TeVPa 2016

(12-16 September, CERN)

"DARK MATTER FACES MULTIJETS"

Bryan Zaldivar, LAPTh

Based on work in progress, in collaboration with:

S. Banerjee, D. Barducci, G. Bélanger

B. Fuks and A. Goudelis (LPTHE)

MOTIVATION

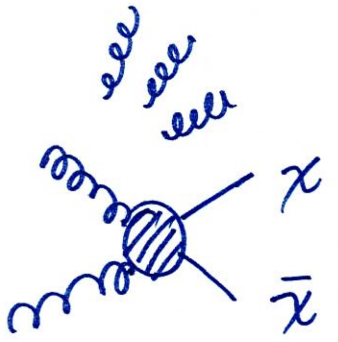
- Dark Matter interpretation of LHC results

EFT $$\mathcal{L} = \frac{1}{\Lambda^2}(\bar{\chi}\Gamma^\mu\chi)(\bar{q}\Gamma_\mu q)$$

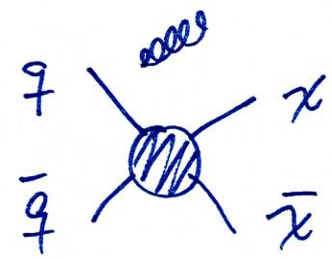
$$\Gamma^\mu = \mathbb{1}, \gamma^\mu, \gamma^\mu\gamma^5, \ldots$$

Simplified models $$\mathcal{L} = g_\chi P_M \bar{\chi}\Gamma^M\chi + g_q P_N \bar{q}\Gamma^N q$$

$M, N = 1, \mu$ (scalar or vector)



vs.

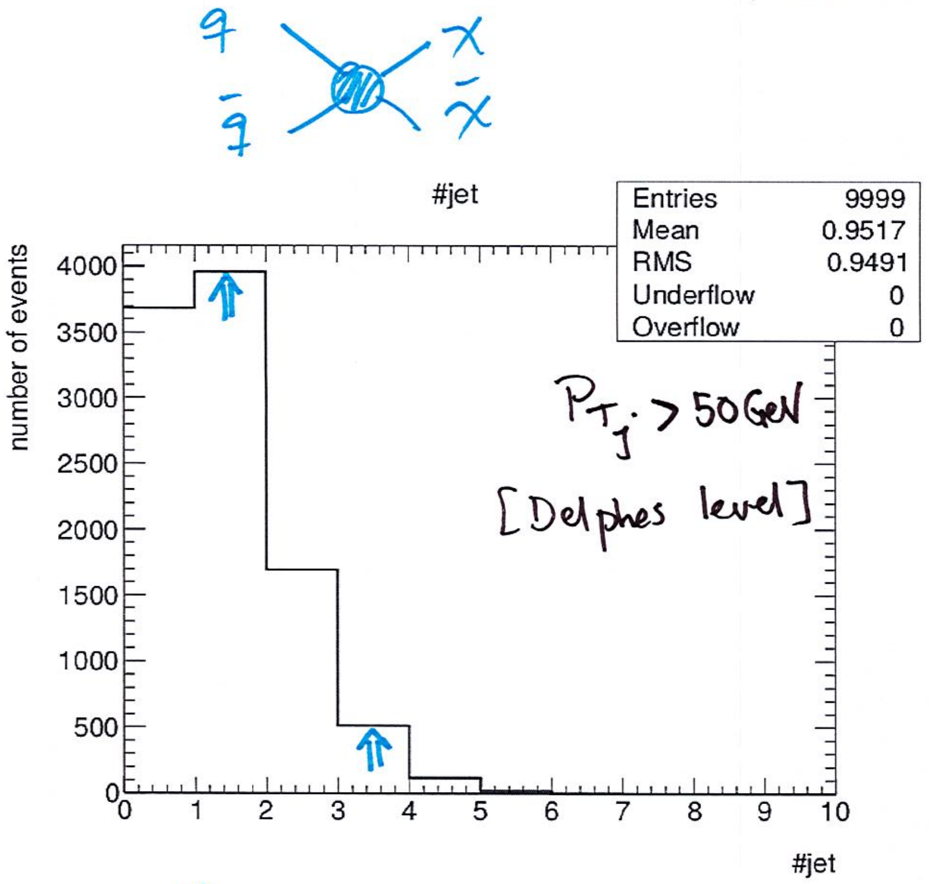


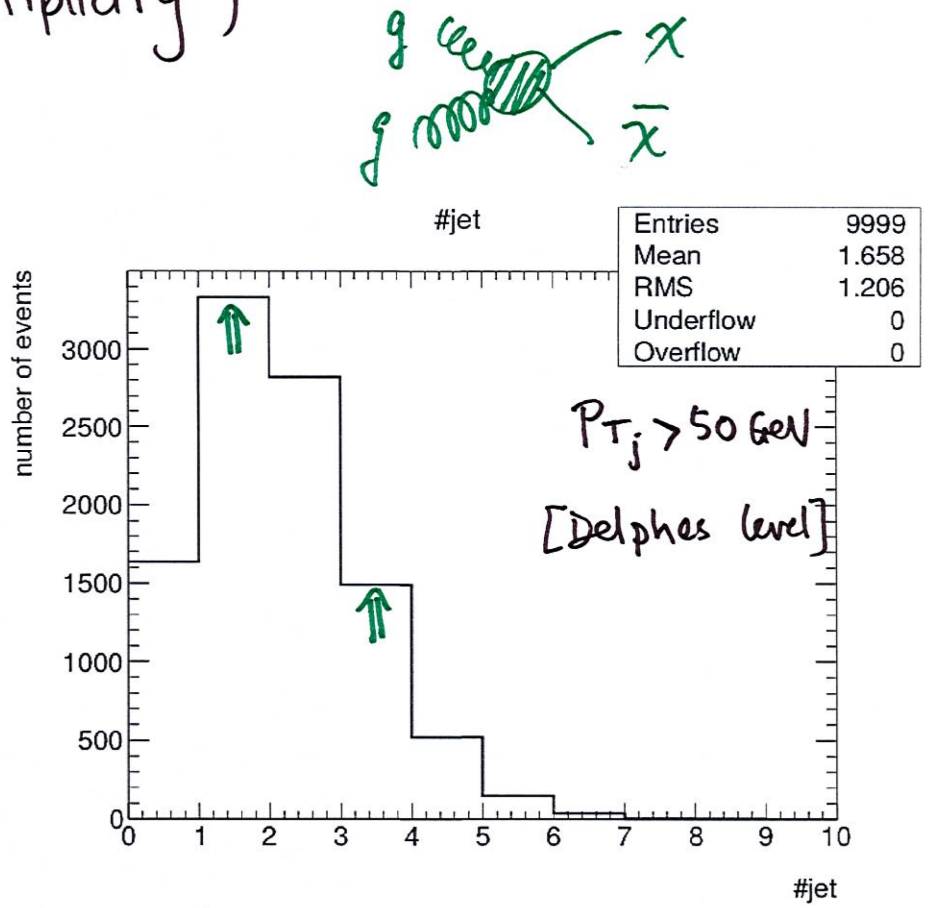
} gluon-fusion produces more hadronic activity

⇒ CONSIDER MULTIJET + MET ANALYSES!

$\bar{q}q$- versus gg production

(Jet Multiplicity)





$N_{3j}/N_{1j} \sim 1/8$

$N_{3j}/N_{1j} \sim 0,44$

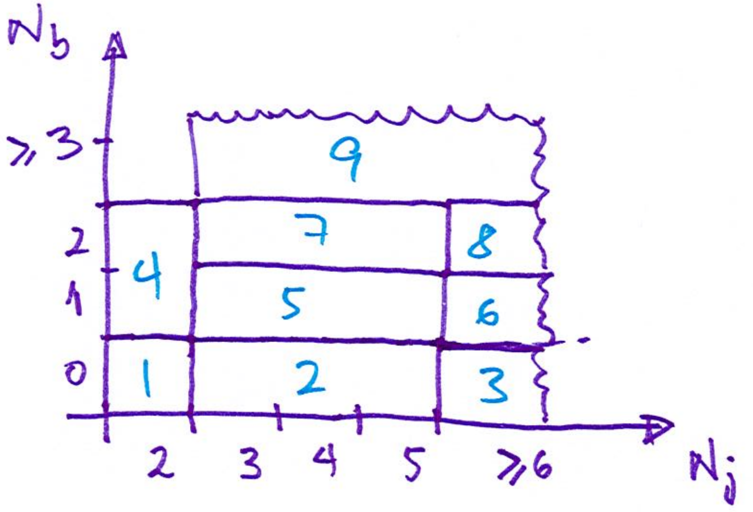
$\Rightarrow$ Allowing for larger jet multiplicities should increase the exclusion power

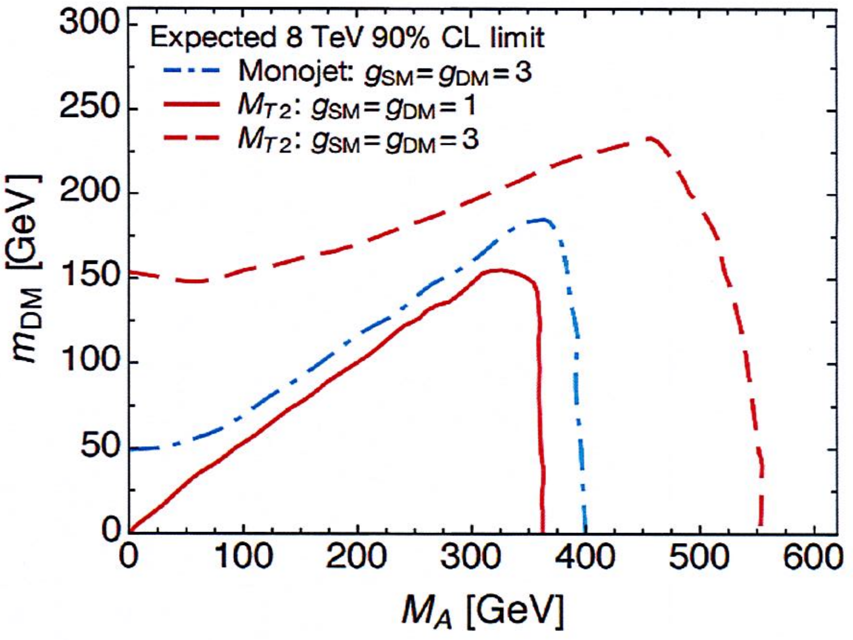
$\Rightarrow$ More suitable for Simplified Models with *Scalar* mediators

⊛ EXISTING EXAMPLE : M_{T_2} - ANALYSIS @ 8 TeV (1502.04358)

Buchmueller, Malik, McCabe, Penning
(1505.07826)

Signal Regions

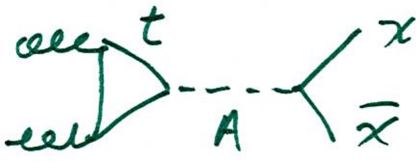




$\mathcal{L} = 20\,\text{fb}^{-1}$

Model

$$\mathcal{L}_{int} = i g_{DM} A \bar{\chi} \gamma^5 \chi + i g_{SM} \sum_q \frac{m_q}{v} A \bar{q} \gamma^5 q$$



Here it is pointed out the importance
of $N_j > 2$ signal regions

OTHER MULTIJET+MET ANALYSES @ 8 TeV

[available at ⇒

1) Squark and Gluino searches
(ATLAS, 1405.7875)

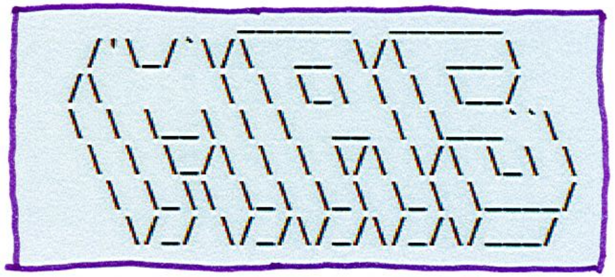
- Signal Regions covering
  $N_j = 2, 3, 4, 5, 6$
- Analysis mostly based on m_{eff} variable

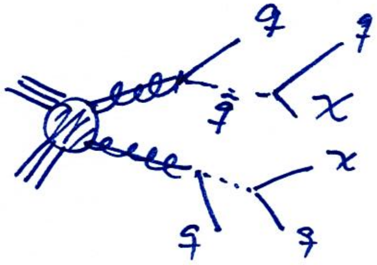
2) Squark and Gluino searches too
(CMS, 1402.4770)

- Three Jet multiplicity categories:
  3–5, 6–7, ≥8 jets
- Looking at H_T variable distributions

RECASTING TOOL:

"MadAnalysis 5"





Searches optimised for SUSY
(logical: hadronic activity produced in the final state)

RESULTS

RECASTING OF A MULTIJET+MET SEARCH AT 13 TeV

(ATLAS 1605.03814)

- Seven SR's with $N_j = 2, 4, 5, 6$
- Interpretation : SUSY models (squark & gluino production)

Note : No 3-jet SR (harder for DM simplified models)

⇒ We have implemented this search in MadAnalysis 5.

- Successful Validation up to ~ 15%

Requirement	Signal Region						
	2jl	2jm	2jt	4jt	5j	6jm	6jt
E_T^{miss} [GeV] >	200						
$p_T(j_1)$ [GeV] >	200	300	200				
$p_T(j_2)$ [GeV] >	200	50	200	100			
$p_T(j_3)$ [GeV] >	–			100			
$p_T(j_4)$ [GeV] >	–			100			
$p_T(j_5)$ [GeV] >	–				50		
$p_T(j_6)$ [GeV] >	–					50	
$\Delta\phi(\text{jet}_{1,2,(3)}, \boldsymbol{E}_T^{\text{miss}})_{\text{min}}$ >	0.8	0.4	0.8	0.4			
$\Delta\phi(\text{jet}_{i>3}, \boldsymbol{E}_T^{\text{miss}})_{\text{min}}$ >	–			0.2			
$E_T^{\text{miss}} / \sqrt{H_T}$ [GeV$^{1/2}$] >	15		20	–			
Aplanarity >	–			0.04			
$E_T^{\text{miss}} / m_{\text{eff}}(N_j)$ >	–			0.2	0.25		0.2
$m_{\text{eff}}(\text{incl.})$ [GeV] >	1200	1600	2000	2200	1600	1600	2000

⇒ {Efficiency Table}

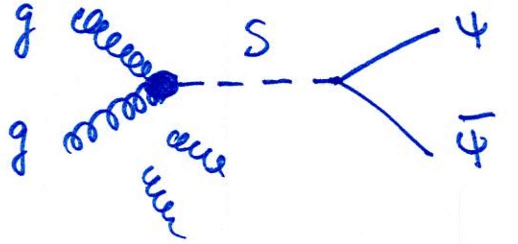
Cut / Signal Region	2jl	2jm	2jt	4jt	5j	6jm	6jt
	Us - ATLAS	Us - ATLAS	Us - ATLAS	Us - ATLAS	Us - ATLAS	Us - ATLAS	Us - ATLAS
Preselection	0.92 - 0.90	0.91 - 0.90	0.92 - 0.90	0.92 - 0.90	0.92 - 0.90	0.92 - 0.90	0.92 - 0.90
Jet Multiplicity	1.00 - 1.00	1.00 - 1.00	1.00 - 1.00	0.94 - 0.95	0.70 - 0.71	0.40 - 0.41	0.40 - 0.41
min(Δ Φ(MET,jet))	0.61 - 0.61	0.80 - 0.80	0.61 - 0.61	0.70 - 0.70	0.68 - 0.68	0.65 - 0.64	0.65 - 0.64
pTj2	0.98 - 0.99	1.00 - 1.00	0.98 - 0.99	1.00 - 1.00	1.00 - 1.00	1.00 - 1.00	1.00 - 1.00
pTj4				0.86 - 0.87	0.92 - 0.92	0.96 - 0.95	0.96 - 0.95
Aplanarity				0.68 - 0.68	0.71 - 0.71	0.75 - 0.75	0.75 - 0.75
MET/sqrt[HT]	0.54 - 0.54	0.49 - 0.48	0.30 - 0.31				
MET/meff(Nj)				0.71 - 0.71	0.49 - 0.49	0.45 - 0.45	0.64 - 0.63
meff(incl.)	1.00 - 1.00	0.98 - 0.99	0.94 - 0.96	0.86 - 0.85	0.99 - 0.99	0.99 - 0.99	0.95 - 0.93

Validation cutflow of one (out of three) benchmarks (gluino production)

MONOJET vs. MULTIJET @ 13TeV

Example: CP-odd scalar mediator:

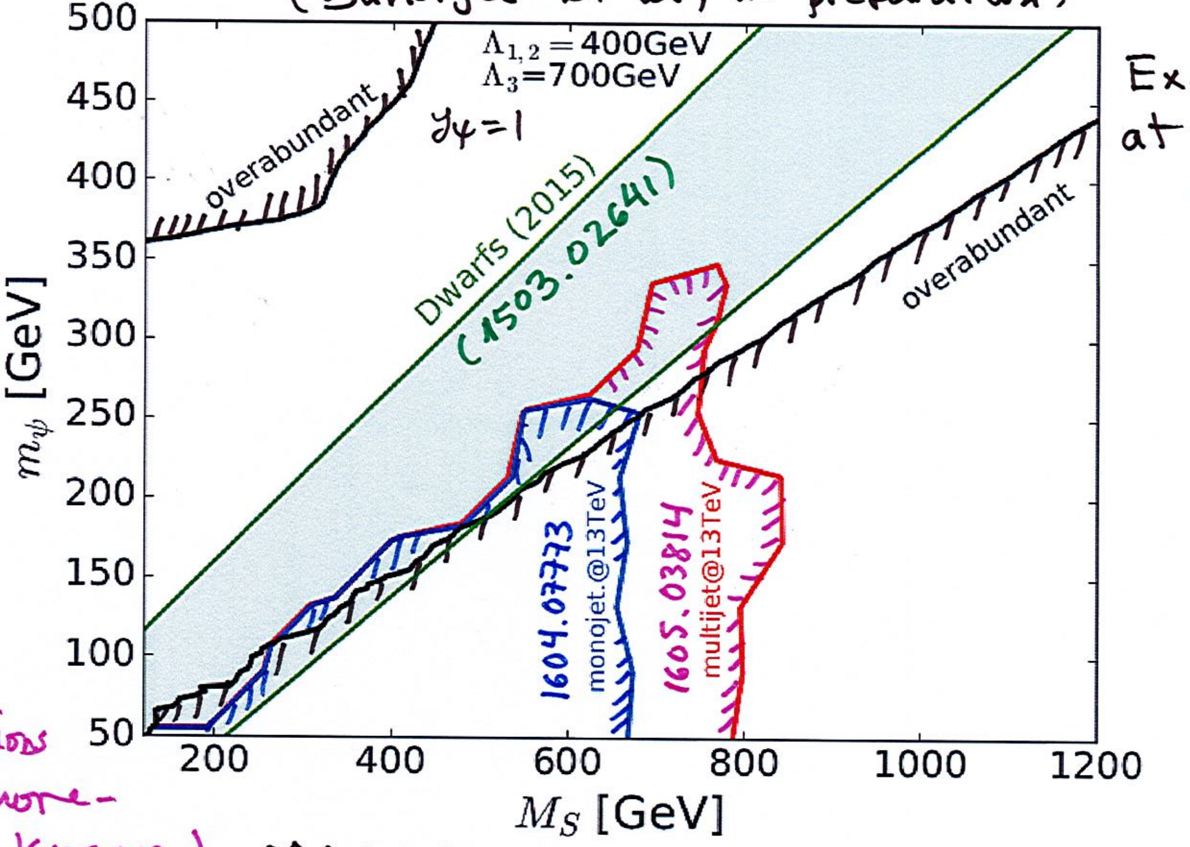
$$\mathcal{L} \supset -\frac{\alpha_1}{4\Lambda_1} S B_{\mu\nu}\tilde{B}^{\mu\nu} - \frac{\alpha_2}{4\Lambda_2} S W_{\mu\nu}\tilde{W}^{\mu\nu} - \frac{\alpha_s}{4\Lambda_3} S G^{\mu\nu}\tilde{G}^{\mu\nu} - i\frac{y_\psi}{2} S \bar{\psi}\gamma^5\psi$$



- Multijet analysis dominated by systematic uncertainties
  - experimental } may improve with time (soonish?)
  - theoretical } NO IDEA! (NNLO predictions with 2-or more-jets not known)

⇓ unless reduced, no significant improvement by increasing luminosity

(Banerjee et al, in preparation)



Exclusion at 95% CL.

- Dark Matter Abundance and Indirect Det. with micrOMEGAs.
- Diffuse gammas obtained from primary gluons (99% BR)

8 TeV vs. 13 TeV

Analyses @ 8TeV

- ATLAS_SUSY_2013-21 (monojet) → 20.3 fb^{-1}
- ATLAS: 1405.7875 (multijet) → 3.2 fb^{-1}

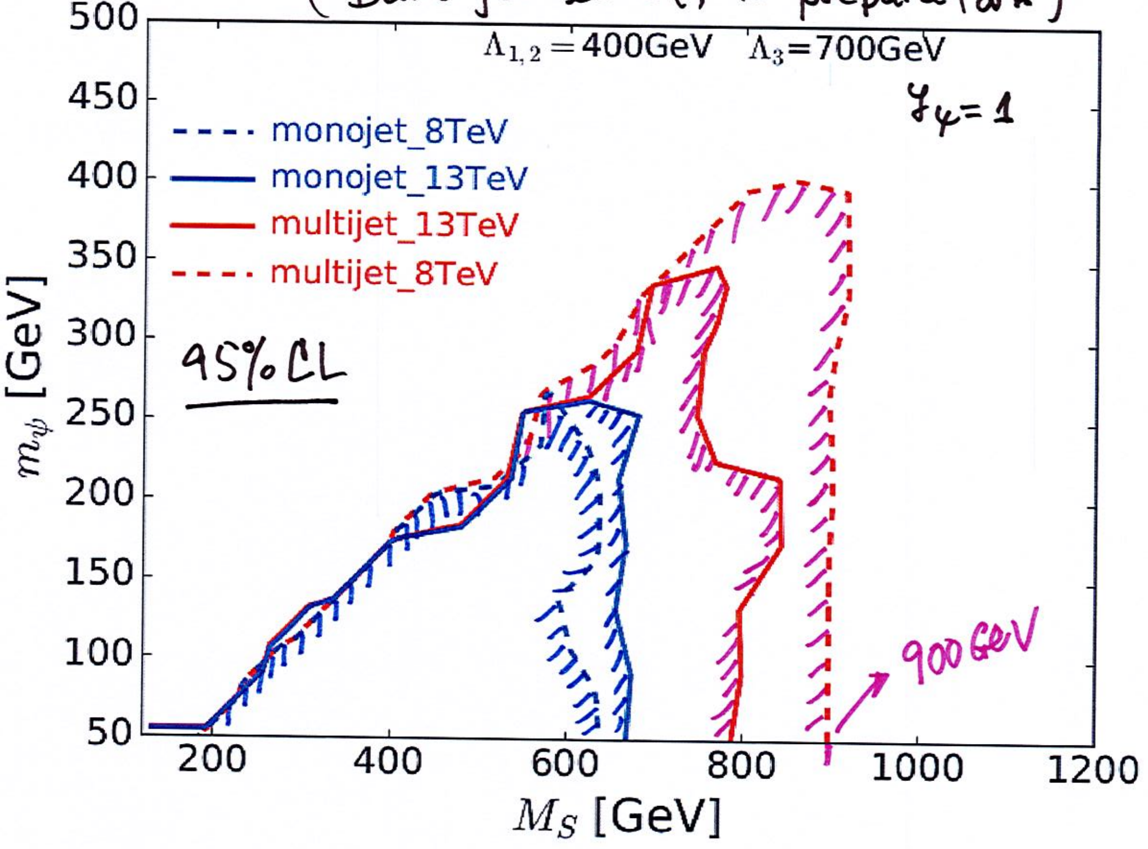
(Importance of systematic uncertainties)

$$\sigma \sim \frac{S}{\sqrt{S+B+(\delta B)^2}}$$

Uncertainties

- 2% – 4% (monojet @ 8 TeV)
- 4% – 11% (monojet @ 13 TeV)
- 8% – 24% (multijet @ 8 TeV for SR ($N_j \leq 3$))
- 8% – 17% (multijet at 13TeV for SR ($N_j = 2$))

(Banerjee et al, in preparation)



Multijet analyses

- 8 TeV analyses ⇒ SR with $N_{jets} = 4$ quite populated
- 13 TeV analysis ⇒ Essentially only SR with $N_{jet} = 2$.

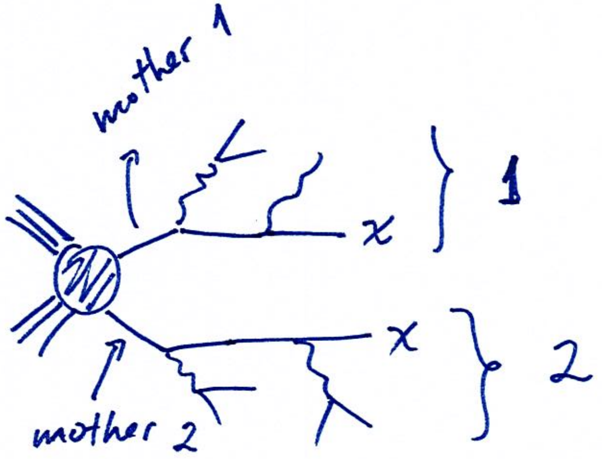
} 8 TeV analysis gives stronger constraints!

CONCLUSIONS

- Including $N \geq 2$ hard jets to the analyses produces stronger constraints than monojet configuration
- Spin-0 s-channel Simplified Models specially concerned (production dominated by gluon-fusion)
- Signal regions with 3 and 4 jets contribute in an important way
  [optimisations in the cuts are required for the Simplified Model interpretation]
- 8 TeV multijet +MET stronger than 13 TeV
  [design of signal regions bet suited for Simpl. Models in the former analysis]
- Multijet +MET @ 13 TeV [1605.03814]
  - . dominated by large systematic uncertainties ⇒ hard to reduce
  - . Prospects with increasing luminosity not too appealing for the time being

Thank you!

BCKP #1 (M_{T_2})



$$(M_T^{(i)})^2 = (m^{vis(i)})^2 + m_X^2 + 2\left[E_T^{vis(i)} E_T^{X(i)} - \vec{p}_T^{\,vis(i)} \cdot \vec{p}_T^{\,X(i)} \right]$$

$$M_{T_2} = \min_{\vec{p}_T^{\,X(1)} + \vec{p}_T^{\,X(2)} = \vec{p}_T^{\,mis}} \left[\max\left(M_T^{(1)}, M_T^{(2)} \right) \right]$$

$M_T^{1,2} \leq m_{mother_{1,2}}$ if true $\vec{p}_T^{\,X_{1,2}}$ is used

ensures that, for the correct mass m_X, $M_{T_2} \leq m_{mother_{1=2}}$

$\Downarrow$

distribution with endpoint