The LHC is ON!

First Di-photon Distribution in CMS

• \( M(\pi^0) \) is lower in both data and MC
• Mostly due to the readout threshold (100 MeV/Crystal).
• Conversions: part of the energy is deposited upstream of ECAL.
• Event timing is consistent
and the last problem set is on the web...

Cornell University
Department of Physics

Phys 7661 December 1, 2009

Collider Physics, Fall 2009

Homework Assignment # 8

(“Due” Tuesday, December 8.)

Problems:

1. Squark Search at the Tevatron

In this problem, we will perform a (much simplified) analysis of the sensitivity of the Tevatron search for squarks of the Minimal Supersymmetric Standard Model (MSSM).

- Download the param card.dat file from the course web site. Review it and identify the squark masses. Which squarks do you expect to be predominantly produced at the Tevatron? How do they decay? **NOTE:** The spectrum in this sample file is chosen by hand to simplify the problem, and is not representative of any realistic SUSY breaking model!
- Simulate the process \( p\bar{p} \to \tilde{q}_R \tilde{q}'_R \), with \( q = u \) and \( c \), followed by decays \( \tilde{q}_R \to q\tilde{\chi}_1^0 \) at the Tevatron. (Note: \( uu^* \) and \( cc^* \) processes have different matrix elements and need to be simulated separately, even though the masses are the same — make sure you understand why!) How many events of this kind would you expect in the currently available event sample of 5 fb\(^{-1}\)? **HINT:** To speed things up, set QCD=2, QED=2 in the proc card.dat — this gets rid of many diagrams and only has a small effect on the results since \( \alpha_s \gg \alpha \). You can also set P=\( u\bar{d}d\bar{g} \) in the same file, that is, ignore strange and charm content of the proton.
- Repeat the above analysis for same-sign squark production, \( p\bar{p} \to \tilde{u}_R \tilde{u}'_R \) and \( p\bar{p} \to \tilde{d}_R \tilde{d}'_R \). (No need to do this for \( \tilde{c}_R \) — make sure you understand why!)
- Simulate the main irreducible background to the squark searches, \( p\bar{p} \to Zjj \) with \( Z \) decaying into a neutrino pair. (You do not need to simulate \( Z \) decays — just take into account the branching ratio.) Impose cuts on jets as necessary, see Homework 5, Problem 3.
- With the cuts you imposed in the previous part, what is the signal/background ratio? What is \( S/\sqrt{B} \) with 5 fb\(^{-1} \) of data?
- Plot the distribution of jet \( p_T \) and “missing transverse energy” \( E_T = |\sum p_T| \), where the sum is over all charged and neutral leptons and photons (progressively more inclusive) as a function of the total transverse energy \( E_T \).
and \( \tilde{\chi}_0^2 \), two-body decays into sneutrinos open up, leading to a smaller branching fraction into three charged leptons.

FIG. 7: Upper limit at the 95% C.L. on \( \sigma \times \text{BR}(3\ell) \) as a function of \( \tilde{\chi}_1^\pm \) mass, in comparison with the expectation for two SUSY scenarios (see text). PDF and renormalization/factorization scale uncertainties on the predicted cross section are shown as shaded bands.

FIG. 8: Region in the \( m_0-m_{1/2} \) plane excluded by the combination of the D0 analyses (green), by LEP searches for charginos (light grey) and sleptons (dark grey) \cite{2} and CDF (black line) \cite{4}. The assumed mSUGRA parameters are \( \tan \beta = 3, A_0 = 0 \) and \( \mu > 0 \).

Trileptons: D0, 0901.0646 [hep-ex]
FIG. 1: The $E_T$ distribution in $\gamma\gamma$ data with $W/Z + \gamma\gamma$ background (hatched histogram), instrumental background with no genuine $E_T$: $\gamma\gamma$ (solid black line) and multi-jet (filled histogram), and background from processes with genuine $E_T$ and a misidentified electron (cross-hatched histogram). The expected $E_T$ distributions if GMSB SUSY events were present are shown as dotted and dashed lines.

FIG. 2: Predicted cross section for the Snowmass Slope model versus $\Lambda$. The observed and expected 95% C.L. limits are shown in solid and dash-dotted lines, respectively.

2 gamma + MET:

D0, 0710.3946 [hep-ex]
CMS Benchmark SUSY Search

mSUGRA: \( M_0 = 60 \text{ GeV/c}^2, M_{1/2} = 250 \text{ GeV/c}^2, A_0 = 0, \mu > 0 \) and \( \tan \beta = 10 \)

Spectrum: \( m(\tilde{g}) \sim 600 \text{ GeV/c}^2, m(\tilde{q}) \sim 550 \text{ GeV/c}^2, (m(\tilde{g}) > m(\tilde{q})) \)

LO sigma = 49 pb: \( \tilde{g}q \) is 53\%, \( \tilde{q}q \) 28\% and \( \tilde{g}\tilde{g} \) 12\%.

Decay Channels: \( \tilde{g} \rightarrow q \tilde{q}_{L,R} \) or \( \tilde{g} \rightarrow \tilde{q}\tilde{q}_{L,R} \)

\( \tilde{q}_R \rightarrow q \tilde{\chi}_1^0 \), (100\%) \hspace{1cm} \tilde{\chi}_2^0 \rightarrow \tilde{\ell}_R\ell, (11.2\%)

\( \tilde{q}_L \rightarrow q + \tilde{\chi}_2^0 \), (30\%) \hspace{1cm} \tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1\tau, (46\%)

\( \tilde{q}_L \rightarrow q + \tilde{\chi}_1^+, (70\%) \hspace{1cm} \tilde{\chi}_1^+ \rightarrow \tilde{\nu}_L\ell, (36\%)

Signature: MET + multi-jet + X
Instrumental Background: QCD (mis-measured jets)

Figure 4.9: $E_T^{\text{miss}}$ distribution in QCD 3-jet events.

Figure 4.10: $\delta \phi_1$ versus $\delta \phi_2$ for (left) SUSY signal and (right) QCD di-jet events

Indirect Lepton Veto (tops, Ws)

$W \rightarrow e\nu+\geq 2$

SUSY
Irreducible Background: $Z + \text{jets}$, $Z \rightarrow \nu\bar{\nu} + \geq 2$ jets

Figure 4.15: $E_T^{\text{miss}}$ in $Z \rightarrow \mu\mu + \geq 2$ jets candle sample and normalised $E_T^{\text{miss}}$ in $Z \rightarrow \nu\bar{\nu} + \geq 2$ jets sample.
Table 4.2: The $E_T^{\text{miss}}$ + multi-jet SUSY search analysis path

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Level-1 trigger eff. parametr.</td>
</tr>
<tr>
<td>HLT, $E_T^{\text{miss}} &gt; 200 \text{ GeV}$</td>
<td>trigger/signal signature</td>
</tr>
<tr>
<td>primary vertex $\geq 1$</td>
<td>primary cleanup</td>
</tr>
<tr>
<td>$F_{em} \geq 0.175$, $F_{ch} \geq 0.1$</td>
<td>primary cleanup</td>
</tr>
<tr>
<td>$N_j \geq 3,</td>
<td>\eta_j^T</td>
</tr>
<tr>
<td>$\delta \phi_{\text{min}}(E_T^{\text{miss}} - \text{jet}) \geq 0.3 \text{ rad}$, $R1, R2 &gt; 0.5 \text{ rad}$</td>
<td>$QCD$ rejection</td>
</tr>
<tr>
<td>$\delta \phi(E_T^{\text{miss}} - j(2)) &gt; 20^\circ$</td>
<td>$QCD$ rejection</td>
</tr>
<tr>
<td>$\delta \phi^{\text{dijet}} = 0$</td>
<td>ILV (I) $W/Z/\bar{t}t$ rejection</td>
</tr>
<tr>
<td>$\delta \phi^{\text{dijet}} = 0$</td>
<td>ILV (II), $W/Z/\bar{t}t$ rejection</td>
</tr>
<tr>
<td>$E_{T,j(1)} &gt; 180 \text{ GeV}, E_{T,j(2)} &gt; 110 \text{ GeV}$</td>
<td>signal/background optimisation</td>
</tr>
<tr>
<td>$H_T &gt; 500 \text{ GeV}$</td>
<td>signal/background optimisation</td>
</tr>
<tr>
<td>SUSY LM1 signal efficiency 13%</td>
<td></td>
</tr>
</tbody>
</table>

Table 4.3: Selected SUSY and Standard Model background events for 1 fb$^{-1}$

<table>
<thead>
<tr>
<th>Signal</th>
<th>$tt$</th>
<th>single $t$</th>
<th>$Z(\rightarrow \nu\bar{\nu}) + \text{jets}$</th>
<th>$(W/Z,WW/ZZ/ZW) + \text{jets}$</th>
<th>QCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>6319</td>
<td>53.9</td>
<td>2.6</td>
<td>48</td>
<td>33</td>
<td>107</td>
</tr>
</tbody>
</table>

Table 4.4: Standard Model background components and uncertainties for 1 fb$^{-1}$

<table>
<thead>
<tr>
<th>$tt$, single top</th>
<th>$Z(\rightarrow \nu\bar{\nu}) + \text{jets}$</th>
<th>$(W/Z,WW/ZZ/ZW) + \text{jets}$</th>
<th>QCD</th>
</tr>
</thead>
<tbody>
<tr>
<td>56 ± 11(sys) ± 7.5(stat)</td>
<td>48 ± 3.5 (all)</td>
<td>33 ± 2.5 (all)</td>
<td>107 ± 25(sys) ± 10(stat)</td>
</tr>
</tbody>
</table>

In conclusion, based on the Standard Model background estimates and their uncertainties, a 5$\sigma$ observation of low mass SUSY at LM1 (gluino mass 600 GeV/c$^2$) is in principle achievable with $\sim$6 pb$^{-1}$ in events with large missing energy plus multi-jets. It is found that with $\sim 1.5$ fb$^{-1}$ the $W/Z$+jets background including the invisible decays of the Z boson which constitutes a large irreducible background component can be reliably normalised using the $Z \rightarrow \mu\mu$ and $Z \rightarrow ee + \text{multi-jet}$ data candle. With adequate data-based strategies of controlling and estimating the Standard Model backgrounds and their uncertainties, low mass SUSY will be discovered with 0.1-1 fb$^{-1}$. Furthermore the global raw $E_T^{\text{miss}}$ measurement
Figure 7: The MSSM exclusions, at 95% c.L(light-green) and 99.7% c.L. (dark-green), for the $m_h$-max benchmark scenario, with $m_t = 179.3$ GeV/c$^2$. The figure shows the excluded and theoretically inaccessible regions in four projections of the MSSM parameters: $(m_h, m_A)$, $(m_h, \tan\beta)$, $(m_A, \tan\beta)$ and $(m_{H^\pm}, \tan\beta)$. The dashed lines indicate the boundaries of the regions expected to be excluded on the basis of Monte Carlo simulations with no signal. In the $(m_h, \tan\beta)$ projection (top right plot), the upper edge of the parameter space is indicated for various top quark masses; from left to right: $m_t = 169.3$, 174.3, 179.3 and 183.0 GeV/c$^2$. 
MSSM Higgs Search: Assoc. Prod. with b’s

FIG. 5: The 95% C.L. upper limit on $\tan \beta$ as a function of $m_A$ for two scenarios of the MSSM, “no mixing” and “maximal mixing.” Also shown are the limits obtained by the LEP experiments for the same two scenarios of the MSSM [3].

DØ, hep-ex/0504018
Figure 4: Top (a): contour plots of kinematic variables, demonstrating that they all measure the same function of \((m_{t'}, m_N)\). On the left is the case of \(t'\) fermion \(N\) scalar; at right, \(t'\) scalar \(N\) fermion. Bottom (b): the same plots, with contours of constant cross section superimposed. At left, \(t'\) fermion \(N\) scalar; at right, \(t'\) scalar \(N\) fermion. Approximately, the kinematic variables are all sensitive only to the mass difference, while the cross section is sensitive to the \(t'\) mass. \((\langle H_t \rangle\) is in red, \(\langle |E_T| \rangle\) is in blue, \(\langle M_{eff} \rangle\) is in purple, \(M_{T2}^{max}\) is in gold, and in (b) \(\sigma\) is in black.)

Meade and Reece, hep-ph/0601124