SUSY Physics with early data ***Understanding the ATLAS detector*** ***and*** ***the background***

***The 14th International Conference on Supersymmetry
and the Unification of Fundamental Interactions (SUSY06)
Irvine, California, USA***

***Naoko Kanaya (Kobe University)
on behalf of the ATLAS collaboration***

Special thanks to Dan Tovey and Shoji Asai

SUSY signature at LHC

In most case, SUSY signature is characterised by Missing transverse energy(MET)+mutli-jets final state.

Colored sparticle pair-production is dominated at LHC (unless squarks/gluino are too heavy).

$$s(\text{SUSY}) \sim M_{\text{SUSY}} (= \min(\tilde{m}_q, \tilde{m}_g)) \sim M_{\text{eff}}$$

good correlation in mSUGRA

Important to understand
Missing ET and high-multiplicity SM background.

Contents

- **LHC and ATLAS detector**
- **Commissioning**
- **Background estimation with data**
- **SUSY discovery potential**
- **Summary**

LHC and ATLAS detector

Large Hadron Collider

- Center-of-mass energy 14TeV proton-proton collision
- Bunch crossing 40MHz
- Design Luminosity $10^{34} \text{ cm}^{-2}\text{s}^{-1}$
 - 2007 : $10^{31-32} \text{ cm}^{-2}\text{s}^{-1}$ ($>0.1\text{fb}^{-1}$)
 - 2008 : $10^{32-33} \text{ cm}^{-2}\text{s}^{-1}$ ($>1\text{fb}^{-1}$)

physics process

event yield (1fb^{-1})

$W(\text{mn})$	10^7
$Z(\text{mm})$	10^6
$t\bar{t} \rightarrow (\text{m}+\text{x})$	10^5
$\tilde{g}\tilde{g}$ ($M_{\text{susy}}=1\text{TeV}$)	10^{2-3}

*useful for
commissioning!*

A Troidal LHC ApparatuS

Inner Detector ($\eta < 2.5$)

- 2T field with a solenoid magnet
- Semiconductor pixel and strip detector ($R_{\text{inner}} = 5\text{cm}$)
- Transition radiation tracker straw-tube

Muon Spectrometer ($\eta < 2.7$)

- 0.5T field (average) with air-core troidal magnet
- Precision chamber
- Trigger chamber

Calorimeter system ($\eta < 4.9$)

- EM (Liquid argon/Lead)
- HAD barrel : scintillation-tile/Iron
- bEC/Fwd : Liquid argon/copper or tungsten

Commissioning

Commissioning

Firstly, need to understand and calibrate detector, trigger and software in situ using well-known physics process.

- (e.g.)
- Drell-Yan $Z \rightarrow e\bar{e}, \mu\bar{\mu}$ for ECAL calibration, muon system alignment
 - top-pair ($b\bar{b}j\bar{j}l\nu$) for jet energy scale and b-tagging.

Expected Detector Performance

	<u>Day-0 (2007)</u>	<u>Goal for physics</u>
ECAL uniformity	~1%	<1%
Lepton energy scale	0.5-2%	0.1%
HCAL uniformity	2-3%	<1%
Jet energy scale	<10%	1%
Tracker alignment	20-200mm in rf	O(10)mm in rf

Jet Energy Scale (1)

template method

Generate template histograms smearing quark energy from W in tt events with a set of α (scale) and β (relative resolution).

Fit themplate histograms to 'data' and extract α, β with minimum χ^2 .

$$E_{\text{jet}} = a \times (E_{\text{quark}} + \text{Gaus}(0, b \times (3.8 + 0.063 \times E_{\text{quark}})))$$

$\sim 1,200$ event / 500pb^{-1}
Purity $\sim 83\%$

- a : Extracted $\sim 0.5\%$ over 50-250GeV.
- b : Need to consider jet angular resolution and energy correction between jets.

smearing	b	a
energy, angle +energy corr.	1.07 ± 0.05	0.958 ± 0.005

systematic. error

- combinatorial bkg (flat by 15-20%)
a by 1%, b by 5%(increasing)
- top mass(160-190GeV), $< 0.1\%$

Jet Energy Scale (2)

Z/g + jet balance

Use the p_T balance between Z/g and highest p_T jet.

Rate @ $10^{33} \text{cm}^{-2} \text{s}^{-1}$ for $p_T > 50 \text{ GeV}$

- $g+\text{jet} \sim 2\text{Hz}$, $Z+\text{jet} \sim 1/10\text{Hz}$

Advantage:

- Enlarged E and h reach wrt $W \rightarrow jj$
- includes 6% of b-jets
- large stats: $g+\text{jet}$ with $p_T > 20 \text{ GeV}$: $\sim 10\text{K}$ events/min. (not incl. eff. & trigger)

Difficulties:

- Easy to introduce biases via selection
- sensitivity to ISR modeling, esp at low p_T
- background to g or Z^0 can add additional bias
- p_T range covered with good statistics limited.
- Trigger issue

difficult $< 1\%$

$p_T(\text{GeV})$	20-60	60-120	>120
	0.049	0.015	0.004

Missing Transverse Energy

Need to validate Missing transverse energy : resolution, scale and tail.

Naively, MET resolution is a function of scalar pT sum(Σ/P_T).
Resolution can be checked up to $\Sigma/P_T \sim 300\text{GeV}$ with minimum bias event (depends on band width of MB trigger)

Need to validate MET at higher Σ/P_T region and check scalability.
Study with W(ln)+njets and QCD di-jet(with high Σ/P_T) are on-going.

Background Estimation using real data

SUSY inclusive search

Effective mass

0-lepton mode, $L=1\text{fb}^{-1}$

Effective mass (after bkg. subtraction)

0-lepton mode, $L=1\text{fb}^{-1}$

Result with fast simulation.
only scale is changed (slope is same).

Important to understand background scale and slope.

SM background

Typical SUSY cut

- $N_{\text{Jet}} > 3$ with $P_T^{1\text{st}} > 100\text{GeV}$, $p_T^{4\text{th}} > 50\text{GeV}$
- $\text{MET} > 100\text{GeV}$ and $\text{MET} > 0.2 \times M_{\text{eff}}$
- $S_T > 0.2$
- $N_{\text{lepton}} = 0$ or > 0

less uncertainty
from QCD

- Main background : tt, W(ln), Z(nn)+njets and multi-jets.
- 1-lepton mode is smaller rate but **less uncertainty**.
- Have to estimate background with real data and/or applying tighter cut to reduce uncertainty (calibrate MC at the same time).

tt background estimation (1)

- Select background calibration sample with low MET.
- Extrapolate into high MET signal region.
- Use semi-leptonic tt events.
- Assume b-tag is not available at the initial phase.

Top mass is reasonably

Combinatorial background ~~is not related to MET~~ estimated using sideband ($m_t = 200 \sim 260 \text{ GeV}$) is subtracted from signal region ($m_t = 140 \sim 200 \text{ GeV}$).

Missing ET distribution

(signal – sideband) normalised with event in $\text{MET} = 100 \sim 200 \text{ GeV}$.
Here SUSY contribution is small.

tt background estimation (2)

Apply estimation with top to events(tt+SUSY).

For high MET region ($\text{MET} > 500 \text{ GeV}$)

• $N_{\text{obs}}(\text{w SUSY}) = 503 \pm 22$

• $N_{\text{est}}(\text{w/o SUSY}) = 7 \pm 35$

($L = 10 \text{ fb}^{-1}$)

→ Clear excess (13s)!

Similar methods for other background (W/Z+njets and QCD) are necessary: i.e.

**Need to find a variable uncorrelated to MET
and a way to reduce contribution from others bkg.**

Z(vv)+njets background estimation

Use **W(mn)+njets** replacing $p_T(\text{mn})$ with **MET** for estimation of Z(nn)+njets background. Use fast simulation as the first step.

Selection (SUSY cut)

- $N_{\text{Jet}} > 3$ with $P_T^{1\text{st}} > 100\text{GeV}$, $p_T^{4\text{th}} > 50\text{GeV}$
- $\text{MET} > 100\text{GeV}$ and $\text{MET} > 0.2 \times \text{Meff}$
- $N_m > 0$ with $p_T(m) > 10\text{GeV}$

Normalisation

By # of events with low MET
(=100-150GeV).

Result (MET > 300GeV, 1fb⁻¹)

Z(nn)+njets : 157+/-13
Estimated : 134+/-10

Good agreement.

- The method looks promising.
- Need to consider top contribution.
- Redo full simulation data.

Discovery Potential

SUSY inclusive search

Missing E_T has excellent power to distinguish signal from SM background.

Missing E_T distribution

* background is generated by Alpgen.

SUSY standard cut

- Missing $E_T > 100\text{GeV}$
- $p_T^{1st} > 100\text{GeV}$, $p_T^{4th} > 50\text{GeV}$
- Transverse sphericity > 0.2

Missing E_T is the most powerful observable.

Better significance can be obtained optimising missing E_T cut according to SUSY mass scale.

Event Selection Optimisation

Standard SUSY selection is optimized for the best significance to see the maximum archievement. Examine the optimization on m_0 - $m_{1/2}$ plane with fixed $\tan\beta=10$, $A=0$ and $m>0$ within mSUGRA.

Following variables are tuned.

- Missing ET
- 1st jet momentum
- 4th jet momentum

$m(\tilde{c}_1^0)$ is heavier as $m_{1/2}$ becomes larger.
Then, optimal missing ET is higher.

Discovery Potential

5-sigma discovery potential on m_0 - $m_{1/2}$ plane

Fast simulation result

Signal : Isawig/Jimmy

Background : Alpgen

- Only statistical error is included.
 - Background is estimated by Alpgen.
 - 0-lepton mode : More statistics is available.
 - 1-lepton mode : Relatively smaller background uncertainty.
- Major background is $t\bar{t}(+n\text{jets})$ is comparatively predictable.

Summary

**SUSY can be discovered with $100\text{pb}^{-1} \sim 1\text{fb}^{-1}$
if SUSY mass scale around $1\sim 1.5\text{TeV}$.**

This is true only when we understand detector and background.

- **Missing transverse energy and effective mass are very important for SUSY discovery.**
- **Commissioning of MET and JES are mandatory. Need to extrapolate to high energy region. Various study is on-going.**
- **Background should be estimated with real data, especially in the early period of experiment. Most of study are quite new and need more detailed study.**

**Work in progress towards SUSY discovery
in early experimental period!**

Backup slides

Background estimation with ME

Parton Shower (PS) is used in the previous study. But PS has some problem.

- For example, Jet is emitted in top pair-production. This figure shows Pt distribution of this jet.
- Hard jet is not emitted in Parton Shower.
 - PS is not good approximation at high Pt region.
 - BG estimation using PS model is underestimated in high Pt region.

Background Generation with ME

- Generation
 1. High Pt partons are generated with ME(Alpgen)
 2. Collinear and soft regions are covered with PS(Pythia) model.
 - Pt ordering is applied.

- But, there is double counting problem.
- “Mangano Matching” is applied in order to remove double counts.

Detail is Mangano's HP
<http://mlm.home.cern.ch/mlm/>

Mangano Matching

- We applied Mangano method
- Jet should be matched to the parton generated with ME ($R=0.7$) except for the soft and collinear regions.
- For example, let's consider $Z+4\text{jets}$ sample
 - Blue show perfect matching between ME parton and jet.
 - Soft jet was emitted collinearly. $\rightarrow$ Matched (Accepted)
 - One parton divided into 2 jets. (outside ME cone 0.7) $\rightarrow$ Not Matched
 - Such event should be covered with 5jet ME. (double counting) $\rightarrow$ this event is discarded.

Smearing quarks with correlation (JES template method)

- Smearing the quark energies with the correlation, we obtain the energy resolutions in the third column
- qq mass peak width goes from 7.6 GeV to 8.7 GeV
- Using the correlation in the templates, we get

- $a = 0.958 \pm 0.005$
- $b = 1.07 \pm 0.05$

	Jet - quark	Smeared q - quark	Correlated+smeared quark - quark
$\sigma(E_1)$	10.7	11.1	11.3
$\sigma(E_2)$	9.1	8.1(*)	8.2
$\sigma(E_1) \oplus \sigma(E_2)$	14.0	13.7	14.0
$\sigma(E_1+E_2)$	16.5	14.1	17.1

JES by g + jet (QCD di-jet background)

Default cuts: S/B~10%
Efficiency $\gamma \sim 90\%$

Optimised cuts: S/B~30%
Efficiency $\gamma \sim 15\%$

low pT sample $\langle ET \rangle \sim 30$ GeV

Mean (-0.6, 0.6) window	Cone 0.4	Cone 0.7	kT
Signal	$-13 \pm 0.8\%$	$2 \pm 0.9\%$	$1 \pm 0.9\%$
Background	$-15 \pm 2\%$	$1 \pm 2\%$	$-1 \pm 2\%$

Data sample Athena 7.2.0 DC1 data

remaining jet background ~ 0

statistical error

tt background estimation

Validate the normalisation with higher MET event as well as non-top event (SUSY).

top sample ($p_T^{\text{top}} > 500 \text{ GeV}$)

$$\begin{aligned} N_{\text{top}} &= 50 \\ N_{\text{estimated}} &= 55 + 17 \\ (L=10\text{fb}^{-1}) \end{aligned}$$

top + SUSY ($M_{\text{SUSY}} \sim 0.7 \text{ TeV}$)
Normalisation method works.

Z($\nu\nu$)+njets background

Estimate Z(nn)+njets background is estimated **with Z(mm)+njets replacing $p_T(\text{mm})$ with MET**. Use fast simulation as the first step.

Apply SUSY cut

- $N_{\text{Jet}} > 3$ with $P_T^{1\text{st}} > 100\text{GeV}$, $p_T^{4\text{th}} > 50\text{GeV}$
- $\text{MET} > 100\text{GeV}$ and $\text{MET} > 0.2 \times M_{\text{eff}}$
- $N_m > 1$ with $p_T(m) > 10\text{GeV}$ (for $Z \rightarrow m m$)

Normalization

- $\text{BR}(Z \rightarrow \nu\nu) \sim 6 \times \text{BR}(Z \rightarrow \mu\mu)$
- reconstruction efficiency

Reconstruction efficiency (full simulation)

MET from Z(mm)

Number of events ($\text{MET} > 300\text{GeV}$, 1fb^{-1})

Z(nn)+njets : 157 $\pm$ 13

Estimated : 142 $\pm$ 39

Good agreement, but poor statistics.

Calorimetry

The most important observable is **Missing transverse energy**, which dominantly measured by Calorimetry system.

- Coverage : $\eta < 4.9$
- Fine granurarity
- Lateral readout system

EMB-LAr

- 3-longitudinal segments
 - $dhx/df = 0.025/8 \sim 0.05$
 - $s(E)/E \sim 10\%/\sqrt{E} + 1\%$
 - $e/h \sim 1.7$
- depends on segment

HEC-LAr

- 4-longitudinal segments
- $dhx/df = 0.1, 0.2$
- $s(E)/E \sim 70\%/\sqrt{E} + 5\%$
- $e/h \sim 1.5$

HB-Tile

- 3-longitudinal segments
- $dhx/df = 0.1, 0.2$
- $s(E)/E \sim 50\%/\sqrt{E} + 5\%$
- $e/h \sim 1.4$