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Fittino Workshop
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Parameter determination of GMSB models with photon final states using the ATLAS detector

Overview

- The GMSB model
  - → Basics and benchmark scenario
  - → Neutralino lifetime and sparticle mass measurements
- Parameter determination with Fittino
  - → Expectations and performance
  - → Parameters from "realistic" measurements
  - → Alternative data interpretations
- Summary and outlook

GMSB model - basics

- SUSY breaking: mediated via SM gauge interactions (GMSB) from hidden/secluded sector to electroweak scale
- Intermediate messenger sector
- Model described by 6 parameters (in addition to Standard Model)

Par.	Description
Λ	Effective SUSY breaking scale
M_{mess}	Messenger mass scale
N	Number of messenger multiplets
$\tan\beta$	Ratio of Higgs VEVs
$\mathrm{sign}(\mu)$	Sign of Higgs mass parameter
C_{grav}	Scale factor of Neutralino lifetime

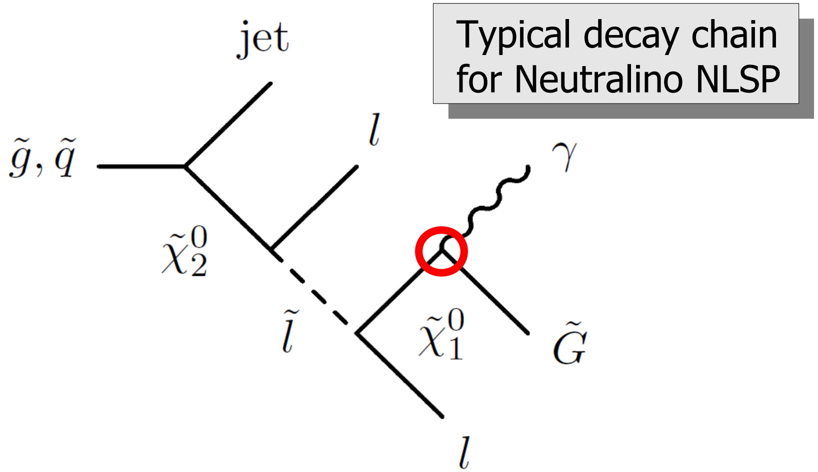
Properties:

- Lightest SUSY particle: Goldstino/Gravitino (m ~ O(eV))
- Next-to-lightest SUSY particle: Neutralino or Slepton (NLSP)

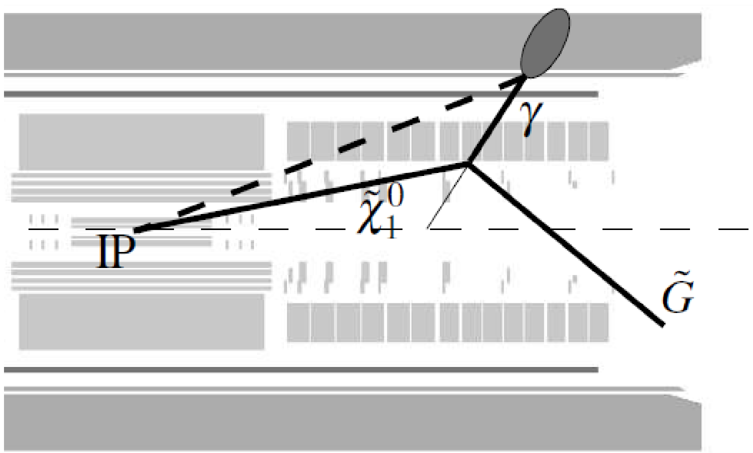
- Missing energy from Gravitino
- Final state: hard photons, leptons

GMSB model – final state

- Investigated final state:



- NLSP can have non-vanishing lifetime
- Delayed photons in final state



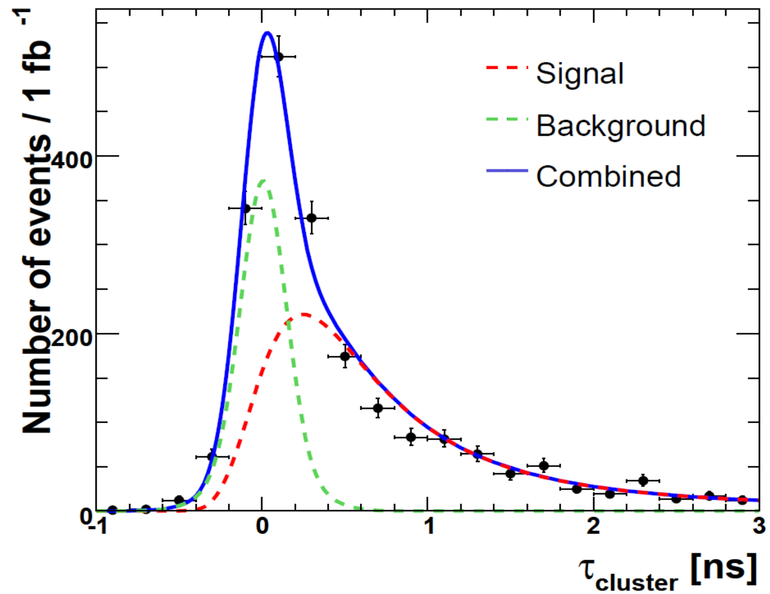
Idea:

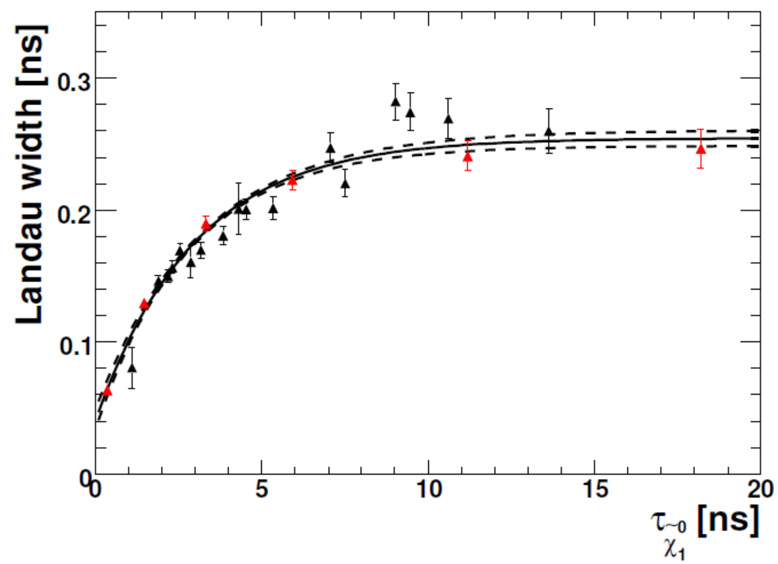
- Additional discriminating variable: arrival time of photon in ECal (clustertime) (resolution: a few 100 ps)
- Fit clustertime distribution to separate signal from background
- Measure Neutralino lifetime with calibration curve

Neutralino lifetime measurement

- Fit Gaussian plus Landau to BG plus signal
  - → Use Landau width for calibration curve
  - → Simulate samples with different lifetimes and kinematics
  - → Scale lifetime with C_{grav} parameter
  - → Measure width of each sample
- Plot Landau widths as function of lifetime, fit calibration curve

τ_{theo} [ns]	τ_{meas}±stat.±syst. [ns]
0.37	$0.35 \pm^{0.03}_{0.03} \pm^{0.08}_{0.12}$
1.5	$1.6 \pm^{0.1}_{0.1} \pm^{0.1}_{0.1}$
3.3	$3.6 \pm^{0.3}_{0.2} \pm^{0.1}_{0.1}$
5.9	$5.7 \pm^{0.8}_{0.6} \pm^{0.3}_{0.2}$
11.2	$8.2 \pm^{5.4}_{1.8} \pm^{1.1}_{0.6}$

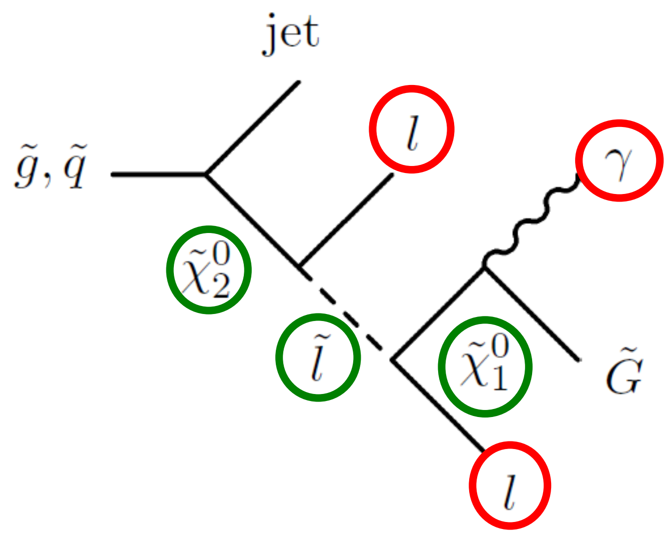


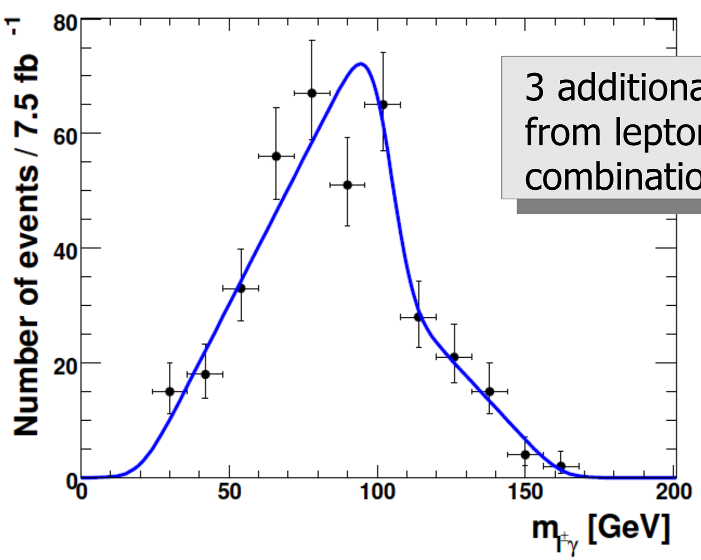


Invariant mass distributions

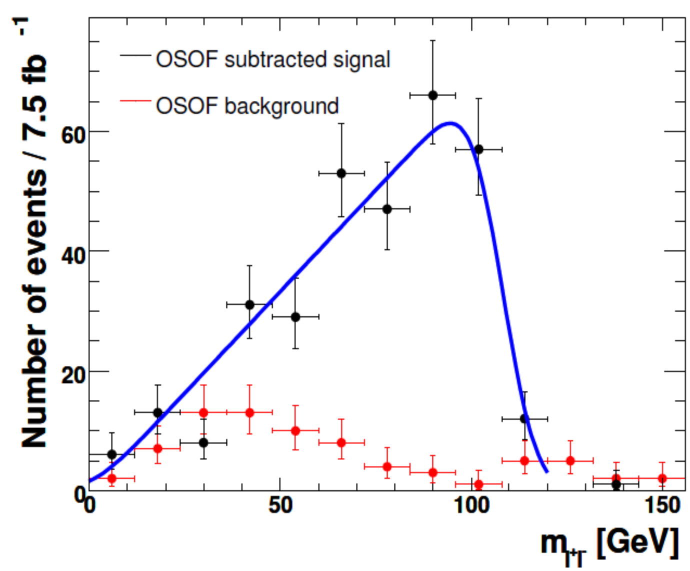
- SUSY mass determination via endpoints in invariant mass distributions (functions of particle masses)
- Event selection for 7.5 fb^{-1}
- Select opposite-sign-same-flavour (OSSF) lepton pairs, subtract OSOF BG
- Example:

  $M_{ll,max,theo}$ = 106.4 GeV, $M_{ll,max,fit}$ = 108.0 ± 4.3 GeV





3 additional endpoints from lepton-photon combinations



GMSB fit - expectations

- Can the model parameters be determined with the measured observables?
  → Perform a fit of the model to SUSY observables
  → Obtain model parameters and their uncertainties

Par.	Description
Λ	Enters masses linearly
M_{mess}	Enters masses logarithmically/lifetime quadratically as product with C_{grav} (and Λ)
N	Is fixed to 1 due to photon final states
$\tan\beta$	Does not enter directly the measured observables
sign(μ)	Is fixed to 1
C_{grav}	Enters lifetime quadratically

Expectation:

→ Λ can be measured well
→ M_{mess} and C_{grav} can only be measured as a product
→ $\tan\beta$ can not be measured

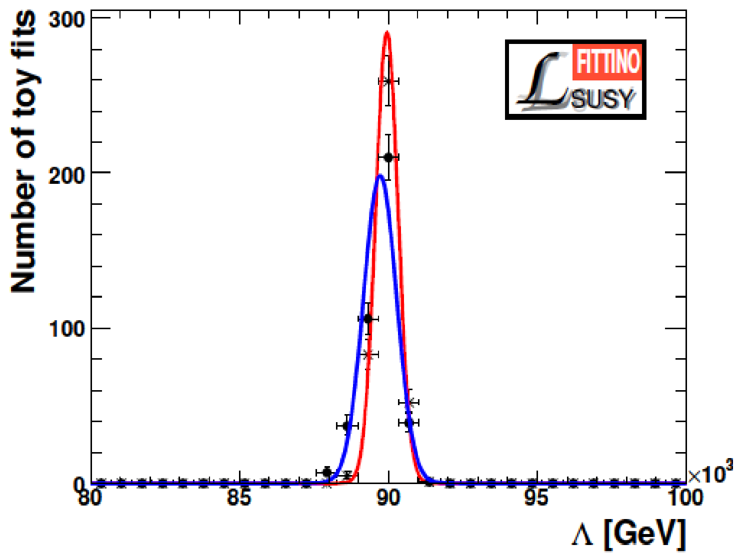
GMSB fit - input

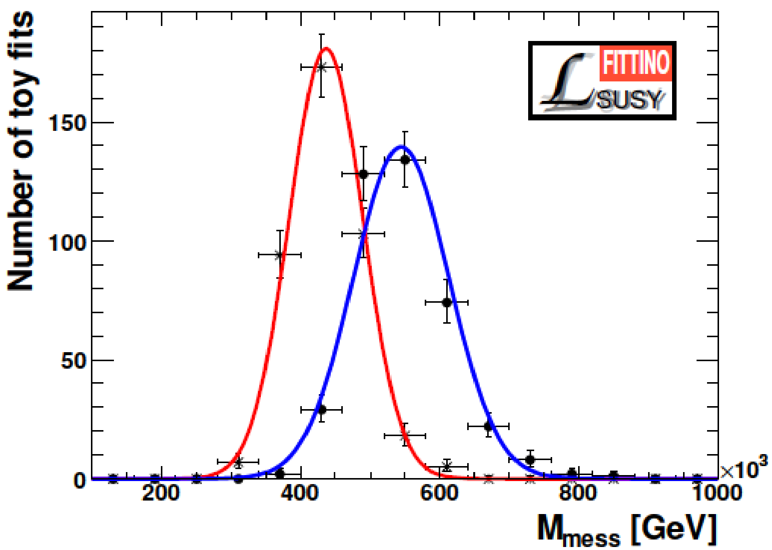
- Observables (taken from GMSB2 benchmark scenario):
  - $\longrightarrow$ Neutralino lifetime (used Neutralino width in the code)
  - $\longrightarrow$ 4 invariant mass endpoints (formulas implemented in Fittino code (necessary???))
  - $\longrightarrow$ Values have to be shifted from ISAJET to SPheno prediction to avoid bias
- Used simulated annealing, 400 toy fits per run
  - $\longrightarrow$ Steering parameters optimized to avoid local minima
- SPheno: some fixes for Neutralino width (thanks to Werner)

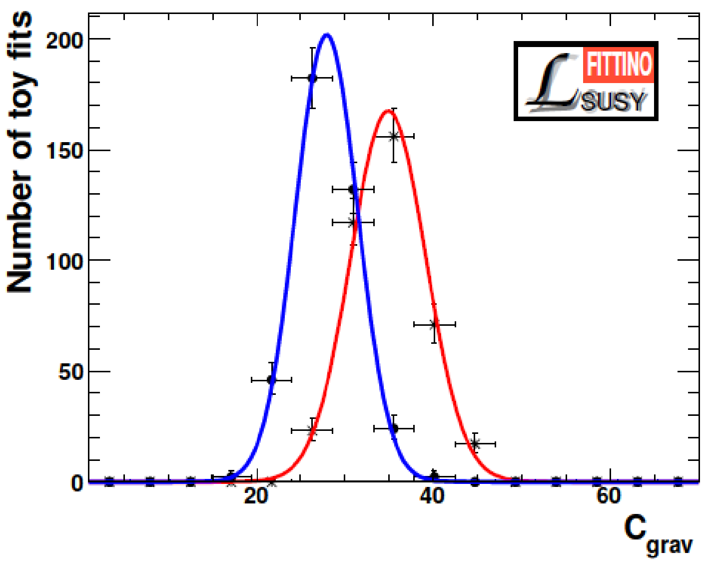
Observable	theoretical value (ISAJET)	measured value	$v_{\mathrm{ISAJET}} - v_{\mathrm{SPheno}}$
$M_{l^+l^-}^{\mathrm{max}}$	106.4 GeV	108.0±4.3 GeV	-2.0 GeV
$M_{l^+l^-\gamma}^{\mathrm{max}}$	191.6 GeV	189.6±3.8 GeV	-2.1 GeV
$M_{l^\pm\gamma}^{\mathrm{near,max}}$	107.9 GeV	104.4±3.7 GeV	-7.2 GeV
$M_{l^\pm\gamma}^{\mathrm{far,max}}$	158.3 GeV	161.9±3.9 GeV	2.5 GeV
$\tau_{\tilde{\chi}_1^0}$	3.3 ns	3.6±0.3 ns	0.6 ns

GMSB fit - performance

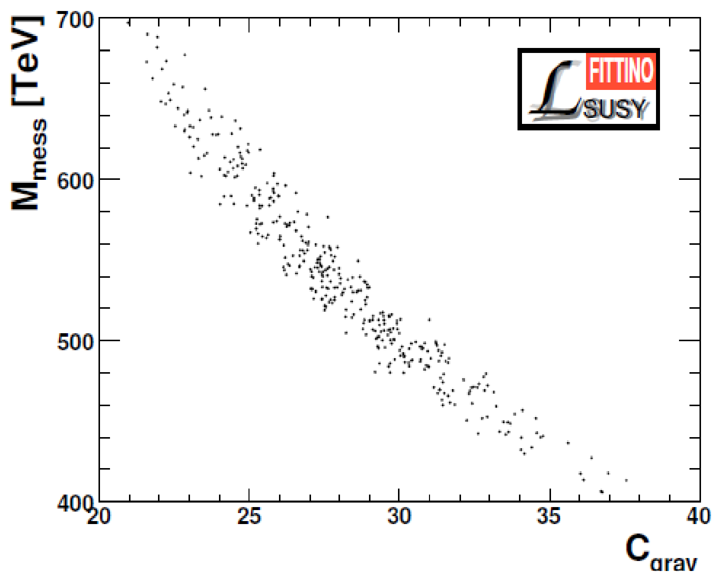
- First fit to theoretical values of NLSP lifetime and invariant mass endpoints
  - → Assume 1% uncertainty
  - → 2 sets of starting values (red and blue)
  - → Parameter estimate given by mean, uncertainty given by width of Gaussian
- Plots for Λ = 90 TeV, M_{mess} = 500 TeV, C_{grav} = 30, $\tan\beta$ = 5, sgn(μ)=+

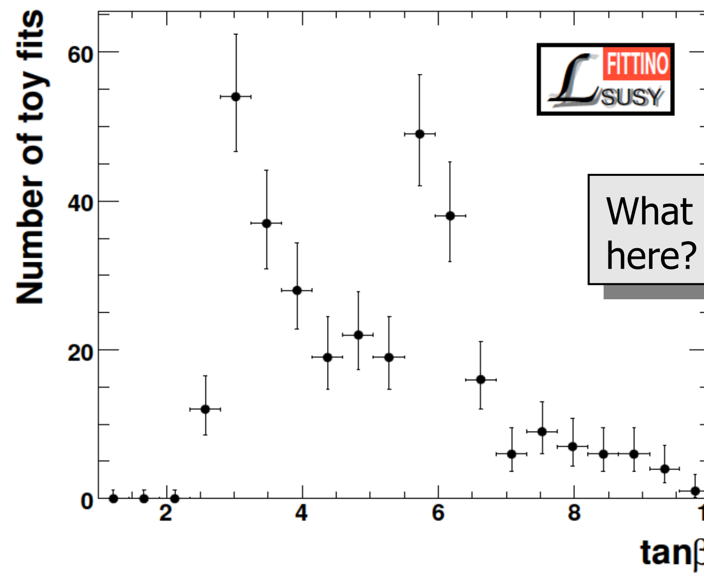


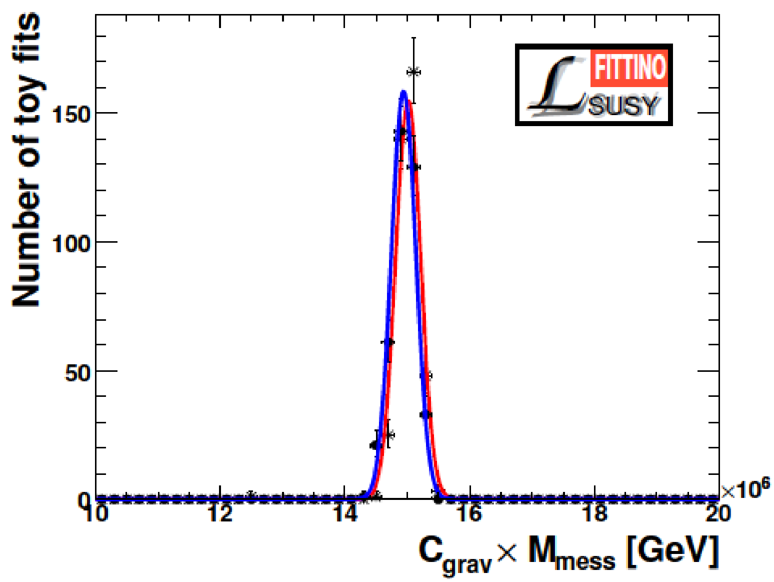




GMSB fit – tanβ, C_{grav} and M_{mess}







- M_{mess} and C_{grav} strongly correlated
  → Only product is stable
- No clear result yet for tanβ

Idea:

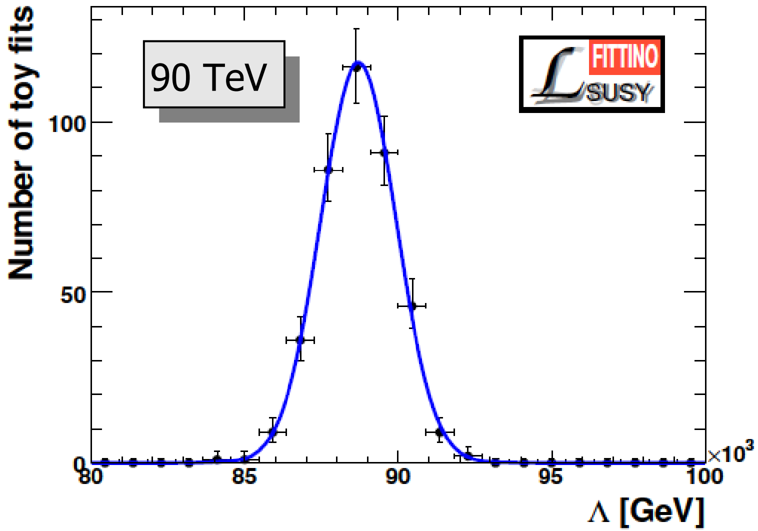
- Measure the real breaking scale

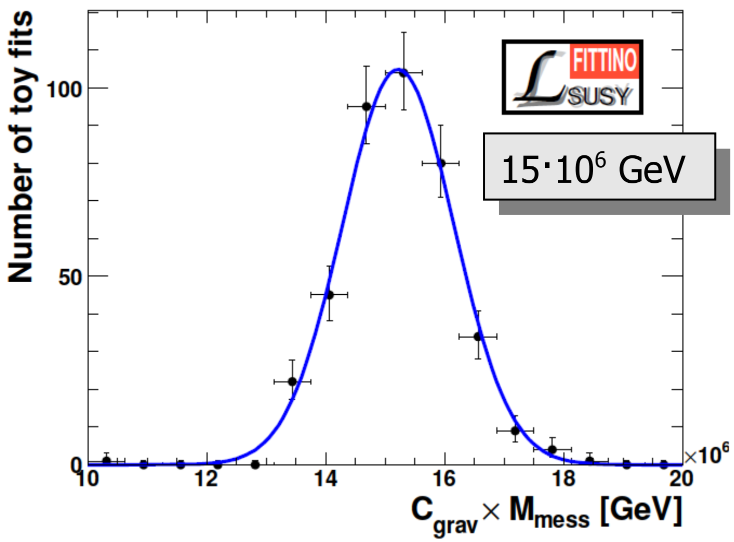
→ $F = \Lambda \cdot M_{mess} \cdot C_{grav}$

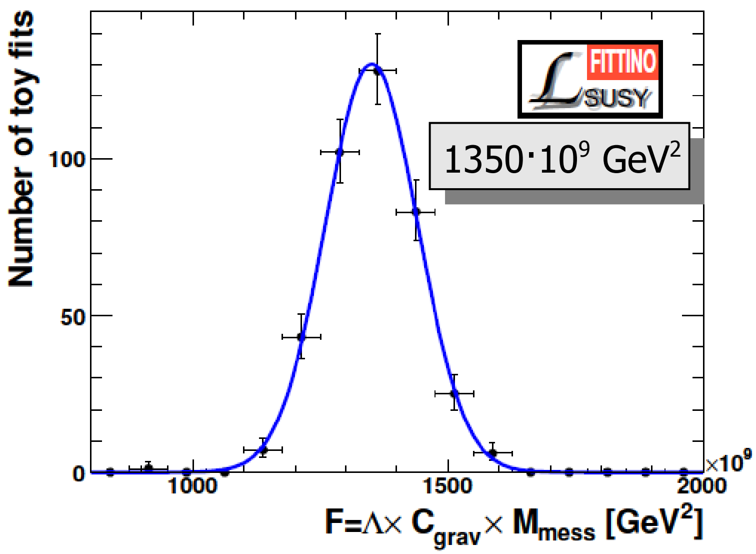
GMSB fit - “realistic” results

- Fit model to measurements of Neutralino lifetime and invariant mass endpoints
  → Central values well determined

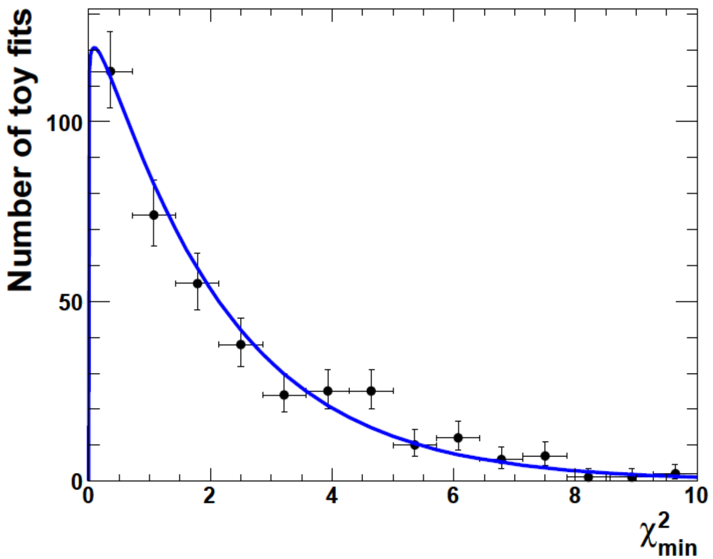
→ Underlying SUSY breaking scale determined precisely from measurements!



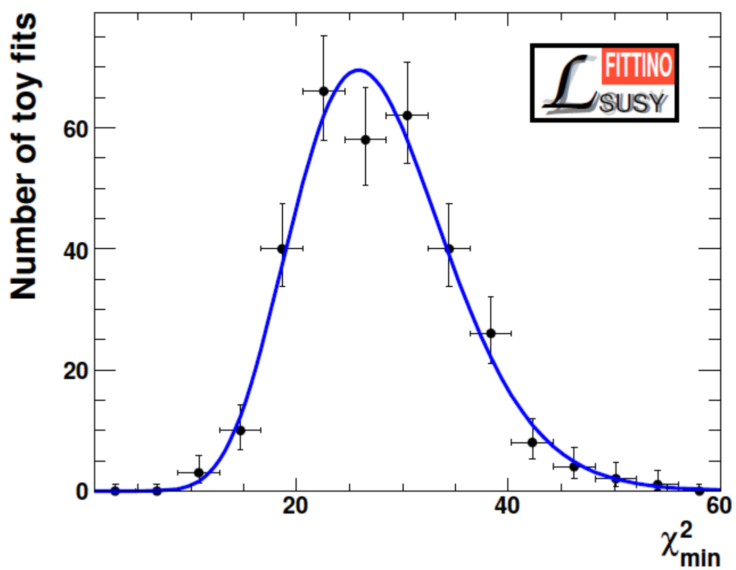


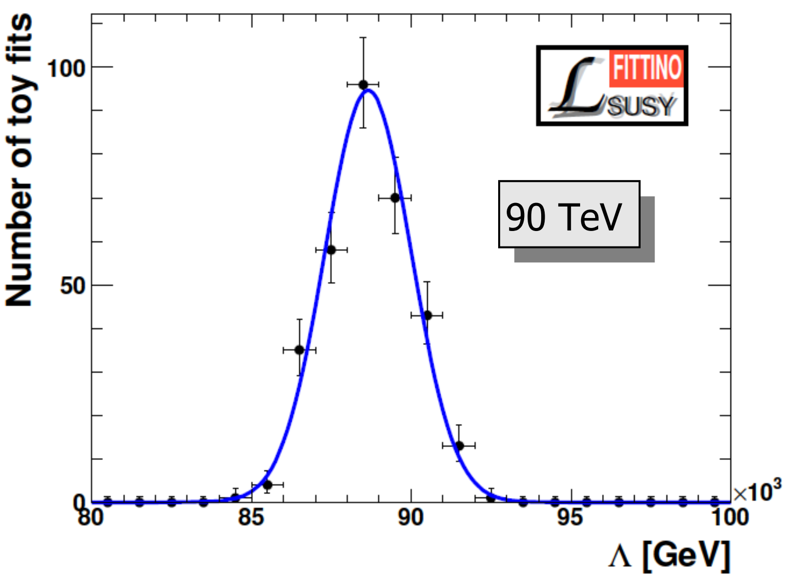


GMSB fit - "realistic" results



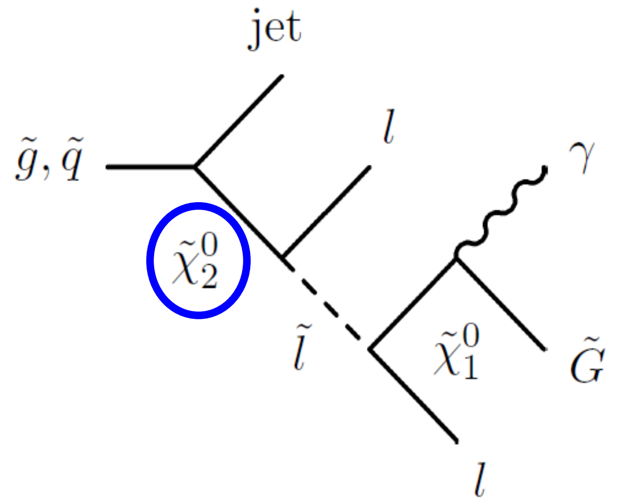
- χ^2 distribution in good agreement with expectation (#dof ~ 2)
- What happens when including LEObs?
  - → Shift values to GMSB benchmark prediction to avoid bias!
  - → Again, χ^2 distribution looks good
  - → No improvement of parameter uncertainties





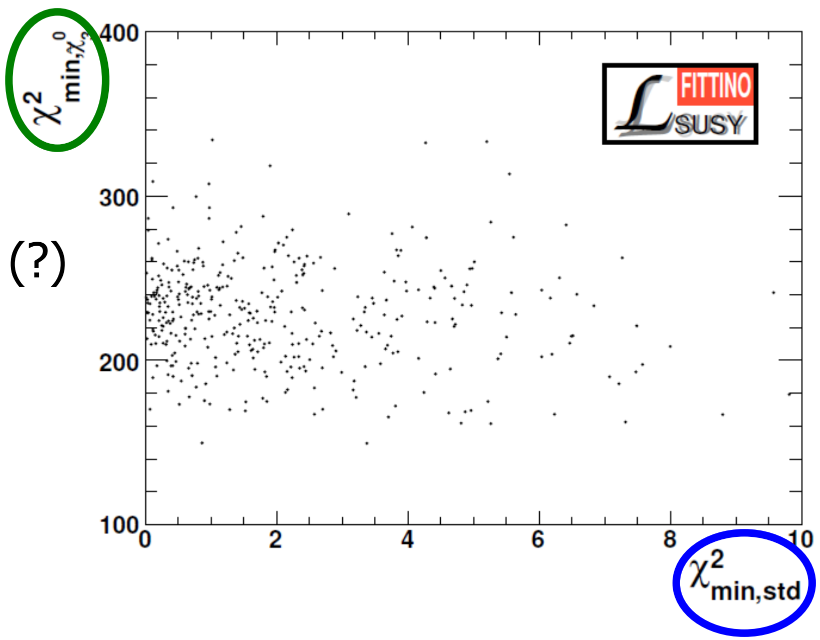
GMSB fit - interpretations

- Is the assumed interpretation of the decay chain used in the fit correct?
  $\rightarrow$ Invariant mass endpoints functions of particle masses!
- Example alternative:
  - Replace the second lightest Neutralino:



$$\tilde{q} \rightarrow \tilde{\chi}_3^0 q \rightarrow \tilde{l}_R^{\pm} l^{\mp} q \rightarrow \tilde{\chi}_1^0 l^+ l^- q \rightarrow \tilde{G} \gamma l^+ l^- q$$

$\rightarrow$ Calculate χ^2_{min} correlations

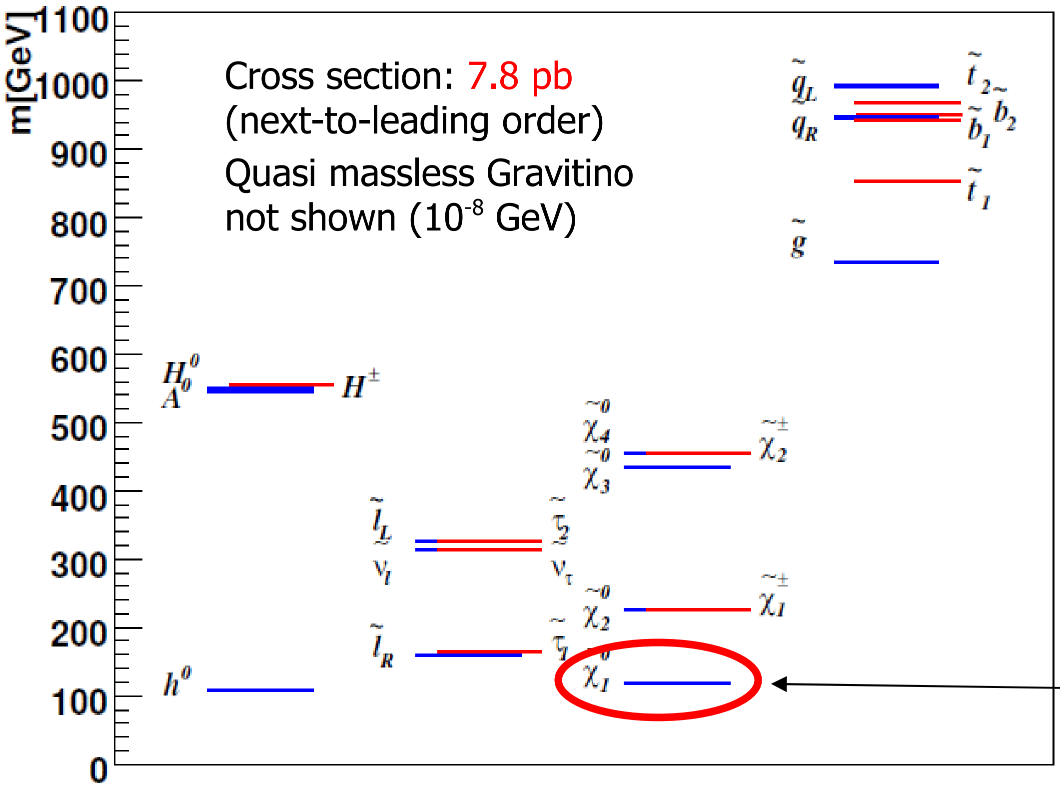


- (How) Many other alternatives possible (?)
  $\rightarrow$ How to quantify?
  $\rightarrow$ How to scan?
  $\rightarrow$ see Takanoris talk

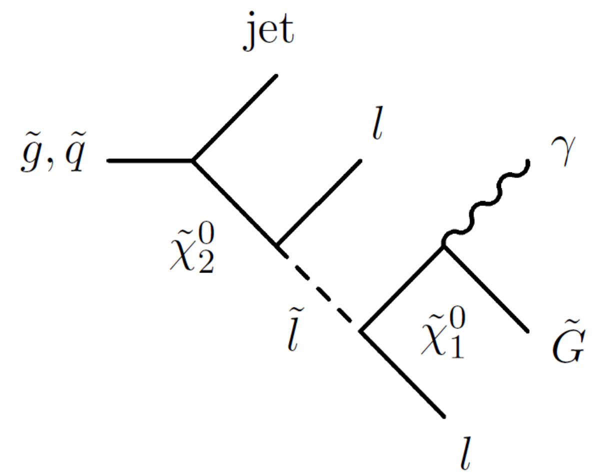
Summary and outlook

- GMSB possible extension of Standard Model
- Di-photon analysis:
  - $\rightarrow$ Use kinematic endpoints to measure SUSY particle masses
  - $\rightarrow$ Use ECal timing to measure Neutralino lifetime
- Fit of GMSB model to observables
  - $\rightarrow$ Precise determination of underlying SUSY breaking scale
  - $\rightarrow$ Distinction between interpretations possible (more work needed)
- What about other parameters?
  - $\rightarrow$ $\tan\beta$ determination with stau mass measurement?
  - $\rightarrow$ Inclusion of stau mass didn't give a good result... (more work?)
  - $\rightarrow$ Other observables? Higgs? Suggestions?

Mass spectrum, lifetime formula



Neutralino NLSP



$$c\tau_{\tilde{\chi}_1^0} \approx \left(\frac{100\,\mu\mathrm{m}}{\cos^2\theta_W}\right)\left(\frac{100\,\mathrm{GeV}}{m_{\tilde{\chi}_1^0}}\right)^5\left(\frac{\sqrt{F}}{100\,\mathrm{TeV}}\right)^4$$

with $F = C_{\mathrm{grav}} \cdot \Lambda \cdot M_{\mathrm{mess}}$