Leptons in SUSY signal

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   lepton is a crucial key for the SUSY hunting

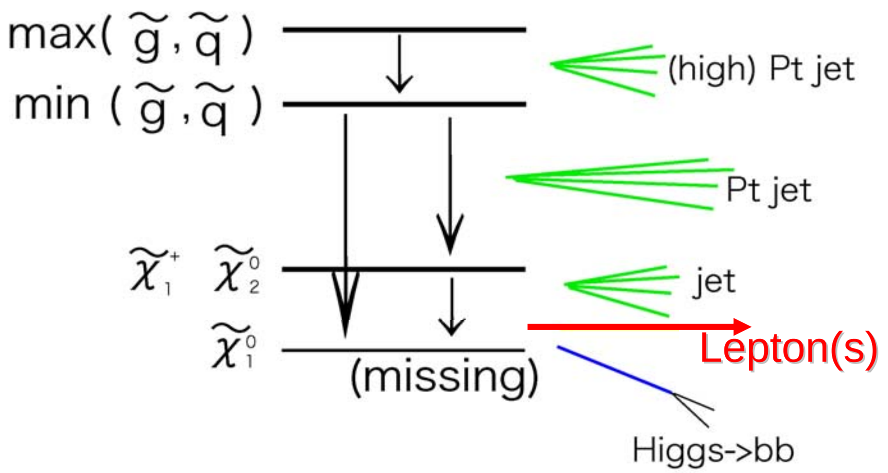
2. Study on the experimental approach for the lepton identification in ATLAS SUSY

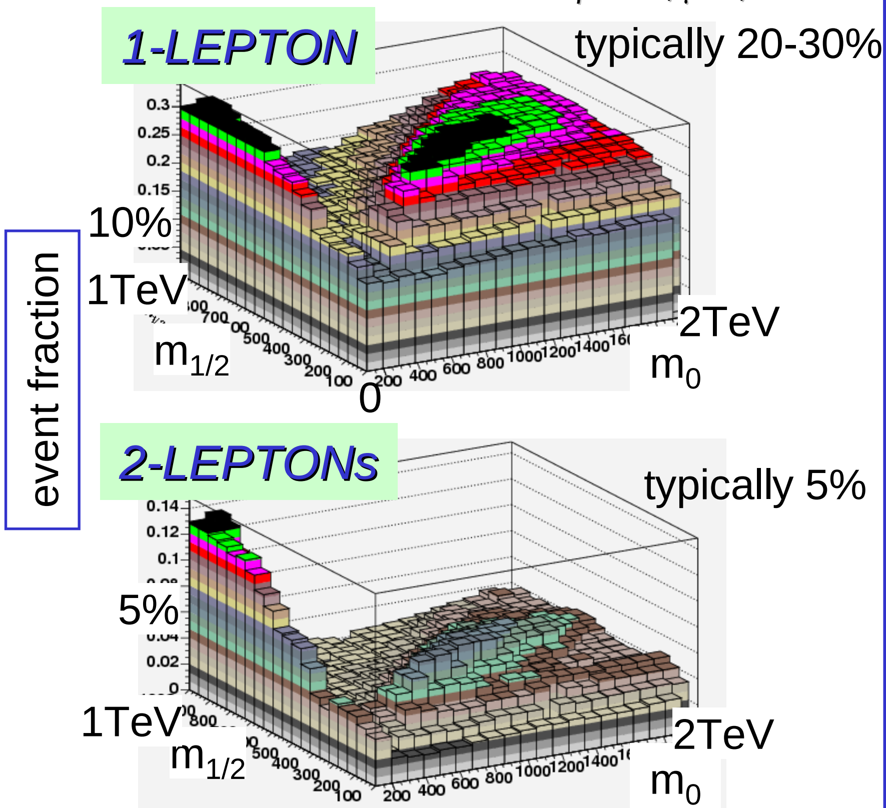
3. A potential new background source

4. Summary

Leptons in the Susy decay

Pt > 10GeV
|eta| < 2.5, effi = 0.90
tan β = 10, μ>0, A=0





In the SUSY events at LHC, strongly interacting particles (squarks, gluinos) dominates the production

Leptons are emitted from $\tilde{l}$, $\tilde{\chi}_2^0$, $\tilde{\chi}_1^{\pm}$ decays during the cascade

- Most of the mSugra parameter space, events contain lepton signatures
- At least 10% of events contain 1-lepton and at least 1% of events contain 2-leptons

Lepton signatures in different steps

Importance of lepton in SUSY study will be explained in following steps

A. Discovery → find the excess

B. Inclusive study →

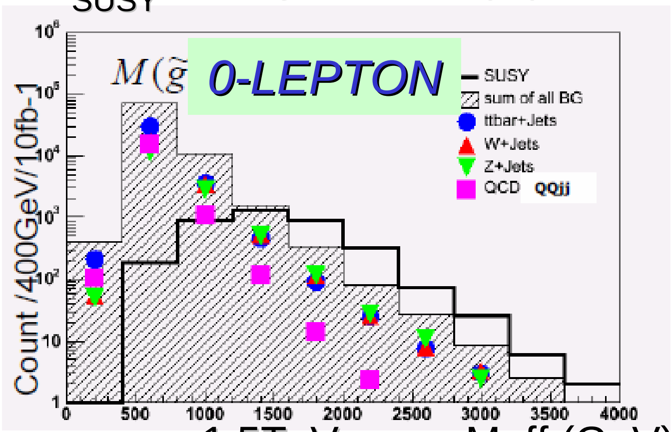
Basic parameters (M_{SUSY}, m_0, $m_{1/2}$, etc)

C. Exclusive study →

More details (SUSY particle masses, etc)

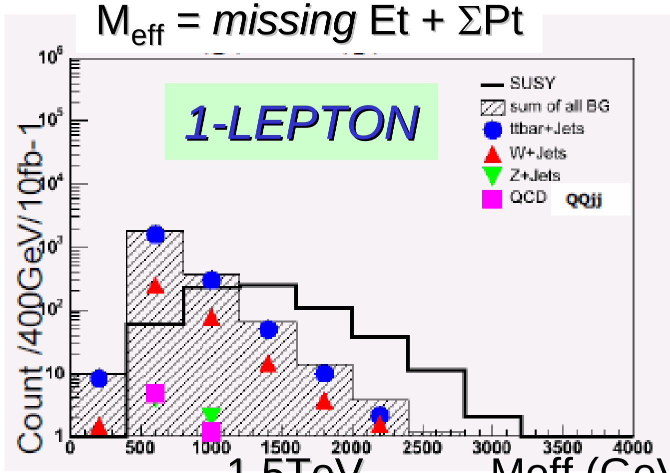
(A) SUSY discovery

M_{SUSY} = 1TeV   L=10fb^{-1}



1.5TeV   Meff (GeV)

M_{eff} = *missing* Et + ΣPt



1.5TeV   Meff (GeV)

- At the discovery stage, calculate M_{eff} (scalar sum of masses of all jets and missing Et) and look for an excess
- In no lepton mode, the background is severe and discovery is not so easy
- On the other hand in 1-lepton mode, the signal excess (in this case ~1.5TeV) becomes much clear, and backgrounds (mainly $t\bar{t}$ + Jets) are predictable
- 1-lepton mode is the key for the SUSY discovery

(B) Inclusive study

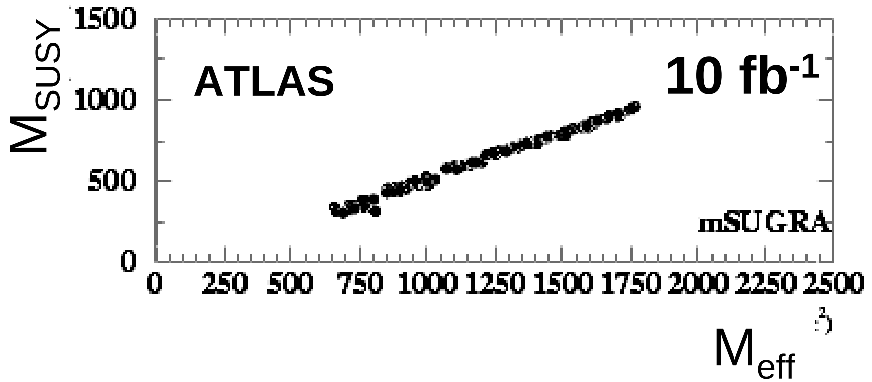
At the discovery stage, one can determine the SUSY parameters through inclusive studies

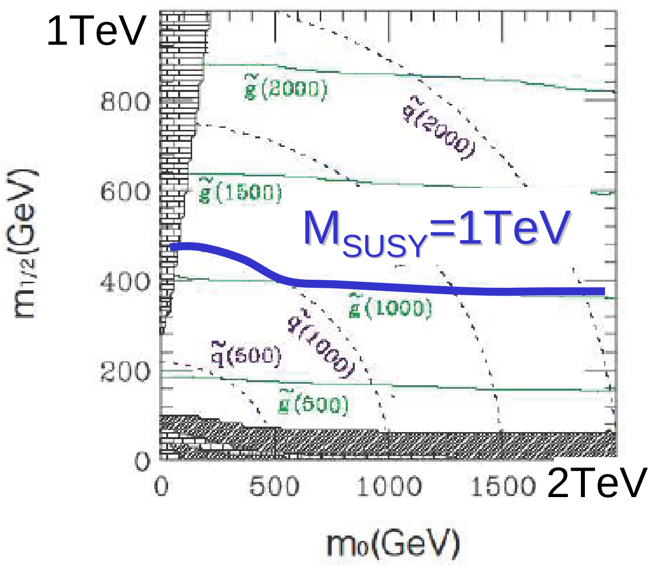
a) M_{eff}, Cross sections carry the information on the Mass scale

b) Event fraction including leptons carry the information on decay type → we can determine m_0, $m_{1/2}$ (with help of (a))

a) M_{eff} and SUSY mass scale (=M_{SUSY}) have a strong correlation, thus we can determine M_{SUSY} by measuring the position of M_{eff} excess

Determined M_{SUSY} corresponds to a line in the plane, we need information about m_0 for further constrain



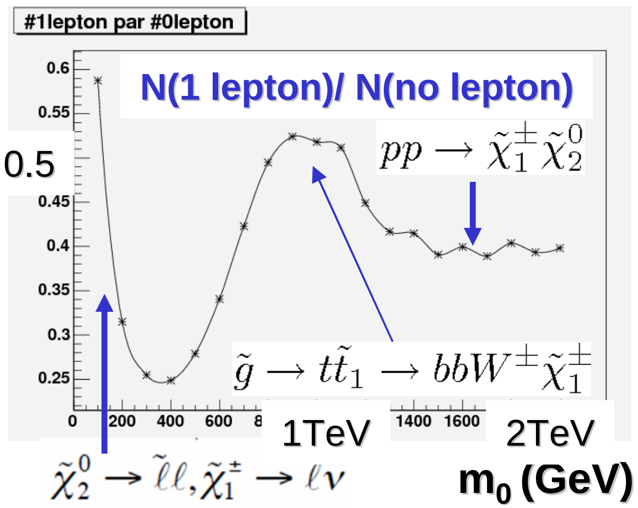


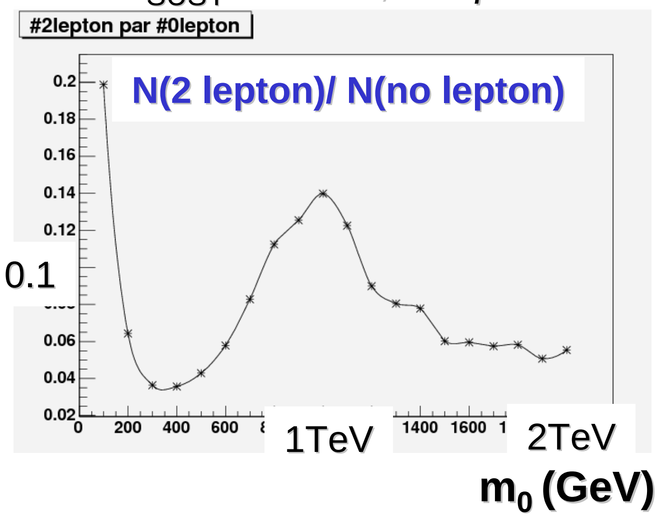
(B) Inclusive study cont.

b) Number of leptons carry the information of SUSY parameters

Measured ratio of excesses in different topologies (0-lepton, 1-lepton, 2-leptons, etc) can be compared with the calculations → information on m_0 can be obtained

M_{SUSY} = 1TeV, tan β =10





These inclusive studies strongly rely on the lepton ID performance of signal (efficiency, purity) and of backgrounds (lepton fake)

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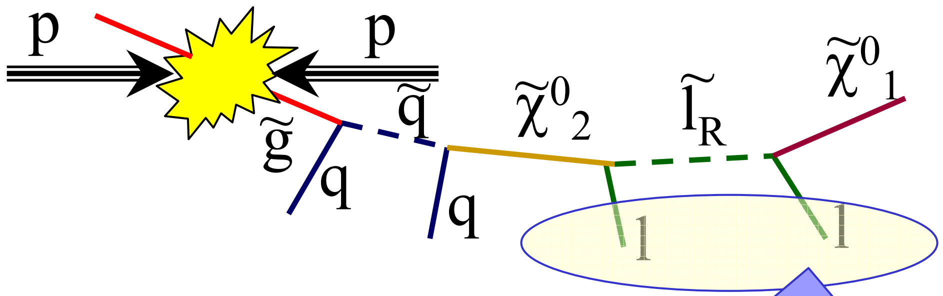
(C) Leptons in exclusive study

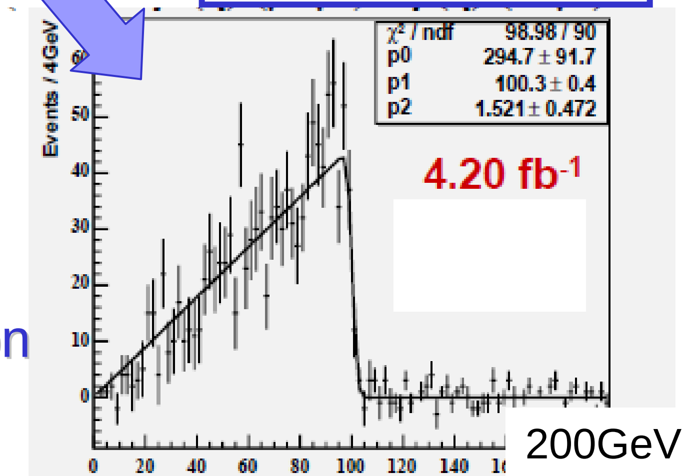
- With more luminosity and enough statistics, studies with exclusive channels become possible
- By using leptons, one can exclusively reconstruct the decay chain



- Reconstruct OS SF di-lepton invariant mass and measured the edge
- Sensitive to masses of sparticles

$$M_{\ell\ell}^{max} = M(\tilde{\chi}_2^0)\sqrt{1-\frac{M^2(\tilde{l}_R)}{M^2(\tilde{\chi}_2^0)}}\sqrt{1-\frac{M^2(\tilde{\chi}_1^0)}{M^2(\tilde{l}_R)}}$$

ATLAS Preliminary

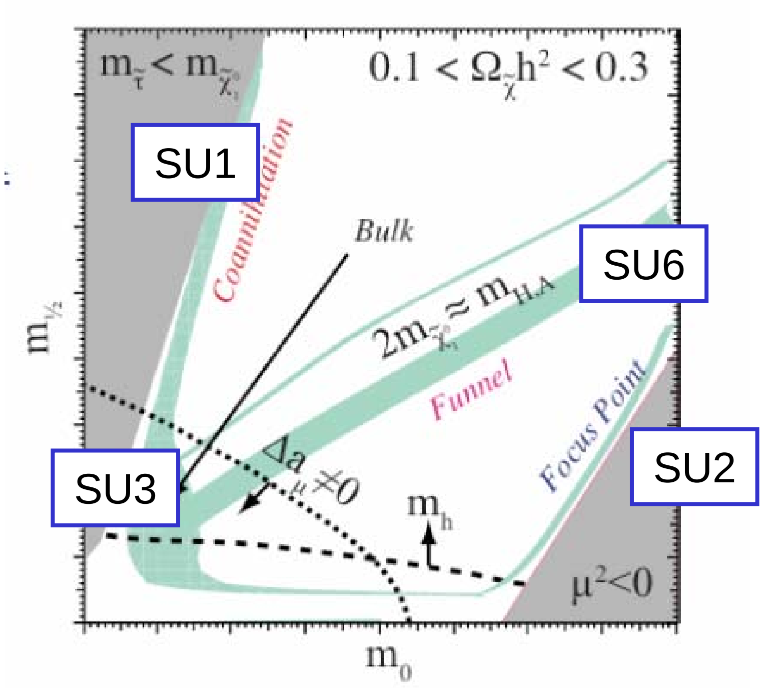


Edge = 100.3 ± 0.4 GeV

Lepton is the starting point of the reconstruction and the key for the exclusive study
correct flavor, charge tagging is important

(C) Exclusive studies in post WMAP mSUGRA points

- mSUGRA parameter space strongly constrained by WMAP satellite data ($\tilde{\chi}_1^0$ as a cold dark matter candidates)
- Reconstruction of the decay chain is possible in each mSUGRA point
- Each mSUGRA point includes lepton signatures in main decay chains
- SU3 (bulk) point will be used in later study as a typical SUSY point



SU1, SU3

two sequential two-body decays

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0\, q \rightarrow \tilde{l}_{L.R}\, l\, q \rightarrow llq\, \tilde{\chi}_1^0$$

SU2

sleptons are too heavy $\tilde{\chi}$ direct decay (three-body decays)

$$\tilde{\chi}_3^0\,,\ \tilde{\chi}_2^0 \rightarrow l\, l\, \tilde{\chi}_1^0$$

SU6

sleptons are heavier than gauginos but open channel for staus (tanβ large)

$$\tilde{q} \rightarrow q\tilde{\chi}_2^0 \rightarrow q\tau_2^{\pm}\tilde{\tau}_1^{\mp} \rightarrow q\tau_2^{\pm}\tau_1^{\mp}\tilde{\chi}_1^0$$

Tau signature is important in this point

Lepton identifications in SUSY

A. Discovery → 1-lepton mode

B. Inclusive study → M_{SUSY}, M_0, etc

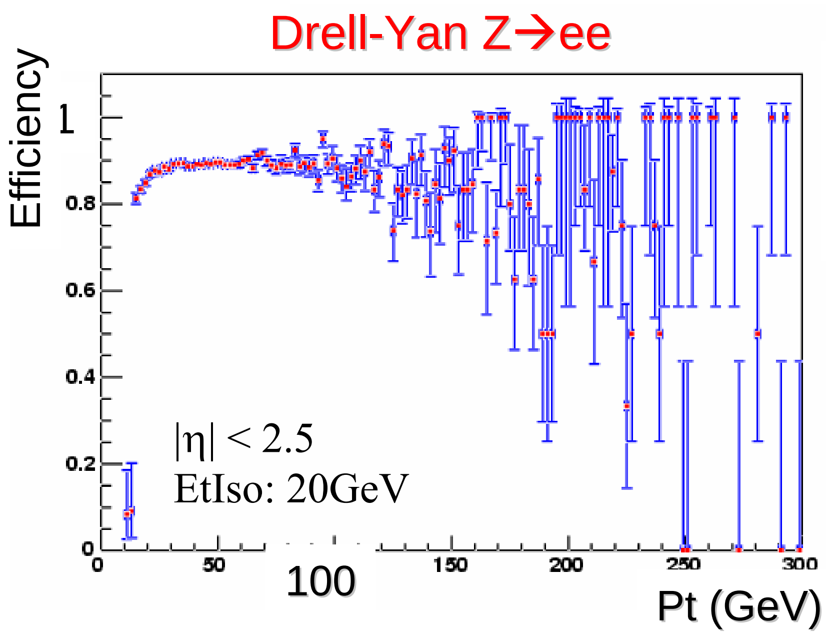
C. Exclusive study → spartilcle masses, etc

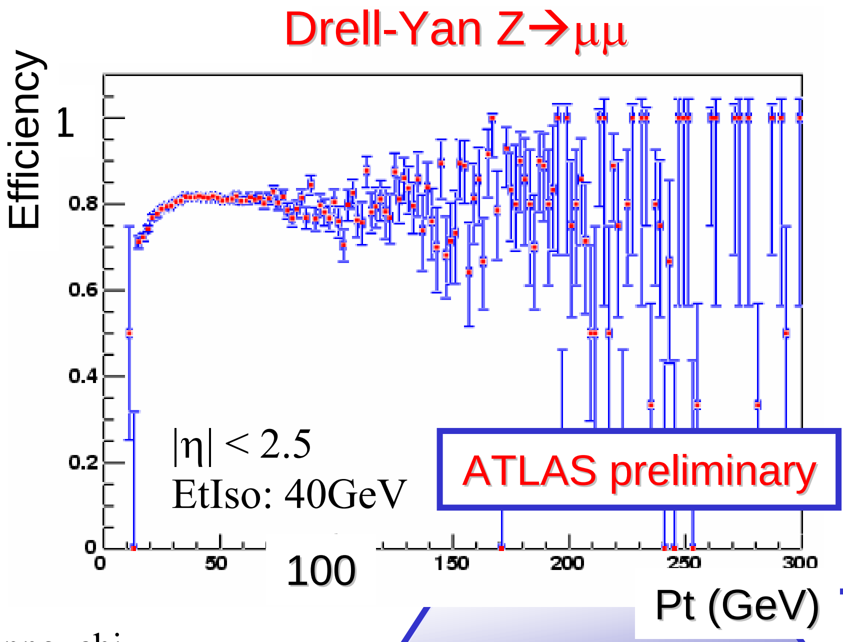
In all steps, lepton is the key

- One has to experimentally determine the lepton ID performance using good control sample (for example DY) and needs to establish the procedure to extrapolate it to ID performance in SUSY events
- However SUSY signal (with high Pt & high multiplicity jets signature) may have worse lepton ID performance than the SM samples, which will be reported later
- Need to be Quantitatively understood

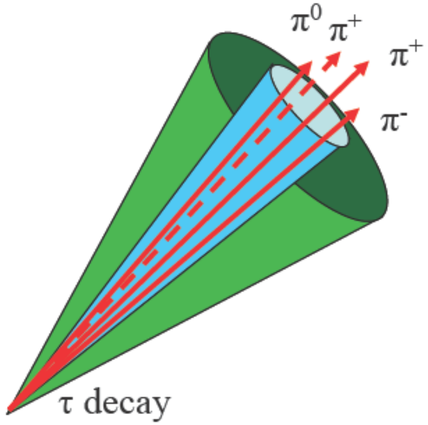
Lepton identification performance (e,μ)

- Lepton reconstruction efficiency (ε) and the lepton fake (will be explained soon) have a strong correlation, and this relation needs to be determined from real data
- These values directly depend on the lepton isolation condition
- Scalar sum of Et around lepton (δR<0.4) is used for isolation criteria
- Lepton efficiency (e, μ) in ATLAS is high (80-90%) (measurable from 10GeV, flat after quick rise)





Tau identification in ATLAS



Tau decay modes

- Use only Hadronic decay (cannot identify $\tau \rightarrow l\nu\nu$ with vertex detector)
- 1 prong 77% (one charged pion + π^0s)
- 3 prong 23% (three charged pions + π^0s)

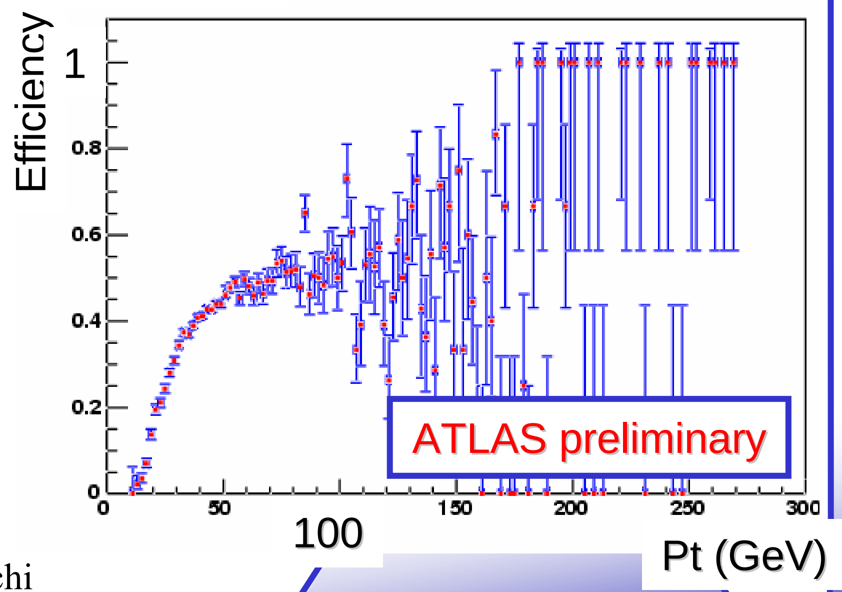
Tau candidate (hadronic) reconstruction

- Collimated Calorimeter Cluster with 1 or 3 associated charged tracks

Identification

- Look for the narrowness and Isolation
  - R_{EM}(EM jet radius)
  - Isofrac(Et fraction in 0.1<R<0.2),
  - N_{track}, Charge, Impact parameter, etc
- →One optimized Likelihood ratio value

Drell-Yan Z→ττ



QCD jet is the major backgrounds mis-identified as taus

Typically ε=40-50%, Jet Rejection ~100

Lepton fake candidates

From light flavor jets

Electrons

- Electrons from π^0 Dalitz decay
  $\pi^0 \rightarrow e\, e\, \gamma$ (1.2%)
- e^+e^- pair productions from γ

Muons

- Punch through pions
- pions decay on flight inside detector

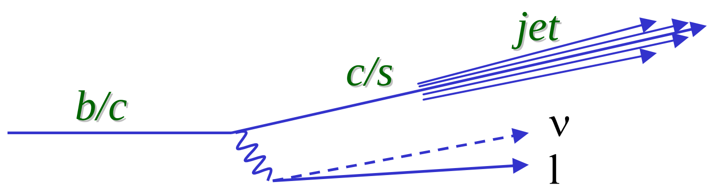
Taus

- Some fraction of jets satisfy Tau-jet criteria and identified as Taus

From heavy flavor jets

Electrons & Muons & Taus

Semi-leptonic decays of *b,c* when jets become soft, the isolated leptons are observed



Study with ATLAS simulation data

- Efficiency and fake ratio is examined with ATLAS simulation samples (100k events each)
  - [DY] Drell-Yan samples ($Z\rightarrow ee$, $Z\rightarrow \mu\mu$, $Z\rightarrow \tau\tau$)
  - [TOP] $t\bar{t}$ + Njets sample
  - [SUSY] SUSY samples – SU3 (Bulk point)
- The fake ratio (=1 - Purity)
  - fake probability (light or heavy jets → lepton) is considered to be common between different samples, however the fake ratio (fake leptons/ observed total leptons) is different in different samples
  - for example electron's case,

    [DY]ee $\langle N_{electron}\rangle = 1.7$ $\langle N_{jets}\rangle = 0.64$

    [Top] $\langle N_{electron}\rangle = 0.4$ $\langle N_{jets}\rangle = 4.2$

    [TOP] sample has 4.2/0.64 * 1.7/0.4 = ~30 higher fake ratio than [DY]ee sample (this is calculable)

Experimental procedure

Extrapolate lepton ID performance obtained with DY to SUSY, based on the amount of hadron activity

Lepton ID performance
experimentally measurable

not measurable

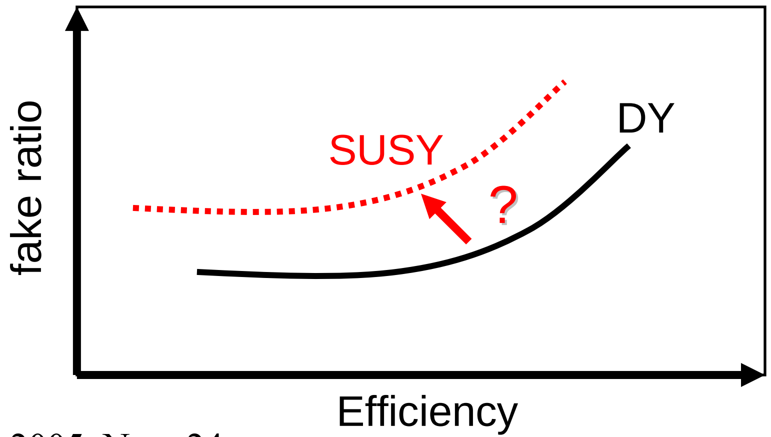
[DY] → [TOP] → extrapolate → [SUSY]

Measure

Measure & Test

Predict

[TOP] is a good test sample which has a large hadron activity and experimentally measurable

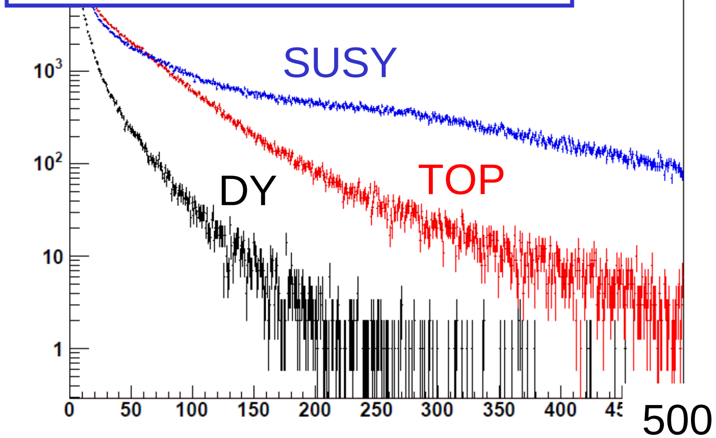


- have to decide this relations with real data

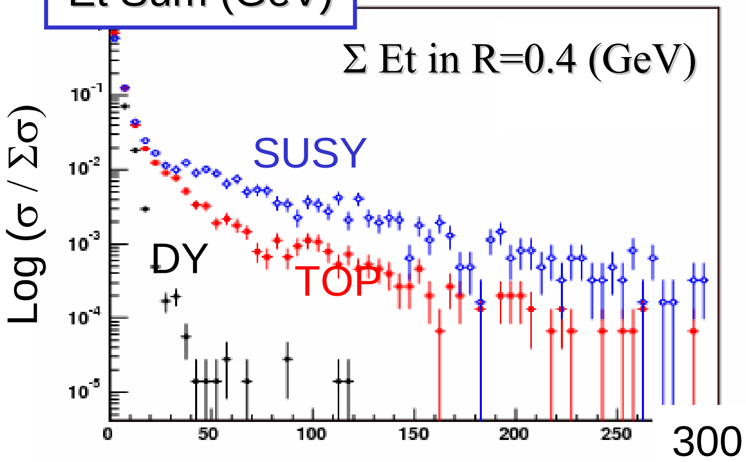
Hadron activities under SUSY environment

SUSY sample has larger tail in Jet Pt distributions also in Et sum (within cone 0.4) distribution

Pt distribution of Jets (GeV)



Et Sum (GeV)



Isolation cut at 20GeV

Electrons	DY	TOP	SUSY
Lepton EFFICIENCY	0.89	0.85	0.72
Fraction in Et Sum distribution		0.84	0.74

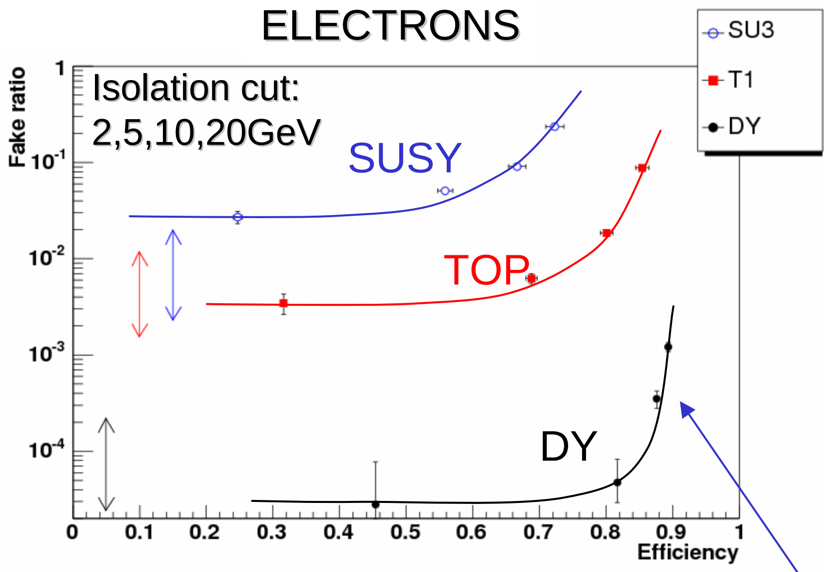
Isolation cut at 40GeV

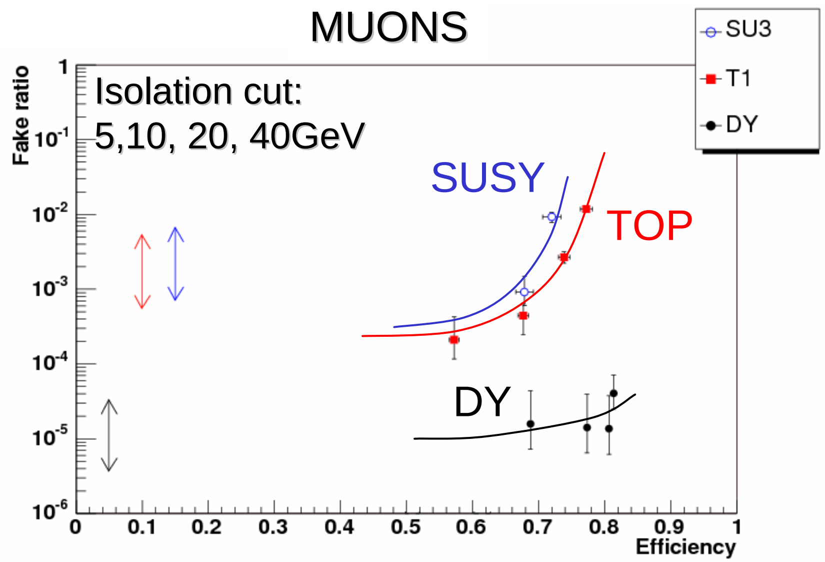
Muons	DY	TOP	SUSY
Lepton EFFICIENCY	0.81	0.77	0.72
Fraction in Et Sum distribution		0.78	0.72

Efficiency and Isolation cut efficiency completely coincide

Low efficiencies in SUSY are explained by difference in hadron activity around lepton

Fake ratio vs. efficiency from simulation





The arrows show predictions using the N_{lep} , N_j, N_b and fake probability obtained with QCD di-jets sample

start to pick up the fake events from *b/c* – jets

ATLAS preliminary

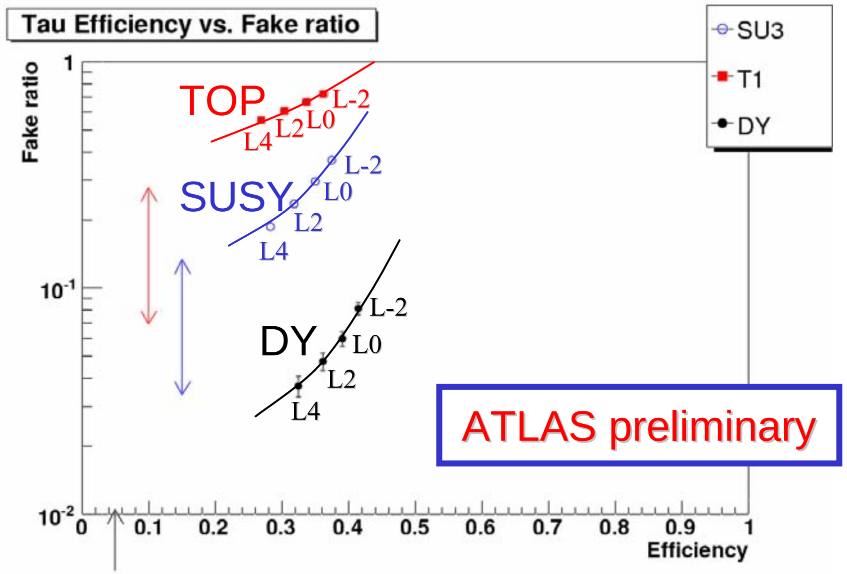
- In general, efficiencies are lower in SUSY sample than SM sample when the same isolation cut applied
  - Electrons SU3—68% DY—88% (10GeV)
  - Muons SU3—68% DY—82% (20GeV)

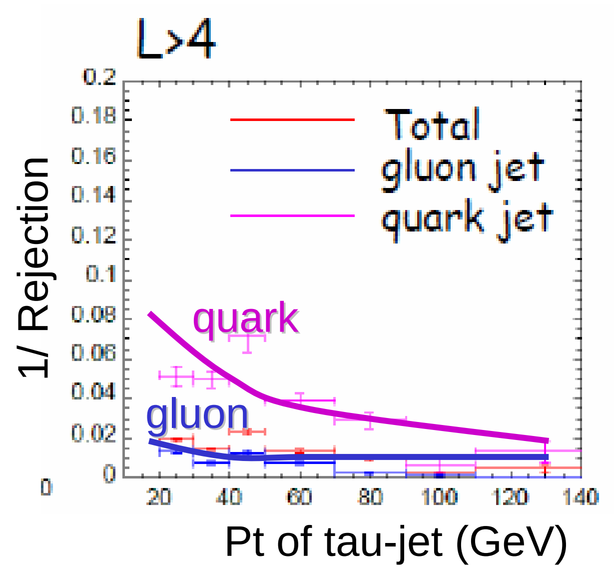
  This was understood (previous page)
- Electron fake ratio is high for SUSY sample against prediction

  This is under study

Efficiency vs. fake ratio τ's case

- Instead of isolation criteria, use likelihood parameter to see efficiency vs. fake ratio relation
- Predictions do not match with the data points
  - Jet rejection power is based on QCD di-jet samples (gluon dominant)
  - Jets in TOP, SUSY, DY samples are quark dominant
  - Rejection power with likelihood …. [quark] << [gluon]



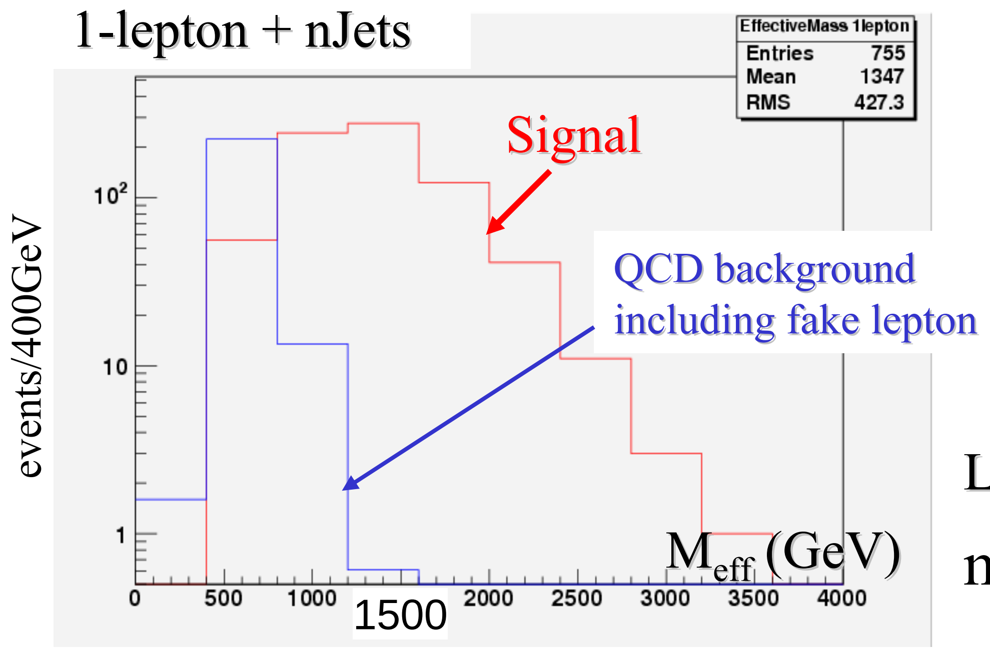


decomposing gluon/quark jets
- possible in MC works
- experimentally difficult to implement (this is under study)

Fake contribution to the background

Previously, background study with fake leptons never been considered seriously

Applied to the QCD multi jet with huge cross section (σ ~190nb)



Fake probability Implemented in ATLAS simulation

Estimated contribution of multi-jet QCD background

$L = 10fb^{-1}$

$m(\tilde{q}), m(\tilde{g}) = 1TeV$

Only affect in the lower M_{eff} region (<1TeV) The effect is not serious this case

But the fake lepton related background study becomes more important

Summary

- Leptons have a crucial role in all steps of the SUSY study (discovery, inclusive, exclusive)
- Lepton ID from experimental approach is studied
- The goal is to obtain the SUSY signal lepton ID performance from the control sample (ex. DY)
  - Degradation of the efficiency is understood
  - Electron fake is high in SUSY sample (under study)
  - Taus are more difficult (in progress)
- Lepton fake related new background source was found
- Lepton id study in SUSY using full simulation data just started with limited statistics → complete study and understanding necessary before the real data

Prospects

- LHC will start data taking in 2-years
- Background studies closely associated with detector performance such as fake leptons, fake missing Et, etc. become more and more important during the coming two years
- These must be determined by data itself
- We just begin to tackle these issues with realistic approaches, and will be ready for the first data from ATLAS in 2007

backup slides …

Study on full simulation data

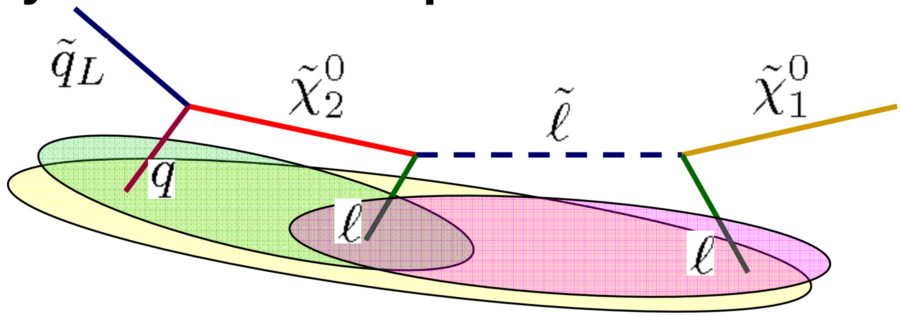
- Rome full simulation samples generated for ATLAS Rome Physics workshop (100k events each)
  - *tt* + Njets sample (T1)
  - Drell-Yan samples (Zee, Zμμ, Zττ)
  - SUSY samples – SU3 (Bulk point)
- Analysis is based on the SUSY plot package (Algs 00-04-02)

$N_{leptons}$, N_{jets} per event $|\eta| < 2.5$

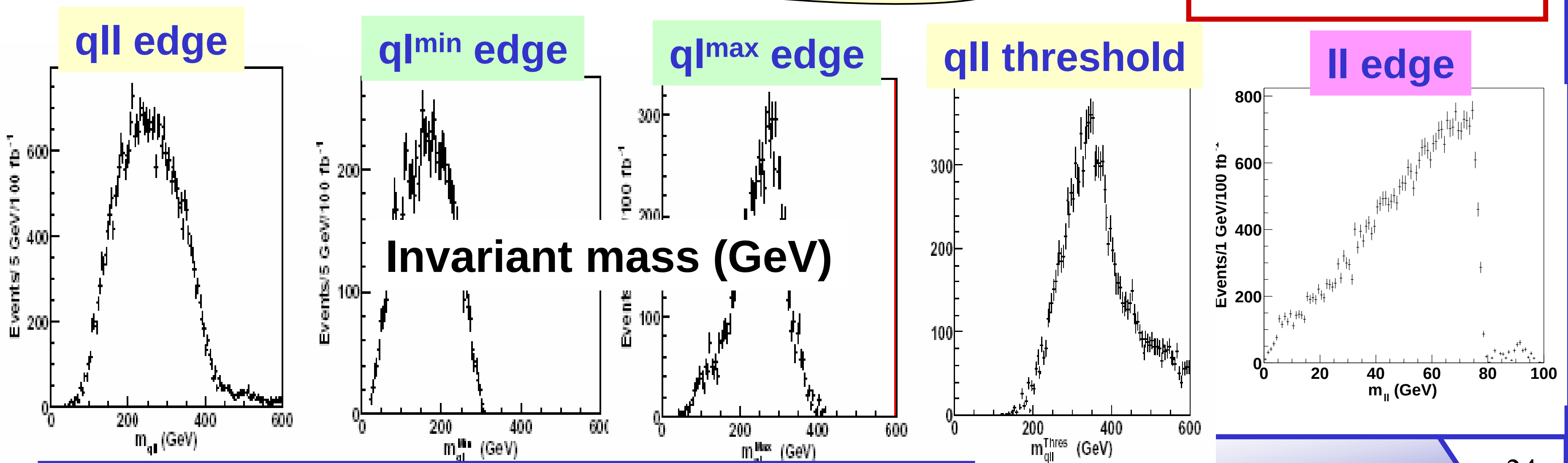
	$\langle N_e \rangle$	$\langle N_\mu \rangle$	$\langle N_\tau \rangle$	$\langle N_{jets} \rangle$	$\langle N_{bjets} \rangle$
DY Zee	1.7			0.64	0.02
DY Zμμ		1.9		0.60	0.02
DY Zττ			1.5	1.80	0.03
T1	0.40	0.40	0.29	4.2	1.7
SU3	0.25	0.23	0.69	4.9	0.63

Leptons + jets edge measurement

- **Dilepton edge starting point for reconstruction of decay chain.**
- **Make invariant mass combinations of leptons and jets.**
- **Gives five constraints on combinations of four masses.**
- **Sensitivity to individual sparticle masses.**



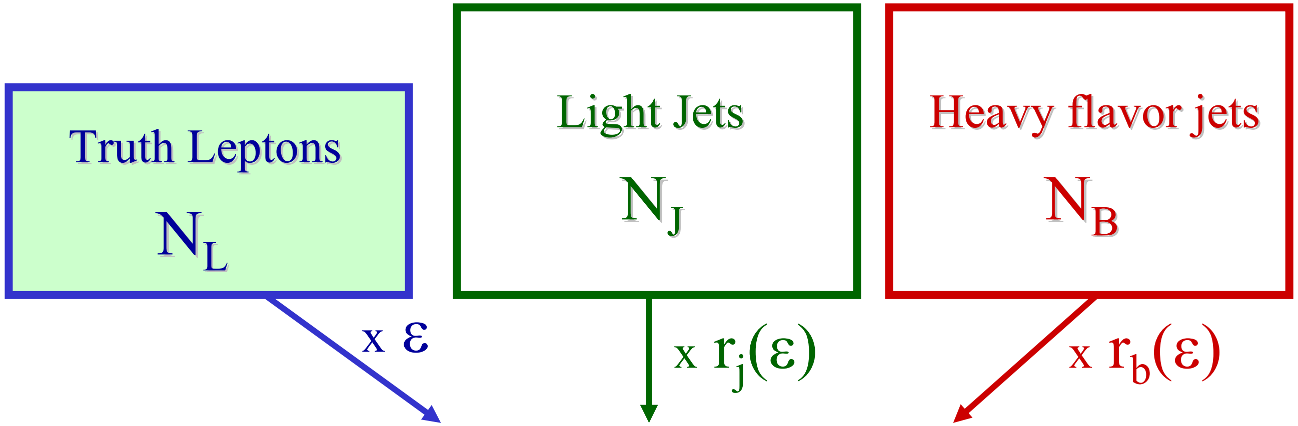
L=100 fb^{-1}
fast simulation



Gjelsten, Lytken, Miller, Osland, Polesello,ATL-PHYS-2004-007

fake leptons in the signal

Simple Scheme based on the Number of Jets



$$N_{\text{reco leptons}} = \varepsilon N_L + r_j(\varepsilon) N_J + r_b(\varepsilon) N_B$$

$$\text{fake ratio} = (r_j(\varepsilon) N_J + r_b(\varepsilon) N_B) \,/\, N_{\text{reco leptons}}$$

- N_{reco}, N_J, N_B are experimentally measurable quantities, ‘r’s are estimated with MC → the fake ratio can be determined experimentally
- Need to check whether ‘r’s are same in SUSY signals

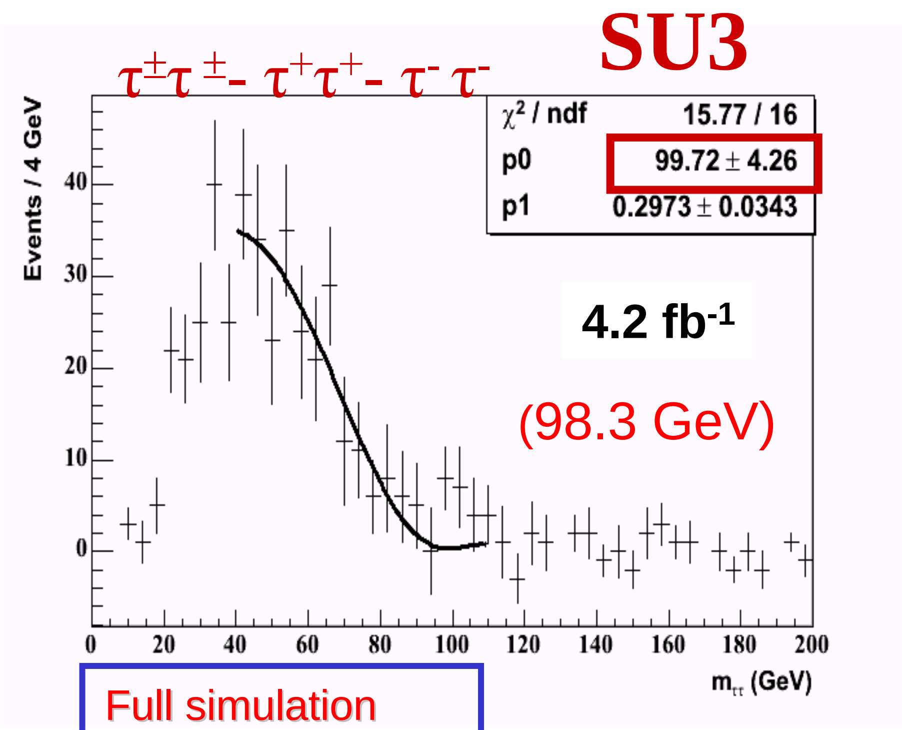
mass reconstruction with τ's

- hadronic taus : calorimeter seeded objects (ATLAS standard) associated by narrow jet with 1 or 3 tracks
- cannot fully reconstruct mass (no edge) due to missing Et sources (LSP, neutrinos) → look for the end point instead

$$\tilde{\chi}_2^0 \rightarrow \tilde{\tau}_1^{\pm} \tau^{\mp} \rightarrow \tau^{\pm}\tau^{\mp} \tilde{\chi}_1^0$$

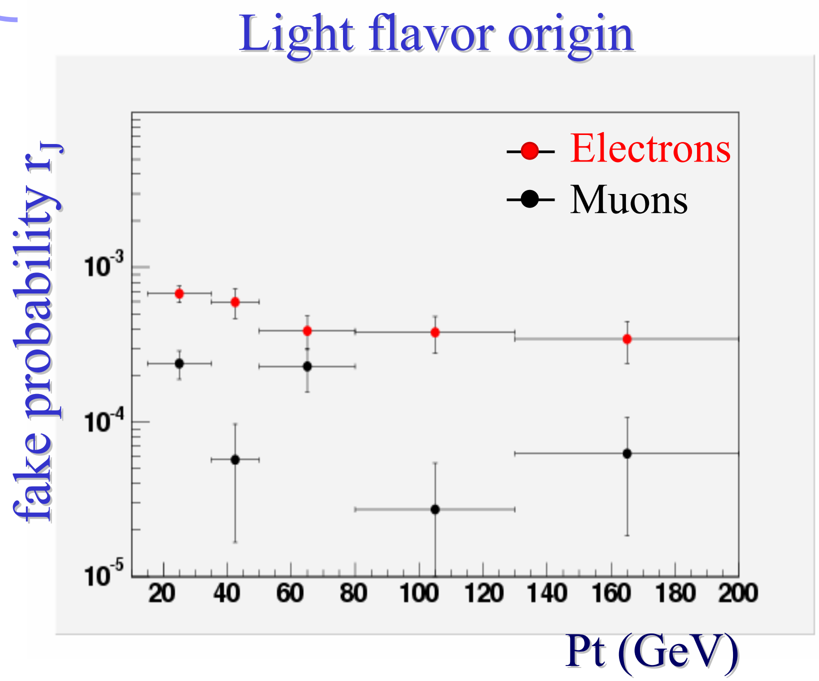
- high fake ratio compared to e, μ, and low efficiency especially in the low Pt range

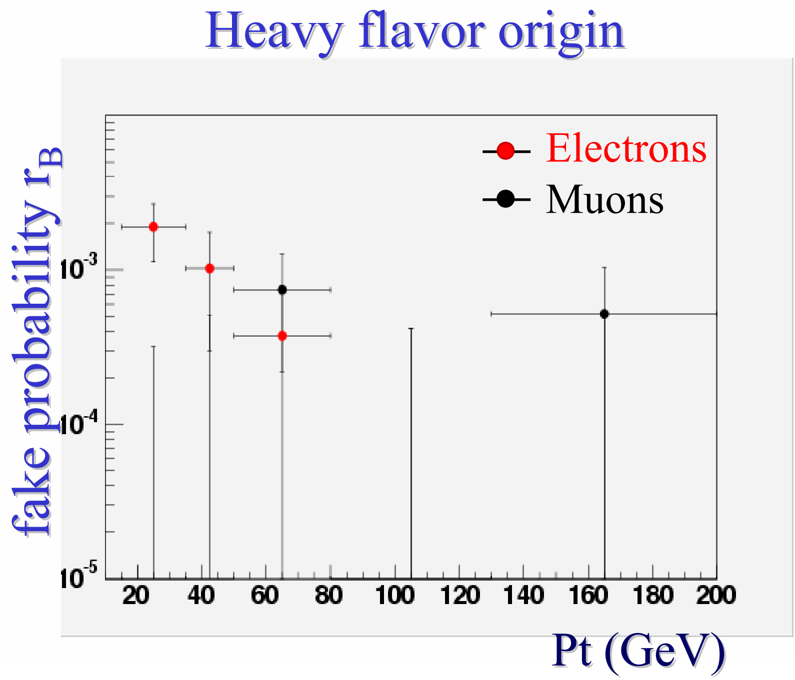
- exact relation between ε vs. fake is extremely important



Full simulation
ATLAS preliminary

Fake probabilities estimated from QCD Jet samples





- Used Rome QCD Jet samples (J1-J8) to estimate the probability (Jet faked as lepton)
- Reconstructed leptons (isolation Et e:5GeV, μ:10GeV) in these samples are purely fake (since there is no original lepton)
- Fake probability estimated by,

  r = (# of isolated leptons in Pt range)/ (# of jets in the same Pt range)
- Due to the statistical limitations, the values are obtained by order of magnitudes