Search for dark matter in mono-top signature at the LHC

Top-LHC-France 2017
4-5 May 2017, Marseille

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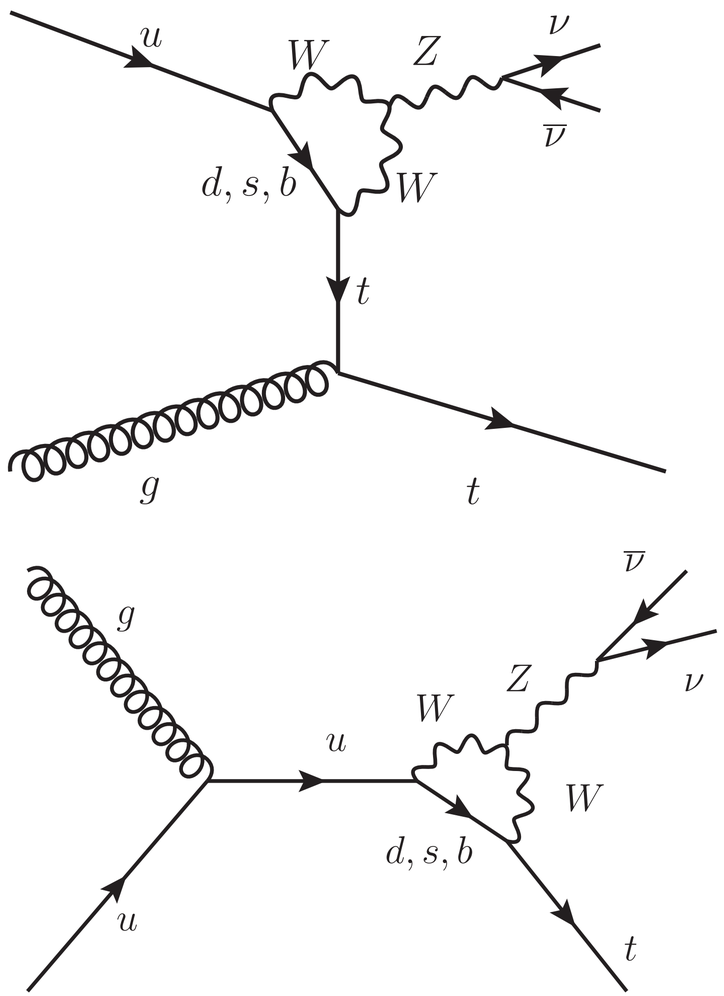
on behalf of the ATLAS and CMS Collaborations

Motivation

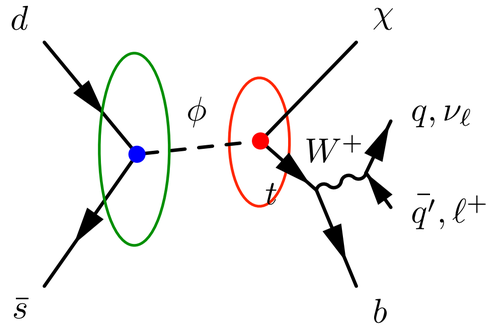
- mono-top: a final state of a single-top plus large missing transverse energy (E_T^{miss})
- In SM, this signature could only occur as the **loop-induced associate production with a Z boson** decaying into a pair of neutrinos
- But such **Flavour-Changing Neutral Current (FCNC) process is suppressed in SM** (by the GIM mechanism)
- Therefore, any significant excess in such a final state would be a clear and strong sign of new physics
- Comparing with the final states of mono-jet, the mono-top search gives **a much clearer and easier signature to discriminate than a light jet**, and **more advantages of fixing the flavor of the final state and restricting the partons in the initial state**.



Introduction of signal models

- **Resonant scalar mediator:**
  - Majorana fermion as DM, a colored scalar (ϕ) decaying to top quark and DM

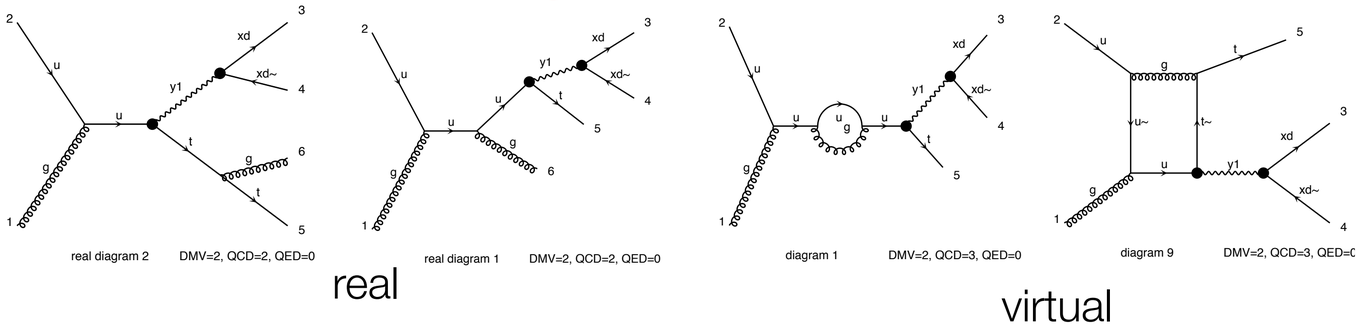
$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{kin}(\phi_s, \chi) + (\phi \bar{d}_i^C [(a_{SR}^q)^{ij} + (b_{SR}^q)^{ij}\gamma^5] d_j + \phi \bar{t}[a_{SR}^{1/2} + b_{SR}^{1/2}\gamma^5]\chi + \text{h.c.})$$

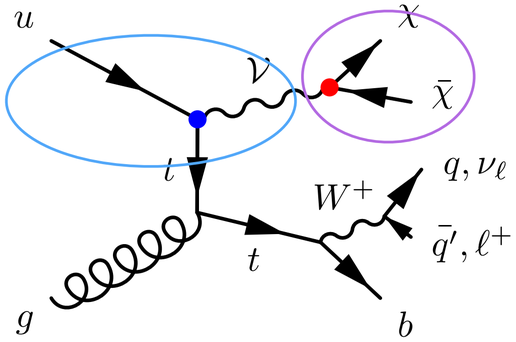


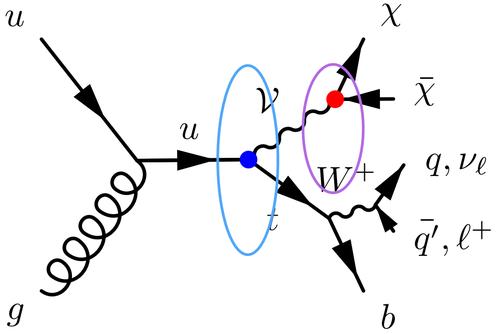
- **Non-resonant vector mediator FCNC model:**
  - Dirac fermion as DM (or vector mediator as DM directly)

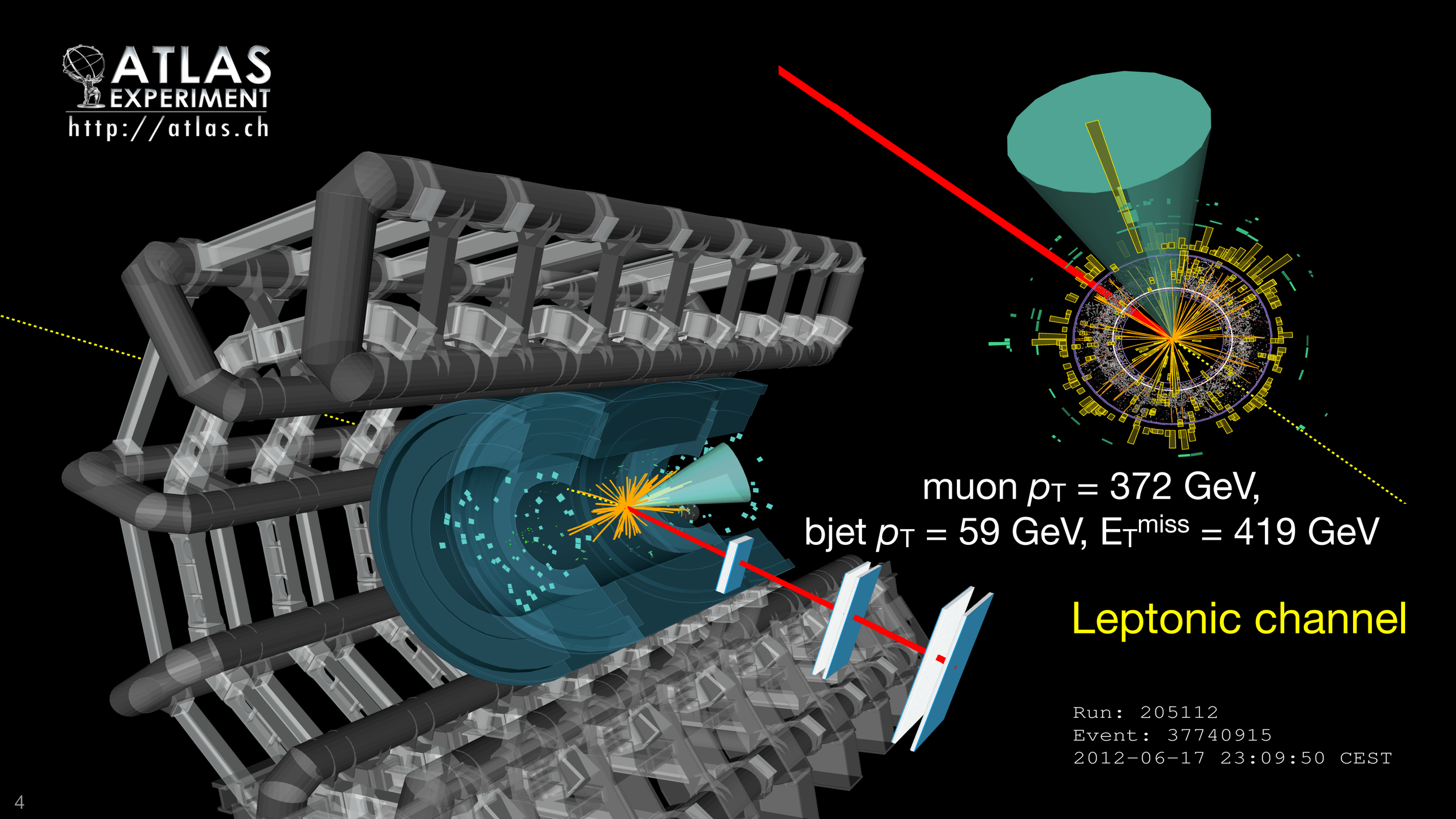
$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{kin} + V_\mu(g_{R_\chi}\bar{\chi}_R\gamma^\mu\chi_R + g_{L_\chi}\bar{\chi}_L\gamma^\mu\chi_L) + V_\mu\bar{u}_i[(a_{FC})^{ij}\gamma^\mu + (b_{FC})^{ij}\gamma^\mu\gamma^5]u_j + \text{h.c.}$$

NLO model is being used now in both CMS & ATLAS





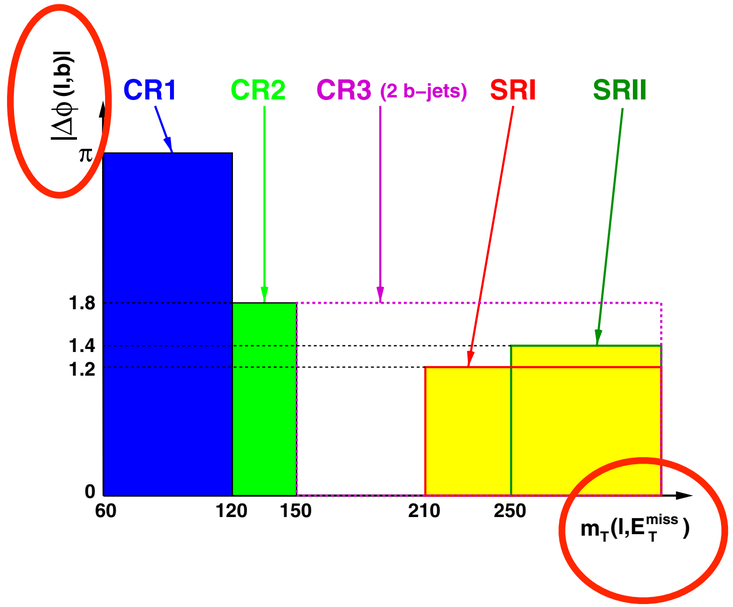



ATLAS
EXPERIMENT
http://atlas.ch
muon p_T = 372 GeV,
bjet p_T = 59 GeV, E_T^{miss} = 419 GeV
Leptonic channel
Run: 205112
Event: 37740915
2012-06-17 23:09:50 CEST

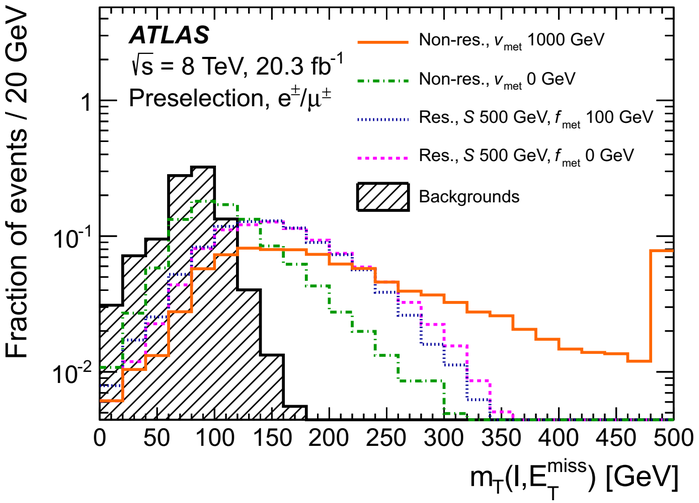
Leptonic channel @ 8TeV

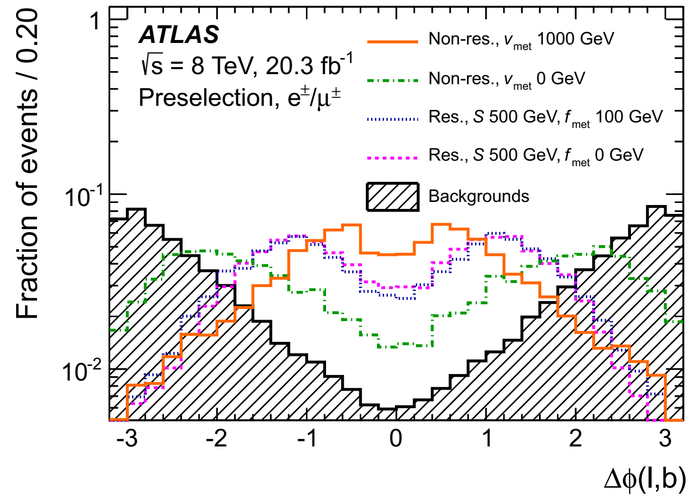
Eur. Phys. J. C75 (2015) 79

- Signature: one isolated charged lepton (electron/muon) from the W decay, one b-tagged jet, large E_T^{miss}
  - a well-defined electron or muon with $p_T > 30$ GeV
  - one b-tagged jet with $p_T > 25$ GeV (Eff: 57%)
  - $E_T^{miss} > 35$ GeV, $mT(\ell, E_T^{miss})+E_T^{miss} > 60$ GeV



SRI (resonant model)	$mT(\ell, E_T^{miss}) > 210$ GeV $\lvert\Delta\phi(\ell, b)\rvert < 1.2$
SR2 (non-resonant model)	$mT(\ell, E_T^{miss}) > 250$ GeV $\lvert\Delta\phi(\ell, b)\rvert < 1.4$
CR1	$60 < mT(\ell, E_T^{miss}) < 120$ GeV
CR2	$120 < mT(\ell, E_T^{miss}) < 150$ GeV $\lvert\Delta\phi(\ell, b)\rvert < 1.8$
CR3	one extra bjet, pT < 50 GeV $mT(\ell, E_T^{miss}) > 150$ GeV, $\lvert\Delta\phi(\ell, b)\rvert < 1.8$





Leptonic channel @ 8TeV

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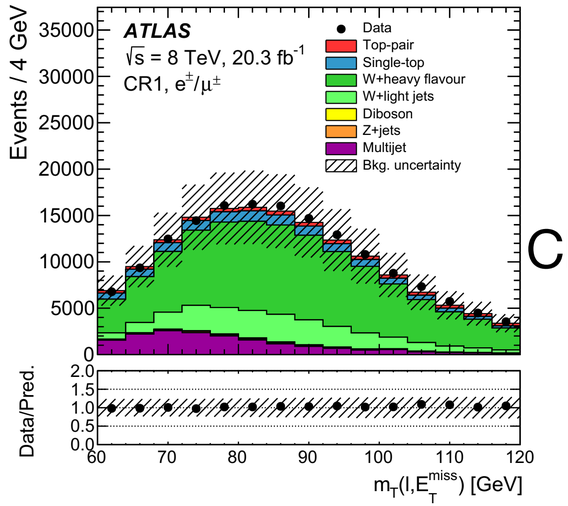
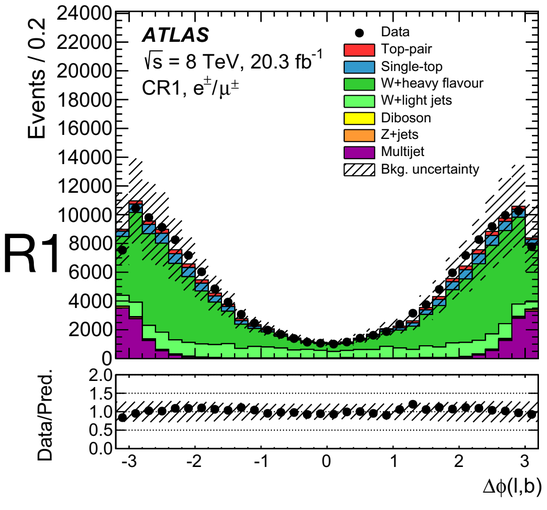
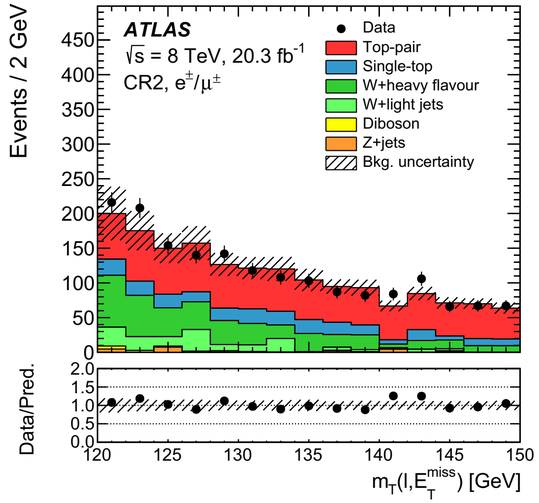
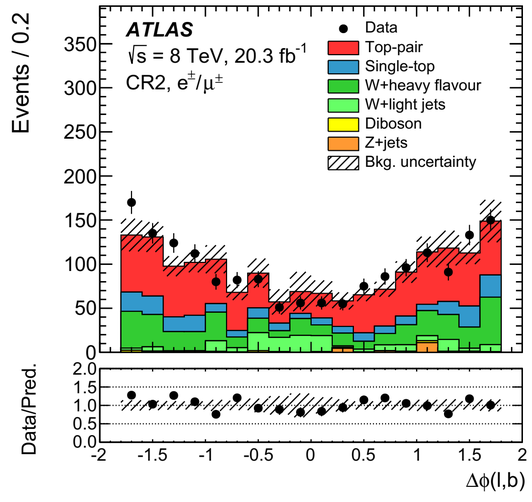


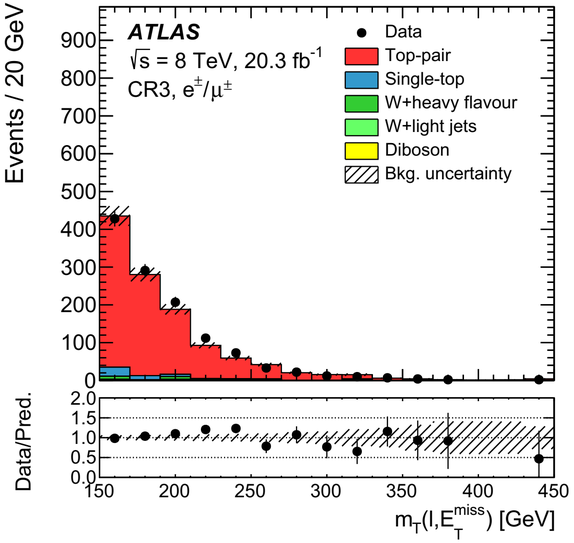


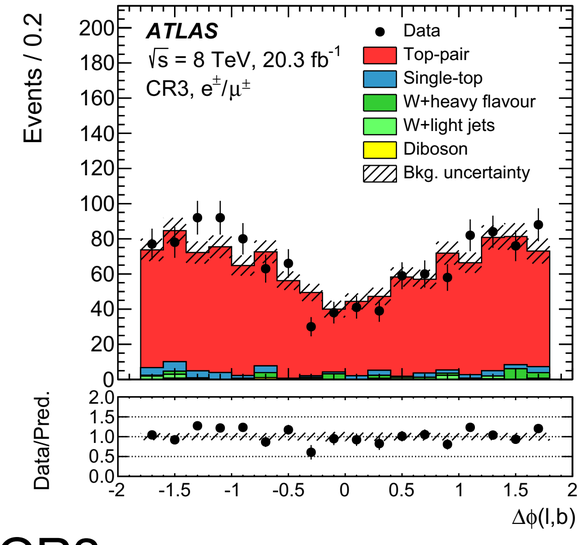
CR1





CR2





CR3

Good agreement between data and prediction!

Leptonic channel @ 8TeV

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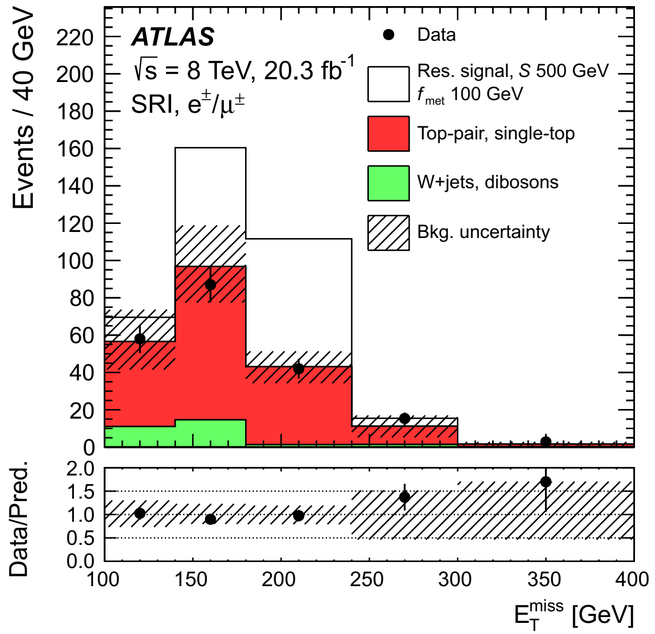
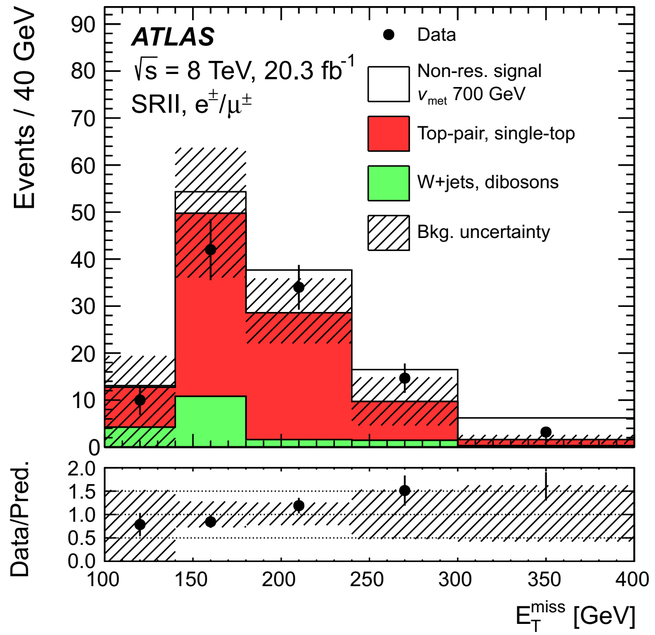
- Experimental uncertainties in signal (background)
  - **jet energy scale: 1-5% (9-10%),** jet energy resolution: 2-3% (**1-2%**)
  - jet vertex fraction: 2-3% (**2-6%**), b-tagging efficiency 3-5%
  - luminosity: 2.8%
- Signal & background acceptance modeling
  - PDF+α_S: 4-11% (**5-6%**)
  - **ttbar: 5-11% (different generators),** Wt: 5-8%
- Background normalization
  - **ttbar: 5-6%**, Wt: 7%, VV/W+jets: 25%

	SR1	SR2
Total background	240±10±50	124±11±27
Data	238	133

Good agreement between data and background, no significant excess is observed!





Leptonic channel @ 8TeV

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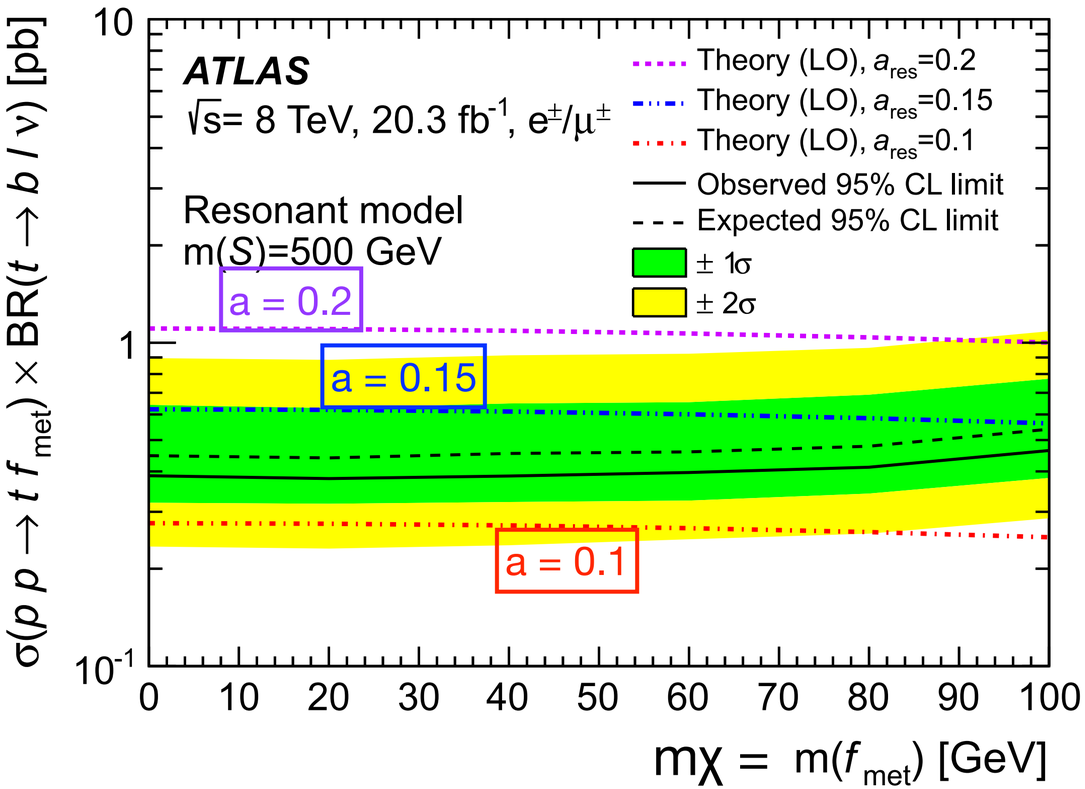
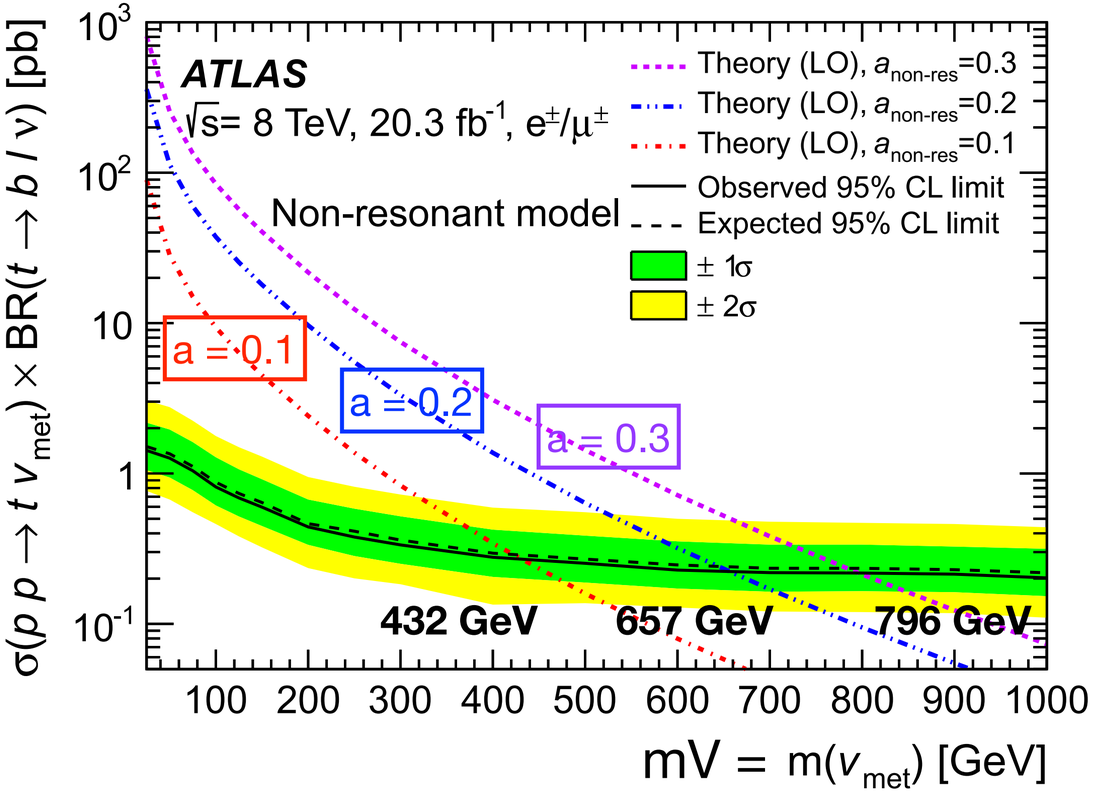
- No excess is observed.
- At 95%CL, resonant model with effective coupling = 0.2 are excluded in the whole mass range
- For the non-resonant model, cross-sections corresponding to coupling = 0.1 (0.2, 0.3) are excluded up to mV = 432 GeV (657 GeV, 796 GeV)

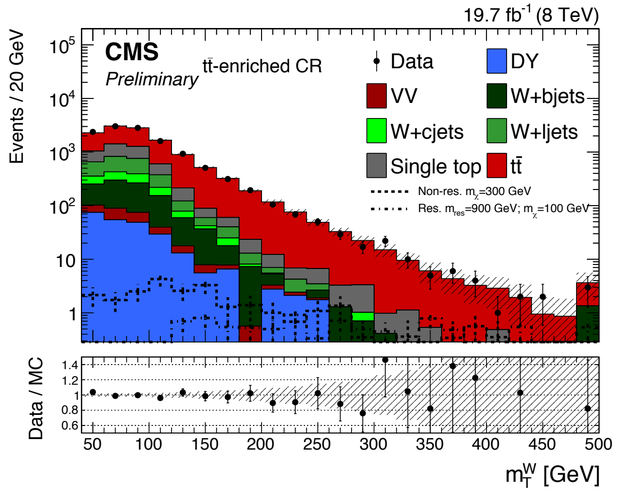


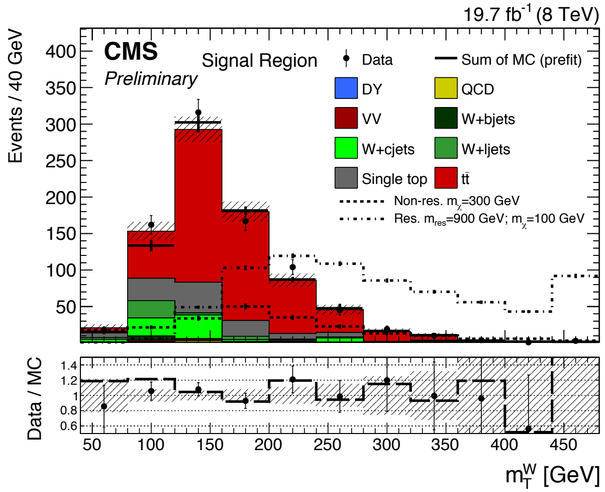


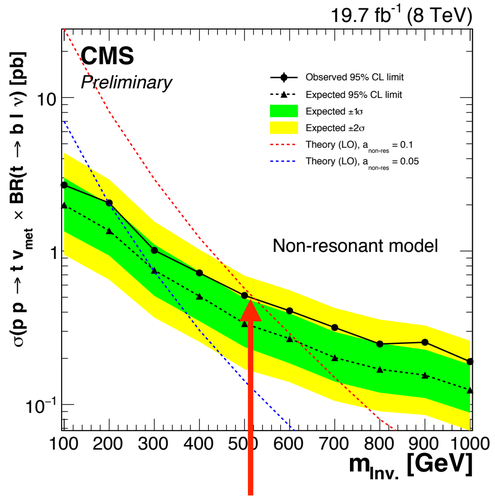
Leptonic channel @ 8TeV

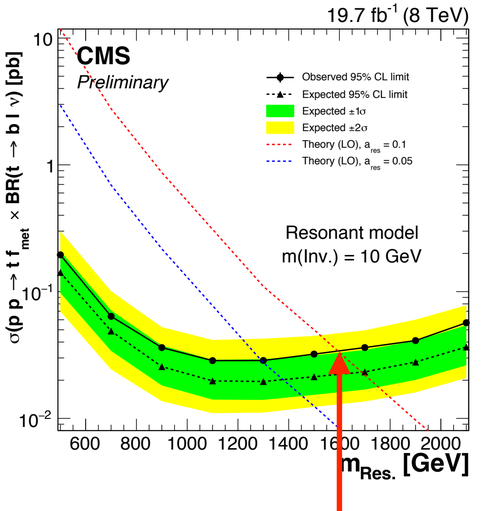
CMS-PAS-B2G-15-001

- A muon channel of mono-top search is also performed by CMS
  - one isolated muon ($p_T > 33$ GeV), no extra leptons
  - one b-tagged jet with pt > 70 GeV, no extra jets ($p_T > 30$ GeV)
  - $\Delta\phi$(muon, jets) < 1.7 rad, $E_T^{miss} > 100$ GeV, mT(ℓ, E_T^{miss}) > 50 GeV
- Two CRs (zero btag, two btags) are defined to estimate the W+jets and ttbar background from data
- Simultaneous fit is performed on the SR and two CRs, good agreement between the data and the SM predictions, no excess is observed.
- At 95%CL, **mV < 523 GeV** is excluded for **vector mediator**, **mϕ < 1.6 TeV is excluded for mDM = 10 GeV** for **scalar mediator**





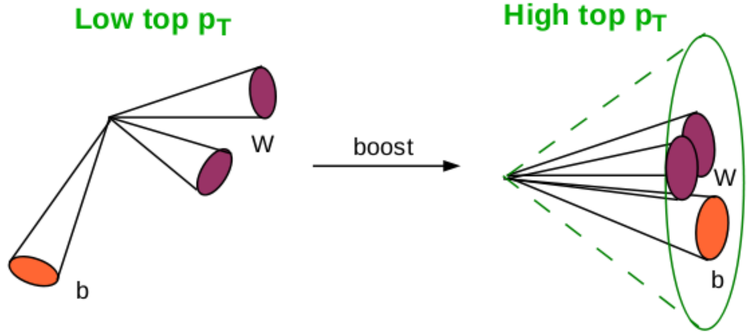




Hadronic channel @13TeV

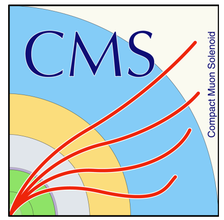
CMS-PAS-EXO-16-040

- Signature: large E_T^{miss} plus a hadronically decaying W boson from top quark decay
  - largest branching fraction
  - reconstructible of boosted top quark: a single large-R jet, jet substructure
- Trigger: no muon MET/MHT > 110 GeV, (Eff>99%, when E_T^{miss}>250 GeV)
- Background:
  - Z(vv) + jets, ttbar, W(ℓv) + jets (data-driven)
  - Single-top, VV, QCD (MC estimated)
- Selection:
  - E_T^{miss} > 250 GeV
  - Narrow jet (anti-kT (0.4), p_T>30 GeV, |eta|<4.5) — veto QCD and ttbar
    - $\Delta\phi(E_T^{miss}, jets) > 1.1$, no extra b-jet with ΔR (Fatjet, bjets) < 1.5
  - Electron (p_T> 10 GeV), muon(p_T> 15 GeV), hadronic tau(p_T> 18 GeV) veto
  - **Large-R jet**

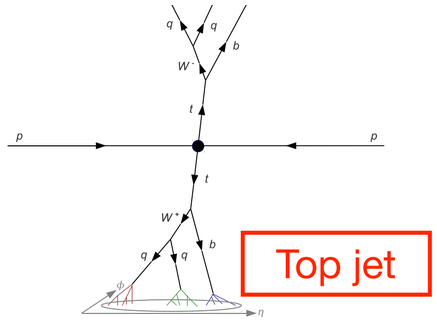


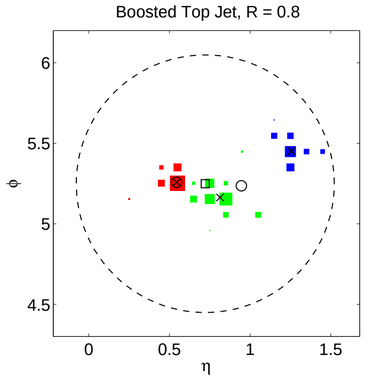
Hadronic channel @13TeV— boost top tagging

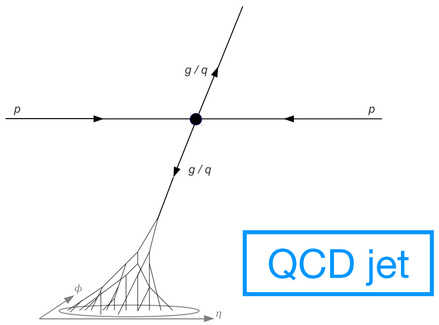
CMS-PAS-EXO-16-040

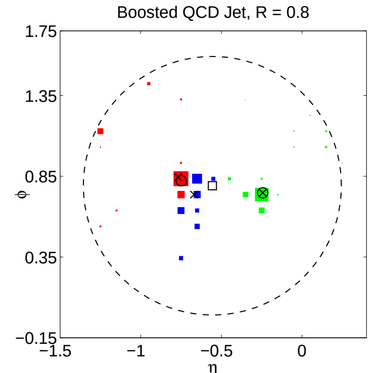


- **Large-R jet (Cambridge-Aachen (1.5), pT > 250 GeV, |eta|<2.5) — selecting hadronically-decaying top quark**
  - mach with bjet inside the fat jet cone
  - 110 GeV < mJ < 210 GeV
  - τ_3/τ_2 (eff:13%), compatibility of a jet has N subjet (τ_N)

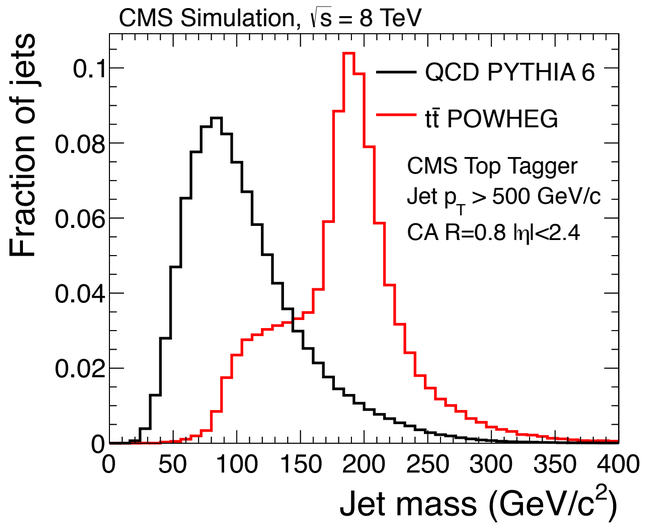


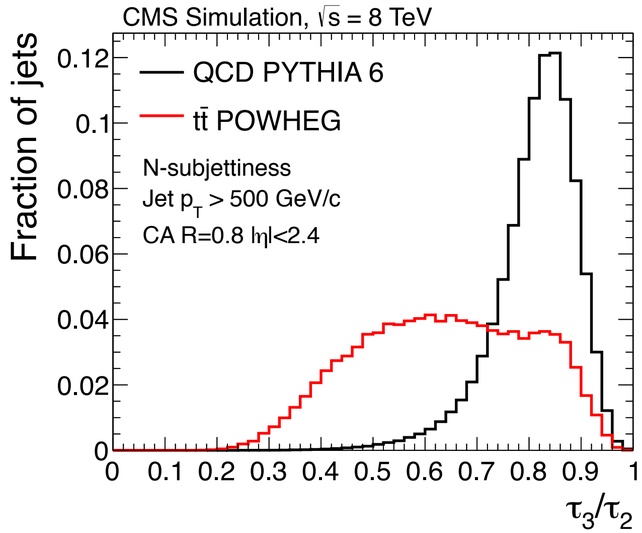






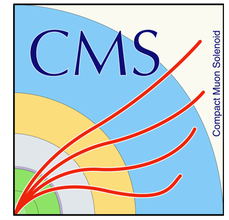
- **top tagging efficiency: 3% (ttbar)**
- **mis-tagging of a non-top jet: 3% (tγ+jets)**





Hadronic channel @13TeV— Background estimation

CMS-PAS-EXO-16-040



- To constrain three main backgrounds: Z(vv) + jets, ttbar, and W(ℓv) + jets, global simultaneous likelihood fits to 7 CRs and SR are used
  - Z(vv) + jets: CRs from Z(ee/μμ) + jets, and γ + jets **(large statistics, similar jet multiplicity, underlying event, and pileup conditions as the DY process for the region of interest at high pT region)**
  - ttbar: Single-lepton CRs, **requiring at least one narrow btagged jet**, and ΔR (Fatjet, bjets) > 1.5
  - W(ℓv) + jets: Single-lepton CRs, **no narrow btagged jet** with ΔR (Fatjet, bjets) > 1.5

$$\mathcal{L}^{Bkg}(\mu_i^{Bkg}, \mu, \theta_i) = \prod_{X}^{ee,\mu\mu,\gamma,e,\mu,eb,\mu b} \text{Poisson}\left(d_i^X | B_i^X(\theta_i) + \frac{\mu_i^{Bkg}}{R_i^X(\theta_i)}\right) \times \text{Poisson}\left(d_i^{SR} | B_i^{SR}(\theta_i) + \mu_i^{Bkg} + \mu \cdot S_i(\theta_i)\right)$$

$$R_i^X(\theta_i) = \frac{\mu_i^{Bkg}}{N_i^X(\theta_i)}, \qquad X = \begin{cases} ee, \mu\mu, \gamma, & Bkg = Z \to \nu\nu \\ e, \mu, & Bkg = W \to \ell\nu \\ eb, \mu b, & Bkg = t\bar{t} \end{cases}$$

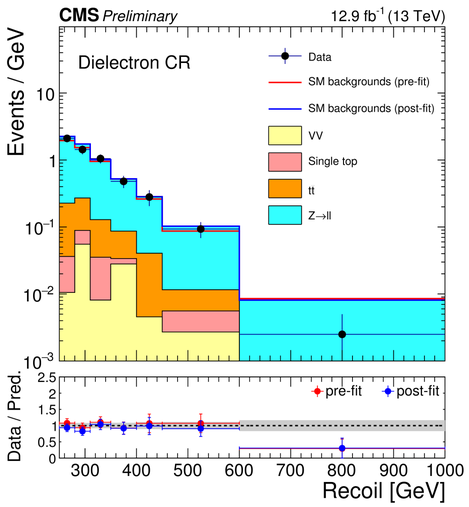
7 CRs

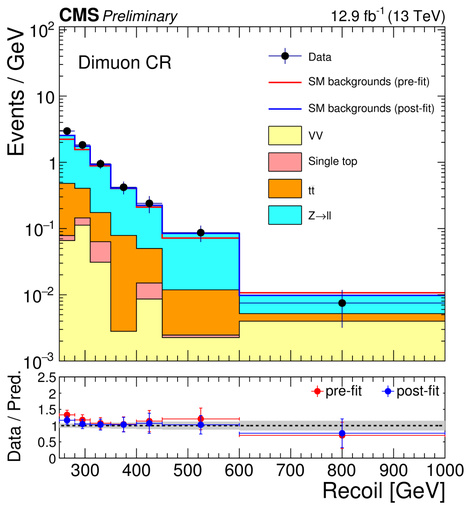
3 Bkgs

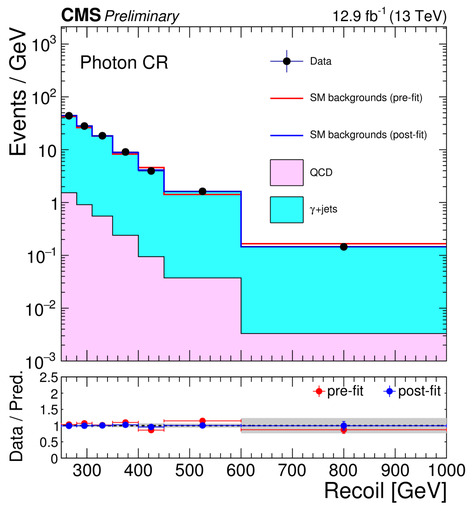
$S_i(\theta_i)$		the expected number of signal events in SR
μ_i^{Bkg}		the number of bkg events in SR regions
$R_i^X(\theta_i)$		transfer factor from SR to each of CRs
$B_i^X(\theta_i)$	$B_i^{SR}(\theta_i)$	the number of other expected background in CR the number of other expected background in SR
d_i^X	d_i^{SR}	the observed number of events in CR the observed number of events in SR

Hadronic channel @13TeV— Background estimation

CMS-PAS-EXO-16-040

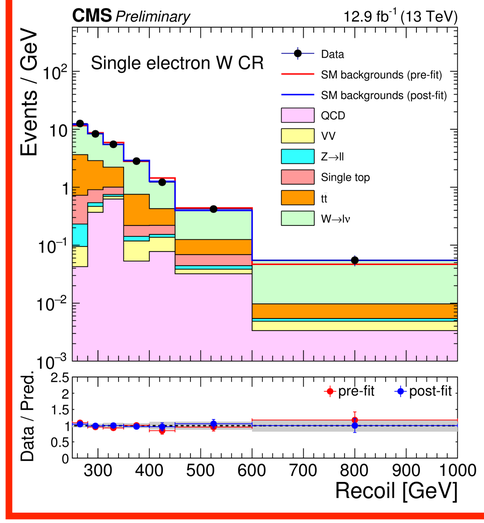


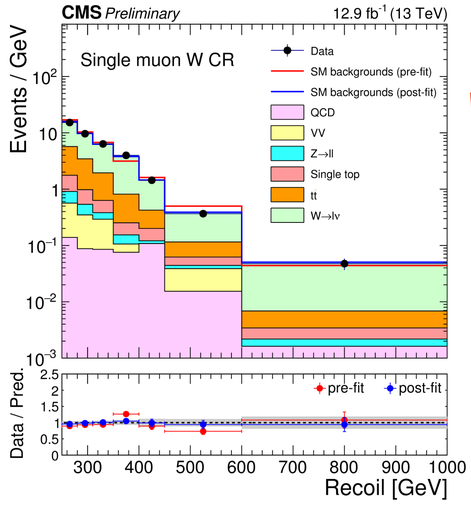




Z(νν) + jets

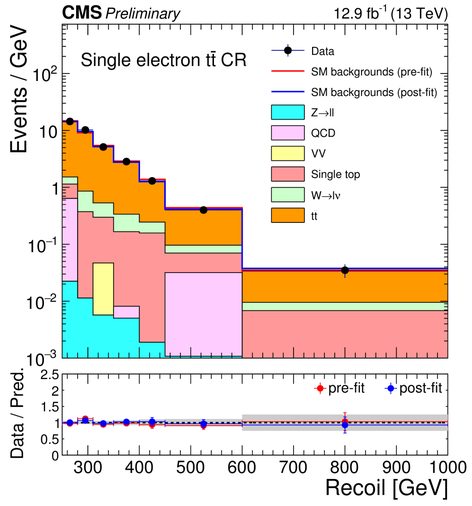
Good agreement between data and prediction!

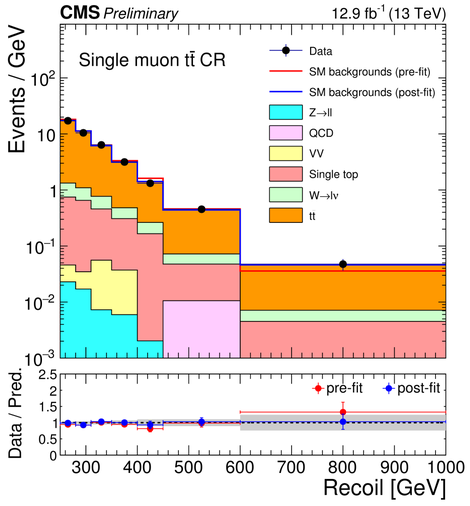




W(ℓν) + jets

Recoil: MET with removal of leptons and photons

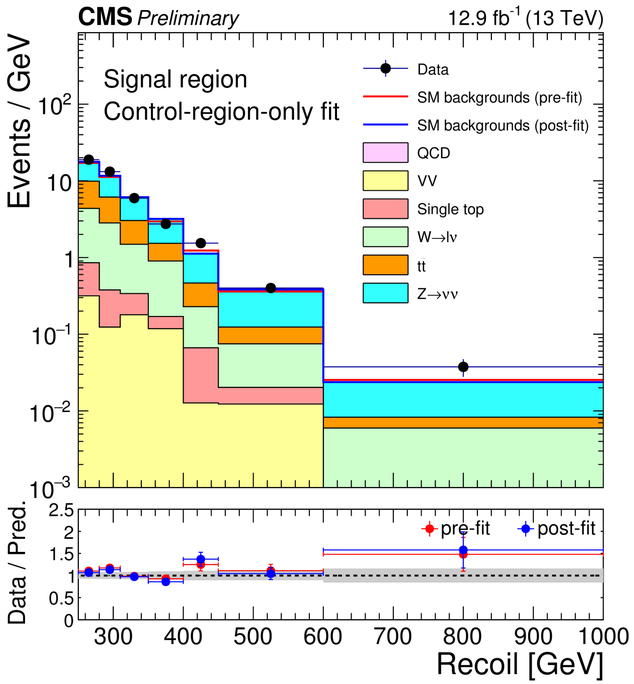




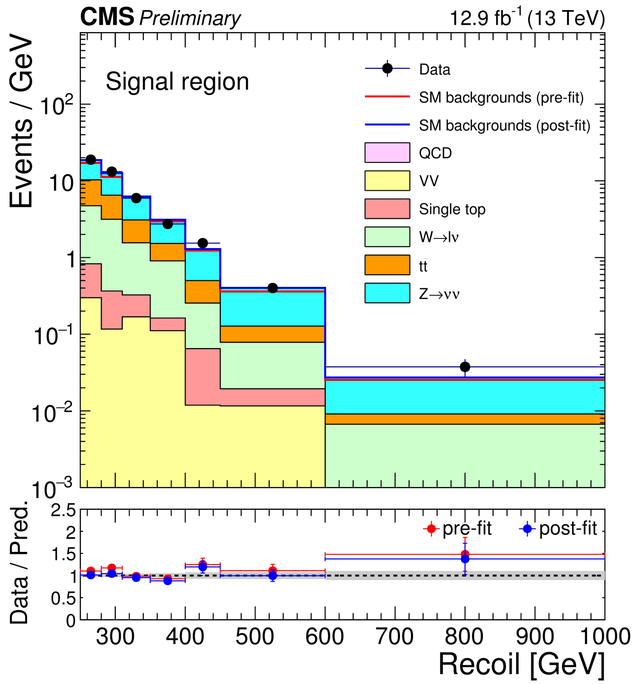
ttbar

Hadronic channel @13TeV— Results

CMS-PAS-EXO-16-040



7 CRs only fit



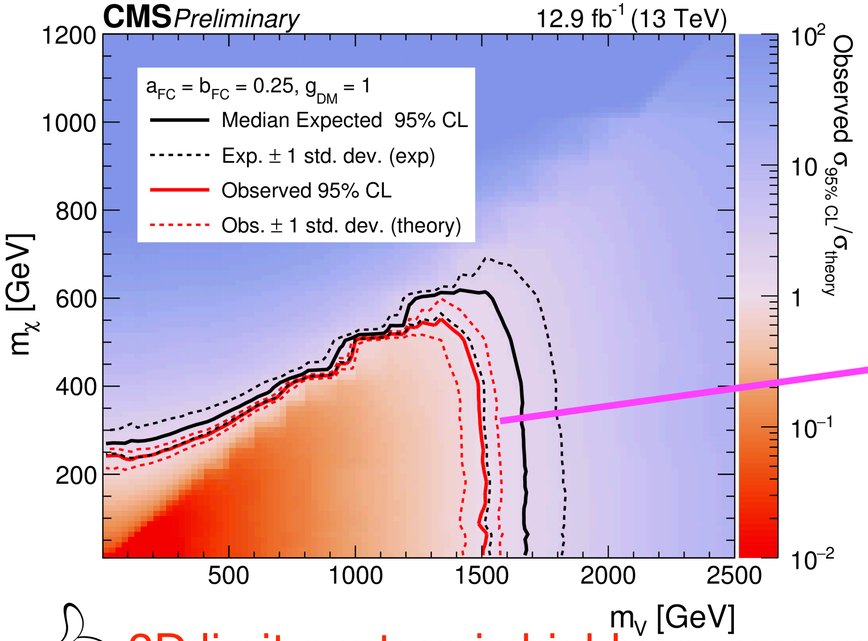
7 CRs + 1 SR fit

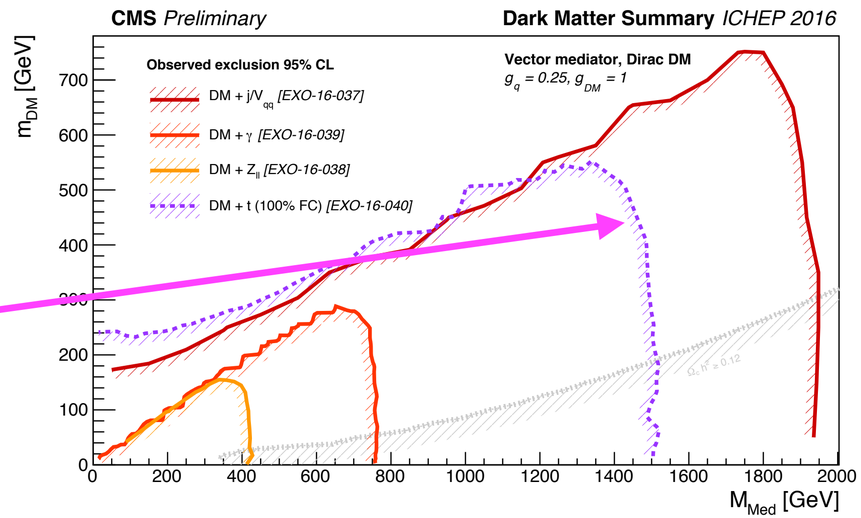
- **Good agreement between data and background, no significant excess is observed!**
- Experimental uncertainties
  - electron/muon/photon/tau selection efficiency: 2-3%
  - **top tagging efficiency: 3% (ttbar)**
  - **mis-tagging of a non-top jet: 3% (tγ+jets)**
  - luminosity: 6.2%
- Background modeling:
  - **V+jets: 1-4%** (W+HF: 21%, Z+HF: 22%)
  - single-top, VV: 20%
  - QCD: 80% (negligible)

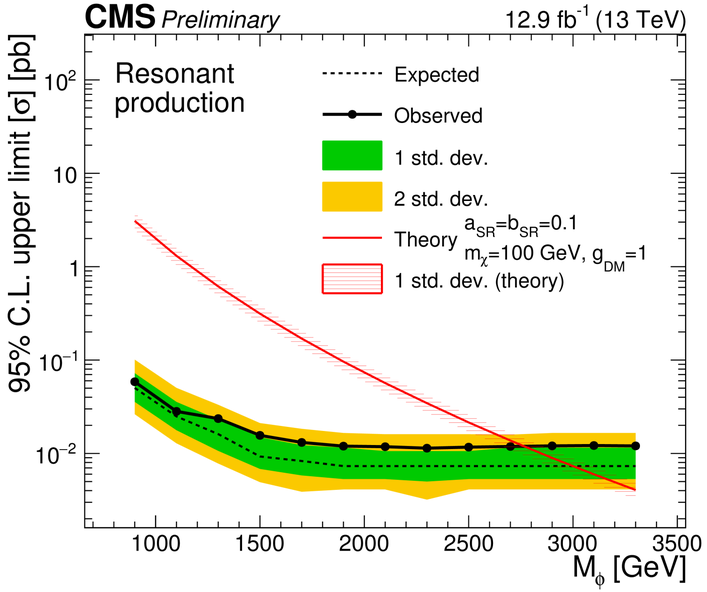
Hadronic channel @13TeV— Results

CMS-PAS-EXO-16-040

- Good agreement with SM predictions
- The **FCNC is excluded for vector mediator 0.3 < mV < 1.5 TeV, assuming mχ = 10 GeV**
  - with 100% FC, much more sensitive than mono-V, complementary to mono-jet
- For **mχ = 100 GeV**, the **resonant scalar model** is excluded for **0.9 < Mϕ < 2.7 TeV** at 95% CL







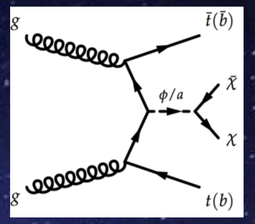
2D limit contour is highly recommended

Conclusion & outlook

- Dark Matter searches in mono-top signature from ATLAS & CMS at 8/13 TeV are summarized
- Both leptonic and hadronic channels are considered
  - @8 TeV: ATLAS LPC Clermont + CMS IPHC Strasbourg
  - **@13 TeV: ATLAS LPNHE-Paris: mono-top (hadronic, leptonic) + CMS IPHC Strasbourg**

- Consistent with Direct and Indirect searches, no DM candidate has been seen at the LHC yet
  - **with 100% FC, mono-top is more sensitive than mono-V, complementary to mono-jet**
  - **becoming one of important DM+HF channel: sizable contribution to tt+DM searches (in range 30% to 200%)**

- ***Results from using full 2015+2016 dataset is being prepared, stay tuned!***



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