SUSY (s)lepton flavour studies with ATLAS

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Flavour in the era of the LHC, 7-10 November, CERN

Outline

- mSUGRA
- Sleptons
- Fast simulation studies
- Full simulation studies
- Spin measurement
- Slepton non-universality

mSUGRA

Parameter space: m_0, $m_{1/2}$, A_0, $\tan(\beta)$, $\mathrm{sgn}(\mu)$

R-parity is conserved:

At the end of every SUSY decay chain is LSP, no mass peaks, no direct mass measurement

Techniques for mass measurement:

- kinematic endpoints
- stransverse mass

Sleptons

Production:

indirectly: from decays of heavier gauginos

$$\tilde{\chi}_2^0 \rightarrow \tilde{l}_{R,L}\, l$$

directly: $\tilde{l}_L \tilde{l}_L$, $\tilde{l}_R \tilde{l}_R$ (small cross sections)

Decays: to kinematically open gauginos

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

$$\tilde{l}_L \rightarrow l\, \tilde{\chi}_1^0 ,\ l\, \tilde{\chi}_2^0 ,\ \nu \tilde{\chi}_1^{\pm}$$

Mixings, masses

- At the unification scale SUSY scalars are mass degenerate. At the EW scale: $m(\tilde{f}_L) > m(\tilde{f}_R)$

- L/R mixing is proportional to fermion masses, and can be neglected for selectrons, smuons. In the stau case, L/R stau mixing is significant. Mass eigenstates are: $\tilde{\tau}_1$, $\tilde{\tau}_2$. $\tilde{\tau}_1$ is the lightest slepton.

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Fast simulation studies

SPS1a (bulk region)
m_0= 100 GeV,
$m_{1/2}$= 250 GeV,
A_0= -100 GeV,
tan(β)=10 , μ>0

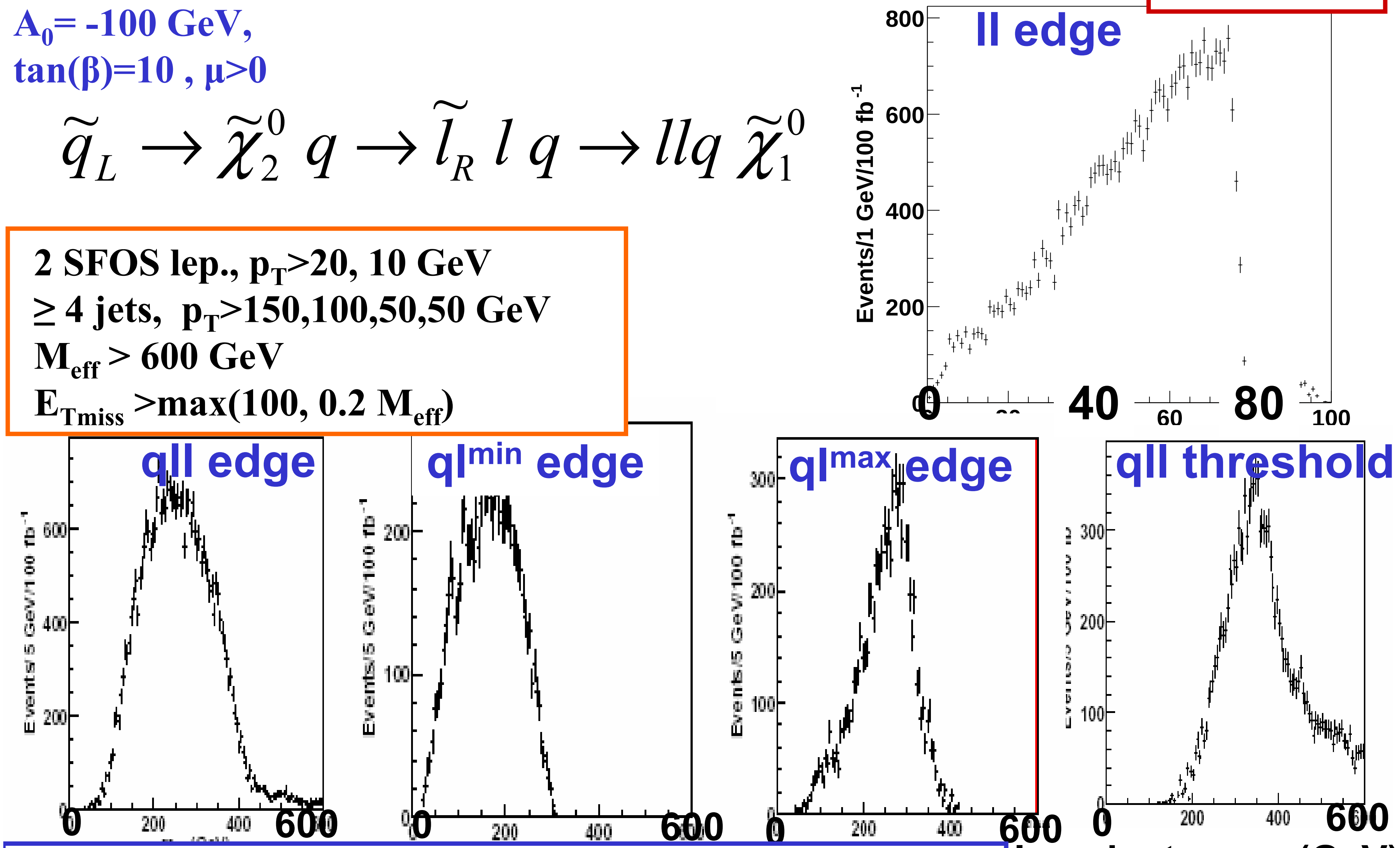
Left squark cascade decay

fast sim.

L=100 fb^{-1}

$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0\, q \rightarrow \tilde{l}_R\, l\, q \rightarrow llq\, \tilde{\chi}_1^0$$

2 SFOS lep., p_T>20, 10 GeV
≥ 4 jets, p_T>150,100,50,50 GeV
M_{eff} > 600 GeV
E_{Tmiss} >max(100, 0.2 M_{eff})



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

L=100 fb^{-1}

Fit results

Edge	Nominal Value	Fit Value	Syst. Error Energy Scale	Statistical Error
$m(ll)^{edge}$	77.077	77.024	0.08	0.05
$m(qll)^{edge}$	431.1	431.3	4.3	2.4
$m(ql)^{edge}_{min}$	302.1	300.8	3.0	1.5
$m(ql)^{edge}_{max}$	380.3	379.4	3.8	1.8
$m(qll)^{thres}$	203.0	204.6	2.0	2.8

Mass reconstruction

5 endpoints measurements, 4 unknown masses

$$\chi^2 = \sum \chi_j^2 = \sum \left[\frac{E_j^{theory}(\vec{m}) - E_j^{exp}}{\sigma_j^{exp}} \right]^2$$

$$E_j^i = E_j^{nom} + a_j^i \sigma_j^{fit} + b^i \sigma_j^{Escale}$$

$m(\chi_1^0) = 96$ GeV
$m(l_R) = 143$ GeV
$m(\chi_2^0) = 177$ GeV
$m(q_L) = 540$ GeV

$\Delta m(\chi_1^0) = 4.8$ GeV, $\Delta m(\chi_2^0) = 4.7$ GeV,
$\Delta m(l_R) = 4.8$ GeV, $\Delta m(q_L) = 8.7$ GeV

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

Direct slepton production

$$\tilde{l}_R \tilde{l}_R \, , \; \tilde{l}_L \tilde{l}_L \rightarrow l^+ l^- + E_T^{miss}$$

Signature: 2 SFOS leptons + missing transverse energy

It is possible to estimate slepton mass by using stransverse mass:

$$M_{T2} = \min_{E_T^{miss} = E_{T1}^{miss} + E_{T2}^{miss}} \left\{ \max\left\{ m_T^2\left(p_T^{l1}, E_{T1}^{miss}\right), \; m_T^2\left(p_T^{l2}, E_{T2}^{miss}\right) \right\} \right\}$$

(Lester et al., Phys.Lett.B463 (1999) 99)

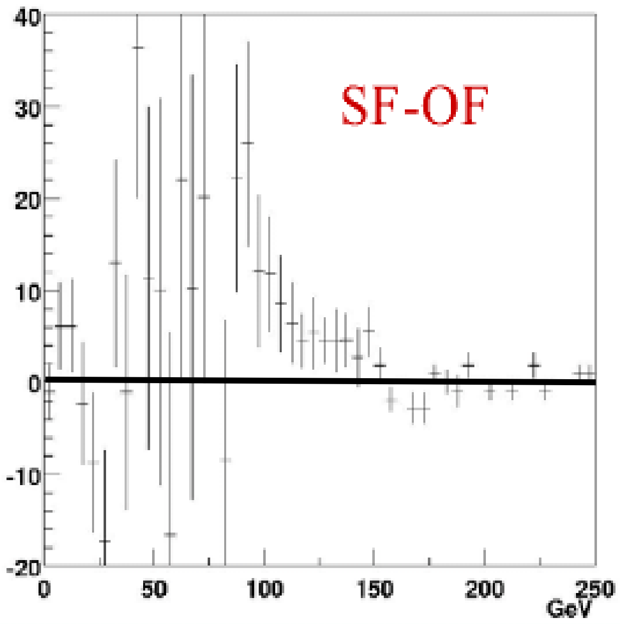
Endpoint of the stransverse mass is function of the mass difference between slepton and LSP

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

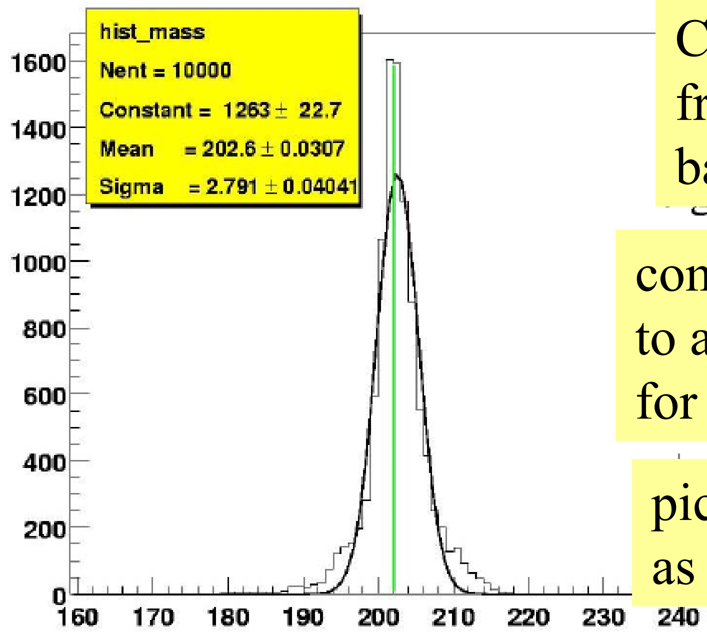
Example: SPS1a

$$M(\tilde{\chi}_1^0) = 96\,GeV,\ M(\tilde{l}_R) = 143\,GeV,\ M(\tilde{l}_L) = 202\,GeV$$

Stransverse mass M_{T2} after cuts



Left slepton mass



Create a data sample from signal and background events

compare shape of result to a set of signal distrib. for different $\tilde{l}_L$ masses

pick fit with lowest χ^2 as the mass

$\tilde{l}_L$ can be estimated to 3-4 GeV

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

Full simulation studies

Data Challenges for Rome Physics Workshop

Preliminary results of new full simulated data for set of mSUGRA points chosen according to recent experimental data. Full simulation SM background data are currnetly produced and studied.

DC1 bulk region point - SU3

m_0 =100 GeV, $m_{1/2}$ = 300 GeV, A_0 = -300 GeV, $\tan\beta$ = 6, sgn(μ) = +

Coannihilation point – SU1

m_0 =70 GeV, $m_{1/2}$ = 350 GeV, A_0 = 0 GeV, $\tan\beta$ = 10, sgn(μ) = +

Focus point – SU2

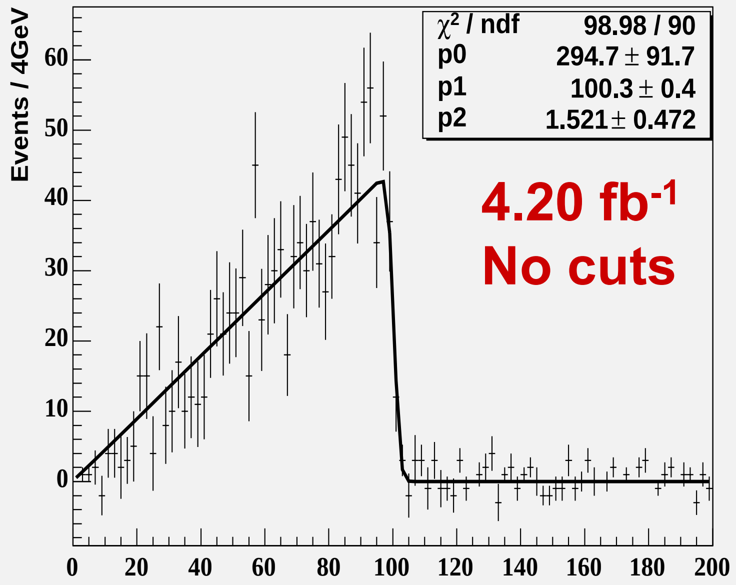
m_0 = 3350 GeV, $m_{1/2}$ = 300 GeV, A_0 = 0 GeV, $\tan\beta$ = 10, sgn(μ) = +

SU3 dileptons

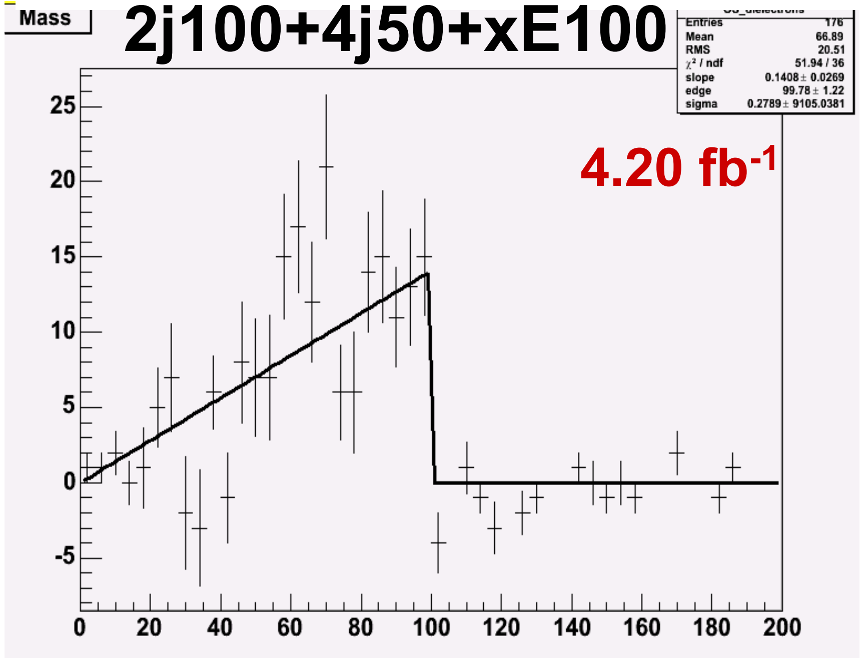
ATLAS preliminary

Selected events with two OS leptons.

$(e+e-) + \beta^2(\eta)\ (\mu+\mu-) - \beta(\eta)\ (e+\mu-)$



Edge = 100.3 ± 0.4 GeV



Edge after cuts: 99.8 ± 1.2 GeV

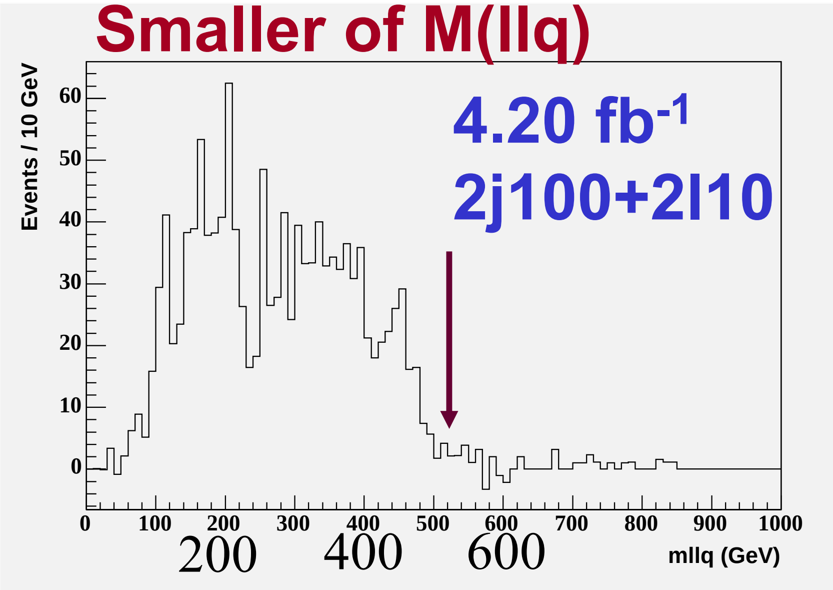
Fit with a triangular distribution with gaussian smearing.
Edge in good agreement with true value 100.31 GeV

SM Background expected to be <u>negligible</u> after cuts. However, SUSY statistic also reduced. Study of SM background and optimization of cuts generally still under way

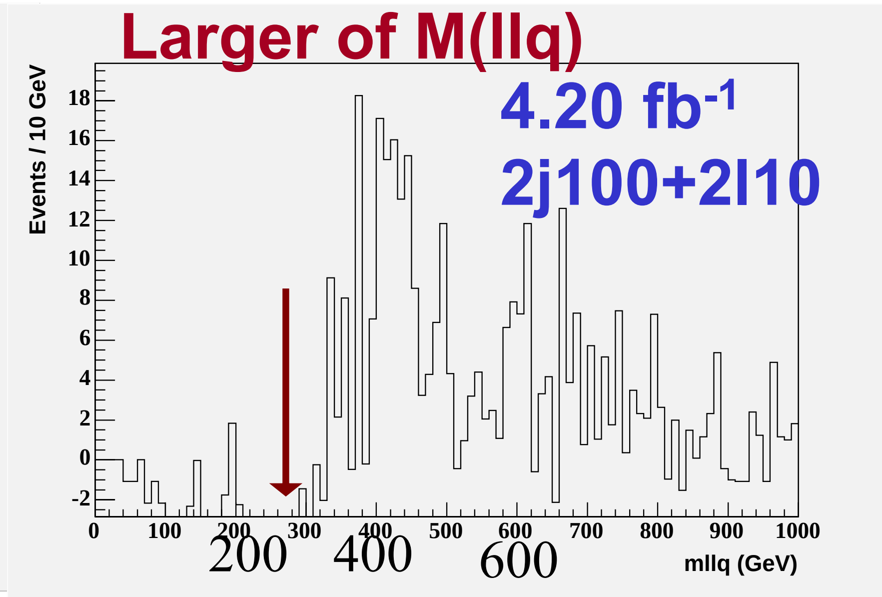
SU3: leptons+jets

ATLAS preliminary

Leptons combined with two jets with highest P_T
Flavour subtraction & efficiency correction applied



M_{llq}^{max} =501 GeV



M_{llq}^{min} =271 GeV

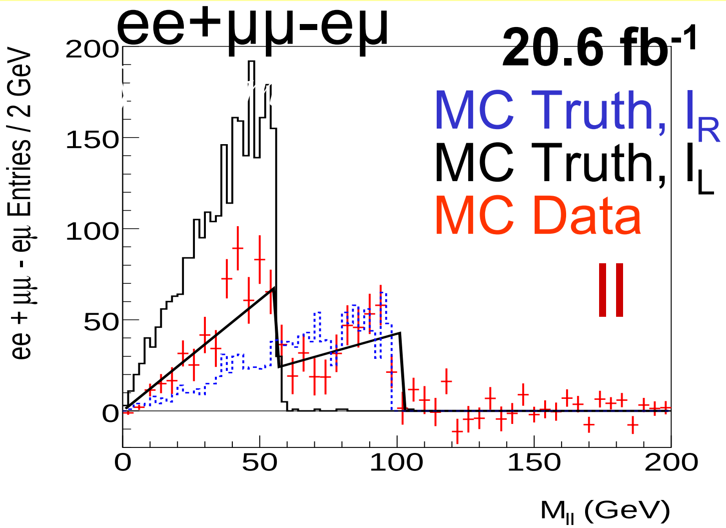
SU1

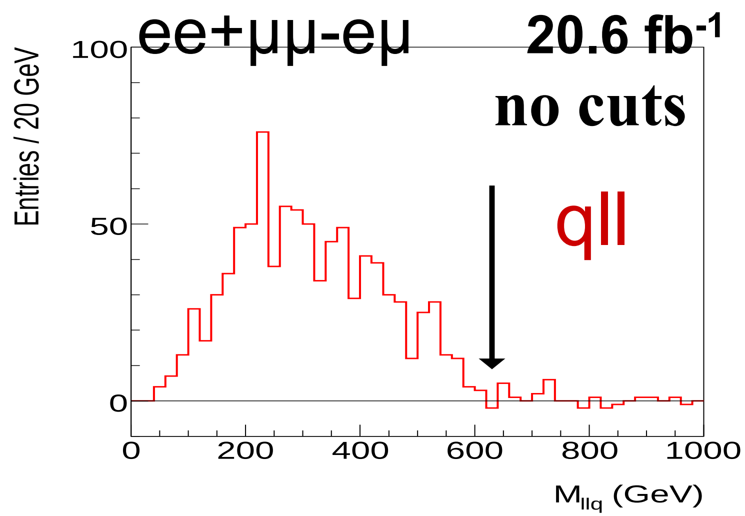
$$\tilde{q}_L \rightarrow \tilde{\chi}_2^0\, q \rightarrow \tilde{l}_{L,R}\, l\, q \rightarrow llq\, \tilde{\chi}_1^0$$

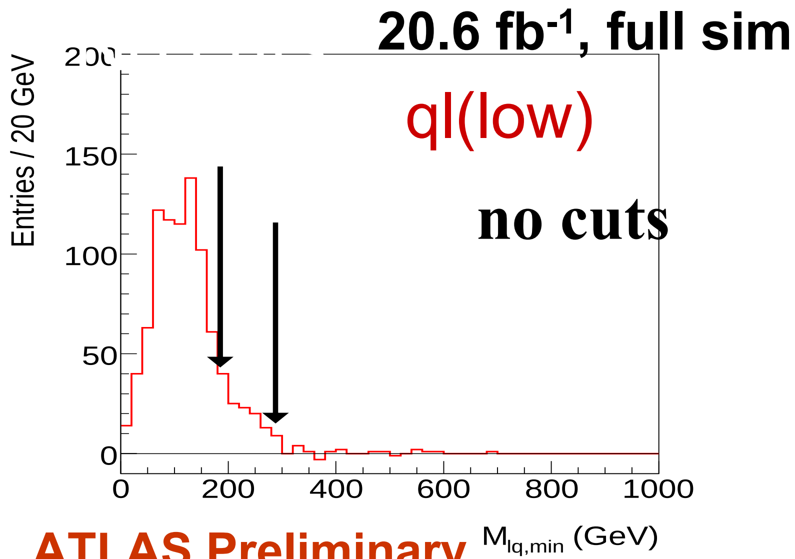
264   255, 154   137

Each s-lepton is close in mass to one of the neutralinos – **one of the leptons is soft**

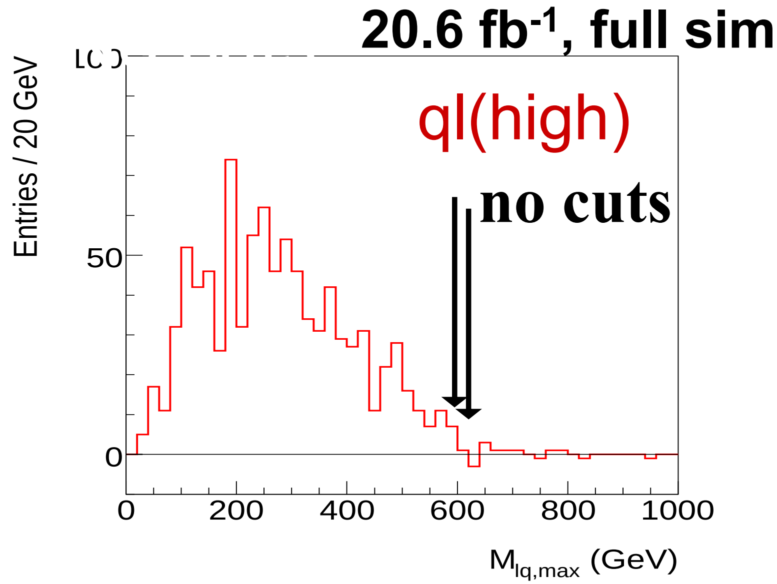
- Selection: e^+e^- or $\mu^+\mu^-$ pair







ATLAS Preliminary



SU2

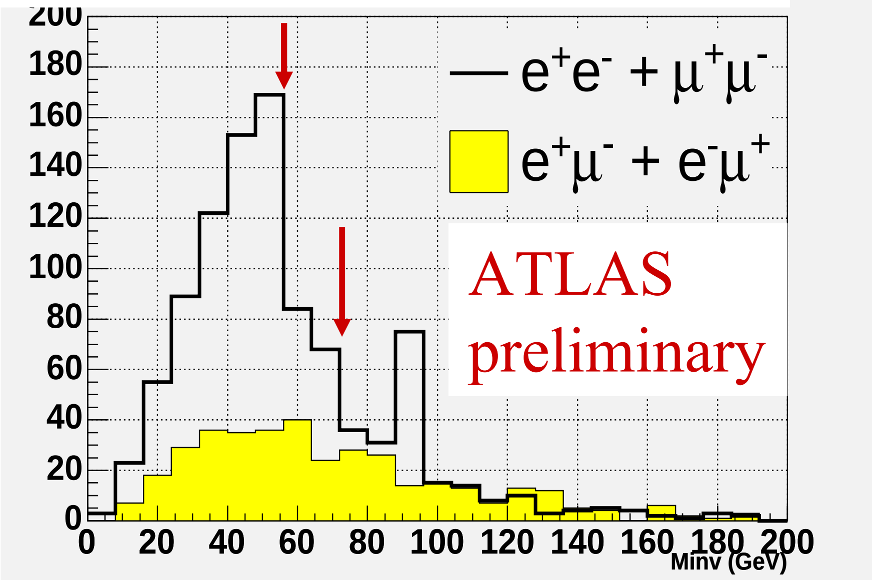
$$\tilde{\chi}_3^0 , \tilde{\chi}_2^0 \rightarrow l\, l\, \tilde{\chi}_1^0$$

179 160 103

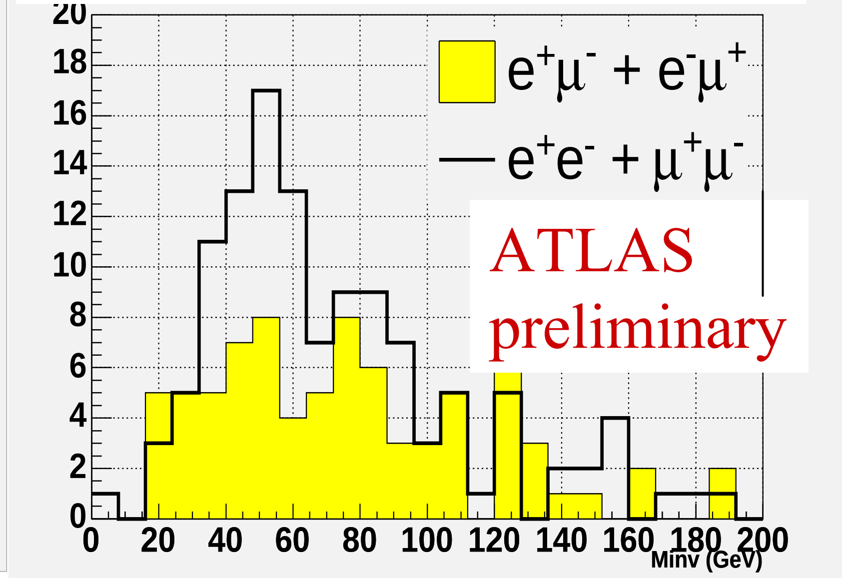
$\Delta m = m(\chi_n^0) - m(\chi_1^0) = 57, 76$ GeV

Focus-Point
Heavy scalars: no scalar lepton in χ decay

Dilepton mass **6.9 fb^{-1}**



Dilepton mass after cuts **6.9 fb^{-1}**



Cuts to reject SM: 2j100+4j50+xE100

With only 6.9 fb^{-1} of data we begin to see the edge structure emerge. More statistic needed for fit.

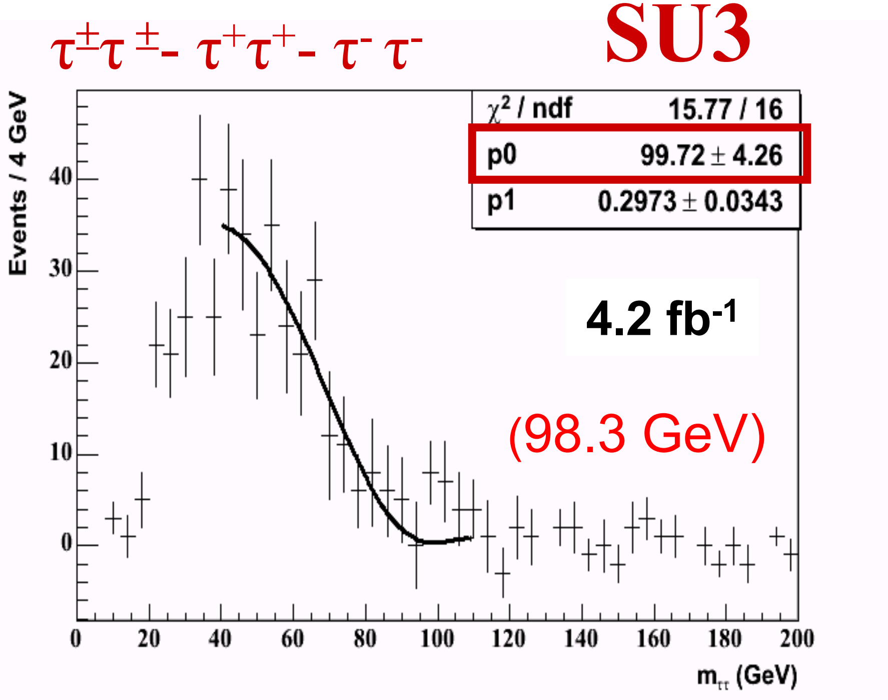
Tau signatures

- Taus provide independent information on SUSY model even if lepton signatures are available
- Tau ID is much harder than electron or muon ID, particularly for soft taus (e.g. co-annihilation point)
- Need to focus on hadronic decays since the LHC vertex detectors cannot cleanly identify $\tau \rightarrow l\nu\nu$.
- Looked at ditau invariant mass distributions from decay:

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

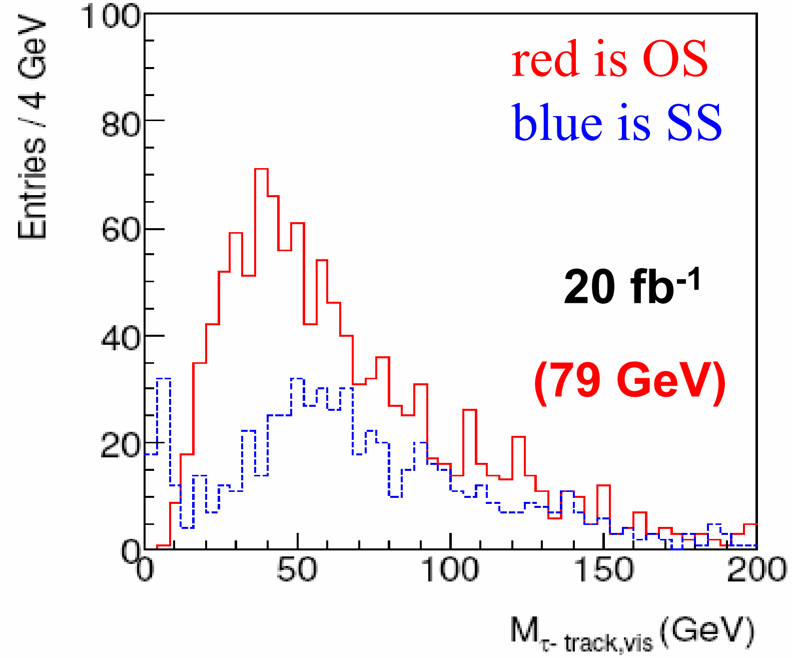
- Triangular ditau mass shape is distorted due to missing energy from neutrinos. Available statistics are much lower due to tau reconstruction efficiency.

Events with 2 OS tau leptons



- Use MC fit and apply it to the background subtracted distribution using the endpoint and normalisation as parameters.
- It gives good description of the endpoint

ATLAS preliminary



One of the taus produced in the squark cascade decay chain is very soft

$\Rightarrow$ Limited statistics

- One possible solution is to combine the hard τ (E_T > 40 GeV) with any track having p_T > 6 GeV and no other track with p_T > 1 GeV in R < 0.4 . Signal is clear, but need more statistic for fit.

Spin measurement,
slepton non-universality

Spin measurement

It is vital to measure the spins of the new particles to demonstrate that they are indeed the predicted super-partners

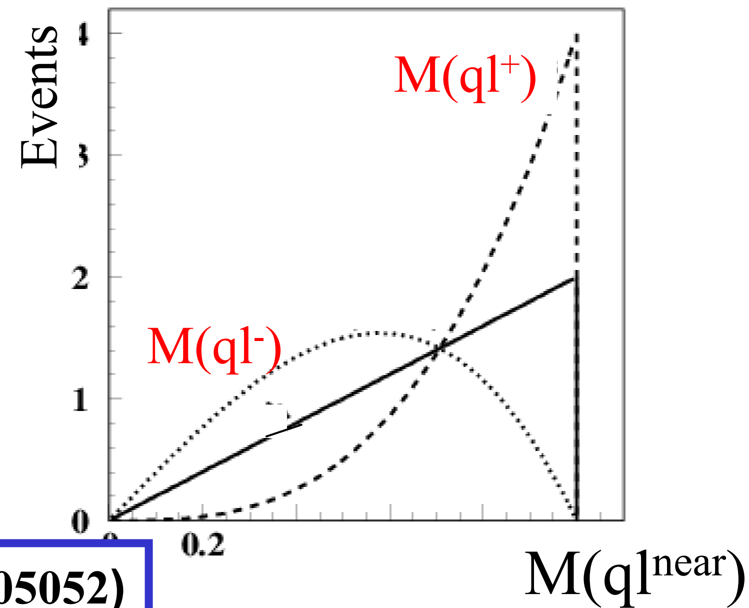
$$\overset{0}{\tilde{q}_L} \rightarrow q\, \overset{1/2}{\tilde{\chi}_2^0} \rightarrow q\, \overset{0}{\tilde{l}_R}\, l^{near} \rightarrow q\, l^+\, l^- + \tilde{\chi}_1^0$$

First emitted lepton ("near")

l = e, μ

Due to neutralino spin 1/2, angular distrib. of slepton is not spherically symmetric, invariant mass $M(ql^{near})$ is charge asymmetric.

Ideal distribution



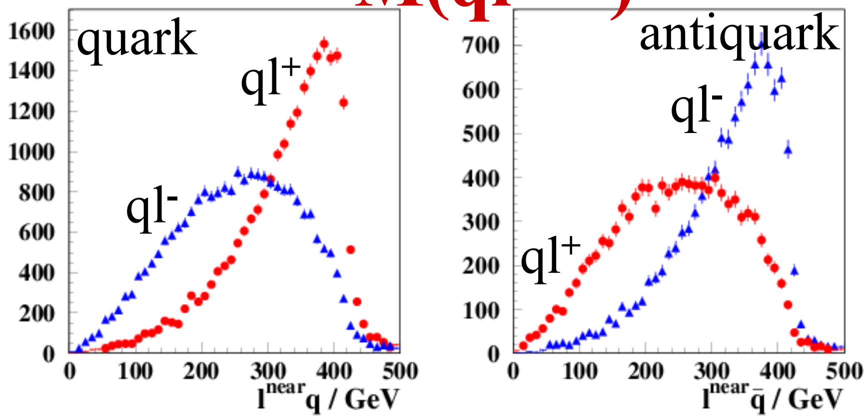
A.J. Barr, Phys. Lett. B596 (2004) 205 (hep-ph/0405052)

Example

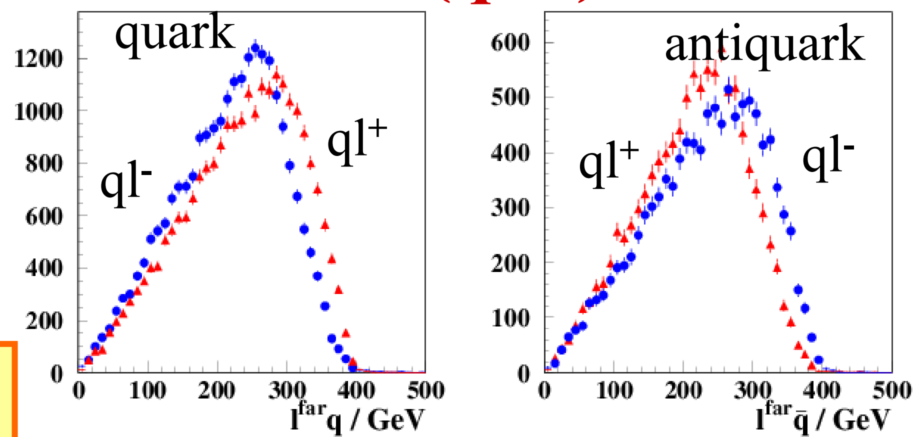
LHCC5: m_0 =100 GeV
$m_{1/2}$ =300 GeV
A_0 =-300 GeV
tan(β) =2.1
sign(μ)=+

Parton distributions

$M(ql^{near})$

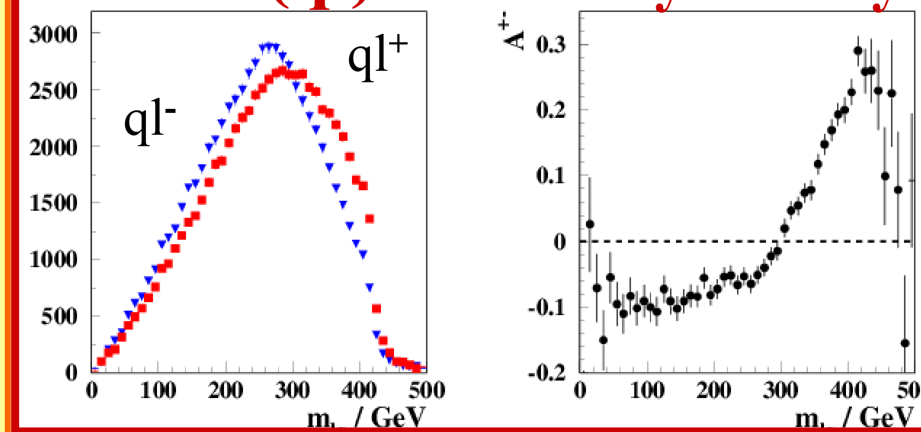


$M(ql^{far})$



l^{near} and l^{far} are experimentally indistinguishable. Instead, study of $M(l^-q)$ and $M(l^+q)$ distributions. Each distribution contain contribution from both near and far lepton and contribution from both quark and antiquark.
Quark and antiquarks have opposite asymmetries and are experimentally indistinguishable. LHC is pp collider → more quarks then antiquarks will be produced

M(ql) asymmetry



A.J. Barr, Phys. Lett. B596 (2004) 205

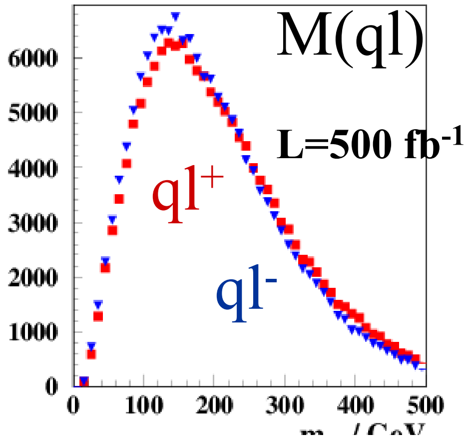
Asymmetry

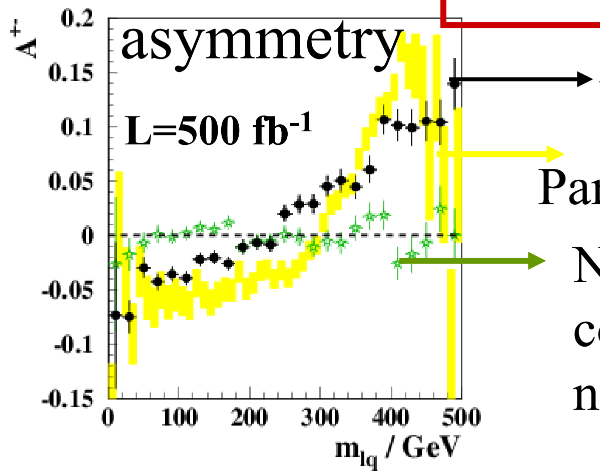
Fast simulation

LHCC5

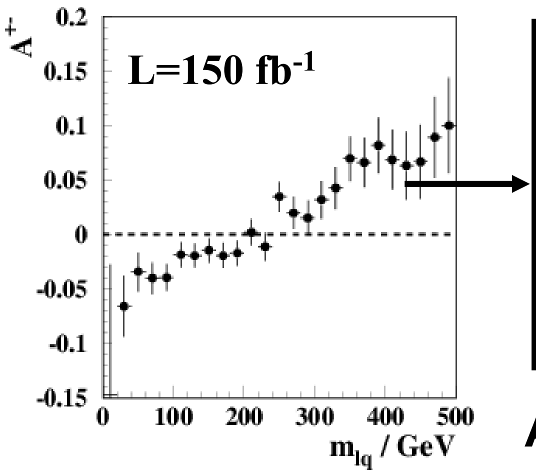
$$A = \frac{s^+ - s^-}{s^+ + s^-}$$

$$s^{\pm} = \frac{d\sigma}{d(m_{l^\pm q})}$$





asymmetry



Asymmetry is negative for low values of M(lq) and positive for large values. This is consistent with spin ½ neutralino and spin 0 slepton

A.J. Barr, Phys. Lett. B596 (2004) 205

SPS1a Non-zero M(ql) asymmetry may be observed with $30\mathrm{fb}^{-1}$ (**Goto, Kawagoe, Nojiri, PRD 70, 075016**)

Asymmetry

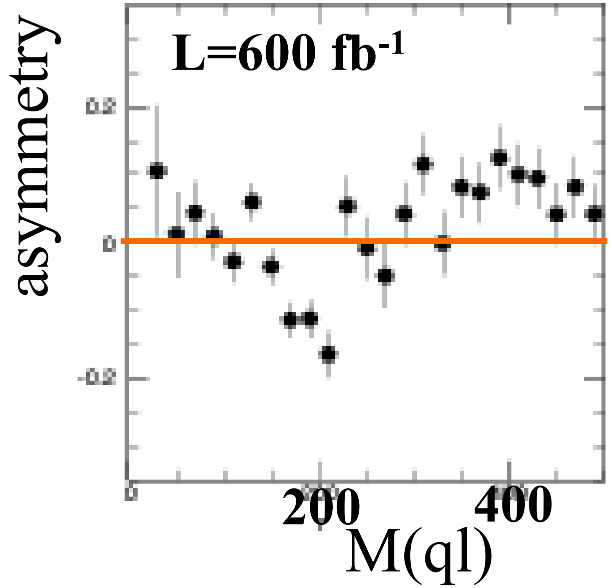
SPS3:
m_0 =90 GeV
$m_{1/2}$ =400 GeV
A_0 =0 GeV
sign(μ)=+
tg(β)=10

Fast simulation

Decay of neutralino to both left and right slepton is open.
Decays of second neutralino to left and right slepton have opposite sign asymmetries

$$\tilde{\chi}_2^0 \to \tilde{l}_R\, l,\ \tilde{l}_L\, l \qquad l = e, \mu$$

dominant mode



$M(ql^{near})_L$ = 209 GeV
$M(ql^{near})_R$ = 620 GeV

Asymmetry is negative near smaller M(ql) endpoint.

Negative asymmetry may still be seen with L=300 fb^{-1} .

Goto, Kawagoe, Nojiri, PRD 70, 075016 (hep-ph/0406317)

L-R slepton mixing

Left/right slepton mixing affect

- the charge asymmetry

- $\tilde{\chi}_2^0 \rightarrow \tilde{l}\, l$ **decay width for l=μ, τ**

SELECTRONS: L-R mixing negligible, maximal asymmetry

SMUONS: asymmetry smaller then in selectron case if L-R mixing is observable.

STAUS: L-R mixing siginificant, asymmetry opposite to selectron case

$$\Gamma(\tilde{\chi}_2^0 \rightarrow \tau\tilde{\tau}_1) > \Gamma(\tilde{\chi}_2^0 \rightarrow \mu\tilde{\mu}_1) > \Gamma(\tilde{\chi}_2^0 \rightarrow e\tilde{e}_1)$$

In order to get small systematic error on endpoints and BR need to understand: lepton efficiency and acceptance, lepton energy scale

Example

Calculated ratio of asymmetries and widths

	$A(e):A(\mu):A(\tau)$	$\Gamma(e): \Gamma(\mu): \Gamma(\tau)$
SPS1a		
$\tan(\beta)=10$	**1 : 0.93 : -0.84**	**1 : 1.04 : 13.7**
$\tan(\beta)=15$	**1 : 0.83 : -0.95**	**1 : 1.09 : 37.6**
$\tan(\beta)=20$	**1 : 0.70 : -0.99**	**1 : 1.17 : 80.2**

With larger $\tan(\beta)$, stronger L-R mixing.

Needed tools: L-R mixing in 1st two generations (available in SPHENO, but not in ISAJET/HERWIG/PYTHIA)

Goto, Kawagoe, Nojiri, PRD 70, 075016 (hep-ph/0406317)

Detectability of selectron/smuon non-universality

- Statistical significance of the non-universal effect between selectron and smuon for large tan(β) is investigated at point SPS1a with modified tan(β).
- With larger tan(β), L-R mixing is larger, but
  BR($\tilde{\chi}_2^0 \rightarrow \tilde{l}_R\, l$) l=e, μ, is more suppressed.
- Non-universal asymmetry is too small effect.
- Non-universal BRs are more sensitive and with 300fb^{-1} can see an effect of selectron/smuon non-universality.

  One may test non-universality by comparing: e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$ endpoints which can be measured with 0.1GeV precision.

Goto, Kawagoe, Nojiri, PRD 70, 075016 (hep-ph/0406317)

Conclusions

Fast simlation studies shows that by using kinematic endpoint technique and stransverse mass SUSY masses can be reconstructed.

Preliminary full simulation results shows that large number of mass relations can be measured for leptonic and tau signatures with few fb^{-1} of data in different mSUGRA regions. To be studied more carefully: acceptance, callibration, trigger, SM background, fit to distributions

Measurement of charge asymmetry in left squark decay are consistent with neutralino spin ½ and slepton spin 0.

Non-universal BR for selectron and smuon can be observed at ATLAS.