Neutralino spin measurement with ATLAS

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on behalf of the ATLAS Collaboration

Flavour in the era of the LHC , 4th meeting – CERN, 9 Oct 2006

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- Spin measurement
- SU1 and SU3 points: kinematics
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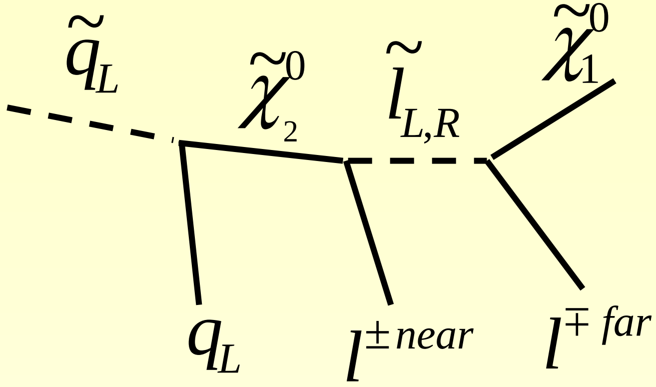
Spin measurement



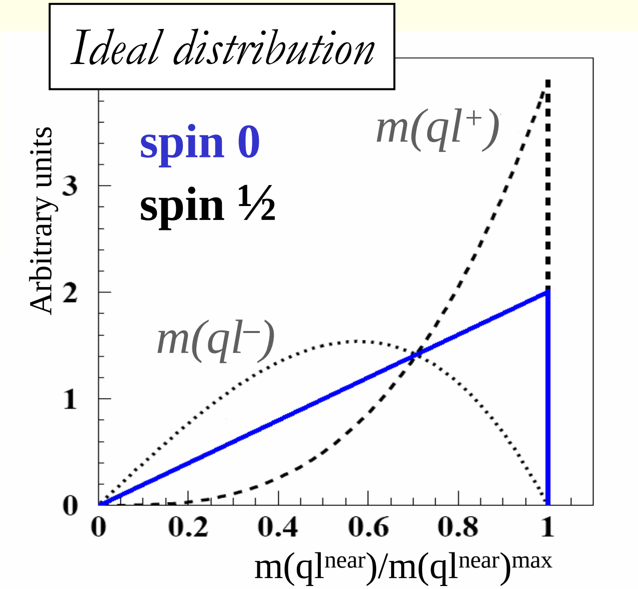
- **Left squark cascade decay**

  $$\tilde{q}_L \to q\, \tilde{\chi}_2^0 \to q\, \tilde{l}_{L,R}^{\mp}\, l^{\pm} \to q l^{\pm} l^{\mp} \tilde{\chi}_1^0$$

  Only electrons and muons considered, from $\tilde{l} = \tilde{e}, \tilde{\mu}$

If neutralino spin is ½ , angular distribution of slepton is not spherically symmetric, therefore invariant mass **m(ql$^{\pm}$)** is charge asymmetric:

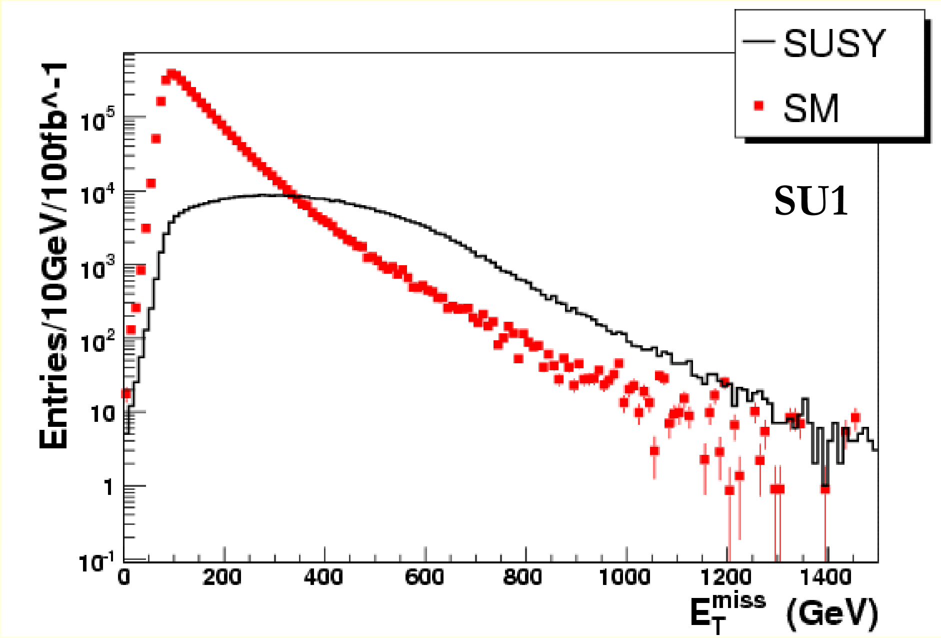
$$A_{ql} = \frac{s^+ - s^-}{s^+ + s^-} \qquad s^{\pm} = \frac{d\sigma}{d(m_{ql^{\pm}})}$$



- Studies for **LHCC5** point by A. J. Barr
  Phys.Lett.B596 (2004) 205

Event topology

- In **mSUGRA** events, strongly interacting sparticles ($\tilde{q}$, $\tilde{g}$) dominate LHC production
- Cascade decays to the stable, weakly interacting lightest neutralino (**L**ightest **S**upersymmetric **P**article) follow, *e.g.* left squark cascade decay.



- **Typical final state signature:**
  - **Large E_T^{miss}** (from LSP)
  - **High p_T jets** (from squark/gluino decay)
  - **Two same-flavour opposite-sign (SFOS) leptons**
- Charge asymmetry $\mathbf{A_{ql}}$ is suppressed by $\tilde{q}/\bar{\tilde{q}}$ cancelation (anyway at the LHC much more squarks than antisquarks are expected)
- Asymmetry can be also diluted by the experimental impossibility to distinguish **near** from **far** lepton

mSUGRA points considered

- **Point SU1** – stau coannihilation point

  $\mathbf{m_0 = 70\ GeV\ ,\ \ m_{1/2} = 350\ GeV\ ,\ A_0 = 0\ GeV}$

  $\mathbf{\tan(\beta) = 10\ ,\ sign(\mu) = +}$

  $\boldsymbol{\sigma_{LO} = 7.8\ pb}$ (**100** $\mathbf{fb^{-1}}$ analysed sample)

- **Point SU3** – bulk region point

  $\mathbf{m_0 = 100\ GeV\ ,\ \ m_{1/2} = 300\ GeV\ ,\ A_0 = -300\ GeV}$

  $\mathbf{\tan(\beta) = 6\ ,\ sign(\mu) = +}$

  $\boldsymbol{\sigma_{LO} = 19.5\ pb}$ (**30** $\mathbf{fb^{-1}}$ analysed sample)

ATLAS official Fast Simulation samples + dedicated production in Napoli ATLAS-Tier2

SU1 point kinematics

- Both $\tilde{\chi}_2^0 \to \tilde{l}_L^{\pm} l^{\mp}$ and $\tilde{\chi}_2^0 \to \tilde{l}_R^{\pm} l^{\mp}$ decays are allowed in SU1

  (masses are: $m_{\tilde{\chi}_2^0} = 264\,GeV, m_{\tilde{l}_L} = 255\,GeV, m_{\tilde{l}_R} = 154\,GeV$)

$$\tilde{q}_L \to q\,\tilde{\chi}_2^0 \to q\,\tilde{l}_L\,l^{\pm} \to q l^{\pm} l^{\mp} + \tilde{\chi}_1^0$$

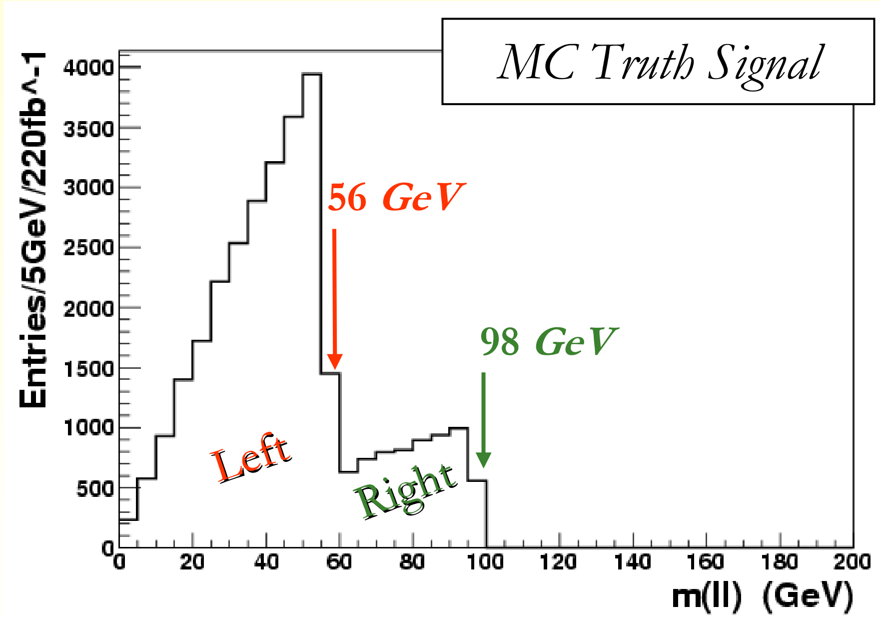
264 255 soft hard 137

$$\tilde{q}_L \to q\,\tilde{\chi}_2^0 \to q\,\tilde{l}_R\,l^{\pm} \to q l^{\pm} l^{\mp} + \tilde{\chi}_1^0$$

264 154 hard soft 137

- **Two edges** in the dilepton mass (for **L**eft/**R**ight slepton chains)

$$m(ll)^{max} = \left[\frac{(m^2_{\tilde{\chi}_2^0} - m^2_{\tilde{l}_{L,R}})(m^2_{\tilde{l}_{L,R}} - m^2_{\tilde{\chi}_1^0})}{m^2_{\tilde{l}_{L,R}}} \right]^{1/2}$$



- After **Left**/**Right** slepton decay chain identification, ***near*** and ***far*** leptons are distinguishable with high probability from their momenta.

SU3 point kinematics

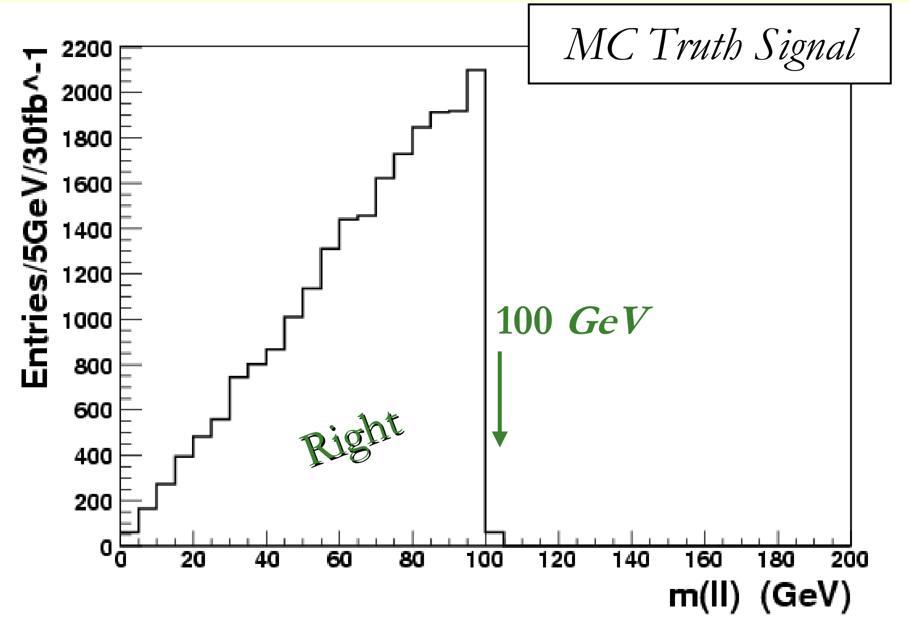
- Only the right slepton decay $\tilde{\chi}_2^0 \to \tilde{l}_R^{\pm}\, l^{\mp}$ is allowed in SU3

(masses are: $m_{\tilde{\chi}_2^0} = 219\, GeV$, $m_{\tilde{l}_L} = 230\, GeV$, $m_{\tilde{l}_R} = 155\, GeV$)

$$\underset{}{\tilde{q}_L} \to q\, \underset{219}{\tilde{\chi}_2^0} \to q\, \underset{155}{\tilde{l}_R}\, l^{\pm} \to q l^{\pm} l^{\mp} + \underset{118}{\tilde{\chi}_1^0}$$

- **One edge** in the dilepton mass (for **R**ight slepton chain).

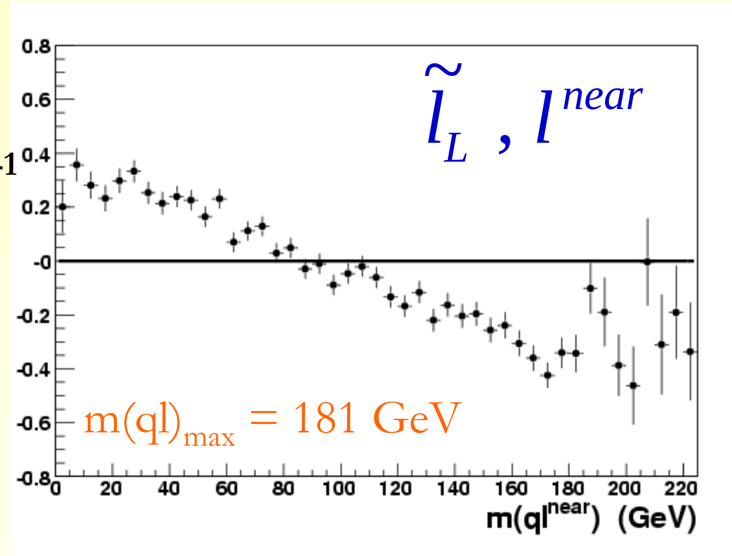
- Here ***near*** and ***far*** leptons are undistinguishable.

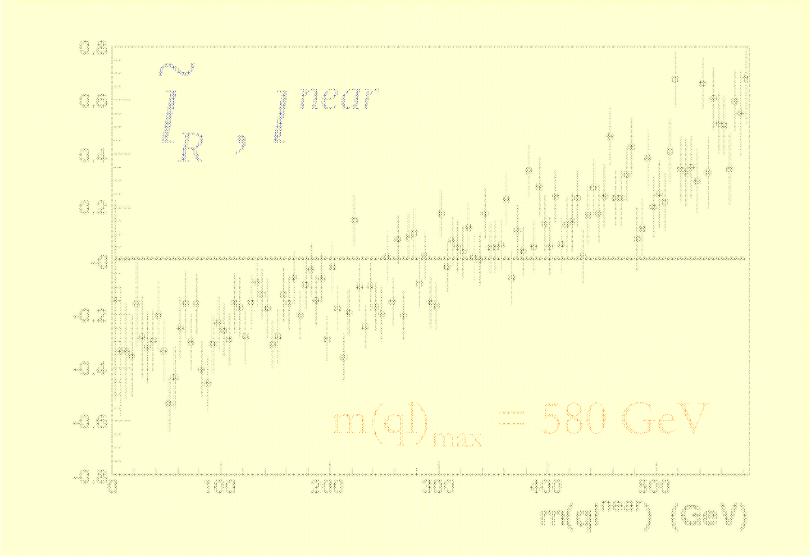


$m(ql^{\pm})$ asymmetry for MC truth signal

SU1

L=220 fb^{-1}
generated sample





In SU1, the ***Left Near*** scenario looks to be the most promising:

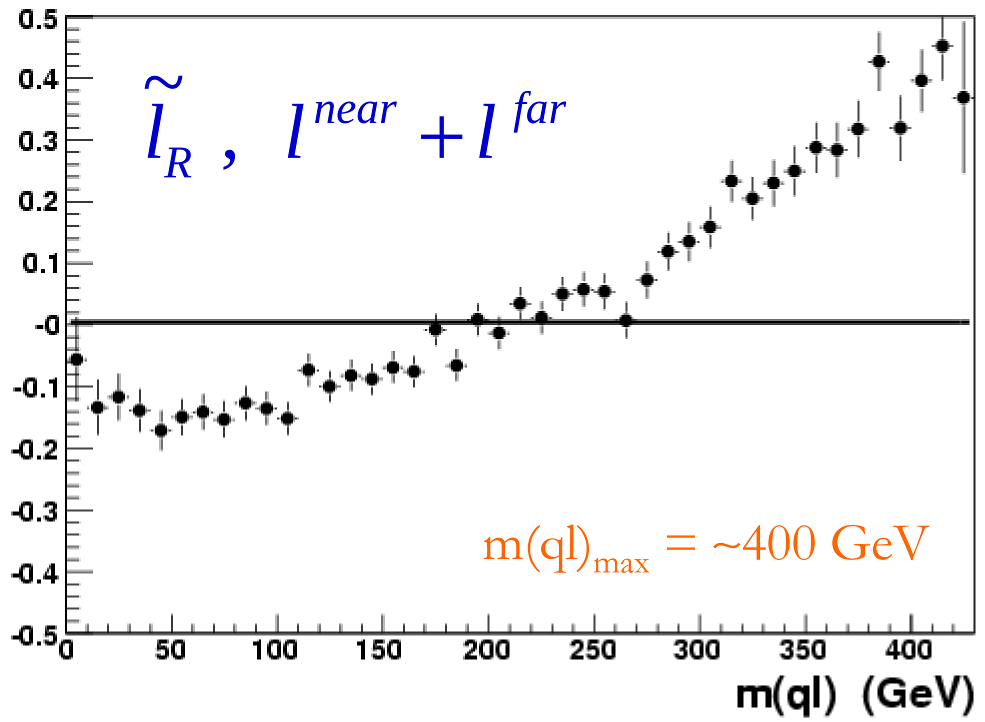
- Charge asymmetry is the most enhanced.
- No significant contamination from **Z** , asking **m(ll) < m(ll)$^{L}_{max}$**

Only this case has been considered from now on.

m(ql$^{\pm}$) asymmetry for MC truth signal

SU3

L=30 fb^{-1} generated sample



Even if ***near*** and ***far*** leptons are not distinguishable, in SU3 point charge asymmetry is <u>more pronounced</u> than in SU1, owing to the larger cross section and to the higher branching ratios of decays involved in the left squark cascade decay.

Event selection

- $E_T^{miss} > 100$ GeV
- At least 4 jets
  - $p_T(j_1) >$ **100 GeV**,
  - $p_T(j_i) >$ **50 GeV** , i=2,3,4

Preselection cuts
Mostly against Standard Model

- Two SFOS leptons
  - $p_T(l) >$ **6 GeV** *(for SU1)*, **10 GeV** *(for SU3)*
  - $|\eta|<$**2.5**, $E_T^{isol}<$**10 GeV** in $\Delta R<0.2$

Lepton selection
Cuts on single isolated leptons

- m(ll) < 100 GeV
- m(jll) < 615 GeV *(for SU1)*
  < 500 GeV *(for SU3)*

Analysis cuts
Based on model kinematics, to be applied after observing invariant mass endpoints

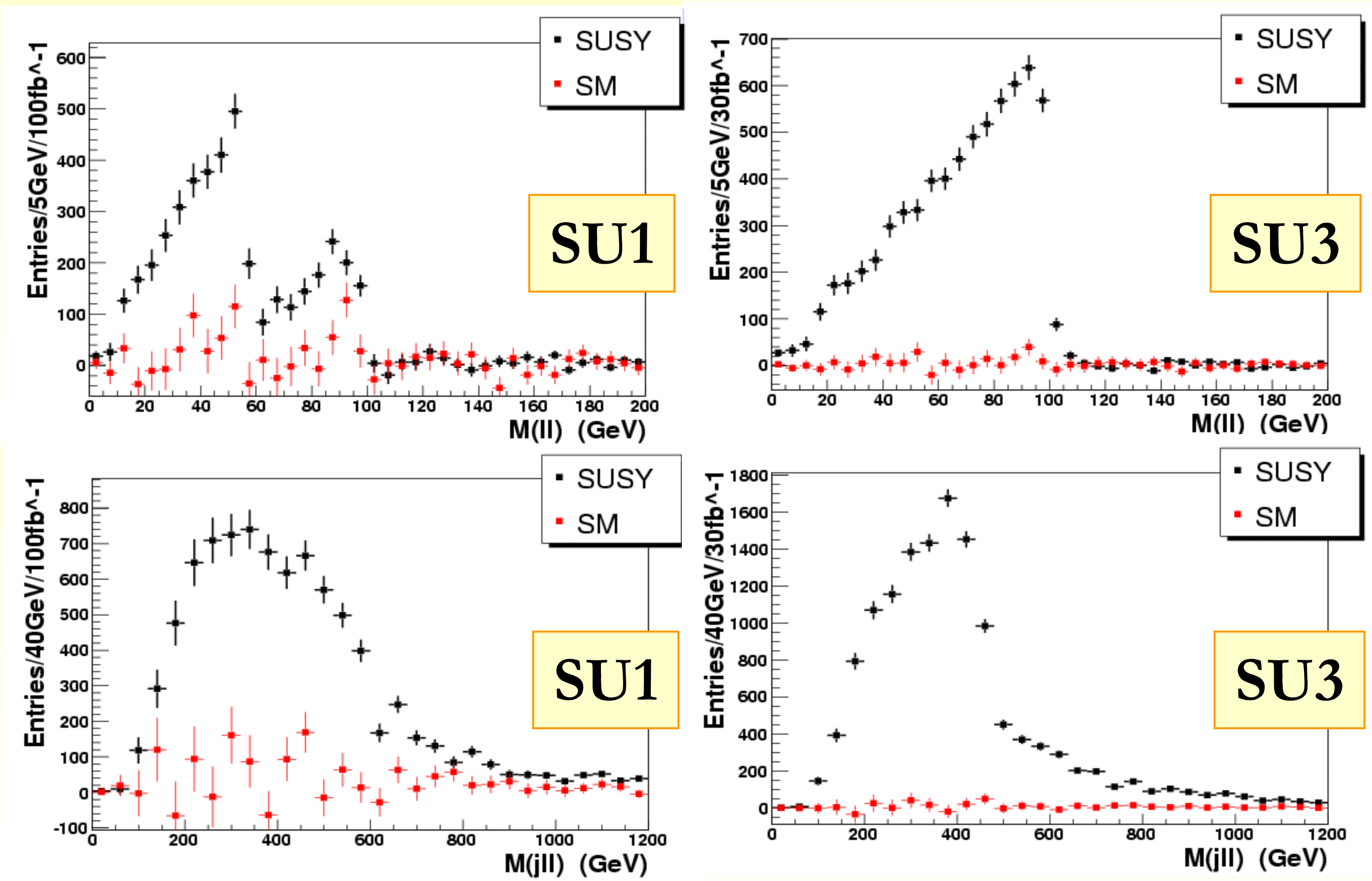
- In SU1, the decay chain with **L**eft/**R**ight slepton is selected according to dilepton mass: **N**ear/**F**ar leptons are discriminated by their p_T

Left : **m(ll) < 57 *GeV***
Right : **57 *GeV* < m(ll) < 100 *GeV***

Reconstructed invariant masses

- Simulated (*fast*) **SM** processes:
  - $t\bar{t}$ + jets
  - W+jets
  - Z+jets

- The first two energetic jets in the event are used to form **m(jll)**: no significant effect on $\mathbf{A}_{ql}$ due to wrong jet



- Events with two opposite-flavour opposite-sign (**OFOS**) leptons are kept and statistically subtracted to SFOS events to cancel background from uncorrelated lepton pairs: $\mu^+\mu^- + e^+e^- - \mu^\pm e^\mp$

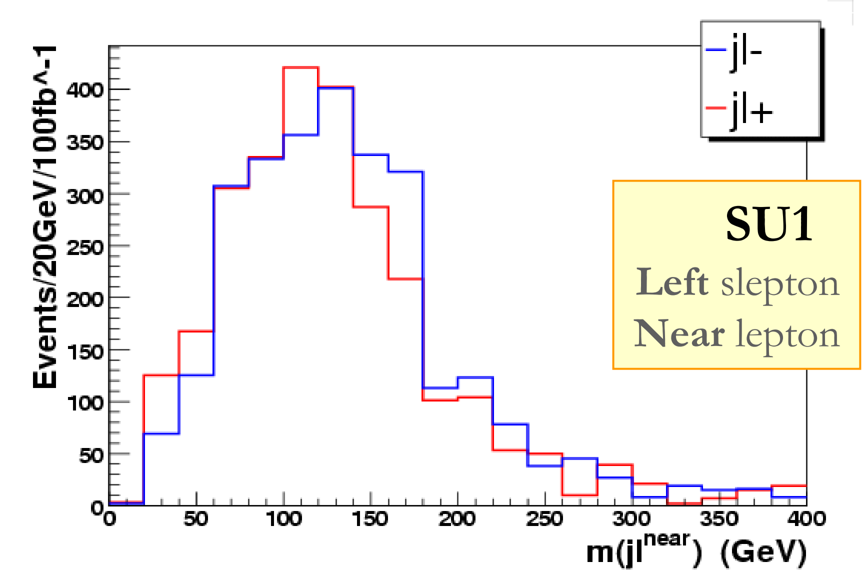
Efficiencies and contaminations

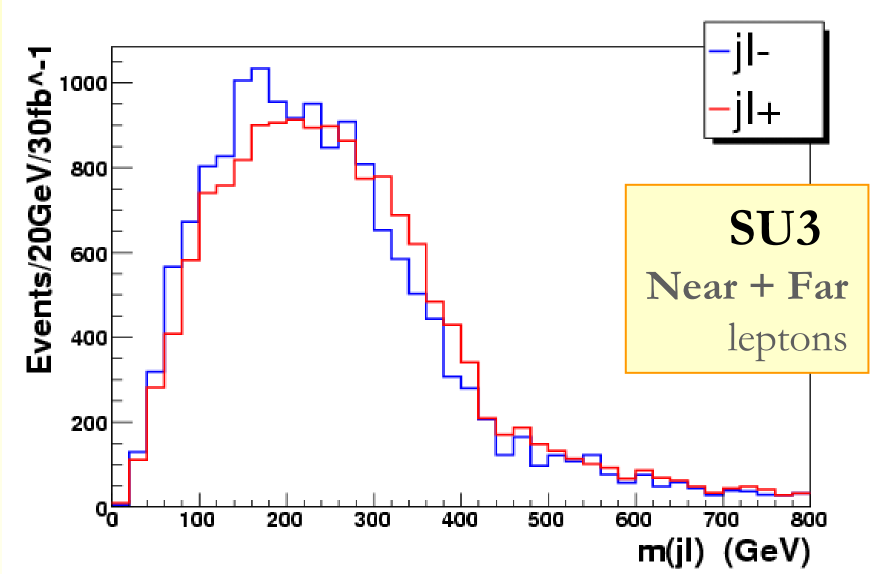
- Before *OFOS subtraction*

Before ***OFOS subtraction***	Efficiency (SU1)	S/B (SU1)	Efficiency (SU3)	S/B (SU3)
Signal	(17.0 ± 0.3) %	/	(20.0 ± 0.3)%	/
SUSY Background	(0.94 ± 0.01)%	0.33	(0.75 ± 0.01)%	1
$t\bar{t}$ + 0 jets ($l\nu qq$)	$(1.3 \pm 0.3)\ 10^{-6}$	~80	$(4 \pm 1)\ 10^{-7}$	~1500
$t\bar{t}$ + 1 jets ($l\nu qq$)	$(2.9 \pm 0.2)\ 10^{-5}$	6.3	$(1.2 \pm 0.1)\ 10^{-5}$	90
$t\bar{t}$ + 2 jets ($l\nu qq$)	$(1.3 \pm 0.1)\ 10^{-4}$	3.5	$(5.9 \pm 0.4)\ 10^{-5}$	45
$t\bar{t}$ + $\geq$ 3 jets ($l\nu qq$)	$(5.3 \pm 0.2)\ 10^{-4}$	2.6	$(2.3 \pm 0.1)\ 10^{-4}$	37
$t\bar{t}$ + 0 jets ($l\nu l\nu$)	$(1.9 \pm 0.4)\ 10^{-6}$	~200	$(3.0 \pm 0.5)\ 10^{-6}$	~1000
$t\bar{t}$ + 1 jets ($l\nu l\nu$)	$(1.5 \pm 0.1)\ 10^{-4}$	4.8	$(2.2 \pm 0.1)\ 10^{-4}$	20
$t\bar{t}$ + 2 jets ($l\nu l\nu$)	$(2.93 \pm 0.04)\ 10^{-3}$	0.64	$(3.89 \pm 0.05)\ 10^{-3}$	2.9
$t\bar{t}$ + $\geq$ 3 jets ($l\nu l\nu$)	(1.65 ± 0.02) %	0.34	(2.10 ± 0.02) %	1.6
W + 4 jets ($l\nu l\nu$)	$(1 \pm 1)\ 10^{-5}$	24	$(2 \pm 2)\ 10^{-6}$	~1000
W + $\geq$ 5 jets ($l\nu l\nu$)	$(2 \pm 2)\ 10^{-5}$	50	$(1 \pm 1)\ 10^{-5}$	~500
Z + 3 jets	$(3.1 \pm 0.4)\ 10^{-5}$	~500	$(3.1 \pm 0.4)\ 10^{-5}$	~2000
Z + 4 jets	$(2.0 \pm 0.1)\ 10^{-3}$	27	$(1.7 \pm 0.1)\ 10^{-3}$	~200
Z + $\geq$ 5 jets	$(7.0 \pm 0.2)\ 10^{-3}$	24	$(5.6 \pm 0.2)\ 10^{-3}$	~200

- After ***OFOS subtraction*** :
  - most of irreducible background comes from **SUSY** *(e.g.: correlated leptons from direct/indirect χ_2^0 production)*, with S/B > 1 *(for SU1)*
  - **SM** background from ttbar/W+jets becomes compatible with 0. Small Z+jets fraction survives.

m(jl$^{\pm}$) reconstructed distributions





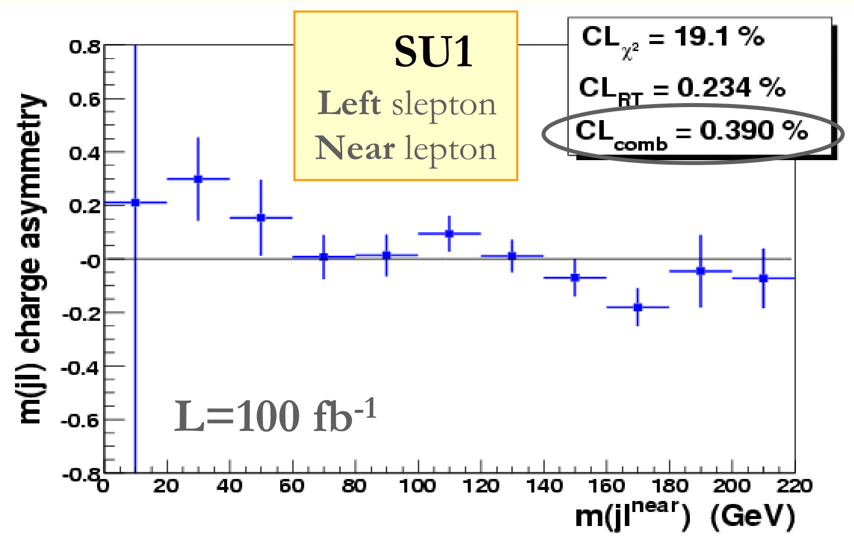
- After event selection and OFOS subtraction, reconstructed m(jl$^+$) and m(jl$^-$) are taken bin-by-bin to get asymmetry:

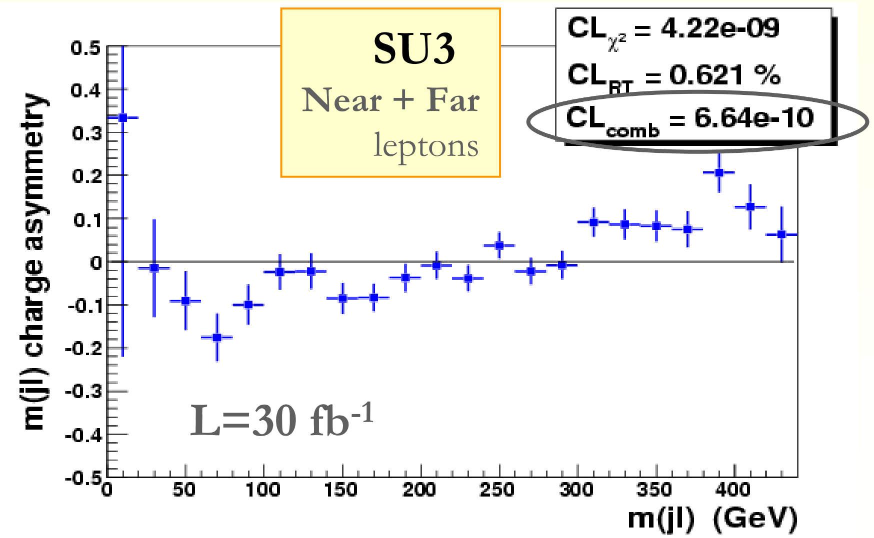
$$A_{ql,i} = \frac{m_i(jl^+) - m_i(jl^-)}{m_i(jl^+) + m_i(jl^-)}$$

- Suitable binning to get a compromise between:
  - good granularity in m(jl),
  - proper statistical treatment of asymmetry and errors.
- m(jl) ranges fixed according to endpoints and expected resolutions: **[0,220]** GeV (*for SU1*) and **[0,420]** GeV (*for SU3*)

Evaluation of $m(jl^{\pm})$ asymmetry

- Two statistical methods are used to detect a non-zero charge asymmetry:
  - a non-parametric χ^2 test to a zero constant (= hypothesis of symmetry),
  - the ***Run Test*** * method, based on the number of observed (vs. expected) fluctuations of bin contents with respect to zero.
- The two methods provide independent **confidence levels** : $CL_{\chi 2}$ and CL_{RT} , which can be combined to get CL_{comb} .
- Low confidence level ⇒ good evidence of a non-zero asymmetry.





* A.G. Frodesen, O. Skjeggestad, H. Tofte, *Probability and Statistics in Particle Physics*, Bergen, Norway: Universitetsforlaget (1979)

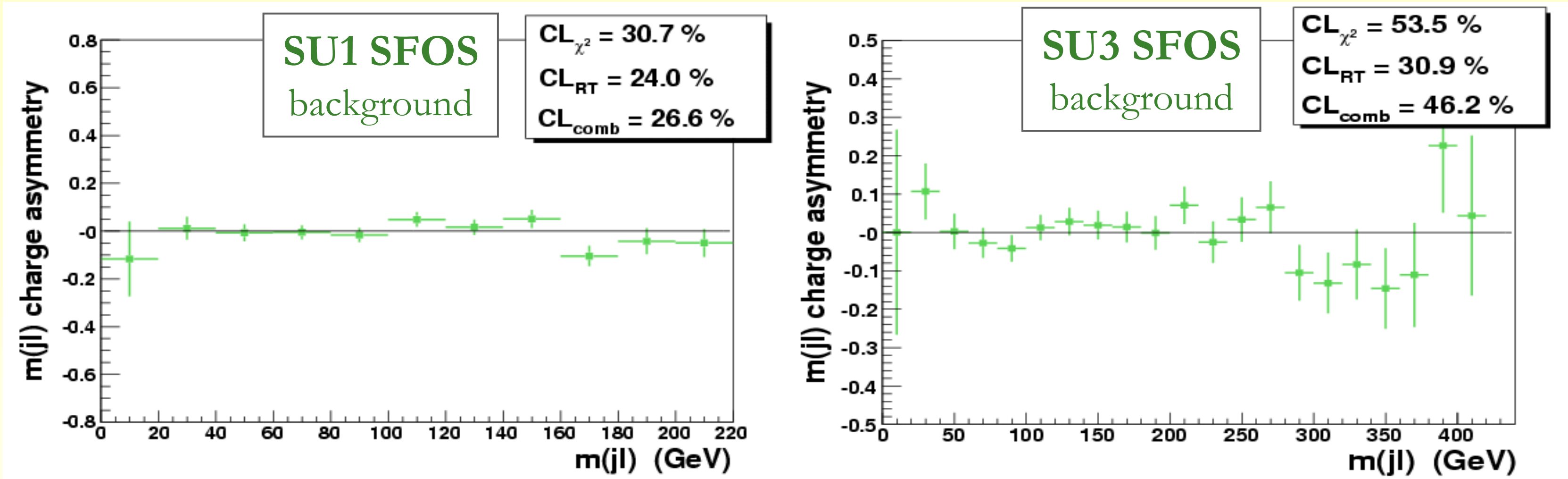
Diluting effects on m(jl$^{\pm}$) asymmetry

a) **SUSY** SFOS background contribution
b) **SUSY** OFOS contribution
c) **SM** SFOS and OFOS contributions
d) Selection of ***wrong*** **jet** in m(jl$^{\pm}$)

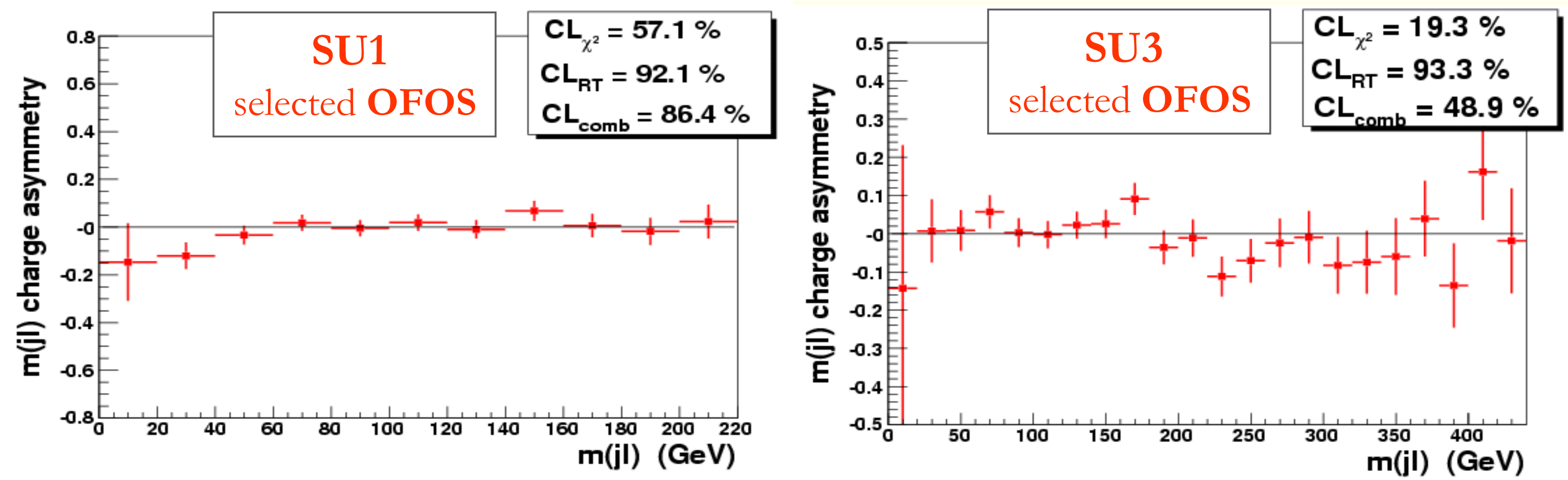
Although not definitively suppressed in the final selection, all of these **background** contributions to $\mathbf{A_{ql}}$ are proved to have a flat behaviour vs. m(jl$^{\pm}$) and not to spoil significantly the contribution given by **signal** events.

SUSY background asymmetry

a)



b)



- No relevant impact on the final $\mathbf{A_{ql}}$ asymmetry can be observed

SM background asymmetry

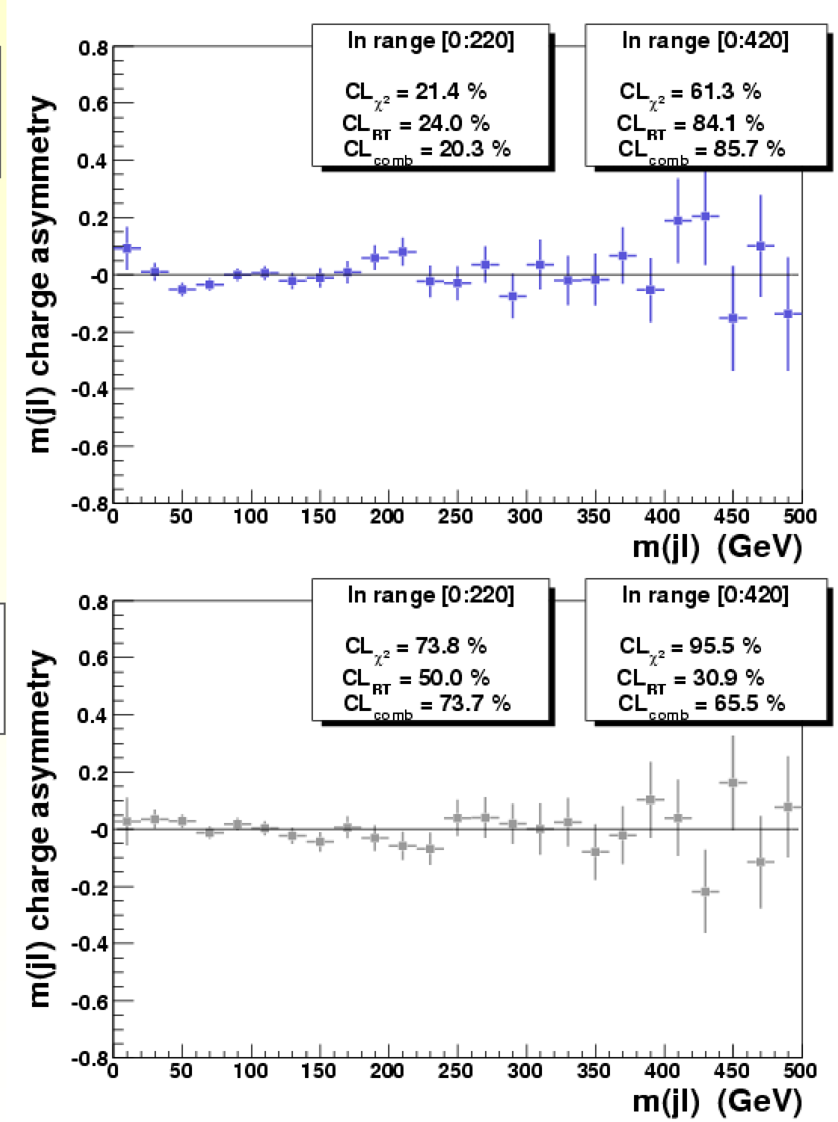
- Both **SFOS** and **OFOS** **SM** selected lepton pairs show reasonably flat charge asymmetries with high $\mathbf{CL_{comb}}$ compared to SUSY (signal+background) events.
- This is tested on both m(jl) ranges used for SU1 and SU3.
- Similar results varying bin-width and range values.

SM SFOS
background

c')

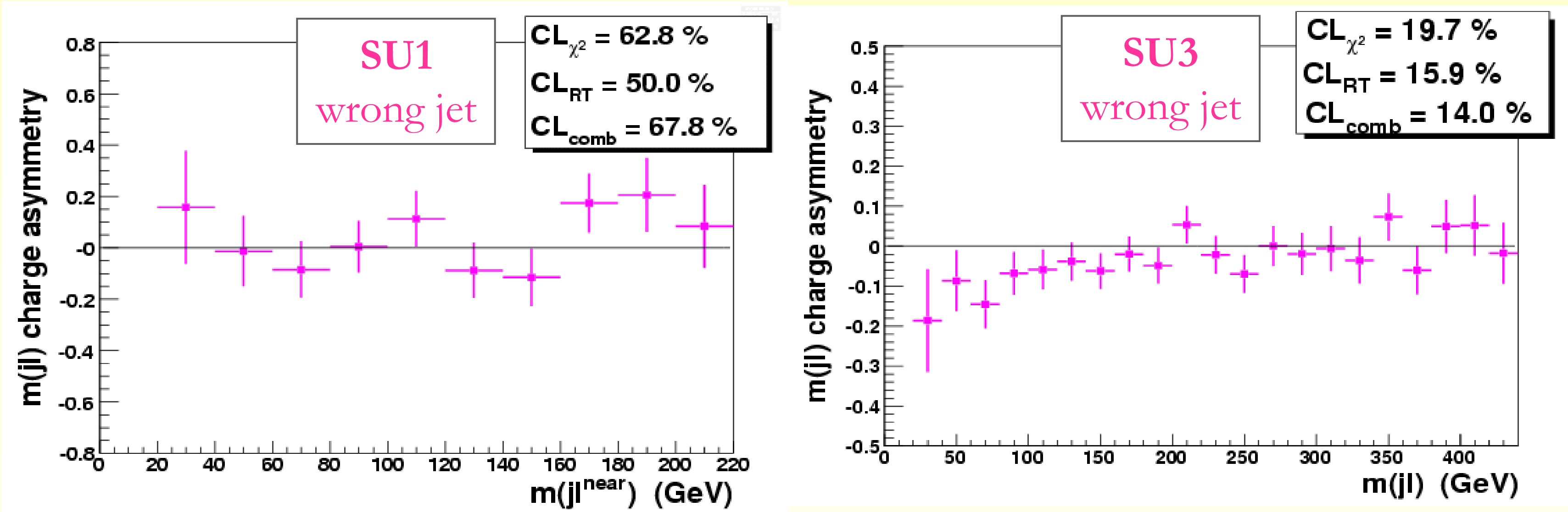
SM OFOS
selection

c'')



Wrong jet selection

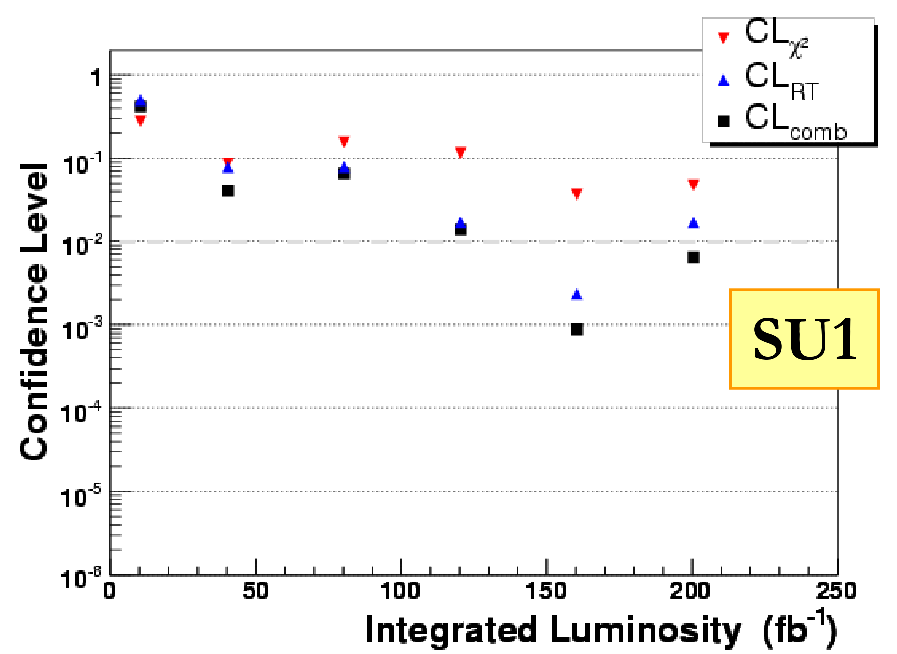
d)

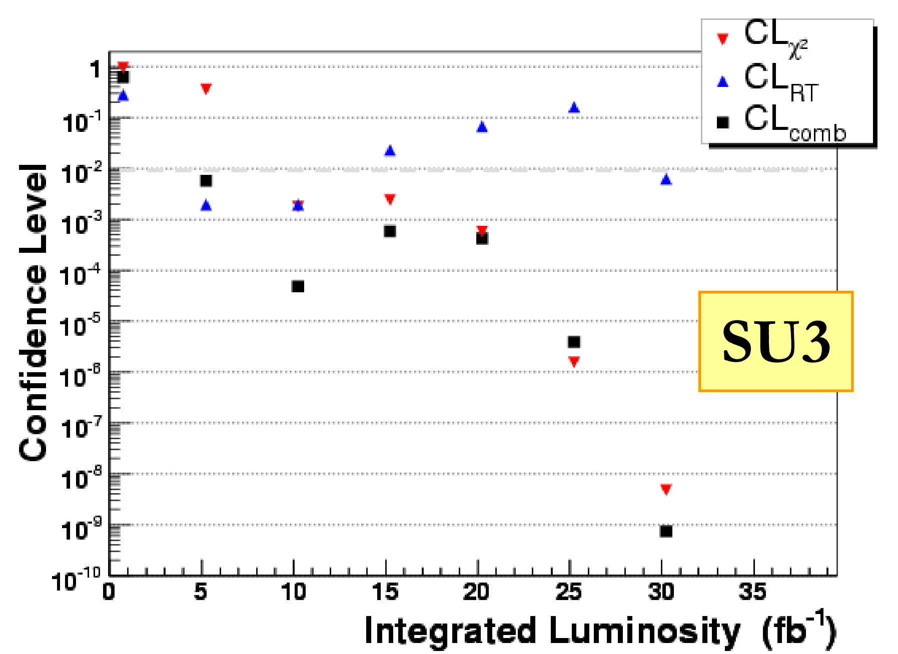


- In both SU1 and SU3 points, **SFOS** events with a wrongly selected jet (wrt the signal quark) provide no significant $m(jl^{\pm})$ asymmetry.
- Selecting the two highest p_T jets in the event systematically brings to retain (at least) one wrong jet: this is an acceptable compromise for keeping the largest possible signal yield without spoiling asymmetry.

Confidence level vs. luminosity

- Results have been obtained for different integrated luminosities.
  - In **SU1** point at least **100 fb^{-1}** are needed to observe some non-zero charge asymmetry (e.g. with CL_{comb}<**1%**).
  - For the case of **SU3** point, **5÷10 fb^{-1}** could be already enough.





Summary and conclusions

- If **SUSY** will be discovered at **LHC**, measuring properties of new particles (*e.g.* spin) is needed for demostrating that they are indeed the predicted super-partners.
- The method used here on two selected **mSUGRA** points shows that **m(ql$^{\pm}$)** charge asymmetry is detectable with few fb^{-1} (in SU3) or at least 100fb^{-1} (in SU1).
- The study must be also performed with more realistic (*full*) ATLAS simulation and for other SUSY points.
- New techniques to detect charge asymmetry and reduce diluting effects (background, systematics, etc.) are under investigation.

Backup slides

Branching ratios & mass endpoints

Point SU1

$$\sigma(\tilde{q}_R\tilde{g}) = 1.757\ pb\ , \quad \sigma(\tilde{q}_L\tilde{g}) = 1.620\ pb\ ,$$
$$\sigma(\tilde{q}_L\tilde{q}_R) = 0.885\ pb\ , \quad \sigma(\tilde{q}_L\tilde{q}_L) = 0.665\ pb\ ,$$
$$\sigma(\tilde{g}\tilde{g}) = 0.554\ pb\ , \quad \sigma(\tilde{q}_L\tilde{\chi}_2^0) = 0.154\ pb\ .$$

$$BR(\tilde{q}_L \to q\tilde{\chi}_2^0) = 31.5\,\%, \quad BR(\tilde{\chi}_2^0 \to \tilde{l}_L\,l) = 6\,\%,$$
$$BR(\tilde{\chi}_2^0 \to \tilde{l}_R\,l) = 3\,\%, \quad BR(\tilde{l}_{L,R} \to \tilde{\chi}_1^0\,l) = 100\,\%.$$

$$m(ll)^{max} = \left[\frac{(M^2_{\tilde{\chi}_2^0} - M^2_{\tilde{l}_{L,R}})(M^2_{\tilde{l}_{L,R}} - M^2_{\tilde{\chi}_1^0})}{M^2_{\tilde{l}_{L,R}}}\right]^{1/2} =$$
$$= 56.05\ \text{GeV (left)}, \quad 97.93\ \text{GeV (right)}\ ,$$
$$m(qll)^{max} = \left[\frac{(M^2_{\tilde{q}_L} - M^2_{\tilde{\chi}_2^0})(M^2_{\tilde{\chi}_2^0} - M^2_{\tilde{\chi}_1^0})}{M^2_{\tilde{\chi}_2^0}}\right]^{1/2} =$$
$$= 611.64\ \text{GeV (left, right)}\ ,$$
$$m(ql^{near})^{max} = \left[\frac{(M^2_{\tilde{q}_L} - M^2_{\tilde{\chi}_2^0})(M^2_{\tilde{\chi}_2^0} - M^2_{\tilde{l}_{L,R}})}{M^2_{\tilde{\chi}_2^0}}\right]^{1/2} =$$
$$= 180.14\ \text{GeV (left)}, \quad 580.09\ \text{GeV (right)}\ ,$$
$$m(ql^{far})^{max} = \left[\frac{(M^2_{\tilde{q}_L} - M^2_{\tilde{\chi}_2^0})(M^2_{\tilde{l}_{L,R}} - M^2_{\tilde{\chi}_1^0})}{M^2_{\tilde{l}_{L,R}}}\right]^{1/2} =$$
$$= 327.21\ \text{GeV (right)}, \quad 603.08\ \text{GeV (left)}\ .$$

Point SU3

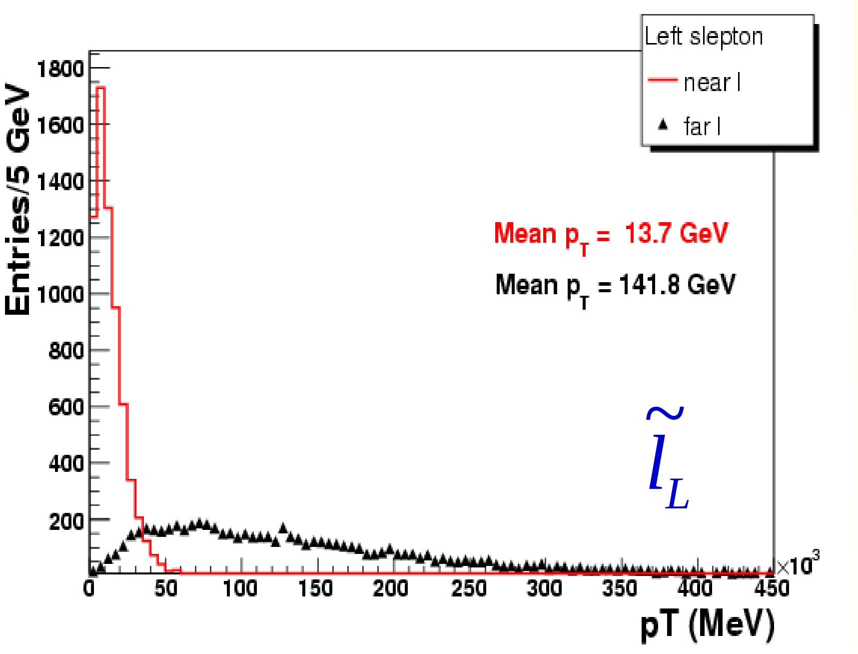
$$\sigma(\tilde{q}_R\tilde{g}) = 4.469\ pb\ , \quad \sigma(\tilde{q}_L\tilde{g}) = 4.426\ pb\ ,$$
$$\sigma(\tilde{q}_L\tilde{q}_R) = 2.085\ pb\ , \quad \sigma(\tilde{q}_L\tilde{q}_L) = 1.716\ pb\ ,$$
$$\sigma(\tilde{g}\tilde{g}) = 1.544\ pb\ , \quad \sigma(\tilde{q}_L\tilde{\chi}_2^0) = 0.203\ pb\ .$$

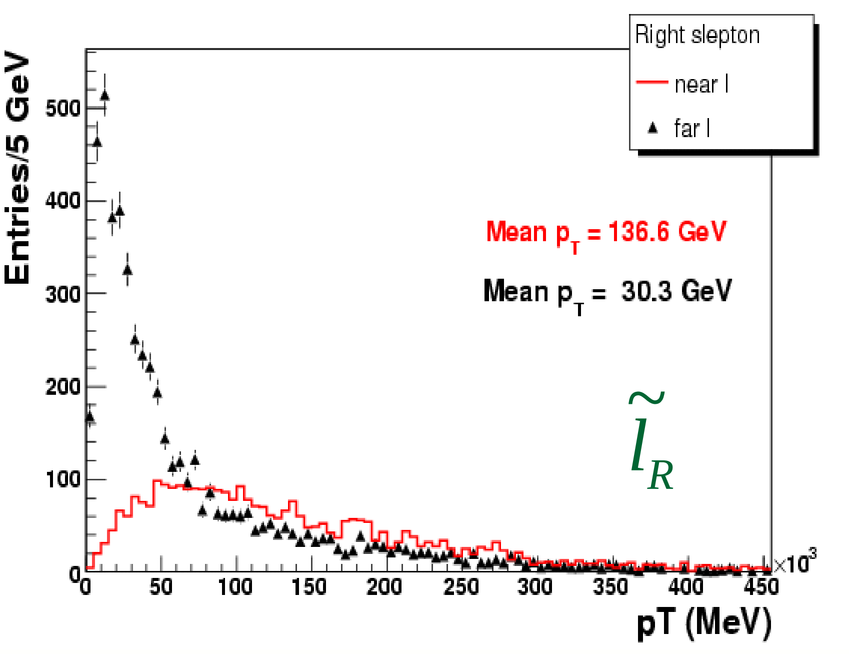
$$BR(\tilde{q}_L \to q\tilde{\chi}_2^0) = 32\,\%, \quad BR(\tilde{\chi}_2^0 \to \tilde{l}_R\,l) = 17.6\%,$$
$$BR(\tilde{l}_{L,R} \to \tilde{\chi}_1^0\,l) = 100\,\%,$$

$$m(ll)^{max} = 100.17\ \text{GeV},$$
$$m(qll)^{max} = 500.34\ \text{GeV},$$
$$m(ql^{near})^{max} = 417.74\ \text{GeV},$$
$$m(ql^{far})^{max} = 385.85\ \text{GeV}.$$

Distinguishability of leptons in SU1

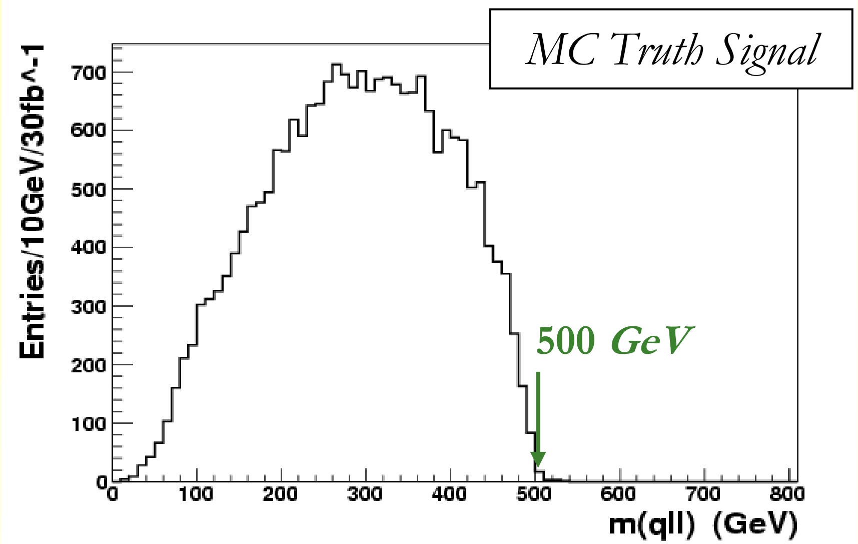
- After **Left**/**Right** slepton decay chain identification, ***near*** and ***far*** leptons are easily distinguishable from their momenta



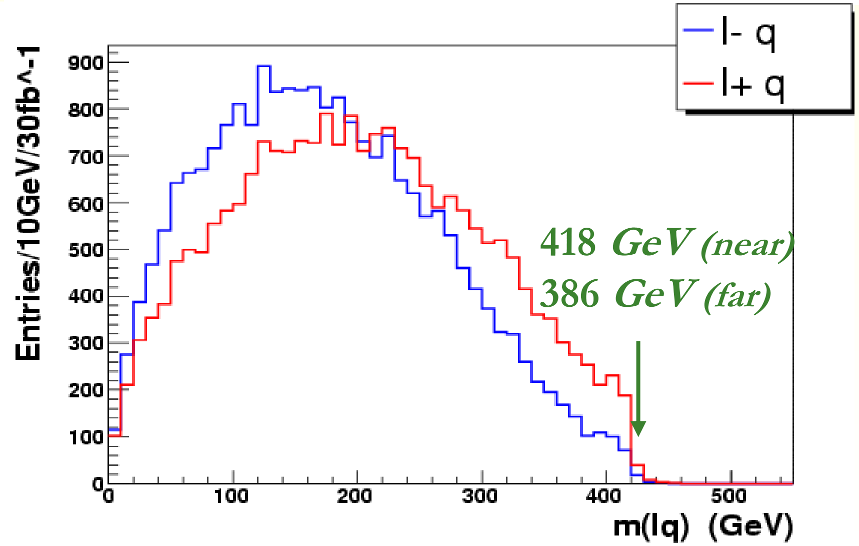


SU3 mass distributions for truth signal

- Lepton-lepton-quark invariant mass distribution



- Lepton-quark invariant mass distribution



SUSY vs. Universal Extra Dimensions

J. M. Smillie and B. R. Webber, *JHEP (2005) 069, [hep-ph/0507170]*

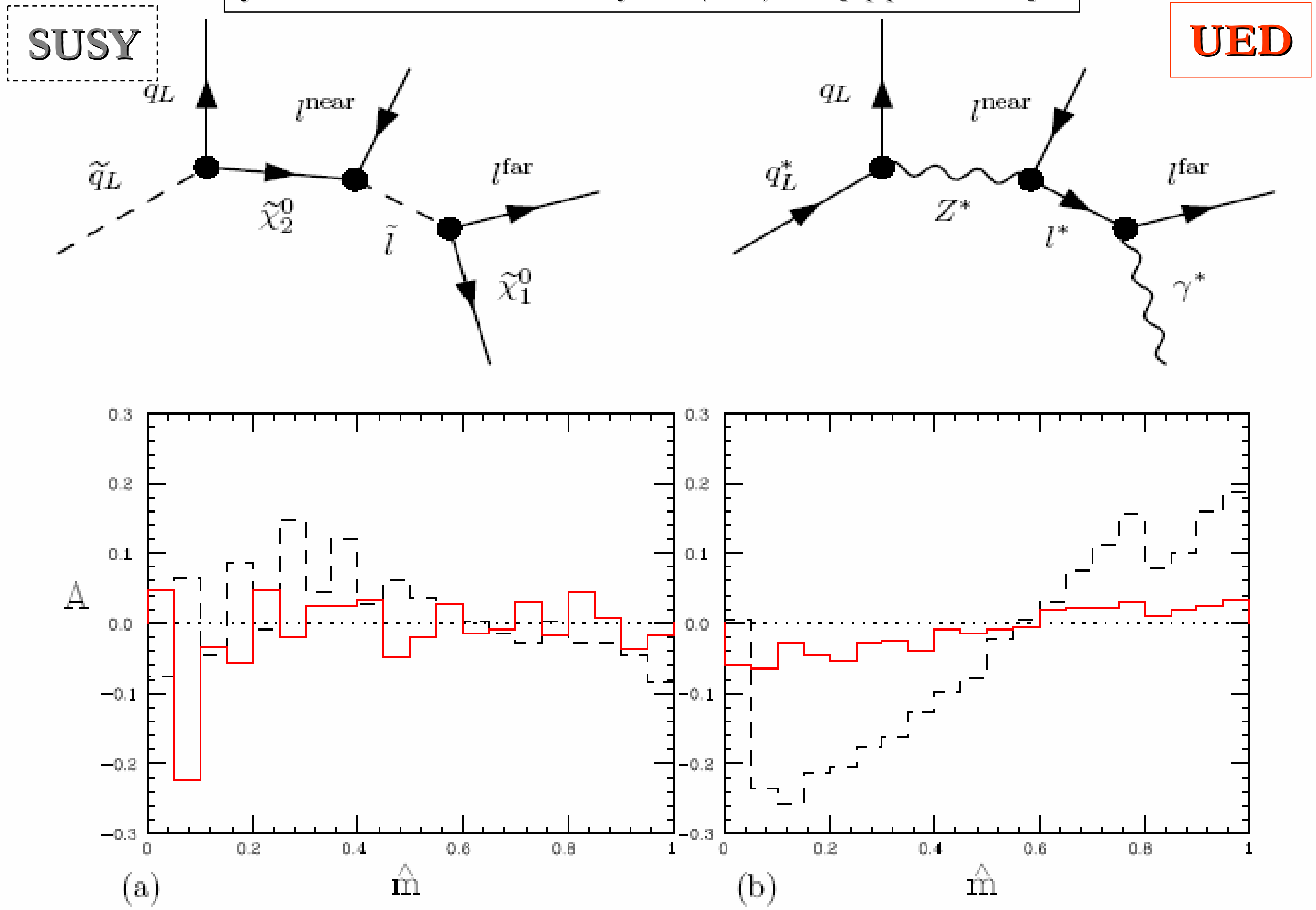


Figure 12: Detector-level charge asymmetries with respect to the jet + lepton rescaled invariant mass, for the (a) UED and (b) SUSY mass spectra given above. Dashed: SUSY. Solid/red: UED.