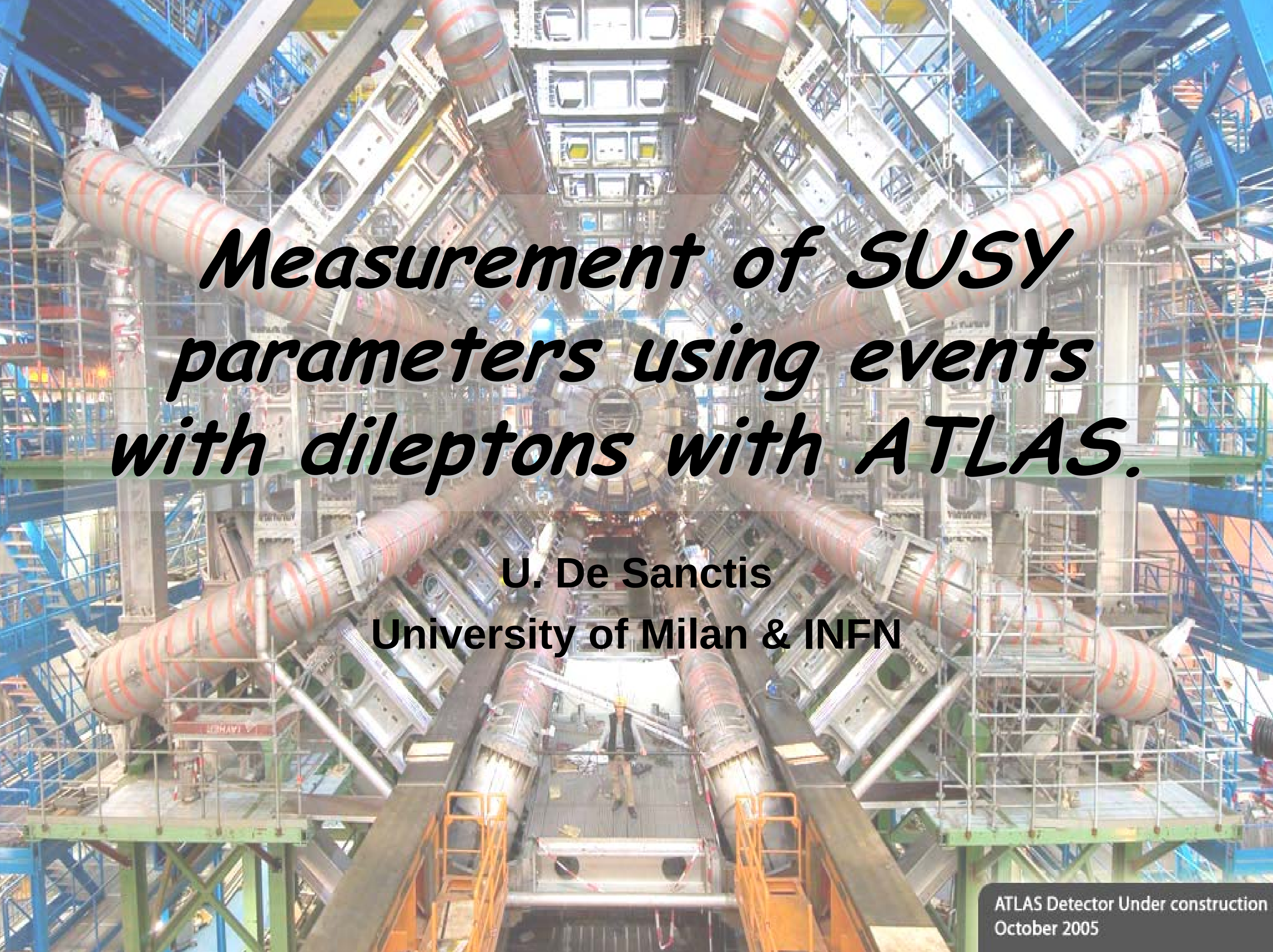


Measurement of SUSY parameters using events with dileptons with ATLAS.

U. De Sanctis
University of Milan & INFN

ATLAS Detector Under construction
October 2005

Outline

- Reminder of SUSY and mSUGRA framework;
- Topology of the SUSY events;
- Leptons identification;
- Measurement of masses and other properties of SUSY particles in the 2-lepton channel.
- Extracting masses and parameters from measurements

SUPERSYMMETRY REMINDER

Adds to each SM **fermion** (**boson**) a **bosonic** (**fermionic**) partner.

SM Particles	SUSY Particles		
quarks: q	q	squarks: $\tilde{q}$	
leptons: l	l	sleptons: $\tilde{l}$	
gluons: g	g	gluino: $\tilde{g}$	
charged weak boson: $W^{\pm}$	$W^{\pm}$	Wino: $\tilde{W}^{\pm}$	$\tilde{\chi}^{\pm}_{1,2}$ chargino
Higgs: H^0	$H^{\pm}$	charged higgsino: $\tilde{H}^{\pm}$	$\tilde{\chi}^{\pm}_{1,2}$ chargino
	h^0, A^0, H^0	neutral higgsino: $\tilde{h}^0, \tilde{A}^0$,	$\tilde{\chi}^{0}_{1,2,3,4}$ neutralino
neutral weak boson: Z^0	Z^0	Zino: $\tilde{Z}^0$	$\tilde{\chi}^{0}_{1,2,3,4}$ neutralino
photon: γ	γ	photino: $\tilde{\gamma}$	$\tilde{\chi}^{0}_{1,2,3,4}$ neutralino

- **R-parity** $R=(-1)^{3(B-L)+2S}$ can be conserved (**RPC**) or violated (**RPV**)
- **RPC** implies:
  - SUSY particles produced in pairs
  - stable and neutral lightest SUSY particle (**LSP**)
  - no proton decay
- **LSP** is a good candidate for cold **Dark Matter**

MSSM Lagrangian depends on 105 parameters

mSUGRA requires only 5 parameters

- Also other SUSY models exist: **GMSB**, **AMSB**, …

Par.	Description
m_0	Common scalar mass
$m_{1/2}$	Common gaugino mass
A_0	Common trilinear term
$\tan\beta$	Ratio of Higgs vev
sign(μ)	μ from Higgs sector

mSUGRA benchmark points

SUSY benchmark points chosen in the **(m_0, $m_{1/2}$)** plane for different **tan**β values:

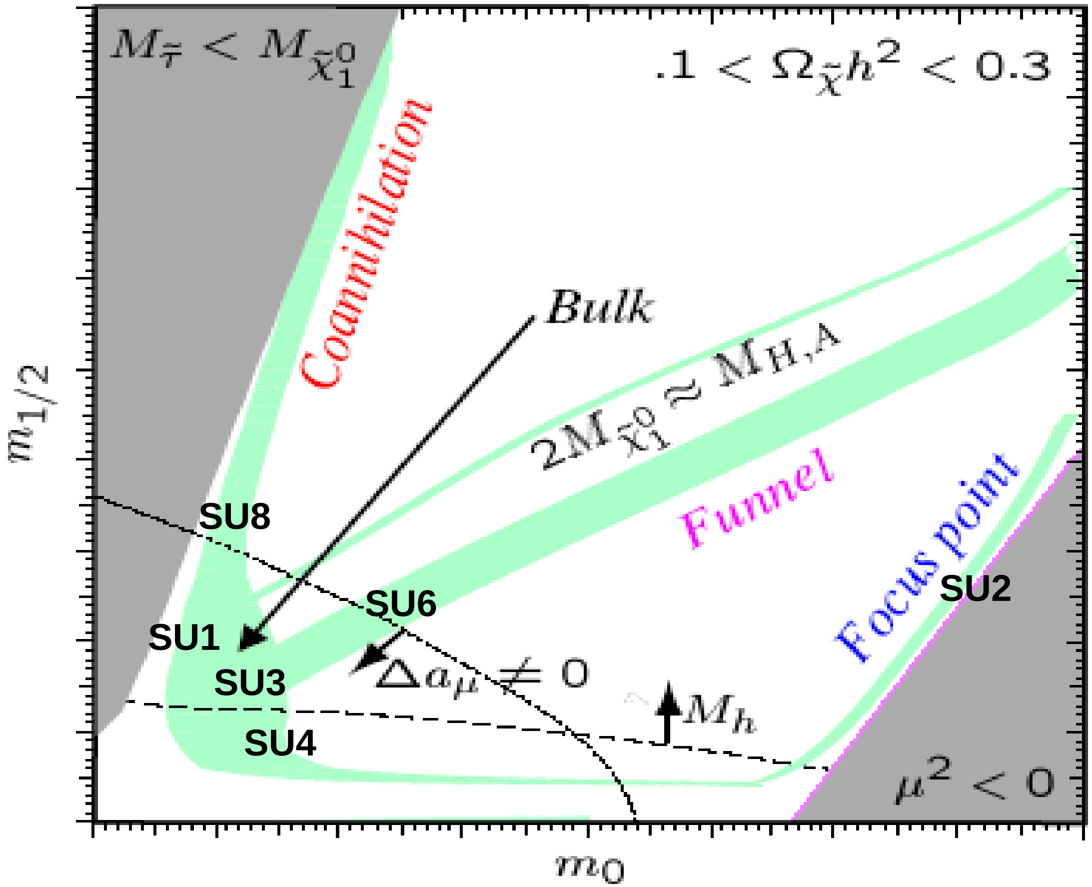
- ✓ Systematically exploring phenomenological signatures
- ✓ Scanning the parameter phase space constrained by latest experimental data and Cold Dark Matter abundance.

Coannihilation: Light $\tilde{\tau}_1$ in equilibrium with $\tilde{\chi}_1^0$, so annihilate via $\tilde{\chi}_1^0 \tilde{\tau}_1 \to \gamma\tau$.

Bulk: bino $\tilde{\chi}_1^0$; light $\tilde{\ell}_R$ enhances annihilation.

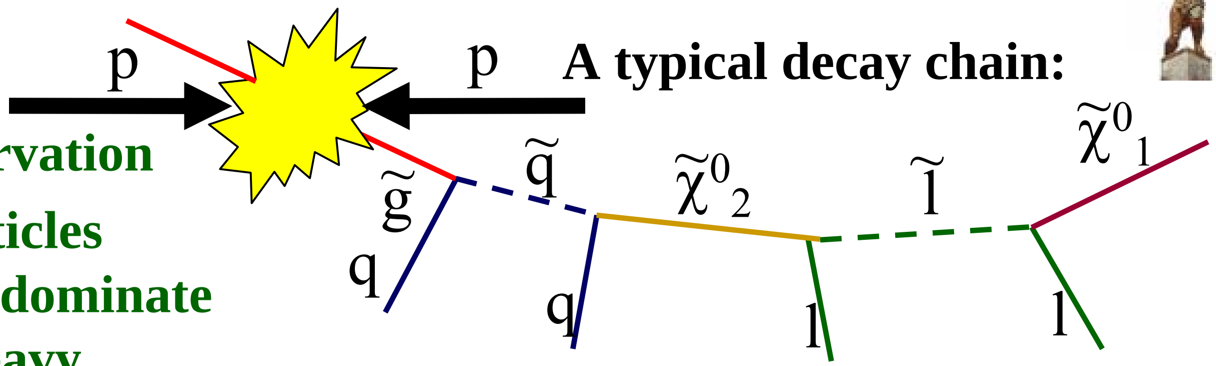
Funnel: H,A poles enhance annihilation for $\tan\beta \gg 1$.

Focus point: Small μ^2, so Higgsino $\tilde{\chi}_1^0$ annihilate. Heavy s-fermions, so small FCNC.



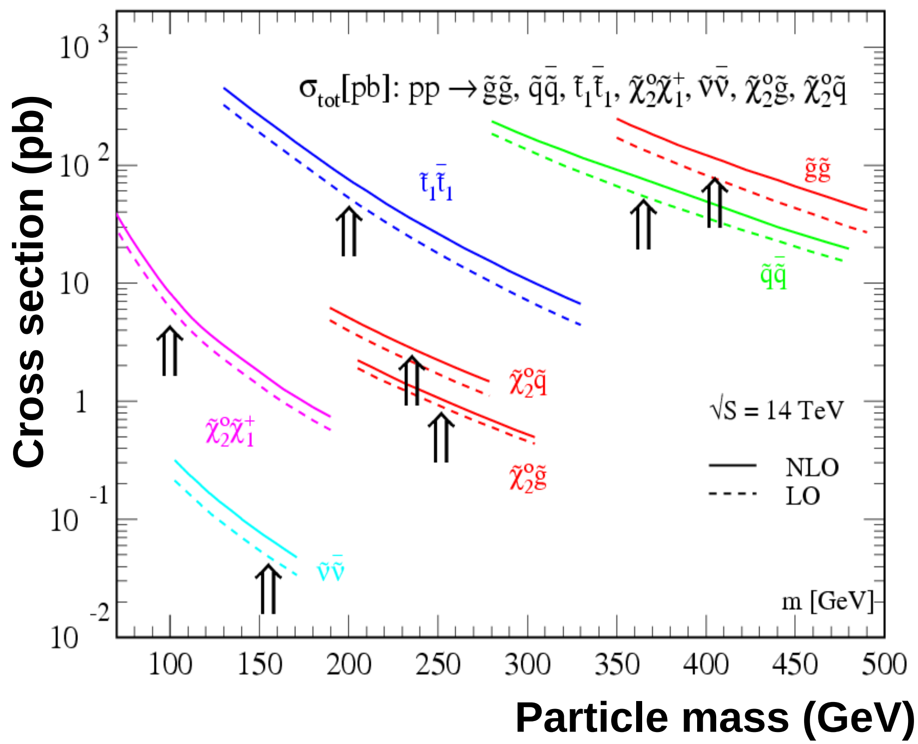
SUSY signatures at an hadronic collider

A typical decay chain:



- **Assuming R-parity conservation**
- **Strongly interacting sparticles (squarks, gluinos) should dominate production unless very heavy.**
- **Cascade decays to the stable, weakly interacting lightest neutralino follows.**
- **Event topology:**
  - **high p_T jets (from squark/gluino decay)**
  - **Large E_T^{miss} signature (from LSP)**
  - **High p_T leptons, b-jets, τ-jets (depending on model parameters).**

Several other possibilities exist, but our effort has to be as more "model independent" as possible.

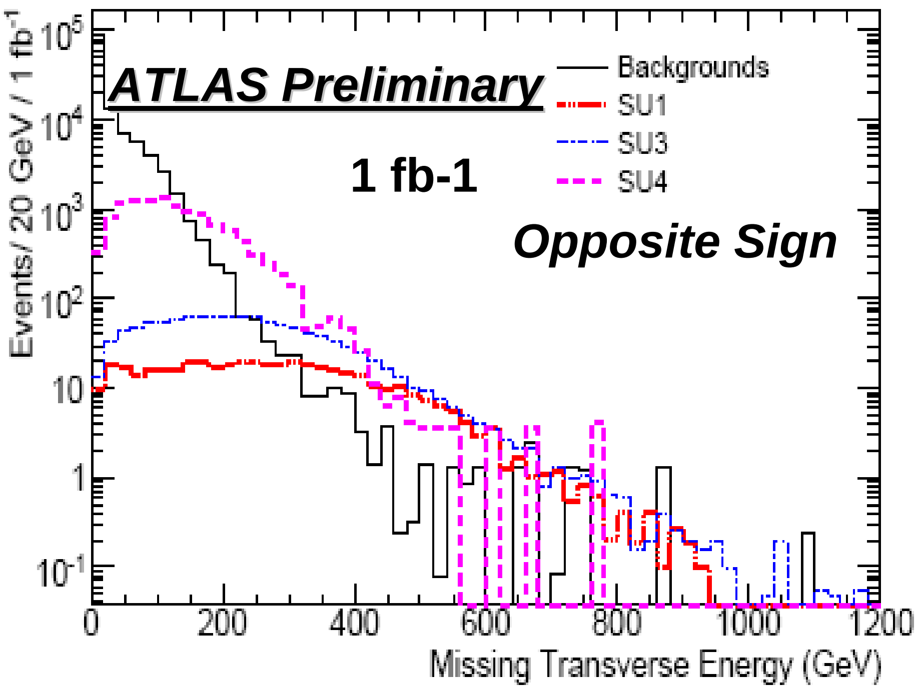


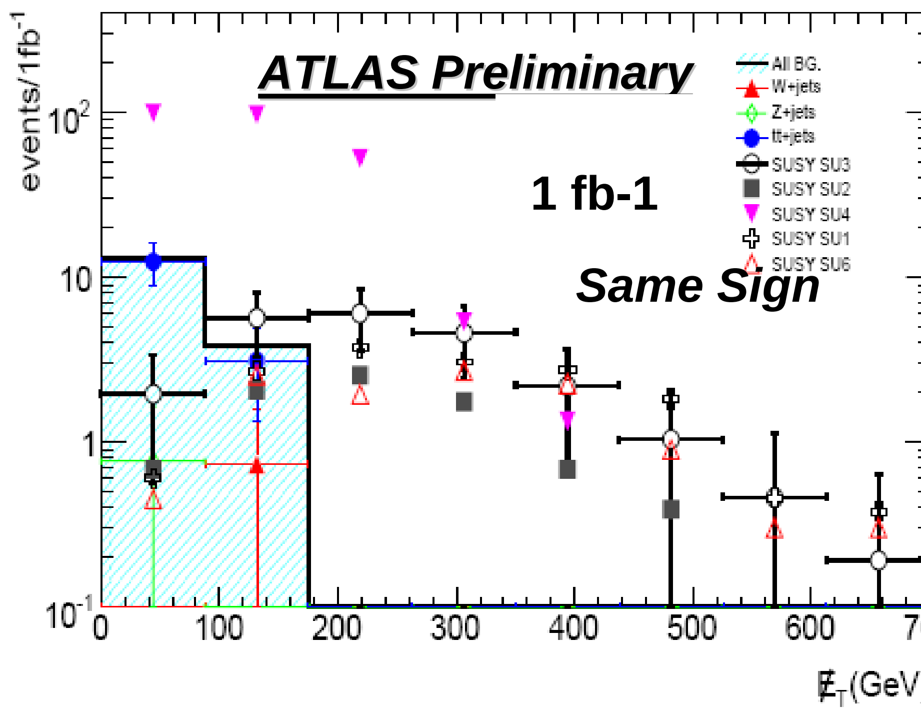
2-lepton channel: strengths and weaknesses

– Reduces the signal because of (model dependent) leptonic BRs;
– Heavily suppresses the background: top is the dominant one;
– Statistical significance is smaller but S/B ratio larger.
– The Same Sign channel has the best S/B ratio – but limited by signal rate

<u>Baseline selection :</u>

- Jet multiplicity ≥ 4, $p_T^{1st} > 100GeV$, $p_T^{others} > 50GeV$
- $E_T^{miss} > max(100GeV, 0.2xM_{eff})$; Transverse sphericity > 0.2 .





Electron & Muon selections for 2-leptons channel

- $P_t > 10$ GeV, $|\eta|<2.5$;
- Calorimetric isolation < 10 GeV in a 0.2 radius cone;
- Combined muons (e.g. using information from both the muon spectrometer and the Inner Detector)
- Overlap removal procedure.

  Say ΔR (muon, jet) the distance muon-jet in (η,ϕ) plane:

  - if $\Delta R < 0.4$ → muon discarded

- $P_t > 10$ GeV, $|\eta|<2.5$;
- Calorimetric isolation < 10 GeV in a 0.2 radius cone;
- If an electron is found in the $1.37 < |\eta| < 1.52$ region, the event is rejected (ID services and ECAL barrel-extended barrel transition worsen the performances);
- Overlap removal procedure.

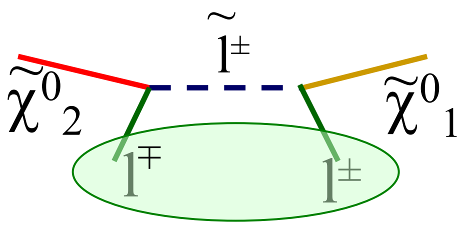
  Say ΔR (e, jet) the distance electron-jet in (η,ϕ) plane:

  - if $\Delta R < 0.2$ → jet discarded

  - if $0.2 < \Delta R < 0.4$ → electron discarded.

Di-Lepton Edge mass measurement (1)

- In case of a discovery of SUSY, **particle properties** can be measured to verify that they are indeed SUSY partners



- Edge(s) of **di-lepton invariant mass** correlated with slepton and neutralino masses

$$\tilde{\chi}^0{}_2 \rightarrow \tilde{l}\, l \rightarrow \tilde{\chi}^0{}_1 \; l^+ l^-$$

- Impossible to reconstruct peaks because $\chi^0{}_1$ (LSP) escapes detection, more complicated relations between masses of particles involved.

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

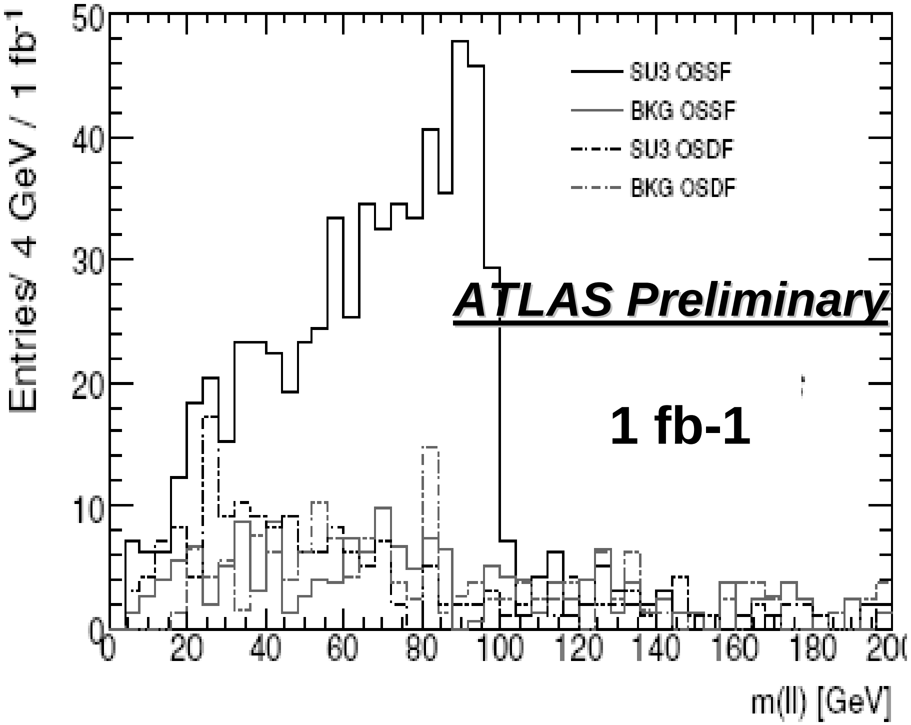
- ✓ Uncorrelated (SUSY+SM) background (two leptons from independent chains) **removed** by **flavour subtraction**:

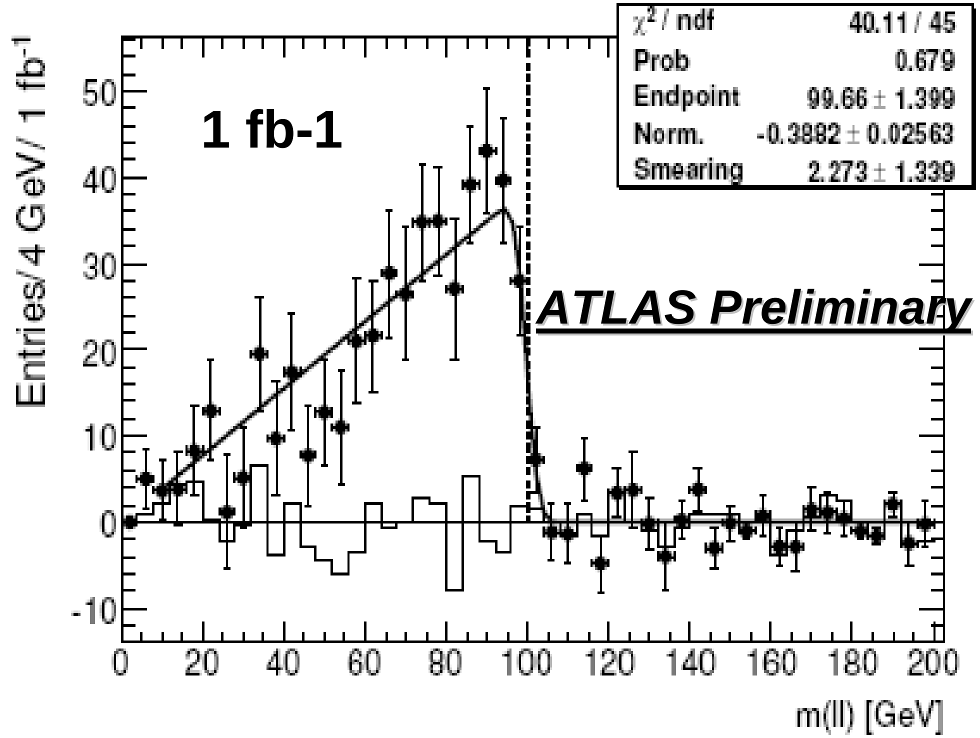
  $e^+e^- + \beta^2 \mu^+\mu^- - \beta\, (e^+\mu^- - e^-\mu^+)$, $\beta = \varepsilon_e / \varepsilon_\mu$

- ✓ Leptons can also be combined with jets of the full decay chain to look for other **kinematical edges** (M_{llj} or M_{lj})

Di-Lepton Edge mass measurement (2)

Flavour subtraction at work….





SU3, 1 fb^{-1}
Edge: (99.7±1.4) GeV
Truth: 100.2 GeV

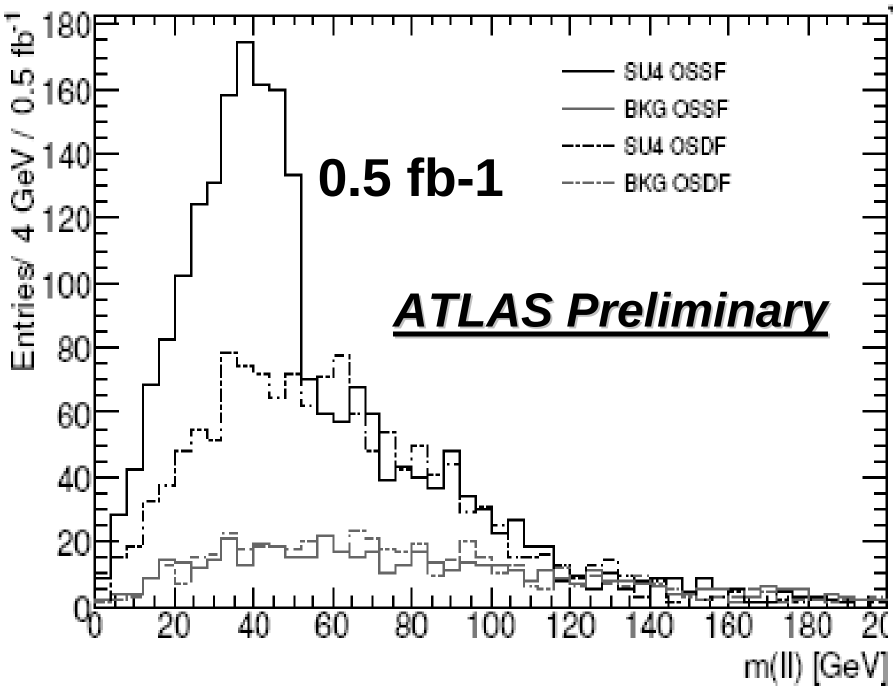
Flavour Subtraction

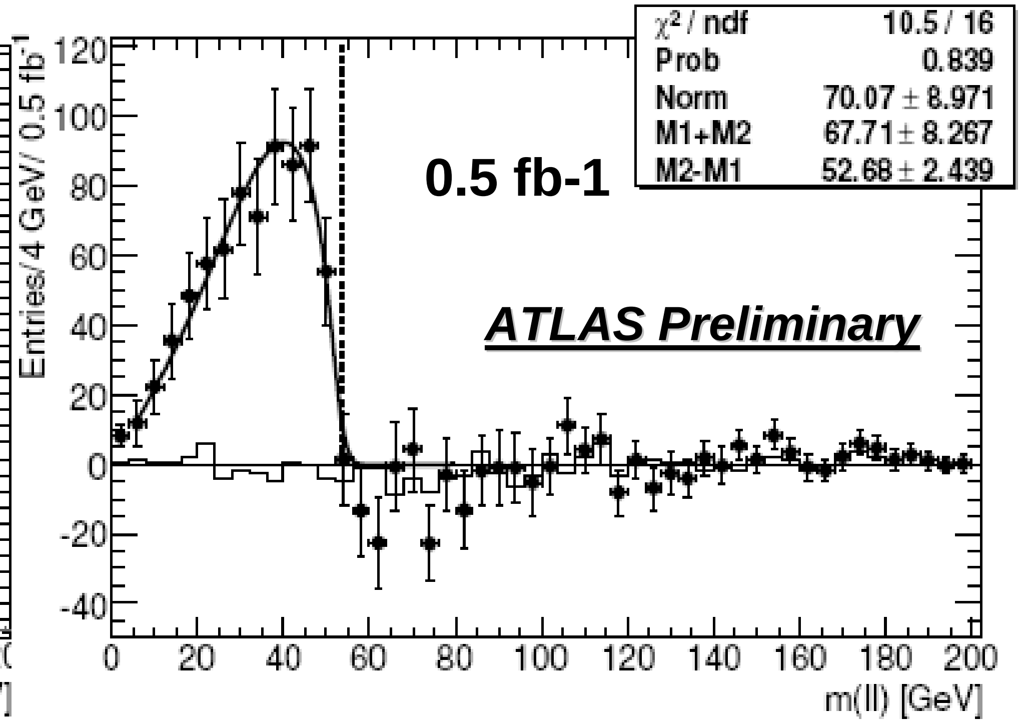
Fitting function:
Triangle smeared with a Gaussian with $\sigma = 2$ GeV (to take into account experimental resolution)

Di-Lepton Edge mass measurement (3)

For **SU4**, the slepton is heavier than χ_2^0 → The decay is: $\chi_2^0 \rightarrow \chi_1^0 l^+ l^-$

$$\frac{d\Gamma}{dM_{\rm inv}} = 2CM_{\rm inv}\frac{\sqrt{M_{\rm inv}^4 - M_{\rm inv}^2(\mu^2+M^2)+(\mu M)^2}}{(M_{\rm inv}^2 - m_Z^2)^2}\cdot\left[-2M_{\rm inv}^4 + M_{\rm inv}^2(2M^2+\mu^2)+(\mu M)^2\right]$$



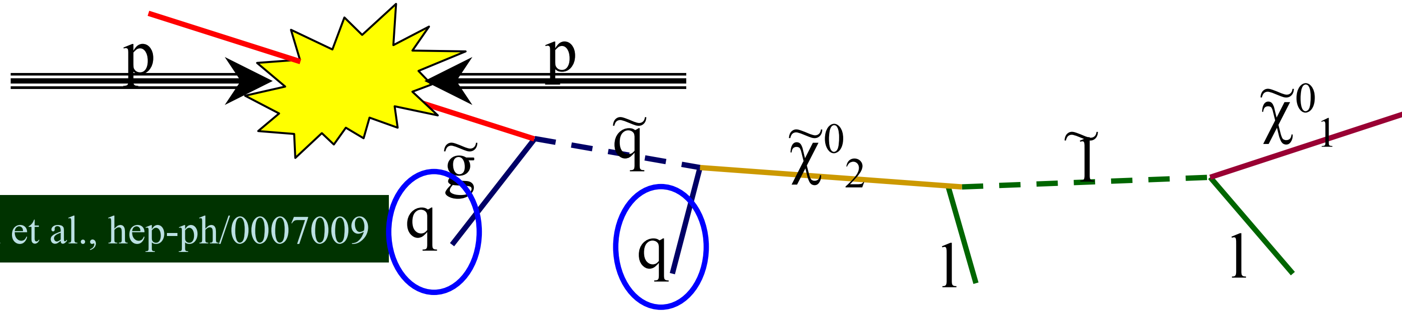


SU4, 0.5 fb^{-1}
Edge: (52.7±2.4) GeV
Truth: 53.6 GeV

Flavour Subtraction

Fitting function:
Theoretical three body decay function in the limit of large slepton mass, smeared by the experimental resolution with $\sigma = 2$ GeV.

Lepton+jets combination



Formulas in Allanach et al., hep-ph/0007009

Assuming that the squarks decays originate the **two hardest jets** of the event, one can use the ***qll*** combinations. Each combination has a minimum or a maximum which provides one constraint on the masses of $\tilde{\chi}^0{}_1$ $\tilde{\chi}^0{}_2$ $\tilde{l}$ $\tilde{q}$.

$$m_{llq}^{EDGE} \rightarrow llq_1, \; llq_2 \quad \Rightarrow$$

Keep the minimum

$$M_{llq}^{\max} = \left[\frac{(M^2_{\tilde{q}_L} - M^2_{\tilde{\chi}^0_2})(M^2_{\tilde{\chi}^0_2} - M^2_{\tilde{\chi}^0_1})}{M^2_{\tilde{\chi}^0_2}}\right]^{1/2}$$

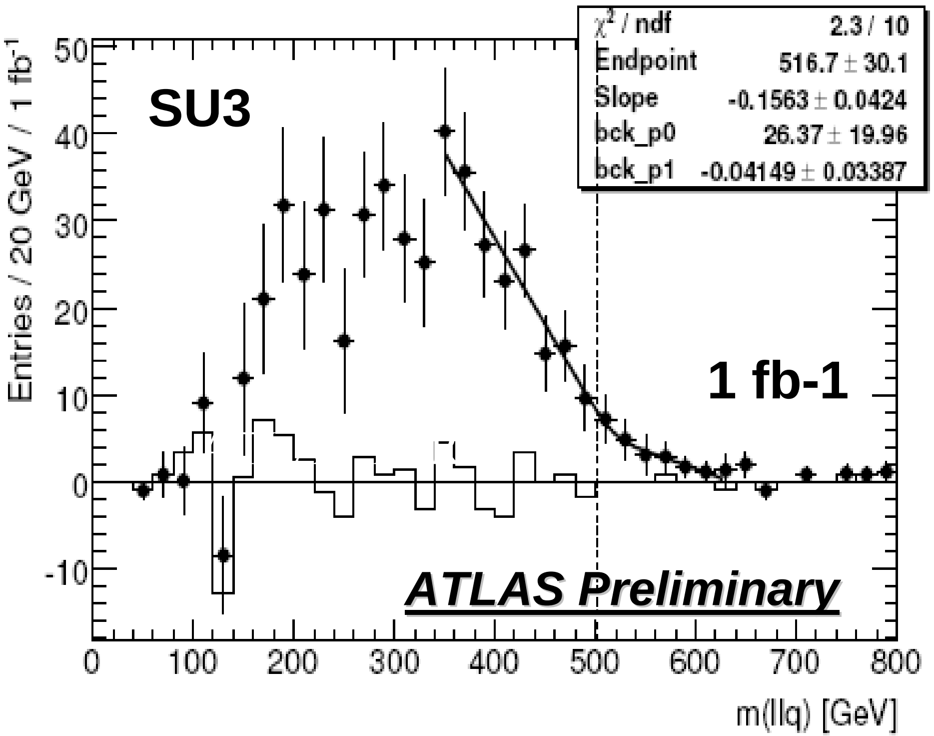
$$m_{llq}^{THRESH} \rightarrow llq_1, \; llq_2 \quad \Rightarrow$$

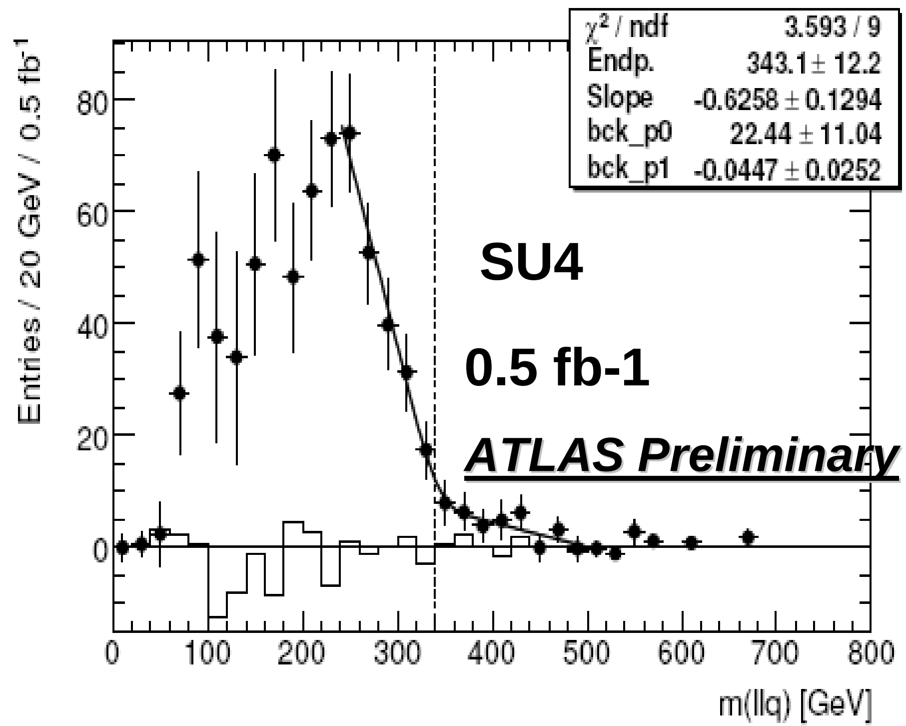
Keep the maximum

$$\left(m^2_{qll}\right)^{\text{thres}} = [(m^2_{\tilde{q}_L} + m^2_{\tilde{\chi}^0_2})(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{l}_R})(m^2_{\tilde{l}_R} - m^2_{\tilde{\chi}^0_1}) - (m^2_{\tilde{q}_L} - m^2_{\tilde{\chi}^0_2})\sqrt{(m^2_{\tilde{\chi}^0_2} + m^2_{\tilde{l}_R})^2 (m^2_{\tilde{l}_R} + m^2_{\tilde{\chi}^0_1})^2 - 16 m^2_{\tilde{\chi}^0_2} m^4_{\tilde{l}_R} m^2_{\tilde{\chi}^0_1}} + 2 m^2_{\tilde{l}_R}(m^2_{\tilde{q}_L} - m^2_{\tilde{\chi}^0_2})(m^2_{\tilde{\chi}^0_2} - m^2_{\tilde{\chi}^0_1})]/(4 m^2_{\tilde{l}_R} m^2_{\tilde{\chi}^0_2})$$

Lepton+jets combination (2)

llq edges





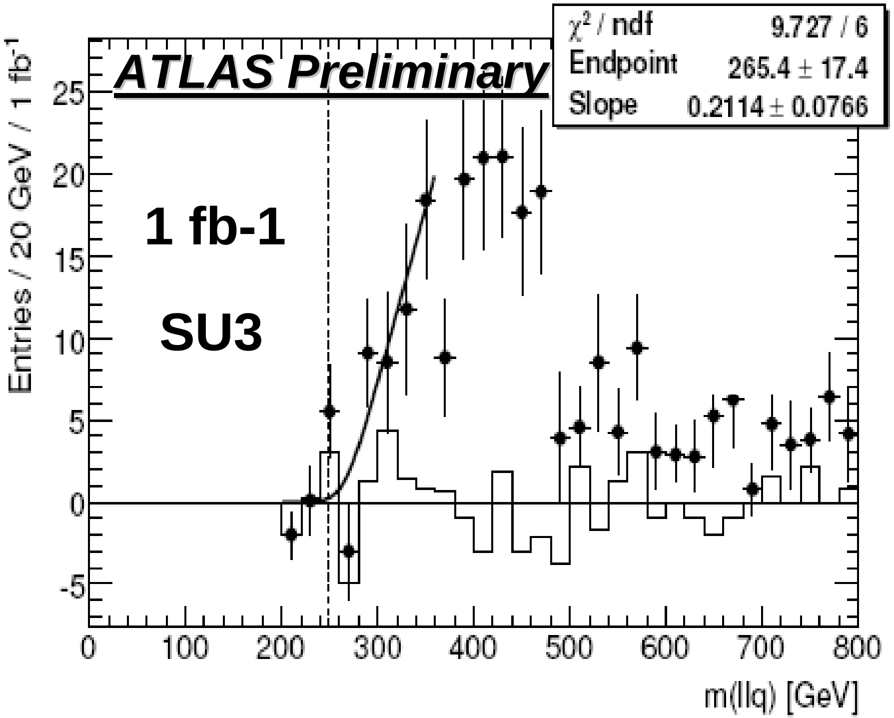
Fit formula: 2 straight lines (for signal and background) smeared by a Gaussian distribution to take into account the experimental resolution.

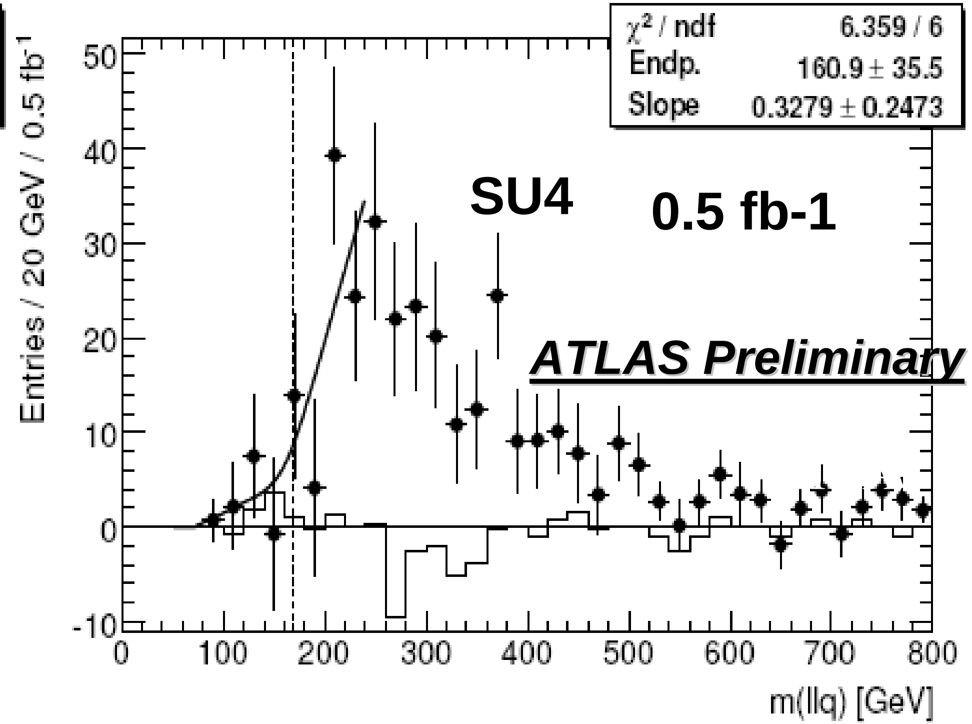
Edge: 517±30±10±13 GeV
Truth: 501 GeV

Edge: 343±12±3±9 GeV
Truth: 340 GeV

Lepton+jets combination (3)

llq thresholds





Fit formula: 2 straight lines (for signal and background) smeared by a Gaussian distribution to take into account the experimental resolution.

Edge: 265±17±15±7 GeV
Truth: 249 GeV

Edge: 161±36±20±4 GeV
Truth: 168 GeV

Extracting masses and parameters

Using the previous measurements (with also $q\ell$ edges and thresholds) , a global fit is performed in order to extract the value of the masses of the particles involved:

Masses of SUSY particles

Observable	SU3 $m_{\rm meas}$ [GeV/c^2]	SU3 $m_{\rm MC}$ [GeV/c^2]	SU4 $m_{\rm meas}$ [GeV/c^2]	SU4 $m_{\rm MC}$ [GeV/c^2]
$m_{\tilde\chi^0_1}$	$88 \pm 60 \mp 2$	118	$62 \pm 126 \mp 0.4$	60
$m_{\tilde\chi^0_2}$	$189 \pm 60 \mp 2$	219	$115 \pm 126 \mp 0.4$	114
$m_{\tilde q}$	$614 \pm 91 \pm 11$	634	$406 \pm 180 \pm 9$	416
$m_{\tilde l}$	$122 \pm 61 \mp 2$	155		

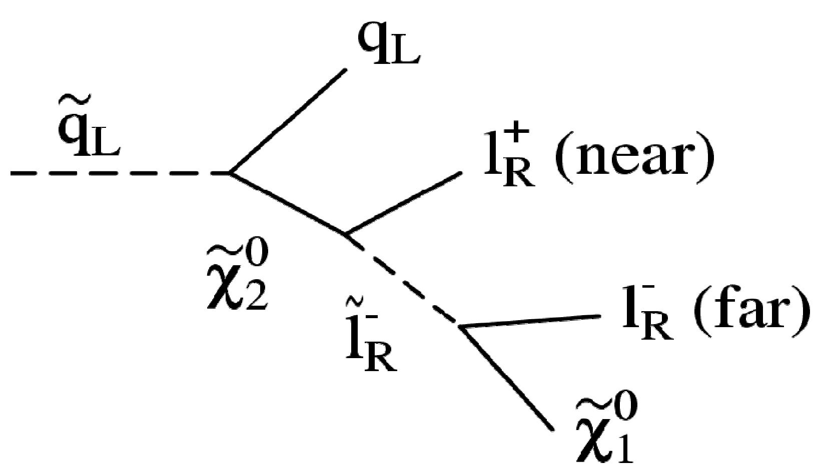
mSUGRA parameters determination

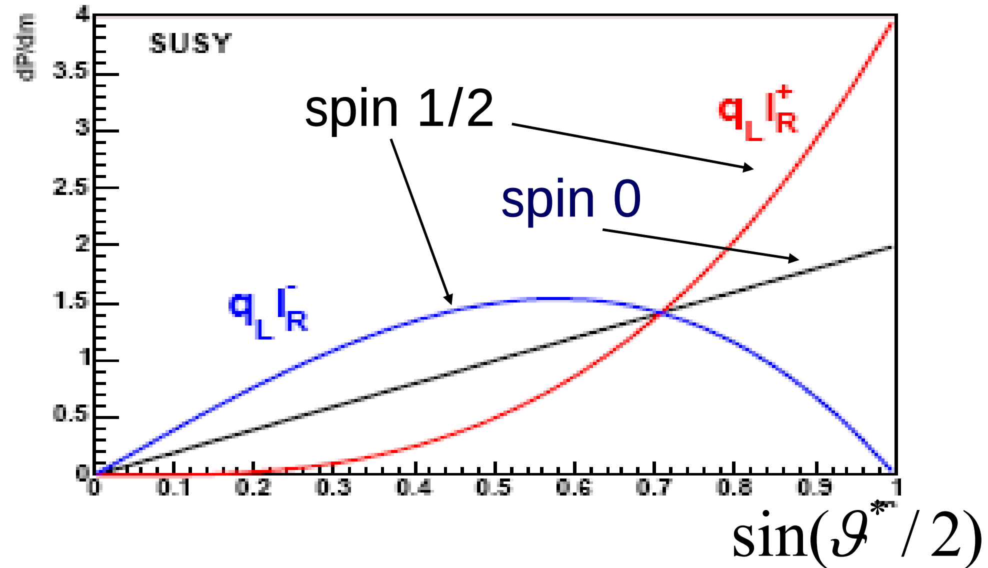
Parameter	SU3 value	fitted value	exp. unc.
	$\mathrm{sign}(\mu) = +1$		
$\tan\beta$	6	7.4	4.6
M_0	100 GeV	98.5 GeV	± 9.3 GeV
$M_{1/2}$	300 GeV	317.7 GeV	± 6.9 GeV
A_0	-300 GeV	445 GeV	± 408 GeV
	$\mathrm{sign}(\mu) = -1$		
$\tan\beta$		13.9	± 2.8
M_0		104 GeV	± 18 GeV
$M_{1/2}$		309.6 GeV	± 5.9 GeV
A_0		489 GeV	± 189 GeV

With **1 fb-1** the uncertainties on the masses and on the mSUGRA space parameters are very big → more statistics is needed.

Measurement of neutralino spin (1)

Important to measure the spin of new particles: it's the fundamental check to ensure that what we have discovered is SUSY!!





The charge asymmetry is **diluted** because:

1. Usually it is not possible to discriminate the *near* and *far* leptons: we sum $m(ql^{far})$ and $m(ql^{near})$ invariant masses
2. The charge conjugated cascade decay (from the anti-squark) gives the opposite asymmetry. However, cancelation is not exact because at LHC a larger number of squarks than anti-squarks is produced (pp collider)

Measurement of neutralino spin (2)

SU1 point: 7.8 pb x 1.6%

Ratio squarks/anti-squarks ~3.5

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

264   255 soft   hard 137

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

264   154 hard   soft 137

SU3 point: 19.3 pb x 3.8%

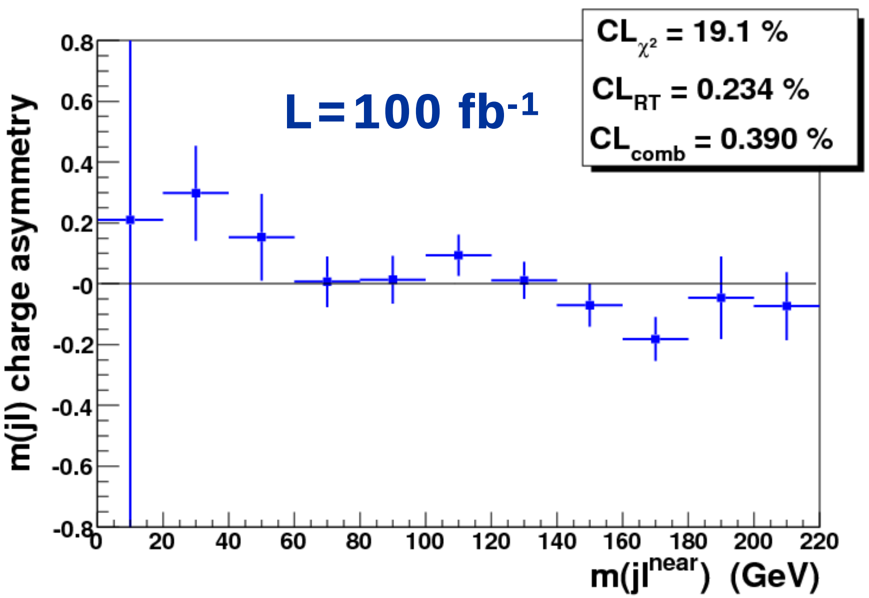
Ratio squarks/anti-squarks ~3

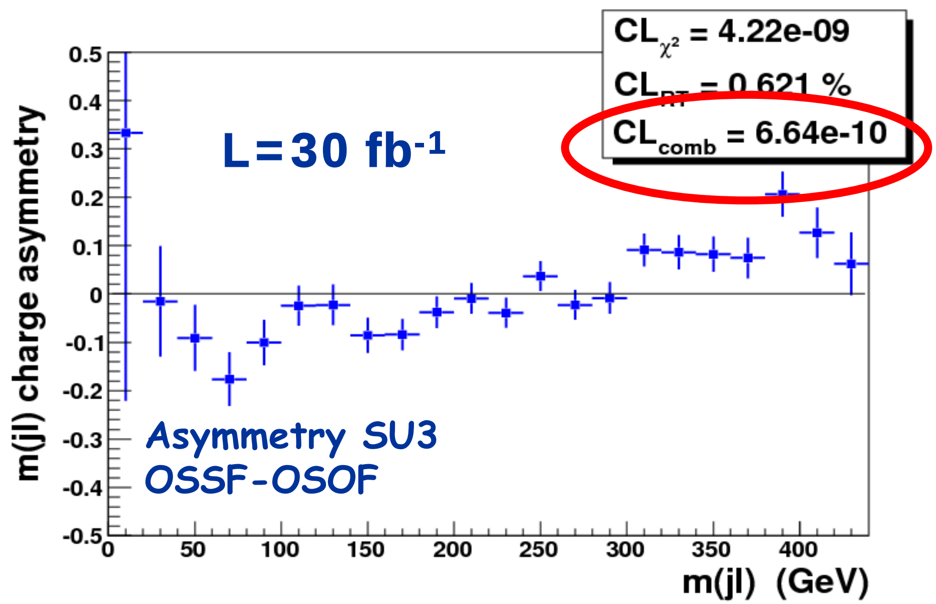
$$\tilde{q}_L \rightarrow q\,\tilde{\chi}_2^0 \rightarrow q\,\tilde{l}_R\,l^{\pm} \rightarrow q l^{\pm} l^{\mp} + \tilde{\chi}_1^0$$

219   155   118

- Cuts on missing energy and jet pt to reject SM background
- 2 Opposite Sign, Same Flavour (OSSF) electrons or muons.
- Subtract background from independent decay chains with the combination $\mu^+\mu^- + e^+e^- - \mu^{\pm}e^{\mp}$

In **SU3** point, **5÷10 fb^{-1}** are **already enough** to exclude charge symmetry





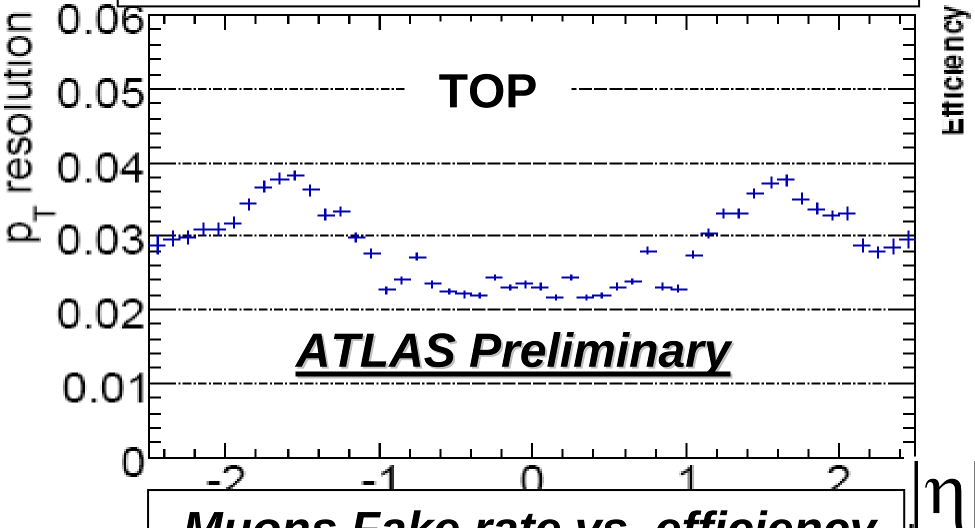
Conclusions

- A brief review of the search strategies for SUSY in the 2-leptons channels with ATLAS has been presented;
  - New discoveries possible with early LHC data (O(100)pb^{-1})
- Accurate knowledge of SM physics and of detector performance needed for any new discovery
  - **First data** taking period devoted to understanding of detector
  - After that, di-lepton channel could be competitive in the early LHC phase because its clear signature.
- Relations among masses can be determined with a 2-5% precision already with 1 fb-1 of “well understood” data.
- Larger statistics needed to measure the neutralino spin and to use the relations above to constraint the parameter space of mSUGRA and eventually to discriminate among the various SUSY models.

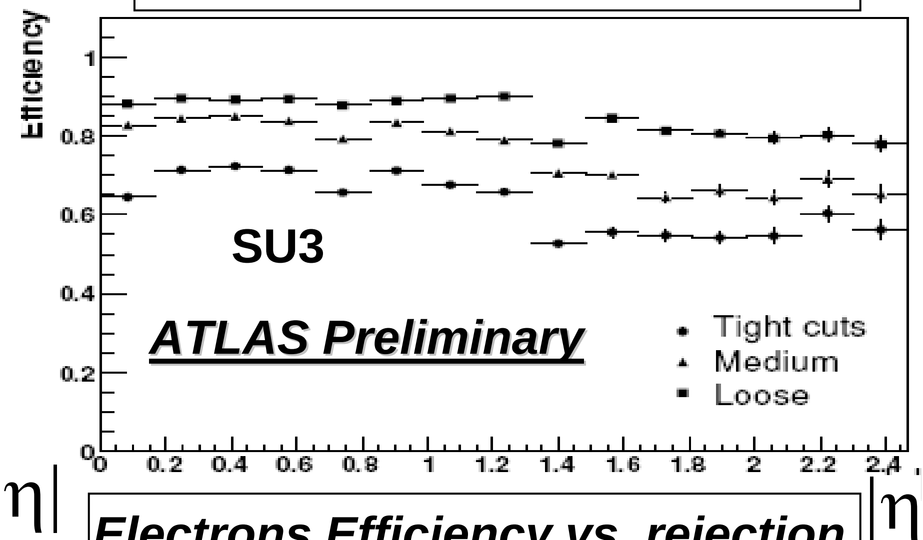
BACKUP SLIDES

Electron & Muon Performances

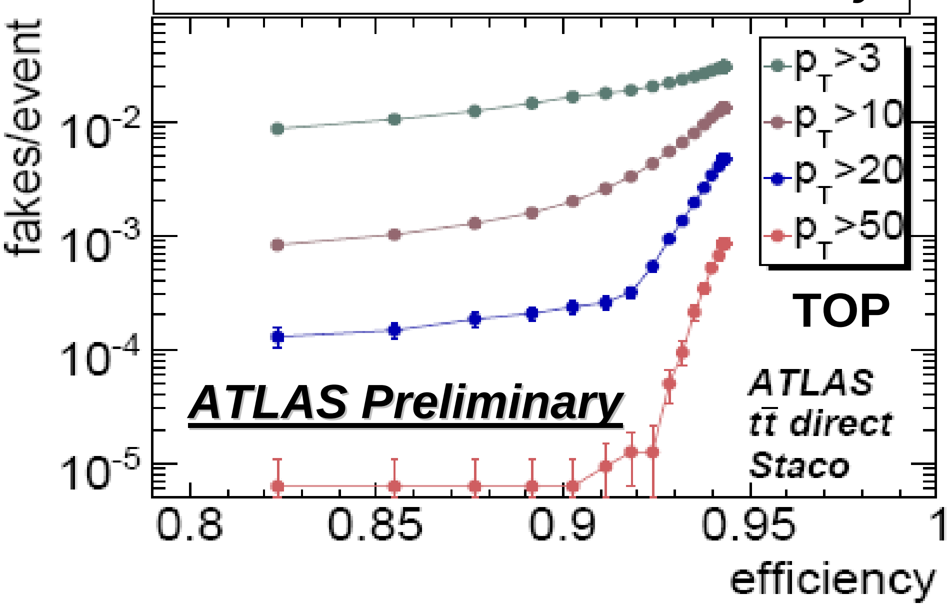
Muons $(P_T^{RECO} - P_T^{TRUTH}) / P_T^{RECO}$



Electrons Efficiency vs |η|



Muons Fake rate vs. efficiency



Electrons Efficiency vs. rejection