Beam Diagnostics with Forward Calorimeters

Glen White, SLAC/QMUL

Snowmass 2005

- **Luminosity scans using Radiative Bhabhas (O. Napoly).**
- **IP beam parameter reconstruction from beamstrahlung (pairs and photons). W. Lohmann, G. White.**

Post-IP Energy Spectra

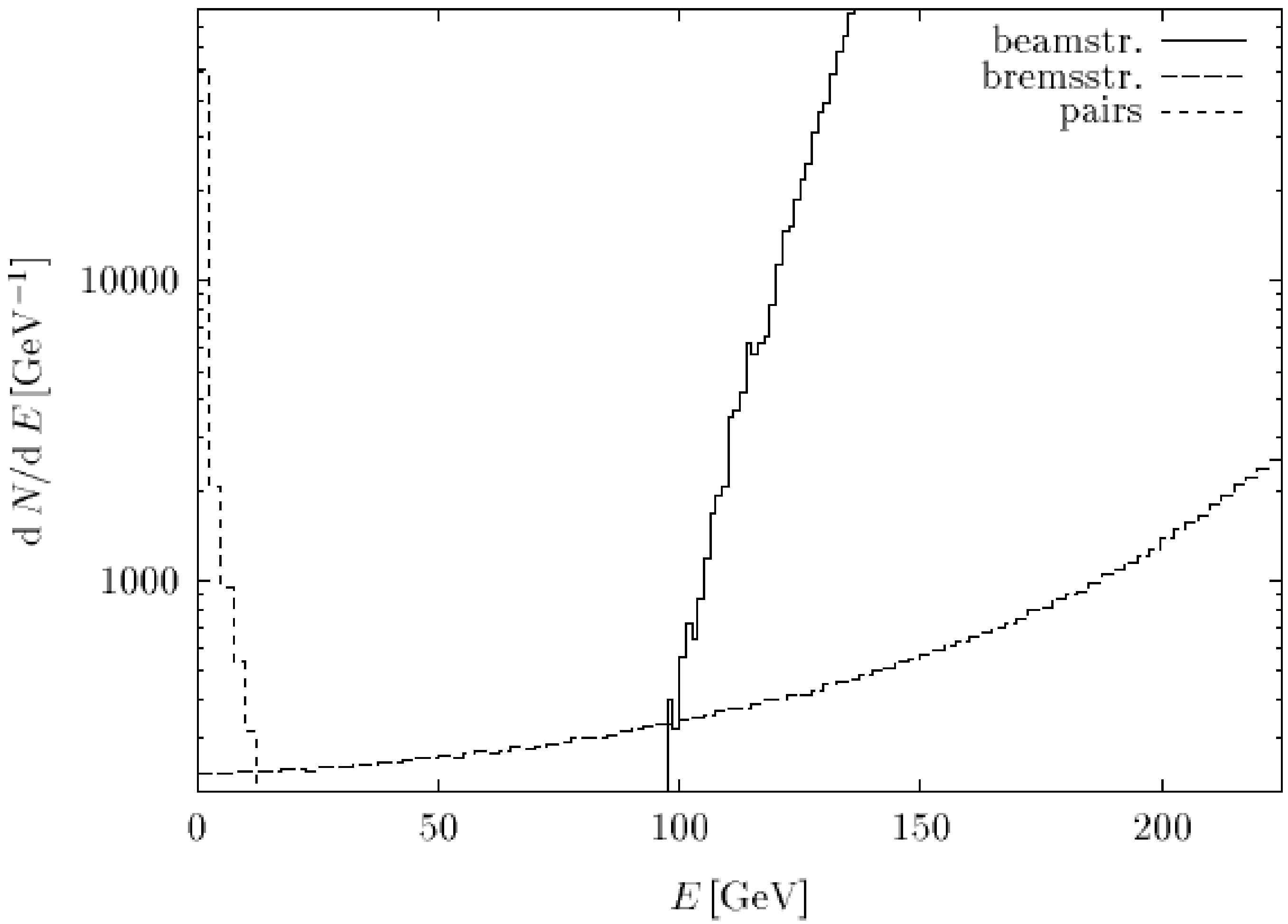
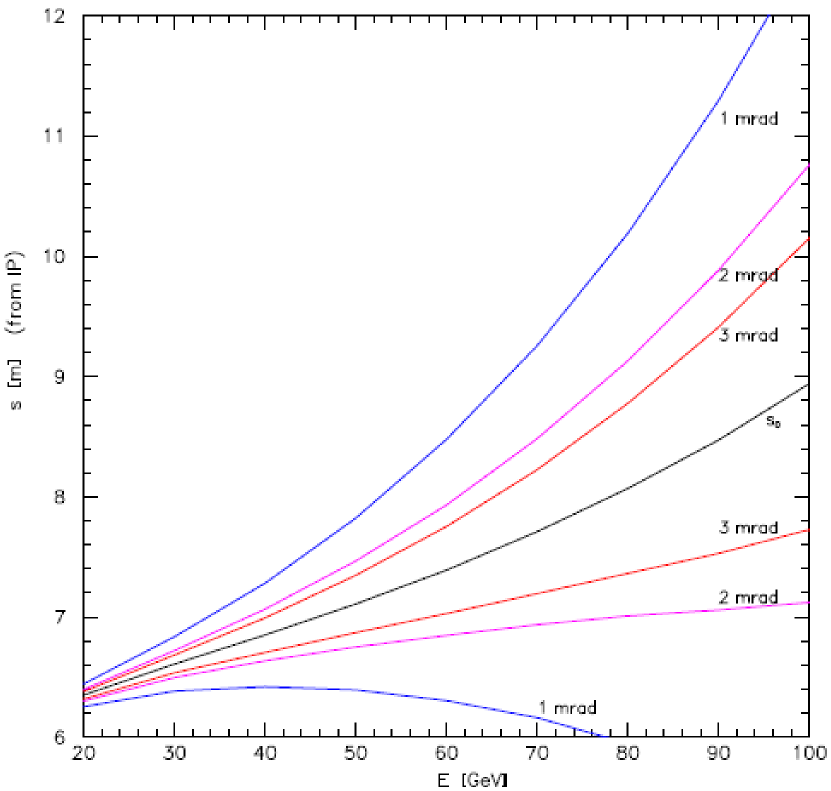
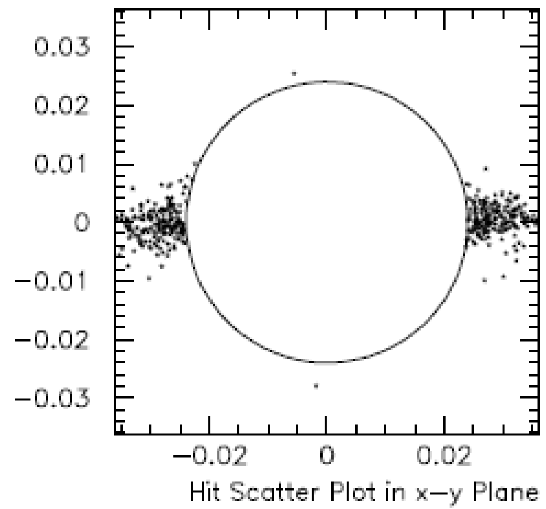


Figure 1: The energy spectrum of the particles due to pair production, bremsstrahlung and beamstrahlung for TESLA (500 GeV c.m.) parameters.

Radiative Bhabha Luminosity Calorimeter

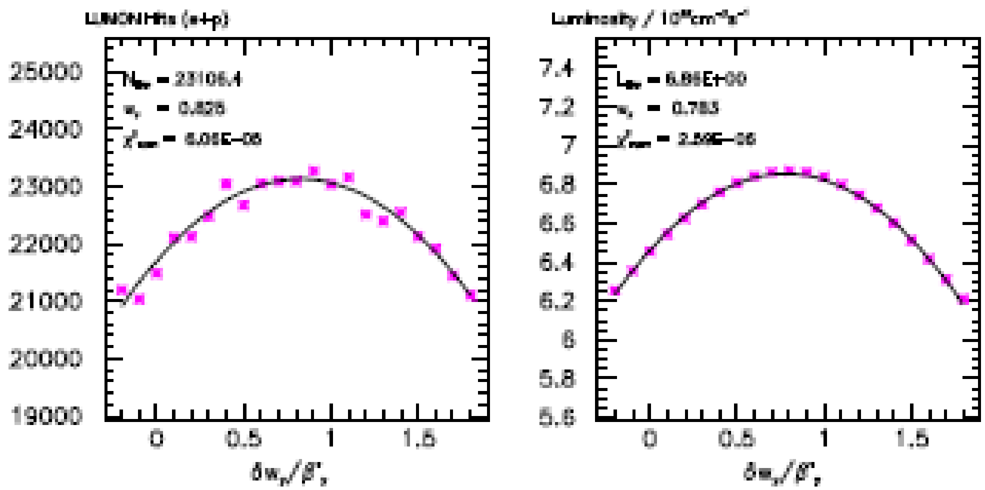


•**Final Doublet acts as a rough spectrometer to outgoing electrons/positrons,**



•**Hits in the Bhabha luminosity calorimeter 8.5m downstream from the IP.**

Scans Using Bhabha Luminosity Calorimeter



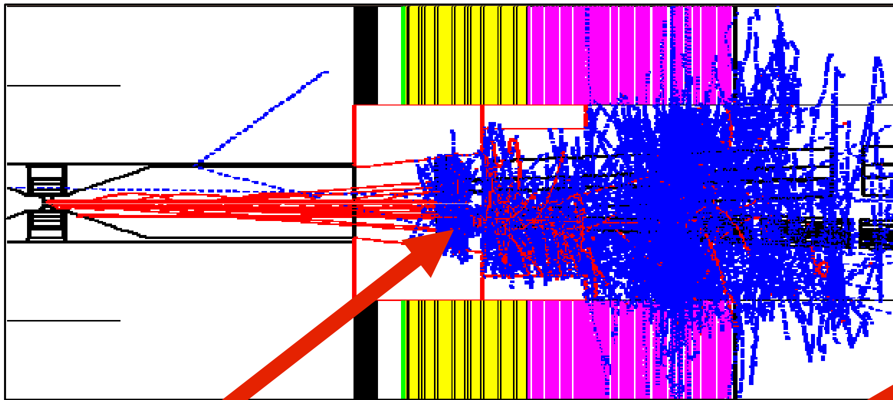
- **Total hits in Lumi Cal and corresponding calculated Luminosity for an IP Beam Waist scan.**

	Waist	Dispersion	Coupling
e^--hits	$2.0 \cdot 10^{-5}$	$2.3 \cdot 10^{-5}$	$3.1 \cdot 10^{-6}$
e^+-hits	$5.1 \cdot 10^{-4}$	$3.6 \cdot 10^{-4}$	$1.7 \cdot 10^{-5}$
(e^-+e^+)-hits	$1.7 \cdot 10^{-4}$	$4.8 \cdot 10^{-5}$	$1.5 \cdot 10^{-6}$
e^--energy	$2.3 \cdot 10^{-5}$	$5.4 \cdot 10^{-5}$	$2.6 \cdot 10^{-7}$
e^+-energy	$4.5 \cdot 10^{-4}$	$4.0 \cdot 10^{-4}$	$2.8 \cdot 10^{-5}$
(e^-+e^+)-energy	$1.6 \cdot 10^{-4}$	$3.6 \cdot 10^{-5}$	$8.3 \cdot 10^{-6}$

- **Relative dL/L precision in determining optimal luminosity for various scans.**

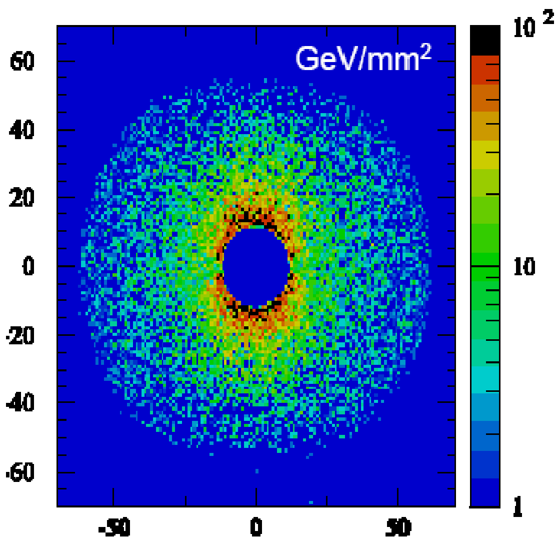
IP Beam Parameter Reconstruction

ILC IR

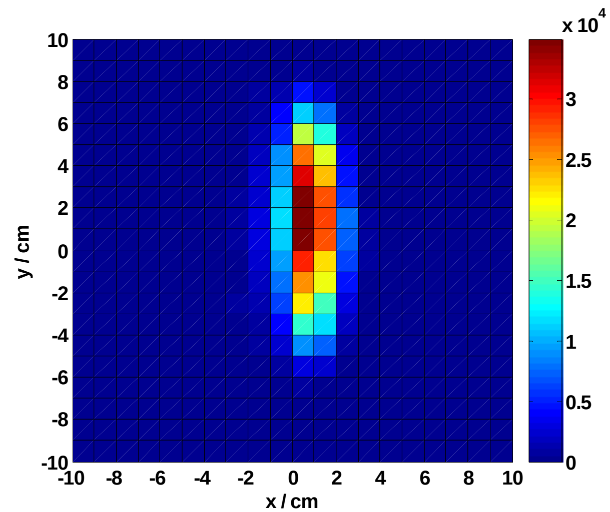


200m

BeamCal



Photon Detector

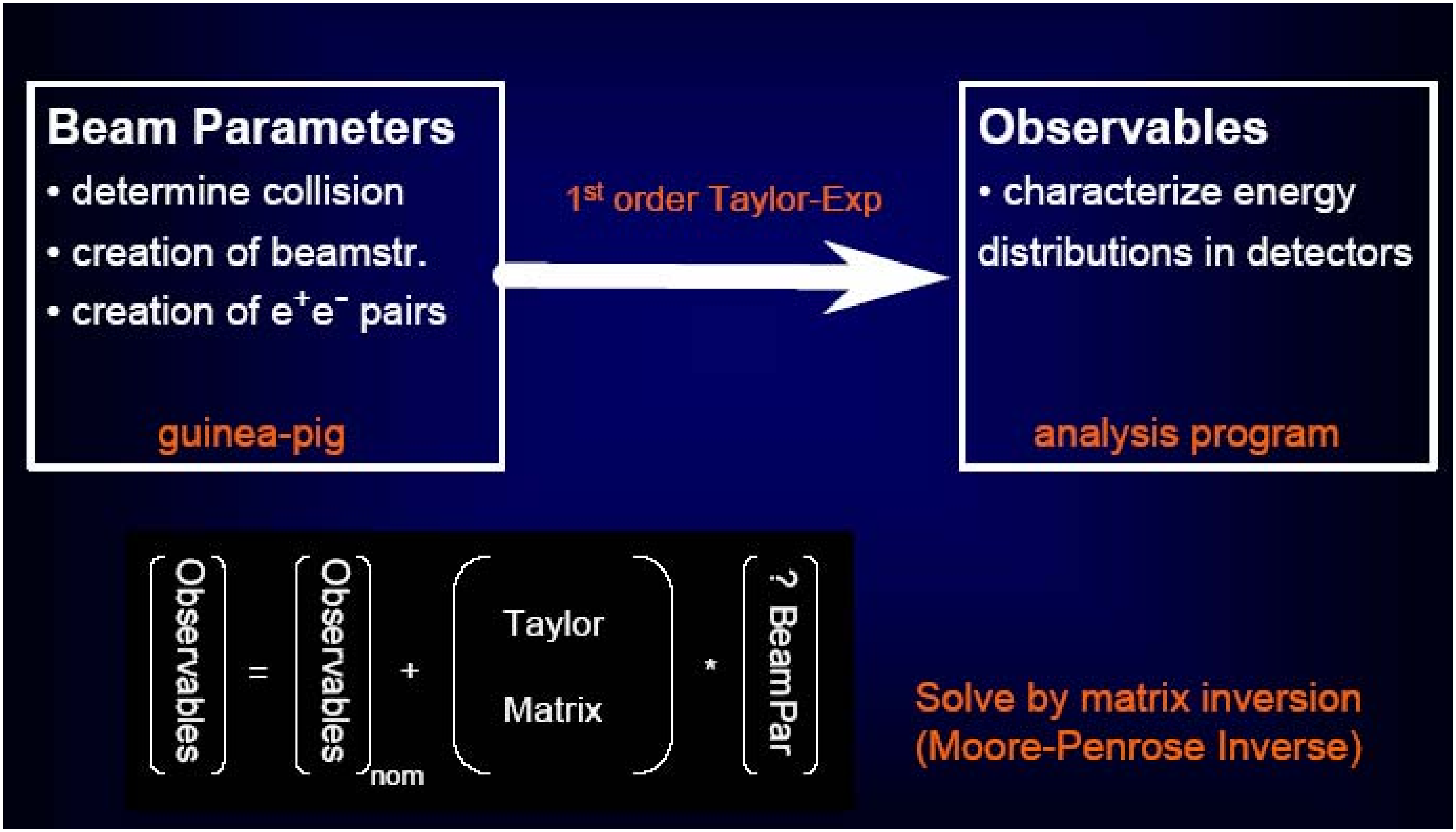


Diagnostics of bunches at IP.

3 potential sources of information:

1. **Energy-distribution of Pairs.**
2. **Number-distribution of Pairs.**
3. **Energy-distribution of Photons.**

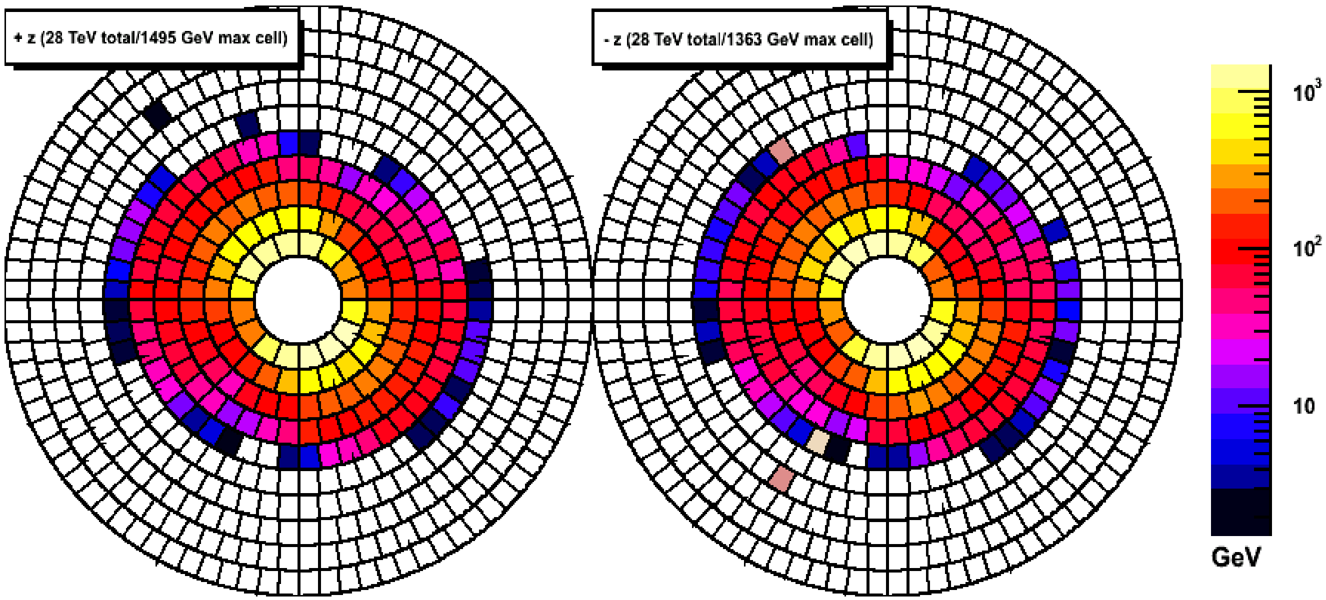
Linear Taylor Matrix Solution (A. Stahl, W. Lohmann et al.)



Linear Taylor Matrix Solution (A. Stahl, W. Lohmann et al.)

Observables

total energy
first radial moment
thrust value
angular spread
L/R, U/D F/B
asymmetries

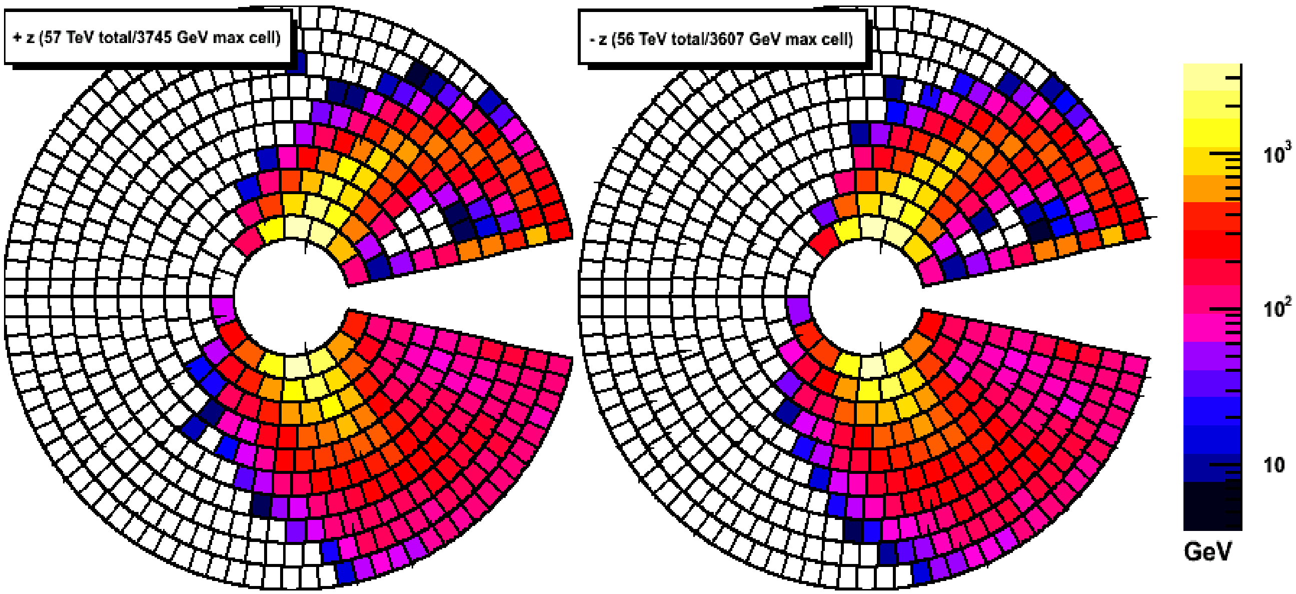


Quantity	Nominal Value	Precision
σx	553 nm	1.2 nm
σy	5.0 nm	0.1 nm
σz	300 μm	4.3 μm
Δy	0	0.4 nm

$\sqrt{s}$ = 500 GeV

zero or 2 mrad Crossing angle

Linear Taylor Matrix Solution (A. Stahl, W. Lohmann et al.)



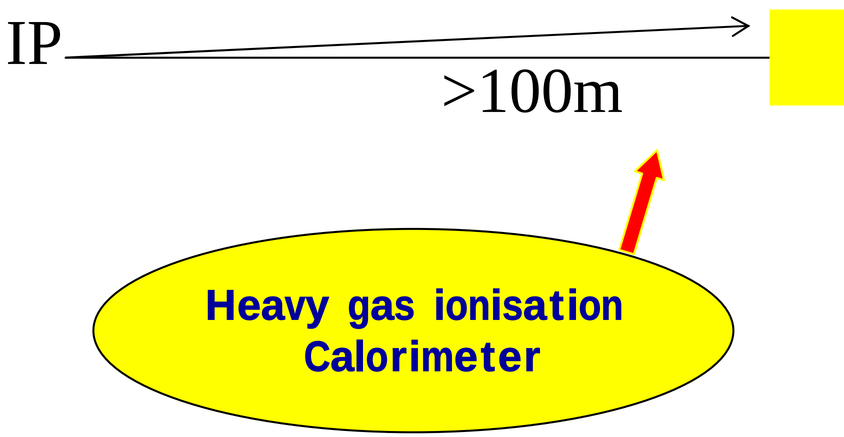
Quantity	Nominal Value	Precision
σx	553 nm	4.8nm
σy	5.0 nm	0.1 nm
σz	300 μm	11.5 μm
Δy	0	2.0nm

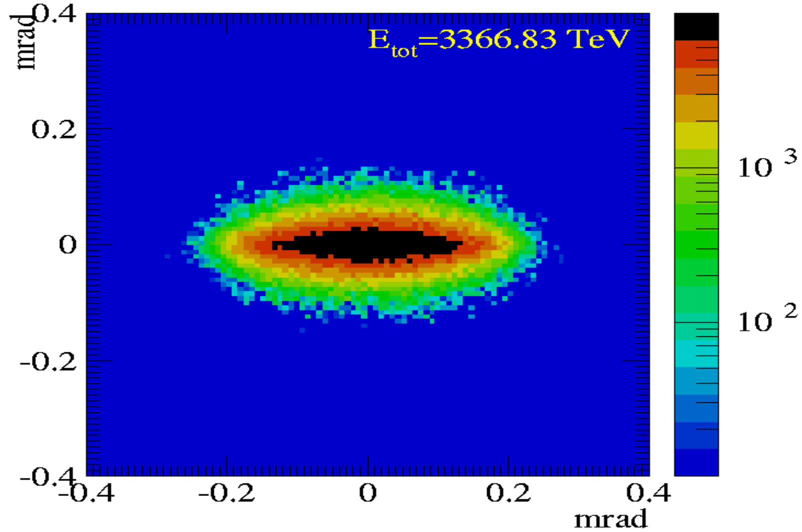
20 mrad crossing angle

PRELIMINARY!

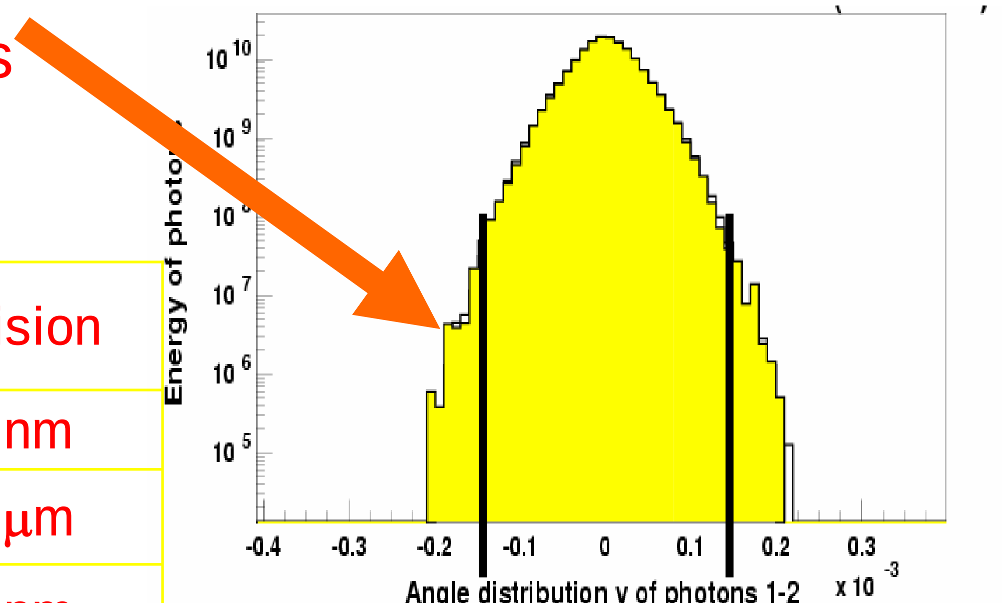
Photon Calorimeter

Photons from Beamstrahlung



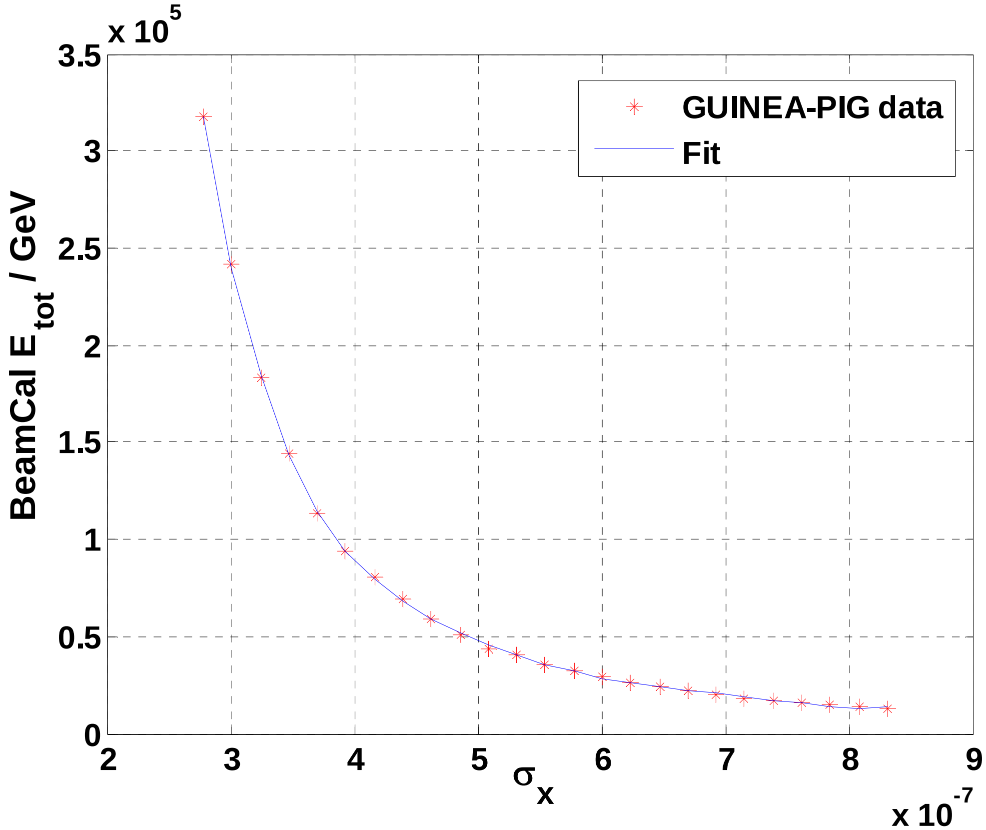


L/R, U/D F/B asymmetries of energy in the angular tails



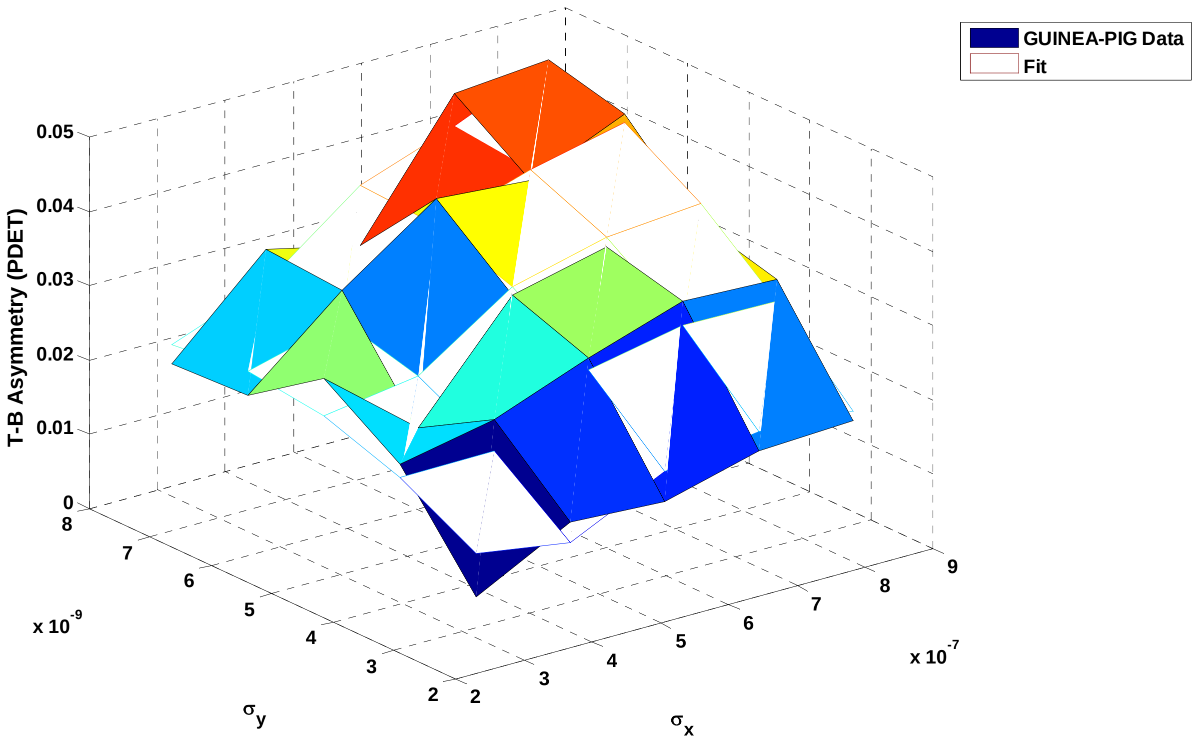
Quantity	Nominal Value	Precision
σx	553 nm	4.2 nm
σz	300 μm	7.5 μm
Δy	0	0.2 nm

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
Full Taylor Matrix Analysis

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

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

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

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

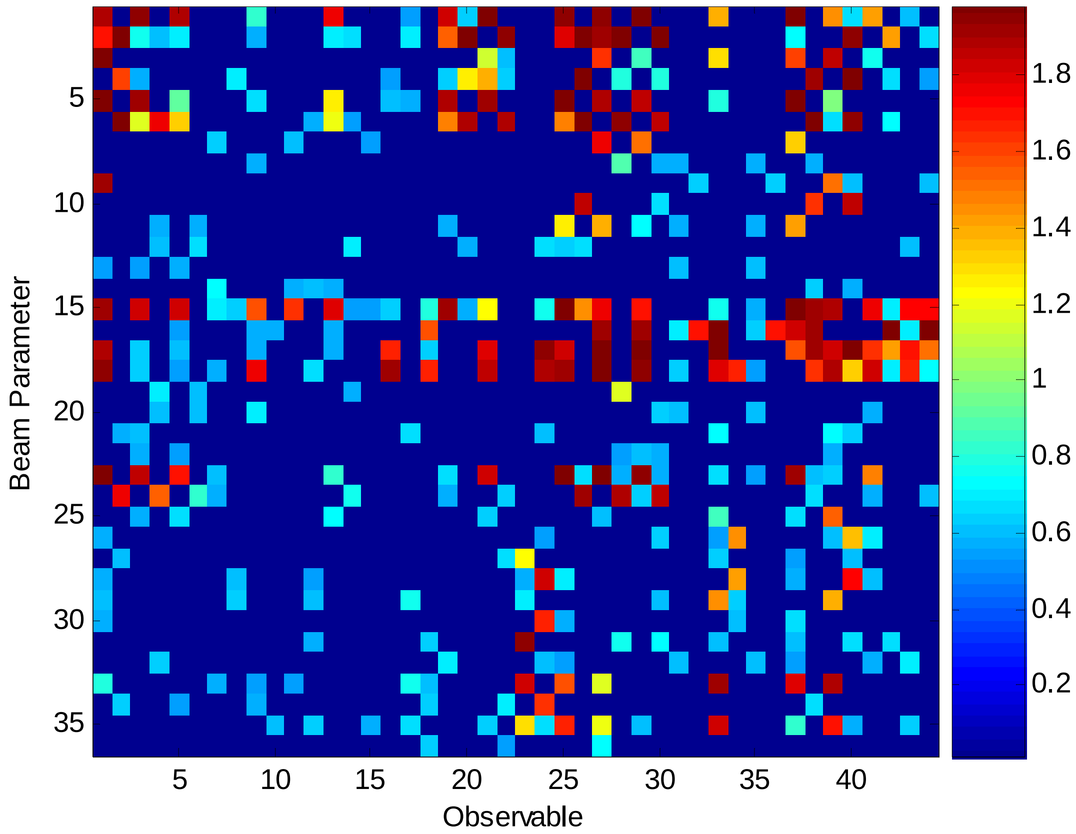
$$f^n(x) = f^n(x^*) + (x - x^*)' div.[f^n(x^*)] + \frac{1}{2}(x - x^*)' \tilde{A}(x - x^*) + \ldots$$

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

•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).

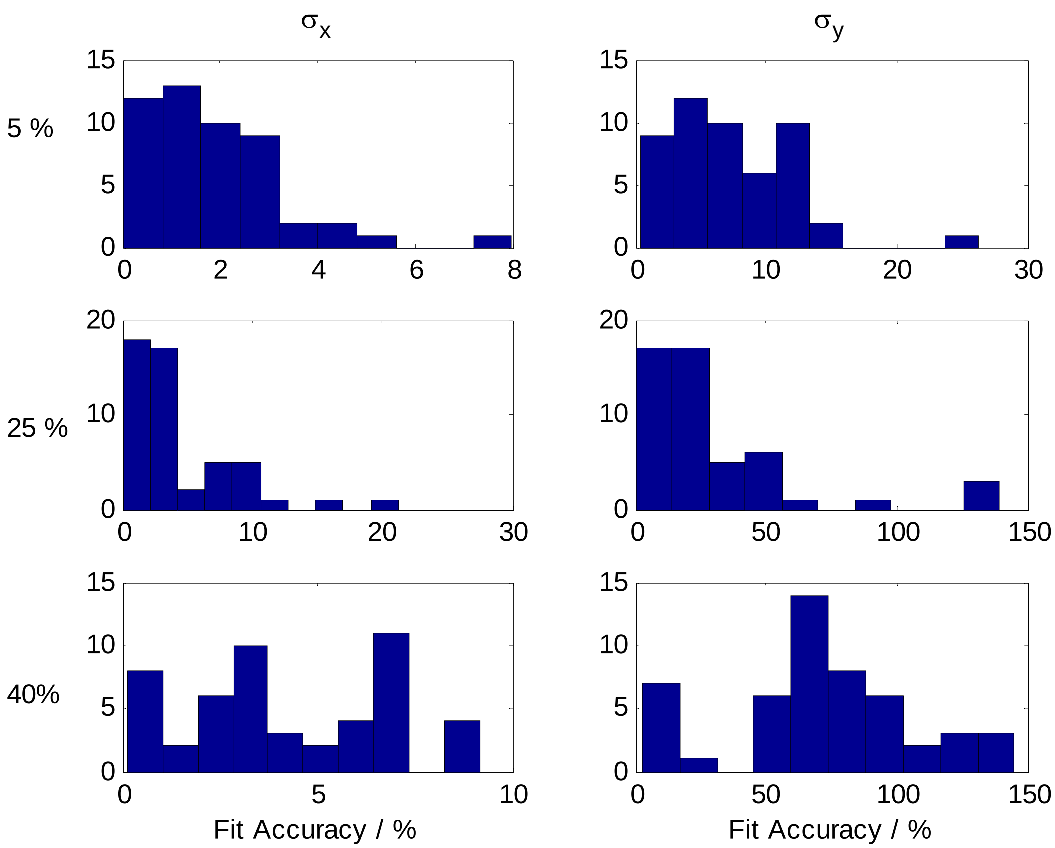
•For parameter reconstruction: Solve x for given f(x) using multi-parameter fit. Unique solution not guaranteed- choice of fit technique is important.

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.
- Very non-orthogonal matrix, need complex multi-parameter non-linear fitting routuine.

Test of Fitting With Realistic Observable Errors



Best Accuracy from lowest Fit Chi-Squared

2.8% 11.5%

0.3% 0.9%

0.14% 2.7%

- **Using Advanced Multi-Parameter non-linear fitting algorithm (Sequential Quadratic Programming Method) with 10-parameter fit (x ,y, x', y' and z IP sigmas).**
- **Fitter confused by errors, but averaging over 50 bunches, get above results by choosing best fit chi-squared.**

Summary

- Forward Calorimeters can provide a lot of valuable information about the IP beam collisions.
- The beamcal can be used for both fast bunch-bunch luminosity monitoring and also used in conjunction with a downstream Photon calorimeter to provide insights into the properties of the colliding beams.
- An additional downstream calorimeter can also be used to provide detailed luminosity scan data from radiative bhabhas.
- There is still much work to be done to get the most amount of information possible about the colliding beams.
- If successful, this will allow access to IP beam data not possible with beam instrumentation e.g. bunch rotation angles and y-z ‘banana’ correlations.