SUSY physics with early data

Understanding ATLAS detector and backgrounds

PHYSICS AT LHC 3-8 July 2006 in Cracow Poland

on behalf of the ATLAS Collaboration

(Special thanks to ATLAS SUSY WG)

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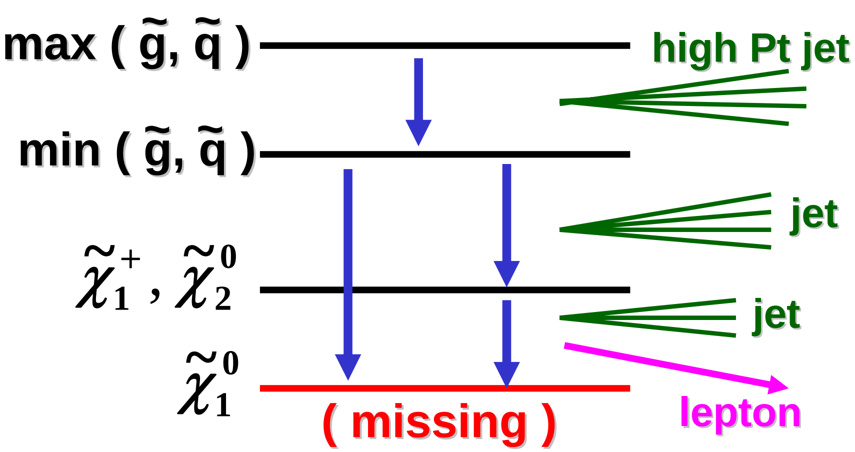
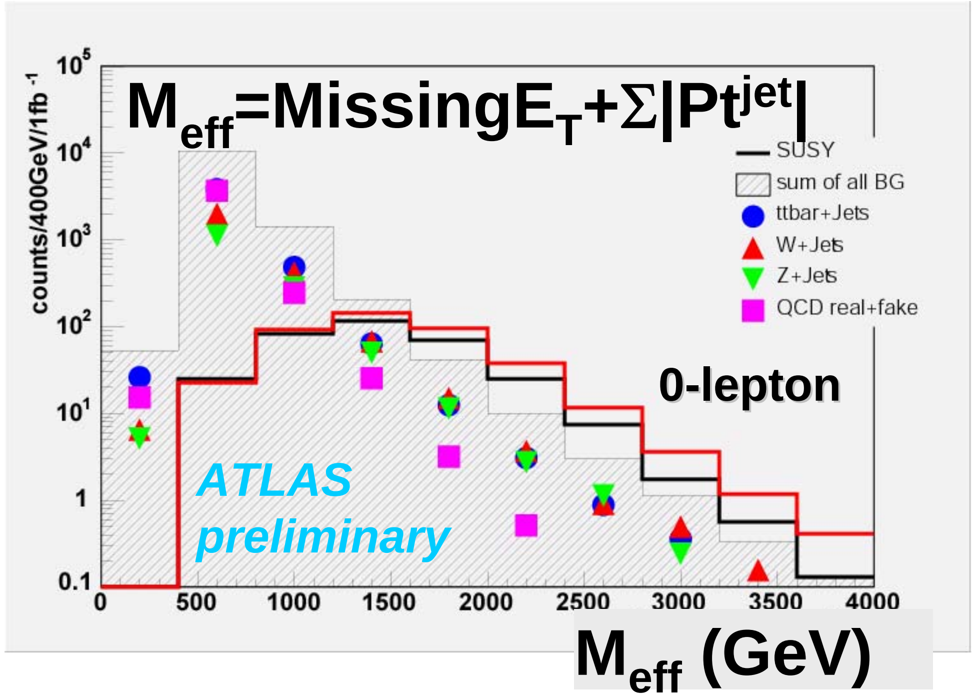
KEK

SUSY signature at LHC

Colored sparticle pair-productions dominate at LHC





In most cases, SUSY signature is characterised by
Missing E_T + mutli-jets (+lepton) final state.

M_{eff} correlates to M_{SUSY}(=min($m_{\tilde{q}}$,$m_{\tilde{g}}$)) and σ(SUSY)

Important to understand
Missing E_T and high-multiplicity jets SM background

Outline

1. ATLAS detector
   + Commissioning

2. BG estimation using matrix element calculation + real data

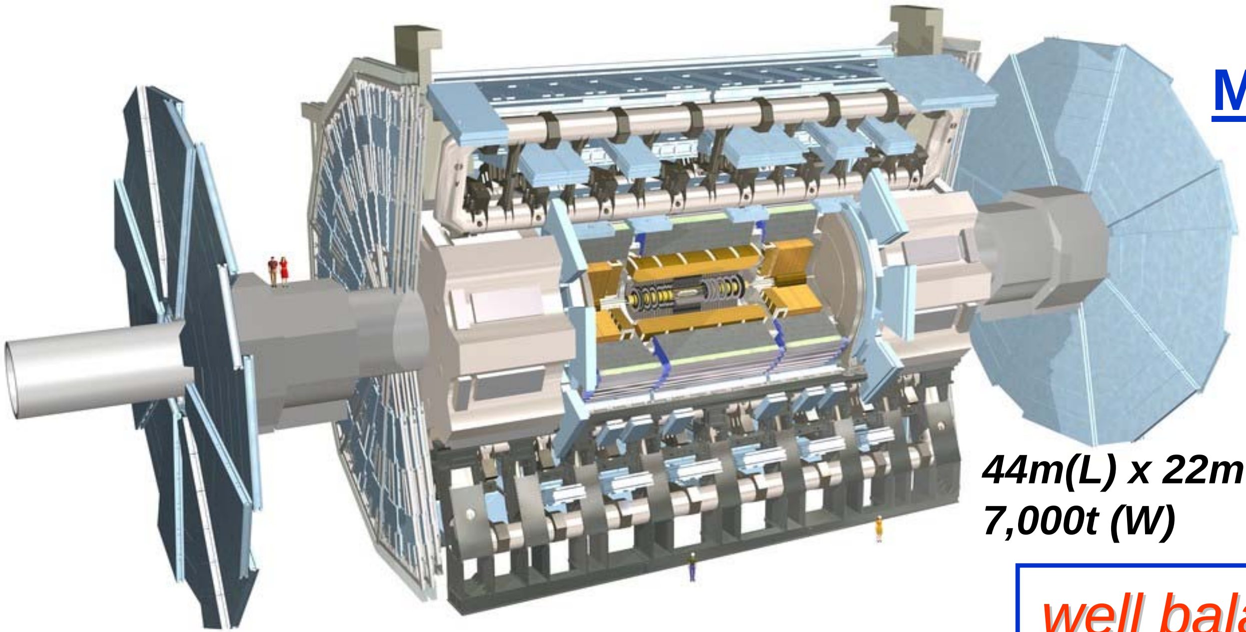
3. SUSY discovery potential

1. ATLAS detector + Commissioning

A Troidal LHC ApparatuS

Inner Detector (|eta|<2.5)

- 2T field with a solenoid magnet
- Semiconductor pixel/strip detectors, Transition radiation tracker straw-tube
- ~4% momentum resolution for 100GeV charged track



Muon Spectrometer (|eta|<2.7)

- 0.5T field with air-core troidal magnet
- Precision and Trigger chambers
- ~2% momentum resolution

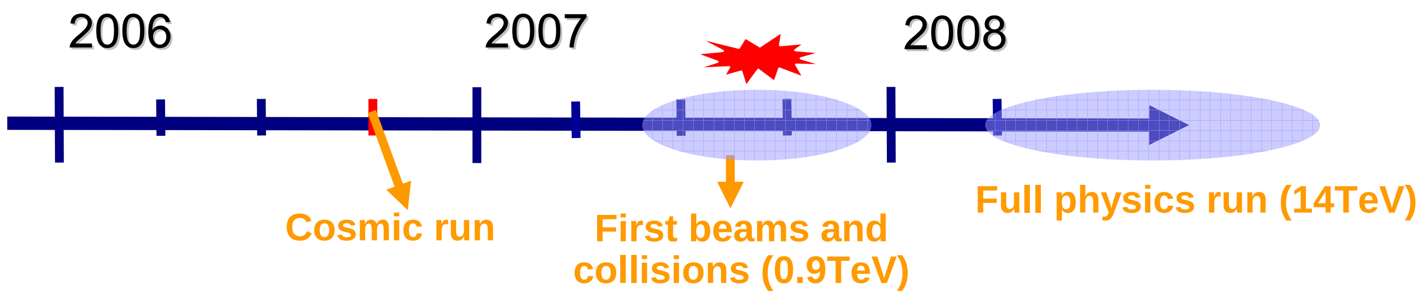
44m(L) x 22m (D)
7,000t (W)

well balanced detector systems,
good performance and large coverage
*for **e, γ, μ, jet** and **Missing E_T***
measurement

Calorimeter system (|eta|<4.9)

- EM : Liquid argon/Lead
- HAD barrel : scintillation-tile/Iron
- EC/Fwd : Liquid argon/copper or tangsten
- 1.5% for e/γ, 8% for hadron jet at 100GeV

Commissioning



In commissioning, need to understand and calibrate detectors
- Do the 'in situ' calibration using well-known physics process
- Transport well-calibrated EM scale to Hadronic scale

- Drell-Yan Z(→ ee, μμ) for ECAL calibration / Muon system alignment
- Top-pair (bjj+blν) for jet energy scale and b-tagging

Expected Detector Performancec

	Day-0	Goal for physics
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 rϕ	O(10)mm in rϕ

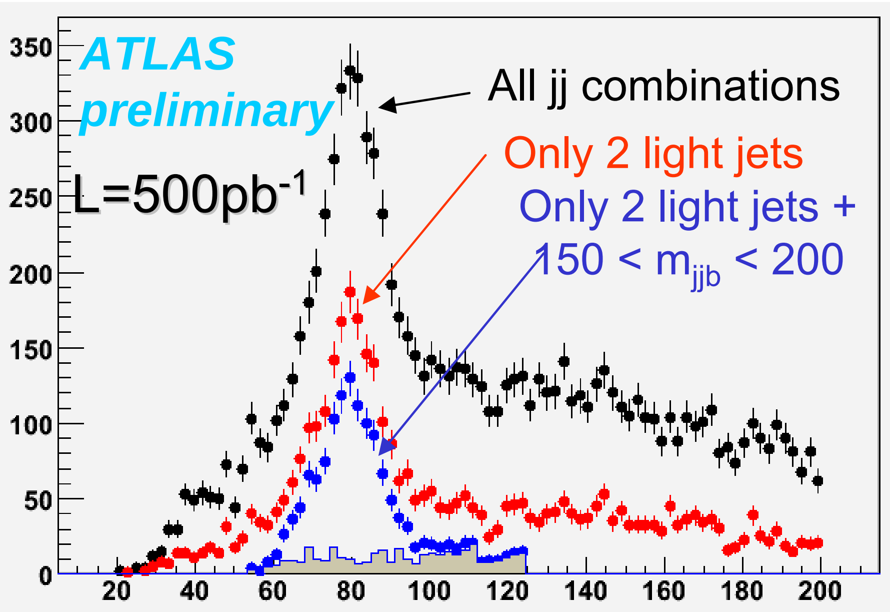
Jet Energy Scale (method 1)

template method (a la CDF)

Generate template histograms of ($W \rightarrow qq$ in $t\bar{t}$ events) and smear the quark energy with α (scale) and β (relative resolution)

$$E_{jet} = \alpha \times [\, E_{quark} + \mathrm{Gaus}(0, \beta\, \sigma(E_{quark}))\,]$$

Fit template histograms to 'real data' and extract α, β



~1200 event / 500pb^{-1}
Purity ~ 83%

- α : precision ~0.5% over 50-250GeV.
- β : Need to consider jet angular resolution and energy correction between jets.

smearing	β	α
energy,angle +energy corr.	1.07+/-0.05	0.958+/-0.005

systematic. error
- combinatorial bkg (flat by 15-20%) α ~ 1%, β ~ 5%(increasing)
- top mass(160-190GeV) < 0.1%

Good energy scale calibration is available even at early stage

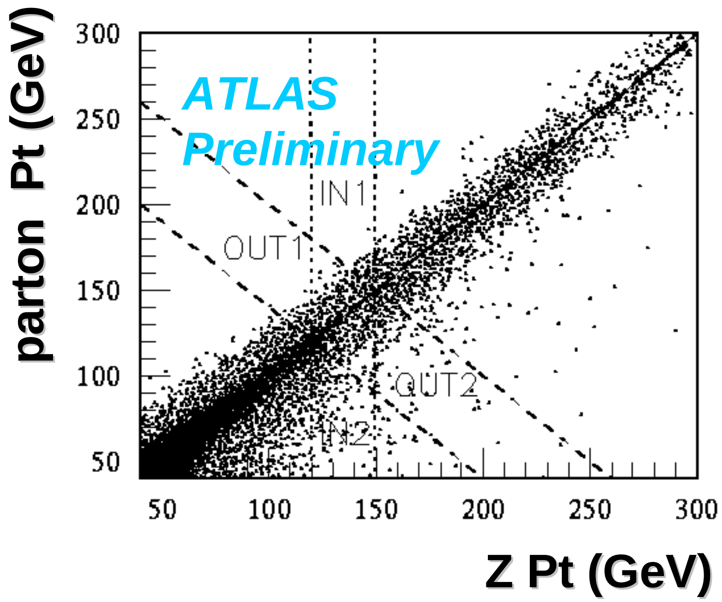
Jet Energy Scale (method 2)

Z (or γ) + jet balance

Use well calibrated EM objects, balancing the recoiling hadronic system

Large stats. available: @$10^{33}cm^{-2}s^{-1}$

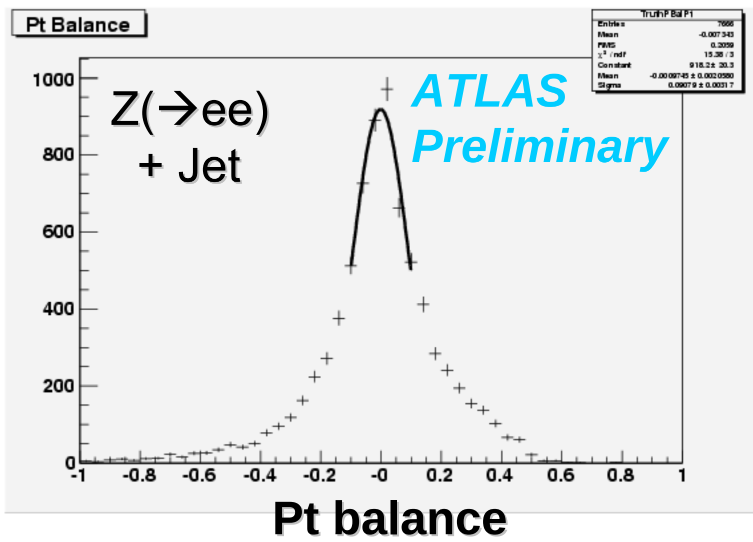
γ+jets ~ 2Hz, Z+jets~0.1Hz (for Pt > 60 GeV)



Pt balance = (Pt jet – Pt Z) / Pt Z
selecting events with only 1 jet

Advantage compared to ***W→jj*** :

- enlarged *Et* and η reach
- allow b-jet calibration as well (5% stats.)



Issues:

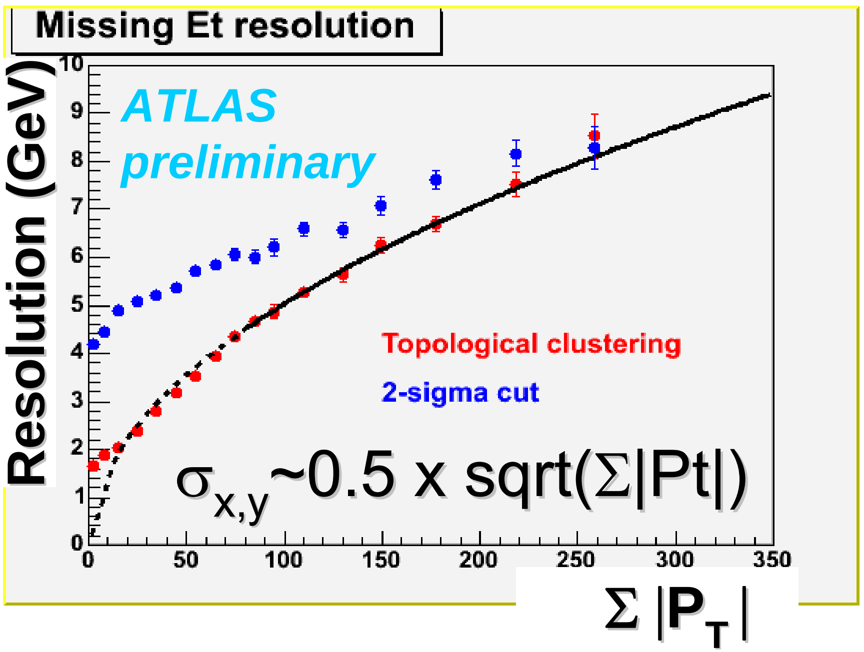
- ISR/FSR effects: multi-jets background
- hard to achieve <1% in lower Pt(Jet)

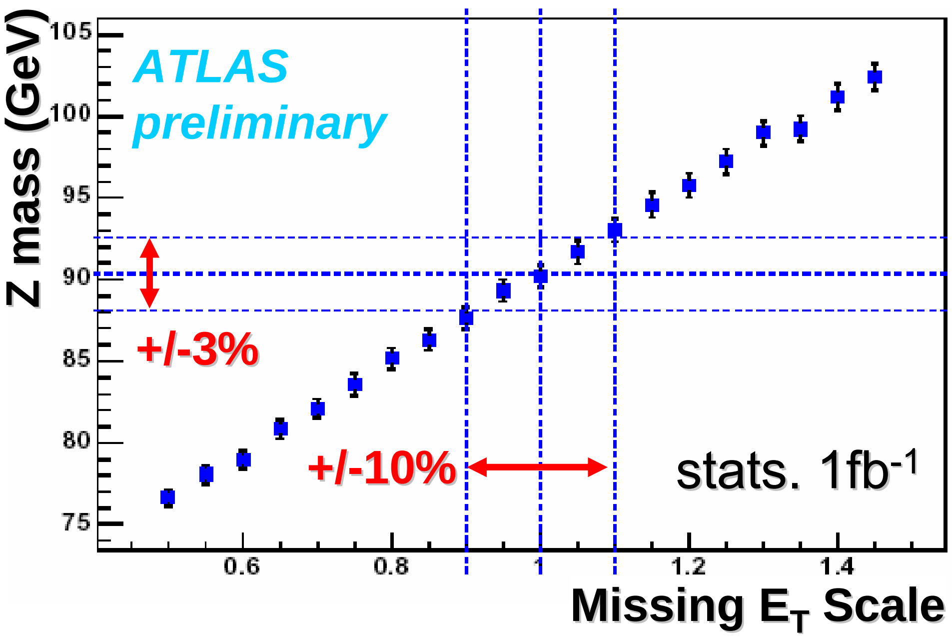
Missing E_T

using Minimum bias / $Z\rightarrow\tau\tau$ data

Validation of the Missing E_T **resolution** and **scale** at commissioning

- Resolution can be checked with minimum bias events (depends on MB trigger width)
- Scale calibration possible using $Z\tau\tau$ (lept+had decay) process $m_{\tau\tau}$ reconstruction





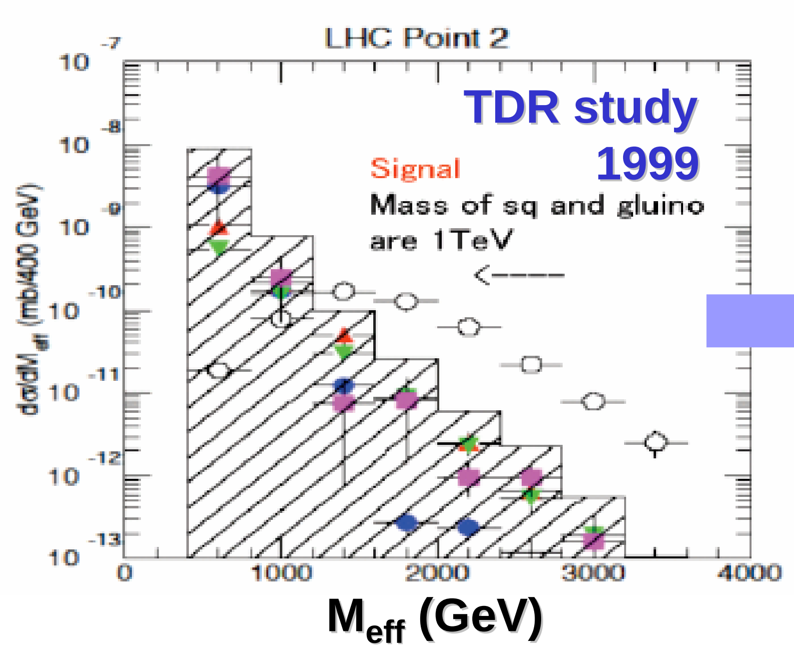
(Resolution) Noise-suppression scheme works, need validations at higher $\Sigma|Pt|$
(Study with W(lν) and QCD di-jets are on-going)

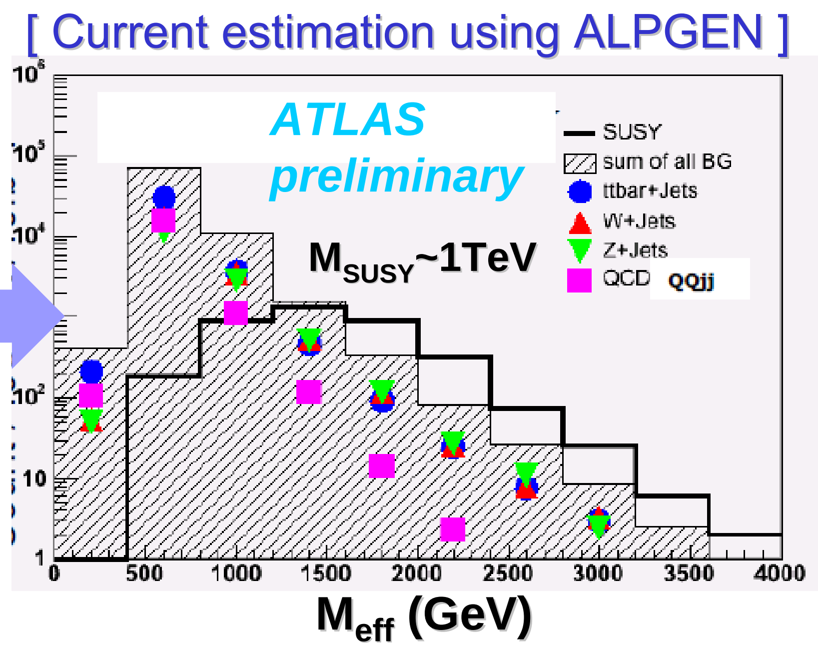
(Scale) Z mass +/-3% corresponds to 10% in Missing E_T scale, need a detailed background study

2. Background Estimation using matrix element + real data

Background estimation with matrix element (ME)

- Parton shower (PS) jets have been used to estimate SUSY background in ATLAS TDR
  - PS is a good approximation in collinear region
  - However PS cannot emit the hard jet → underestimate for BG
  - The matching of the **soft region (PS)** and the **hard region (ME)** for more realistic estimation **(ALPGEN)**





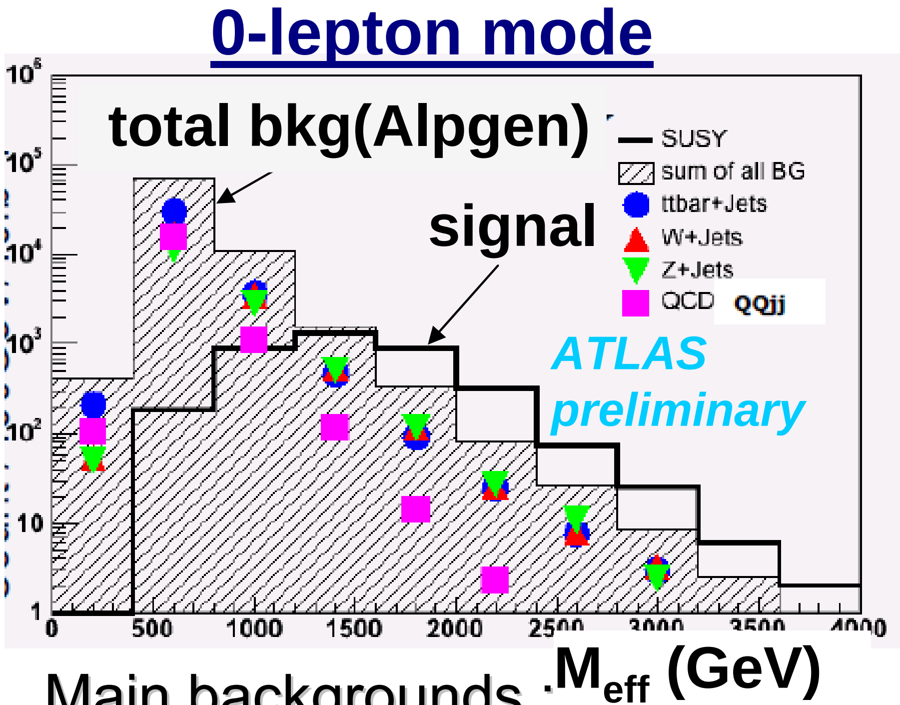
Background estimation increased by about 2-5 times

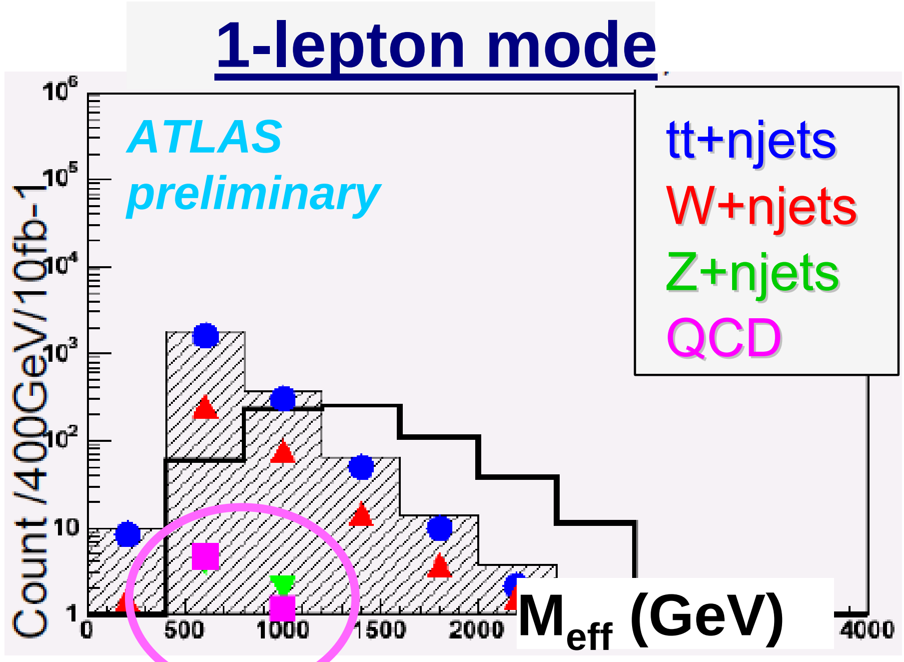
SM backgrounds

Typical SUSY cut

- N_{Jet}>=4 (P_T^{1st}>100GeV, p_T^{4th}>50GeV)
- MET>100GeV and MET>0.2xMeff
- S_T>0.2

Understand the contribution of the SM backgrounds





Main backgrounds :

$t\bar{t}$, W(l ν), Z(νν)+njets **and** ***QCD multi-jets***

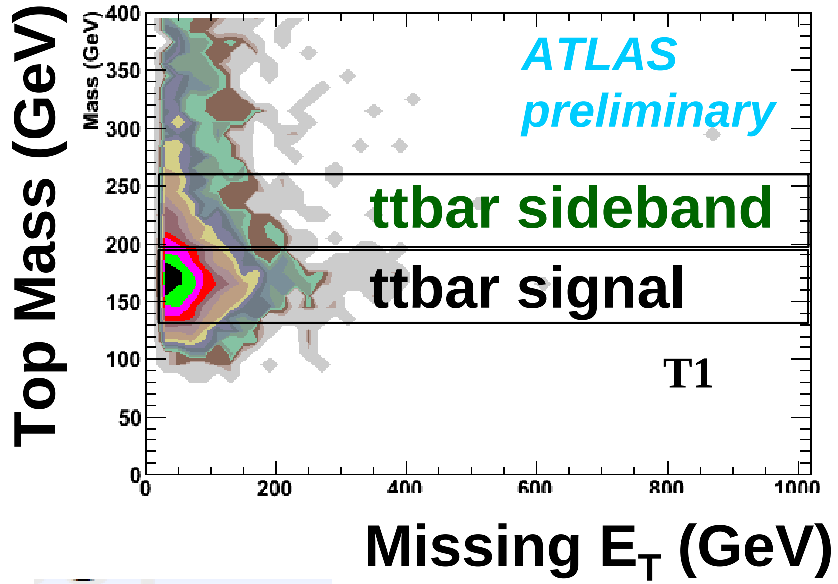
1-lepton mode : better S/B

$t\bar{t}$+njets, W+njets become dominant bkg (similar event topology to SUSY) understanding of ***$t\bar{t}$*** background is the highest priority

$t\bar{t}$ background estimation (1)

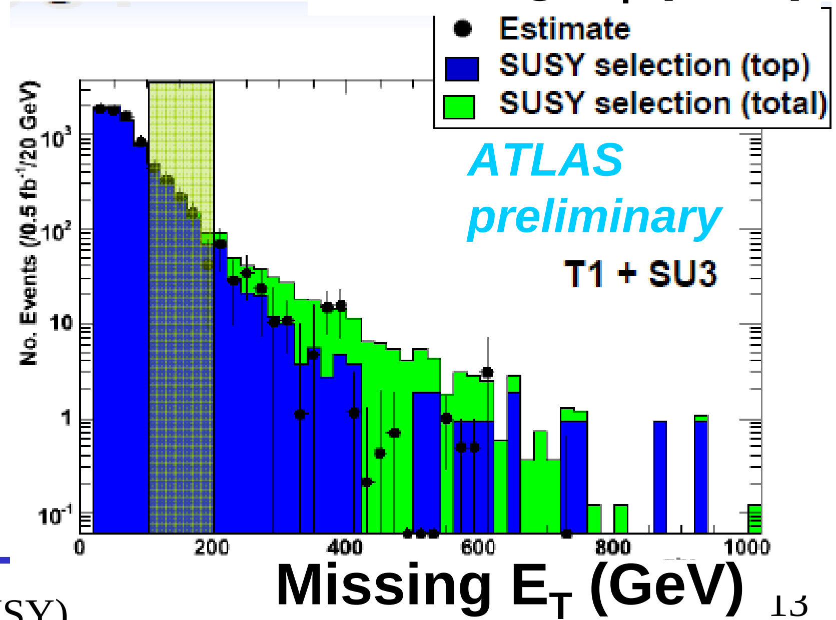
- Estimating top background from 'real data' is the first priority
- Idea is to find a variable uncorrelated to Missing E_T
  make control sample at lower Missing E_T
  → extrapolate it to higher Missing E_T

Top mass is reasonably uncorrelated to Missing E_T can be used to isolate top sample



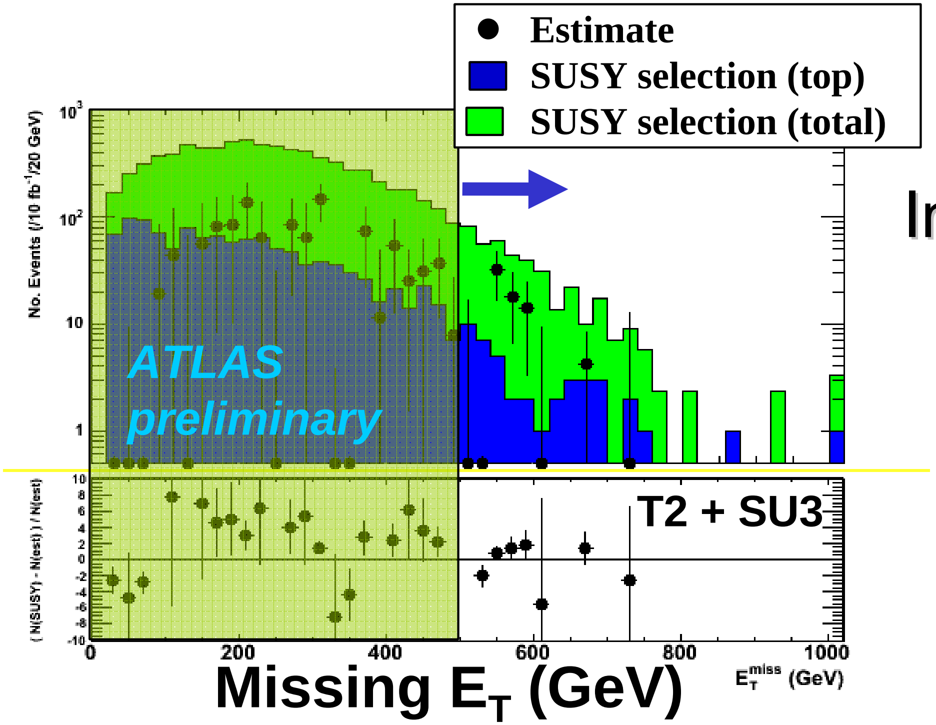
- Select semi-leptonic top candidates
- Using early data: no b-tagging available
  Combinatorial background estimated from the sideband (M_{top}=200-260GeV)

- Control sample (ttbar signal – sideband) is normalized to data using low Missing E_T region where SUSY contribution is small



$t\bar{t}$ background estimation (2)

Estimating the precision with1 year statistics at low lumi. (10fb^{-1})
[using high Pt validation sample (top Pt>500GeV)]



In high Missing E_T region (>500GeV)

- N_{obs}(w SUSY) = 503 ±22
- $N_{estimation}$ (w/o SUSY) = 7 ± 35

→ **Clear excesss (13σ)!**
the method proved to be valid

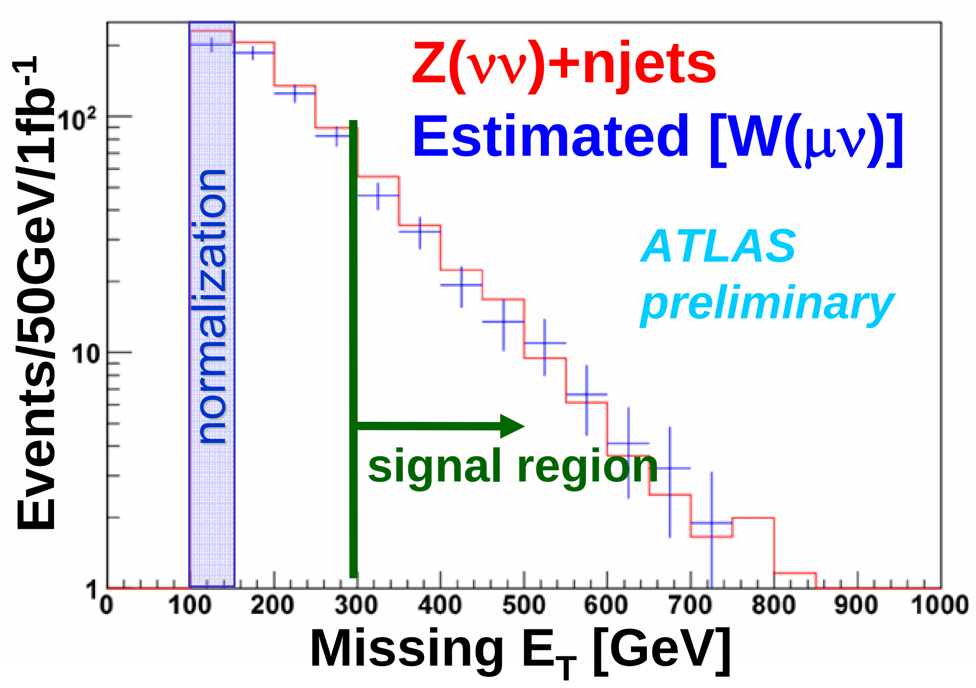
Estimating the top bkg from 'real data' looks promising
How about the other background sources?

Z(νν)+njets background estimation

Estimate the Z(νν) background esp. in high Missing E_T region

Use W(μν)+njets sample, replacing Pt (μν) with Missing E_T

(same kinematics to Z(νν), 10 times larger σ than Drell-Yan)



SUSY cut

- N_{Jet}>=4 (P_T^{1st}>100GeV, p_T^{4th}>50GeV)
- MET>100GeV and MET>0.2xMeff
- Nμ>0 with Pt(μ)>10GeV

Normalization

low Missing E_T region (=100-150GeV)

Result (Missing E_T>300GeV, $1fb^{-1}$)

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

Good agreement

- The method looks promising
- W(μν) needs discrimination from the top events

other backgrounds w/o mass peak

Need to find the second variable which is uncorrelated to Missing E_T

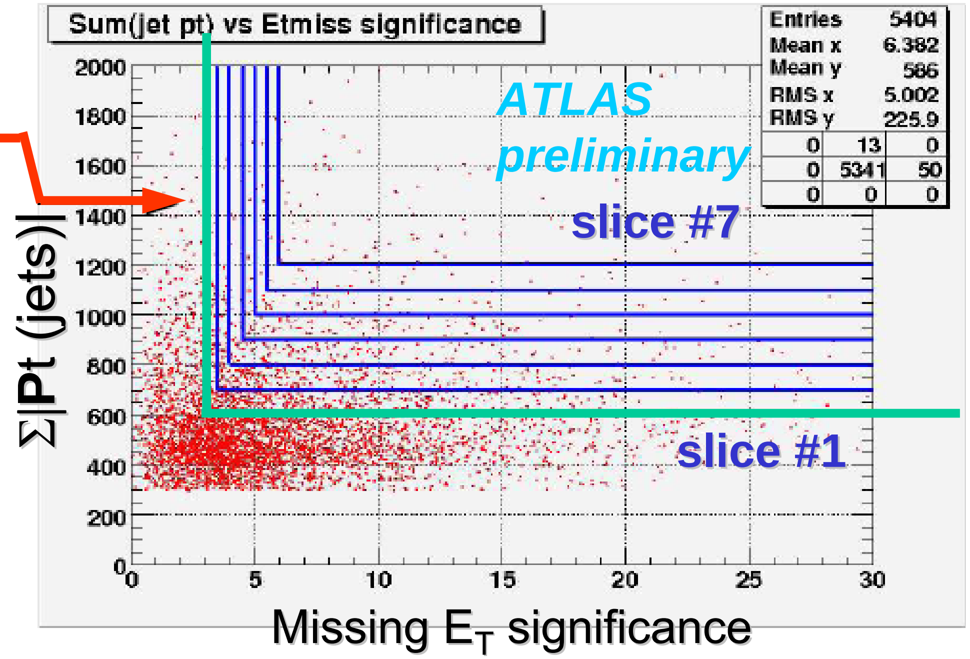
Σ|Pt (jets)| (scalar sum over 4 highest Pt jets) is one candidate

Estimate backgrounds in blinded signal region using only the data outside the signal region

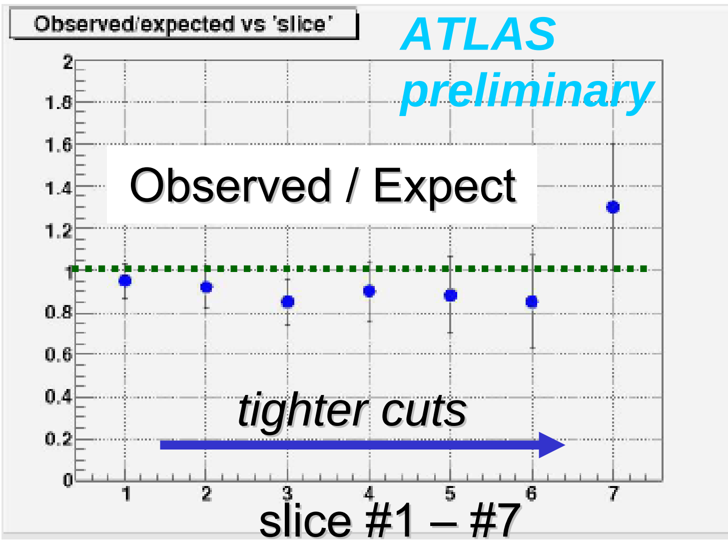
W+njets background full simulation

Define a series of cut contours

Predict the number of events that fall inside each contour, based on the events outside the loosest contour



(cut range : 3.0 – 6.0)



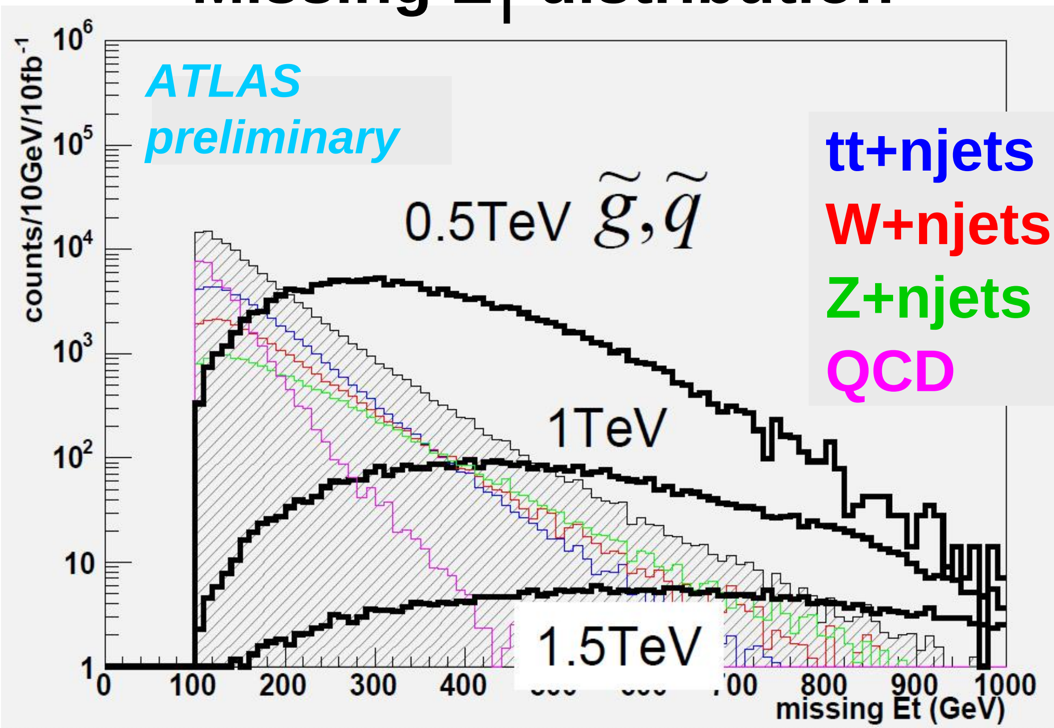
- This technique proved to be feasible
- The same approaches are possible for Z(νν), ttbar, QCD multi-jets background
- need further investigations

3. Discovery Potential

SUSY inclusive search

Missing E_T has an excellent discrimination power of signal from SM background

Missing E_T distribution



background is estimated with ALPGEN

Standard SUSY cut

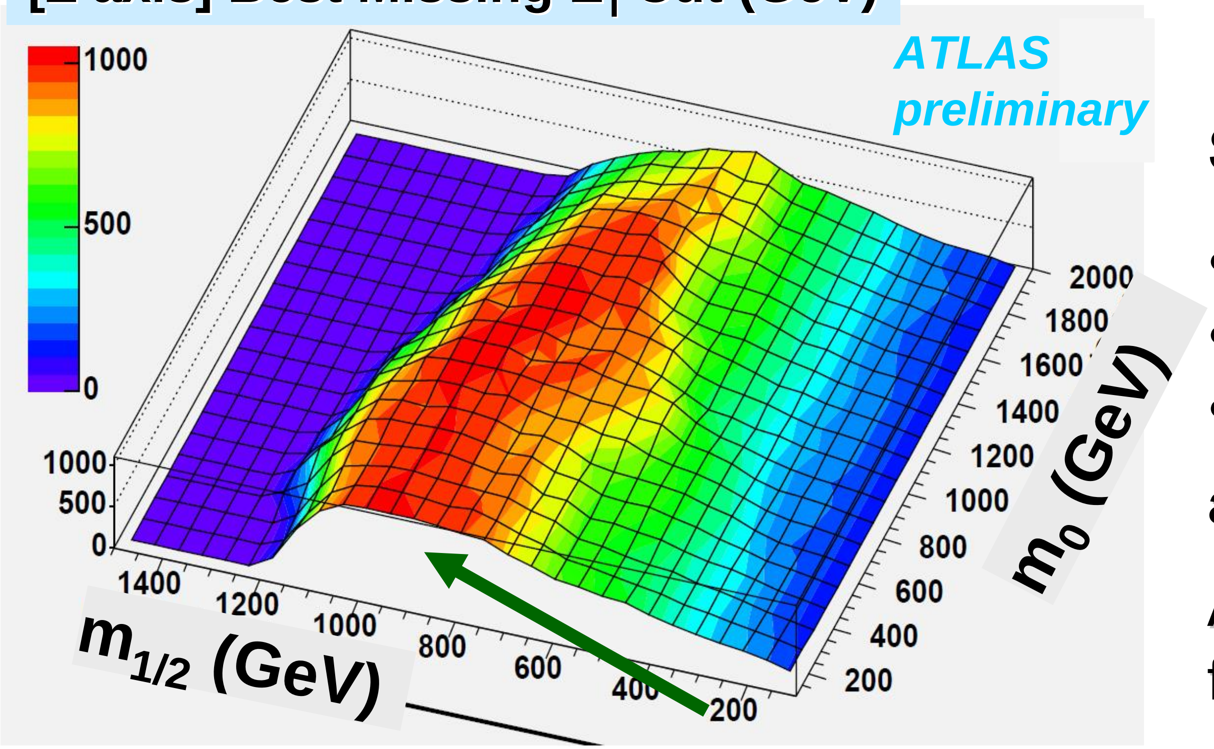
- Missing E_T > 100GeV
- p_T^{1st}>100GeV, p_T^{4th}>50GeV
- Transverse sphericity>0.2

Better signal significance can be achieved by optimising missing E_T cut, depending on the SUSY mass scale

SUSY Cut Optimization

- Scan through the mSUGRA parameter grid ($m_{1/2}$, m_0 plane)
- Optimize the SUSY cut to maximize the signal significance
- Fixed parameters: $\tan\beta$ = 10, A=0, μ>0

[Z axis] Best Missing E_T Cut (GeV)



Similarly tunes for,

- the best **1st jet energy** cut
- the best **2nd jet energy** cut
- the best **4th jet energy** cut

also carried out simultaneously

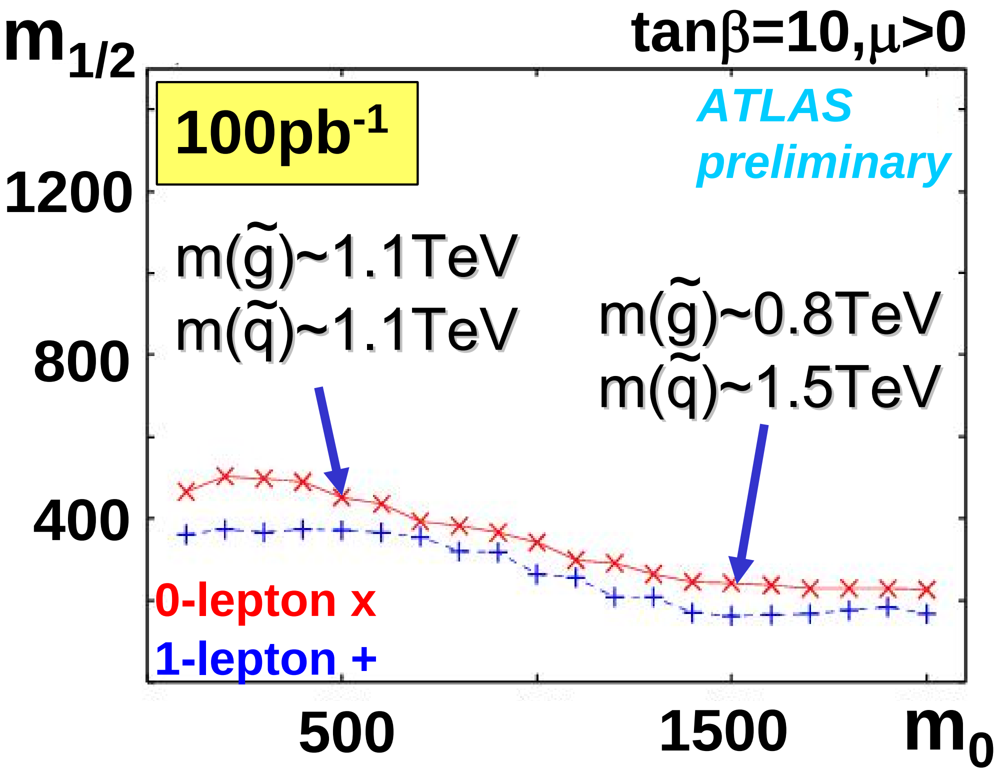
Achieve the optimal SUSY cut for each grid point

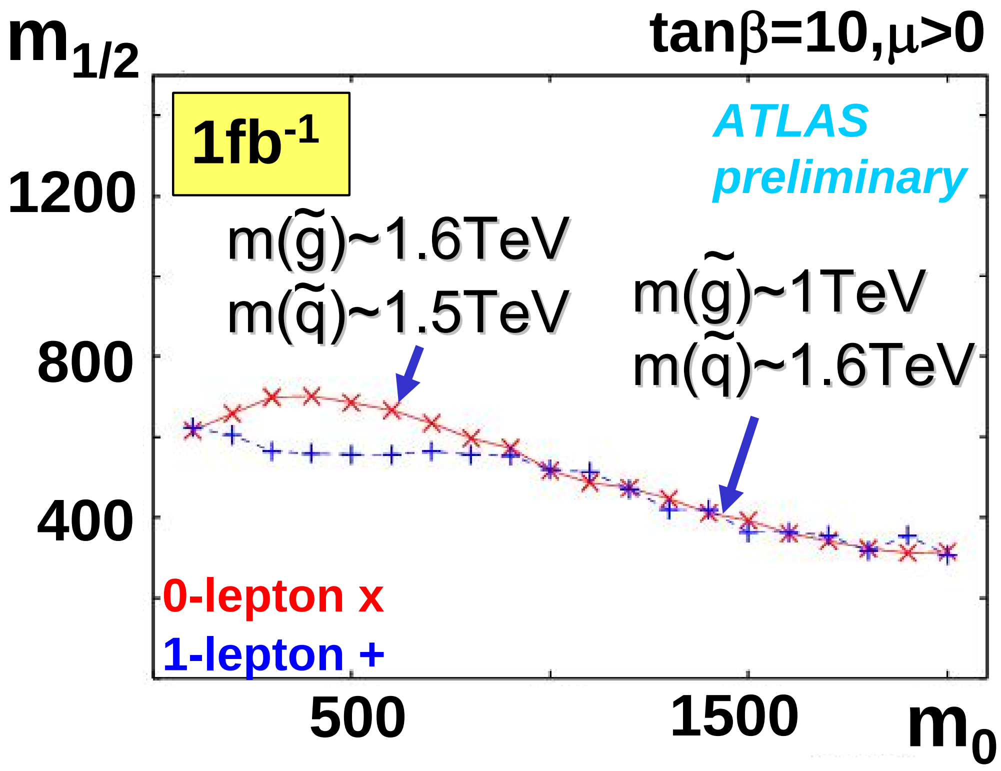
$m(\chi^0_1)$ (~$0.4m_{1/2}$) is heavier, thus optimal missing E_T becomes higher (less sensitive to M_0)

Discovery Potential

Fast simulation result
Signal : Isawig/Jimmy

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





- Background is re-examined by Matrix Element calc (ALPGEN)
- 0-lepton mode : More statistics is available
- 1-lepton mode : smaller systematic uncertainty

The discovery potential for the early data M_{SUSY}<1.1TeV at L=100pb^{-1}
M_{SUSY}<1.5TeV at L=1fb^{-1}

Summary

- ATLAS starts data taking very shortly
  first collisions at 2007, full physics run from 2008 –
- Commissioning of Missing E_T and Jet Energy Scale calibration is the key for the SUSY discovery in the early stage
  - Various studies are on-going, these look to be promising
- Background estimation using real data is necessary
  - Various ideas have been examined, they are feasible using early data
  - Need detailed studies using state-of-the-art MC with realistic conditions
- Expected potential for the SUSY discovery reach is re-examined with new background estimation and cut optimization
  - $L=100\ pb^{-1}$ $M_{SUSY} \sim 1.1TeV$
  - $L=1\ fb^{-1}$ $M_{SUSY} \sim 1.5TeV$

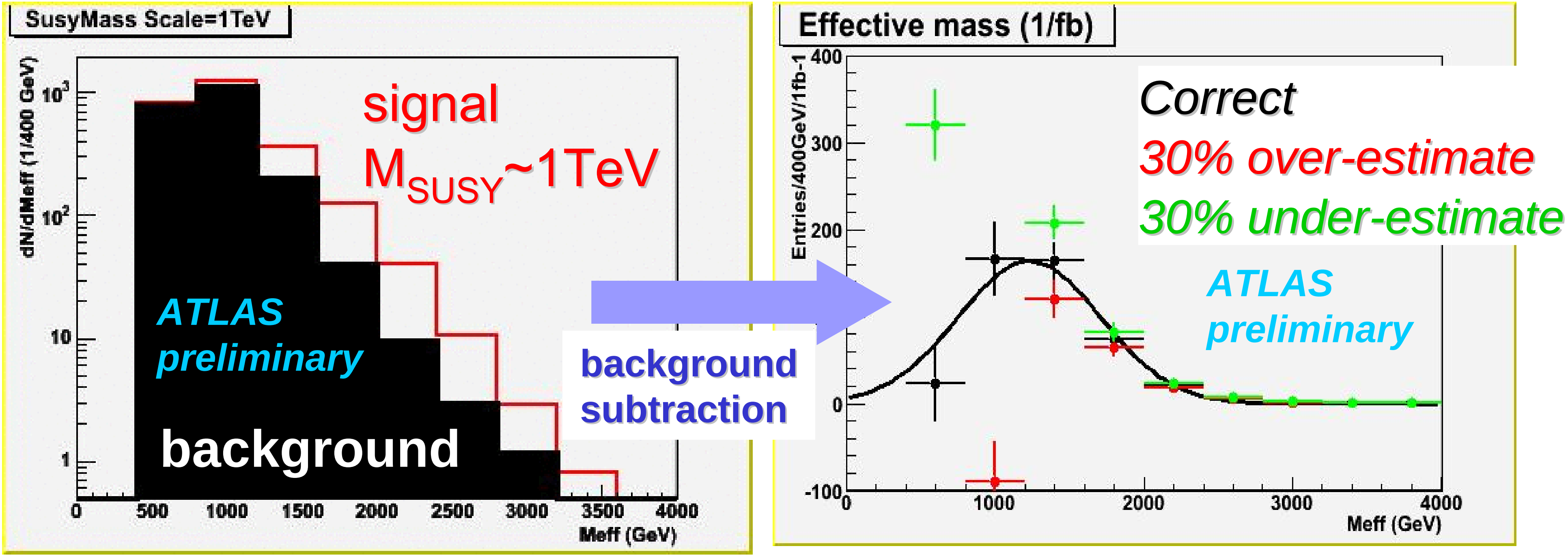
We have a good discovery potential with early data of 2008
It is extremely important to estimate the BG and understand the detector using the real data

backup …

Impact of the background estimation

SUSY inclusive search at $L=1fb^{-1}$

Effective mass 0-lepton mode



Result with fast simulation.

only scale is changed (slope is fixed)

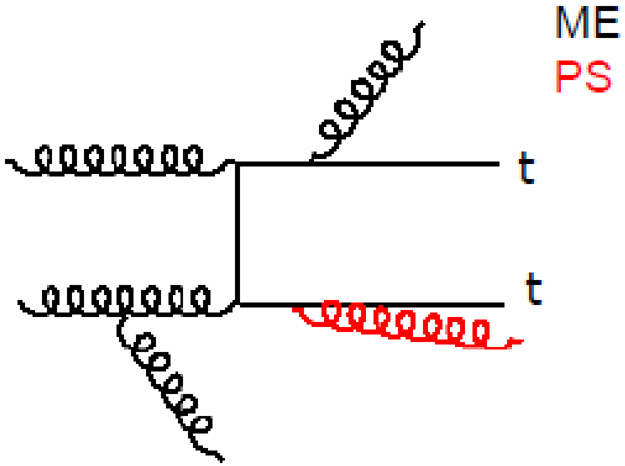
<u>Significant impact on the SUSY discovery study</u>

Also understanding the **scale** and **slope** of the SM background is important for M_{SUSY} determination

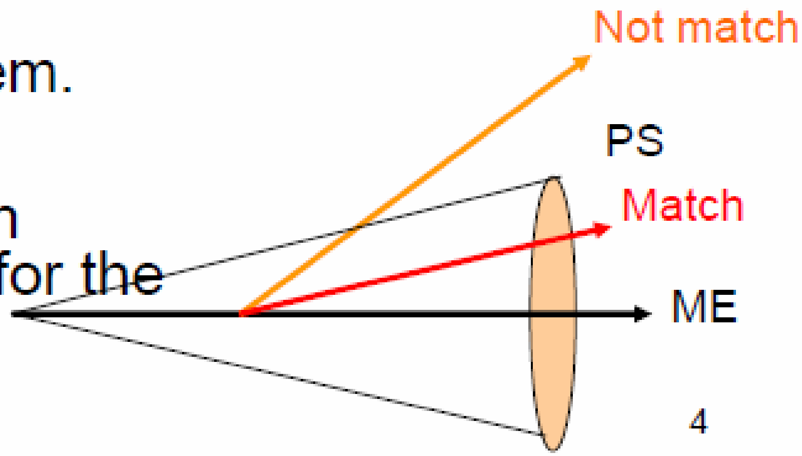
background sample generation using ME

Generation

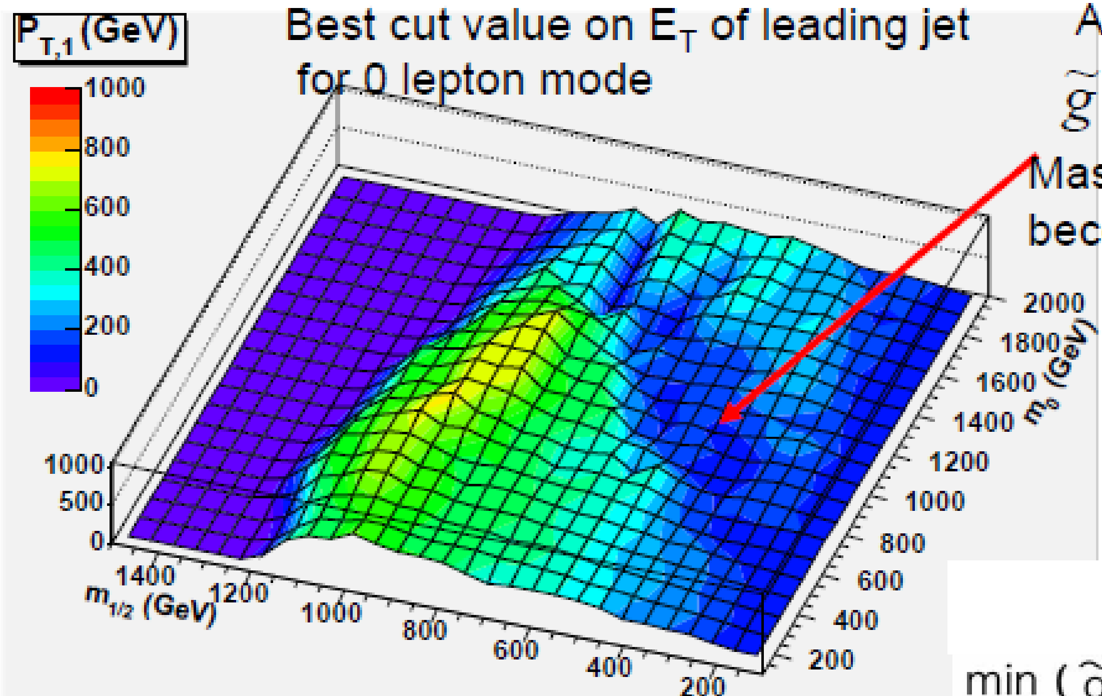
1. High Pt partons are generated with ME(Alpgen 1.33).
2. Collinear and soft regions are covered with PS(Pythia) .



But, there is double counting problem.
I applied Mangano matching.
Jet should be matched to the parton generated with ME (R=0.7) except for the soft and collinear regions.



optimization on the leading jet Pt



A dip is observed.

$\tilde{g}$ decay via $\tilde{t}$

Mass difference between $\tilde{t}$ and $\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}$ become small.

E_T of leading jet become small.

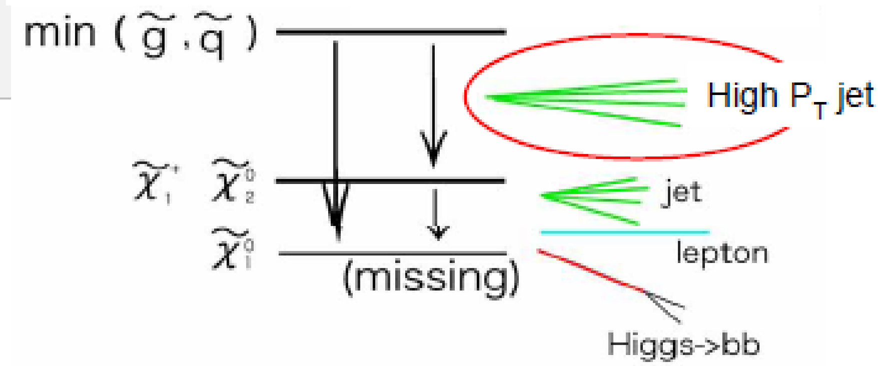
Large E_T can not be required in this region.

Mass difference between $\tilde{g}$ and $\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}$ is about $2m_{1/2}$

Mass difference between $\tilde{q}$ and $\tilde{\chi}_2^0, \tilde{\chi}_1^{\pm}$ is about $\sqrt{m_0^2 + 6m_{1/2}^2} - 0.8m_{1/2}$

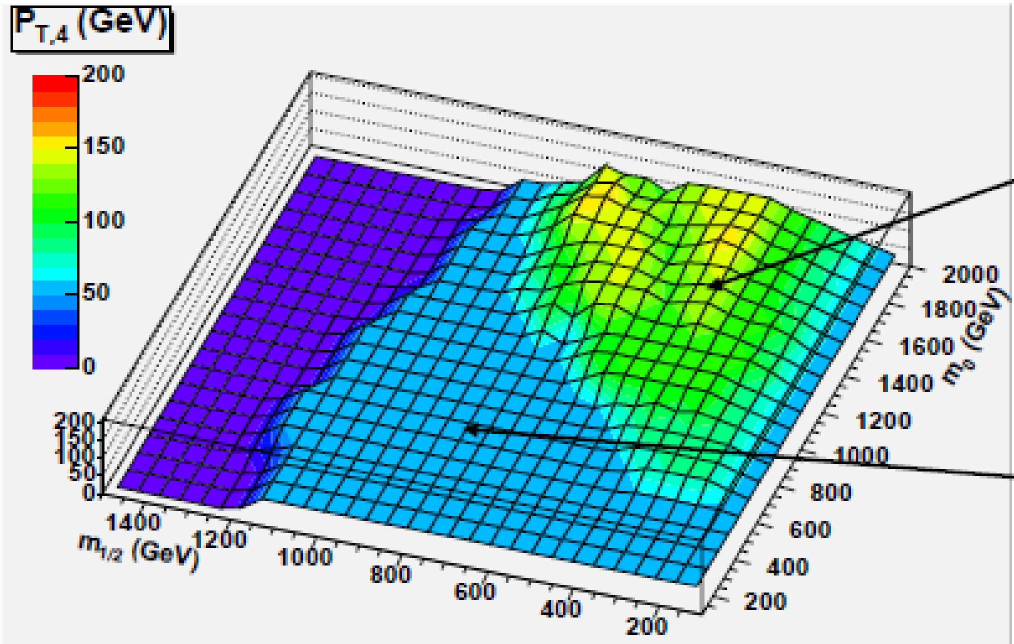
Hard jet is emitted in large $m_{1/2}$resigon.

Then cut value become large.



optimization on the 4th jet Pt

Best cut value on E_T of 4th jet
for 0 lepton mode



Parameter space divide into 2 region.

Mainly $\tilde{g}$ is produced.

$\tilde{g} \rightarrow q\bar{q}\tilde{\chi}$

2jets

Event topology become 4jet like.

Mainly $\tilde{q}$ is produced.

$\tilde{q} \rightarrow q\tilde{\chi}$

1jet

Event topology become 2jet like.

Cut value strongly relate to event topology of SUSY.

Expected event rates ($10^{33} cm^{-2}s^{-1}$)

Process	Events/s	Events for 10 fb^{-1}	Total statistics collected at previous machines by 2007
$W \to e\nu$	15	10^8	10^4 LEP / 10^7 Tevatron
$Z \to ee$	1.5	10^7	10^7 LEP
$t\bar{t}$	1	10^7	10^4 Tevatron
$b\bar{b}$	10^6	$10^{12} - 10^{13}$	10^9 Belle/BaBar ?
H m=130 GeV	0.02	10^5	?
$\tilde{g}\tilde{g}$ m= 1 TeV	0.001	10^4	---
Black holes	0.0001	10^3	---

- W,Z and Top will serve as calibration sample.
- Once running begins, systematics issues will quickly dominate over statistics