Searches for monotop events at 8 TeV

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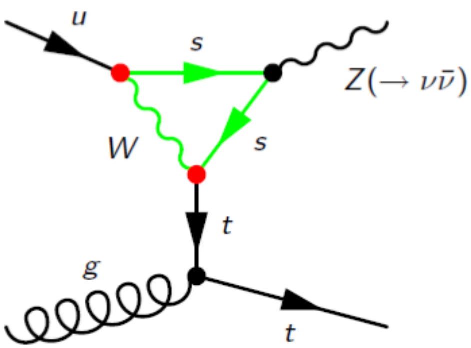
Introduction to monotops

- **Monotop :** **top + MET** (possibly DM candidate) $pp \to t + \not{E}_T$
- **Effective theory approach :** all possible production mechanisms in a single lagrangian ⇨ model independent
- **In the SM :**



Loop + **GIM-suppressed** : observing monotop at the LHC ⟺ BSM physics

- **Models with same signature :** RPV SUSY [1], leptoquarks [2], Z' model [3] ...
- **Outline :** overview of the current CMS results on searches for monotop events

2014 — **CMS hadronic analysis** B2G-12-022 10.11003/PhysRevLett.114.101801

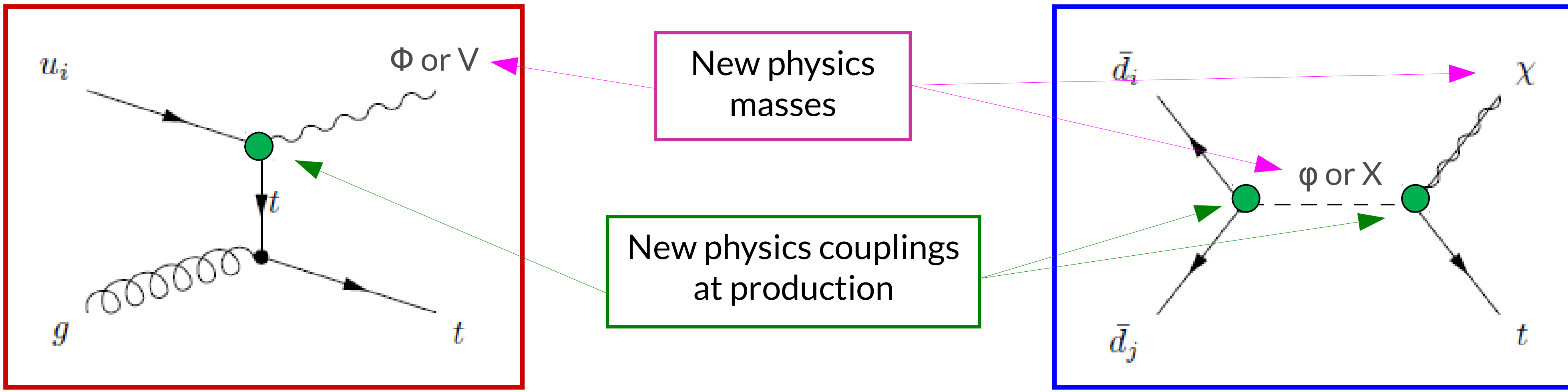
2015 — **ATLAS leptonic analysis** Eur. Phys. J. C75:79 (2015) 1541

2016 — **CMS leptonic analysis** B2G-15-001

Monotop production

More about the model : here

- Monotop signature either produced via **« non-resonant » (FCNC)** or **« resonant »** diagrams:



Non-resonant

$$\mathcal{L}_{\text{non-res}} = \phi \bar{t}[a^0 + b^0\gamma_5]u_i + V_\mu \bar{t}\gamma^\mu[a^1 + b^1\gamma_5]u_i$$

- Spin 0 or 1 missing energy (possibly **DM** candidate).
- A lot of **free parameters** (masses, couplings).

Resonant

$$\mathcal{L}_{\text{res}} = \varphi \bar{d}_i^c[a^q + b^q\gamma_5]\bar{d}_j + \varphi t[a^{1/2} + b^{1/2}\gamma_5]\chi$$
$$+ X_\mu \bar{d}_i^c\gamma^\mu[a^q + b^q\gamma_5]\bar{d}_j + X_\mu t\gamma_\mu[a^{1/2} + b^{1/2}\gamma_5]\chi$$

- Spin 0 or1 mediator.
- Spin 1/2 missing energy (possibly **DM** candidate).
- A lot of **free parameters** (masses, couplings).

Simplified models

Non-resonant

Hadronic channel : *Phys. Rev. Lett. 114 (2015) 101801*

- Both spin-0 and spin-1 invisible particles.
- No pseudo-scalar nor axial couplings (a=0.1, b=0).

Leptonic channel : *Public results*

- Only spin-1 invisible particles.
- Only couplings to right-handed quarks (a=b=0.1).

→ Only **2 free parameters** (**coupling a**, **mass m_V** or **m_ϕ**).

Range of production :

- **Fixing a = 0.1**, **scanning invisible masses from 0 to 1 TeV**.

Resonant

Leptonic channel : *Public results*

- Only spin-0 mediator.
- Only couplings to right-handed quarks (a=b=0.1).
- Consider BR(S → t χ) = 100 %.
- Assume fixed width (NWA).

→ Only 3 **free parameters** per model (**coupling a**, **masses m_φ** and **m_χ**).

Range of production :

- **Fixing a = 0.1**, **scanning m_φ from 500 to 2100 GeV with invisible masses m_χ from 10 to 200 GeV**.

CMS leptonic analysis

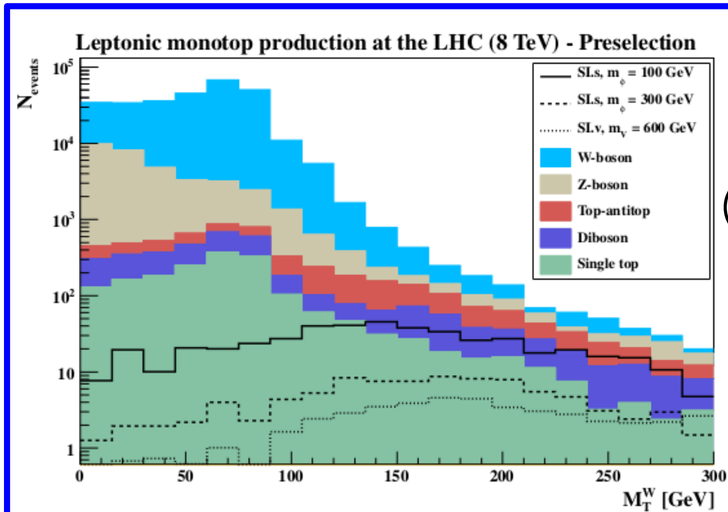
Analysis strategy

Inspired from SingleTop t-channel

1) **Shape analysis using $m_T(W)$ distribution**: in each region and for each systematic, produce **$m_T(W)$-templates** for each signal benchmark and each background.

$$M_T^W = \sqrt{2p_T^\ell \not{E}_T \left[1 - \cos \Delta\phi_{\ell,\not{E}_T}\right]}$$

$m_T(W)$: simple variable that helps to discriminate signal (2 sources of MET) from background (mostly true W).



Non-resonant monotop production (using Delphes fastsim) from **pheno** paper :

Buttignol et al.
PhysRevD.89.014028

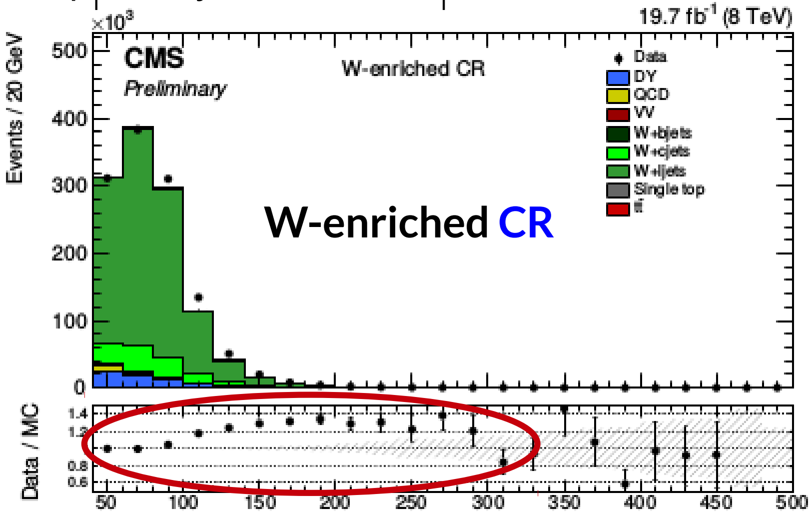
2) Main backgrounds (W+jets, ttbar) → define a W+jets enriched (1j0b) CR, a ttbar enriched (2j2b) CR and a signal region (1j1b). Cinematic cuts taken from pheno study.

3) Estimate **QCD multijets from data**.

4) **Simultaneous** likelihood fit of the **three regions** (W+jets, ttbar, signal) to better constrain the backgrounds. All systematics are treated as nuisance parameters.

Regions (prefit)

Selection : njets = 1, nbjet = 0, p_T(lead. jet)>70 GeV, m_T(W) > 40 GeV



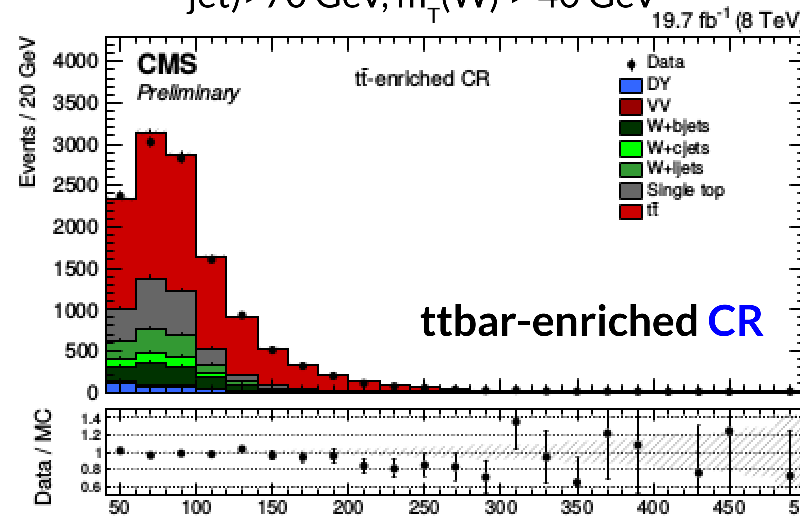
m_T(W) [GeV]

Seen elsewhere

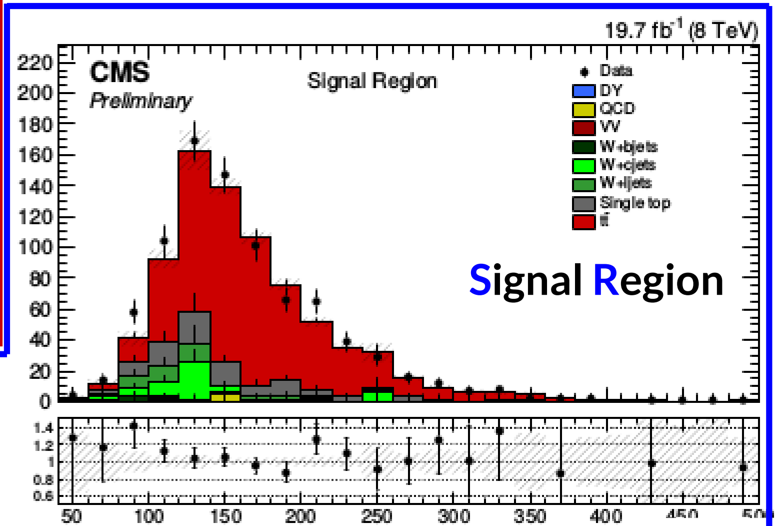
Will be corrected with W+b, W+c, W+light free in the fit.

m_T(W)

Selection : njets = 2, nbjet = 2, p_T(lead. jet)>70 GeV, m_T(W) > 40 GeV



m_T(W) [GeV]



m_T(W) [GeV]

Selection : njets=1bjet, m_T(W) > 40 GeV, p_T(W) > 70 GeV, p_T(lead. jet)>70 GeV, MET > 100 GeV, $\Delta\varphi(\mu - b) < 1.7$

Agreements

Excellent in ttbar-enriched CR,
Reasonable in SR,
Unsatisfactory in W-enriched CR.

Likelihood fit

Fit the three regions at the same time to better constrain the backgrounds.
All systematics are treated as nuisance parameters.

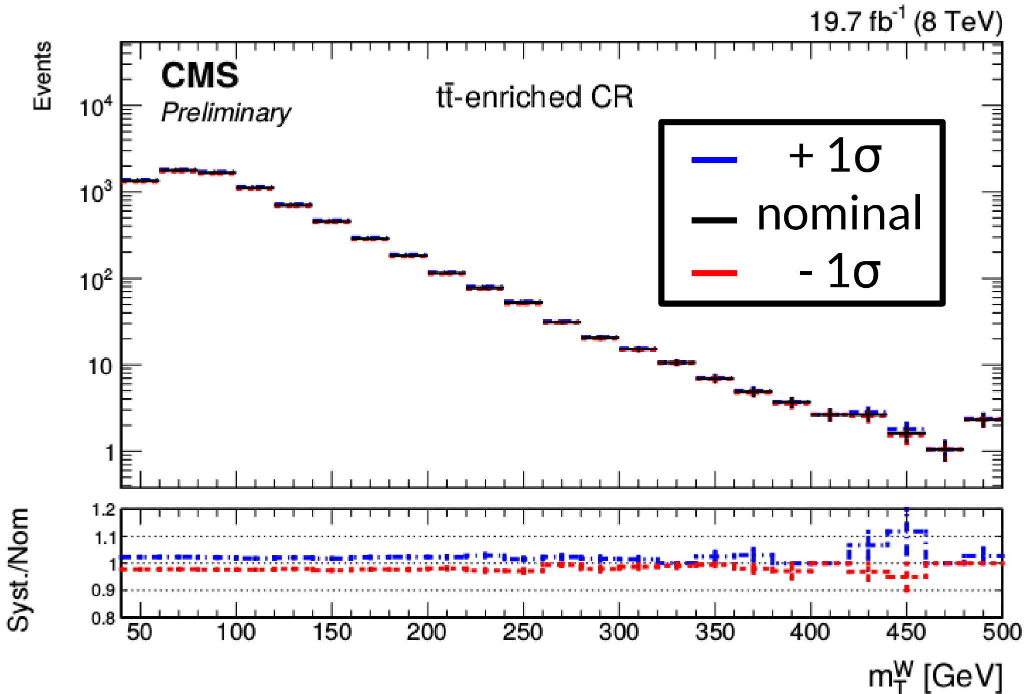
Considered systematics :

- jet energy scale (JES),
- jet energy resolution (JER),

propagated to the MET

- trigger efficiency,
- btagging/mistagging,
- pileup,
- Parton Density Function (PDF),
- lepton efficiency,
- toppt/scale/matching, ← on ttbar only
- inverted isolation, bkgd contam.

coming from the datadriven estimation of QCD



Uncertainty on bkgd rate :

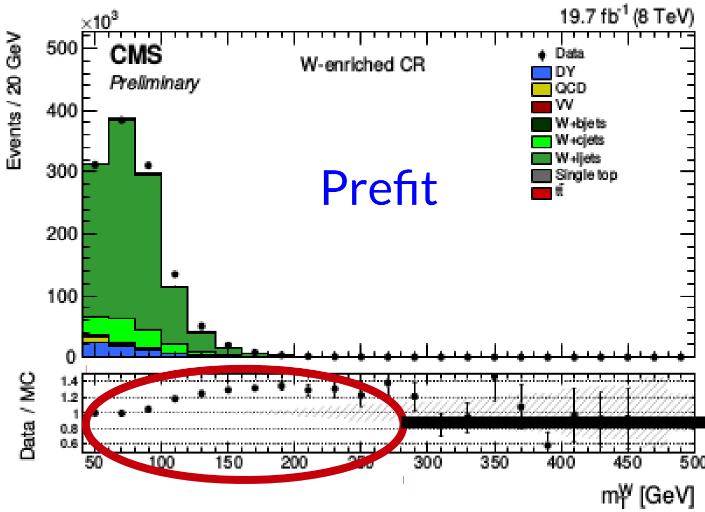
- QCD	50 %
- W+b	100 %
- W+c	30 %
- W+l	15 %
- Other bkgds :	30 %

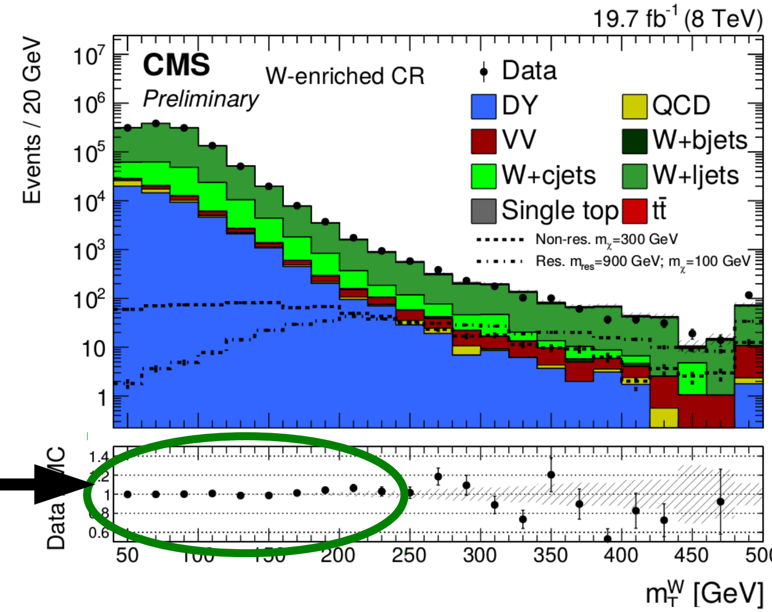
← norm. almost free in the fit to correct flavor composition

Regions (postfit)

W-enriched CR

Before the likelihood fit



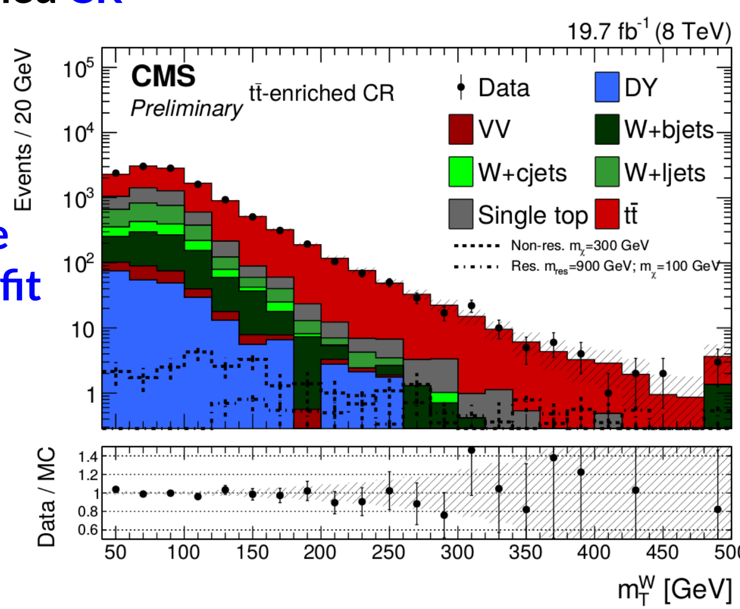


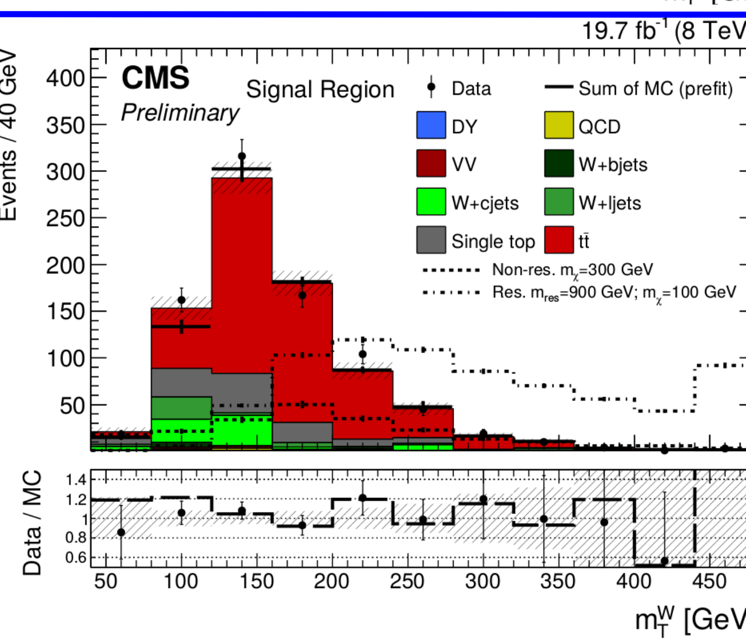
W-enriched CR

After the likelihood fit

ttbar-enriched CR

After the likelihood fit





Signal Region

After the likelihood fit

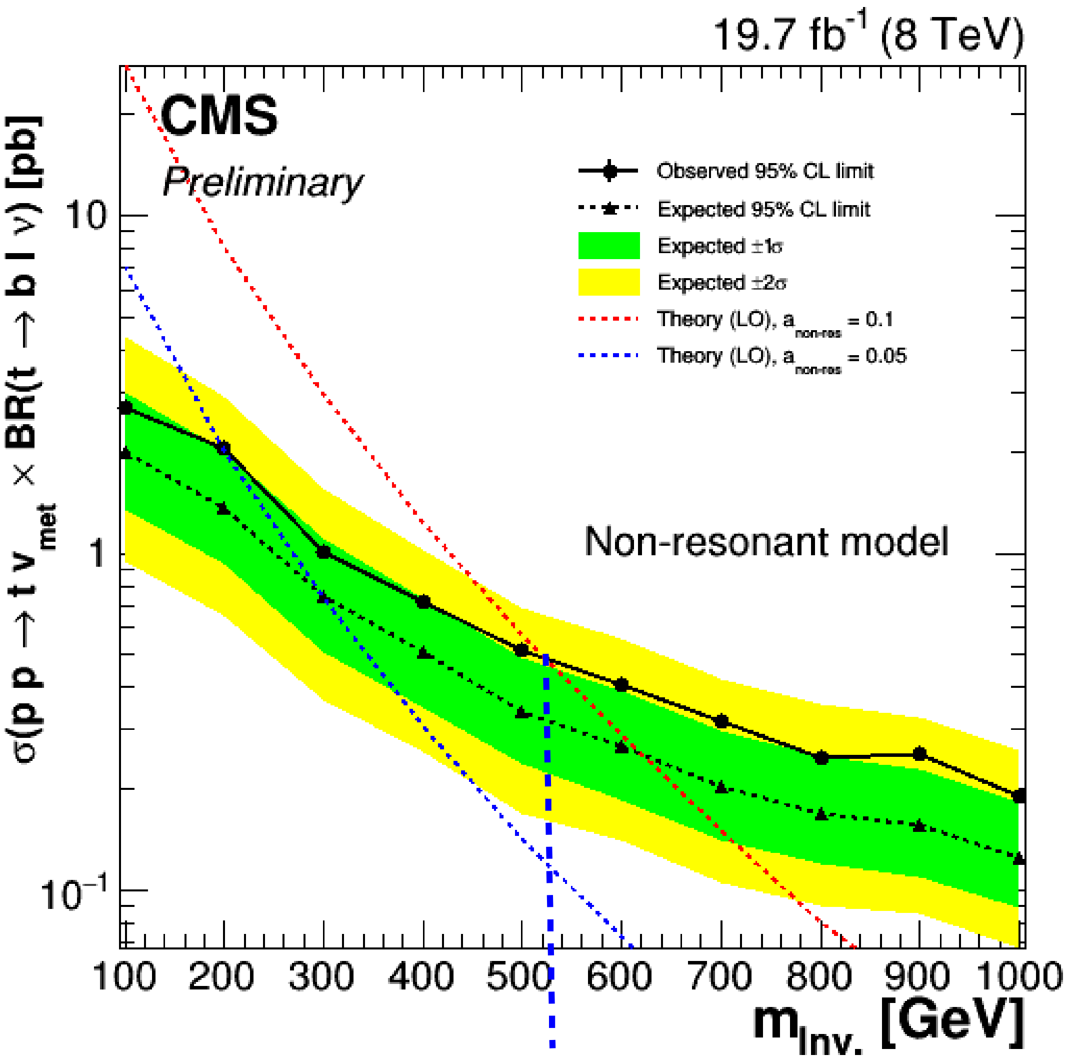
→ Compute the 95 % CL limits using Bayesian techniques !

Limits (Non-resonant)

- **95 % CL** limits computed using bayesian techniques.
- **Reminder :**

  - **2 free parameters** (coupling strength **a** and mass of invisible particle $m_{Inv.}$).

  - **range :** $m_{Inv.}$ **in [100;1000] GeV**



Excluded range when **a = 0.1** : $m_{Inv.}$ **< 523 GeV.**

Limits (Resonant)

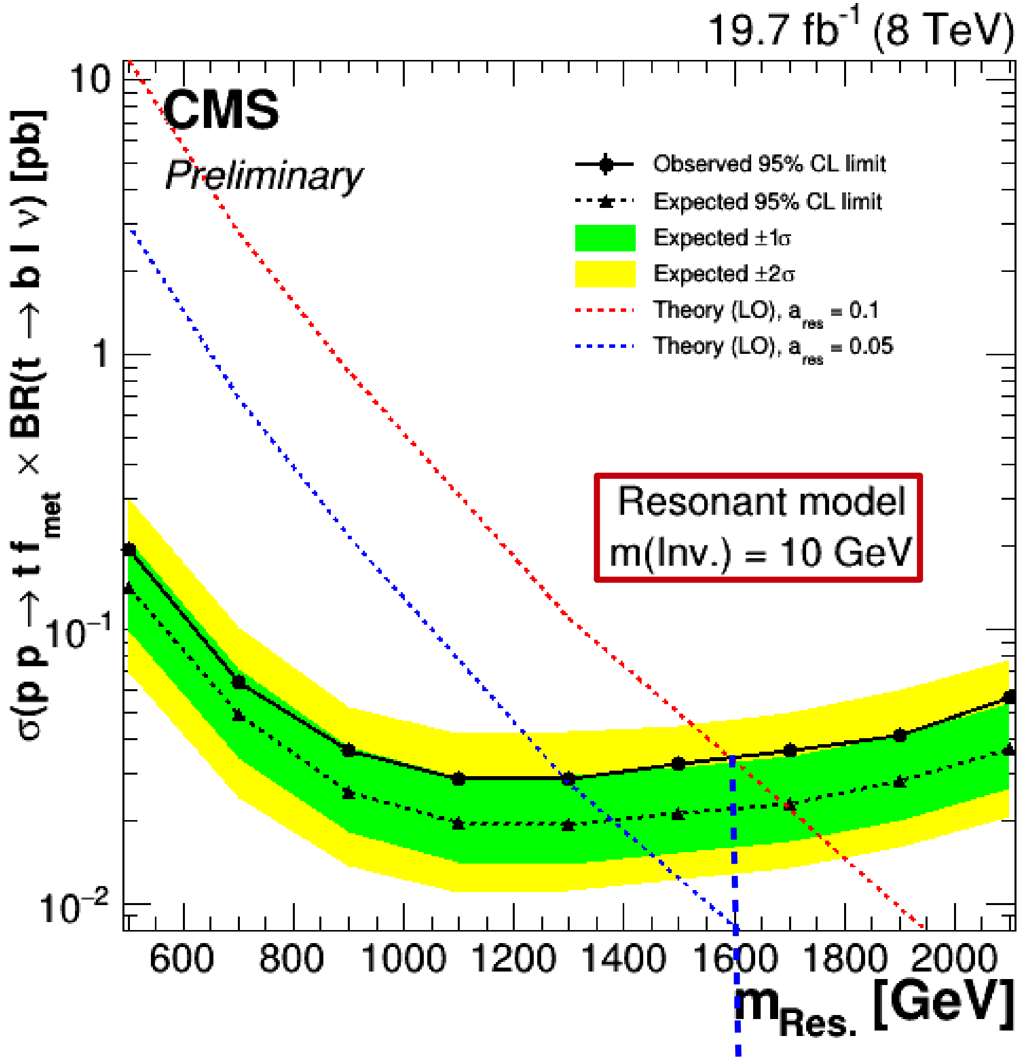
- **95 % CL** limits computed using bayesian techniques.

- **Reminder :**

  - **3 free parameters** (coupling strength **a**, mass of the resonant particle $m_{Res.}$ and mass of invisible particle $m_{Inv.}$).

  - **range :** $m_{Res.}$ in [500;2100] GeV

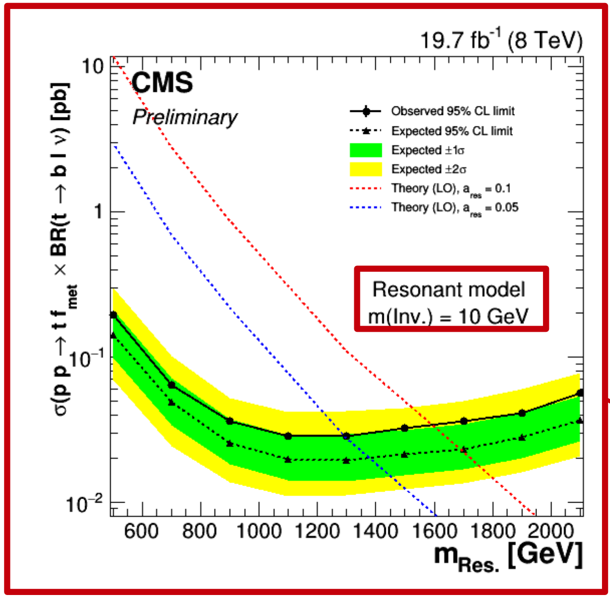
    $m_{Inv.}$ in [10;200] GeV

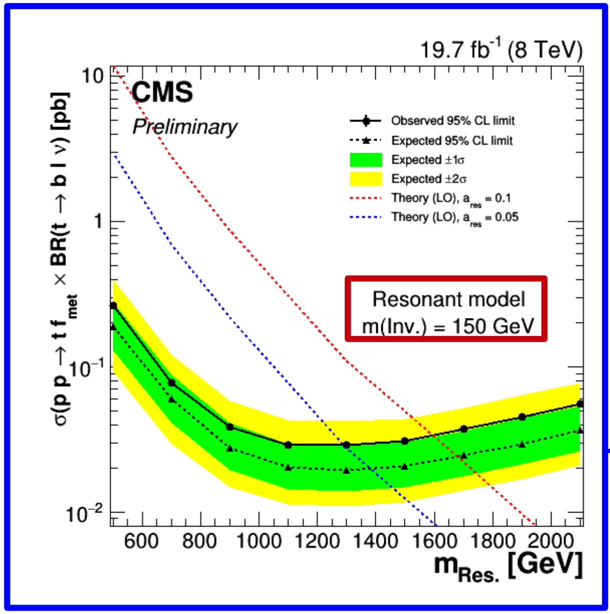


Excluded range when **a = 0.1** and $m_{Inv.}$ **= 10 GeV** : $m_{Res.}$ **< 1610 GeV.**

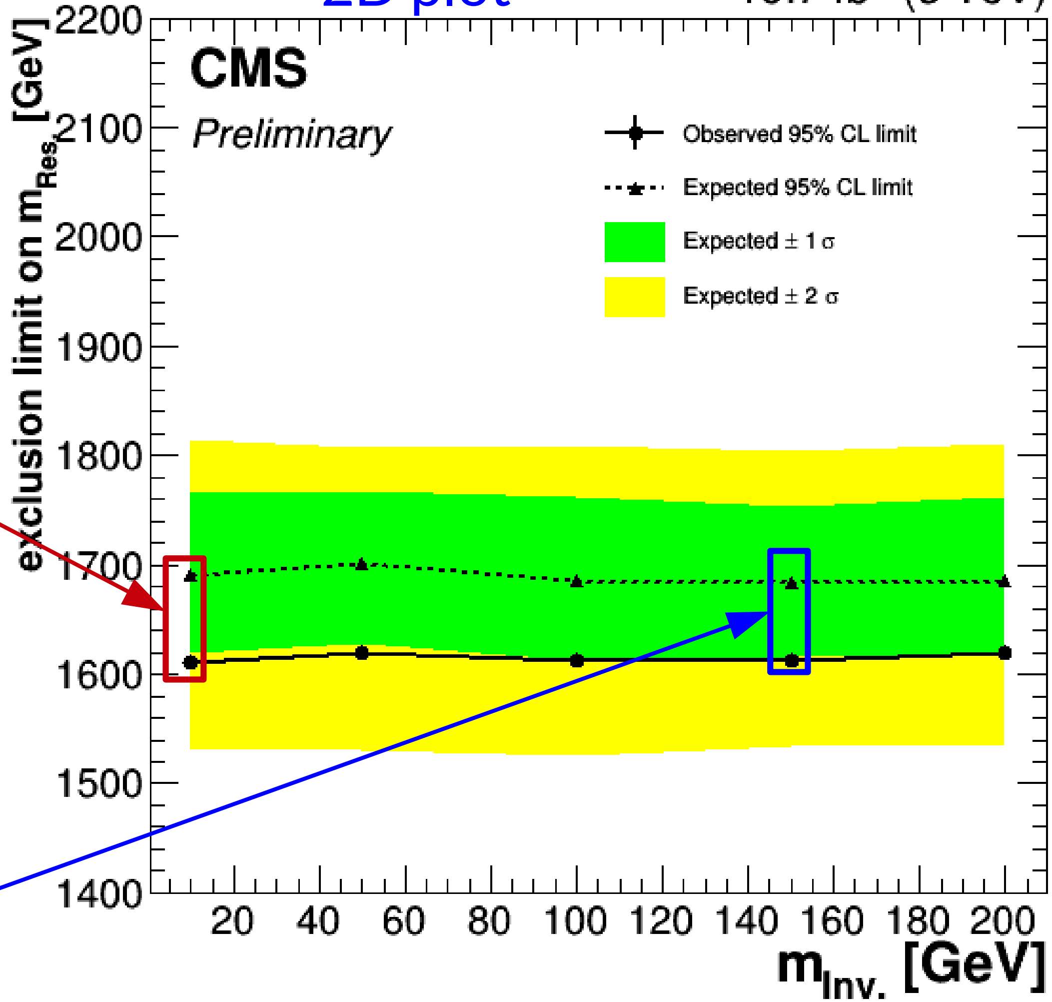
Limits (Resonant)

1D plots





2D plot

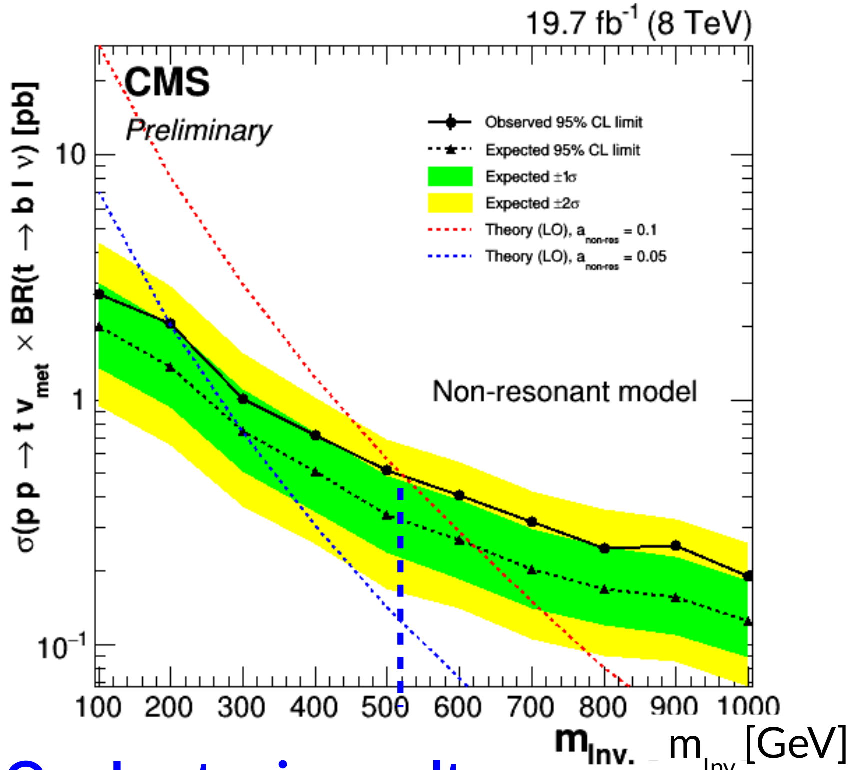


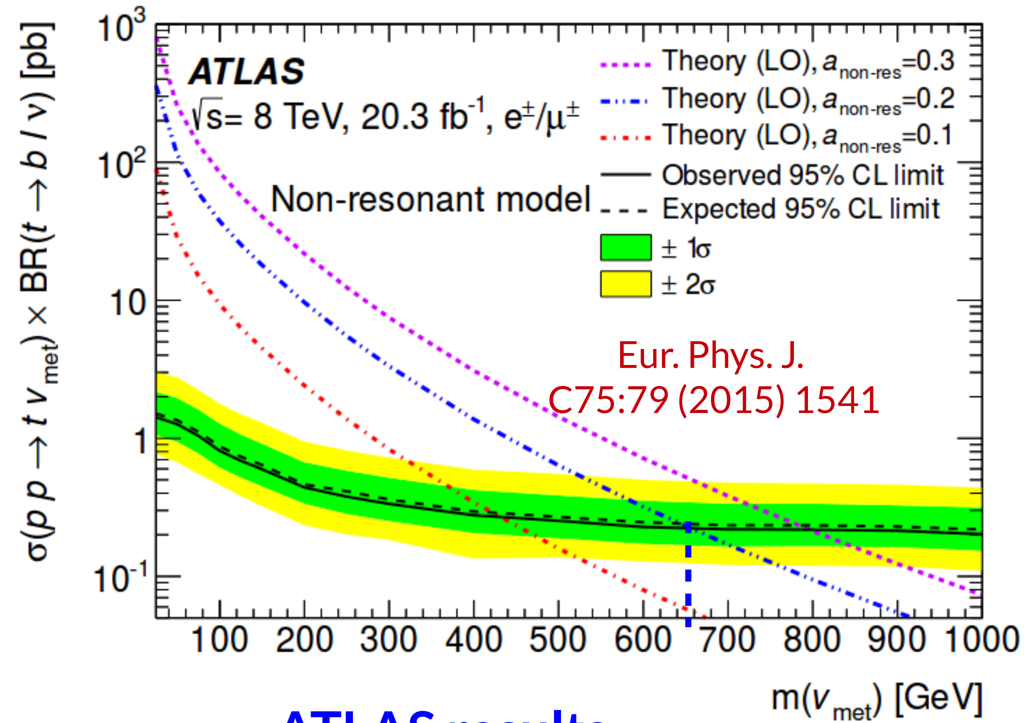
Excluded range when **a = 0.1** and $m_{Inv.}$ in [10;200] GeV :

$m_{Res.}$ <~ 1610 GeV.

CMS vs ATLAS

95 % CL limits





Our Leptonic results

ATLAS results

Excluded range : **m_{Inv} < ~520 GeV (muon channel only)**

Excluded range : **m_{Inv} < ~650 GeV (muon and electron channels)**

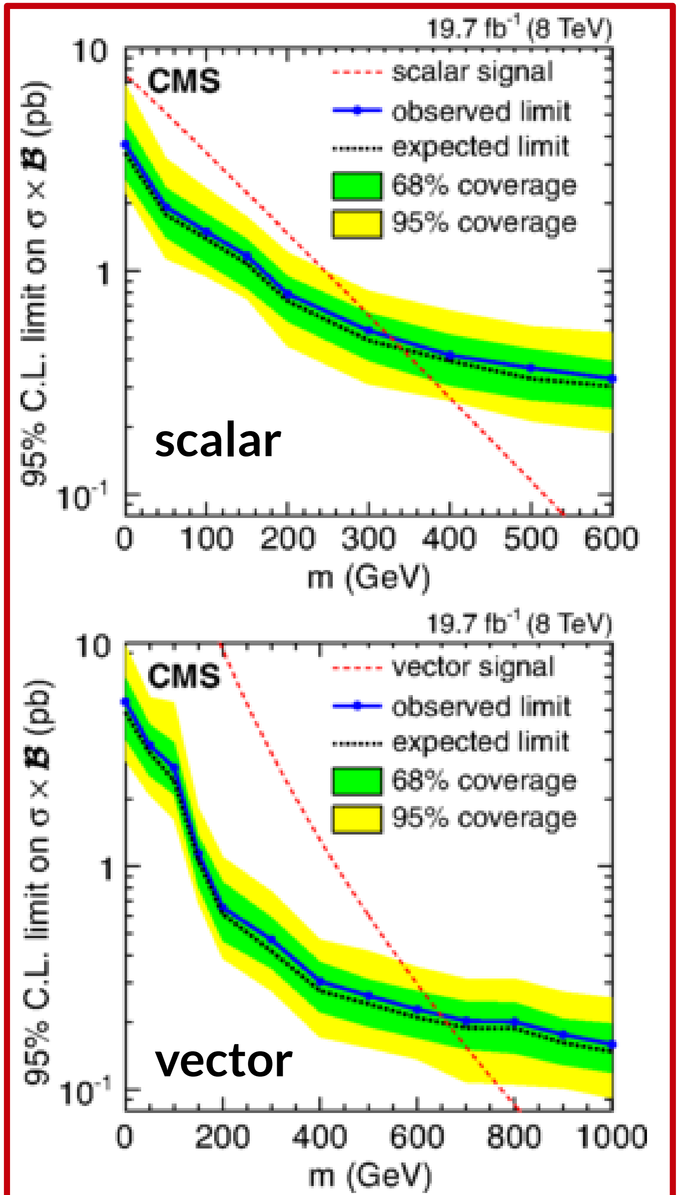
We seem to be **competitive with ATLAS** non-resonant model too !

(please compare the ATLAS (a = 0.2) to CMS (a = 0.1) for consistency)

CMS hadronic analysis

CMS hadronic 8 TeV search

Non-resonant

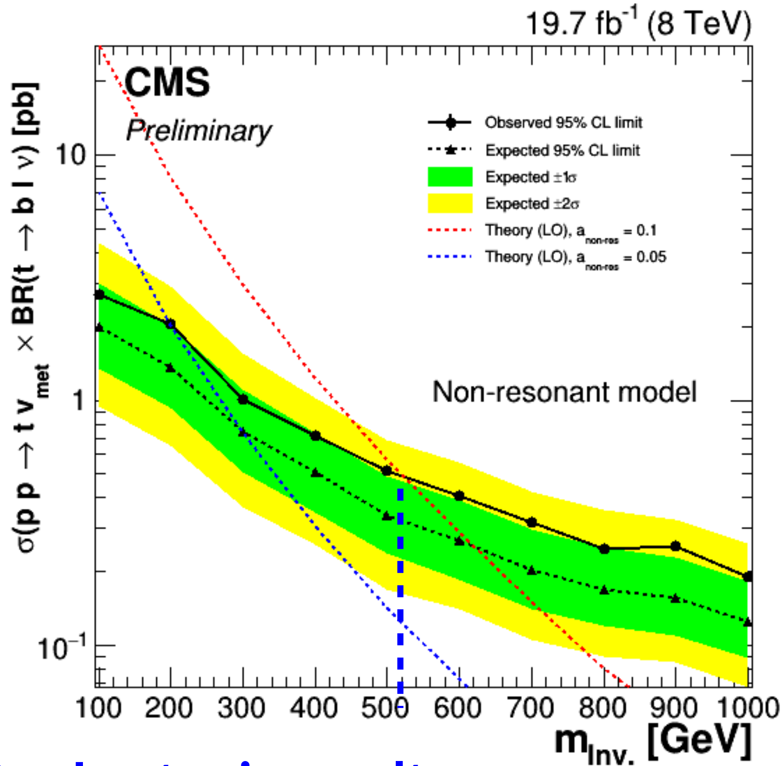


Strategy

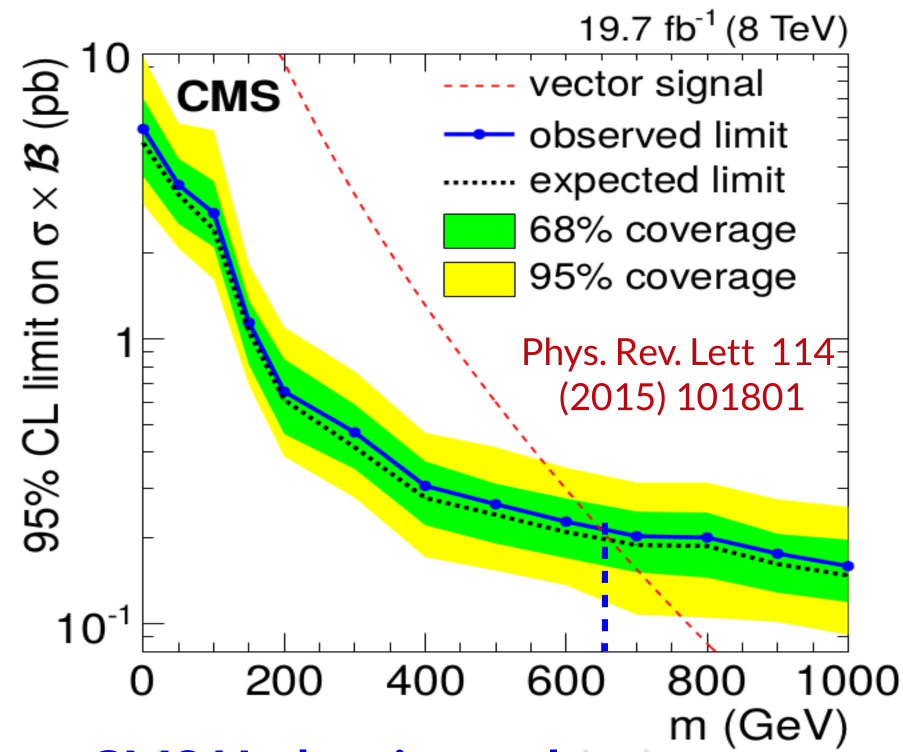
- **Final state :** bjj + MET
- **Main backgrounds :** Z → νν + jets, W → lν + jets
- **Trigger :** MET > 150 GeV
- Possible top-quark reconstruction
- **Selection :** 3j1b, MET > 350 GeV, m_T(bjj) < 250 GeV
- **Strategy :** Cut&Count
- **Results :** no excess observed → 95 % CL limits
  - **m(scalar) < 330 GeV excluded**
  - **m(vector) < 650 GeV excluded**

Leptonic vs Hadronic

95 % CL limits



Our Leptonic results



CMS Hadronic results

Excluded range : m_{Inv} < ~520 GeV (muon channel only)

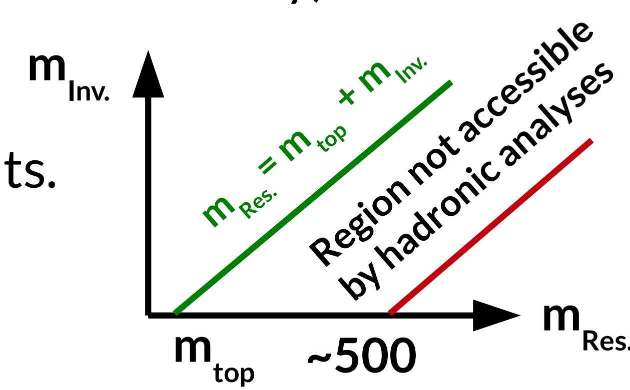
Excluded range : m_{Inv} < 660 GeV

We seem to be **competitive with the hadronic channel !**

Conclusions

Summary

- **CMS results** on both hadronic/leptonic monotop searches **at 8 TeV are public**.
- Monotop events **searched for the first time** via a resonant production mode in scanning both resonant and invisible masses.
- Leptonic results found **competitive** but not as sensitive (μ-channel only) **with ATLAS results** (eμ-channel, non-resonant).
- **Combination possible** between hadronic and leptonic results.



Perspectives

- **Possible improvements :** keep using a shape analysis (if possible w/o theta because not supported anymore), probe compressed phase space, ...
- **13 TeV analyses already ongoing and soon-to-be public** (need more luminosity...).

Back up

References

- Various theoretical (pheno) papers :

J. Andrea, B. Fuks, and F. Maltoni, "Monotops at the LHC" Phys.Rev. D84, 074025 (2011), arXiv:1106.6199 [hep-ph].

J. Wang et al., "Search for the signal of monotop production at the early LHC" Phys.Rev. D86, 034008 (2012), arXiv:1109.5963 [hep-ph]

B.Fuks, "Beyond the Minimal Supersymmetric Standard Model: from theory to phenomenology", Int. J. Mod. Phys. A 27 (2012) 1230007, arXiv:1202.4769 [hep-ph]

E. Alvarez et al., "Leptonic Monotops at LHC"(2013), arXiv:1310.7600 [hep-ph].

J-L Agram, J. Andrea, M. Buttignol, E. Conte, B. Fuks, **"Monotop phenomenology at the LHC" (2013), arXiv:1311.6478v1 [hep-ph], accepted by PRD.**

B.Fuks et al., "Revisiting monotop production at the LHC", JHEP 1501 (2015) 017, arXiv:1407.7529 [hep-ph]

Signal samples

- **Signal :** private recipe FeynRules, Madgraph5(**LO** x-sections), Pythia8, Fullsim.

- $N_{gen\text{-}events}$: ~35 kEvents/benchmark.

- Non-resonant production (FCNC), a = 0.1 :

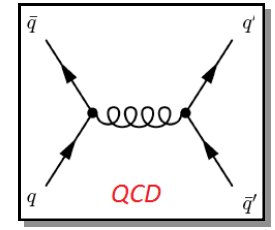
Inv.mass (GeV)	100	200	300	400	500	600	700	800	900	1000
X-section (pb)	28	8.1	2.94	1.22	0.57	0.29	0.15	0.08	0.05	0.03

- Resonant production, a = 0.1 :

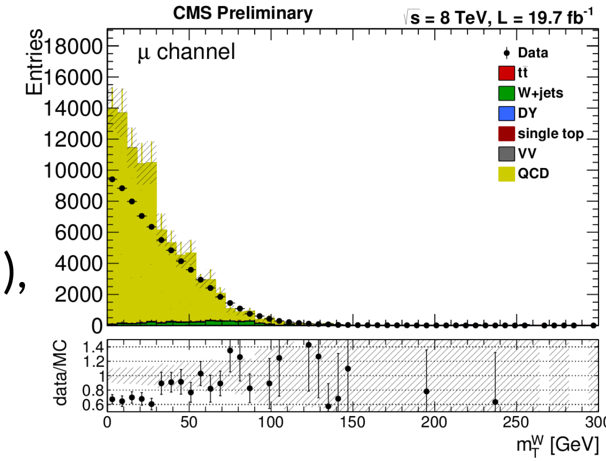
Res. mass (GeV)	300	500	700	900	1100	1300	1500	1700	1900	2100
X-section (pb)	77	11.8	2.77	0.87	0.31	0.11	0.05	0.022	0.0097	0.0045

Same x-sections for $m_{Inv.}$ = 10, 50, 100, 150, 200 GeV

QCD multijets



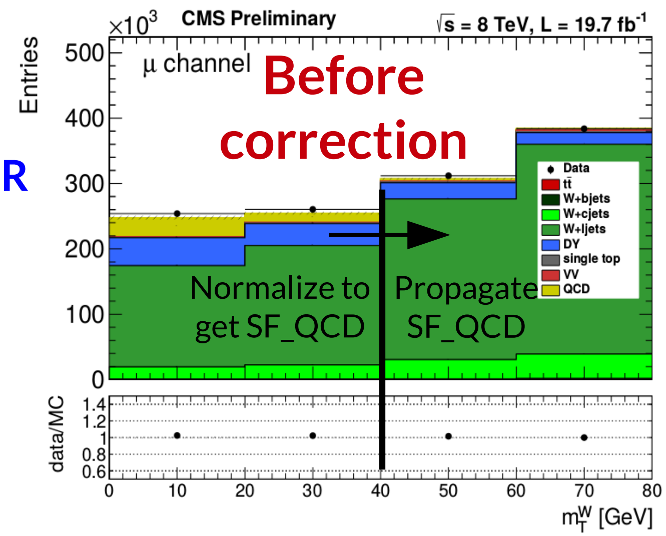
Method : - Create a QCD multijets CR :iso(μ) > 0.5,
- Define QCD sample from data = (data – remaining bkgd),
- Normalize this shape to data in iso(μ) < 0.12 &&
m_T(W) < 40 GeV to get the scaling factor.

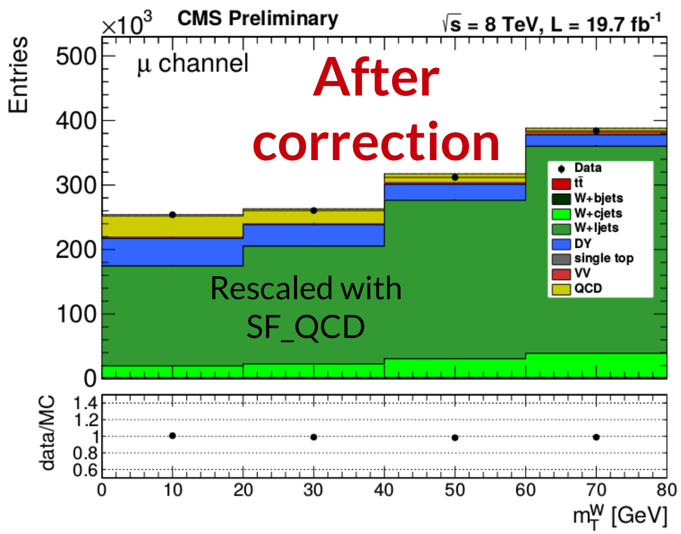


Uncert. : - Definition of QCD CR (**down :** iso(μ) > 0.6, **up :** iso(μ) > 0.4),
- Bkgd Contamination in QCD CR (**down :** no removing of remaining bkgd, **up :** twice removing of remaining bkgd).

Results :

W-enriched CR





W-enriched CR

Conclusion : - QCD multijets template datadriven (even if it is expected to be negligible in the SR),
- Correction (SF_QCD) found to be very low.

CMS leptonic 8 TeV search

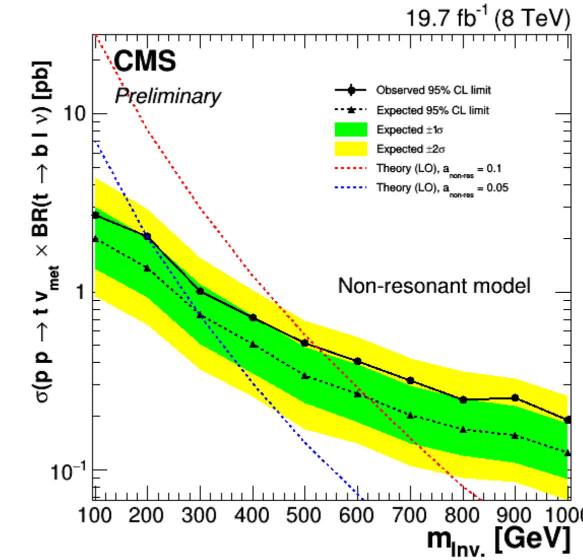
Strategy

- **Final state :** b + μ + MET
- **Main backgrounds :** tt → blν blν, W → lν + jets
- **Trigger :** single muon
- **Selection :** 1j1b, MET > 100 GeV, p_T (b) > 70 GeV, m_T(W) > 40 GeV, p_T(W) > 50 GeV, |Δφ(μ-b)| < 1.7
- **Strategy :** m_T(W) shape analysis
- **Results :** no excess observed → 95 % CL limits

with a = 0.1

- **m(vector) < 523 GeV excluded**
- **m(scalar mediator) < 1610 GeV excluded when 10 GeV < m(fermionic) < 200 GeV**

Non-resonant



Resonant