QCD background smearing function studies

CMS Hamburg / DESY Meeting

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GEFÖRDERT VOM

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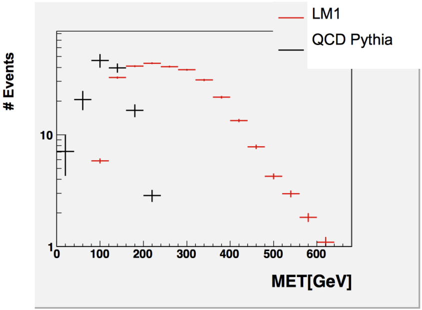
Motivation: Understanding the QCD background to $\not\!\!E_T$

- Missing transverse energy, $\not\!\!E_T$, is an important signature in the search for new physics
- Large $\not\!\!E_T$-background expected from QCD events in the all-hadronic channel:
  - Particles invisible to the calorimeter e.g. μ or ν
  - Mismeasurement due to intrinsic calorimeter resolution
  - Mismeasurement due to detector acceptance
  - ...



Understanding of QCD contribution to $\not\!\!E_T$ important

Outline

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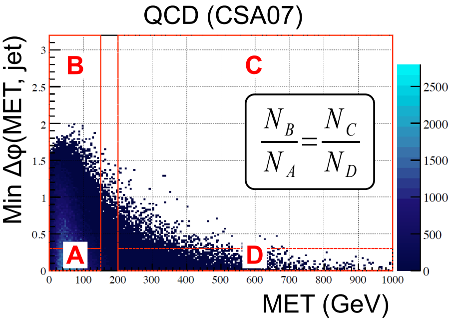
Different concepts to estimate the QCD $\not{E}_T$ contribution

- Estimation from MC simulation
- ABCD method[1]
  - Two uncorrelated variables
  - Definition of background (**A**, **B**, **D**) and signal (**C**) dominated regions by cuts on these variables
  - Prediction of **number** of QCD events in signal region

$$\boxed{N_C = N_D \frac{N_B}{N_A}}$$

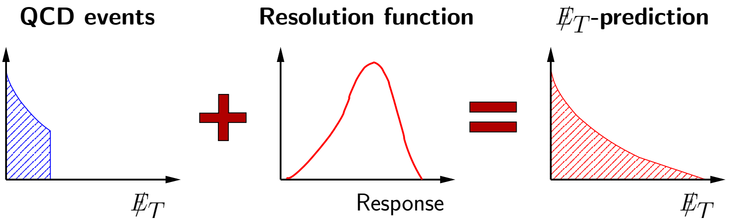


- Jet smearing method
  - This talk

[1] Talk by T. Schum http://indico.cern.ch/conferenceOtherViews.py?view=cms\&confId=37672

The jet smearing method

1. Selection of well measured QCD events
2. Smearing with resolution function $p_T^{\text{meas}}/p_T^{\text{true}}$

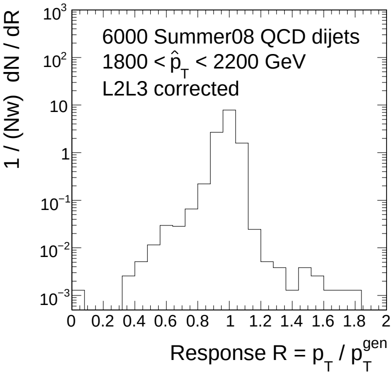


- Application of resolution function to QCD events[2] (UCSB)
  - Selection criteria
  - Normalisation of smeared events
  - Effect of double smearing
- Determination of resolution function $\longrightarrow$ This talk

[2] Talk by M. Rydenfelt http://indico.cern.ch/conferenceDisplay.py?confId=61021

Determination of the resolution function

- True jet p_T from MC simulation
  - Depends completely on simulation
- γ-jet or Z-jet events
  - $p_T^{\gamma,Z}$ relatively well measured
  - Low statistics
- MET projection method[3] (Iowa)
  - N-jets with $\not{E}_T$ parallel to one jet
  - Other jets assumed to be measured correctly
  - Neglects mismeasurement of other jets



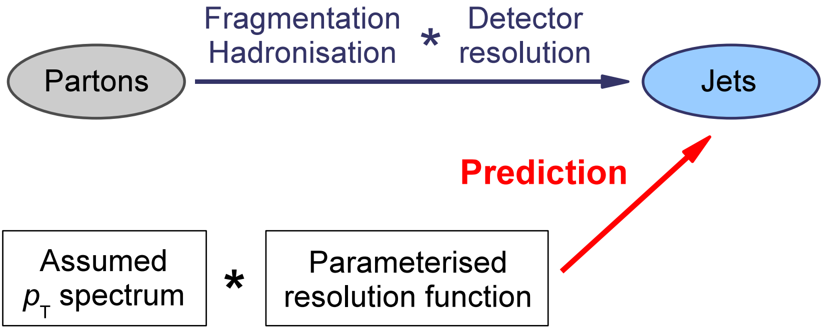
Resolution fit ⟶ this talk

- N-jet events
- All jets assumed to be mismeasured by resolution function

[3] Talk by E. Albayrak `http://indico.cern.ch/conferenceDisplay.py?confId=62099`

Outline

Concept of the resolution fit method



Details for dijet events

- In each event i, probability for a given dijet configuration p_T^{j1}, p_T^{j2} is

$$\mathcal{P}^i_{1,2} = \frac{1}{\text{norm}} \int_0^\infty \mathrm{d}p_T^{\text{true}}\, f(p_T^{\text{true}}) \cdot r_b(p_T^{j1}/p_T^{\text{true}}) \cdot r_b(p_T^{j2}/p_T^{\text{true}})$$

  - f is the probability density function (pdf) of p_T^{true}
  - r_b is the parameterised resolution function i.e. the response pdf
- Likelihood $\tilde{\mathcal{L}} = \prod_{i=0}^{N_{\text{evt}}} \mathcal{P}^i_{1,2}$ maximal for correct resolution function r_b
- Minimisation w.r.t. b of negative log-likelihood function

$$\mathcal{L} = -\sum_{i=0}^{N_{\text{evt}}} \ln(\mathcal{P}^i_{1,2})$$

- Appropriate definition of probability allows to include other data types e.g. γ-jet events

Possible parameterisations of the resolution function

Analytic function

- Smooth behaviour
- Small number of parameters
- Normalisation simple in some cases
- Functional form difficult to determine

Step function

- Normalisation simple
- Describes any distribution if appropriately binned
- Many parameters
- Discontinuities

Spline

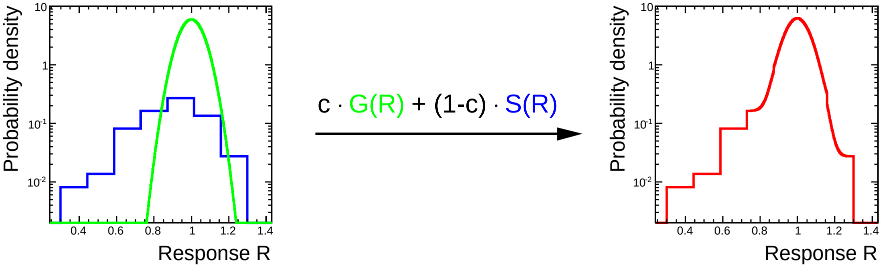
- Smooth behaviour
- Normalisation difficult
- Technically complex

The used resolution parameterisation

Superposition of Gaussian and interpolated step function

$$r_b(R) = c \cdot G(R; 1, \sigma) + (1 - c) \cdot S_N(R; \mathbf{b})$$

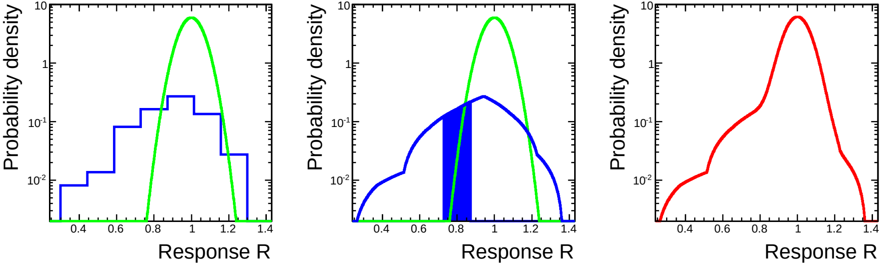
- Normalisation c
- Central Gaussian G around 1 (assume calibrated jets)
- Step function S with N parameters $\mathbf{b}$ to describe tails



Details of the resolution parameterisation

Step function S with N parameters $\mathbf{b}$ to describe tails

- Bin content $b_i \geq 0$ by construction — fit guided by penalty terms
- Actual $S_N(R)$ is linear interpolation of adjacent bin contents
- Only $N-1$ parameters are fitted $\longrightarrow$ fixed scale



The fitting framework

- Extension of the *Kalibri* tool from the University of Hamburg
- Originally developed for jet calibration via an **unbinned fit**
- Utilises `LVMINI` by V. Blobel
  - Limited memory Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm
  - Support for $\mathcal{O}(10^4)$ parameters
- Highly configurable object-oriented framework
- Support for **different parameterisations** and data sets
- Support for **parameter limits**
- **Multiple threads** to exploit use of multi-core processors
- Automated production of **control plots**
- Validation via **Toy Monte Carlo**
  - Generation of jet 4-momenta according to specified p_T spectrum
  - Distribution of jet energy on towers according to specified jet shape
  - Simulation of tower measurement according to specified resolution model

More information at `http://wwwiexp.desy.de/groups/cms/kalibri/api/index.html`

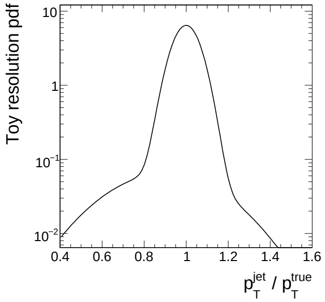
Outline

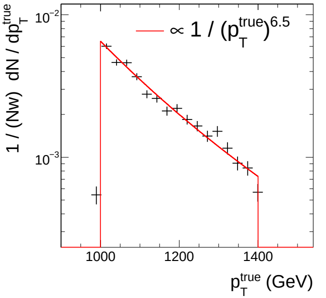
Input sample from ToyMC

- Generation of 2000 dijet events
- Simulated resolution is sum of two Gaussians

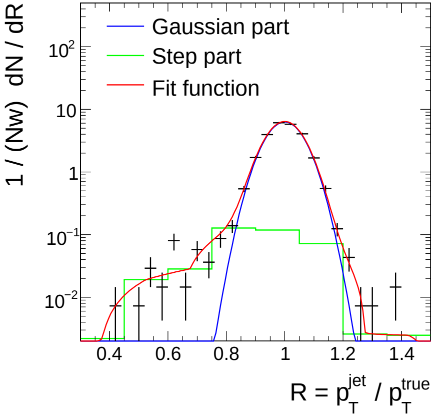
$$c \cdot G_0(1, \sigma_0) + (1 - c) \cdot G_1(\mu_1, \sigma_1)$$

  where
  - $c = 0.96$
  - $\sigma_0 = 0.06$
  - $\mu_1 = 0.9$
  - $\sigma_1 = 0.25$
- Resolution is energy independent
- p_T^{true}-spectrum falling as $1/x^{6.5}$





Results from Toy MC



- Step function with 8 bins from $0.3 < R < 1.5$
- Correct spectrum $\propto 1/(p_T^{true})^{6.5}$ assumed during fit
- Fit reproduces resolution well (numbers in the backup)

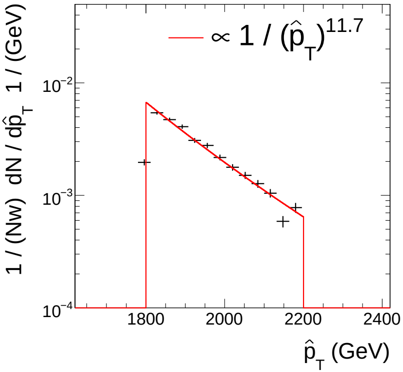
Outline

Application on Summer08 QCD dijets

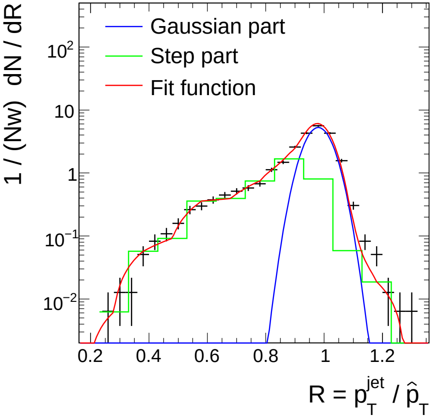
- Example $\hat{p}_T$ bin
  - $1800 < \hat{p}_T < 2200$ GeV
- Selected 1963 events out of 2000
  - Two jets leading in p_T^{gen}
  - `Jet - GenJet` matching criteria $\Delta R < 0.25$
  - $|\eta| < 1.3$ for both jets
  - $0.05 <$ hadronic fraction < 0.95
- No weights applied
- p_T^{true}-spectrum from fit on $\hat{p}_T$

$$\frac{\mathrm{d}N}{\mathrm{d}\hat{p}_T} \propto \frac{1}{\hat{p}_T^n}, \qquad n = 11.7$$

- L2L3 jet energy corrections applied

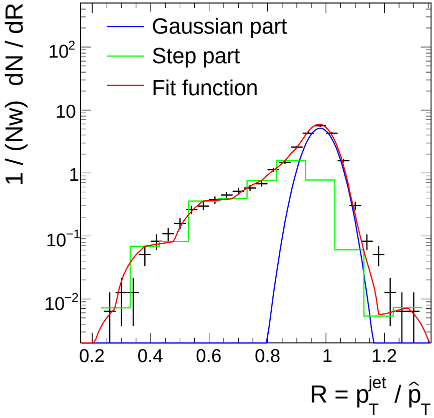


Results for Summer08 QCD dijets



- Step function with 11 bins from $0.23 < R < 1.33$
- Correct $\hat{p}_T$ spectrum $\propto 1/\hat{p}_T^{11.7}$ assumed during fit
- Fit reproduces resolution reasonably well (numbers in the backup)

Results for a fitted $\hat{p}_T$ spectrum



- Exponent n in $\hat{p}_T$ power law spectrum determined by fit
- Result $n = 11.8 \pm 0.5$ compatible with correct value 11.7
- Method can unfold spectrum and resolution

Summary

- The jet smearing method allows an estimation of the $\not{E}_T$ contribution from QCD events
- A data driven approach for the determination of the resolution function has been presented
- The method fits a parameterised resolution function using dijet events
- The resolution fit has been demonstrated to work for events generated by a Toy MC simulation
- First promising results from the Summer08 dijet production have been shown

Outlook

- Determination of resolution function for different $\hat{p}_T$ and η bins
  - Interpolation possible?
  - (How to) use knowledge of E-dependence of detector resolution?
- In data binning in p_T^{jet} and η
  - Cuts for selection of clean dijet signatures ($\Delta\phi$, E_T^{Jet3})?
  - Bias due to falling spectrum and cut-off effects?
- Knowledge about heavy flavour jet contribution
  - (How to) use in resolution parameterisation?

Backup

Mathematical details on the resolution fit method

In each event i, probability for a given dijet configuration p_T^{j1}, p_T^{j2} is

$$\mathcal{P}_{1,2}^i = \frac{1}{\text{norm}} \int_0^\infty \mathrm{d}p_T^{\text{true}}\, f(p_T^{\text{true}}) \cdot r_b(p_T^{j1}/p_T^{\text{true}}) \cdot r_b(p_T^{j2}/p_T^{\text{true}})$$

- f is the probability density function (pdf) of p_T^{true}
- r_b is the parameterised resolution function
- The normalisation is

$$\text{norm} = \int\int\int \mathrm{d}p_T^{\text{true}} \mathrm{d}p_T^{j1} \mathrm{d}p_T^{j1}\, f(p_T^{\text{true}}) \cdot r_b(p_T^{j1}/p_T^{\text{true}}) \cdot r_b(p_T^{j2}/p_T^{\text{true}})$$

Fitted parameters for Toy example

Parameter	Scale	Start value	Fitted value
c	1	0.96	0.944033
μ	1	1	1
σ	0.1	0.6	0.599104
0	0.01	1	0.928335
1	0.1	1	0.806321
2	0.1	1	1.19273
3	0.5	1	1.07337
4	0.5	1	1
5	0.5	1	0.604311
6	0.1	1	0.10949
7	0.01	1	1.04362

Fitted parameters for Summer08 dijets — fixed spectrum

Index	Scale	Start value	Fitted value
c	1	0.7	0.578505
μ	1	0.98	0.98
σ	0.1	0.5	0.436586
0	0.01	1	0.834385
1	0.1	1	0.76398
2	0.1	1	1.22063
3	0.5	1	0.954766
4	0.5	1	1.05236
5	1	1	1
6	2	1	1.11558
7	1	1	1.07393
8	0.1	1	0.782341
9	0.05	1	0.496435
10	0.01	1	0.0246184

Fitted parameters for Summer08 dijets — fitted spectrum

Index	Scale	Start value	Fitted value
c	1	0.7	0.590911
μ	1	0.98	0.98
σ	0.1	0.5	0.4589
0	0.01	1	0.943574
1	0.1	1	0.896644
2	0.1	1	1.06795
3	0.5	1	0.934932
4	0.5	1	1.02109
5	1	1	1
6	2	1	1.02793
7	1	1	1.01331
8	0.1	1	0.78706
9	0.05	1	0.139978
10	0.01	1	0.951093