Phenomenological study of Monotop channels in search of physics beyond the standard model

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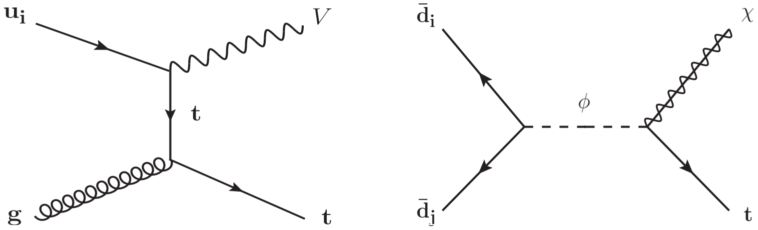
Outline

1. Physics beyond SM, Monotop models
    - Theoretical model
    - Possible experimental scenarios
    - Motivation about the chiral nature of DM candidates
2. The Analysis
    - SM background estimation
    - The event selection criteria
3. Results
    - The transverse mass. m_T
    - Leptonic channel
    - Hadronic Channel
4. Conclusions
5. References

Feynman diagrams Monotop to tree-level



Monotop production can occur via two mechanism:

- top is produced through a flavor-changing interaction plus (V) a new bosonic state.
- top is produced plus χ a new fermionic state through of color particle ϕ. [1]

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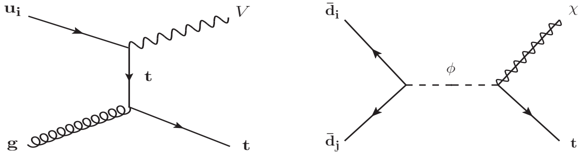
[1] **arxiv:1106.6199 arxiv:1311.6478**

Monotop Lagrangian



$$
\begin{aligned}
\mathcal{L} \;=\;& \mathcal{L}_{SM} \\
+\;& \phi\bar{u}\left[a^{0}_{FC} + b^{0}_{FC}\gamma_5\right]u + V_\mu\bar{u}\left[a^{1}_{FC}\gamma^\mu + b^{1}_{FC}\gamma^\mu\gamma_5\right]u \\
+\;& \epsilon^{ijk}\varphi_i\bar{d}^c_j\left[a^{0}_{SR} + b^{q}_{SR}\gamma_5\right]d_k + \varphi_i\bar{u}^i\left[a^{1/2}_{SR} + b^{1/2}_{SR}\gamma_5\right]\chi \\
+\;& \epsilon^{ijk}\widetilde{\varphi}_i\bar{d}^c_j\left[\widetilde{a}^{0}_{SR} + \widetilde{b}^{q}_{SR}\gamma_5\right]u_k + \widetilde{\varphi}_i\bar{d}^i\left[\widetilde{a}^{1/2}_{SR} + \widetilde{b}^{1/2}_{SR}\gamma_5\right]\chi \\
+\;& \epsilon^{ijk}X_{\mu,i}\bar{d}^c_j\left[a^{q}_{VR}\gamma^\mu + b^{q}_{VR}\gamma^\mu\gamma_5\right]d_k \\
+\;& X_{\mu,i}\bar{u}^i\left[a^{1/2}_{VR}\gamma^\mu + b^{1/2}_{VR}\gamma^\mu\gamma_5\right]\chi + h.c.,
\end{aligned}
\tag{1}
$$

[2]

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[2] **arxiv:1106.6199 arxiv:1311.6478**

Monotop production in more general theories

Such processes occur in:

- R-parity violation SUSY
- Intermediate particle is a (possibly on-shell) squark
- χ is the lightest neutralino ($d\bar{s} \rightarrow \tilde{u}_i \rightarrow t\tilde{\chi}_1^0$, where $\tilde{u}_i$ are any up squarks)
- $SU(5)$ models the leptoquark V decays into a top and a neutrino ($\bar{d}\bar{d} \rightarrow V \rightarrow t\bar{\nu}$)

$dd' \rightarrow X \rightarrow uN$ Monojet Constrains: $|\lambda_1\lambda_2| \leq 10^{-2}$
Recent Monotop searches constrain the top coupling

$$\lambda^{\alpha,3} \sim 10^{-1}$$

This correspond to $\lambda_1\lambda_2 \sim 10^{-2}$ if there are only third generation top and u-type quark couplings

Masses: $m_X \sim 1$ TeV, $m_N \sim 1$ GeV

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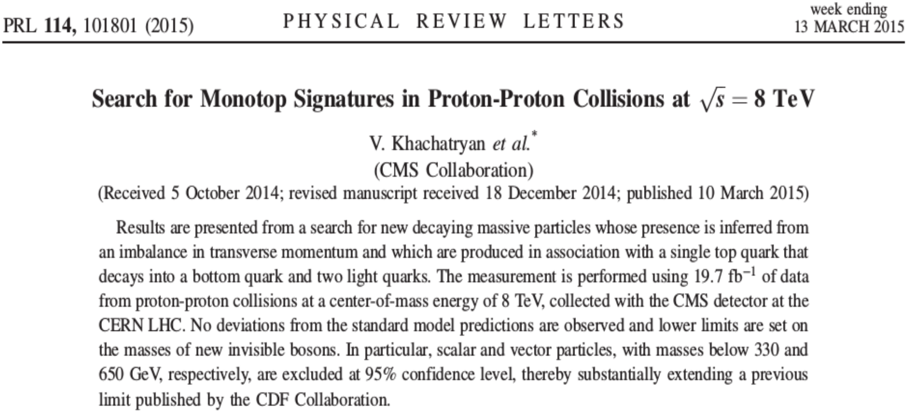


PRL **114,** 101801 (2015) PHYSICAL REVIEW LETTERS week ending 13 MARCH 2015

Search for Monotop Signatures in Proton-Proton Collisions at $\sqrt{s} = 8$ TeV

V. Khachatryan *et al.*[*]
(CMS Collaboration)

(Received 5 October 2014; revised manuscript received 18 December 2014; published 10 March 2015)

Results are presented from a search for new decaying massive particles whose presence is inferred from an imbalance in transverse momentum and which are produced in association with a single top quark that decays into a bottom quark and two light quarks. The measurement is performed using 19.7 fb^{-1} of data from proton-proton collisions at a center-of-mass energy of 8 TeV, collected with the CMS detector at the CERN LHC. No deviations from the standard model predictions are observed and lower limits are set on the masses of new invisible bosons. In particular, scalar and vector particles, with masses below 330 and 650 GeV, respectively, are excluded at 95% confidence level, thereby substantially extending a previous limit published by the CDF Collaboration.

Distinguishing Standard Model Extensions using Monotop Chirality at the LHC

Rouzbeh Allahverdi[1], Mykhailo Dalchenko[2], Bhaskar Dutta[2], Andrés Flórez[3], Yu Gao[2], Teruki Kamon[2,4], Nikolay Kolev[5], Ryan Mueller[2], and Manuel Segura[3]

We present two minimal extensions of the standard model, each giving rise to baryogenesis. They include heavy color-triplet scalars interacting with a light Majorana fermion that can be the dark matter (DM) candidate. The electroweak charges of the new scalars govern their couplings to quarks of different chirality, which leads to different collider signals. These models predict monotop events at the LHC and the energy spectrum of decay products of highly polarized top quarks can be used to establish the chiral nature of the interactions involving the heavy scalars and the DM. Detailed simulation of signal and standard model background events is performed, showing that top quark chirality can be distinguished in hadronic and leptonic decays of the top quarks.

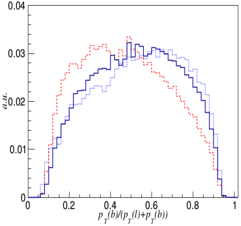


FIG. 4: Normalized b+lepton transverse momentum fraction spectrum from the semileptonic decay of left-handed (dotted) and right-handed (dashed) tops. The unpolarized (solid) spectrum is shown in black.

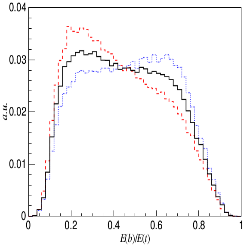
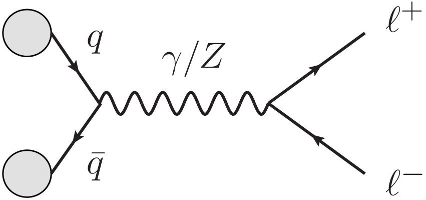


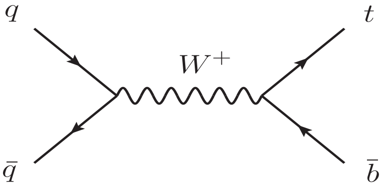
FIG. 3: Normalized b energy fraction spectrum from left-handed (dotted) and right-handed (dashed) top decays. The unpolarized (solid) spectrum is shown in black.

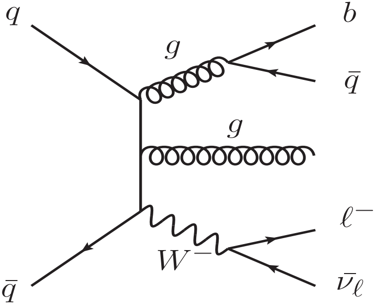
Main backgrounds

Monotop production can be classified according to the top quark decays

$$pp \to t + \not{E}_T \to bW + \not{E}_T \to bjj + \not{E}_T \qquad \text{or} \qquad bl + \not{E}_T \tag{2}$$







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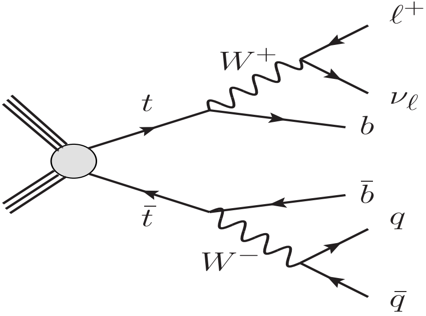

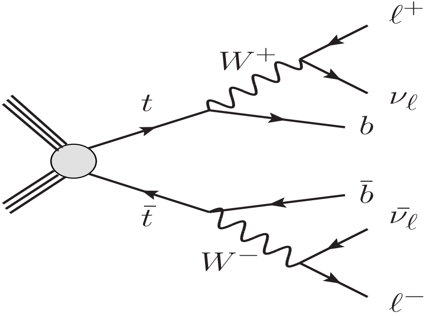

Main backgrounds, signals and their cross sections

Monotop production can be classified according to the top quark decays

$$pp \to t + \not{E}_T \to bW + \not{E}_T \to bjj + \not{E}_T \qquad \text{or} \qquad bl + \not{E}_T \tag{4}$$

Backgrounds	σ [pb]
$W(\to \ell\nu)$ + jets	31800
$\gamma^*/Z(\to 2\ell/2\nu)$ +jets	2240
Single top + jets	429.3
$t\bar{t}(\to$ 4jets 1ℓ $1\nu)$+ jets	151.9
$t\bar{t}(\to$ 2jets 2ℓ $2\nu)$+ jets	25.5
Signals	
Mono-right	0.0435
Mono-left	0.0434
Mono-mixing	0.0672

Table : Background and signal processes with their cross sections.

Others SM processes	σ [pb]
$t\bar{t}W$ + jets [incl.]	0.25
$t\bar{t}Z$ + jets [incl.]	0.21
$t/\bar{t} + Z$ + jets [incl.]	0.046
$t\bar{t}WW$ + jets [incl.]	0.013
$t\bar{t}t\bar{t}$ + jets [incl.]	0.007
$WW(\to 1\ell$ 1ν 2jets)+ jets	24.3
$WW(\to 2\ell$ $2\nu)$+ jets	5.87
$WZ(\to 1\ell$ 1ν 2jets)+ jets	5.03
$WZ(\to 2\nu$ 2jets)+ jets	2.98
$WZ(\to 2\ell$ 2jets)+ jets	1.58
$WZ(\to 1\ell$ $3\nu)$+ jets	1.44
$WZ(\to 3\ell$ $1\nu)$+ jets	0.76

[4]

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[4] **arxiv:1311.6478**

Event selection criteria for $100fb^{-1}$

Leptonic Channel

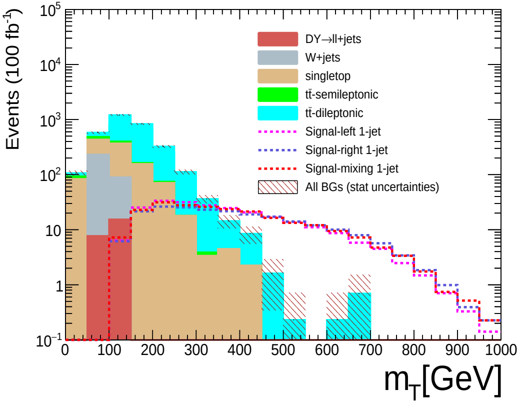
CMS Selections	value
$N\ j(b)$	$= 1$
$p_T\ j(b)$	> 70 GeV
$\|\eta(j(b))\|$	< 2.5
$N\ j$	$= 0$
$p_T\ j$	> 30 GeV
$\|\eta(j)\|$	< 2.5
$N\ \ell\ (\ell = \mu - OR - e\ )$	$= 1$
$p_T\ \ell$	> 30 GeV
$\|\eta(\ell)\|$	< 2.1
N another ℓ	$= 0$
$\vec{p}_T(W)$	> 50 GeV
$\|\Delta\phi(\ell, j(b))\|$	< 1.7
Overlaps removal	$\Delta R > 0.3$
$\not{E}_T$	> 100 GeV
m_T	> 400 GeV

Hadronic Channel

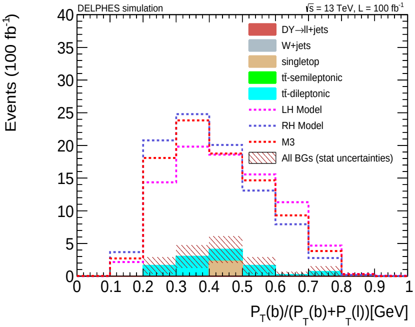
CMS Selections	value
$N\ j(b)$	$= 1$
$p_T\ j(b)$	> 70 GeV
$\|\eta(j(b))\|$	< 2.5
$N\ j$	$= 2$
$p_T\ j$	> 30 GeV
$\|\eta(j)\|$	< 2.5
$N(\ell)$	$= 0$
$\not{E}_T$	> 350 GeV
$m(j, j, b)$	< 450 GeV

Why the last cut? (m_T)

$$m_T = \sqrt{2|\vec{p}_\ell||\not{E}_T|[1 - \cos\Delta\phi_{\ell,\not{E}_T}]} \tag{5}$$



Results for leptonic channel (Helicity)



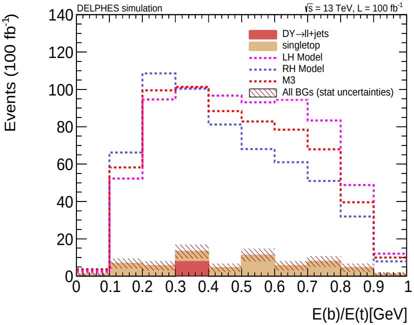
Process	Events
Mono-left	86
Mono-right	93
Mono-full	91
Single-top	2
$t\bar{t}$ di	9

$$\frac{S}{\sqrt{S+B}} = 8.9 \tag{6}$$

$$\frac{S}{\sqrt{S+B}} = 9.1 \tag{7}$$

$$\frac{S}{\sqrt{S+B}} = 9.0 \tag{8}$$

Results for hadronic channel (Helicity)



Process	Events
Mono-left	678
Mono-right	580
Mono-full	629
Single-top	63
Drell-yan	8

$$\frac{S}{\sqrt{S+B}} = 24.7 \tag{9}$$

$$\frac{S}{\sqrt{S+B}} = 22.6 \tag{10}$$

$$\frac{S}{\sqrt{S+B}} = 23.7 \tag{11}$$

Conclusions

- We have discussed minimal extension of the SM, the motivation and the strategies
- New cuts were implemented in order to improve the statistical significance of the experimental search
- As chiral couplings to top quarks are common in BSM models, spectral analysis of the top quark final states is a promising method to distinguish between different model and SM background
- This study allows us to understand the possible Baryogenesis scenarios

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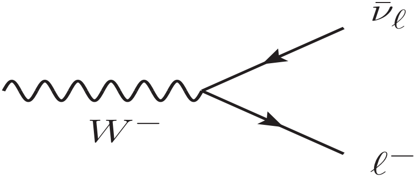
$\boxed{Thanks}$

Transverse Mass (m_T)



$$\begin{aligned} P_i^\mu &= P_W^\alpha, & P_\mu P^\mu &= M_W^2 \\ P_f^\nu &= P_\ell^\beta + P_{\bar{\nu}}^\gamma & P_\nu P^\nu &= (E_\ell + E_{\bar{\nu}})^2 - (\vec{p}_\ell + \vec{p}_{\bar{\nu}})^2 \end{aligned} \tag{12}$$

$$\begin{aligned} m_W^2 &= E_\ell^2 + E_{\bar{\nu}}^2 + 2E_\ell E_{\bar{\nu}} - |\vec{p}_\ell|^2 - |\vec{p}_{\bar{\nu}}|^2 - 2|\vec{p}_\ell||\vec{p}_{\bar{\nu}}|\cos\Delta\phi_{\ell,\bar{\nu}} \\ m_W^2 &= m_\ell^2 + m_{\bar{\nu}}^2 + 2[E_\ell E_{\bar{\nu}} - |\vec{p}_\ell||\vec{p}_{\bar{\nu}}|\cos\Delta\phi_{\ell,\bar{\nu}}] \end{aligned} \tag{13}$$

$$m_T = \sqrt{2|\vec{p}_\ell||\not{E}_T|[1 - \cos\Delta\phi_{\ell,\not{E}_T}]} \tag{14}$$