A simple model of the ILC alignment process for use in LET simulations

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Linear Collider Alignment & Survey

Overview

- Purpose of this talk
- Real survey & alignment processes
- The simplified model
- What to do with this in the future
- Appendix: Terminology

Note: most of what I say here is in essence contained in the paper called:
“Alignment model of ILC LET components – for beam dynamics simulations”
by Kyoshi Kubo, Daniel Schulte, Armin Reichold, et. al.
please read it!
It should become the agreed method for describing alignment in the ILC

Purpose

- Solve two long standing problems:
  - LET simulation studies have to date used models of alignment that were not fully comparable to any potential survey and alignment process that may once be used in the ILC

  ➔ we may have missed some problems that alignments may cause for LET

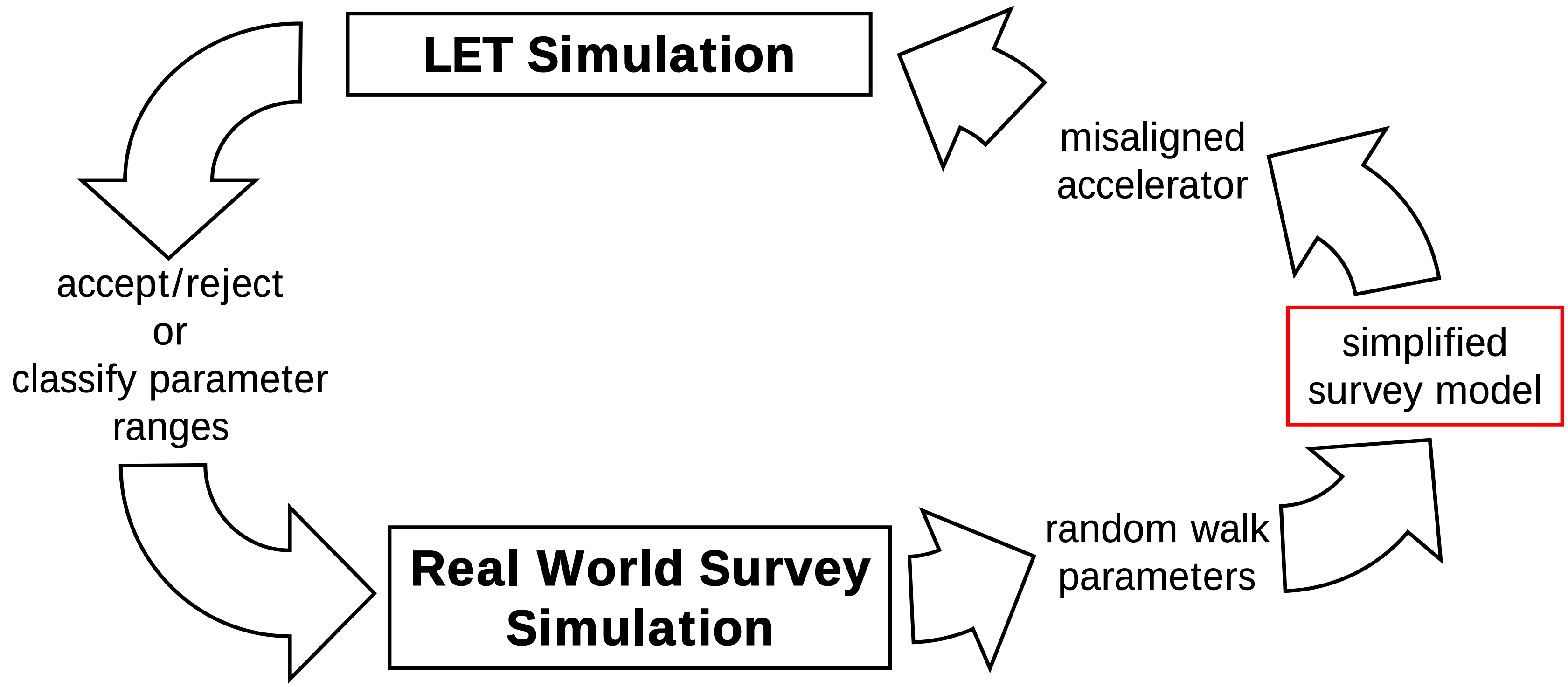
  - The parameters describing these models could not be translated into requirements for survey processes

  ➔ we have not determined which survey and alignment processes do or don't satisfy the ILC-LET requirements

We don't have a real world alignment model for ILC!

Purpose

- Bootstrap a real optimisation loop between LET simulations and the development of new survey and alignment techniques



Real Survey & Alignment Processes

- Survey and alignment for the ILC will consist of many techniques using many different measurements
- We don't know the entire chain yet
  - we know candidates for the linear tunnel reference survey (i.e. LiCAS)
  - we know candidates for the site wide reference network O(km) ➔ differential GPS
  - The manpower to develop these techniques is very small because the pressure on this is very low (do you understand why?)

Real Survey & Alignment Processes

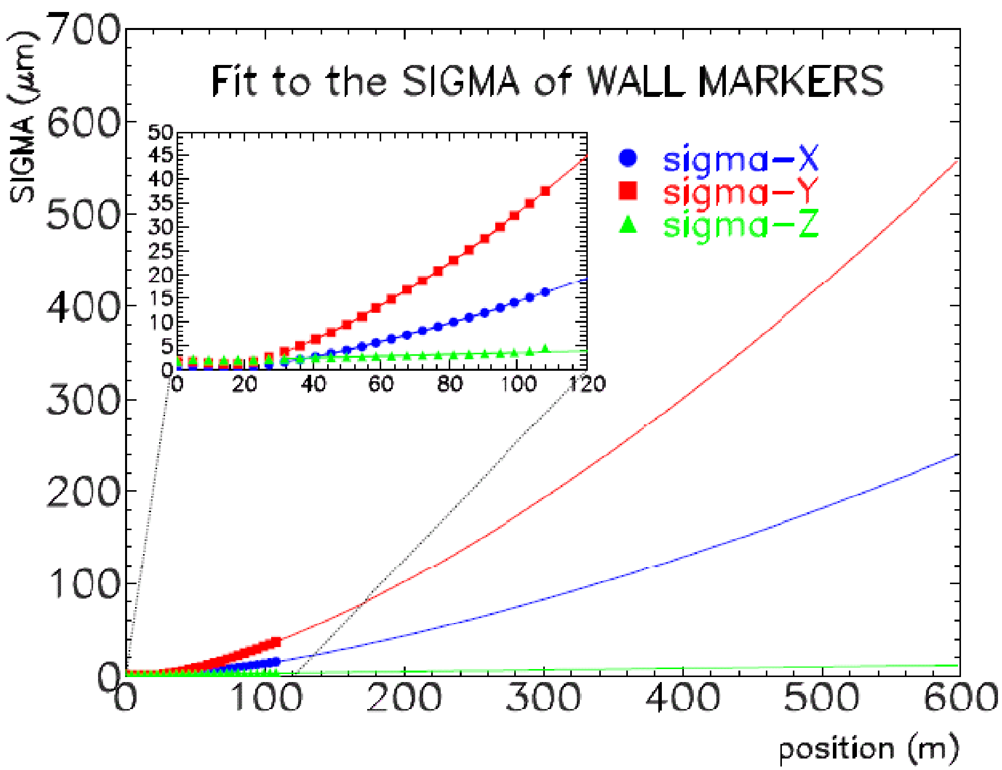
- Q: if we don't know what the process will be how can we make a simplified model of it?
- A: The statistical and systematic properties of many possible survey techniques in long linear tunnels can be modelled by special forms of random walk.
  - Works for classical optical survey, LiCAS style survey, stretched wires
  - Exceptions: HLS or single straightness monitor (x-ray) along the entire tunnel
  - surveyors still have to fit such random walk models to the statistical and systematic errors of their favourite survey technique.

Extracting a random walk model

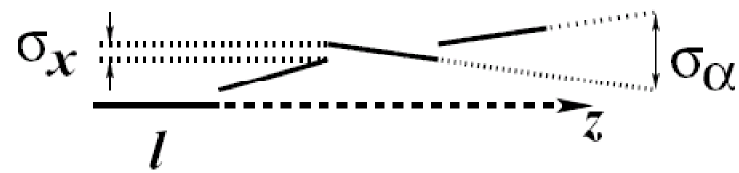
- From simulations of the full survey process one can predict how the errors will grow with length along the tunnel
- A random walk model also makes prediction how these errors should grow
- One can fit the parameters of a random walk model so that it reproduces the errors predicted by the full simulations
- Often the full simulations only cover a short length of tunnel as they are “expensive”
- The fitted random walk model can also be used to extrapolate error predictions to long tunnel lenghts
- See next slide for an example

The Over Simplified model

- Only Statistical errors via a 3D random walk with angular correlations between steps



- extrapolation using random walk model:



- off-sets and angles are relative to the previous "ruler"
- asymptotic behaviour: $\sigma_{xy,n} \sim n^{\frac{3}{2}}, \quad \sigma_{z,n} \sim n$

$$\sigma_{xy,n} = \sqrt{l^2 \sigma_\alpha^2 \frac{n(n+1)(2n+1)}{6} + \sigma_{xy}^2 \frac{n(n+1)}{2}}, \quad \sigma_{z,n} = \sqrt{\sigma_z^2 \frac{n(n+1)}{2}}$$

n – wall marker number, l – effective length of the ruler (here: distance between cars),
errors: σ_α – angular $(\sim 0.1\,\mu rad)$, σ_{xy} – transverse $(\sim 0.5\,\mu m)$, σ_z – longitudinal $(\sim 0.1\,\mu m)$

The Simplified model

- Must add systematic errors to the model as they start dominating over long distances

Model of the step:

$$\theta_{j,n+1} = \theta_{j,n} + G(a_\theta, t_\theta) + \Delta\theta_{systematic}$$

$$y_{0,j,n+1} = y_{0,j,n} + G(a_y, t_y) + l_{step}\theta_{j,n+1} + \Delta y_{systematic}$$

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

The Simplified Model

- Resulting statistical and systematic errors

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

$$\sigma_{z,n,stat.} = \sqrt{a_z^2 \frac{n(n+1)}{2}}$$

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

$$\sigma_{z,n,syst.} = n\Delta z_{systematic}$$

The Simplified Model

- Example parameters from LiCAS simulations:
- Statistical errors
  - $a_{vertical} < 5\,\mu$m; $a_{\theta\text{-}vertical} < 55.4$ nrad
  - $a_{horizontal} < 5\,\mu$m; $a_{\theta\text{-}horizontal} < 25.8$ nrad
  - Note that the transverse displacement errors are compatible with zero withing their errors and negligible compared to the
- Systematic errors with 1 (5) μm calibration
  - $\Delta\theta_{vertical}$ = 58 (260) nrad $\Delta\theta_{horizontal}$ = 25 (115) nrad
  - $\Delta y_{vertical}$ = 1.2 (5.3) mm, $\Delta y_{horizontal}$ = 2.7 (12.1) mm
- l_{step} = 25m
- Note: the mean of all systematic parameters when averaged over many random walks is zero

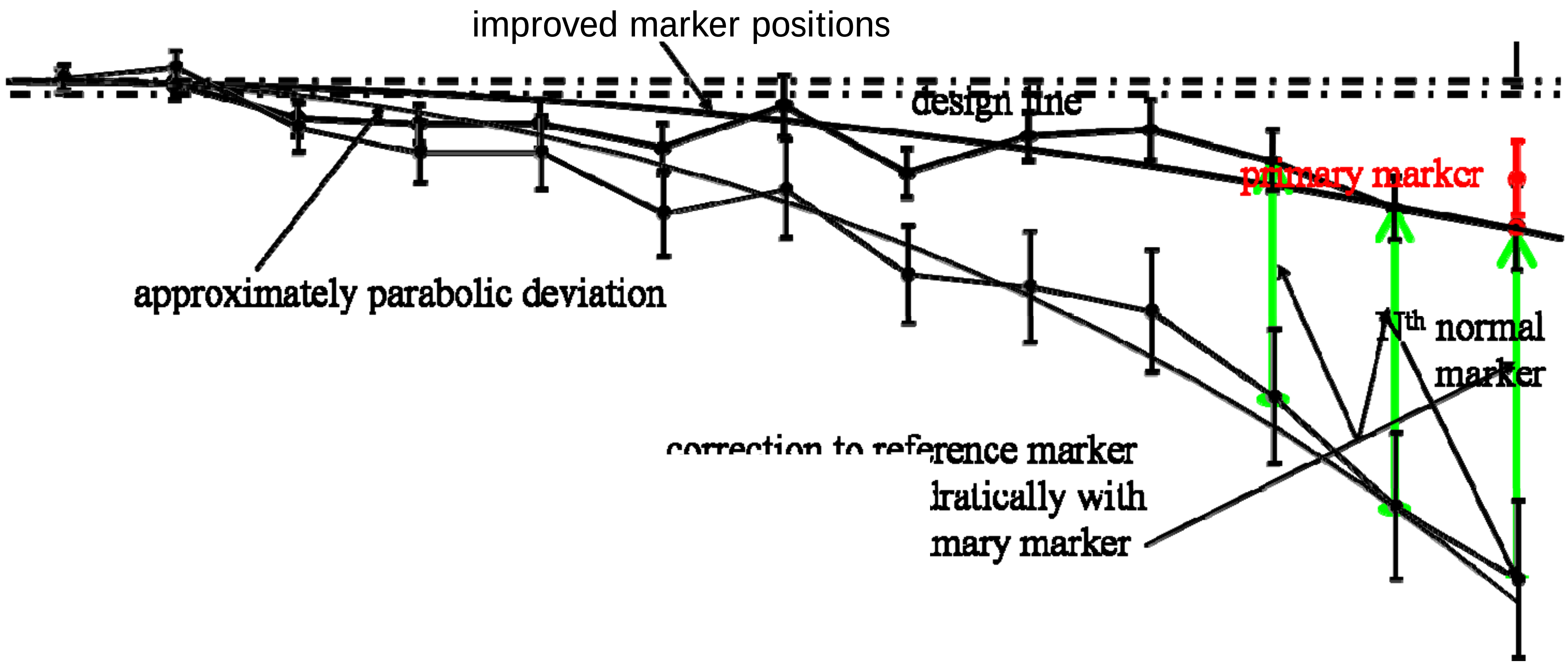
The Simplified Model

- The primary reference markers aka "A slight complication"
- Systematic survey errors grow quadraticaly with distance
- GPS co-ordinate errors grow slower with distance (although they are worse to start with)

➔at some distance external GPS co-ordinates are "better" than "in-tunnel" survey and can be used to improve them

- Every 2.5 km GPS information is transferred into the tunnel onto a "primary reference marker"
- We need to describe in our simplified model how "in-tunnel" survey co-ordinates are to be adjusted to become compatible with the primary markers

- correct the in-tunnel network by an amount that reduces quadratically with the distance from the primary reference marker.



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

The Simplified Model

- “The paper” describes in detail how to compute accelerator component positions and orientations
- This is done partially
  - wrt. to the adjusted random walk line
  - and wrt. to local gravity
- In this process additional statistical errors (“stake-out-instrument” errors) are incurred
- Co-ordinates computed wrt. to the random walk line often use a “fit to the local line”
- effectively using multiple points from the random walk line to reduce statistical stake-out errors
- this is very good practise in reality

What to do next

- Implement ONE simple code that can generate aligned collider component co-ordinates in the way described by the paper (this may be pseudo code?)
- check the statistical properties of the co-ordinates against expectations from experts. I.e. Fourier transforms, total systematic turning angle/meter, RMS scatter on local segments, etc.
- distribute the code to all LET simulators
- check if the default (LiCAS) parameters for the alignment are satisfactory?
- check anybody else's parameters when the become available
- reduce quality of alignment until LET breaks
- tell survey community about the minimum parameters LET needs

Closing remarks

- You will be surprised about the colour on a surveyors face when you ask him/her for survey accuracies in units of nrad/m
- Remember that the random walk is only a model of the real survey process
- The real survey process culminates in a big simultaneous fit of a very over determined least squares problem
- Surveyors do not misalign things, they **align** them!

Thanks for your attention

Terminology

- Fiducialisation: the process of measuring the relative positions and orientations of the "active centre vectors" of accelerator components wrt externally surveyable "fiducial markers". E.g. vector of magnetic axis in a quadrupole.
- Reference Network: collection of surveyable reference markers (e.g. sphere mounted retro reflectors) placed throughout the tunnel. The R.N. materialises (part of) the co-ordinate system of the survey. Other parts may be expressed by gravity vectors.
- Reference Survey: the process of determining (measure and compute using assumptions) the location of all reference markers in the reference network and expressing them in some co-ordinate system.
- Survey: the process of determining (measure location of fiducial markers and computation) the geometric location of accelerator active centre vectors inside the tunnel with respect to the reference networks co-ordinate system.
- Survey errors: statistical uncertainty of the co-ordinates produced by a survey
- Alignment: the process of physically bringing elements of the accelerator into a "desired" position in the tunnel.
- Misalignments: deviation of active centre vector locations and orientations wrt. their nominal design values.
- Primary Reference Markers: every 2.5 km above the ILC tunnel GPS co-ordinates are measured and transferred into the tunnel onto a primary reference marker (see later in this talk)