Simplified models

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"Inverse map", N. Arkani-Hamed et al. 0512.190

Simplified models for new Physics:
- "4 models", J. Alwall et al. 0810.3921
- "List of models", LHC New physics WG 1105.2838

Simplified models for dark matter:
- "List of models", DM@LHC 1506.0311
- "Review", A. De Simone, T. Jacques 1603.08002

What is a simplified model?

A simplified model is a model with only few new particles and interactions.

It can either be specified through a (renormalizable) Lagrangian with the new particles masses and the couplings as free parameters,

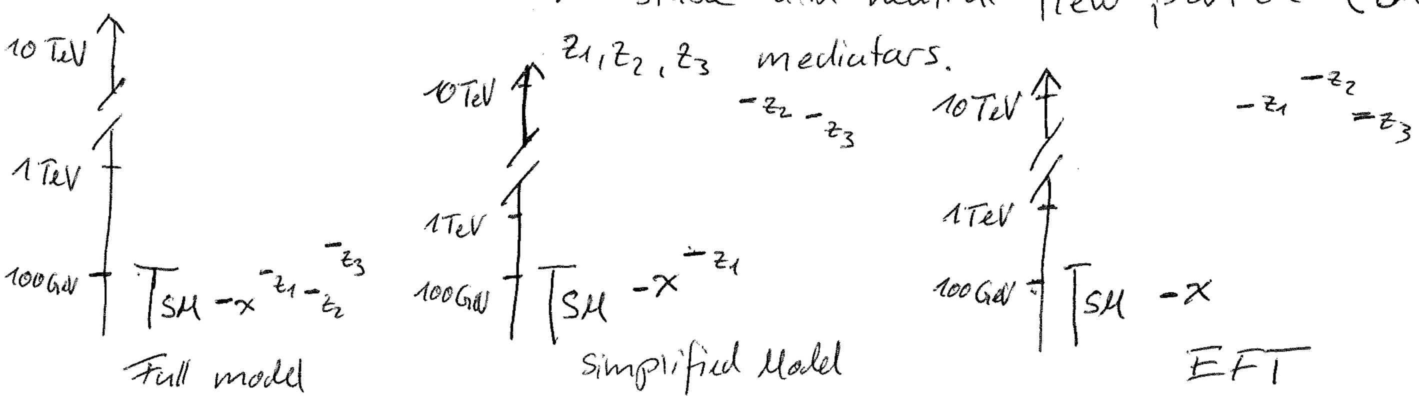
or by treating the particles masses (and widths) and production crossection and branching ratios as free parameters.

Motivation and justification

Very basic example:

Dark sector with: χ stable and neutral new particle (DM candidate)

z_1, z_2, z_3 mediators.



Three main domains (scenarios) of interest:

① Before LHC Run (-II)

- Provide theoretical basis for a classification and identification of different signatures.

We don't want to miss interesting physics at LHC.

⇒ Long lists of simplified models and their topologies (ArXiv: 1105.2838 / 1506.0311 / 1603.08002)

- Assess search sensitivities:

for example: How do reconstruction and selection efficiencies depend on the mass difference between particles?

② Setting limits:

Identify regions in parameter space consistent with data.
Can be translated to limits on a full model.
If limits are provided by experimental collaboration they are independant of detector effects.

③ Discovery:

Fit of simplified models to data is computationally possible.

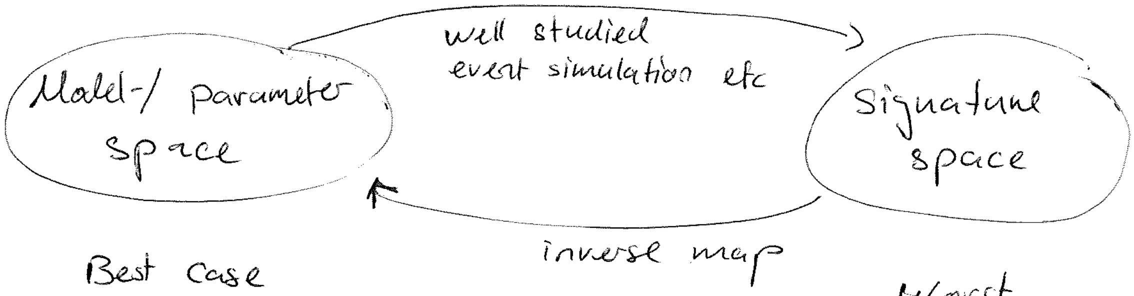
Narrow down paramete space for full models

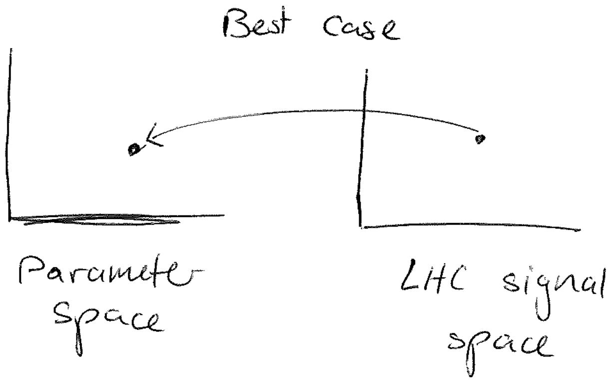
⇒ Identify degeneracies.

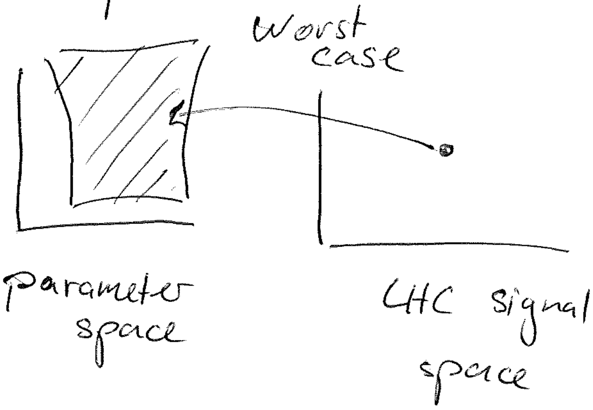
⇒ develop search strategies to lift degeneracies.

Inverse Map problem

(Nima et al. 0512.190)







15 free parameters in MSSM (14 soft masses & $\tan\beta$)

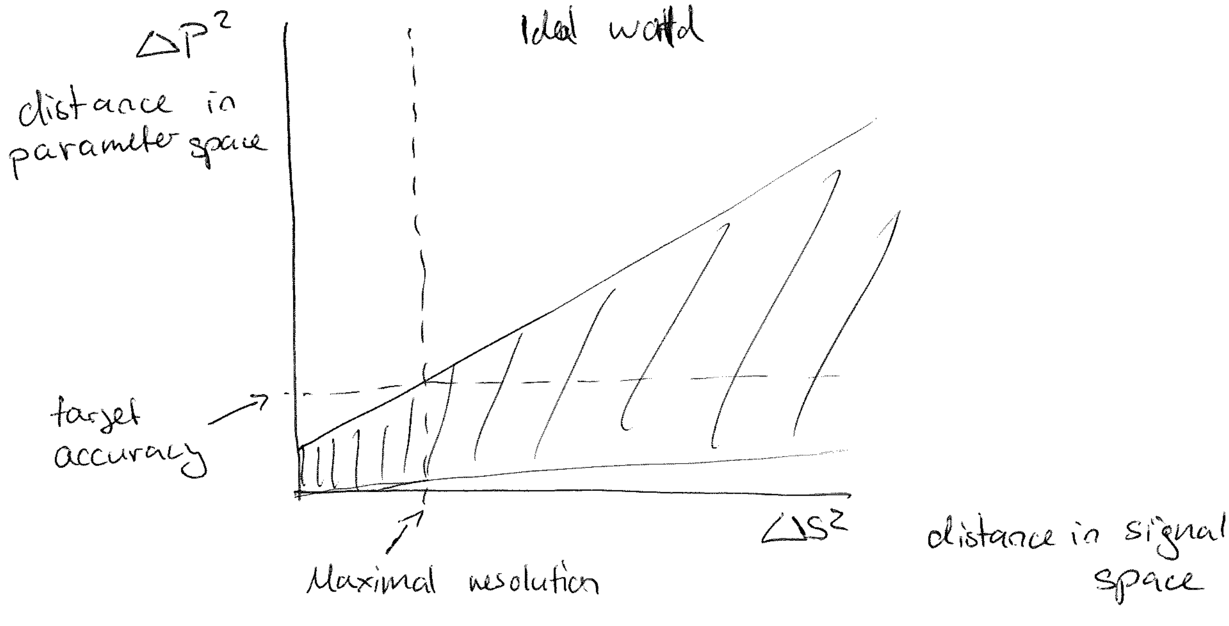
Scan all models ⇒ $\sim O(10^{15})$ models to simulate ↯

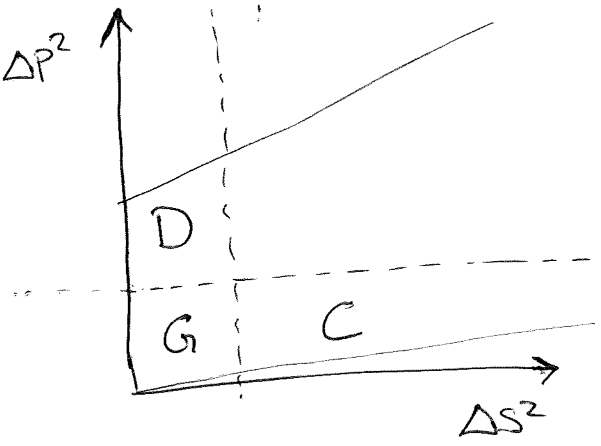
⇒ Simulated 43 026 random MSSMs.

Compared 1808 different signatures

- jet counts
- lepton counts
- invariant mass distribution (decile method)
- etc.

naively: 15 D parameter space maped to 1808 D signal space ⇒ map should be 1 to 1





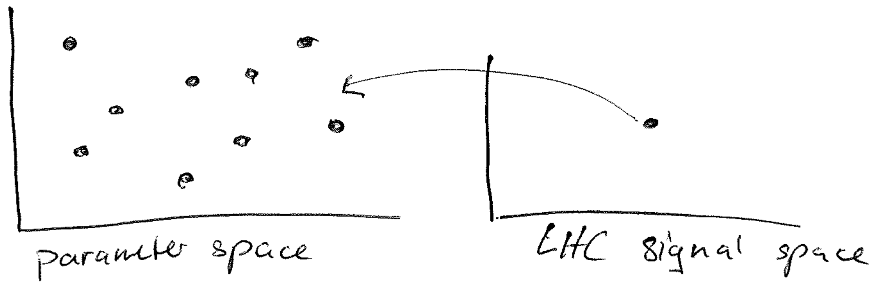
Degenerate pairs
Good pairs
Cliffs

$\langle \text{degeneracies} \rangle = \langle d \rangle = \frac{G+D}{G}$ "close in signal space but far in parameter space"

$\langle \text{cliffs} \rangle = \langle c \rangle = \frac{G+C}{G}$ "close in parameter space but far in signal space"

$\langle d \rangle \sim O(10-100)$

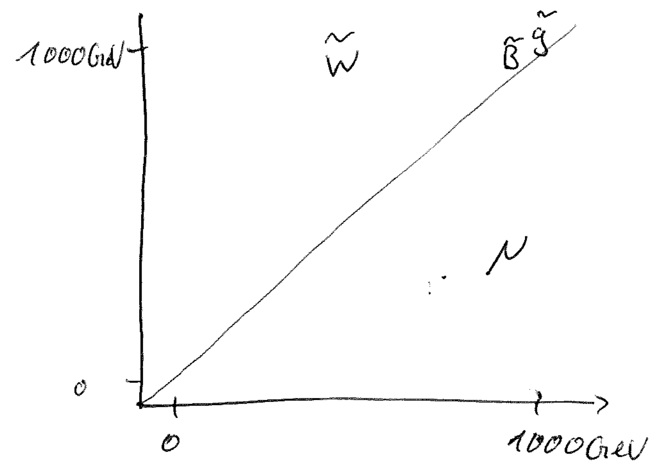
$\langle c \rangle \sim O(10^3-10^4)$ → 1 bin in parameter space maps to multiple bins in signature space



⇒ 1 point in signature space corresponds to O(10–100) small "islands" in parameter space.

⇒ many signatures are correlated.
estimate effective number of signal dimensions
$\sim O(5-14)$

Example
Of a degeneracy



SUSY inspired simplified models

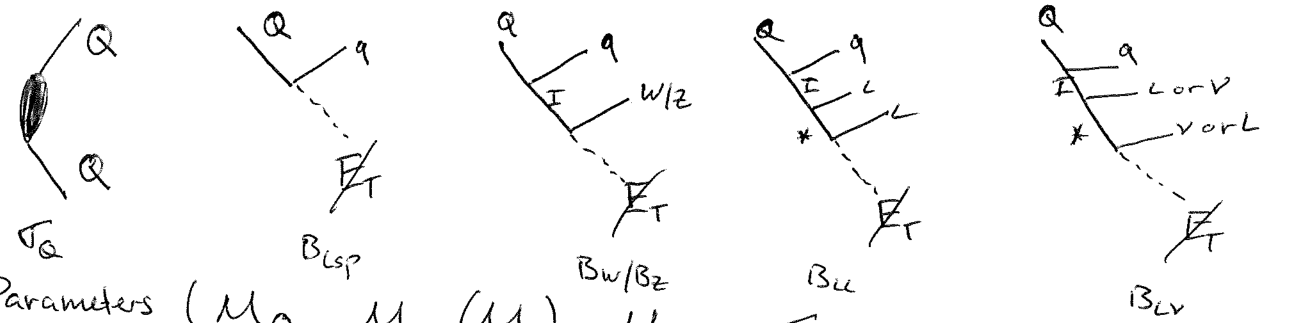
(0810.3921)
(1105.2838)

Many susy models present long decay chains.

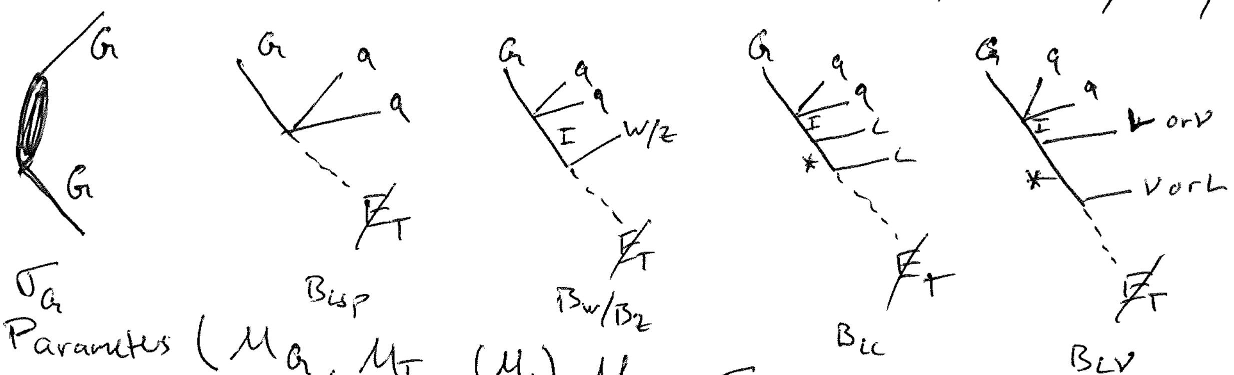
LHC will mainly produce squarks and gluinos due to QCD couplings.

Assumption: Only squark ~~and~~ or gluino pair production.

⇒ 2 simplified models for decay chains.



Parameters $(M_Q, M_I, (M_L), M_{LSP}, \sigma_Q, B_{LSP}, B_W/B_Z, B_{LL}, B_{L\nu})$



Parameters $(M_G, M_I, (M_L), M_{LSP}, \sigma_G, B_{LSP}, B_W/B_Z, B_{LL}, B_{L\nu})$

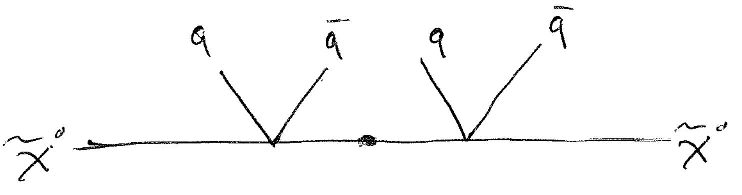
Domination by squark pair production (2 hard partons) or gluino pair production (4 hard parton)
(if tendency for 3 hard partons, should consider associate production)

What SU(2) modes are present?
- L^+L^- invariant mass (Z-pole, slepton on- or off-shell)
- $L\nu$ and W hard to distinguish
  ⇒ degeneracy.

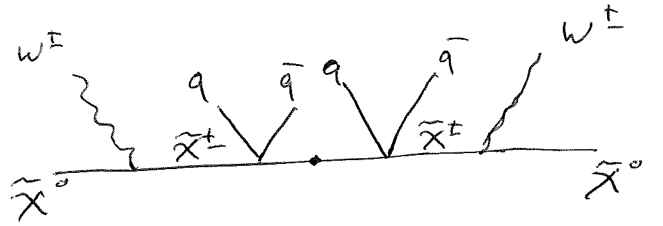
Combining topologies

many parameters left in simplified model for Gluino pair production and decay.

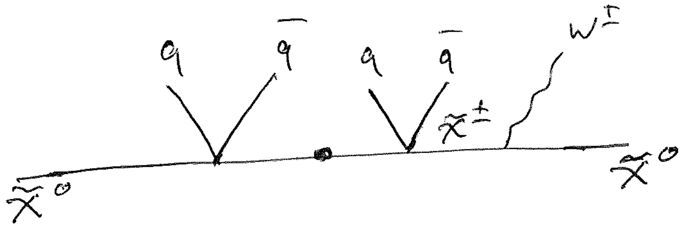
⇒ set all but one branching ratios to zero. Study an even more limited simplified model!



Model A A



Model B B



Model A B

$$\sigma_{max} = \frac{N_{max}}{B_A^2 \epsilon_{AA} + 2 B_A B_B \epsilon_{AB} + B_B^2 \epsilon_{BB}}$$

N_{max} = max # of events in signal region

B = branching ratio

ϵ = efficiency for model to populate SR

If ϵ_{AB} not known: $0 \leq \epsilon_{AB} \leq 1$ gives conservative bound

If model A and B have similar signatures in signal region:

$$\min(\epsilon_{AA}, \epsilon_{BB}) \lesssim \epsilon_{AB} \lesssim \max(\epsilon_{AA}, \epsilon_{BB})$$

However in a 1 lepton search $\epsilon_{AB} \gg \epsilon_{AA}, \epsilon_{BB}$

⇒ care is needed but some robust bounds can be extracted.

Example of simplified model for DM

(1506.03111)
(1603.08002)

Requirements
1) simple enough
2) complete enough
} SM + 1 stable DM + 1 mediator

3) not already ruled out

$\mathcal{L}$ should respect exact and approximate global symmetries of the SM.

Intermezzo: Minimal flavour Violation (MFV)

Severe constraints on FCNCs exist.
can be avoided by MFV.

Any new physics interaction should either be invariant under the SM flavour group $G = U(3)_q \times U(3)_u \times U(3)_d$
or the breaking should be associated with ~~the~~ the SM Yukawas.

Easy way to construct models that respect MFV:

transformation properties under G:

$$q \sim (3,1,1)$$
$$u \sim (1,3,1)$$
$$d \sim (1,1,3)$$

SM Higgs Yukawa $Y^u_{ij}\, \bar{q}_i H u_j$; $Y^d_{ij}\, \bar{q}_i H d_j$

$\Rightarrow$ Promote Yukawas to non-dinamical fields transforming as

$$Y^u \sim (3,\bar{3},1)$$
$$Y^d \sim (3,1,\bar{3})$$

Real scalar s-channel mediator φ coupling to a dirac DM particle χ

$$\mathcal{L}_{int} = -g_\chi \varphi \bar{\chi}\chi - \frac{\varphi}{\sqrt{2}} \sum_i \left(g_u y_i^u \bar{u}_i u_i + g_d y_i^d \bar{d}_i d_i + g_L y_i^L \bar{l}_i l_i \right)$$

MFV Assumption

we will assume $g_u = g_d = g_L \equiv g_{SM}$

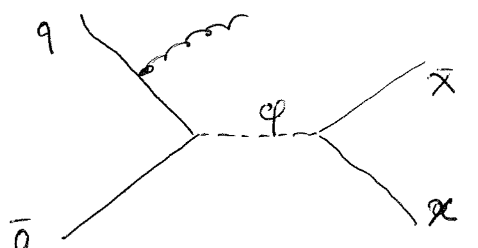
$\Rightarrow$ free parameters are $\{ m_\chi, m_\varphi, g_\chi, g_{SM} \}$

Γ_φ can be calculated using $\mathcal{L}_{int}$ but φ might decay into other particles of a (potentially) much richer Dark sector.

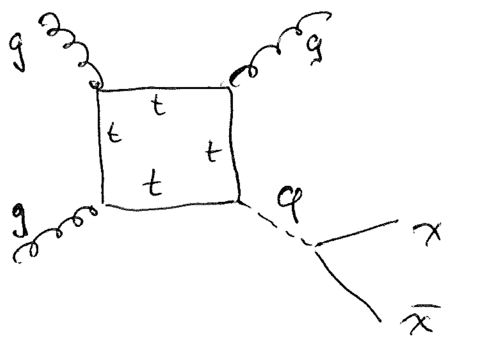
$\Rightarrow$ treat Γ_φ as additional free parameter.

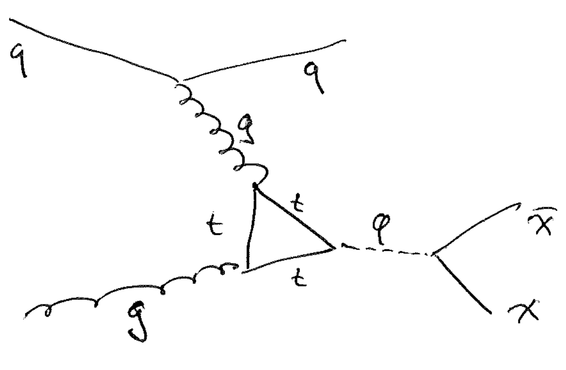
LHC Searches

$\not{E}_T + j$ signature



suppressed by Yukawa $\Rightarrow$

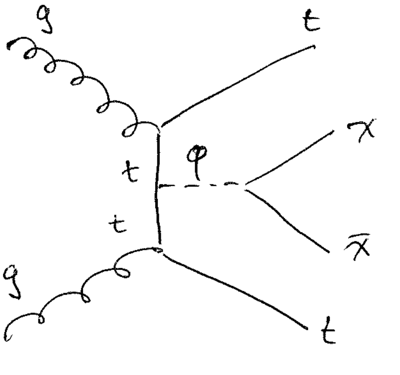




Cross section is hard to predict because the energy is high enough to resolve the top loop.

Other possible signature:

$\not{E}_T + t\bar{t}$ (maybe also $\not{E}_T + b\bar{b}$)



Note: for constraint from direct detection the mediator and the top quark can be intedrated out

$$\Rightarrow \quad \mathcal{O}_\varphi = \frac{g_\chi g_{SM} y_q}{\sqrt{2}\, m_\varphi^2} \bar{\chi}\chi \bar{q} q$$

$$\mathcal{O}_G = \frac{g_\chi g_{SM} \alpha_s}{12\pi v m_\varphi^2} \bar{\chi}\chi G^a_{\mu\nu} G^{a\,\mu\nu}$$

Conclusions

Simplified models are a great tool for characterizing new physics and quickly constrain models and identify good parameters for potential discovery.

Should always keep in mind that it is an approximation and specify the assumptions.