Experimental Summary

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September 18, 2015

8th International Workshop
on Top Quark Physics
Ischia, Italy
14-18 September 2015

8th International Workshop on Top Quark Physics

Another superb edition in this exciting series of conferences !

130±3 Top Enthusiasts

excellent talks (65) and posters (23)

lively discussions!

Italian food,

wine,

and strong coffee

A happy top quark!

Expected a focus on 3 special "themes" in 2015:

- Top turned 20 …not so much emphasis
- Many new LHC Run 1 and Tevatron "legacy" results YES
- A first glimpse of 13 TeV data ! YES

New: Young Scientist Forum
New: Differential cross-sections mini workshop

Plan B

- The “Past” : Legacy Results from Tevatron and LHC Run 1

- The “Future” : First results of LHC Run 2 and beyond

Plan B

- The “Past” : Legacy Results from Tevatron and LHC Run 1

  But the “past” is not yet over…

- The “Future” : First results of LHC Run 2 and beyond

  .. And the “future” has already started!

A word of warning

- Too many excellent results to attempt a complete summary
- I will show a personal selection of high-lights

Legend:

"I don't get no respect"

= Something somebody said, perhaps quoted inaccurately and out of context

→ Peskin

= reference to talk with more information about this topic

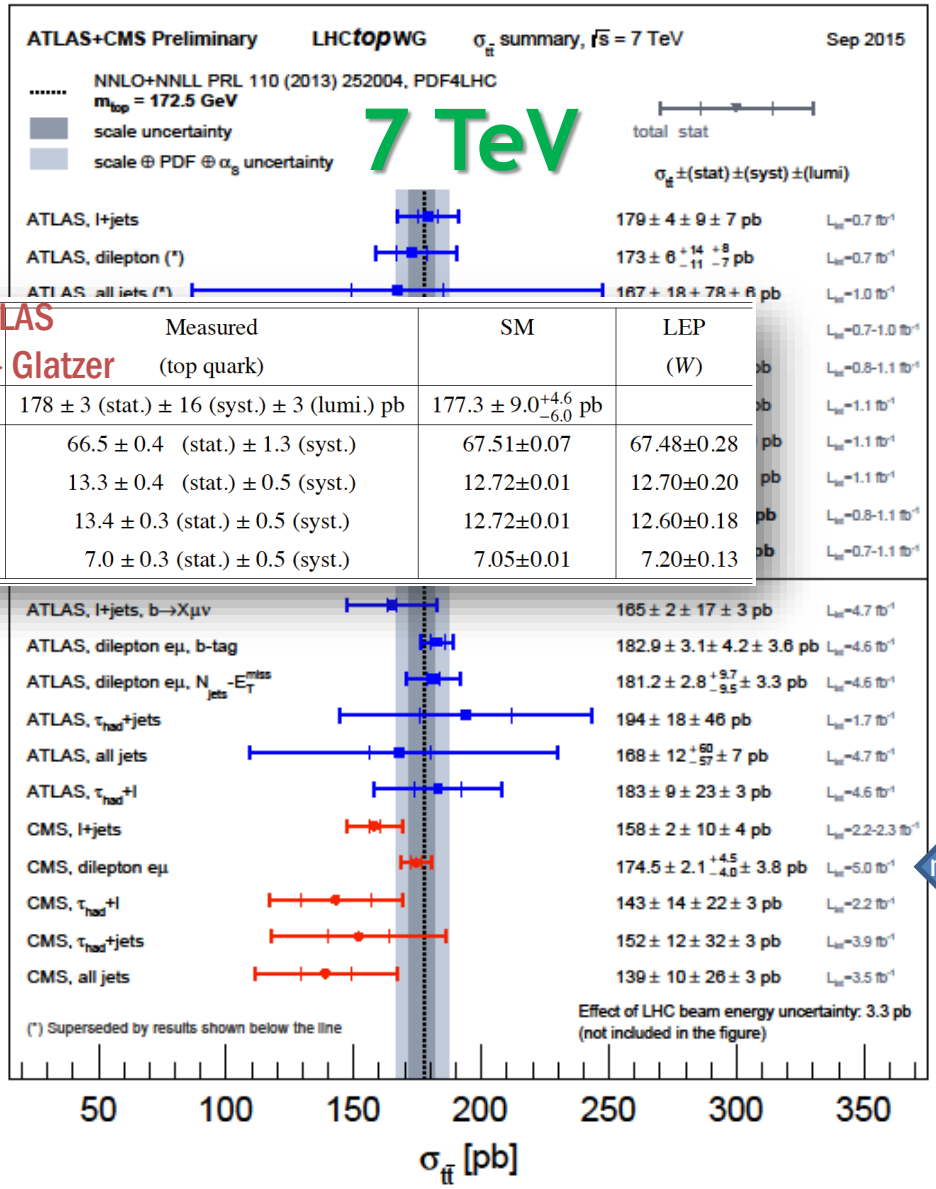
1. The “Past”

… still going strong

New Tevatron and LHC Run 1 legacy results

More Precise than ever

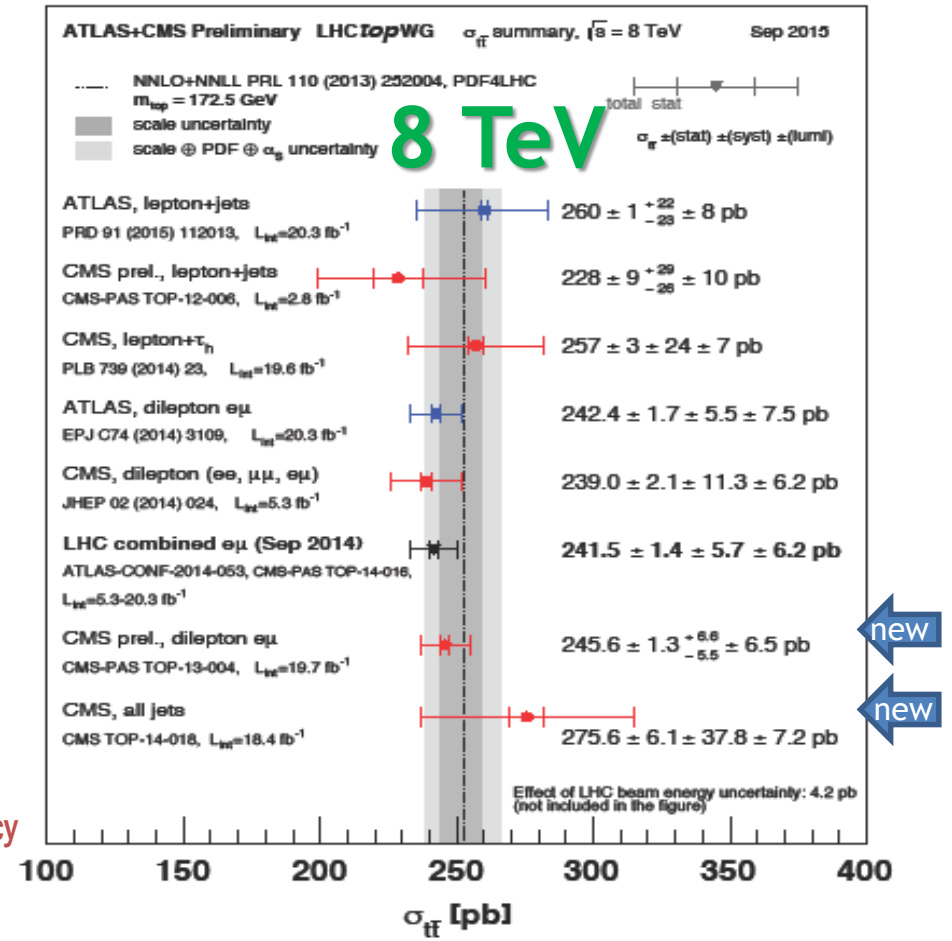
Inclusive top pair cross-sections



ATLAS → Glatzer

	Measured (top quark)	SM	LEP (W)
$\sigma_{t\bar{t}}$	178 ± 3 (stat.) ± 16 (syst.) ± 3 (lumi.) pb	$177.3 \pm 9.0^{+4.6}_{-6.0}$ pb	
B_j	66.5 ± 0.4 (stat.) ± 1.3 (syst.)	67.51±0.07	67.48±0.28
B_e	13.3 ± 0.4 (stat.) ± 0.5 (syst.)	12.72±0.01	12.70±0.20
B_μ	13.4 ± 0.3 (stat.) ± 0.5 (syst.)	12.72±0.01	12.60±0.18
B_τ	7.0 ± 0.3 (stat.) ± 0.5 (syst.)	7.05±0.01	7.20±0.13

CMS → Crucy



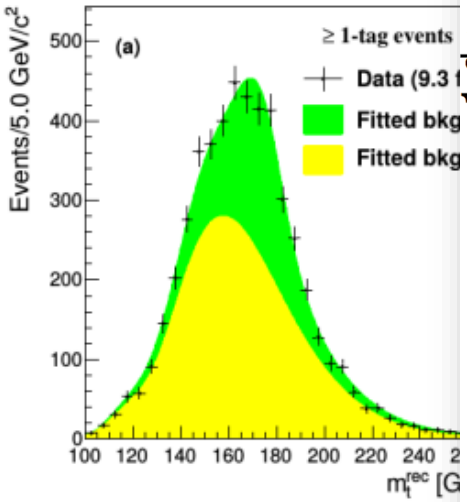
- All channels covered and consistent with SM
- Good agreement with NNLO+NNLL
- Precision of ~4% (di-lepton channel), similar to theoretical prediction

"I don't get no respect"

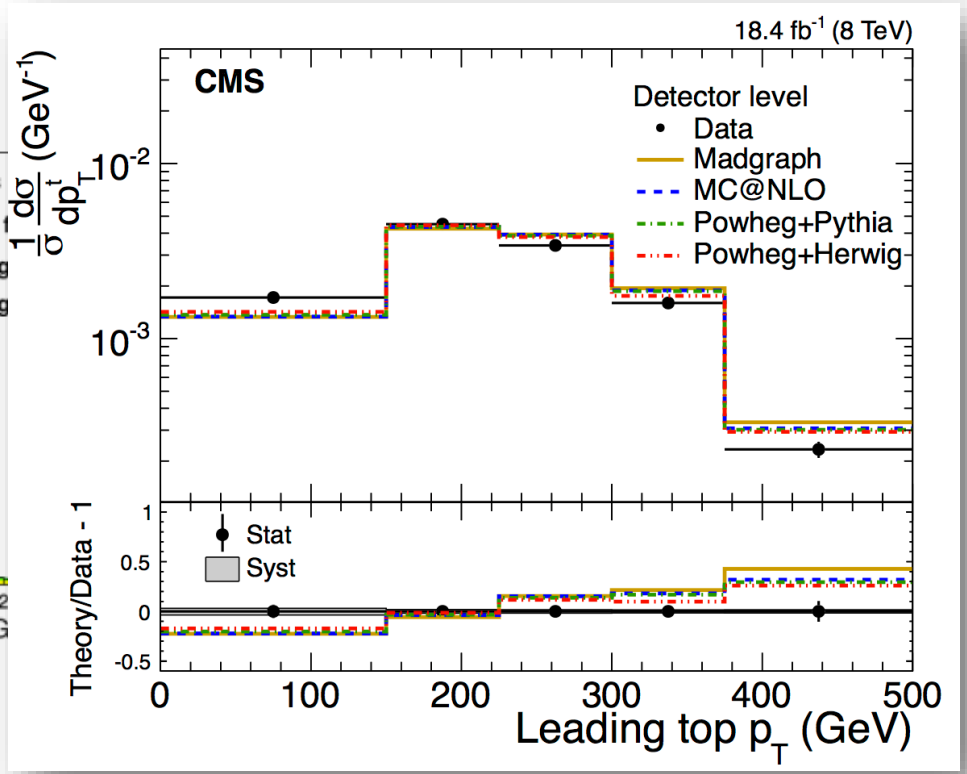
The all-jets channel

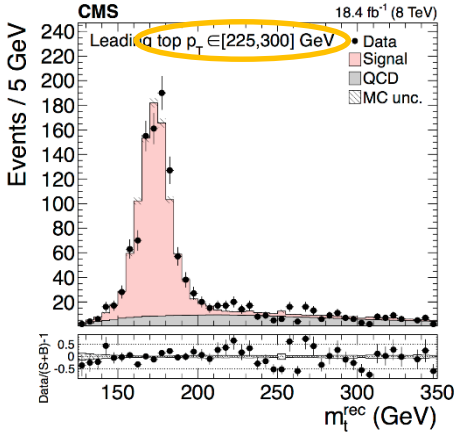
→ Crucy
→ Hindrichs

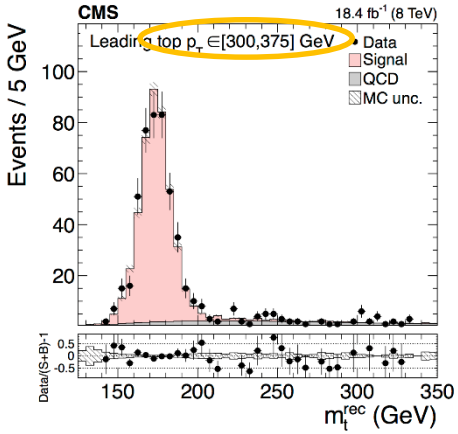
- Traditionally the most challenging final state (backgrounds!)
- But: large branching fraction
- No neutrinos = superior kinematic information + resolution
- At 8 TeV CMS used "parked data" to afford trigger rate
- S/B improves with higher top pT, and with higher √s

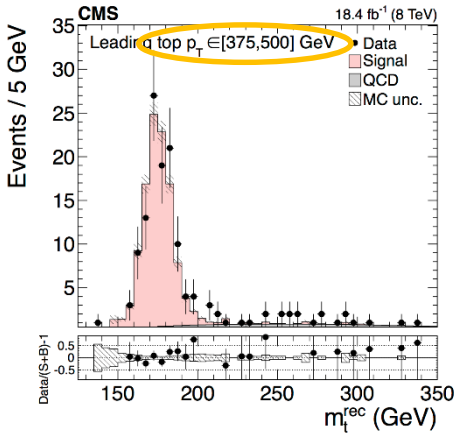


CDF
→ Deterre

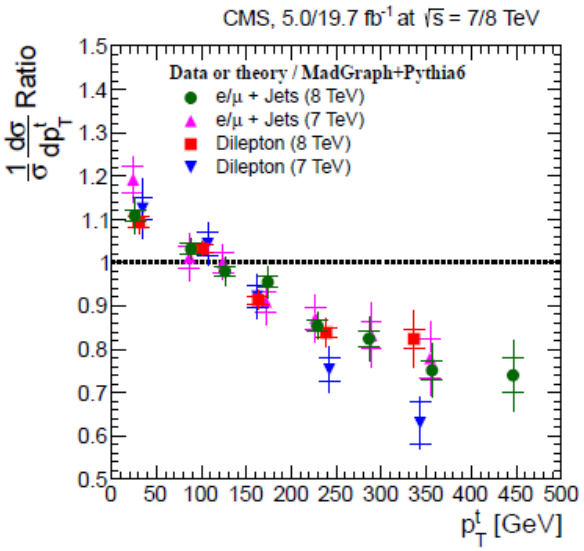


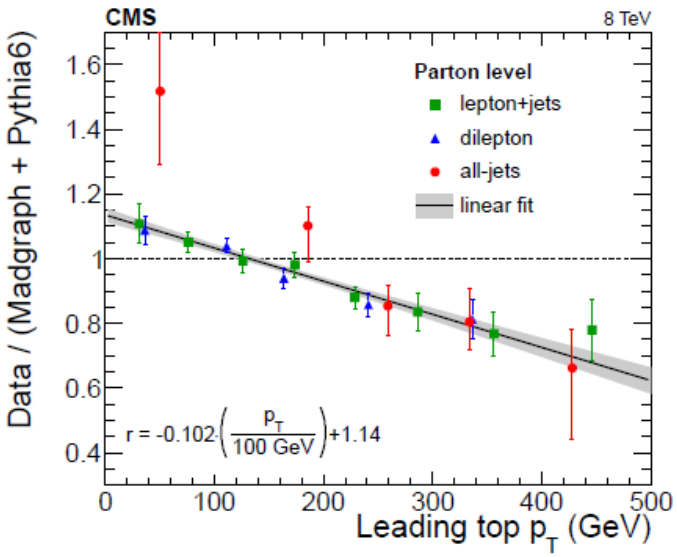


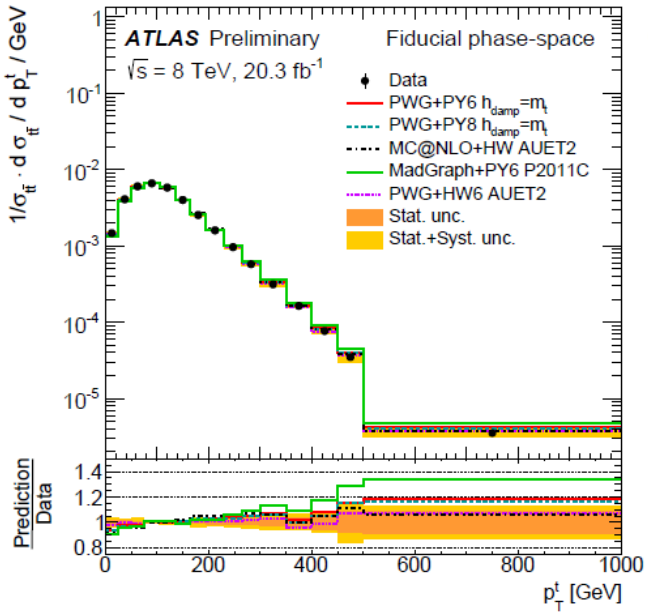


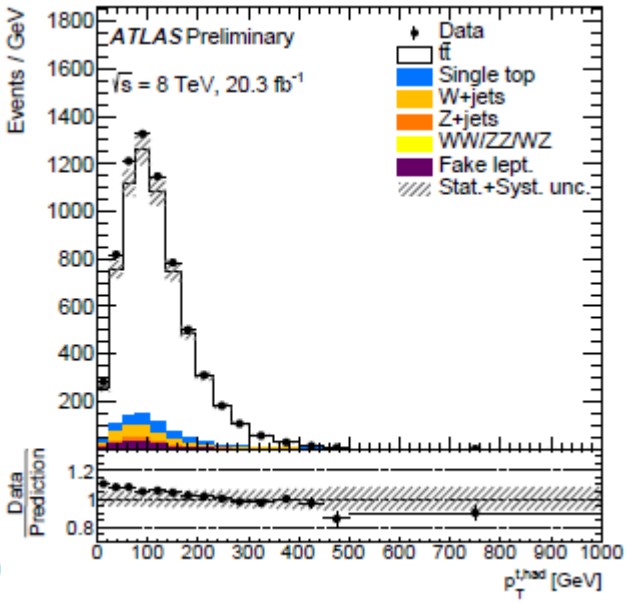


New ! Top p_T differential distribution









"you see here a nice slope"

My observations:

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

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

= = =

ATLAS and CMS data appear in good agreement at 8 TeV

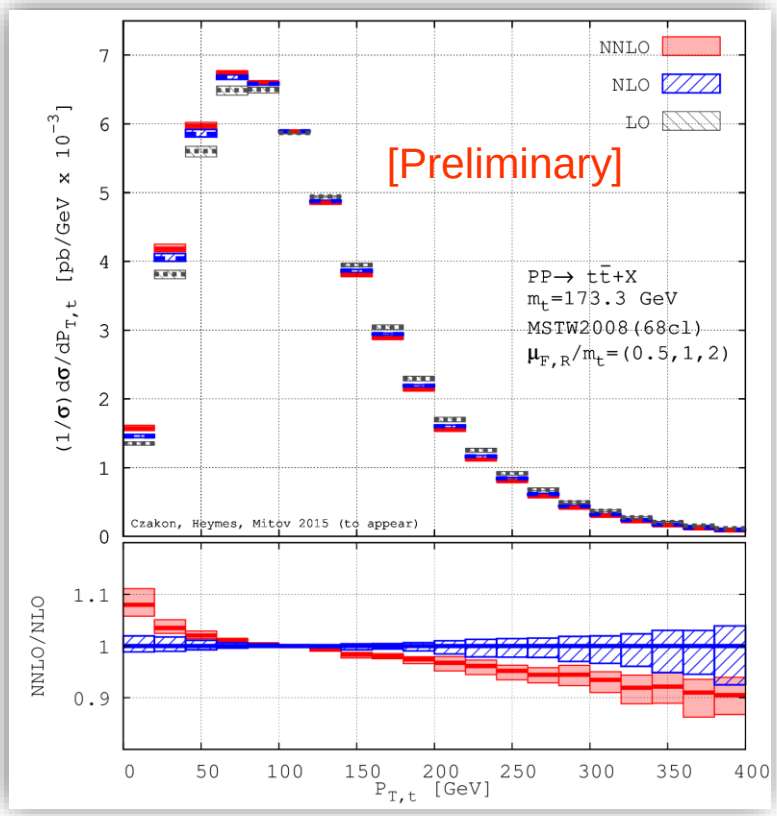
ATLAS PWG+PY (hdamp=mt) and other MCs do better than MG+PY

"if you take all correlations into account chi2/ndof = 1"

Top p_T modeling: the verdict

→ Heymes

Really NEW (yesterday!):



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

- Full NNLO correction "confirms" observed slope, in direction closer to the data
- Use k-factors to reweight NLO+PS MCs ?
- Ultimately NNLO+PS would be great ☺

➔ Great to see this dialogue between LHC precision measurements and state-of-the art theory calculations

➔ Important step forward in our understanding of Top production !!

→ Komm

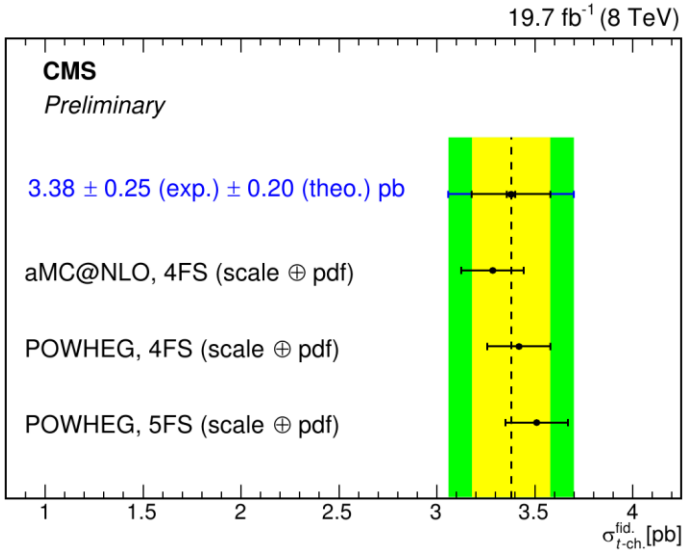
Single Top: in-fiducial

→ Gabaldon

NEW

in-fiducial measurement t-channel at 8 TeV

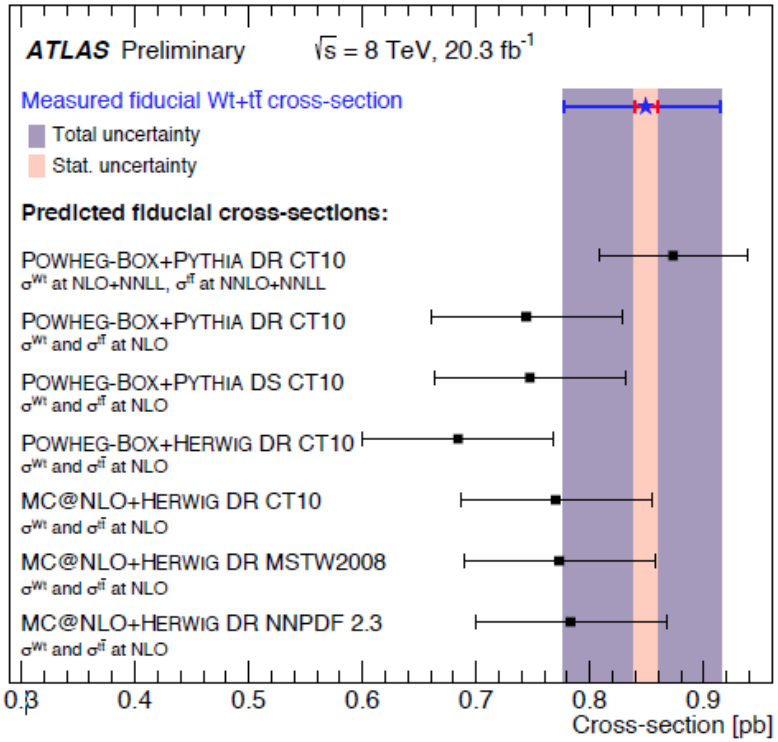
- event selection same as inclusive 8 TeV cross section measurement
- fiducial selection on generator particles
  - consider particle $c \cdot \tau > 10$ mm as stable
  - 1 "dressed" e/μ (anti-k_T, $R = 0.1$) with $p_T > 30$ GeV, $|\eta| < 2.4$
  - 2 jets (anti-k_T, $R = 0.5$) with $p_T > 40$ GeV, $|\eta| < 5$
  - 1 b-jet using the **"ghost b-hadrons" method** ($p_T > 40$ GeV, $|\eta| < 2.4$)
    - find non-resonant b-hadrons not decaying to other hardons
    - rescale momentum to very small value & allow them to be clustered into jets



in-fiducial measurement tt + Wt at 8 TeV

NEW

- Benefits of a fiducial measurement:
  - Separation of experimental and theoretical uncertainties
  - Reduce the dependence on the theory assumptions



→ Gabaldon

Single top s-channel evidence

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

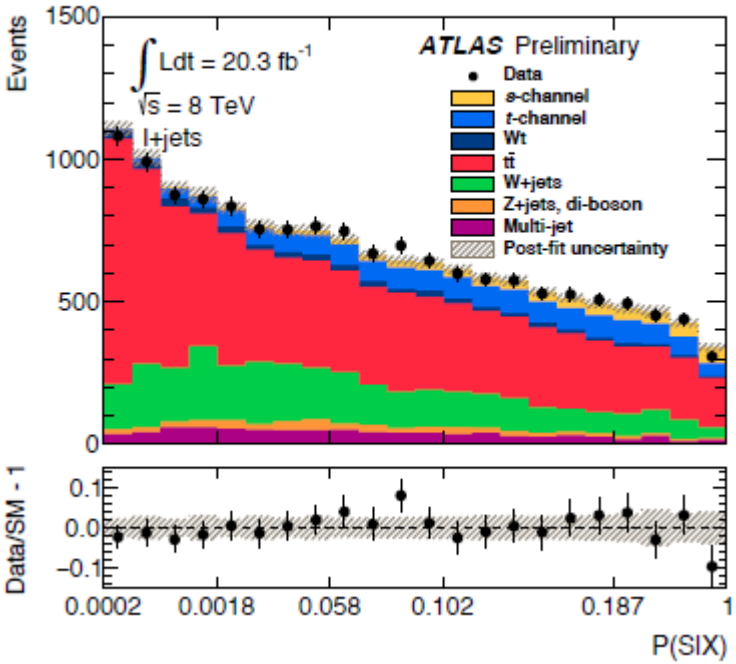
Significance: 3.2σ (exp. 3.9σ)

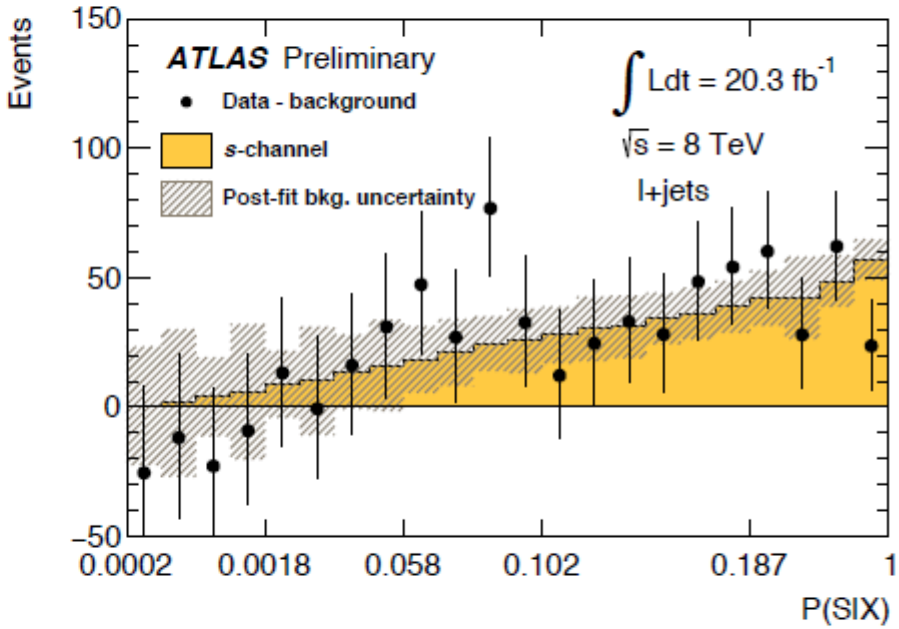
→ Consistent with SM expectation:

$\sigma^{theory}_{s-ch.} = 5.61 \pm 0.22$ pb

Uses the Matrix Element method to squeeze out optimal sensitivity…

2-jet 2-tag (∼ 4.3% of *s*-channel)



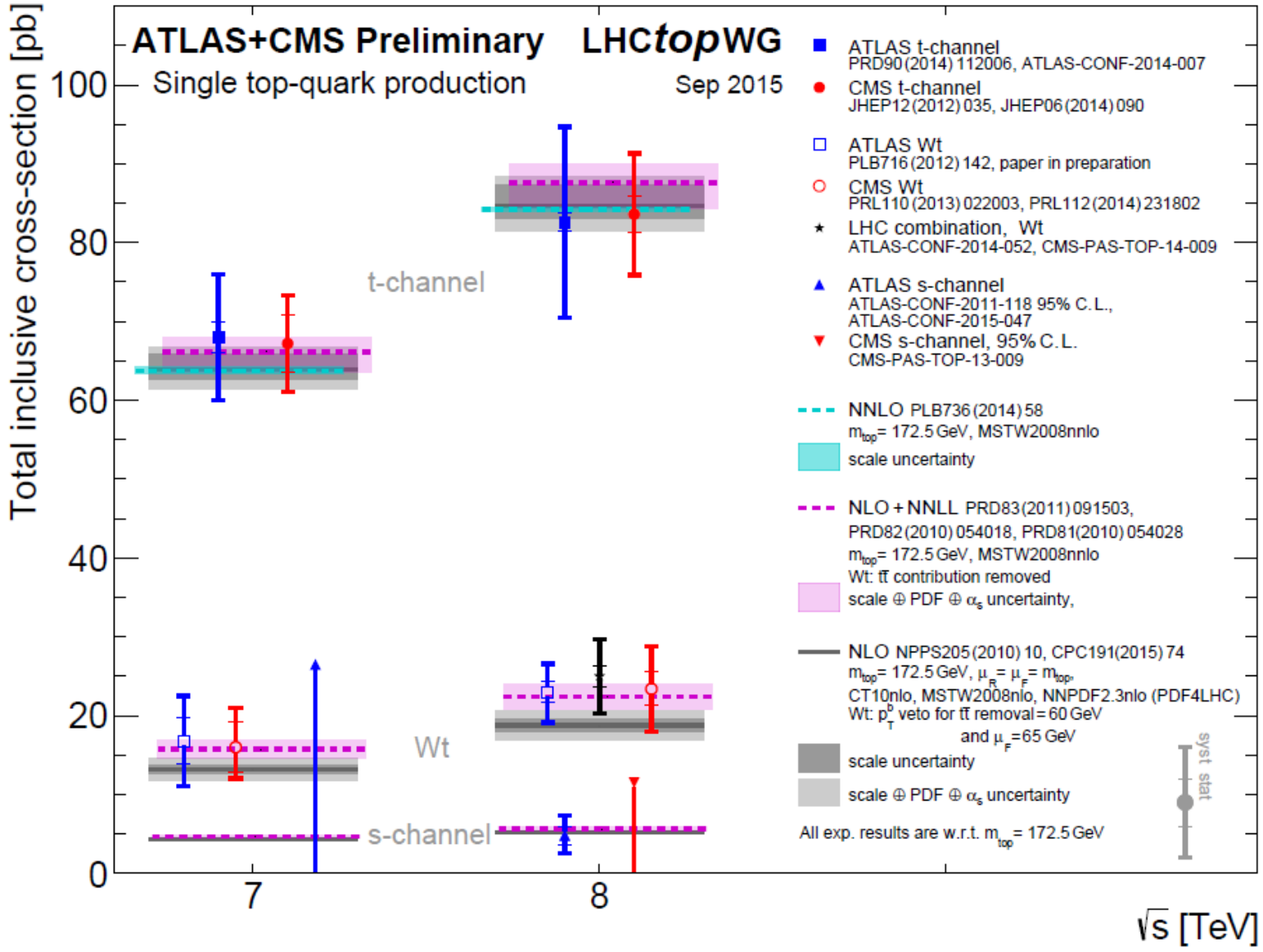


First EVIDENCE

of the *s*-channel production at LHC

Note: this will *not* get easier at 13 TeV!

Single Top: the complete picture



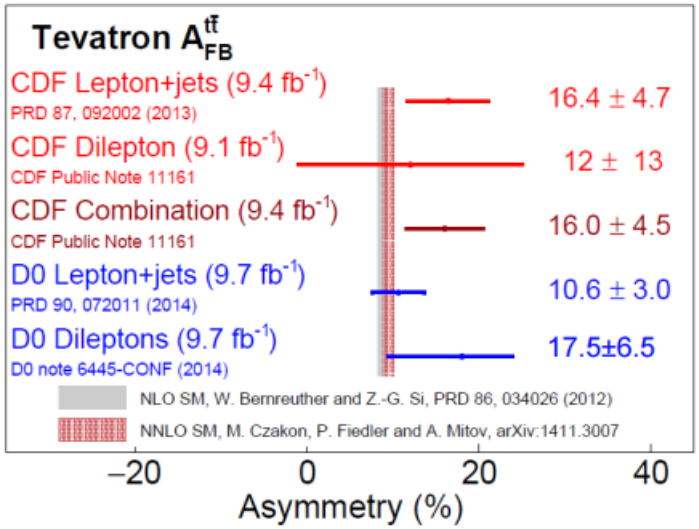
→ Chiarelli

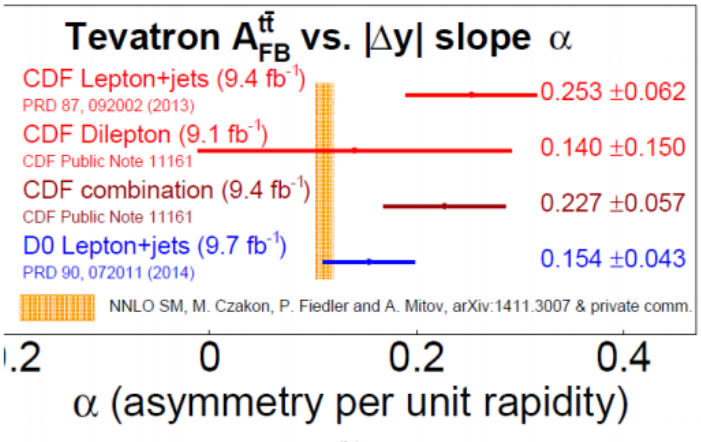
Asymmetries

→ Schwarz

→ higher order QCD is important!
→ high precision measurement is essential

Tevatron A_{FB} discrepancy is no more!



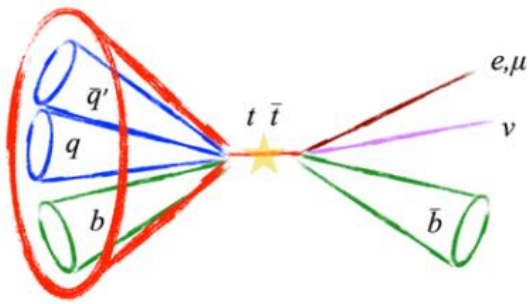


LHC, 8 TeV lepton+jets:

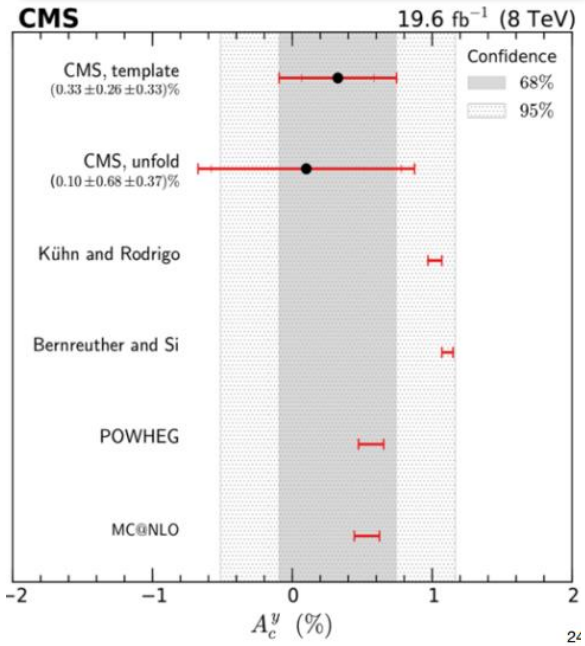
		stat	syst	
A_C =	0.0010	± 0.0068	± 0.0037	CMS
		Submitted to Phys.Lett. B arxiv:1507.03119		
A_C =	0.009	± 0.005 stat+syst		ATLAS
		Submitted to EPJC arxiv:1509.02358		
A_C =	0.0101		± 0.0005	NNLO
			Kuhn, Rodrigo	

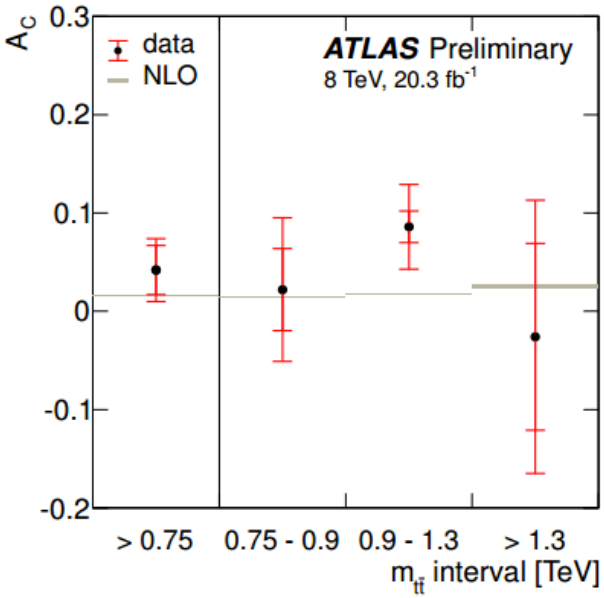
→ ready for combination

ATLAS Boosted :

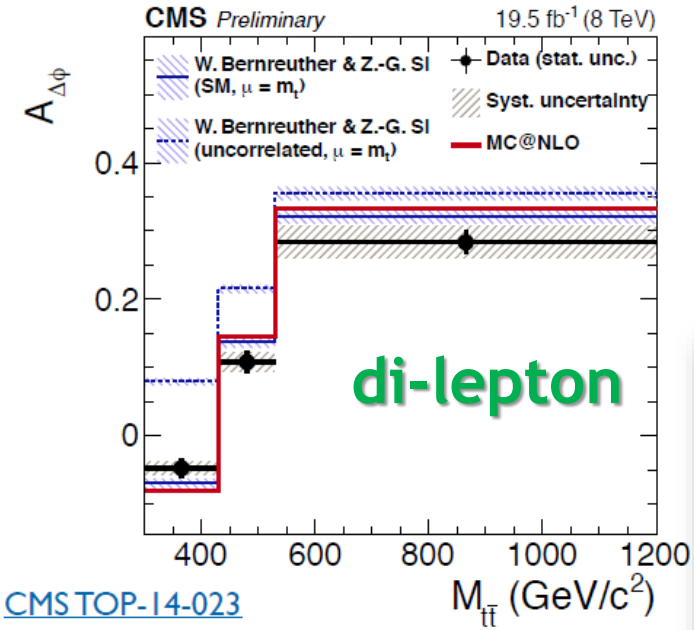


What is better: Template or Unfolding?





Top spin polarization



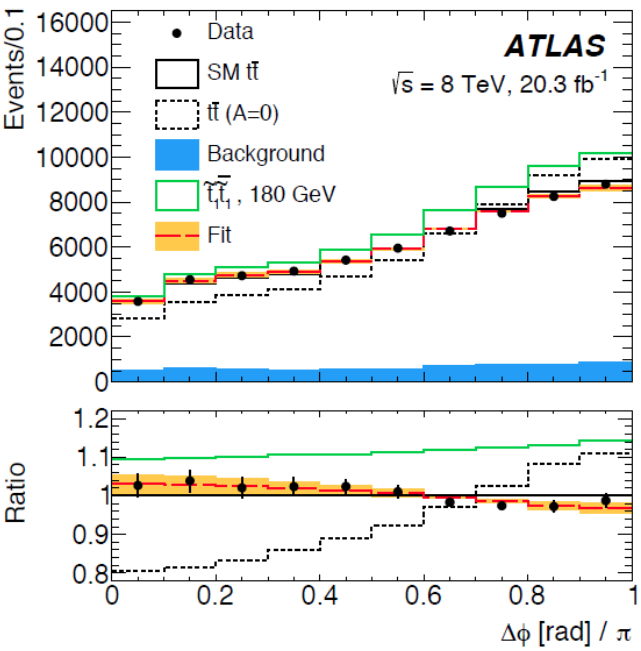
CMS TOP-14-023

→ Linacre

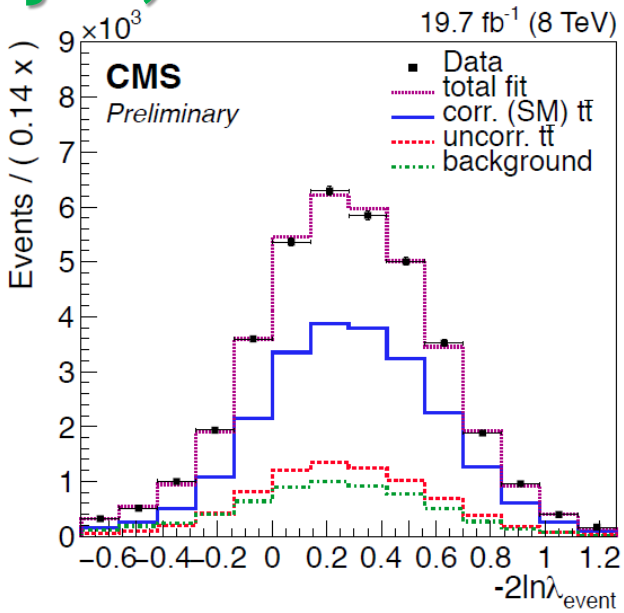
Variable	Channel	Collaboration	f_{SM}
Δφ	dilepton	ATLAS (8 TeV)	1.20 ± 0.14
ME-based (S-ratio)	dilepton	ATLAS (7 TeV)	0.87 ± 0.18 *
Δφ	lepton+jets	ATLAS (7 TeV)	1.12 ± 0.25
Δφ	dilepton	CMS (8 TeV)	1.16 ± 0.15
D	dilepton	CMS (8 TeV)	0.90 ± 0.16
ME-based	lepton+jets	CMS (8 TeV)	0.72 ± 0.17

di-lepton

PRL 114, 142001 (2015)



l+jets, ME method

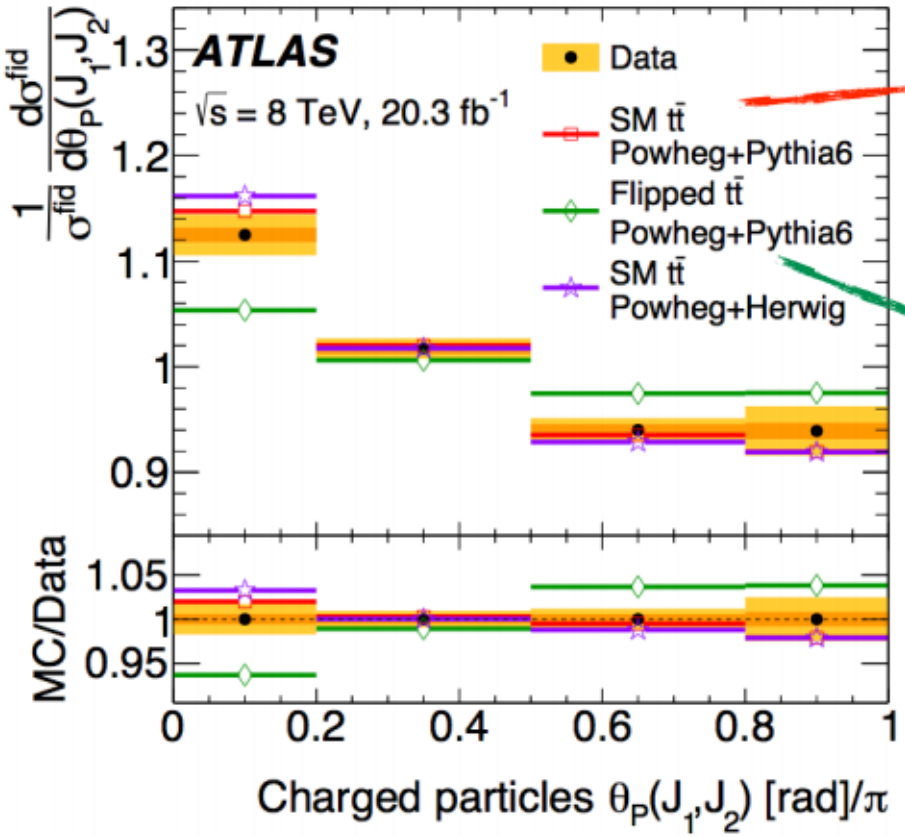


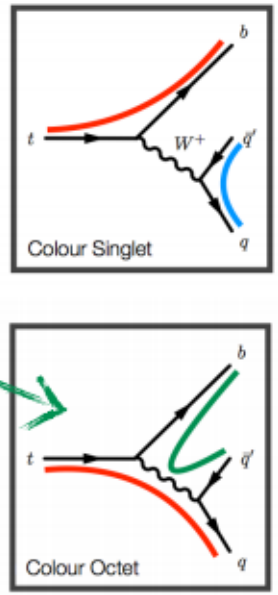
- All consistent with $f_{SM} = 1$
- $f_{SM} = 0$ strongly disfavoured

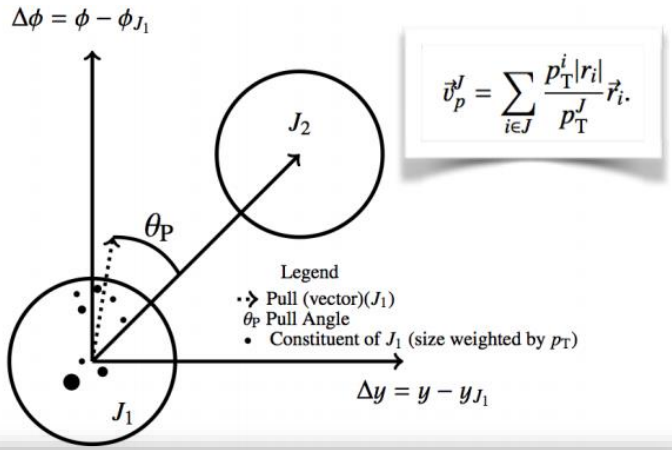
Proof top really behaves like a ‘bare’ quark

Color Flow using Jet pull angle

→ Danninger







$$\vec{v}_p^J = \sum_{i \in J} \frac{p_T^i |r_i|}{p_T^J} \vec{r}_i.$$

Results:

- The jet pull angle is found to correctly characterise the *W* boson as a colour singlet.
- Data disfavouring an alternative colour–octet model at greater than 3σ

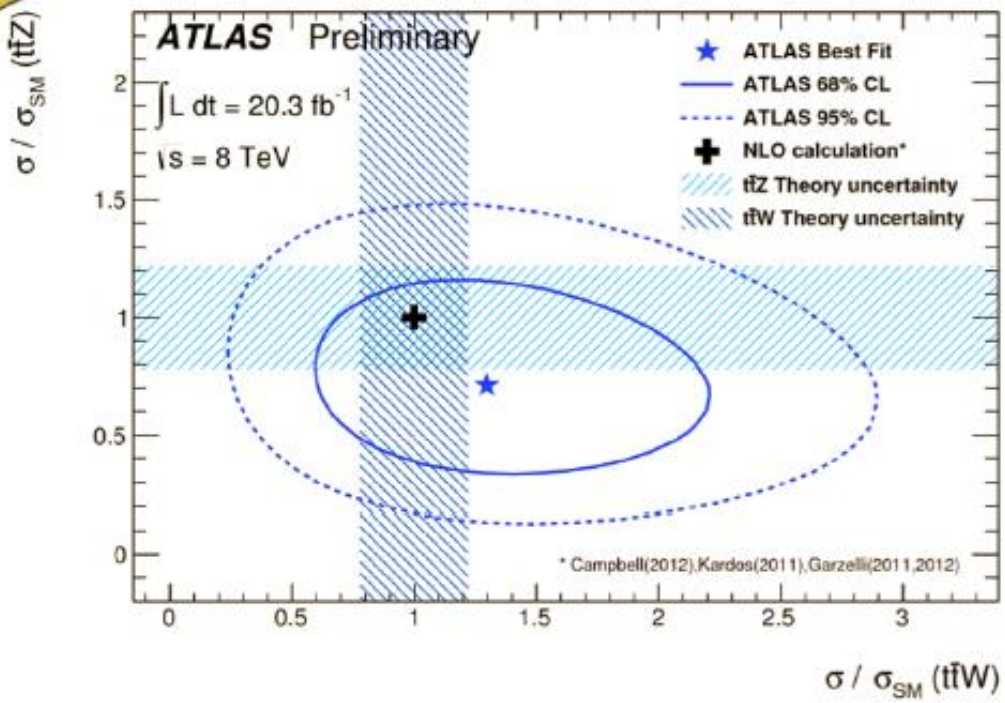
Great particle-level study!

Future: can this type of measurement be used to constrain color reconnection models ?!

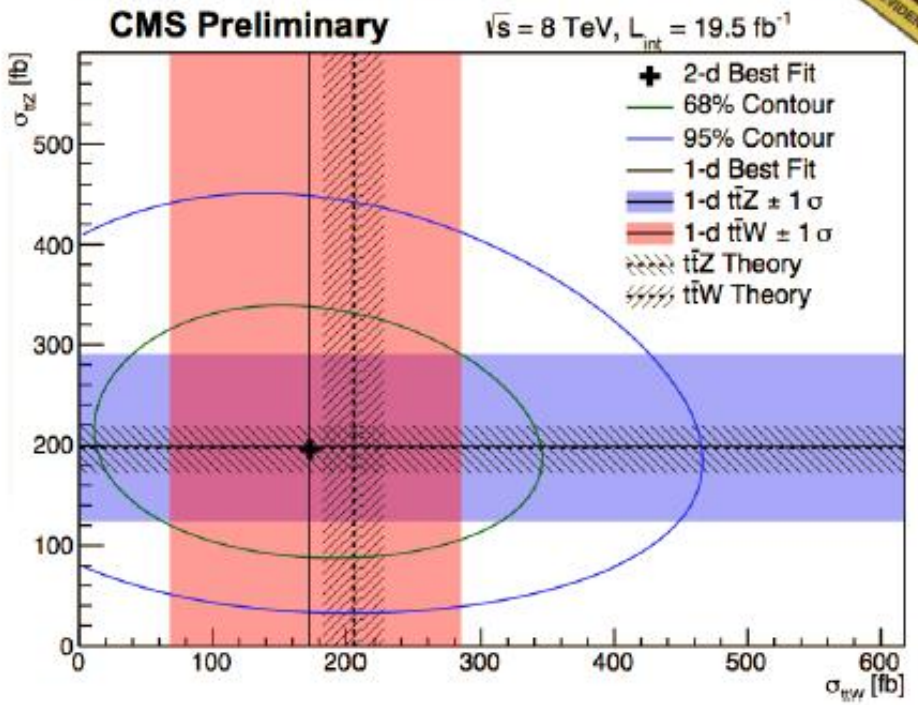
ttV: from Evidence to Observation

TOP 2014

Evidence for ttZ and ttW!



Evidence for ttZ!

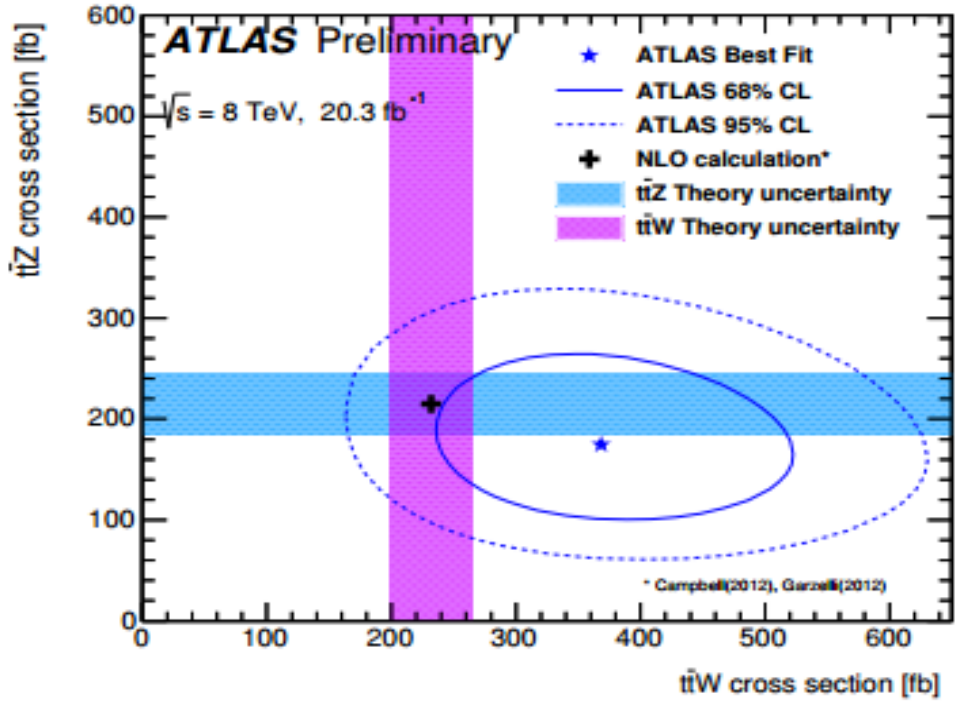


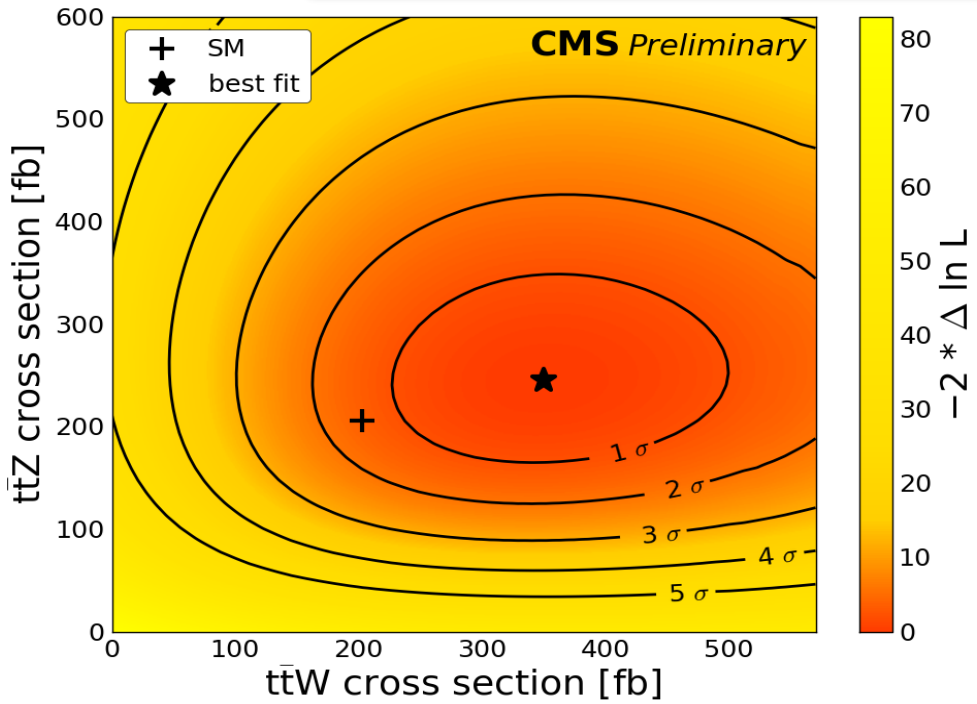
ttV: from Evidence to Observation

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

TOP 2015

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





(this morning) arXiv:1509.05276

→ Great candidate for LHC combination !

→ Will become a lot more precise at 13 TeV

+ limits on 6D EFT operators

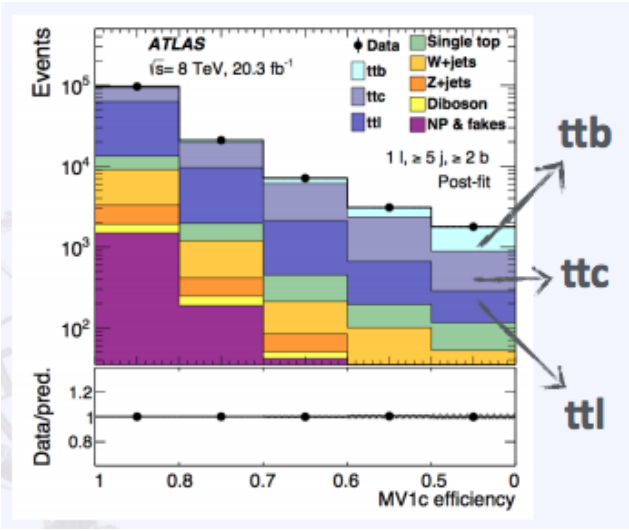
Nice demonstration of future goal of these measurements

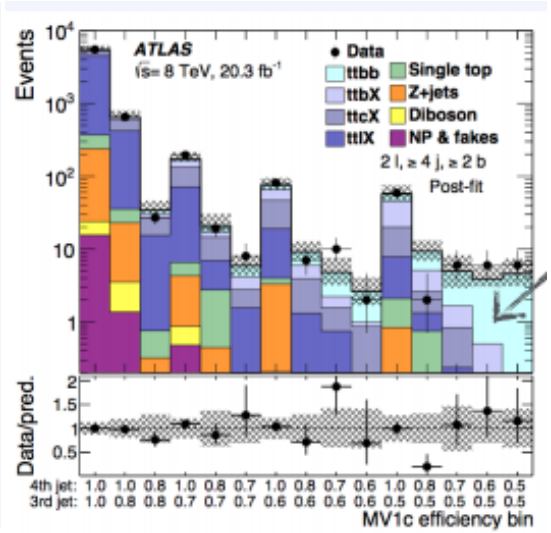
→ Sjoelin

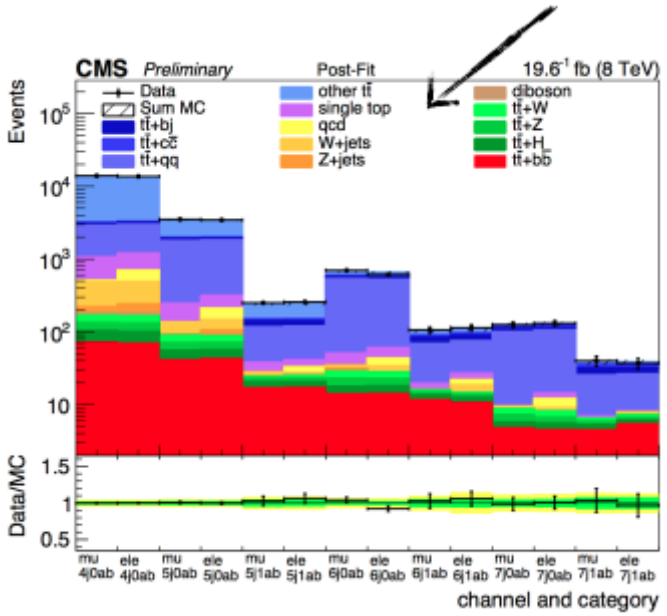
→ Danninger

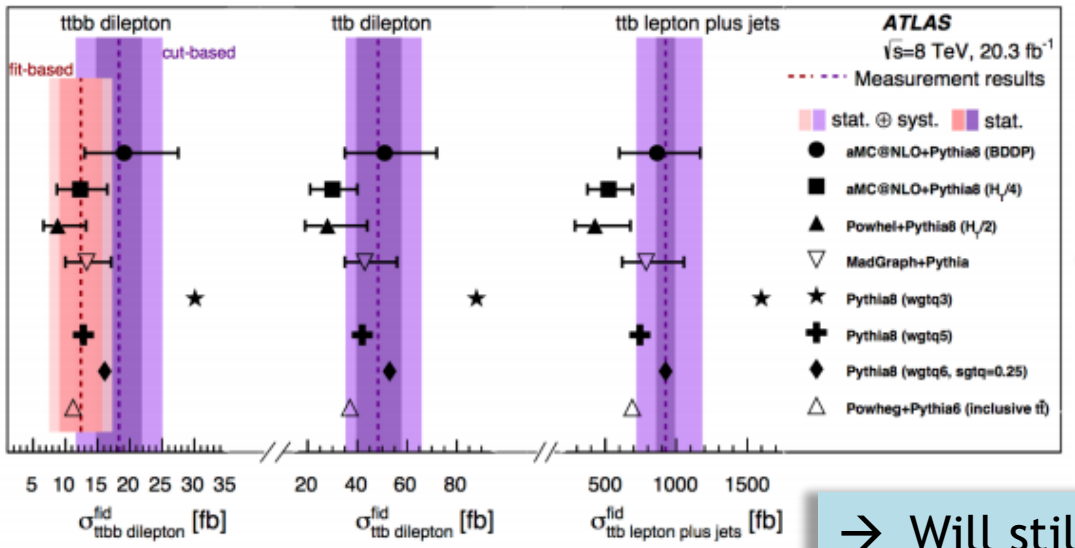
Top and extra (HF) jets

Very important (and very hard) measurement









	$\sigma_{t\bar{t}b\bar{b}}/\sigma_{t\bar{t}jj}$
hardB:	
this analysis	$0.012 \pm 34\%$
theory NLO[4]	$0.011\ ^{+39\%}_{-13\%}$
MADGRAPH +PYTHIA	$0.007 \pm 10\%$
hadronB:	
this analysis	$0.015 \pm 32\%$
CMS dilepton[3]	$0.022 \pm 29\%$
MADGRAPH +PYTHIA	$0.009 \pm 14\%$

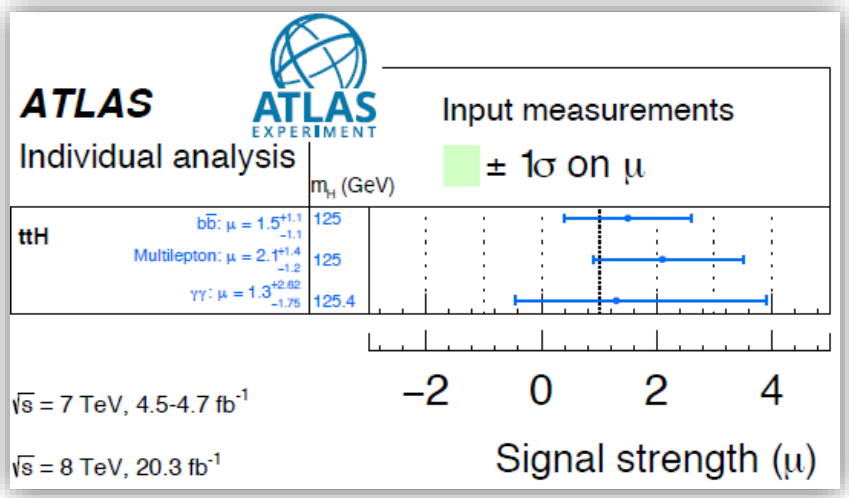
→ Will still be challenging, but more precise, at 13 TeV

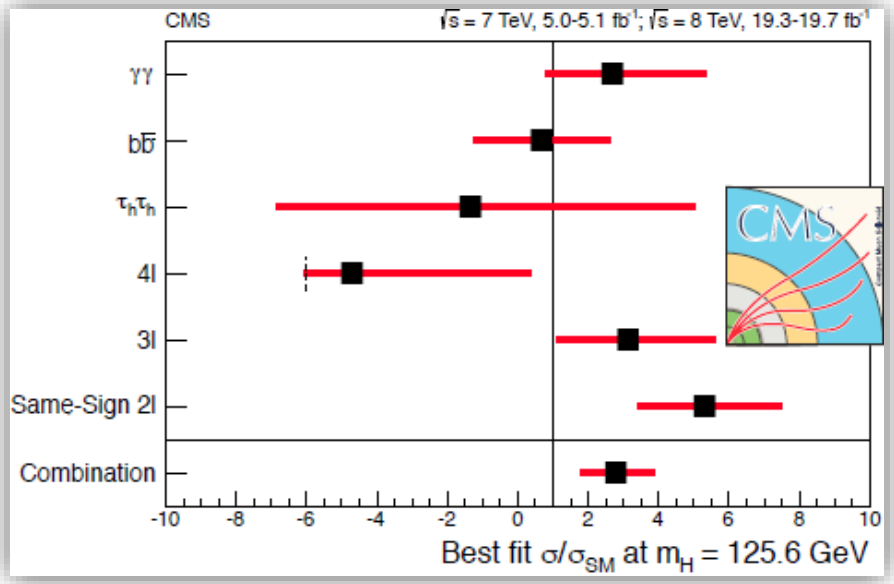
Top and Higgs

→ Puigh

→ Mcfayden

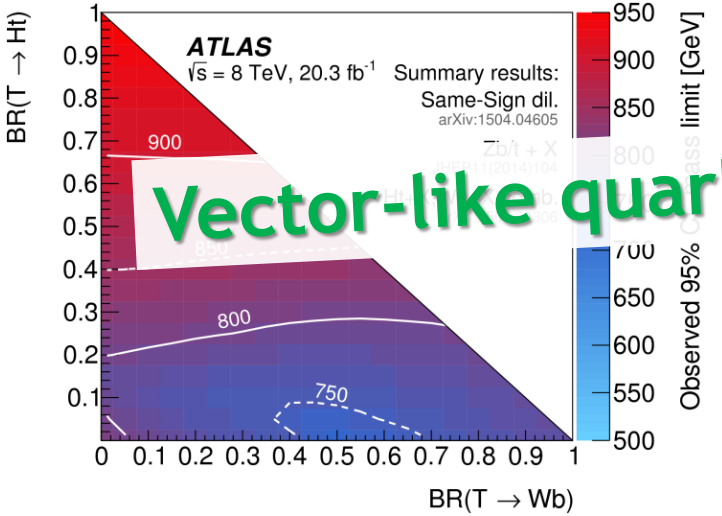
- ttH and tH are only avenues to directly extract top quark Yukawa
- Sophisticated searches have been performed at 7 and 8 TeV
  - **Rapidly approaching standard model sensitivity!**



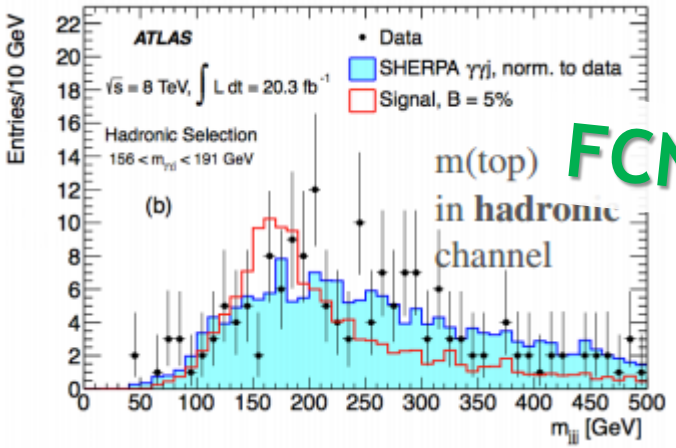


- ATLAS + CMS published the Run 1 combined measurements ! →
  - $\mu_{ttH} = 2.3^{+0.7}_{-0.6}$
  - Significance: 4.4σ (2.0σ expected)
- **Looking forward to interesting results with 13 TeV data!**

Top: a window to BSM physics ?

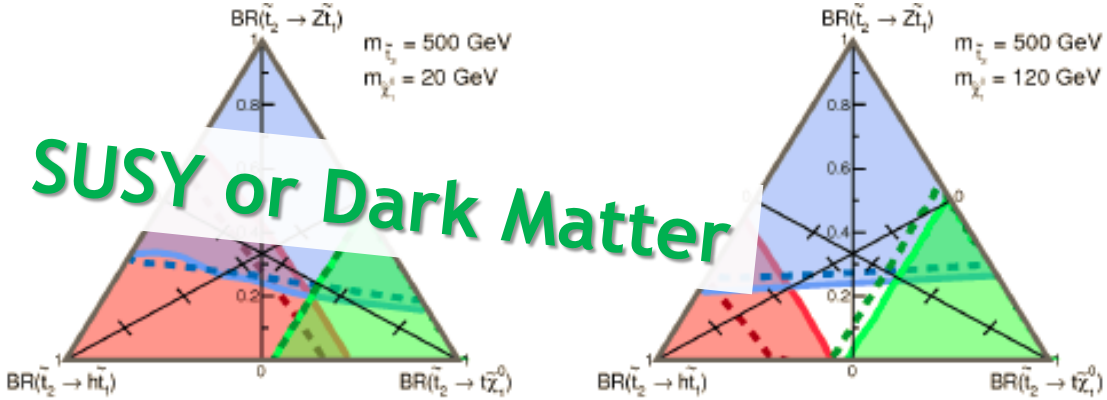


Vector-like quarks?

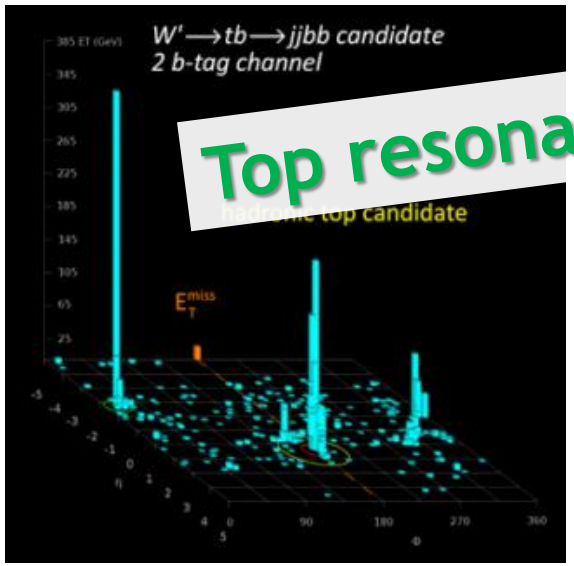


FCNCs ?

→ Tseng
→ M. Kim
→ Pataraia
→ Skovpen



SUSY or Dark Matter



Top resonances ?

- No significant excess observed yet
- Eagerly await analysis of 13 TeV data

Apologies for skipping over this part with extreme brevity, in the interest of time

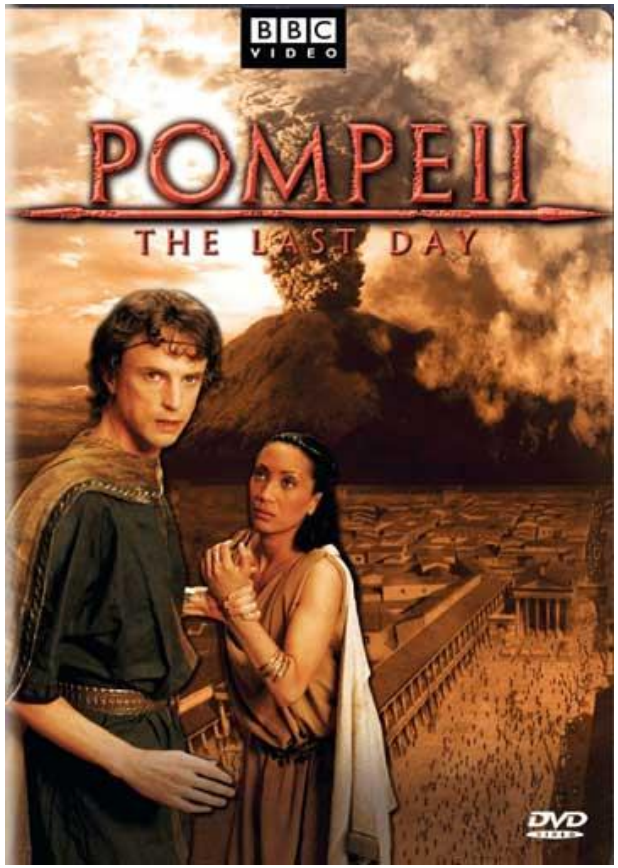
1b: Intermezzo
“Living Dangerously”

What if there is no BSM physics up to high Energy Scales ?

Living Dangerously

Vesuvius!

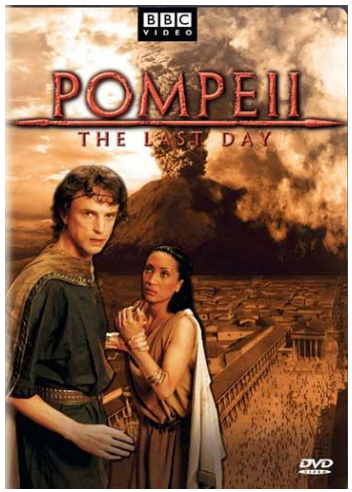
in Napels…



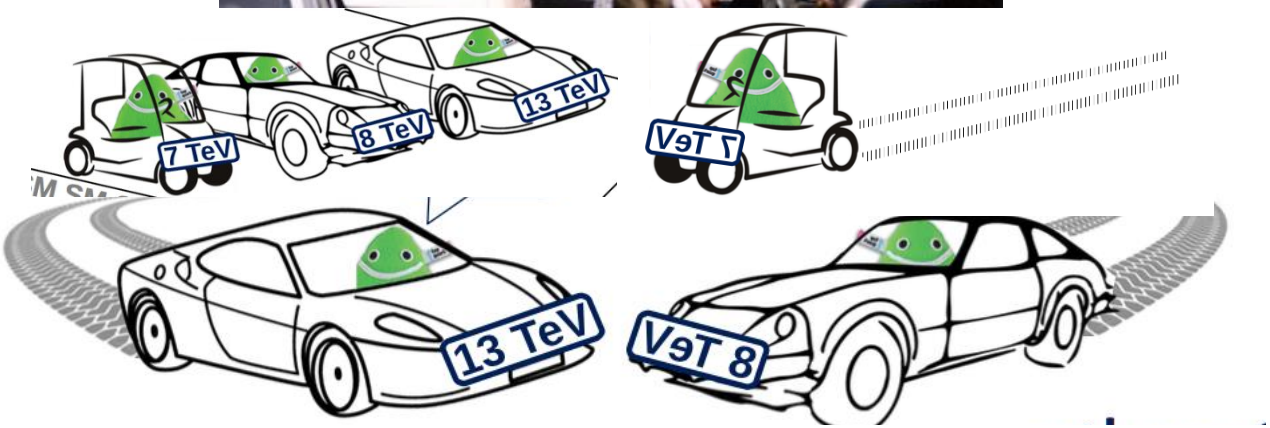
Wikinapoli
Your guide to the good life in Naples

Living Dangerously

Vesuvius!



The Traffic in Napels...



Italians are known as "crazy" drivers, and Naples is infamous for having the "worst" drivers in Italy! However, this is because they simply follow different rules than Americans. Or, more precisely, they only follow one rule:

The First (And Only) Rule of Italian Driving: Do not hit anything that is in front of you.

Corollaries to the First Rule of Italian Driving:

- **There are no other "rules."** This means that quaint American rules like "always stop at stoplights/signals", "stay in your lane", "don't drive on the shoulder/sidewalk", "stop for pedestrians", "don't drive in reverse on the highway", etc. don't apply—as long as you don't hit anything/anyone!

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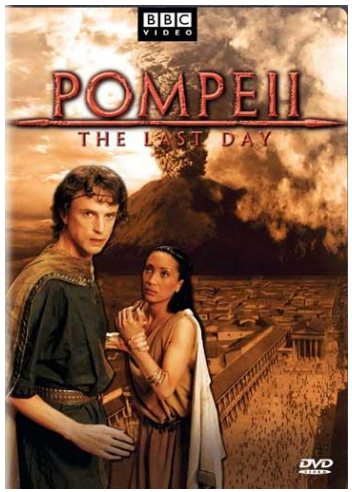

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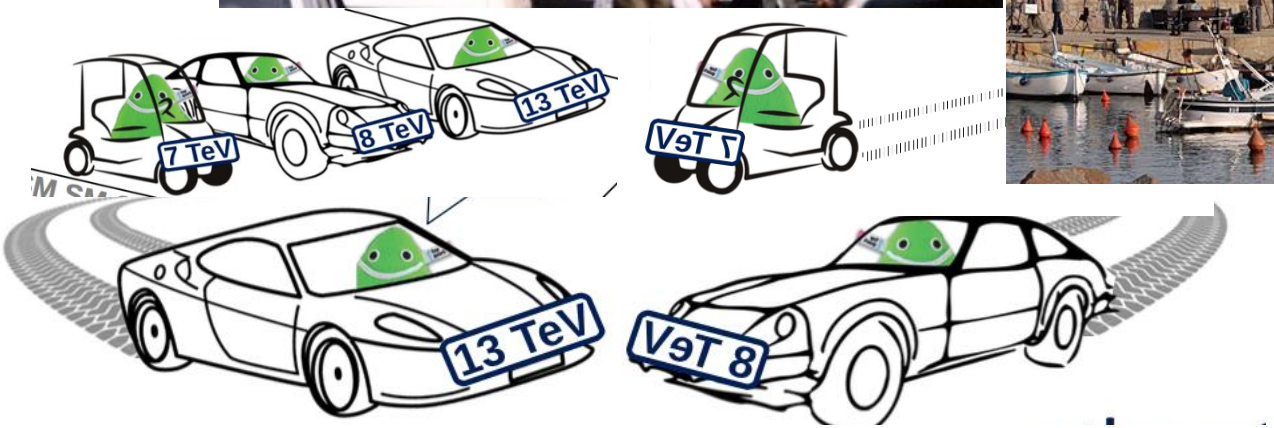

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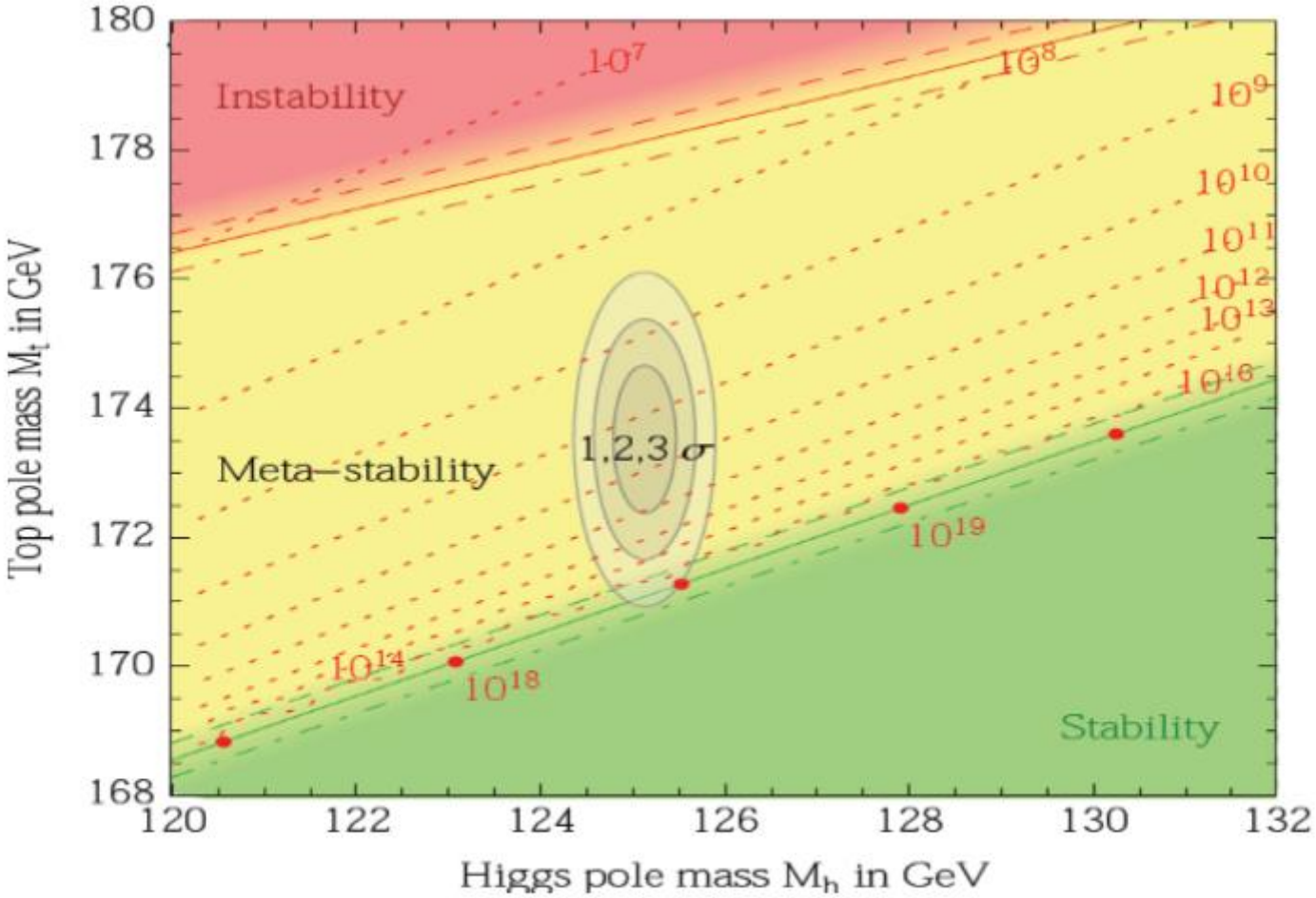
... and at sea: The Concordia

How Stable is the Vacuum ? → Espinosa

in Napels (+ light cone):



Good motivation to improve M_{top} determination !

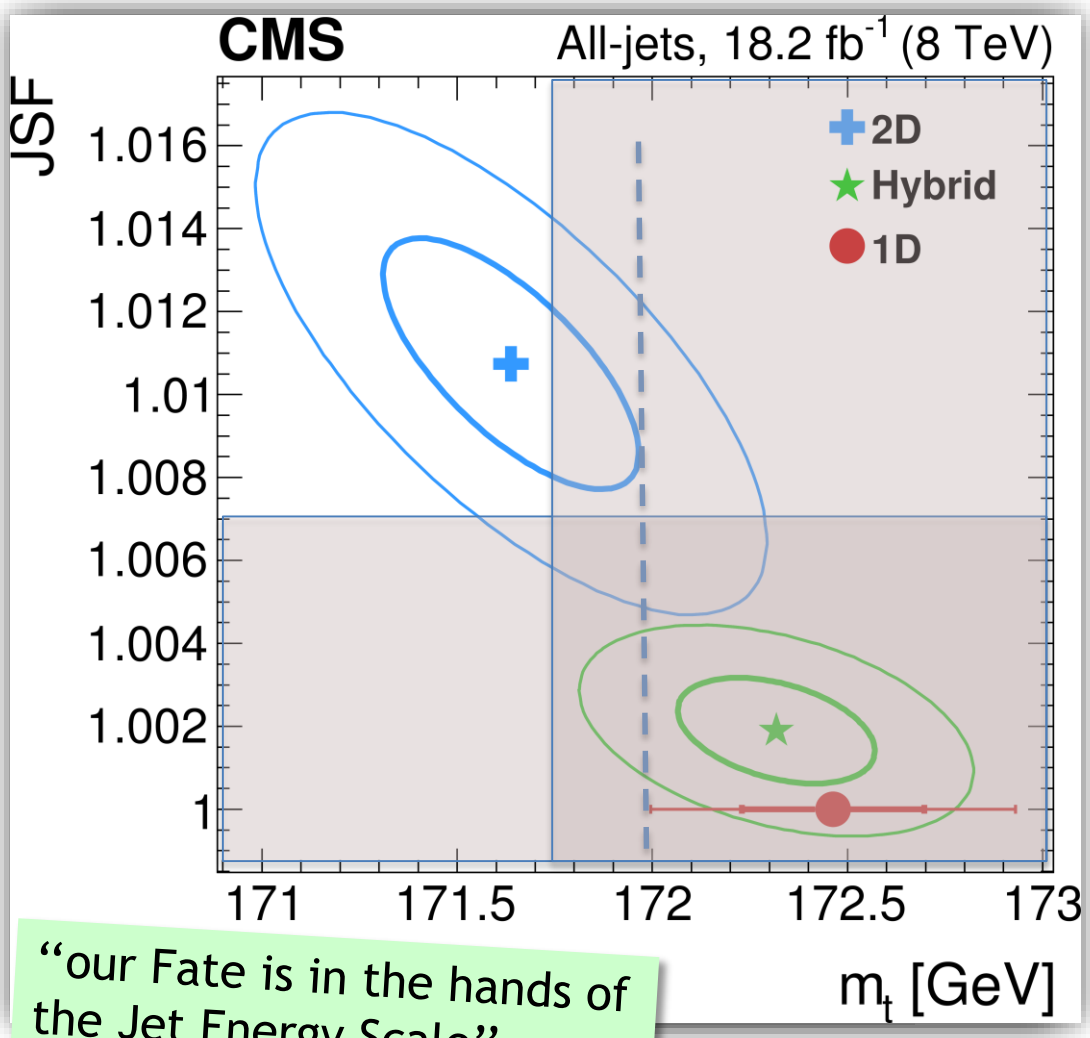
Top Mass Progress

→ Castro

→ Vos

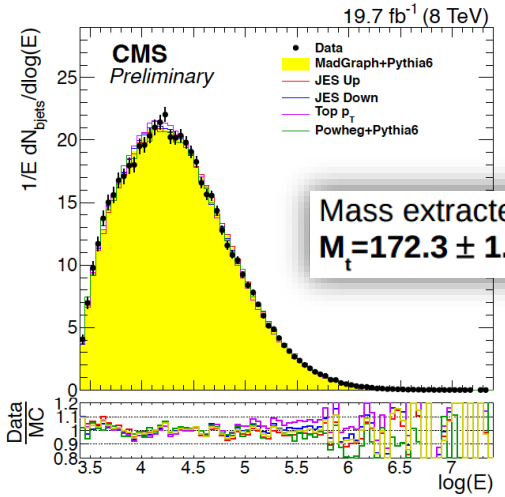
→ Deterre

Improved Precision (< 0.3 %)



"our Fate is in the hands of the Jet Energy Scale"

New Method:

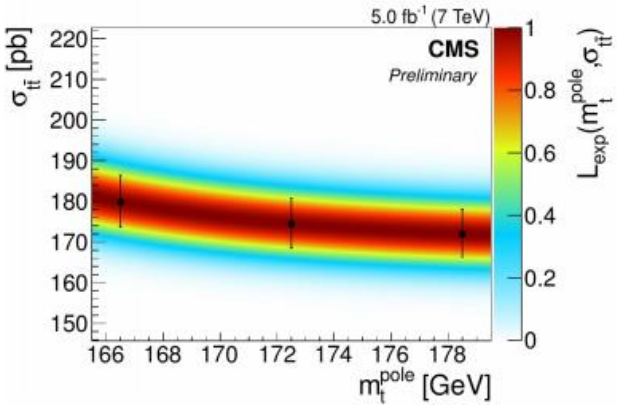


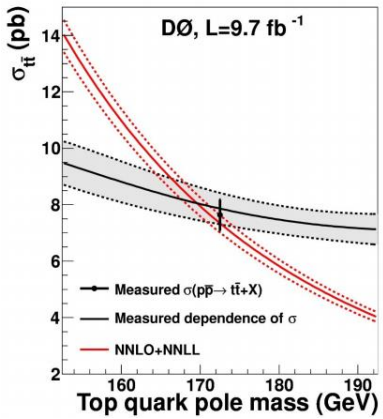
b-jet energy peak

K. Agashe, R. Franceschini, D. Kim, PRD88

Mass extracted using simple kinematical relation:
M_t=172.3 ± 1.2 (stat.) ± 2.7 (syst.) GeV

New pole mass results from incl. σ:



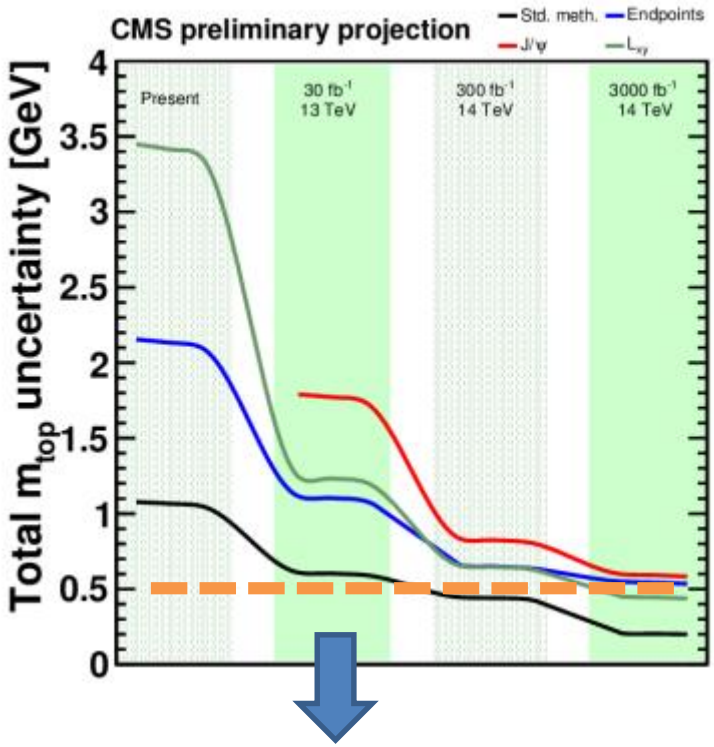


Top Mass Progress

→ Castro

→ Vos
→ Corcella

Improved Precision (< 0.3 %)



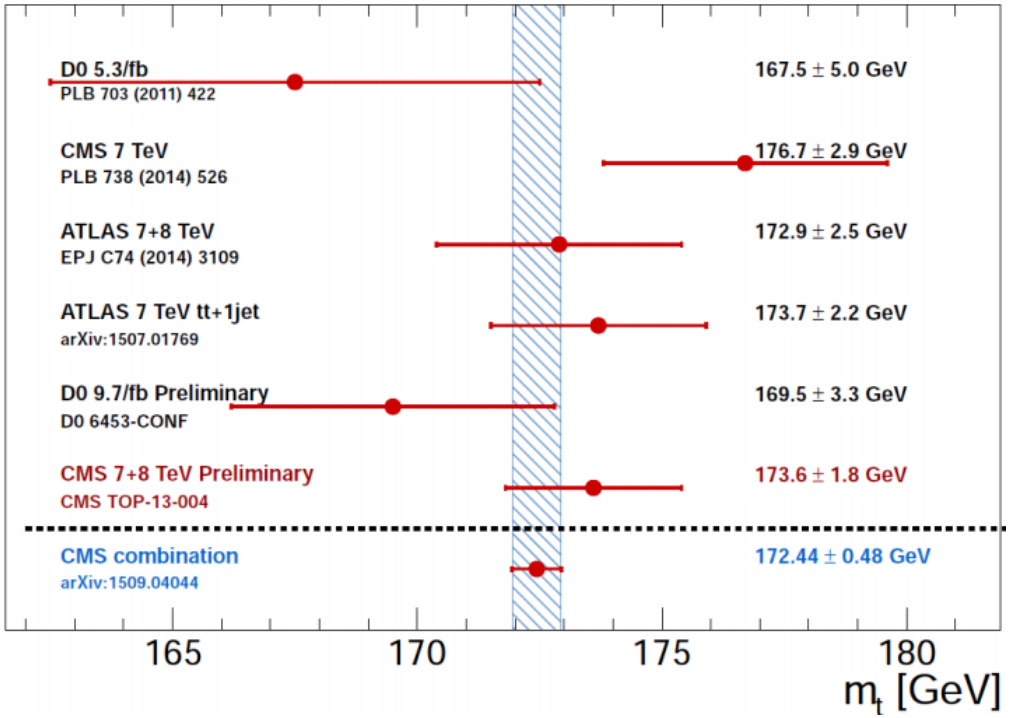
surpassed the experimental precision projected for the end (!) of Run 2

But what are we measuring exactly?

→ ongoing discussions + studies

- Also use other observables
- NLO production and NLO (+PS) decay needed to extract top mass in well-defined scheme from top decay

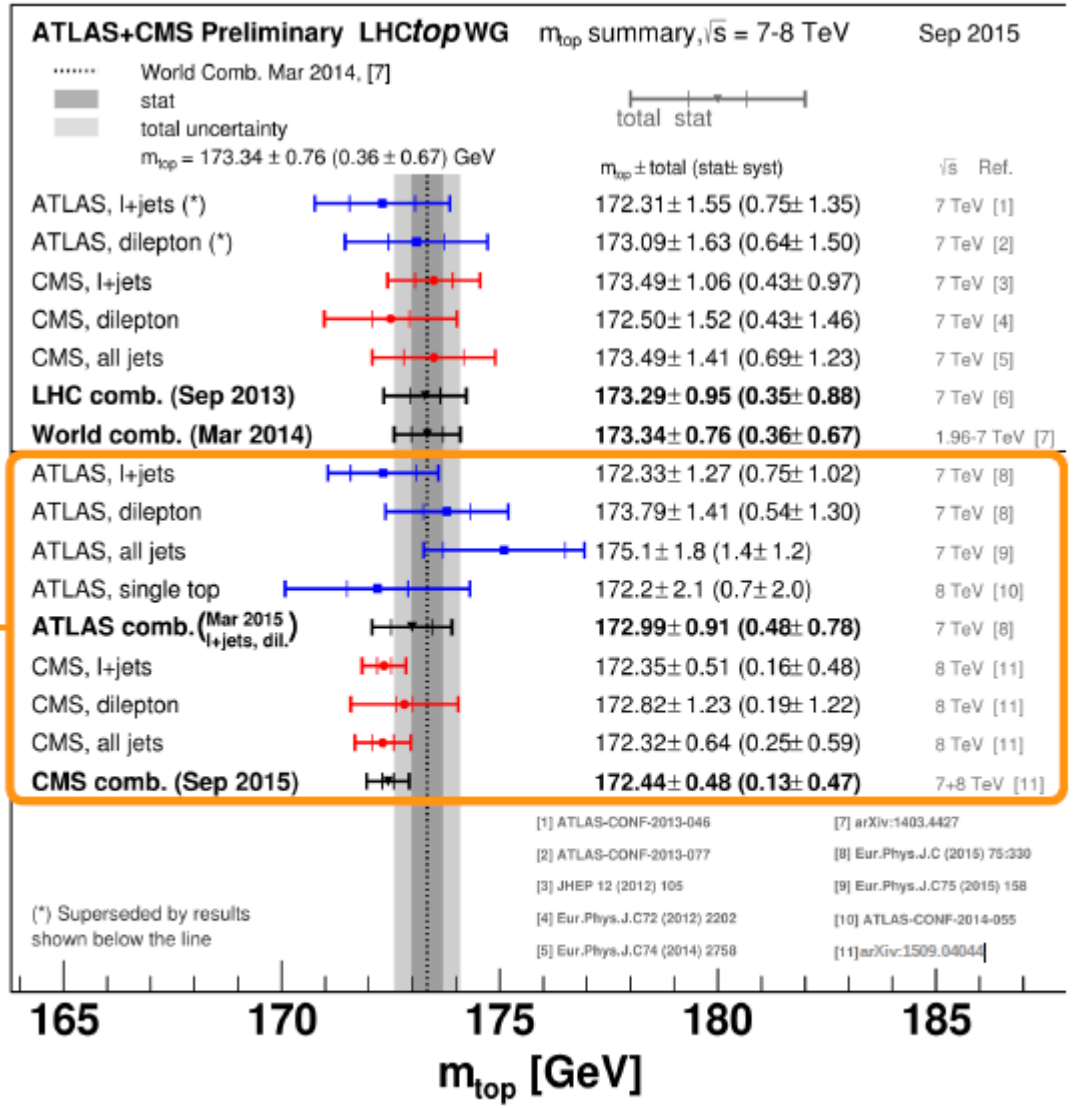
Pole mass extractions starting to reach interesting precision:



Top mass combination?

→ Soares
→ Maier

- The most precise measurements per channel have been combined for
  - Tevatron and LHC[1] (2014)
  - LHC[2] (2013)
  - Tevatron[3] (2014)
  - CMS only[4] (2015)
  - ATLAS only[5] (2015)
- The relevant correlations have carefully been estimated and stability tests have been performed



"this number hides a multitude of sins"

New results waiting for combination!
(in addition to latest results from Tevatron)

[1] arXiv:1403.4427 [hep-ex] [2] ATLAS-CONF-2013-102 / CMS PAS TOP-13-005 [3] arXiv:1407.2682 [hep-ex] [4] arXiv:1509.04044 NEW [5] Eur. Phys. J. C (2015) 75:330

TOPLHCWG → LHC*top*WG

- Wish for TOP2016: updated combinations !!
- New combinations, such as ttW / ttZ

- Expect lively discussions about (

)-correlations, precise and consistent treatment of systematic uncertainties, etc

- Compare performance in ATLAS and CMS of new MC samples for Run 2 as early as possible (establish a common benchmark?)

"at LEP we did both"

→ Soares

Move from combining published measurements to publishing combined measurements?

→ Maier

"in the remaining -1 minute I will discuss"

2. The "Future"

… which has already started !

13 TeV data is here

The LHC Run 2 has started

→ Lamont

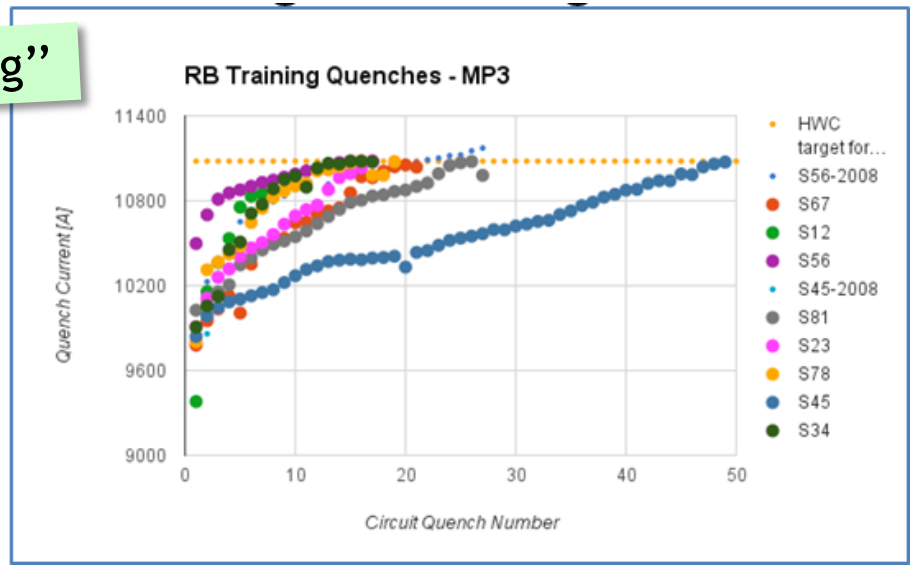
… but not without challenges!

- ULOs, UFOs, DUFOs, MUFOs, QPS, TDIs, Earth faults
- Main issue (25 ns): electron-cloud

Painful for 2015 – a commissioning year – but these shouldn't be long term issues for Run 2

"lot's of things can go wrong"

"it is a miracle that this is working at all"



- Still 13 TeV data has started to arrive
- Big thanks to our LHC colleagues!

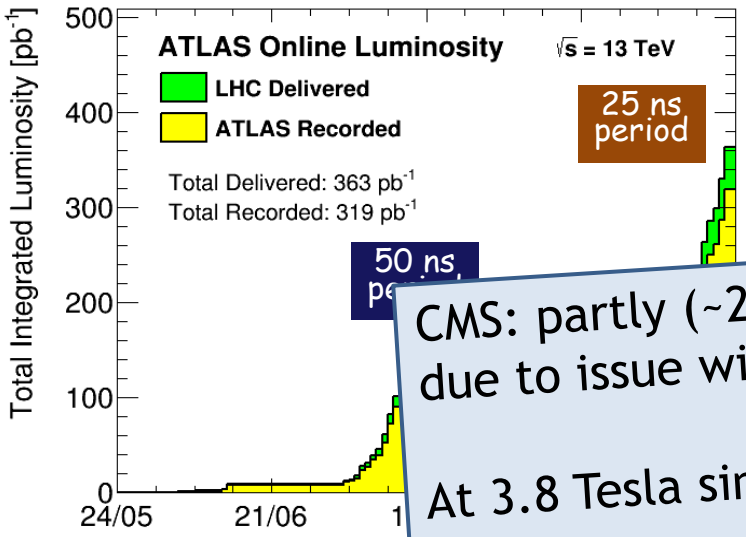
>> Respect! <<

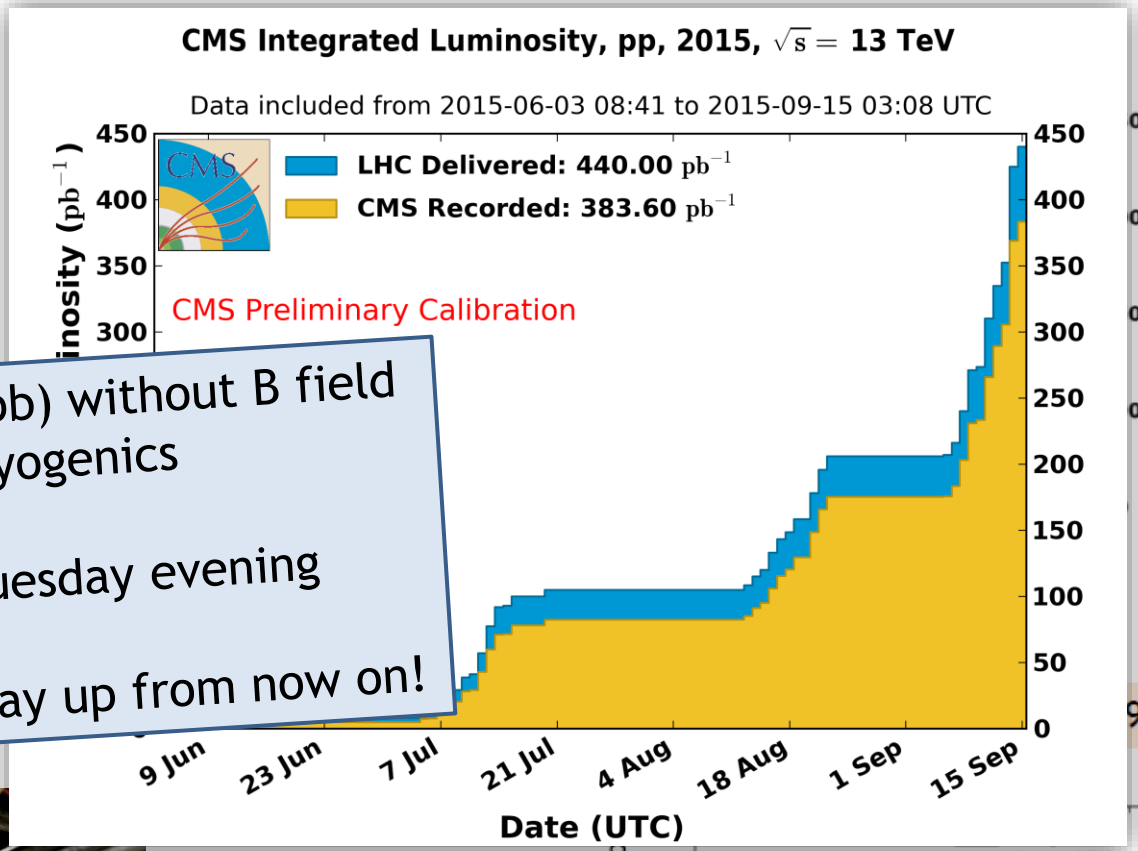
13 TeV data

→ Riu

→ TJ Kim

ATLAS integrated luminosity at √s = 13 TeV





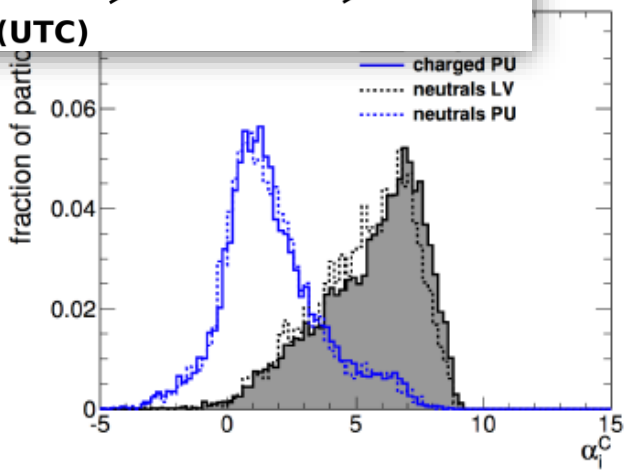
CMS: partly (~250 /pb) without B field due to issue with cryogenics

At 3.8 Tesla since Tuesday evening

Let's hope it will stay up from now on!

Detector Improvements:

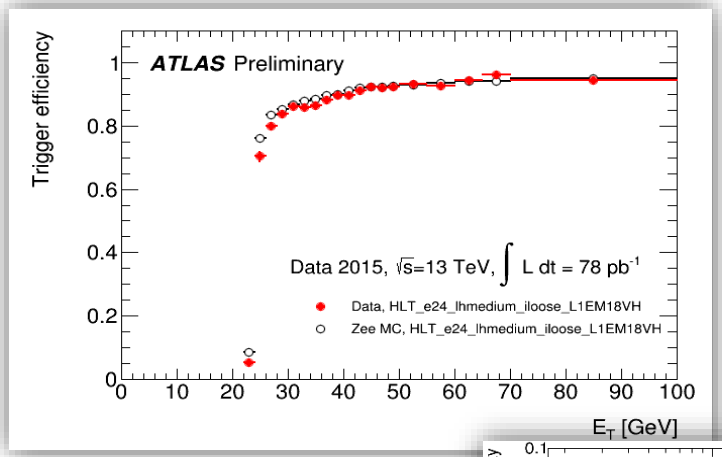
Reconstruction Improvements, Eg PUPPI (pile-up per particle identification):

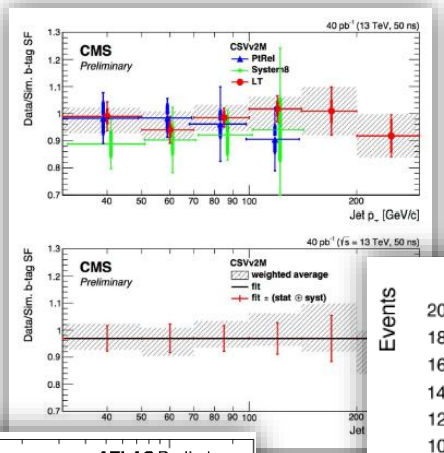


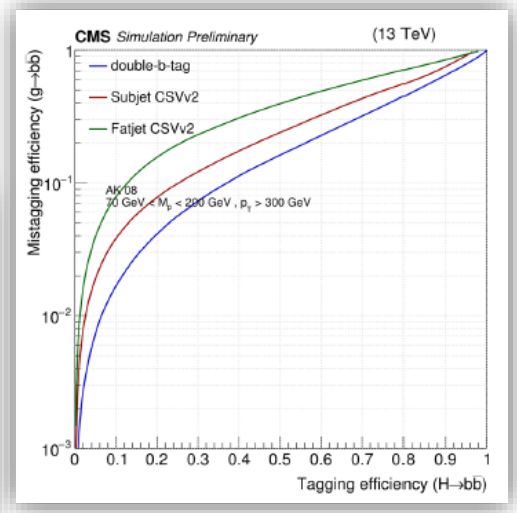
Performance Jets, (double) b-tag, lepton ID…

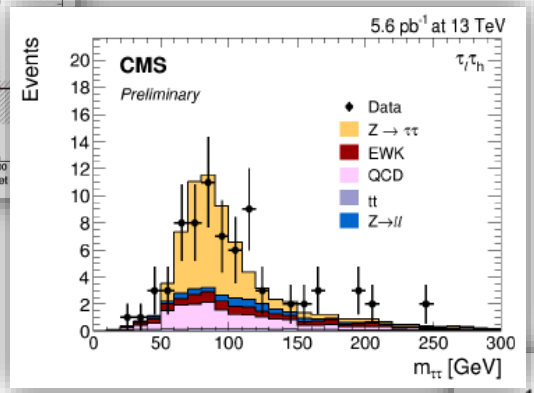
→ TJ Kim

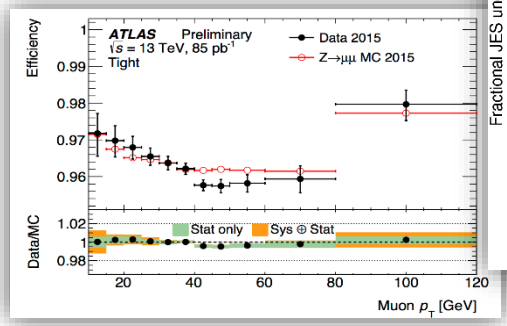
→ Riu

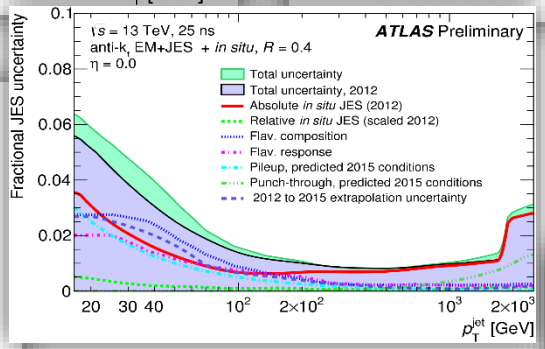


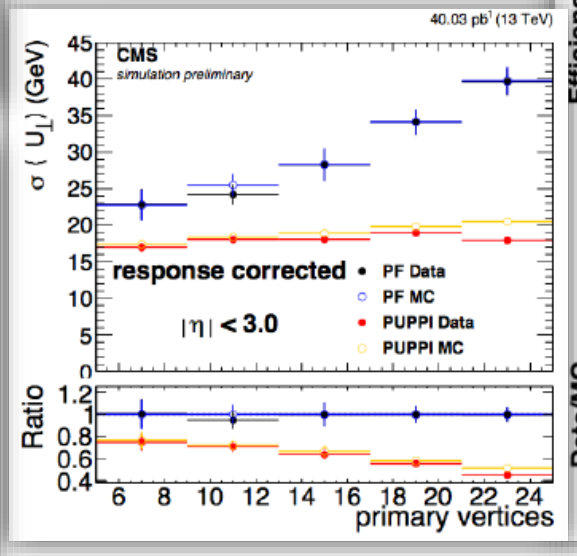


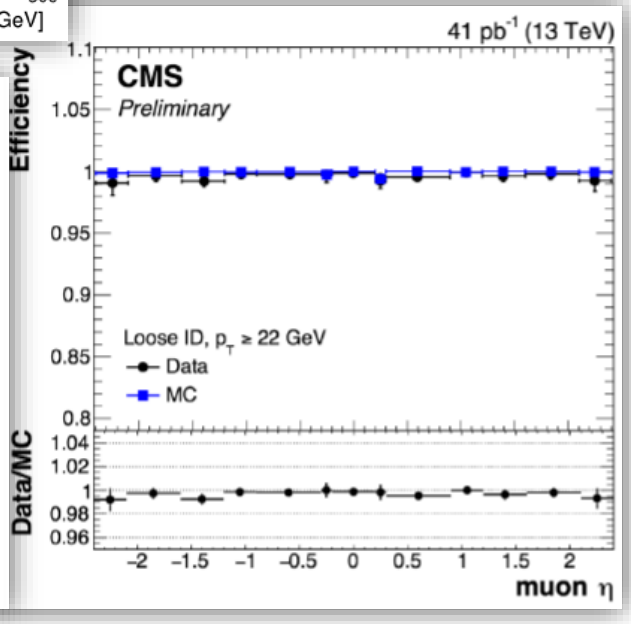


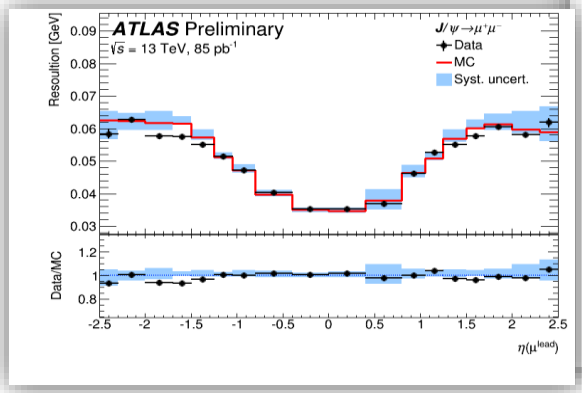


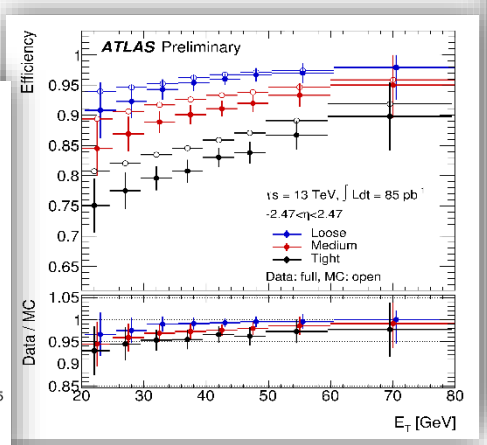








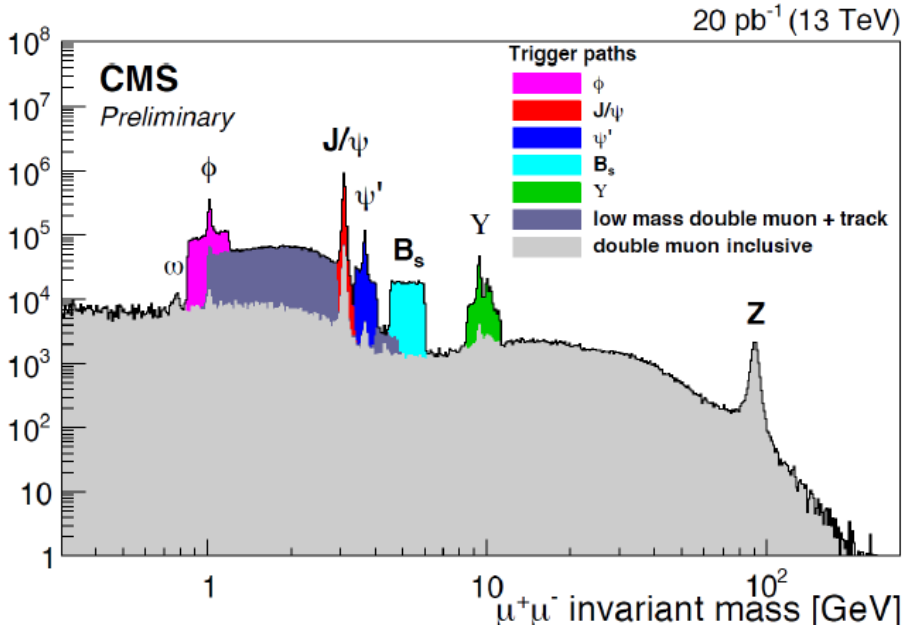


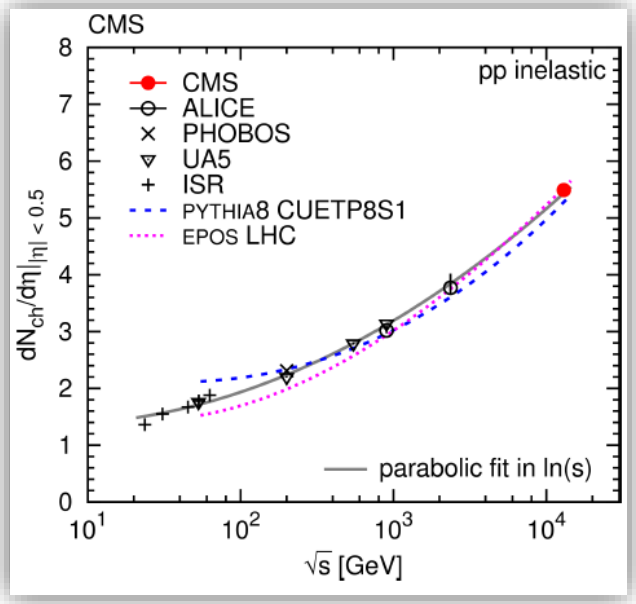


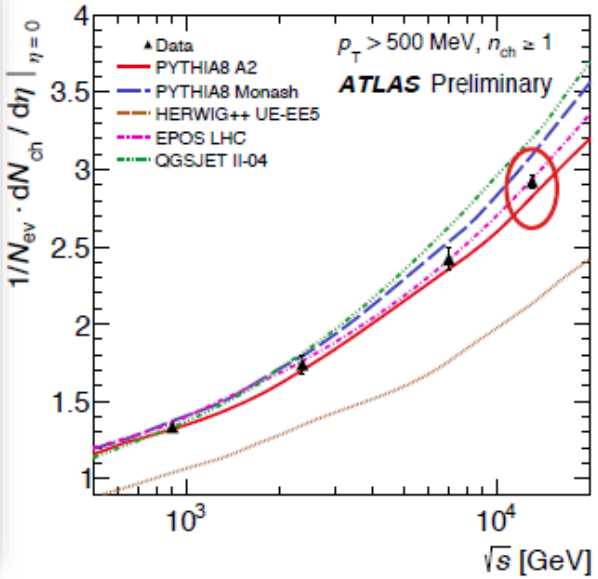
Non-Top "stuff" at 13 TeV

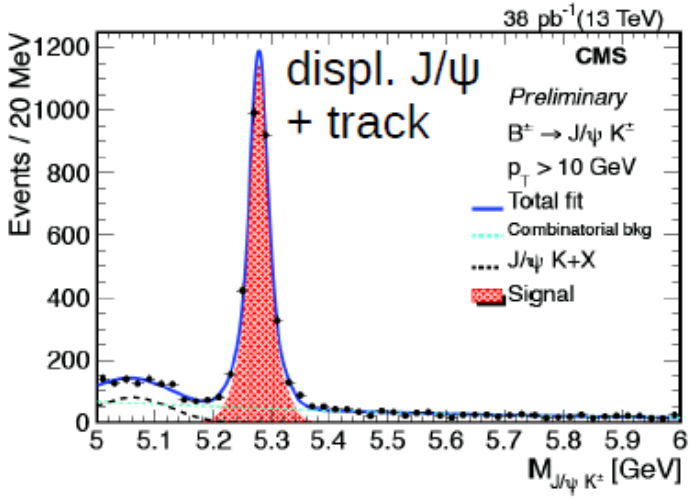
→ Vizan

→ Laycock

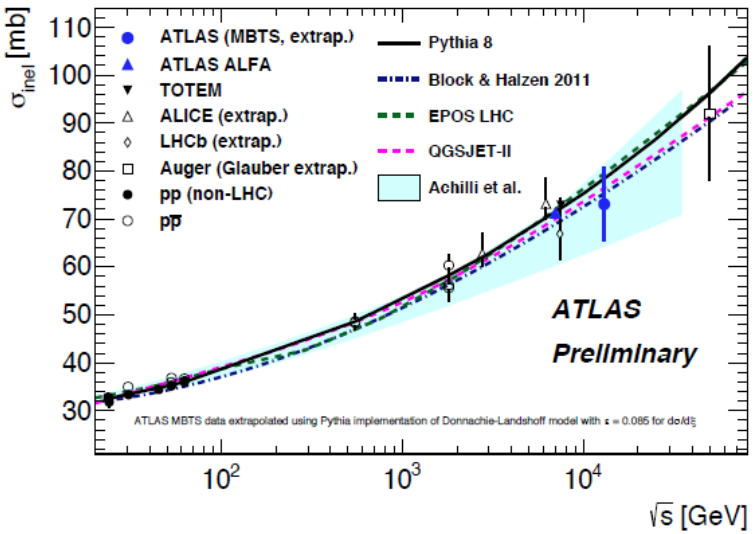








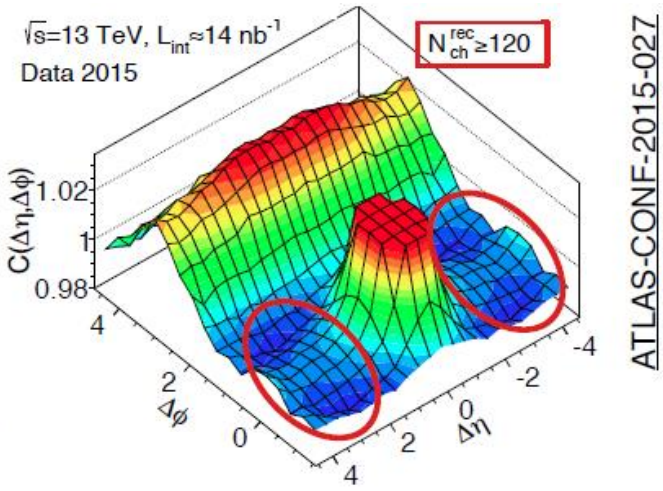
CMS: first publication at 13 TeV (with B=0..!)



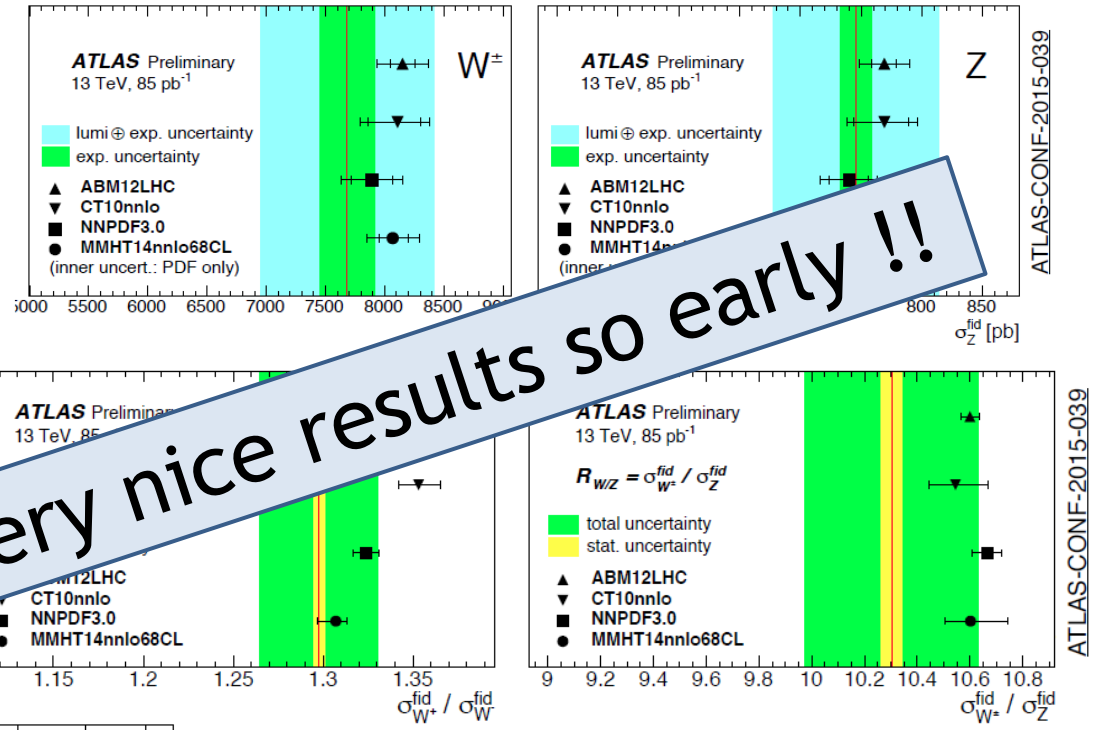
Other 13 TeV SM measurements

→ Laycock

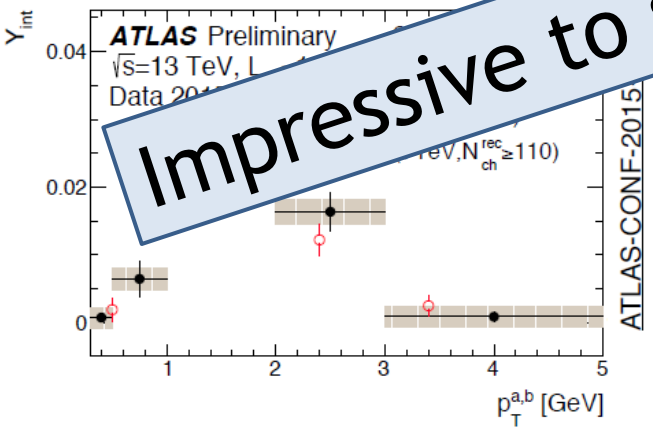
The “CMS Ridge” in ATLAS:



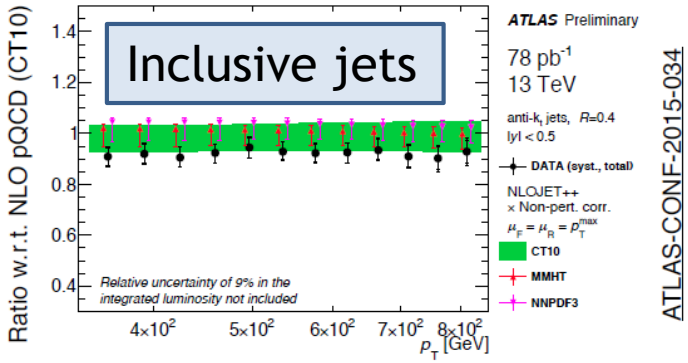
1 million Ws and 100k Z --> rates and ratios:

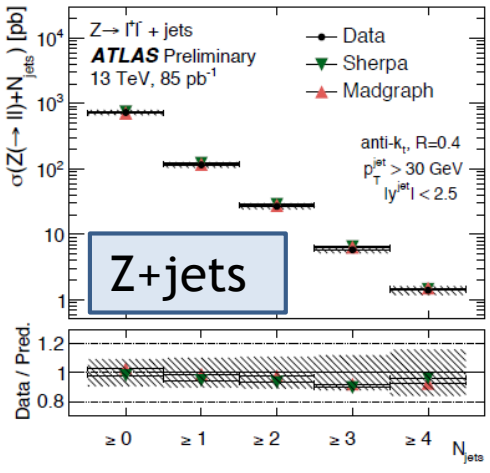


→ Same behavior as at 7 TeV ?



Impressive to see these very nice results so early !!

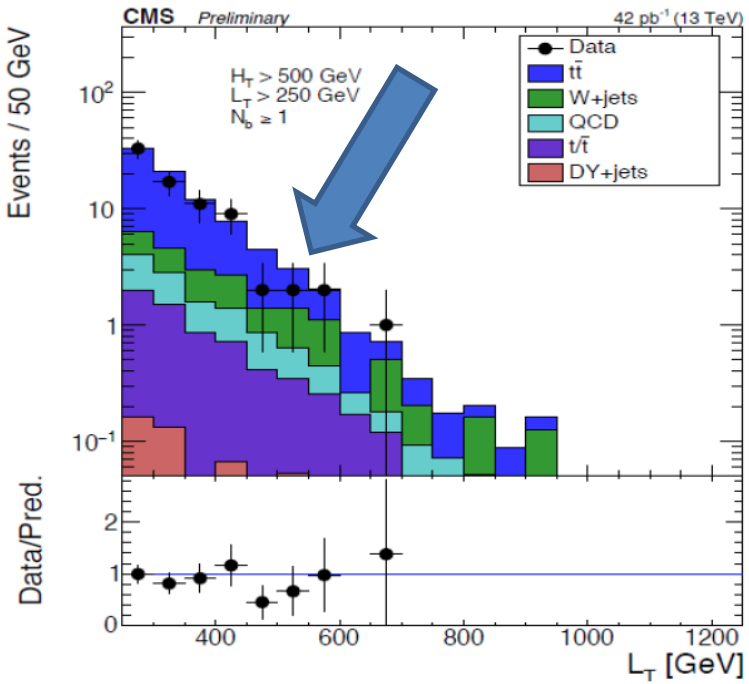


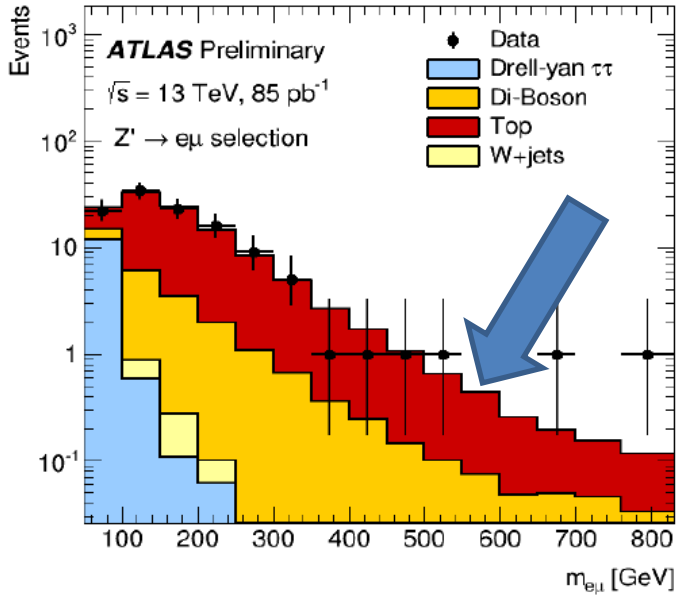


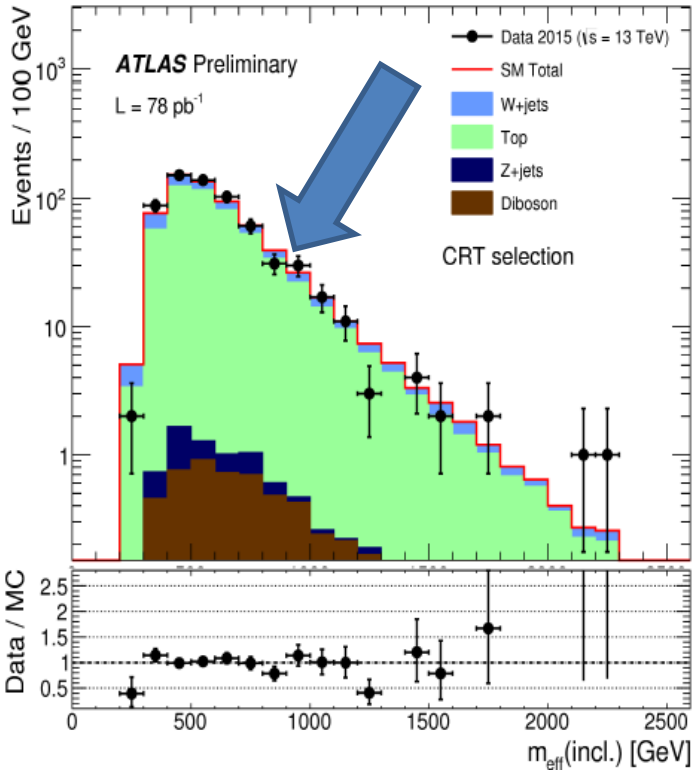
BSM Searchers validating Top at 13 TeV

→ Jeremy (Andrea)

→ Jeremy prime (Love)





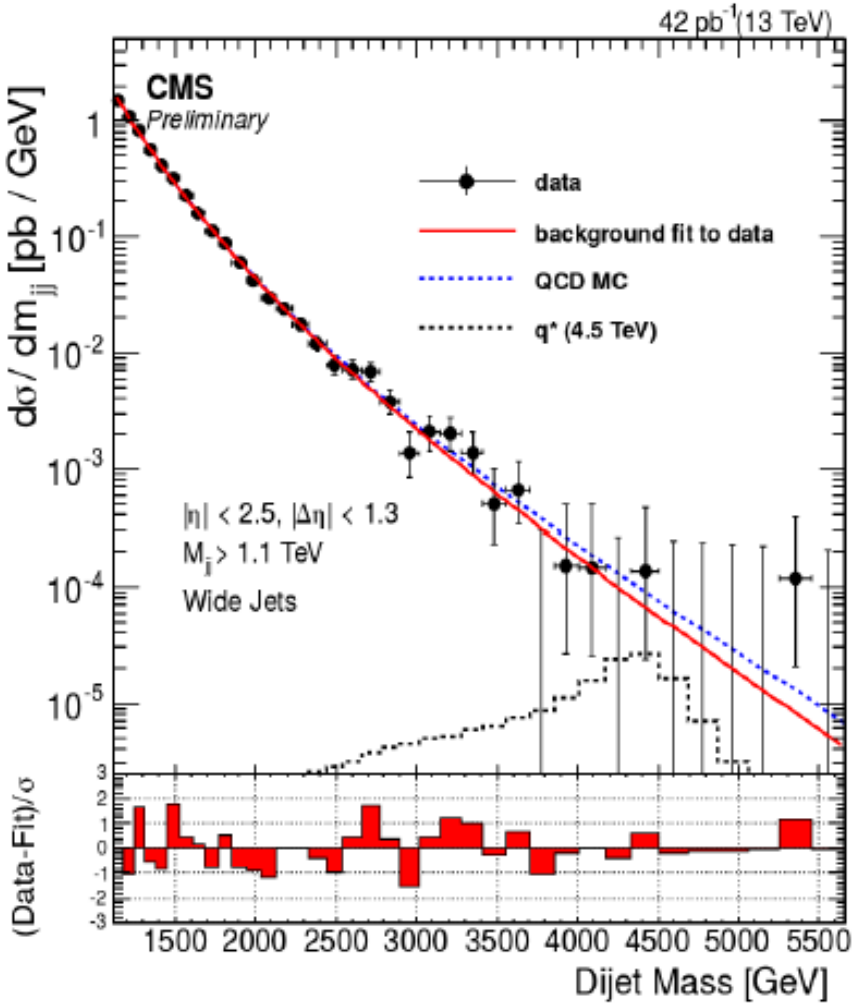


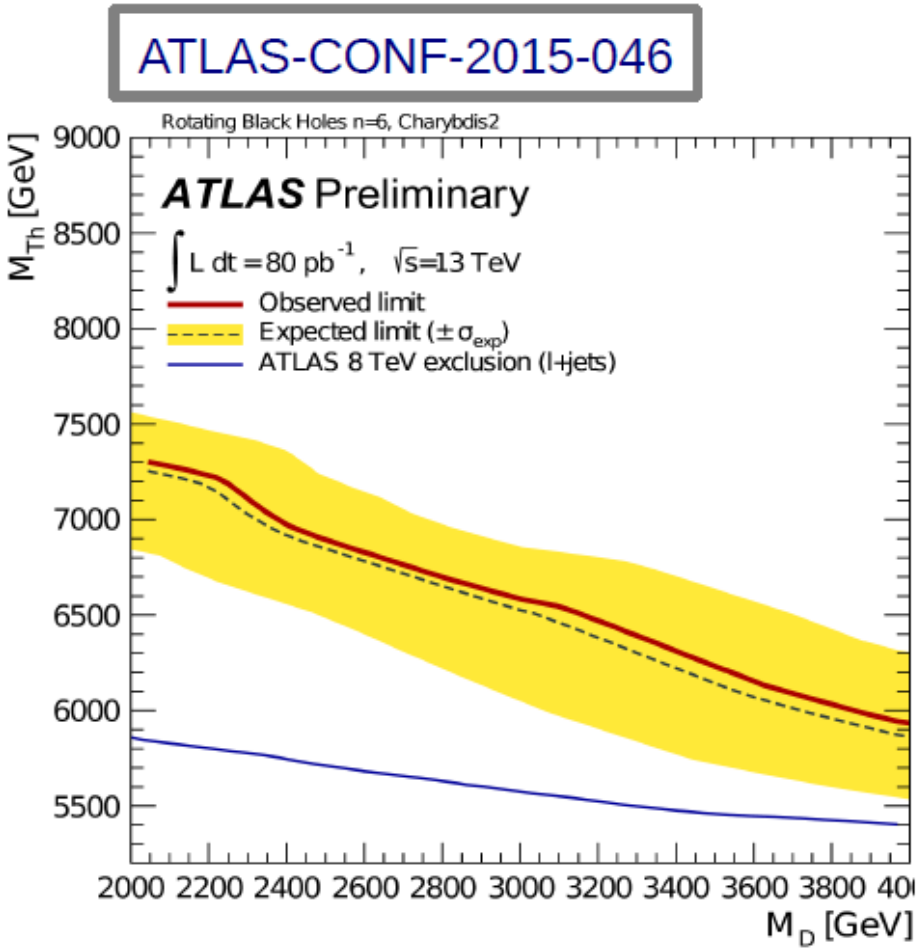
Not yet sensitive → use relaxed cuts to validate data
Top is an important background for many BSM searches

"SUSY is over-rated"

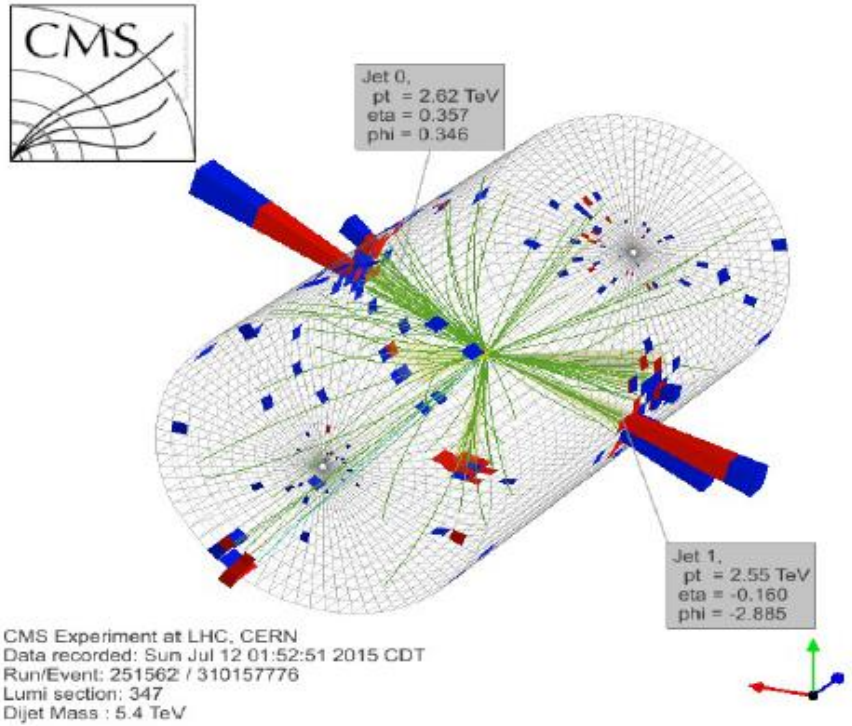
High mass searches immediately interesting

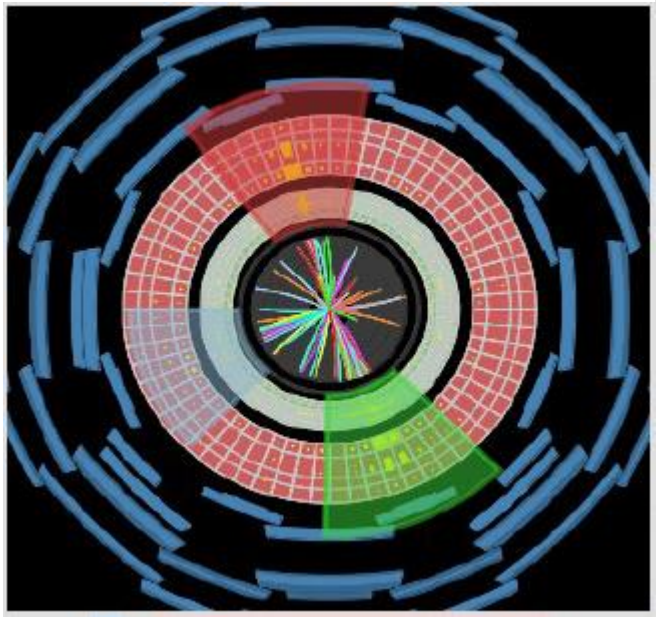
→ in some cases already surpassing LHC Run 1 sensitivity and limits





Di-jet events with Mjj > 5 TeV

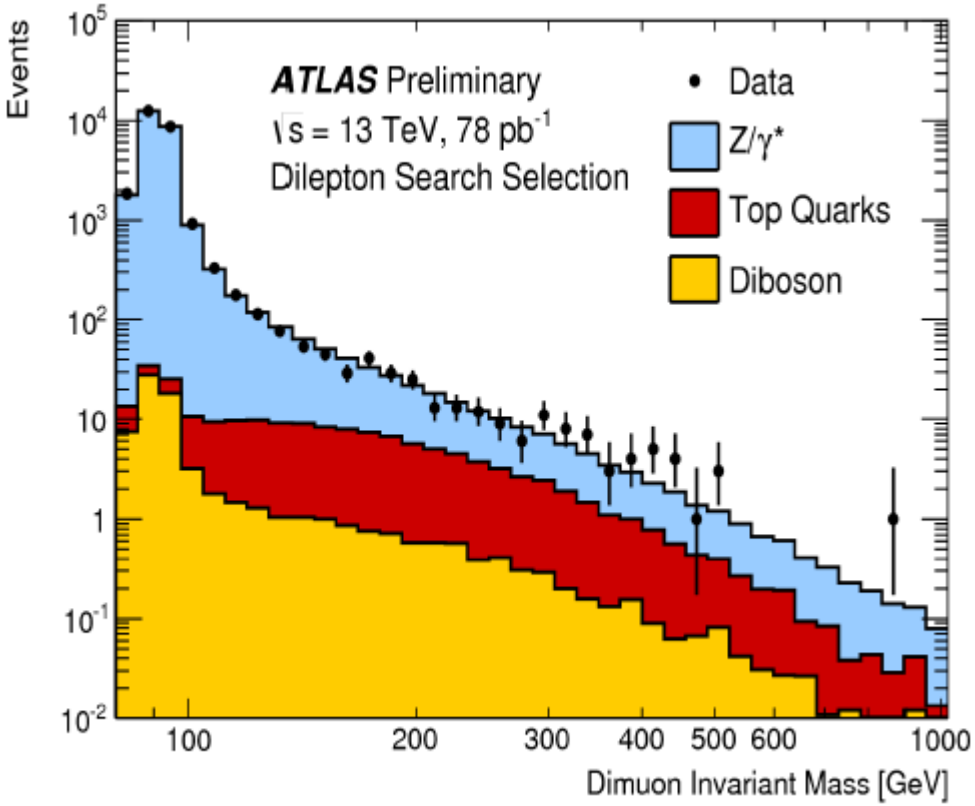


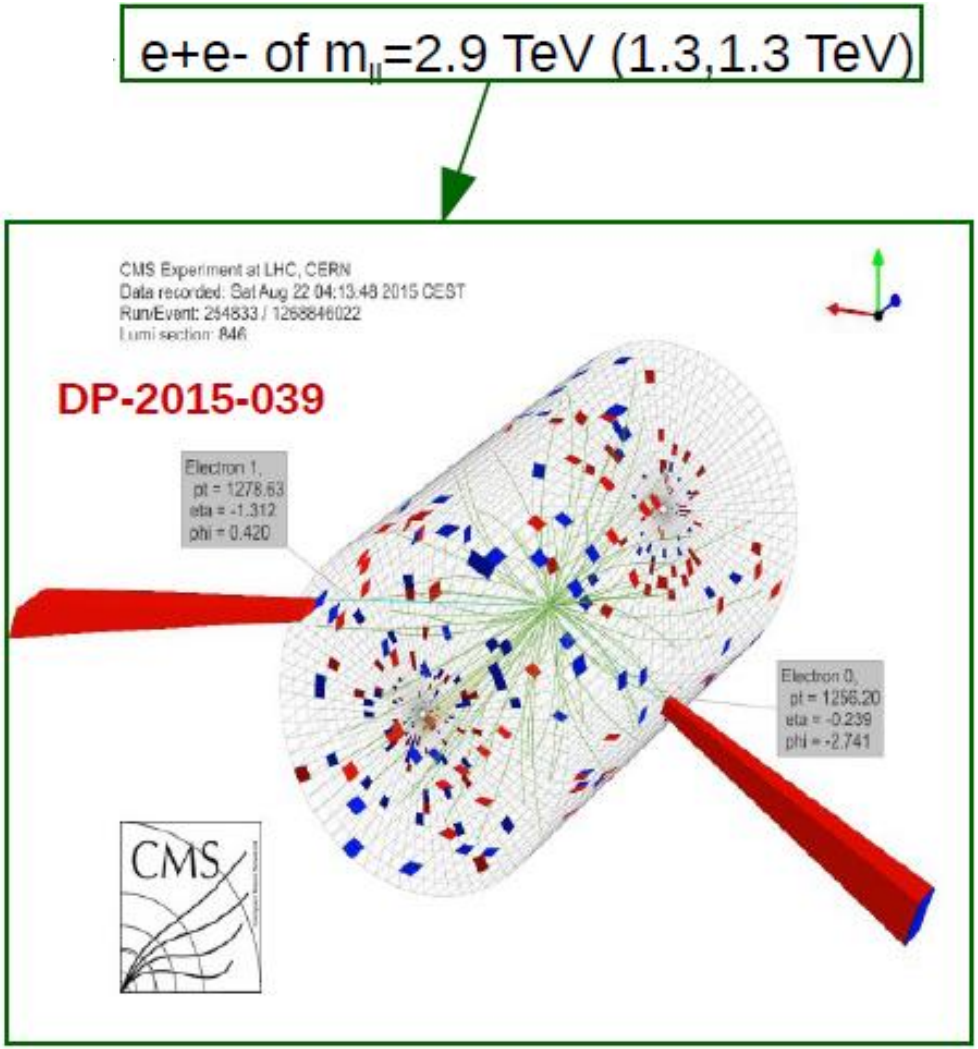


CMS: Mjj = 5.4 TeV

ATLAS: Mjj = 5.2 TeV

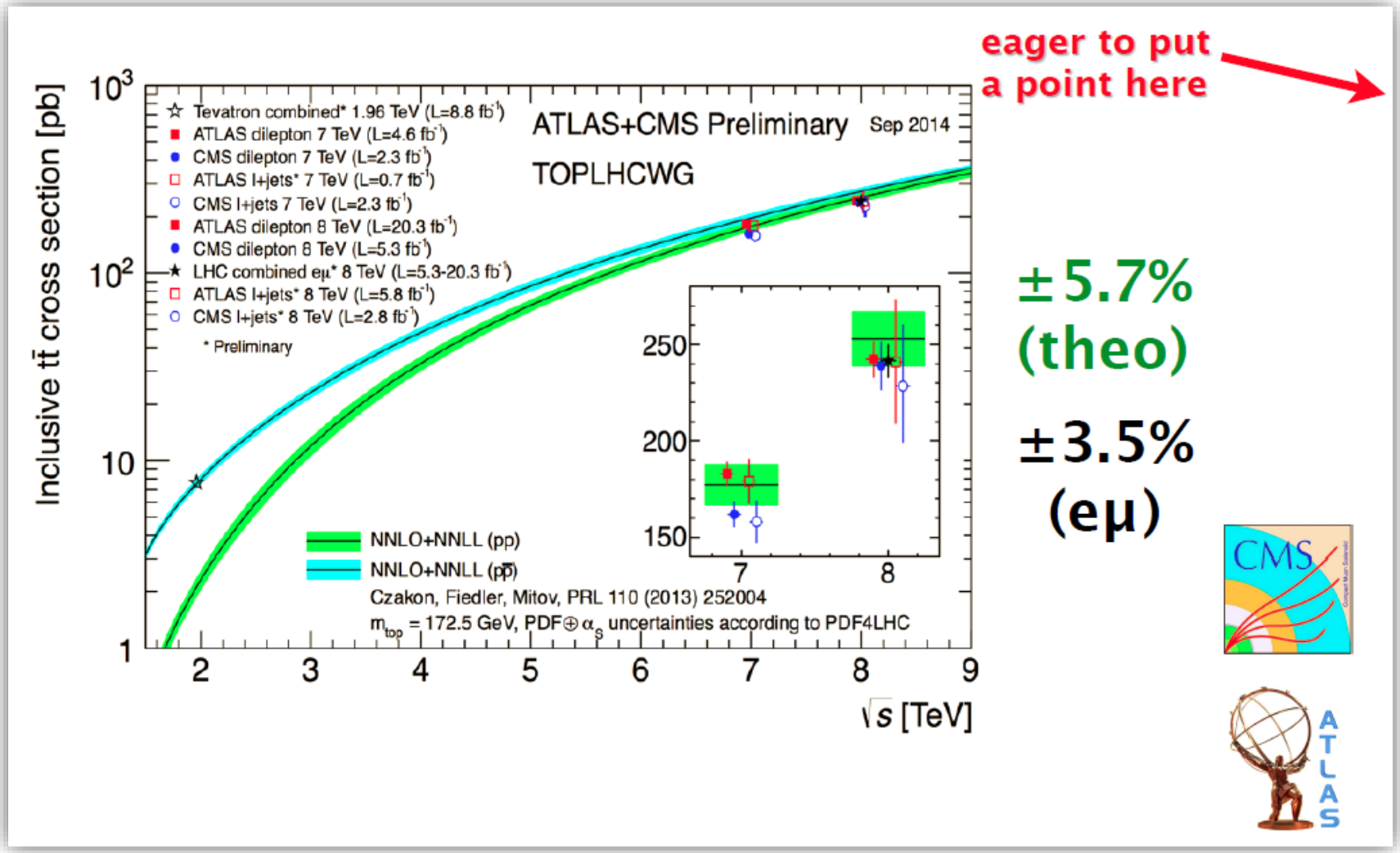
Monitoring closely: di-lepton mass spectrum



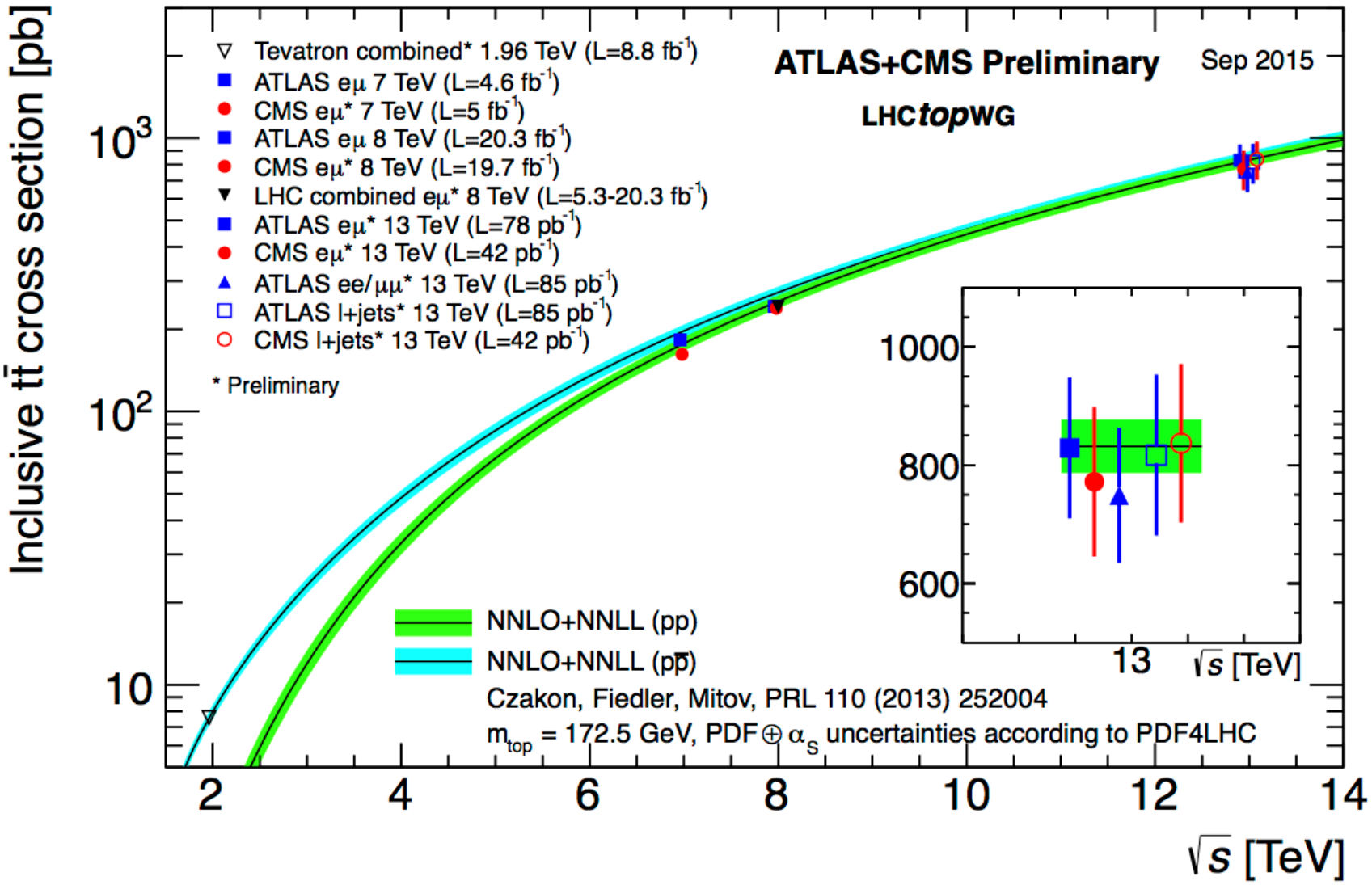


What about Top measurements at 13 TeV ?

A wish from TOP2014 (C. Schwanenberger):



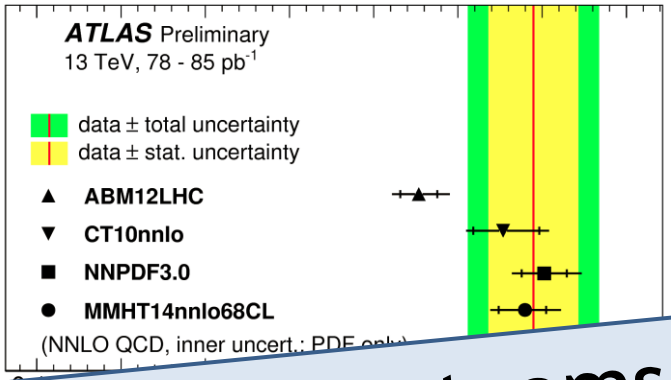
We have 5 inclusive measurements:



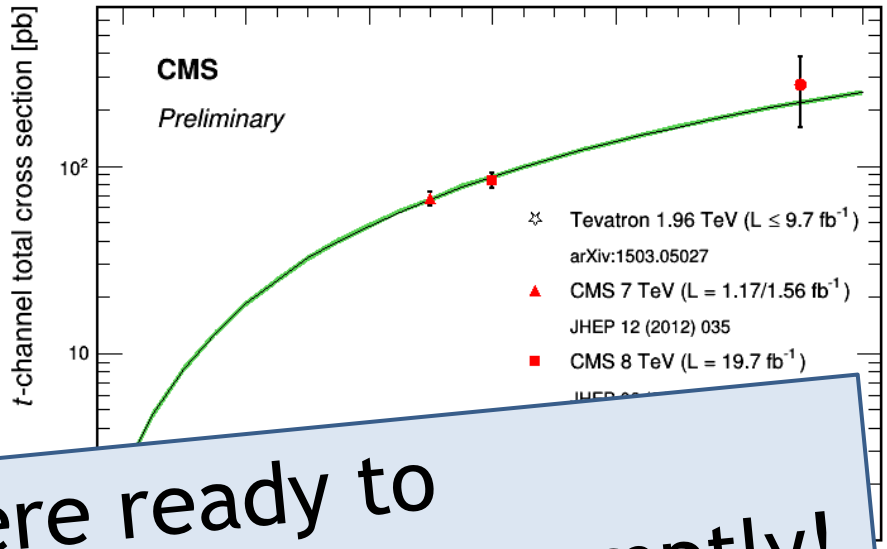
And more!

→ Glatzer
→ Crucy
→ Komm
→ Hindrichs

Ratio to Z



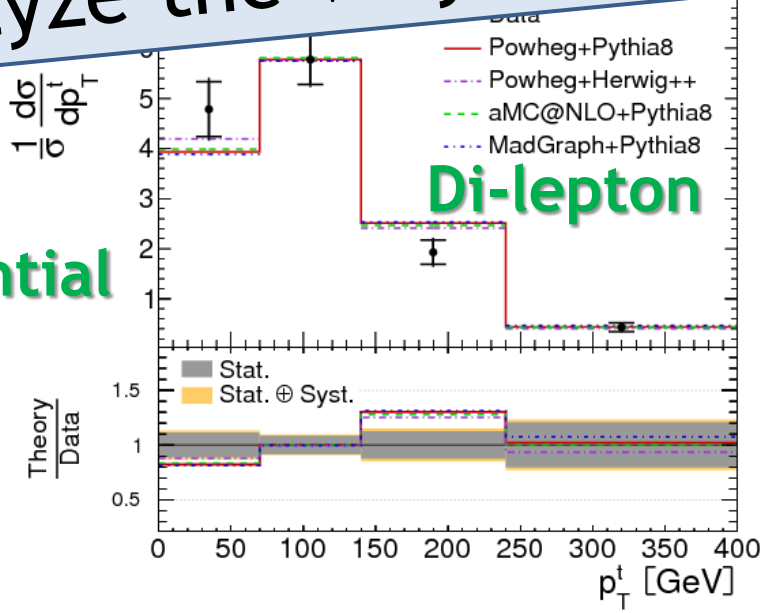
Single top!



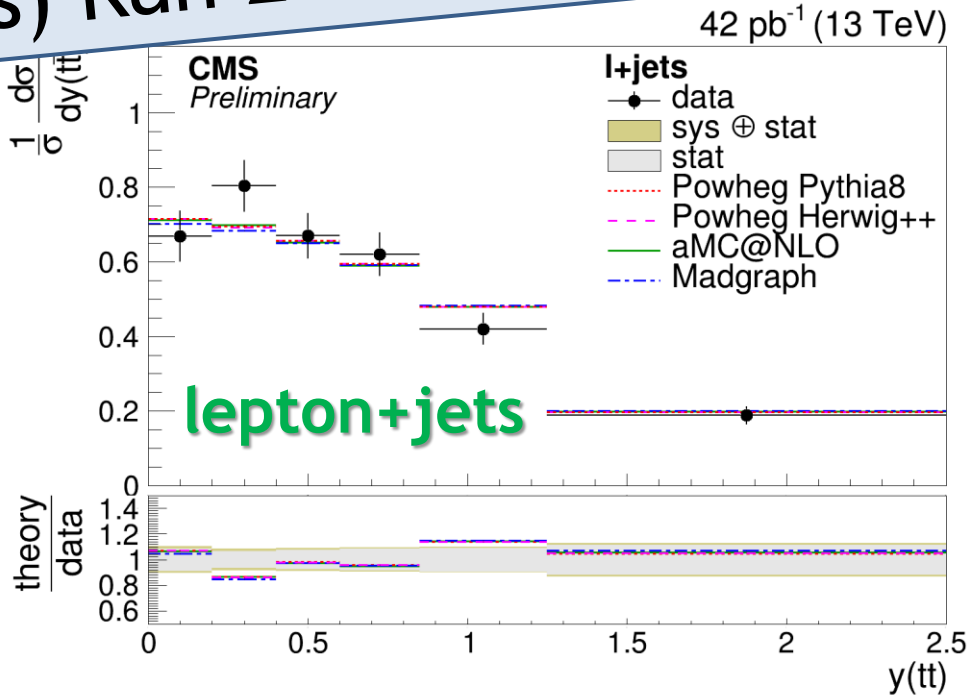
ATLAS and CMS Top teams were ready to analyze the very first (50 ns) Run 2 data promptly!

Differential

Di-lepton

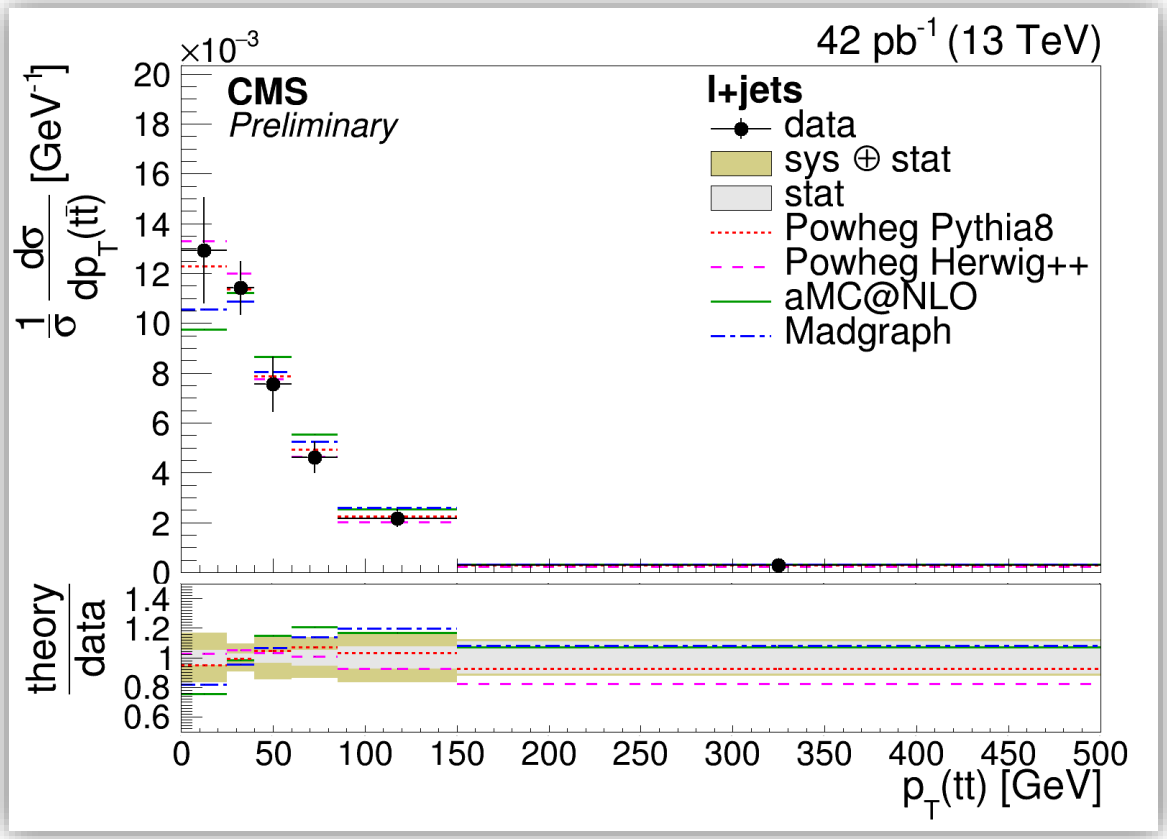


lepton+jets



New generation of MC tools

- Good to see new generation multi-leg (NLO + PS) MC tools available, with new tunes and configurations, ready to be compared to data and to each other



- So far in agreement, but still early results with large uncertainties

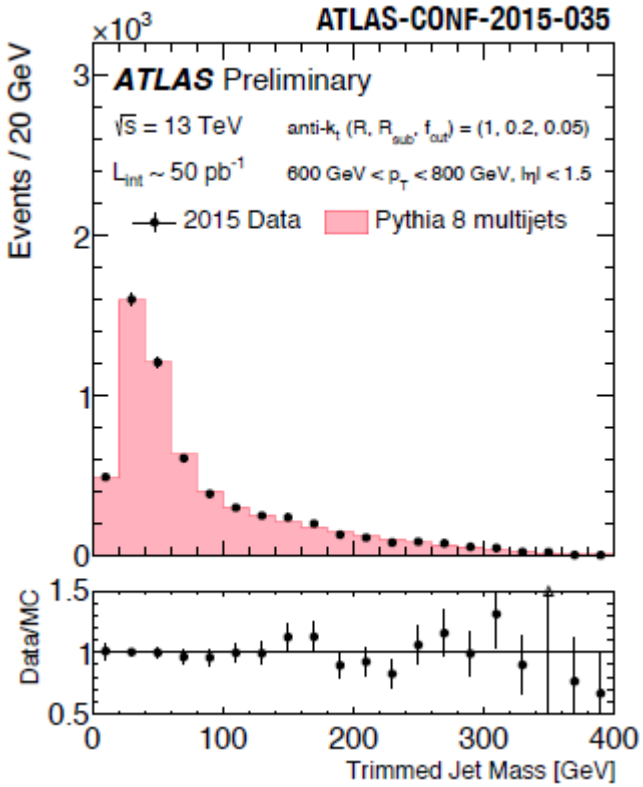
Looking forward to
(a lot) more 13 TeV data!

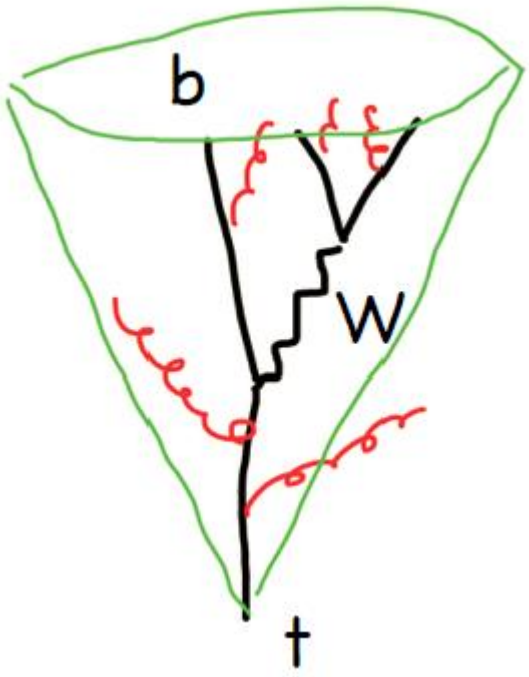
Boosted Top reconstruction

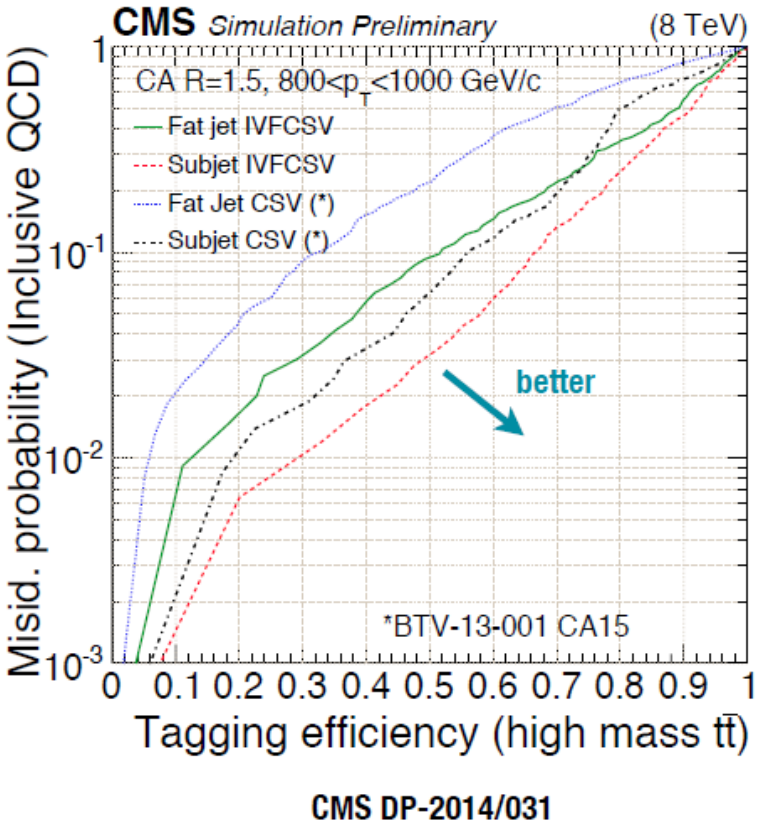
→ Skinnari

→ Spannowsky

- Increasingly important at higher centre-off-mass energies!
- Many many different algorithms, also dedicated b-tagging
- Being commissioned for 13 TeV data

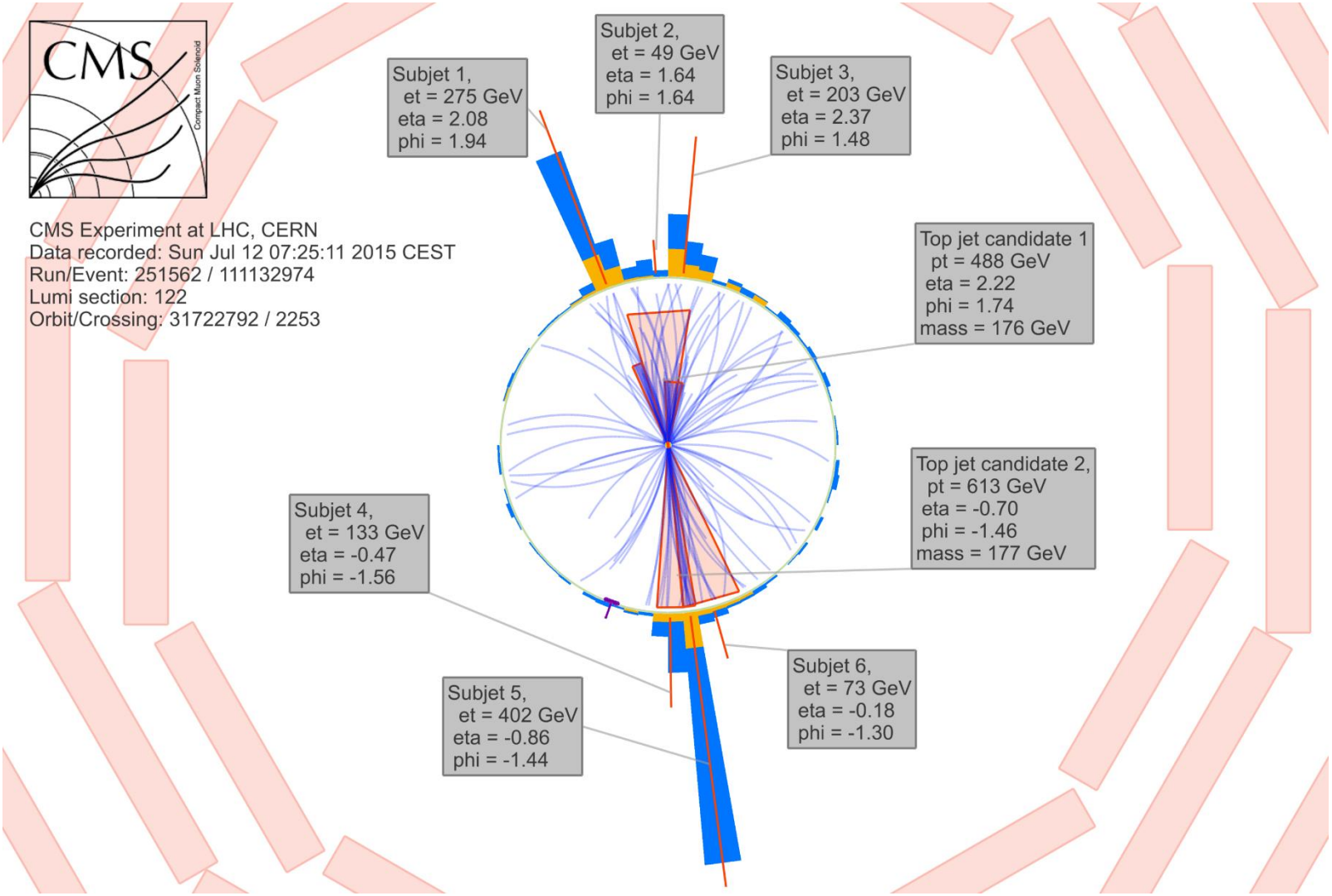






Boosted ttbar candidate (Mtt = 2.49 TeV)

→ Skinnari



m(topjet1)=177 GeV, pt(topjet1)=0.61 TeV 6 subjets,
m(topjet2)=176 GeV, pT(topjet2)=0.49 TeV 1 b-tagged subjet

(Summary)^2

→ Mulders

- Legacy of 20 years of Top Physics at Tevatron and LHC Run 1: we have learned quite a bit about the top quark!
- Many exciting new results at TOP2015 (experiment and theory)
- Expect next revolution in top quark exploration from
  - (Lots of) 13 TeV data
  - Ever more precise MC Tools and theory (NLO+EW+PS / NNLO, PDFs)
  - New reconstruction algorithms (esp in Boosted top regime)
  - and with a bit of luck: a 21st Birthday Surprise Maybe (BSM)

Travel home safely … and see you at TOP2016 !!

Grazie Mille!!

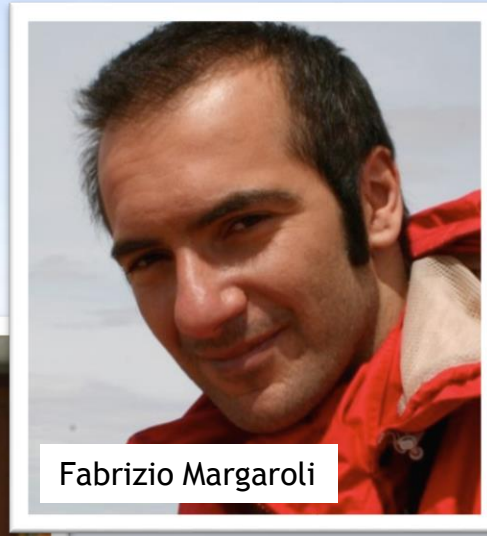

Paolo Meridiani


Marco Rescigno


Orso Iorio


Luca Lista


Francesco Fabozzi


Fabrizio Margaroli


Francesco Tramontano