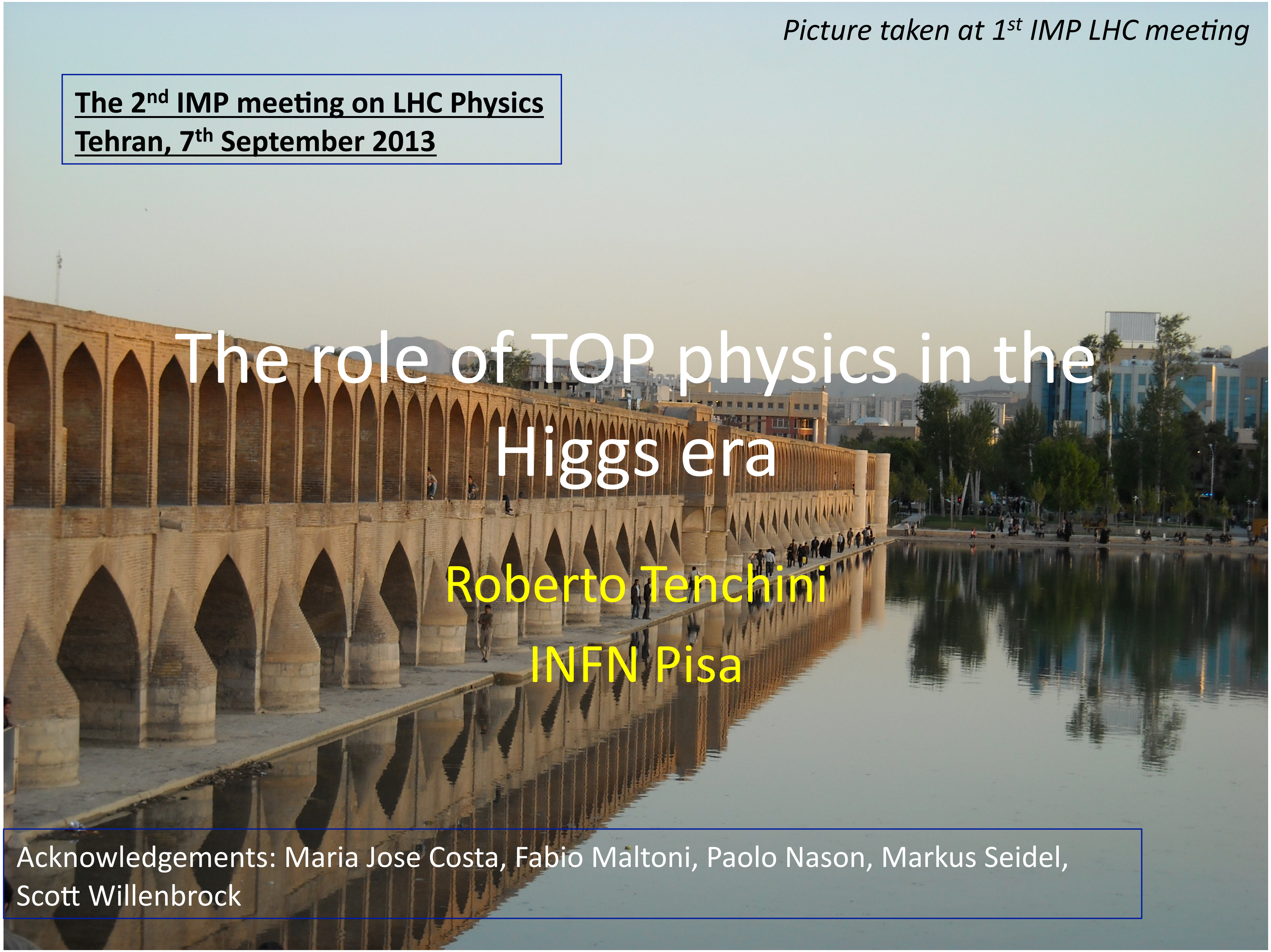


Picture taken at 1st IMP LHC meeting

The 2nd IMP meeting on LHC Physics
Tehran, 7th September 2013

The role of TOP physics in the Higgs era

Roberto Tenchini
INFN Pisa

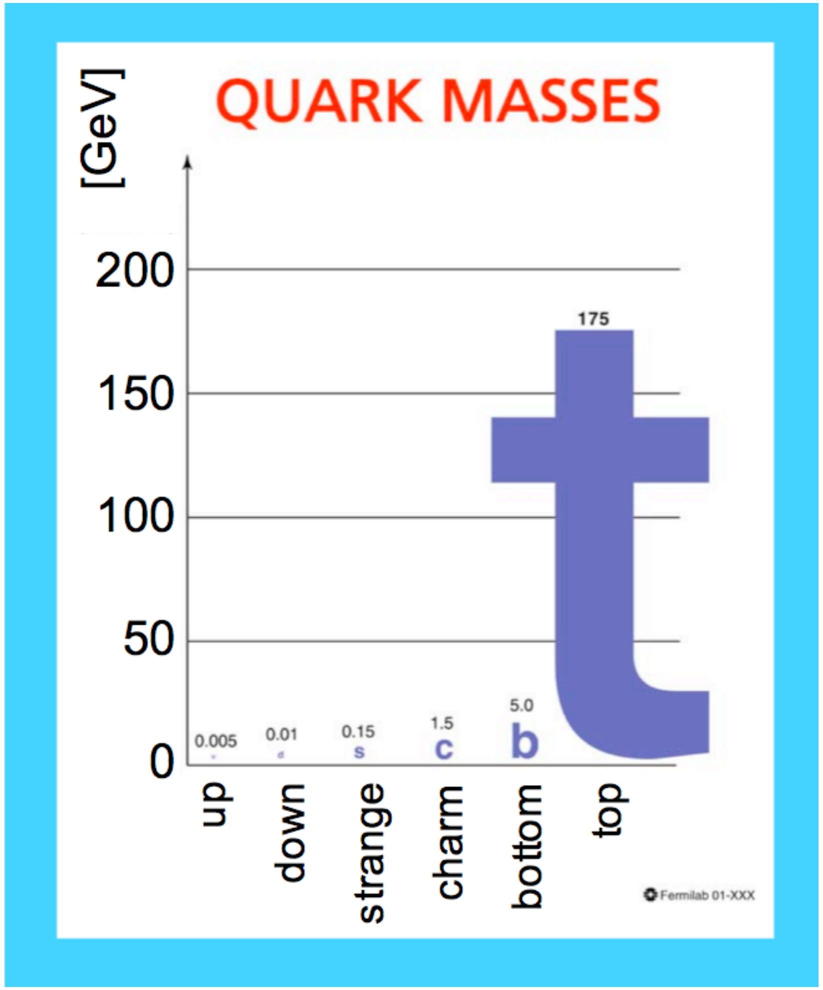
Acknowledgements: Maria Jose Costa, Fabio Maltoni, Paolo Nason, Markus Seidel, Scott Willenbrock

The sixth guy stands up !

- The up-like quark of the third family, the top quark, has **a mass comparable to a tungsten atom** !
- In other words, **the top – Higgs Yukawa coupling is large (≈1)**:
    - *top is a window to electroweak symmetry breaking*

$$Y = \sqrt{2}\frac{m_{top}}{\text{v.e.v.}(\sim 246\ \text{GeV})}$$

$$\Gamma(H \to f\bar{f}) = \frac{N_c g^2 m_f^2}{32\pi m_W^2}\beta^3 m_H$$



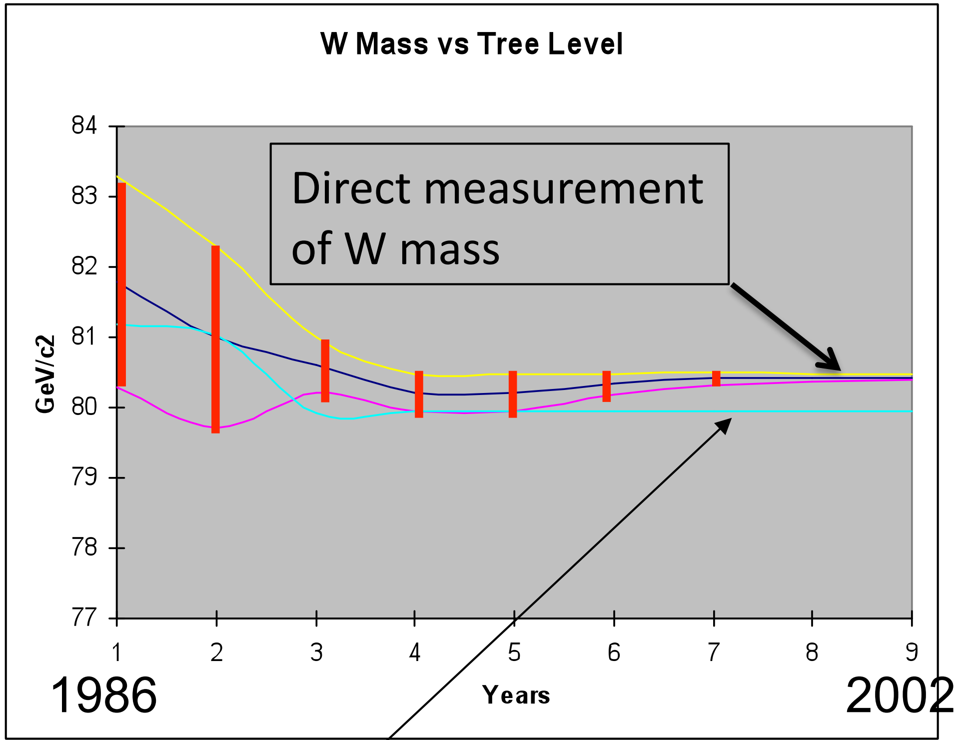
Some consequences of the large top mass (the large top-Higgs Yukawa coupling)

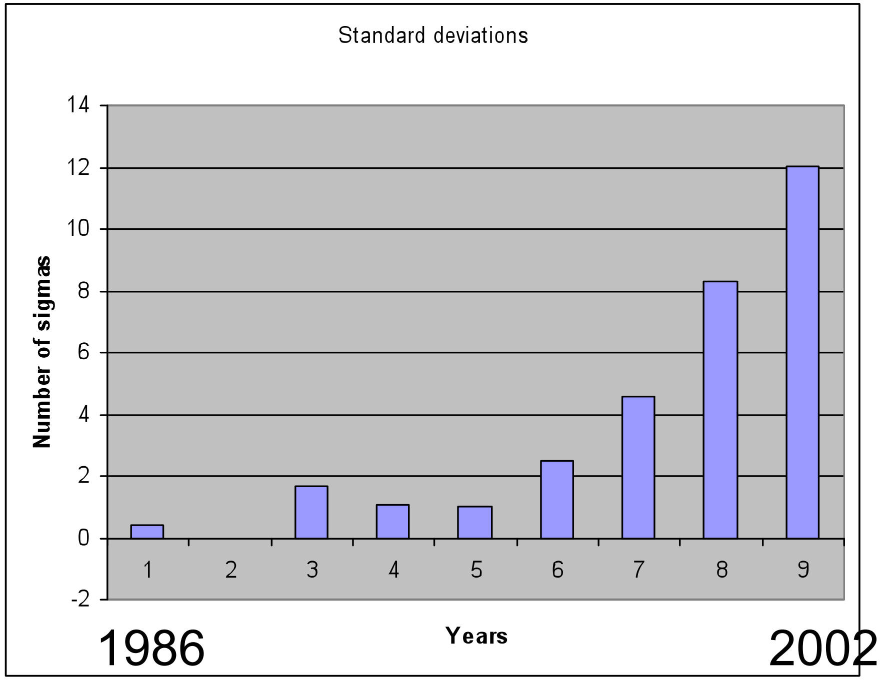
- Due to the non-decoupling properties of electroweak interactions (Maiani and Veltman, 1977) the top quark gives large contributions to pure EWK radiative corrections $\approx G_F m_t^2$
- Very short lifetime: bound states are not formed, opportunity to study a free quark

$\tau_{top} \simeq 0.4 \times 10^{-24}\, s$

$$\Gamma(t \to bW) = \frac{G_F}{8\pi\sqrt{(2)}} m_t^3 |V_{tb}|^2 \approx 1.5\,\mathrm{GeV/c^2}.$$

Evidence of electroweak loops





Strong Evidence of pure E.W. Higher Order Corrections

E.W. Tree level SM relation

(with running α QED)

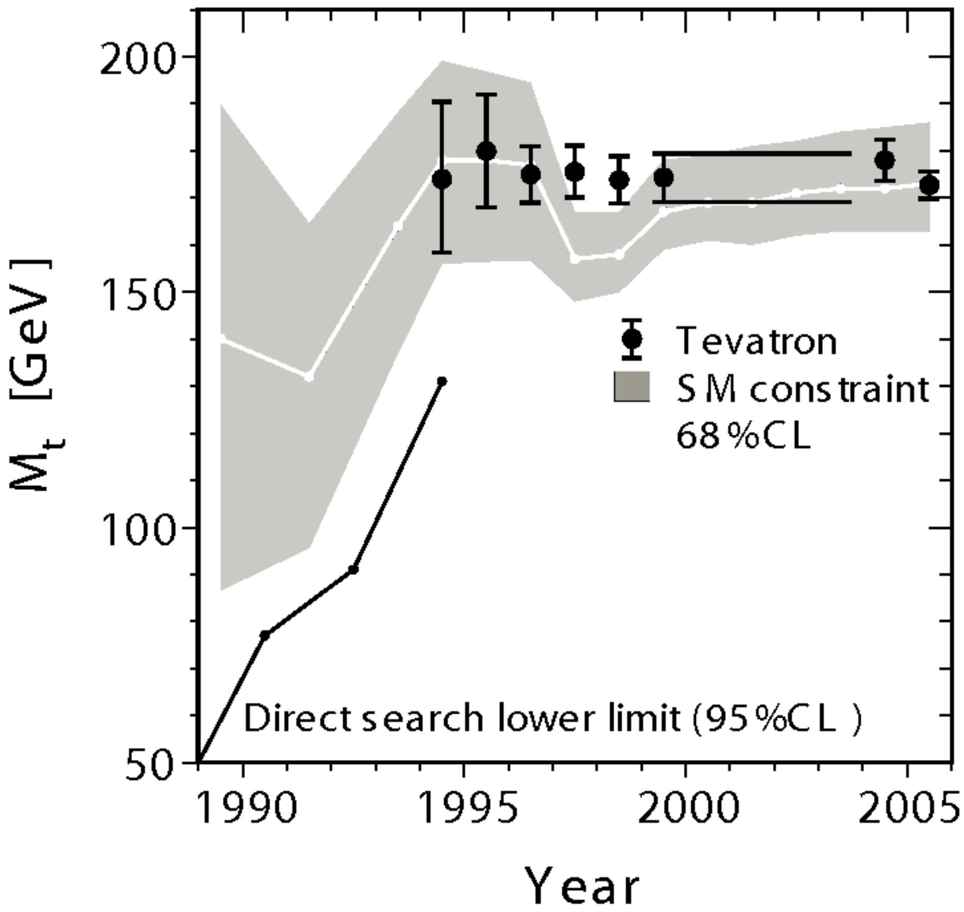
$$M_W^{\ 2}\left(1-\frac{M_W^{\ 2}}{M_Z^{\ 2}}\right)=\frac{\pi\alpha(M_Z)}{\sqrt{2}}\frac{1}{G_F}$$

$$\alpha(\sqrt{s}=\mathrm{M}_Z)=\frac{1}{128.936\pm0.046}$$

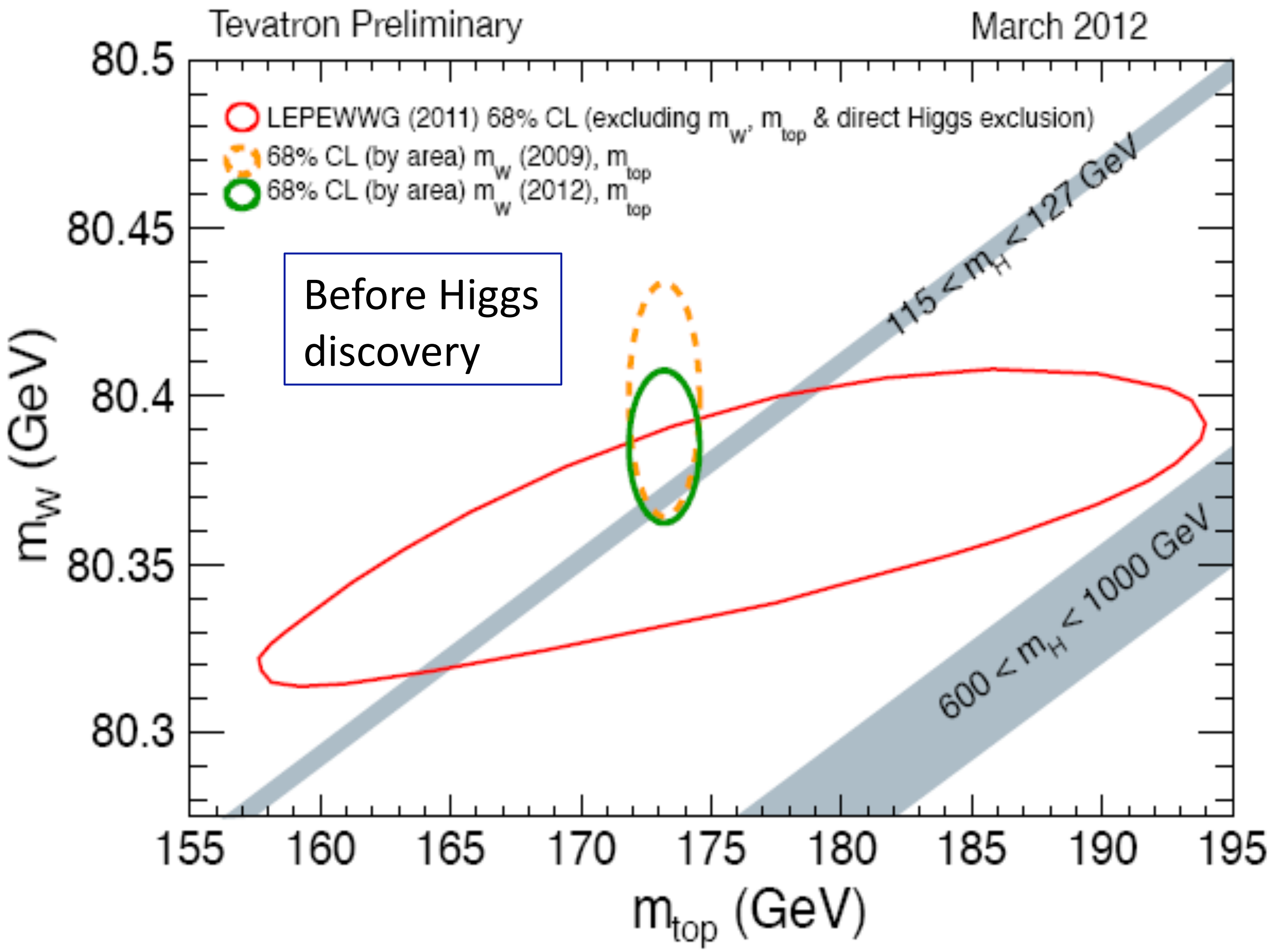
Top quark discovery and indirect determination from electroweak loops

The **precision measurements** of the W and Z mass, together with other electroweak observables (e.g. initial and final state asymmetries) **test the Standard Model at the level of radiative corrections**

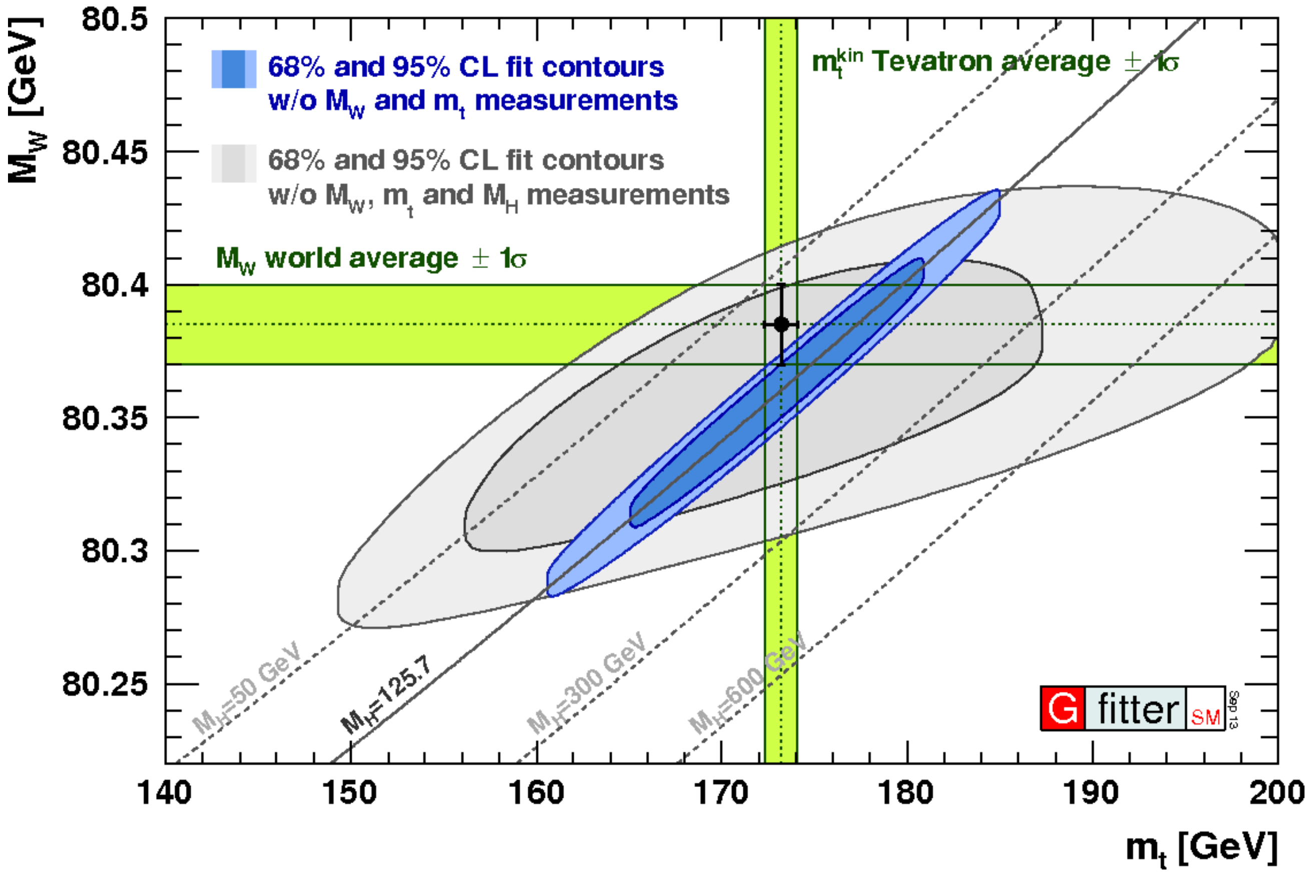
The **top quark mass** from the **direct** measurement **matches** the **indirect** determination from radiative corrections !



Relation between W, top and logarithmic sensitivity to the Higgs mass

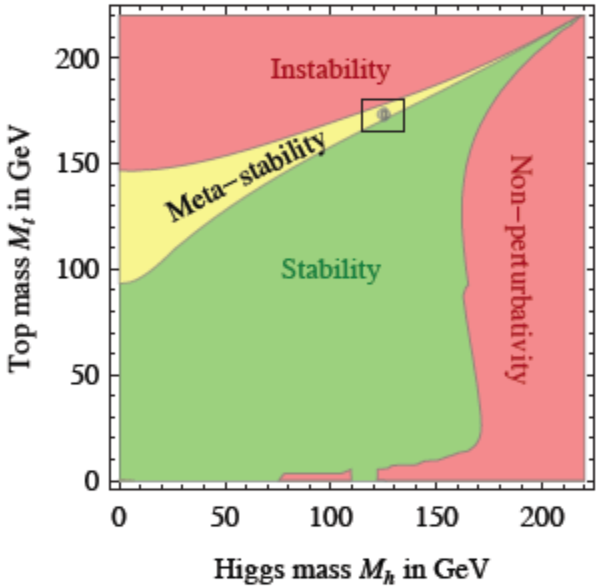


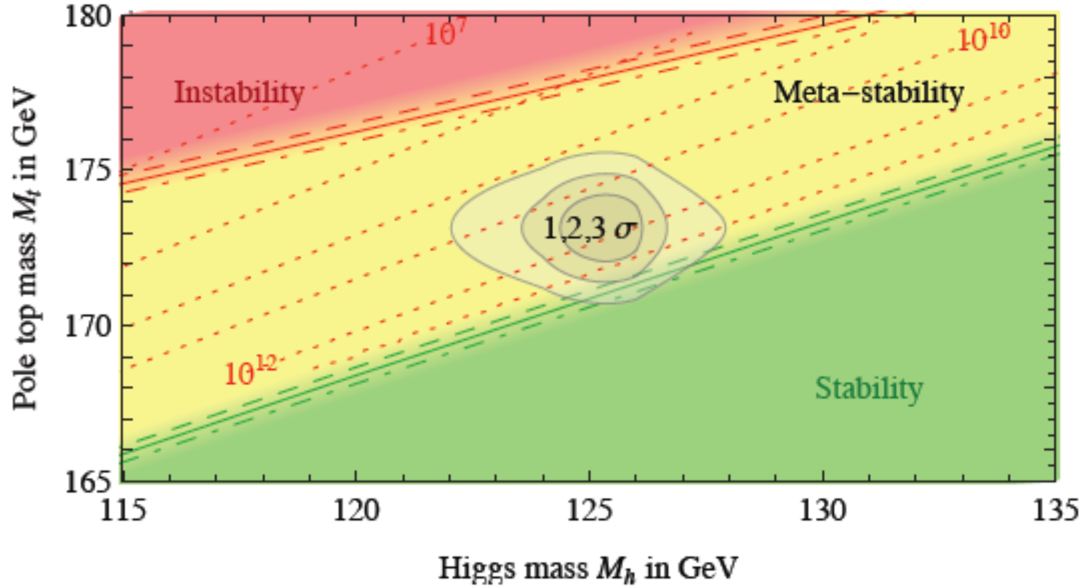
After Higgs discovery the same plot represents an important test of the SM



Relation between top and Higgs masses and stability of the vacuum in our universe

Electroweak Vacuum → $V = \frac{1}{2}\mu^2\Phi^2 + \frac{1}{4}\lambda(scale)\Phi^4$



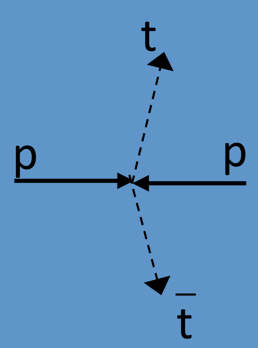


De Grassi et al. ArXiv:1205.6497

TOP PRODUCTION AND DECAY: GETTING THE DATA SAMPLES

Top Quark Production at the LHC

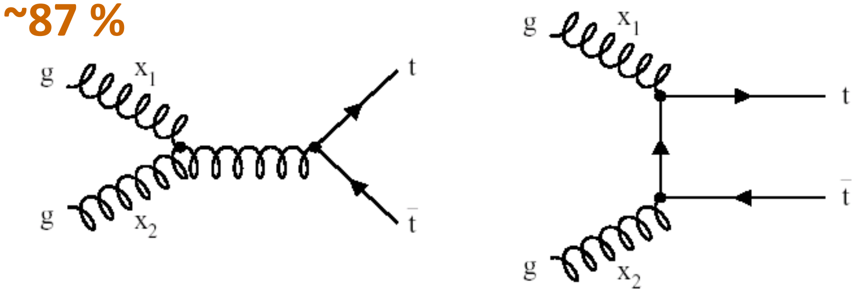
top pairs

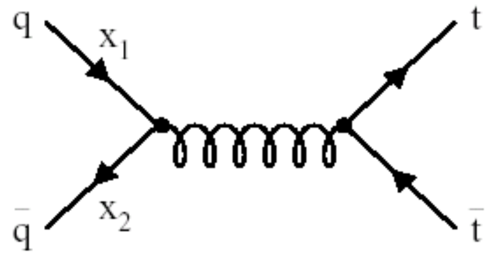


10 $t\bar{t}$ pairs per day @ Tevatron → 1 $t\bar{t}$ pair per second @ LHC

$q\bar{q} \rightarrow t\bar{t}$: 85% *$gg \rightarrow t\bar{t}$: 87%*

~87 %

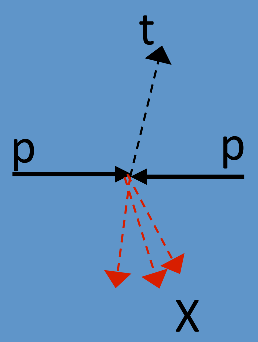




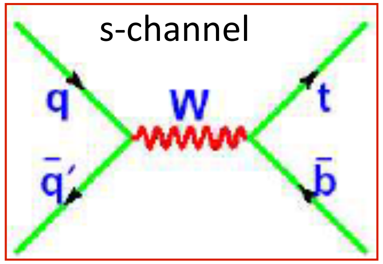
❖ NLO cross-section σ^{NLO} = **232** pb at 8 TeV ~2 M events/10fb^{-1}

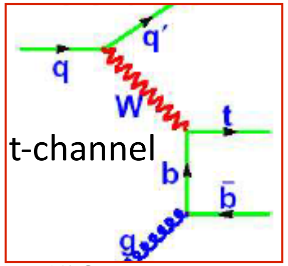
Some references (not a complete list!): (top pairs) N.Nason *et al.* Nucl.Phys. B303 (1988) 607, S.Catani *et al.* Nucl.Phys. B478 (1996) 273, M.Beneke *et al.* hep-ph/0003033, N.Kidonakis and R.Vogt, Phys.Rev. D68 (2003) 114014, W.Bernreuther et al. Nucl.Phys. B690 (2004) 81-137 (single-top) T.Stelzer et al. Phys.Rev. D56 (1997) 5919, M.C.Smith and S.Willenbrock Phys.Rev. D54 (1996) 6696, T.M.Tait Phys.Rev. D61 (2000) 034001

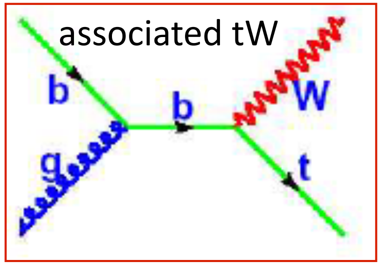
single-top



30 single-tops per minute @ LHC







σ_{top} & $\sigma_{anti\text{-}top}$ not equal

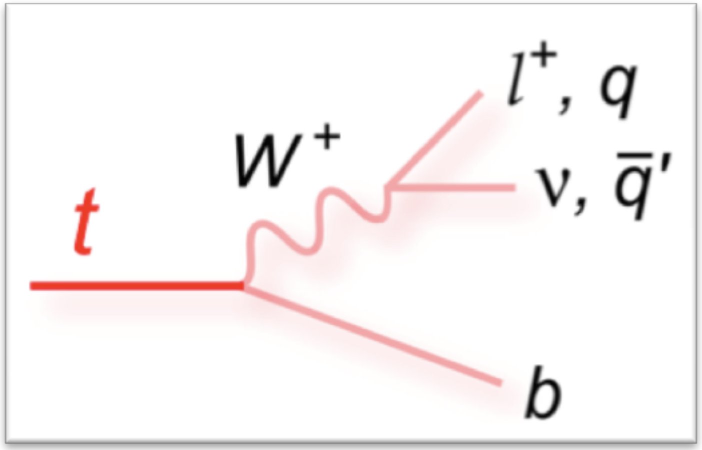
σ^{NLO}(total) 8 TeV = **112** pb

~1 M events/10fb^{-1}

s-channel	t-channel	associated tW	
σ^{NLO} = 3.4 pb	σ^{NLO} = 53 pb	σ^{NLO} = 11 pb	→ top production
σ^{NLO} = 2.1 pb	σ^{NLO} = 30 pb	σ^{NLO} = 11 pb	→ anti-top production

Top Quark decays

It decays almost excusively to Wb, from CKM elements V_{tu}, V_{ts}, V_{tb} :



$$\frac{BR(t \to Wb)}{BR(t \to Wq)} \approx 0.99825 \pm 0.00005$$

$$BR(t \to cZ, c\gamma, cg) \approx O(10^{-33})$$

<u>W decays are used to classify top final states</u>

Decay topologies for ttbar :

- Dileptonic
- Lepton+jets
- Fully hadronic

For single top measurements only W leptonic decays are used

ttbar topologies

Lepton + jets ≈ 34%

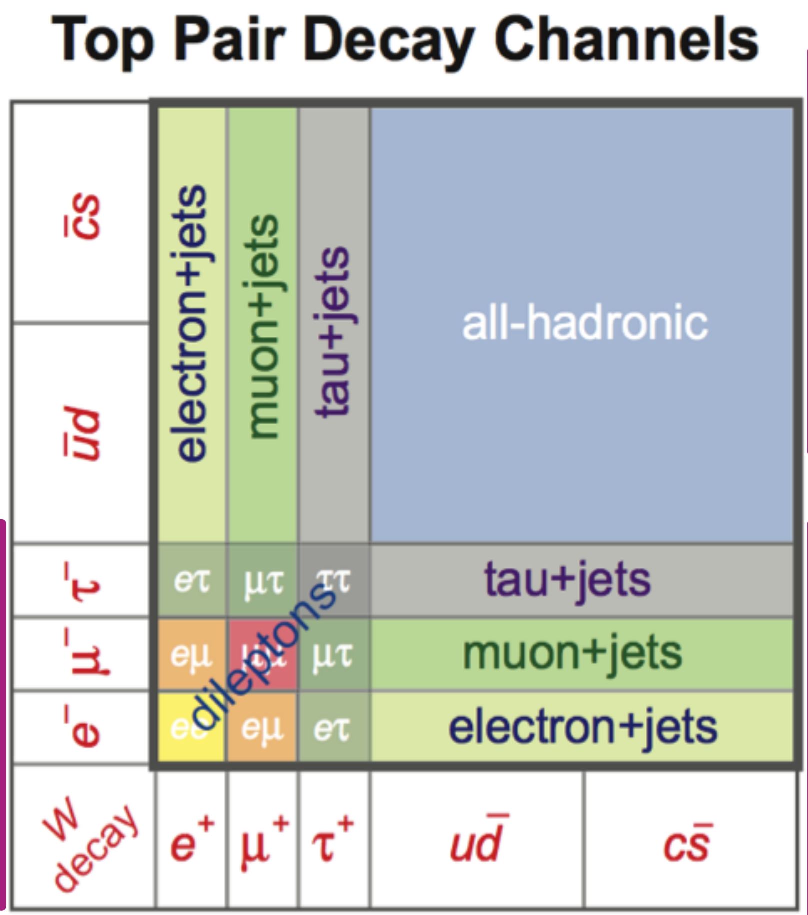
Low background

Main background:
W + jet

Dileptonic ≈ 6%

Very low background

main background:
Drell-Yan



Fully hadronic ≈ 46%

important background from QCD multijet events

Tau channels ≈ 14%

Important background from W + jet, QCD, other ttbar decays

Statistics with 20 fb-1 at 8 TeV

Channel	σ (NLO)	BR	Trigger eff	# Events
ttbar SL e mu	232	0.3	0.8	1 090 000
ttbar SL tau	232	0.15	0.5	340 000
ttbar DL (e, mu)	232	0.053	0.9	220 000
ttbar DL 1 tau	232	0.053	0.8	200 000
single top t-ch e mu	83	0.22	0.7	250 000
single top s-ch e mu	45.5	0.22	0.7	17 000
single top tW e mu	23	0.22	0.7	70 000

- **Typically two orders of magnitude more than final Tevatron statistics**
- Selection efficiencies not included !
- Trigger efficiency, **guesstimates** from present tables ... **(fully hadronic not included)**

EXPERIMENTAL METHODS FOR TOP MASS MEASUREMENTS:

- EXAMPLES IN THE LEPTON+JETS CHANNEL

- WHAT ARE WE MEASURING ?

- ALTERNATIVE METHODS

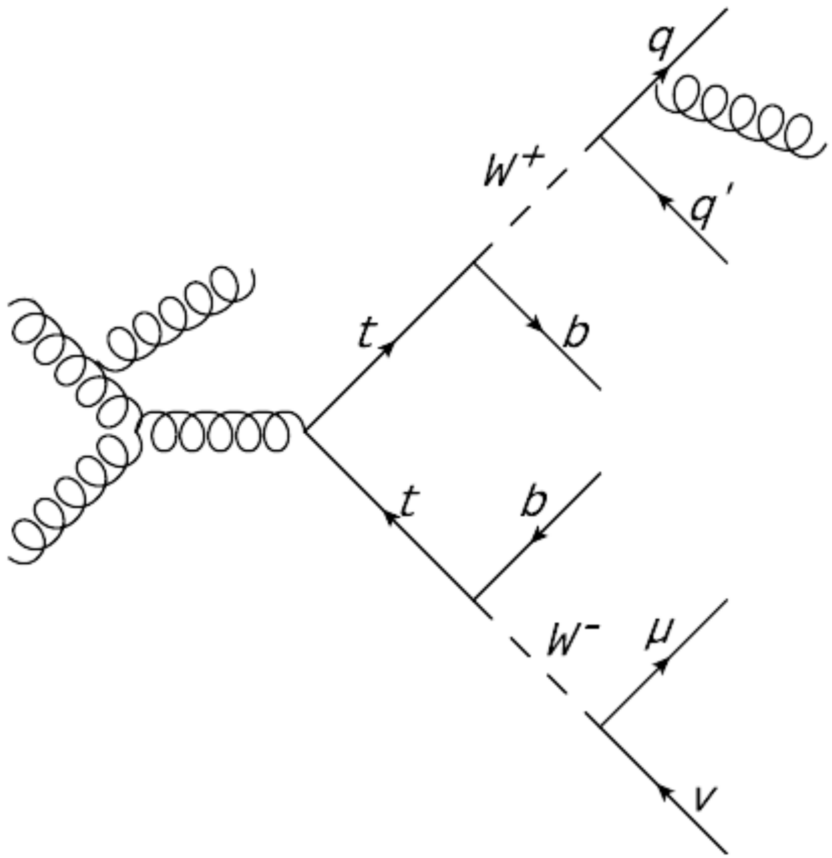
- DIFFERENTIAL TOP MASS

Methods for top mass measurement

- Template fit in its simplest version: measure invariant mass of, e.g. three jets in lepton+jets events
  - Choose the right b-jet for the 3-jet combination
  - Can use the W mass to constraint light **jet energy scale (JES)** from two-jet invariant mass: the **JES** is one of the most important sources of uncertanity
- Better use of the full event information to gain sensitivity: Matrix Element method, Ideogram method

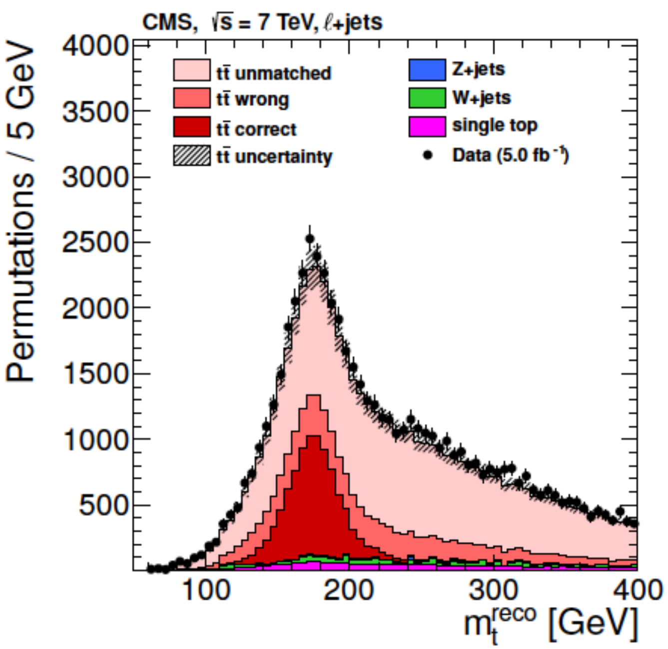
Event selection: lepton+jets final state (example from CMS)

- Trigger for isolated muon or electron + jets (pT > 24 GeV)
- Exactly 1 isolated lepton with p_T >30 GeV, |η|<2.1 (veto additional isolated e, μ)
- ≥ 4 "particle flow" jets (anti-kt , R = 0.5) with p_T >30GeV, |η|<2.4
- ≥ 2 jets b-tagged among the 4 leading jets
- 17985 events in 5 fb−1 2011 data selected
- Composition:
- 92% $t\bar{t}$, 3% W+jets, 4% single-top, 1% other

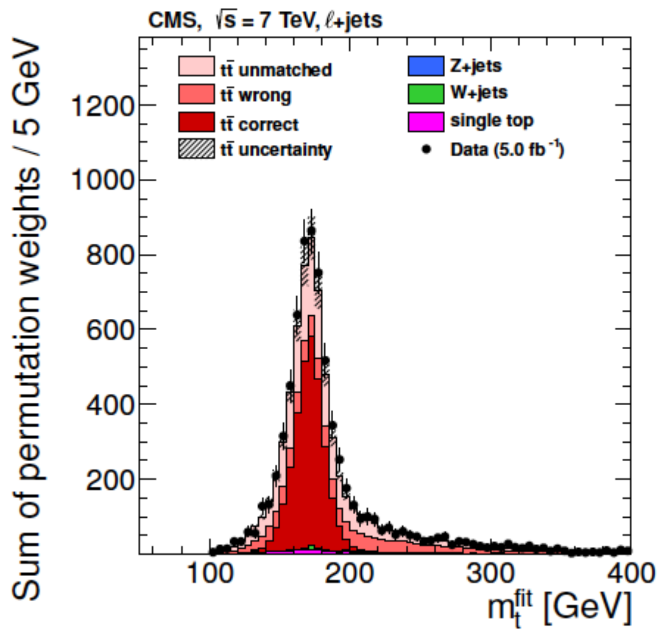


Event reconstruction

- Assign 4 leading jets to partons from $\bar{t}t$ decay (obey b-tag)
  - Kinematic fit with constraints: m_W = 80.4 GeV, $m_t = m_{tbar}$
  - Weight each permutation by $P_{gof} = \exp-(1/2\chi^2)$, select $P_{gof} > 0.2$
- 5192 events in 5 fb−1 2011 data (96% $\bar{t}t$, 44% correct)

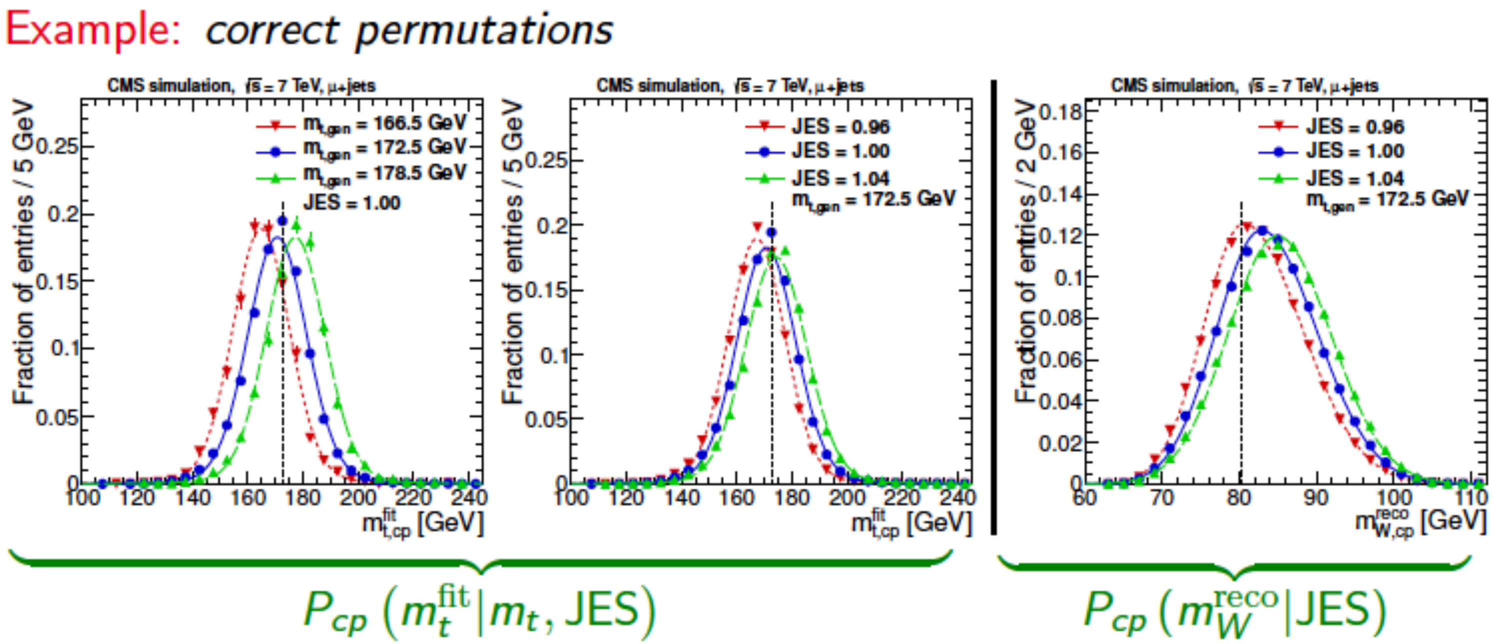


$P_{gof} > 0.2$



Ideogram method: probability densities

- Simulated samples with
  - 9 different top masses: 161.5–184.5 GeV
  - 3 different JES: 0.96, 1.00, 1.04
- Fit $m(top)_{fit}$, $m(W)_{reco}$ distributions with analytical expressions
- Parametrize linearly in m_t , JES, $m_t \times$ JES



Ideogram method

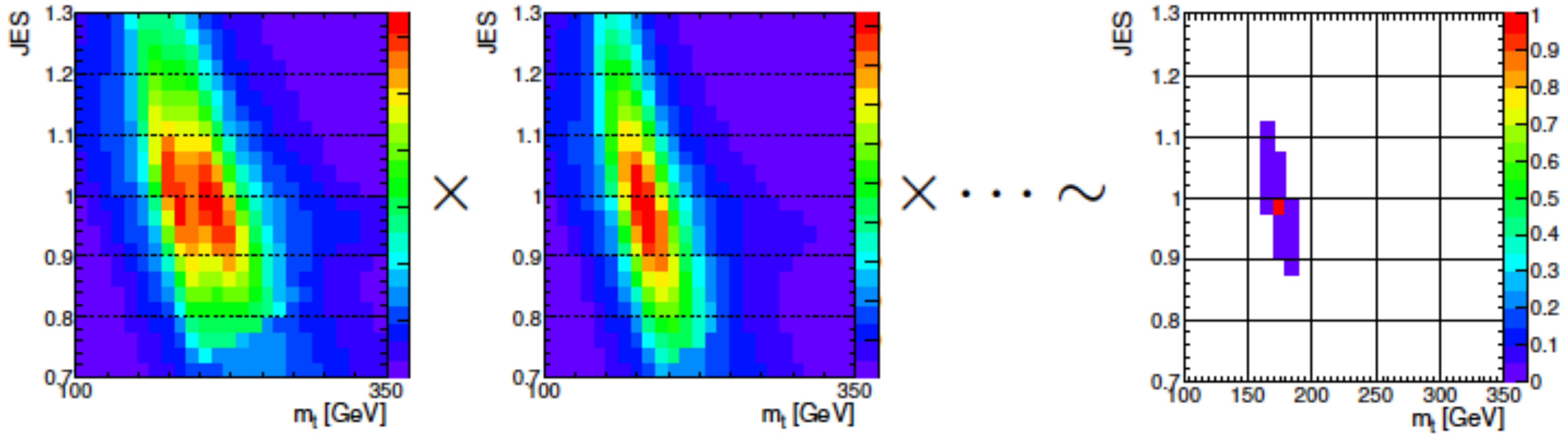
- Calculate likelihood for event with n permutations, j denotes *correct*, *wrong* and *unmatched* permutations

$$\mathcal{L}(\text{event}|m_t, \text{JES}) = \sum_{i=0}^{n} P_{gof}(i)\, P\left(m_{t,i}^{fit}, m_{W,i}^{reco}|m_t, \text{JES}\right),$$

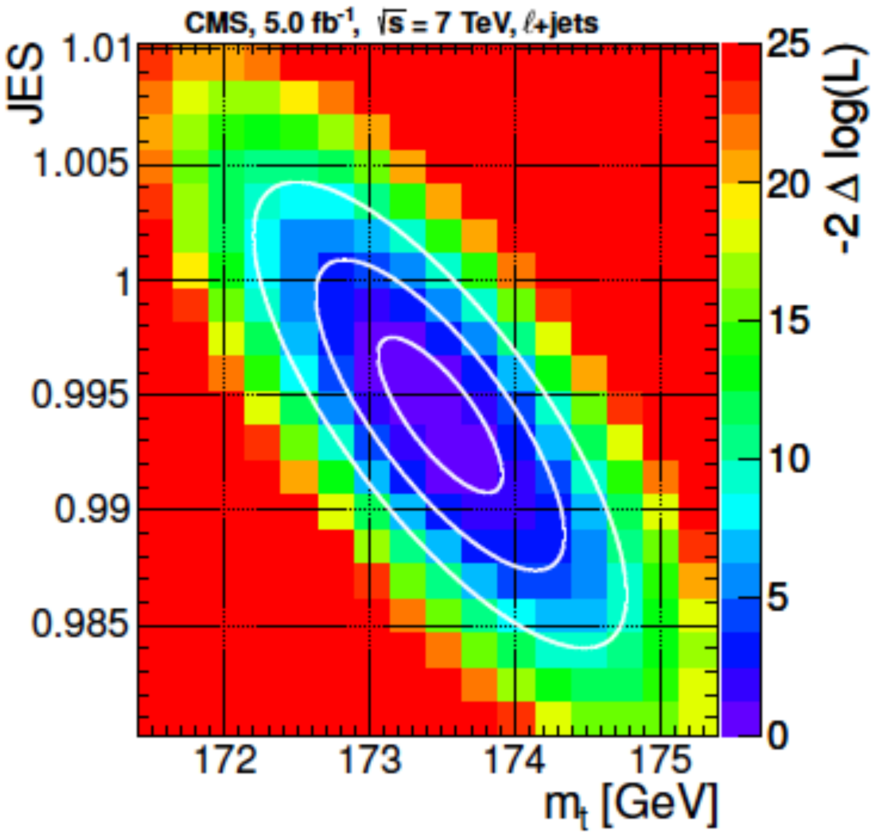
$$P\left(m_{t,i}^{fit}, m_{W,i}^{reco}|m_t, \text{JES}\right) = \sum_{j} f_j P_j\left(m_{t,i}^{fit}|m_t, \text{JES}\right) \cdot P_j\left(m_{W,i}^{reco}|m_t, \text{JES}\right)$$

- Most likely m_t and JES by maximizing

$$\mathcal{L}(m_t, \text{JES}|\text{sample}) \sim \prod_{\text{events}} \mathcal{L}(\text{event}|m_t, \text{JES})^{w_{\text{event}}}$$



Example: top mass from 2D fit



$$m_t = 173.49 \pm \underbrace{0.43}_{\text{stat+JES}} \pm \underbrace{0.98}_{\text{syst}} \text{ GeV}$$

$$\text{JES} = 0.994 \pm \underbrace{0.003}_{\text{stat+JES}} \pm \underbrace{0.008}_{\text{syst}}$$

- Documentation:
  CMS TOP-11-015, JHEP 12 (2012) 105, arXiv:1209.2319

Systematic Uncertainties

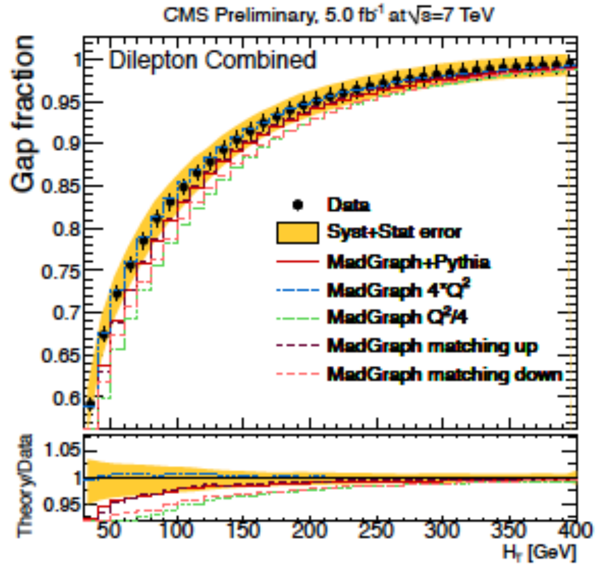
$t\bar{t}$ modelling uncertainties

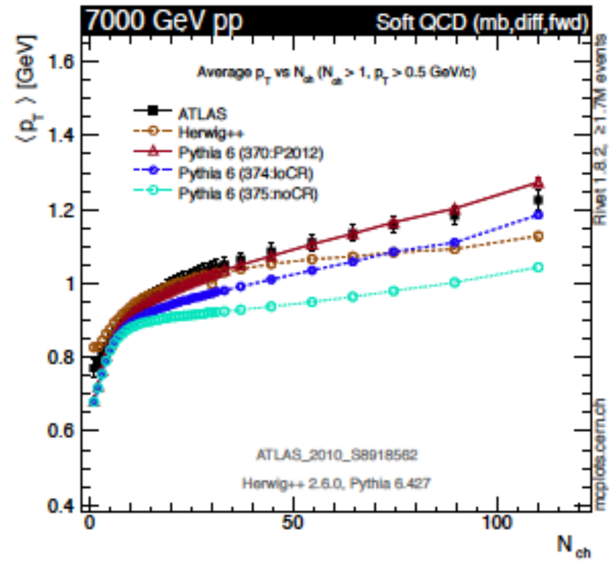
Perturbative QCD

- Factorization and renormalization scales
  Vary by factors of 1/2 and 2 → 0.24 GeV
- ME-PS matching threshold
  Vary by factors of 1/2 and 2 → 0.18 GeV
- MC generator (as cross-check)
  MadGraph vs. Powheg → 0.04 GeV

Non-perturbative QCD

- Hadronization (included as b-JES)
  Pythia vs. Herwig → 0.61 GeV
- Underlying event
  Tunes with more/less MPI → 0.15 GeV
- Colour reconnection
  Tunes with CR on/off → 0.54 GeV





Data will be eventually used to decrease these uncertainties !

From Maria Costa LHCp talk

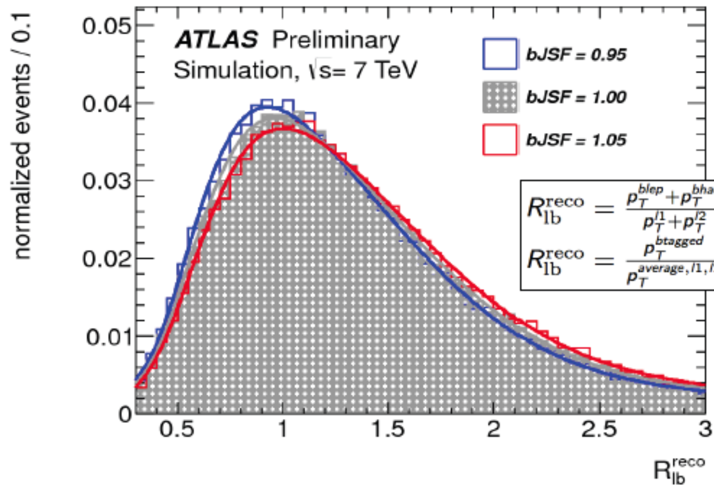
ATLAS-CONF-2013-046

NEW

ATLAS TOP MASS: 3D TEMPLATE

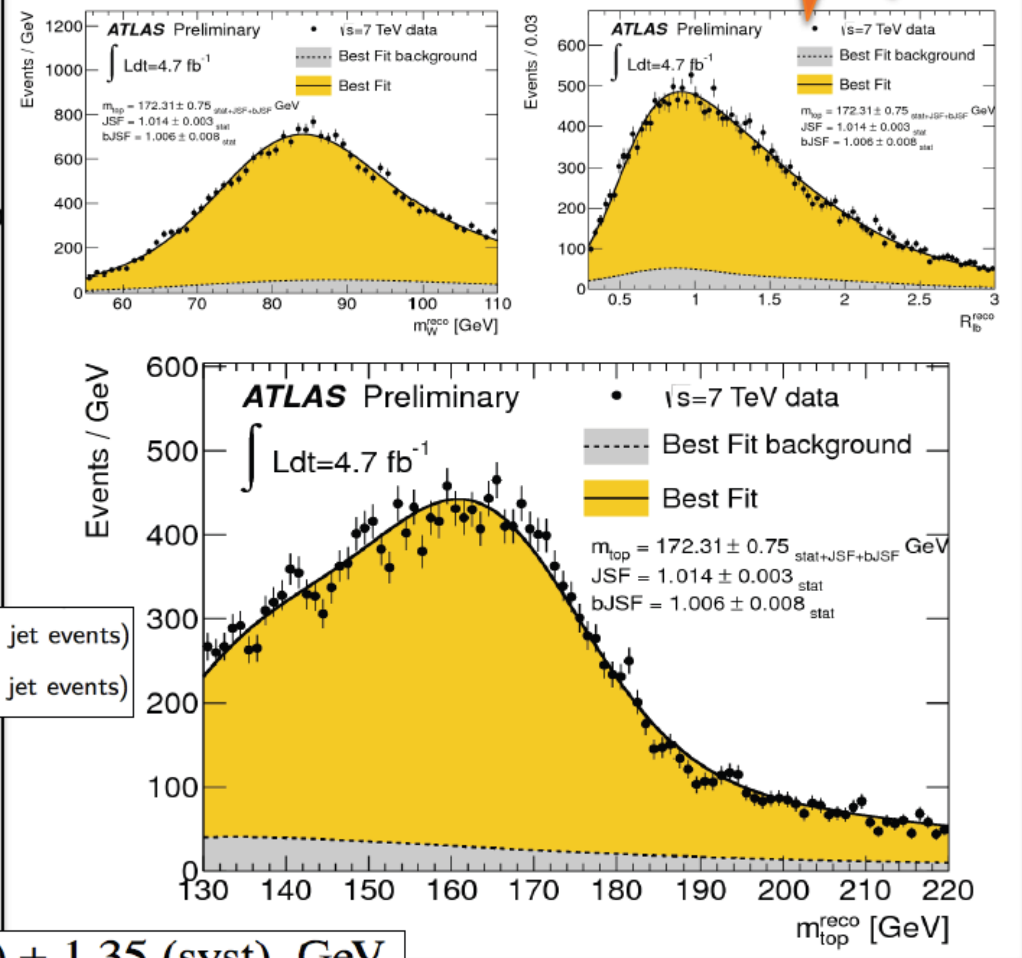
- Lepton+jets, 4.7 fb-1
- Method: 3D template fit to m_{top}^{reco}, m_W^{reco} and R_{lb}^{reco} → m_{top}, JSF, bJSF

R_{lb}^{reco} sensitive to bJES → constrain bJES from data



$$R_{lb}^{reco} = \frac{p_T^{blep}+p_T^{bhad}}{p_T^{j1}+p_T^{j2}} \quad \text{(2b-tagged jet events)}$$

$$R_{lb}^{reco} = \frac{p_T^{btagged}}{p_T^{average,j1,j2}} \quad \text{(1b-tagged jet events)}$$

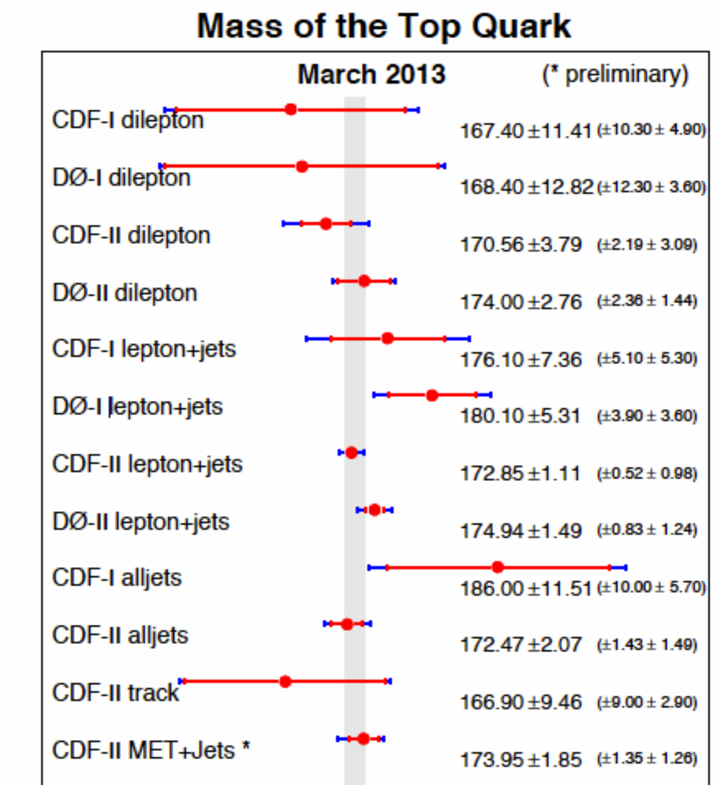


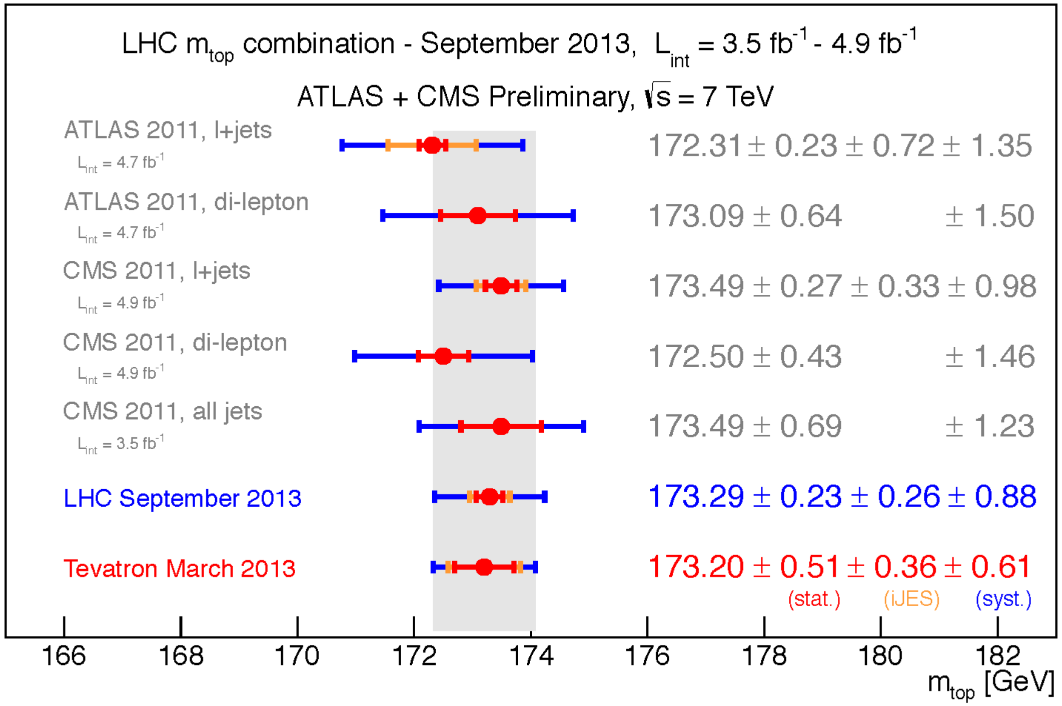
$$\begin{aligned} m_{top} &= 172.31 \pm 0.75\,(\text{stat}+\text{JSF}+\text{bJSF}) \pm 1.35\,(\text{syst})\ \text{GeV}, \\ \text{JSF} &= 1.014 \pm 0.003\,(\text{stat}) \pm 0.021\,(\text{syst}), \\ \text{bJSF} &= 1.006 \pm 0.008\,(\text{stat}) \pm 0.020\,(\text{syst}). \end{aligned}$$

(0.89%)

10

Other top mass measurements (with "top reconstruction" methods)





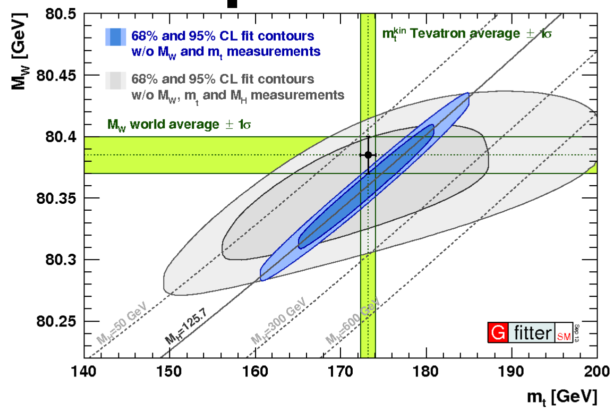
< LHC m_top > = 173.29 +/- 0.23 (stat.) +/- 0.92 (syst.) GeV

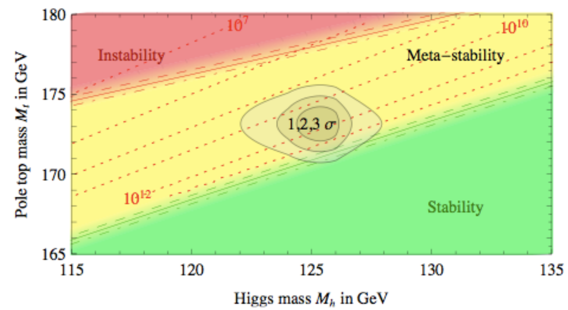
$$M_t^{TEV} = 173.20 \pm 0.51(stat) \pm 0.71(syst)\ GeV$$

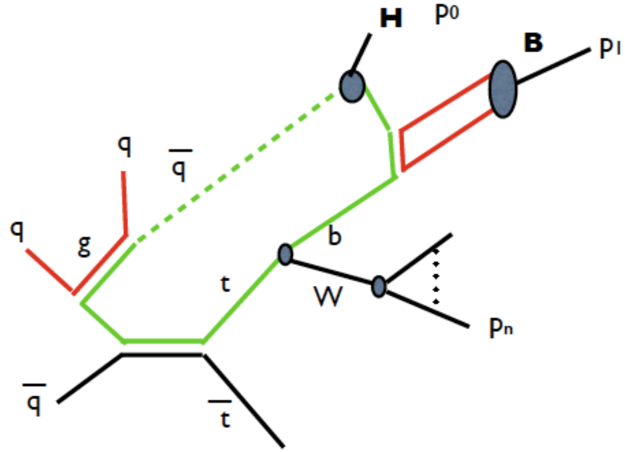
WHICH TOP MASS ARE WE MEASURING ?

Interpretation of the top mass

- The interpretation of the measurement in term of “pole mass” is crucial, a shift ≈ 1 GeV can make a lot of difference
- This is related to the fact top is a coloured object, there is a link between this “interpretation” issue and non-perturbative effects like Colour Reconnection (CR), which are at present studied with toy models







Which top mass we measure with top reconstruction techniques ?

Electron

$$\frac{1}{p^2 - m^2} \qquad m = 0.511 \text{ MeV}$$

Quark

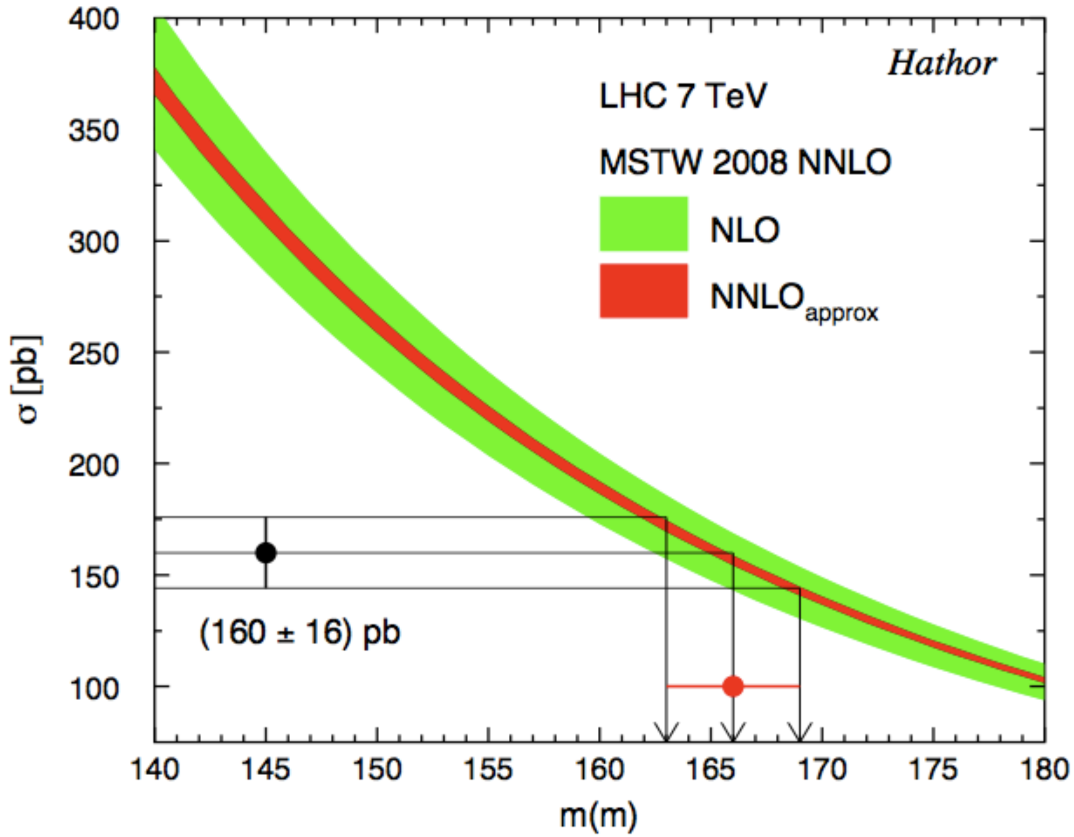
$$\frac{1}{p^2 - m^2}$$

1. The pole mass for a coloured particle has an intrinsic uncertainty of $\approx \Lambda_{QCD}$
2. The kinematic reconstruction of the top-quark momentum from the decay products introduce an uncertainty due colour reconnection, non-perturbative effect, again $\approx \Lambda_{QCD}$ some study indicates ≈ 500 MeV

A proposal as a way out

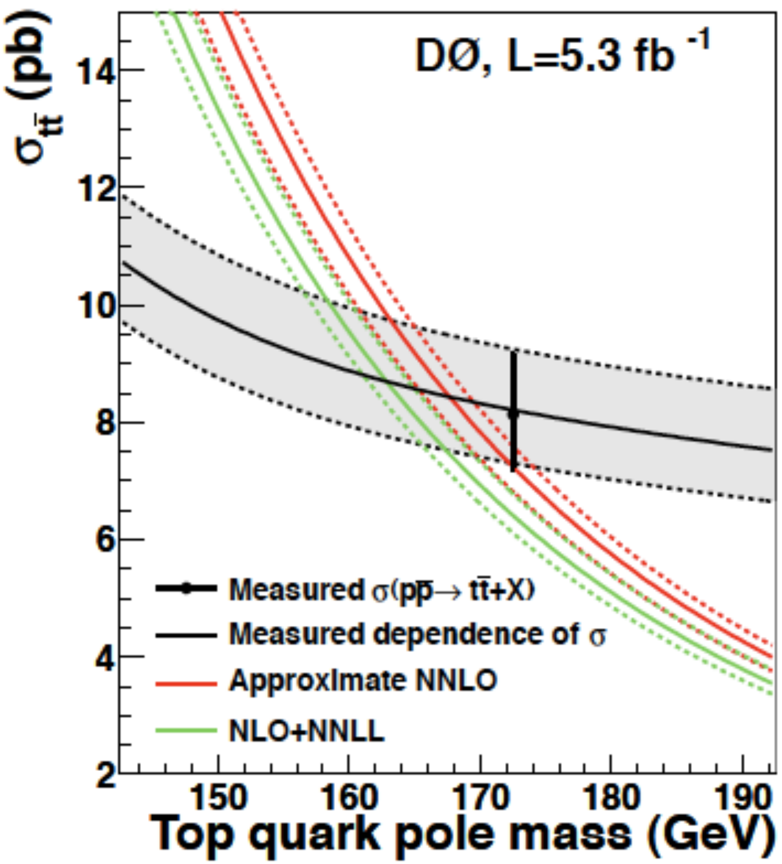
S. Moch, P. Uwer
Phys.Rev. D80 (2009) 054009

- Measure the mass from the cross section, possibly using a short-distance mass scheme ($\overline{\text{MS}}$)

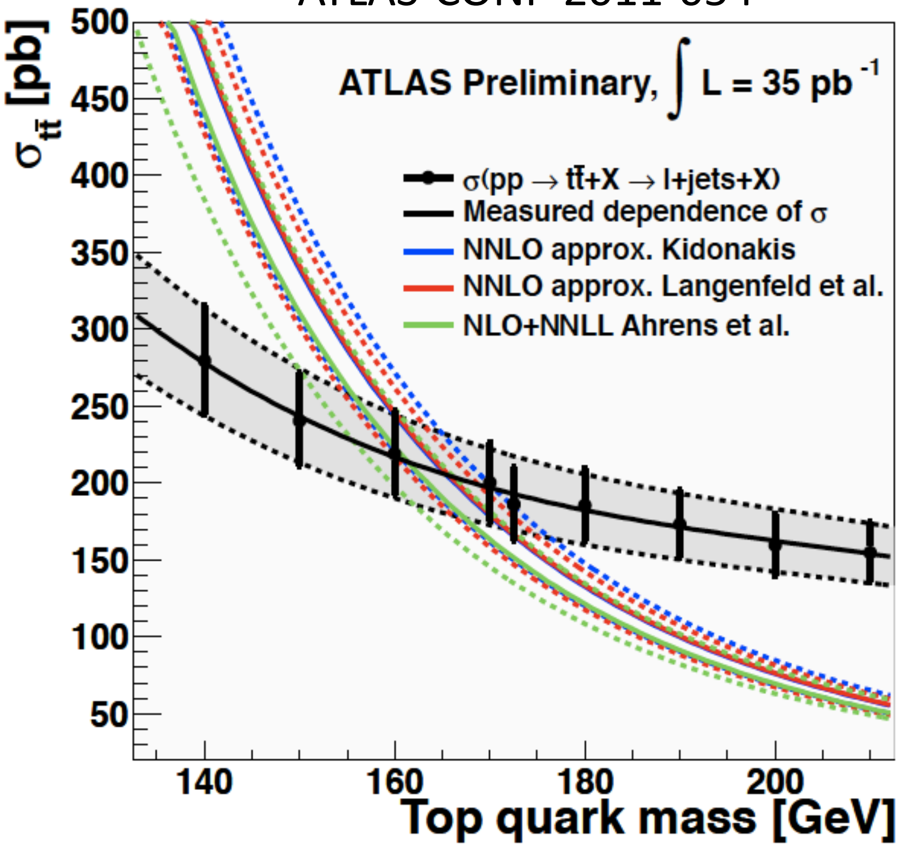


It works, but the error is large (and it will be eventually limited by the uncertainty on luminosity)

arXiv:1104.2887



ATLAS-CONF-2011-054



$$m_{top}^{pole} = (166.4\,^{+7.8}_{-7.3})\ \mathrm{GeV}$$

TOP mass from alternative techniques

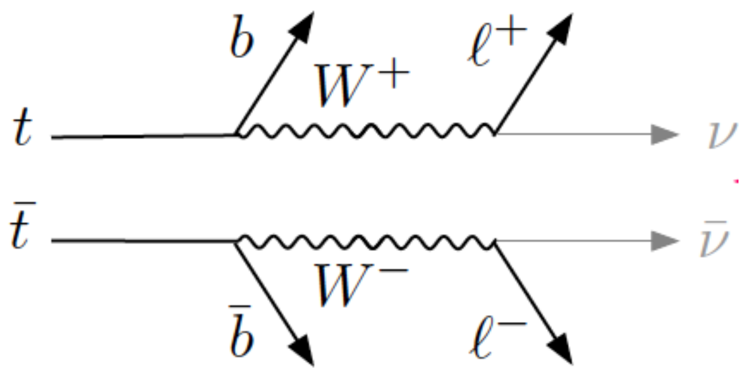
- **Standard methods**: based on the invariant mass of decay products associated to the reconstructed top in a given channel (lepton+jets, dilepton, fully hadronic channels).
- Given the issues related to the top mass interpretation, important to explore **alternative techniques**, e.g.
  - Measure the **decay length** (the boost) of B hadrons produced in top decays, the boost is related to the original top mass
  - Measure the **endpoint** of the lepton **spectrum** or other quantities in top decays
  - Select **specific channels**, for example top with $W \rightarrow l\ \nu$ and $B \rightarrow J/\psi+X$ decays and measure the three-lepton invariant mass
- Alternative methods have typically larger statistical uncertainties, however at LHC we have large ttbar samples.
  - Systematic uncertainties can be controlled with data, again large samples help.

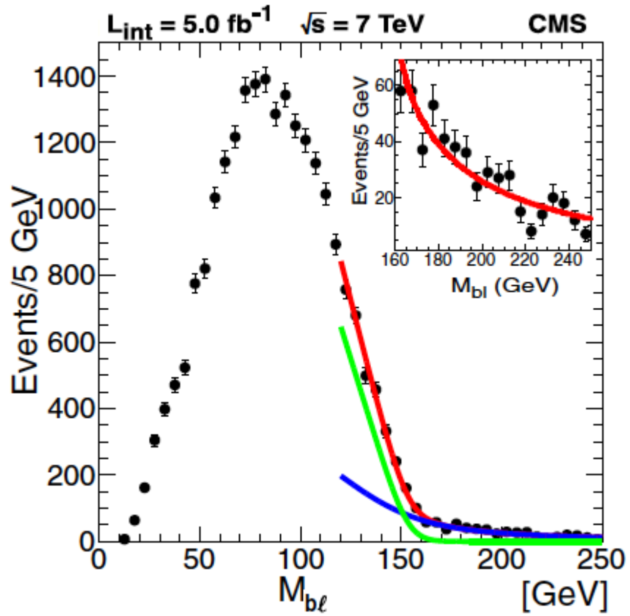
TOP mass from alternate techniques

- Example of a technique already yielding interesting precision: Endpoint method
- The shape of the signal can be computed analytically, background data-driven
- Use of MC limited to study underlying assumption: independent decay of two tops (color connections and reconnections violate this assumption)

arXiv:1304.7498

$$M_t = 173.9 \pm 0.9\,(\text{stat.})^{+1.6}_{-2.0}\,(\text{syst.})\,\text{GeV}$$

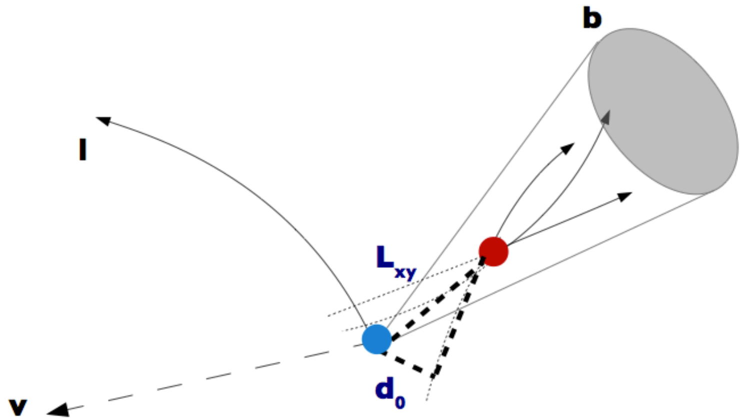


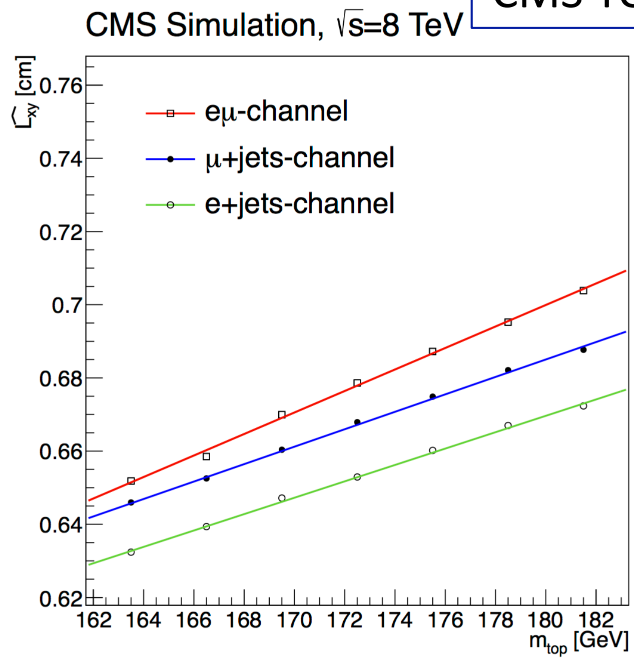


Another example: top mass from the b decay length

- The decay length of b hadrons from top decays is correlated to their boost, i.e. to the top mass

CMS TOP-12-030

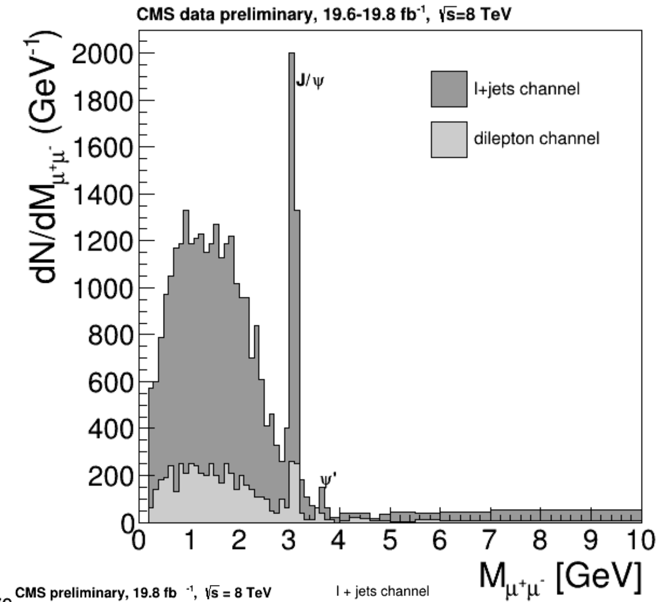


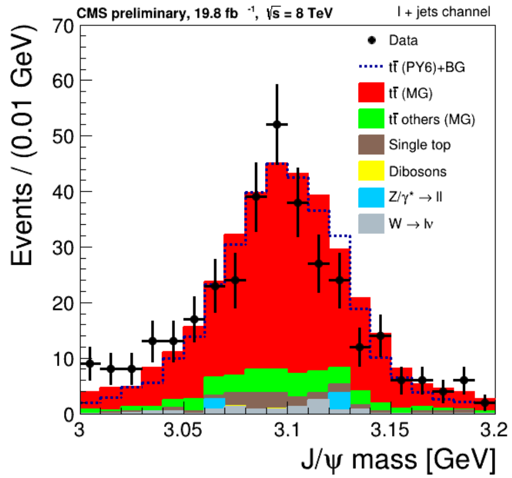


mt = 173.5 ± 1.5stat ± 1.3syst ± 2.6p_t(top) GeV,

A promising channel: top mass from top to B→J/ψ+X decays

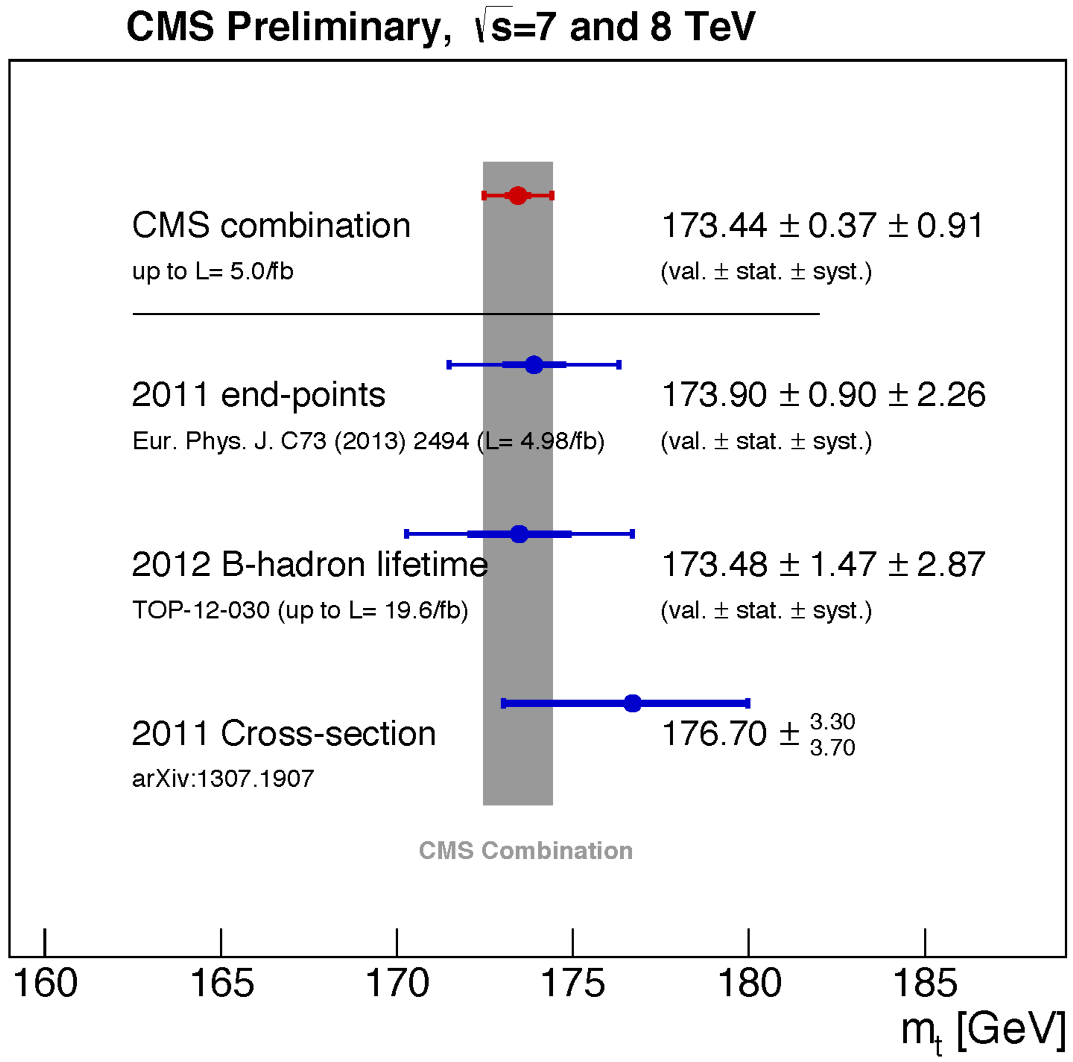
- the three-lepton invariant mass in top with W→l ν and B→J/ψ+X decays is correlated to the top mass
- J/ψ in top production recently observed





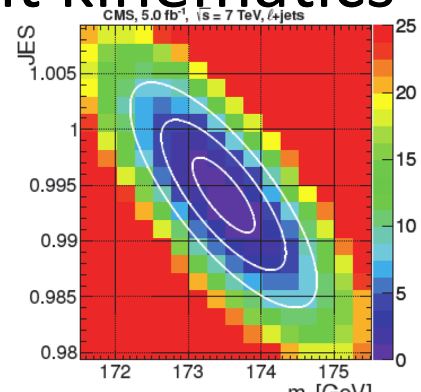
CMS TOP-13-007

Standard vs alternative methods

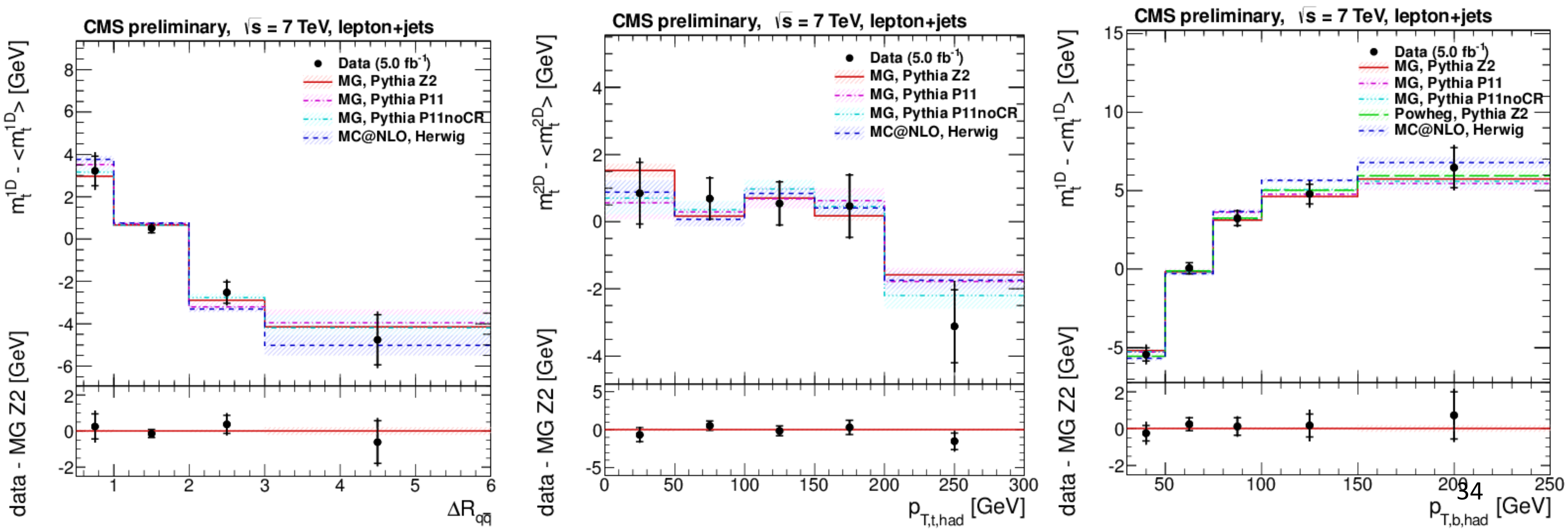


Dependence of Top Mass observable on event kinematics

- How does the measured m_t relate to the fundamental m_t parameter in the SM?
  - The relation contains (non)perturbative QCD corrections, expected to depend on event kinematics
  - Is this kinematic dependence properly modeled by MC? → 12 kinematic variables checked
  - Good data/MC agreement rules out dramatic effects



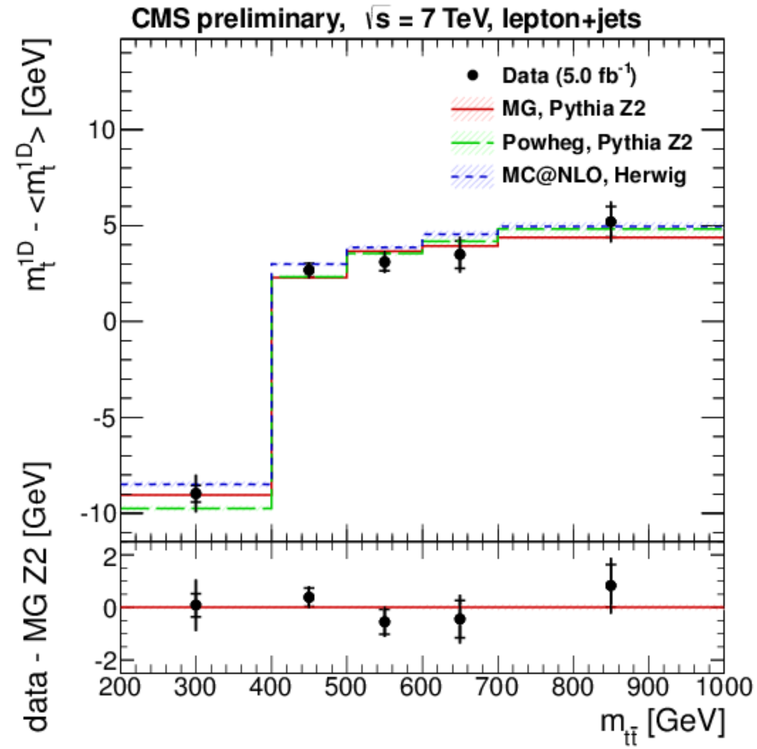
JHEP 12 (2012) 105



Dependence of Top Mass on Event Kinematics

CMS-PAS-TOP-12-029

	Fig.	Observable
color recon.	1	$\Delta R_{q\bar{q}}$
	2	$\Delta\phi_{q\bar{q}}$
	3	$p_{T,t,had}$
	4	$\lvert\eta_{t,had}\rvert$
ISR/FSR	5	H_T
	6	$m_{t\bar{t}}$
	7	$p_{T,t\bar{t}}$
	8	Jet multiplicity
b-quark kin.	9	$p_{T,b,had}$
	10	$\lvert\eta_{b,had}\rvert$
	11	$\Delta R_{b\bar{b}}$
	12	$\Delta\phi_{b\bar{b}}$

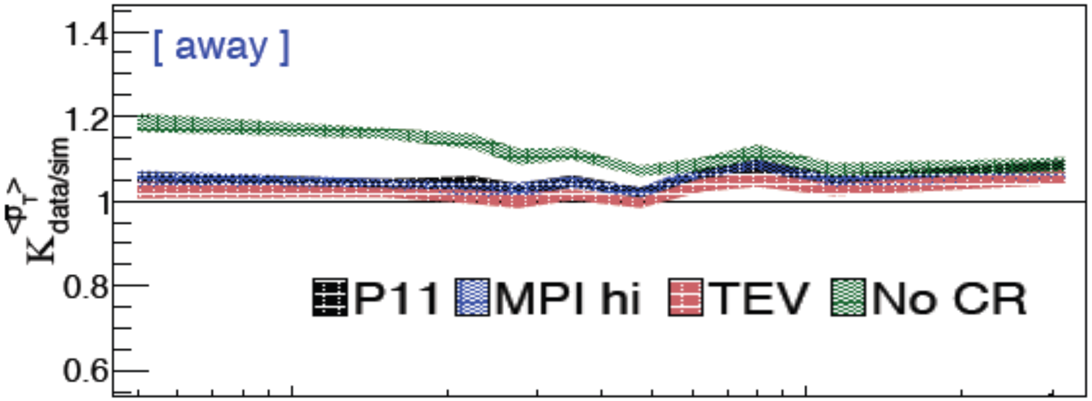


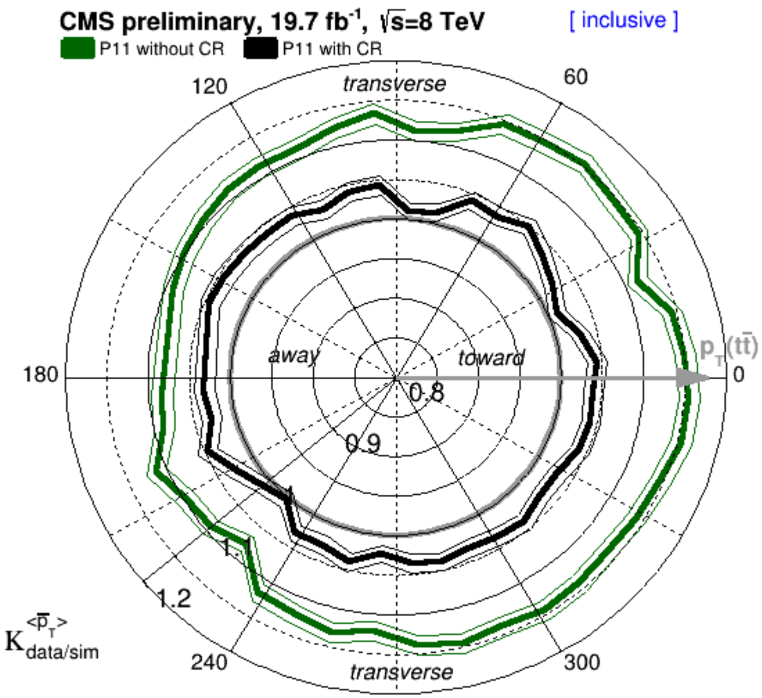
With the current precision, no mis-modelling found as function of variables related to color reconnection, ISR/FSR, b-quark kinematics.

Underlying Event in ttbar

TOP-13-002

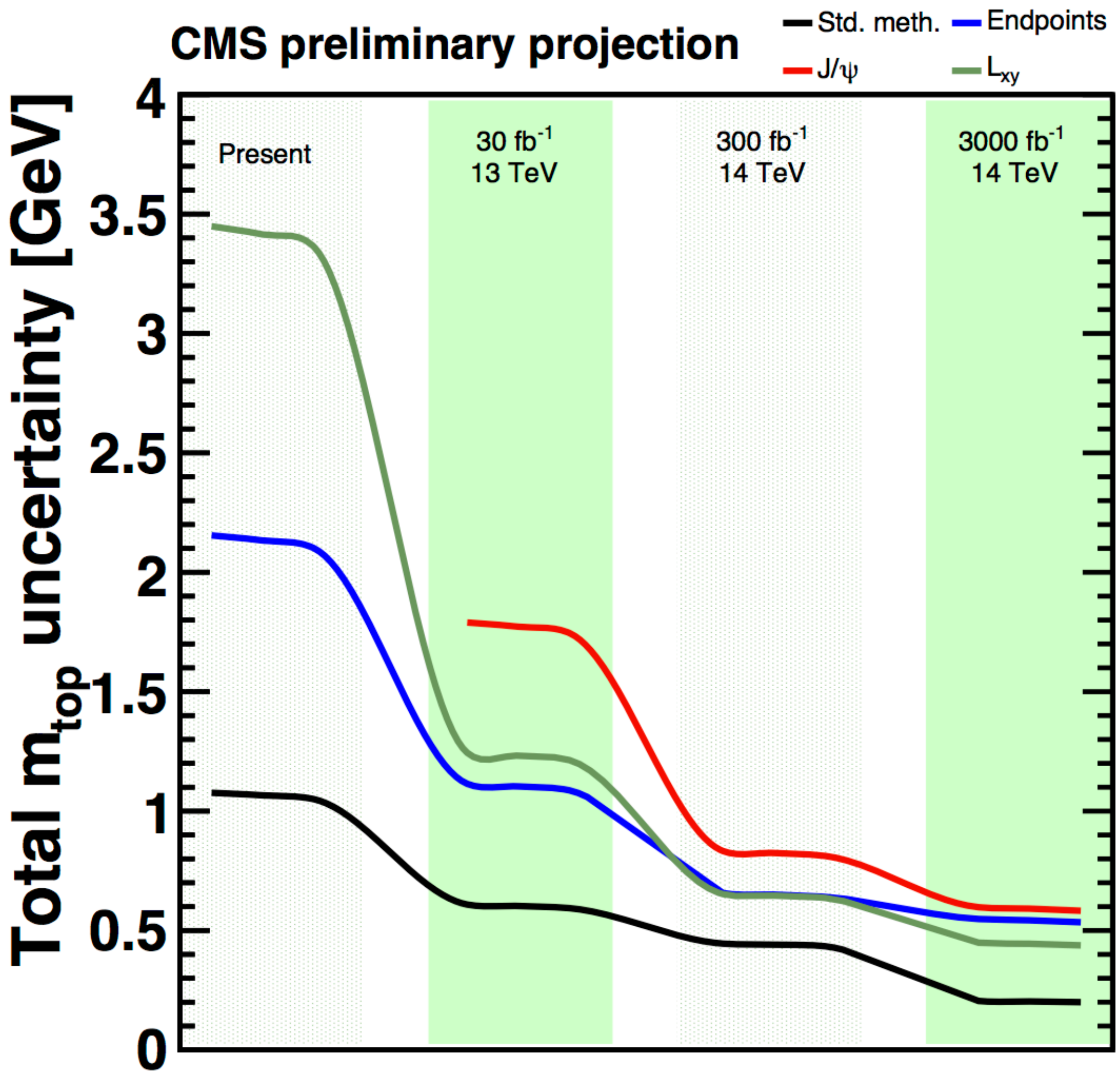
- **Studying underlying event in ttbar** is also very promising to constrain generator tunes





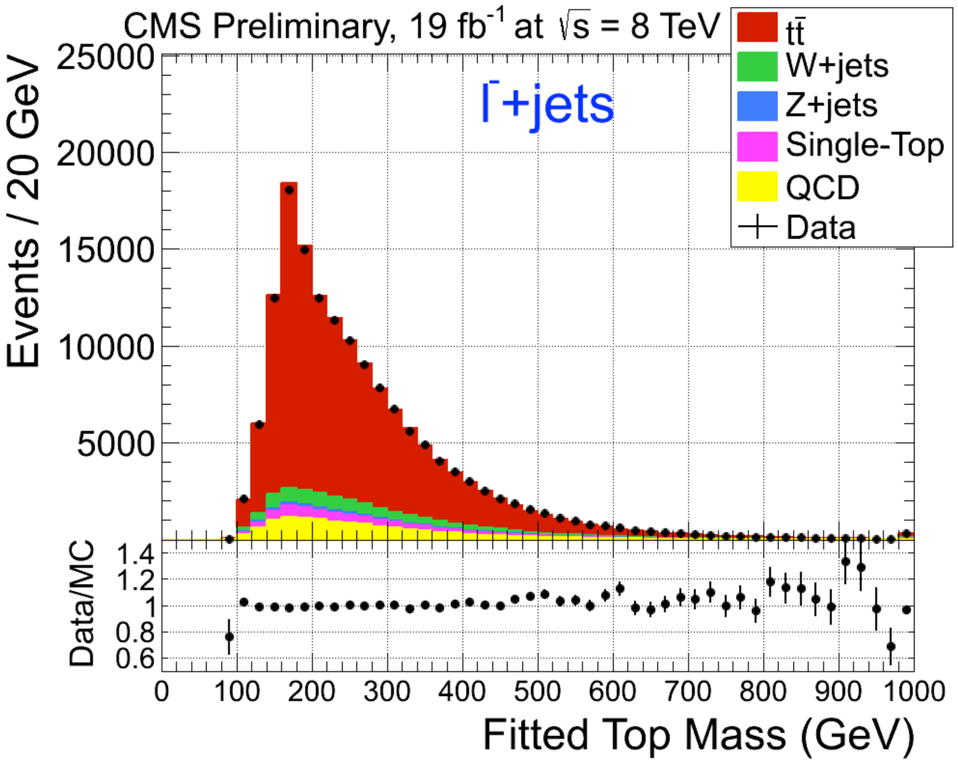
ttbar direction

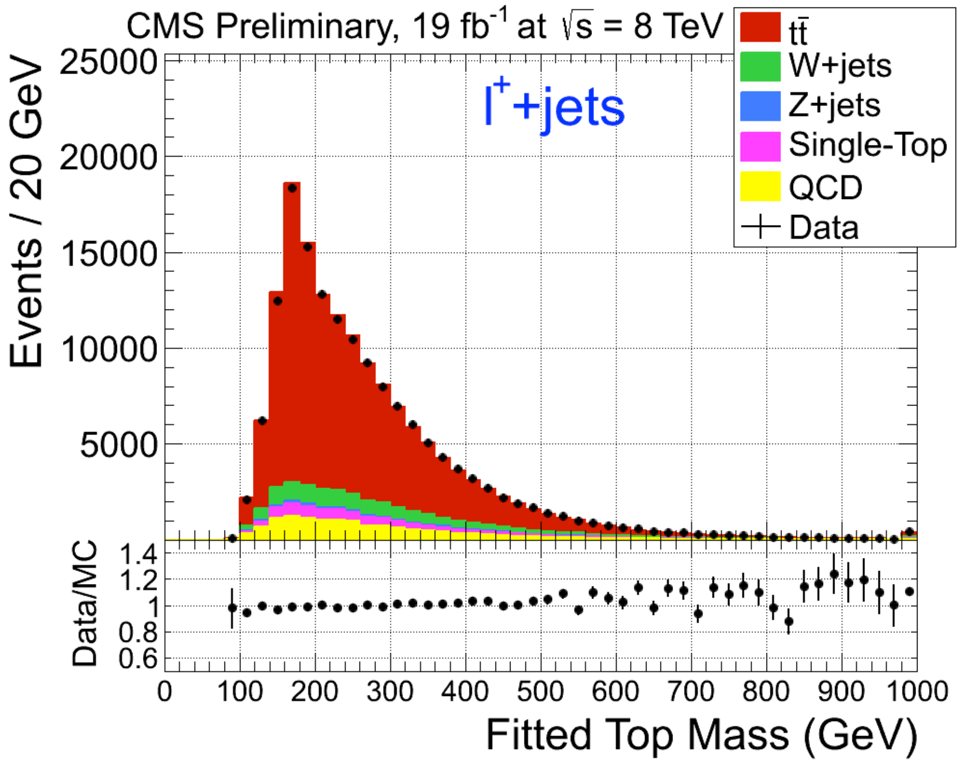
Prospects for top mass at the LHC



top – antitop mass difference: a CPT test

$$\Delta m_t = -272 \pm 196\ (\text{stat.}) \pm 122\ (\text{syst.})\ \text{MeV}$$



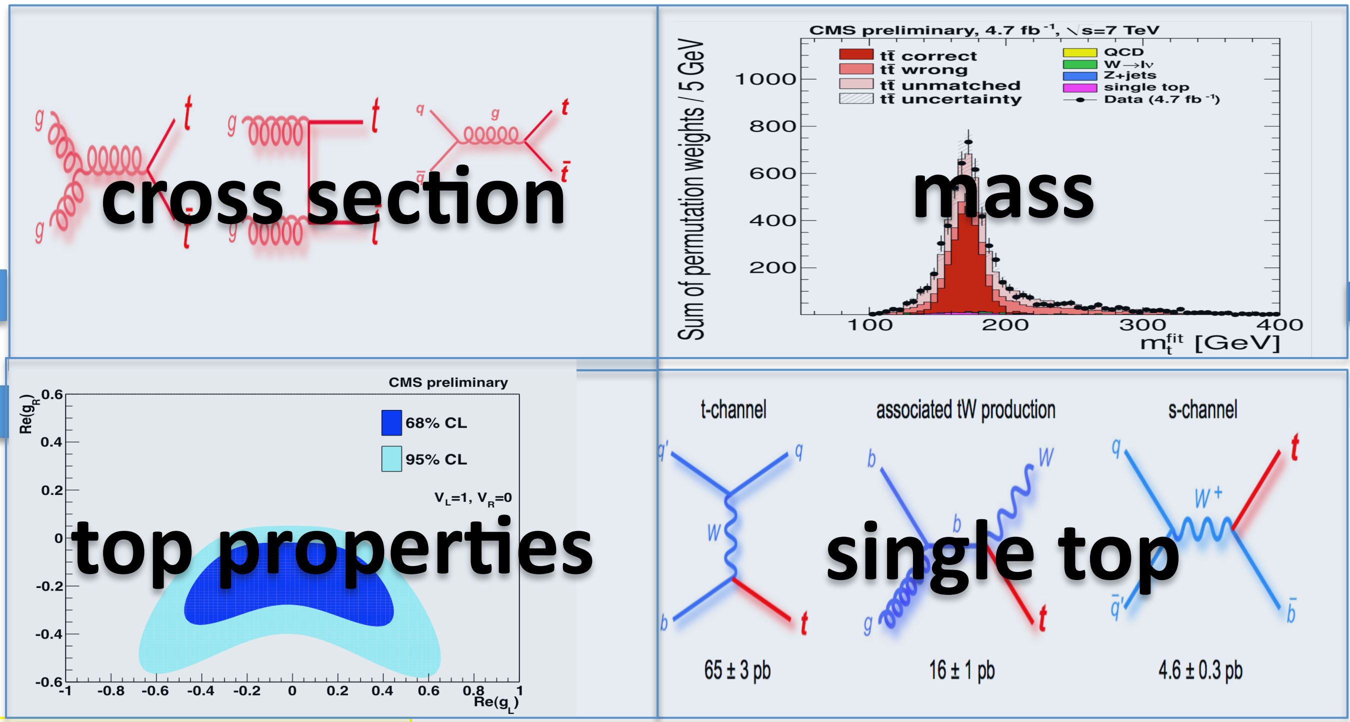


TOP AND HIGGS: NOT ONLY THE MASS

The top areas of study

Total and differential cross sections, Test of production mechanism(QCD, EWK), tt +jets production, measure PDF

Precision measurement of top mass, ΔM(t-tbar) (CPT test)



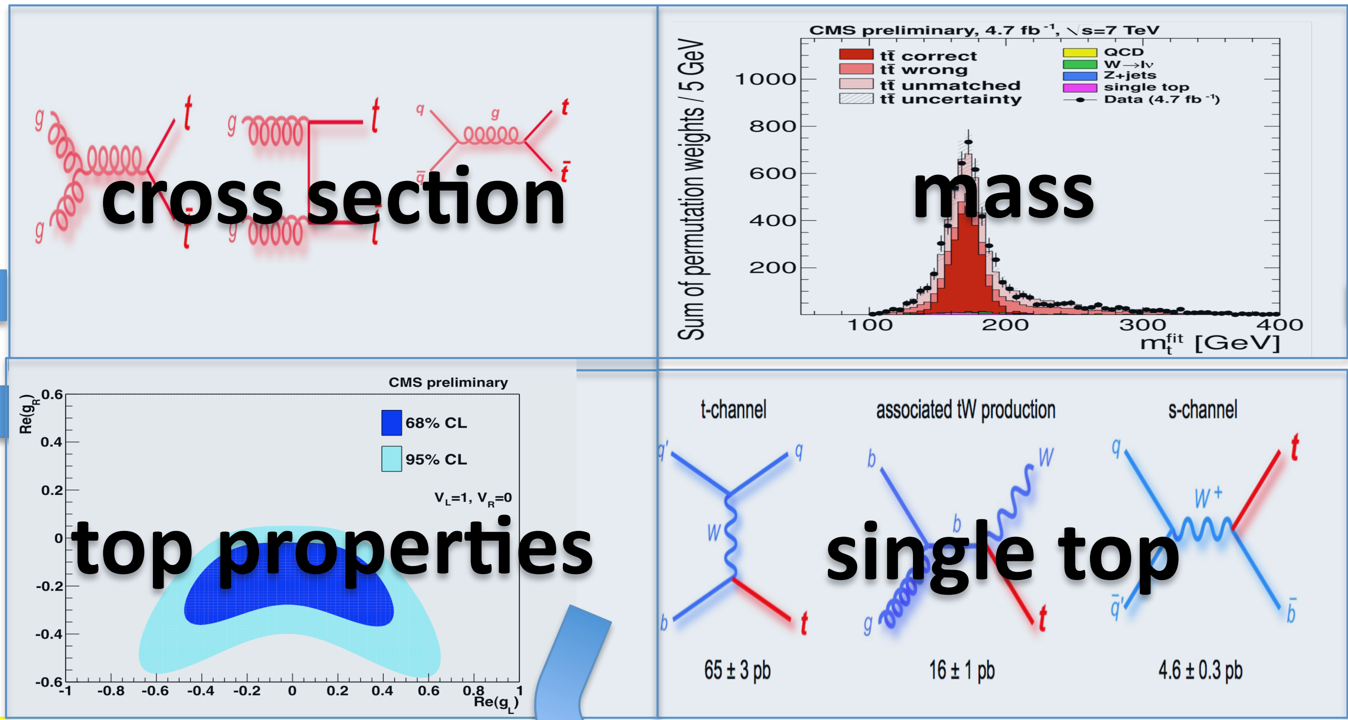
Couplings, branching ratios, charge, width, W helicity, spin correlations, charge asymmetry associated production (ttW, ttZ, ttH, tt+MET)

t, s and tW channels, EWK production properties, Vtb measurement, new physics in single top

The role of top in the Higgs era

ttbar is our monitoring for gluon gluon fusion !

Do we interpret the top mass correctly when we match top, W and Higgs Masses ?



Are top properties consistent with our view of electroweak symmetry breaking ?

Is there any sign of new physics in top production and decay ?

The ttbar cross section

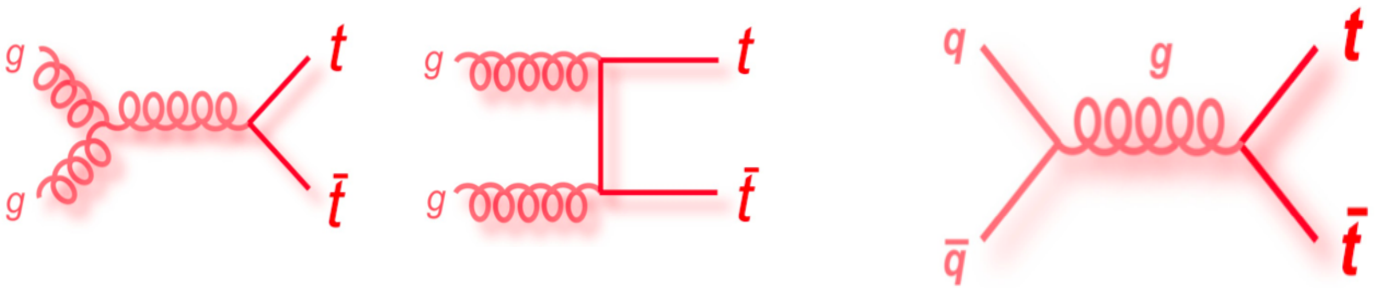
$$\sigma(s, m_t^2) = \sum_{a,b} \int_0^1 dx_1 \int_0^1 dx_2\, f_{h1}^{a}(x_1, \mu_f^2)\, f_{h2}^{b}(x_2, \mu_f^2)\, \hat{\sigma}_{ab}(\hat{s}, m_t, \alpha_s(\mu_f^2))$$

Parton combinations

PDF's

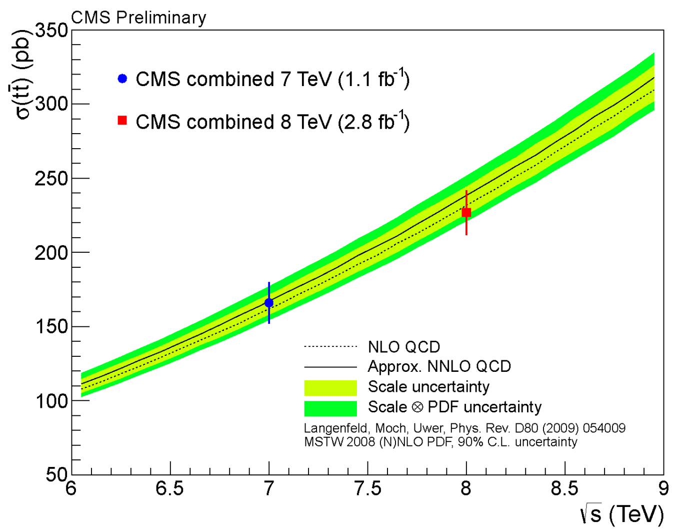
Momentum fraction with respect to the proton

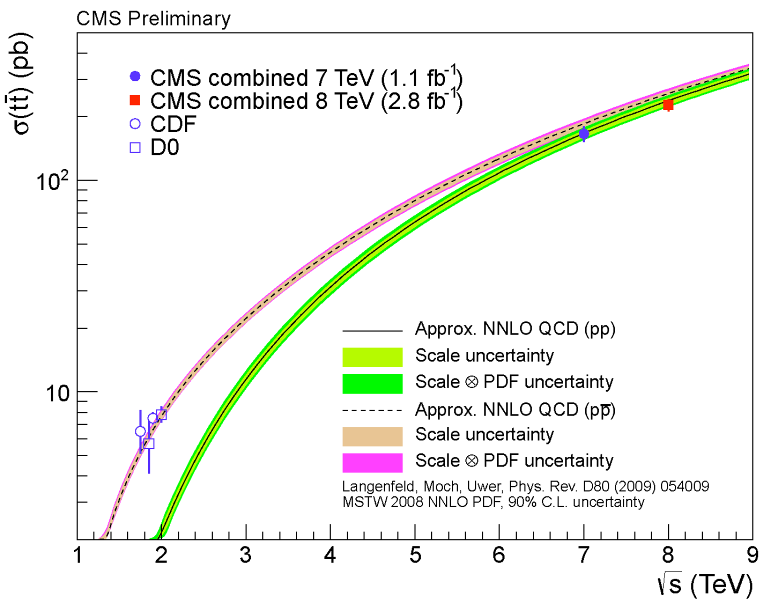
Cross section of the elementary process



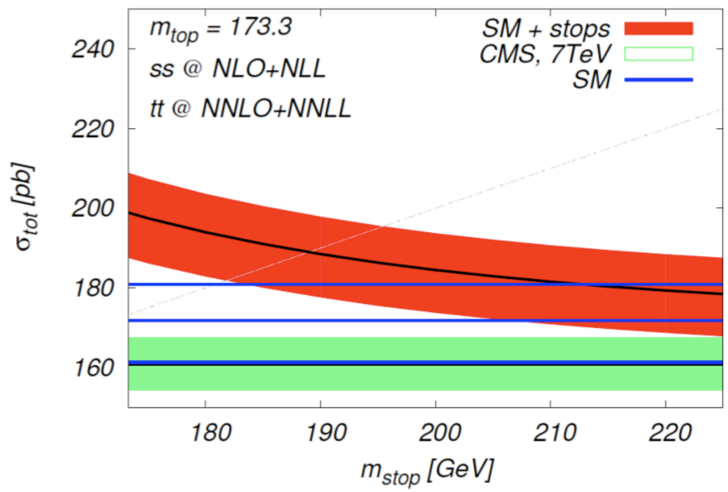
ttbar cross section at 7 and 8 TeV

- The cross section raises as foreseen
- Program of accurate measurement of the 8/7 TeV ratio (total and differential) and σ(tt)/σ(Z) for a precise test and PDF constraints





Interest for new physics: stealth stop !

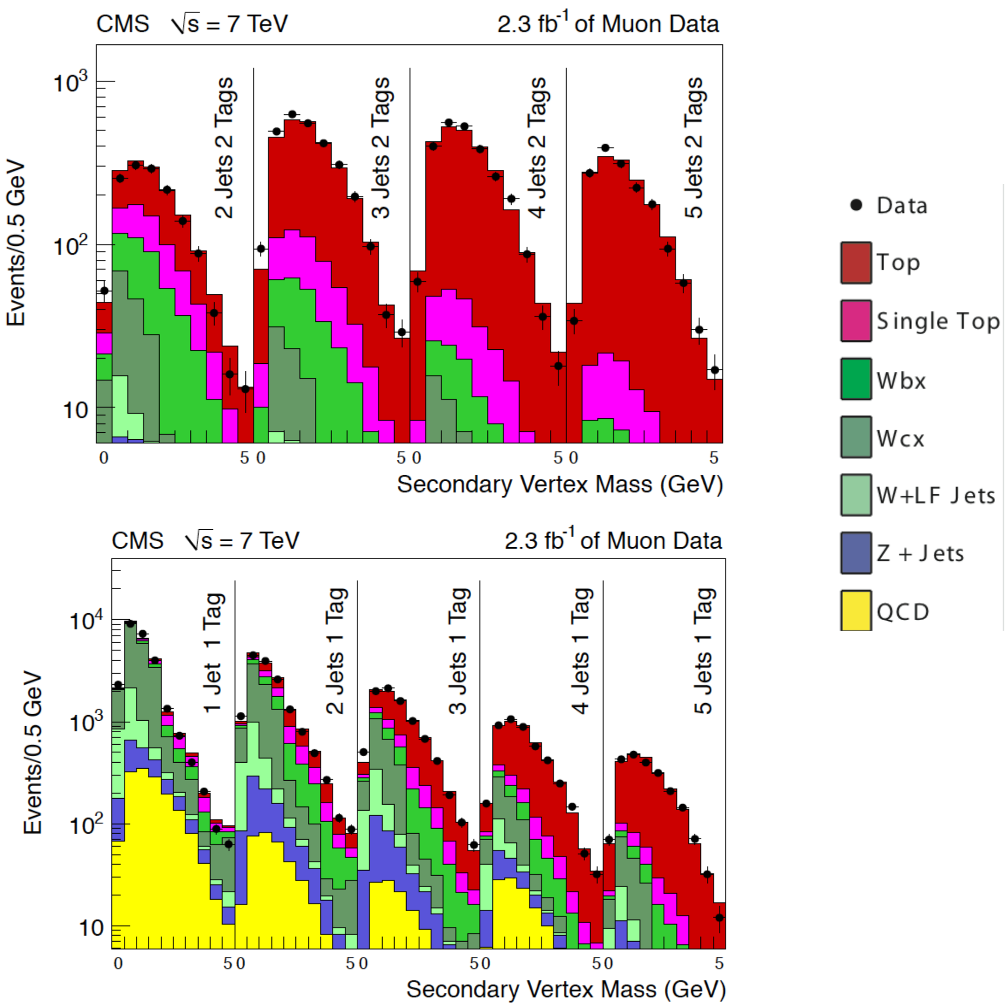


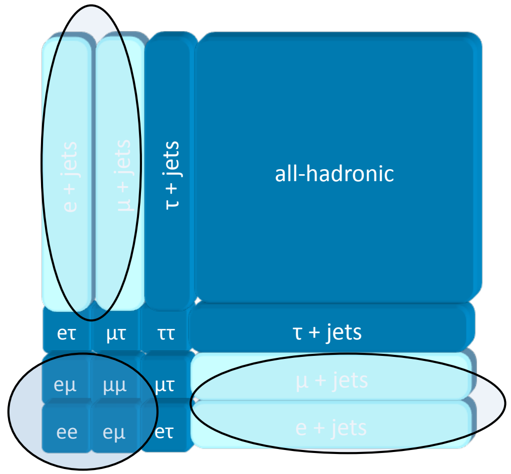
Selection of ttbar in the lepton+jets and dilepton channels

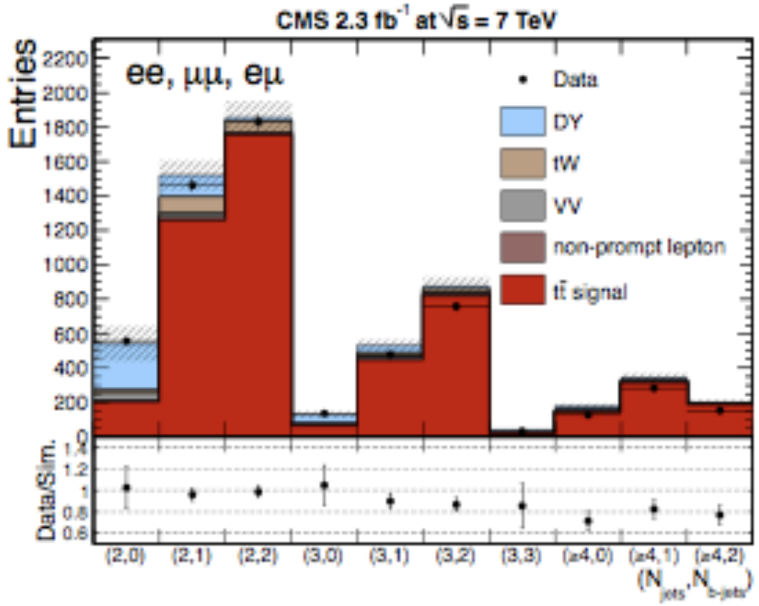
- Require one (or two) isolated leptons
- Lepton reconstruction and identification efficiency measured from data (Z→ ll) with tag-and-probe technique.
- Background measured from data using control samples
  - looser identification to get a background dominated sample and knowledge of tight-to-loose ratio for background leptons from another control sample
- B tagging used to further reduce the background

Leptons+jets and dileptons (e, μ)

- Excellent background control thanks to jet categorization, b tagging and in situ measurement of jet-energy scale



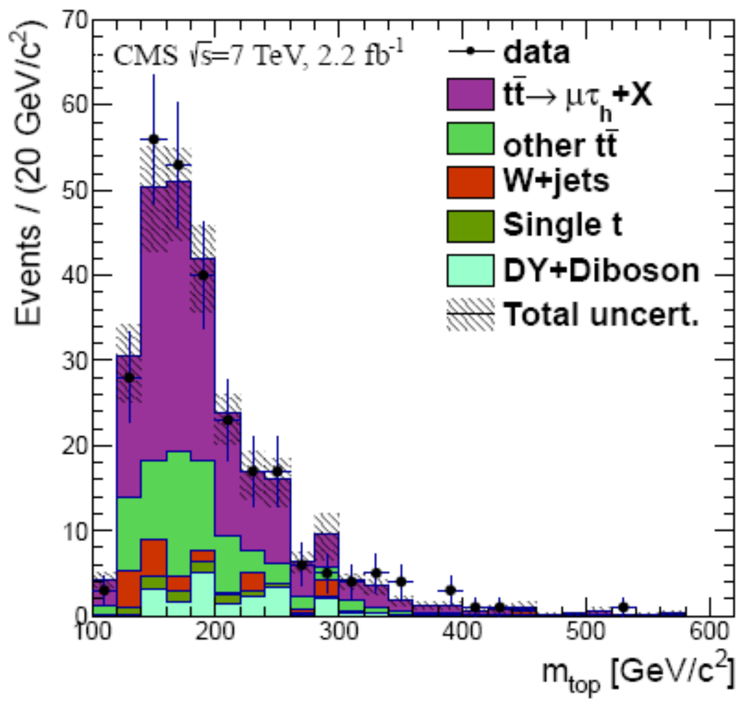




CMS TOP-11-005

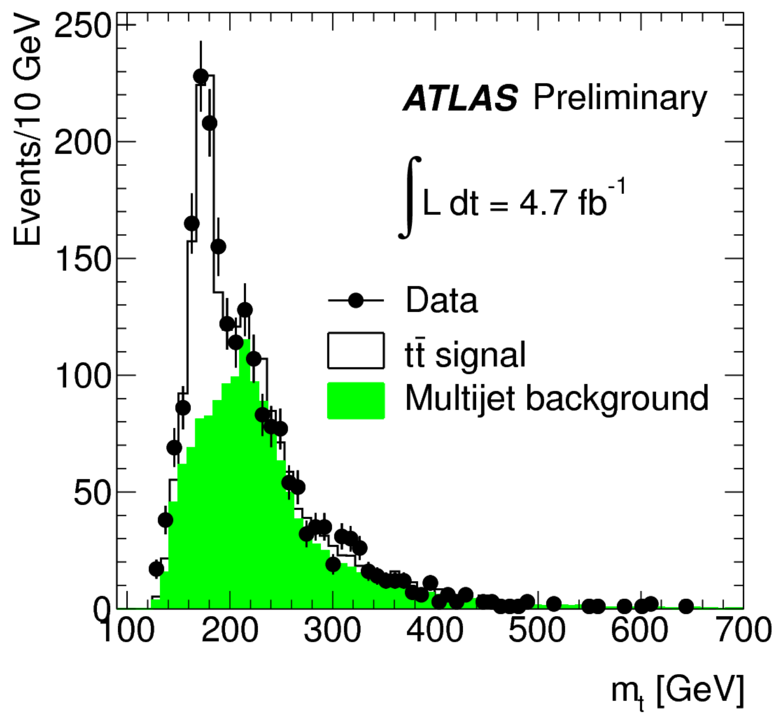
Other channels

$t\bar{t} \rightarrow \tau + \mu$



CMS arXiv:1203.6810

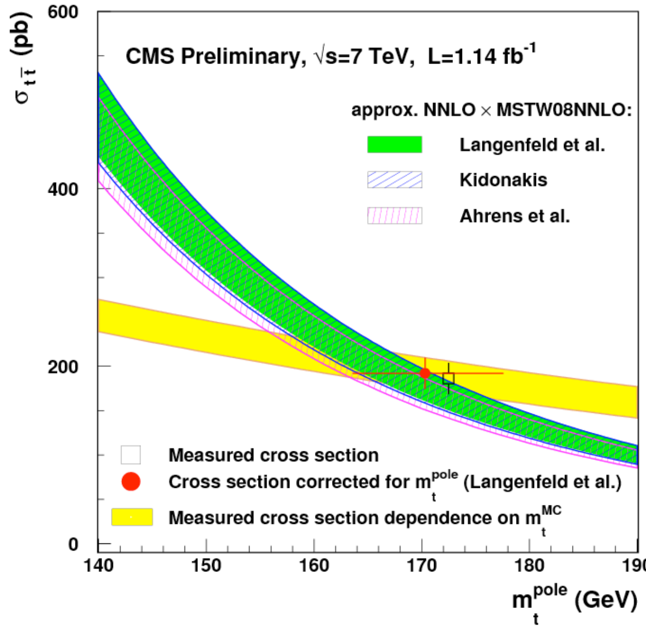
$t\bar{t} \rightarrow$ all hadronic

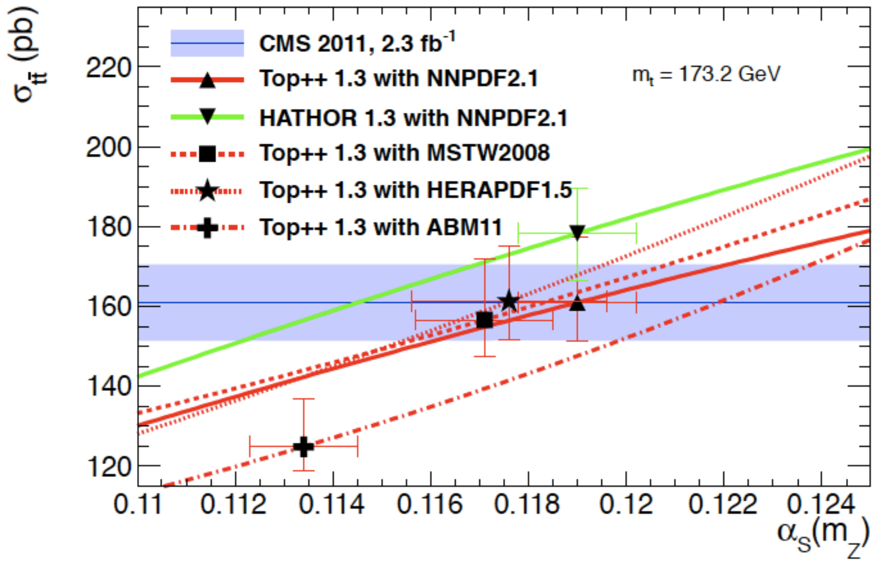


ATLAS CONF-2012-031

ttbar cross section interpretation

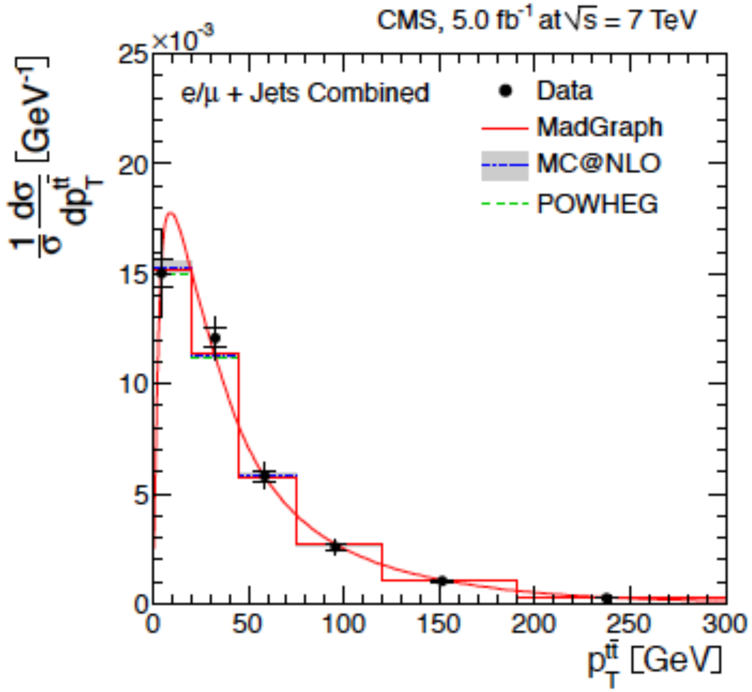
- Total cross section interpretation
  - as a measurement of the top mass (m_top= 176.7+3.8-3.4 GeV)
  - as a precise measurement of α_s [alphaS(mZ) = 0.1151+0.0033-0.0032 is extracted.]





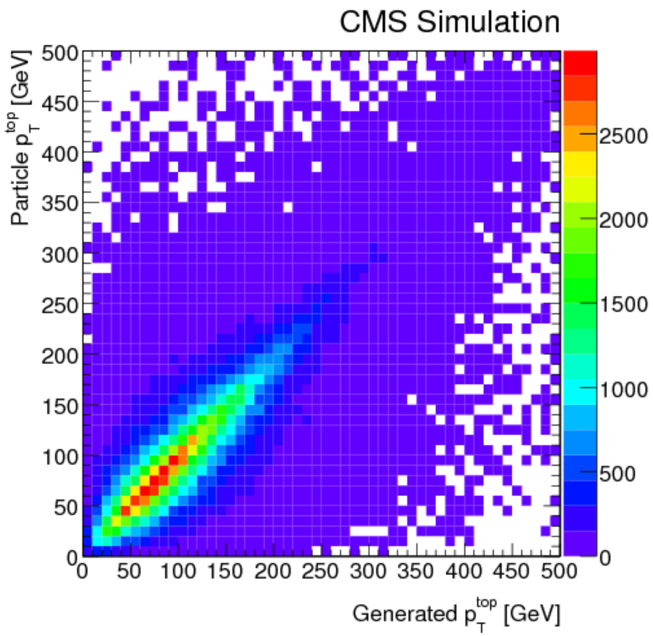
Differential cross sections

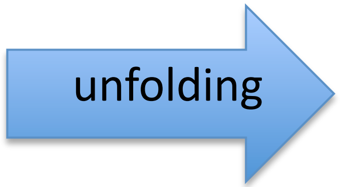
- Important measurements, they will play an important role for
  - i) investigate limitations of present MC (which QCD predictions and models describe our data best, in the search areas like high m(tt) and high multiplicities)
  - ii) provide independent interpretations (e.g. mass AND alpha_s from cross section)
  - Iii) sensitivity to high-x gluon (y(tt))

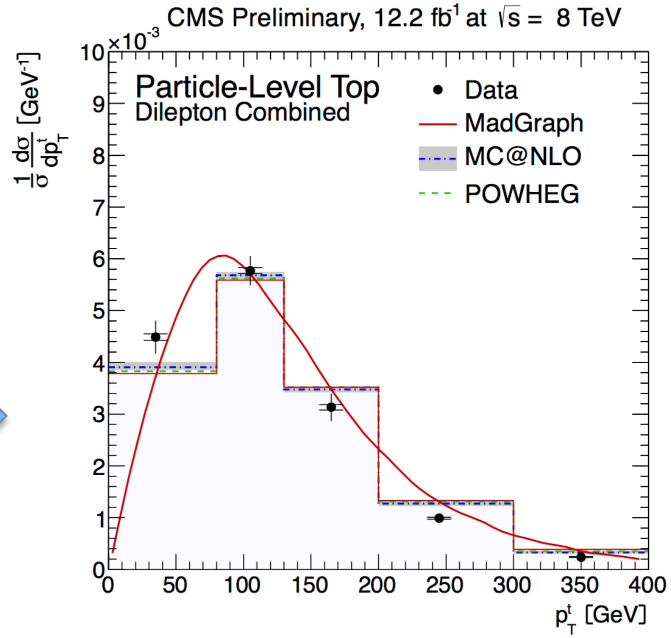


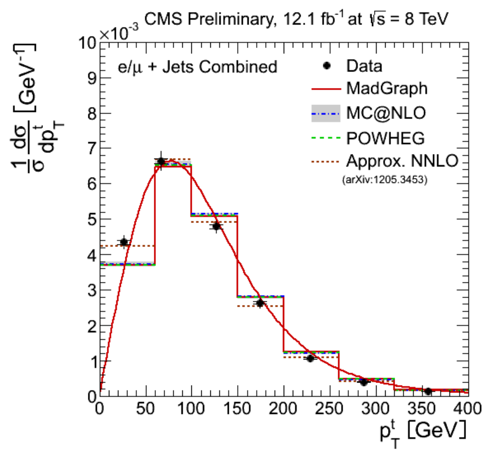
arXiv:1211.2220

Differential distributions and MC tuning already see discrepancies with respect to NLO generators !





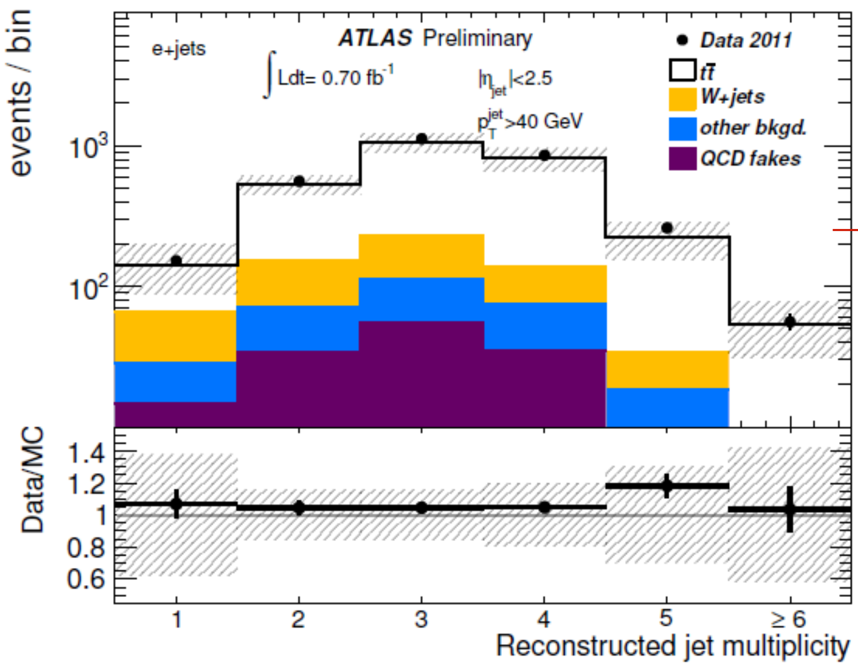




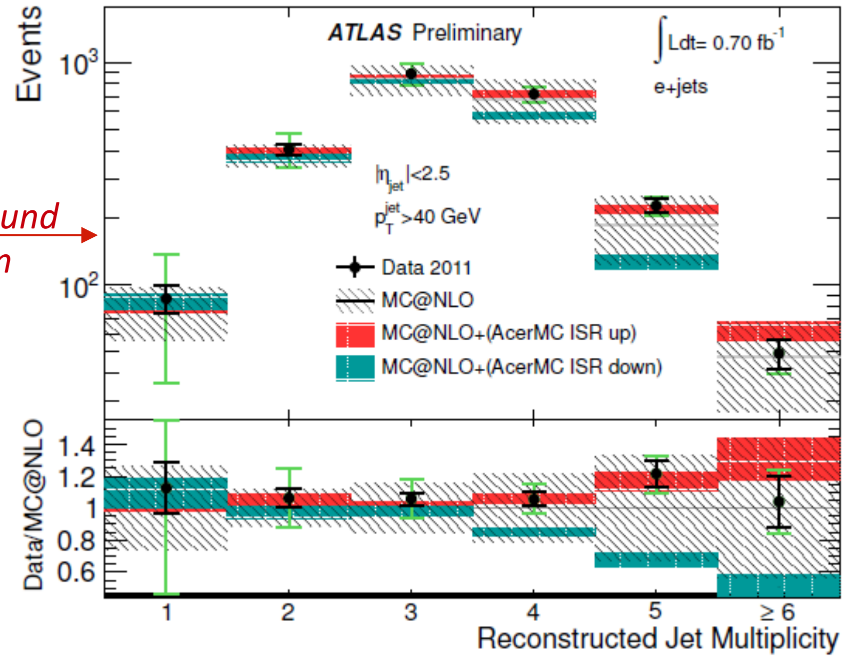
Ttbar and additional jets

- Study of QCD radiation pattern

ATLAS CONF-2011-142
CMS PAS TOP-12-023



After background subtraction

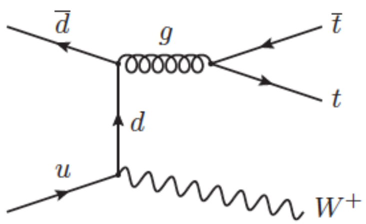


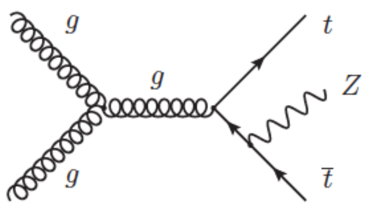
A few examples of other important topics in top physics

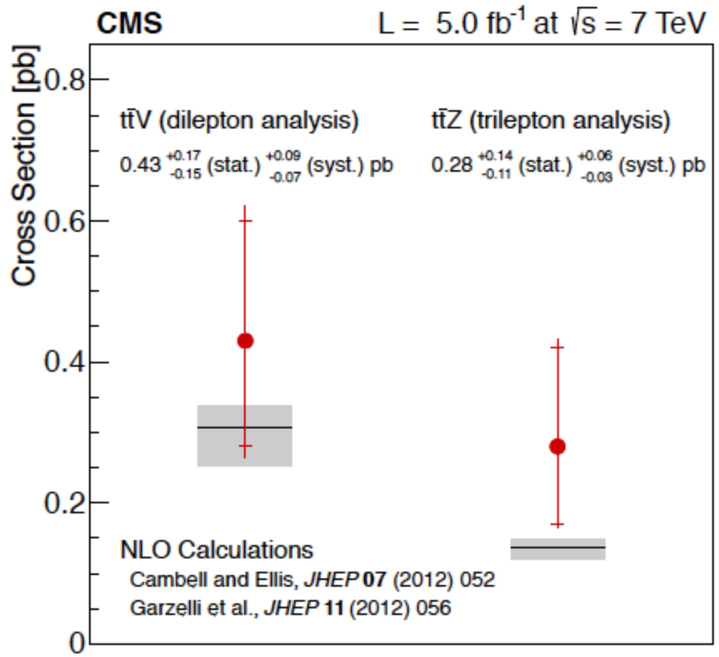
Rare processes: tt+X

- Important to measure low cross section processes
- Example: ttW and ttZ

(arXiv:1303.3239)



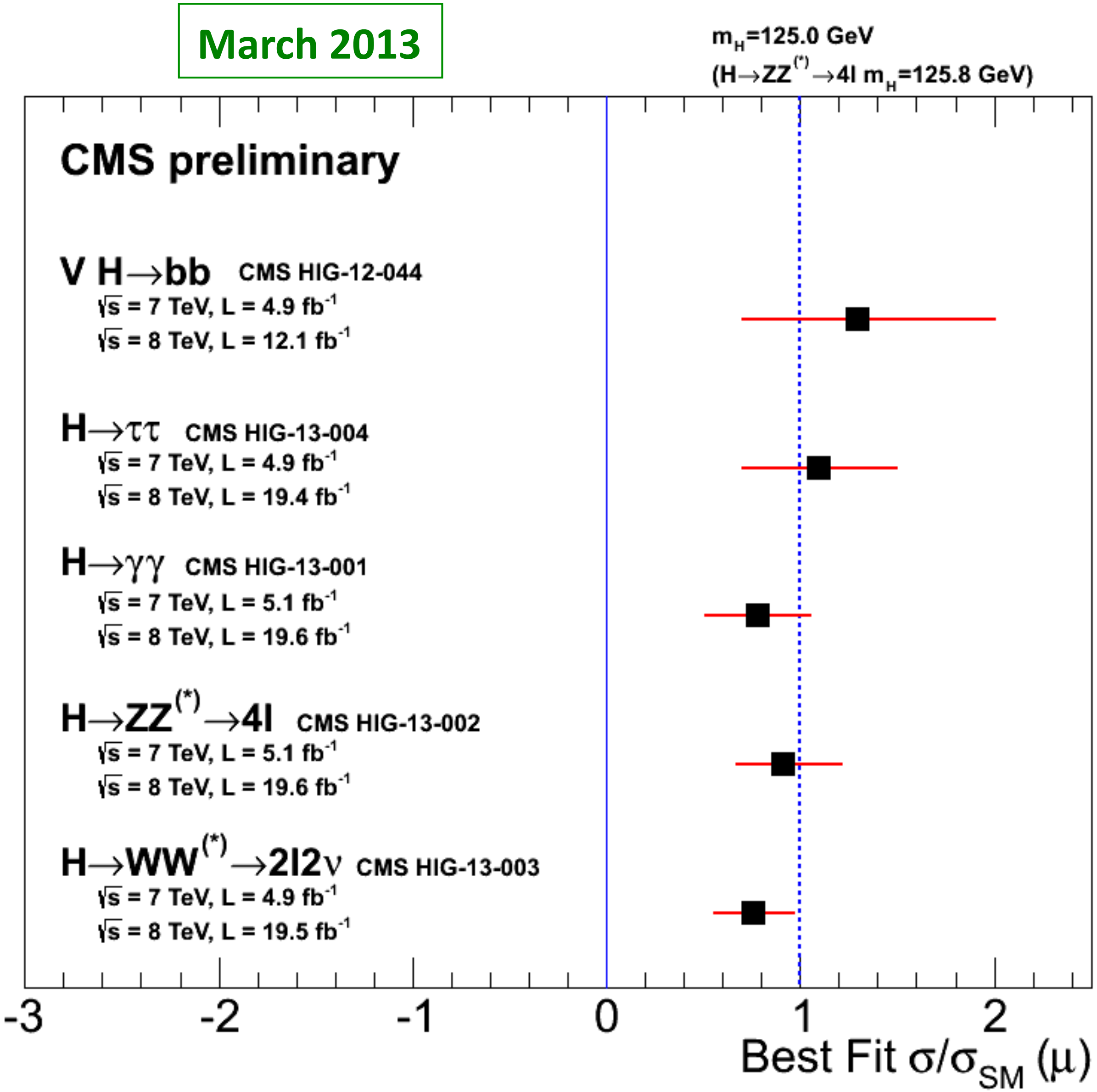




- Other processes tt+X
  - **Very important tt+bb and ttH**,
  - tt+MET , Four tops
  - tt+γ and interpretation as top charge measurement

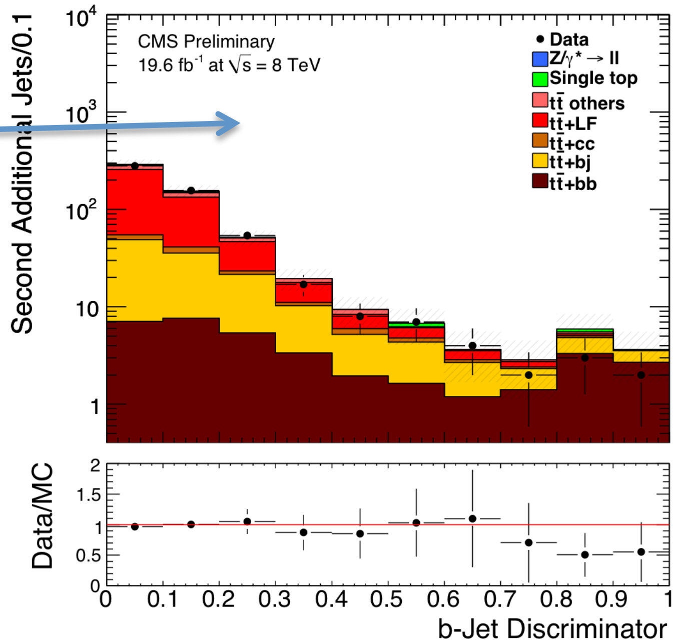
Higgs boson observation in various channels, what about coupling to top ?

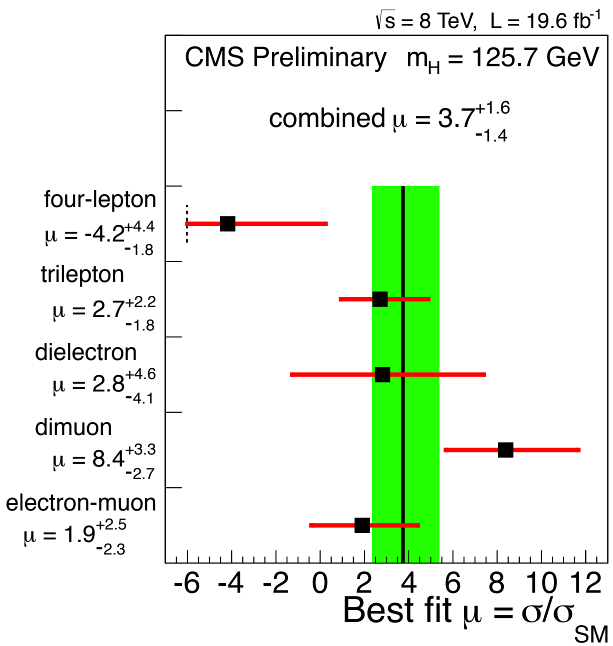
March 2013



Toward a direct measurement of the top-Higgs Yukawa coupling

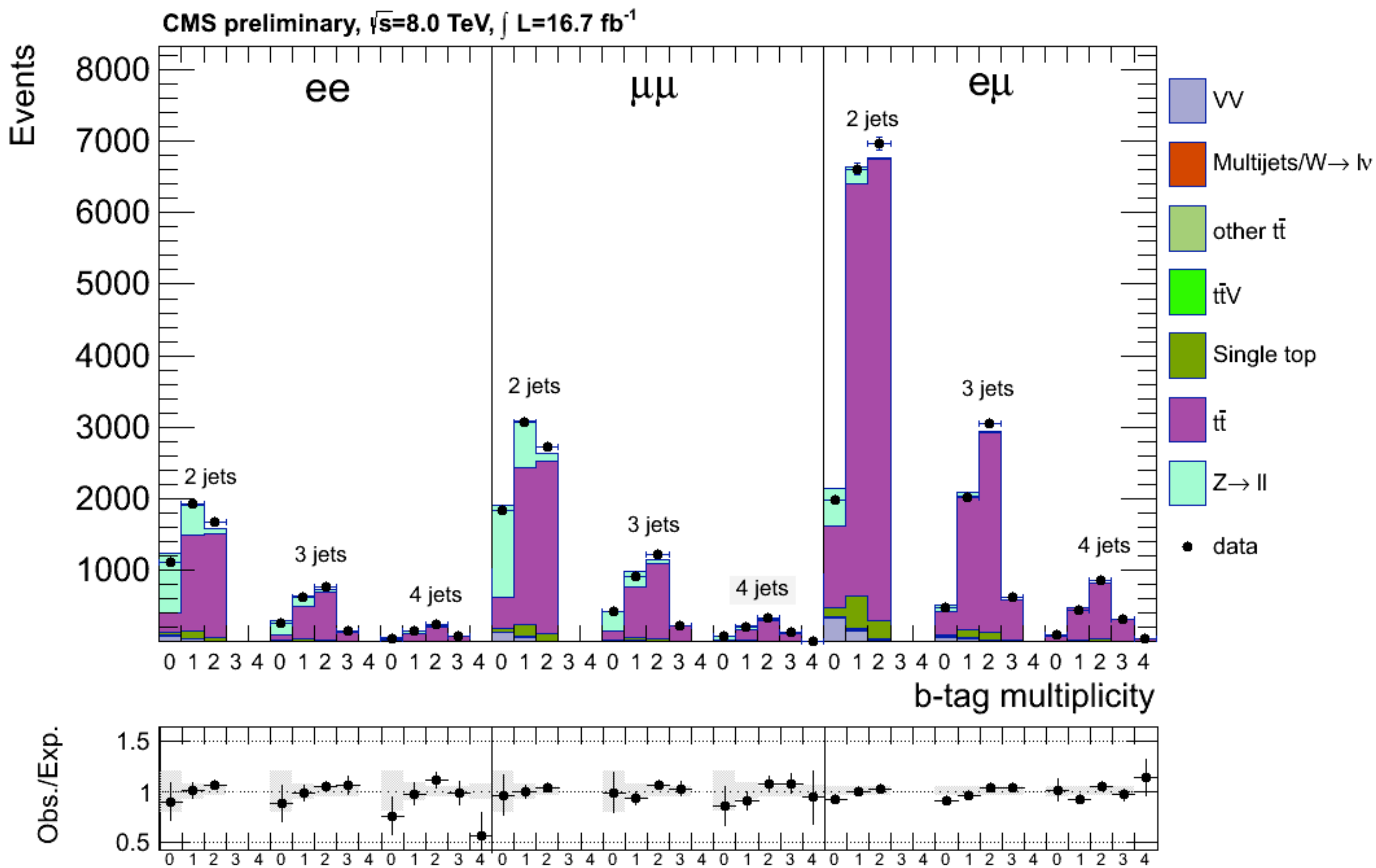
- First measurements of a typical background, ttbb
- From a recent ttH search in leptonic final states





TESTING TOP DECAYS

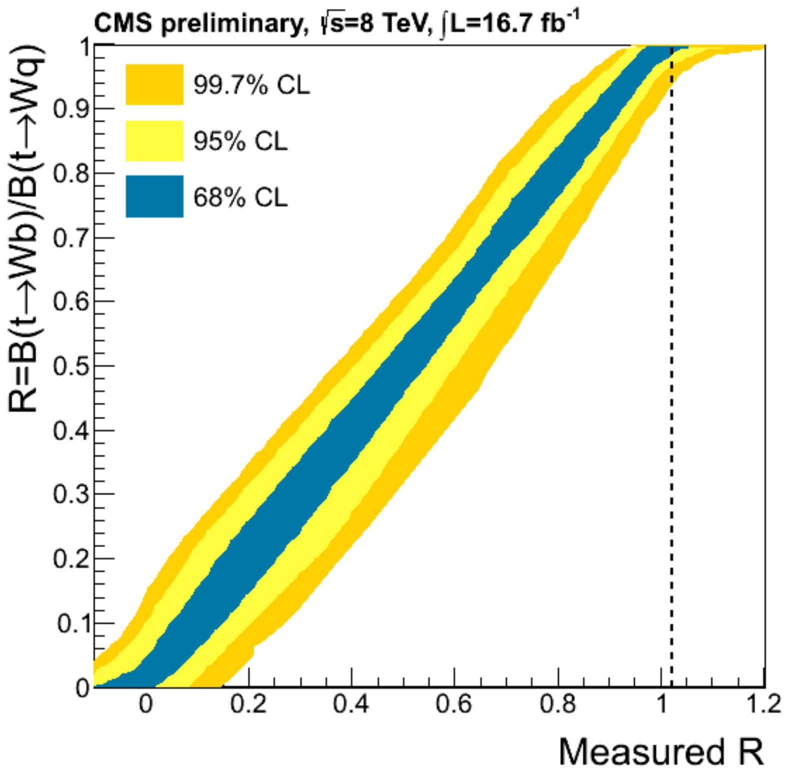
Measurement of the ratio R=B(t → Wb) / B(t → Wq)

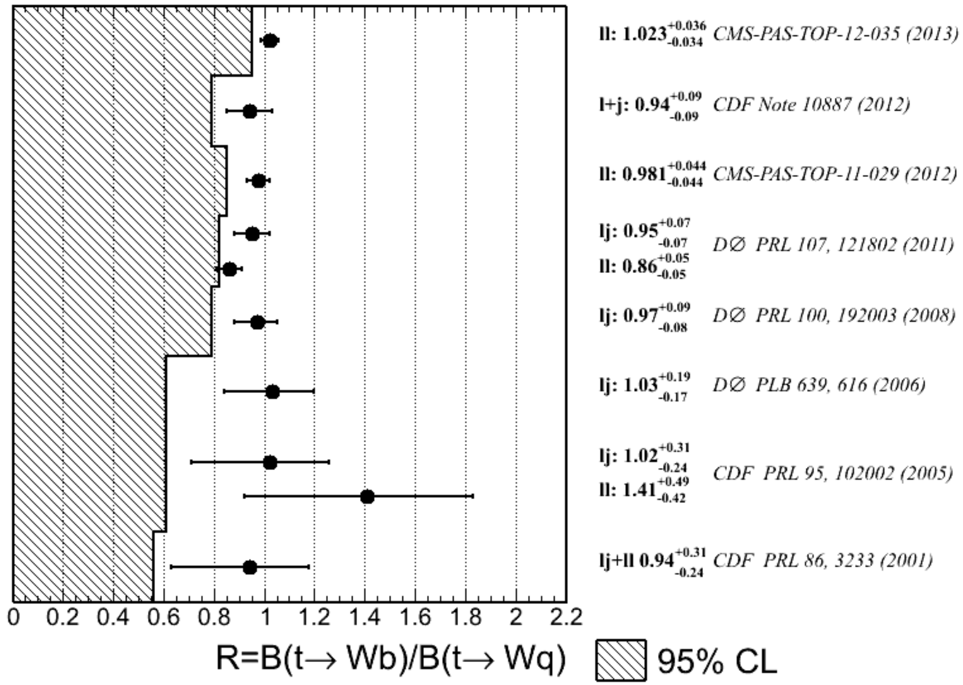


CMS TOP-12-035

Measurement of the ratio $R = B(t \to Wb) / B(t \to Wq)$

A lower limit R>0.945 at 95% CL is obtained after requiring that R≤1



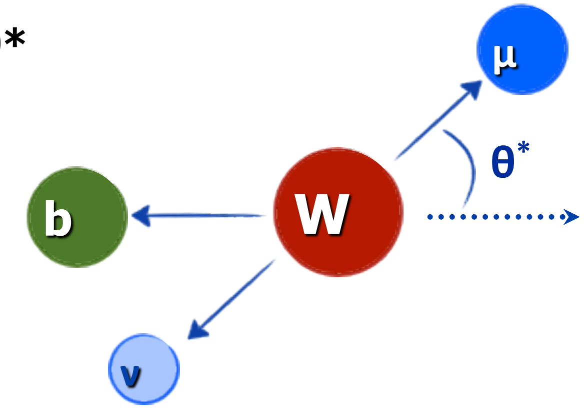


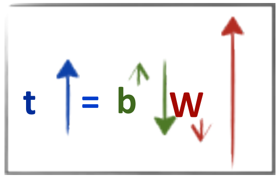
CMS TOP-12-035

W helicity in top decays

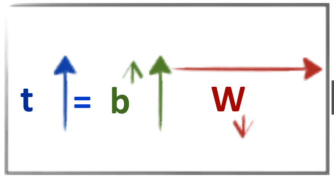
V-A SM nature of the tWb coupling can be probed using θ*

- compute cosθ* to measure contributions from different helicities
- $F_{0/L/R}$ relative contributions for SM are well known
- Different relative contrib. can indicate new physics
  - in SM only $V_L \neq 0$ and $g_R = g_L = V_R = 0$

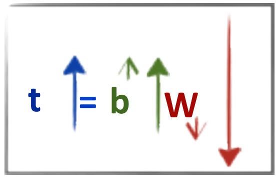




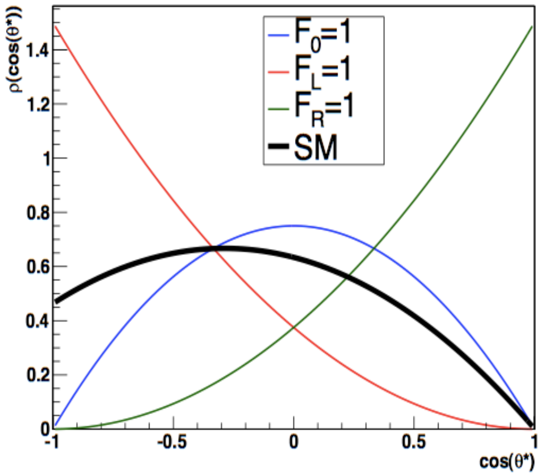
F_L [SM≃0.311]



F_0 [SM≃0.687]

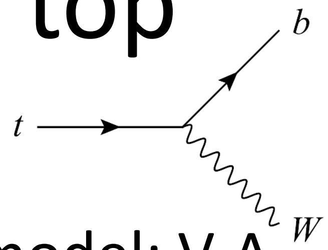


F_R [SM≃0.001]

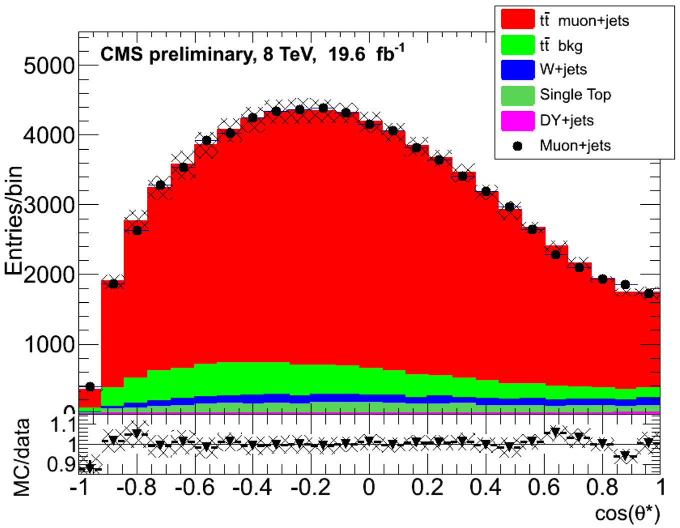


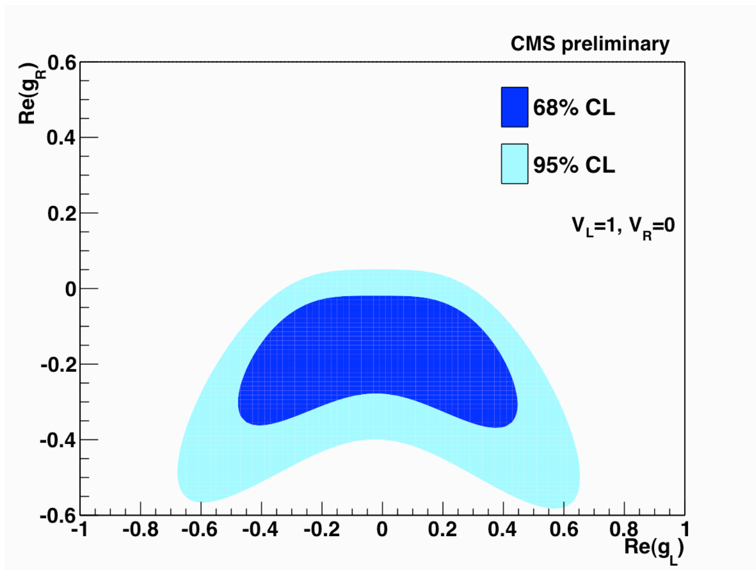
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)F_0 + \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{8}(1+\cos\theta^*)^2 F_R$$

The tWb vertex : W helicity in top decays



- The W helicity precisely predicted in the standard model: V-A structure of the decay
  - Longitudinal W polarization F0 ≈ 70%, **intimately related to the ewk breaking mechanism !**
  - Left polarization FL≈30%, Right pol FR ≈0





W helicity in top decays: results

ATLAS (l+jets + dilepton combined)
[JHEP 1206 (2012) 088]

- F_0 = 0.67 ± 0.03 (stat) ± 0.06 (syst)
- F_L = 0.32 ± 0.02 (stat) ± 0.03 (syst)
- F_R = 0.01 ± 0.01 (stat) ± 0.04 (syst)

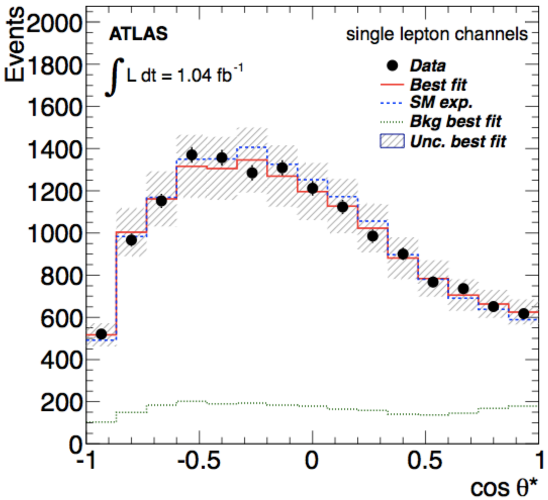
CMS (dilepton)
[CMS PAS TOP-12-15]

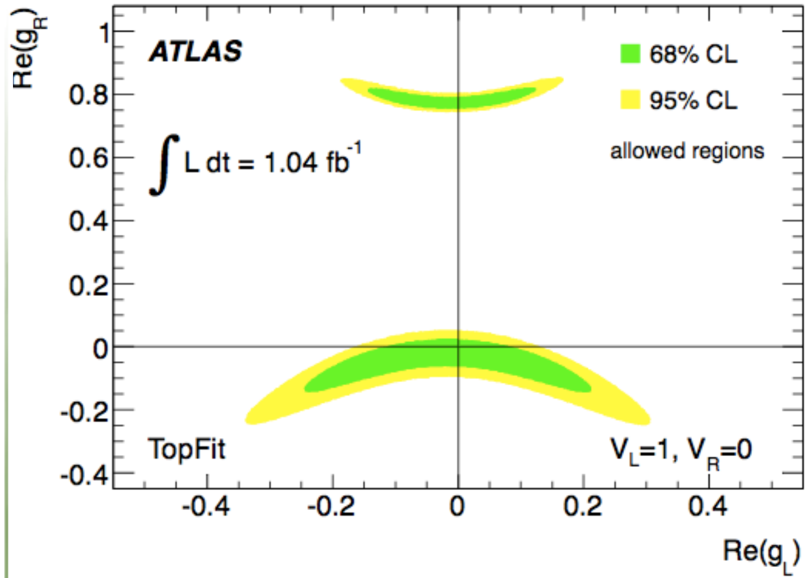
- F_0 = 0.698 ± 0.057 (stat) ± 0.063 (syst)
- F_L = 0.288 ± 0.035 (stat) ± 0.050 (syst)
- F_R = -0.014 ± 0.027 (stat) ± 0.055 (syst)

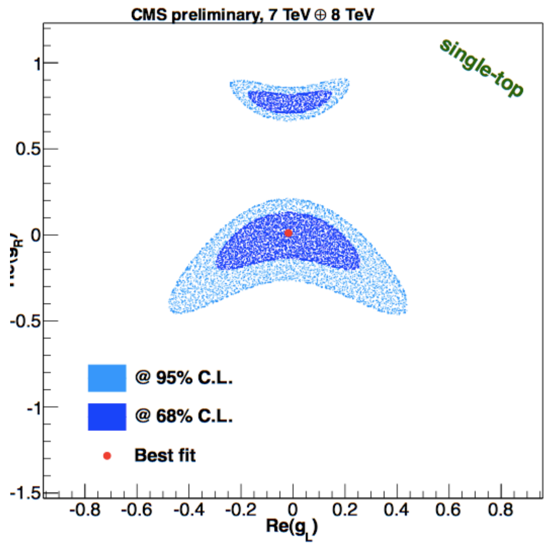
CMS (single top 7TeV + 8TeV)
[CMS PAS TOP-12-20]

- F_0 = 0.713 ± 0.114 (stat) ± 0.023 (syst)
- F_L = 0.293 ± 0.069 (stat) ± 0.030 (syst)
- F_R = -0.006 ± 0.057 (stat) ± 0.027 (syst)

Results compatible with SM



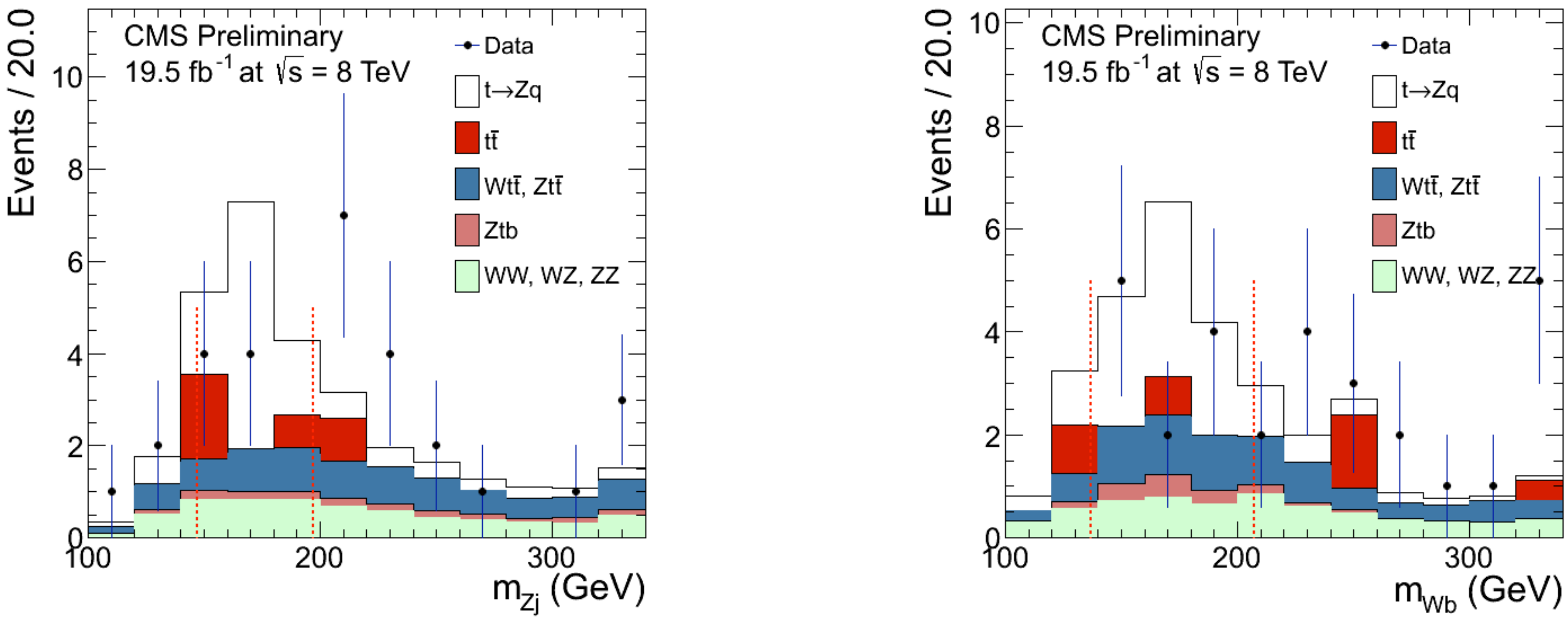




Used to probe anomalous couplings

Rare processes: limits on FCNC t→Zq

- FCNC searches have improved a lot with 20/fb
  - Current result from ttbar/trilepton searches: A t → Zq branching fraction greater than 0.07 % is excluded at the 95 % confidence level.

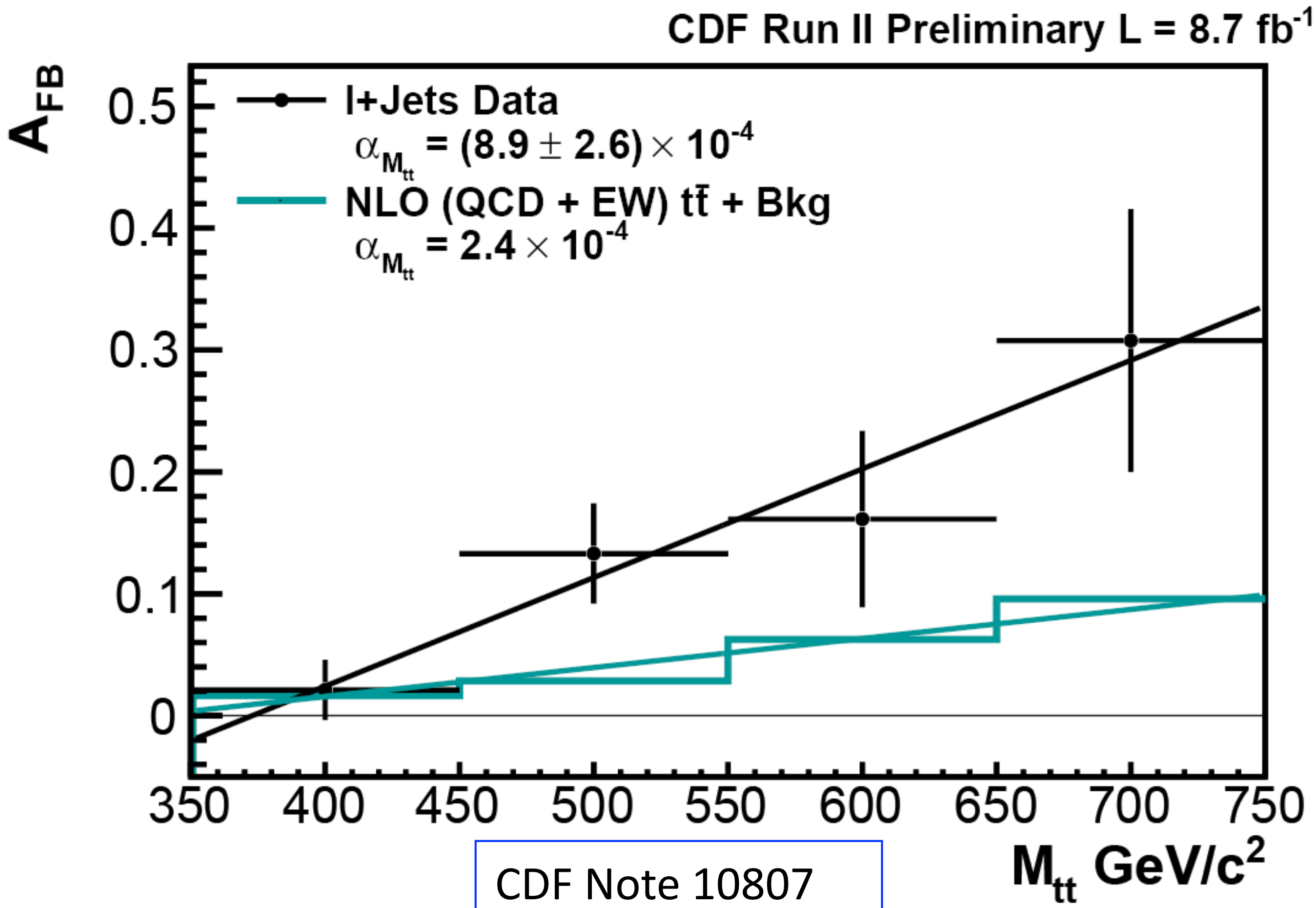


TESTING TOP PRODUCTION PROPERTIES

A discrepancy ? … A_{FB} in $p\bar{p}$

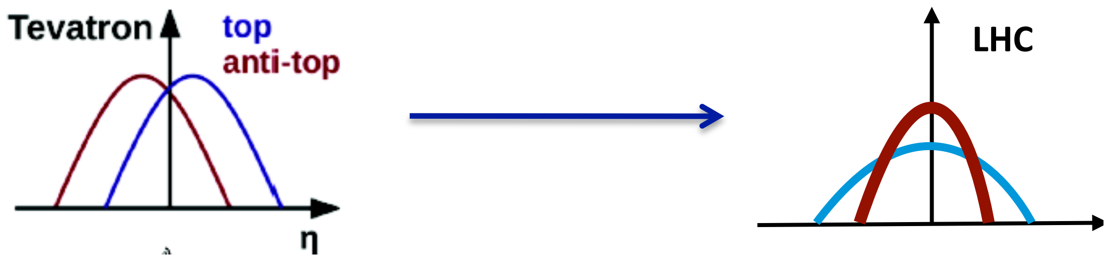
$$q\bar{q} \rightarrow t\bar{t}$$

- SM asymmetry from interference (higher order QCD ~ 7%)



CDF Note 10807

A_{FB} a LHC → charge asymmetry



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

$$\Delta|y| = |y(t)| - |y(\bar{t})|$$

• top / anti-top rapidity asymmetry at LHC from quark-antiquark annihilation, gluon-gluon fusion, dominant process, intrinsically symmetric

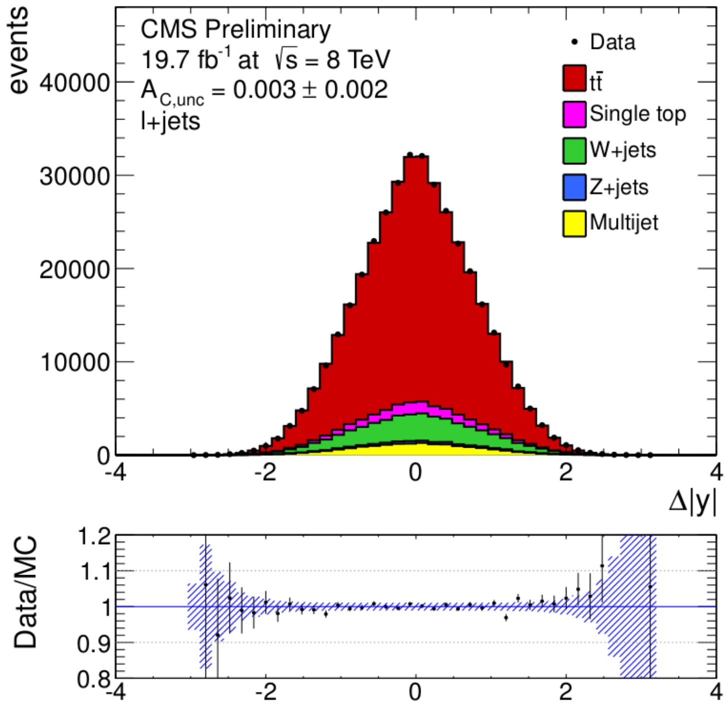
$$14\ \mathrm{TeV}\ gg \to t\bar{t}\ (90\%),\ q\bar{q} \to t\bar{t}\ (10\%)$$

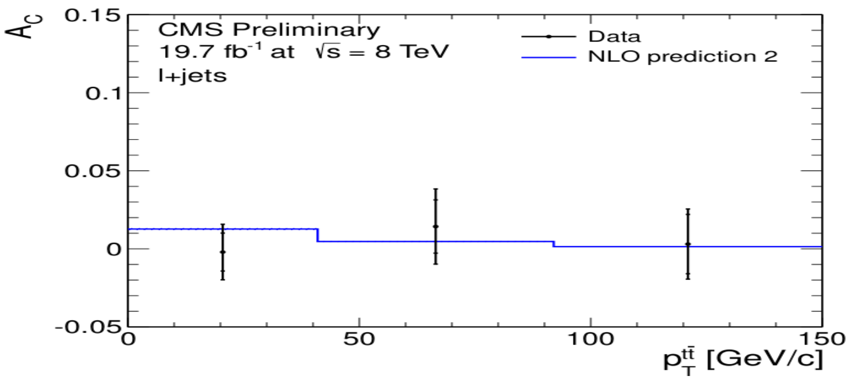
• **Important at LHC to study differential asymmetries**, to enhance new physics

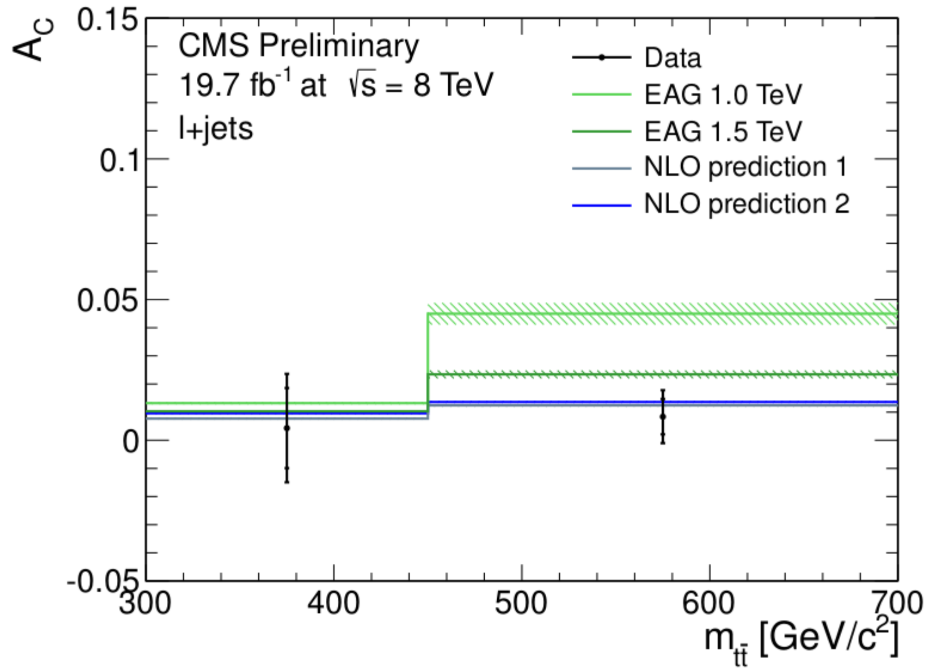
- **Sum of t and tbar rapidity to disentangle quark-antiquark and gluon-gluon fusion**
- **ttbar invariant mass sensitive to new heavy states**
- **Transverse momentum of the ttbar system sensitive to interference due to ISR**

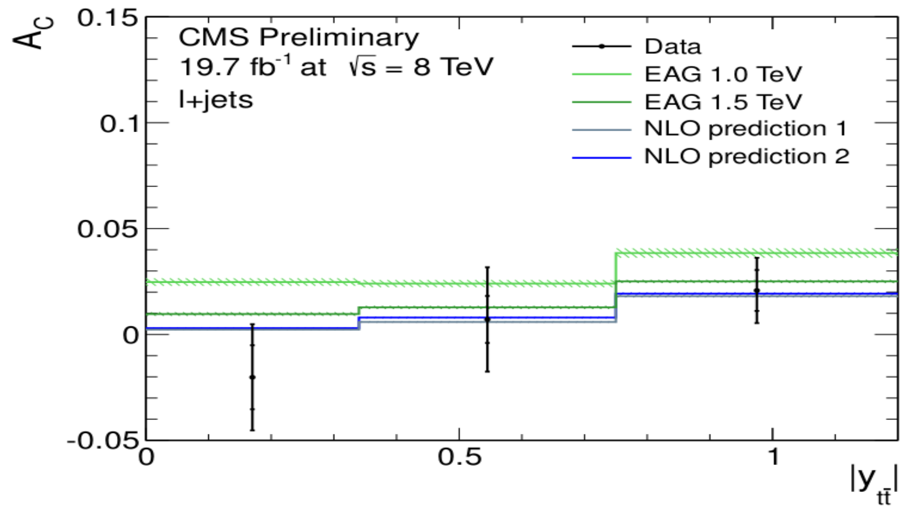
CMS PAS TOP-12-033

Charge asymmetry at LHC





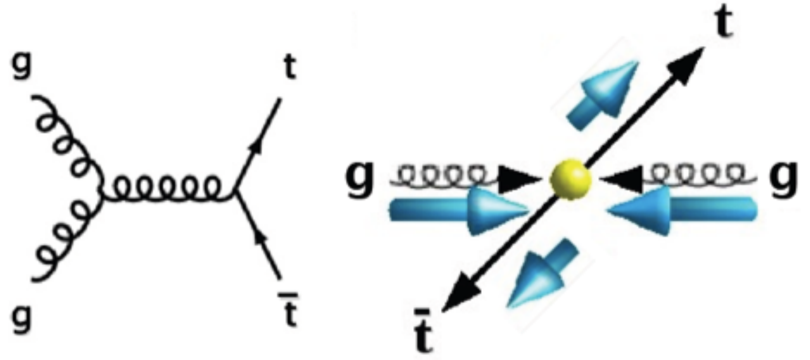




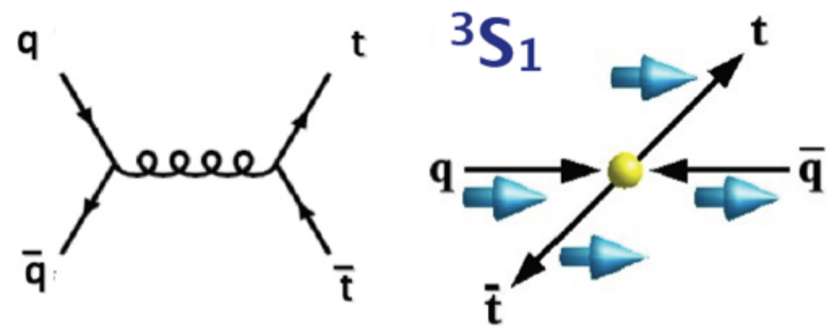
Spin correlations in ttbar

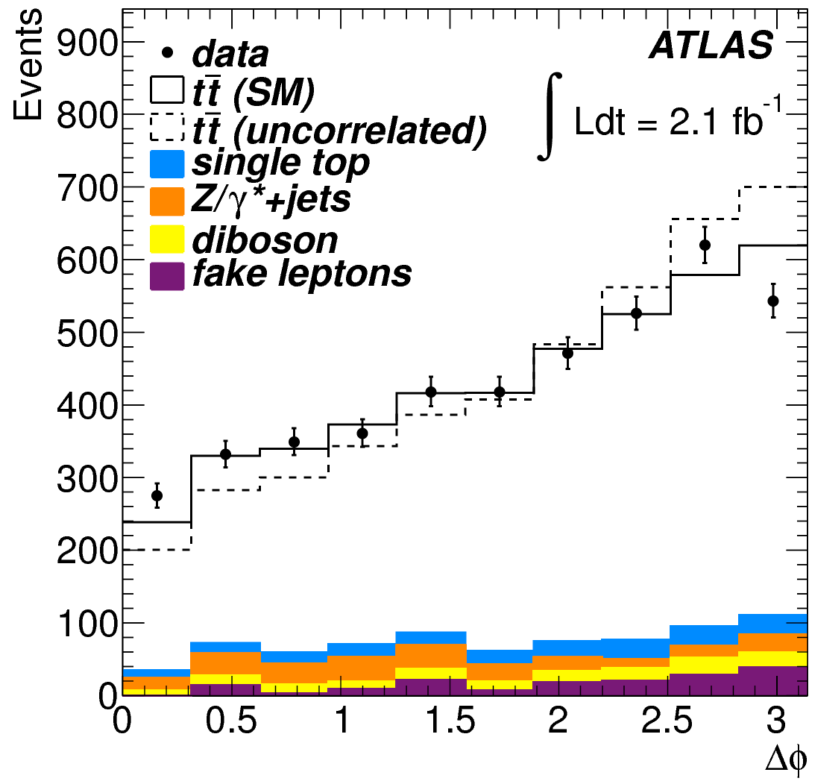
Another tool to investigate the production mechanism, possible only for the top quark
Investigating it now, but will become a precision tool with high statistics

gluon-gluon example at high boost

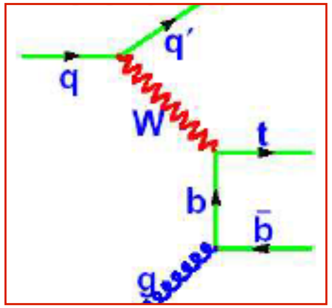


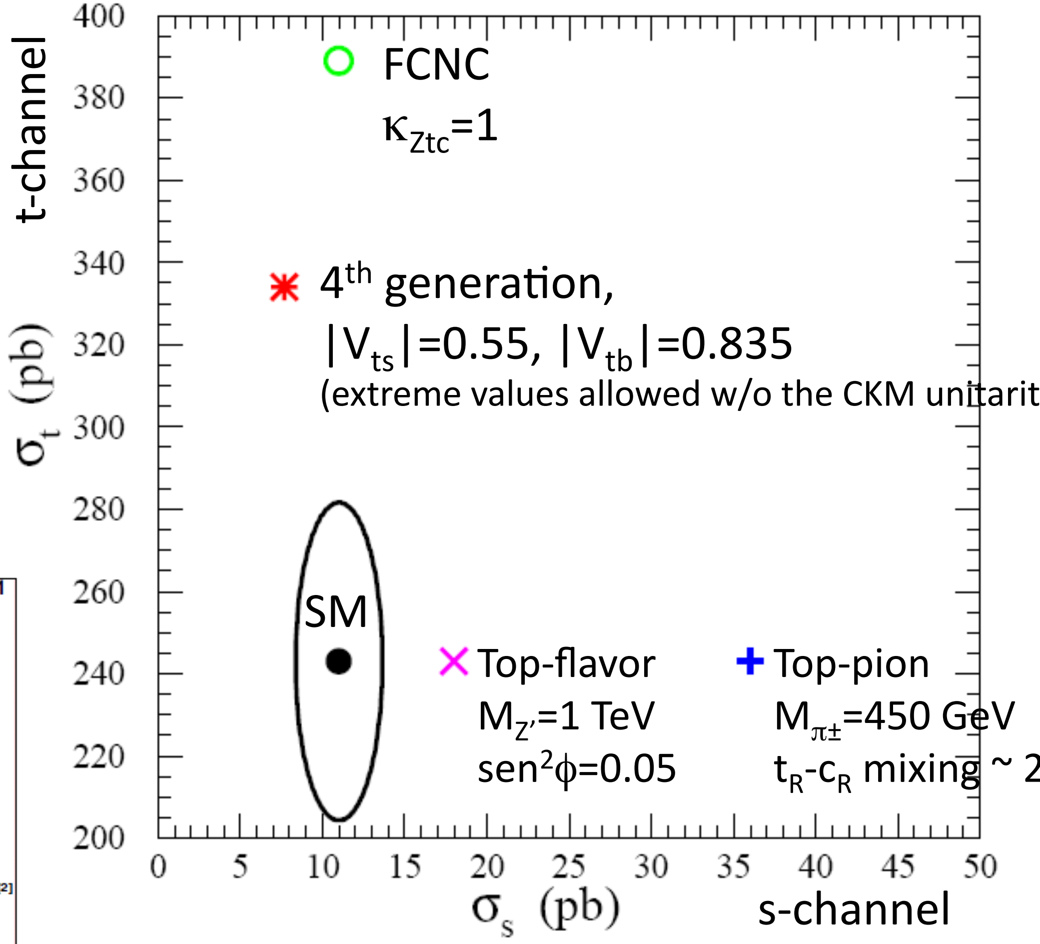
qqbar example at threshold



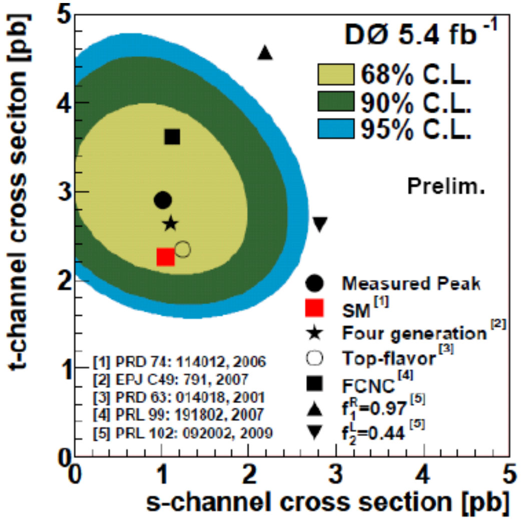


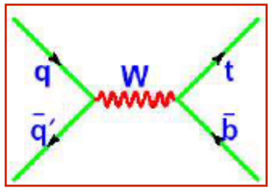
Single top in t and s channel sensitive to different aspects of New Physics (tW, too !)





(plot for 14 TeV)



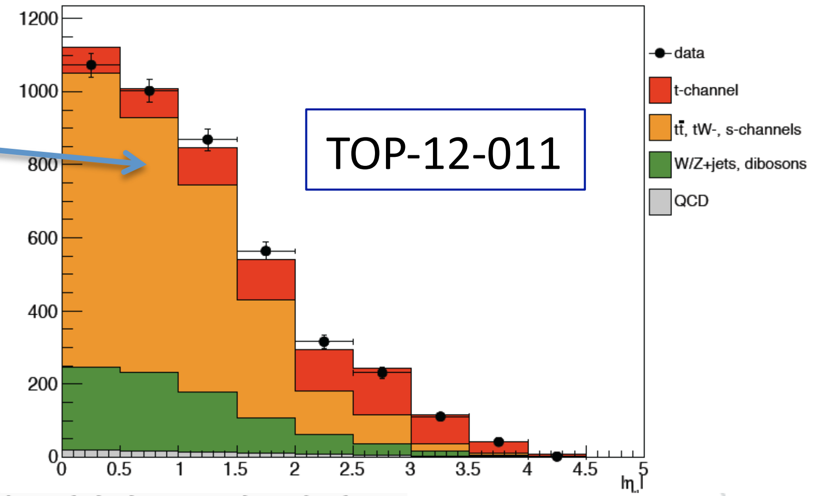


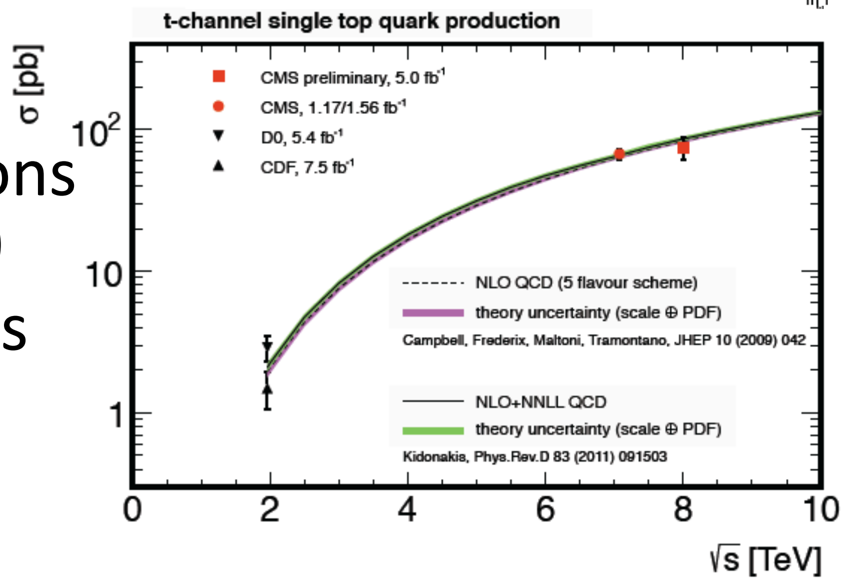
T.Tait, C.-P.Yuan, Phys.Rev. D63 (2001) 0140018

Single top

- Recent LHC publications at 7 TeV (t-channel and tW)
- Preliminary t-chan 8 TeV
- Tackle s-channel with the full statistics
- W helicity in single top topologies
- Other studies
  - new physics interpretations (e.g. FCNC in production)
  - differential cross sections

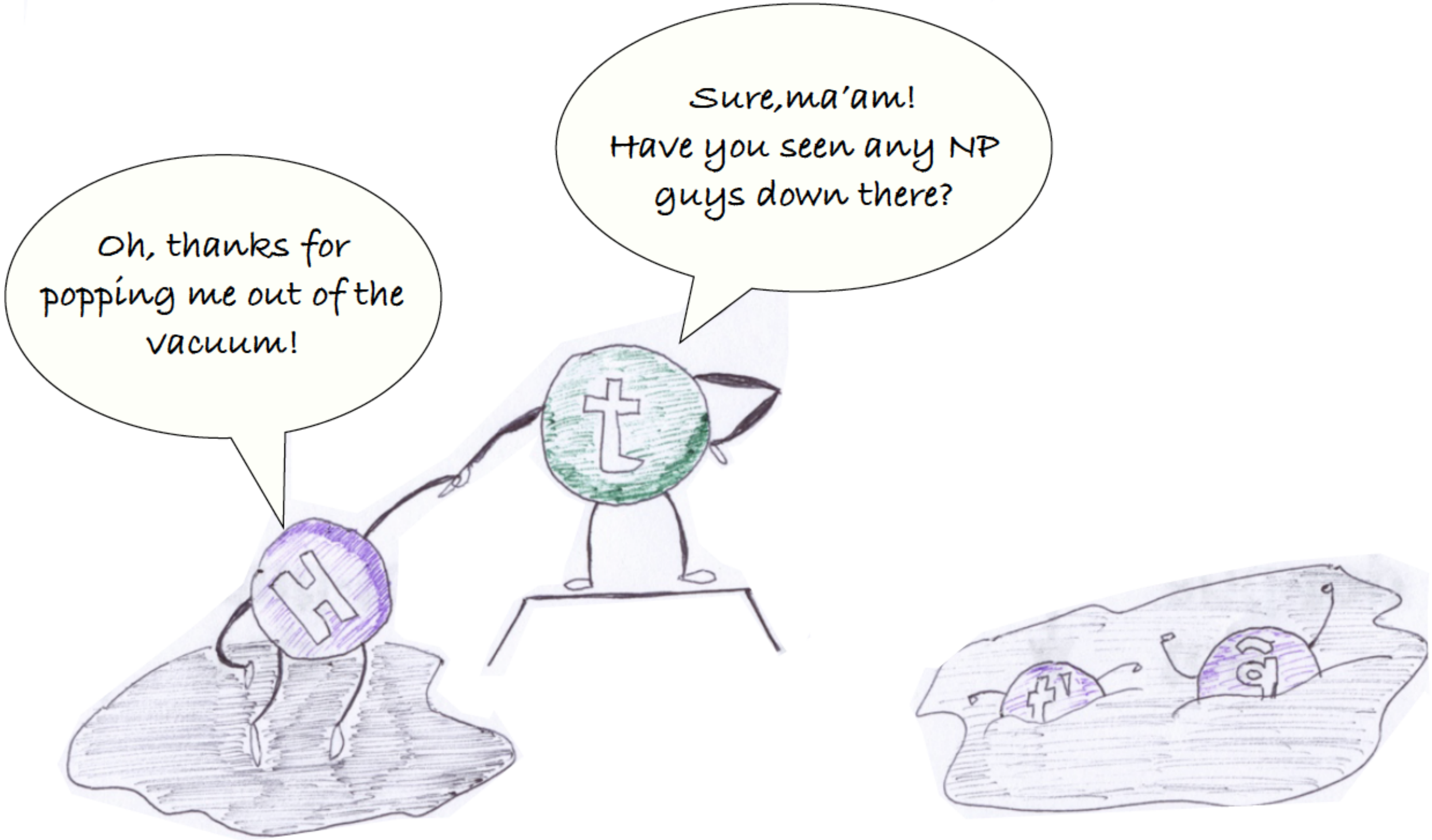
First result in t-channel at 8 TeV





Conclusions

- **Top physics an important sector of electroweak-symmetry-breaking studies**
  - **A complement to direct Higgs measurements**
- After first three years of top-physics results **at the LHC-top-factory**, now entering a new phase
- **Entering uncharted territory in terms of (statistical) precision, use statistics as a tool to reduce systematic uncertainties**



Courtesy of Fabio Maltoni