Reconstruction of IP Beam Parameters at the ILC from Beamstrahlung

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Aims

- Try to unfold information about the parameters of the colliding bunches at the ILC from the generated 'beamstrahlung' radiation (electron-positron pairs and photons).
- Taken over analysis of A. Stahl -> transfer analysis from f77/HBOOK to Matlab. Completed.
- Compute Taylor matrices to go from beamstrahlung observables in detectors to a list of IP beam parameters (Using GUINEA-PIG to generate beamstrahlung from user-generated IP bunches, varying beam parameters to generate Taylor matrices). Completed for 500 GeV TDR Parameters and TESLA IR.
- Test usefulness of matrices to determine IP parameters and/or to generate luminosity tuning knobs by seeing how well analysis works in test simulations (i.e. generate colliding bunches with known deviations from ideal bunch parameters). Currently under study.
- Test with 'real' beams passed through ILC simulation, comparing actual vs. reconstructed IP parameters.

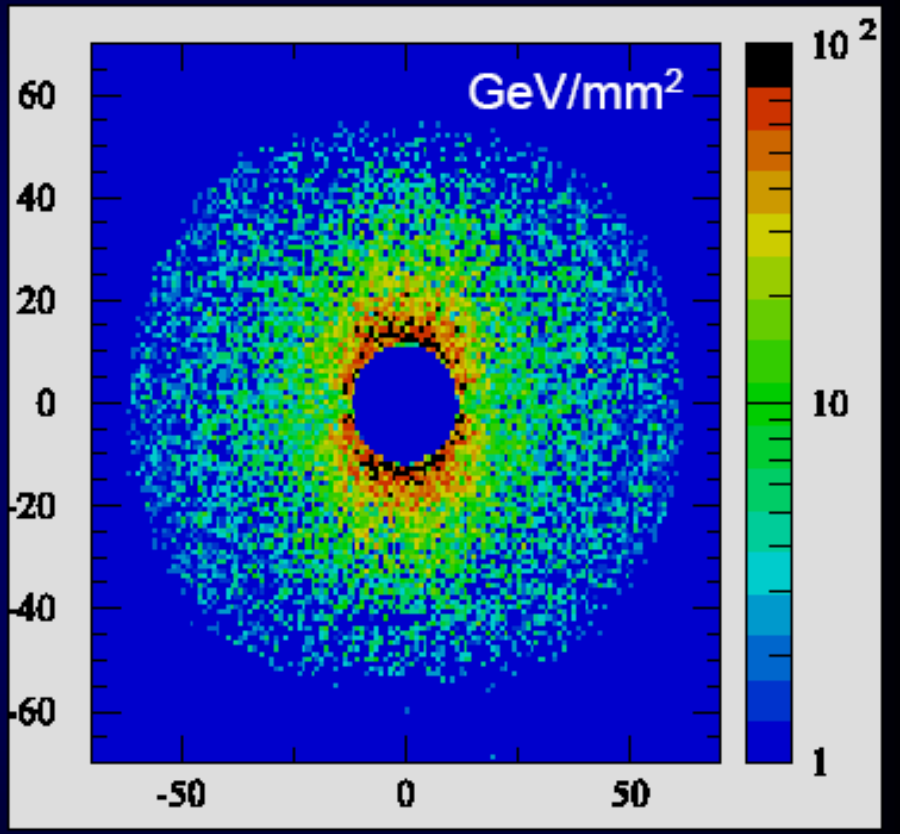
Beam Strahlung

Diagnostics of bunches at IP

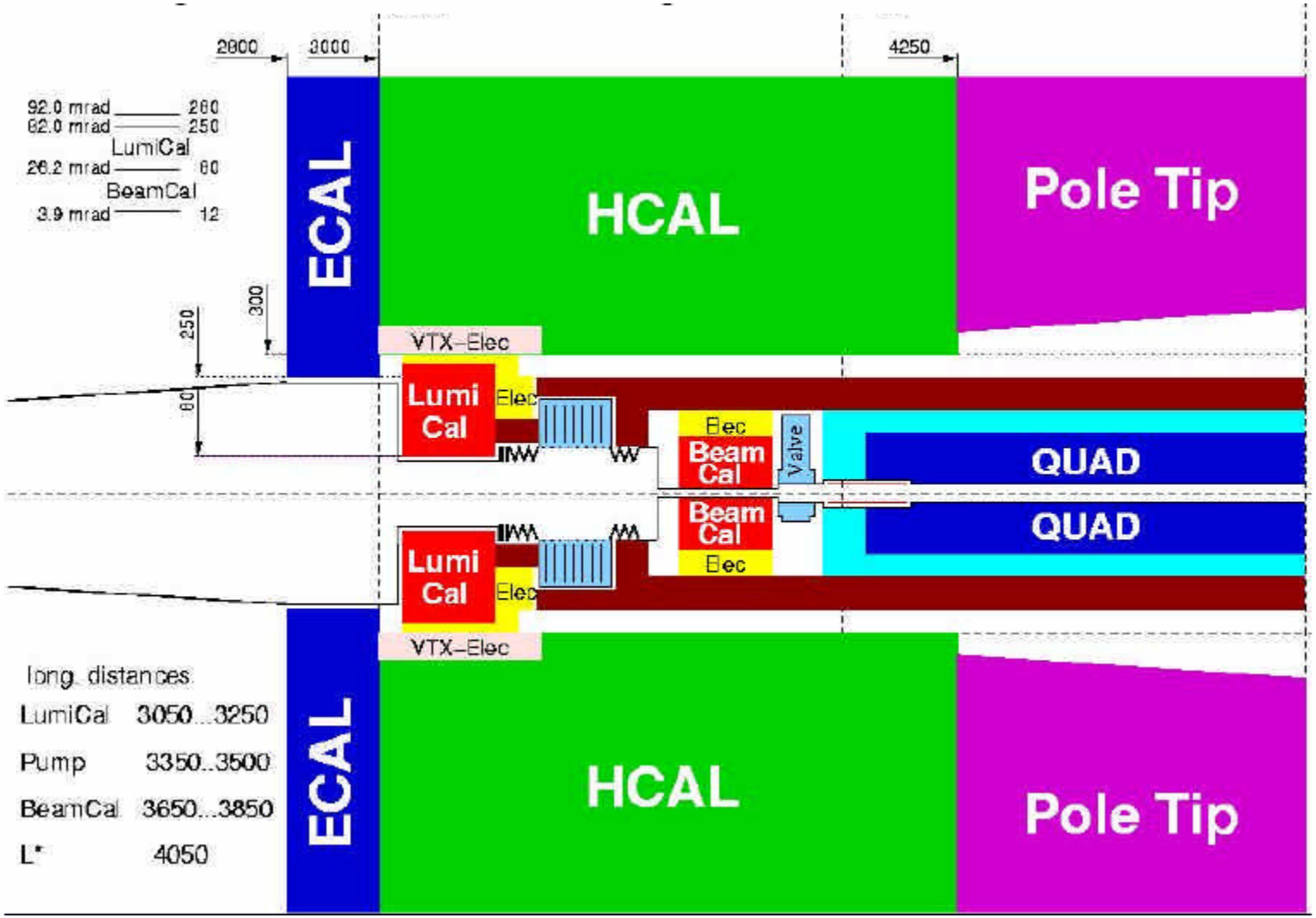
3 potential sources of information
- energy-distribution of pairs
- number-distribution of pairs
- distribution of photons

Over-simplified detector simulation
- detectors subdivided into cells
- sum energy impact on cells

main source of uncertainty
→ stat. fluctuations of beam str.



IR Layout


2800
3000
4250
92.0 mrad
82.0 mrad
LumiCal
26.2 mrad
BeamCal
3.9 mrad
260
250
60
12
ECAL
HCAL
Pole Tip
300
250
60
VTX–Elec
Lumi Cal
Elec
Beam Cal
Valve
QUAD
QUAD
Beam Cal
Lumi Cal
Elec
Elec
VTX–Elec
long. distances
LumiCal 3050...3250
Pump 3350..3500
BeamCal 3650...3850
L* 4050
ECAL
HCAL
Pole Tip

IP Beam Parameters Simulated

- Current list of IP beam parameters included in Taylor Matrix:

  1. Sigma x
  2. Sigma y
  3. Sigma z
  4. Sigma x'
  5. Sigma y'
  6. E
  7. E spread
  8. x Offset
  9. x' offset
  10. y offset
  11. y' offset
  12. x-waist shift
  13. y-waist shift
  14. Bunch rotation
  15. N particles/bunch
  16. Amount of y+y’ type-1 banana
  17. Amount of y+y’ type-2 banana
  18. Amount of y+y’ type-3 banana

- For each parameter (apart from offsets and waist-shifts), split into mean and difference (between e+ and e- bunches)- total of 36 parameters.

Generating Observables – e^-e^+ Pairs

- Beamcal design based on TESLA TDR design.
- Beamcal simulated as a number of similar sized crystals (completely space-filling) (dr:mean(width)~1.2) in 7 concentric rings (178 crystals).
- Transport pairs to beamcal through constant Bz=4T field (Upgrade to using solenoid field map later).
- From pairs files, generate total hits and Energy counts per crystal. Simple binning for now- upgrade to proper cal simulation including energy smearing etc when GEANT model available.
- Energy resolution assumed to be 10%.$\sqrt{E}$ over full angular coverage (approx. relates to TDR estimate).

Generating Observables - Photons

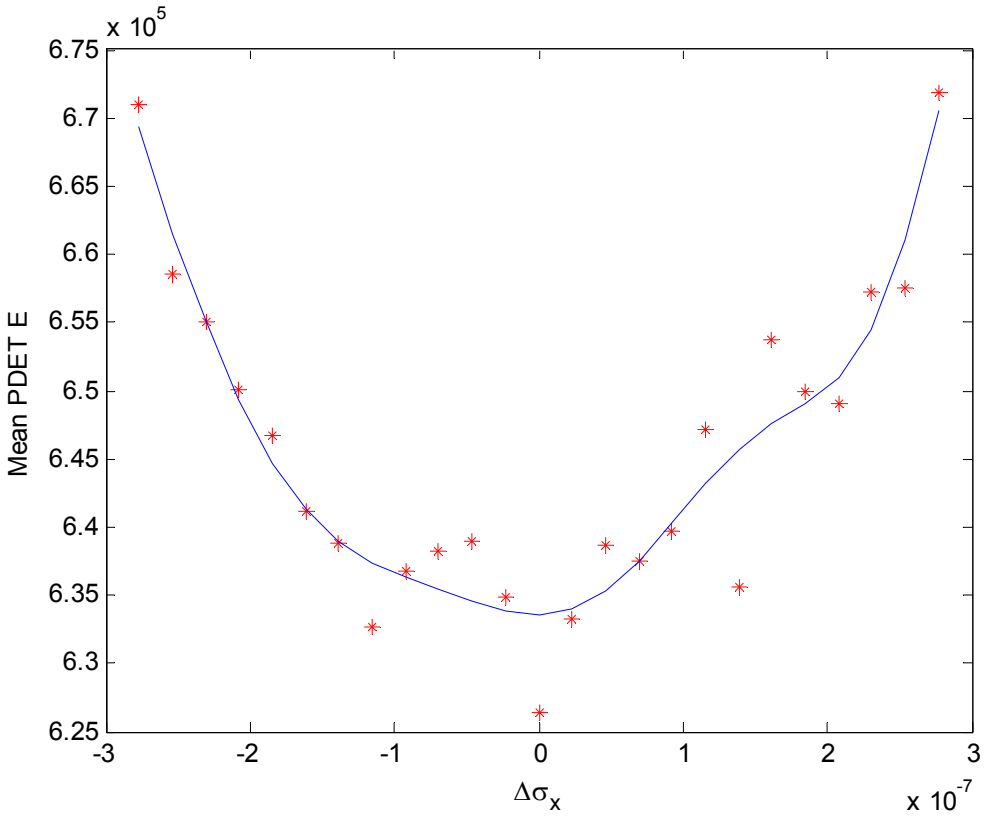
- No existing design for this detector, make something up for now: based on ideas laid out in a note by Tauchi/Delarue (KEK) (arXiv.physics/0408132):
  - Assume detector is an ionization chamber detector with thick copper end plate to convert photons to e^-e^+ pairs, contains segmented pad readout.
  - Assume 20×20 1cm^2 pads located 200m downstream from IP.
  - Assume perfect selection of photons at energies above pair production threshold (~30MeV).
  - Ignore background issues from final doublet synchrotron radiation for now.
  - Assume 10% accuracy in readout.

Observables List

- Pairs:
  - E_tot
  - r moment
  - 1/r moment
  - Thrust Direction
  - Thrust Value
  - Angular Spread
  - E_out/E_in
  - L-R Asymmetry
  - T-B Asymmetry
  - Diagonal Asymmetry
  - N/E_tot
  - Beam-Beam Kick
- Photons:
  - E_tot
  - r moment
  - 1/r moment
  - Thrust Direction
  - Thrust Value
  - Angular Spread
  - E_out/E_in
  - L-R Asymmetry
  - T-B Asymmetry
  - Diagonal Asymmetry

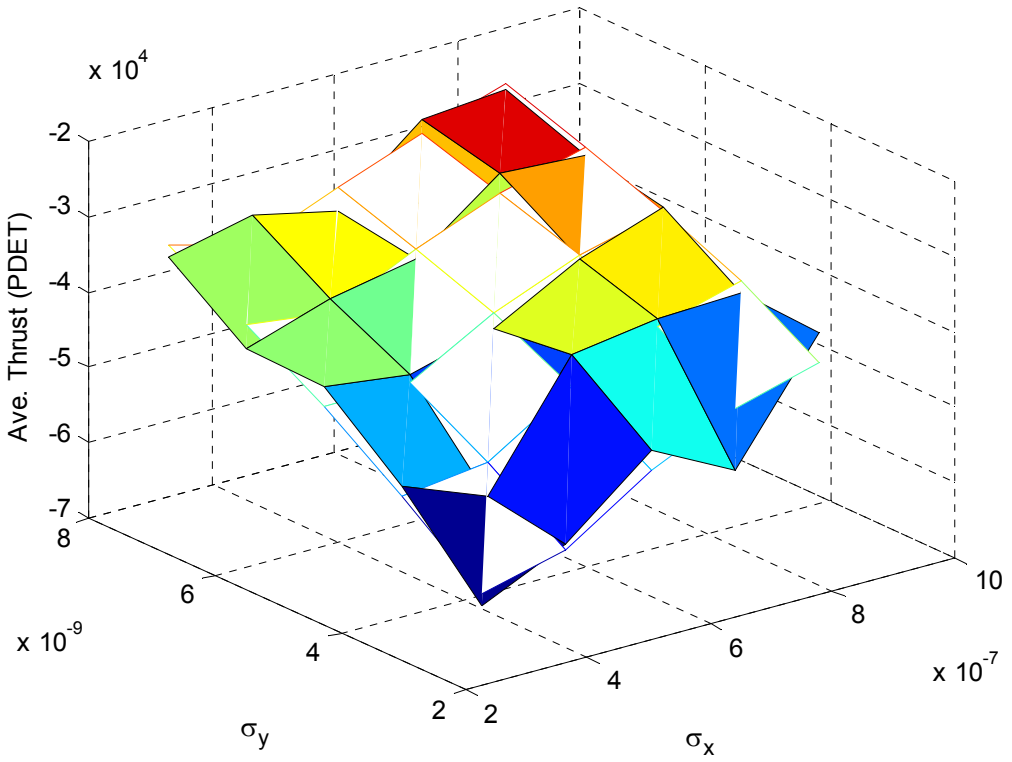
•For each observable, split into difference and mean between detectors on left and right side of IP. Total of 44 Observables.

Non-Linear Functions



- Most observables, like the example shown above are non-linear and/or zero at the design point.
- Thus, to get from the measured observables to the beam parameters requires a greater than first-order, multi-parameter, nonlinear fitting technique.

Second-Order Calculations



- Several observables have multi-parameter dependencies.
- Only up to second order considered due to cpu time constraints.

Beam Parameter Reconstruction Procedure – Taylor Matrices

$$x = [x_1, x_2, \ldots . x_n]'$$

$$x^* = x_{Design}$$

$$f^n(x) = \text{observable n for x vector}$$

$$f^n(x^*) = \text{observable n for x}^* \text{ design vector}$$

$$f^n(x) = f^n(x^*) + (x - x^*)' div.[f^n(x^*)] + \frac{1}{2}(x - x^*)' \tilde{A}(x - x^*) + \ldots$$

$$\tilde{A} = \begin{bmatrix} \frac{\partial^2 f}{\partial x_1^2} & \frac{\partial^2 f}{\partial x_1 \partial x_2} & . & \frac{\partial^2 f}{\partial x_1 \partial x_n} \\ \frac{\partial^2 f}{\partial x_2 \partial x_1} & . & . & . \\ . & . & . & . \\ \frac{\partial^2 f}{\partial x_n \partial x_1} & . & . & \frac{\partial^2 f}{\partial x_n^2} \end{bmatrix}$$

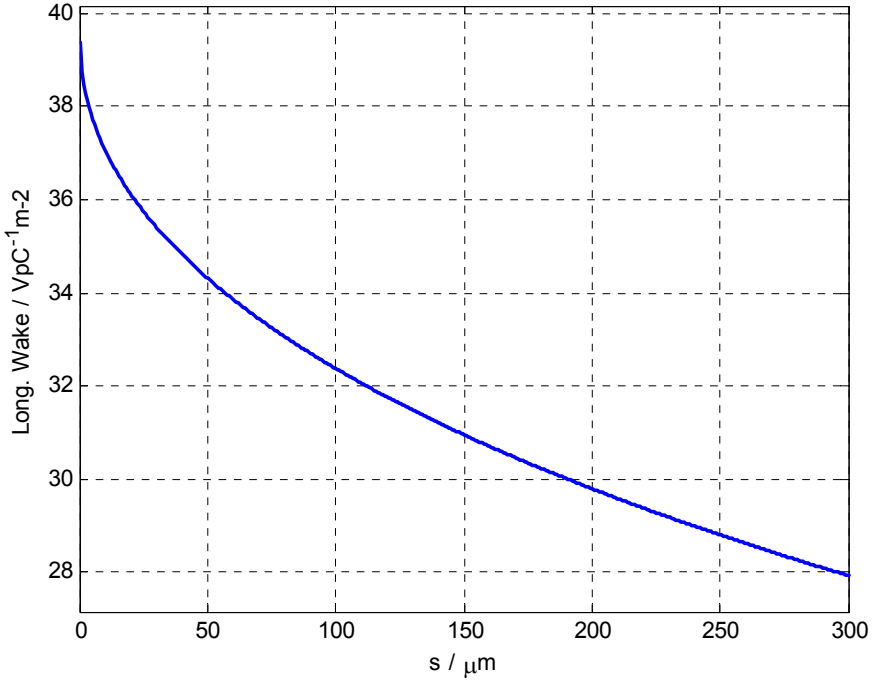
- **Compute Taylor matrices through multiple GP runs varying beam params-> use Grid computing at QM to do in finite time (Generate full matrix elements for first and second order terms, and diagonal only elements up to 9th order).**
- **For parameter reconstruction: Solve x for given f(x) using multi-parameter fit. Unique solution not guaranteed- choice of fit technique is important.**

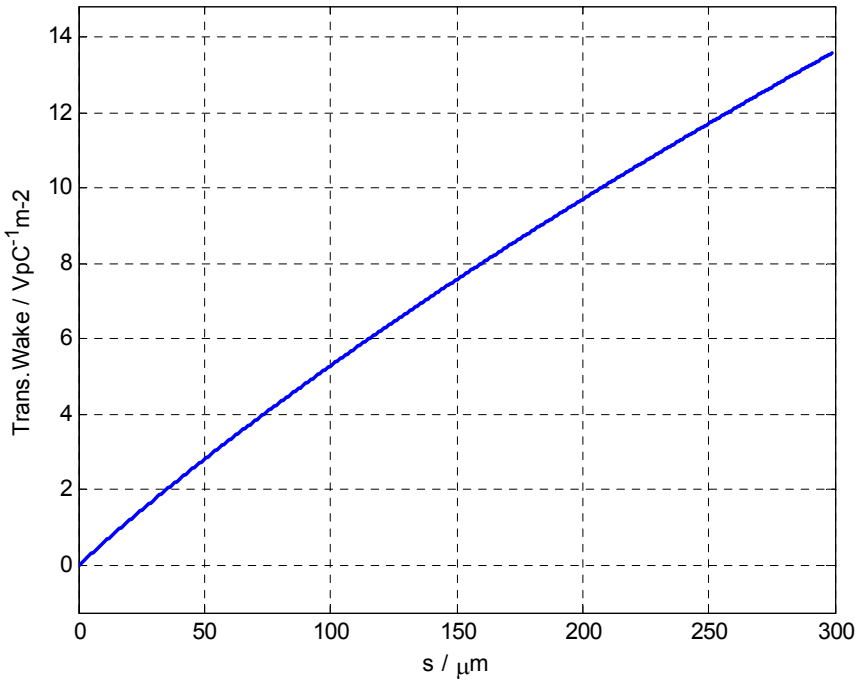
Generation of Taylor Matrices

- Calculate 1st and 2nd order slopes by generating sets of IP beams, running GUINEA-PIG and calculating changes in all observables. Slopes calculated by fitting up to 9th order polynomial in 1 or up to 5th order in 2 dimensions to observable sets and then analytically calculating derivatives at design point.
- To generate Taylor matrices:
  - Need to run GUINEA-PIG 36*36=1296-30=1266/2+30=663*100 =**66,300 times** (assuming $d^2f/dx_m dx_n = d^2f/dx_n dx_m$).
  - With electron_ratio & photon_ratio =0.1, time per GP run ~= 240 secs on 2.8GHz P4 Xeon.
  - Matlab processing ~= 60 secs per run.
  - Time to complete using 100 cpus **> 7 days.**

Parameterising Bananas

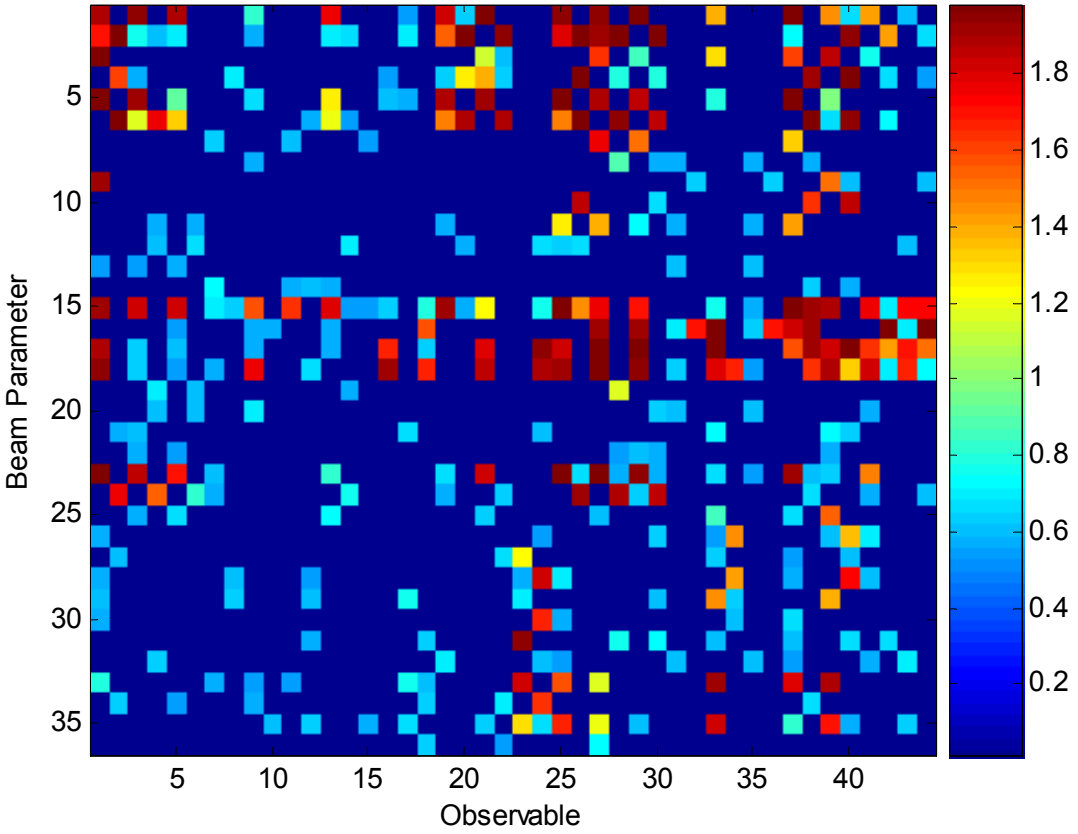
- **Systematic distortion in z-y and z-y' parameterised by linear superposition of 3 banana terms due to longitudinal and transverse short-range cavity wakes and wakes from collimators.**





- **Collimator wakes simulated with quadratic distortion- cavity wakes as above.**
- **y_s = a1 * B1 + a2 * B2 + a3 * B3 (similar for y')**

Beam Parameters – Observables Correlation Matrix



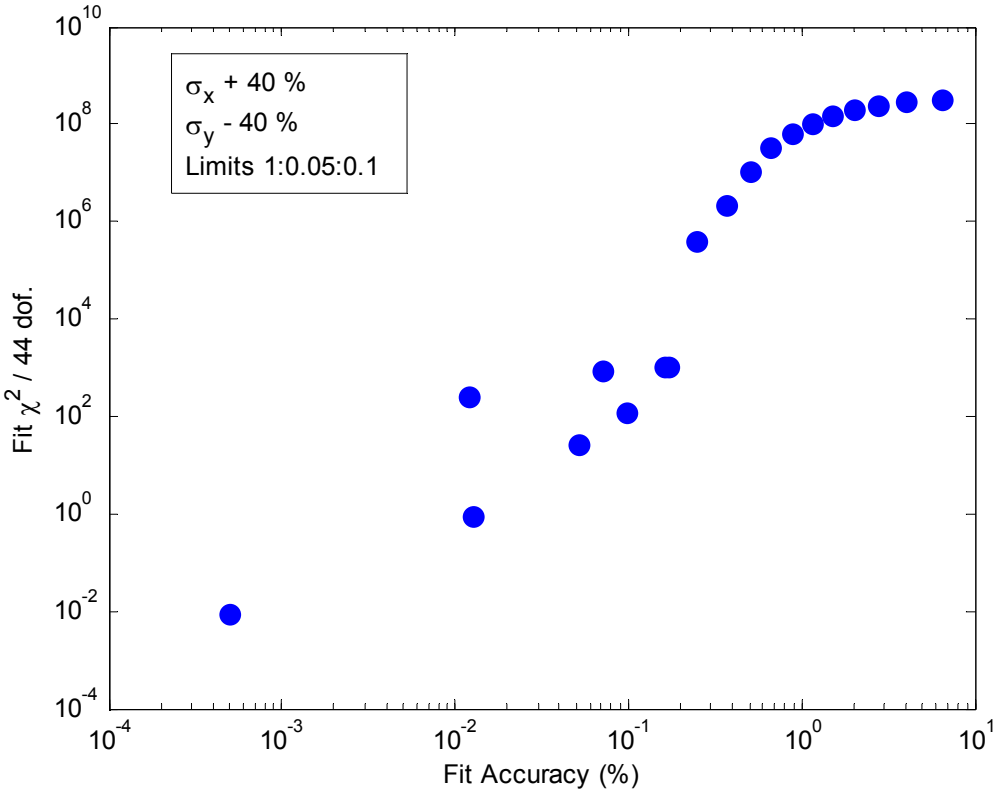
•Correlation coefficients defined as: C(i,j)/SQRT(C(i,i)*C(j,j)) where C(i,j) is the covariance matrix for an observable-beam parameter pair.

•Entries <0.2 are deemed to be useless for the purposes of this analysis and ignored as having no predictive power and no ability to significantly perturb fits.

Tests of Beam Parameter Reconstruction

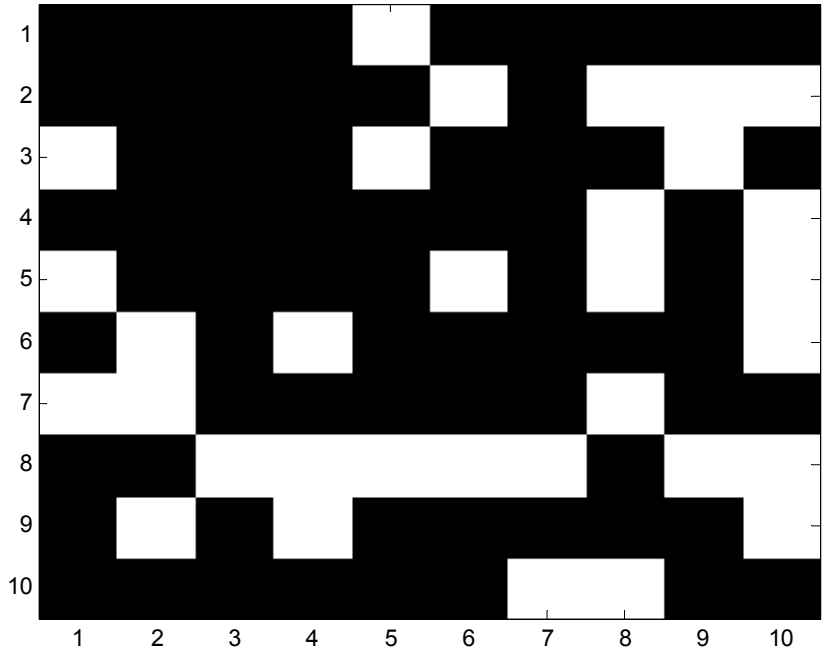
- Standard Matlab unconstrained multi-parameter optimisation routine (fminsearch) found to be un-effective for this task.
- Test fmincon, a constrained multi-parameter fitter contained in the Matlab optimisation toolbox.
- Uses a variety of techniques, with many, many parameters to play with.
- First test, assume only first 10 (sigma x,y,z,x',y') parameters can be in error:
  - Test fitting algorithm by taking every combination of 2 parameters and try to fit given errors (try small, medium and large errors ~ 5, 25 and 40%), parameter 1 shifted +ve, 2 shifted –ve.
  - Assume no errors in observables at this stage, only a test of algorithm.
  - Use all 44 observables.

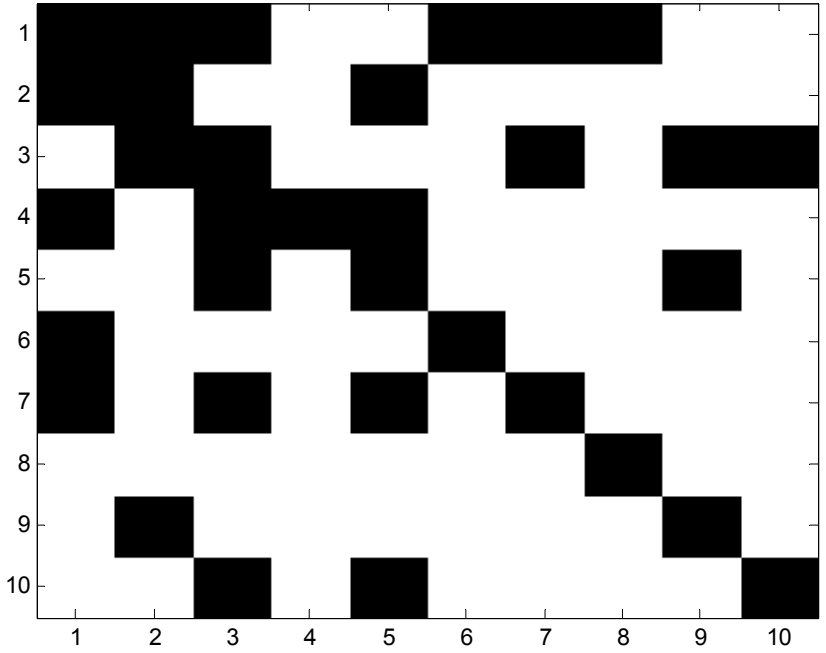
Constraining Fit Algorithm



- Fit success depends on limits used on constrained fit
- Iterate through reducing fit limits
- Assume minimum chi-squared corresponds to best fit.

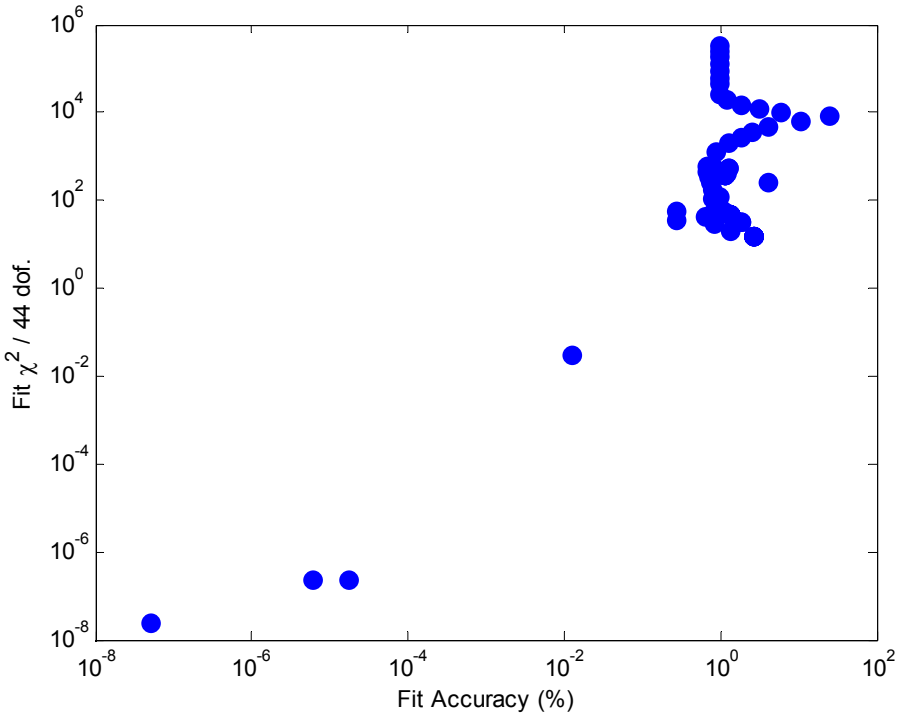
Test Results

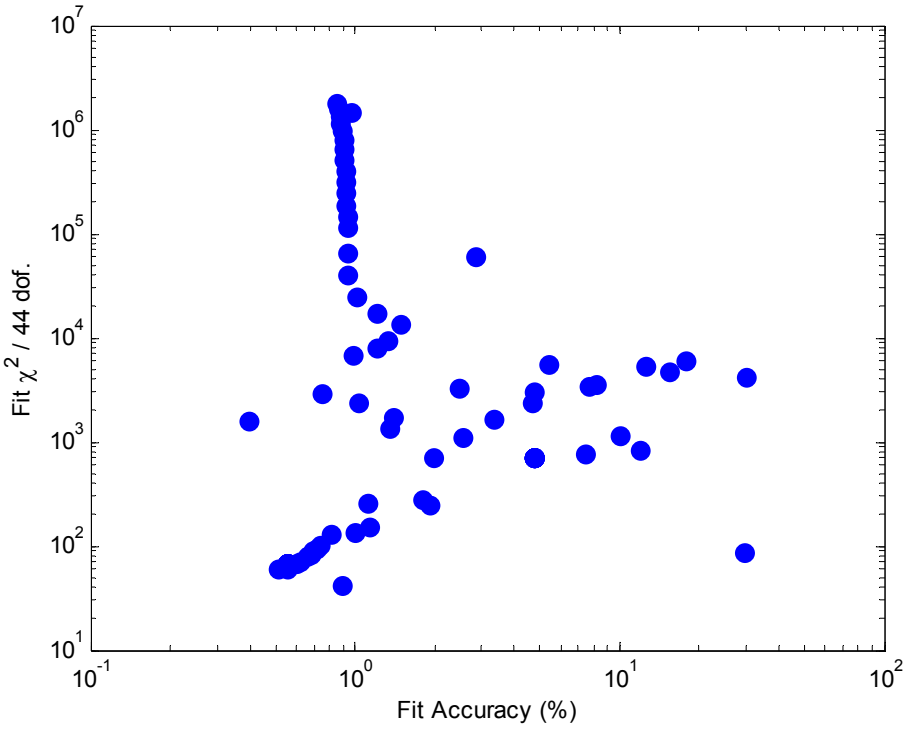




- All small error tests resulted in fits reconstructing beam errors to better than 1%
- Some medium and many large error fits failed (fits worse than 10%) (white squares above, left plot medium, right large).

Increased Constraint Step Resolution





- Increased constrain step resolution for sigma_z + delta sigma_x case.
- Causes medium error case to converge, but not large error case. (left plot, medium error case, right plot is large error case).

Status And Future Considerations

- Taylor matrices generated for pairs and photon observables.
- Need to develop working and efficient process to reconstruct beam parameters using computed Taylor matrices.
- Current observables are probably far too non-orthogonal for a simple fitting algorithm, need to somehow develop more orthogonal ones or reach for more complex tools:
  - Use more advanced fitting routines.
  - Consider using a neural network analysis.
- If all fails, back off from trying to fit parameters in isolation, use beam-based measurements and other assumptions as constraints to try to get at some harder to measure parameters.
- If solution reached:
  - Add observation error analysis.
  - Include in ILC simulations to see how well ‘real’ beam parameters are reconstructed.
- Improve error estimates on observables by developing more realistic simulation of BeamCal and photon detector.
- Worry about real-life generation of Taylor matrices, can only vary some parameters with the real machine, and with varying accuracy.