Search for a New Hadronic Resonance Using Jet Ensembles at CDF

Amitabh Lath
with
Rouven Essig, Eva Halkiadakis, Tim Lou, Claudia Seitz, Scott Thomas
Rutgers, The State University of New Jersey
Has there been a blind spot in new physics searches?

- Most new physics searches require either
  - leptons (e, \(\mu\))
  - missing momentum (i.e., MET) from \(\nu\), lightest neutralino, extra dimensions...
  - Photons
- What if new physics has color (\(q\)- or \(g\)-like)?
  - Not produced at \(e^+e^-\) colliders
  - Could be pair produced at hadron colliders
  - Of course, \textbf{massive} QCD backgrounds
  - \textit{Important exception: Ongoing dijet bump hunt at Tevatron/LHC. Not as sensitive to multiple jet final states.}
### New or Excited Fermions

<table>
<thead>
<tr>
<th>Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>t' in Lepton + Jets + Missing E_T</td>
</tr>
<tr>
<td>Right-Handed Quarks in Dileptons + X</td>
</tr>
<tr>
<td>Long-Lived b' Quarks in the Z + X Channel</td>
</tr>
</tbody>
</table>

### SUSY

#### Search

**Squark and/or Gluino Production**

- Stop → c + neutralino in Jets + Missing E_T
- Stop → b + l + sneutrino in Dilepton + Jet + Missing E_T

**Chargino + Neutralino Production**

- Unified Trilepton and Dilepton + Track
- Gaugino Pair Production in Z + W + Missing E_T
- Low p_T ee + Track
- R-parity Violation
- Sneutrino in eμ, eτ, μτ channels

### High Mass Resonances

<table>
<thead>
<tr>
<th>Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS Graviton to ee (+diphotons)</td>
</tr>
<tr>
<td>W' search</td>
</tr>
<tr>
<td>3-jet resonances</td>
</tr>
<tr>
<td>μμ Channel</td>
</tr>
<tr>
<td>ZZ Channel (Graviton)</td>
</tr>
<tr>
<td>tt Channel (Massive Gluon)</td>
</tr>
</tbody>
</table>

### Signature-based

<table>
<thead>
<tr>
<th>Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon + Jet ( + Missing E_T)</td>
</tr>
<tr>
<td>Lepton+Photon+MET+Bjet (and top-antitop+photon production cross section)</td>
</tr>
<tr>
<td>Photon + Jet ( + Missing E_T)</td>
</tr>
<tr>
<td>Z Boson Production at High p_T^Z</td>
</tr>
<tr>
<td>Photon + Heavy Quark (b, c)</td>
</tr>
</tbody>
</table>
### New or Excited Fermions

<table>
<thead>
<tr>
<th>Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t'$ in Lepton + Jets + Missing $E_T$</td>
</tr>
<tr>
<td>Right-Handed Quarks in Dileptons + X</td>
</tr>
<tr>
<td>Long-Lived $b'$ Quarks in the Z + X Channel</td>
</tr>
</tbody>
</table>

### High Mass Resonances

<table>
<thead>
<tr>
<th>Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>RS Graviton to $ee$ (+diphotons)</td>
</tr>
<tr>
<td><strong>W'</strong> search</td>
</tr>
<tr>
<td>3-jet resonances</td>
</tr>
<tr>
<td>$\mu\mu$ Channel</td>
</tr>
<tr>
<td>$ZZ$ Channel (Graviton)</td>
</tr>
<tr>
<td>$ZZ$ Channel (Massive Gluon)</td>
</tr>
</tbody>
</table>

### Signature-based

**Search**

<table>
<thead>
<tr>
<th>Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stop $\rightarrow c + $ neutral in Jets + Missing $E_T$</td>
</tr>
<tr>
<td>Stop $\rightarrow b + $ Jet in Dileptons + Track</td>
</tr>
<tr>
<td>Chargino Pair Production in $Z + W +$ Missing $E_T$</td>
</tr>
<tr>
<td>Unified Trilepton and Dilepton + Track</td>
</tr>
<tr>
<td>Gaugino Pair Production in $Z + W +$ Missing $E_T$</td>
</tr>
<tr>
<td>Low $p_T$ ee + Track</td>
</tr>
<tr>
<td>R-parity Violation</td>
</tr>
<tr>
<td>Sneutrino in $e\mu, \eta, \mu\tau$ channels</td>
</tr>
</tbody>
</table>

**Search**

<table>
<thead>
<tr>
<th>Search</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photon + Jet (+ Missing $E_T$)</td>
</tr>
<tr>
<td>Lepton+Photon+MET+Bjet (and top-antitop+photon production cross section)</td>
</tr>
<tr>
<td>Photon + Jet (+ Missing $E_T$)</td>
</tr>
<tr>
<td>$Z$ Boson Production at High $p_T^Z$</td>
</tr>
<tr>
<td>Photon + Heavy Quark (b, c)</td>
</tr>
</tbody>
</table>
New Physics with Color

$pp \rightarrow QQ$  

$Q = g$  

$Q = \tilde{g} = SU(3)_c$ Adjoint Majorana Fermion

No leptons, No MET, No W resonance, No $b$
Some questions before we start

- **Is this even possible?**
- **Test:** Can you find the top quark?
  - **Cons:** Top really heavy, our analysis is geared to lighter objects, produced with some boost.
  - **Pros:** Know top is there...
- **How will you handle backgrounds?**
  - Has to be data-driven..
Usual tricks do not work

- Picking the correct 3 jets in a multiple-jet event is difficult.
  - In a 6-jet event, there are 6-choose-3=20 different triplets.
  - Some hard jets are from initial- and final-state radiation (not part of signal)
- Techniques like \( \min[M(a,b,c) - M(d,e,f)] \) just don't work.
- NN etc are good only if you are very sure of your model’s kinematics.
- QCD 6-jet cross-section, kinematics not known well (except that it's huge).
Our technique: Look at them all

- *Ensemble* method
- There are several jet triplets in a multi-jet event.
- Plot the invariant mass
  \[ m_{jjj} \text{ vs } \Sigma \text{Pt}_{jjj} \]
- We look at them all (multiple entry plot).
The CDF Detector

Tracker:

Momentum Resolution: $\sigma(p_T) / p_T$
- COT alone: 0.15% $p_T$ [GeV/c]-1
- COT + SVX + ISL: 0.07% $p_T$ [GeV/c]-1
- COT beam constrained: 0.05% $p_T$ [GeV/c]-1

Calorimeter

EM Energy Resolution:
$\sigma(E)/E = 13.5% / \sqrt{E \sin(\theta)} + 2%$

HAD Energy Resolution:
$\sigma(E)/E = 0.5 / \sqrt{E}$ [GeV]

Slightly worse for the PLUG (endcaps)

Momentum Resolution: $\sigma(p_T) / p_T$
- COT alone: 0.15% $p_T$ [GeV/c]-1
- COT + SVX + ISL: 0.07% $p_T$ [GeV/c]-1
- COT beam constrained: 0.05% $p_T$ [GeV/c]-1
CDF Monte Carlo: ttbar

CDF RUN II Preliminary

PYTHIA \( \ell \)

\( m = 172.5 \text{ GeV}/c \)

\( \geq 20 \text{ entries per event} \)

\[ \sum_{jjj} |p_t| \text{ [GeV/c]} \]
CDF Monte Carlo: ttbar

CDF RUN II Preliminary

3 jet invariant mass [GeV/c^2]

PYTHIA \( \bar{t} \)

\( m = 172.5 \text{ GeV/c}^2 \)

\( \geq 20 \) entries per event

\( \sum_{jjj} |p_t| [\text{GeV/c}] \)
CDF Monte Carlo: ttbar

CDF RUN II Preliminary

3 jet invariant mass [GeV/c²]

PYTHIA ℓ
m=172.5 GeV/𝑐

Correct triplet combination along horizontal

Wrong triplet combination along diagonal

\[ \sum_{jjj} |p_\ell| [\text{GeV/c}] \]
The diagonal offset cut

For ANY triplet of jets require:

\[ M_{jjj} < \sum |p_{T,jjj}| - \text{diagonal-offset} \]

- where \( M_{jjj} \) is the invariant mass of the 3 jets
- \( \sum |p_{T,jjj}| \) is the scalar sum \( |p_{T}| \) of the 3 jets
R-Parity Violating Gluino MC

CDF RUN II Preliminary

PYTHIA RPV Gluino
$m=133$ GeV/$\tilde{c}$
$\geq 20$ entries per event

CDF RUN II Preliminary

PYTHIA RPV Gluino
$m=190$ GeV/$\tilde{c}$
$\geq 20$ entries per event
Notes on the technique

• We look for just one 3-jet mass resonance in a multi-jet environment.
  – No attempt to fully reconstruct both decays.
  – **Nothing model dependent:** no b-quarks, no internal resonances, no requirements on geometry (hemisphere, \( \Delta R \), etc.)

• New physics with strong couplings will have large cross sections.
  – Recall ttbar production is \( \sim 7 \) pb.
  – RPV gluinos are similar, \( \sim 10 \) pb at \( m_{\text{top}} \), rising to \( \sim 200 \) pb at 90 GeV/c\(^2\) (LO, higher with NLO).
  – The power of this technique is in the focus on (slightly) boosted decays. Reduces QCD and combinatoric backgrounds.
Trigger

- CDF has an interesting *Quad-Jet* trigger
  - Designed for top and Higgs (all hadronic) modes
  - Constructs calorimeter clusters at trigger Level 2 (raw, *energy not corrected*).
  - Thresholds changed as luminosity went up (total L2 rate ~300 Hz).
- Triggers on 4 jets @L2 (15 GeV raw each) and SumEt >175 GeV raw.
  - This is ideal for our search.
Basic Event Selection

- \( \text{MET} < 50 \) (get rid of beam splash)
- Vertex: between 1 and 4
- Jets: between 6 and 8
- \( \sum \text{pt of top 6 jets} > 250 \text{ GeV} \)

Multiple interactions could be a large background:
  - Two 3-jet (or three di-jet) events may be more likely than 6-jet events.
Jet Z Requirement

- **CDF Beamline is z-coordinate**
  - Event with multiple interactions will typically be a multiple vertex event.
  - Cannot simply cut on Nvertex

- **Calorimeter jets do not come with Z info.**
- Need to create.
  - Loop over tracks (pt > 1 Gev)
  - Associate w/ jet (cone 0.4)

- Take mean z of tracks as Jet-z.
- If RMS_z > 4cm, treat as no Z info.

- Event must have >3 jets w/ Z info
- “Good” triplet must have at least 2 jets w/ Z info.

This lowers our acceptance for forward clusters
Summary of jet Z

- Define

\[ \bar{z}_j = \frac{\sum_{\text{tracks}} z_0}{N_{\text{tracks}}} \]

(mean position of all the tracks within a jet)

- Error on \( z_{\text{jet}} \):

\[ \delta(z_j) = \sqrt{\frac{z_j^2 - \bar{z}_j^2}{N_{\text{tracks}}}}. \]

- Define \( z_{\text{rms}} \)

\[ z_{\text{rms}} = \sqrt{\frac{\left( \sum_{\text{jets}} z_j^2 / N_{\text{jets}} \right) - \left( \sum_{\text{jets}} z_j / N_{\text{jets}} \right)^2}{N_{\text{jets}}}} \]

\( z_{\text{rms}} < 0.5 \)

- **Within a triplet,**
  - \( \delta(z_{\text{jet}}) \) for any jet in triplet < 2.5
    - Event level cut was < 4
  - number of jets without z info <= 1
    - These tend to be high eta jets w/out tracks
  - \( |\bar{z}_j - \text{VTX-z}| < 10 \text{ cm} \) for all jets in triplet
Summary of jet Z

- Define $\bar{z}_j = \frac{\sum_{\text{tracks}} z_0}{N_{\text{tracks}}}$ (mean position of all the tracks within a jet).

- Error on $z_{\text{jet}}$: $\delta(z_j) = \sqrt{\frac{z_j^2 - \bar{z}_j^2}{N_{\text{tracks}}}$. Make sure tracks pointing to cluster come from same point on the beamline.

- Define $z_{\text{rms}} = \sqrt{\frac{(\sum_{\text{jets}} z_j^2)/N_{\text{jets}} - \left(\sum_{\text{jets}} z_j/N_{\text{jets}}\right)^2}{N_{\text{jets}}}$. $z_{\text{rms}} < 0.5$ Make sure (almost) all jets come from same point on the beamline.

- Within a triplet,
  - $\delta(z_{\text{jet}})$ for any jet in triplet < 2.5
    - Event level cut was < 4
    - number of jets without z info <= 1
      - These tend to be high eta jets w/out tracks
    - $|\bar{z}_j - \text{VTX-z}| < 10$ cm for all jets in triplet
CDF Data

CDF RUN II Preliminary 3.2 fb

DATA
≥ 20 entries per event

\[ \sum_{jjj} |p_t| \text{ [GeV/c]} \]
CDF Data

CDF RUN II Preliminary 3.2 fb

3 jet invariant mass [GeV/c]

DATA
≥ 20 entries per event

Edge due to cone 0.4 definition of Jet

\[ \sum_{jjj} |p_t| \text{ [GeV/c]} \]
Backgrounds

• QCD and combinatoric (both have Landau shape)
• Also need to optimize diagonal offset cut
• Need parametrized background function.
  – Why not just fit the data with Landau+Gaussian and let Minuit handle it?
  – Minuit will chase fluctuations, we need an independent background estimate.
Background Procedure

- Get 5-jet sample and make triplets.
  - Statistically independent
- Create ratio of triplet $\Sigma pt$
  - (6-jet/5-jet)
- Correct the 5-jet mass distribution by this weight.
- Fit the scaled 5-jet mass dist with Landau
  - Extract MPV, width..
- Use parameters from scaled 5-jet fit on the 6+-jet data
Background Procedure

CDF RUN II Preliminary 3.2 fb⁻¹

- 5jet Data
- QCD Landau fit
  (diagonal cut offset 155 GeV/c²)

CDF RUN II Preliminary 3.2 fb⁻¹

- 5jet Data
- QCD Landau fit
  (diagonal cut offset 155 GeV/c²)

CDF RUN II Preliminary 3.2 fb⁻¹

- ≥ 6jet Data
- QCD Landau prediction
  (diagonal cut offset 155 GeV/c²)

CDF RUN II Preliminary 3.2 fb⁻¹

- ≥ 6jet Data
- QCD Landau prediction
  (diagonal cut offset 155 GeV/c²)
Comment on Background Procedure

- The 6-jet triplets have a softer $\Sigma pt$ distribution than the 5-jet
  - The main difference between a QCD 5-jet and QCD 6-jet is a soft gluon emission.

- We use the $pt$ (non-invariant) ratio to correct the mass (invariant).
  - Note that for signal, $pt$ and mass are not correlated

- What if there is signal in the 5-jet?
  - Tough problem when doing data-driven backgrounds. But we note that Landau parameters are smooth functions of diagonal offset cut.
  - $\sigma$(QCD 5-jet) is $\sim 10x \ \sigma$(QCD 6-jet).
Background Parameters

- **5jet scaled** and **6jet w/ top window blind** MPV, Width nearly agree
- Amplitude curves obviously different.
- When we fit for signal we **FIX background params.**
Optimizing the diagonal cut

- What is the best diagonal cut for a given $m_{\text{gluino}}$?
  - Cannot avoid signal MC
- Use signal/background as metric
  - We have a (*data-driven*) background estimate as function of diagonal cut.
  - Make pseudoexpts by adding signal MC
  - Vary diagonal cut, fit. Extract optimal diagonal cut.

- Note: fitting background & optimizing cuts in same step with data *does not work.*
Optimized diagonal cut

<table>
<thead>
<tr>
<th>Pole mass</th>
<th>Optimal diagonal cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>110.1</td>
<td>145</td>
</tr>
<tr>
<td>133.5</td>
<td>180</td>
</tr>
<tr>
<td>167.9</td>
<td>185</td>
</tr>
<tr>
<td>190.3</td>
<td>195</td>
</tr>
<tr>
<td>223.3</td>
<td>205</td>
</tr>
<tr>
<td>245.0</td>
<td>195</td>
</tr>
<tr>
<td>tttop25</td>
<td>190</td>
</tr>
</tbody>
</table>
What do we expect to see?

- We need to quantify our expectation before we can claim we see anything.
- Get background shape (Landau) and signal (Gaussian)
- Use as parent distribution to throw pseudoexperiments.
- Recover #events (signal and background) and calculate $\sigma_{95}$
- Systematic uncertainties incorporated as jitter in parent Landau parameters
  - Adding systematics does not change the mean # events found, but raises the $\sigma_{95}$. 

$M_{jj}$ (GeV/c$^2$)  
#events from fit
What do we expect to see?

- We need to quantify our expectation before we can claim we see anything.
- Get background shape (Landau) and signal (Gaussian)
- Use as parent distribution to throw pseudoexperiments.
- Recover #events (signal and background) and calculate $\sigma_{95}$
- Systematic uncertainties incorporated as jitter in parent Landau parameters
  - Adding systematics does not change the mean # events found, but raises the $\sigma_{95}$. 

[Graphs showing distributions and fit results]
Expected Limits

- Gluino acceptance is $(4.9 \pm 1.1) \times 10^{-5}$.

- Systematic uncertainties:
  - Jet Energy Scale: 38%
  - ISR/FSR: 20%
  - PDF: 10%

- Systematics incorporated as jitter of parent distribution Landau params in the pseudoexperiments.
  - For signal extraction we **fix** background params at nominal values.

![Expected 95% Conf. Limit](chart.png)

- Without systematics
- With systematics

In the absence of signal.
We fit data the same way:
**Fix** background params
**Float** Gaussian amplitude
**Extract** #events (sig,bckg)
Fits to Data

CDF RUN II Preliminary 3.2 fb⁻¹

≥ 6jet Data

QCD Landau prediction
+ Gaussian fit

m=94 GeV
Diagonal 134 GeV

m=112 GeV
Diagonal 155 GeV

CDF RUN II Preliminary 3.2 fb⁻¹

≥ 6jet Data

QCD Landau prediction
+ Gaussian fit
fixed at m=175 GeV/c²
(diagonal cut offset 190 GeV/c)

m=175 GeV
Diagonal 190 GeV
Fits to Data

See ~2σ excess. More on this fit later...

\[ m=94 \text{ GeV} \]
Diagonal 134 GeV

\[ m=112 \text{ GeV} \]
Diagonal 155 GeV

\[ m=175 \text{ GeV} \]
Diagonal 190 GeV
The m=175 fit

At the top mass, we expect ~1 event,
But see 11 events (±1 σ integral of Gaussian)
Limits

CDF RUN II Preliminary 3.2 fb$^{-1}$

\[ \sigma(p\bar{p} \to \tilde{g}\tilde{g} \to 6j) \times BR(\tilde{g} \tilde{g} \to 6j) [pb] \]

- 95% C.L. $\sigma$ observed
- 95% C.L. $\sigma$ expected

$\pm 1\sigma$ on 95% C.L.

$\sigma$ (p$\bar{p}$ → $\tilde{g}\tilde{g}$) × BR($\tilde{g}\tilde{g}$ → 6j) [pb] vs. gluino mass [GeV/c$^2$]
Limits

CDF RUN II Preliminary 3.2 fb⁻¹

\[ \sigma \times BR(p\bar{p} \rightarrow 3j + 3j) \]

- 0.5 TeV/c² < \( m_{\tilde{q}} \) < 0.7 TeV/c²
- \( m_{\tilde{q}} = m_{\tilde{g}} + 10 \) GeV/c²
- Observed 95% C.L. limit
- Expected 95% C.L. limit
- ± 1σ on expected limit

\( m_{\tilde{q}} \) vs. gluino mass [GeV/c²]

38
Limits

RPV gluino cross section
NLO corrected with PROSPINO

Significance of excess
~ 2 sigma
Examine top acceptance

- We looked at various top MC
  - PYTHIA (various mtop)
  - CTEQ and MRST PDFs
  - more/less ISR and FSR
  - ALPGEN → PYTHIA
  - MC@NLO
- All predict 0.75 – 1.5 events after diagonal cut of 190 GeV.
- Excess is robust wrt sliding pt, diagonal cut around nominal.
- These are 3.2 fb-1 plots. We also looked at
  - 6 fb-1 of data
  - JET100 trigger (not good for m=90, but fine for m>150)
  - Semileptonic top (in lepton+4jet events)
- Bottom line: excess is real, there is a discrepancy with MC
Toy top study

- Generator-level study
- PYTHIA → FastJet
  - Perfect detector output.
- After just eta, pt, diagonal cuts:
  - Expect 5.5 events.
- Note that jet_z, detector ineff. not taken into account at all.
- MC simply *not producing* enough top with high pt.
Conclusion

- Developed a new technique (ensemble method) to extract correlated objects in a multi-object background
  - Working closely with theorists pays off big!
    - Rouven Essig (theory GS) thesis on ensemble technique
  - Used it to look at 3jet in multi-jet events
  - Technique will work with other objects.
    - Add leptons, photons, MET?
- Found an excess at top mass. Significance $\sim 2\sigma$
  - Studying this with more data now.
  - Same group doing this analysis on CMS.
Backup
Data event display, in mass window

Event: 5047087  Run: 201543  EventType: DATA  Unpresc: 33, 35, 4, 36, 37, 6, 38, 39, 8, 10, 11, 43, 12, 14, 48, 50, 19, 20, 52, 53, 23, 55, 24, 26, 60, 29, 30, 62, 31  Presc:

Missing Et
Et=23.4 phi=0.6

List of Tracks
Id  pt     phi   eta
Cdf Tracks: first 5
809  -43.7  -3.0  -0.4
810  -36.1  -0.1  -0.6
811  -31.6  -0.1  -0.6
812  -29.0  -3.1  -0.3
813  23.9   -0.1  -0.6

To select track type
SelectCdfTrack(Id)

Svt Tracks: first 5
14   -180.8  3.3
6    30.1   6.2
16   -25.0  3.2
5    -16.4  6.2
18   16.4   3.2

To select track type
SelectSvtTrack(Id)

Particles: first 5
pdg  pt     phi   eta
11   43.7  3.3  -0.4
13   43.7  3.3  -0.4
11   36.1  6.1  -0.6
13   21.8  6.1  -0.6
11   4.5   3.0  -1.0

To list all particles
ListCdfParticles()

Jets(R = 0.4): first 5
Em/Tot  pt   phi   eta
0.6    255.2  6.2  -0.6
0.5    232.1  3.3  -0.4
0.7    66.1   3.0  -0.9
0.7    37.1   2.5  0.3
0.6    36.8   0.6  2.1

To list all jets
ListCdfJets()
Data event display, in mass window
Data event display, in mass window

Event: 887377  Run: 167977  EventType: DATA  Unpresc: 0,32,1,33,34,35,4,8,9,10,11,43,12,13,45,46,15,16,48,17,49,21,22,23,55,25,26,27,28,30  Presc: 

Missing Et
Et=38.3 phi=5.9

List of Tracks
Id  pt  phi  eta

Cdf Tracks: first 5
604  -46.0  2.9  -0.4
605  -31.3  3.1  -0.4
641   20.5  0.1  0.1
606  19.5  2.9  -0.5
568  -12.0  0.1  0.1

To select track type
SelectCdfTrack(Id)

Svt Tracks: first 5
4   -90.4  0.1
12  -20.1  3.0
10  -18.1  0.1
13  -13.9  3.1
2   -12.1  0.1

To select track type
SelectSvtTrack(Id)

Particles: first 5
pdg  pt  phi  eta
11   46.0  2.9  -0.4
11   20.5  0.1  0.1
13   11.2  0.0  0.1
11    6.8  3.1  -0.5
13    6.5  3.0  -0.4

To list all particles
ListCdfParticles()

Jets(R = 0.4): first 5
Em/Tot  et  phi  eta
0.6   325.3  0.1  0.2
0.7  314.9  3.0  -0.4
0.5  18.9  4.0  -1.6
0.5   11.8  5.7  -0.3
0.9   10.4  4.4  0.4

To list all jets
ListCdfJets()
Data event display, in mass window

Event: 887377  Run: 167977  EventType: DATA  Unpere: 0.32,1.33,34,35,4,8,9,10,11,43,12,13,45,46,15,16,48,17,49,21,22,23,55,25,26,27,28,30  Prese: 0.32,33,34
MC ttbar event display, in mass window

Event: 518  Run: 155393  EventType: MC  |  Unpresc: 0,1,3,3,5,4,7,8,9,10,11,43,44,13,45,14,15,17,49,20,23,24,25,26,27,28 Presc: 0,1,3,3,5,4,7,8,9,10,11

Missing Et
Et = 29.8 phi = 2.4

List of Tracks
Id  pt  phi  eta

Cdf Tracks: first 5
516  -64.2 -0.9  0.8
483  -43.5  1.9 -0.2
484  -36.0 -0.9  0.8
543   29.5 -0.9  0.8
517   15.6  2.0 -0.1

To select track type
SelectCdfTrack(Id)

Svt Tracks: first 5
2    60.3  1.9
20   -30.1  5.4
9    25.0  2.0
21   22.6  5.4
3    13.9  1.9

To select track type
SelectSvtTrack(Id)

Particles: first 5
pdg  pt  phi  eta
11   64.2  5.4  0.8
22   22.7  2.3  0.5
13    5.6  2.1  0.1
22    3.8  6.2  1.3
22    3.8  5.9  2.2

To list all particles
ListCdfParticles()

Jets(R = 0.4): first 5
Em/Tot  et  phi  eta
0.7  310.6  5.4  0.8
0.5  204.5  1.9 -0.1
0.5   73.8  2.2  0.4
0.3   33.0  3.1 -0.1
0.3    27.0  3.6 -0.4

To list all jets
ListCdfJets()

Et = 304.48 GeV
MC ttbar event display, in mass window

Event: 2047  Run: 160823  EventType: MC  Unpresc: 0,1,3,35,4,7,8,9,11,44,13,14,15,17,49,20,23,24,25,26,27,28  Presc: 0,1,3,35,4,7,8,9,11,44,13,14,15

Missing Et
Et=16.5 phi=1.7

List of Tracks
Id  pt  phi  eta

Cdf Tracks: first 5
346  -154.6 -0.9  0.2
347  36.3  -1.0  0.7
348  -18.1  2.3  -0.6
379  11.8  2.2  -0.6
380  -15.7  -1.0  0.7

To select track type
SelectCdfTrack(Id)

Svt Tracks: first 5
  5  -7.9  2.7
  15  7.5  5.4
  1  -7.5  0.7
  18  -7.0  5.2
  13  -6.5  5.4

To select track type
SelectSvtTrack(Id)

Et = 254.06 GeV

Particles: first 5
pdg  pt  phi  eta
  1  18.1  2.3  -0.6
  11  5.9  3.2  0.5
  11  2.8  5.2  0.6
  22  2.5  1.6  -0.4
  11  1.2  6.0  -0.8
To list all particles
ListCdfParticles()

Jets(R = 0.4): first 5
Em/Tot  et  phi  eta
  0.8  209.5  2.3  -0.5
  0.4  201.8  5.4  0.1
  0.5  84.7  5.2  0.7
  0.7  47.8  2.8  0.2
  0.3  35.7  1.8  -0.7
To list all jets
ListCdfJets()