Les Houches BSM WG Summary

Matthew D, Matthew M and Gustaaf

Exotica is the new Normal

- Long lived particles: signatures, recasting
- Exotic VLQ signatures/decays
- Exotic spin-1 resonance signatures/decays
- Only SUSY: Squark decays beyond MFV

Recasting for LLPs

Kinds of searches available:

- Charged tracks (easiest)
- Disappearing track
- Displaced vertex
- Displaced jets/leptons
- R-hadrons
- MET (but these are too standard, so we ignore for now)

Questions for proceedings:

1. How well can we validate these searches? Is enough information provided?
2. What more information can we ask from experimentalists to make the recast "model independent" (we don't know how e.g. trigger, vertex efficiency changes)? Do our own fits to efficiency functions?
3. [Maybe] Survey what models are not detectable using these searches.

Other:

Can we leverage LHCb capabilities to improve sensitivity to models with disappearing track (by tracking the soft pion)?

Devising strategies for lifetime measurement of LLPs

Strategy

- Case study $pp \rightarrow H \rightarrow \phi\phi$ Many ϕ decays possible: $\phi \rightarrow \ell^+\ell^-, jj...$

- ϕ can decay into the Tracker, ECAL, HCAL….

- Classification based on final state and localization of the decay vertex

- Simple case: $\phi \rightarrow \ell^+\ell^-$ in the tracker

Difficulties

- Uncertainties in the reconstruction of the secondary vertex
- Decay inside ECAL, HCAL
- Missing transverse energy in the decay
- Estimation of backgrounds

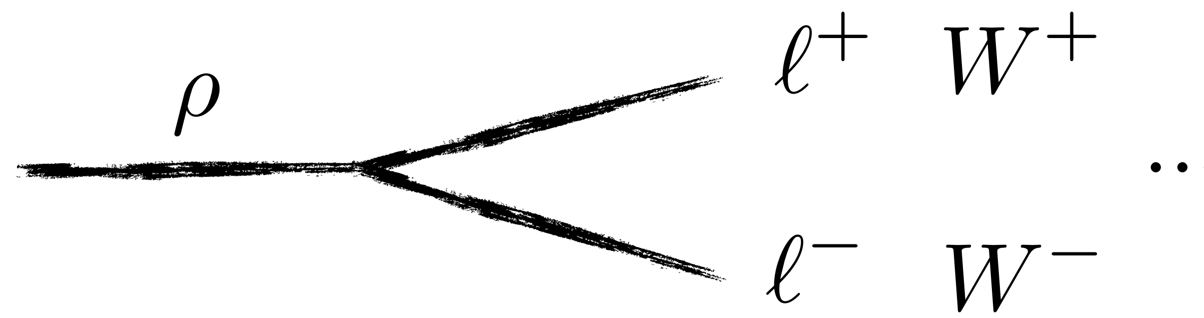
$\mathcal{Q}$ How many events needed to measure the lifetime with a given precision?

People interested

Shankha Banerjee, Daniele Barducci, Biplob Bhattacherjee, Andreas Goudelis, Bjoern Herrmann, Dipan Senguta

Exotic decays of spin-1 resonances

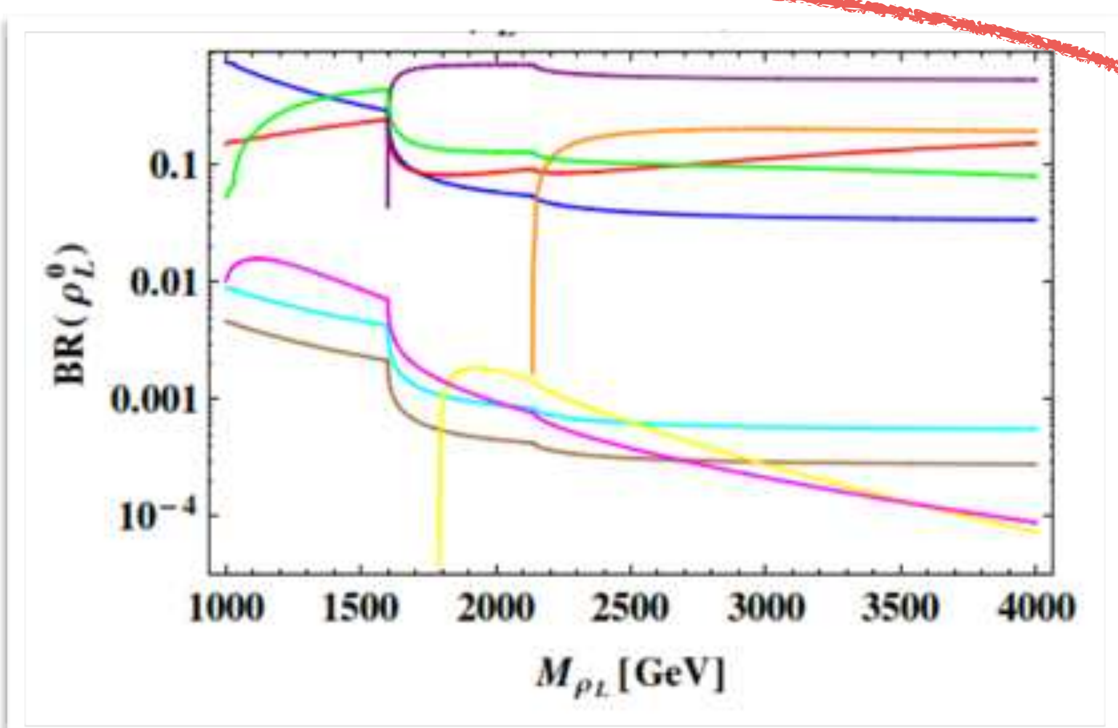
Heavy spin-1 resonances are searched for into a pair of SM states



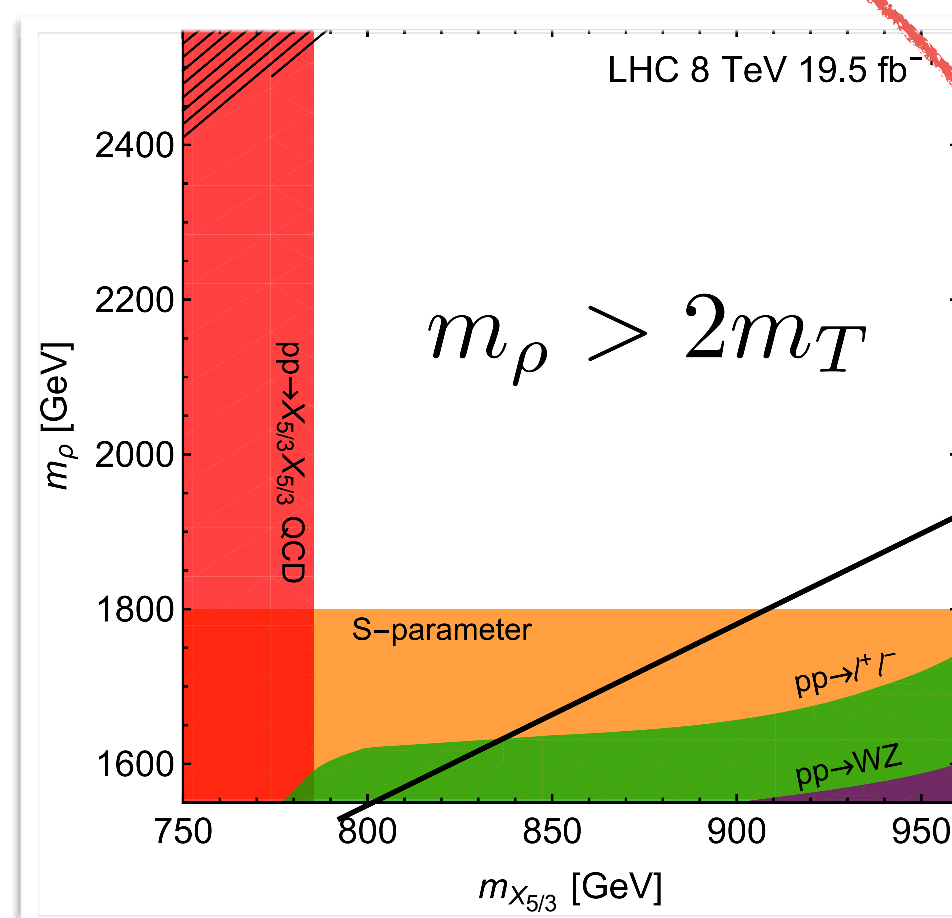
Decays into NP can suppress decay rates into SM states

Standard searches loose sensitivity

$$\mathrm{BR}(\rho \to Tt) \gg \mathrm{BR}(\rho \to \ell^+\ell^-)$$



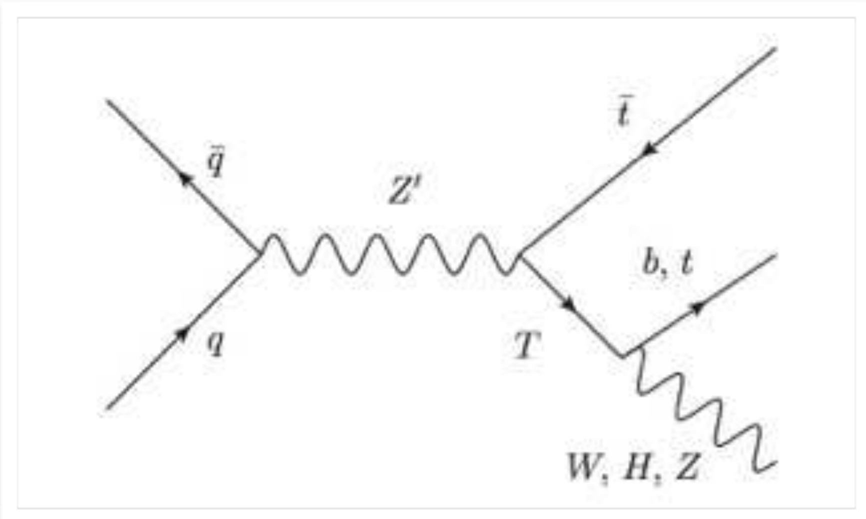
[Greco et al. '15]



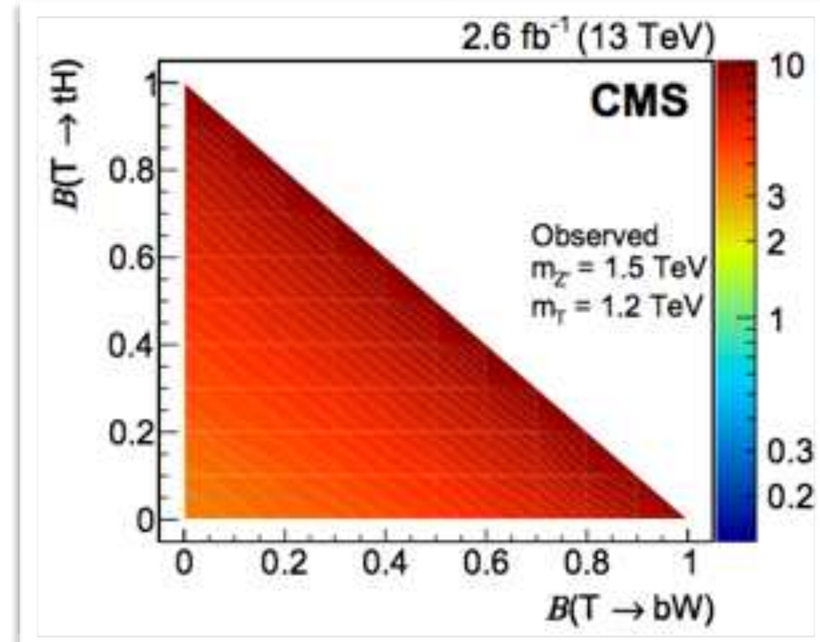
[Barducci and Delaunay '15]

Exotic decays of spin-1 resonances

CMS results on searches for heavy resonances in BSM final states



[CMS-B2G-16-013]



Goals

- Categorize possible final states depending on the resonance quantum numbers
  - c.f.r. More resonance working group
- Check the coverage and sensitivity of SM searches, e.g. ttZ [Contur…]
- Check the sensitivity of available non-resonant and single production searches
- Identify possible search strategies

People interested

- Daniele Barducci, Thomas Flacke, Minho Son, Benjamin Fuks, Devdatta Majumder, Ramona Groeber, Haiying Cai, Tetiana Berger-Hryn'ova , Alexandra Carvalho, Abhishek Iyer…

More resonances

Goal: to ensure that all possible di-object (non LLP) final states are covered by current ATLAS and CMS searches

Team: Benjamin, Gabriel, Gustaaf, JoAnne, Tanya, Tom, …

Plan update https://arxiv.org/abs/1610.09392 (D. Whiteson et al) with new experimental results, including MET.

TABLE I. Existing two-body exclusive final state resonance searches at $\sqrt{s} = 8$ TeV. The ∅ symbol indicates no existing search at the LHC.

	e	μ	τ	γ	j	b	t	W	Z	h
e	±∓[4],±±[5]	±±[5],[6] ±∓[6],[7]	[7]	∅	∅	∅	∅	∅	∅	∅
μ		±∓[4],±±[5]	[7]	∅	∅	∅	∅	∅	∅	∅
τ			[8]	∅	∅	∅	[9]	∅	∅	∅
γ				[10]	[11]-[13]	∅	∅	[14]	[14]	∅
j					[15]	[16]	[17]	[18]	[18]	∅
b						[16]	[19]	∅	∅	∅
t							[20]	[21]	∅	∅
W								[22]-[25]	[23],[24],[26],[27]	[28]-[30]
Z									[23],[25],[31]	[28],[30],[32],[33]
h										[34]-[37]

Expand current exclusive 2-particle-resonance requirement to include searches with associated production and pair production

More resonances

Goal: to ensure that all possible di-object (non LLP) final states are covered by current ATLAS and CMS searches

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Plan update https://arxiv.org/abs/1610.09392 (D. Whiteson et al) with new experimental results.

	e	μ	τ	γ	j	b	t	W	Z	h
e	$Z', H^{\pm\pm}$	$\not{R}, H^{\pm\pm}$	$\not{R}, H^{\pm\pm}$	L^*	$LQ, \not{R}$	$LQ, \not{R}$	$LQ, \not{R}$	L^*, ν_{KK}	L^*, e_{KK}	L^*
μ		$Z', H^{\pm\pm}$	$\not{R}, H^{\pm\pm}$	L^*	$LQ, \not{R}$	$LQ, \not{R}$	$LQ, \not{R}$	L^*, ν_{KK}	L^*, μ_{KK}	L^*
τ			$Z', H, H^{\pm\pm}$	L^*	$LQ, \not{R}$	$LQ, \not{R}$	$LQ, \not{R}$	L^*, ν_{KK}	L^*, τ_{KK}	L^*
γ				H, G_{KK}, Q	Q^*	Q^*	Q^*	W_{KK}, Q	H, Q	Z_{KK}
j					Z', ρ, G_{KK}	$W', \not{R}$	$T', \not{R}$	Q^*, Q_{KK}	Q^*, Q_{KK}	Q'
b						Z', H	$W', \not{R}, H^{\pm}$	T', Q^*, Q_{KK}	Q^*, Q_{KK}	B'
t							H, G', Z'	T'	T'	T'
W								H, G_{KK}, ρ	W', Q	$H^{\pm}, Q, \rho$
Z									H, G_{KK}, ρ	A, ρ
h										H, G_{KK}

Review conservation constraints on exclusive finals states to exclude some channels and to motivate associated and pair productions.

VLQ Decays

- Experiments use *very* simplified models
  - Assuming e.g. BR(T→Wb)+BR(T→ht)+BR(T→Zt)=1
- But new fermions typically implies new bosons
  - Investigated ~2 years ago
    - More decays — e.g. Anandakrishnan, Colins, Farina, Kuflik, Perelstein, arXiv:1506.05130, Serra, arXiv:1506.05110
    - Final states for experiments — Brooijmans, Cacciapaglia, Les Houches 2015

T/B	qH	ql^+l^-	$q\ E_T^{miss}$	$ql^+\nu$	qqq	qW^+W^-	qZH/Z	qHH	qW^+Z	qW^+H
res.	η_0	Z, LQ	Z, H_{inv} LQ, DM	W, LQ	$Z/W/H$ $\eta_0/\eta^\pm/\phi_c$	H, VLQ Z', η_0	H, VLQ	VLQ	W', VLQ $\eta^\pm$	VLQ
tops T/B	1/0	1/0	1/0	0/1	3/2	1/0	1/0	1/0	0/1	0/1
single	D	A	C	B	A/E	B	A	D	A	B
qH	D	-								
ql^+l^-	A	A	-							
$q\ E_T^{miss}$	C	A	C	-						
$ql^-\nu$	D	A	C	A	-					
qqq	E	A	B/C	A/B	A/E	-				
qW^+W^-	B	A	B	A	A/B	A	-			
qZH/Z	A	A	A	A	A	A	A	-		
qHH	D	A	C	B	B/D	B	A	D	-	
qW^-Z	A	A	A	A	A	A	A	A	A	-
qW^-H	D	A	C	B	A/D	A	A	D	A	B

VLQ Decays

- Observations since then:
  - SUSY searches cover the three simple decays well: A. Biekötter et al, https://arxiv.org/abs/1608.01312
  - Decays to a light scalar studied specifically: M. Chala, https://arxiv.org/abs/1705.03013
- 2017 LH plan: check other "exotic" decays

T	q Z	q H	q' W-	q t t	q j j	q l+ l-	q MET	q W+ W-	q Z H	q H H	q' b t	q' j j	q' l- n	q' W- Z	q' W- H	q q'MET	q q'Z	q q'W	q q'H	q g	q gamma
Interm res				Z', eta0, phi_c	Z', H, eta0, phi_c, Z'	LQ, Z'	Z, Hinv, LQ, DM, Z'	H, VLQ, Z', eta0	eta0	eta0	W', eta+-	W', eta+-	LQ, W'	W', eta+-	eta+-, W'	VLQ	VLQ	VLQ	VLQ		
Single light	yes	yes?			unlikely?																yes
single q=b																					
single q=t																					
q Z	2t,1t,0t																				
q H	2t,1t,0t	2t,1t,0t																			
q' W+	(1t,0t) x (1b,0b)	(1t,0t) x (1b,0b)	2b, 1b, 0b																		
q t t	4t, 3t, 2t	4t, 3t, 2t	(3t,2t) x (1b,0b)	6t, 5t, 4t, 3t, 2t, 1t, 0t																	
q j j	(2t,1t,0t) x (2b,0b)	(2t,1t,0t) x (2b,0b)	(1t,0t) x (3b,2b,1b,0b)	(4t,3t,2t) x (2b,0b))	(2t,1t,0t) x (4b,2b,0b)																
q l+ l-	2t,1t,0t	2t,1t,0t	1t1b,1b,1t,0t	(4t,3t,2t)	(2t,1t,0t) x	2t,1t,0t															

JoAnne, Tom, Gabriel, Tetiana, Benjamin, Gustaaf

Flavor-violating squarks @ the LHC

Abishek, Amit, Benjamin, Björn, Giacomo, Mihoko, Motoi, Priscilla, Ramona

- Squarks are admixtures of different flavors
- Simplified model: right stop-scharm mixing

$$\begin{pmatrix} \tilde{u}_1 \\ \tilde{u}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_{tc} & \sin\theta_{tc} \\ -\sin\theta_{tc} & \cos\theta_{tc} \end{pmatrix} \begin{pmatrix} \tilde{c}_R \\ \tilde{t}_R \end{pmatrix}$$

- 3D parameter space (2 masses, one mixing angle)

$m_{\tilde{u}_1}, m_{\tilde{u}_2}, \theta_{tc}$

- Possible flavor-violating decays: $\tilde{u}_i \to t + \not{E}_T$ or $c + \not{E}_T$

- Signatures

$t\bar{t} + E_T^{miss}$ ➢1407.0583

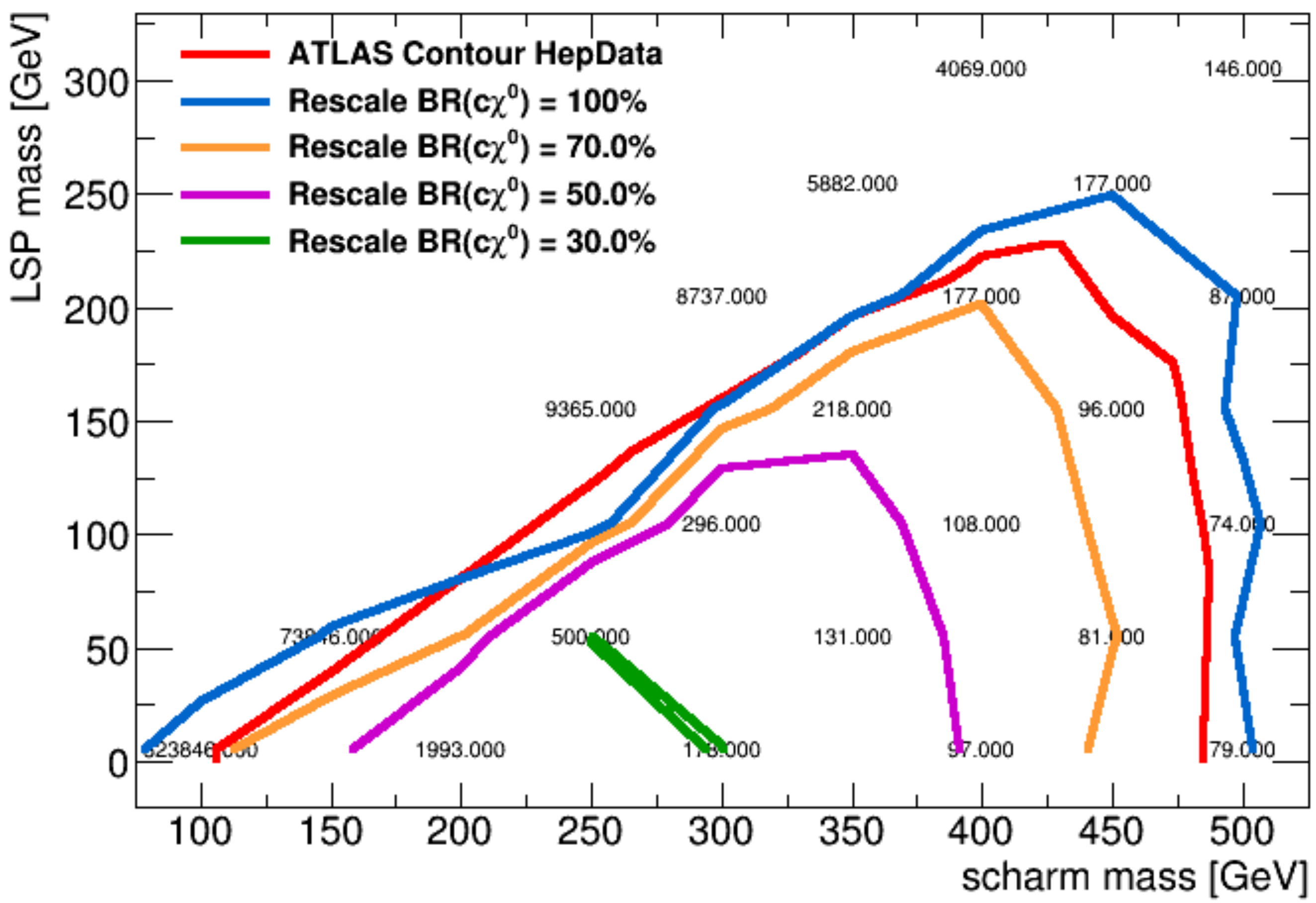
$c\bar{c} + E_T^{miss}$ ➢1501.01325

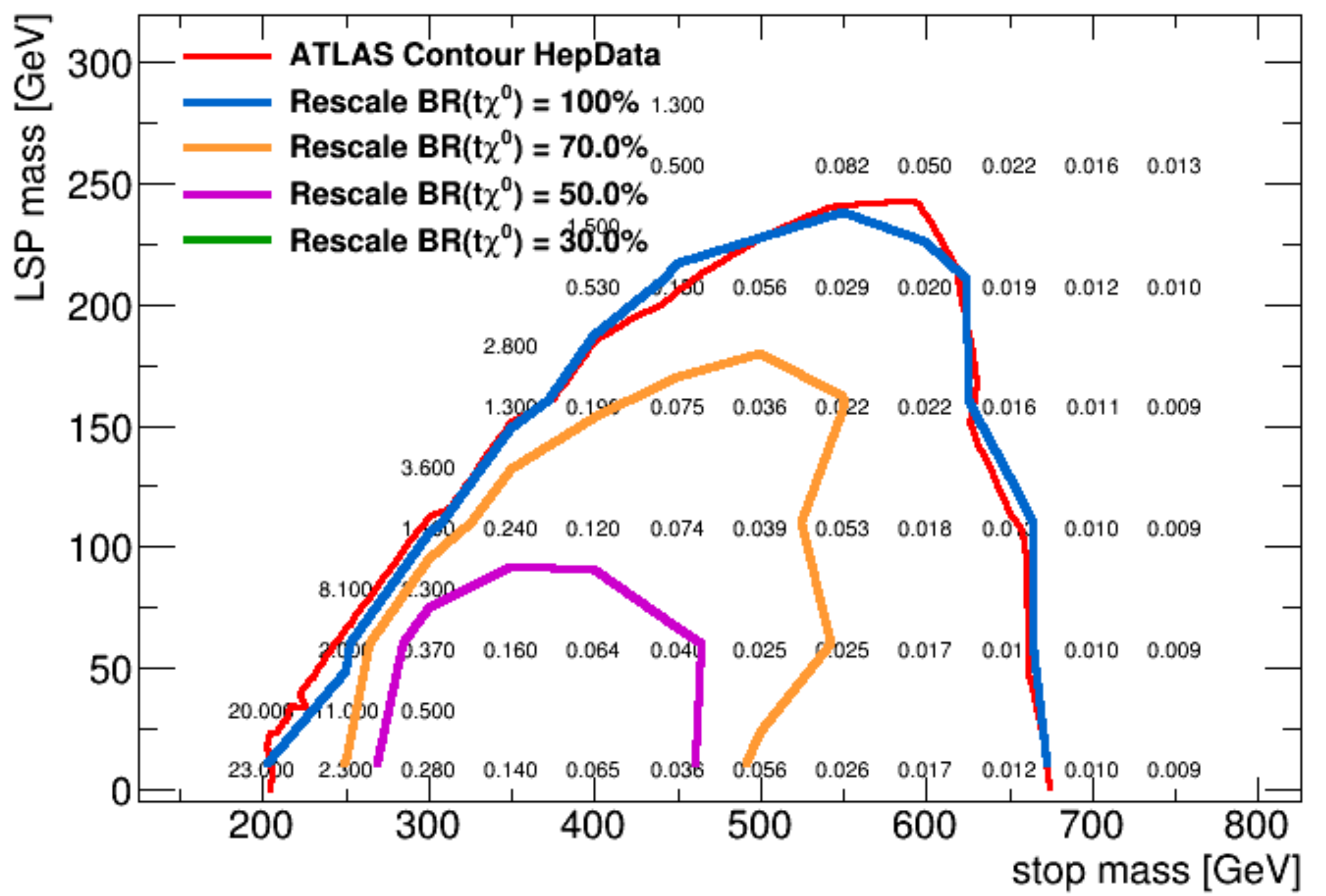
$c + t + E_T^{miss}$ ➢ Monotops?

Objectives:

- Coverage of current searches ?
- Potential of a dedicated top-charm analysis

Rescaling the limits





Rescaled using HepData from Run 1 references

Assumptions:

- Only one particle (u1)
- No contamination of tt+MET from cc+MET and ct+MET and viceversa

Next steps

- Prepared a code that calculates all BR for all u1/u1 assumptions

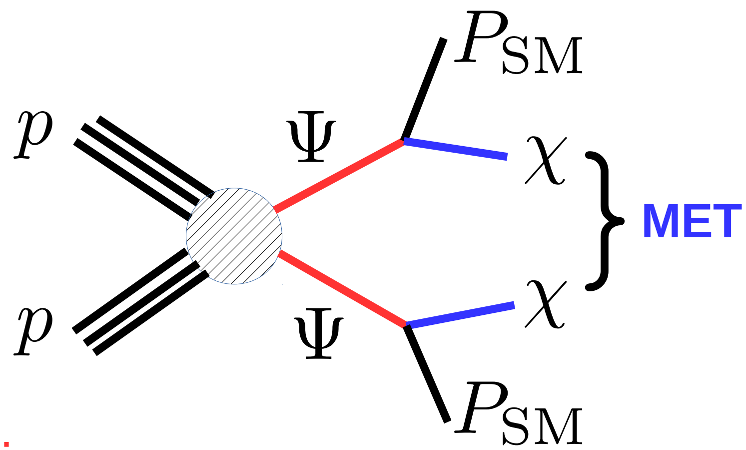
- Implementing acceptance x efficiency from HepData of stop and scharm analyses

- Obtaining exclusions vs u1/u2/alpha from UL

```
BR1 BR2 alpha, u1, u2, signal, accepted?
1.0 500 800 signal =  6.46800075688 excluded
1.0 550 800 signal =  6.41650897439 excluded
1.0 600 800 signal =  5.39521717792 excluded
1.0 650 800 signal =  4.08024491753 not excluded
1.0 700 800 signal =  3.06534614271 not excluded
1.0 750 800 signal =  2.25312782681 not excluded
1.0 800 800 signal =  1.47807430705 not excluded
```

Non-thermal dark matter and long-lived particles

Idea:



Interaction-type:

$$\mathcal{L} \supset y \Psi P_{\rm SM} \chi$$

Ψ properties:

- Long-lived:
  $10\text{mm} \lesssim c\tau_{\Psi} \lesssim \text{few m}$
- Z_2 odd
- gauge couplings with SM
- mass
  $(\text{few } 100\text{GeV}) \lesssim m_{\Psi} \lesssim 1\text{TeV}$
- spin-1/2 or spin-0

χ properties:

- Dark matter candidate
- spin-0 or spin-1/2
- Z_2 odd
- mass
  $10\text{keV} \lesssim m_{\chi} \lesssim m_{\Psi}/2$

Coupling:

$$10^{-9} \lesssim y \lesssim 10^{-7}$$

*** The coupling is too small for DM to have standard Freeze-Out***

DM will be likely non-thermal:
find the consistent cosmological history!

Non-thermal dark matter and long-lived particles

Who's interested:

J. Zurita
A. Lessa
JM. No
A. Goudelis
J. Harz
G. Facini
S. Sekmen
D. Sengupta
J. Quevillon
N. Desai
F. Bruemmer
H. Cai
D. Barducci
G. Belanger
A. Pukhov
B. Zaldivar
You?

Progress so far:

- Extract the relevant bibliography on the subject
- Understand what has been done so far
- Identify new concrete things to do
- Working plan
- Assignment of tasks

Hall, Jedamzik, March-Russell, West, 2009
Co, D'Eramo, Hall, Pappadopulo, 2015
Molinaro, Yaguna, Zapata, 2014
Hessler, Ibarra, Molinaro, Vogl, 2016
Ghosh, Mondal, Mukhopadhyaya, 2017

Discussions (quite active!!):

- Approach of the project: **bottom-up**
- Cosmological histories consistent with DM & LLP signatures (**freeze-in** mechanism, role of **reheating** epoch, …)
- Classification of possible interactions (**spins** of particles, SU(2)/SU(3) **representations**, ...)
- Possible (new?) LHC triggers
- Include **also** new proposals as **MATHUSLA**

Outlook & TO-DOs:

- Write down **relevant operators** according to trigger possibilities & feasibility of the signature
- Determine useful **benchmarks** from LLP perspective
- Implement the models (UFO + MicrOMEGAs)
- **Connection with cosmology / DM abundance**

Single top + DM

Aim: verify whether single top + DM signature can be used to access additional information on a DM model with scalar/pseudoscalar mediator with respect to tt(bb)+DM, mono jet, mono h, mono Z

Concentrate for the start on the 2HDM+a model , with a pseudoscalar singlet, of arXiV:1701.07427.

Cross section scan for

$pp \rightarrow t\, j\, \chi\chi$ +

$pp \rightarrow t\, W\, \chi\chi$

Parameters:

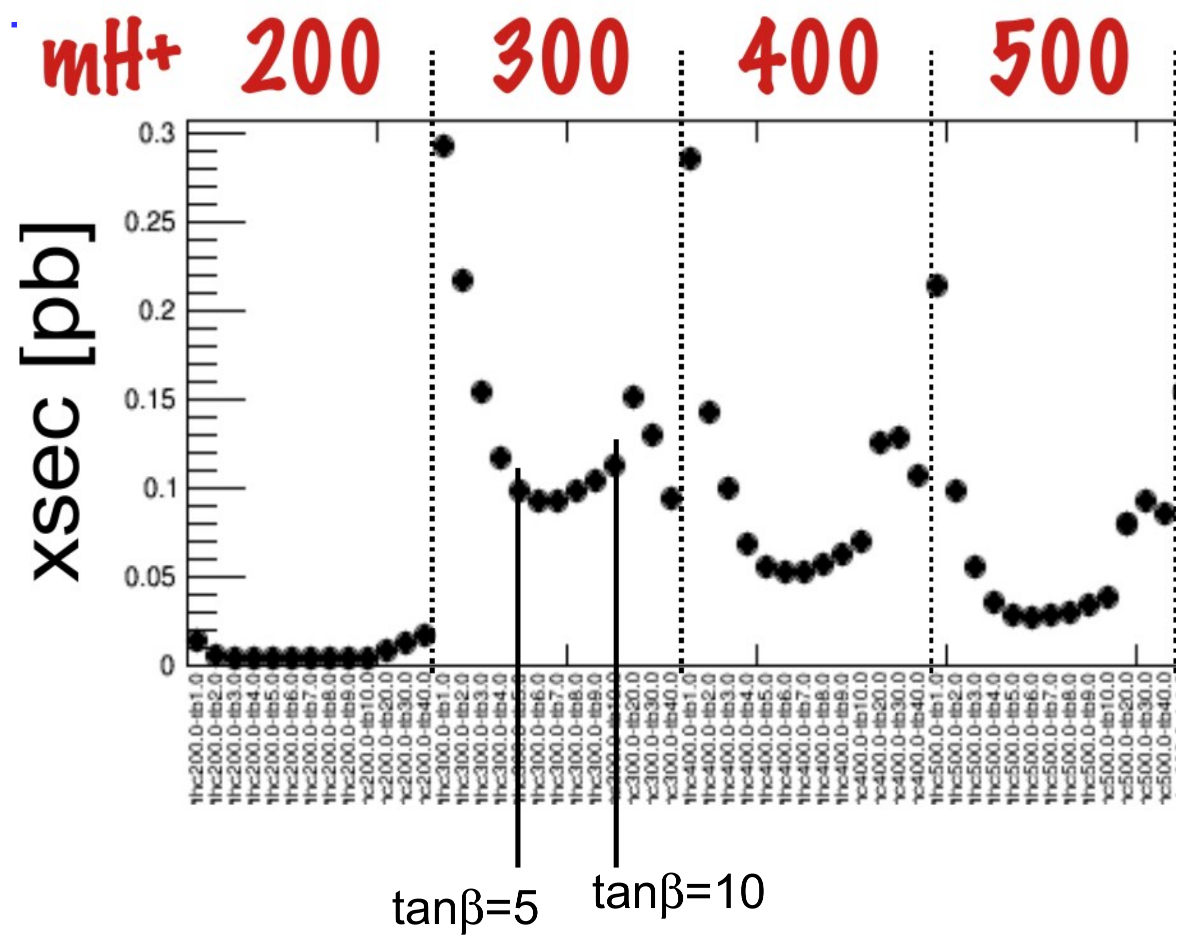
sint=0.7 (mixing of doublet And Singlet)

m(A)=m(H)=750 GeV

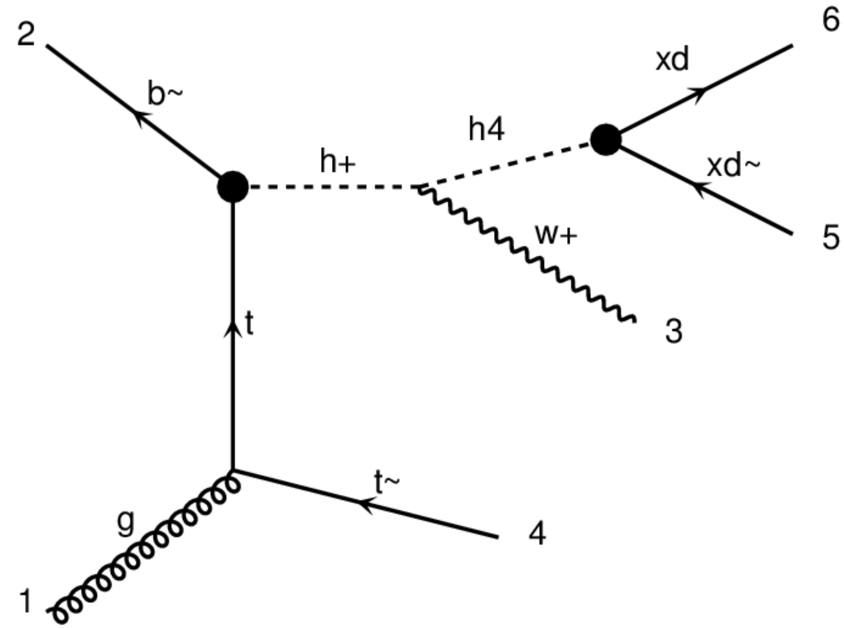
m(a)=150 GeV

Scan over m(h^+) and over

tanβ between 1 and 40



Promising cross-sections, dominant process is th^+ production with h^+ decaying on-shell to a, pseudoscalar singlet and a W boson



Interesting final state topology, involving charged higgs

plan to verify coverage of existing analyses: jets+Etmiss, monotop

Further: dedicated optimisation and assessment of coverage in $m(h^+)$-$\tan\beta$ plane for 300 fb^{-1}

Additional topics:

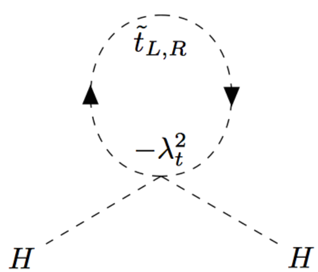
- Study h^+h^- production and compare with chargino analyisis
- Check diphoton constraints on A/H for low $\tan\beta$

People involved: Benj, Bryan, Fabio, Genevieve, Giacomo, Jose-Miguel, Priscilla

The Hyperbolic Higgs

Top Partners in Natural Theories

Taken from 1506.06141.



		scalar	*fermion*
strong direct production	*QCD*	SUSY	Composite Higgs/ RS
DY direct production	*EW*	folded SUSY	Quirky Little Higgs
Higgs portal direct production	*singlet*	?	Twin Higgs

Mirror Glueballs
Higgs portal observables

Higgs coupling shifts
$\sim$ tuning

Tim, Matthew.

Well done everybody!