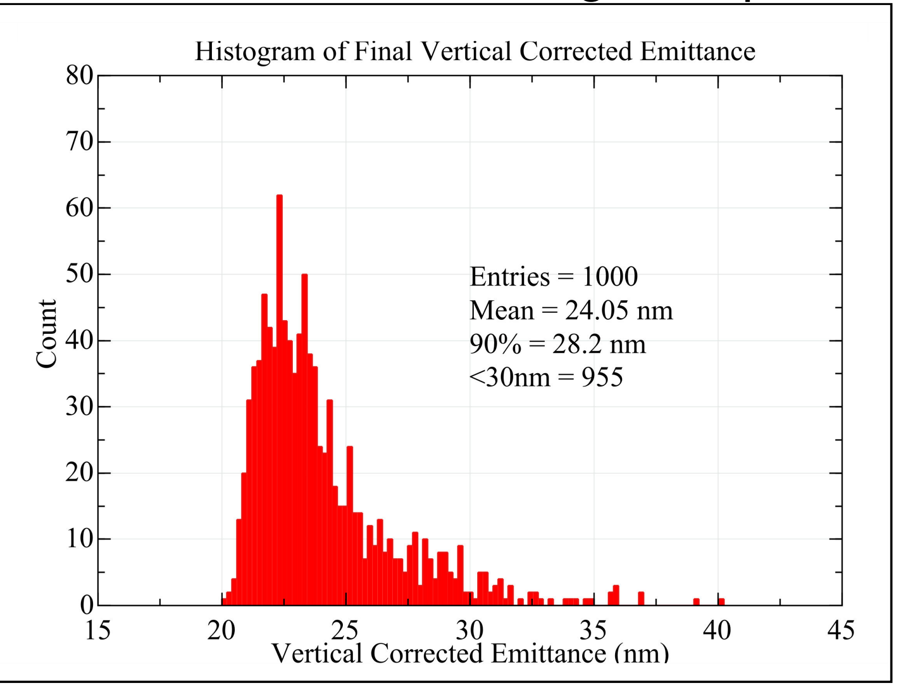
PANDA DMS Results

- 100 networks simulated with and without PRMs.
- For each network 10 DMS simulations performed.

Without PRMs 30% pass
Without RTML matching 10% pass



With PRMs 96% pass
Without RTML matching 39% pass



PANDA Limitations

- Can only simulate networks measured with conventional techniques
  - Want to see effect of novel measurement techniques.
- Need to be an expert to use
- A commercial package
  - Have to pay for licences

Simplified Network Simulation Model Concept

- To be able to simulated different types of devices.

- Don’t need to be a survey expert to use.

- Have a device model
  - Measures small number of RMs rings e.g. 4
  - Moves on one RM ring each stop and repeats measurement
  - Measurements in the devices frame
  - Device frame can rotate around the X,Y and Z axis
  - Determines vector difference between RMs
  - Only the error on the vector difference measurements are required

- PRM measurements are vector difference measurements between PRM’s
  - Measurements are in the global frame
  - Only the error on the vector difference measurements are required

Simplified Network Simulation Model Concept

- Inputs are:
  - Network ring structure
  - Number of marker rings measured at one stop
  - Network ring spacing
  - Device Measurement precision
  - PRM positions
  - PRM measurement precision
- Outputs are:
  - Reference network
  - Reference network errors

The Linearised Model

- Measurement Vector L
  - Contains device and PRM vector differences
- Measurement Covariance Matrix P
  - Simple diagonal matrix assuming no cross dependency on measurements
- Variables Vector X
  - Contains all the markers positions and device rotations
- Prediction Vector F(X)
  - Predicts L
- Difference Vector $W = F(X) - L$
- Design Matrix $A = \delta F(X)/\delta X$

The Linearised Model

- Normal Non-linear least squares minimises W^TW leading to an improvement of estimates given by

$$\Delta X = -(A^TPA)^{-1}A^TPW$$

- Problem A^TPA is singular and not invertible
  - Model Requires Constraints.
- Standard way in geodesy is a free network constraint
  - The constraints are calculated using a single value decomposition of A^TPA
  - The singular vectors with zero eigenvalues are the constraint vectors
- SVD needs to be calculated every iteration
  - As the networks are very large, the calculation of the SVD is slow (approximately 15 hours to solve full network[1]

[1]timimg based on four markers per ring not seven

Constraints

- Can speed up process by calculating the eigenvalue decomposition (EVD) of A^TPA instead of the SVD.
  - A^TPA is positive, symmetric and square so EVD is equivalent to SVD
  - EVD can be calculated faster.
  - However calculating the EVD each iteration is still slow
  - 10 hours to solve a single network[1]

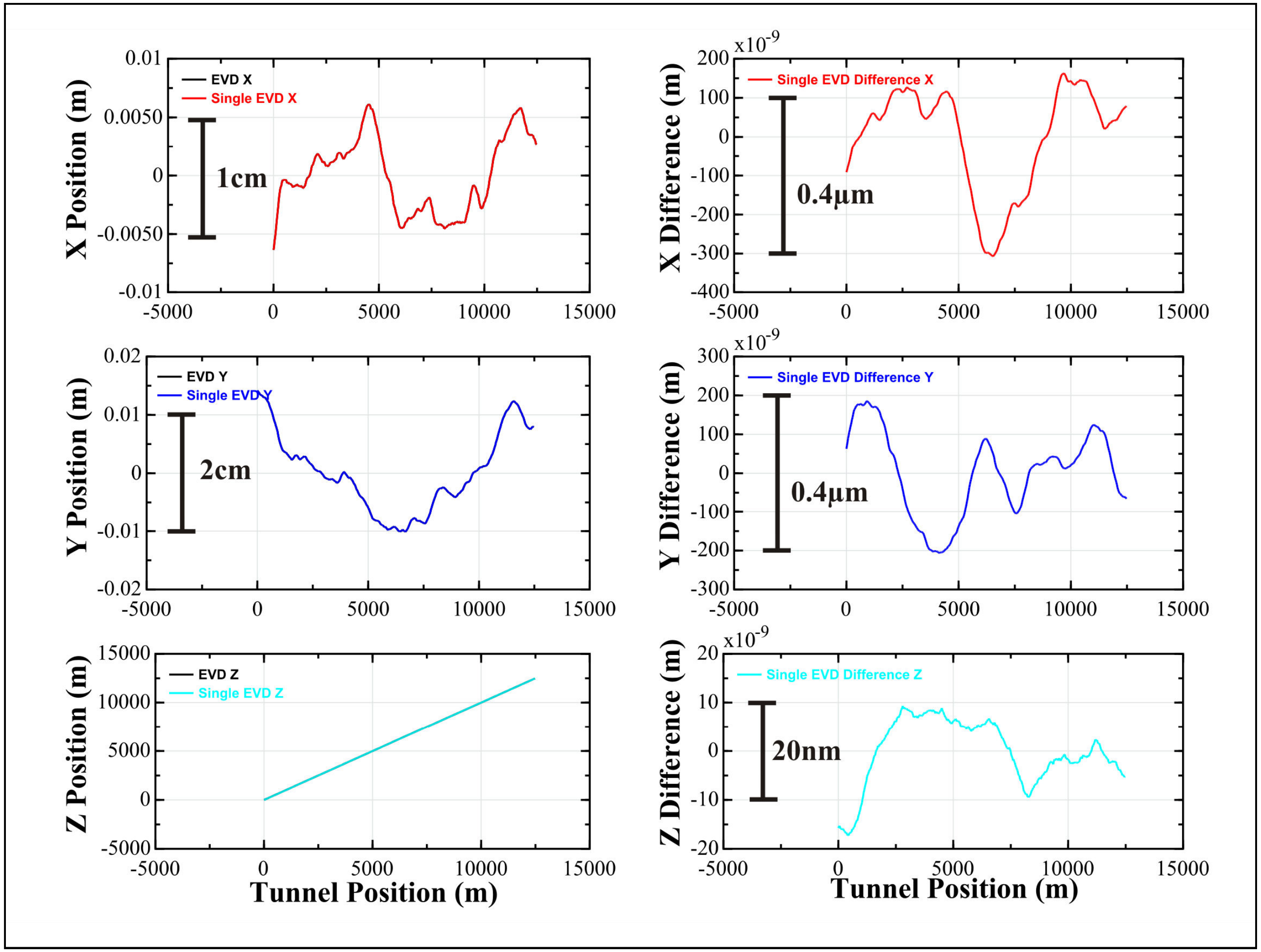
- Instead of calculating the EVD each iteration, calculate only once and use for every iteration
  - Approximately 1 hour to solve single network[1]

- When generating large numbers of networks one EVD can be used to constrain all networks
  - Approximately 20 minutes per additional network[1]

[1]timimg based on four markers per ring not seven

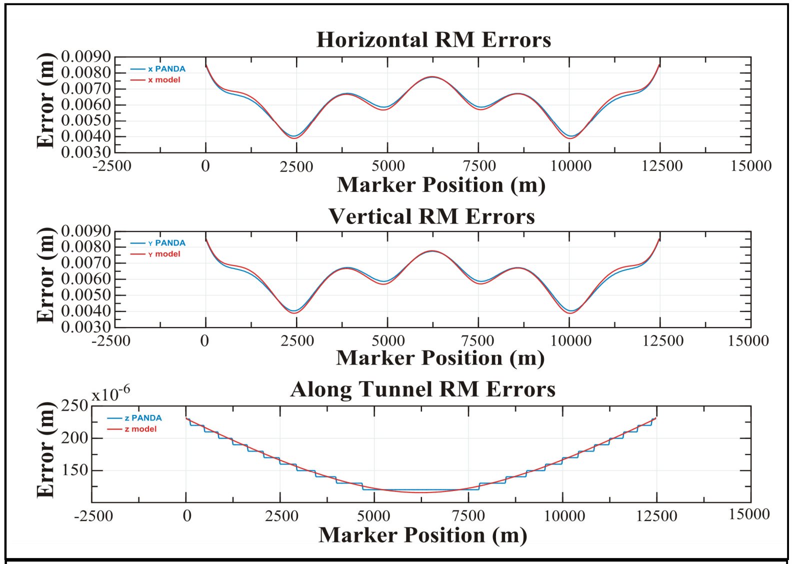
Single EVD to full EVD comparison

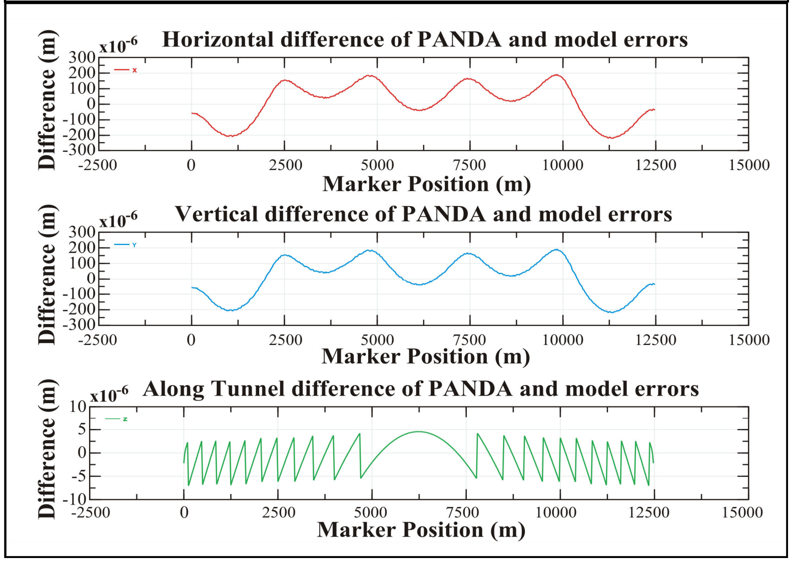
To compare the two methods a set of input data was analysed by both methods with the networks and differences shown below



Error Curve Comparison

- Use Model to generate laser tracker measured network with PRM's
- Model error input parameters tuned to match PANDA error curves
- Model Parameters:
  - No Rings = 500
  - Markers in a Ring = 4
  - Space between markers = 25 m
  - No PRM's = 6
  - Space between PRM's = 2500 m
  - $\sigma x = 9.693 \times 10^{-5}$ m
  - $\sigma y = 9.692 \times 10^{-5}$ m
  - $\sigma z = 3.097 \times 10^{-5}$ m
  - $\sigma GPS = 1.015 \times 10^{-2}$ m

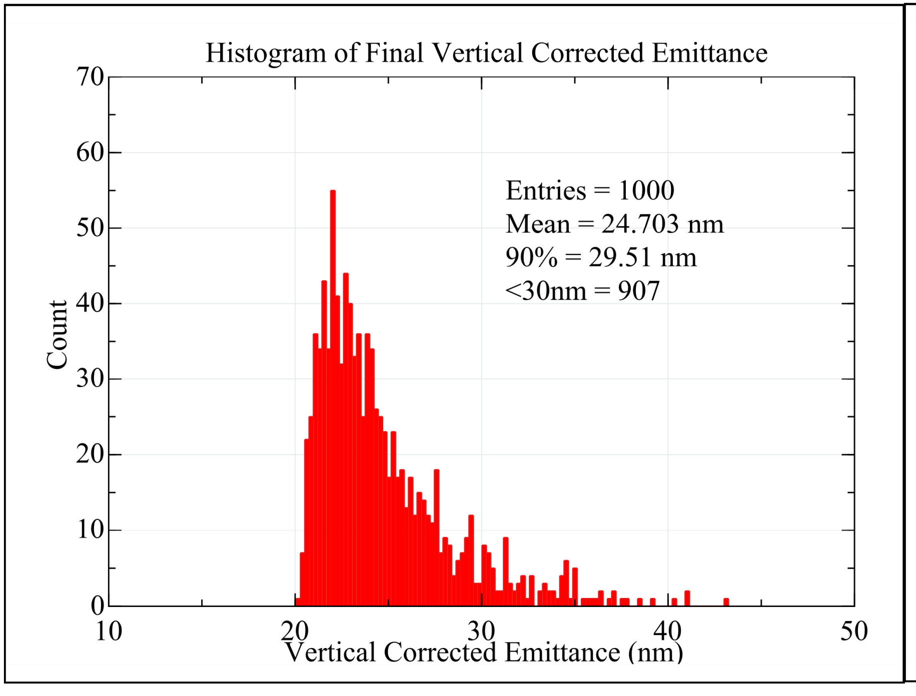




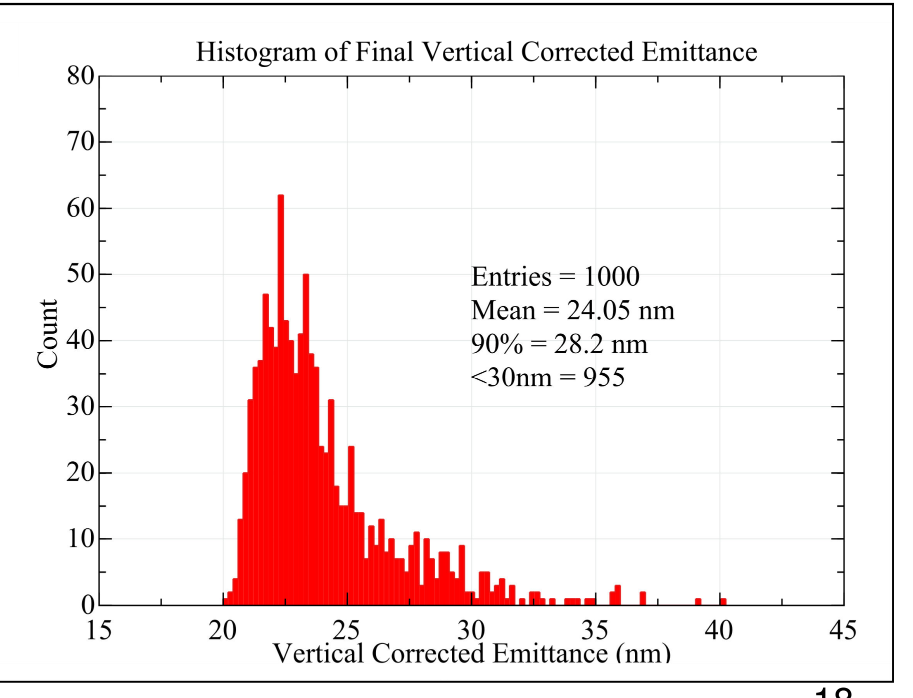
DMS Comparison

- 100 networks simulated using the simplified Network simulation model.
- For each network 10 DMS simulations performed.

Model 91% pass



PANDA 96% pass



Summary

- Conventional methods with RTML matching produces acceptable performance
  - No systematic errors are taken account of
- Simulation model works
  - DMS simulations pessimistic
    - expected network layout is simplified
  - With model performance improvements could do more complex network
  - Need to implement systematic errors