Monotop leptonic search at the LHC

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Workshop on Higgs and Beyond the Standard Model Physics at the LHC
Trieste - ITALY

26/06/13

Outline

1- Introduction: Monotop searches at LHC.

2- New Physics: New physics models with monotop signature.

- 2.1- FCNC Z' model to explain A_{FB} and A_C
- 2.2 - 2HDM+DM

4- Monotop signal and backgrounds

5- Monotop Search Strategy

6- Conclusions

Monotop searches at LHC

- NP prefers coupling to third generation quarks.

- Top quark produced copiously at the LHC.

- ***Monotop signature***: $pp \to t(\bar{t}) + \not{E}_T$

- Monotop signal search has been perfomed at Tevatron **(arXiv: 1202.5653)**.

- Monotop in ***hadronic mode*** has been studied **(arXiv: 1106.6199)** → large systematic uncertanties from QCD multijet bckg.

- Monotop in ***leptonic mode*** is promising (BR~ 0.3). Studied for searches at Tevatron **(hep-ph/9903549 - hep-ph/0012184)**

- Monotop vs. Single-top signatures ?

New physics models with monotop signature

1- ***Z' model*** → explains the apparent disagreement between A_{FB} at Tevatron and A_C at LHC.

E. Alvarez, E.C.L
J. Drobnak, A. L. Kagan, J. F. Kamenik, G. Perez, J. Zupan

Top Quark Asymmetries at Tevatron and LHC

Forward-Backward Asymmetry

$$A_{FB} = \frac{N(\Delta y>0)-N(\Delta y<0)}{N(\Delta y>0)+N(\Delta y<0)}$$

$$\Delta y = y_t - y_{\bar{t}}$$

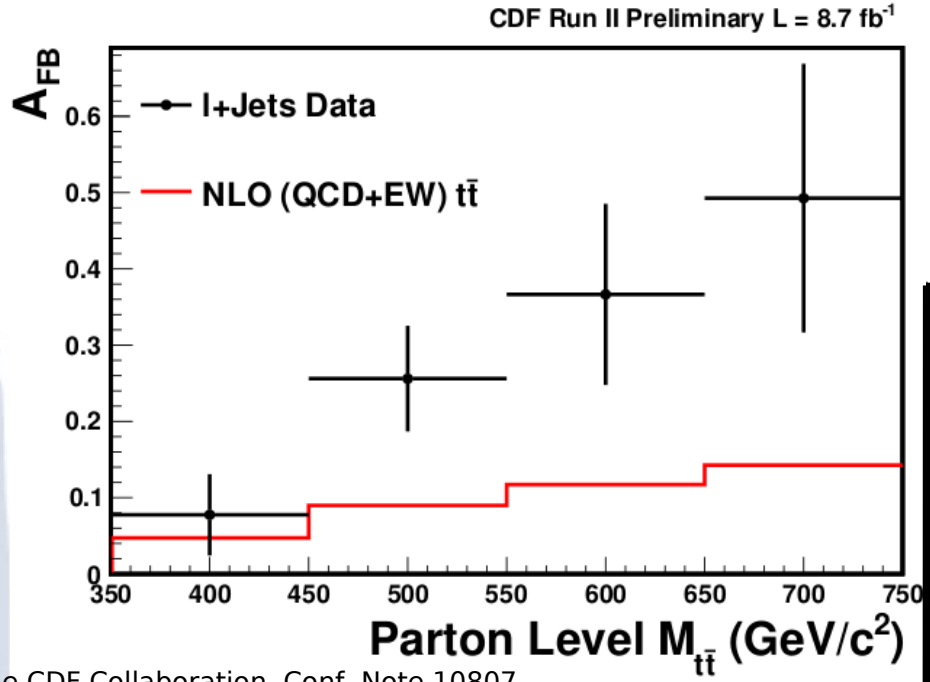
Charge Asymmetry → **LHC**: symmetric initial state

$$A_C = \frac{N(\Delta|y|>0)-N(\Delta|y|<0)}{N(\Delta|y|>0)+N(\Delta|y|<0)}$$

$$\Delta|y| = |y_t| - |y_{\bar{t}}|$$

E

At Tevatron:

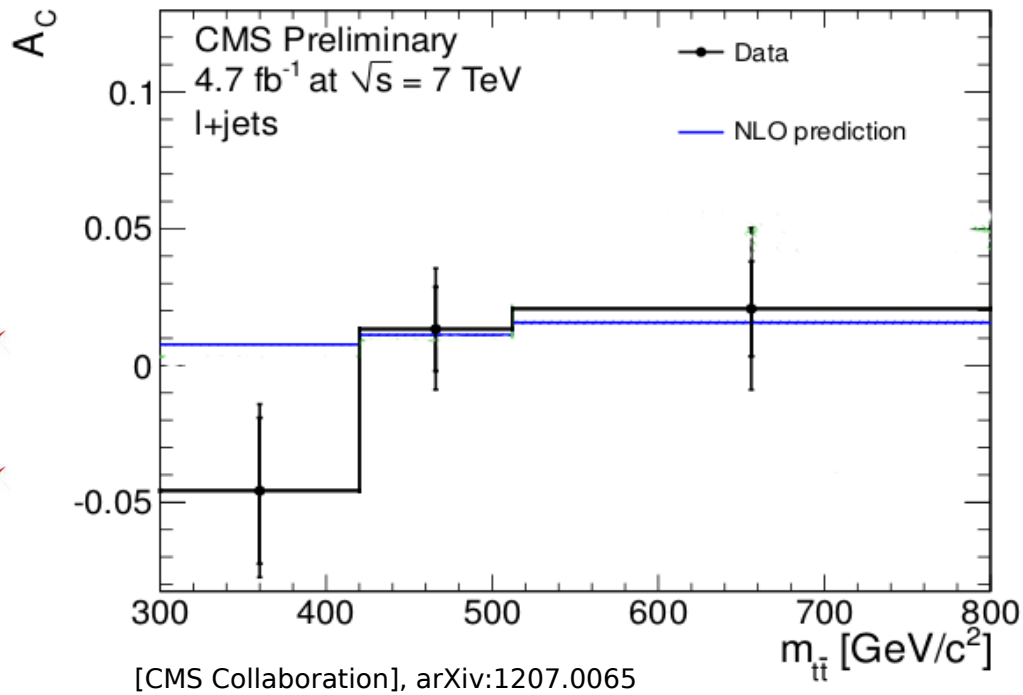


The CDF Collaboration, Conf. Note 10807

A_{FB} ✗ (p-value=0.006)

$\sigma(t\bar{t}) = 7.50 \pm 0.48$ pb ✓

At LHC:



[CMS Collaboration], arXiv:1207.0065

Is there anything wrong?

OR *Could both be* ***explained simultaneously!?***

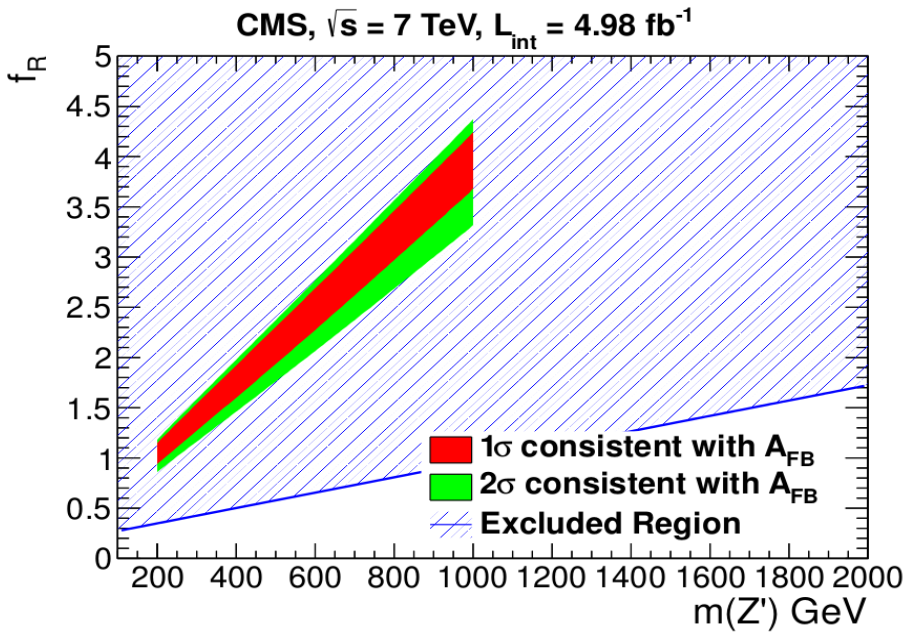
A_C ✓

$\sigma(t\bar{t})$ ✓

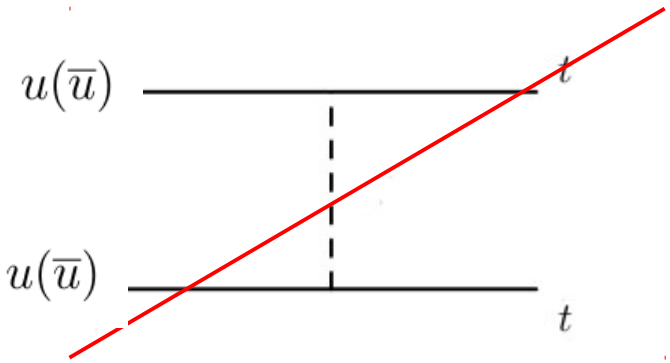
The New Phenomenological term of the Lagrangean is given by:

$$f_R \bar{t}\gamma^\mu P_R u Z'_{C\mu} + f_R \bar{u}\gamma^\mu P_R t Z'^{\dagger}_{C\mu} \quad with \quad Z'_{C\mu} \neq Z'^{\dagger}_{C\mu}$$

No same sign tops!



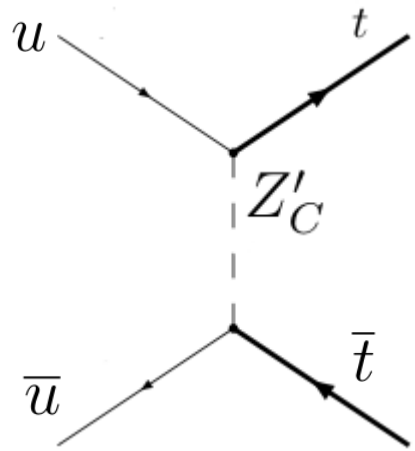
[CMS Collaboration], arXiv:1205.3933



Feynman 's Diagrams involving a Z'_C boson

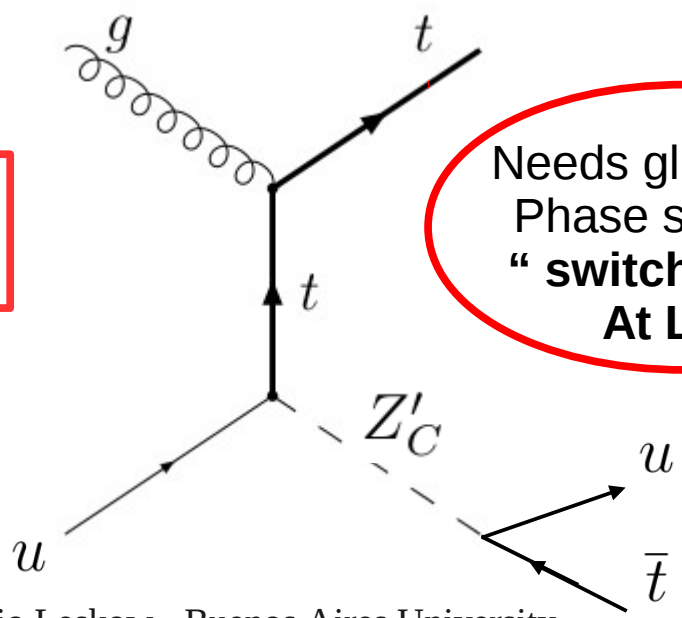
So.... there is a cancellation at LHC!

Needs antiquarks!
So **Dominates**
At Tevatron

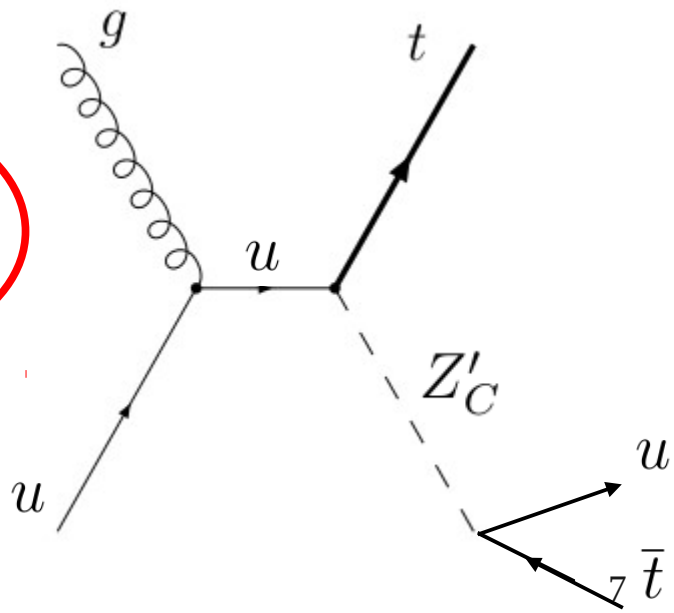


t- channel:
Ac > 0

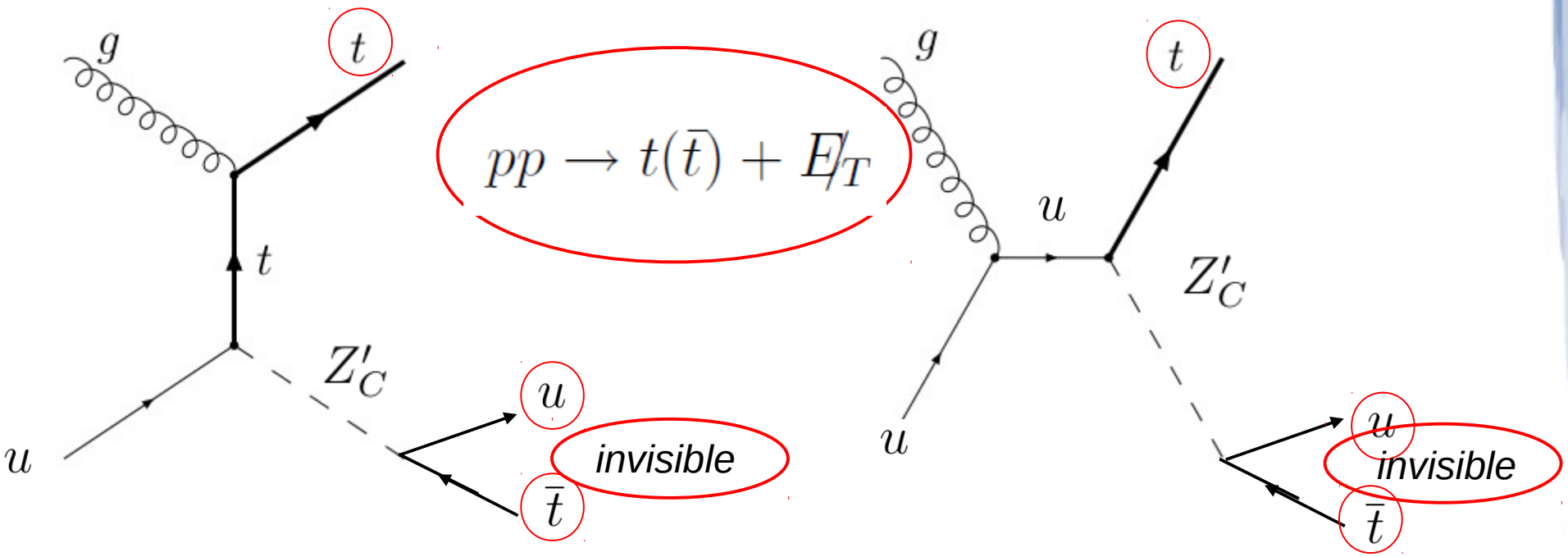
s- channel:
Ac < 0



Needs gluons and
Phase space so
" switched on "
At LHC!

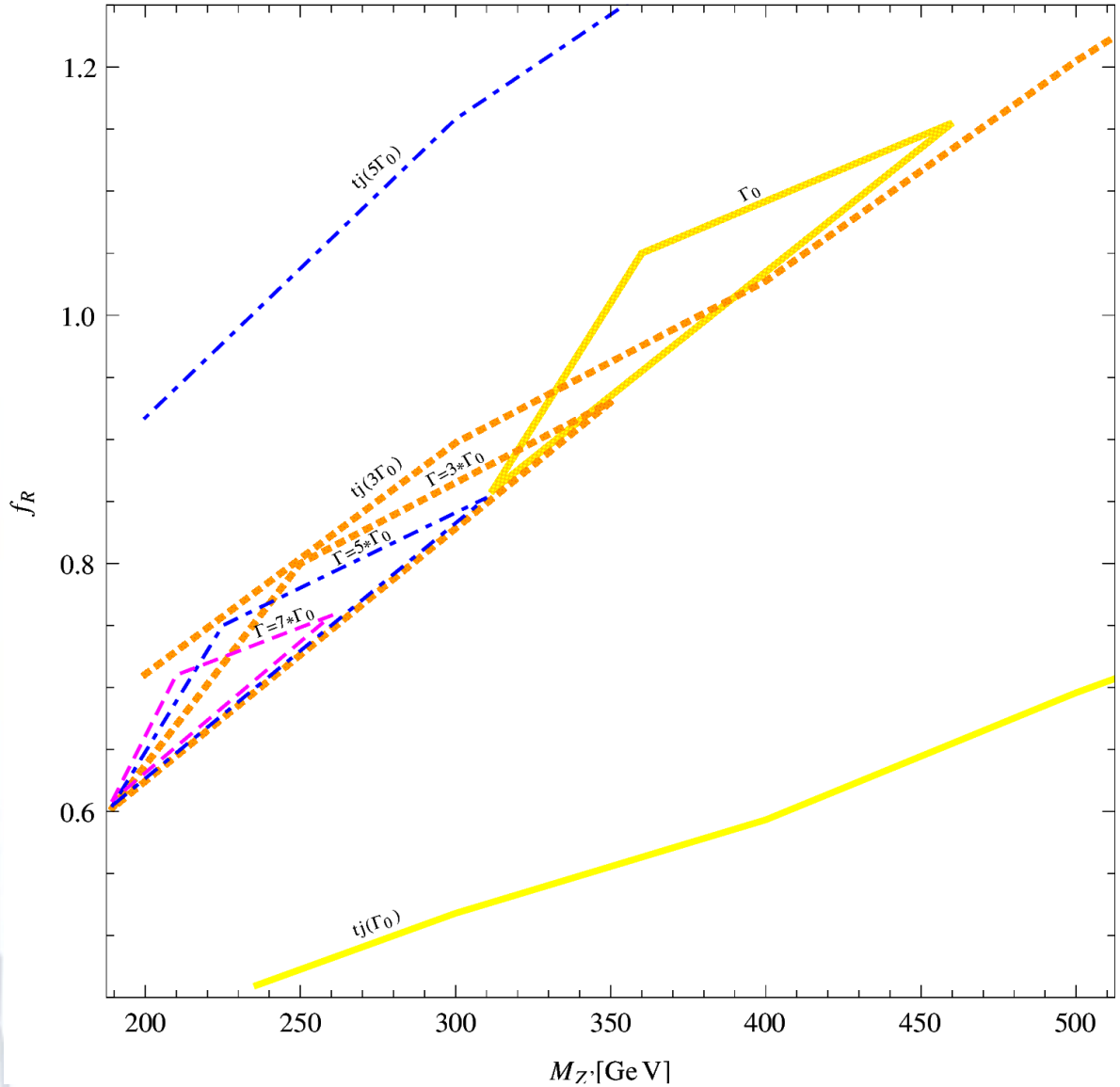


tt+j constraints at the LHC



relaxed if Z_c' width is larger → invisible decays

MONOTOP SIGNATURE (and SINGLE-TOP!)



Allowed Parameter space

$\uparrow \Gamma_{Z'_C}$ $\downarrow \sigma(t\bar{t}j)$

Larger allowed region!

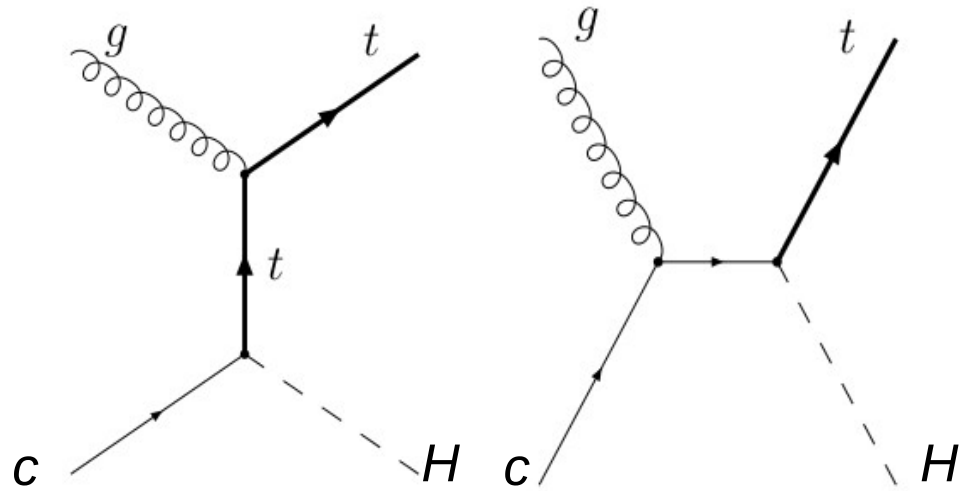
2 - 2HDM+Dark Matter

arXiv:1101.3576 [hep-ph]

→ ***Scalar mediator model***
To complement the analysis

$$\mathcal{L}_D = \frac{\lambda_D}{4} D^4 + \frac{m_0^2}{2} D^2 + D^2(\lambda_1 H_1^\dagger H_1 + \lambda_2 H_2^\dagger H_2 + \lambda_3 (H_1^\dagger H_2 + H_2^\dagger H_1)).$$

- 2HDM III, both H_1 and H_2 provide masses to up and down type quarks, and charged leptons. Tree level FCNC
- All flavor-non-diagonal couplings of the SM-like Higgs are now suppressed by Higgs data, so the coupling needs to go through the heavier one (H).
- $\tan(\beta) \sim 1$
- $g_{tcH} \sim \sqrt{(m_t * m_c)/v}$
- $M_H \sim 200 GeV$
- $BR(H \to DD) \sim 1$



Signal (leptonic mode):

$$t(\bar{t}) + \not{E}_T \rightarrow bW^{\pm} + \not{E}_T \rightarrow bl^{\pm} + \not{E}_T$$

- 1 *b*-tagged jet
- 1 lepton
- E_T^{miss}

Main Backgrounds:

- t tbar
- Single-top
- W + jets
- Diboson

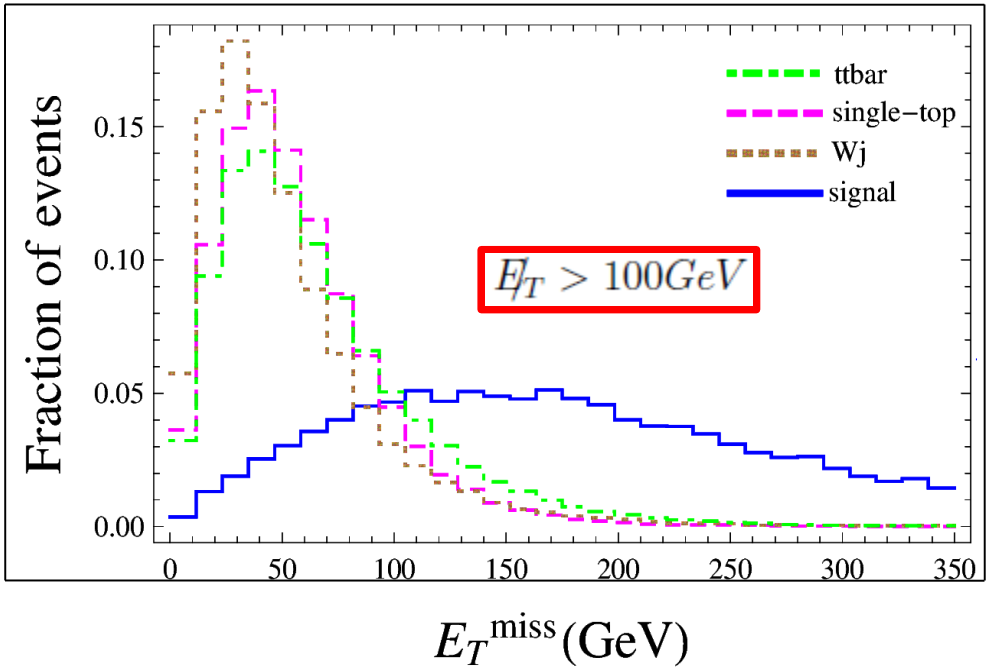
Signal (hadronic mode):

$$bjj + \not{E}_T$$

Main Background:

- Very large QCD multijet background (large systematic uncertanties)

We can get rid of them in leptonic mode with a proper cut.



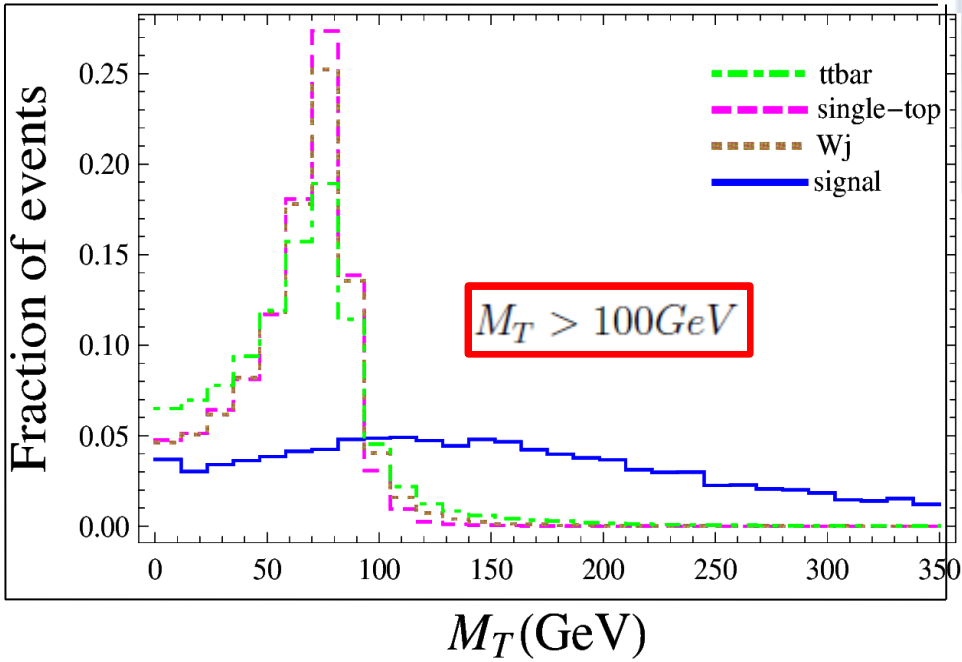
Z' Model

Pre-selection

- 1 *b*-tagged jet with p_T < 25 GeV
- 1 lepton with p_T < 20 GeV

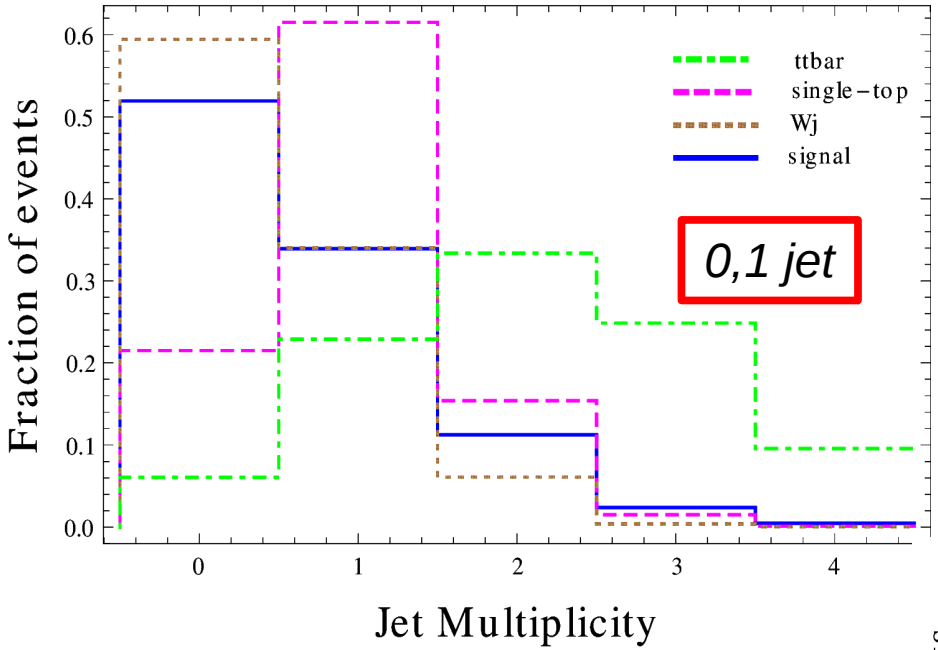
- $M_{Z'} = 325GeV$
- $f_R = 0.85$

$$M_T^2 = [E_T(1) + E_T(2)]^2 - [\bar{p}_T(1) + \bar{p}_T(2)]^2$$

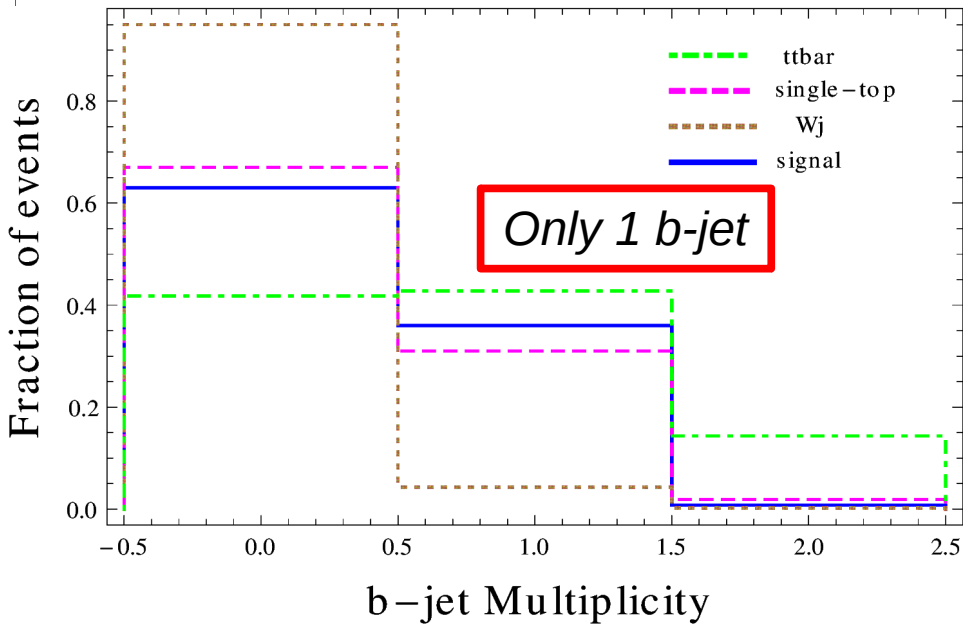


- Signal: Large $\not{E}_T$ coming from the invisible Z' decay.

- M_T has an end-point in $M_T^{max} = M_W$ for all bckg.
- Signal M_T spectrum shifted because it has larger $\not{E}_T$!!



With a veto in events with 2 or more jets we can get rid of a good fraction of ttbar events.



Selecting events with **only 1 b-jet** diminishes the **W+jets** fraction of events considerably (~10^{-2})!

Monotop search strategy

- 1 l^+, $p_T > 20GeV$, $|\eta| < 2.5$
- 1 b-jet, $p_T > 25GeV$, $|\eta| < 4.5$
- $M_T > 100GeV$
- $\not{E}_T > 100GeV$
- Up to 1 jet, $20GeV < p_T < 80GeV$, $|\eta| < 4.5$

Avoids QCD multijet Background!

Can only produce large E_T^{miss} from high p_T misreconstructed jets.

Cut- Flow Table for Z' model:

Large cross section!!

l^+	b-jets	M_T (GeV)	E_T^{miss} (GeV)	jets ($20GeV < p_T < 80GeV$)	$\sigma_{t\bar{t}j}$ (pb)	σ_{Wj} (pb)	σ_{tj} (pb)	σ_{VV} (pb)	σ_{signal} (pb)	$\frac{S}{\sqrt{B}}$
-	-	-	-	-	239	3407	39.05	74.2	7.69	
1	-	-	-	-	31.60	1827.27	18.43	7.76	5.44	18.47
1	1	-	-	-	12.65	35.09	5.54	0.27	1.60	32.13
1	1	> 100	-	-	1.23	0.45	0.18	$5.00*10^{-3}$	1.11	119.42
1	1	> 100	> 100	-	0.02	$1.50*10^{-2}$	0.03	$7.00*10^{-4}$	0.90	195.53
1	1	> 100	> 100	≤ 1	0.14	$5.00*10^{-3}$	0.01	$5.50*10^{-4}$	0.55	200.34

Very large significance!!

Monotop search strategy

- 1 l^+, $p_T > 20GeV$, $|\eta| < 2.5$
- 1 b-jet, $p_T > 25GeV$, $|\eta| < 4.5$
- $M_T > 100GeV$
- $\not{E}_T > 100GeV$
- Up to 1 jet, $20GeV < p_T < 80GeV$, $|\eta| < 4.5$

Avoids QCD multijet Background!

Can only produce large E_T^{miss} from high p_T misreconstructed jets.

Cut- Flow Table for 2HDM+DM model:

Much Lower cross section!!

l^+	b-jets	M_T (GeV)	E_T^{miss} (GeV)	jets ($20GeV < p_T < 80GeV$)	$\sigma_{t\bar{t}j}$ (pb)	σ_{Wj} (pb)	σ_{tj} (pb)	σ_{VV} (pb)	σ_{signal} (pb)	$\frac{S}{\sqrt{B}}$
-	-	-	-	-	239	3407	39.05	74.2	$4.50\ 10^{-2}$	
1	-	-	-	-	31.60	1827.27	18.43	7.76	$1.27*10^{-2}$	$4.31*10^{-2}$
1	1	-	-	-	12.65	35.09	5.54	0.27	$4.00*10^{-3}$	$8.00*10^{-2}$
1	1	> 100	-	-	1.23	0.45	0.18	$5.00*10^{-3}$	$2.00*10^{-3}$	$2.27*10^{-1}$
1	1	> 100	> 100	-	0.02	$1.50*10^{-2}$	0.03	$7.00*10^{-4}$	$1.46*10^{-3}$	$3.17*10^{-1}$
1	1	> 100	> 100	≤ 1	0.14	$5.00*10^{-3}$	0.01	$5.50*10^{-4}$	1.0210^{-3}	$3.75*10^{-1}$

Much lower significance!!

How can the background be suppressed even more?

- ttbar is the main background → charge **symmetry**!
- Signal → charge **asymmetry**!

S_1= number of signal events with l^+ - number of signal events with l^-

B_1= number of bckg. events with l^+ - number of bckg. events with l^-

	$Z' Model$	2HDM+DM
$\frac{S_1}{\sqrt{B_1}}$	1016	0!

Different PDFs for u and $\bar{u}$ quarks!

Same PDFs for c and $\bar{c}$ quarks!

Conclusions I

- ***Monotop searches seem promising to test NP models, particularly many FCNC ones.***

- ***We have developped a search strategy for monotop signature in the leptonic mode. Hadronic mode has large systematic uncertanties coming from QCD backg.***

- ***We have found a large significance in the discovery reach for the Z' model (large cross section!)***

- ***We found that the 2HDM+DM model is a more challenging one. Observation could be achieved with larger integrated luminosity collected at s=√14 TeV.***

- ***We can take advantage of the charge asymmetry of a signal to get rid of charge symmetric backgrounds.***

- ***In progress:***

  1- monotop for constraining flavour-changing neutral currents for the SM utZ vertex.

  2- Cut scanning.

Conclusions II

A monotop signature can be " transparent" to a single-top search strategy:

@7TeV and 1.04 fb^{-1} of integrated luminosity:

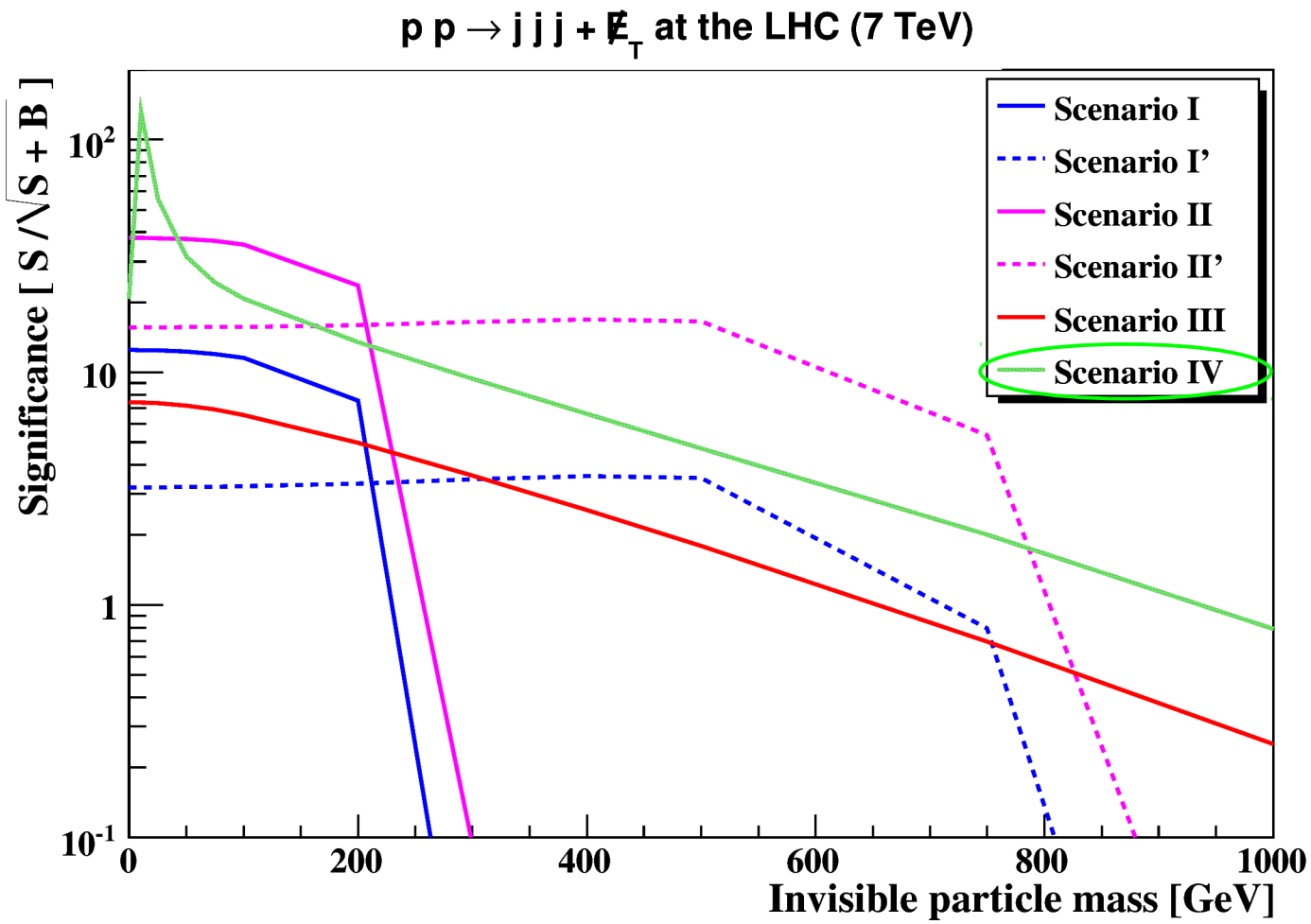
Significance for a single top search strategy: ~1
Significance for a monotop search strategy: ~20

Estefanía Coluccio Leskow - Buenos Aires University .

Thank you!

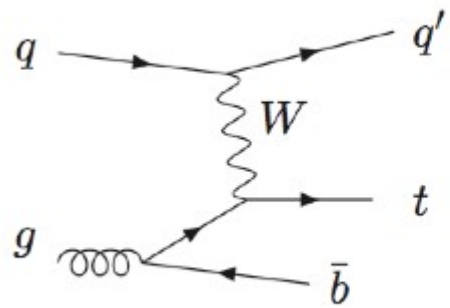
Back - Up Slides

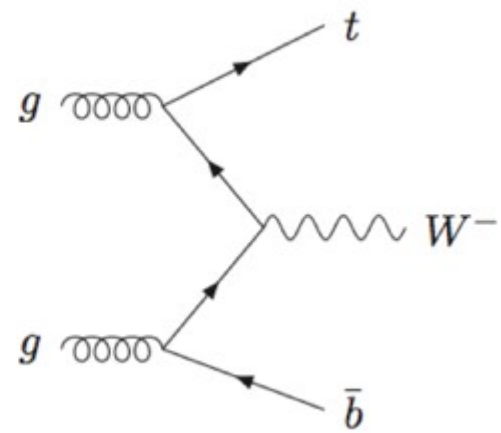
Monotop hadronic mode



J. Andrea, B. Fuks, F. Maltoni and , Phys. Rev. D 84 (2011) 074025 [arXiv:1106.6199[hep-ph]].

t-channel single-top Production diagrams





The New Phenomenological term of the Lagrangean is given by:

$$f_R \bar{t}\gamma^\mu P_R u Z'_{C\mu} + f_R \bar{u}\gamma^\mu P_R t Z'^{\dagger}_{C\mu} \quad with \quad Z'_{C\mu} \neq Z'^{\dagger}_{C\mu}$$

Some remarks:

- Left handed coupling constrained by *B* physics
- $M_{Z'} > m_t$ (avoids Flavour Change Top Decay)
- No same sign tops production ⇒ no constraint!
- Atomic parity violation ⇒ relaxed because Z'_N and $M_{Z'} > m_t$

  (arxiv: 1203.1320)
- $t\bar{t} + j$ constraints at the LHC ⇒ relaxed by making $\Gamma_{Z'_C}$ larger (DM?, Invisible?)

(arxiv: 1203.4489, ATLAS-CONF-2011-100., ATLAS-CONF-2011-121, ATLAS-CONF-2011-142, CMS PAS TOP-11-005, See ATLAS talk by Merlin DAVIES)

- ***Asymmetry cancellation at LHC not present at Tevatron*** ⇒ ***EXPLAINS RESULTS!!***

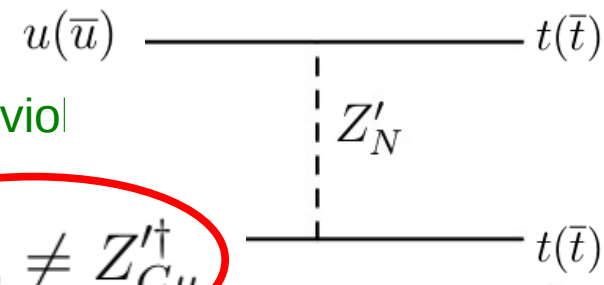
New Physics Models arise to explain the discrepancies.

- Extra light gluon G ' with a broad width
- Extra Scalars
- Extra *W '* with *d-t-W '* interaction
- Extra *Z'* boson with flavor - conserving interaction
- Extra *Z'* **Neutral** boson with flavor - violating interaction
- …. etc

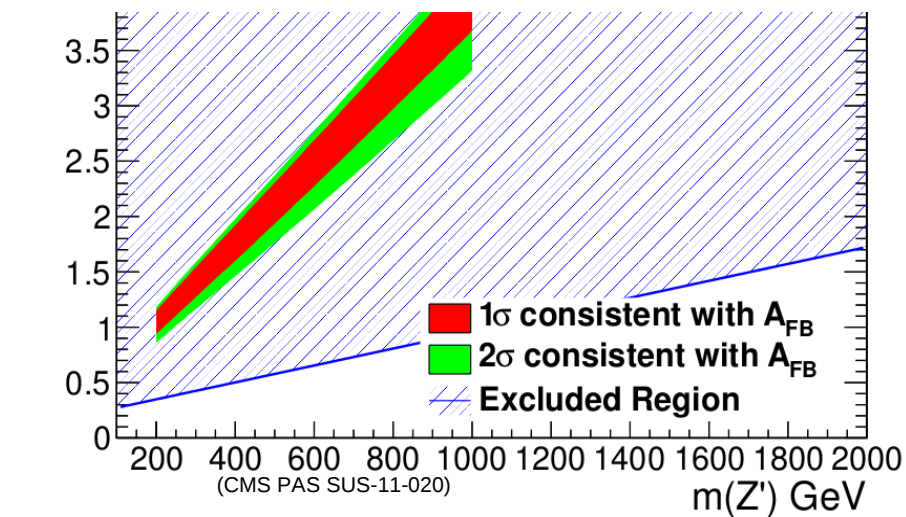
- Excluded by LHC
- Not Excluded by LHC

$$f_R \bar{t}\gamma^\mu P_R u Z'_{N\mu} + f_R \bar{u}\gamma^\mu P_R t Z'^{\dagger}_{N\mu} \quad with \quad Z'_{N\mu} = Z'^{\dagger}_{N\mu}$$

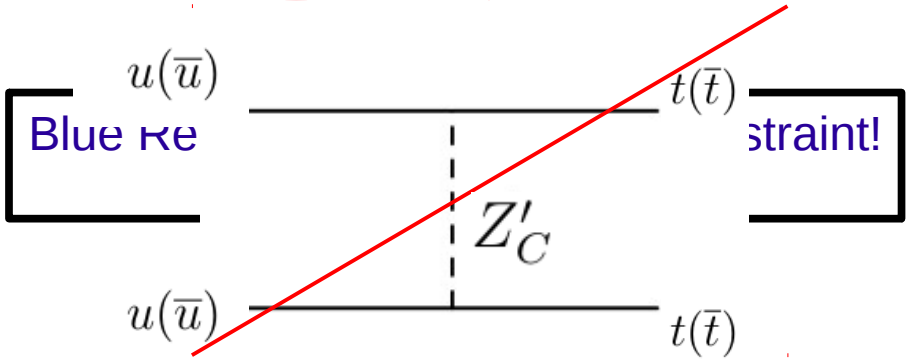
'our- viol ven



$$f_R \bar{t}\gamma^\mu P_R u Z'_{C\mu} + f_R \bar{u}\gamma^\mu P_R t Z'^{\dagger}_{C\mu} \quad with \quad Z'_{C\mu} \neq Z'^{\dagger}_{C\mu}$$



(CMS PAS SUS-11-020)



How do we search for the cancellation?

- Using MADGRAPH we simulate:

$$pp \to t\bar{t}(u) \longrightarrow \text{SM + NP}$$

- We make a χ^2 test with the last measurements at:

Tevatron:

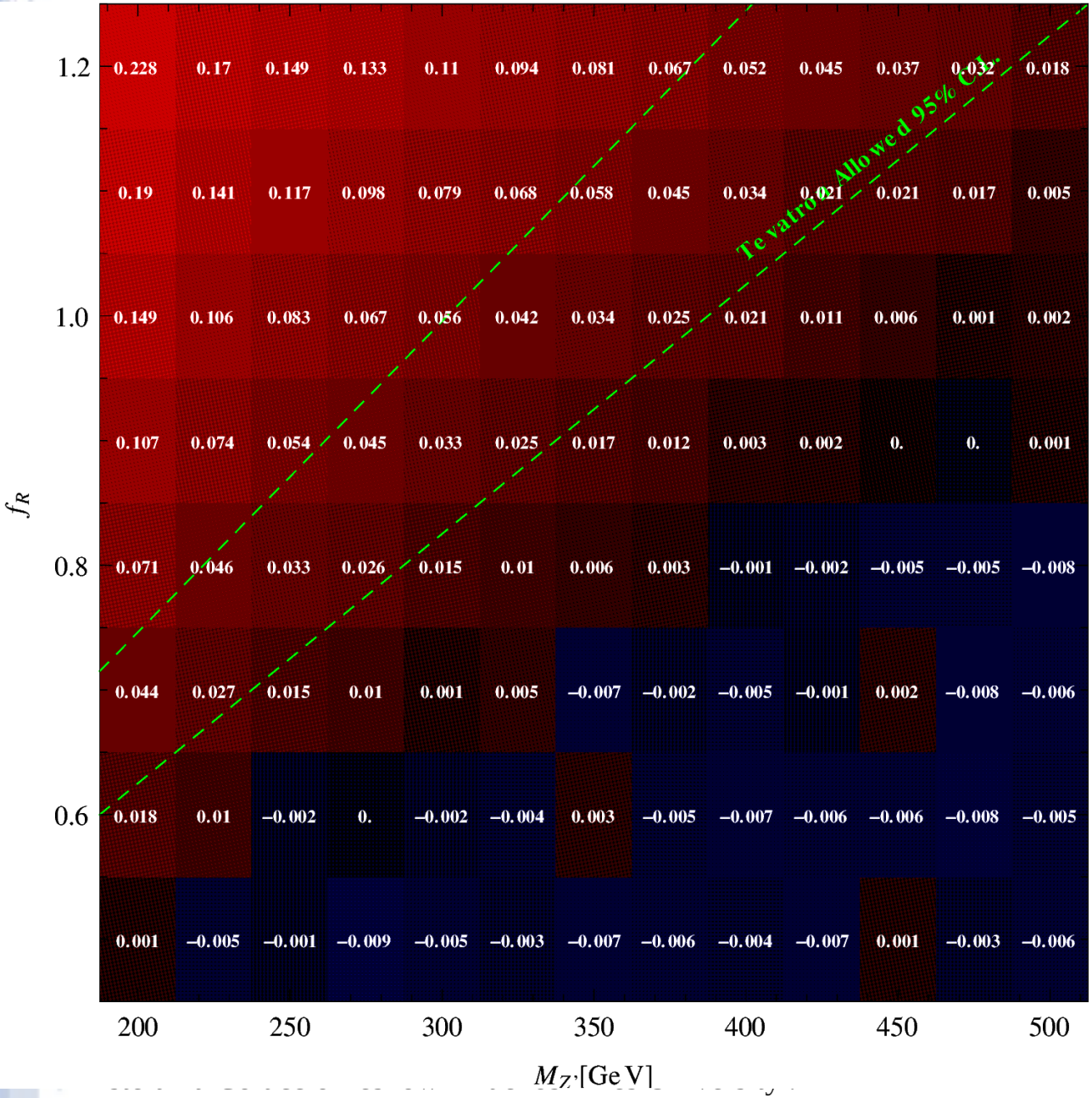
- A_{FB} for $M_{t\bar{t}} < 450$ GeV
- A_{FB} for $450\ \text{GeV} < \text{M}_{t\bar{t}} < 550$ GeV
- A_{FB} for $550\ \text{GeV} < \text{M}_{t\bar{t}} < 650$ GeV
- A_{FB} for $M_{t\bar{t}} > 650$ GeV
- A_{FB} for $\Delta y < 0.5$
- A_{FB} for $0.5 < \Delta y < 1$
- A_{FB} for $1 < \Delta y < 1.5$
- A_{FB} for $\Delta y > 1.5$
- $\sigma(t\bar{t})$

LHC:

- A_C
- $\sigma(t\bar{t})$

Region of parameter space:

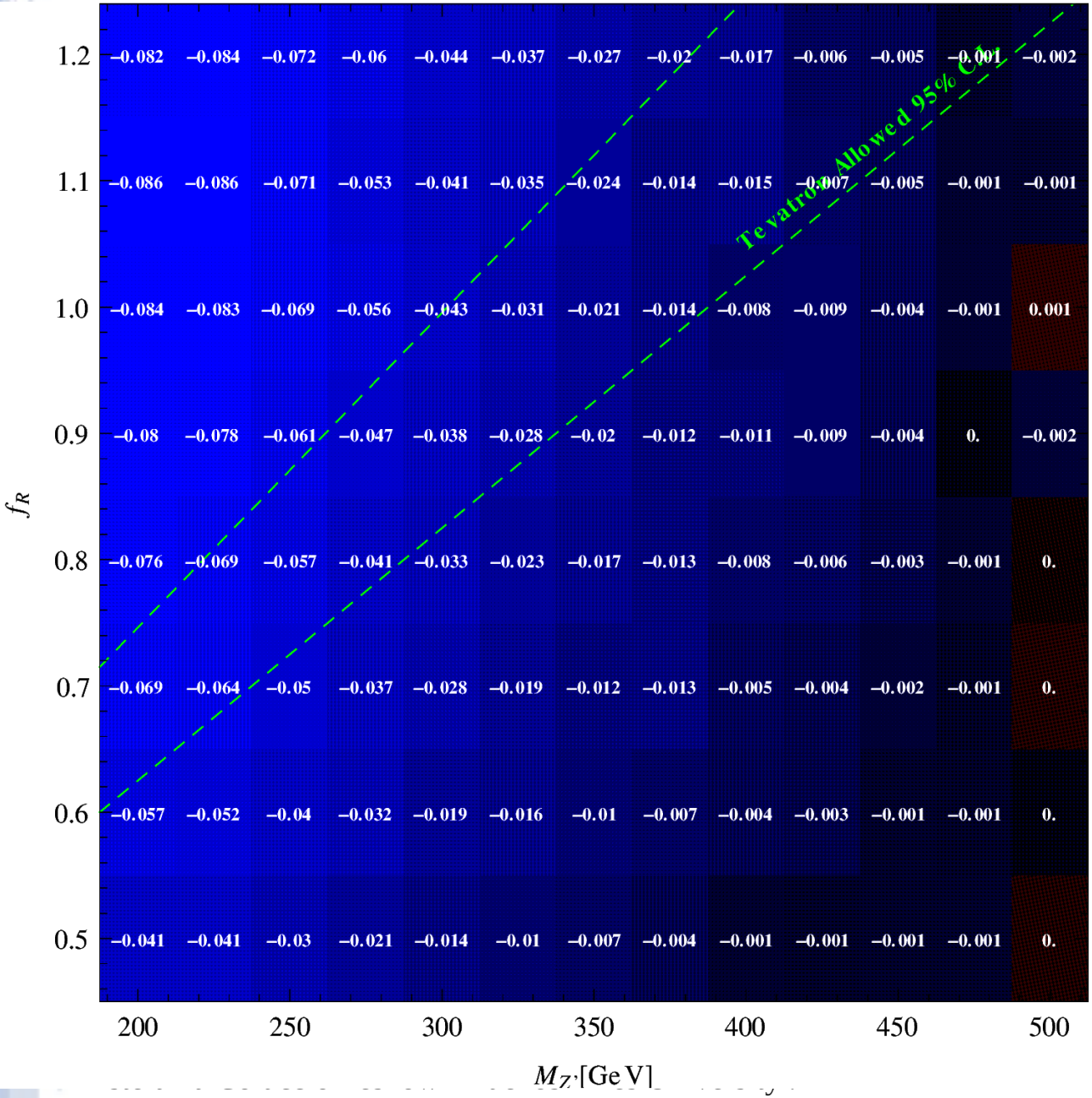
175 GeV < Mz' < 550 GeV
0.5 < fr < 1.2



Results:

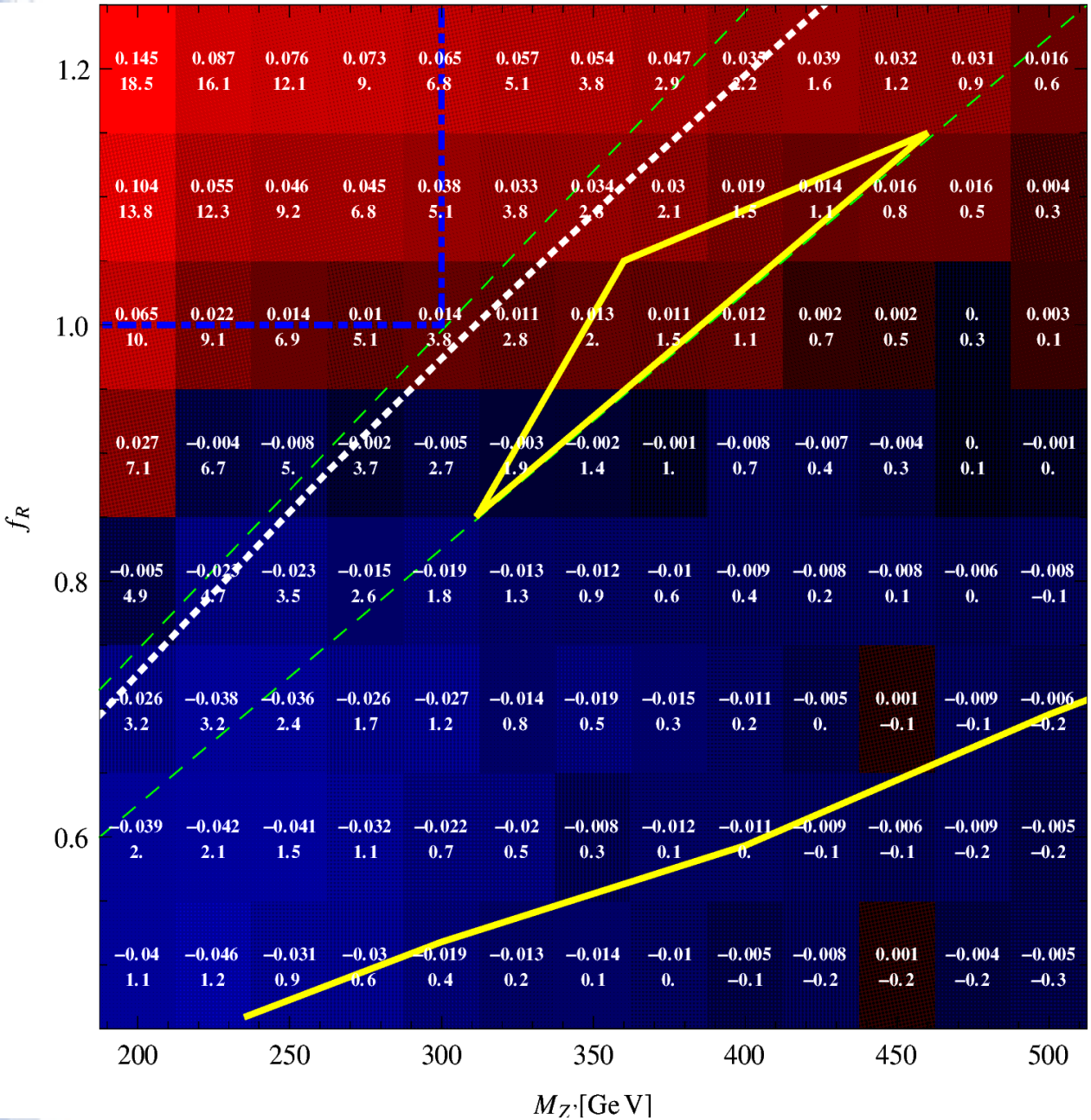
t – channel contribution Positive Ac

- *Ac (NP) > 0*
- *Ac (NP) < 0*
- *Numbers: t- channel charge asymmetry.*



s – channel contribution Negative Ac

- *Ac (NP) > 0*
- *Ac (NP) < 0*
- *Numbers: s- channel charge asymmetry.*



All : Expected Cancellation!!

- tj resonance searches by ATLAS
- *Ac (NP) > 0*
- tj resonance searches by CDF
- *Ac (NP) < 0*
- *Upper Number: NP contribution to the charge asymmetry.*
- APV
- Yellow Triangle: Points consistent at 95%CL
- *Lower Number: Difference (in σ) to measured values of* $\sigma(t\bar{t})$
- Tevatron limits

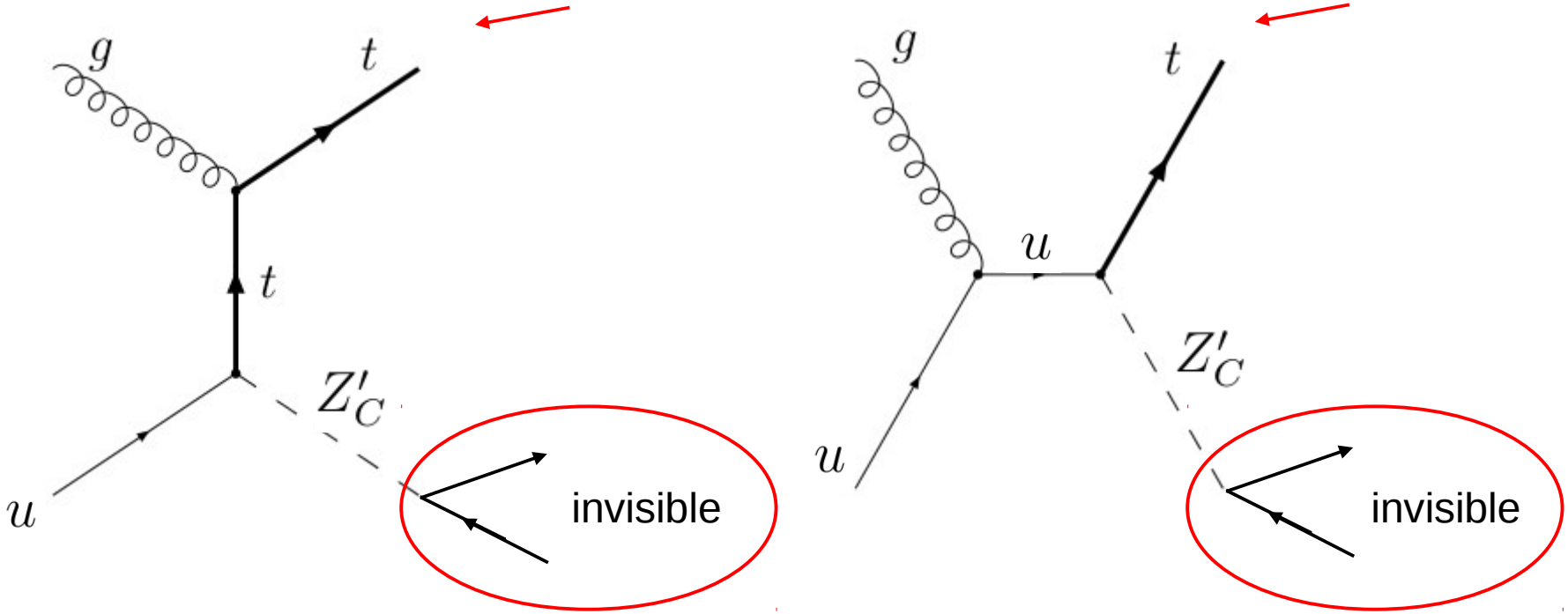
Remember?

→ $t\bar{t} + j$ constraints at the LHC

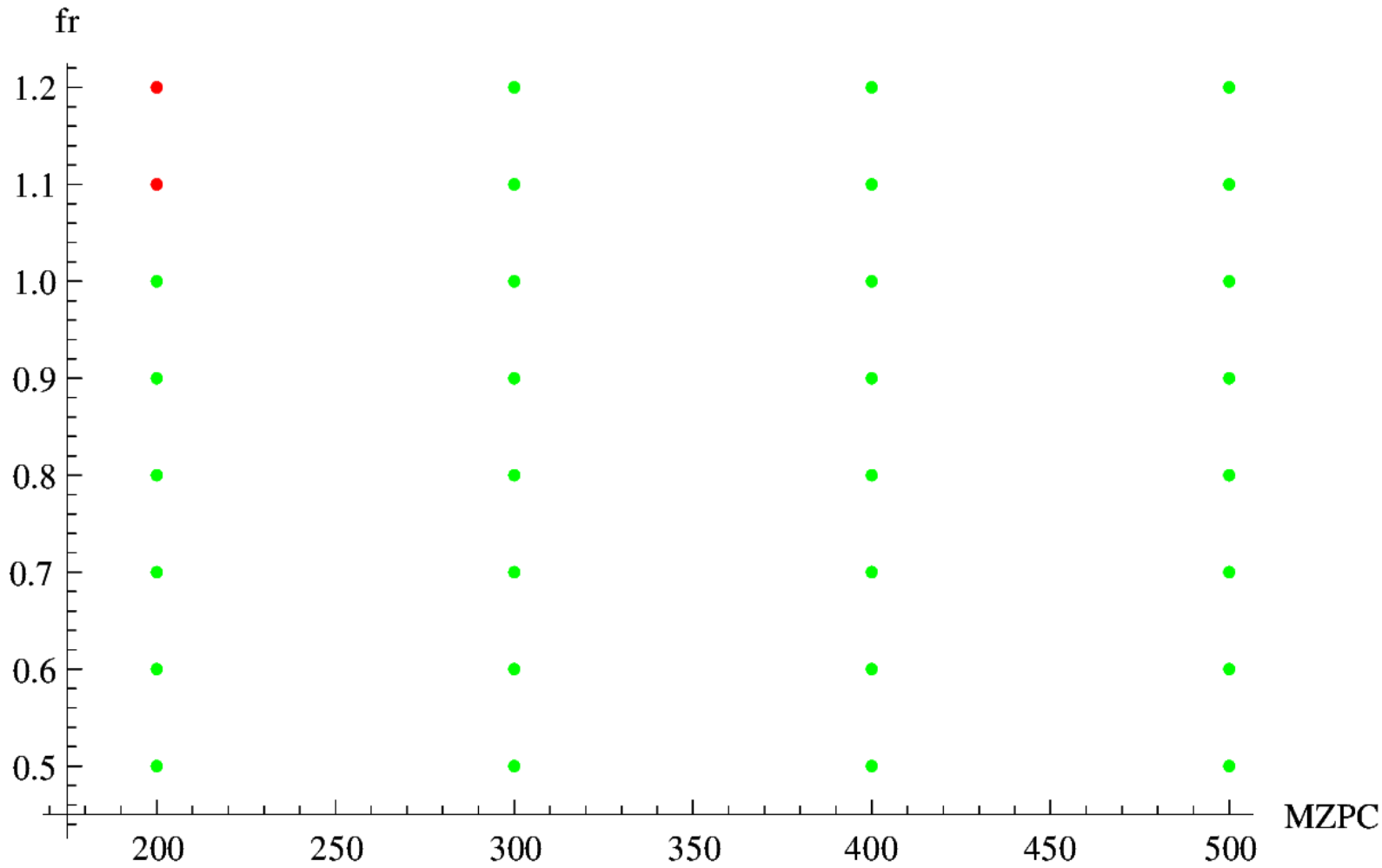
can be relaxed by making

$\Gamma_{Z'_C}$ larger...

Single-top production!



ATLAS measurement of the t-channel single top production cross section

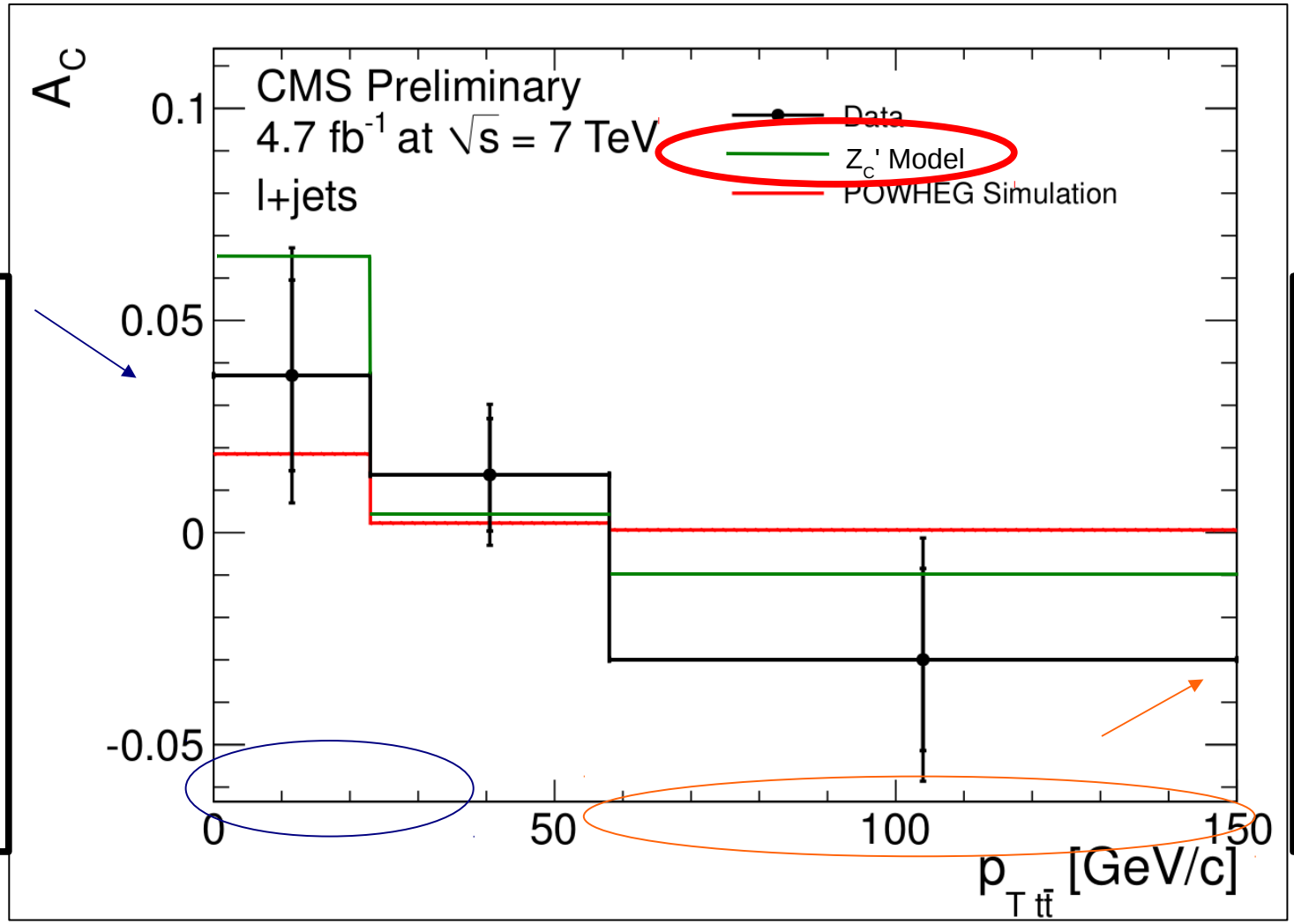


Distinctive features of the Model

Low pT

Channel-s
OFF
Channel-t
ON

$A_C > 0$

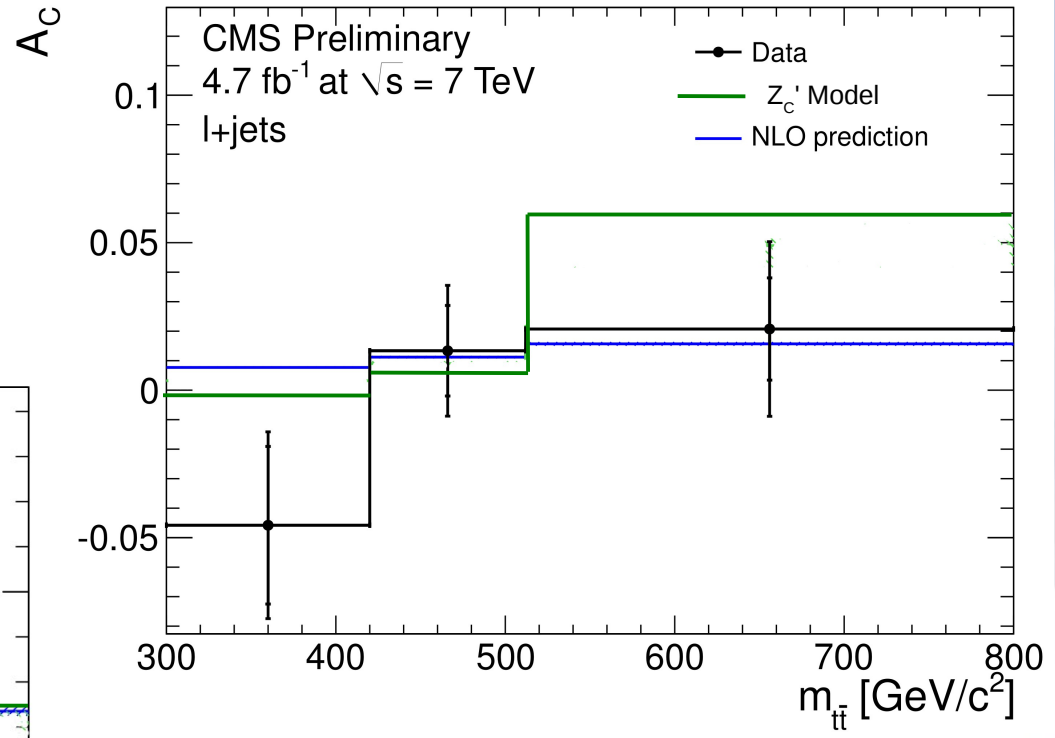


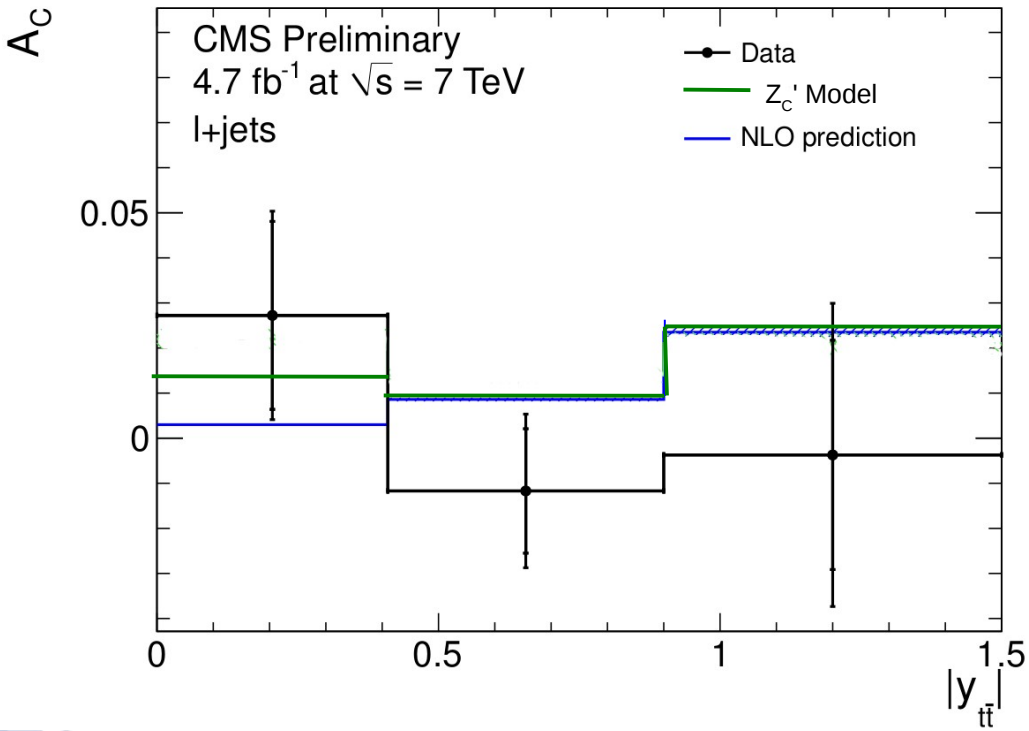
High pT

Channel-s
ON
Channel-t
OFF

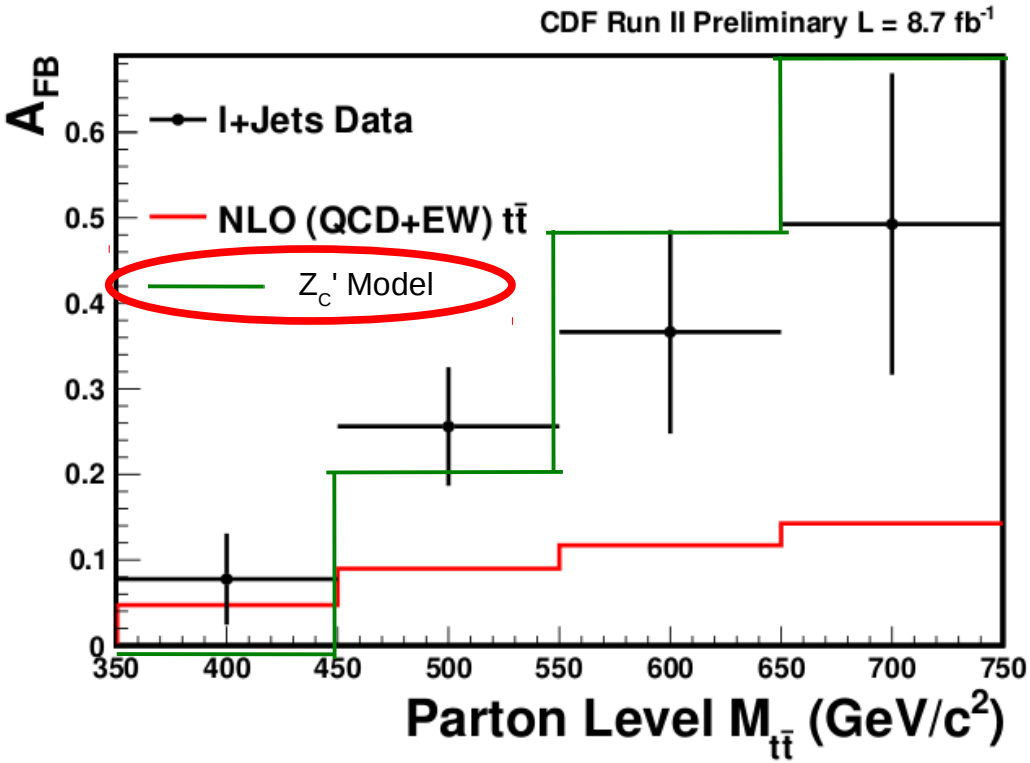
$A_C \downarrow$

Other differential observables of the Model





And what about the A_{FB} at Tevatron ?



Definitions of A_C in the t-channel and s-channel

$$A_{C_{t-channel}} = \frac{N^+(t,SM) - N^-(t,SM)}{N^+(t,SM) + N^+(s) + N^-(s) + N^-(t,SM) + N^-(s)} \quad (1)$$

$$A_{C_{s-channel}} = \frac{N^+(s) - N^-(s)}{N^+(t,SM) + N^+(s) + N^-(s) + N^-(t,SM) + N^-(s)} \quad (2)$$

$$A_{C_{Total}} = A_{t-channel} + A_{s-channel} \quad (3)$$

Standard Deviation of $\sigma_{t\bar{t}}$

We consider the CMS Combination of $\sigma_{t\bar{t}}$ measurements (CMS-PAS-TOP-11-024) of

$$\boxed{165.8 \pm 13.3 \text{ pb}} \tag{4}$$

and the theoretical calculation made with HATHOR, (Hadronic Top and Heavy quarks Cross Section Calculator-(Comput. Phys. Commun. 182(2011) 1034 - (http://arxiv.org/abs/1007.1327)), which gives:

$$\boxed{164 + 11/ - 16 \text{ pb}} \tag{5}$$

for the LHC at 7 TeV.

Considering an error of 16 pb in this calculation and summing in quadrature with the experimental error, we get a total error of 20.8 pb, which represents a %13 of the measured cross section, thus

$$\boxed{1\sigma = \%13} \tag{6}$$

Calculation of the asymmetries with NP

If the NP contribution to the total cross section is small, $\sigma_{SM} \gg \sigma_{NP}$ (where σ_{NP} contains both INT and NPS contributions), we can approximate the asymmetry by

$$A \approx A^{SM} + A^{NP}, \tag{11}$$

where, in the numerator of A^{NP} we include INT+NPS terms given at tree level, whereas in the denominator we only take into account the SM term given at tree level. [Alvarez,E.,Da Rold,L. and Szynkman,A., JHEP **1105** (2011) 070 arXiv:1011.6557]