Highlights from Moriond Electroweak.

A selection of Interesting results from the LHC experiments

N. Styles,
DESY LHC Physics Discussions,
04/05/15

HELMHOLTZ GEMEINSCHAFT

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Introduction



- In March, 50th Rencontres de Moriond took place
  - La Thuile, Val d'Aosta, Italy
- A Very Intensive Week of interesting Physics
  - With some fringe benefits...
- Will present a selection of Highlights from the LHC Physics talks
  - Far, far too many talks to mention every interesting item presented
  - A personal selection, apologies if I miss something of particular interest
  - Many interesting talks on Dark Matter, Neutrinos, Tevatron... not covered here

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A Bit of History...

G. Altarelli

TABLE DES MATIERES

In '66 almost all speakers were french

Proceedings mostly in french

Only ~20 part. mainly from Orsay, Ec. Polytechnique....

1er TOME

I - PHOTOPRODUCTION ET ELECTROPRODUCTION

M. GOURDIN	Some applications of the Algebra of Current to Electromagnetic Interactions
J. PEREZ-Y-JORBA	Spectromètre à triple focalisation de la Salle du GeV à Orsay
J. PEREZ-Y-JORBA	Photoproduction des π^+ et des π^- à Orsay
P. LEHMANN	Double Photoproduction sur le Proton
J. LEFRANÇOIS	Photoproduction du π^o sur le Proton
J. PEREZ-Y-JORBA	Mesure de la Polarisation du Proton de Recu dans la Photoproduction du π_o sur le Proton entre 500 et 950 MeV
J. LEFRANÇOIS	Photoproduction de K^+ sur le Deutérium
P. LEHMANN	Photoproduction Cohérente des Mésons π^o sur D_2 et He^4
G. MENNESSIER	Le Renversement du Temps en Photoproduction
J.P. LOUBATON	Pion Electroproduction

II - PROBLEMES AVEC LE DEUTERON

J. TRAN THANH VAN	Sur la Fonction d'Onde du Deutéron
D. SCHIFF	Photodésintégration du Deutéron et Rôle du N dans des Réactions comportant le Deutéron
B. GROSSETETE	Diffusion Electron Deutéron
Y. RENARD	Diffusion Elastique Electron Deutéron
F.M. RENARD	Etat des Connaissances Actuelles sur la Diffusion Inélastique Electron Deutéron

2ème TOME

III - EXPERIENCES SUR LES ANNEAUX DE COLLISIONS

J. HAISSINSKI	Expériences auprès des Anneaux de Collisions à Electrons et Positrons

IV - ECHANGE DE PLUSIEURS PHOTONS

M. GOURDIN	Quelques Aspects Théoriques de l'Echange de Plusieurs Photons
B. GROSSETETE	Expériences Positrons

V - SUJETS THEORIQUES DIVERS

F.M. RENARD	Interaction dans l'Etat Final à deux Particules
J. MICHEL	Vertex Electromagnétiques Elastiques et Inélastiques
G. MENNESSIER	Les Nouvelles Résonances Pion Nucléon
F. GUERIN	Structure Hyperfine de l'Hydrogène
C. DE CALAN	Corrections Radiatives

VI - SUJETS EXPERIMENTAUX DIVERS only 2 from abroad

G. WEBER	Experiments at DESY
C. SCHAERF	Experiments at Frascati
P. BOUNIN	Possibilités d'Expériences avec une cible de Protons Polarisés
P. BOUNIN	Expérience de Coincidences sur un Accélérateur d'Electrons

A gathering of friends and colleagues to discuss topics of mutual current interest

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Higgs Results

- Overviews of Run 1 Higgs results presented by G. Piacquadio (ATLAS) and J. Bendavid (CMS)
  - Showed the highly impressive amount of measurement made by the experiments
  - Already know a lot about this particle a relatively short time after its discovery!
  - Plans for Run 2 (and beyond) were outlined
- Will focus on a few items
  - Combinations of ATLAS+CMS Higgs results (M. Duehrssen)
  - Indirect Width constraints from Higgs decaying 4 leptons (J. Bendavid)
  - ATLAS evidence for Higgs decaying to taus (A. Tuna)
  - Searches for rare Higgs decays (P. Meridiani)
- Also interesting talks on
  - Searches for additional high-mass Higgs states (M. Pelliccioni, E. Navarro De Martino)

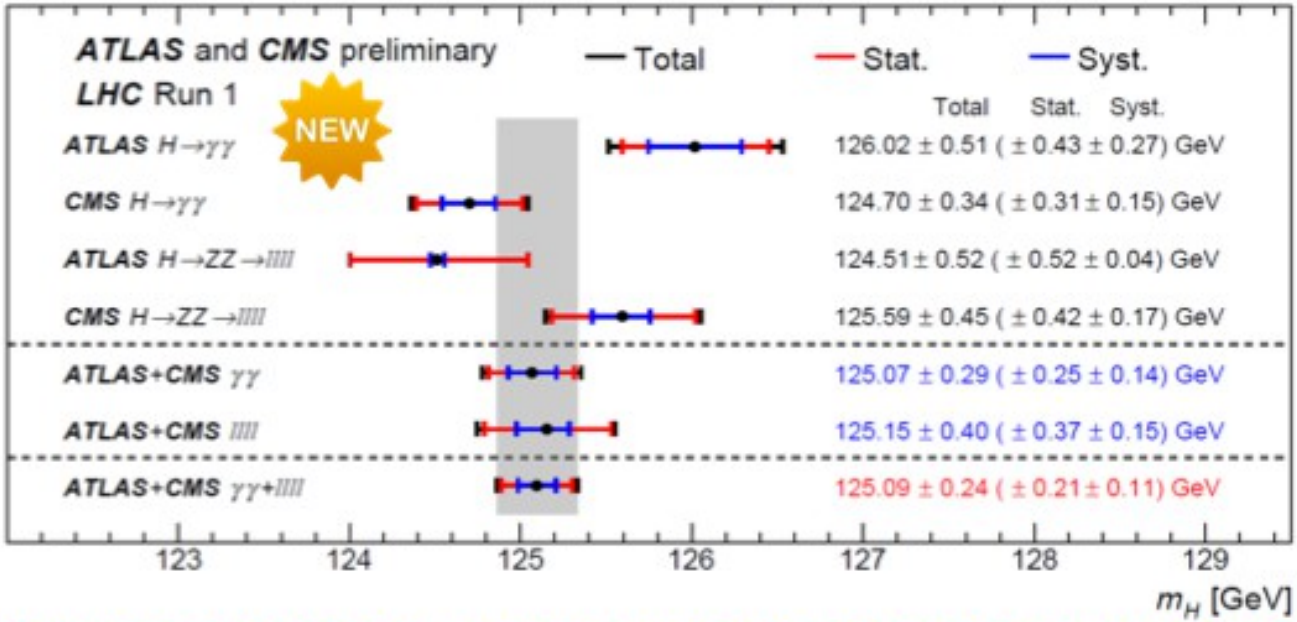
ATLAS + CMS Higgs Combinations

ATLAS+CMS Higgs mass combination

… and the ATLAS+CMS combined Higgs boson mass is:

$$m_H = 125.09 \pm 0.24 \text{ GeV}$$ **(0.19% precision!)**

$$= 125.09 \pm 0.21(\text{stat.}) \pm 0.11(\text{syst.}) \text{ GeV}$$



Compatibility of the 4 m_H measurements with the combined mass: 7-10%

Michael Duehrssen | Higgs combination | 7

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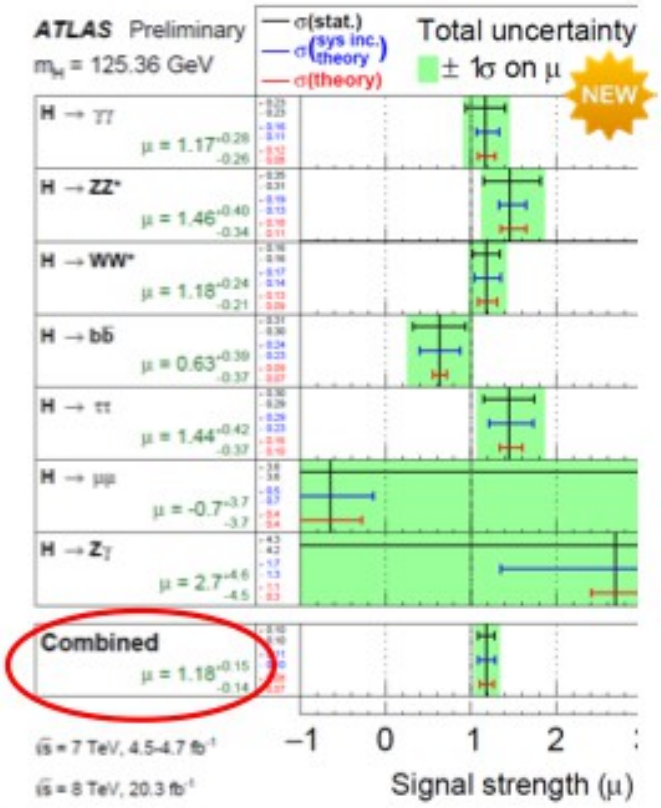
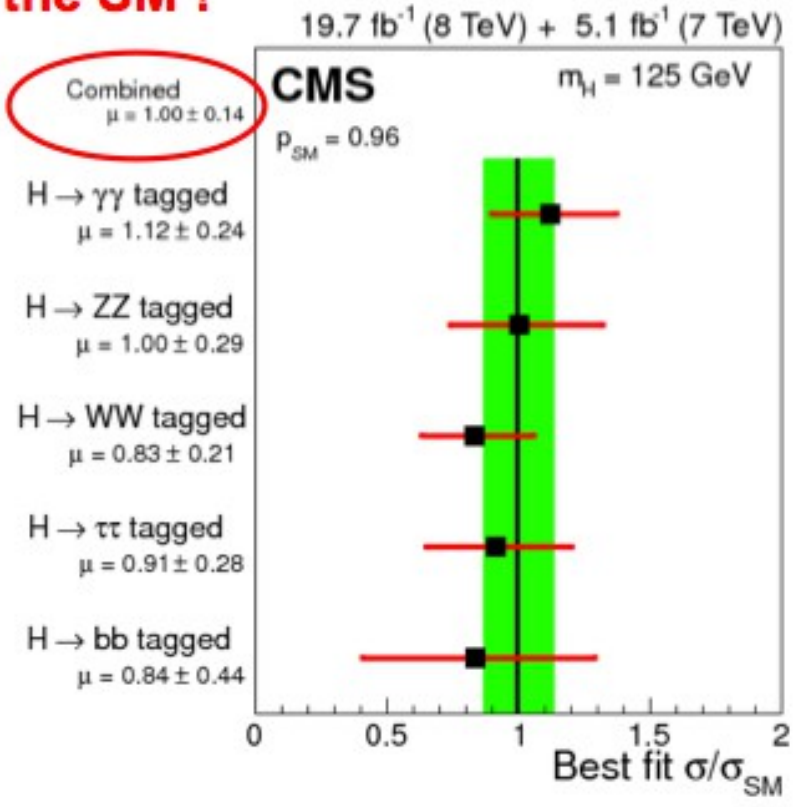
ATLAS + CMS Higgs Combinations

Signal strength: grouping by decay

- SM values for ratios between different production cross sections are assumed
- Results are consistent with the SM !

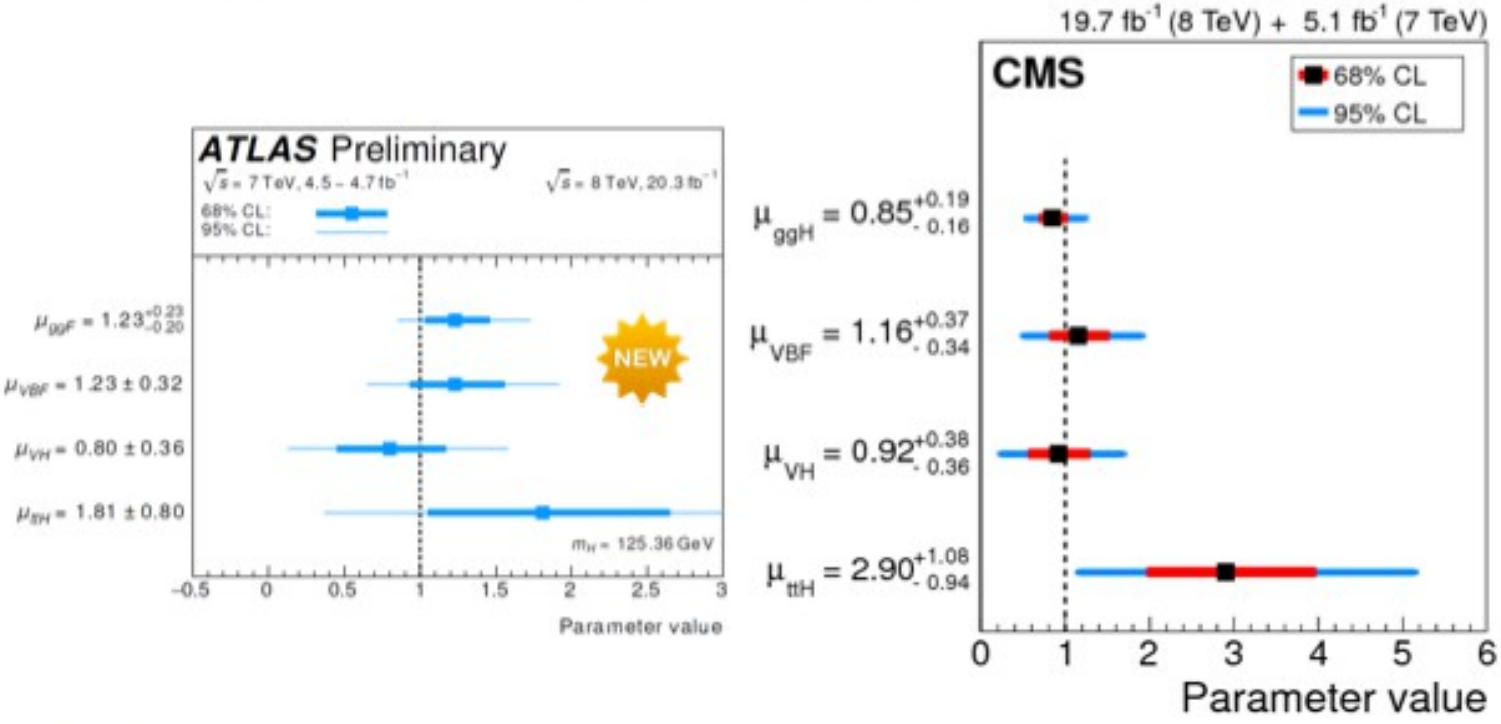




ATLAS + CMS Higgs Combinations

Signal strength: grouping by production

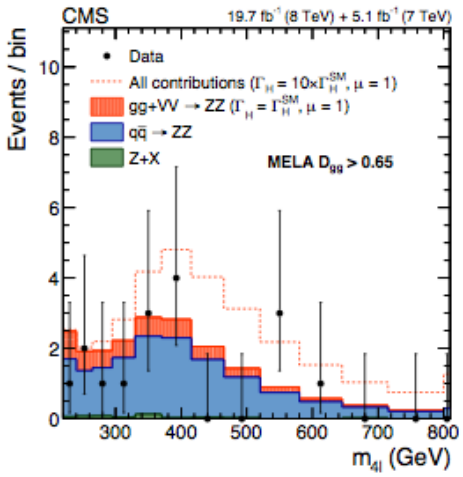
- SM values for ratios between different branching fractions are assumed
- **Results are consistent with the SM !**
  (but we can keep hoping for a ttH excess beyond the SM)

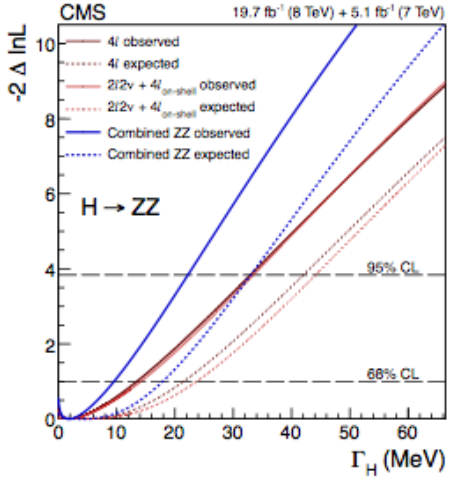


Indirect Width Constraints

$H \to ZZ \to 4\ell$: Indirect Width Constraint

- High mass tail sensitive to Higgs width through $gg \to H^* \to ZZ + gg \to ZZ$+interference
- Indirect constraint on width with simultaneous fit to high mass region (assuming no new particles in the gluon fusion production loop)

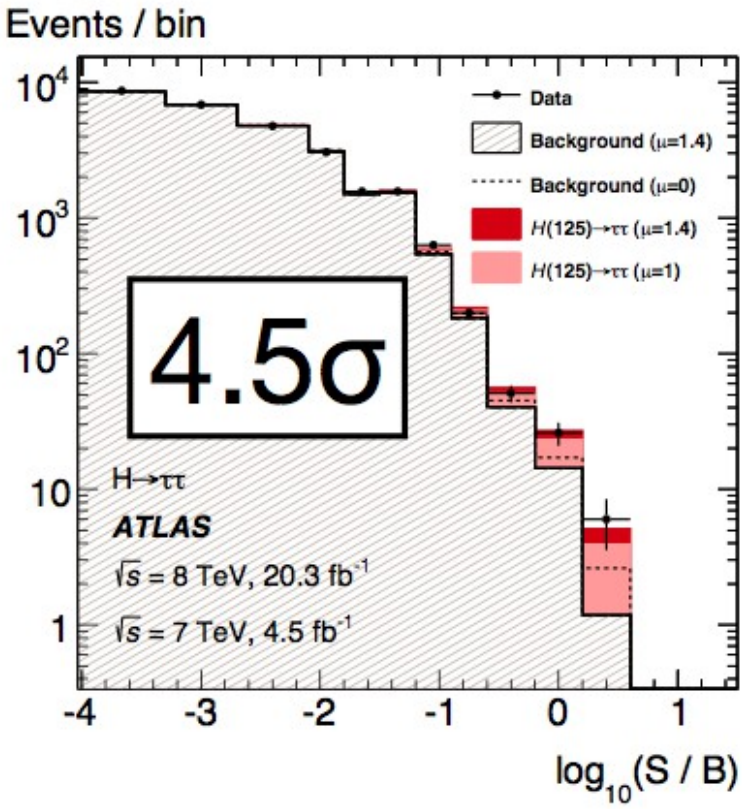




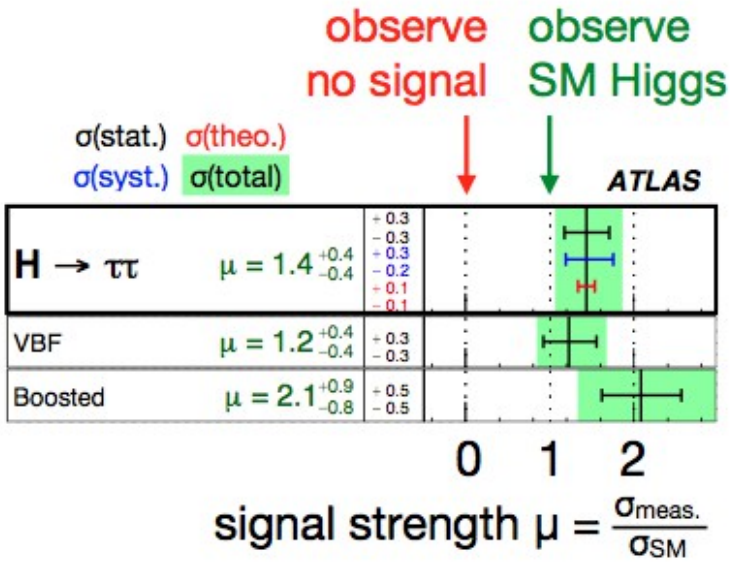
- $\Gamma_H < 22$ MeV (95% C.L.) ($\Gamma_{SM} \sim= 4$ MeV)

ATLAS Evidence for H→ττ

H→ττ results



BDT bins from all six categories, ordered by S/B



signal hypothesis favored

μ = 1.4 ± 0.4

Search for rare Higgs decays

H→μμ & H→ee

BR(H→μμ)=2.2x10^{-4} ~ 1/10 x BR(H→γγ)

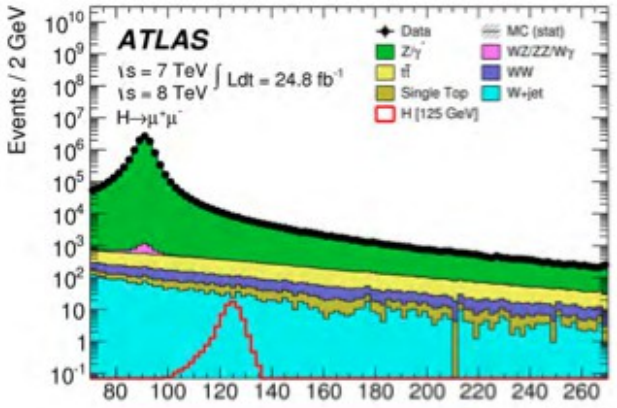
H(125)→μμ 95% CL observed (expected) limits on σ/σ$_{SM}$

ATLAS: PLB 738 (2015)	7.0(7.2)
CMS: arXiv:1410.6679	7.4(6.5)

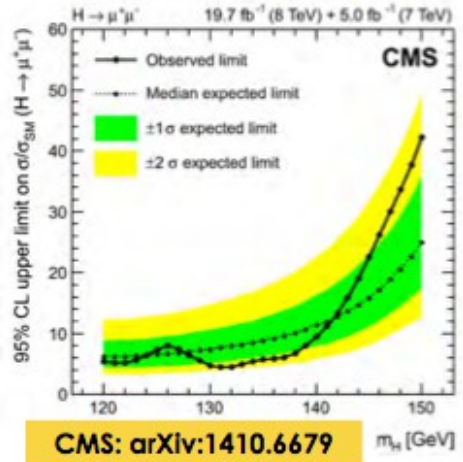
Together with evidence of H→ττ, confirm lepton non-universality

With 300 fb^{-1} @ 13 TeV sensitivity to ~exclude H→μμ

H→ee: CMS put 95% CL exclusion limit on σ x BR(H(125)→ee)=41fb



ATLAS: PLB 738 (2015) 68



CMS: arXiv:1410.6679

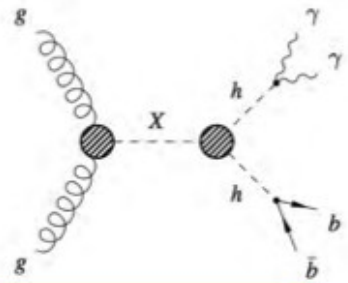
Search for Higgs pair production

HH Searches in Run I

Best channel at low m_{HH} is γγbb
- allows exclusion of some region of 2HDM space parameter (m_X<2m_t)

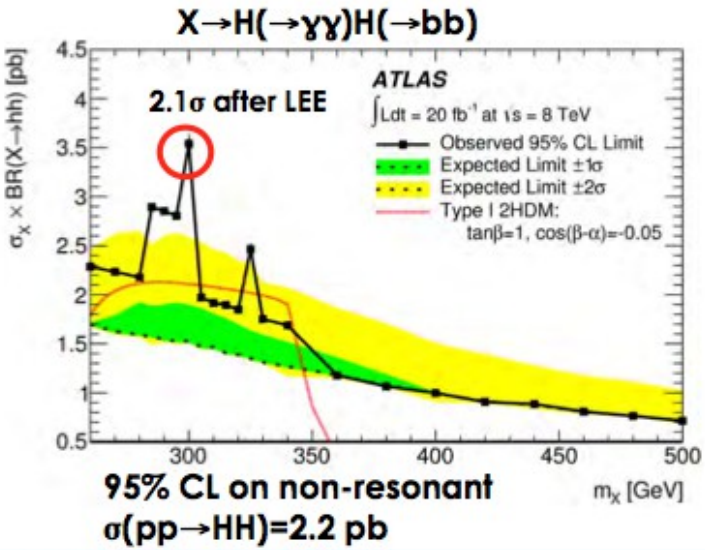
4b analysis most sensitive at high m_{HH}

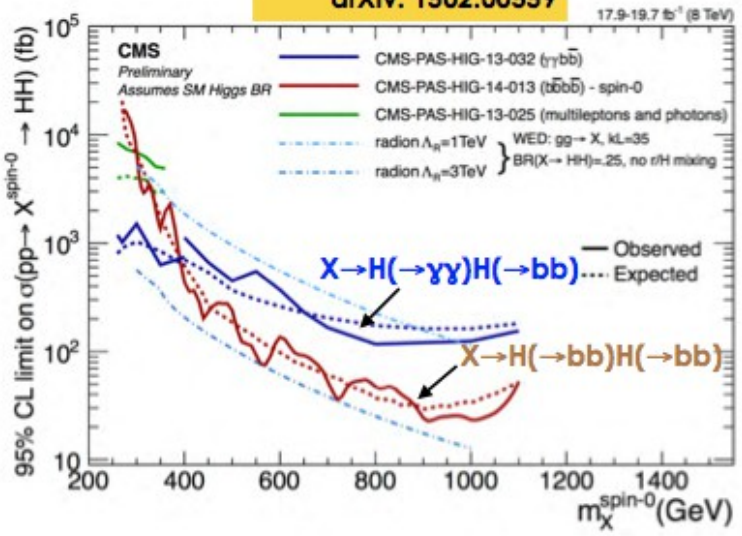
Non-resonant SM HH production too small to be probed during RunI: $\sigma_{NNLO}(pp\rightarrow HH)$ @ 8 TeV=9.96 fb
- non-resonant production m_{HH} ~ 300-400 GeV



CMS: PRD 90, 112013
HIG-13-032
arXiv: 1502.00559

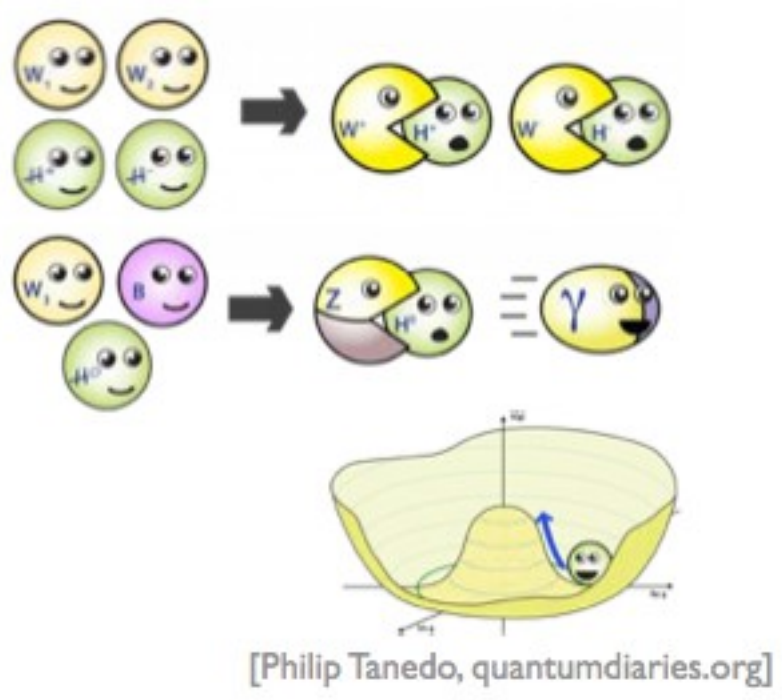
ATLAS: Phys. Rev. Lett. 114, 081802 (2015)





Standard Model Electroweak Results

- Given that this was the Electroweak edition of Moriond, should show some EW results ;-)
- Interesting new LHC Results
  - Presented by L. Perozzi
- Latest Global Electroweak fits from Gfitter group
  - Presented by R. Kogler
- Many interesting new Tevatron results in addition
  - M. Bauce, Not shown here here...



WW Cross Section

aTGC

11

W^+W^- production and aTGC at 8 TeV in CMS

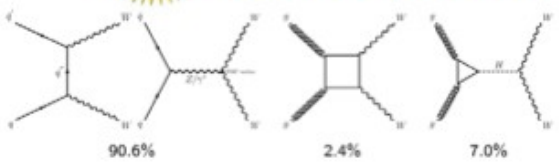
- ATLAS (ATLAS-CONF-2014-033) reports 2σ excess wrt to NLO (also previous CMS meas., see backup)

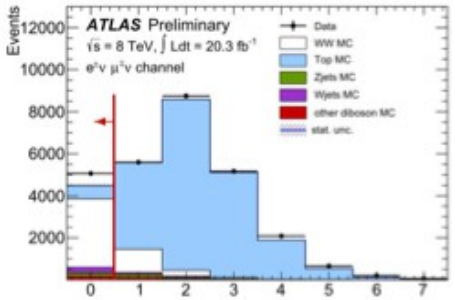
- Measurement in electron and muon channels, with 19.4 fb^{-1} at 8 TeV
  - Selection: 2 isolated leptons, kinematic range $p_{T,l}$>20 GeV, $|\eta_{ele}|$<2.5 , $|\eta_{\mu}|$<2.4, *projected* missing E_T>20 GeV, $p_{T,ll}$>45 GeV
- Several techniques to reduce the large background
  - Anti b-tagging and jet veto (N_{jets} < 2) for t-tbar
  - Dilepton boost and Z mass veto to reject Z→ll events
  - Third lepton veto for WZ and ZZ contamination
  - Multiple control regions to estimate the yields
- Systematics dominated by jet veto and lepton efficiency uncertainties
- Total measured cross section (after removing Higgs contribution)

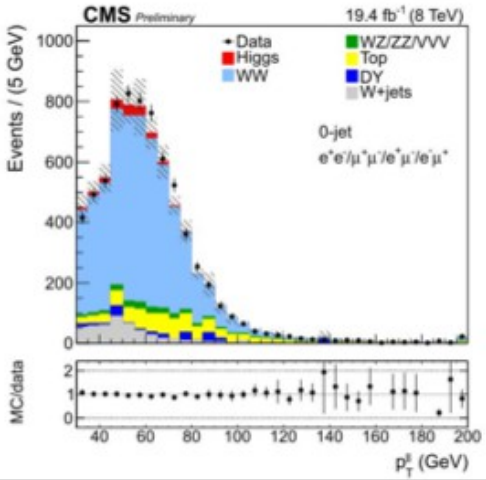
$$\sigma_{W^+W^-} = 60.1 \pm 0.9\,(\text{stat.}) \pm 3.2\,(\text{exp.}) \pm 3.1\,(\text{th.}) \pm 1.6\,(\text{lum.})\,\text{pb}$$

compatible with NNLO theory prediction: $59.8^{+1.3}_{-1.1}$ pb

NEW! CMS-PAS-SMP-14-016







Evidence for Wγγ

aQGC

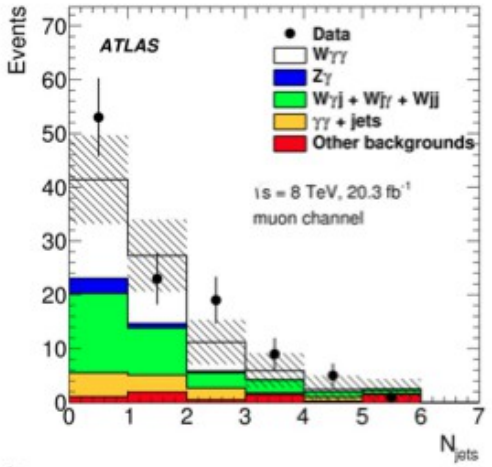
Evidence of Wγγ production in ATLAS

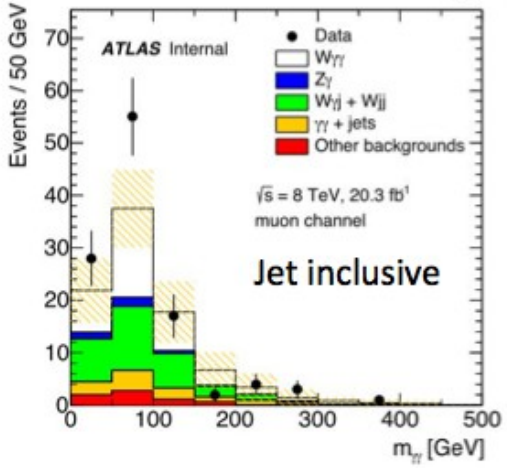
NEW! arXiv:1503.03243 submitted to PRL

- Cross section measured in muon and electron channels, with 20.3 fb^{-1} at 8 TeV
- Analysis performed in jet inclusive (≥0) and exclusive (=0) in the fiducial phase spaces
- Dominant systematic uncertainties from data-driven background and jet energy scale
  - Data-driven fake photon background in Wγj+Wjj events estimated with 2D template fit of the isolation distributions of the two γ candidates

- Total significance is 3.7 σ in the inclusive case, and 2.2 σ in the exclusive case (no expected quoted) → first Wγγ evidence
  - Electron and muon channels are compatible within 1 σ
- The fiducial cross sections is 1.9 σ higher than MCFM predictions in the inclusive case, 1.3 σ in the exclusive case

	σ^{fid} [fb]	σ^{MCFM} [fb]
Inclusive ($N_{\text{jet}} \geq 0$)		
$\mu\nu\gamma\gamma$	$7.1\ ^{+1.3}_{-1.2}$ (stat.) ±1.5 (syst.) ±0.2 (lumi.)	
$e\nu\gamma\gamma$	$4.3\ ^{+1.8}_{-1.6}$ (stat.) $^{+1.9}_{-1.8}$ (syst.) ±0.2 (lumi.)	2.90 ± 0.16
$\ell\nu\gamma\gamma$	$6.1\ ^{+1.1}_{-1.0}$ (stat.) ±1.2 (syst.) ±0.2 (lumi.)	
Exclusive ($N_{\text{jet}} = 0$)		
$\mu\nu\gamma\gamma$	3.5 ± 0.9 (stat.) $^{+1.1}_{-1.0}$ (syst.) ±0.1 (lumi.)	
$e\nu\gamma\gamma$	$1.9\ ^{+1.4}_{-1.1}$ (stat.) $^{+1.1}_{-1.2}$ (syst.) ±0.1 (lumi.)	1.88 ± 0.20
$\ell\nu\gamma\gamma$	$2.9\ ^{+0.8}_{-0.7}$ (stat.) $^{+1.0}_{-0.9}$ (syst.) ±0.1 (lumi.)	





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Global Electroweak Fit

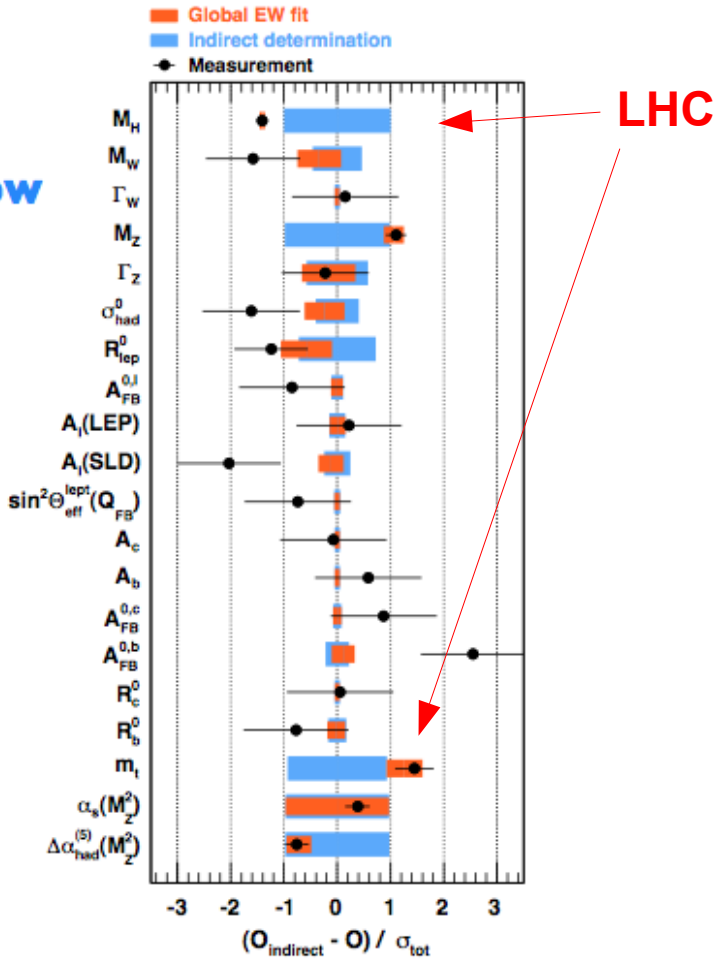
SM Fit Results

black: direct measurement (data)

orange: full fit

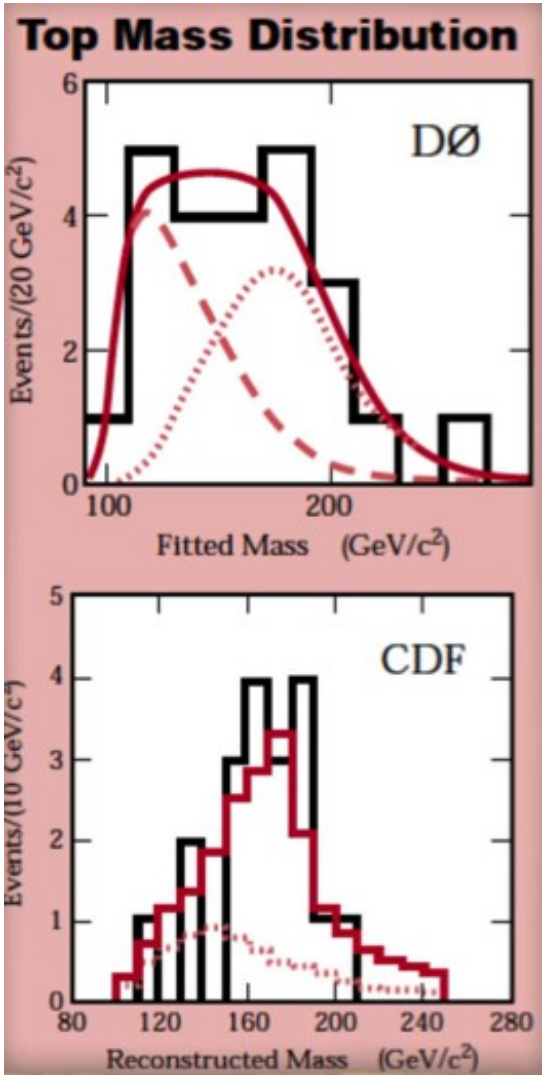
light-blue: fit excluding input from row

- goodness of fit, p-value:
  χ^2_{min}= **17.8** Prob(χ^2_{min}, 14) = **21%**
  Pseudo experiments: 21 ± 2 (theo)%
  - χ^2_{min}(Z widths in 1-loop) = 18.0
  - χ^2_{min}(no theory uncertainties) = 18.2
- no individual value exceeds 3σ
- largest deviations in b-sector:
  - $A^{0,b}_{FB}$ with 2.5σ
    → largest contribution to χ^2
- small pulls for M_H, M_Z
  - input accuracies exceed fit requirements

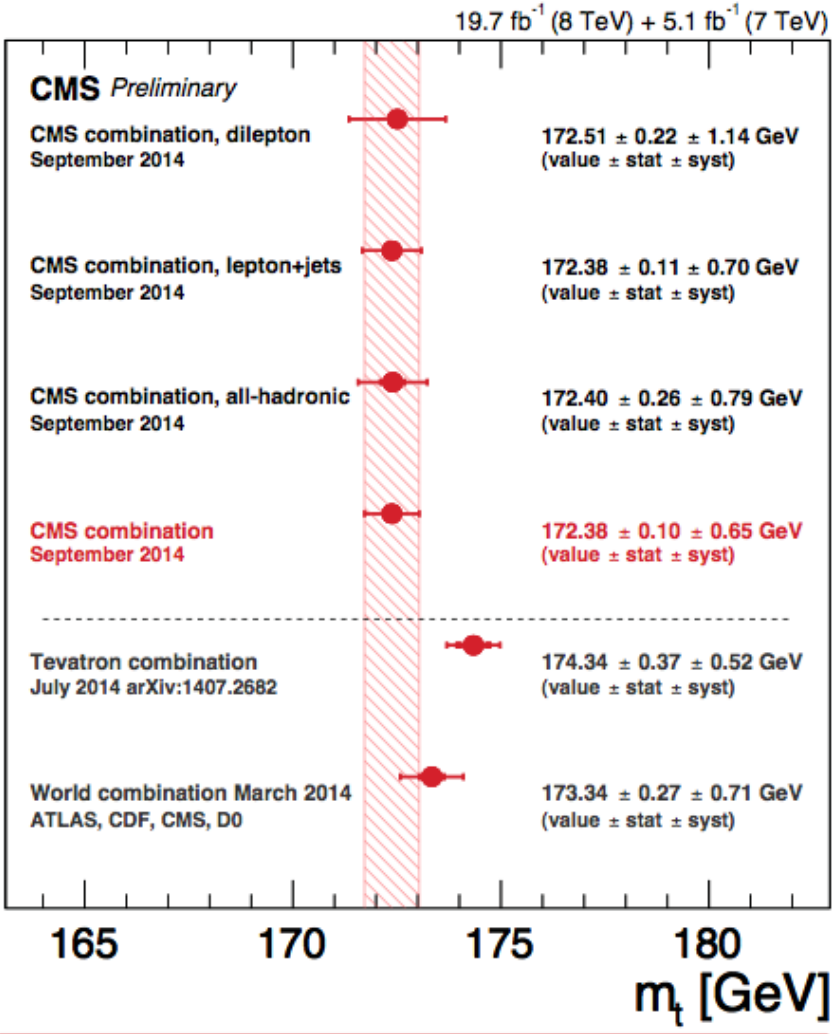


Top Physics Results

- As well as 50th anniversary of Moriond, also celebrated 20th anniversary of Top quark discovery!
  - Treated to a historical overview of the discovery by P. Azzi
  - A. Jung presented latest results from the Tevatron, showing that the interesting work continues 20 years on...
- Two very nice overview talks for LHC experiments
  - Top mass (M. Voutilainen)
  - Top properties (A. Loginov)

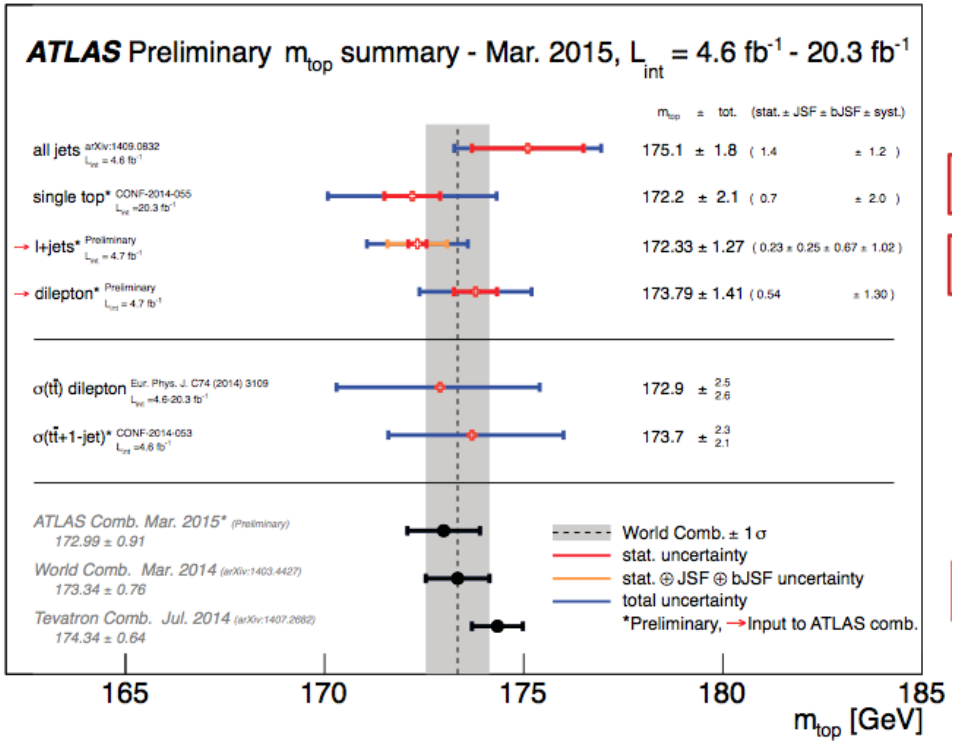


ATLAS+CMS Top mass combinations



$m_t = 172.4 \pm 0.1(\text{stat}) \pm 0.7(\text{syst})$ GeV

CMS-PAS-TOP-14-015 (Sep '14)



$m_t^{cmb} = 173.0 \pm 0.5 \pm 0.8$ GeV

ATLAS-TOPQ-2013-03
(Mar '15)

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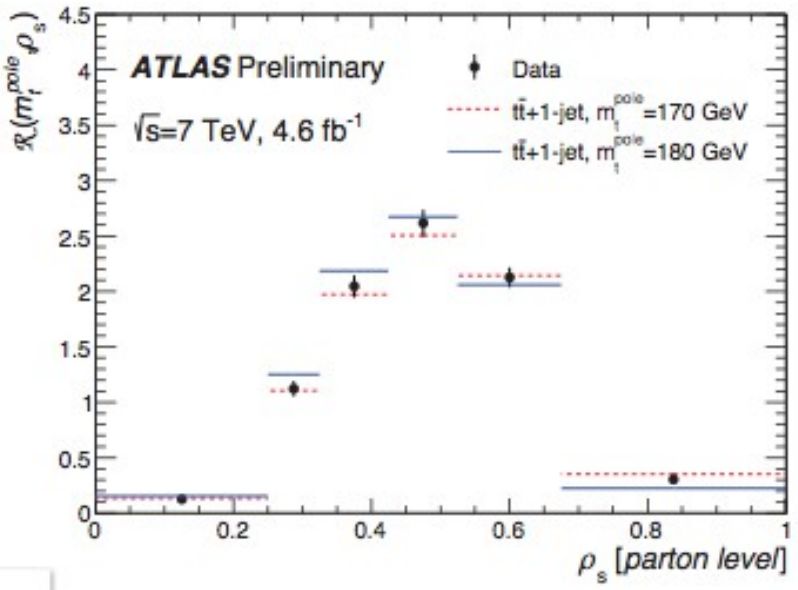
Pole mass measurement

tt+jet differential

- Most precise m_t^{pole} to date
  - Differential tt+jet cross section enhances m_t sensitivity w.r.t. σ_{tt}
- Theoretical calculations at NLO+PS (σ_{tt} NNLO)
  - theory syst.: scale (+0.99, -0.44 GeV)
- Competitive with standard methods
  - experimental syst.: JES (0.94 GeV)
- Limited by statistical uncertainty so will further improve at 8 TeV



$$\mathcal{R}(m_t^{pole}, \rho_s) = \frac{1}{\sigma_{t\bar{t}+1\text{-jet}}} \frac{d\sigma_{t\bar{t}+1\text{-jet}}}{d\rho_s}(m_t^{pole}, \rho_s),$$

$$\rho_s = \frac{2m_0}{\sqrt{s_{t\bar{t}j}}}, \quad m_0 = 170 \text{ GeV (arbitrary)}$$

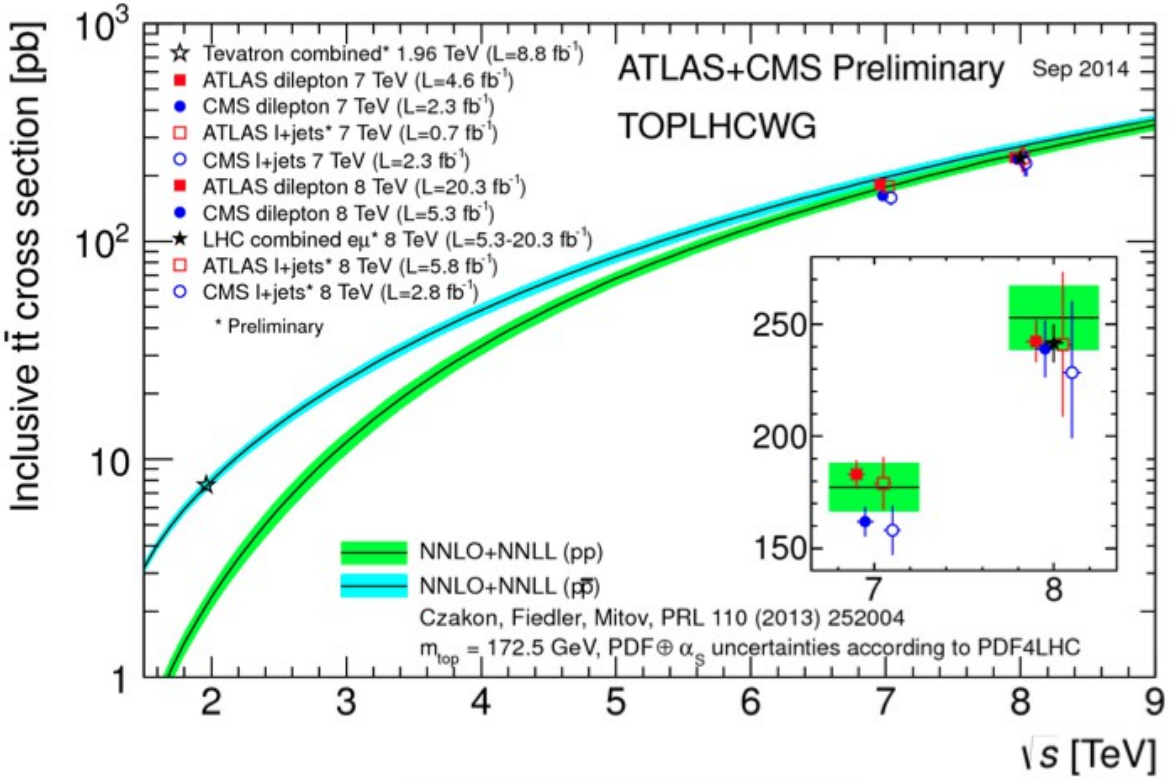
m_t = 173.7 ± 1.5(stat) ± 1.6(syst) GeV

ATLAS-CONF-2014-053 (Sep '14)

Top Pair Production

Top-quark pair production: 2015

- Summary of LHC and Tevatron measurements of top-pair production cross sections

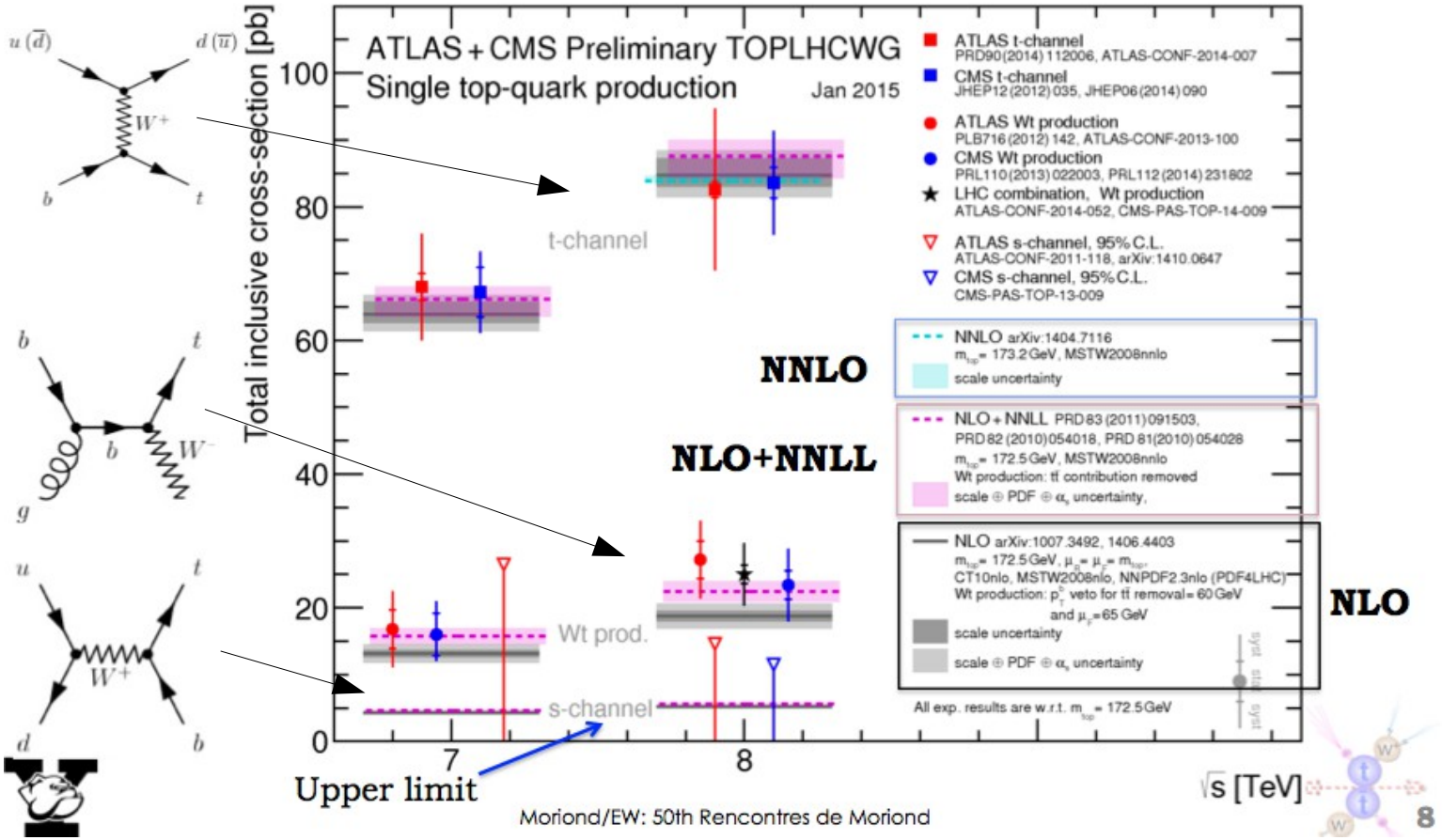


Moriond/EW: 50th Rencontres de Moriond

Single Top Production

Single-top-quark production: Summary

- Different processes sensitive to **different new physics mechanisms**



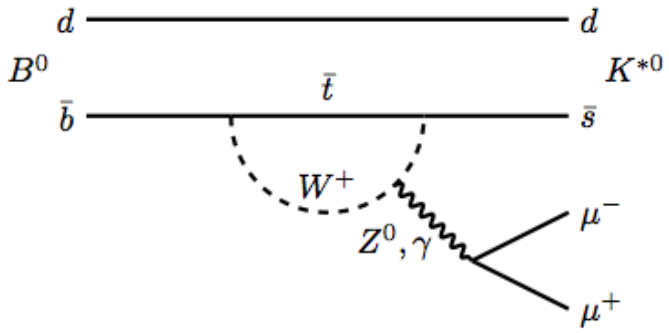
Moriond/EW: 50th Rencontres de Moriond

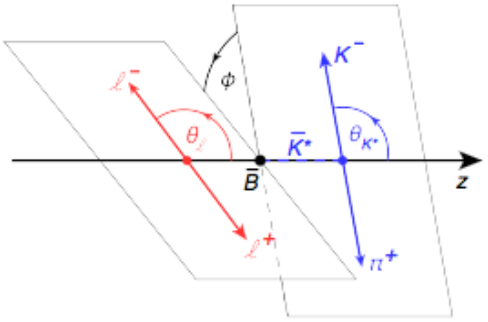
B-Physics Results

- LHCb results were among the most anticipated of the conference
  - Intriguing deviations from SM in rare decays (C. Langenbruch)
  - Interesting tension in CKM matrix element determination (W. Sutcliffe)
- Much interesting Theoretical discussion
  - Can effect be due to larger-than-expected charm-loop contribution?
- Again, many other interesting talks
  - CP Violation in B_s^0 sector (J. Wishahi)
  - Constraint of CKM γ angle (A. Vallier)
  - Search for Mixing and CP Violation in Charm sector (E. Gersabeck)
  - ATLAS +CMS b-physics measurements (P. Ronchese)

P'_5 in $B0 \to K^{*0}\mu^+\mu^-$

Golden decay $B^0 \to K^{*0}[\to K^+\pi^-]\mu^+\mu^-$





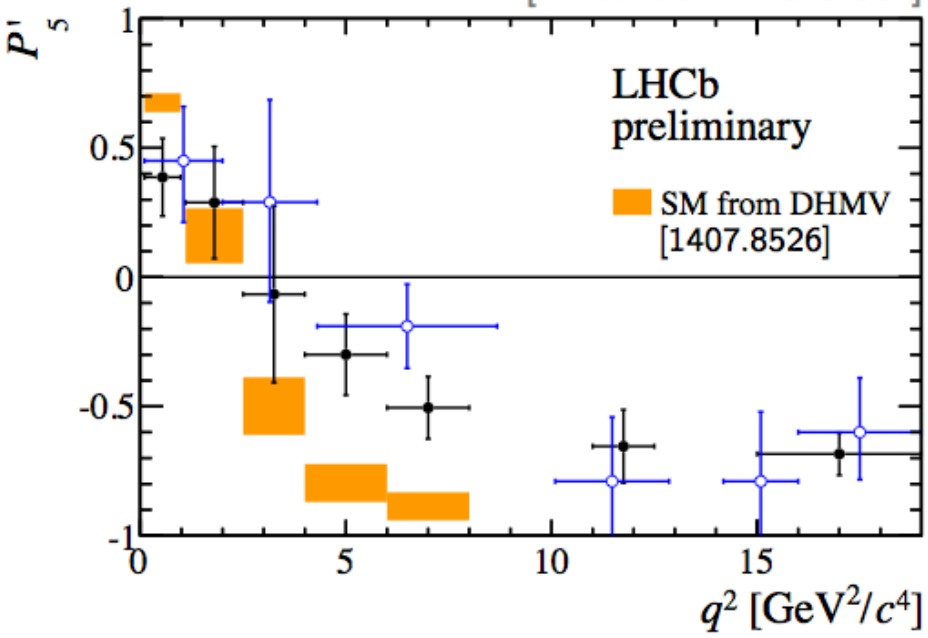
- Decay fully described by three helicity angles $\vec{\Omega} = (\theta_\ell, \theta_K, \phi)$ and $q^2 = m^2_{\mu\mu}$
- $$\frac{1}{\mathrm{d}(\Gamma+\bar{\Gamma})/\mathrm{d}q^2}\frac{\mathrm{d}^3(\Gamma+\bar{\Gamma})}{\mathrm{d}\vec{\Omega}} = \frac{9}{32\pi}\Big[\tfrac{3}{4}(1-F_\mathrm{L})\sin^2\theta_K + F_\mathrm{L}\cos^2\theta_K + \tfrac{1}{4}(1-F_\mathrm{L})\sin^2\theta_K\cos 2\theta_\ell$$
$$- F_\mathrm{L}\cos^2\theta_K\cos 2\theta_\ell + S_3\sin^2\theta_K\sin^2\theta_\ell\cos 2\phi$$
$$+ S_4\sin 2\theta_K\sin 2\theta_\ell\cos\phi + S_5\sin 2\theta_K\sin\theta_\ell\cos\phi$$
$$+ \tfrac{4}{3}A_\mathrm{FB}\sin^2\theta_K\cos\theta_\ell + S_7\sin 2\theta_K\sin\theta_\ell\sin\phi$$
$$+ S_8\sin 2\theta_K\sin 2\theta_\ell\sin\phi + S_9\sin^2\theta_K\sin^2\theta_\ell\sin 2\phi\Big]$$
- $F_\mathrm{L}, A_\mathrm{FB}, S_i$ combinations of K^{*0} spin amplitudes depending on Wilson coefficients $C_7^{(\prime)}$, $C_9^{(\prime)}$, $C_{10}^{(\prime)}$
- Large part of theory uncertainty due to hadronic form-factors

P'_5 in B0 $\rightarrow K^{*0}\mu^+\mu^-$

P'_5

- Less FF dependent observables P'_i introduced in [JHEP 05 (2013) 137]
- For $P'_{4,5} = S_{4,5}/\sqrt{F_L(1-F_L)}$ leading FF uncertainties cancel for all q^2

[LHCb-CONF-2015-002]

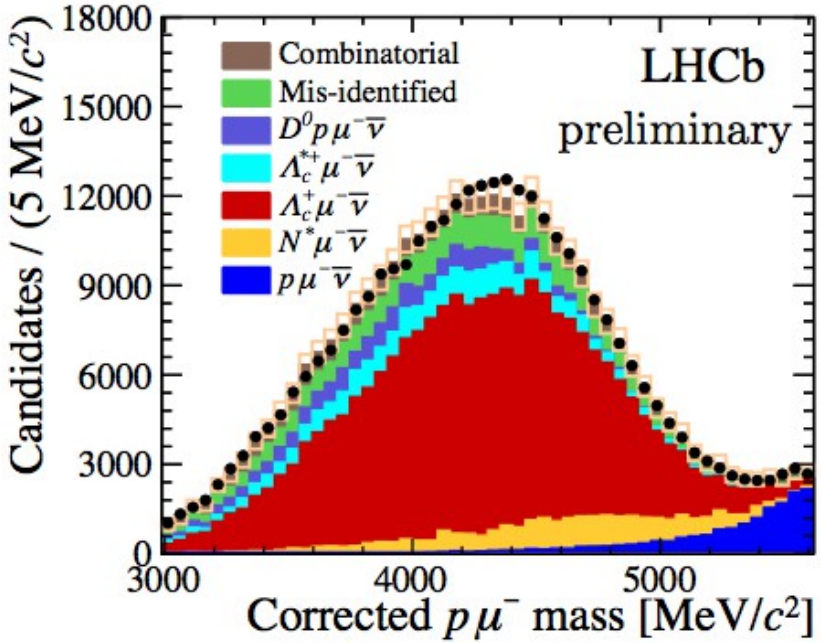


- Tension seen in P'_5 in [PRL 111, 191801 (2013)] confirmed
- $[4.0, 6.0]$ and $[6.0, 8.0]\,\mathrm{GeV}^2/c^4$ show deviations of 2.9σ each
- Naive combination results in a significance of 3.7σ
- Compatible with $1\,\mathrm{fb}^{-1}$ measurement

$|V_{ub}|$ determination from $\Lambda \to p\mu\nu$

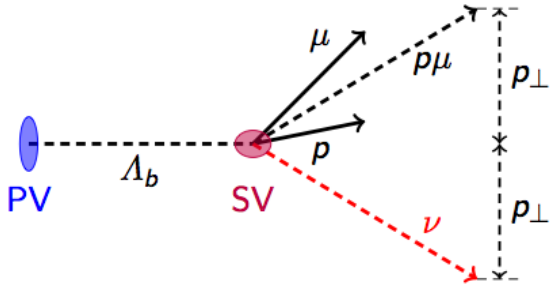
Signal fit

- Fit $p\mu$ corrected mass, $N(\Lambda_b \to p\mu^-\overline{\nu}_\mu) = 17687 \pm 733$.



- Fit the corrected mass:

$$M_{corr} = \sqrt{p_\perp^2 + M_{p\mu}^2} + p_\perp$$



- First observation of the decay $\Lambda_b \to p\mu^-\overline{\nu}_\mu$.

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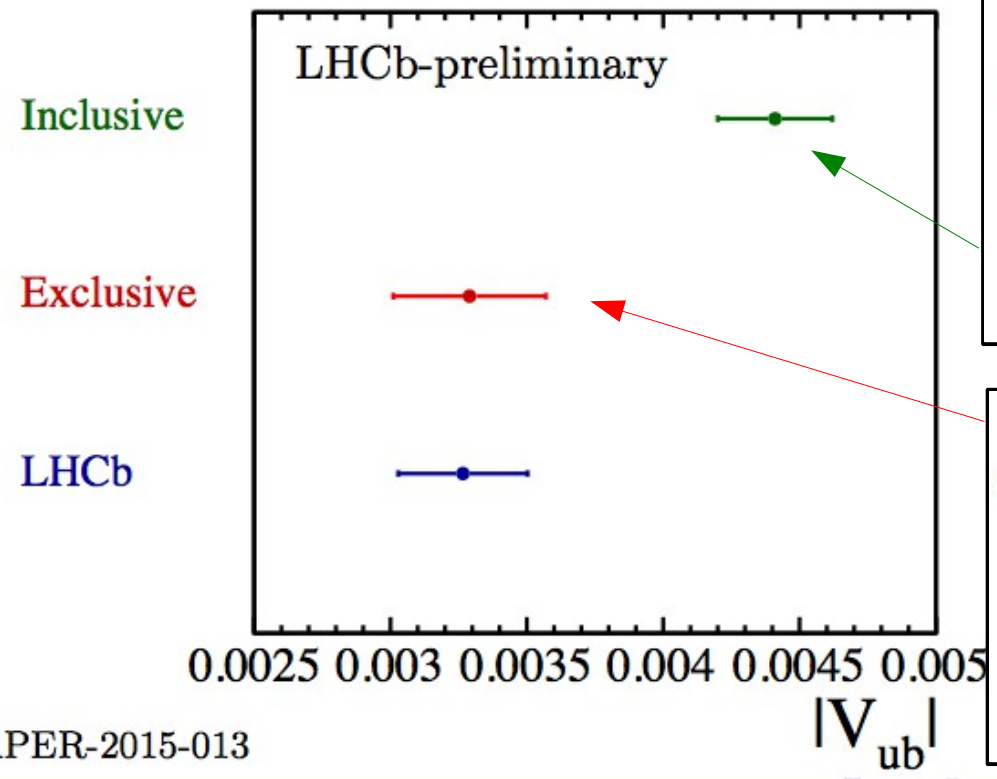
$|V_{ub}|$ determination from $\Lambda \to p\mu\nu$

What can LHCb say?

$$|V_{ub}| = (3.27 \pm 0.15(exp) \pm 0.17(theory) \pm 0.06(|V_{cb}|)) \times 10^{-3}$$



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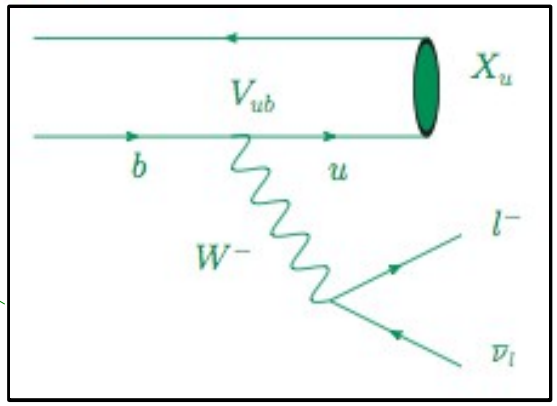

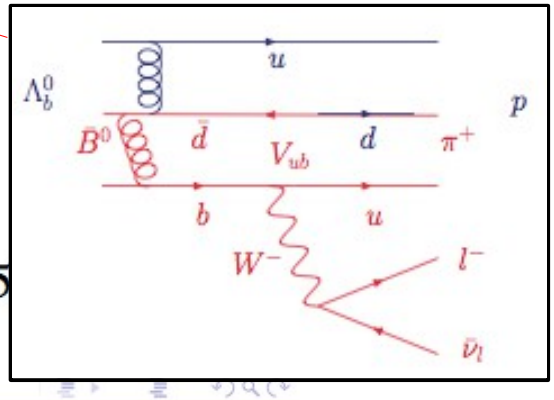

BSM Searches

- Huge number of BSM searches presented
  - Unfortunately no sign of New Physics *YET*
- To quote Terry Wyatt's Experimental Summary:
  - All the 'easy' stuff was done by Moriond 2013! Subsequently: great ingenuity in 'leaving no stone unturned'
- Will show a few searches using interesting techniques
  - presented by H. Hayward and J. Stupak
- See also very interesting and thorough overviews from
  - K. Leney on Exotics
  - S. Majewski on using top quarks for searches at ATLAS
  - R. Bainbridge on 'Compressed' SUSY scenarios with CMS

Meta-stable LLP search using Pixel dE/dX

New!

Using the pixel detector to search for meta-stable LLP

- Search for heavy muon-like particles with β<<1
  - high dE/dx measured from pixel detector
- If particle travels at least 45 cm (in r) can be studied,
  - Little dependence on interactions in calorimeter, muon spectrometer or on LLP decay mode
- Met Trigger, Met> 100 GeV,
- Rejection of muons from W decays
  - M_T> 130 GeV
  - For stable signal region : veto on the track candidate being matched to a reconstructed muon
- Track level (at least one track with):
  - High momentum, isolated track: pT>80 GeV
  - high ionization:
    - dE/dx > 1.800 - 0.034|η| + 0.101|η|² - 0.029|η|³ MeV/g cm⁻²

Event Selection

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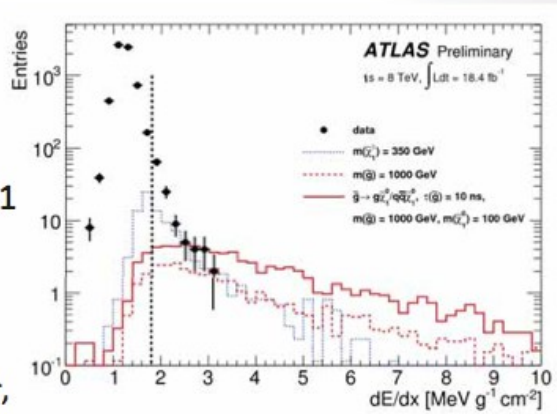
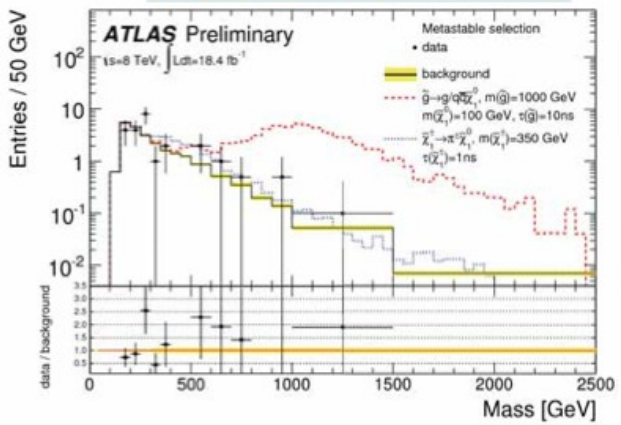
ATLAS-CONF-2015-013



MetaStable Search



Helen Hayward 19/03/2015

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DESY

Z'→tt using boosted topologies

(Extended gauge sectors, colorons, axigluons, pseudoscalar Higgs, extra dimensions)

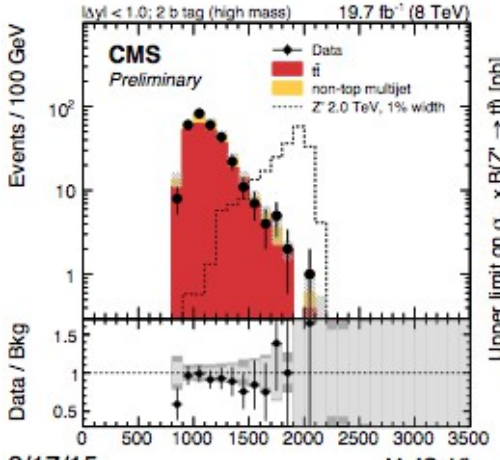
Brand New!

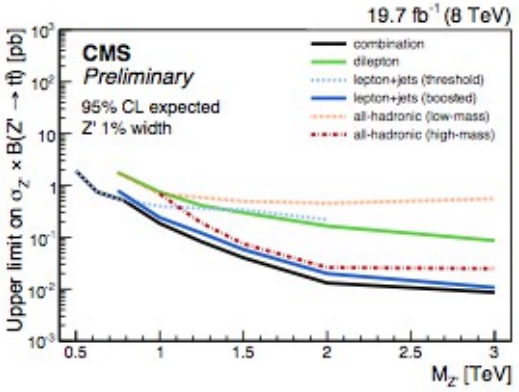
Z′→tt

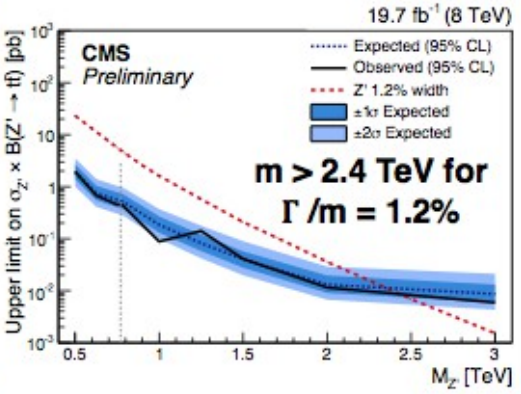
[CMS PAS B2G-13-008]

- Combination of searches for tt resonance in 0,1,2 lepton events
  - Hadronic channel
    - Dijet topology w/ 2 top tags
    - Separate high and low mass optimizations
    - QCD mistag rate measured in data

	Top Tagger	b-tagging	N-subjettiness
Low Mass	HEP (R = 1.5)	sub-jet	
High Mass	CMS (R = 0.8)		$\tau_{32} = \tau_3/\tau_2$







Finally... Run 2 Outlook

- In many presentations, the preparations outlook for Run 2 were discussed
  - To summarise: All physics groups are ready to hit the ground running when first data arrives
  - Everyone extremely excited to see what surprises (hopefully) will appear with the increases in energy and luminosity
- Rather than go through all the Run 2 outlooks...
  - ...lets look forward to the 51st Rencontres de Moriond in 2016 where we will see the results for real