Statistical Methods in Particle Physics / WS 13

Lecture IX

Statistical Tests
Systematic uncertainties

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Part IX:

Statistical Tests

Part X:

Systematic uncertainties

In Brief:

Reducing statistical uncertainties requires more data

Reducing systematic uncertainties requires more work

Also:

Estimating statistical uncertainties is a science
(see what we did so far)

Estimating systematic uncertainties is an art

"... there are known knowns; there are things we know that we know.
There are known unknowns; that is to say, there are things that we now know we don't know.
But there are also unknown unknowns – there are things we do not know we don't know."

Donald Rumsfeld, US Secretary of Defence

Sources of uncertainties

If we measure a cross-section using a number of data events, luminosity and an efficiency from MC simulation, uncertainties arise

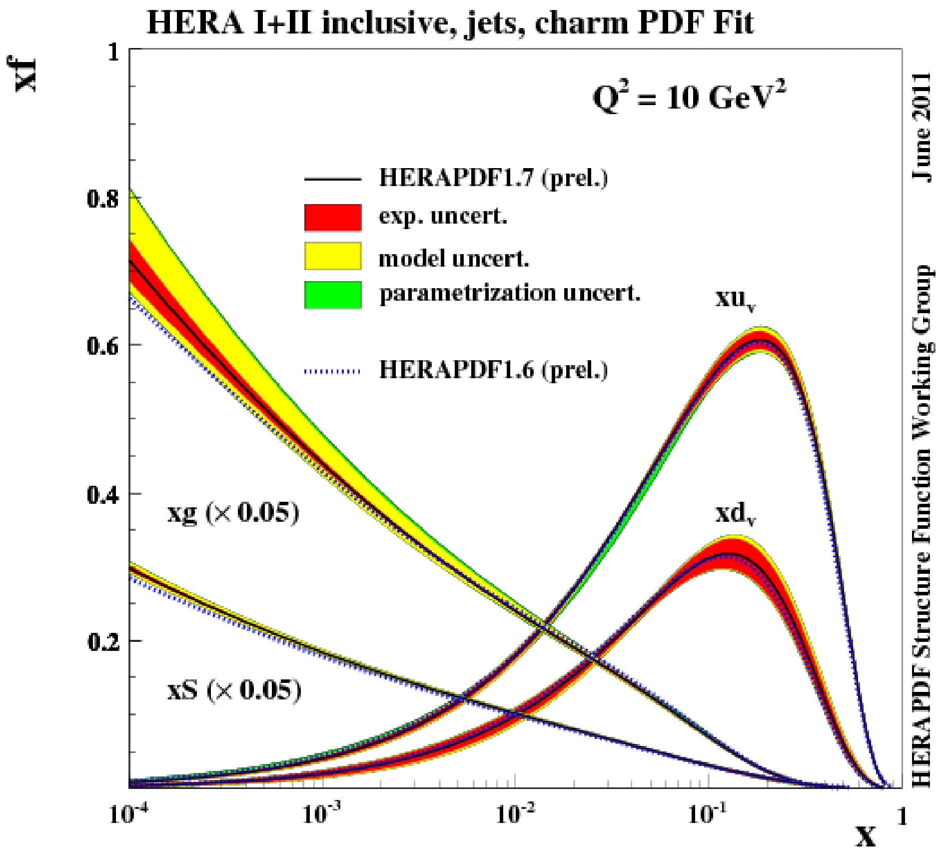
- Due to the luminosity measurement - easy to treat, as the luminosity usually comes with a well-defined uncertainty
- Due to statistical fluctuations in the number of data event - easy to treat, e.g. Poisson
- Due to uncertainties in the simulation (e.g. knowledge of parton density functions)
- Due to imperfections in the detector not simulated
- And this all assumes that there are no bugs...

10.1. Simulation uncertainties

What is my initial state?

- In e^+e^- fairly well known, initial state radiation can be calculated fairly accurately
- Anything involving hadrons (e.g. protons), not so much
- Proton described by parton density functions, obtained from fits to many measurements
- In the old days: Used to take results from two fitting groups, take difference as a systematic error
- Now: PDFs come with uncertainties (resp. with a whole set of pdfs representing the uncertainties - CTEQ 6.6. comes with an extra set of 44 eigenvector pdfs plus the central value)
- Use weighting instead of resimulation!

Parton Density Functions



- Make sure your PDF is matched to your matrix element (LO, NLO, NNLO...)
- Where to evaluate your PDF? If I produce top quark pairs, is my scale m_t, $2m_t$ or something else entirely?

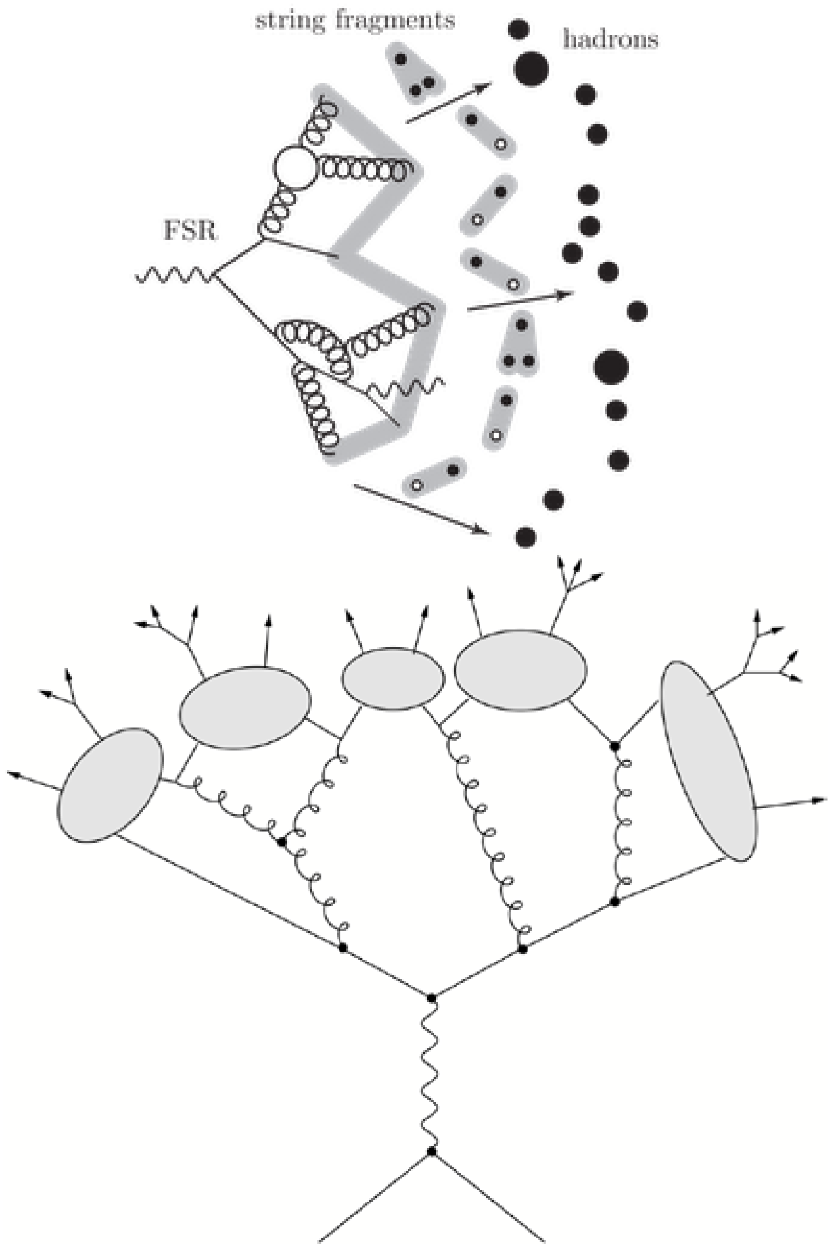
Scale uncertainty:

- Usually estimated by varying the scale by a factor of two - why?
- Further uncertainty due to missing higher orders in matrix element - can your theorist help you?

From partons to hadrons

Need a model for fragmentation and hadronization

- These models are well tuned on data
  - but do they apply to your case?
- Very hard to come up with a well justified way to estimate systematics
- Usually compare results from two different programs
- At least make sure that the programs are not using the same model internally!



Uncertainties in the simulation: Geant

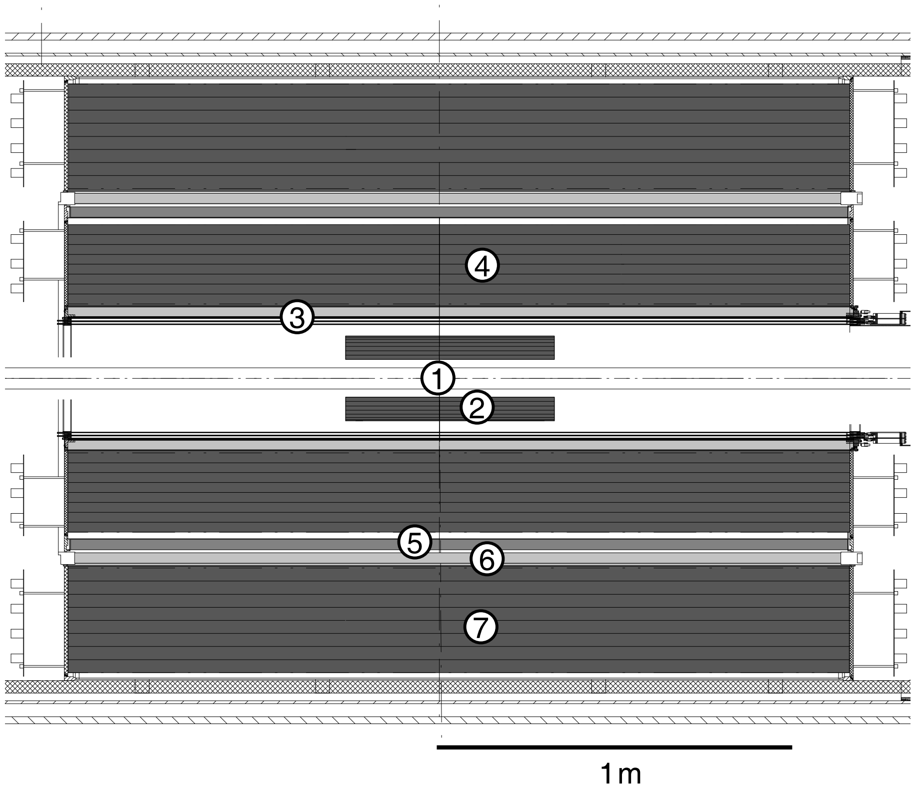
Interactions of particles with matter are parameterized:

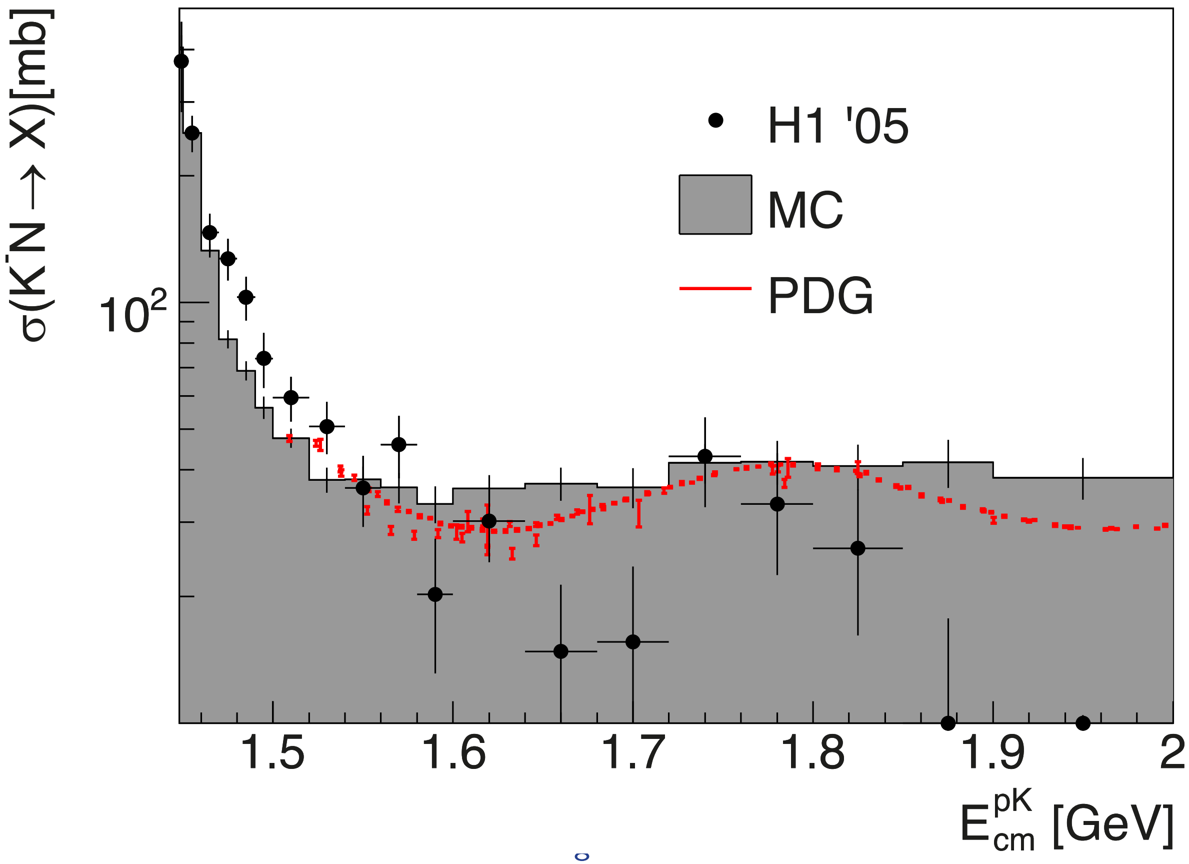
- Is the parameterization good enough?
- Is the matter description good enough?
  (Ususally not - think cables...)

- What to do about it?

- Reweighting?
- Using difference as uncertainty?
- Symmetric or not?

Stopping Kaons





10.2. Calibrations

- How well do we measure momenta, energies, times?
- A lot of effort goes into calibration
- Especially absolute calorimeter energy scales are a large uncertainty factor

How to propagate to the measurements?

- Do or do not do energy cuts
- Vary energy cuts
- Vary energies in the simulation, propagate through analysis
- Use as an additional free parameter in the final fit (many top mass measurements)

10.3. Systematic checks vs. systematic uncertainties

- All the systematic uncertainties are usually added quadratically
- We can also perform variations of the analysis as checks, without adding them for the result
- Examples:
  - Split data set for different conditions
  - Remove a cut
  - Use a different algorithm
  - Count instead of fitting or vice versa
  - Change binning
  - etc.

10.4. Examples

	$J/\psi \longrightarrow \pi^+\pi^-\pi^0$		$\psi' \longrightarrow \pi^+\pi^-\pi^0$	
Source of systematic	Upward Change (%)	Downward Change (%)	Upward Change (%)	Downward Change (%)
MC simulation	0.25	-0.23	1.20	-1.20
EMC Energy scale	0.02	-0.02	0.18	-0.15
γ efficiency	2.04	-1.96	2.04	-1.96
π^0 kinematic fit	0.28	-0.27	0.27	-0.27
tracking efficiency	1.64	-1.59	1.80	-1.75
Muon cut	—	—	1.28	-0.75
Trigger efficiency	0.20	0.00	0.20	0.00
Resonance background	0.67	-0.67	1.45	-1.45
Syst. w/o normalization	2.74	-2.64	3.57	3.33
Normalization	1.26	-1.23	4.17	-3.85
Total syst. uncertainty	3.01	-2.91	5.49	5.09
Syst. + stat. uncertainty	3.02	-2.91	5.72	5.34

Table 2: Impact of the systematic uncertainties on the measured branching fractions; the various sources of systematic uncertainties lead to the listed upward and downward changes in the branching fractions.

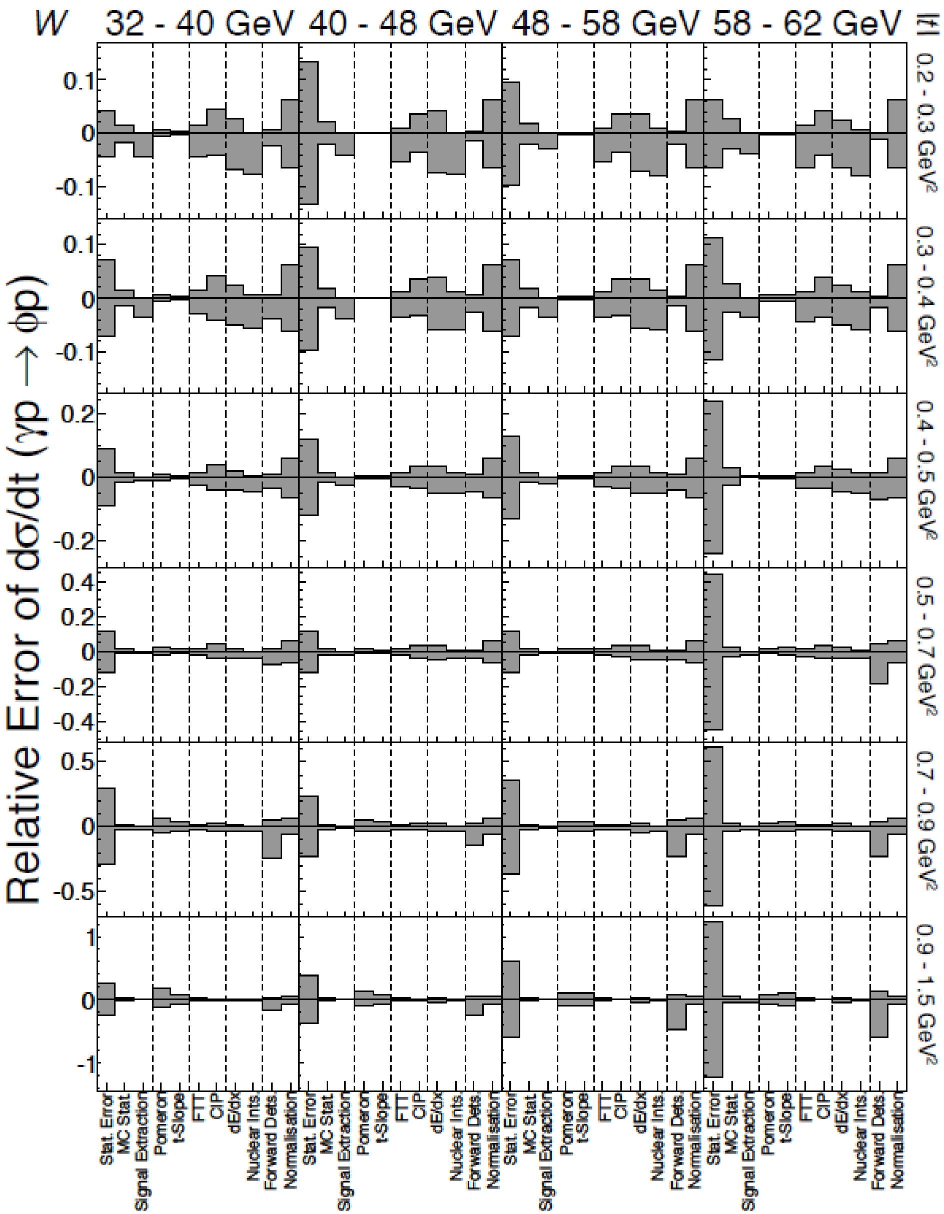


FIGURE 10.5: *Relative errors on the elastic cross sections in 24 bins in W and t. The first bin in each histogram shows the statistical error, the following bins depict the systematic errors studied. The bin labelled "forward detectors" contains both contributions from efficiency variations and variations of the M_Y spectrum.*

Besides the statistical error, the results are also affected by systematic uncertainties. These uncertainties were estimated by varying corrections and then repeating the full analysis chain. 30 variations in ten classes were considered, namely:

A: Statistical uncertainty of the correction derived from the simulation:

- A.1 the bin wise corrections are varied simultaneously by 1σ of the Monte Carlo statistical error upward;
- A.2 the bin wise corrections are varied simultaneously by 1σ of the Monte Carlo statistical error downward.

B: Variations in the W and t dependence of the Monte Carlo:

- B.1 increase the pomeron intercept $\alpha(0)$ by 0.04;
- B.2 decrease the pomeron intercept $\alpha(0)$ by 0.04;
- B.3 increase the pomeron slope α' by 0.25 GeV^{-2};
- B.4 decrease the pomeron slope α' by 0.25 GeV^{-2};
- B.5 increase the t slope parameter b_0 by 10%;
- B.6 decrease the t slope parameter b_0 by 10%.

C: Variations in the FTT efficiency (see figure 10.3 for the effects on the reweights and figure 10.4 for the corresponding efficiency distributions):

- C.1 decrease the p_T dependence by setting the reweight parameter A_1 to -0.015;
- C.2 increase the p_T dependence by setting the reweight parameter A_1 to 0.025;
- C.3 decrease the magnitude of the dip at $\vartheta = 90°$ by setting A_2 to 0;

C.4 increase the magnitude of the dip at $\vartheta = 90^\circ$ by setting A_2 to $3 \cdot 10^{-9}$;

C.5 change the forward-backward asymmetry forwards by expanding around $\vartheta = 88.5^\circ$;

C.6 change the forward-backward asymmetry forwards by expanding around $\vartheta = 92.5^\circ$;

C.7 increase the reweight for the multiplicity veto and the topology condition by 20%;

C.8 decrease the reweight for the multiplicity veto and the topology condition by 20%;

D: Variations in the CIP efficiency:

D.1 increase the CIP reweight by 20%;

D.2 decrease the CIP reweight by 20%.

E: Variations in the $\mathrm{d}E/\mathrm{d}x$ efficiency:

E.1 increase the measured inefficiency of the $\mathrm{d}E/\mathrm{d}x$ cut by 50%;

E.2 decrease the measured inefficiency of the $\mathrm{d}E/\mathrm{d}x$ cut by 25%.

F: Nuclear interactions not simulated in the Monte Carlo:

F.1 double the amount of additional nuclear interactions;

F.2 half the amount of additional nuclear interactions.

G: Variations in the efficiency of the forward tagging:

G.1 induce no additional inefficiency to the FMD (default 10%);

G.2 induce 30% additional inefficiency to the FMD;

G.3 increase the FTS efficiency for tagging dissociative events by 20%;

G.4 decrease the FTS efficiency for tagging dissociative events by 20%;

G.5 tag at plug energies above 13 GeV in the simulation (12 GeV in data);

G.6 tag at plug energies above 11 GeV in the simulation.

H: Variations in the proton dissociative mass (M_Y) spectrum. The M_Y spectrum is modelled by DiffVM according to a $1/M_Y^{2(1+\epsilon)}$ behaviour. This spectrum is altered according to

$$f_{M_Y}(M_Y) = \left(\frac{M_Y^2}{M_{Y,0}^2}\right)^{\delta} \tag{10.9}$$

with a scaling factor of $M_{Y,0} = 5$ GeV and δ the slope of the alteration [17,212]:

H.1 set the slope to $\delta = +0.15$;

H.2 set the slope to $\delta = -0.15$.

I: Global normalisation uncertainties (values commonly used in H1):

I.1 the luminosity measurement is accurate to 1.5%;

I.2 the tracking efficiency is uncertain to 2.5% per track, giving an uncertainty of 5%;

I.3 the overall FTT efficiency has an uncertainty of 3%;

I.4 the inefficiencies from the ToF system are known to 0.5%;

I.5 the inefficiency of the liquid argon calorimeter vetoes is estimated at 2%.

Adding these contributions in quadrature results in a global normalisation uncertainty of 6.4%.

The relative magnitude of the systematic errors in different areas of the phase space under study are shown in figure 10.5.

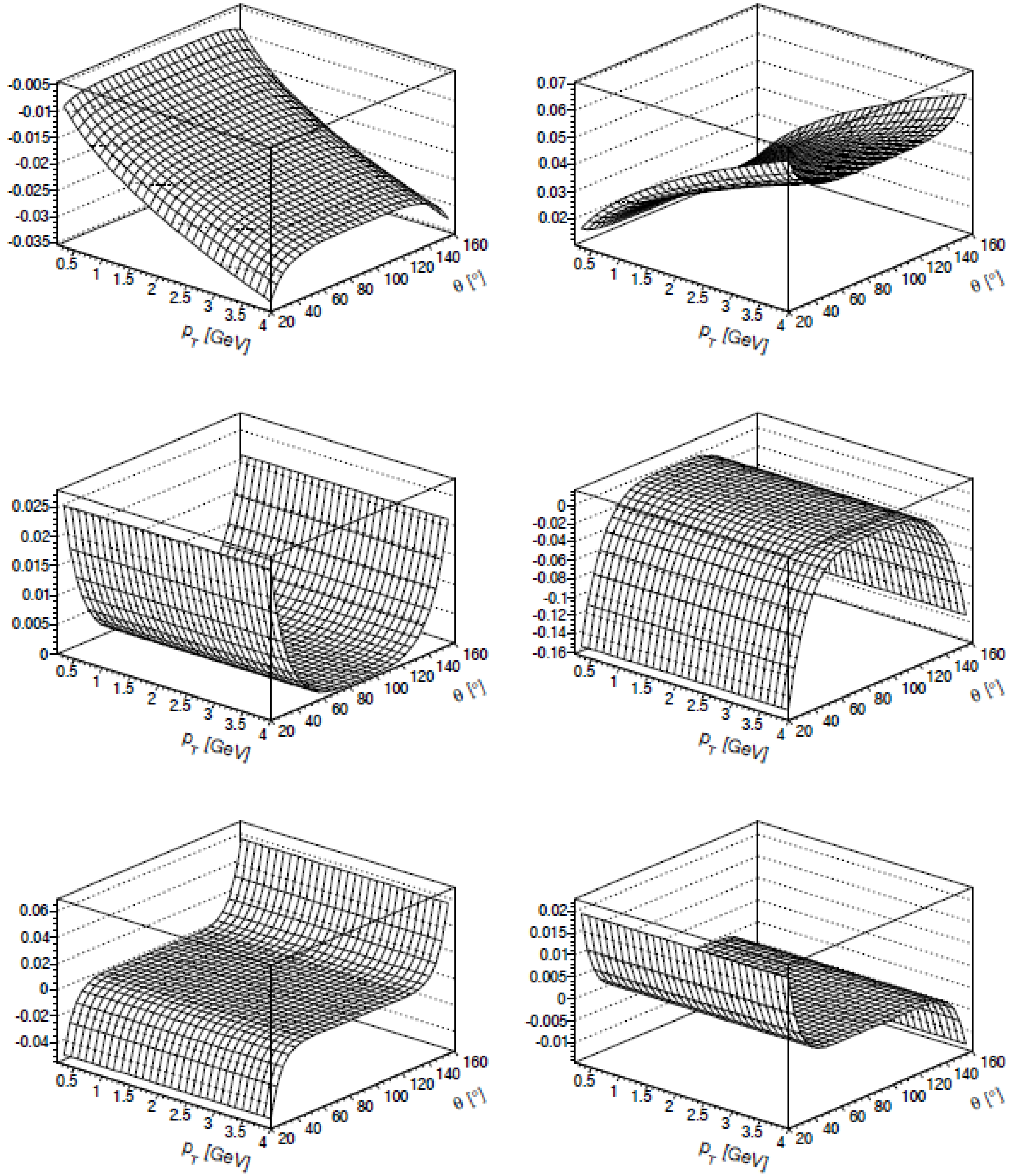


FIGURE 10.3: *Changes of the MC reweight used for the study of systematic effects from the FTT trigger efficiency.*

Some general tips

- Even tough you want first results quickly, design your analysis code for systematic studies
- You will have to run it with small changes again and again
  - Code structure and naming schemes (root does not like histograms with the same name)
  - Be ready to scale/weight all input variables
  - Make everything as automatic as possible
- You will have to deal with weighted events
  - Prepare fits and statistics code for this
- If your experiment provides systematics, use them
  - A three percent efficiency gain is never worth a new jet calibration
- Never say "I just have to do the systematics..."

Part XI:

Confidence Intervals and Limits