

# LHC-ATLAS 実験 重心系エネルギー 7, 8TeV における Top Quark Physics

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新学術領域研究

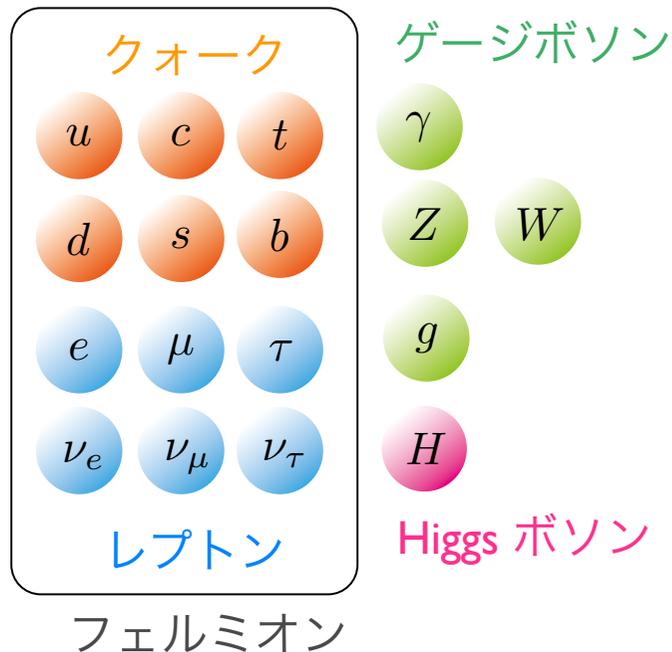
先端加速器LHCが切り拓くテラスケールの素粒子物理学

～真空と時空への新たな挑戦～

研究会

<http://www.hepl.phys.nagoya-u.ac.jp/atlas/terascale2013/Program.html>

# <sup>2</sup>/<sub>18</sub> Top quark physics



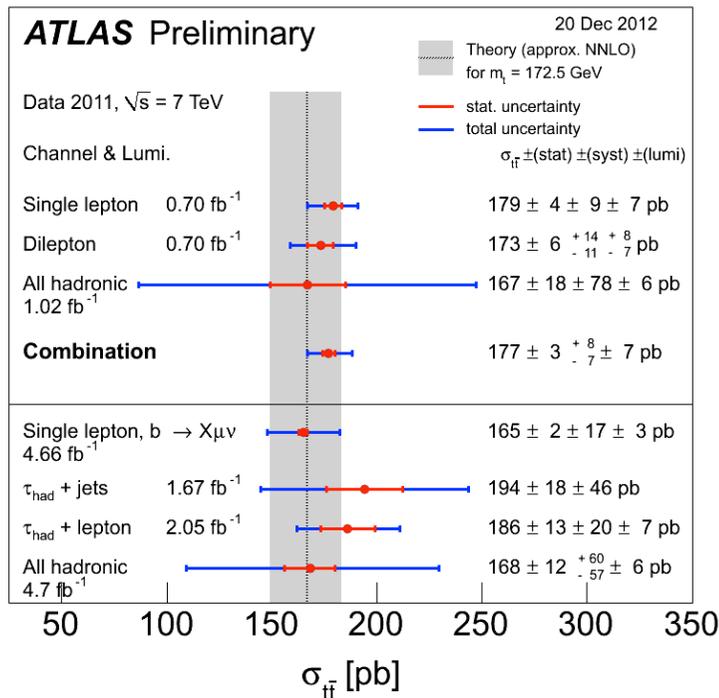
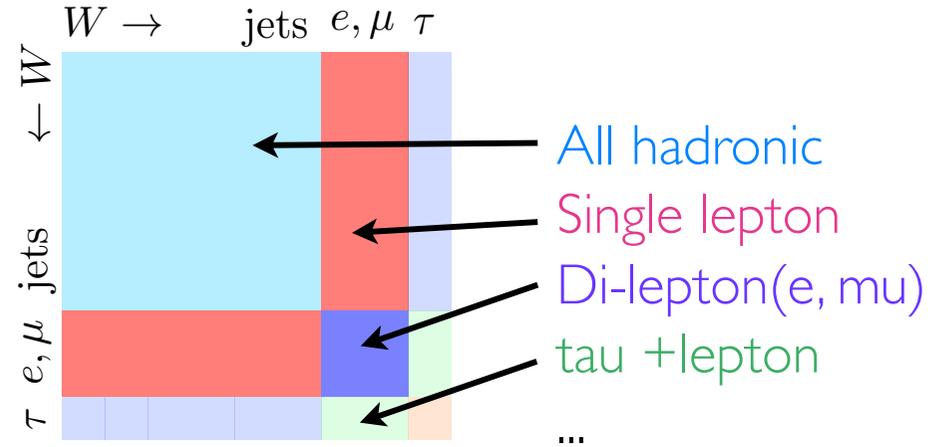
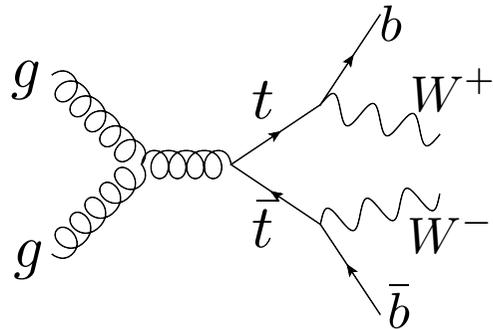
- Top quark : mass 173 GeV
- 新しい物理との関係が示唆される
- ほぼ 100% で  $Wb$  に崩壊
- 崩壊幅  $1 \text{ GeV} > \Lambda_{\text{QCD}} \sim 200 \text{ MeV}$
- Hadron化を起こす前に崩壊
- クォーク単体の性質が現れる

様々な物理量から **100 GeV** スケールでの **SM** の検証が可能

# 7,8 TeV でのトップクォーク対生成

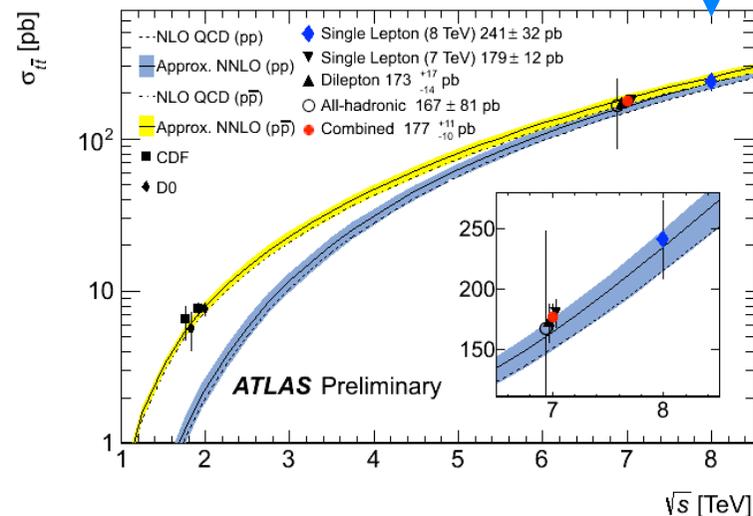
$$\sigma_{t\bar{t}, \sqrt{s}=7\text{TeV}}^{\text{theory}} = 164.6^{+11}_{-16} \text{pb}$$

$$\sigma_{t\bar{t}, \sqrt{s}=8\text{TeV}}^{\text{theory}} = 238^{+22}_{-24} \text{pb} : 20/\text{fb} \rightarrow 400\text{万対}$$



$$\sigma = 241 \pm 2(\text{stat.}) \pm 31(\text{syst.}) \pm 9(\text{lumi.}) \text{pb}$$

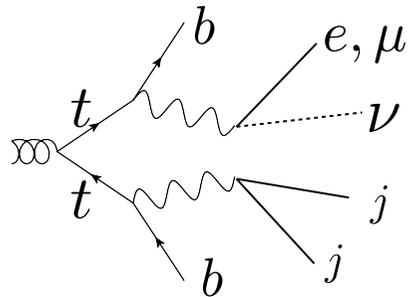
ATLAS-CONF-2012-149



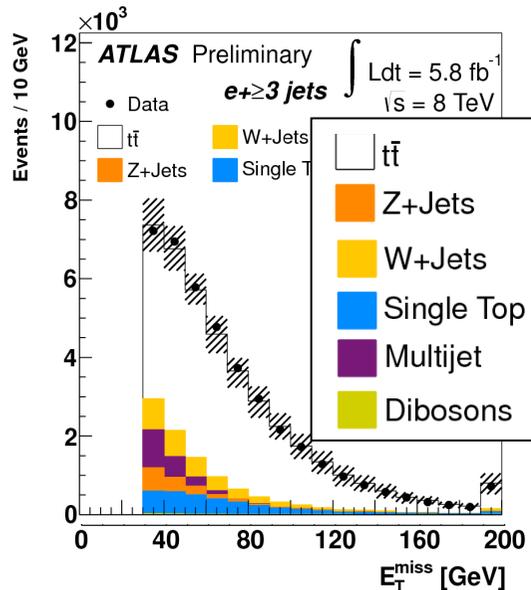
Combination plot from

# 4/18 Inclusive から exclusive measurement へ

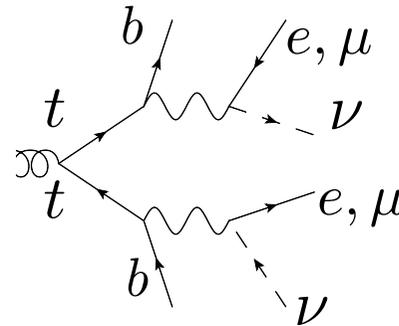
## Single lepton



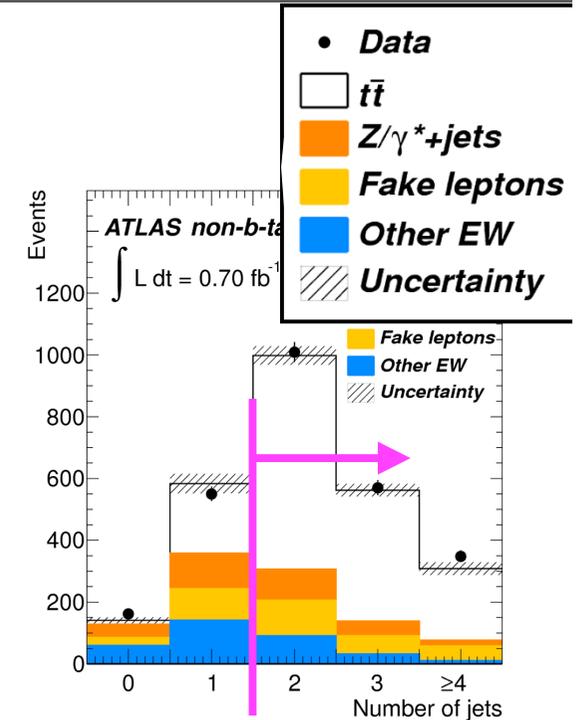
Charged lepton  
MissET (MT)  
4 jets,  
b-tagged jets



## Di-lepton



2 charged lepton  
MissET  
2 jets,  
b-tagged jets



高 purity かつ大統計のトップクォーク(対)サンプルの収集ができています

このInclusive cross section 研究をベースにしてトップクォークの性質を検証していく

### Production process

Differential cross section  
mtt dependence  
ttbar + X

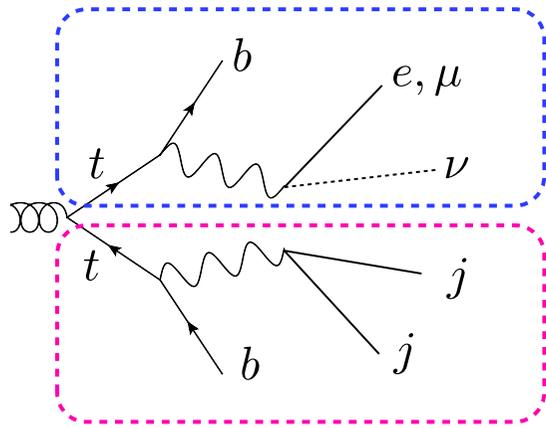
### Properties

Top quark kinematics  
charge asymmetry  
spin correlation

W-t-b vertex  
Mass

# 5/18 ttbar differential cross section

7TeV 2.05/fb, ttbar single lepton channel

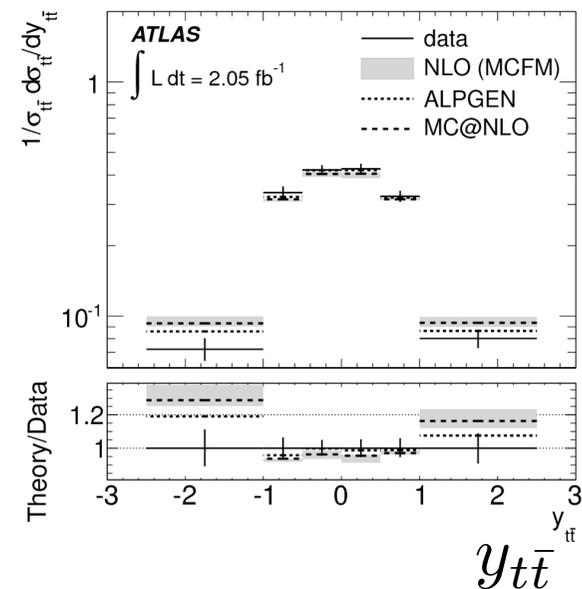
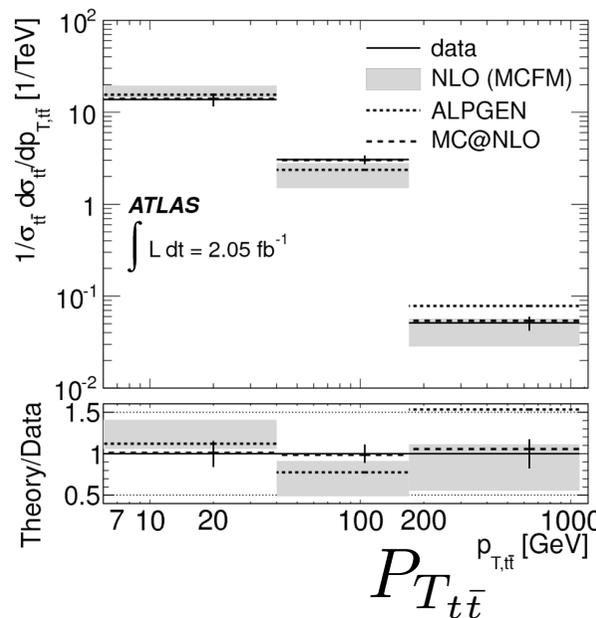
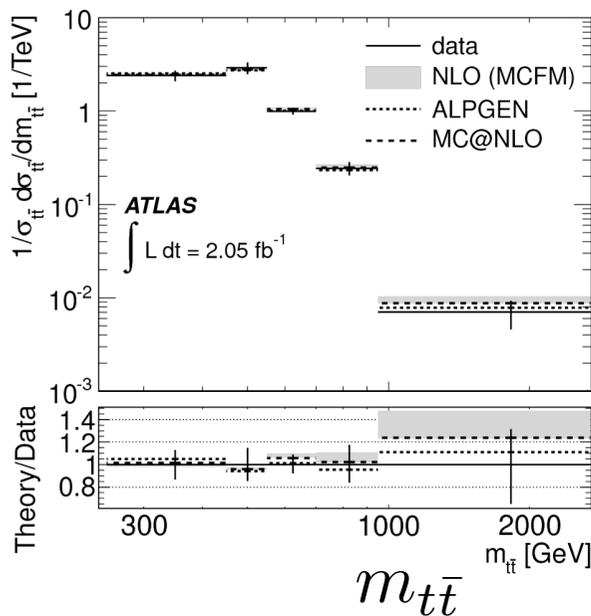


## トップクォーク対の再構成

事象選別後は lepton, jet  $\geq 4$ , missing  $E_t$   
Likelihood に基づき  $b_l \nu$ ,  $b_{jj}$  の組の決定

$m_{top}, m_W$  は固定

$\Gamma_{top}, \Gamma_W, \sigma_{jet}, \text{eff}_{b-tag}$  を考慮し算出

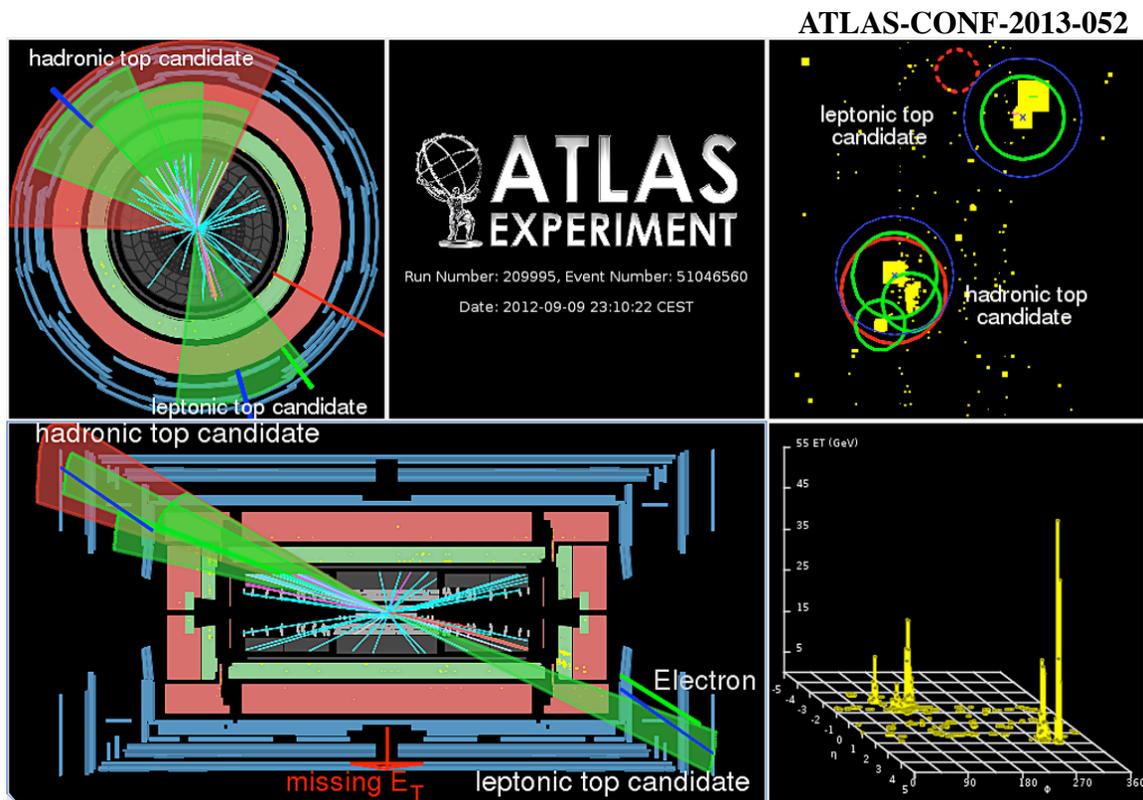
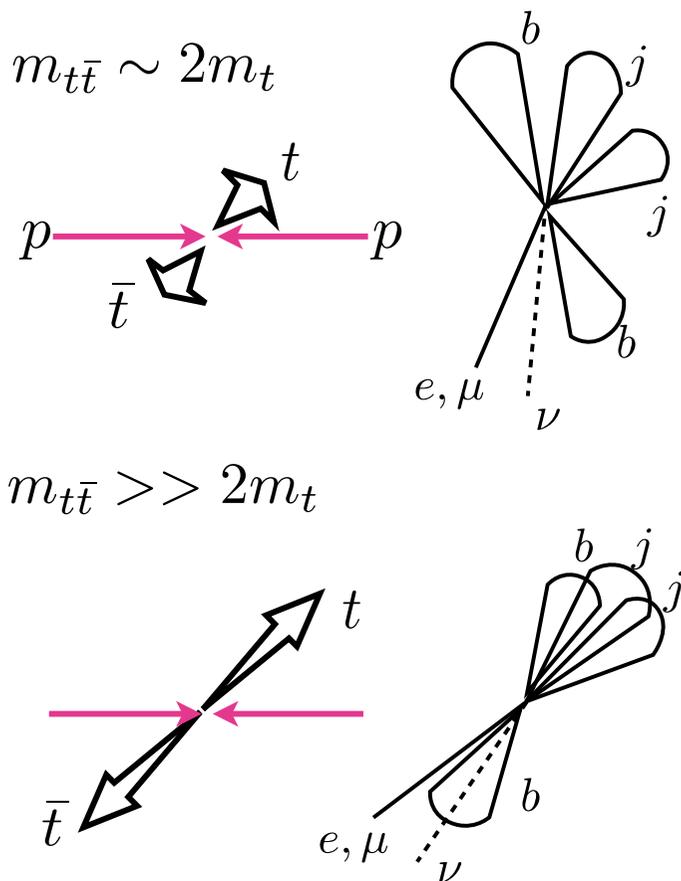


# 6/18 boosted top tagging の必要性

BSM粒子 (e.g. Z', gKK) のトッパークォークペアへの崩壊

トッパークォークの特徴的な終状態に注目し背景事象の選別が可能

mtt->大 : boosted top quark = 崩壊粒子が collinear に



Boosted top quark の tagging が課題

# 7/18 boosted top 解析

## 8 TeV | 4/fb, ttbar single lepton channel での解析

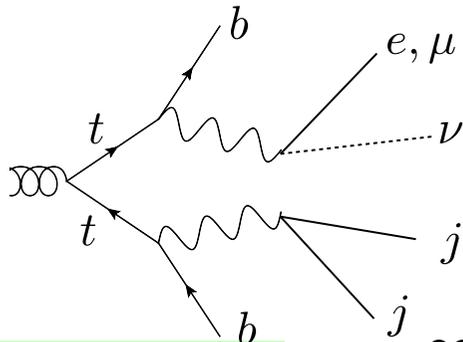
Electron or Muon

e : MissEt > 30GeV, MT > 30GeV

μ : MissEt > 20GeV, MissET+MT > 60 GeV

$m_{t\bar{t}} \sim 2m_t$  (A)

$$m_T(W) = \sqrt{2p_T(\ell)E_T^{\text{miss}} [1 - \cos \Delta\phi(\ell, E_T^{\text{miss}})]}$$



4 jet もしくは  
3 jet (うち 一つは  $m_{\text{jet}} > 60 \text{ GeV}$ )  
少なくとも一本は b-tagged jet

$m_{t\bar{t}} \gg 2m_t$  (B)

cone R=0.4 の通常の Jet 1つ

b-tag されていること

lepton との距離  $\Delta R < 1.5$

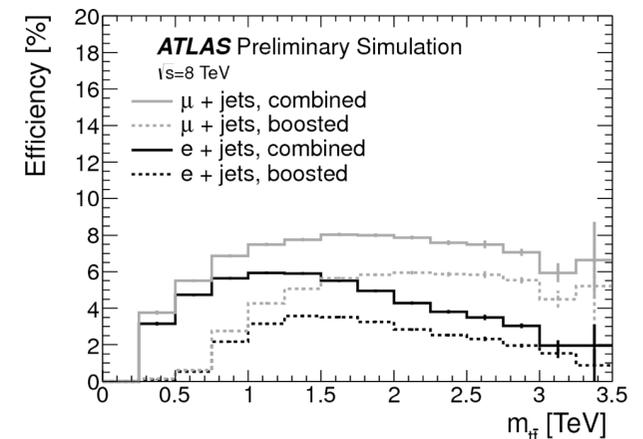
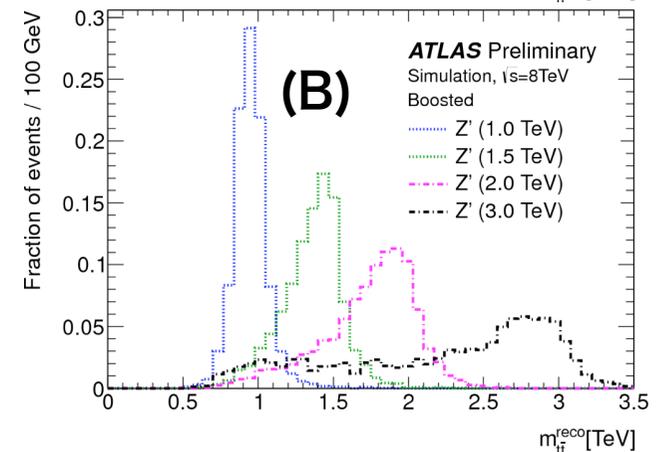
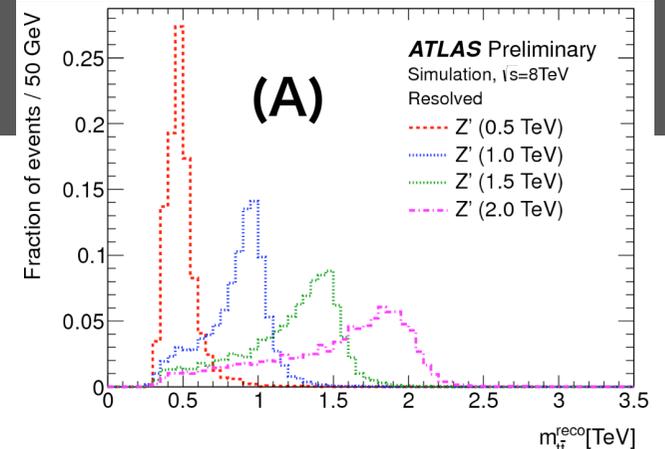
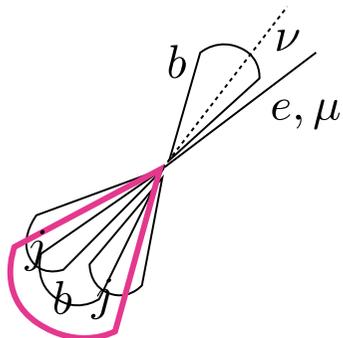
$$(\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2})$$

cone R=1.0 の **“Fat Jet”** 1つ

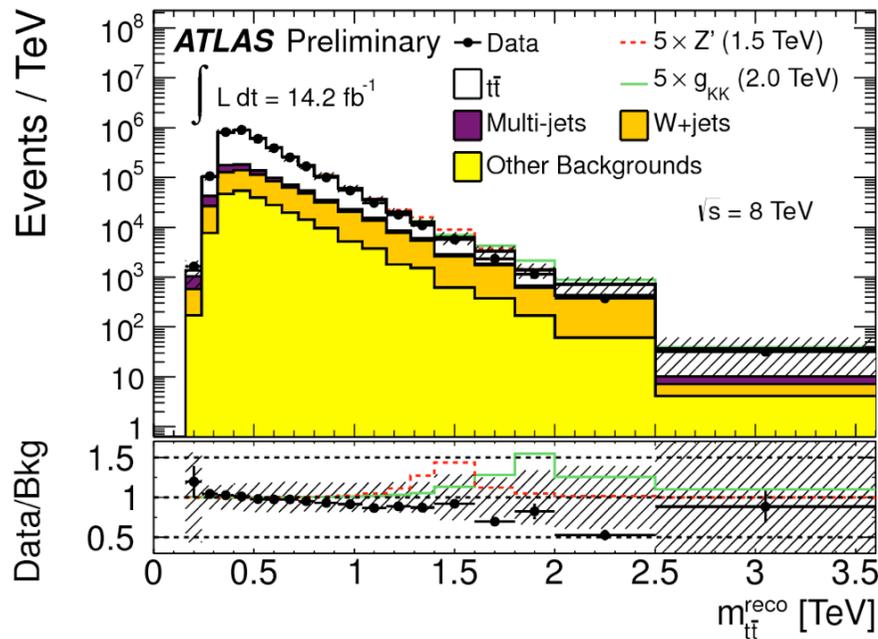
ジェットの質量 > 100 GeV

スプリッティングスケール

$$\sqrt{d_{1,2}} = \min(P_{T,1}, P_{T,2})\Delta R(j_1, j_2) > 40 \text{ GeV}$$

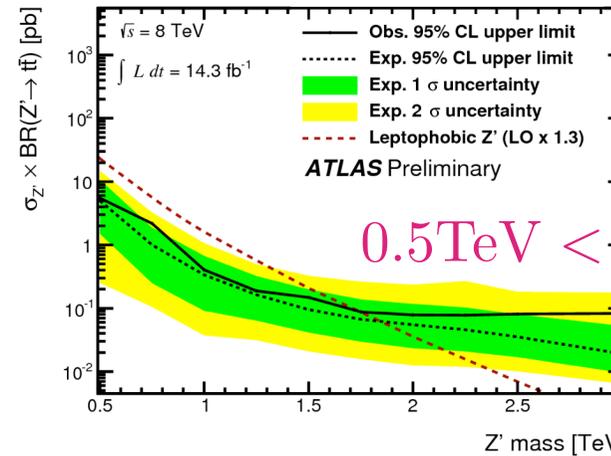


# 18/8 boosted top 解析



(CMS-PAS-B2G-12-006, 8 TeV 20/fb, single lepton)

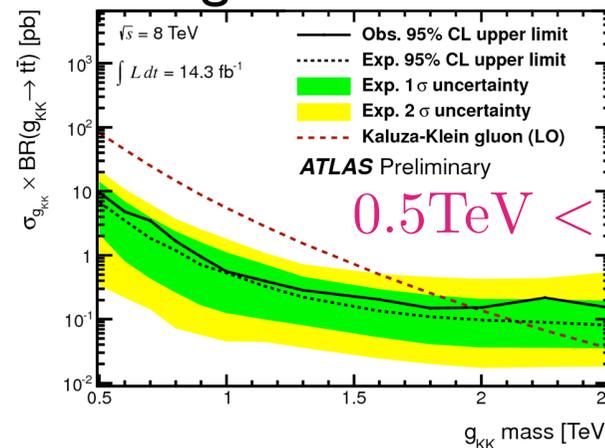
$Z'$   $\Gamma/m = 1.2\%$



$0.5 \text{ TeV} < M_{Z'} < 1.8 \text{ TeV}$   
(95% C.L.)

CMS :  $M_{Z'} < 2.10 \text{ TeV}$

KK gluon  $\Gamma/m = 15.3\%$



$0.5 \text{ TeV} < M_{g_{KK}} < 2.1 \text{ TeV}$   
(95% C.L.)

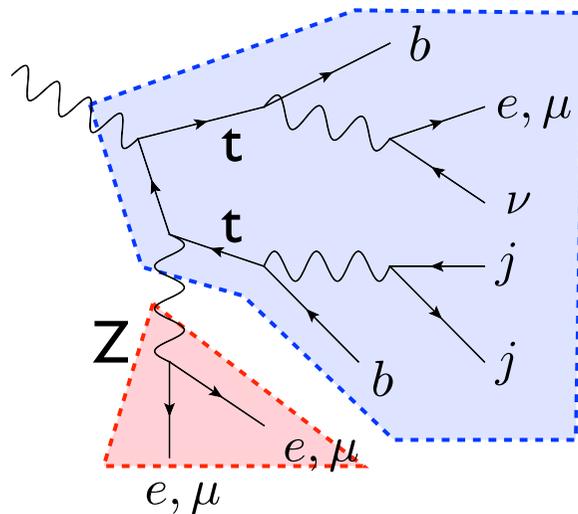
CMS :  $M_{g_{KK}} < 2.54 \text{ TeV}$

# 9/18 ttbar + X 生成断面積測定

ttbar + Z 事象

$t\bar{t}Z$  couplingの直接検証

Single lepton +  $Z \rightarrow \mu\mu$  (7 TeV, 4.7/fb)



荷電レプトン 3 本

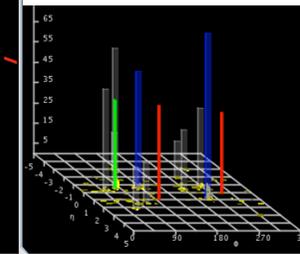
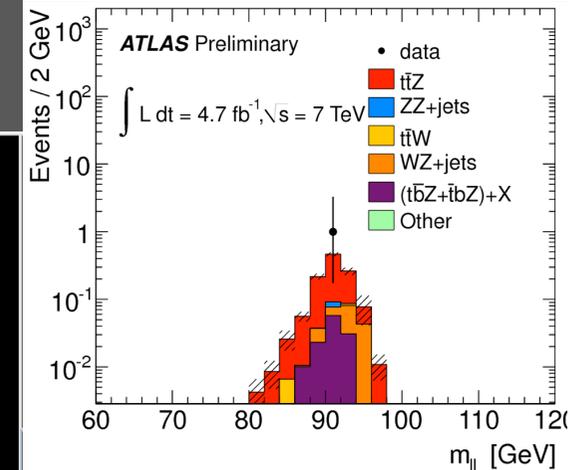
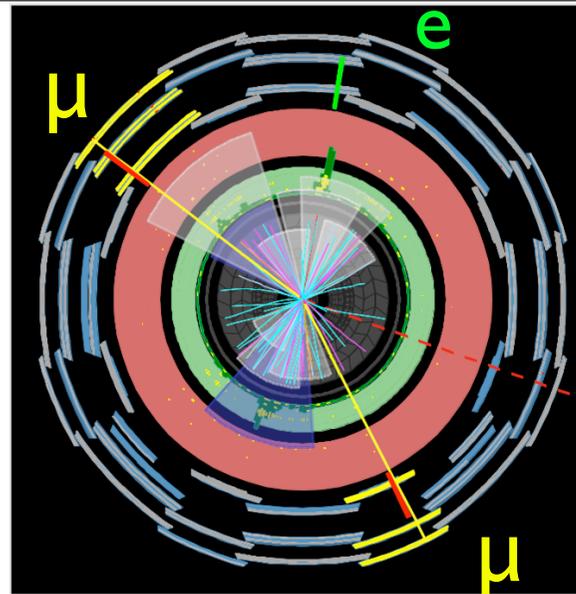
一対が Same flavor, Opposite sign

$|M_{ll} - M_Z| < 10 \text{ GeV}$

MissEt > 30 GeV

4 jets, 少なくとも 1 b-tagged jet

→ 1 event 観測



expected signal :

$$0.85 \pm 0.04 \text{ (stat.)} \pm 0.14 \text{ (syst.)}$$

expected background :

$$0.28 \pm 0.05 \text{ (stat.)} \pm 0.14 \text{ (syst.)}$$

$\sigma_{t\bar{t}Z}$  upper limit (95% C.L.) : 0.71 pb

$$\sigma_{t\bar{t}Z}^{SM} = 0.14 \text{ pb}$$

同様に ttbar +  $\gamma$  の解析より (7 TeV, 1.04 /fb)

$$\sigma_{t\bar{t}\gamma} \cdot \text{Br} = 2.0 \pm 0.5 \text{ (stat.)} \pm 0.7 \text{ (syst.)} \pm 0.08 \text{ (lumi.)}$$

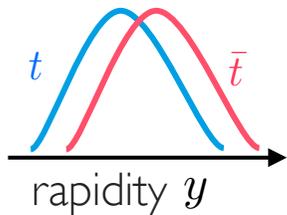
$$(\sigma_{t\bar{t}\gamma} \cdot \text{Br})^{SM} = 2.1 \pm 0.4 \text{ pb}$$

ATLAS-CONF-2011-153

# 10/18 Charge asymmetry

トップクォーク対生成事象でのトップ・反トップクォークの生成方向非対称性

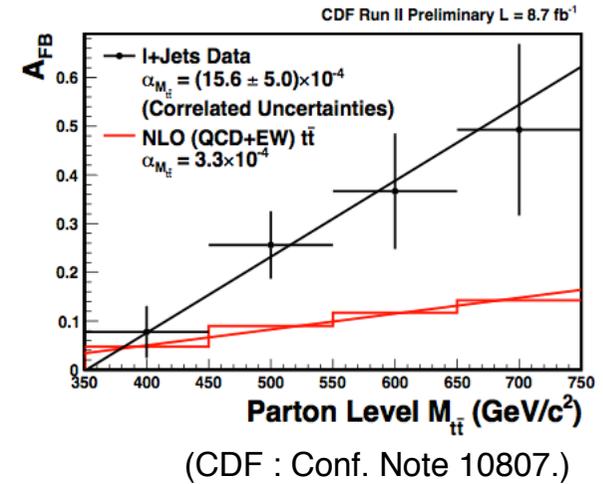
Tevatron( $p\bar{p}$ ) → Forward backward asymmetry.



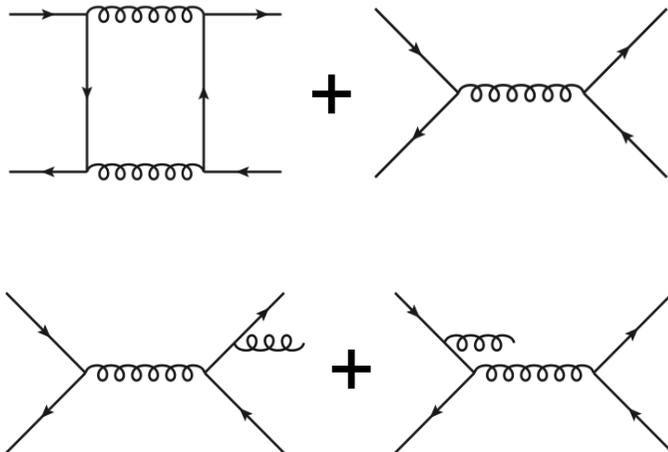
$$\Delta y = y_t - y_{\bar{t}} \quad A_{FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)}$$

CDF :  $A_{FB} = 0.162 \pm 0.047$  (stat. + syst.)

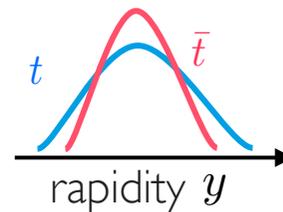
Expectation :  $A_{FB} = 0.066$  (POWHEG)       $A_{FB} = 0.067$  (MC@NLO)



LHC( $pp$ ) = Forward-backward については対称



→ Central/Forward asymmetry.



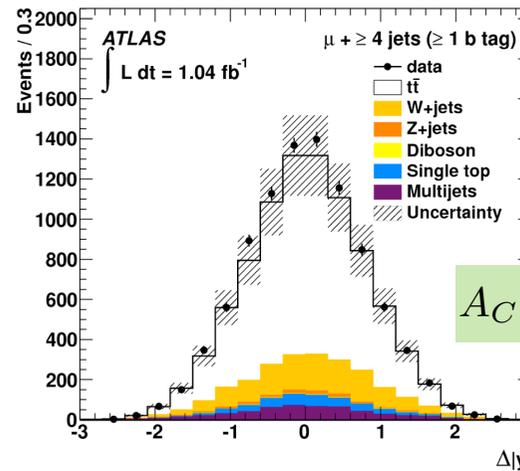
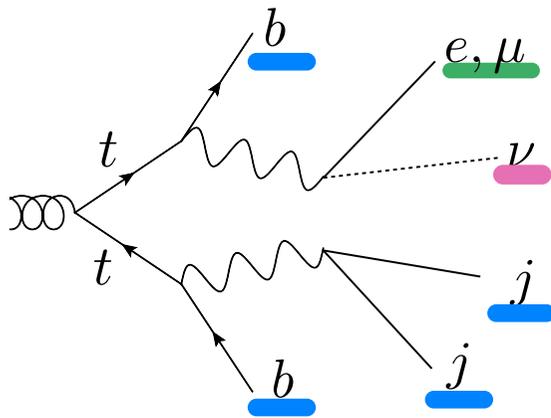
$$\Delta y = |y_t| - |y_{\bar{t}}|$$

$A_{C,expect} = 0.006 \pm 0.002$  MC@NLO generator

# 11/18 Charge asymmetry : single lepton channel

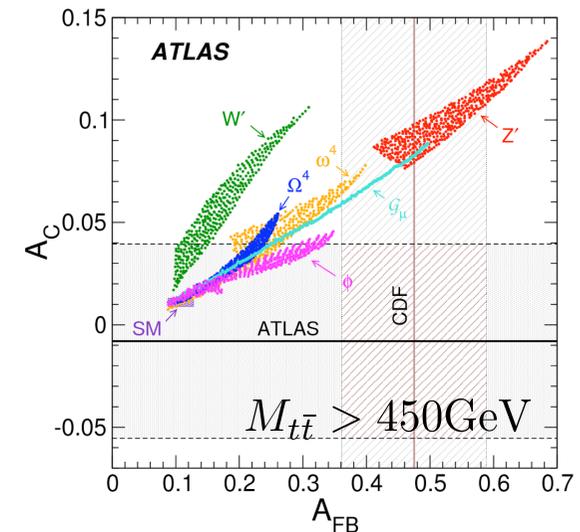
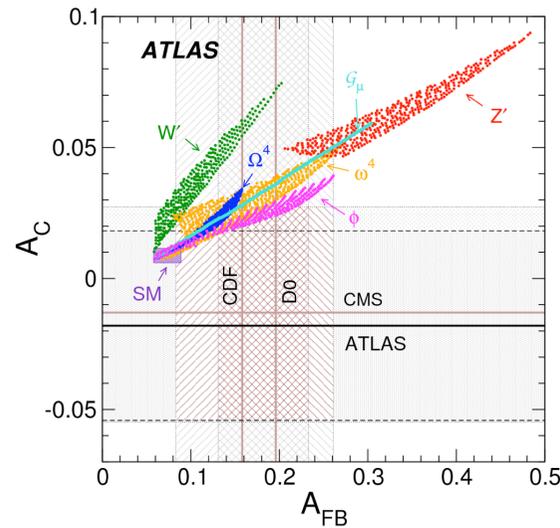
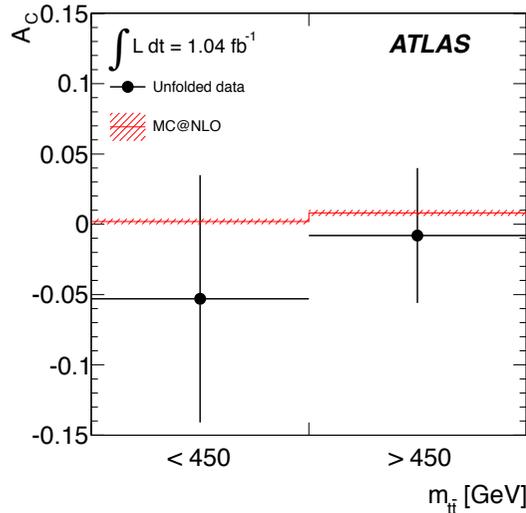
7 TeV, 1.04/fb, Single lepton channel での解析

先の differential cross section measurement と同様の事象選別 + 再構成



$$A_C = -0.018 \pm 0.028(\text{stat.}) \pm 0.023(\text{syst.})$$

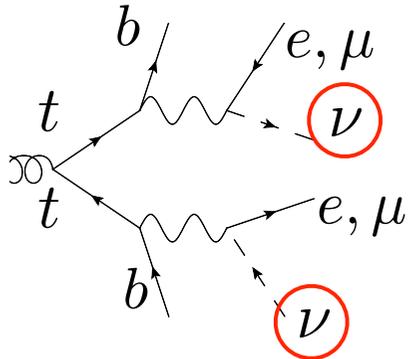
$$A_{C,\text{expect}} = 0.006 \pm 0.002$$



12  
18

# Charge asymmetry : di-lepton channel

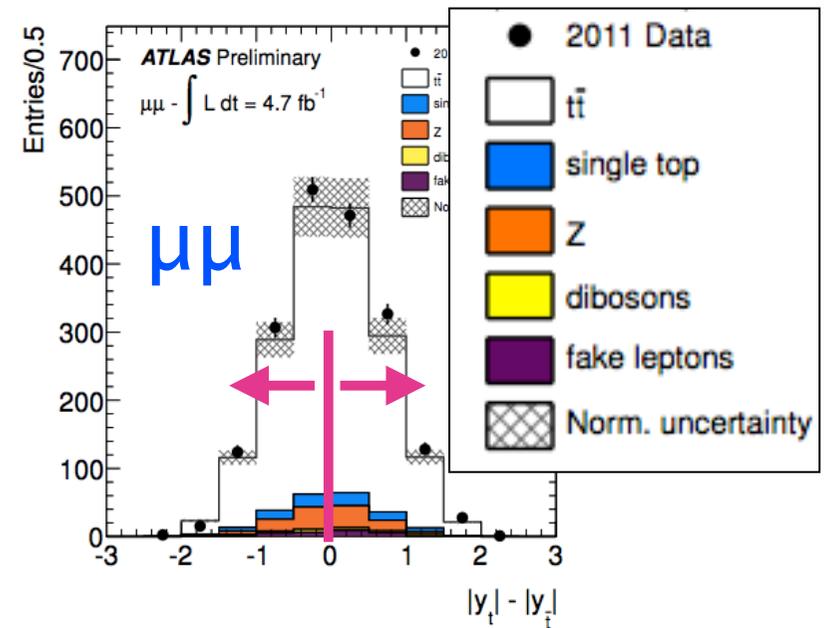
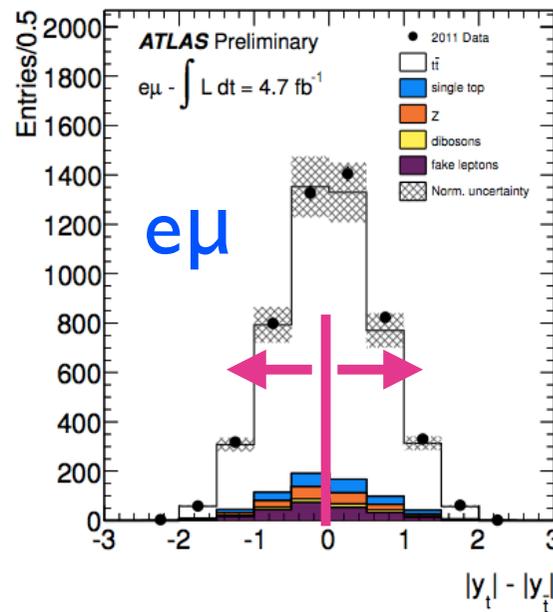
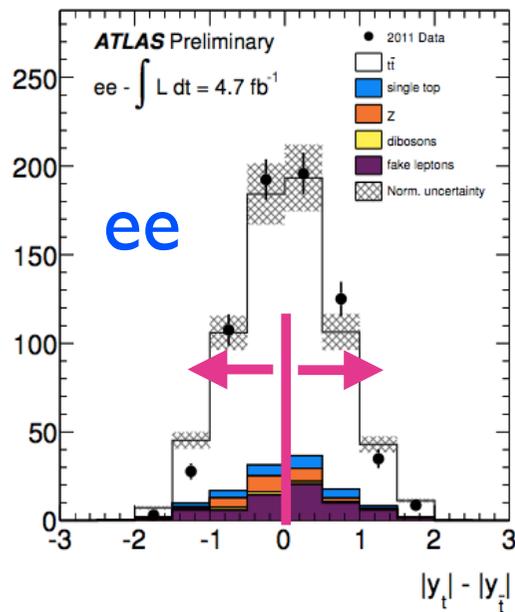
(7 TeV, 4.7/fb)



## トップクォーク対の再構成

課題：ニュートリノ 2 個の運動量 = 6 未知数

$$\begin{aligned}
 p_\nu^x + p_{\bar{\nu}}^x &= \text{MissEx} & (p_{\bar{\ell}} + p_\nu + p_b)^2 &= m_t^2 & (p_\ell + p_{\bar{\nu}} + p_{\bar{b}})^2 &= m_t^2 \\
 p_\nu^y + p_{\bar{\nu}}^y &= \text{MissEy} & (p_{\bar{\ell}} + p_\nu)^2 &= m_W^2 & (p_\ell + p_{\bar{\nu}})^2 &= m_W^2
 \end{aligned}$$



$$\begin{aligned}
 A_C^{t\bar{t}} &= 0.079 \pm 0.087 \text{ (stat.)} \pm 0.028 \text{ (syst.)} && (ee \text{ channel}), \\
 A_C^{t\bar{t}} &= 0.078 \pm 0.029 \text{ (stat.)} \pm 0.017 \text{ (syst.)} && (e\mu \text{ channel}), \\
 A_C^{t\bar{t}} &= 0.000 \pm 0.046 \text{ (stat.)} \pm 0.021 \text{ (syst.)} && (\mu\mu \text{ channel}).
 \end{aligned}$$

$$A_C^{t\bar{t}} = 0.057 \pm 0.024 \text{ (stat.)} \pm 0.015 \text{ (syst.)}$$

$$A_{C,\text{expect}}^{t\bar{t}} = 0.006 \pm 0.002 \quad \text{MC@NLO}$$

# 13 / 18 Spin correlation

対生成でのトップ・反トップクォークのスピンの相関：生成過程の検証

トップクォーク対静止系にてトップクォークの運動量方向を軸に

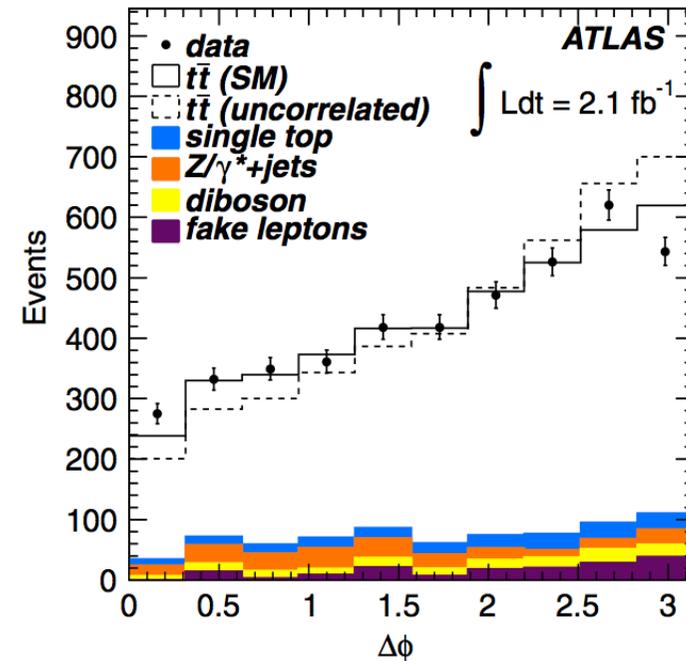
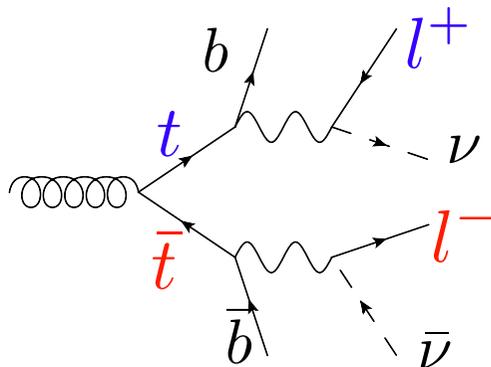
$$A = \frac{N(\uparrow\uparrow) + N(\downarrow\downarrow) - N(\uparrow\downarrow) - N(\downarrow\uparrow)}{N(\uparrow\uparrow) + N(\downarrow\downarrow) + N(\uparrow\downarrow) + N(\downarrow\uparrow)} \quad \text{を定義} \quad A_{\text{helicity}}^{\text{SM}} = 0.31$$

トップクォークのスピン

→崩壊粒子の放出角度分布に反映される

di-lepton 終状態に着目

荷電レプトン対の開き角  $\Delta\phi$  を測定



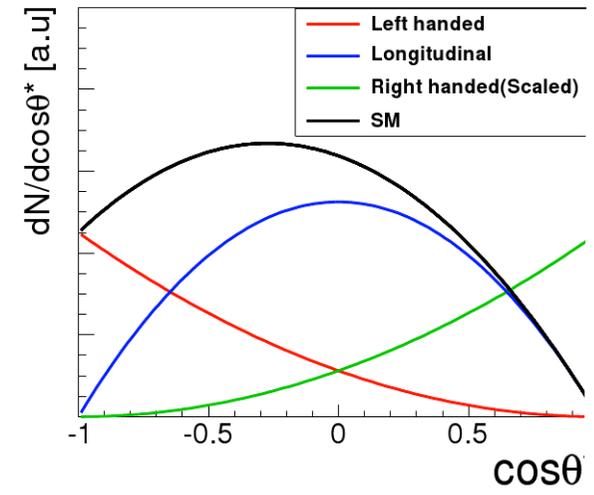
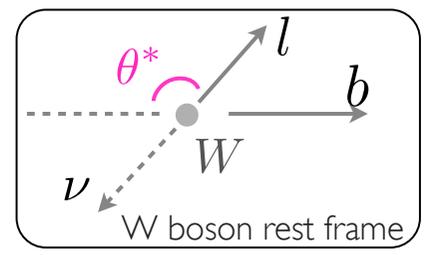
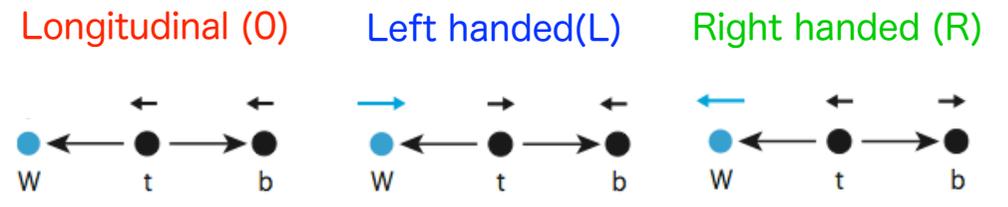
$$A_{\text{helicity}} = 0.40 \pm 0.04(\text{stat.}) \pm_{0.07}^{0.08}(\text{syst.})$$

# 14/18 トップクォーク崩壊時のW boson polarization

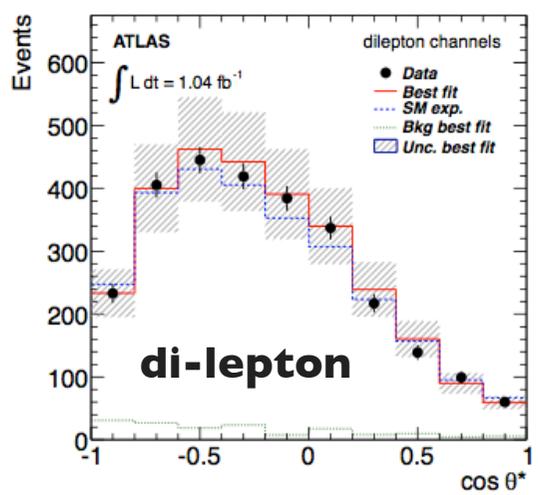
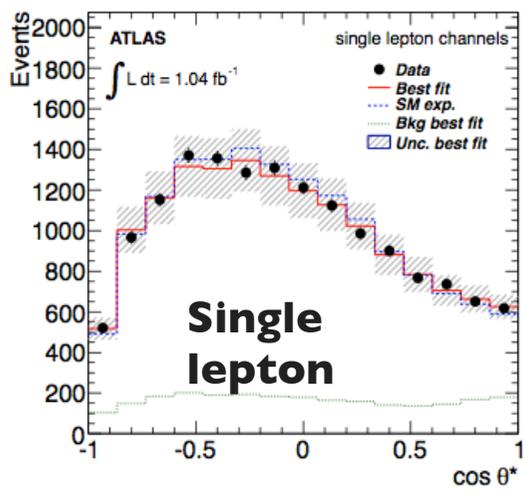
SM V-A interaction

$$\mathcal{L} = -\frac{g}{\sqrt{2}} \bar{b} \gamma^\mu (V_L P_L + V_R P_R) t W_\mu^- - \frac{g}{\sqrt{2}} \bar{b} \frac{i\sigma^{\mu\nu} q_\nu}{m_W} (g_L P_L + g_R P_R) t W_\mu^- + \text{h.c.}$$

$(P_L = (1 - \gamma^5)/2, P_R = (1 + \gamma^5)/2)$



	F0	FL	FR
SM	0.687 ± 0.005	0.311 ± 0.005	0.0017 ± 0.0001
Tevatron (CDF+D0)	0.722 ±0.081		- 0.033 ± 0.046



## ATLAS

$$F_0 = 0.67 \pm 0.03(\text{stat.}) \pm 0.06(\text{syst.}) \quad (\pm 0.07)$$

$$F_L = 0.32 \pm 0.02(\text{stat.}) \pm 0.03(\text{syst.}) \quad (\pm 0.04)$$

$$F_R = 0.01 \pm 0.01(\text{stat.}) \pm 0.04(\text{syst.}) \quad (\pm 0.05)$$

## ATLAS+CMS combination

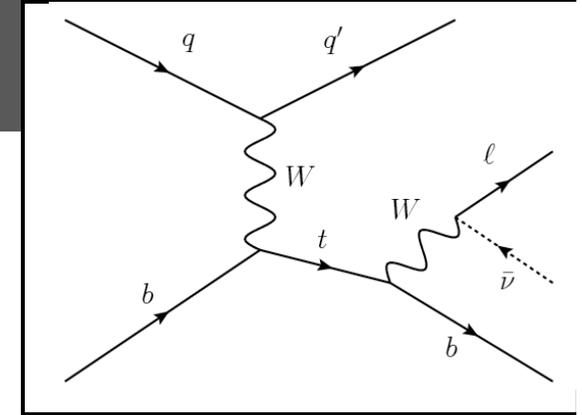
$$F_0 = 0.626 \pm 0.034(\text{stat.}) \pm 0.048(\text{syst.})$$

$$F_L = 0.359 \pm 0.021(\text{stat.}) \pm 0.028(\text{syst.})$$

## Tevatronを更新する測定精度を達成

# 15/18 CP violation search

t-channel single top production : top quark polarized :  $P \sim 0.9$   
 Top spin( $\vec{s}_t$ ) を軸にして  $\text{Im}(g_R)$  にアクセスできる



## 事象選別

$e, \mu$

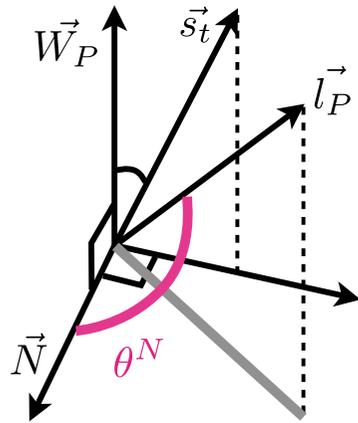
$M_T > 30 \text{ GeV}$

1 b-tagged jet  $|\eta| < 2.5$

1 non-b-tagged jet  $|\eta| < 4.5$

$\Delta \eta(\text{b-jet, jet}) > 1$

$HT(\text{include MissET}) > 210 \text{ GeV}$



$\cos \theta^N$  の Asymmetry を

$$A_{FB}^N = \frac{N(\cos \theta^N > 0) - N(\cos \theta^N < 0)}{N(\cos \theta^N > 0) + N(\cos \theta^N < 0)}$$

と定義すると

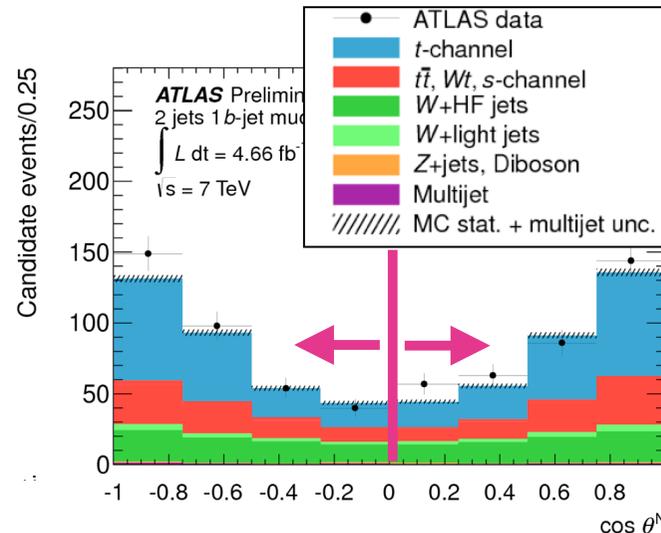
$$A_{FB}^N = 0.64 P \text{Im}(g_R)$$

## 事象再構成

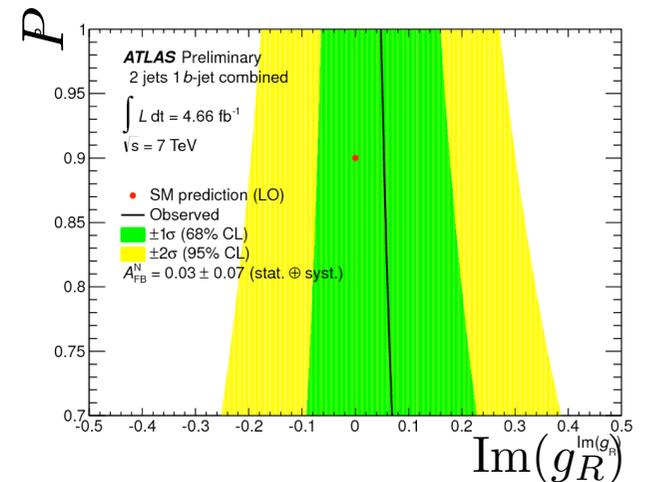
トップ由来 b, lepton は自明

$P_{\nu}$  は W boson の質量から算出

$M(\text{bl}\nu) = 150\text{-}190 \text{ GeV}$  に制限



$$A_{FB}^N = 0.031 \pm 0.065(\text{stat.}) \pm 0.029(\text{syst.}) \pm 0.031(\text{syst.})$$



$$\text{Im}(g_R) = [-0.20, 0.30]$$

# トップクォーク質量測定

Tevatron での測定 :  $m_t = 173.18 \pm 0.56(\text{stat.}) \pm 0.75(\text{syst.})\text{GeV}$

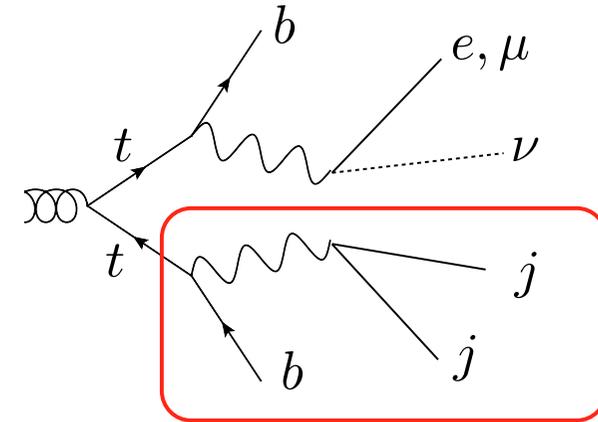
[arXiv:1207.1069 \[hep-ex\]](https://arxiv.org/abs/1207.1069)

解析チャンネル( 7 TeV, 1.04/fb )

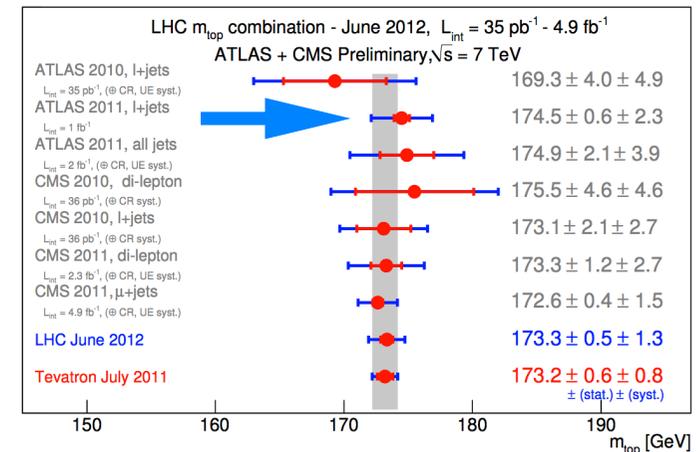
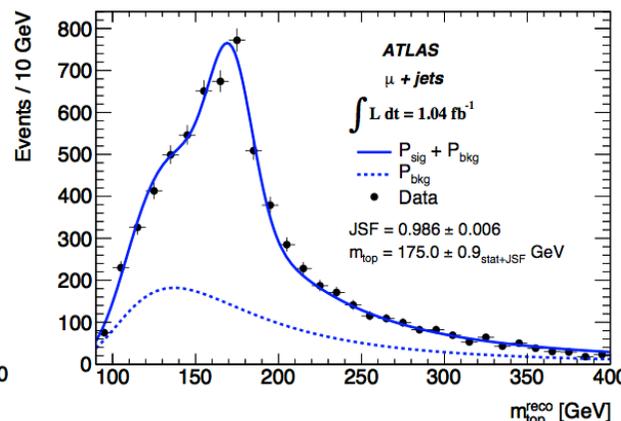
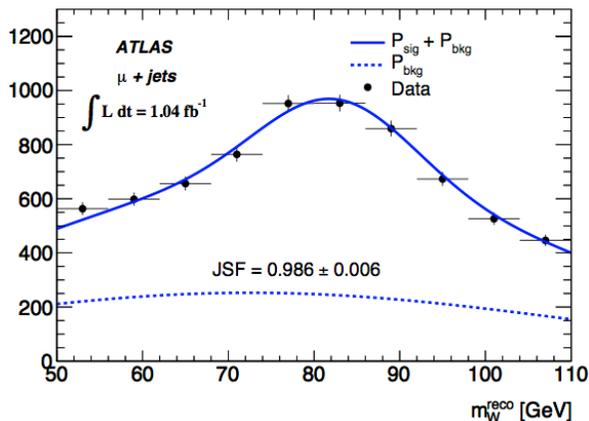
Single lepton

トップクォーク崩壊事象  $t \rightarrow bjj$  再構成

2 light jet( $50 < m_{jj} < 110\text{GeV}$ ) + b-tagged jet



$m_W^{\text{reco}}, m_{\text{top}}^{\text{reco}}$  2次元でのテンプレートフィッティング



$m_{\text{top}} = 174.5 \pm 0.6(\text{stat}) \pm 2.3(\text{syst})\text{ GeV}$

$m_{\text{top}} = 173.3 \pm 0.5(\text{stat}) \pm 1.3(\text{syst})\text{ GeV}$

**Tevatronに迫る精度にまで到達**

# 17 18 まとめ

7,8 TeV データを用いたトップクォーク物理

大統計トップクォークサンプルを用いた、SM の詳細な検証

## Production process

Differential cross section

boosted top tagging の確立

$$0.5\text{TeV} < M_{g_{KK}} < 2.1\text{TeV}$$

$$0.5\text{TeV} < M_{Z'} < 1.8\text{TeV}$$

$t\bar{t} + X$

$t\bar{t} + \gamma$

$$\sigma_{t\bar{t}\gamma} \cdot \text{Br} = 2.0 \pm 0.5(\text{stat.}) \\ \pm 0.7(\text{syst.}) \pm 0.08(\text{lumi.})$$

$t\bar{t} + Z$

$$\sigma_{t\bar{t}Z} \text{ upper limit (95\%C.L.) : } 0.71\text{pb}$$

## Properties

charge asymmetry

spin correlation

Tevatron との相補的な測定

W-t-b vertex

W boson polarization measurement

Tevatron を更新する精度での測定

Single top production

$$\text{Im}(g_R) = [-0.20, 0.30]$$

Mass

ATLAS+CMS combination

LHC から精度1.4GeV での測定達成

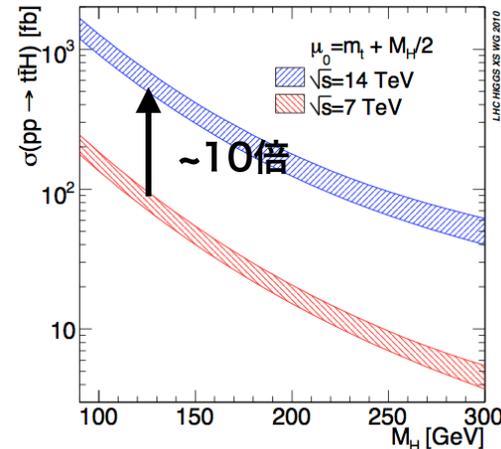
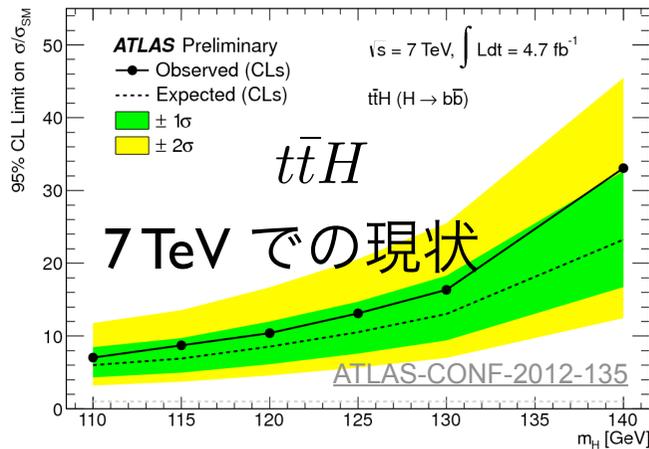
**Tevatron に迫る/更新する測定精度を達成**

**0.1 pb ( $t\bar{t}Z$ ) スケールにまで SM の実証が進めてこれた**

**BSM 探索が ~2 TeVにまで到達( $Z'$ ,  $g_{KK}$ )**

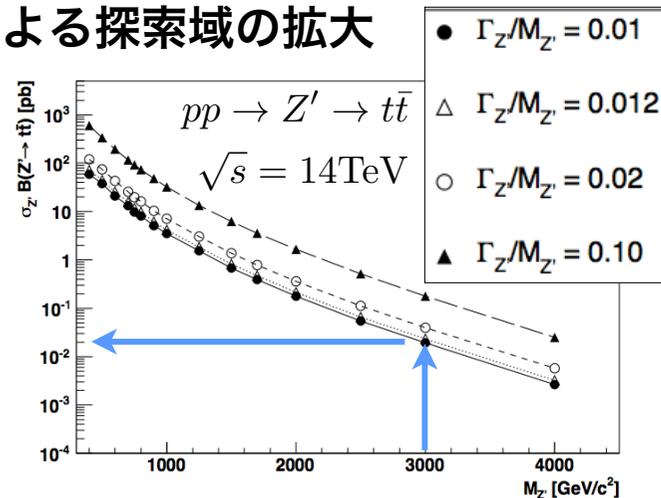
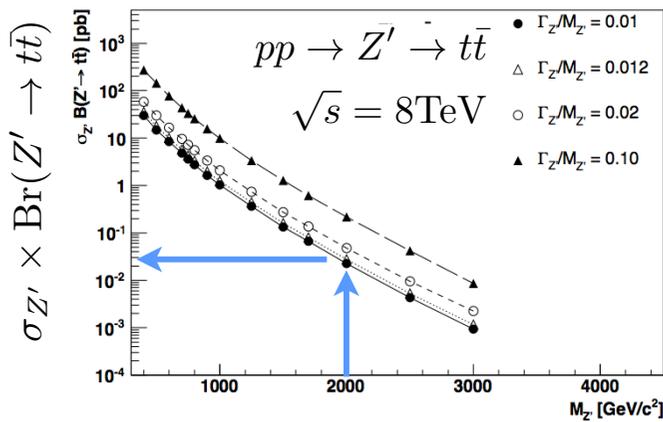
# 14 TeV でのトップクォーク物理の展望

$\sigma(ttH)$ @ 14 TeV ~ 0.6 pb, ~100/pb で見えてくる物理



arXiv:1101.0593 [hep-ph]

## BSM 探索：エネルギー増加による探索域の拡大



$$\sigma \text{Br}(Z' \rightarrow t\bar{t}) \frac{M_{Z'}=3\text{TeV}}{\sqrt{s}=14\text{TeV}}$$

$$\sim \sigma \text{Br}(Z' \rightarrow t\bar{t}) \frac{M_{Z'}=2\text{TeV}}{\sqrt{s}=8\text{TeV}}$$

$$\sim 10^{-2} \text{pb}$$

arXiv:1112.4928 [hep-ph]

7,8 TeV での解析手法(特に $t\bar{t}+X$ , boosted top)が14 TeV での研究に直結。  
これら成果を基礎として、移行していく事が重要

**backup slides**

# 20 18 Jet activity

$$f(Q_0) = \frac{n(Q_0)}{N} \quad \begin{array}{l} n(Q_0) : P_T > Q_0 \text{ を持った追加のジェットが居ないイベント数} \\ N : tt\text{bar event 総数} \end{array}$$

## Di-lepton channel

(追加のジェットの有無が明確)

Electron, Muon x 2

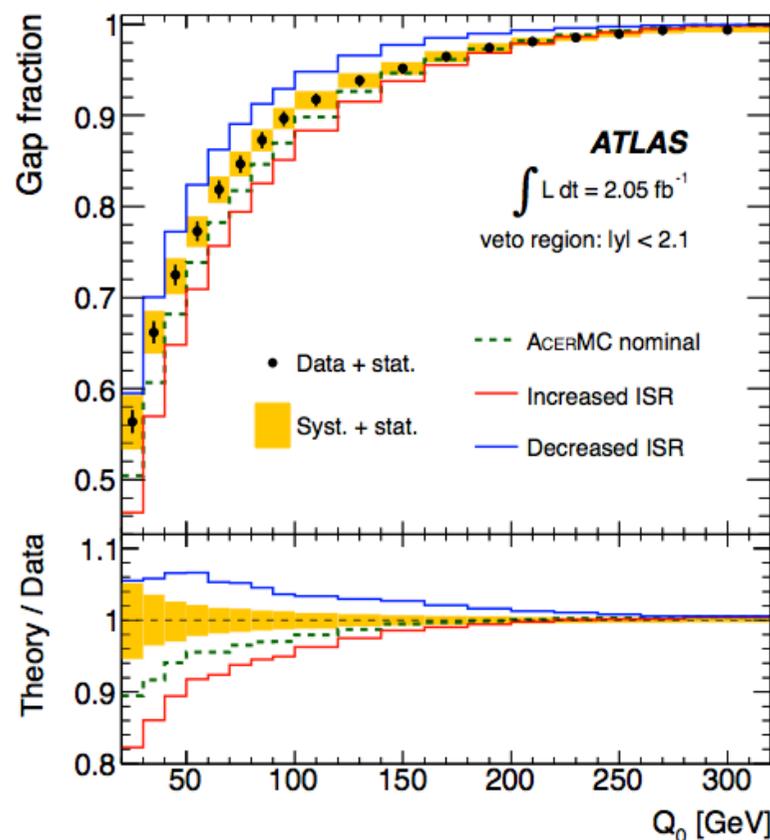
B-tagged jet x 2

Miss  $E_t > 40 \text{ GeV}$  (ee, mm)

$|M_{ll} - Z\text{mass}| > 10 \text{ GeV}$  (ee, mm)

$HT > 130 \text{ GeV}$  (em)

追加ジェットは  $|\eta| < 2.1$



# Charge asymmetry

Table 4: SM cut-independent asymmetries  $A_\eta$  and  $A_y$  at different LHC energies.

	$A_C^\eta$	$A_C^y$
LHC 7 TeV	0.0136 (8)	0.0115 (6)
LHC 8 TeV	0.0122 (7)	0.0102 (5)
LHC 10 TeV	0.0101 (6)	0.0082 (4)
LHC 12 TeV	0.0087 (5)	0.0068 (3)
LHC 14 TeV	0.0077 (4)	0.0059 (3)
LHC 7 TeV CMS [45] $1.09 \text{ fb}^{-1}$	$-0.016 \pm 0.030$ $^{+0.010}_{-0.019}$	$-0.013 \pm 0.026$ $^{+0.026}_{-0.021}$
LHC 7 TeV ATLAS [46] $0.7 \text{ fb}^{-1}$		$-0.024 \pm 0.016 \pm 0.023$

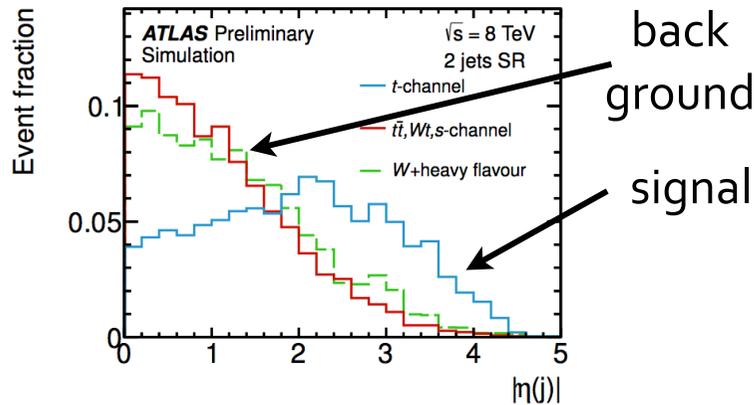
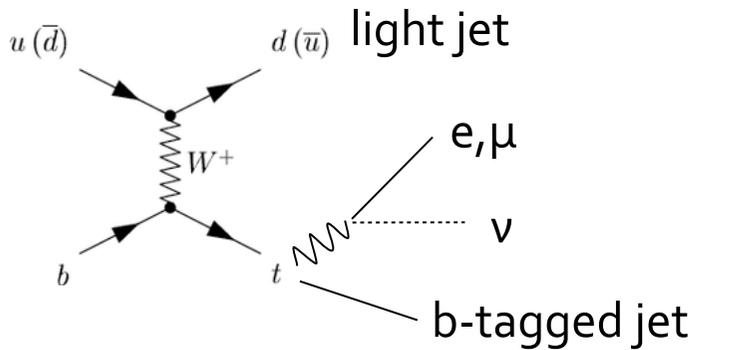
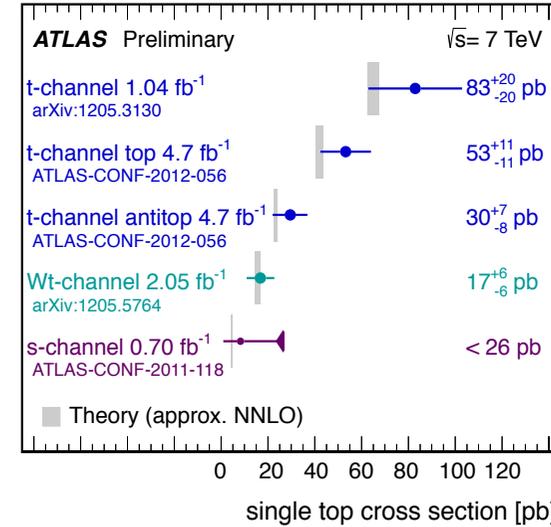
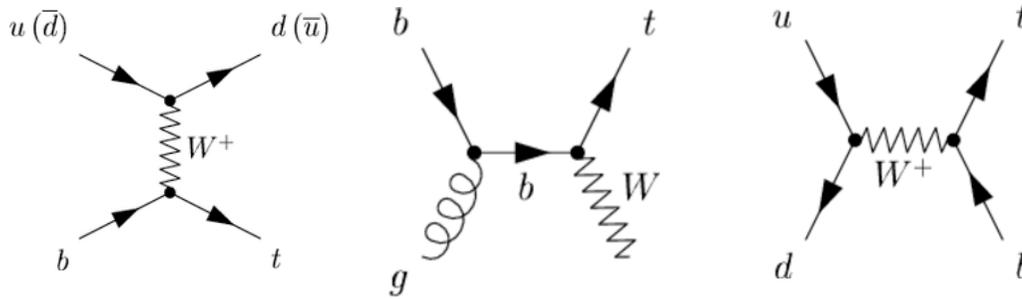
[arXiv:1109.6830](https://arxiv.org/abs/1109.6830) [hep-ph]

22  
18

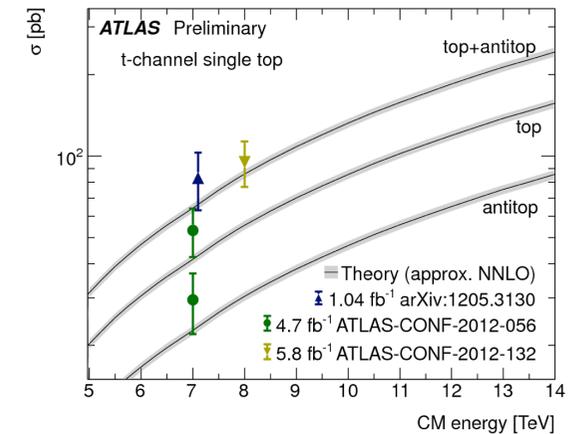
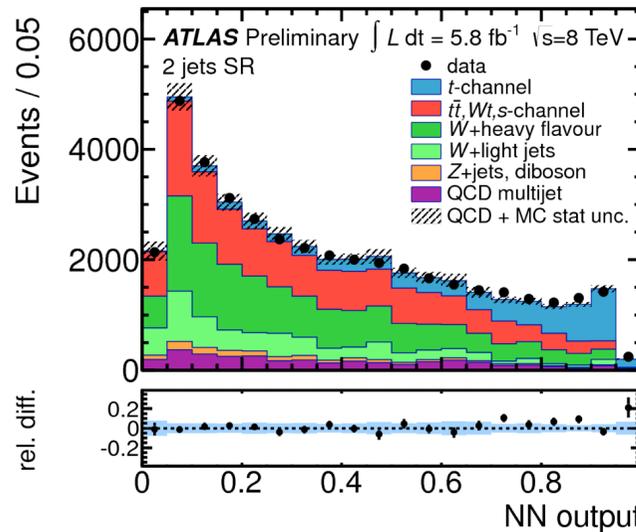
# Single top 生成断面積測定

The summary plot from <https://twiki.cern.ch/twiki/bin/view/AtlasPublic/CombinedSummaryPlots>

**t-channel** **Wt-channel** **s-channel**



合計11変数を用いたNN



# トップクォーク質量測定 : eμ channel

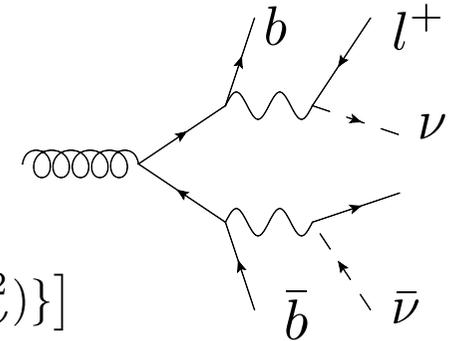
emu channel での top quark mass 測定

Met から 2個のニュートリノの reconstruct は困難

MT2 (stransverse mass)からの測定

$$m_{T2} = \min_{\vec{p}_\nu^1 + \vec{p}_\nu^2 = \vec{p}_{\text{miss}}} [\max\{m_T(p_l^1, p_{b\text{-jet}}^1, \vec{p}_\nu^1), m_T(p_l^2, p_{b\text{-jet}}^2, \vec{p}_\nu^2)\}]$$

→親粒子の質量下限に相当する



## 事象選別

e + μ

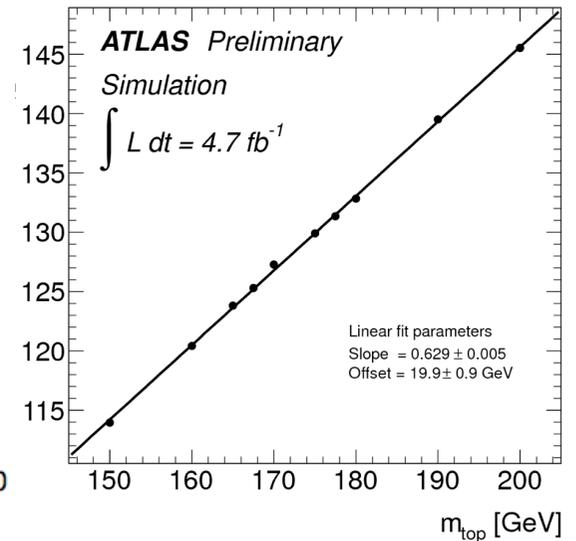
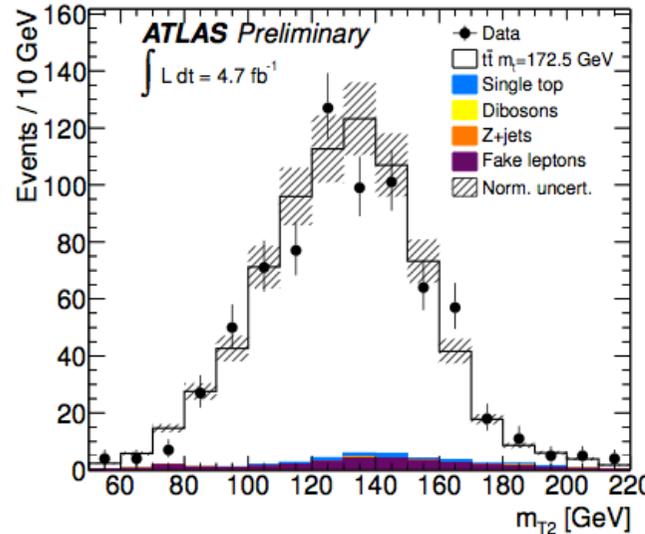
2 b-tagged jets, PT>45GeV

delta phi > 2.2

MissEt > 20 GeV

HT = sum|PT| > 130 GeV

MT2<220 GeV

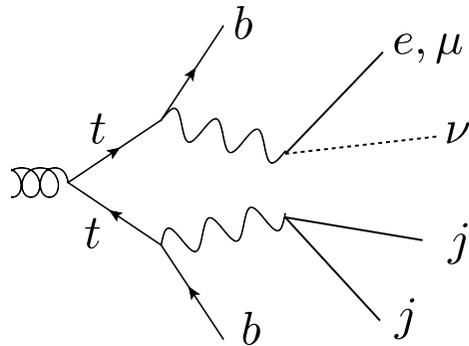


MT2 mean -> Mtop mass に換算する

$$m_{\text{top}} = 175.2 \pm 1.6(\text{stat.})_{-2.8}^{+3.1}(\text{syst.}) \text{ GeV}$$

# 24 / 18 8 TeV でのトップクォーク対生成断面積測定

8 TeV, 5.8/fb, Single lepton channel での解析



Electron  $E_T > 40 \text{ GeV}$ , Muon  $P_T > 40 \text{ GeV}$ ,

e :  $MissE_T > 30 \text{ GeV}$ ,  $M_T > 30 \text{ GeV}$

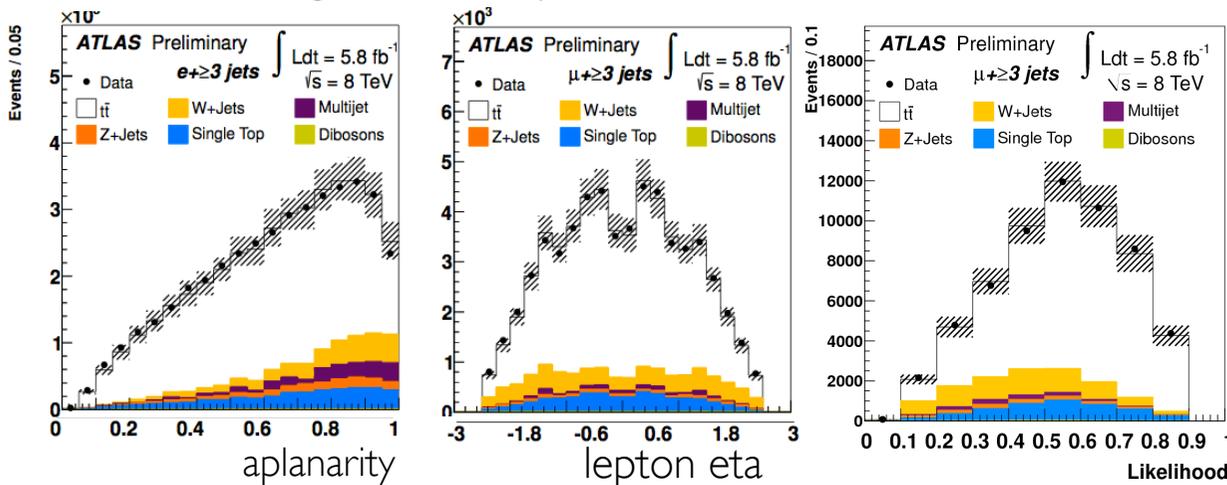
mu :  $MissE_T > 20 \text{ GeV}$ ,  $M_T + MissE_T > 60 \text{ GeV}$

$$m_T(W) = \sqrt{2p_T(\ell)E_T^{\text{miss}} [1 - \cos \Delta\phi(\ell, E_T^{\text{miss}})]}$$

3 jets,  $P_T > 25 \text{ GeV}$ ,  $|\eta| < 2.5$

at least one b-tagged

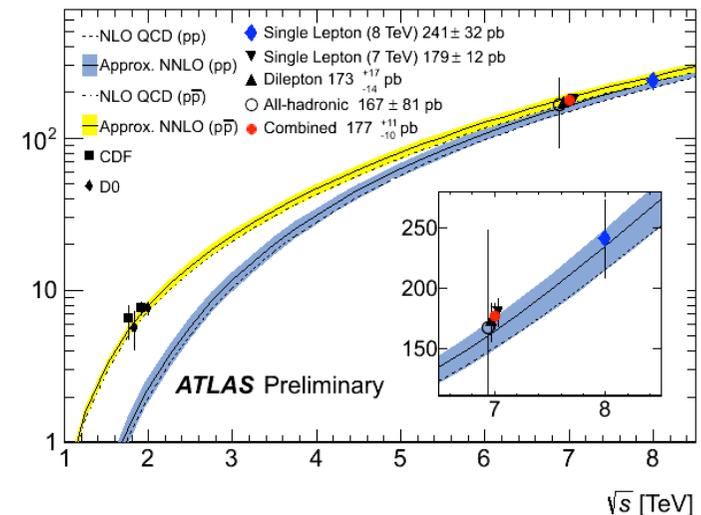
Signal vs W+jets の Likelihood



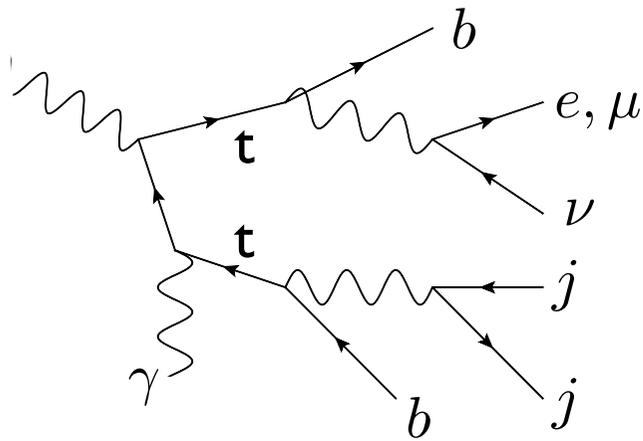
signal,  $W \rightarrow e\mu$ ,  $W \rightarrow \mu\nu$  の寄与を Fitting から算出

$$\sigma = 241 \pm 2(\text{stat.}) \pm 31(\text{syst.}) \pm 9(\text{lumi.}) \text{ pb}$$

$$\sigma_{t\bar{t}}^{\text{theory}} = 238^{+22}_{-24} \text{ pb}$$



25 / 18 **ttbar +  $\gamma$  生成断面積測定**

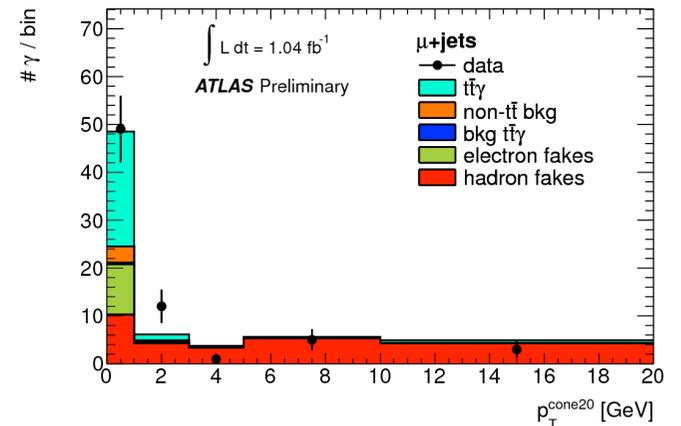
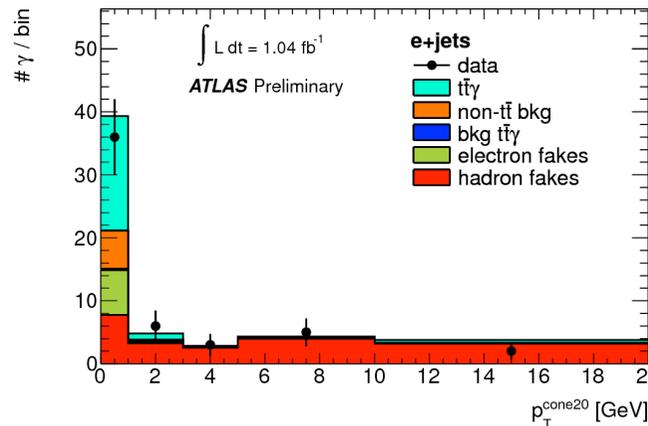
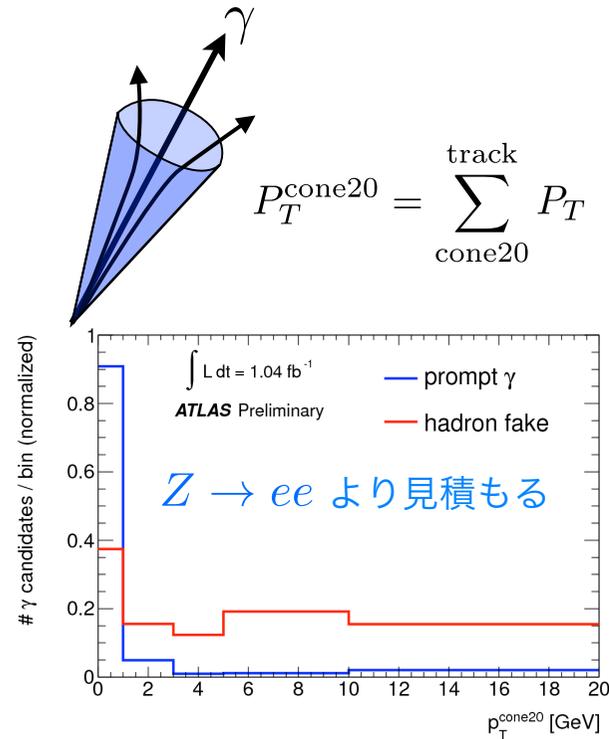


7 TeV, 1.04 /fb を用いた解析

Single lepton channel +  $\gamma$  終状態

$t\bar{t}$  { Electron  $E_T > 40\text{GeV}$ , Muon  $P_T > 40\text{GeV}$ ,  
 e :  $\text{Miss}E_T > 30\text{GeV}$ ,  $M_T > 30\text{GeV}$   
 mu :  $\text{Miss}E_T > 20\text{ GeV}$ ,  $M_T + \text{Miss}E_T > 60\text{GeV}$   
 3 jets,  $P_T > 25\text{GeV}$ ,  $|\eta| < 2.5$ , at least one b-tagged  
 Photon  $P_T > 15\text{ GeV}$

$m(e\gamma) < 86\text{ GeV}$  OR  $m(e\gamma) > 86\text{ GeV}$

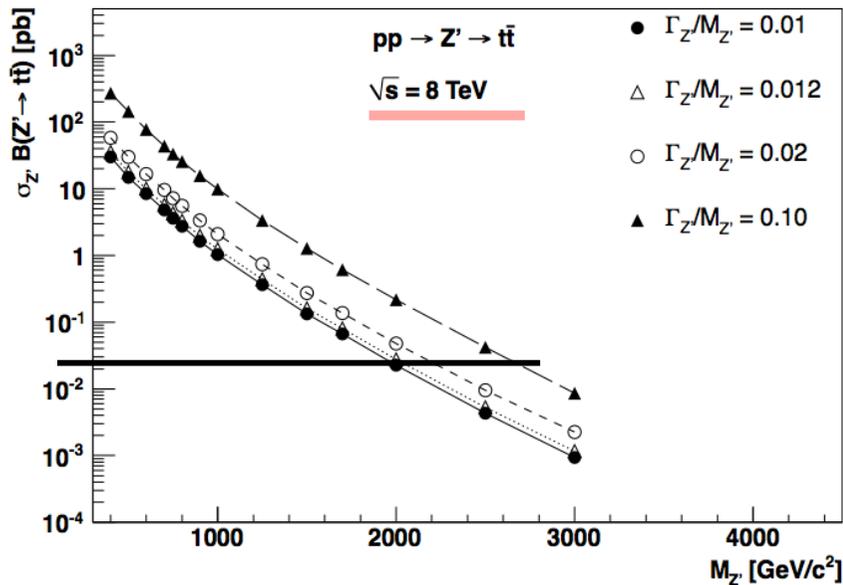
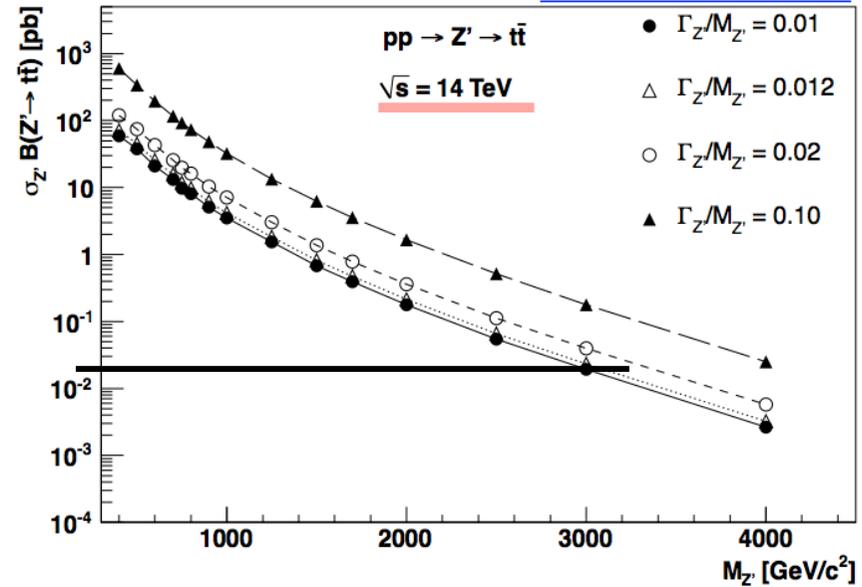
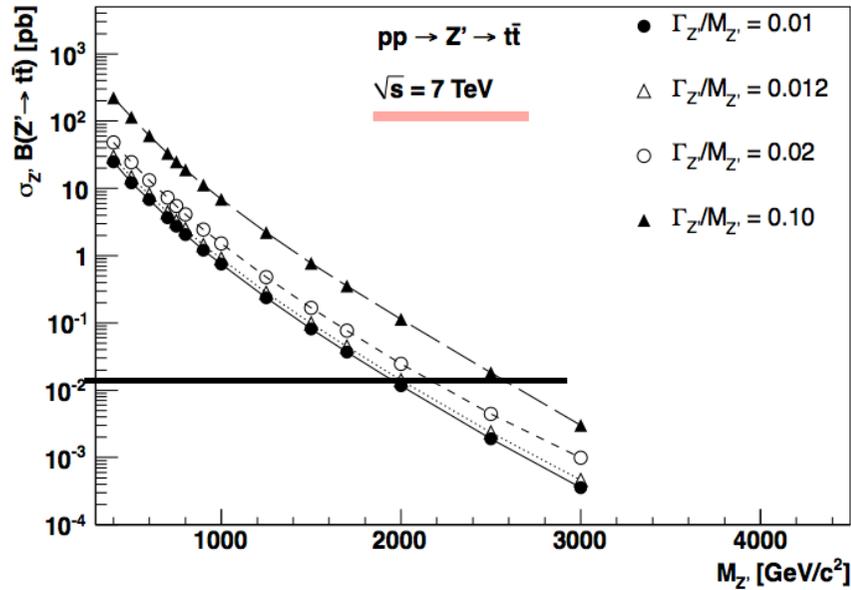


$$\sigma_{t\bar{t}\gamma} \cdot \text{Br} = 2.0 \pm 0.5(\text{stat.}) \pm 0.7(\text{syst.}) \pm 0.08(\text{lumi.})$$

$$(\sigma_{t\bar{t}\gamma} \cdot \text{Br})^{\text{SM}} = 2.1 \pm 0.4\text{pb}$$

“Cross Sections for Leptophobic Topcolor Z' decaying to top-antitop”

arXiv:1112.4928 [hep-ph]





## ttbar resonance

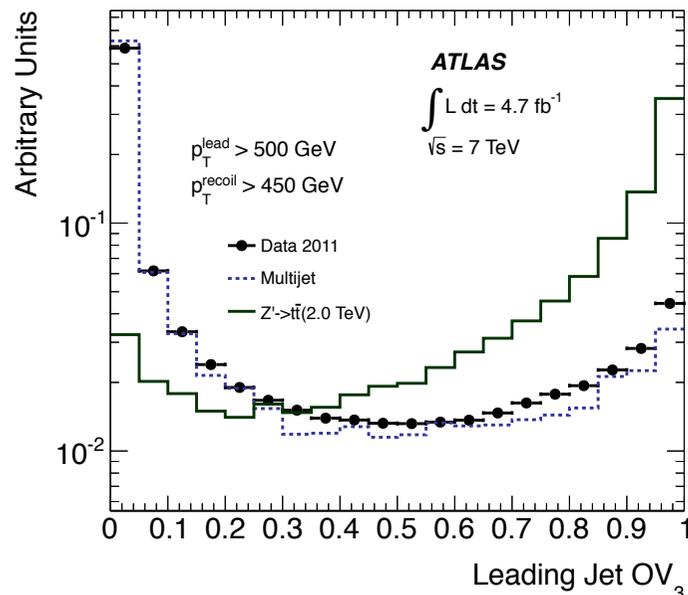
7 TeV 4.7/fb,

full hadron channel : top 由来の lepton & b-jet overlap の問題が無い

Fat jet の top quark tagging

HEPTopTagger : Fat jet を  $ET < 50 \text{ GeV}$  の subjet にまで成分分解し  $t \rightarrow bjj$  に対応する 3 ジェットの組の有無で判別

Template tagger : シミュレーションで top quark 娘粒子の力学分布テンプレートを複数用意し、Fat Jet 中のクラスター分布と比較、[0-1]で点数化



Selection

HEPTopTagger :

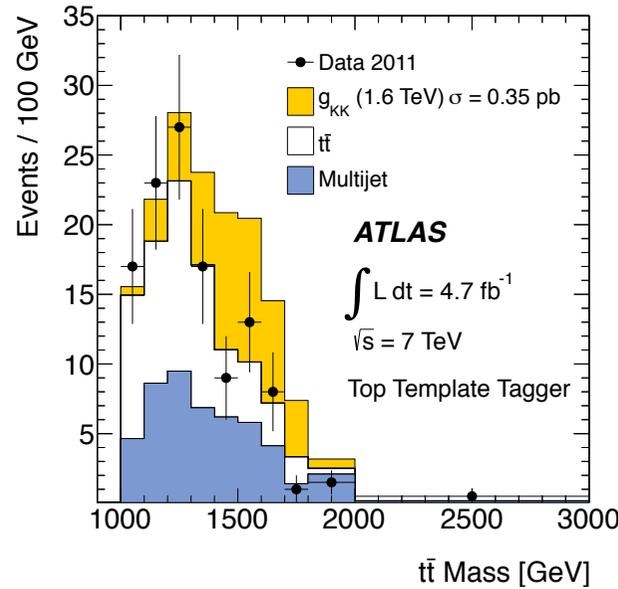
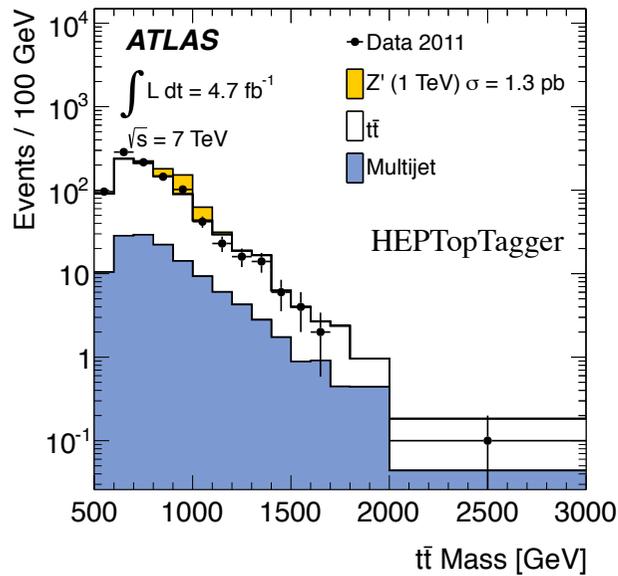
cone 1.5 の Fat jets x2 :  $PT > 200 \text{ GeV}, |\eta| < 2.0$

Template Tagger :

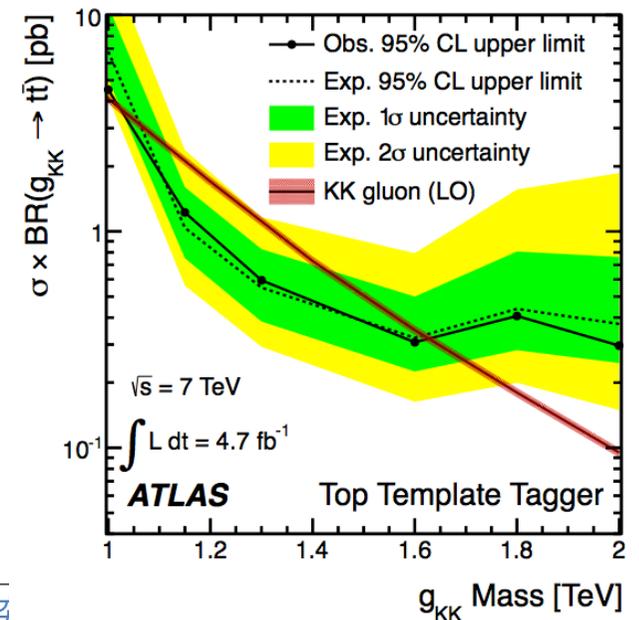
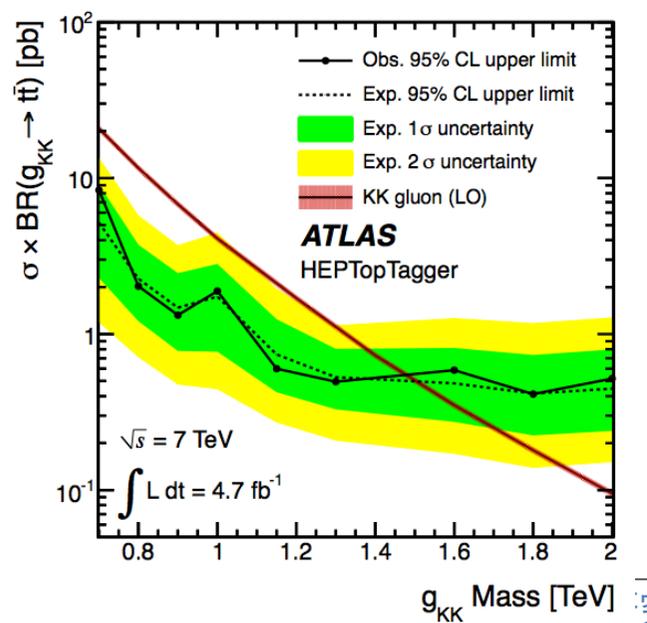
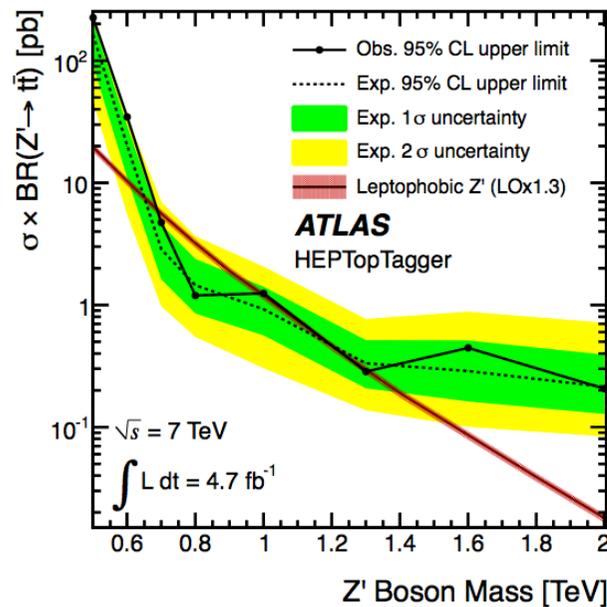
cone 1.0 fat jet x2 :  $PT > 500, 450 \text{ GeV}, |\eta| < 2.5$

各 fat jet の sub-jet が b-tagged されている事。

29 / 18 ttbar resonance



Model	Obs. Limit (TeV)
HEPTopTagger	
Z'	$0.70 < m_{Z'} < 1.00$ $1.28 < m_{Z'} < 1.32$
KK gluon	$0.70 < m_{g_{KK}} < 1.48$
Top Template Tag	
KK gluon	$1.02 < m_{g_{KK}} < 1.62$



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18

# Same sign top-quark production

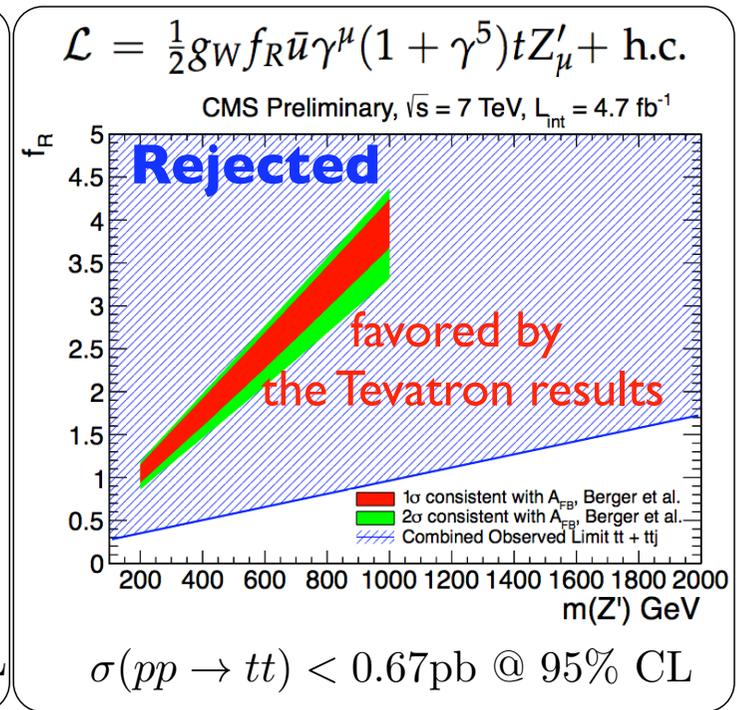
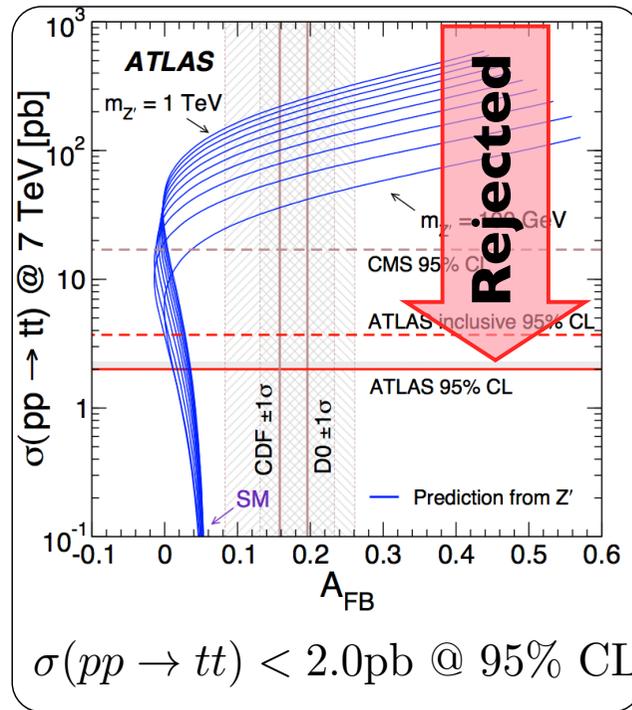
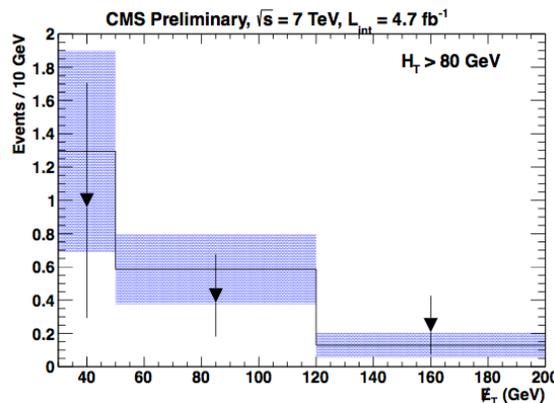
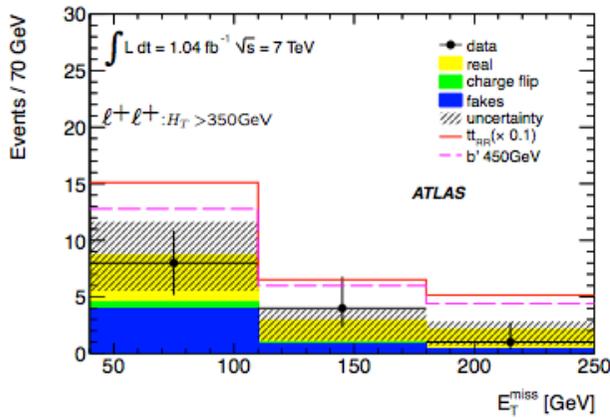
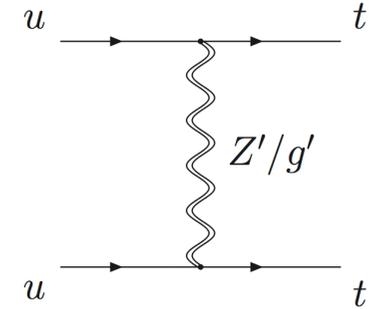
It is interesting especially for Z' search.

-- Z' can explain charge asymmetry observed at the Tevatron.

Basic strategy : di-lepton with the same charge, missing E<sub>T</sub>, two jet

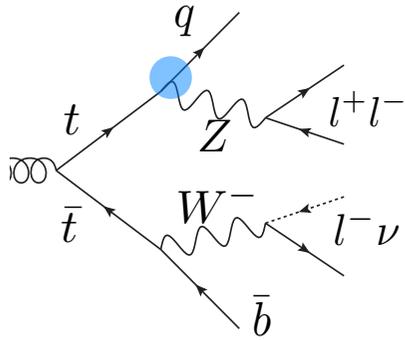
CMS required two b-tagged jets to reduce t $\bar{t}$  background.

No excess was observed in ATLAS and CMS.



**Both results excluded Z' parameter region favored by the Tevatron's F/B asymmetry results.**

# 31/18 “tZq” search in top quark pair decay



**Basic strategy** :  $t\bar{t} \rightarrow bW + qZ \rightarrow bl\nu + qll$  and reconstruction.

**ATLAS** : reconstruct event based on chi2 minimization.

$$\chi^2 = \frac{(m_{ja\ell_b}^{\text{reco}} - m_t)^2}{\sigma_t^2} + \frac{(m_{jb\ell_c\nu}^{\text{reco}} - m_t)^2}{\sigma_t^2} + \frac{(m_{\ell_c\nu}^{\text{reco}} - m_W)^2}{\sigma_W^2} + \frac{(m_{\ell_a\ell_b}^{\text{reco}} - m_Z)^2}{\sigma_Z^2},$$

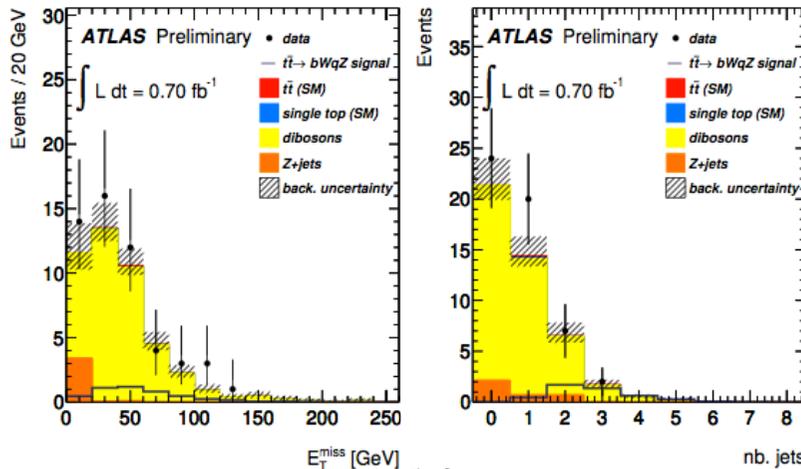
$\sigma_t = 14 \text{ GeV},$   
 $\sigma_W = 10 \text{ GeV}$   
 $\sigma_Z = 3 \text{ GeV}.$

Additional cut :  $|m_{l\nu}^{\text{reco}} - m_W| < 30\text{GeV}, |M_t^{\text{reco}} - M_t| < 40\text{GeV}$

**CMS** : reconstruct neutrino momentum from missing ET assuming W boson mass.

Additional cut : at least one b-tagged jet,  $|M_{Zj} - M_t| < 25\text{GeV}, |M_{Wb} - M_t| < 35\text{GeV}$

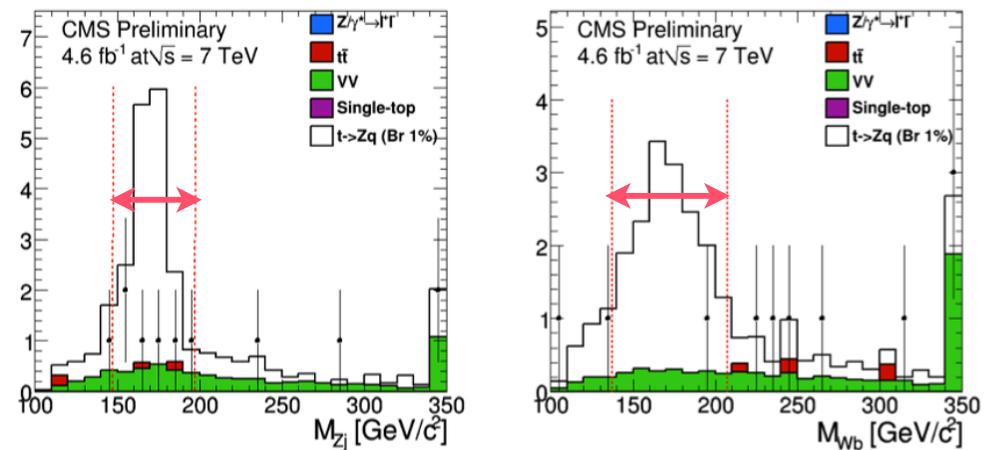
Distributions after the basic selection.



Expected BG =  $2.4_{-0.3}^{+1.8}$  events, 2 observed

**Br(t->Zq) < 1.13% 95% C.L.**

Distributions after reconstruction.



Expected BG =  $0.6_{-0.1}^{+0.1}$  events, 0 observed

**Br(t->Zq) < 0.34% 95% C.L.**

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# “tqg” in single top production

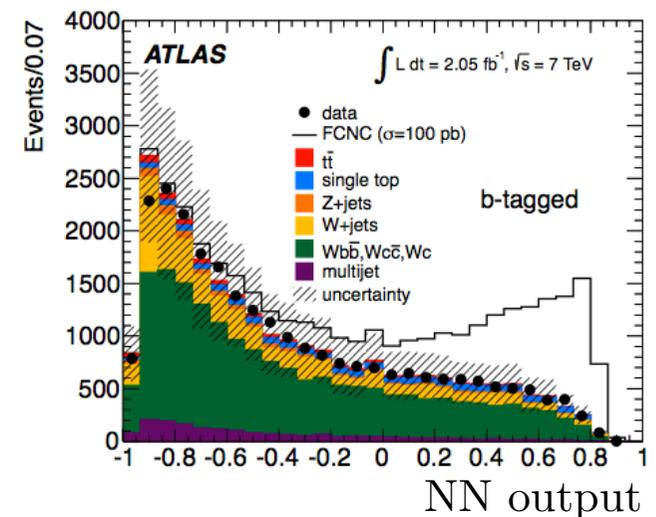
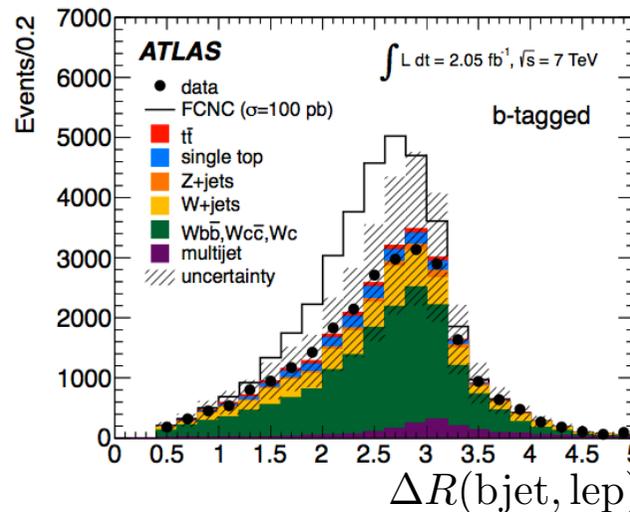
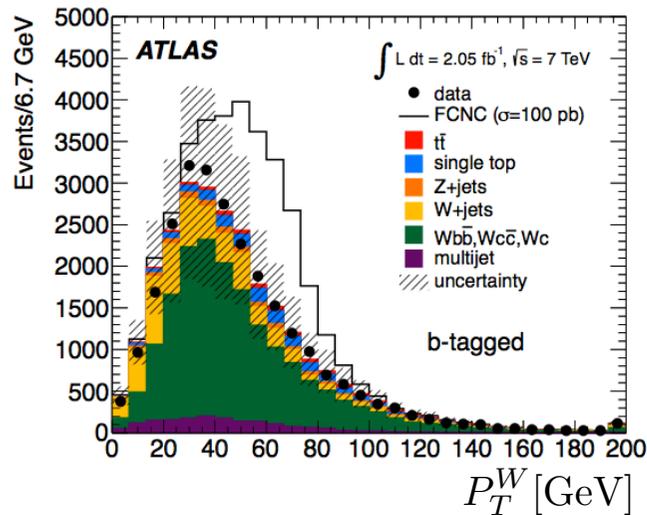
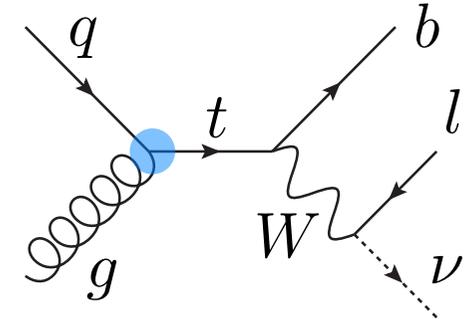
Target : Single top production via the FCNC + leptonic decay

Basic selection : exact one lepton and b-tagged jet, large missing  $E_T$ .

Neural Network to separate from SM background : 11 inputs

$P_T^W$  : is large since W boson emitted from a top quark.

$\Delta R(\text{bjet}, \text{lep})$  : is large since top quark is produced almost without transverse momentum.



Upper limit is set

$$\sigma(qg \rightarrow t) < 3.9 \text{ pb (95\% CL.)}$$

and it corresponds to

$$\text{Br}(t \rightarrow ug) < 5.7 \cdot 10^{-5}$$

$$\text{Br}(t \rightarrow cg) < 2.7 \cdot 10^{-4}$$