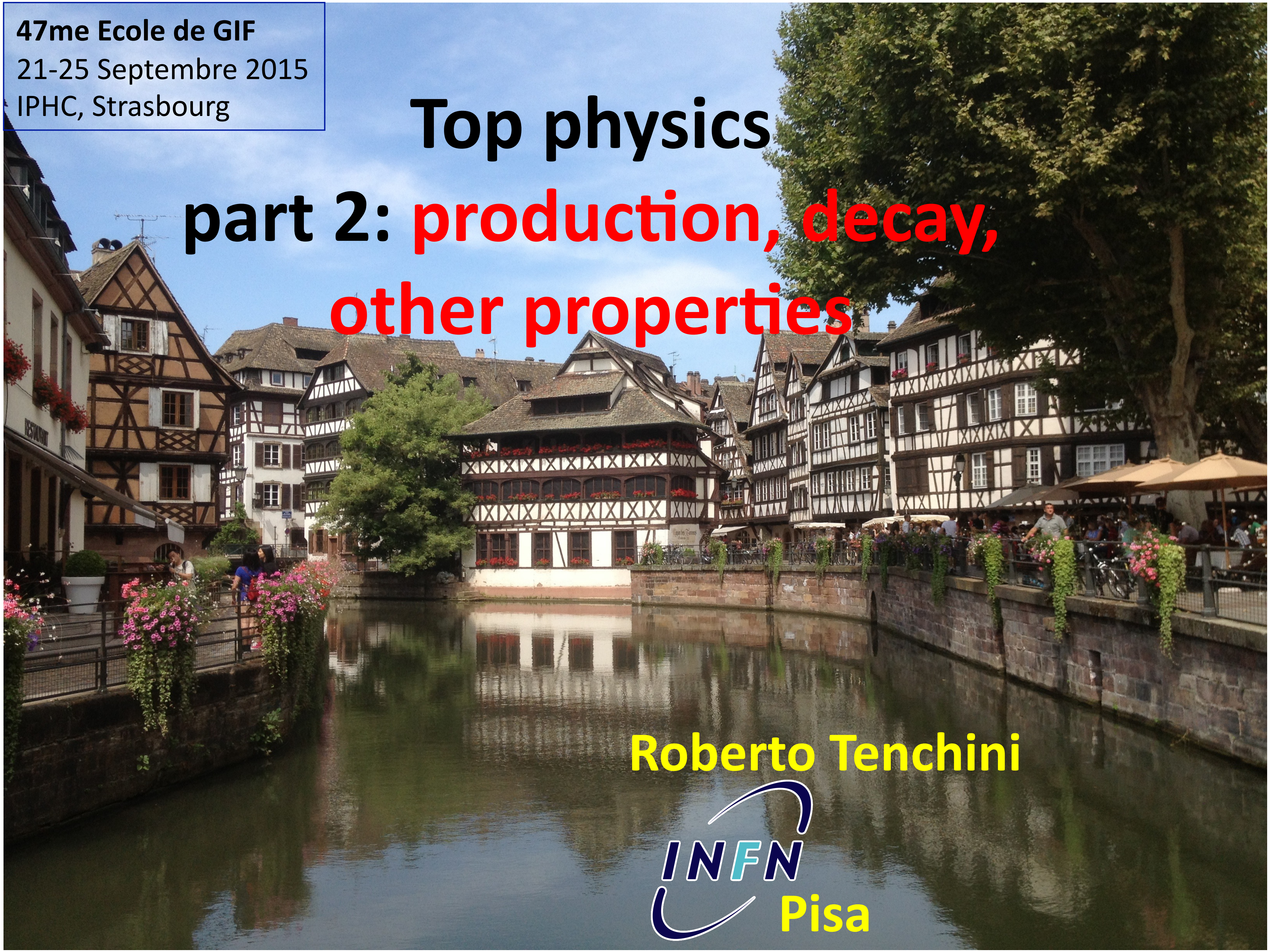


47me Ecole de GIF
21-25 Septembre 2015
IPHC, Strasbourg

Top physics
part 2: production, decay, other properties

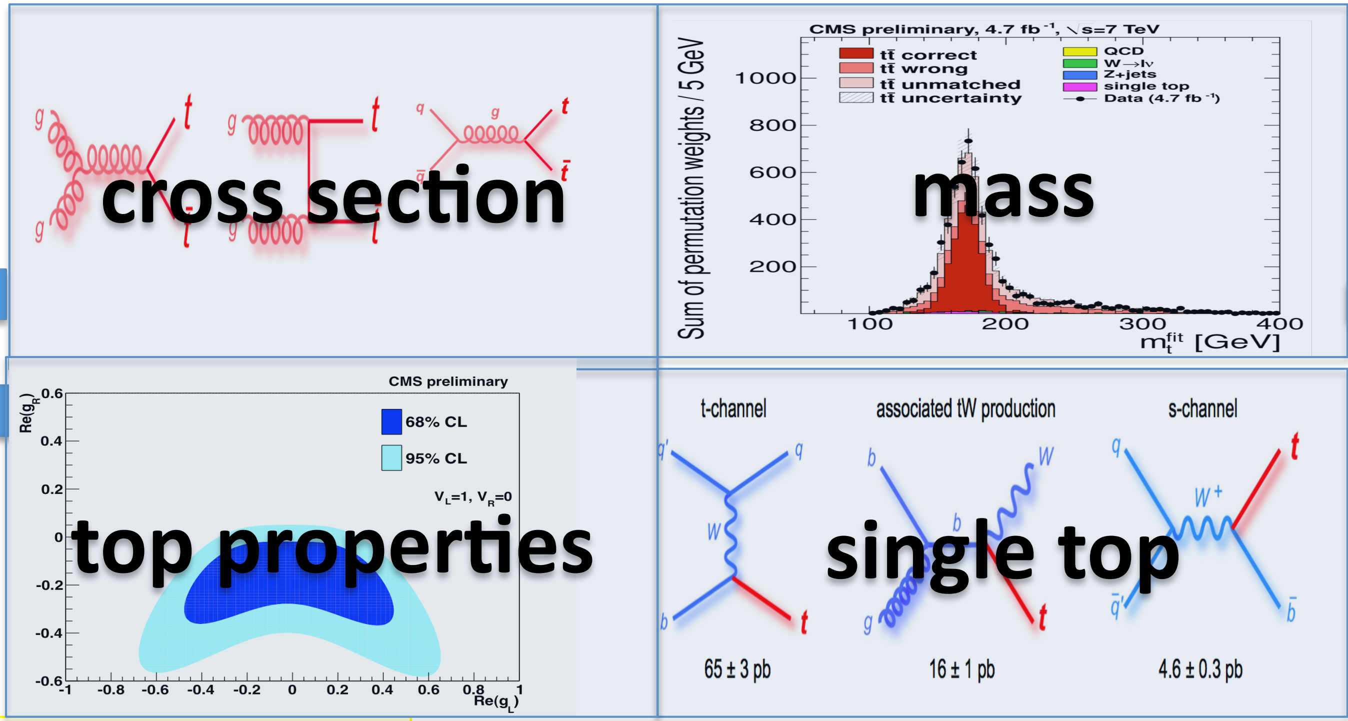
Roberto Tenchini

INFN Pisa

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)



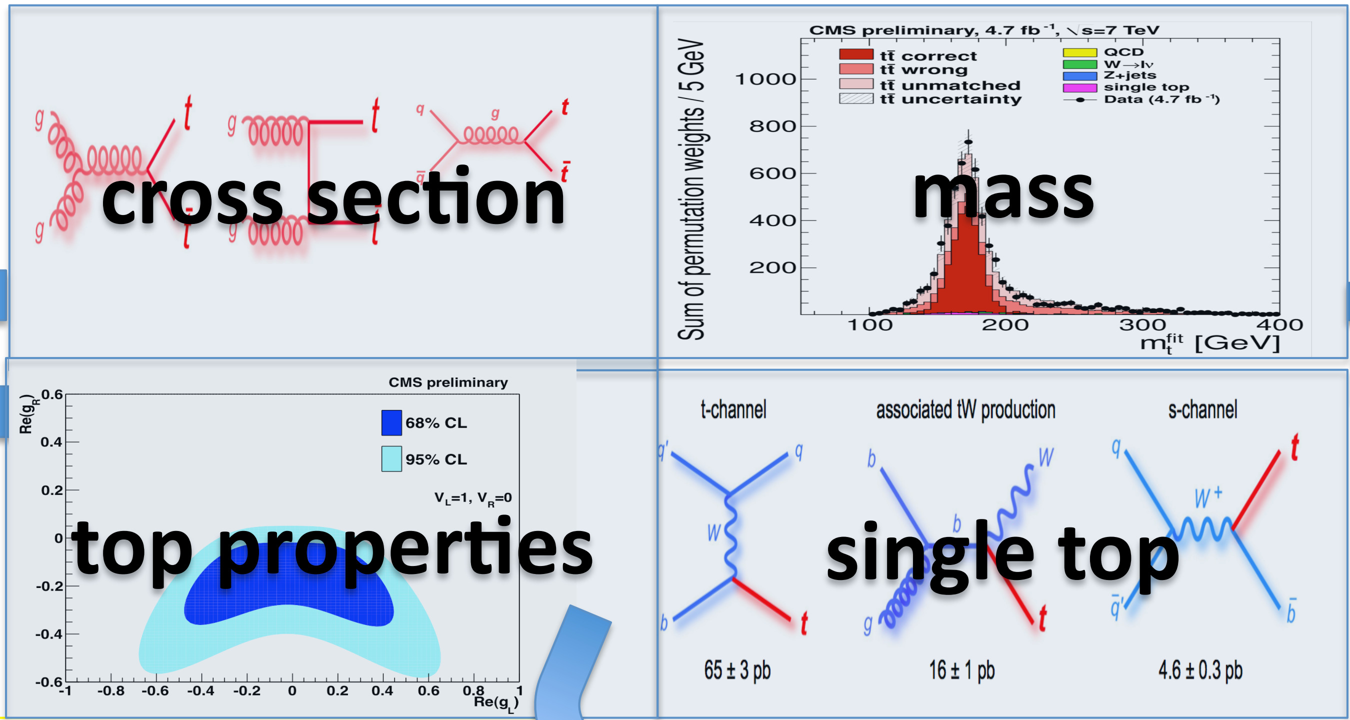
Couplings, branching ratios, charge, width, W helicity, spin correlations, charge asymmetry associated production (ttW, ttZ, ttH, tt+MET)

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 INCLUSIVE CROSS SECTION

The ttbar cross section at hadron colliders

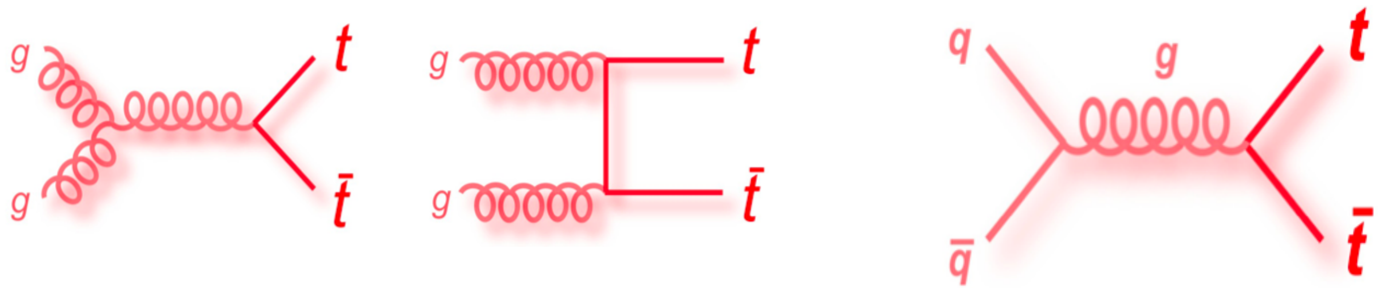
$$\sigma(s, m_t^2) = \sum_{a,b} \int_0^1 dx_1 \int_0^1 dx_2 \, f^{a}_{h1}(x_1, \mu_f^2) \, f^{b}_{h2}(x_2, \mu_f^2) \, \hat{\sigma}_{ab}(\hat{s}, m_t, \alpha_s(\mu_f^2))$$

Parton combinations

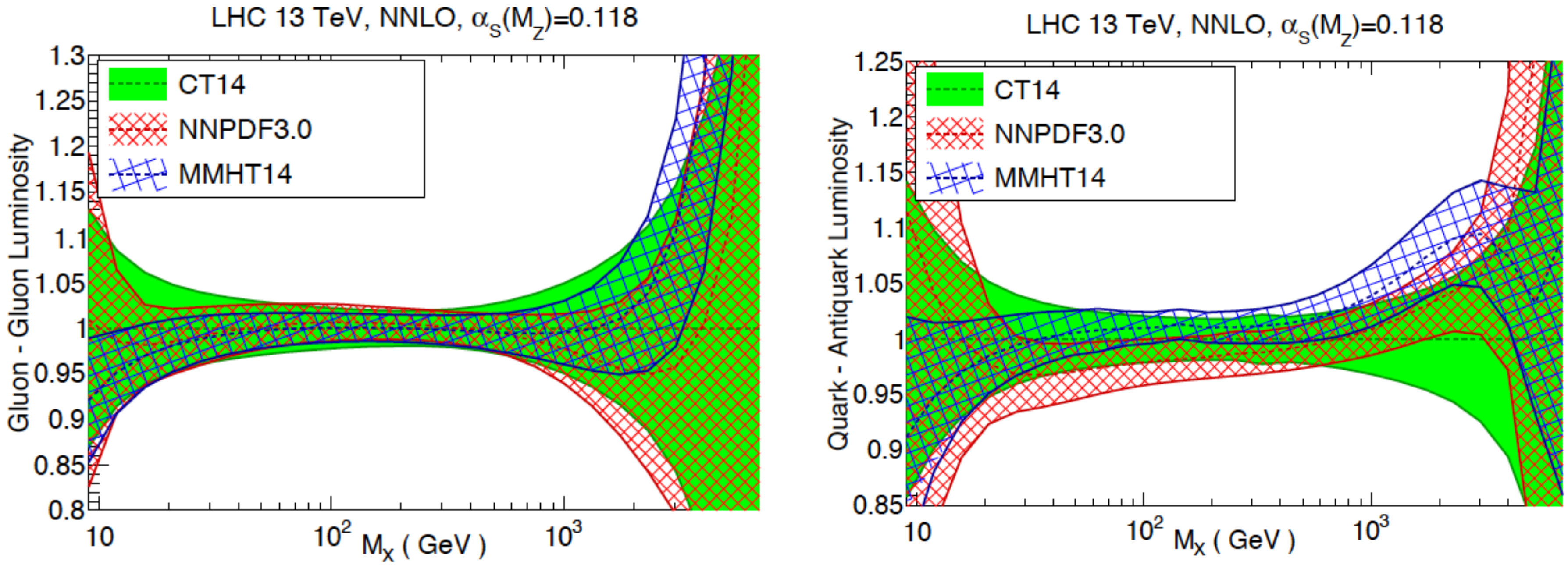
PDF's

Momentum fraction with respect to the proton

Cross section of the elementary process

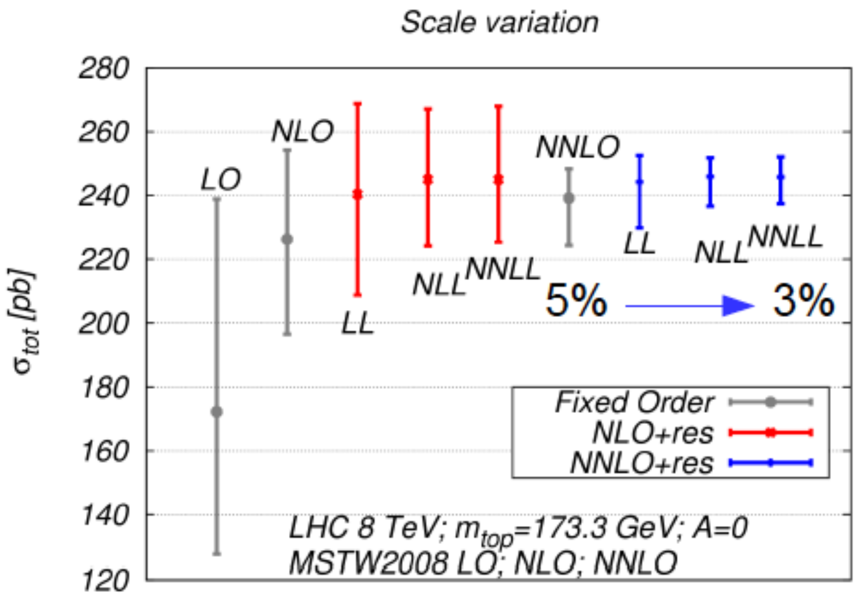


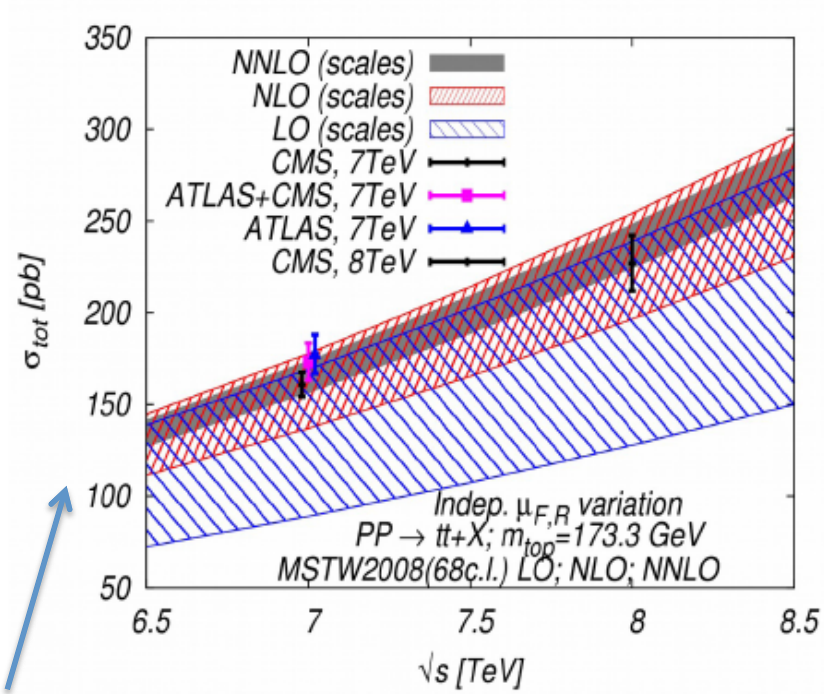
Parton Distribution Functions



Inclusive cross section computed at NNLO (+NNLL)

[Czakon, Fiedler, Mitov; 2013]





- Uncertainties
  - Scales: ~ 3 %
  - PDF (68% cl): ~ 2 – 3 %
  - Top – mass: ~ 3 %
  - Coupling: ~ 1.5 %

good perturbative convergence

Collider	σ_{tot} [pb]	scales [pb]	pdf [pb]
Tevatron	7.164	$+0.110(1.5\%)$ $-0.200(2.8\%)$	$+0.169(2.4\%)$ $-0.122(1.7\%)$
LHC 7 TeV	172.0	$+4.4(2.6\%)$ $-5.8(3.4\%)$	$+4.7(2.7\%)$ $-4.8(2.8\%)$
LHC 8 TeV	245.8	$+6.2(2.5\%)$ $-8.4(3.4\%)$	$+6.2(2.5\%)$ $-6.4(2.6\%)$
LHC 14 TeV	953.6	$+22.7(2.4\%)$ $-33.9(3.6\%)$	$+16.2(1.7\%)$ $-17.8(1.9\%)$

Quick reminder on ttbar topologies

Lepton + jets ≈ 34%

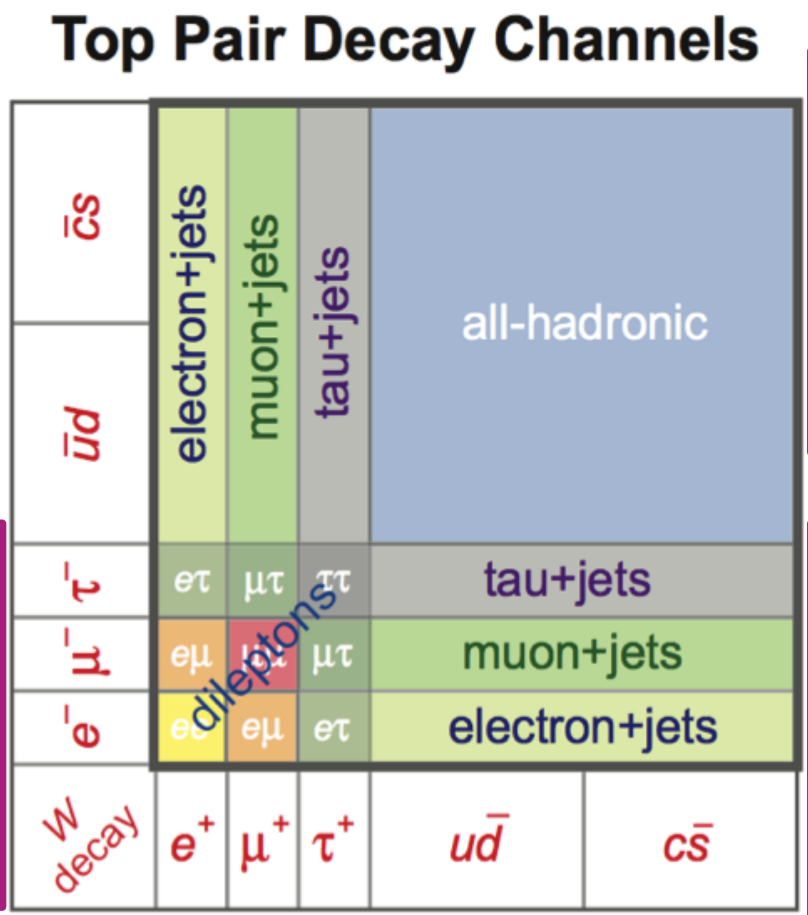
Low background

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

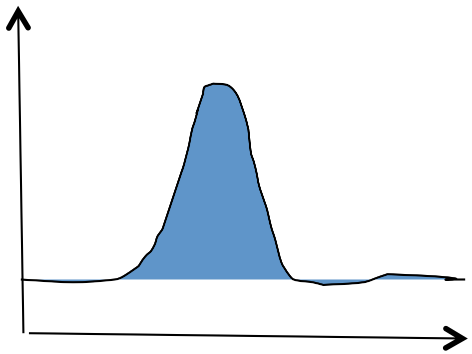
Quick reminder on measuring a cross section

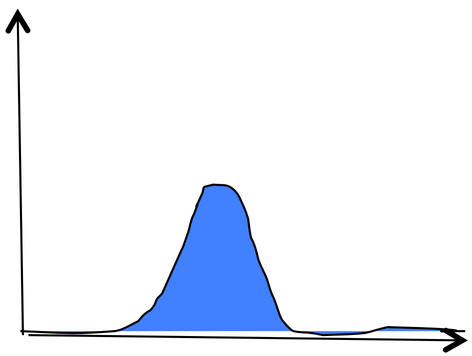
$$\sigma \times \mathrm{BR}(\mathrm{t\bar{t}} \rightarrow \mathrm{topology}) = \frac{\mathrm{N}_{\mathrm{obs}} - \mathrm{N}_{\mathrm{bkg}}}{\varepsilon_{\mathrm{selection}} \times A \times \int \mathrm{L}\, \mathrm{dt}}$$

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

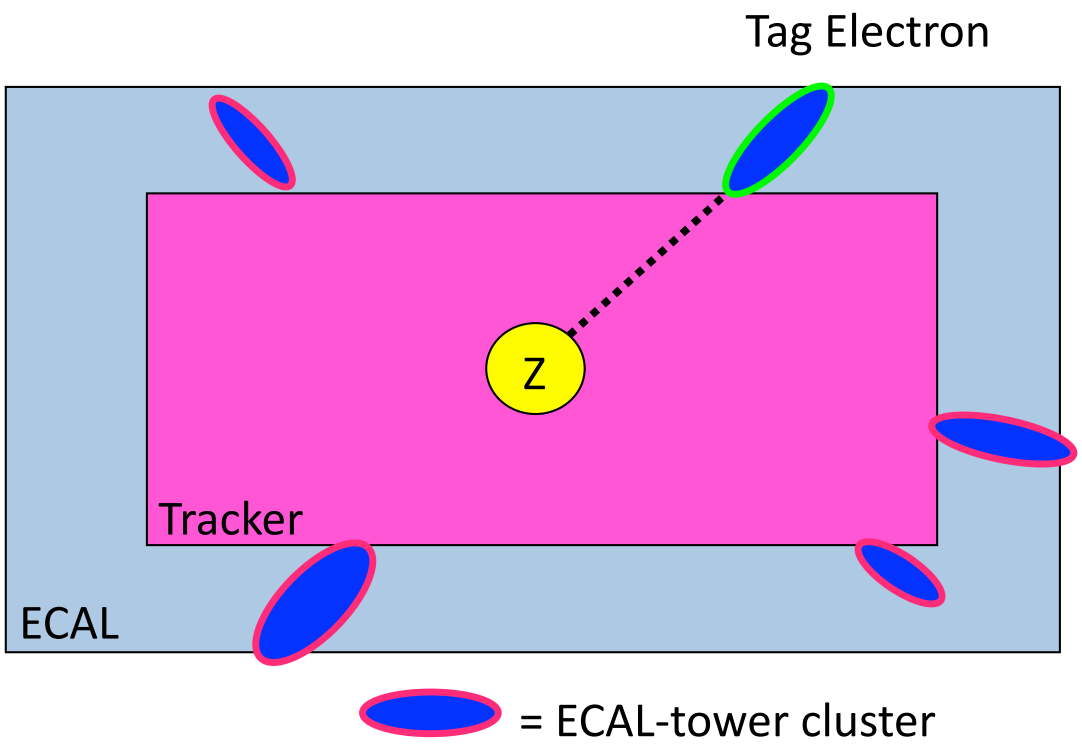
example of data driven methods: Tag & Probe





- Tag and Probe (TP) is a method used with real data to identify a physics object in an unbiased way in order to study efficiencies.
- One object, the tag, has strict criteria imposed on it to identify it. The probe is another object with looser criteria to meet, with an additional property that links it to the Tag object to ensure a pure sample.
- $Z \rightarrow ee$ or $Z \rightarrow \mu\mu$ events are appropriate for TP because one lepton, meeting tight criteria, can be used as the tag, and the other can be a probe, providing the invariant mass of the pair is $\approx m_Z$
- Important to keep the method unbiased: the identification of the tag and the probe should be uncorrelated

Tag and Probe (Example)



Compute ECAL-tracker matching efficiency

$$eff = \frac{\text{number of matched probes}}{\text{number of probes}}$$

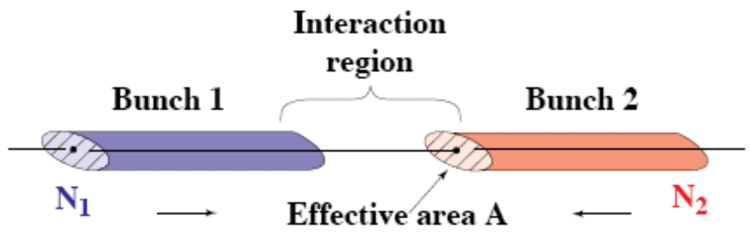
1. Find a good electron in a Z→ee event that meets Tag criteria
2. Loop over ECAL-tower clusters in the event with transverse energy above, e.g., 15 GeV and calculate the cluster-Tag invariant mass (M)
3. The cluster satisfying, e.g. : 82<M<100 GeV is a Probe

Luminosity determination

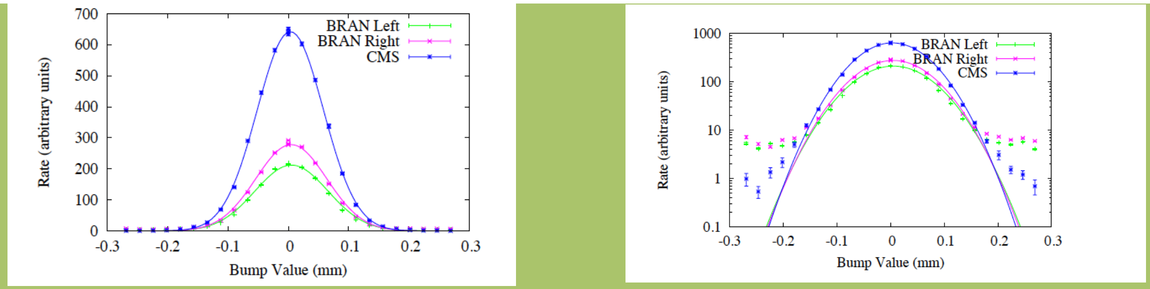
$$\text{Rate} = \frac{\sigma}{L}$$

- The method is known as "Van Der Meer scan"

$$\mathcal{L} = \frac{N_1 N_2 f}{A_{\text{eff}}}$$



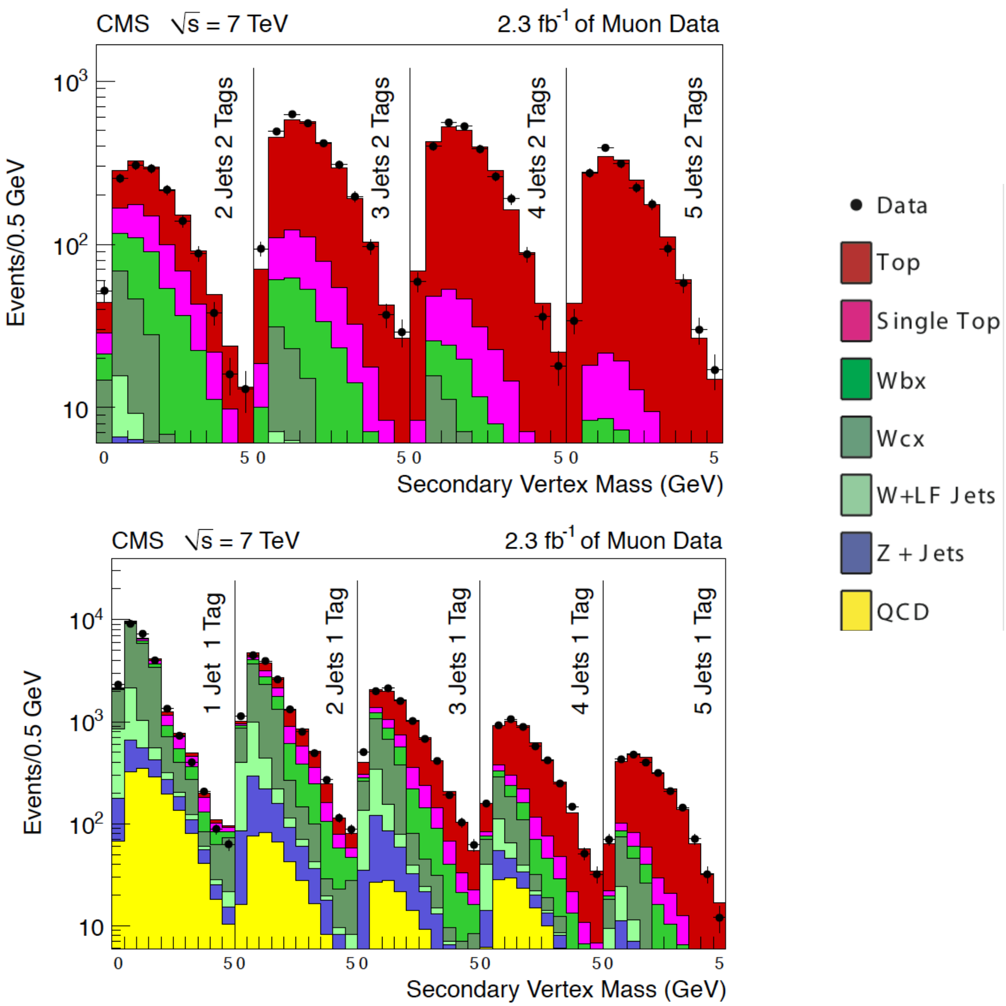
Beam intensities and crossing frequency are known with good accuracy
The effective overlap area A can be determined by scans in separation

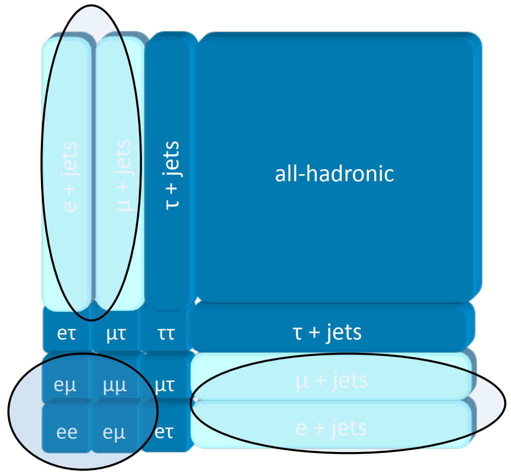


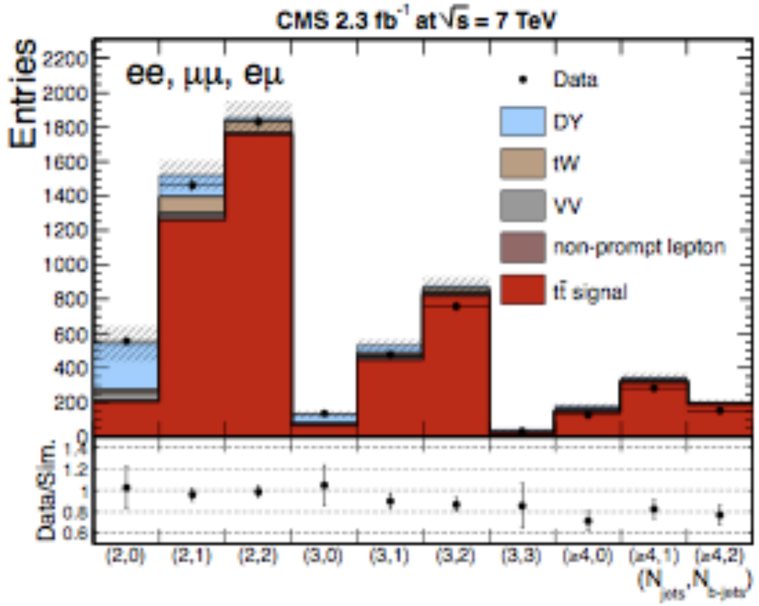
Details : LHC Report 1019 by Grafstrøm Burkhardt http://cdsweb.cern.ch/record/1056691

Leptons+jets and dileptons (e, μ)

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



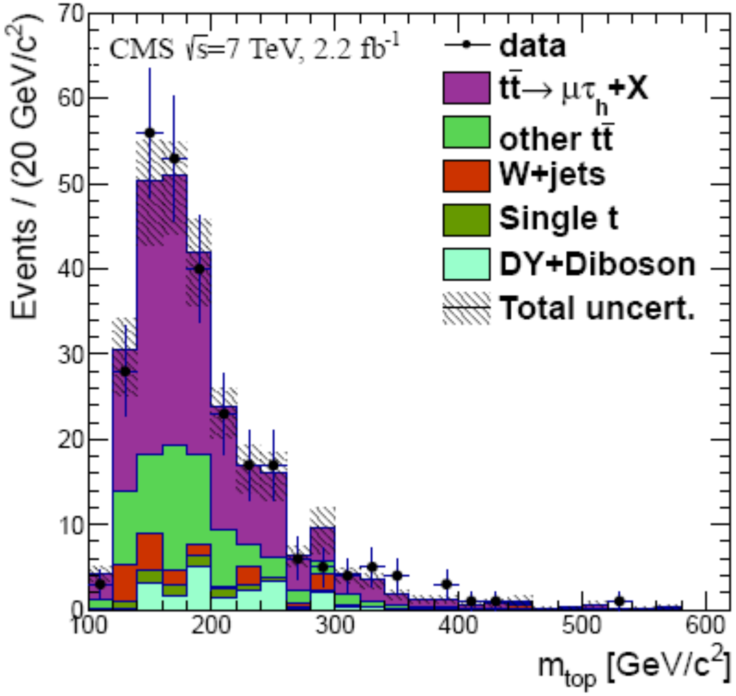




CMS TOP-11-005

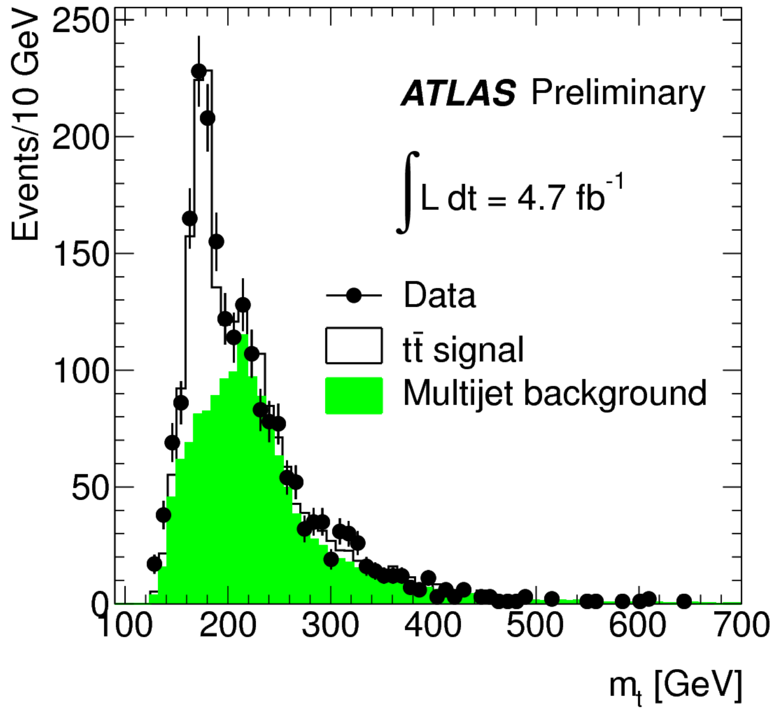
Other channels

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



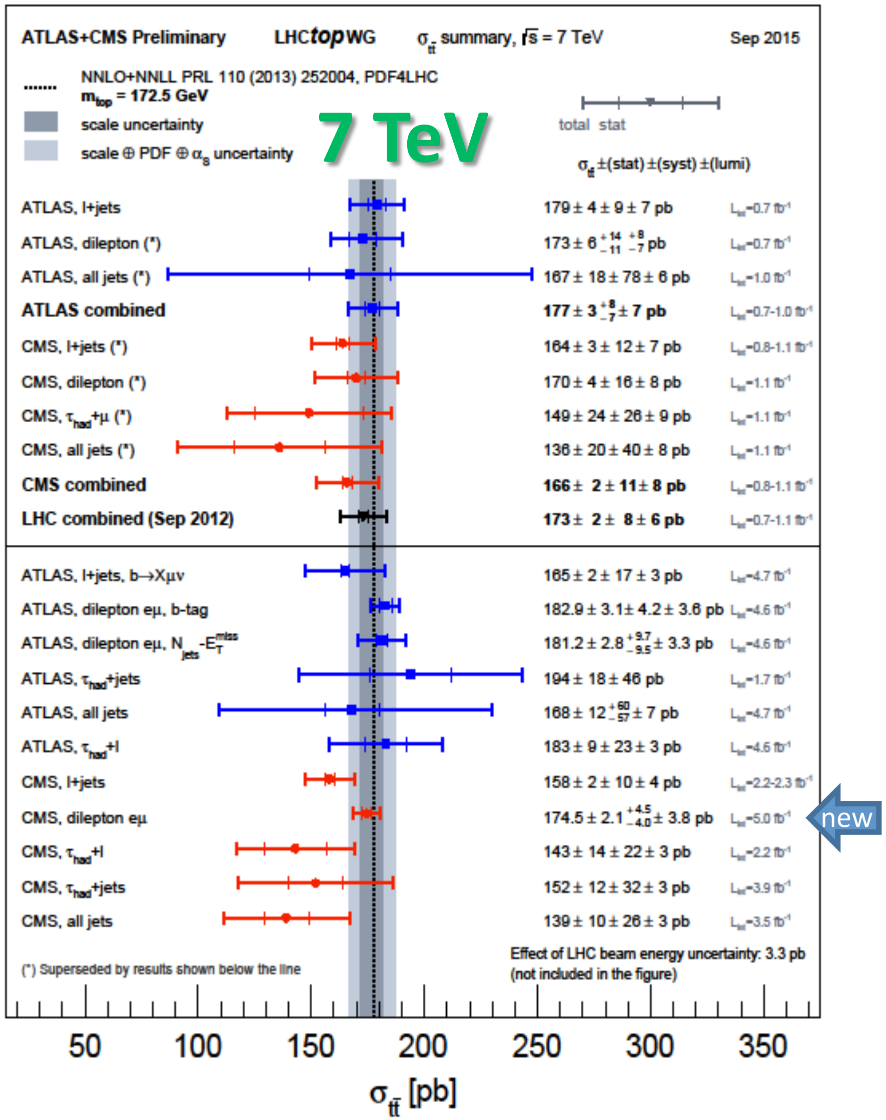
CMS arXiv:1203.6810

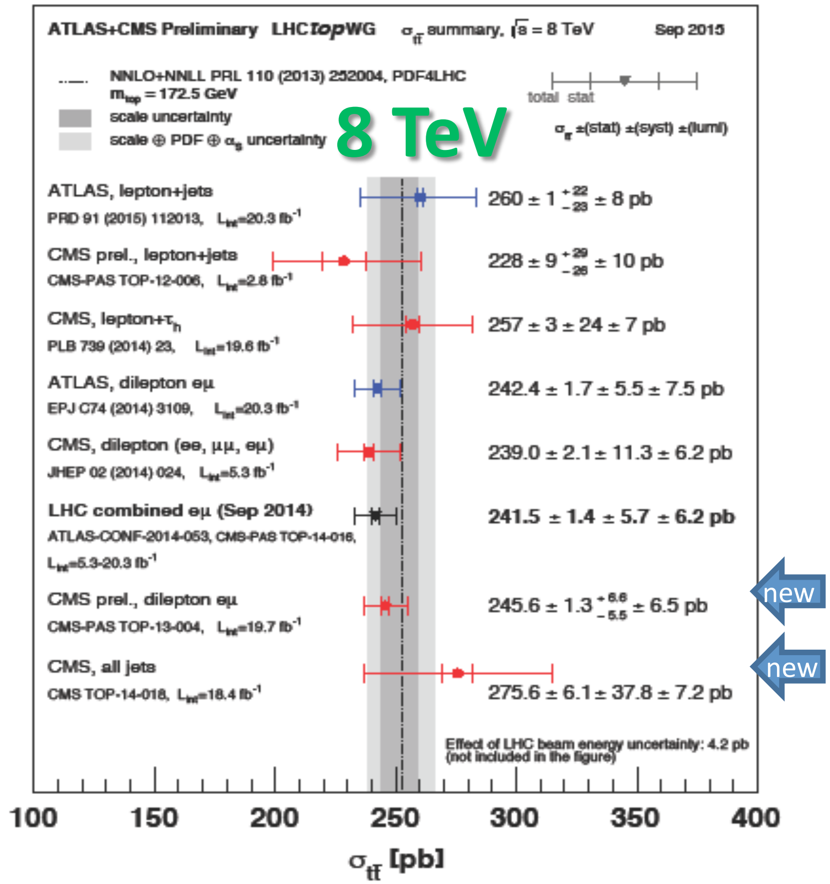
$t\bar{t} \rightarrow$ all hadronic



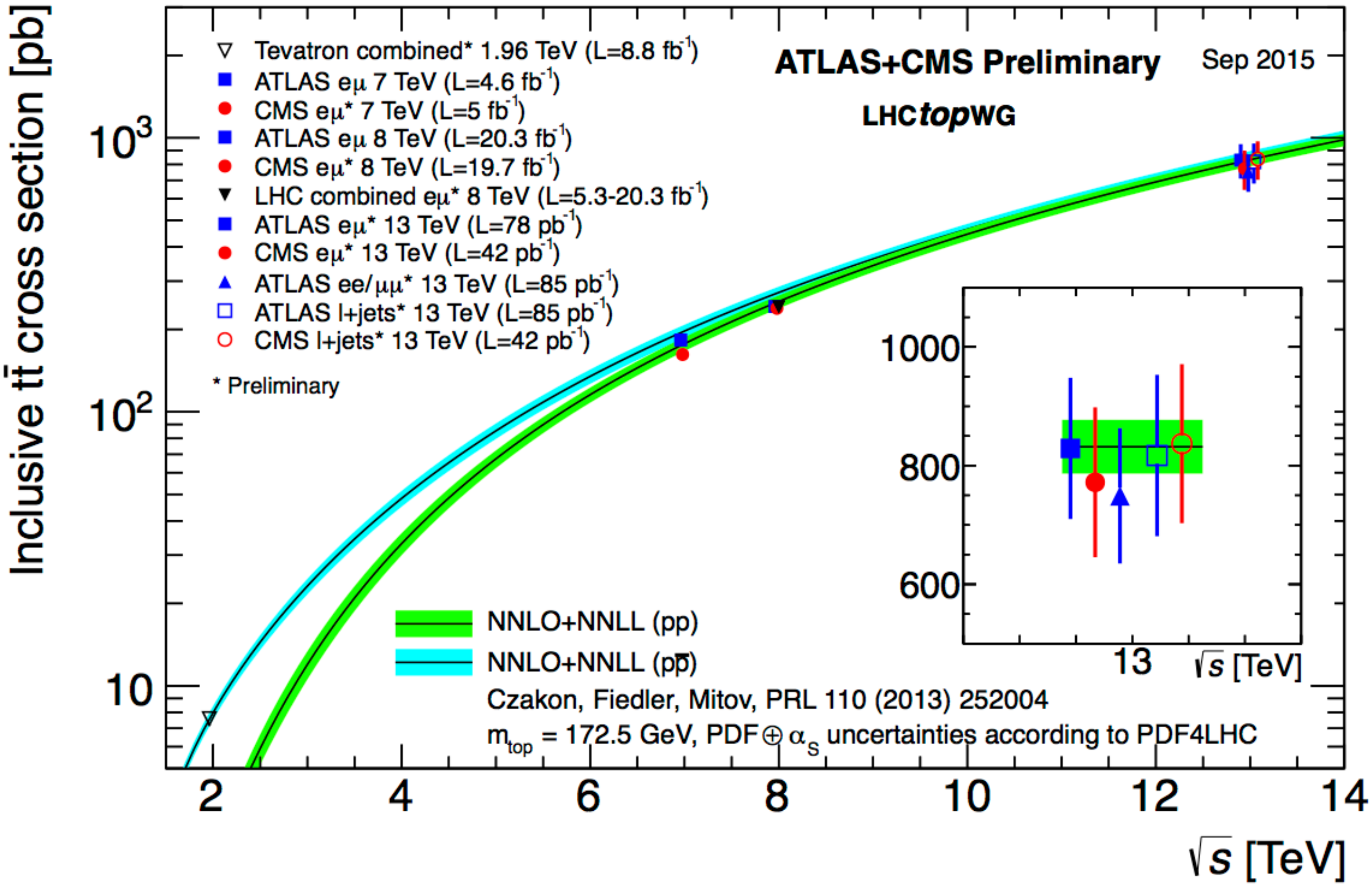
ATLAS CONF-2012-031

Inclusive top pair cross-sections





- All channels covered and consistent with SM
- Good agreement with NNLO+NNLL
- Precision of ~4% (di-lepton channel), similar to theoretical prediction

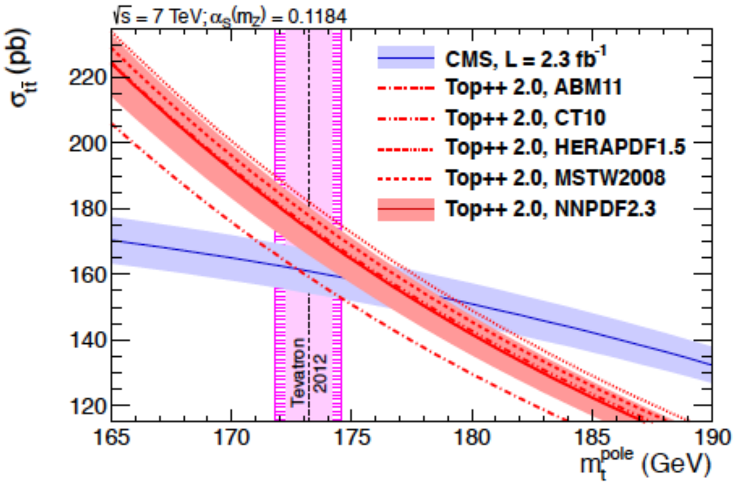

Inclusive tt̄ cross section [pb]
▽ Tevatron combined* 1.96 TeV (L=8.8 fb-1)
ATLAS eμ 7 TeV (L=4.6 fb-1)
CMS eμ* 7 TeV (L=5 fb-1)
ATLAS eμ 8 TeV (L=20.3 fb-1)
CMS eμ* 8 TeV (L=19.7 fb-1)
LHC combined eμ* 8 TeV (L=5.3-20.3 fb-1)
ATLAS eμ* 13 TeV (L=78 pb-1)
CMS eμ* 13 TeV (L=42 pb-1)
ATLAS ee/μμ* 13 TeV (L=85 pb-1)
ATLAS l+jets* 13 TeV (L=85 pb-1)
CMS l+jets* 13 TeV (L=42 pb-1)
* Preliminary
ATLAS+CMS Preliminary
Sep 2015
LHCtopWG
1000
800
600
13
√s [TeV]
NNLO+NNLL (pp)
NNLO+NNLL (pp̄)
Czakon, Fiedler, Mitov, PRL 110 (2013) 252004
m_top = 172.5 GeV, PDF ⊕ α_S uncertainties according to PDF4LHC
10³
10²
10
2
4
6
8
10
12
14
√s [TeV]

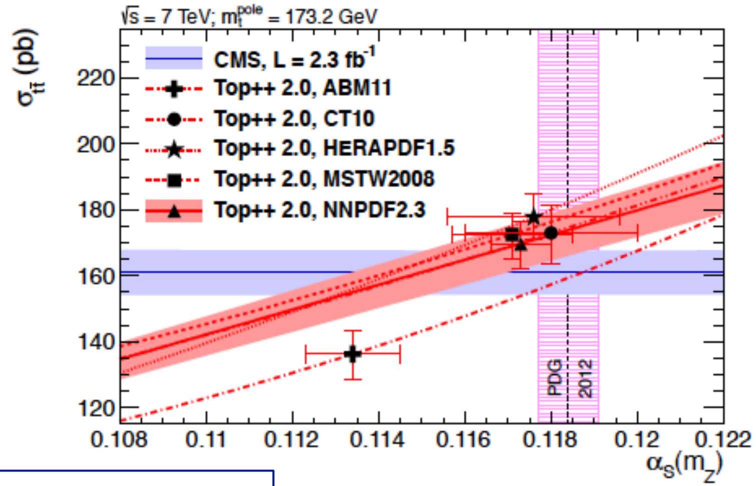
use ttbar cross section for top mass and α_s

[arXiv:1307.1908]

- Measure cross section in the most precise channel: dilepton eμ
- Use recent NNLO calculation (*) of top pair cross section to extract m_t
- Provides also a measurement of α_s
- The method takes advantage of the excellent luminosity knowledge at LHC (~2%), which is also the long-term experimental limitation, together with the knowledge of the LHC beam energy

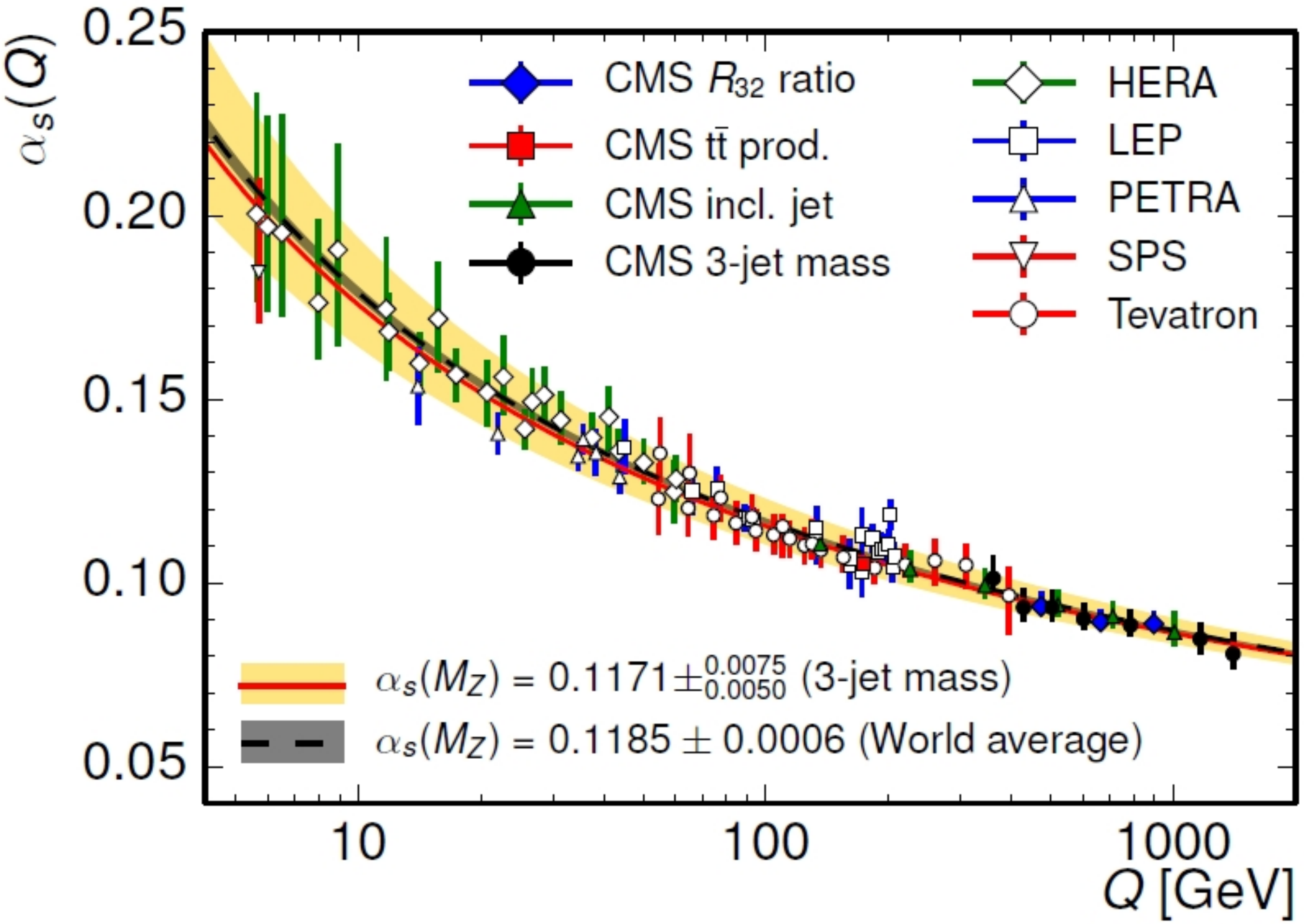
$$m_t = 176.7^{+3.0}_{-2.8}\ \text{GeV}$$
$$\alpha_s = 0.1151^{+0.0028}_{-0.0027}$$





(*) Czakon, Fiedler, Mitov, (2013) arxiv:1303.6254, PRL 110.252004

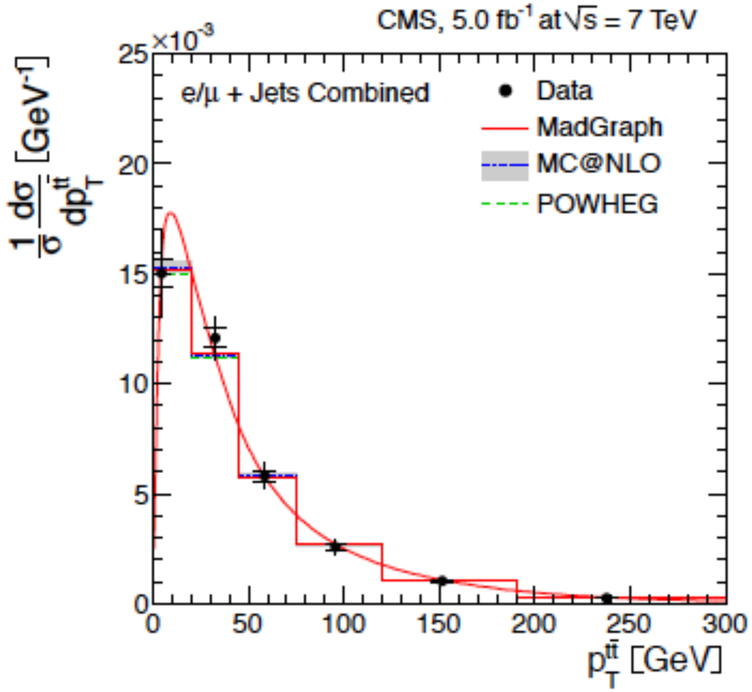
Running of α_s
- a very precise point from ttbar -



DIFFERENTIAL CROSS SECTIONS

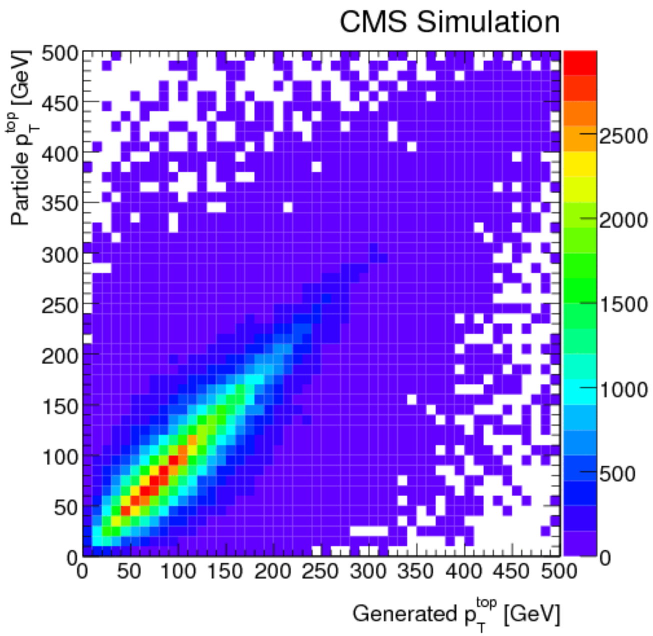
Differential cross sections

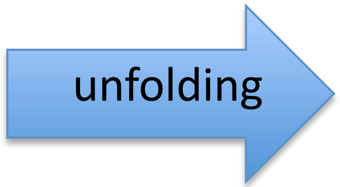
- Important measurements, they will play an important role for
  - i) investigate limitations of present MC (which QCD predictions and models describe our data best, in the search areas like high m(tt) and high multiplicities)
  - ii) provide independent interpretations (e.g. mass AND alpha_s from cross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

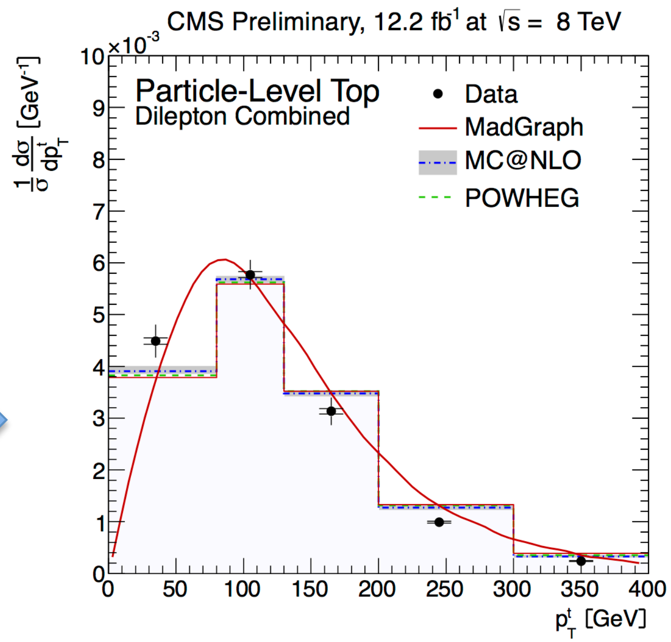


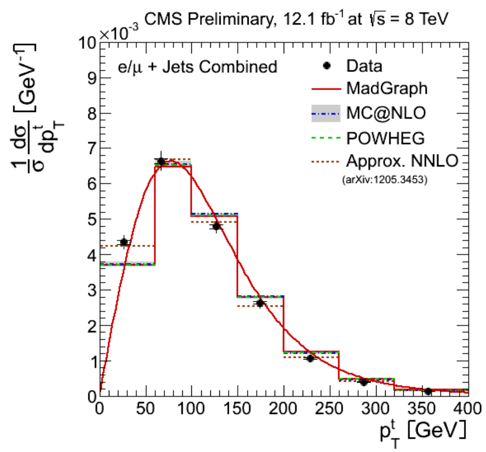
arXiv:1211.2220

Measurements of differential cross section – unfolding is required

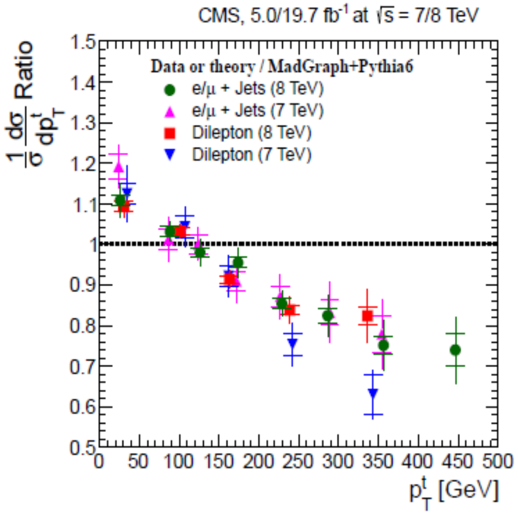


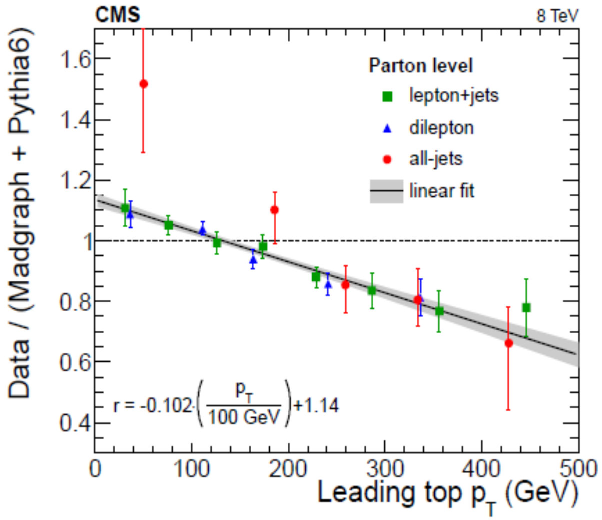


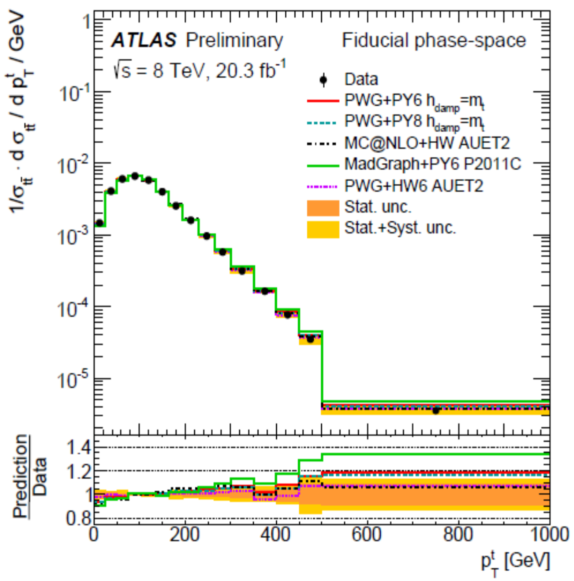


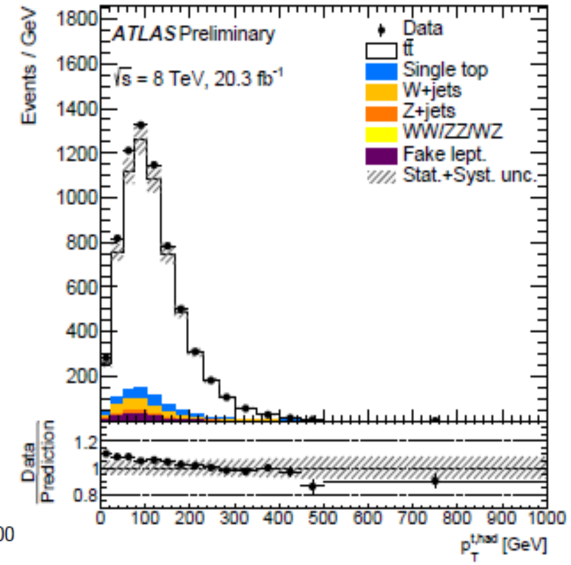


Top p_T differential distribution









Martijn Mulders, top2015:

CMS – consistent slope between data and default MG+PY6 in all channels, 7 and 8 TeV

Full difference counted as additional systematic effect (also for Searches, eg ttH)

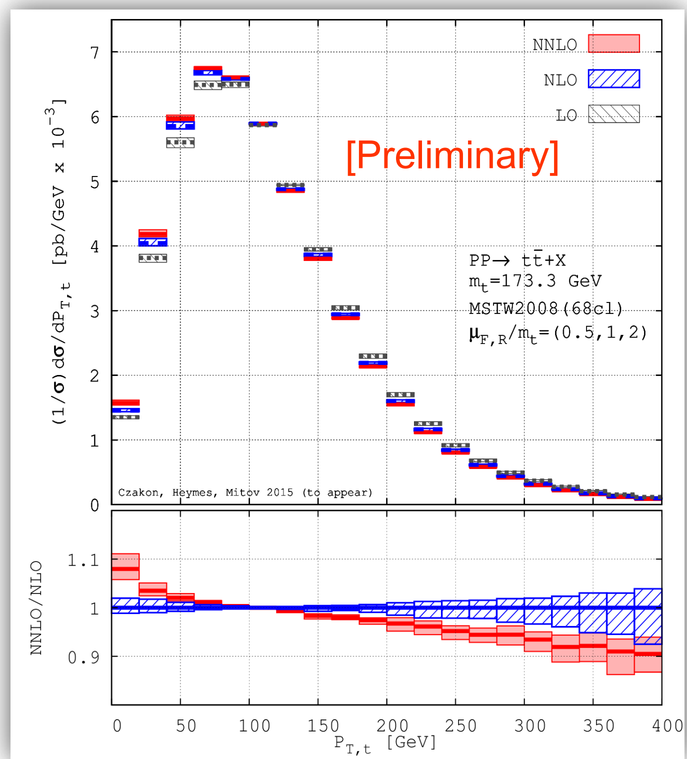
= = =

ATLAS and CMS data appear in good agreement at 8 TeV

ATLAS PWG+PY (hdamp=mt) and other MCs do better than MG+PY

Top p_T modeling: the verdict @ top2015

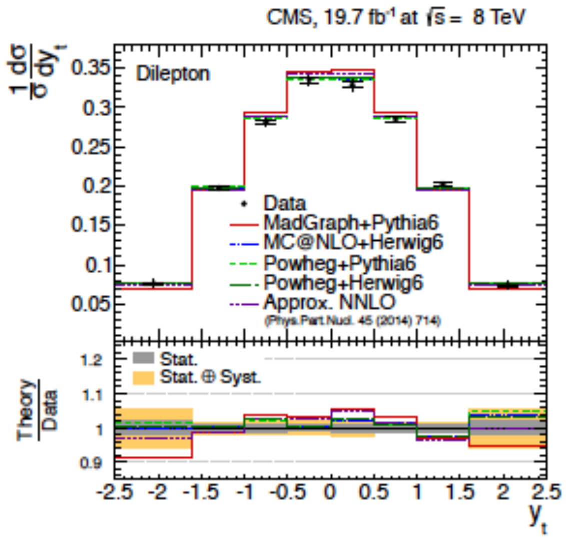
Really NEW (last week, A. Mitov et al.):

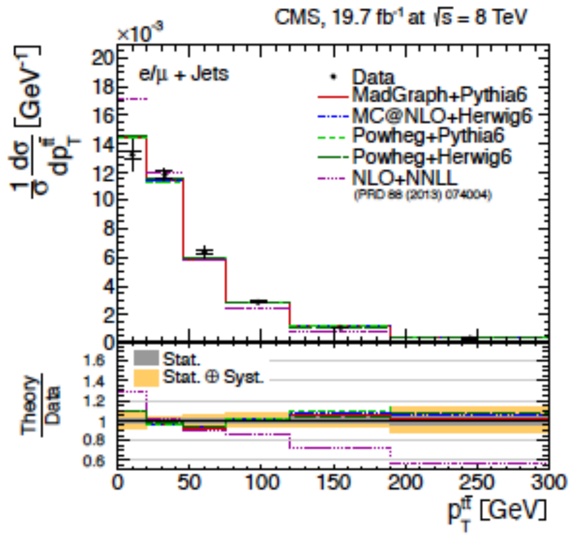


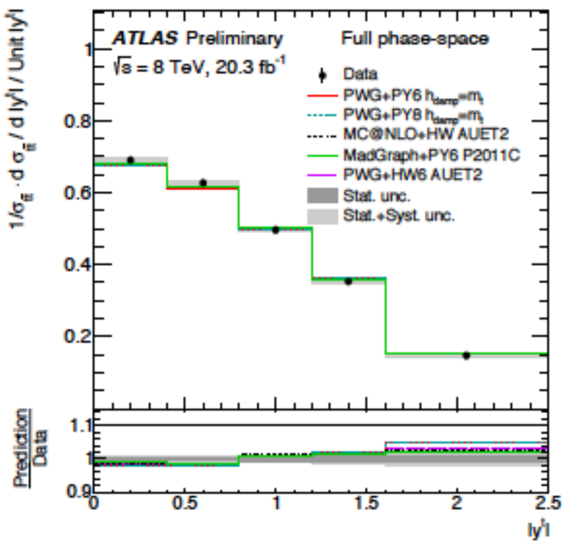
Full NNLO/NLO k-factor vs top pT : a slope!

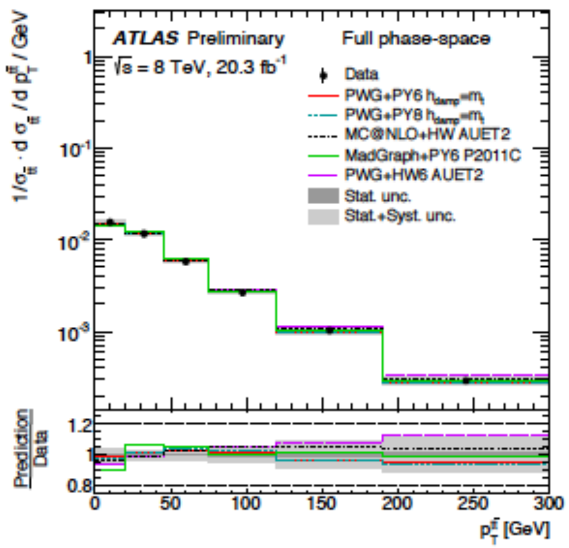
- Preliminary full NNLO calculation seem to confirm observed slope, in direction closer to the data

Other differential x-sections





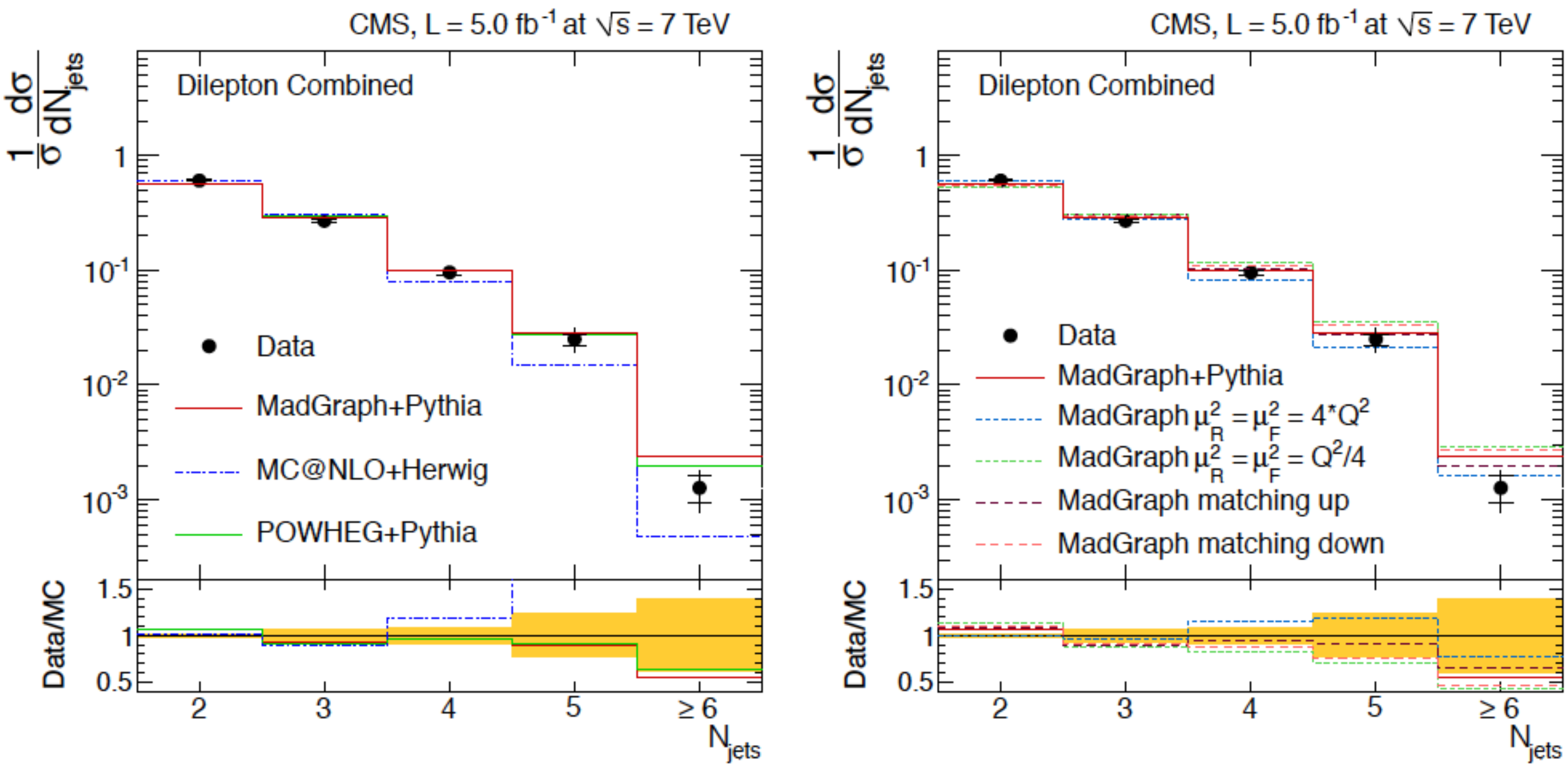




Ttbar and additional jets

- Study of QCD radiation pattern

arXiv:1404.3171

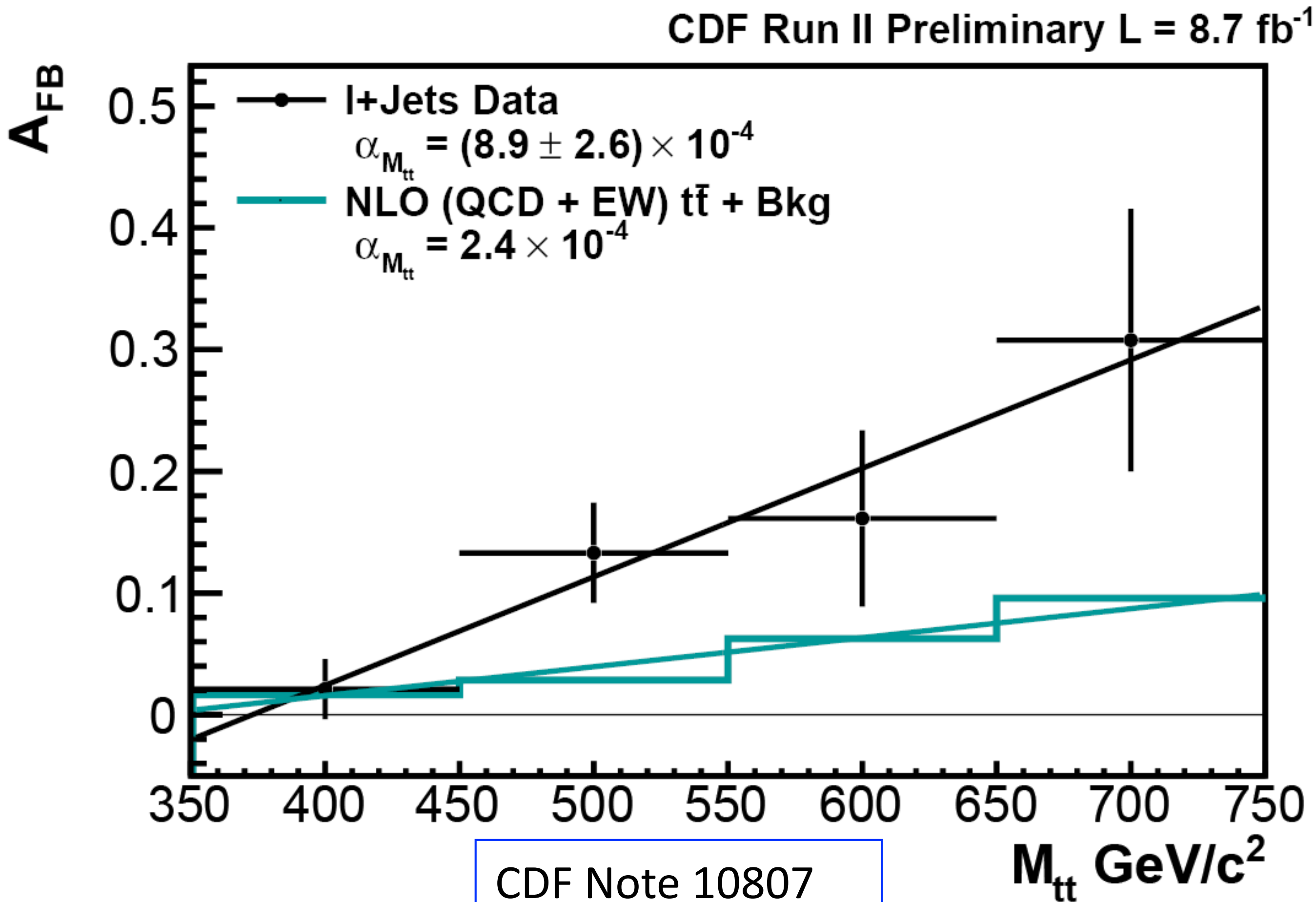


ASYMMETRIES AND CORRELATIONS BETWEEN TOP AND ANTITOP

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

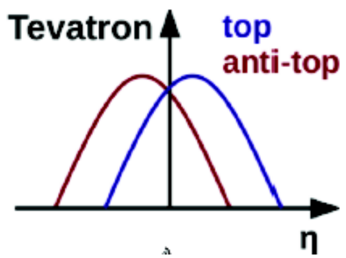
$$q\bar{q} \rightarrow t\bar{t}$$

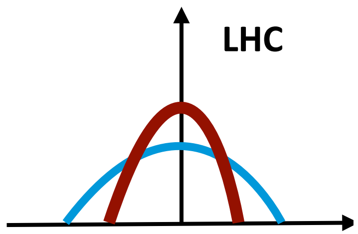
- SM asymmetry from interference (higher order QCD ~ 7%)



CDF Note 10807

A_{FB} a LHC → charge asymmetry





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

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

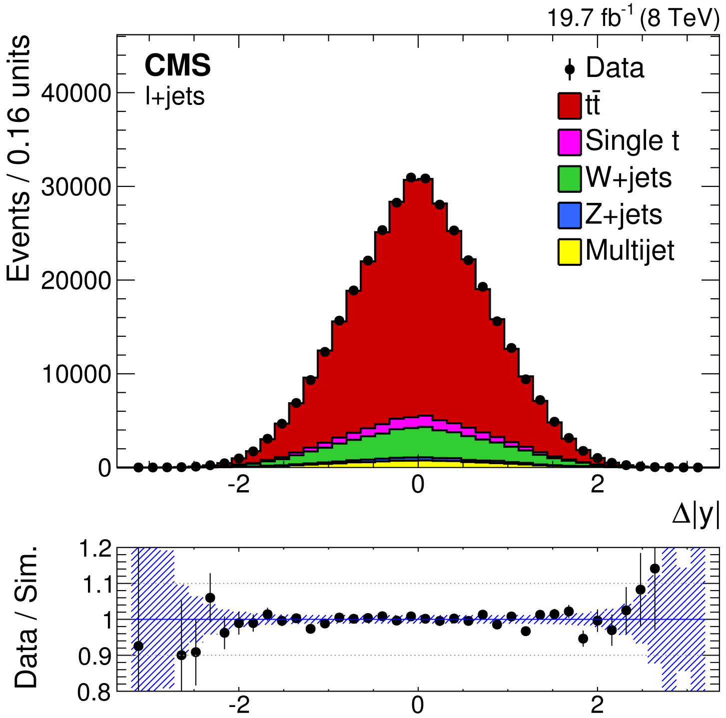
- top / anti-top rapidity asymmetry at LHC from quark-antiquark annihilation, gluon-gluon fusion, dominant process, intrinsically symmetric

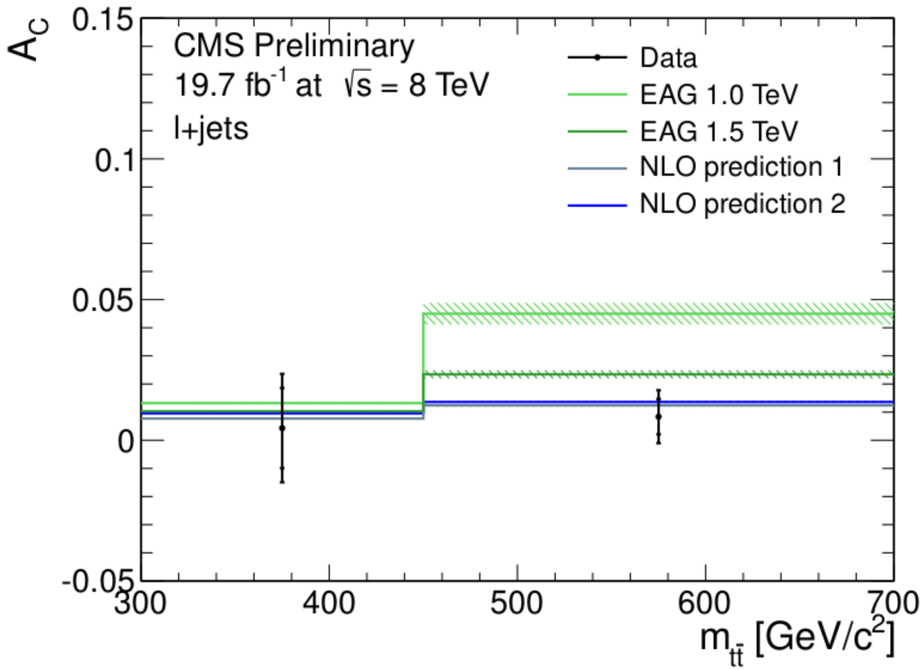
$$14\ \text{TeV}\ gg \to t\bar{t}\ (90\%),\ q\bar{q} \to t\bar{t}\ (10\%)$$

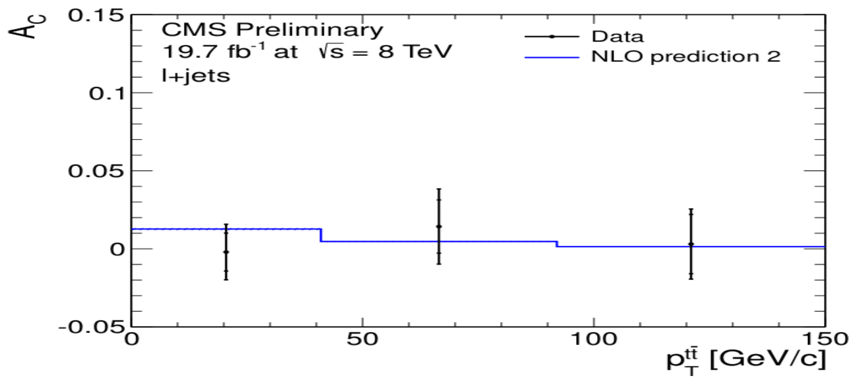
- **Important at LHC to study differential asymmetries**, to enhance new physics
  - **Sum of t and tbar rapidity to disentangle quark-antiquark and gluon-gluon fusion**
  - **ttbar invariant mass sensitive to new heavy states**
  - **Transverse momentum of the ttbar system sensitive to interference due to ISR**

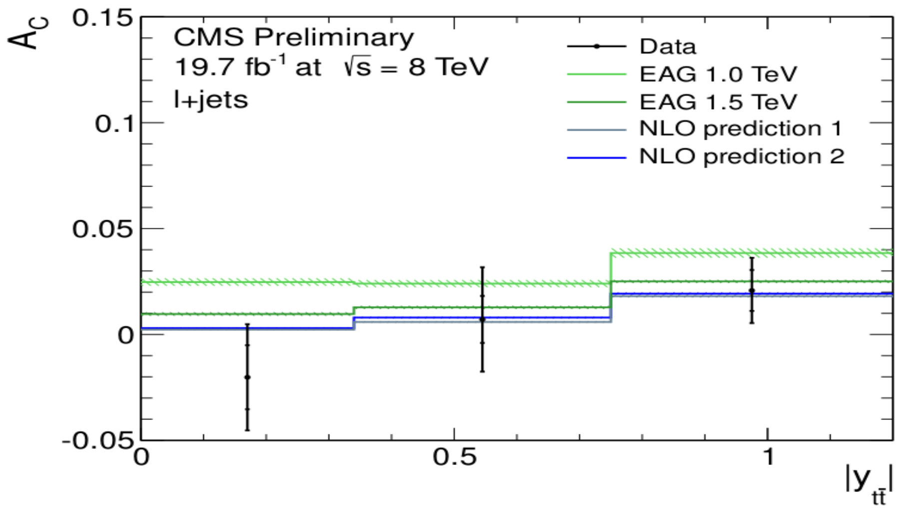
CMS PAS TOP-12-033

Charge asymmetry at LHC

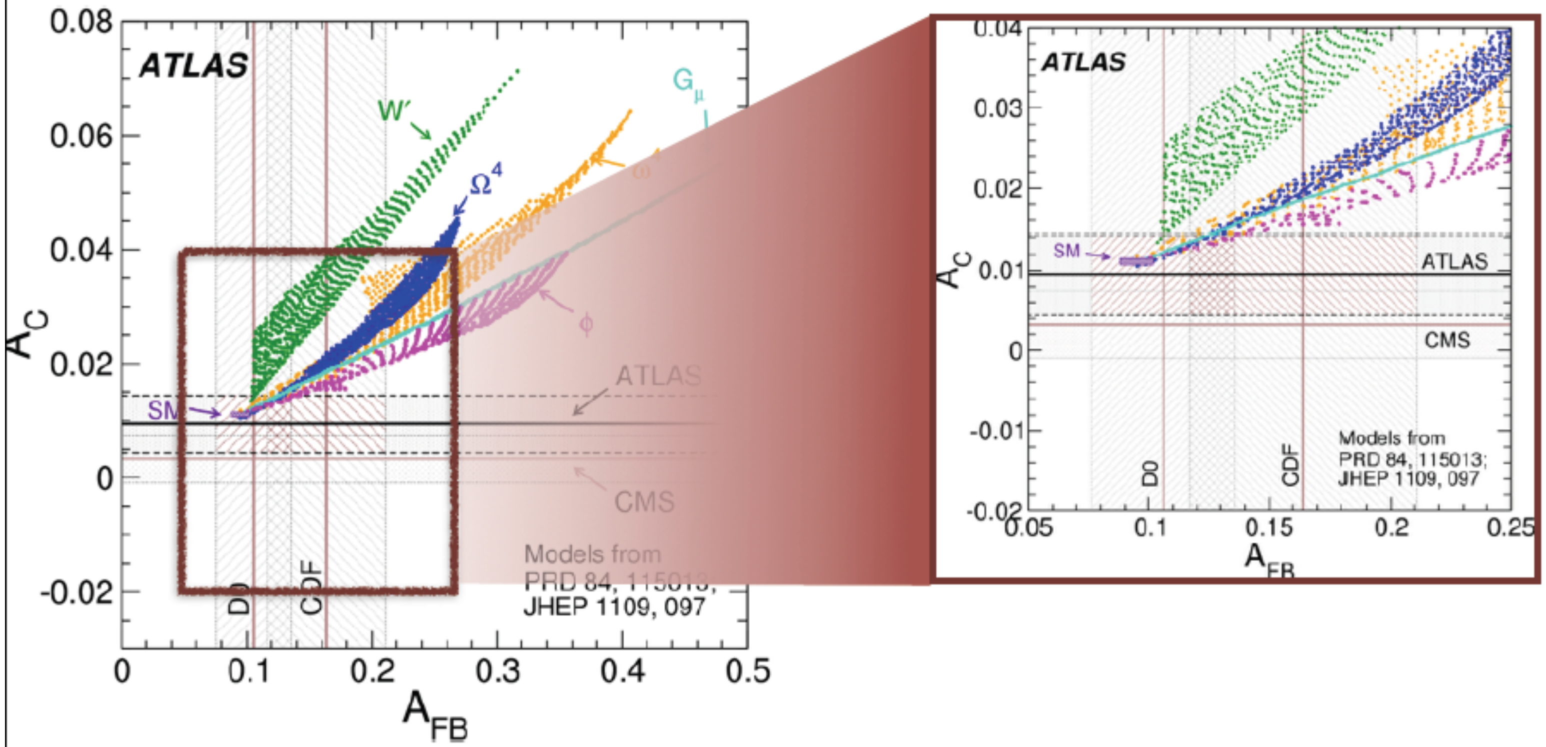








Killing models



Gμ : A new color-octet neutral vector boson exchanged in the s channel

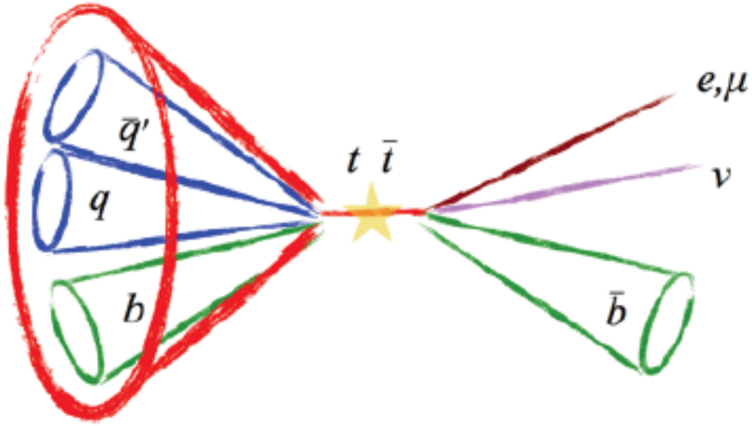
W′: A charged color-singlet vector boson Z exchanged in the t channel in $d\bar{d} \rightarrow t\bar{t}$

ϕ : A color-singlet scalar doublet with hypercharge −1/2 exchanged in t channel

Ω4 : A charge 4/3 scalar color sextet exchanged in the u channel

ω4 : A charge 4/3 scalar color triplet exchanged in the u channel

Asymmetry in Boosted Top Quark Events



Leptonic Top

Lepton, Small-R Jet

$p_T > 25$ GeV

**mini-isolation*

MET > 20 GeV

MET+MTW > 60 GeV

Hadronic Top

- 1 Anti-k_T R=1.0 Large-R Jet
  Trimmed: $r_{sub}=0.3$, $f_{cut}=5\%$
- $p_T > 300$ GeV
- $m > 100$ GeV
- $\sqrt{d_{12}} > 40$ GeV

Other Criteria

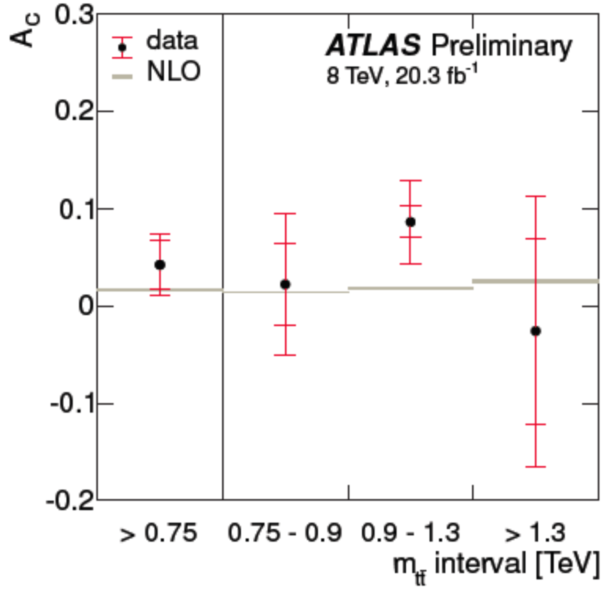
$\Delta\phi(\ell$,Large-R Jet$) > 2.3$

$\Delta R(\ell$,Small-R Jet$) < 1.5$

ΔR(Small-R,Large-R) > 1.5

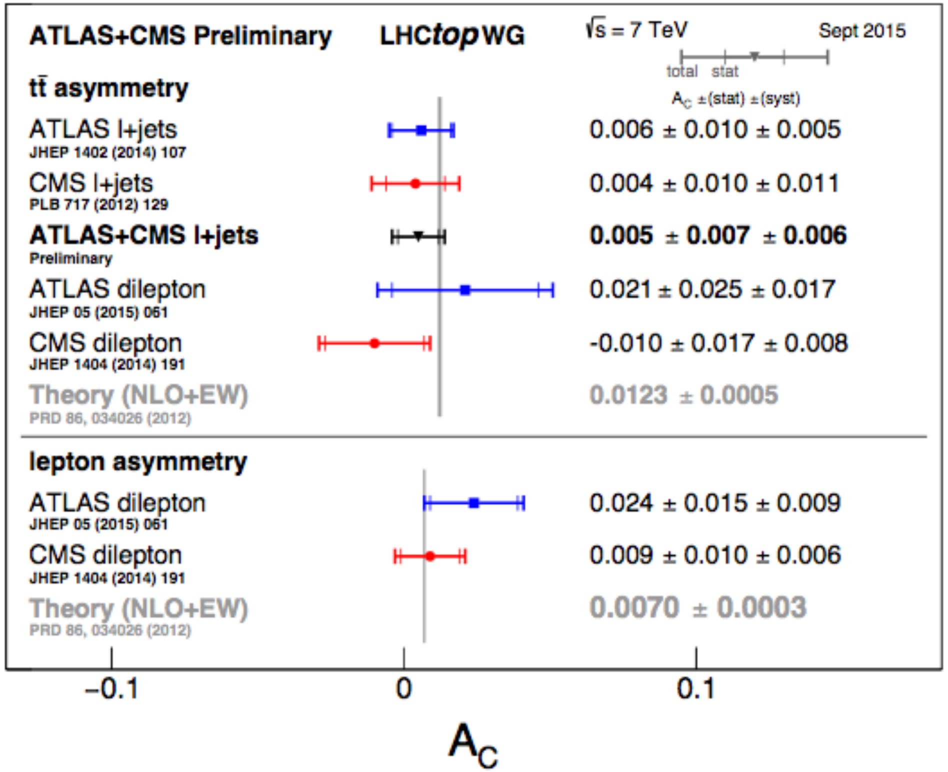
≥ 1 b-tagged Jet

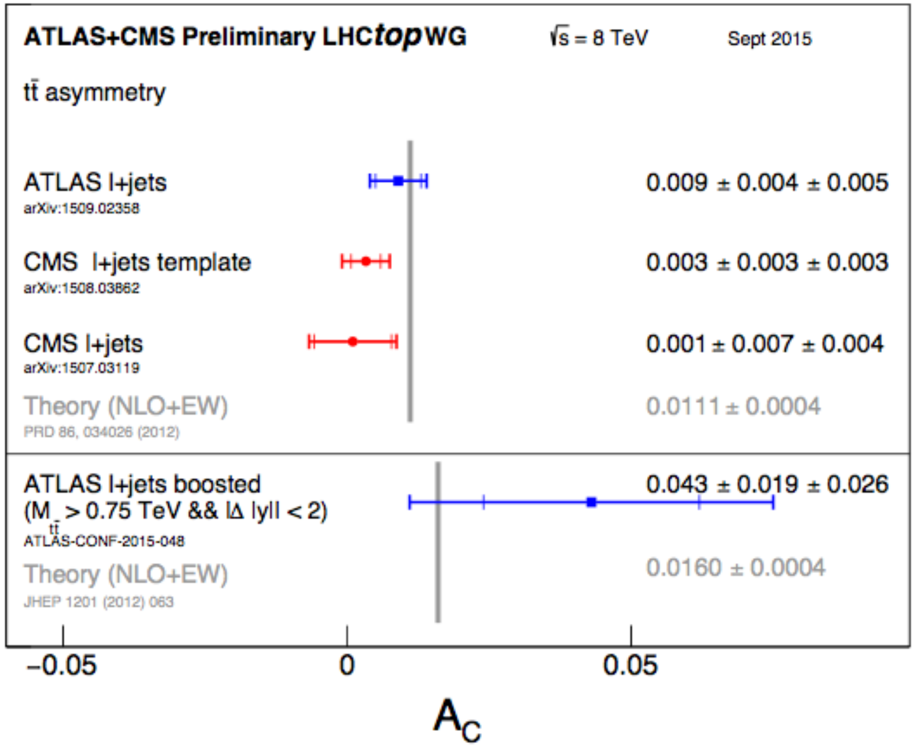
$m_{tt} > 750$ GeV**



	e+jets	μ+jets
$t\bar{t}$	4100 ± 600	3600 ± 500
W+jets	263 ± 32	264 ± 32
Single Top	140 ± 20	138 ± 19
Multi-jet	44 ± 8	4 ± 1
Z+jets	40 ± 27	16 ± 11
Dibosons	20 ± 7	18 ± 7
$t\bar{t}V$	37 ± 19	33 ± 17
Prediction	4600 ± 600	4000 ± 500
Data	4130	3600

LHC A_c Summaries



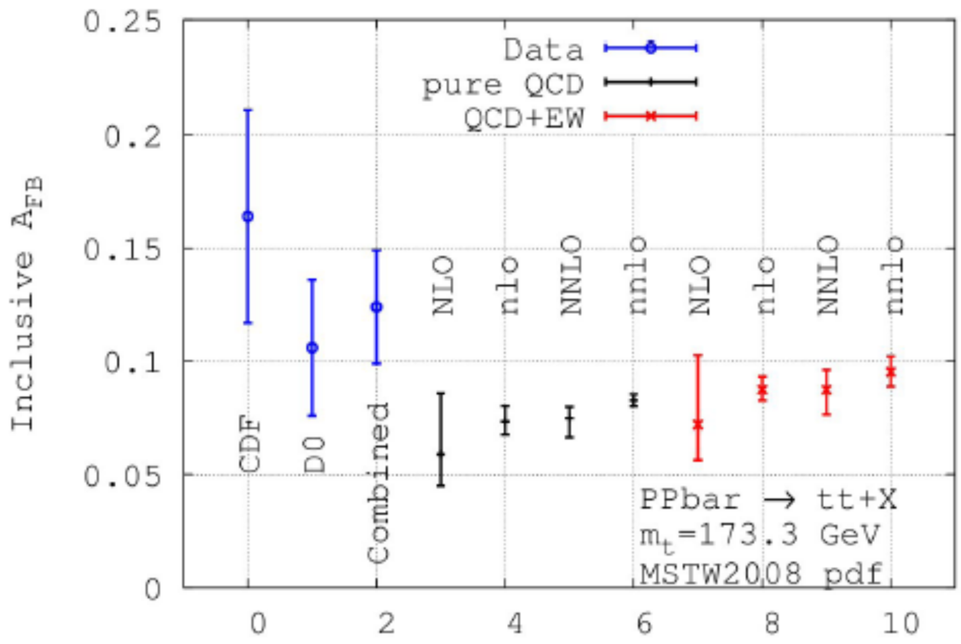


Latest news: Tevatron discrepancy has gone ...

- At fixed order, state of the art is NNLO

[Baernreuther,Czakon,Fiedler,Heymes.Mitov '12-]

[talk by Heymes top2015

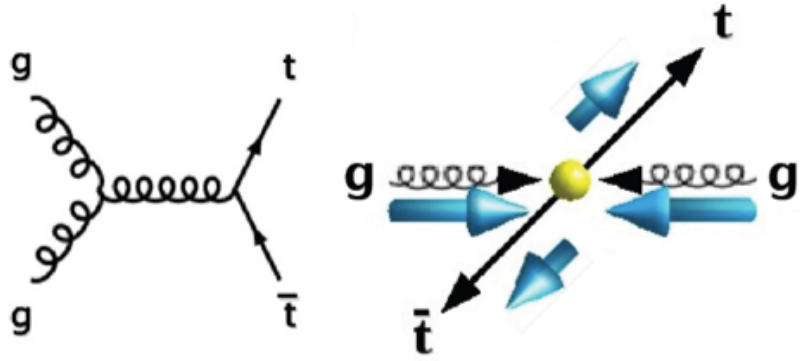


- good perturbative convergence
- matching to NNLL resummation improves (scale) uncertainty: $5\% \to 3\%$
- improves on Tevatron A_{FB} asymmetry

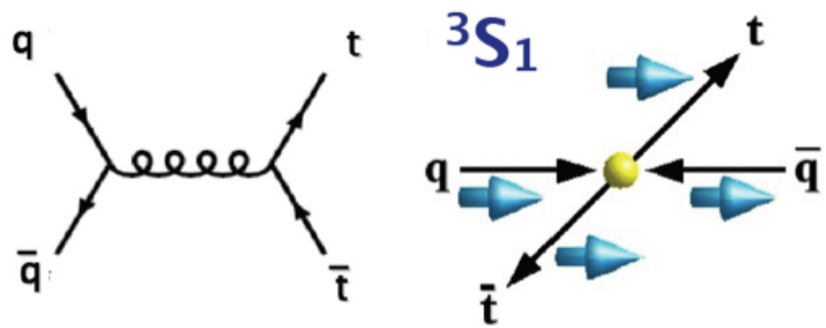
Spin correlations in ttbar

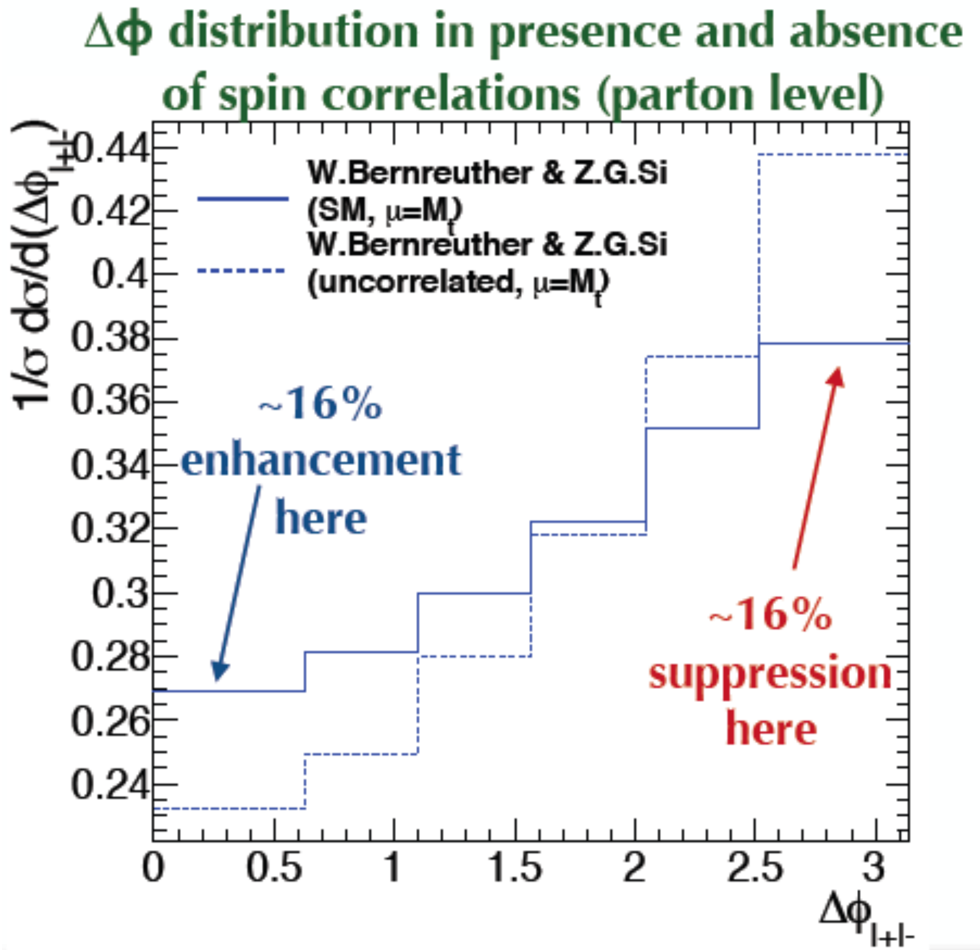
Another tool to investigate the production mechanism, possible only for the top quark
Investigating it now, but will become a precision tool with high statistics

gluon-gluon example at high boost



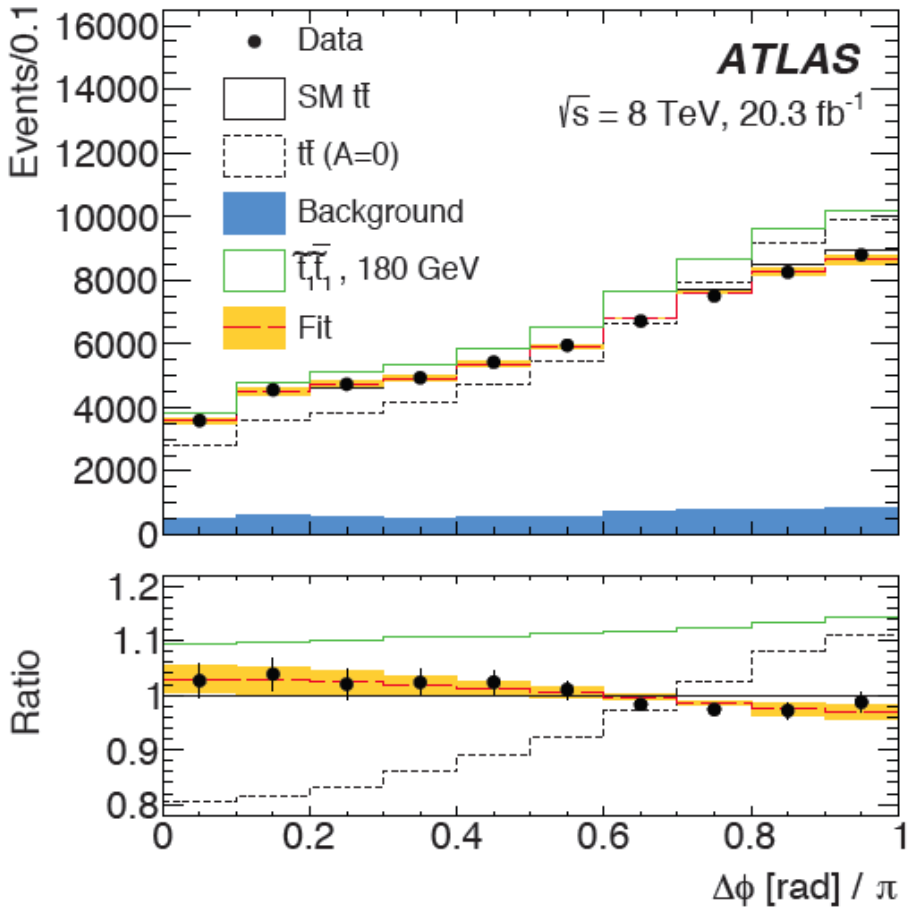
qqbar example at threshold



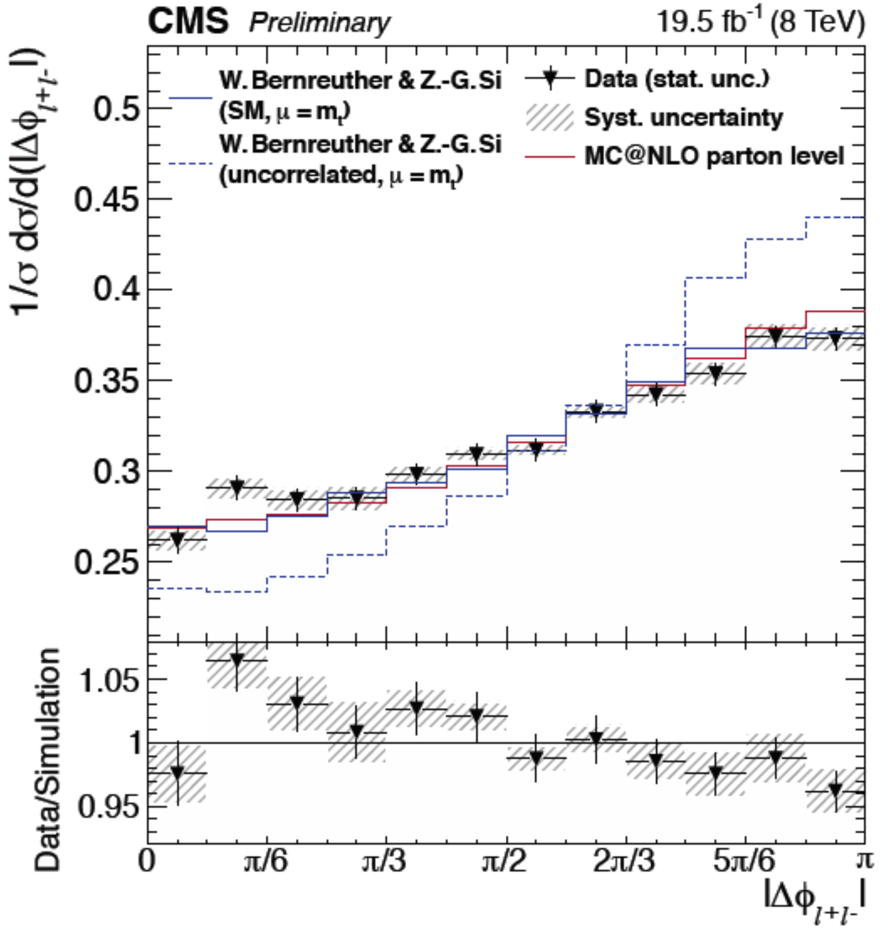


Δϕ results from ATLAS and CMS

PRL 114, 142001 (2015)



CMS TOP-14-023

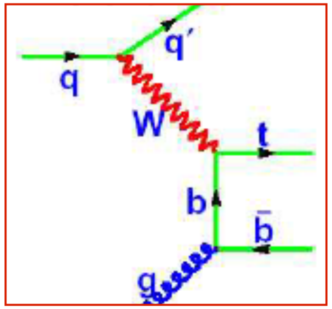


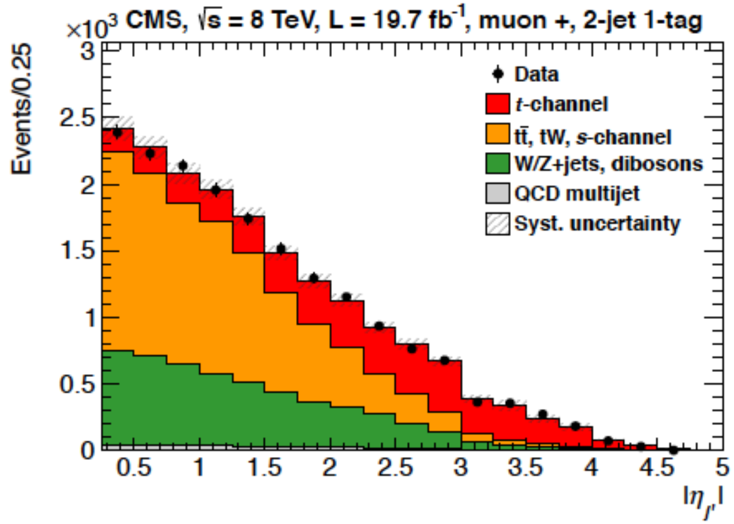
can extract limits to chromomagnetic dipole moments or to probe SUSY (stop)

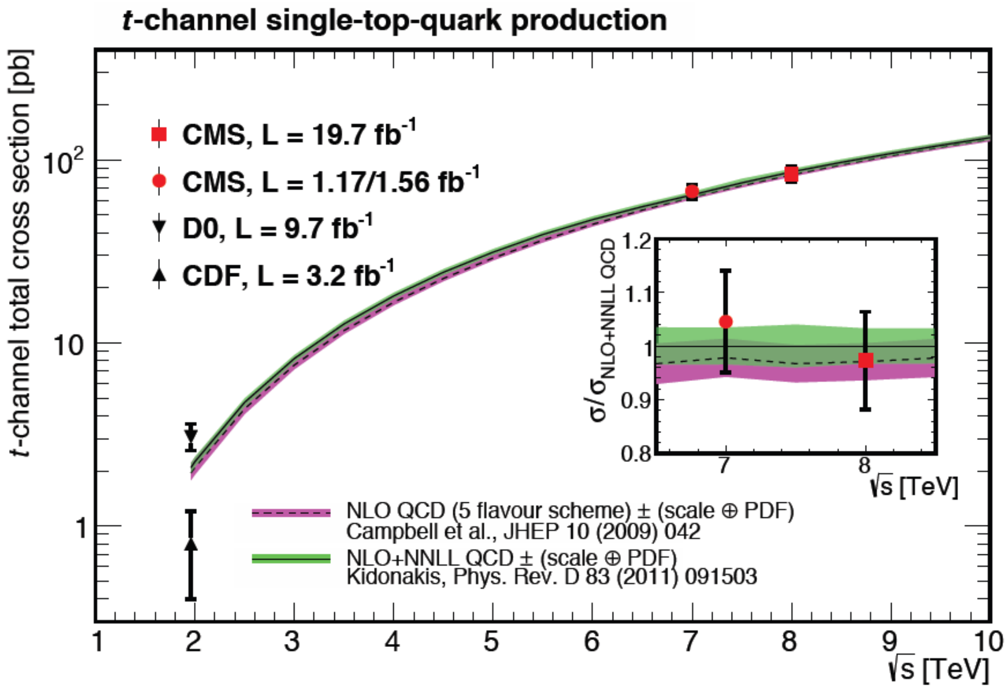
$-0.050 < \mathrm{Re}(\hat{\mu}_t) < 0.076$ (95% CL) (CMS TOP-14-023)

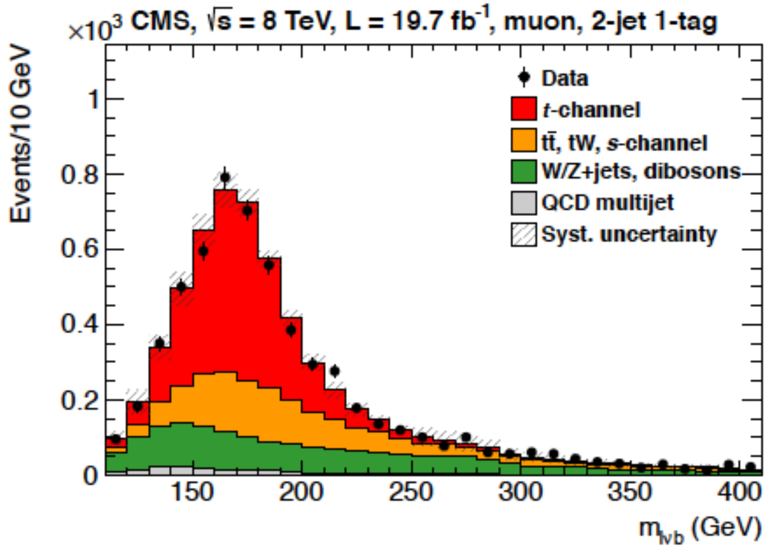
SINGLE TOP

Single top t-channel



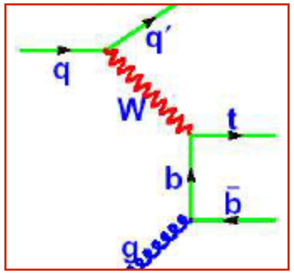


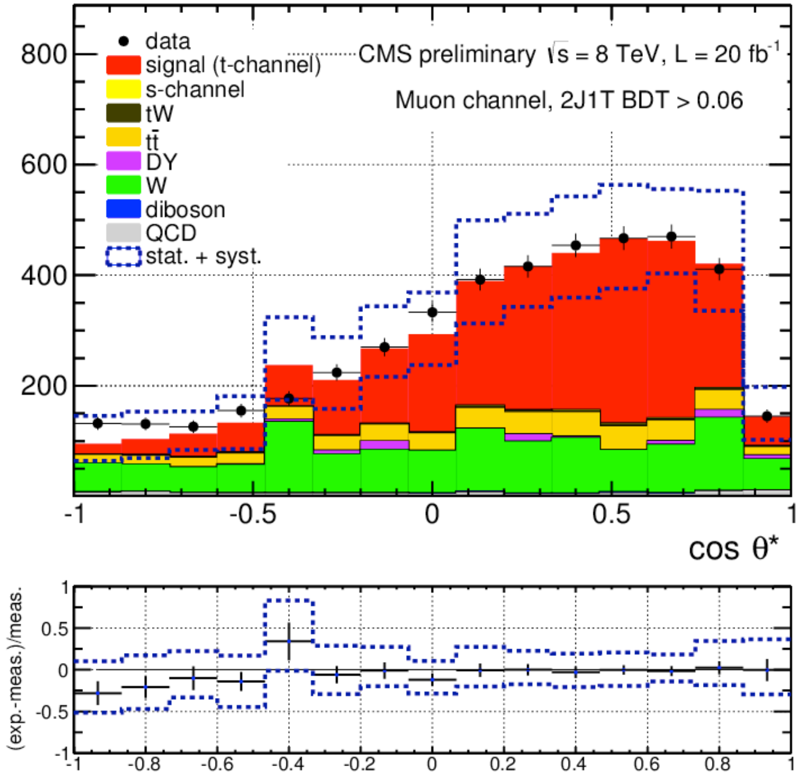


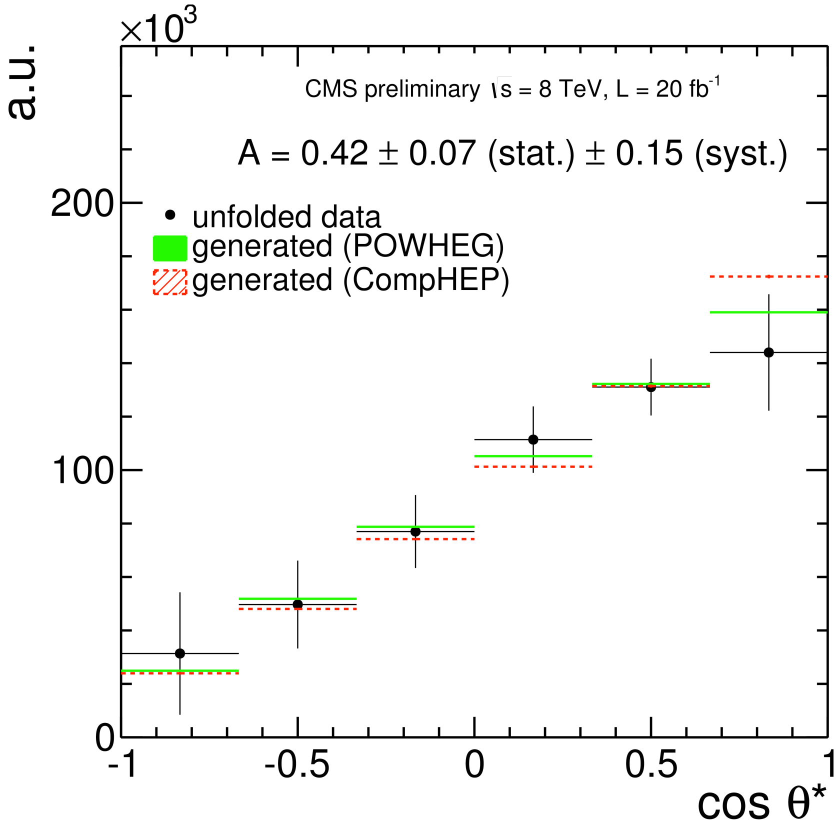


single top polarization in t-channel

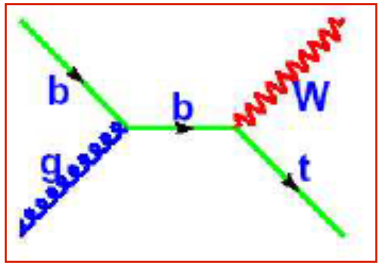
- V-A current, top 100% polarized !



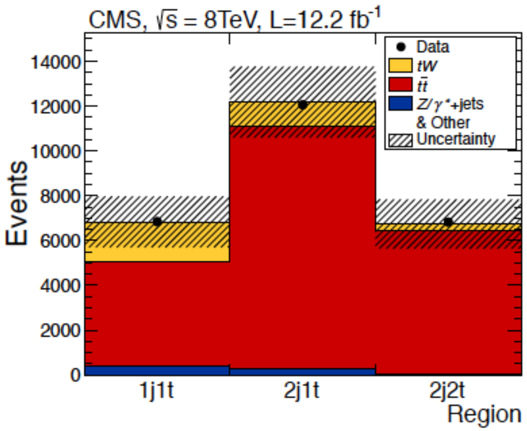


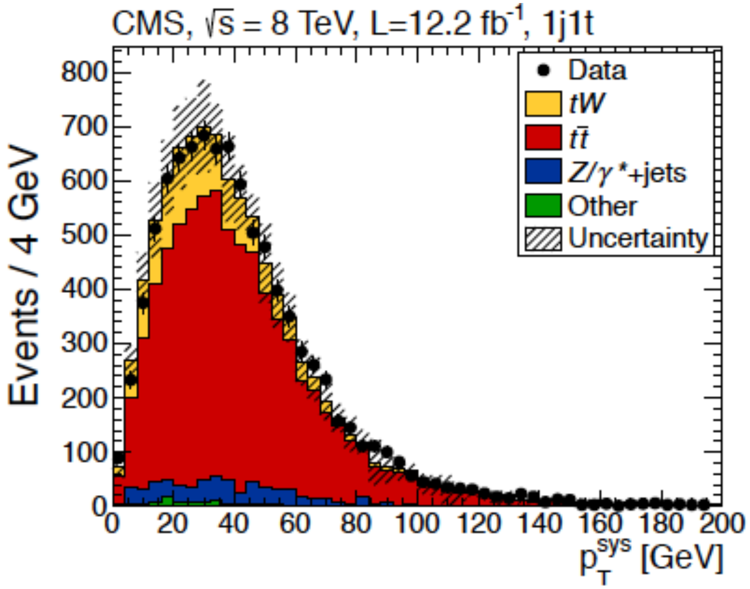


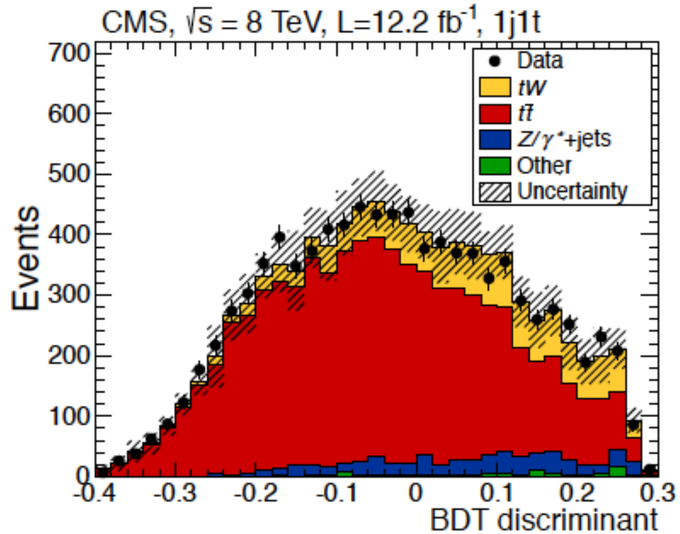
single top tW channel



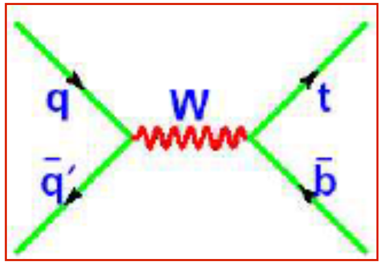
categorization important !







Single top s-channel



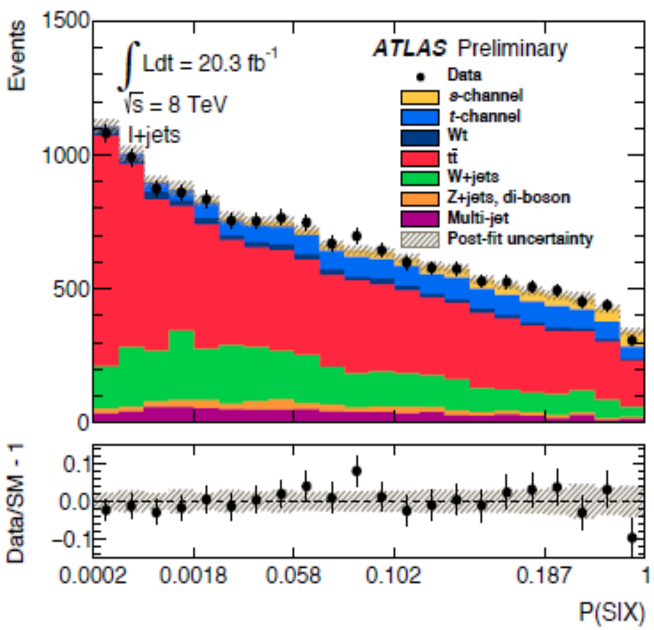
$$\sigma_s = 4.8 \pm 1.1\ (\text{stat.})^{+2.2}_{-2.0}\ (\text{syst.})\text{pb}$$

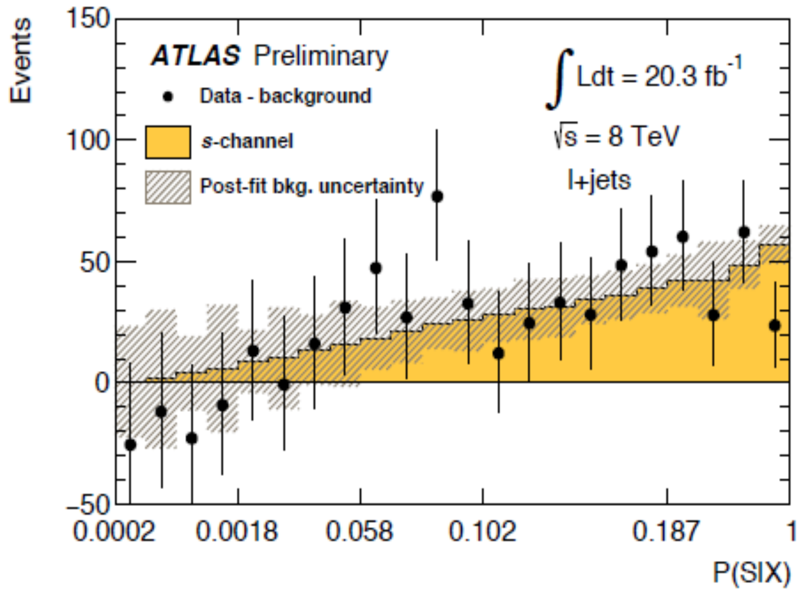
Significance: 3.2σ (exp. 3.9σ)

→ Consistent with SM expectation: $\sigma^{theory}_{s-ch.} = 5.61 \pm 0.22$ pb

Uses the Matrix Element method to squeeze out optimal sensitivity…

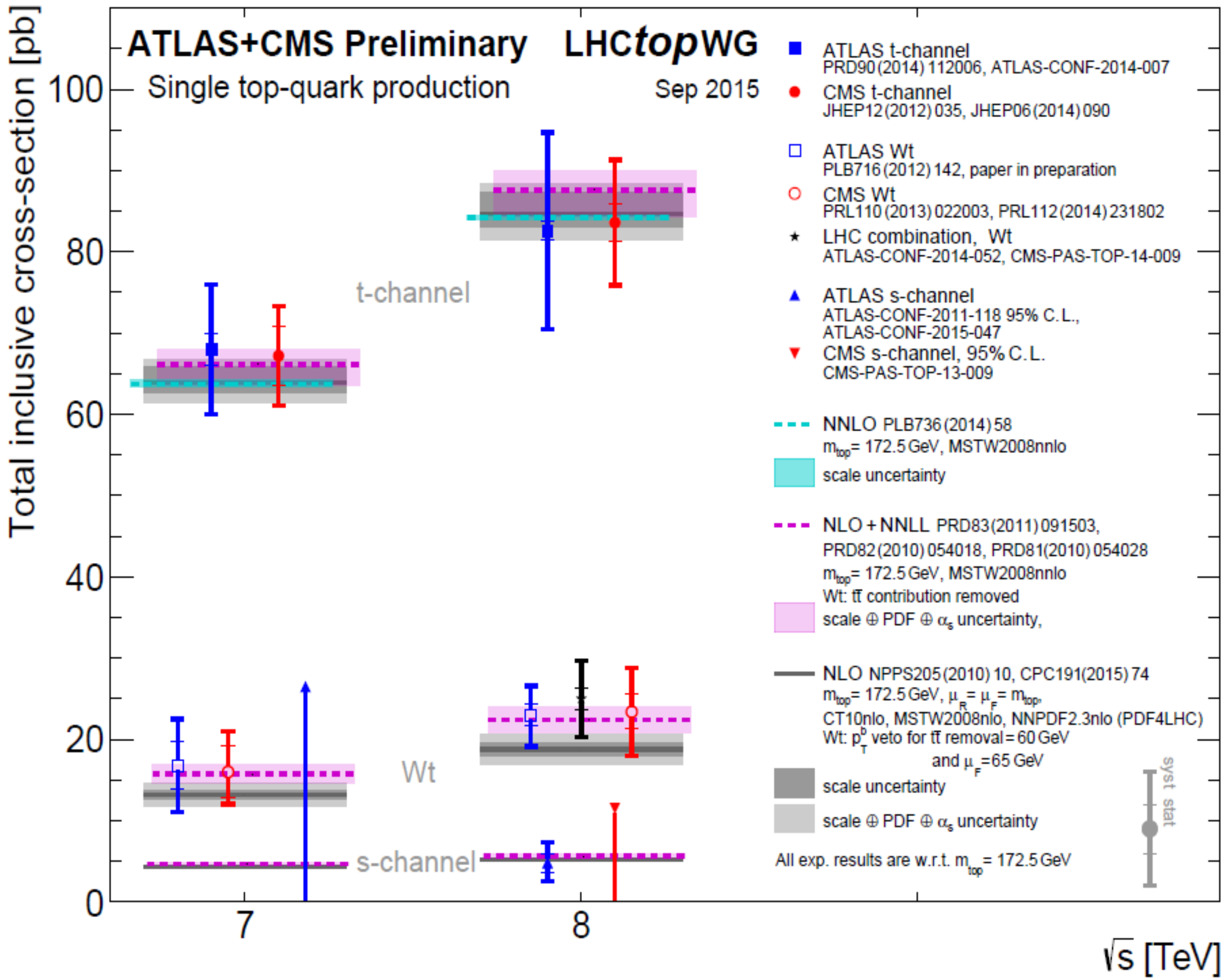
2-jet 2-tag ($\sim$ 4.3% of s-channel)



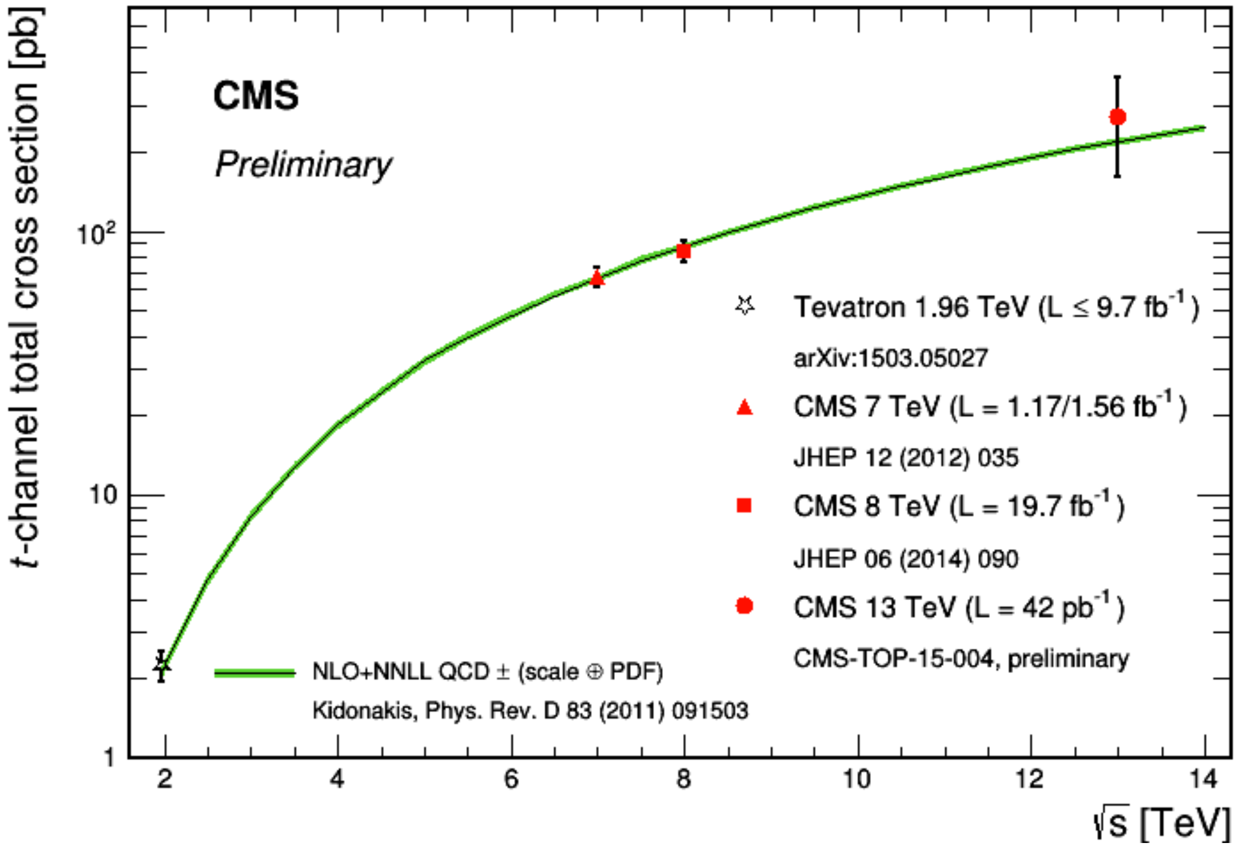


First EVIDENCE of the s-channel production at LHC

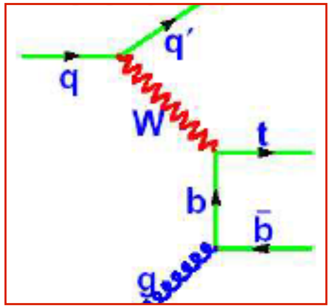
Single Top: the complete picture

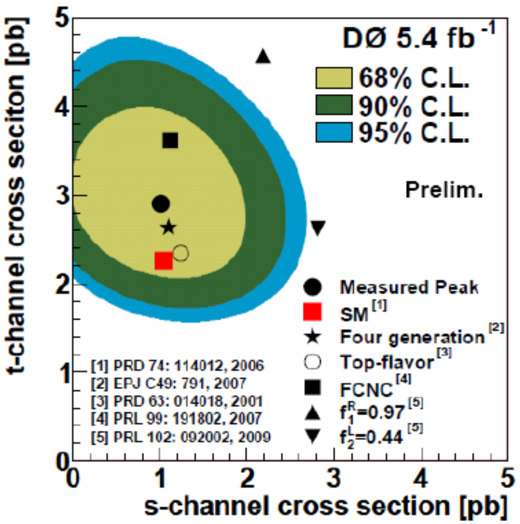


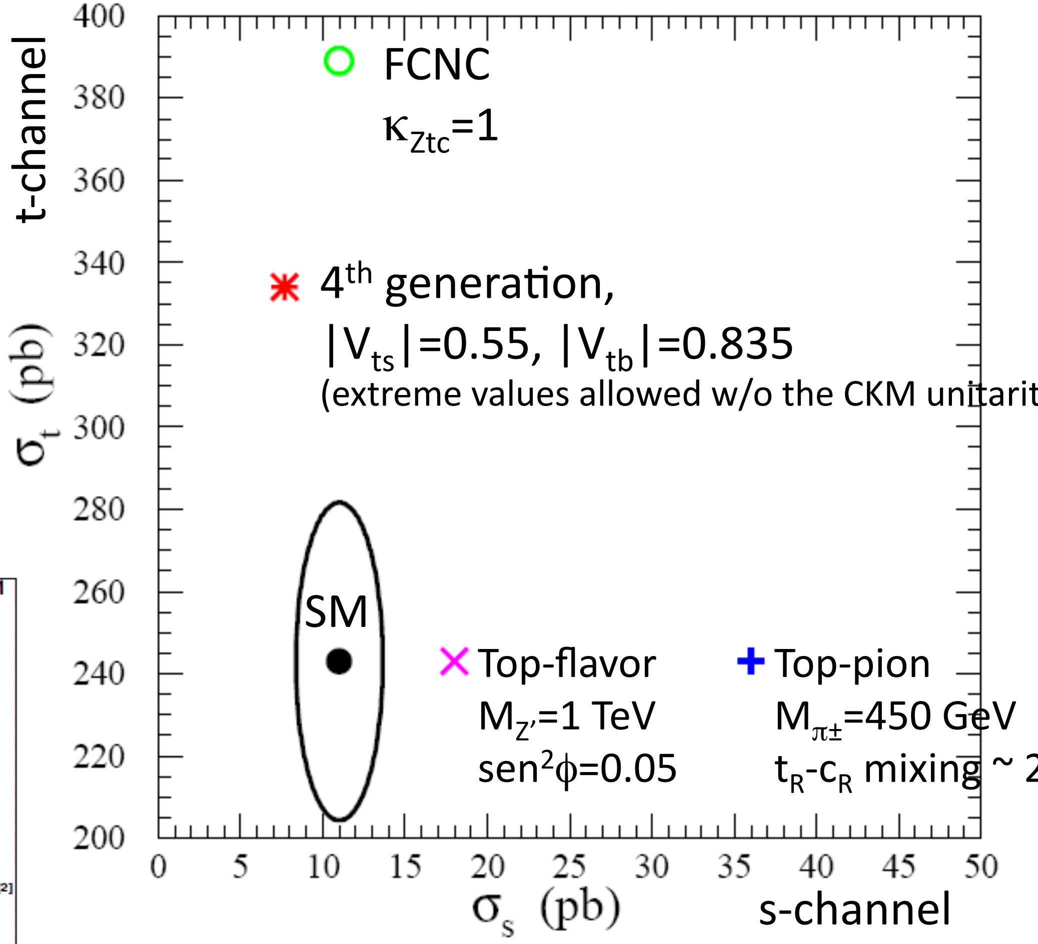
single top cross section vs sqrt(s)



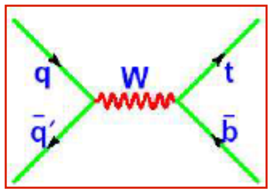
Single top in t and s channel sensitive to different aspects of New Physics (tW, too !)





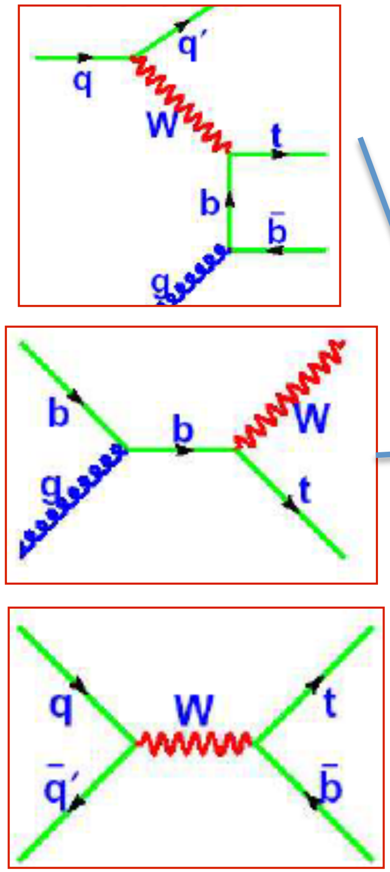


(plot for 14 TeV)

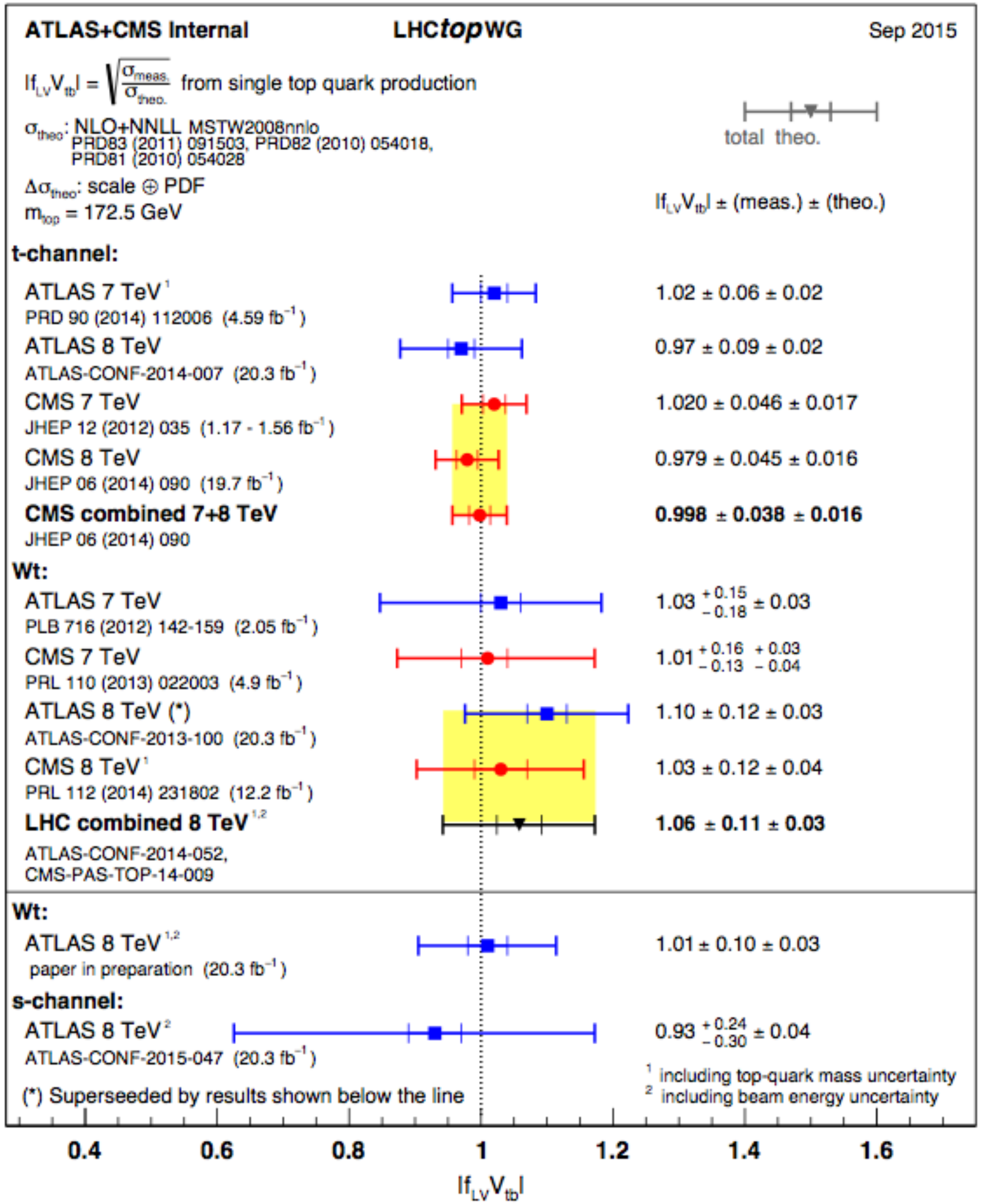


T.Tait, C.-P.Yuan, Phys.Rev. D63 (2001) 0140018

Single top and $|V_{tb}|$

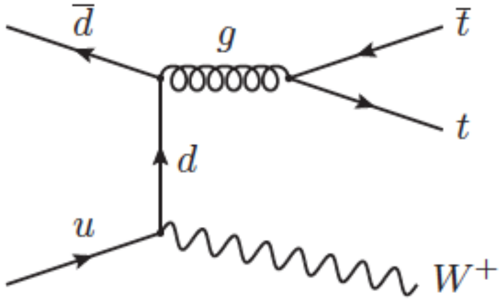


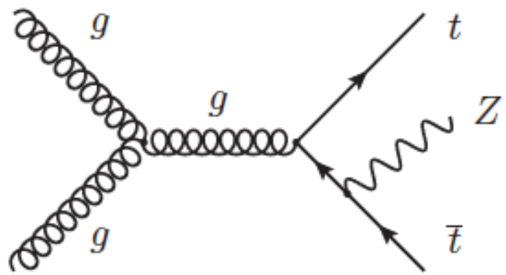
$$\sigma \propto |V_{tb}|^2$$



ASSOCIATED PRODUCTION OF TOP AND BOSONS (AND MORE ...)

Associated production of top pair and **vector** boson





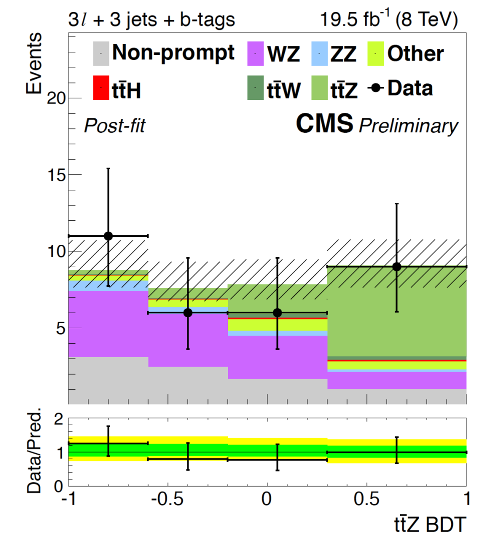
CMS TOP-14-021

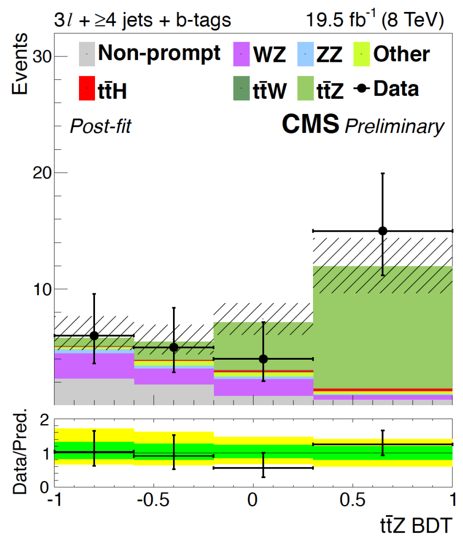
ATLAS arXiv:1509.05276

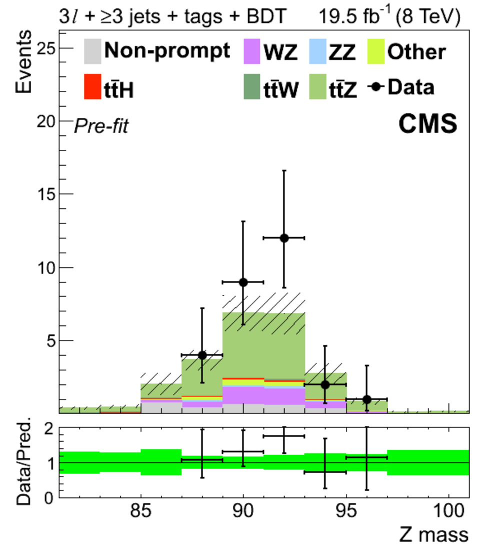
- The ttZ process provides direct access to Z-top couplings
- Both ttW and ttZ processes can be altered by BSM physics
- Measured **ttW** and **ttZ** cross sections with 19.5 fb^{-1} of data collected at 8 TeV
- Measurement performed in multilepton (e or μ) final states
  - **ttZ measured in channels with two, three, or four leptons, with exactly one pair of same-flavor opposite-sign (OS) leptons close to the Z mass**.
  - **ttW measured in in channels with two same-sign (SS) leptons or three leptons, where no lepton pair is consistent with coming from a Z boson decay.**
  - **full or partial reconstruction of the ttW or ttZ system with a linear discriminant that matches leptons and jets to their parent particles using mass, charge, and b tagging information.**

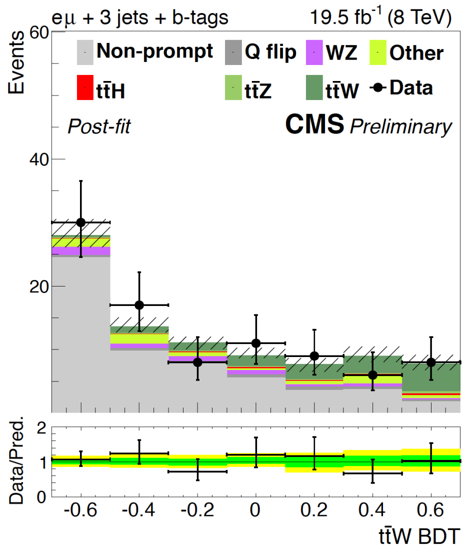
CMS TOP-14-021

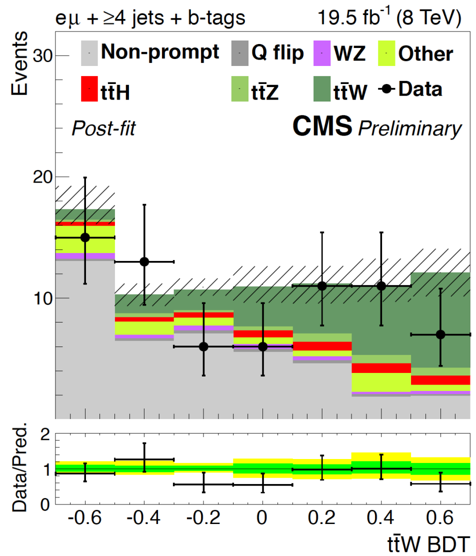
ttZ and ttW signals

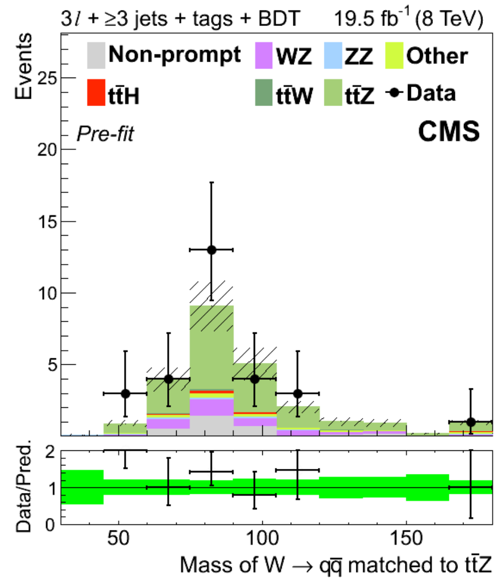












CMS TOP-14-021

ttW e ttZ cross section measurements

	Cross section (fb)		Signal strength (μ)		Significance	
Channels	Expected	Observed	Expected	Observed	Expected	Observed
SS	203^{+88}_{-73}	414^{+135}_{-112}	$1.0^{+0.45}_{-0.36}$	$2.04^{+0.74(+1.52)}_{-0.61(-1.05)}$	3.44	4.89
3ℓ	203^{+215}_{-94}	210^{+225}_{-203}	$1.0^{+1.09}_{-0.96}$	$1.03^{+1.07(+2.39)}_{-0.99(-1.92)}$	1.03	1.03
SS + 3ℓ	203^{+84}_{-71}	382^{+117}_{-102}	$1.0^{+0.43}_{-0.35}$	$1.88^{+0.66(+1.35)}_{-0.56(-0.95)}$	3.54	4.81

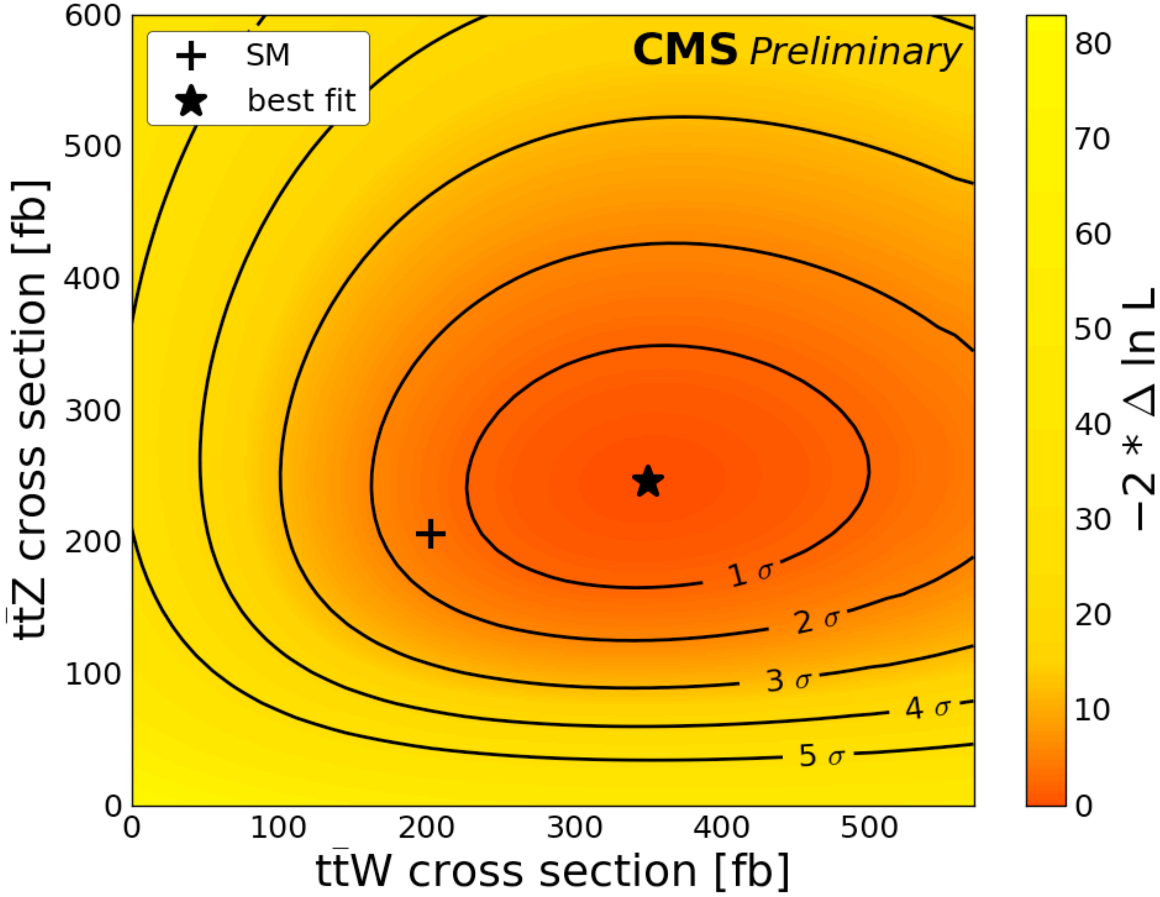
ttW

	Cross section (fb)		Signal strength (μ)		Significance	
Channels	Expected	Observed	Expected	Observed	Expected	Observed
OS	206^{+142}_{-118}	257^{+158}_{-129}	$1.0^{+0.72}_{-0.57}$	$1.25^{+0.76(+1.76)}_{-0.62(-1.16)}$	1.84	2.12
3ℓ	206^{+79}_{-63}	257^{+85}_{-67}	$1.0^{+0.42}_{-0.32}$	$1.25^{+0.45(+1.02)}_{-0.36(-0.62)}$	4.55	5.11
4ℓ	206^{+153}_{-109}	228^{+150}_{-107}	$1.0^{+0.77}_{-0.53}$	$1.11^{+0.76(+1.79)}_{-0.52(-0.86)}$	2.65	3.39
OS + 3ℓ + 4ℓ	206^{+62}_{-52}	242^{+65}_{-55}	$1.0^{+0.34}_{-0.27}$	$1.18^{+0.35(+0.79)}_{-0.29(-0.51)}$	5.73	6.44

ttZ

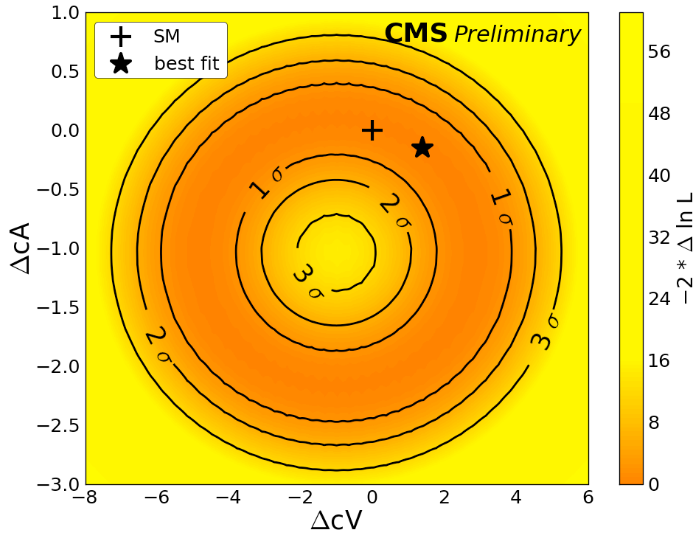
CMS TOP-14-021

ttW e ttZ cross sections



CMS TOP-14-021

ttZ couplings



Constraints on vector and axial couplings

$$\mathcal{L}_{\text{eff}} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda}\mathcal{L}_1 + \frac{1}{\Lambda^2}\mathcal{L}_2 + \cdots$$
$$= \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda}\sum_i (c_i \mathcal{O}_i + \text{h.c.}) + \frac{1}{\Lambda^2}\sum_i (c_i \mathcal{O}_i + \text{h.c.}) + \cdots$$

Constraints on dimension-6 operators

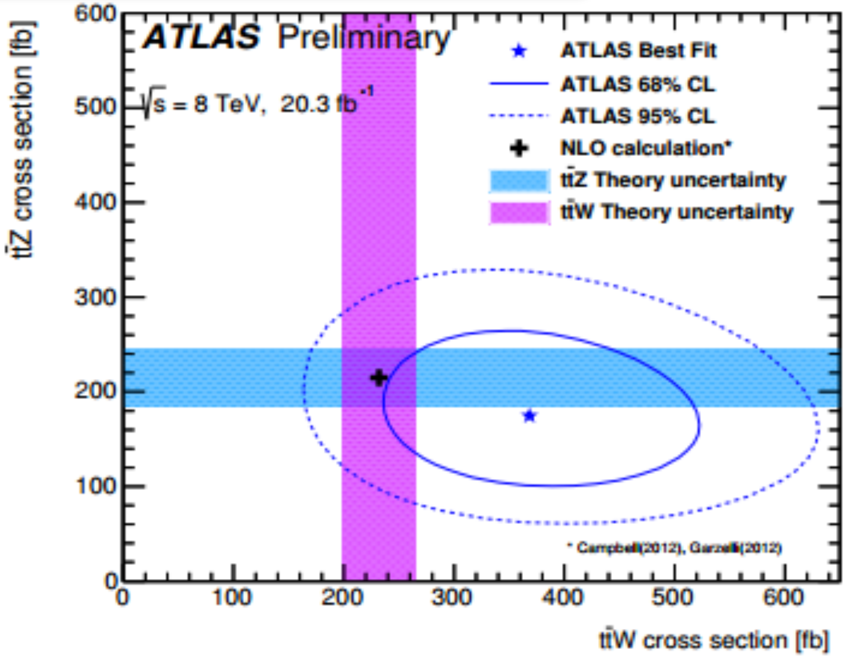
operator	best fit point(s)	1σ CL	2σ CL
$\bar{c}_{uB}$	-0.07 and 0.07	{-0.11, 0.11}	{-0.14, 0.14}
$\bar{c}'_{HQ}$	0.12	{-0.07, 0.18}	{-0.33, -0.24} and {-0.02, 0.23}
$\bar{c}_{HQ}$	-0.09 and 0.41	{-0.22, 0.08} and {0.24, 0.54}	{-0.31, 0.63}
$\bar{c}_{Hu}$	-0.47 and 0.13	{-0.60, -0.23} and {-0.11, 0.26}	{-0.71, 0.37}
$\bar{c}_{3W}$	-0.28 and 0.28	{-0.36, -0.18} and {0.18, 0.36}	{-0.43, 0.43}

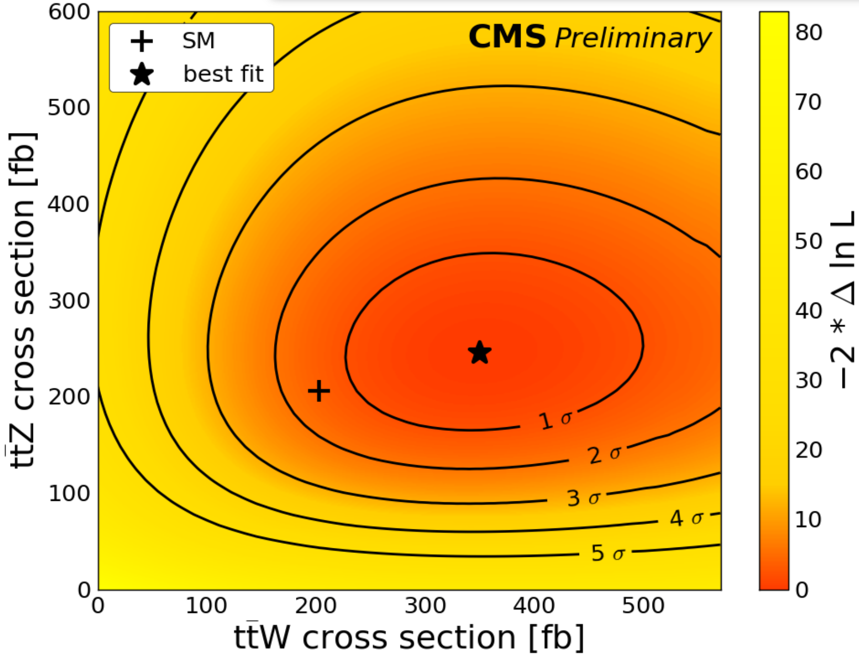
ttV: Observation !

ttW: 3.2 σ (exp) 5.0 σ (obs)
ttZ: 4.5 σ (exp) 4.2 σ (obs)

TOP 2015

ttW: 3.8 σ (exp) 4.8 σ (obs)
ttZ: 5.7 σ (exp) 6.4 σ (obs)





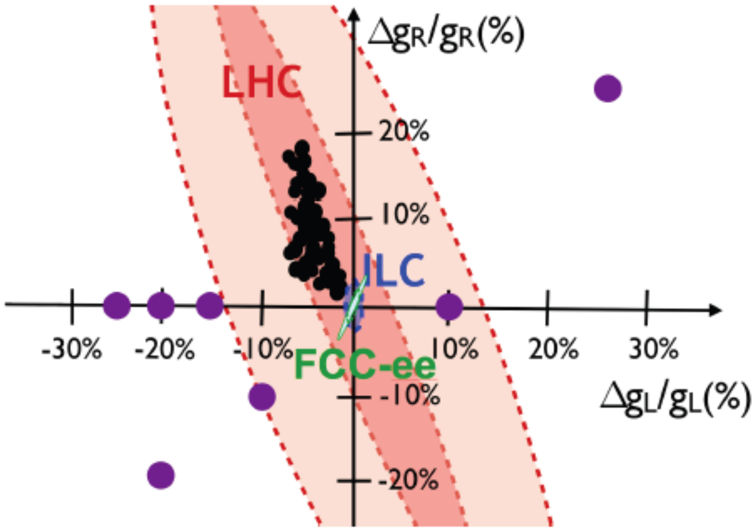
arXiv:1509.05276

+ limits on 6D EFT operators

The future of top-Z couplings

Stefania De Curtis et al., arXiv:1504.05407

P. Janot, JHEP 1504 (2015) 182



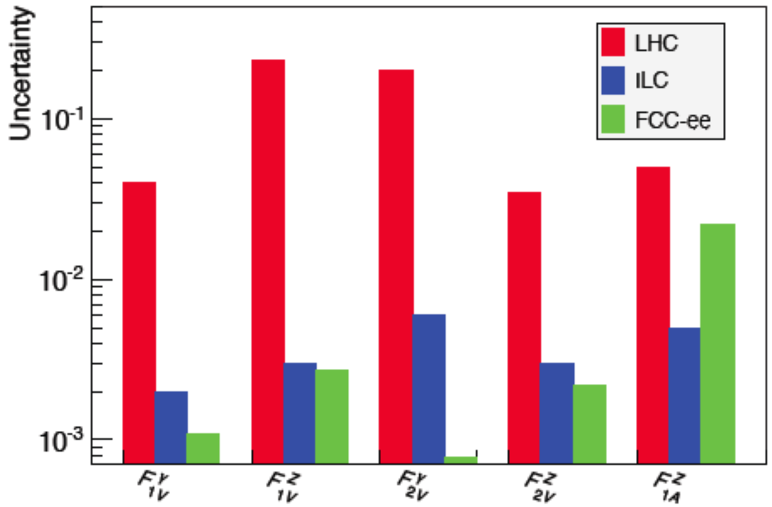
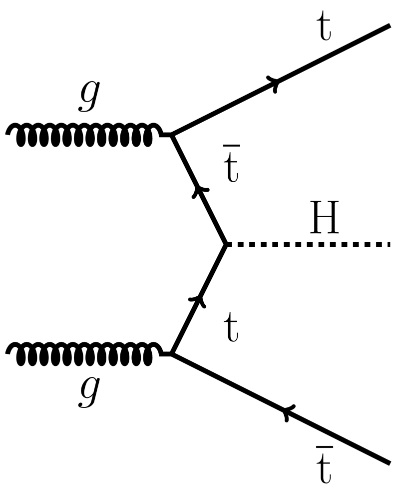


Fig. 17: *Left: Predicted deviations of Z couplings to t_L and t_R in various NP models [143, 148]. Also shown are the expected sensitivities of LHC (300 $fb^{-1}$and 3000 fb^{-1}), ILC and FCC-ee. Right: Comparison of statistical precisions on CP conserving axial and vector form factors expected at LHC with 300 fb^{-1} [145] at ILC500 with 500 fb^{-1} [147] and at FCC-ee with 2.4 ab^{-1} [142]. The FCC-ee (ILC) projections are obtained at $\sqrt{s} = 365\,GeV$ ($\sqrt{s} = 500\,GeV$). In the case of FCC-ee lepton-angular and energy distributions are used, while ILC projections are based on the use of beam polarization.*

from **White Paper of INFN-CSN1**, published in Frascati Physics Series, May 2015

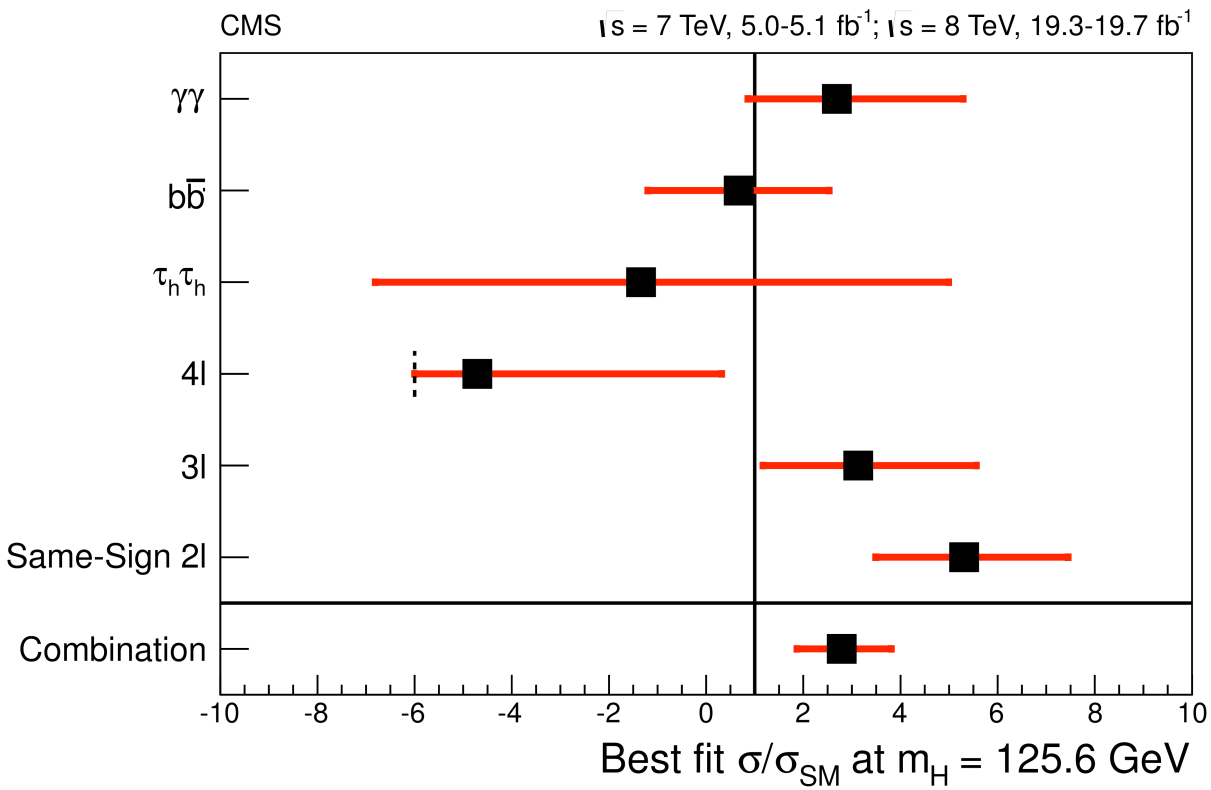
Associated production of top pair and **scalar** boson



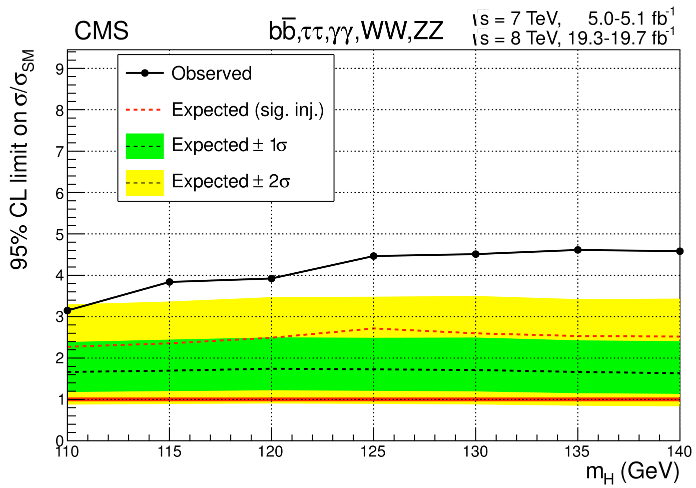
CMS HIG-14-021

- The ttH process gives direct access to the top-Higgs Yukawa coupling.
- The process can be altered by BSM physics
- Searched with 5.1 fb^{-1} at 7 TeV and 19.7 fb^{-1} of at 8 TeV
- Measurement performed in several final states
  - top pair all hadronic, lepton+jets, dilepton
  - with H→hadrons, H→ leptons, H→ $\gamma\gamma$
  - categorization includes H→bb and H→ $\tau\tau$

Results for ttH search



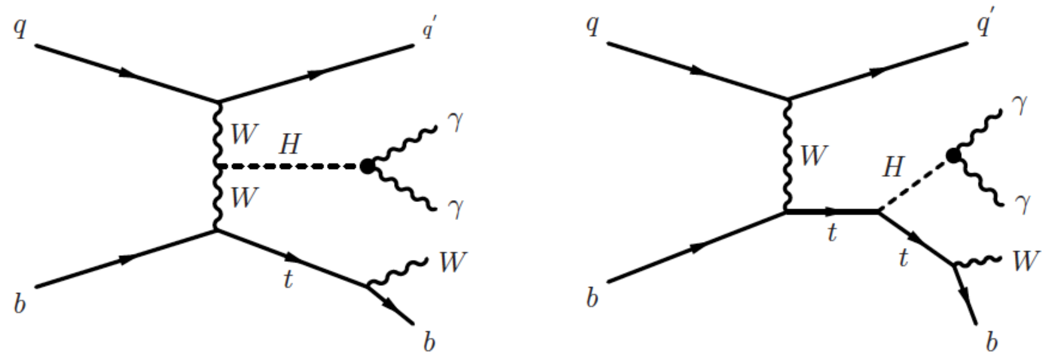
CMS HIG-14-021
JHEP 09 (2014) 087



μ=2.8±1.0 for an Higgs boson mass of 125.6 GeV

Associated production of single top and Higgs boson

CMS HIG-14-001



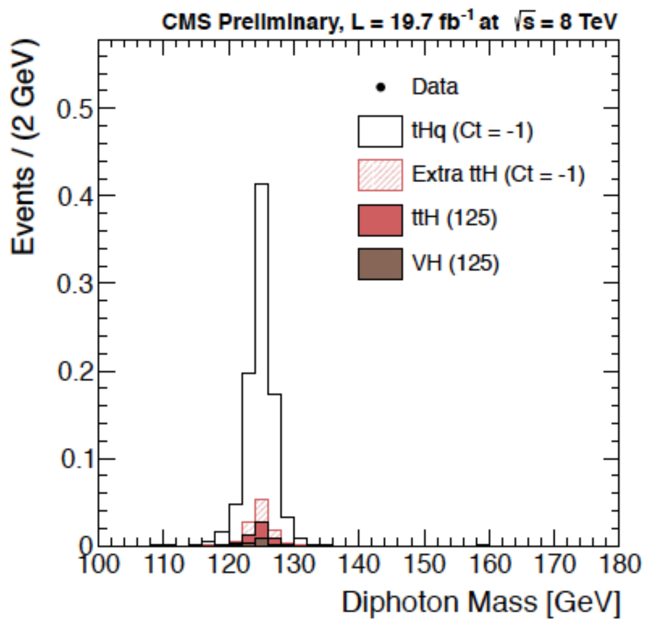
- Potentially gives the relative sign of the top-Higgs Yukawa coupling with respect to the Higgs-W coupling
- The two diagrams interfere destructively in the SM (σ=18 fb), but with flipped sign cross section increases by a factor 15
- Analysis performed in the $H \rightarrow \gamma\gamma$ channel

$$\mathrm{tHq} \rightarrow (\mathrm{t} \rightarrow \mathrm{b}\ell\nu)(\mathrm{H} \rightarrow \gamma\gamma)q \quad \text{with } \ell = \mathrm{e}, \mu$$

CMS HIG-14-001

Results for tHq search

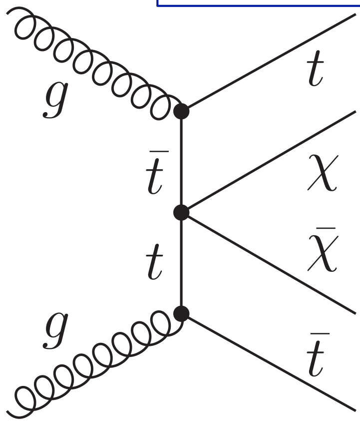
- Zero events found: an observed 95% UL is set at 4.1 times the expected cross section with inverted Ct (= -1).

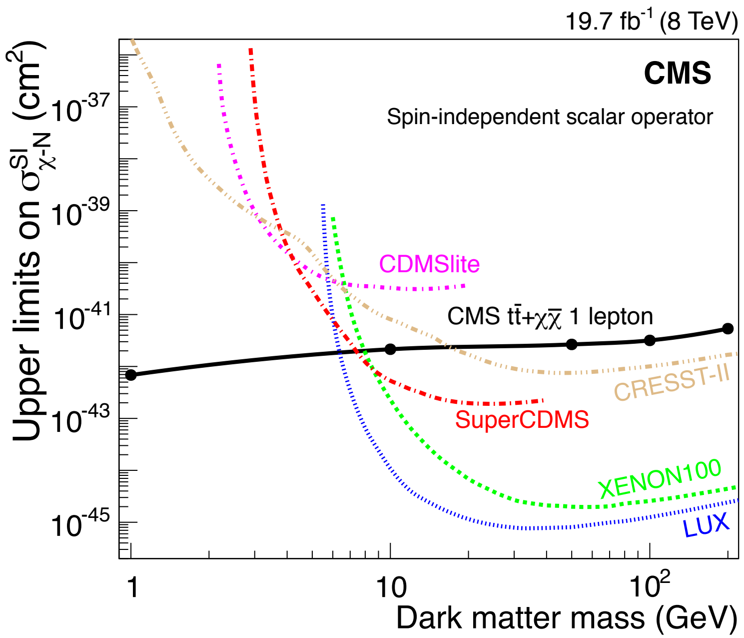


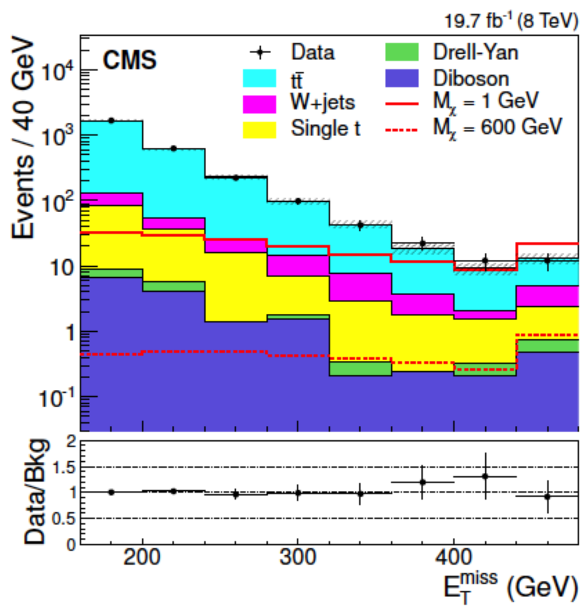
Search for Dark Matter produced in association with top pairs

JHEP 06 (2015) 221

- Dark matter could couple to heavy fermions through contact interactions
- Search requires the presence of one lepton, multiple jets, and large missing transverse energy.

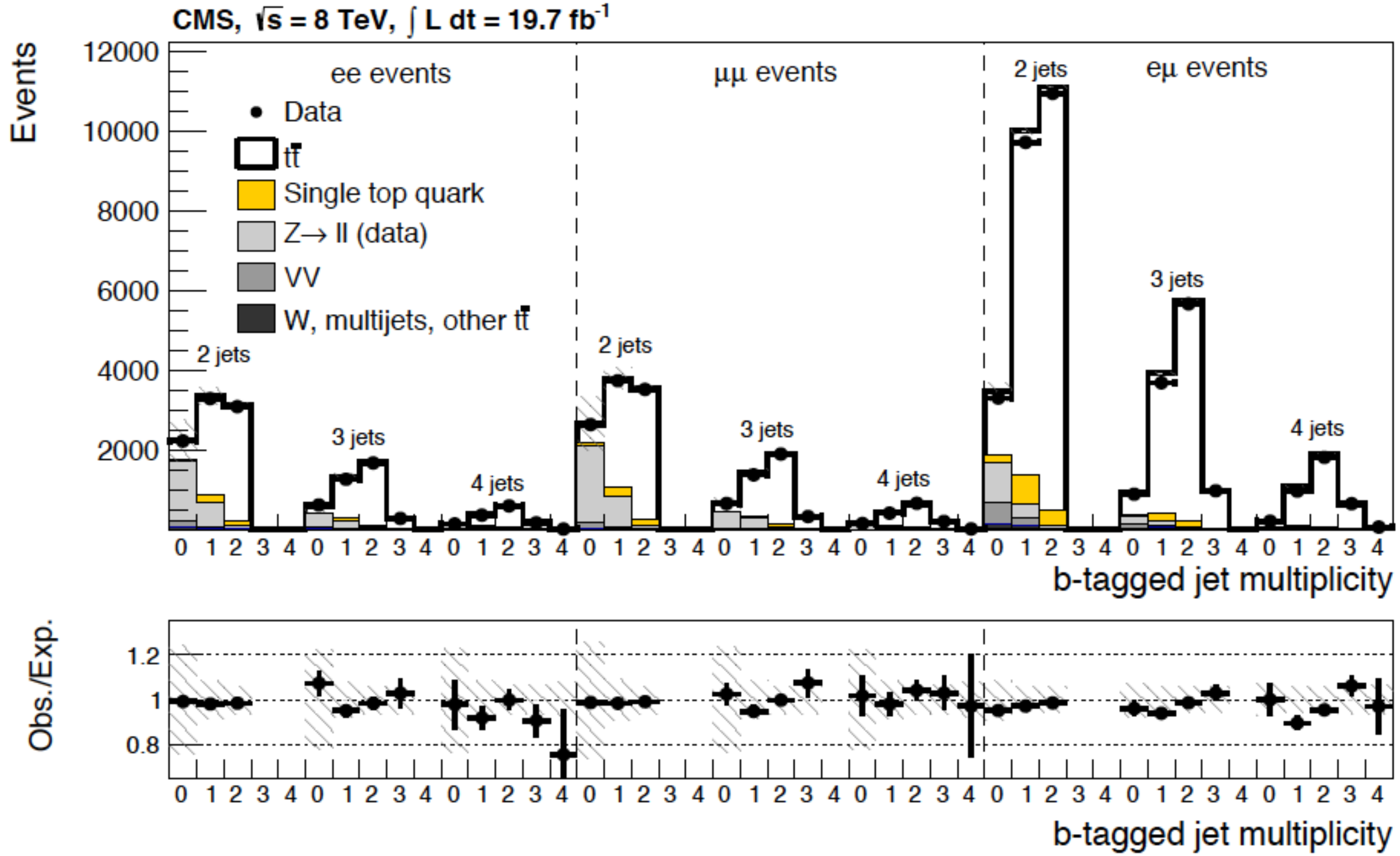






TESTING TOP DECAYS

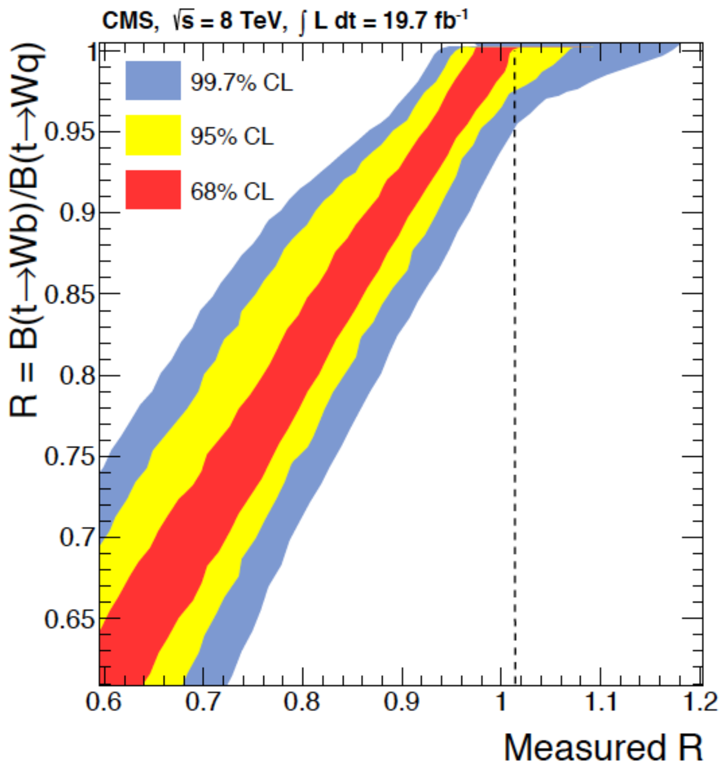
Measurement of the ratio R=B(t → Wb) / B(t → Wq)

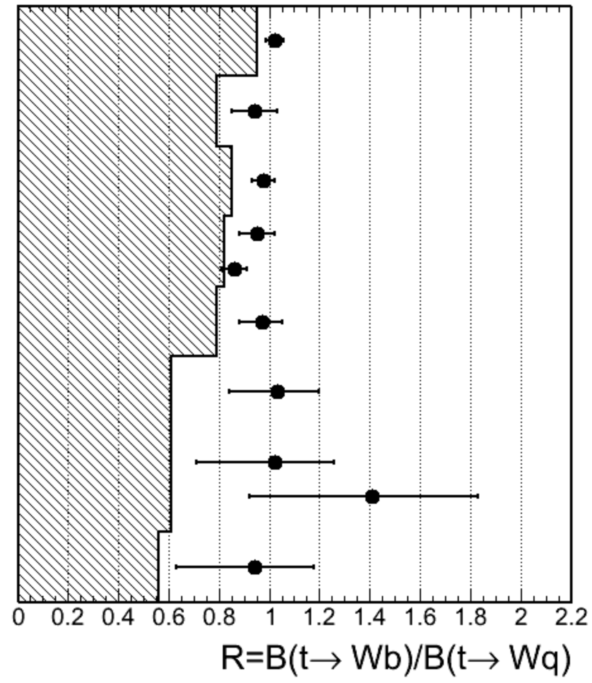


CMS TOP-12-035 – arXiv:1404.2292

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

A lower limit R>0.955 at 95% CL is obtained after requiring that R≤1





CMS TOP-12-035

Interpretation of R in terms of $|V_{tb}|$ and top width

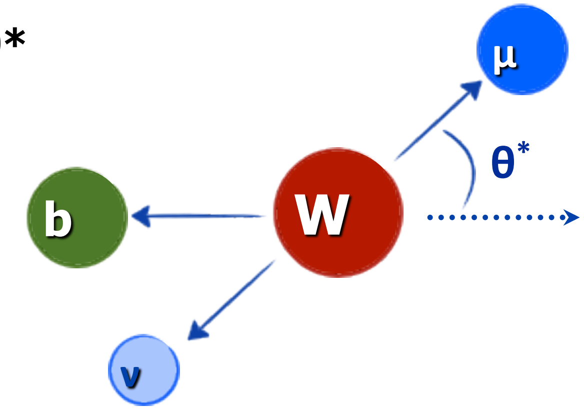
- assuming the unitarity of the three-generation CKM matrix $R=|V_{tb}|^2$ leading to $|V_{tb}| > 0.975$ at 95% CL
- combined with a measurement of the single-top-quark production cross section in the t-channel R yields an indirect determination of the top-quark total width $\Gamma_t = 1.36 \pm 0.02\,(\text{stat})^{+0.14}_{-0.11}\,(\text{syst})\,\text{GeV}$

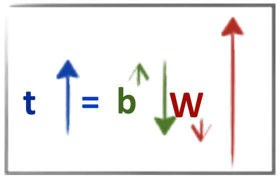
$$\Gamma_t = \frac{\sigma_{t\text{-ch.}}}{\mathcal{B}(t \to Wb)} \cdot \frac{\Gamma(t \to Wb)}{\sigma_{t\text{-ch.}}^{\text{theor.}}}$$

W helicity in top decays

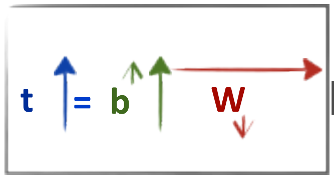
V-A SM nature of the tWb coupling can be probed using θ*

- 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 $g_R = g_L = V_R = 0$

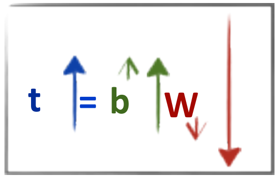




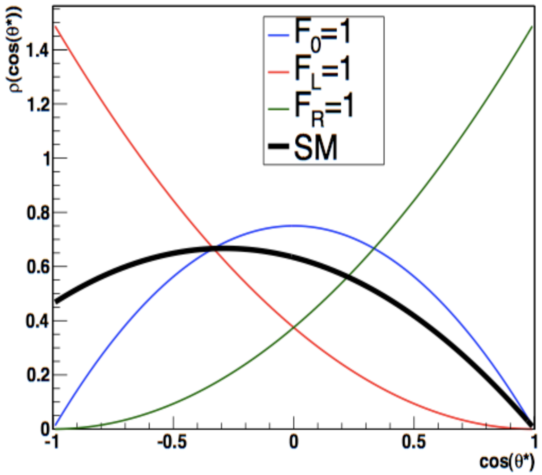
F_L [SM≃0.311]



F_0 [SM≃0.687]

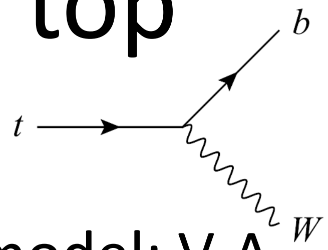


F_R [SM≃0.001]

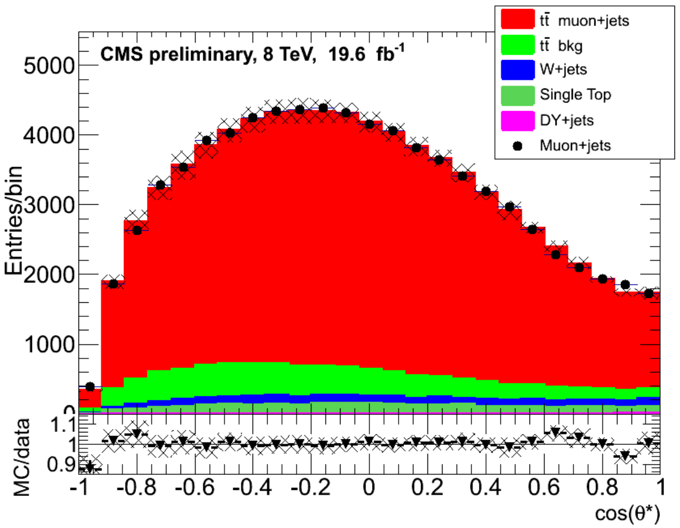


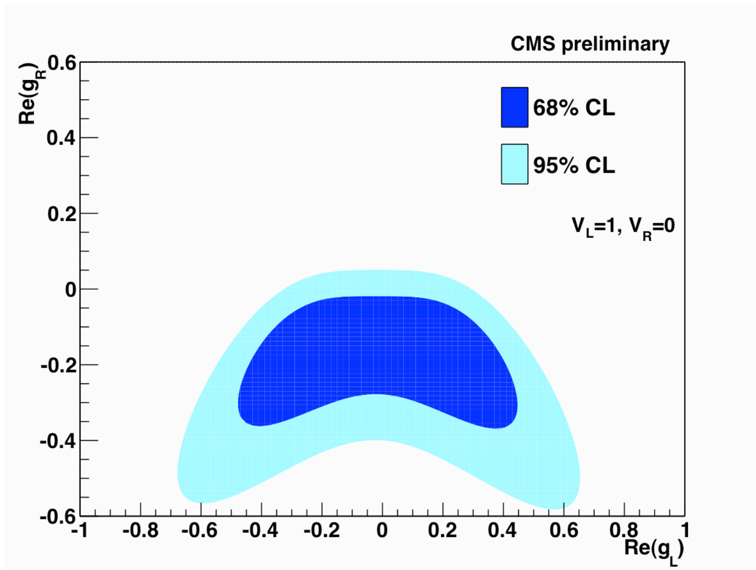
$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*} = \frac{3}{4}(1-\cos^2\theta^*)F_0 + \frac{3}{8}(1-\cos\theta^*)^2 F_L + \frac{3}{8}(1+\cos\theta^*)^2 F_R$$

The tWb vertex : W helicity in top decays



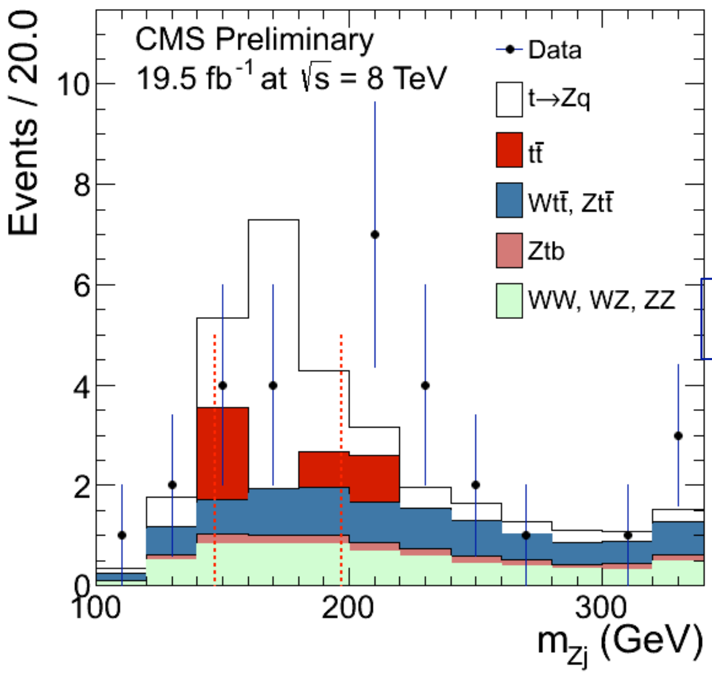
- The W helicity precisely predicted in the standard model: V-A structure of the decay
  - Longitudinal W polarization F0 ≈ 70%, **intimately related to the ewk breaking mechanism !**
  - Left polarization FL≈30%, Right pol FR ≈0



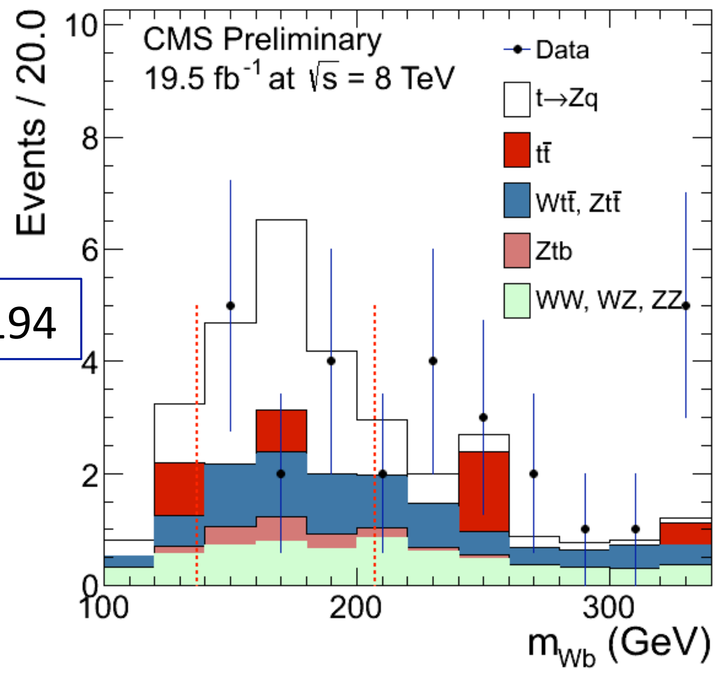


Rare top decays: limits on FCNC t→Zq, t→Hq

- FCNC searches requires statistics, promising for Run 2 and HL-LHC
  - Current result from ttbar/trilepton searches: **A t → Zq branching fraction greater than 0.07 % is excluded at the 95 % confidence level.**



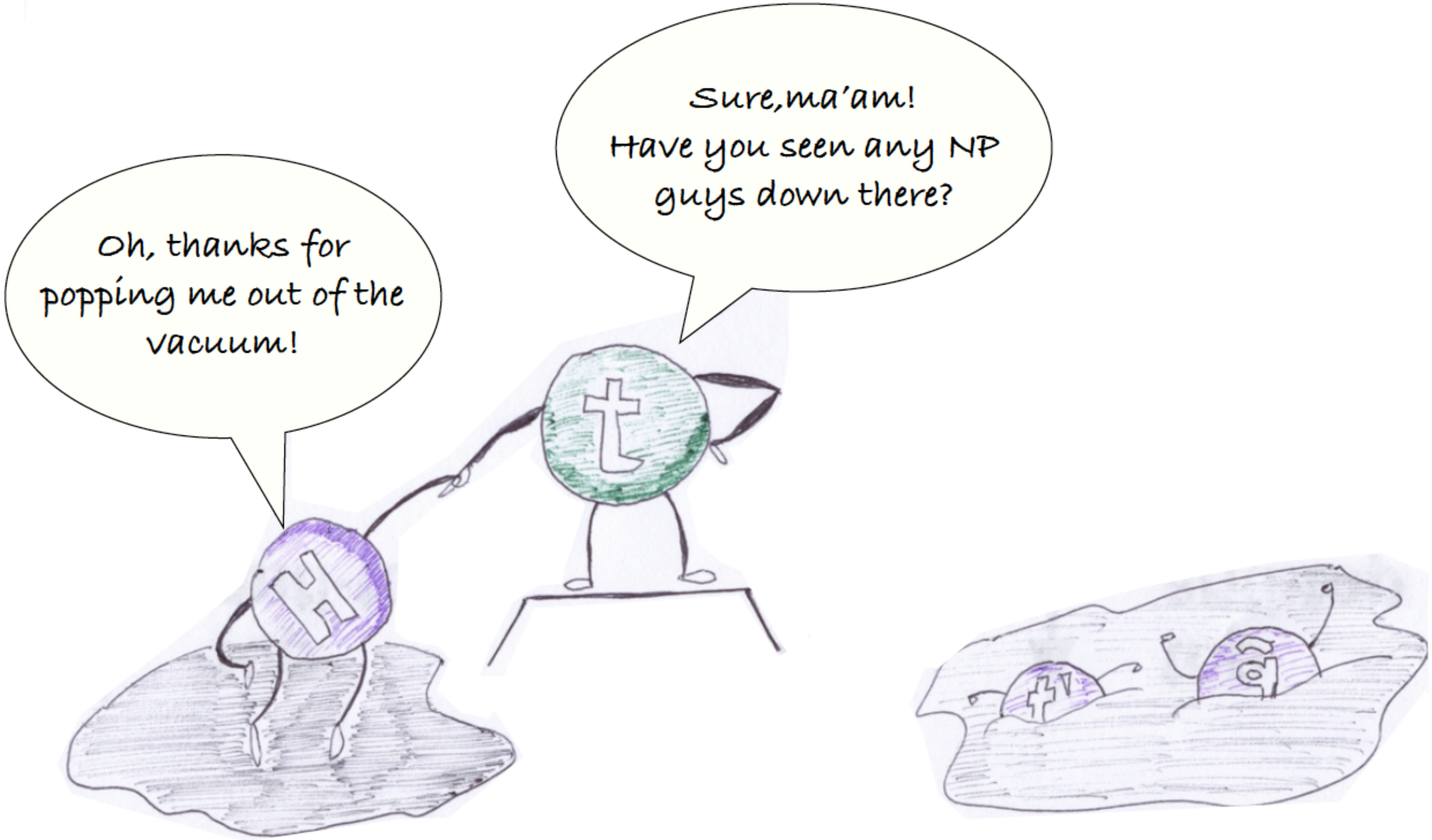
arXiv:1312.4194



  - Search **for t→Hc(u) decays with in the H→γγ channel gives 0.47(0.42)% at the 95% confidence level** [TOP-14-019]

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