Dark Matter Simplified models

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Physics at the High-Luminosity LHC

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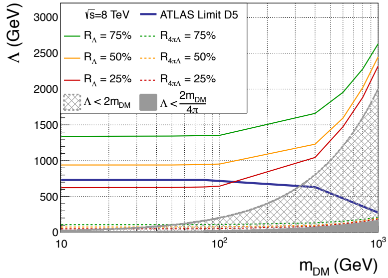
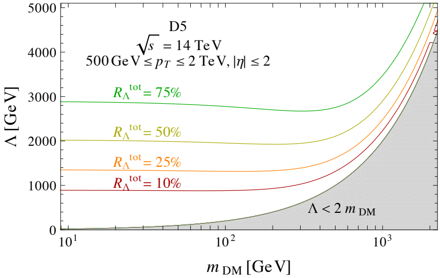
EFT not an option..

- EFT are a powerful and general tool, but must used *cum grano salis*
- At LEP and Teveatron the use of EFT was perfectly legitimate
- At LHC8, and even more at LHC14, the regime of validity of EFT is shrinking
- Quantitatively well illustrated by the quantity R_Λ: the ratio of the cross section obtained in the EFT with the requirement $Q_{tr} < \Lambda$ over the total cross section obtained in the EFT.
  It gives a measure of the fraction of events with momentum transfer lower than the EFT cutoff scale: $R_\Lambda < 1$ signals the failure of EFT description.
- EX: $D5 = \bar{\chi}\gamma_\mu\chi\,\bar{q}\gamma^\mu q$

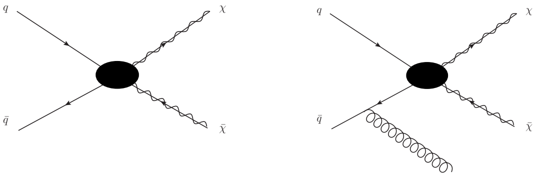




[G.Busoni, A.De Simone, J.Gramling, E.Morgante, A.Riotto]

Dark Matter at colliders: what to look for?

- Dark matter: particle stable on collider time scales
- If dark matter is the lightest state odd under an (approximate) Z_2 symmetry it will pair produced at collider
- Leading signal: $pp \to MET$



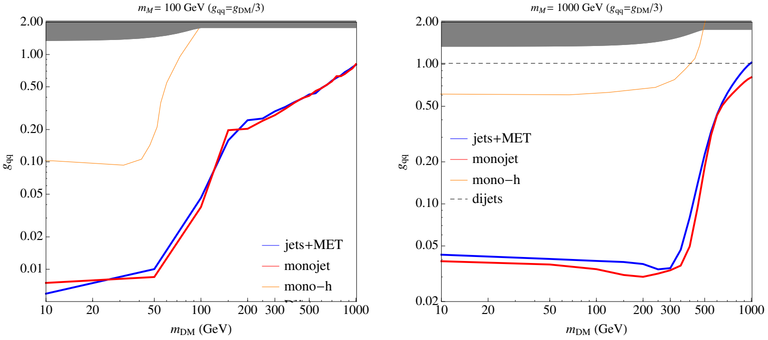
- Most common strategy is to dress the leading process with bosons and look for mono-X (X: jet, Z, W, γ, Higgs)
- This not necessarily the best strategy: for a given simplified model the search for the mediator is complementary and sometimes more constraining

  EX: t-channel scalar mediator (squark like) + fermion DM
  Dijets+MET are more constraining than mono-jet or any other mono-X search ex: [M. Papucci, AV, K. Zurek]

Vector s-channel mediator: Leptophobic Z'

$$\mathcal{L} \supset g_q Z'_\mu \sum_{i=1,2} \left(\bar{Q}^i_L \gamma^\mu Q^i_L + \bar{u}^i_R \gamma^\mu u^i_R + \bar{d}^i_R \gamma^\mu d^i_R\right) + g_{DM} Z'_\mu \bar{\chi}\gamma^\mu \chi + \mu_{Z'} h Z'_\mu Z'^\mu .$$

- $m_{DM} > m_{Z'}/2$: poor sensitivity at 8 TeV
- $m_{DM} \leq m_{Z'}/2$: Jets+MET ($\equiv$ monojet) win



[S.P.Liew, M. Papucci, AV, K. Zurek]

Vector s-channel mediator: Leptophobic Z'

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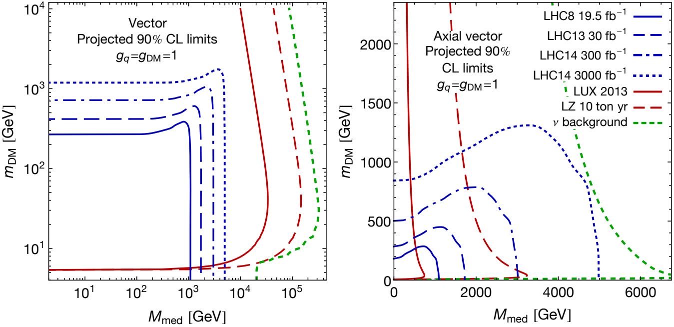
- What about HL-LHC?



[O.Buchmueller, M.J. Dolan,S.A. Malik,C.McCabe]

- So far only mono-jet studies have been performed: sensible increase in reach for $m_{DM} \leq m_{Z'}/2$.

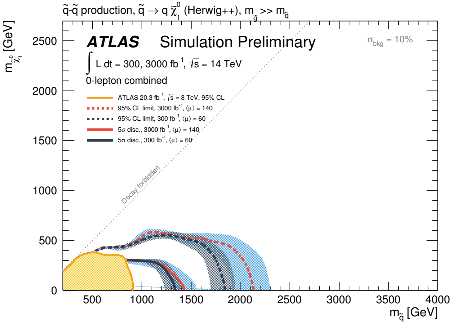
Wish list:

- ATLAS/CMS reinterpretation of dijet resonance search and angular distribution search as limits on g_q

Susy-like simplified models: squarks+DM

$$\mathcal{L} \supset g_{DM} \sum_{i=1,2} \left(\widetilde{Q}^i_L \bar{Q}^i_L + \tilde{u}^i_R \bar{u}^i_R + \tilde{d}^i_R \bar{d}^i_R \right) \chi + \text{mass terms} + h.c.$$

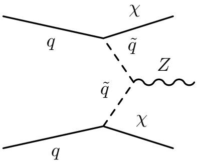
- model well studied by susy searches: jets+MET are the most constraining search in the bulk of parameter space



- Projections show poor sensitivity in the compressed region
- mono-X will help in the compressed region

Mono-Z

- When Z bosons are emitted from the initial state the process is not expected to have sizeable cross sections.
- Z boson radiated from final (or internal) states can have sizeable signal



- In a squarks+DM model, generically this analysis still gives negligible limits w.r.t. a jets+MET search
- When $m_{SQ} \simeq m_{DM}$, cross section enhanced by the process:

$$gg \longrightarrow \widetilde{q}\widetilde{q}^{\dagger} Z \longrightarrow 2(\text{soft})j + Z + \text{MET} \qquad \text{mono-Z final state}$$

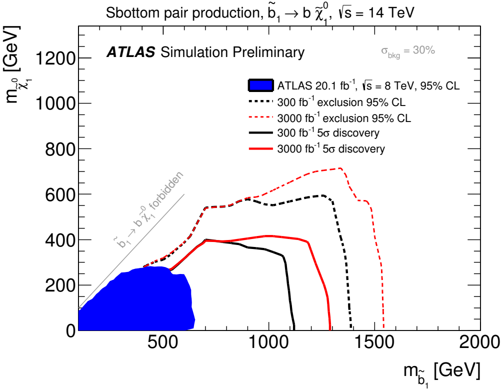
HL-LHC projections shows exclusion limits up to $m_{SQ} \simeq 500GeV$, $(m_{SQ} - m_{DM} = 10GeV)$.
[S.P.Liew, M. Papucci, AV, K. Zurek]

Wish list:
Study the impact of an hybrid analysis Z+MET+(not so soft)jets

Susy-like simplified models: sbottoms+DM

Similar to previous slides:

- model well studied by susy searches: jets+MET are the most constraining search in the bulk of parameter space

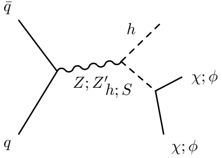


- Projections show poor sensitivity in the compressed region
- mono-jet and mono-Z will help in the compressed region
- Sbottom can have sizeable coupling to the Higgs without introducing flavour issues ($g_H \sim m_b$)
- HL-LHC starts being sensitive to mono-Higgs signals, but still not competitive using current analysis

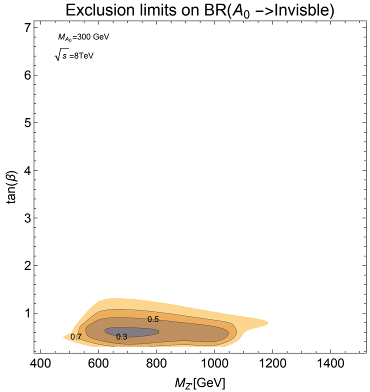
Mono-Higgs

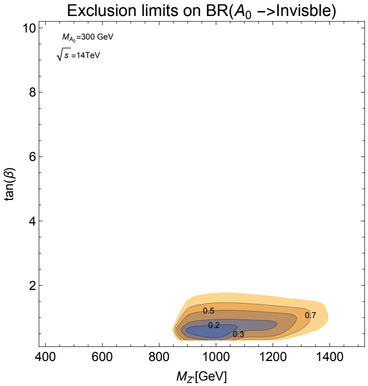
(Not so) Simplified model where mono-Higgs can play a fundamental role: [A.Berlin, T.Lin, L.T.Wang]

- 2 Higgs doublet model
- Heavy Z' coupled to quarks and higgs sector only
- DM coupled to pseudo-scalar A_0



Mono-Higgs complementary to dijets and jets+met searches





Mono-Higgs

- At present no dedicated mono-Higgs analysis exists.
- Current limits are obtained recasting the limits on the signal strength:

$$\mu = \frac{\sigma(pp \to hZ(Z \to \nu\bar{nu}))}{\sigma_{SM}}$$

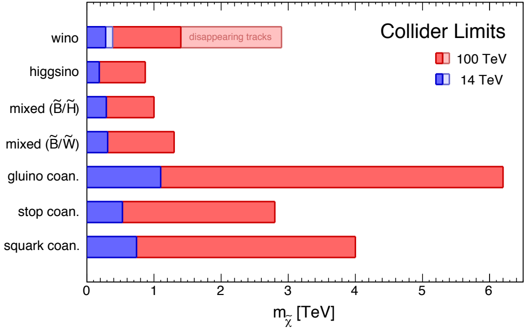
- Not binned on missing energy or Higgs p_T

Wish list:
Optimise a mono-Higgs analysis for different simplified models

Neutralinos

For the first time we will be sensitive to Simplified Models where the Dark Matter is the only light state.

- Can be though as a limit of MSSM
- Also, in the framework of minimal dark matter, one introduces one electroweak multiplet at the time and uses the neutral component as dark matter candidate
- Explaining the relic abundance fixes the DM mass
- Higgsino, Wino are most considered examples, but other can be studied



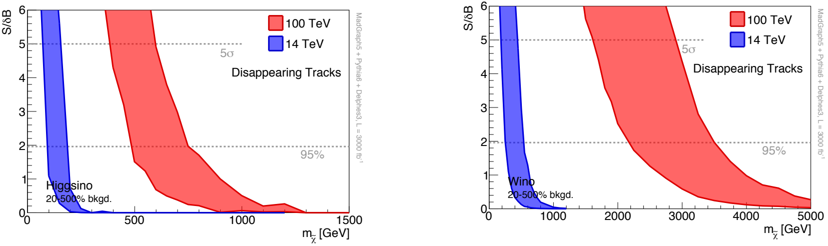
[M.Low, L.T.Wang]

Disappearing tracks

- A standard and agnostic method to look for neutralinos is the use of mono-X (mostly mono-jet) searches.
- Starting from HL-LHC this is not the most effective technique
- In the minimal scenario where only one multiplet is light, charged and neutral components are split by loop effects:

$$m_{\chi^\pm} - m_{\chi^0} \simeq 166 \text{ MeV (355MeV) for a Wino (Higgsino)}$$

- The small splitting results is a macroscopic lifetime of the chargino, which then can leave a trace in the detector before decaying: disappearing tracks are the smoking gun of this Simplified Model.



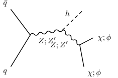
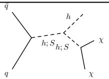
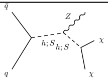
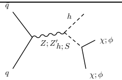
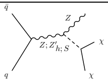
[M.Low, L.T.Wang]

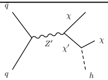
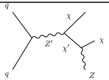
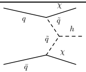
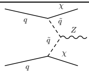
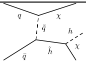
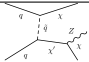
- Soft leptons and VBF not as constraining.
- To saturate the relic abundance $m_W \sim 3.1$TeV, $m_H \sim 1$TeV: HL-LHC can't close the parameter space but it can start carving it out.

Conclusions

- HL-LHC will definitively improve the reach of DM searches
- Complementarity of different channels will be important, since they are sensitive to different combination of simplified models couplings
- Optimise the searches based on Simplified models will be a key aspect

In this talk I only focused on a small subset of simplified models. A more complete list of Simplified models for mono-X (other than mono-jet) could be:

Model	mono-Higgs	mono-Z
s-channel vector		
s-channel scalar		
2HDM		

Model	mono-Higgs	mono-Z
Inelastic DM		
Squark/sbottom		
Inelastic squark		

[S.P.Liew, M. Papucci, AV, K. Zurek]