Polarimeter offline analysis: recent developments

- Offline analysis concept: old/new fit
- Fit function and parameters
- Lepton beam and TPOL IP
- Energy pedestals and gain factors
- The calorimeter resolution
- The ηy transformation
- Pileup of Compton photons
- Analysis test using December 2006 data

Offline analysis concept: “old” fit

Basic Idea: describe 2-dimensional data histograms (E vs η) by analytical function with many parameters.

Analytical function: Compton cross-section folded with lepton beam parameters and calorimeter response.

“Old” offline fit by Jenny:

- three seperate fits to reduce number of parameters per fit:
  L+R (E), L+R (E, η), L-R (E, η)
- Extra η resolution term from MonteCarlo introduced (?)
- Lepton beam modelled by simple Gaussian
- No pileup
- No asymmetry in energy resolution U, D allowed
- Fit gives unreasonable values for some parameters (e.g. $S_1^{L,R}$)
- Unknown correlation of fit parameters from seperate fits
- Poor χ^2/N_{DF} for L+R fit
- Development stopped in 2003 (?)

Offline analysis concept: “new” fit

Basic Idea: describe 2-dimensional data histograms (E vs η) by analytical function with many parameters.

Analytical function: Compton cross-section folded with lepton beam parameters, calorimeter response, Compton pileup.

“New” offline fit:

- Simultaneous fit of L (E, η) and R (E, η) histograms
- Lepton beam modelled by double-Gaussian
- Pileup of Compton photons (2 photons in one event) included
- Possibility to have asymmetric U and D resolution
- Possibility for asymmetric η response function
- Closer look at $\eta - y$ transformation
- No need for extra η resolution term from MonteCarlo

Fit parameters

Analytical functions for L and R depend on:

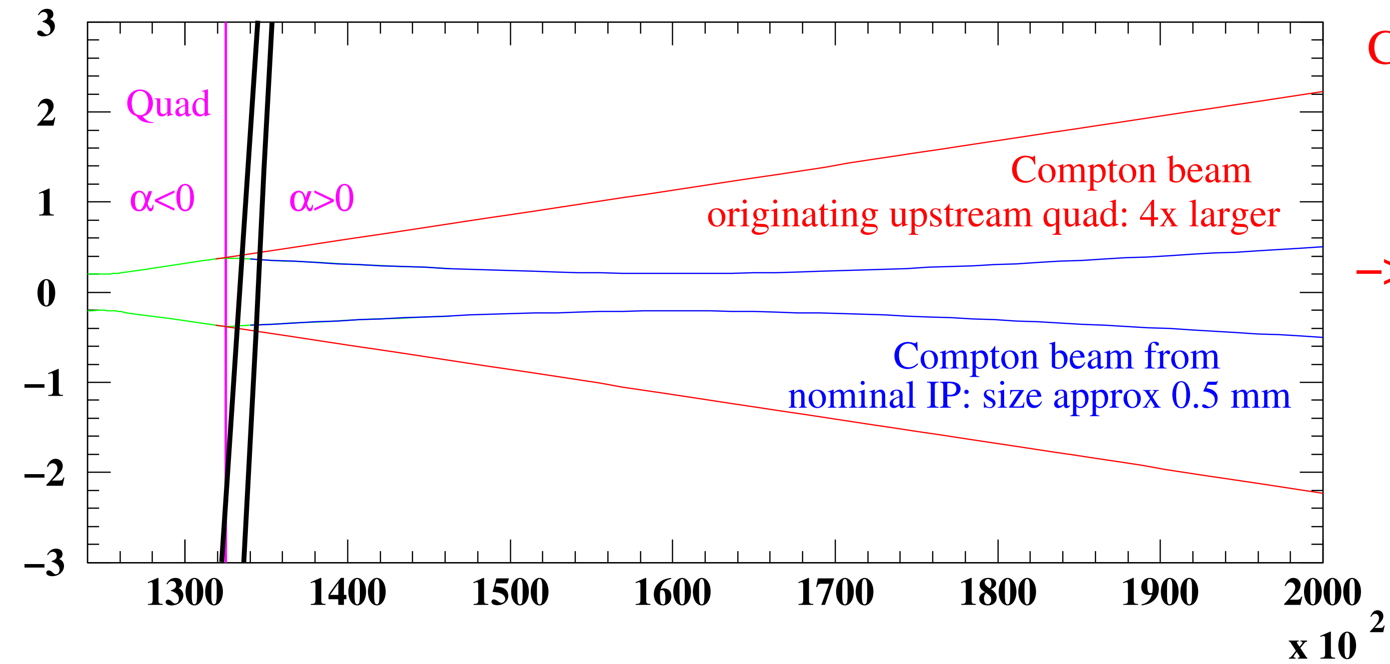
	Parameter for L	Parameter for R	Common parameter
Normalisation	N_L, N_L^{bgr}	N_R, N_R^{bgr}	
Pileup	N_L^{pileup}	N_R^{pileup}	
Lepton polarisation			P_y, P_z
Laser beam	S_L^1, S_L^3	S_R^1, S_R^3	
Lepton beam			y_{off}, σ_y, y_{off2}, r_σ, f_{tail}
Energy offset			Δ_U, Δ_D
Gain factors			f_U, f_D
Calorimeter resolution			σ_E, V_{ud}, r_η, S_η
Distance to IP			D_0
$\eta - y$ transformation			y_s, y_E, R, A, p_1, $\ldots p_N$

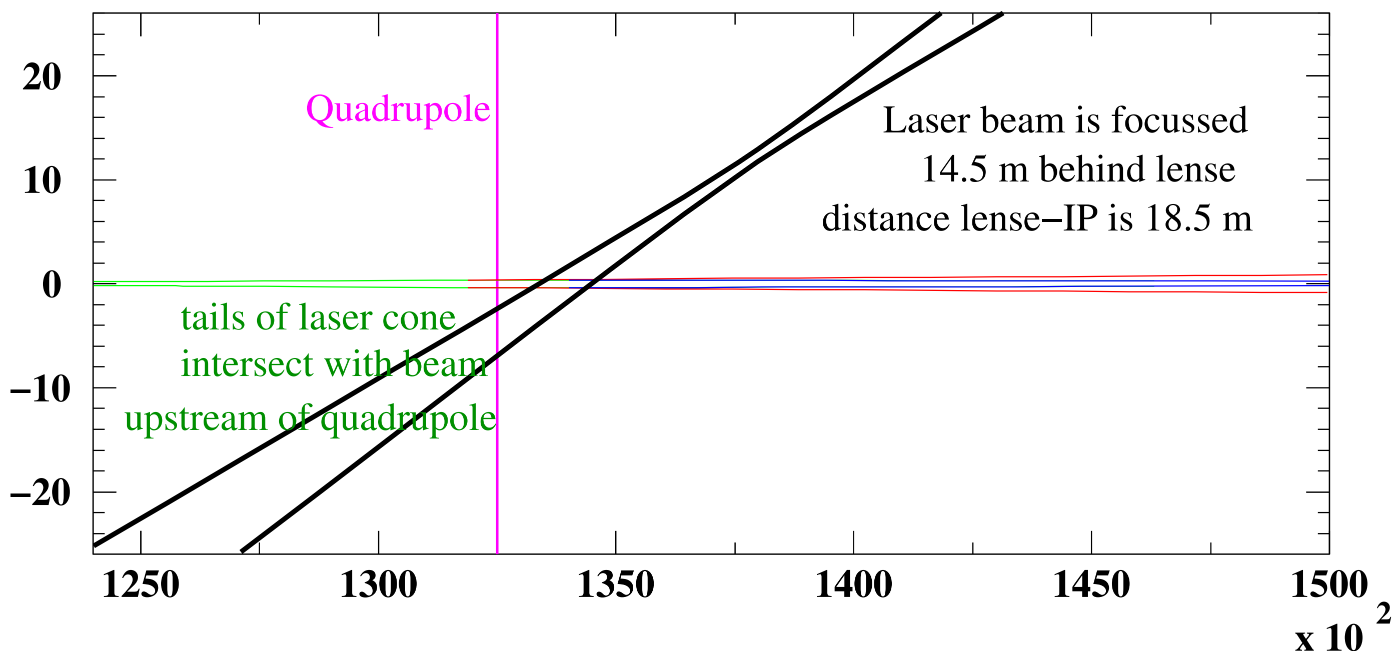
More parameters can be studied: alternative $\eta - y$ transformation, UD correlation, ...

Not all parameters can be determined simultaneously:

- S_L^3 and S_R^3 fixed to ± 1 or taken from optical measurements (not independent of p_y and p_z)
- Distance to IP D_0 and absolute scale of ηy transformation y_s are not independent
  $\rightarrow$ fix $D_0 = 65000\,\text{mm}$ or calibrate ηy from other sources

Lepton beam and TPOL IP





Conclusion: Compton beam has contribution from interactions downstream of Quadrupole

−> need double−Gaussian to describe Compton beam at calo

Core component:

- width σ_y
- offset $y_{\rm off}$
- normalisation $1 - f^2_{\rm tail}$

Secondary component:

- width $\sigma_y(1 + r^2_\sigma)$
- offset $y_{\rm off2}$
- normalisation $f^2_{\rm tail}$

Energy pedestals and gain factors

Synchrotron radiation may cause energy offsets. Energie deposited in calorimeter is increased and energy sharing is distorted:

$$E_{\mathrm{depos}} = U_{\mathrm{Compton}} + D_{\mathrm{Compton}} + \Delta_U + \Delta_D$$

$$\eta_{\mathrm{depos}} = \frac{U_{\mathrm{Compton}} - D_{\mathrm{Compton}} + \Delta_U - \Delta_D}{U_{\mathrm{Compton}} + D_{\mathrm{Compton}} + \Delta_U + \Delta_D}$$

Imperfect calorimeter calibration requires gain factors on observed energies:

$$E_{\mathrm{calib}} = E_{\mathrm{uncal}} \left(\frac{f_U + f_D}{2} + \eta_{\mathrm{uncal}} \frac{f_U - f_D}{2} \right)$$

$$\eta_{\mathrm{calib}} = \frac{\eta_{\mathrm{uncal}} \times (f_U + f_D) + f_U - f_D}{\eta_{\mathrm{uncal}} \times (f_U - f_D) + f_U + f_D}$$

The Calorimeter resolution

Upper and lower halves are assumed to work as independent calorimeters.

Energy resolution $\frac{\delta U}{U} = \frac{\sigma_U}{\sqrt{U}}$, $\frac{\delta D}{D} = \frac{\sigma_D}{\sqrt{D}}$.

Expect $\sigma_U \approx \sigma_D \approx 25\%\,\mathrm{GeV}^{\frac{1}{2}}$.

Transform to uncorrelated variables z (approximately equal to energy) and η.

$$\frac{1}{\sigma_E^2} = \frac{1}{2}\left(\frac{1}{\sigma_U^2} + \frac{1}{\sigma_D^2}\right)$$

$$V_{UD} = \frac{\sigma_D^2 - \sigma_U^2}{\sigma_D^2 + \sigma_U^2}$$

$$z = (U + D) \times (1 + \eta \times V_{UD}), \quad \eta = \frac{U - D}{U + D}$$

Response is given by two **independent** Gaussians. Allow for extra term in η resolution and asymmetric Gaussian:

$$\sigma_z = \sqrt{z}\sigma_E$$

$$\sigma_\eta = \frac{\sigma_E r_\eta (1 \pm \eta S_\eta)\sqrt{1 - \eta^2}}{\sqrt{z}} \frac{(1 + \eta V_{UD})}{\sqrt{1 - V_{UD}^2}}$$

The ηy transformation

Compton beam folded with double-Gaussian is projected on calorimeter halves → coordinate y.

Unknown transformation $\eta = \eta(y)$ to predict energy sharing required for fit. But: Integral over y is transformed to η space:

Need **inverse** function $\eta(y) = y^{-1}(\eta)$ and its derivative $\frac{dy}{d\eta}$.

Fit requirement: $\frac{dy}{d\eta} > 0$ for any choice of y and fit parameters.

$$y = y_{\text{scale}}(E) \times \int_0^{w(\eta)} dw' \left(1 + p_1 w'^2 + \dots\right)^2$$

Slope at $\eta = 0$: $y_{\text{scale}}(E) = y_s + y_E \times (\sqrt{E} - 3.2)$. Simple form: $y_E = 0$

w transformation valid near center of calorimeter:

$$w(\eta) = \eta \left(1 + \frac{A\eta^2}{R^2 + \eta^2}\right)$$

Explicit form of ηy transformation with one correction parameter p_1:

$$y(\eta, E) = y_{\text{scale}}(E) \times w(\eta) \times (1 + \frac{2}{3} p_1 w(\eta)^2 + \frac{1}{5} p_1^2 w(\eta)^4)$$

Pileup of Compton photons

Compton interaction rate is 50 KHz, bunch-crossing rate is 10 MHz.

→ Compton interaction probability 0.5%

If the event has already been triggered, there is a 0.5% probability to find a second Compton photon.

$E = E_1 + E_2$ and $\eta = \frac{\eta_1 \times E_1 + \eta_2 \times E_2}{E}$

→ the Spectrum is shifted to higher energies and the η asymmetry is diluted.

Numerical evaluation: integrate over E_2 and η_2 for each E_1 and η_1 bin

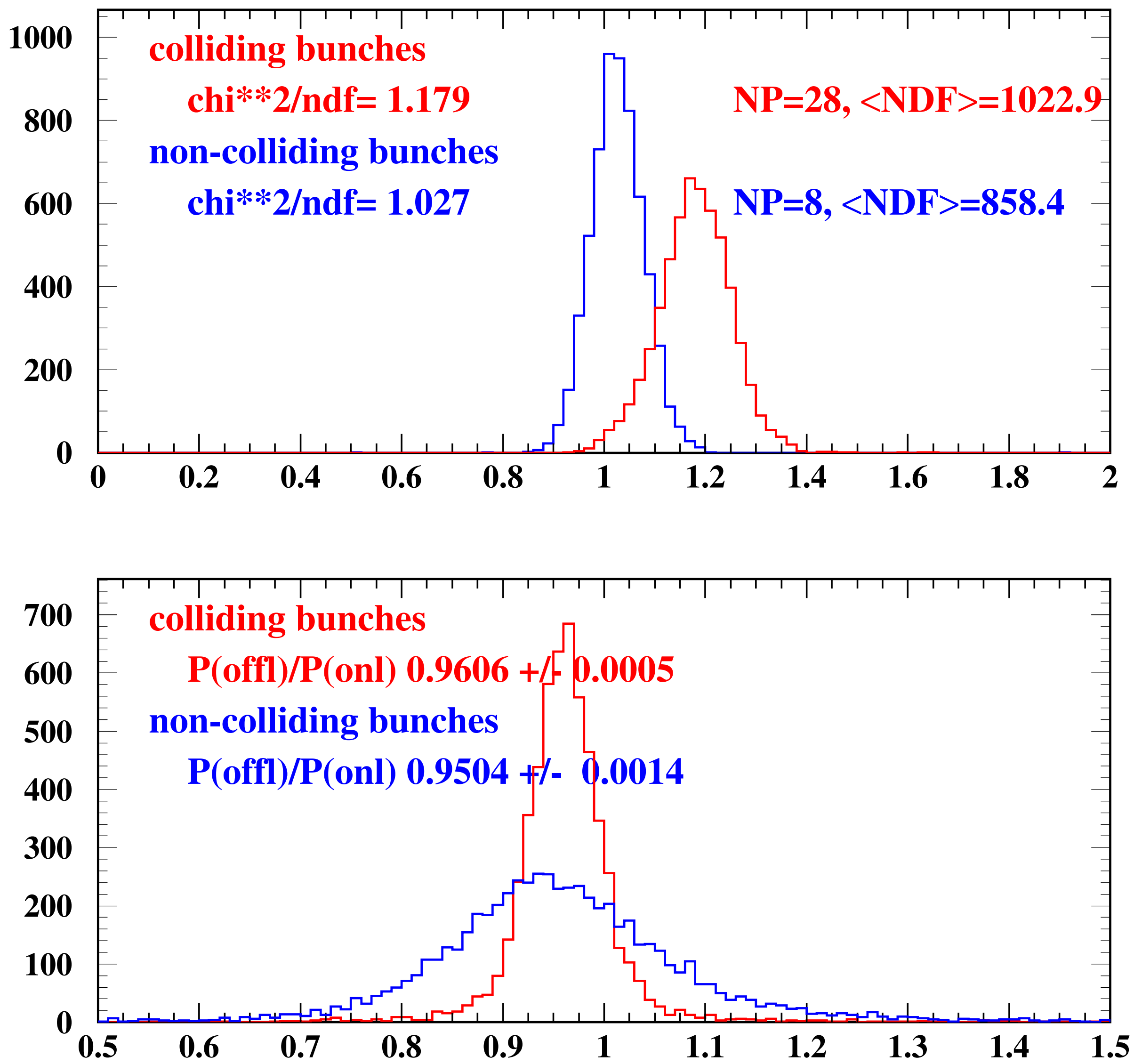
→ very expensive in terms of computing time if number of histogram bins is large.

Present strategy: combine 2x2 (E, η)-bins into a new bin: (12×44) bins with $4.8 < E < 16.2$ and $-0.7 < \eta < 0.7$.

Summary: fit function

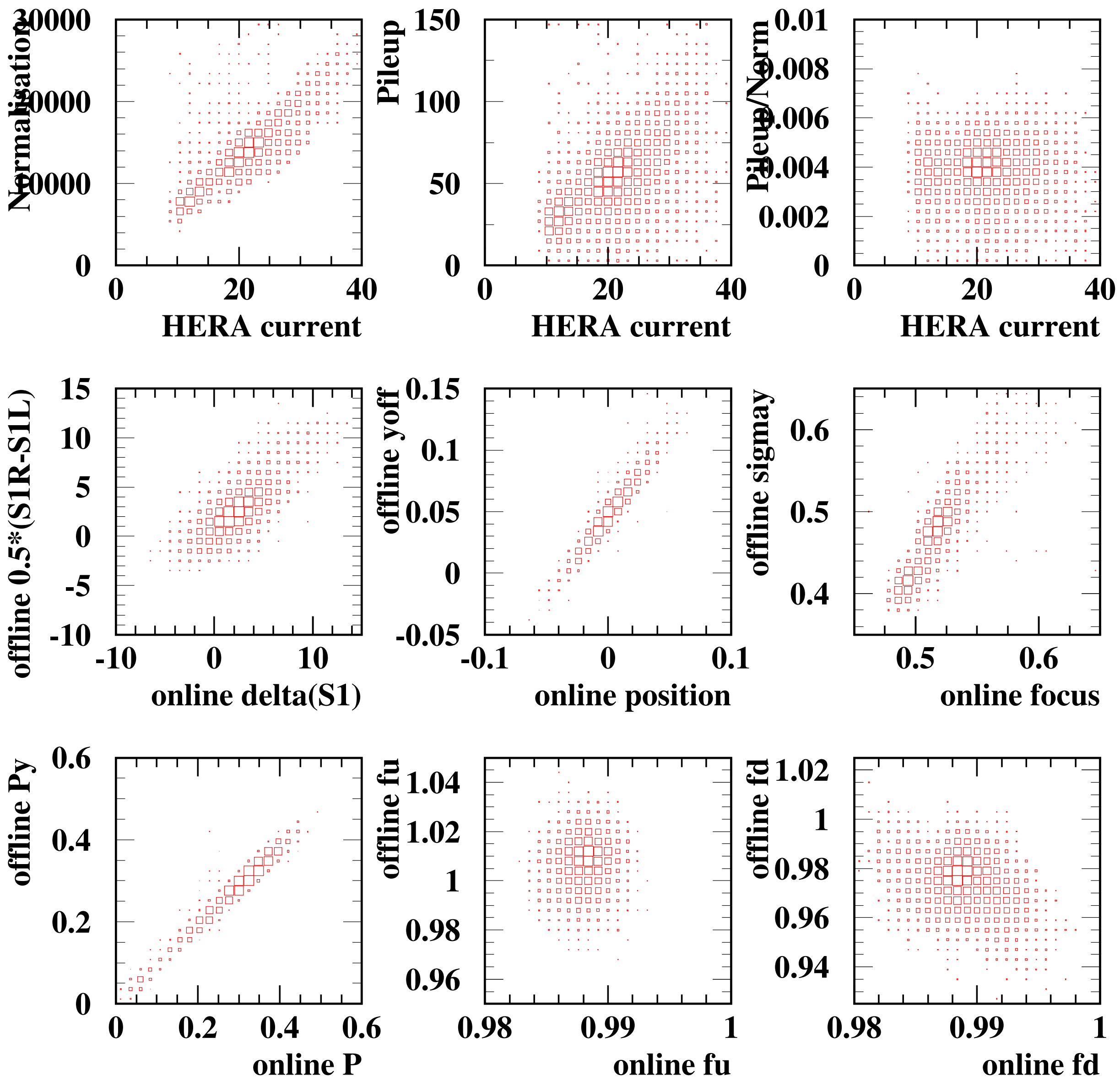
- Fold L, R Compton cross-section with double-Gaussian beam (ϕ integration)
- Fold result with η response function (aysmmetric Gaussian, η integration)
- Fold result with Energy response function (Gaussian, z integration)
- Fold result with itself (pileup, (η, E) integration)

Analysis test using December 2006 data (1)



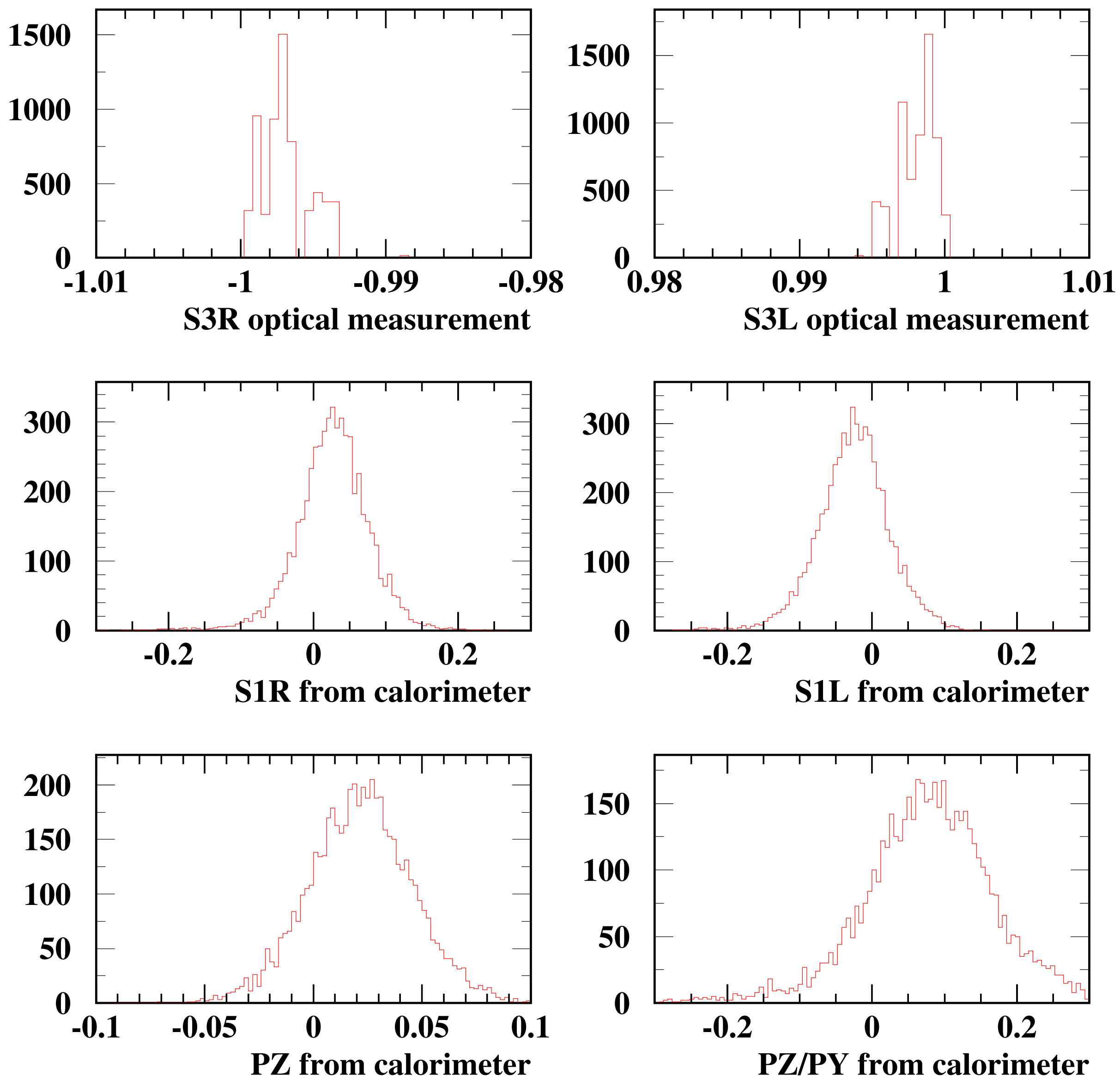
- non-colliding bunches: small statistics, use parameters from colliding bunches
- χ^2/N_{DF} improved compared to earlier attemps
- Still not completely satisfactory
- Agreement between online/offline of order $3-4\%$, depending on number of fit parameters (systematics)
- Offline fit predicts lower polarisation.

Analysis test using December 2006 data (2)



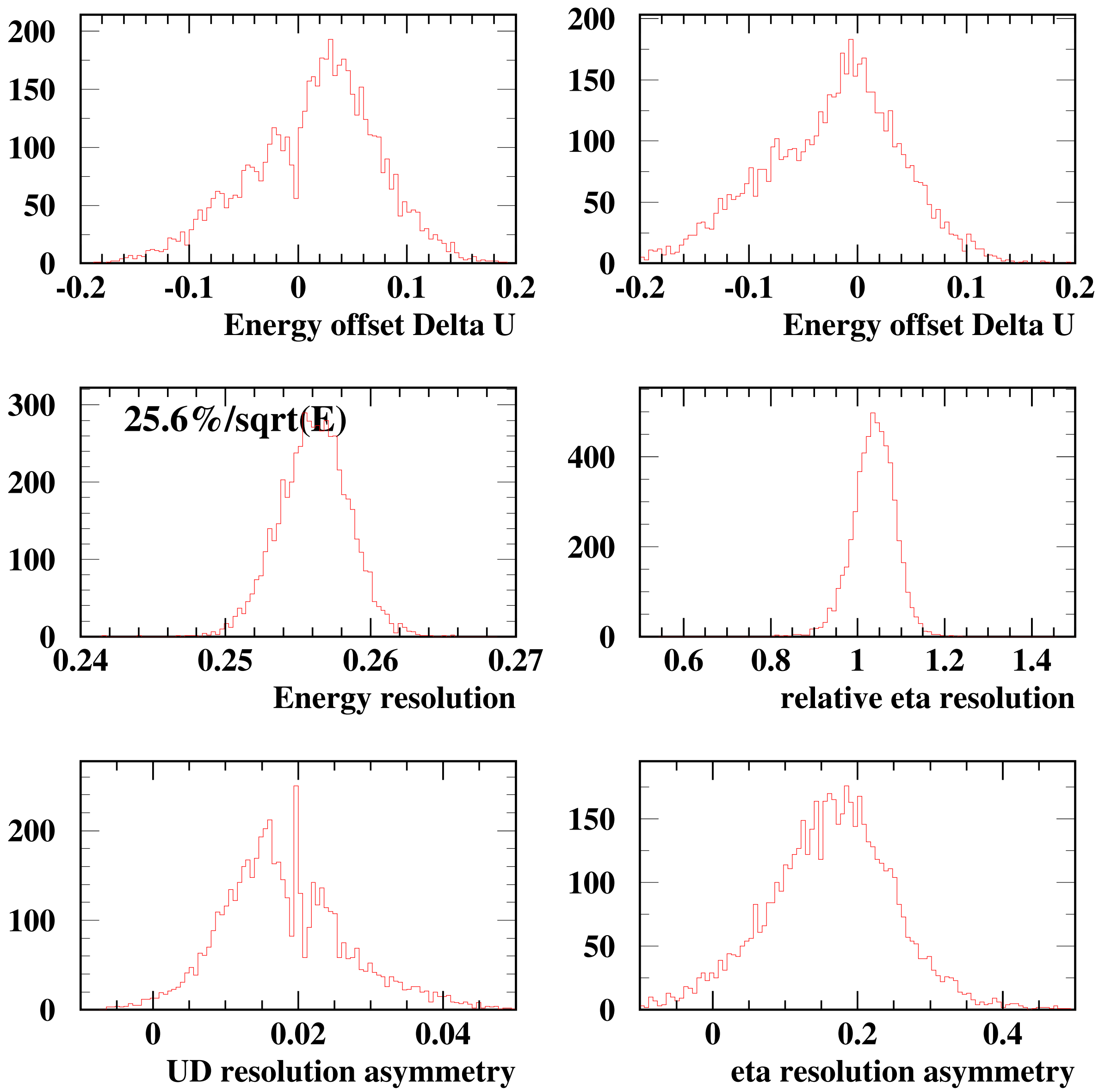
- Offline fit parameters nicely correlated with corresponding online parameters
- Observed offset in beam position
- pileup expected to have quadratic dependence on beam current
- Gain factors determined very differently for online
  → no strong (anti-)correlation

Analysis test using December 2006 data (3)



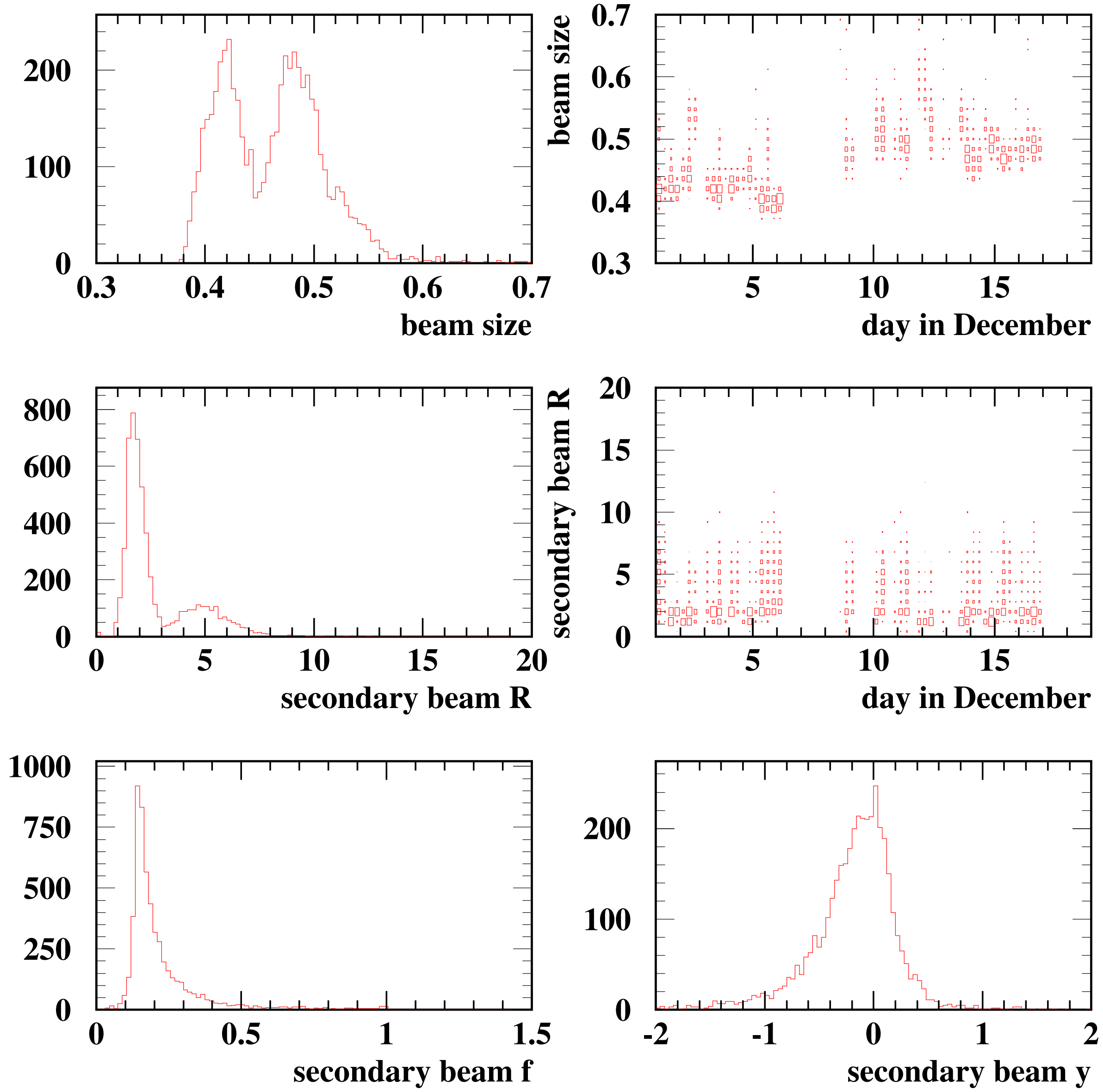
- Optical measurements consistent with $S_3^{LR} = \pm 1$
- Calorimeter measurements for S_1^{LR} look reasonable
- Longitidinal component of beam polarisation size 100 mrad completely excluded by machine design. $\rightarrow$ fit artefact, constrain p_z to zero

Analysis test using December 2006 data (4)



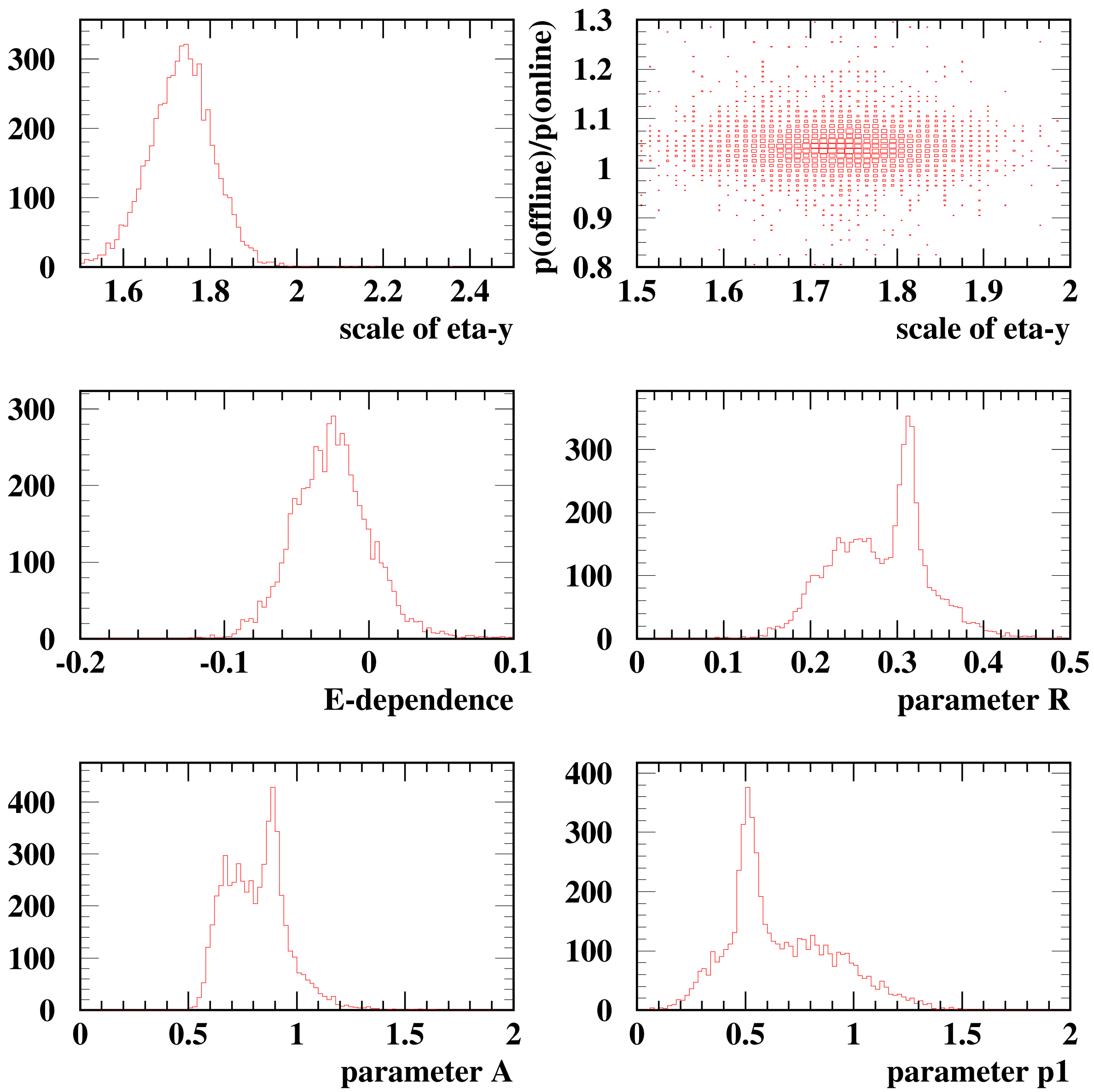
- U offset compatible with zero
  $\rightarrow$ synchrotron radiation in lower part of calorimeter
- Energy resolution compatible with test-beam
- Relative η resolution compatible with 1
  $\rightarrow$ constrain to 1
- η resolution is not symmetric: smaller width for η_{obs} pionting to calorimeter center
- V_{UD} of order 2%: calorimeter photon statistics is better for D part
  Strange shape of distribution: fit artefact?

Analysis test using December 2006 data (5)



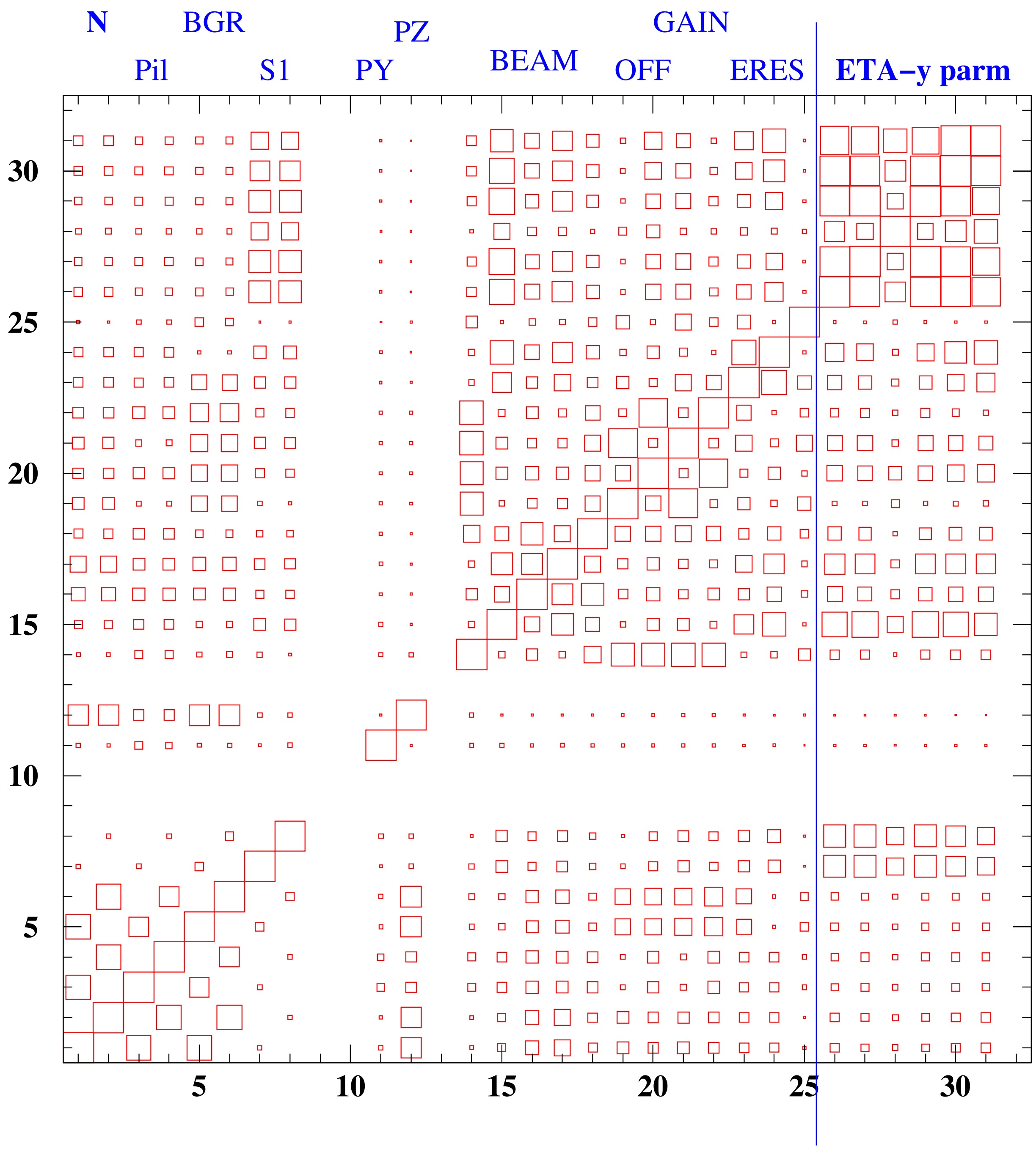
- Small/large beam size coincides with helicity flip
- Secondary beam $r_\sigma = 1.8$:
  $\sigma_{y,2} = \sigma_y \times (1 + 1.8^2) = \sigma_y \times 4.2$
  Approx. compatible with HERA machine parameters
- Secondary beam $f_{\text{tail}} = 0.15$:
  normalisation $f^2 = 2.3\%$
  Expected order of magnitude
- secondary beam position compatible with zero?

Analysis test using December 2006 data (6)



- y_s expected to be correlated with mirror position to be studied further
- Energy dependence is small → constrain to zero
- Strange double-peak structure for other parameters: fit artefact.

Analysis test using December 2006 data (7)



- Average correlation matrix
- $\eta - y$ parameters seem overconstrained
- little correlation for P_y and P_z
  Expect no big change by constraining other parameters

Analysis test using December 2006 data (7)

Try to eliminate unneeded parameters:

- Background normalisation (not shown)
- p_z: longitudinal polarisation
- r_η: independent η resolution
- y_E: energy-dependent ηy transformation

χ^2/N_{DF} changes from 1.17 to 1.2

offline/online changes from 0.961 to 0.972

Summary

- Fit is working technically
- Still rather high χ^2: impossible to include all beam and detector effects in analytic form
- Offline result approx $3-4\%$ lower than online
- Systematic effect from changing parameter set: $1-2\%$