Top-quark Physics at LHC

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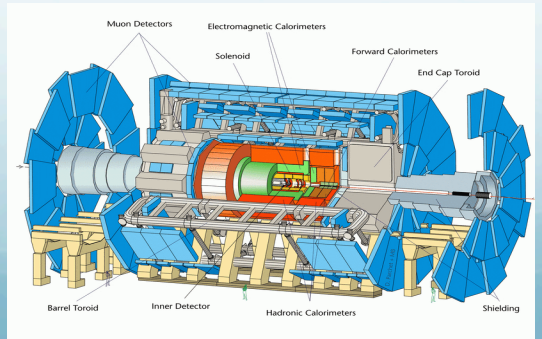
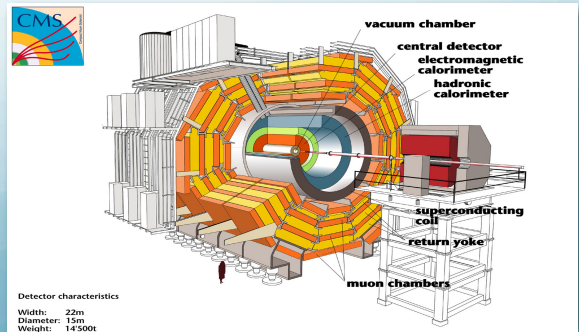
- 2005—2008: IHEP/CPPM co-tutor Ph.D: ttH
  - superviosr: E. Monnier and S. Jin
  - First graduated Ph.D within FCPPL framework
- 2008—2010: CPPM, Calorimeter related calibration
- Recent work on Wt, b* (editorship of 3 papers)
- Will join IHEP CMS group in June 2013 (CAS 100-talent plan)

26th, Mar. 2013; Nanjing, China



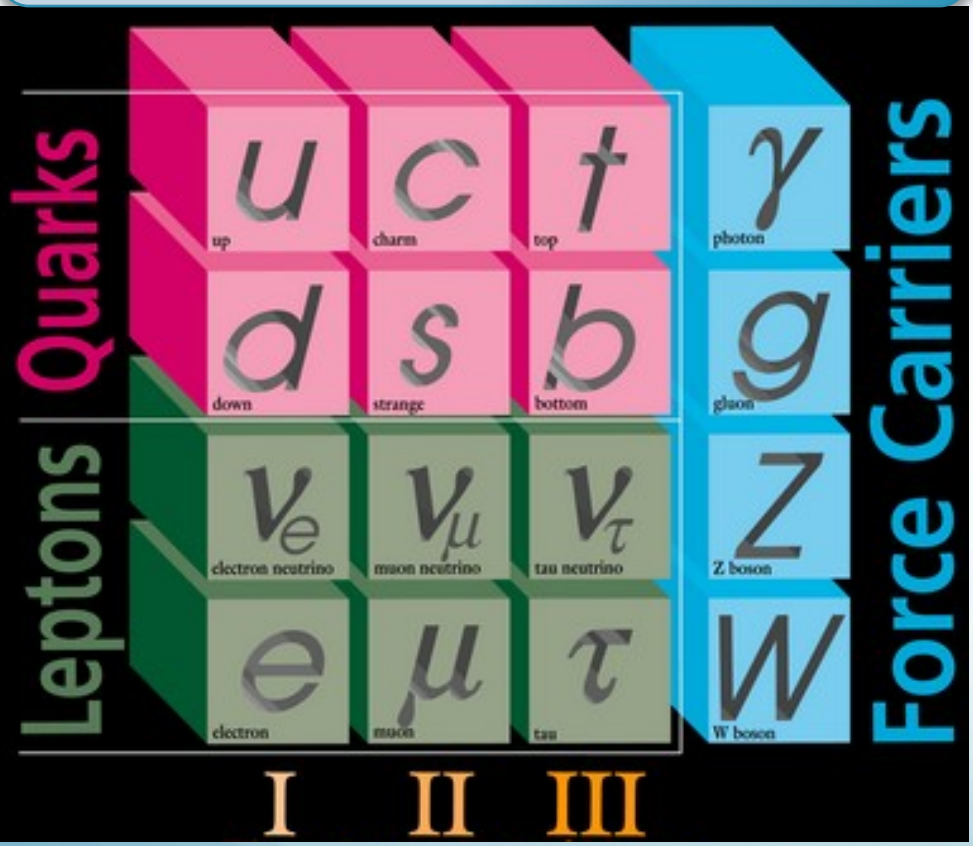


Outline

- Introduction of top quark physics
- Top quark physics at LHC
  - Measurements with top pair
  - Measurements with single top
  - New physics with top signature
- Summary

Why Top Quark

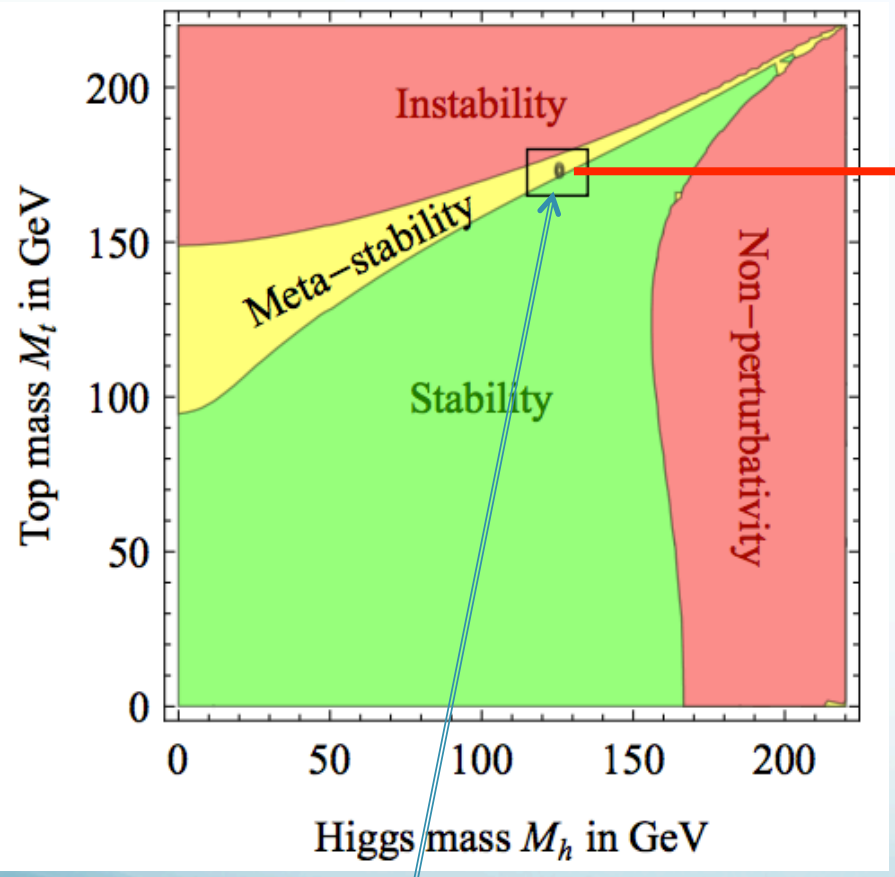
Higgs => Mass



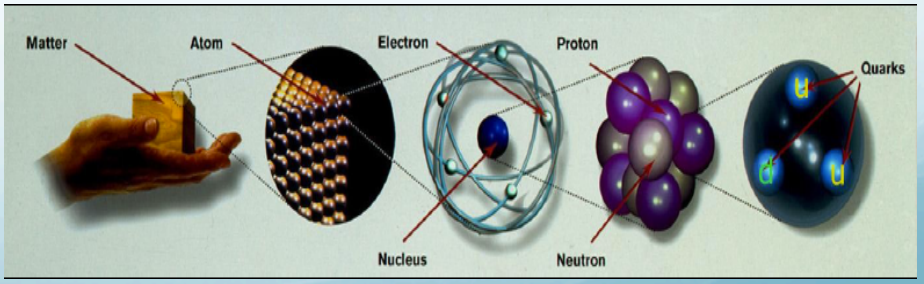
- Mass: ~173 GeV
  - The known heaviest element
- Large Yukawa Couplings
  - With Higgs: Yt=√2Mt/vev ~1
- Life time: ~$4*10^{-25}$
  - Decay before hadronization
- Produced with strong or electroweak interaction
- Precision test of SM
  - $\alpha_s(Mt) \sim 0.1$
  - pQCD calculation accurate

Top Mass

Metastable Universe?



Substructure of top quark?



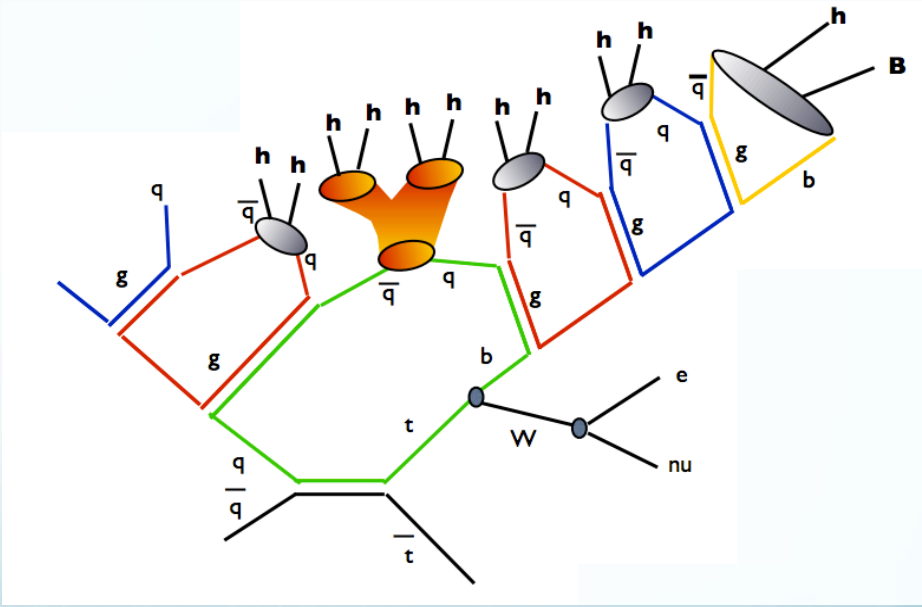
Main uncertainties from Top-quark Mass

Top quark Yukawa Couplings

- How to confirm the new observed boson is higgs?
  - Spin/Parity
  - Couplings to boson
  - Couplings to fermions =>Yukawa coupling
- Top quark Yukawa Coupling
  - With Higgs: $Yt=\sqrt{2}Mt/vev \sim 1$
  - The only Yukawa coupling that could be measure @ LHC
- Large Yt suggest special role of top in the electroweak symmetry breaking (EWSB)
- New physics concerning to EWSB preferably couple to top quark

Top quark lifetime

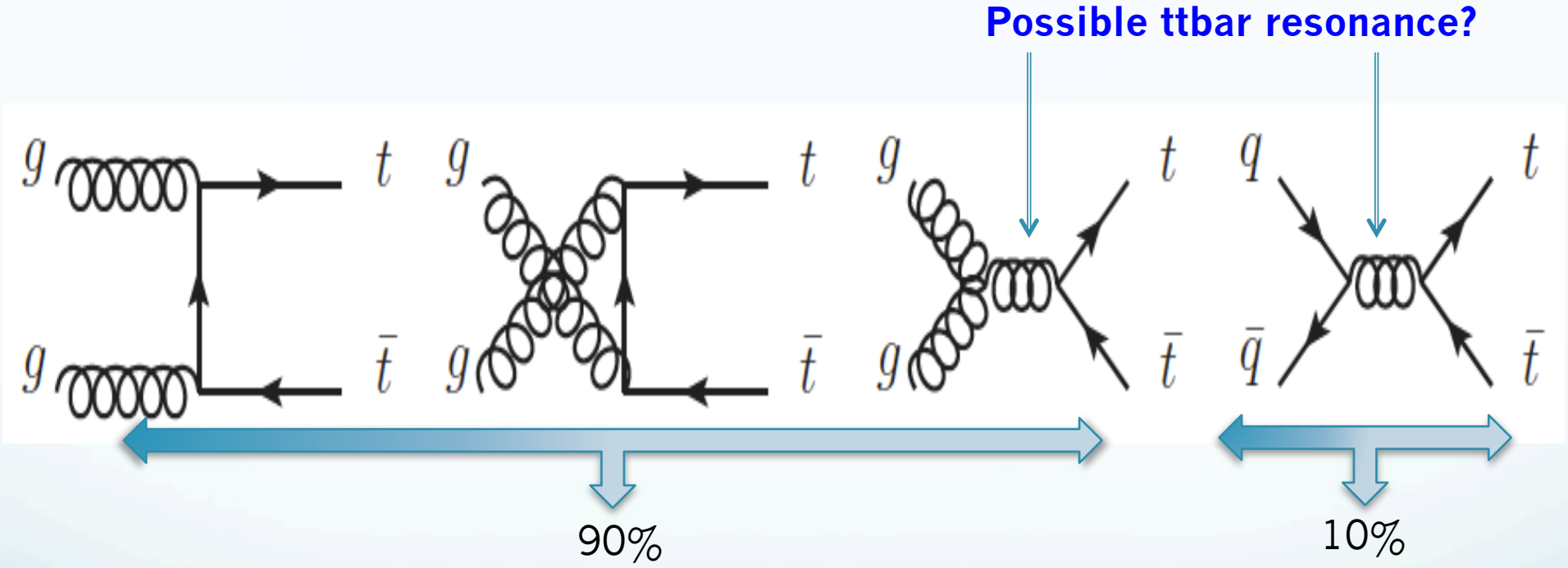
- Lifetime: ~4*10^{-25} Sec
  - Typical hadronization time ~3*10^{-24} Sec
  - Decay before hadronization
- Only place to study a “bare” quark properties
  - Mass
  - Spin
  - Polarization
  - Vtb
  - Charge



Top quark is a laboratory to precise test SM

top quark pair production

- Predicted by SM, production via **strong** interaction



164^{+13}_{-10} pb @ 7TeV

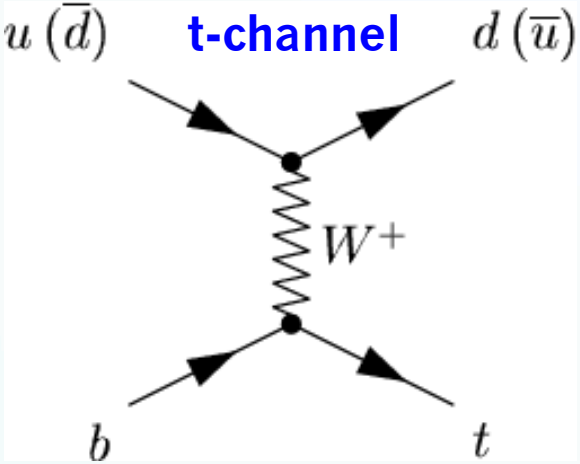
238^{+22}_{-24} pb @ 8TeV

Comput. Phys. Commun. 182 (2011) 1034

- First time observed at Tevatron in 1995

Single top-quark production

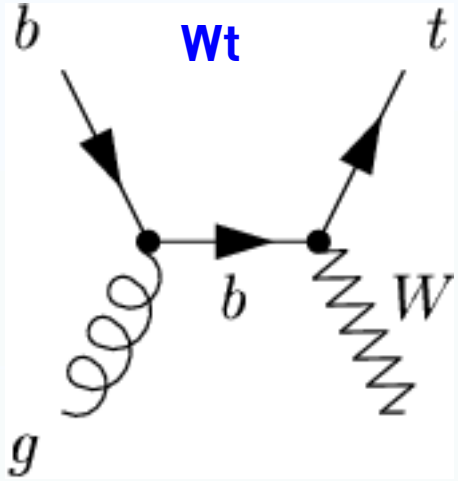
- Predicted by SM, production via **electroweak** interaction



$64.6^{+2.7}_{-2.0}$ pb @ 7TeV

$87.8^{+3.4}_{-1.9}$ pb @ 8TeV

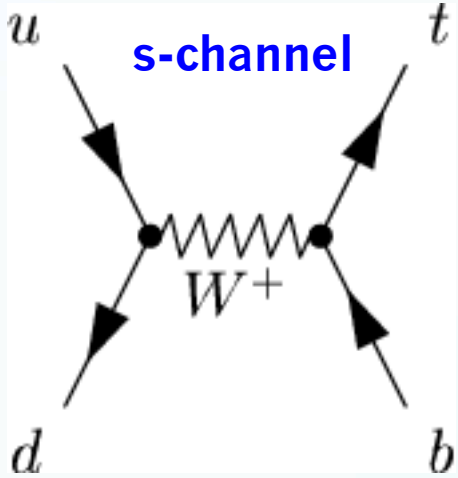
Calculated at NNLO approx. N. Kidonakis, Phys. Rev. D 83 (2011) 091503



15.7±1.1 pb @ 7TeV

22.4±1.5 pb @ 8TeV

Calculated at NNLO approx. N. Kidonakis, Phys. Rev. D 82 (2010) 054018



4.6±0.2 pb @ 7TeV

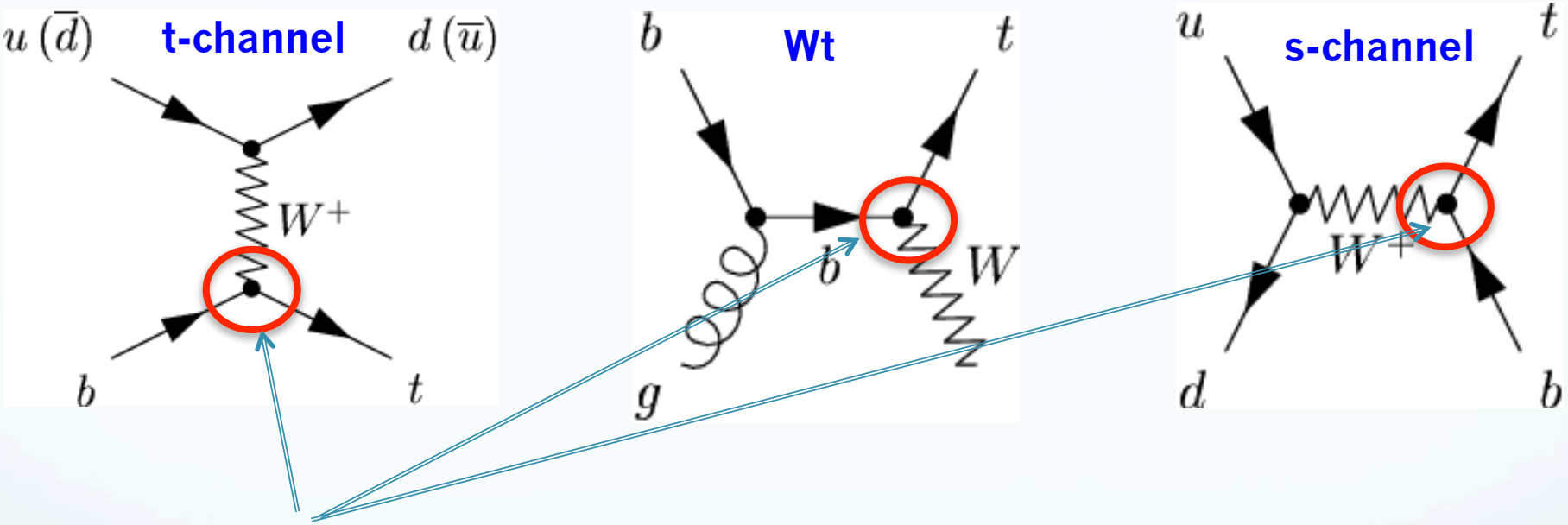
5.6±0.2 pb @ 8TeV

Calculated at NNLO approx. N. Kidonakis, Phys. Rev. D 81 (2010) 054028

- t-channel already observed at both Tevatron (2009) and LHC (2011)

Top quark physics (1)

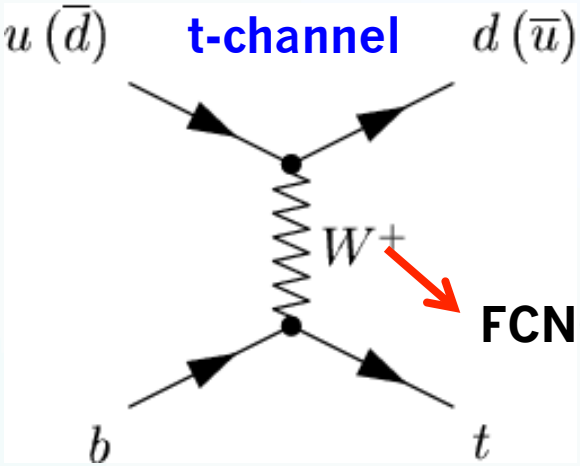
- Predicted by SM, production via electroweak interaction

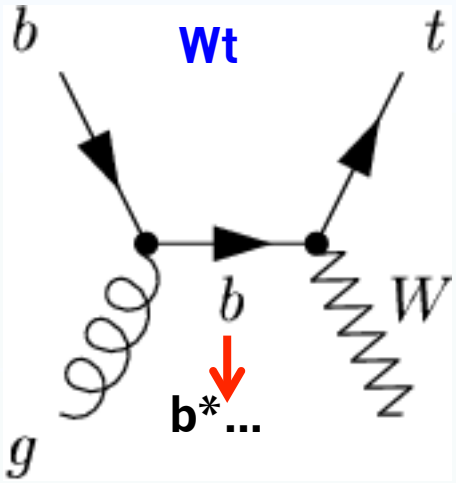


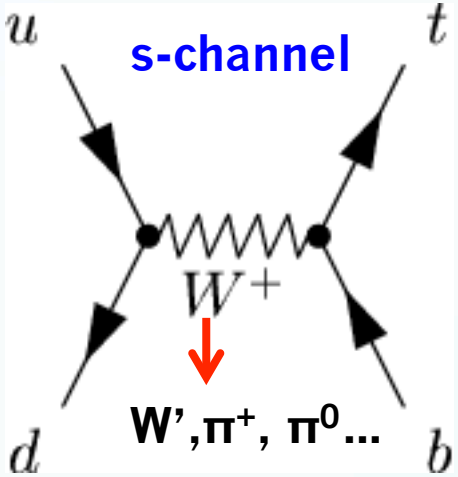
- Involve $|V_{tb}|$ in the production vertices: Direct measurement of $|V_{tb}|$.
- Production cross section proportional to $|V_{tb}|^2$: Very sensitive to modifications of $|V_{tb}|$.

Top quark physics (2)

- Predicted by SM, production via electroweak interaction

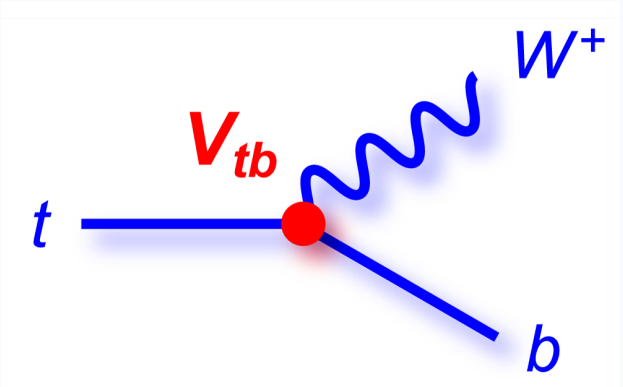




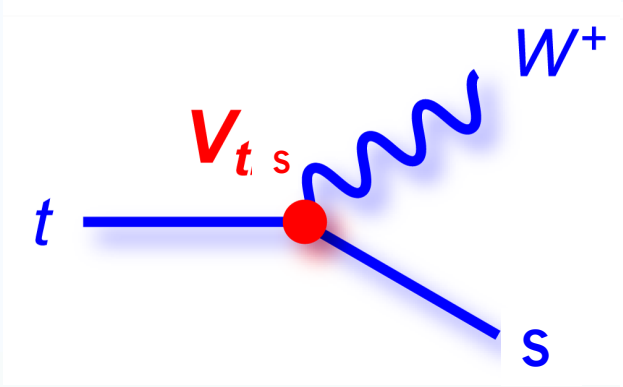


- Could involve beyond SM particles in the production: Direct search of new physics through EW interactions.
  - Complementary/Leading sensitivity to new physics searches
- Entangle the new physics once see different modification of single top-quark production cross section of these 3 channels

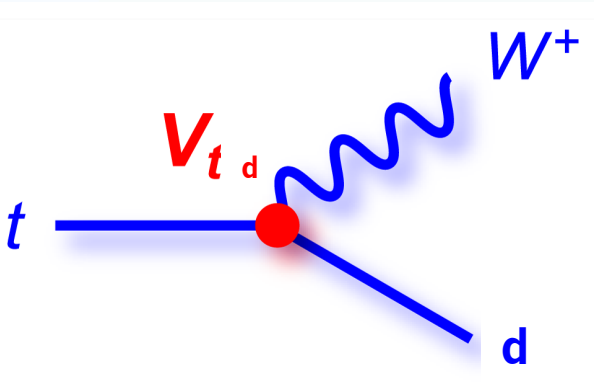
Top quark physics (3)



$Br(t \to bW^+) \simeq 0.998$

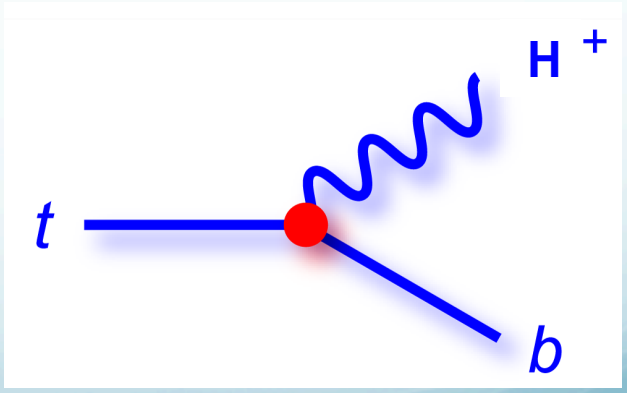


$Br(t \to sW^+) \simeq 0.0019$



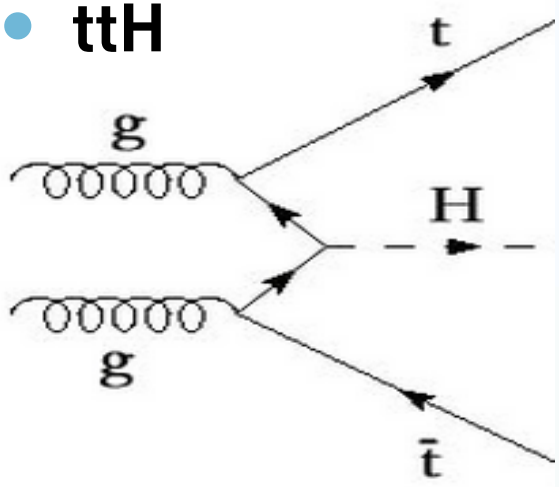
$Br(t \to dW^+) \simeq 0.0001$

- Check top decay products properties
  - Top polarization/W helicity
  - Charge Higgs searches
- Check extra radiations
- With Top pair
  - Spin Correlations

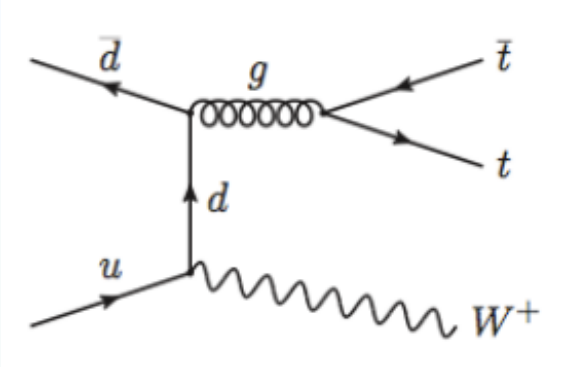


Other interesting top process

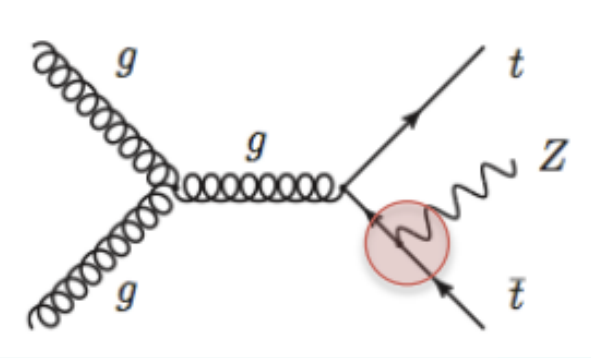
- **ttH**



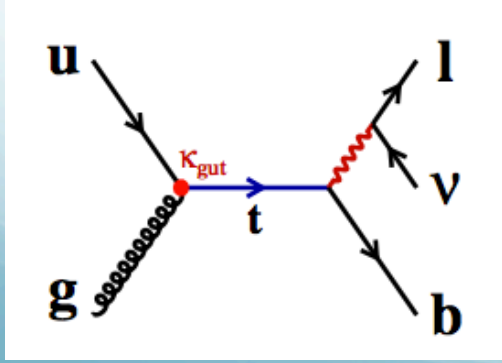
- **ttW**



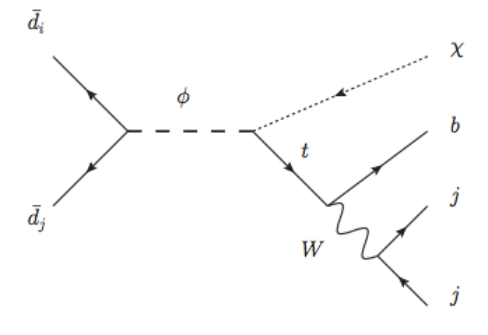
- **ttZ**



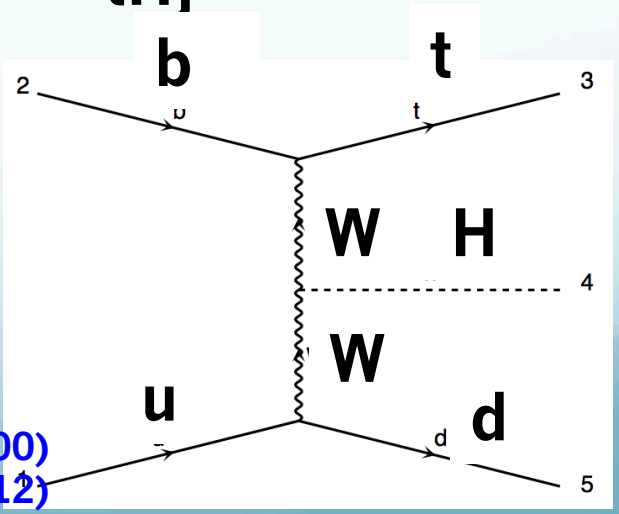
- **FCNC**



- **tX (RPV)**



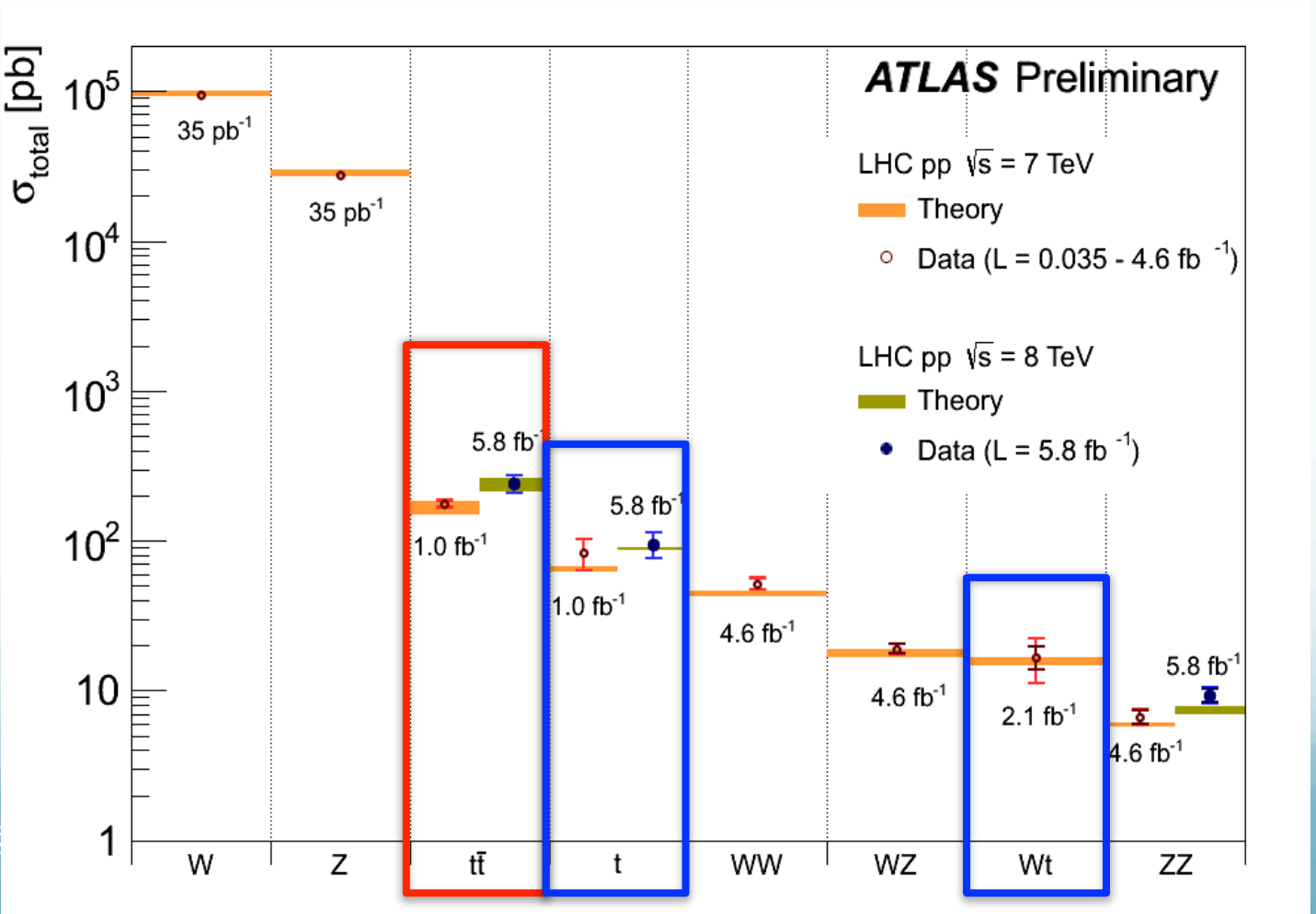
- **tHj**



Phys. Rev. D 63 014018 (2000)
Phys. Rev. D 86 034008 (2012)

top-quark @ LHC

- LHC is a top factory: 240k top events/fb @ 7TeV
- LHC Delivered per experiment: 5.7 M top pair, 2.7 M single top
  - 5fb-1 @ 7TeV, 20 fb-1 @ 8 TeV data



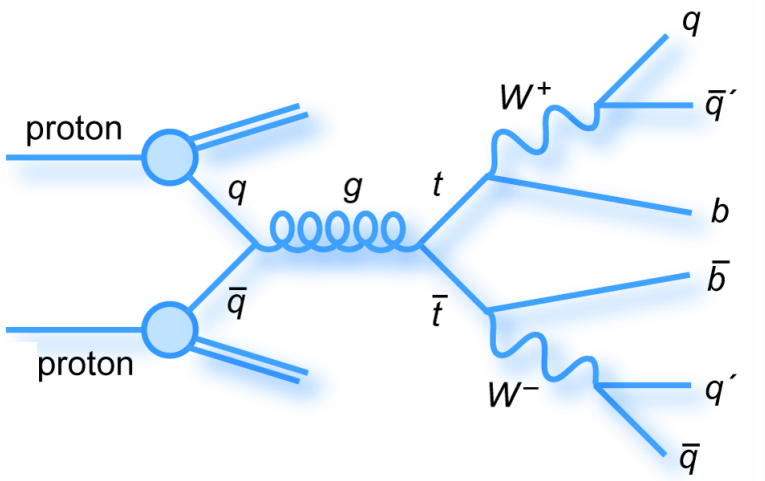
Top pair

top pair measurement @ LHC

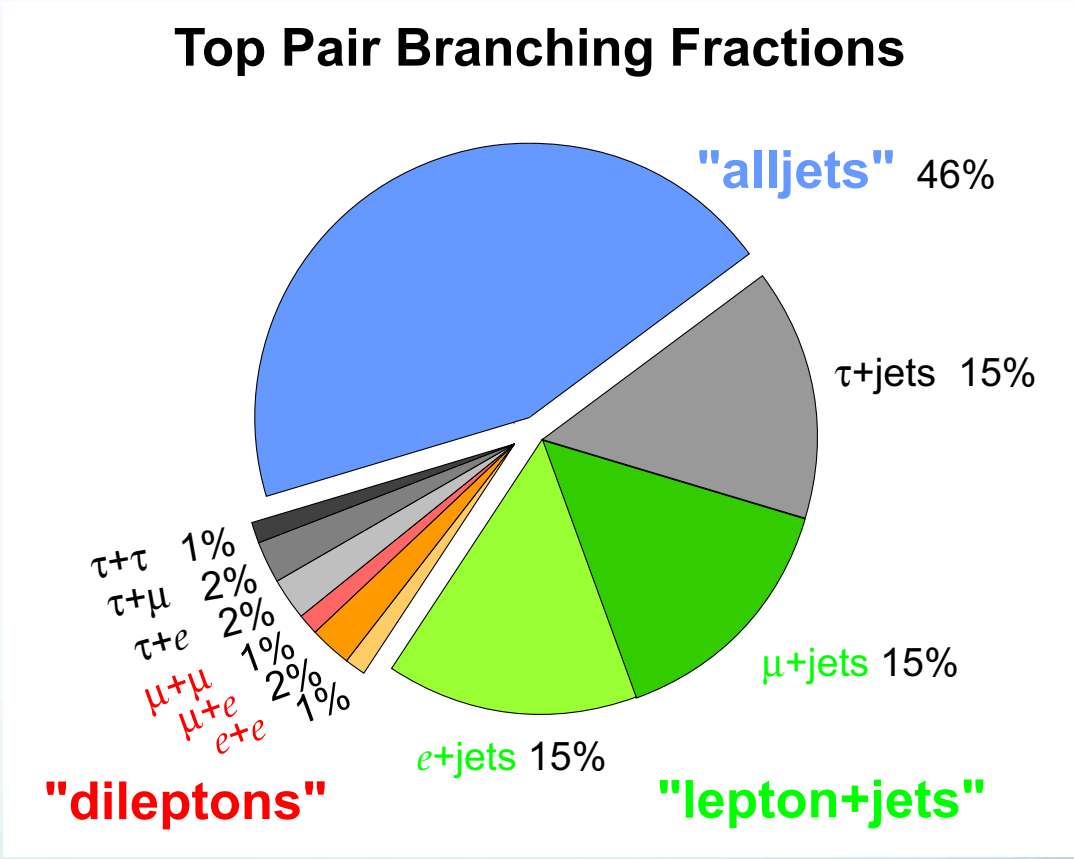
- Will cover:
  - Top mass; W helicity
  - Top pair production cross section/differential/extra jet

- Will not covered:
  - Top anti-top mass differences
  - Top pair associate with heavy flavor production
  - ttW/ttZ/ttgamma production measurement
  - Bottom quark content in top decay
  - Charge/FCNC/....

Top quark pair @ LHC



- Final state used with dedicated selection and background modeling
  - Lepton + jets channel
  - Dileptonic channel
  - Full hardronic channel
  - Tau final state channel

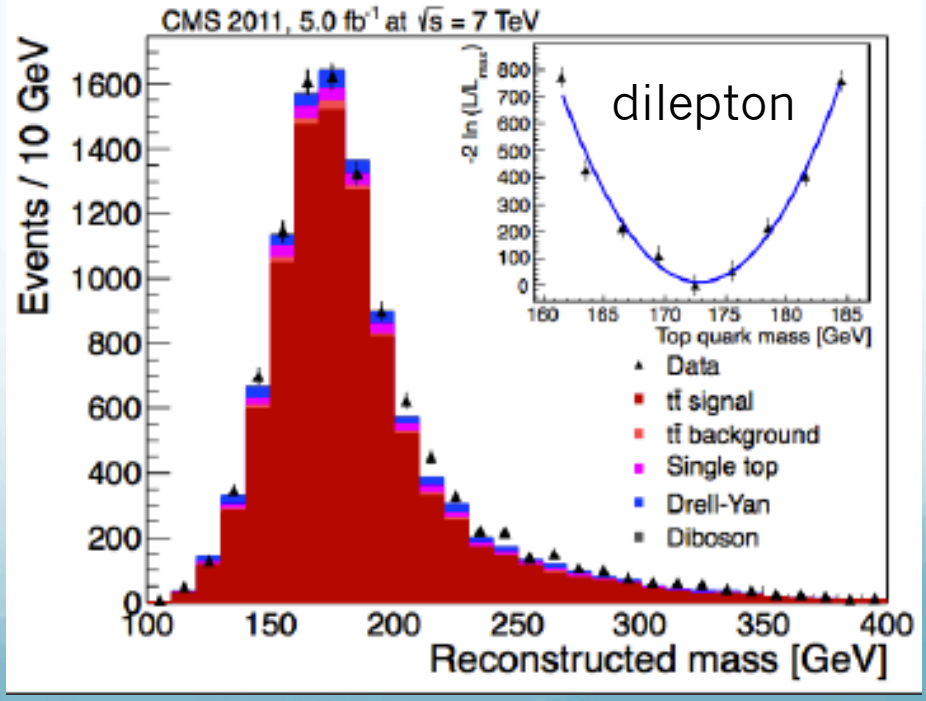


Top pair event selection

- Common to ATLAS and CMS, sel. according to event topology
- Lepton + jets channel
  - One high Pt lepton (e/mu), typical Pt>25 GeV
  - At least 4 high Pt jets, typical Pt>25 GeV
  - B-jets multiplicity requires, typically =2
- Dilepton channel
  - Two high Pt lepton (e/mu), typical Pt>25GeV
  - At least 2 jets, typical Pt>25 GeV
  - B-jets multiplicity requires, typically =2
- Full hadronic channel
  - At least 6 high Pt jets, of which 2 are b jets
- Channel involve tau lepton
  - Hadronic tau ID (tau equal e/mu in other topology)

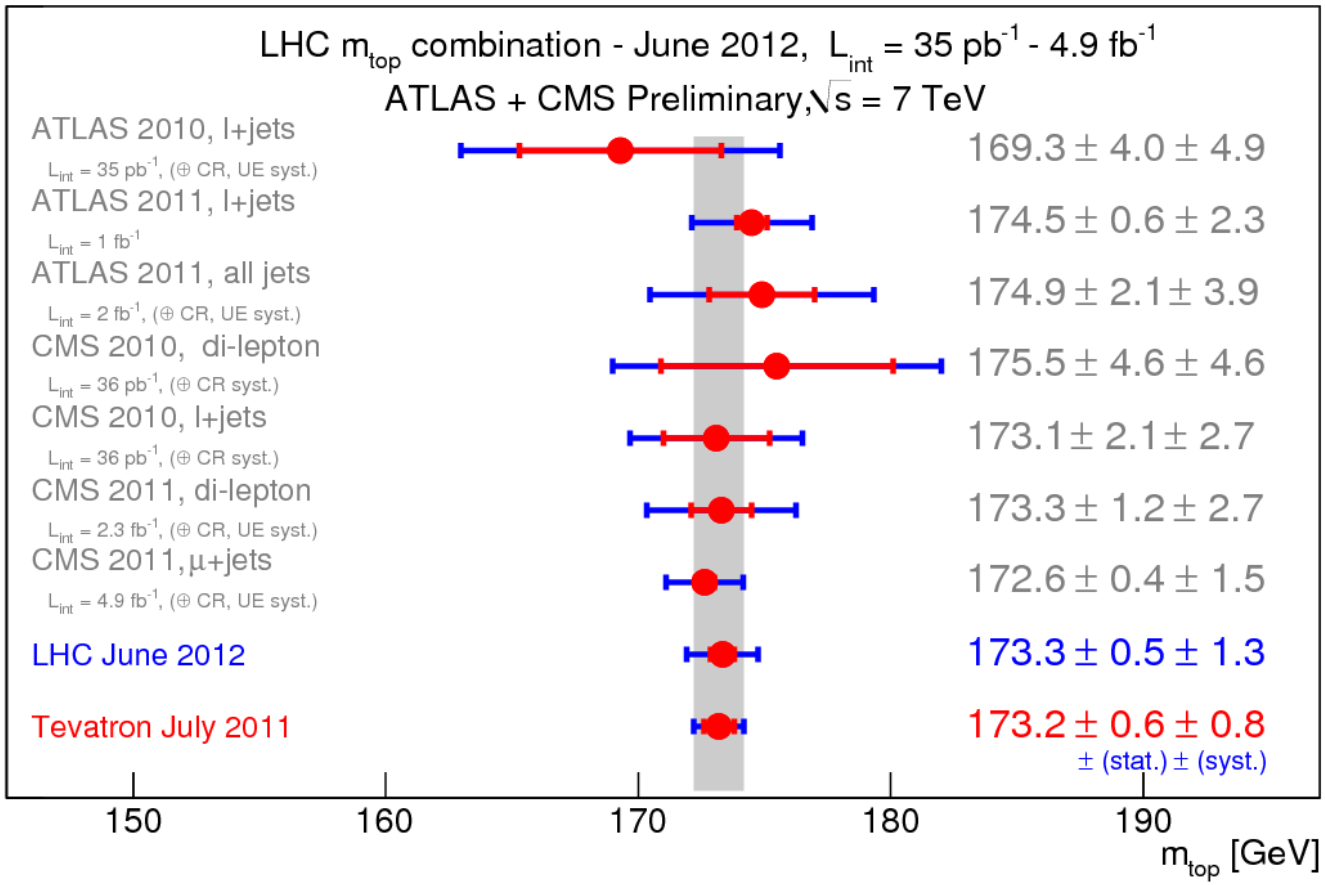
Top Mass Measurement

- Top mass limit our knowledge to the stability of vacuum
- Performed in lepton+jets, dilepton, full hadronic final states @ both ATLAS and CMS
  - Fully reconstruct in lepton+jets and full hadronic FS
  - Special weighting procedure in dilepton FS
- Combination of different experiments => best meas.
  - ATLAS+CMS
  - Tevatron
- Systematics
  - Detector effects
  - Signal modeling



Top Mass measurement

ATLAS-CONF-2012-095
CMS-PAS-TOP-12-001



Combination with BLUE (Best Linear Unbiased Estimator)

- **challenge: correlation of uncertainties especially different theory treatment**

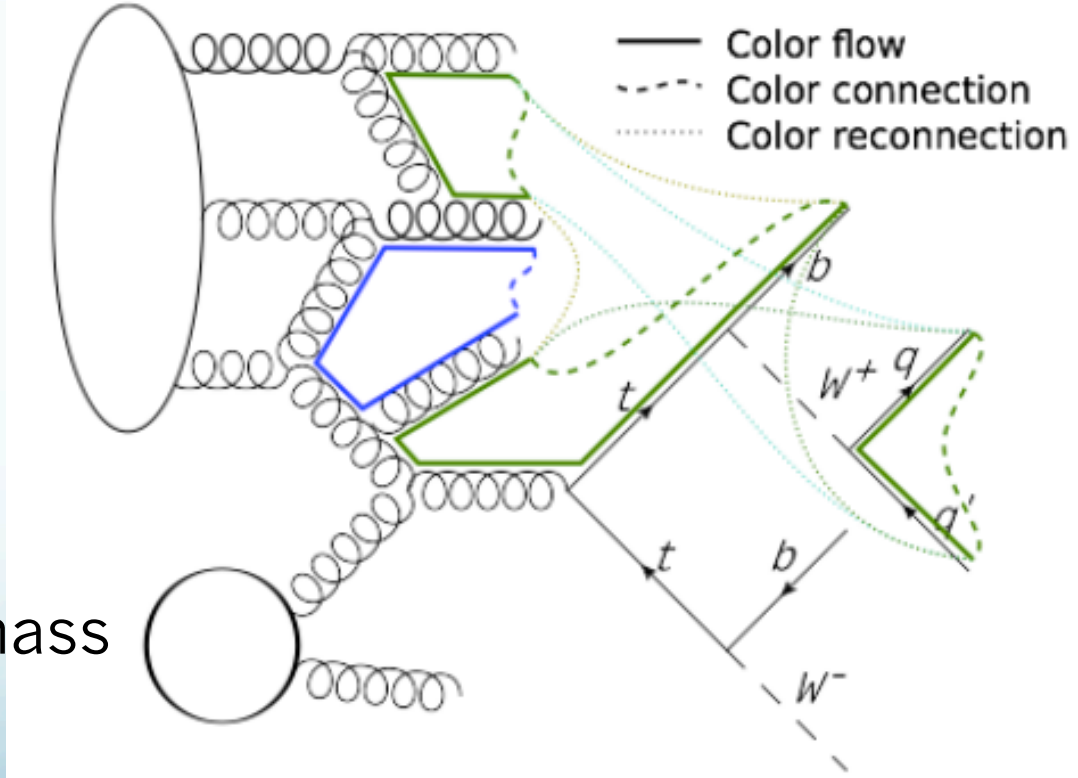
$$m_{\text{top}} = 173.3 \pm 0.5\ (\text{stat}) \pm 1.3\ (\text{syst})\ \ \text{GeV}.$$

Challenge in Mass meas.

- Top decay before Hadronization
  - Need extra antiquarks be added later
  - M_{top}^{exp} != M_{top}^{pole}
  - Mtop dependent on how event evovled
    - Event dependent mass
- LHC main uncertainties
  - Jet calibration
  - Signal modeling
  - Underlying event tune
- Lasted individual result with event dependent mass

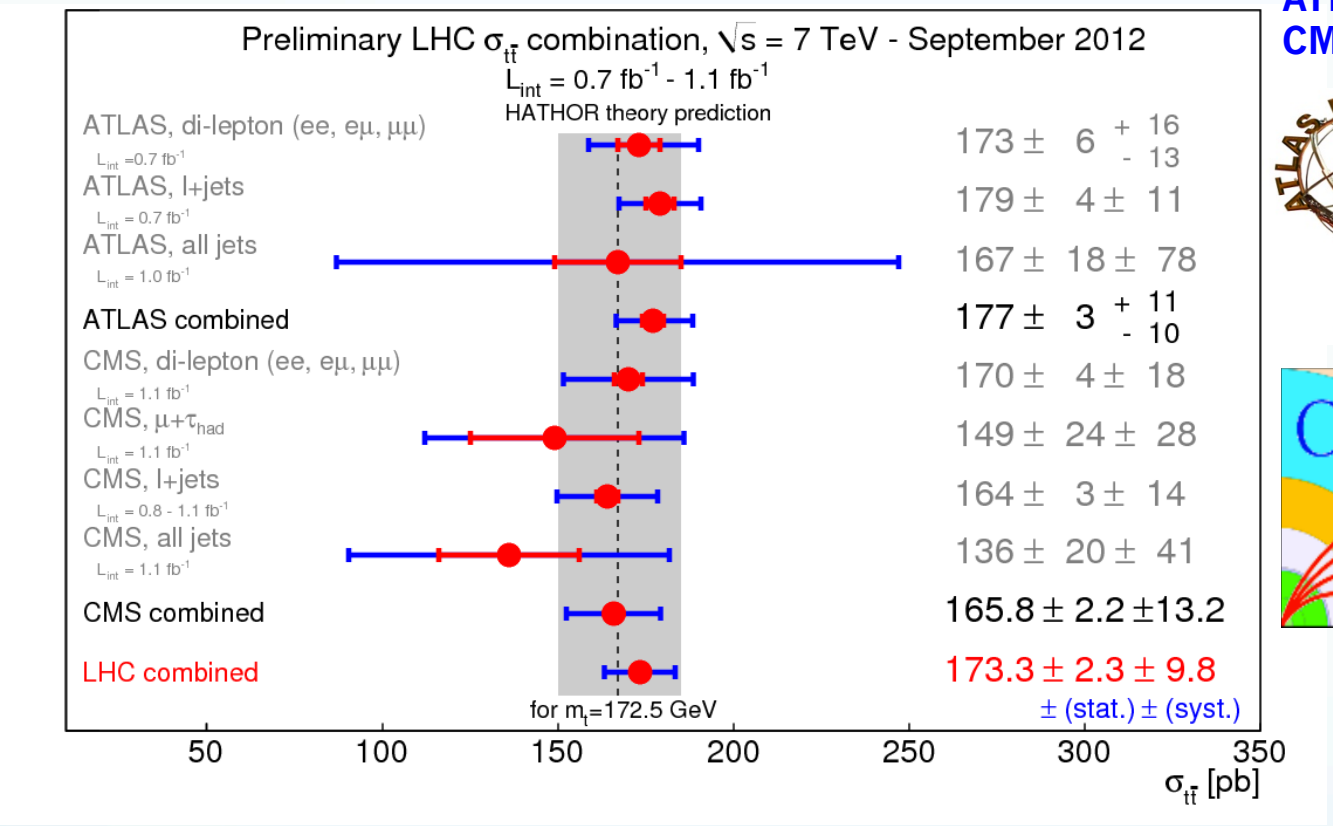
CMS-PAS-TOP-12-029

https://indico.cern.ch/getFile.py/access?contribId=3&resId=0&materialId=slides&confId=189617



Top pair cross section meas.

ATLAS-CONF-2012-134
CMS-PAS-TOP-12-003



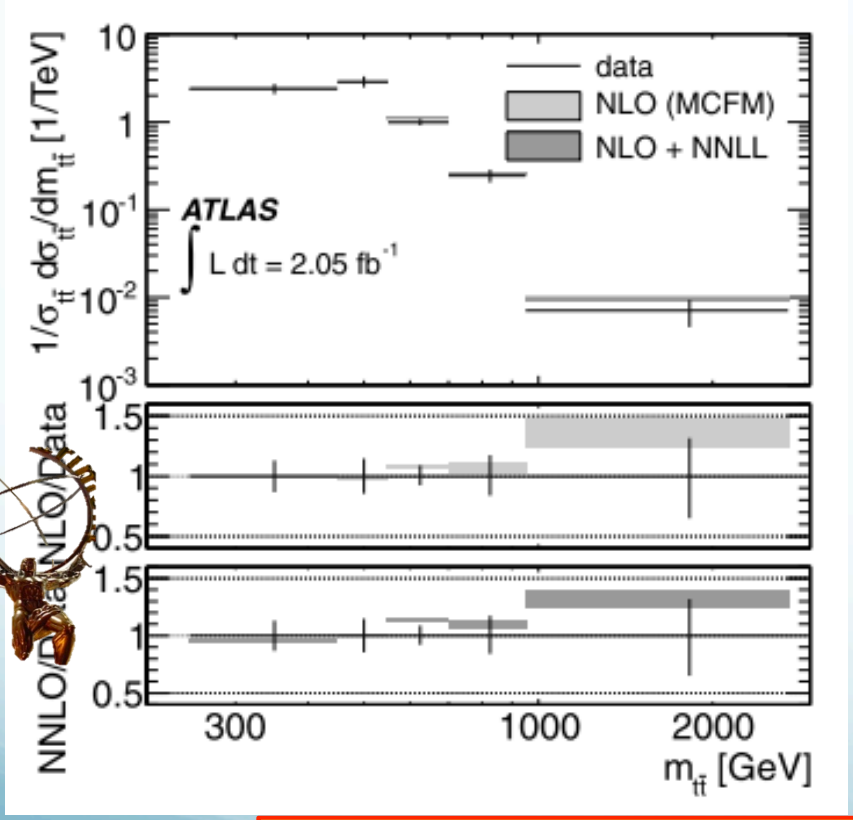
- **Measurement performed with dilepton, lepton+jets, full hadronic channel at both ATLAS and CMS**
- **First LHC combination with BLUE (Best Linear Unbiased Estimator)**
- **Dominate uncertainties: Luminosity, Detector modeling**

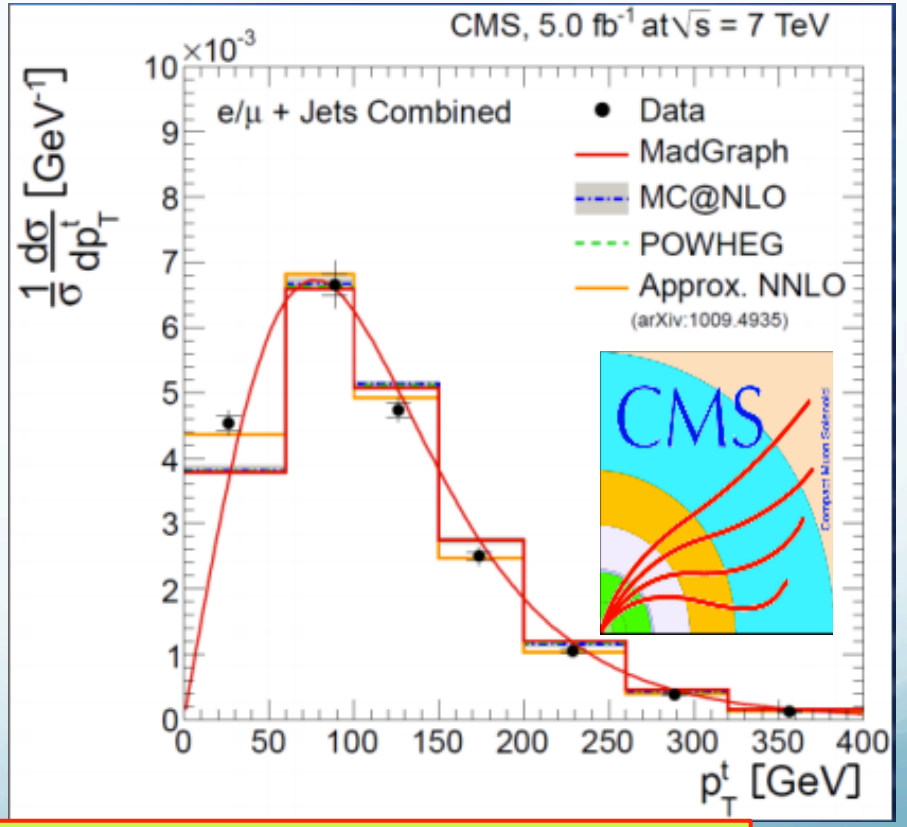
$$\sigma_{t\bar{t}} = 173.3 \pm 2.3\,(\text{stat.}) \pm 7.6\,(\text{syst.}) \pm 6.3\,(\text{lumi.})\ \text{pb}$$

Top pair differential cross section

EPJC(2013)73:2261/arXiv:1211.2220

- Precise test of pQCD
- Unfolding experimental observables back to theory interested quality => compare to theory





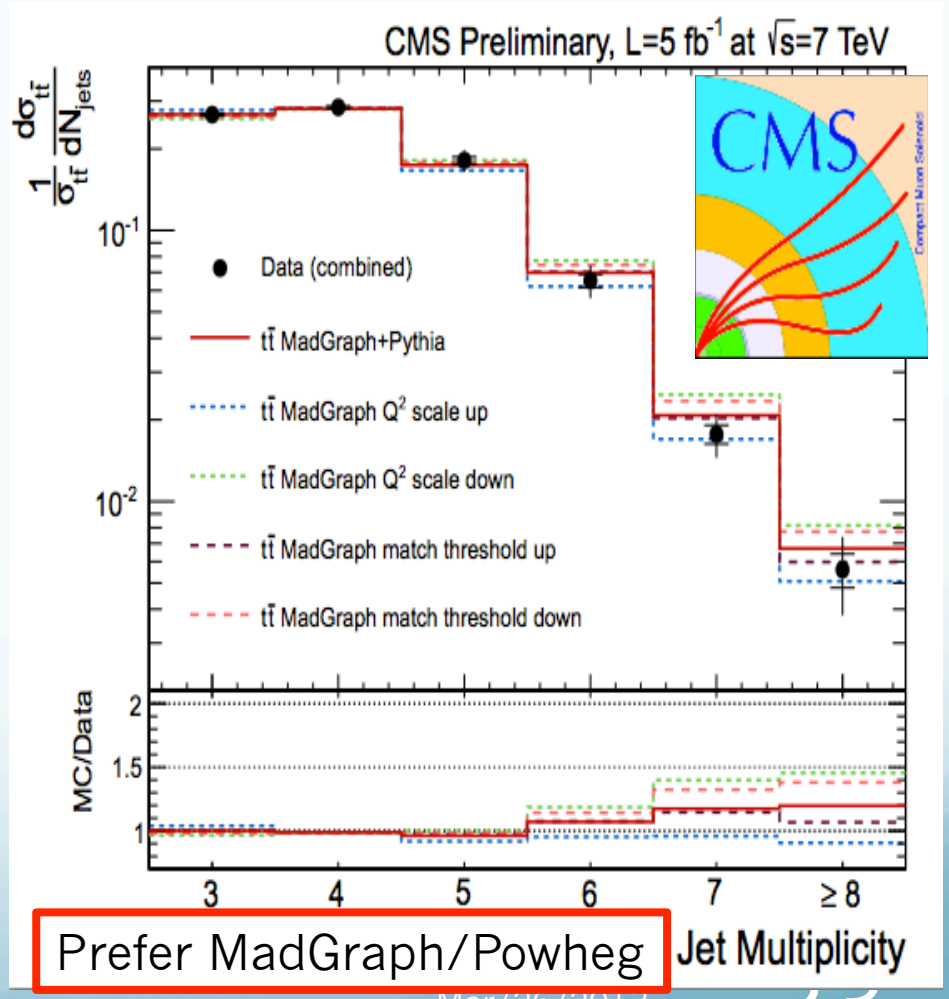
Good agreement between data and app. NNLO prediction

Extra jets activity (1)

- Test Radiation from Initial/final state
- Unfold Njet dist. Compare with several MC model
- Systematics dominated by Jet/EtMiss reco.

ATLAS-CONF-2012-155
CMS-PAS-TOP-12-018

Prefer Alpgen/Powheg

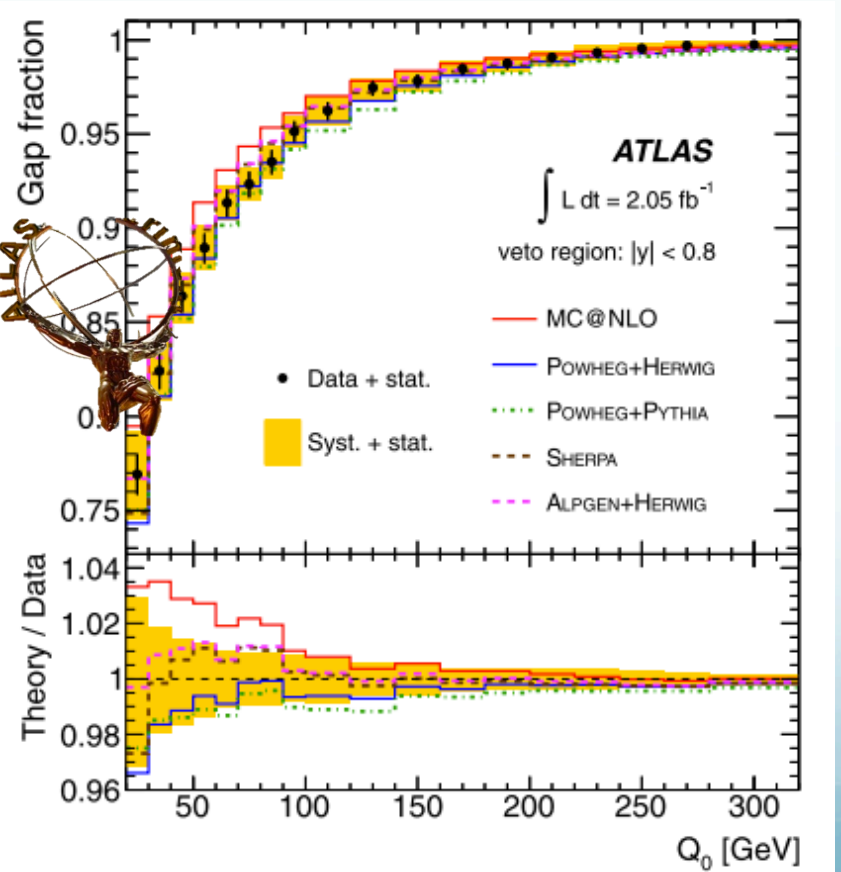


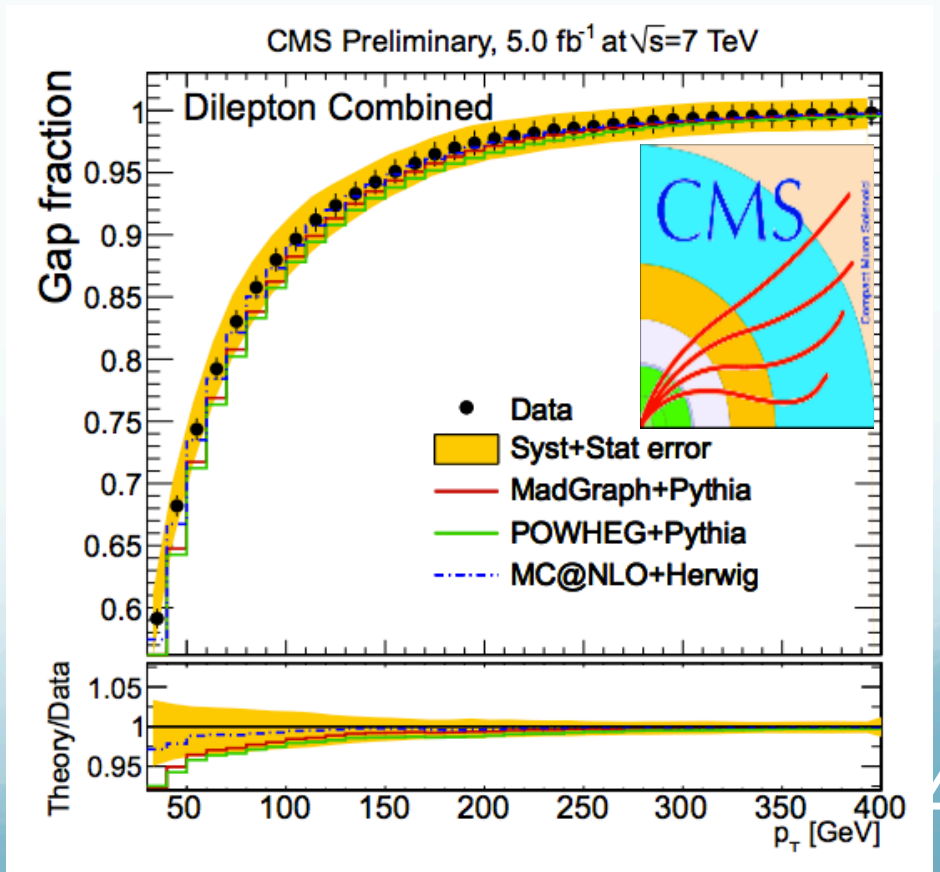
Prefer MadGraph/Powheg

Extra jets activity (2)

EPJC 72 (2012) 2043
CMS-PAS-TOP-12-023

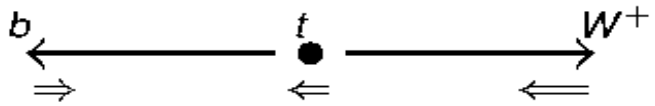
- Exclusively select dilepton final states with 2 b-jets
  - Any extra light jets should come from ISR/FSR
- Tuning Simulation to have proper ISR/FSR radiation



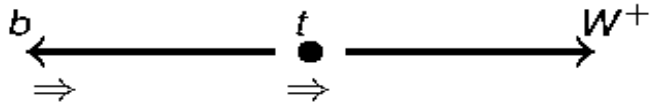


W boson helicity

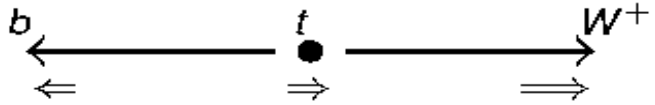
- $t \to bW^+(h_W = -1)$ Allowed: *Prob.* $\sim 30\%$.

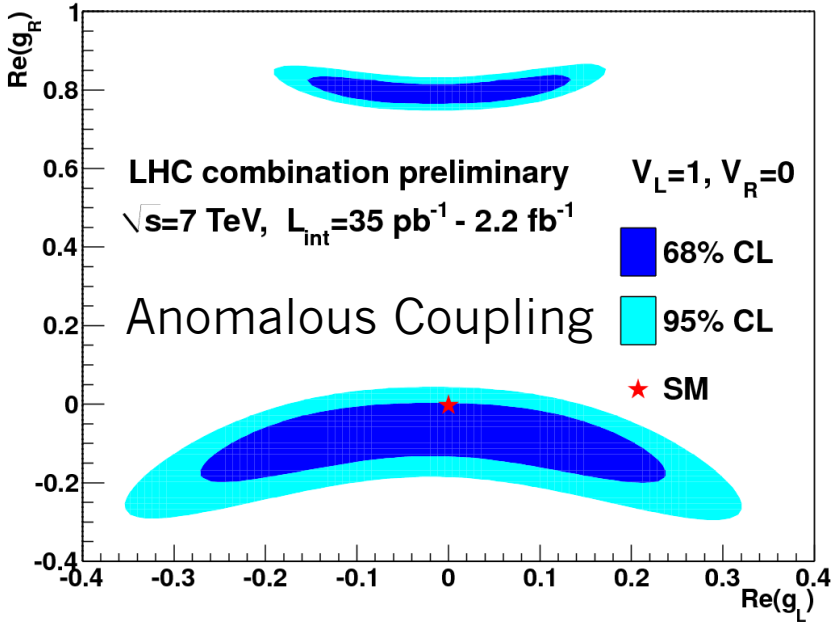


- $t \to bW^+(h_W = 0)$ Allowed: *Prob.* $\sim 70\%$.

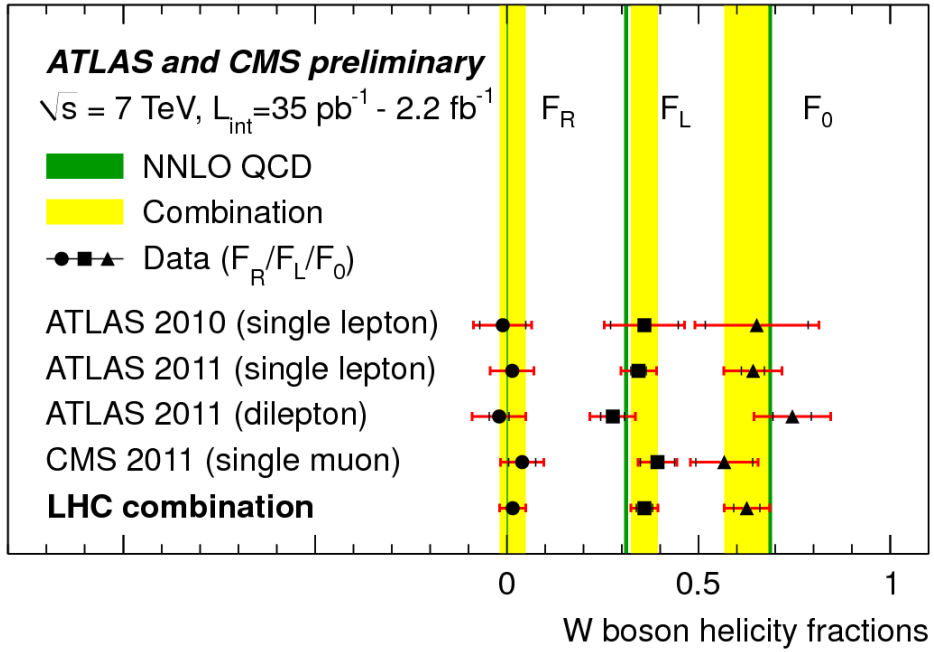


- $t \to bW^+(h_W = +1)$ Forbidden for $m_b = 0$



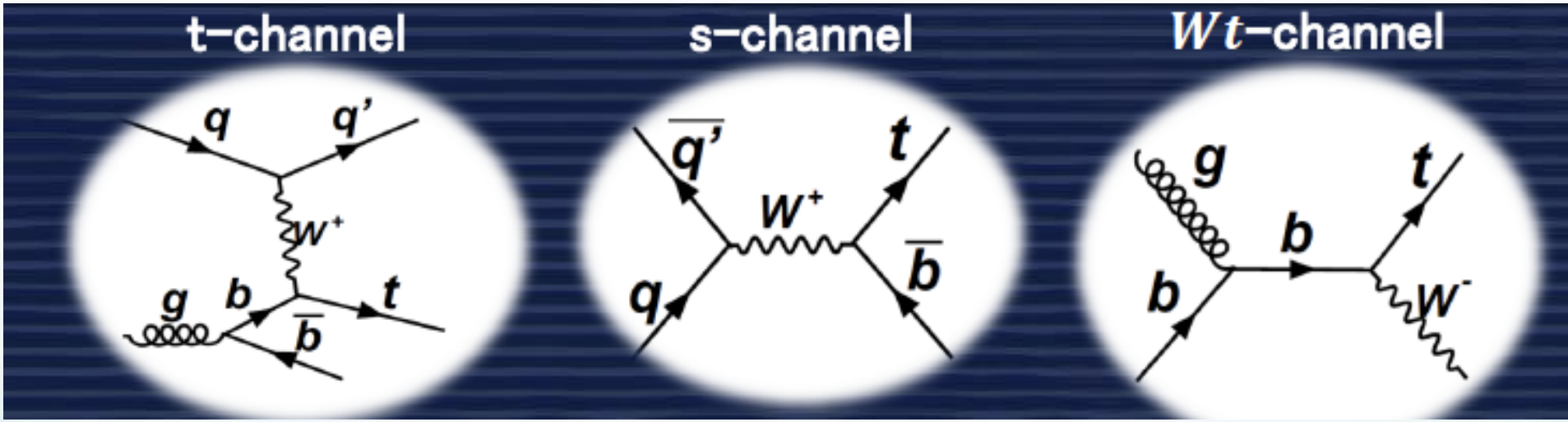


ATLAS-CONF-2013-033
CMS-PAS-TOP-12-025



$$F_0 = 0.626 \pm 0.034\ (\text{stat.}) \pm 0.048\ (\text{syst.})$$
$$F_L = 0.359 \pm 0.021\ (\text{stat.}) \pm 0.028\ (\text{syst.})$$

Single top

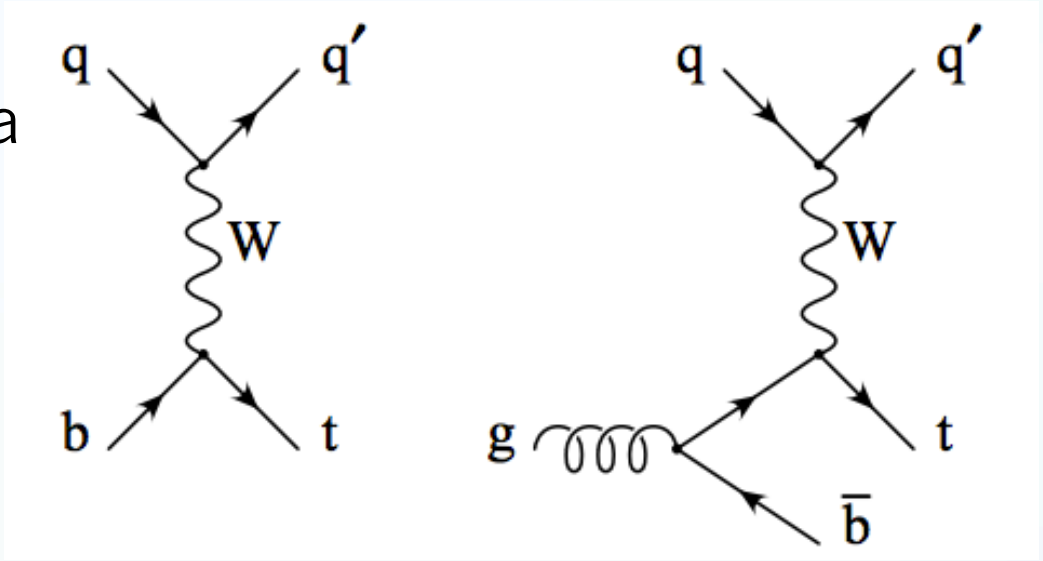


SM single top-quark analysis

- t-channel single top-quark measurement
  - Precision measurement at 8 TeV
- Wt channel single top-quark Evidence
  - Only accessible at LHC
  - Evidence with 7 TeV data (This talk)
  - Expect observation/measurement with 8 TeV data
- s-channel single top-quark searches
  - First limit setting (This talk)
  - Still a long way to an observation

t-channel single top

- Interaction of light quark and b-quark by exchange a W boson
  - Single top-quark + recoil light quark
- More than 1/3 of top-pair cross section

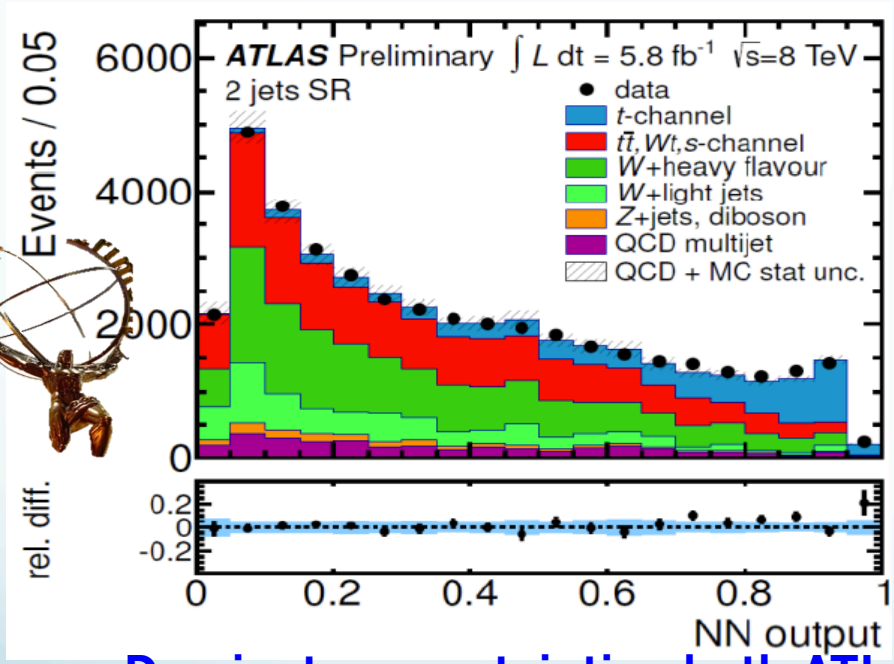


- Searches with top quark leptonic decay
  - Select events with one lepton + 2 jets, during one is b jet
  - Single top-quark system could be reconstructed
- Observed both at Tevatron and LHC

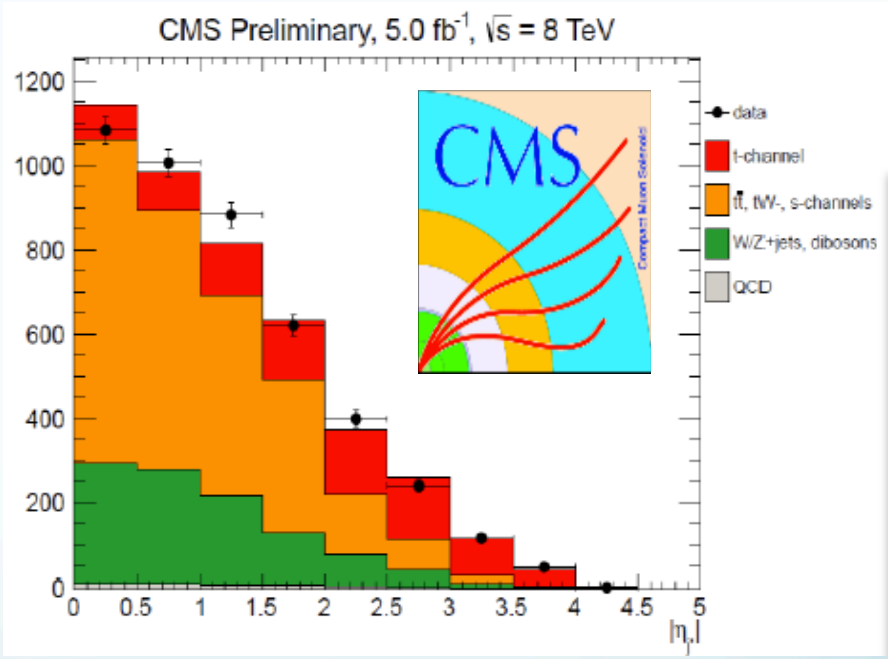
t-channel: meas. @ 8 TeV

ATLAS-CONF-2012-132/CMS-PAS-TOP-12-011

- **Use Neural Network to combine several variables**
- **Fit the NN output to extract signal**



- **Fit the recoil light jet |eta| to extract signal**
- **Direct measurement of |Vtb|**

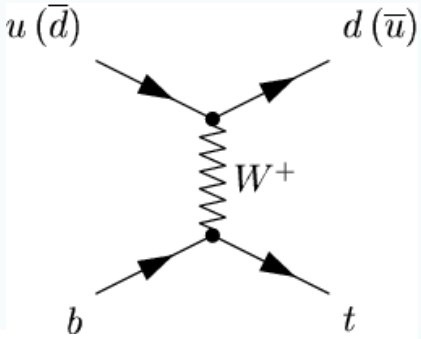


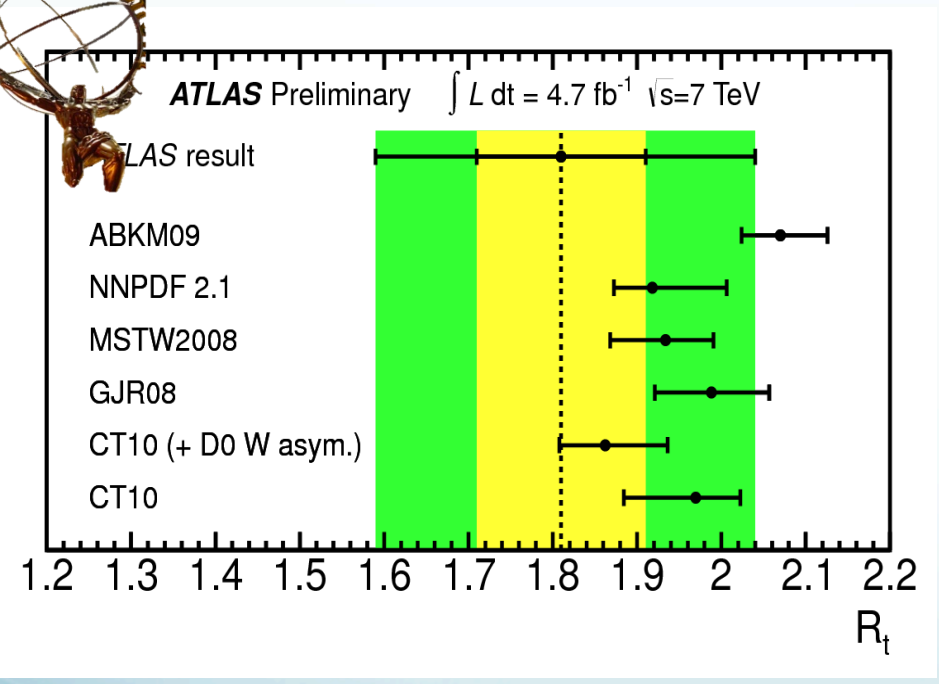
Dominate uncertainties both ATLAS/CMS: JES/b-tag/modeling

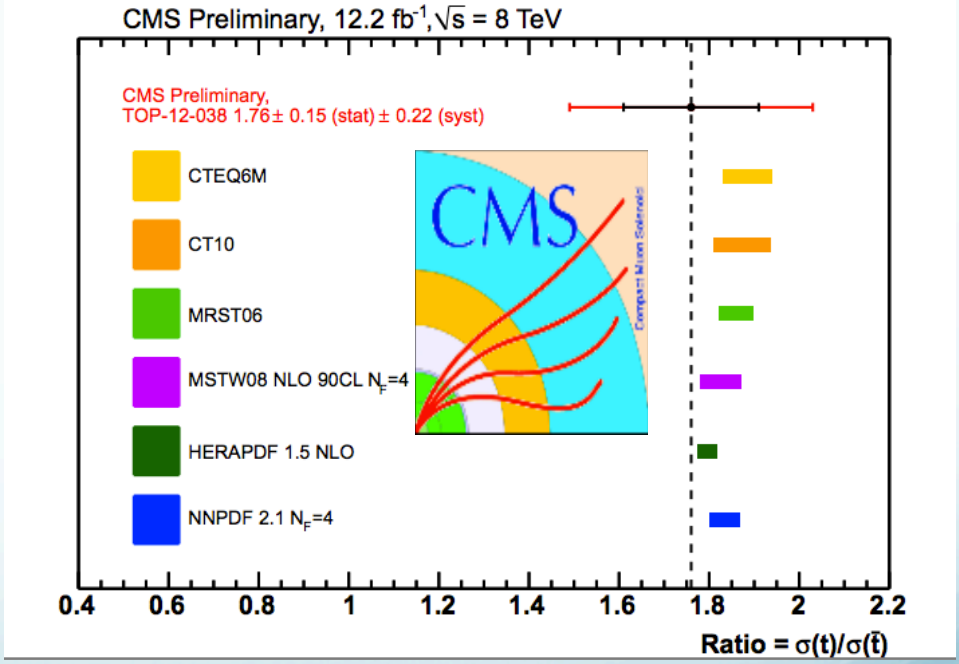
	L[fb^{-1}]	t-channel cross section [pb]	$\|V_{tb}\|$
ATLAS	5.8	$95.1 \pm 2.4(\text{stat.}) \pm 18.0(\text{syst.})$	$1.04^{+0.10}_{-0.11}$
CMS	5.0	$80.1 \pm 5.7(\text{stat.}) \pm 11.0(\text{syst.}) \pm 4.0(\text{lumi.})$	$0.96 \pm 0.08(\text{exp.}) \pm 0.02(\text{th.})$

t-channel: Charge asymmetry

- Same strategy as t-channel analysis, charge separated
- Initial u/d quark determines the final state lepton charge
- Ratio of t-channel lepton charge => light quark PDF info.
- Dominate uncertainties: JES/background modeling
- Agreement with SM predictions







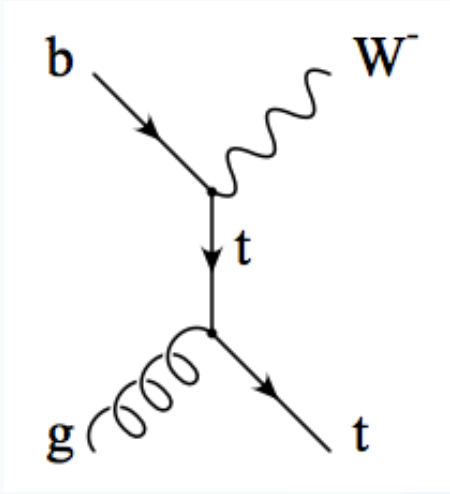
$$R_t = 1.81 \pm 0.10\,(\text{stat.})\,^{+0.21}_{-0.20}\,(\text{syst.})$$

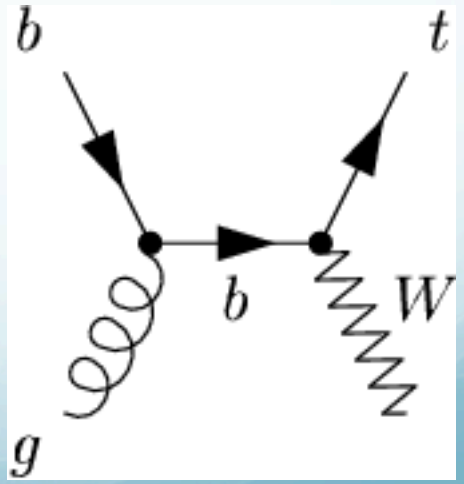
$$R_{t\text{-ch.}} = 1.76 \pm 0.15(\text{stat.}) \pm 0.22(\text{syst.})$$

ATLAS-CONF-2012-056
CMS-PAS-TOP-12-038

Wt-channel single top

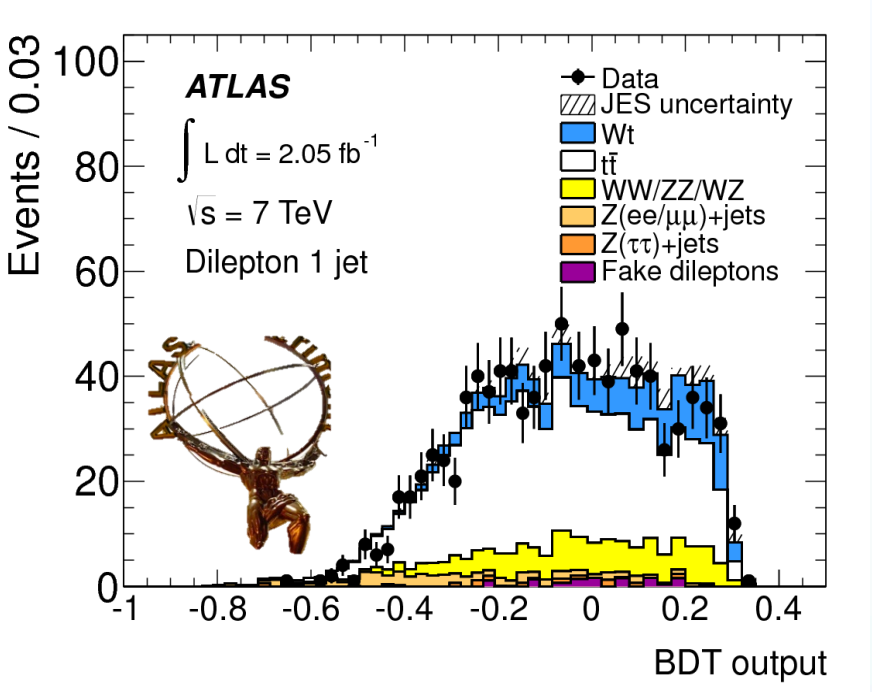
- Single top quark associate production with a W Boson
- 1/10 of ttbar cross section
  - Abundant signal
- Difficulty: Separation against top-pair events
- Searches both at the tow W all leptonic decay channel (Dilepton) signal region:
  - Two leptons+jet+MET
  - CMS require the extra jet is b-jet
- **First evidence** seen by ATLAS with 2 fb^{-1} data and confirmed by CMS with 5 fb^{-1} data
- Observation expected with 8 TeV data



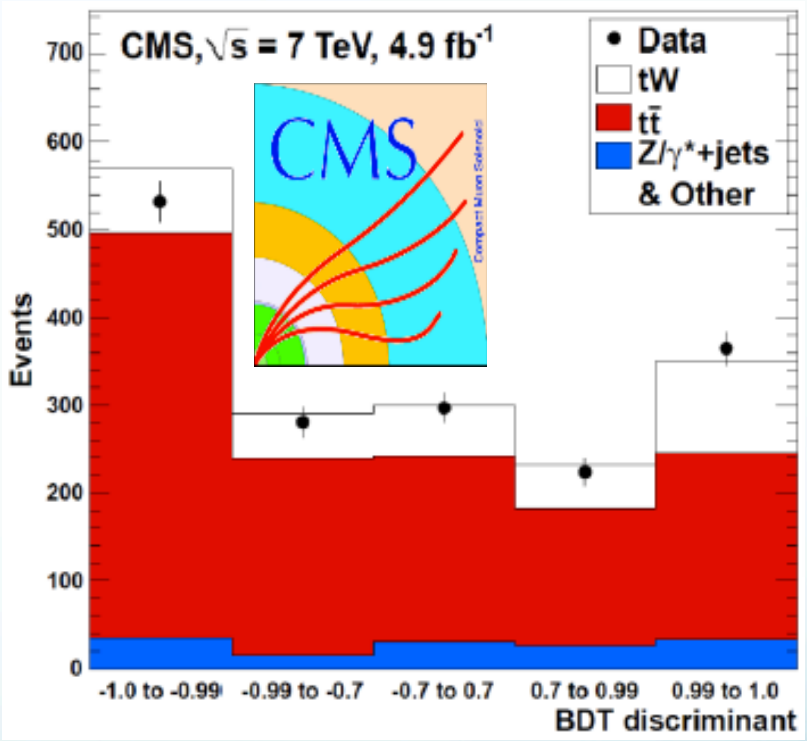


Wt channel: strategy

- BDT analysis with 22 var.



- BDT analysis with 4 var.
  - Cross check with cut based



- **Maximum likelihood fit to BDT output Includs extra jet bin to control top pair**
- Simultaneous determination of signal and background rates
- Interpreted to |Vtb| by assume Wt mainly produced from |Vtb|, without any assumption on top decay

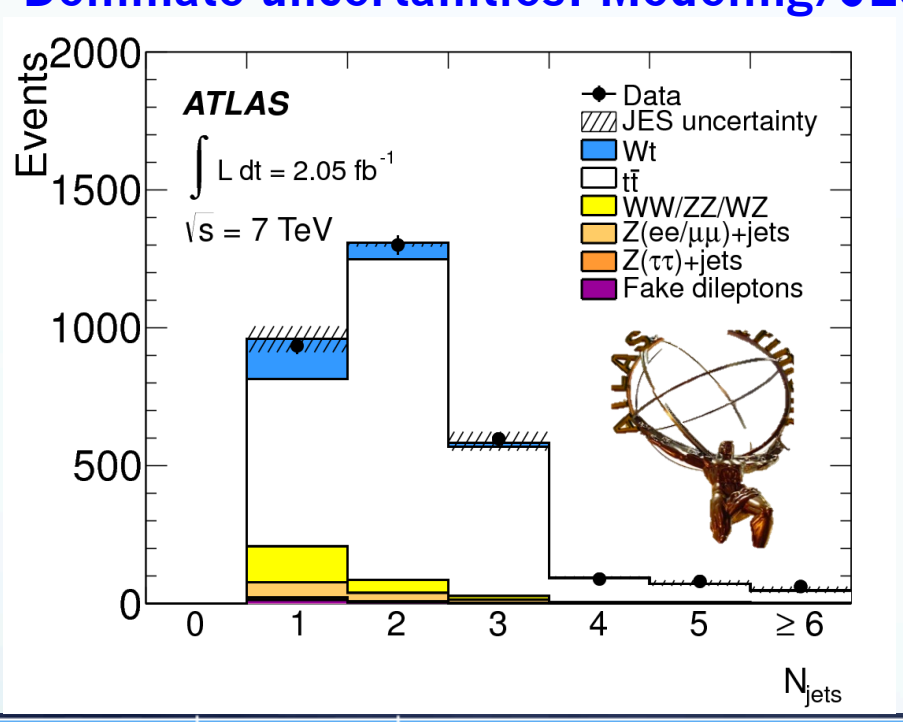
$$\mathcal{L}(\sigma_{Wt}, \vec{\alpha}) = \prod_{i=1}^{3} \prod_{j=1}^{N_{bin}} \mathcal{P}\left(N_{i,j}^{obs} | N_{i,j}^{exp}(\vec{\alpha})\right) \prod_{k=1}^{N_{syst}} G(\alpha_k | 0, 1)$$

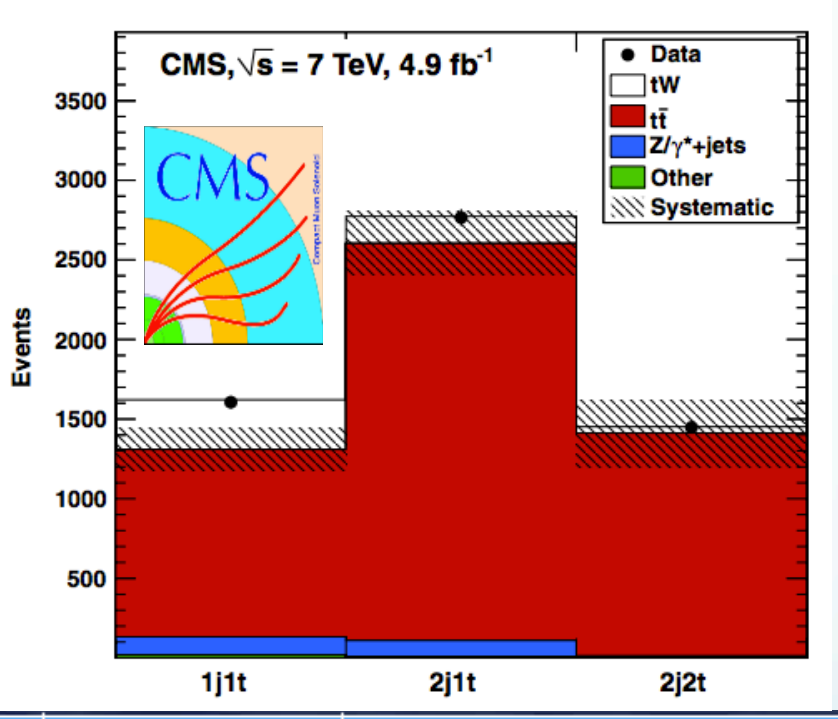
Wt channel: results

Total uncertainties: 34% (ATLAS) vs 31%(CMS)

Dominate uncertainties: Modeling/JES/Statistics

PLB 716 (2012) 142-159
PRL 110, 2013 022003





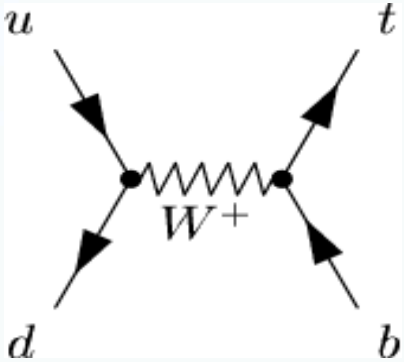
	L [fb^{-1}]	Wt cross section [pb]	Significance	$\|V_{tb}\|$
ATLAS	2.05	$16.8 \pm 2.9(\text{stat.}) \pm 4.9(\text{syst.})$	3.3σ	$1.03^{+0.16}_{-0.19}$
CMS	4.9	16^{+5}_{-4}	$4.0\,\sigma$	$1.01^{+0.16}_{-0.13}(\text{exp.})^{+0.03}_{-0.04}(\text{th.})$

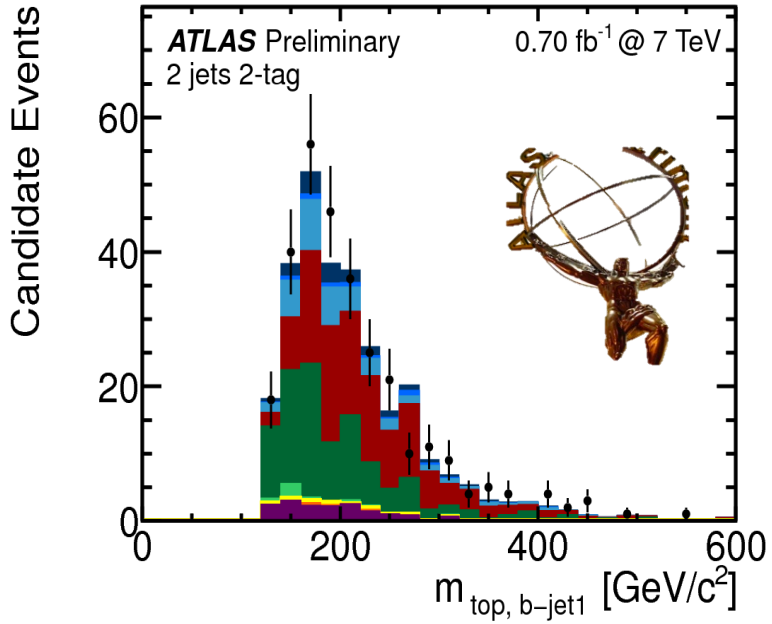
First evidence

s-channel single top

- Production through an off-shell W boson
  - Single top-quark + central b-quark
- Less than 1/30 cross section of top pair events
  - Difficulty: Suffers from large background and small signal cross section
- Searches with leptonic top decays
  - Single top-quark system reco.
- Main uncertainties from:
  - Data statistics 100%
  - Others from 20-60%
- First preliminary limit at ATLAS

$$\sigma_t \text{ (s-channel)} < 26.5 \text{ pb}$$





New physics with top signature searches

New physics with top signature searches @ LHC

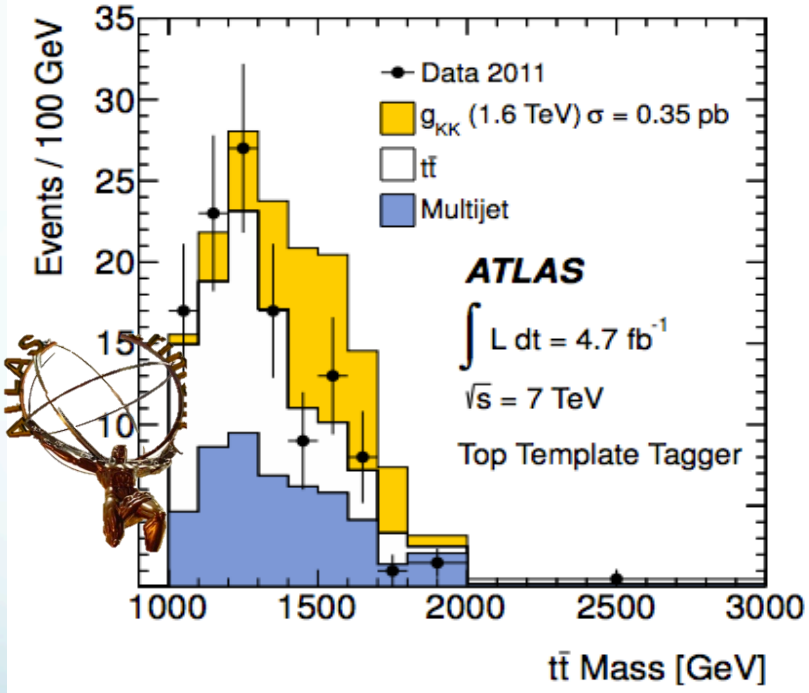
- Only Cover
  - ttbar resonance
  - tb resonance (W') searches
  - Wt resonance (b*) searches
- Will not cover
  - Many other new physics with top signature

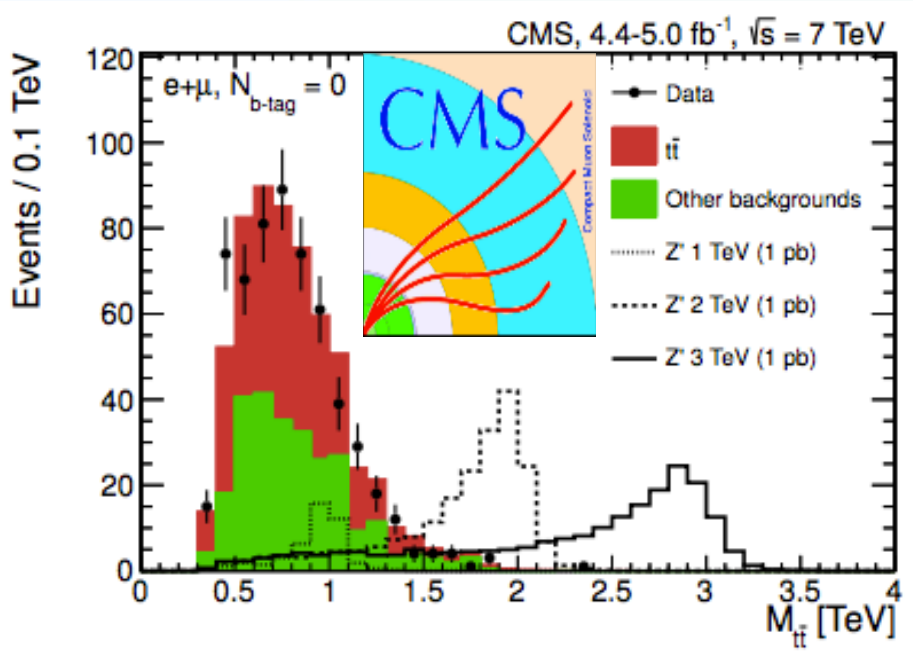
ttbar resonance searches

Reconstruct the invariant mass of top pair in the lepton+jets/full hadronic final states

- **boosted top alg. in full had. analysis**

JHEP 09 (2012) 029 : 5.0 fb-1 @ 7 TeV
JHEP 01(2013) 116 : 4.7 fb-1 @ 7 TeV
ATLAS-CONF-2012-136 : 4.7 fb-1 @ 7 TeV
JHEP 12 (2012) 015 : 5,0 fb-1 @ 7 TeV

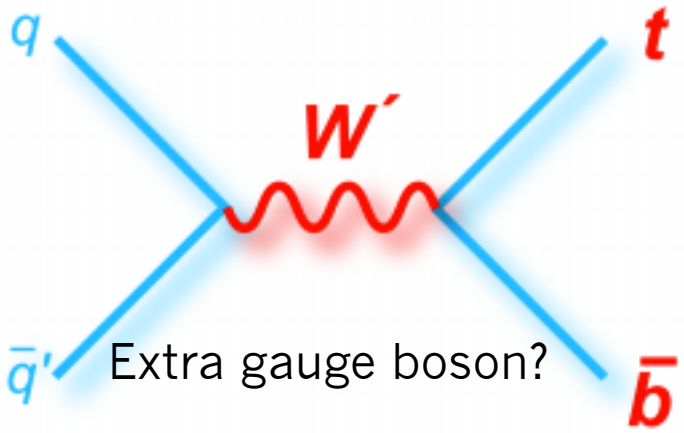




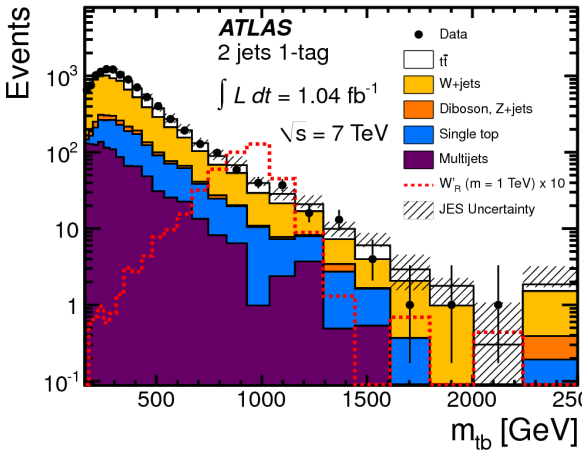
95% C.L. limits on $M_{Z',KKg}$ [TeV]			
model	narrow Z' ($\Gamma = 1\% M_{Z'}$)	wide Z' ($\Gamma = 10\% M_{Z'}$)	KK gluon
ATLAS	$0.5 < M < 1.7$	n/a	$0.7 < M < 1.9$
CMS	$0.5 < M < 1.5$	$0.5 < M < 2.0$	$1 < M < 1.82$

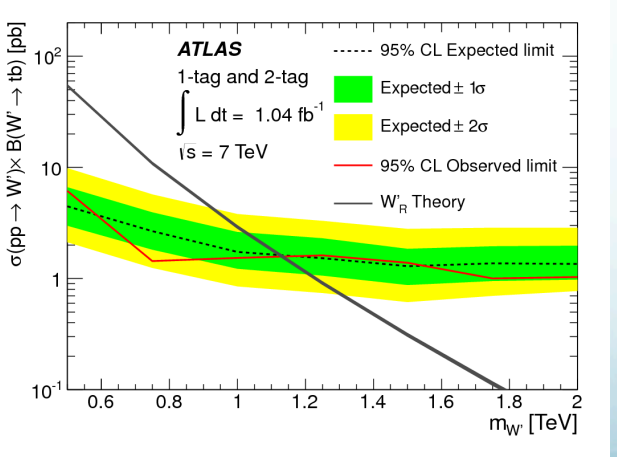
tb resonance searches: W'

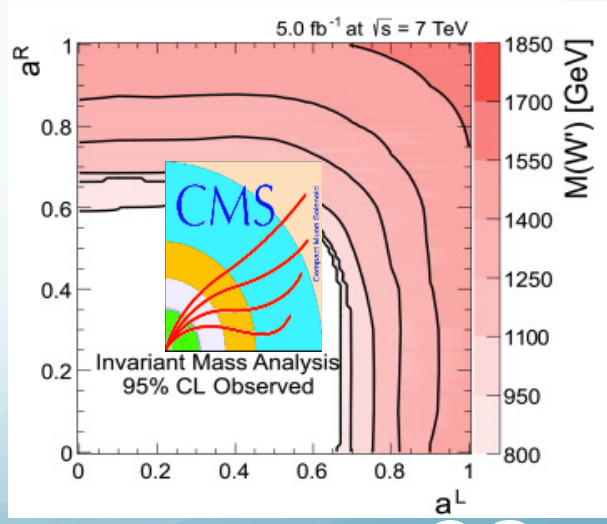
PRL 109 (2012) 081801
PLB 718 (2013) p1229-1251



- **Right handed W'_R model with SM like couplings (PRD 66, 075011 2002)**
  - **CMS extend to set limit at the left/right mix plate**
- **Use the invariant mass of final state t+b as discriminant**
  - **CMS has additional BDT analysis**
- **Combined both 1 and 2 b-tagged events**
- **No excess found, Set limits on W' masses**

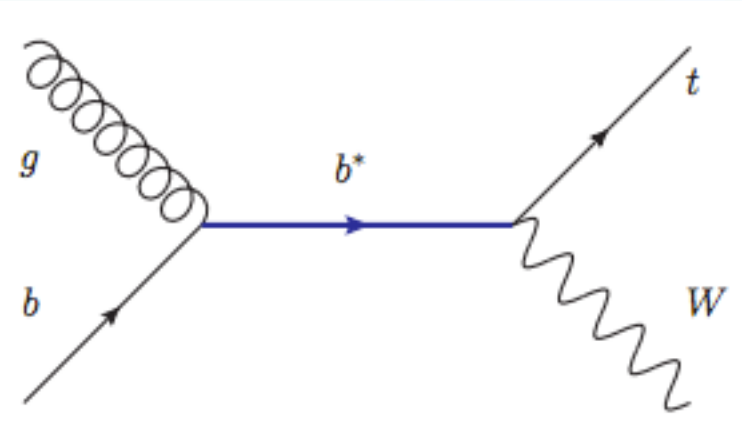




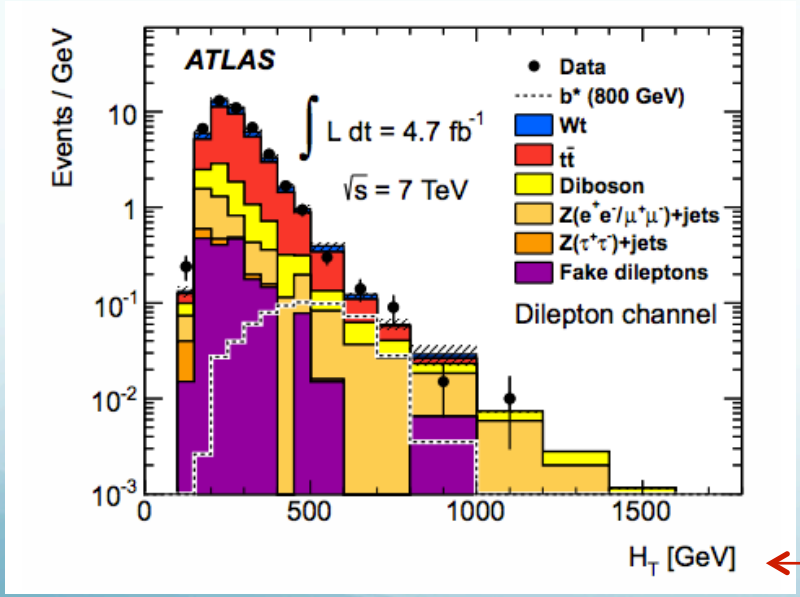


$M_{W'}$>1.13TeV (ATLAS 1.04fb^{-1})

Wt resonance searches: b* (1)



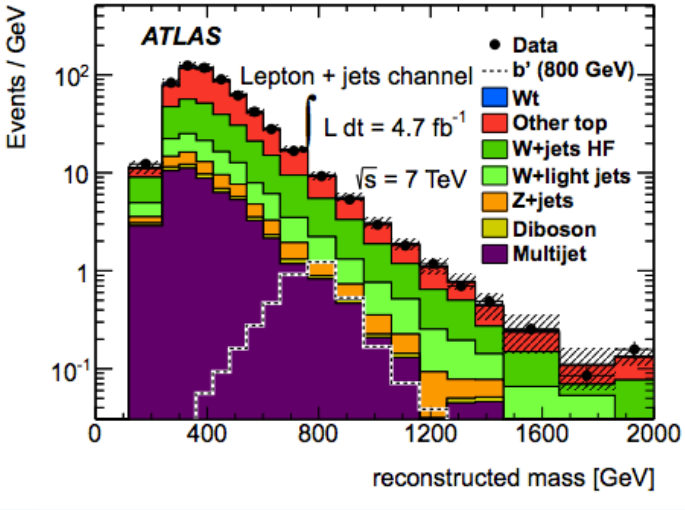
ArXiv:1301.1583, 4.7 fb^{-1}



- Excite quark/lepton could reveal the substructure of SM fundamental particles
- Composite 3rd generation quark model allows FCNC/SM coupling
- Search excited bottom quark in the signature of W boson plus single top-quark
  - Both dileptonic and semileptonic final states are analyzed
- Same selection and background modeling as SM Wt analysis
  - Look at W+t without extra jets

← Dileptonic discriminate: HT

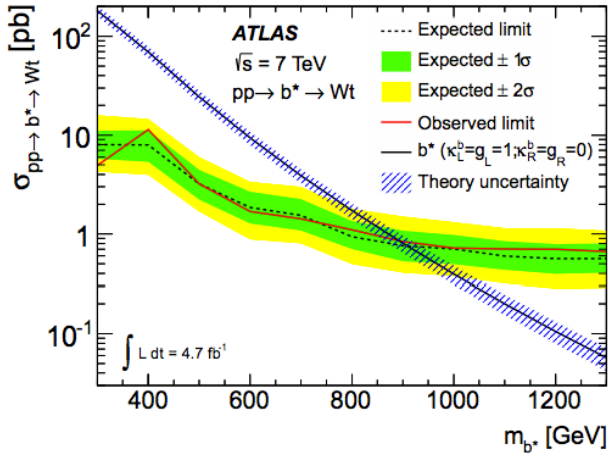
Wt resonance searches: b* (2)



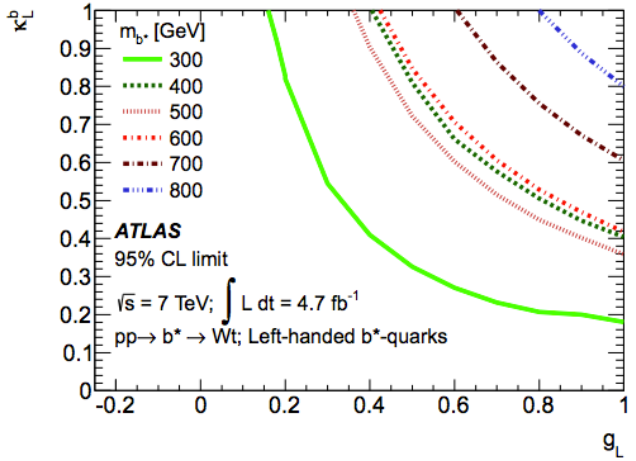
- **Lepton + jets discriminate: b* mass**
- **No excess found, set limit to b* mass**
  - **Bayesian limit set at 95% C. L.**
- **Translate b* mass limit into 2D coupling plate**
- **Set Limits for left-, right- handed and vector like quarks separately**

Left handed b* quark: > 870 GeV @ 95% C.L.
Vector Like b* quark: > 1030 GeV @ 95% C.L.

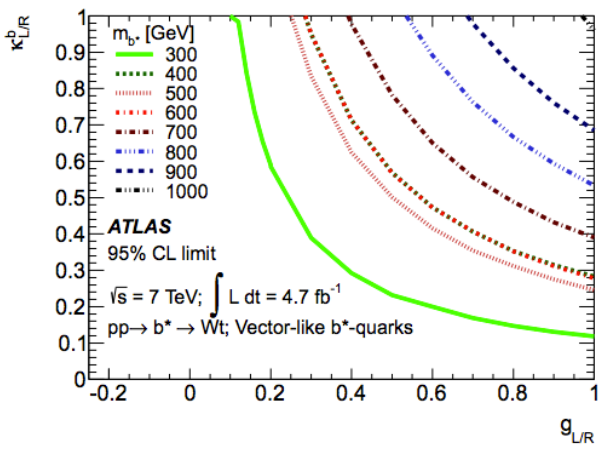
ArXiv:1301.1583, 4.7 fb^{-1}



Left handed b*



Vector like b*



Summary

- Standard Model is tested precisely with top quark physics at LHC
  - Both at the pQCD and electroweak sector
- So far, no deviation from SM is observed
  - Cross section and property measurement agrees with SM predictions
  - No sign of new physics with top quark signature
    - But we believe they were hidden somewhere
- Requires more precise knowledge of top mass
  - A TLEP/Higgs factory of ~350 GeV Ecm needed?
- More results will come with 8 TeV data
  - Stay tuned

Lastes details:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/TopPublicResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

THANK YOU