Identifying future SUSY searches with SmodelS

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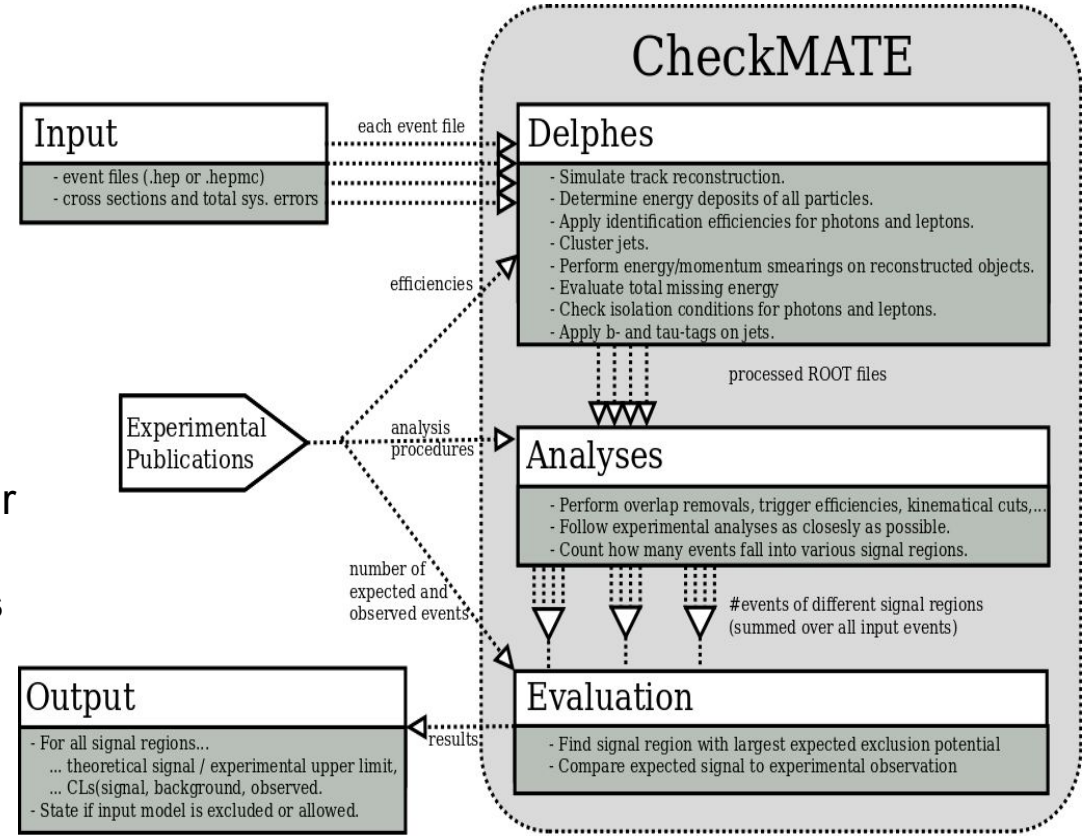
Contents and Motivation

- A lot of SUSY parameter space already excluded, many searches interpreted in terms of simplified models: **What parameter space is not covered?**
- Simplified Model Spectra (SmodelS, arXiv:1701.06586) can **identify uncovered signatures** using simplified model decomposition
- →Use SmodelS on SUSY parameter scan.
- Identify signatures worth looking for

Excluding parameter space

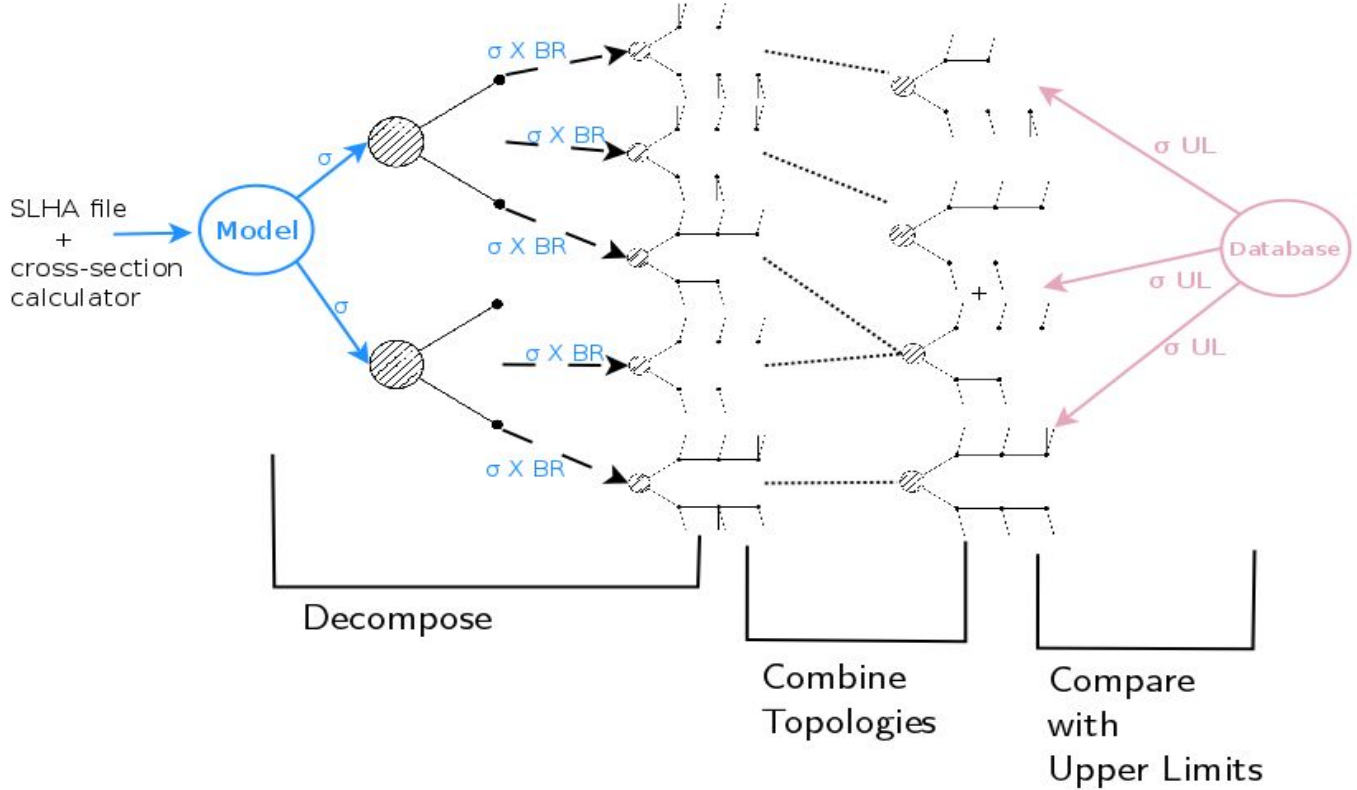
The straightforward approach
(e.g. used by CheckMATE)
arXiv:1611.09856, arXiv:1312.2591

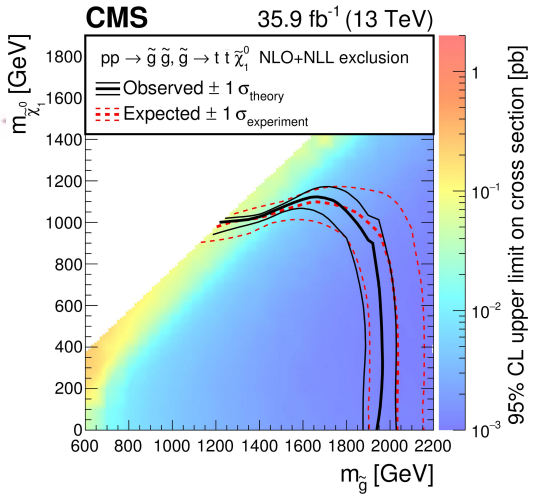
- Take full model, simulate events, reproduce analyses with simulated events, compare to experiment database
- →Model is (not) excluded, get upper limits
- Drawback: **Event simulation takes a lot of time**
- Can this be done without simulation? →SmodelS



Excluding models with SmodelS

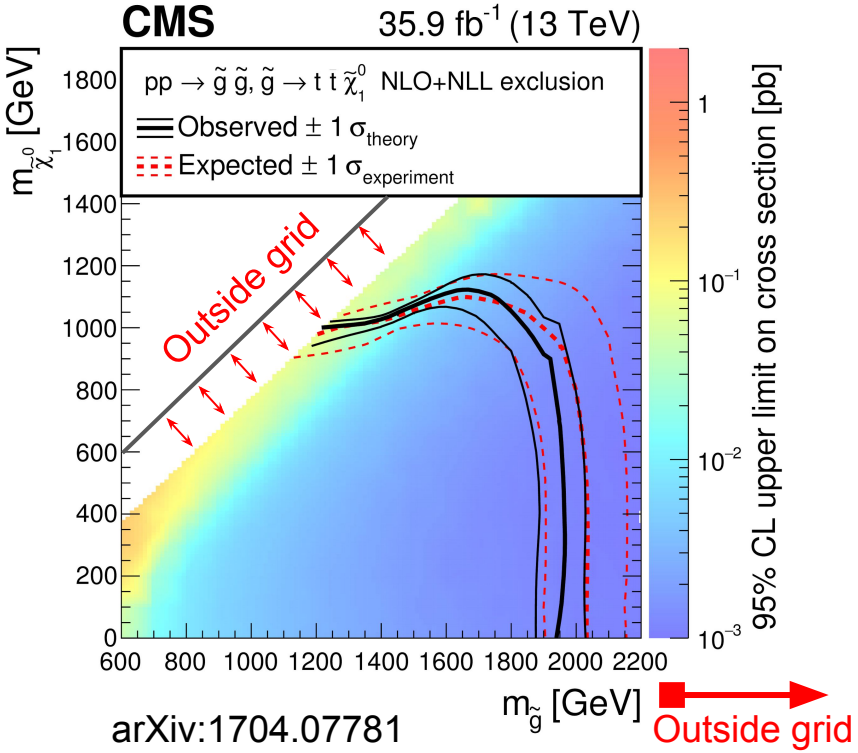
SmodelS process (left, arXiv:1412.1745), UL map example (right, arXiv:1704.07781)





SmodelS: Missing topologies

- Missing topologies: No analysis exists in the database for a predicted simplified model
- →Can help to decide on future searches! For example:
  - Run SmodelS on set of pMSSM points
  - Find important missing topology (e.g. one that occurs in many points)
  - Perform search for topology, incorporate UL map into SmodelS database
  - →Exclude parameter space
- Outside grid topologies: Analysis exists in database, but not for needed masses



arXiv:1704.07781

Using SmodelS: pMSSM parameter scan

For study of the pMSSM, a Monte Carlo Markov Chain scan was used (arXiv:1606.03577)

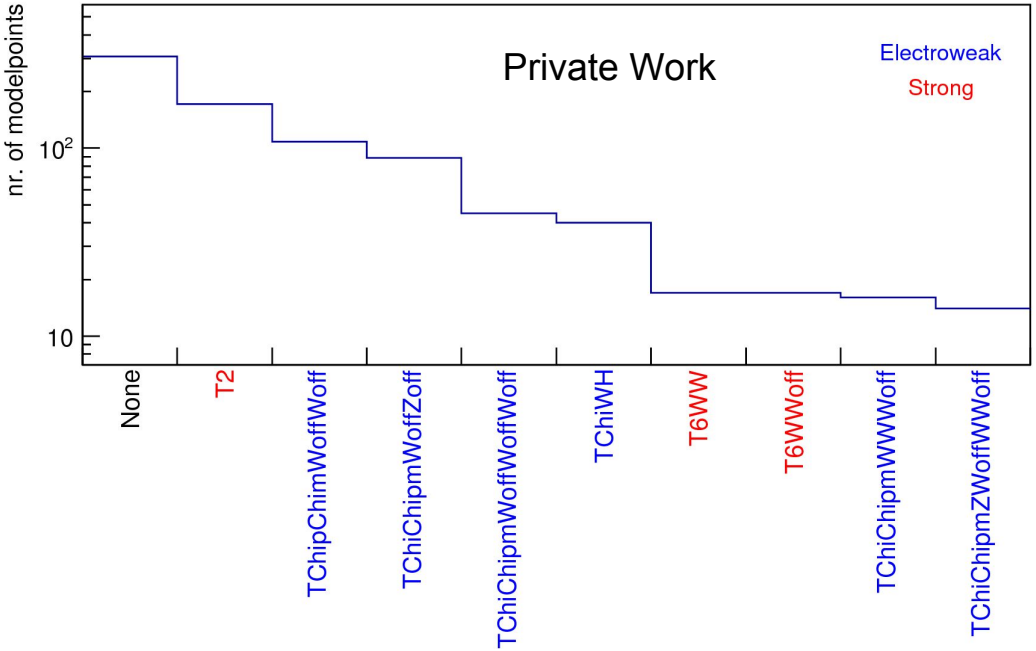
- ~7000 randomly selected points: Masses < 3TeV, prompt BSM particles, low energy constraints
- ~3500 points not excluded after LHC run 1
- Recent: Further exclusion by CMS-SUS-16-033 (jets+MET, E_{CMS}= 13 TeV, L = 35.9 fb^{-1})

→329 remaining points

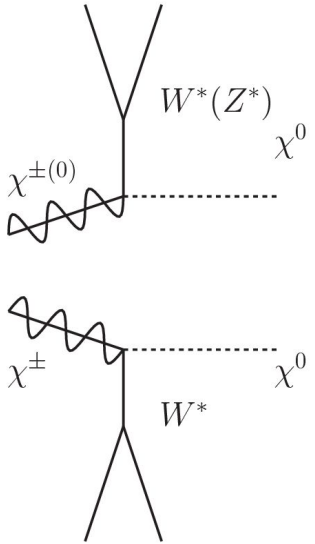
Common missing simplified models

Results of running SmodelS on remaining pMSSM points
(similar studies: arXiv:1606.03577 (Same scan, lists missing models); arXiv:1707.09036 (SmodelS, ATLAS scan))

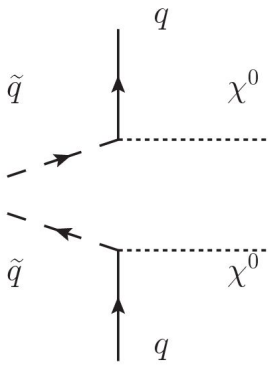
- Electroweak topologies among most occurring missing models
- Outside grid topologies included here→T2 in plot



TChipChimWoffWoff (TChiChipmWoffZoff)



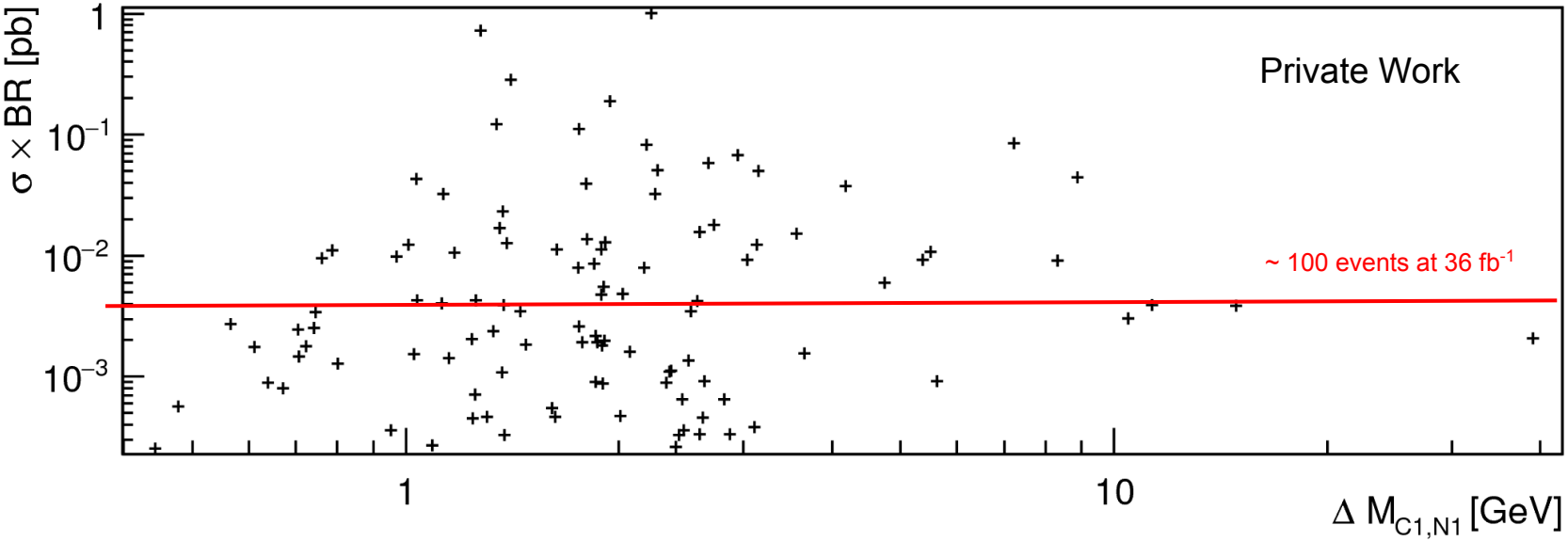
T2



TChipChimWoffWoff: Weight distribution

- Weight can be translated into events produced for given luminosity
- →Number of produced events is indicator for search potential

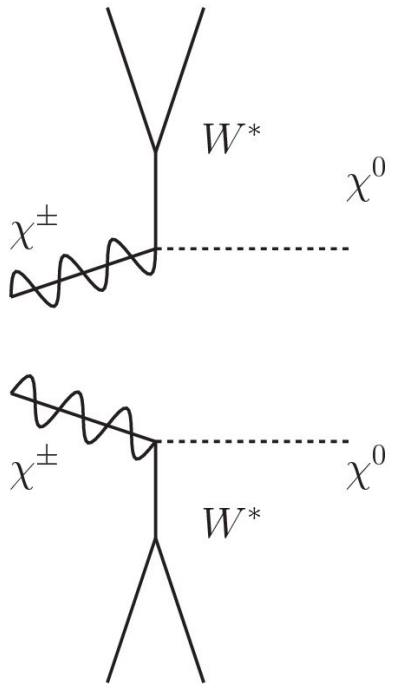
TChipChimWoffWoff: Weight vs. Lsp-Chargino mass splitting



TChipChimWoffWoff: A closer look

- Model is already constrained for high mass splittings (TChiWW / TChipChimWW)
- Expect soft final state, ISR induced MET
- Added incentive to explore TChipChimWoffWoff: It tends to occur in natural models
- →Use ΔEW as variable for naturalness (Phys. Rev. D 88.055026)

TChipChimWoffWoff



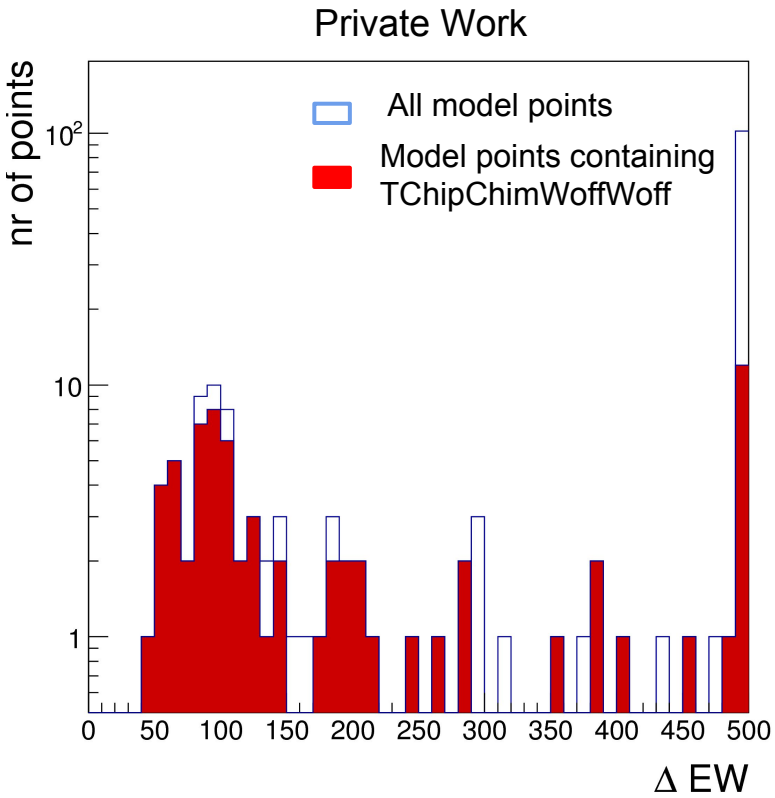
TChipChimWoffWoff: Naturalness

- ΔEW serves as measure for fine tuning in electroweak sector
- Minimize MSSM scalar potential →

$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 + \sum_d^d - \left(m_{H_u}^2 + \sum_u^u\right)\tan^2\beta}{\tan^2\beta - 1} - \mu^2 = \sum_i C_i$$

$$\Delta EW = \frac{\max|C_i|}{\frac{m_Z^2}{2}}$$

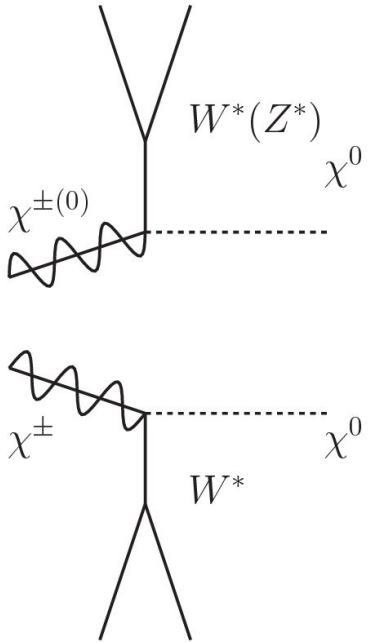
- Low ΔEW requires all terms to be close to m_Z



Summary

- SmodelS is a fast tool to exclude models/theories
- SmodelS also identifies simplified models not covered by searches, which can be used as a decider for future analyses
- Presented study: Run SmodelS on 329 pMSSM points that are not excluded by CMS →interest in TChipChimWoffWoff & TChiChipmWoffZoff
- Preliminary analysis ongoing

TChipChimWoffWoff (TChiChipmWoffZoff)



Backup

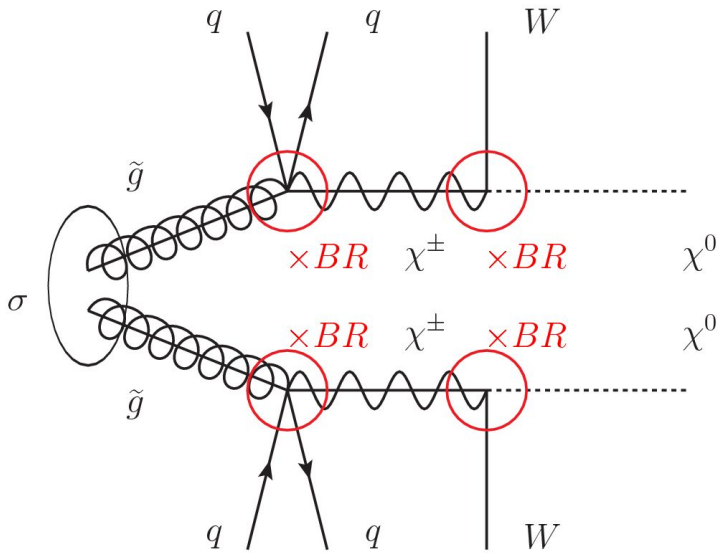
SmodelS: Decomposition

A closer look at decomposition:

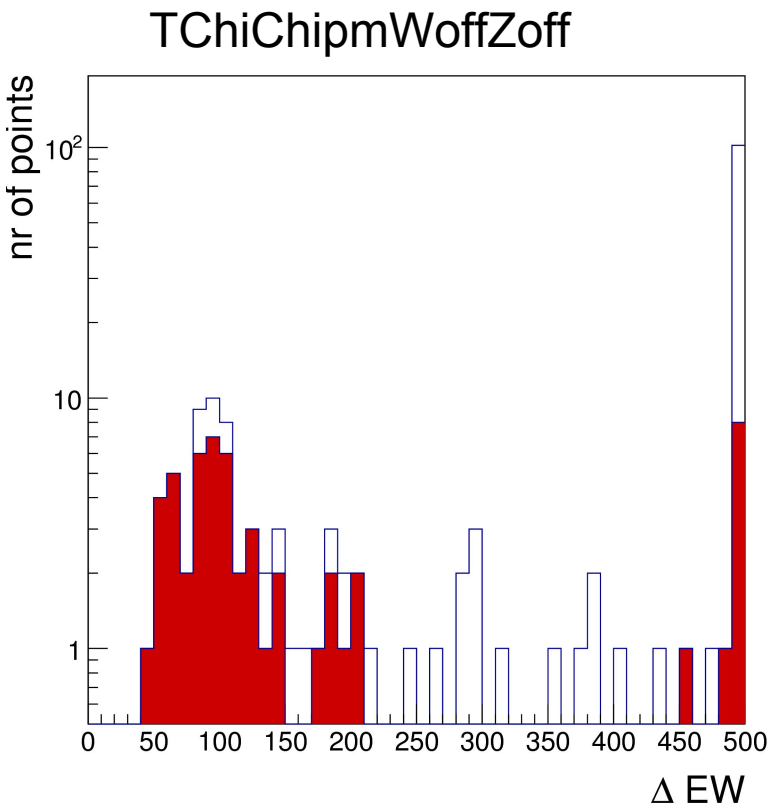
- Start with production cross section for branch mothers
- Sequentially add vertices/decays according to the decay table of the input model
- At each step, compute the weight:

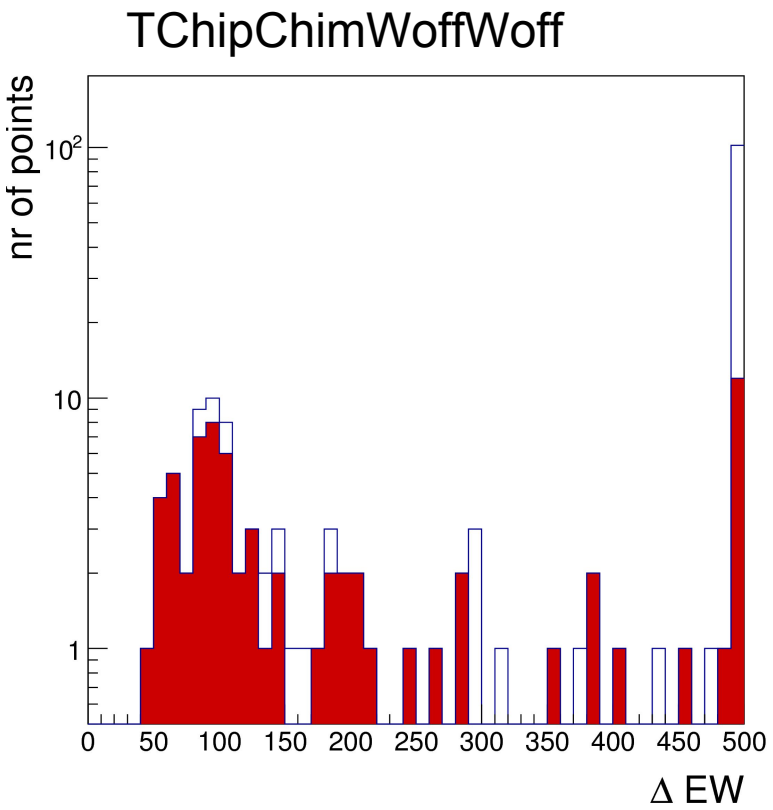
$$\text{weight} = \sigma \cdot \prod_i \text{BR}_i$$

- Decomposition ends when
  - Both branches end in the LSP
    →Simplified model added to spectrum
  - The weight is below a minimum value
    →Simplified model **and all derived models <u>not</u>** part of spectrum



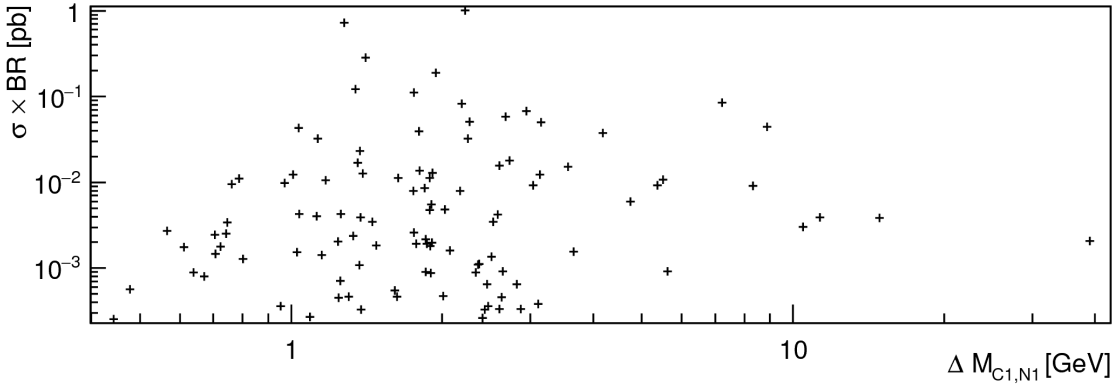
TChiChipmWoffZoff: Naturalness



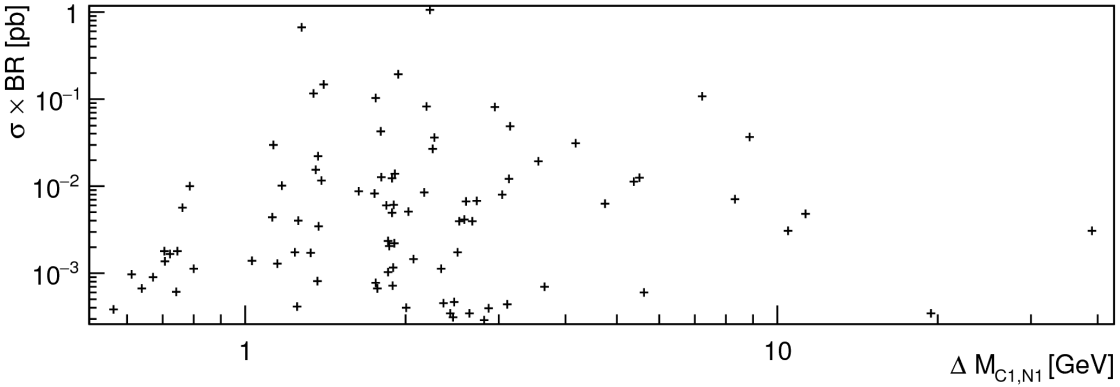


TChiChipmWoffZoff: Weight distribution

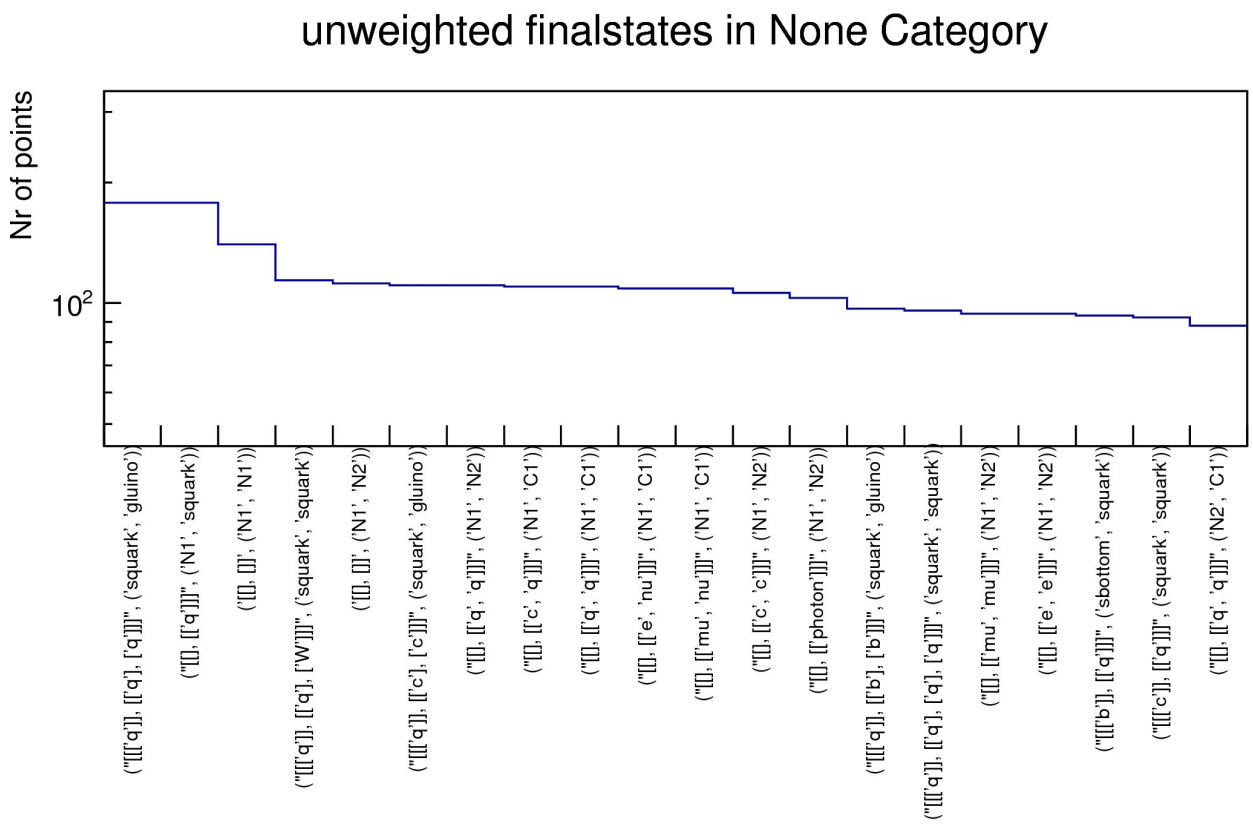
TChipChimWoffWoff: Weight vs. Lsp-Chargino mass splitting



TChiChipmWoffZoff: Weight vs. Lsp-Chargino mass splitting



Finalstates in the ‘None’ category



SmodelS: Assumptions

See SmodelS Manual, section 2 (arXiv:1701,06586)

- Production mode does not significantly influence event kinematics
- No offshell sparticles in cascade, virtual particles replaced by effective vertex
- No quantum numbers (except mass) are considered
- Narrow width approximation for BSM particles
- Z2 symmetry is required
- No significant differences when applying efficiency maps created from simplified models to full models
- **Efficiencies don’t change significantly from simplified to full model**

SmodelS: Assumption studies

- arXiv:1410.0965 (Influence of different production modes in squark simplified models)
- arXiv:1501.03942 (Influence of spin structure in dijet+MET finalstate)
- arXiv:1503.02960 (see above, dilepton+MET)
- arXiv:160702050 (see above, ttbar+MET)

SmodelS is **not** safe in Mono-X searches for dark matter

Scan parameters

$$
\begin{aligned}
-3 \leq\ & M_1, M_2 & \leq 3\,\text{TeV}, \\
0 \leq\ & M_3 & \leq 3\,\text{TeV}, \\
-3 \leq\ & \mu & \leq 3\,\text{TeV}, \\
0 \leq\ & m_{\text{A}} & \leq 3\,\text{TeV}, \\
2 \leq\ & \tan\beta & \leq 60,
\end{aligned}
$$

$$
0 \leq m_{\tilde{\text{Q}}_{1,2}}, m_{\tilde{\text{U}}_{1,2}}, m_{\tilde{\text{D}}_{1,2}}, m_{\tilde{\text{L}}_{1,2}}, m_{\tilde{\text{E}}_{1,2}}, m_{\tilde{\text{Q}}_3}, m_{\tilde{\text{U}}_3}, m_{\tilde{\text{D}}_3}, m_{\tilde{\text{L}}_3}, m_{\tilde{\text{E}}_3} \leq 3\,\text{TeV},
$$

$$
-7 \leq A_{\text{t}}, A_{\text{b}}, A_\tau \leq 7\,\text{TeV},
$$

Scan: Low energy constraints

i	Observable $\mu_i(\theta)$	Constraint $D_i^{\text{non-DCS}}$	Likelihood function $L[D_i^{\text{non-DCS}}\|\mu_i(\theta)]$	Comment
1	$\mathcal{B}(\mathrm{b}\to\mathrm{s}\gamma)$ [45]	$(3.43\pm0.21^{\text{stat}}\pm0.24^{\text{th}}\pm0.07^{\text{sys}})\times10^{-4}$	Gaussian	reweight
2	$\mathcal{B}(\mathrm{B_s}\to\mu\mu)$ [46]	$(2.9\pm0.7\pm0.29^{\text{th}})\times10^{-9}$	Gaussian	reweight
3	$R(\mathrm{B}\to\tau\nu)$ [45]	1.04 ± 0.34	Gaussian	reweight
4	Δa_μ [47]	$(26.1\pm6.3^{\text{exp}}\pm4.9^{\text{SM}}\pm10.0^{\text{SUSY}})\times10^{-10}$	Gaussian	
5	$\alpha_{\mathrm{s}}(m_{\mathrm{Z}})$ [48]	0.1184 ± 0.0007	Gaussian	
6	m_{t} [49]	$173.20\pm0.87^{\text{stat}}\pm1.3^{\text{sys}}\,\text{GeV}$	Gaussian	reweight
7	$m_{\mathrm{b}}(m_{\mathrm{b}})$ [48]	$4.19^{+0.18}_{-0.06}\,\text{GeV}$	Two-sided Gaussian	
8	m_{h}	LHC: $m_{\mathrm{h}}^{\text{low}}=120\,\text{GeV}$, $m_{\mathrm{h}}^{\text{high}}=130\,\text{GeV}$	1 if $m_{\mathrm{h}}^{\text{low}}\le m_{\mathrm{h}}\le m_{\mathrm{h}}^{\text{high}}$ 0 if $m_{\mathrm{h}}<m_{\mathrm{h}}^{\text{low}}$ or $m_{\mathrm{h}}>m_{\mathrm{h}}^{\text{high}}$	reweight
9	μ_{h}	CMS and ATLAS in LHC Run 1, Tevatron	LILITH 1.01 [50, 51]	post-MCMC
10	sparticle masses	LEP [52] (via MICROMEGAS [53–55])	1 if allowed 0 if excluded	

Sources

- LHC picture: http://www.pindex.com/uploads/post_images/original/image_1542.png
- CMS picture: http://www.physikblog.eu/wp-content/uploads/2008/09/cms_aufbau.png
- SM picture: http://cms.web.cern.ch/sites/cms.web.cern.ch/files/styles/large/public/field/image/CMSResult130628_Figure01.jpg?itok=GbuSst8u
- Gravity picture: http://discovermagazine.com/~/media/Images/Issues/2013/July-Aug/apple%20gravity.jpg
- Dark matter picture: http://www.astronomy.ohio-state.edu/~pogge/Ast162/Unit6/Images/RotCurve2.gif
- Baryon asymmetry picture: http://www.fnal.gov/pub/today/archive/archive_2013/images/ROW_Figure01_131031.jpg
- Running couplings picture: https://i.stack.imgur.com/3gARs.png
- Higgs loop contributions picture: http://scienceblogs.com/startswithabang/files/2013/05/1000px-Hqmc-vector.png
- SM parameters: https://i.pinimg.com/originals/9d/4b/fd/9d4bfdeb01d1c40a123cea35ba40a4db.jpg