SModelS

&

Simplified Model Sensitivity to Spin Structure

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Overview

- Introduction to Simplified Models

Interpretation of SUSY searches at the LHC and Simplified Models

- SModelS

Constraining generic new physics models using Simplified Model interpretations

- Scalar vs Fermionic Top Partners in Models with Dark Matter

Spin dependence in Simplified Model interpretation of searches in $t\bar{t}$+MET final states

Interpretation of SUSY searches in ATLAS and CMS

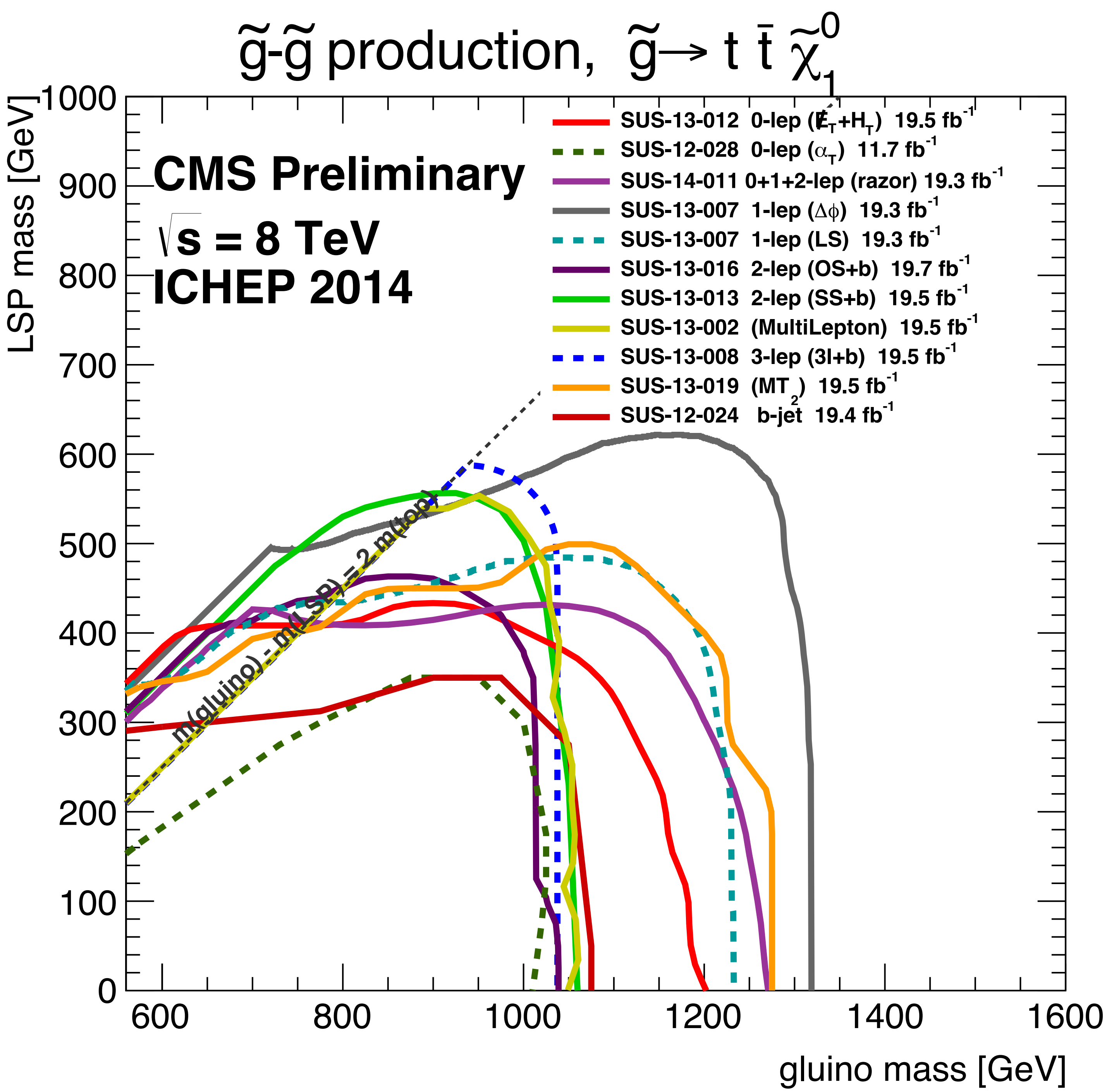
Top down interpretation of SUSY searches, e.g.

- CMSSM - predictive but not generic ~4 parameters
- Full MSSM - generic but not predictive ~100 parameters

Interpretation that is predictive and model independent ?

- Simplified Model Spectra (SMS) based on generic MSSM
- Consider only small subset of new particles
- Simplified model parametrised by particle masses and branching ratios
- Experimental observations constrain the production cross section, assuming 100% BR

Simplified Models



SMS are an "effective Lagrangian" description, containing only a few particles, 100% BR

The free parameters are the masses of the new particles

Intuitive picture, clear comparison, easy to scan

Using Experimental Results to constrain new physics models

Top down interpretation

- Use event generator + detector simulation to evaluate signal prediction for each parameter point
- Precise, but very time consuming
- Tools: ATOM, CheckMATE, MadAnalysis5

Apply Simplified Model exclusion

- Mass limits only valid within the Simplified Model
- Wrong when considering generic model, e.g. arbitrary gluino decays

Decompose full model into Simplified Model components

- Each component can be compared against experimental upper limits
- Conservative, but fast

Tools to use Simplified Model Results

- Fastlim

Constraining MSSM parameter space (natural SUSY)

Papucci, Sakurai, Weiler, Zeune (2014)

- XQCAT

Constraining heavy extra quarks

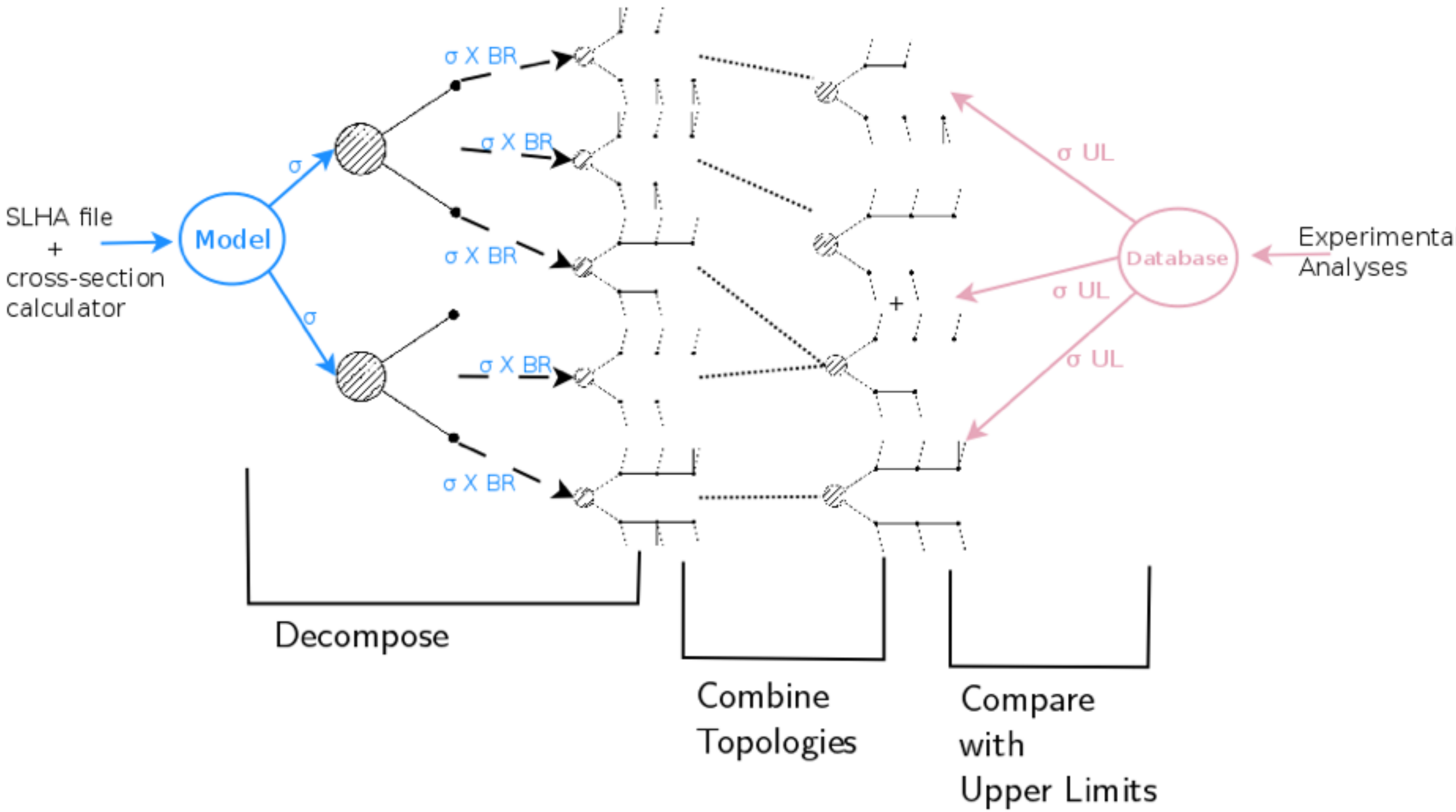
Barducci, Belyaev, Buchkremer, Cacciapaglia et al. (2014)

- SModelS

Constraining generic models with $\mathbb{Z}_2$ symmetry

Kraml, Kulkarni, UL, Lessa et al. (2013)

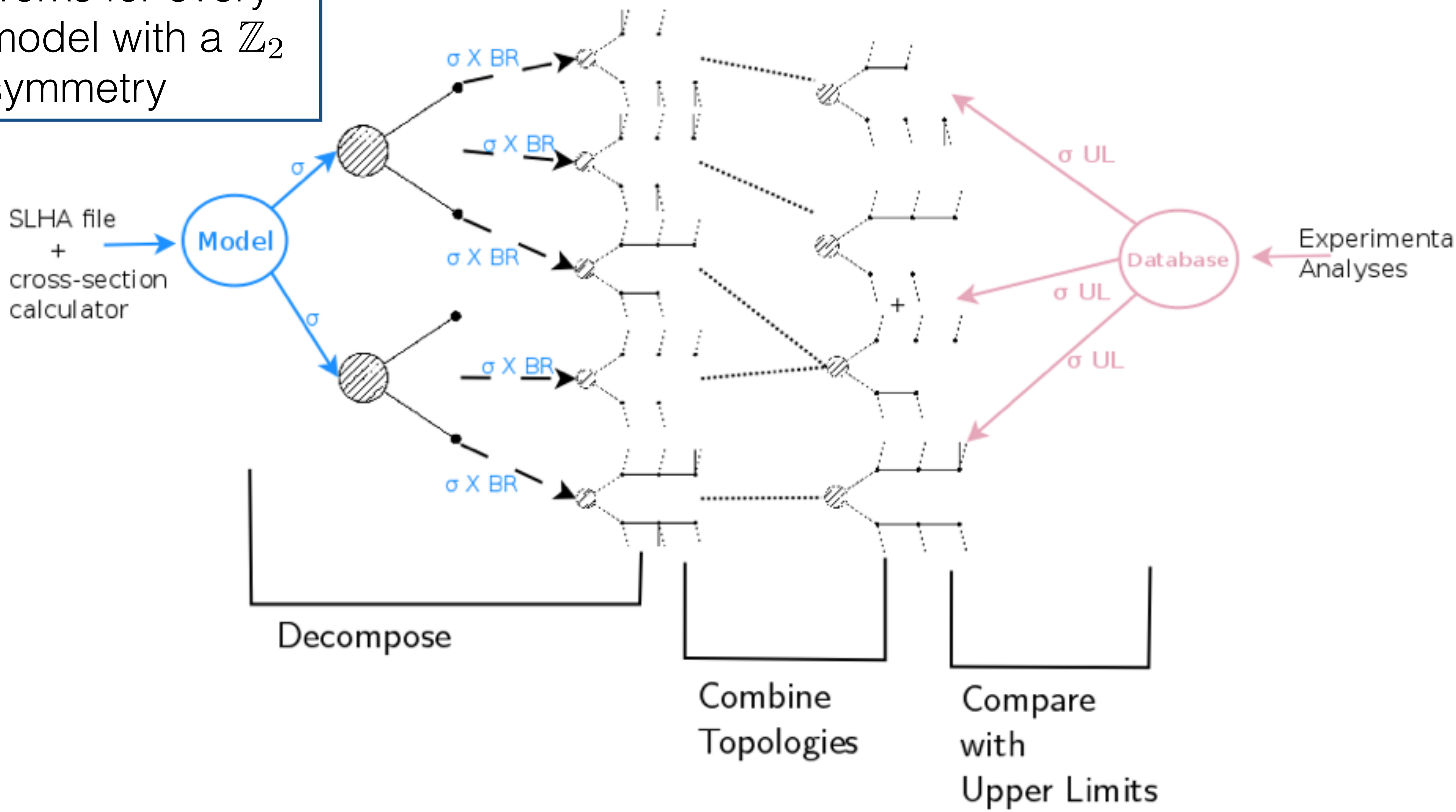
SModelS



SLHA file
+
cross-section
calculator
Model
σ
σ
σ X BR
σ X BR
σ X BR
σ X BR
σ X BR
+
σ UL
σ UL
σ UL
Database
Experimental
Analyses
Decompose
Combine
Topologies
Compare
with
Upper Limits

SModelS

works for every model with a $\mathbb{Z}_2$ symmetry



SModelS

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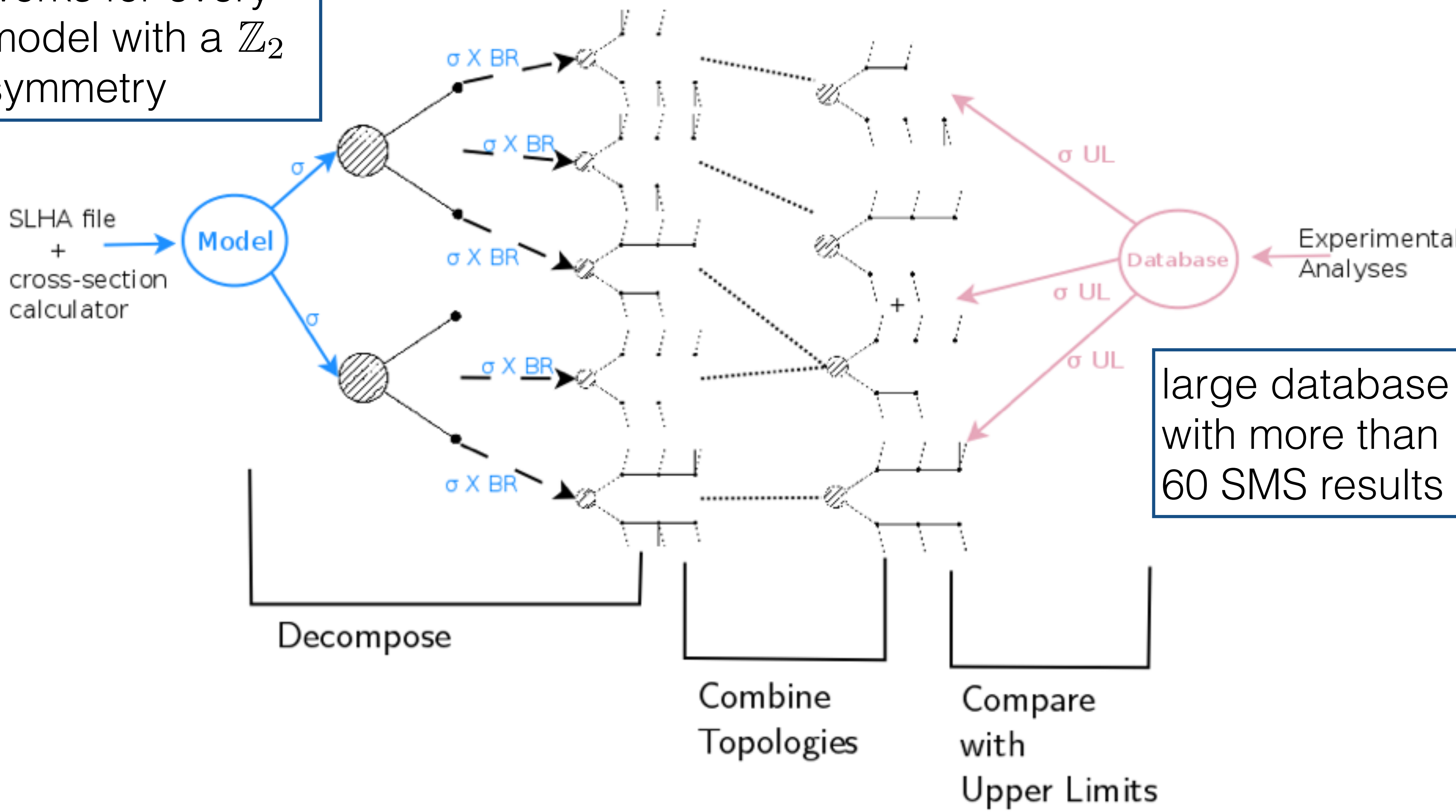

large database with more than 60 SMS results

SModelS

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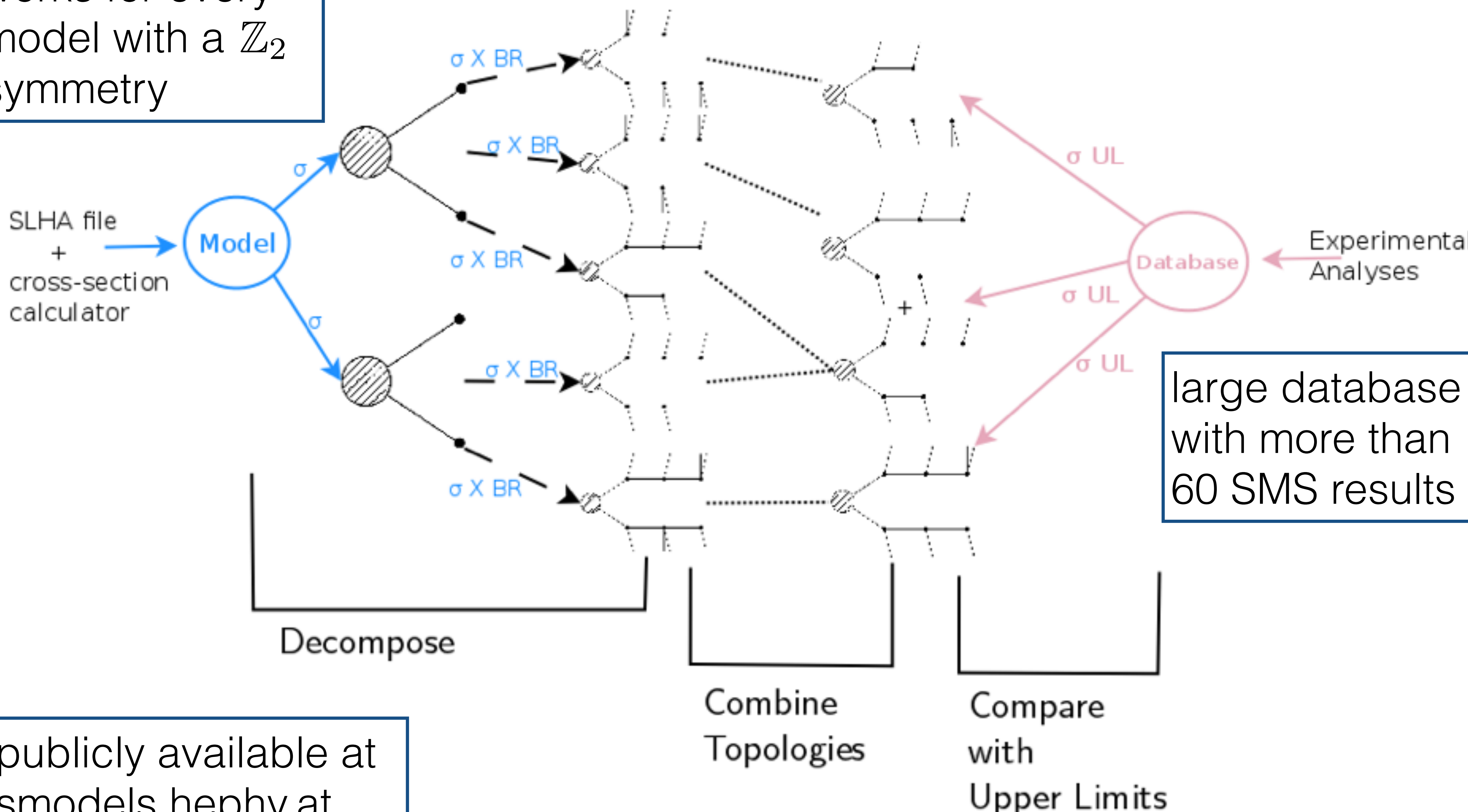

large database with more than 60 SMS results

publicly available at smodels.hephy.at

Advantages

- No need for event simulation → Fast !
- Fully automated decomposition into SMS components, matching to results in the database
- Works "out of the box" also for non-MSSM scenarios
- Large database, easy to add new results
- Identifies also "missing topologies"

Limitations

- Limited to short cascade decays
- Mostly covers symmetric decays (equal branches)
- Relies on assumption that signal efficiencies are largely determined by the mass structure, neglect dependencies on e.g.:
  - Production channel
  - Spin correlations
  - Off-shell states in the decays

for previous studies of these assumptions see e.g. arXiv:1410.0965, arXiv:1501.03942, arXiv:1503.02960

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Here: study effects of spin correlations for scenarios where dark matter couples via a top partner

Scalar versus Fermionic Top Partner Interpretation of tt+MET searches at the LHC

S. Kraml, UL, L. Panizzi, H. Prager (in preparation)

The SUSY scenario

Interaction details depends on both stop and neutralino mixing!

$$\mathcal{L}_{t\tilde{t}\tilde{\chi}^0} = g\,\bar{t}\,(f_{Lk}P_R + h_{Lk}P_L)\,\tilde{\chi}^0_k\,\tilde{t}_L + g\,\bar{t}\,(h_{Rk}P_R + f_{Rk}P_L)\,\tilde{\chi}^0_k\,\tilde{t}_R + \text{h.c.}$$
$$= g\,\bar{t}\,(a^{\tilde{t}}_{ik}P_R + b^{\tilde{t}}_{in}P_L)\,\tilde{\chi}^0_k\,\tilde{t}_i + \text{h.c.}$$

Write stop mixing as

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = R \begin{pmatrix} \tilde{t}_L \\ \tilde{t}_R \end{pmatrix}, \quad R = \begin{pmatrix} \cos\theta_{\tilde{t}} & \sin\theta_{\tilde{t}} \\ -\sin\theta_{\tilde{t}} & \cos\theta_{\tilde{t}} \end{pmatrix}$$

Then for Bino-like LSP (neglecting wino, higgsino components)

$$\mathcal{L}_{t\tilde{t}_1\tilde{\chi}^0_1} \approx -\frac{g}{3\sqrt{2}}\tan\theta_W N_{11}\,\bar{t}\,(\cos\theta_{\tilde{t}}\,P_R - 4\sin\theta_{\tilde{t}}\,P_L)\,\tilde{\chi}^0_1\,\tilde{t}_1 + \text{h.c.}$$

→ stop helicity reflected in top polarisation

see arXiv:1212.3526

The SUSY scenario

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neutralino mixing dependence

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➡ stop helicity reflected in top polarisation

see arXiv:1212.3526

The SUSY scenario

Interaction details depends on both stop and neutralino mixing!

$$\mathcal{L}_{t\tilde{t}\tilde{\chi}^0} = g\,\bar{t}\,(f_{Lk}P_R + h_{Lk}P_L)\,\tilde{\chi}^0_k\,\tilde{t}_L + g\,\bar{t}\,(h_{Rk}P_R + f_{Rk}P_L)\,\tilde{\chi}^0_k\,\tilde{t}_R + \text{h.c.}$$
$$= g\,\bar{t}\,(a^{\tilde{t}}_{ik}P_R + b^{\tilde{t}}_{in}P_L)\,\tilde{\chi}^0_k\,\tilde{t}_i + \text{h.c.}$$

neutralino mixing dependence

+ stop mixing dependence

Write stop mixing as

$$\begin{pmatrix}\tilde{t}_1\\ \tilde{t}_2\end{pmatrix} = R\begin{pmatrix}\tilde{t}_L\\ \tilde{t}_R\end{pmatrix}, \quad R = \begin{pmatrix}\cos\theta_{\tilde{t}} & \sin\theta_{\tilde{t}}\\ -\sin\theta_{\tilde{t}} & \cos\theta_{\tilde{t}}\end{pmatrix}$$

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$$\mathcal{L}_{t\tilde{t}_1\tilde{\chi}^0_1} \approx -\frac{g}{3\sqrt{2}}\tan\theta_W N_{11}\,\bar{t}\,(\cos\theta_{\tilde{t}}\,P_R - 4\sin\theta_{\tilde{t}}\,P_L)\,\tilde{\chi}^0_1\,\tilde{t}_1 + \text{h.c.}$$

→ stop helicity reflected in top polarisation

see arXiv:1212.3526

The extra quark scenario

Consider extra heavy quark (XQ) that is odd under new $\mathbb{Z}_2$ symmetry, mediating interactions between 3rd generation quarks and DM

Dark matter singlet coupling to XQ singlet or doublet $\Psi_{1/6} = \binom{T}{B}$

$$\mathcal{L}_1^S = \left[\lambda_{11}^t \bar{T} P_R t + \lambda_{11}^b \bar{B} P_R b + \lambda_{21} \overline{\Psi}_{1/6} P_L \begin{pmatrix} t \\ b \end{pmatrix}\right] S_{\rm DM}^0 + \text{h.c.}$$

scalar dark matter

$$\mathcal{L}_1^V = \left[g_{11}^t \bar{T} \gamma_\mu P_R t + g_{11}^b \bar{B} \gamma_\mu P_R b + g_{21} \overline{\Psi}_{1/6} \gamma_\mu P_L \begin{pmatrix} t \\ b \end{pmatrix}\right] V_{\rm DM}^{0\mu} + \text{h.c.}$$

vector dark matter

- Vector-like XQ: couplings either purely left or purely right
- Chiral XQ: can couple to both left and right SM quarks

For direct comparison, here we consider the chiral XQ scenario

Setup

- Select 4 benchmarks to cover different polarisations and mass gaps

BP	m_T	m_{DM}	top polarisation
(600,10)L	600 GeV	10 GeV	left-handed
(600,10)R	600 GeV	10 GeV	right-handed
(600,300)L	600 GeV	300 GeV	left-handed
(600,300)R	600 GeV	300 GeV	right-handed

- For each benchmark consider 3 scenarios with equivalent left/right couplings
  - Stop production, Bino LSP (SUSY)
  - Heavy top production, scalar dark matter (XQ SDM)
  - Heavy top production, vector dark matter (XQ VDM)
- In addition: scan in mass vs mass plane to obtain 2D exclusion in each scenario

LHC Searches

- Consider LHC searches at 8 TeV, in $t\bar{t}$+MET final states
- Interpretation:

$$pp \to \tilde{t}_1 \tilde{t}_1^* \to t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$$

Searches can be classified by final state

- Fully hadronic final state
  - ATLAS-CONF-2013-024 (implemented in CheckMATE)
- Single lepton final state
  - ATLAS-SUSY-2013-15 (implemented in CheckMATE)
  - CMS-SUS-13-011 (implemented in MA5)
- Dilepton final state
  - ATLAS-SUSY-2013-19 (implemented in CheckMATE)

Finally consider also effects in generic jets+MET search

- ATLAS-SUSY-2013-02 (implemented in MA5)

Technical Setup

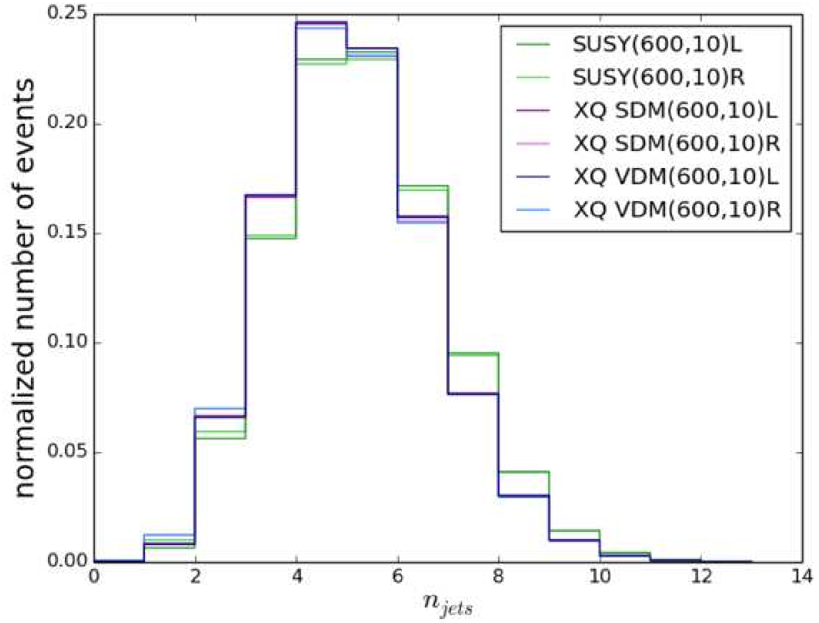
- XQ simplified model implemented in Feynrules
- Use default MSSM implementation for SUSY scenario
- Simulate 200k events in MG (at LO) for

$$pp \to t\,\bar{t}\ \mathrm{DM\ DM} \to (W^+b)(W^-\bar{b})\ \mathrm{DM\ DM}$$

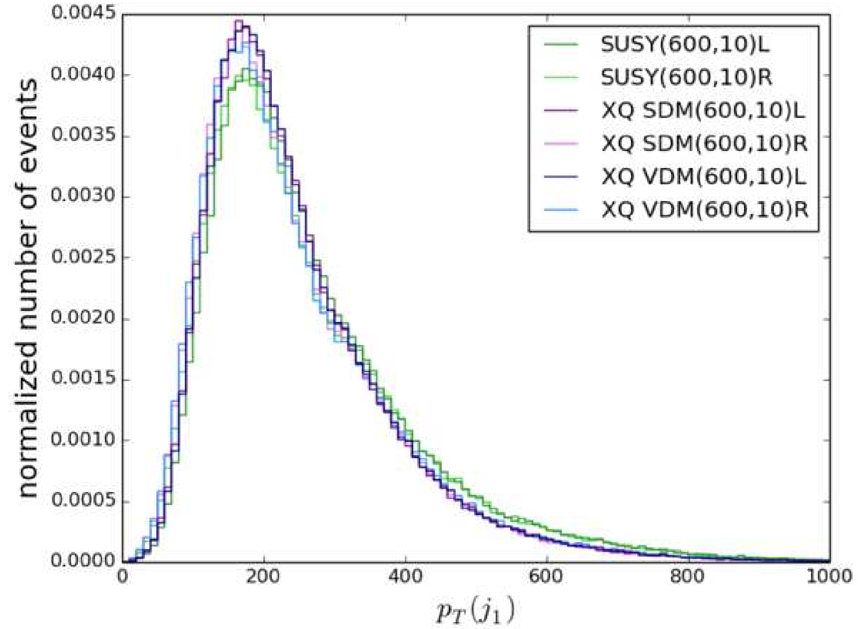
- W decay + showering performed in Pythia6
- Detector simulation using Delphes3
- Efficiencies for ATLAS and CMS analysis implementations in CheckMATE and MadAnalysis5
- Stop production cross sections are calculated at NLO+NLL, XQ cross sections at NLO+NNLL

Generator Level Distributions

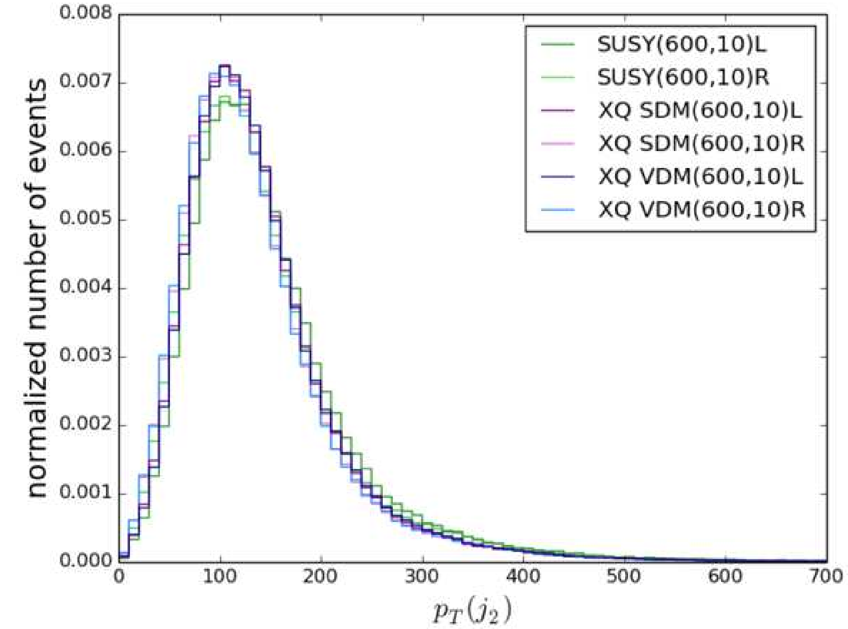
n_{jets}

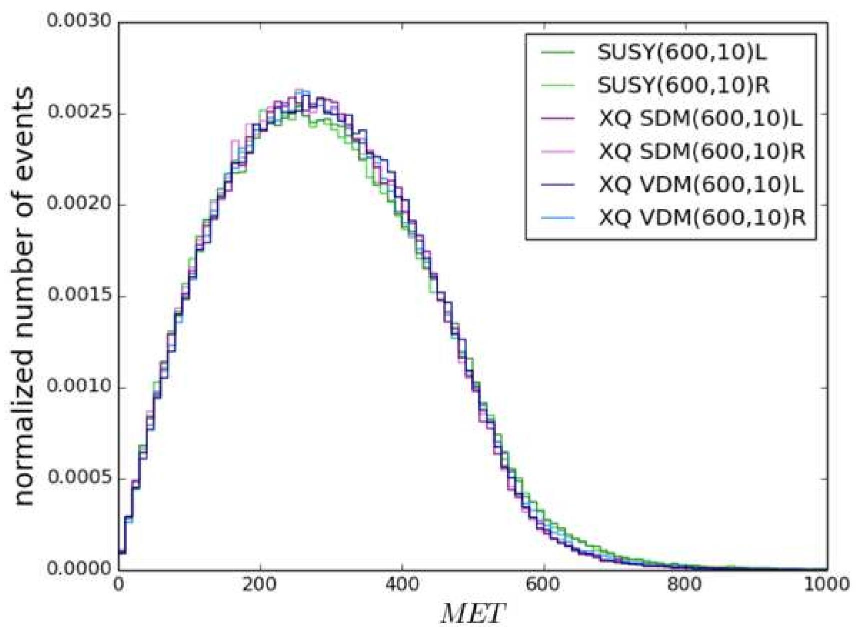


$p_T(j_1)$

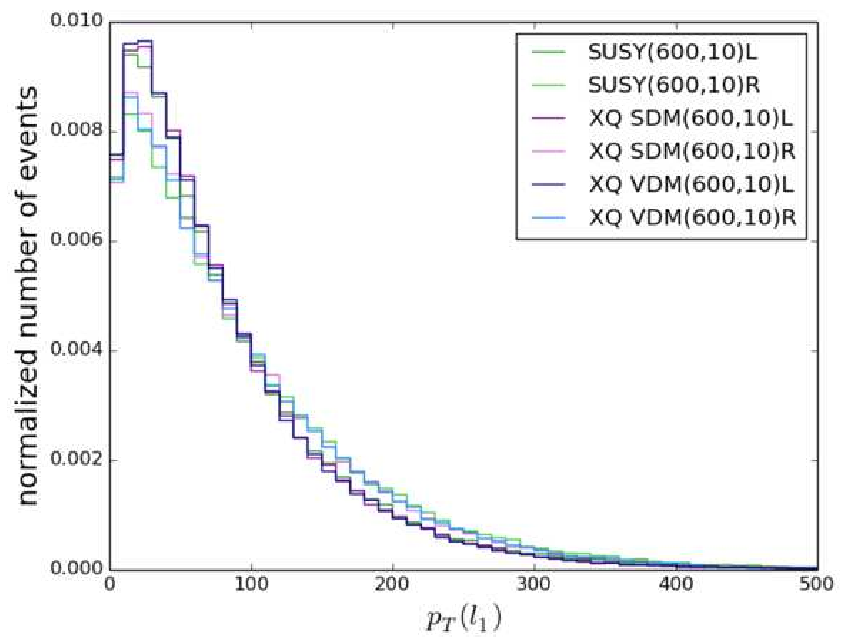


$p_T(j_2)$

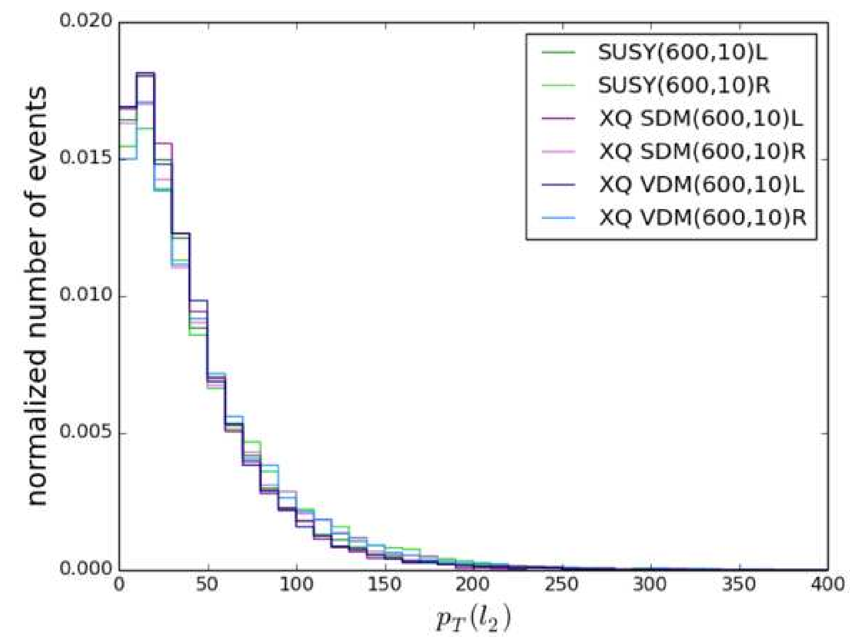




MET



$p_T(l_1)$



$p_T(l_2)$

Generator Level Distributions

- Shapes very similar
- MET, jet p_T slightly harder in SUSY scenarios
- Lepton p_T slightly harder in XQ scenarios
- Helicity dependence can be largest difference, e.g. for lepton p_T
- Somewhat higher jet activity in SUSY scenarios
- Similar picture for benchmarks with small mass gap (600,300)

→ Expect similar efficiencies for all scenarios

Results Fully Hadronic Final State

ATLAS-CONF-2013-024, implemented in CheckMATE

most sensitive SR

Signal selection efficiency

CLs exclusion value

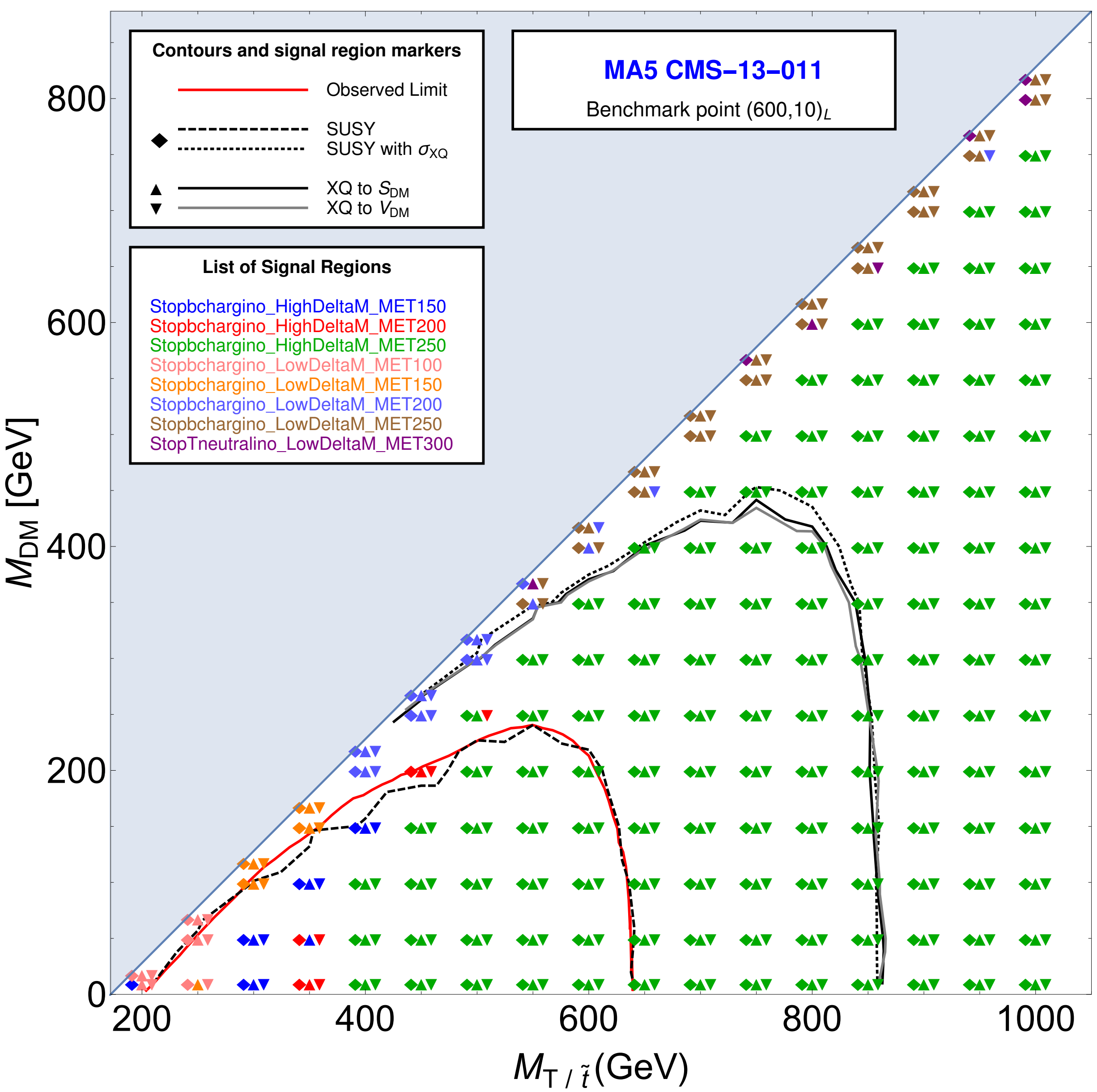
Cross section and mass limits

	Point (600, 10)L			Point (600, 10)R		
	SUSY	XQ-SDM	XQ-VDM	SUSY	XQ-SDM	XQ-VDM
eff. SR1	0.015	0.015	0.016	0.014	0.015	0.014
eff. SR2	0.012	0.012	0.012	0.011	0.012	0.011
eff. SR3*	0.0097	0.0096	0.010	0.0092	0.0095	0.0094
excl. XS [pb]	0.0196	0.0199	0.0189	0.0209	0.0201	0.0205
mass limit/SUSY XS	619	618	622	613	617	615
mass limit/XQ XS	805	803	808	798	802	800
CLs	0.98	1	1	0.97	1	1

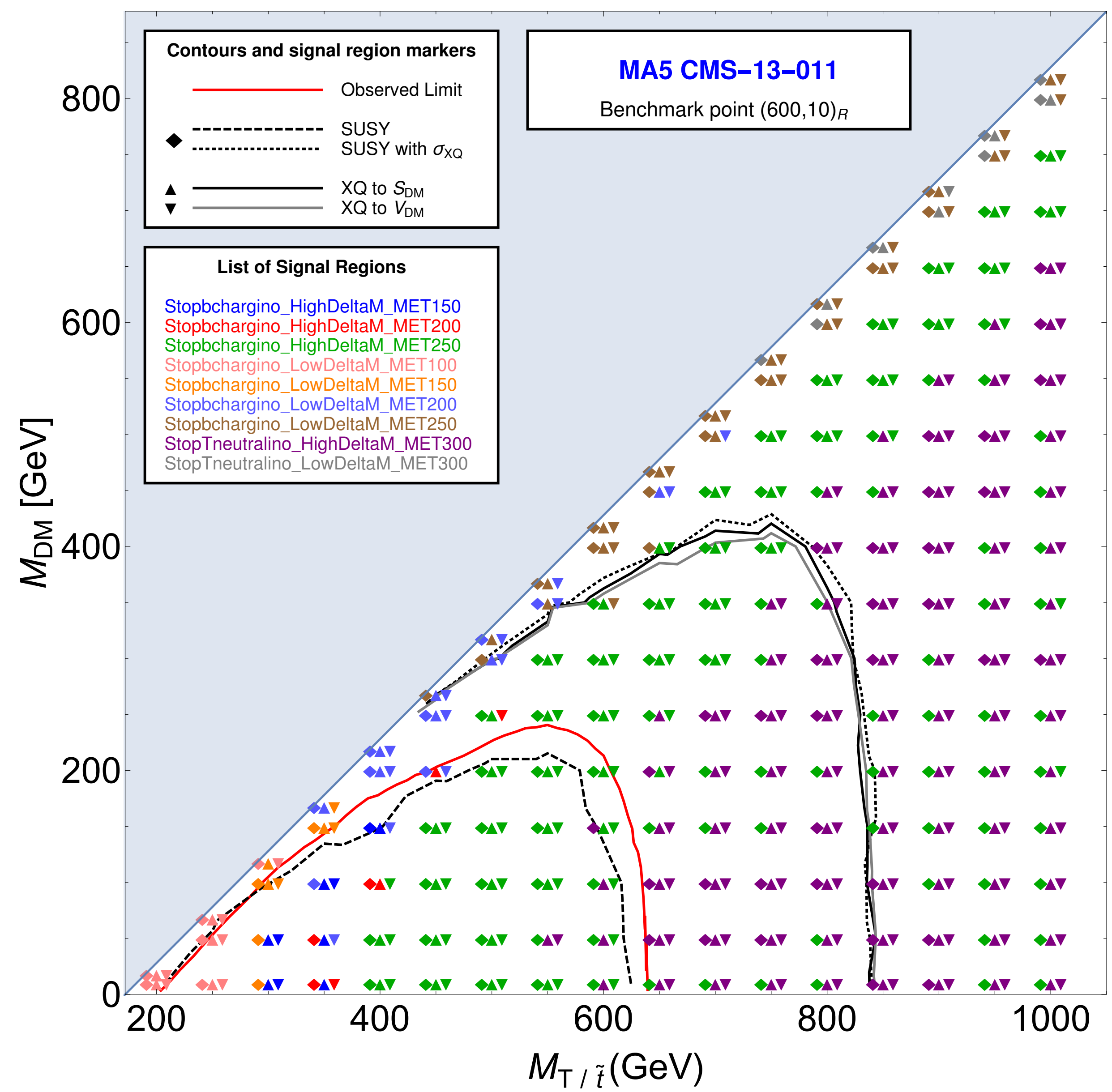
	Point (600, 300)L			Point (600, 300)R		
	SUSY	XQ-SDM	XQ-VDM	SUSY	XQ-SDM	XQ-VDM
eff. SR1*	0.0074	0.0064	0.0062	0.0066	0.0060	0.0053
eff. SR2	0.0039	0.0032	0.0031	0.0035	0.0032	0.0026
eff. SR3	0.0022	0.0016	0.0017	0.0018	0.0016	0.0013
excl. XS [pb]	0.0647	0.0759	0.0772	0.0726	0.0805	0.0910
mass limit/SUSY XS	522	510	509	514	506	497
mass limit/XQ XS	687	671	670	676	666	655
CLs	0.59	1	1	0.54	1	1

Exclusion in the Mass Plane

left-handed couplings



right-handed couplings

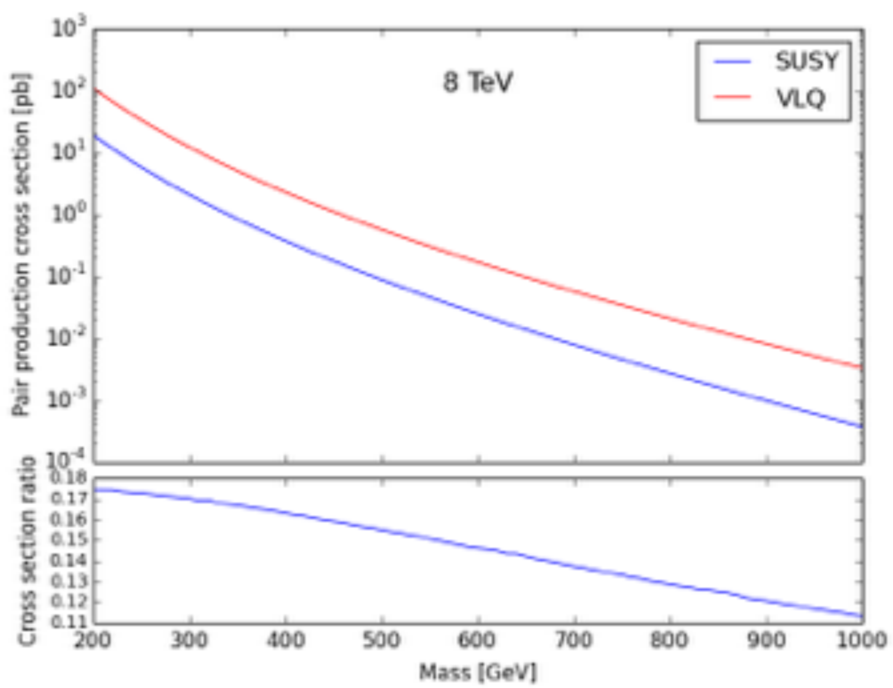


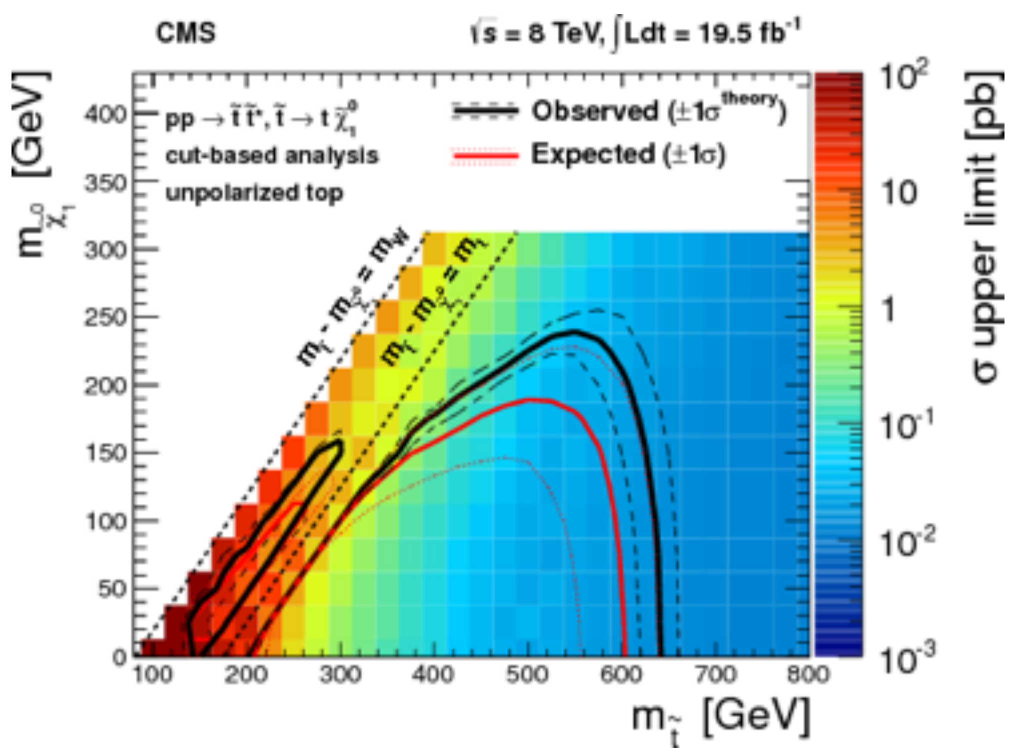
Good agreement between exclusion of XQ with scalar or vector dark matter and when rescaling SUSY efficiencies with XQ cross sections

Conclusions

- Kinematic distributions, efficiencies and exclusions are similar in all 3 scenarios → SUSY SMS cross section limits can be used to constrain XQ scenarios (when narrow width approximation holds)
- Higher production cross section for XQs → useful to consider larger mass range in interpretation
- Correlate observed number of events and effective mass scale to distinguish origin of possible signal

for detailed study see arXiv:1207.4794





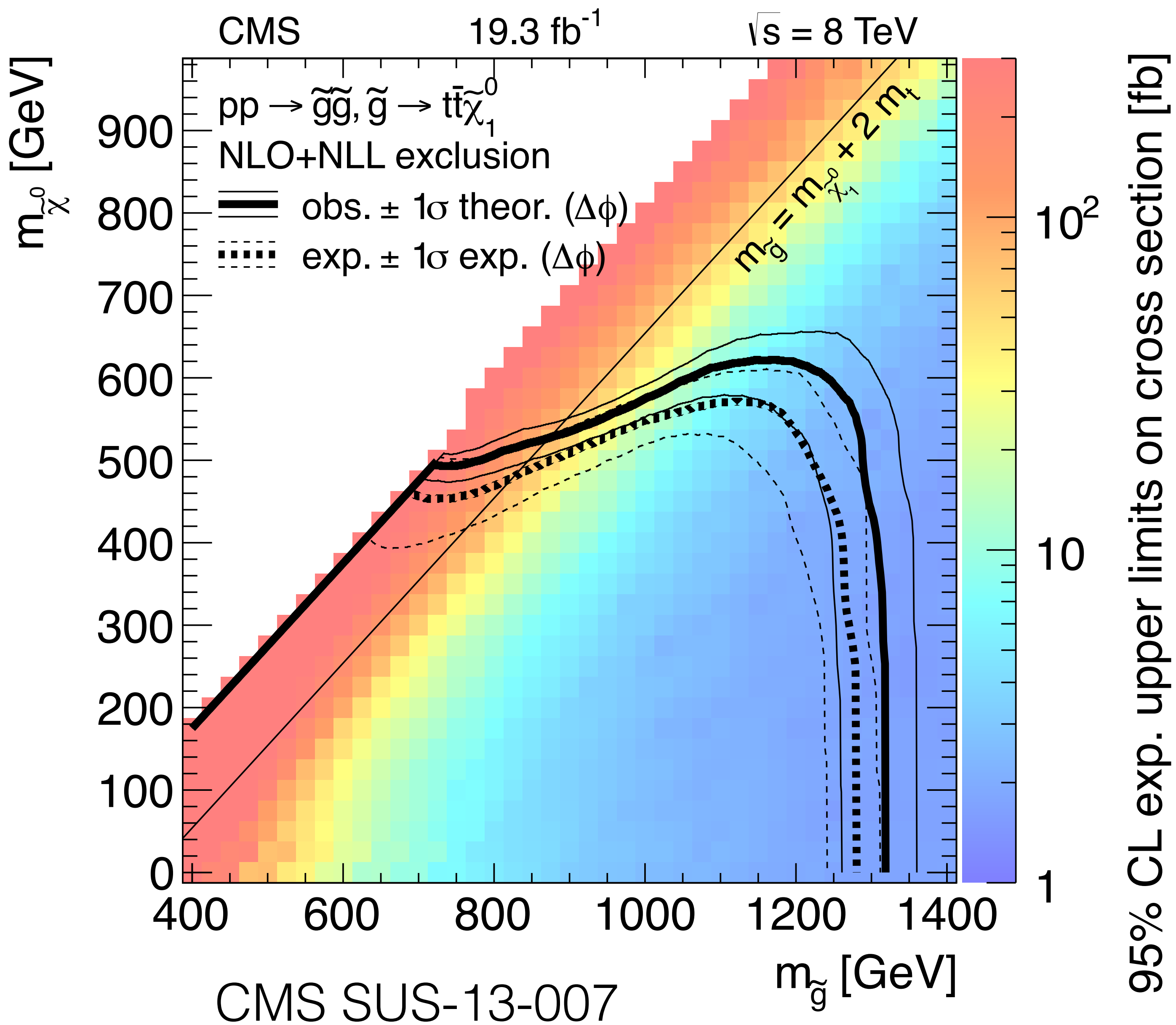
Outlook — SModelS v1.1

- Use of efficiency maps in addition to upper limit maps → stronger constraints when topologies contributing to the same signal region can be combined
- Implementation of first 13 TeV results in the SModelS database
- Addition of “homegrown” efficiency maps, obtained using CheckMATE or MadAnalysis5 → can improve coverage by adding efficiency maps for additional topologies
- Release envisaged (end of) this summer

sign up for updates on smodels.hephy.at

Backup

Using Simplified Model results to constrain generic models



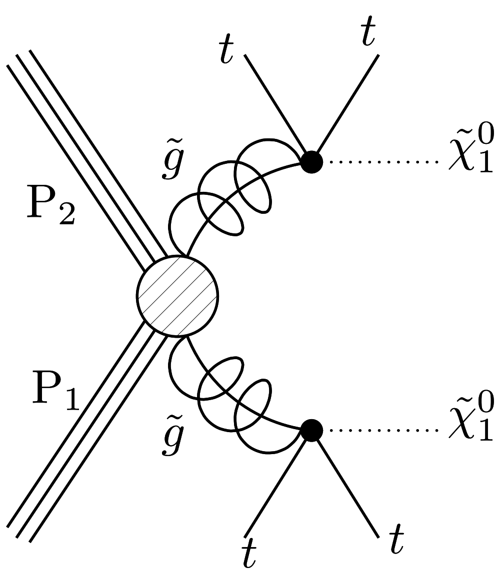
To test realistic models, use upper limits on $\sigma \times \mathcal{BR}$ (exclusion line only valid in the simplified model)

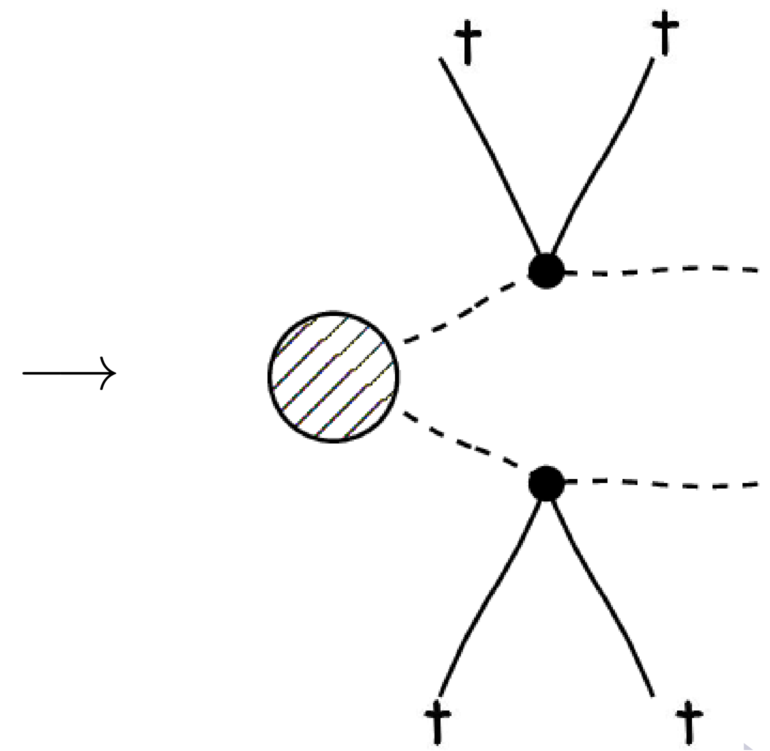
Assumption: upper limits on $\sigma \times \mathcal{BR}$ are mainly a function of the masses of the new particles

→ other quantum numbers may be neglected in first approximation

SModelS Topology Description

Describe topology by vertex structure and outgoing SM particles in each vertex



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[[[t,t]],[[t,t]]]
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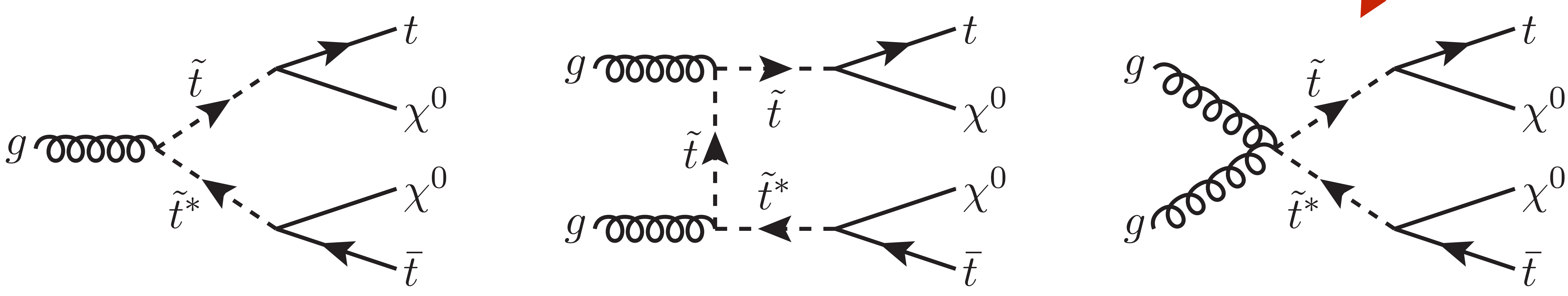
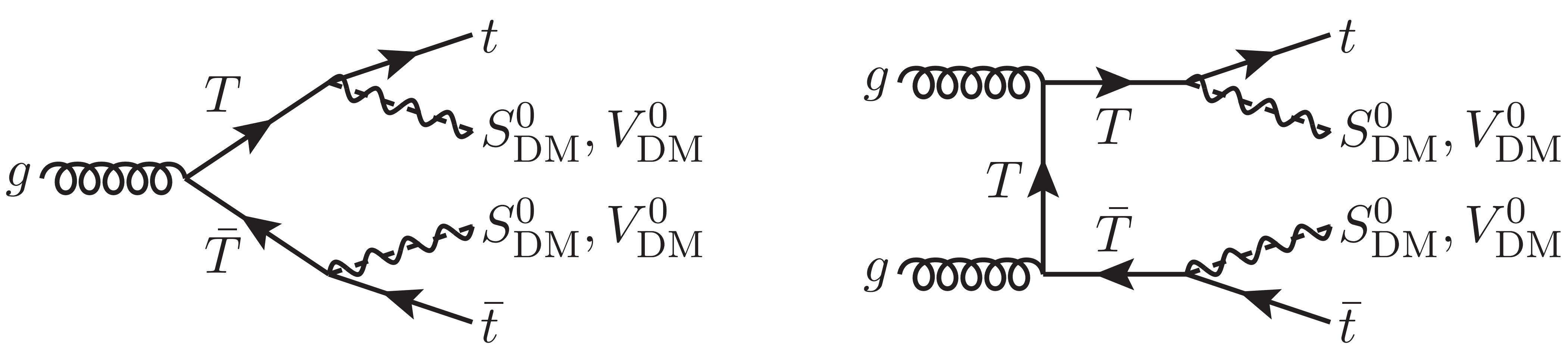
Discard detailed information about the BSM states, only their masses are considered when evaluating constraints

Considered Diagrams

no XQ equivalent !

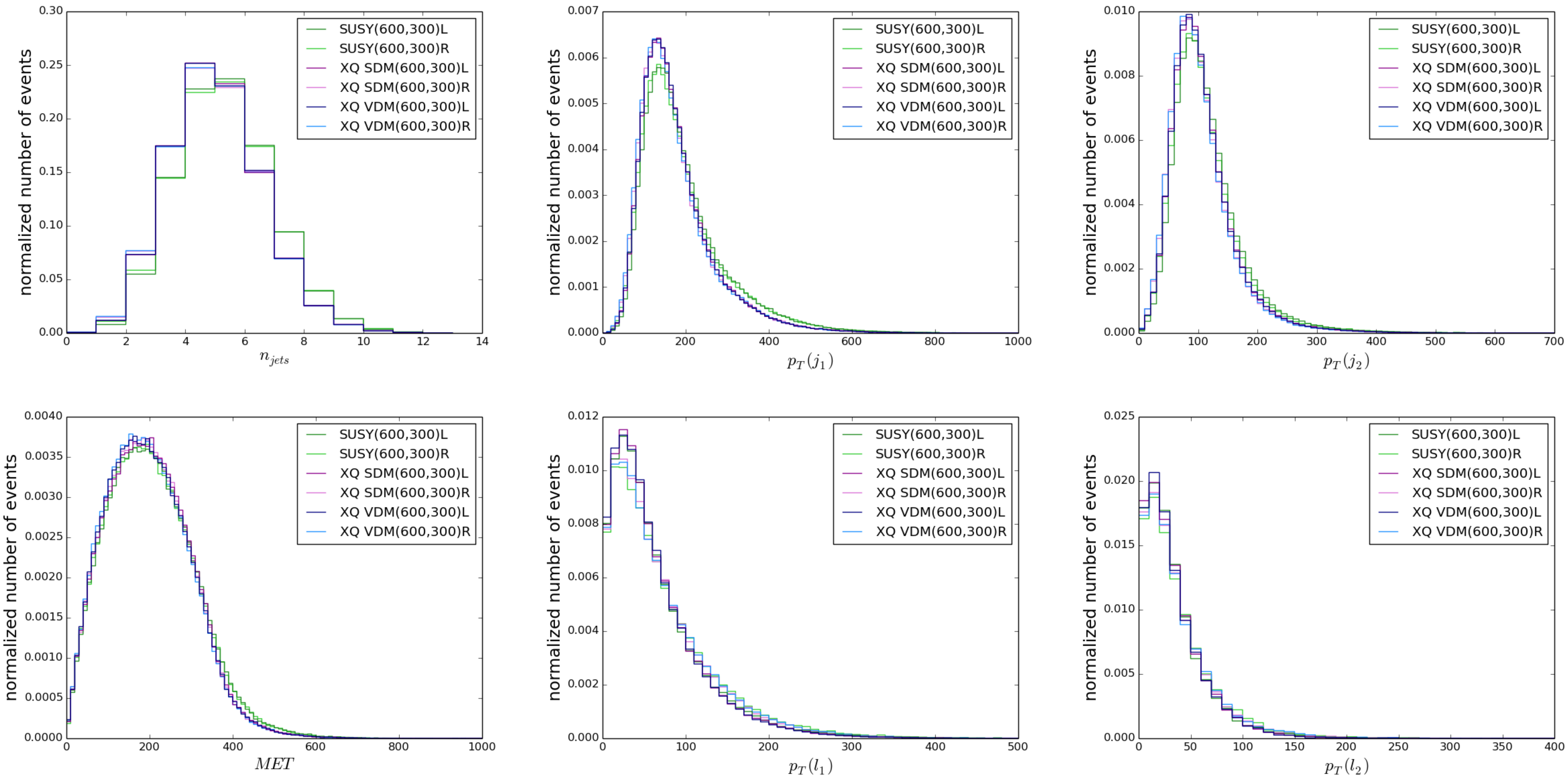
Stop pair production





Heavy top pair production

Generator Level Distributions



Cutflow Example (600,10)L

ATLAS-CONF-2013-024

	SUSY	XQ-SDM	XQ-VDM
Initial no. of events	200000	200000	200000
$E_T^{\rm miss} > 80$ GeV (Trigger)	187834 (-6.08 %)	187872 (-6.06 %)	188358 (-5.82 %)
muon veto ($p_T > 10$ GeV)	154643 (-17.67 %)	153946 (-18.06 %)	154710 (-17.86 %)
electron veto ($p_T > 10$ GeV)	123420 (-20.19 %)	122439 (-20.47 %)	123247 (-20.34 %)
$E_T^{\rm miss} > 130$ GeV	113638 (-7.93 %)	112808 (-7.87 %)	113620 (-7.81 %)
≥ 6 jets, $p_T > 80, 80, 35$ GeV	33044 (-70.92 %)	27987 (-75.19 %)	28285 (-75.11 %)
reconstr. $E_T^{\rm miss,track} > 30$ GeV	32564 (-1.45 %)	27563 (-1.51 %)	27901 (-1.36 %)
$\Delta\phi(E_T^{\rm miss}, E_T^{\rm miss,track}) < \pi/3$	31200 (-4.19 %)	26583 (-3.56 %)	26939 (-3.45 %)
$\Delta\phi(E_T^{\rm miss}$, 3 hdst jets) $> 0.2\pi$	26276 (-15.78 %)	22795 (-14.25 %)	23129 (-14.14 %)
tau veto	22880 (-12.92 %)	19967 (-12.41 %)	20354 (-12.00 %)
2 b jets	9668 (-57.74 %)	8510 (-57.38 %)	8660 (-57.45 %)
$m_T(b\,\text{jets}) > 175$ GeV	7202 (-25.51 %)	6447 (-24.24 %)	6579 (-24.03 %)
3 closest jets 80–270 GeV	6437 (-10.62 %)	5877 (-8.84 %)	5929 (-9.88 %)
same for second closest jets	3272 (-49.17 %)	3186 (-45.79 %)	3351 (-43.48 %)
SR1: $E_T^{\rm miss} \geq 200$ GeV	3230 (-1.28 %)	3156 (-0.94 %)	3312 (-1.16 %)
SR2: $E_T^{\rm miss} \geq 300$ GeV	3067 (-5.05 %)	3000 (-4.94 %)	3161 (-4.56 %)
SR3: $E_T^{\rm miss} \geq 350$ GeV	2795 (-8.87 %)	2732 (-8.93 %)	2867 (-9.30 %)

Results Single Lepton Final State

CMS-SUS-13-011 (cut-based), implemented in MA5

most sensitive SR

Signal selection efficiency

CLs exclusion value

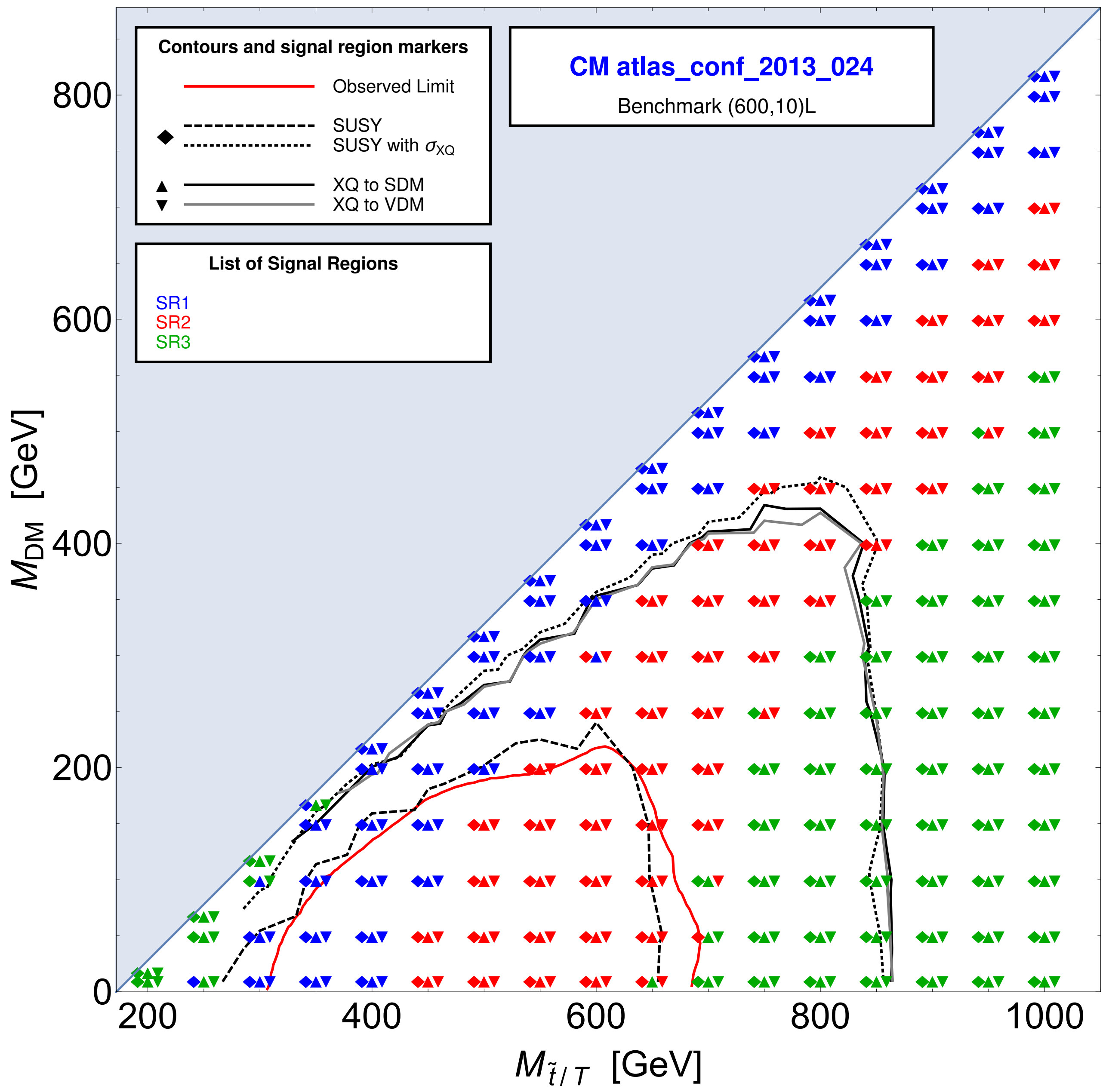
Cross section and mass limits

	Point (600, 10)L			Point (600, 10)R		
	SUSY	XQ-SDM	XQ-VDM	SUSY	XQ-SDM	XQ-VDM
eff. SR-A	0.0108	0.0109	0.0111	0.0108	0.0106	0.0107
eff. SR-B	0.0181	0.0176	0.0184	0.0154	0.0152	0.0153
excl. XS [pb]	0.0169	0.0173	0.0166	0.0210	0.0213	0.0211
mass limit/SUSY XS	631	629	633	613	611	612
mass limit/XQ XS	820	818	822	798	796	797
CLs	0.99	1	1	0.97	1	1

	Point (600, 300)L			Point (600, 300)R		
	SUSY	XQ-SDM	XQ-VDM	SUSY	XQ-SDM	XQ-VDM
eff. SR-A	0.00360	0.00366	0.00346	0.00340	0.00321	0.00315
eff. SR-B	0.00748	0.00685	0.00632	0.00597	0.00570	0.00536
excl. XS [pb]	0.0399	0.0448	0.0480	0.0507	0.0530	0.0563
mass limit/SUSY XS	560	551	546	541	538	533
mass limit/XQ XS	733	722	715	710	706	700
CLs	0.81	1	1	0.72	1	1

Exclusion in the Mass Plane

left-handed couplings



right-handed couplings