Uncovering Natural SUSY with the LHC and DM DD Experiments Interplay

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In preparation

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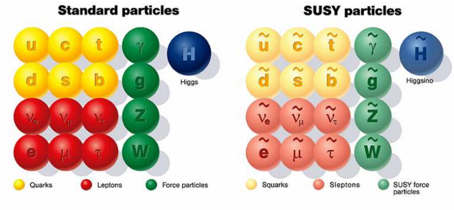
Outline

- Introduction
- Properties of NSUSY scenario
  - Spectrum
  - Dark Matter properties
- Collider searches
  - 8 TeV LHC reach
  - 13 TeV LHC projections
- Conclusions

Introduction

Supersymmetry is still one of the most attractive BSM scenario

- Provides a good DM candidate
- Provides gauge coupling unification
- Alleviate the fine tuning problem of the SM
- ...

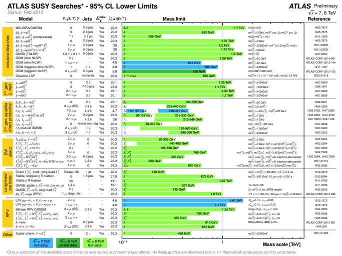


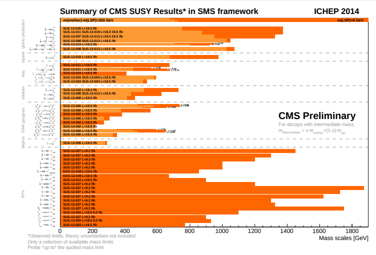
Plenty of particles to be discovered at the LHC

Where is SUSY?

The LHC is currently probing MSSM SUSY scenarios in the ∼TeV region

However no signs of SUSY have been detected so far





LHC 7+8 with ∼ 20 fb^{-1} sets severe bounds on the sparticles masses

- Heavy sparticles ($\tilde{g}$, $\tilde{t}$, ...) doesn't necessary imply high fine tuning (HB/FP of MSSM arXiv:9710473, 9909334, 9908309, 1205.3372...)

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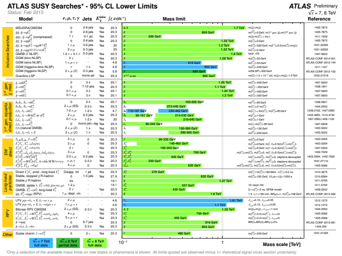
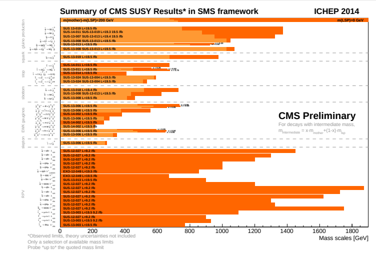




LHC 7+8 with $\sim$ 20 fb^{-1} sets severe bounds on the sparticles masses

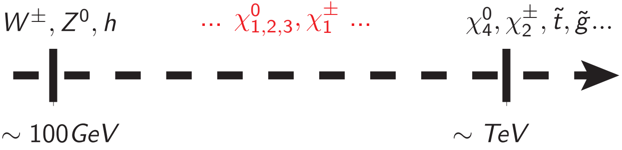
- Heavy sparticles ($\tilde{g}$, $\tilde{t}$, ...) doesn't necessary imply high fine tuning (HB/FP of MSSM arXiv:9710473, 9909334, 9908309, 1205.3372...)
- Low μ parameter scenarios quite interesting under many aspects

NSUSY spectrum

Taking a low μ value as definition of NSUSY

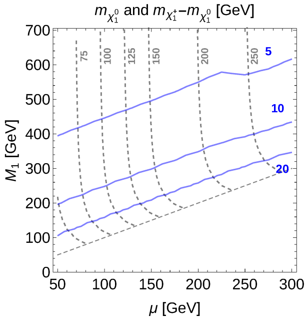
$$M_{\chi^0} = \begin{pmatrix} M_1 & 0 & -M_Z s_W c_\beta & M_Z s_W s_\beta \\ 0 & M_2 & M_Z c_W c_\beta & -M_Z c_W s_\beta \\ -M_Z s_W c_\beta & M_Z c_W c_\beta & & -\mu \\ M_Z s_W s_\beta & -M_Z c_W s_\beta & -\mu & 0 \end{pmatrix} \quad M_{\chi^\pm} = \begin{pmatrix} M_2 & \sqrt{2} M_W s_\beta \\ \sqrt{2} M_W c_\beta & \mu \end{pmatrix}$$

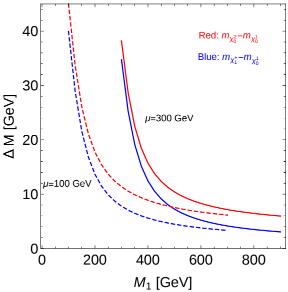
With $M_2 \gg |\mu|$ only $\chi^0_{1,2,3}$ and $\chi^\pm_1$ are accessible



NSUSY spectrum

- The EWino sector is described only by μ and M_1
- It can be mapped in the parameters $m_{\chi_1^0}$ and $\Delta M = m_{\chi_1^\pm} - m_{\chi_1^0}$

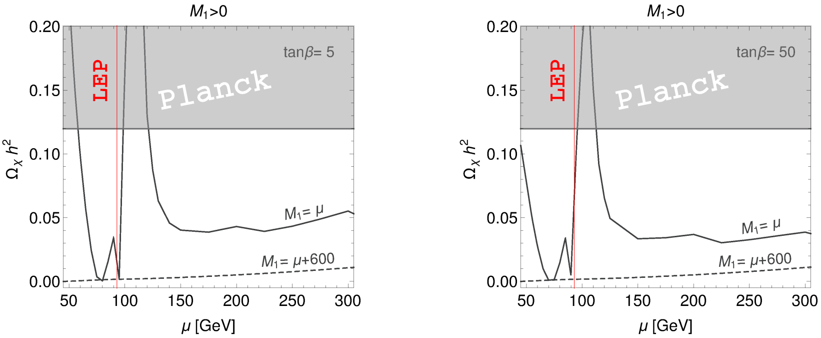




It is a simple scenario with interesting characteristics

Dark Matter properties (Ωh^2)

- $M_1 \gtrsim \mu$ implies a high higgsino component for the LSP
- Efficient annihilation and co-annihilation rates

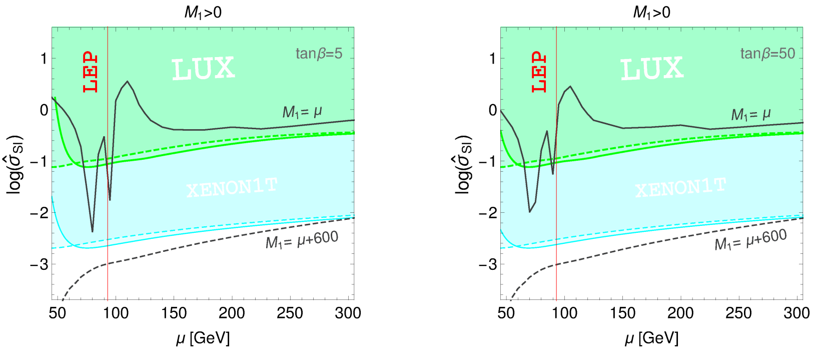


Relic density tipically below Planck bound

Computed with micromegas 4.1.7

Dark Matter properties (Direct Detection)

- Comparing $\hat{\sigma}_{SI}$ with LUX results and prediction for XENON1T



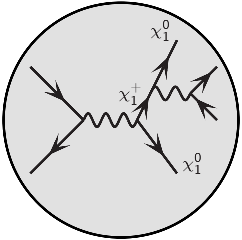
- DD is more sensitive when $\mu \sim M_1$
- This is the region where ΔM is larger

Computed with micromegas 4.1.7

LHC constraints on NSUSY

- The small mass splitting makes this scenario hard to be probed at collider
- Decay products of SUSY particles are soft and not detectable

Process



Detector

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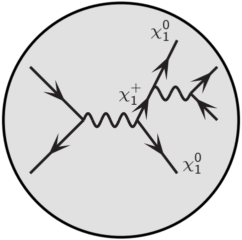

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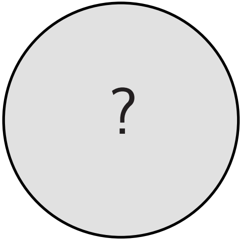

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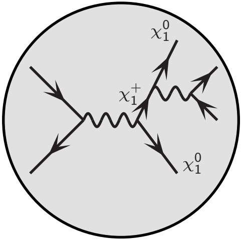

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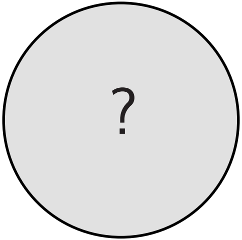

Soft decay products $\longrightarrow$ no visible signature in the detector

LHC constraints on NSUSY

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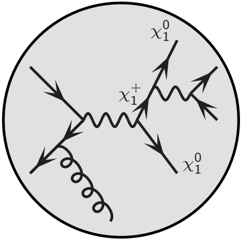
Process **Detector**



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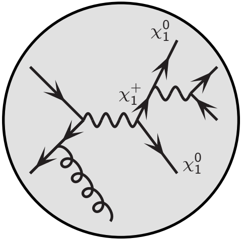

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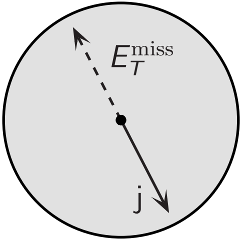

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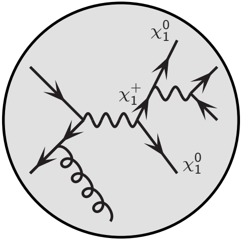

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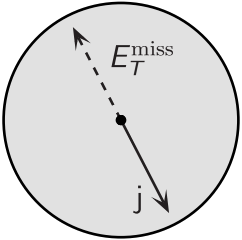


Requiring a hard ISR provides a mono-jet signature

The reach of the 8 TeV LHC

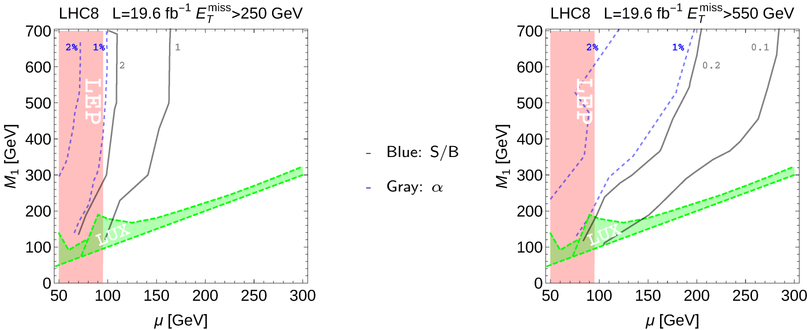
ATLAS and CMS released mono-jet analysis

- One hard jet with $p_T > 110$ GeV
- Veto on third jet
- $\Delta\phi(j_1, j_2) < 2.5$
- Lepton veto
- $E_T^{\rm miss}$ final selection: $>$ 250, 300, 350, 400, 450, 500, 550 GeV

Parameter space and simulation details

- 100 GeV $< \mu <$ 300 GeV, $\mu < M_1 < \mu +$ 600 GeV; SPheno v3
- Signal: $pp \to \chi\chi j$
- MadGraph v.1.5 cross checked with CalcHEP
- Pythia 6 for parton showering, hadronization and decays
- Delphes3 for fast detector simulation

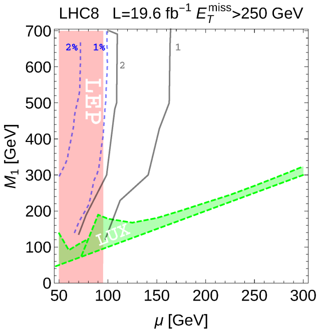
The reach of the 8 TeV LHC



- Blue: S/B
- Gray: α

- $E_T^{\mathrm{miss}} > 250$ GeV: Low Signal over Background ratio
- $E_T^{\mathrm{miss}} > 550$ GeV: S/B increase but α drops down

The reach of the 8 TeV LHC



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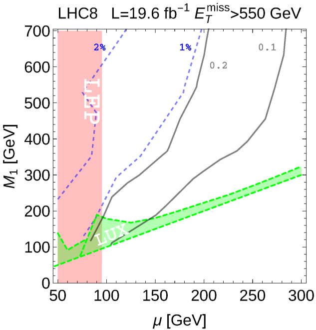


- $E_T^{\rm miss} > 250$ GeV: Low Signal over Background ratio
- $E_T^{\rm miss} > 550$ GeV: S/B increase but α drops down

LHC Run 1 is not sensitive to this scenario

Prospects for the 13 TeV LHC

We apply a monojet-like cut flow for the 13 TeV run of the LHC

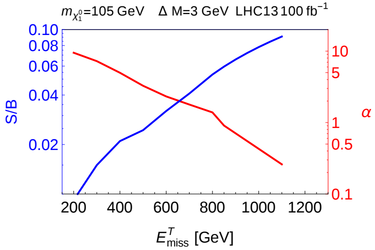
- One hard jet with $p_T > 200$ GeV
- Veto on third jet
- $\Delta\phi(j_1, j_2) < 2.5$
- Lepton veto
- $E_T^{\rm miss}$ final selection: $>$ 300,..., 900 GeV

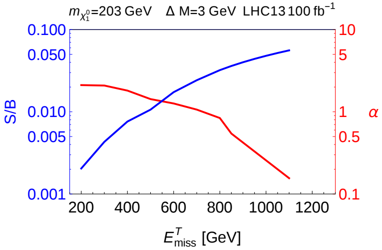
We simulate both signal and background processes

- $pp \to \chi\chi j$
- $pp \to Zj, Z \to \nu\nu$
- $pp \to Wj, W \to l\nu$

Prospects for the 13 TeV LHC

There is a clear tension between an acceptable S/B ratio and α

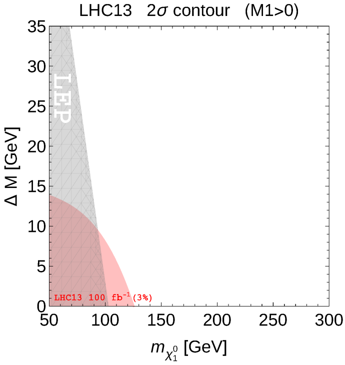


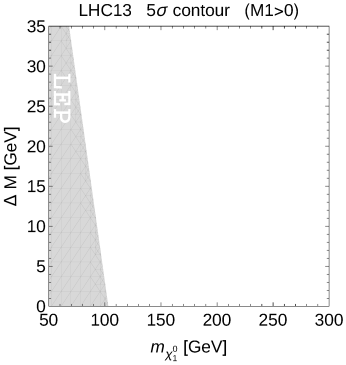


- A harder $E_T^{\rm miss}$ cut is necessary to obtain a S/B ratio $\sim$ 3%, 5%
- Higher $\mathcal{L}$ at LHC13 guarantees high enough statistics
- Need to find an "optimal" cut for given $\mathcal{L}$ and S/B requirement

Prospects for the 13 TeV LHC

LHC13 2σ and 5σ contour

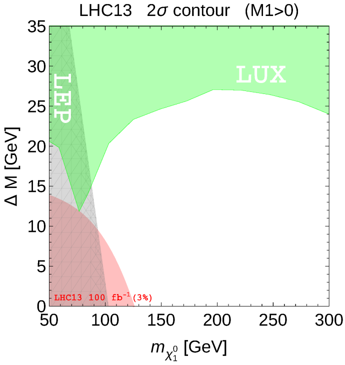


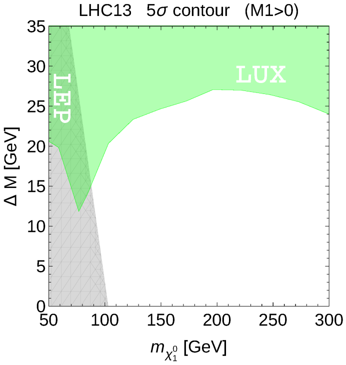


LHC13 with 100 fb^{-1} of $\mathcal{L}$ low exclusion and no discovery power

Prospects for the 13 TeV LHC

LHC13 2σ and 5σ contour





LUX already excludes the region with higher mass splitting

Prospects for the 13 TeV LHC

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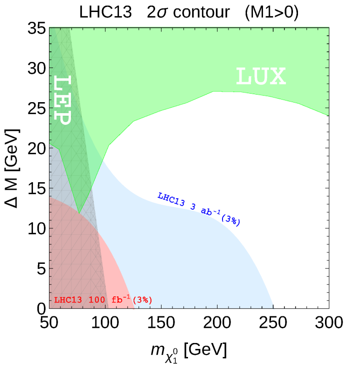
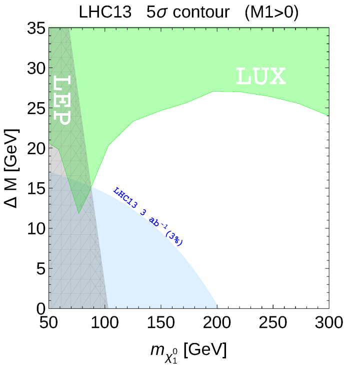
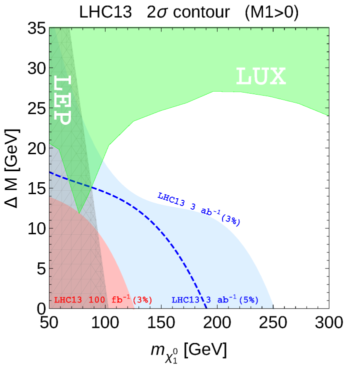


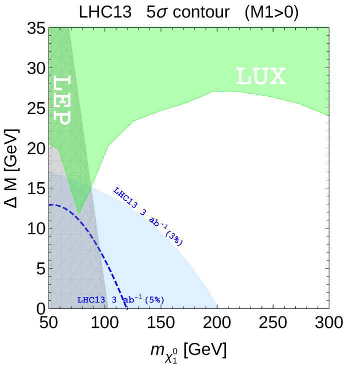


HL-LHC will cover up to 250 GeV LSP with S/B=3 for low $\Delta M\%$

Prospects for the 13 TeV LHC

LHC13 2σ and 5σ contour

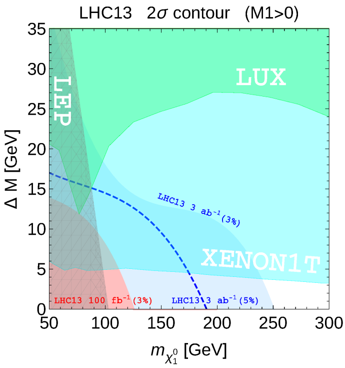


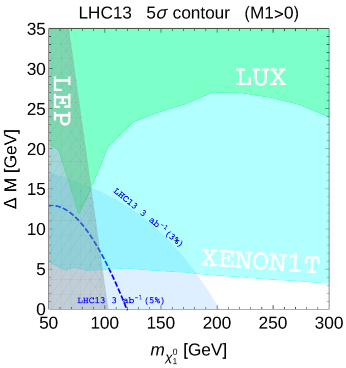


In case of S/B=5% the reach slightly decrease

Prospects for the 13 TeV LHC

LHC13 2σ and 5σ contour





XENON1T will cover region with higher ΔM

Conclusion

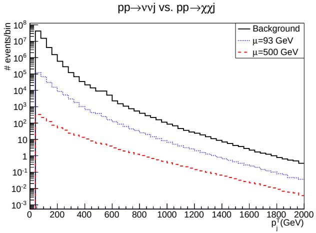
- Low μ MSSM interesting under DM point of view
- The compressed spectrum makes this scenario challenging to be probed at collider
  - Soft SUSY decay products
  - Low S/B ratio, in tension with (expected) systematic uncertainties
- Optimizing $E_T^{\rm miss}$ improves the exclusion power
- Nice complementarity between LHC and DD experiments

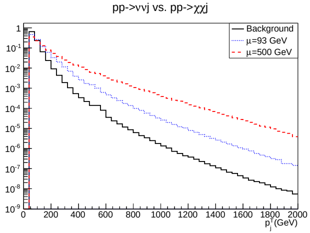
Lets wait for LHC13!!!

Thank you

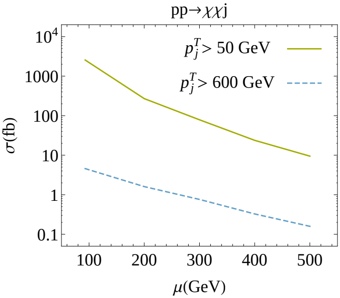
Backup slides

Signal and background shapes





Backup slides



Backup slides

	Zj, $Z \to \nu\nu$	Wj $Z \to l\nu$	$\mu = 100$ GeV M_1=700 GeV	$\mu = 200$ GeV M_1=800 GeV
Initial	$3.15{\cdot}10^6$	$1.25{\cdot}10^7$	$3.63{\cdot}10^5$	$6.45{\cdot}10^3$
$p_j^T > 200$ GeV $\lvert\eta\rvert < 2.4$	$1.05{\cdot}10^6$	$4.11{\cdot}10^6$	$1.73{\cdot}10^5$	3528
Jet veto	$8.7{\cdot}10^5$	$3.13{\cdot}10^6$	$1.33{\cdot}10^5$	2691
$\Delta\phi(j_1, j_2) < 2.5$	$7.2{\cdot}10^5$	$2.3\ {\cdot}10^6$	$1.10{\cdot}10^5$	2320
Veto $e^{\pm}, \mu^{\pm}, \tau^{\pm}$	$7.2{\cdot}10^5$	$6.8\ {\cdot}10^5$	$1.08{\cdot}10^5$	2301
$E^T_{\text{miss}} > 200$ GeV	$6.4{\cdot}10^5$	$4.3{\cdot}10^5$	9846	2188
$E^T_{\text{miss}} > 600$ GeV	4353	1002	171	93
$E^T_{\text{miss}} > 700$ GeV	1703	250	80	47
$E^T_{\text{miss}} > 800$ GeV	694	0	37	22

Table: Cutflow for the two main SM background and two choices of signal for the 13 TeV LHC with 100 fb^{-1} of integrated luminosity.

LAPTh Annecy-le-Vieux

Backup slides

E_T^{miss} (GeV)	>250	>300	>350	>400	>450	>500	>550
$Z\nu\nu$+jets	32100 ± 1600	12700 ± 720	5450 ± 360	2740 ± 220	1460 ± 140	747 ± 96	362 ± 64
WJets	17600 ± 900	6060 ± 320	2380 ± 130	1030 ± 65	501 ± 36	249 ± 22	123 ± 13
$t\bar{t}$	446 ± 220	167 ± 84	69 ± 35	31 ± 16	15 ± 7.7	6.6 ± 3.3	2.8 ± 1.4
$Z(ll)$+jets	139 ± 70	44 ± 22	18 ± 9.0	8.9 ± 4.4	5.2 ± 2.6	2.3 ± 1.2	1.0 ± 0.5
Single t	155 ± 77	53 ± 26	18 ± 9.1	6.1 ± 3.1	0.9 ± 0.4	—	—
QCD multijets	443 ± 270	94 ± 57	29 ± 18	4.9 ± 3.0	2.0 ± 1.2	1.0 ± 0.6	0.5 ± 0.3
Diboson	980 ± 490	440 ± 220	220 ± 110	118 ± 59	65 ± 33	36 ± 18	20 ± 10
Total SM	51800 ± 2000	19600 ± 830	8190 ± 400	3930 ± 230	2050 ± 150	1040 ± 100	509 ± 66
Data	52200	19800	8320	3830	1830	934	519
Exp. upper limit+1σ	5940	2470	1200	639	410	221	187
Exp. upper limit -1σ	2870	1270	638	357	168	123	104
Exp. upper limit	4250	1800	910	452	266	173	137
Obs. upper limit	4510	1940	961	397	154	120	142

Backup slides

$E_T^{\rm miss}$ (GeV)	>250	>300	>350	>400	>450	>500	>550
(1) $Z\mu\mu$+jets statistical unc.	1.7	2.7	4.0	5.6	7.8	11	16
(2) Background	1.4	1.7	2.1	2.4	2.7	3.2	3.9
(3) Acceptance	2.0	2.1	2.1	2.2	2.3	2.6	2.8
(4) Selection efficiency	2.1	2.2	2.2	2.4	2.7	3.1	3.7
(5) $\mathrm{R_{BF}}$	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Total uncertainty (%)	5.1	5.6	6.6	7.9	9.9	13	18

Table: Summary of the statistical and systematic contributions to the total uncertainty on the $Z\nu\nu$ background.

Backup slides