Geant 4 simulation of the DEPFET beam test

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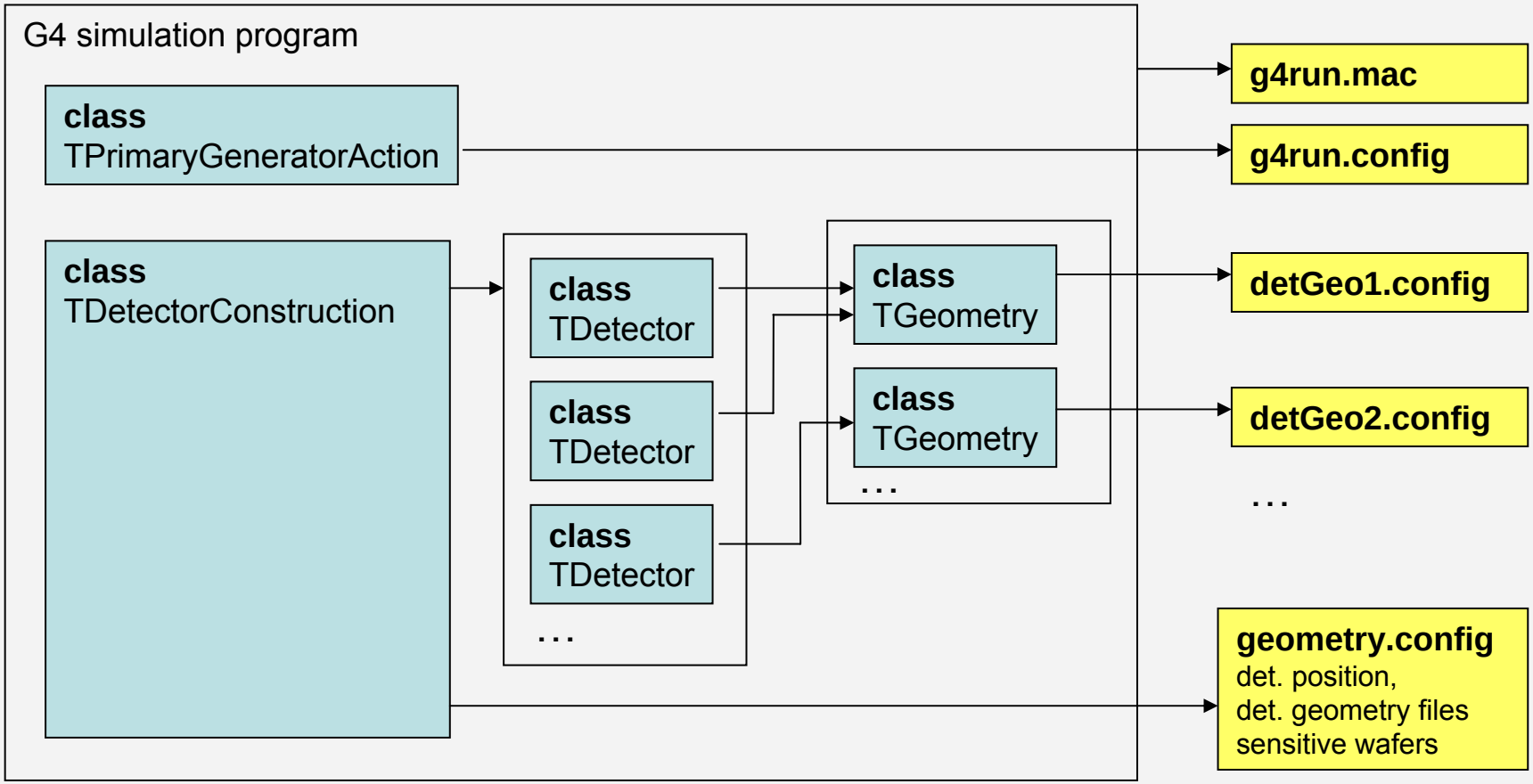
Geant 4 simulation program

- More about Geant 4 framework at **www.cern.ch/geant4**
- C++ object oriented architecture
- Parameters are loaded from files



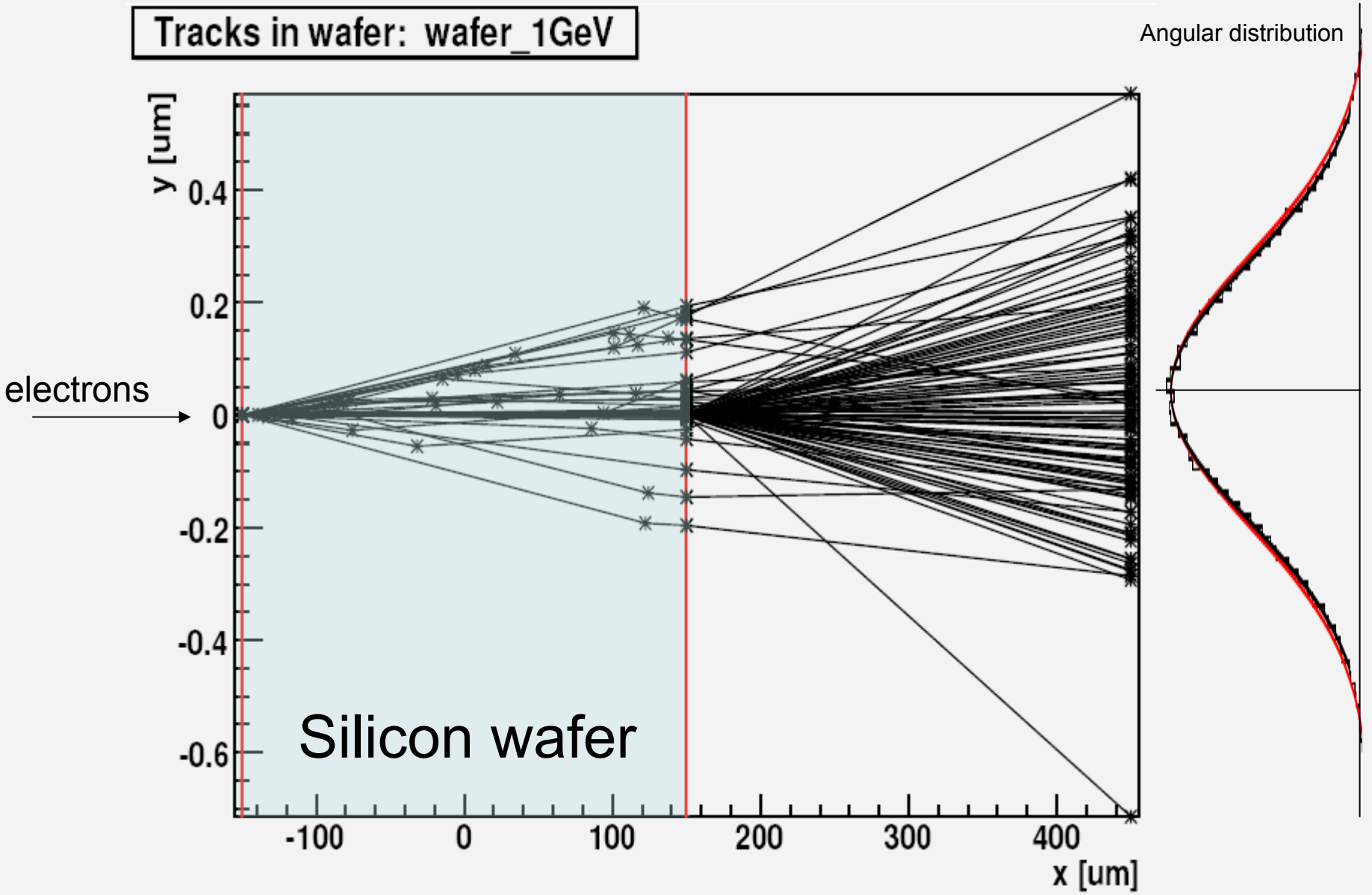
Model validation

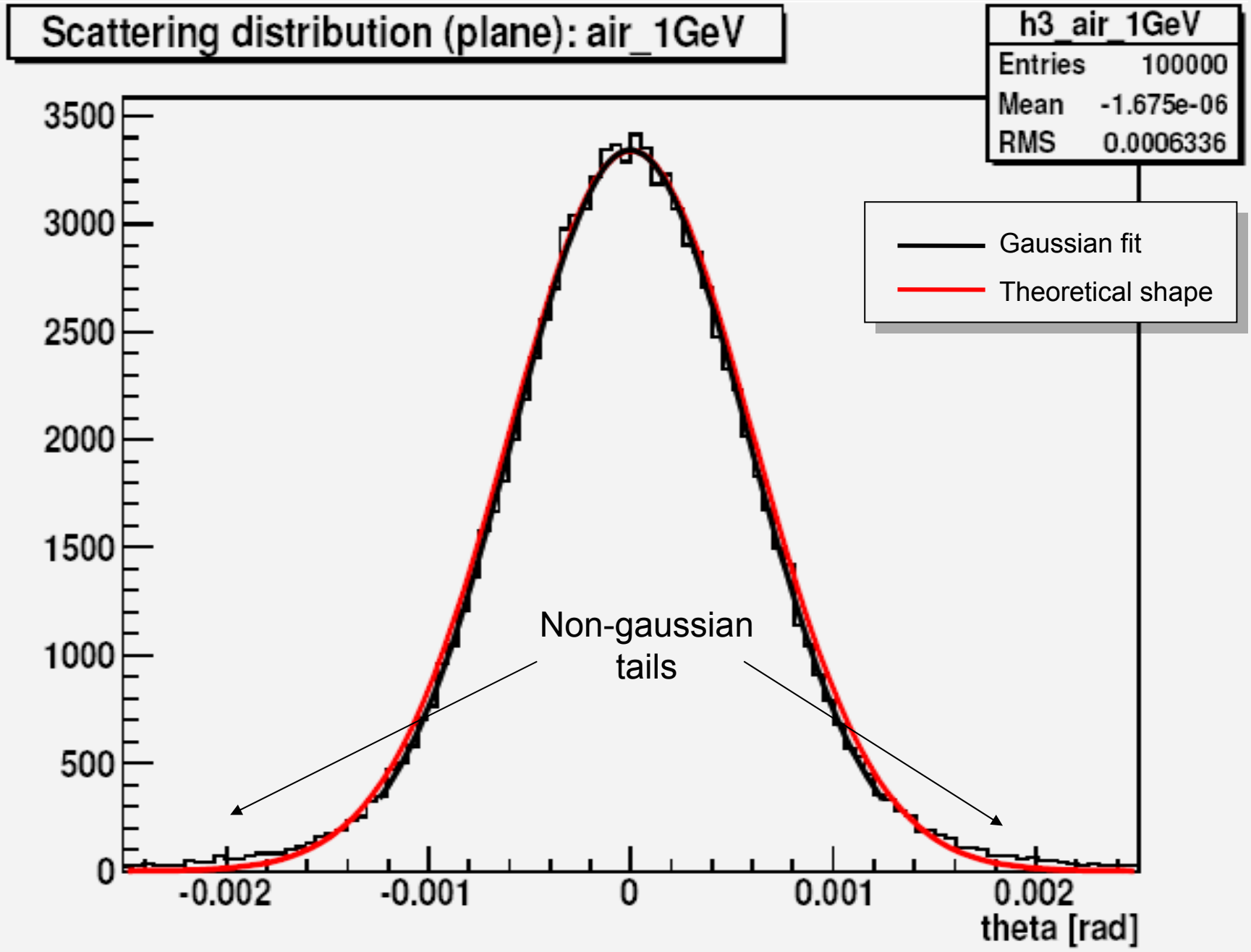
- Simulation of an electron scattering in the 300 μm silicon wafer
- Angular distribution histogram
- Comparison with a theoretical shape of the distribution. According to the Particle Physics Review it is approximately Gaussian with a width given by the formula:

$$\theta_0 = 13.6\text{MeV}\, z\sqrt{\frac{x}{X_0}}\left(1 + 0.038\ \ln\left(\frac{x}{X_0}\right)\right)\beta^{-1}c^{-1}p^{-1}$$

where *p*, β and *z* are the momentum, velocity and charge number, and x/X_0 is the thickness in radiation length. Accuracy of θ_0 is 11% or better.

Example of an electron scattering




Scattering distribution (plane): air_1GeV
h3_air_1GeV
Entries 100000
Mean -1.675e-06
RMS 0.0006336
Gaussian fit
Theoretical shape
Non-gaussian tails
3500
3000
2500
2000
1500
1000
500
0
-0.002
-0.001
0
0.001
0.002
theta [rad]

Results: simulation vs. theory

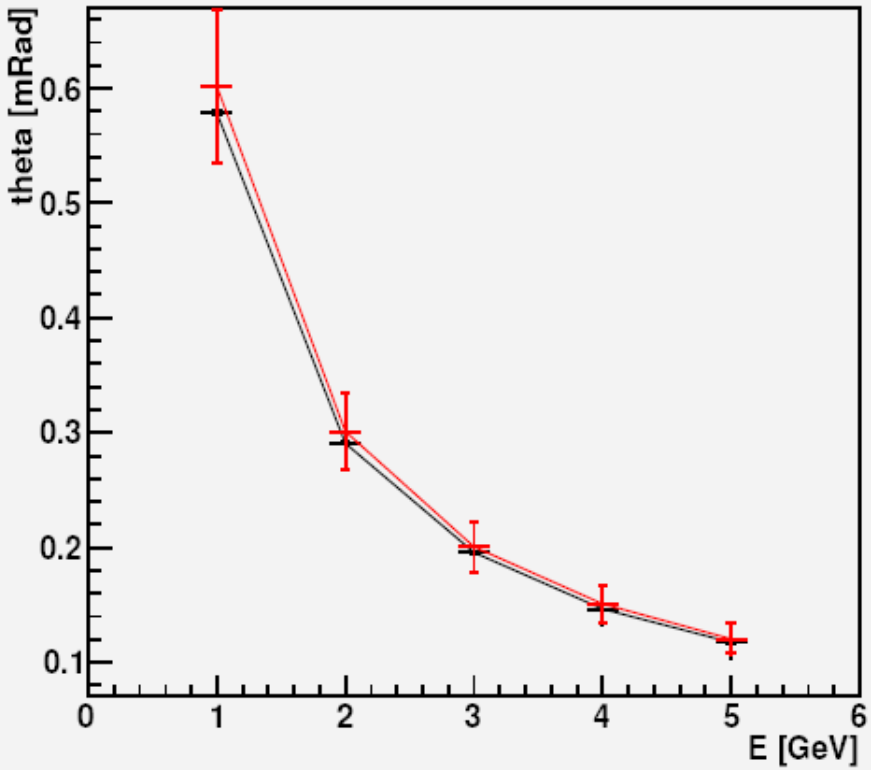
ϑ_0... width of the theoretical Gaussian distribution

σ…width of the fitted Gaussian

accuracy of ϑ_0 parametrisation (theory) is 11% or better

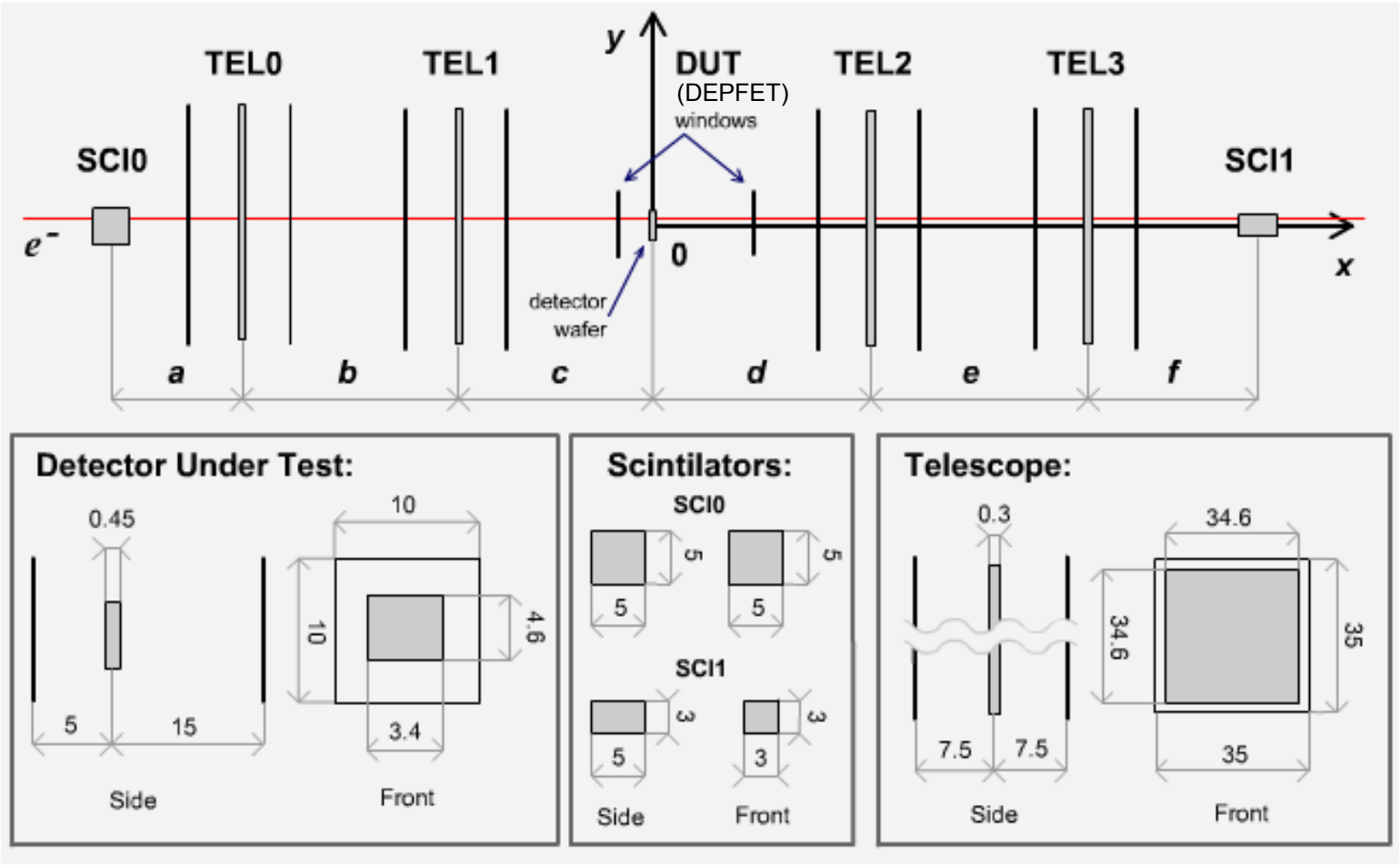
	Simulation	Theory	
E [GeV]	σ [mRad]	ϑ_0 [mRad]	ϑ_0/σ
1	0.57905 ± 0.00191	0.602 ± 0.066	0.96
2	0.29061 ± 0.00087	0.301 ± 0.033	0.97
3	0.19550 ± 0.00055	0.201 ± 0.022	0.97
4	0.14610 ± 0.00041	0.150 ± 0.017	0.97
5	0.11719 ± 0.00032	0.120 ± 0.013	0.97

Sigma and theta0 vs. energy



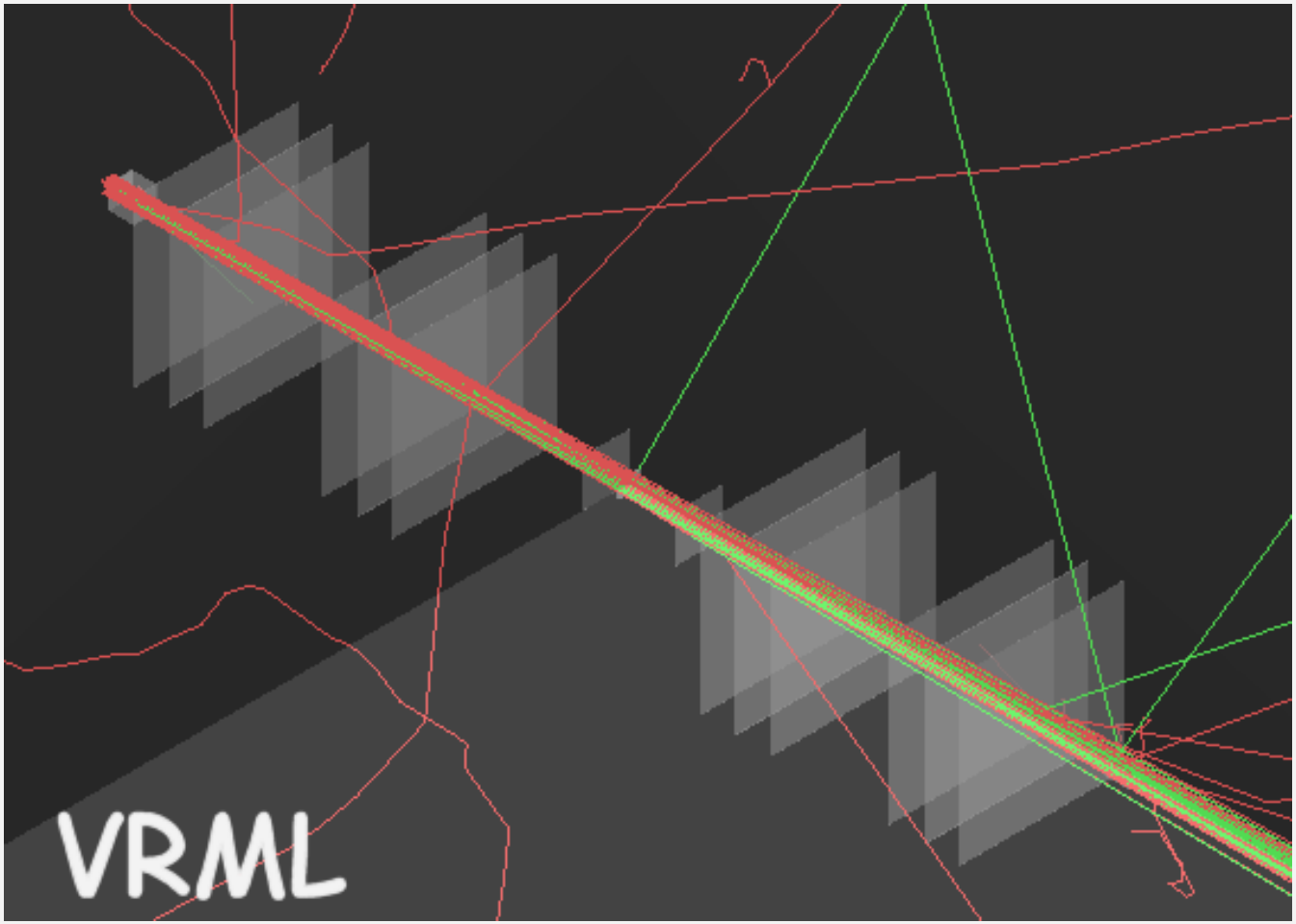
Good agreement between the G4 simulation and the theory

Geometry of the beam test



Electron beam: 3x3 mm^2, homogenous, parallel with x-axis

Geometry of the beam test: example



Configurations used for the simulation

as planned for January 2006 TB – info from Lars Reuen, October 2005

Geometry 1

a [mm]	b [mm]	c [mm]	d [mm]	e [mm]	f [mm]
15	40	40	40	40	15

Module windows:
- 50 μm copper foils
- no foils
- 150 μm copper foils

Geometry 2

a [mm]	b [mm]	c [mm]	d [mm]	e [mm]	f [mm]
15	140	40	40	140	15

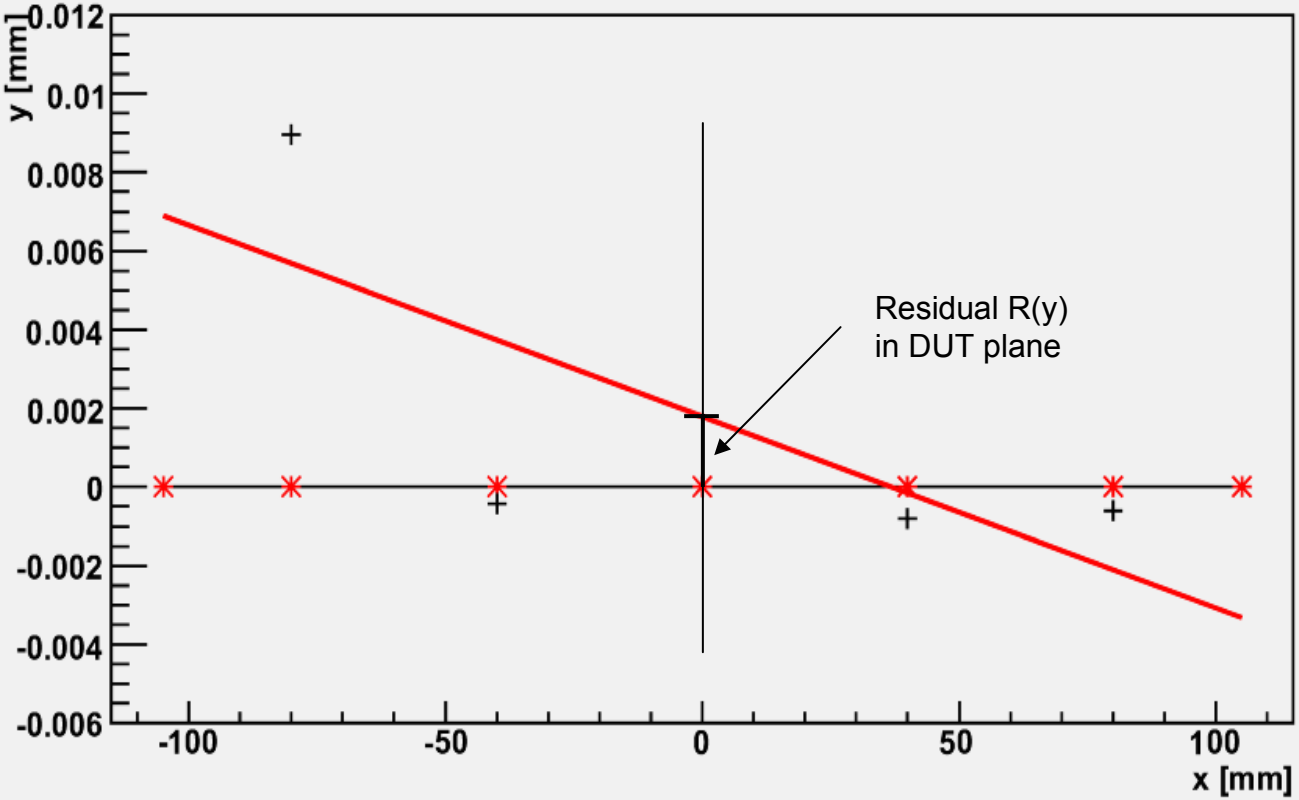
Module windows:
- 50 μm copper foils

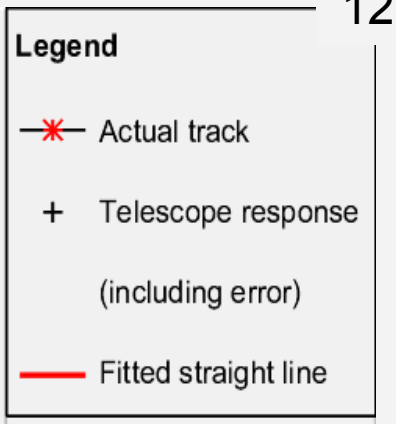
Unscattered particle

- Intersects of an unscattered particle lies on a straight line.
- A resolution of telescopes is approximately

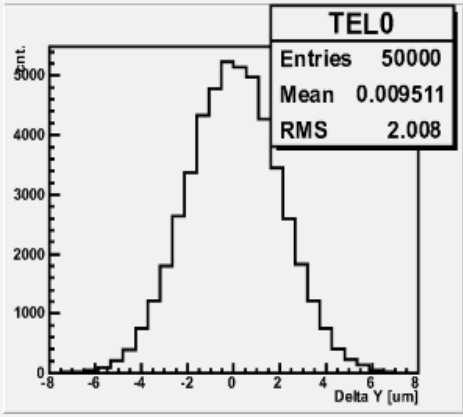
  pitch/(S/N) ~ 2 μm.
- Positions of intersects in telescopes plane were blurred with a Gaussian to simulate telescope resolution.
- These points were fitted by a straight line.

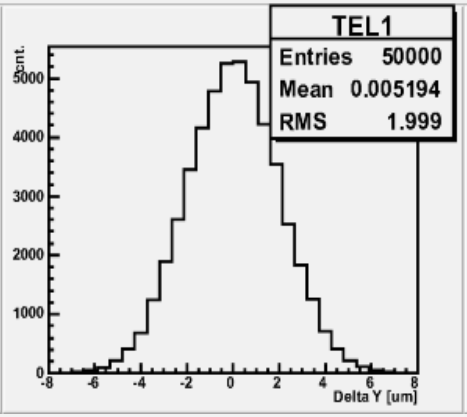
Reconstructed tracks from telescopes intersects

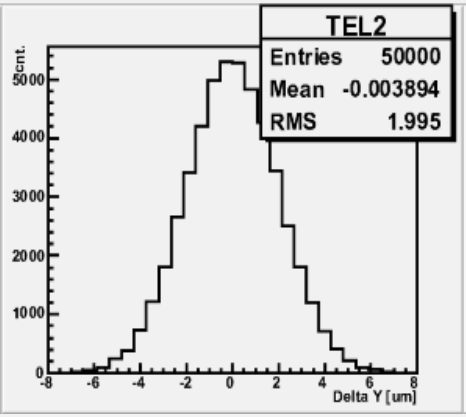


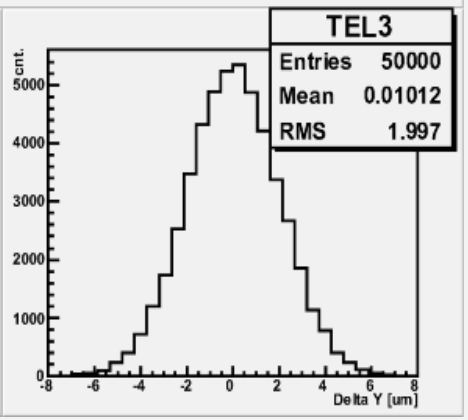


Error distribution of telescopes intersects





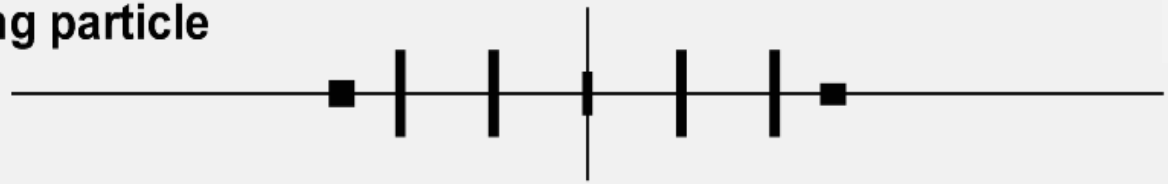




Y residual plots: non-scattering particle

Geometry 1

No. of events: 50000

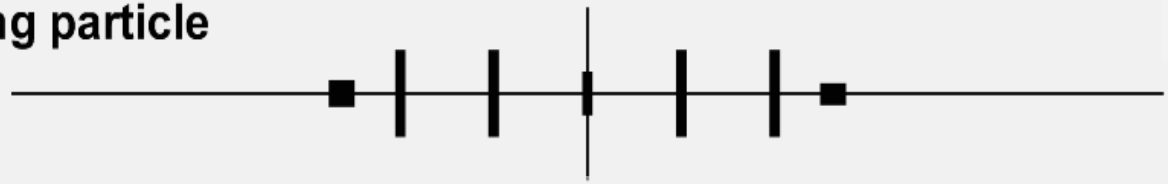


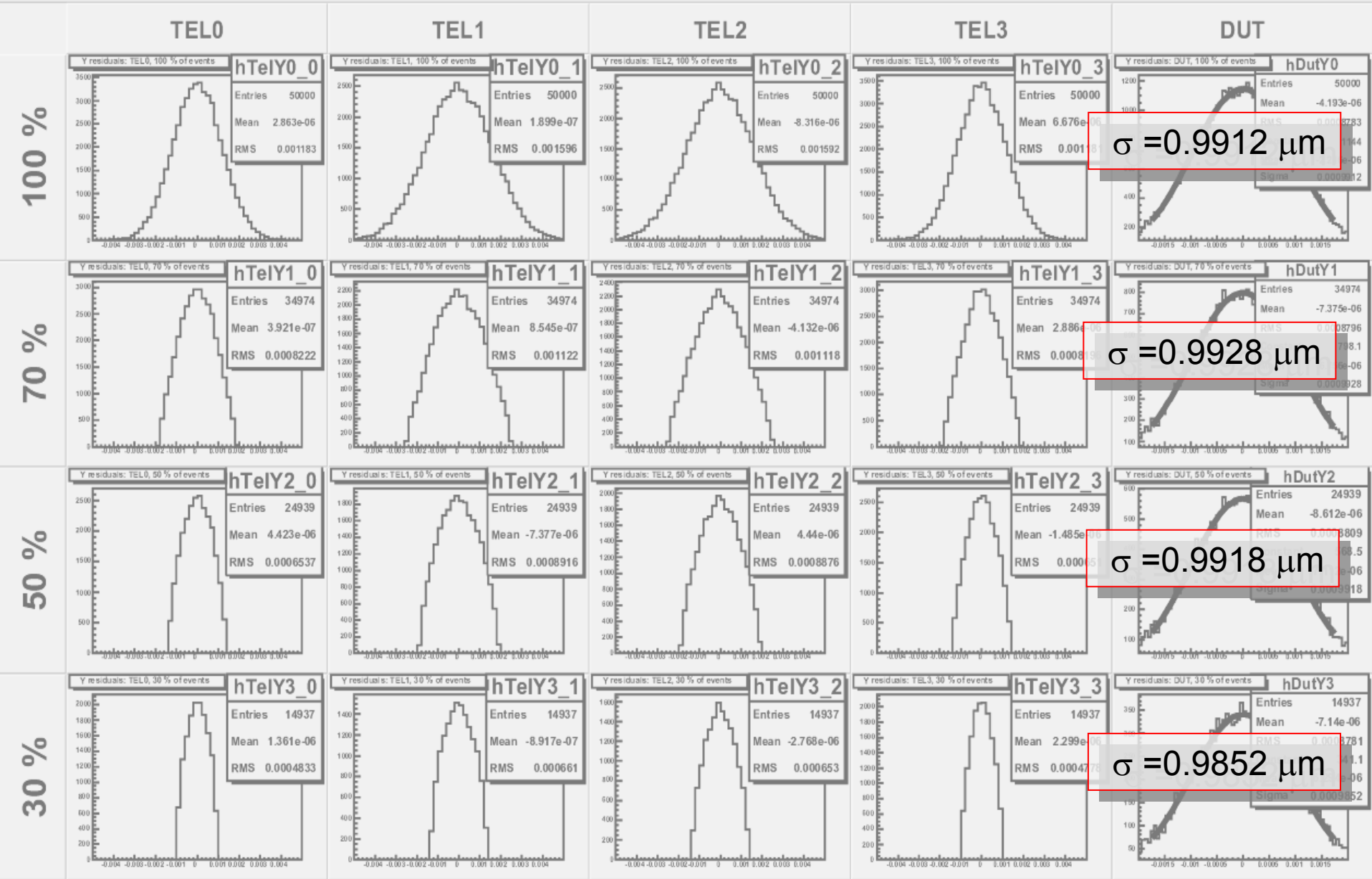
	TEL0	TEL1	TEL2	TEL3	DUT
100 %	Y residuals: TEL0, 100 % of events hTelY0_0 Entries 50000 Mean 2.863e-06 RMS 0.001183	Y residuals: TEL1, 100 % of events hTelY0_1 Entries 50000 Mean 1.899e-07 RMS 0.001596	Y residuals: TEL2, 100 % of events hTelY0_2 Entries 50000 Mean -8.316e-06 RMS 0.001592	Y residuals: TEL3, 100 % of events hTelY0_3 Entries 50000 Mean 6.676e-06 RMS 0.001181	Y residuals: DUT, 100 % of events hDutY0 Entries 50000 Mean -4.193e-06 RMS 0.0008783 Constant 1144 Mean -2.216e-06 Sigma 0.0009912
70 %	Y residuals: TEL0, 70 % of events hTelY1_0 Entries 34974 Mean 3.921e-07 RMS 0.0008222	Y residuals: TEL1, 70 % of events hTelY1_1 Entries 34974 Mean 8.545e-07 RMS 0.001122	Y residuals: TEL2, 70 % of events hTelY1_2 Entries 34974 Mean -4.132e-06 RMS 0.001118	Y residuals: TEL3, 70 % of events hTelY1_3 Entries 34974 Mean 2.886e-06 RMS 0.0008196	Y residuals: DUT, 70 % of events hDutY1 Entries 34974 Mean -7.375e-06 RMS 0.0008796 Constant 798.1 Mean -6.756e-06 Sigma 0.0009928
50 %	Y residuals: TEL0, 50 % of events hTelY2_0 Entries 24939 Mean 4.423e-06 RMS 0.0006537	Y residuals: TEL1, 50 % of events hTelY2_1 Entries 24939 Mean -7.377e-06 RMS 0.0008916	Y residuals: TEL2, 50 % of events hTelY2_2 Entries 24939 Mean 4.44e-06 RMS 0.0008876	Y residuals: TEL3, 50 % of events hTelY2_3 Entries 24939 Mean -1.485e-06 RMS 0.000651	Y residuals: DUT, 50 % of events hDutY2 Entries 24939 Mean -8.612e-06 RMS 0.0008809 Constant 568.5 Mean -7.112e-06 Sigma 0.0009918
30 %	Y residuals: TEL0, 30 % of events hTelY3_0 Entries 14937 Mean 1.361e-06 RMS 0.0004833	Y residuals: TEL1, 30 % of events hTelY3_1 Entries 14937 Mean -8.917e-07 RMS 0.000661	Y residuals: TEL2, 30 % of events hTelY3_2 Entries 14937 Mean -2.768e-06 RMS 0.000653	Y residuals: TEL3, 30 % of events hTelY3_3 Entries 14937 Mean 2.299e-06 RMS 0.0004778	Y residuals: DUT, 30 % of events hDutY3 Entries 14937 Mean -7.14e-06 RMS 0.0008781 Constant 341.1 Mean -6.294e-06 Sigma 0.0009852

Y residual plots: non-scattering particle

Geometry 1

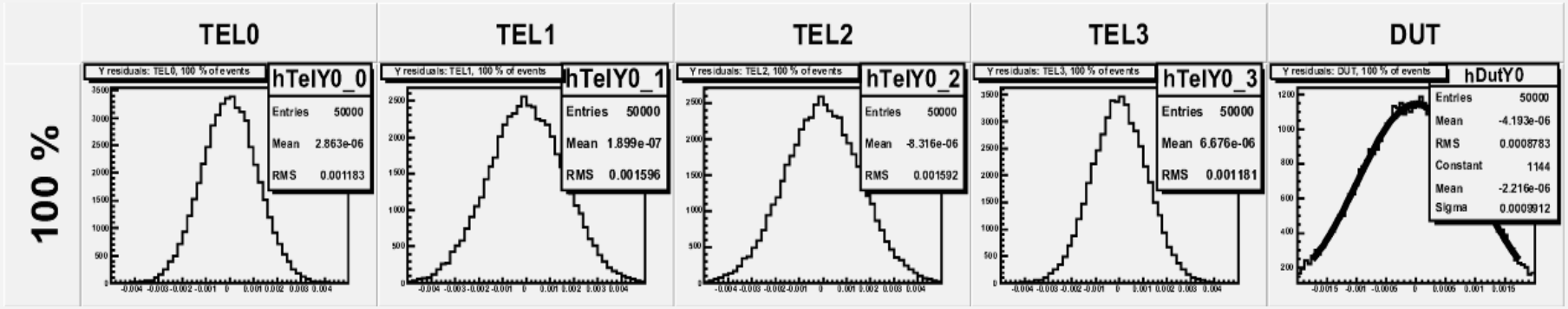
No. of events: 50000





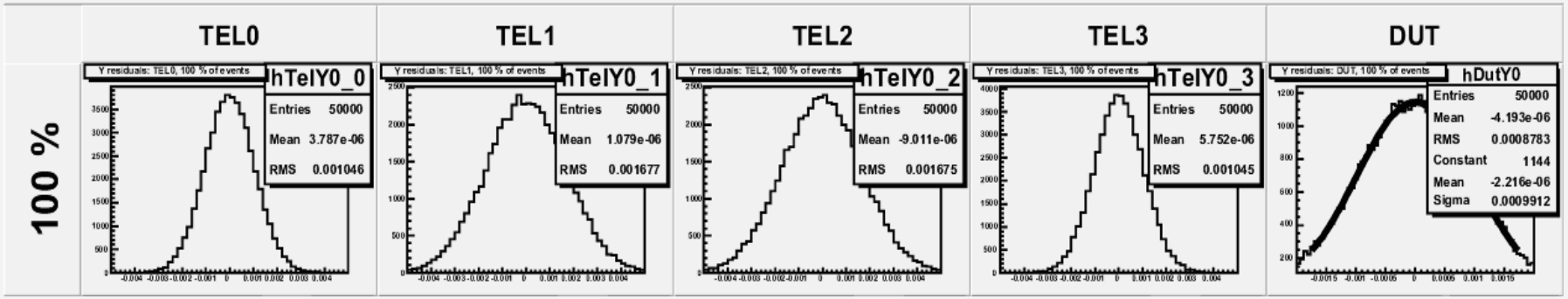
Unscattered particles: residual plots

Geometry 1



σ = 1.19 μm σ = 1.60 μm σ = 1.60 μm σ = 1.18 μm σ = 0.99 μm

Geometry 2

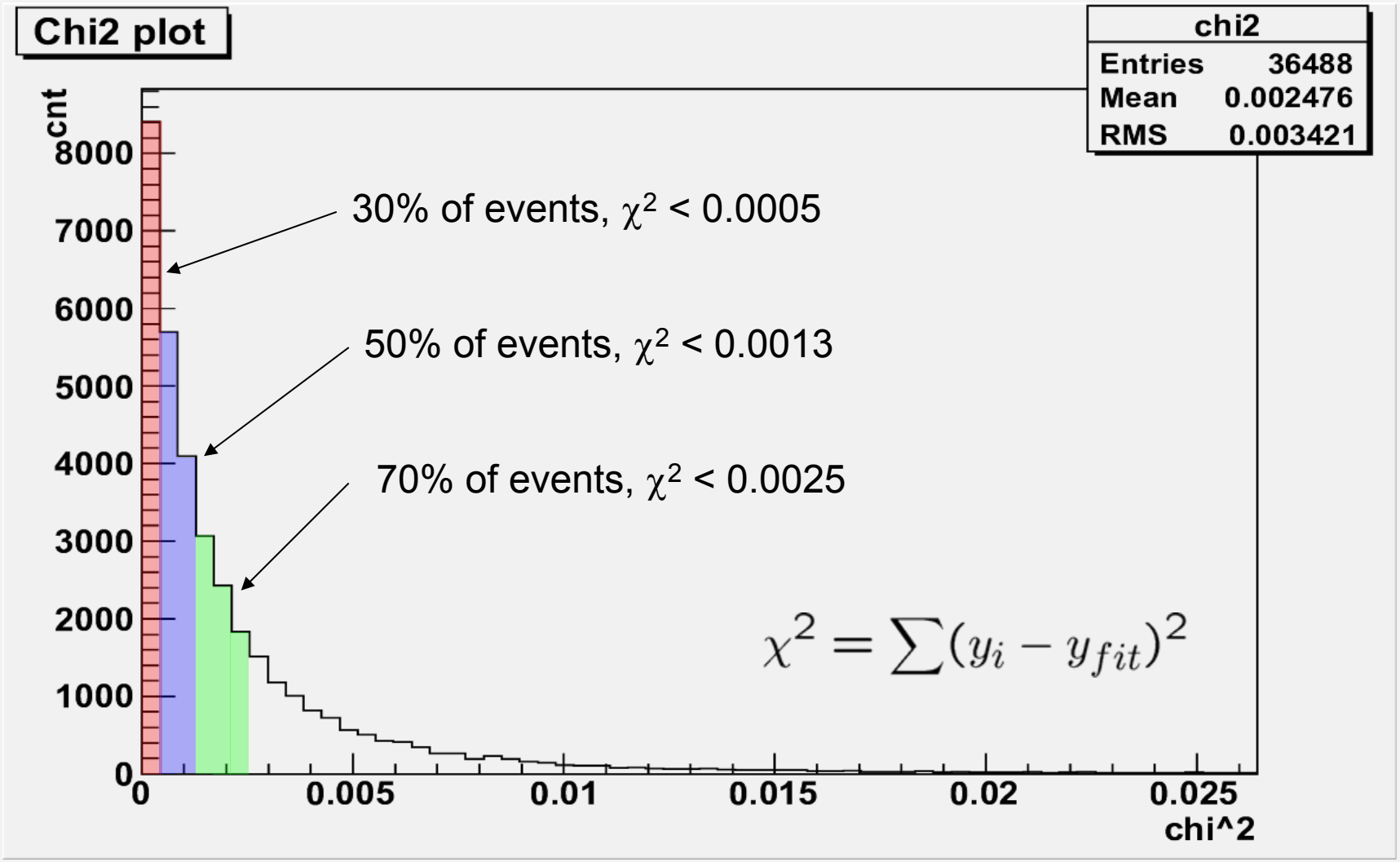


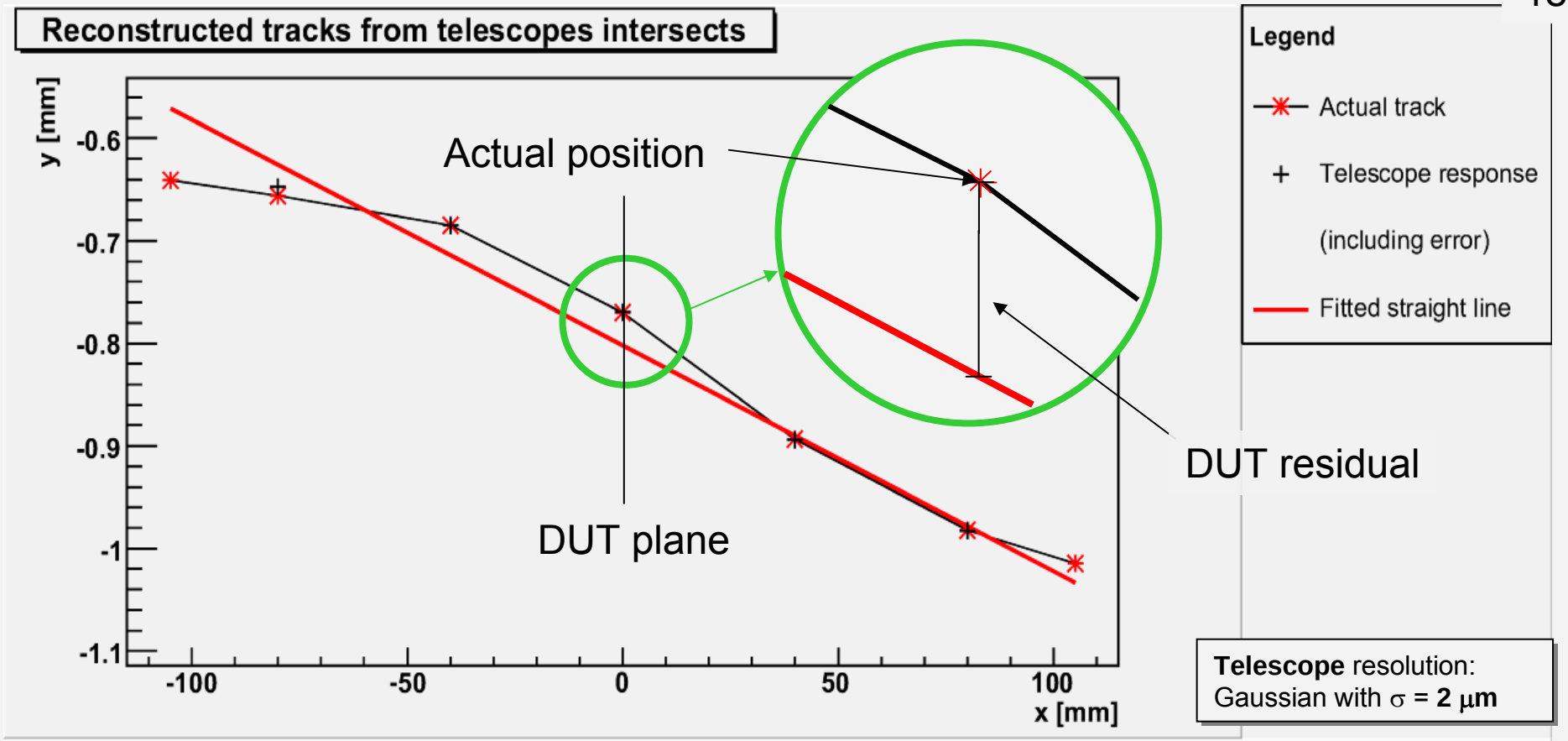
σ = 1.05 μm σ = 1.68 μm σ = 1.68 μm σ = 1.05 μm σ = 0.99 μm

Electron beam simulation

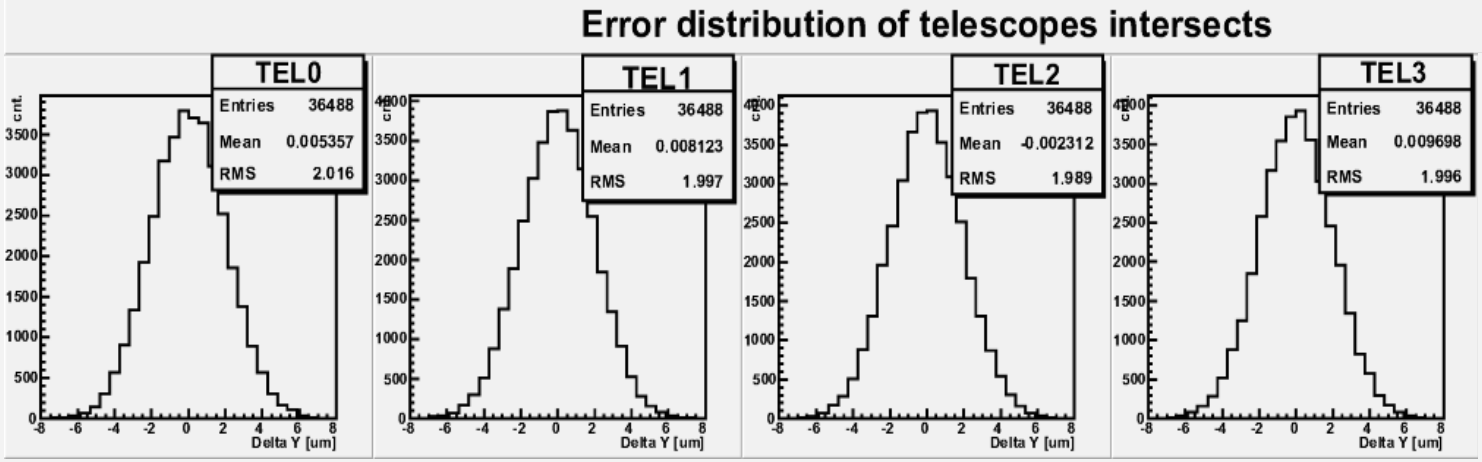
- There are 2 main contributions to the residual plots RMS:
  - Multiple scattering
  - Telescope resolution
- Simulation was done for 1 GeV to 5 GeV electrons, 50000 events for each run
- Particles that didn't hit the both scintillators were excluded from the analysis
- χ^2 cuts were applied to exclude bad fits

Example of χ^2 cuts



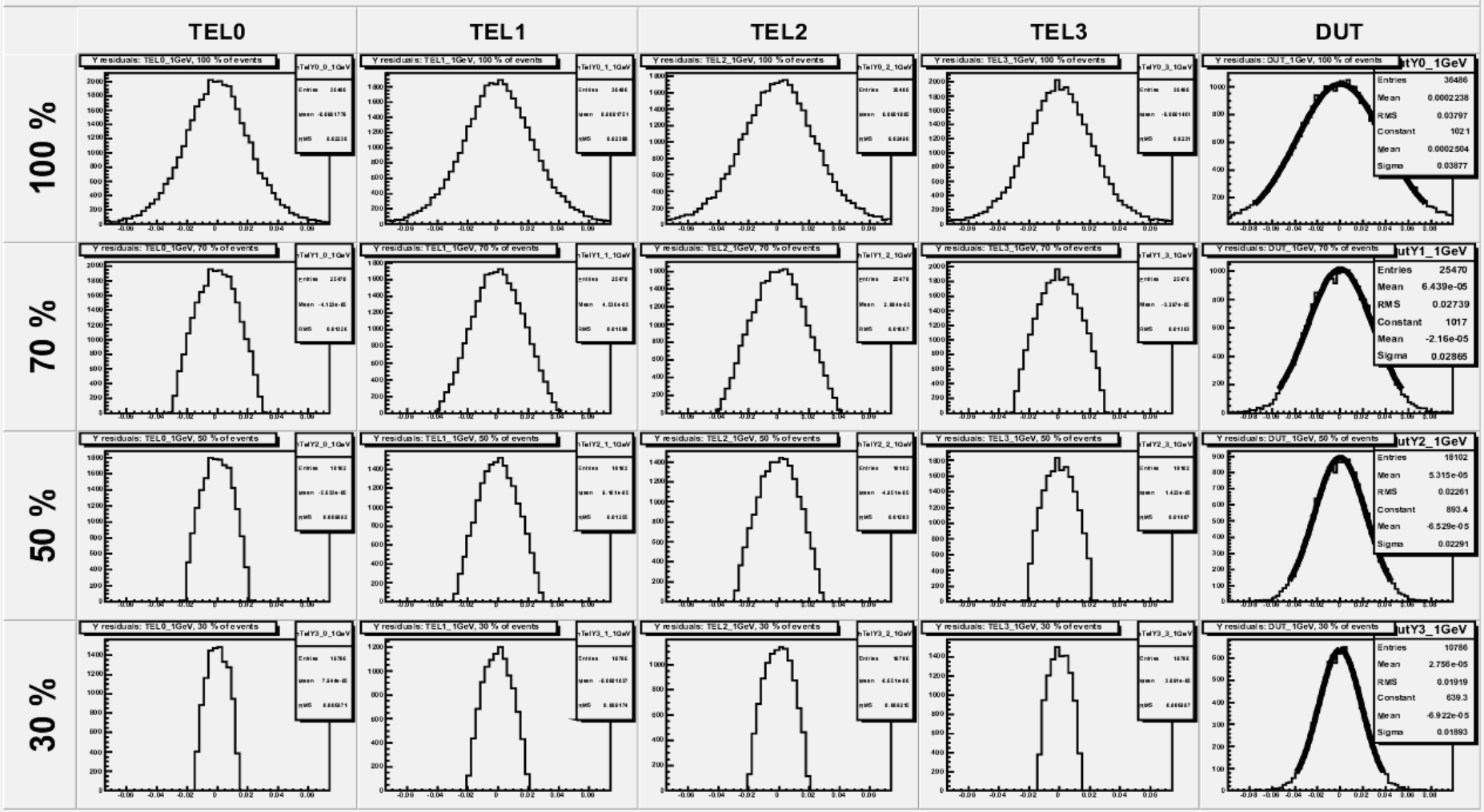


Telescope resolution:
Gaussian with σ = **2 μm**



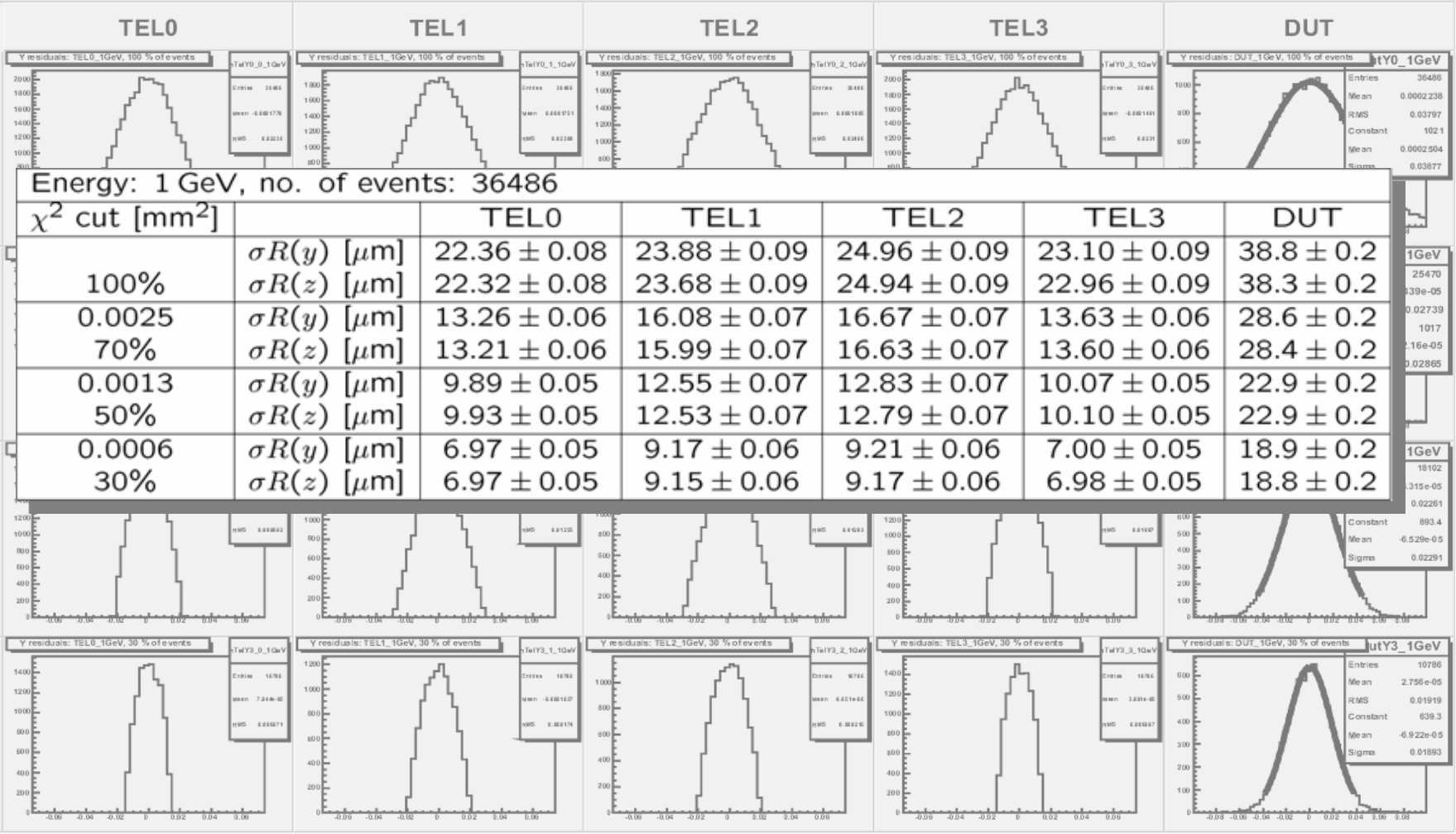
Electron beam simulation: residual plots

Y residual plots: 1GeV
Geometry 1
No. of events: 36486



Electron beam simulation: residual plots

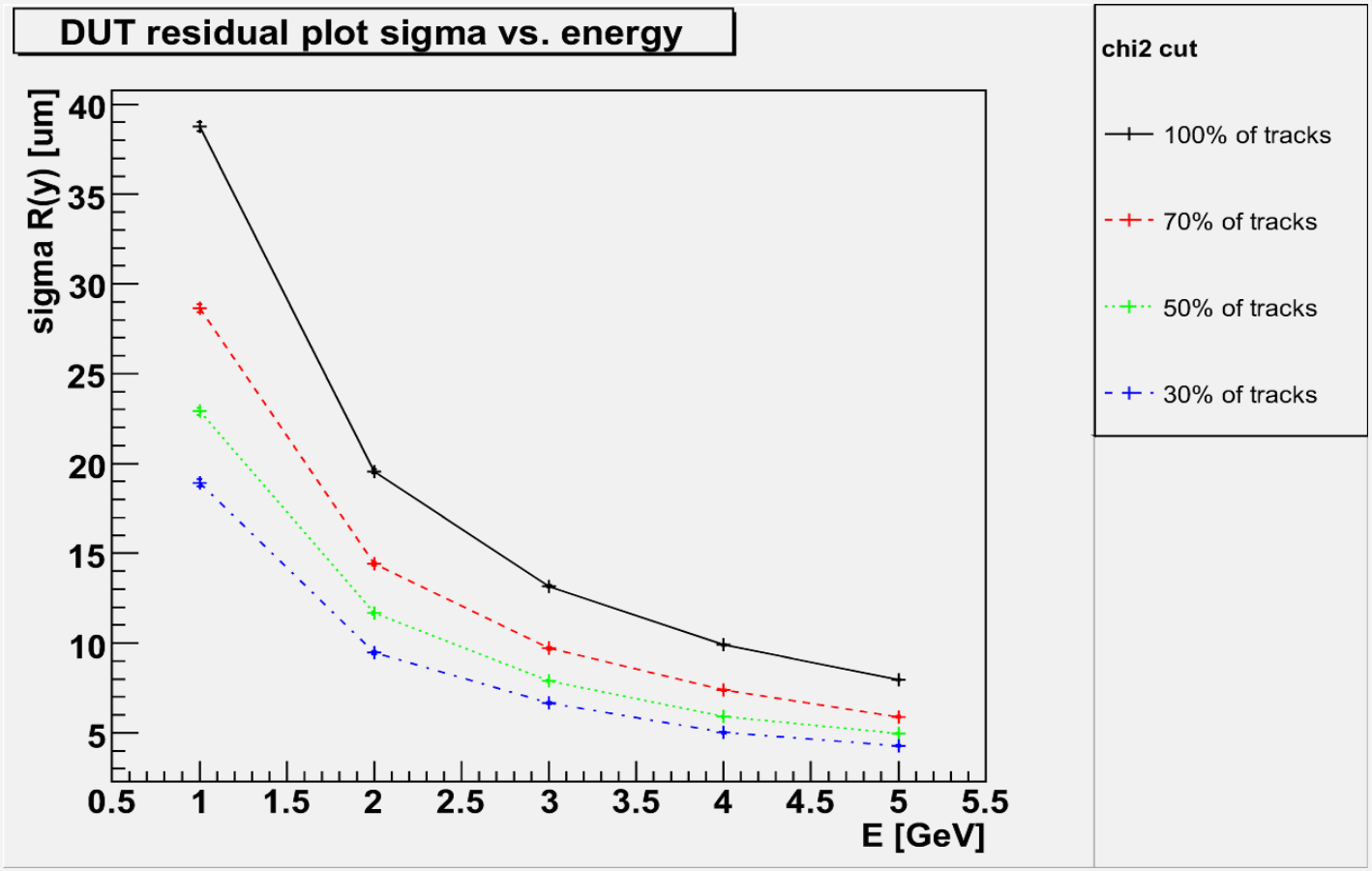
Y residual plots: 1GeV
Geometry 1
No. of events: 36486



Energy: 1 GeV, no. of events: 36486

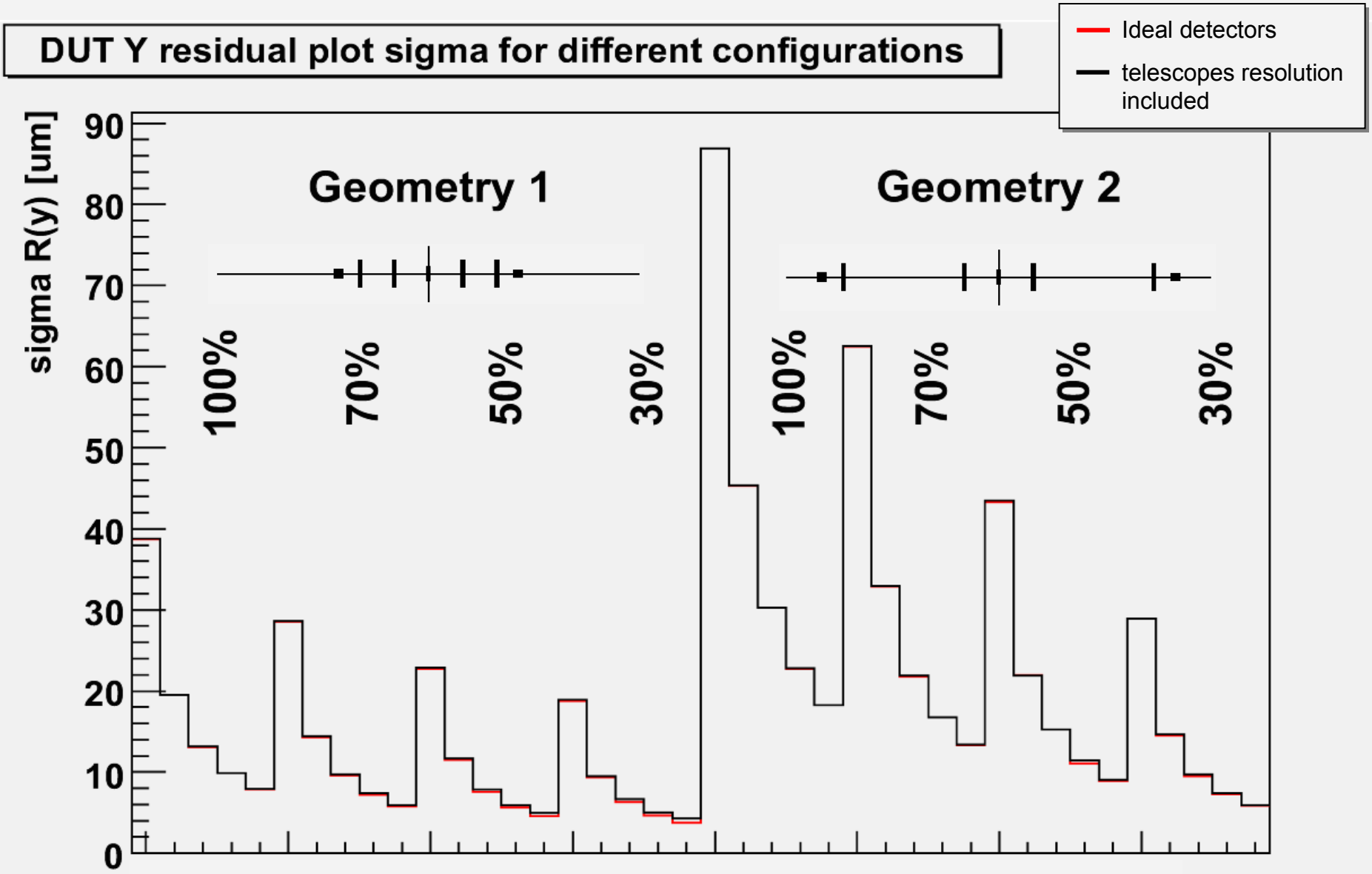
χ^2 cut [mm^2]		TEL0	TEL1	TEL2	TEL3	DUT
	$\sigma R(y)$ [μm]	22.36 ± 0.08	23.88 ± 0.09	24.96 ± 0.09	23.10 ± 0.09	38.8 ± 0.2
100%	$\sigma R(z)$ [μm]	22.32 ± 0.08	23.68 ± 0.09	24.94 ± 0.09	22.96 ± 0.09	38.3 ± 0.2
0.0025	$\sigma R(y)$ [μm]	13.26 ± 0.06	16.08 ± 0.07	16.67 ± 0.07	13.63 ± 0.06	28.6 ± 0.2
70%	$\sigma R(z)$ [μm]	13.21 ± 0.06	15.99 ± 0.07	16.63 ± 0.07	13.60 ± 0.06	28.4 ± 0.2
0.0013	$\sigma R(y)$ [μm]	9.89 ± 0.05	12.55 ± 0.07	12.83 ± 0.07	10.07 ± 0.05	22.9 ± 0.2
50%	$\sigma R(z)$ [μm]	9.93 ± 0.05	12.53 ± 0.07	12.79 ± 0.07	10.10 ± 0.05	22.9 ± 0.2
0.0006	$\sigma R(y)$ [μm]	6.97 ± 0.05	9.17 ± 0.06	9.21 ± 0.06	7.00 ± 0.05	18.9 ± 0.2
30%	$\sigma R(z)$ [μm]	6.97 ± 0.05	9.15 ± 0.06	9.17 ± 0.06	6.98 ± 0.05	18.8 ± 0.2

Residual-plot sigma vs. particle energy

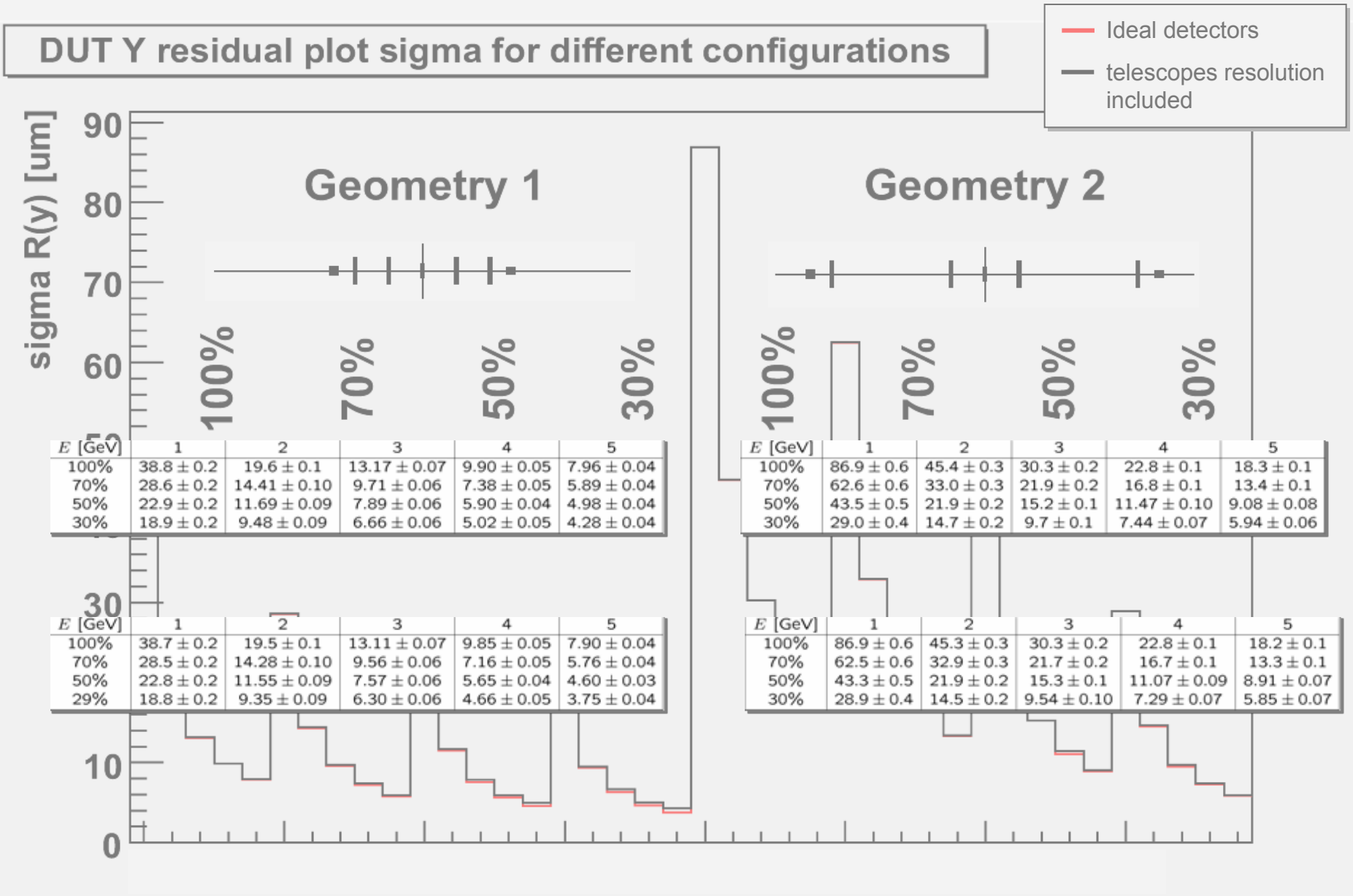


E [GeV]	1	2	3	4	5
100%	38.8 ± 0.2	19.6 ± 0.1	13.17 ± 0.07	9.90 ± 0.05	7.96 ± 0.04
70%	28.6 ± 0.2	14.41 ± 0.10	9.71 ± 0.06	7.38 ± 0.05	5.89 ± 0.04
50%	22.9 ± 0.2	11.69 ± 0.09	7.89 ± 0.06	5.90 ± 0.04	4.98 ± 0.04
30%	18.9 ± 0.2	9.48 ± 0.09	6.66 ± 0.06	5.02 ± 0.05	4.28 ± 0.04

Residual plots: two geometries



Residual plots: two geometries



E [GeV]	1	2	3	4	5
100%	38.8 ± 0.2	19.6 ± 0.1	13.17 ± 0.07	9.90 ± 0.05	7.96 ± 0.04
70%	28.6 ± 0.2	14.41 ± 0.10	9.71 ± 0.06	7.38 ± 0.05	5.89 ± 0.04
50%	22.9 ± 0.2	11.69 ± 0.09	7.89 ± 0.06	5.90 ± 0.04	4.98 ± 0.04
30%	18.9 ± 0.2	9.48 ± 0.09	6.66 ± 0.06	5.02 ± 0.05	4.28 ± 0.04

E [GeV]	1	2	3	4	5
100%	86.9 ± 0.6	45.4 ± 0.3	30.3 ± 0.2	22.8 ± 0.1	18.3 ± 0.1
70%	62.6 ± 0.6	33.0 ± 0.3	21.9 ± 0.2	16.8 ± 0.1	13.4 ± 0.1
50%	43.5 ± 0.5	21.9 ± 0.2	15.2 ± 0.1	11.47 ± 0.10	9.08 ± 0.08
30%	29.0 ± 0.4	14.7 ± 0.2	9.7 ± 0.1	7.44 ± 0.07	5.94 ± 0.06

E [GeV]	1	2	3	4	5
100%	38.7 ± 0.2	19.5 ± 0.1	13.11 ± 0.07	9.85 ± 0.05	7.90 ± 0.04
70%	28.5 ± 0.2	14.28 ± 0.10	9.56 ± 0.06	7.16 ± 0.05	5.76 ± 0.04
50%	22.8 ± 0.2	11.55 ± 0.09	7.57 ± 0.06	5.65 ± 0.04	4.60 ± 0.03
29%	18.8 ± 0.2	9.35 ± 0.09	6.30 ± 0.06	4.66 ± 0.05	3.75 ± 0.04

E [GeV]	1	2	3	4	5
100%	86.9 ± 0.6	45.3 ± 0.3	30.3 ± 0.2	22.8 ± 0.1	18.2 ± 0.1
70%	62.5 ± 0.6	32.9 ± 0.3	21.7 ± 0.2	16.7 ± 0.1	13.3 ± 0.1
50%	43.3 ± 0.5	21.9 ± 0.2	15.3 ± 0.1	11.07 ± 0.09	8.91 ± 0.07
30%	28.9 ± 0.4	14.5 ± 0.2	9.54 ± 0.10	7.29 ± 0.07	5.85 ± 0.07

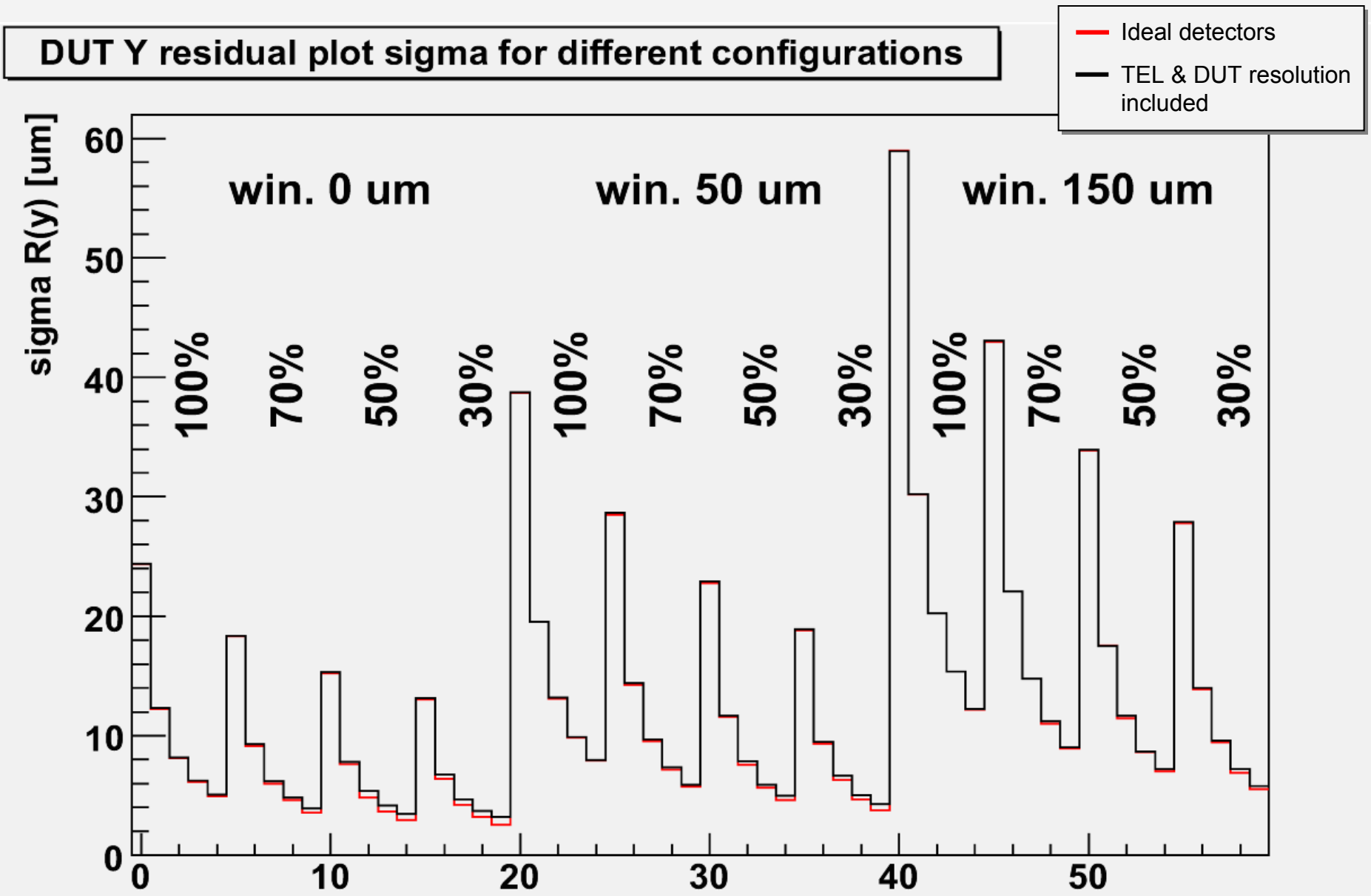
Three windows thicknesses for the geometry 1

Geometry 1

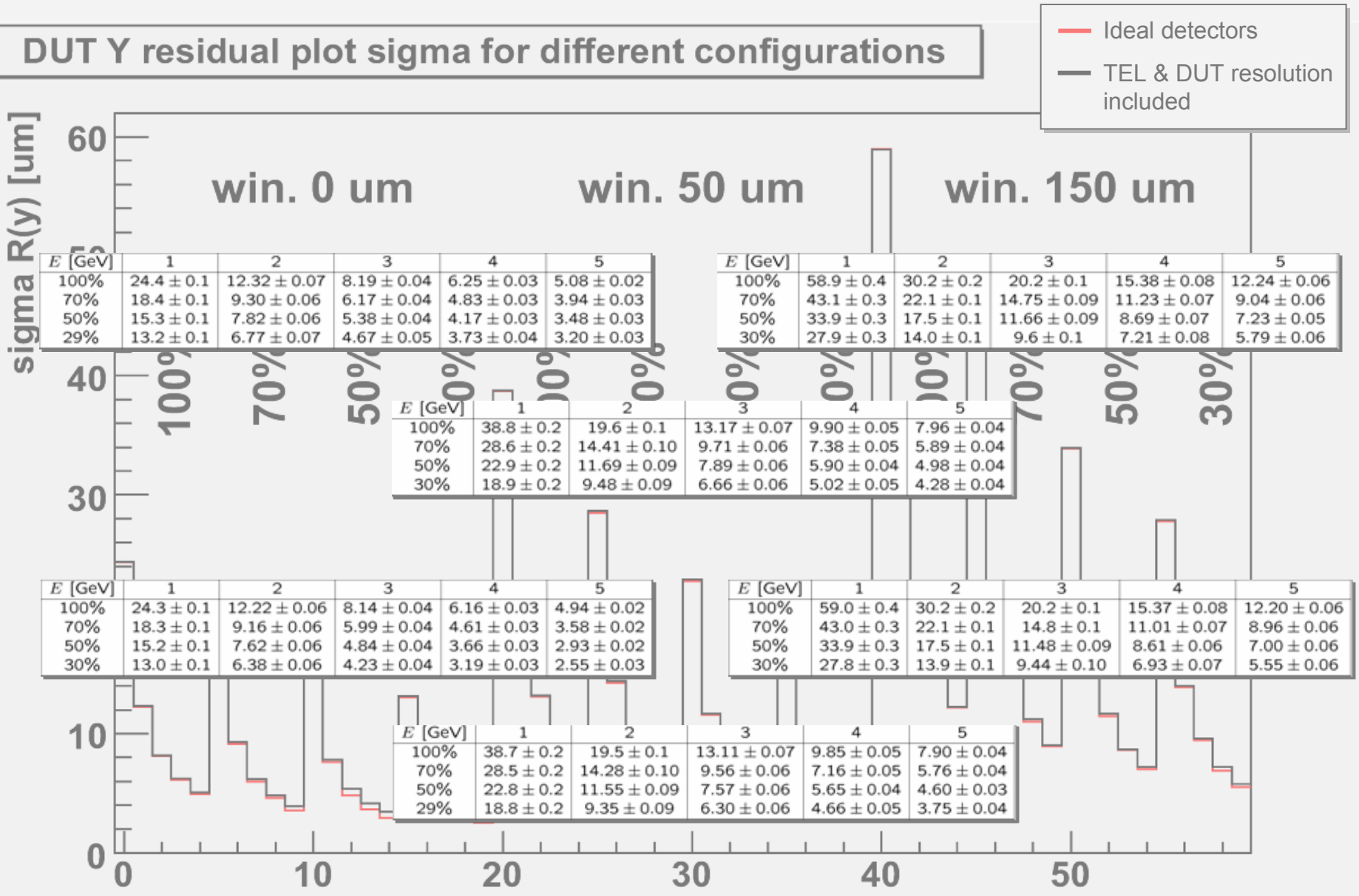
Module windows:

- no foils
- 50 μm copper foils
- 150 μm copper foils

Residual plots: three thicknesses



Residual plots: three thicknesses



E [GeV]	1	2	3	4	5
100%	24.4 ± 0.1	12.32 ± 0.07	8.19 ± 0.04	6.25 ± 0.03	5.08 ± 0.02
70%	18.4 ± 0.1	9.30 ± 0.06	6.17 ± 0.04	4.83 ± 0.03	3.94 ± 0.03
50%	15.3 ± 0.1	7.82 ± 0.06	5.38 ± 0.04	4.17 ± 0.03	3.48 ± 0.03
29%	13.2 ± 0.1	6.77 ± 0.07	4.67 ± 0.05	3.73 ± 0.04	3.20 ± 0.03

E [GeV]	1	2	3	4	5
100%	58.9 ± 0.4	30.2 ± 0.2	20.2 ± 0.1	15.38 ± 0.08	12.24 ± 0.06
70%	43.1 ± 0.3	22.1 ± 0.1	14.75 ± 0.09	11.23 ± 0.07	9.04 ± 0.06
50%	33.9 ± 0.3	17.5 ± 0.1	11.66 ± 0.09	8.69 ± 0.07	7.23 ± 0.05
30%	27.9 ± 0.3	14.0 ± 0.1	9.6 ± 0.1	7.21 ± 0.08	5.79 ± 0.06

E [GeV]	1	2	3	4	5
100%	38.8 ± 0.2	19.6 ± 0.1	13.17 ± 0.07	9.90 ± 0.05	7.96 ± 0.04
70%	28.6 ± 0.2	14.41 ± 0.10	9.71 ± 0.06	7.38 ± 0.05	5.89 ± 0.04
50%	22.9 ± 0.2	11.69 ± 0.09	7.89 ± 0.06	5.90 ± 0.04	4.98 ± 0.04
30%	18.9 ± 0.2	9.48 ± 0.09	6.66 ± 0.06	5.02 ± 0.05	4.28 ± 0.04

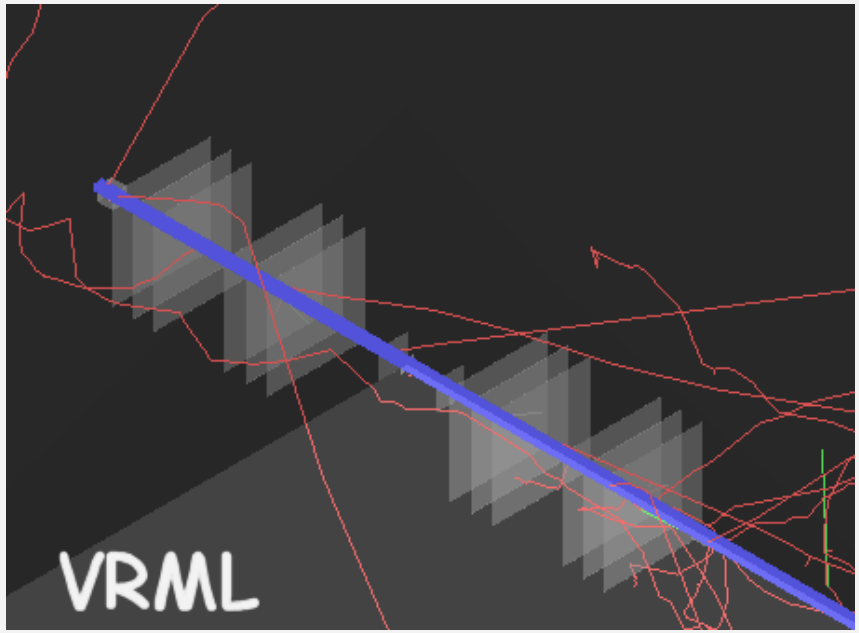
E [GeV]	1	2	3	4	5
100%	24.3 ± 0.1	12.22 ± 0.06	8.14 ± 0.04	6.16 ± 0.03	4.94 ± 0.02
70%	18.3 ± 0.1	9.16 ± 0.06	5.99 ± 0.04	4.61 ± 0.03	3.58 ± 0.02
50%	15.2 ± 0.1	7.62 ± 0.06	4.84 ± 0.04	3.66 ± 0.03	2.93 ± 0.02
30%	13.0 ± 0.1	6.38 ± 0.06	4.23 ± 0.04	3.19 ± 0.03	2.55 ± 0.03

E [GeV]	1	2	3	4	5
100%	59.0 ± 0.4	30.2 ± 0.2	20.2 ± 0.1	15.37 ± 0.08	12.20 ± 0.06
70%	43.0 ± 0.3	22.1 ± 0.1	14.8 ± 0.1	11.01 ± 0.07	8.96 ± 0.06
50%	33.9 ± 0.3	17.5 ± 0.1	11.48 ± 0.09	8.61 ± 0.06	7.00 ± 0.06
30%	27.8 ± 0.3	13.9 ± 0.1	9.44 ± 0.10	6.93 ± 0.07	5.55 ± 0.06

E [GeV]	1	2	3	4	5
100%	38.7 ± 0.2	19.5 ± 0.1	13.11 ± 0.07	9.85 ± 0.05	7.90 ± 0.04
70%	28.5 ± 0.2	14.28 ± 0.10	9.56 ± 0.06	7.16 ± 0.05	5.76 ± 0.04
50%	22.8 ± 0.2	11.55 ± 0.09	7.57 ± 0.06	5.65 ± 0.04	4.60 ± 0.03
29%	18.8 ± 0.2	9.35 ± 0.09	6.30 ± 0.06	4.66 ± 0.05	3.75 ± 0.04

Pion beam simulation

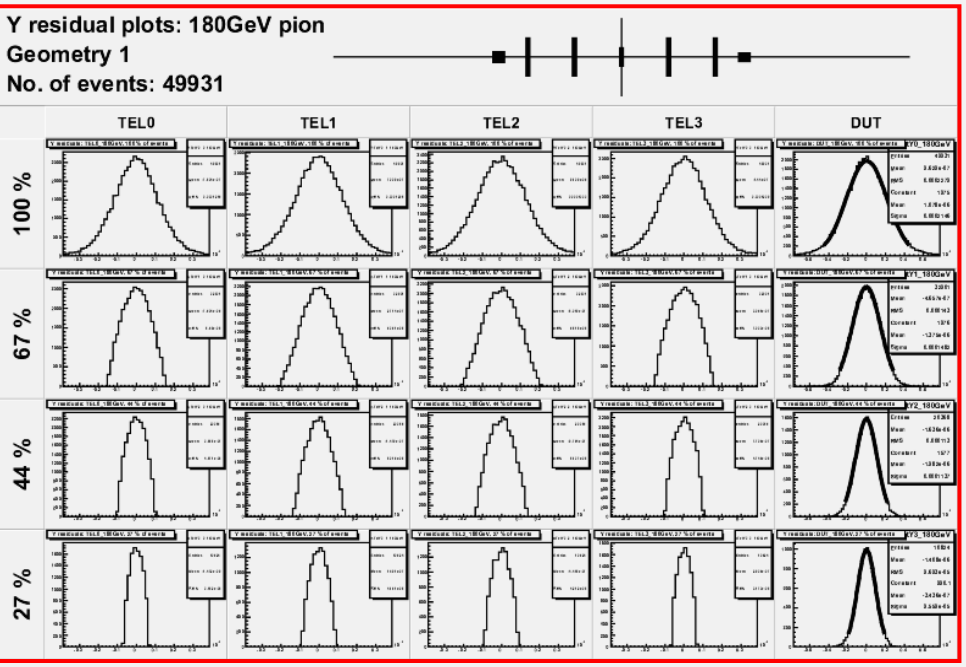
- CERN 180 GeV pion beam was simulated
- Geometries 1 and 2 were tested

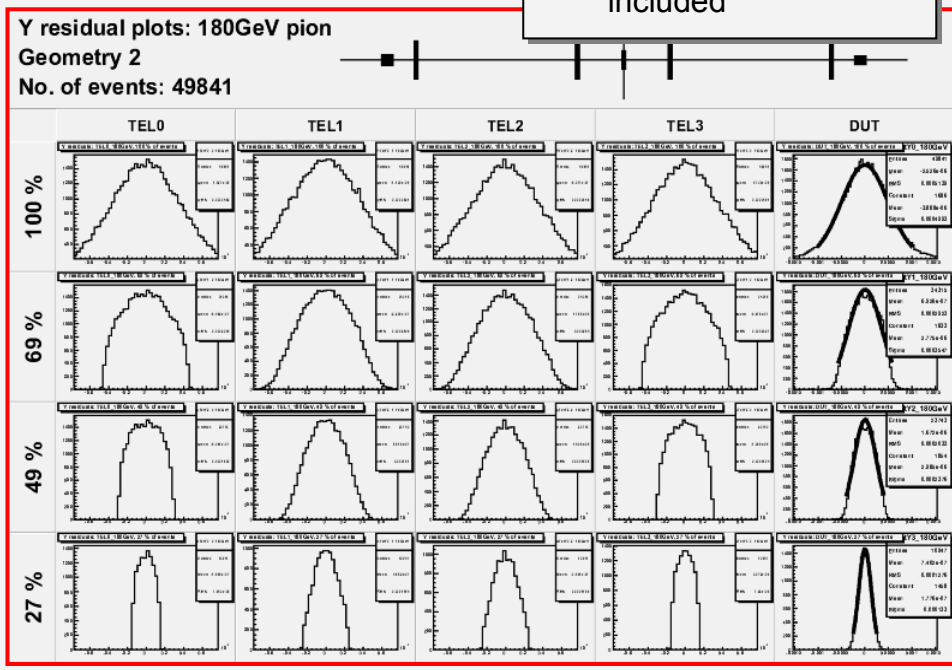


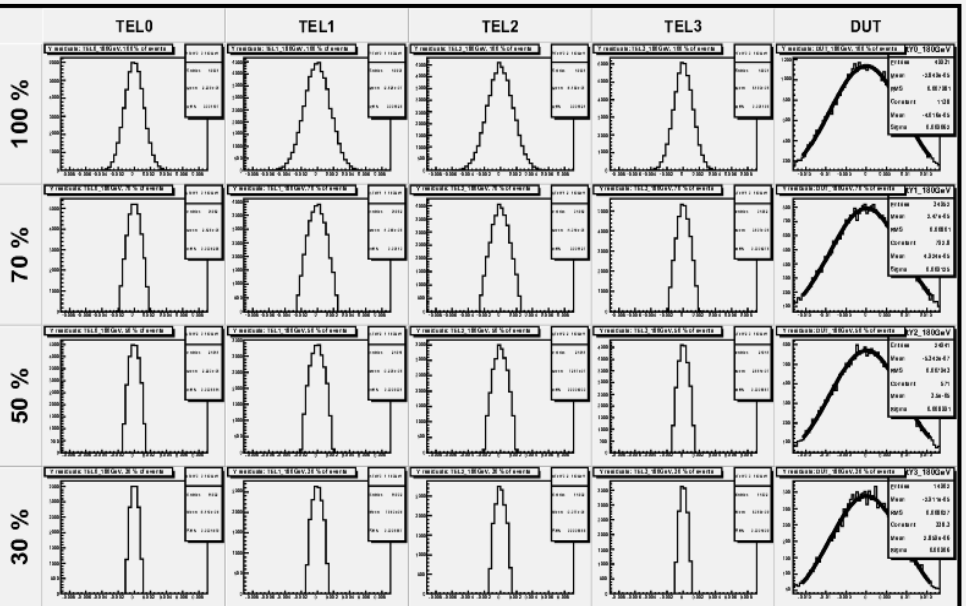
Pion beam: residual plots

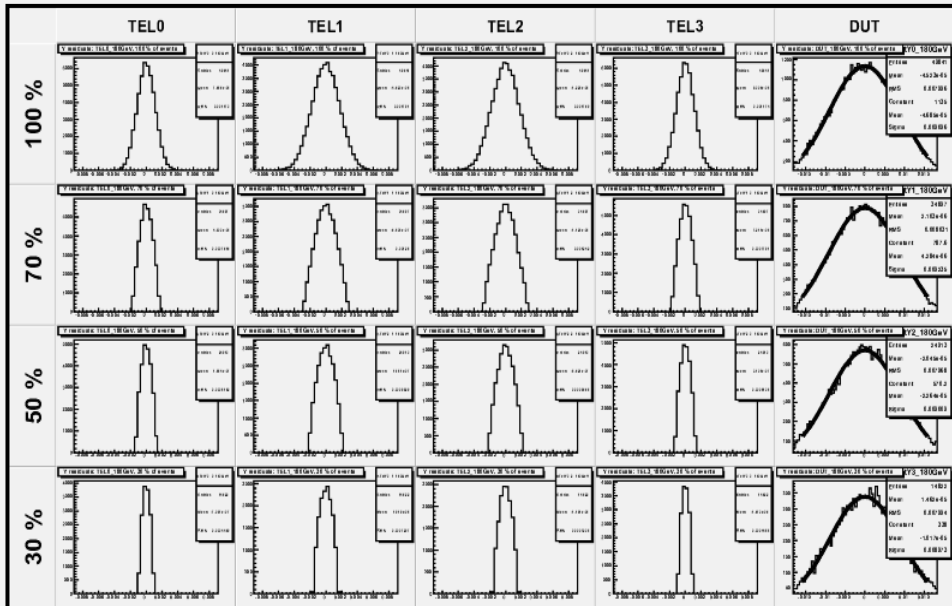
Ideal detectors

TEL & DUT resolution included







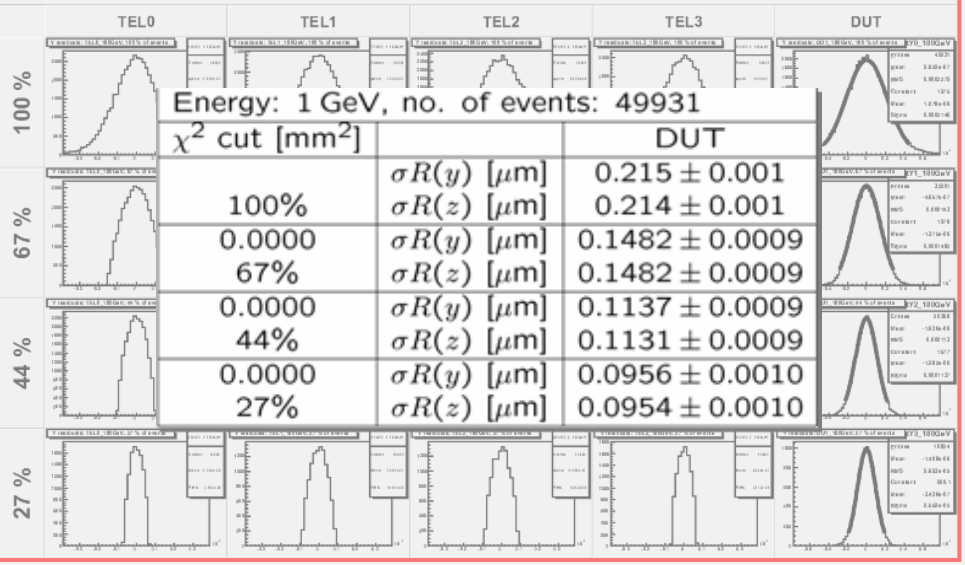


Pion beam: residual plots

Ideal detectors

TEL & DUT resolution included

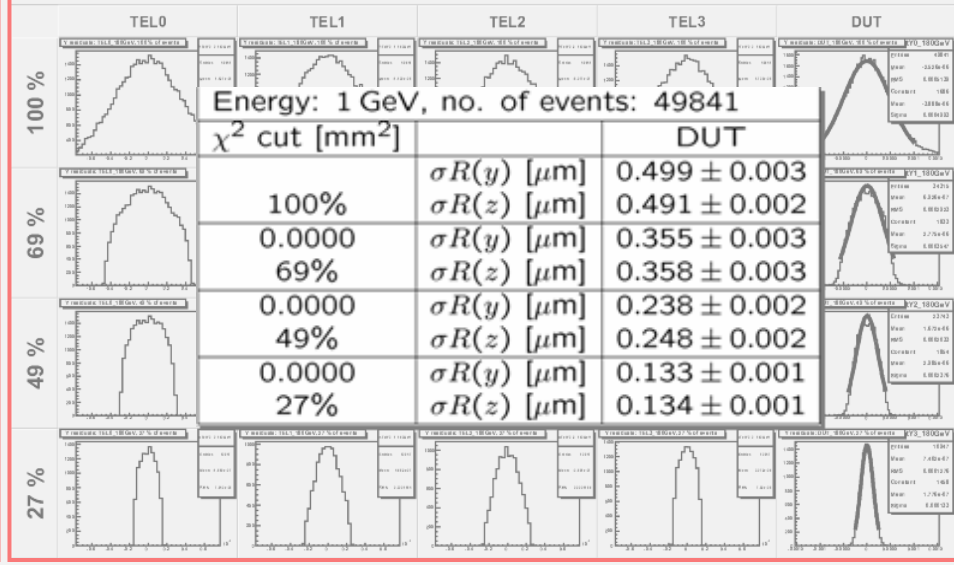
Y residual plots: 180GeV pion
Geometry 1
No. of events: 49931



Energy: 1 GeV, no. of events: 49931

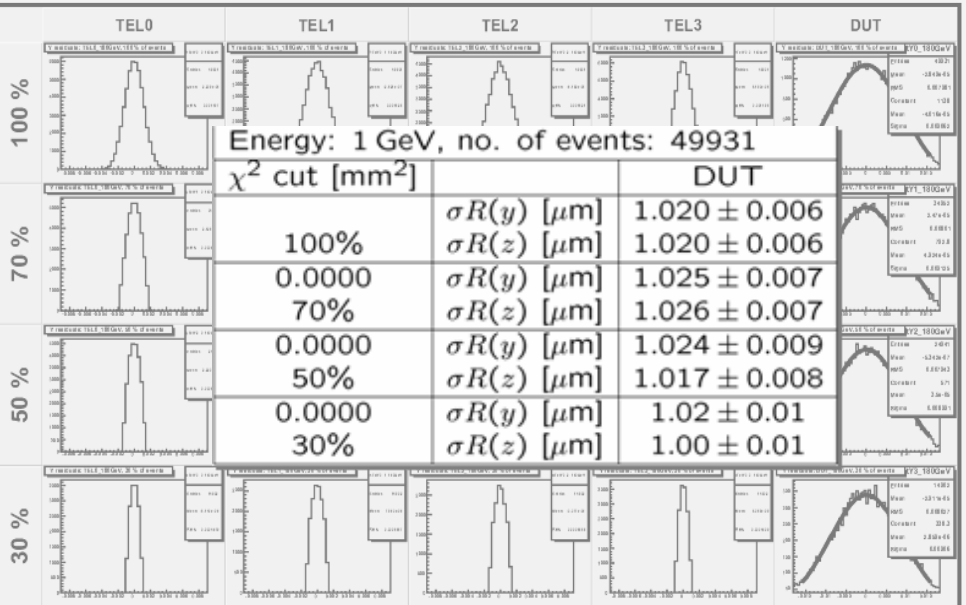
χ^2 cut [mm^2]		DUT
100%	$\sigma R(y)$ [μm]	0.215 ± 0.001
	$\sigma R(z)$ [μm]	0.214 ± 0.001
0.0000	$\sigma R(y)$ [μm]	0.1482 ± 0.0009
67%	$\sigma R(z)$ [μm]	0.1482 ± 0.0009
0.0000	$\sigma R(y)$ [μm]	0.1137 ± 0.0009
44%	$\sigma R(z)$ [μm]	0.1131 ± 0.0009
0.0000	$\sigma R(y)$ [μm]	0.0956 ± 0.0010
27%	$\sigma R(z)$ [μm]	0.0954 ± 0.0010

Y residual plots: 180GeV pion
Geometry 2
No. of events: 49841



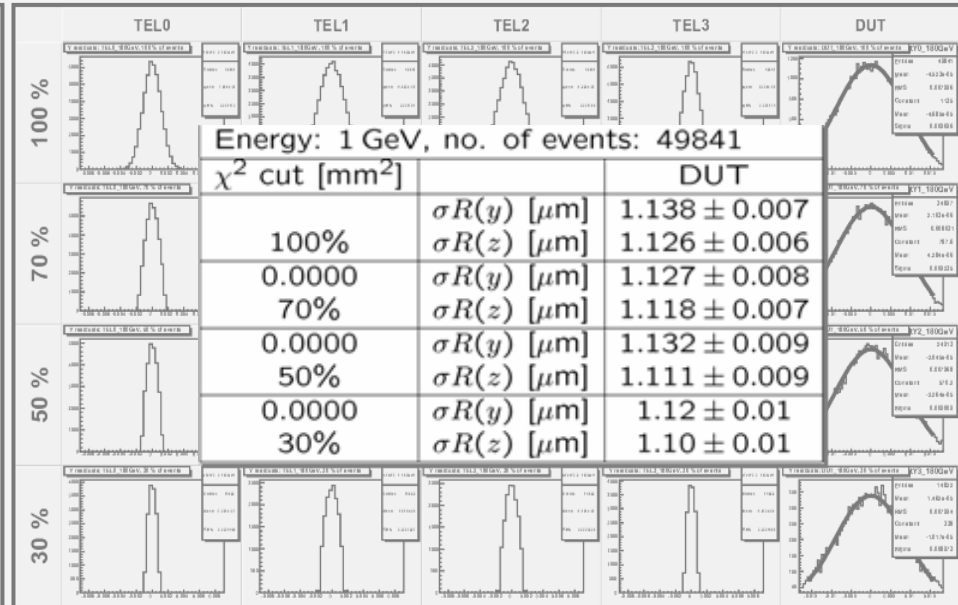
Energy: 1 GeV, no. of events: 49841

χ^2 cut [mm^2]		DUT
100%	$\sigma R(y)$ [μm]	0.499 ± 0.003
	$\sigma R(z)$ [μm]	0.491 ± 0.002
0.0000	$\sigma R(y)$ [μm]	0.355 ± 0.003
69%	$\sigma R(z)$ [μm]	0.358 ± 0.003
0.0000	$\sigma R(y)$ [μm]	0.238 ± 0.002
49%	$\sigma R(z)$ [μm]	0.248 ± 0.002
0.0000	$\sigma R(y)$ [μm]	0.133 ± 0.001
27%	$\sigma R(z)$ [μm]	0.134 ± 0.001



Energy: 1 GeV, no. of events: 49931

χ^2 cut [mm^2]		DUT
100%	$\sigma R(y)$ [μm]	1.020 ± 0.006
	$\sigma R(z)$ [μm]	1.020 ± 0.006
0.0000	$\sigma R(y)$ [μm]	1.025 ± 0.007
70%	$\sigma R(z)$ [μm]	1.026 ± 0.007
0.0000	$\sigma R(y)$ [μm]	1.024 ± 0.009
50%	$\sigma R(z)$ [μm]	1.017 ± 0.008
0.0000	$\sigma R(y)$ [μm]	1.02 ± 0.01
30%	$\sigma R(z)$ [μm]	1.00 ± 0.01



Energy: 1 GeV, no. of events: 49841

χ^2 cut [mm^2]		DUT
100%	$\sigma R(y)$ [μm]	1.138 ± 0.007
	$\sigma R(z)$ [μm]	1.126 ± 0.006
0.0000	$\sigma R(y)$ [μm]	1.127 ± 0.008
70%	$\sigma R(z)$ [μm]	1.118 ± 0.007
0.0000	$\sigma R(y)$ [μm]	1.132 ± 0.009
50%	$\sigma R(z)$ [μm]	1.111 ± 0.009
0.0000	$\sigma R(y)$ [μm]	1.12 ± 0.01
30%	$\sigma R(z)$ [μm]	1.10 ± 0.01

Conclusions

- Software for a simulation and data analysis has been created. Now it's not a problem to run it all again with different parameters.
- There is no significant difference between the geometry 1 and 2 for unscattered particles.
- We can improve the resolution by excluding bad fits.
- Geometry 2 gives wider residual plots due to a multiple scattering. For 5 GeV electrons and 30% χ^2 cut σ = **4.28 μm** for the Geometry 1 and σ = **5.94 μm** for the Geometry 2.

Conclusions

- For 5 GeV electrons and 30% χ^2 cut there is approximately 1 μm difference between simulations with no module windows and 50 μm copper windows.
- CERN 180 GeV pion beam has a significantly lower multiple scattering. The main contribution to its residual plot width come from the telescopes intrinsic resolution.