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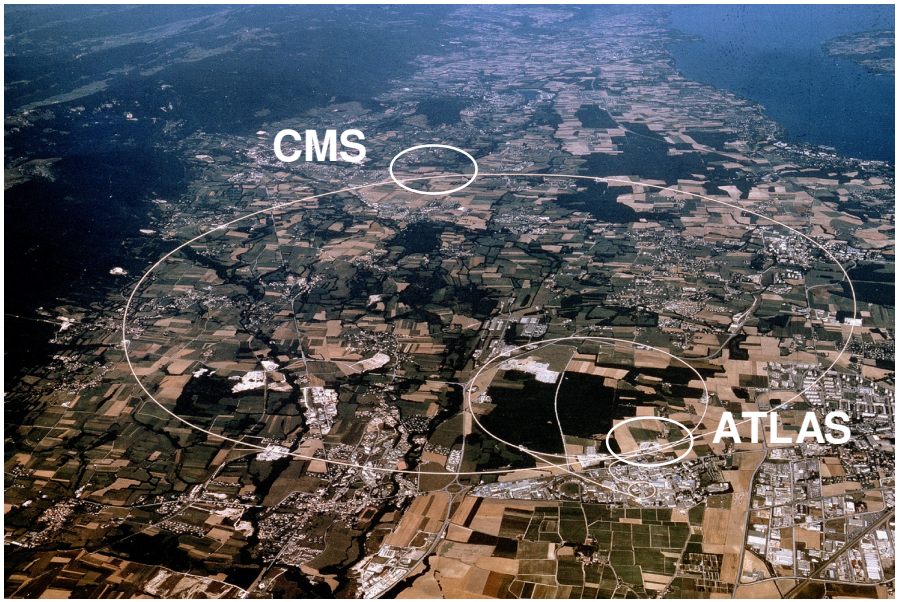
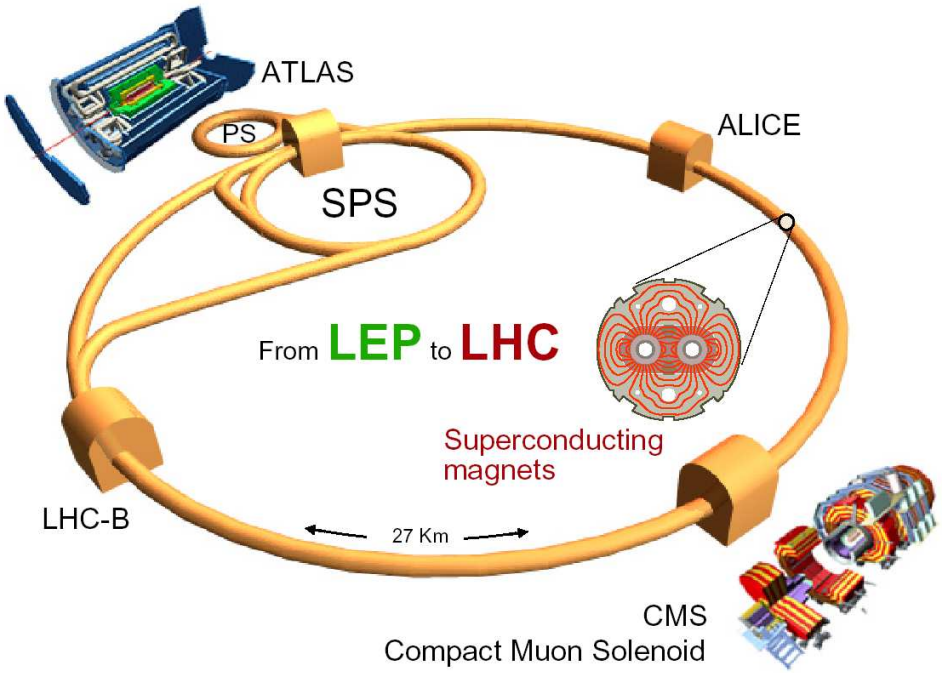
SUSY Searches : Review of LHC Potential

Outline

- LHC and the Detectors
- SUSY : MSSM, mSUGRA …
- SUSY signatures
- Triggering on SUSY
- Inclusive SUSY searches
- SUSY spectroscopy
- Summary

Large Hadron Collider (LHC)



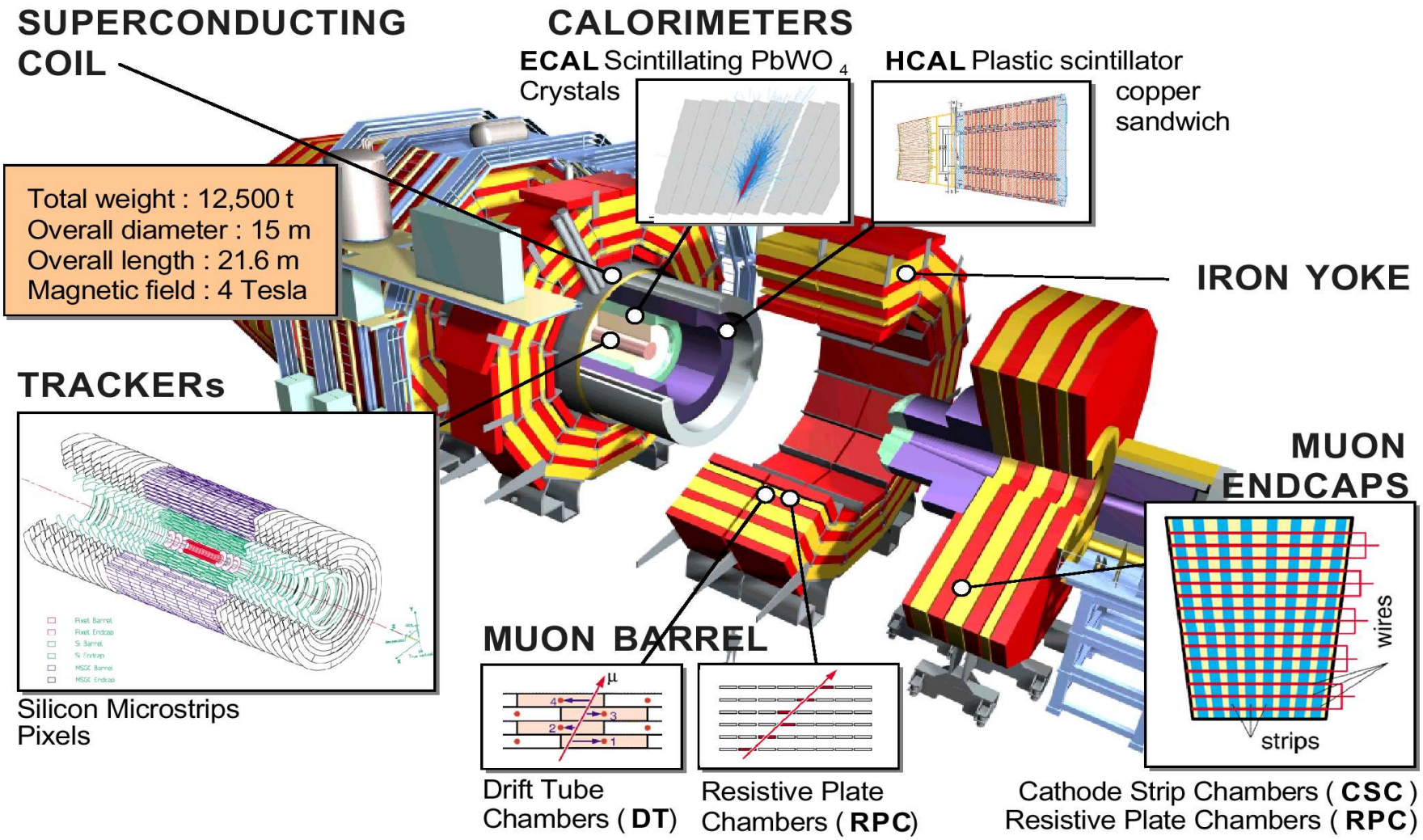


- Design luminosity L = $10^{34}cm^{-1}s^{-1}$
  ~ 100 fb^{-1}/ year
  Pile up ~ 20 collisions/crossing
  40 MHz pp bunch-crossing rate
- Start-up luminosity L = $10^{33}cm^{-1}s^{-1}$
  ~ 10 fb^{-1}/ year
- Completion : mid 2007

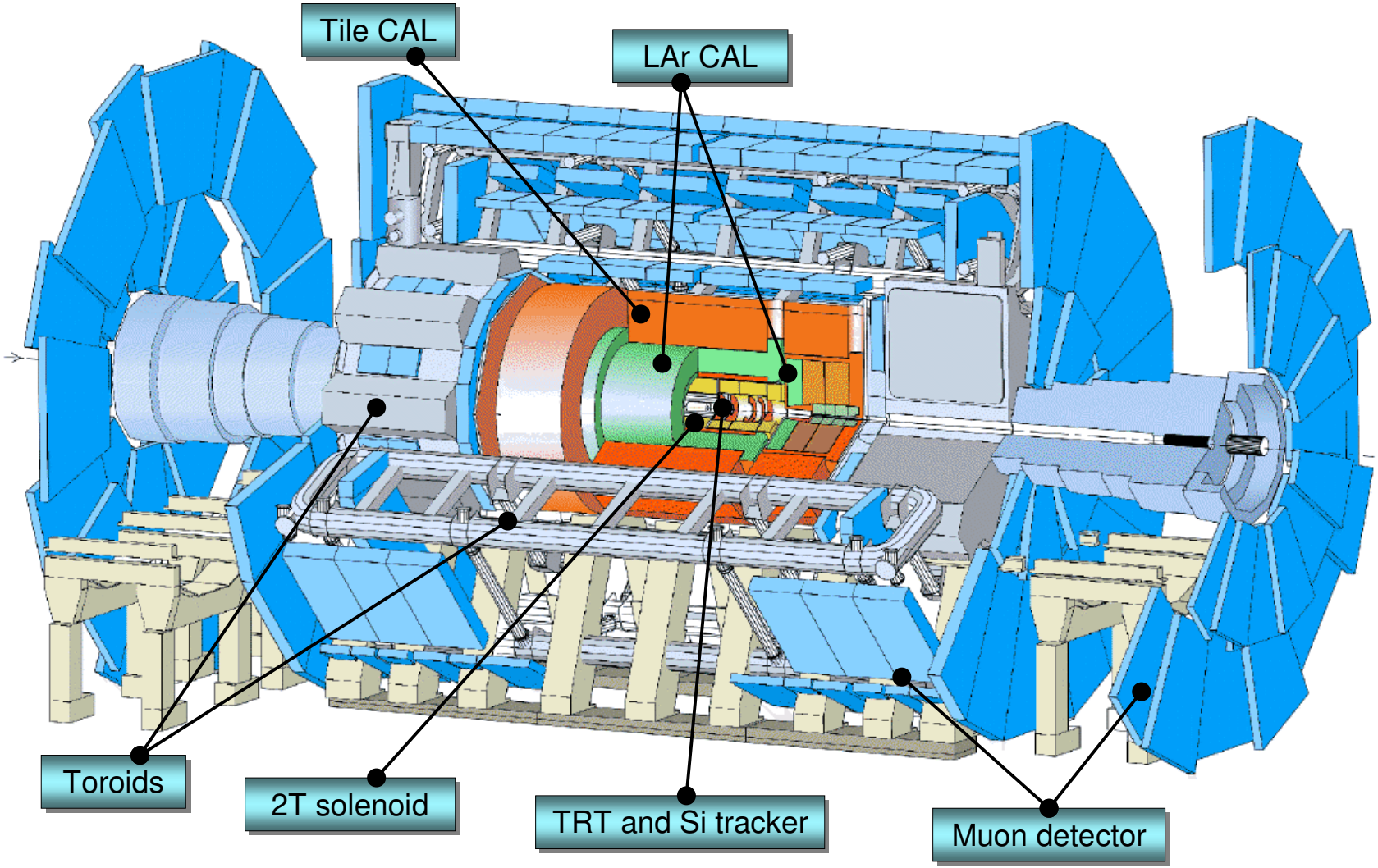
	Beams	Energy		Luminosity
LEP	e^+ e^-	200	GeV	$10^{32}\,cm^{-2}s^{-1}$
LHC	p p	14	TeV	$10^{34}\,cm^{-2}s^{-1}$
	Pb Pb	1312	TeV	$10^{27}\,cm^{-2}s^{-1}$

General-Purpose Detectors : CMS

The Compact Muon Solenoid (CMS)



General-Purpose Detectors : ATLAS



A Little Bit of SUSY Phenomenology

SUperSYmmetry -> MSSM

- SUSY – symmetry between bosons and fermions
- MSSM – minimal …
  - Two Higgs doublets which couple to fermions T = -1/2 and T = 1/2, (after 3 out of 8 degrees of freedom absorbed to give W/Z masses) 5 physical Higgs bosons - $h, H^0, A, H^{\pm}$
  - SUSY partner for each SM particle and every Higgs boson, so e.g. squarks and sleptons: $\tilde{q}, \tilde{l}$ - scalar counterparts to fermions
  - Conserved $R_p = (-1)^{3(B-L)+2S}$
    - LSP is stable and sparticles produced in pairs
  - Charginos and neutralinos : $\tilde{\chi}^{\pm}_{1,2}$, $\tilde{\chi}^{0}_{1,2,3,4}$ - eigenstates of mixing of fermionic partners of EW gauge and Higgs bosons (gauginos and Higgsinos)
  - LSP = $\tilde{\chi}^{0}_{1}$ is a possible candidate for the Cold Dark Matter
- 105 new parameters (for arbitrary soft SUSY breaking), but cancels Higgs mass loop divergence (SM fine tuning problem)

-> mSUGRA

- Motivated by SUperGRAvity unification
- Universal gravitational interactions communicate symmetry breaking from (introduced) hidden sector to the MSSM sector.
- SUSY breaking scale sqrt(F)~10^{11} GeV close to Planck mass scale
- Five free parameters
  - m_0 – common scalar mass
  - $m_{1/2}$ – common gaugino mass
  - A_0 – common scalar trilinear (Higgs-sfermion-sfermion) coupling

  } at the GUT scale
  - tanβ – ratio of v.e.v. of Higgs doublets

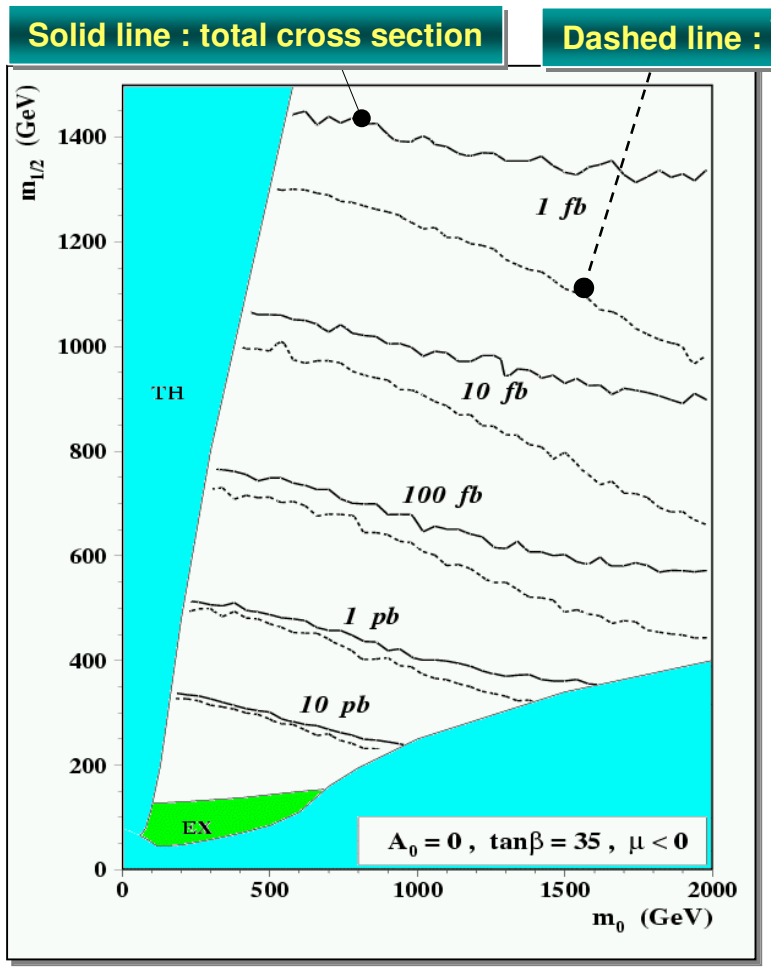
  } at the EW scale
  - sign(μ) – sign of Higgsino mixing parameters

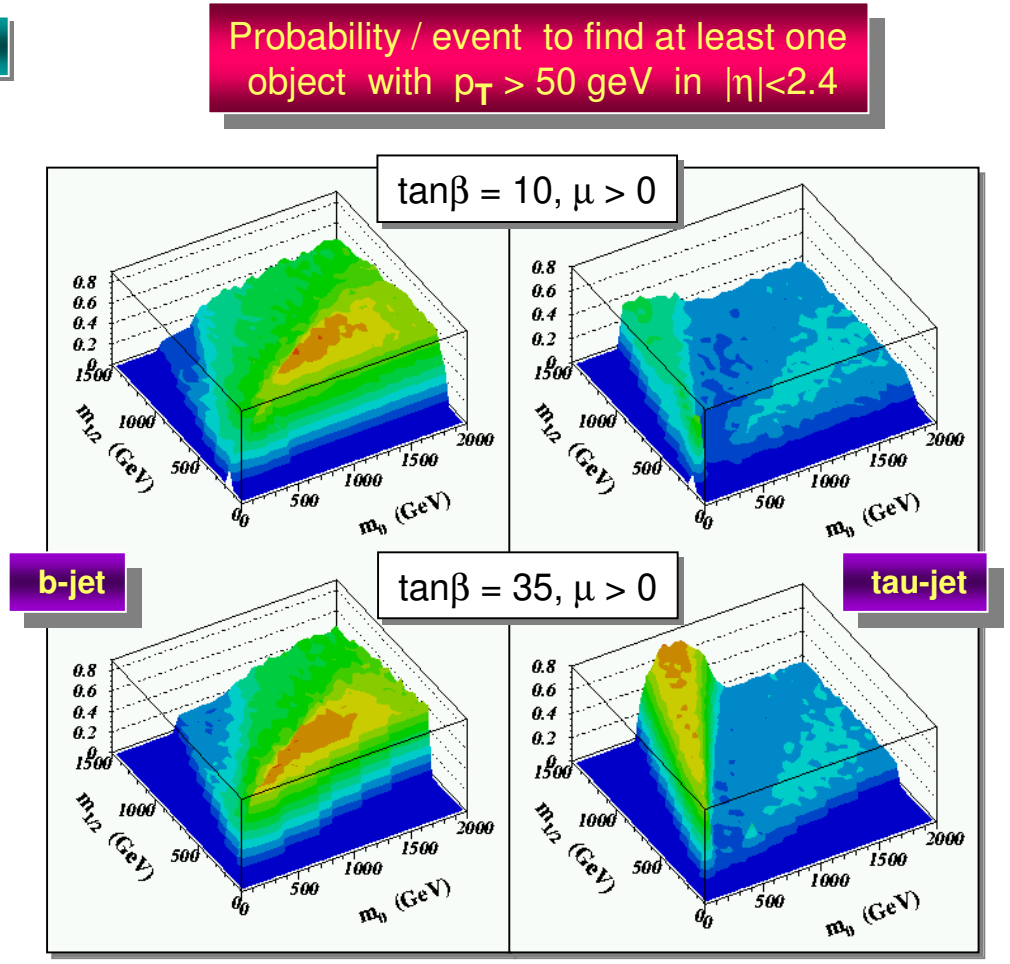
- Renormalization Group Equations (RGE) translate masses from SUSY-breaking to EW scale

- Some typical mass relations
  - $M(\tilde{\chi}_1^{\pm}) \approx M(\tilde{\chi}_2^0) \approx 2M(\tilde{\chi}_1^0) \approx 1/3\ M(\tilde{g})$
  - $M(\tilde{g}) \gtrsim M(\tilde{q})^* > M(\tilde{\chi})$

    * for large $m_{1/2}$ squarks can be heavy
  - $\tilde{t}_1$ – lightest squark

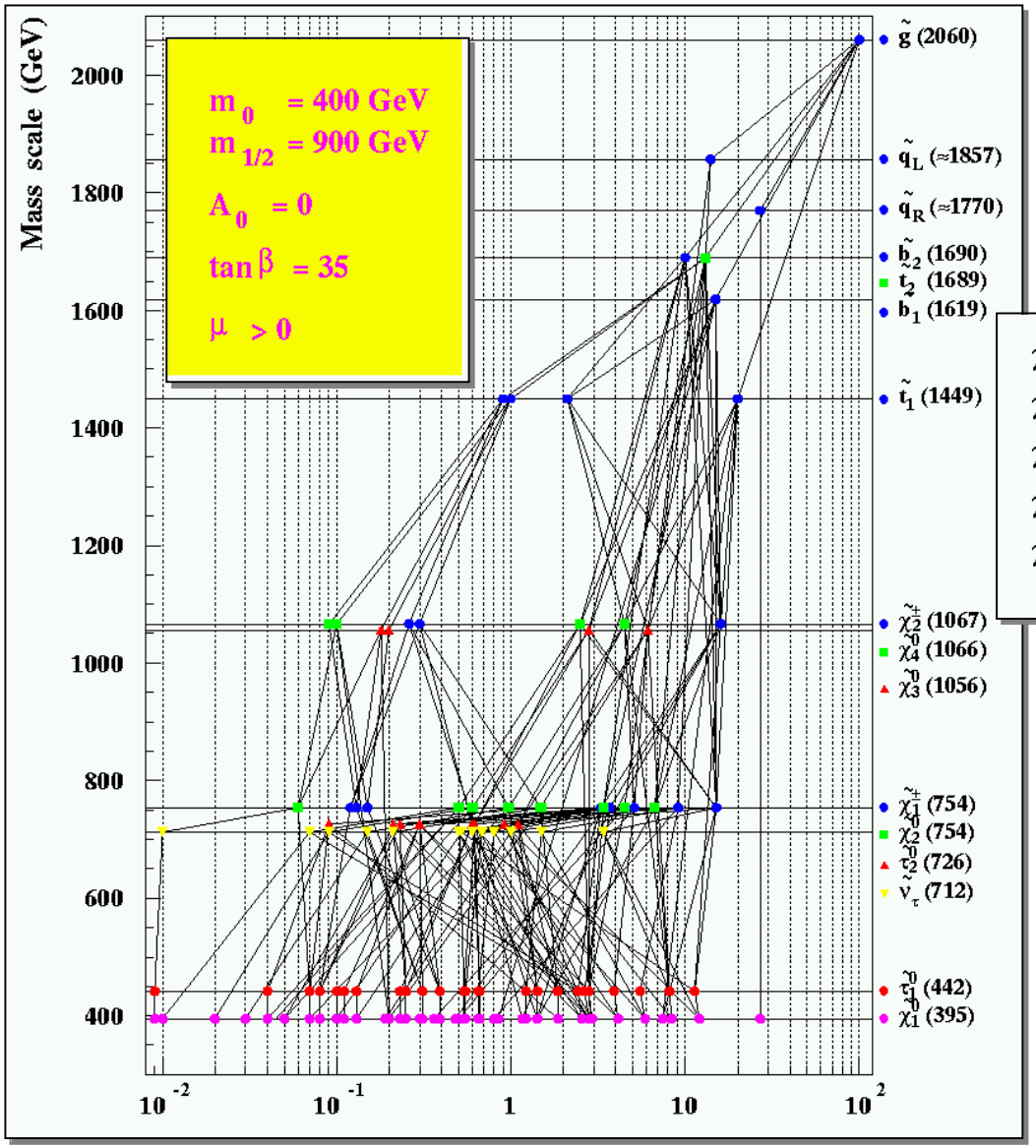
More mSUGRA …





- Squark-gluino production dominates the total cross section at low mass scale
- Cross sections don't vary much with μ, tanβ
- Abundant b,τ production (the latter – especially at large tanβ)

Multi-Jet + Missing E_T Signatures

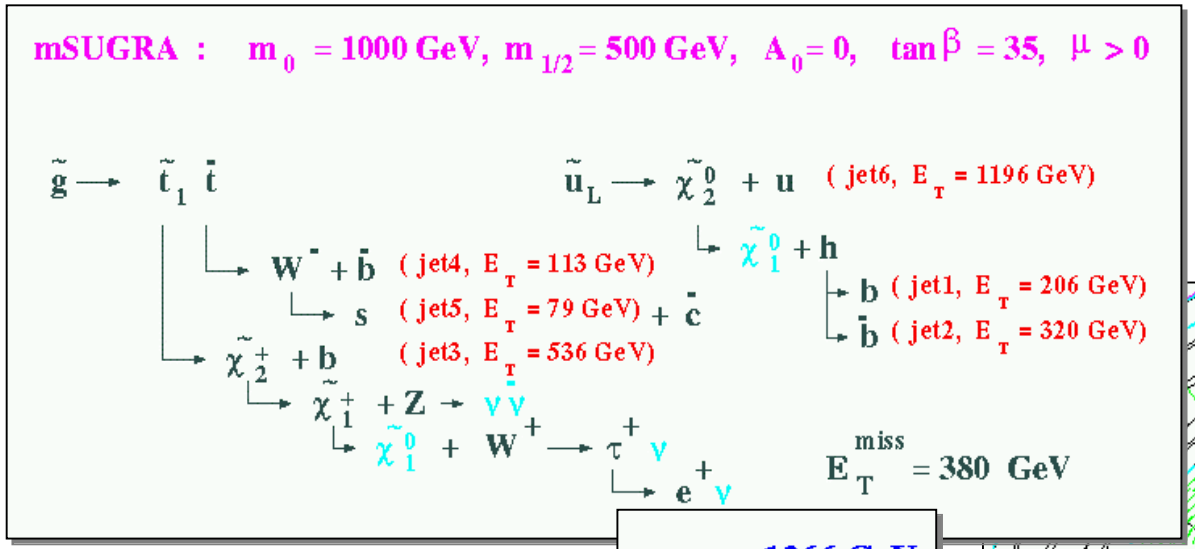


Heavy gluino branching ratio chart

$\tilde{\chi}_1^0$ qq	(27.0 %)	$\tilde{\chi}_1^0$ τνWWWbb	(4.1 %)
$\tilde{\chi}_1^0$ τνWbb	(12.1 %)	$\tilde{\chi}_1^0$ ττbb	(2.9 %)
$\tilde{\chi}_1^0$ ττWWbb	(8.4 %)	$\tilde{\chi}_1^0$ ττqq	(2.9 %)
$\tilde{\chi}_1^0$ WWbb	(7.4 %)	$\tilde{\chi}_1^0$ τνZWbb	(2.8 %)
$\tilde{\chi}_1^0$ τνqq	(5.9 %)	$\tilde{\chi}_1^0$ τνhWbb	(2.6 %)

- Large amount of Missing E_T from LSP and ν ($\tilde{\nu}$, τ, W/Z, b-jets)
- μ,e from chargino, neutralino if tanβ is not too large and decays to stau -> tau dominate; aslo from Z,W

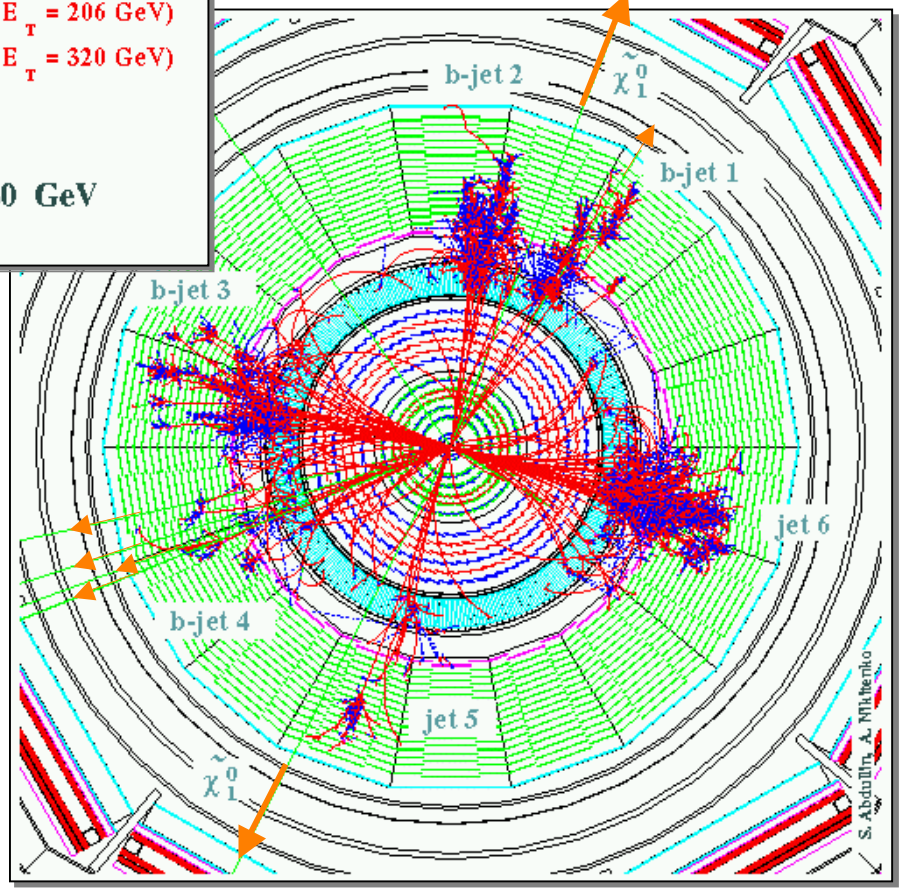
Event Display



4 hard b-jets
+2 hard jets
+2 LSP + > 4ν
(+ leptons)

- Squark-gluino production
- Full simulation in CMS detector yet with GEANT3 ☹

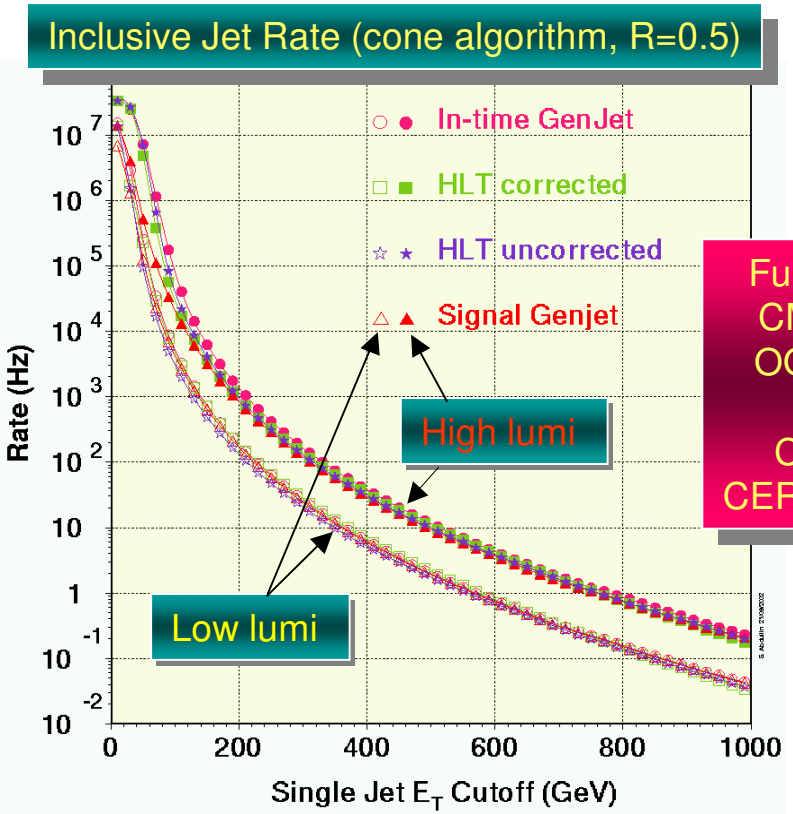
$m_{\tilde{g}} = 1266$ GeV
$m_{\tilde{u}_L} = 1450$ GeV
$m_{\tilde{t}_1} = 1026$ GeV
$m_{\tilde{\chi}_2^0} = 410$ GeV
$m_{\tilde{\chi}_1^0} = 214$ GeV
$m_h = 119$ GeV



Triggering on SUSY

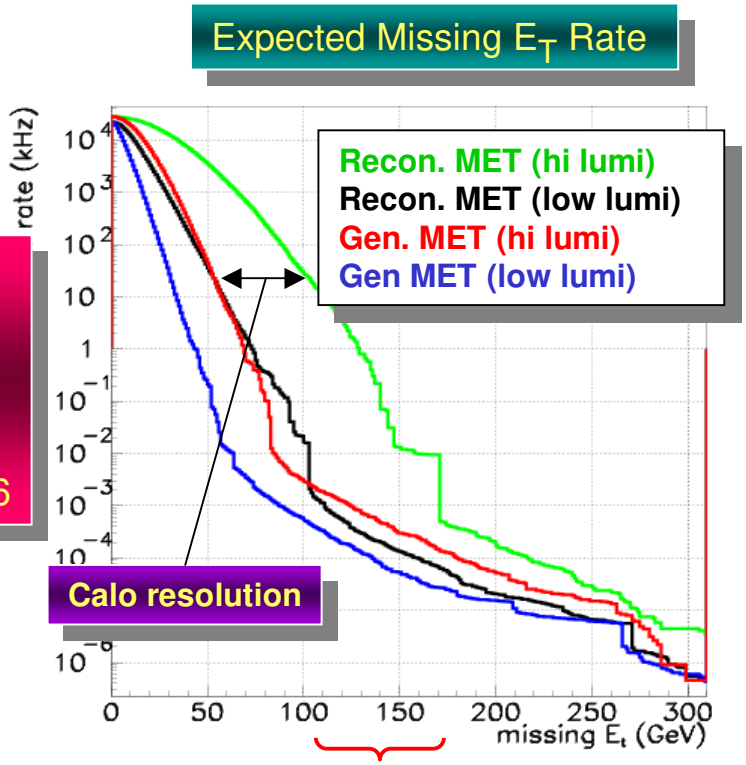
Triggering on SUSY : Rate Challenge

- Task : reduce 40 MHz bx rate (~1 GHz pp) → O(100 Hz)
  - To preserve maximal SUSY signal efficiency in jets + $\not{E}_T$ channel



Full GEANT-based CMS simulation + OO reconstruction

CMS DAQ TDR CERN/LHCC 2002-26

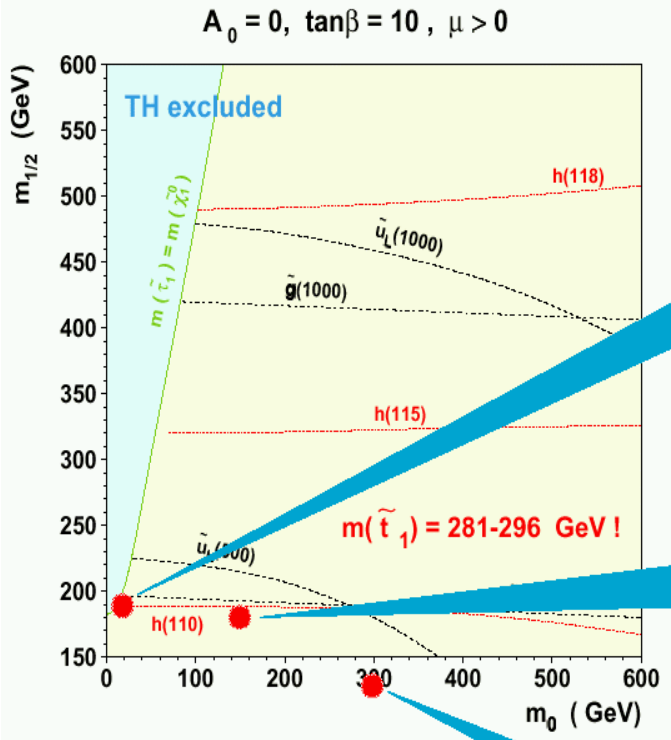


☞ Requiring a rate to tape of a ~few Hz implies an inclusive jet threshold of 400-600 GeV and an inclusive missing ET threshold of 100-150 GeV

SUSY Trigger Study (CMS)

- Consider several test points near the Tevatron II reach (most difficult for LHC)
  - Consider points w/wo R_p conservation
    For $\not{R}_p$ choose most difficult case : $\tilde{\chi}_1^0 \rightarrow 3j$
  - Run full GEANT-based detector simulation on SUSY signals and SM backgrounds to evaluate trigger performance

H.Baer et al., hep-ph/9802441; Phys.Rev.D58:075008, 1998



$m(\tilde{\chi}_1^0) = 70$ GeV $m(h) = 110$ GeV
$m(\tilde{g}) = 466$ GeV $m(\tilde{u}_L) = 410$ GeV
$\sigma \sim 181$ pb tau-enriched,
4 20,190 quite enough sleptons

$m(\tilde{\chi}_1^0) = 66$ GeV $m(h) = 110$ GeV
$m(\tilde{g}) = 447$ GeV $m(\tilde{u}_L) = 415$ GeV
$\sigma \sim 213$ pb nothing special
5 150,180

$m(\tilde{\chi}_1^0) = 45$ GeV $m(h) = 106$ GeV
$m(\tilde{g}) = 349$ GeV $m(\tilde{u}_L) = 406$ GeV
$\sigma \sim 500$ pb $\tilde{q} \rightarrow \tilde{g} + X$, $\tilde{g} \rightarrow$ 3 body,
6 300,130 more jets, less MET

Require $\int Ldt < 10\ pb^{-1}$
(one day of running)

Arbitrary (internal CMS) enumeration has nothing to do with LHCC (1996) points

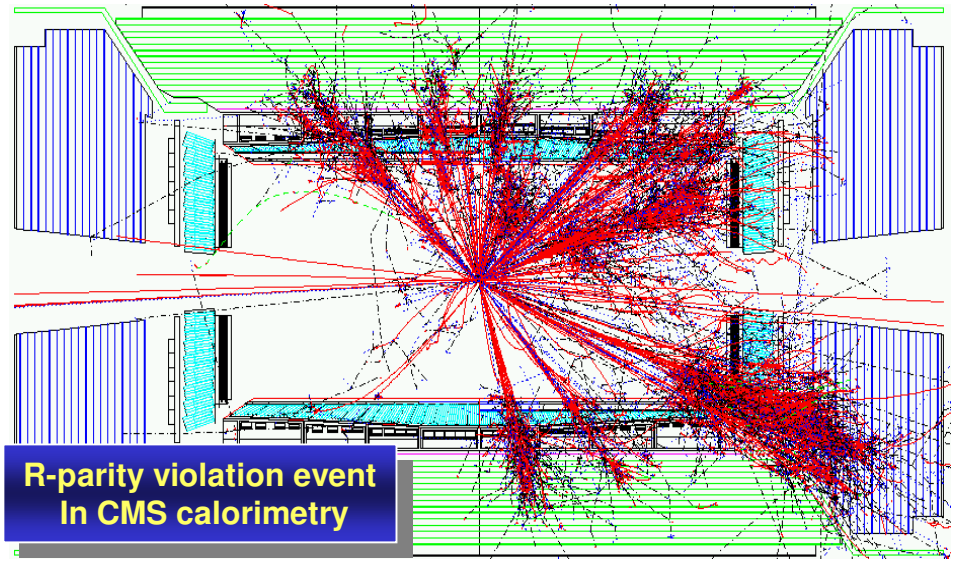
- Optimize efficiency for a rate to tape O(10 Hz)

Step Aside : R-Parity Violation Issue

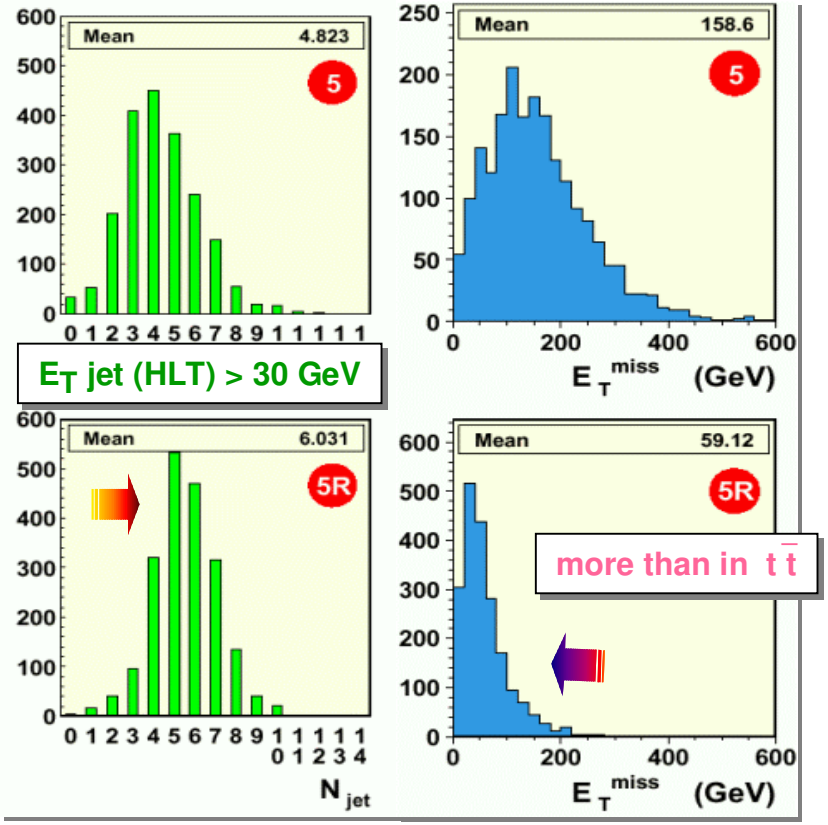
- Non-conservation of $R_p = (-1)^{3(B-L)+2S}$ leads to 3 new groups of terms (45 terms in total) in SUSY superpotential :

$$W = \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} Q_i L_j D^c_k + \lambda''_{ijk} U^c_i L^c_j D^c_k$$

- Most challenging for the trigger is the last group – barion number violation: $\tilde{\chi}^0_1 \rightarrow 3j$



R-parity violation event In CMS calorimetry



- Missing ET is reduced, but still substantial
- Number of jets increases

SUSY : Low Lumnosity Strategy

- $L = 2 \times 10^{33}\ cm^{-1}s^{-1}$
- "Genetic algorithm" is applied both at Level-1 and Level-2 triggers to get maximal sum of signal efficiencies while keeping trigger rate under control
- Minimal number of significant (essential) cuts remains
- Possible triggers at Level-2 (values at 95 % efficiency w.r.t generated quantities) :
  - 1 jet with $E_T > 180$ GeV & missing $E_T > 123$ GeV
  - 4 jets with $E_T > 113$ GeV
- Overall efficiencies to pass both trigger levels are :

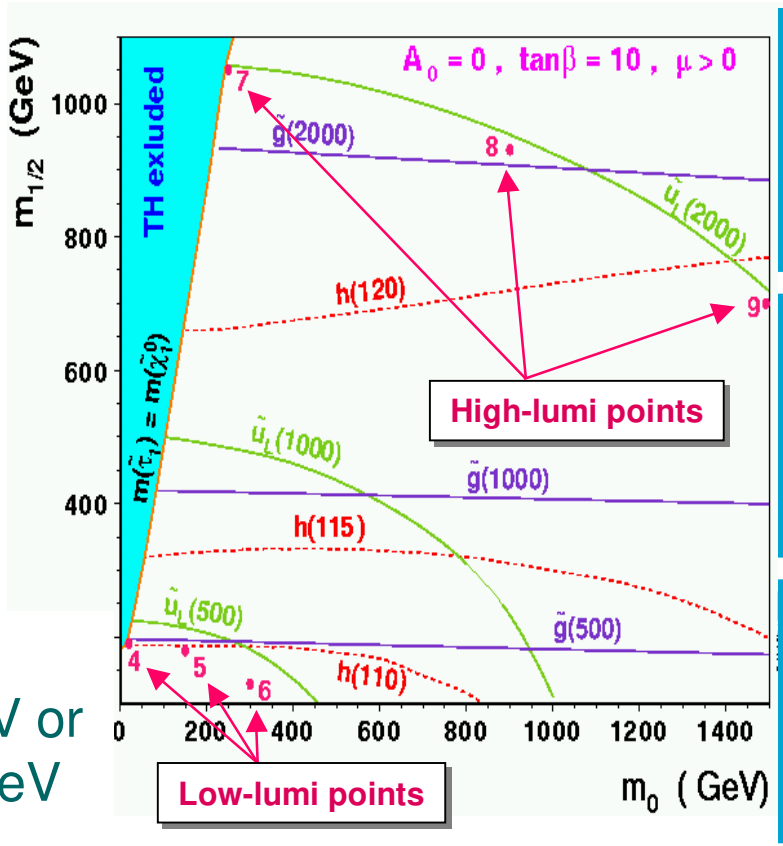
	4	5	6	4R	5R	6R
Eff.	0.69	0.68	0.64	0.44	0.46	0.26

With $\not{R}_p$

- Background rate (dominated by QCD) ~ 12 Hz
- More complex exclusive triggers (e.g. event shape) may slightly improve efficiency

SUSY : High Lumnosity Triggers

- Consider several test points at 2 TeV mass scale
- Consider also R-parity violation
- Level-1 and Level-2 triggers optimization
- Level-2 cuts : missing E_T > 239 GeV or 4 jets with E_T >185 GeV



$m(\tilde{\chi}_1^0)$ = 445 GeV m(h) = 122 GeV
$m(\tilde{g})$ = 2235 GeV $m(\tilde{u}_L)$ = 1986 GeV
σ ~ 17 fb tau and sneutrino – enriched
7 250,1050

$m(\tilde{\chi}_1^0)$ = 391 GeV m(h) = 121 GeV
$m(\tilde{g})$ = 2032 GeV $m(\tilde{u}_L)$ = 1962 GeV
σ ~ 22 fb "spoiling" dcays of chargino–neutralino
8 900,930

$m(\tilde{\chi}_1^0)$ = 293 GeV m(h) = 120 GeV
$m(\tilde{g})$ = 1625 GeV $m(\tilde{u}_L)$ = 1975 GeV
σ ~ 59 fb more jets, less MET
9 1500,700

- Overall efficiencies to pass both trigger levels are :

	7	8	9	7R	8R	9R
Eff.	0.85	0.92	0.76	0.90	0.88	0.64

With $\not{R}_p$

Inclusive SUSY Searches

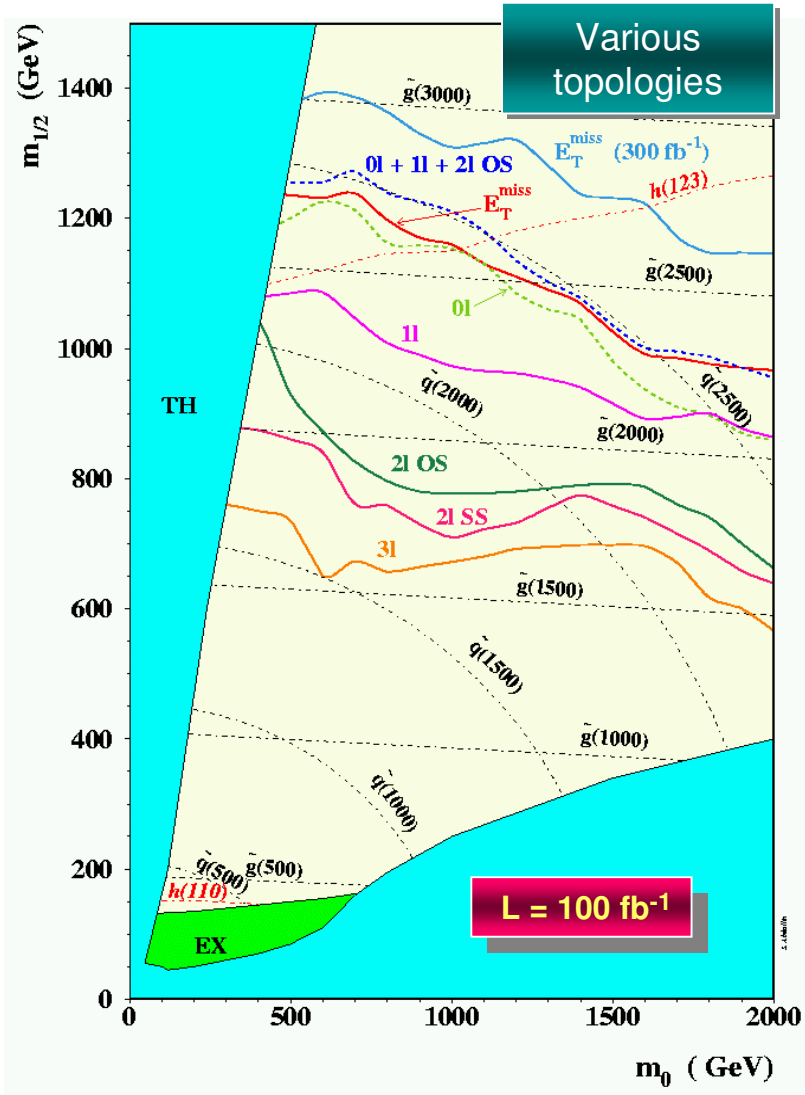
Inclusive SUSY Searches

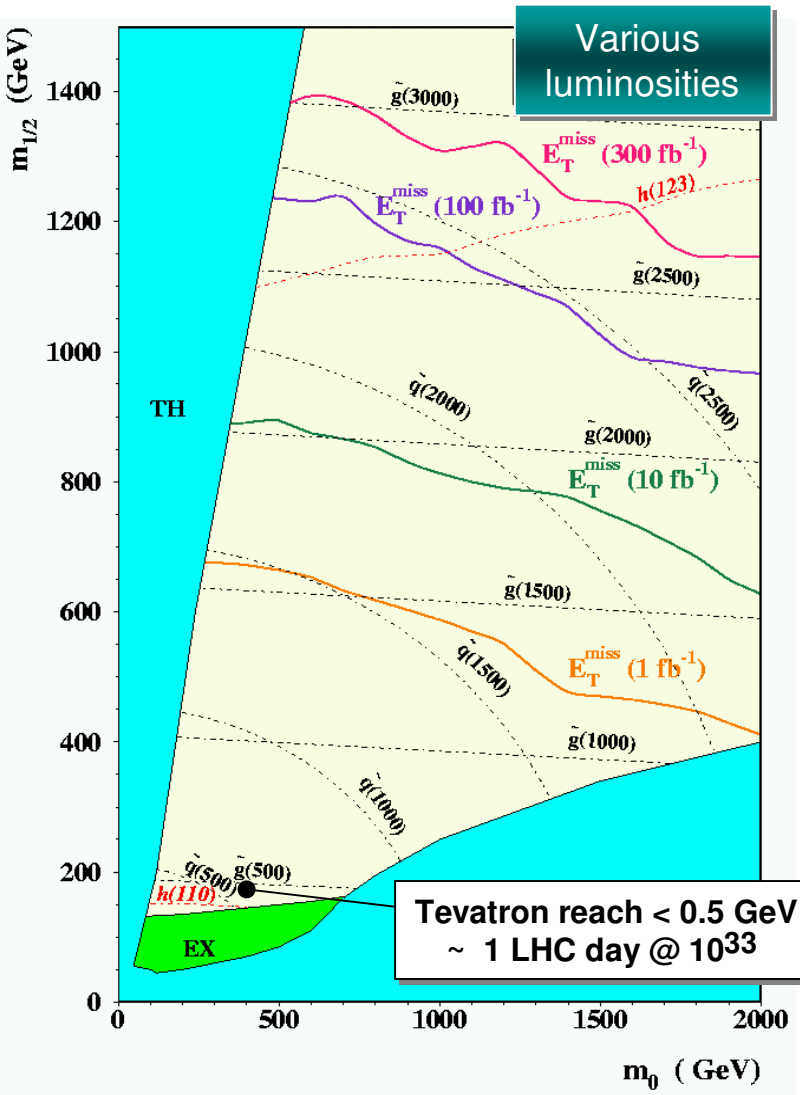
- Counting excess of events over SM expectations
  - Discovery mode SUSY search
  - Explicit sparticle reconstruction not done
- Multitude of final states analysed
- Standard model background
  (a few x10^8 events)
- Simulated with fast MC :
  ATLFAST, CMSJET

- E_T^{miss}: jets+MET
- 2lOS: 2 leptons, opposite sign
- Ol: no leptons
- 1l: 1 lepton
- 2lSS: 2 leptons, same sign
- 3l: 3 leptons

- CMS Study :
  - Common cuts : missing E_T >200 GeV, min. 2 jets with E_T >40 GeV in $|\eta|<3$
  - Electrons: isolated, with p_T >20 GeV in $|\eta|<2.4$
  - Muons: isolated or not, with p_T>10 GeV in $|\eta|<2.4$
  - Vary cuts in 6 categories (~ 10^4 combinations) :
    #Jets & E_T^{jet} , MET, angular and shape variables, muon isolation
  - Optimize S/sqrt(S+B) in a counting experiment and plot 5σ sensitivity contours

Inclusive SUSY Searches (mSUGRA)





$A_0 = 0$
$\tan\beta = 35$
$\mu > 0$

~1 year @10^{34}

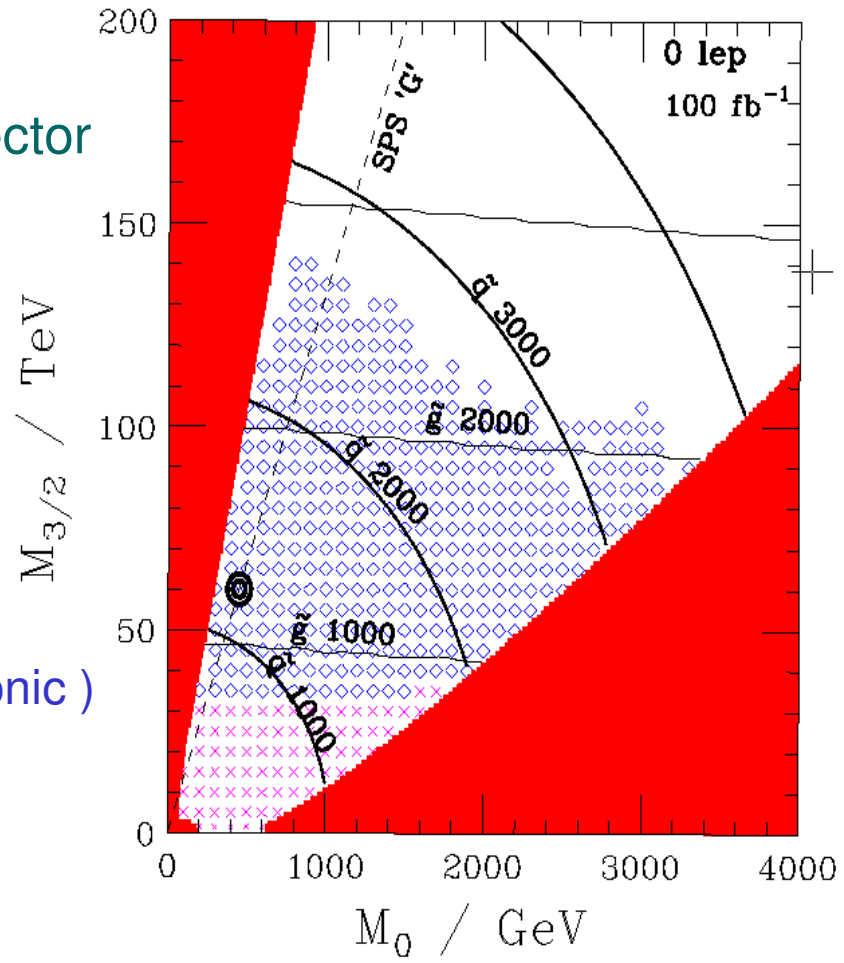
~1 year @10^{33}

~1 month @10^{33}

- Jets+MET gives greatest sensitivity, 2lOS – useful for sparticle reconstruction

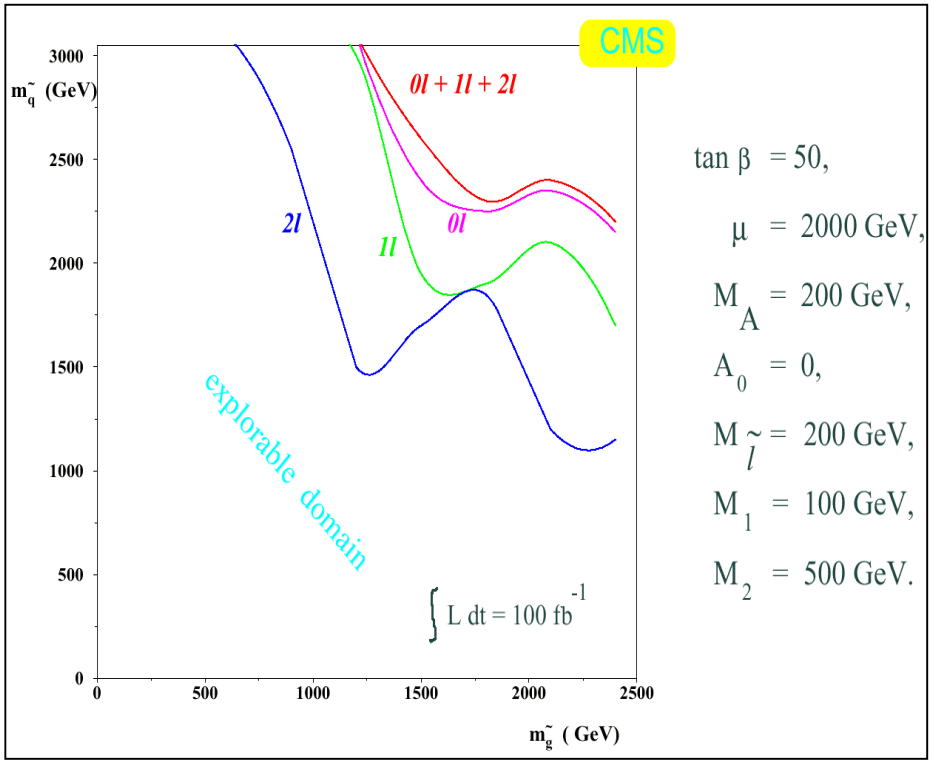
Inclusive Searches – AMSB …

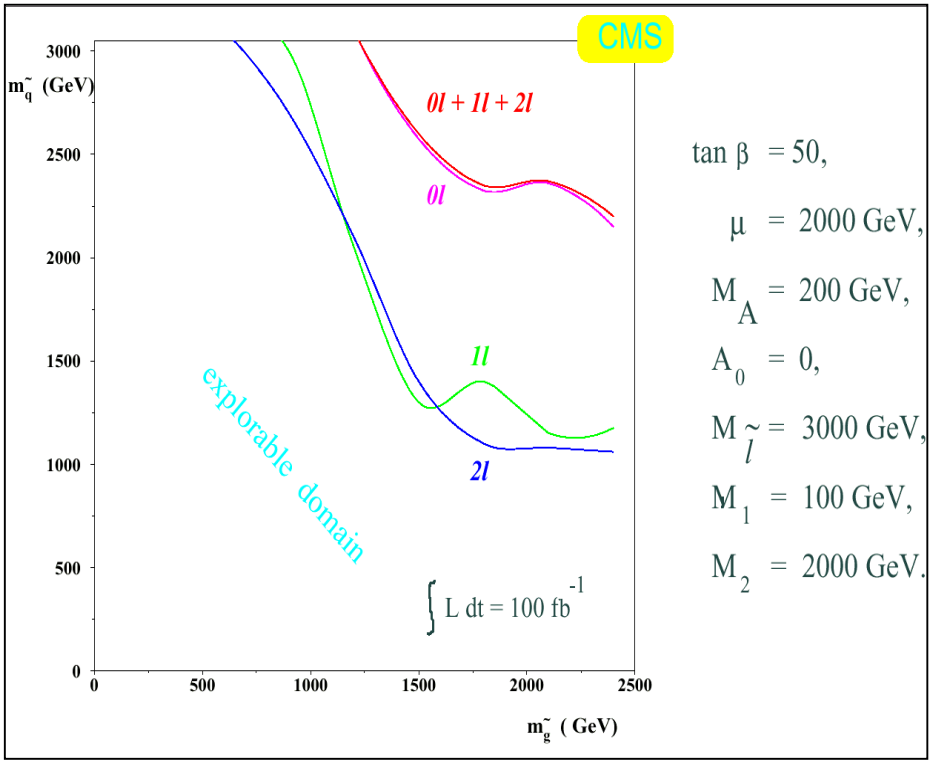
- Special case of gravity mediation :
  No direct tree-level coupling to transmit SUSY breaking from hidden to visible sector
- SUSY breaking on a separate membrane is communicated to the visible sector via super-Weyl anomaly
- Four parameters :
  - $m_{3/2}$ – SUSY breaking scale
  - m_0 – additional mass scale for scalars (to keep sleptons from being tachyonic)
  - tan β
  - sign(μ)
- Distinctive feature
  - $M(\tilde{\chi}_1^{\pm}) \approx M(\tilde{\chi}_1^0)$



☞ Similar reach in $M(\tilde{g})$, $M(\tilde{q})$ as for mSUGRA, > 2.5 TeV for 100 fb^{-1}

.. or even MSSM !



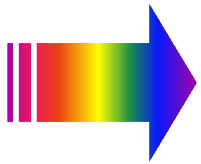


- Overall reach depends mainly on $\sigma(M_{\tilde{g}}, M_{\tilde{q}})$ and $M_{\tilde{\chi}_1^0} << M_{\tilde{g}}, M_{\tilde{q}}$
- Expect similar reach in various R_p-conserving models

Reconstructing SUSY

After SUSY Reveals itself in $\not{E}_T$ + jets …

- Obviously it is not enough to observe the excess over the Standard Model…



DISCOVERY

SUSY SPECTROSCOPY

- This requires a different approach…
  - Take a point in the parameter space
  - Get spectra, evaluate the characteristic features, such as endpoints, as invisible LSP gives no mass peaks …
  - From mass combinations - reconstruct sparticles

Exclusive Di-Lepton Reconstruction

- Measure invariant mass distribution of OS SF leptons

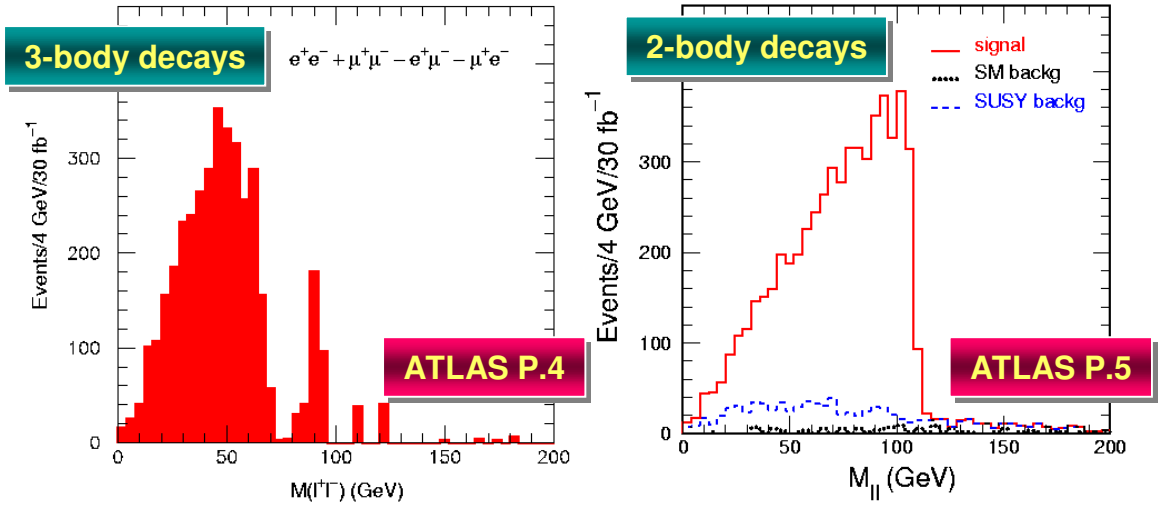
Simplest case: $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \ell^+ \ell^-$ gives dilepton endpoint at

$$M_{\ell\ell} = M_{\tilde{\chi}_2^0} - M_{\tilde{\chi}_1^0}$$

Cascade decay $\tilde{\chi}_2^0 \to \tilde{\ell}^{\pm} \ell^{\mp} \to \tilde{\chi}_1^0 \ell^+ \ell^-$ gives endpoint at

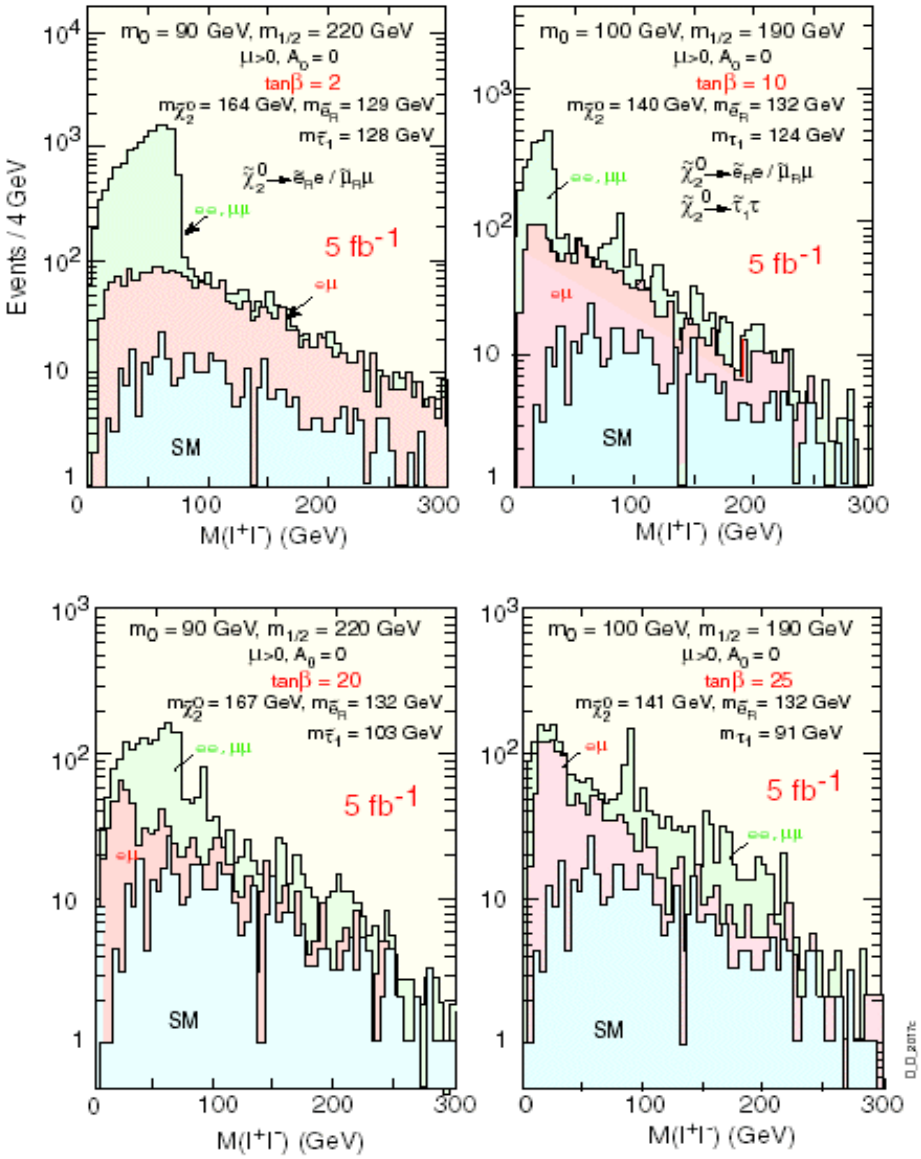
$$M_{\ell\ell} = \frac{1}{M_{\tilde{\ell}}} \sqrt{(M_{\tilde{\chi}_2^0}^2 - M_{\tilde{\ell}}^2)(M_{\tilde{\ell}}^2 - M_{\tilde{\chi}_1^0}^2)}$$

- Require 2 isolated leptons, jets + large E_T -main SM background is $t\bar{t}$
- Form combination $e^+e^- + \mu^+\mu^-$ - $e^{\pm}\mu^{\pm}$ to cancel independent decays (SM & SUSY)
- $\tilde{\chi}_2^0$ can be produced via Drell-Yan, but more abundant in decays of $\tilde{q}$, $\tilde{g}$



- 2-body and 3-body decays can be distinguished by additional shapes

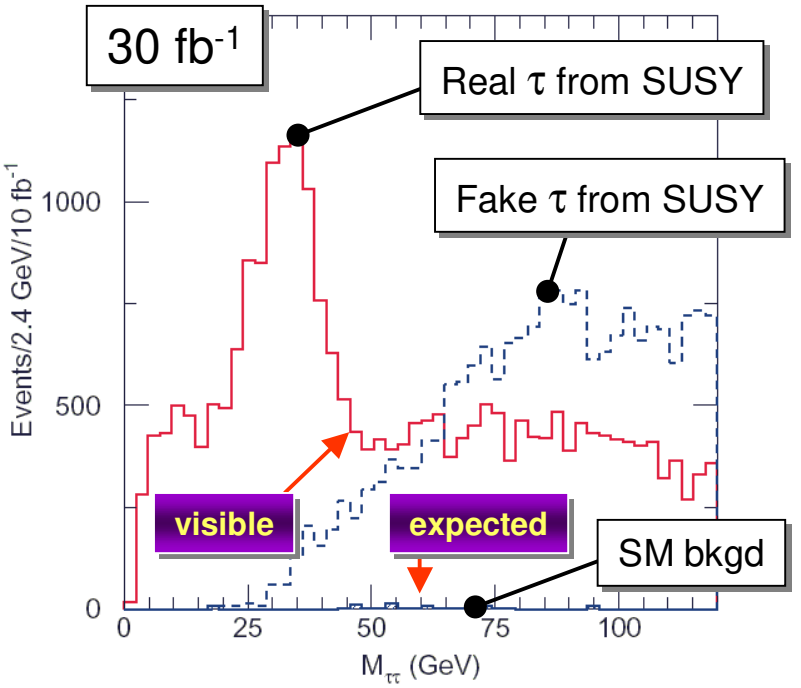
Evolution of Di-lepton Edge



- SUSY may reveal itself early through pecularities in the inclusive di-lepton spectra
- Structures tend to be less evident with increasing tanβ
  - where $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \tau^+\tau^-$ dominates

Di-Tau Edge Reconstruction

- As $\tau \to l\ \nu\ \bar{\nu}$ identification is not possible, must rely on hadronic decays – narrow, 1-prong jets (large QCD bkgd though)
  - Can typically achieve τ/jet ~100 for ε_τ ~50-60 %
- ATLAS Physics TDR study (full GEANT simulation) example ("Point 6") :
  - Narrow isolated jets selection : $R_{jet} = 0.2$, $R_{isol} = 0.4$
  - Require 0.8 GeV < M_{jet} < 3.6 GeV (biased against 1-prong, but Improves di-tau mass resolution - less neutrino momentum)
  - Di-tau efficiency = 41 %
  - $M_{vis} = 0.66\ M_{\tau\tau}$
  - Additional cuts : min. 4 jets : $E_T^1 > 100$ GeV, $E_T^{2\text{-}4} > 50$ GeV missing $E_T > 100$ GeV, no e,μ with pT > 20 GeV



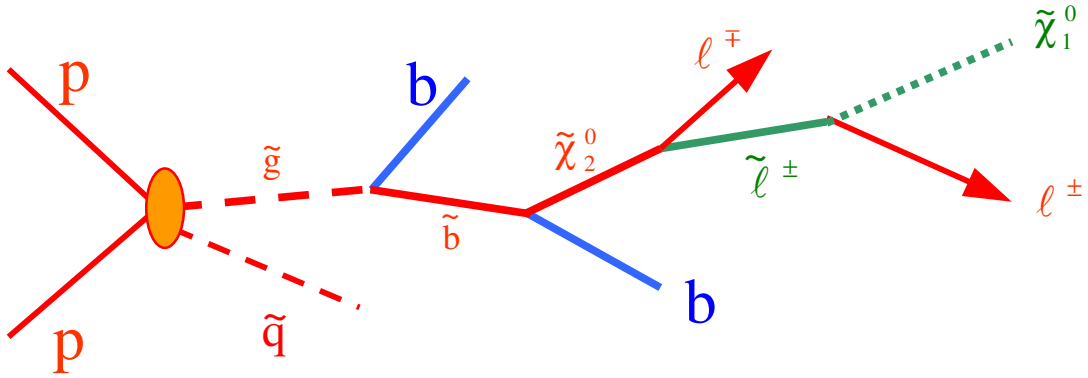
Recent results (yet unpublished) – even more encouraging…

Point B : Exclusive Reconstruction

(more details - in the talk of M.Chiorboli)

- Point B of "Proposed Post-LEP Benchmarks for SUSY" (hep-ph/0106204)

$m_{1/2} = 250$
$m_0 = 100$
$\tan\beta = 10$
$\mathrm{sign}(\mu) = +$
$A_0 = 0$



Sparticles spectrum (GeV)

g	595.1	**t_1**	392.9
b_1	496.0	**t_2**	575.9
b_2	524.0	**χ_4^0**	361.1
q_L	540	**χ_3^0**	339.9
q_R	520	**χ_2^0**	174.4
l_L	196.5	**$\chi_2^\pm$**	361.6
l_R	136.2	**$\chi_1^\pm$**	173.8
		χ_1^0 = LSP	95.6

$pp \rightarrow \tilde{g} \rightarrow \tilde{b}b$ (17% b_1, 10% b_2)

$\hookrightarrow \tilde{\chi}_2^0 b$ (37 % b_1, 25% b_2)

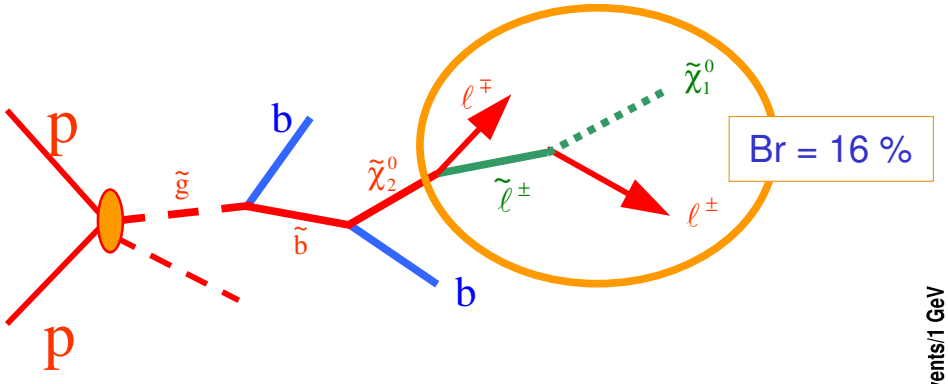
$\hookrightarrow \tilde{\chi}_1^0 \ell^+\ell^-$ (0.04 %)

$\hookrightarrow \tilde{\ell}^\pm\ell^\mp \rightarrow \tilde{\chi}_1^0\ell^+\ell^-$ (16.4%)

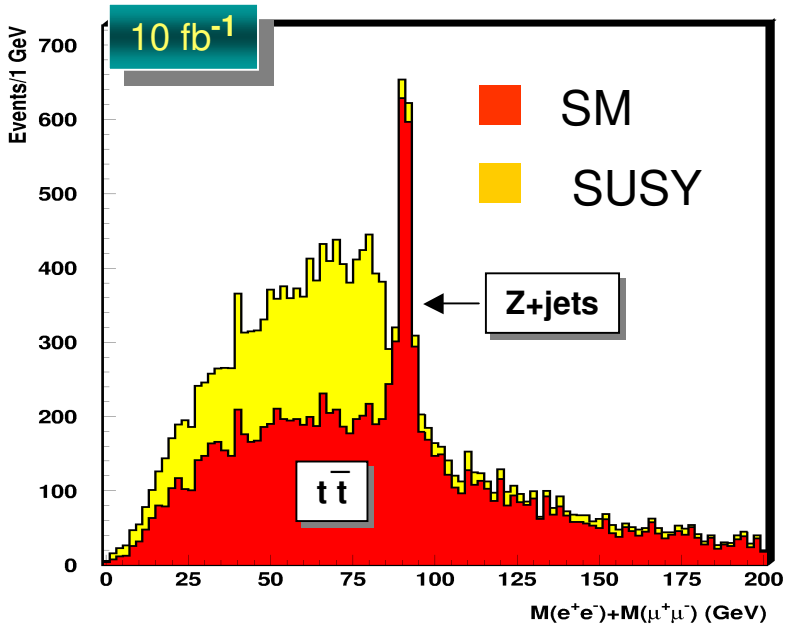
$\hookrightarrow \tilde{\tau}^\pm\tau^\mp \rightarrow \tilde{\chi}_1^0\tau^+\tau^-$ (83.2%)

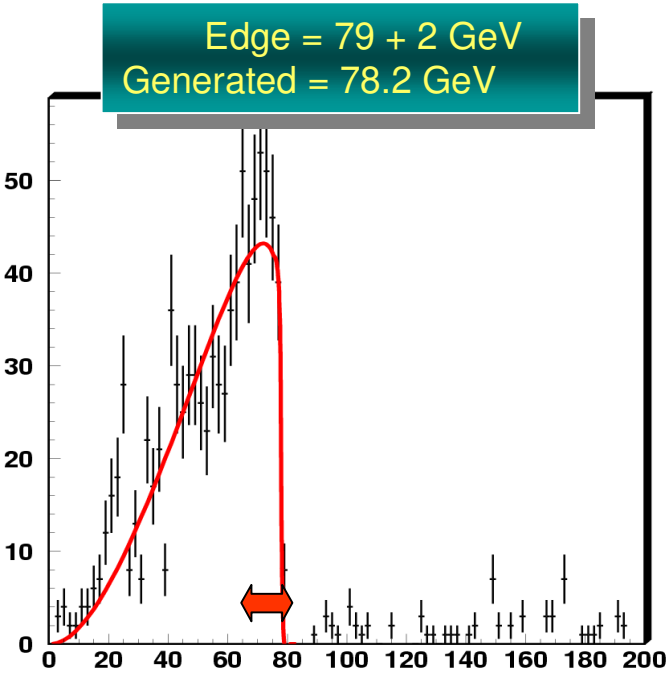
$\sigma^{\mathrm{TOT}}_{\mathrm{SUSY}} = 57.77$ pb

Step 1 : Di-Lepton Mass Reconstruction



- ≥2 SF OS isolated leptons, p_T>15 GeV, |η|<2.4
- MET > 150 GeV, E(ll) > 100 GeV



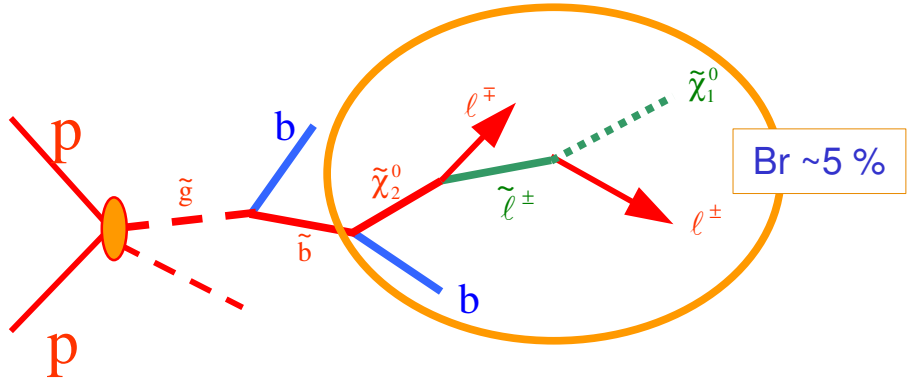


$M(e^+e^-)+M(\mu^+\mu^-)-M(e^+\mu^-)-M(e^+\mu^-)$ (GeV)

- Selection in 15 GeV window $\tilde{\chi}_1^0$ at rest in the rest frame of $\tilde{\chi}_2^0$

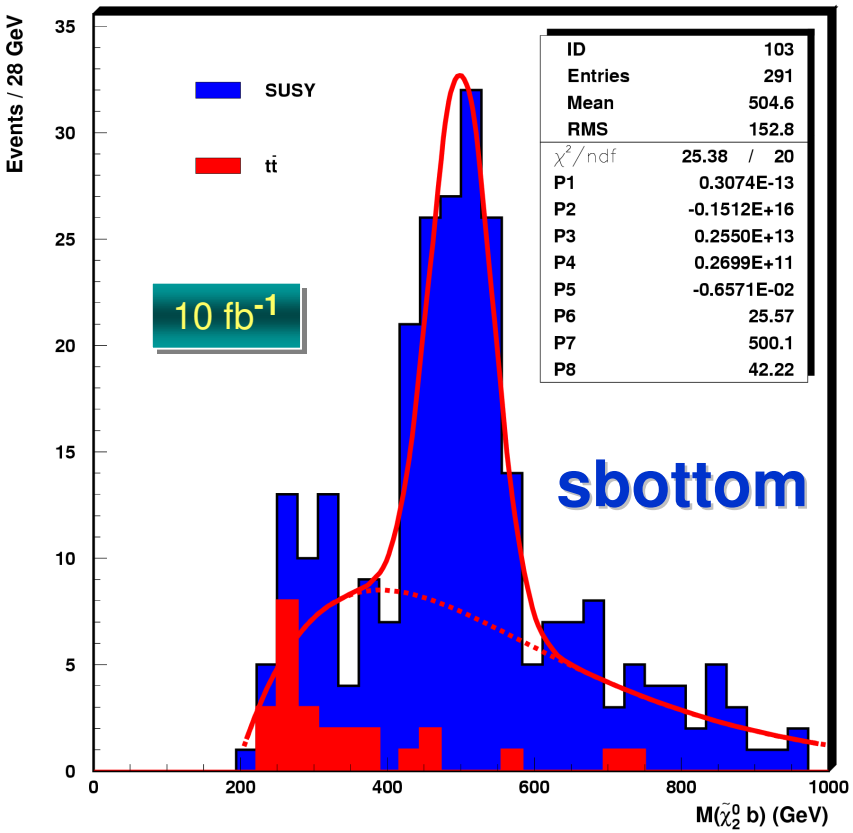
$$\vec{p}_{\tilde{\chi}_2^0} = \left(1+\frac{M_{\tilde{\chi}_1^0}}{M_{\ell^+\ell^-}}\right)\vec{p}_{\ell^+\ell^-}$$

Step 2 : Sbottom Reconstruction



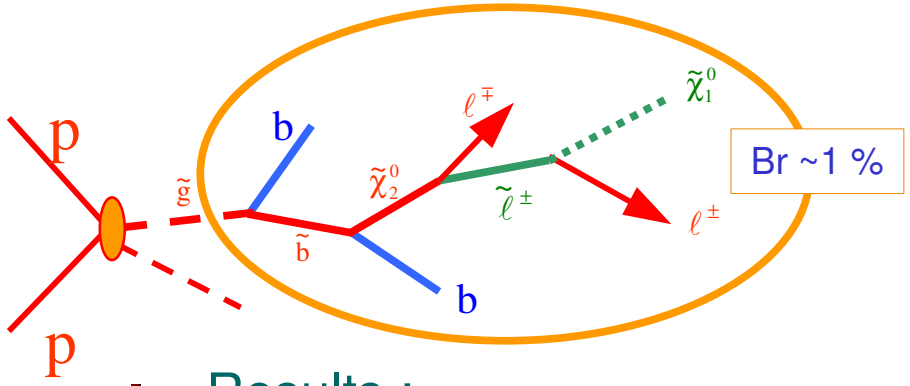
- Add most energetic b-jet to reconstruct sbottom
  - $E_{b\text{-jet}} > 250$ GeV, $|\eta|<2.4$
  - b-jet : min.2 tracks with IP significance > 3σ
- Results :
  - $M(\tilde{b}) = 500 \pm 7$ GeV, $\sigma_M = 42$ GeV
  - Generated : $M(\tilde{b}_1) = 496$ GeV
    $M(\tilde{b}_2) = 524$ GeV

- Assume $M(\tilde{\chi}_1^0)$ is known ("educated" guess : edge value)



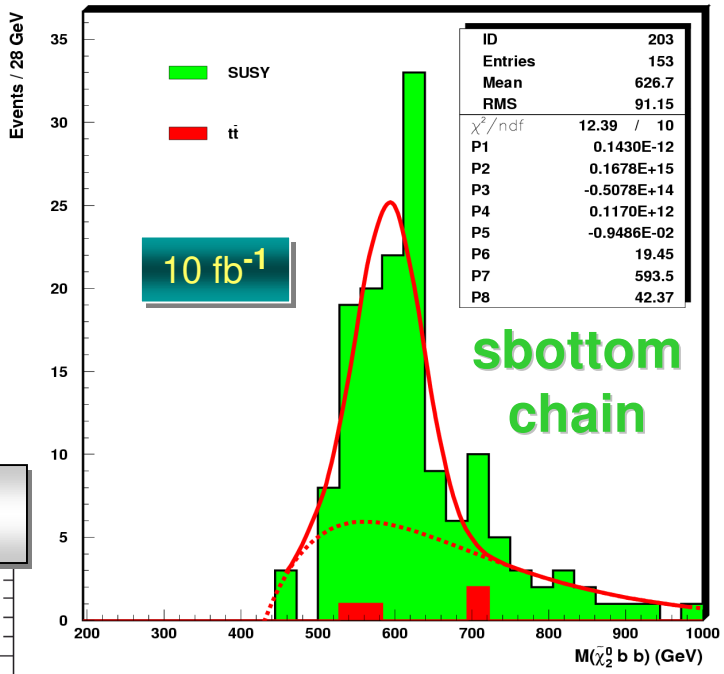
Window : 400 GeV < $M(\chi_2^0 b)$ < 600 GeV

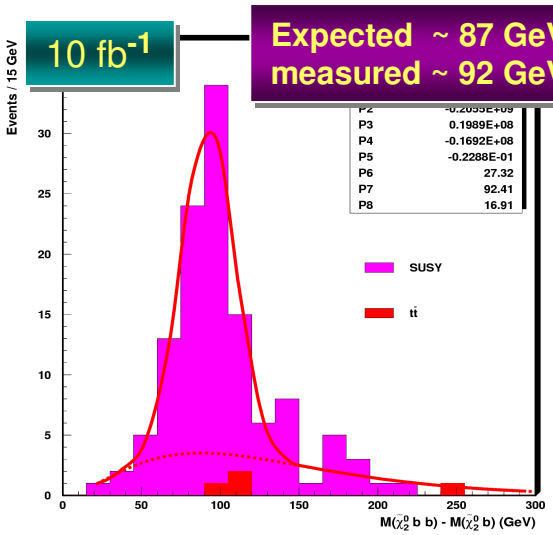
Step 3 : Gluino Reconstruction

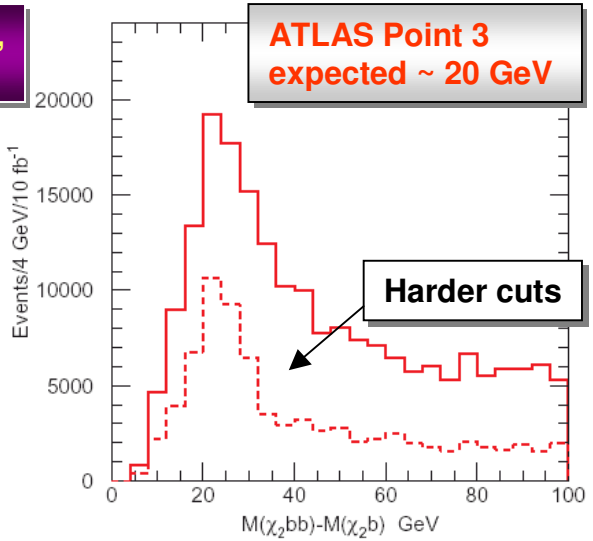


- Results :
  - $M(\tilde{g})$ = 594 ± 7 GeV, σ_M = 42 GeV
  - Generated : $M(\tilde{g})$ = 596 GeV

- Add another (closest in ϕ) b-jet



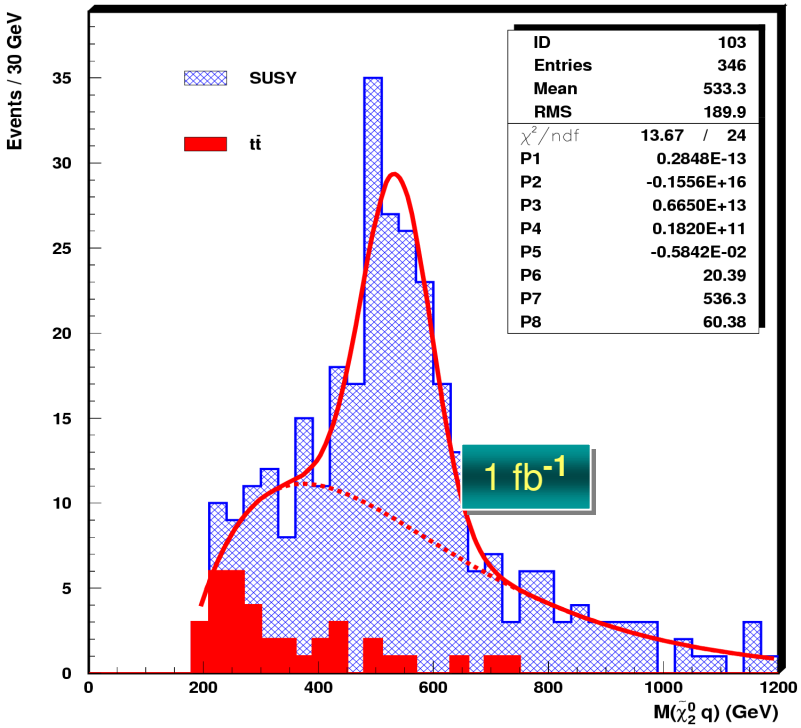




- $M(\tilde{g}) - M(\tilde{b})$ is independent of $M(\tilde{\chi}_1^0)$

Point B : Non-b Squark Reconstruction

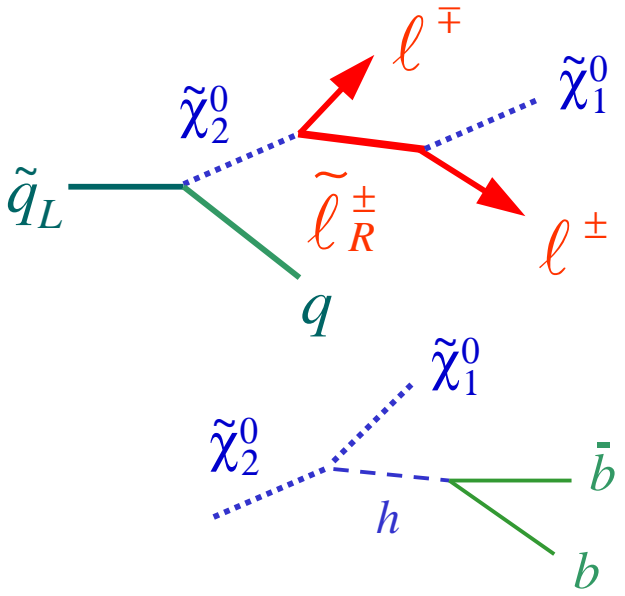
- Expect more combinatorial background with non-b jets
  - Upper cut on the second-ET jet to reduce combinatorics
- Veto all b-jets
  - Tracks with the second largest IP significance < 2σ
  - Helps to reject sbottom/stop decays
- Less luminosity required ($1fb^{-1}$)
- Same di-lepton edge selection as before
- Results :
  - $M(\tilde{q}) = 536 \pm 10$ GeV, $\sigma_M = 60$ GeV
  - Generated : $M(\tilde{q}) = 537\text{-}543$ GeV
- Eventually – gluino reconstruction
  - Combine reconstructed squark with the nearest jet



Example of Masses Reconstruction Using Kinematic Constraints (ATLAS Point 5)

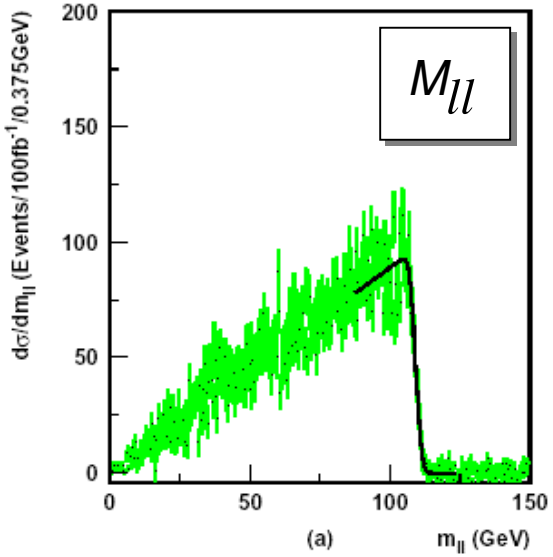
Thresholds and Model-Independent Analysis

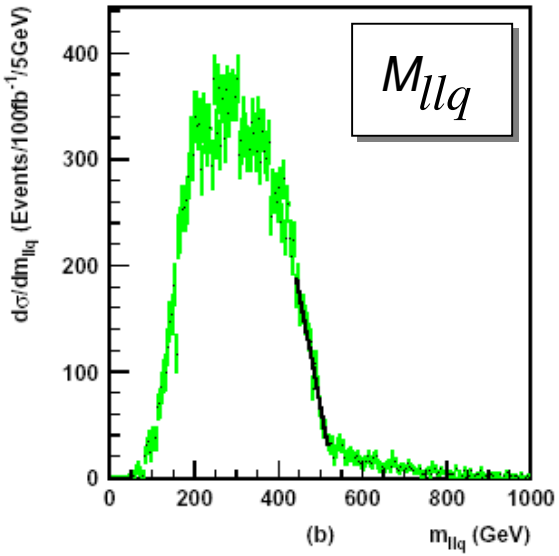
- Long decay chains allow multiple measurements
  - In general both maximum and minimum value due to 2-body (in many cases) kinematics
- Starting point : di-lepton OS SF mass edge
- The main reconstruction chain :
- Assume 2 hardest jets are from squarks, combine each of these with leptons to from :
  - Endpoints: M_{llq}, $M_{lq}^{>}$, $M_{lq}^{<}$
  - Threshold : T_{llq}, requiring $M_{ll} > M_{ll}^{max}/\sqrt{2}$
  - Also used endpoint from M_{hq} from $h \to b\bar{b}$
    (see more details in the yesterday's talk of Sasha Nikitenko)

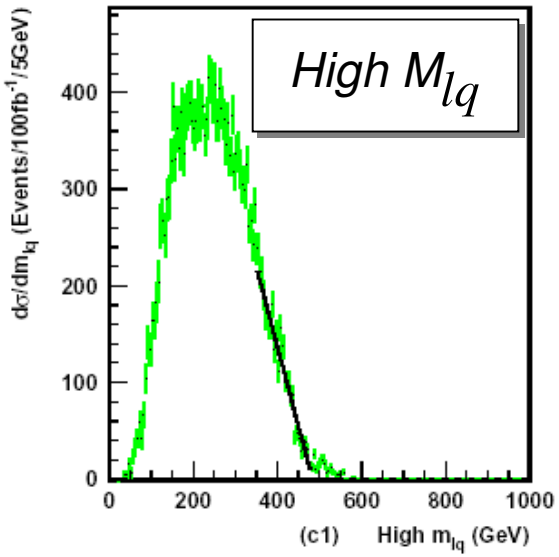


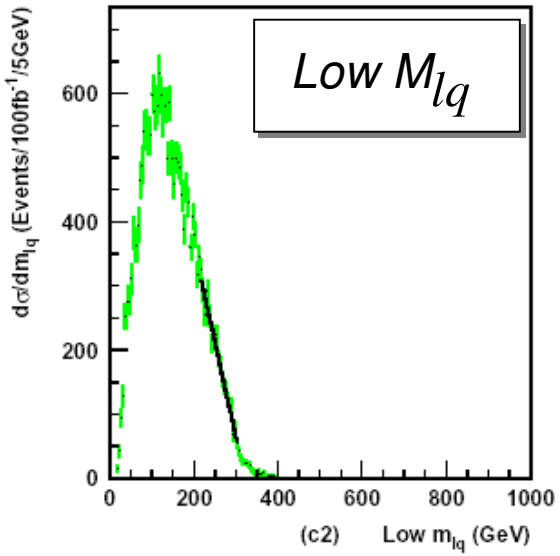
- Turns out to have enough constraints to determine all masses involved (!)
- Can measure mass relations to ~1% as a function of LSP mass, determined to ~10 %

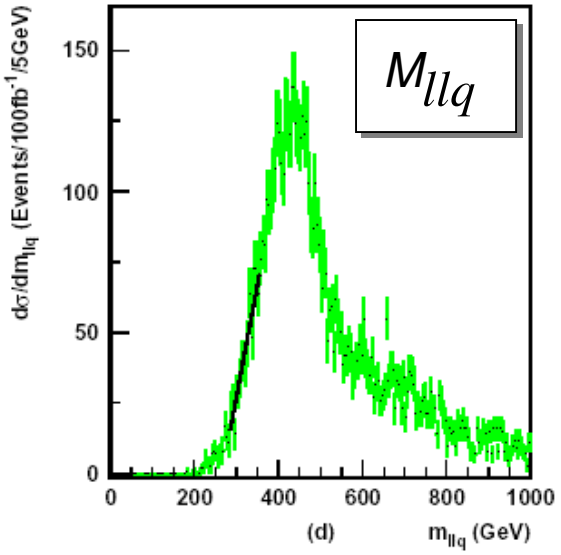
ATLAS Point 5 : Distributions

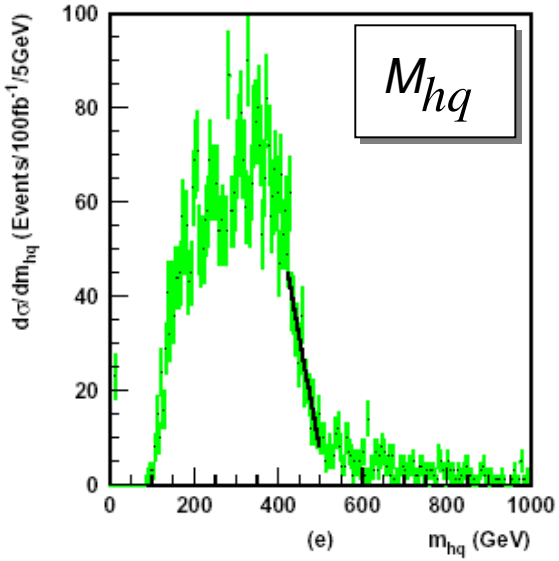






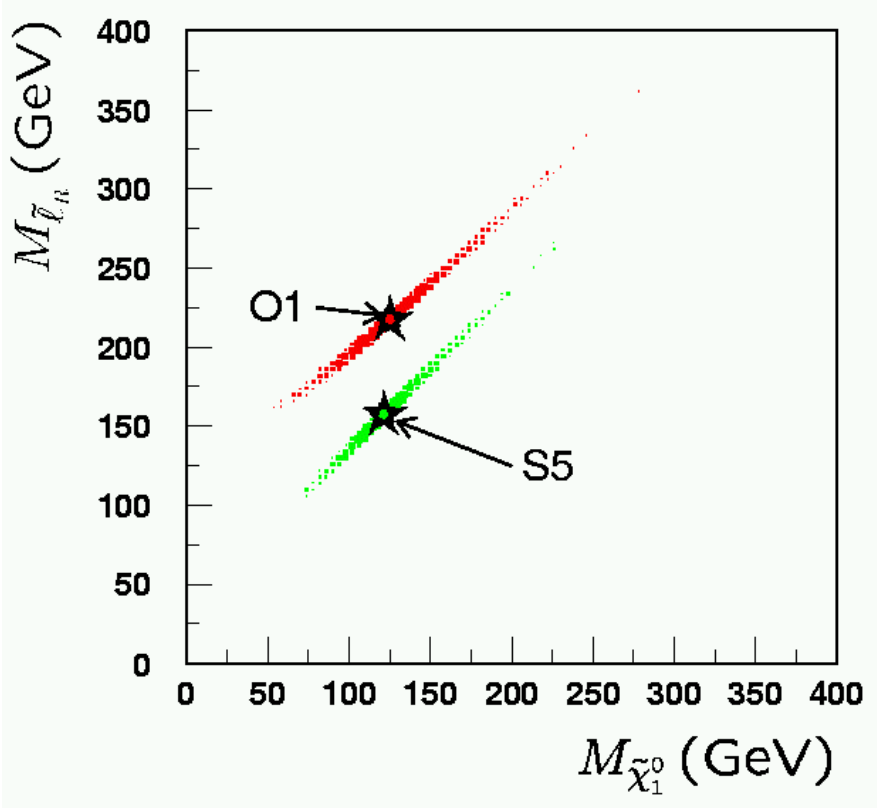


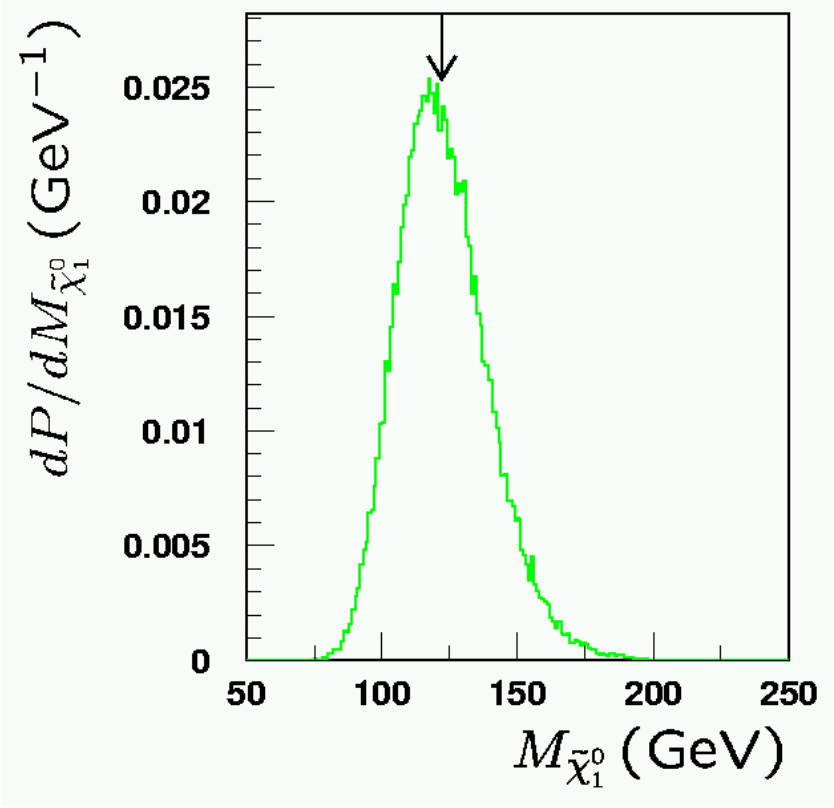




ATLAS Point 5 : LSP Reconstruction

- Fit for masses for Point 5 (S5) and similar "Optimized String Model" (O1)





- Models clearly distinguished, LSP mass determined to ~10%
- LSP mass is small, effect on kinematics vanishes as M($\tilde{\chi}_1^0$) -> 0

GMSB Signatures

GMSB Model

Gauge Mediated SUSY Breaking

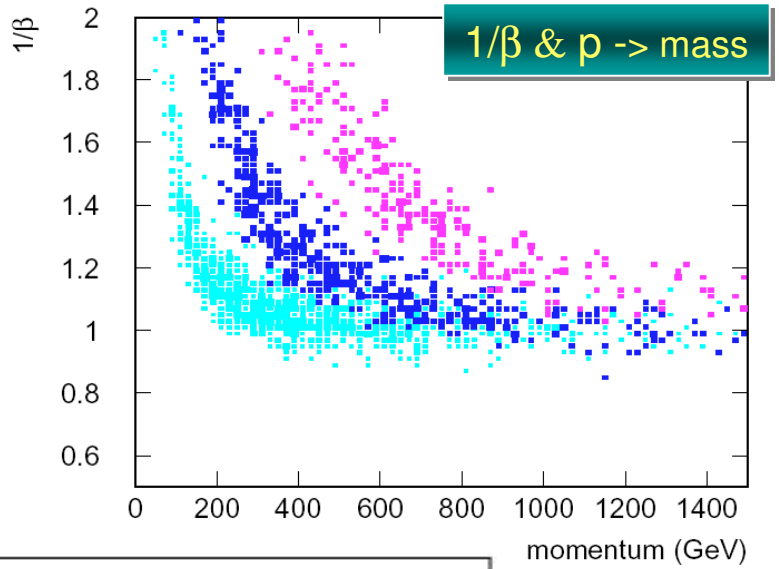
- Uses SM gauge interactions to communicate SUSY breaking (instead of gravity in mSUGRA)
- Particles get mass from SM gauge interactions at a messenger scale $M_m \sim O(1000\ TeV) << M_{Pl}$
- n = number of SU(5) messenger fields, $\Lambda = F/M_m \sim 10\text{-}100\ TeV$ – scale of SUSY Breaking
  - $\tilde{G}$ is LSP (M << 1 GeV)
  - NLSP : $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ (n=1, low tanβ) or $\tilde{\tau} \rightarrow \tilde{G}\,\tau$ (n>1 or high tanβ)
- NLSP lifetime :

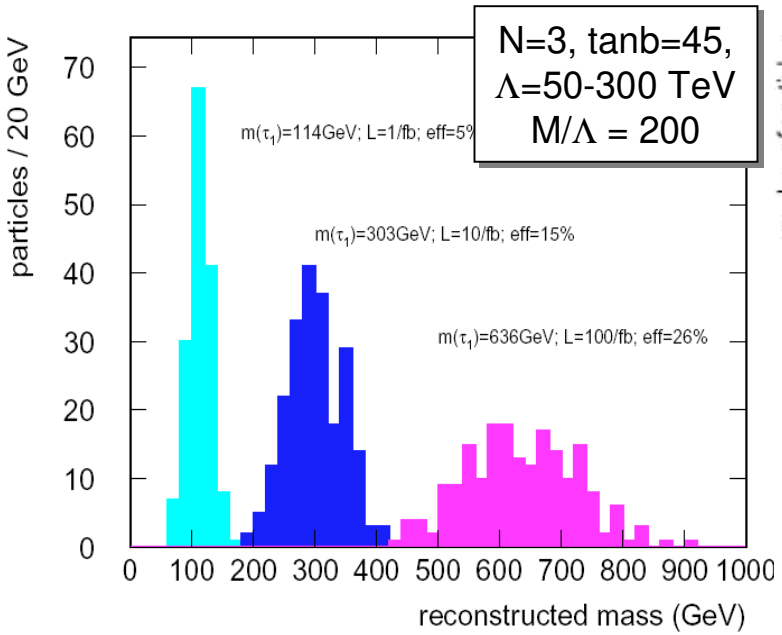
$$C\tau \sim 1.3\text{m} \left(\frac{100\ \text{GeV}}{M_{NLSP}}\right)^5 \left(\frac{\sqrt{F}}{1000\ \text{TeV}}\right)^4$$

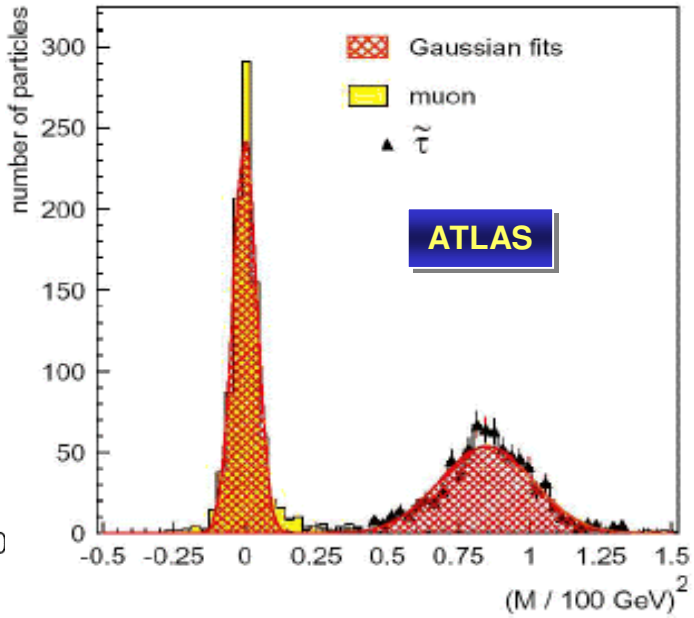
  - $C\tau$ >> detector size : slepton($\tilde{\tau}$) is a long-lived heavy lepton (like μ)
    $\tilde{\chi}_1^0$ - leads to MET, like in mSUGRA
  - $C\tau \sim$ detector size : estimate F by measuring NLSP lifetime
  - $C\tau$ << detector size : radiative decay with $\gamma(\tau)$ – two additional per event

GMSB ($\tilde{\tau}$ – NLSP) : Heavy Lepton Search

- Use drift-tube muon system (both ATLAS and CMS) to measure time-of-flight for heavy leptons (~ 1ns)
- Can measure $\tilde{\tau}$ mass in a wide range : 90-700 GeV for 100fb^{-1}
- The upper limit corresponds to σ~1 fb^{-1} and sguark/gluino masses ~ 4 TeV



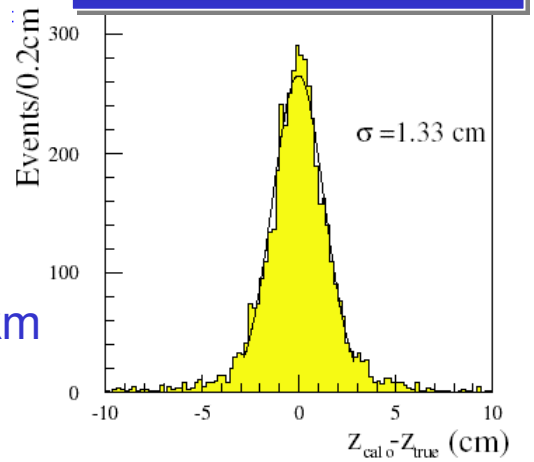


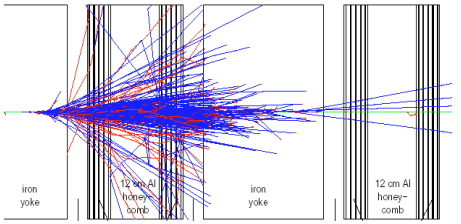


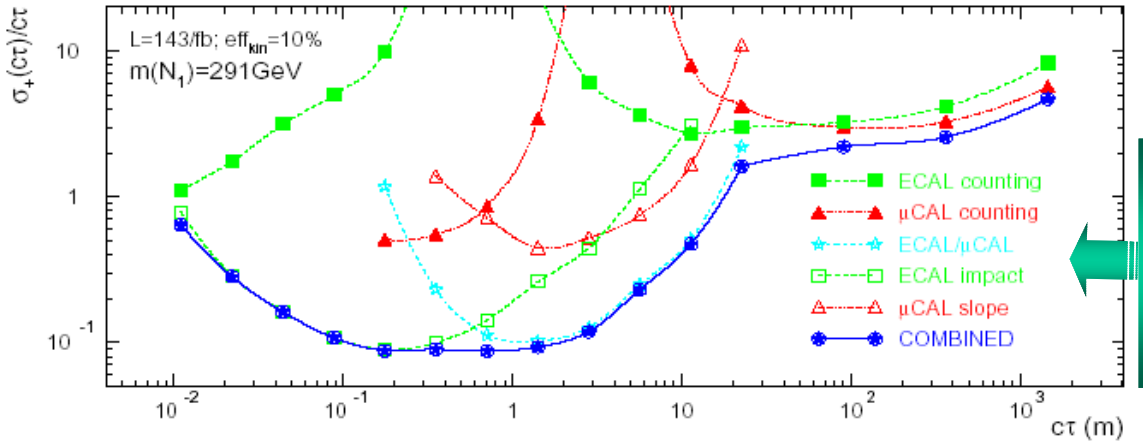
GMSB ($\tilde{\chi}_1^0$ - NLSP) : Lifetime Measurement

- Look for unusual phenomena inside detectors
  - Electromagnetic showers not pointing to the vertex
    - Use fine angular resolution from LAr EM calorimeter (ATLAS) and $PbWO_4$ crystals (CMS)
    - ATLAS : if no non-pointing γ's for 30 fb^{-1}-> $c\tau$ >100 km (Λ=90 TeV, M=500 TeV, n=1)
  - EM showers (!) in muon system
    - Identify showers with high hit multiplicity

ATLAS vertex resolution for H -> $\gamma\gamma$





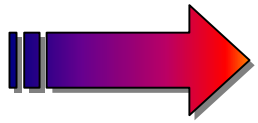


Using complementary methods CMS can measure $\tilde{\chi}_1^0$ $c\tau$ from 1 cm to 1 km for scenarios with σ_{SUSY} > 100 fb^{-1}

Can SUSY Remain Hidden from LHC Searches ?

What Might Hamper SUSY Searches

- The worst scenario : no SUSY at the EW scale
  - Might be at the GUT scale only…
  - Problems “solved” by low-energy SUSY might be find solution in other theories, ex. extra-dimensions
- Less extreme case
  - First two generations are very heavy (5-10 TeV), only 3^{d} generation possibly reaches 2-3 TeV, making only h detectable …
- Various “unpleasant” scenario



Unpleasant Scenarios

- Hiding missing E_T, R-parity broken this way: $\tilde{\chi}_1^0$ -> cds, $\bar{c}\bar{d}\bar{s}$
  - No b-tagging possible
  - Multi-jet + missing E_T reach might be reduced
  - Di-lepton edge, if possible

- Encore worse : hiding leptons, all gluinos, charginos and neutralinos -> cds, $\bar{c}\bar{d}\bar{s}$
  - Just muili-jet events – really **"dark spot"** in SUSY searches

Non-Universal Gaugino Masses (I)

- Snowmass-96 : SUSY SU(5) GUT phenomenology with non-universal gaugino mass examined …
  - $\tilde{\chi}^{\pm}_{1}$ $\tilde{\chi}^{0}_{1,2}$ degenerate within a few GeV

- Similarly within MSSM :

$\tan\beta = 50, \quad A_t = A_b = A_\tau = 0, \quad m_A = 1000,$

μ	M_1	M_2	$m_{\tilde{g}}$	$m_{\tilde{q}}$	$m_{\tilde{l}}$	
1500	1450	2000	1500	1520	1520	GeV

  - Almost completely degenerate mass hierarchy …
  - Sleptons are too heavy (a bit “artificial”)

$m_{\tilde{b}_1} = 1445$ GeV (lightest)

$m_{\tilde{b}_2} = 1593$ GeV (heaviest)

$m_{\tilde{\chi}^0_2} = 1501.2$ GeV

$m_{\tilde{\chi}^{\pm}_1} = 1494.3$ GeV

$m_{\tilde{\chi}^0_1} = 1433.7$ GeV

$m_h = 117.7$ GeV

$\sigma = 0.126$ pb

Non-Universal Gaugino Masses (II)

$\tilde{g} \rightarrow \tilde{b}_1 b$
$\quad \hookrightarrow \tilde{\chi}^0_1 b$

$\tilde{q}_L \rightarrow \tilde{\chi}^0_1 q \quad \sim 2\text{-}5\ \%$
$\quad\quad \tilde{g} q \quad \sim 95\text{-}98\ \%$

$\tilde{q}_R \rightarrow \tilde{\chi}^0_1 q \quad \sim 12\text{-}35\ \%$
$\quad\quad \tilde{g} q \quad \sim 64\text{-}88\ \%$

$\tilde{b}_1 \rightarrow \tilde{\chi}^0_1 b \quad \sim 100\ \%$

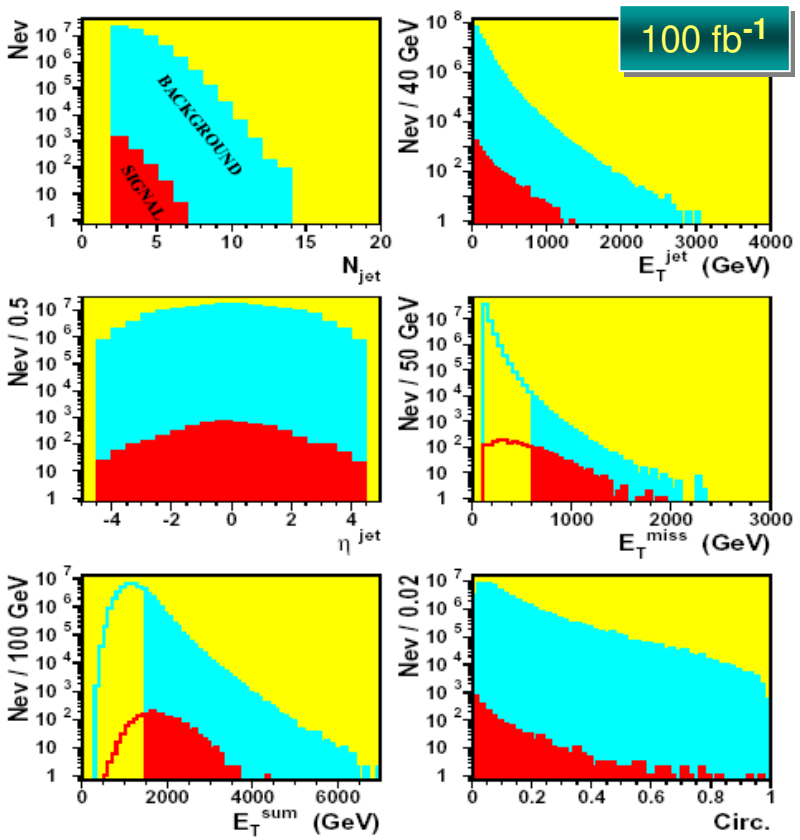
$\tilde{b}_2 \rightarrow \tilde{g} b \quad \sim 50\ \%$
$\quad\quad \tilde{b}_1 Z \quad \sim 38\ \%$

$\tilde{t}_1 \rightarrow W \tilde{b}_1 \quad \sim 100\ \%$

$\tilde{t}_2 \rightarrow W \tilde{b}_1 \quad \sim 21\ \%$
$\quad\quad \tilde{\chi}^\pm_1 b \quad \sim 79\ \%$

$\tilde{\chi}^0_2 \rightarrow \tilde{b}_1 b \quad \sim 98\ \%$

$\tilde{\chi}^\pm_1 \rightarrow \tilde{\tau}_1 \nu \quad \sim 79\ \%$
$\quad\quad \tilde{\chi}^0_1 l^\pm \nu \sim 4.5\ \%$



- Difficult to find an excess even at 100 fb^{-1}, might be at 300 fb^{-1} or/and using excess of b's
- Leptonic decays would be helpful …

Summary

LHC Summary (I)

- Discovery of SUSY, if it exist at TeV scale, is almost assured at the LHC
  - Inclusive squark/gluino discovery reach up to 1.5 TeV with 1 fb^{-1} ultimate reach – up to 3 TeV
  - Once discovered, search for special features
    - Kinematical peculiarities (end-points)
    - Excess of b/τ
    - Pairs of leptons OS (SF), SS
    - Multi-lepton and multi-γ final states (R-parity violation, GMSB)
    - heavy leptons, off-pointing photons (GMSB)
  - Use collected information for disentangling decay chains and establishing mass relations and constraints

LHC Summary (II)

- Trigger strategies are being developed for efficient coverage of the parameter space in various models
- Possibility to reconstruct sparticle decays shown in a few prototype analyses
  - In some cases could be done in a model-independent way
  - Otherwise a global fit to model is required
  - Mass resolution ~ 10 % under some assumptions
  - Generally require significant statistics (years)

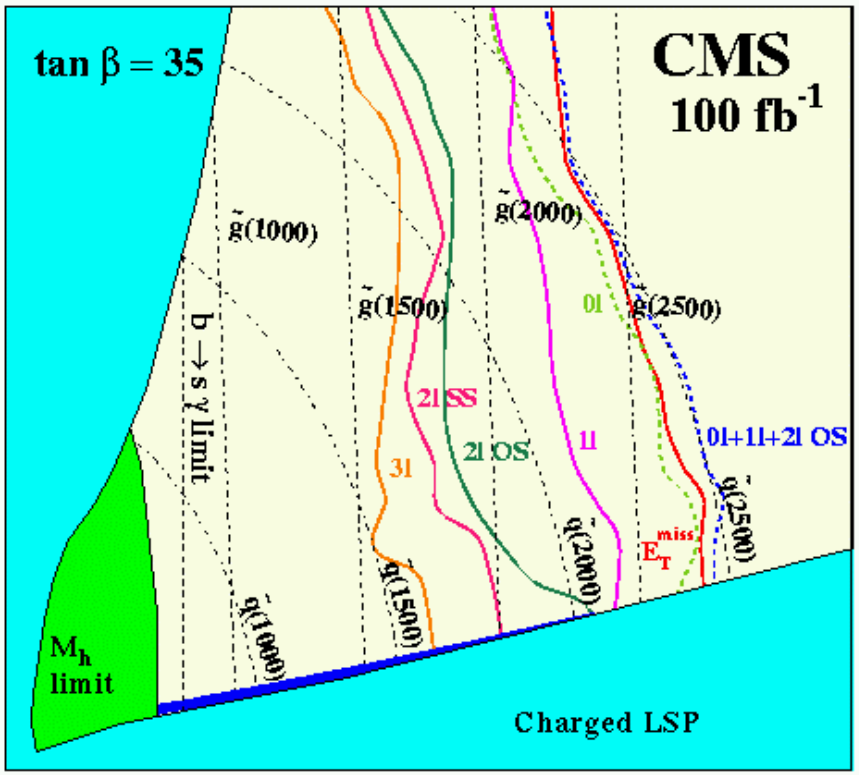
Acknowledgement

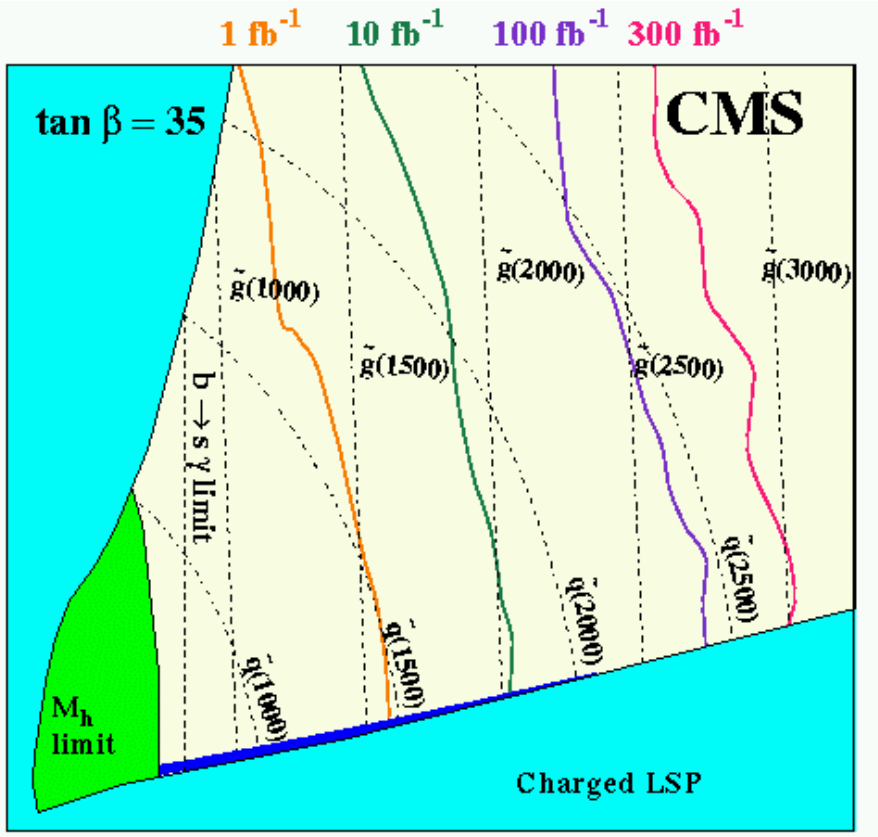
- Many thanks to:

  Frank Paige (ATLAS)
  Darin Acosta (CMS)
  Massimiliano Chiorboli (CMS)

ADDENDUM (ATTIC)

CDM vs LHC Reach



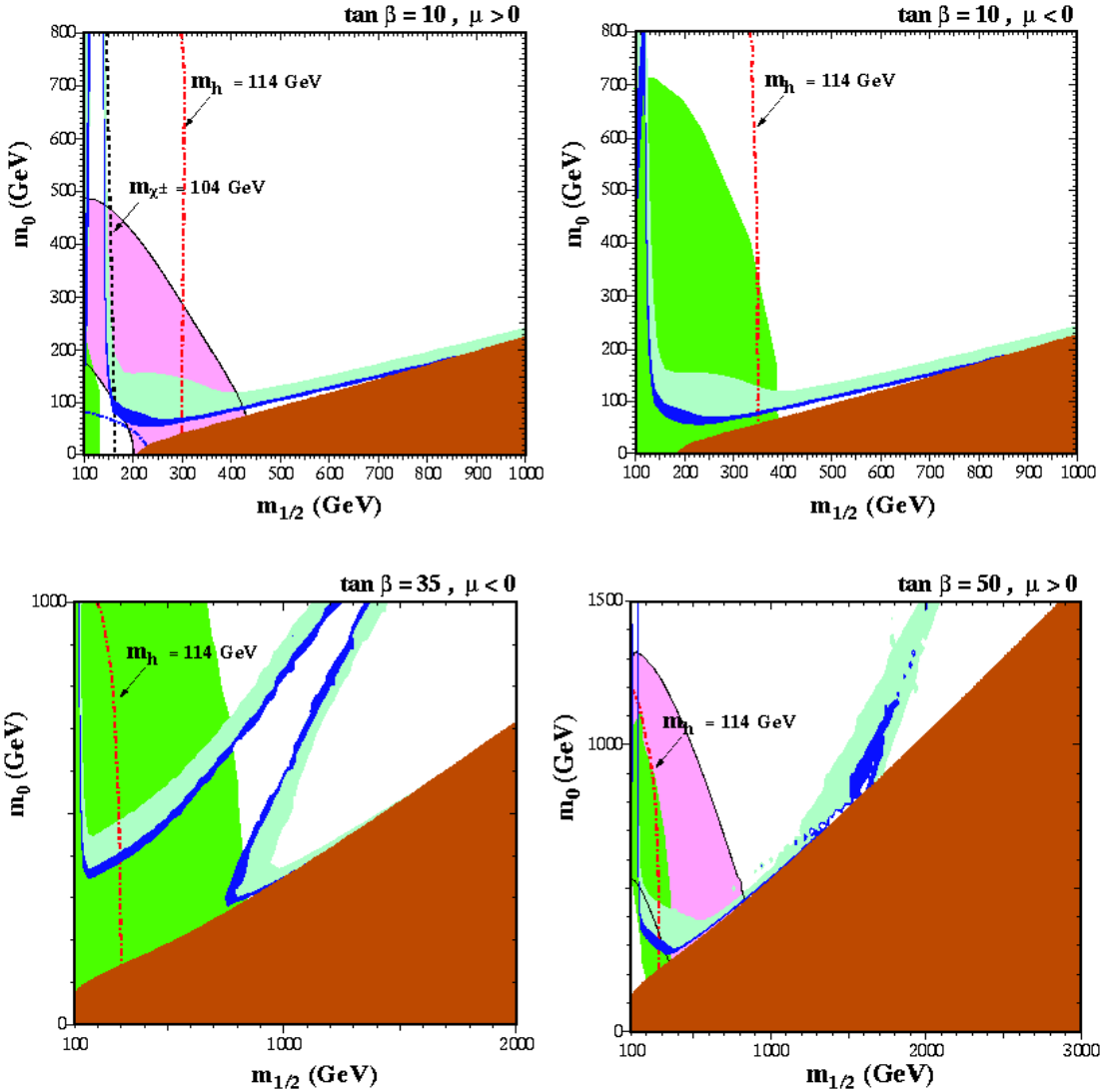
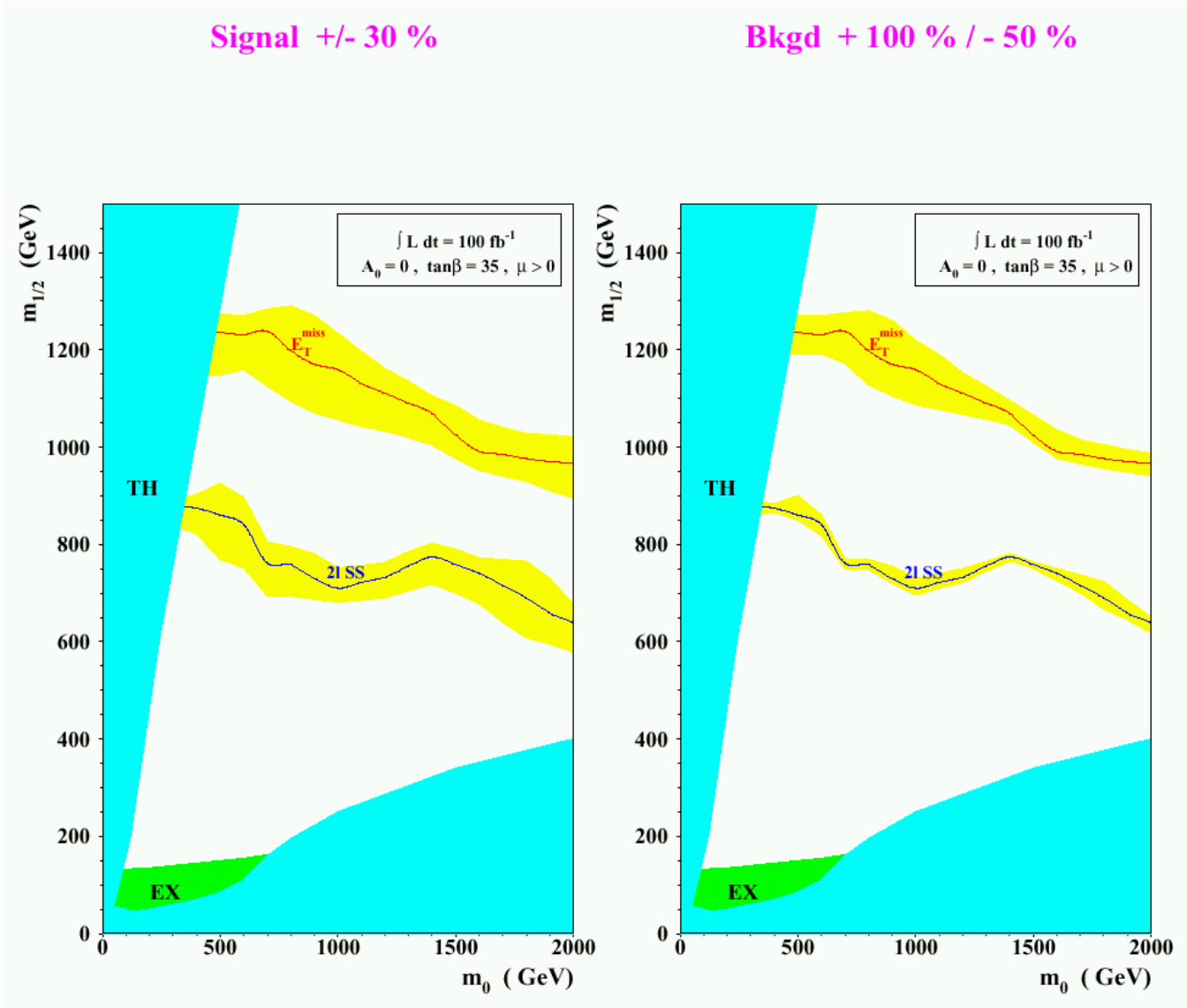


CDM Constraints from Recent WMAP Data

J.Ellis et al., hep-ph/0303043

Legend :

- older cosmological constraint $0.1 < \Omega_x h^2 < 0.3$
- newer cosmological constraint $0.094 < \Omega_x h^2 < 0.129$
- $\tilde{\chi}_1^0$ is not LSP
- excluded by b -> s γ
- favored by $g_\mu - 2$ at 2-σ level



SUSY Reach Systematics : Some Estimates