Using Laserwires to Measure Emittance at the ILC

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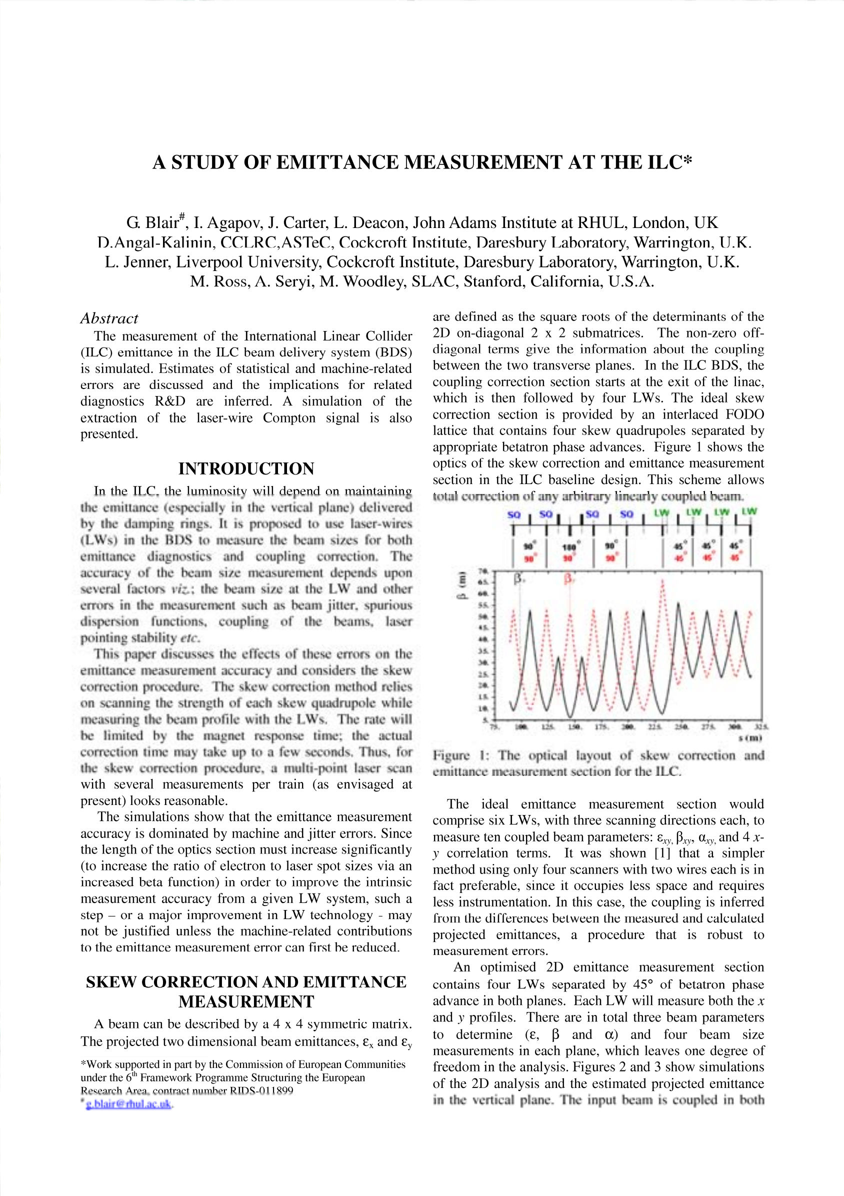
ASTeC

Outline…

- Use laserwires in Beam Delivery System, specifically to measure emittance for skew correction
- ILC Beam Delivery System, RDR Layout, 2006b Release (Mark Woodley, SLAC)
- Linac simulations for realistic coupling (Daniel Schulte)
- Errors on Laserwire measurements
- X,Y, Roll error / correction



A STUDY OF EMITTANCE MEASUREMENT AT THE ILC*

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Abstract

The measurement of the International Linear Collider (ILC) emittance in the ILC beam delivery system (BDS) is simulated. Estimates of statistical and machine-related errors are discussed and the implications for related diagnostics R&D are inferred. A simulation of the extraction of the laser-wire Compton signal is also presented.

INTRODUCTION

In the ILC, the luminosity will depend on maintaining the emittance (especially in the vertical plane) delivered by the damping rings. It is proposed to use laser-wires (LWs) in the BDS to measure the beam sizes for both emittance diagnostics and coupling correction. The accuracy of the beam size measurement depends upon several factors *viz.*; the beam size at the LW and other errors in the measurement such as beam jitter, spurious dispersion functions, coupling of the beams, laser pointing stability *etc.*

This paper discusses the effects of these errors on the emittance measurement accuracy and considers the skew correction procedure. The skew correction method relies on scanning the strength of each skew quadrupole while measuring the beam profile with the LWs. The rate will be limited by the magnet response time; the actual correction time may take up to a few seconds. Thus, for the skew correction procedure, a multi-point laser scan with several measurements per train (as envisaged at present) looks reasonable.

The simulations show that the emittance measurement accuracy is dominated by machine and jitter errors. Since the length of the optics section must increase significantly (to increase the ratio of electron to laser spot sizes via an increased beta function) in order to improve the intrinsic measurement accuracy from a given LW system, such a step – or a major improvement in LW technology - may not be justified unless the machine-related contributions to the emittance measurement error can first be reduced.

SKEW CORRECTION AND EMITTANCE MEASUREMENT

A beam can be described by a 4 x 4 symmetric matrix. The projected two dimensional beam emittances, ε_x and ε_y are defined as the square roots of the determinants of the 2D on-diagonal 2 x 2 submatrices. The non-zero off-diagonal terms give the information about the coupling between the two transverse planes. In the ILC BDS, the coupling correction section starts at the exit of the linac, which is then followed by four LWs. The ideal skew correction section is provided by an interlaced FODO lattice that contains four skew quadrupoles separated by appropriate betatron phase advances. Figure 1 shows the optics of the skew correction and emittance measurement section in the ILC baseline design. This scheme allows total correction of any arbitrary linearly coupled beam.

Figure 1: The optical layout of skew correction and emittance measurement section for the ILC.

The ideal emittance measurement section would comprise six LWs, with three scanning directions each, to measure ten coupled beam parameters: ε_{xy}, β_{xy}, α_{xy}, and 4 *x*-*y* correlation terms. It was shown [1] that a simpler method using only four scanners with two wires each is in fact preferable, since it occupies less space and requires less instrumentation. In this case, the coupling is inferred from the differences between the measured and calculated projected emittances, a procedure that is robust to measurement errors.

An optimised 2D emittance measurement section contains four LWs separated by 45° of betatron phase advance in both planes. Each LW will measure both the *x* and *y* profiles. There are in total three beam parameters to determine (ε, β and α) and four beam size measurements in each plane, which leaves one degree of freedom in the analysis. Figures 2 and 3 show simulations of the 2D analysis and the estimated projected emittance in the vertical plane. The input beam is coupled in both

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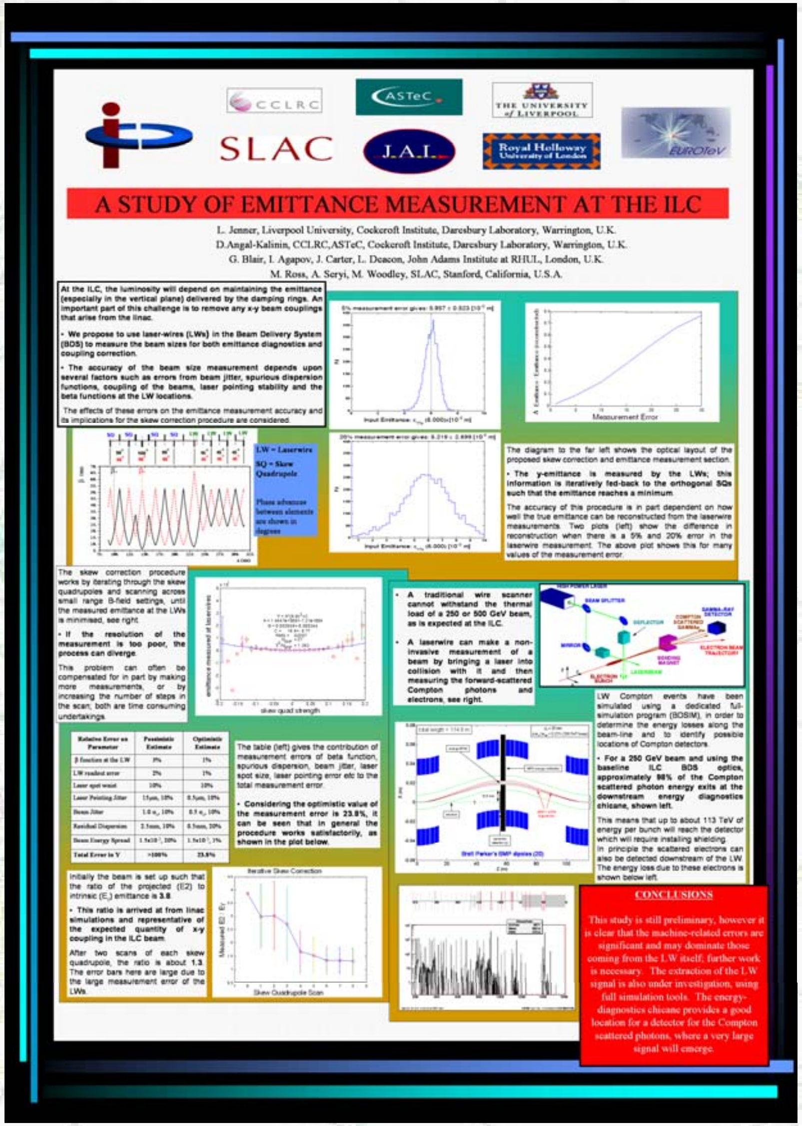

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At the ILC, the luminosity will depend on maintaining the emittance (especially in the vertical plane) delivered by the damping rings. An important part of this challenge is to remove any x-y beam couplings that arise from the linac.

- **We propose to use laser-wires (LWs) in the Beam Delivery System (BDS) to measure the beam sizes for both emittance diagnostics and coupling correction.**
- **The accuracy of the beam size measurement depends upon several factors such as errors from beam jitter, spurious dispersion functions, coupling of the beams, laser pointing stability and the beta functions at the LW locations.**

The effects of these errors on the emittance measurement accuracy and its implications for the skew correction procedure are considered.

LW = Laserwire

SQ = Skew Quadrupole

Phase advances between elements are shown in degrees

The diagram to the far left shows the optical layout of the proposed skew correction and emittance measurement section.

- **The y-emittance is measured by the LWs; this information is iteratively fed-back to the orthogonal SQs such that the emittance reaches a minimum.**

The accuracy of this procedure is in part dependent on how well the true emittance can be reconstructed from the laserwire measurements. Two plots (left) show the difference in reconstruction when there is a 5% and 20% error in the laserwire measurement. The above plot shows this for many values of the measurement error.

The skew correction procedure works by iterating through the skew quadrupoles and scanning across small range B-field settings, until the measured emittance at the LWs is minimised, see right.

- **If the resolution of the measurement is too poor, the process can diverge.**

This problem can often be compensated for in part by making more measurements, or by increasing the number of steps in the scan; both are time consuming undertakings.

- **A traditional wire scanner cannot withstand the thermal load of a 250 or 500 GeV beam, as is expected at the ILC.**
- **A laserwire can make a non-invasive measurement of a beam by bringing a laser into collision with it and then measuring the forward-scattered Compton photons and electrons, see right.**

Relative Error on Parameter	Pessimistic Estimate	Optimistic Estimate
β function at the LW	3%	1%
LW readout error	2%	1%
Laser spot waist	10%	10%
Laser Pointing Jitter	15μm, 10%	0.5μm, 10%
Beam Jitter	1.0 σ_y, 10%	0.5 σ_y, 10%
Residual Dispersion	2.5mm, 10%	0.5mm, 20%
Beam Energy Spread	1.5x10⁻³, 20%	1.5x10⁻³, 1%
Total Error in Y	>100%	23.8%

The table (left) gives the contribution of measurement errors of beta function, spurious dispersion, beam jitter, laser spot size, laser pointing error etc to the total measurement error.

- **Considering the optimistic value of the measurement error is 23.8%, it can be seen that in general the procedure works satisfactorily, as shown in the plot below.**

Initially the beam is set up such that the ratio of the projected (E2) to intrinsic (E_i) emittance is 3.8.

- **This ratio is arrived at from linac simulations and representative of the expected quantity of x-y coupling in the ILC beam.**

After two scans of each skew quadrupole, the ratio is about 1.3. The error bars here are large due to the large measurement error of the LWs.

LW Compton events have been simulated using a dedicated full-simulation program (BDSIM), in order to determine the energy losses along the beam-line and to identify possible locations of Compton detectors.

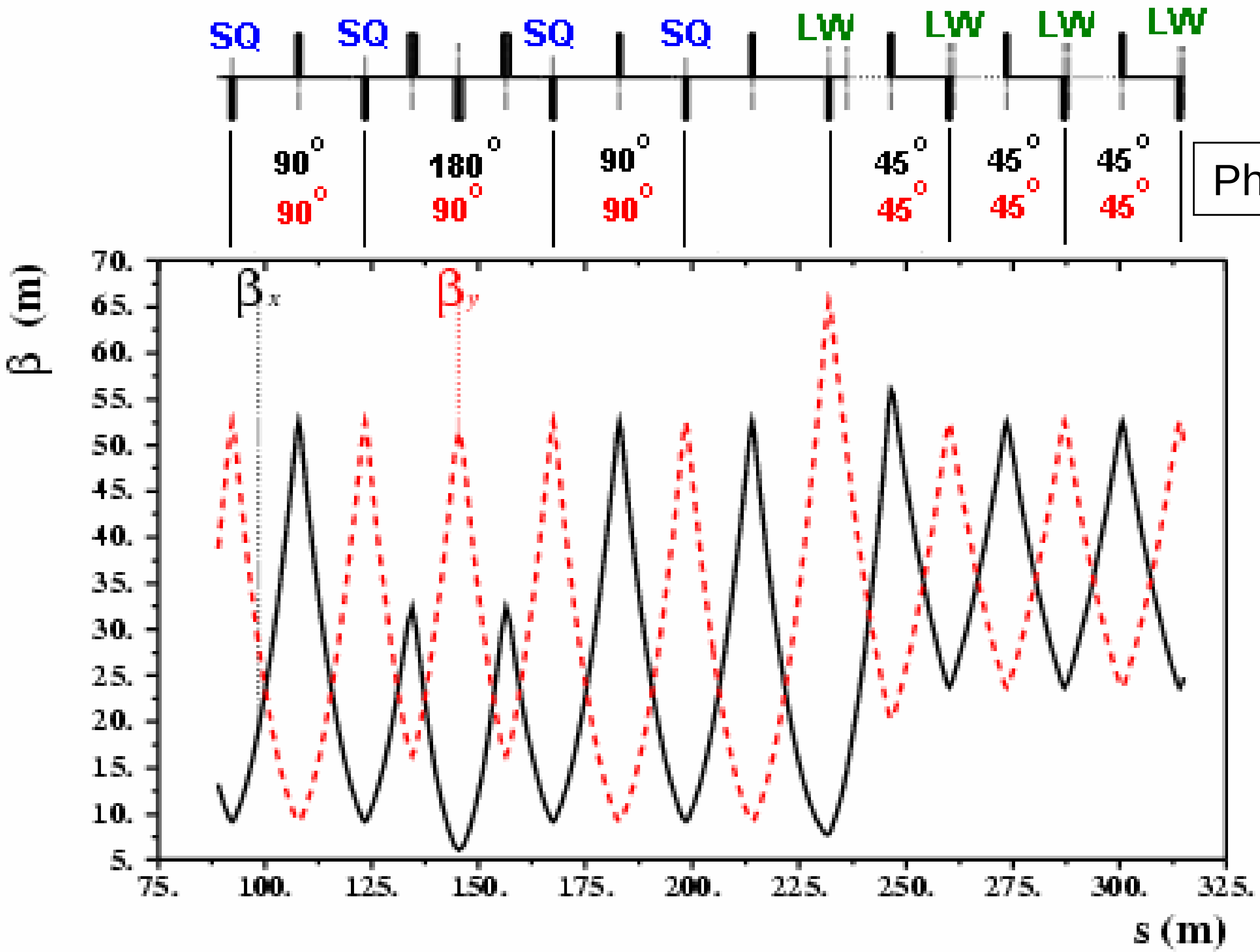
- **For a 250 GeV beam and using the baseline ILC BDS optics, approximately 98% of the Compton scattered photon energy exits at the downstream energy diagnostics chicane, shown left.**

This means that up to about 113 TeV of energy per bunch will reach the detector which will require installing shielding.
In principle the scattered electrons can also be detected downstream of the LW. The energy loss due to these electrons is shown below left.

CONCLUSIONS

This study is still preliminary, however it is clear that the machine-related errors are significant and may dominate those coming from the LW itself; further work is necessary. The extraction of the LW signal is also under investigation, using full simulation tools. The energy-diagnostics chicane provides a good location for a detector for the Compton scattered photons, where a very large signal will emerge.

4 Orthogonal Skew Quads



Phase Advance

G. Blair, RHUL

Relative Error on Parameter	**Pessimistic Estimate**	**Optimistic Estimate**
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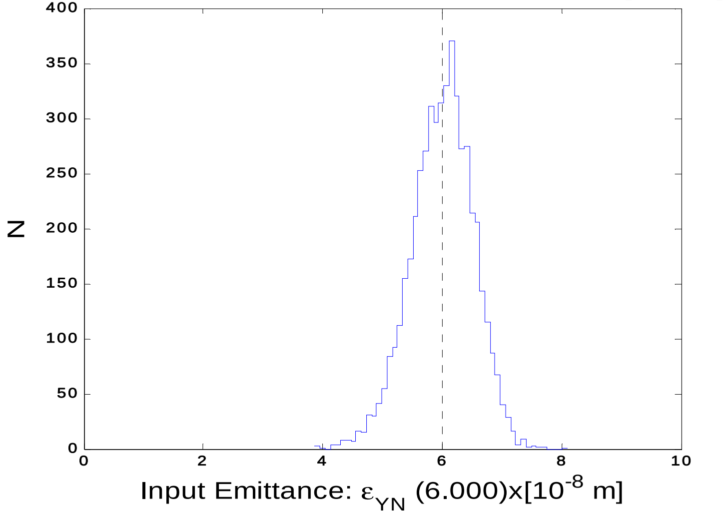
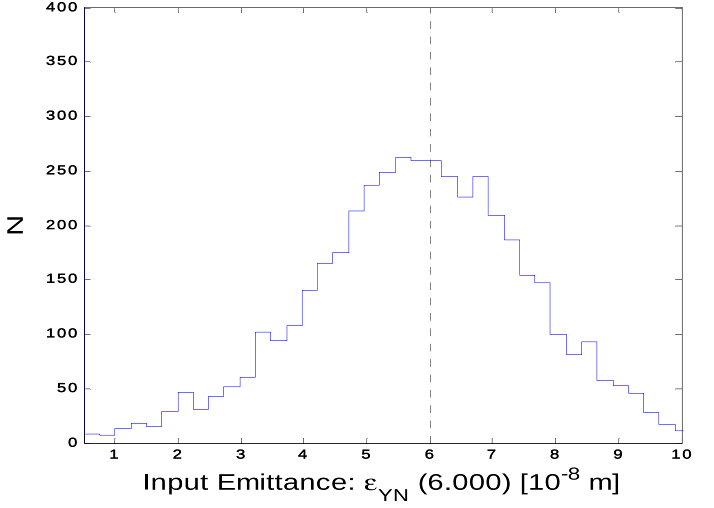
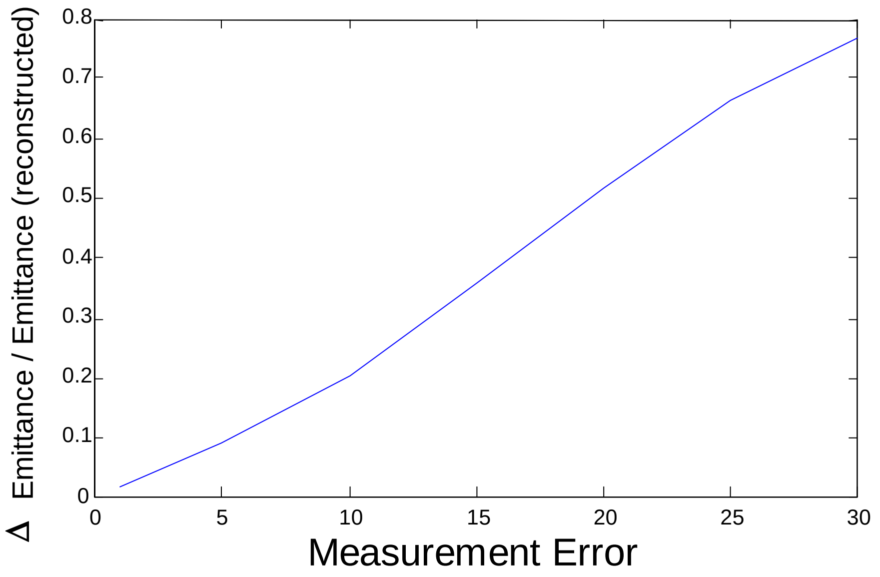
LW readout error	2%	1%
Laser spot waist	10%	10%
Laser Pointing Jitter	15μm, 10%	0.5μm, 10%
Beam Jitter	1.0 σ_e, 10%	0.5 σ_e, 10%
Residual Dispersion	2.5mm, 10%	0.5mm, 20%
Beam Energy Spread	1.5×10^{-3}, 20%	1.5×10^{-3}, 1%
Total Error	**>100%**	**23.8%**

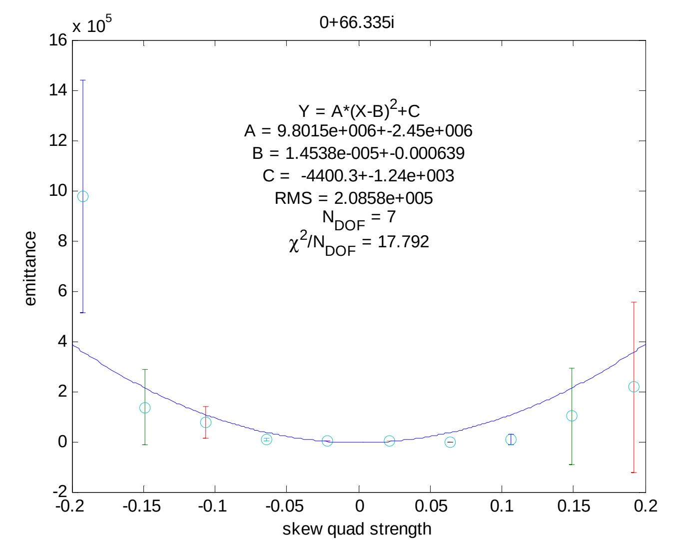
The Optimistic case requires the limits on these ‘planned’ errors to really be pushed…

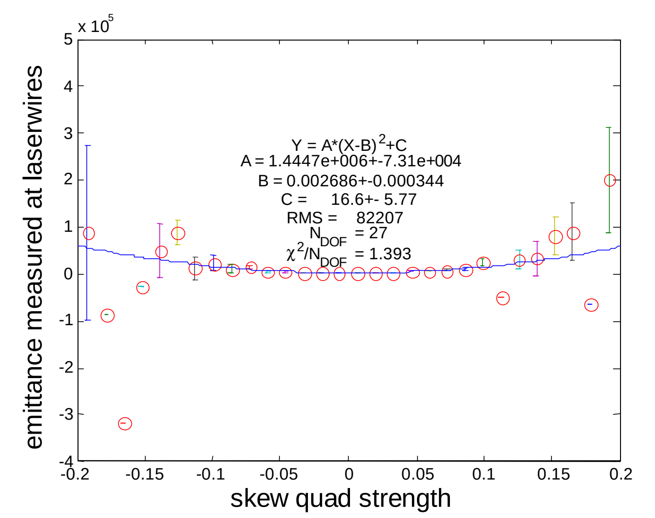
Machine Alignment Errors still to come!

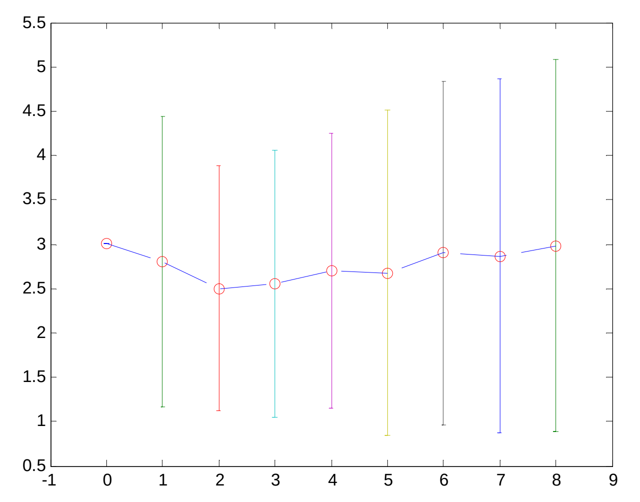

5% measurement error gives: 5.957 ± 0.523 [10^{-8} m]

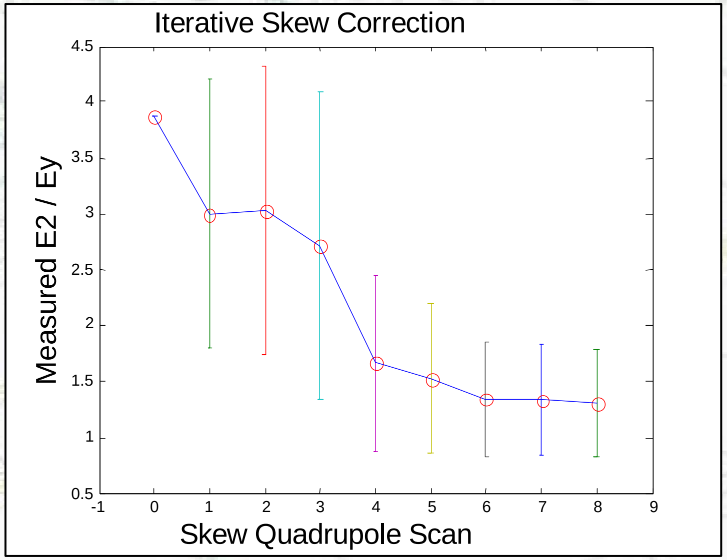

20% measurement error gives: 5.219 ± 2.699 [10^{-8} m]

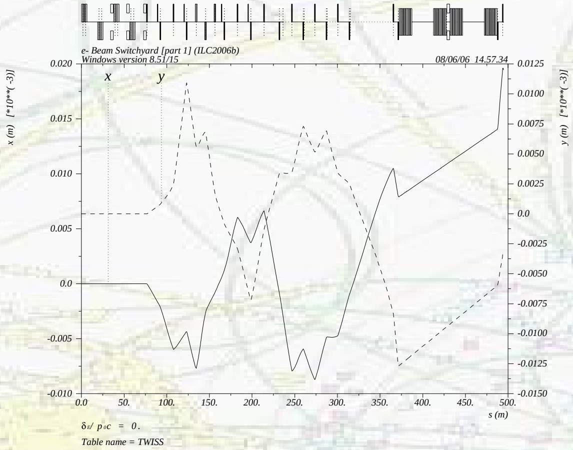


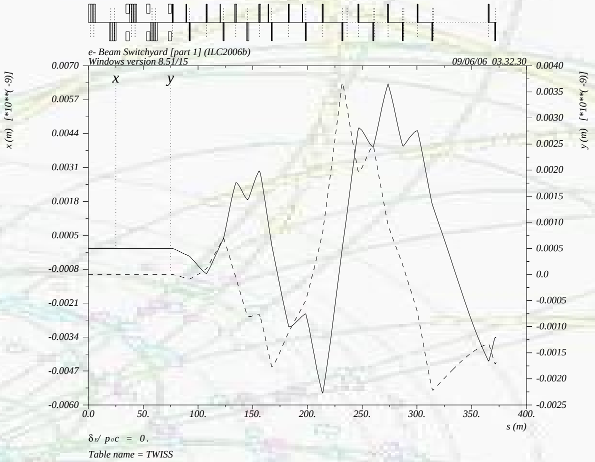







Iterative Skew Correction





- X, Y, roll errors in quads
- Position errors corrected to ~1micron with BPMs
- Additional dispersion caused adds 1% error up to 20 microns
- Roll of up to 3 degrees adds 1% error

Conclusions…

- paper and poster presented
- skew correction and emittance diagnostic section design in place
- laserwire measurement errors are large
- emittance: more measurement points but more time
- Increasing beta-function at laserwires might be easiest way to improve the situation
- Reasonable x, y, roll errors don’t seem to effect emittance measurement too much