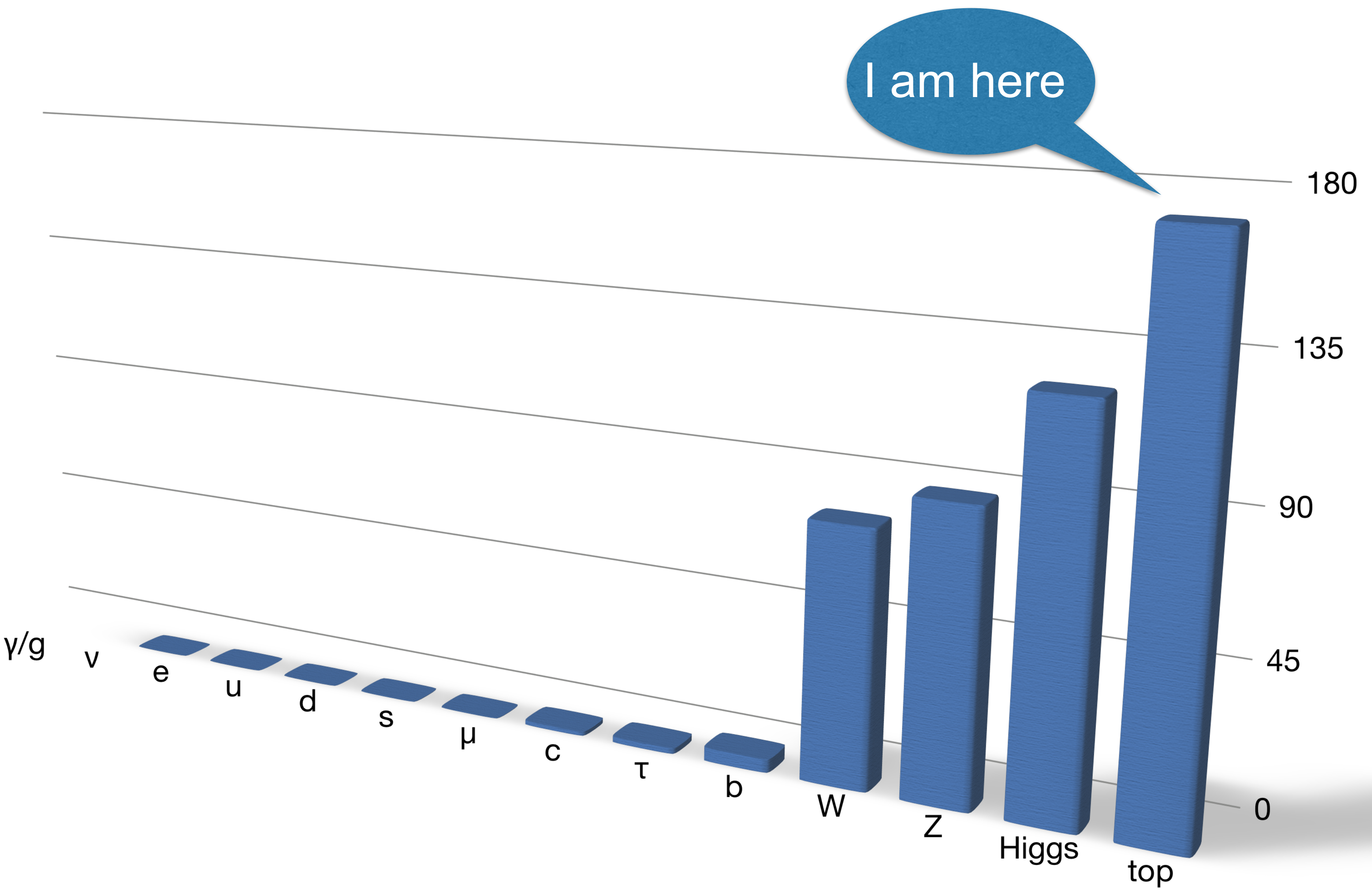
Top quark physics, AD 2014

Fabrizio Margaroli (Sapienza and INFN)
on behalf of ATLAS/CMS/CDF/D0
collaborations

WHY TOP QUARK PHYSICS?



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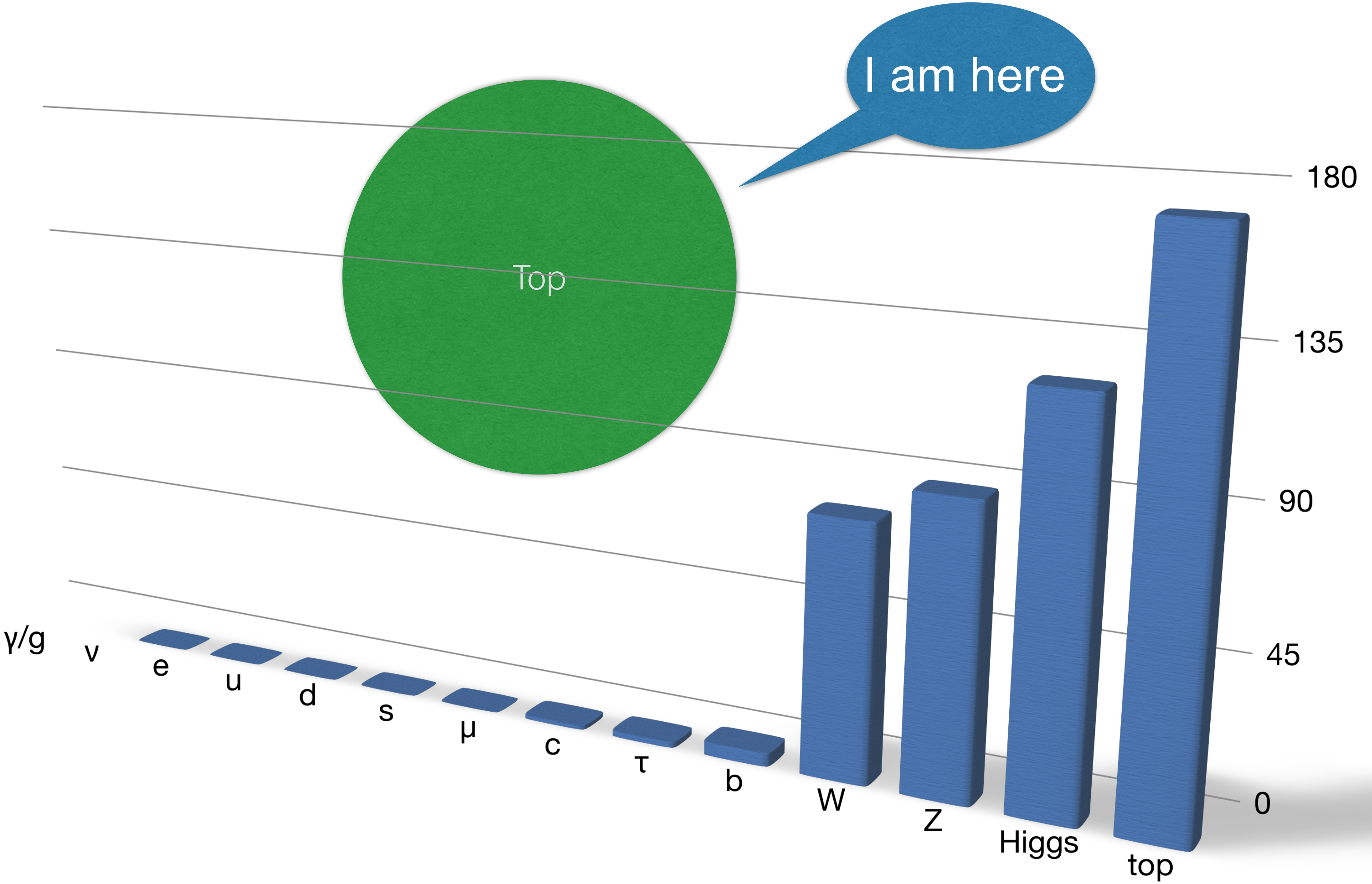

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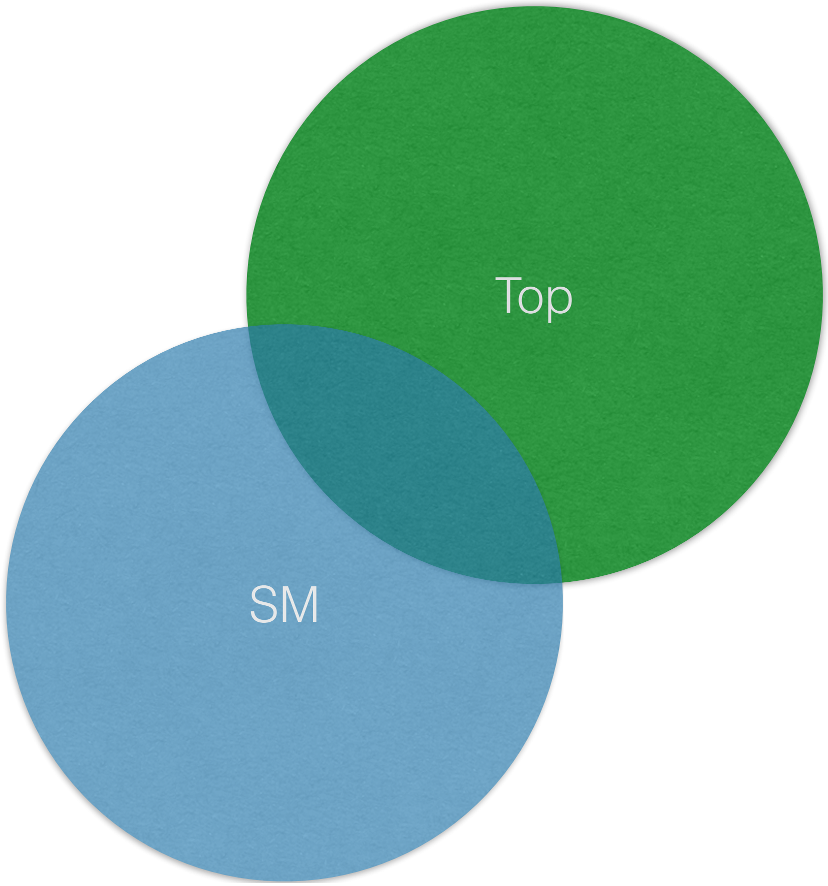
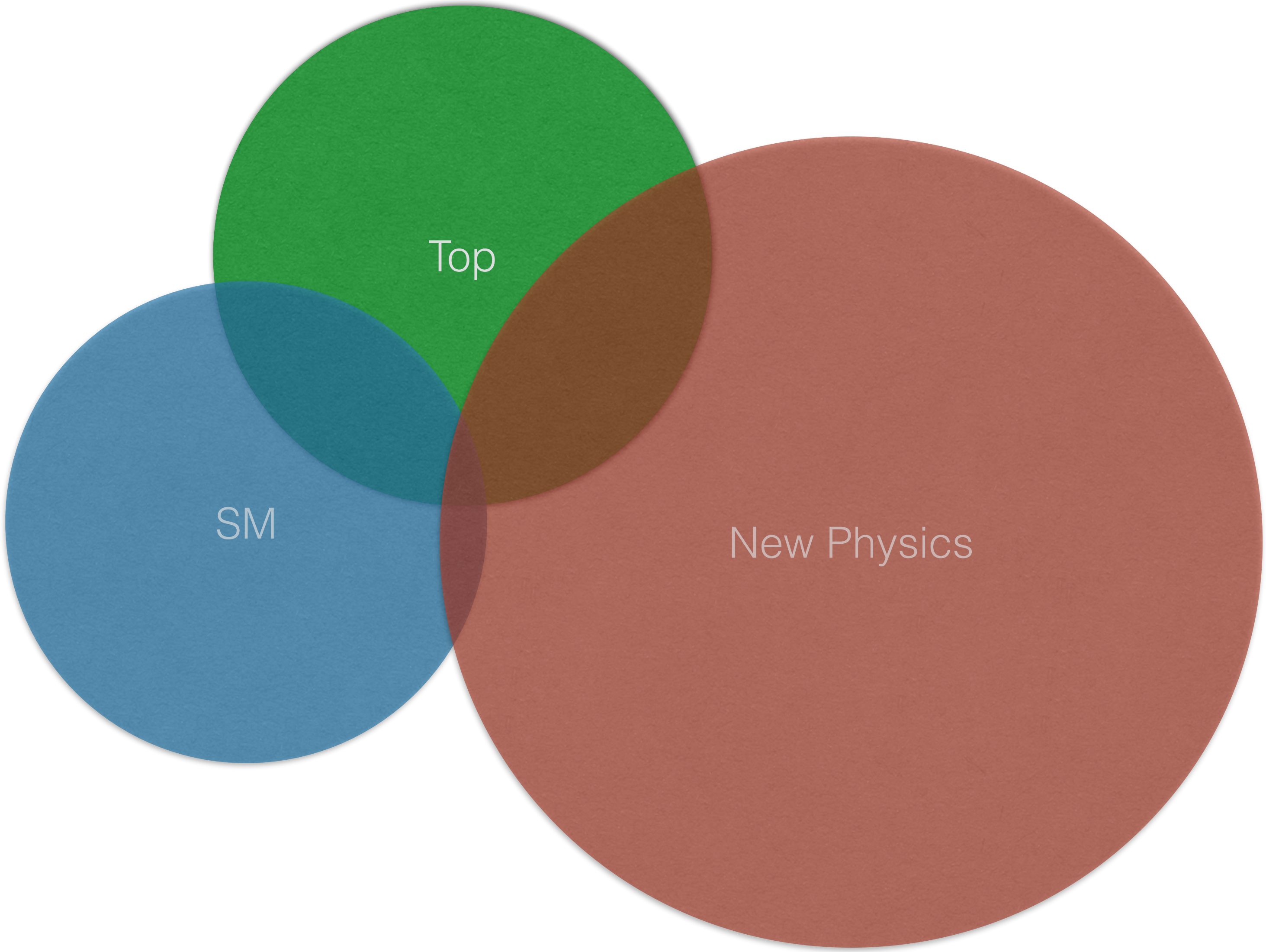


Why Top quark physics?



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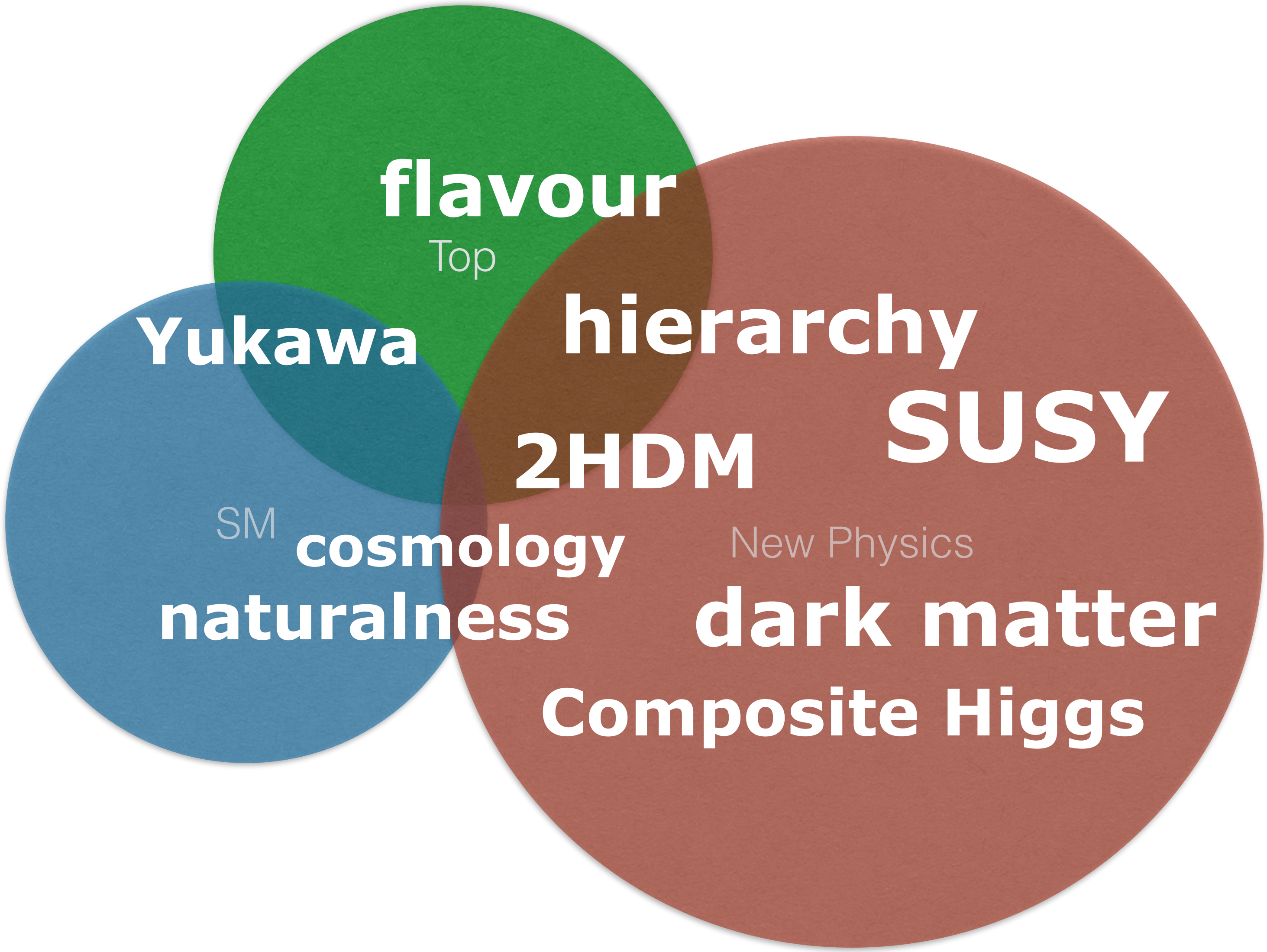
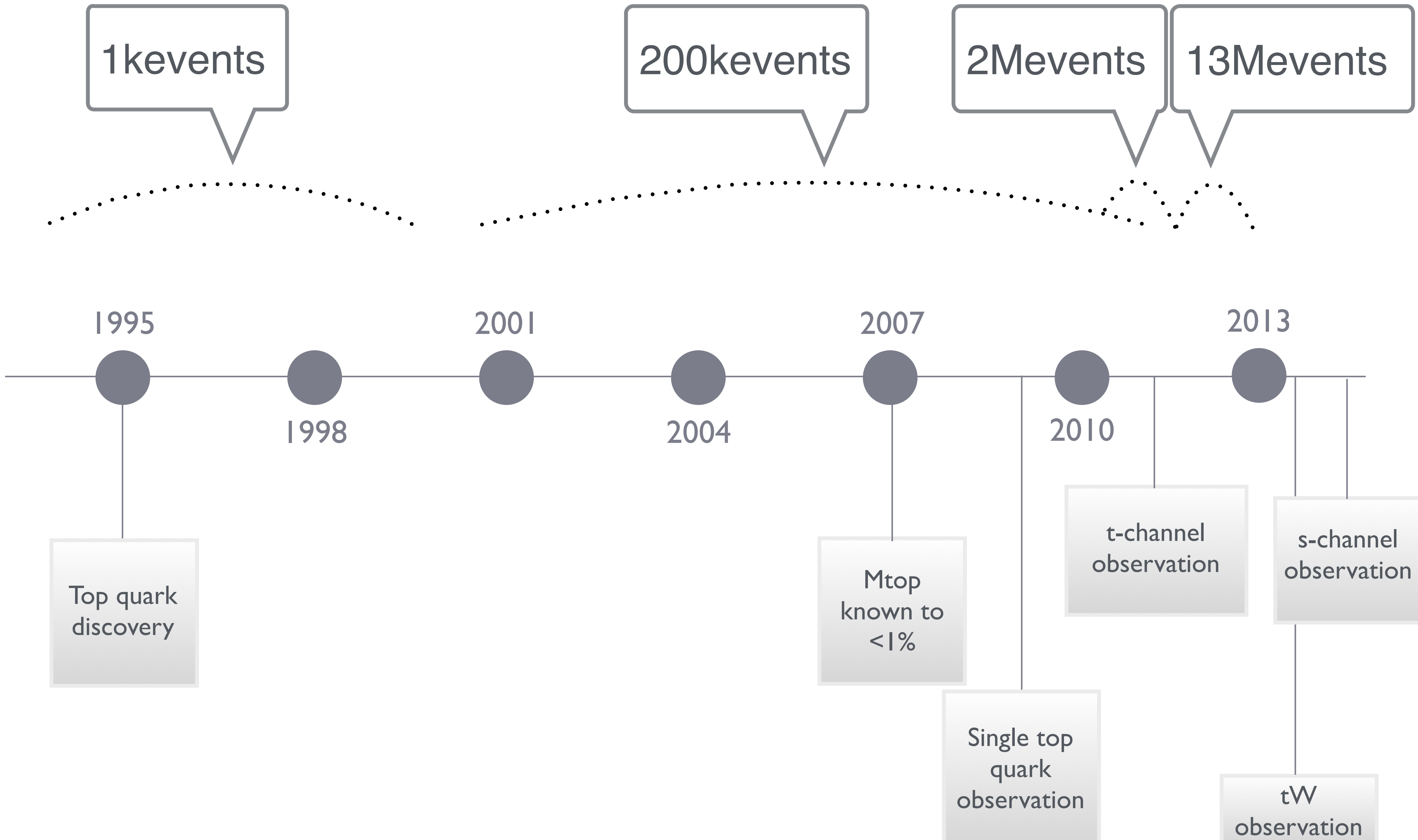


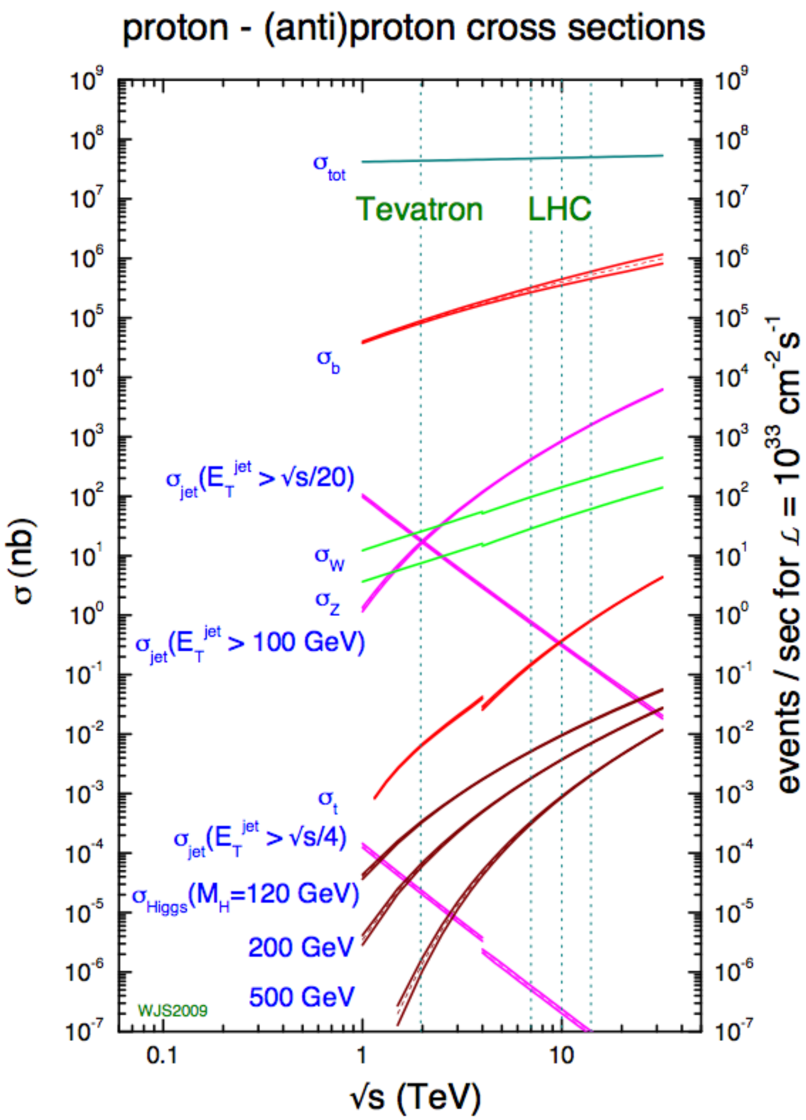
LIFE OF A QUARK

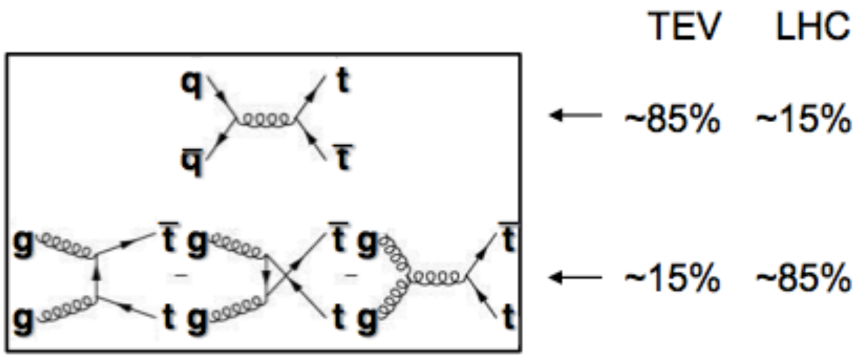


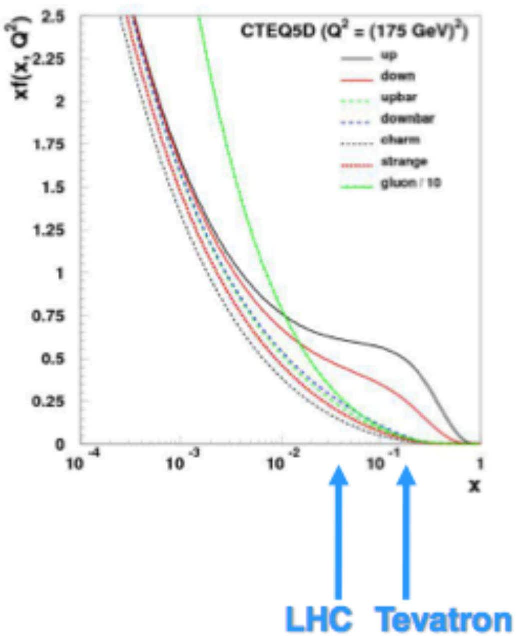
FROM TEVATRON TO LHC

~O(10^5) tops produced, at Tevatron, about 10^4 analyzed at the Tevatron

~O(10^7) tops produced at LHC (7+8TeV), yet to analyze full datasets

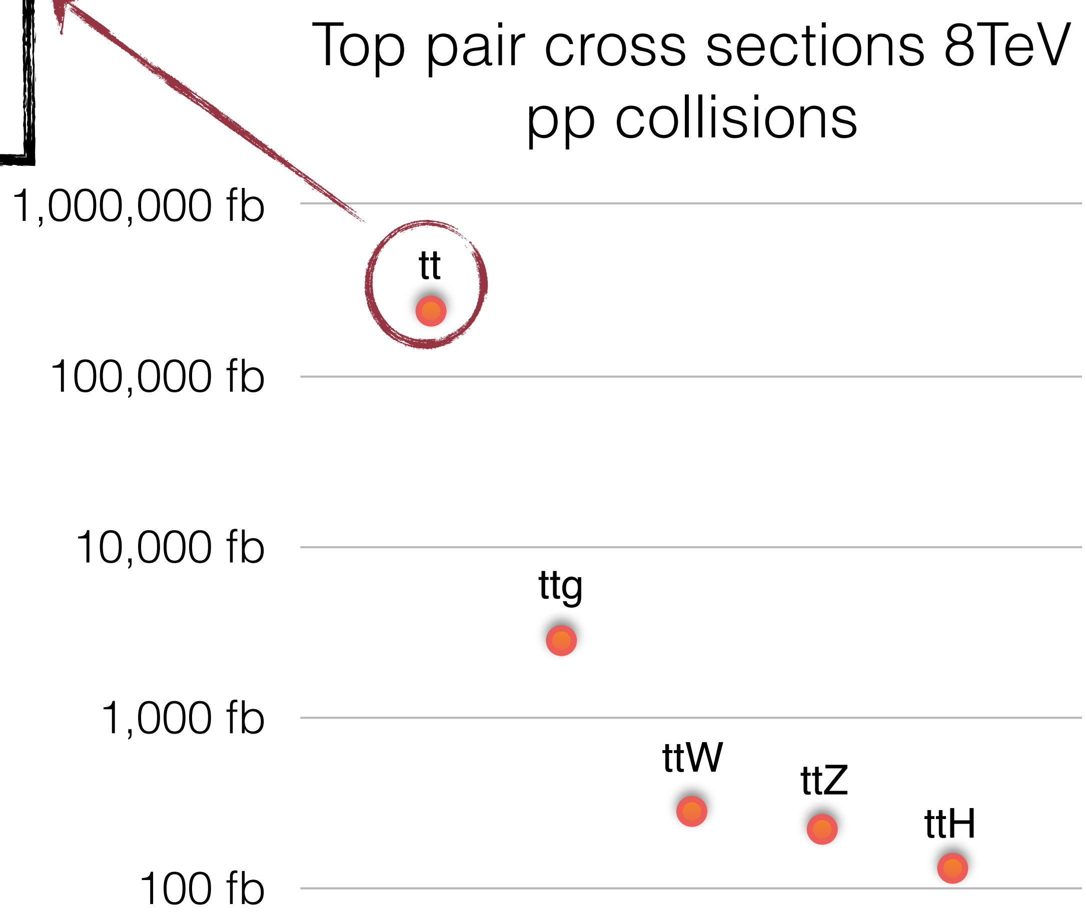






WHAT TO MEASURE

Mass, charge, width, spin correlation, alpha_s, jet shapes, forward-backward asymmetry, FCNC, B violation, CPT violation



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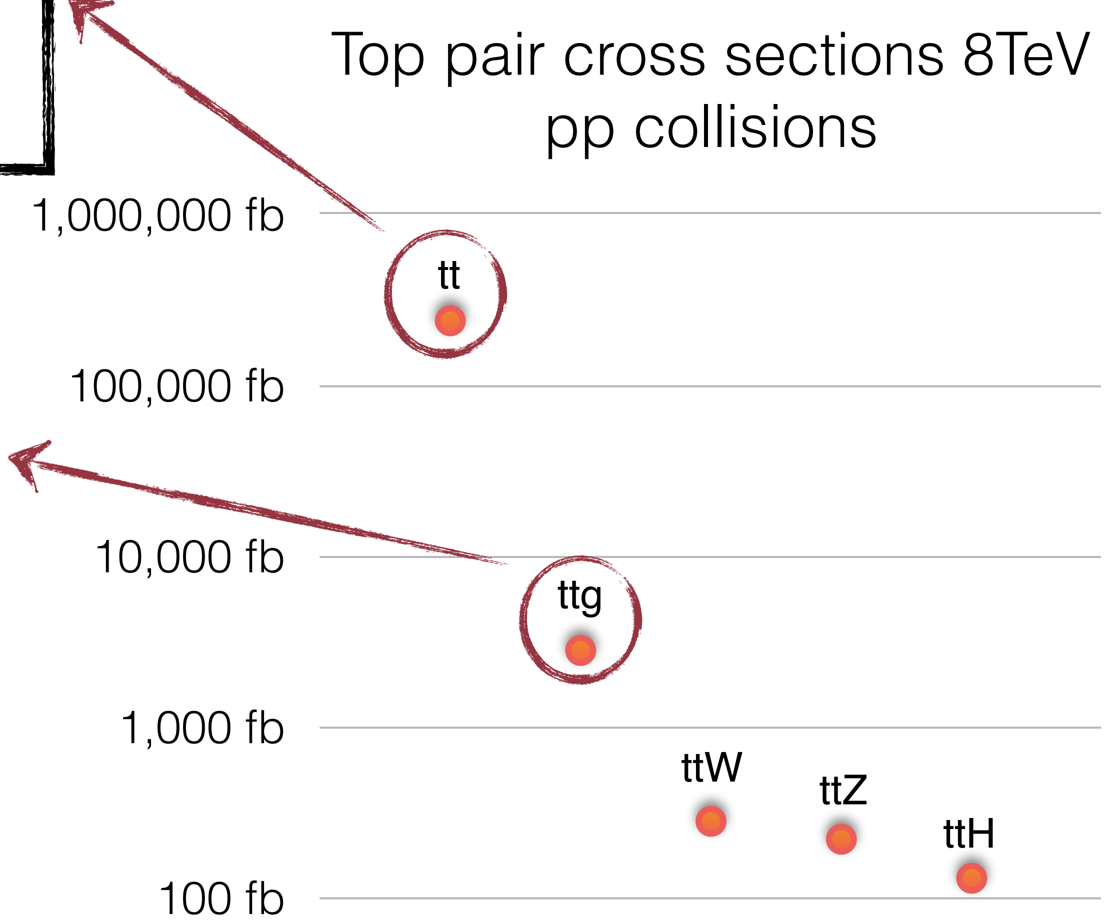
Top charge, background to ttH



What to measure

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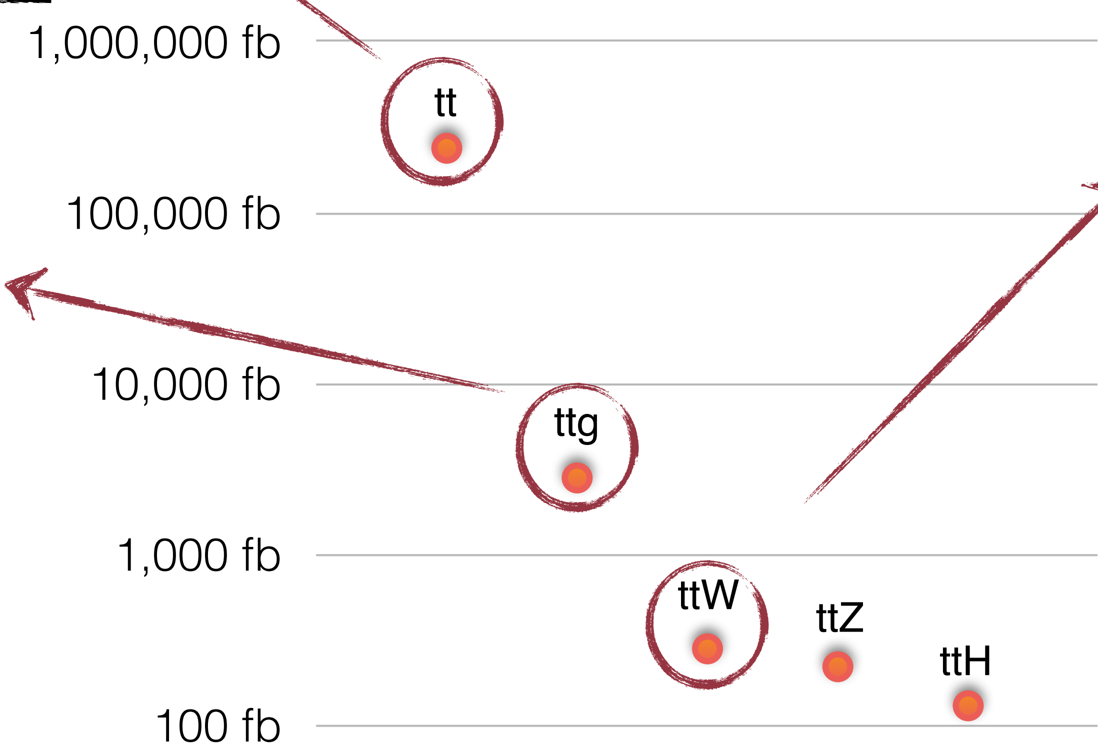
Top charge, background to ttH

Backgrounds to natural NP

Top pair cross sections 8TeV pp collisions



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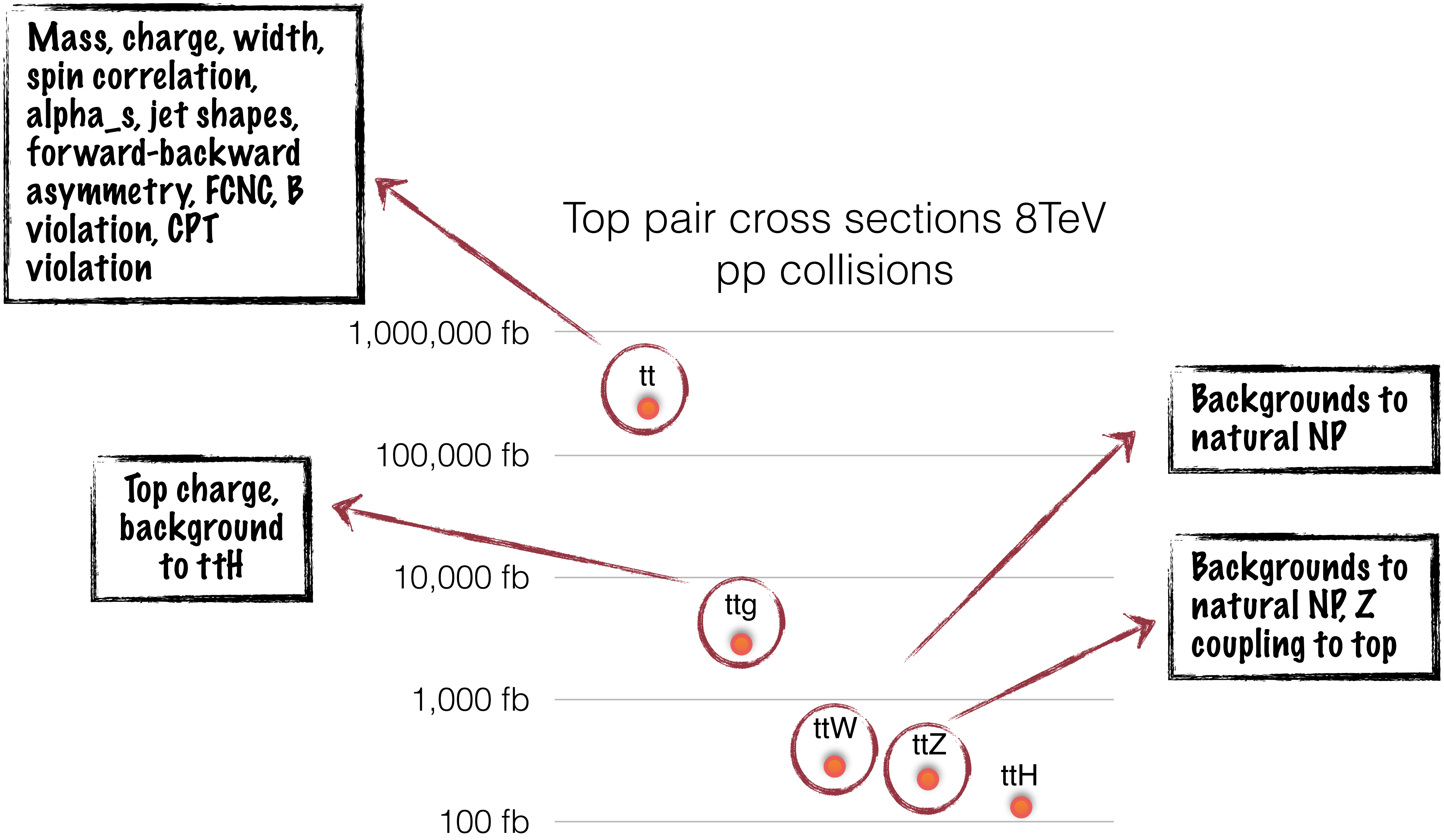

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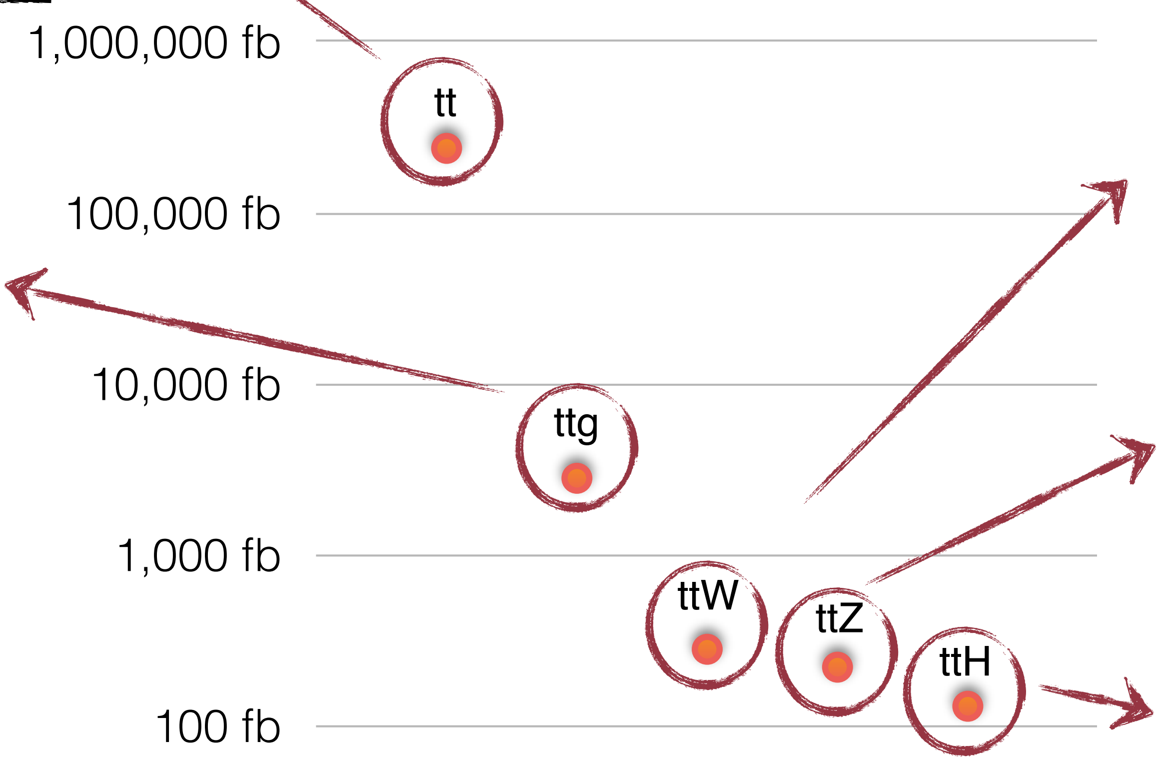


Top charge, background to ttH

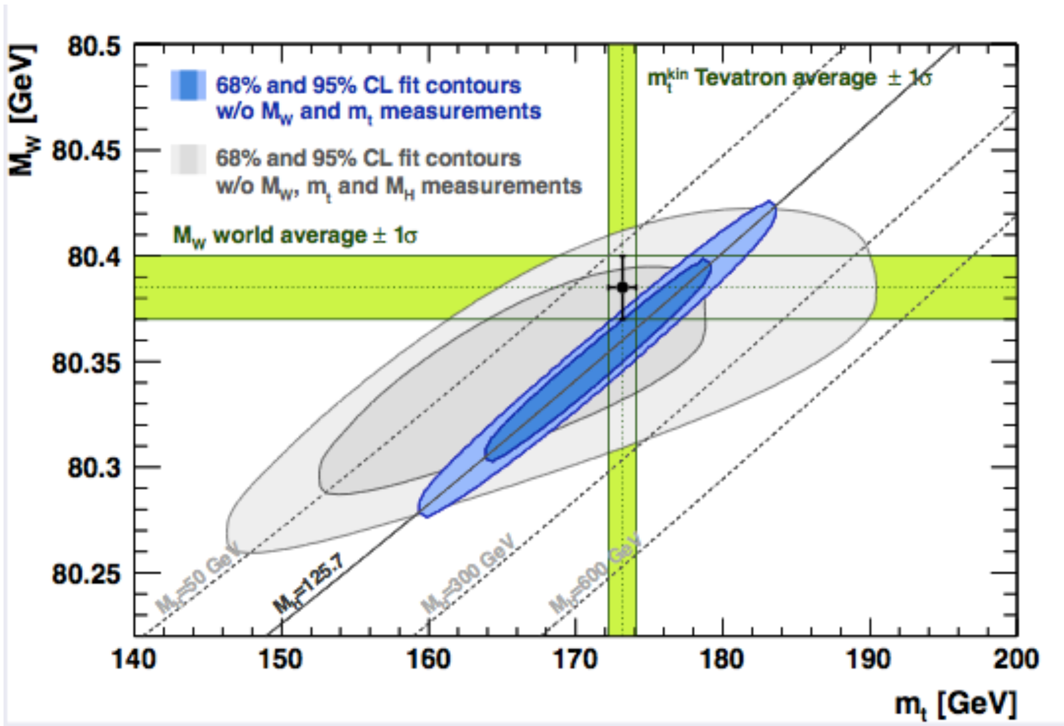
Backgrounds to natural NP

Backgrounds to natural NP, Z coupling to top

Yukawa coupling top

TOP, HIGGS, AND ALL OF US

- W,Z, even Higgs(!) masses already known with amazing precision: 10^{-3} to 10^{-5} precision, no ambiguity on mass definition
- Measuring a quark mass is a pretty different business
- Precise top quark mass provides additional predictions: mH=94±24GeV



EPJ C72 2205

Predicted Higgs boson to be within 1sigma to where we found it!
Knowledge of Higgs mass allows prediction of Mtop to 1% level: Mtop=175.8±2.5GeV

TOP, HIGGS, AND ALL OF US

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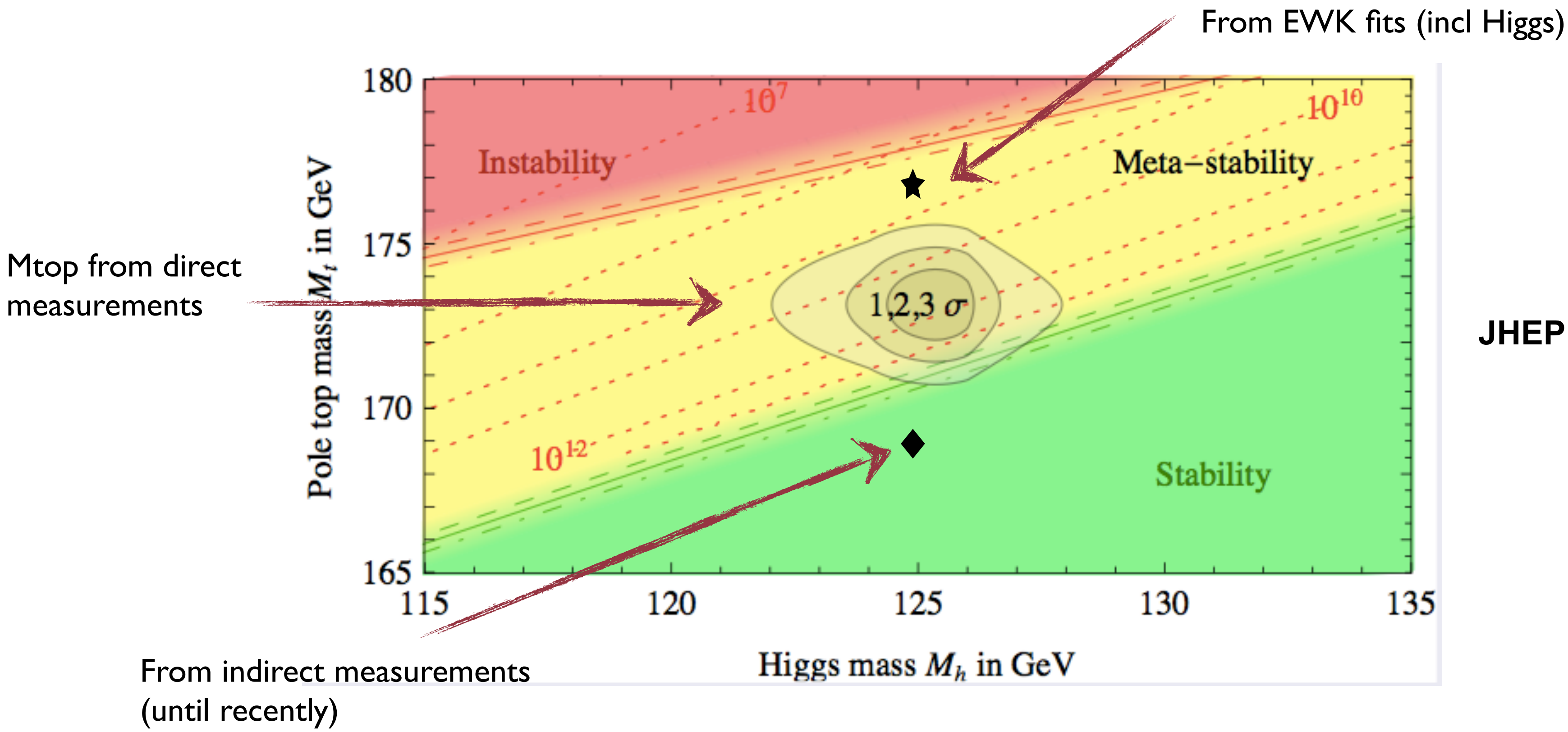
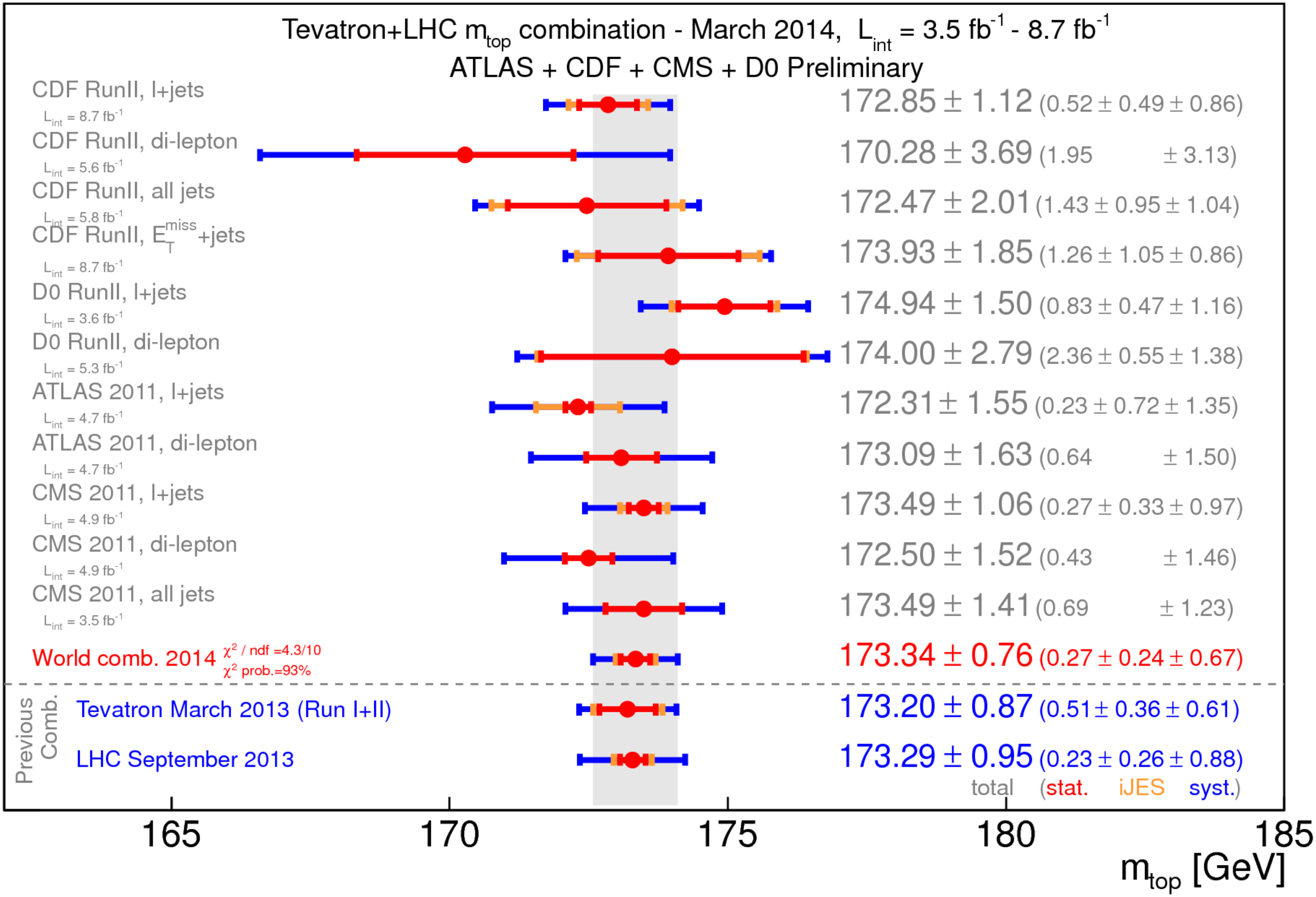
- Measuring a quark mass is a pretty different business
- Precise top quark mass provides additional predictions: mH=94±24GeV
- Oh BTW, it also helps us predict the fate of the universe...

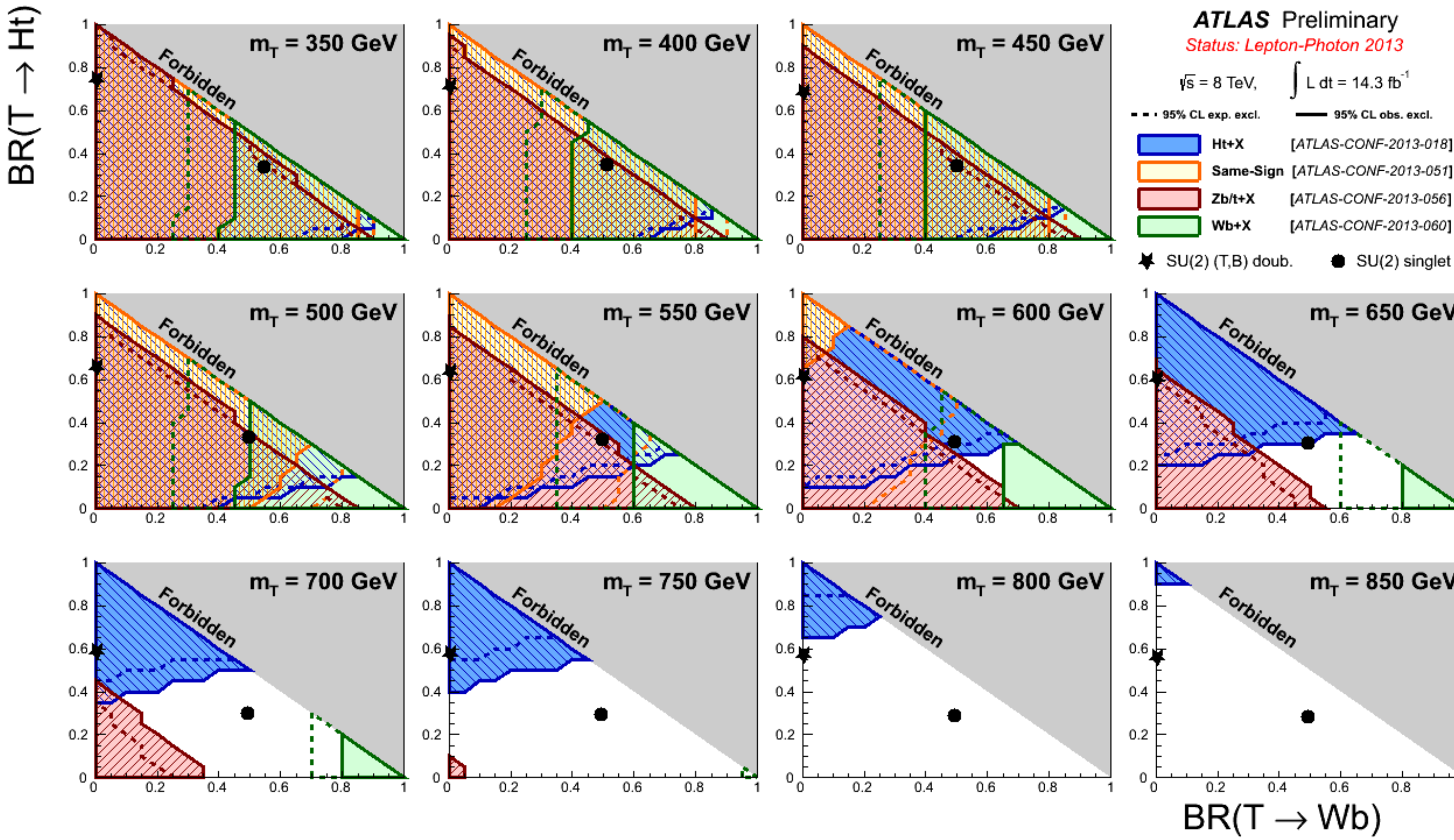


JHEP 1208 098

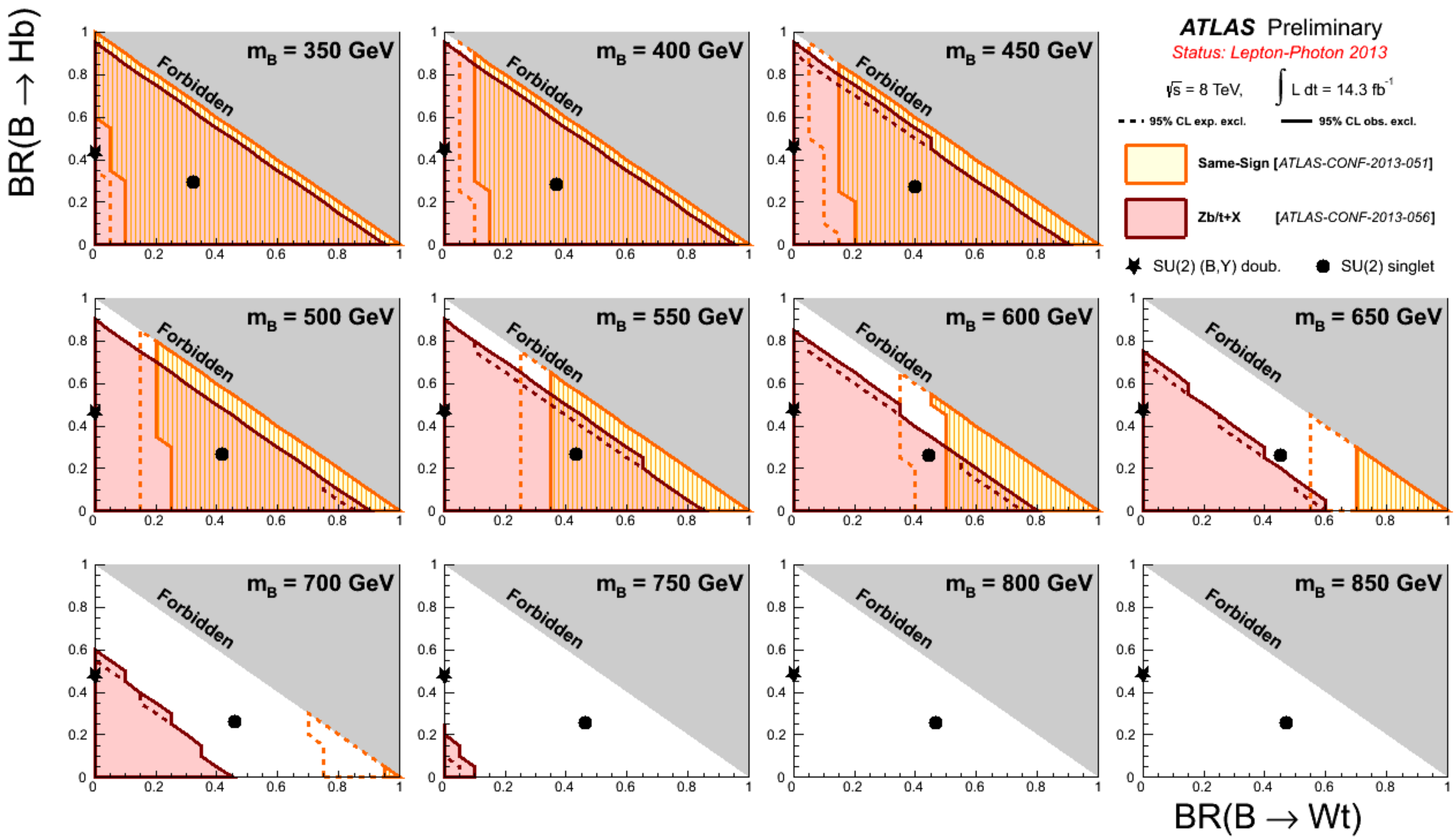
DIRECT MTOP RESULTS



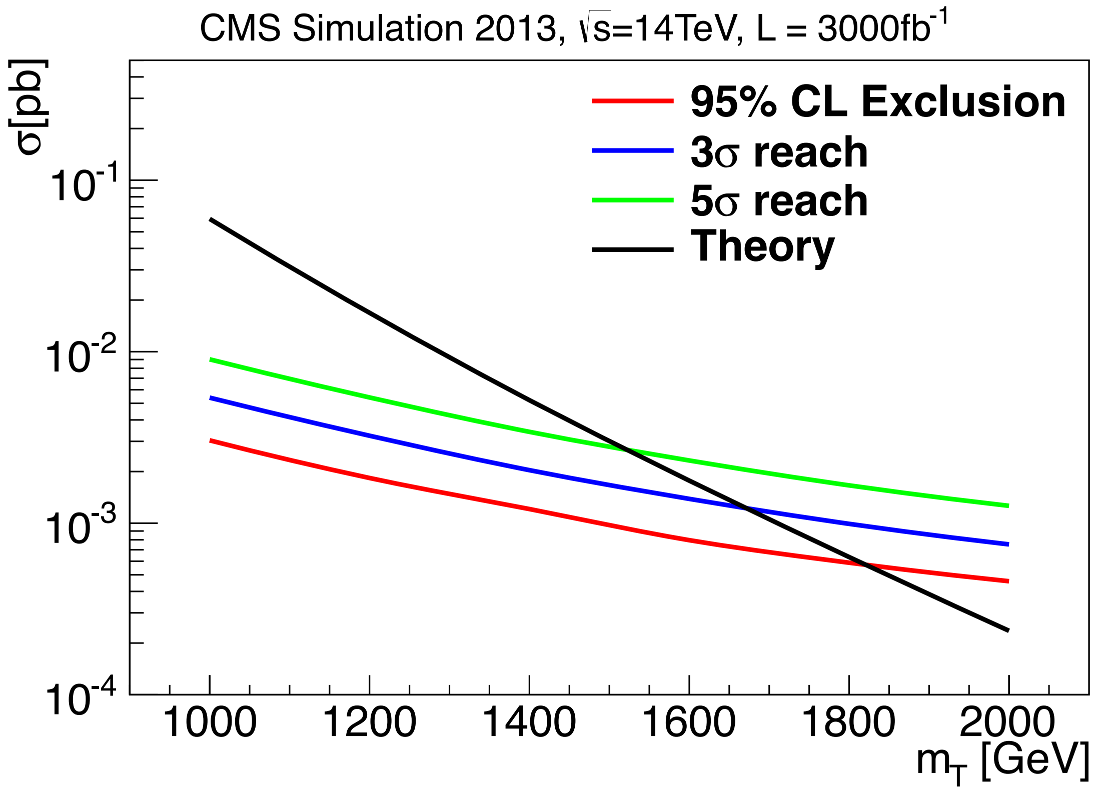
FERMIONIC TOP PARTNERS



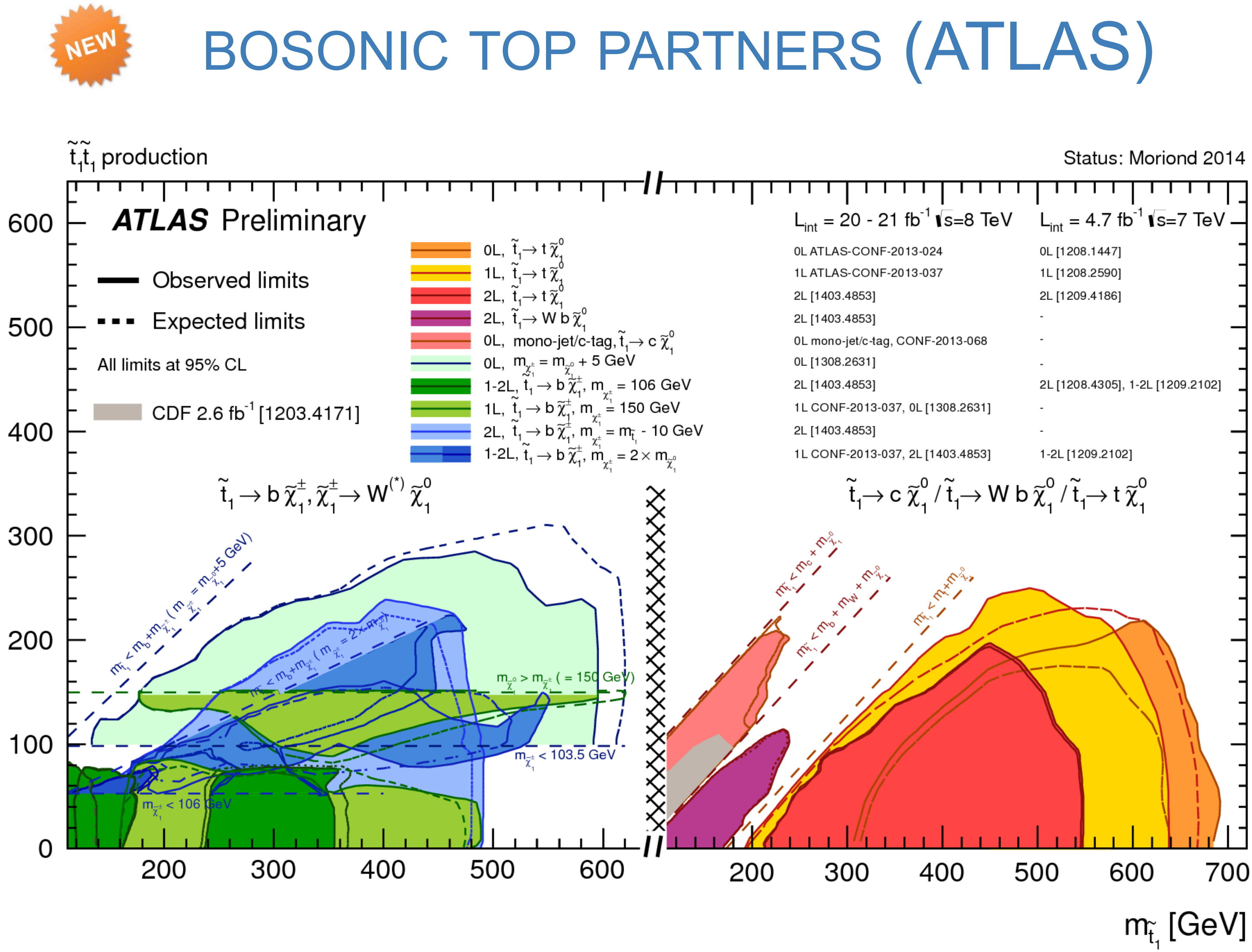
FERMIONIC BOTTOM PARTNERS



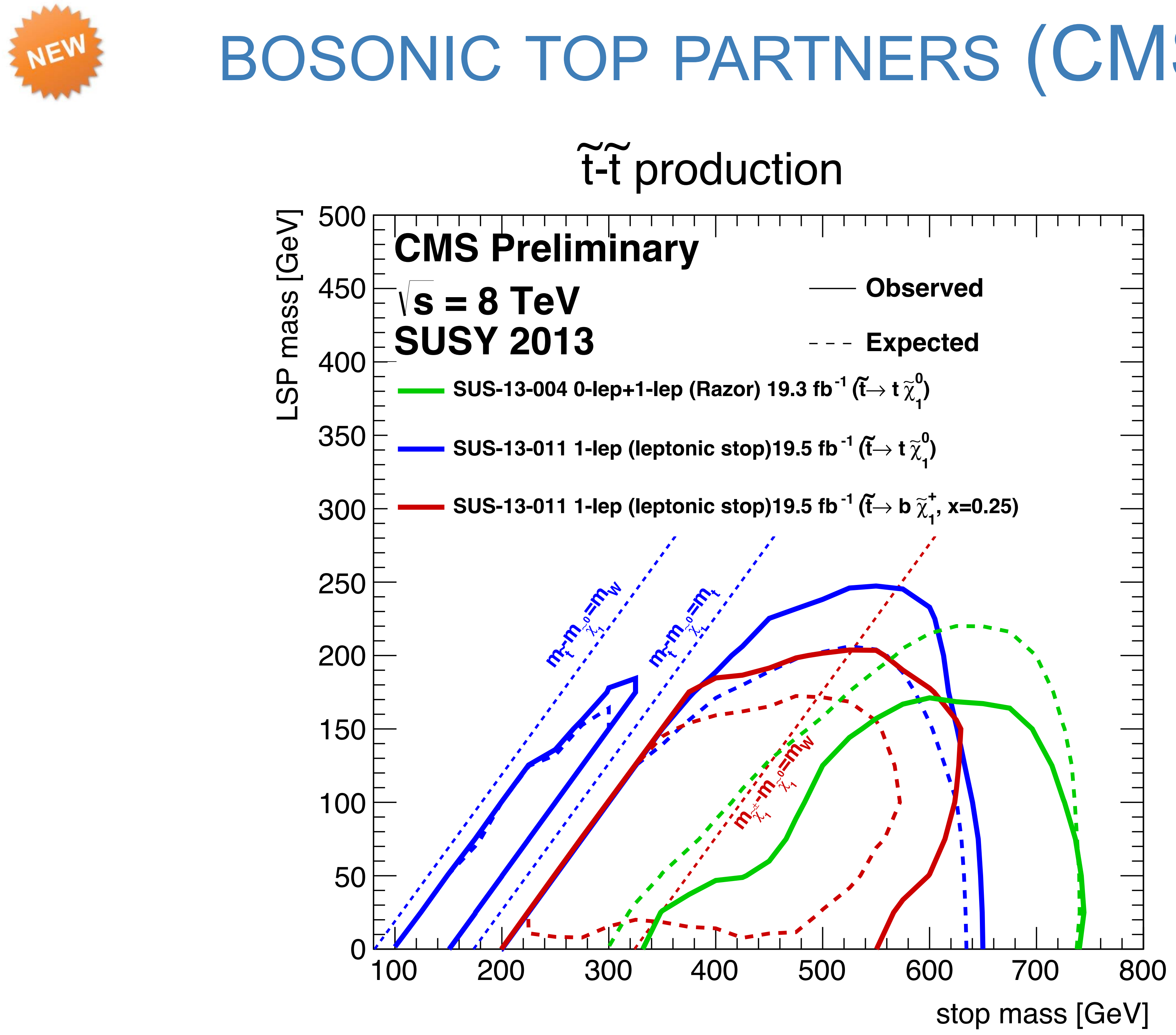
FERMIONIC TOP PARTNERS, PROJECTIONS TO 3AB-1



BOSONIC TOP PARTNERS (ATLAS)



BOSONIC TOP PARTNERS (CMS)

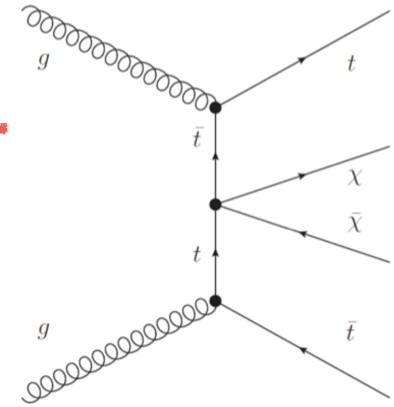


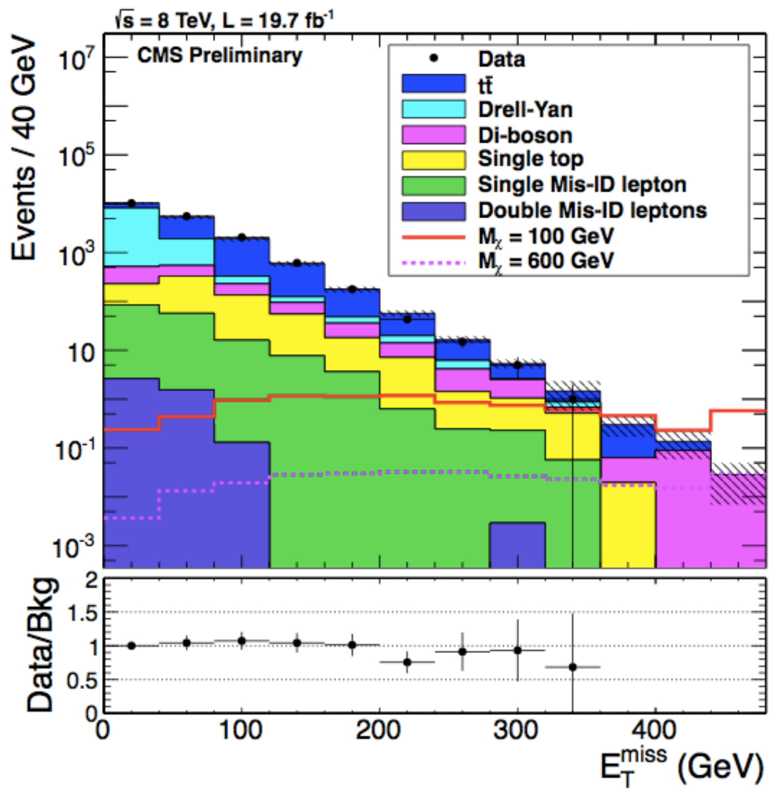
DARK MATTER AND TOP

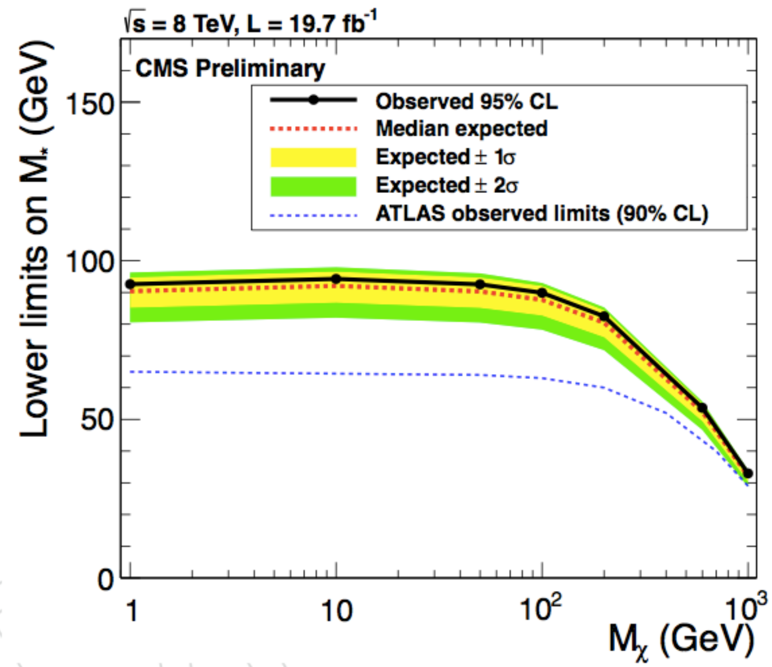
Lin, Kolb, Wang Phys.Rev. D88 (2013) 6, 063510

Both collider and direct searches are the least sensitive to Yukawa-like lagrangian for dark matter

Name	Initial state	Type	Operator
D1	$q\bar{q}$	Scalar	$\frac{m_q}{M_*^3}\bar{q}q\bar{\chi}\chi$
D5	$q\bar{q}$	Vector	$\frac{1}{M_*^2}\bar{q}\gamma^\mu q\bar{\chi}\gamma_\mu\chi$
D8	$q\bar{q}$	Axial-vector	$\frac{1}{M_*^2}\bar{q}\gamma^\mu\gamma^5 q\bar{\chi}\gamma_\mu\gamma^5\chi$
D9	$q\bar{q}$	Tensor	$\frac{1}{M_*^2}\bar{q}\sigma_{\mu\nu}q\bar{\chi}\sigma^{\mu\nu}\chi$
D11	gg	Scalar	$\frac{1}{4M_*^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

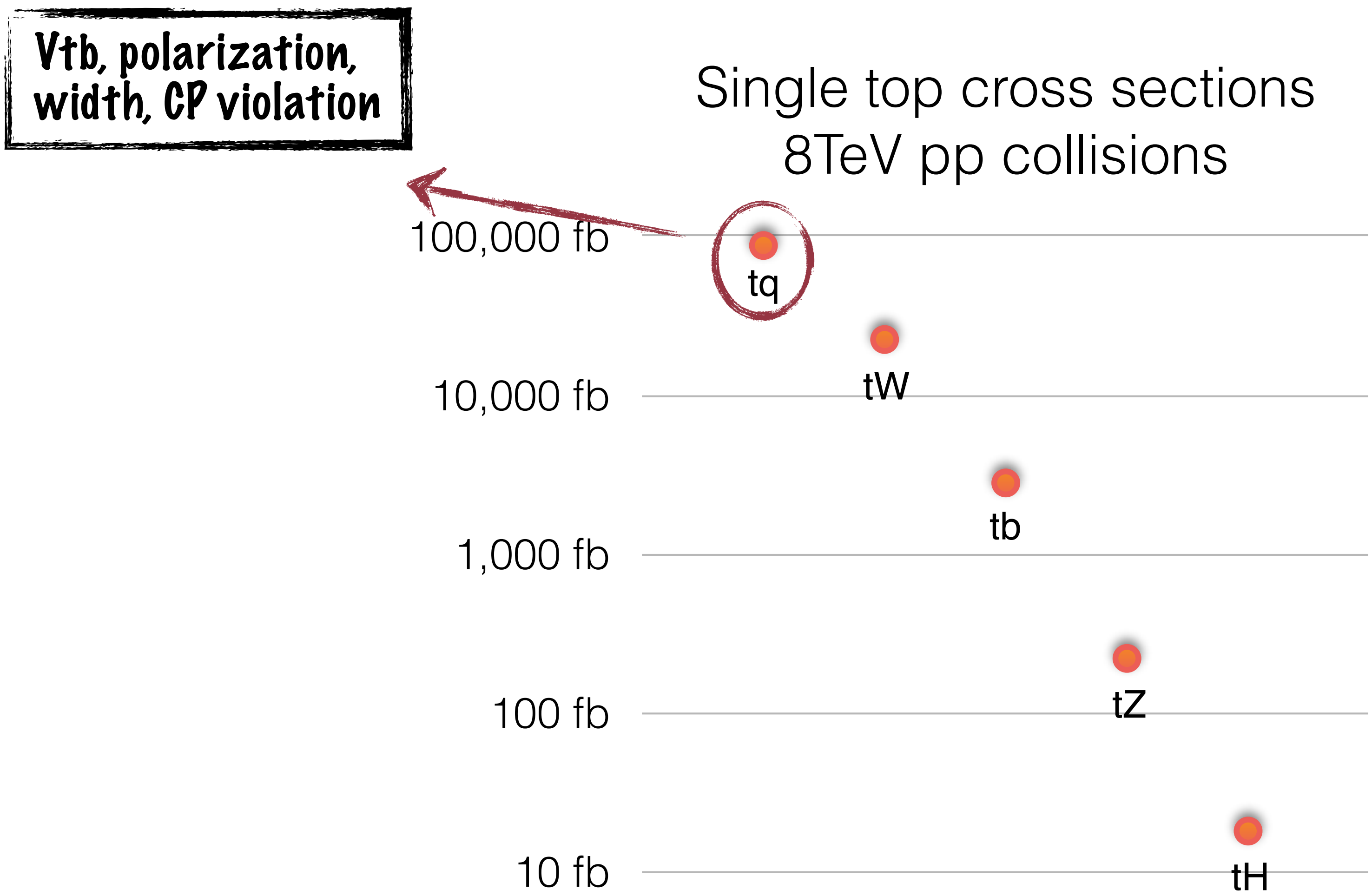






CMS-B2G-13-004

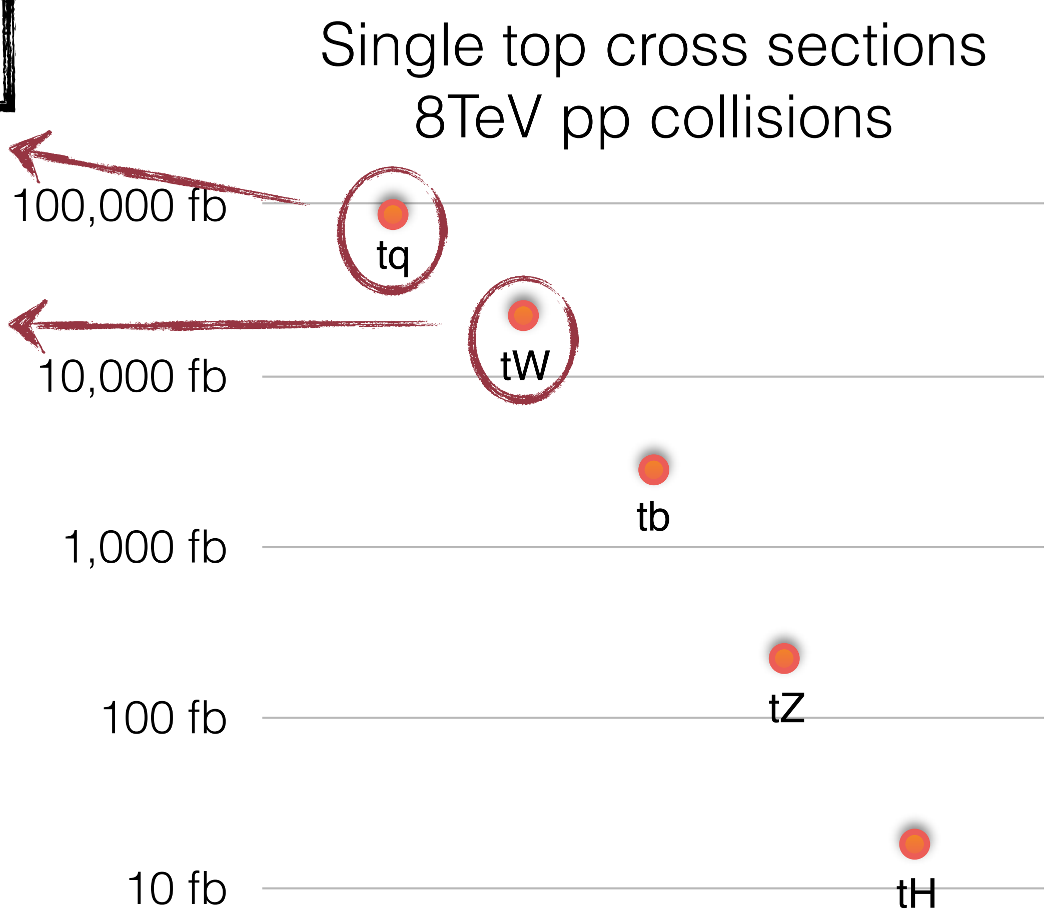
TOP PROPERTIES FROM SINGLE TOP



TOP PROPERTIES FROM SINGLE TOP

Vtb, polarization, width, CP violation

Vtb, background to natural NP



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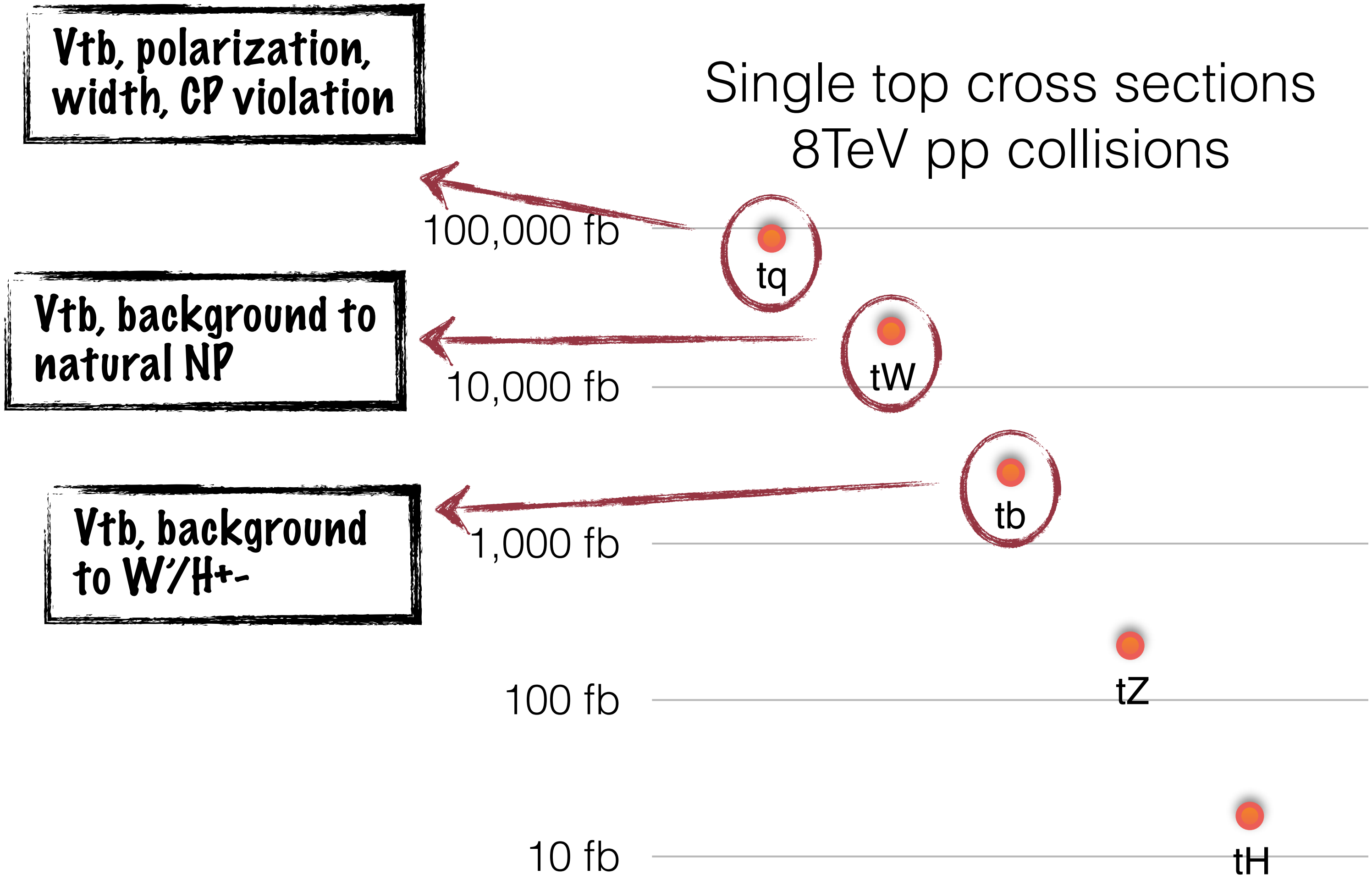

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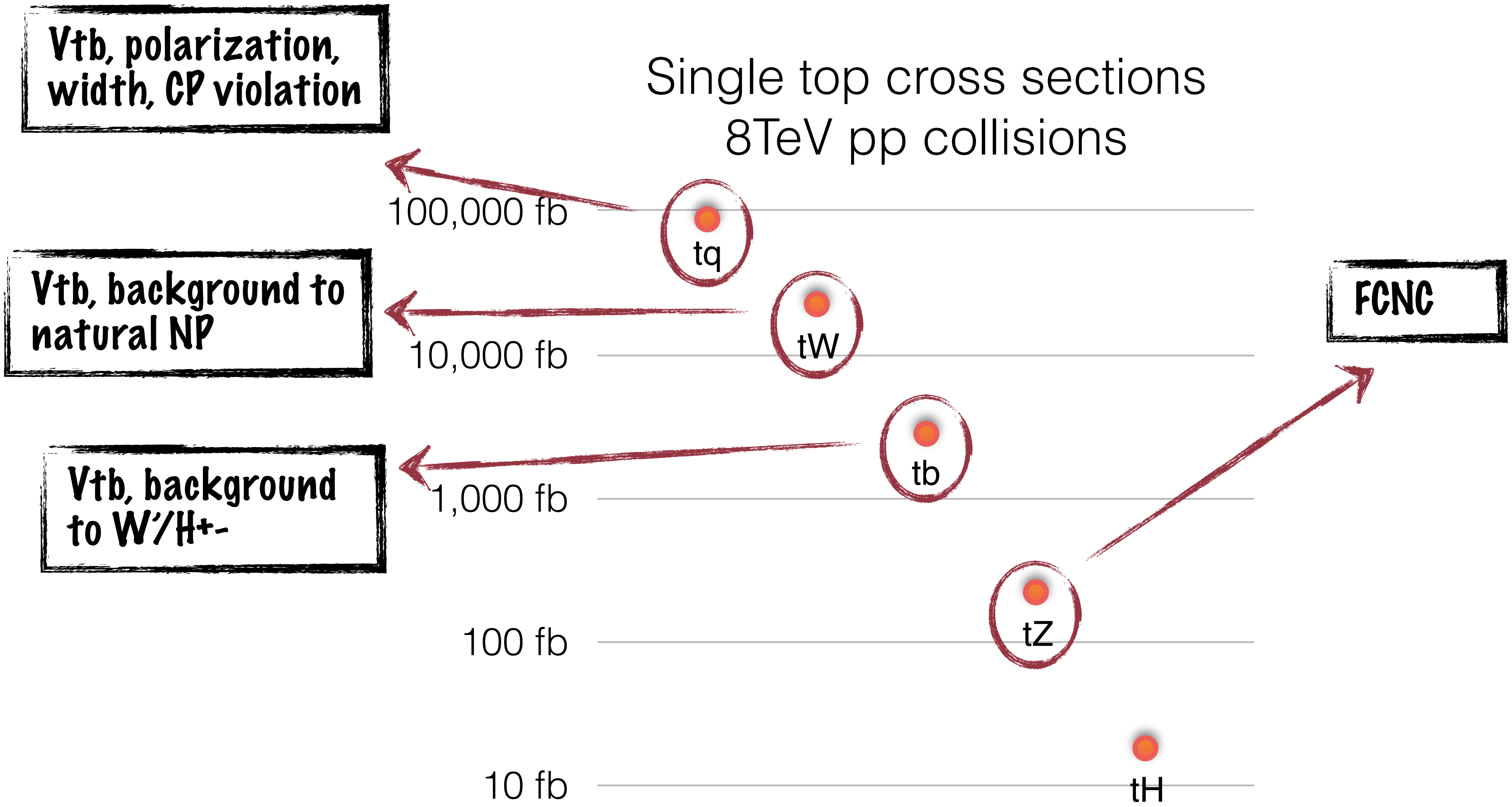

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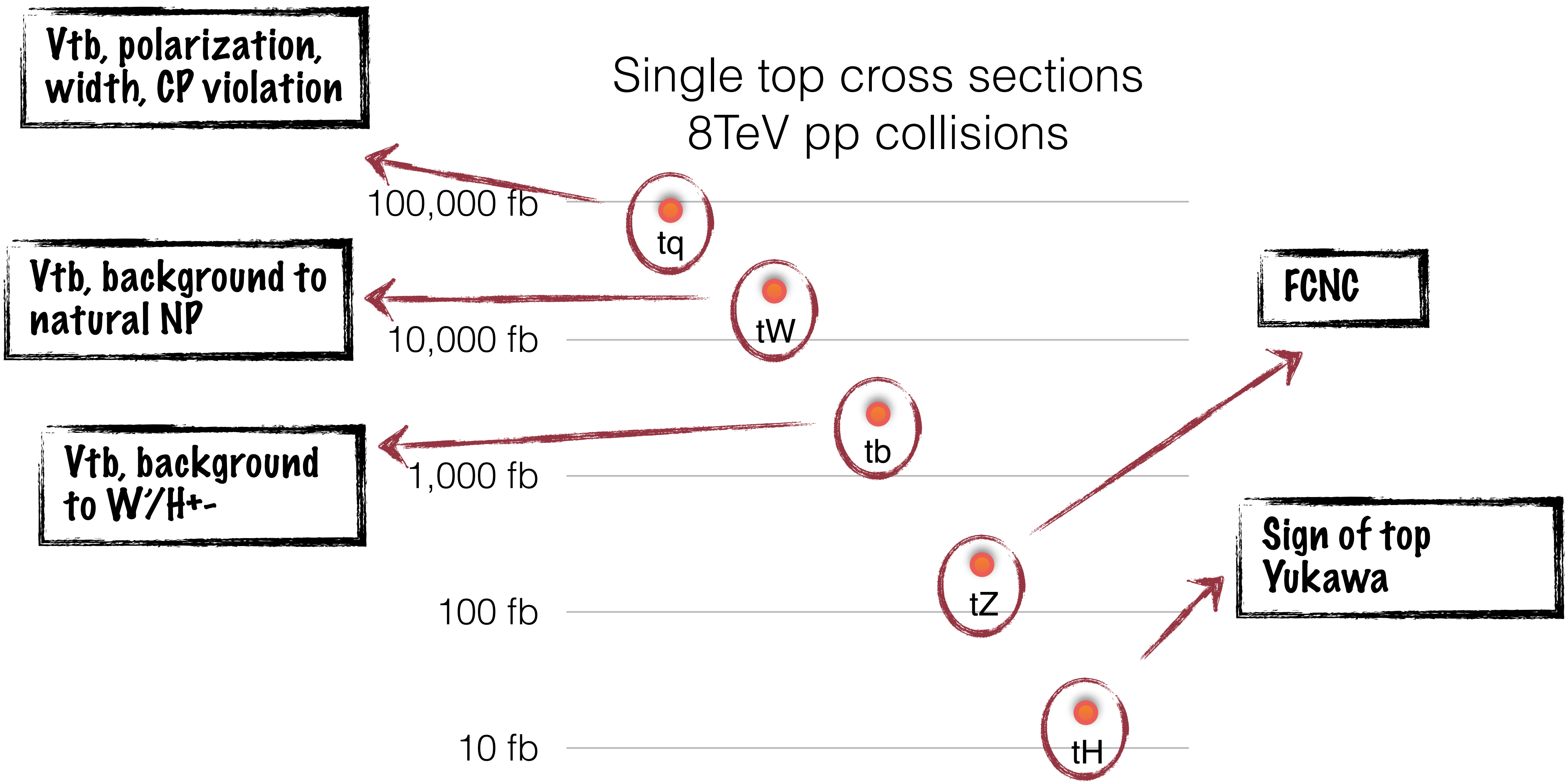


VTB EXTRACTION

- Several Vtb results in three different single top production modes (t-chann s-channel, tW) measured at Tevatron and LHC collaborations,
- all leading to compatible results
- many results do not use yet full dataset
- combination of results could bring additional benefit

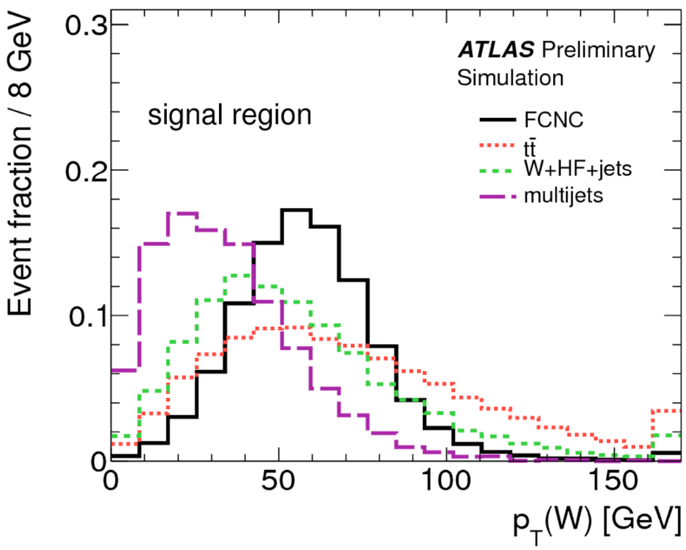
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

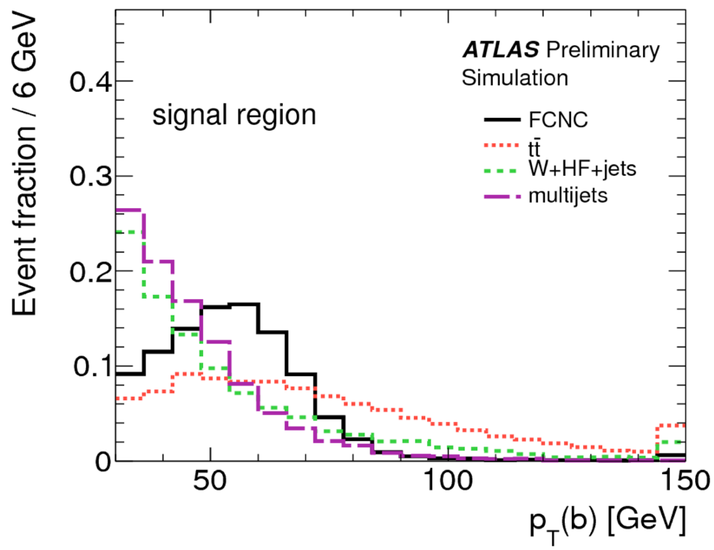
0.91	± 0.08 (exp+th) s+t channels, Tevatron <3.2fb-1	0908.2171	
0.92	± 0.10(exp)±0.05(theo) s+t channels CDF 7.5fb-1	CDF conf Note 10793	
1.12	± 0.09 s+t channels D0 9. 7fb-1	arXiv: 1307.0731	
1.020	± 0.046 (meas.) ± 0.017 (theor.) tchannel, CMS 7TeV	JHEP 12(2012)035	
1.00	± 0.04 (exp.) ± 0.02 (theor.) t-channel, CMS 8TeV	1403.7366	NEW
0.97	± 0.06(exp.) ±0.06(th) t-channel ATLAS 8TeV 20.3fb-1	ATLAS-CONF-2014-007	NEW
1.03	± 0.12(exp.)±0.04(th.) tW channel 8TeV 13fb-1	CMS PAS TOP-12-040	

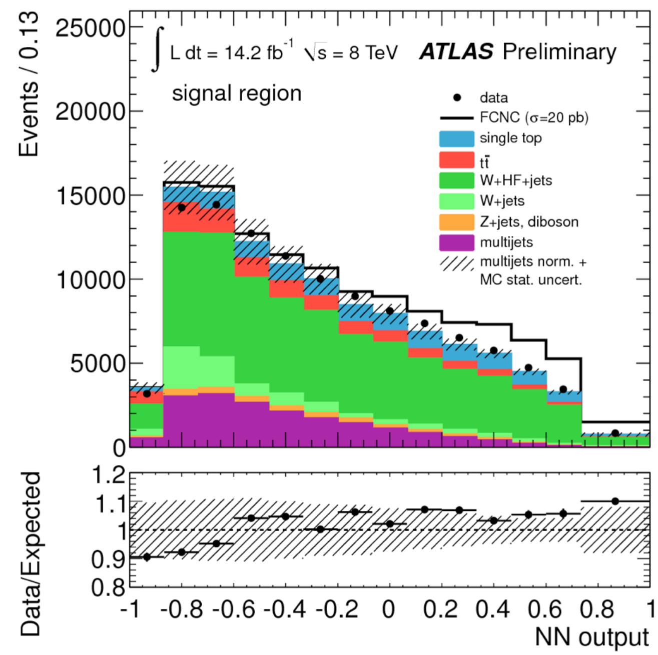
FCNC, GLUONS

ATLAS-CONF-2013-063

- Several NP models (R-parity-violating SUSY/topcolor technicolor), predict enhancements of FCNC decay that lie in LHC sensitivity range (10-3 to 10-5)
- uct, ugt can be better probed from single top production $qg \rightarrow t \rightarrow Wb \rightarrow \ell\nu b \; (q = u, c)$
- top produced alone rather than singly, decay products ~boosted and back to back
  - use NLO predictions and simulations for accurate modeling







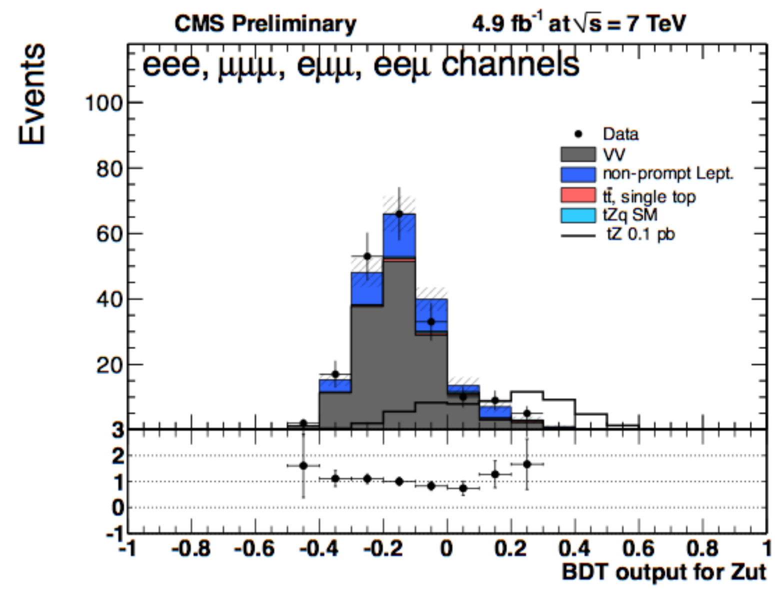
- BR(t→ug)<3.1 x 10-5
- BR(t→cg)<1.6 x 10-4
- currently most stringent results

FCNC, Z BOSONS

CMS-PAS-TOP-12-021

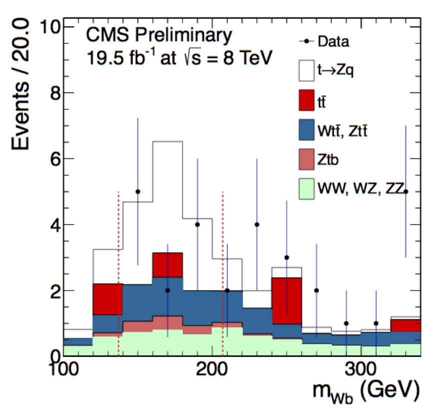
- Use for the first time tZ events to search for FCNC using 7TeV data
  - tZ→trileptons+bjet
- Can identify Z and top separately, use all infos to isolate signal
- Set limits on several anomalous couplings

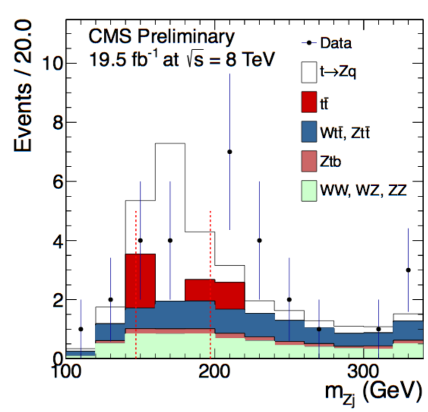
$BR(t \to Zu) \leq 0.51\%$

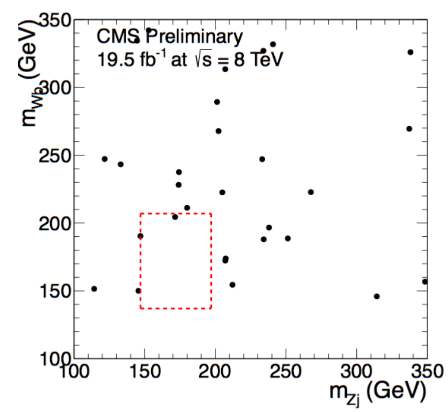


OR

- Use ttbar→bWZq
- Selecting W and Z leptonic decays, full event reconstruction is unambiguous







CMS PAS TOP-12-037

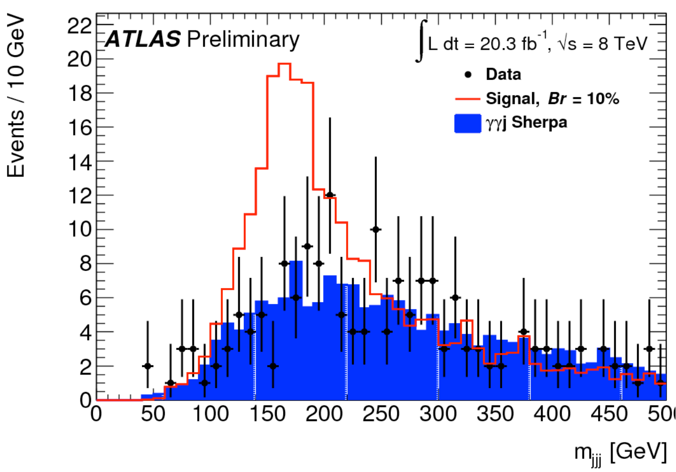
BR(t→Zu)<0.07%

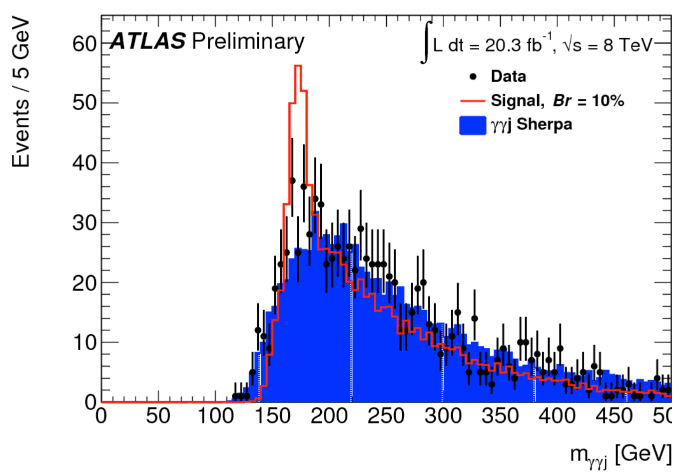
- results are comparable once scaled to same lumi, can be combined in the future

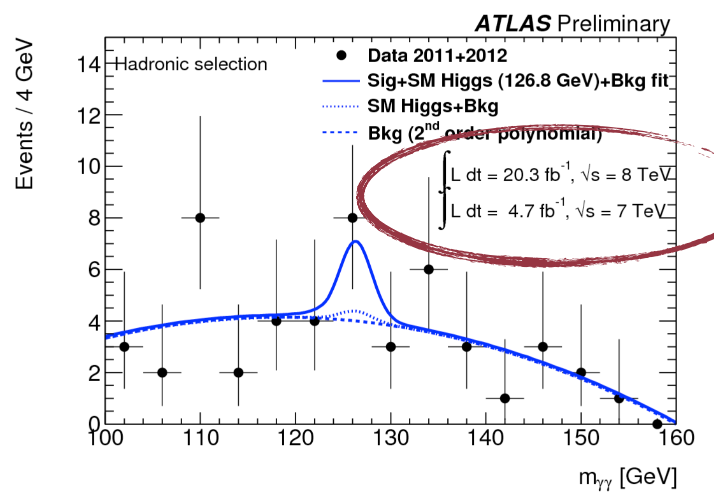
FCNC, HIGGS BOSON

arXiv:1403.6293

- Take the dominant ttbar production mode, look for events with one FCNC decay of the kind t→Hc
- Split into hadronic (tt→cHWb→cHqqb) events and leptonic (tt→cHWb→cgammagamma lnub) events
  - former contain residual combinatorics, latter unambiguous
- Choose topological and kinematic (top quark mass cuts) final states consistent with the FCNH hypothesis, scan over diphoton spectrum



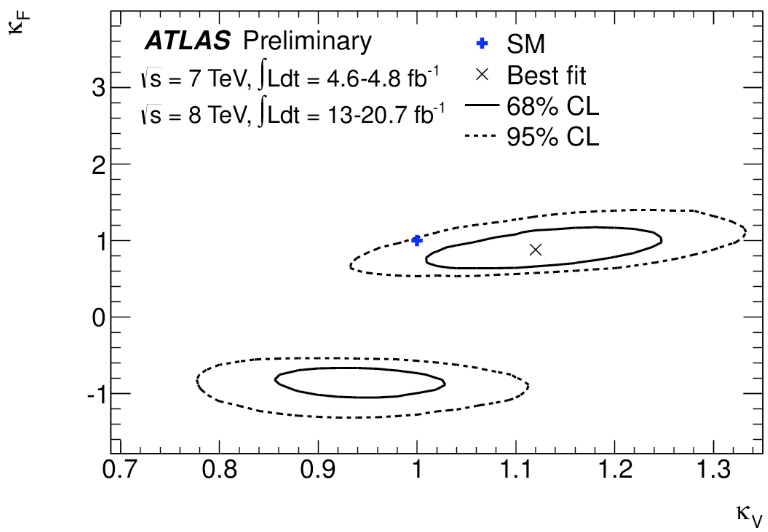


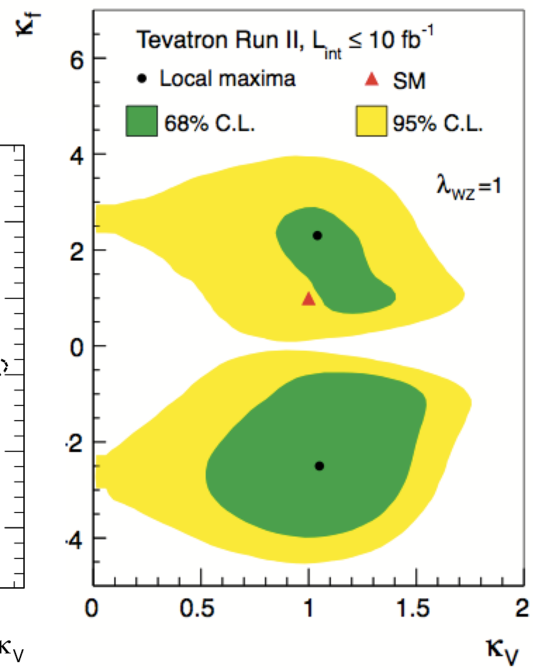


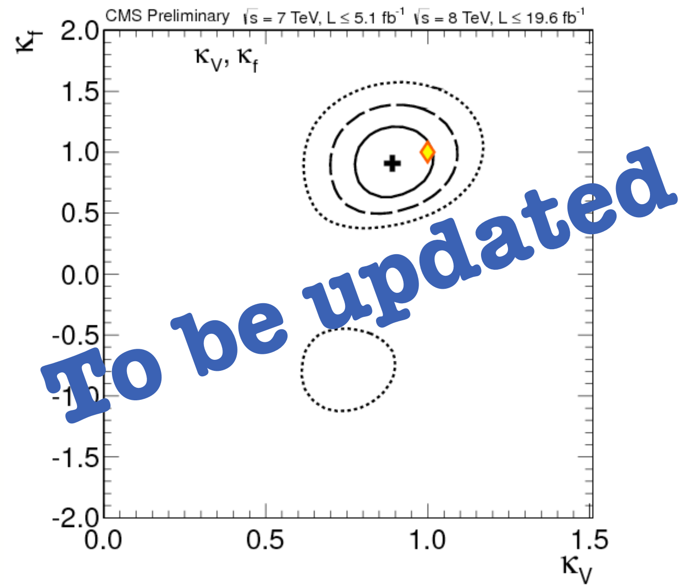
- No significant signal is observed and an upper limit on the branching ratio of 0.83% (0.53% expected) at the 95% confidence level is set. The corresponding limit on the tcH coupling is 0.17 (0.14 expected)

Single top quark + Higgs

- Measurement of this production mode would probe ttH/WWH interference
  - same kind of interference that bring current Higgs data to allow negative coupling of Higgs to fermions (ATLAS, Tev)

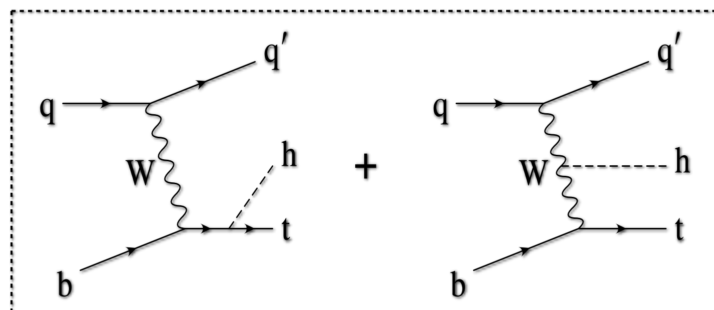






- t-channel tHq production especially sensitive to sign of Yukawa coupling, as it would bring large enhancement in cross section (would exceed ttH production)

Biswas, Gabrielli, Mele et al. JHEP 01 (2013) 088
Farina, Grojean, Maltoni, Salvioni, Thamm JHEP 05 (2013) 022
Biswas, Gabrielli, Margaroli, Mele et al. JHEP 07 (2013) 073



SINGLE TOP QUARK + HIGGS

CMS-HIG-14-001

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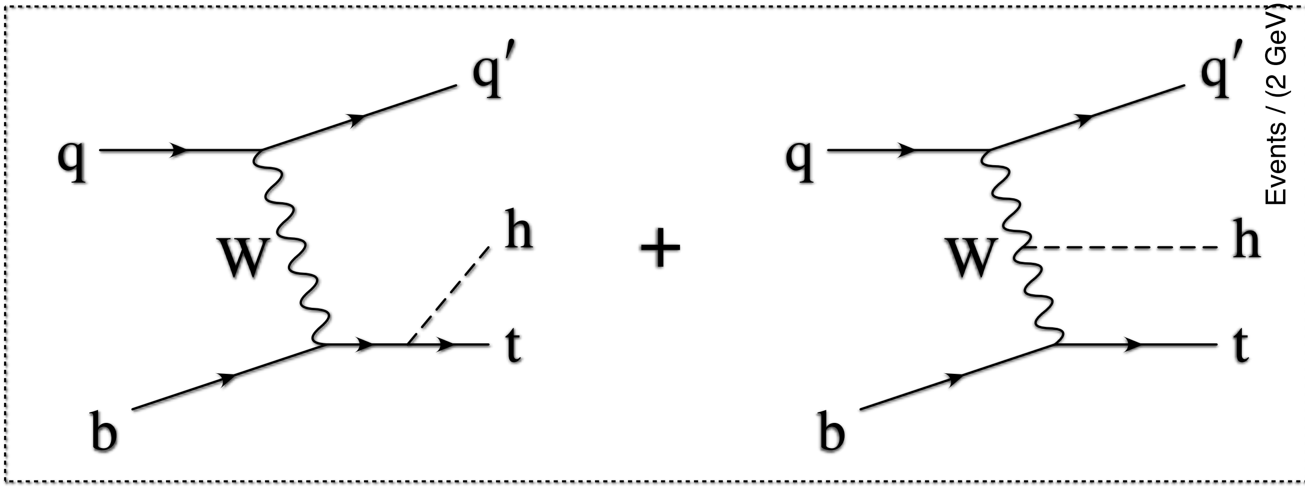

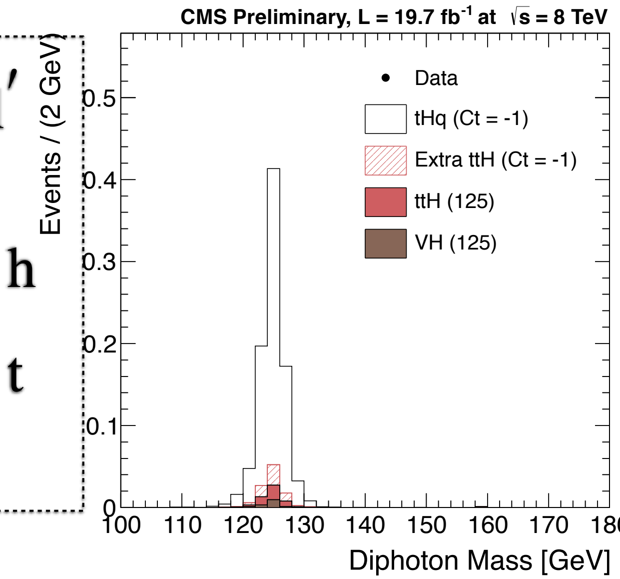

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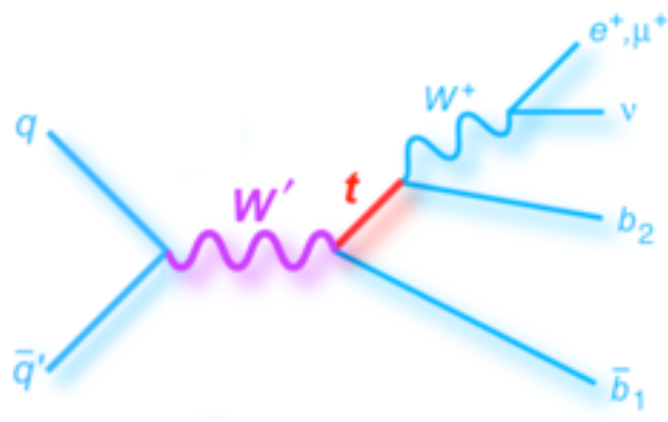
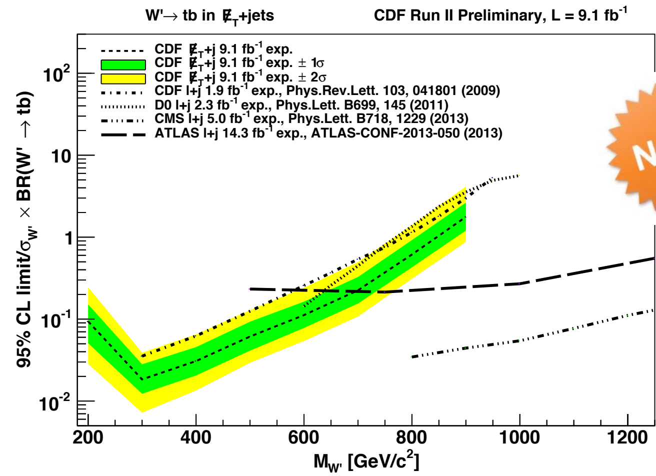
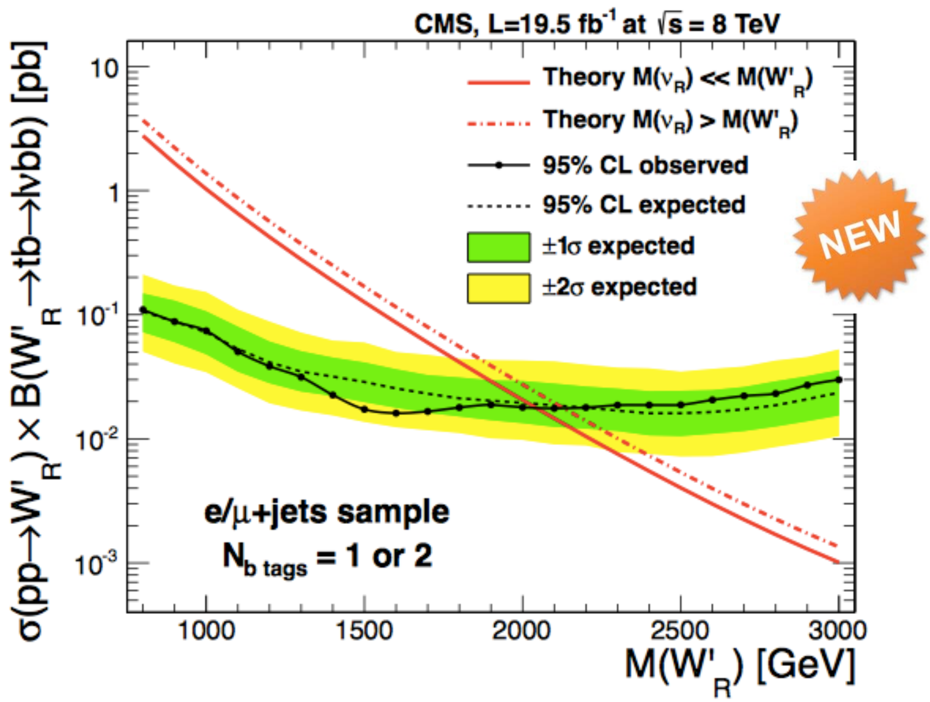
W'->TB



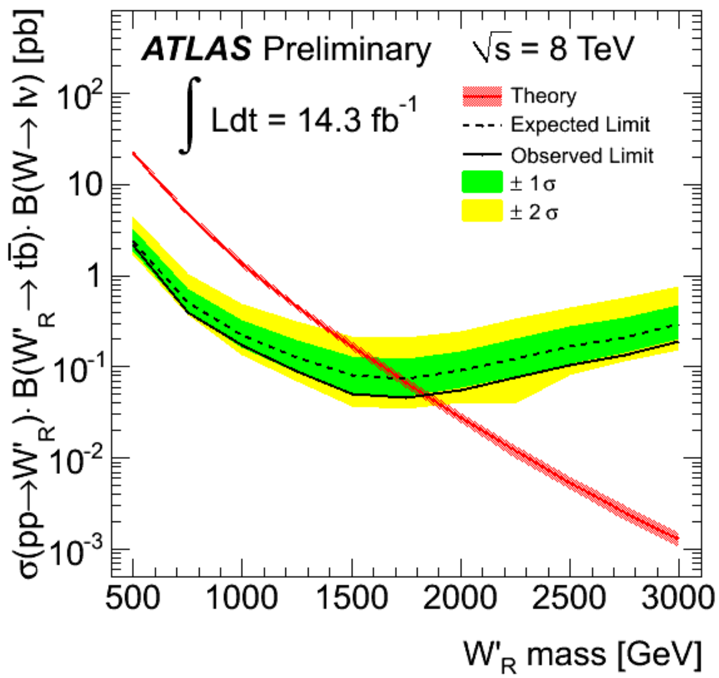
Conf. Note 11079



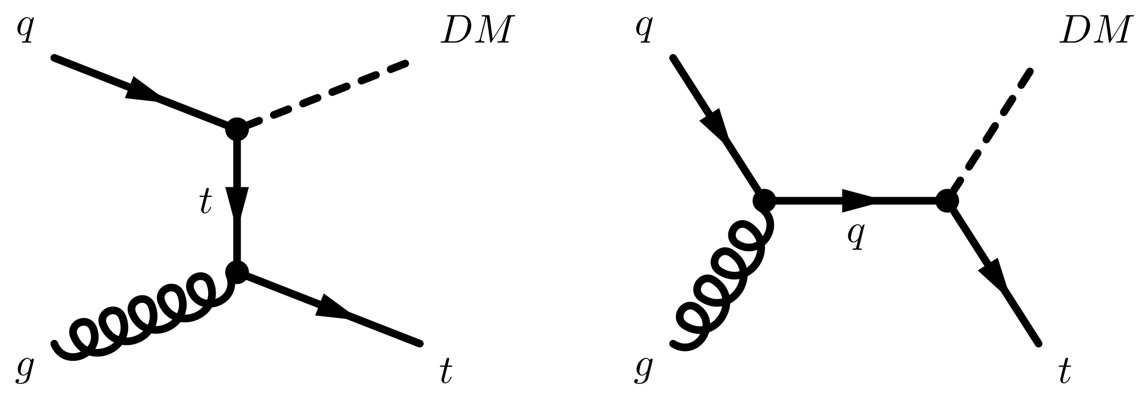
arxiv:1402.2176



ATLAS-CONF-2013-050

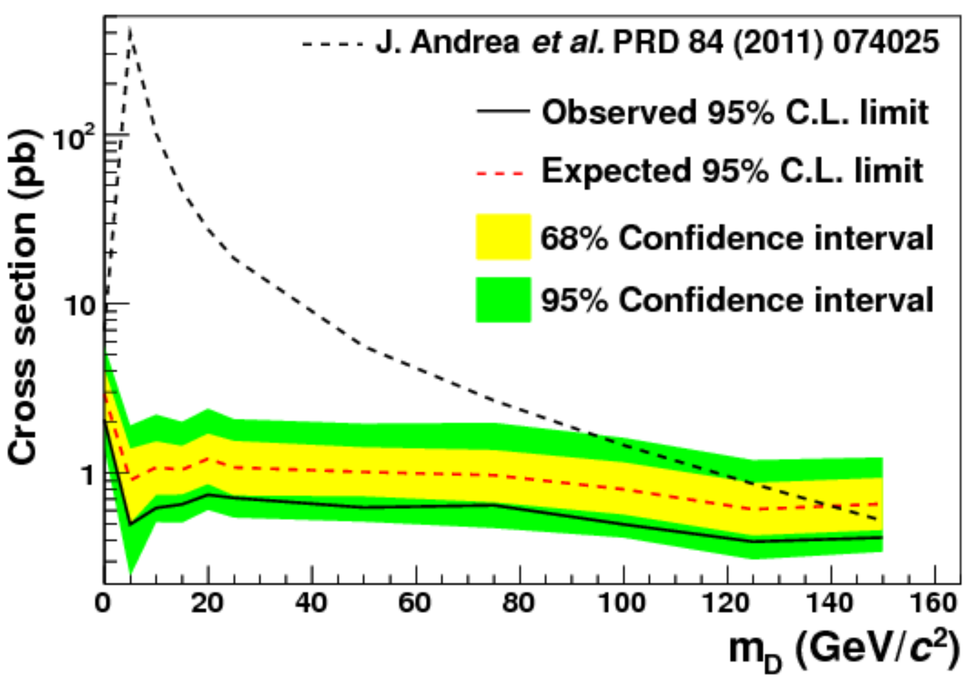


MONOTOP



NEW

Phys.Rev.Lett. 108 (2012) 201802



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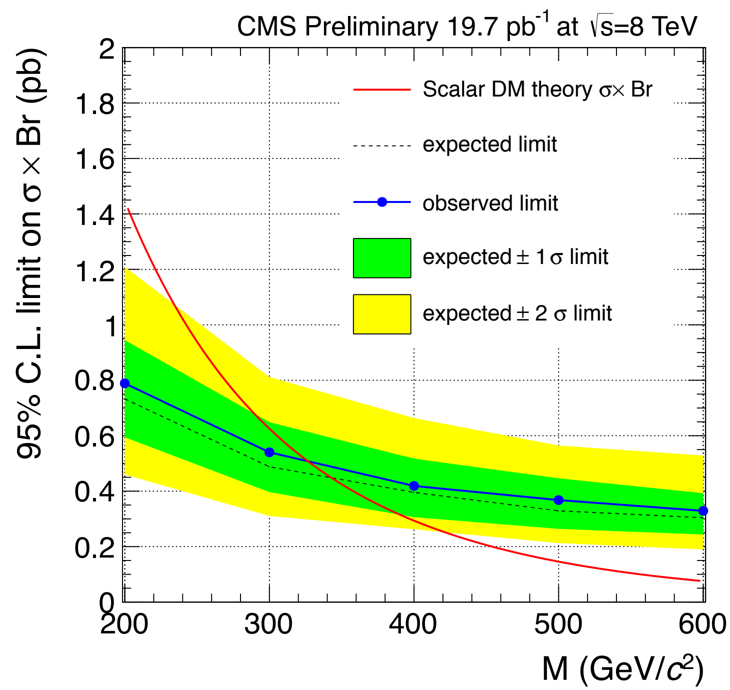
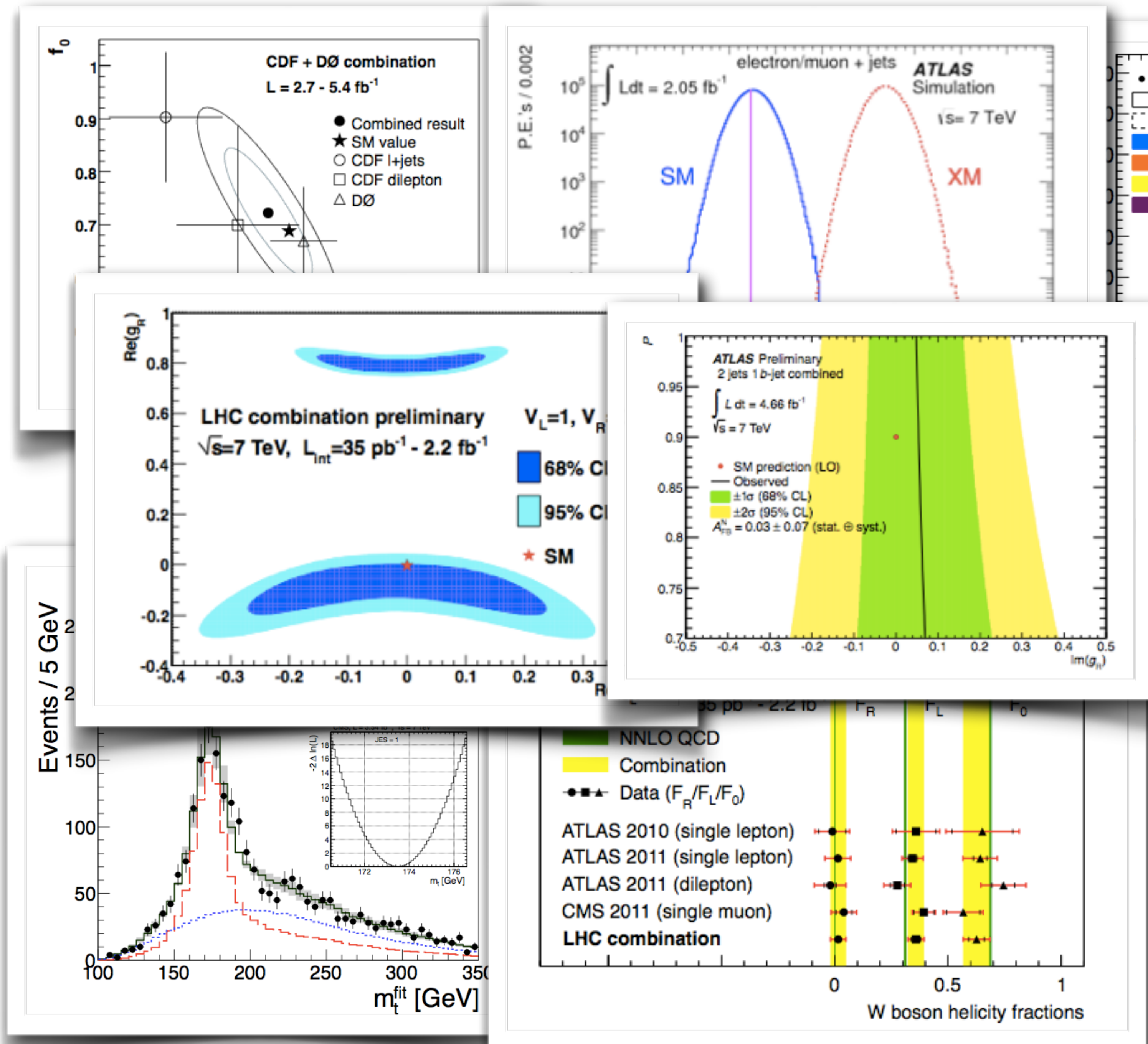
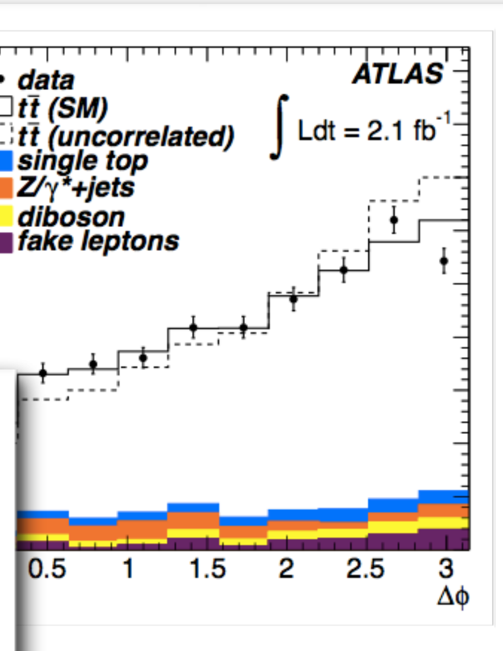
CMS-PAS-B2G-12-022



And much more

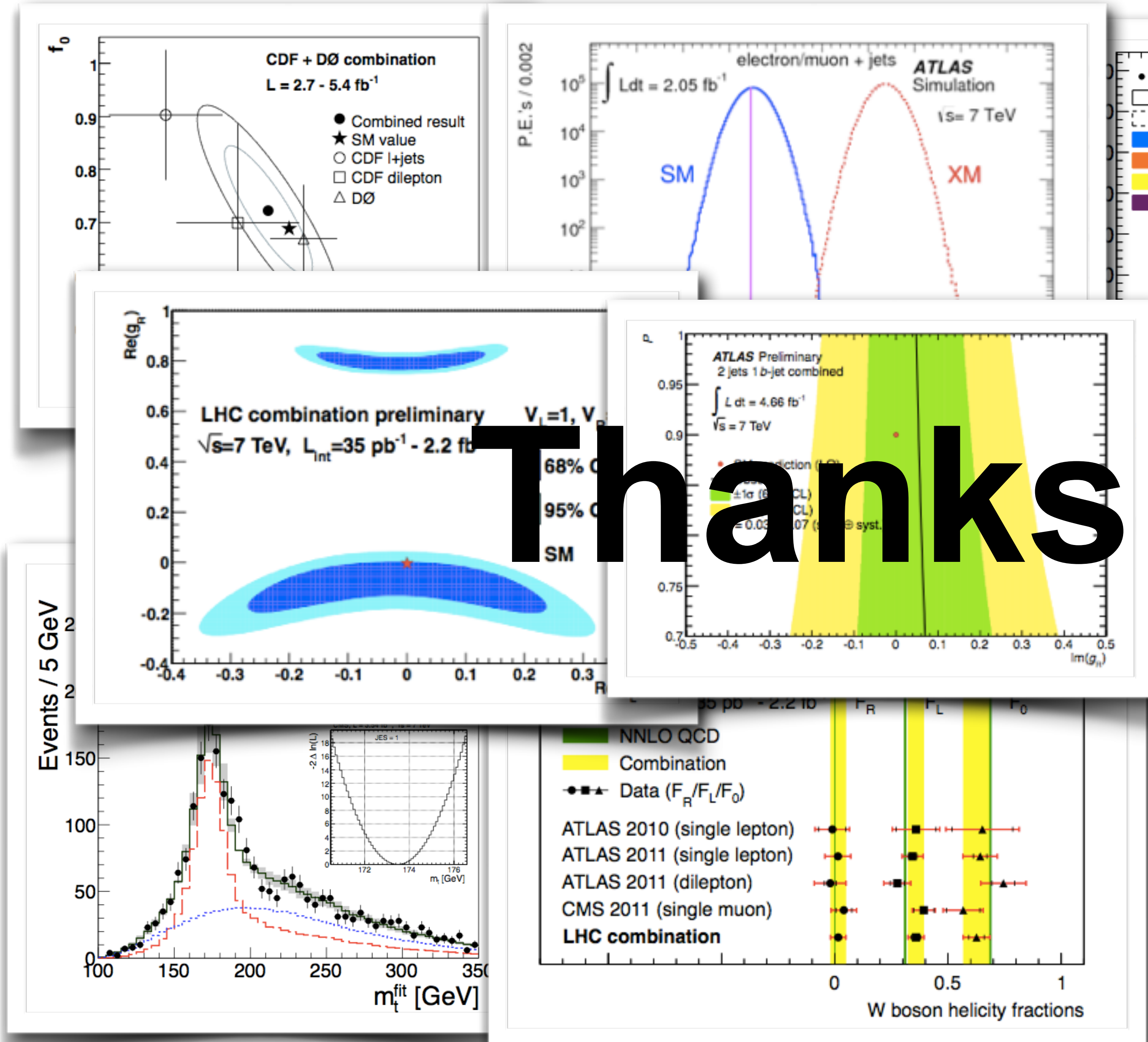


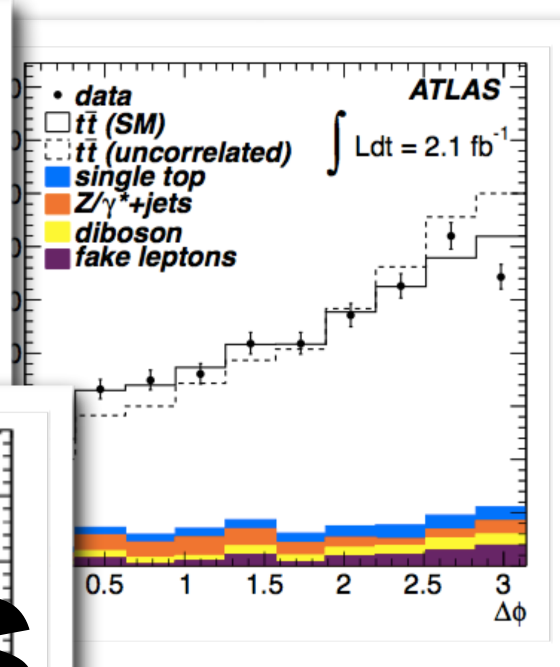


Many more results left out.

Please look at the D0/CDF/ATLAS/CMS webpages for more, interesting results!

And much more





Thanks

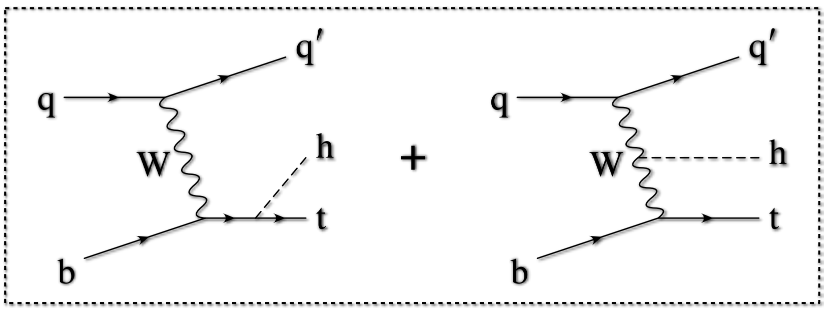
Many more results left out.

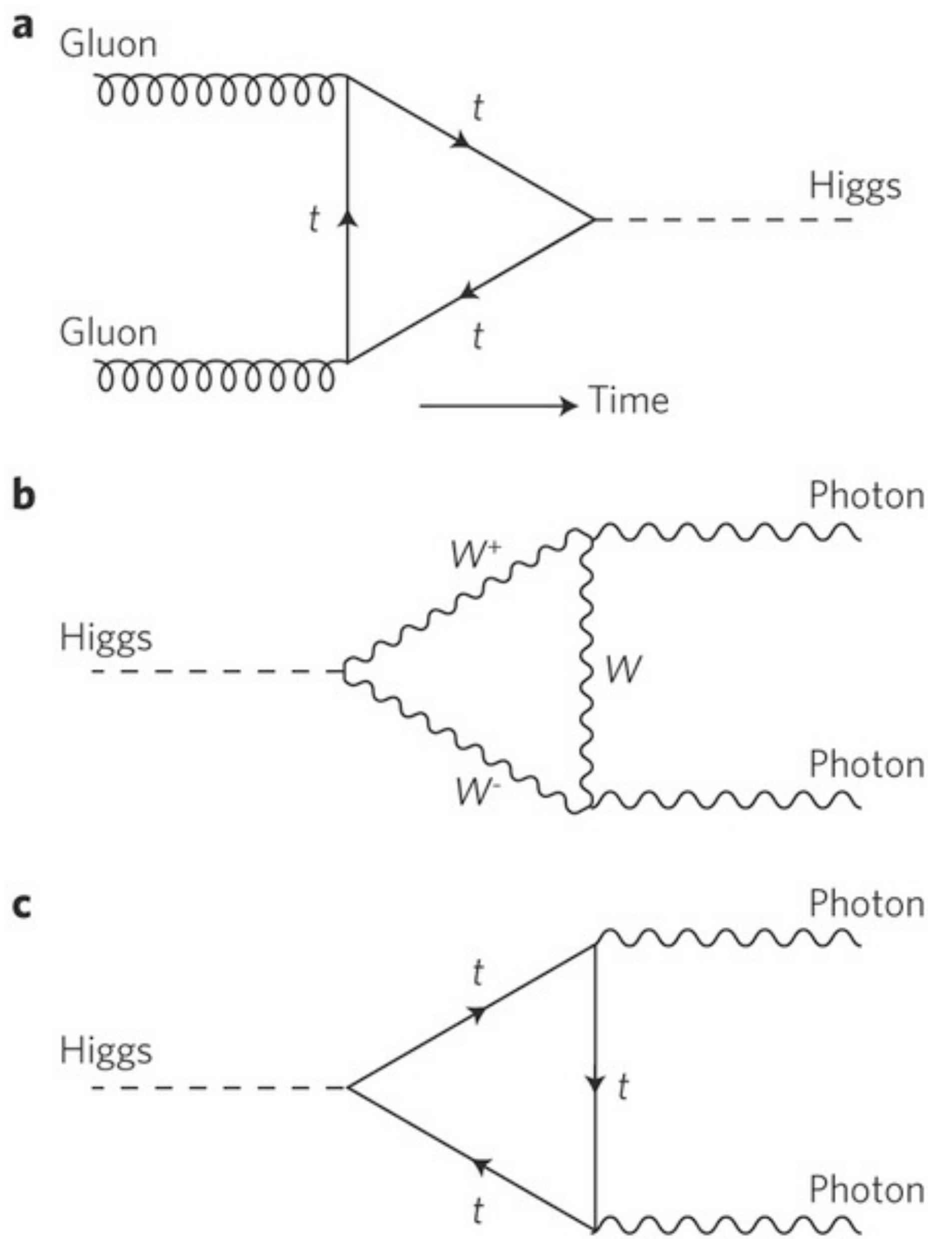
Please look at the D0/CDF/ATLAS/CMS webpages for more, interesting results!

BACKUP

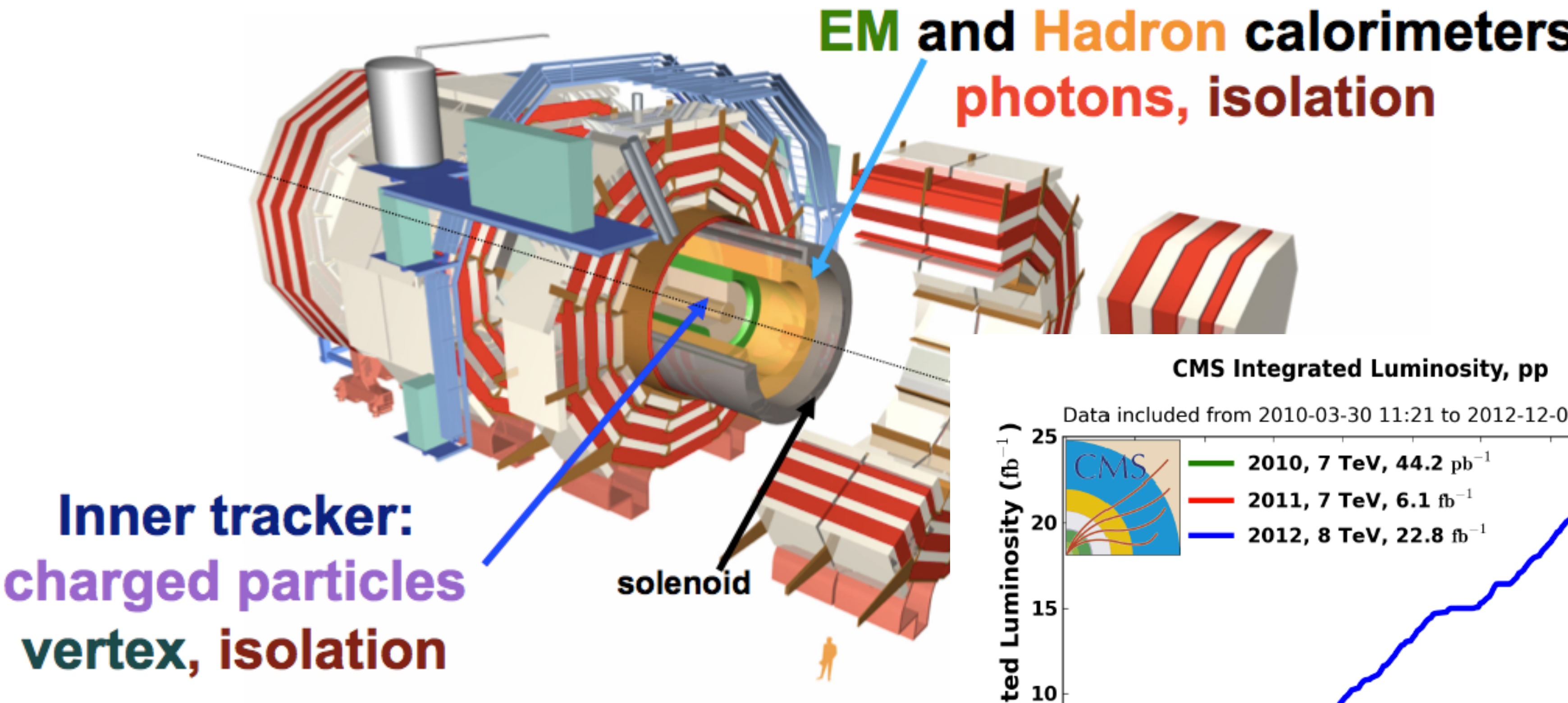
HIGGS AND FERMIONS

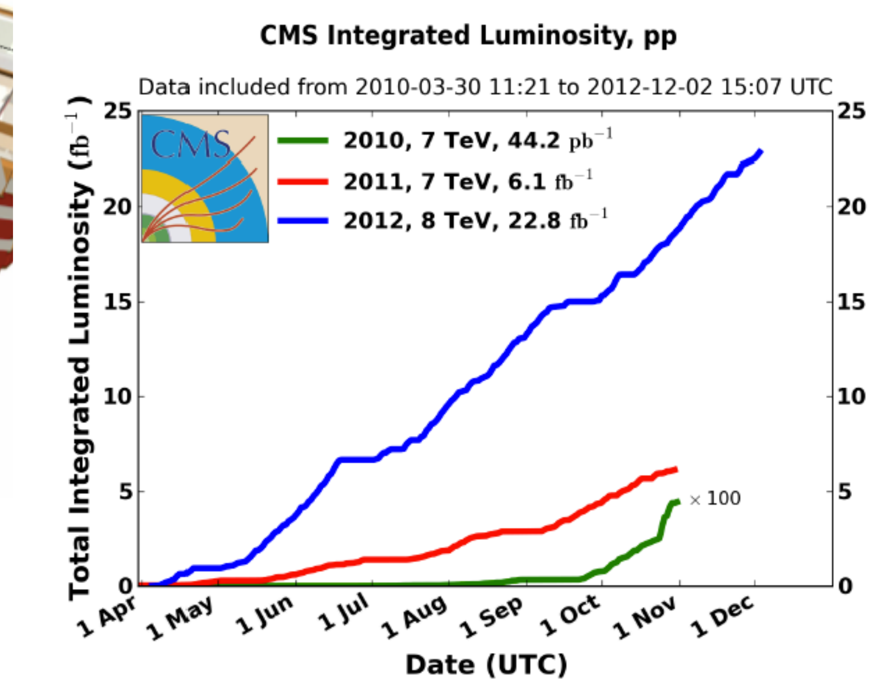
- We know there is a Higgs boson in LHC data
- it first appeared decaying into two bosons
- the big picture is still far from clear, as there are a multitude of loops where new physics might be hiding
- not to mention interference between diagrams...

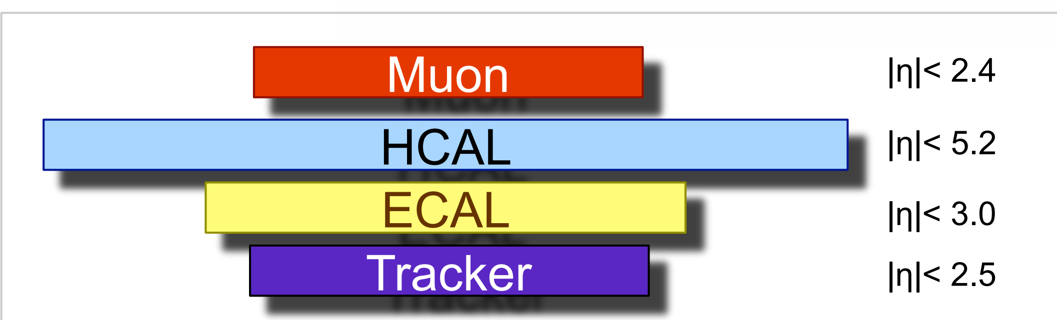




THE CMS DETECTOR



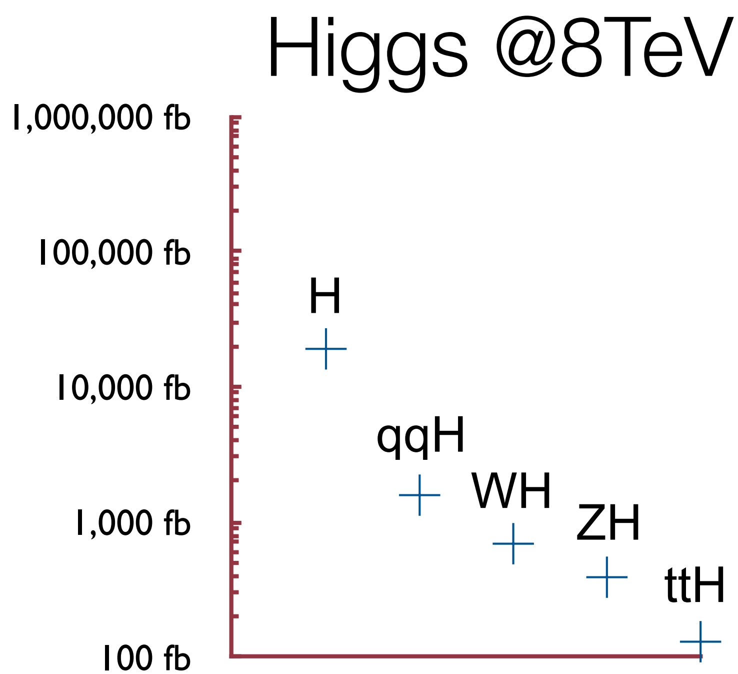


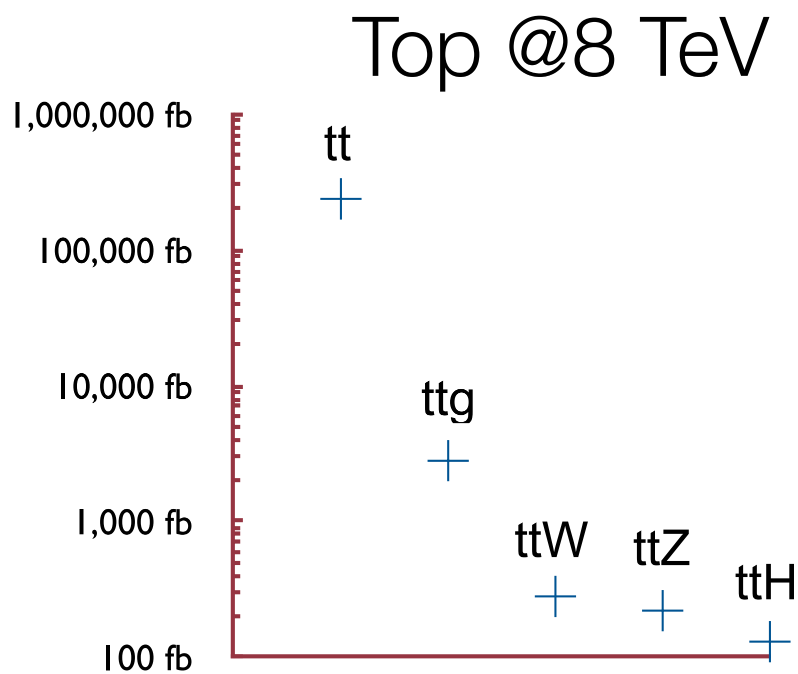


The search for ttH requires all subdetectors!

DIG DEEPER INTO THE LHC GOLD

Higgs and top cross sections at 8 TeV pp collisions





TECHNICALITIES

Signal and background modeling

- ttH, WW, WZ, ZZ Pythia
- ttW/ttZ/ttgamma/ttgammagamma/gamma+jets/gammagamma+jets MadGraph
- tq/tW Powheg

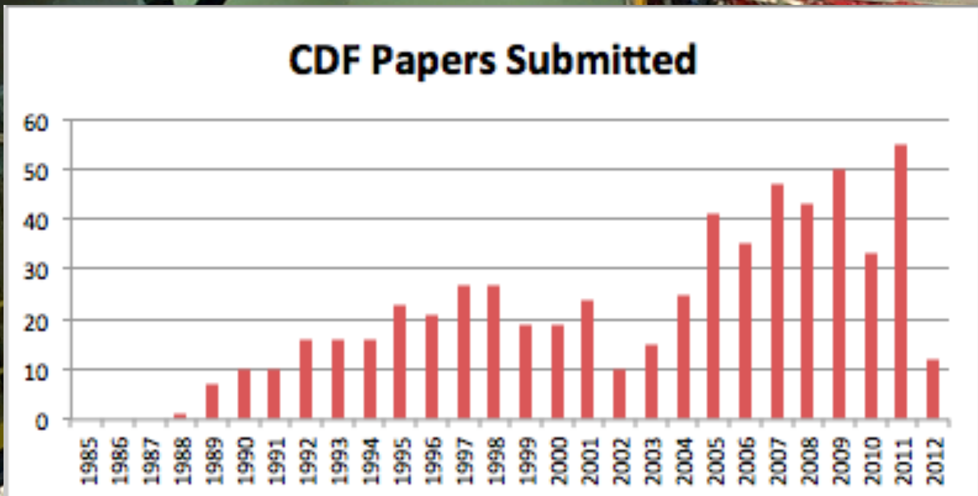
Triggers used:

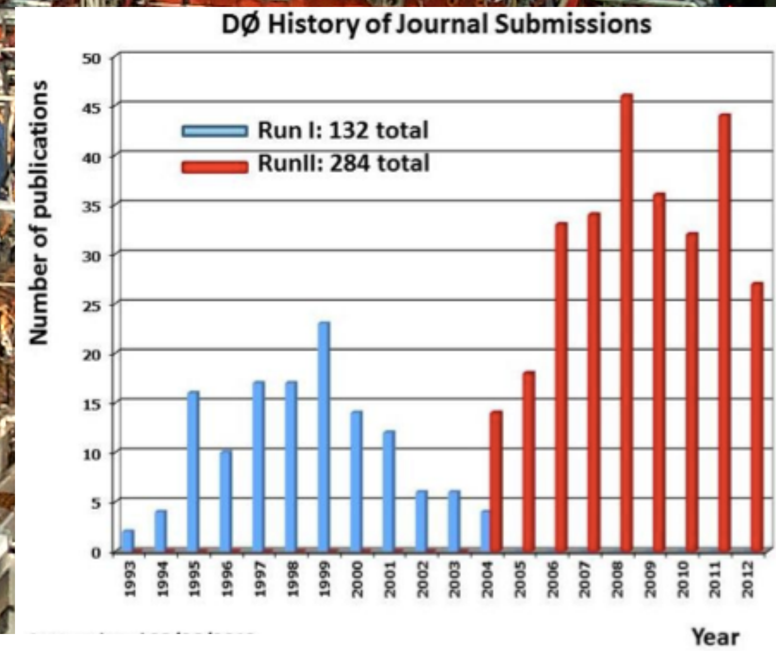
- Diphoton trigger
- Electron trigger
- Muon trigger
- ee/emu/mumu triggers

btagging

- Combined secondary vertex, medium OP
- H->bb also uses full CSV spectrum

Top at the Tevatron

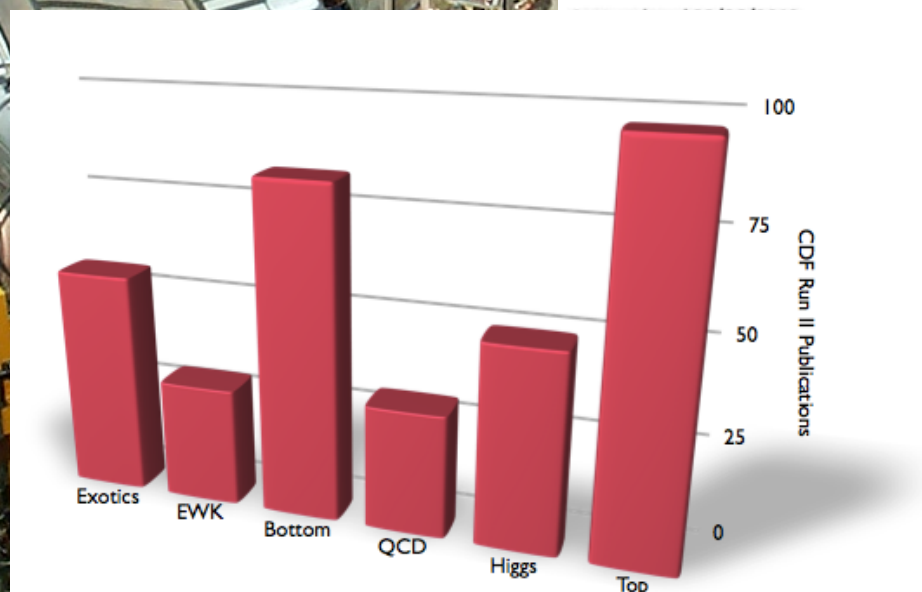




Over 1000 papers total

Over 600 RunII papers

More than a quarter are top results



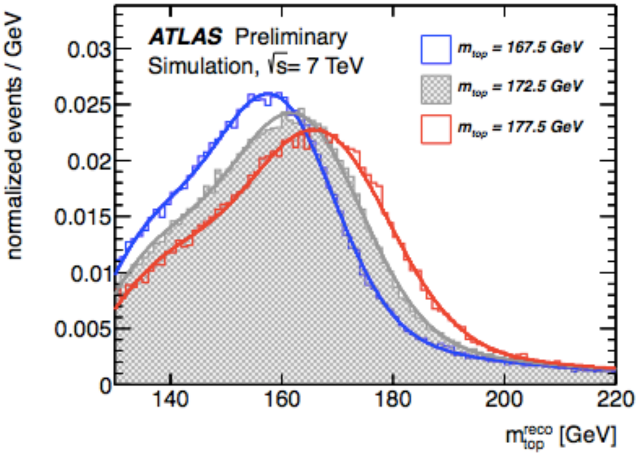
CDF histo.Similar numbers for D0

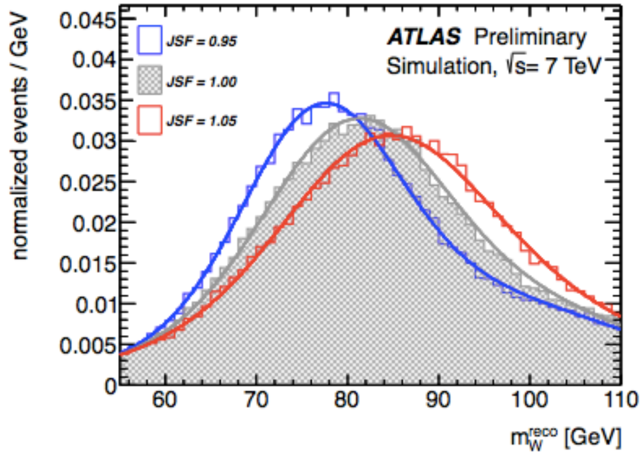
NEW

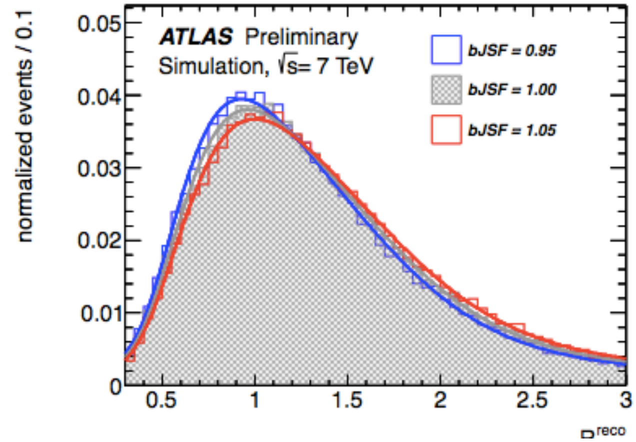
NEW ATLAS MEASUREMENT

ATLAS-CONF-2013-046

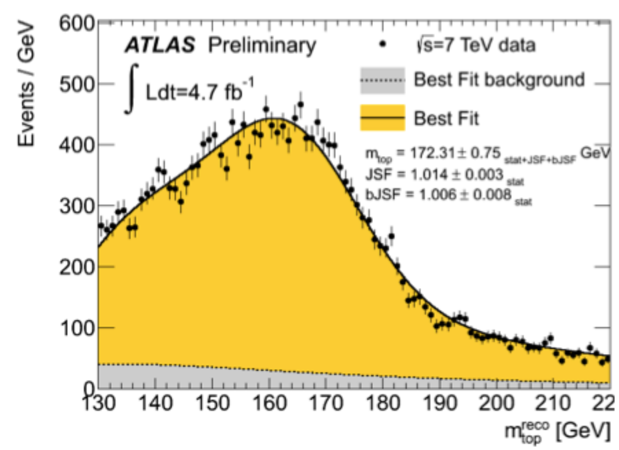
- Typically most performing analyses fit to
  - an observable sensitive to Mtop
  - an observable sensitive to Jet Scale Factor(JSF) in order to limit its systematic
- ATLAS adds a third observable, ratio between Pt of b-jets and Pt of light jets, in order to limit the effect of bJSF







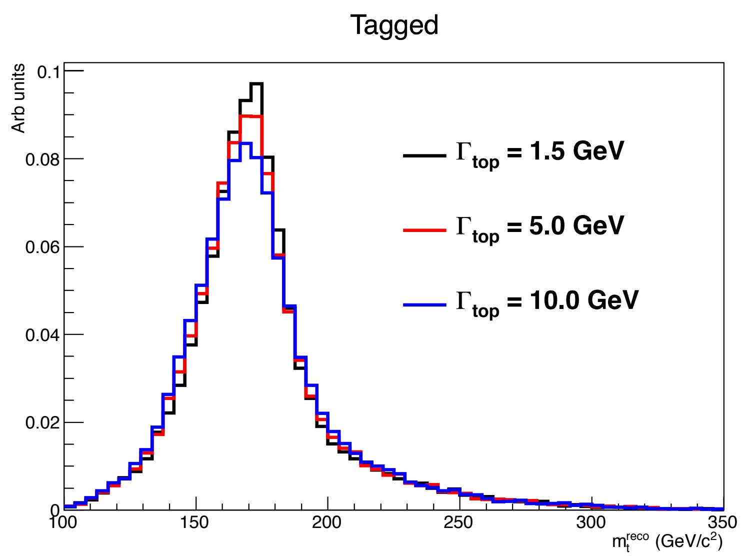
- m_{top}=172.31±0.23(stat)±0.27(JSF)±0.67(bJSF)±1.35(syst)GeV
- Sensibly reduced the impact of bJSF
- Fit for JSF and bJSF compatible with a priori knowledge

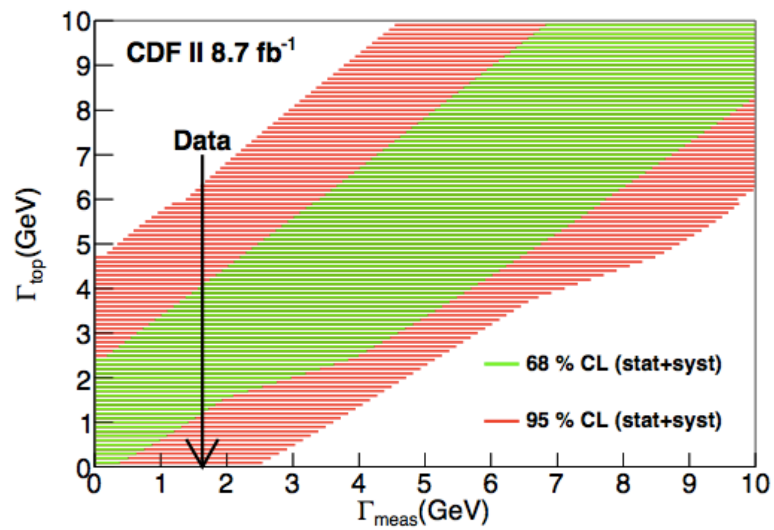


TOP QUARK WIDTH

Just submitted
arxiv:1308.4050v1

- Width has been computed at NNLO = 1.32 GeV (for Mtop=172.5)
- Deviations are model-independent ways to probe for new top decays: H± stops, FCNC
- Analysis strategy: fully reconstruct semileptonic top decays using known MW, Mtop, reduce jet energy resolution through NN-based regression, jet energy scale through W→qq decays, extract from top mass limits on width



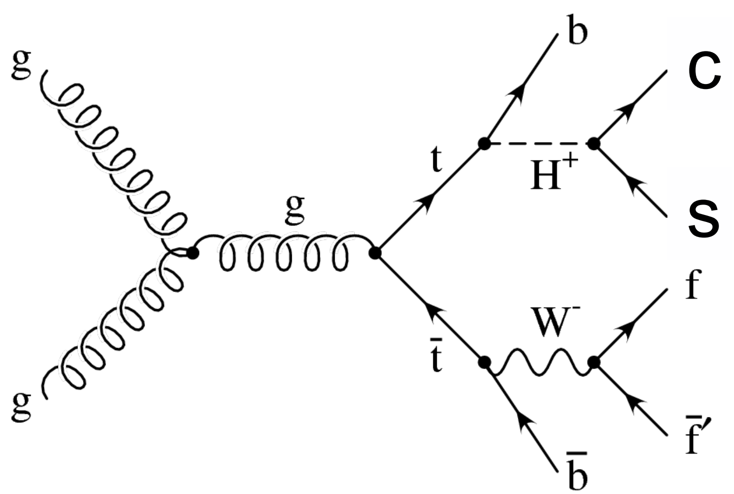


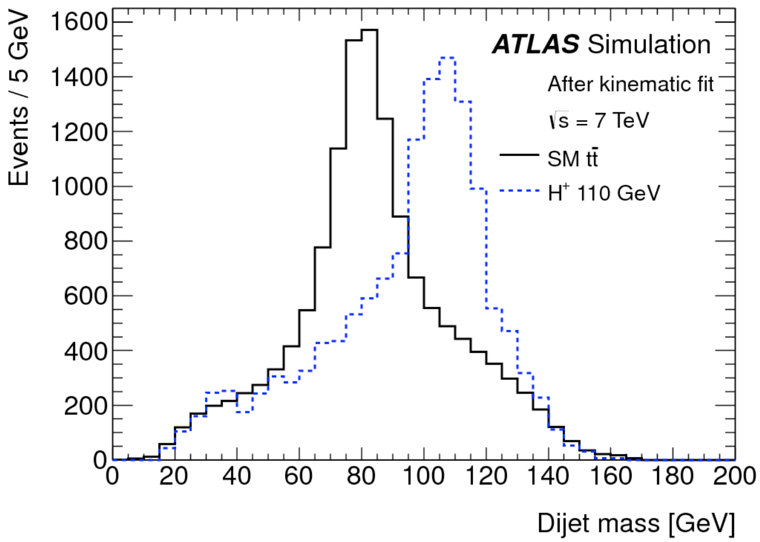
- Set a two-sided limit of 1.10 < Γtop < 4.05 GeV at the 68% C.L, or $\Gamma_{top} = 2.2^{+1.8}_{-1.1}$ GeV
- The D0 Collaboration has determined the width to be Γ = 2.00±0.47GeV using a model-dependent, indirect measurement that assumes SM couplings PRD 85, 091104 (2012).

CHARGED HIGGS FROM TOP

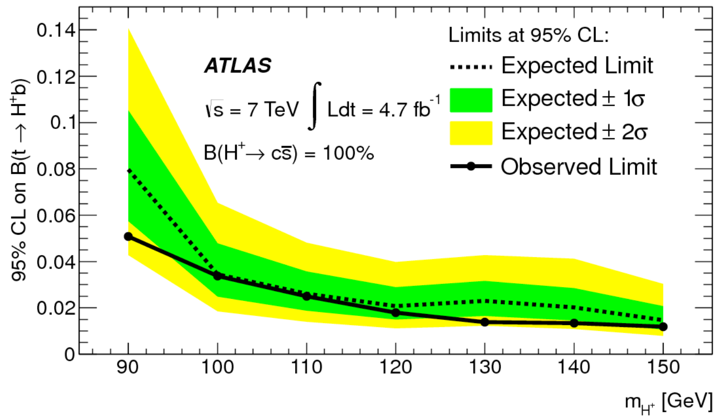
Eur. Phys. J. C, 73 6 (2013) 2465

- Charged Higgs appearing in two Higgs doublet models (2HDM) such as SUSY or triplets
- For H± mass < m(t-b), then decays might appear from top events
- In SUSY, depending on tan(beta), charged Higgses decay dominantly to taunubar, csbar (charge-conjugated processes implied)





- If H± → csbar, then fully reconstruct the event and scan for an hadronic resonance around the W mass
- Set limits on BR(t→Hb) branching ratio of approximately 2% depending on mass hypothesis



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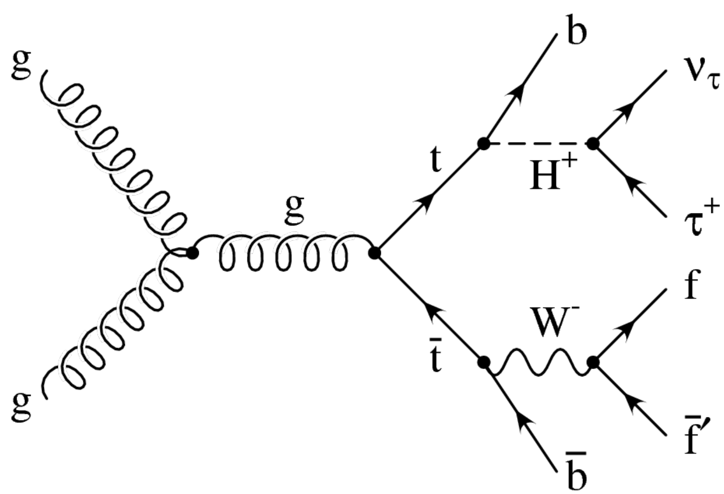
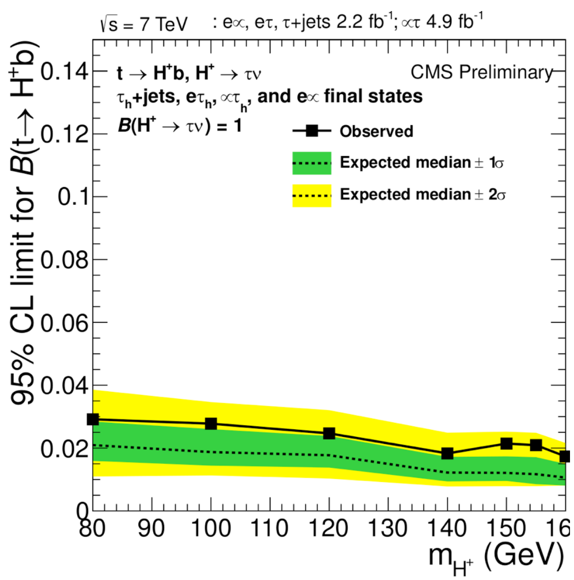
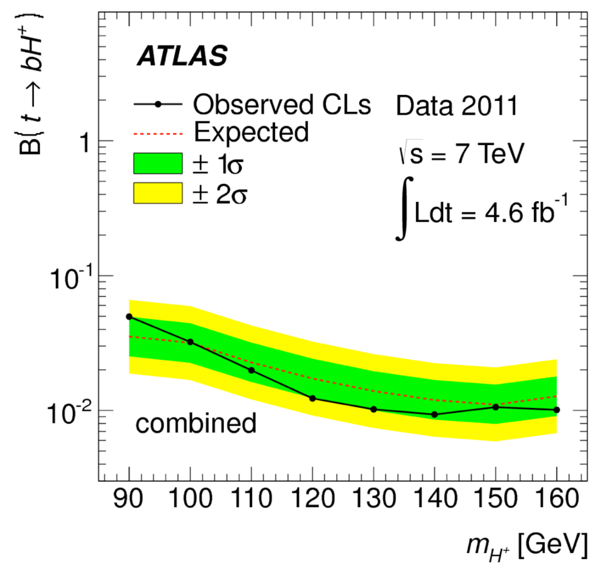


CMS-PAS-HIG-12-052



JHEP 1206 (2012) 039

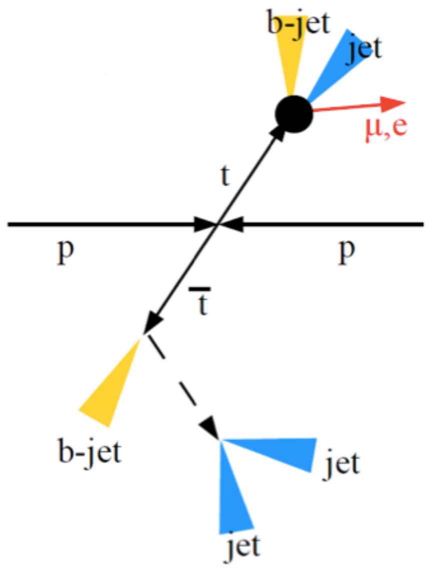


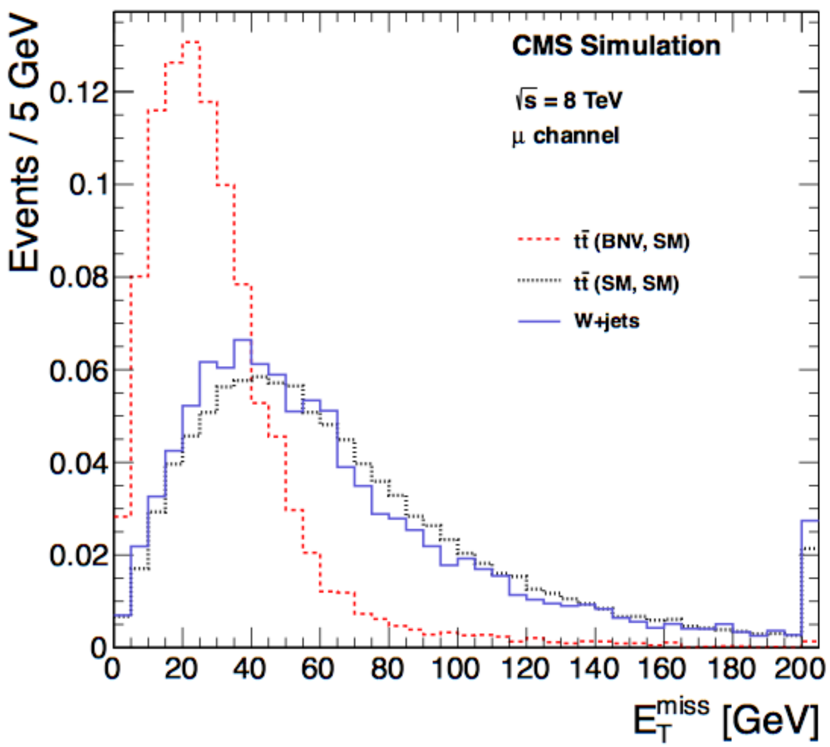
- e-tau, mu-tayu e-mu, tau+jets final states analyzed (here for tau it is assumed hadronic tau decays)
- Both collaboration set limits at the % level

BARYON NUMBER VIOLATION

CMS-PAS-B2G-12-023

- Baryon number violation possible in several BSM scenarios. (SUSY, GUTs, black-hole)
- Limits set on BNV in nucleon, taus, mesons, Z
- Search for $t\bar{t}$ events in which one top decays through $t \to \bar{b}\bar{c}\mu^+$ or $t \to \bar{b}\bar{u}e^+$
  - no neutrinos!





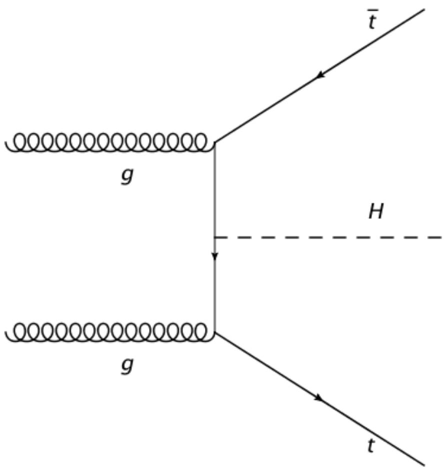
- No significant excess has been found, first uper limits BNV in top events set to be:

$$BR(t \to \bar{b}\bar{c}\mu^+) < 0.0016 \text{ @ 95\% C.L.}$$

$$BR(t \to \bar{b}\bar{u}e^+) < 0.0017 \text{ @ 95\% C.L.}$$

TTH: *VERY* COMPLEX FINAL STATE

- Cross section is only ~1/200 of the inclusive Higgs production cross section, ~1/2000 of ttbar production
- Large multiplicity of objects in the final state (signature is dominated by the t/tbar decays)
- Need to find the best combination of top and Higgs decays to isolate the small signal (130fb)



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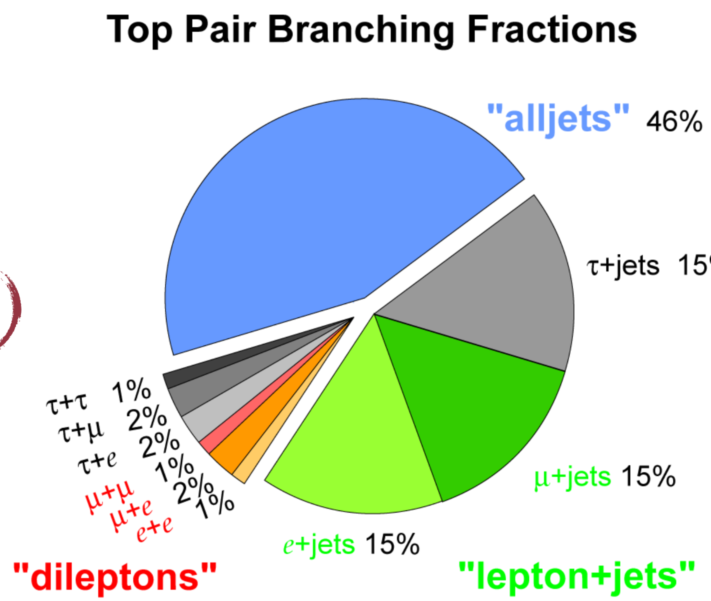

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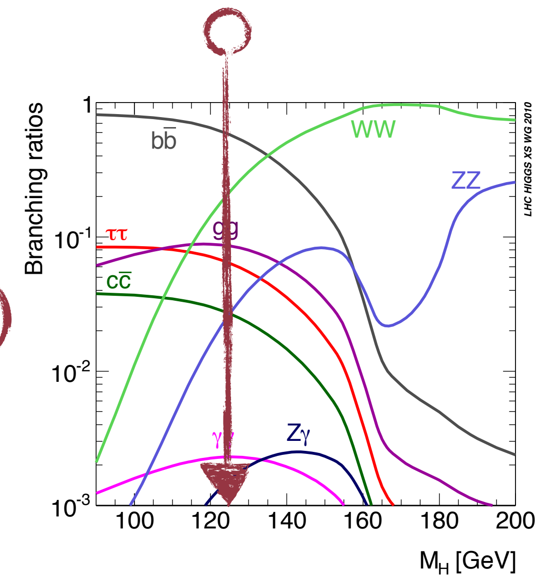
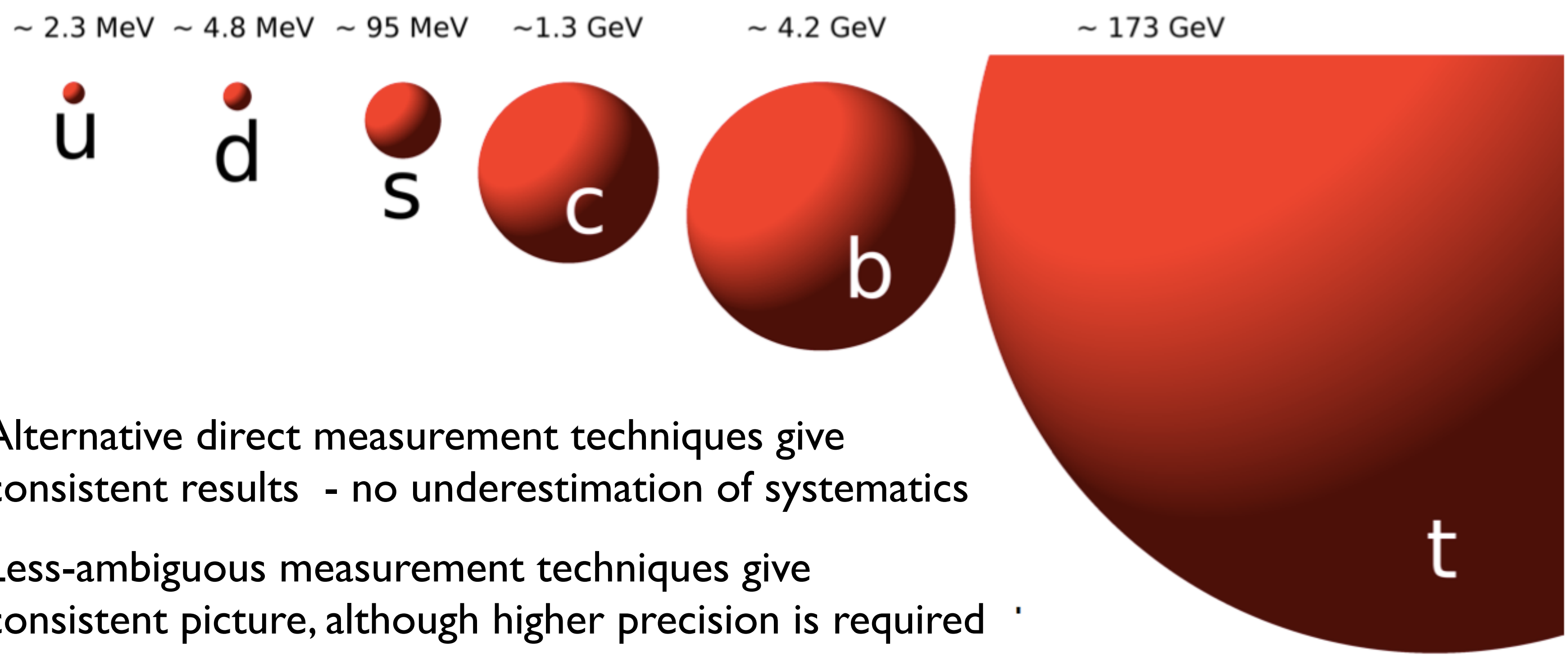


- Studying for now:
  - tt→leptonic, Higgs to bb
  - tt→leptonic, Higgs to tautau
  - tt→anything, Higgs to gamma gamma

MTOP: WHERE ARE WE

- Tevatron still provides the best mass measurement, with an uncertainty of 0.5%.
- Best single LHC measurement (from CMS) reaches 0.6%.
- LHC results mainly coming from 7TeV dataset - lots of room for improvements before LHC reopening!
- Updated LHC mass combination in progress. → Harmonise systematic treatment e.g. generator modeling.

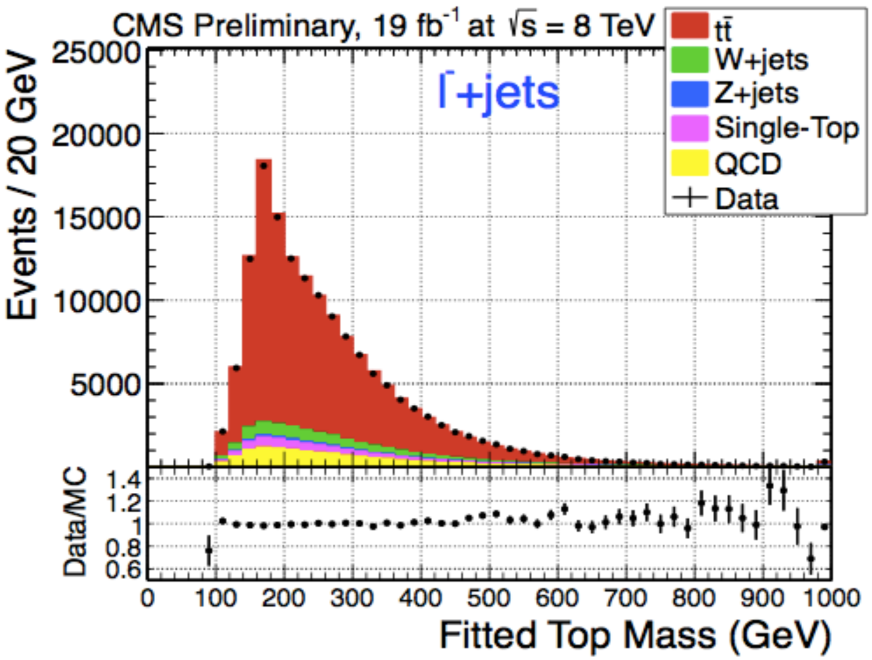


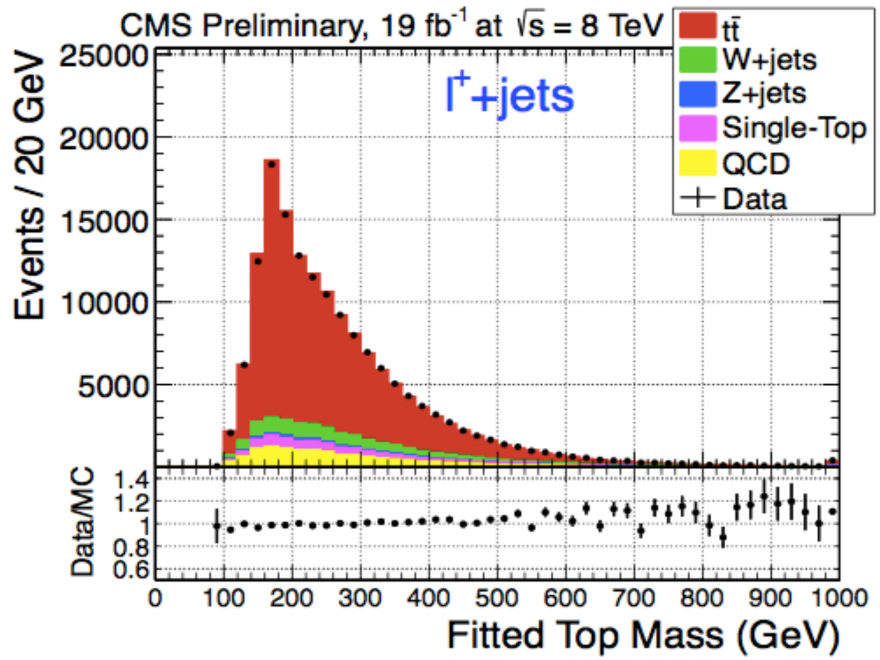
- Alternative direct measurement techniques give consistent results - no underestimation of systematics
- Less-ambiguous measurement techniques give consistent picture, although higher precision is required

CPT VIOLATION

CMS PAS-12-031

- CMS provides the stringent test of CPT violation in top quark physics, by measuring Mtop-Mantitop. Tag leptonic top, reconstruct mass of hadronic top?





- DeltaMt = -0.27±0.20±0.12 GeV (this result)
- CDF: -1.95±1.26GeV (8.7fb^{-1}) PRD 87 052013
- D0: 0.8±1.9GeV (3.6fb^{-1}) PRD 84 052005

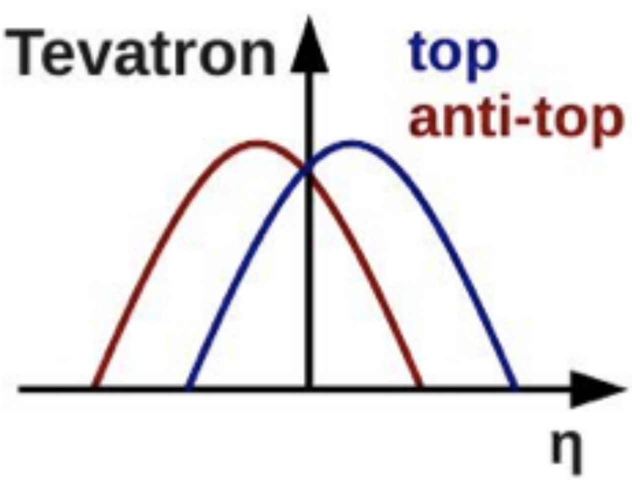
Source	Estimated effect (MeV)
Jet energy scale	**17** ± 15
Jet energy resolution	8 ± **11**
b vs. $\bar{b}$ jet response	**64** ± 7
Signal fraction	**45** ± 2
Background charge asymmetry	**12.43** ± 0.03
Background composition	**50** ± 1
Pileup	**17.4** ± 0.4
b-tagging efficiency	**20** ± 8
b vs. $\bar{b}$ tagging efficiency	**43** ± 6
Method calibration	15 ± **54**
Parton distribution functions	**12** ± 3
Total	122

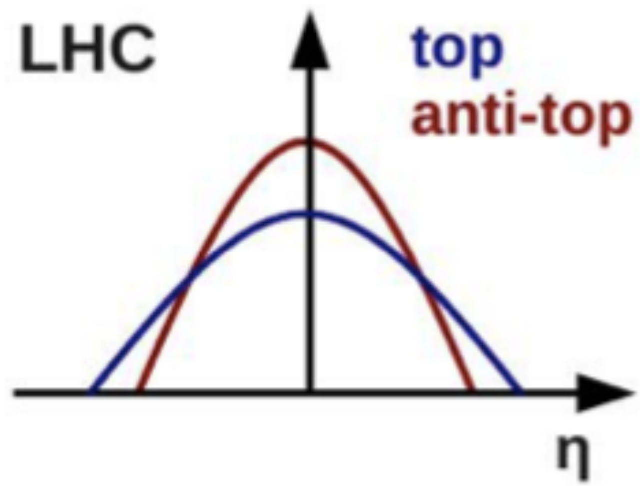
Asymmetries

- Different top quark production modes, different asymmetries at Tev and LHC

Proton-antiproton is a CP eigenstate.
NLO QCD (plus some EW) terms create asymmetry.

Proton-proton not a CP eigenstate.
Small asymmetry comes from PDFs.



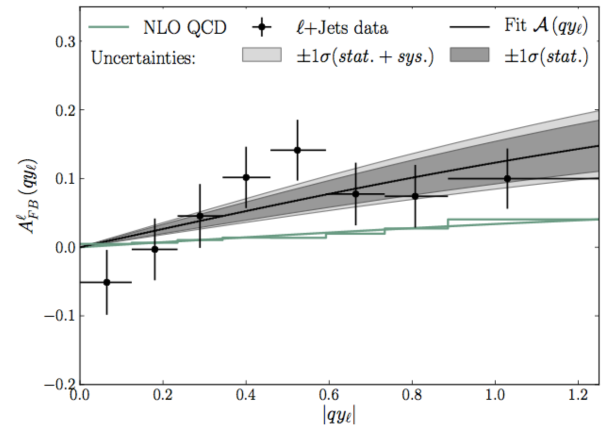


- This is still among hottest TOPics. Want proof? Citation vs time dist. is nearly flat

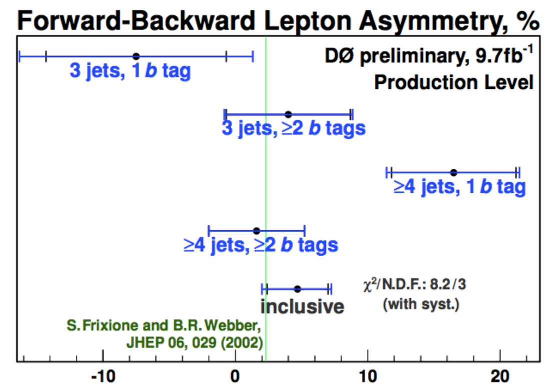
AT THE TEVATRON

- CDF finds several AFB deviations:
  - deviation depend on mttbar, deltaYt PRD 87 092002
  - not dependent on Pt(ttbar) PRD 87 092002
  - deviation appear mostly in first Legendre poly arxiv:1306.2357
    - more s-channel like new physics
  - leptonic asymmetry gives hints of polarization
    - favors right-handed models

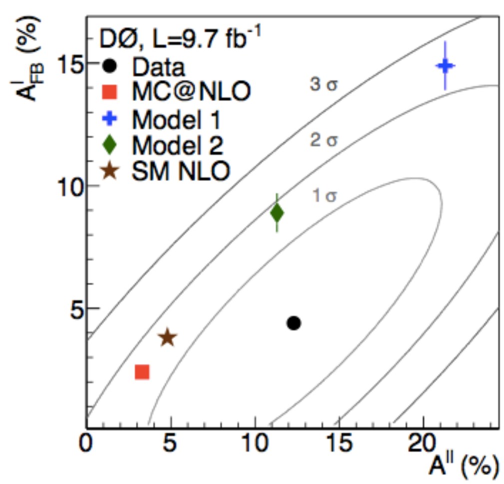
- D0 results are generally between SM and CDF, no significant trends shown
  - latest result analyzes much larger dataset
  - deviation remain only in a subset of data
  - overall good agreement with SM
- Update analysis on lepton asymmetry in dilepton events as well
  - now closer to SM predictions



arxiv:1308.1120



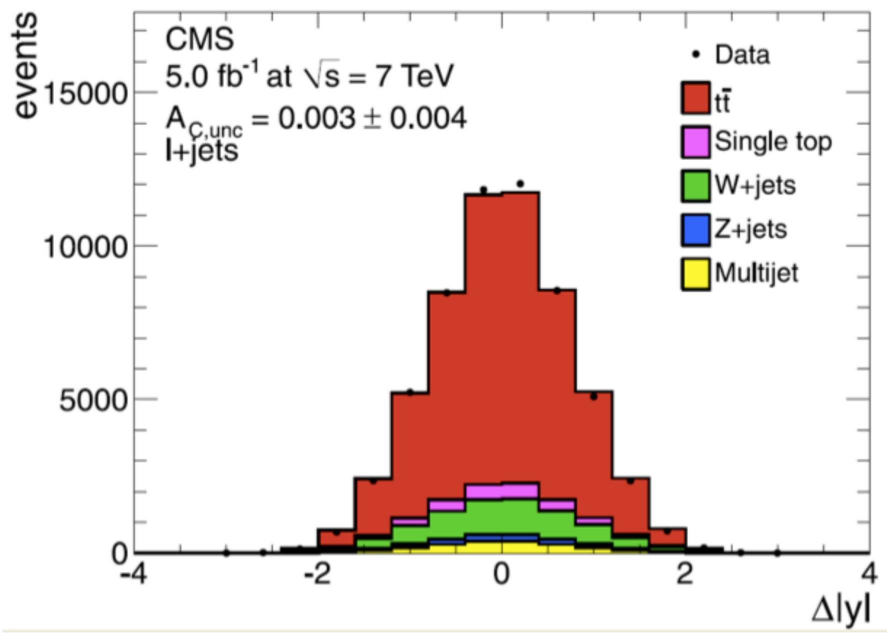
D0 CONF-6394



arxiv:1308.6690

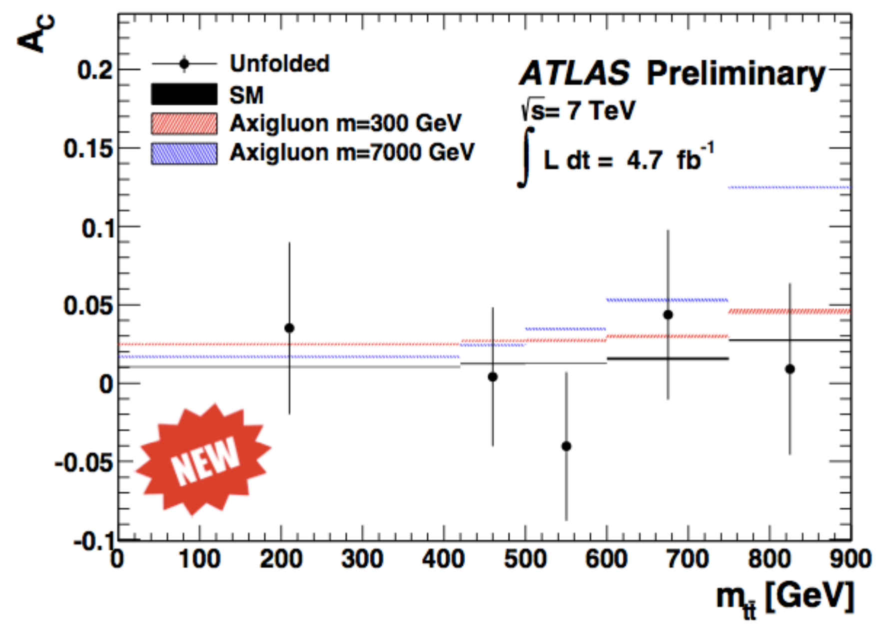
AT THE LHC

- CMS and ATLAS study both inclusive and differential charge asymmetries
- very difficult measurement as theory prediction ~1%, requires very large precision



CMS PAS TOP-12-004

PLB 717 (2012) 109

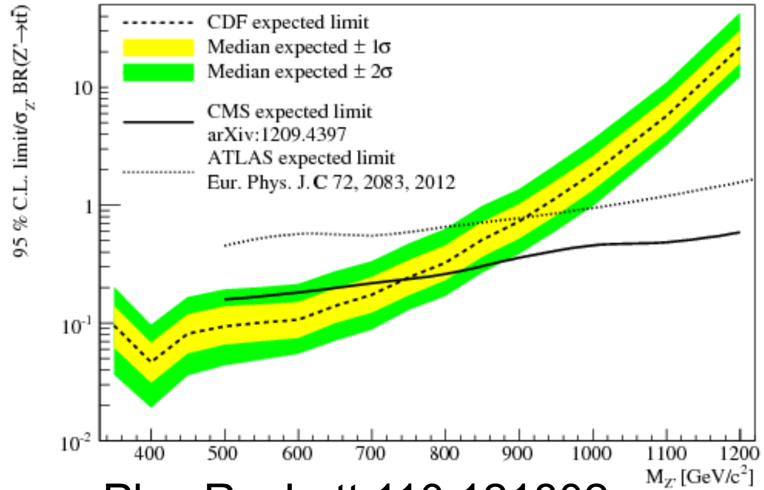


ATLAS-CONF-2013-078

ATLAS-CONF-2012-057

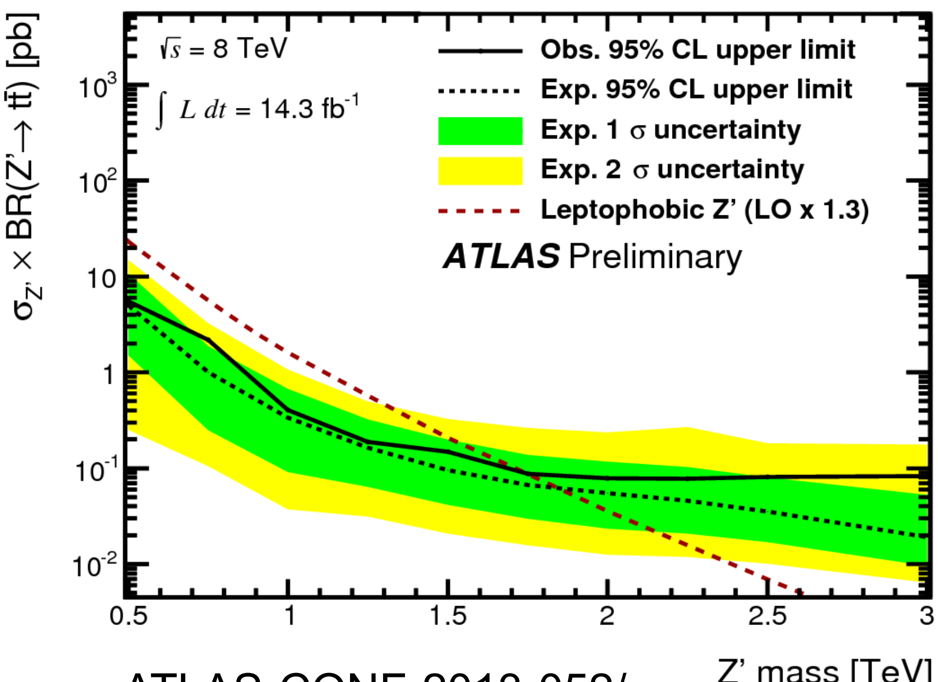
- results consistent with SM, but must be noted that AC and AFB correlate only under assumptions

RESONANT TTBAR PRODUCTION (Z'/G*)

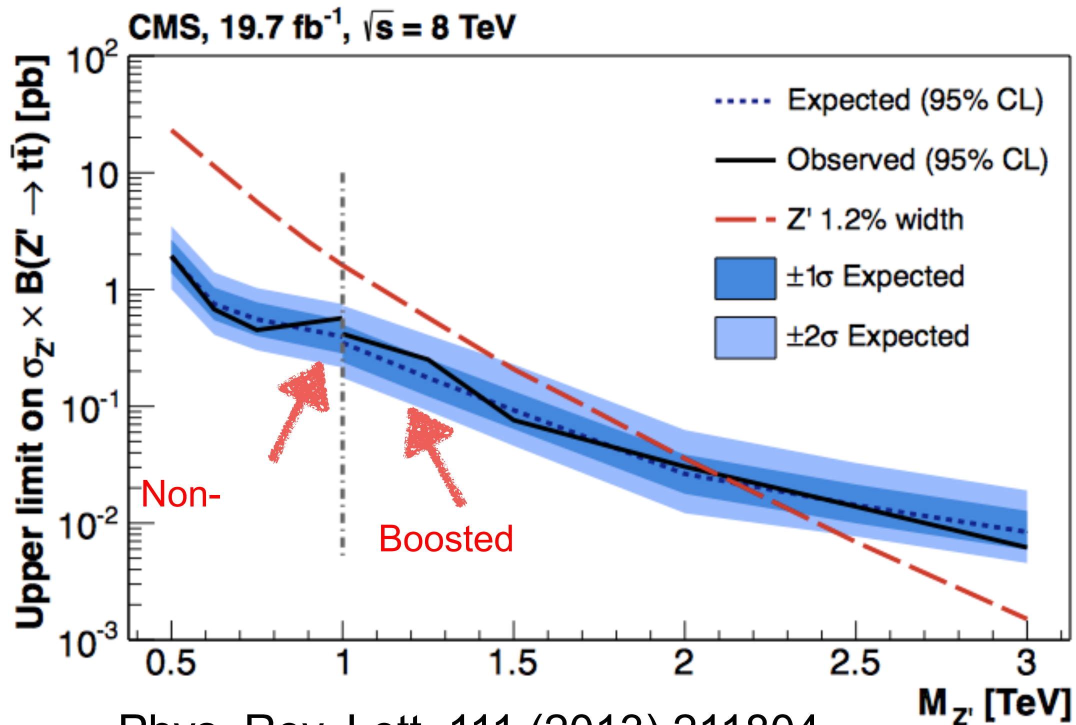


PhysRevLett 110 121802

Caveat: limits for heavy gluons extend beyond 2TeV



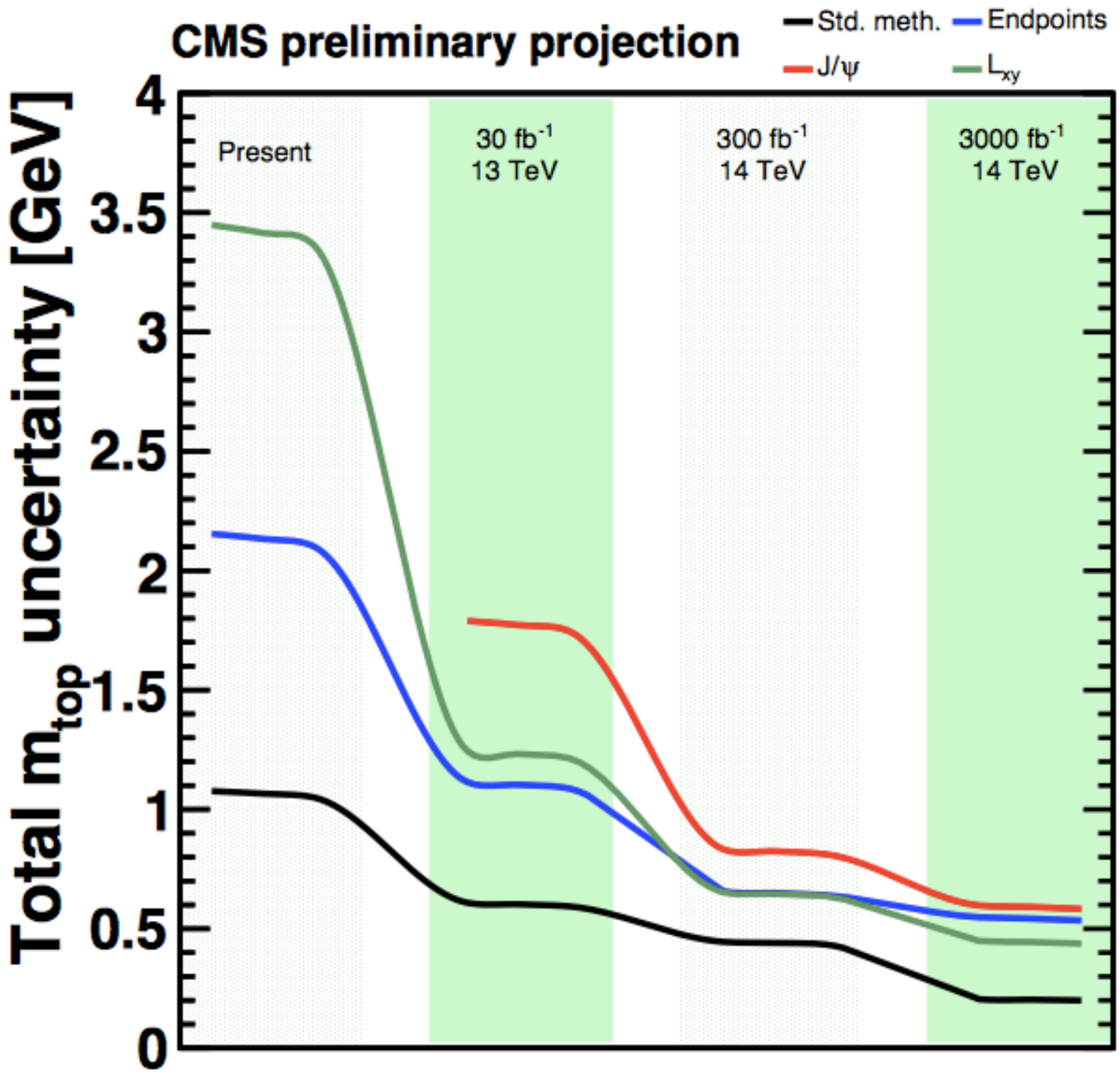
ATLAS-CONF-2013-052/



Phys. Rev. Lett. 111 (2013) 211804

MTOP: WHERE WE WILL BE

NEW



CMS-FTR-13-017