Strategy for early SUSY searches at ATLAS

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Outline

✓ Introduction
✓ Strategy for early SUSY searches
✓ Commissioning for missing transverse energy
✓ Data-driven estimation for SUSY backgrounds
✓ Summary
Large Hadron Collider (LHC) is getting ready for 2008 spring startup with hardware fully commissioned up to $E_{\text{beam}} = 7\text{TeV}$.

ATLAS, one of two general purpose experiments/detectors at LHC, is also approaching completion toward the first p-p collision at $\sqrt{s} = 14\text{TeV}$ in 2008 summer.

Current SUSY studies at ATLAS:

- Usual SUSY breaking scenarios: mSUGRA, GMSB, AMSB
- Full detector simulation basis for detector commissioning and understanding systematics.
- Techniques to estimate background using real data.
- (Post-discovery measurements of mass scale etc. and unusual signatures of long-lived stau and R-hadron.)

This talk focuses on the early SUSY searches (first data of $10^{31-32}\text{cm}^2\text{s}^{-1}$, up to $\sim 1\text{fb}^{-1}$)
1. Strategy for early SUSY searches
Strategy for early SUSY searches

✓ We use the golden discovery channels “multi-Jets + n-leptons + $E_T^{\text{miss}}$”
  
  Fair and less model-dependent features of SUSY :
  
  1. gluinos/squarks are produced via strong interactions.
  2. gluinos/squarks are heaviest.
  3. their decays give rise to high-$p_T$ jets
  4. neutralinos/charginos decay via emission of leptons
  5. (assuming R-parity conservation) LSP is stable and neutral, escaping from the detector (large $E_T^{\text{miss}}$)

✓ Early SUSY studies will proceed :
  
  1. Commissioning for missing transverse energy ($E_T^{\text{miss}}$) → part 2.
  2. Data-driven background estimation → part 3.

Need to establish a robust background estimation
Event topologies and baseline selection

Early searches try to cover a broad range of experimental signatures, but they are classified based on the event topology:

| Jet multiplicity | Additional signature | SUSY scenario | Backgrounds |
|------------------|----------------------|---------------|-------------|
| ≥ 4              | No lepton            | mSUGRA, AMSB, split SUSY, heavy squark | QCD, ttbar, W/Z |
|                  | One lepton (e, μ)    | mSUGRA, AMSB, split SUSY, heavy squark | ttbar, W |
|                  | di-lepton            | mSUGRA, AMSB, GMSB | ttbar |
|                  | di-tau               | GMSB, large tan β | ttbar, W |
| ~2               | γγ                   | GMSB | free |

Baseline selection (to be optimized)

- Jet multiplicity ≥ 4, \( p_T^{1st} > 100\text{GeV} \), \( p_T^{\text{others}} > 50\text{GeV} \)
- \( E_T^{\text{miss}} > \max(100\text{GeV}, 0.2\times M_{\text{eff}}) \)
- Transverse sphericity > 0.2
- (Additional cuts depending on signature)
  - Transverse mass > 100\text{GeV}, \( p_T^{\text{lepton}} > 20\text{GeV} \) (for one-lepton mode)
SUSY searches with each event topology

- Effective mass \( M_{\text{eff}} = \Sigma p_T^i + E_T^{\text{miss}} \) discriminates SUSY and SM backgrounds.

- Moreover, \( M_{\text{eff}} \) is strongly correlated to the mass of sparticles produced via p-p collisions.

- We hopefully find excess over the background estimation in the signal region of large \( M_{\text{eff}} \).

Benchmark point SU3:
\[ m_0=100\text{GeV}, \ m_{1/2}=300\text{GeV}, \ A_0=-300, \ \tan\beta=6, \ \text{sign}(\mu)=+ \]

(full detector simulation, 1fb\(^{-1}\))
Discovery potential with $L \sim 1 fb^{-1}$

- $5\sigma$-discovery potential on $m_{1/2} - m_0$ ($m_{\text{gluino}} - m_{\text{squark}}$) space is shown.
  - Require $S > 10$ and $S/\sqrt{B} > 5$
  - Factor of 2 generator-level uncertainty included (hatched)

- ATLAS has the potential for discovery of $\sim 1$ TeV scale SUSY with first data for each event topology.
  - Also shows a stable potential against $\tan \beta$.

\[\tan \beta = 10\]
2. Commissioning for missing transverse energy using early data
Transverse missing energy

✓ $E_T^{\text{miss}}$ is a discriminating variable for SUSY discovery
  — Our searches rely on the excess in the $E_T^{\text{miss}}(M_{\text{eff}})$ distribution.

✓ However, controlling its energy scale and resolution is very difficult experimentally.
  — Fake muons
  — Dead material and crack
  — Industrial effects in the detector
    (hot, dead and noisy calorimeter cells)

✓ Large tail in $E_T^{\text{miss}}$ due to the fake is serious for SUSY searches.
  — Especially for QCD-jet background
    (almost no truth $E_T^{\text{miss}}$, but large x-section)

In-situ measurements for $E_T^{\text{miss}}$ scale/resolution determination and understanding of fake $E_T^{\text{miss}}$ sources are our priorities straight.
In-situ measurements for $E_T^{\text{miss}}$ scale/resolution determination

**W→lν sample**

Shape of transverse mass distribution depends on $E_T^{\text{miss}}$ scale and resolution.

**Z→ττ (l-h channel) sample**

Use the collinear approximation for mass reconstruction.

$\sigma(M_{\tau\tau}) \sim E_T^{\text{miss}}/|\sin\phi_{\tau\tau}|$

ATLAS Preliminary

| $Z\rightarrow\tau\tau$ |
|---------------------|
| Mean = 90.7 GeV |
| $\sigma = 14.2$ GeV |

QCD jets

$W \rightarrow \mu\nu$

$W \rightarrow e\nu$

$tt\text{bar}$

ATLAS Preliminary

| $M_{\tau\tau}$ vs. $E_T^{\text{miss}}$ scale |
|---------------------|

(signal only)

ATLAS Preliminary

10% in $E_T^{\text{miss}}$ scale $\Leftrightarrow$ 3% shift in Z mass
Fake and large $E_T^{\text{miss}}$ tails

- The industrial effect in the detector is crucial.
- Its suppression is under study.
  - Online/offline monitoring tools
  - Event-by-event basis corrections

Detector failure (example):
- 0.1% LAr EM HV lines
- 2 LAr Frond-end crate (barrel and endcap)
- 2 tile drawers
3. Data-driven background estimation for early SUSY searches
Even if we get early indications, they cannot justify the discovery of “beyond SM”:

- Generator-level uncertainties affect the normalization and shapes of backgrounds.

We use the real data for BG estimations (data-driven)

Example of $Z(\rightarrow \nu\nu)$ background in no-lepton mode:

✓ determine the BG MC normalization factor by comparing $Z\rightarrow ll$ data with MC

✓ apply it to normalize the MC distribution of $Z\rightarrow \nu\nu$.

✓ it can be also applied to $W\rightarrow l\nu$ (almost the same production mechanism)

This scaling method works fine!
1. Isolate the background and signal processes based on transverse mass (control sample with <100GeV, signal sample with >100GeV)

2. Estimate the $E_T^{\text{miss}}/M_{\text{eff}}$ shapes of background processes using control sample

3. Determine the normalization of backgrounds with low $E_T^{\text{miss}}$ regions of control and signal samples.

- Satisfying performances with the $M_T$ discrimination technique.
- However, taking account of SUSY signal contamination in the control sample, this estimate appears to be over the mark. (By a factor of 2.5 for SU3)
QCD background estimation

✓ QCD background is hard to estimate based on MC:
  — Mainly originated from the industrial fake $E_T^{\text{miss}}$
  — Full understanding of detector response needs time... (difficult at the early stage)

Method of estimate:

step 1: Measure jet smearing function from data
  — Select events: $E_T^{\text{miss}} > 60$ GeV, $\Delta\phi(E_T^{\text{miss}}, \text{jet}) < 0.1$
  — Estimate $p_T$ of jet closest to $E_T^{\text{miss}}$ as $p_T^{\text{estimate}} = p_T^{\text{jet}} + E_T^{\text{miss}}$

step 2: Smear QCD events with low $E_T^{\text{miss}}$ by the smearing function.

Reproduces the $E_T^{\text{miss}}$ tail well!
The countdown to the startup of LHC and experiments has begun, and studies of early SUSY searches and detector commissioning have been performed actively.

The discovery potential using early data (1fb⁻¹) reaches ~1TeV scale SUSY with each event topology.

However, establishing robust background estimations is crucial for the discovery at the early stage.

- Origins of fake $E_T^{\text{miss}}$ and tails are going to be made known with the full detector simulation.
- New techniques for $E_T^{\text{miss}}$ calibration have been also performed.
- Variety of data-driven SM background estimations have been studied.

Large efforts of many working groups toward the early discovery.

News of “beyond SM” hopefully in 2009 summer!
Non-pointing photon is a distinctive signature of GMSB:
  • NLSP decays only via gravitational coupling
  • NLSP could have a long lifetime

ATLAS could cover GMSB requiring “photons + multi-jets + large $E_T^{miss}$.”
1. Top mass is largely uncorrelated with $E_T^{\text{miss}}$ — used as a calibration variable

2. Select semi-leptonic top candidates — mass window: 140-200 GeV

3. Contributions of combinatorial BG to top mass are estimated from the sideband events ($200 \text{ GeV} < m_{\text{top}} < 260 \text{ GeV}$)

4. Normalize the $E_T^{\text{miss}}$ distribution in low $E_T^{\text{miss}}$ region where SUSY signal contamination is small.

5. Extrapolate it to high $E_T^{\text{MISS}}$ region and estimate the background with SUSY signal selection.