Probing composite models using the same-sign dilepton (2SSL) channel with the ATLAS detector

Romain Kukla

CEA Saclay/DRF/IRFU/SPP

22 juillet 2016

Outline

▶ **Introduction**
SM/BSM, top, partial compositeness

▶ **Run 1 analyses**
Tevatron, ATLAS 7 TeV and 8 TeV

▶ **Current searches for exotic partners**
ATLAS analysis 13 TeV (3.2 fb^{-1})

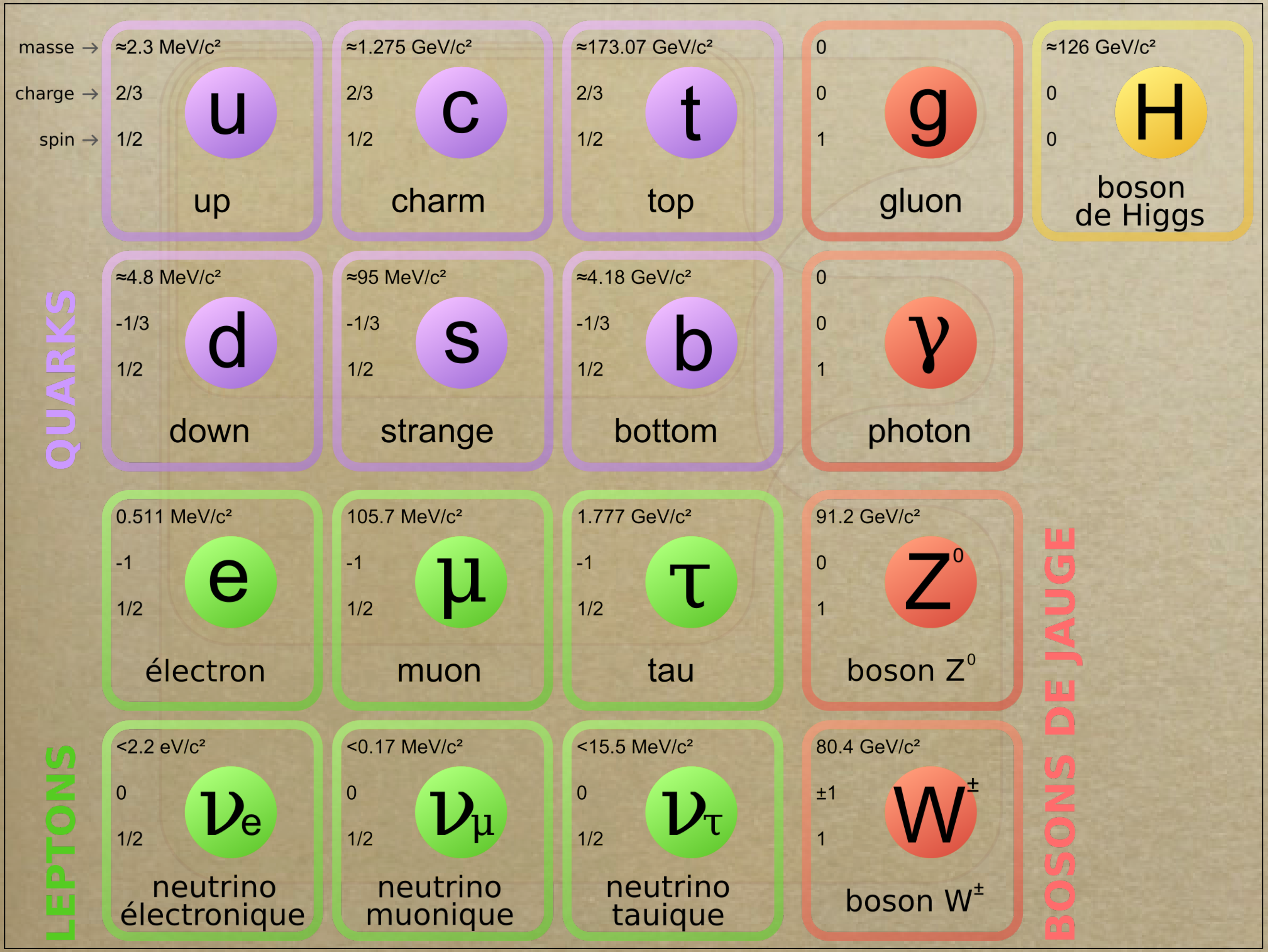
▶ **Prospects for future studies with 4 tops**
Discovery potential of SM/BSM $t\bar{t}t\bar{t}$ at 14 TeV

▶ **Conclusion**

Introduction

- **Introduction**
- Run 1 analyses
- Current searches for exotic partners
- Prospects for future studies with 4 tops
- Conclusion

The Standard Model



Standard Model (SM)

$SU(3)_C x SU(2)_L x U(1)_Y$

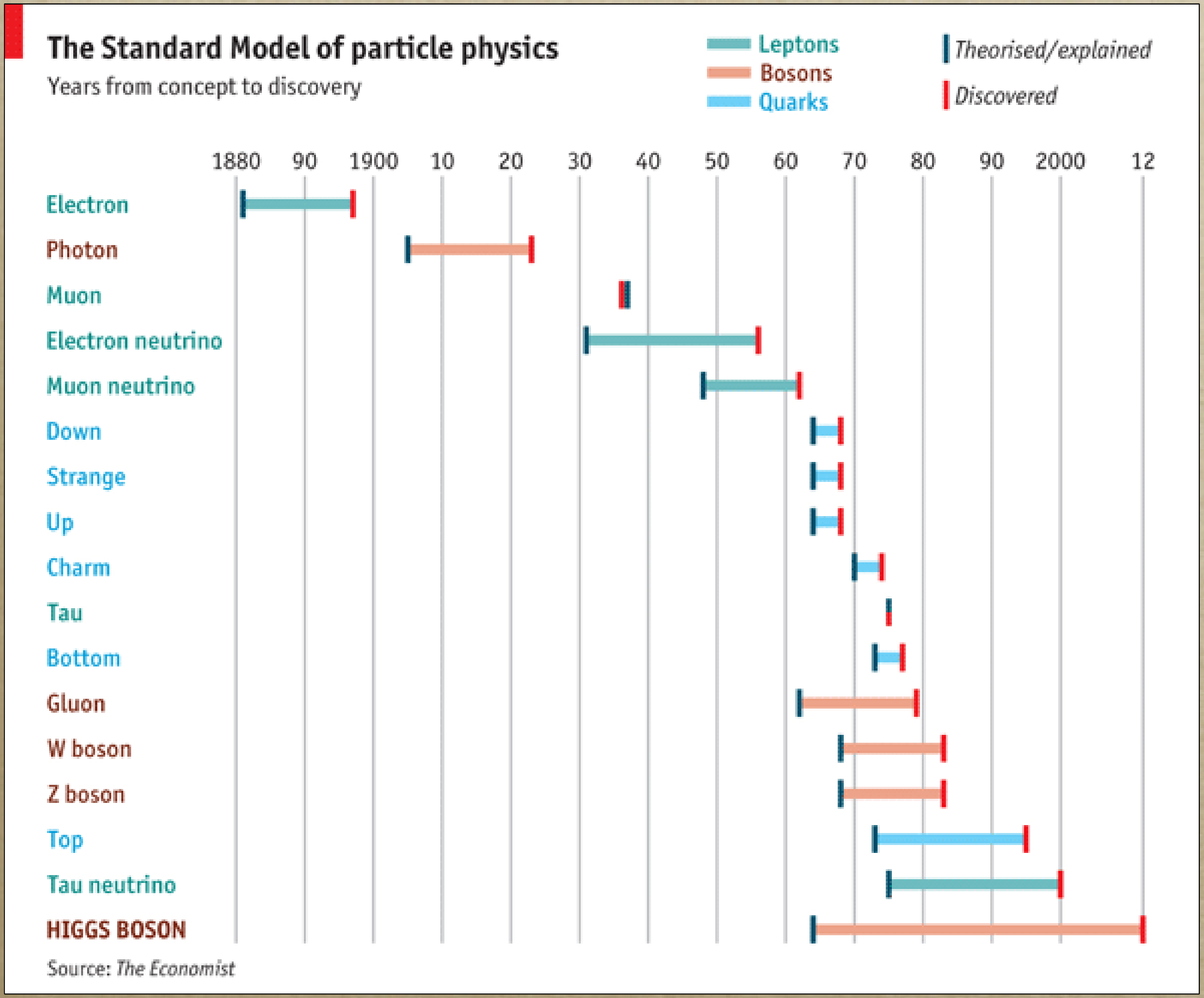
▶ gauge theory based on different symmetries of the matter

▶ describes 3 of the 4 fundamental interactions (EM, weak, strong)

▶ matter particles (fermions) and force carriers (boses)

▶ includes the Higgs mechanismto generate the mass

The Standard Model



Standard Model (SM)
$SU(3)_C x SU(2)_L x U(1)_Y$

▶ gauge theory based on different symmetries of the matter

▶ describes 3 of the 4 fundamental interactions (EM, weak, strong)

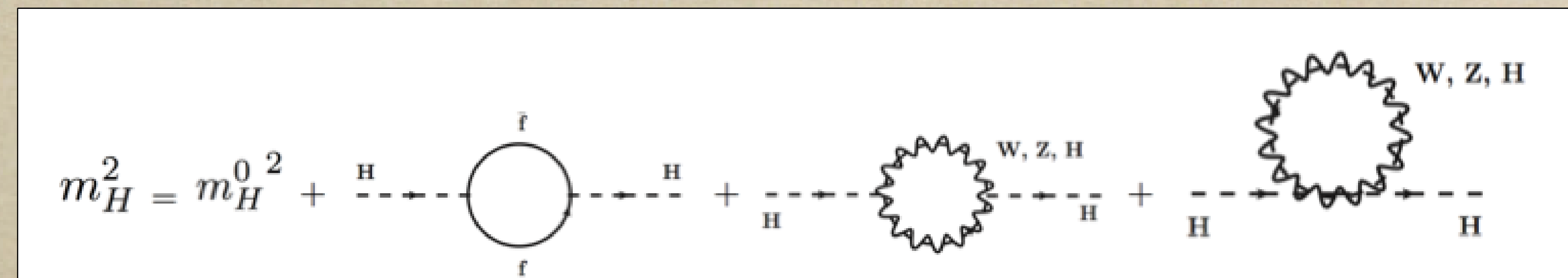
▶ matter particles (fermions) and force carriers (boses)

▶ includes the Higgs mechanismto generate the mass

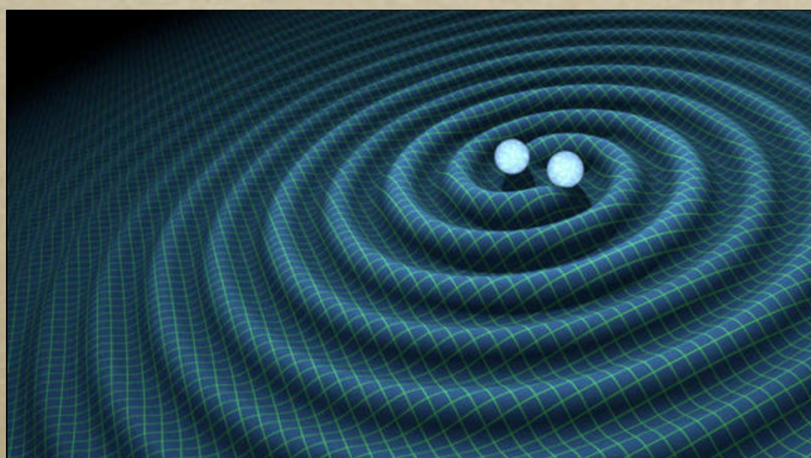
SM = result of >100 years of research in subatomic physics

The SM is not enough

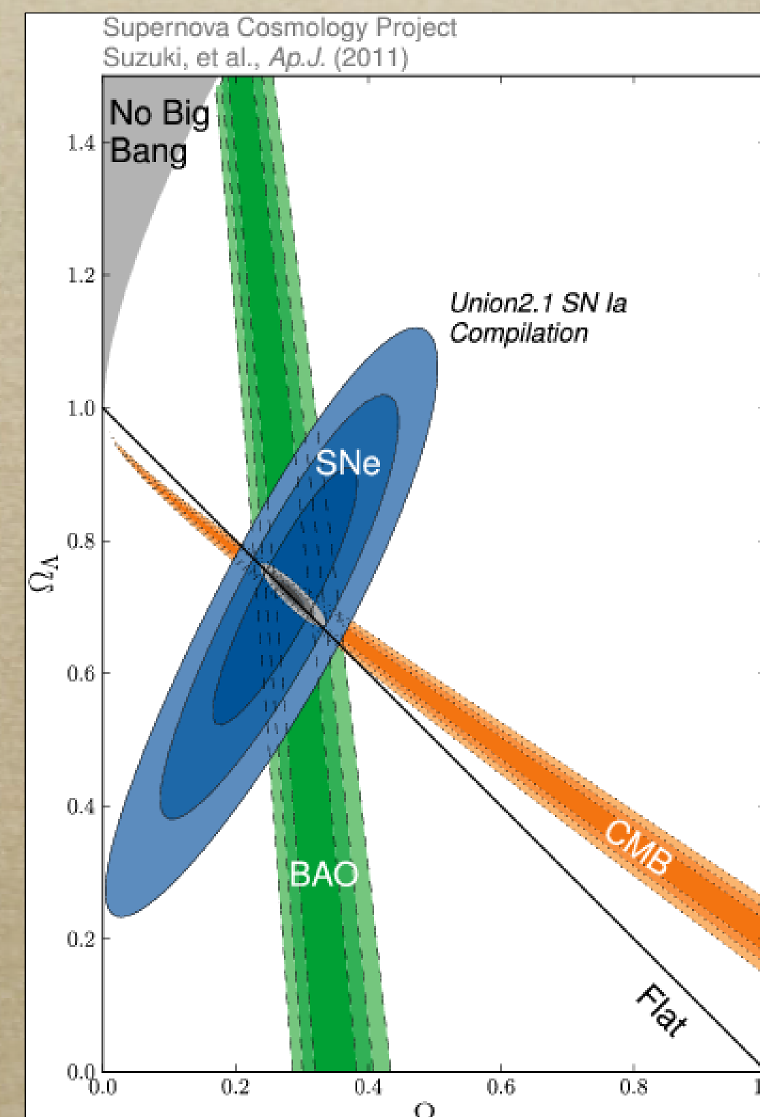
Fine tuning



Gravitation

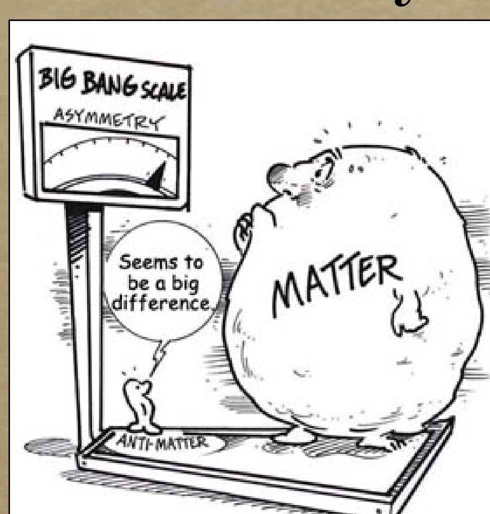


Dark matter/energy



Neutrinos masses

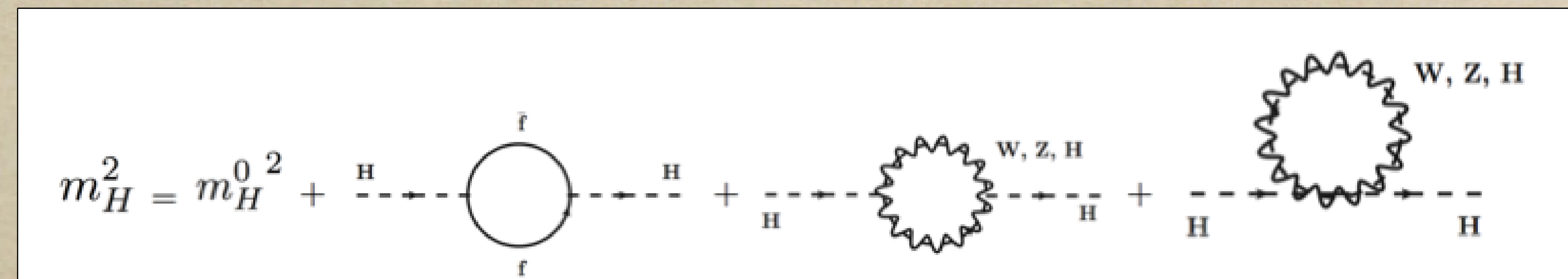
Matter/antimatter asymetry



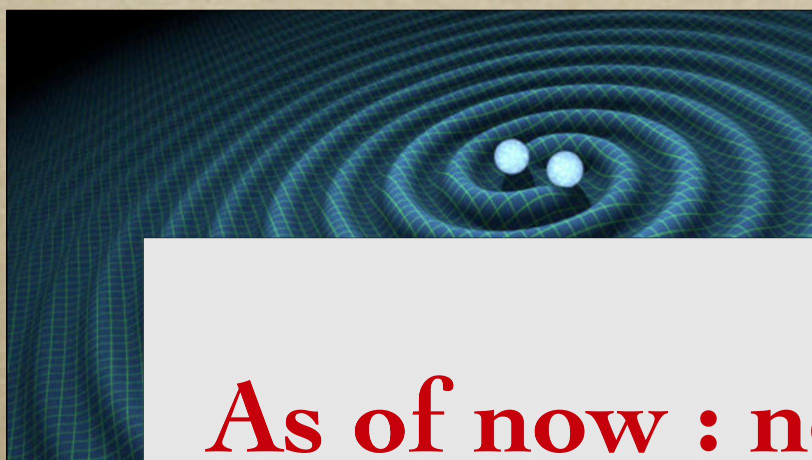
+ strong CP problem

The SM is not enough

Fine tuning

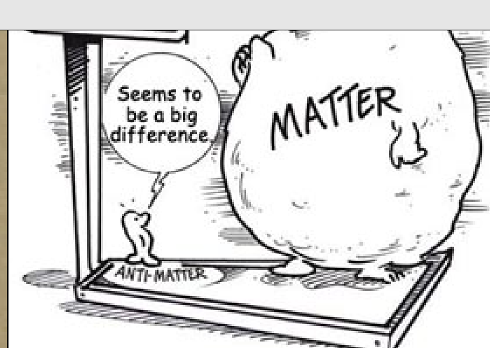


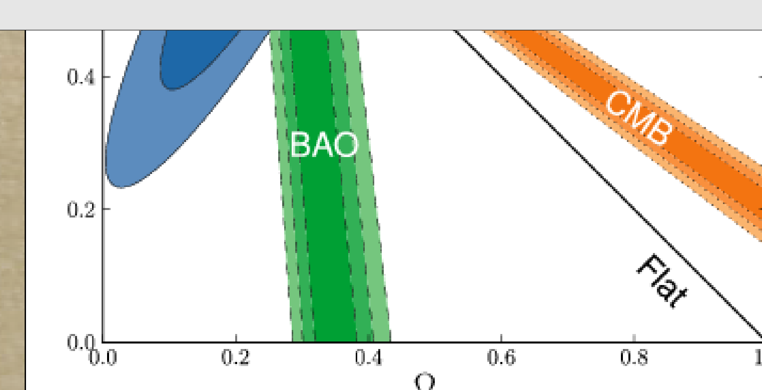
Gravitation



As of now : no experimental proof of BSM physics

But new physics is needed to explain these phenomena with the SM.

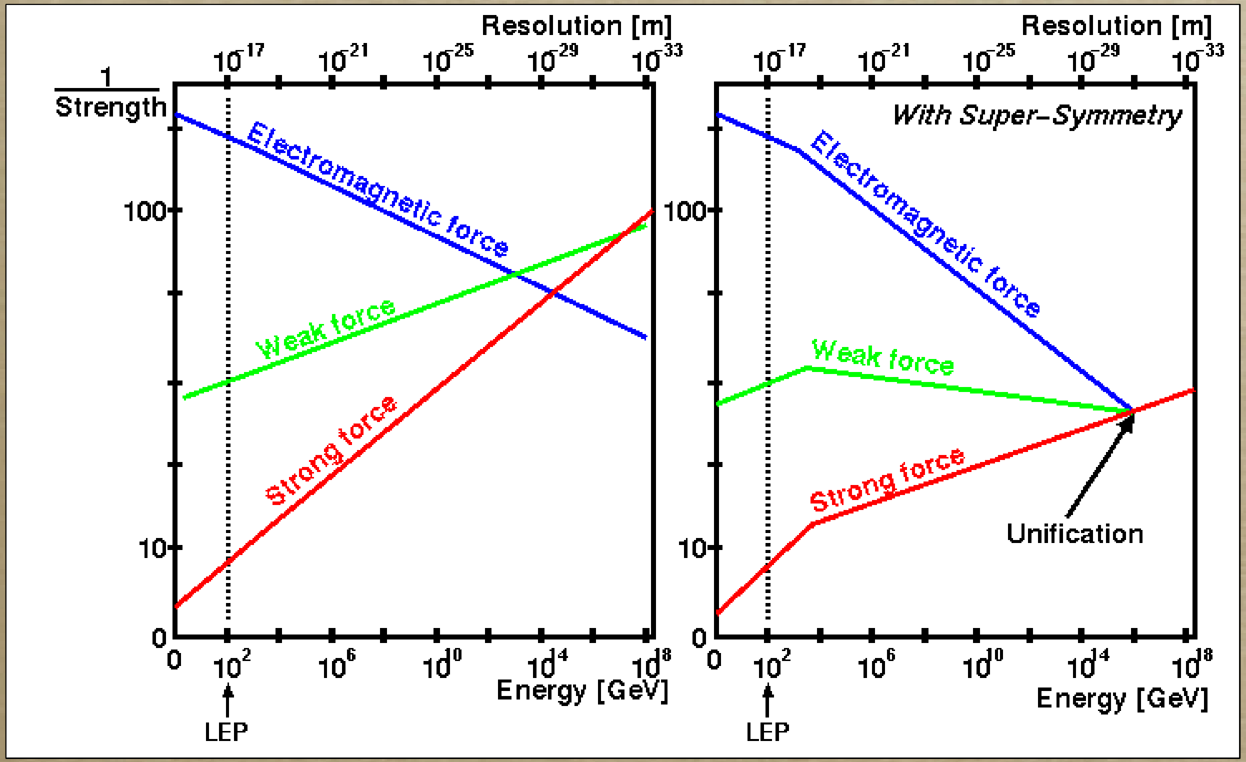




Which BSM ?

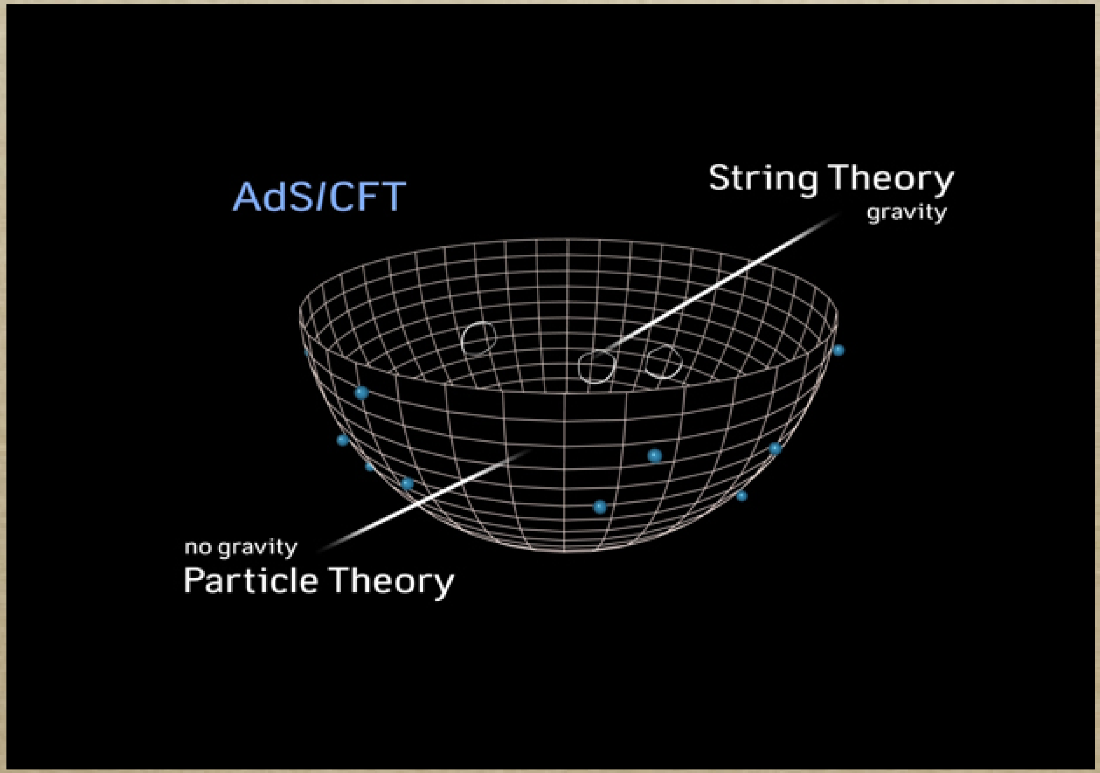
Weakly coupled = SUSY

Each SM particle has a superpartner : suppresses the quadratic divergences of m_{Higgs} and unifies the gauge couplings.



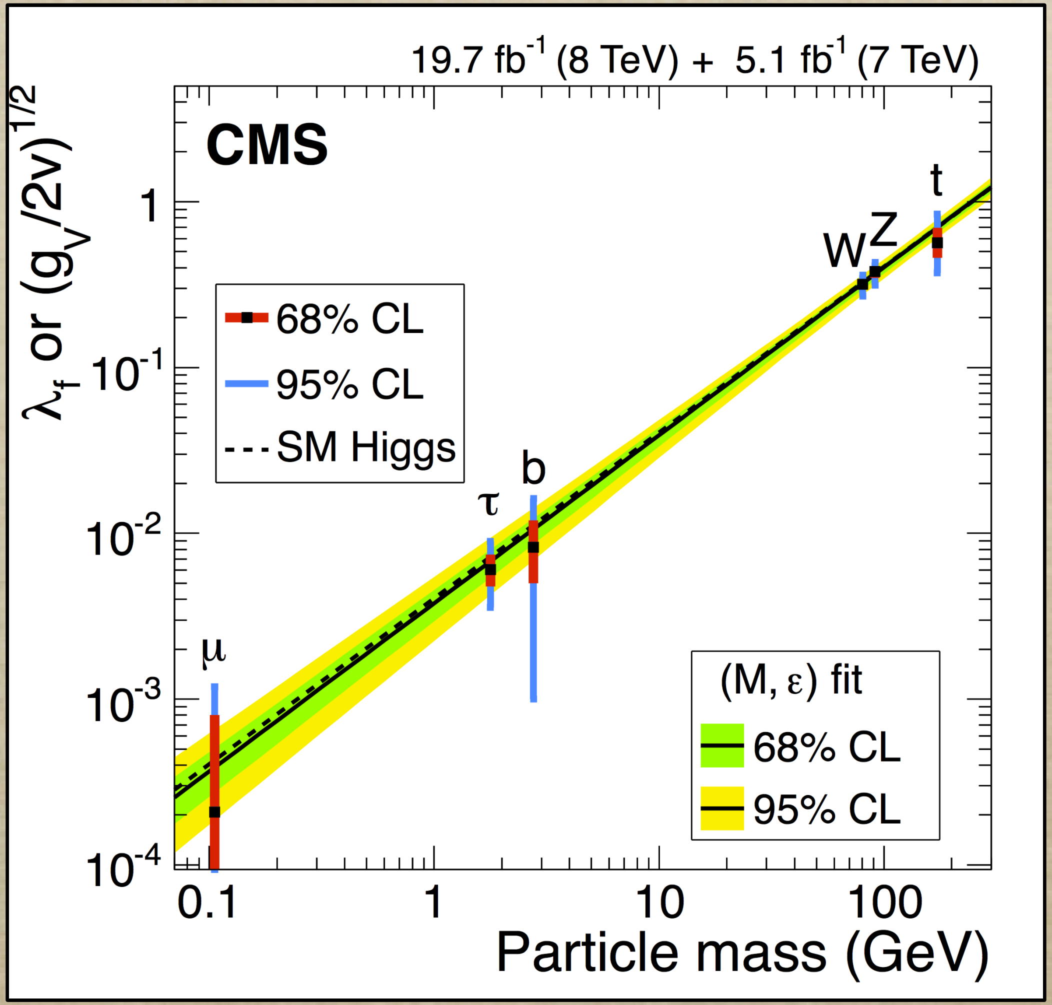
Strongly coupled

The Higgs boson is a composite object.
Link between extra dimensions and strongly coupled theories (AdS/CFT).



We expect new physics in the Higgs sector.
Higgs-top coupling ~ 1 : the top quark is a logical probe of such BSM

Top quark properties



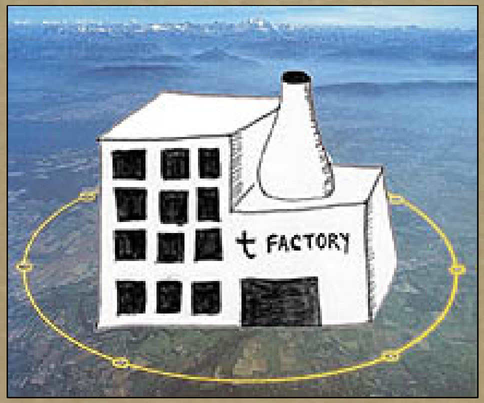
- m_t=173 GeV, heaviest SM particle.

- life time ~ 5.10^{-25} s < hadronization time
→ no « toponium », decays in $bW+$.

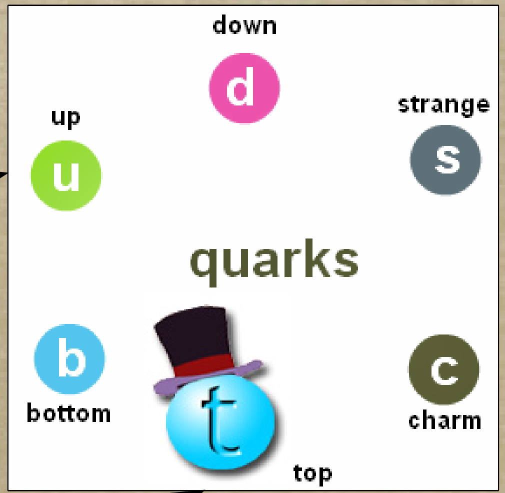
- Yukawa coupling to the Higgs boson ~1

- involved in the fine tuning.

- LHC = top factory
3,9 millions of top pairs produced in 2012.



Up quark
= **2.4 MeV**

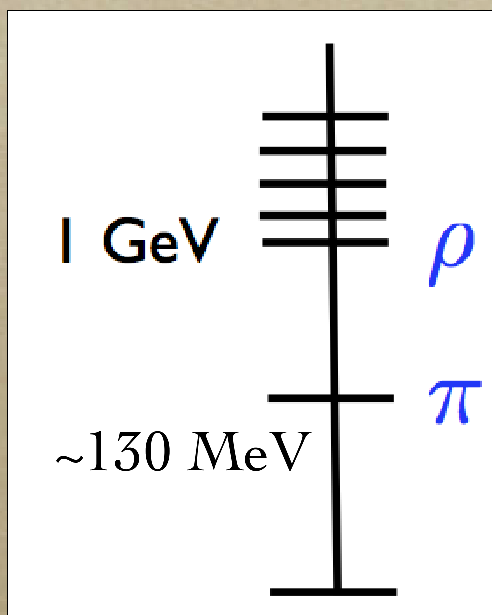


Top quark = **173 GeV**

The compositeness paradigm

Panico & Wulzer arXiv :1506.01961

The SM is not fundamental ⟶ effective theory up to a scale Λ_{SM}.
Inspiration from QCD pseudo-scalars :

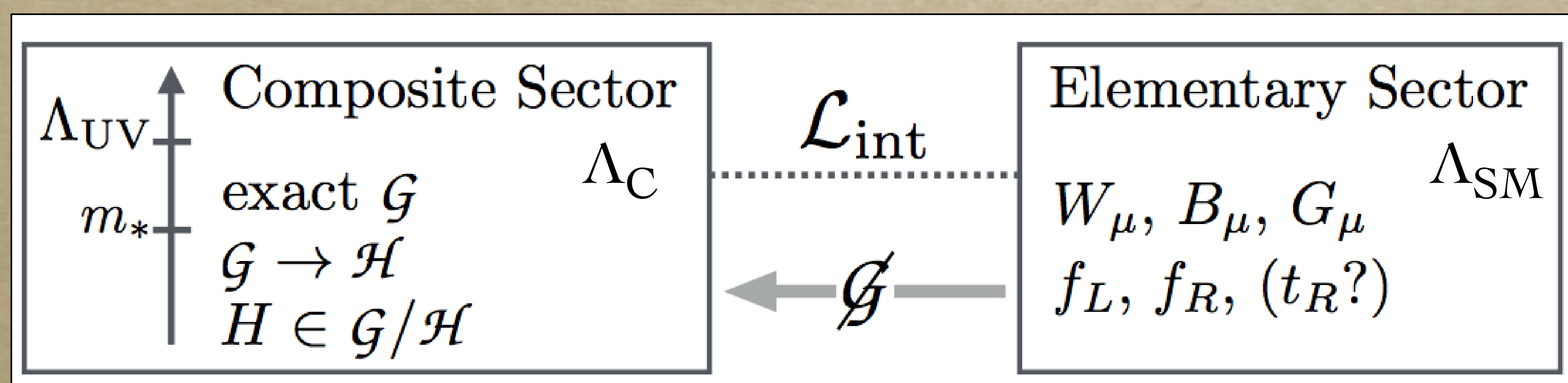


Spontaneous breaking of $SU(2)_L \times SU(2)_R \rightarrow SU(2)_V$ creates pions π^0, $\pi^{\pm}$ as pseudo-goldstones, well below typical meson masses (neutron = 950 MeV, rho = 770 MeV).

QCD

The composite (scalar) Higgs boson is a PGB of a larger global symmetry breaking $\mathcal{G} \rightarrow \mathcal{H}$

$\Lambda_{SM} >> \Lambda_C$



Composite sector includes TeV scale resonances and leads to a light PGB Higgs boson. Elementary contains light SM particles + SU(2)xU(1).

Partial compositeness

Contino arXiv :0612180

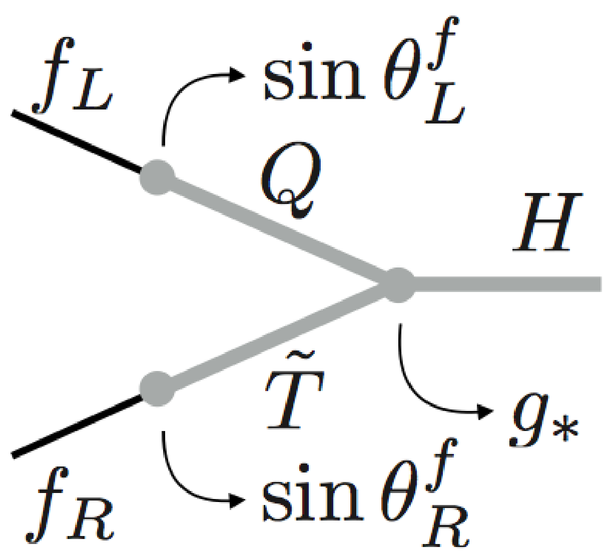
Partial compositeness = Linear mixing between the elementary and the composite states to give massive states (both SM and heavy)

$$|\mathrm{SM}_n\rangle = \cos\phi_n|\mathrm{elementaire}_n\rangle + \sin\phi_n|\mathrm{composite}_n\rangle$$

$$|\mathrm{Lourd}_n\rangle = -\sin\phi_n|\mathrm{elementaire}_n\rangle + \cos\phi_n|\mathrm{composite}_n\rangle$$

The Yukawa interaction between the Higgs boson and the SM fermions is :

$y_t =$



$= g_* \cdot \sin\theta_L^f \cdot \sin\theta_R^f$

where g* is the composite Yukawa coupling

After EWSB : High mass ⇔ High y_t ⇔ High sinθ ⇔ Highly composite

The top quark is the most composite fermion in the SM

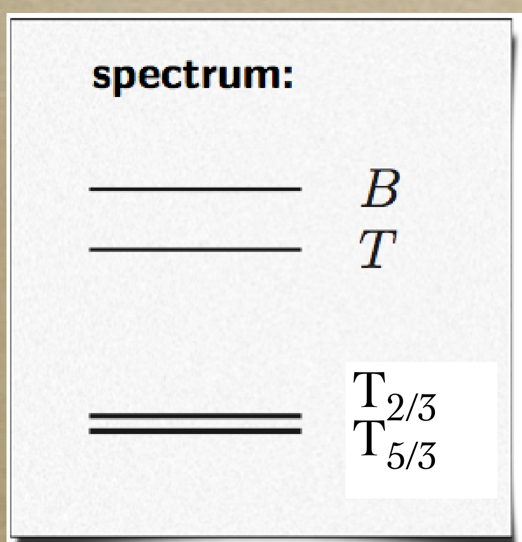
Partial compositeness (2)

Different choices for the global symmetry (usually SO(5)→SO(4)) and its representations.

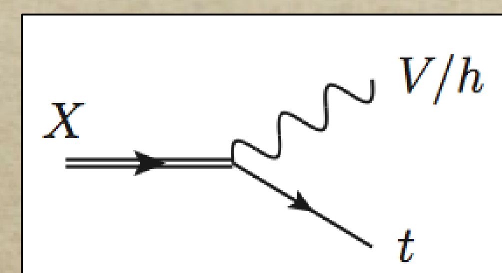
Contino & Servant 0801.1679
De Simone & al. 1211.5663

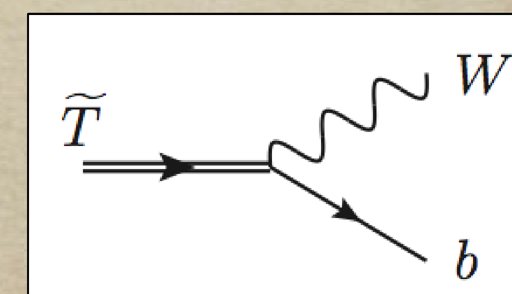
$$L_{Yukawa} = Y_* \sin\phi_L \sin\phi_R(\bar{t_L}\phi_0 t_R) + Y_* \cos\phi_L \sin\phi_R(\tilde{T}\phi_0 t_R - \bar{B}\phi^- t_R)$$
$$+Y_* \sin\phi_L \cos\phi_R(\bar{t_L}\phi_0\tilde{T} - \bar{b_L}\phi^-\tilde{T}) + Y_* \sin\phi_R(\bar{T_{5/3}}\phi^+ t_R + \bar{T_{2/3}}\phi_0 t_R) + ...$$

Y_* is the composite Yukawa coupling



The $T_{5/3}$ is always the lightest exotic state.



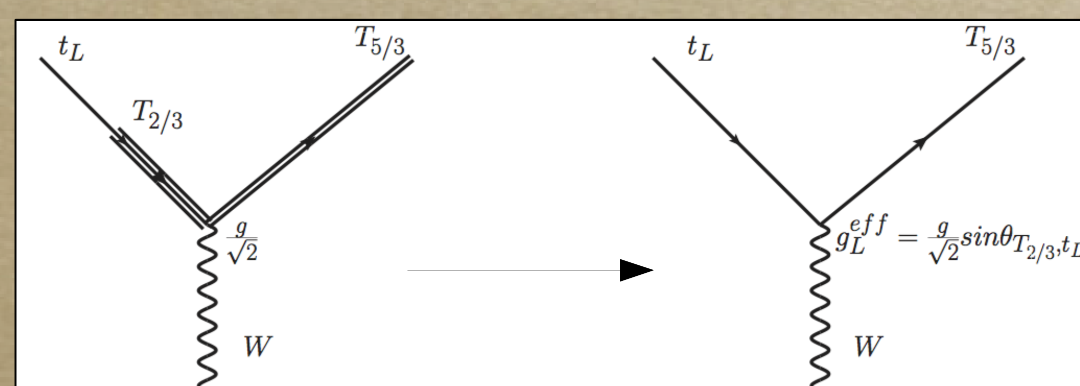


Fourplets (X) and singlet (T) couplings

Heavy sector

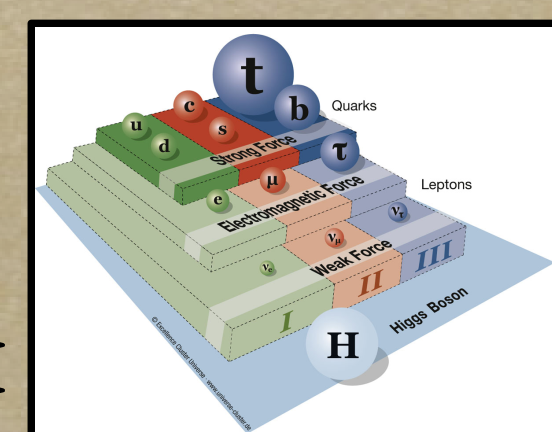
$$\begin{bmatrix} \phi_0^* & \phi^+ \\ -\phi^- & \phi_0 \end{bmatrix} \quad \begin{bmatrix} T & T_{5/3} \\ B & T_{2/3} \end{bmatrix}$$

$$[\tilde{t_1}, \tilde{t_2}]$$



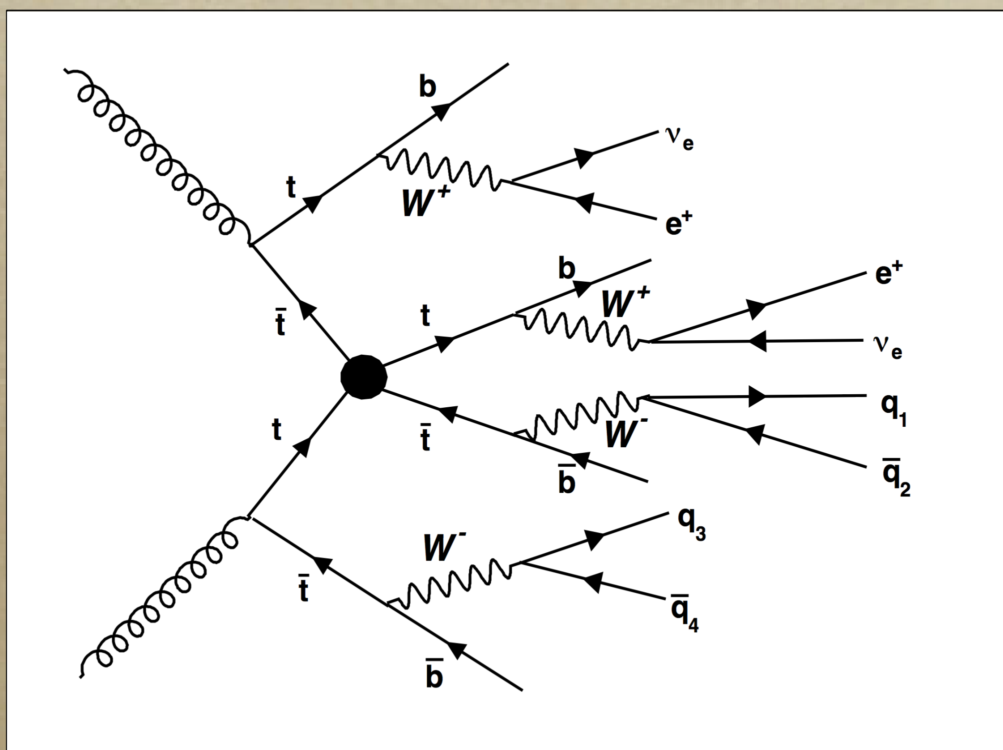
Effective coupling between SM and heavy

SM sector



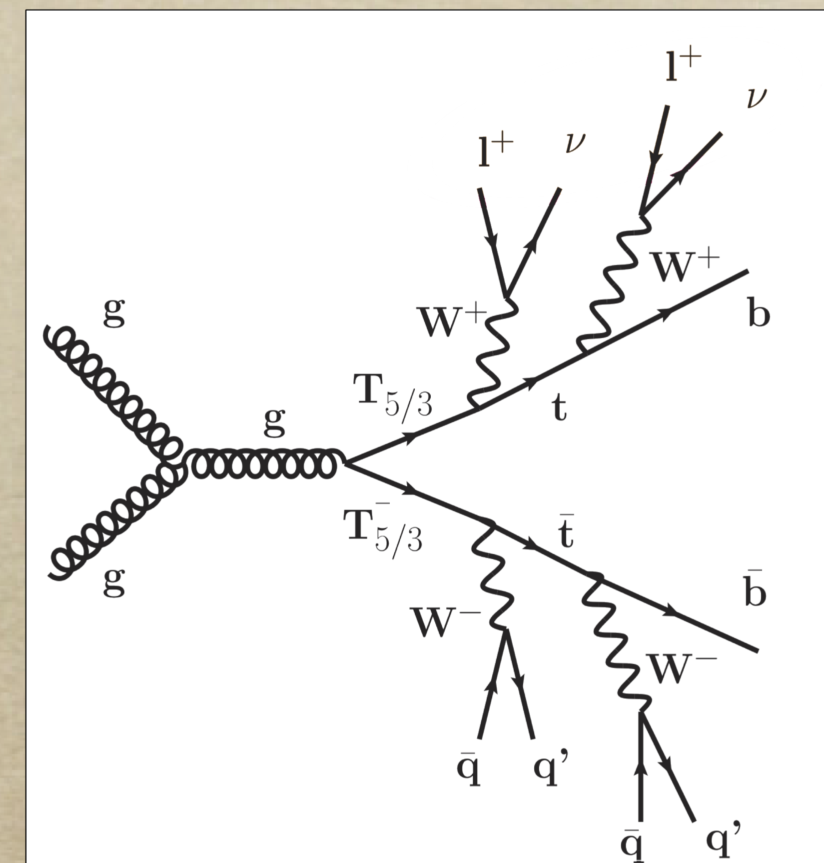
Probing compositeness with the top quark

Two possible ways to test it :



4 top production

Enhanced by BSM contributions, such as top-philic Z' composite resonance.



Heavy quark production

($T_{5/3}$ f.eg.) which decays in tops.

For these 2 processes, one can look at the 2 same-sign leptons channel which has a very low SM background.

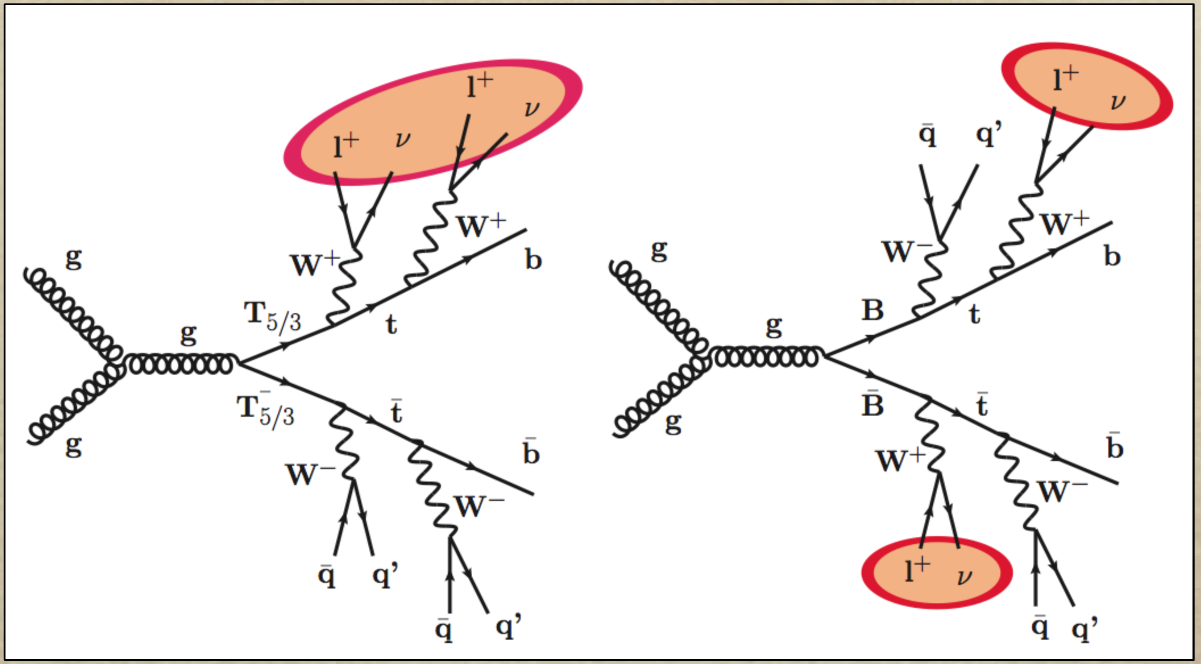
Run 1 analyses

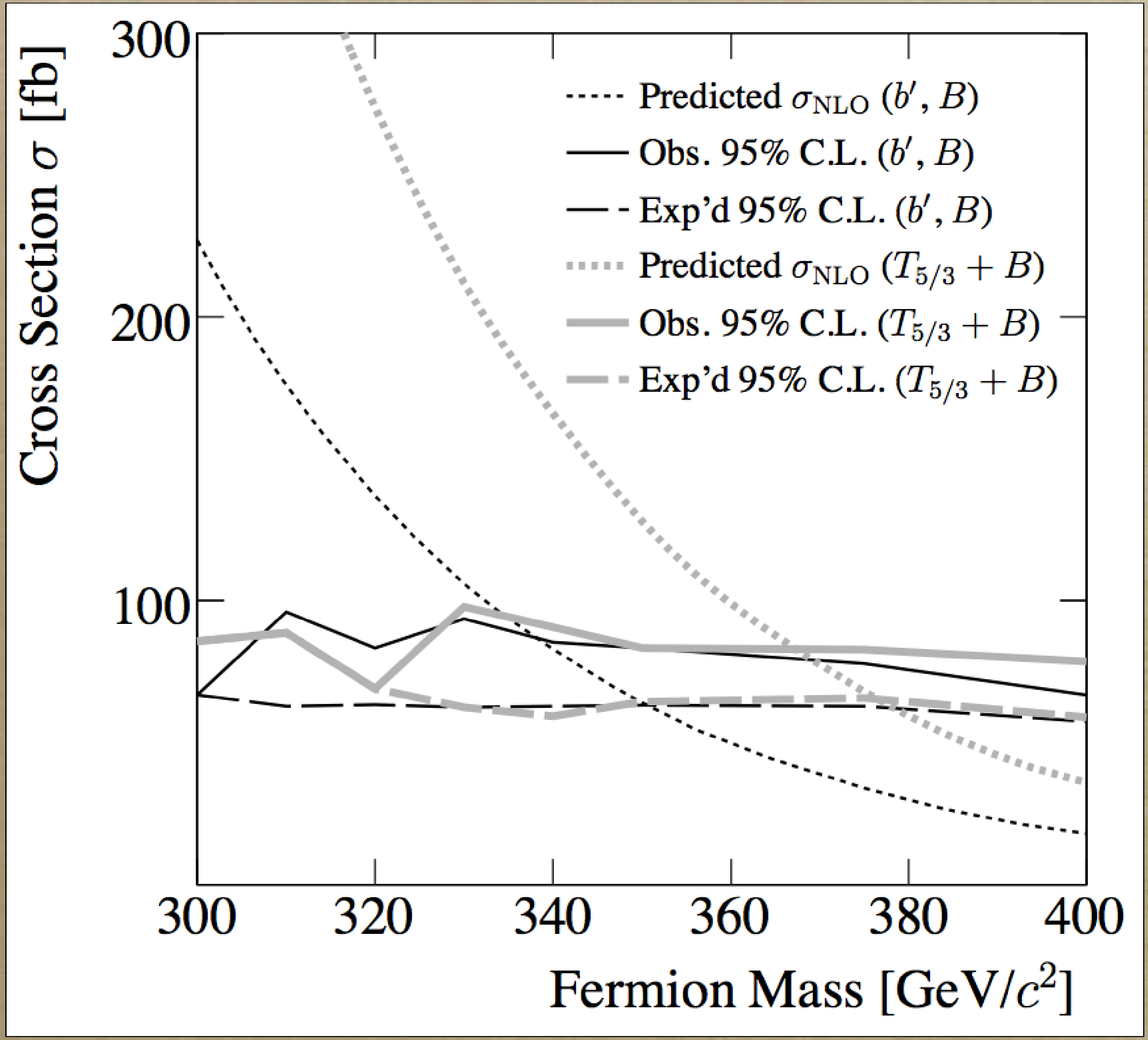
First search for top partners at Tevatron

$\sqrt{s}$=0,98 TeV

CDF arXiv :0912.1057

Pair production of $T_{5/3}$ and B in the 2LSS channel with 2.7 fb^{-1}. Assuming $m(T_{5/3})=m(B)$ and $BR(T_{5/3} / B \rightarrow tW)=1$, the total yield is doubled.





2 same-charge leptons with p_T > 20 GeV
At least 2 jets with p_T > 15 GeV including one b-tagged
MET > 20 GeV

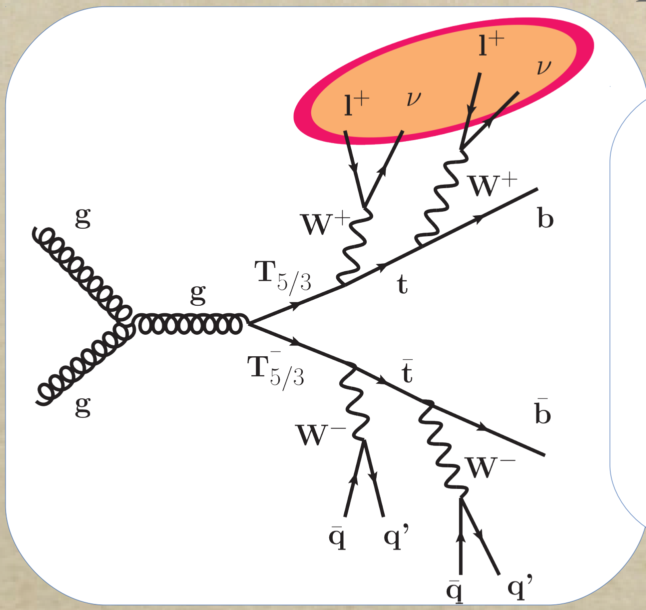
1st limit from CDF : **m > 365 GeV**

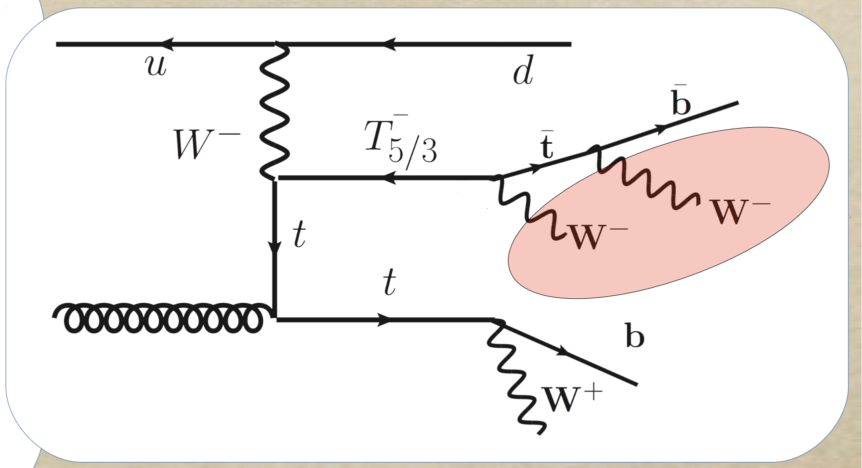
First search for top partners at the LHC

$\sqrt{s}$=7 TeV

ATLAS-CONF-2012-130

Pair production and single production of $T_{5/3}$ in the 2LSS channel with 4.7 fb^{-1}. The total cross-section is coupling dependant.





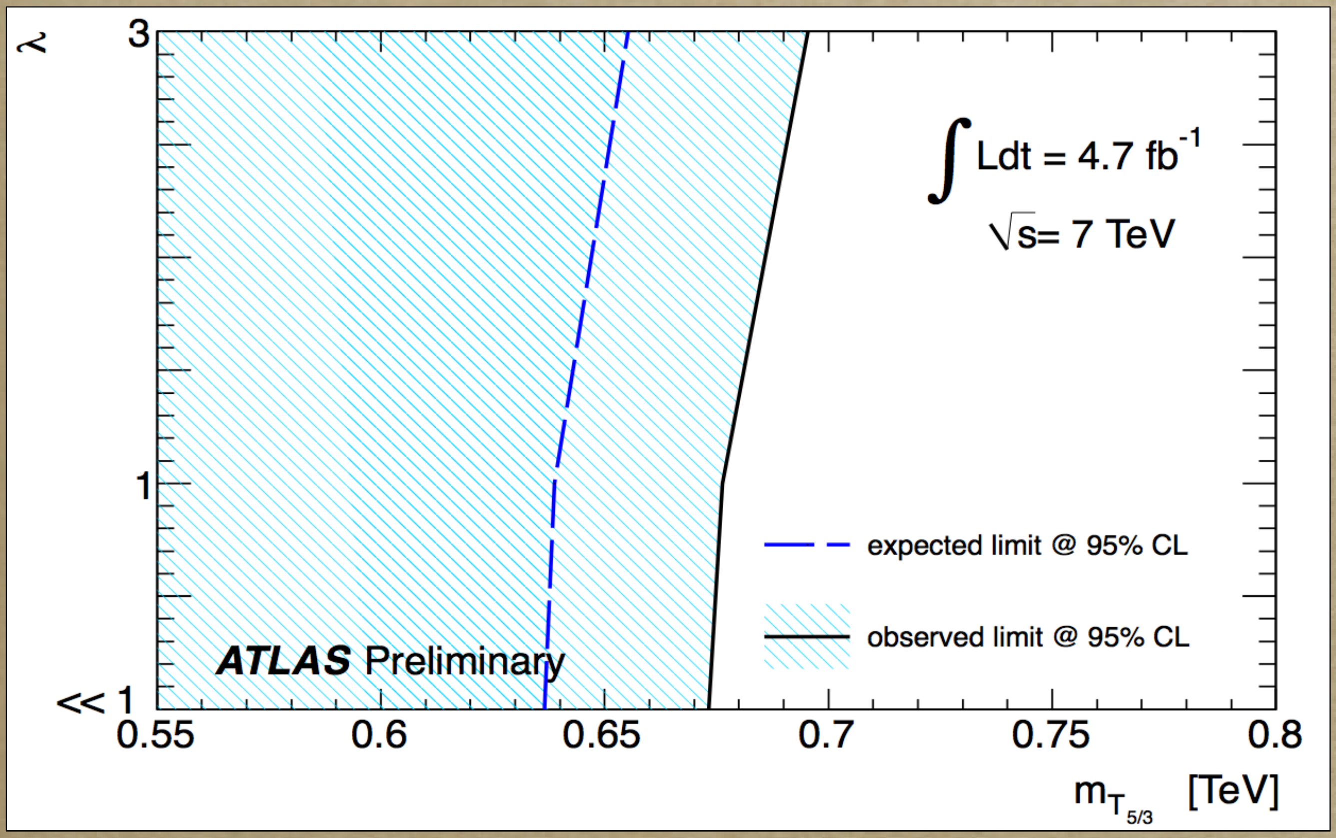
2 same-charge leptons with p_T > 25 GeV

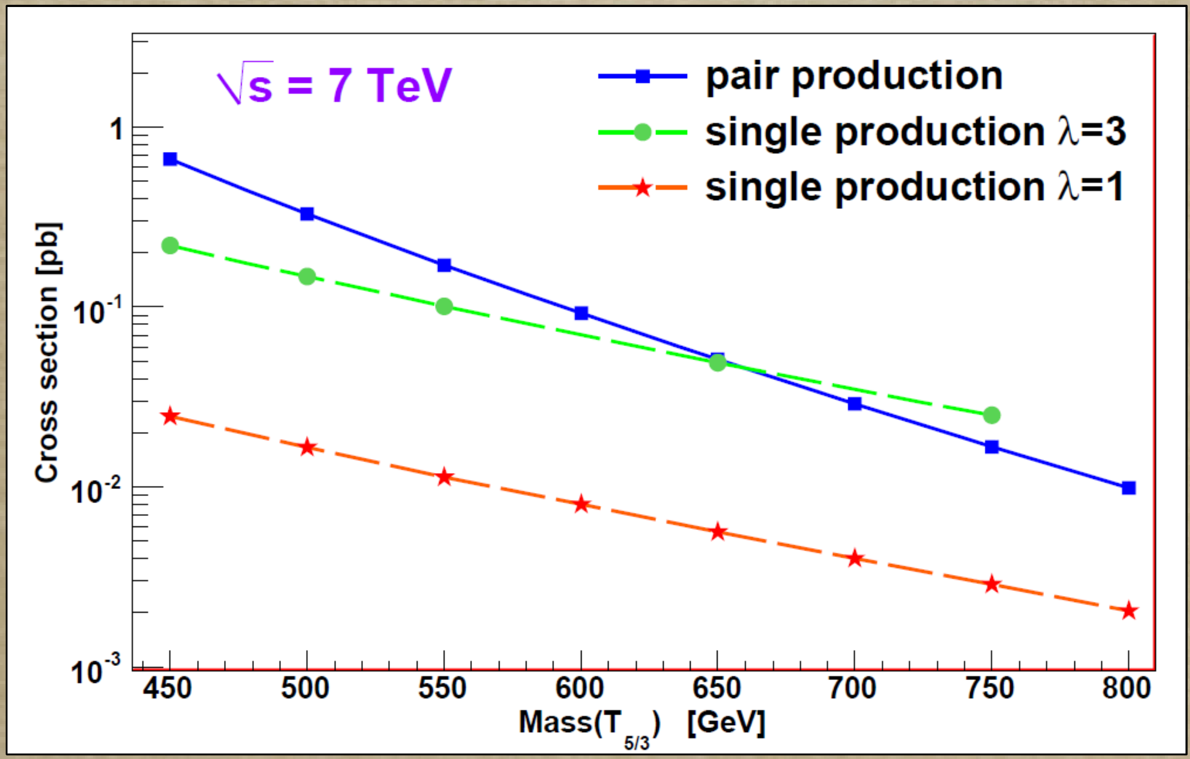
At least 2 jets with p_T > 25 GeV including one b-tagged

MET > 40 GeV

H_T > 550 GeV

1st limit from ATLAS: **m > *677-699* GeV**



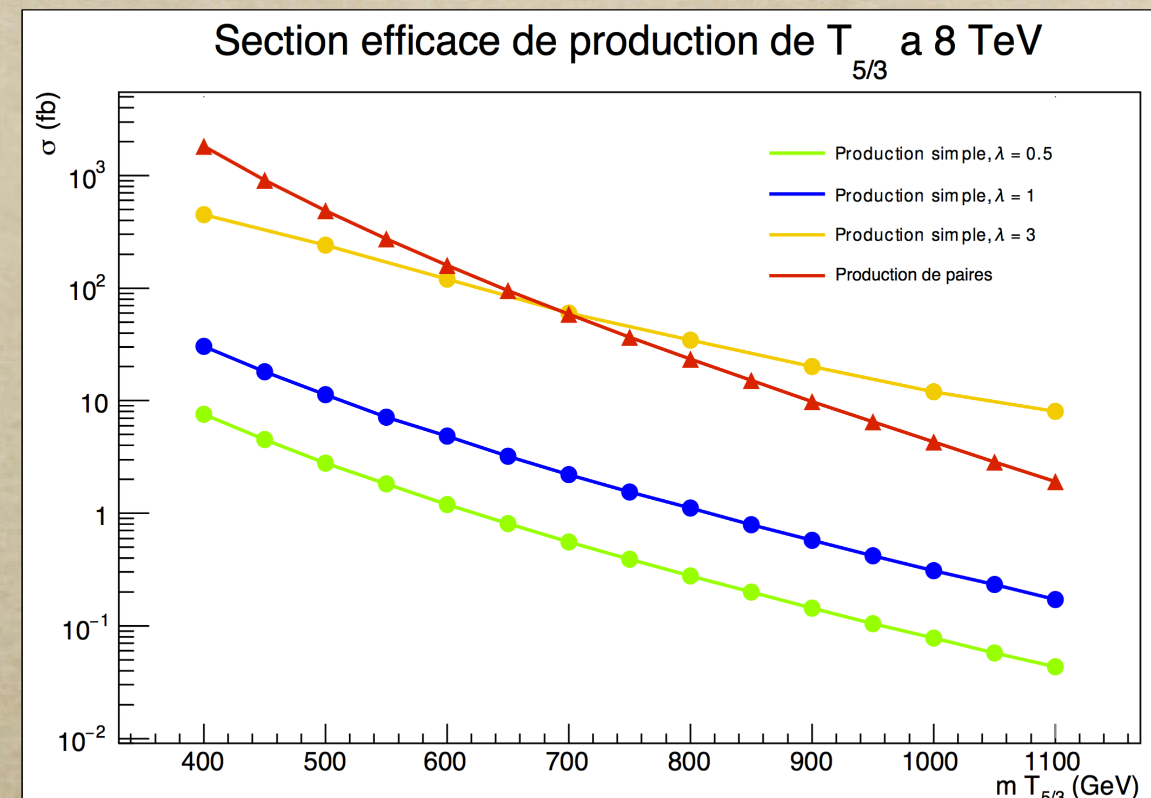


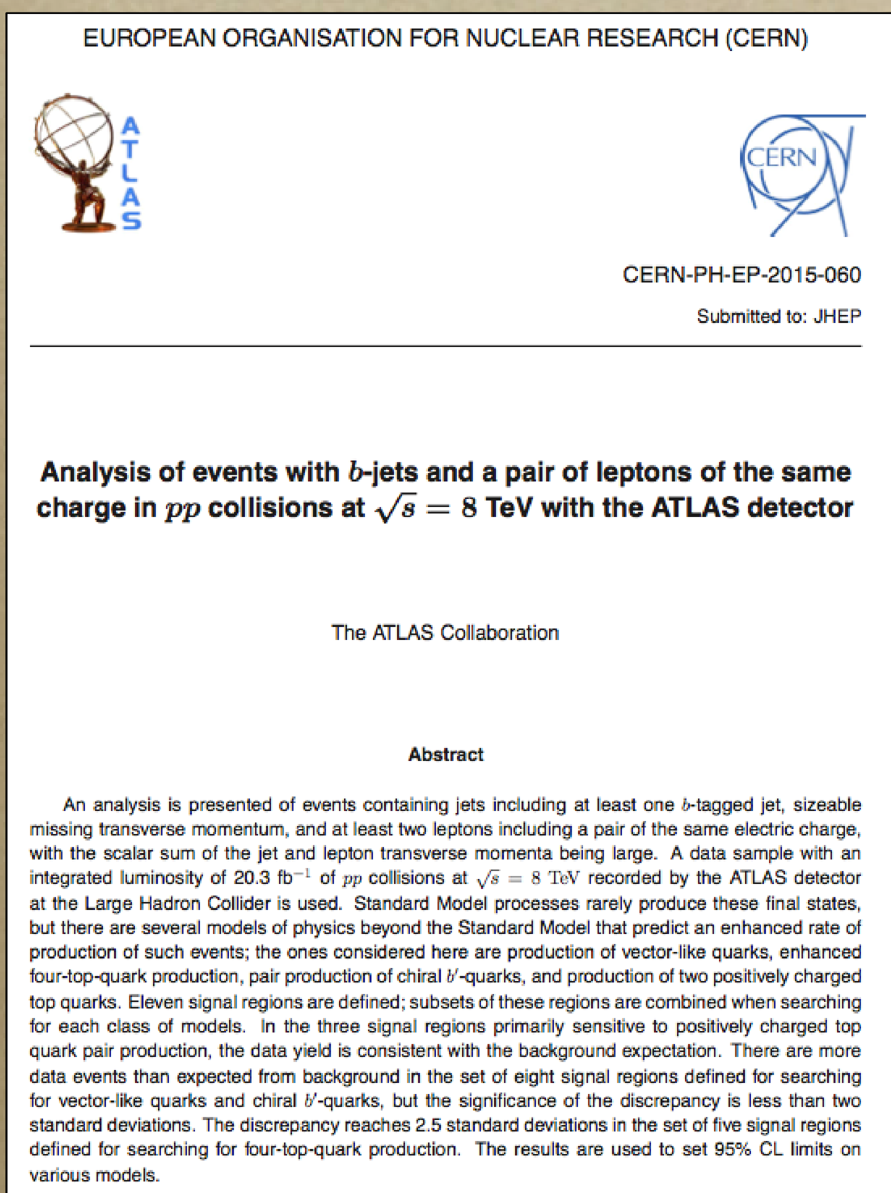
Search for $T_{5/3}$ production at 8 TeV

$\sqrt{s}$=8 TeV

ATLAS CERN-PH-EP-2015-060

We consider both pair and single $T_{5/3}$ productions, for small couplings.
2LSS + 3L channels for several signals




EUROPEAN ORGANISATION FOR NUCLEAR RESEARCH (CERN)

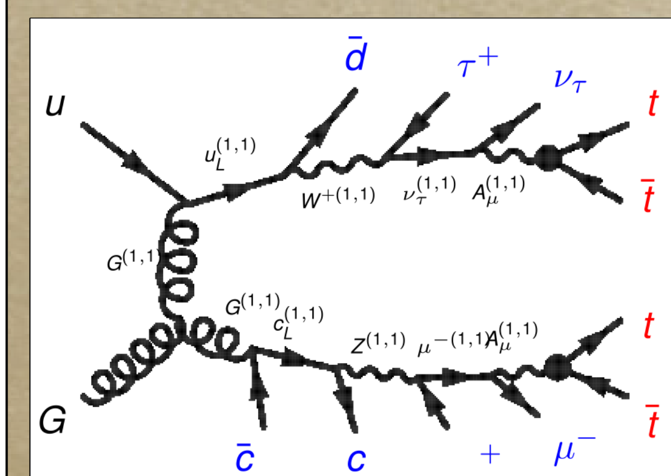
CERN-PH-EP-2015-060
Submitted to: JHEP

Analysis of events with b-jets and a pair of leptons of the same charge in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector

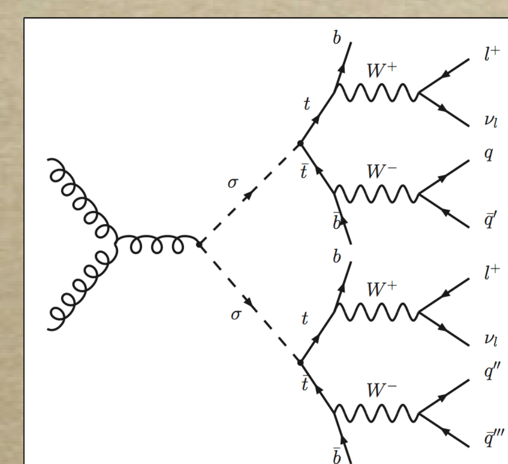
The ATLAS Collaboration

Abstract

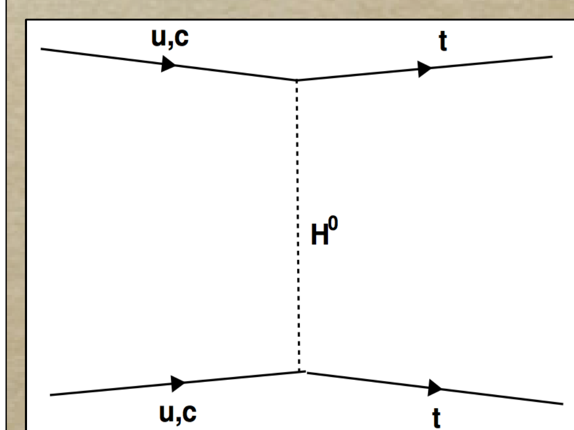
An analysis is presented of events containing jets including at least one b-tagged jet, sizeable missing transverse momentum, and at least two leptons including a pair of the same electric charge, with the scalar sum of the jet and lepton transverse momenta being large. A data sample with an integrated luminosity of 20.3 fb^{-1} of pp collisions at $\sqrt{s} = 8$ TeV recorded by the ATLAS detector at the Large Hadron Collider is used. Standard Model processes rarely produce these final states, but there are several models of physics beyond the Standard Model that predict an enhanced rate of production of such events; the ones considered here are production of vector-like quarks, enhanced four-top-quark production, pair production of chiral b'-quarks, and production of two positively charged top quarks. Eleven signal regions are defined; subsets of these regions are combined when searching for each class of models. In the three signal regions primarily sensitive to positively charged top quark pair production, the data yield is consistent with the background expectation. There are more data events than expected from background in the set of eight signal regions defined for searching for vector-like quarks and chiral b'-quarks, but the significance of the discrepancy is less than two standard deviations. The discrepancy reaches 2.5 standard deviations in the set of five signal regions defined for searching for four-top-quark production. The results are used to set 95% CL limits on various models.



4 tops UED/RPP



SUSY



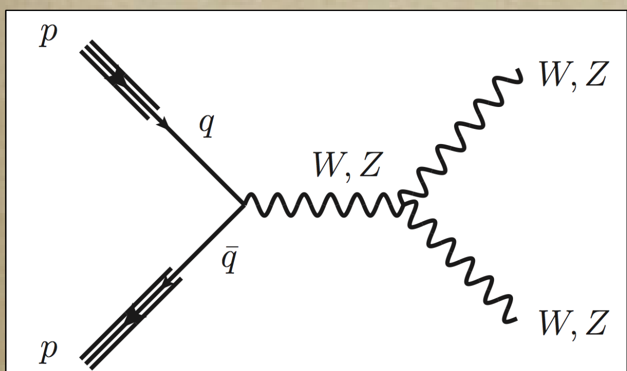
FCNC (tt)

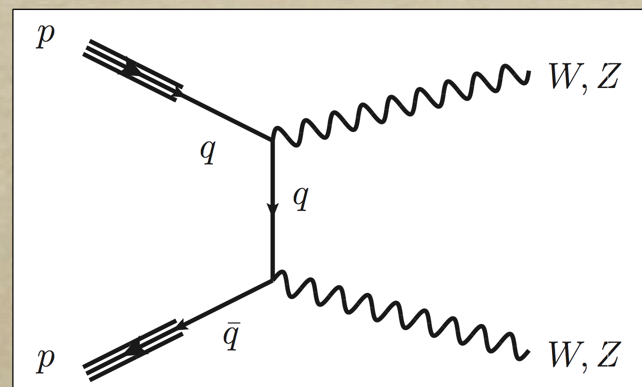
+ VLQ (TT, BB)

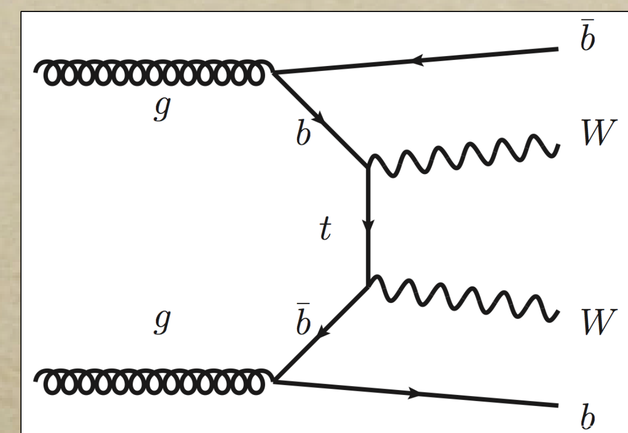
Search for $T_{5/3}$ production at 8 TeV

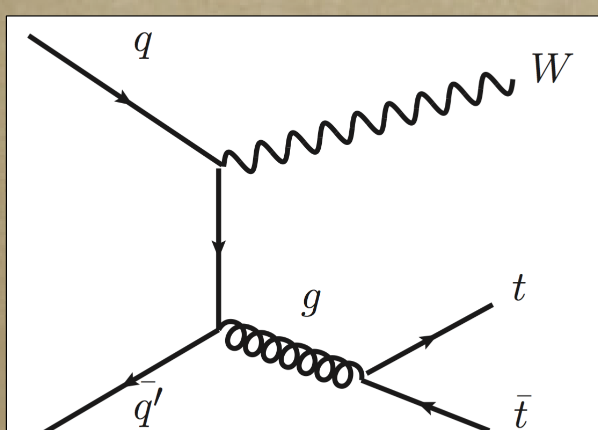
√s=8 TeV

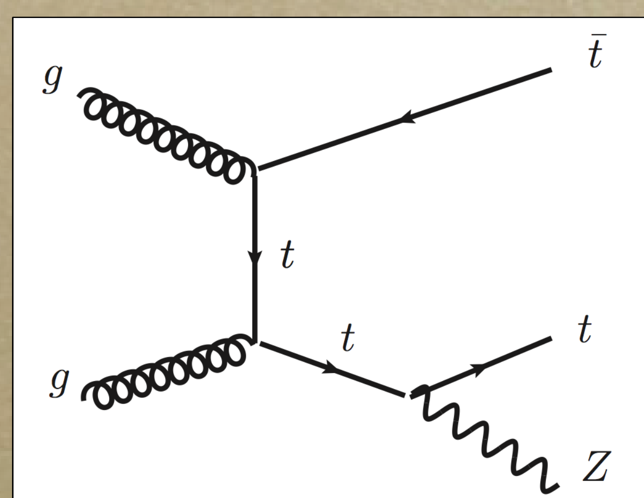
SM processes giving 2SSL real final states

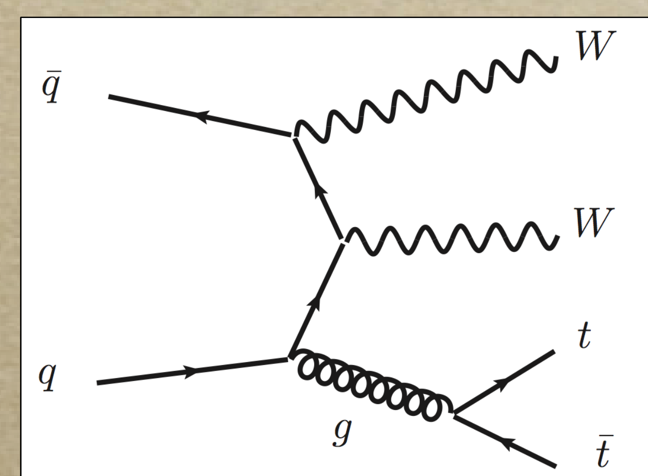












Dibosons ~ 10 pb
WW
WZ
ZZ

+ other:
VVV ~ 10 fb
VH ~ 100 fb
ttH ~ 30 fb
tV ~ 10 fb

ttV(V) ~ 400 fb
ttW
ttZ
ttWW

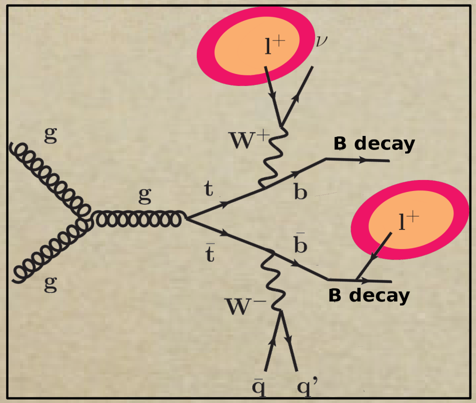
Monte-Carlo simulations

Search for $T_{5/3}$ production at 8 TeV

√s=8 TeV

Instrumental backgrounds

Fakes/non-prompt

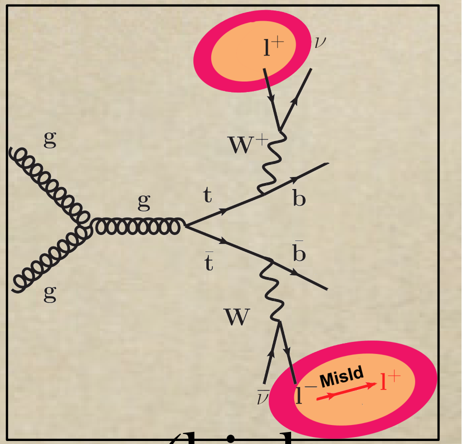


A secondary lepton
passes the analyse's quality cuts

How to estimate it ?
Define 2 qualities for the objects (*tight* and *loose*, relaxed)

→ Estimate in data the probabilité that a real/fake loose lepton passes the tight criteria in control region and apply it in signal regions.

Charge mis-identification



The electron's charge is wrong (high p_T or tridents)

How to estimate it ?

Estimate the charge flip rate in a pure ($Z \rightarrow e^+e^-$) control region in the data.

Apply then the rate on OS data events

Data-driven methods

Search for $T_{5/3}$ production at 8 TeV

√s=8 TeV Fakes/non-prompts : Matrix method

Tight = analysis selection (isolation, tight ++)
Loose = medium++ electrons, tight muons, no isolation

Real leptons efficiency (r) : high MET or $m_T(W)$ CR
Fake leptons efficiency (f) : low MET, $m_T(W)$ or high impact parameter $|d_0 \mathrm{sign}|$ CR

Systematics : CR choice, statistics, MC background substraction
70 % uncertainties in SR.

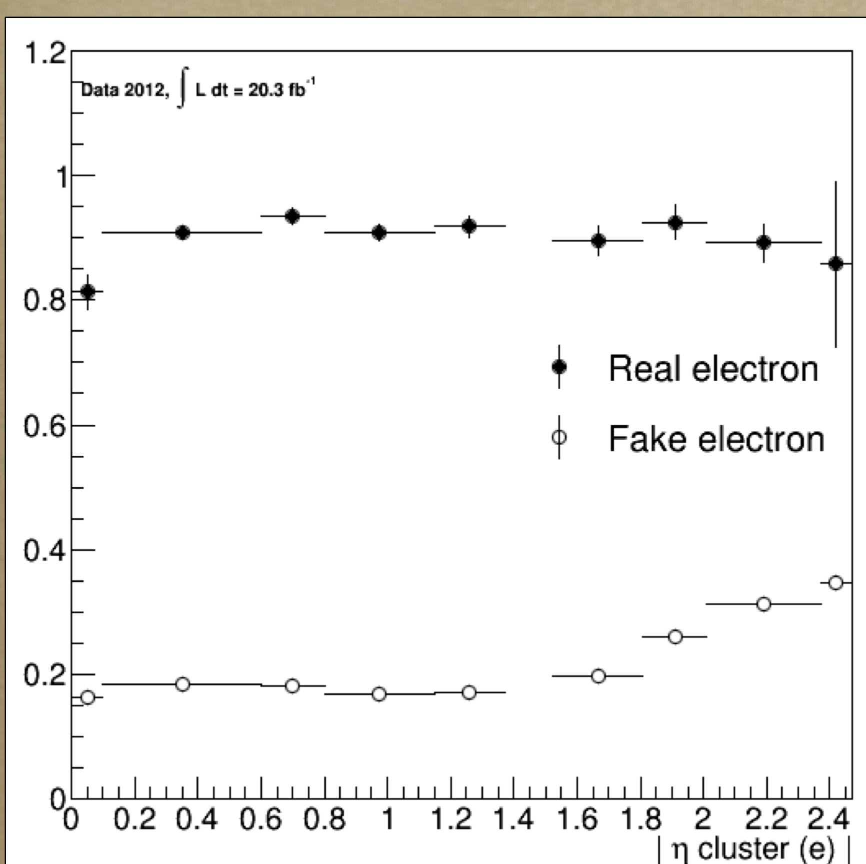
$$\begin{pmatrix} N^{tt} \\ N^{t\bar{t}} \\ N^{\bar{t}t} \\ N^{\bar{t}\bar{t}} \end{pmatrix} = \mathbf{M} \begin{pmatrix} N^{ll}_{rr} \\ N^{ll}_{rf} \\ N^{ll}_{fr} \\ N^{ll}_{ff} \end{pmatrix}$$

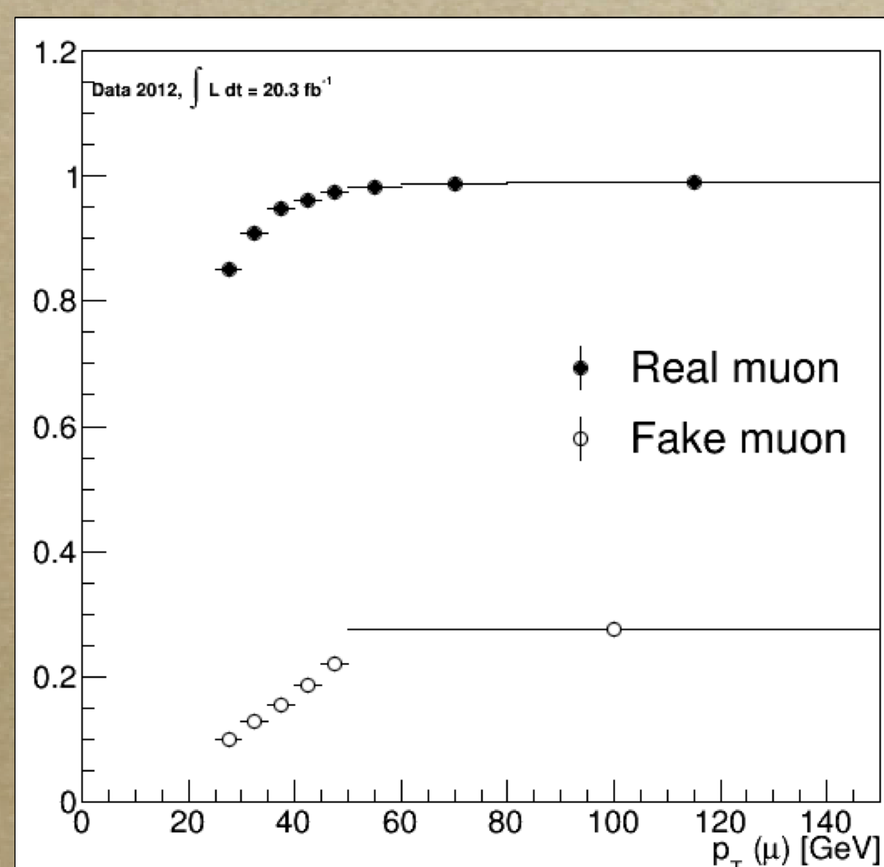
Observed in data

Estimated

$$\mathbf{M} = \begin{pmatrix} r_1 r_2 & r_1 f_2 & f_1 r_2 & f_1 f_2 \\ r_1 \overline{r_2} & r_1 \overline{f_2} & f_1 \overline{r_2} & f_1 \overline{f_2} \\ \overline{r_1} r_2 & \overline{r_1} f_2 & \overline{f_1} r_2 & \overline{f_1} f_2 \\ \overline{r_1}\,\overline{r_2} & \overline{r_1}\,\overline{f_2} & \overline{f_1}\,\overline{r_2} & \overline{f_1}\,\overline{f_2} \end{pmatrix}$$

$$\begin{aligned} N^{tt}_{\mathrm{fake}} &= N^{tt}_{rf} + N^{tt}_{fr} + N^{tt}_{ff} \\ &= r_1 f_2 N^{ll}_{rf} + f_1 r_2 N^{ll}_{fr} + f_1 f_2 N^{ll}_{ff} \end{aligned}$$





r and f are parametrized in function of p_T, η and angular distances, for different triggers.

Search for $T_{5/3}$ production at 8 TeV

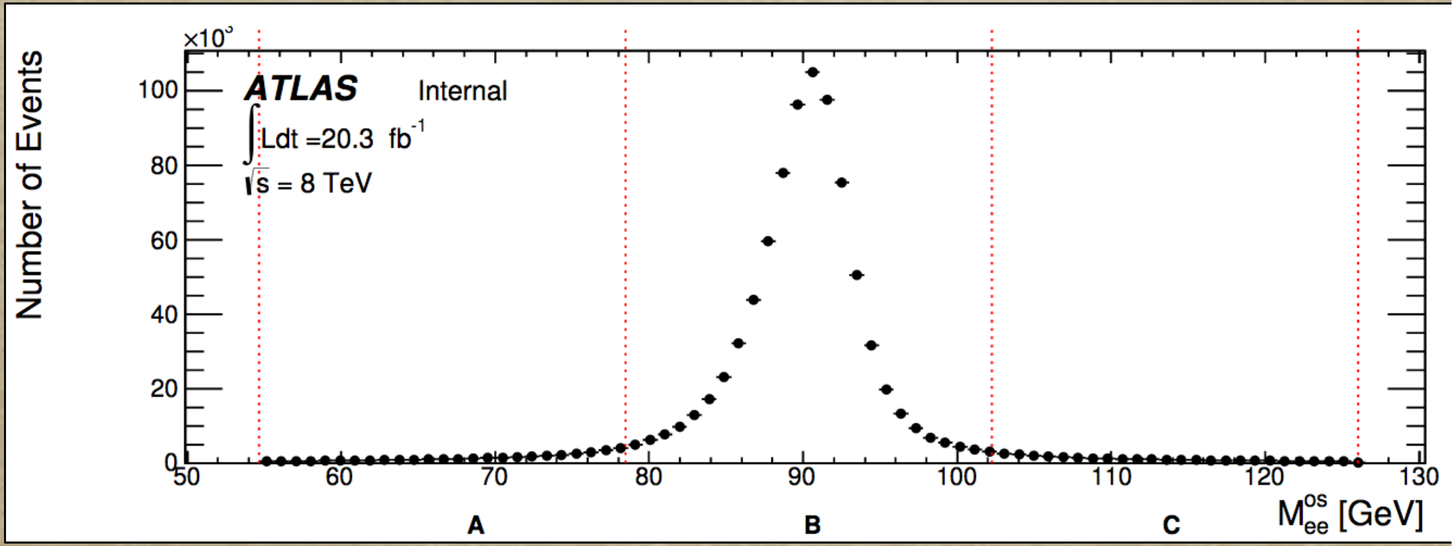
√s=8 TeV Charge flip : Likelihood method
(neglected for muons)

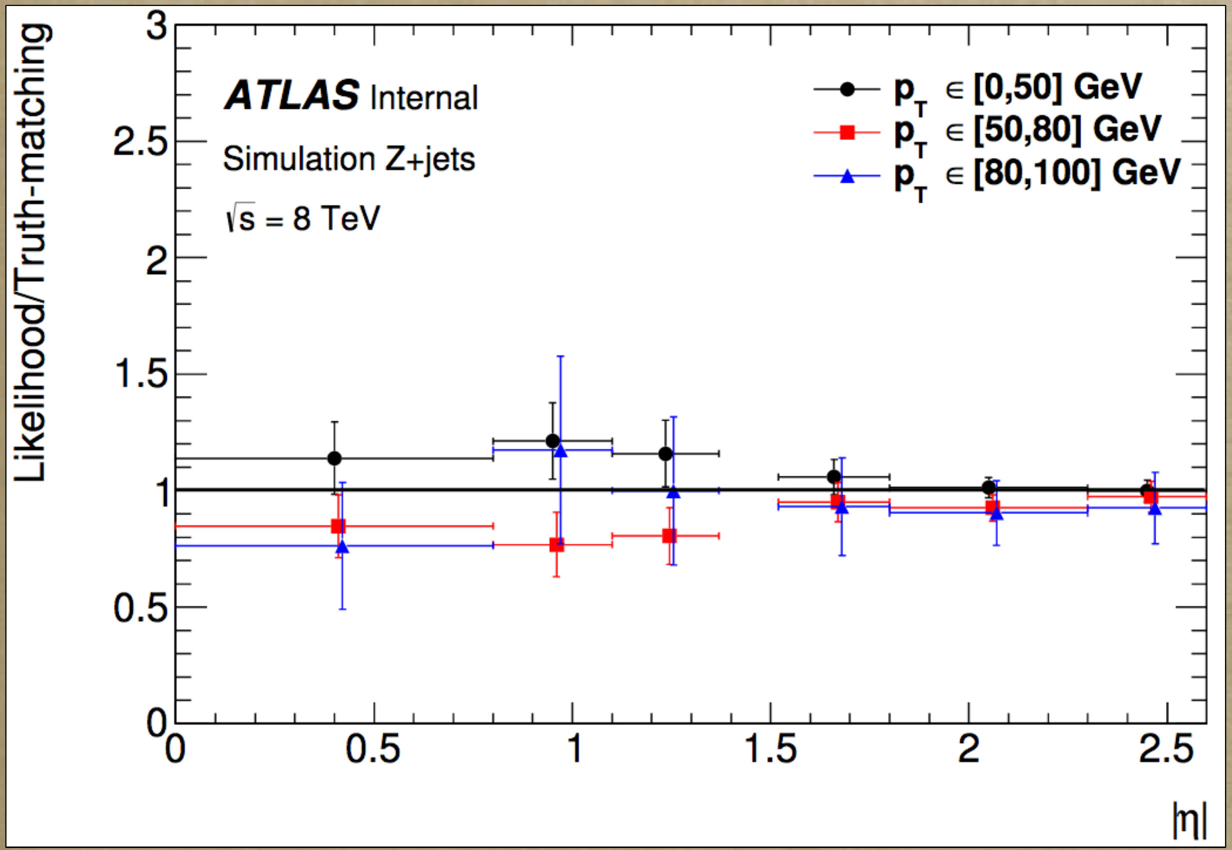
Charge flip for electrons i and j

$$N_{ss}^{ik,jl} \approx N^{ik,jl}(\varepsilon_{ik} + \varepsilon_{jl})$$

SS/OS events under the Z peak gives the probability of flipping the electron charge in function of p_T, η.
High-p_T extrapolation using $t\bar{t}$ MC samples.

Systematics : statistics error of the likelihood method, high p_T extrapolation, Z peak definition, fake leptons substraction.
→ 30-40 % uncertainties in SR





Non Z events are susbtracted using the side-bands method

Search for $T_{5/3}$ production at 8 TeV

$\sqrt{s}$=8 TeV

Selection variables :

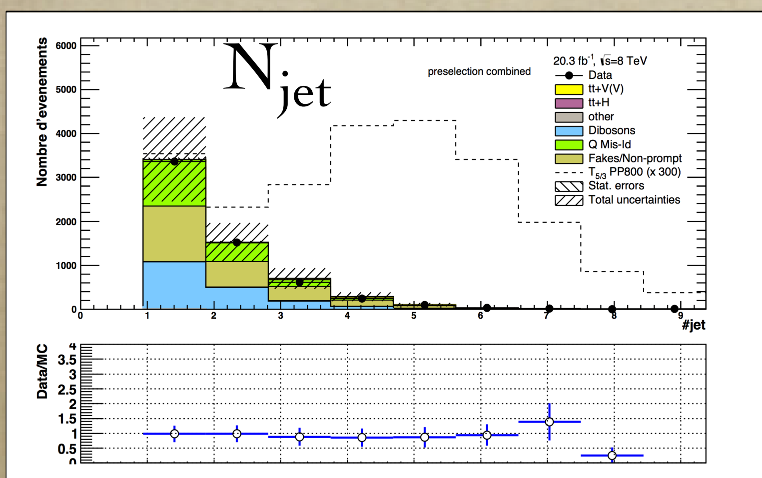
H_T, jets/b-jets numbers, MET

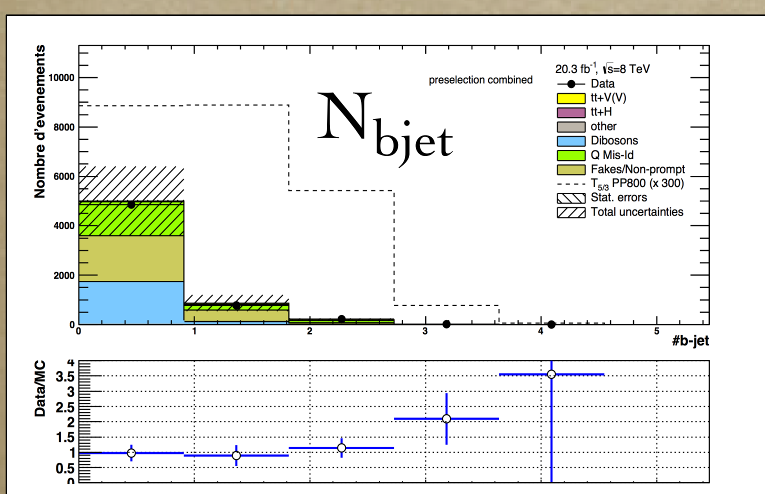
Preselection :

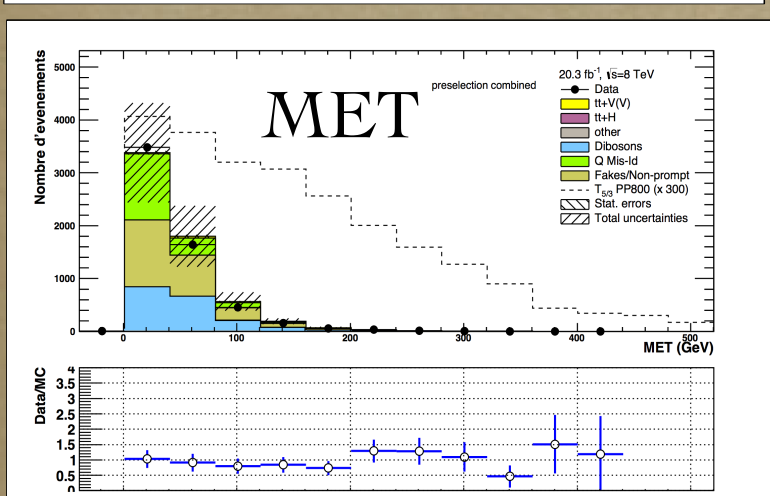
- trigger 1 lepton (e/μ)
- 1 primary vertex
- no e/μ overlap
- no error (LAr, Tile)

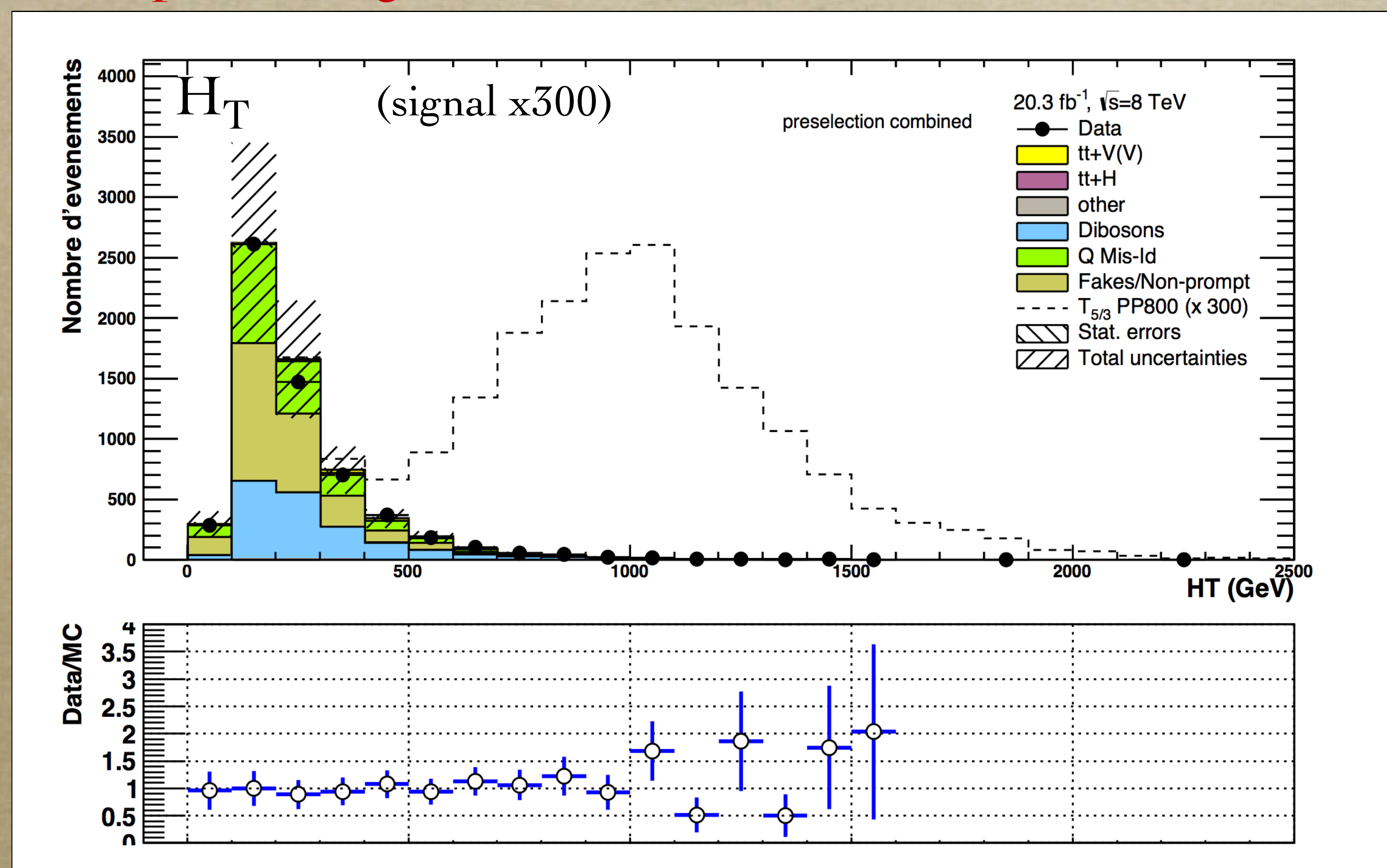
- no cosmics
- at least 1 jet
- $m_{ee} \geq 15$ & $|m_{ee} - 91| \geq 10$
- one trigger matched lepton

+ 2 same-sign leptons if 2 tight leptons (+ additionnal loose)
(trilepton = 3 tight)









Search for $T_{5/3}$ production at 8 TeV

√s=8 TeV

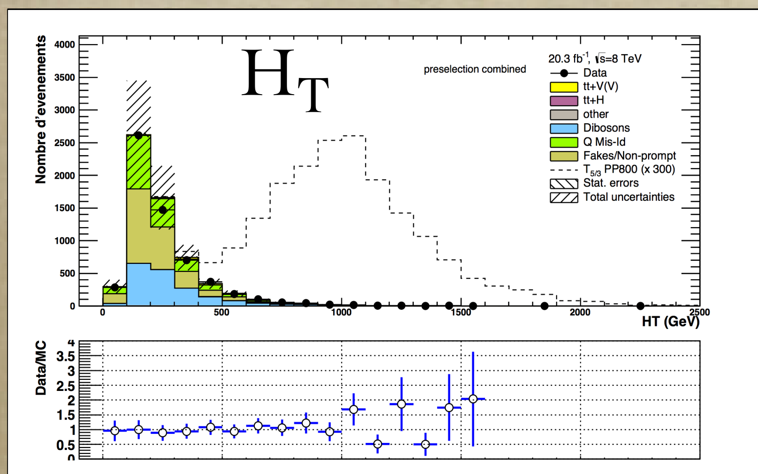
Selection variables :

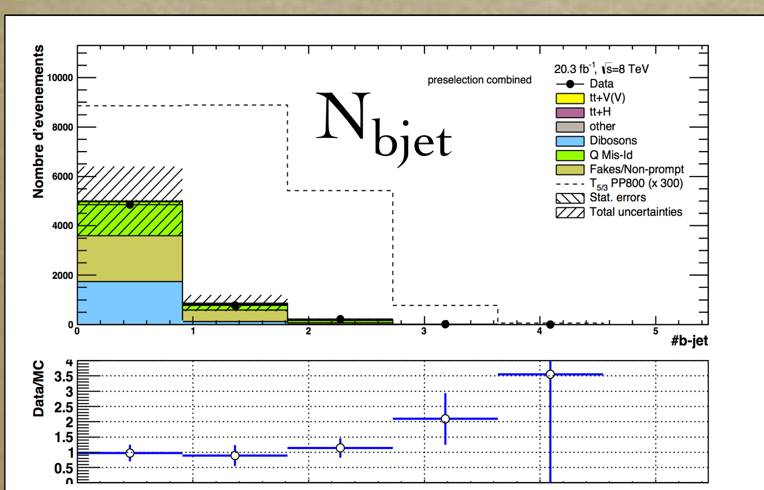
H_T, jets/b-jets numbers, MET

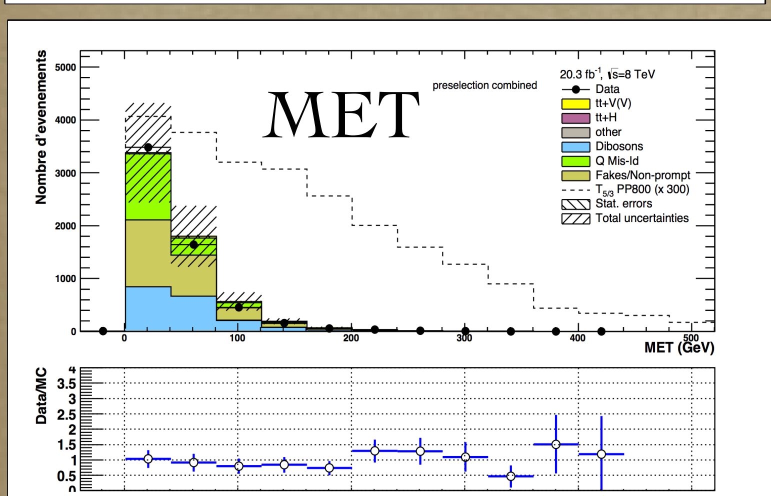
Preselection :

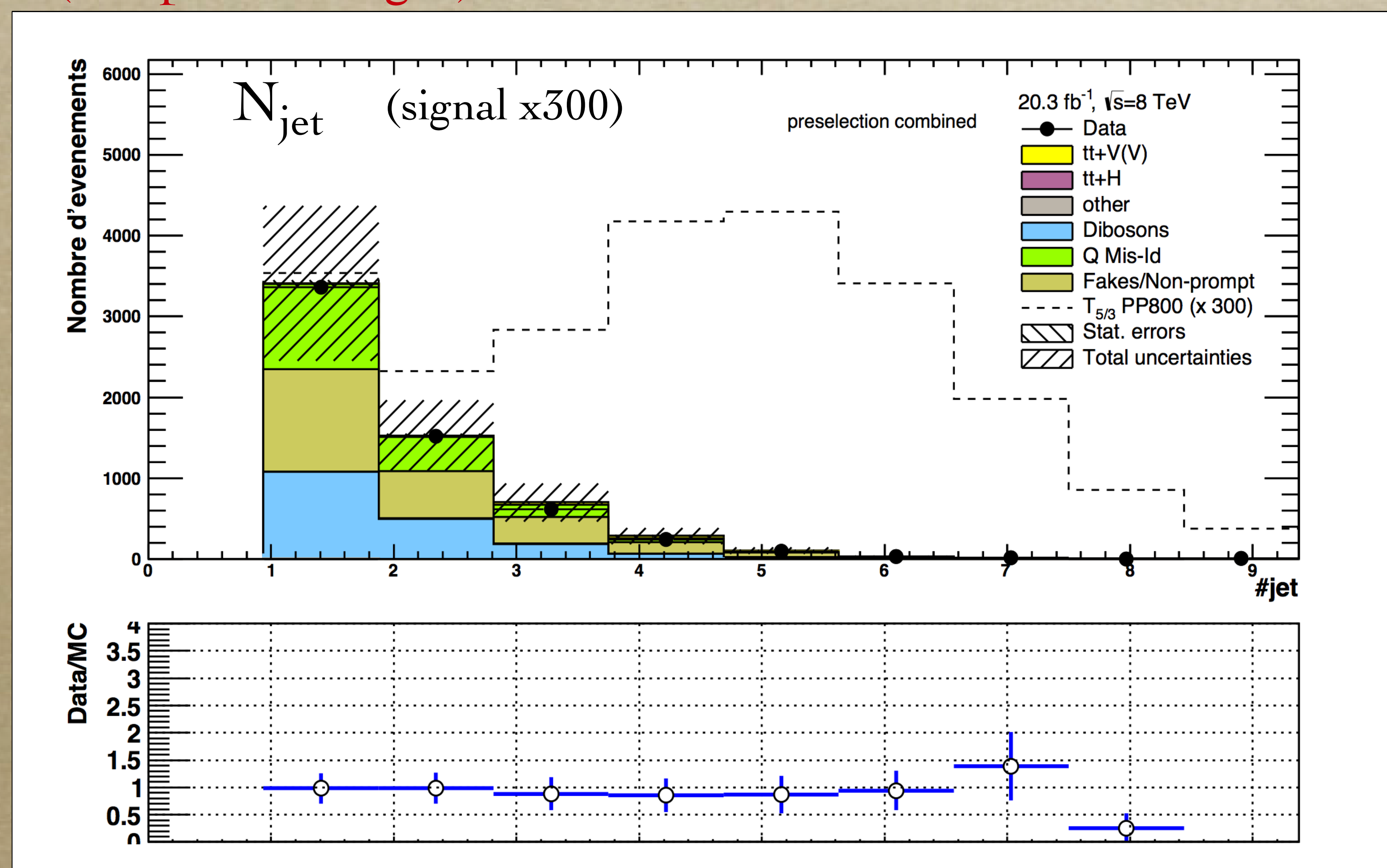
- trigger 1 lepton (e/μ)
- 1 primary vertex
- no e/μ overlap
- no error (LAr, Tile)
- no cosmics
- at least 1 jet
- $m_{ee} \geq 15$ & $|m_{ee} - 91| \geq 10$
- one trigger matched lepton

+ 2 same-sign leptons if 2 tight leptons (+ additionnal loose)
(trilepton = 3 tight)









Search for $T_{5/3}$ production at 8 TeV

$\sqrt{s}$=8 TeV

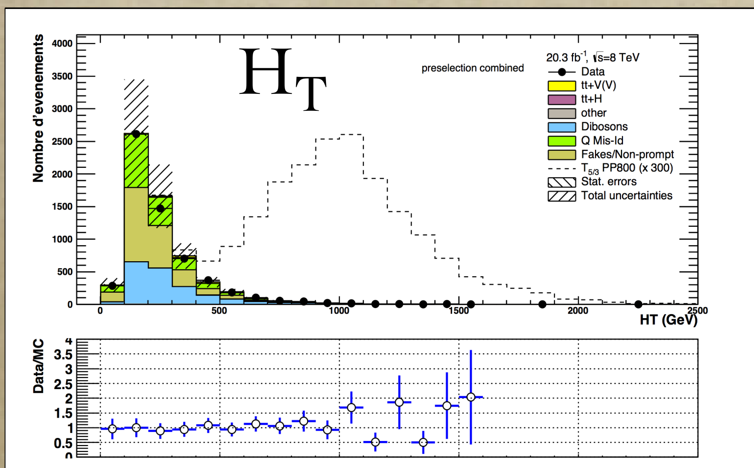
Selection variables :

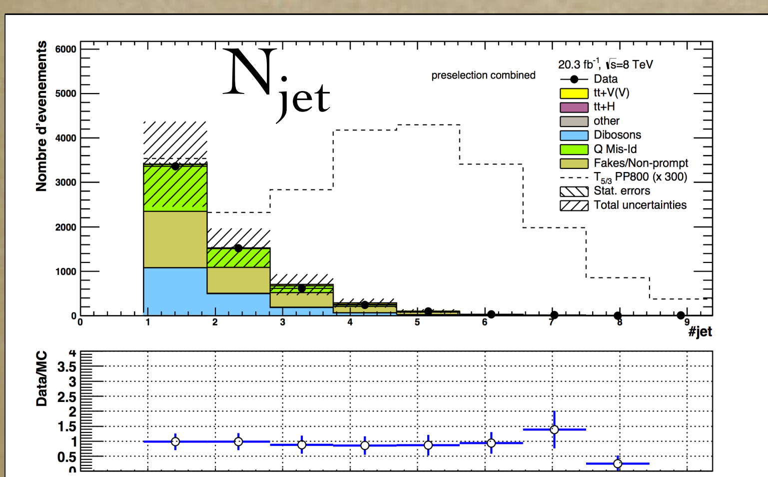
H_T, jets/b-jets numbers, MET

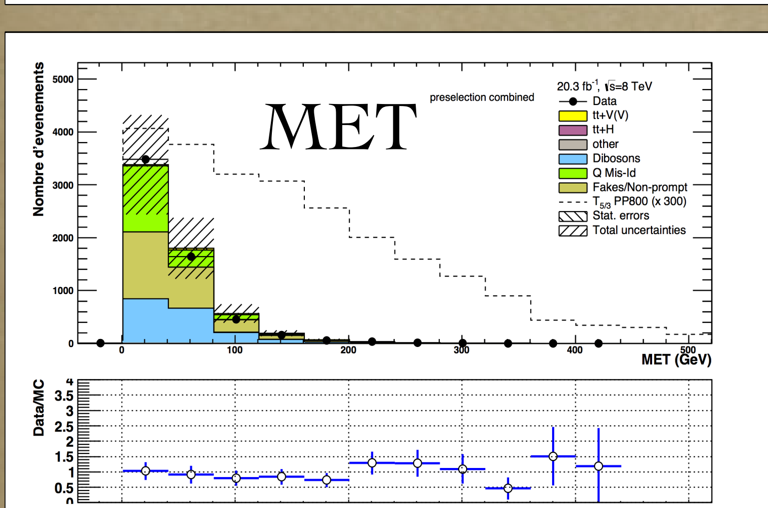
Preselection :

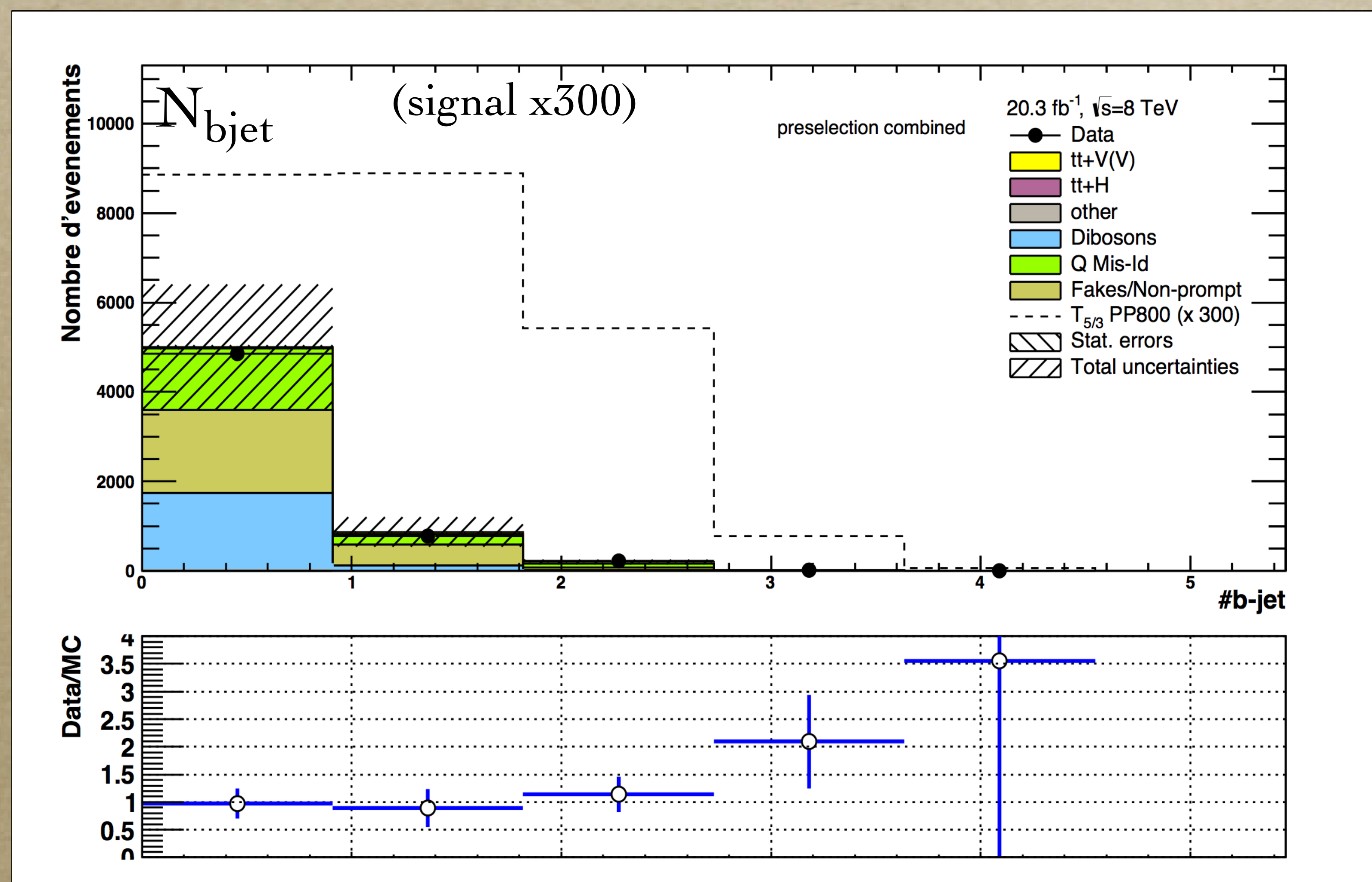
- trigger 1 lepton (e/μ)
- 1 primary vertex
- no e/μ overlap
- no error (LAr, Tile)
- no cosmics
- at least 1 jet
- $m_{ee} \geq 15$ & $|m_{ee} - 91| \geq 10$
- one trigger matched lepton

+ 2 same-sign leptons if 2 tight leptons (+ additionnal loose) (trilepton = 3 tight)









Search for $T_{5/3}$ production at 8 TeV

$\sqrt{s}$=8 TeV

Selection variables :

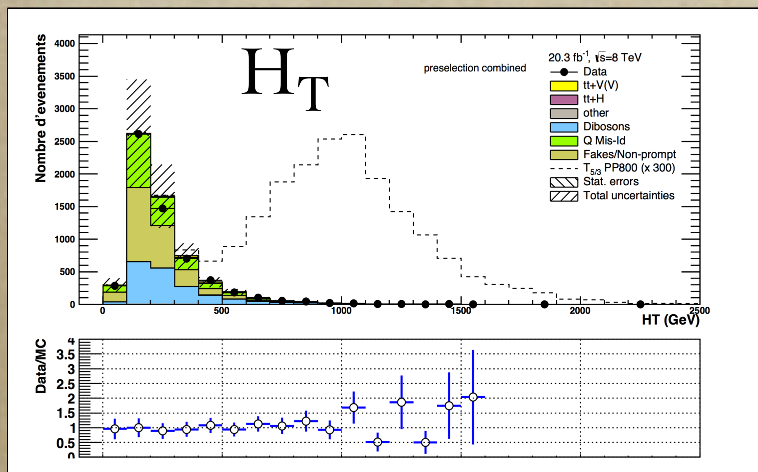
H_T, jets/b-jets numbers, MET

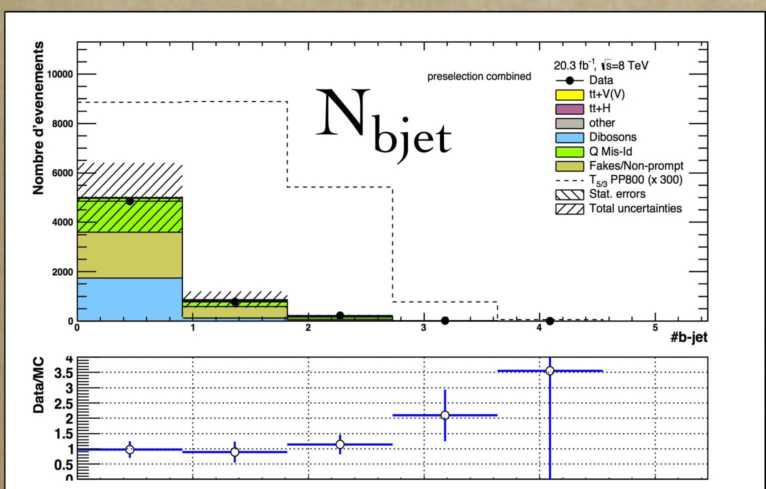
Preselection :

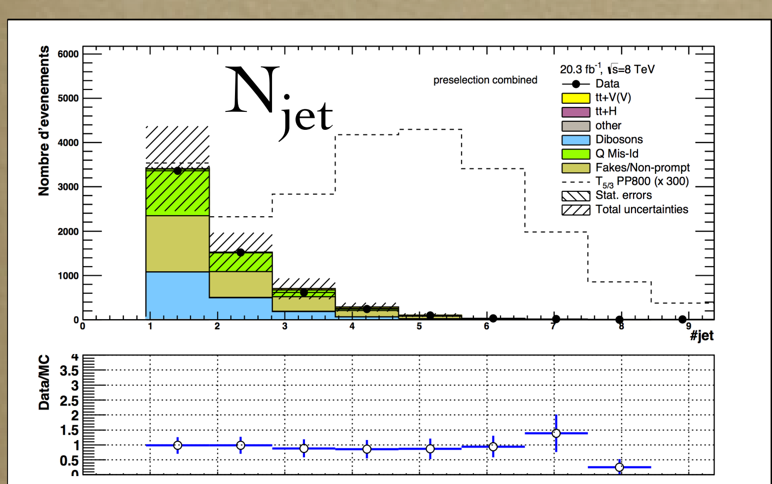
- trigger 1 lepton (e/μ)
- 1 primary vertex
- no e/μ overlap
- no error (LAr, Tile)

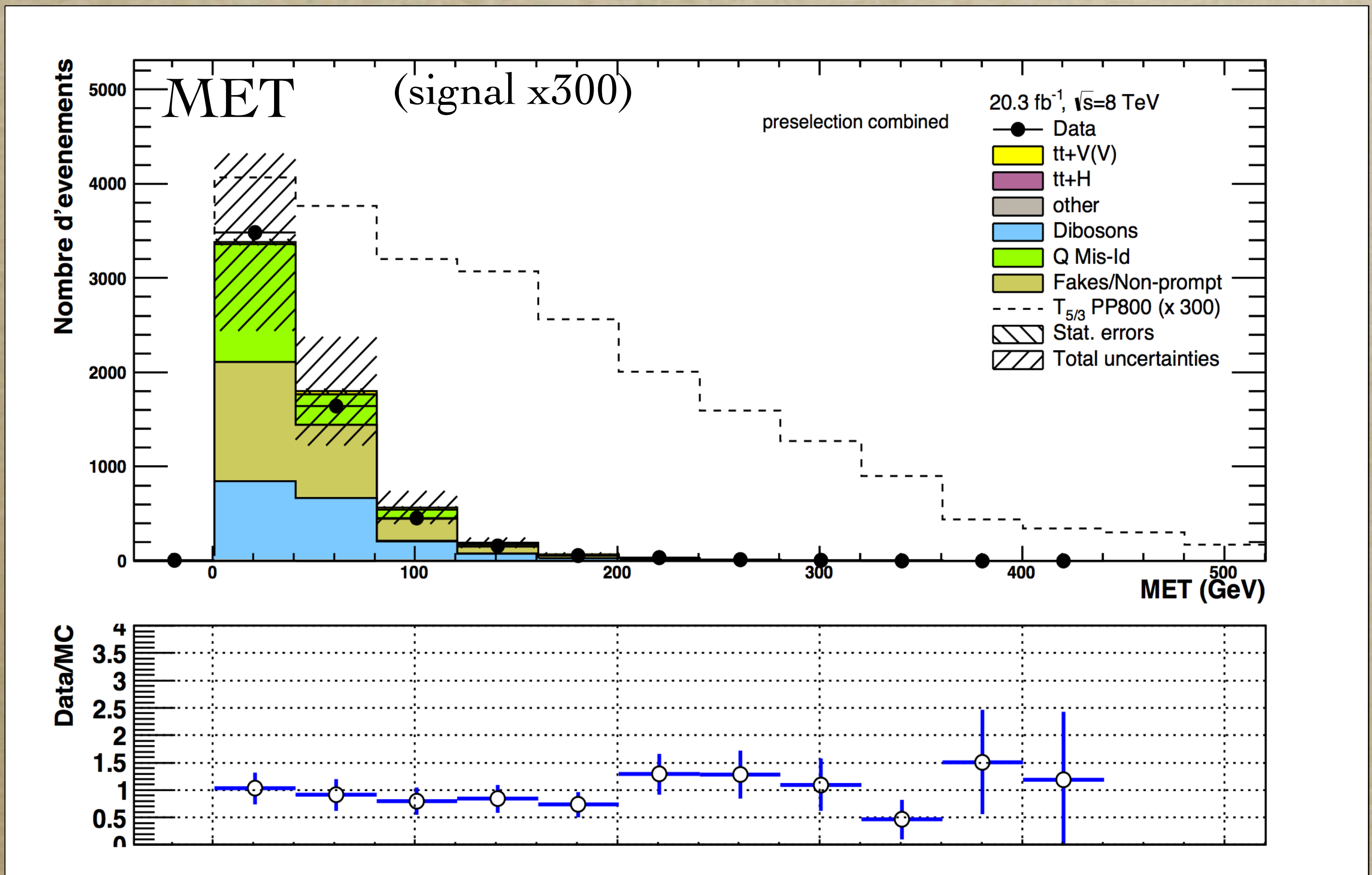
- no cosmics
- at least 1 jet
- $m_{ee} \geq 15$ & $|m_{ee} - 91| \geq 10$
- one trigger matched lepton

+ 2 same-sign leptons if 2 tight leptons (+ additionnal loose)
(trilepton = 3 tight)









Search for $T_{5/3}$ production at 8 TeV

√s=8 TeV

Control region = no signal expected. The background is validated against the data

2 control regions :

- low H_T + 0b =

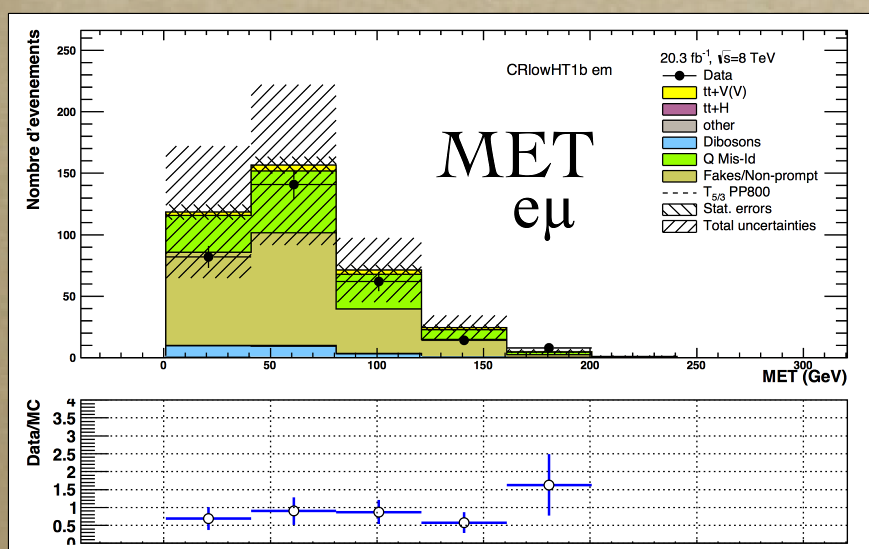
100 < H_T < 400 GeV + 0 bjets

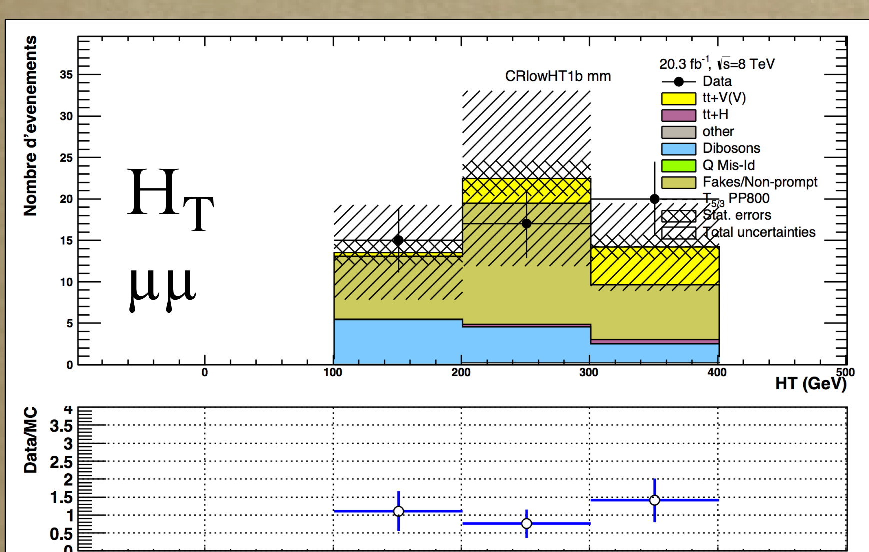
- low H_T + 1b =

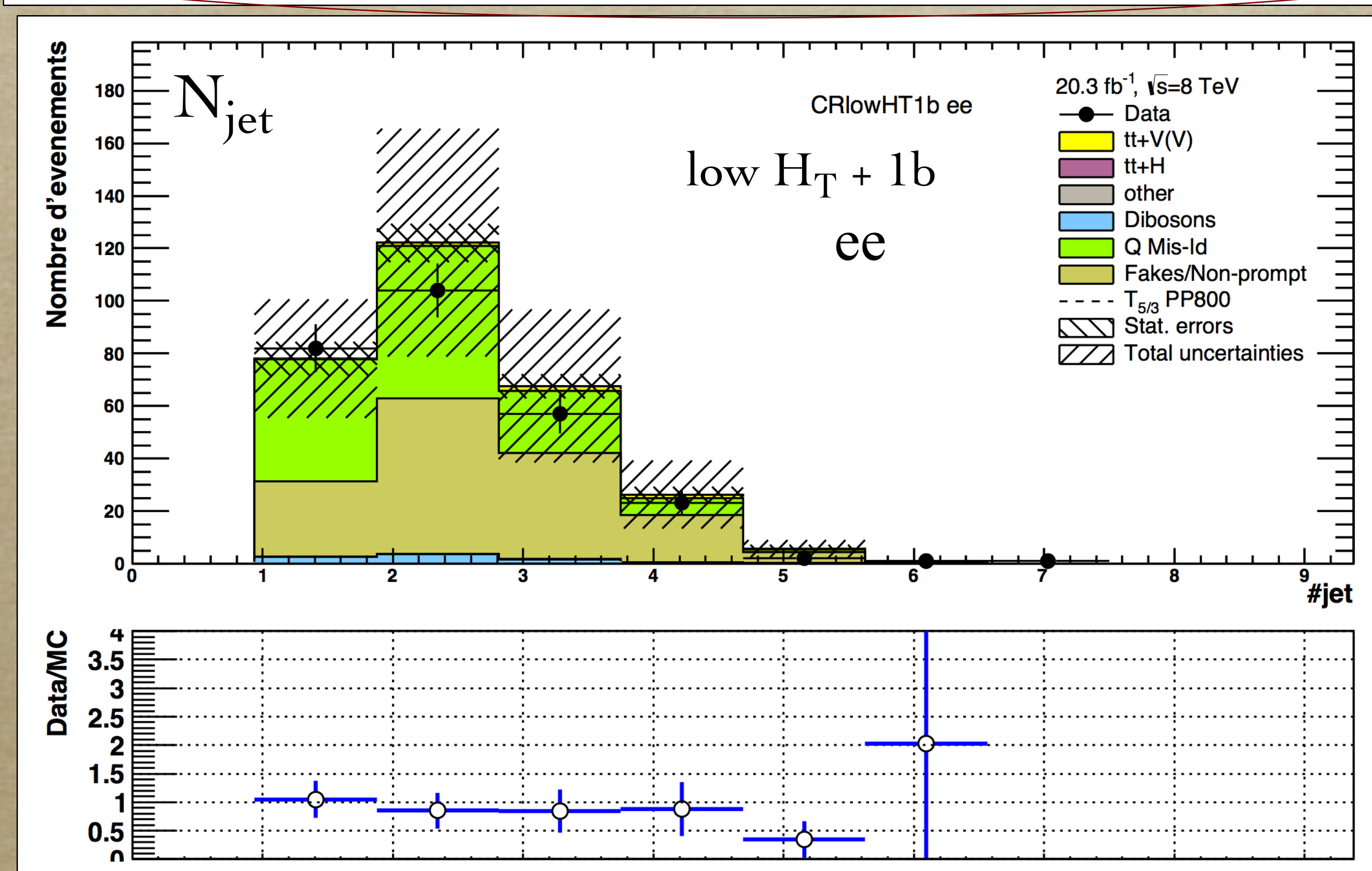
100 < H_T < 400 GeV + ≥1 bjet

X ± erreur statistique ± erreur systématique

Échantillon	"faible H_T+1b" ee	"faible H_T+1b" $e\mu$	"faible H_T+1b" $\mu\mu$	"faibleH_T+0b" $\mu\mu$
VV	7.56 ±0.55±2.14	21.37±0.94±6.01	11.75±0.70±3.40	178.23±2.70±48.98
$ttW/Z(W)$	4.62±0.18±2.03	13.59±0.32±5.92	8.01±0.25±3.54	2.79±0.16±1.26
$t\bar{t}H$	0.48±0.04±0.10	1.50±0.08±0.20	0.85±0.06±0.16	0.24±0.03±0.09
VVV	0.06±0.01±0.01	0.14±0.02±0.03	0.08±0.01±0.01	1.51±0.06±0.10
VH	0.37±0.17±0.12	0.86±0.28±0.15	0.31±0.09±0.06	7.62±0.80±0.86
tX	0.16±0.01±0.03	0.43±0.02±0.08	0.25±0.01±0.05	0.15±0.01±0.03
$Fake$	150.71±11.16±105.49	220.19±10.27±154.13	28.78±2.84±20.14	36.51±3.48±25.55
$Qmis-id$	135.96±1.80±23.82	118.43±1.44±20.74	-	-
Bruit tot.	299.96±11.32±108.19	376.55±10.42±155.75	50.07±2.94±20.72	227.10±4.49±55.26
Données	271	307	52	208







Search for $T_{5/3}$ production at 8 TeV

√s=8 TeV

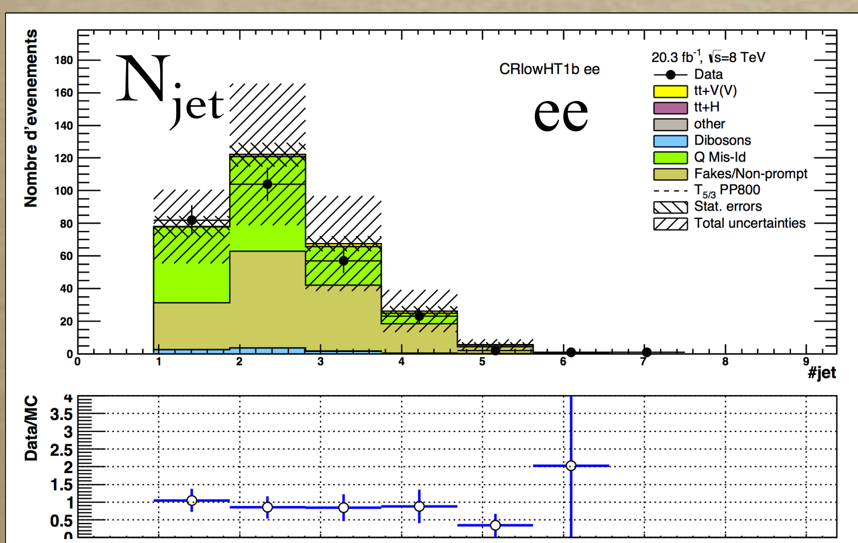
Control region = no signal expected. The background is validated against the data

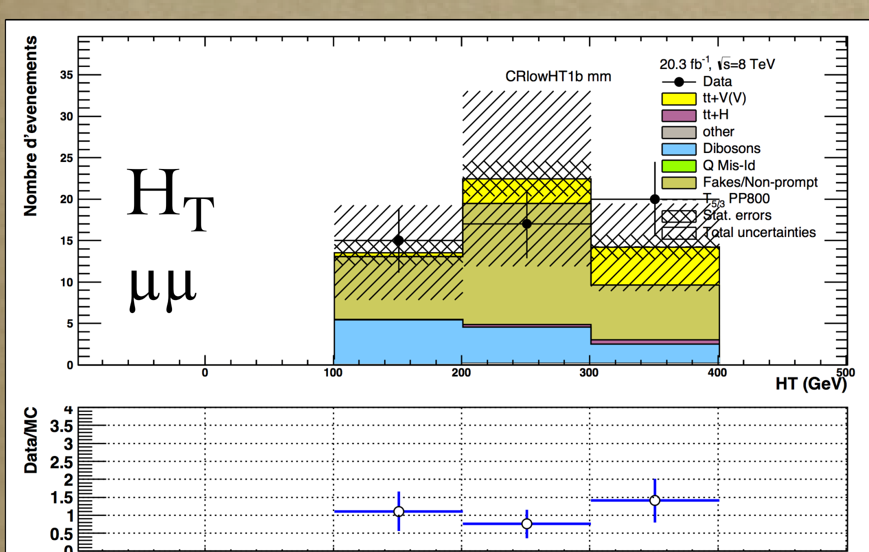
2 control regions :

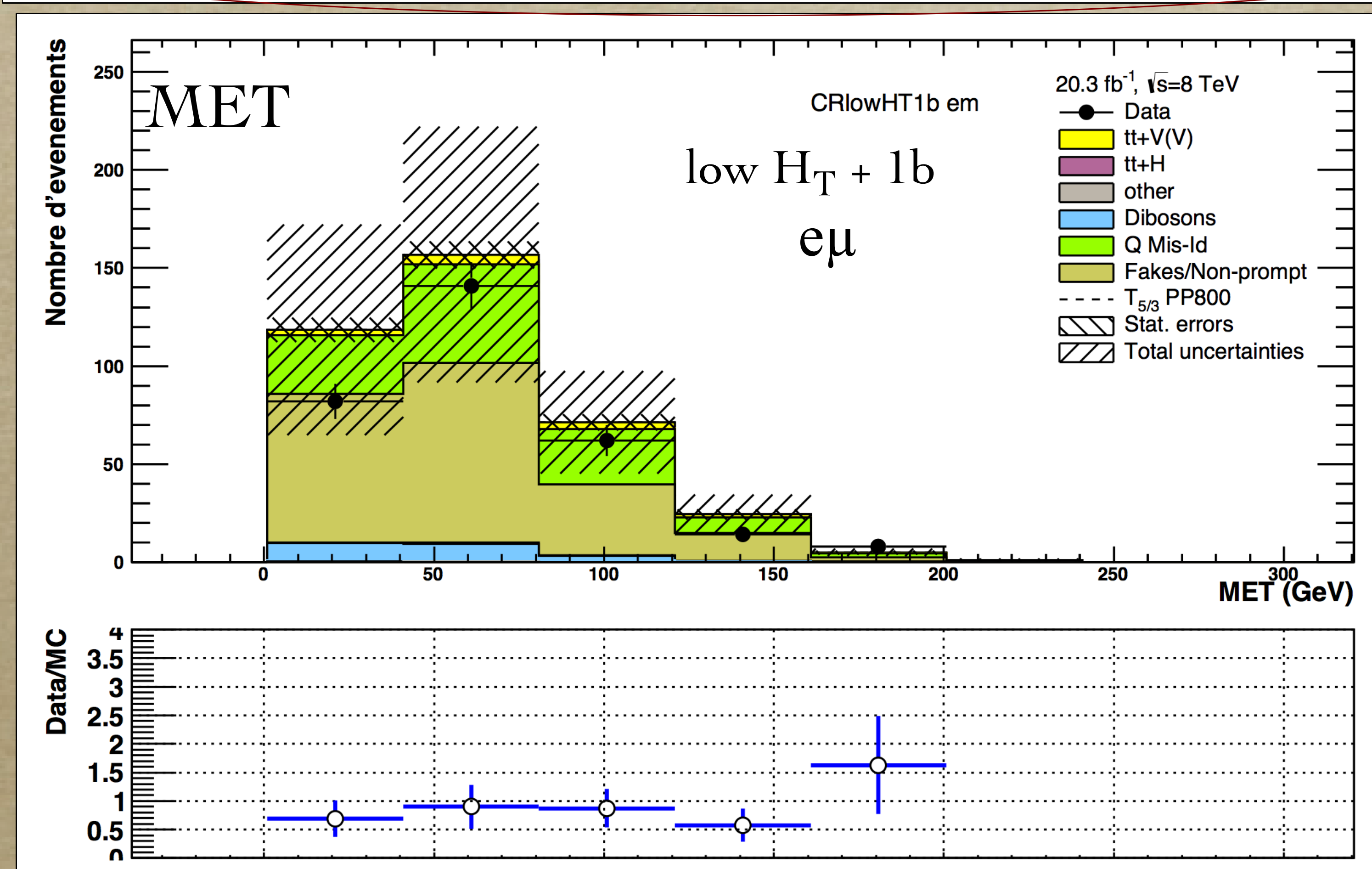
- low H_T + 0b = 100 < H_T < 400 GeV + 0 bjets
- low H_T + 1b = 100 < H_T < 400 GeV + ≥1 bjet

X ± erreur statistique ± erreur systématique

Échantillon	"faible H_T+1b" ee	"faible H_T+1b" eμ	"faible H_T+1b" μμ	"faible H_T+0b" μμ
VV	7.56 ±0.55±2.14	21.37±0.94±6.01	11.75±0.70±3.40	178.23±2.70±48.98
$ttW/Z(W)$	4.62±0.18±2.03	13.59±0.32±5.92	8.01±0.25±3.54	2.79±0.16±1.26
$t\bar{t}H$	0.48±0.04±0.10	1.50±0.08±0.20	0.85±0.06±0.16	0.24±0.03±0.09
VVV	0.06±0.01±0.01	0.14±0.02±0.03	0.08±0.01±0.01	1.51±0.06±0.10
VH	0.37±0.17±0.12	0.86±0.28±0.15	0.31±0.09±0.06	7.62±0.80±0.86
tX	0.16±0.01±0.03	0.43±0.02±0.08	0.25±0.01±0.05	0.15±0.01±0.03
$Fake$	150.71±11.16±105.49	220.19±10.27±154.13	28.78±2.84±20.14	36.51±3.48±25.55
$Qmis-id$	135.96±1.80±23.82	118.43±1.44±20.74	-	-
Bruit tot.	299.96±11.32±108.19	376.55±10.42±155.75	50.07±2.94±20.72	227.10±4.49±55.26
Données	271	307	52	208







Search for $T_{5/3}$ production at 8 TeV

$\sqrt{s}$=8 TeV

Control region = no signal expected. The background is validated against the data

2 control regions :

- low H_T + 0b =

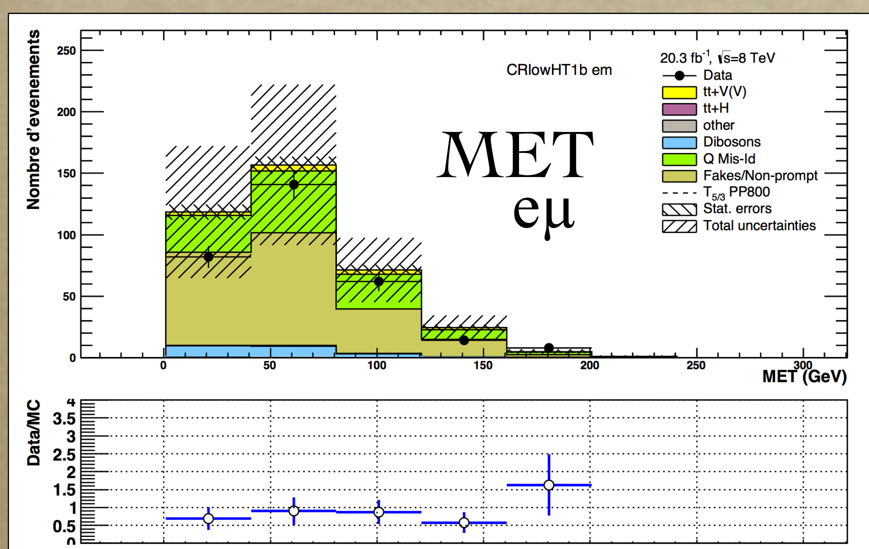
100 < H_T < 400 GeV + 0 bjets

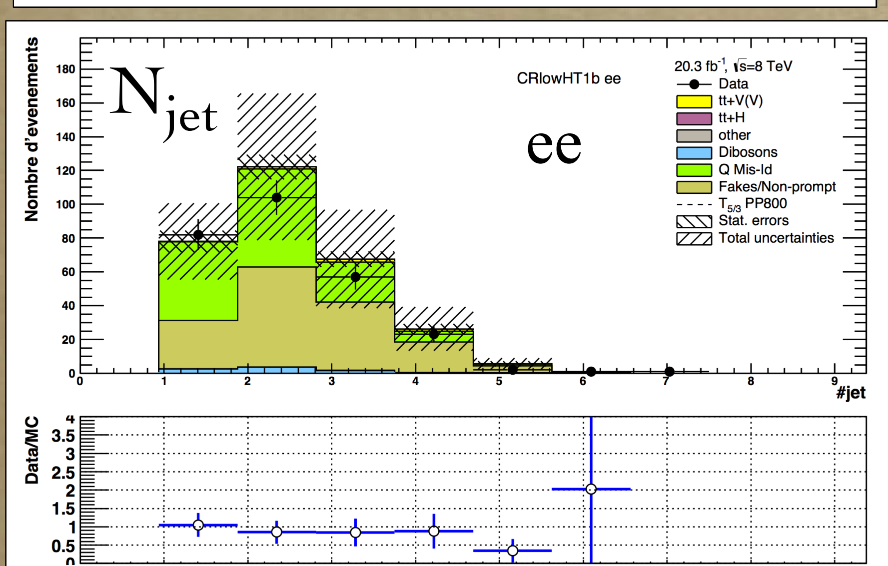
- low H_T + 1b =

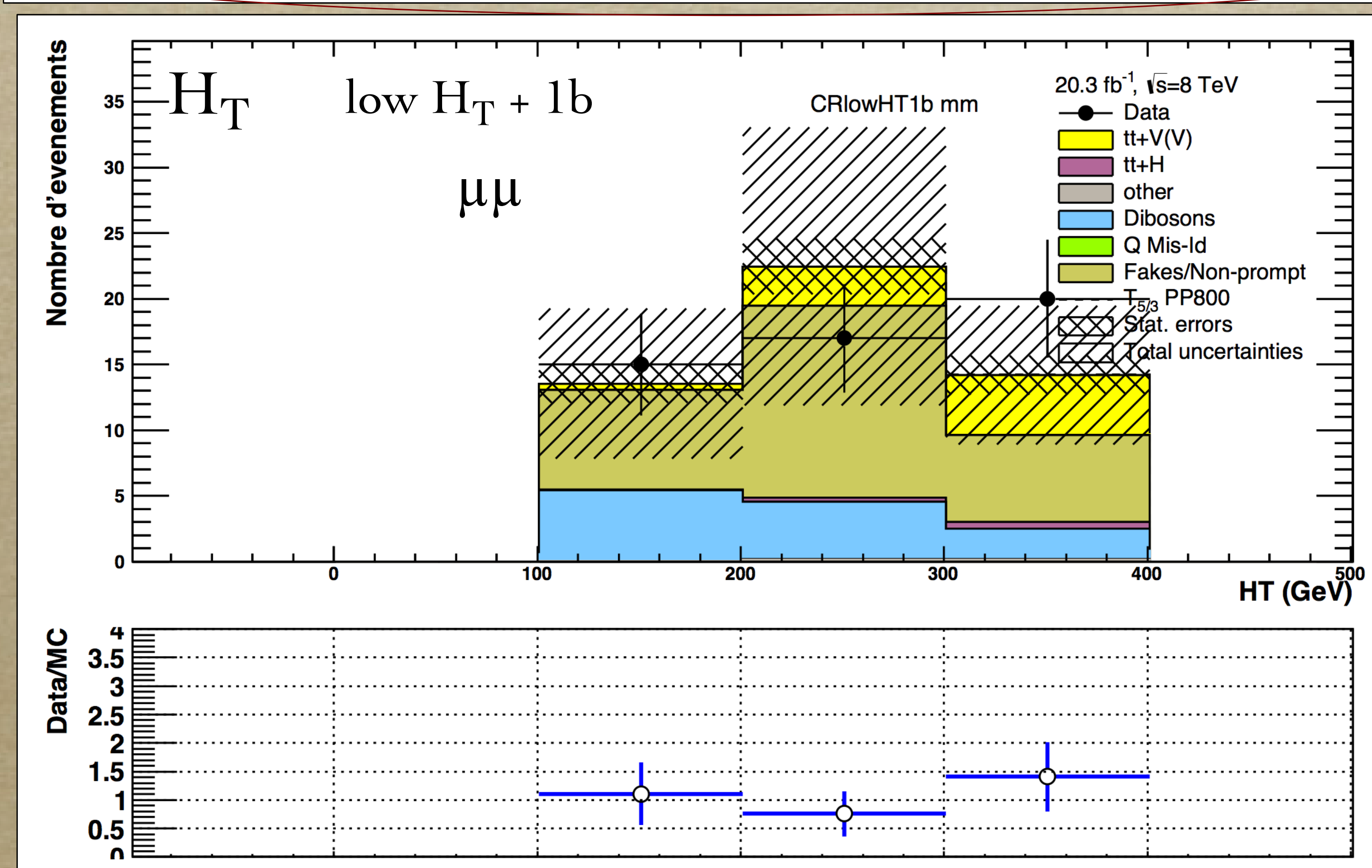
100 < H_T < 400 GeV + ≥1 bjet

X ± erreur statistique ± erreur systématique

Échantillon	"faible H_T+1b" *ee*	"faible H_T+1b" *eμ*	"faible H_T+1b" *μμ*	"faibleH_T+0b" *μμ*
VV	7.56 ±0.55±2.14	21.37±0.94±6.01	11.75±0.70±3.40	178.23±2.70±48.98
$ttW/Z(W)$	4.62±0.18±2.03	13.59±0.32±5.92	8.01±0.25±3.54	2.79±0.16±1.26
$t\bar{t}H$	0.48±0.04±0.10	1.50±0.08±0.20	0.85±0.06±0.16	0.24±0.03±0.09
VVV	0.06±0.01±0.01	0.14±0.02±0.03	0.08±0.01±0.01	1.51±0.06±0.10
VH	0.37±0.17±0.12	0.86±0.28±0.15	0.31±0.09±0.06	7.62±0.80±0.86
tX	0.16±0.01±0.03	0.43±0.02±0.08	0.25±0.01±0.05	0.15±0.01±0.03
$Fake$	150.71±11.16±105.49	220.19±10.27±154.13	28.78±2.84±20.14	36.51±3.48±25.55
$Qmis-id$	135.96±1.80±23.82	118.43±1.44±20.74	-	-
Bruit tot.	299.96±11.32±108.19	376.55±10.42±155.75	50.07±2.94±20.72	227.10±4.49±55.26
Données	271	307	52	208







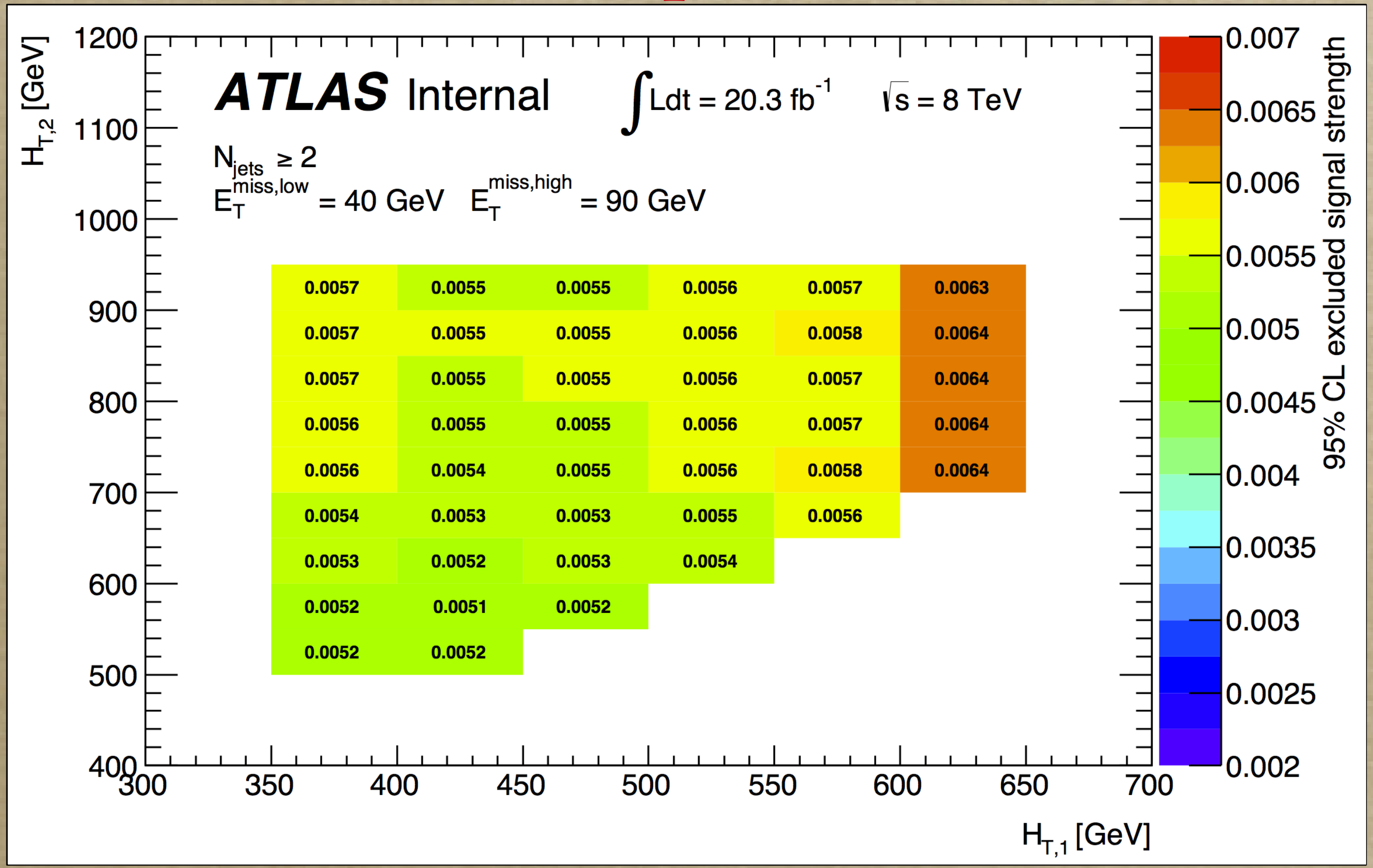
Search for $T_{5/3}$ production at 8 TeV

$\sqrt{s}$=8 TeV

8 orthogonal signal regions defined with H_T, MET and n_{jet} cuts.

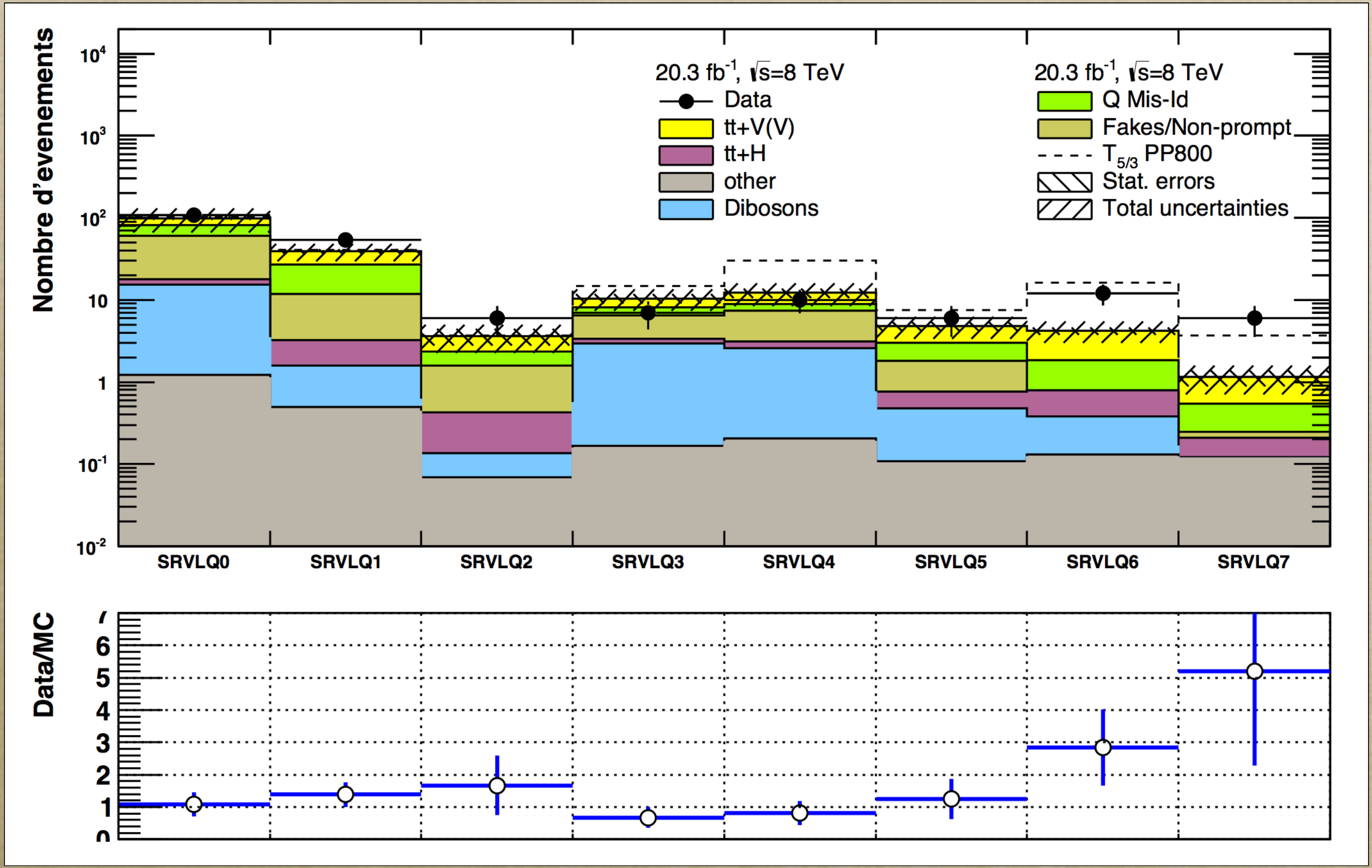
Définition			Nom
$e^\pm e^\pm + e^\pm \mu^\pm + \mu^\pm \mu^\pm + eee + ee\mu + e\mu\mu + \mu\mu\mu$, $N_j \geq 2$			
400 GeV $< H_T <$ 700 GeV	$N_b = 1$	$E_T^{miss} >$ 40 GeV	SRVLQ0
	$N_b = 2$		SRVLQ1
	$N_b \geq 3$		SRVLQ2
$H_T \geq$ 700 GeV	$N_b = 1$	40 GeV $< E_T^{miss} <$ 100 GeV	SRVLQ3
		$E_T^{miss} \geq$ 100 GeV	SRVLQ4
	$N_b = 2$	40 GeV $< E_T^{miss} <$ 100 GeV	SRVLQ5
		$E_T^{miss} \geq$ 100 GeV	SRVLQ6
	$N_b \geq 3$	$E_T^{miss} >$ 40 GeV	SRVLQ7

The cuts have been optimized on a 4 top samples with respect to the expected limit. For VLQ, these cuts are close to the optimal ones.



Search for $T_{5/3}$ production at 8 TeV

√s=8 TeV



In some signal regions (SRVLQ6/7) the observed number of events in the data is higher than the expected prediction for background.

→ **~2 σ local excess**

Search for $T_{5/3}$ production at 8 TeV

√s=8 TeV

For each signal region, the table shows the expected number of events for the background processes and the observed data.

	SRVLQ0	SRVLQ1	SRVLQ2	SRVLQ3	SRVLQ4	SRVLQ5	SRVLQ6	SRVLQ7
$t\bar{t}t\bar{t}$	0.02±0.02	0.04±0.04	0.03±0.03	0.01±0.01	0.03±0.03	0.02±0.02	0.05±0.05	0.09±0.09
$WZ-ZZ$	11.93±0.64±3.93	0.96±0.19±0.33	0.06±0.04±0.05	2.39±0.31±0.95	1.81±0.23±0.74	0.32±0.14±0.25	0.21±0.08±0.14	0
WW	1.89±0.09±0.54	0.09±0.02±0.04	0	0.38±0.04±0.11	0.53±0.05±0.22	0.04±0.01±0.05	0.03±0.01±0.01	0
$ttW-Z$	17.18±0.33±7.51	11.83±0.25±5.40	1.24±0.08±0.59	2.15±0.10±0.96	3.26±0.13±1.43	1.79±0.08±0.82	2.30±0.10±1.05	0.58±0.05±0.29
$t\bar{t}WW$	0.26±0.10	0.17±0.06	0.01±0.01	0.06±0.02	0.10±0.04	0.03±0.01	0.08±0.03	0.02±0.02
$t\bar{t}H$	2.61±0.10±0.34	1.66±0.07±0.31	0.28±0.03±0.09	0.41±0.04±0.08	0.57±0.05±0.09	0.29±0.03±0.06	0.41±0.03±0.13	0.08±0.01±0.04
VVV	0.03±0.01	0	0	0	0	0	0	0
VH	0.30±0.14±0.14	0.01±0.01±0.05	0	0	0±0.47	0	0	0
tX	1.03±0.03±0.18	0.39±0.01±0.10	0.03±0.01	0.13±0.01±0.04	0.14±0.01±0.04	0.07±0.02	0.06±0.02	0.01±0.01
$Fake$	42.12±4.52±29.48	8.60±2.34±6.02	1.16±0.82±0.81	3.08±1.28±2.16	4.23±1.59±2.96	1.02±0.66±0.72	-0.05±0.39±-0.03	0.03±0.24±0.02
$Qmis-id$	20.83±0.71±6.17	15.09±0.55±4.12	0.73±0.11±0.20	1.72±0.21±0.79	1.45±0.16±0.68	1.17±0.16±0.49	1.08±0.13±0.46	0.29±0.09±0.13
Total	98.26±4.63±31.30	38.89±2.42±9.09	3.58±0.83±1.04	10.37±1.34±2.67	12.17±1.62±3.48	4.79±0.71±1.23	4.20±0.44±1.16	1.14±0.26±0.34
Données	107	54	6	7	10	6	12	6

X ± erreur statistique ± erreur systématique

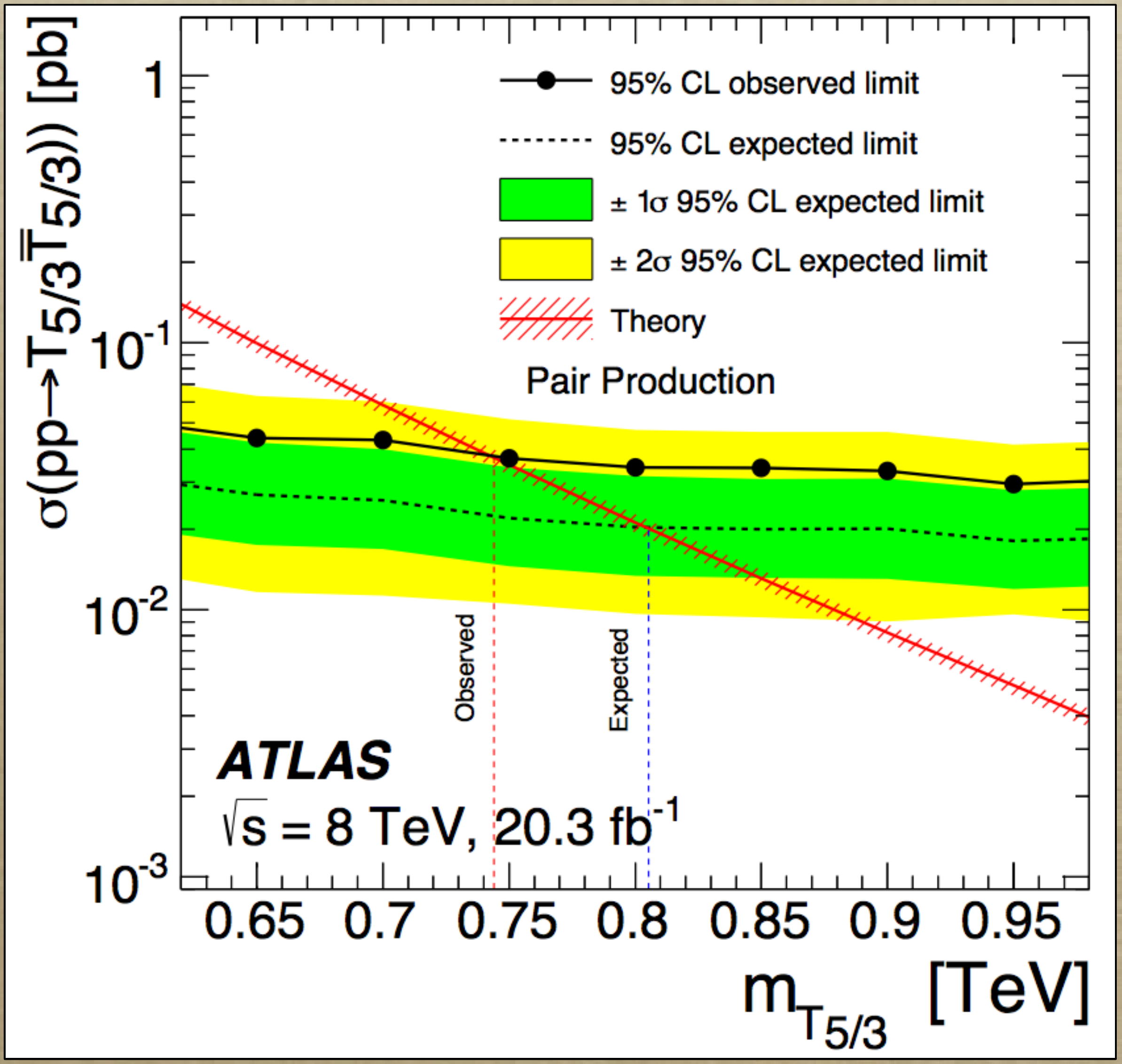
In some signal regions (SRVLQ6/7) the observed number of events in the data is higher than the expected prediction for background.

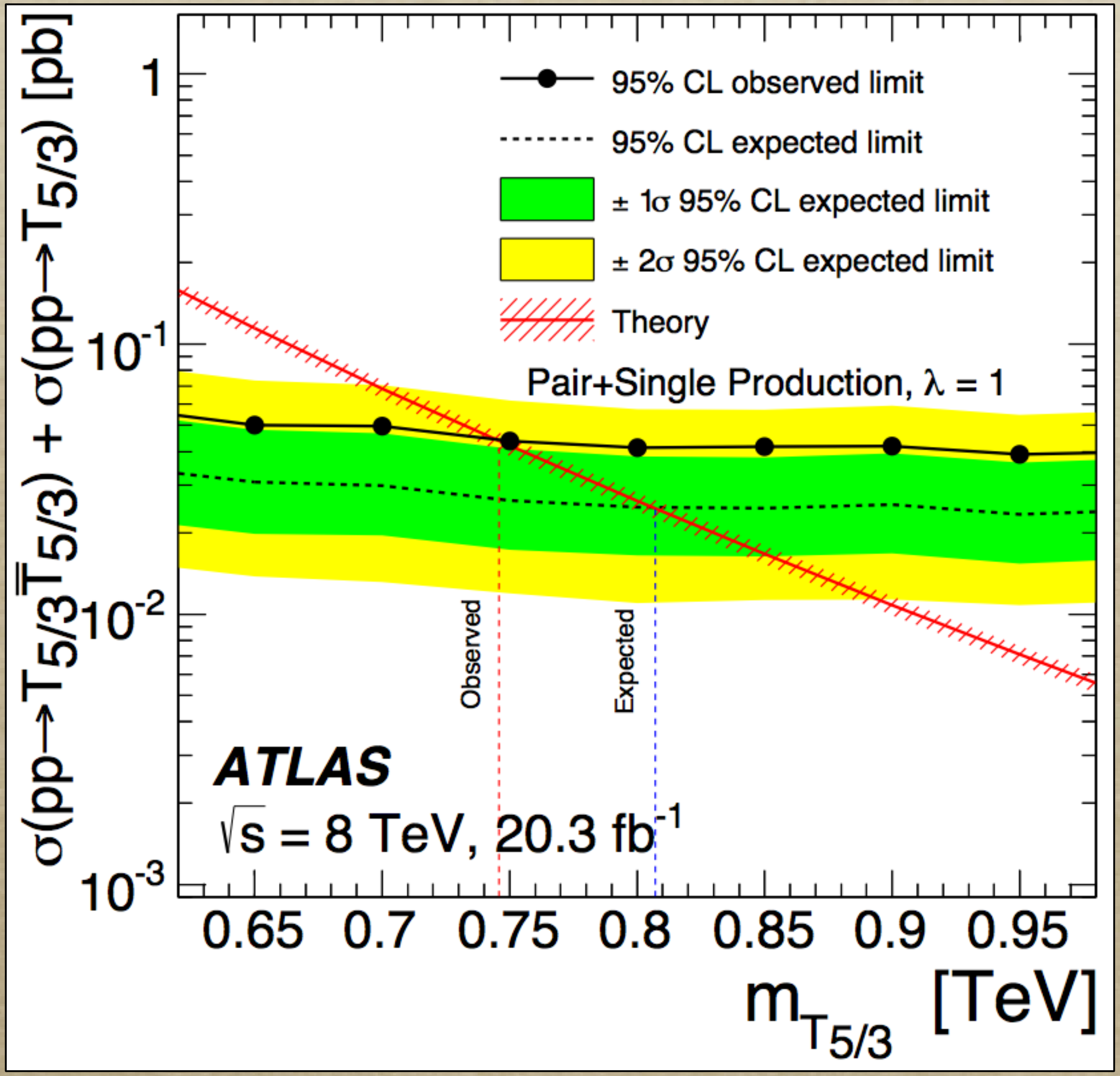
→ **~2 σ local excess**

Search for $T_{5/3}$ production at 8 TeV

√s=8 TeV

In the hypothesis of a statistical fluctuation, these results can be reinterpreted as an inferior limit on the mass of the heavy quark





For $T_{5/3}$ pair production only : **$m(T_{5/3})$ < 0,73 TeV**

For pair+single (low coupling) , **$m(T_{5/3})$ < de 0,73 TeV à 0,76 TeV**

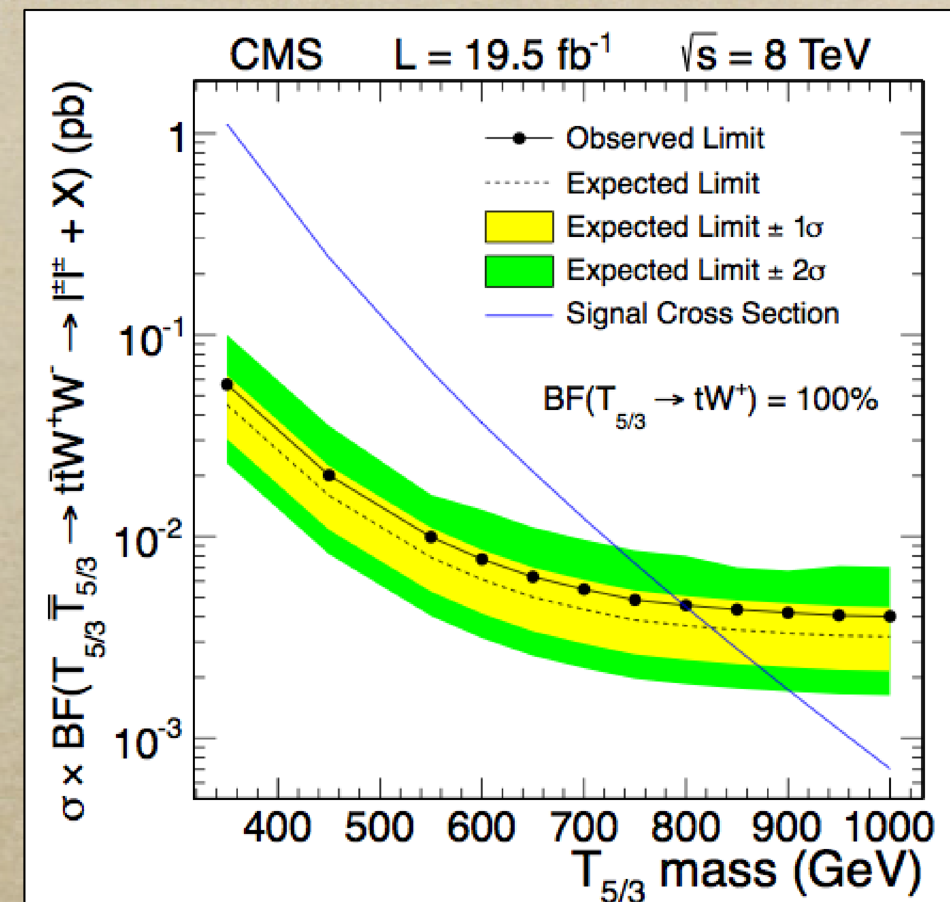
CMS search for $T_{5/3}$ production at 8 TeV

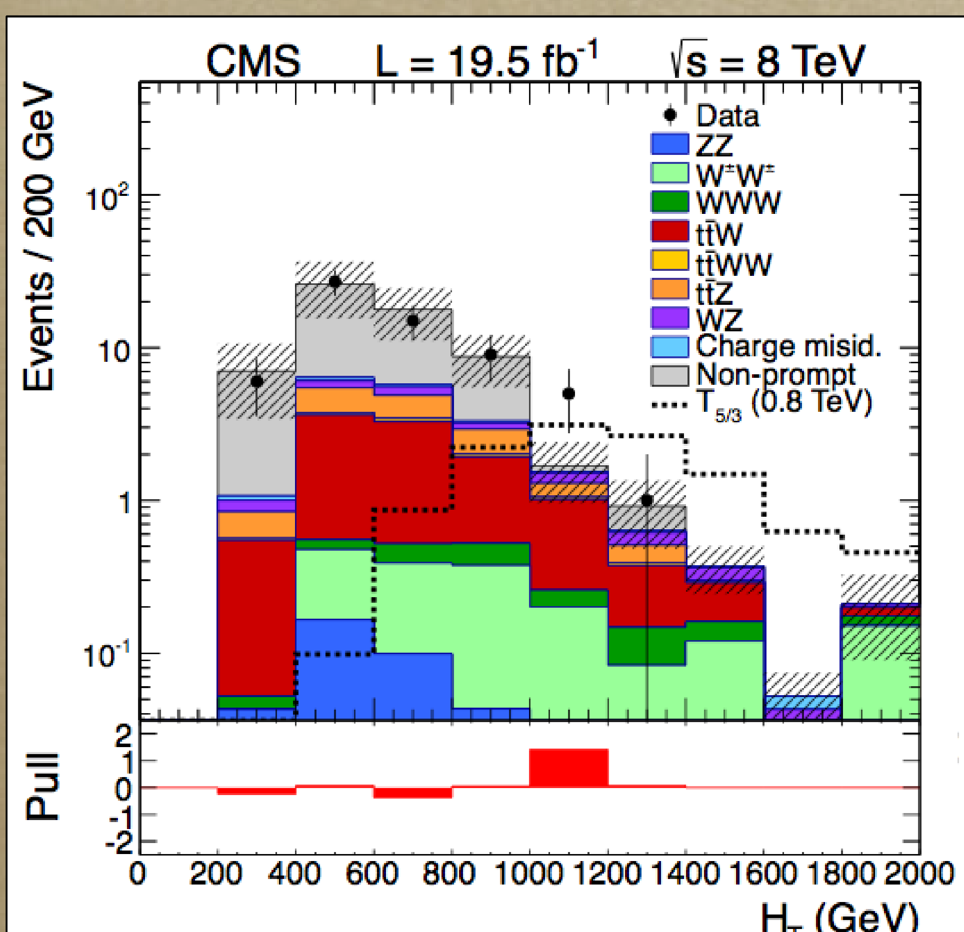
$\sqrt{s}$=8 TeV

CMS-B2G-12-012

Cut and count analysis

Selection of the events :
- Pair production only
- Boosted analysis (enhances 10-20%)
- 2L SS p_T > 30 GeV
- at least 7 constituents (W-jet = 2, top-jet = 3)
- H_T > 900 GeV





95 % CL limit
m(T5/3) > 0.8 GeV

Channel	ee	$e\mu$	$\mu\mu$	All
Same-sign	0.8 ± 0.2	1.9 ± 0.4	1.3 ± 0.3	4.0 ± 0.8
Chrg. misid.	0.06 ± 0.02	0.04 ± 0.01	—	0.11 ± 0.02
Non-prompt	1.9 ± 1.2	0.6 ± 0.9	0.3 ± 0.6	2.8 ± 1.9
Tot. bkgnd	2.7 ± 1.3	2.5 ± 1.0	1.6 ± 0.7	6.8 ± 2.1
Obs. events	0	6	3	9
$T_{5/3}$	2.1 ± 0.1	4.7 ± 0.3	2.8 ± 0.2	9.7 ± 0.5

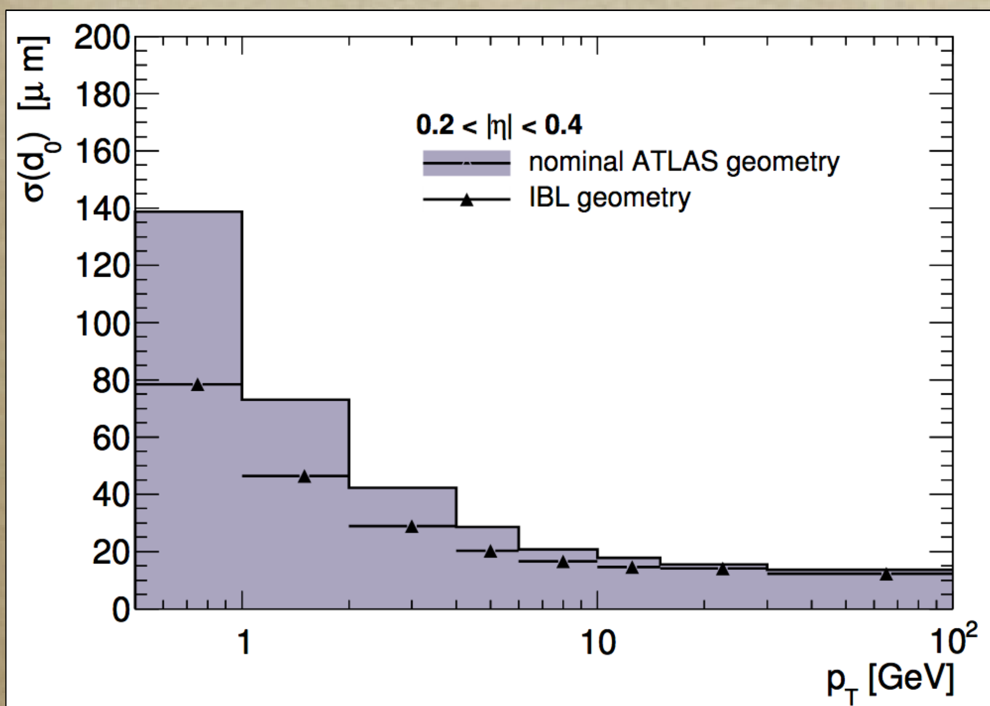
No excess observed

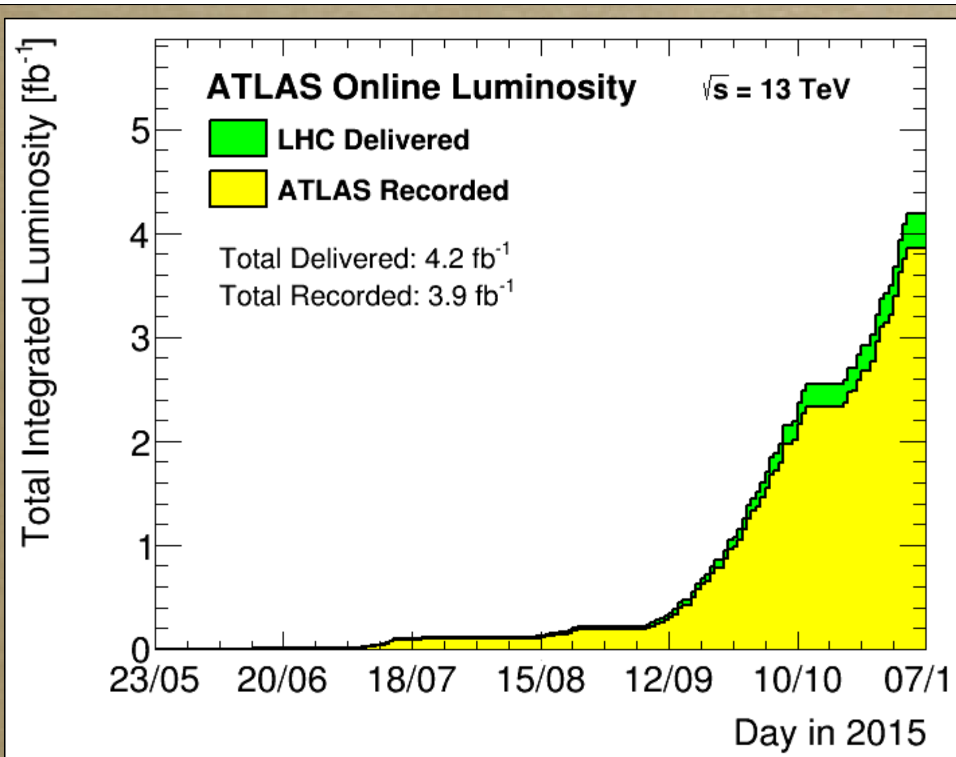
Current searches for exotic partners

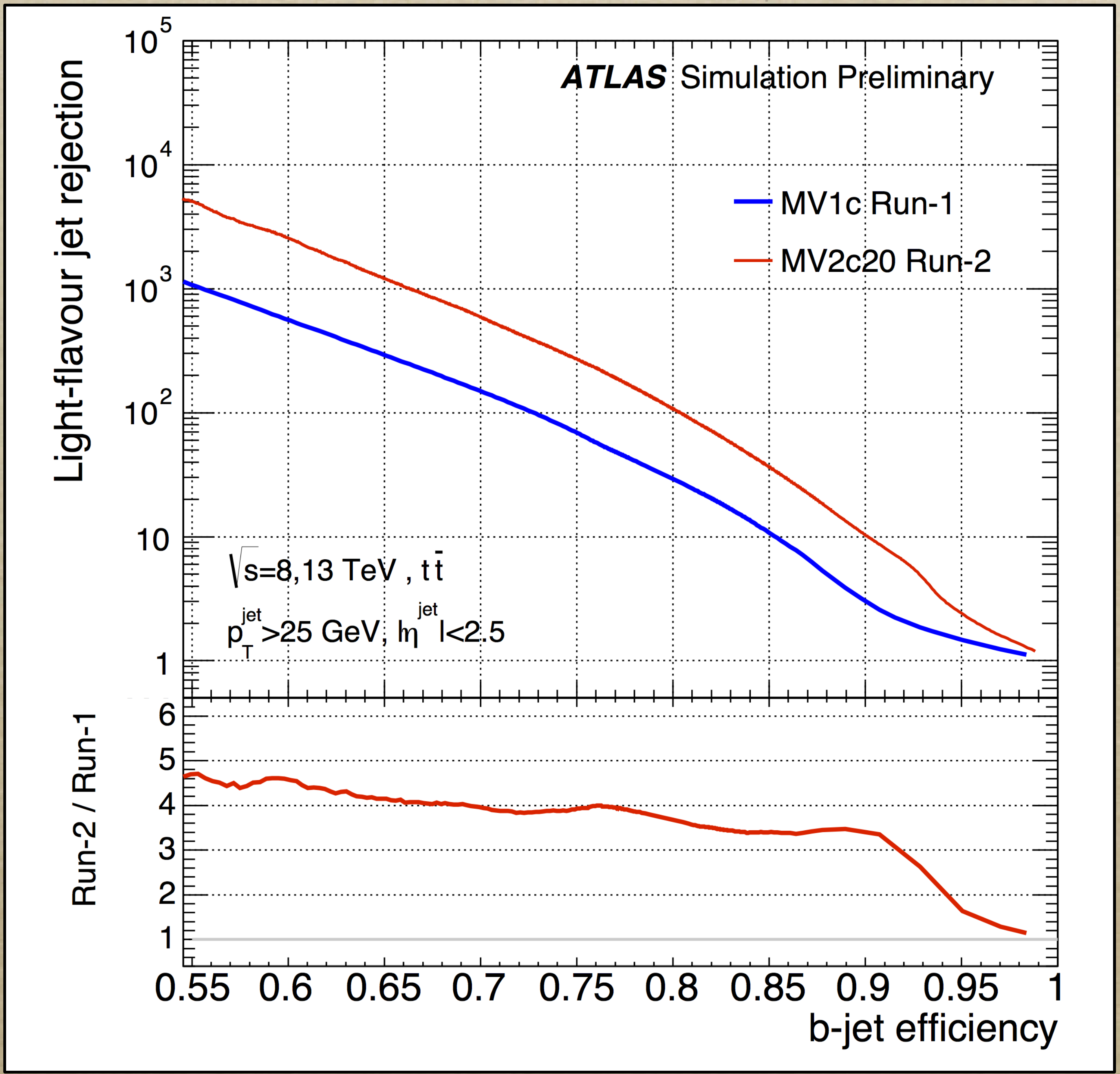
- Introduction
- Run 1 analyses
- **Current searches for exotic partners**
- Prospects for future studies with 4 tops
- Conclusion

LS1 improvements

√s=13 TeV 2013-2015 : Long shutdown for maintenance on the dipoles junctions.
For ATLAS : IBL insertion.







Bunches spacing 50 → 25 ns : for a same luminosity, the calorimeter background increases

13 TeV data in 2015 = **3.2 fb^{-1}**

Expected gains at 13 TeV

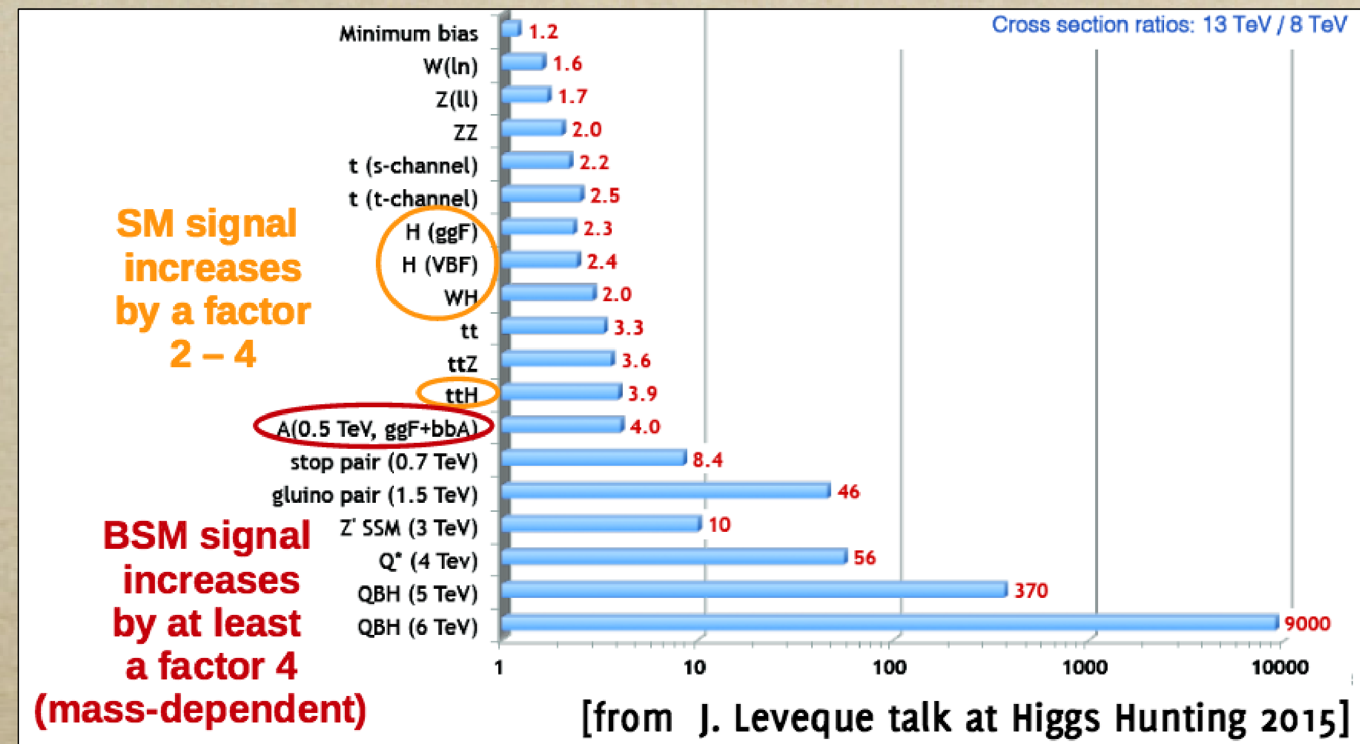
√s=13 TeV

ATLAS-CONF-2016-032

Signal cross-sections x 10-15

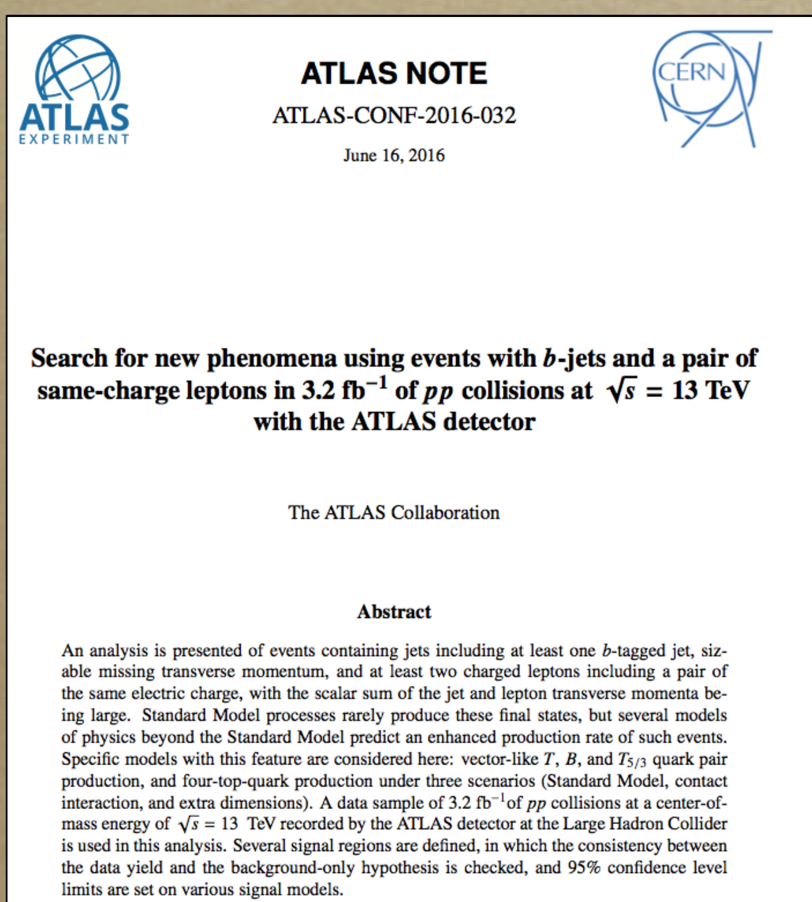
Background ($t\bar{t}$) x 4

→ √3.2/√20.3 x S/√B ~ x 2.5



Exclusion limit around 900 GeV.

For 35 fb^{-1}, the limit increases to 1200 GeV.



ATLAS NOTE

ATLAS-CONF-2016-032

June 16, 2016

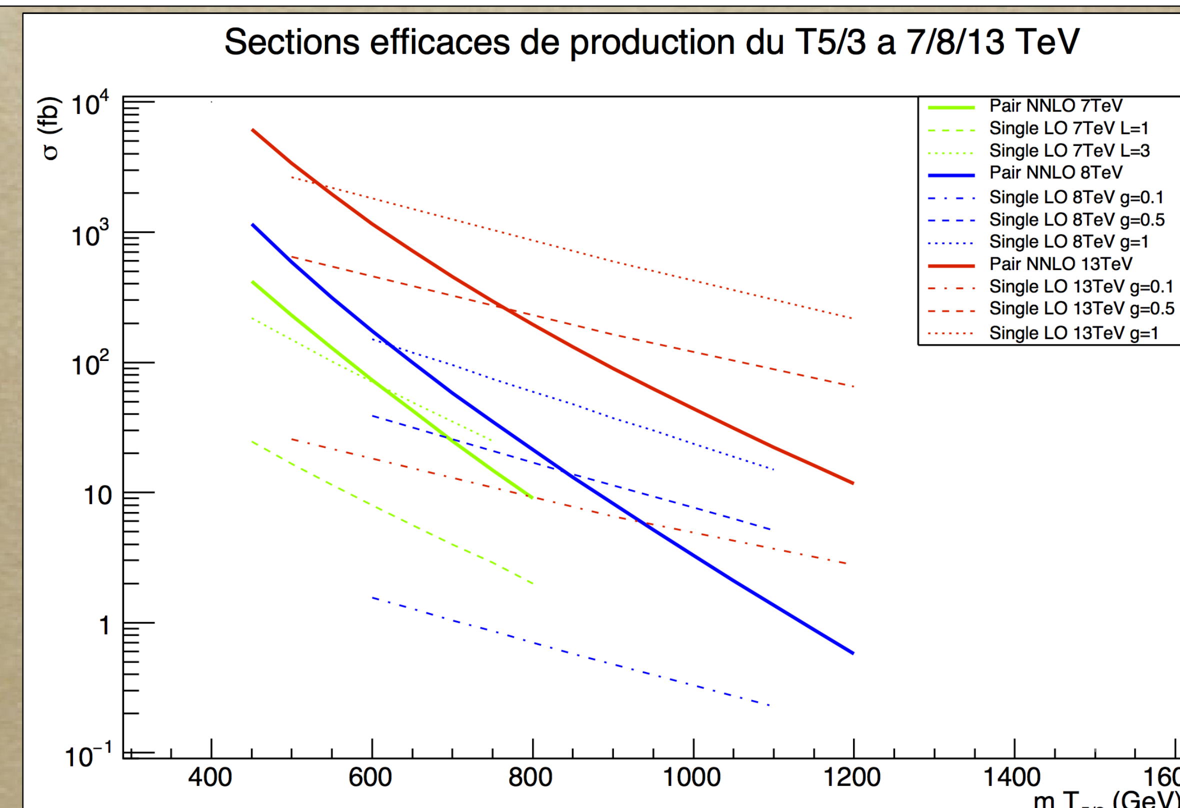
Search for new phenomena using events with *b*-jets and a pair of same-charge leptons in 3.2 fb^{-1} of *pp* collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The ATLAS Collaboration

Abstract

An analysis is presented of events containing jets including at least one *b*-tagged jet, sizable missing transverse momentum, and at least two charged leptons including a pair of the same electric charge, with the scalar sum of the jet and lepton transverse momenta being large. Standard Model processes rarely produce these final states, but several models of physics beyond the Standard Model predict an enhanced production rate of such events. Specific models with this feature are considered here: vector-like T, B, and $T_{5/3}$ quark pair production, and four-top-quark production under three scenarios (Standard Model, contact interaction, and extra dimensions). A data sample of 3.2 fb^{-1} of *pp* collisions at a center-of-mass energy of $\sqrt{s}$ = 13 TeV recorded by the ATLAS detector at the Large Hadron Collider is used in this analysis. Several signal regions are defined, in which the consistency between the data yield and the background-only hypothesis is checked, and 95% confidence level limits are set on various signal models.

Very early analysis to check the observed excess with Run 1 data. Similar cuts and selection are used.

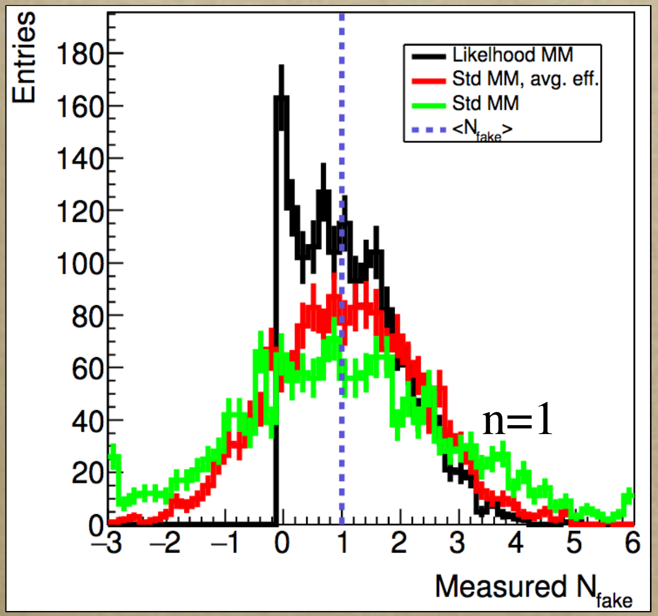


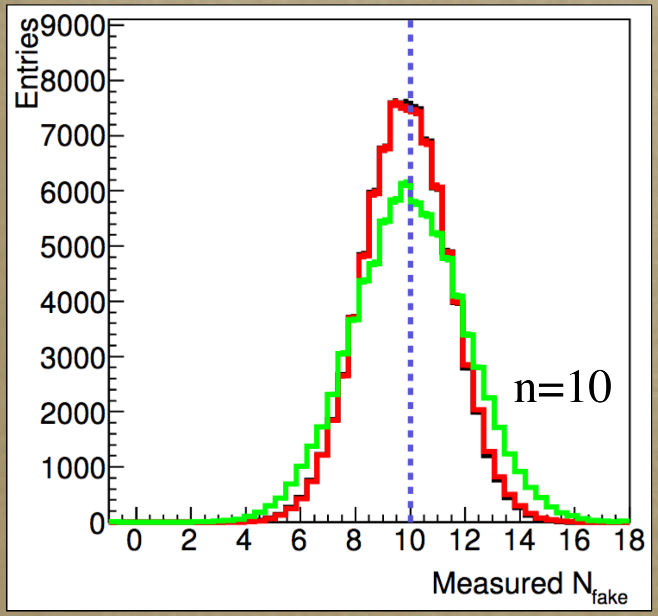
Search for $T_{5/3}$ production at 13 TeV

$\sqrt{s}$=13 TeV

ATL-COM-PHYS-2016-286

Several drawbacks in the matrix method : negative yields, divergences in the matrix inversion when r and f get closer.
=> we use a Poisson likelihood matrix method (LHMM).





Low statistics
(1 event)

LHMM
<MM>
MM
Fakes yield

Higher statistics
(10 events)

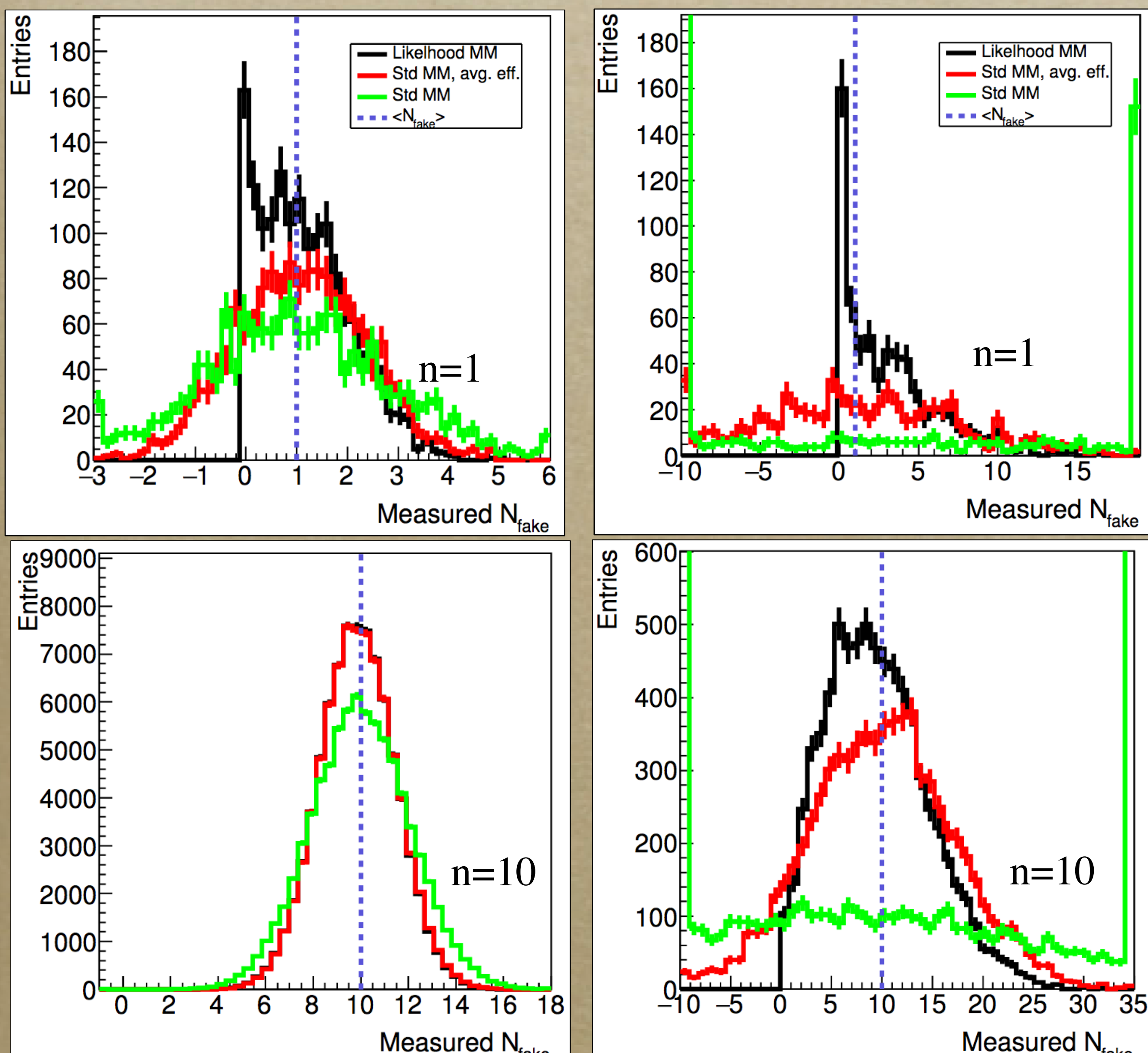
r~0.9 and f~0.2

Search for $T_{5/3}$ production at 13 TeV

√s=13 TeV

Several drawbacks in the matrix method : negative yields, divergences in the matrix inversion when r and f get closer.

=> we use a Poisson likelihood matrix method (LHMM).



r~0.9 and f~0.2

r~0.9 and f~0.5

Low statistics
(1 event)

LHMM
<MM>
MM
Fakes yield

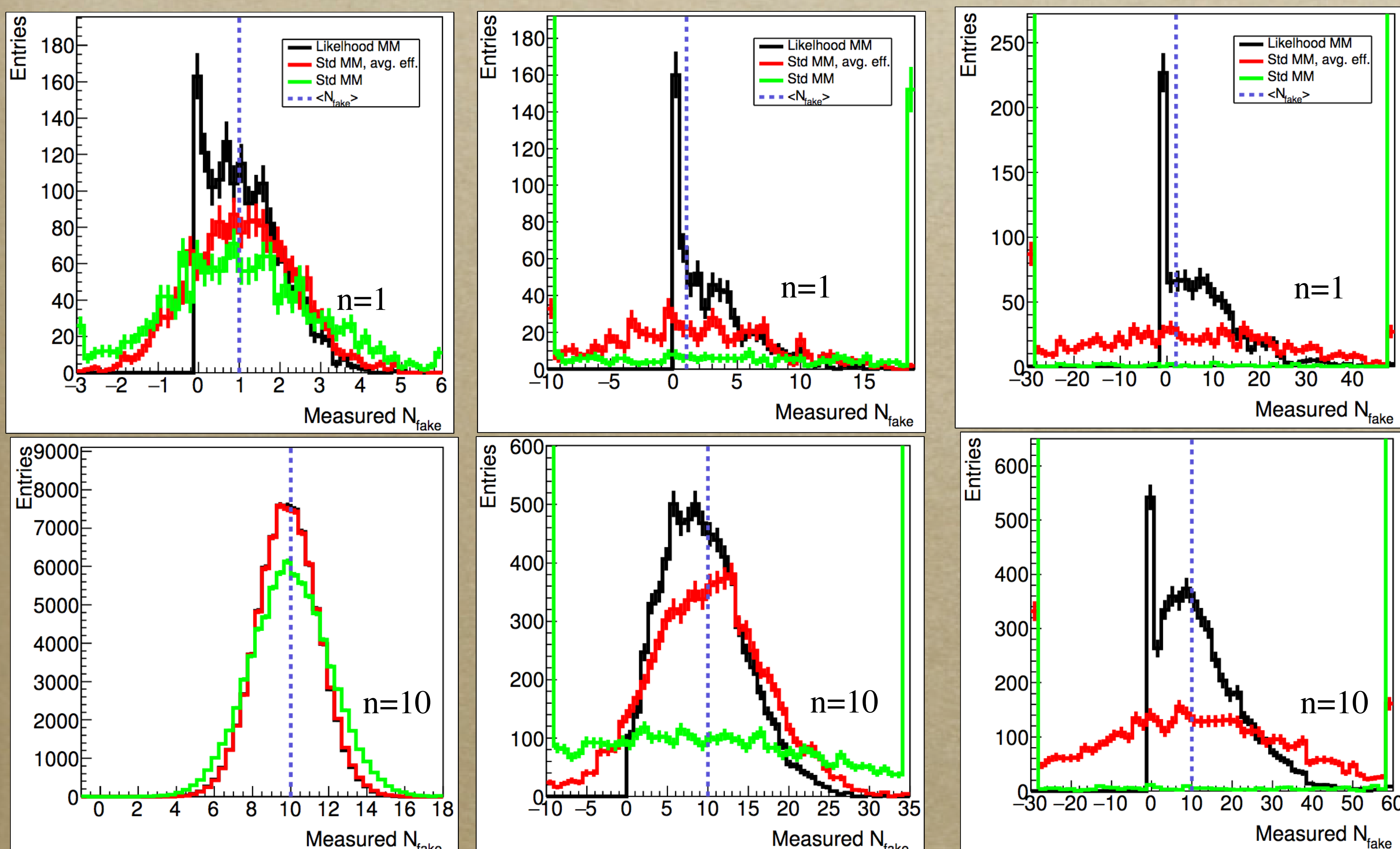
Higher statistics
(10 events)

Search for $T_{5/3}$ production at 13 TeV

$\sqrt{s}$=13 TeV

Several drawbacks in the matrix method : negative yields, divergences in the matrix inversion when r and f get closer.

=> we use a Poisson likelihood matrix method (LHMM).



Low statistics (1 event)

LHMM
<MM>
MM
Fakes yield

Higher statistics (10 events)

r~0.9 and f~0.2 | r~0.9 and f~0.5 | r~0.9 and f~0.7

Search for $T_{5/3}$ production at 13 TeV

√s=13 TeV

Good agreement in control regions.

X ± erreur statistique± erreur systématique

Échantillon	"faible H_T+1b" ee	"faible H_T+1b" $e\mu$	"faible H_T+1b" $\mu\mu$	"faibleH_T+0b" $\mu\mu$
VV	$2.91 \pm 0.49 \pm 0.90$	$7.51 \pm 0.48 \pm 2.34$	$3.97 \pm 0.35 \pm 1.24$	$46.87 \pm 1.20 \pm 14.71$
$ttW/Z(W)$	$1.99 \pm 0.03 \pm 0.14$	$5.84 \pm 0.05 \pm 0.41$	$3.37 \pm 0.04 \pm 0.23$	$0.75 \pm 0.02 \pm 0.05$
$t\bar{t}H$	0.43 ± 0.08	1.30 ± 0.13	0.51 ± 0.09	0.13 ± 0.04
VVV	0.01 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.38 ± 0.03
$Fake$	$26.23 \pm 5.57 \pm 11.28$	$76.00 \pm 7.14 \pm 32.68$	$27.33 \pm 3.11 \pm 11.75$	$60.15 \pm 12.95 \pm 7.82$
$Qmis-id$	$84.02 \pm 1.82 \pm 21.00$	$82.89 \pm 1.60 \pm 20.72$	–	–
Bruit tot.	$115.60 \pm 5.88 \pm 24.57$	$173.56 \pm 7.34 \pm 39.45$	$35.20 \pm 3.13 \pm 12.23$	$108.28 \pm 13.00 \pm 21.14$
Données	135	144	30	80

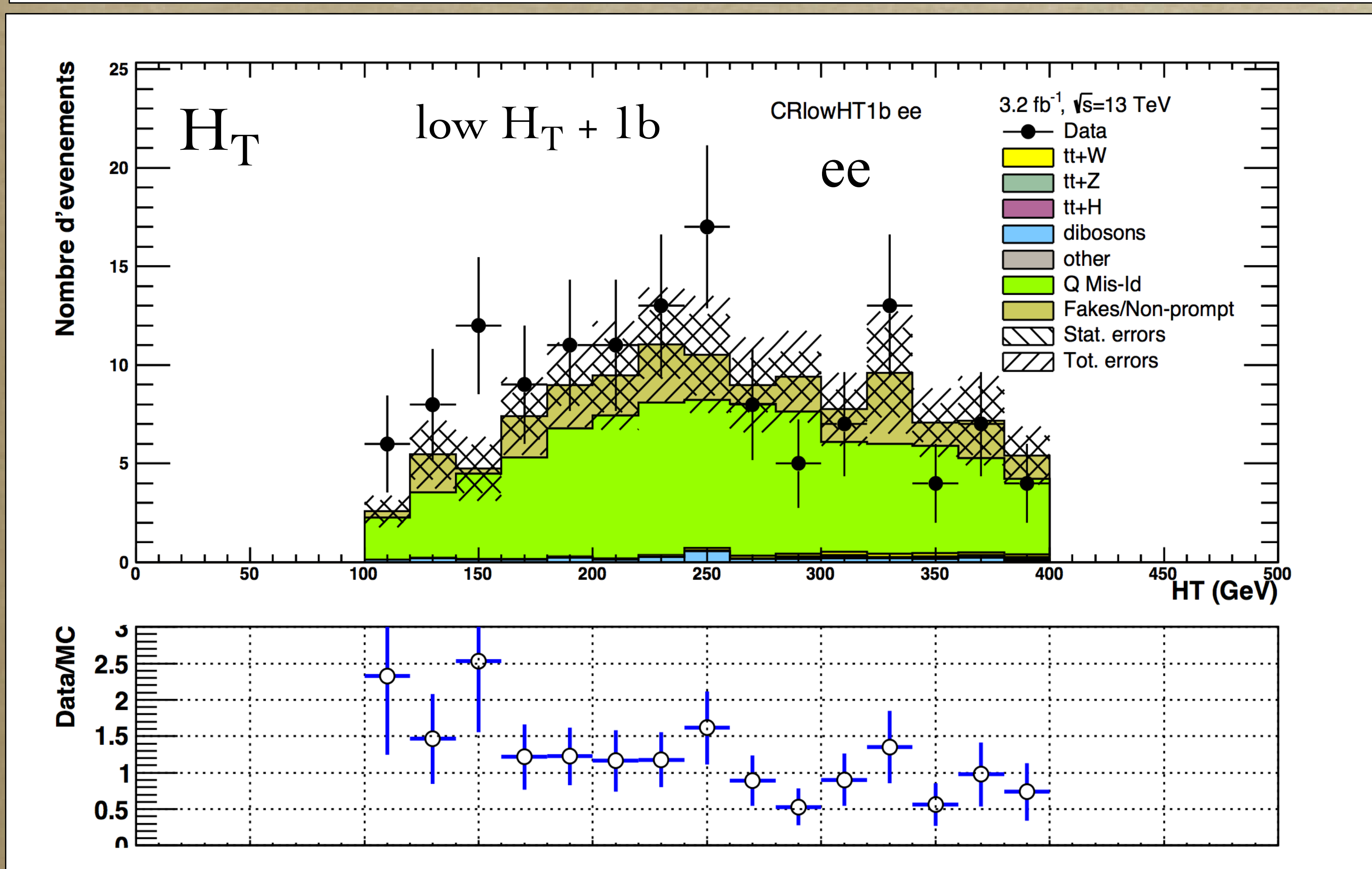
Same definitions as at 8 TeV :

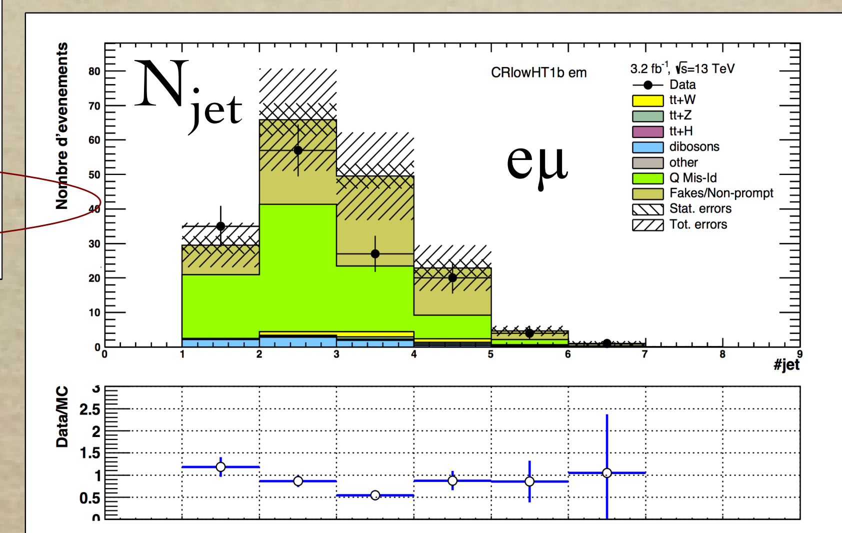
- low H_T + 0b =

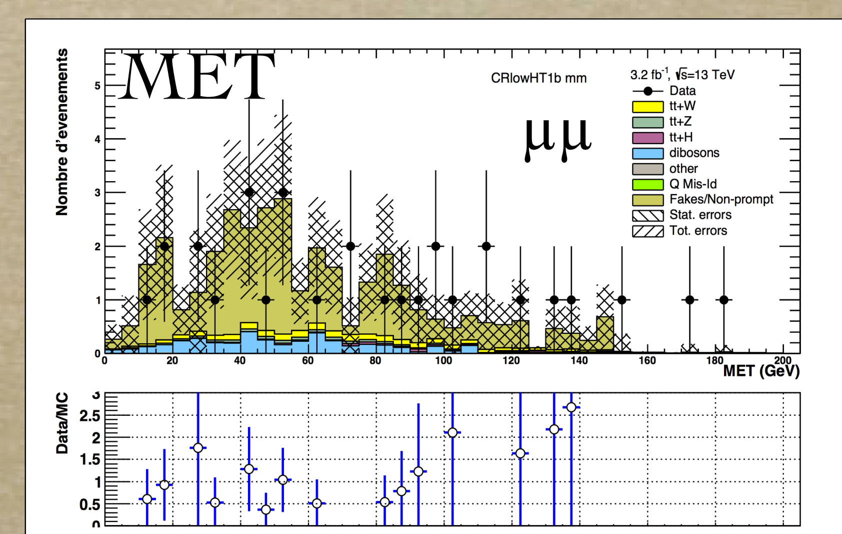
100 < H_T < 400 GeV + 0 bjets

- low H_T + 1b =

100 < H_T < 400 GeV + ≥1 bjet







Search for $T_{5/3}$ production at 13 TeV

$\sqrt{s}$=13 TeV

Good agreement in control regions.

X ± erreur statistique± erreur systématique

Échantillon	"faible H_T+1b" ee	$e\mu$	$\mu\mu$	"faibleH_T+0b" $\mu\mu$
VV	$2.91 \pm 0.49 \pm 0.90$	$7.51 \pm 0.48 \pm 2.34$	$3.97 \pm 0.35 \pm 1.24$	$46.87 \pm 1.20 \pm 14.71$
$ttW/Z(W)$	$1.99 \pm 0.03 \pm 0.14$	$5.84 \pm 0.05 \pm 0.41$	$3.37 \pm 0.04 \pm 0.23$	$0.75 \pm 0.02 \pm 0.05$
$t\bar{t}H$	0.43 ± 0.08	1.30 ± 0.13	0.51 ± 0.09	0.13 ± 0.04
VVV	0.01 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.38 ± 0.03
$Fake$	$26.23 \pm 5.57 \pm 11.28$	$76.00 \pm 7.14 \pm 32.68$	$27.33 \pm 3.11 \pm 11.75$	$60.15 \pm 12.95 \pm 7.82$
$Qmis-id$	$84.02 \pm 1.82 \pm 21.00$	$82.89 \pm 1.60 \pm 20.72$	$-$	$-$
Bruit tot.	$115.60 \pm 5.88 \pm 24.57$	$173.56 \pm 7.34 \pm 39.45$	$35.20 \pm 3.13 \pm 12.23$	$108.28 \pm 13.00 \pm 21.14$
Données	135	144	30	80

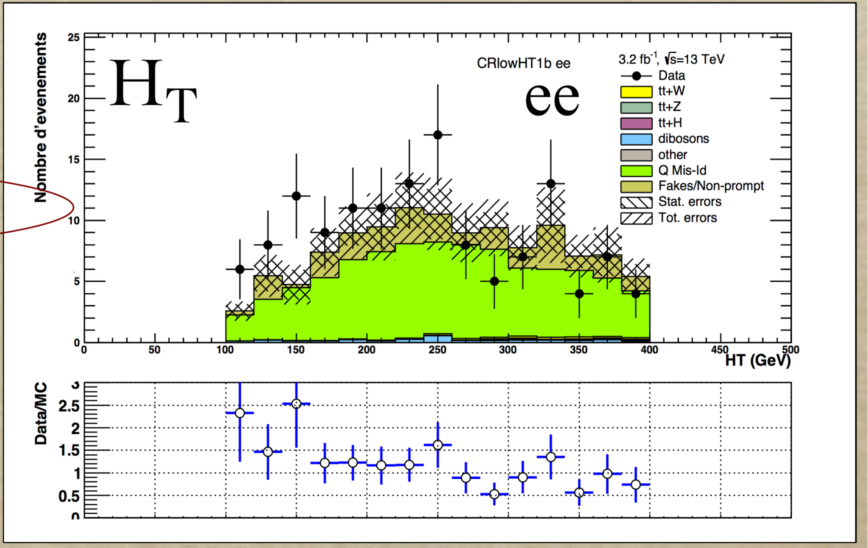
Same definitions as at 8 TeV :

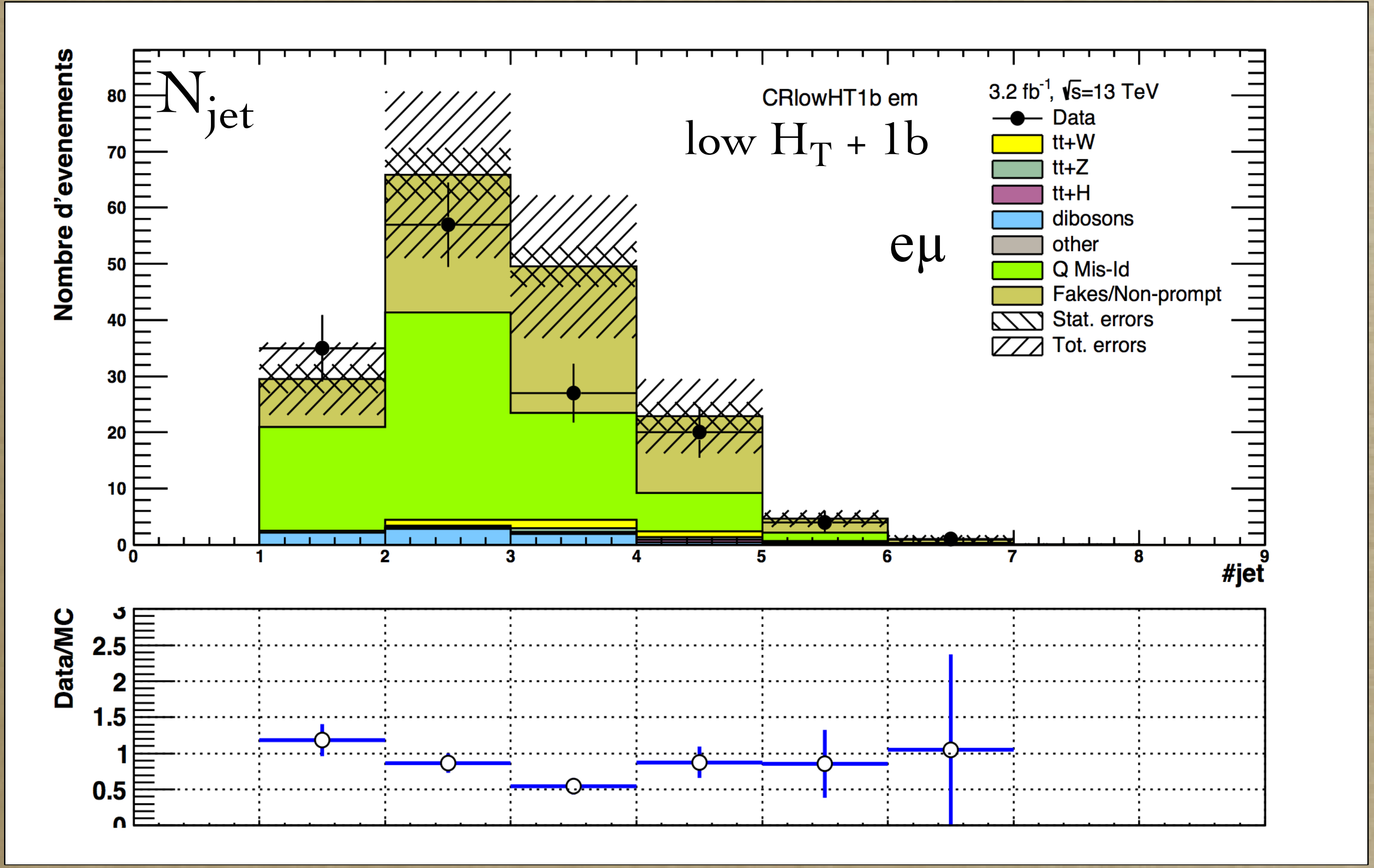
- low H_T + 0b =

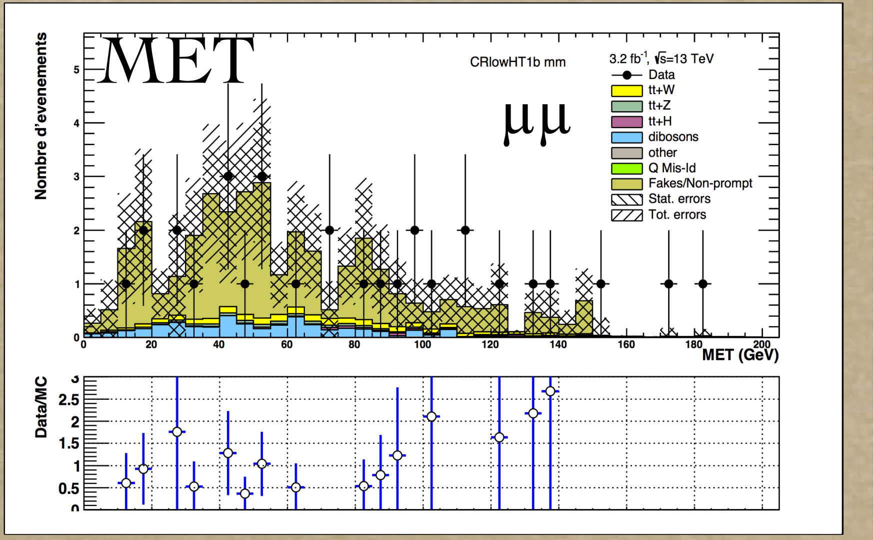
100 < H_T < 400 GeV + 0 bjets

- low H_T + 1b =

100 < H_T < 400 GeV + ≥1 bjet







Search for $T_{5/3}$ production at 13 TeV

$\sqrt{s}$=13 TeV

Good agreement in control regions.

X ± erreur statistique± erreur systématique

Échantillon	"faible H_T+1b"			"faibleH_T+0b"
	ee	$e\mu$	$\mu\mu$	$\mu\mu$
VV	$2.91 \pm 0.49 \pm 0.90$	$7.51 \pm 0.48 \pm 2.34$	$3.97 \pm 0.35 \pm 1.24$	$46.87 \pm 1.20 \pm 14.71$
$ttW/Z(W)$	$1.99 \pm 0.03 \pm 0.14$	$5.84 \pm 0.05 \pm 0.41$	$3.37 \pm 0.04 \pm 0.23$	$0.75 \pm 0.02 \pm 0.05$
$t\bar{t}H$	0.43 ± 0.08	1.30 ± 0.13	0.51 ± 0.09	0.13 ± 0.04
VVV	0.01 ± 0.01	0.03 ± 0.01	0.03 ± 0.01	0.38 ± 0.03
$Fake$	$26.23 \pm 5.57 \pm 11.28$	$76.00 \pm 7.14 \pm 32.68$	$27.33 \pm 3.11 \pm 11.75$	$60.15 \pm 12.95 \pm 7.82$
$Qmis-id$	$84.02 \pm 1.82 \pm 21.00$	$82.89 \pm 1.60 \pm 20.72$	–	–
Bruit tot.	$115.60 \pm 5.88 \pm 24.57$	$173.56 \pm 7.34 \pm 39.45$	$35.20 \pm 3.13 \pm 12.23$	$108.28 \pm 13.00 \pm 21.14$
Données	135	144	30	80

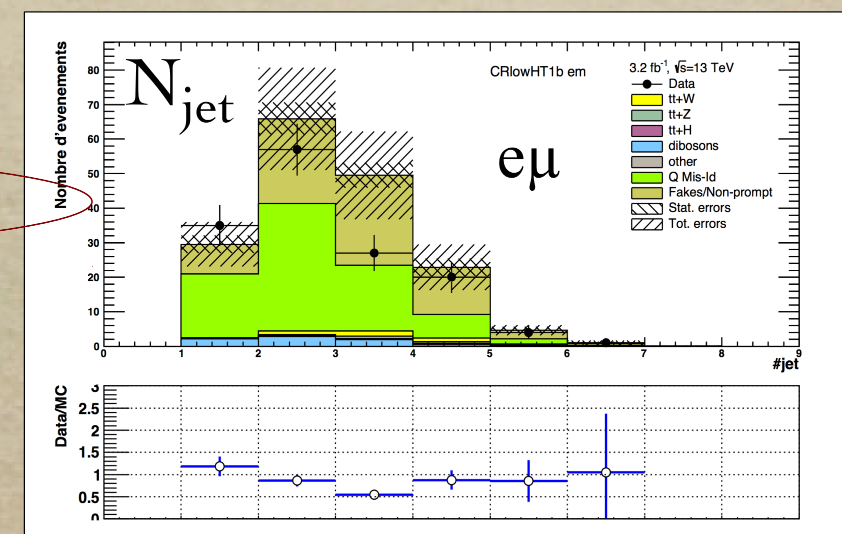
Same definitions as at 8 TeV :

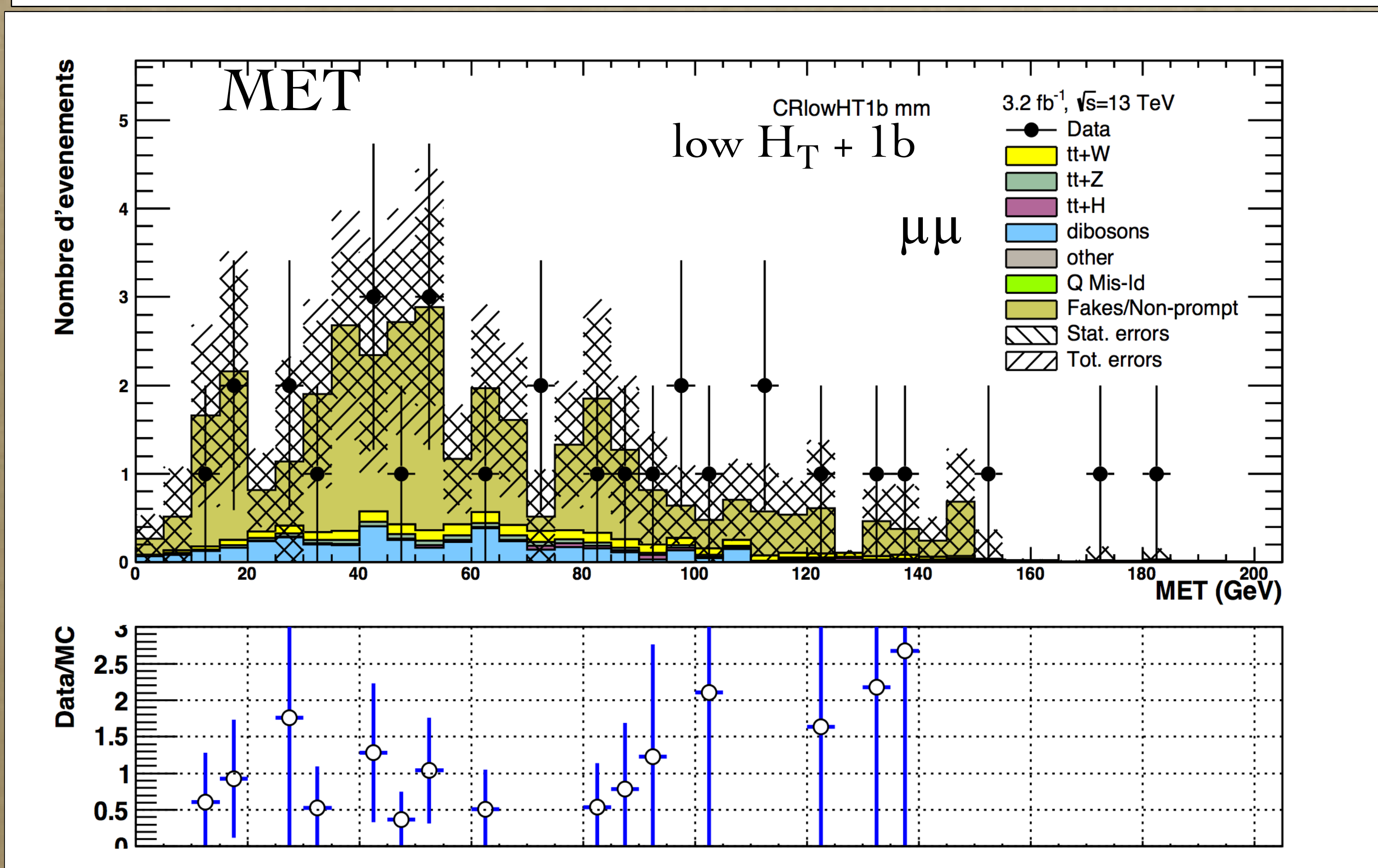
- low H_T + 0b =

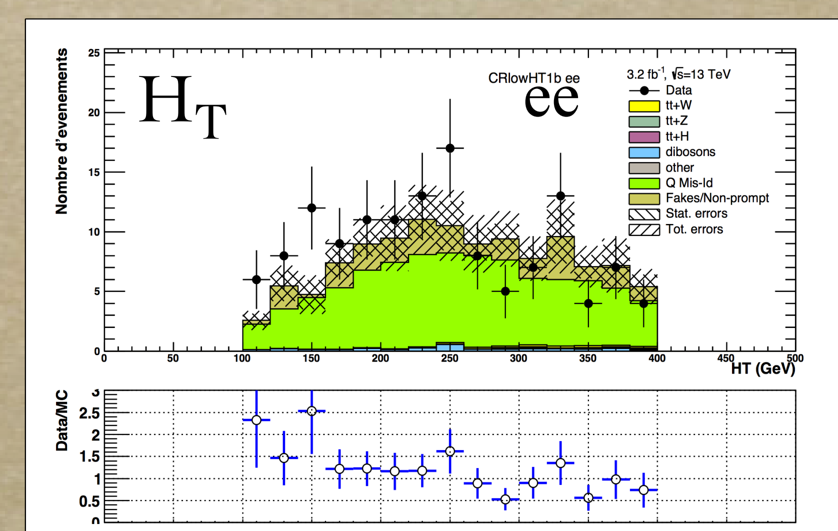
100 < H_T < 400 GeV + 0 bjets

- low H_T + 1b =

100 < H_T < 400 GeV + ≥1 bjet



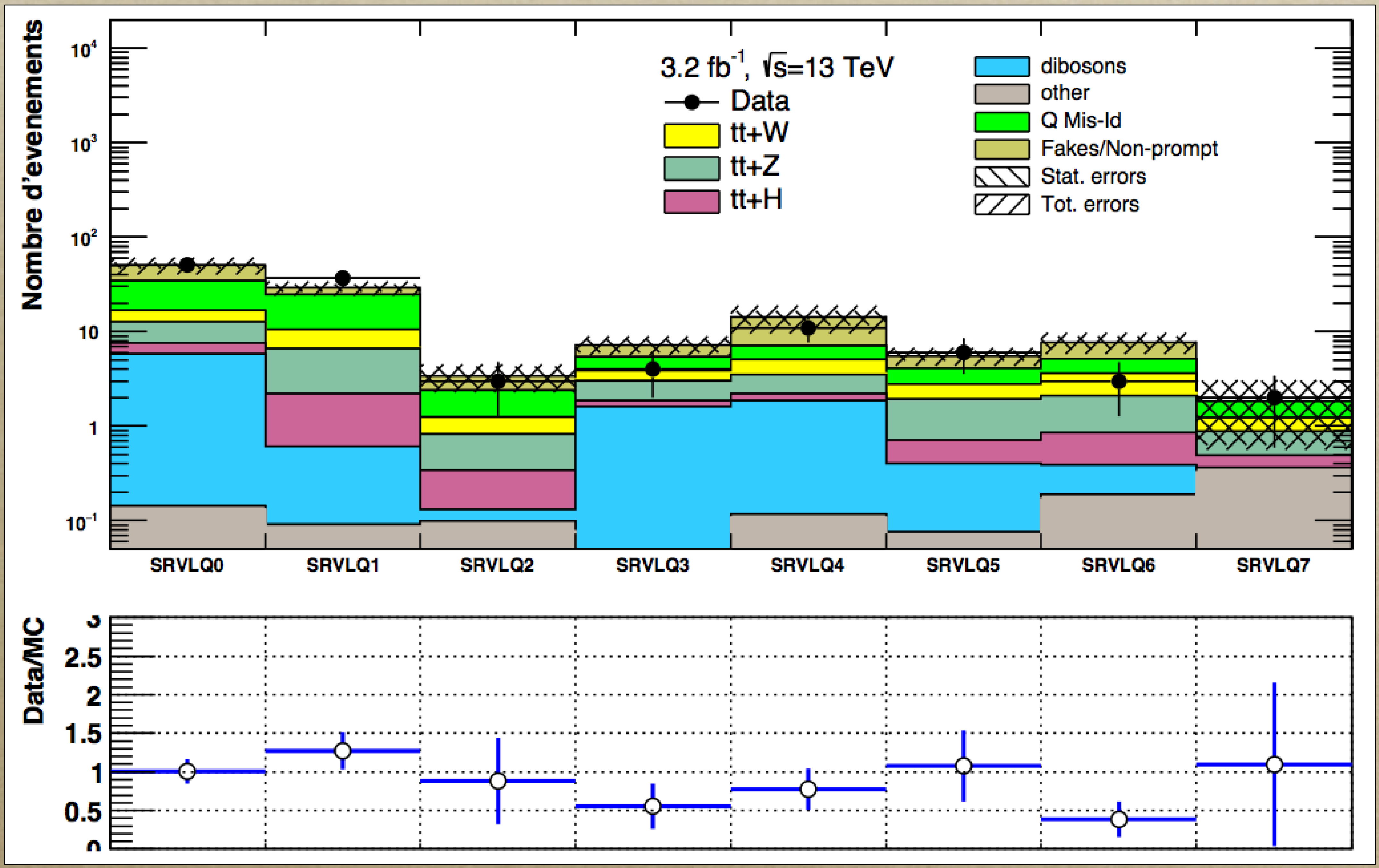




Search for $T_{5/3}$ production at 13 TeV

√s=13 TeV

Background composition in SR very similar to 8 TeV. No excess.



Search for $T_{5/3}$ production at 13 TeV

$\sqrt{s}$=13 TeV

Background composition in SR very similar to 8 TeV. No excess.

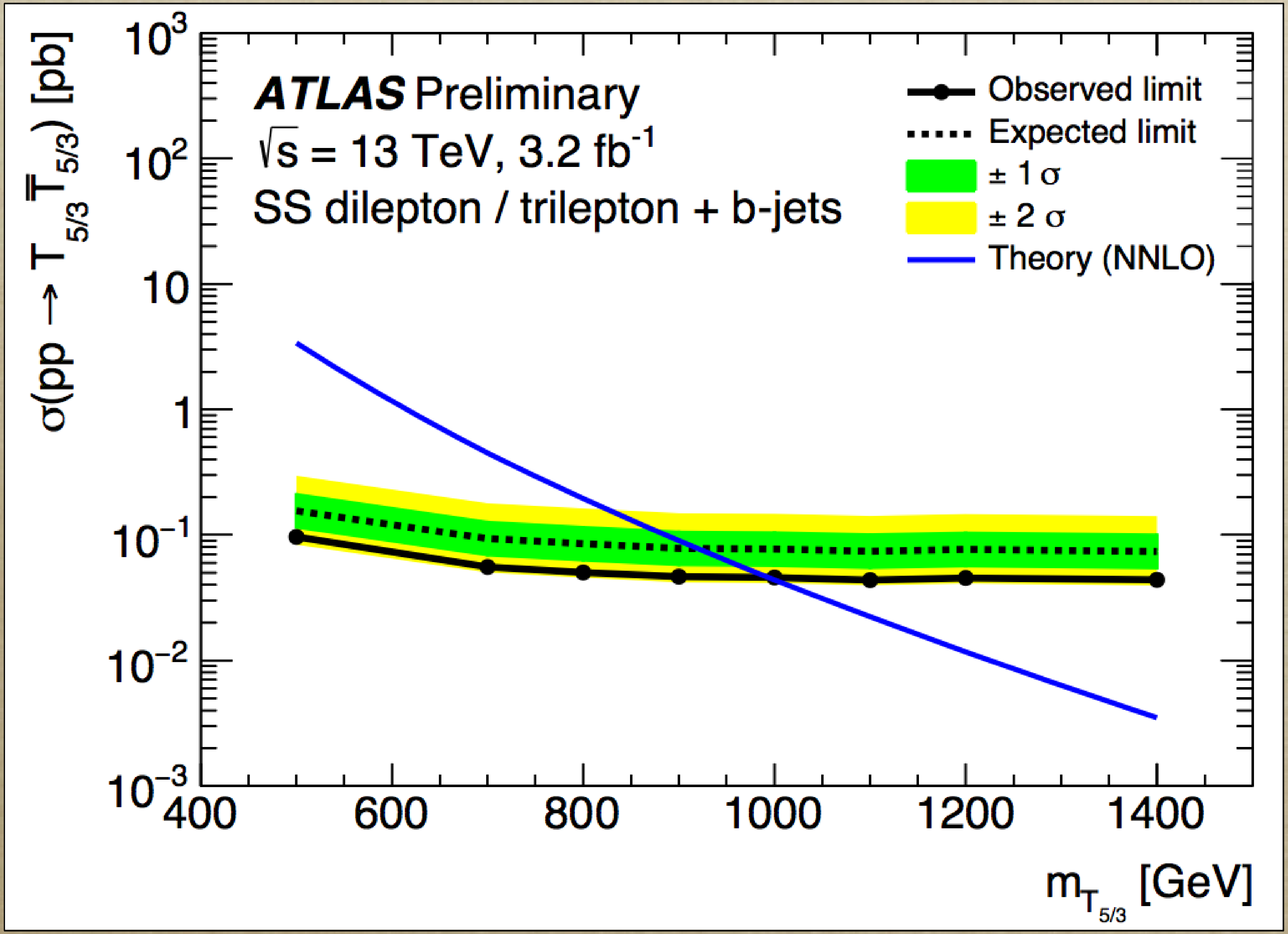
	SRVLQ0	SRVLQ1	SRVLQ2	SRVLQ3	SRVLQ4	SRVLQ5	SRVLQ6	SRVLQ7
$t\bar{t}t\bar{t}$	0.04 ± 0.01	0.07 ± 0.01	0.08 ± 0.01	0.01 ± 0.01	0.05 ± 0.01	0.07 ± 0.01	0.16 ± 0.01	0.33 ± 0.02
VV	$5.70 \pm 0.37 \pm 0.91$	$0.52 \pm 0.10 \pm 0.13$	$0.03 \pm 0.02 \pm 0.03$	$1.56 \pm 0.21 \pm 0.34$	$1.76 \pm 0.18 \pm 0.35$	$0.33 \pm 0.09 \pm 0.07$	$0.20 \pm 0.05 \pm 0.07$	0
ttV	$9.07 \pm 0.06 \pm 1.18$	$8.25 \pm 0.05 \pm 1.07$	$0.90 \pm 0.02 \pm 0.29$	$1.95 \pm 0.03 \pm 0.30$	$2.74 \pm 0.03 \pm 0.41$	$2.01 \pm 0.03 \pm 0.50$	$2.69 \pm 0.03 \pm 0.59$	$0.69 \pm 0.02 \pm 0.36$
$t\bar{t}WW$	0.16 ± 0.03	0.14 ± 0.03	0.02 ± 0.01	0.08 ± 0.02	0.13 ± 0.02	0.07 ± 0.02	0.12 ± 0.02	0.05 ± 0.01
$t\bar{t}H$	1.76 ± 0.15	1.58 ± 0.14	0.21 ± 0.05	0.27 ± 0.07	0.34 ± 0.07	0.30 ± 0.06	0.47 ± 0.08	0.13 ± 0.04
VVV	0.09 ± 0.01	0.01 ± 0.01	0	≤ 0.01	0.06 ± 0.01	≤ 0.01	0.01 ± 0.01	0
Fake	$16.33 \pm 3.90 \pm 8.82$	$4.24 \pm 2.55 \pm 2.29$	$1.00 \pm 0.87 \pm 0.54$	$1.79 \pm 1.15 \pm 0.97$	$7.15 \pm 2.43 \pm 3.86$	$1.45 \pm 0.64 \pm 0.78$	$2.62 \pm 1.17 \pm 1.41$	0.00 ± 1.18
$Qmis - id$	$17.44 \pm 0.90 \pm 4.36$	$14.24 \pm 0.73 \pm 3.56$	$1.15 \pm 0.17 \pm 0.29$	$1.56 \pm 0.26 \pm 0.39$	$1.94 \pm 0.27 \pm 0.49$	$1.33 \pm 0.21 \pm 0.33$	$1.48 \pm 0.25 \pm 0.37$	$0.58 \pm 0.14 \pm 0.15$
Total	$50.59 \pm 4.02 \pm 10.73$	$29.04 \pm 2.65 \pm 5.11$	$3.39 \pm 0.89 \pm 1.12$	$7.24 \pm 1.20 \pm 1.66$	$14.16 \pm 2.46 \pm 4.63$	$5.55 \pm 0.68 \pm 1.21$	$7.74 \pm 1.20 \pm 1.99$	$1.78 \pm 1.19 \pm 1.26$
Données	51	37	3	4	11	6	3	2

X ± erreur statistique ± erreur systématique

Search for $T_{5/3}$ production at 13 TeV

$\sqrt{s}$=13 TeV

Statistical interpretation : mass inferior limit.



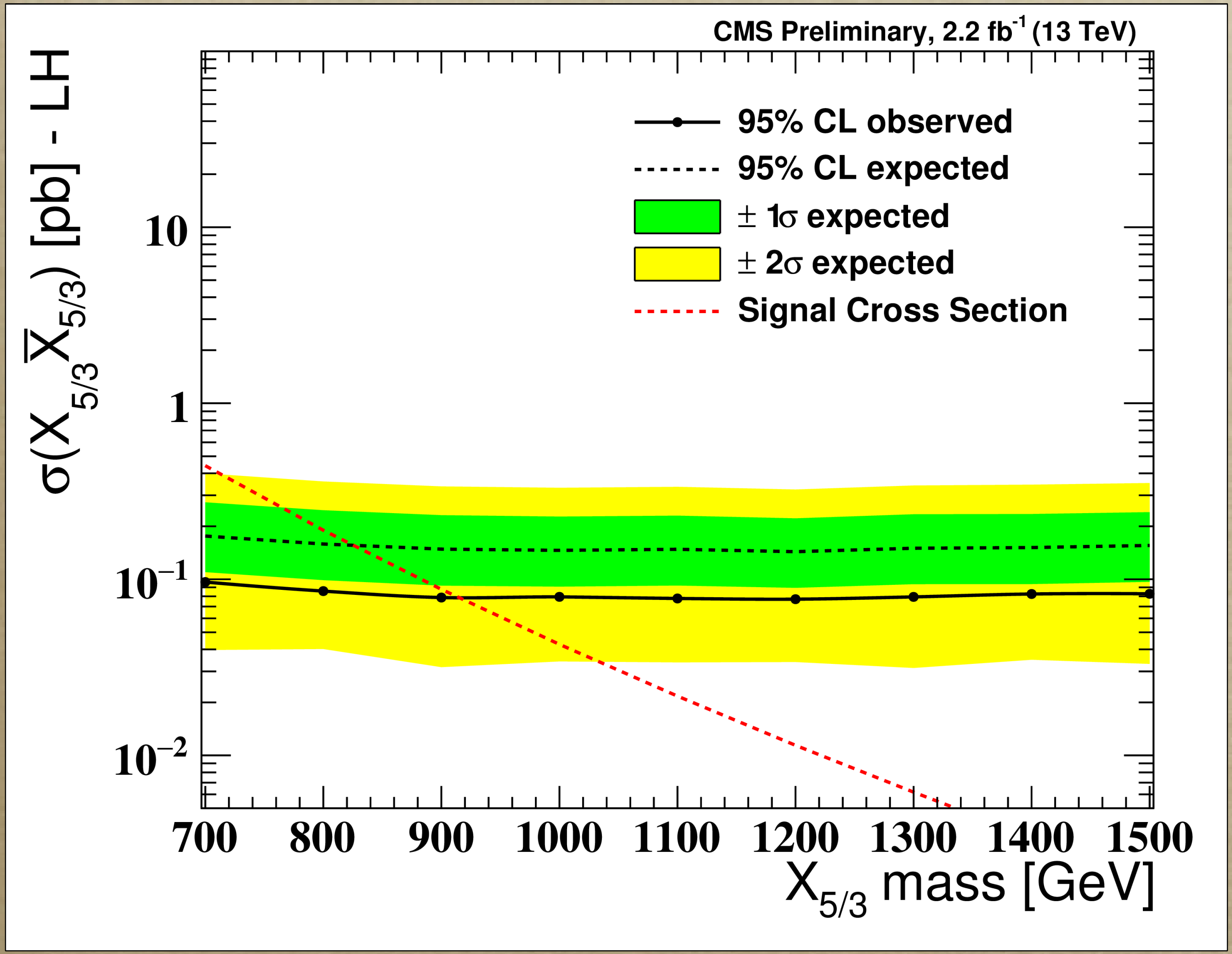
For $T_{5/3}$ pair production only : **$m(T_{5/3})$ < 0,99 TeV**

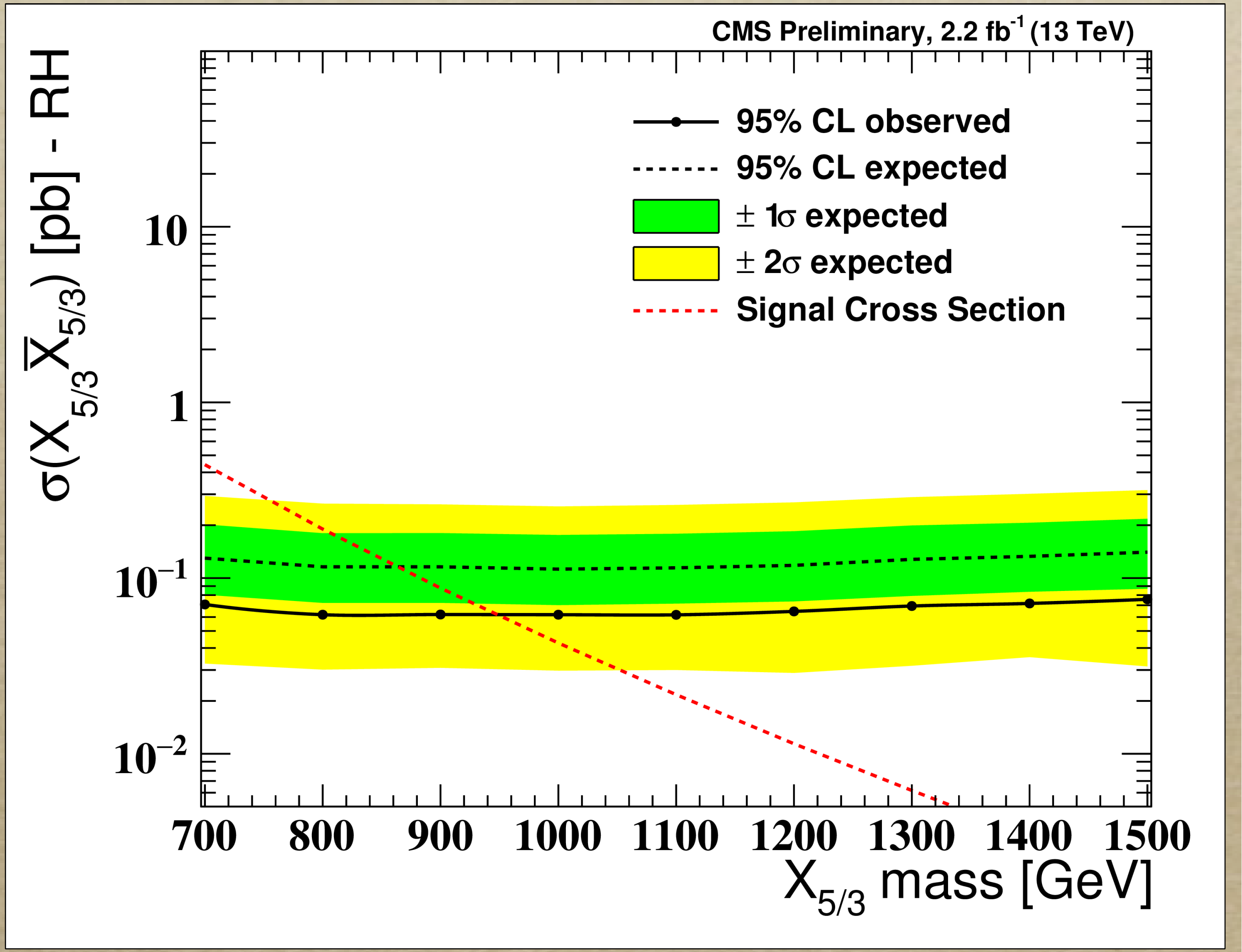
CMS analysis on $T_{5/3}$ production at 13 TeV

$\sqrt{s}$=13 TeV

CMS-PAS-B2G-15-006

With 2.2 fb^{-1}, observed limit in 2LSS for 2 chiralities of the $T_{5/3}$





For the T5/3 pair production : **m($T_{5/3}$) < 0,91 TeV** (LH) and **0,95 TeV** (RH)

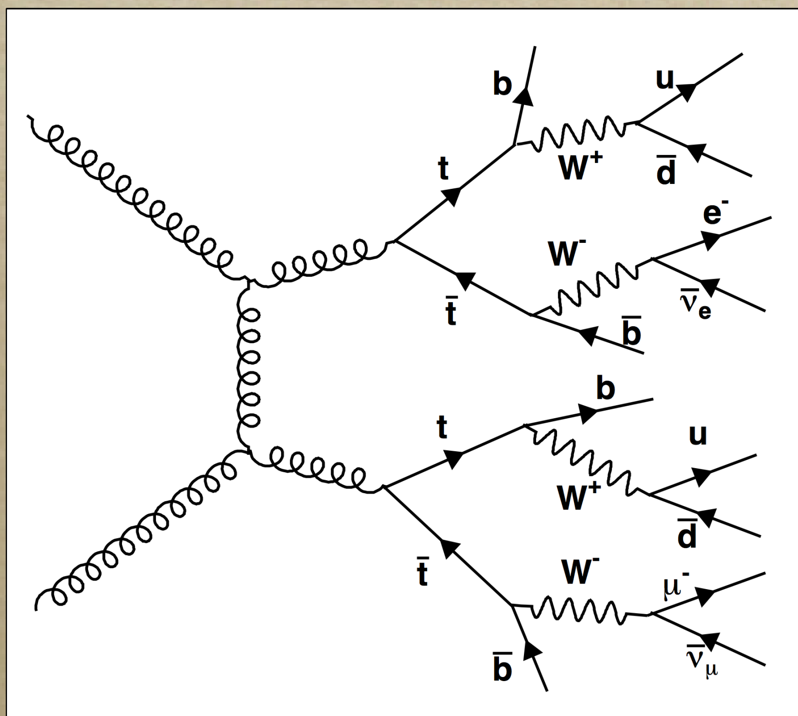
Combined with the 1 lepton channel :

m($T_{5/3}$) < 0,94 TeV (LH) and **0,96 TeV** (RH)

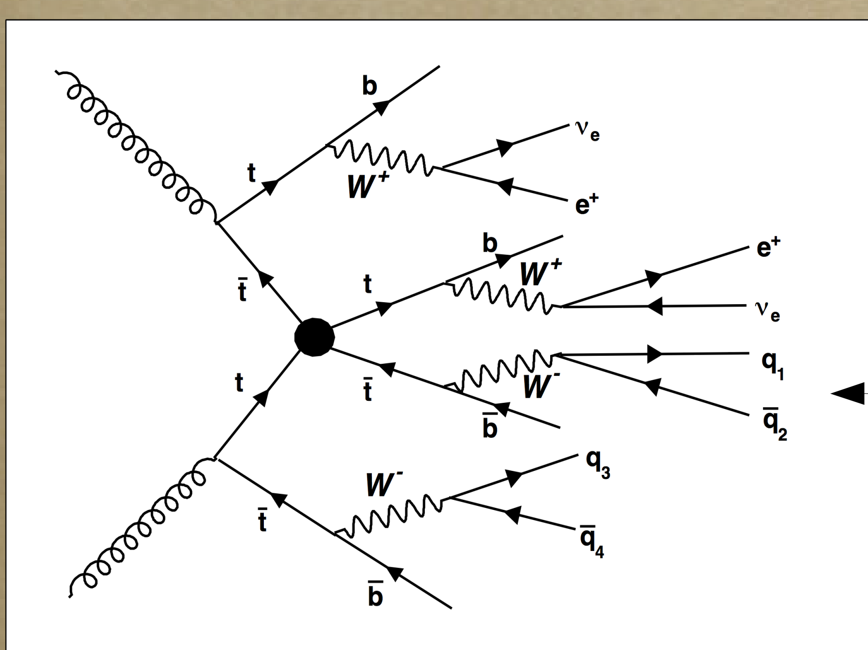
Prospects for future studies with 4 tops

Why are 4 tops events interesting ?

$\sqrt{s}$=14 TeV



Examples of new physics



Very rare SM process

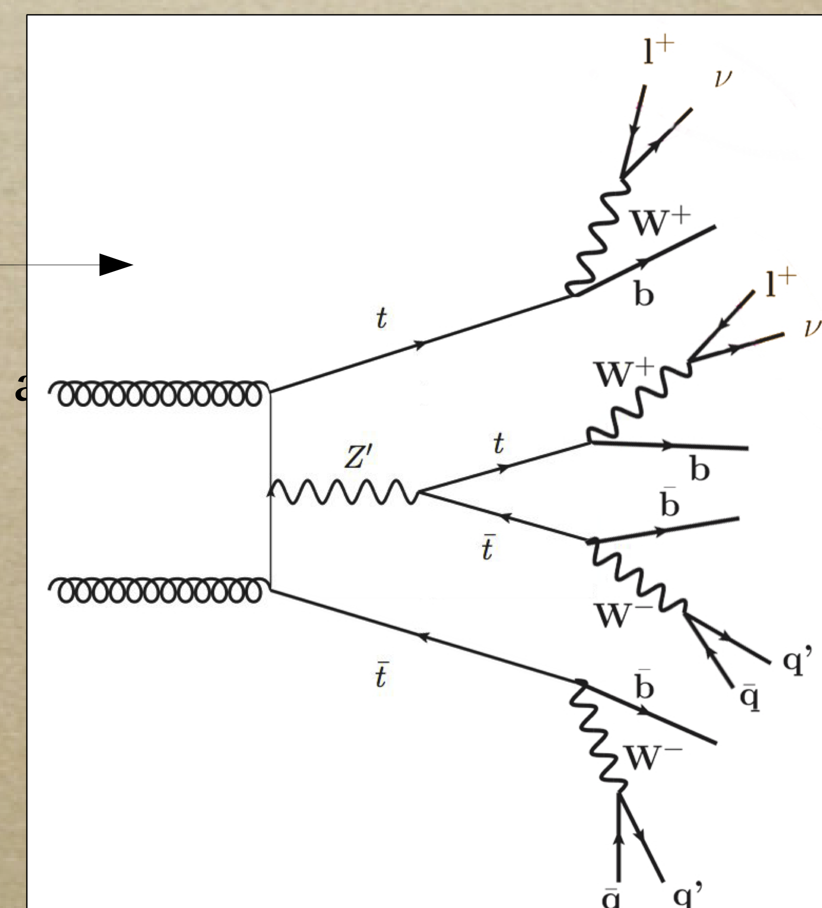
14 events produced (~90 % by gluon fusion) in 2012 dataset (8 TeV, σ=1 fb) vs 3.9 millions of $t\bar{t}$ pairs.

Cross-section of 15 fb at 14 TeV, very sensible to any new top-related physics.

Top-philic Z' resonance

BR($Z' \rightarrow t\bar{t}$) = 100 %

(σ~150 fb for a mass of 1 TeV and a coupling to t_R of g=3)



4 tops contact interaction

Effective theory

(σ~25 fb for an effective scale of 1 TeV)

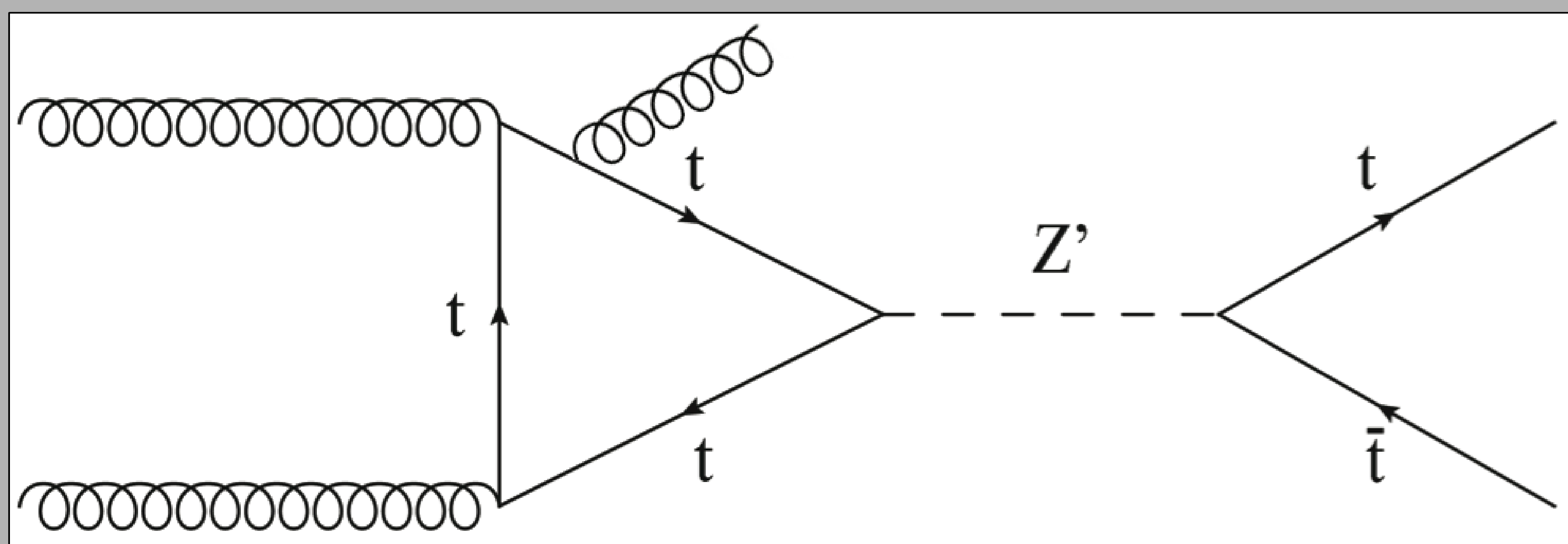
Why are 4 tops events interesting ?

$\sqrt{s}$=14 TeV

Very rare SM process

14 events produced (~90 % by gluon fusion) in 2012

Direct $t\bar{t}$ resonance could be possible via a top loop requiring an ISR to have an on-shell Z' (Landau-Yang).



This point is not totally clear : Heurtier 1509.05615v1 & Greiner 1410.6099
VS Maltoni 1306.6464 annex A

Following Maltoni : we consider this process negligible and focus on the only way to produce Z' : via 4 tops

(σ~25 fb for an effective scale of 1 TeV)

Phenomenology of $t\bar{t}t\bar{t}$ events

$\sqrt{s}$=14 TeV

Servant Kukla 2016. in prep.

Study of the discovery potential for 4 tops (SM/BSM) in different leptonic channels (1L, 2LOS, 2LSS, 3L) using cut & count selection at 14 TeV.

	Processus	σ_{incl} (fb)	
	$\sqrt{s}$	13 TeV	14 TeV
signals	SM $t\bar{t}t\bar{t}$	10.5	14
signals	Z'(1 TeV)	110	149.5
signals	Z'(2 TeV)	17.3	23.6
signals	Eff.(Λ =0.5TeV)	119.6	166.6
signals	Eff.(Λ =1TeV)	18.4	24.9
signals	Eff.(Λ =1.5TeV)	12.8	17
SM backgrounds	$t\bar{t}$	615k	731k
SM backgrounds	ttW	493	573
SM backgrounds	ttZ	630	765
SM backgrounds	ttH	452	547
SM backgrounds	tZq	771	651

MC generation with MadGraph for both signals and background + estimation of instrumental effects.

Dibosons (WW, WZ, ZZ, WH, ZH) not in the table because the ≥ 3 b cuts that we do in the following slides will suppress them

Phenomenological study : here, no ATLAS simulation

Phenomenology of $t\bar{t}t\bar{t}$ events

$\sqrt{s}$=14 TeV In the 2SSL and 3L channels, we will have misid and fakes contributions

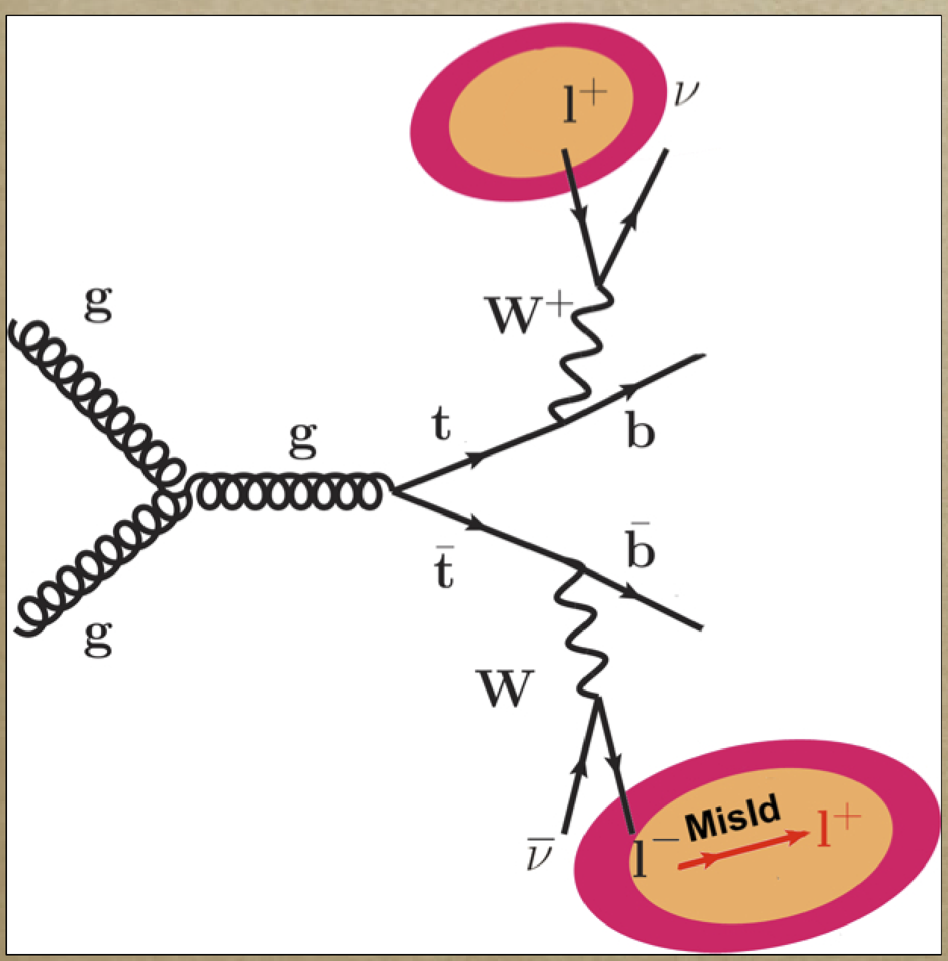
Electron's charge flip (neglected for μ).

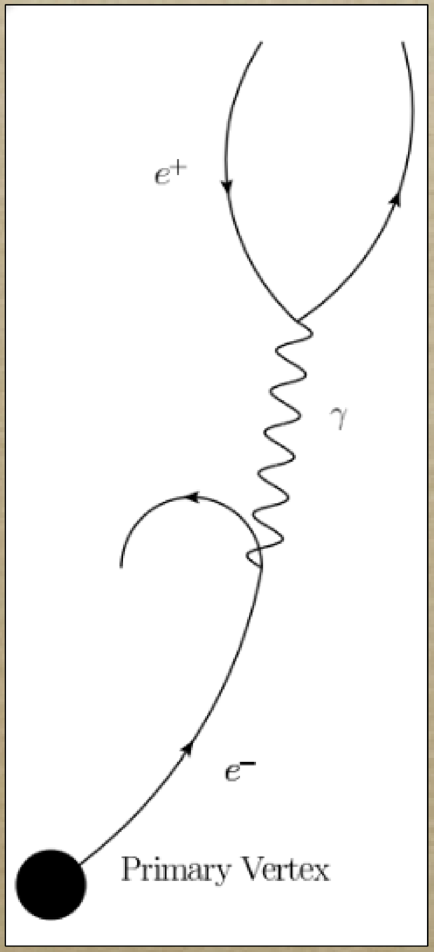
Fakes leptons not coming from a partonic W but from, f.eg, a B decay

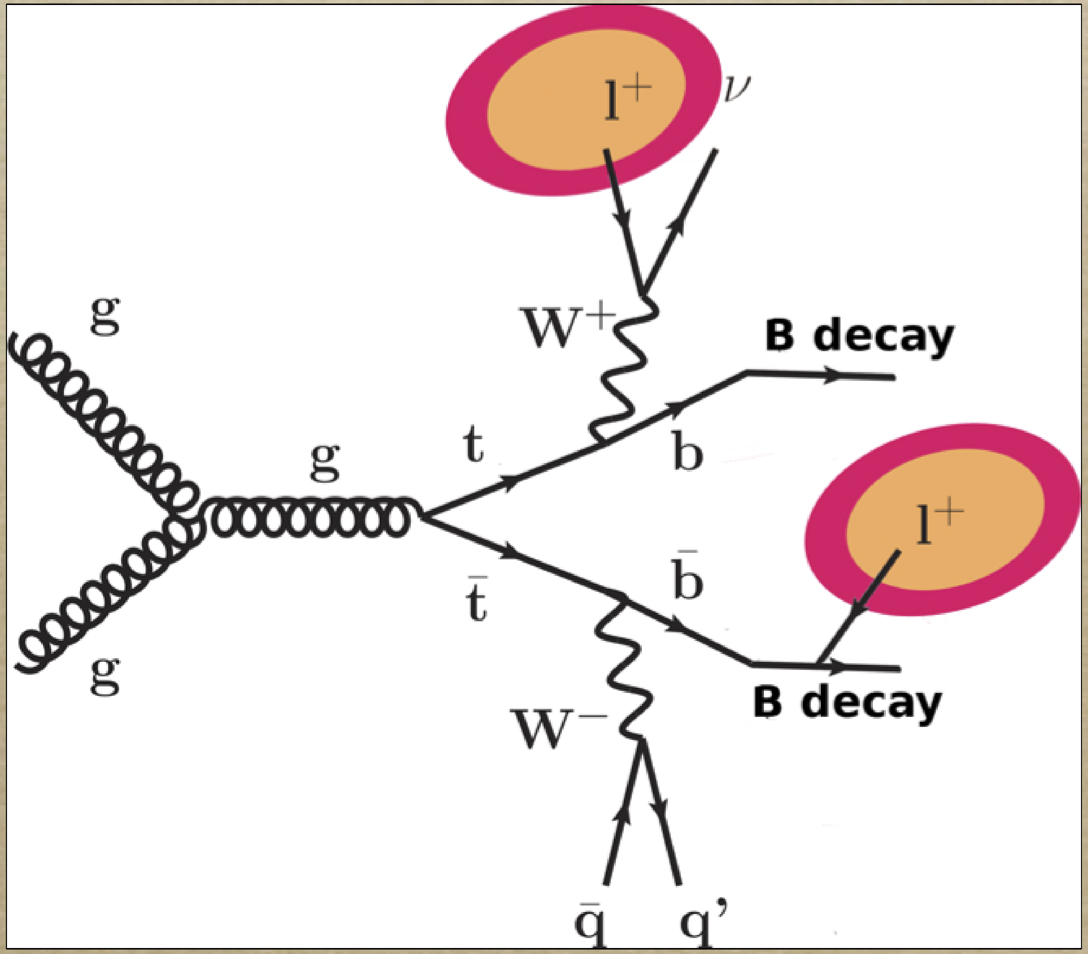
We can obtain a SS pair from these two processes

$t\bar{t}$ -> l^+l^- (2L OS)

$t\bar{t}$ -> l +jet





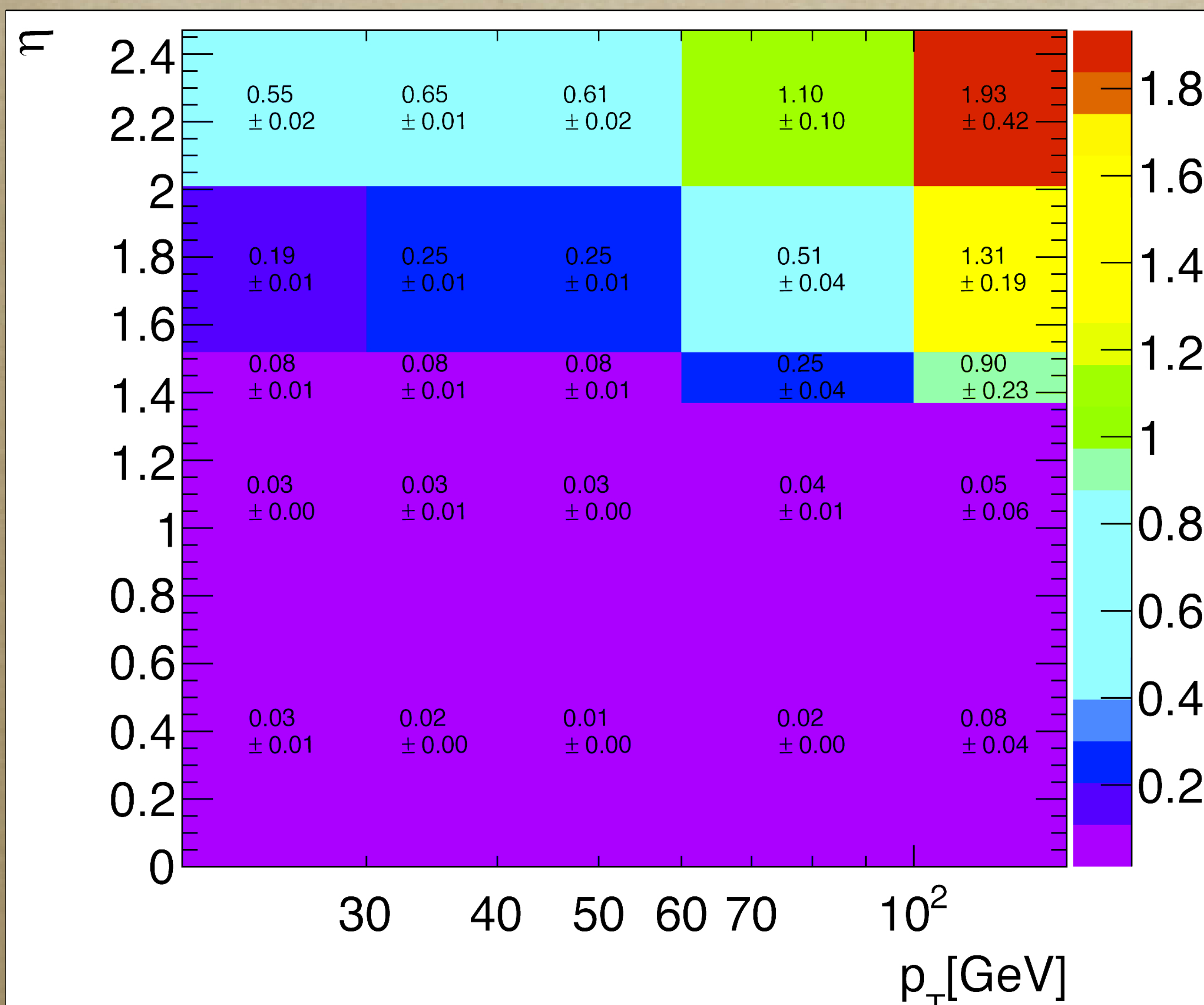


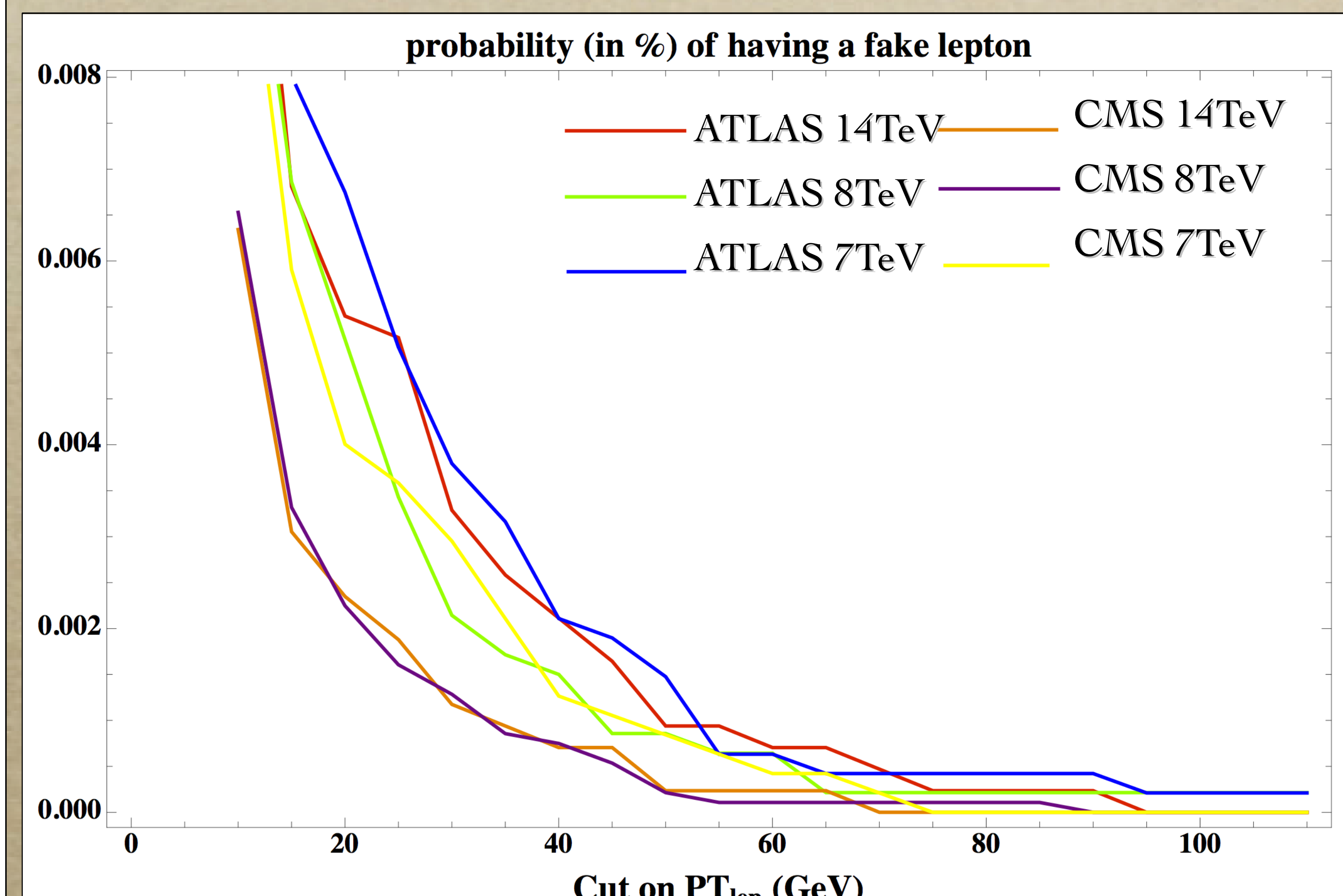
Phenomenology of $t\bar{t}t\bar{t}$ events

$\sqrt{s}$=14 TeV In the 2SSL and 3L channels, we will have misid and fakes contributions

Electron's charge flip (neglected for μ).
⟶ ATLAS public results

Fakes leptons not coming from a partonic W but from, f.eg, a B decay
⟶ DELPHES package uses a parametrized response of the ATLAS/CMS detectors.





Extracted in data (Z peak)

Applied to $t\bar{t}$ ⟶ 2 leptons (OS)

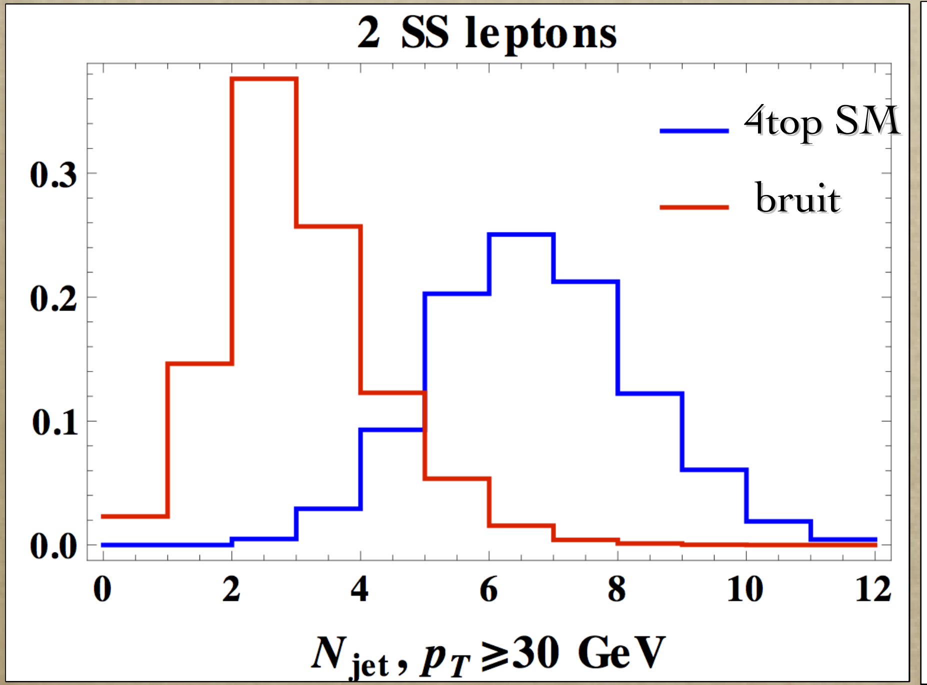
Computed on hadronic $t\bar{t}$.

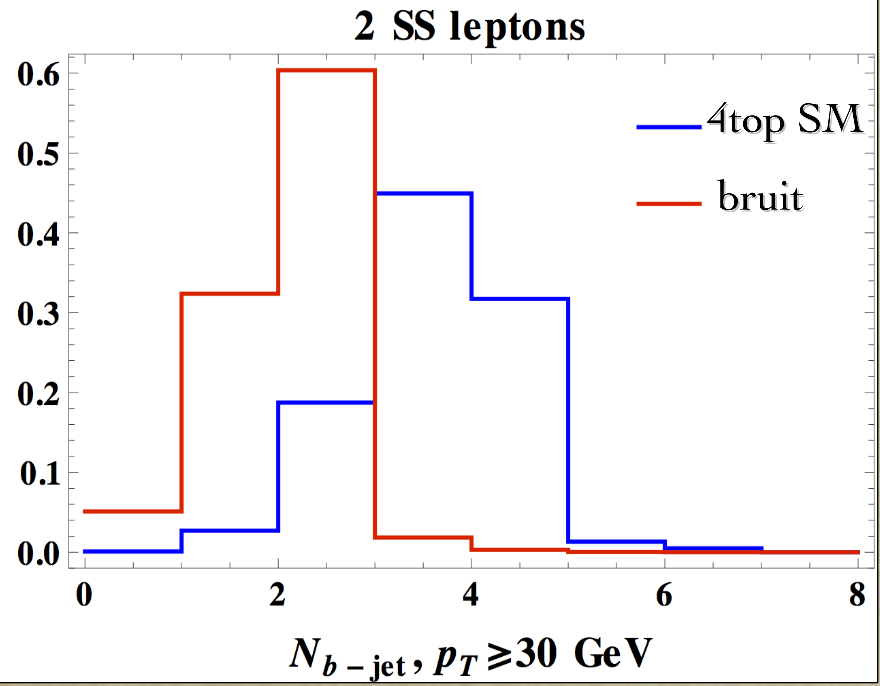
Applied to $t\bar{t}$ ⟶ 1 ou 2 leptons

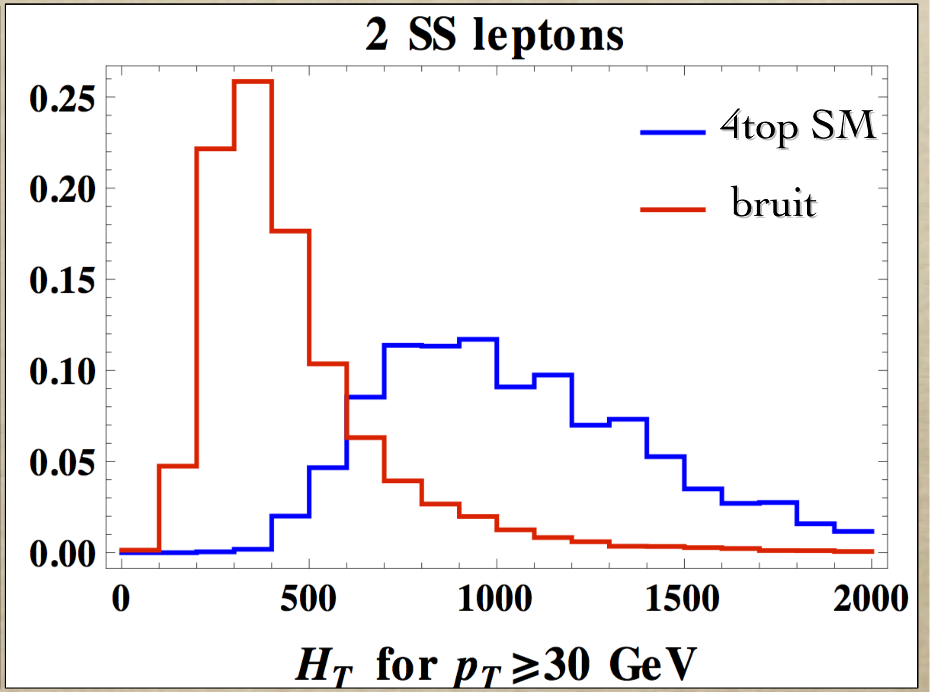
Phenomenology of $t\bar{t}t\bar{t}$ events

$\sqrt{s}$=14 TeV

The events are selected after optimized cuts on : jets/b-jets multiplicities, H_T (=$\sum p_T$)







		1 lepton	2 OS leptons	2 SS leptons	3 leptons	combinaison
	4 tops du Modèle Standard (nombres extrapolés à 100 fb^{-1})					
	N_{Signal}	60.7 ± 1.0	15.0 ± 0.2	7.3 ± 0.2	3.0 ± 0.1	-
	N_{Bruit}	6034.4 ± 392.6	512.5 ± 22.4	3.2 ± 0.8	3.4 ± 0.6	-
	σ	0.78	0.66	4.1	1.63	4.53
2σ	$\mathcal{L}_{obs}$ en fb^{-1}	655	908	23.9	150.7	20
5σ	$\mathcal{L}_d$ en fb^{-1}	4094	5677	150	942	122

Results for SM 4 tops at 14 TeV

2SSL is the most sensitive channel with a 5σ sensitivity dès 150-200 fb^{-1}.

Phenomenology of $t\bar{t}t\bar{t}$ events

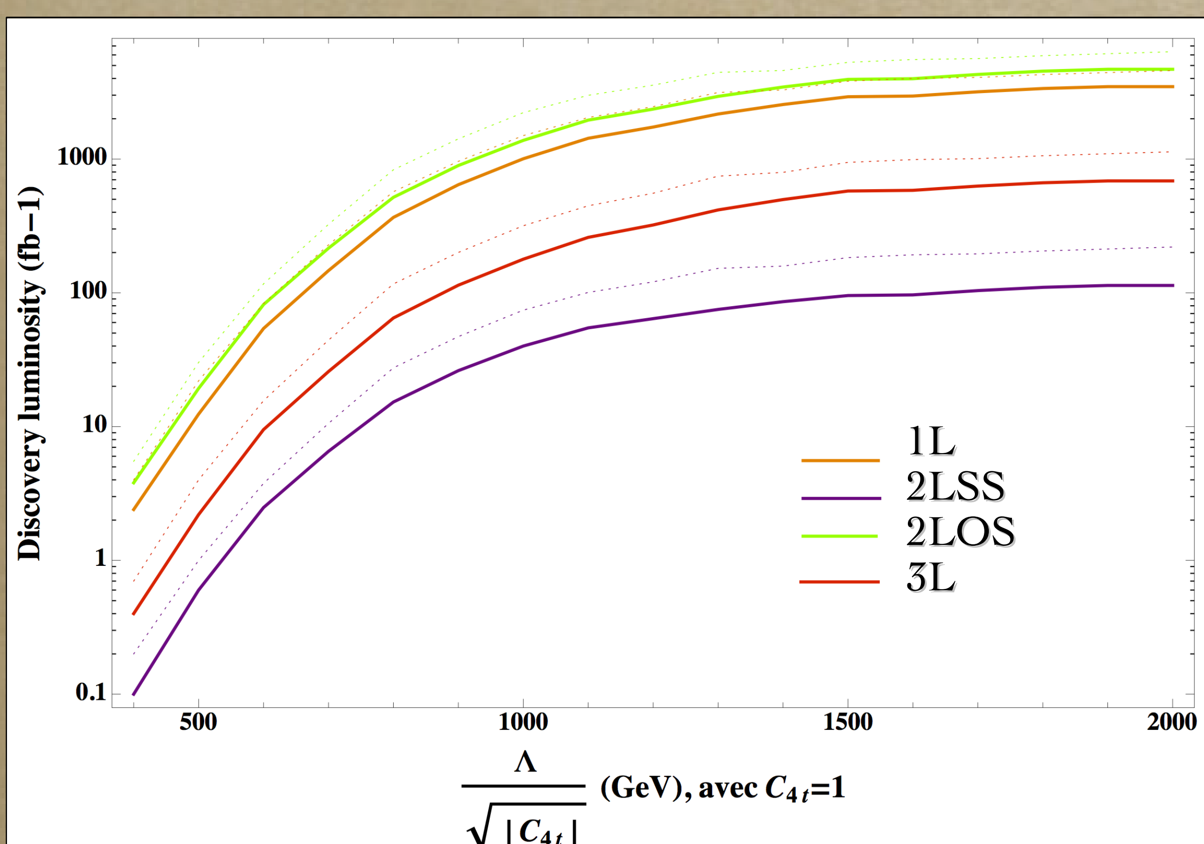
$\sqrt{s}$=14 TeV

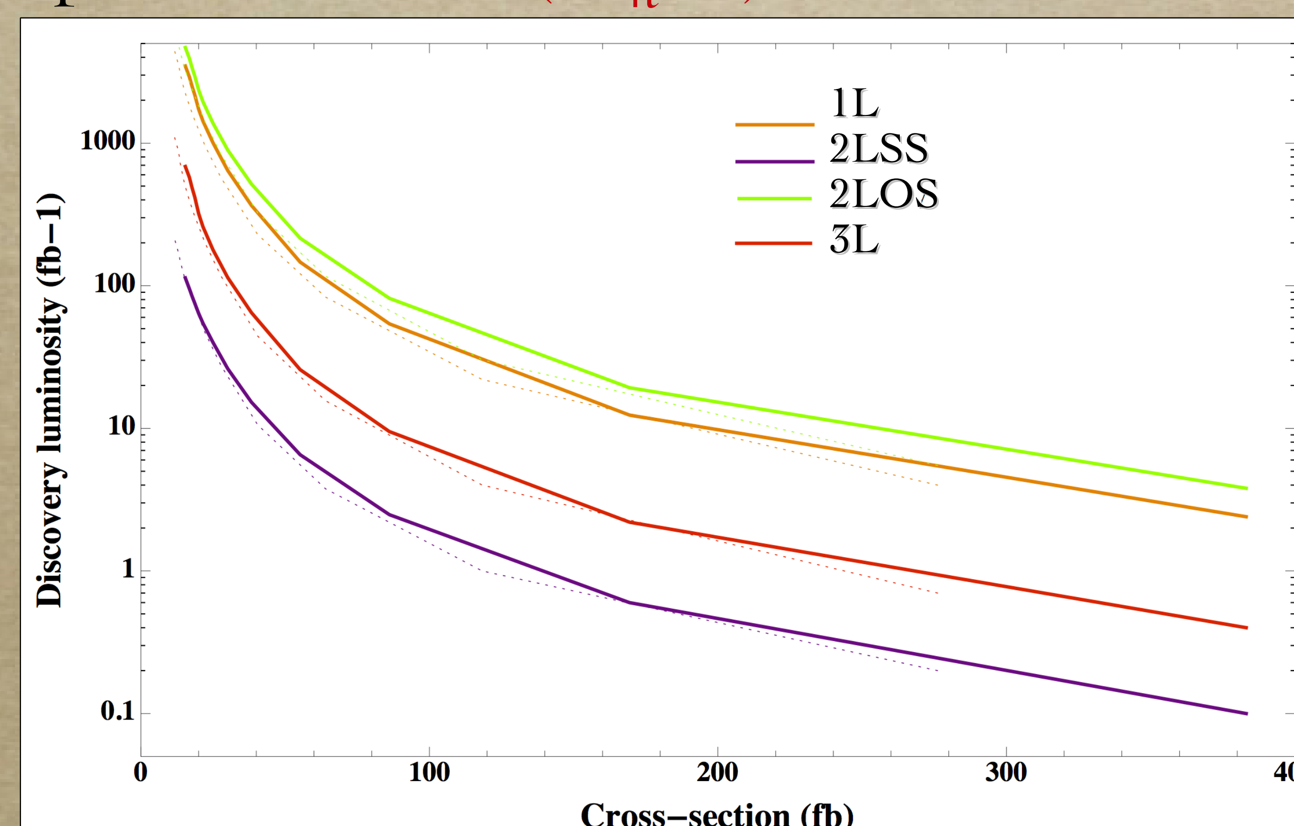
For BSM contributions :

Z' (1-2 TeV, g=3) can be seen with 40 fb^{-1} at 14 TeV.

		1 lepton	2 OS leptons	2 SS leptons	3 leptons	combinaison
		Z' topophile M =1 TeV et M =2 TeV (nombres extrapolés à 100 fb^{-1})				
	N_{Signal}	652.6, 94.9	161.8, 24.9	92.9, 14.2	38.7, 4.4	-
		$\pm$ 12.9, $\pm$ 1.5	$\pm$ 4.1, $\pm$ 0.5	$\pm$ 3.1, $\pm$ 0.4	$\pm$ 1.4, $\pm$ 0.1	-
	N_{Bruit}	3388.0, 3388.0	340.9, 340.9	3.2, 3.2	2.9, 1.4	-
		$\pm$ 283.8, $\pm$ 283.8	$\pm$ 14.1, $\pm$ 14.1	$\pm$ 0.8, $\pm$ 0.8	$\pm$ 0.5, $\pm$ 0.3	-
	σ	11.2, 1.63	8.76, 1.35	52, 7.95	22.8, 3.7	58.5, 9
2σ	$\mathcal{L}_{obs}$ en fb^{-1}	3.2, 150.5	5.2, 220	0.15, 6.3	0.77, 29.1	0.1, 5
5σ	$\mathcal{L}_{d}$ en fb^{-1}	19.9, 940	32.5, 1375	0.9, 39.7	4.8, 182	0.73, 31

The effective theory up to Λ =1.5 TeV ($|C_{4t}|$=1)

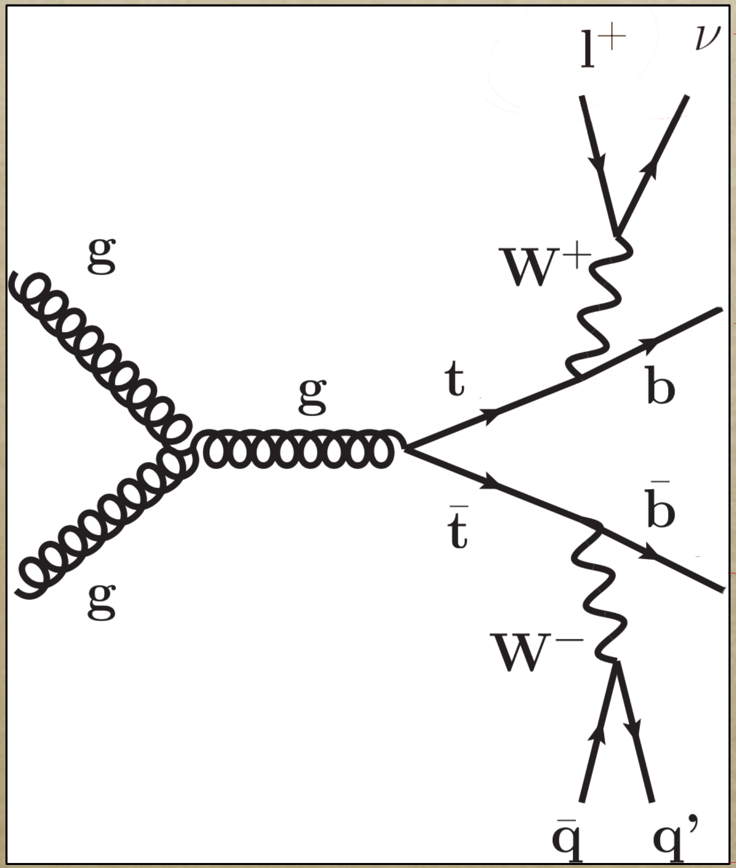




Top quark reconstruction in the 1 lep channel

√s=14 TeV

This final states allows us to reconstruct the leptonic top to study its polarization



Leptonic top :

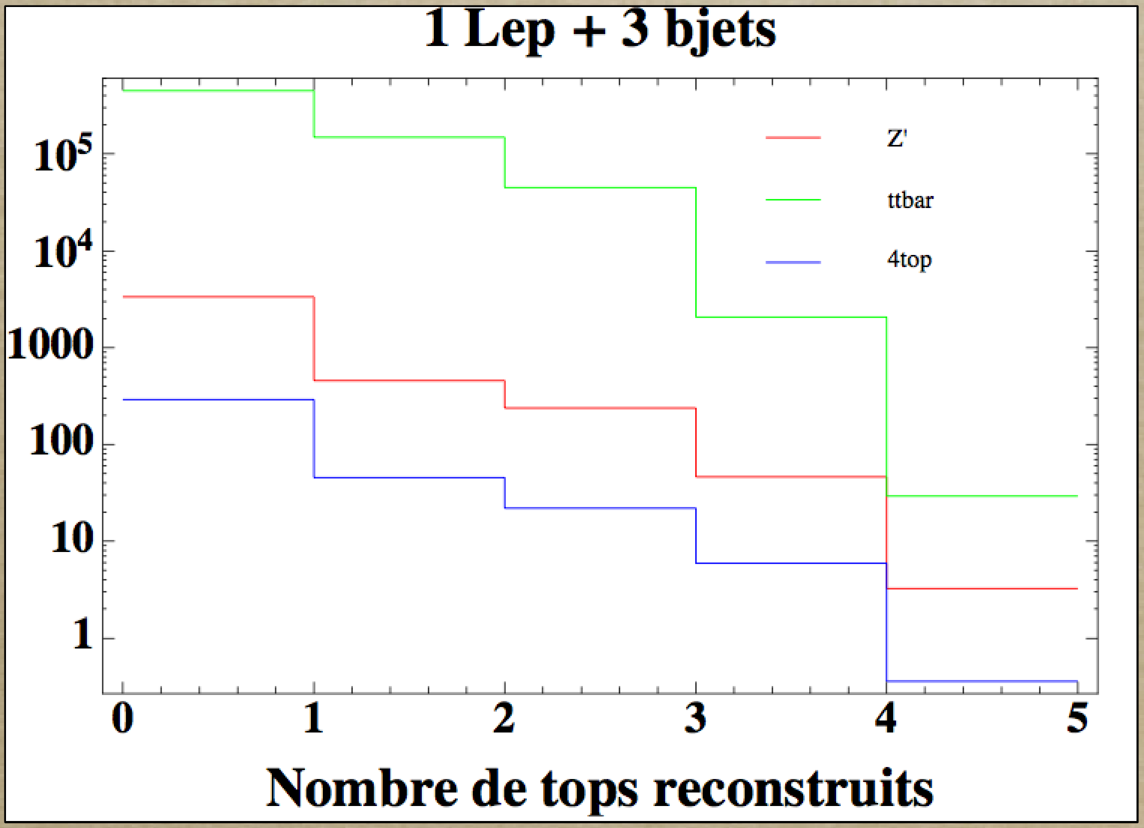
W = MET + lepton such that |m(W reco) – 80|<20

Top = reco W + b which minimizes |m(top reco) – 173|

Hadronic top :

W = MET + 2 jets such that |m(W reco) – 80|<20

Top = reco W + b which minimizes |m(top reco) – 173|



Expect to have only 4tops samples for at least 3 reconstructed tops but the jets combinatory gives ttbar events.

Top quark polarization in the 1 lep channel

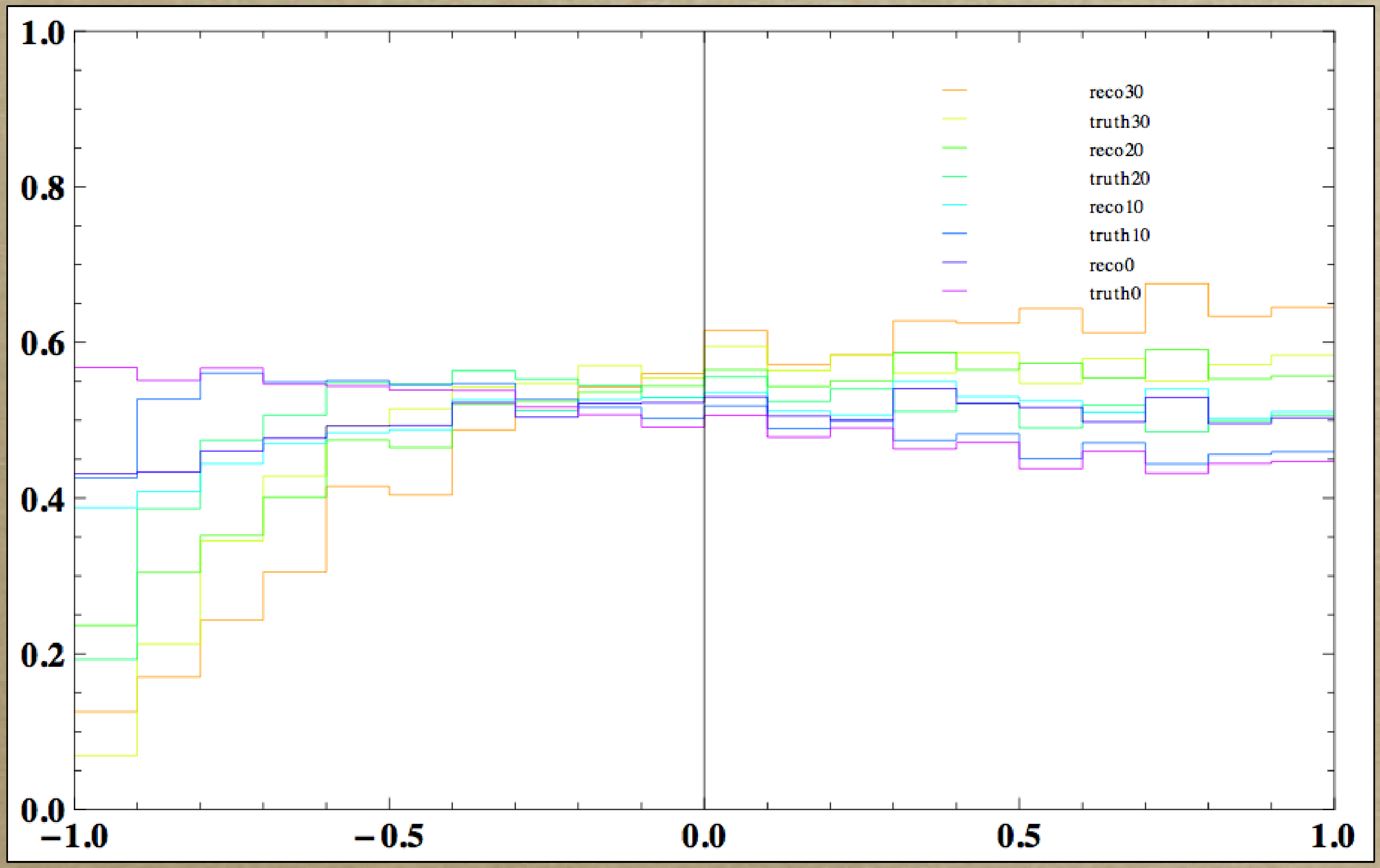
$\sqrt{s}$=14 TeV

Pomarol Serra 0806.3247

Let's consider the leptonic quark.
In the SM, both chiralities are produced, while for Z', only the top right is considered $\longrightarrow$ should see it in the polarization distribution

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta_{lep}} = \frac{1}{2} + (A - \frac{1}{2})\alpha_{lep}\cos\theta_{lep}$$

cosθ is the angle (in the top rest frame) between the top and its leptonic decay product, where α~1. The A constant is expected to be 0.5 for the SM.



For ttbar :

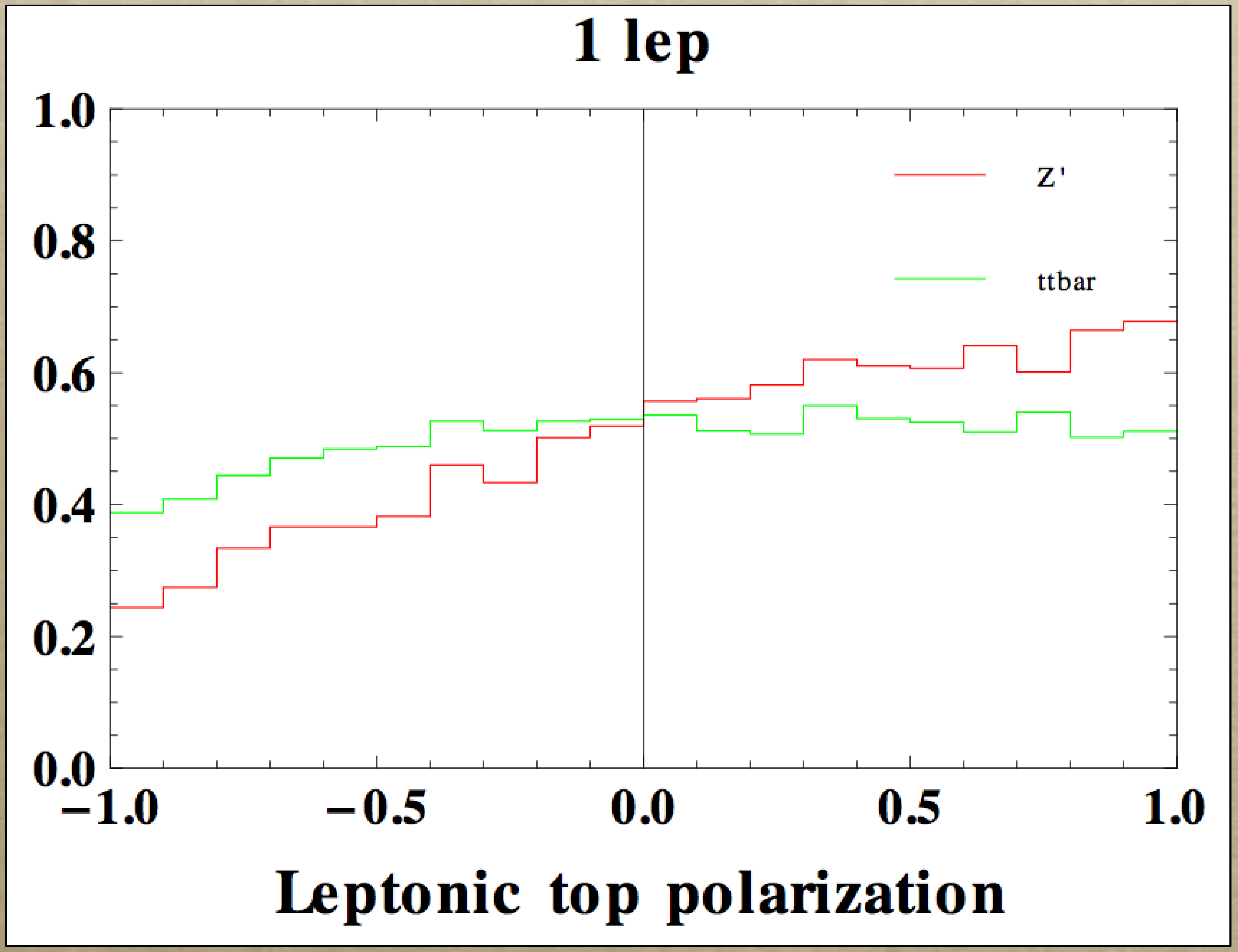
- the p_T cut has an effect on the (flat) shape
- the shape is similar between partonic top and reconstructed top $\longrightarrow$ reco algorithm works

Top quark polarization in the 1 lep channel (2)

$\sqrt{s}$=14 TeV

Pomarol Serra 0806.3247

Using only reconstructed top for both the background and the Z'(1 TeV) we have



p_T cut	$t\bar{t}$	Z' (1 TeV)
5	0.52	0.70
10	0.53	0.72
15	0.55	0.75
20	0.57	0.80
25	0.70	0.84
30	0.75	0.89

A values for different cuts (linear fit)
Compatible with theoretical prediction

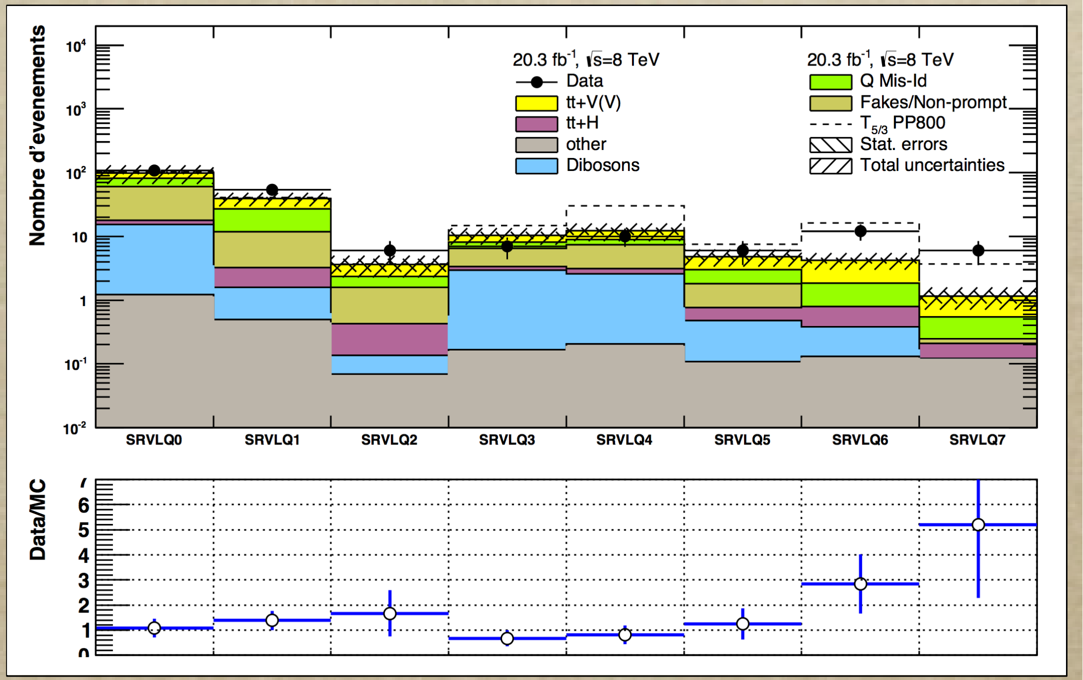
This observable can be used to probe BSM contribution in four tops events

Conclusion

Conclusion I

▶ Study of new physics in the top sector : composite models

▶ 8 TeV analysis with 20.3 fb^{-1} in the 2 same-sign leptons + 3 leptons : excess observed

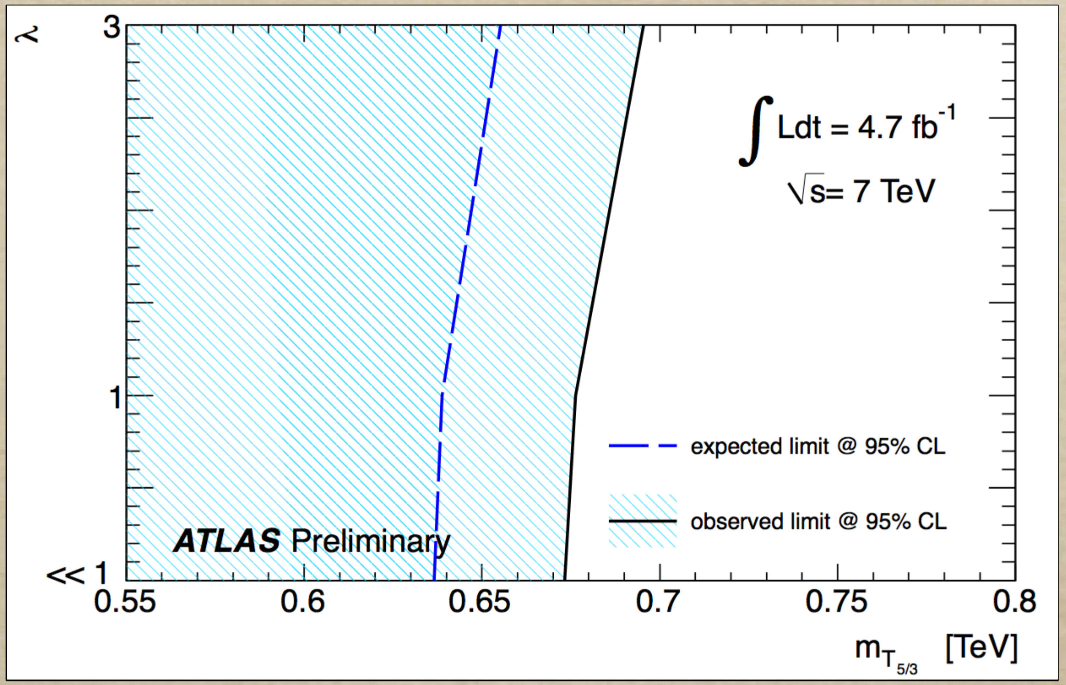


Conclusion I

▶ Study of new physics in the top sector : composite models

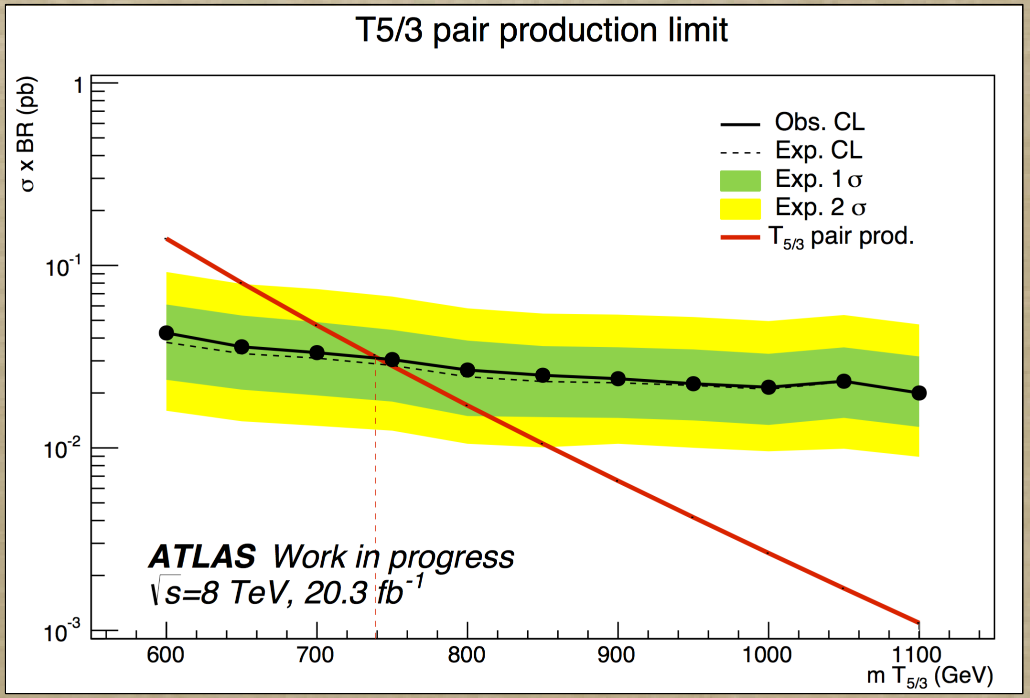
▶ 8 TeV analysis with 20.3 fb^{-1} in the 2 same-sign leptons + 3 leptons : excess observed

▶ Constraint put on the mass of the top partner $T_{5/3}$ at 8 TeV : 745 GeV.
Improves the 7 TeV existing limit, which was ~680 GeV.



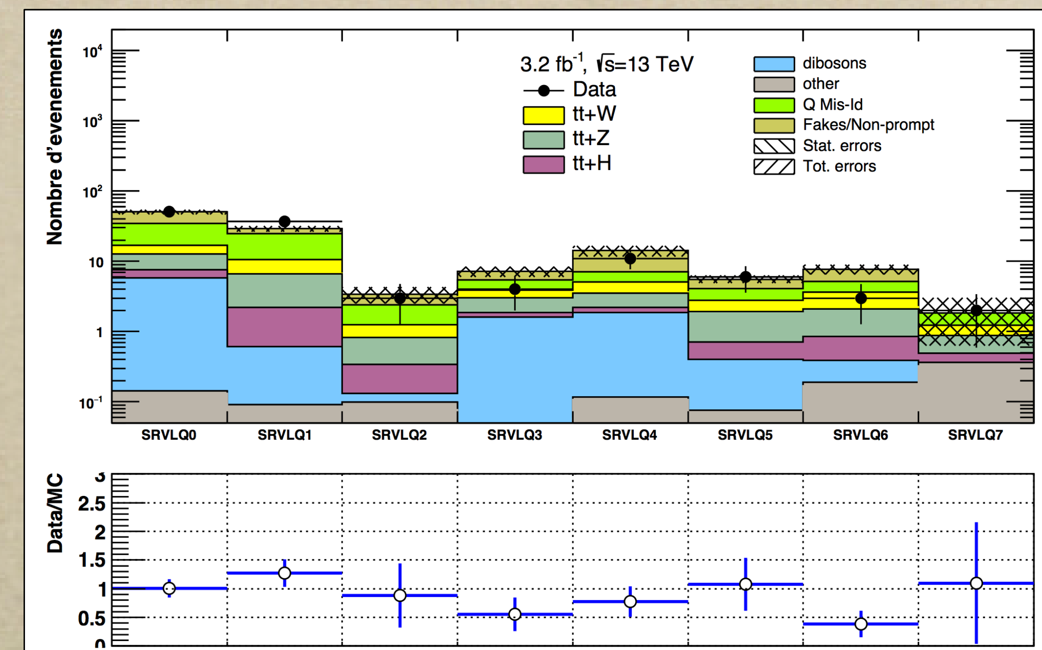
Limite at 7 TeV (2011) ~ 680 GeV

Limite at 8 TeV (2012) ~ 745 GeV

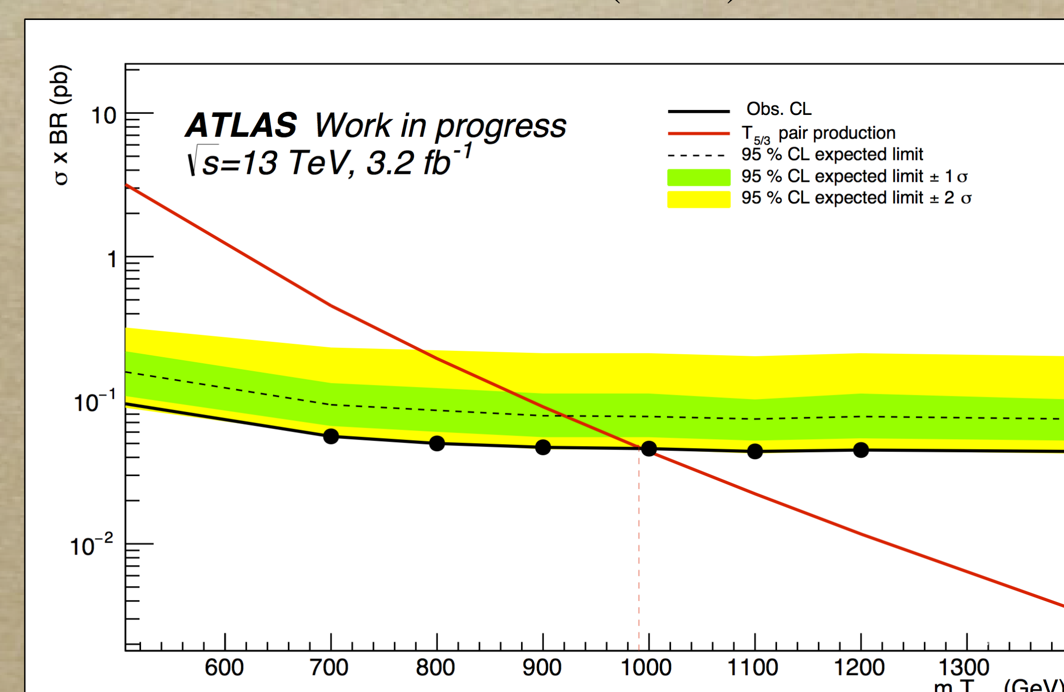


Outlook

▶ Using 3.2 fb^{-1} of 13 TeV data, new analysis in the 2SSL+3L channel. No excess observed, top partners masses below 990 GeV are excluded at 95 % C.L.



Limite à 13 TeV (2015) ~ 990 GeV

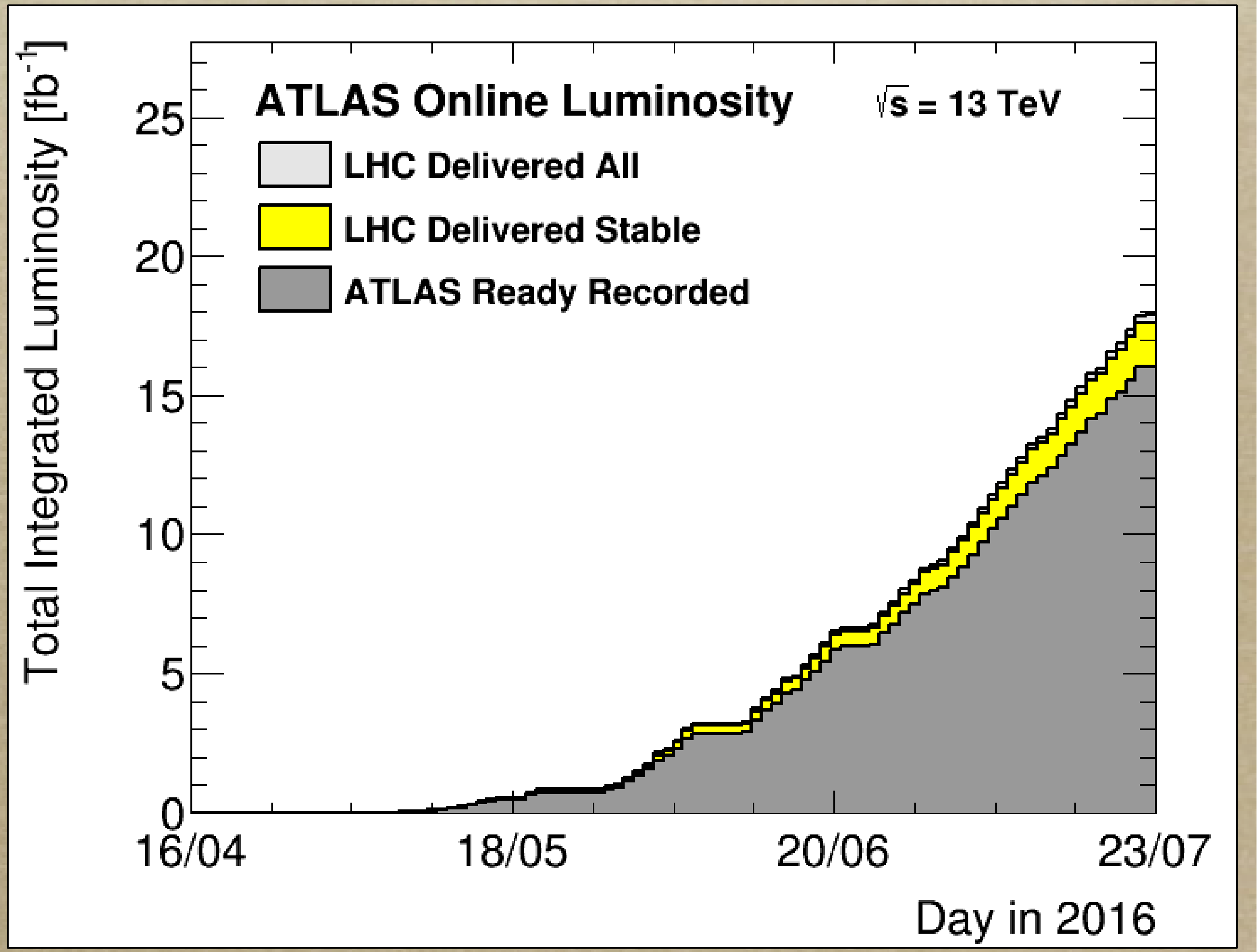


Perspectives

▶ Using 3.2 fb^{-1} of 13 TeV data, new analysis in the 2SSL+3L channel. No excess observed, top partners masses below 990 GeV are excluded at 95 % C.L.

▶ For 35 fb^{-1} of 2016 data, the limit will increase to 1.2 TeV.

New analysis started with ~15 fb^{-1}



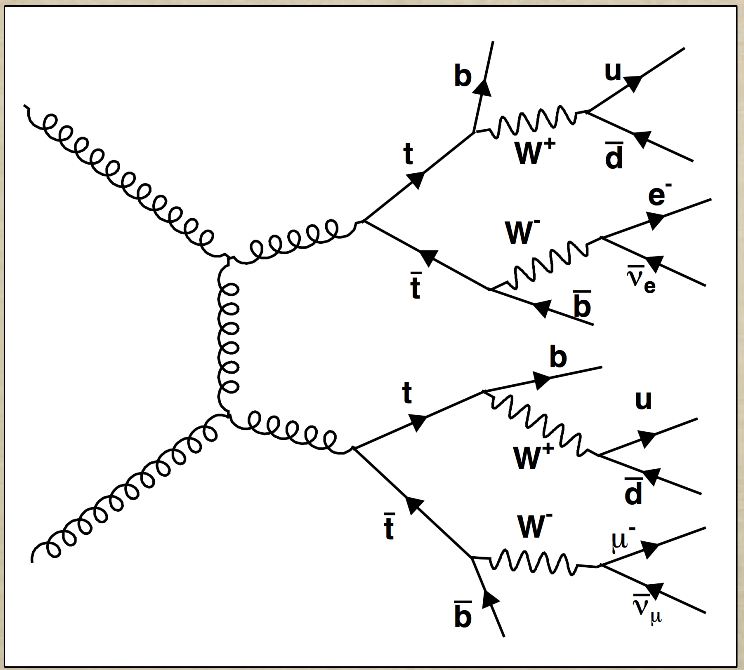
Perspectives

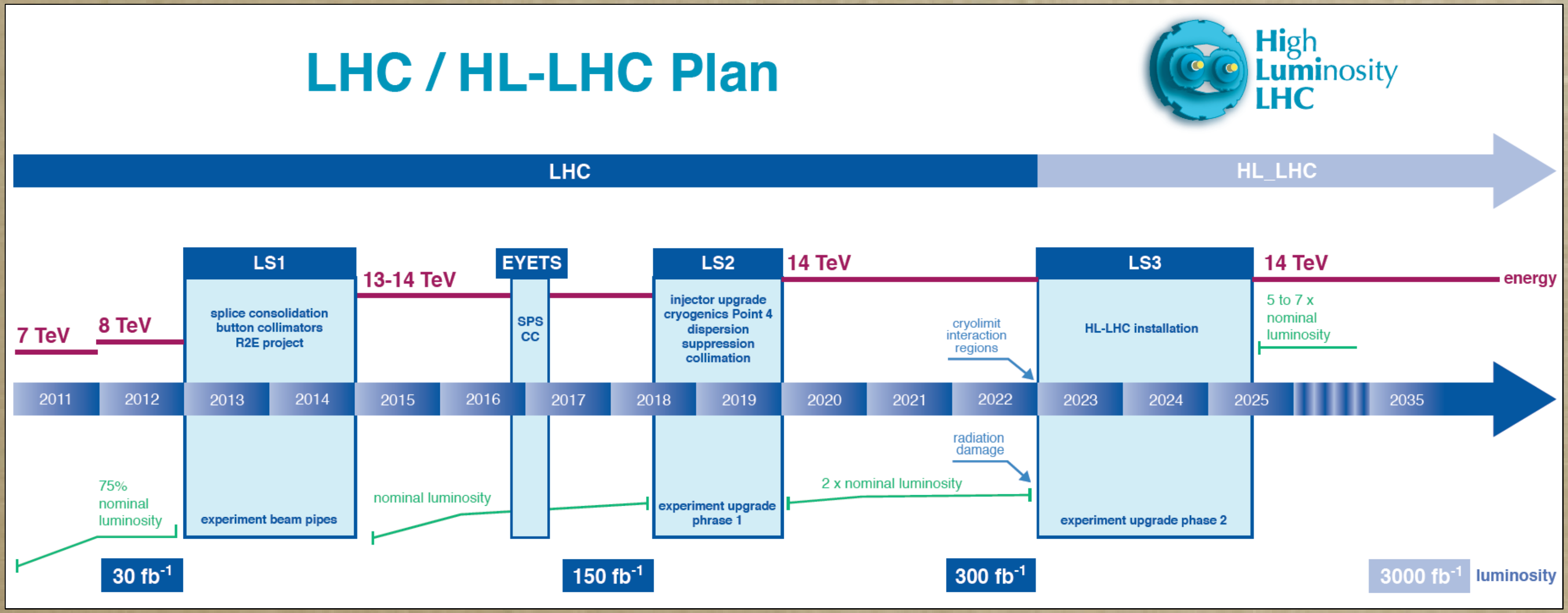
▶ Using 3.2 fb^{-1} of 13 TeV data, new analysis in the 2SSL+3L channel. No excess observed, top partners masses below 990 GeV are excluded at 95 % C.L.

▶ For 35 fb^{-1} of 2016 data, the limit will increase to 1.2 TeV.

New analysis started with ~15 fb^{-1}

▶ At 14 TeV, discovery potential of 4 tops SM in 2SSL at 150 fb^{-1} + possibility to explore BSM models up to ~1.5/2 TeV.





Backup

Échantillons signal 8 TeV

Masse (GeV)	Generateur	PDF	Section efficace [fb]	Nombre événements
Production de paires (NLO)				
600	MG5+PYTHIA6	CTEQ6L1	174,0	100 000
650	MG5+PYTHIA6	CTEQ6L1	99,6	99 999
700	MG5+PYTHIA6	CTEQ6L1	58,3	100 000
750	MG5+PYTHIA6	CTEQ6L1	34,9	100 000
800	MG5+PYTHIA6	CTEQ6L1	21,2	100 000
850	MG5+PYTHIA6	CTEQ6L1	13,1	100 000
900	MG5+PYTHIA6	CTEQ6L1	8,19	100 000
950	MG5+PYTHIA6	CTEQ6L1	5,17	99 999
1000	MG5+PYTHIA6	CTEQ6L1	3,29	100 000
Production simple $\lambda = 1$ (LO)				
600	MG5+PYTHIA6	CTEQ6L1	21,7	100 000
650	MG5+PYTHIA6	CTEQ6L1	14,7	99 999
700	MG5+PYTHIA6	CTEQ6L1	10,1	100 000
750	MG5+PYTHIA6	CTEQ6L1	7,1	100 000
800	MG5+PYTHIA6	CTEQ6L1	5,0	100 000
850	MG5+PYTHIA6	CTEQ6L1	3,6	99 000
900	MG5+PYTHIA6	CTEQ6L1	2,6	100 000
950	MG5+PYTHIA6	CTEQ6L1	1,9	100 000
1000	MG5+PYTHIA6	CTEQ6L1	1,4	100 000

Masse (GeV)	$n_b = 1$, $\not{E}_T \geq 40$ GeV, $400 \leq H_T \leq 700$ GeV	$n_b = 1$, $\not{E}_T \geq 100$ GeV, $H_T \geq 700$ GeV	$n_b = 2$, $\not{E}_T \geq 100$ GeV, $H_T \geq 700$ GeV	$n_b \geq 3$, $\not{E}_T \geq 100$ GeV, $H_T \geq 700$ GeV
Production de paires (NLO)				
600	0.471 ± 0.02	1.321 ± 0.036	0.793 ± 0.025	0.209 ± 0.013
800	0.186 ± 0.013	1.797 ± 0.042	1.18 ± 0.031	0.244 ± 0.014
1000	0.072 ± 0.008	2.116 ± 0.046	1.283 ± 0.032	0.206 ± 0.012
Production simple $\lambda = 1$ (LO)				
600	4.57 ± 0.171	11.006 ± 0.298	6.647 ± 0.209	1.748 ± 0.111
800	1.403 ± 0.093	7.895 ± 0.179	5.052 ± 0.131	1.032 ± 0.059
1000	0.624 ± 0.027	5.578 ± 0.111	3.393 ± 0.077	0.541 ± 0.03

Échantillons bruit 8 TeV

Processus	Générateur	PDF	Section efficace [pb]	K facteur	$\mathcal{L}$ (fb^{-1})	Simulation détecteur	LO NLO
			$t\bar{t}$+boson(s)				
$t\bar{t}W$	MG+PYTH.	CTEQ6L1	0.104	1.17	3284	Geant4	LO
$t\bar{t}W$j excl.	MG+PYTH.	CTEQ6L1	0.053	1.17	6404	Geant4	LO
$t\bar{t}W$jj incl.	MG+PYTH.	CTEQ6L1	0.041	1.17	8237	Geant4	LO
$t\bar{t}Z$	MG+PYTH.	CTEQ6L1	0.068	1.35	4377	Geant4	LO
$t\bar{t}Z$j excl.	MG+PYTH.	CTEQ6L1	0.045	1.35	6532	Geant4	LO
$t\bar{t}Z$jj incl.	MG+PYTH.	CTEQ6L1	0.040	1.35	7446	Geant4	LO
$t\bar{t}W^+W^-$	MG+PYTH.	MSTW2008	0.0022	1	91730	AltFast2	NLO
			$t\bar{t}H$				
$H \to W^+W^-$	Pythia	CTEQ6L1	0.0195	1.43	7014	Geant4	LO
$H \to ZZ$	PYTHIA 8	CTEQ6L1	0.0023	1.45	29300	Geant4	LO
$H \to \tau^+\tau^- \to \ell h$	Pythia 8	CTEQ6L1	0.0029	1.30	8051	Geant4	LO
			Diboson				
$W^\pm W^\pm \to \ell\nu\ell\nu$ EWK	SHERPA	CT10	0.028	0.84	4332	Geant4	LO
$W^\pm W^\pm \to \ell\nu\ell\nu$ QCD	SHERPA	CT10	0.016	1.04	6007	Geant4	LO
$WZ \to \ell\ell\ell\nu$ EWK	SHERPA	CT10	0.082	0.89	6809	Geant4	LO
$WZ \to \ell\ell\ell\nu$ QCD	SHERPA	CT10	2.34	1.27	672	Geant4	LO
$ZZ \to \ell\ell\ell\ell$ EWK	SHERPA	CT10	0.0069	1	27120	Geant4	NLO
$ZZ \to \ell\ell\ell\ell$ QCD	SHERPA	CT10	8.73	1.11	186	Geant4	LO

Échantillons bruit 8 TeV

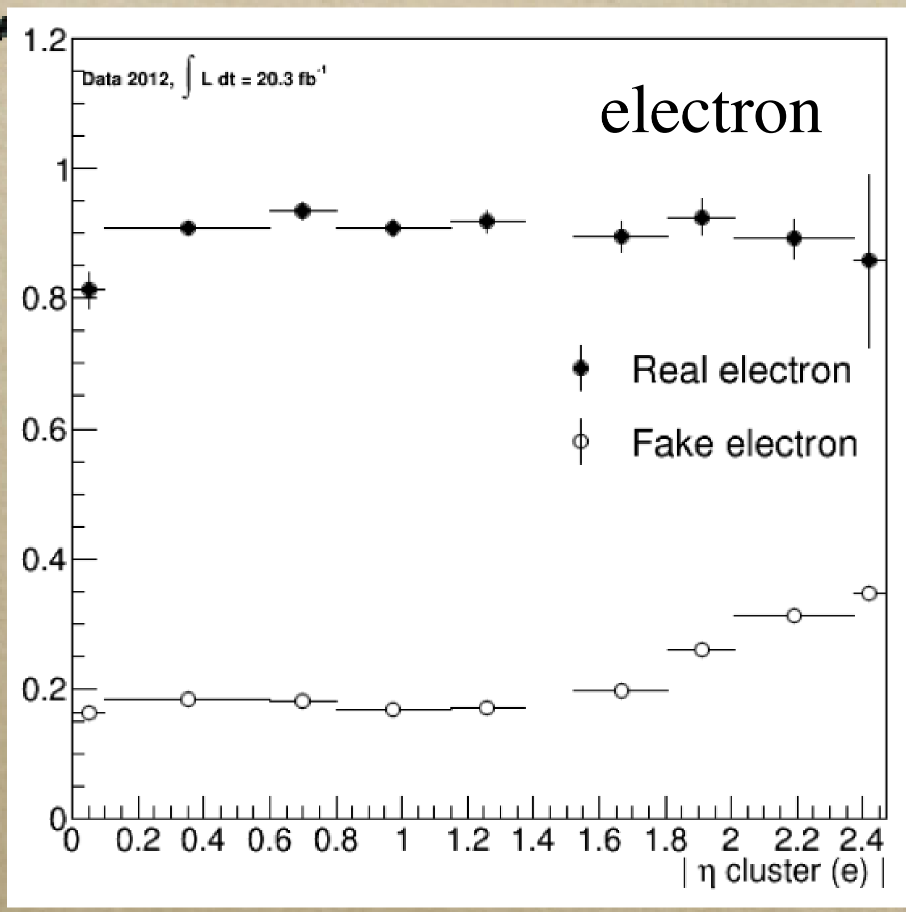
$W^{\pm}W^{\pm}$jj (DPI)							
DPI W+jet	Pythia 8	CTEQ6L1	0.0019	1	10310	Geant4	NLO
WH							
$H \to W^+W^- \to \ell\nu qq$	Pythia 8	CTEQ6L1	0.053	1.25	301	Geant4	LO
$H \to W^+W^- \to \ell\nu\ell\nu$	Pythia 8	CTEQ6L1	0.012	1.32	1213	Geant4	LO
$H \to \tau^+\tau^- \to \ell h$	Pythia 8	CTEQ6L1	0.018	1.18	24060	Geant4	LO
ZH							
$H \to W^+W^- \to \ell\nu qq$	Pythia 8	CTEQ6L1	0.028	1.38	5623	Geant4	LO
$H \to W^+W^- \to \ell\nu\ell\nu$	Pythia 8	CTEQ6L1	0.0068	1.43	2058	Geant4	LO
Triboson							
$WWW^* \to \ell\nu\ell\nu\ell\nu$	MG+Pyth.	CTEQ6L1	0.0051	1	9811	Geant4	NLO
$ZWW^* \to \ell\ell\ell\nu\ell\nu$	MG+Pyth.	CTEQ6L1	0.0016	1	32160	Geant4	NLO
tWZ							
$Z \to \ell\ell$	MG+Pyth.	CTEQ6L1	0.0041	1	24211	Geant4	NLO
tH							
$H \to WW$	MG+Pyth.	CT10	0.00366	1	273596	Geant4	NLO
$H \to ZZ$	MG+Pyth.	CT10	0.00981	1	1113855	Geant4	NLO
$H \to \tau\tau$	MG+Pyth.	CT10	0.000449	1	465374	Geant4	NLO

Choix des efficacités en fonction du trigger

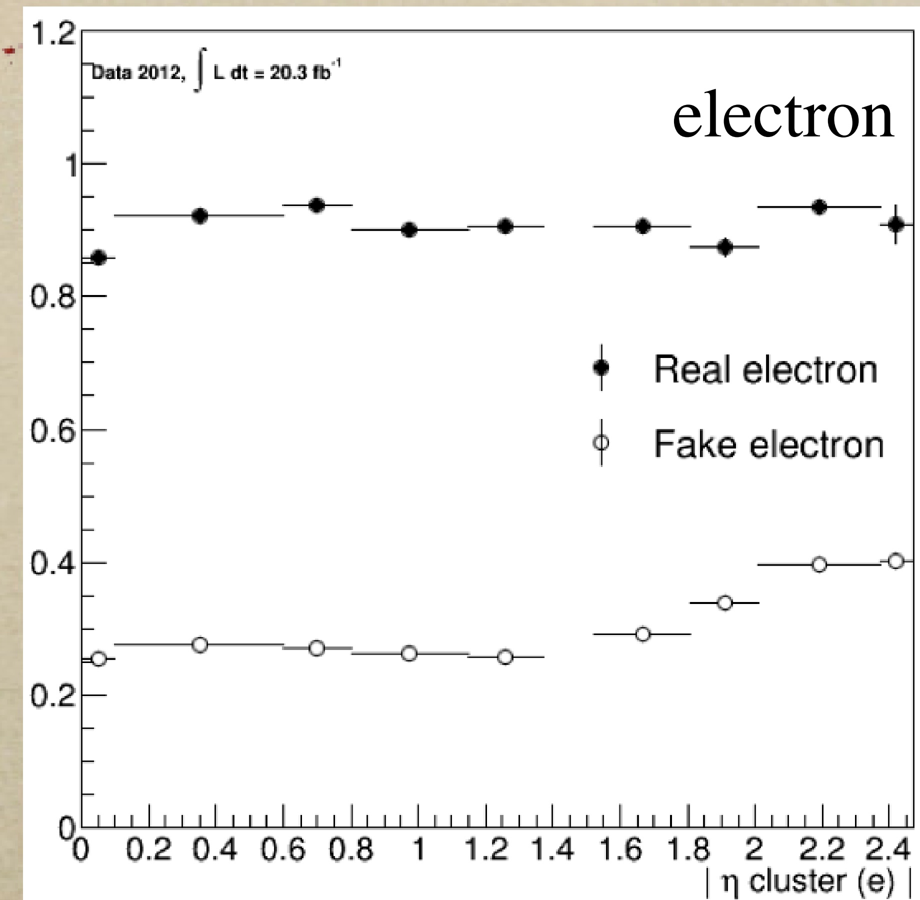
Le trigger à haut p_T correspond-il à un lepton ?	Rang du lepton parmi ceux qui ont déclenché	p_T du lepton	Probabilités appliquées
Oui, ≥ 1	N'importe	Haut p_T	Haut p_T non biaisé
Oui, ≥ 1	N'importe	Bas p_T	Bas p_T non biaisé
Non, 0	Premier	N'importe	Bas p_T biaisé
Non, 0	Suivant	Haut p_T	Haut p_T non biaisé
Non, 0	Suivant	Bas p_T	Bas p_T non biaisé

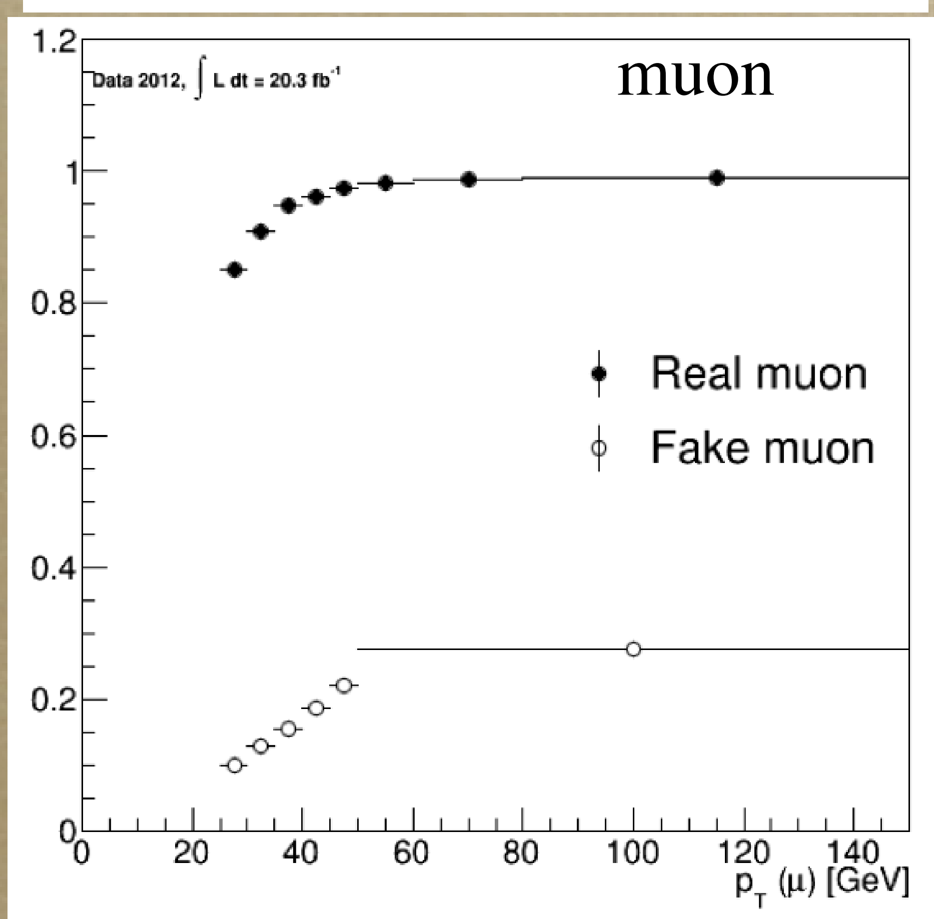
Rappel :
- trigger électron : (isolé et $p_T > 24$ GeV) ou ($p_T > 60$ GeV)
- trigger muon : (isolé et $p_T > 24$ GeV) ou ($p_T > 36$ GeV)

Effet de l'isolation sur les efficacités

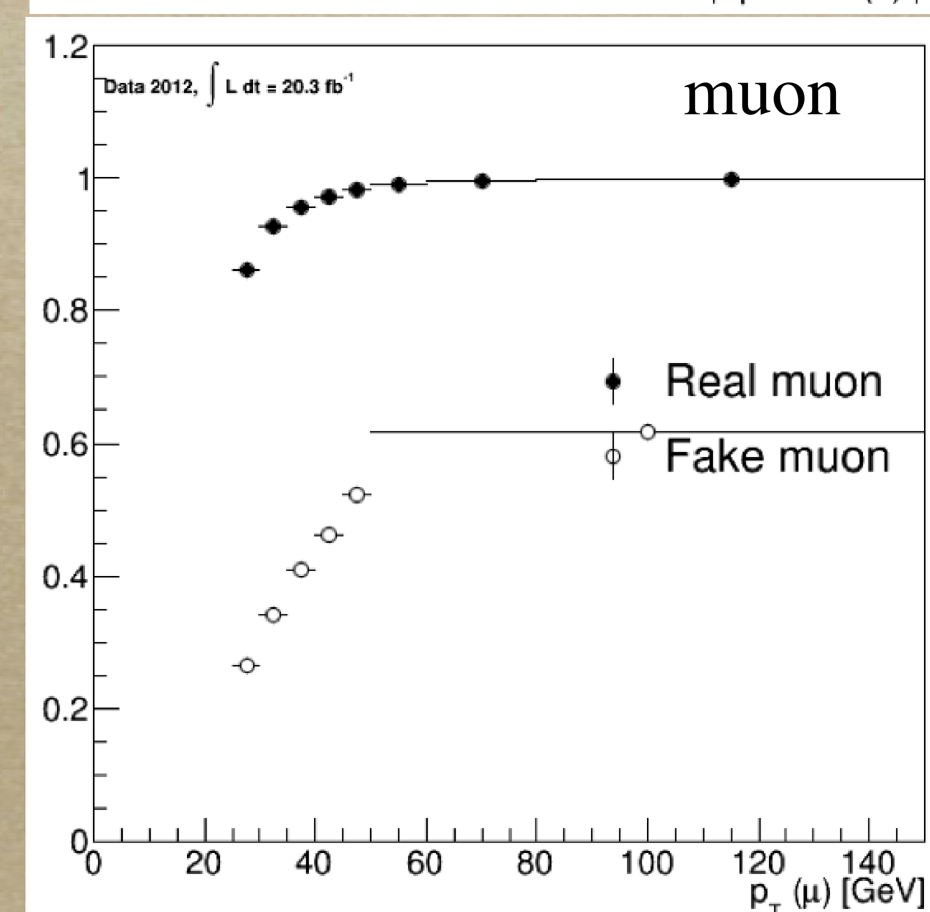


+ isolation





+ isolation



Mauvaise reconstruction de la charge

Connaissant la probabilité d'une erreur de charge pour 2 électrons

$$P(\epsilon_i\epsilon_j|N_{SS}^{ij}, N_{ij}) = \frac{[N^{ij}(\epsilon_i+\epsilon_j)]^{N_{SS}^{ij}} e^{-N^{ij}(\epsilon_i+\epsilon_j)}}{N_{SS}^{ij}!}$$

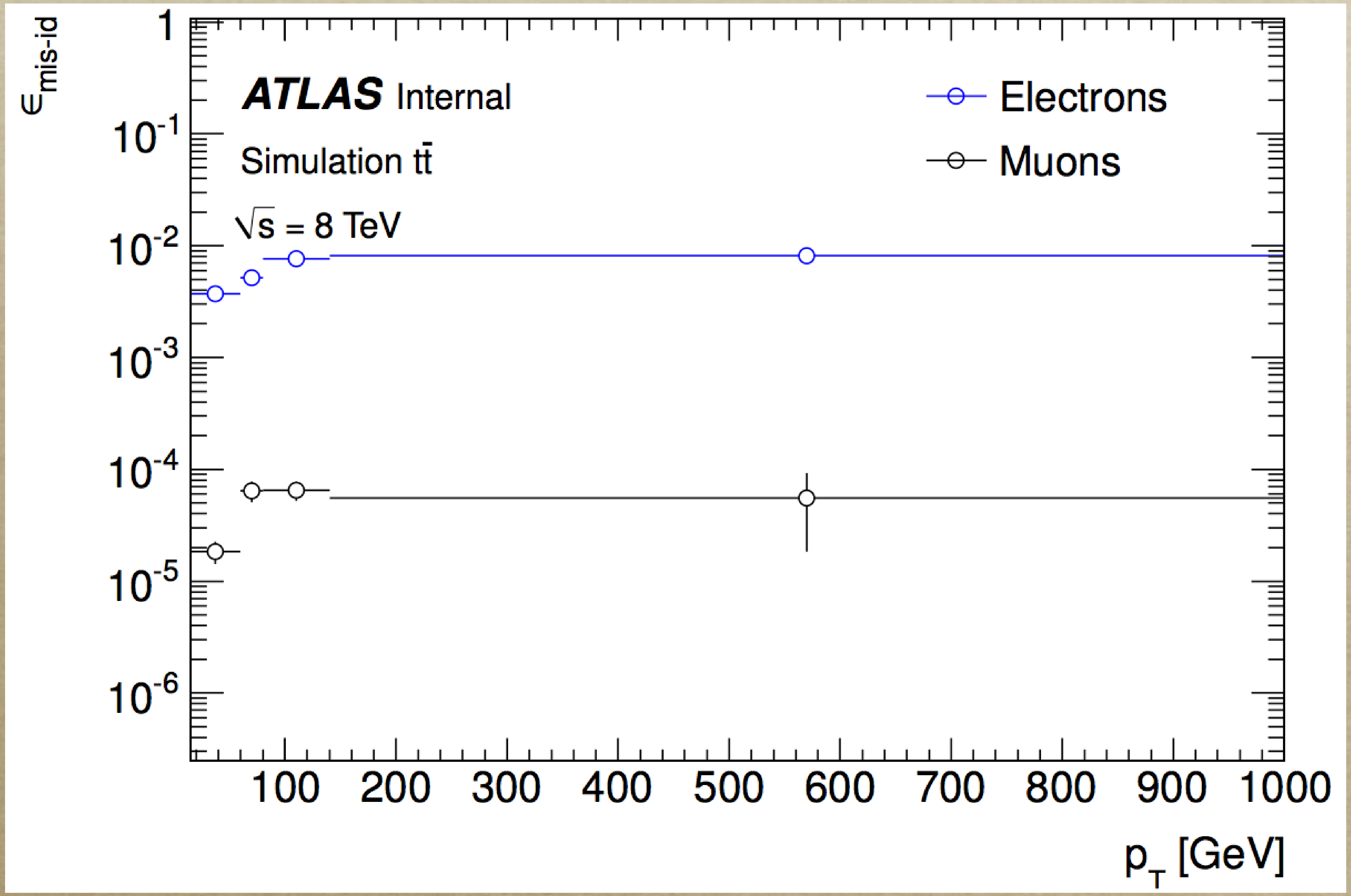
Il suffit de minimiser :

$$-ln\prod P(\epsilon_i\epsilon_j) \approx \sum N_{SS}^{ij} \times ln[N^{ij}(\epsilon_i+\epsilon_j)] - N^{ij}(\epsilon_i+\epsilon_j)$$

À haut pT, un facteur correctif provenant d'un MC de paires de tops

$$\alpha_{t\bar{t}}(\eta, p_T) = \frac{\epsilon_{t\bar{t}}(\eta, p_T)}{\epsilon_{t\bar{t}}(\eta, p_T \in [80, 100]GeV)}$$

Mauvaise reconstruction de la charge des muons



Liste des événements de l'excès à 8 TeV

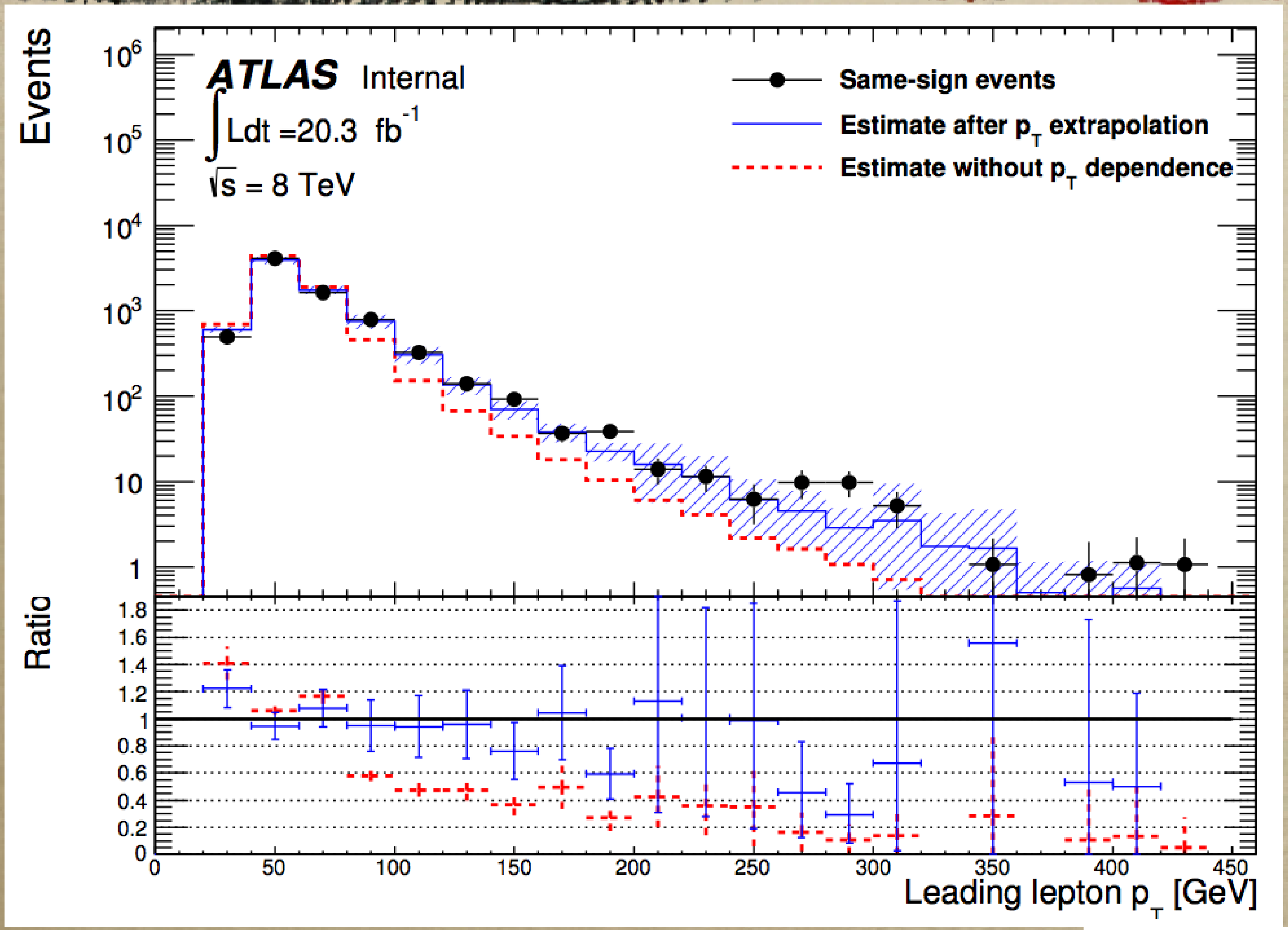
Table 110: List of data events in the SR4t3/VLQ6 category (by definition, all events have exactly two b-jets, the $E_{\mathrm{T}}^{\mathrm{miss}}$ is above 100 GeV and the H_{T} above 700 GeV).

Run	Event	Type	N_{jets}	H_{T} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]
212144	175400909	e^-e^-	3	806.9	170.5
214390	8419976	e^+e^+	5	861.9	267.5
214523	51618848	e^+e^+	5	867.6	112.5
204474	85334196	μ^-e^-	6	1345.8	352.9
204932	57341766	$e^+\mu^+$	5	810.4	105.8
206409	69687314	$e^-\mu^-$	3	706.9	184.0
209254	61806612	$e^-\mu^-$	2	706.0	173.8
210308	300382237	μ^+e^+	8	882.1	149.7
214021	166457942	μ^+e^+	4	860.1	111.7
203524	12861013	$\mu^+\mu^+$	5	887.8	110.5
203258	67068306	$\mu^-e^+e^+$	5	773.1	196.9
209580	240775276	$\mu^-e^+e^+$	9	968.0	355.3

Table 111: List of data events in the SR4t4/VLQ7 category (by definition, the $E_{\mathrm{T}}^{\mathrm{miss}}$ is above 40 GeV and the H_{T} above 700 GeV).

Run	Event	Type	N_{jets}	N_{b-jets}	H_{T} [GeV]	$E_{\mathrm{T}}^{\mathrm{miss}}$ [GeV]
204134	3904947	e^+e^+	4	3	708.7	298.3
213155	67090933	e^+e^+	6	3	799.9	137.4
212199	87054576	$e^+\mu^+$	5	3	744.0	215.8
213754	173534800	$e^+\mu^+$	4	3	887.9	154.5
214390	56385621	μ^+e^+	3	3	1439.0	238.8
203524	16345986	$\mu^-\mu^+\mu^-$	4	4	1072.4	175.9

Extrapolation à haut p_T



	Standard p_T binning	Extended p_T binning
SRVLQ0	20.81 ± 0.72	20.82 ± 0.74
SR4t0/VLQ1	15.09 ± 0.55	15.06 ± 0.55
SR4t1/VLQ2	0.740 ± 0.110	0.738 ± 0.110
SRVLQ3	1.72 ± 0.22	1.85 ± 0.27
SRVLQ4	1.46 ± 0.17	1.47 ± 0.17
SR4t2/VLQ5	1.173 ± 0.164	1.165 ± 0.162
SR4t3/VLQ6	1.088 ± 0.135	1.091 ± 0.136
SR4t4/VLQ7	0.295 ± 0.093	0.296 ± 0.093

Méthode d'interprétation statistique au Run 1

Méthode hybride sous MCLimit :

Test statistique log-likelihood ratio

$$LLR = -2 \log \frac{L_{s+b}}{L_b}$$

Où L_b est un likelihood de Poisson d'observer les données sour l'hypothèse bruit, $L_{(s+b)}$ sous l'hypothèse signal + bruit.

Incertitudes statistiques modélisées par statistique de Poisson, incertitudes systématiques par une statistique gaussienne.

Des pseudo-expériences sont générées, avec des gaussiennes tronquées à zéros (p.ex si le nombre d'événement est faible avec une grande erreur)

Le LLR global est la somme des LLR de chaque canal, puis la fraction des s+b et b pseudo-expériences avec LLR > médianne définissent $CL_{(s+b)}$ et CL_b. Les sections efficaces exclues sont : $CL_s = CL_{(s+b)}/CL_b < 0.05$

Méthode d'interprétation statistique au Run 2

Méthode fréquentiste sous ttHFitter:

$$\mathcal{L}(\mu,\theta) = \mathcal{L}_{\text{poiss}}(N_{\text{data}} \mid \mu s(\theta) + b(\theta)) \times \mathcal{L}_{\text{gauss}}(\theta)$$

Test statistique profiled likelihood ratio

$$q_\mu = -2\ln\left(\frac{\mathcal{L}(\mu,\hat{\hat{\theta}}_\mu)}{\mathcal{L}(\hat{\mu},\hat{\theta})}\right)$$

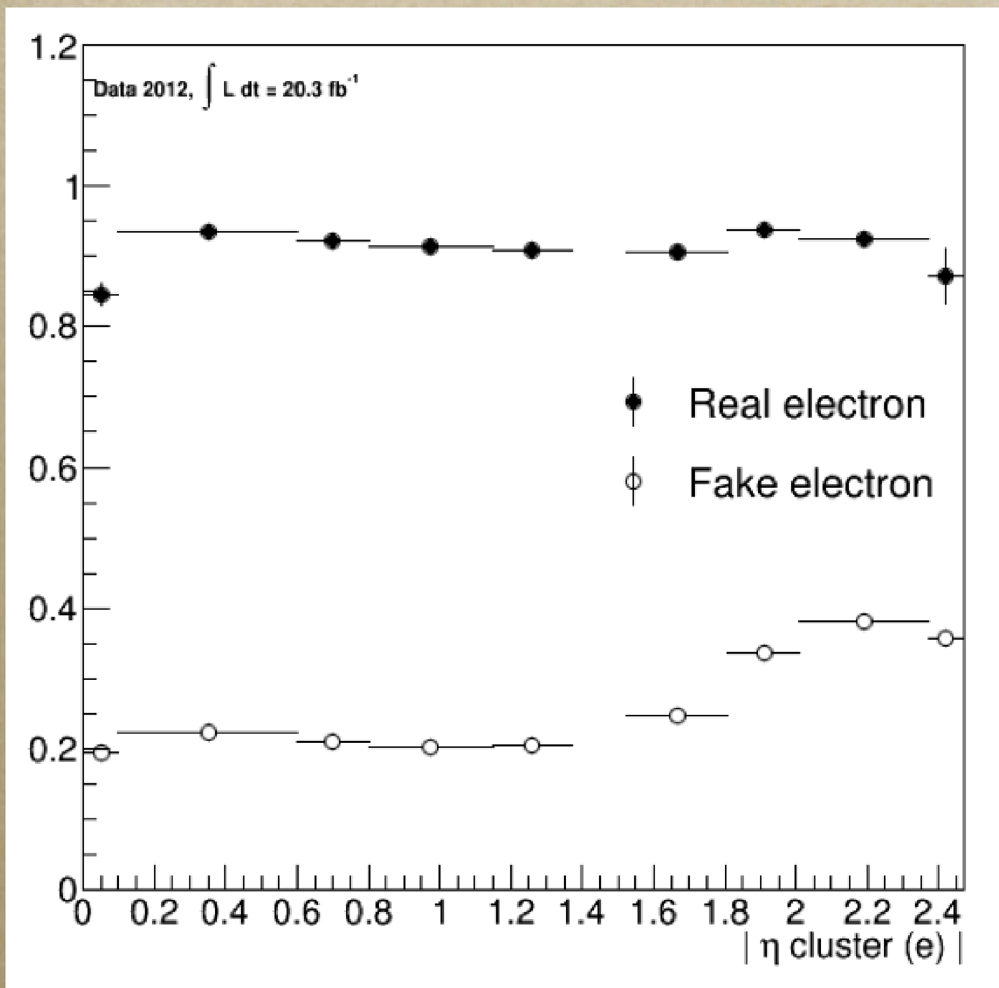
Où le numérateur est une seule fonction des paramètres de nuisance
Et le dénumérateur l'extremum global de la fonction à 2D

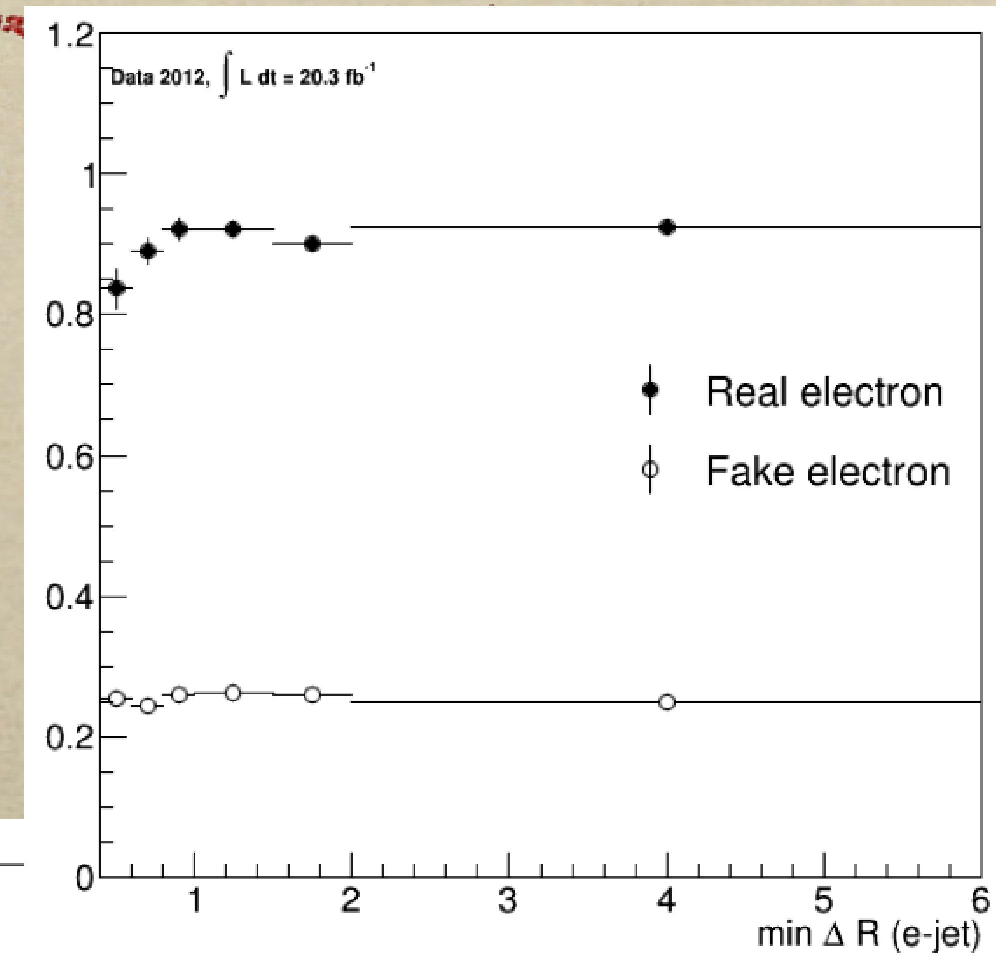
$$p_{\text{b}} = P(q_\mu < q_\mu^{\text{ref}}|\text{B}) = \int_{-\infty}^{q_\mu^{\text{ref}}} f(q_\mu|\text{B})\,\text{d}q_\mu$$

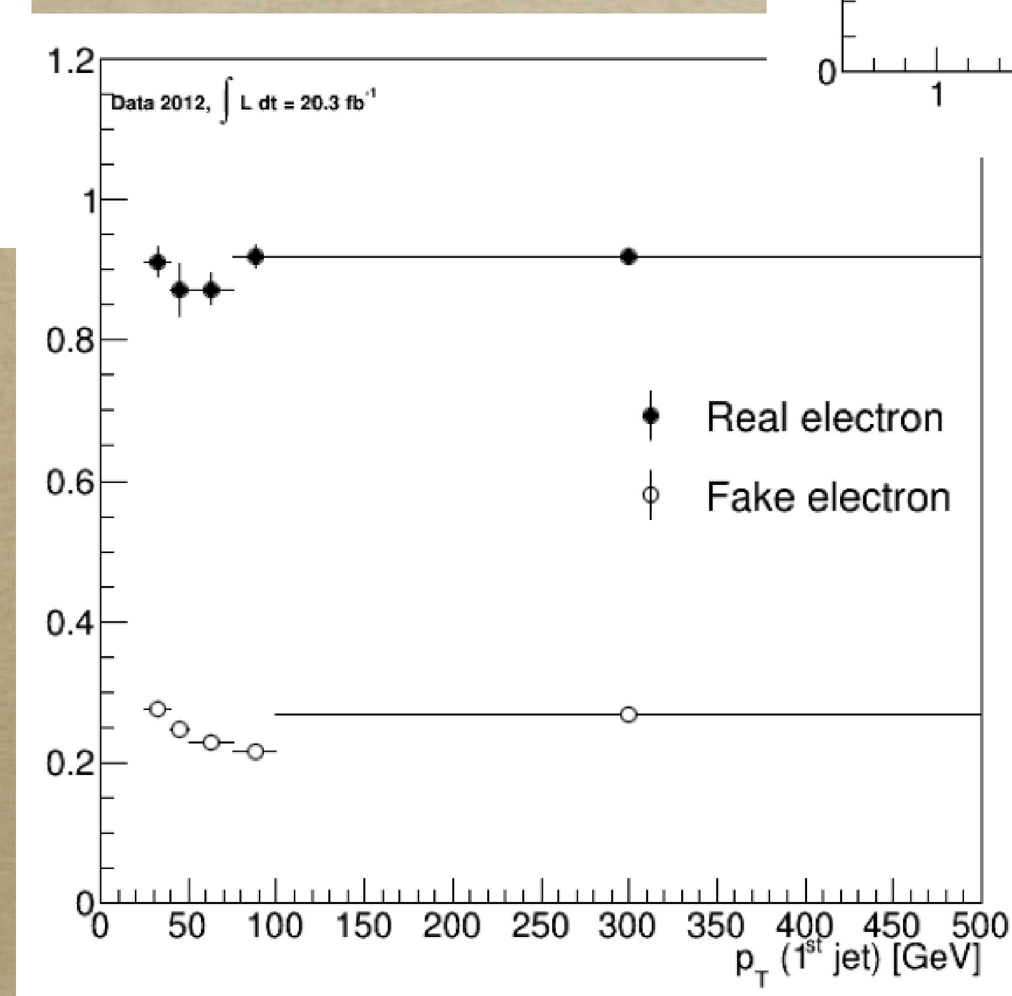
$$p_{\text{s+b}} = P(q_\mu > q_\mu^{\text{ref}}|\text{S+B}) = \int_{q_\mu^{\text{ref}}}^{+\infty} f(q_\mu|\text{S+B})\,\text{d}q_\mu$$

$$\text{CL}_{\text{s}} \equiv \frac{p_{\text{s+b}}}{1 - p_{\text{b}}}$$

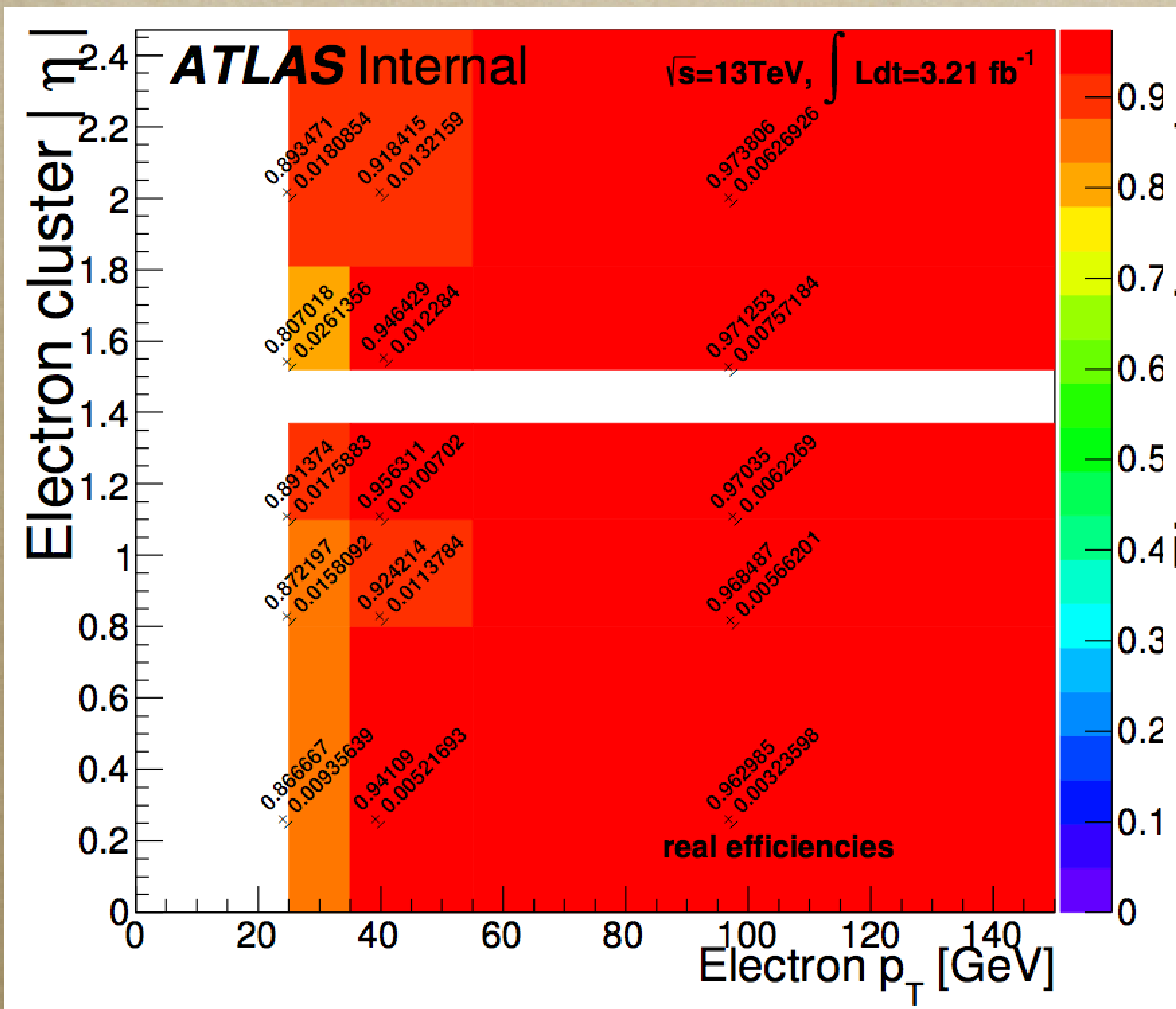
Efficacités des fakes au Run 1 des électrons

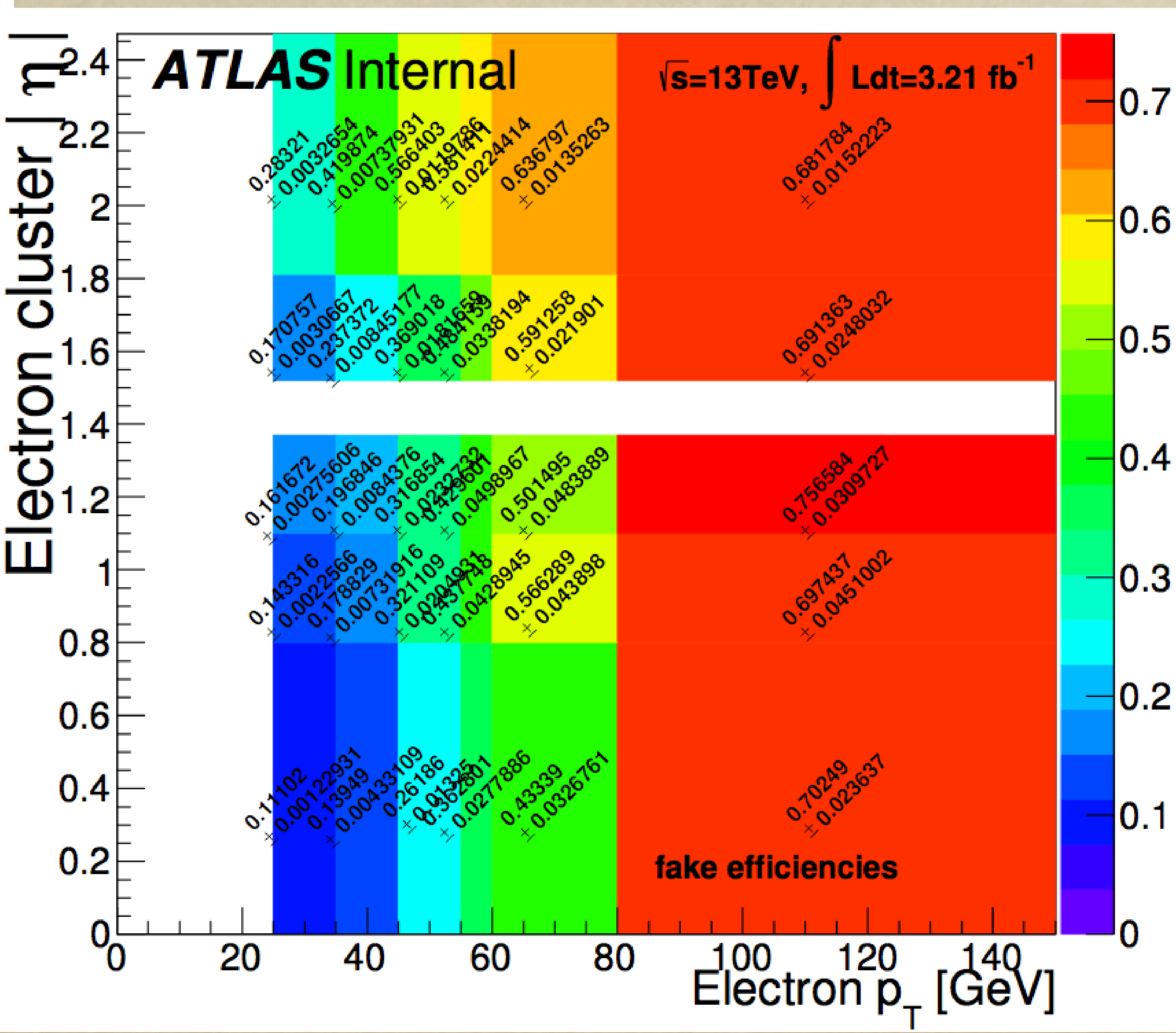




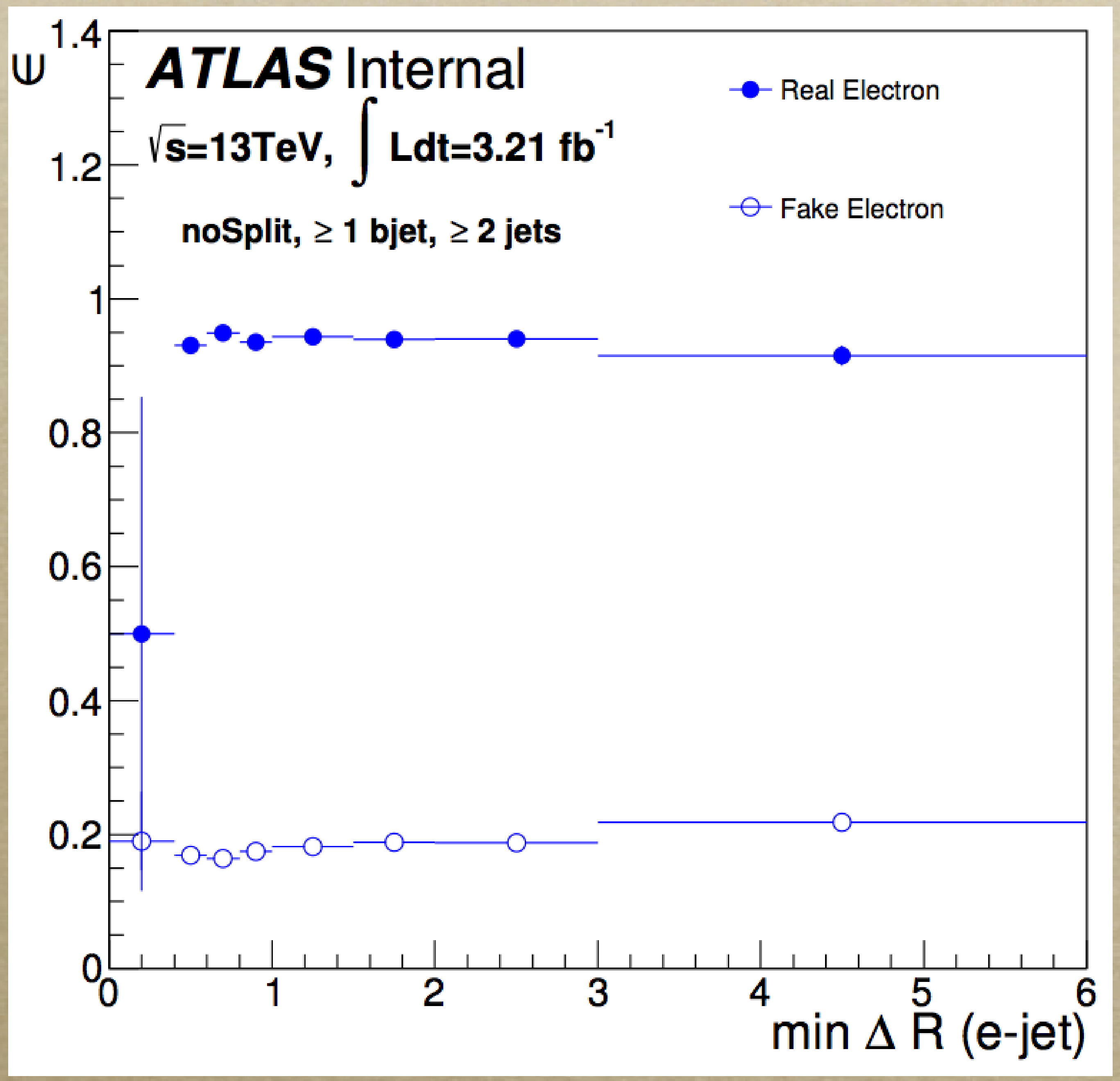


Efficacités des fakes au Run 2 des électrons





Efficacités des fakes au Run 2 des électrons



Sélection des électrons au Run 1

- $E_T > 25$ GeV
- tight (sélection ATLAS)
- $|\eta| < 2.47$ excluant la zone habituelle [1.37-1.52]
- Origine à moins de 2 mm du vertex primaire en z
- Isolés avec mini-isolation : DR=min(0.4, 10 GeV / p_T)
- Isolation des cellules du calo : somme des p_T des traces < 0.05 p_T el
- Isolation avec jets (DR(e, jet) > 0.4).
- Pour les électrons de la matrice méthode : sélection « medium » d'ATLAS

Medium = forme transverse des gerbes dans la 2ème couche du calo EM + perte d'énergie dans le calorimètre hadronique + coupure sur le nombre de coups dans le détecteur interne (pixels/silicium) + profils latéraux de la gerbe dans la 1ère couche du calo EM + coupure sur le paramètre d'impact (5 mm) + lien en η entre trace et cluster.

Tight : medium + nombre de vertex dans l'ID + nombre de coups à haute énergie dans le TRT + isolation cluster EM

Sélection des électrons au Run 2

- $p_T > 25$ GeV
- likelihood tight (sélection ATLAS)
- $|\eta| < 2.47$ excluant la zone habituelle [1.37-1.52]
- Origine à moins de 2 mm du vertex primaire en z
- Isolés : DR=min(0.2, 10 GeV / p_T)
- Isolation des traces : somme des p_T des traces < 0.06 p_T el
- Isolation avec jets (DR(e, jet) > 0.2-0.4), avec muons
- coupures sur les paramètres d'impact (d_0 sig < 5 et $|\Delta z0 \sin\theta| < 0.5$mm)
- Pour les électrons de la matrice méthode : enlève l'isolation

OVERLAP removal :

- effectué sur les électrons « MM-loose » (sans isolation)

Par exemple : un électron non-isolé avec jet DR<0.2

OR MM-loose : supprime le jet, donc l'électron peut se retrouver isolé

OR MM-tight : électron pas considéré.

Sélection des électrons au Run 2

Calorimeter isolation ($< 0.06\ E_T$)

$$\text{topoetcone20} = \sum_{\Delta R<0.2} E_T^{\text{topo}}$$

Tracking isolation ($< 0.06\ p_T$)

$$\text{ptvarcone20} = \sum_{\Delta R<\Delta R_{\max}} p_T^{\text{trk}}$$

$$\Delta R_{\max} = \min\{10\ \text{GeV}/p_T\ ,\ 0.2\}$$

	Electrons		Muons		Jets	*b*-jets
	MM-loose	MM-tight	MM-loose	MM-tight		
p_T lower limit (GeV)	25	25	25	25	25	25
$\|\eta\|$ upper limit	2.47	2.47	2.5	2.5	2.5	2.5
Crack region veto	yes	yes	no	no	no	no
ID quality	medLH	tightLH	med	med		MV2c20, 77%
Isolation (after OVR)	no	trk + calo	no	trk		
Track cut (after OVR):						
$-\ \|d_0^{\text{sig}}\|$	< 5	< 5	<3	< 3		
$-\ \|\Delta z_0 \times \sin\theta\|$ (mm)	< 0.5	< 0.5	< 0.5	< 0.5		

Overlap removal procedure

1. if a calorimeter-tagged muon shares a track with an electron, the muon is removed.
2. if $\Delta R(j, e) < 0.2$, the jet is removed
3. if $\Delta R(e, j) < 0.4$, the electron is removed
4. if $\Delta R(j, \mu) < 0.2$, the jet is removed
5. if $\Delta R(\mu, j) < 0.04 + 10\ \text{GeV}/p_T$, the muon is removed

MM-tight:
→final lepton used in the analysis
MM-loose:
→looser lepton for the **M**atrix **M**ethod (fake lepton bkg estimation)