V workshop italiano sulla fisica p-p ad LHC
Perugia, 2 febbraio 2008

1) Experimental overview
Daniele del Re
Università “La Sapienza” e INFN Roma

Andrea Ventura
Università del Salento e INFN Lecce

2) Z’: current bounds and theoretical prejudices
Roberto Contino
CERN

3) Discussion
All
BSM & Exotics

Experimental Overview

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Outline

- Physics beyond SM can show up in many different ways
  – many models exist and many others could be possibly explored
- **In this talk:** be as much as possible model independent and only experimental details
  ⇒ focus on signatures and experimental techniques
  ⇒ very short intro’s on SUSY and physics BSM
- Describe **representative analyses** for each different signature and reconstructed quantities
- Focus on **analyses needing low statistics** (<$O(fb^{-1})$) for discoveries
- Details on common **experimental systematics**, methods to extract backgrounds directly from data and **trigger issues**

- Most of **CMS** results shown here are from PTDR (2006)
- **ATLAS** PTDR released in 1999: here few updated results
  … waiting for **ATLAS CSC notes** (coming soon!)
Physics at the LHC: SM and beyond

😊 New energy domain for *discoveries*
😊 But *huge background* rates to deal with

<table>
<thead>
<tr>
<th>Channel</th>
<th>( \sigma ) @ 14 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>pp (inelastic)</td>
<td>( \sim 80 \text{ mb} )</td>
</tr>
<tr>
<td>Inclusive bbbar</td>
<td>500 ( \mu \text{b} )</td>
</tr>
<tr>
<td>QCD (&gt;50 GeV)</td>
<td>24 ( \mu \text{b} )</td>
</tr>
<tr>
<td>Inclusive W</td>
<td>140 nb</td>
</tr>
<tr>
<td>Inclusive Z</td>
<td>43 nb</td>
</tr>
<tr>
<td>DY (&gt;20 GeV)</td>
<td>53 nb</td>
</tr>
<tr>
<td>Inclusive ttbar</td>
<td>830 pb \text{ NLO}</td>
</tr>
<tr>
<td>Inclusive Higgs</td>
<td>1÷30 pb</td>
</tr>
<tr>
<td>Inclusive SUSY @ ( m_{a,a} \sim 1\text{TeV} )</td>
<td>( \sim 50 \text{ pb} )</td>
</tr>
<tr>
<td>( Z' @ 2\text{TeV} )</td>
<td>&lt; 1 pb</td>
</tr>
</tbody>
</table>

Hard cuts needed to suppress background and *robust* analyses to extract signal and reduce effects of tails
Signatures: MET

- New Physics predicts **undetectable** particles
- **MET**: large missing E in transverse plane identifies new physics processes

...but MET very sensitive to detector inefficiencies and bad behaviors \(\Rightarrow\) need to keep background very low

- In addition to MET: presence of other particles to identify specific final states and suppress backgrounds
  - **leptons**
  - **jets**
  - **photons**

Example of decay chain for low mass RPC SUSY
Signatures: resonances and long lived

**Resonances**
- Many new particles predicted to decay in *di-objects*
  - leptons, jets, photons
- Best candidates for *indisputable discovery*
  - detector effects can’t fake peaks
- High efficiencies and reasonably low backgrounds needed

**Long lived**
New charged and neutral long lived objects leave peculiar and identifiable signatures
⇒ small measured $\beta$
⇒ displaced vertexes
Supersymmetry reminder

Add to each SM \textit{fermion} (\textit{boson}) a \textit{bosonic} (\textit{fermionic}) partner.

- \textbf{R-parity} $R = (-1)^{3(B-L)+2s}$ can be \textit{conserved} (RPC) or \textit{violated} (RPV)
- RPC implies:
  - SUSY particles produced in pairs
  - stable and neutral lightest SUSY particle (LSP)
  - no proton decay
- LSP is a \textit{good candidate} for cold \textit{Dark Matter}

\textbf{MSSM} Lagrangian depends on 105 parameters
\textbf{mSUGRA} requires only 5 parameters
  - Also other SUSY models exist: \textit{GMSB}, \textit{AMSB}, …

\begin{tabular}{|c|c|}
\hline
\textbf{SM Particles} & \textbf{SUSY Particles} \\
\hline
quarks: $q$ & squarks: $\tilde{q}$ \\
leptons: $l$ & sleptons: $\tilde{l}$ \\
gluons: $g$ & gluino: $\tilde{g}$ \\
charged weak boson: $W^\pm$ & Wino: $\tilde{W}^\pm$ \\
Higgs: $H^0$ & charged higgsino: $\tilde{H}^\pm$ \\
neutral weak boson: $Z^0$ & neutral higgsino: $\tilde{h}^0, \tilde{A}^0$ \\
photon: $\gamma$ & photino: $\tilde{\gamma}$ \\
\hline
\end{tabular}
mSUGRA benchmark points

SUSY benchmark points chosen in the \((m_0, m_{1/2})\) plane for different \(\tan\beta\) values:

- Systematically exploring phenomenological signatures
- Scanning the parameter phase space constrained by latest experimental data

<table>
<thead>
<tr>
<th>CMS Point</th>
<th>(m(-q))</th>
<th>(m(-g))</th>
<th>(\tan\beta)</th>
<th>(\text{sgn}(\mu))</th>
<th>(A_0)</th>
<th>x-sec (pb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM1</td>
<td>559</td>
<td>611</td>
<td>10</td>
<td>+</td>
<td>0</td>
<td>55</td>
</tr>
<tr>
<td>LM2</td>
<td>779</td>
<td>834</td>
<td>35</td>
<td>+</td>
<td>0</td>
<td>9.4</td>
</tr>
<tr>
<td>LM3</td>
<td>626</td>
<td>602</td>
<td>20</td>
<td>+</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td>LM4</td>
<td>661</td>
<td>695</td>
<td>10</td>
<td>+</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>LM5</td>
<td>810</td>
<td>858</td>
<td>10</td>
<td>+</td>
<td>0</td>
<td>7.7</td>
</tr>
<tr>
<td>LM6</td>
<td>860</td>
<td>940</td>
<td>10</td>
<td>+</td>
<td>0</td>
<td>4.9</td>
</tr>
<tr>
<td>LM7</td>
<td>3004</td>
<td>678</td>
<td>10</td>
<td>+</td>
<td>0</td>
<td>6.8</td>
</tr>
<tr>
<td>LM8</td>
<td>820</td>
<td>745</td>
<td>10</td>
<td>+</td>
<td>-300</td>
<td>12</td>
</tr>
<tr>
<td>LM9</td>
<td>1480</td>
<td>507</td>
<td>50</td>
<td>+</td>
<td>0</td>
<td>40</td>
</tr>
<tr>
<td>LM10</td>
<td>3133</td>
<td>1295</td>
<td>10</td>
<td>+</td>
<td>0</td>
<td>0.076</td>
</tr>
<tr>
<td>HM1</td>
<td>1721</td>
<td>1886</td>
<td>10</td>
<td>+</td>
<td>0</td>
<td>0.045</td>
</tr>
<tr>
<td>HM2</td>
<td>1656</td>
<td>1785</td>
<td>35</td>
<td>+</td>
<td>0</td>
<td>0.065</td>
</tr>
<tr>
<td>HM3</td>
<td>1762</td>
<td>1804</td>
<td>10</td>
<td>+</td>
<td>0</td>
<td>0.047</td>
</tr>
<tr>
<td>HM4</td>
<td>1816</td>
<td>1434</td>
<td>10</td>
<td>+</td>
<td>0</td>
<td>0.102</td>
</tr>
</tbody>
</table>

Similar mSUGRA points are studied by ATLAS (SUx.y)
SUSY production at the LHC

LHC production is dominated by heavy strongly interacting sparticles, followed by decay chains between SUSY states.

Event topology

- High-\(p_T\) jets from squark/gluino decays
- Large \(E_T^{\text{miss}}\) from LSP
- High-\(p_T\) leptons from gaugino/slepton
- High-\(p_T\) b-jets/\(\tau\)-jets (depending on model)

In RPC models, chains end up with the LSP.

- In RPV models the LSP decays:
  - higher jet multiplicity
  - \(E_T^{\text{miss}}\) signature is lost
Early SUSY search

Golden discovery channels: “$E_T^{\text{miss}} + \text{multijets (+ n-leptons)}$”

A typical SUSY event selection:
- 1 jet with $p_T > 100$ GeV,
- 4 jets with $p_T > 50$ GeV
- $E_T^{\text{miss}} > \max(100 \text{ GeV}, 0.2M_{\text{eff}})$
- Transverse sphericity $S_T > 0.2$
- (Isolated $\mu$ or $e$ with $p_T > 20$ GeV)

SUSY discriminated from SM via:

$$M_{\text{eff}} = E_T^{\text{miss}} + \sum_i |p_T^{\text{jet}}|$$

<table>
<thead>
<tr>
<th>Jet multiplicity</th>
<th>Additional signature</th>
<th>SUSY scenario</th>
<th>Backgrounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥4</td>
<td>No lepton</td>
<td>mSUGRA, AMSB, split SUSY, heavy squark</td>
<td>QCD, ttbar, W/Z</td>
</tr>
<tr>
<td></td>
<td>One lepton</td>
<td>“</td>
<td>ttbar, W</td>
</tr>
<tr>
<td></td>
<td>Di-lepton</td>
<td>mSUGRA, AMSB, GMSB</td>
<td>ttbar</td>
</tr>
<tr>
<td></td>
<td>Di-tau</td>
<td>GMSB, large tan$\beta$</td>
<td>ttbar, W</td>
</tr>
<tr>
<td></td>
<td>γγ</td>
<td>GMSB</td>
<td>Free</td>
</tr>
</tbody>
</table>

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10
Inclusive SUSY searches

Missing $E_T + \text{jets} + 0 \text{ leptons}$

- Data-driven estimation of $Z \rightarrow \nu\nu$ bkg $E_T^{\text{miss}}$ shape and normalization using $Z \rightarrow \mu\mu$ sample and replacing $\mu$ with $\nu$

Measure in $Z \rightarrow \mu\mu$ Use in $Z \rightarrow \nu\nu$

Low mass (LM1)

Signal and background in $E_T^{\text{miss}}$
Inclusive SUSY: dileptons

Opposite Sign leptons
- From neutralino decays, e.g.: $\tilde{\chi}_2^0 \rightarrow \ell^+ \ell^- \tilde{\chi}_1^0$
- From 2 independent 1-lepton decays

Same Sign leptons
- Clean event signature (especially same sign)
- Crucial for exclusive studies (see later in this talk)
- Smaller yield than 0, 1 lepton modes
- Largest background: $t\bar{t} \rightarrow b\bar{b} \ell \nu \ell \nu$ but also SUSY chains with leptonic decays of $W$ or top contribute.

Bkg small but hard to estimate
1 fb^{-1} of ATLAS/CMS data enough to discover SUSY if squark/gluino mass lower than 1.5-2 TeV. Discovery needs:

- Good knowledge of the detector, jet scale, E_T^{miss} tails, lepton ID
- SM control samples to be collected (W+jets, Z+jets, top, ...)

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In case of a discovery of SUSY, particle properties can be measured to verify that they are indeed SUSY partners.

Edge(s) of dilepton invariant mass correlated with slepton and neutralino masses.

![Diagram showing SUSY mass measurements](image)

**SU3, 1 fb⁻¹**  
Edge: (99.7±0.8) GeV  
Truth: 100.7 GeV

\[ M_{ll}^{\text{max}} = M(\tilde{\chi}_2^0) \left[ 1 - \frac{M^2(\tilde{\tau}_R)}{M^2(\tilde{\chi}_2^0)} \right] \left[ 1 - \frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{\tau}_R)} \right] \]

✓ Uncorrelated (SUSY+SM) background (two leptons from independent chains) removed by flavor subtraction:  
\[ e^+e^- + \beta^2 \mu^+\mu^- - \beta (e^+\mu^- - e^-\mu^+) \quad , \quad \beta = \varepsilon_e/\varepsilon_\mu \]

✓ Leptons can also be combined with jets of the full decay chain to look for other kinematical edges \((M_{llj} \text{ or } M_{lj})\)
**SUSY spin measurements**

- **Spin** is the defining property of SUSY
  - Crucial to distinguish from similar-looking models that can mimic SUSY (e.g.: Universal Extra Dimensions)

- It is difficult to measure @ LHC
  - No polarised beams
  - Indeterminate initial state from pp collision...

- **Example**: second neutralino spin from angles in
  \[ \tilde{q}_L \rightarrow q \tilde{\chi}_2^0 \rightarrow q \tilde{l}_L^\pm \rightarrow q l^\pm \tilde{\chi}_1^0 \]

  If neutralino spin is \( \frac{1}{2} \), angular distribution of slepton is not spherical
  \( \Rightarrow \) the lepton-quark invariant mass \( m(ql^\pm) \) is charge asymmetric

  In **SU3** point, \( 5-10 \text{ fb}^{-1} \) are already enough to exclude charge symmetry
GMSB

- Gauge Mediated Supersymmetry Breaking. Models for SUSY breaking, alternative to mSUGRA

- SUSY breaking transmitted from Hidden sector to visible sector via gauge interactions ("messengers")

- Why interesting?
  - more natural suppression of FCNC
  - not huge $\sigma$ but clear signature to claim early discovery or exclusion
    - $\sigma \sim 0.1 \div 1$ pb (model dependent)

- LSP is the Gravitino ($m \lesssim$keV)
  - light, stable and weakly interacting
  - possible candidate for Dark Matter

<table>
<thead>
<tr>
<th>Par.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda$</td>
<td>SUSY breaking scale</td>
</tr>
<tr>
<td>$M_m$</td>
<td>Messenger mass scale</td>
</tr>
<tr>
<td>$\tan\beta$</td>
<td>Ratio of Higgs vev</td>
</tr>
<tr>
<td>$N_m$</td>
<td>Number of SU(5) messenger multiplets</td>
</tr>
<tr>
<td>$\text{sign}(\mu)$</td>
<td>$\mu$ from Higgs sector</td>
</tr>
<tr>
<td>$C_{grav}$</td>
<td>Sets NLSP lifetime</td>
</tr>
</tbody>
</table>

Present limits: Tevatron, $\Lambda > 80$ TeV, $m(\text{neutralino,chargino}) > 108, 195$ GeV
GMSB with γ’s

- If NLSP is neutralino ⇒ 2γ in event
- Selection
  - γ, isolation, \( p_T > 80 \text{ GeV} \)
  - High MET, \( N_{jets} > 3 \)
- Main backgrounds
  - γ+jets
  - W+jets
- If lifetime(χ) ≠ 0 ⇒ non-pointing γ
  ⇒ possible to extract lifetime
- MET tails critical for early discoveries

![Diagram of GMSB with photons](image)

For \( \Lambda = 140 \text{ TeV} \)

### Diagram Details
- MET + photons
- Selection
- Main backgrounds
- Jet and photon interactions for early discoveries
Extra Dimensions and Hierarchy

- Main motivation **Hierarchy Problem**: $M_{EW}/M_{Pl} \sim 10^{-17}$
- Possible solution: existence of extra dimensions
  - Gravity scale lowered to $\sim 1$ TeV if gravitons propagate in 4+n dimensions
- Different models:
  
  **Randall-Sundrum Scenario**
  - Warped ED
  - Gravitons propagate in bulk
  - Graviton resonances

  **Universal ED**
  - ED of scale $\text{TeV}^{-1}$
  - KK pair production
  - Resonances from KK excitations

  **Large Extra Dimension**
  - Virtual graviton exchange
  - Direct graviton production
  - Black holes
Dijets

Dijets invariant mass used to spot resonances \((q^*, Z', \ldots)\) decaying to two quarks

Dijet cleaning done with:
- \(\text{MET} / \Sigma E_T < 0.3\)
  - (no QCD background rejection but unphysical background gone)
- Cut on \(\eta\):
  - QCD at large \(|\eta|\) due to t-channel pole

Same approach for inclusive study for new physics (contact interactions)

\[
\text{Dijet Resonance} \quad \begin{array}{c}
q, q, g \\
q, q, g \\
q, q, g
\end{array}
\quad \begin{array}{c}
X \\
\text{s-channel}
\end{array}
\quad \begin{array}{c}
q, q, g \\
q, q, g \\
q, q, g
\end{array}
\quad \text{QCD} \quad \begin{array}{c}
\text{mainly t-channel}
\end{array}
\]
Dijets: physics potential

- Measure rate vs. dijet mass and look for resonances
  - Use a smooth distribution or QCD prediction to model background

- Resonances seen with low statistics
  - Convincing signal for a 2 TeV excited quark in 100 pb⁻¹
    (Tevatron excluded up to 0.78 TeV)

- Crucial issues: trigger efficiency at low $p_T$ and jet $E$ resolution
Z' and W'

- **New gauge bosons** predicted by many extensions of the Standard Model with extended gauge symmetries:
  - Super-string inspired and GUT theories;
  - Left-Right Symmetric Models based on the gauge group $SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ predicting substructures of the known “elementary particles”;
  - Little Higgs Models.

- Produced via **Drell-Yan process**

- **Stringent limits** from precision EW experiments and direct searches *(see Roberto’s talk)*

  ![Diagram showing Drell-Yan process](attachment:image.png)

  **TEVATRON limits ~ 1 TeV**
**Z’ analysis**

**Straightforward analysis:**
- Two leptons (high $p_T$, OS and isolated)
- Invariant mass used for signal extraction (unb. likelihood fit)

**Backgrounds:**
- Small. Mainly Drell-Yan
  (negligible at very high masses)

Ideal for early discoveries …but discovery potential $\propto$ to resolutions

$\Rightarrow$ Detector performances under control at startup!

---

*Figure: ATLAS*
Z′: discovery reach

Discovery possible for very low luminosity (depending on model)

Crucial issues:

- **Muons:** Preliminary alignment at low luminosity below 3 TeV
- **Electrons:** resolution improves with mass but saturation effects important after 3 TeV (CMS)

Backward-forward asymmetry with high statistics to distinguish models
**W' analysis**

### Very clear signature: MET+lepton
- Large $E_T^{\text{miss}}$ (e.g.: $> 50$ GeV)
- Only 1 high-$p_T$ lepton, (e.g.: $|\eta|<2.5$, $p_T>50$ GeV)
- Lepton isolation:
  - ATLAS: $p_T$ sum ($0.02<\Delta R<0.2$) $< 2$ GeV
  - CMS: no track ($p_T>0.8$ GeV) in $\Delta R<0.17$

- Helpful for analysis: b-jet veto, leptonic fraction
- Transverse mass: $M_T = \sqrt{2p_T E_T^{\text{miss}} (1-\cos\Delta\Phi_{l,E_{T^{\text{miss}}}})}$

- Clean event, easy to identify
- Quite low LVL1 trigger $\mu$ acceptance*efficiency (~80%)
- Main background: $W\rightarrow l\nu_l$, ttbar, QCD dijets
- Small $E_T^{\text{miss}}$ core of resolution compared to large $E_T^{\text{miss}}$ of signal events
  - ... but $E_T^{\text{miss}}$ tails due to background can be critical
**W’ mass reach**

Even a large mass $W'$ (~5 TeV) discovered with 1-10 fb$^{-1}$

<table>
<thead>
<tr>
<th>$W'$ mass (TeV)</th>
<th>$M_T$ window (TeV)</th>
<th>Luminosity (pb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.6 – 1.7</td>
<td>3.0 ± 0.3</td>
</tr>
<tr>
<td>1.5</td>
<td>0.9 – 2.0</td>
<td>14.6 ± 1.4</td>
</tr>
<tr>
<td>2</td>
<td>1.2 – 2.9</td>
<td>84 ± 9</td>
</tr>
<tr>
<td>2.5</td>
<td>1.6 – 3.2</td>
<td>283 ± 31</td>
</tr>
</tbody>
</table>

5σ significance for ATLAS discovery (likelihood ratio method) $[Kr]$
Long-lived

Heavy Stable Charged Particles

- Many models predict new stable, heavy, electrically and colored charged particles (e.g., stau in GMSB) (HSCP)
- Detected measuring $\beta$ and $p$ of the particle
- In CMS two measurements are combined ($0.6<\beta<0.8$):
  - $dE/dx$ measured in the silicon tracker
  - time-of-flight (TOF) using the muon drift tubes

- Selection details:
  - single muon trigger with transverse momentum $>50$ GeV (no isolation criteria in case of R-hadrons)
  - max delay in muon system $= 12.5\text{ns}$ with respect to muon
  - $\beta$ measurement from $dE/dx < 0.85$
  - consistency with $\beta$ from TOF (within 0.1)
HSCP: discovery potential

- Discovery possible at early stages of LHC data taking
  - Tiny backgrounds after offline selection

- Crucial issues:
  - Trigger of slow particles
  - R-hadrons interaction in matter. Charge flip during flight, hard to track.
    - But can be used to distinguish different particle types (R-hadrons – staus)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mass resolution</th>
<th>Trigger efficiency</th>
<th>Total eff. for discovery</th>
<th>5σ int. lumi (pb⁻¹)</th>
<th>Expected events</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 GeV gluino</td>
<td>7%</td>
<td>0.044</td>
<td>0.014</td>
<td>0.2</td>
<td>67</td>
</tr>
<tr>
<td>300 GeV gluino</td>
<td>8%</td>
<td>0.093</td>
<td>0.038</td>
<td>30</td>
<td>190</td>
</tr>
<tr>
<td>600 GeV gluino</td>
<td>10%</td>
<td>0.13</td>
<td>0.058</td>
<td>500</td>
<td>88</td>
</tr>
<tr>
<td>152.3 GeV stau</td>
<td>7%</td>
<td>0.87</td>
<td>0.25</td>
<td>500</td>
<td>75</td>
</tr>
</tbody>
</table>

[HC]
Several extensions of SM have neutral, weakly-coupled unstable particles with macroscopic decay lengths.

- **GMSB, MSSM R-parity violation, split SUSY**
- **Hidden Valley**: a hidden sector is separated from SM by a barrier. Some HV particles can decay only to SM states and are long-lived.
  - “Communicators” HV-SM include Higgs boson, $Z'$ boson, neutralinos…
- Hard to trigger these decays
  - Unrevealed neutral objects
  - Jets originating throughout the detector
- HV is a good candidate to train and implement new trigger strategies

### Diagrams

**Higgs**

- $g \rightarrow h, h_v \rightarrow X, X \rightarrow b, b$
- Mixing

**$Z'$**

- $q \rightarrow Z', Z' \rightarrow X, X \rightarrow b, b$
- $N(X) \sim 3 - 6$ ($X \rightarrow bb$)
- $N(Y) \sim 6 - 12$ ($Y \rightarrow \text{MET}$)

*Four b decays, two displaced vertices*

*Many b decays and displaced vertices*
### In Muon System

- **LVL1**: 6 GeV mu

### In Calorimeters

- **LVL1**: 35 GeV jet

### In Inner Detector

- **LVL1**: 35 GeV jet

#### Decays at the end of HCAL and before MS pivot plane
- Get multiple LVL1 μ ROIs in a narrow $\eta\phi$-cone around decay-point $\Rightarrow$ a LVL2 clustering algorithm is optimised

#### Decays at the end of ECAL
- Show non-standard sharing of jet energy between HCAL/ECAL
- High $p_T$ LVL1 jets show peak at large $E_{\text{HAD}}/E_{\text{EM}}$ due to decays in HCAL, absent in QCD background

#### Decays beyond the pixels
- Produce no track in pixels
- LVL2 tracking has low efficiency vertex reco.
- # of LVL2 tracks shows peak at 0, absent in di-jets

---

**Hidden Valley decays**

**Trigger optimisation**

- Z' events (PYTHIA-based HVMC)
Micro Black Holes

Models with large EDs can allow $M_{PL} \sim 1\text{TeV}$: there can exist short-lived black holes ($\tau \sim 10^{-26}\text{s}$) decaying via Hawking radiation, $\sigma \sim \pi R_s^2 \sim O(100)\text{pb}$

- **Spectacular states expected**
  - Large multiplicities
  - Large $E_T$ and missing $E_T$
  - Hadrons: Leptons $\sim 5:1$
  - Highly spherical compared to background
  - "Democratic" decay

- **High multiplicity** events with **very high $p_T$** particles

- Invariant mass resolution better than 5% for mass under 300 GeV

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## Priorities for discovery

<table>
<thead>
<tr>
<th>SUSY</th>
<th>BSM Physics analysis</th>
<th>Signature</th>
<th>Min Luminosity</th>
<th>Background</th>
<th>Model / Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inclusive with MET + j</td>
<td>MET</td>
<td>10 pb⁻¹</td>
<td>QCD, tt</td>
<td>Low Mass (LM1)</td>
</tr>
<tr>
<td></td>
<td>Inclusive with MET + j + l</td>
<td>MET,e,µ</td>
<td>100 pb⁻¹</td>
<td>W+j, tt</td>
<td>“</td>
</tr>
<tr>
<td></td>
<td>Inclusive SS di-leptons</td>
<td>MET,e,µ</td>
<td>500 pb⁻¹</td>
<td>tt</td>
<td>“</td>
</tr>
<tr>
<td></td>
<td>Inclusive OS di-leptons</td>
<td>MET,e,µ</td>
<td>50 pb⁻¹</td>
<td>tt</td>
<td>“</td>
</tr>
<tr>
<td></td>
<td>Inclusive with di-τ (had)</td>
<td>MET,τ</td>
<td>100 pb⁻¹</td>
<td>QCD</td>
<td>“</td>
</tr>
<tr>
<td></td>
<td>e-µ (LFV)</td>
<td>MET,e+µ</td>
<td>500 pb⁻¹</td>
<td>tt</td>
<td>“</td>
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<tr>
<td></td>
<td>GMSB</td>
<td>γγ</td>
<td>1 fb⁻¹</td>
<td>γ,W+jets</td>
<td>NLSP = χ₁⁰</td>
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<tr>
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<td>Z’, γ¹/Z¹, G → e e</td>
<td>e,µ HE</td>
<td>100 pb⁻¹</td>
<td>2TeV</td>
<td>SSM Z’</td>
</tr>
<tr>
<td></td>
<td>Z’, γ¹/Z¹, G → µ µ</td>
<td>µ HE</td>
<td>1 fb⁻¹</td>
<td>3.5TeV</td>
<td>ADD n=3</td>
</tr>
<tr>
<td></td>
<td>W’, W¹ → µ ν</td>
<td>µ HE</td>
<td>1 fb⁻¹</td>
<td>3.5TeV</td>
<td>W</td>
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<tr>
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<td>W’/W’, γ¹/Z¹, G → q-q</td>
<td>jet HE</td>
<td>100 pb⁻¹</td>
<td>2TeV</td>
<td>QCD</td>
</tr>
<tr>
<td></td>
<td>γ + G</td>
<td>γ</td>
<td>200 pb⁻¹</td>
<td>γZ(vv), γW(lv)</td>
<td>ADD n=2-4</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>1 pb⁻¹ 1.7 TeV</td>
<td></td>
<td></td>
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<tr>
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<td>HCSP</td>
<td>low β trk</td>
<td>10⁻⁵⁻⁰ pb⁻¹</td>
<td>W→µν, bb</td>
<td>stau, g</td>
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<td>UED, stable γ¹KK</td>
<td>4l</td>
<td>200 pb⁻¹</td>
<td>tt, ZZ</td>
<td>4µ</td>
</tr>
<tr>
<td></td>
<td>Black Holes</td>
<td>Multi-part</td>
<td>1 fb⁻¹</td>
<td>QCD</td>
<td>M₉=5 TeV</td>
</tr>
</tbody>
</table>

LHC start-up: possible steps

- **10 pb⁻¹**
  - First check on $E_T^{miss}$ shape and on lepton/jet energy scale
  - Partial trigger functionality (at least high threshold jets)
  - First boot-strap check of trigger efficiency and calibration from data
  - Preliminary data-driven estimates of non-gaussian QCD tails
    - First EW analyses / tuning SM candles / trying to look for first BSM signals

- **100 pb⁻¹**
  - Assume $E_T^{miss}$ scale + gaussian resolution reasonably clear (tails reduced?)
  - More advanced triggers available (including high-$p_T$ leptons/photons)
  - More detailed data-driven trigger validation and bckg estimates via control samples
  - First optimisation of inclusive search event selection
    - SUSY: $E_T^{miss}$ + jets + 0,1 leptons; resonances in leptons and jets

- **1000 pb⁻¹**
  - Assume $E_T^{miss}$ scale + gaussian resolution understood, non-gaussian tails reduced.
  - Assume full trigger functionality (multijet, leptons, photons, $E_T^{miss}$, etc.)
  - Further trigger validation and accurate background estimates
  - First validation of some minor-background estimates with data (e.g. WW, single-top, etc)?
    - SUSY: $E_T^{miss}$ + jets + 0,1,2 leptons; $W'$, $\gamma+G$, MBH, …
Conclusions

- Many possible models of BSM Physics (Supersymmetry, Extra Dimensions, New Vector Bosons, …)
  - New discoveries at ATLAS and CMS possible with early LHC data ($O(100)\text{pb}^{-1}$)
- Accurate knowledge of SM physics and of detector performance needed for any new discovery
  - First data taking period devoted to understanding of detector
- Any claim of new physics requires check of trigger refinements and data-driven estimates of syst./background
  - First, focus on less systematics-affected analyses (e.g. striking signatures and resonances)
- Larger statistics needed for full scan over New Physics parameter space and discrimination between models
- Few points for open discussion follow…
Some of the sources

[Cms] CMS Physics TDR: CERN/LHCC 06-021
[Ba] A. Barr – PASCOS 2006
[Ya] S. Yamamoto – SUSY07
[DR] A. De Roeck – RDMS06
[Bi] M. Biglietti et al. – ATL-PHYS-PUB-2007-004
[Za] P. Zalewski – SUSY07
[DJ] CMS PAS SBM 07 001
[Kr] G. Krobath – SUSY07
[HC] CMS AN-NOTE-2006/112 – hep-ex/0612161
[St] R. Ströhmer – WIN07
[To] D. Tovey – ATLAS Analysis strategies, Sept. 2007
BSM & Exotics

Discussion

V workshop italiano sulla fisica p-p ad LHC
Perugia, 2 febbraio 2008

Daniele del Re
Università “La Sapienza” e INFN Roma

Andrea Ventura
Università del Salento e INFN Lecce
Discussion: signatures

- Strategy to maximize discovery potential minimizing the number of signatures to analyze.
  - Discovery potentials
  - Reconsider priorities taking into account latest theoretical insight (e.g. see Roberto’s talk)

- Confirmation of discovery with multiple channels, set up strategy.
  - excess in one signature but not confirmed, e.g. MET+jet confirmed by MET+jet+leptons in SUSY, $Z'\rightarrow e^+e^- / \mu^+\mu^-$, …

- Interpret excesses when we see them. Tools exist (e.g. like OSETs). Needed?

- Extraction of signal and statistical significance (low bkg events from tails, resonances with unknown masses, …)
  - blind analysis
  - safe confidence levels and minimum number of events (S/B can be very high for SUSY/BSM analyses)
Discussion: detector systematics and background

- Identify the most important systematic uncertainties for early data taking. Techniques to estimate them on data.

- Tune MC with real data
- Tune detector response
  - Jet calibration (energy scale and relative)
  - MET resolution
  - Lepton and photon energy scale
  - Track misalignment

- Extrapolating bkg: control samples and data-driven subtractions/estimates
  - In signal extraction dealing with tails (e.g. in MET): signal, wrong background modeling or wrong detector resolution?

Understanding of first data needed

Should be done before data taking
Discussion: theory

- theoretical systematics
  - SM at 14TeV. How well can we today predict SM processes at 14 TeV/what are the uncertainties?
  - Systematics on signals
Discussion: trigger

- Trigger crucial at the beginning of data taking. Comparison between ATLAS and CMS
  - comparison of thresholds and trigger paths: are we missing anything?

- Optimization/implementation for BSM signatures which could be lost (HSCP, Hidden Valley, Black Holes,...)
  - e.g. different possible decays in Hidden Valley scenario