SUSY at the LHC

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(for the ATLAS/CMS Collaboration)

SUSY at the LHC

- If SUSY exists at the TeV scale
  - **gluinos and squarks strongly produced**
  - **Distinctive topological decays**
  - **Easy to discover**
  - **Precision measurements is the challenge**
- ATLAS & CMS have done studies of various models:
  - **minimal SUGRA models**
  - **minimal GMSB models**
  - **R-parity violating models**
- Studies at generator level (spythia/isajet) with idealized detector resolutions.
- Main background is SUSY itself
  - **Necessary to generate entire SUSY cross-section**
  - **+ Relevant SM backgrounds**

SUGRA Models

- Parameter of SUGRA points selected by LHC experiments for study

Point	m_0 (GeV)	$m_{1/2}$ (GeV)	A_0 (GeV)	$\tan\beta$	sgn μ
1	400	400	0	2	+
2	400	400	0	10	+
3	200	100	0	2	-
4	800	200	0	10	+
5	100	300	300	2.1	+
6	200	200	0	45	-

- Total SUSY cross-section:
  - **~ few pb (for M_{SUSY} ~ 1 TeV)**
  - **~ 1 nb (for M_{SUSY} ~ 300 GeV)**

Inclusive Signatures

- Many complex SUSY signatures:

$$\tilde{g} \rightarrow \tilde{q}q \quad \text{or} \quad \tilde{\chi}_i^0 q\bar{q} \quad \text{or} \quad \tilde{\chi}_i^{\pm} qq'$$

$$\tilde{q} \rightarrow \tilde{\chi}_1^0 q \quad \text{or} \quad \tilde{\chi}_2^0 q \quad \text{or} \quad \tilde{\chi}_1^{\pm} q$$

$$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^- \quad \text{or} \quad \tilde{\chi}_1^0 Z^0 \quad \text{or} \quad \tilde{\chi}_1^0 h$$

$$\tilde{\chi}_1^{\pm} \rightarrow \tilde{\chi}_1^0 l^{\pm} \nu \quad \text{or} \quad \tilde{\chi}_1^0 W$$

- Final State may consist of:

Multi Jets + Missing E_T

+ (n = 1,2,3,4) high P_T leptons

+ same sign (SS) lepton pairs

- Define Resulting Reach :

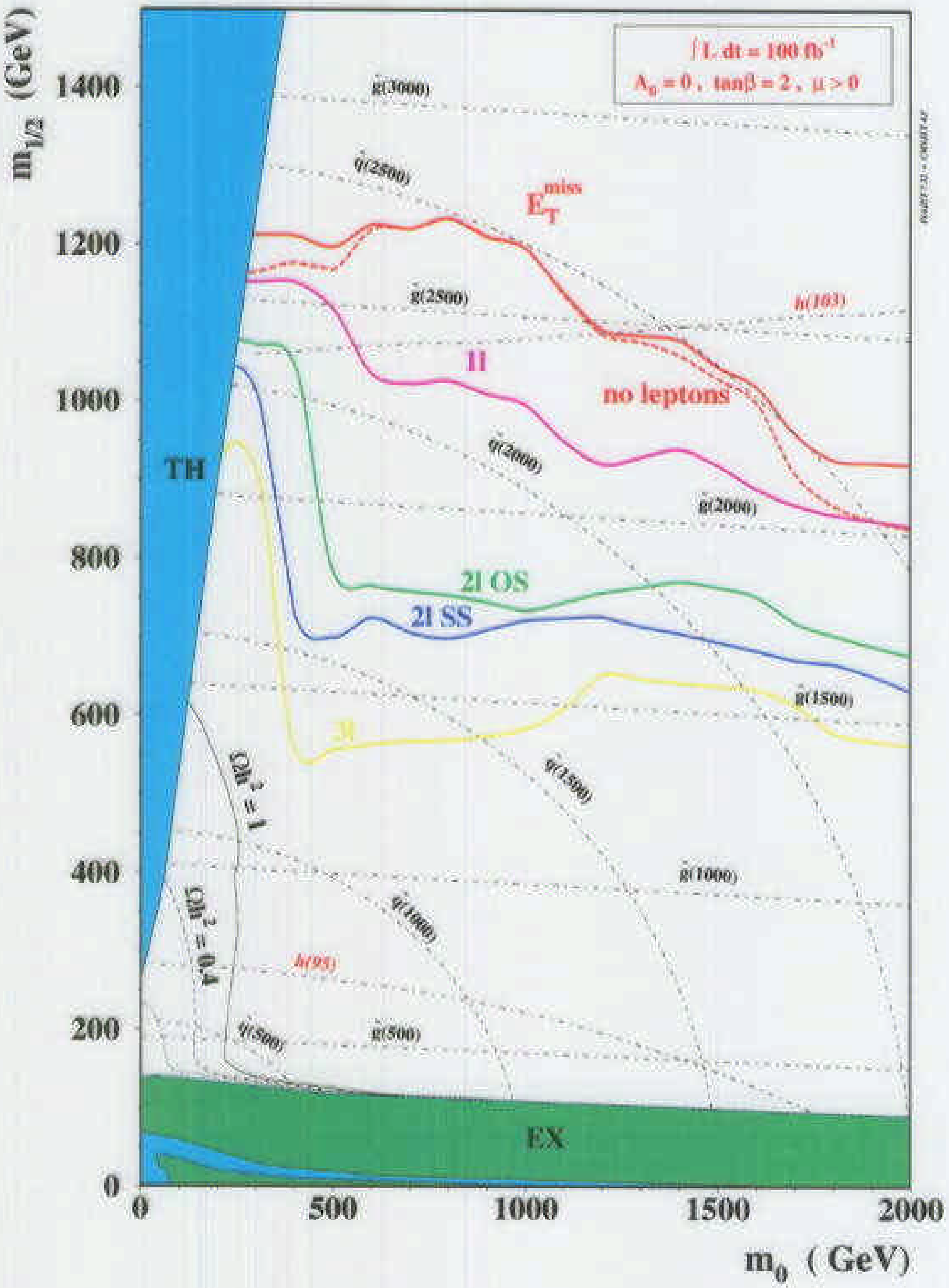
  ∗ **Require at least 10 events**

  ∗ **$S/\sqrt{B} > 5$**

  ∗ **for an integrated $L = 10\ fb^{-1}$**

  (one year low luminosity LHC running)

SUSY reach at LHC

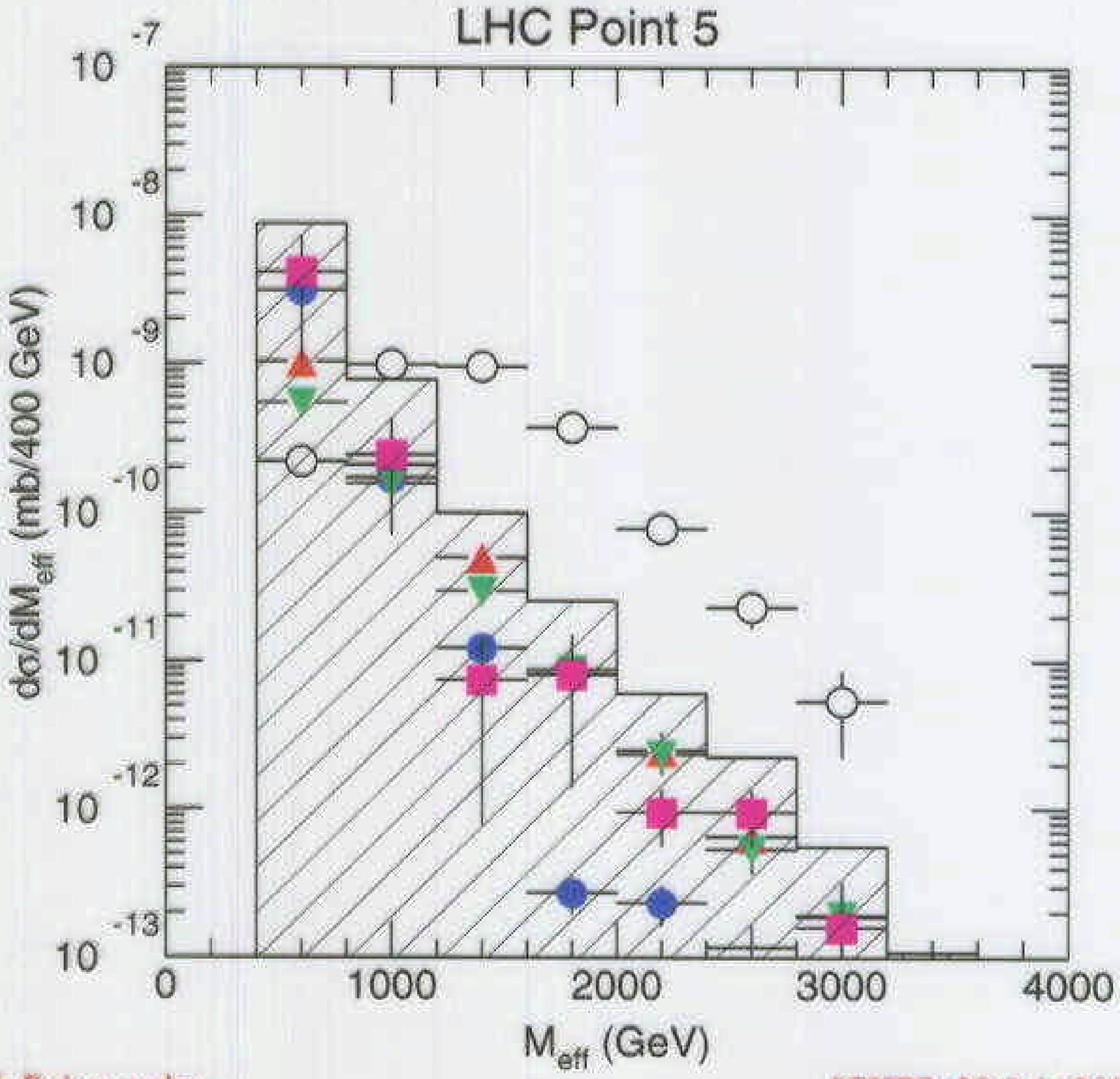


Estimate of Effective Mass

$$M_{EFF} = \not{E}_T + \sum_{i=1}^{4} E_T^i \qquad \text{(4 hardest jets)}$$

- ✳ **S/B ~ 10 at high M_{EFF}**
- ✳ **Estimate M_{SUSY} (α M_{EFF}) ~ 10% precision**

Backgrounds modeled: (W+jets, Z+jets, $t\bar{t}$, QCD)



Precision measurements

- Identify bottom of decay chain.
- Measure kinematic endpoints
- Determine masses
- Make fit for model parameters

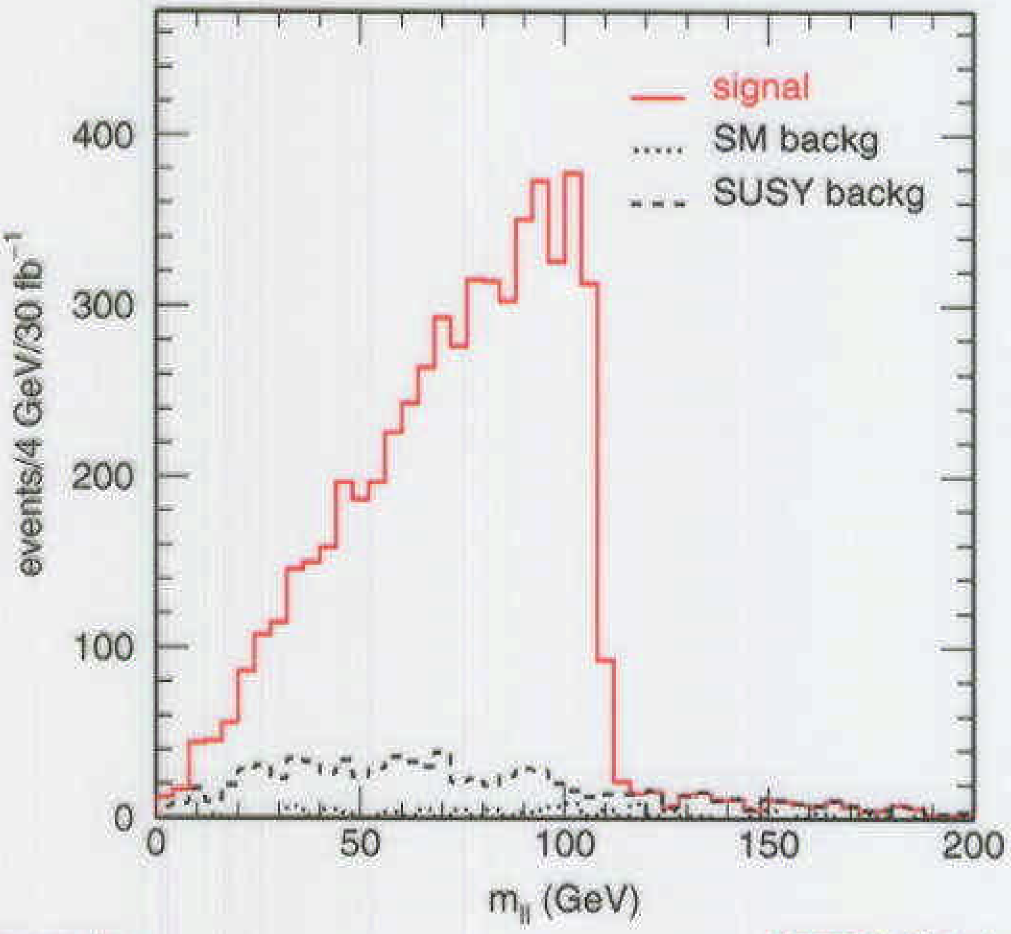
- Taking SUGRA point 5 as an example:

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

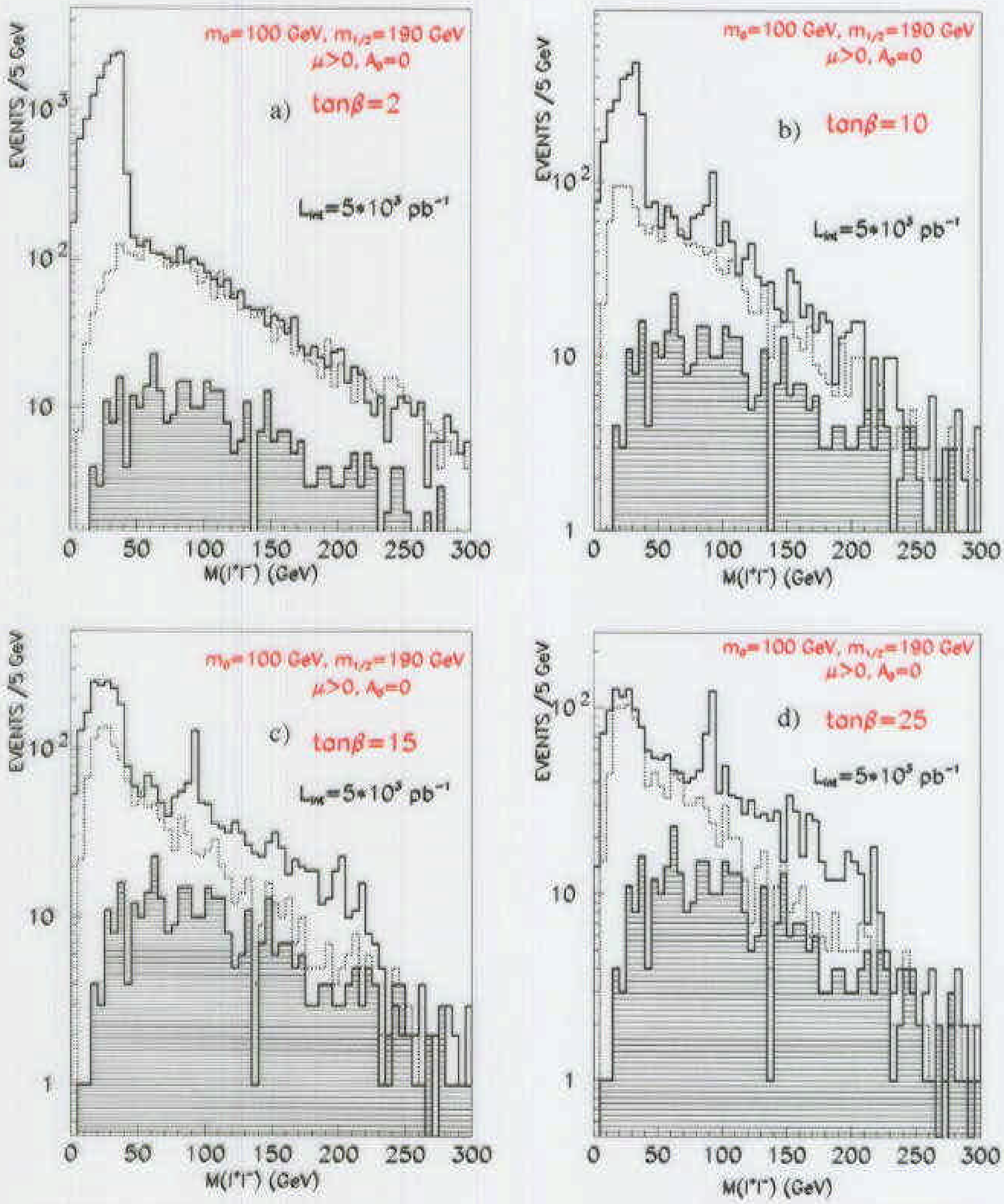
- Determine constraints from measuring the kinematic end points of m_{ll}, m_{lq}, m_{llq}

Dilepton Edges

- Two body decays produces much sharper edge compared to three body decays.
- Flavour subtraction $(e^+e^- + \mu^+\mu^- - e^\pm\mu^\mp)$ to reduce background & combinatorics
- 0.1% precision edge measurement **(100 fb^{-1})**



Effect of tan(β)

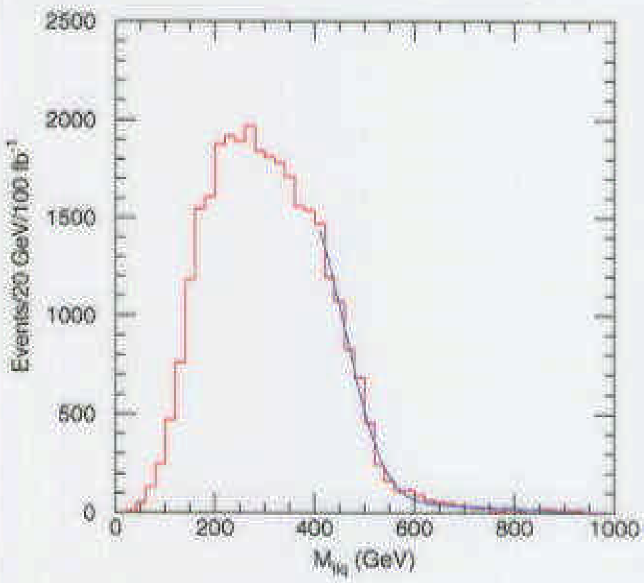


*l*q & *ll*q Edges

- Use 2 hardest jets to fit for *lq* and *llq* edges

Fit to the smaller of the two *ll*q mass

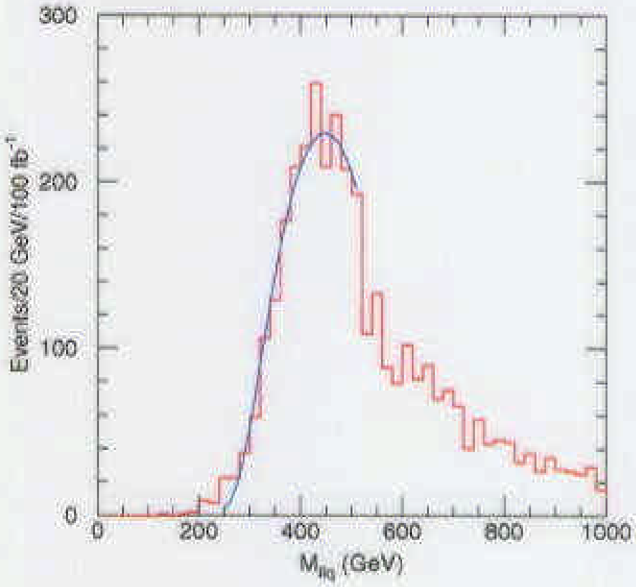
Error ~ 1%



Lower edge from the larger *ll*q mass

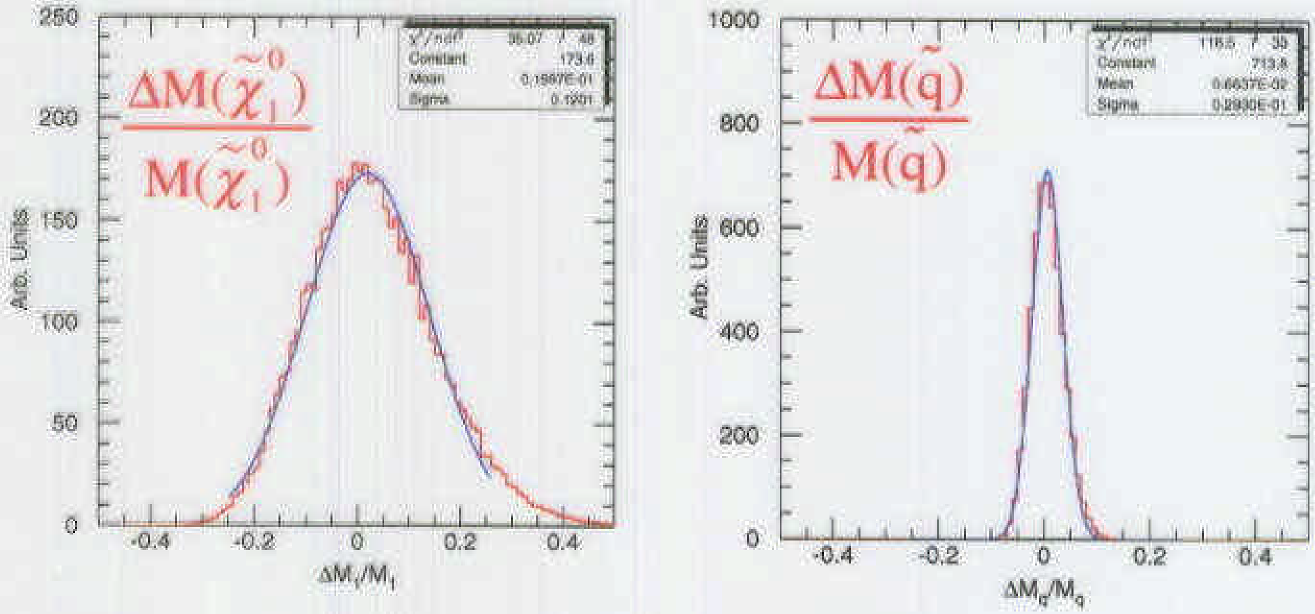
Longer tail due to FSR

Error ~ 2%



Fitting for SUSY masses

- Generate random SUSY masses.
- Solve numerically for the end-points
- χ^2 fit to the measured endpoints



- Reconstruct (**for SUGRA point 5** & 100 fb^{-1}):

$$\tilde{q}_L : \pm 3\%, \ \tilde{\chi}_1^0 : \pm 12\%$$

- Reconstruct mSUGRA parameters :

m_0: ± 1.4%, $m_{1/2}$: ± 0.9%, $\tan\beta$: ± 5.5%

$\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 + h(\rightarrow b\bar{b})$

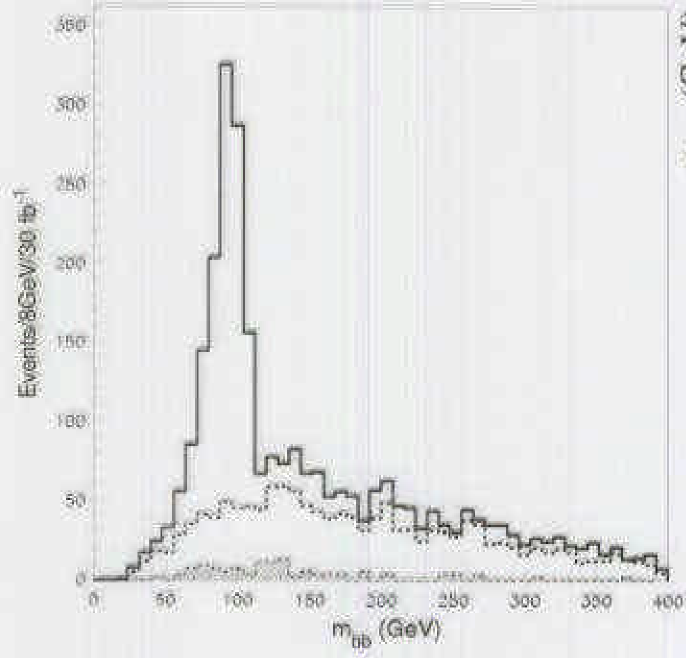
★ Most of SUGRA parameter space covered.

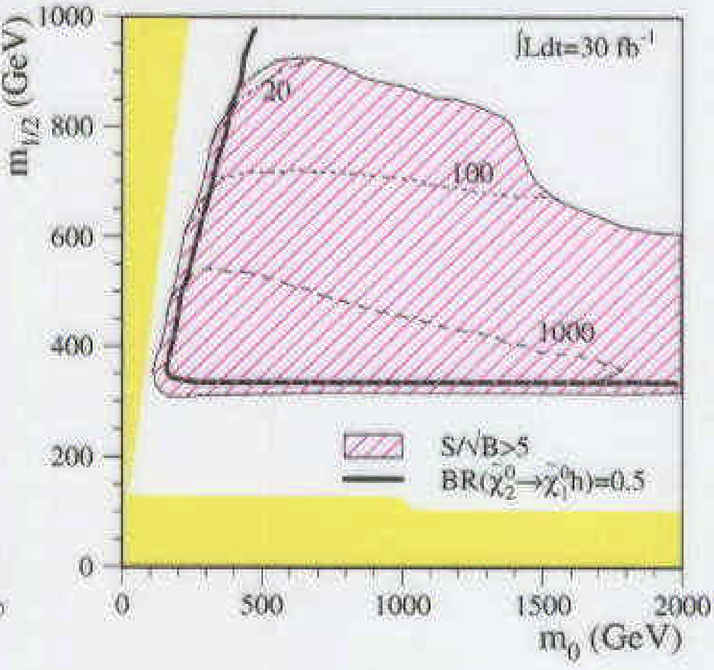
★ Impossible for large (m_0, $m_{1/2}$) where chargino pair production dominates.

- ✳ **Overwhelming SUSY and SM backgrounds**

$m_0 = 400 \;\; m_{1/2} = 400 \;\; \tan\beta = 2 \;\; \mathrm{sgn}(\mu) = +$

$\int L = 30 fb^{-1} \;\; S/B \sim 4:1$





GMSB

- Analysis approach similar to SUGRA

  Reconstruct masses from kinematic endpoints
- The following points have been studied:

Λ (TeV)	M_m (GeV)	N_5	NLSP	$c\tau$ (km)	x-sec (pb)
90	500	1	χ^0_1	~ 0	7.6
90	500	1	χ^0_1	~ 1	7.6
30	250	3	$\tilde{\tau}_1$	~ 0	23
30	250	3	$\tilde{\tau}_1$	~ 1	23

P1: **Two hard isolated photons : SM bkg negligible**

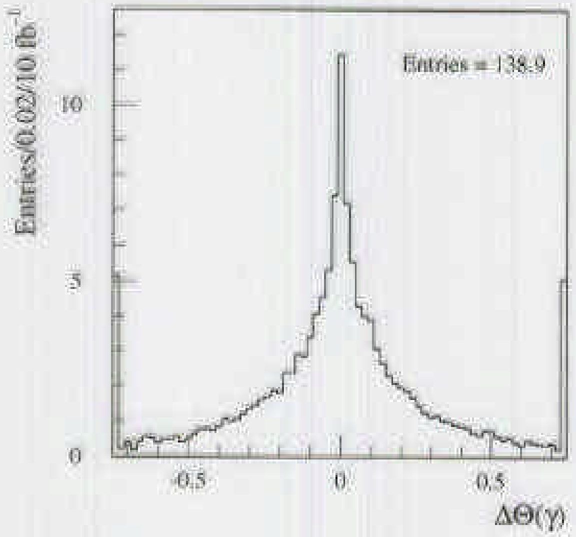
P2: **NLSP decay in tracker for fraction of events**

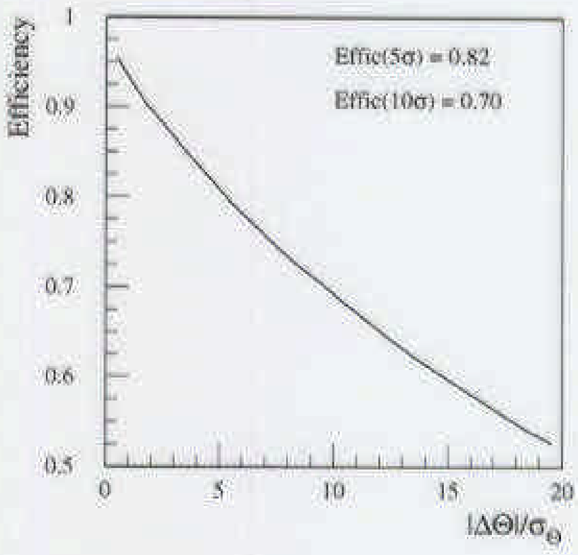
P3: **effectively 3 NLSPs :** $(\tilde{e}_R, \tilde{\mu}_R, \tilde{\tau}_1)$
Multiple leptons in final state

P4: **Long lived sleptons are μ-like but with $\beta < 1$**
Measure slepton masses using TOF

$\tilde{\chi}_1^0$ Lifetime measurement

Non-pointing photons in EM Cal
$\Delta\theta = 70$ mrad/ $\sqrt{E}$ (ATLAS)





For $c\tau = 1.1$ km & 10 fb^{-1}

- **152,000 $\tilde{\chi}_1^0$ are produced**
- **180 decay in tracker**
- **90 detected (50% efficiency)**

If no non-pointing photons are detected in 50 fb^{-1}
Lower limit of $c\tau$ ~ 100 km at 95% CL

Conclusion

- Discovery of SUSY at TeV scale is easy
  - * **squarks & gluinos copiously produced**
- Goal is to determine the underlying SUSY model
- Various signatures in the mSUGRA, GMSB and R-parity violating models have been studied.
- Precision measurement is challenging
  - * **Too many complex signatures to sort through**
  - * **Main background is SUSY itself**
  - * **Analysis Strategy needs to mature**
  - * **Need for further studies under more realistic LHC environment.**

Direct Slepton Production

Direct $qq \rightarrow \tilde{l}^{+}\tilde{l}^{-}$ (& $\tilde{\chi}_2^0 \tilde{\chi}_1^{\pm}$) production are hard

- **Rapidly falling cross-sections**
- **Large backgrounds**

$m(\tilde{l})$ reach via $\tilde{l}_L^{+} \tilde{l}_L^{-} \rightarrow l^{+}l^{-} \tilde{\chi}_1^0 \tilde{\chi}_1^0$

< 160 GeV (10 fb^{-1}); < 340 GeV (100 fb^{-1})