Estimating E_T^{miss} Spectrum in QCD Events By Using a Data Driven Method

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Introduction and Motivation

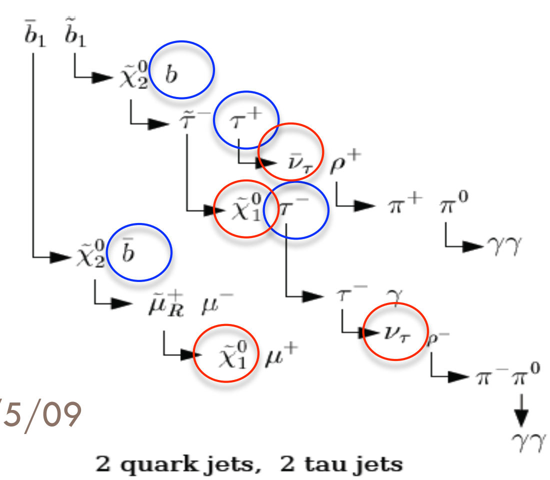
- The missing transverse energy (E_T^{miss}) is the measurement of imbalanced energy in the detector.
  - It is calculated by summing individual calorimeter towers having energy E_n , polar angle θ_n and azimuthal angle ϕ_n .

$$\vec{E}_T^{miss} = -\sum_n (E_n \sin\theta_n \cos\phi_n \hat{i} + E_n \sin\theta_n \sin\phi_n \hat{j})$$

- The E_T^{miss} is a key measurement in LHC discoveries such as:
  - Production of Higgs boson decaying taus
  - Supersymmetry (SUSY) events
  - Extra dimensions
- As University of Iowa HEP group we are working on SUSY analysis within LPC JetMet Topology Group (also CMS All Hadronic SUSY Group), especially for reduction of background with large E_T^{miss} in QCD events.

Supersymmetry

- is a new symmetry that unifies particles and forces.
- Every particle in SM has a partner (sparticle).
  - They are not observed: SUSY must be broken
- There are many models, with their free parameters, provide breaking mechanism in SUSY.
- Experimentally most studied SUSY model is R-parity conserving SUSY in a common mass scale (~mSUGRA)
  - Sparticles are pair produced and lightest sparticle (LSP) is stable
  - Long cascade decays of sparticles give rich particle content in the final state (multijets + leptons)
  - LSP weakly interacts with matter (E_T^{miss})



Why QCD Events Make Life Difficult:

QCD (quantum chromodynamics) multi-jet events will be a crucial background especially in large E_T^{miss} region.

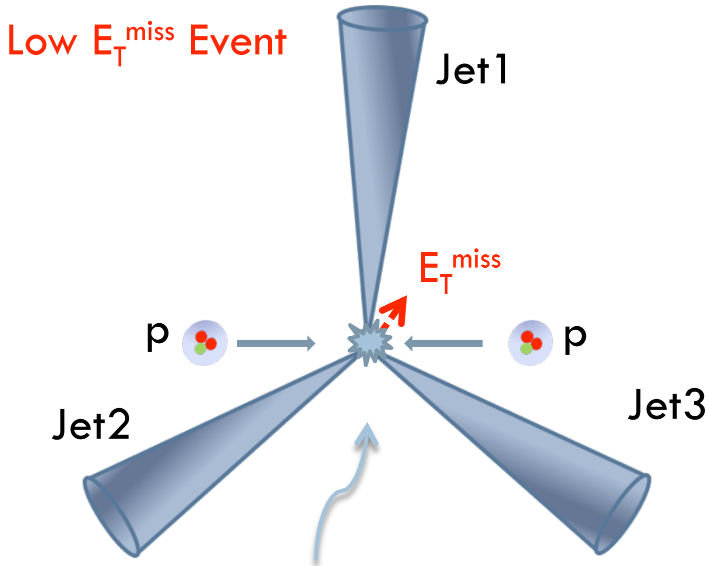
- QCD processes have large cross sections
- QCD events contributes to E_T^{miss} via
  - Semi-leptonic decay of b/c quarks (small fraction)
  - Jet mismeasurements (large fraction)

If the underlying mechanisms of mismeasurements are known, we can form a data driven method by using well measured QCD events to estimate the large E_T^{miss} events [1, 2, 3].

Method

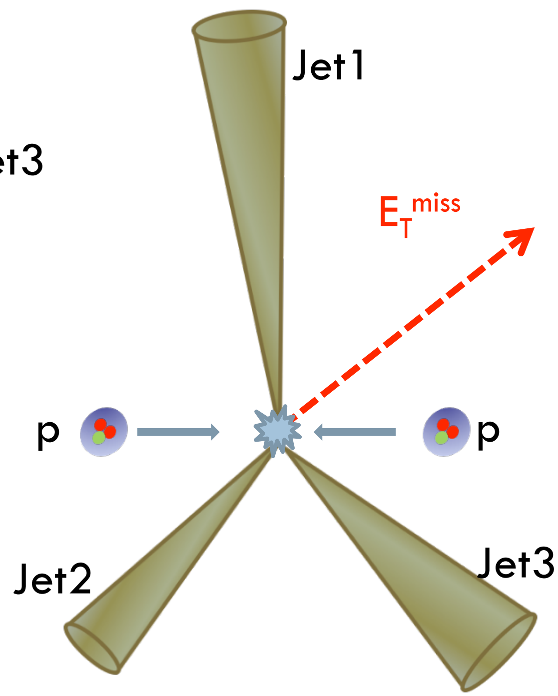
Response Function

Estimating Large E_T^{miss} Tail



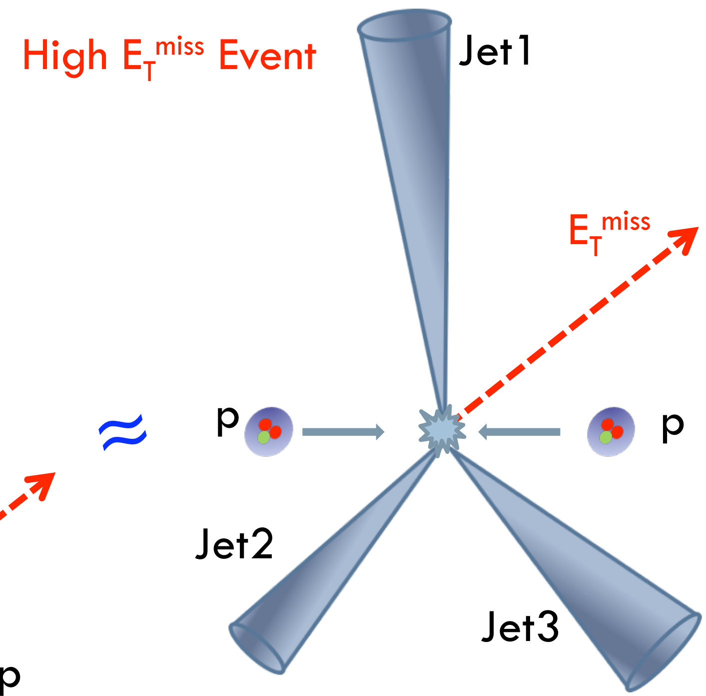
Introduce artificial imbalance by smearing p_T of the jets.

Smearing is done by using a <u>response function</u>.



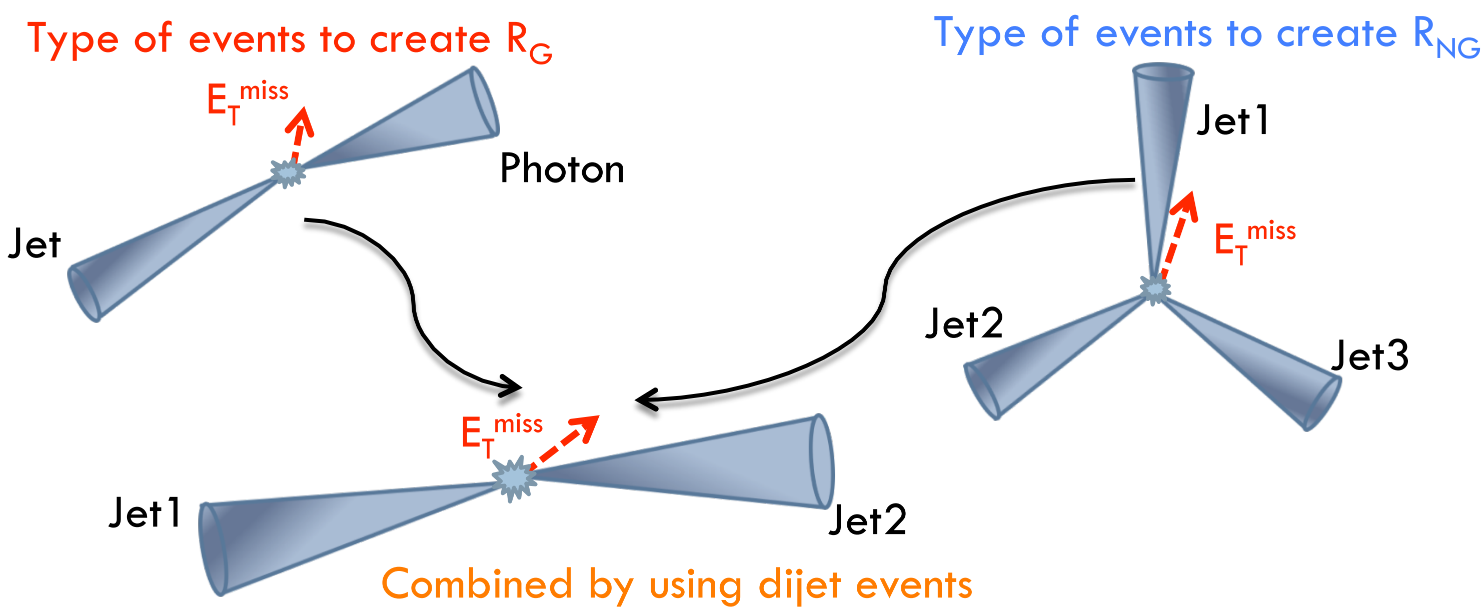
Smeared High E_T^{miss} Event

$\approx$



Response Function

- Response function represents the effect of jet mismeasurements on E_T^{miss}.
- It is combination of a Gaussian (R_G) and a non-Gaussian (R_{NG}) response.
  - R_G is formed by using photon-jet events.
  - R_{NG} is formed by using QCD multi-jet events.
  - Gaussian and non-Gaussian response functions are combined by using a relative normalization constant which is found by using dijet events



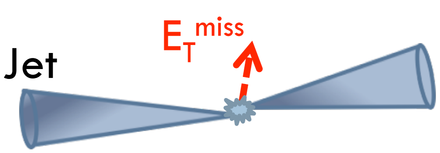
Software and Data Set

- CMSSW_2_2_X
  - SUSY PAT for 2_2_X family.
  - A custom analysis code based on EDAnalyzer
- Data Set [4]
  - We used Ntuples created by SusyParLayer1 effort[5].
  - QCD (Summer08)
    - Phythia (6 Pt hats 80-1400 GeV)
    - ~15M events
  - Photon-Jet (Summer08)
    - MadGraph (H_T 0 - ∞)
    - ~4M events
  - This analysis is done for $\int L dt = 100\ pb^{-1}$.

Gaussian Response Function (R_G)

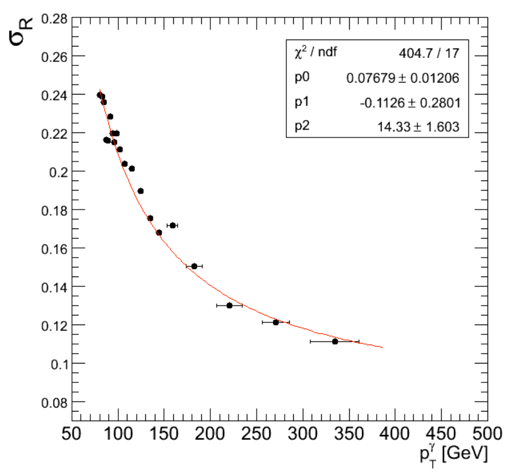
- Response is obtained from the distribution of γ-jet p_T balance by using

$$R = 1 + \frac{\vec{p}_T^{\gamma} \cdot \vec{\not{E}}_T}{\left|\vec{p}_T^{\gamma}\right|^2}$$

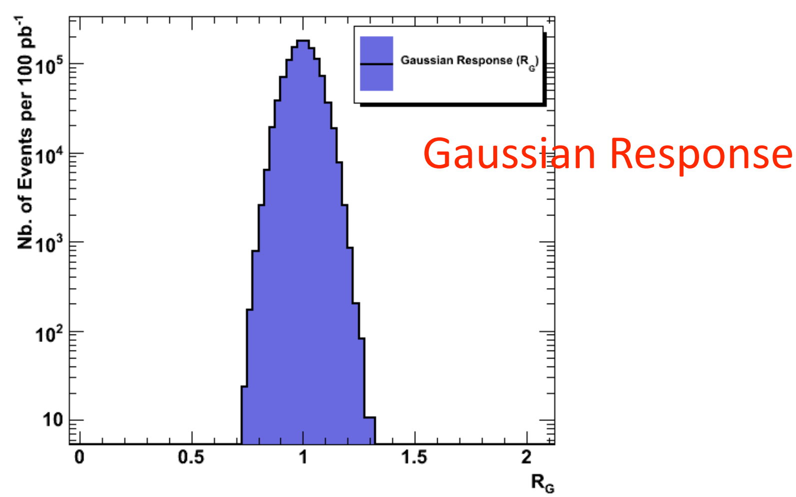


- R is measured in different γ p_T bins and Gaussian fit is applied to each R distributions.
- By using σ_R values from the Gaussian fits we plot σ_R vs γ p_T and apply a fit to this curve.

The σ_R vs. p_T^{γ} was fitted with $f(x) = p_0+(p_1/\sqrt{x})+(p_2/x)$



p0 , p1, and leading jet p_T are used to calculate Gaussian Response function



Non-Gaussian Response Function (R_{NG})

- The non-Gaussian response of calorimeter to the jets is measured by using

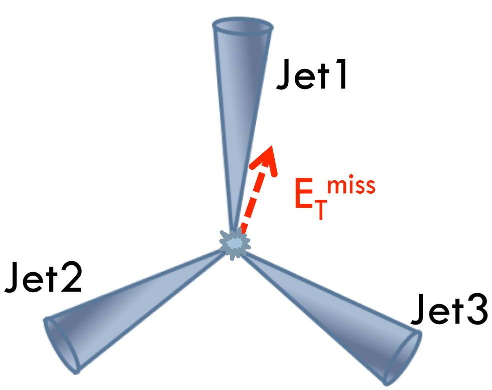
$$R_{NG} = \frac{\vec{p}_T^{\,jet} \cdot \vec{p}_T^{\,(jet,true)}}{\left|\vec{p}_T^{\,(jet,true)}\right|^2}$$

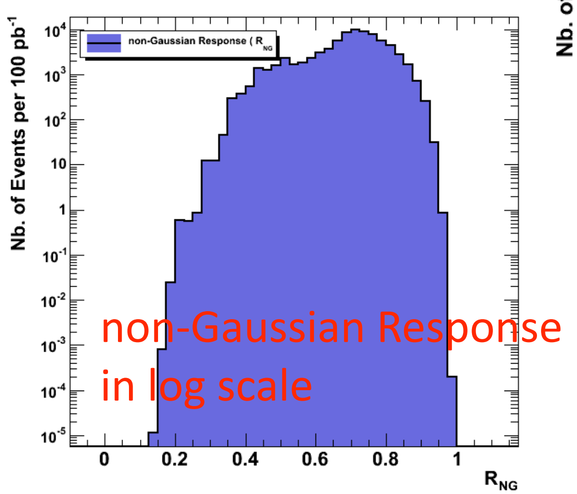
$\vec{p}_T^{\,jet}$ reconstructed transverse momentum of jet

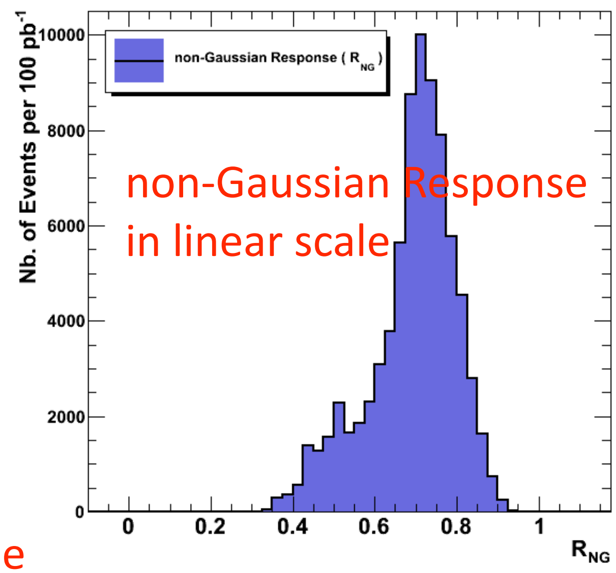
$$\vec{p}_T^{\,(jet,true)} \approx \vec{p}_T^{\,jet} + \vec{E\!\!\!/}_T$$

Here the assumption is that the E_T^{miss} is caused by mismeasured jets.

- In non-Gaussian response function calculation multi-jet events are used in which there is only 1 jet associated with E_T^{miss} (parallel).





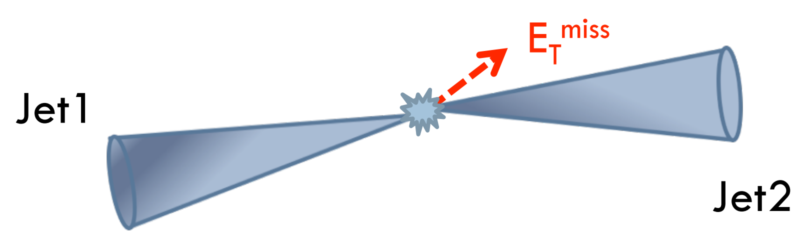


Dijet Response (1)

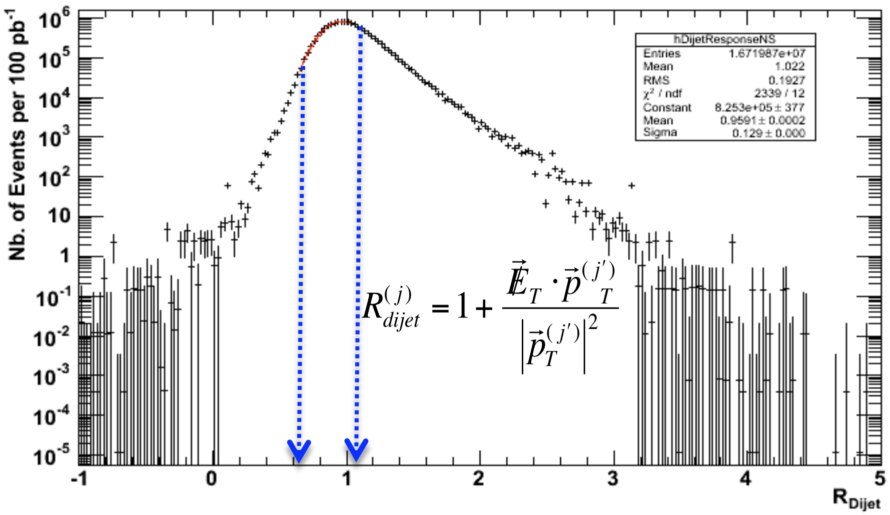
- Jet response function in dijet events include both Gaussian and non-Gaussian components.
- Relative normalization of the Gaussian response to the and non-Gaussian response is measured by using dijet events.
- Response is calculated for the events with only two jets where jets are back to back :

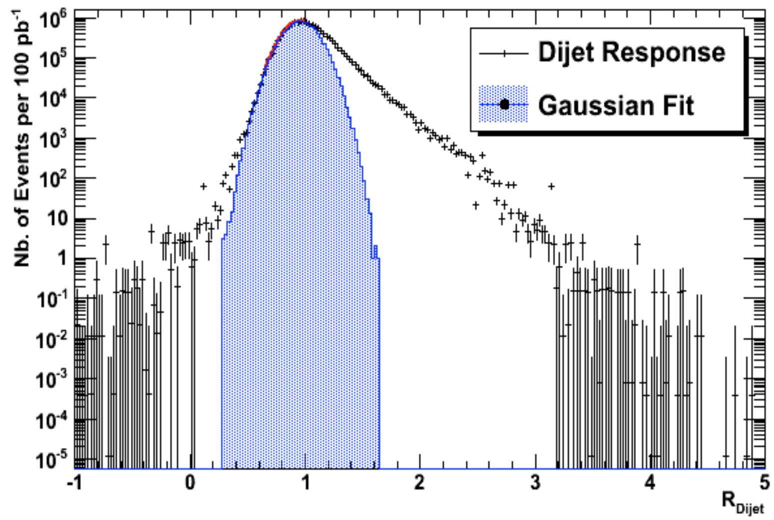
$$R_{dijet}^{(j)} = 1 + \frac{\vec{\not{E}}_T \cdot \vec{p}_T^{(j')}}{\left|\vec{p}_T^{(j')}\right|^2}$$

(Repeated for each jet to take into account Gaussian and non-Gaussian component.)



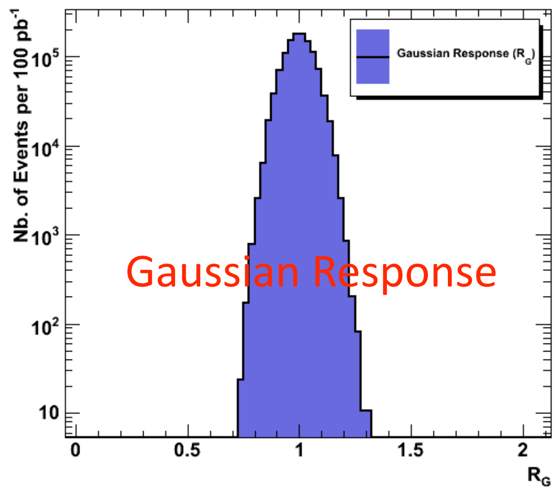
Dijet Response (2)

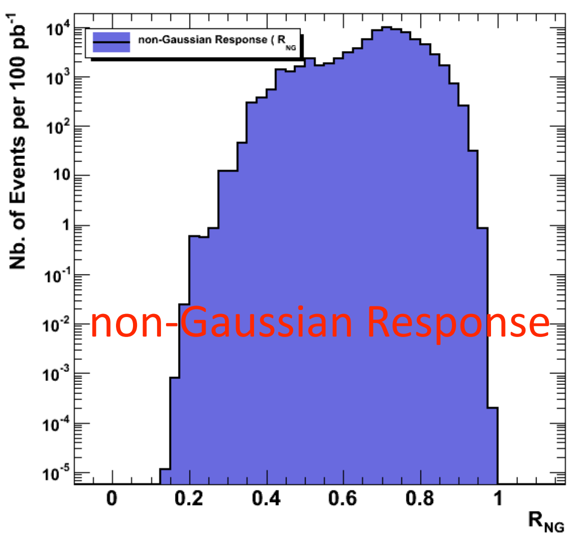




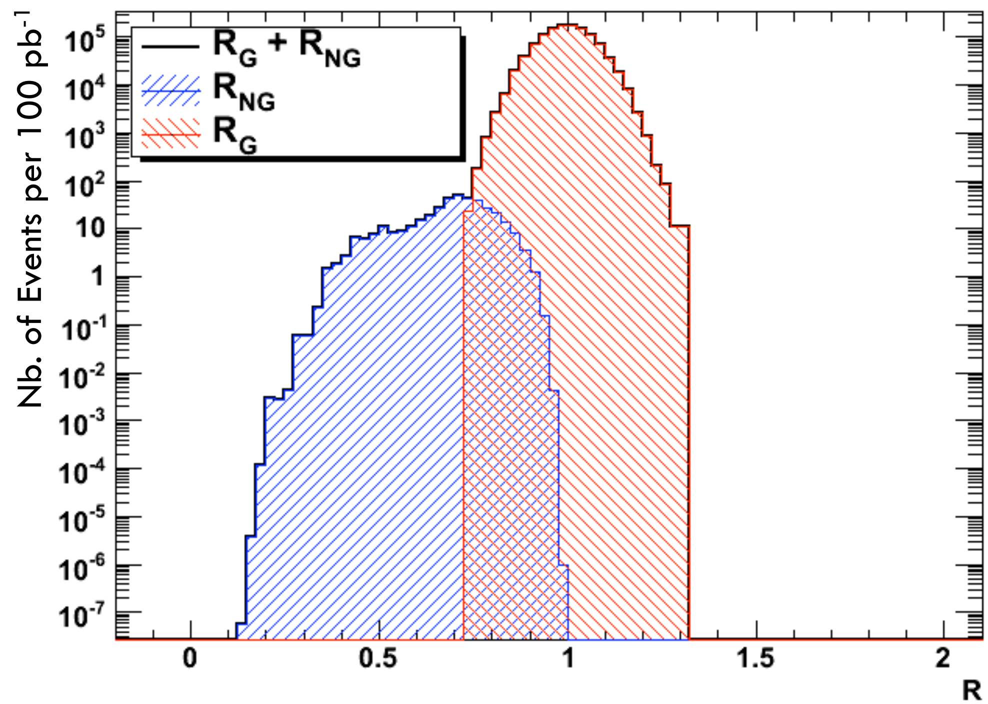
- A Gaussian fit is applied between 0.65 and 1.1 (This choice will contribute to systematical error)
- The number of events under that Gaussian fit are counted as the number of Gaussian events (N_A) .
- The number of events under dijet response tail (left side) are counted as the number of non-Gaussian events (N_B) .
- N_A and N_B are used to normalize the Gaussian and non-Gaussian response functions.

Response Function





Response Function



Results

Application of Response Function

- We form a multi-jet sample with low E_T^{miss}
  - $E_T^{miss} < 60$ GeV and E_T^{miss} significance < 0.5
  - At least 3 jets with $p_T^{jets} > 50$ GeV , $|eta| < 3$, and $f_{em} < 0.9$
  - 1[st] jet $p_T > 180$ GeV , $|eta| < 2.5$
- p_T of each jets in the low E_T^{miss} sample is smeared by the response function as

$$\vec{p}_T'^{\,jet} = \vec{p}_T^{\,jet} * [1 + R^{G+NG}(\vec{p}_T^{\,jet})]$$

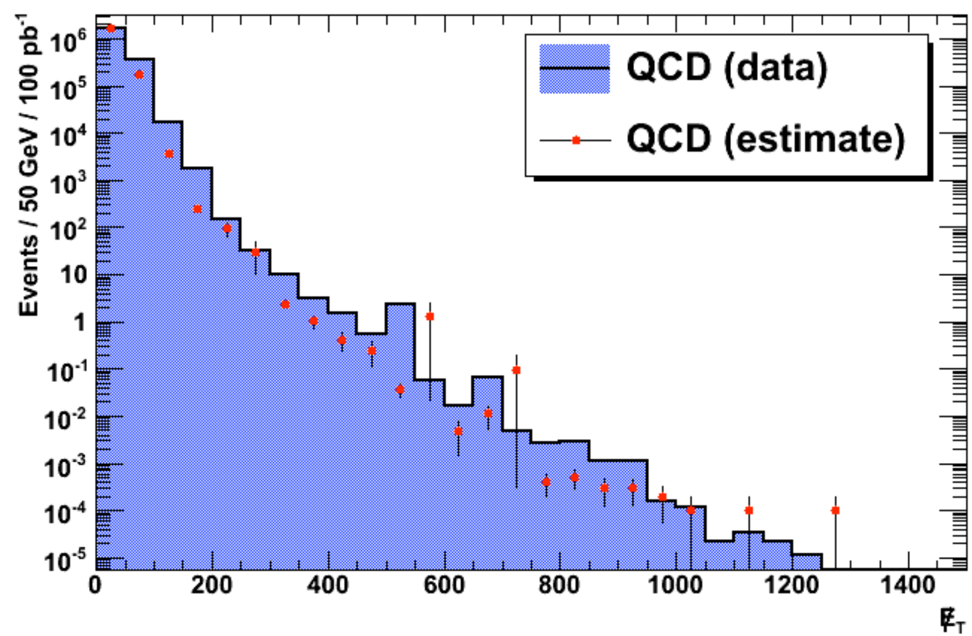
- E_T^{miss} is recalculated for low E_T^{miss} events.

$$\vec{\not{E}}_T' = \vec{\not{E}}_T^C + \sum_{i=1}^{n_{jets}} (\vec{p}_T'^{\,jet,i} - \vec{p}_T^{\,jet,i})$$

An additional contribution from photon-jet sample "p_2" is taken into account in the first term (see Missing E_T^C)

Smeared E_T^{miss}

- E_T^{miss} distribution is shown for the QCD events (data and estimate) where:
  - At least 3 jets events with |eta|<3 and $f_{em} < 0.9$
  - 1^{st} jet with p_T >180 GeV and |eta|<2.5
  - 2^{nd} jet with p_T >100 GeV
  - 3^{rd} jet with p_T >80 GeV



Conclusion and Future Plans

- Smearing function is obtained for the events with $E_T^{miss} > 65$ GeV.
- It is applied to low E_T^{miss} events where $E_T^{miss} < 60$ GeV and E_T^{miss} Significance < 0.5 GeV$^{0.5}$
  - p_T of each jet is smeared by a random number called from S.F
- E_T^{miss} is recalculated by using these smeared jets.
- Preliminary results show that there is an underestimation for E_T^{miss} tail.

<u>Future Plans:</u>

- Start calculating systematical and statistical errors.
- In CMS there are other efforts for data driven techniques for QCD background estimation. We are in the process of writing a combined analysis note.
- In SUSY analysis group there are new ntuples. We will rerun our analysis with these.

References

[1] ATLAS Physics TDR, arXiv:0901.0512v1 [hep-ex]

[2] B. Abbott *et al.*, *Nucl. Instrum. Meth.* A424 (1999) 352–394.

[3] F. Abe et al. (CDF Collaboration), Phys. Rev. Lett. 69 (1992) 2896 .

[4] Summer08 Production page:

https://twiki.cern.ch/twiki/bin/view/CMS/ProductionSummer2008

[5] SusyPatLayer1 twiki page:

https://twiki.cern.ch/twiki/bin/view/CMS/SusyPatLayer1

Backup Slides

Derivation of R_G[2]

In γ - jet events , the particle level or true photon and recoil transverse energies, $\mathrm{E}_{\mathrm{T}\gamma}$ and $\mathrm{E}_{\mathrm{Trecoil}}$ satisfy

$$\vec{E}_{T\gamma} + \vec{E}_{Trecoil} = 0 \quad (1)$$

In a real calorimeter the photon and jet responses are less than unity so (1) transforms to (2)

$$\vec{E}^{meas}_{T\gamma} + \vec{E}^{meas}_{Trecoil} = -\vec{\not{E}}^{meas}_{T} \quad (2) \text{ wheras } \vec{E}^{meas}_{T\gamma} = R_{em}\vec{E}_{T\gamma} \text{ and } \vec{E}^{meas}_{Trecoil} = R_{recoil}\vec{E}_{Trecoil}$$

If $\vec{E}^{meas}_{T\gamma}$ is corrected for energy scale in γ - jet data sample, Eq (2) becomes

$$\vec{E}_{T\gamma} + R_{recoil}\vec{E}_{Trecoil} = -\vec{\not{E}}_{T} \quad (3)$$

$$\hat{\mathrm{n}}_{\mathrm{T}\gamma} \bullet (3) \;\Rightarrow\; \left|\vec{E}_{T\gamma}\right| + R_{recoil}(\hat{\mathrm{n}}_{\mathrm{T}\gamma} \bullet \vec{E}_{Trecoil}) = -(\hat{\mathrm{n}}_{\mathrm{T}\gamma} \bullet \vec{\not{E}}_{T}) \quad (4)$$

Divide (4) by $\left|\vec{E}_{T\gamma}\right|$ we get

$$1 + R_{recoil}\frac{(\hat{\mathrm{n}}_{\mathrm{T}\gamma} \bullet \vec{E}_{Trecoil})}{\left|\vec{E}_{T\gamma}\right|} = -\frac{(\hat{\mathrm{n}}_{\mathrm{T}\gamma} \bullet \vec{\not{E}}_{T})}{\left|\vec{E}_{T\gamma}\right|} \quad (5) \text{ wheras } \hat{\mathrm{n}}_{\mathrm{T}\gamma} = \frac{\vec{E}_{T\gamma}}{\left|\vec{E}_{T\gamma}\right|}$$

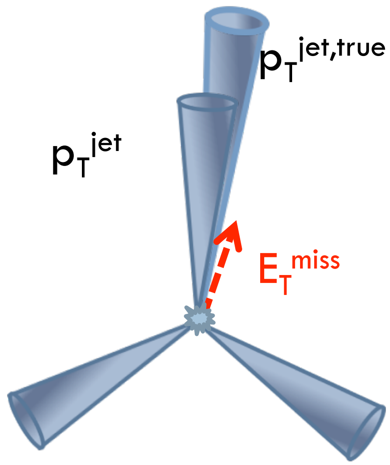
(1) can be written as $\left|\vec{E}_{T\gamma}\right| = -(\hat{\mathrm{n}}_{\mathrm{T}\gamma} \bullet \vec{E}_{Trecoil})$ (6)

Then (5) becomes $1 + \dfrac{(\vec{\not{E}}_{T} \bullet \hat{\mathrm{n}}_{\mathrm{T}\gamma})}{\left|\vec{E}_{T\gamma}\right|} = R_{recoil}$ (7)

If we rewrite (7)

$$R_{recoil} = 1 + \frac{\vec{\not{E}}_{T} \bullet \vec{E}_{T\gamma}}{\left|\vec{E}_{T\gamma}\right|^{2}} \quad (8)$$

Derivation of R_{NG}



$$R_{NG} = \frac{\vec{p}_T^{\,jet} \cdot \vec{p}_T^{\,(jet,true)}}{\left|\vec{p}_T^{\,(jet,true)}\right|^2}$$

$\vec{p}_T^{\,jet}$ *reconstructed transverse momentum of jet*

$$\vec{p}_T^{\,(jet,true)} \approx \vec{p}_T^{\,jet} + \vec{\not{E}}_T$$

$$\text{Response} = \frac{\left|\vec{p}_T^{\,measured}\right|}{\left|\vec{p}_T^{\,generated}\right|} = \frac{\left|\vec{p}_T^{\,jet}\right|}{\left|\vec{p}_T^{\,jet,true}\right|} \quad (1)$$

Multiply (1) $\left|\vec{p}_T^{\,jet,true}\right|$ and it transforms to $R = \frac{\left|\vec{p}_T^{\,jet}\right|\left|\vec{p}_T^{\,jet,true}\right|}{\left|\vec{p}_T^{\,jet,true}\right|\left|\vec{p}_T^{\,jet,true}\right|}$ (2)

In this method we used $\vec{p}_T^{\,jet}$ which is parallel to $\not{E}_T$ so $\vec{p}_T^{\,jet,true}$ is also parallel to $\not{E}_T$

Then (2) can be written as $R_{NG} = \frac{\vec{p}_T^{\,jet} \cdot \vec{p}_T^{\,jet,true}}{\left|\vec{p}_T^{\,jet,true}\right|^2}$

Derivation of R_{Dijet}

Equation (8) from slide number 20 , $R_{recoil} = 1 + \frac{\vec{E}\!\!\!/_T \bullet \vec{E}_{T\gamma}}{\left|\vec{E}_{T\gamma}\right|^2}$ (8) can be generalized for dijet events however

for dijet events there is an ambiguity. We do not know which jet is well measured (behave like photon) and which jet is mismeasured. One approach is to calculate Eq (8) as

$R_{recoil} = 1 + \frac{\vec{E}\!\!\!/_T \bullet \vec{E}_T^{\,jet}}{\left|\vec{E}_T^{\,jet}\right|^2}$ for each jet in the event.