SCIPP

universitätbonn

bctp Bethe Center for Theoretical Physics

SUSY Parameter Determination at the LHC Using Kinematic Edges and Cross Sections

Herbi Dreiner

Collaboration with: Michael Krämer **(Aachen)**
Jonas Lindert **(Aachen)**
Ben O'Leary **(Aachen)**

. **Paper**: **JHEP** 1004:109,2010

Main Idea

- Extend **Fittino** to include total cross sections at the LHC
- How do the fits improve?
- Substantial improvement at low energy and luminosity: 7 TeV, 1 fb^{-1}; not so much at high energy and lumi
- Our extension will be included in next release of **Fittino**

FITTINO

- Numerical fitting program to SUSY Lagrangian parameters

- *Fittino, a program for determining MSSM parameters from collider observables using an iterative method*

  Philip Bechtle, Klaus Desch, Peter Wienemann,

  Comput.Phys.Commun.174:47-70,2006; hep-ph/0412012

- *Constraining SUSY models with Fittino using measurements before, with and beyond the LHC*

  Philip Bechtle, Klaus Desch, Mathias Uhlenbrock, Peter Wienemann,

  Eur.Phys.J.C66:215-259,2010; arXiv:0907.2589 [hep-ph]

Basics of Fittino

- Start from pMSSM: 19 $\mathcal{L}_{\mathsf{SUSY}}$ parameters, P_j

  (CP conservation, MFV, degen. 1st & 2nd generation, only $A_{\tau,b,t}$)

- Define set of observables O_i which depend through loops on all P_j

$$O_i = f(\text{all parameters } P_j)$$

- Unbiased starting point
- Move in parameter space with various techniques
  - Simulated Annealing
  - Markov Chain
  - χ^2 minimization via MINIMIZE in MINUIT
- Find best fit

Possible LHC Observables in Fittino

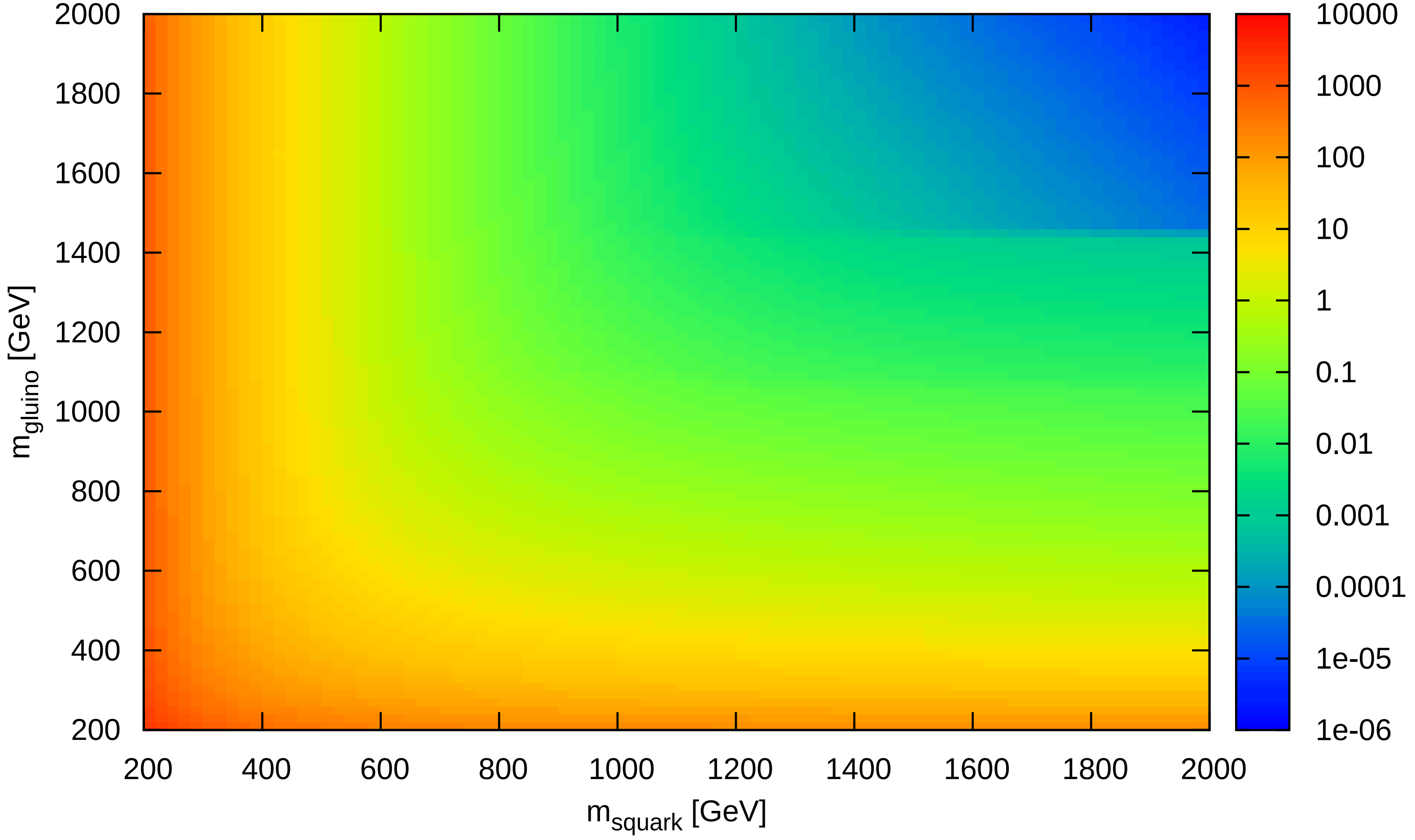
(• Low energy observables)

- Masses, limits on masses of unobserved particles
- Widths & branching fractions
- Edges in mass spectra
- Products of cross–sections and branching fractions
- Ratios of branching fractions

Extend to include total rates

Inclusive Cross Section

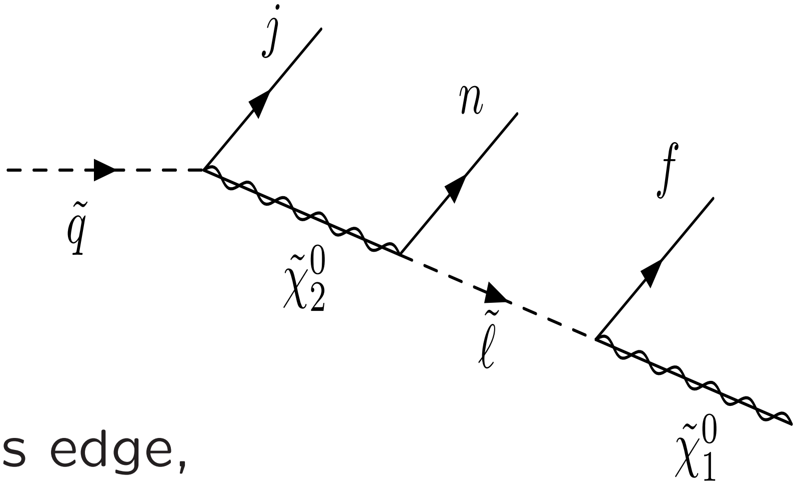
- $pp \longrightarrow \tilde{g}\tilde{g},\ \tilde{g}\tilde{q},\ \tilde{g}\tilde{q}^*,\ \tilde{q}\tilde{q},\ \tilde{q}\tilde{q}^*,\ \tilde{q}^*\tilde{q}^*$



- Varies over about 5 orders of magnitude in the detectable range

Standard Cascade Chain

- Use the following observables in **Fittino**



Group I:

- $m_{\ell\ell}^{\text{max}}$, the dilepton invariant mass edge,
- $m_{q\ell\ell}^{\text{max}}$, the jet-dilepton invariant mass edge,
- $m_{q\ell}^{\text{low}}$, the jet-lepton low invariant mass edge,
- $m_{q\ell}^{\text{high}}$, the jet-lepton high invariant mass edge.

- Extend to more observables (Group II & III) for high Lumi and energy

Cross Sections – Rates

- Why weren't they included before in **Fittino**? (ILC X-sections are)
  - Theoretical uncertainties expected to be too large (NLO?)
  - Computation of rate signatures is too time consuming to be efficiently used in fit algorithms: **HERWIG/PYTHIA** with cuts
- Note: "Determining SUSY model parameters and masses at the LHC using cross-sections, kinematic edges and other observables"; C. G. Lester, M. A. Parker, M. J. White, JHEP 0601 (2006) 080; hep-ph/0508143
- Also problematical: supercomputer, small number of points, non–reproducable results, "only" LO
- What is our proposal for implementation?

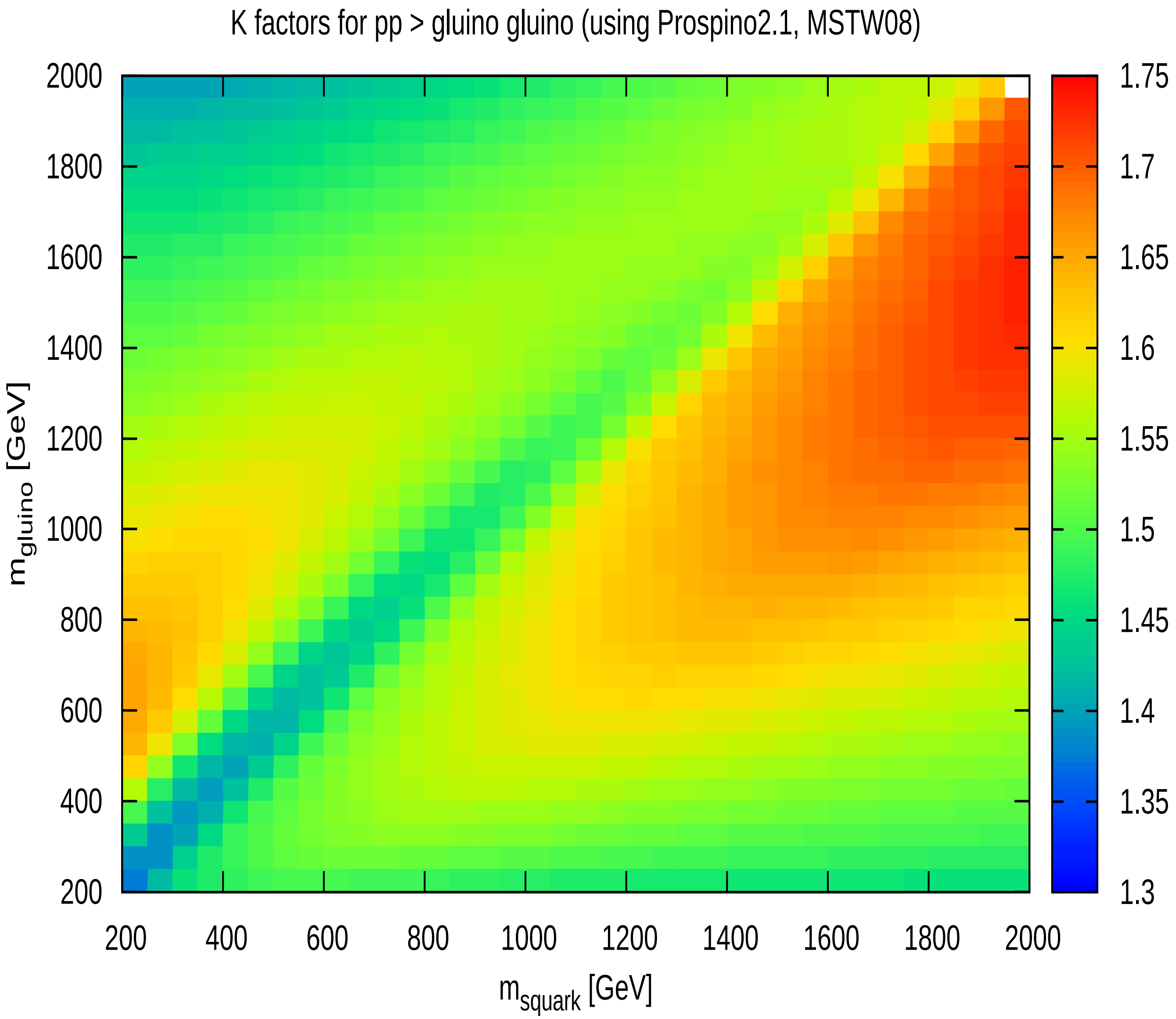
Consider Two Signatures

1. Inclusive signal of $n_{\text{jet}} \geq 2$ with $p_{T,\text{jet}} > 50\,\text{GeV}$, $|\eta_{\text{jet}}| < 2.5$ plus $\not{E}_T > 100\,\text{GeV}$
2. Exclusive signal: 2 OSSF leptons (e or μ) with $p_{T,\ell} > 10\,\text{GeV}$ and $|\eta_\ell| < 2.5$ plus signature 1.

- Rate: $$\boxed{\frac{N}{\text{Lumi}} = \sigma_{\text{theor}} \times \text{BR} \times \text{Acceptance}}$$
- BR easily calculated with **SPheno** in **Fittino**
- Assume narrow–width approx. to factorize production and decay

Cross–Section: Look–up Tables

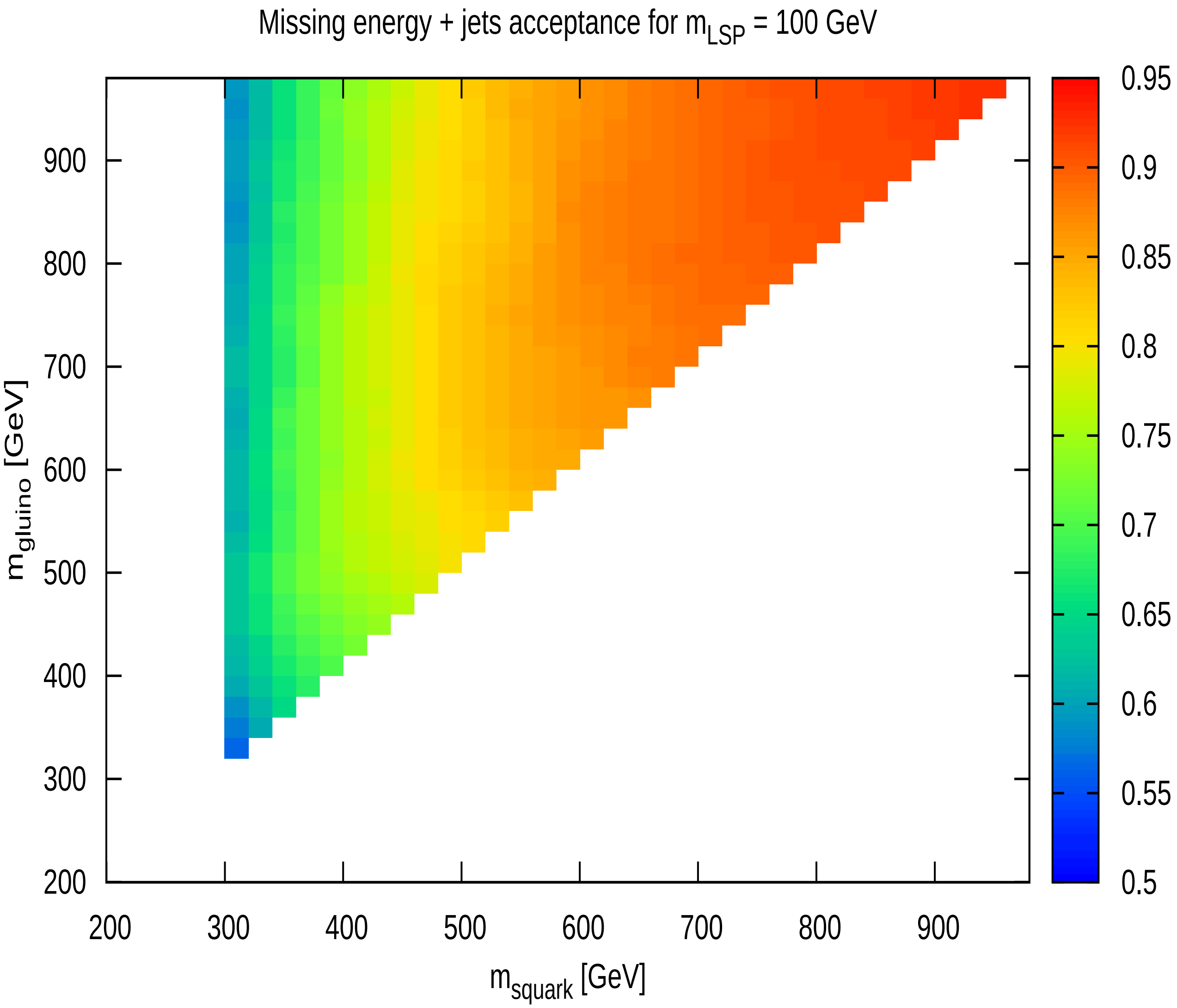
- Compute LO cross section $pp \longrightarrow \tilde{g}\tilde{g},\ \tilde{g}\tilde{q},\ \tilde{g}\tilde{q}^*,\ \tilde{q}\tilde{q},\ \tilde{q}\tilde{q}^*,\ \tilde{q}^*\tilde{q}^*$
- Store in $(m_{\tilde{g}}, m_{\tilde{q}})$–grid: Masses 200 – 2000 GeV (Step size 20 GeV)
- Compute NLO K-factors (**Prospino**) and store in $(m_{\tilde{g}}, m_{\tilde{q}})$–grid. Averaged over $\tilde{q}, \tilde{q}^*$ and $\tilde{q}_L, \tilde{q}_R$ (Step size 50 GeV)
- NLO X–section uncertainty (scale dependence) ±10%
- PDF uncertainty ±5%
- Assume overall theoretical uncertainty on X–section: ±15%


K factors for pp > gluino gluino (using Prospino2.1, MSTW08)
2000
1800
1600
1400
1200
1000
800
600
400
200
200
400
600
800
1000
1200
1400
1600
1800
2000
m_gluino [GeV]
m_squark [GeV]
1.75
1.7
1.65
1.6
1.55
1.5
1.45
1.4
1.35
1.3

- $\sqrt{s} = 10$ TeV

Acceptance: Jet & Missing Energy Cuts

- Simple parton–level MC simulation
- Decayed all particles by phase space
- Ignored spin–correlations: averaging over charges in the final state
  $\longrightarrow$ P. Richardson, hep-ph/0110108
- Furthermore: effects of intermediate decays from $\tilde{q}$ to χ_1^0 tend to average out
- $\not{E}_T$–cut is well approx. as a function of the hard process (squark boosts) and the mass difference $m_{\tilde{q}} - m_{\chi_1^0}$
- Accept. grid for each prod. process for [jets + $\not{E}_T$]: $(m_{\tilde{g}}, m_{\tilde{q}}, m_{\chi_1^0})$



- $\mathrm{AC(est.)} = \dfrac{\sigma^{\mathrm{cuts}}_{\mathrm{inclusive}}}{\sigma_{\mathrm{inclusive}}}$

Acceptance: Leptons

- Compute analytical expressions for the distributions of near and far leptons in the squark rest frame
- Numerically estimate effect of the boost to the lab frame for generic lepton: store effect in grid
- Multiply the generic acceptance with the number of leptons at a given energy
- Multiply together all the acceptances (ignore correlations)

Acceptance: Compare with Herwig++

- Full parton–level simulation

- Including spin–correlations

- Random set of mSUGRA points (flat priors), with $m_{\tilde{g}} > m_{\tilde{q}}$

- Agree within ±5% or better $\longrightarrow$ Uncertainty of Accept.

- Overall theoretical uncertainty on Xsection x Acceptance: ±20%

$\longrightarrow$ **RESULTS**

Uncertainties on Input Observables

observable	nominal value	statistical uncertainty for 7 TeV/1 fb^{-1}	for 14 TeV/1 fb^{-1}	for 14 TeV/10 fb^{-1}
group I				
$m_{\ell\ell}^{\max}$	80.4	4.4	1.5	0.43
$m_{q\ell\ell}^{\max}$	452.1	36.0	12.0	3.6
$m_{q\ell}^{\text{low}}$	318.6	19.7	6.5	3.0
$m_{q\ell}^{\text{high}}$	396.0	13.5	4.5	3.9

Event rate [fb]	7 TeV		14 TeV	
	nominal value	uncertainty	nominal value	uncertainty
$R_{jj\not{E}_T}$	4.6×10^3	9.1×10^2	4.8×10^4	9.5×10^3
$R_{\ell\ell jj\not{E}_T}$	1.6×10^2	3.2×10^1	1.5×10^3	3.0×10^2

SPS1a mSUGRA Fit

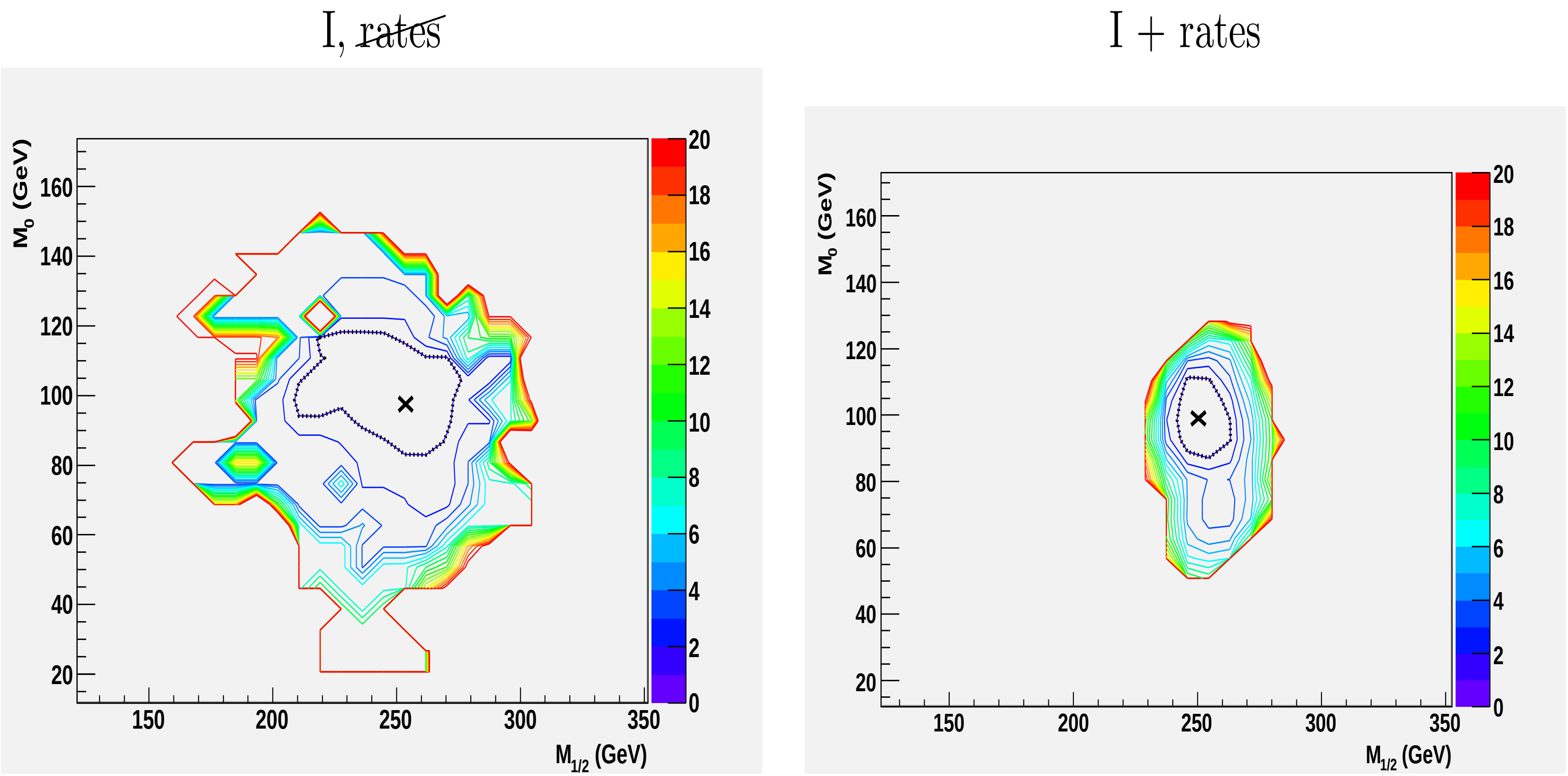
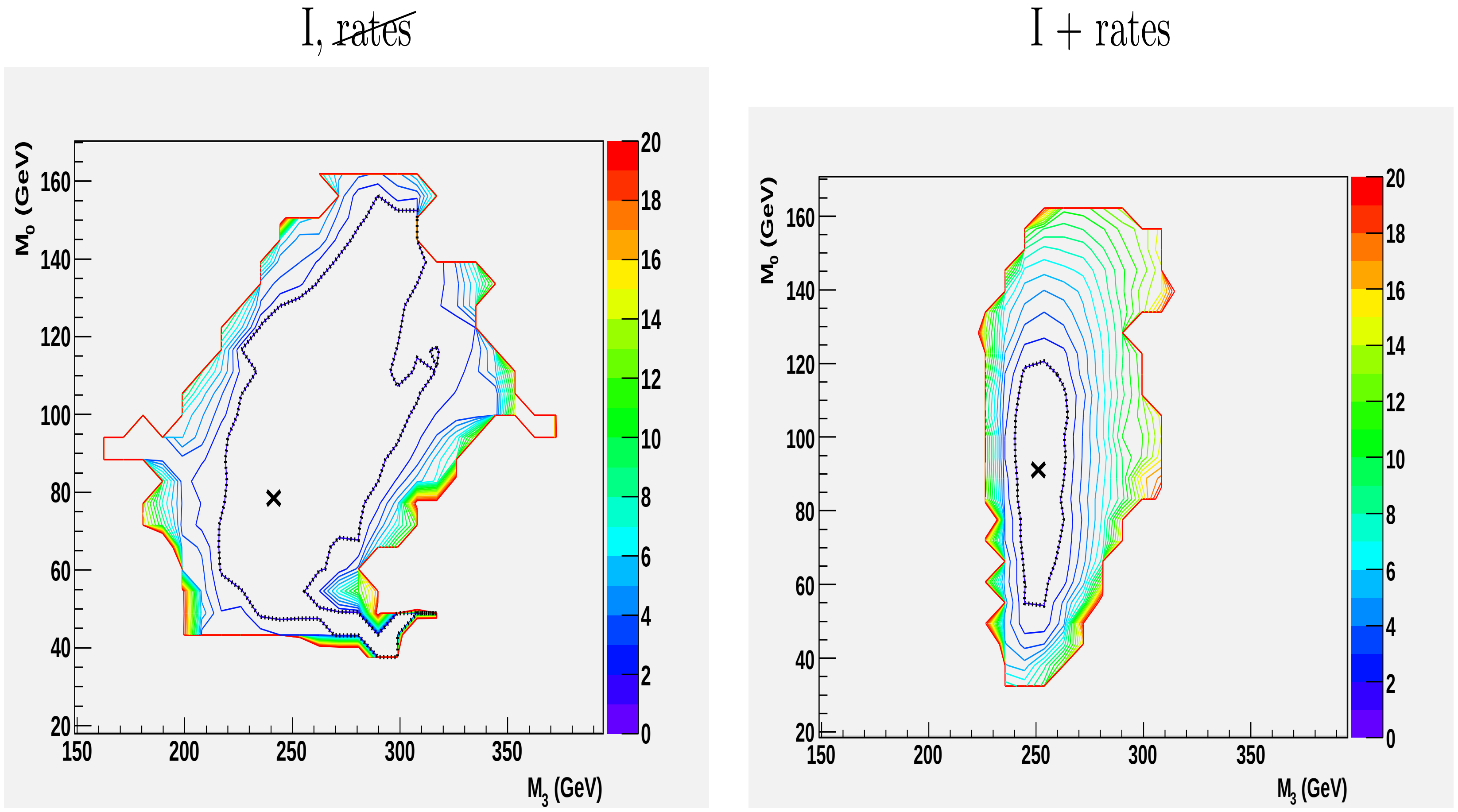


Figure 3: $\Delta\chi^2 = -2\ln\mathcal{L} + 2\ln\mathcal{L}_{\max}$ contours showing M_0 against $M_{1/2}$ for 7 TeV/1 fb^{-1} data. Fits are based on the four standard edges of group I without rates (“I, ~~rates~~”, left) and with rates (“I + rates”, right). $\mathcal{L}$ is the two-dimensional profile likelihood and $\mathcal{L}_{\max}$ the global maximum of the likelihood. The black dotted contours represent $\Delta\chi^2 = 1$ contours. See [15] for more details.

Quality of the Fit

	M_0 [GeV]	$M_{1/2}$ [GeV]	$\tan\beta$	A_0 [GeV]
SPS1a	100	250	10	-100
7 TeV and 1 fb^{-1}				
I + rates	$99.0\,^{+9.9}_{-9.1}$	$250.0\,^{+8.7}_{-6.5}$	$10.7\,^{+4.0}_{-8.8}$	$55.2\,^{+1048}_{-254}$

Non-Universal Gaugino Masses



I, ~~rates~~

I + rates

Figure 6: $\Delta\chi^2$ contours showing M_0 against M_3 for 7 TeV/1 fb^{-1} data. Fits are based on the four standard edges of group I without (left) and with rates (right).

Quality of the Fit

	M_0 [GeV]	M_1 [GeV]	M_2 [GeV]	M_3 [GeV]	$\tan\beta$	A_0 [GeV]
SPS1a	100	250	250	250	10	-100
7 TeV and 1 fb^{-1}						
I + rates	$91.1\,^{+27.3}_{-36.1}$	$236.5\,^{+67.1}_{-57.9}$	$242.6^{+51.6}_{-33.7}$	$251.0^{+9.5}_{-8.5}$	$10.5\,^{+7.4}_{-7.3}$	$-6.0\,^{+1088}_{-582}$

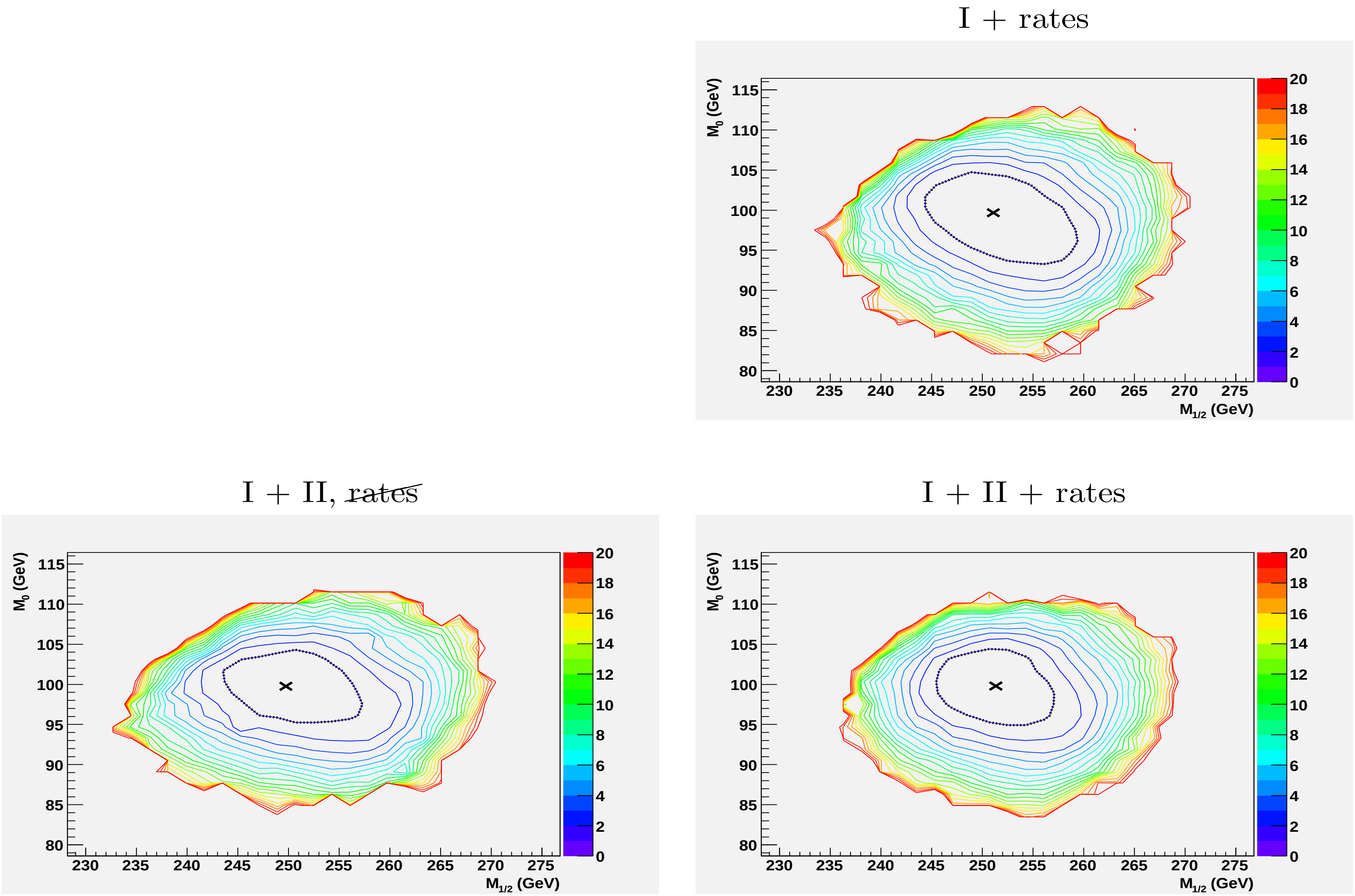
More (challenging) Kinematic Observables

Involving Third Generation

Group II:

- $m_{q\ell\ell}^{\text{thr.}}$, the jet-dilepton threshold invariant mass edge,
- $m_{T2}^{\tilde{q}}$, the squark stransverse mass,
- $m_{\tau\tau}^{\text{max}}$, the di-tau invariant mass edge,
- m_{tb}^{w}, the weighted top-bottom invariant mass edge,
- $r_{\tilde{\ell}\tilde{\tau}\text{BR}}$, the ratio of selectron- to stau-mediated $\tilde{\chi}_2^0$ decays.

Fit with Group II



I + rates

I + II, ~~rates~~

I + II + rates

Figure 4: $\Delta\chi^2$ contours showing M_0 against $M_{1/2}$ for 14 TeV/1 fb^{-1} data. Fits are based on the four standard edges of group I with rates (upper right), and on the observables of groups I and II with (lower right) and without rates (lower left).

Future: Using Rates

- Pure Kinematical Signatures suffer from problems
  - Depending on SUSY point might not be sufficient for unambiguous and/or precise SUSY parameter determination
  - Interpretation of mass endpoints assumes a mass hierarchy. Not necessarily distinct enough to resolve ambiguous hierarchies
  - In split–SUSY scenario with heavy leptons, no cascade to leptons: usual approach breaks down
- Clearly the more information the better: include X–sections


α
n
γ
g
μ⁻
e⁻
c
b
d
t
s
u
p
νμ