Recent Top Quark Production Results

Harvest of LHC Run I and first measurements at 13 TeV

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LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

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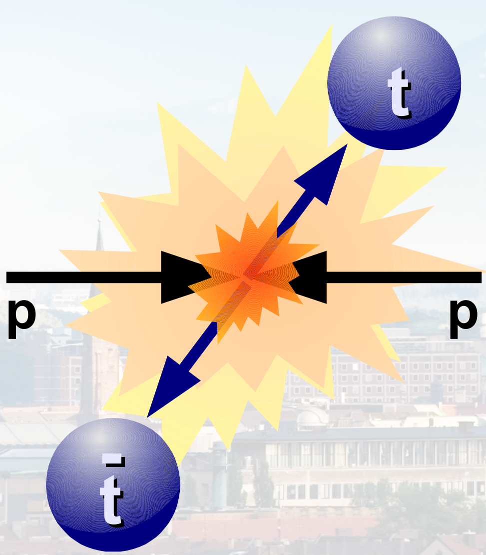
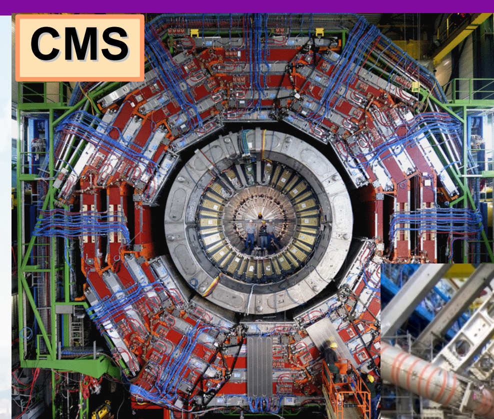
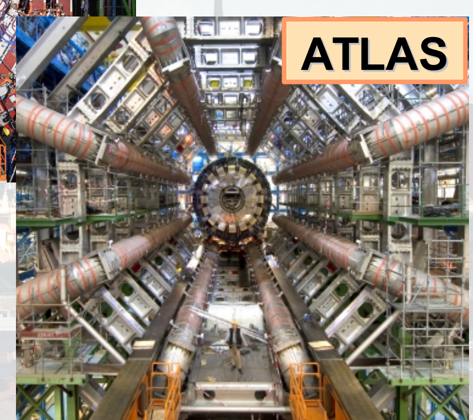
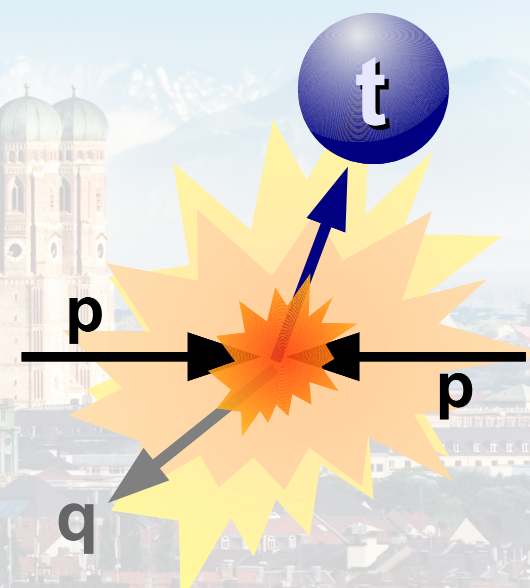


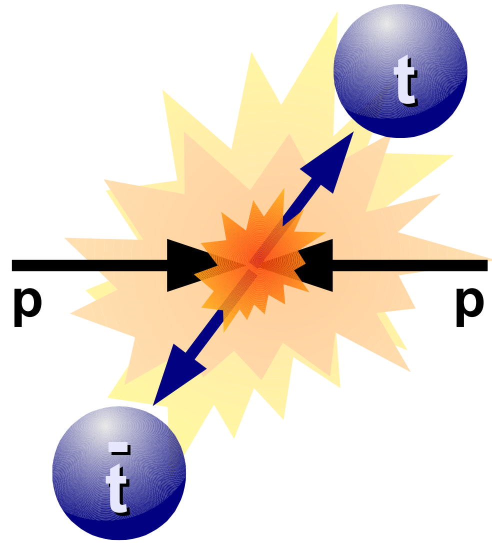


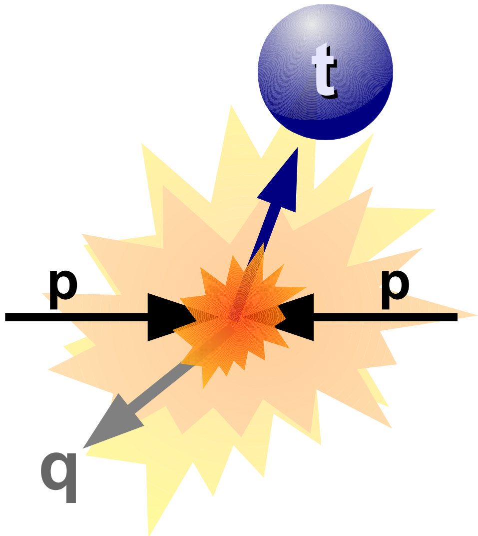




Outline

- **Introduction**
- Recent results on top quark pair production
- Recent results on single top quark production

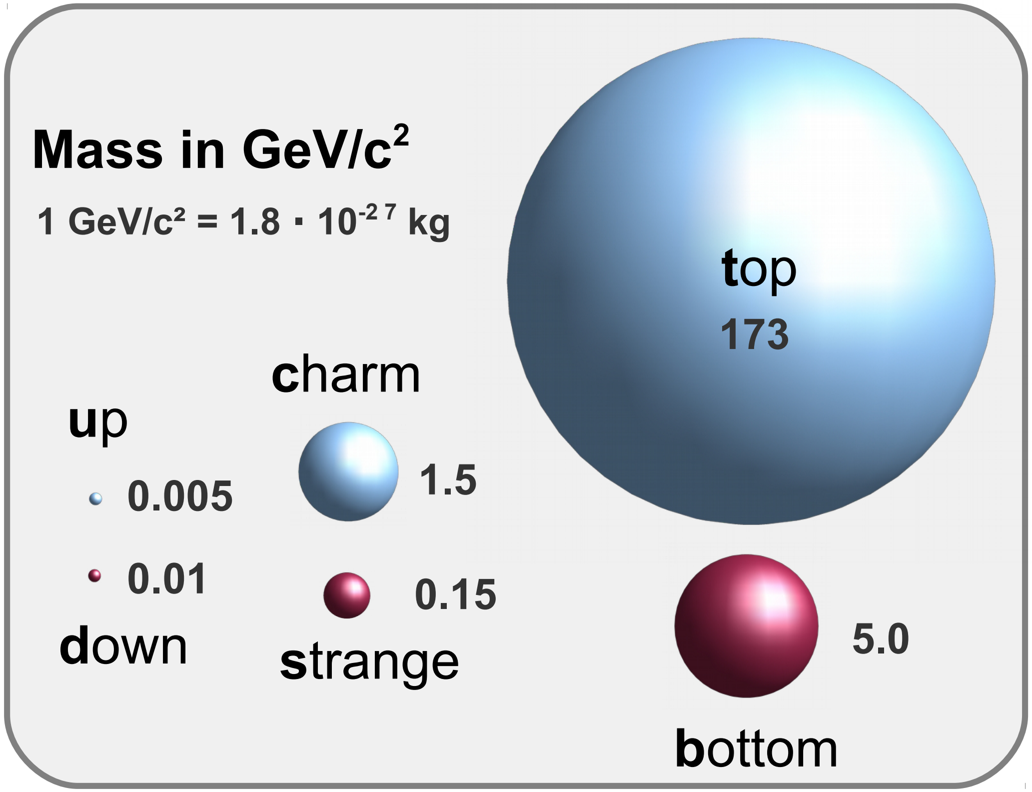




Top Quark

- By far the heaviest quark
  → it decays before it can hadronize
  → investigation of a bare quark

- Large coupling to the Higgs boson
  → top plays an important role in the SM



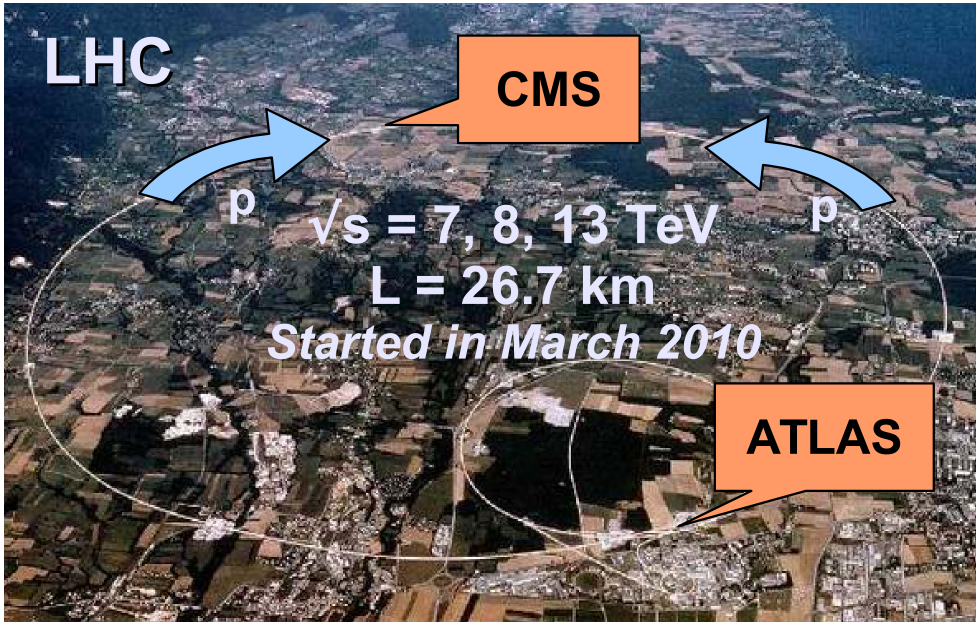
Open questions of SM:

- Dark matter and dark energy
- Matter antimatter asymmetry
- Unification of forces

Expect SM to be a low-energy approximation of a more general theory

Top quark plays an important role in many BSM models

LHC Accelerator



LHC:

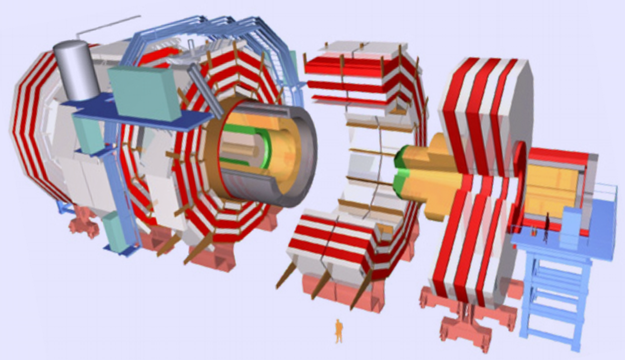
Run I started in spring 2010
2010 and 2011: $\sqrt{s}$ = 7 TeV
2012: $\sqrt{s}$ = 8 TeV

Run II started in spring 2015
with $\sqrt{s}$ = 13 TeV

	LHC Run I	LHC Run II
Delivered luminosity	~ 23 fb^{-1}	~2.6 fb^{-1}
Max. inst. luminosity	~$7.7 \cdot 10^{33}$ $cm^{-2}s^{-1}$	~$4.6 \cdot 10^{33}$ $cm^{-2}s^{-1}$
Luminosity on tape	~ 22 fb^{-1}	~2.4 fb^{-1}
Luminosity used in analyses	~ 20 fb^{-1}	~0.4 fb^{-1}
	2012 data taking period	*October 2015*

Detectors

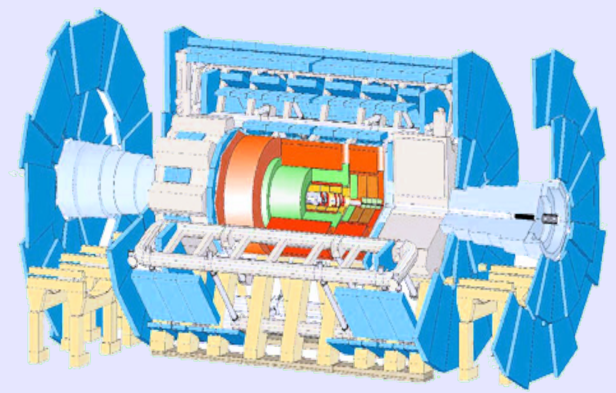
CMS



Length: 22 m
Height: 15 m
Weight: 14 kt

B-field: 3.8 T (solenoid)

ATLAS



Length: 46 m
Height: 25 m
Weight: 7 kt

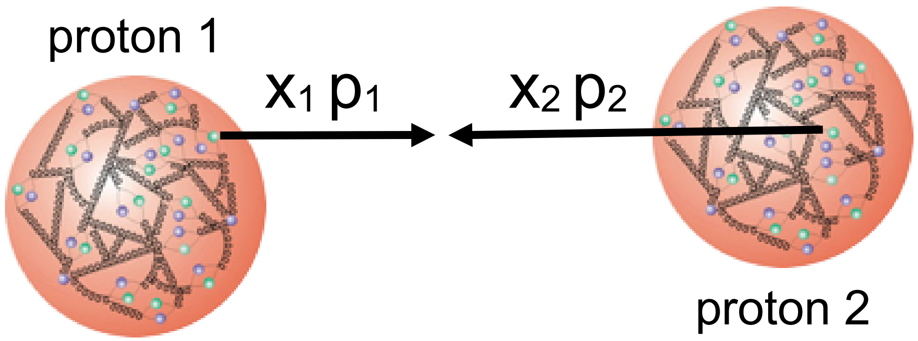
B-field: 4T *(toroidal)*

- Excellent momentum and vertex resolution *(~200 m^2 silicon sensors)*
- Good EM calorimeter resolution

- Very good momentum resolution
- Excellent hadron cal. resolution

Hadron Collider

Highest energies achievable with hadron colliders



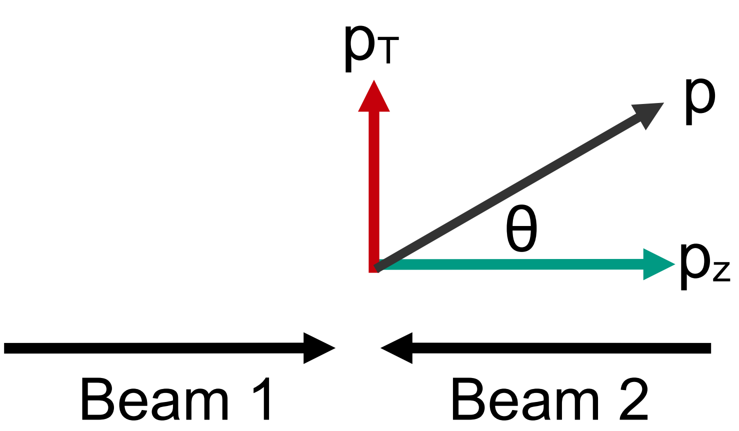
Hadron collisions = collisions of "broadband" parton beams

Longitudinal momentum fractions x_i unknown → partonic center of mass energy unknown

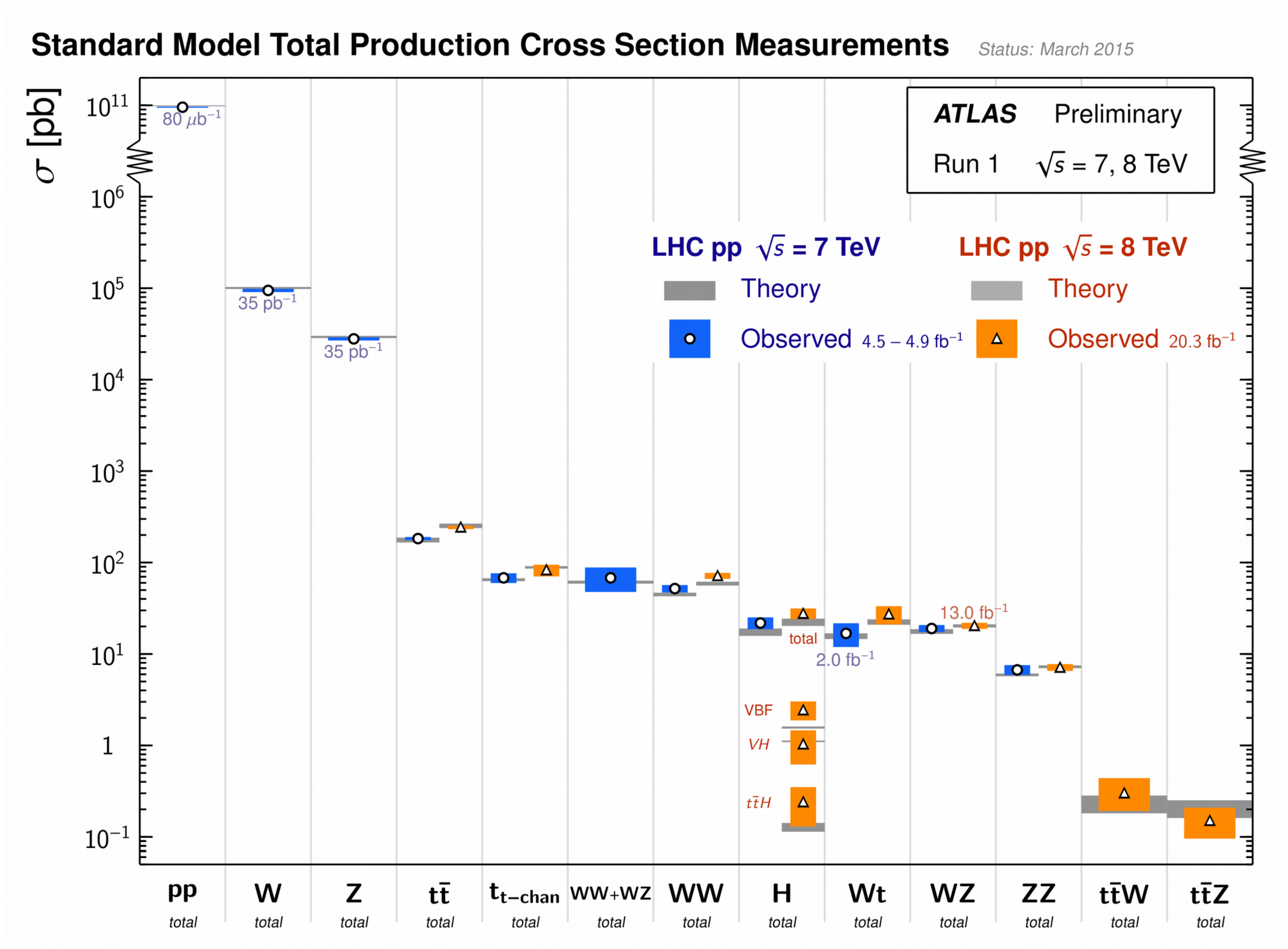
Consequence: use only Lorentz invariant transverse quantities, e.g. transverse momentum $p_T = \sqrt{p_x^2 + p_y^2} = p \sin\theta$

Instead of polar angle use pseudorapidity

$\eta = -\ln\left(\tan\frac{\theta}{2}\right)$ or Lorentz invariant rapidity $y = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$



Top quark production rate



	LHC 8TeV
pp incl.	~90 per μs
W boson	~100 per s
Top pairs	15 per min
Single top (t-chan)	5 per min
Higgs	(1-2) per min

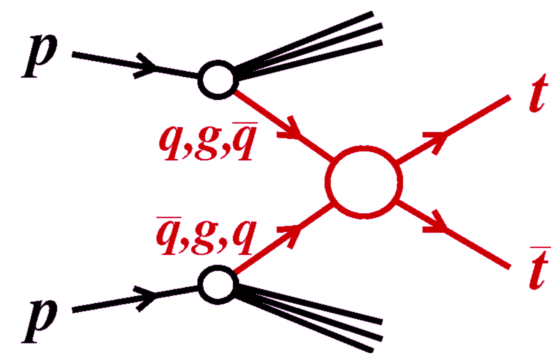
2012 data taking period

LHC: ~ 5,000,000 top pairs (2012, 8TeV, about $20 fb^{-1}$)

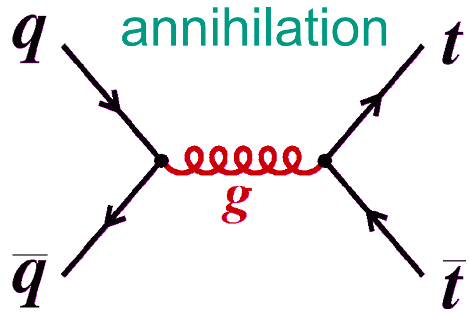
LHC is a top quark factory !

Top quark pair production

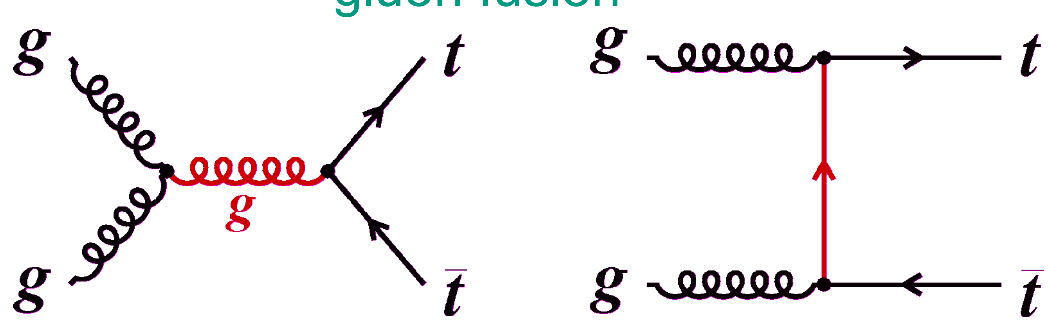
- Top quark pair production via strong interaction (dominant process)
- Electroweak production of single top quarks (factor 2-3 smaller than pair prod.)



quark-antiquark annihilation



gluon fusion



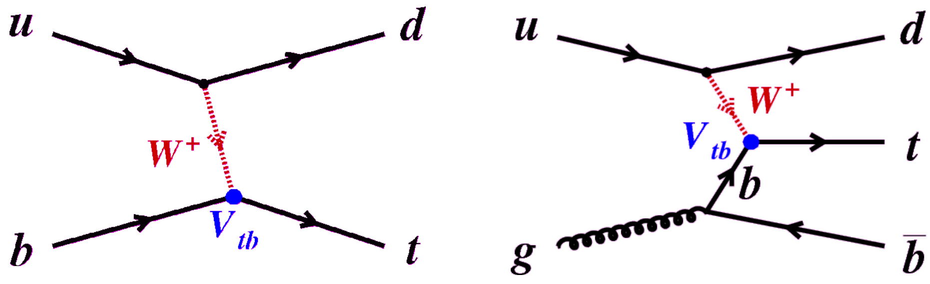
(+ u-channel)

	Tevatron	LHC 7TeV	LHC 8TeV	LHC 14 TeV
Cross section	7.2 pb	172 pb	246 pb	954 pb
Gluon fusion	~15%	~80%	≥80%	~90%

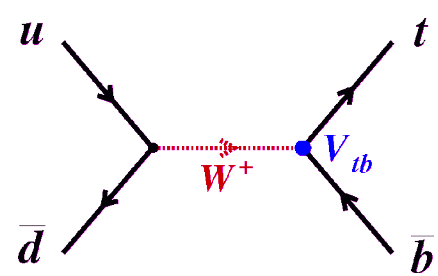
NNLO+NNLL:
PRL 110, 252004 (2013)

Single top quark production

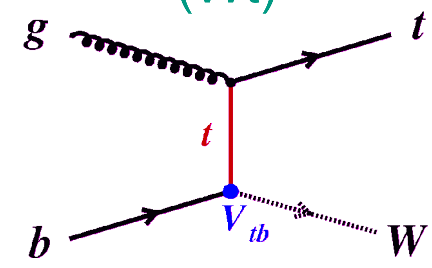
t-channel



s-channel



associated production (Wt)

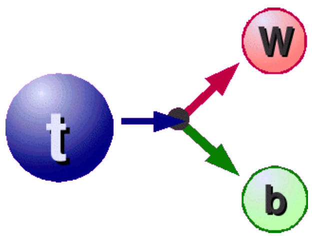


- Electroweak production mode of top quarks
- t-channel most abundant production mode for single top quarks
- Direct measurement of $|V_{tb}|^2$

	Tevatron [pb] $\sqrt{s}$=1.96 TeV	LHC [pb] $\sqrt{s}$=7 TeV	LHC [pb] $\sqrt{s}$=8 TeV	LHC [pb] $\sqrt{s}$=14 TeV
s-channel	1.0	5	6	12
t-channel	2.1	66	87	243
Wt	0.26 *)	16	22	84

Approximate NNLO (based on threshold resummation at NNLL accuracy): PRD 83, 091503 (2011); PRD 81, 054028 (2010); PRD 82, 054018 (2010); arXiv:1210.7813
*) Approximate NNLO (based on threshold resummation at NLL accuracy): PRD 74, 114012 (2006)

Top Quark Decay Channels

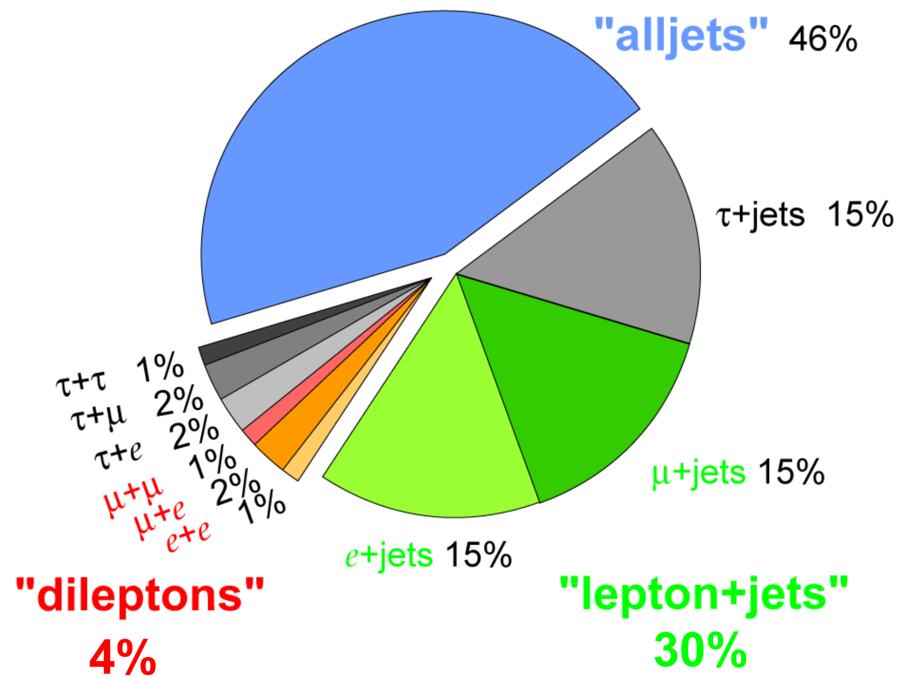


SM:

t → b W ≈ 100 %

W → e/μ/τ ν ≈ 10 %

W → hadronisch ≈ 70 %



t- and s-channel single top:

- Decay of 1 W-boson
- Most analyses use the "leptonic" decays W → eν and W → μν (~20%)

$t\bar{t}$ and Wt:

- Decay channels classified according to the decay of the two W-bosons
- Most $t\bar{t}$ properties analyses use the "lepton+jets" channel
- Most Wt analyses use the dilepton channel

$t\bar{t}$: "lepton+jets"-channel:

(e+jets and μ+jets)

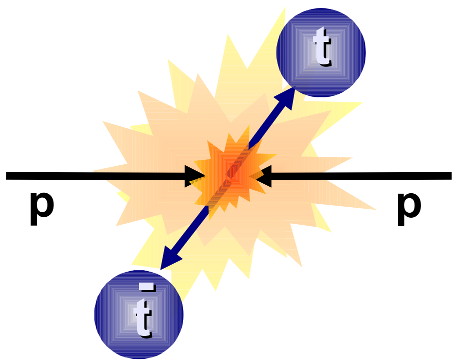
- Moderate background
- Relative high branching ratio (~30%)

Survey of top quark

1995: Discovery of the top quark by both Tevatron experiments CDF and D0

Since then the top quark has been studied widly ...

Production:

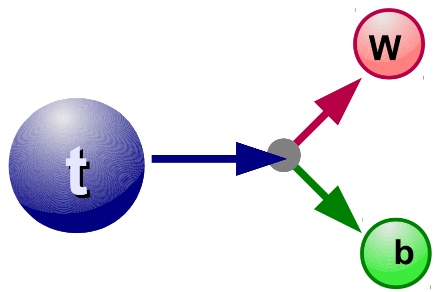


- Production rate of different processes *(strong and EW)*
- Differential distributions
- New production mechanisms

Intrinsic properties:

- Top quark mass →constraints on Higgs mass
- Charge
- Lifetime

Decay:



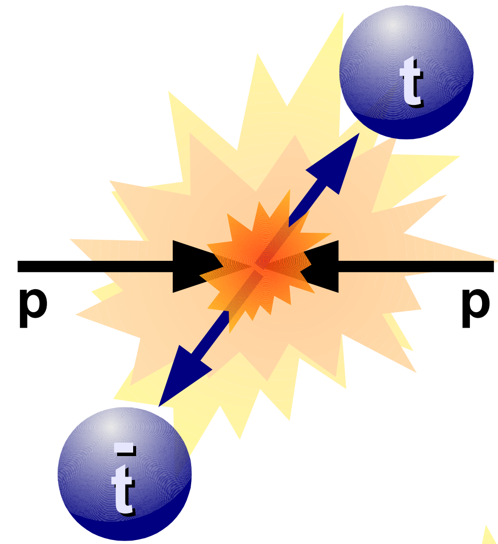
- Decay channels *(SM and new)*
- Couplings

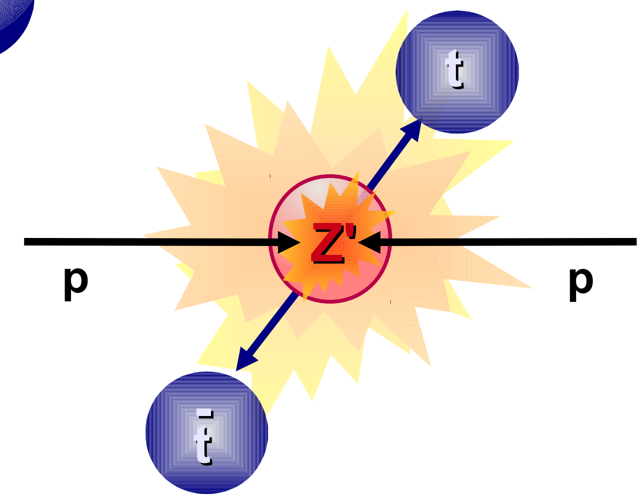
Outline

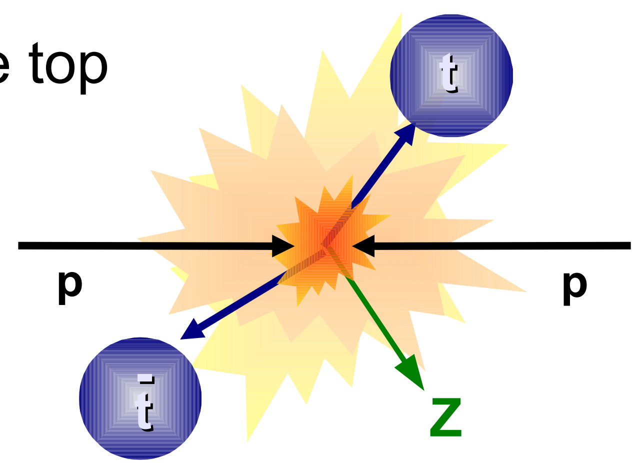
- Introduction

- **Recent results on top quark pair production:**
  - Top quark pair cross section
  - Charge asymmetry
  - Search for resonant production
  - $t\bar{t}V$ cross section

- Recent results on single top quark production

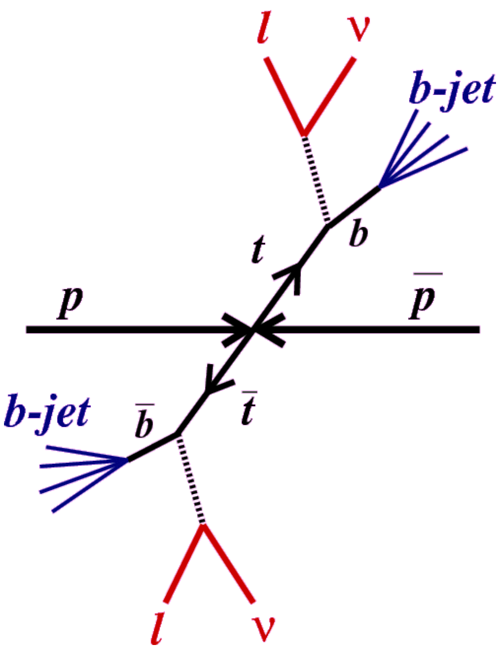




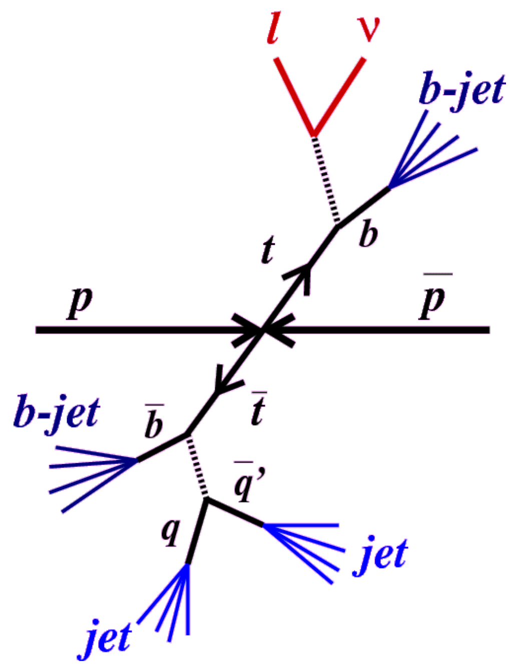


Top pair event signatures

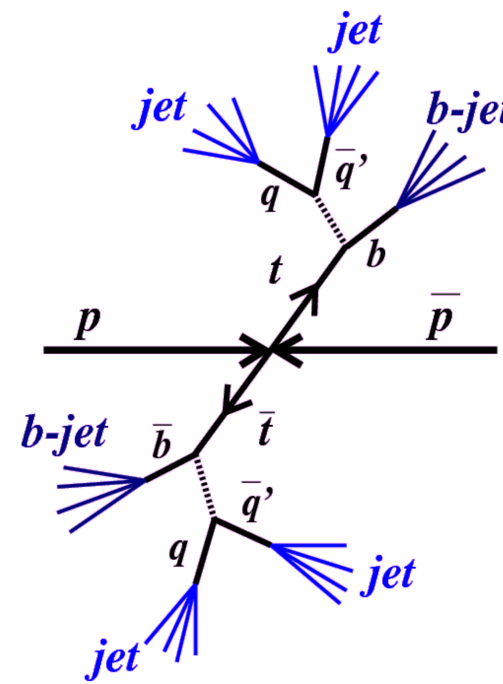
Dilepton



Lepton+jets

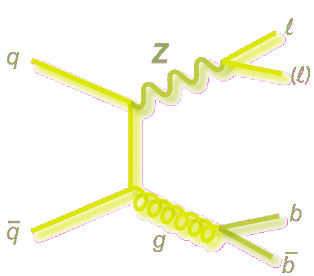


All hadronic

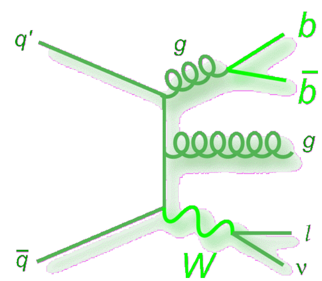


BR: ≈ 5 % | ≈ 30 % | ≈ 44 %

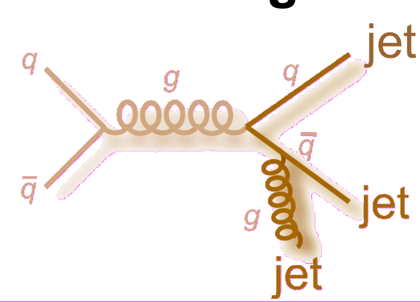
BG: few | moderate | huge



Mainly Z+jets



Mainly W+jets

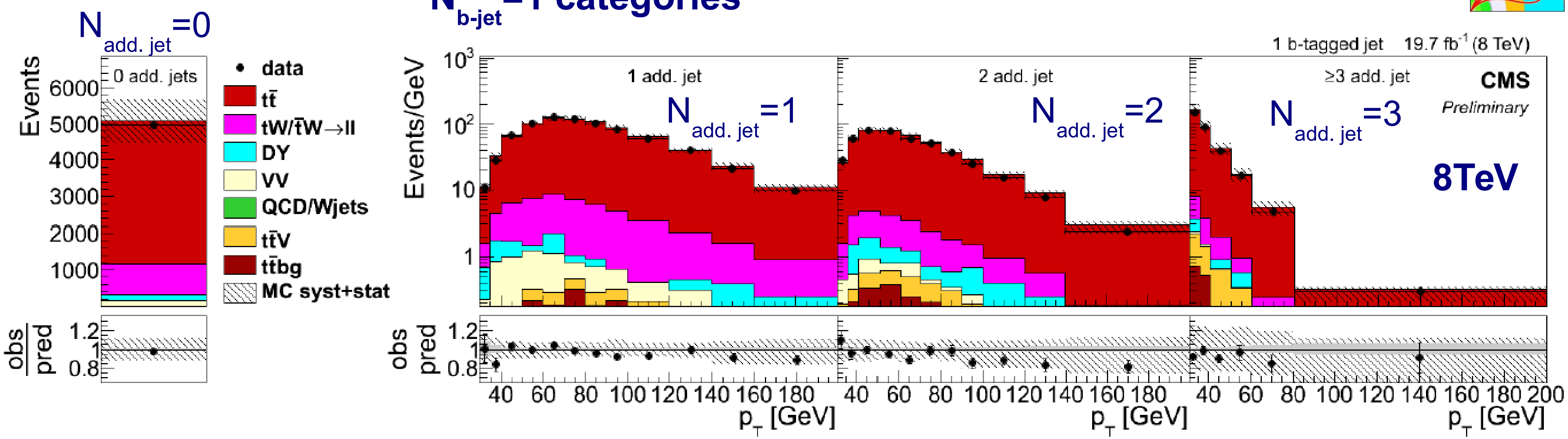


Mainly multijets

Recent top quark pair cross section measurement in the eμ channel from CMS

CMS PAS TOP-13-004

$N_{b\text{-jet}}$=1 categories



- Select events with opposite charged eμ pairs and categorize events in 12 classes according to $N_{b\text{-jets}}$ = 0,1,2 and $N_{\text{add. jets}}$ = 0,1,2,3 *(add. jets: non b-jets)*
- Perform binned likelihood fit to event number ($N_{\text{add. Jets}}$=0) and to p_T of the least energetic add. jet ($N_{\text{add. Jets}}$>0) in these 12 classes
- Constrain systematic uncertainties insitu with likelihood fit

Result:

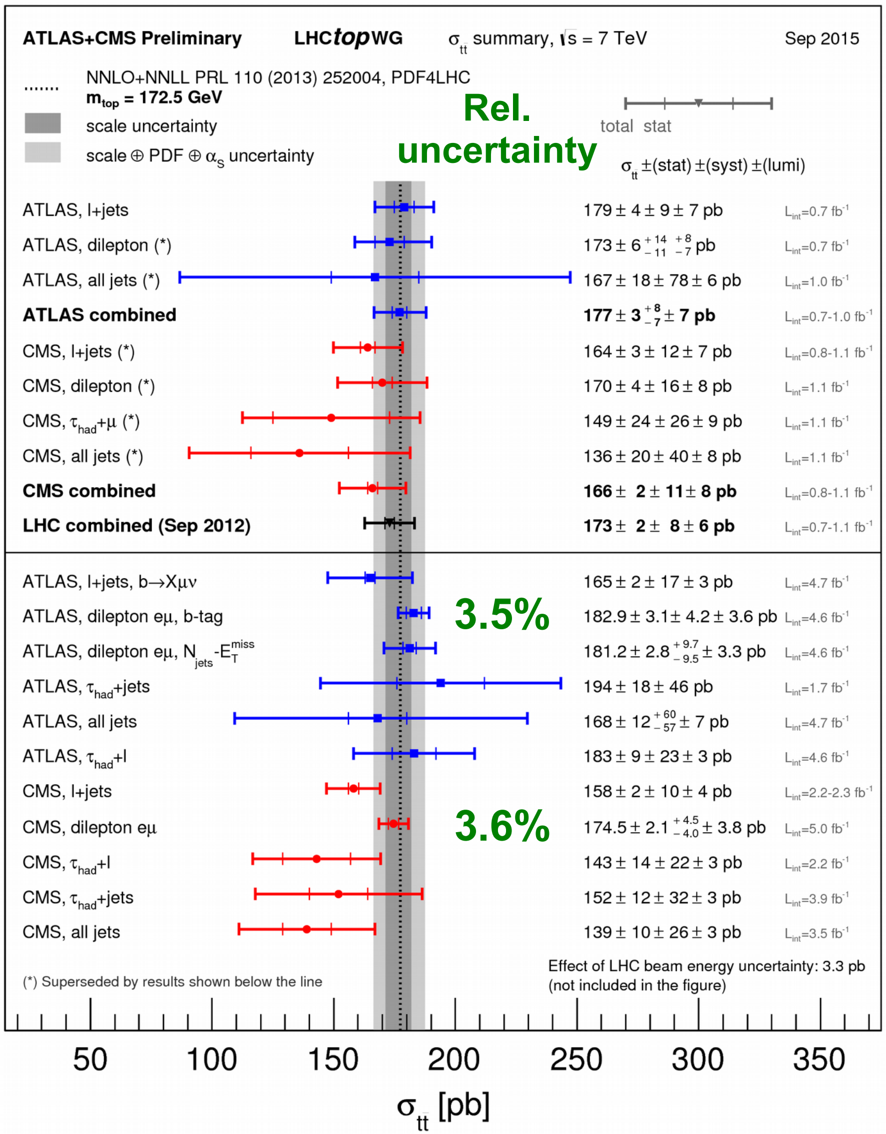
$$\sigma_{t\bar{t}} = 174.5 \pm 2.1\,(\text{stat}) \pm^{4.5}_{4.0}\,(\text{syst}) \pm 3.8\,(\text{lumi})\,\text{pb} \quad \text{at } \sqrt{s} = 7\,\text{TeV}$$

$$\sigma_{t\bar{t}} = 245.6 \pm 1.3\,(\text{stat}) \pm^{6.6}_{5.5}\,(\text{syst}) \pm 6.5\,(\text{lumi})\,\text{pb} \quad \text{at } \sqrt{s} = 8\,\text{TeV}$$

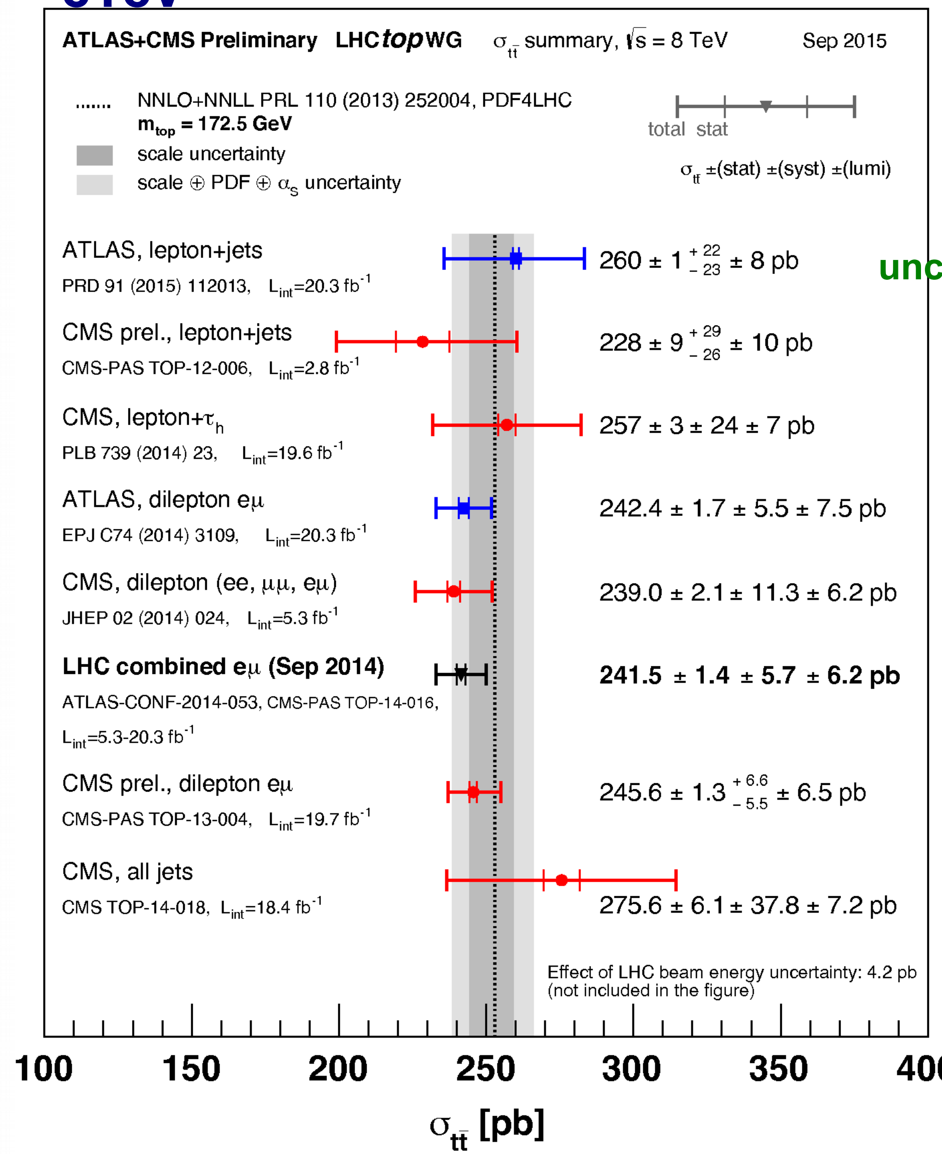
Relative uncertainty: < 4% ; good agreement with SM theory prediction

Summary of LHC Run I $t\bar{t}$ cross section measurements

7TeV



8TeV



Rel. uncertainty

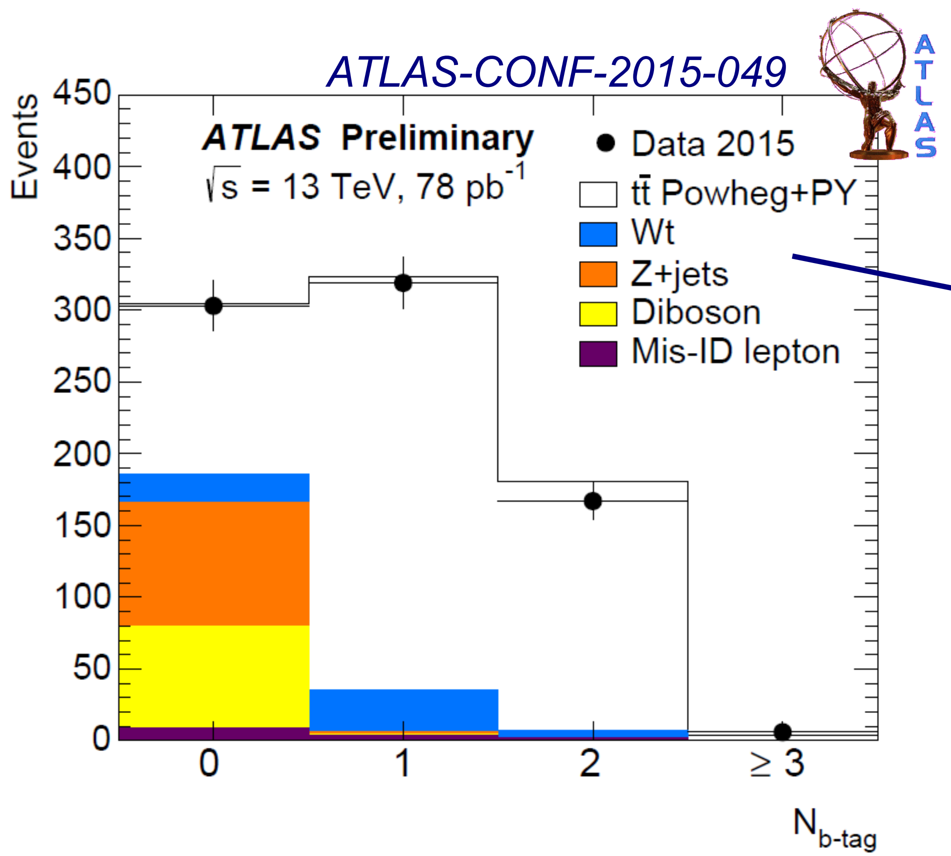
3.9%

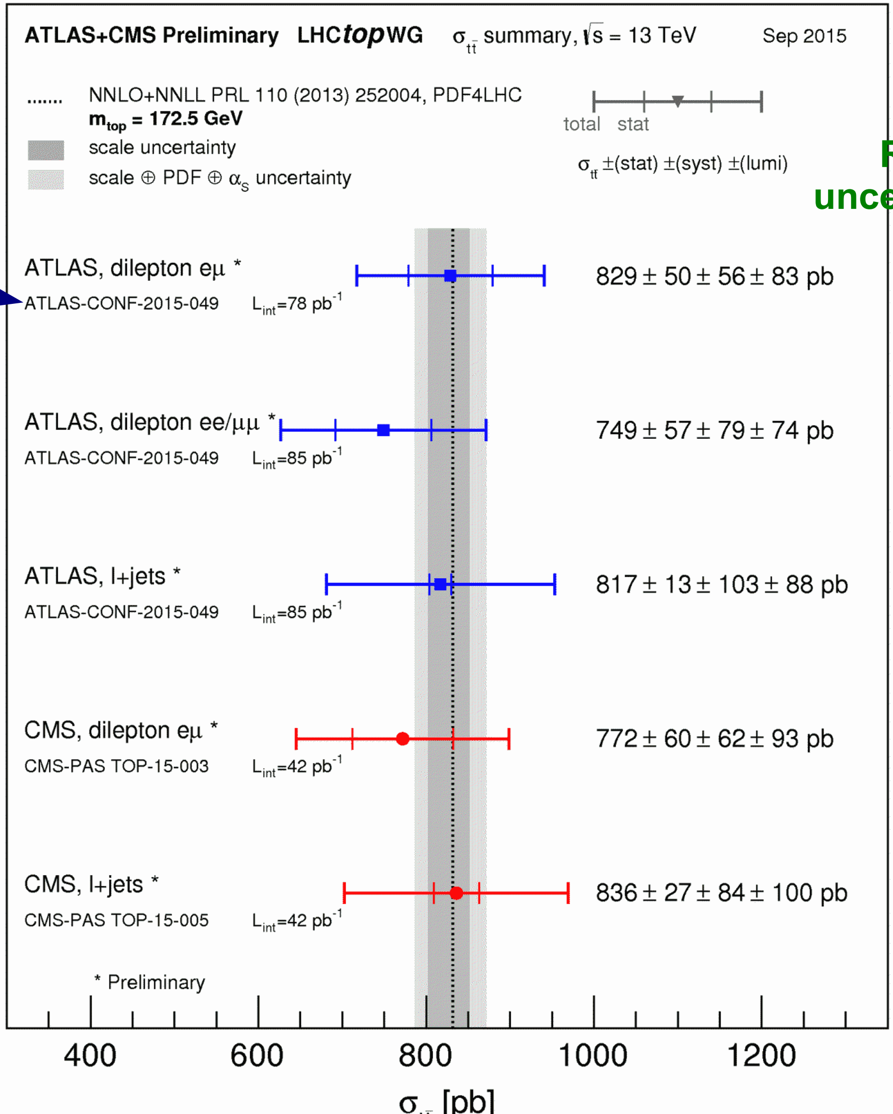
3.5%

3.8%

Measurements in different channels are in good with each other and with SM pred.
Relative uncertainty of most precise measurements (eμ) < 4%

Top quark pair cross section measurements at 13 TeV





Rel. uncertainty

13.5%

15.3%

16.7%

16.4%

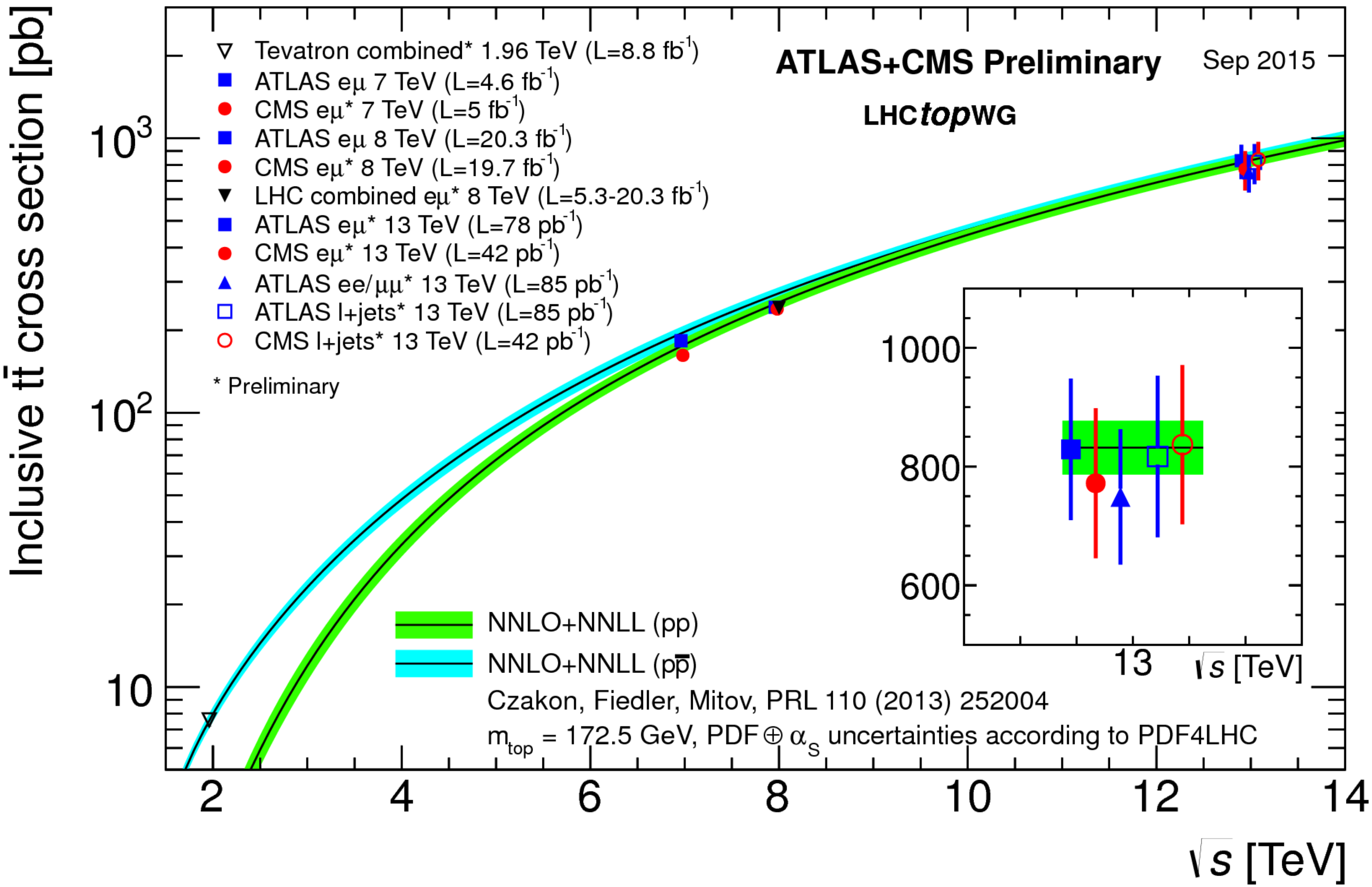
15.9%

- Counting experiment using opposite sign eμ pairs with 1 or 2 b-tags

First measurements are in good agreement with SM prediction

Rel. uncertainty of most precise measurement: <14%

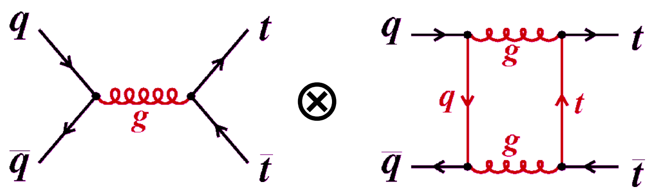
$t\bar{t}$ cross section - summary

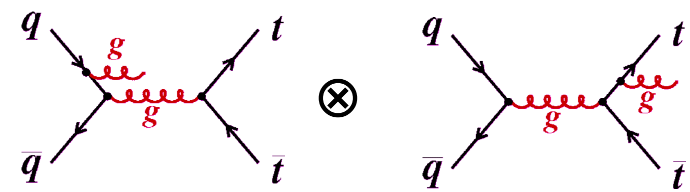


Total top pair cross section in good agreement with SM theory prediction

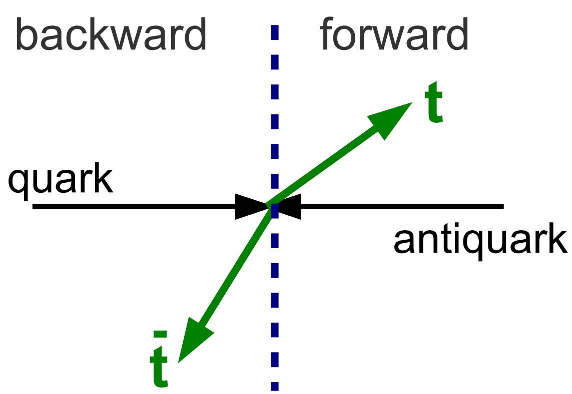
Charge Asymmetry in Top Quark Pair Production

SM: Small asymmetry caused by higher order interference effect, which occurs for asymmetric initial states only ($q\bar{q}$,qg)



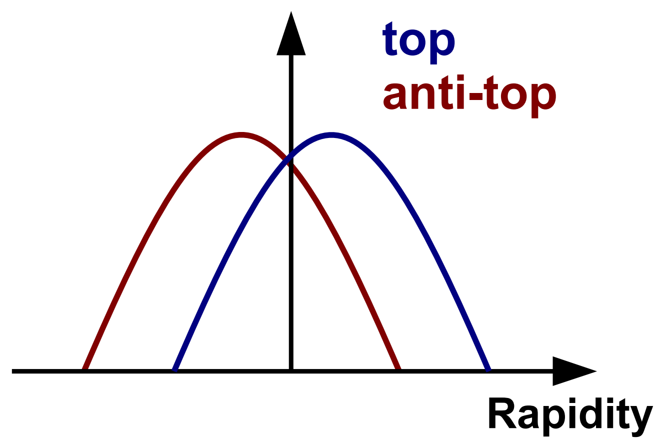


parton restframe



t (anti-t) are preferentially produced in q (anti-q) direction

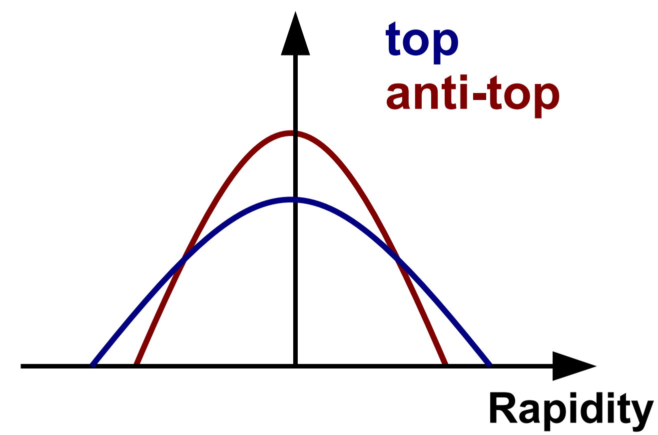
$p\bar{p}$ - Tevatron



q (anti-q) mostly from proton (antiproton)

→forward-backward asymmetry A_{FB}

pp - LHC

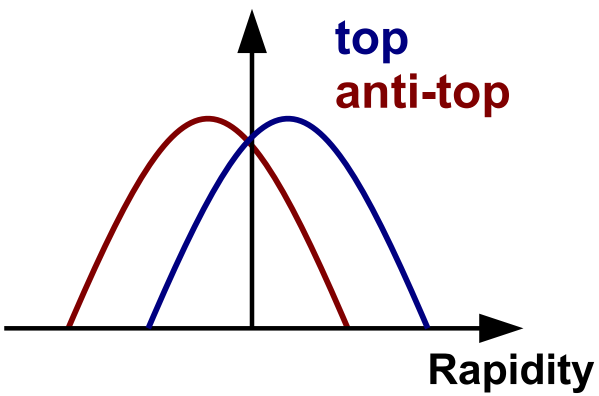


average quark momentum fraction $x_q > x_{anti-q}$

→ central-peripheral asymmetry A_C

SM Predictions for the Charge Asymmetry

$p\bar{p}$ – Tevatron:



Sensitive variables: rapidity in lab or in $t\bar{t}$-frame

Asym. in $t\bar{t}$-frame > Asym in lab-frame

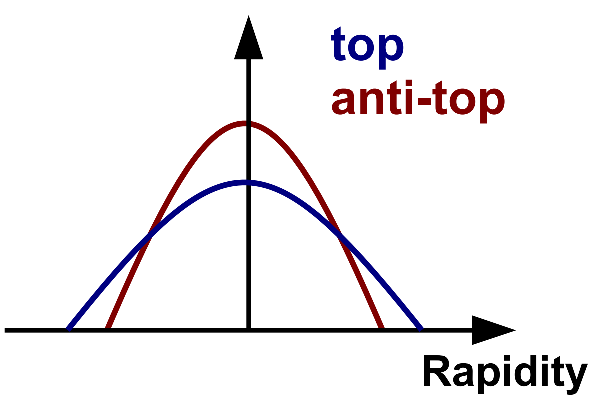
$t\bar{t}$-frame: $\Delta Y = y_t - y_{anti\text{-}t} = 2\, y_t^{tt}$

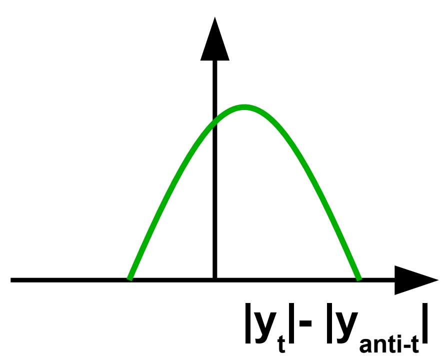
$A_{FB} \approx$ 8% (2007, NLO calc. with estimated EW cor.)

$\approx$ 9% (2011, NLO calc. with full EW cor.)

$\approx$ 10% (2014, NNLO calc. with full NLO EW cor.)

pp – LHC:



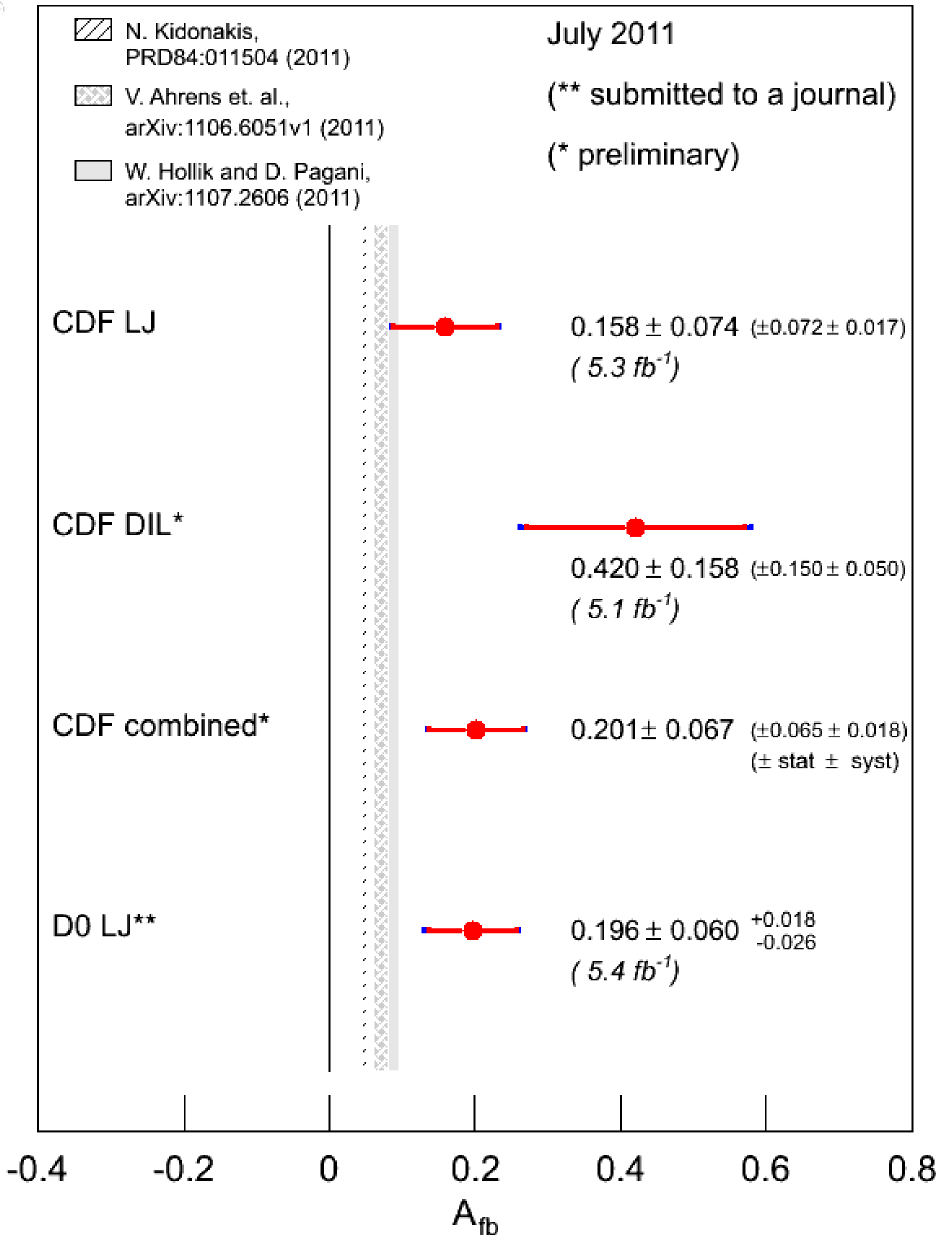


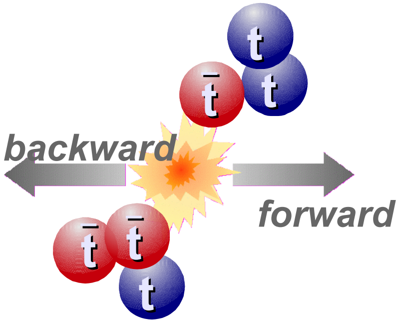
Sensitive variable:
Difference of the absolute values of the top and anti-top rapidities in the lab frame, $\Delta|y|=|y_t|- |y_{anti\text{-}t}|$

$A_C \approx$ 1.2%

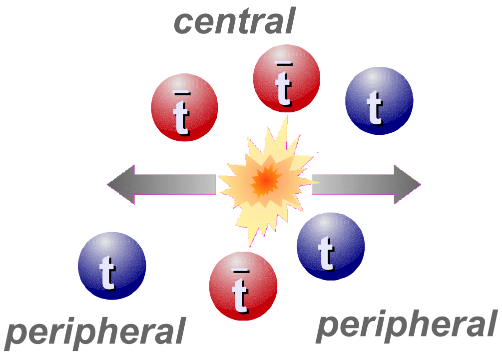
(2012, NLO calc. with full EW cor.)

Tevatron A_{FB} Saga





- In 2008, first measurements indicated a larger inclusive A_{FB} than predicted
- In 2011, both Tevatron experiments measure a larger inclusive A_{FB} than predicted by SM
- Leptonic asymmetry measured by D0 in the L+J channel is also larger than the SM prediction
  (3.3σ compared to MC@NLO)
- CDF measured a large asymmetry for M_{tt}>450GeV, but D0 not
  (3.4σ ?compared to MC@NLO)
- Observed deviation generated large number of theoretical BSM explanations



Measurement of A_C in lepton+jets channel

- Select events with 1 isolated central e/μ, ≥ 4 jets whereof at least one jet is b-tagged
- Reconstruction of $t\bar{t}$ kinematic;

  lepton charge determines the charge of semileptonically decaying t-quark:

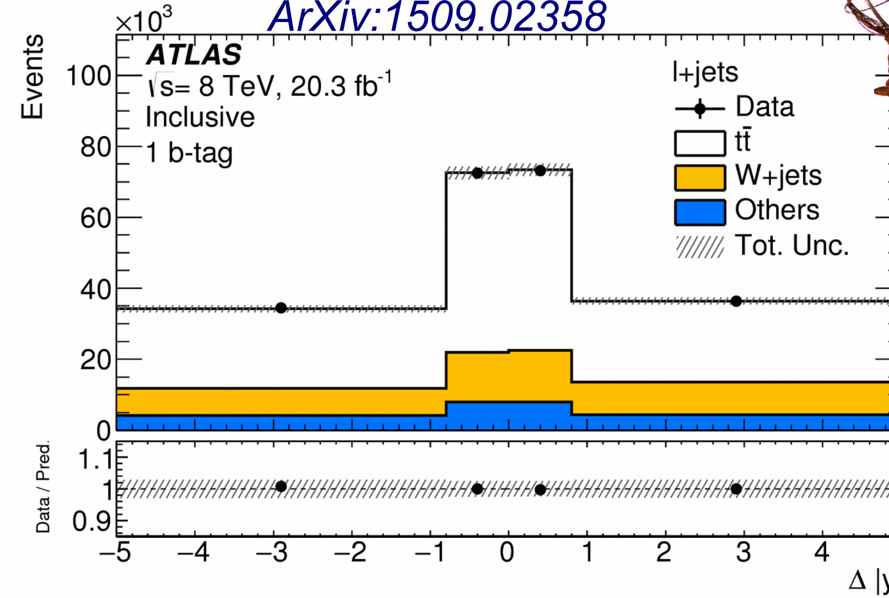
  $\Delta|y| = |y_t| - |y_{anti\text{-}t}| = Q_l \cdot (|y_{lep}| - |y_{had}|)$
- Perform unfolding to account for biases due to event selection and non-perfect reconstruction

Result: $A_C = 0.0010 \pm 0.0077$ (CMS)

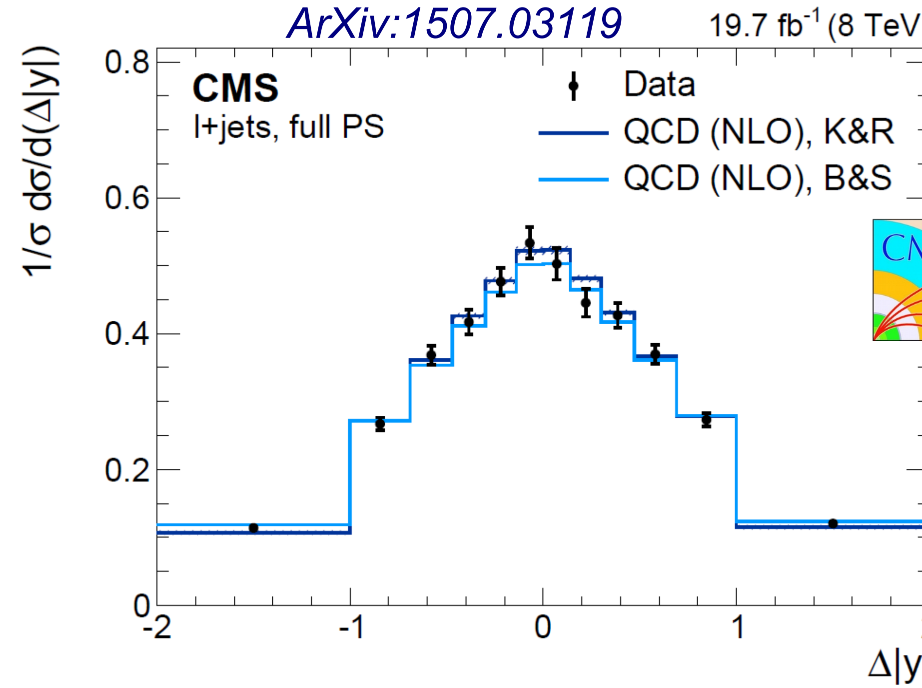
$A_C = 0.009 \pm 0.005$ (ATLAS)

Measurements are in good agreement with SM prediction

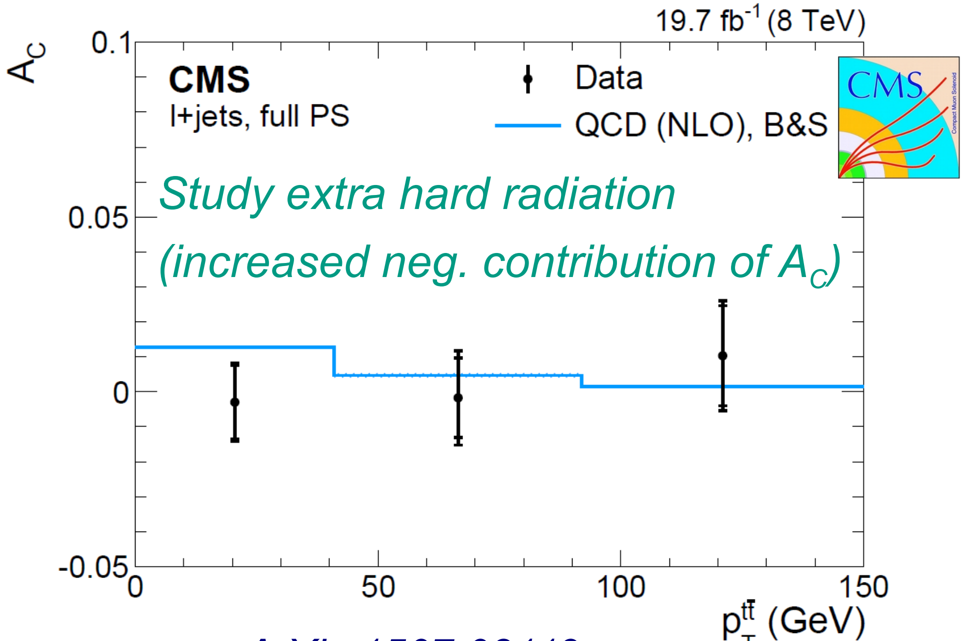
ArXiv:1509.02358



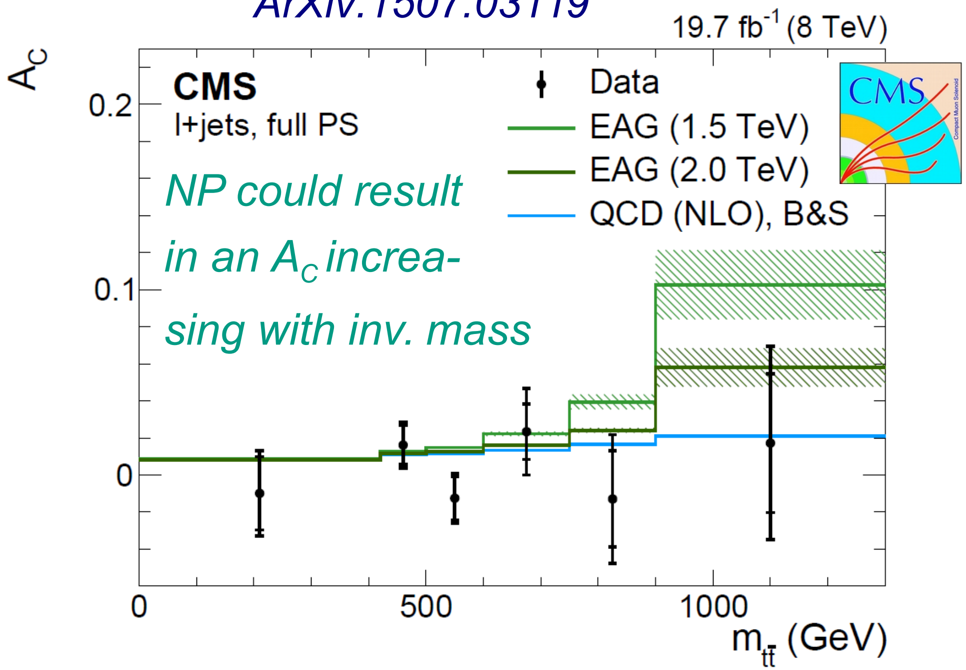
ArXiv:1507.03119



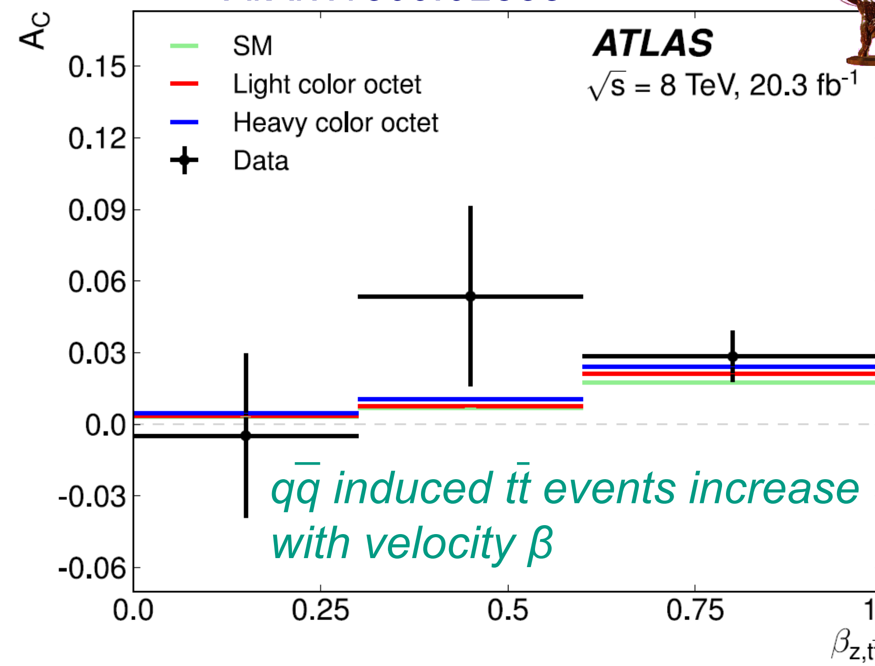
Differential A_C – Investigation of different aspects of A_C



ArXiv:1507.03119



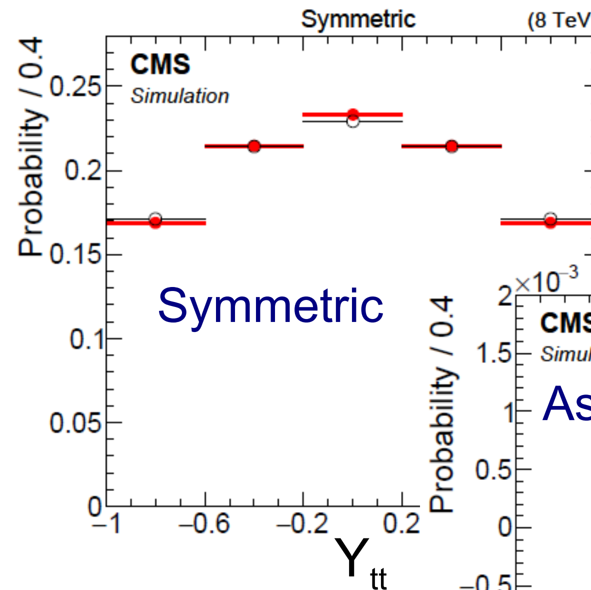
ArXiv:1509.02358



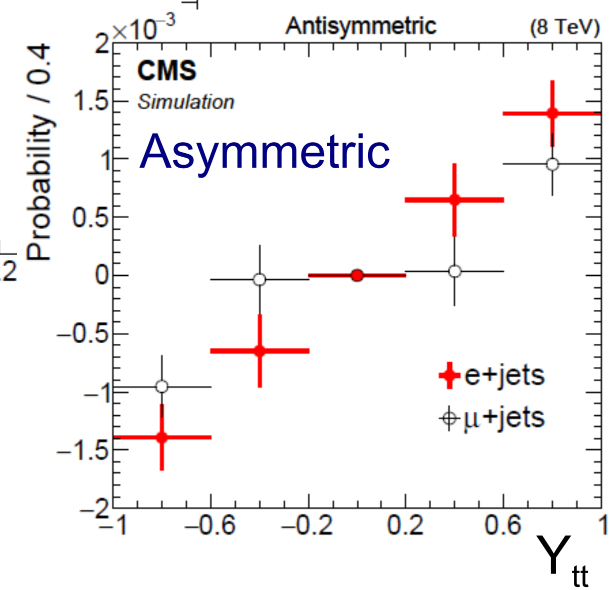
- Differential AC measurements at the LHC are in good agreement with SM predictions
- In particular there is no indication that there is a strong rise of A_C with the inv. mass (as seen by CDF)

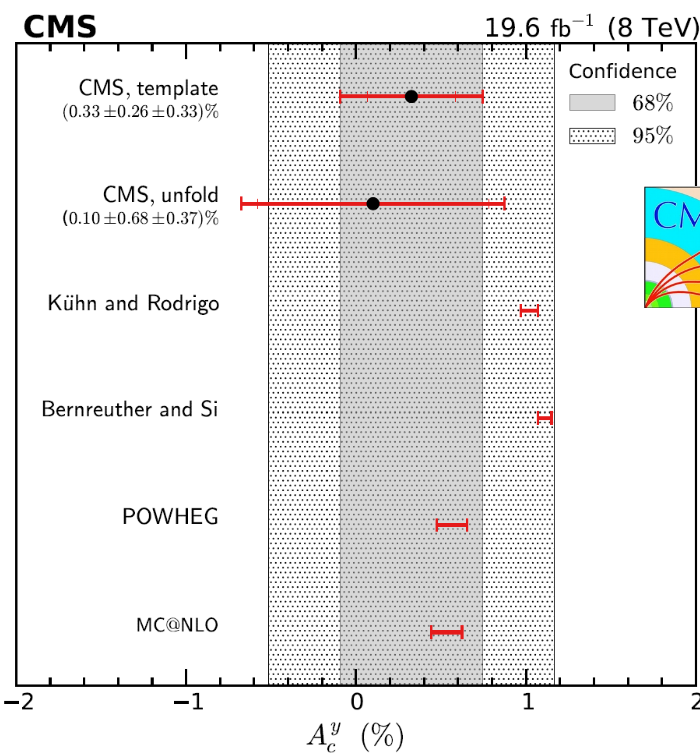
Inclusive charge asymmetry using the template method

- Fit symmetric and asymmetric $t\bar{t}$ templates to sensitive variable Y_{tt}=tanh(Δ|y|)
- Use fitted relative magnitude of sym. and asym. components to determine the asymmetry



ArXiv:1508.03862

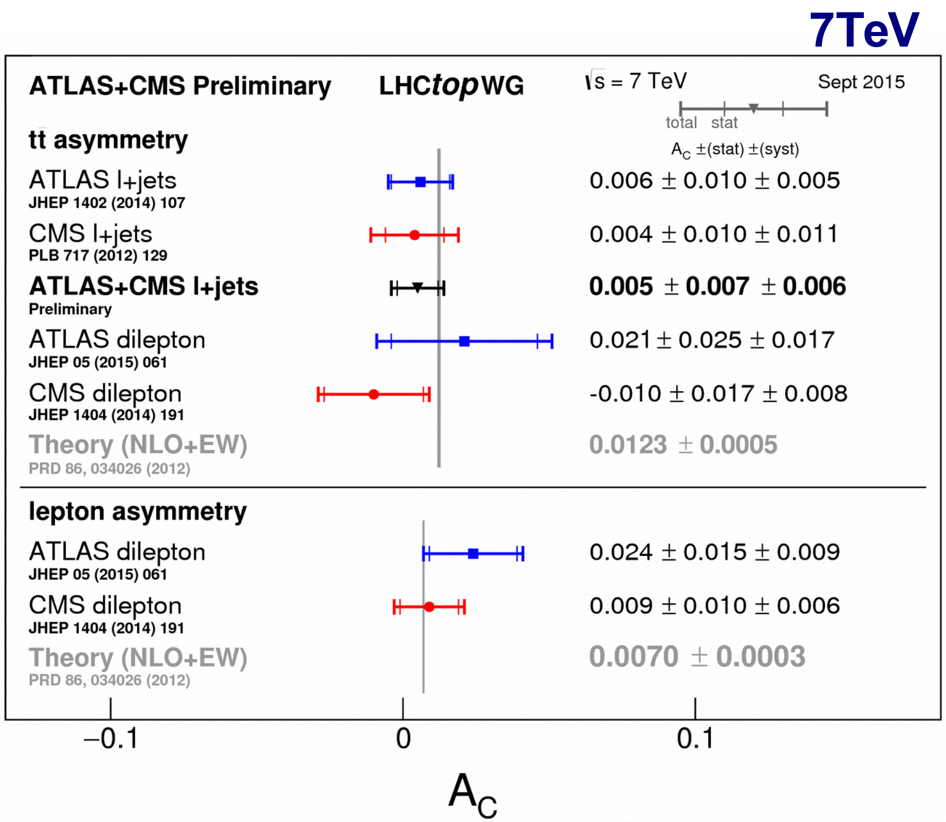


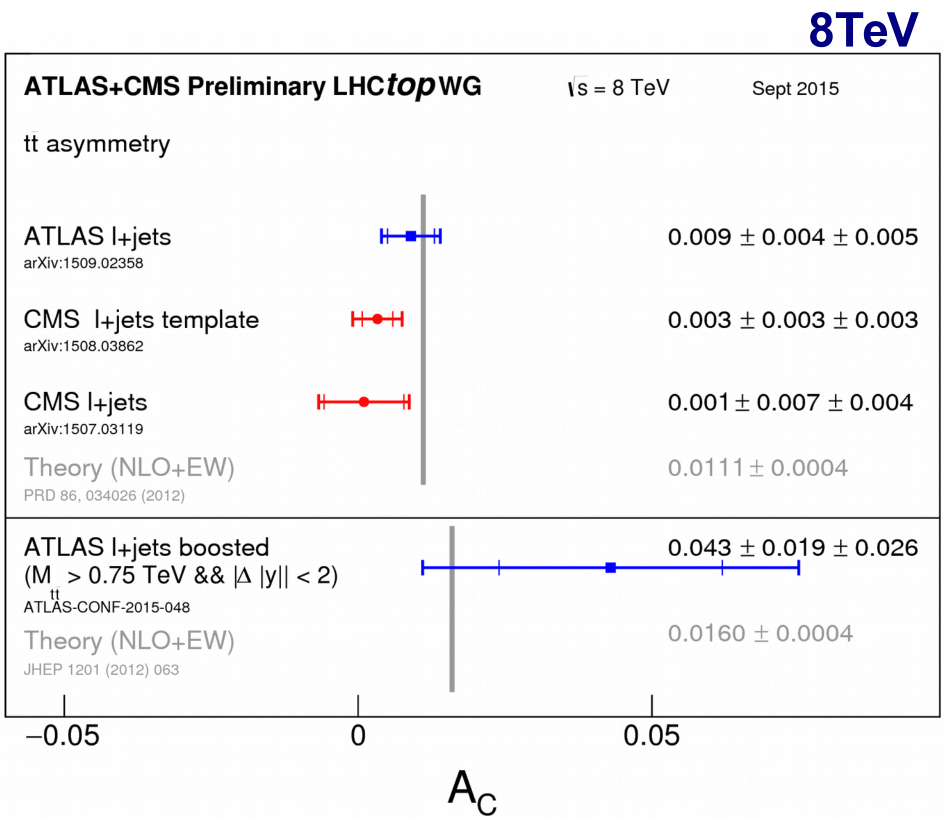


- New template method (TM) assumes SM-like distributions for sym. and asym. components
- TM results in a larger model dependence but the statistical uncertainty is substantially smaller than in the standard method (unfolding)

Measured inclusive and differential A are well

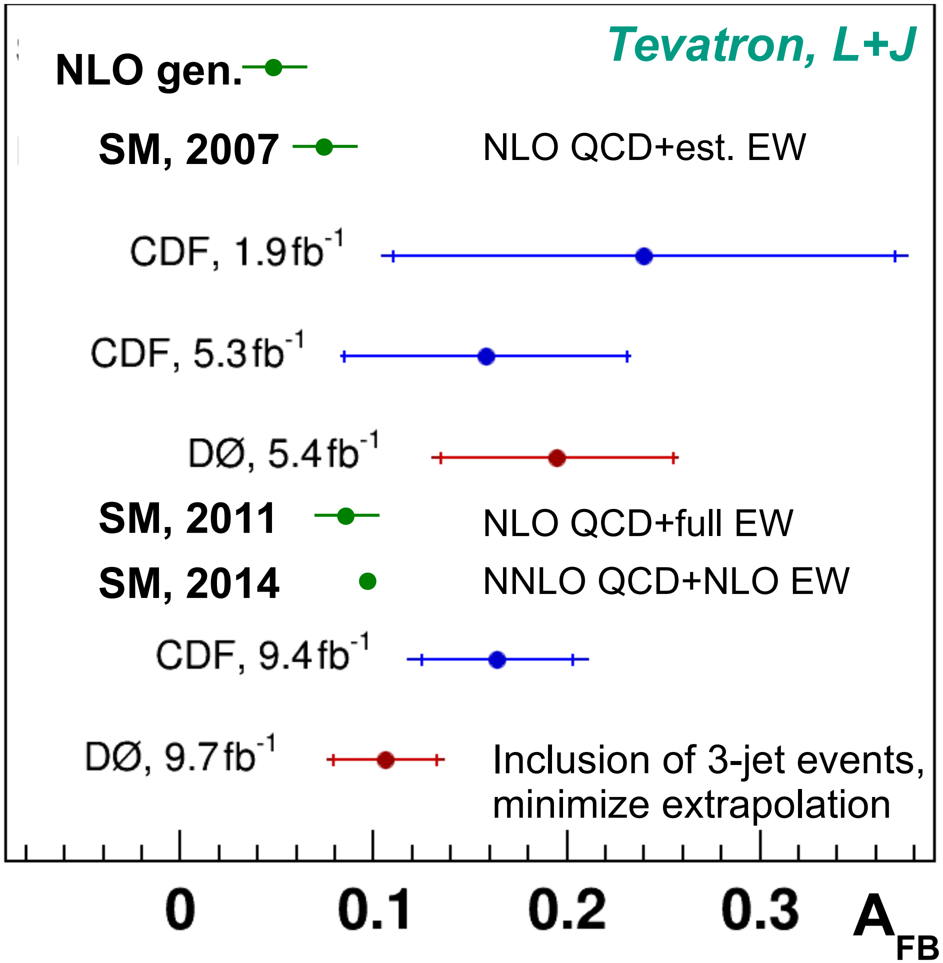
Overview of Asymmetry measurements at the LHC





- All $t\bar{t}$ asymmetry and lepton asymmetry measurements are consistent with each other and with the SM prediction
- There is no indication for new physics from the A_C measurements at the LHC

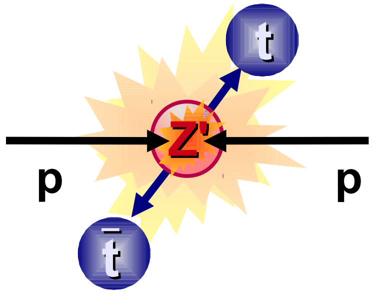
State of the Charge Asymmetry in 2015



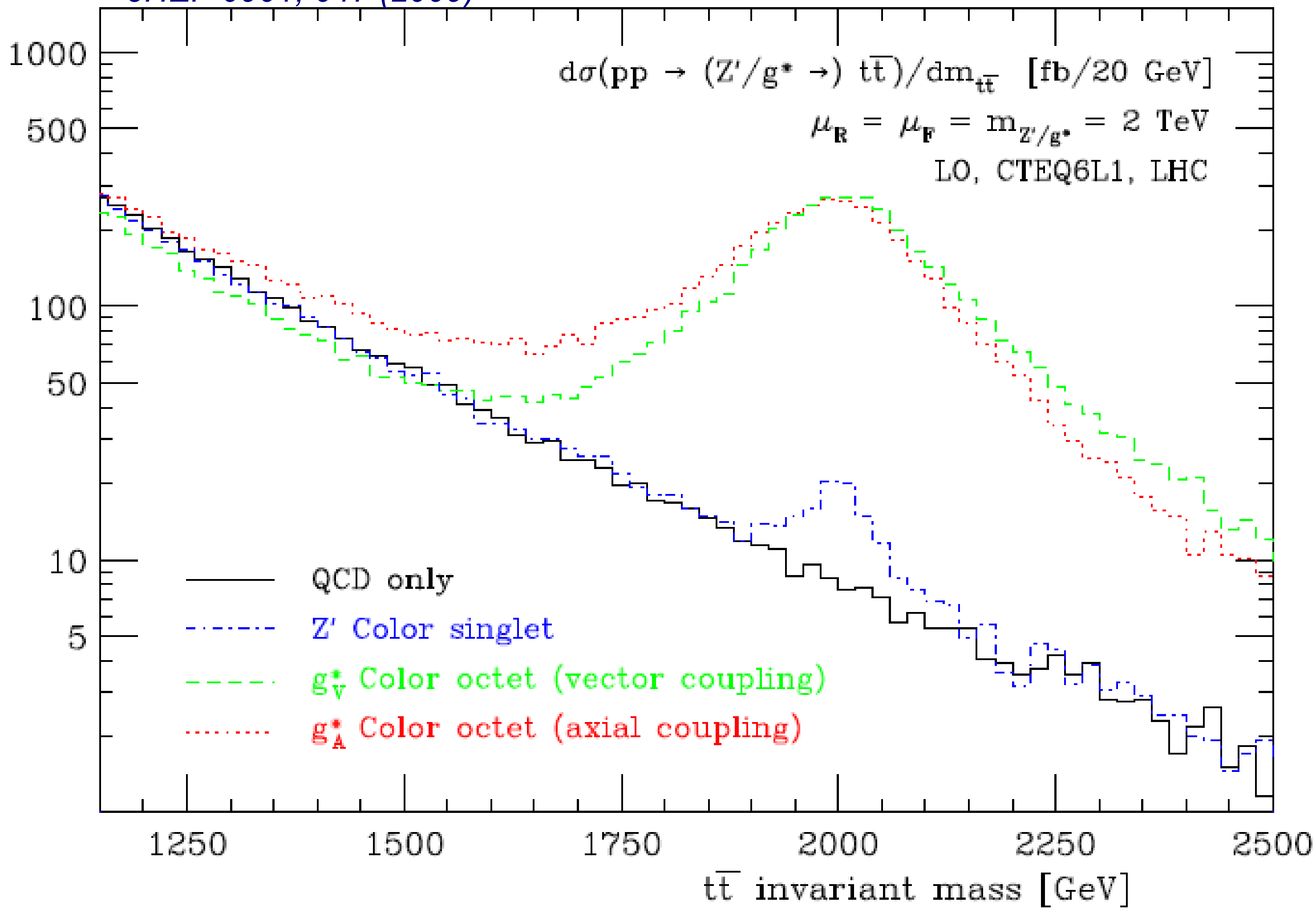
- *Theory:* SM prediction increased (full EW contribution, NNLO QCD pred.)
- *LHC:* All A_C measurements and leptonic asym. are consistent with the SM prediction
- *Tevatron:* Latest A_{FB} measurements and leptonic asym. (not shown, larger unc.) are larger but consistent with the SM prediction

Charge asymmetry puzzle seems to be solved, but full NNLO QCD calculations and full EW corrections are important for $t\bar{t}$ modeling

Search for resonances decaying to $t\bar{t}$



JHEP 0901, 047 (2009)

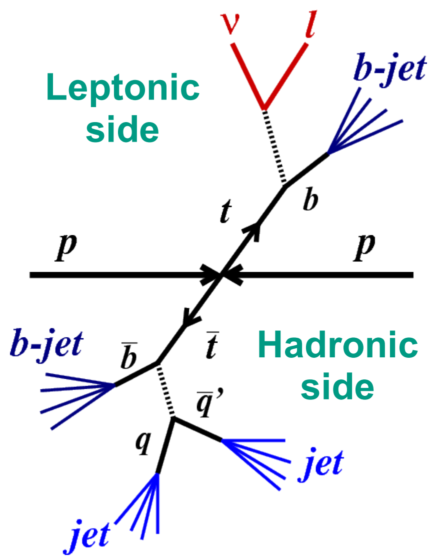


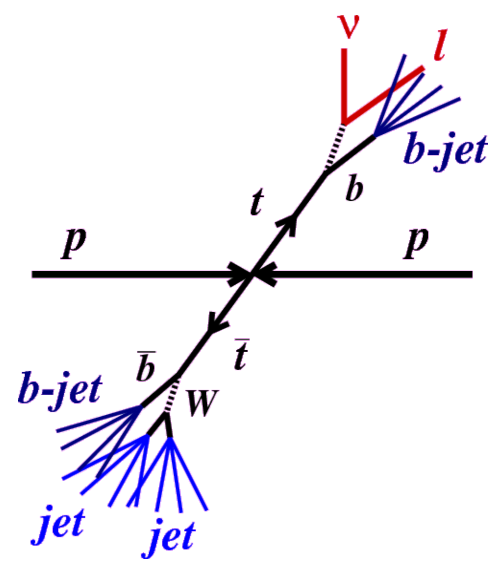
In many models with NP occur heavy resonances decaying preferentially to $t\bar{t}$

No indication for heavy resonances at the Tevatron (sub-TeV range)

With the LHC the TeV range can be explored for the first time

Boosted top pairs - challenge





The larger the invariant top pair mass $M_{t\bar{t}}$, the more boosted the top quarks and the smaller the angles between the decay products

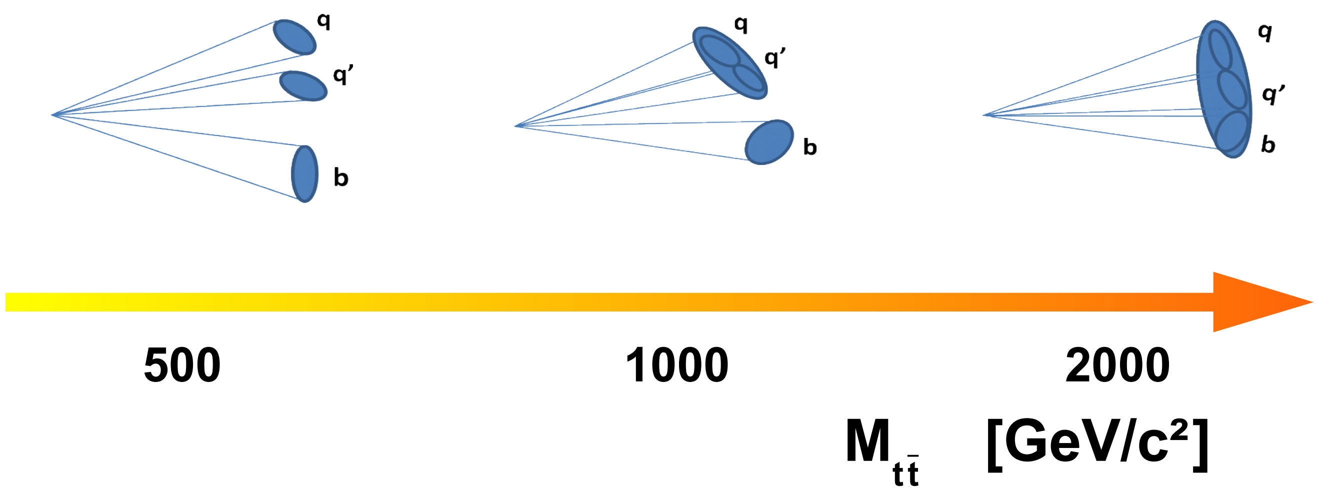
Leptonic side:

Lepton close to b-jet or in b-jet
(lepton not isolated)

Hadronic side:

Jets overlap → recon-struction of 1 or 2 jets instead of 3
(jet with substructure)

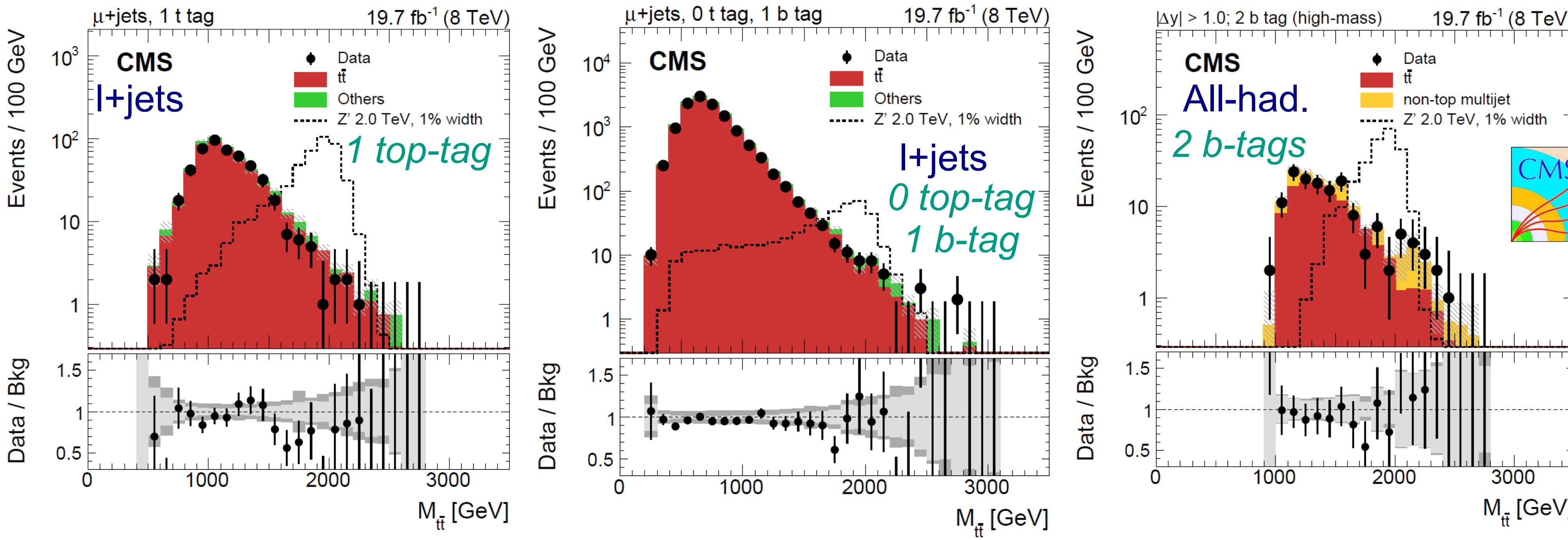
Hadronic side



Search for resonant $t\bar{t}$ production at the LHC – latest result (I)

High mass analyses:

ArXiv:1506.03062, submitted to PRD

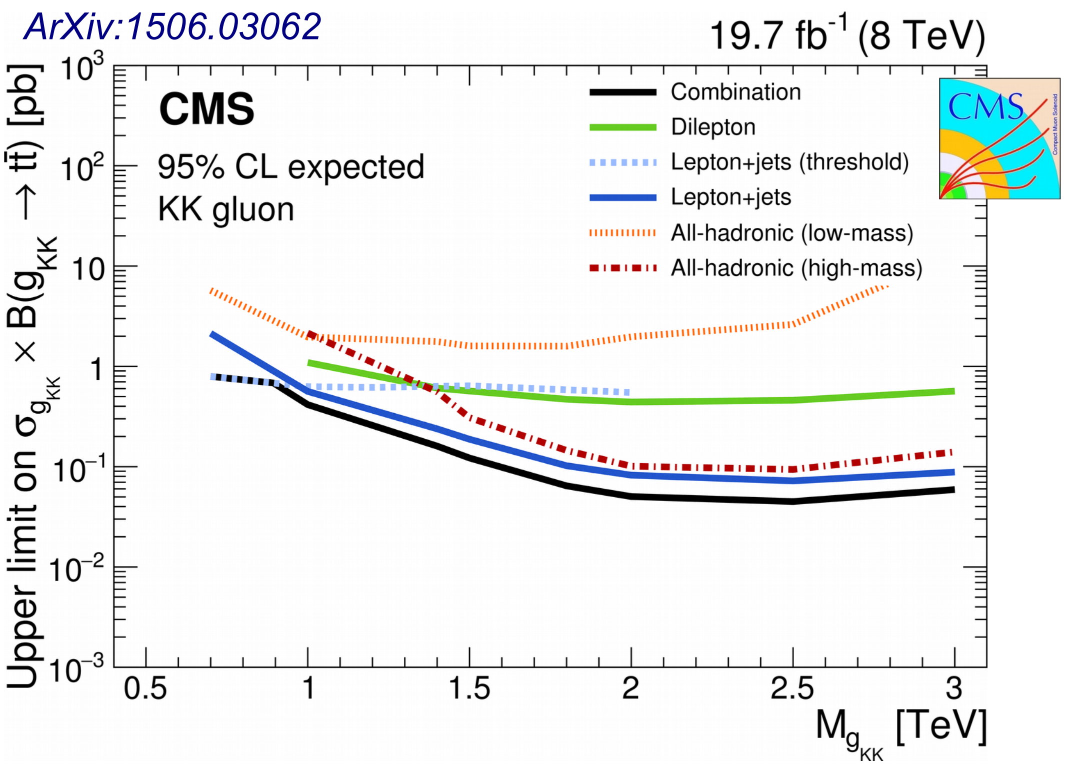


- Separate analyses for high and low inv. $t\bar{t}$ mass regions
- Event selections in the high inv. $t\bar{t}$ mass region designed to cope with the boosted topology:

  all-had: Require 2 jets that are identified as top-jets (via substructure in merged fat jets) and categorize events according to the number of b-tags

  lepton+jets: Require ≥2 jets and one non-isolated l, categorize events according to the number of top-tags and b-tags

Search for resonant $t\bar{t}$ production at the LHC – latest result (II)

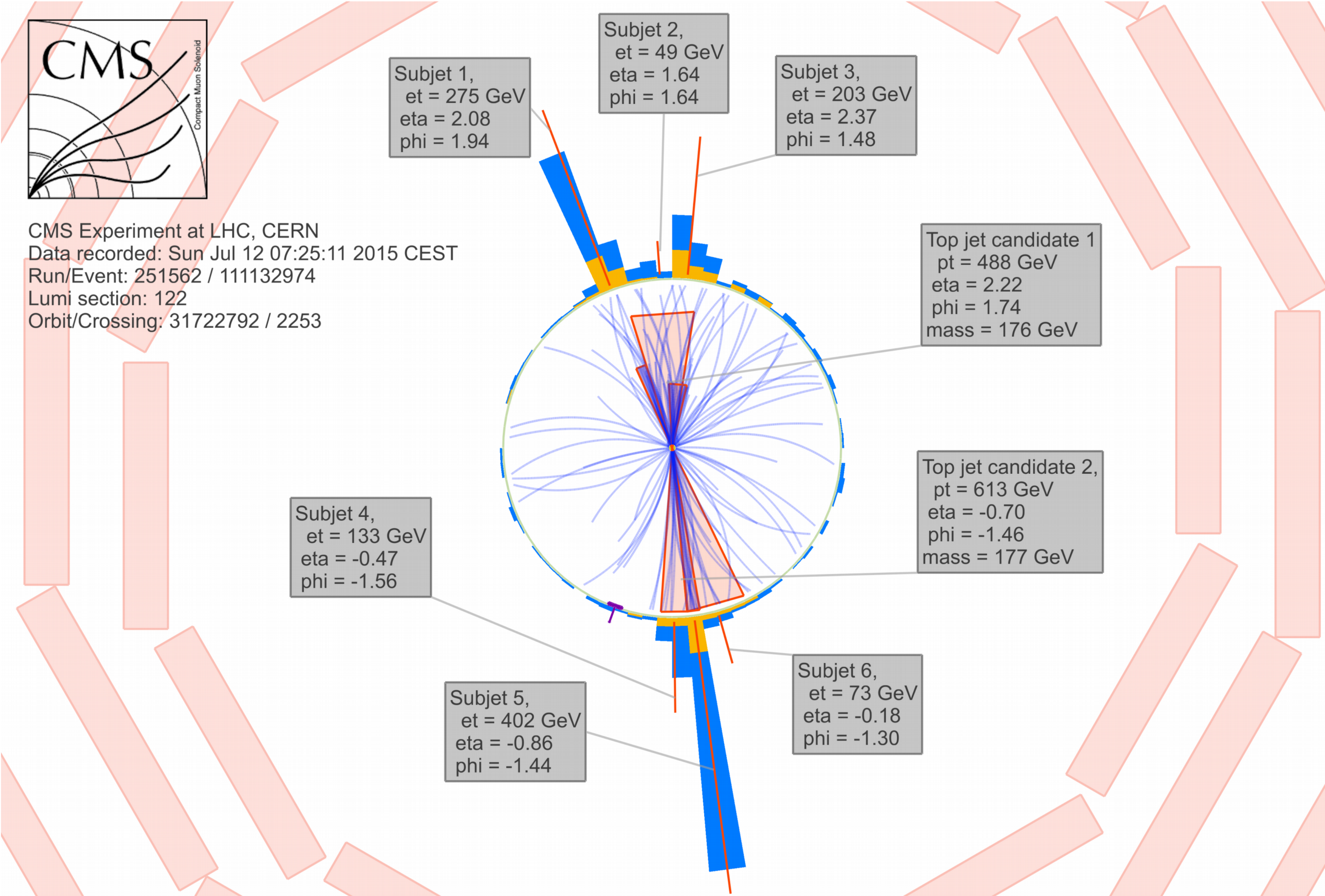


- Use reconstructed inv. mass of $t\bar{t}$ for statistical inference
- No indication for heavy resonances decaying to top quark pairs
- Most stringent limits on topcolor narrow and 10% wide Z' and KK gluon excitation: 2.4 TeV, 2.9 TeV, 2.8 TeV at 95% CL
- Search from ATLAS in the l+jets channel ***(JHEP08 (2015), 148)*** results in similar exclusion limits as l+jets analysis from CMS

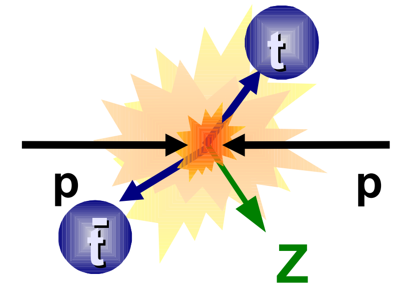
Top pair events with $M_{t\bar{t}}$ > 1TeV/c² observed but no indication for heavy resonances decaying to $t\bar{t}$

LHC Run II will allow to explore multi-TeV range

13TeV data – Boosted $t\bar{t}$ candidate (all-hadronic)



$t\bar{t}$V – Decay Channels



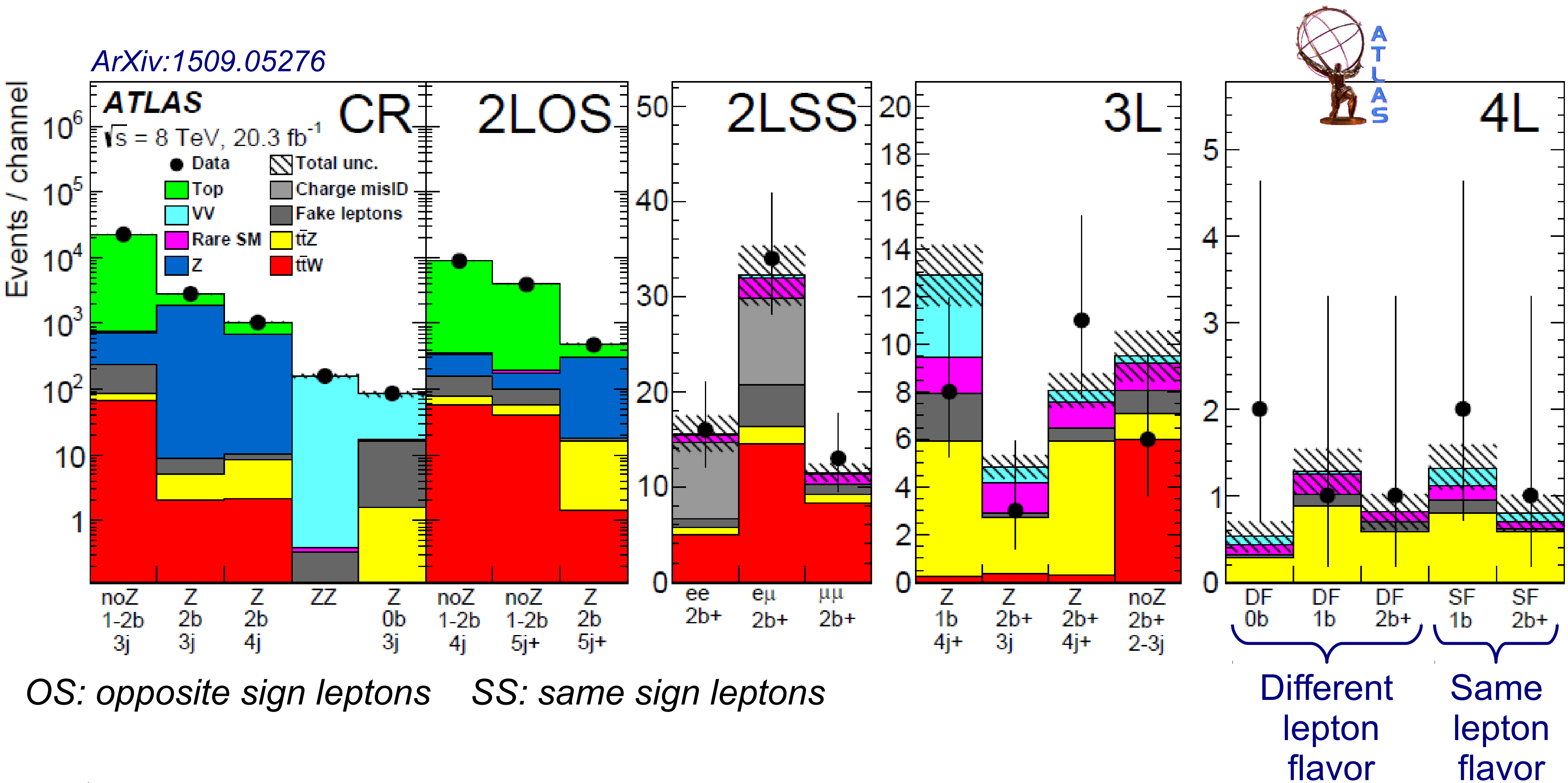
Process	$t\bar{t}$ decay	Boson decay	Channel	$Z \to \ell^+\ell^-$	jets
$t\bar{t}W^\pm$	lepton+jets	$\ell^\mp\nu$	OS dilepton	no	4
	dilepton	$q\bar{q}$	OS dilepton	no	4
	lepton+jets	$\ell^\pm\nu$	SS dilepton	no	4
	dilepton	$\ell^\pm\nu$	Trilepton	no	2
$t\bar{t}Z$	dilepton	$q\bar{q}$	OS dilepton	no	4
	all-hadronic	$\ell^+\ell^-$	OS dilepton	yes	6
	lepton+jets	$\ell^+\ell^-$	Trilepton	yes	4
	dilepton	$\ell^+\ell^-$	Tetralepton	yes	2

– *Most sensitive channels* *OS: opposite sign leptons* *SS: same sign leptons*

Channel	Signal	Dominant background
OS dilepton	$t\bar{t}$Z	$t\bar{t}$, Z+jets
	$t\bar{t}$W (ATLAS only)	$t\bar{t}$
SS dilepton	$t\bar{t}$W	$t\bar{t}$ with non-prompt lepton
Trileptons:	$t\bar{t}$Z	Z+jets and $t\bar{t}$ with non-prompt lepton, WZ
	$t\bar{t}$W	$t\bar{t}$ with non-prompt lepton, WZ
Tetraleptons:	$t\bar{t}$Z	ZZ

Measurement of the $t\bar{t}V$ cross sections at ATLAS

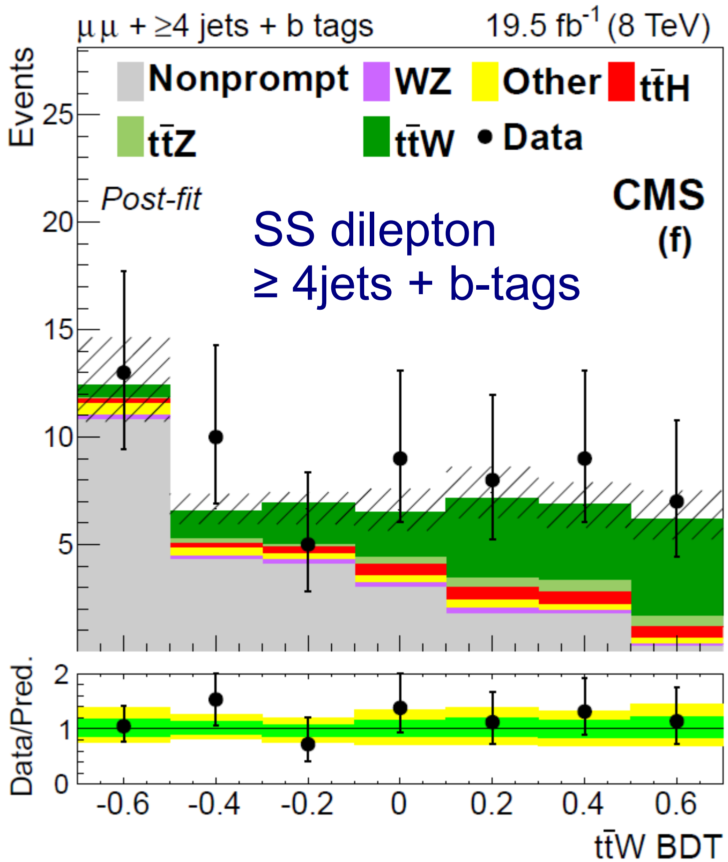
ArXiv:1509.05276

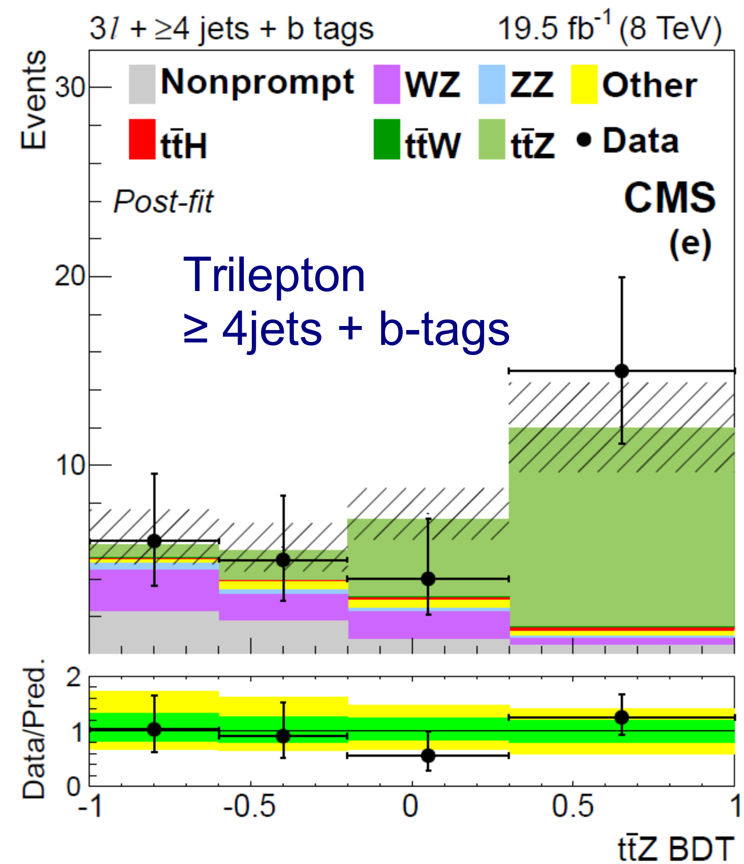


OS: opposite sign leptons *SS: same sign leptons*

- Use of 15 SR and 5 CR
- Perform a fit to the event numbers in all 20 categories
- In case of the dilepton (2L) categories also shape information is used

Measurement of the $t\bar{t}V$ cross sections at CMS

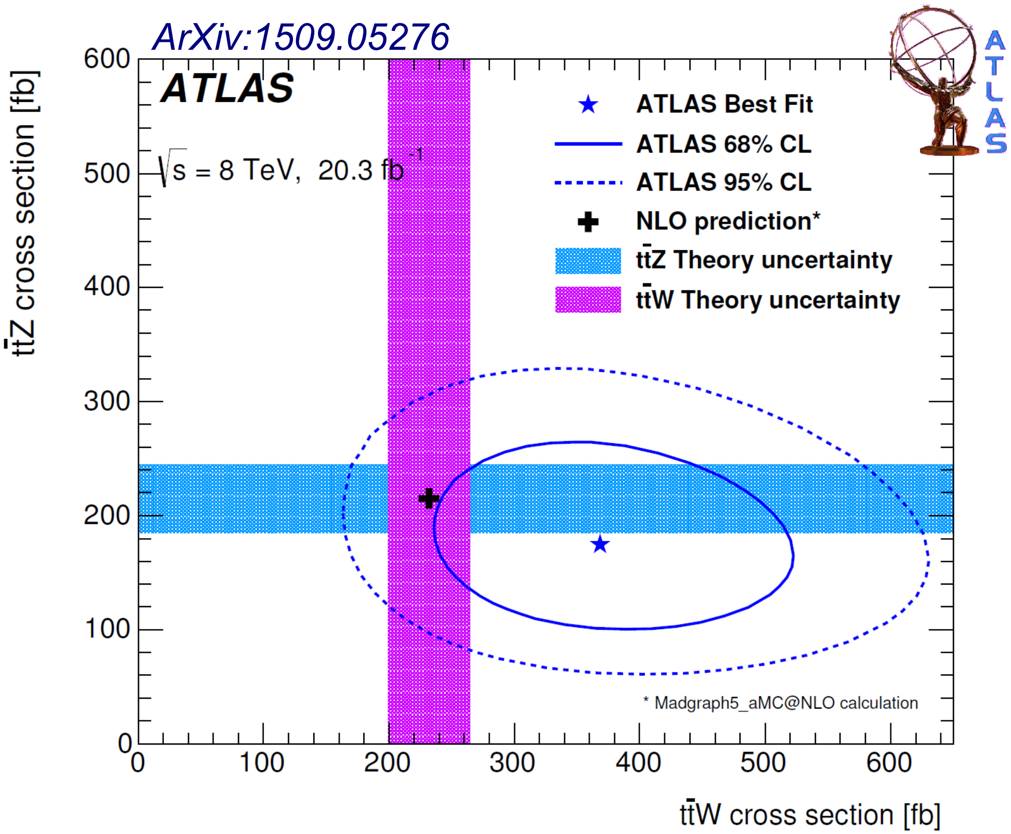


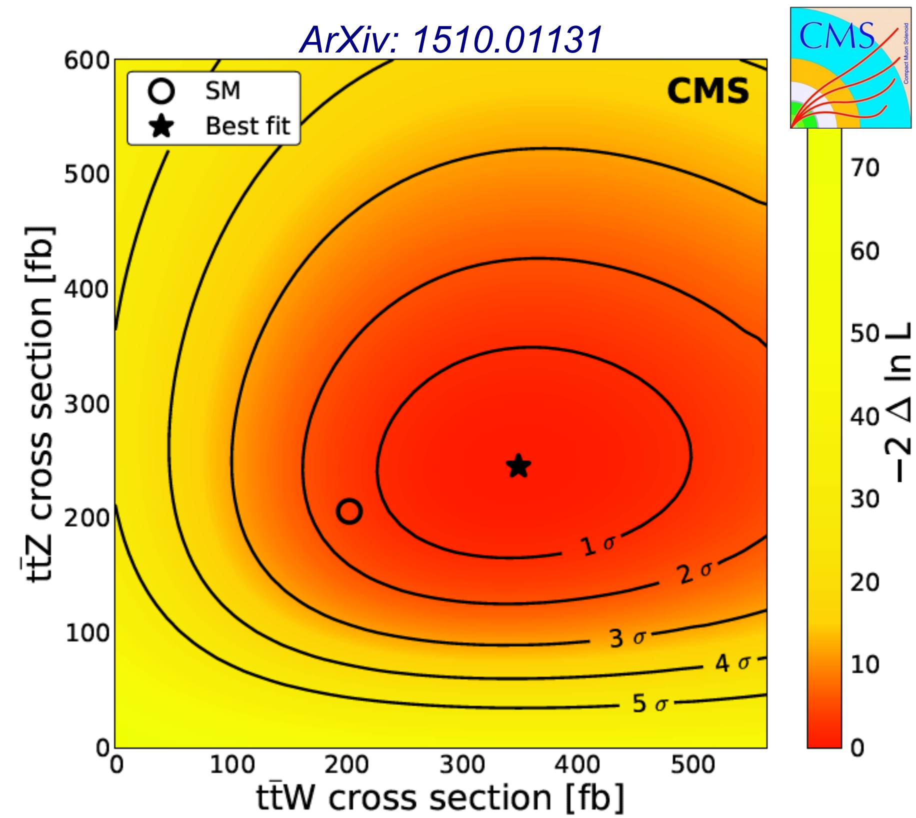


ArXiv: 1510.01131

- Use of 5 SR with subcategories (N_{jets}, lepton-type)
- Some backgrounds (non-prompt, charge mis. id.) determined from data CR
- Reconstruction of $t\bar{t}$-system
- $t\bar{t}$ rec. and kin. event variables used in BDT
- Extract cross sections from fit to BDT outputs

Observation of the $t\bar{t}V$ process at the LHC



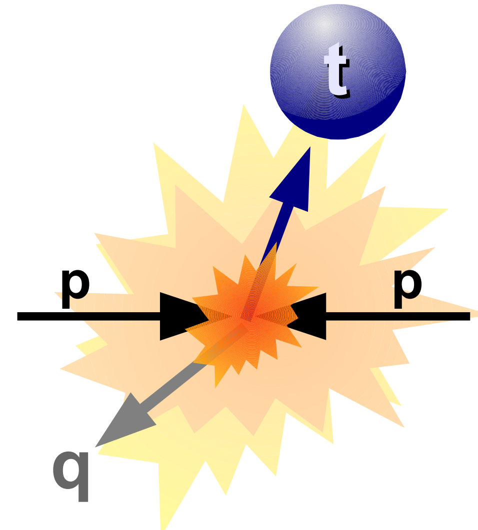


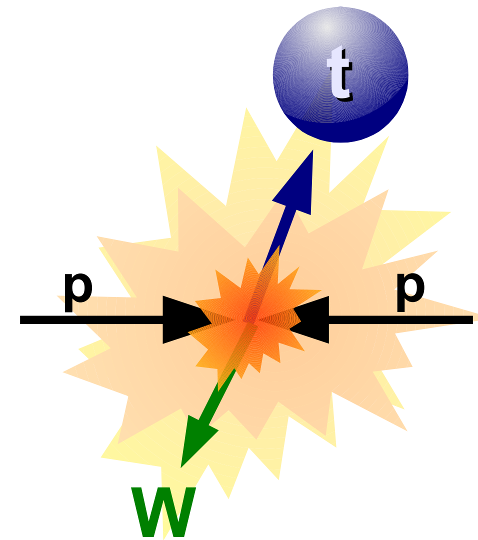
	Significance of $t\bar{t}W$		Significance of $t\bar{t}Z$		Cross section of $t\bar{t}V$ [fb]	
	Exp.	Obs.	Exp.	Obs.	$t\bar{t}W$	$t\bar{t}Z$
ATLAS	3.2σ	**5.0σ**	3.2σ	4.8σ	369^{+100}_{-91}	176^{+58}_{-52}
CMS	3.5σ	4.8σ	5.7σ	**6.4.σ**	382^{+117}_{-102}	242^{+65}_{-55}

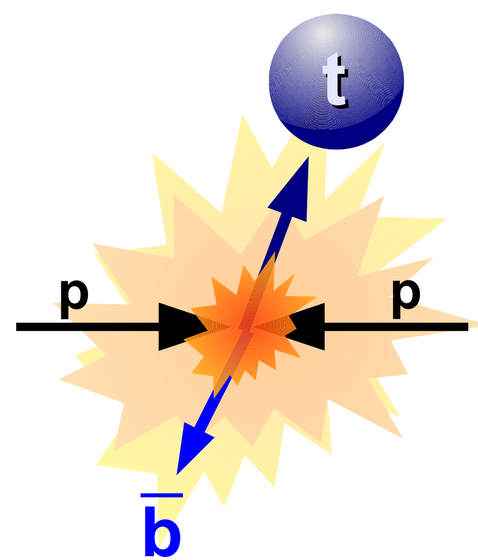
Rare SM processes ttV have been observed and measured cross sections are consistent with SM prediction

Outline

- Introduction
- Overview of the current status in top quark physics
- Recent results on top quark pair production
- **Recent results on single top quark production:**
  - t-channel
  - Wt production
  - s-channel

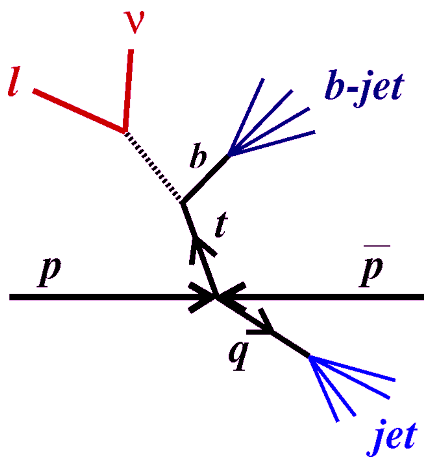




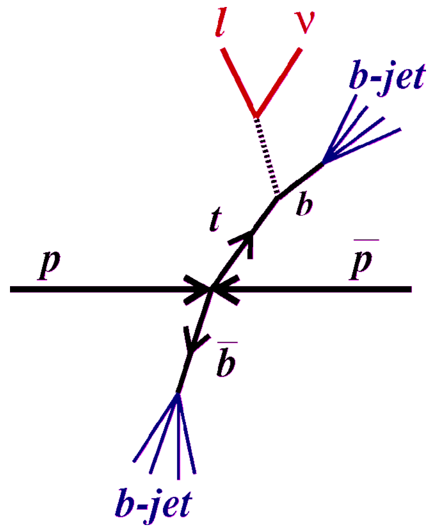


Single top event signature

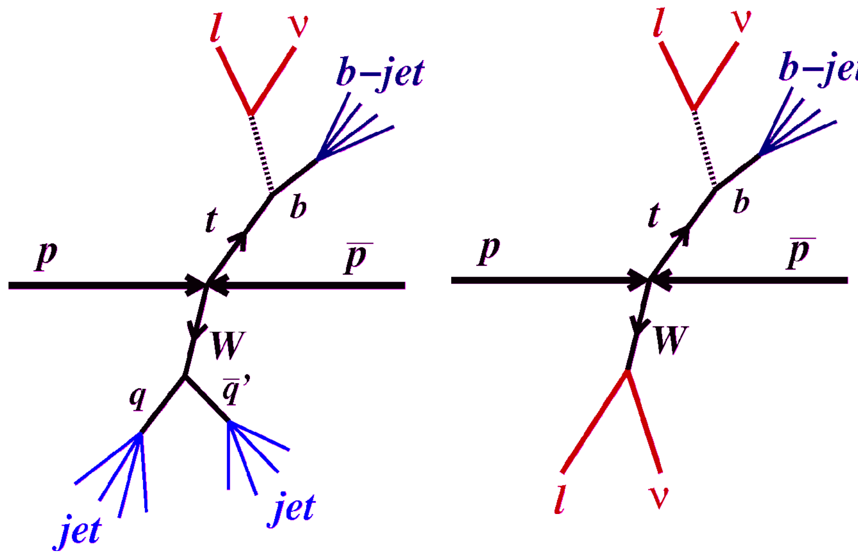
t-channel (tqb)



s-channel (tb)



Wt production

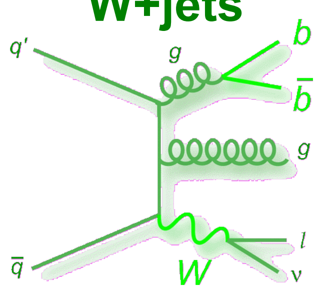


Distinct event signature

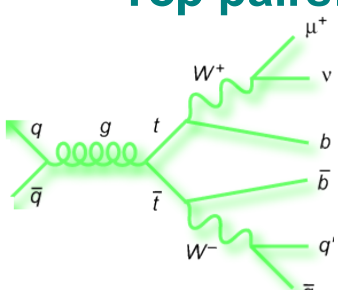
Very similar event signature as top pairs

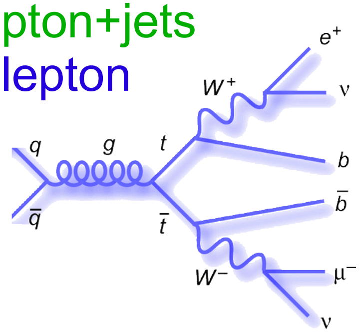
Backgrounds:

W+jets

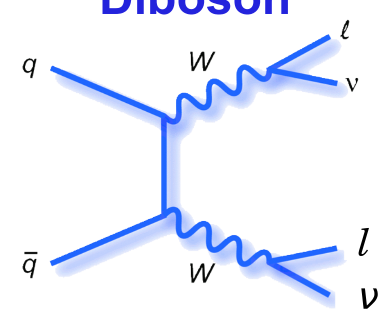


Top pairs: lepton+jets dilepton

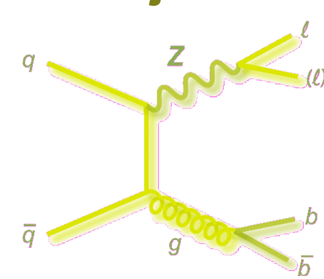




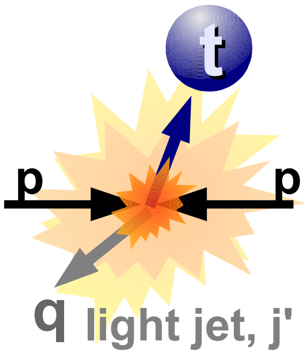
Diboson

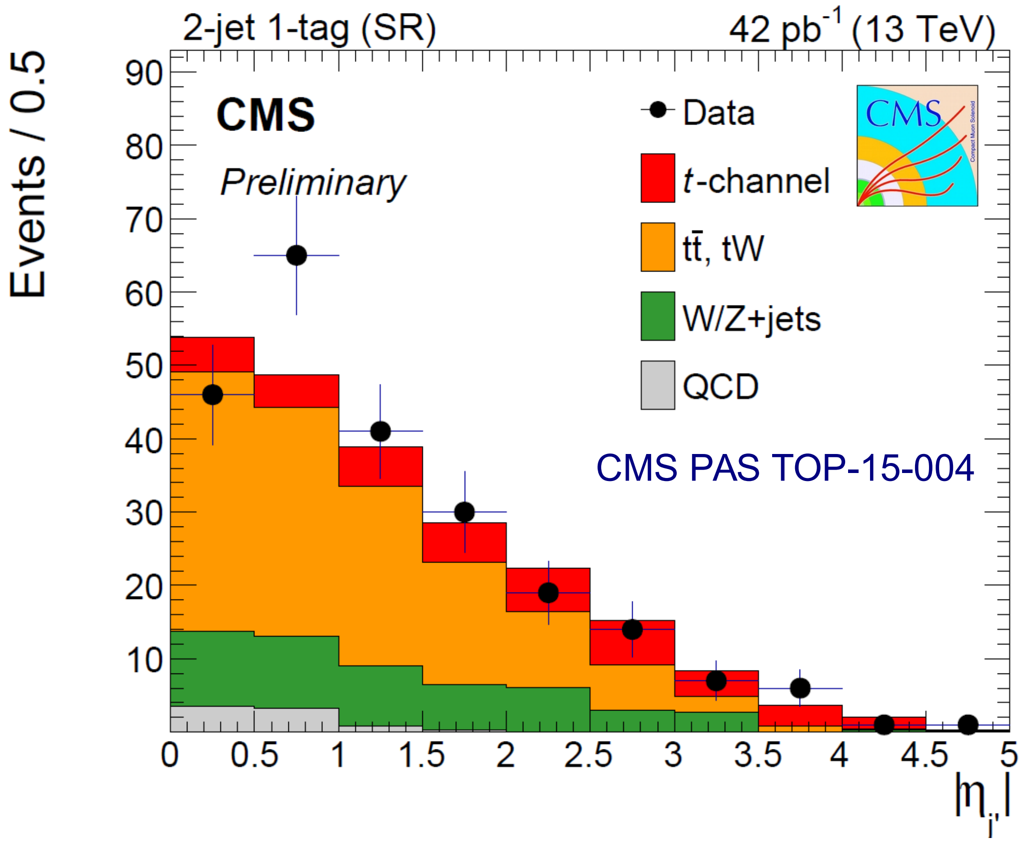


Z+jets



First single top t-channel cross section measurements at 13TeV





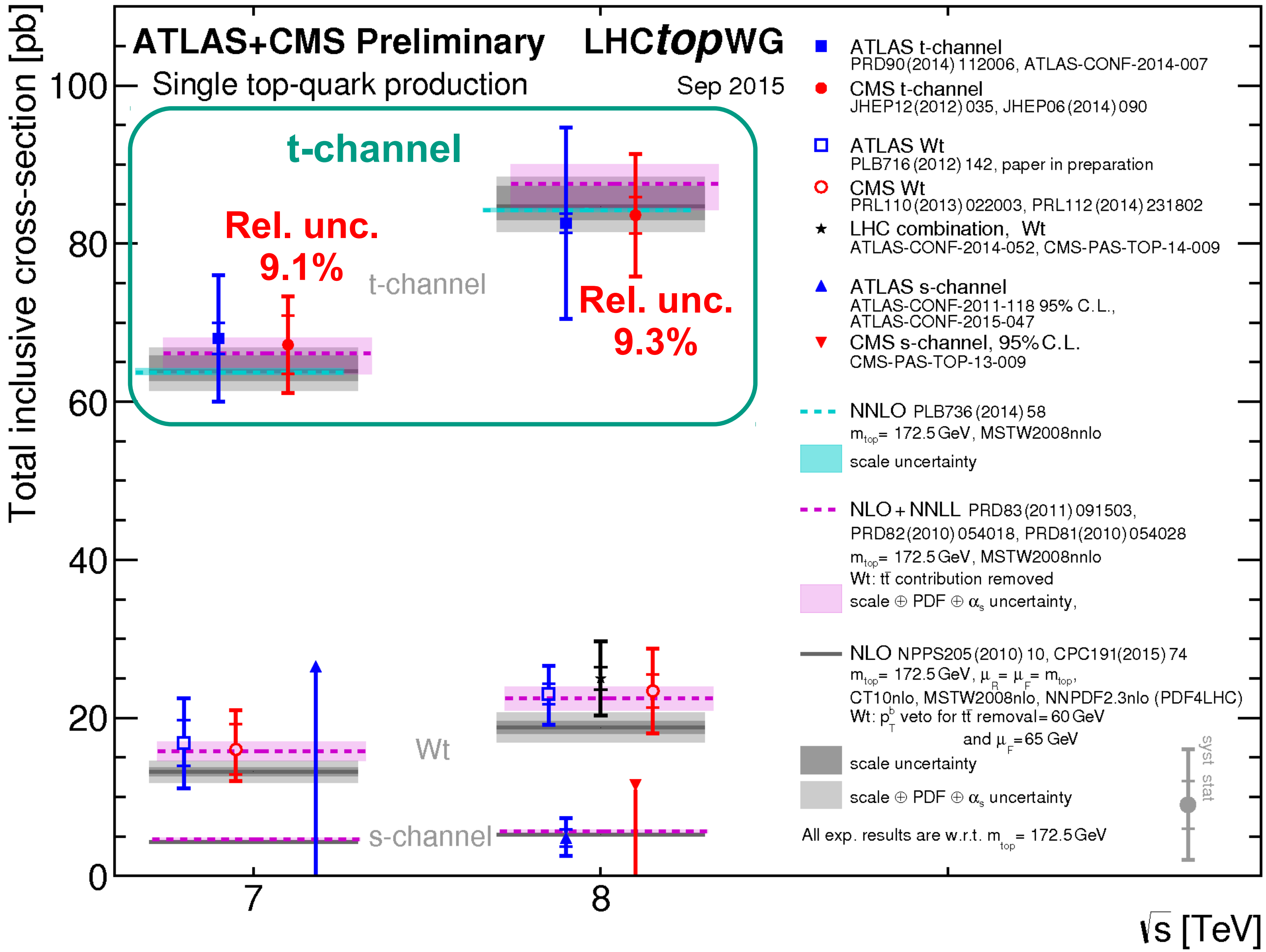
- Consider leptonic decay of W-boson
- Require 1 e/μ, 2 jets (up to $|\eta|<5$), whereof one is b-tagged, minimum transverse mass of W to reduce QCD background and a rec. top quark mass m_{lvb} compatible with the top mass
- Validate W+jets backgrounds in side band regions of m_{lvb}
- Perform simultaneous fit to $|\eta_{j'}|$ in the SR and in an $t\bar{t}$ enriched region (3Jets, 2 b-tags)

Measured cross section at 13 TeV: $\sigma = (274 \pm 116)$ pb

SM prediction: $\sigma \approx 217$ pb (NLO 5FS, HARTHOR)

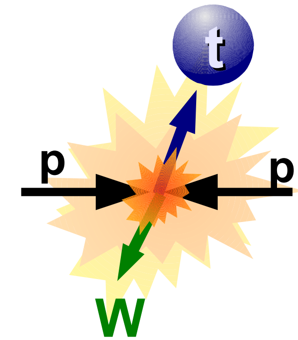
First single top t-channel events seen at 13TeV, measured cross section is consistent with SM prediction

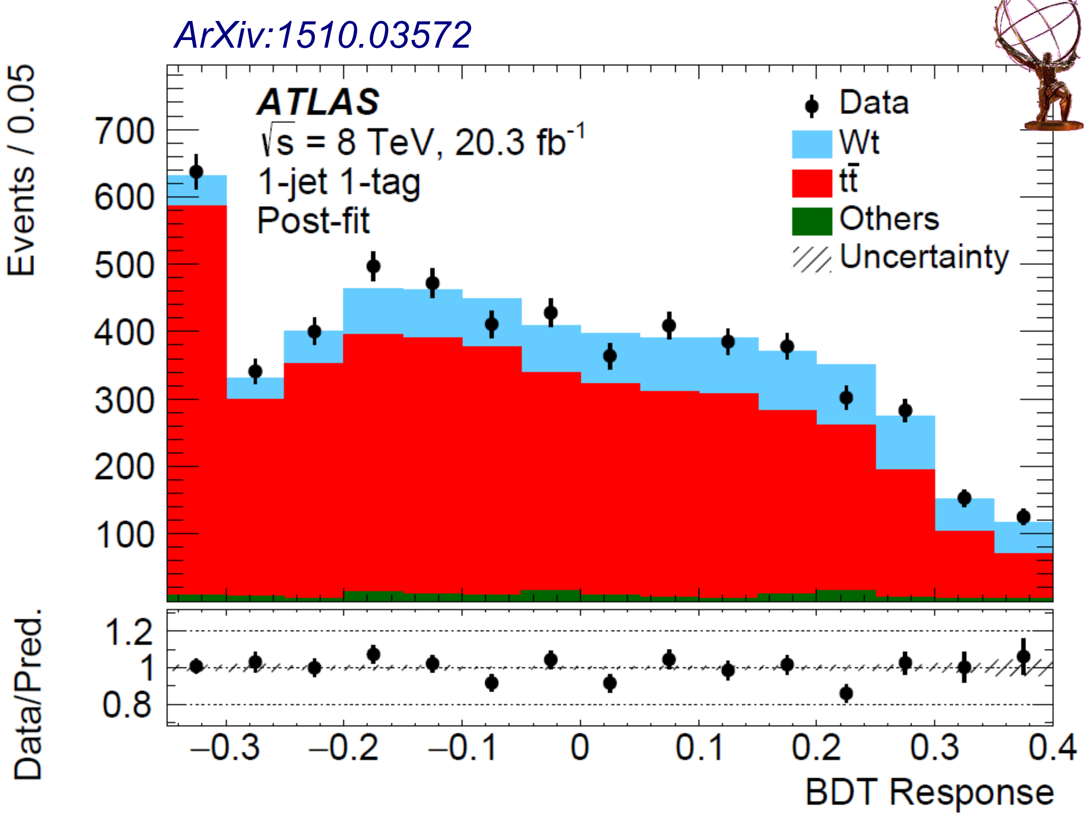
Overview of single top t-channel measurements at Run I



Measured single top t-channel cross sections at 7 and 8TeV are in good agreement with SM prediction

Measurement of the Wt cross section





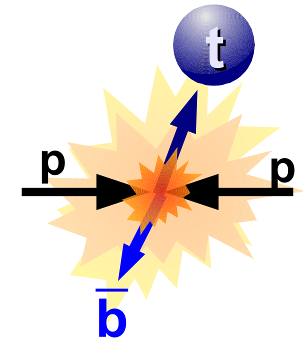
- Consider dilepton channels: ee,μμ, eμ
- SR: opposite sign lepton pair, 1 b-tagged jet, missing transverse energy
- Use of BDTs to separate Wt and $t\bar{t}$
- Perform simultaneous fit to BDT outputs in SR and in two $t\bar{t}$ enriched regions (2 jets, 1 or 2 b-tags)
- Systematic uncertainties are constrained insitu via nuissance parameters

Measured Wt cross section at 8 TeV: $\sigma = (\, 23.0^{+3.6}_{-3.9}\,)$ pb

SM prediction: $\sigma \approx 22$ pb (NLO + NNLL)

Measured Wt cross section is in good agreement with SM prediction, relative uncertainty of measurement is about 16%

Search for single top s-channel with the ME method



Idea of ME method: Compute event probability for signal and background hypotheses

$$P(x|H_{proc}) = \frac{1}{\sigma} \int d^n\sigma(y)\, dq_1\, dq_2\, f(q_1)\, f(q_2)\, W(x|y)$$

X: reconstructed final state

Differential Cross section

PDF's

Transferfunction: Parton(y) ⟶ rec. object(x)

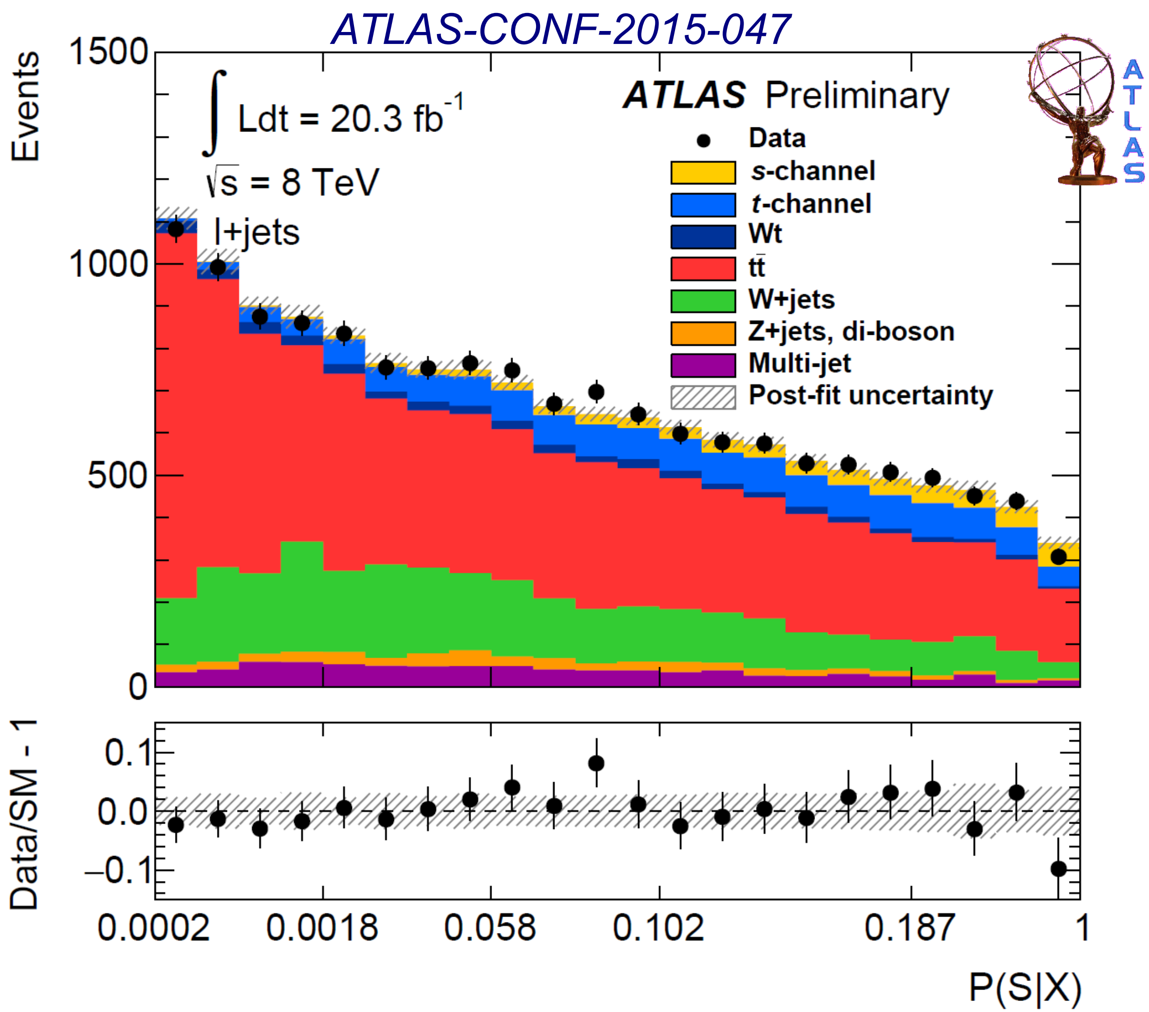
H_{proc}: Process of Hypothesis

- Use full kinematic information of events, integrate over unknown or poorly measured quantities
- Calculate probability densities for signal *(s-channel with 2 or 3 partons)* and backgrounds *(t-channel 4FS, $t\bar{t}$, W+qq, W+qc,W+bb)*
- Discriminant (prob. for an event with rec. final state x being a signal event):

$$P(S|x) = \frac{\sum_i \alpha_{S_i} P(x|S_i)}{\sum_i \alpha_{S_i} P(x|S_i) + \sum_j \alpha_{B_j} P(x|B_j)}$$

$\alpha_{S_i}, \alpha_{B_j}$: **Expected fractions of signal/ background process events after selection**

Evidence for single top s-channel



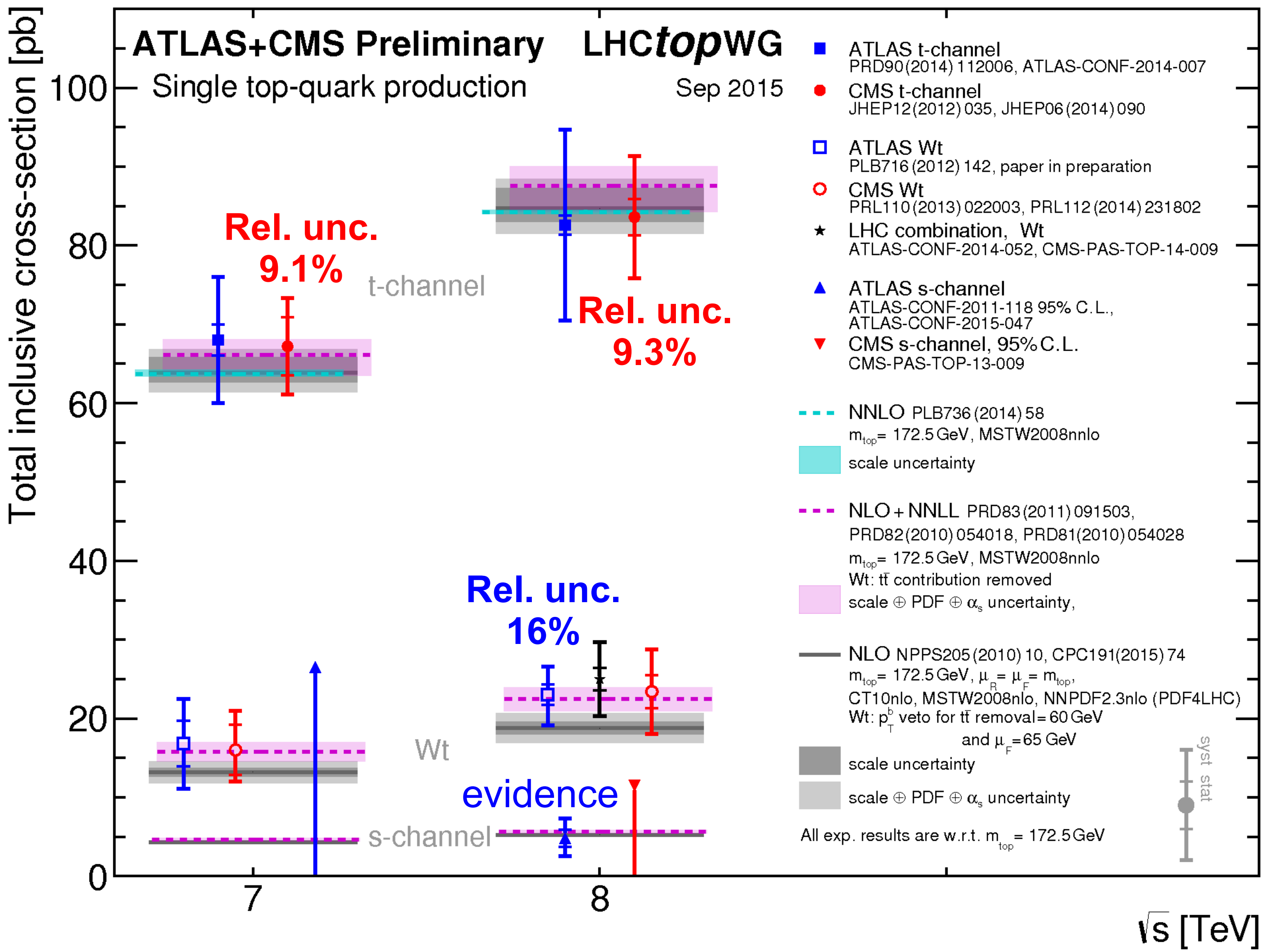
- Select events with one e or μ, exactly two jets which are b-tagged, MET, veto events with an add. loosely rec. e or μ
- Validate $t\bar{t}$ and W+jets in control regions
- Perform a fit to the ME discriminant P(S|X) in the SR and to the charge of the lepton in the W+jets CR
- Constrain syst. unc. insitu

Observed significance: 3.2σ (exp. significance: 3.9σ)

Measured cross section: $4.8^{+2.5}_{-2.2}$ pb (SM: σ ≈ 5.6 pb (NLO + NNLL))

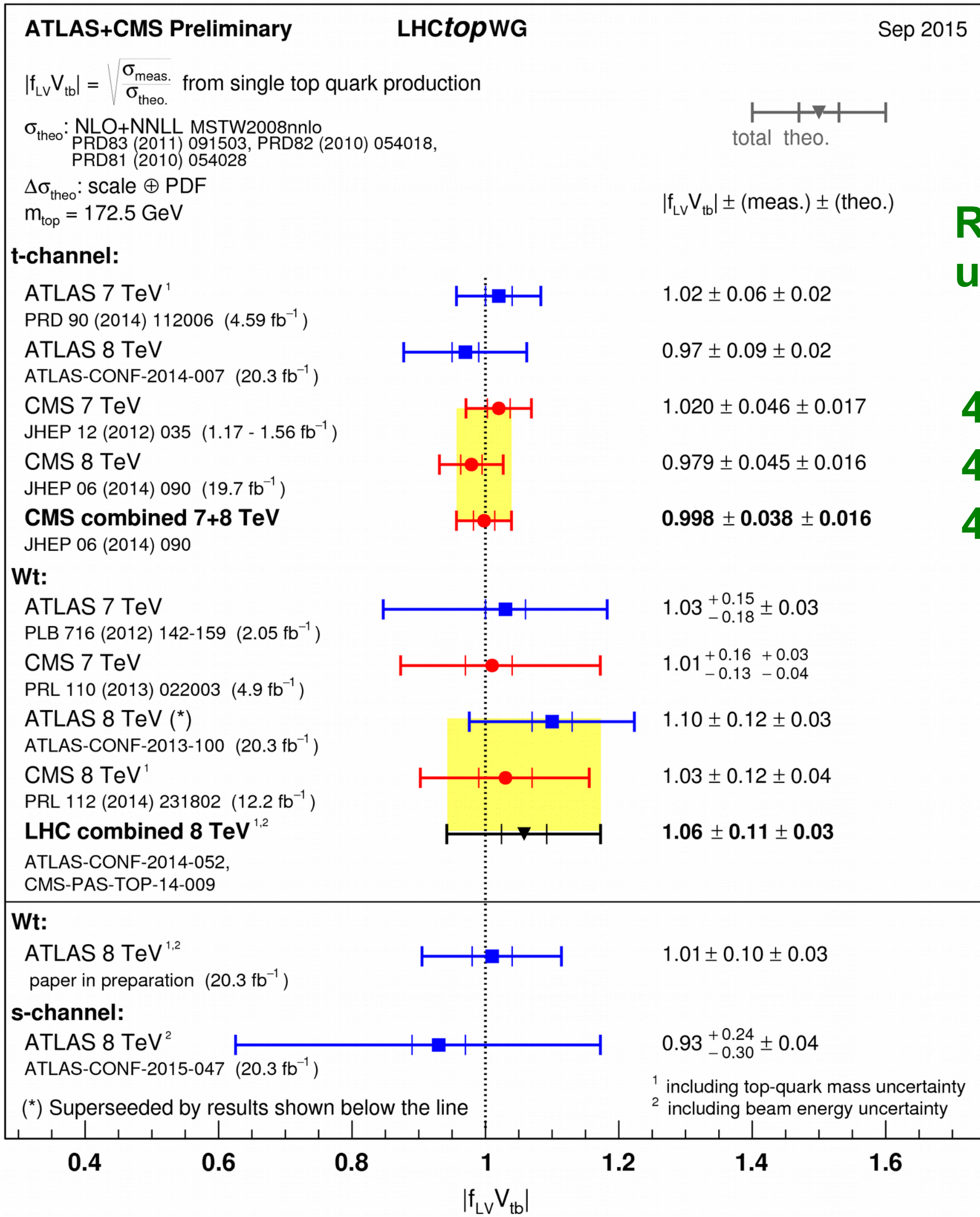
There is evidence for single top s-channel production at the LHC

Status of single top quark production cross sections in 2015



Measured single top quark cross sections are in good agreement with SM prediction

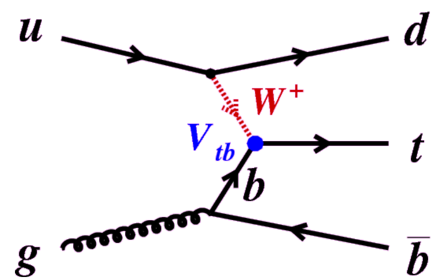
Extraction of the CKM matrix element $|V_{tb}|$



Rel. unc.

4.8%
4.9%
4.1%

Extract $|V_{tb}|$ from measured single top quark cross sections



$$\sigma \sim V_{tb}^2$$

Assuming $|V_{td}|, |V_{ts}| \ll |V_{tb}|$:

$$|f_{L_V} V_{tb}| = \sqrt{\frac{\sigma_{single\ top}}{\sigma^{theory}_{single\ top}}}$$

$|V_{tb}|=1$

f_{LV}: possible anomalous form factor (SM: f_{LV}=1)

Relative uncertainty of $|V_{tb}|$ determination from t-channel single top production at the 5% level

Conclusion

Recent results from top quark production at the LHC

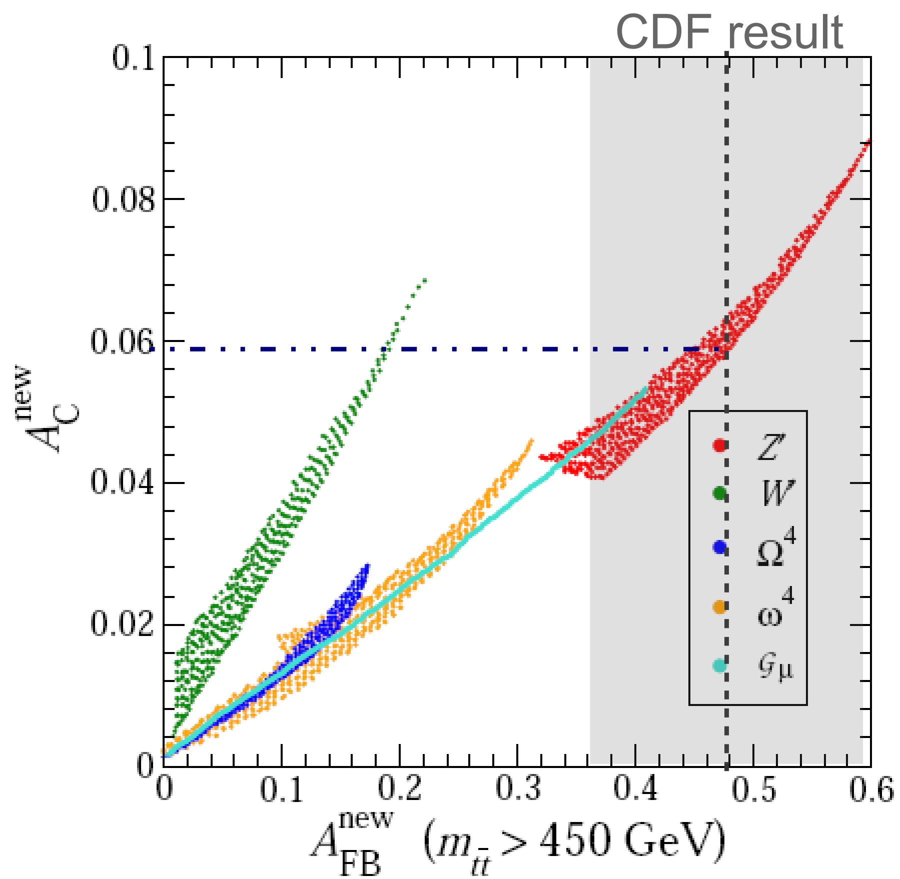
- **Harvest from Run I:**
  - Measured $t\bar{t}$ and single top σ are in good agreement with SM pred.
  - Inclusive σ of $t\bar{t}$, single top t-channel, Wt measured with a precision of below 4%, below 10% and of about 16%
  - Puzzle of large asymmetries at the Tevatron seems to be solved but full NNLO QCD calc. and full EW corrections are important for $t\bar{t}$ modeling
  - Observed $t\bar{t}$ events in M_{tt}=1-3 TeV range, no indication for resonant prod.
  - Observed ttV production, consistent with SM
  - Evidence for s-channel single top quark production

- **First Measurements/studies at 13TeV:**
  - $t\bar{t}$ cross section measured with a rel. unc. of <14%, first t-channel single top events seen at 13TeV
  - Have seen nice $t\bar{t}$ events which are highly boosted

- **Looking forward to more detailed studies at 13 TeV**

Back-Up Slides

Charge asymmetry in new physics models

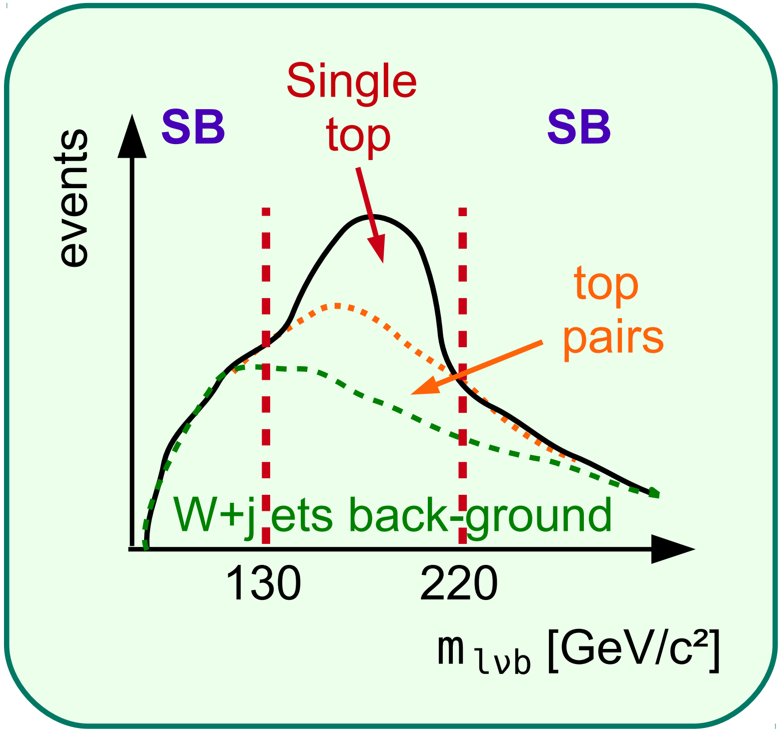


J. Aguilar-Saavedra, M. Perez-Victoria, arXiv:1105.4606

- Z': Flavor violating Z' exchanged in t-channel in $u\bar{u} \to t\bar{t}$ and with right-handed Z'tu couplings
- W': W' boson with right-handed couplings exchanged in t-channel in $d\bar{d} \to t\bar{t}$
- Ω^4: Color-sextet scalar with right-handed flavor violating tu-couplings and exchanged in u-channel
- ω^4: Color triplet with flavor violating tu-couplings, right-handed, exchanged in u-channel in $u\bar{u} \to t\bar{t}$
- $\mathcal{G}_\mu$: Axigluon, color octet vector with axial couplings

LHC charge asymmetry measurement provides complementary information

t-channel: Signal and background modeling



Monte-Carlo:

- Single top processes: POWHEG+Pythia
- $t\bar{t}$+jets, W+jets, Z+jets: MadGraph+Pythia
- Diboson (WW,WZ, ZZ): Pythia

Data-driven multijet QCD modeling:

- Template obtained from loose lepton selection
- Normalization determined from fit to $M_{T,W}$ (μ) and MET(e), respectively

Data-driven W+jets modeling ($|\eta_{j'}|$-analysis):

- W+jets yield and $|\eta_{j'}|$-template is extracted from data in $m_{l\nu b}$ sideband (SB)
- Non-W+jets backgrounds are subtracted

Data-driven top pair modeling ($|\eta_{j'}|$-analysis at 8TeV):

- $|\eta_{j'}|$-template is obtained using the 3-jets 2-tags data sample
- Normalization is taken from the simulation