Status of Reference Network Simulations

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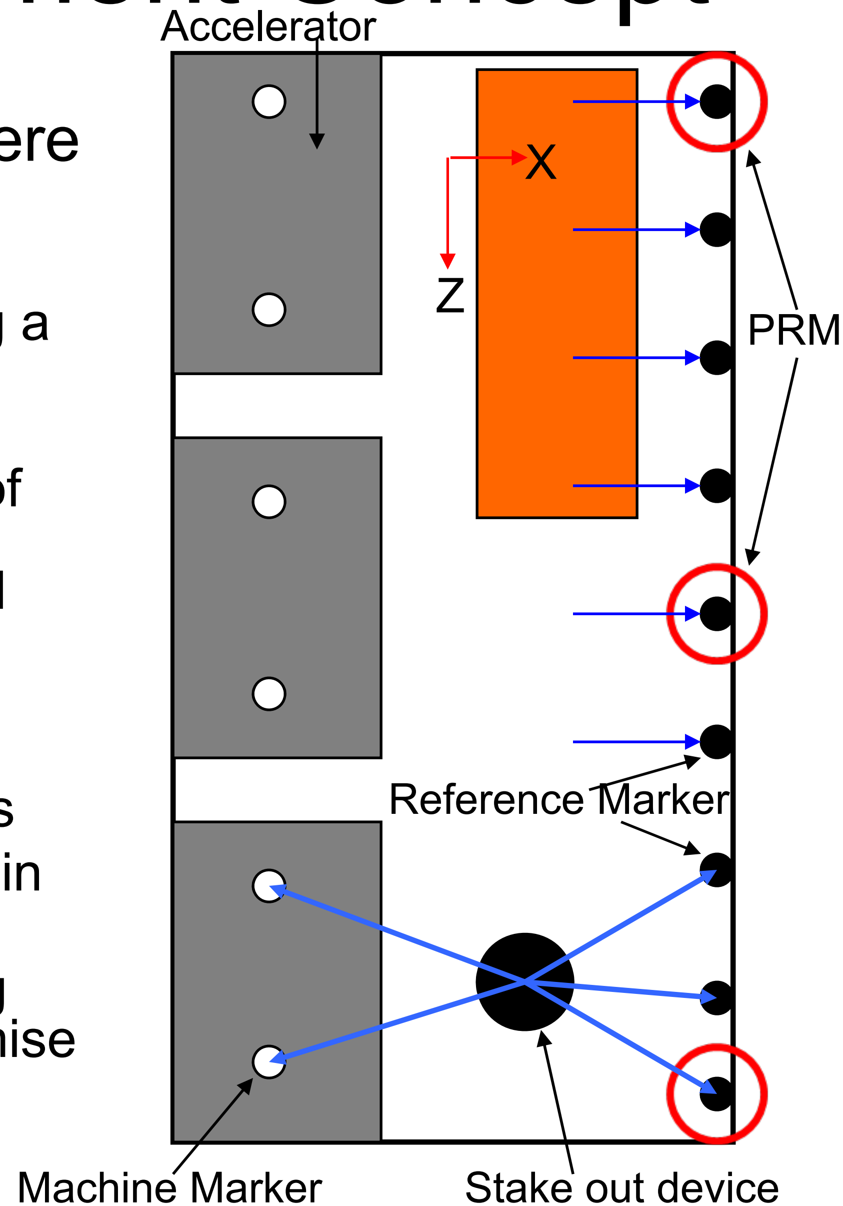
Introduction

- Accelerator Alignment Concept
- Reference Network Simulations Model
  - Concept
  - Linearised model
  - Free network constraint
- Reference Network Simulation Results
  - Error Curves
  - Dispersion Matched Steering (DMS) results

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, stretched wires or 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



Reference Network Simulation Aims

- Generate ILC reference network solutions which can be used for LET simulations
- Easy to use
- Quickly (minutes not days)
- Correct statistical properties
- Capable of simulating existing as well as novel network measurement techniques

Possible Approaches

- Commercial survey adjustment software
  - Expensive
  - Need to be survey expert to use
  - Usually only use laser tracker/tachometers
- Full simulation of a specific device
  - Slow to generate networks
  - Restricted to one measurement technique
- Simplified Model
  - If designed correctly can be quick
  - Can be used to model novel devices

Simplified Model

- Have a device model
  - Measures small number of RMs e.g. 4
  - Moves on one RM each stop and repeats measurement
  - Determines vector difference between RMs
  - Vector difference smeared by input error
  - Knowledge of measurement procedure not necessary
  - Rotates around the X and Y axis

- PRM measurements
  - Vector difference measurements between PRM’s
  - Measurements smeared by input error

The Linearised Model

- M device stops, N reference Markers Total, O PRMs Total, device measures 4 markers per stop
- 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
- 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.

Free Network Constraints

- Five constraints required
- Could constrain first point to be at (0,0,0) and both the rotations of first stop to be 0.
  - Gives zero error at one end and large error at other. Not the desired form

- Use a free network constraint
  - Technique developed in Geodesy
  - The free network constraint is that $X^T X$ is minimised.
  - If $X^T X$ = min the trace of the output covariance matrix is also minimised
  - Equivalent to a generalised inverse
  - The least squares minimises $W^T W$ and $X^T X$ to give a unique solution

Free Network Constraint

- Break Up A^TPA into sub-matrices
  - N11 Must be non-singular
  - N22 size 5*5

$$A^T PA = \begin{bmatrix} N_{11} & N_{12} \\ N_{21} & N_{22} \end{bmatrix}$$

- Leading to constraint Matrix A2

$$A_2 = ((N_{11}^{-1} N_{12})^T - I)$$

- Improvement given by

$$\Delta X = -\begin{bmatrix} A^T PA & A_2^T \\ A_2 & 0 \end{bmatrix}^{-1} \begin{bmatrix} A^T PW \\ 0 \end{bmatrix}$$

- Output Covariance matrix given by
  - Contains the errors on the RM positions

$$\Sigma_X = \begin{bmatrix} A^T PA & A_2^T \\ A_2 & 0 \end{bmatrix}^{-1}$$

- Note ΔX and Σ_X are longer than X, but extra elements are zero.

Model Summary

- Input
  - Device Measurement Errors
  - Number RMs measured by device in one stop
  - PRM Measurement Errors
  - Network Parameters
    - Number RMs, Number PRMS, RM spaceing, PRM spacing
- Output
  - Reference marker position difference from truth
  - Reference marker position statistical error

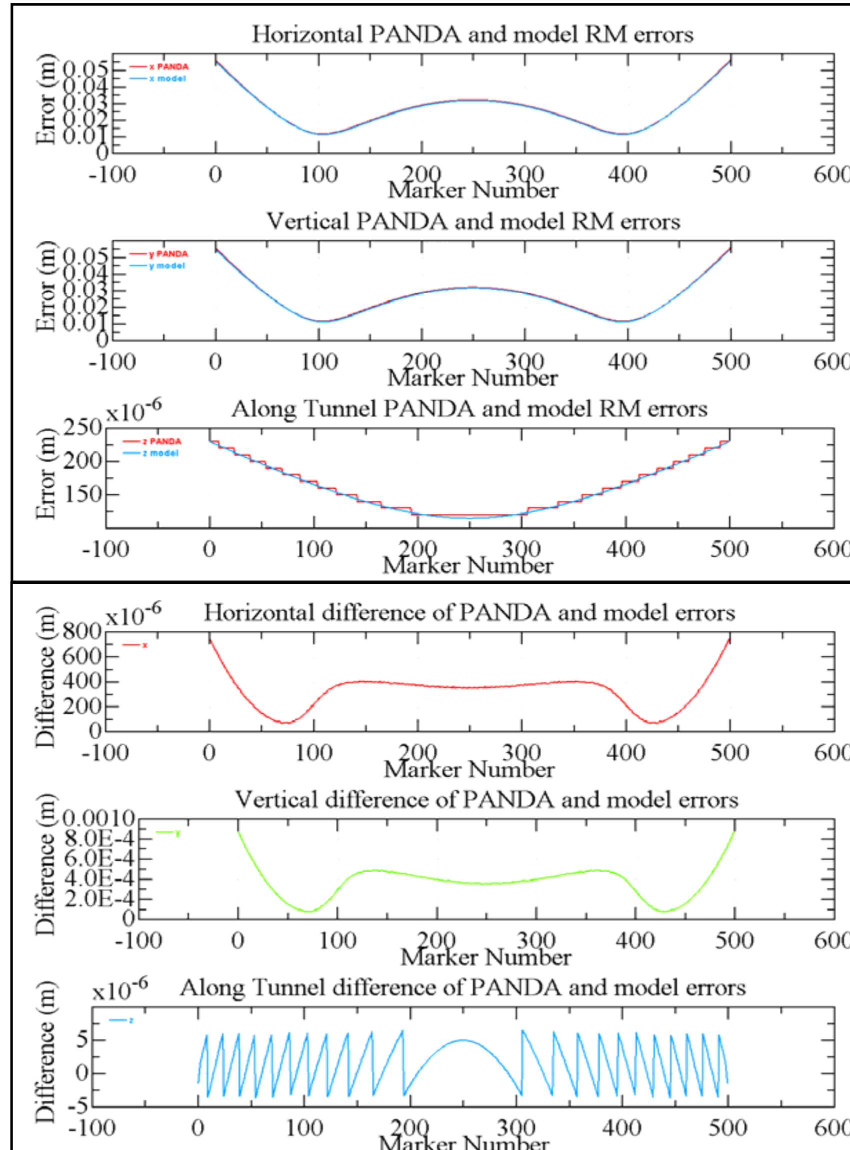
Laser Tracker Network Simulation

- Test model by comparing to laser tracker network
- Can simulate ILC laser tracker networks using PANDA
- Use PANDA output to determine model parameters
  - minimising the difference between the PANDA statistical errors and the model statistical errors
  - Minimiser can adjust the model input parameters
  - minisation using JMinuit
- minisation done for networks with and without PRMs

Error Curve Comparison

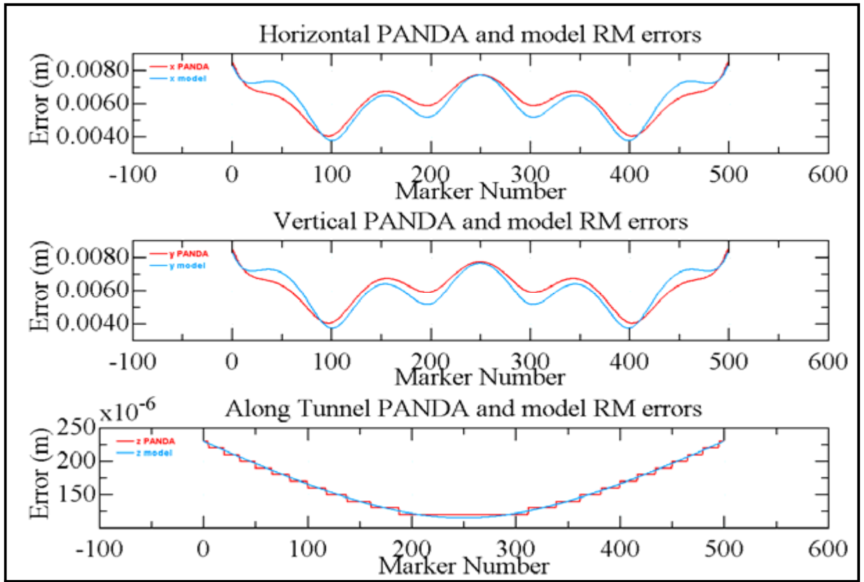
- Use Model to generate laser tracker measured network without PRM's

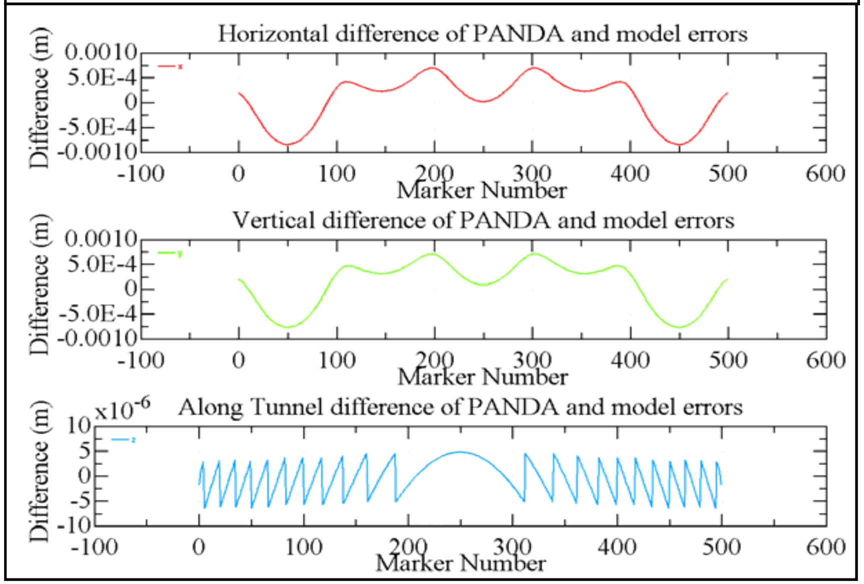
- Model used to produce network with the following parameters
  - No markers = 500
  - Space between markers = 25m
  - σx = 7.2192622E-5
  - σy = 7.1554098E-5
  - σz = 3.0863441E-5



Error Curve Comparison

- Use Model to generate laser tracker measured network with PRM's
- Model used to produce network using the following parameters
  - No markers = 500
  - Space between markers = 25m
  - No PRM's = 6
  - Space between PRM's = 2500m
  - σx = 8.0791025E-05
  - σy = 7.9445123E-05
  - σz = 3.0896634E-05
  - σGPS = 9.3551598E-03





Simulation of DMS using Merlin

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

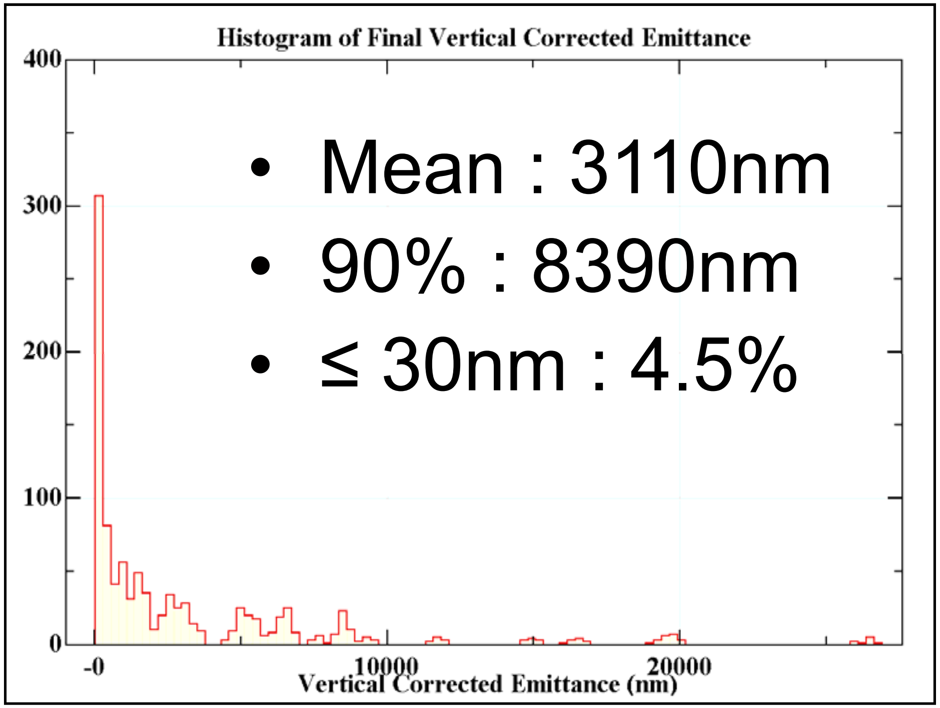
- The Merlin based ILCDFS package
  - Is performing the tracking through the curved main linac (positron side)
  - It has implementation of the Beam Based Alignment method based on Dispersion Matched Steering

- 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%

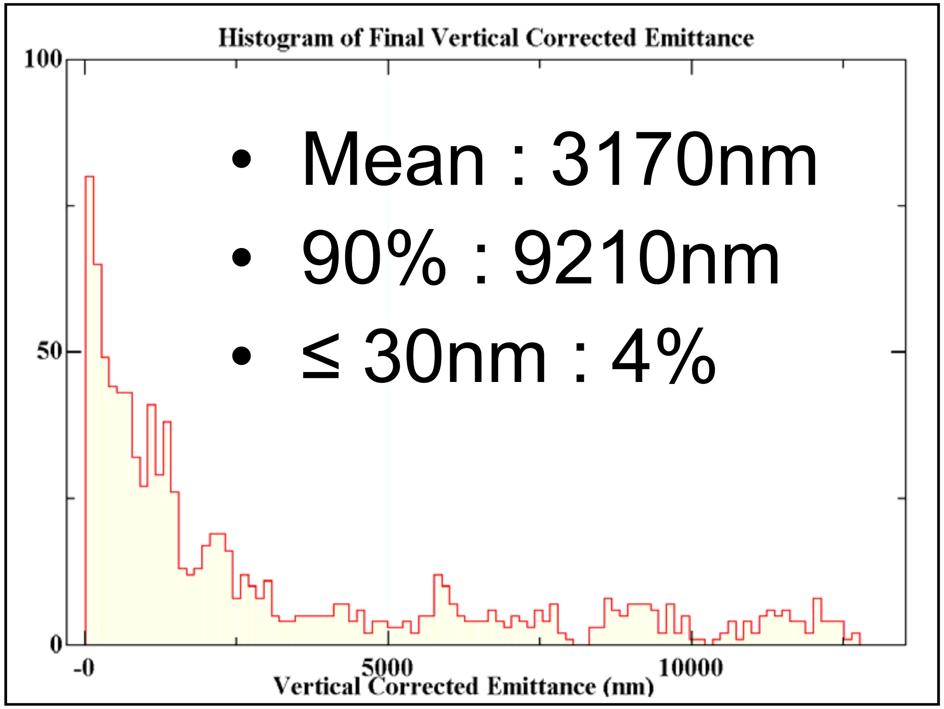
DMS Simulations for Laser trackers

- 100 networks generated without PRMs using PANDA and the model
- 10 DMS simulations performed on each network using Merlin
- Note: PANDA results are revised compared to LCWS 2008

Model



PANDA



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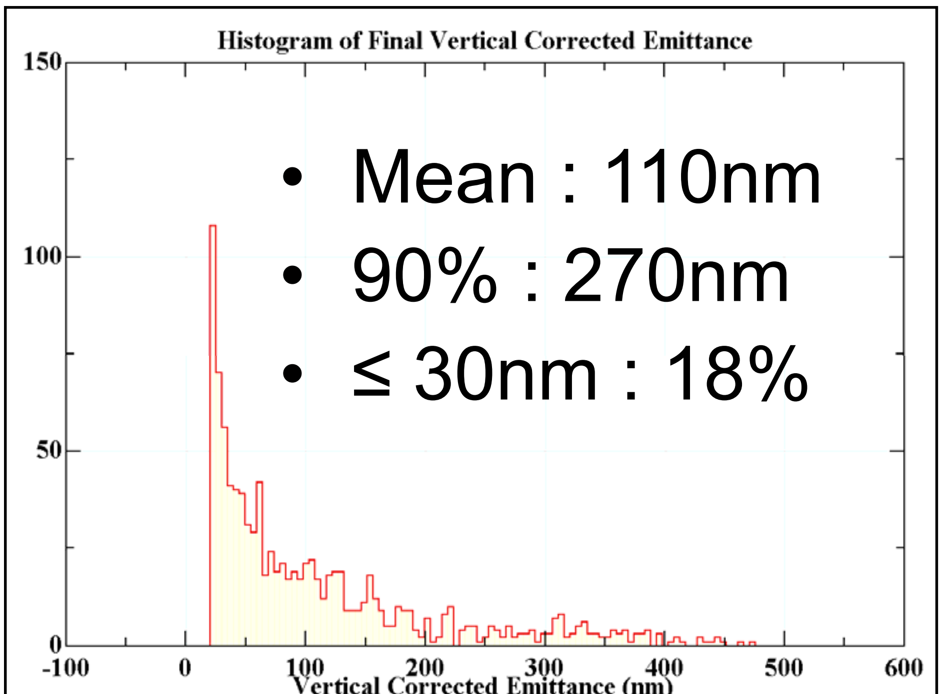

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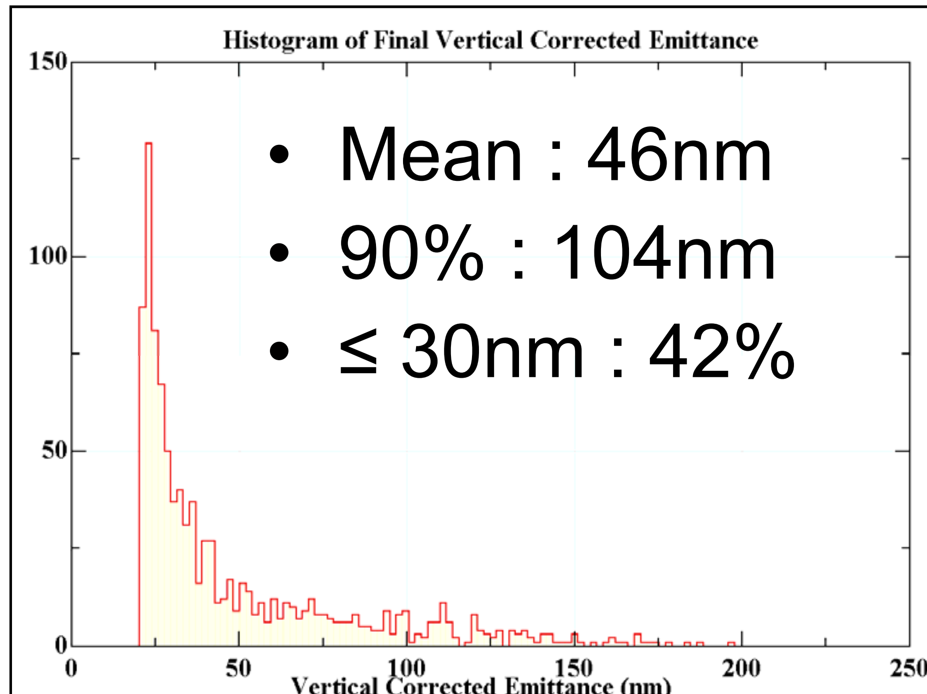

Conclusion

- Model works without Primary Reference Markers
- Implementation of Primary Reference Markers needs improvement
- Laser tracker network not suitable for the ILC as only 42% of machines below 30 nm

Future Work

- Fix GPS problem in model
- Determine LiCAS Model Parameters
- Introduce systematics
- Verify DMS results using different code