Early SUSY searches at the LHC

Alex Tapper

Searching for SUSY at the LHC and interplay with astroparticle physics

Institute of Physics Workshop, 24th March 2010, Imperial College London
Many different SUSY scenarios investigated by LHC expts

My brief is to describe plans for early SUSY searches

What we plan to do with the 2010 and 2011 data

Covering discovery not really mass, spin etc. determination
The Large Hadron Collider

Overall view of the LHC experiments.

7 TeV  →  p  →  7 TeV
The Large Hadron Collider

Overall view of the LHC experiments.

\[ p \rightarrow p \]

3.5 TeV  3.5 TeV

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The Large Hadron Collider

100 pb⁻¹ by end of 2010

1 fb⁻¹ by end of 2011

p
3.5 TeV

3.5 TeV

M. Fero-Luzzi
The ATLAS detector

- Muon chambers
- Toroid magnets
- Solenoid magnet
- Semiconductor tracker
- Pixel detector
- Transition radiation tracker
- LAr electromagnetic calorimeters
- LAr hadronic end-cap and forward calorimeters
- Tile calorimeters

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The ATLAS detector
The CMS detector

- Superconducting Solenoid (4 Tesla)
- Lead Tungstate Electromagnetic Calorimeter
- Plastic-Brass Hadronic Calorimeter
- Iron Yoke
- Muon Detectors
- Silicon Microstrip Tracker
- Silicon Pixel Detector
The CMS detector
Search strategy

- Be as model independent as possible
  - But the MSSM has > 100 parameters
  - Need more constrained models
  - Choose a set of benchmark points that are representative of a range of topologies and areas of phase space

- Range of models
  - MSUGRA (high and low masses)
  - GMSB
  - Split SUSY

- In this talk MSUGRA at low masses, just above the Tevatron

- SU4 for ATLAS

Full details of benchmark points in backup slides.
Search strategy

- Be as model independent as possible
  - But the MSSM has > 100 parameters
  - Need more constrained models
  - Choose a set of benchmark points that are representative of a range of topologies and areas of phase space
  - Range of models
    - MSUGRA (high and low masses)
    - GMSB
    - Split SUSY
  - In this talk MSUGRA at low masses, just above the Tevatron
  - LM0 and LM1 for CMS


Full details of benchmark points in backup slides
Search strategy

Production

- Squark and gluino expected to dominate
- Strong production so high cross section
- Cross section depends only on masses
- Approx. independent of SUSY model
Search strategy

- **Production**
  - Squark and gluino expected to dominate
  - Strong production so high cross section
  - Cross section depends only on masses
  - Approx. independent of SUSY model

- **Decay**
  - Details of decay chain depend on SUSY model (mass spectra, branching ratios, etc.)
  - Assume $R_P$ conserved $\Rightarrow$ decay to lightest SUSY particle (LSP)
  - Assume squarks and gluinos are heavy $\Rightarrow$ long decay chains

- **Signatures**
  - MET from LSPs, high-$E_T$ jets and leptons from long decay chain

- **Focus on robust and simple signatures**
  - Common to wide variety of models
  - Let Standard Model background and detector performance define searches not models
Searches

- How might such a generic search look?
  - Simple selection → categorise events by numbers of leptons and jets

  - Jet $E_T > 100$ (40) GeV
  - $\Delta \Phi (\text{jet}_i, \text{MET}) > 0.2$ rad
  - Lepton $E_T > 20$ (10) GeV
  - MET > 80 GeV
  - $M_{\text{eff}} = \Sigma E_T^{\text{jet}} + \Sigma E_T^{\text{lep}} + \text{MET}$
  - MET > 0.2-0.3 × $M_{\text{eff}}$
  - $S_T > 0.2$
  - $M_T > 100$ GeV

- Good S/B for most channels (200 pb$^{-1}$ @ 10 TeV COM) but...
- Backgrounds straight from Monte Carlo

- Measuring backgrounds is the key →
Backgrounds

- **Physics**
  - Standard Model processes that give the same signatures as SUSY
  - Cannot rely on Monte Carlo predictions → measure in data

- **Detector effects**
  - Detector noise, mis-measurements etc. that generate MET or extra jets
  - Commissioning and calibration → results from 2009 pilot run

- **Beam related**
  - Beam-halo muons (and cosmic-ray muons), beam-gas events
  - Data and simulation already → measure in situ too
Commissioning and calibration

- Universal astonishment at how well the simulation describes the data
- Detector noise under study → promising start in understanding

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**ATLAS Preliminary**

Cells, I|E|>2

**Topoclusters 4/2/0**

**CMS Preliminary 2009**

\[ \sqrt{s}=900 \text{ GeV} \]

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Commissioning and calibration

- Universal astonishment at how well the simulation describes the data
- Resolutions well described by simulation

![Graph showing METx, METy Resolution vs. \( \Sigma E_T \) (GeV)]

![Histogram showing data and simulation comparison for pf\(E_{x,y} \) vs. pf\(E_{x,y} \) [GeV]]
Commissioning and calibration

- Universal astonishment at how well the simulation describes the data
- Higher-level objects looking good → jet $p_T$ spectrum

$\sqrt{s} = 900$ GeV

Inclusive Jets
anti-$k_T$ (R = 0.5) PFJets
$p_T$ (jet) > 10 GeV
$|\eta|$ (jet) $< 3.0$

CMS preliminary

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Physics backgrounds

- Data-driven background estimates are the key challenge in early SUSY searches.
- General idea is find a control region where SM is dominant and use this to predict SM background in signal region.
- Two approaches pursued:
  - Matrix (ABCD) methods ➔ playing variables off against each other.
  - Replacement methods ➔ modify SM with same topology as signal to predict signal.
- In both cases need to identify clean SM control region.
- Difficult to avoid using Monte Carlo in some way.
- Will discuss searches giving examples of data-driven methods ➔
All-hadronic search

- All-hadronic search highly sensitive to SUSY
- But suffers from many backgrounds
- Nice examples of backgrounds both from detector effects and from Standard Model physics
All-hadronic search

- Mis-measurement of a jet leads to MET along the jet axis
- Remove with $\Delta \Phi(\text{jet}_i, \text{MET}) > 0.2$ rad

Several methods developed to predict MET tail from QCD events

- Matrix methods to estimate from control regions
- Smearing method

All-hadronic search

• Derive Gaussian part of smearing function from $\gamma +$ jet control sample

• Derive non-Gaussian part from Mercedes events, requiring that the MET is co-linear with one of the jets

• Combine smearing functions, normalising with di-jet sample

• Apply smearing function to low MET events to predict the tail in the high MET signal region

All-hadronic search

A novel approach combining angular and energy measurements
No dependence on MET \(\rightarrow\) robust for early LHC running
Originally proposed for di-jet events \(\rightarrow\) generalised up to 6 jets
Perfectly balanced events have \(\alpha_T = 0.5\) (cut at \(\alpha_T > 0.55\))
Mis-measurement of either jet leads to lower values

\[\alpha_T = \frac{E_{T_{j2}}}{M_{T_{j1,j2}}} = \frac{\sqrt{E_{T_{j2}}/E_{T_{j1}}}}{\sqrt{2(1 - \cos \Delta \phi)}}\]


Barr and Gwenlan
arXiv:0907.2713
Background estimates

- **Data-driven background estimates**
  - Find a **control region** in phase space where SM background dominates
  - Use measurements in this region to infer SM background in signal region
  - Example $Z \rightarrow \nu \nu + \text{jets} \rightarrow$ irreducible background
  - **Replacement technique**

- **$Z \rightarrow ll + \text{jets}$**
  - Strength: very clean
  - Weakness: low statistics

- **$W \rightarrow l\nu + \text{jets}$**
  - Strength: larger statistics
  - Weakness: background from SM and SUSY

- **$\gamma + \text{jets}$**
  - Strength: large statistics and clean at high $E_T$
  - Weakness: background at low $E_T$, theoretical errors
Background estimates

- Select $\gamma + \geq 3$ jets with $E_{\gamma} > 150$ GeV
  - Clean sample S/B > 20
  - Remove photon from the event
  - Recalculate MET
  - Normalise with $\sigma(Z+\text{jets})/\sigma(\gamma+\text{jets})$ from MC or measurements

CMS-PAS-SUS-08-002

100 pb$^{-1}$ @ 14 TeV COM
**Single-lepton search**

- Requiring one lepton (e or µ) suppresses QCD background powerfully
- Highly sensitive to SUSY
- Backgrounds come from Standard Model processes with neutrinos → real MET
- In particular top and W decays

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**ATL-PHYS-PUB-2009-084**
Background estimates

- **Data-driven background estimates**
  - Find a **control region** in phase space where SM background dominates
  - Use measurements in this region to infer SM background in signal region
  - Example W, top backgrounds to single-lepton search
  - Playing two discriminate quantities off against each other

- **Well known matrix ($M_T$) method**
  - Use low $M_T$ control region
  - Predict MET spectrum
  - Weaknesses
    - Non-independence of variables
    - Signal contamination
  - More sophisticated methods ➔

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ATL-PHYS-PUB-2009-084
Background estimates

- “Tiles” method
  - Use the Monte Carlo prediction for the shapes of SM backgrounds
  - Assume independence of variables for signal

- Can express $N_{\text{evts}}$ in each region in terms of $f^{\text{SM}}$ and $f^{\text{SUSY}}$
- Take $f^{\text{SM}}$ from MC for each region and solve the system of linear equations

- Predicts the number of SM background and SUSY signal events in each region
- Background prediction not biassed by signal contamination
Di-lepton searches

- Low yields but very interesting properties
- Same sign searches
  - Very low Standard Model background rate
  - Backgrounds from charge mis-identified top events (QCD in $\tau$ channel)
- Opposite sign
  - Use opposite-sign, opposite-flavour sample to subtract SM background
Di-lepton searches

- Fit ee, μμ and eμ distributions simultaneously
  - Resolution function and efficiencies from data
  - 200 pb\(^{-1}\) @ 10 TeV
  - Di-leptonic end-point \(m_{ll,\text{max}}=51.3 \pm 1.5 \text{ (stat.)} \pm 0.9 \text{ (syst.) GeV} [52.7 \text{ GeV}]
- Nice example of what could be done with modest dataset

CMS-PAS-SUS-09-002
Discovery reach @ 10 TeV

- Scan $M_{\text{eff}}$ cut for best sensitivity (50% error on backgrounds)
- All-hadronic and single-lepton searches vie for highest sensitivity
- Clear discovery potential beyond the Tevatron with 200 pb$^{-1}$ @ 10 TeV
Discovery reach @ 7 TeV

- Discovery reach for single-lepton + jets + MET channel
- Need to get above the 400 GeV line to be competitive
- Possible with ~100 pb$^{-1}$ @ 7 TeV
Summary

- Early searches based on robust generic signatures
  - Sensitive as possible to a variety of new physics models

- Detectors in great shape after 2009 LHC pilot run
  - Commissioning progressing well

- A wide range of data-driven techniques developed to measure efficiencies and backgrounds
  - Redundancy builds confidence

- Eagerly awaiting start of 7 TeV LHC collisions next week!
  - LHC should be at the search frontier before the end of 2010
Backup: Links

- **ATLAS latest results**
  - https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults

- **ATLAS Physics TDR**

- **CMS latest results**
  - https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults

- **CMS Physics TDR**
  - http://cmsdoc.cern.ch/cms/cpt/tdr/
## Backup: Benchmark points

### Low mass (LM) mSUGRA benchmarks

<table>
<thead>
<tr>
<th>Benchmark</th>
<th>m0</th>
<th>m1/2</th>
<th>A0</th>
<th>tanb</th>
<th>sgn(mu)</th>
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**Notes:**
- mtop = 175

### High mass (HM) mSUGRA benchmarks

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<th>Benchmark</th>
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<th>m1/2</th>
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### GMSB (GM) benchmarks

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### Particle benchmarks

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35 Institute of Physics Workshop, 24th March 2010, Imperial College London.