Top quark couplings

A. Onofre

(antonio.onofre@cern.ch)

LIP/Physics Department, University of Minho, Portugal

Flavour Physics at the LHC run II

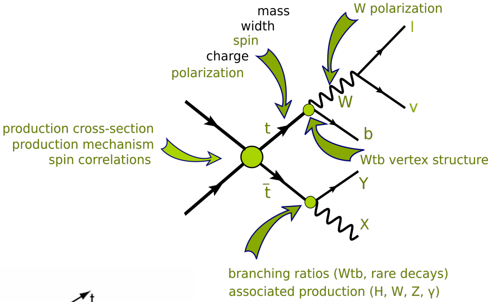
Benasque, Spain, 2017, May 21th - 27th

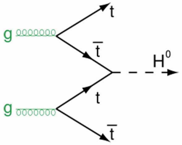
CERN/FP/123619/2011
CERN/FIS-NUC/0051/2015

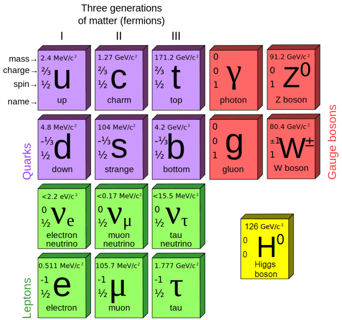
Measuring top quark couplings with precision is quite important ☞ precision tests of the SM and search for BSM

Topics covered in this talk:

- Cross sections @ LHC
  - $t\bar{t}$ production and,
  - single top quark production
- The $t \to bW$ decay in $t\bar{t}$ events
  - the Wtb vertex structure and anomalous couplings
- Top Quark Couplings to Bosons
  - V_{tb} @ LHC
  - ttV ($V = \gamma, Z, W$, H)
- Top quark beyond SM
  - FCNC processes ($tqX, X = \gamma, Z, g, H$)





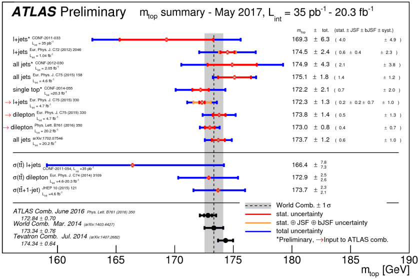


- **The top quark was discovered by CDF and D0 in 1995, 22 years ago**
  PRL**74** 2626-2631 (1995);
  PRL**74** 2632-2637 (1995).

- **Properties:**
  - belongs to 3^{rd} generation of quarks
  - the top quark is the weak-isospin partner of the b-quark
  - spin = $1/2$
  - charge = $+2/3\ |e|$
  - heaviest known fundamental fermion
    ($m_t = 173.34 \pm 0.76$ GeV, World comb.(2014), arXiv:1403.4427)
  - dominant decay mode: $t \to bW$
    $BR(t \to sW) \leq 0.18\%$, $BR(t \to dW) \leq 0.02\%$
  - $\Gamma_t^{SM} = 1.42$ GeV (including m_b, m_W, α_s, EW corrections)
  - τ_t=($3.29^{+0.90}_{-0.63}$) $\times 10^{-25}$s (D0, PRD **85** 091104, 2012)
    $\ll \Lambda_{QCD}^{-1}$ ~(100 MeV)$^{-1}$ $\sim 10^{-23}$s (hadronization time)
    $\Rightarrow$ top decays before hadronization takes place

Summary of Top Quark Mass @ LHC

☞ most precise measurement ever on top quark physics



Direct measurements:

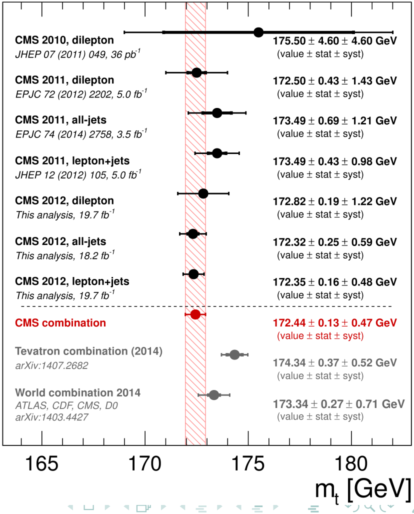
$$\Delta(m_t)/m_t = 0.3\text{-}0.4\ \%$$

Indirect complementary methods for m_t^{pole}:

ATLAS: JHEP **10** (2015) 121

CMS: JHEP **08** (2016) 029

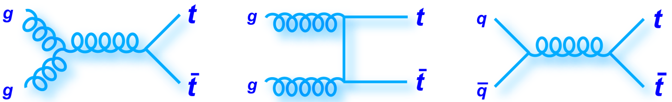
$$\Delta(m_t^{pole})/m_t^{pole} \sim 1\%$$



Top Quark Production

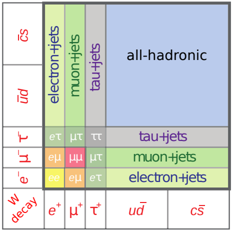
$t\bar{t}$ production at the LHC

- Production at the LHC:

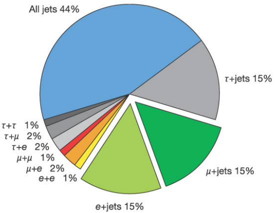


$\sigma(t\bar{t})$=177.3$\pm$9.9$^{+4.6}_{-6.0}$ pb @ 7 TeV, $\sigma(t\bar{t})$=252.9$\pm$11.7$^{+6.4}_{-8.6}$ pb @ 8 TeV, $\sigma(t\bar{t})$=832$^{+40}_{-46}$ pb @ 13 TeV
NNLO+NNLL, m_t =172.5 GeV PLB **710** 612 (2012), PRL **109** 132001(2012), JHEP **1212** 054(2012), JHEP **1301** 080(2013), PRL**110** 252004 (2013).

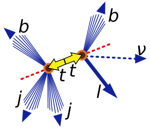
Top pair decay channels



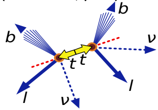
Top pair branching fractions



$\Longrightarrow$ Lepton+jets ($\sim$ 30%):
($\ell = e^{\pm}, \mu^{\pm}$)

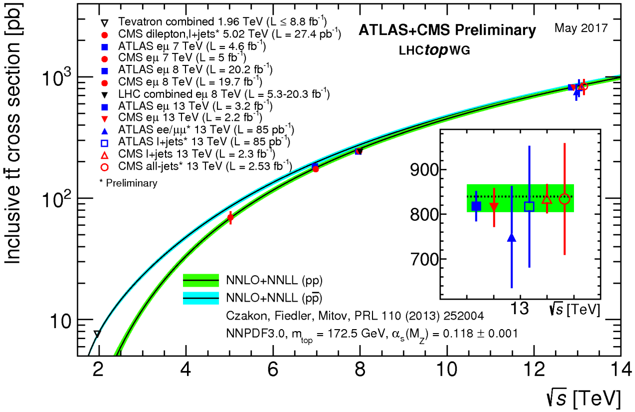


$\Longrightarrow$ Dilepton ($\sim$ 5%):
($\ell = e^{\pm}, \mu^{\pm}$)



Cross-Section Measurements @ 2,7,8 and 13 TeV

☞ significant number of measurements @ LHC (pp) and Tevatron ($p\bar{p}$)

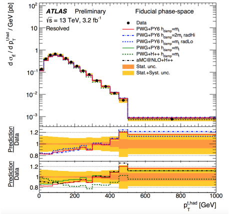


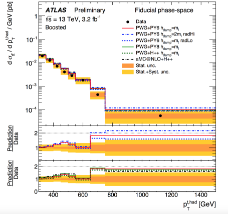
Already quite precise measurements of ATLAS+CMS: $\Delta\sigma_{t\bar{t}}/\sigma_{t\bar{t}} = 4\%$

☞ **experimental precision is $\sim$ to theoretical one (NNLO+NNLL)**

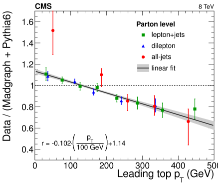
Measure Cross sections with respect to different kinematical variables ☞ Unique opportunity to test SM @ TeV scale

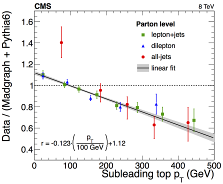
ATLAS-CONF-2016-040 (13 TeV, 3.2 fb^{-1}, ℓ**+jets**, top quarks produced at higher p_T, up to 1.5TeV)





CMS arXiv:1509.06076 [hep-ex], Eur. Phys. J. **C 76** (2016) 128 (already seen @ 8Tev in **all decay topos.**)

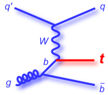


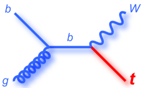


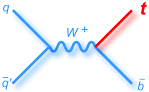
Data softer then MC ☞ requires better modelling

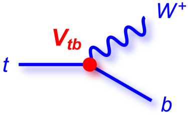
Single top quark

- Single top quark production cross section @ LHC:



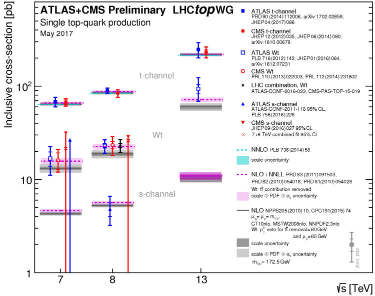






t-channel	(*Wt*-prod.)	(*s*-channel)	
$64.57^{+2.63}_{-1.74}$ pb	$15.74^{+1.17}_{-1.21}$ pb	$4.63^{+0.20}_{-0.18}$ pb	$\Longleftarrow$ @ 7TeV
$87.76^{+3.44}_{-1.91}$ pb	$22.37^{+1.52}_{-1.52}$ pb	$5.61^{+0.22}_{-0.22}$ pb	$\Longleftarrow$ @ 8TeV
217 ± 10 pb	$71.7 \pm 1.8 \pm 3.4$ pb	11.92 ± 0.40 pb	$\Longleftarrow$ @ 13,14TeV

- Powerfull probe of V_{tb} ($\delta V_{tb}/V_{tb}$ few % @ LHC) and Test of physics BSM (FCNC in *t*-channel; W' in *s*-channel)



$\Delta\sigma_t/\sigma_t \sim$10%@ 7-8TeV, 20% @13TeV

$\Delta\sigma_{wt}/\sigma_{wt} \sim$20%@ 7-8TeV, 30% @13TeV

ATLAS@8 TeV:

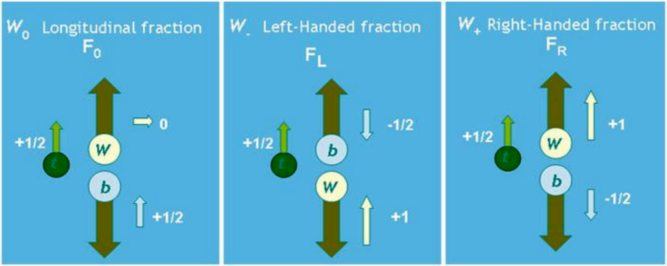
$\sigma_s = 4.8 \pm 0.8(stat.)^{+1.6}_{1.3}$ (syst.) pb (3.2σ sign.)

CMS@8 TeV:

$\sigma_s(95\%) < 28.8$ pb [13.4±7.3(stat+syst) pb]

Top quark properties

Testing a Standard Model prediction: [Phys. Rev. D 45 (1992) 124]



W bosons produced with different helicities:

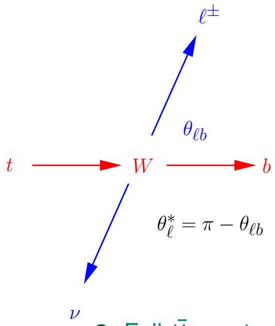
$$F_0^{\rm SM} = 0.687 \pm 0.005 \quad F_{\rm L}^{\rm SM} = 0.311 \pm 0.005 \quad F_{\rm R}^{\rm SM} = 0.0017 \pm 0.0001,$$
$$(F_0 + F_{\rm L} + F_{\rm R} = 1)$$

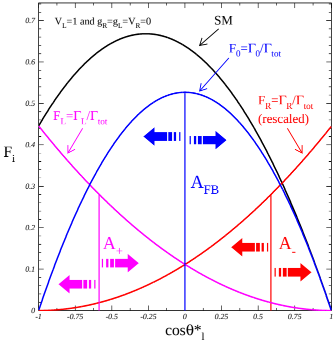
@ NNLO QCD calculation, Phys. Rev. **D81** (2010) 111503

Measuring the W helicity states:

$$\frac{1}{N}\frac{\mathrm{d}N}{\mathrm{d}\cos\theta^*_\ell} = \frac{3}{2}\left[F_0\left(\frac{\sin\theta^*_\ell}{\sqrt{2}}\right)^2 + F_{\mathrm{L}}\left(\frac{1-\cos\theta^*_\ell}{2}\right)^2 + F_{\mathrm{R}}\left(\frac{1+\cos\theta^*_\ell}{2}\right)^2\right]$$

$\theta^*_\ell \to$ the angle between the ℓ (in W rest frame) and the W (in t rest frame)





Asymmetries (@ NNLO):

$$A_t = \frac{N(\cos\theta^*_\ell > t) - N(\cos\theta^*_\ell < t)}{N(\cos\theta^*_\ell > t) + N(\cos\theta^*_\ell < t)}$$

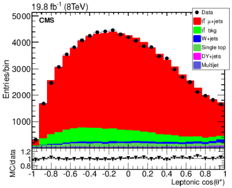
A_{FB}=-0.232±0.004

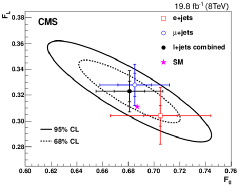
A_+ = 0.537±0.004

A_- =-0.841±0.006

- Full $t\bar{t}$ events reconsctruction required (ℓ+jets and dilepton) and:
  - ☞ fit the $\cos\theta^*$ with templates and evaluate angular asymmetries
  - ☞ these observables allows to probe the Wtb vertex and look for new physics

W Helicity from CMS (19.7 fb^{-1}@ 8 TeV): [PLB**762** (2016) 512]





Systematic Uncertainties (likelihood fit):

F_0: Multijet backg., Fac./Renorm. scales, $t\bar{t}$ MC and Hadronization

F_L: $t\bar{t}$ MC and Hadronization, scales

F_0 = 0.681±0.012(stat)±0.023(syst)

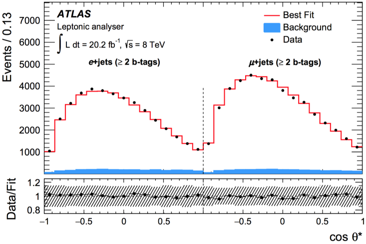
F_L = 0.323±0.008(stat)±0.014(syst)

F_R = -0.004±0.005(stat)±0.014(syst)

☞ single top important: JHEP**01** 053 (2015)
stringent limits on anomalous couplings!!

$\Delta F_0/F_0$=4%, $\Delta F_L/F_L$=5%

W Helicity from ATLAS, Eur.Phys.J. **C27** (2017) 264:



Lepton+Jets @ 8 TeV, 20.2 fb^{-1}:

(ℓ and down-type quark analysers used)

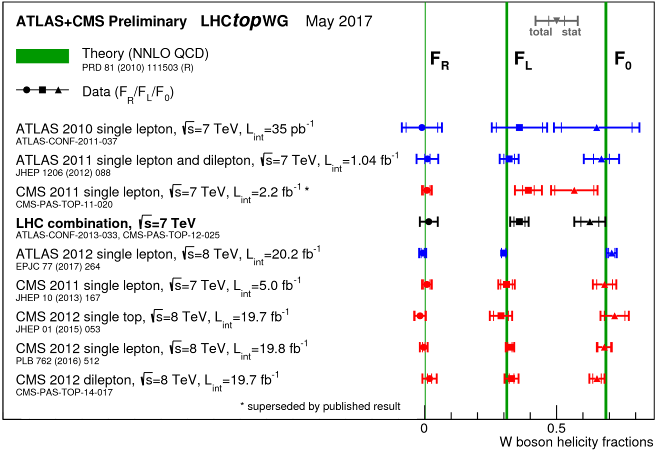
F_0 = 0.709±0.012(stat)±0.015(syst)

F_L = 0.299±0.008(stat)±0.013(syst)

F_R = -0.008±0.006(stat)±0.006(syst)

$\Delta F_0/F_0$=3%, $\Delta F_L/F_L$=5%

Summary of W-boson helicity meas. @ LHC



$\Delta F_0/F_0$=3%, $\Delta F_L/F_L$=5% F_R=-0.008$\pm$0.014

The $t \to bW$ decay in $t\bar{t}$ events

General Wtb vertex

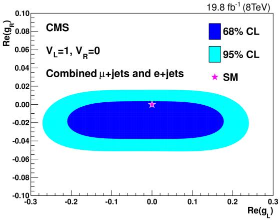
Eur.Phys.J. C50 (2007) 519-533

$$\mathcal{L} = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}\left(V_L P_L + V_R P_R\right) t\, W_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(g_L P_L + g_R P_R\right) t\, W_{\mu}^{-}$$

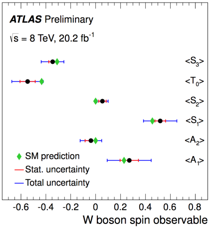
Vector (V_R) and Tensor like couplings (g_L, g_R) zero @ tree level in SM

- Angular distributions of the top decay products (and asymmetries) can be used to probe anomalous couplings at the *Wtb* vertex ☞ **Combinations is the game!**

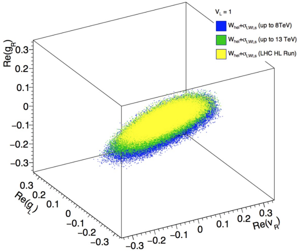
PLB762 (2016) 512



JHEP 04 (2017) 124



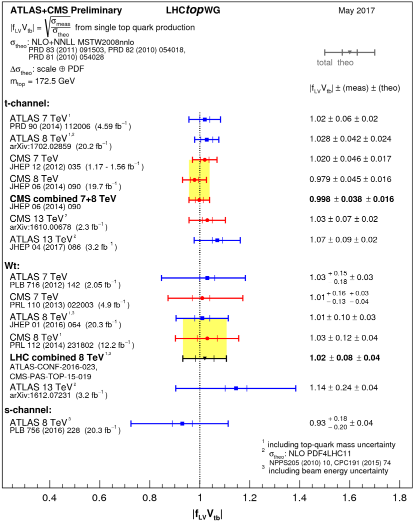
PRD 93 (2016) 11, 113021 (TopFit)



- **Assuming V_L=1 (V_R=0)**

  ☞ **What is the current LHC status of V_{tb} in the SM?**

Summary of V_{tb} Measurements @ LHC



☞ $|V_{tb}|^2$ extracted with:

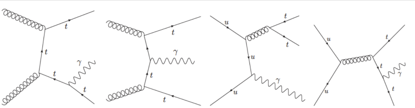
$$|V_{tb,obs.}|^2 = \frac{\sigma_{t,obs.}}{\sigma_{t,SM}} \times |V_{tb,SM}|^2$$

$\delta|V_{tb}|/|V_{tb}|$ @ 5-10%

☞ What about the top quark couplings to the known gauge bosons (γ, W, Z, H)?

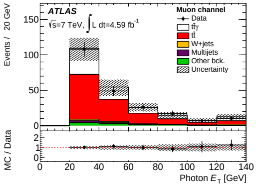
Top Quark Couplings to Gauge Bosons
$t\bar{t}\gamma$, $t\bar{t}Z$, $t\bar{t}W$, $t\bar{t}H$

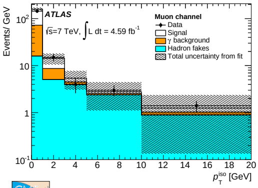
The $t\bar{t}\gamma$ process



$\sigma_{t\bar{t}\gamma}$=48(47)$\pm$10(10) fb Whizard (MadGraph)

ATLAS @ 7 TeV, 4.59 fb^{-1} : PRD**91** 072007 (2015)

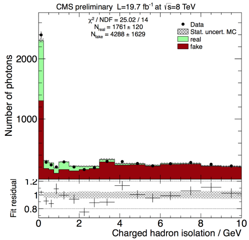




- $\sigma(t\bar{t}\gamma)$ ☞ measurement of top quark EW coupling to γ ($\propto Q_t$)
- fully fiducial measurement
- Analysis: $\ell + jets$ channel $\bigoplus \gamma$ with
  $\Delta R(\gamma,\ell)$< 0.7, $\Delta R(\gamma,j)$<0.5, $|m_{e\gamma} - m_Z|$>5 GeV
  (N_{e+jets}=140 and $N_{\mu+jets}$=222 events in data)
- γ isolation used ☞ $p_{T,\gamma}$ Fit w/ Prompt+Fake Temp.

$$\sigma(t\bar{t}\gamma) \times BR = 63 \pm 8(stat)^{+17}_{-13}(syst) \pm 1(lumi) \text{ fb}, \quad \text{sign. of } 5.3\sigma$$

CMS @ 8 TeV, 19.7 fb^{-1}: CMS-PAS-TOP-13-011



Fiducial region for γ: $E_{T,\gamma}$>20 GeV, $|\Delta(\eta_\gamma, b/\bar{b})|$>0.1 $\sigma^{SM}_{t\bar{t}\gamma} = 1.8 \pm 0.5$ **pb**

Event selection:

☞ $\mu + jets$ **final state** $\oplus\gamma$

☞ **$\geq$4 jets, 2b-jets, $E_{T,\gamma}$>20 GeV, $|\eta_\gamma|$<1.444**

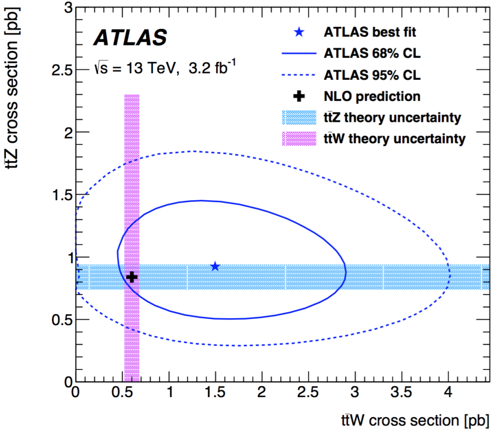
$$\Delta\sigma_{t\bar{t}\gamma}/\sigma_{t\bar{t}\gamma} \sim 30\%$$

$$R = \sigma_{t\bar{t}\gamma}/\sigma_{t\bar{t}} = [1.07 \pm 0.07(stat.) \pm 0.27(syst.)] \times 10^{-2}$$

$$\sigma^{CMS}_{t\bar{t}\gamma} = 2.4 \pm 0.2(stat.) \pm 0.6(syst.) \text{ pb}$$

The $t\bar{t}V(V = Z, W)$ processes: Eur.Phys.J. **C77** (2017) 40

Simultaneous fit of $t\bar{t}Z$ and $t\bar{t}W$ by ATLAS @ 13 TeV, 3.2 fb^{-1}



☞ $t\bar{t}Z$ cross section:

$\sigma_{t\bar{t}Z} = 0.9 \pm 0.3$ pb

$\Delta\sigma/\sigma \sim 30\%$

☞ $t\bar{t}W$ cross section:

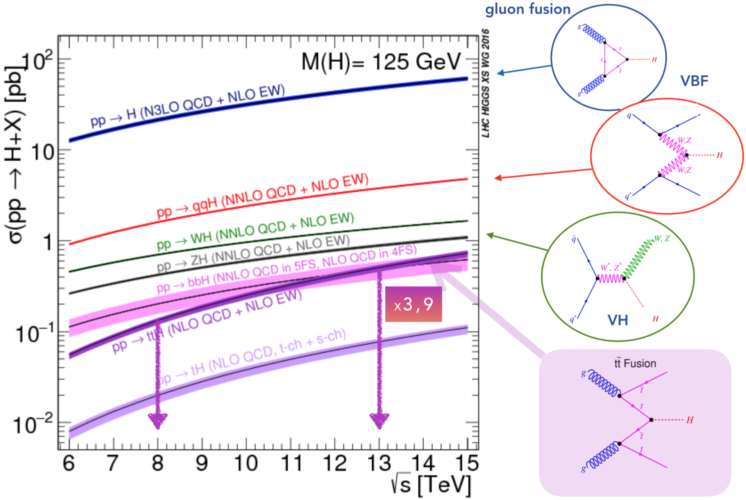
$\sigma_{t\bar{t}W} = 1.5 \pm 0.8$ pb

$\Delta\sigma/\sigma \sim 50\%$

Both OK with NLO QCD theory

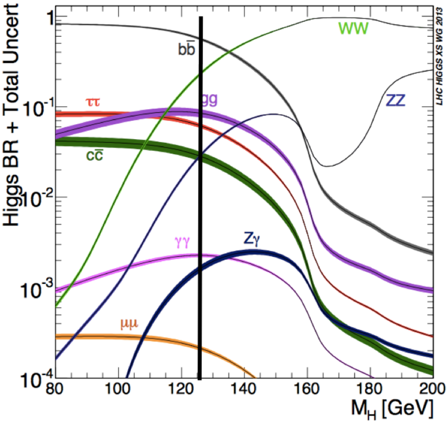
CMS @ 8 TeV $\Delta\sigma_{t\bar{t}V}/\sigma_{t\bar{t}V} =$ 20-30%, sig. of $4.8\sigma(6.4\sigma)$ over back. for $t\bar{t}W(t\bar{t}Z)$

☞ $t\bar{t}H$ Production @ the LHC:



Top Couplings to Bosons ttV ($V = H$)

☞ Higgs Decay Branching Ratios (SM):



Decay channel	Branching ratio [%]
$H \to b\bar{b}$	57.5 ± 1.9
$H \to WW$	21.6 ± 0.9
$H \to gg$	8.56 ± 0.86
$H \to \tau\tau$	6.30 ± 0.36
$H \to c\bar{c}$	2.90 ± 0.35
$H \to ZZ$	2.67 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.155 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001

SM BR theory uncertainties
2-5% for most important decays

☞ Width determined by experimental resolution effects

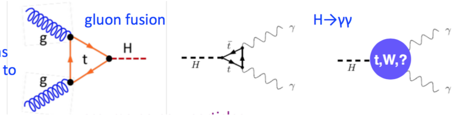
☞ ATLAS+CMS measurements shown by Luca and André

Top Couplings to Bosons ttV ($V = H$)

☞ all about top quark-Higgs Couplings!

- the top quark has the biggest coupling to the Higgs SM boson ($Y_t \sim 1.$)
- precision measurements of top quark Yukawa couplings are really important
- .....as well as deviations !!!
- need also to understand the nature of the coupling ($h = H, A$)
- indirect constraints are important (involve several contributions)

top-Higgs interactions contribute to the loops



☞ probing CP-even(a) -odd(d) nature of couplings in $t\bar{t}H$,

$$L_{hf\bar{f}} \sim [a_f + ib_f\gamma_5] \sim [cos(\alpha) + isin(\alpha)\gamma_5]$$

PRL **76**, 24 (1996)
J.F.Gunion, Xiao-Gang He

$$a_1, a_2, b_1, b_2, b_3...b_4 = \frac{p_t^z p_{\bar{t}}^z}{|p_t||p_{\bar{t}}|}$$

PRD **92**, 1 (2015)
F.Boudjema, R.M.Godbole, D.Guadagnoli, K.A.Mohan

$$\Delta\phi^{t\bar{t}}(l+, l-),\ \beta_{b\bar{b}}\Delta\theta^{lh}(l+, l-)$$

$$\beta \equiv \mathrm{sgn}\left((\vec{p}_b - \vec{p}_{\bar{b}}) \cdot (\vec{p}_{\ell^-} \times \vec{p}_{\ell^+})\right) \qquad \cos(\Delta\theta^{\ell h}(\ell^+, \ell^-)) = \frac{(\vec{p}_h \times \vec{p}_{\ell^+}) \cdot (\vec{p}_h \times \vec{p}_{\ell^-})}{|\vec{p}_h \times \vec{p}_{\ell^+}||\vec{p}_h \times \vec{p}_{\ell^-}|}$$

- need to understand $t\bar{t}H$ production and decay

arXiv:1611.00049v2, A.Broggio,A.Ferroglia,B.D.Pecjak,L.L.Yang

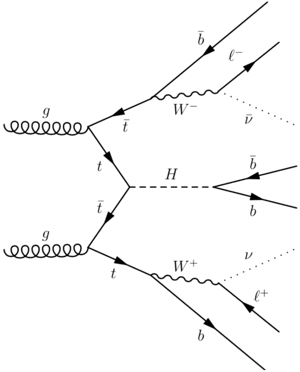
Choice of a Particularly Challenging Final State Topology:

☞ $t\bar{t}H \to (b\ell^+\nu_\ell)(\bar{b}\ell^-\bar{\nu}_\ell)(b\bar{b})$ **(dileptonic topology)**

☞ Event Generation @ 13 TeV:

- MadGraph5_aMC@NLO JHEP **1407**, 079 (2014) J.Alwall *et al.*
  $\oplus$ NNPDF2.3 PDF NPB **867** 244 (2013) R.D.Ball *et al.*
  for $t\bar{t}X, X = A, H$ and $t\bar{t}b\bar{b}$ (@ NLO)
  other backgrounds @ LO with MLM:
  $t\bar{t}$ + *jets*, $t\bar{t}V$ + *jets*, Single t,
  $W(Z)$+jets, $W(Z)b\bar{b}$+jets, VV+jets
- Full spin correlation of $t \to bW^+ \to b\ell^+\nu_\ell$,
  $\bar{t} \to \bar{b}W^- \to \bar{b}\ell^-\bar{\nu}_\ell$, $H \to b\bar{b}$
  by MadSpin JHEP **1303**, 015 (2013) P. Artoisenet *et al.*
- Shower and hadronization by Pythia 6

  JHEP **0605**, 026 (2006) T. Sjostrand, S.Mrenna, P.Z.Skands



☞ Simulation: DELPHES 3 (default ATLAS cards)

JHEP **1402**, 057 (2014)

J. de Favereau, C.Delaere, P. Demin, A.Giammanco, V. Lemaître, A.Mertens, M.Selvaggi

☞ MadAnalysis5 and Event Selection:

EPJC **74, no. 10, 3103 (2014)** E.Conte, B.Dumont, B.Fuks, C.Wymant

N_{jets} **≥4 (**p_T **≥20 GeV,** $|\eta|$ **≤2.5)** $\oplus$ N_{lep} **≥2 (**p_T **≥20 GeV,** $|\eta|$ **≤2.5)**

Dileptonic Signal Reconstruction:

☞ $t\bar{t}H \rightarrow (b\ell^+\nu_\ell)(\bar{b}\ell^-\bar{\nu}_\ell)(b\bar{b})$

☞ Constrained Kinematic fit

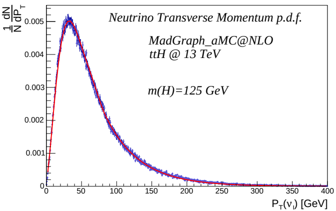
I- Mass constraints (2D-distributions):

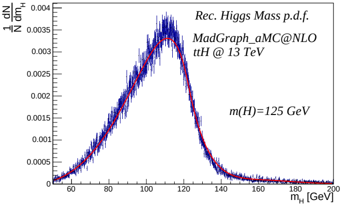
(1) $(p_{W^+} + p_b)^2 = m_t^2$

(2) $(p_{W^-} + p_{\bar{b}})^2 = m_{\bar{t}}^2$

(3) $(p_{\ell^+} + p_\nu)^2 = m_{W^+}^2$

(4) $(p_{\ell^-} + p_{\bar{\nu}})^2 = m_{W^-}^2$





II- Missing Transverse Energy (use p.d.f.):

(1) $p_x^\nu + p_x^{\bar{\nu}} = \not{E}_x$

(2) $p_y^\nu + p_y^{\bar{\nu}} = \not{E}_y$

III- Likelihood probability (use p.d.f.):

(1) $L_{t\bar{t}H} = \frac{1}{p_{T\,\nu} p_{T\,\bar{\nu}}} P(p_{T\,\nu}) P(p_{T\,\bar{\nu}}) \times P(p_{T\,t}) P(p_{T\,\bar{t}}) P(m_t, m_{\bar{t}}) P(p_{T\,t\bar{t}}) P(m_H)$

☞ Two steps: Reconstruction (1) with and (2) without Truth Match, i.e., imposing Reconstructed objects close to Parton objects (based on ΔR) criteria

Top Couplings to Bosons ttV ($V = H$)

Angles between t-quarks and Higgs boson, **arXiv:1704.03565**

☞ angles are measured in $t\bar{t}H$ centre-of-mass system

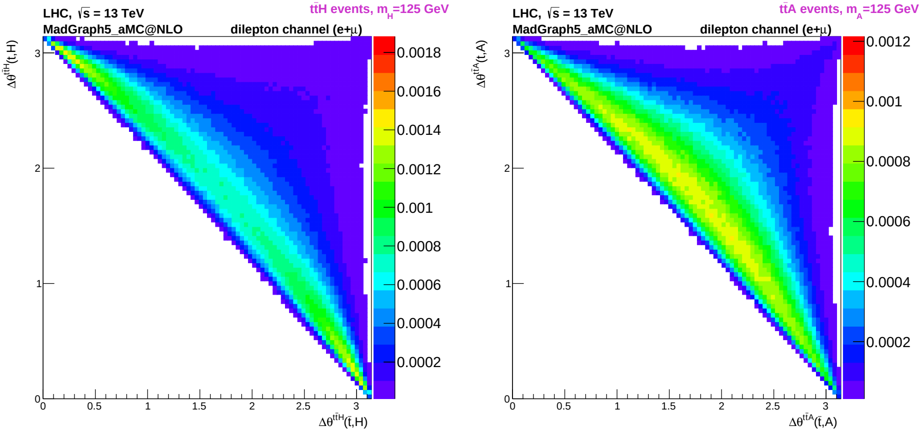


Figure: NLO+Shower angle between the t quark and Higgs boson (x-axis) as a function of the angle between the $\bar{t}$ quark and Higgs boson (y-axis), in the $t\bar{t}H$ centre-of-mass system. The SM Higss boson ($X = H$) distribution (left) and the pure pseudo-scalar Higgs boson ($X = A$) distribution (right) are shown.

Angles between several decay products of $t, \bar{t}, h$

☞ angles are in several centre-of-mass systems

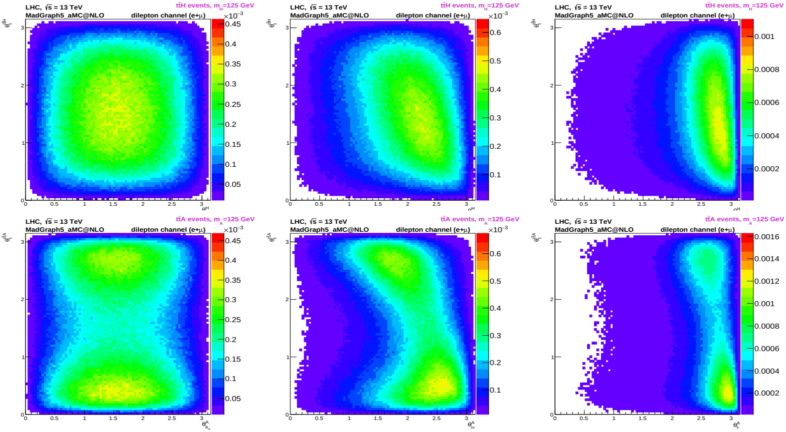


Figure: NLO+Shower angle between decay products (left) b quark from Higgs boson, (middle) ℓ^+ from top quark and (right) ℓ^- from $\bar{t}$ (all boosted to the Higgs centre-of-mass) and Higgs direction in $\bar{t}H$ (x-axis), as a function of the angle between the top quark in the $t\bar{t}H$ centre-of-mass system (y-axis). The top (bottom) distributions correspond to $t\bar{t}H$ ($t\bar{t}A$) without any cuts.

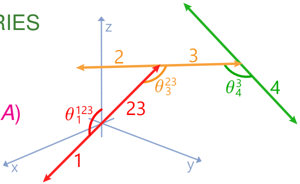
Top Couplings to Bosons ttV $(V = H)$

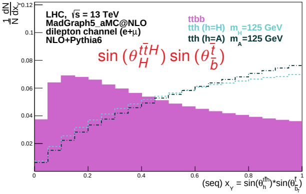
NEW ANGULAR DISTRIBUTIONS AND ASYMMETRIES

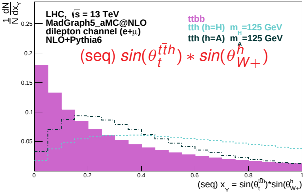
☞ (1) NLO+Shower observables NO CUTs

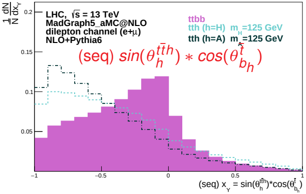
motivated by spin helicity formalism

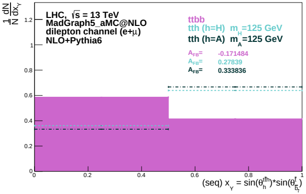
are there good discriminators to separate signals (H, A) from dominant backgrounds? Yes!

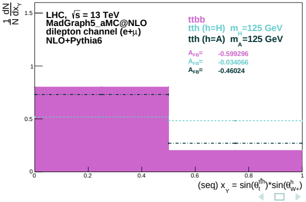


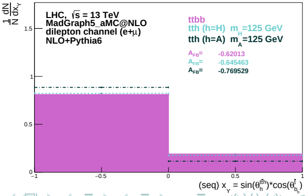










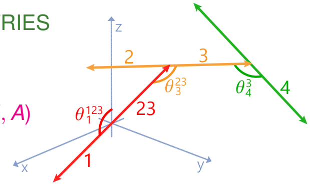


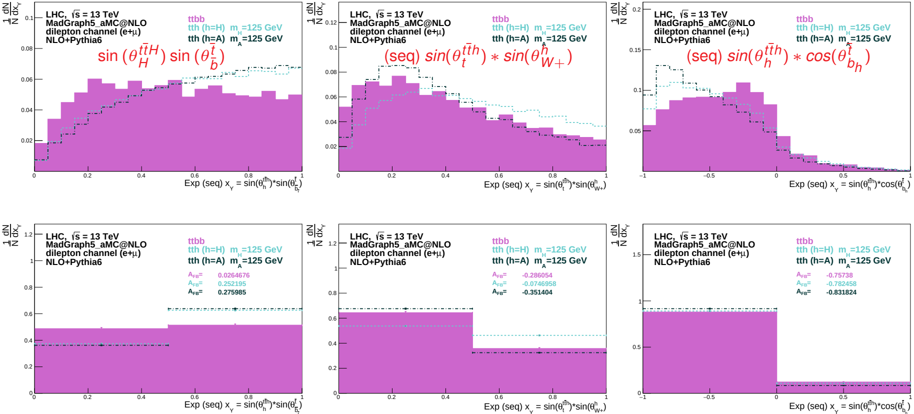
NEW ANGULAR DISTRIBUTIONS AND ASYMMETRIES

☞ (3) REC. LEVEL observables WITH CUTs

motivated by spin helicity formalism

are there good discriminators to separate signals (H, A) from dominant backgrounds? Yes!



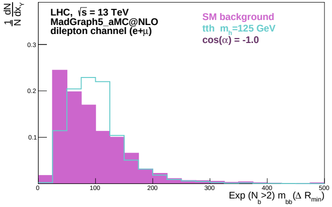


Several TMVA Methods tested: ☞ Boosted Decision Tree (BDTG) chosen with ☞ 15 (best) Kinematical Variables:

I- Proposed in the literature

$$b_4 = \frac{p_t^z p_{\bar{t}}^z}{|\vec{p}_t||\vec{p}_{\bar{t}}|}, \; m_{b\bar{b}}$$

(*) $\Delta\phi^{t\bar{t}}(l+, l-), \beta_{b\bar{b}}\Delta\theta^{lh}(l+, l-)$



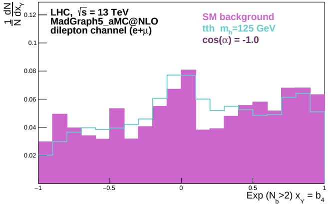
II- Usual ATLAS choices

$\Delta\eta_{jj}^{\max\Delta\eta}$, $m_{bb}^{\min\Delta R}$, $\Delta R_{hl}^{\min\Delta R}$, $\Delta R_{hl}^{\max\Delta R}$, $\Delta R_{bb}^{\max p_T}$, $m_{jj}^{\text{closest to 125 GeV}}$,

jets aplanarity

III- Angular Distributions

$cos(\theta_h^{t\bar{t}h})cos(\theta_{\ell-}^h)$, $sin(\theta_h^{t\bar{t}h})sin(\theta_t^{t\bar{t}})$,
$sin(\theta_{\bar{t}}^{t\bar{t}h})sin(\theta_{b_h}^h)(seq.)$, $sin(\theta_h^{t\bar{t}h})cos(\theta_{b_h}^{\bar{t}})(seq.)$,
$sin(\theta_h^{t\bar{t}h})sin(\theta_{b_{\bar{t}}}^{\bar{t}})(seq.)$, $sin(\theta_t^{t\bar{t}h})sin(\theta_{W^+}^h)(seq.)$



☞ Scan on $\cos(\alpha)$ performed

(*) these variables were not used, they are here for illustration purposes only.

Top Couplings to Bosons ttV ($V = H$)

Expected limits at 95% CL in the background-only hypothesis

☞ 95% C.L. $\sigma \times BR(h \to b\bar{b})$ ☞ 95% C.L. on μ

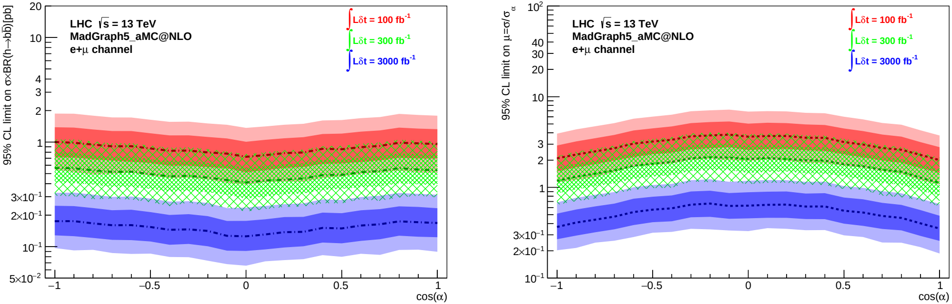


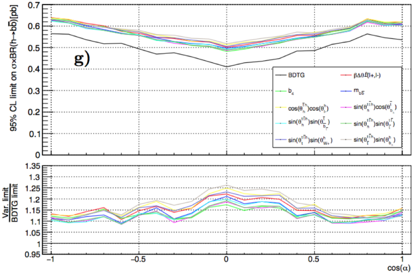
Figure: limits on $\sigma \times BR(h \to b\bar{b})$ (left) and μ (right) obtained with the BDTG output discriminant for integrated luminosites of 100, 300 and 3000 fb^{-1}. The lines correspond to the median, while the narrower(wider) bands correspond to the $1\sigma(2\sigma)$ intervals..

Dilpetonic channel ONLY ☞ Combinations with other channels are expected to improve results quite sigfnificantly

Expected limits at 95% CL Comparison in the background-only hypothesis ☞ variable dependence show an interesting pattern

☞ 95% C.L. $\sigma \times BR(h \to b\bar{b})$:

Angular Distributions



ATLAS variables

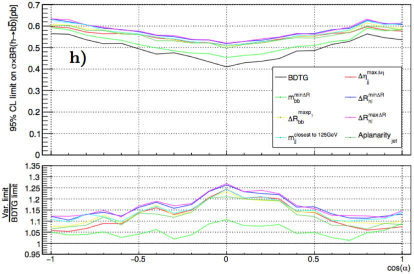


Figure: comparison between limits on $\sigma \times BR(h \to b\bar{b})$, at 300 fb^{-1}, obtained from each one of the individual distributions used in the BDTG. Left: $\beta_{b\bar{b}}\Delta\theta^{\ell h}(\ell^+, \ell^-)$, b_4, $m_{b\bar{b}}$ and angular distributions. Right: remaining distributions used as input for the BDTG. The ratios with respect to the limit obtained from the BDTG distribution are also represented.

Conclusions

- At the LHC ☞ things went really well for top quark and higgs physics i.e., the higgs was discovered and the top quark measurements became a World reality (CDF, D0, ATLAS and CMS) with the best precision ever observed
- New non-SM physics might be just around the corner @ the LHC
- Many top quark measurements are already dominated by systematic errors ☞ need combinations with dedicated tools

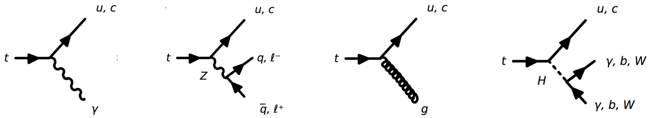
  Still a long way to go @ RUN 2 (looks really promising):

  - top quark production (e.g. s-channel single top and V_{tb})
  - couplings to gauge bosons (ttV, $V = \gamma, Z, W, H$) ☞ form factors
  - rare decays ($t \to Ws$, Wd, FCNC, new physics)
- The higgs production and decay have been measured with precision still room for improvement
- LHC Run-2 @ 13TeV will most definitely improve precision

High Precision Needed @ LHC

Top Quark Rare Decays (FCNC)

- Several $t\bar{t}$ FCNC Decay Channels Studied @ LHC:



Theoretical predictions for the BR of FCNC top quark decays

Process	SM	QS	2HDM	FC 2HDM	MSSM	$\not{R}$ SUSY	RS
$t \to uZ$	8×10^{-17}	1.1×10^{-4}	—	—	2×10^{-6}	3×10^{-5}	—
$t \to u\gamma$	3.7×10^{-16}	7.5×10^{-9}	—	—	2×10^{-6}	1×10^{-6}	—
$t \to ug$	3.7×10^{-14}	1.5×10^{-7}	—	—	8×10^{-5}	2×10^{-4}	—
$t \to uH$	2×10^{-17}	4.1×10^{-5}	5.5×10^{-6}	—	10^{-5}	$\sim 10^{-6}$	—
$t \to cZ$	1×10^{-14}	1.1×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-10}$	2×10^{-6}	3×10^{-5}	$\leq 10^{-5}$
$t \to c\gamma$	4.6×10^{-14}	7.5×10^{-9}	$\sim 10^{-6}$	$\sim 10^{-9}$	2×10^{-6}	1×10^{-6}	$\leq 10^{-9}$
$t \to cg$	4.6×10^{-12}	1.5×10^{-7}	$\sim 10^{-4}$	$\sim 10^{-8}$	8×10^{-5}	2×10^{-4}	$\leq 10^{-10}$
$t \to cH$	3×10^{-15}	4.1×10^{-5}	1.5×10^{-3}	$\sim 10^{-5}$	10^{-5}	$\sim 10^{-6}$	$\leq 10^{-4}$

Acta Phys.Polon.**B35**,2695(2004), arXiv:1311.2028

- In the SM flavour changing neutral currents (FCNC) are forbidden at tree level and much smaller than the dominant decay mode ($t \to bW$) at one loop level
- BSM models predict higher BR for top FCNC decays
  ☞ powerful probe for new physics

FCNC Direct Bounds (short) Summary: