Monolithic Crystals with Two-Sided Readout - a MC study

P.Murat

Sep 05 2011

Introduction

- coordinate resolution of modern PET scanners is limited by the crystal size
- for small animal PET, need crystals smaller than 1x1mm^2
- coordinate resolution of the brain imager we are discussing limited at the level of 5mm
- Studies by the Delft Univ group: relatively large crystals, read out by an SiPM matrix each (talk by D. Schaart, https://indico.cern.ch/getFile.py/access?contribId=46&sessionId=3&resId=0&materialId=slides)
- timing resolution with digital SiPMs and 24x24x20 mm2 LSO:Ca,Ce crystals: CTR = 200ps
- 1-sided readout, very sophisticated coordinate reconstruction
- resolution much better than the the crystal size :
  24x24x10mm crystal: < 1mm FWHM
  24x24x20mm crystal: 1.8-1.9mm FWHM
- this level of coordinate resolution becomes especially useful when it comes with the depth of interaction (DOI) measurements
- use the 2-sided readout?

Simulation

- consider 20x20 mm2 and 40x40 mm2 crystals
- length = 10mm, 20mm, and 30mm, (for LYSO $L_R = 11.4mm$)
- SiPMs : 4x4mm and 2x2mm (just for comparison), PDE = 25%
- reflection: 95%
- interaction point distributed uniformly over the crystal volume
- simulate two-sided readout
- simplified model of the SIPM angular efficiency : $\epsilon = 1 \text{ for } \theta < 60 \text{ deg}$ (http://web.physik.rwth-aachen.de/h̃ebbeker/theses/schumacher_bachelor.pdf)

5.2. Analysis 39

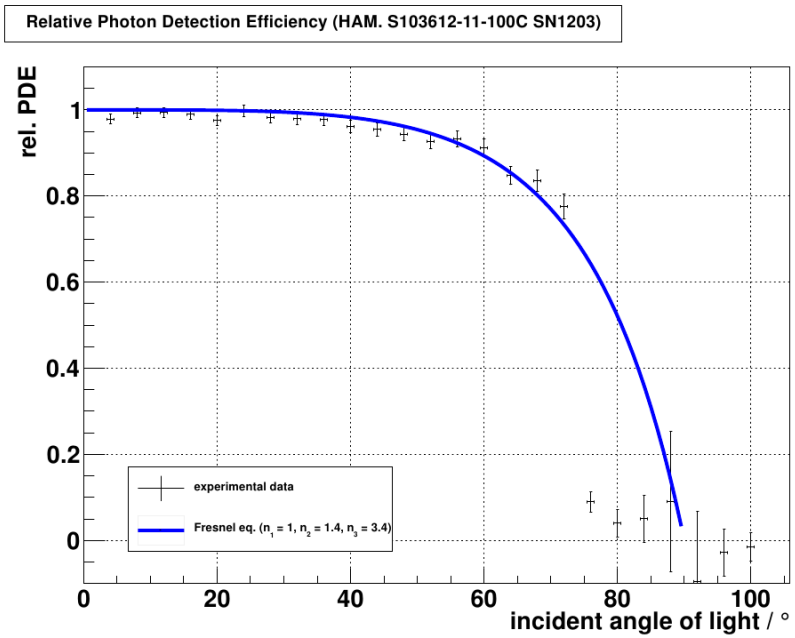
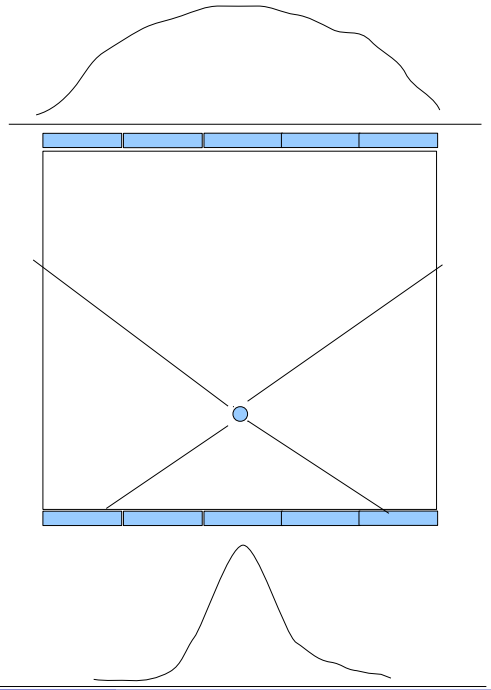
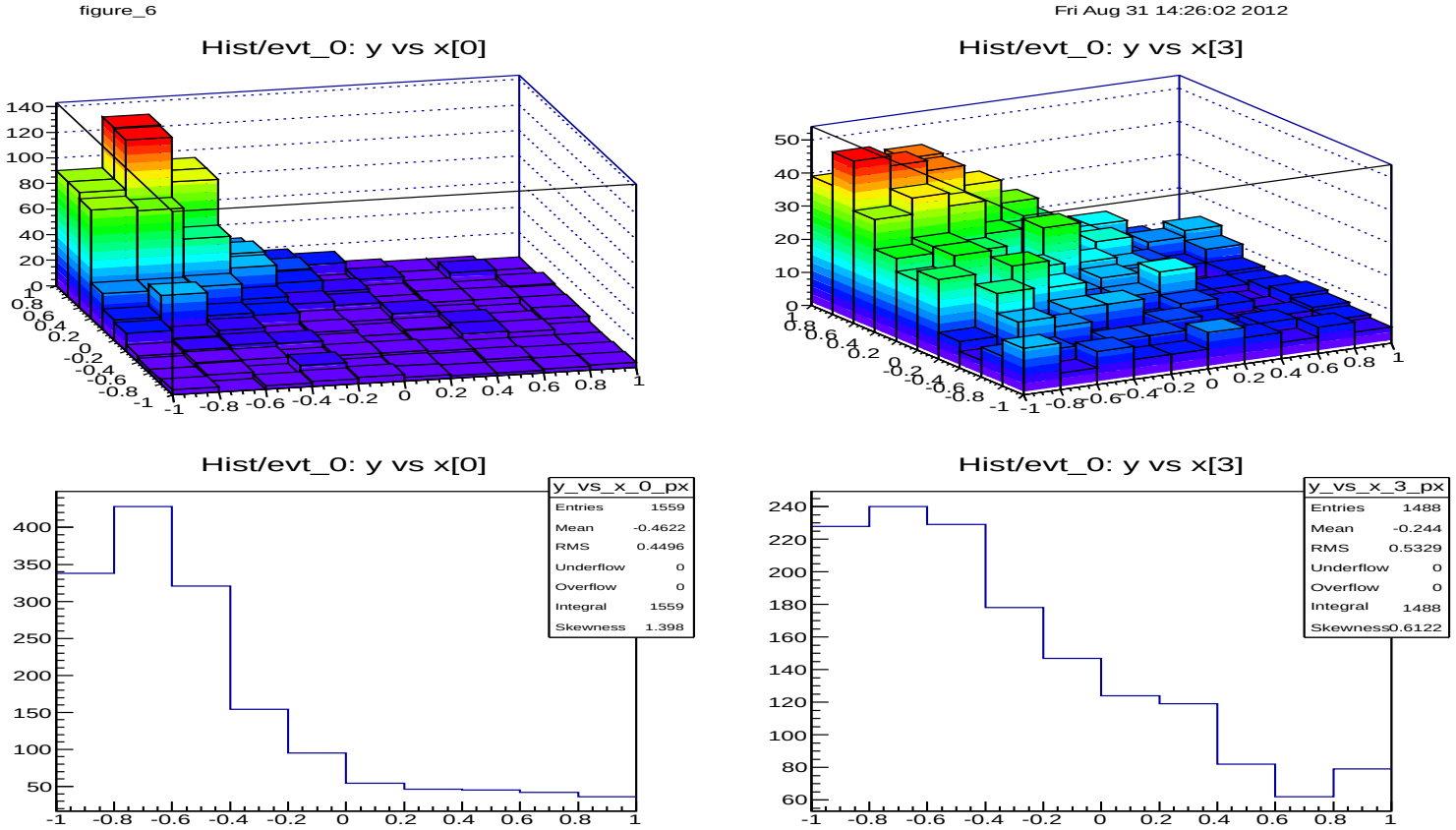


Figure 5.11: Relative Photon Detection Efficiency with Fresnel equation c in equation (5.19) (no approximation).



Simulated Event



- simulated event with 1-sided Y projections, X = 7mm, Y = 7mm, Z > 0
- left: signals on Z = 20mm side, right: signals on Z = 0 side

Reconstruction

Use straightforward clustering

- for each side calculate charge-weighted averages:

$$< X >= \frac{\Sigma X_i \cdot Q_i}{\Sigma Q_i}, < Y >= \frac{\Sigma Y_i \cdot Q_i}{\Sigma Q_i},$$

- and the cluster widths :

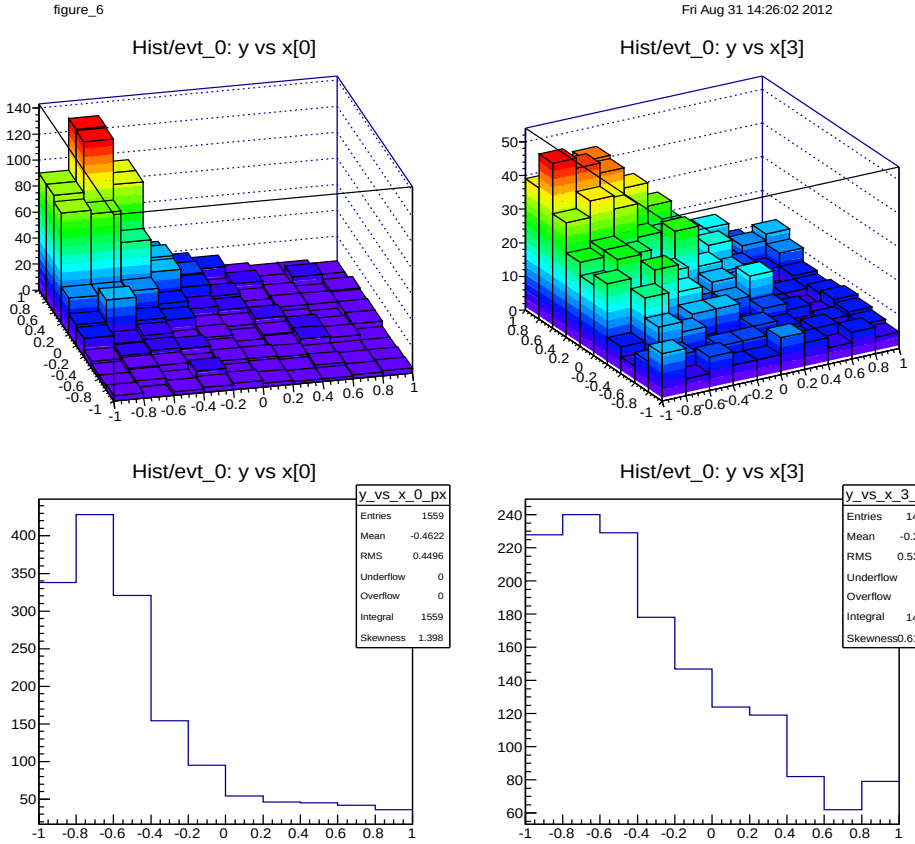
$$\sigma_x{}^2 = < X^2 > - < X >^2$$

- weigh signals on the 2 sides:

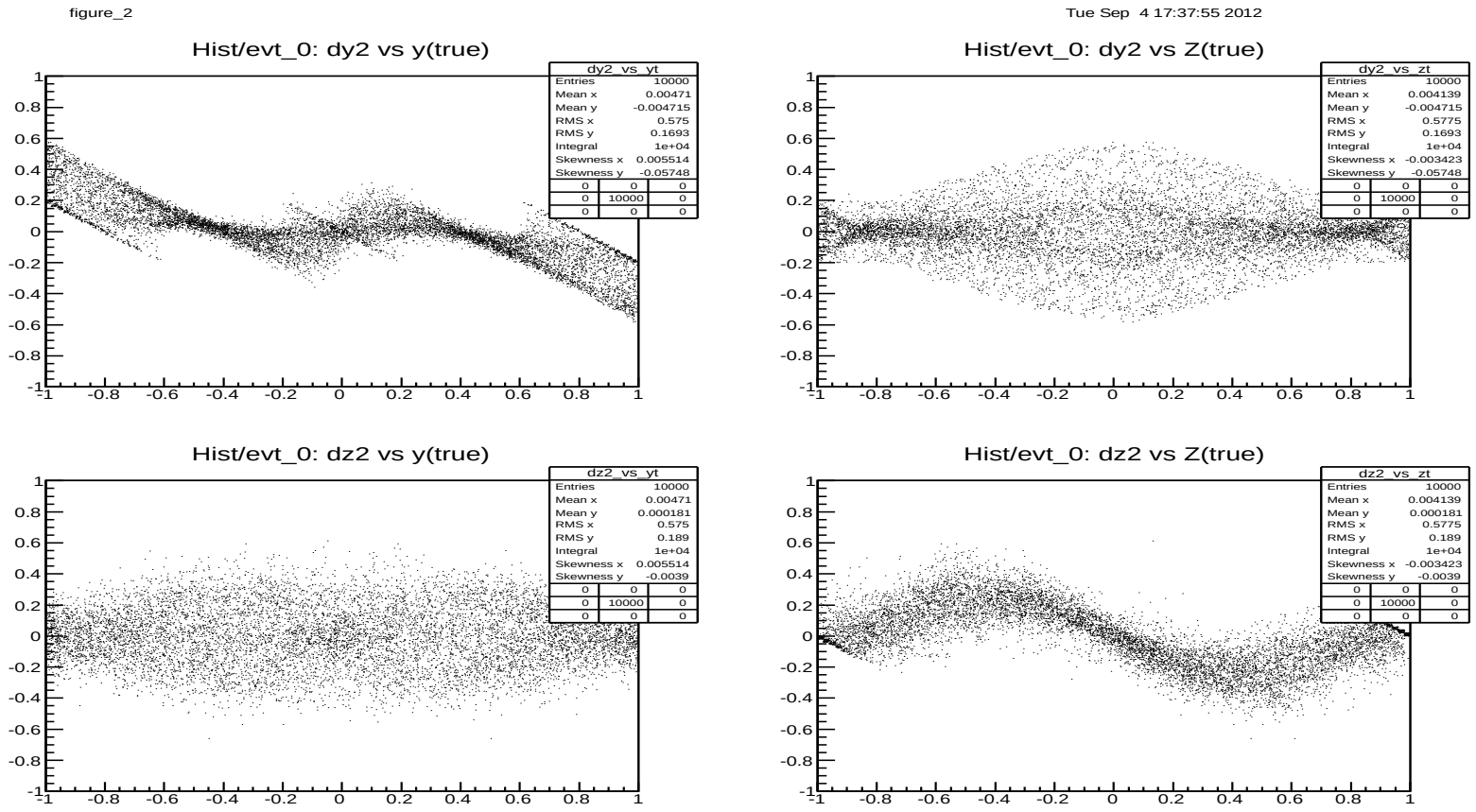
$$X = \frac{X_1 \cdot w_1 + X_2 \cdot w_2}{w_1 + w_2}, \quad w_i = 1/\sigma_i{}^2$$

- same for the Z coordinate:

$$Z = \frac{Z_1 \cdot w_1 + Z_2 \cdot w_2}{w_1 + w_2}$$

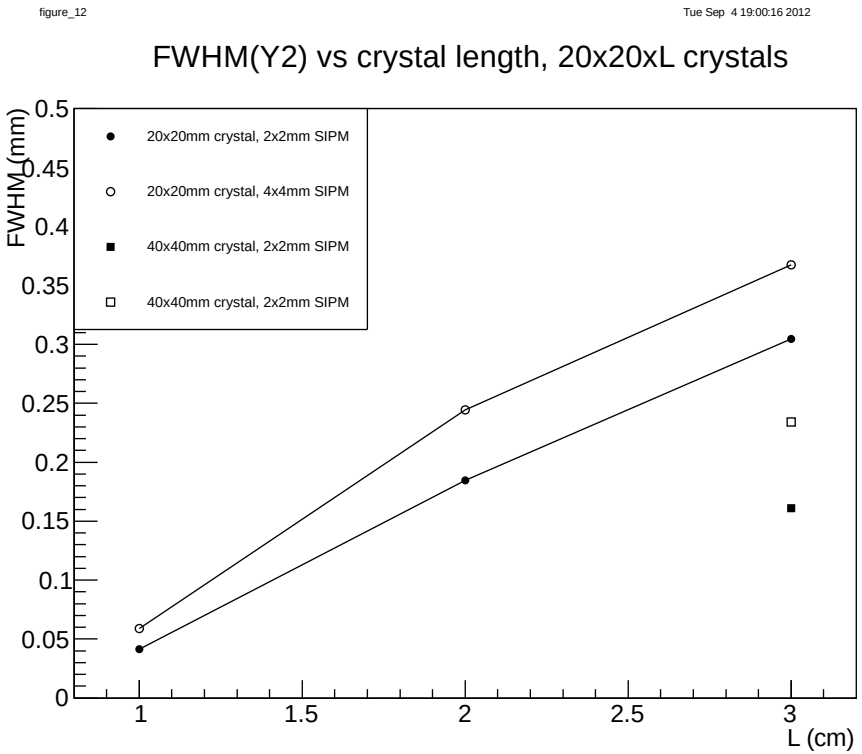


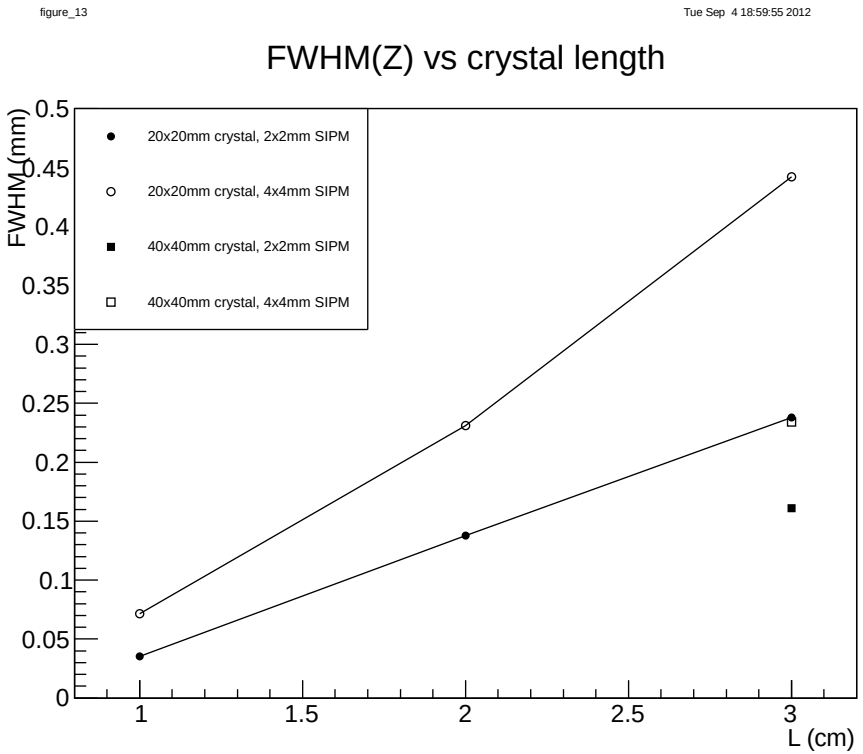
Reconstruction Results, 20x20x20mm^3



- averaged over the crystal volume, Y_{rec} doesn't depend on Z, and Z_{rec} doesn't depend on Y
- systematic dependence of Y_{rec} on Y_{true}, same for Z_{rec}
- edge effects

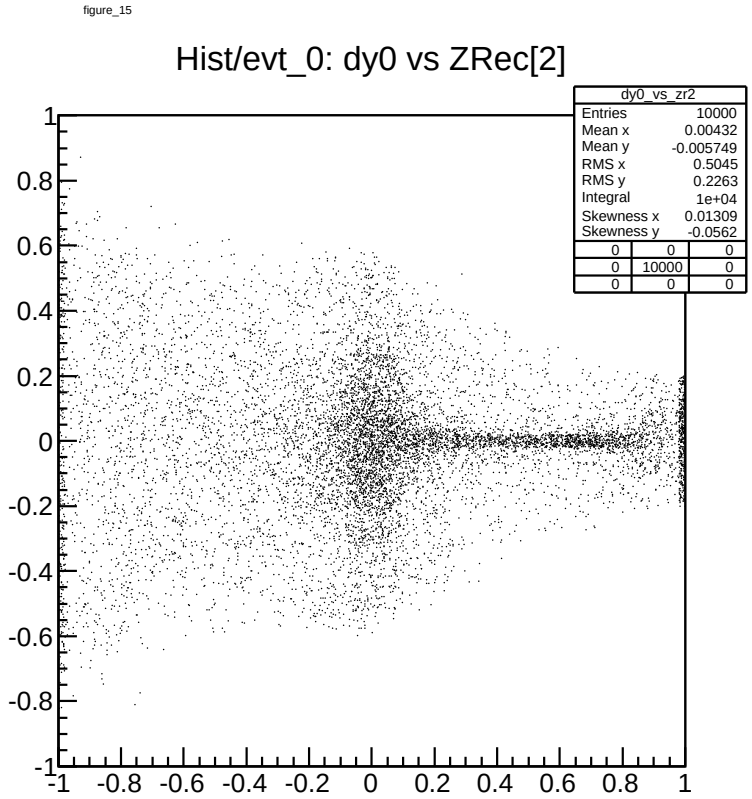
Resolution vs Crystal Size

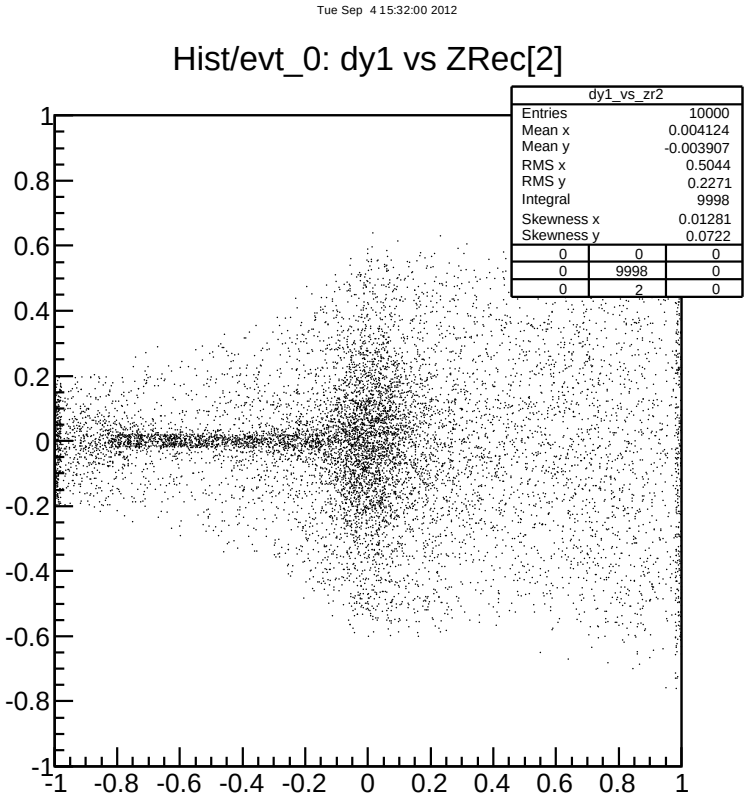




- Y - resolution doesn't depend strongly on the SiPM size,
- for 20mm crystals MC predicts resolution of about 2mm FWHM
- resolution in Z (DOI): for 20mm crystals $\approx$ 2mm FWHM, scales with the SiPM size
- for the same crystal thickness, resolution significantly improves for 40x40mm2 crystals

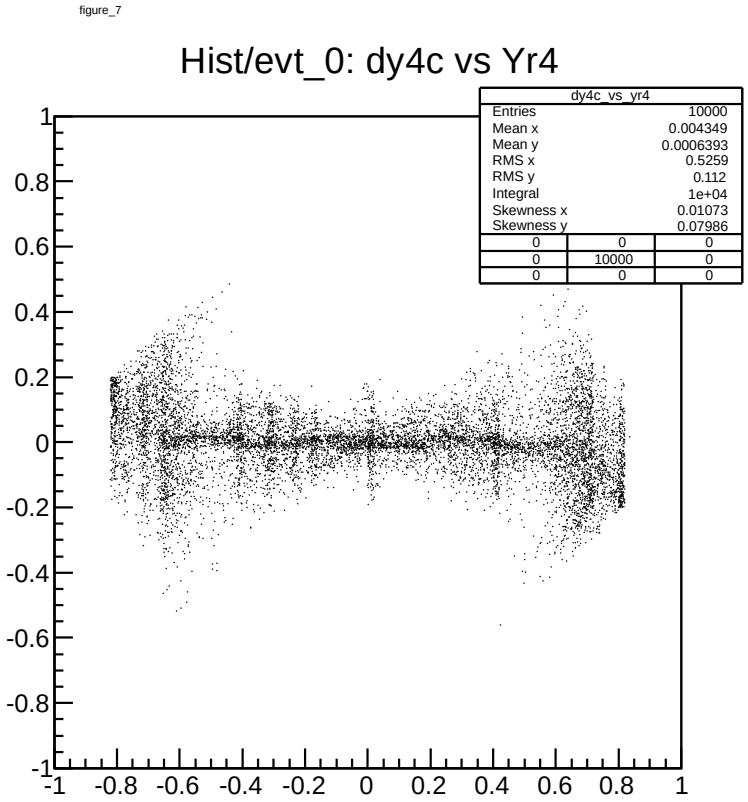
Resolution in Y vs Z(rec)

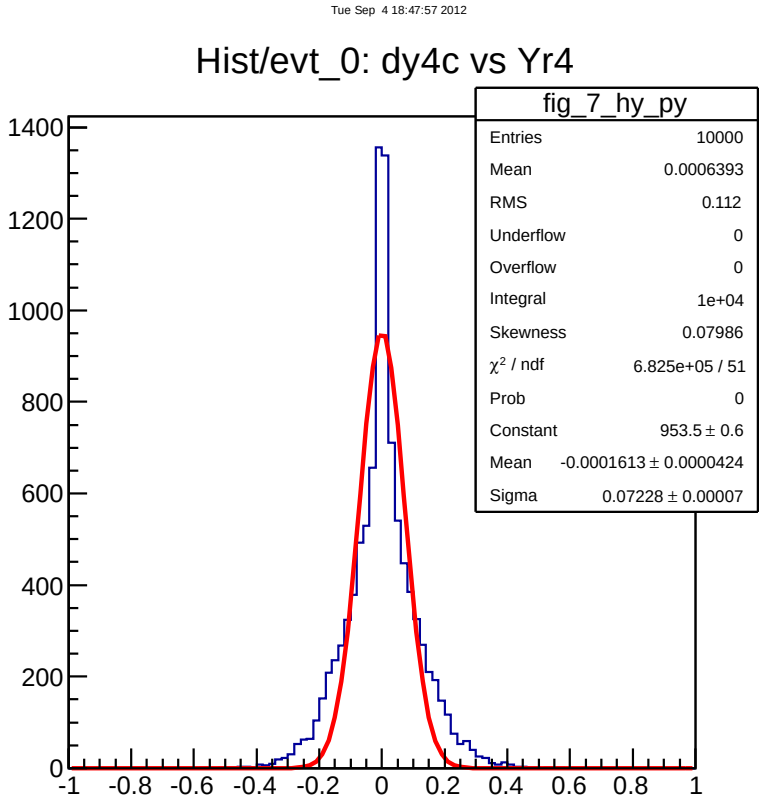




- Approach 2: for $|Zrec|$ > 3mm use Y-coordinate reconstructed on the closest Z side
- for $|Z_{rec}|$ < 3mm use weighted average as described above

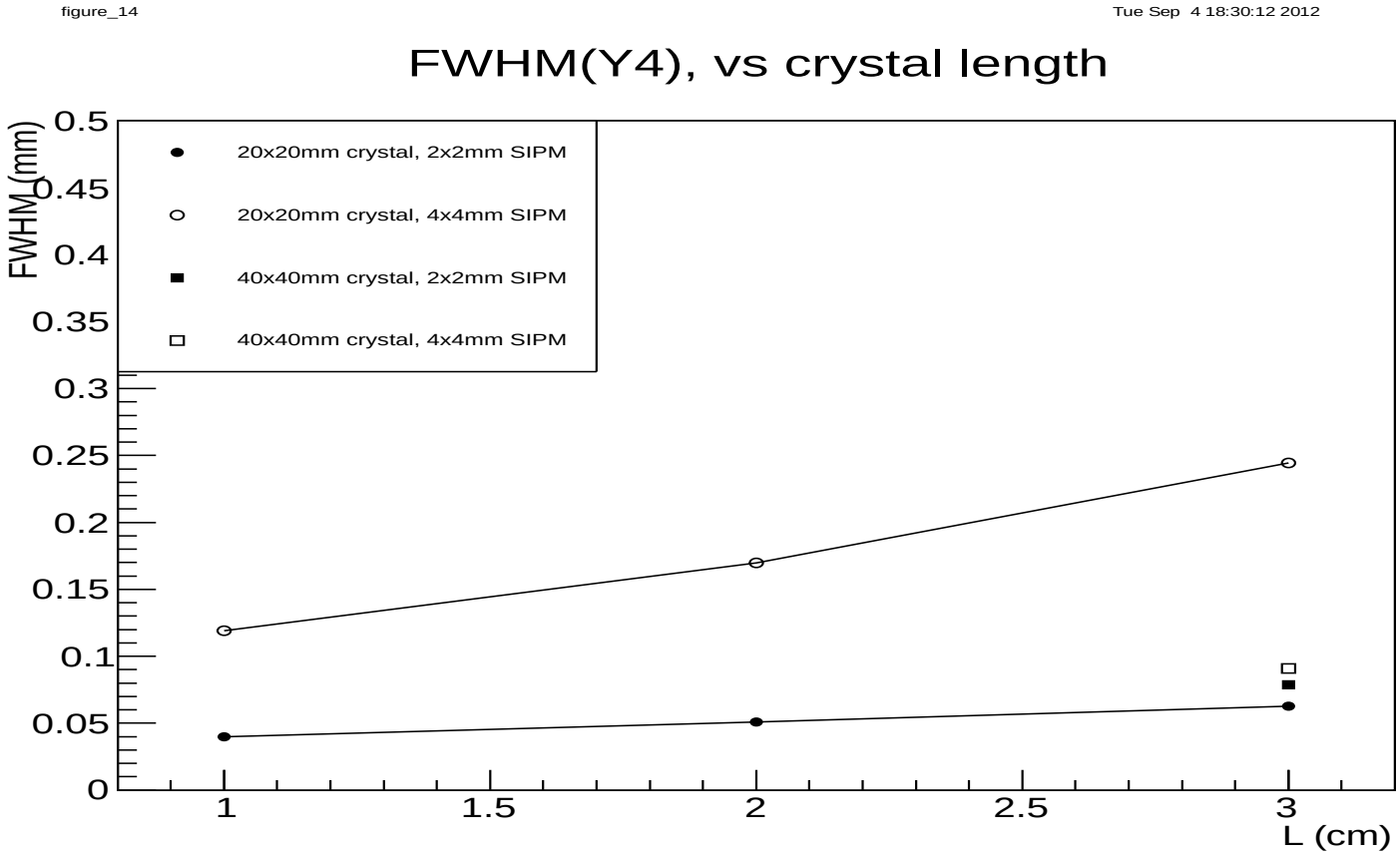
Approach II Results





- after correcting , MC-based, for nonlinearity, see remaining structure
- the resolution peak becomes strongly on-gaussian, however FWHM < 1mm
- gaussian fit resutls in FWHM 1.7mm

Summary, approach II



- with 4x4mm SiPMs can achieve resolution in Y of 2.5mm FWHM even for 20x20x30mm crystals
- with 2x2mm SiPMs predicted resolution in Y is about 0.5mm FWHM (strongly non-gaussian)
- for 40x40mm crystals predicted resolution is in the submillimeter range even for L = 30mm

Summary

- MC predicts that using 2-sided readout of large, 20x20 mm and 40x40 mm, crystals one can achieve coordinate resolution of the order 1-2mm FWHM using fairly simple and fast reconstruction procedures
- MC estimates for transverse resolutons are consistent with the results of the Delft Univ group, which used the single-sided readout
- the depth of interaction (DOI) can be measured with the accuracy of 1.5-45 mm FWHM, depending on the crystal geometry
- DOI resolutioin of about 2mm seems to be achievable
- the resolution improves with SY/SZ
- with rather minimal engineering effort we can perform measurements to test the resolution with the 2-sided SiPM-based readout