# Search for Squark and Gluino Production In Missing Energy+Jets at CDF

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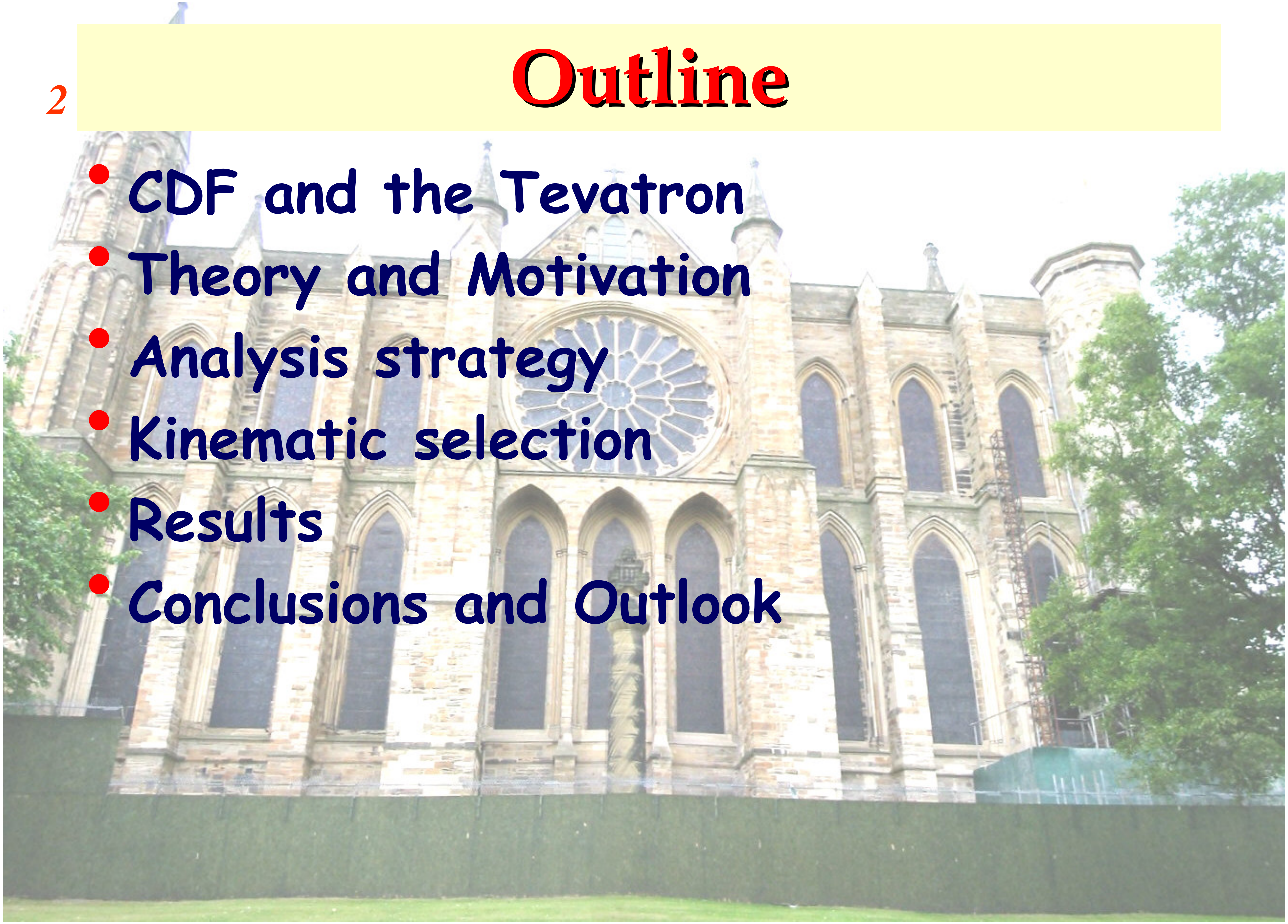
On behalf of the CDF collaboration

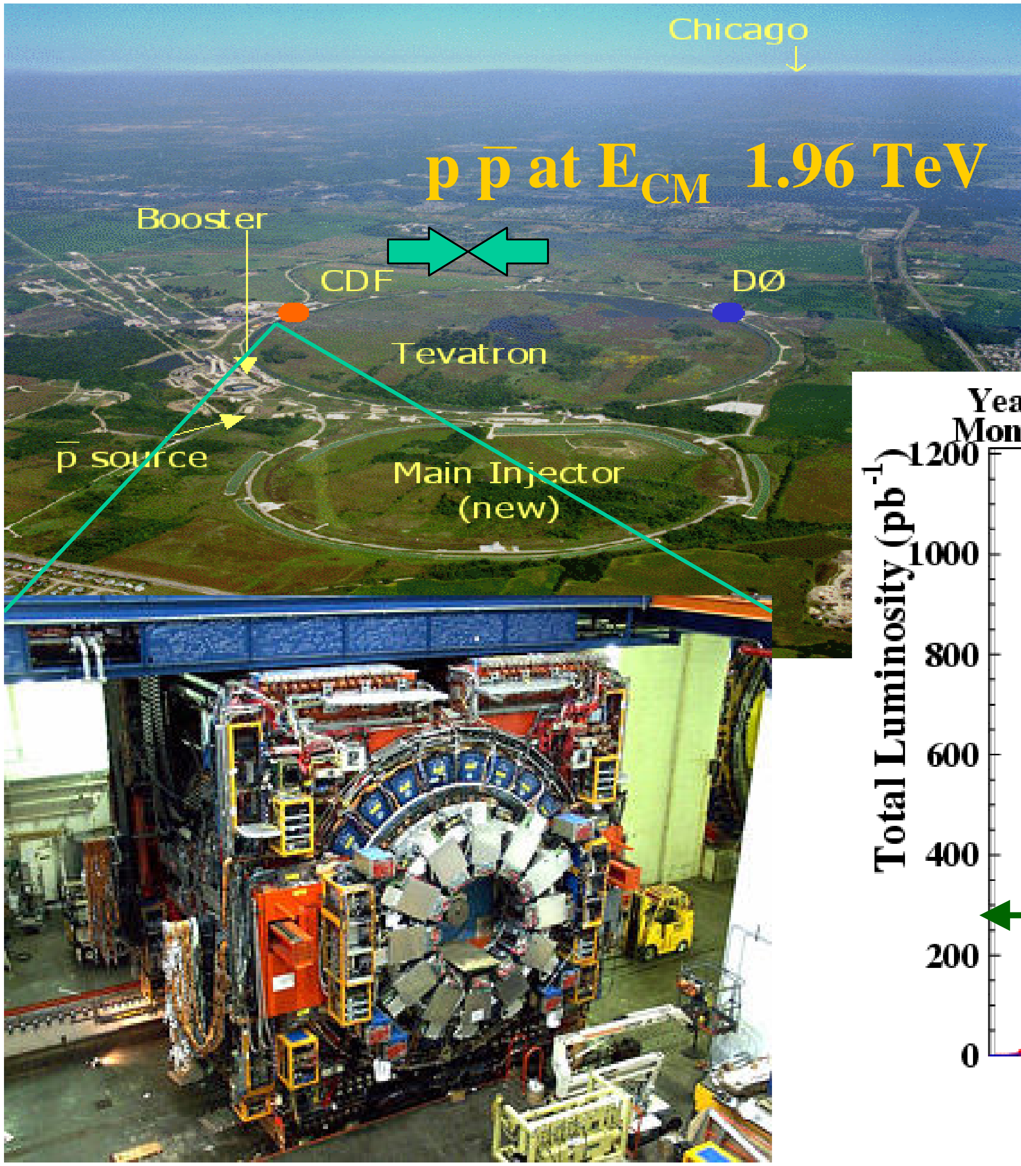
SUSY05, Durham (UK) 18-23 July 2005

# Outline

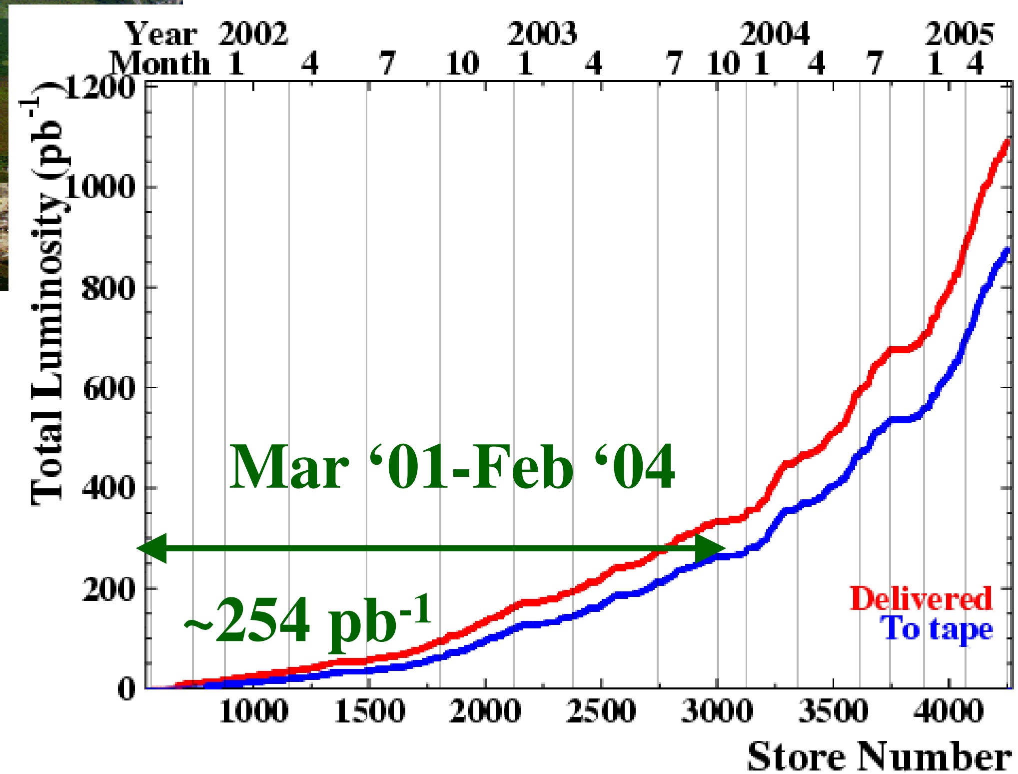


- CDF and the Tevatron
- Theory and Motivation
- Analysis strategy
- Kinematic selection
- Results
- Conclusions and Outlook

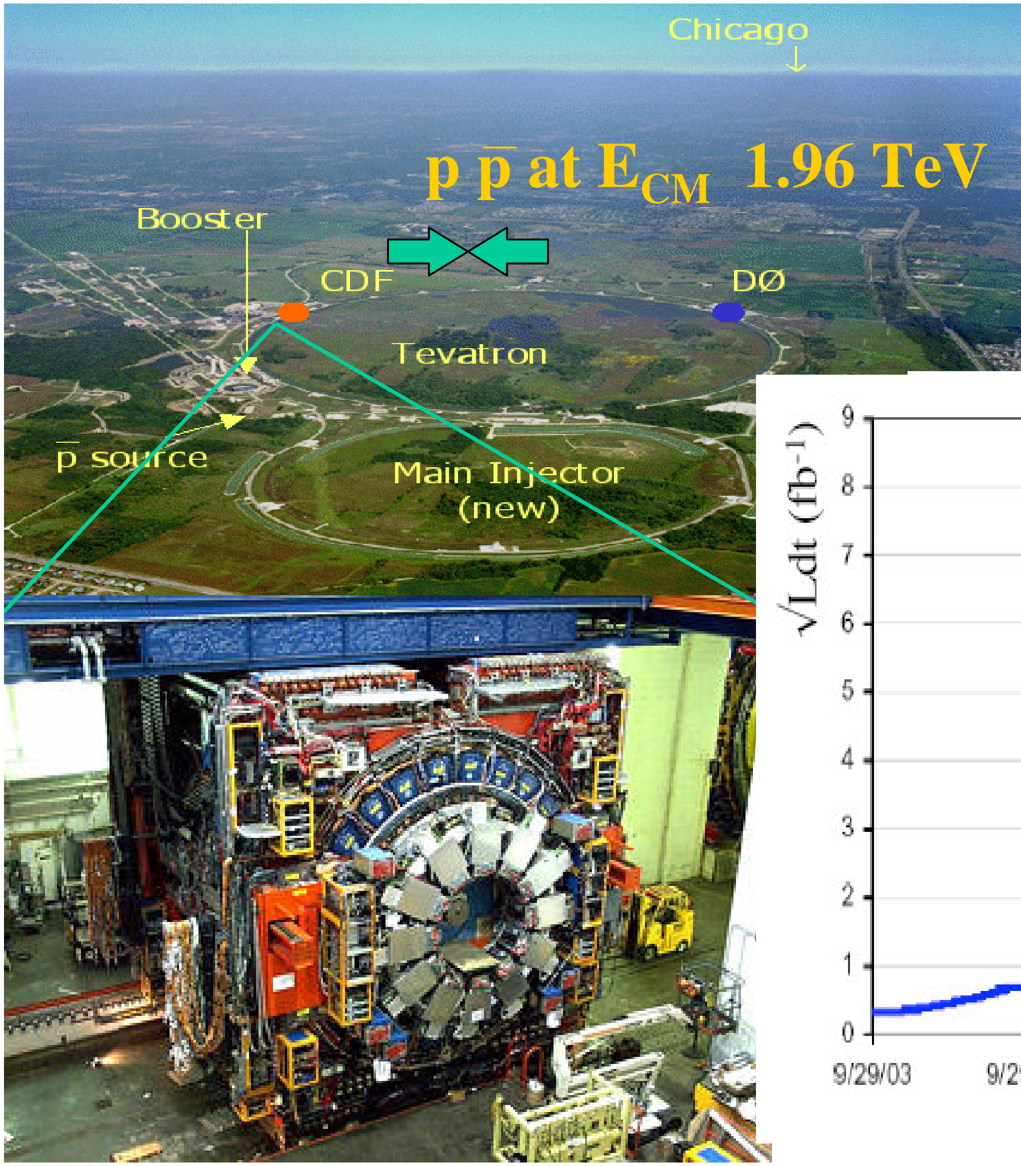
# CDF and the Tevatron




- High Luminosity
  - ➡ Tevatron 1 $fb^{-1}$!
- CDF running at high efficiency



# CDF and the Tevatron

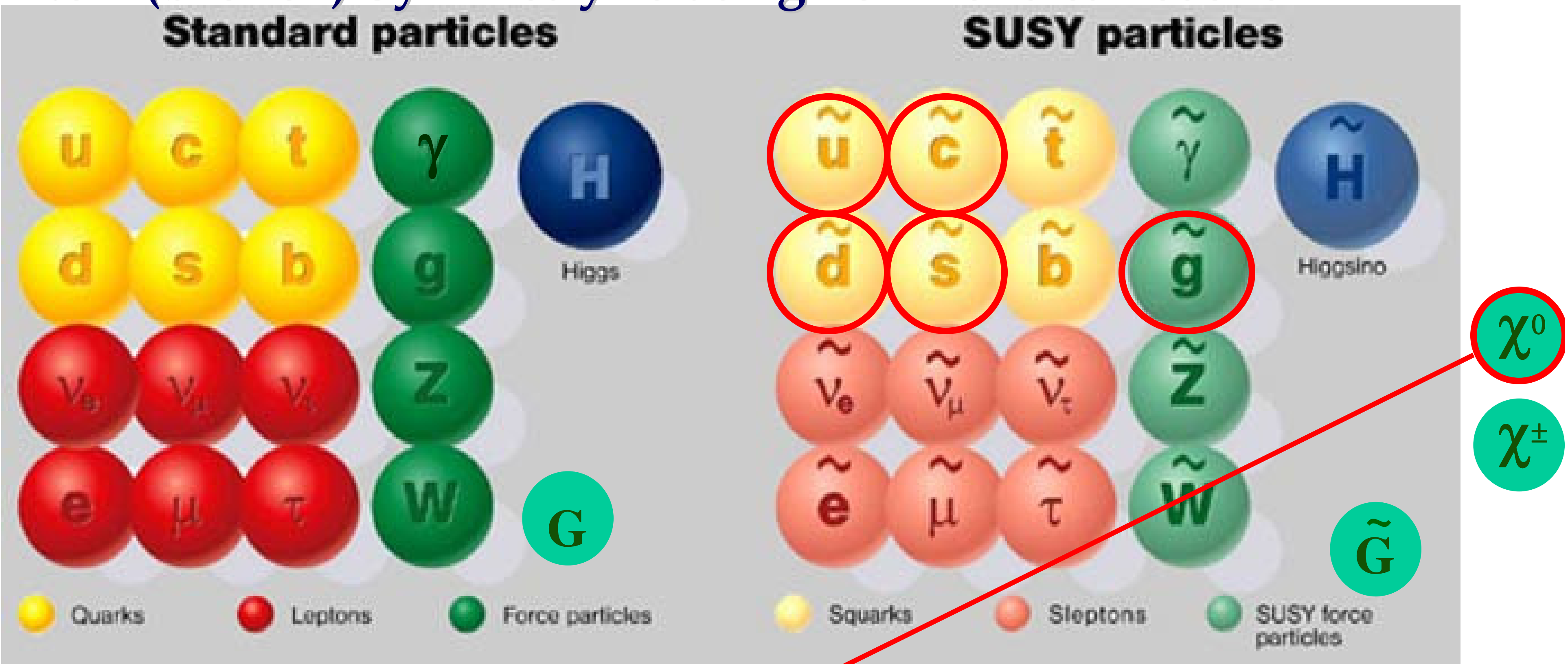



- **High Luminosity**
  - ➡ **Tevatron 1 $fb^{-1}$!**
- **CDF running at high efficiency**

***Still long way to go!***

# Supersymmetry

## New (broken) Symmetry relating Fermions & Bosons

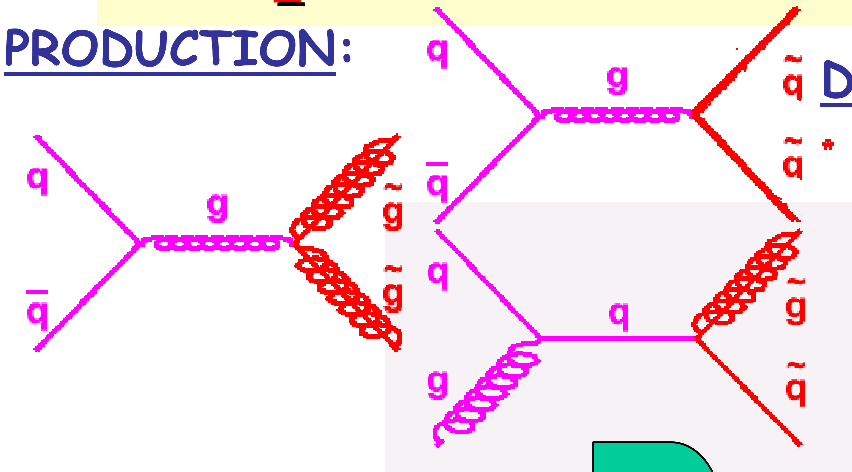



**R-Parity Quantum Number-->** $R_p = (-1)^{B+L+2s}$ $\begin{cases} +1 \text{ (SM particles)} \\ -1 \text{ (Susy particles)} \end{cases}$

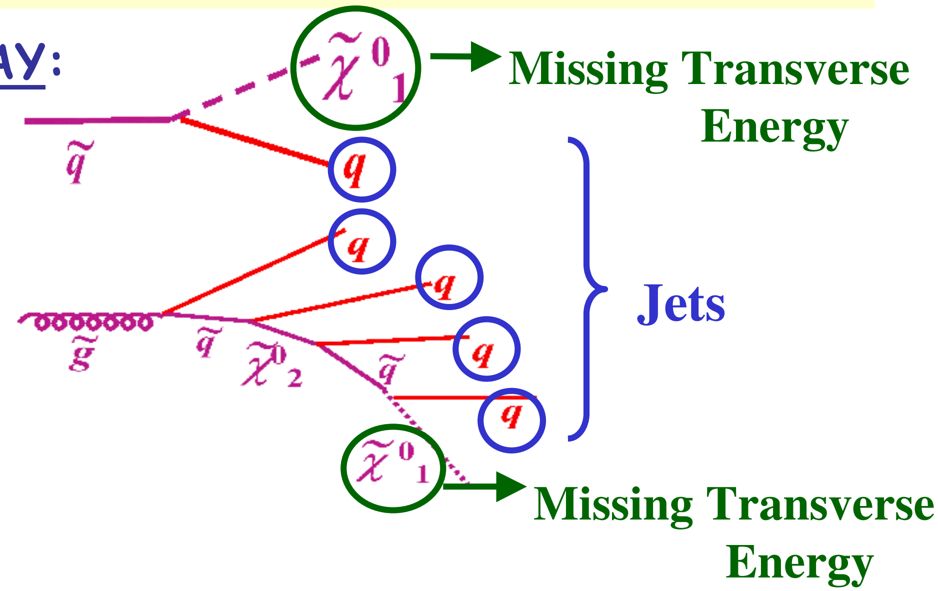
**Benchmark:** mSugra: $\chi^0_1$ LSP, stable (parameters: $M_0, M_{1/2}, \tan\beta, A_0, \mu$)

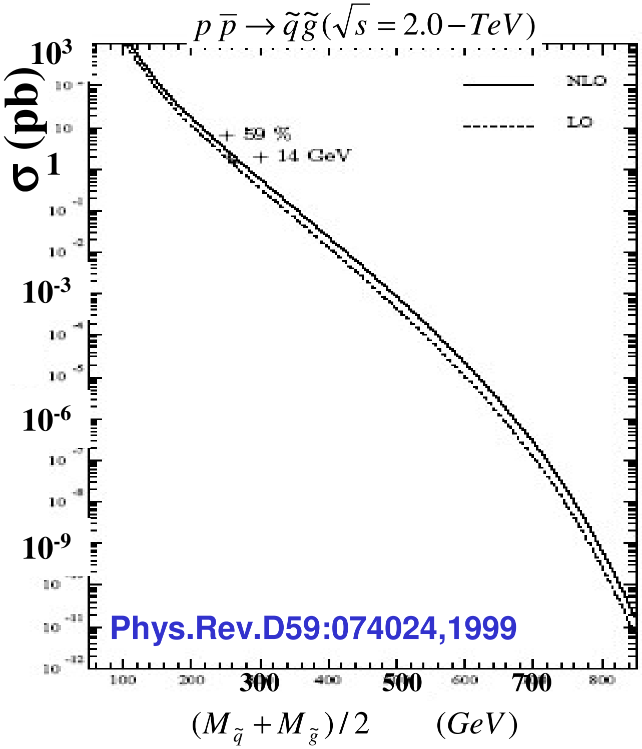
# Squark and Gluino at the Tevatron

**PRODUCTION:**



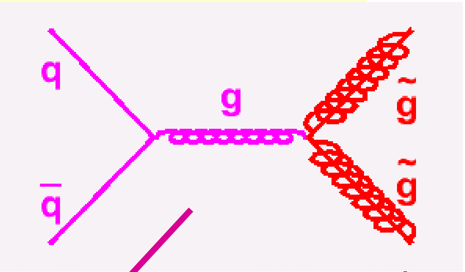

**DECAY:**




- Produced by strong interaction
- Heavy! → Large $H_T = \Sigma_{jets}(E^{jets}_T)$
- Signature: >2 jets +
  - +Large Missing Transverse Energy (MET)
  - + Large Total Transverse Energy

# Current limits




**Present best limits:**

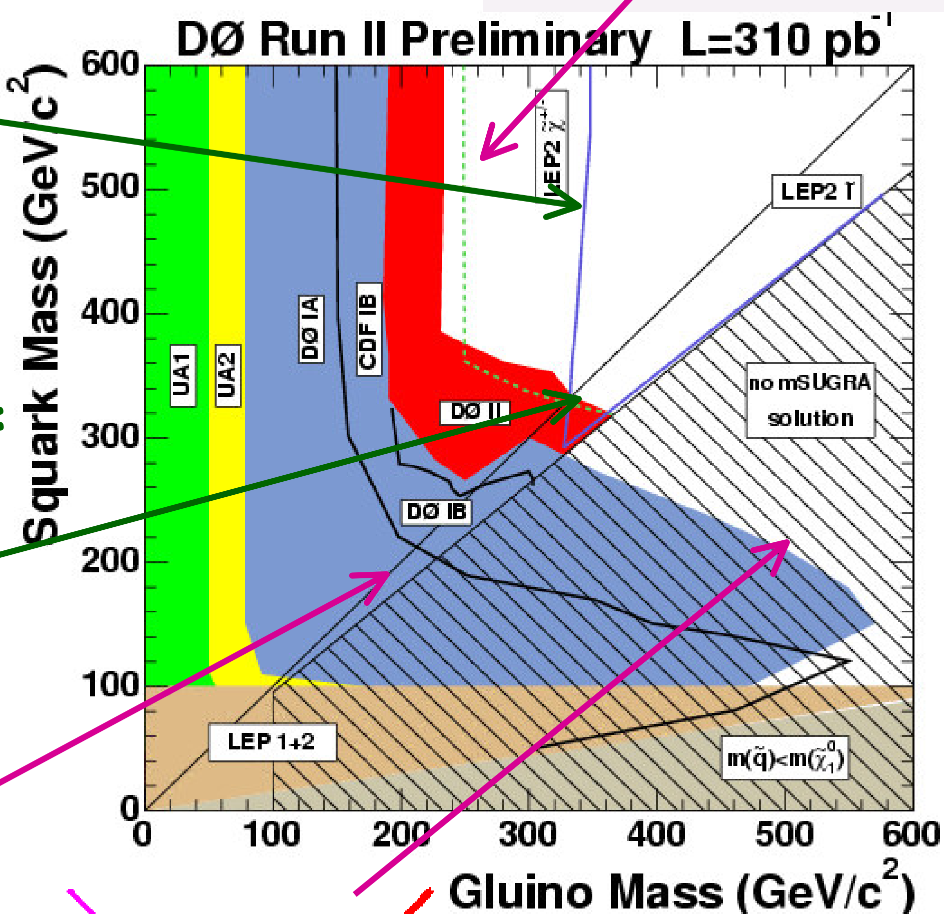
- **LEP II (indirect)**
- **D0 Run II**
  *(see talk from D.Sojot on Friday)*

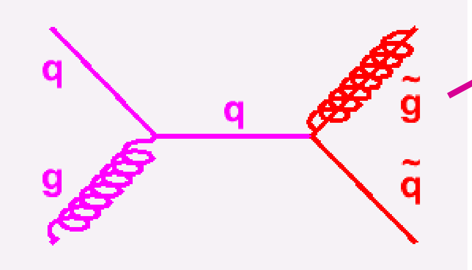
For mSugra: $\tan\beta=3$, $A_0=0$, $\mu<0$, $\tilde{q}=\tilde{u},\tilde{d},\tilde{c},\tilde{s},\tilde{b}$:

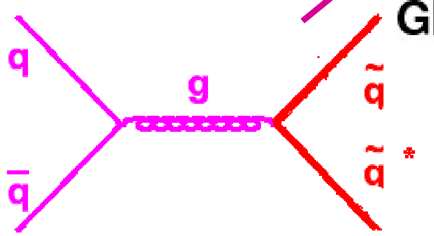
➡ 4j($\tilde{g}\tilde{g}$) : $M_0$=500 GeV-> M($\tilde{g}$) >233 GeV/$c^2$

➡ 3j($\tilde{g}\tilde{q}$) : M($\tilde{g}$)=M($\tilde{q}$) -> M($\tilde{q}$) >333 GeV/$c^2$

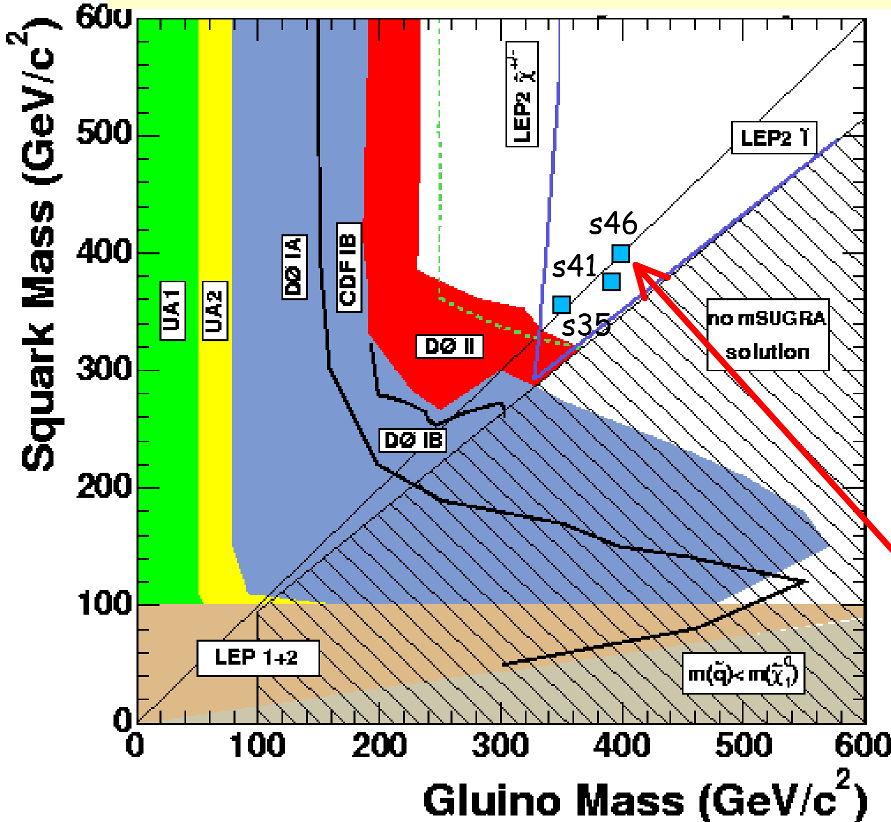
➡ 2j(qq) : $M_0$=25 GeV -> M(q) >318 GeV/$c^2$



# Reference SUSY points

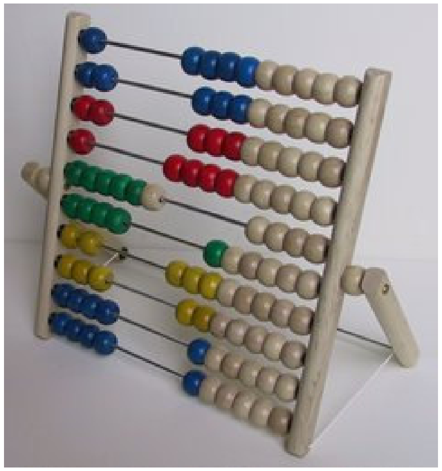



- Chosen region not excluded by other experiments
- Simulated several mSUGRA points in $M_0$-$M_{1/2}$ with $A_0$=0, sign($\mu$)=-1, tan$\beta$=5 and third generation removed from 2 → 2 process (*Isajet*)
- Chosen 3 points to optimise the analysis selection criteria

GeV/$c^2$ (applies to columns $M_0$ through M(LSP))

| Sample | NLO Sigma (pb) | $M_0$ | $M_{1/2}$ | $M(\tilde{q})$ | $M(\tilde{g})$ | $M(\tilde{\chi}^{\pm}_1)$ | M(LSP) |
|---|---|---|---|---|---|---|---|
| s35 | 0.26 | 144 | 148 | 340 | 357 | 110 | 59 |
| s41 | 0.17 | 149 | 156 | 375 | 394 | 116 | 62 |
| s46 | 0.03 | 153 | 164 | 390 | 414 | 122 | 65 |

# Analysis Strategy



## COUNTING EXPERIMENT

- **Optimise** selection criteria for best signal/background value;
- **Apply** selection criteria to the data
- **Define** the signal region and keep it blind

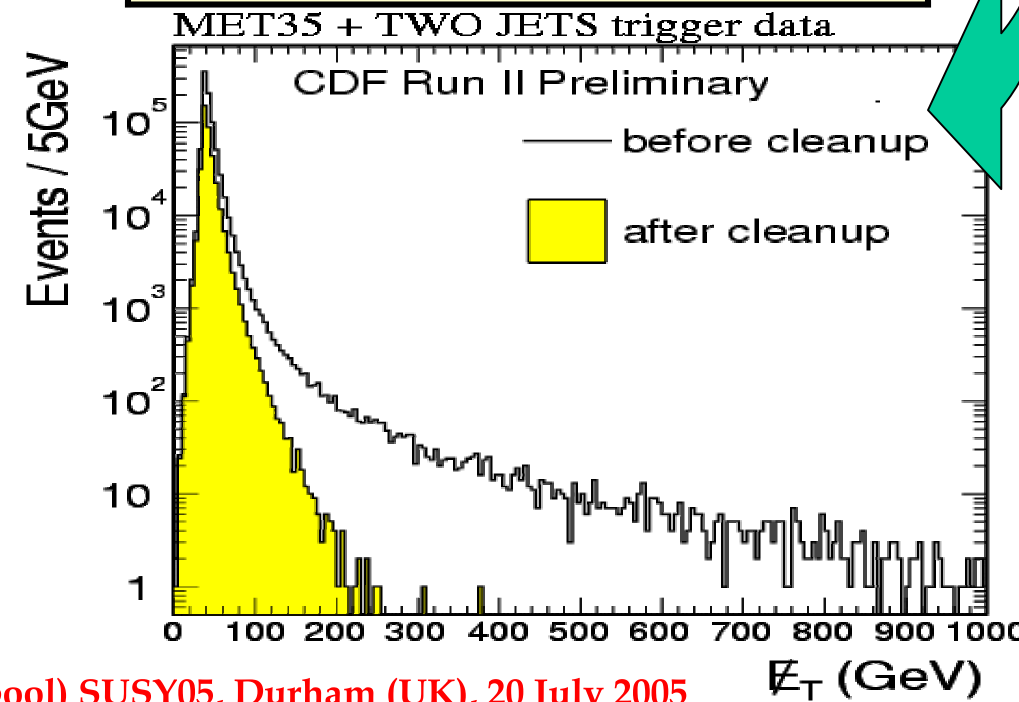
- **Test** agreement observed vs. expected number of events in orthogonal regions ("control regions")
- **Look** in the signal region and count number of SUSY events !!

Or set limit on the model

# Trigger and Event pre-Selection

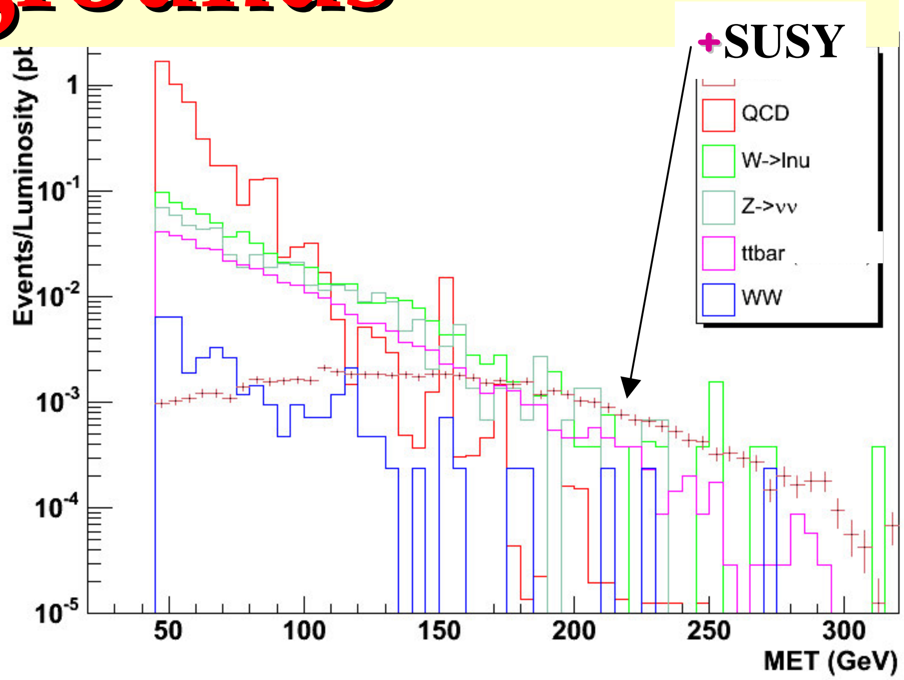
- Trigger on Missing Transverse Energy>35 GeV + 2 jets ($E_T$>10 GeV)
- Apply "Basic Cuts" to clean up the sample and eliminate effects MC does not reproduce
  - beam losses
  - cosmic and beam halo muons
  - detector failures (hot/dead towers, poorly instrumented regions,…)

| BASIC CUTS |
|---|
| MET > 60 GeV |
| Vertex: \|Vz\| < 60 cm and beam background cuts |
| At least 3 jets with $E_T$>25 GeV and \|eta\|<2.0 |
| At least one of them central (\|eta\|<1.1) |



# Backgrounds

- Several SM processes can give jets with missing energy:
  - Z →νν + 3 jets
  - W→ℓν + 2/3 jets
  - Top-antitop
  - Z→ℓℓ + 2/3 jets
  - WW
  - Hadron jets ("QCD" events)

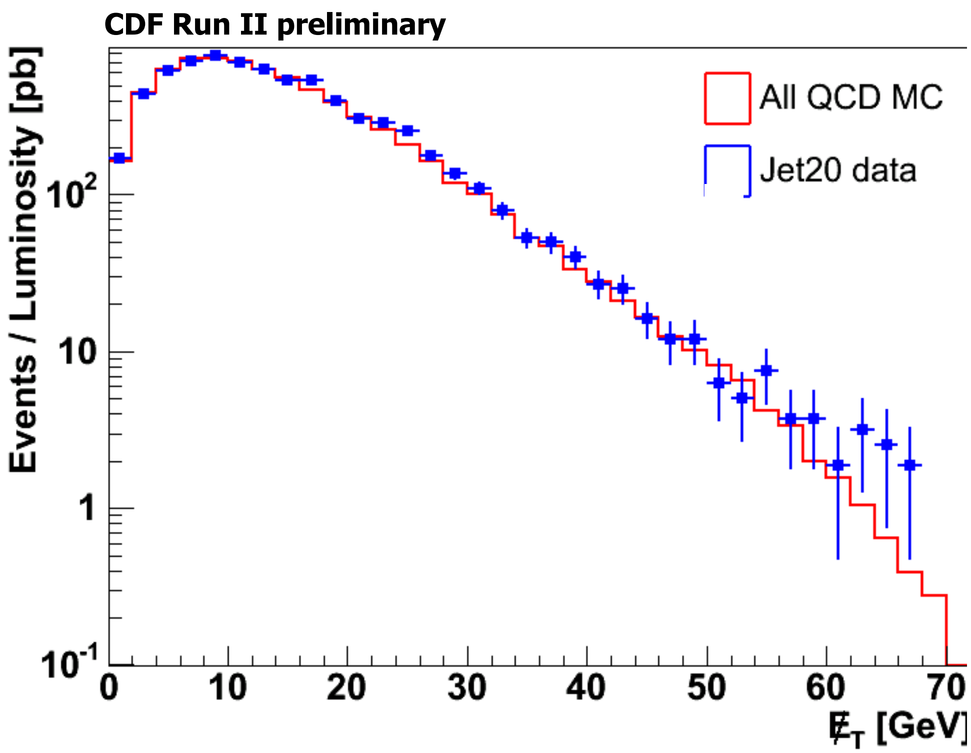


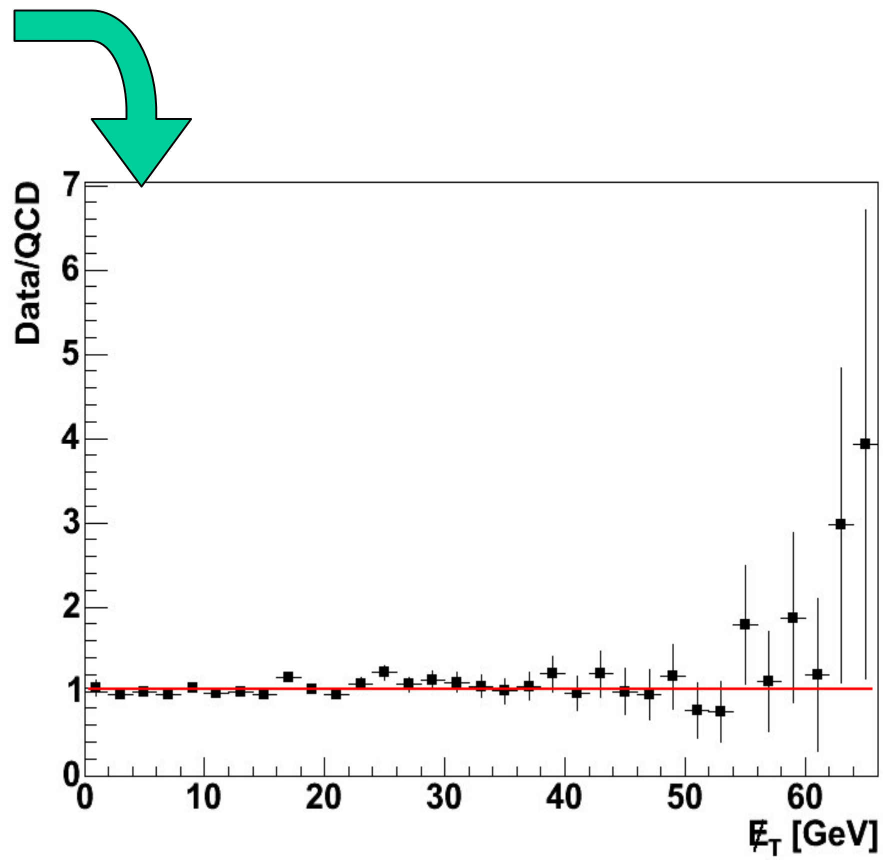

| PROCESS | MC generator | Cross section calculation |
|---|---|---|
| Z+jets | ALPGEN+Herwig | NLO MCFM |
| W+jets | ALPGEN+Herwig | NLO MCFM |
| WW | ALPGEN+Herwig | NLO MCFM |
| ttbar | Herwig | NLO[1] |
| Hadron Jets (QCD) | Pythia | DATA |

[1] Cacciari et. al., JHEP 404, 68(2004)

# Hadron Jets Background

- Selected region dominated by Jet events in the data satisfying the pre-selection criteria
- Compared distributions MC events to data and obtained scale factor to the MC ~1.0



# Analysis Event selection

Selection criteria optimised using $S/\sqrt{B}$

| ANALYSIS SELECTION CRITERIA | |
|---|---|
| $\Delta\phi$ (MET, jet) > 0.7 for all 3 jets | To reject QCD |
| EM Fraction < 0.9 for all 3 jets | To reject electrons |
| $E_T$(1st jet)>125 GeV; $E_T$(2nd jet)>75 GeV | |
| MET>165 GeV | Signal region |
| $H_T \equiv E_T1+E_T2+E_T3$ >350 GeV | Signal region |

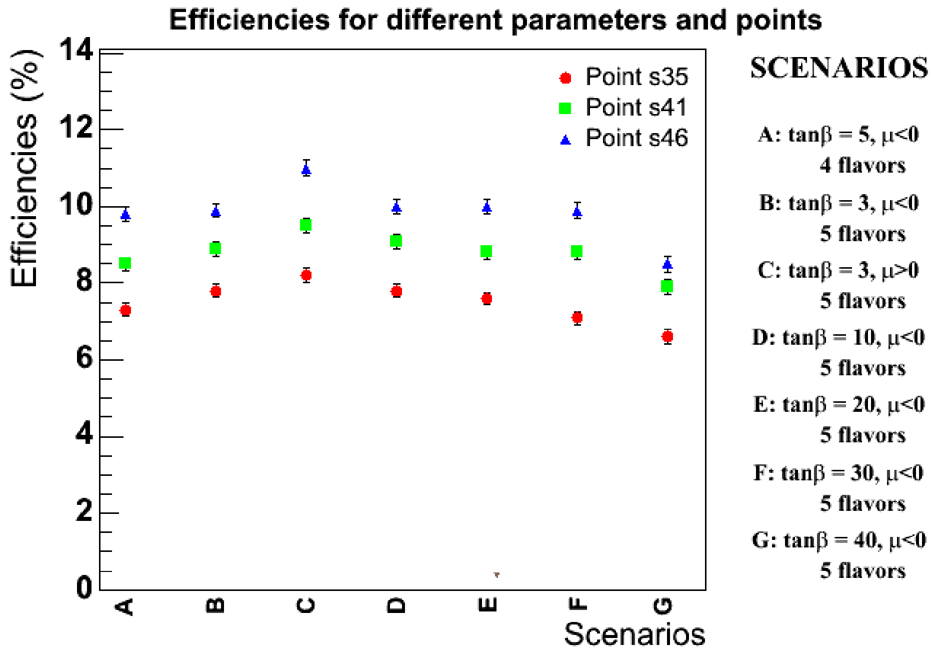
Using these selection criteria: ($254 pb^{-1}$)

| SM Processes | Expected Events |
|---|---|
| Electroweak ($W\to\ell\nu$+nj, $Z\to\ell\ell$+nj, ttbar, WW) | 3.95 |
| QCD | 0.21 |
| SUM SM Backgrounds | $4.1 \pm 1.5$ |

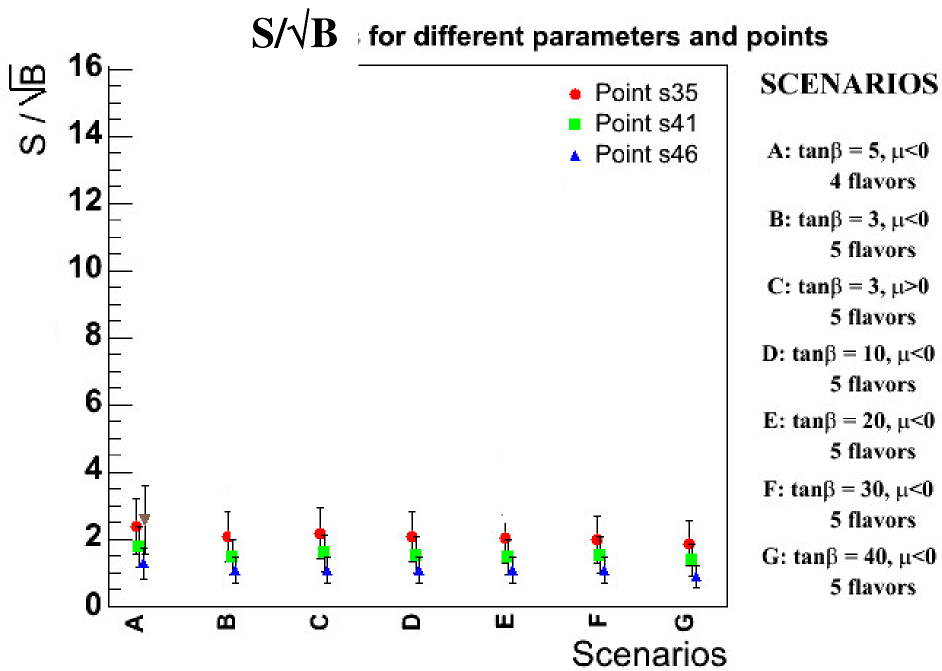
Signal Efficiency: 7-10%

# SUSY Monte Carlo

**Different mSUGRA parameter values have been studied:**
**number of flavours, tanβ and sign of μ for the same value of $M_0$-$M_{1/2}$.**



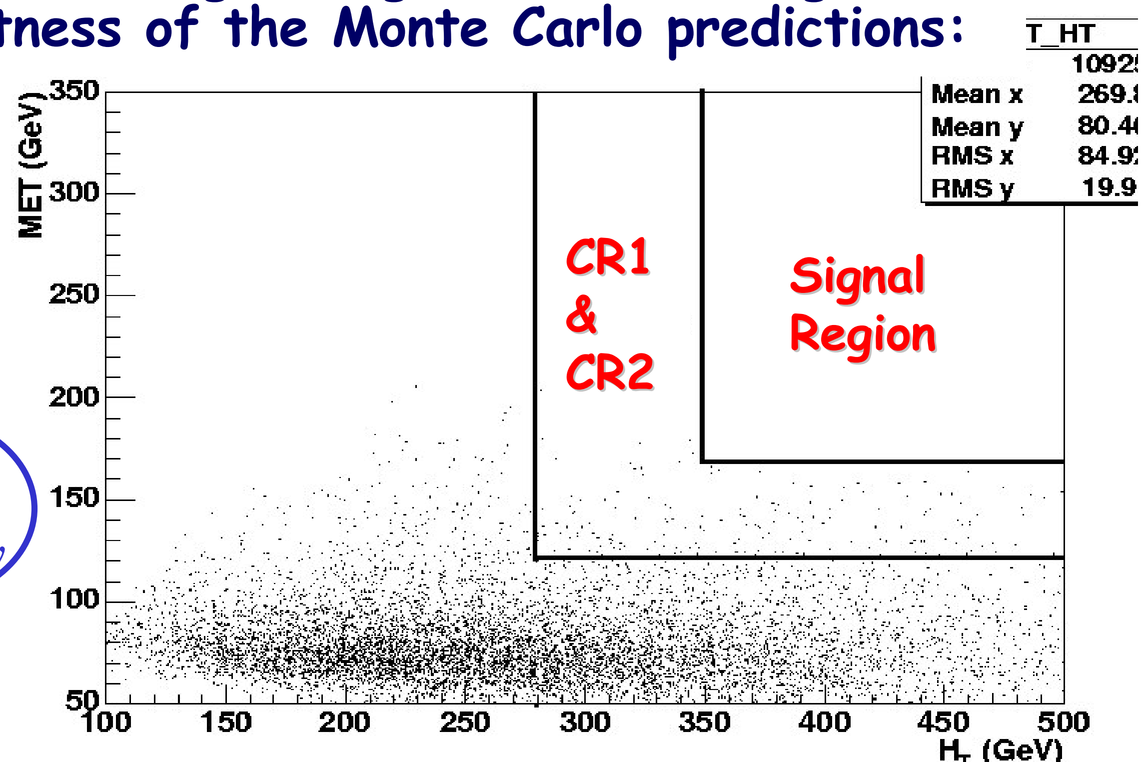

- CDF Run II
- CDF Run I and D0 Run II generations
- CDF Run I changing sign μ




**No large difference observed over all scenarios-> small model dependency**

# Control Regions

Several regions different from the signal region (“control regions”) examined to verify the robustness of the Monte Carlo predictions: analysed two:




**CR1:**

Veto electron (EM fraction < 0.9)
-> QCD dominated

Hadron jets: 165 ± 6

EW: 36 ± 2

Tot Expected: 201 ± 6

Observed: 183 ± 14

*Only statistical uncertainty*

**CR2:**

Require EM fraction > 0.9

-> EW and QCD similar

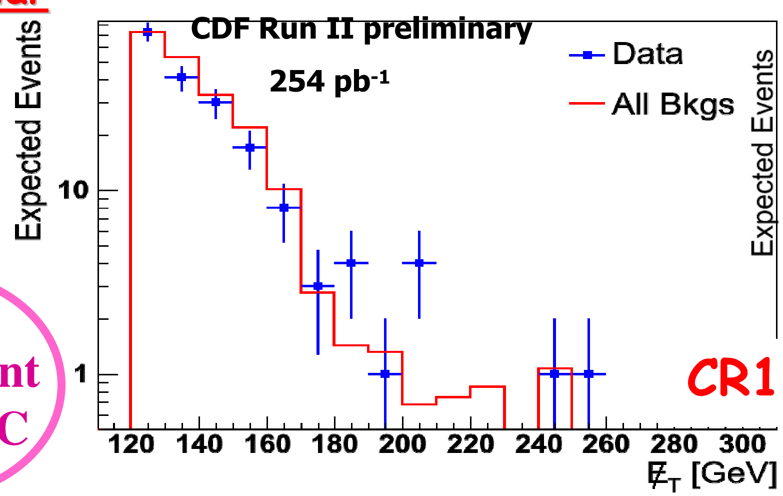
Hadron Jets: 16 ± 1

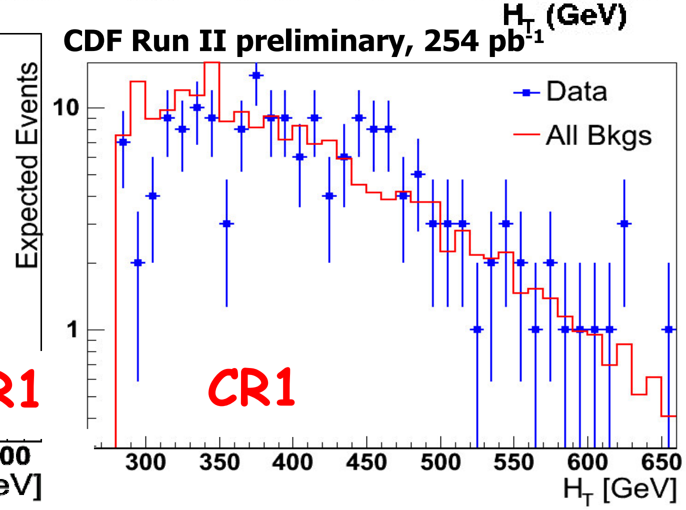
EW : 12 ± 1

Tot Expected: 28±1

Observed: 23±5

**Good agreement Data-MC**



# Systematic Uncertainties

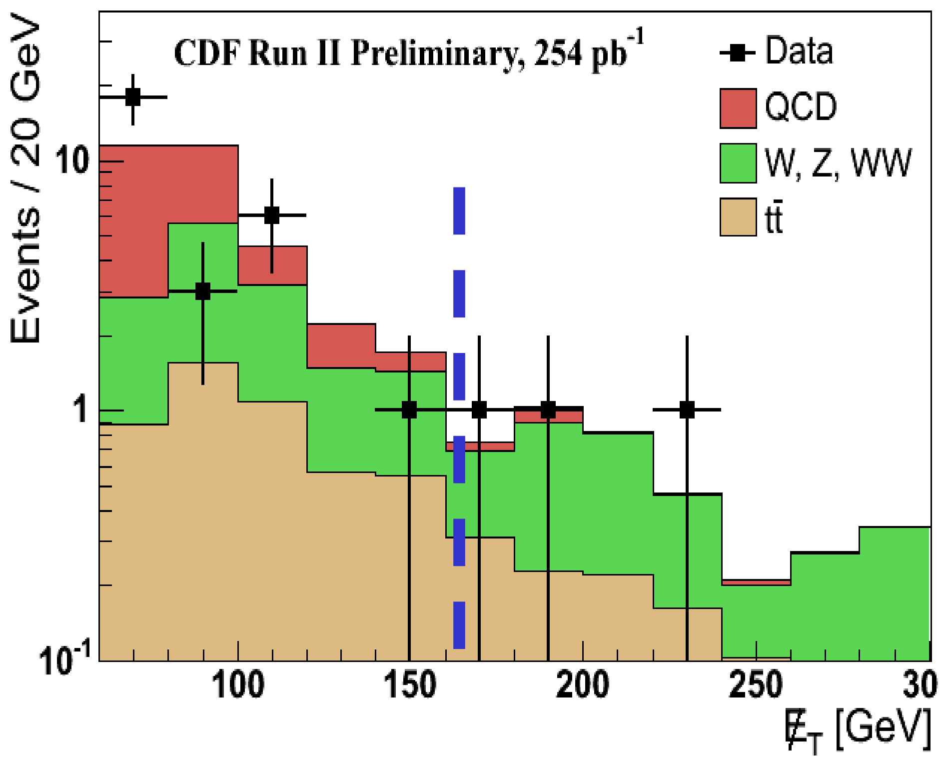
| Source | Uncertainty on final background estimate |
| --- | --- |
| Luminosity | 6% |
| Jet Energy Scale | 29% |
| Jets Background Estimation | 1% |
| ttbar cross section | 3.6% |
| WW cross section | 0.5% |
| W+jets cross section | 14.6% |
| Z+jets cross section | 3.7% |
| TOTAL | 33.4% |

# Looking at the Signal Region

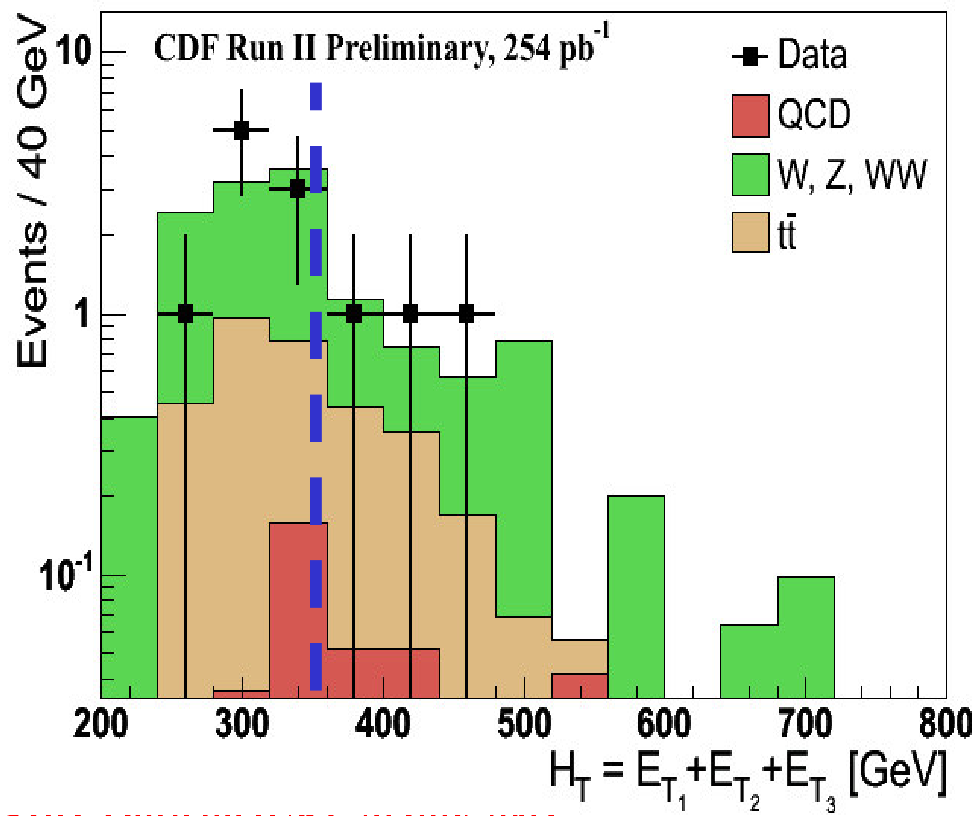
**In L = 254 $pb^{-1}$ :**

- SM Expected Events = 4.1 ± 1.5
- Observed Events = 3

MET distribution after applying all the cuts except MET >165 GeV

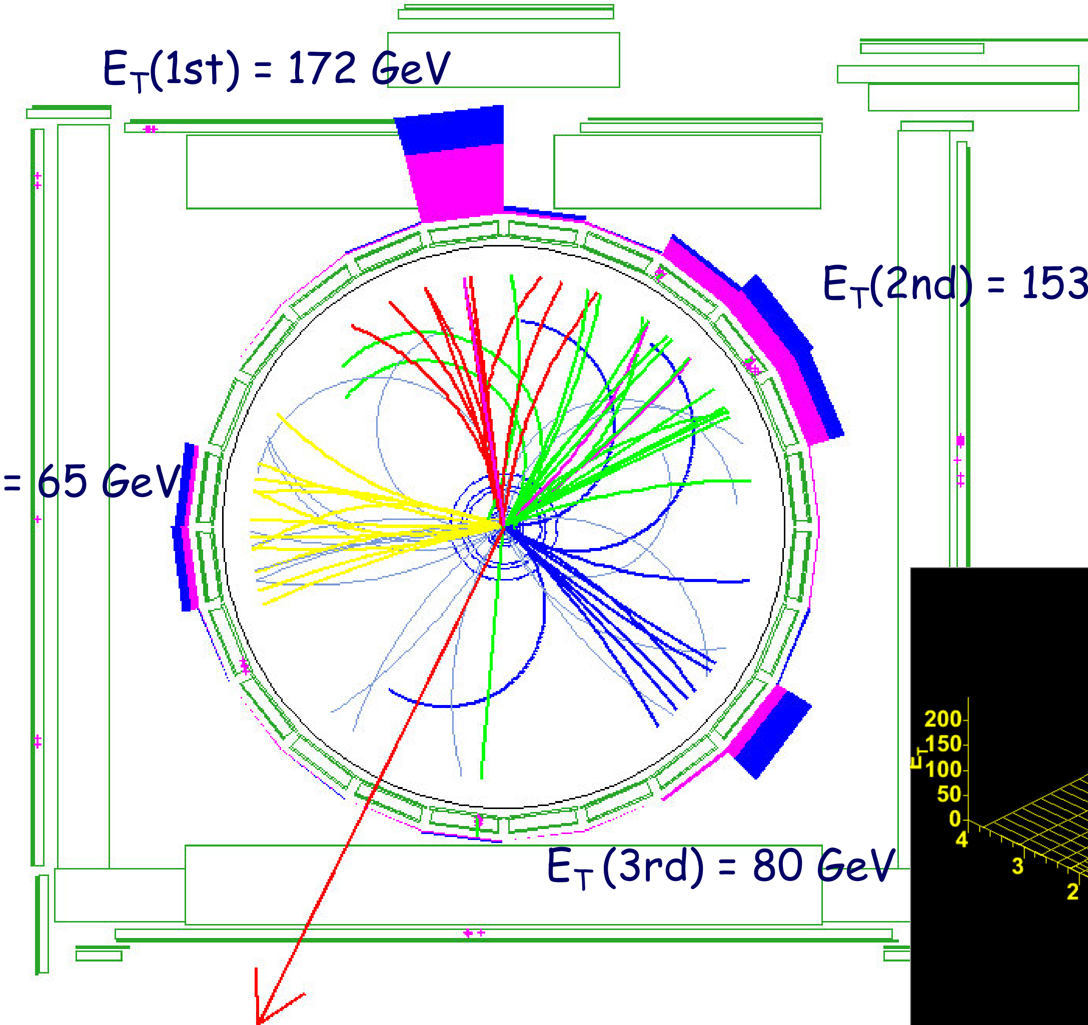


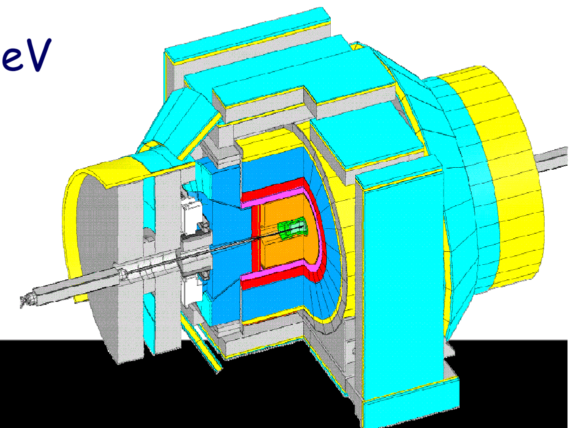

$H_T$ distribution after applying all the cuts except $H_T$ >350 GeV

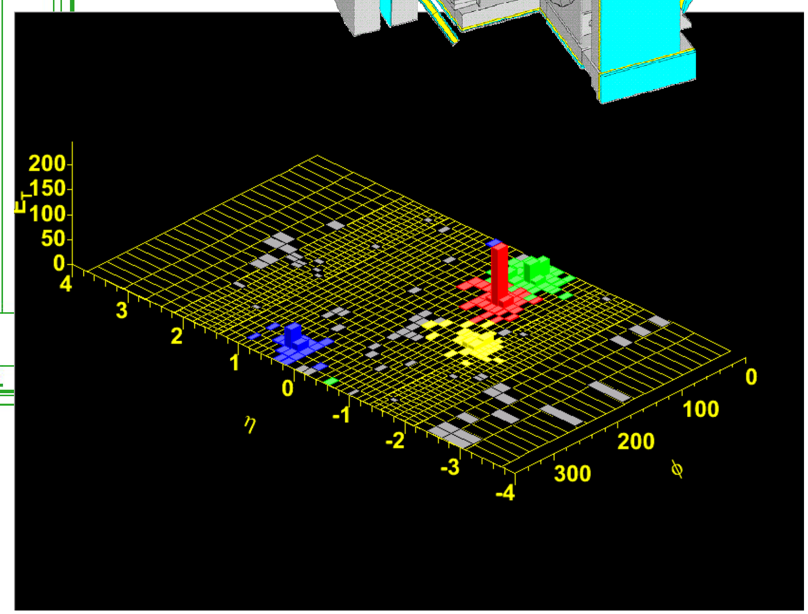


# Event 1

$H_T = E_T(1st) + E_T(2nd) + E_T(3rd) = 404$ GeV



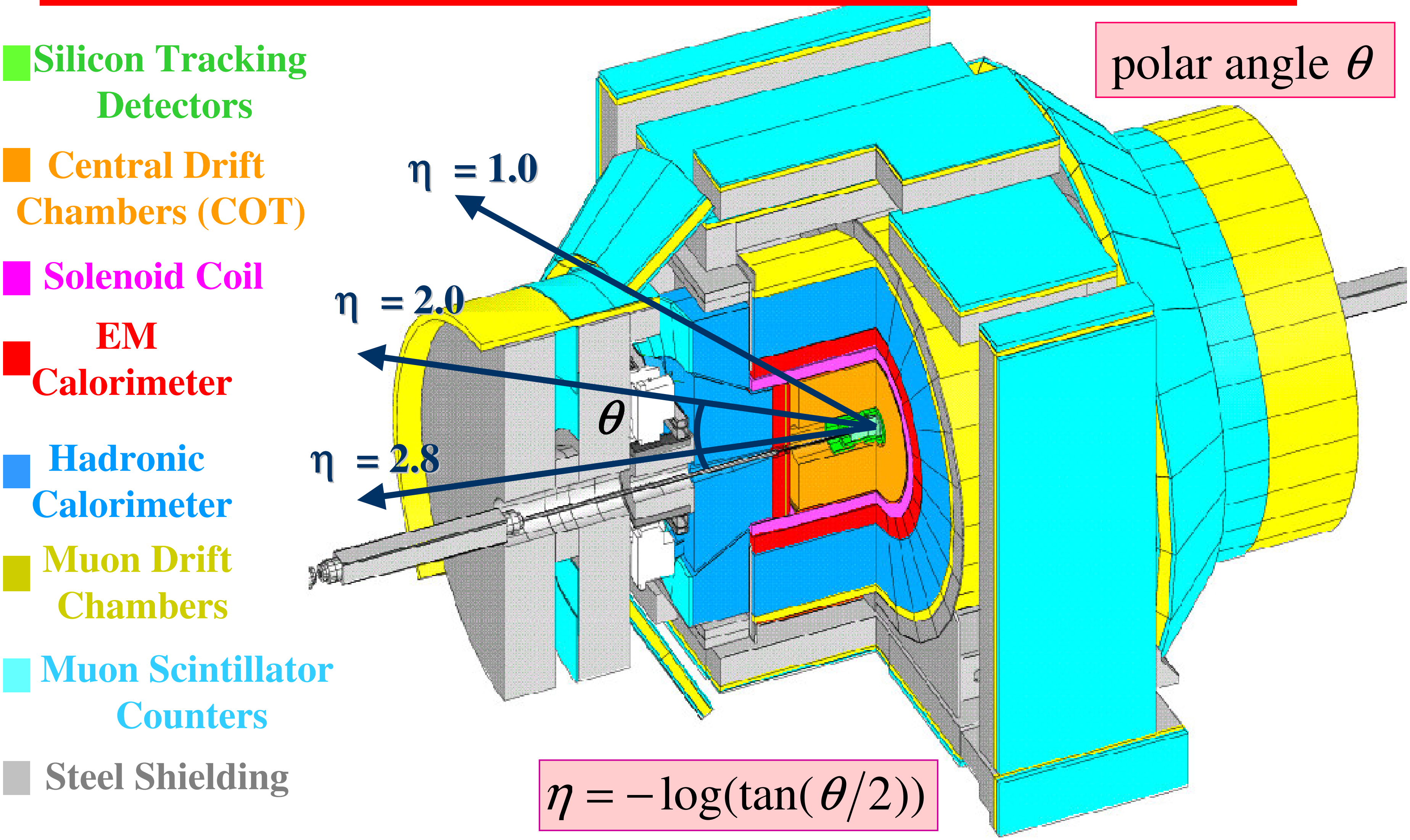


# Conclusions and Outlook

- Performed blind search for squark and gluinos over 254 pb-1 CDF RUN II data
- Selection criteria have been optimised for several mSugra scenarios:
  - Find relatively small dependence on tan$\beta$, sign of $\mu$ and and number of flavours
- Demonstrated good understanding of data and SM backgrounds in "control regions"
- No evidence for Squarks and Gluinos
  - Data agree with background estimate
- Full interpretation in progress
- Future improvements with increased luminosity

# BACK-UP SLIDES

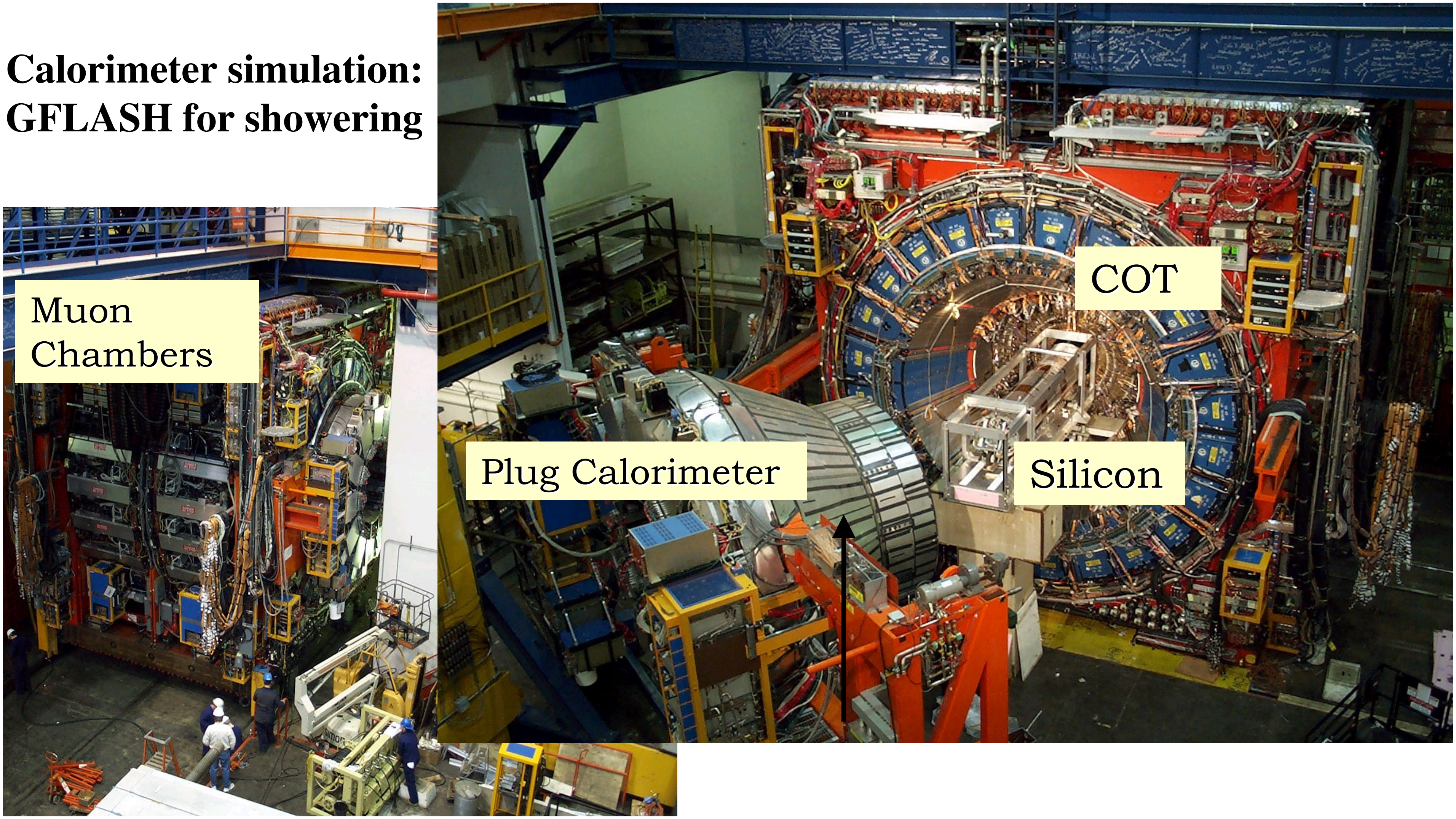
# The CDF-II detector




$$\eta = -\log(\tan(\theta/2))$$

# The CDF-II detector

**Calorimeter simulation: GFLASH for showering**



# Beam Background Cuts

$$\text{EEMF} = \frac{\Sigma_{jets}(E^{jet}_T \times f^{jet}_{EMC})}{\Sigma_{jets}(E^{jets}_T)} > 0.15$$

$$\text{ECHF} = 1/N_{jets} \times \Sigma_{jets} \frac{\Sigma_{tracks}(P^{track}_T)}{E^{jet}_T} > 0.15$$

↑

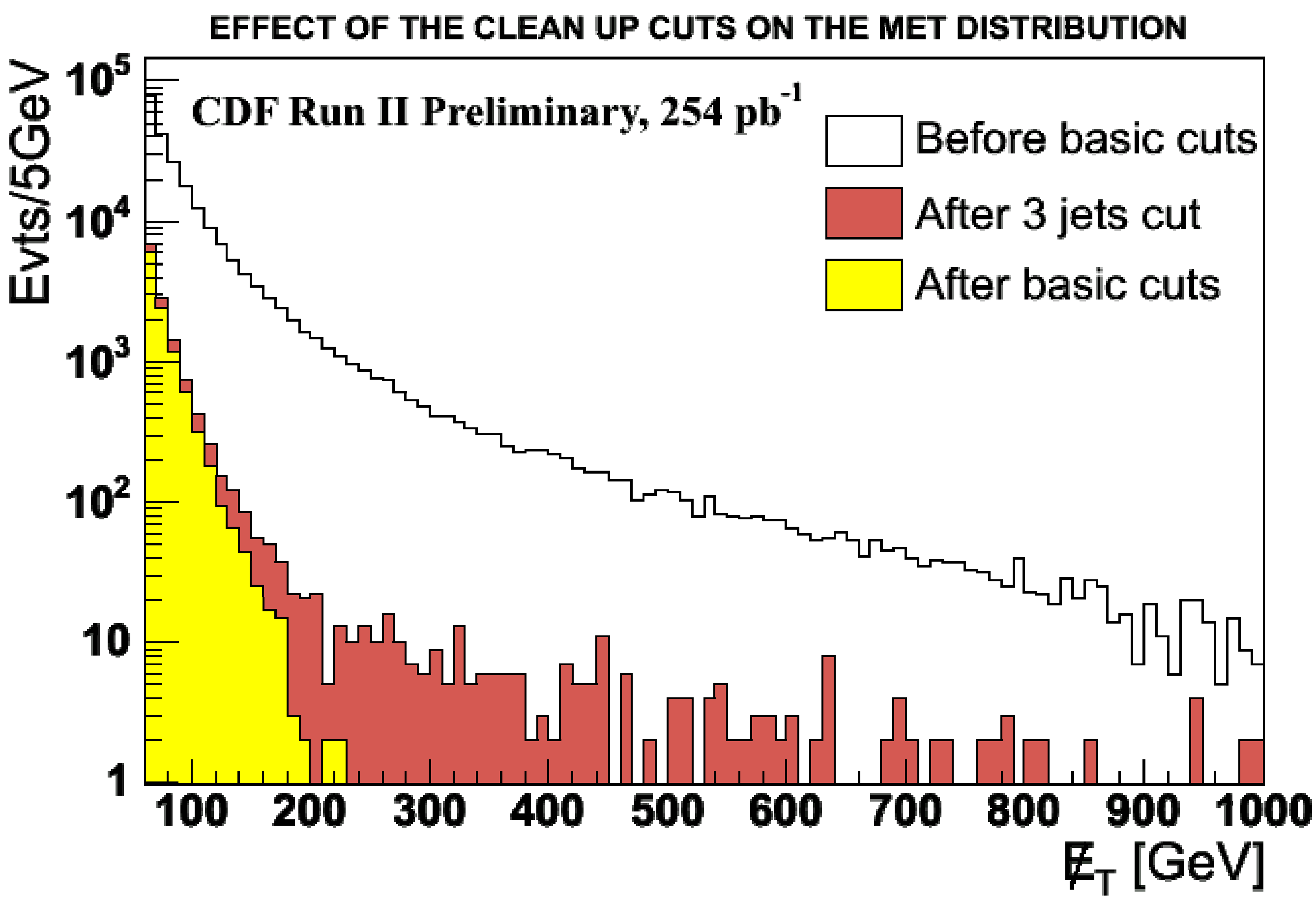
**Only for central (|eta| < 1.1) jets**

# Criteria to select QCD region in data

In JET20 data:

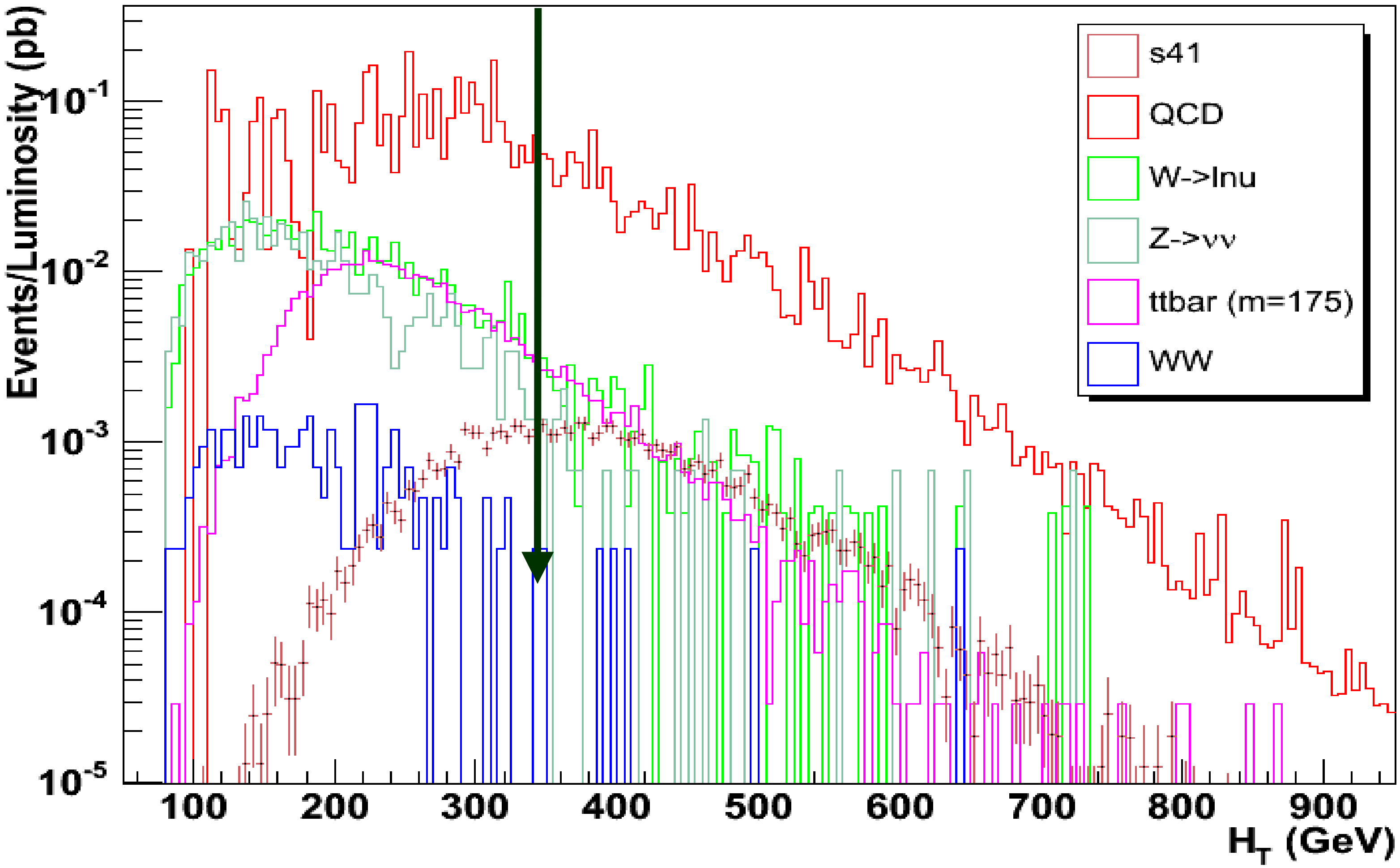
- Basic cuts
- Et(j1)>90 GeV, Et(j2)>60 GeV
- MEt Significance=MEt/$\sqrt{\Sigma_{met\ towers}}$<3.5 $GeV^{-1/2}$
- Et(j1)+Et(j2)+Met<100 GeV

# After Basic Cuts



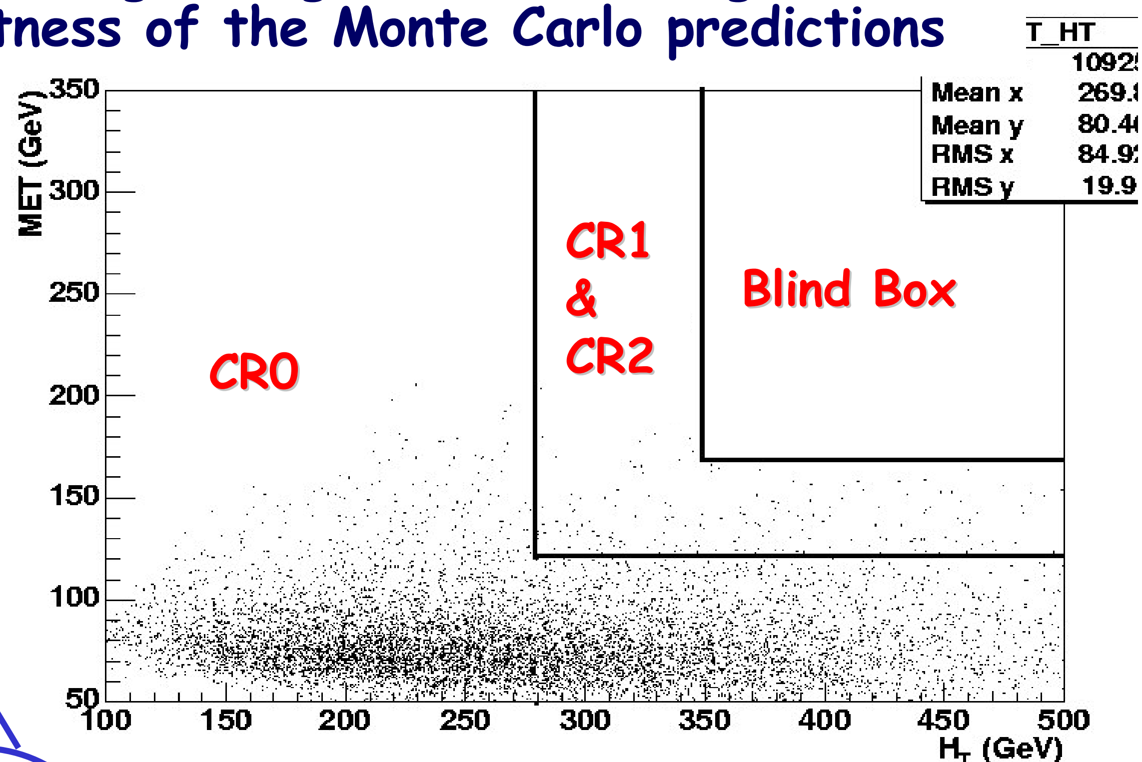
# Delta Phi Optimisation

$H_T \equiv E_{T_1} + E_{T_2} + E_{T_3}$



# Control Regions I

**Three regions orthogonal to the signal region ("Control regions") examined to verify the robustness of the Monte Carlo predictions**




**CR0: QCD dominated**

- Basic cuts
- ET of the jets
- EMF of the jets
- Out of the BB

QCD: 3421

EW: 144

SM Expected: 3564 ± 54

Observed: 4438 ± 67

**CR1: QCD dominated**

- Basic cuts
- ET of the jets
- EMF of the jets
- 120<MET<165
- 280<HT<350 GeV

SM Expected: 201 ± 7

Observed: 183 ± 14

Only statistical uncertainty

**CR2 (EM dominated):**

- Basic cuts
- ET of the jets
- At least one jet with EMF>0.9
- 120<MET<165, 280<HT<350 GeV

SM Expected: 27 ± 0

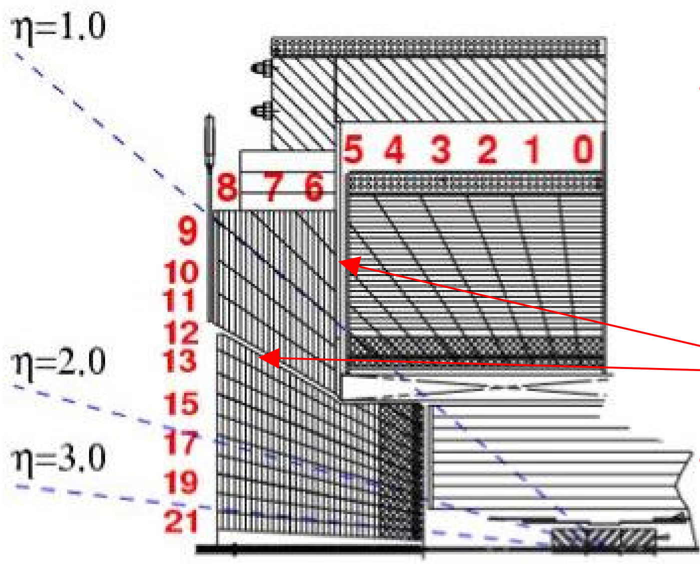
Observed: 23 ± 5

# Efficiency of the signal points

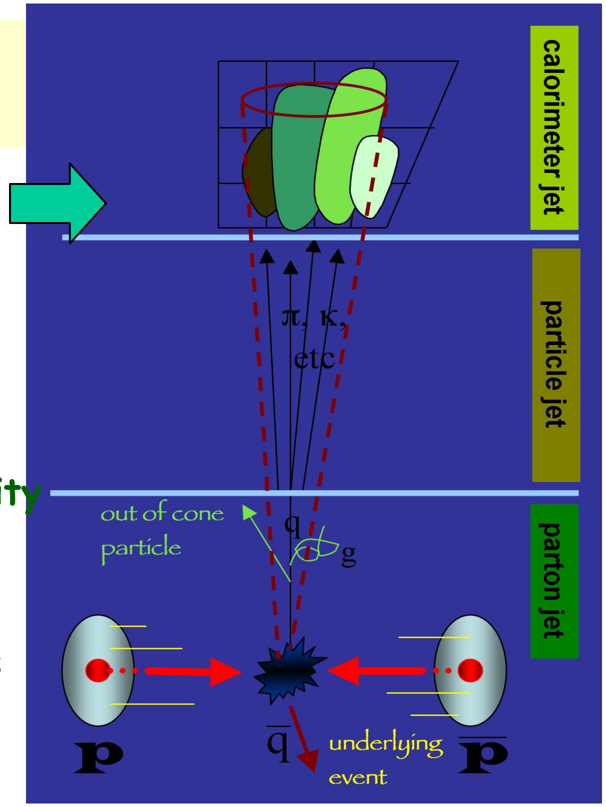
Using these selection criteria:

| Samples | Expected Events ($254 pb^{-1}$) | Efficiency (%) | $S/\sqrt{(B)}$ |
|---|---|---|---|
| Signal s35 | 4.8 ± 0.1 ± 0.7 | 7.2 ± 0.2 ± 0.9 | 2.3 ± 0.8 |
| Signal s41 | 3.6 ± 0.1 ± 0.6 | 8.4 ± 0.2 ± 1.1 | 1.8 ± 0.6 |
| Signal s46 | 0.7 ± 0.0 ± 0.2 | 9.7 ± 0.2 ± 1.3 | 0.4 ± 0.1 |
| SM Background | 4.1 ± 0.6 ± 1.4 | | |

# Jet Energy Scale at CDF

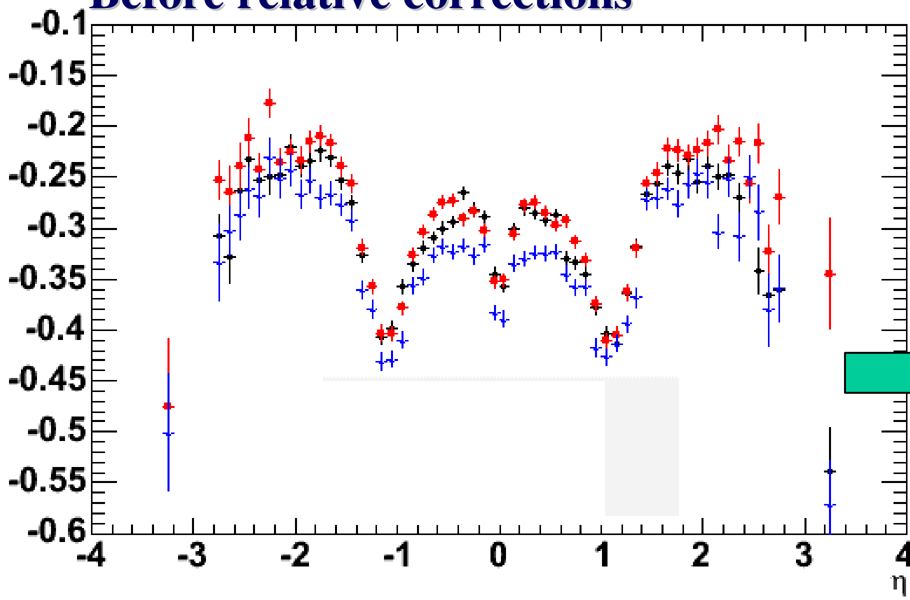



- A **Jet** = energy deposited in the hadronic calorimeter in a cone of R=0.7(this analysis)
- An **Energy Correction** is necessary to scale the measured energy *back to the energy of the final state particle level jet* (due to several effects as non-linearity of the calorimeter or *un-instrumented regions of the detector*)
- The factor we apply accounts for all these effects, using different methods; e.g. balancing γ-jet

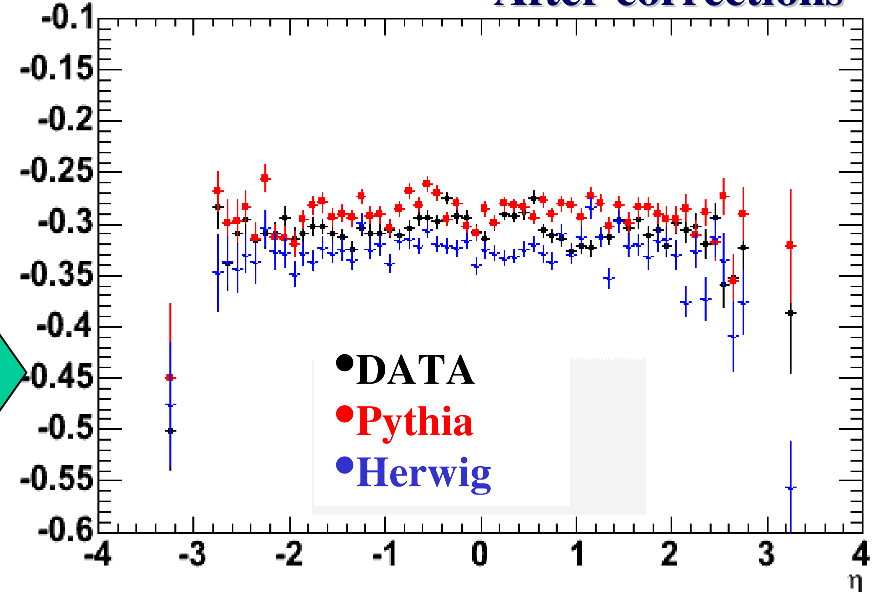



**Pt of the γ-jet system:**

**Before relative corrections**



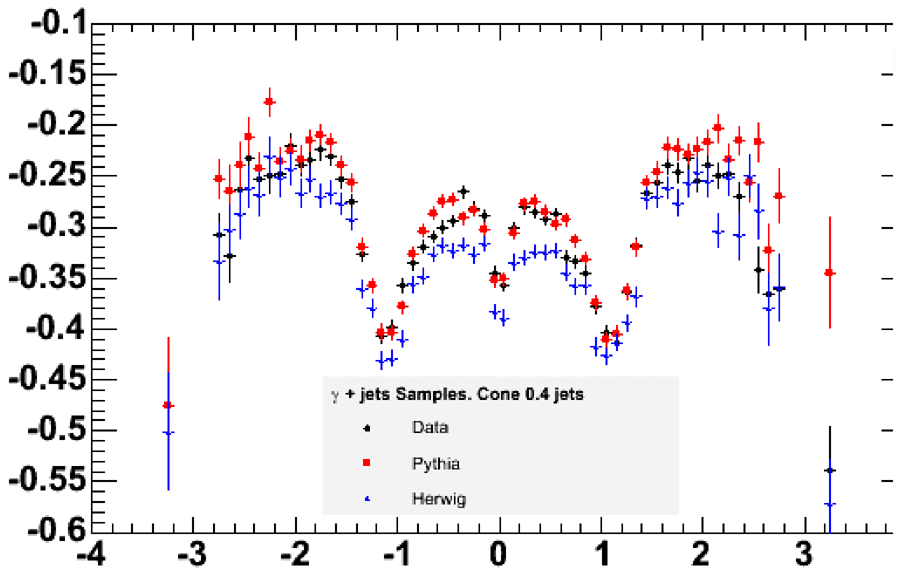

**After corrections**

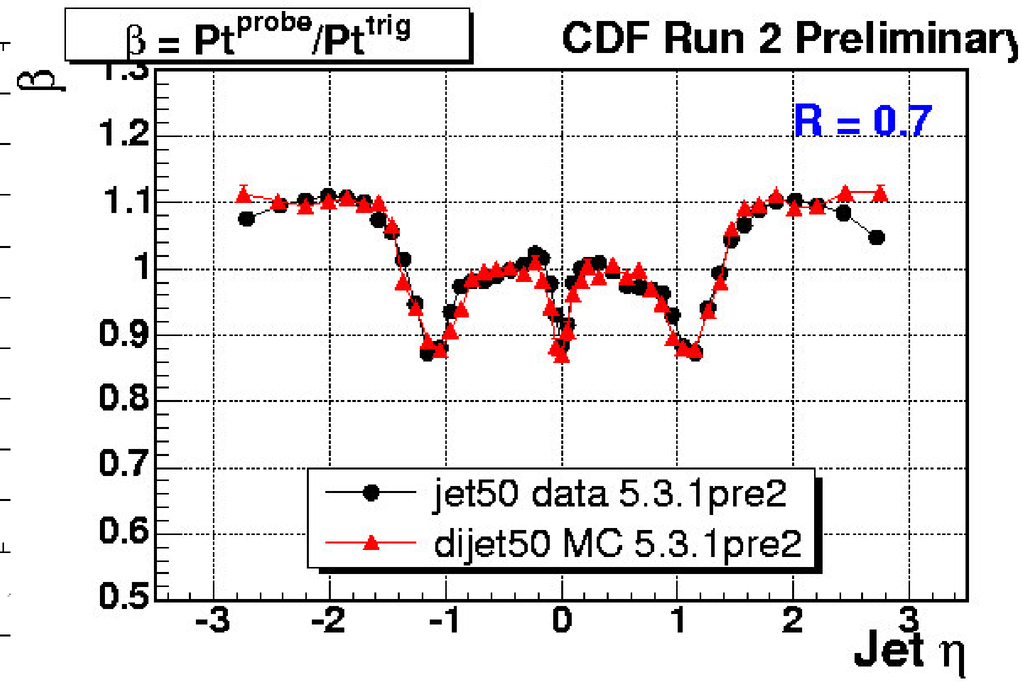


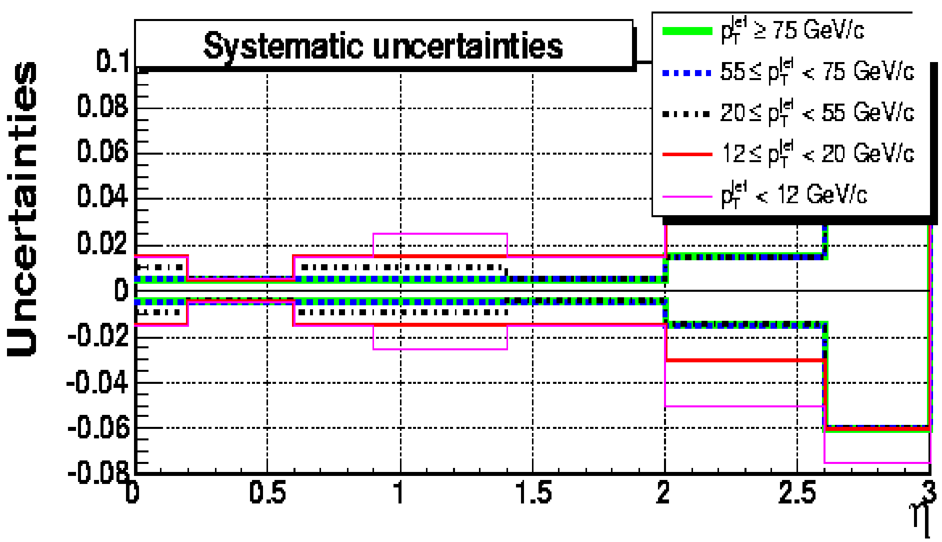
# Different effects that can distort the measured Jet energy

| Correction | Reason | Method | Contribution | Plot |
|---|---|---|---|---|
| **Absolute Scale** | *Non-linearity and energy loss in the un-instrumented regions of each calorimeter* | We measure the fragmentation and single particle response in data and tune the Monte Carlo to describe it<br>Pythia Monte Carlo | **100 GeV: 2.2%**<br>**15 GeV: 1.8%** | Abs Corr |
| **Relative Scale** | *Difference in response in the forward calorimeter respect to the one of the central* | Scale the response in the forward to the central<br>Pythia and Data di-jet events | **100 GeV: 0.5%**<br>**15 GeV: 1.5%** | Rel Corr |
| **Multiple Interactions** | *The energy from different ppbar interactions during the same bunch crossing falls inside the jet cluster, increasing the measured energy of the jet.* | subtracts this contribution in average as function of # vertices<br>Minimum Bias Data | **100 GeV: 0.05%**<br>**15 GeV: 0.4%** | MI corr |
| **Underlying event** | *The energy associated with the spectator partons in a hard collision event* | This contribution subtracted from the particle-level jet energy.<br>Minimum Bias Data (1vertex) | **100 GeV: 0.1%**<br>**15 GeV: 1.0%** | UE corr |
| **Out-of-cone** | *Corrects the particle-level energy for leakage of radiation outside the clustering cone used for jet definition, taking the "jet energy" back to "parent parton energy".* | Difference between Data and Monte Carlo for different topologies. | **100 GeV: 1.5%**<br>**15 GeV: 7.0%** | OO corr |
| TOTAL | | | | |

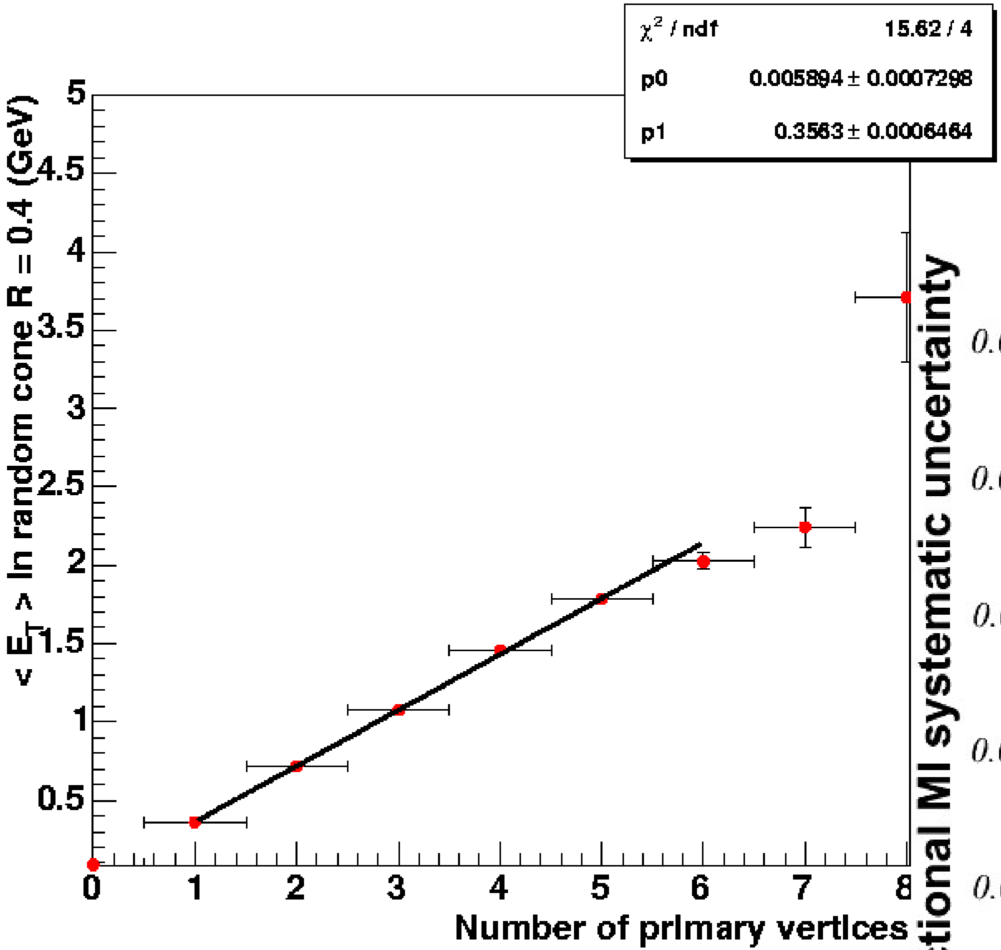
# Relative Scale

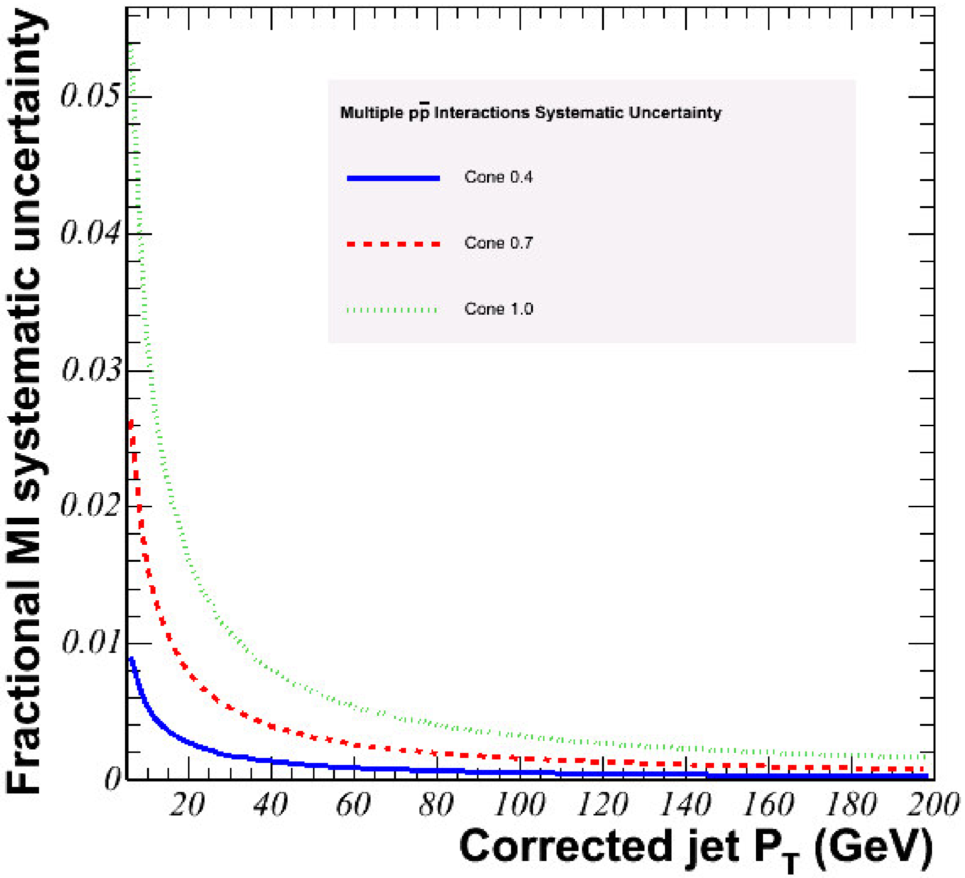


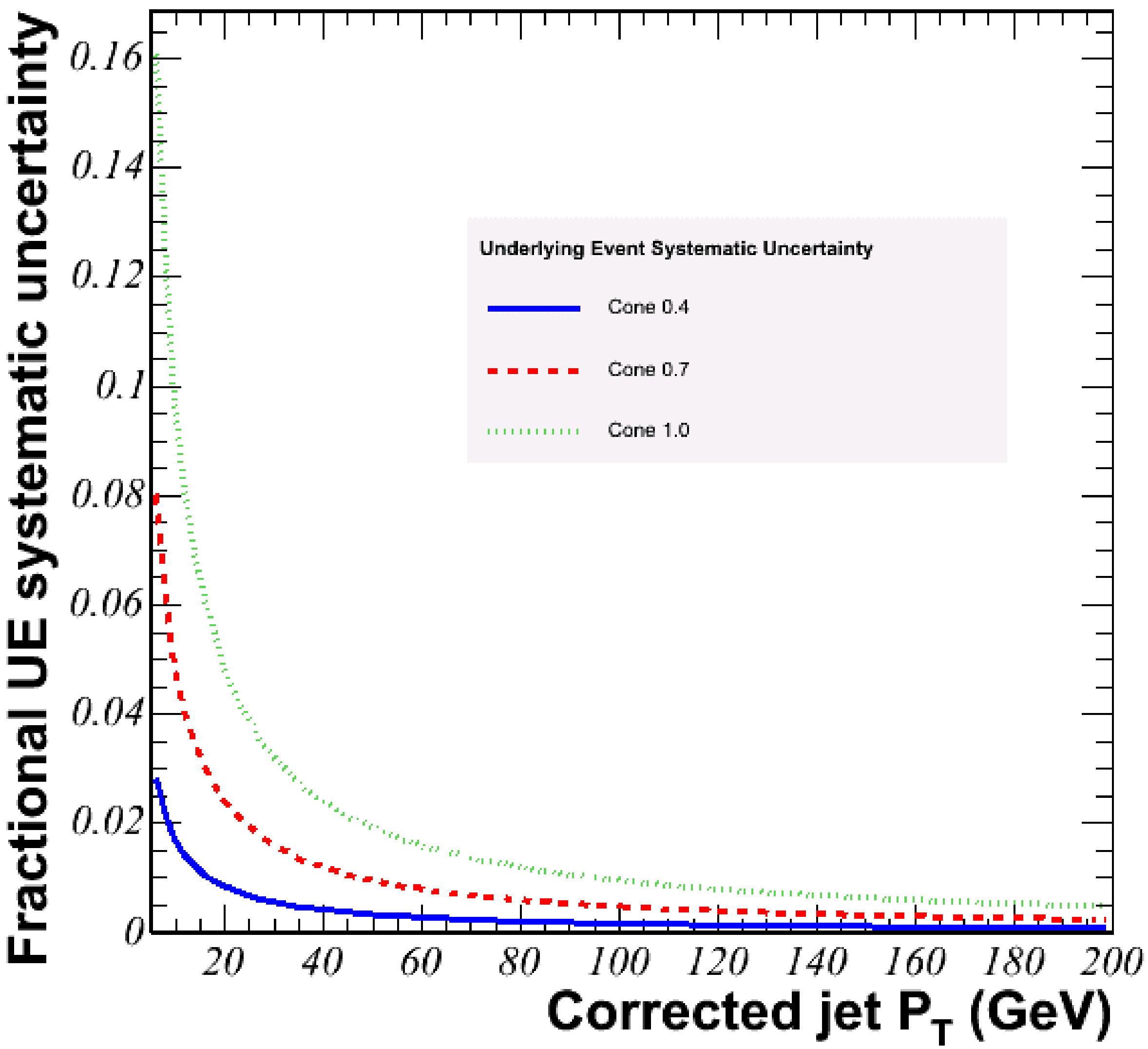



# Multiple Interactions Correction

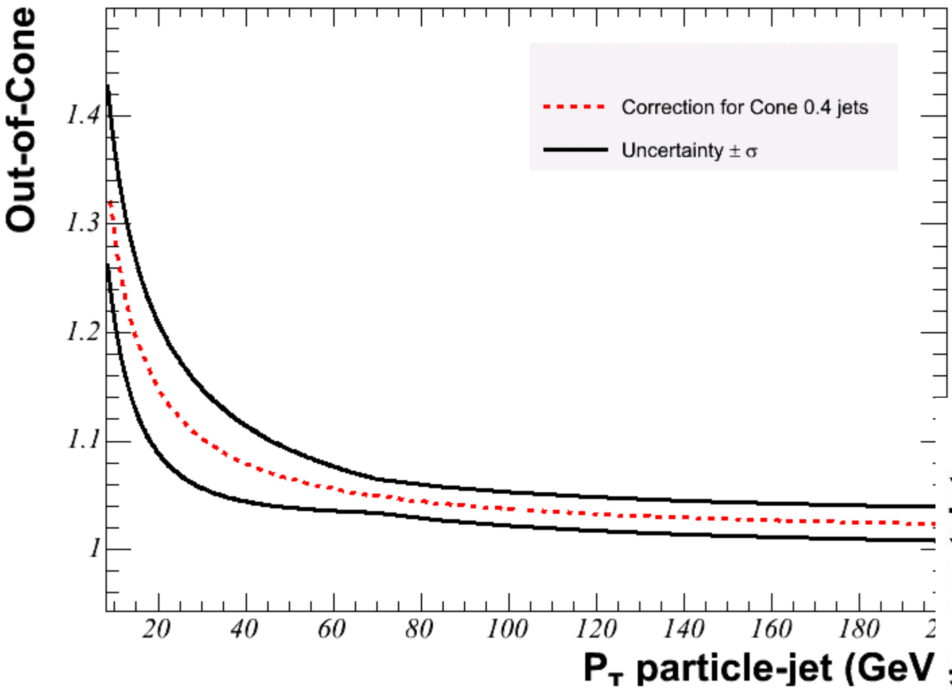


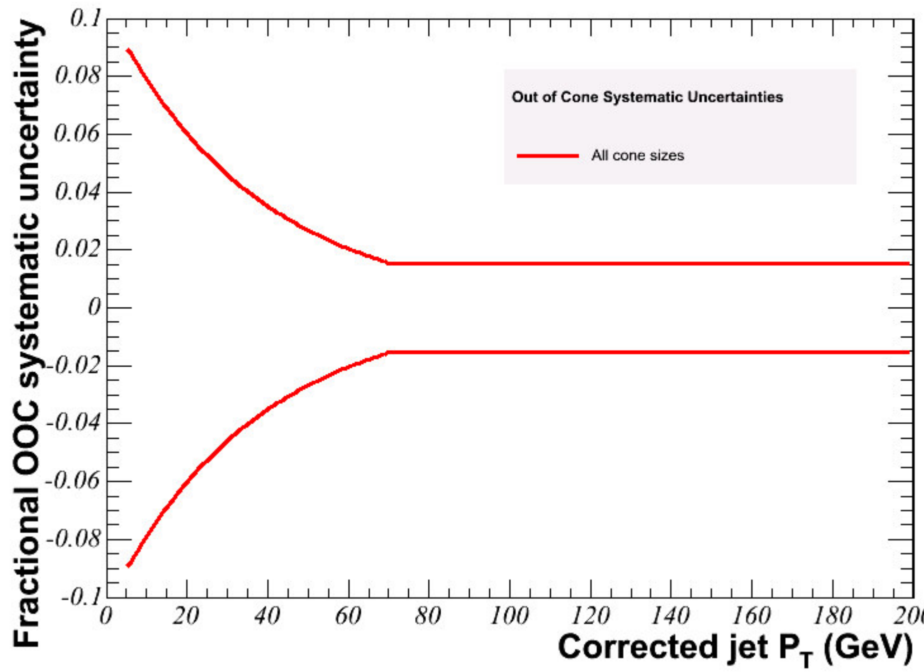



# Underlying Event

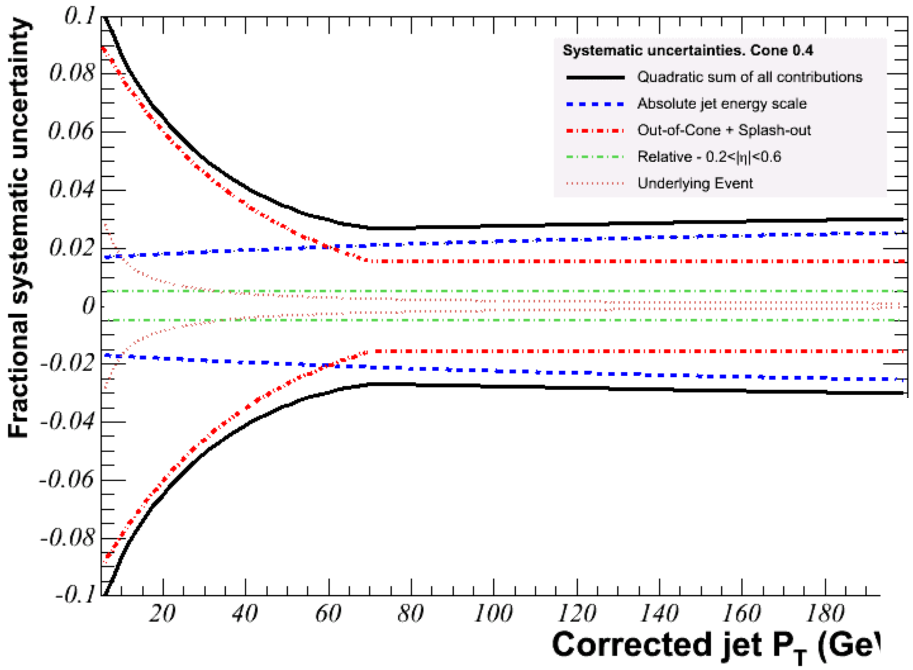


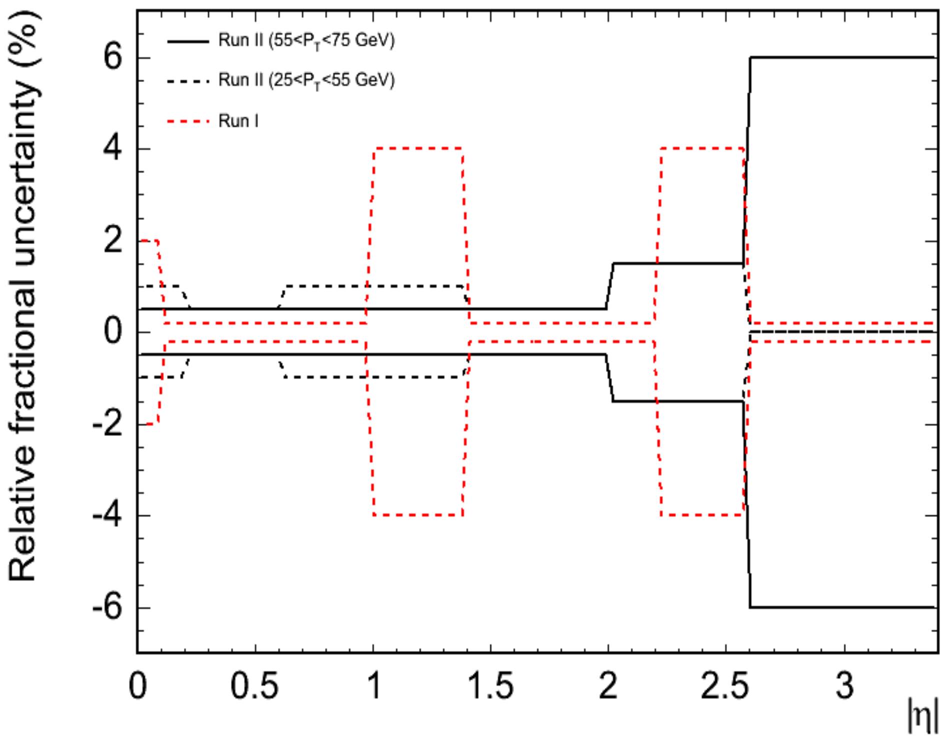
# Out-of-cone corrections



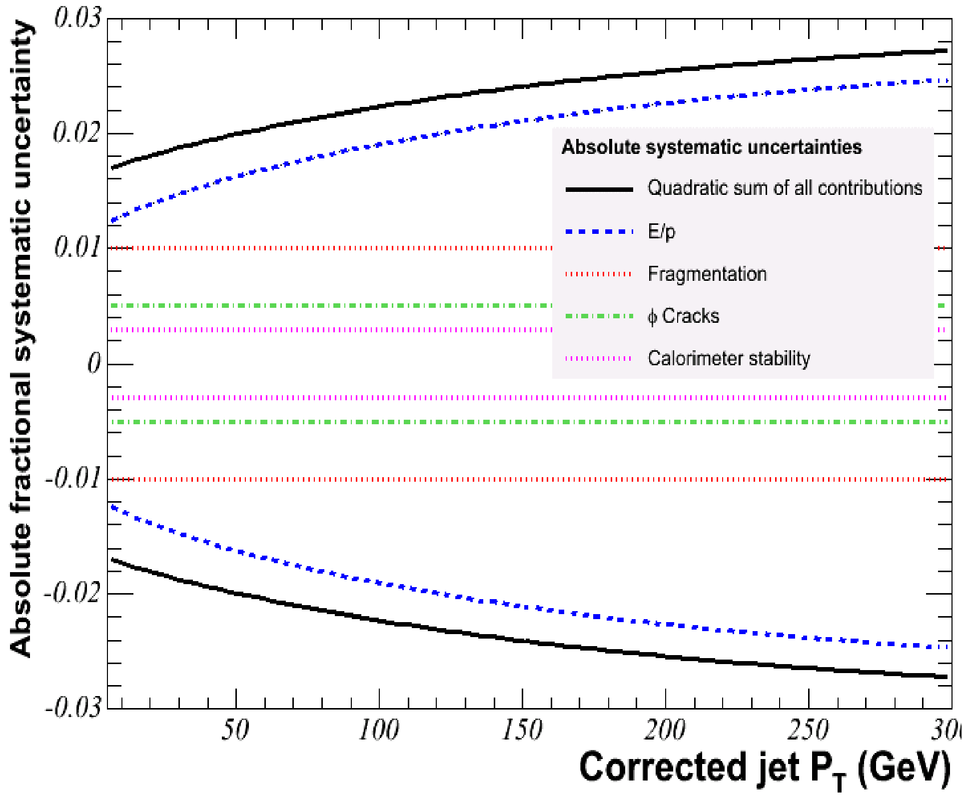



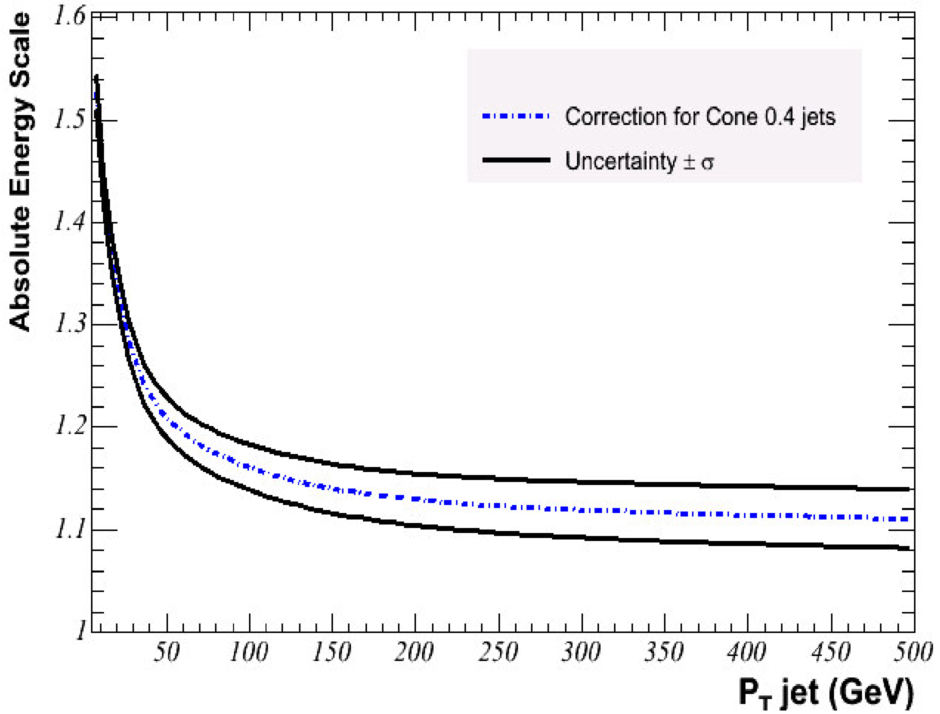
# Total correction



# Absolute Correction



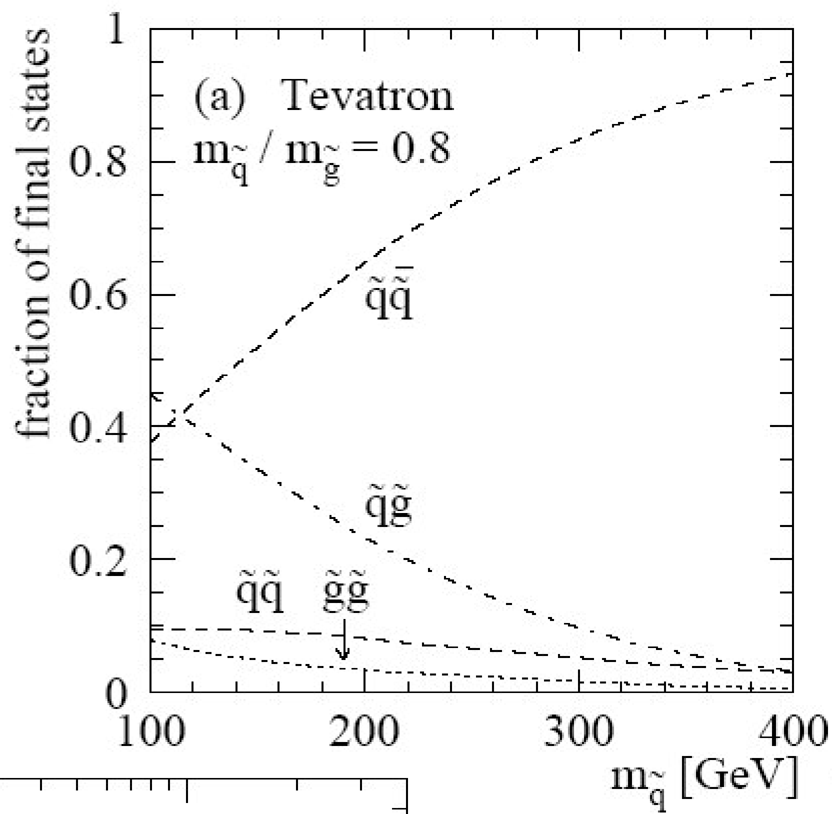



# The Events

- In L = 254 $pb^{-1}$ :
  - SM Expected Events = 4.1 ± 1.5
  - Observed Events = 3

| | MET (GeV) | $H_T$ (GeV) |
|---|---|---|
| Event 1 | 223.3 | 404.2 |
| Event 2 | 195.6 | 470.1 |
| Event 3 | 166.6 | 362.3 |

# Cross sections




- mSugra: squarks 1,2[nd] family
  - ➡ nearly degenerate and heavier than sleptons
  - ➡ cannot be lighter than 0.8*M(gluino)