HEPHY Institute of High Energy Physics

ÖAW Österreichische Akademie der Wissenschaften

Likelihoods in the interpretation of searches for BSM physics

Wolfgang Waltenberger

On the theoretical contexts

For interpretation of BSM searches, theoretical contexts – i.e. models – are needed.
Currently I see three different types of approaches in the community of the SUSY searchers:

– constrained models, e.g. the cMSSM

– phenomenological models, e.g. the pMSSM

– simplified models

On the theoretical contexts

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– simplified models

In this talk I want to skip the constrained models, present one effort done in the context of the pMSSM, then talk a little about the connection between simplified models and likelihoods.

phenomenological models: Likelihoods and the pMSSM

Example:

Interpreting LHC SUSY searches in the phenomenological MSSM

S. Sekmen[a], S. Kraml[b], J. Lykken[c], F. Moortgat[d], S. Padhi[e],
L. Pape[d], M. Pierini[f], H. B. Prosper[a], M. Spiropulu[f,g]

Arxiv:1109.5119

pMSSM parameters:

$$-3\,\mathrm{TeV} \leq M_1, M_2 \leq 3\,\mathrm{TeV}$$
$$0 \leq M_3 \leq 3\,\mathrm{TeV}$$
$$0 \leq \mu \leq 3\,\mathrm{TeV}$$
$$0 \leq m_A \leq 3\,\mathrm{TeV}$$
$$2 \leq \tan\beta \leq 60$$
$$0 \leq \tilde{Q}_{1,2}, \tilde{U}_{1,2}, \tilde{D}_{1,2}, \tilde{L}_{1,2}, \tilde{E}_{1,2}, \tilde{Q}_3, \tilde{U}_3, \tilde{D}_3, \tilde{L}_3, \tilde{E}_3 \leq 3\,\mathrm{TeV}$$
$$-7\,\mathrm{TeV} \leq A_t, A_b, A_\tau \leq 7\,\mathrm{TeV}$$

SM parameters:

$$m_t, m_b(m_b), \alpha_S(M_Z)$$

(constrained by likelihood)

Bayesian MCMC walk in the pMSSM space:

– two-step approach: the prior for the final Bayesian CMS-fit is the posterior of the preCMS data.

$$
\begin{aligned}
P(\theta|D) &= L(D^{\mathrm{CMS}}|\theta)L(D^{\mathrm{preCMS}}|\theta)\pi(\theta) \\
&= L'(D^{\mathrm{CMS}}|\theta)\pi^{\mathrm{preCMS}}(\theta)
\end{aligned}
$$

Bayesian MCMC walk in the pMSSM space:

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$$\boldsymbol{\pi^{\mathrm{preCMS}}(\theta) = \mathsf{L}(\mathsf{D}^{\mathrm{preCMS}}|\theta)\pi(\theta)}$$

posterior for preCMS data*
prior for CMS data

$$\boldsymbol{\mathsf{L}(\mathsf{D}^{\mathrm{CMS}}|\theta)}$$

likelihood for CMS data

* preCMS data: all data but CMS SUSY and EXO results

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$$= L'(D^{\mathrm{CMS}}|\theta)\pi^{\mathrm{preCMS}}(\theta)$$

$\pi(\theta)$

Cowanscher Ur-Prior: flat

$\pi^{\mathrm{preCMS}}(\theta) = L(D^{\mathrm{preCMS}}|\theta)\pi(\theta)$

posterior for preCMS data*
prior for CMS data

$L(D^{\mathrm{CMS}}|\theta)$

likelihood for CMS data

* preCMS data: all data but CMS SUSY and EXO results

preCMS likelihood

$$L(D^{\mathrm{preCMS}}|\theta) = \prod_i L(D_i^{\mathrm{preCMS}}|\mu_i^{\mathrm{preCMS}}(\theta))$$

D_i^{preCMS}: measurement of preCMS observable i

$\mu_i^{\mathrm{preCMS}}(\theta)$: prediction for preCMS observable i

pMSSM

Observable $\mu_j(\theta)$	Experimental result D_j^{preCMS}	Likelihood function $L(D_j^{\mathrm{preCMS}} \vert \mu_j(\theta))$	MCMC / post-MCMC
$BR(b \to s\gamma)$	$(3.55 \pm 0.23 \pm 0.24 \pm 0.09) \times 10^{-4}$	Gaussian	MCMC
$BR(B_s \to \mu\mu)$	observed CLs curve from latest LHC combination: BPH-12-009	$d(1 - CLs)/dx$	MCMC
$R(B_u \to \tau\nu)$	1.63 ± 0.54	Gaussian	MCMC
Δa_μ	$(26.1 \pm 12.8) \times 10^{-10}$ $[e^+e^-]$	Gaussian	MCMC
m_t	173 ± 1.4 GeV	Gaussian	MCMC
$m_b(m_b)$	$4.19^{+0.18}_{-0.06}$ GeV	Two-sided Gaussian	MCMC
$\alpha_s(M_Z)$	0.1184 ± 0.0007	Gaussian	MCMC
m_h	pre-LHC: $m_h^{low} = 112$	1 if $m_h \geq m_h^{low}$ 0 if $m_h < m_h^{low}$	MCMC
m_h	LHC: $m_h^{low} = 120$, $m_h^{up} = 130$	1 if $m_h^{low} \leq m_h \leq m_h^{up}$ 0 if $m_h < m_h^{low}$ or $m_h > m_h^{up}$	post-MCMC
sparticle masses	LEP (micrOMEGAs)	1 if allowed 0 if excluded	MCMC

pMSSM

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Made-up likelihoods!

Likelihoods of simple counting experiments

For each search region l:

$$L(D_l^{CMS}|\theta) = \int \mathrm{Poiss}(N_l|s_l(\theta) + b_l)\, \pi(b_l|B_l, \delta B_l) db_l$$

CMS llhd	Poisson models event count	prior handles uncertainty bkg prediction

N_l: observed count in signal region
s_l: expected signal count
b_l: expected bkg count
B_l: bkg prediction
δ_l: uncertainty bkg prediction

prior for bkg prediction

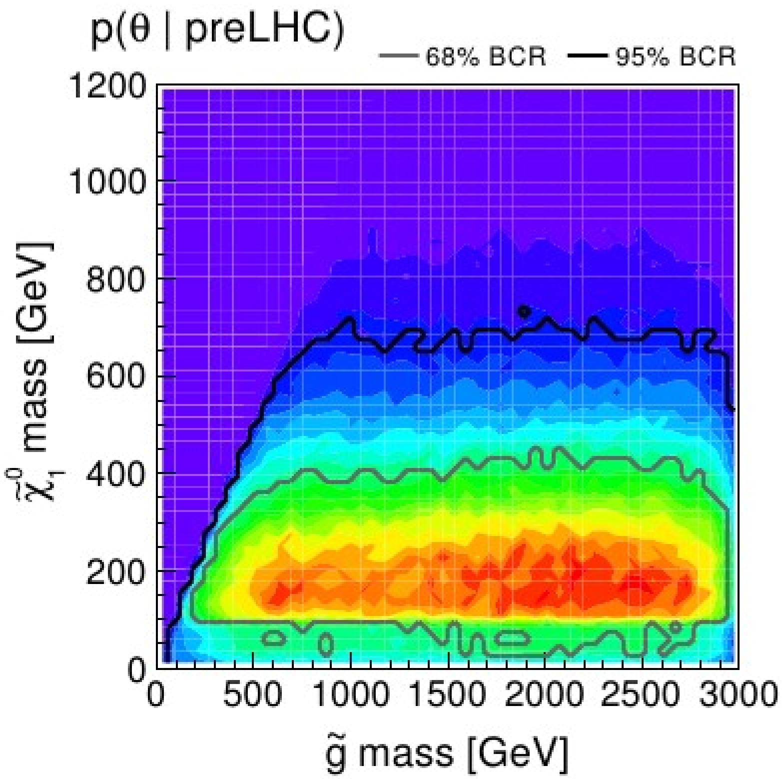
assumption: bkg in signal region is predicted by scaling observed bkg in control region

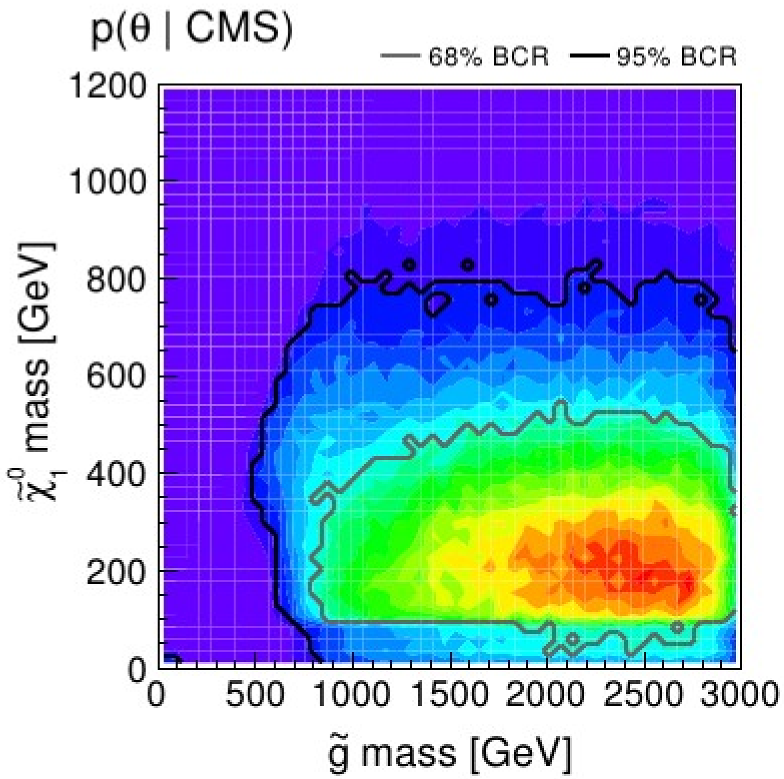
$$\pi(b_l | B_l, \delta B_l) = \mathrm{Gamma}(b_l; Q_l + 1; K_l)$$

scaled poisson distribution

b_l: expected bkg count
B_l: bkg prediction
δ_l: uncertainty bkg prediction
$Q_l = (B_l/\delta B_l)^2$: observed count in control region
$K_l = Q_l/B_l$: scaling factor

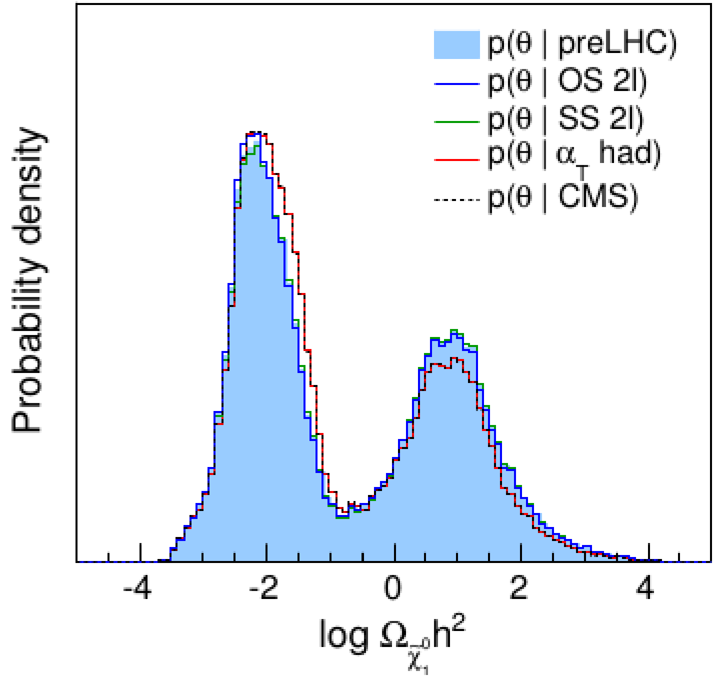
Results

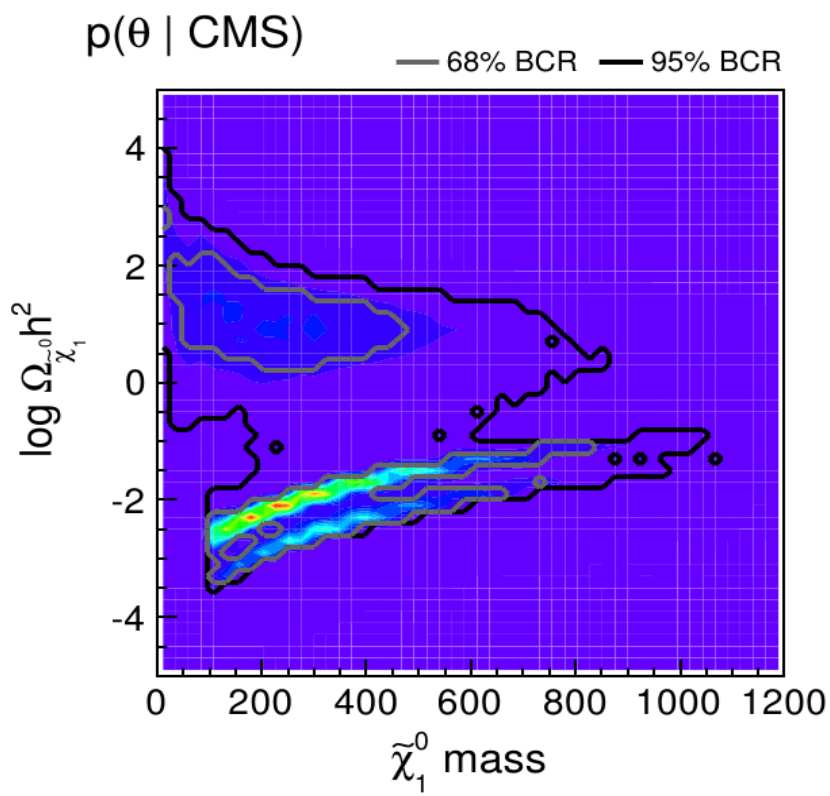




Marginalized posteriors before (left) and after (right) adding CMS searches, gluino mass (x-axis) versus neutralino mass (y-axis). CMS pushes the gluino masses to higher values.

Results

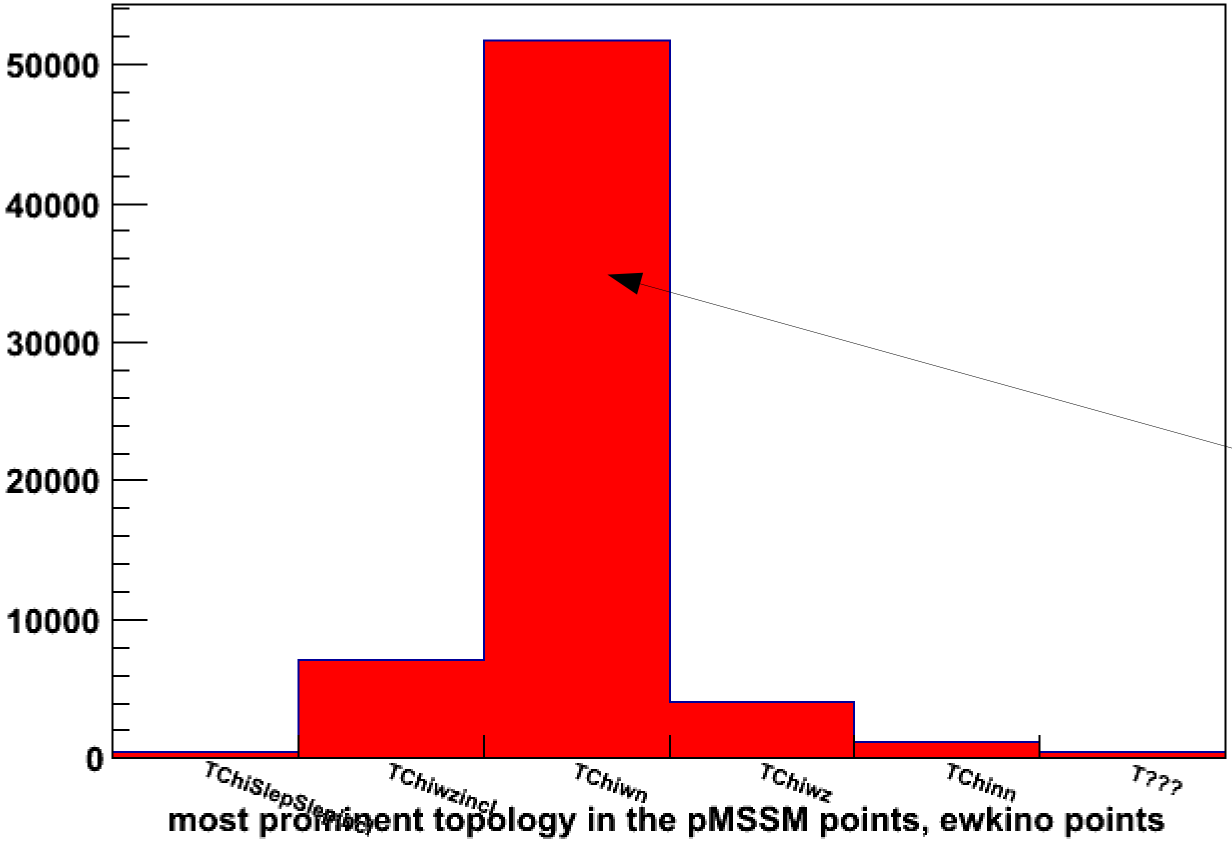




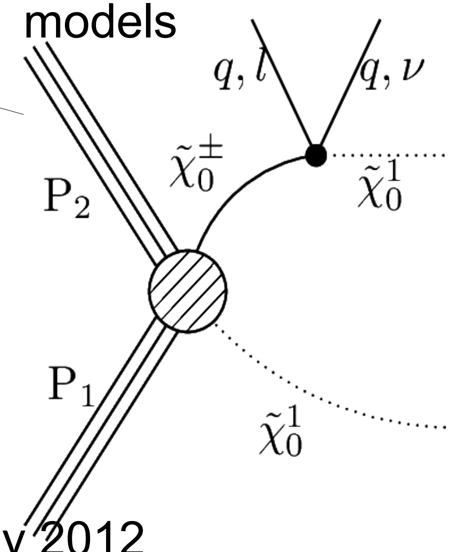
Left: Marginalized posterior of the dark matter relic density, before(filled blue) and after (various lines) including CMS information (left). Right: Dark matter relic density versus neutralino mass, marginalized 2d posterior.

SMS/pMSSM

In a small follow-up work presented in the last LPCC "implications" workshop, we dug into pmssm regions which have high production cross sections, but were nevertheless missed. To answer why they were missed, we used the technique of SMS decomposition:



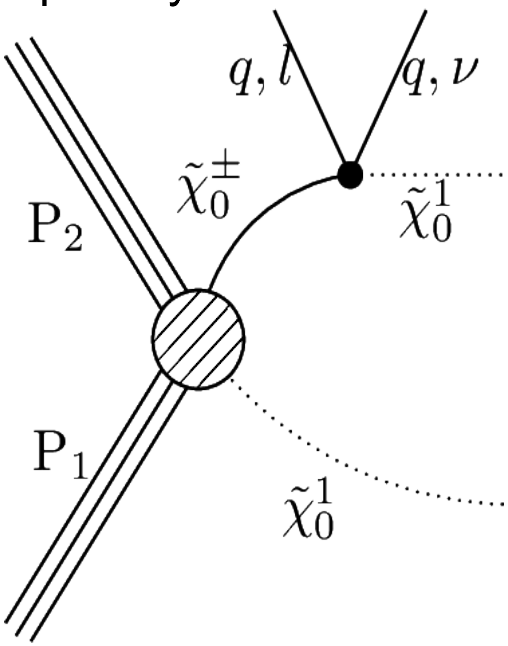
for all points with predominant weakino production, these are the relative occurences of the simplified models

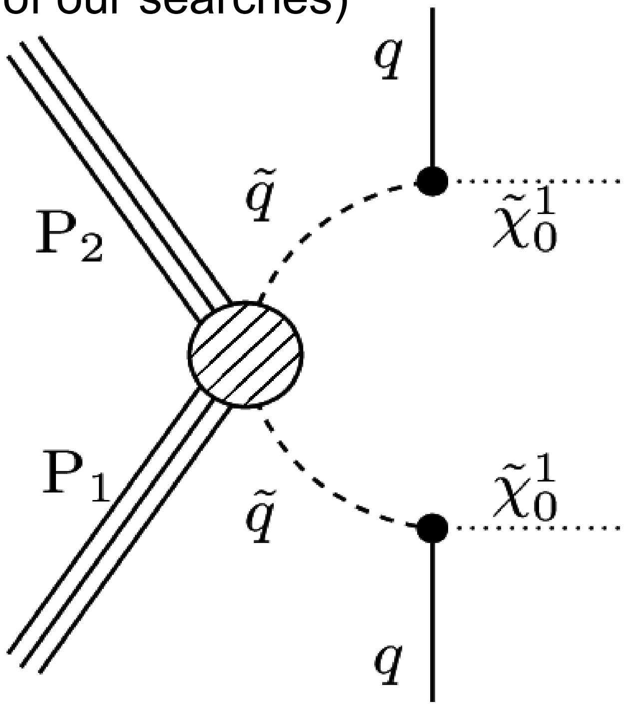


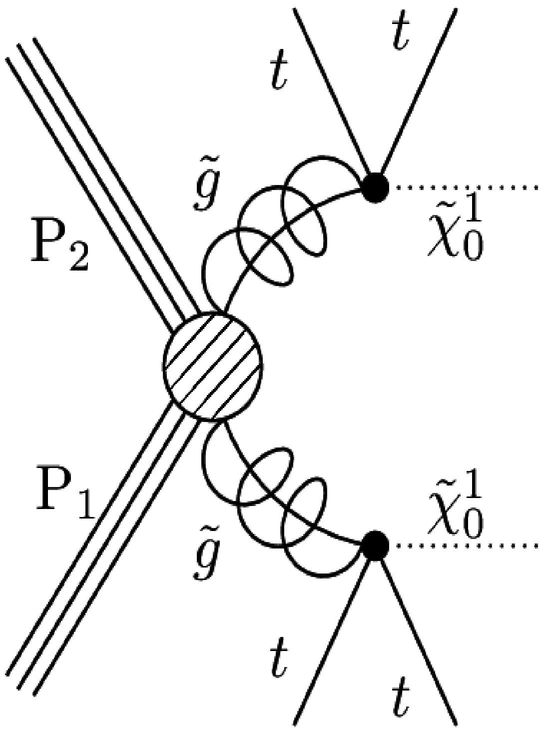
WW, "Implications of LHC results for TeV-scale physics", july 2012

SMSes

(simplified models can be thought of as effective Lagrangians which introduce only a limited number of particles. All masses and branching ratios are free parameters. No production cross section is assumed. We use the SMSes to quantify the sensitivies of our searches)





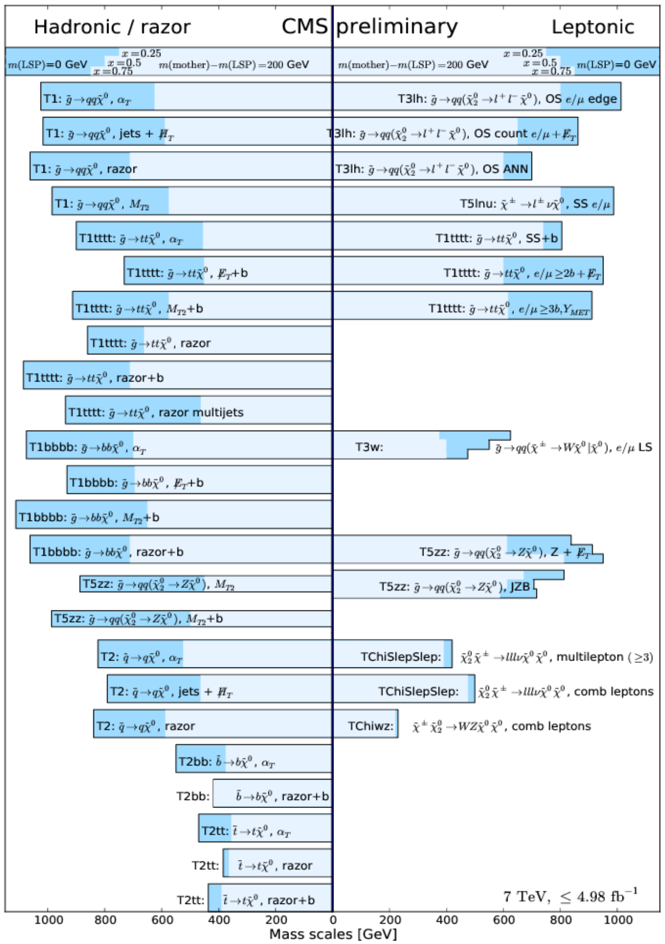


Simplified models: Likelihoods and the SMSes

→ where do we stand right now?

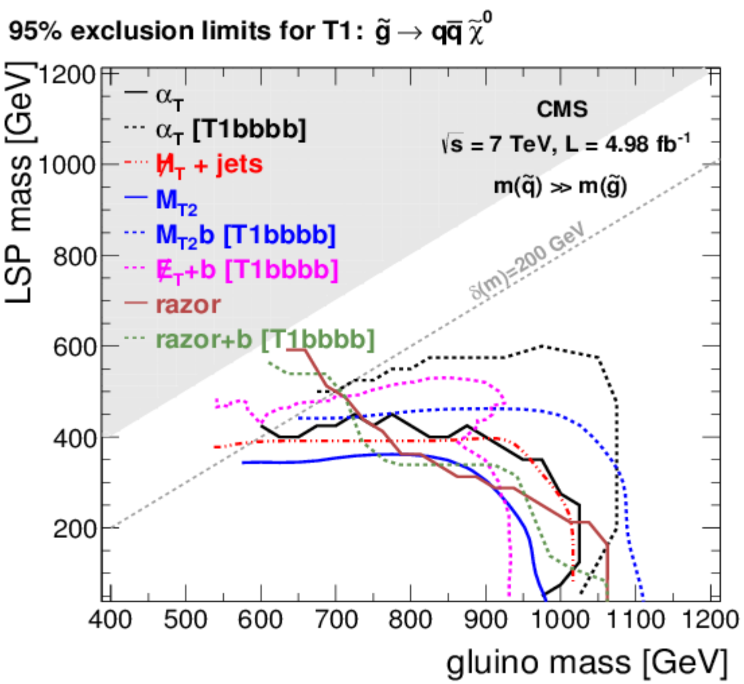
→ where do we want to go from here?

Status: Simplified models and CMS



https://twiki.cern.ch/twiki/bin/view/CMSPublic/SUSYSMSSummaryPlots

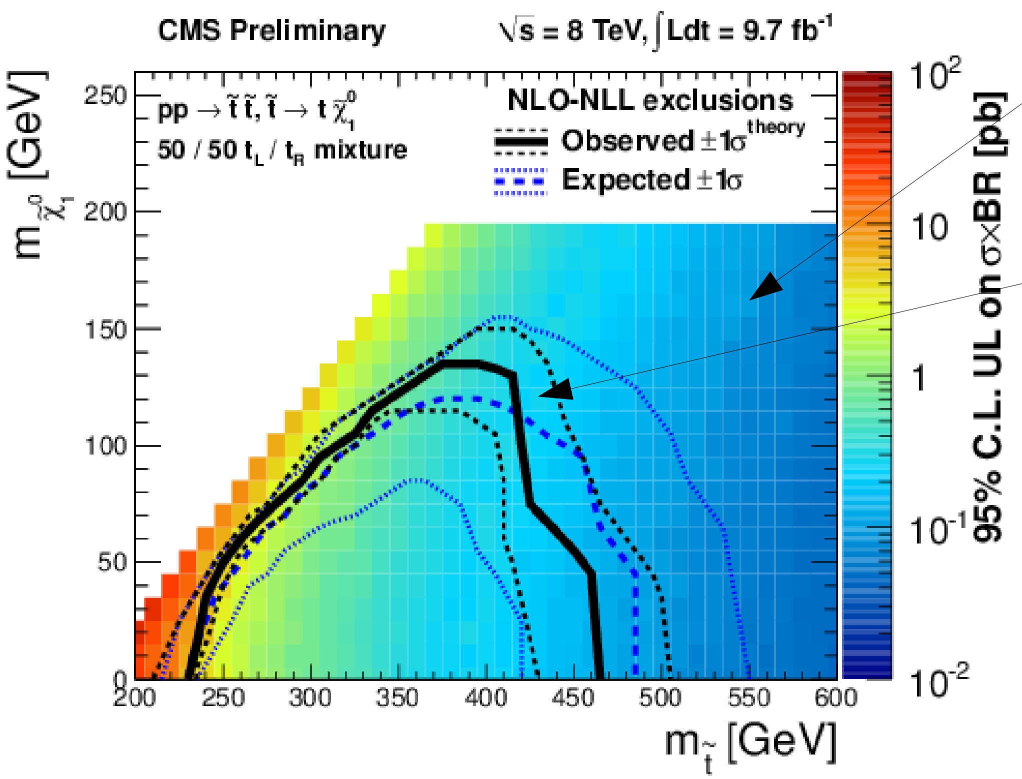
arxiv.org:1301.2175



arXiv:1301.2175

Status: Simplified models and CMS

Most of CMSes SMS results are presented like this:



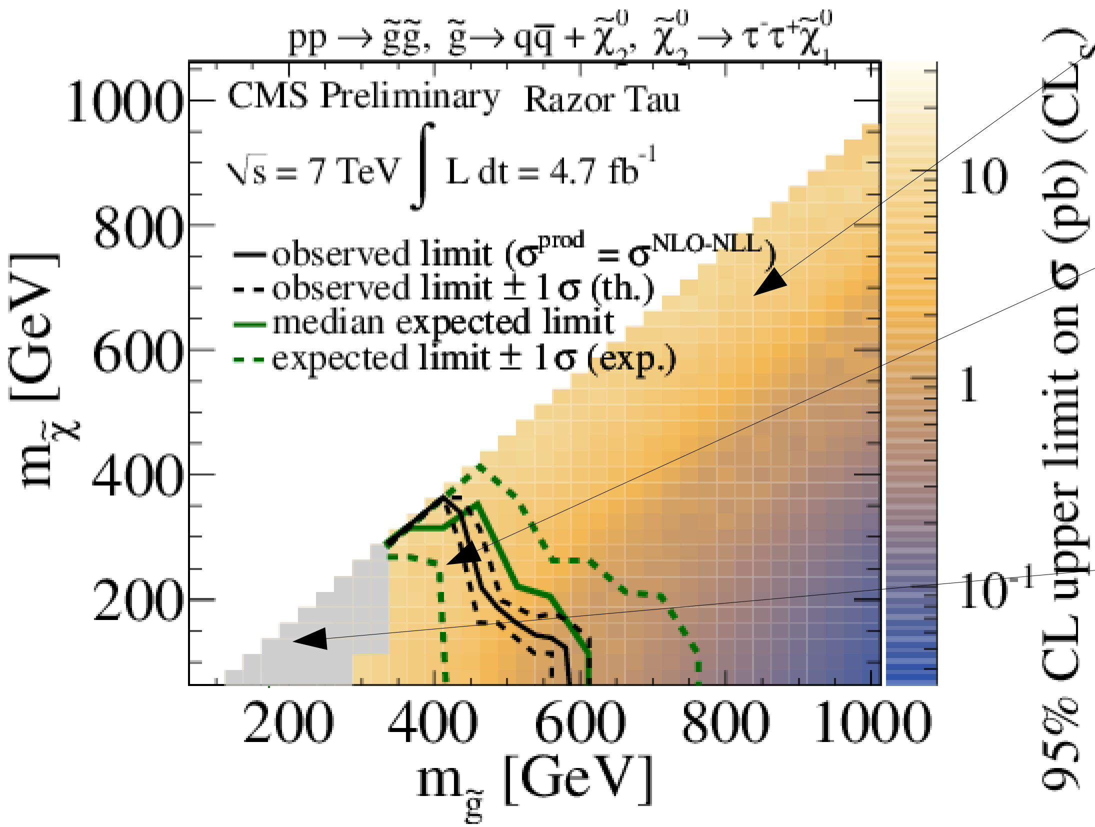
Color represents 95% upper limit on production cross section

Upper limits are compared with reference cross sections (observed/expected, +- 1 sigma)

CMS-SUS-12-023

Status: Simplified models and CMS

Most of CMSes SMS results are presented like this:



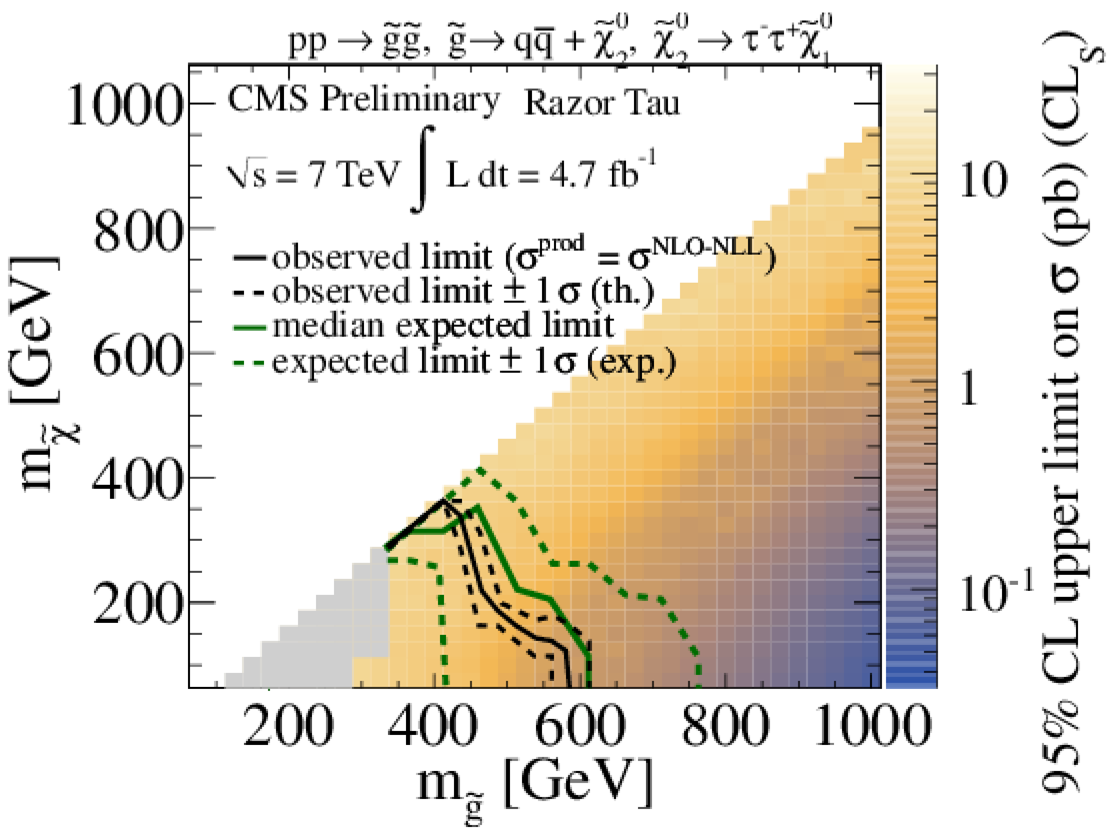
Color represents 95% upper limit on production cross section

Upper limits are compared with reference cross sections (observed/expected, +- 1 sigma)

No statements are made in regions with too low statistics or too large (e.g. ISR) uncertainties.

CMS-SUS-11-029

Status: Simplified models and CMS



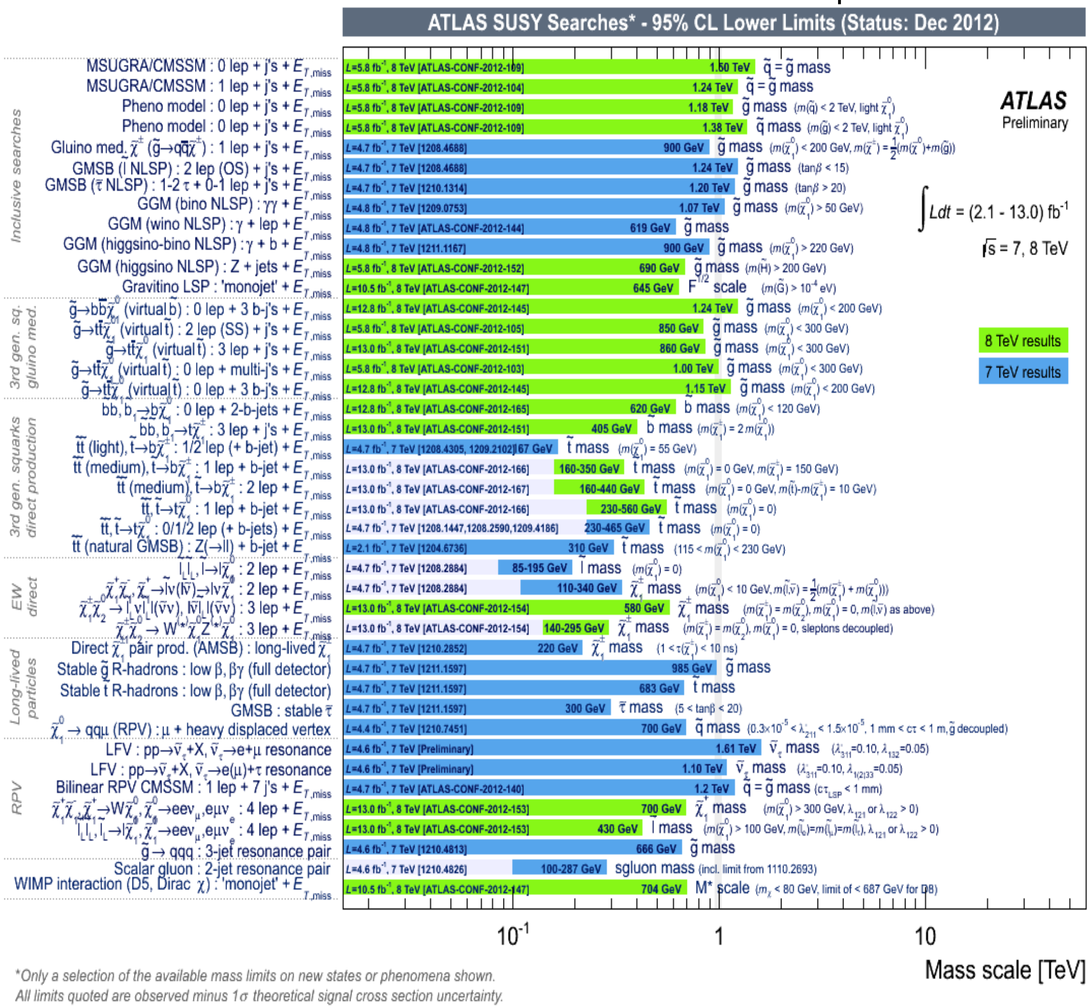
CMS-SUS-11-029

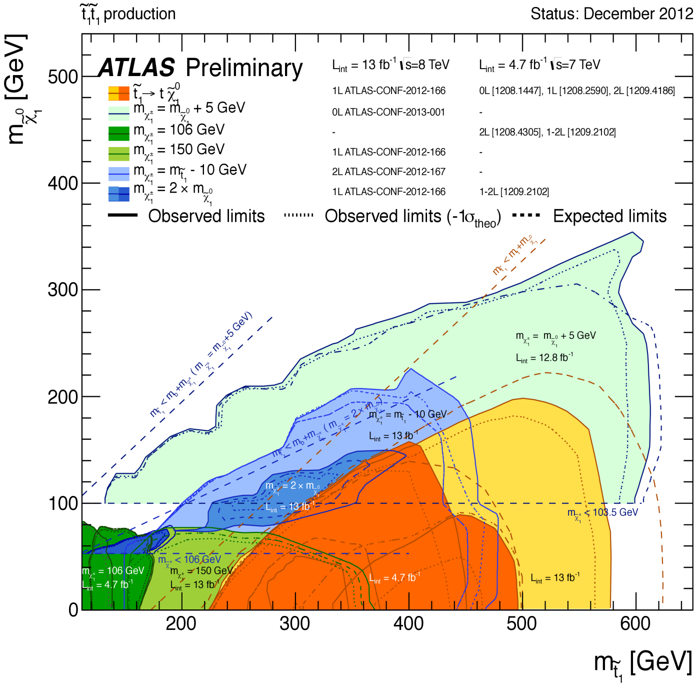
What we would like, though, are the full likelihoods of the production cross sections, for each bin in the plot on the left.

Even further, if we were granted a free wish, we would also like all information and meta information about how the likelihood was constructed.

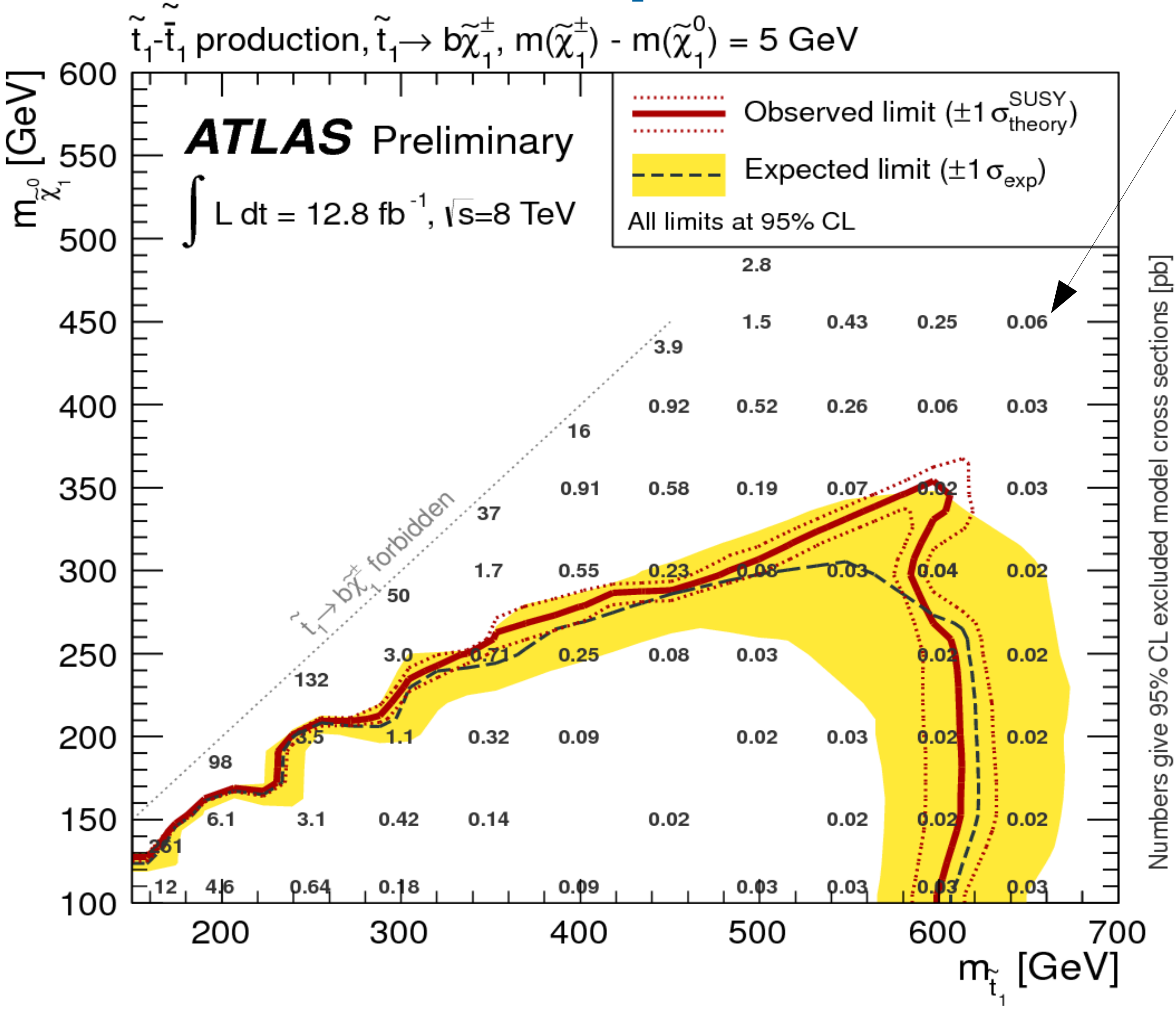
Status: Simplified models and ATLAS

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults





Status: Simplified models and ATLAS



Most recent results now also show upper limits on production cross sections ….

(previous iterations had 1-CLs values instead. We want the full likelihoods. If not the likelihoods, we want the upper limits)

Status: Simplified models and ATLAS

2011 data (7 TeV)

Short Title of the Paper	Date	√s (TeV)	L (fb^{-1})	Document	Plots+Aux. Material	Journal
0-2 leptons + 0-1 b-jets multichannel (razor)	12/2012	7	4.7	1212.6149	Link	Submitted to EPJC
Heavy resonance to eμ, eτ, μτ [RPV-LFV] NEW	12/2012	7	4.6	1212.1272	Link	Submitted to PLB
Long-lived particles [R-hadrons, slepton] NEW	11/2012	7	4.7	1211.1597	Link	Submitted to PLB
1 photon + >=1 b-jet + Etmiss [GGM, higgsino NLSP] NEW	11/2012	7	4.7	1211.1167	Link	Accepted by PLB
Muon + displaced vertex [RPV]	10/2012	7	4.7	1210.7451	Link	Accepted by PLB
Pair of 2-jet resonance [N=1/2 scalar gluon]	10/2012	7	4.6	1210.4826	Link	Accepted by EPJC
Pair of 3-jet resonance [RPV]	10/2012	7	4.6	1210.4813	Link	JHEP 12 (2012) 086
>=4 leptons + Etmiss [RPV]	10/2012	7	4.7	1210.4457	Link (+ data)	JHEP 12 (2012) 124
Monojet + Etmiss [WIMP]	10/2012	7	4.7	1210.4491	Link	Submitted to JHEP
Disappearing track + jets + Etmiss [Direct long-lived charginos - AMSB]	10/2012	7	4.7	1210.2852	Link	Accepted by JHEP
1-2 taus + 0-1 leptons + jets + Etmiss [GMSB]	10/2012	7	4.7	1210.1314	Link	EPJC 72 (2012) 2215
Monophoton [ADD, WIMP]	09/2012	7	4.7	1209.4625	Link	PRL 110 (2013) 011802
2 leptons + jets + Etmiss [Medium stop]	09/2012	7	4.7	1209.4186	Link (+ data)	JHEP 11 (2012) 094
1-2 b-jets + 1-2 leptons + jets + Etmiss [Light Stop]	09/2012	7	4.7	1209.2102	Link	Accepted by PLB
2 photons + Etmiss [GGM, bino NLSP]	09/2012	7	4.7	1209.0753	Link (+ data)	PLB 718 (2012) 411

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

Status: Simplified models and ATLAS

And some results already appeared on hepdata:
http://hepdata.cedar.ac.uk/view/ins1190891

The Durham HepData Project

Durham University

REACTION DATABASE • DATA REVIEWS • PARTON DISTRIBUTION FUNCTION SERVER • OTHER HEP RESOURCES

Reaction Database Full Record Display

View short record or as: plain text, AIDA, PyROOT, YODA, ROOT, mpl or jhepwork

AAD 2012 — Search for R-parity-violating supersymmetry in events with four or more leptons in sqrt{s}=7 with the ATLAS detector

Experiment: **CERN-LHC-ATLAS (ATLAS)**
Preprinted as **CERN-PH-EP-2012-276**
Archived as: **ARXIV:1210.4457**
Record in: **INSPIRE**

CERN-LHC. Measurement of final states with four or more leptons (electrons or muons) produced in proton-proton collisions at a centre-of-mass energy of 7 TeV. The data sample has a total integrated luminosity of 4.7 fb-1. Comparisons with the Standard Model are made in two signal regions: one that requires moderate values of missing transverse momentum and the other that requires large effective mass. The data are interpreted in a simplified model of R-parity-vilaiting supersymmetry and in an R-partiy-violating MSUGRA/CMSSM model. There is a link below to the SLHA files of the analyses
Baseline: Four or more leptons (e,mu) + Veto Z candidates
SR1: Baseline+Missing ET > 50 GeV
SR2: Baseline+Effective mass > 300 GeV (=scalar sum of missing ET, lepton PT and jet PT for jets PT>40GeV.

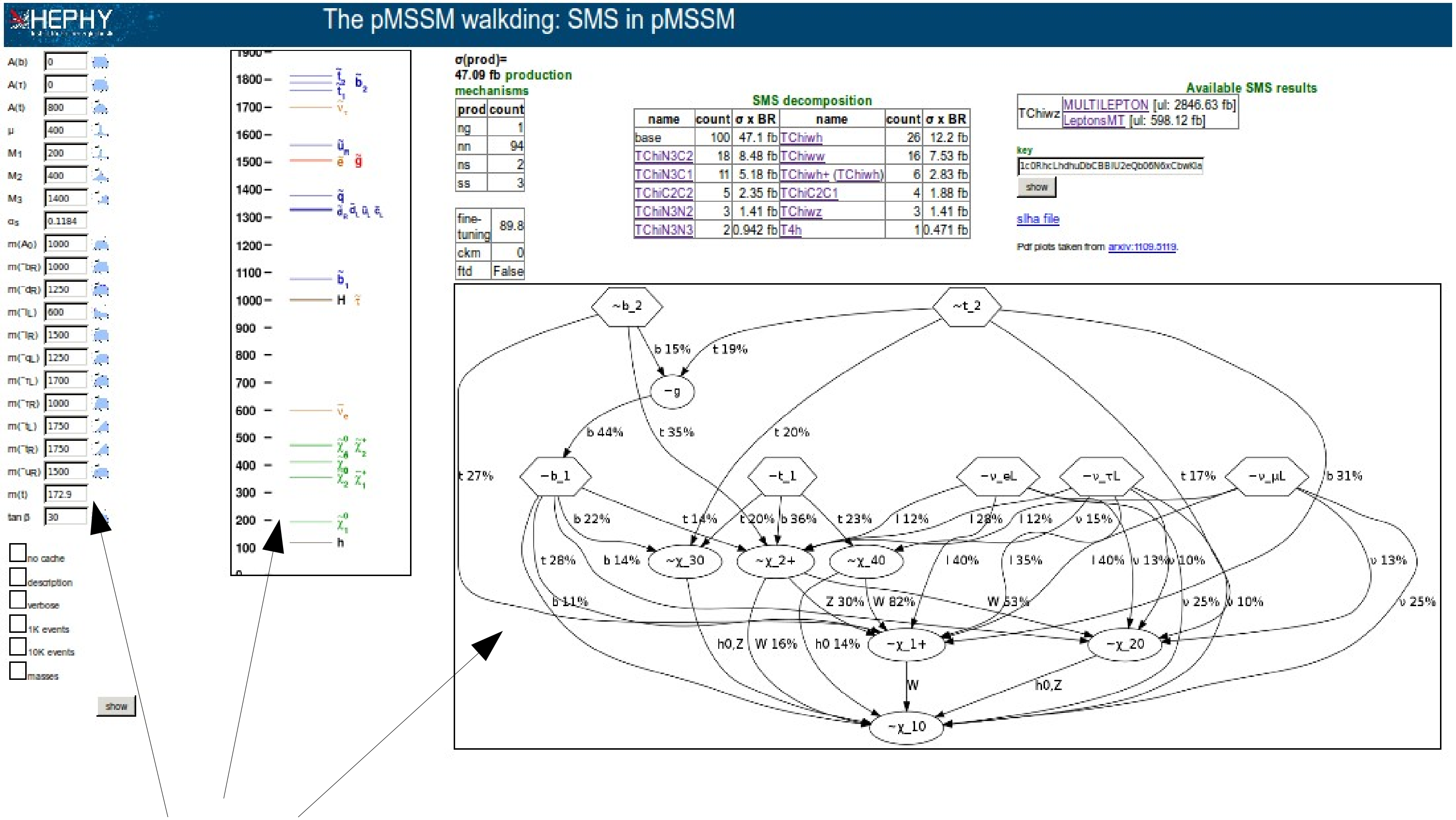
Link to the SLHA files

View list of currently selected plots

Wishes from the experimental collaborations

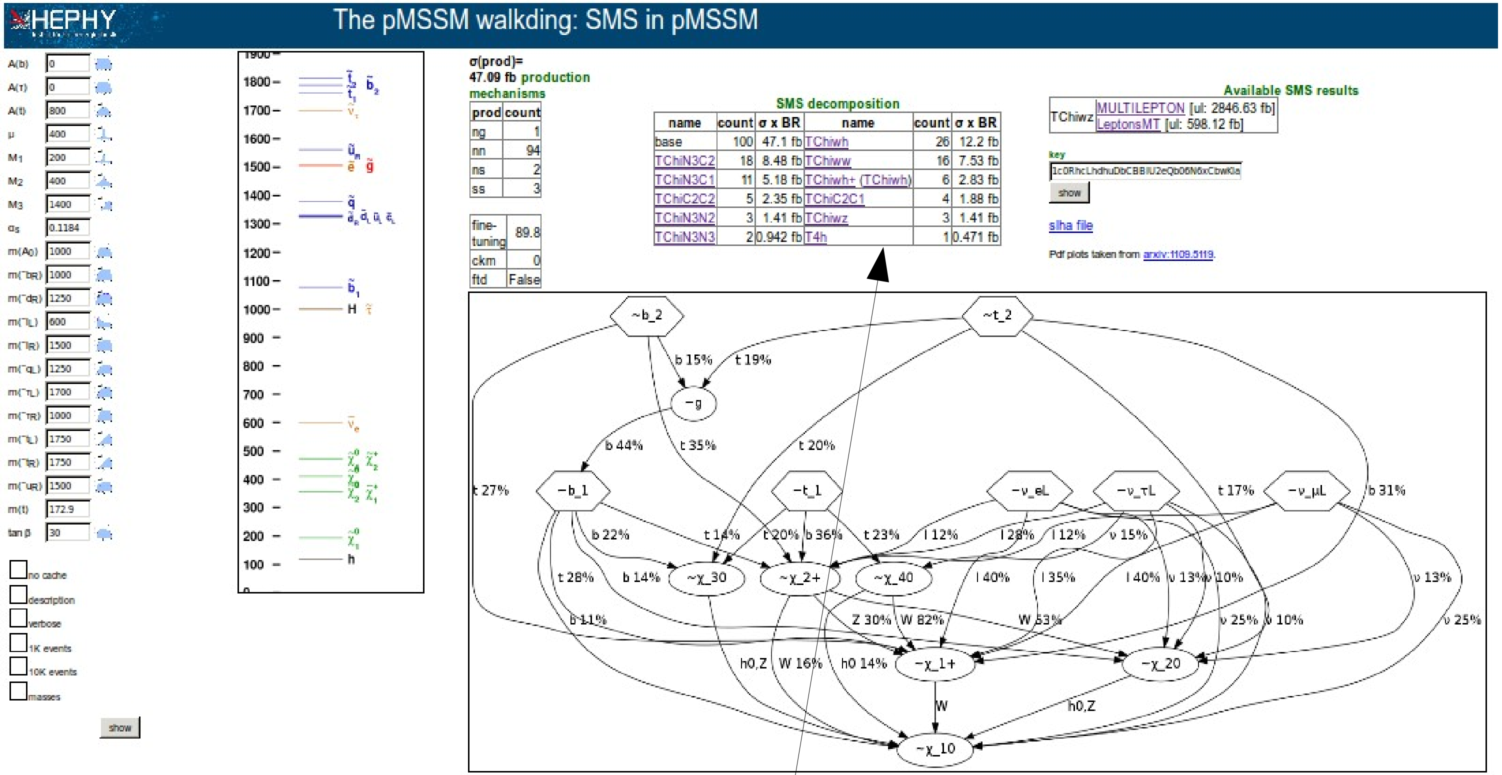
- We would like full bin-by-bin likelihoods also for SMS results
- Please publish using hepdata
- Ultimate vision: e.g. Histfactory + hepdata may make it possible for us to produce all sorts of combined likelihoods, across analyses, across results …..

http://www.hephy.at/user/walten/cgi-bin/pmssm.py,
http://www.hephy.at/user/walten/cgi-bin/pnmssm.py



Our ultimate vision looks like this:

– take a specific parameter point of a model (e.g. via an MCMC walk) http://www.hephy.at/user/walten/cgi-bin/pmssm.py



Our ultimate vision looks like this:

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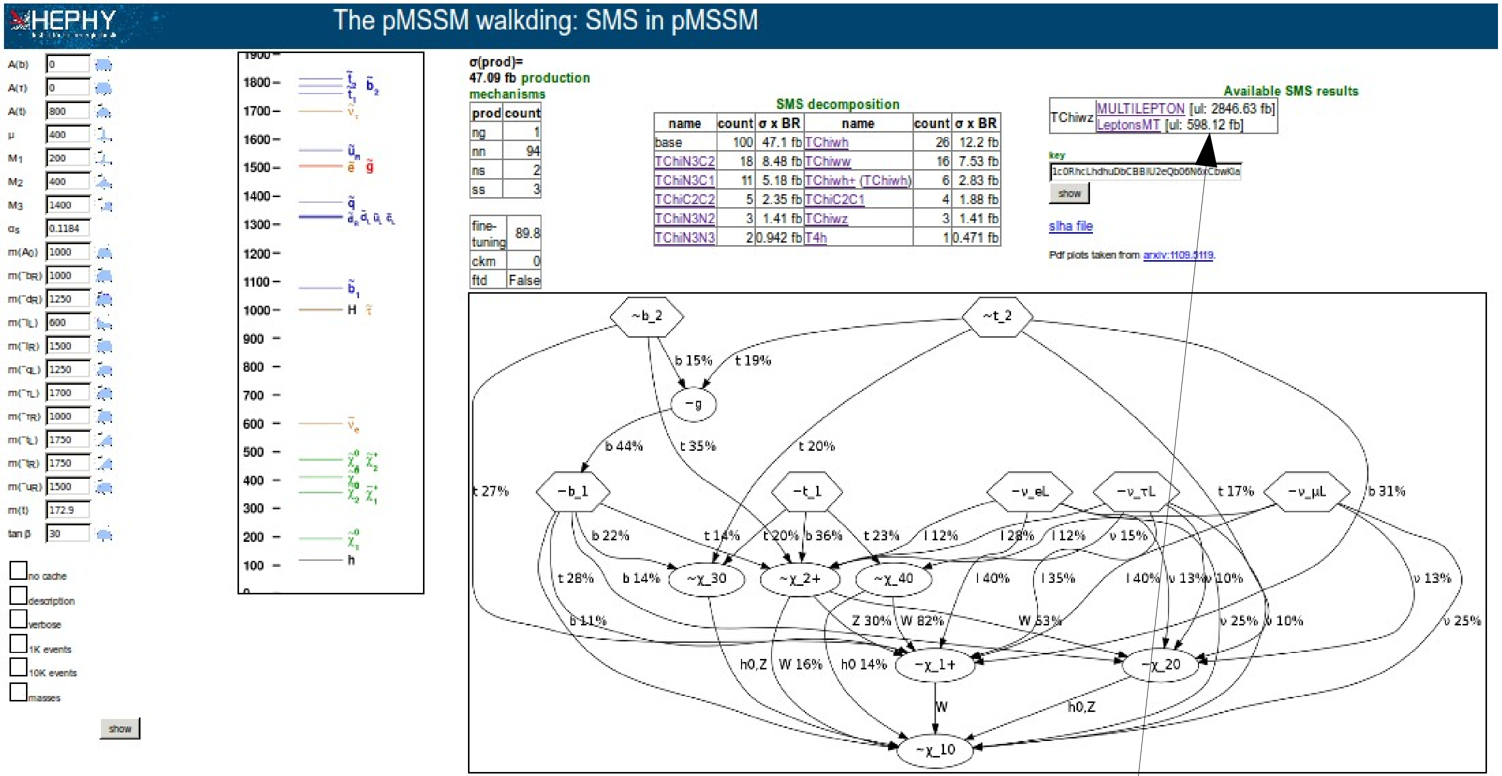
– decompose it into its SMS spectrum

http://www.hephy.at/user/walten/cgi-bin/pmssm.py



Our ultimate vision looks like this:

– take a specific parameter point of a model (e.g. via an MCMC walk)

– decompose it into its SMS spectrum

– check the latest and greatest ATLAS / CMS / non-LHC results for the various topologies

then mix it, cook it, serve it!

- closure tests between direct exclusions in full models and the "combined SMS way", possibly outside the experiments
- side-by-side comparisons between CMS and ATLAS results
- why not mix/combine the best of two worlds?
- simply update to newer results when theyre published
- add non-LHC results to the mix
- have it all searchable and available via inspire → hepdata → histfactory
- ….