Top mass measurements at CMS and (world) averages

Roberto Chierici
CNRS (IPN Lyon)

On behalf of CMS, the TOPLHCWG and the TeVEWWG

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Contents

Highlight the current CMS top mass measurements(*)

1. short recap of direct measurements
2. emphasis on indirect/alternative measurements

Discuss how we are constraining systematics with tt data

Give the global picture of top mass combinations

In-talk discussion is welcome

DISCLAIMER: I will not cover several of the experimental aspects similar to ATLAS or Tevatron (reconstruction techniques, methodologies, assessment of experimental uncertainties…), to leave more time to results [see Sandra's and Marina's talks]

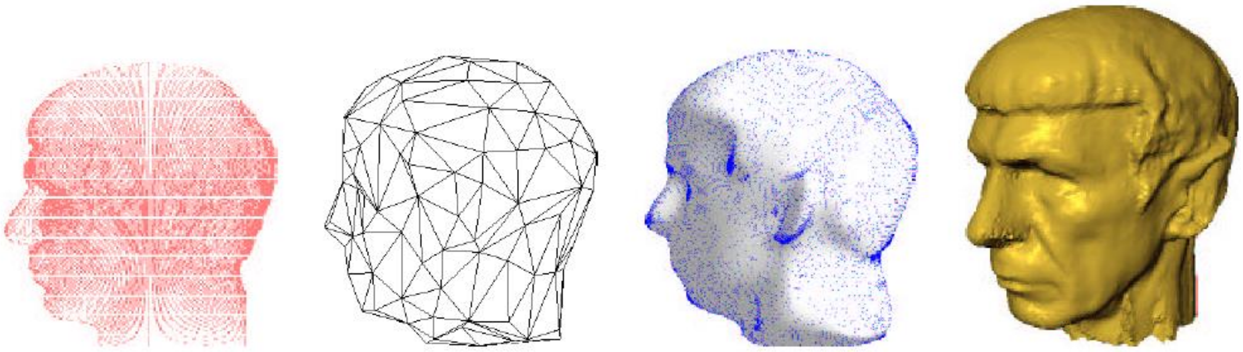
(*) More details here

- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP

Introductory considerations on m_t measurements

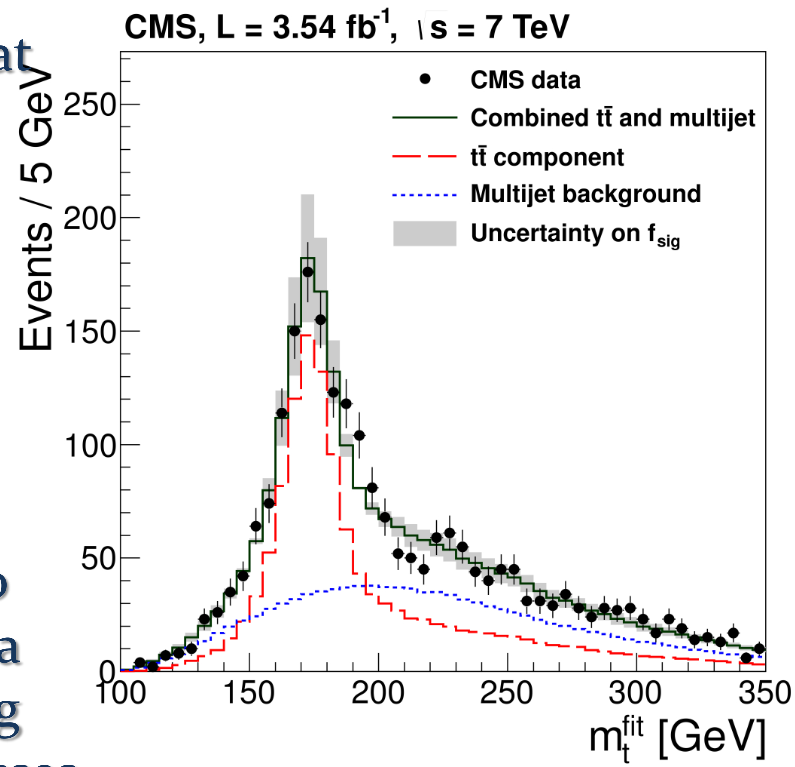
- We are in the domain of systematic uncertainties since a long time now
  - Continuing with standard techniques for determining the top mass will bring progressively less information to our knowledge
- We truly are/will be in a condition of high statistics for top (pair and single) production. This unique opportunity should be exploited in a threefold way:
  - 1) use data to constrain systematic effects whenever possible, with particular emphasis to systematics of theory/modelling origin
  - 2) put in place alternative analyses, not necessarily relying on a direct reconstruction technique. Invent new techniques which can be conceptually uncorrelated to improve the combined errors
  - 3) make measurements in portions of phase space where the influence of systematics is known to be smaller (AKA "we can afford throwing some of our statistics away")
- We should keep collaborating among experiments and theory to get the best out of our data

(QUICK RECAP OF) TOP MASS MEASUREMENTS VIA DIRECT RECONSTRUCTION IN CMS



Direct reconstruction in the fully hadronic channel

- At least four central leading jets with p_T>60, at least two more with p_T>30
  - Two b-tags required
- QCD background determined from data
  - Event mixing in control regions
- Only consider the 6 leading jets in the event: check all combinations 4lights+2heavy jets to form two tops, keep the ones with a χ^2 above a cut from a constrained kinematic fit imposing the W masses and the equality of the top masses



- Ideogram: bi-dimensional maximum likelihood fit to the mass and a jet energy scale factor value for light jets

$$\mathcal{L}\left(\text{sample}|m_t,\text{JSF}\right) = \prod_{\text{events}} \left(f_{\text{sig}} \sum_j f_j P_j(m_t^{\text{fit}}|m_t,\text{JES}) P_j(m_W^{\text{reco}}|m_t,\text{JES}) + (1-f_{\text{sig}}) P_{\text{bkg}}(m_t^{\text{fit}}) P_{\text{bkg}}(m_W^{\text{reco}}) \right)$$

Templates

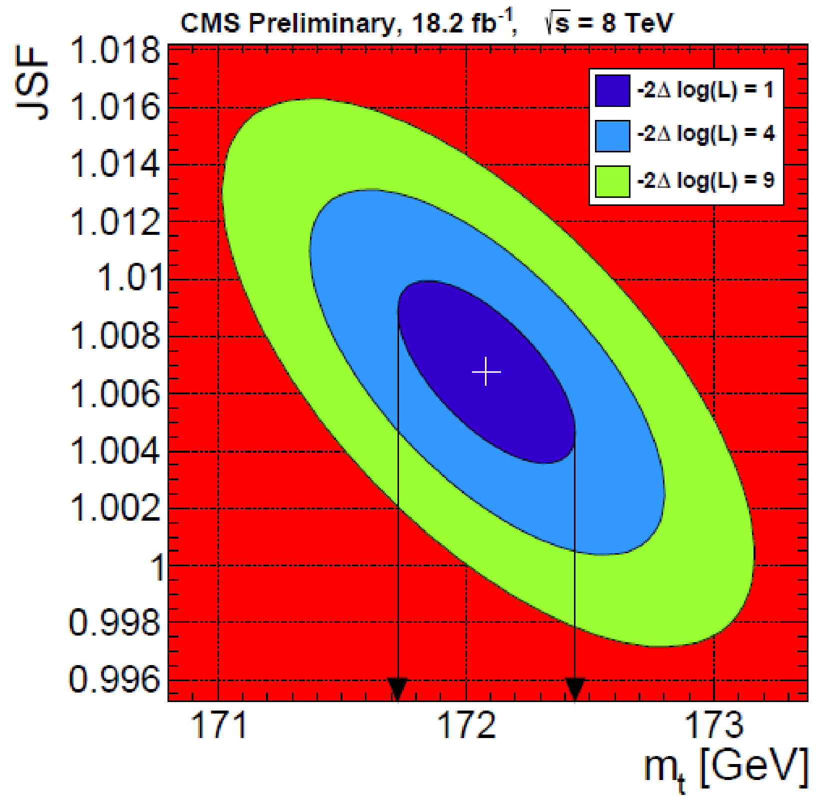
Sum over permutations

Signal fraction

The fully hadronic channel

- Large improvement from the JES constraining via a 2D template fit
  - ➢ The method is calibrated via MCs

Source	Unc. [GeV]	Unc. [GeV]	Unc. [GeV]
JES+PU	0.52	0.97	0.48
bJES+Had	0.80	0.49	0.39
Detector modelling	0.17	0.29	0.21
Signal modelling	0.51	0.46	0.52
Background	0.35	0.13	0.22
Method	0.42	0.13	0.06
Syst.	1.22	1.23	0.86
Stat.	1.40	0.69	0.27
Total	1.86	1.41	0.90



ATLAS@7TeV

m_t = 175.1 ± 1.9 GeV (1.06%)

arXiv:1409.0832

CMS@7TeV

m_t = 173.49 ± 1.41 GeV (0.81%)

Eur. Phys. C74 (2014) 2758

Tighter selection

Better resolution

CMS@8TeV

m_t = 172.08 ± 0.90 GeV (0.53%)

CMS-PAS-TOP-14-002

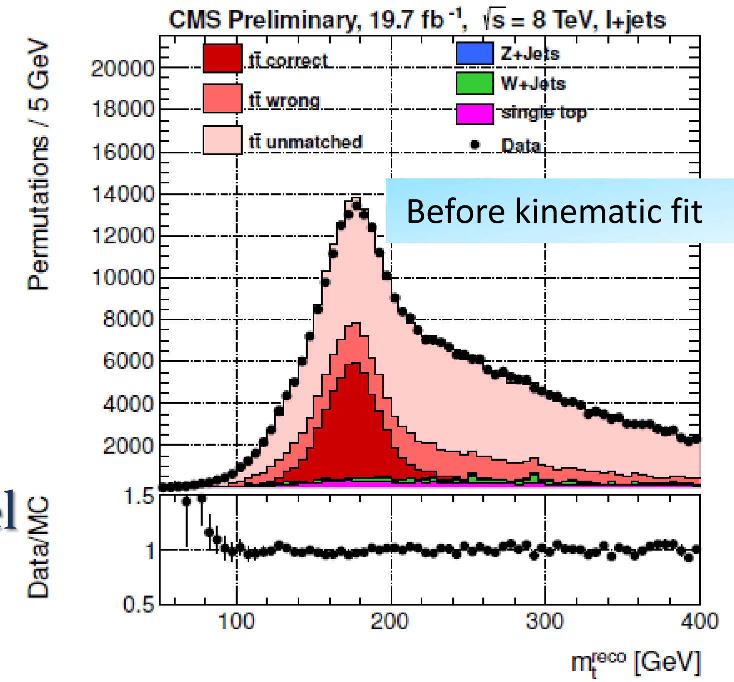
2D fit with JES

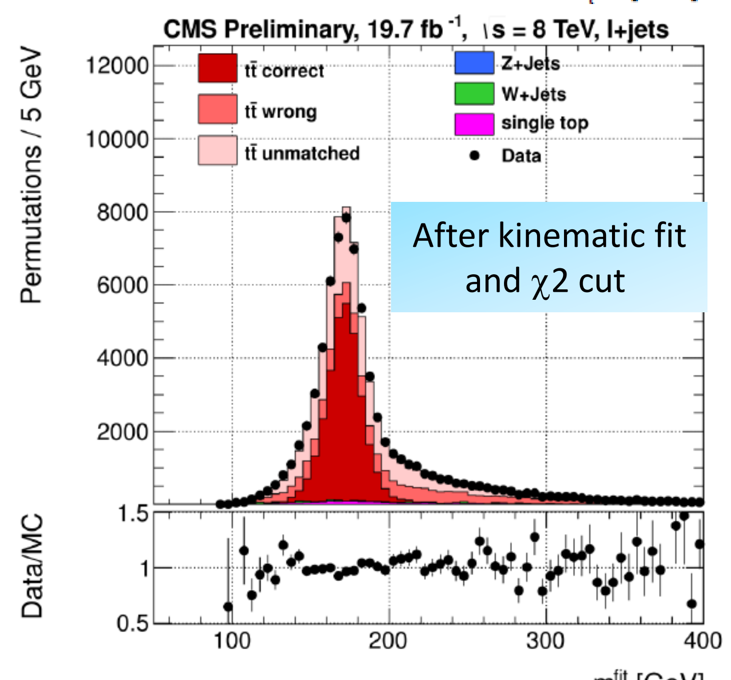
JSF = 1.007 ± 0.011

Larger statistics

Direct reconstruction in the semileptonic channel

- One isolated lepton and at least four central leading jets with p_T>30, of which two are b-tagged
- Analysis strategy similar to the hadronic channel
- Only consider the 4 leading jets in the event: check the two possible combinations of 2lights+2heavy jets to form two tops. Keep the combinations giving the best χ^2 after a constrained kinematic fit imposing the W masses and the equality of the two top masses
- The fitting (and calibration) procedure is there analogous to the fully hadronic channel
    - ➢ Light JES constrained in situ

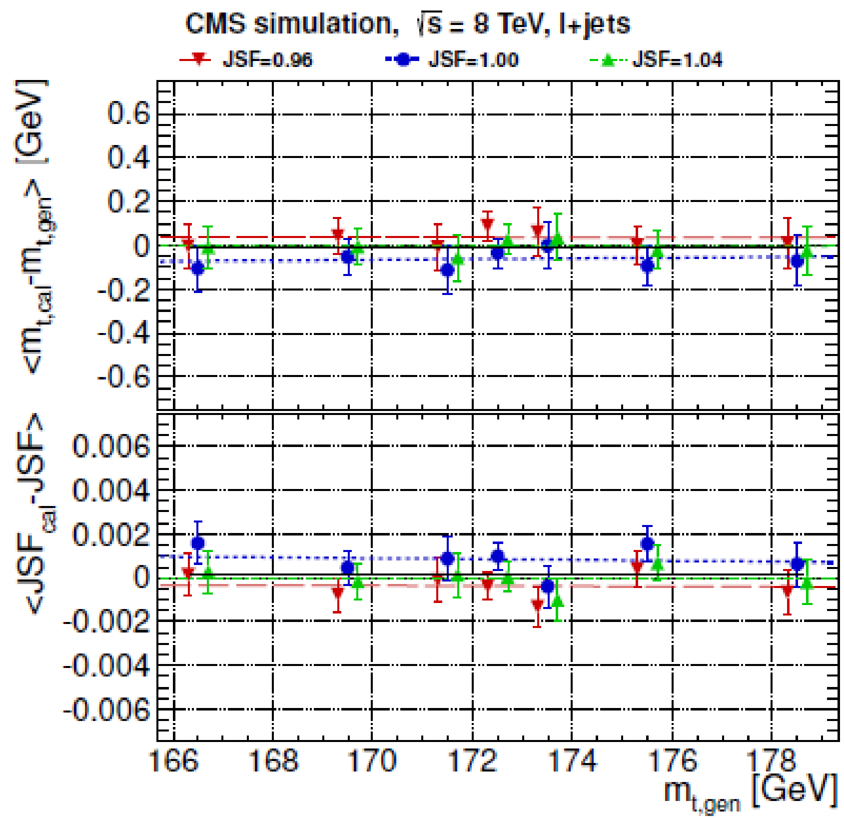




28750 events

The semi-leptonic channel

- Calibration performed is also performed as in the hadronic channel



Source	Unc. [GeV]	Unc. [GeV]	Unc. [GeV]
JES+PU+JSF	0.83	0.43	0.36
bJES+Had+bJSF	0.73	0.61	0.44
Detector modelling	0.84	0.27	0.28
Signal modelling	0.62	0.64	0.39
Background	0.10	0.13	0.11
Method	0.13	0.06	0.10
Syst.	1.53	1.03	0.76
Stat. (m_t only)	0.23	0.27	0.11
Total	1.55	1.06	0.77

ATLAS-CONF-2013-046

ATLAS@7TeV

m_t = 172.31 ± 1.55 GeV (0.90%)

JSF = 1.014 ± 0.021; bJSF = 1.006 ± 0.022

Superseeded by a new measurement with an uncertainty of 0.7%

CMS@7TeV

m_t = 173.49 ± 1.06 GeV (0.61%)

JSF = 0.994 ± 0.009

JHEP 12 (2012) 105

Use all jet permutations

CMS@8TeV

m_t = 172.04 ± 0.77 GeV (0.45%)

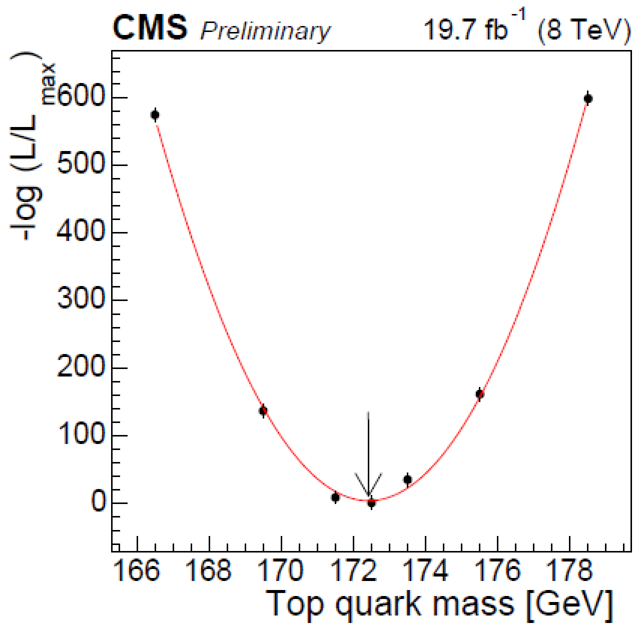
CMS-PAS-TOP-14-001 JSF = 1.007 ± 0.012

Larger dataset and MC

Refined treatment of hadronisation and bJES

Direct reconstruction in the fully leptonic channel

- Two isolated, opposite charge leptons in the event
- At least two jets with p_T>30, one b-tag. Top candidates from the two mostly b-tagged jet in the event
- Weigh analytical solutions function of m_t for the νs
- Small background under control with data



Source	Unc. [GeV]	Unc. [GeV]	Unc. [GeV]	Unc. [GeV]
JES+PU	0.88	0.98	0.69	0.43
bJES+Had	0.84	0.76	0.69	0.72
Detector modelling	0.52	0.25	0.17	0.31
Signal modelling	0.67	0.61	0.99	0.99
Background	0.14	0.05	0.02	0.12
Method	0.07	0.40	0.03	0.07
Syst.	1.49	1.46	1.40	1.29
Stat.	0.64	0.43	0.17	0.32
Total	1.62	1.52	1.41	1.33

ATLAS@7TeV

m_t = 173.09 ± 1.62 GeV (0.94%)

ATLAS-CONF-2013-077 Fit to m(ℓb)

Superseeded by a new measurement with an uncertainty of 0.8%

CMS@7TeV

m_t = 172.50 ± 1.52 GeV (0.88%)

EPJC72 (2012) 2202

Weighting technique

CMS@8TeV

m_t = 172.47 ± 1.41 GeV (0.81%)

CMS-PAS-TOP-14-010 Weighting technique

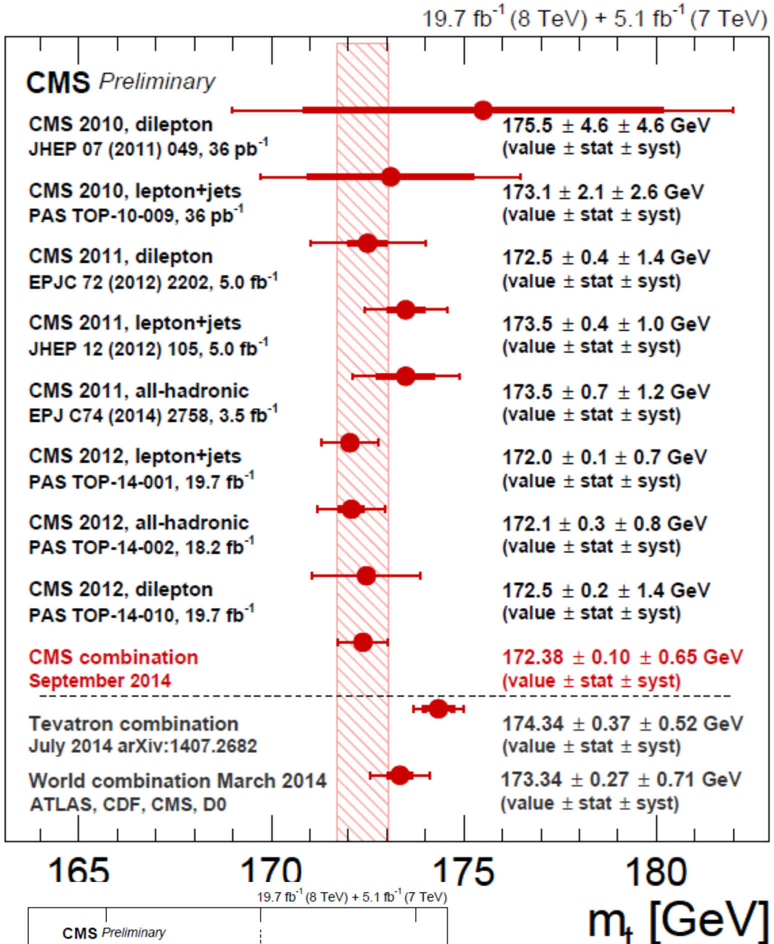
m_t = 172.3 ± 1.33 GeV (0.77%)

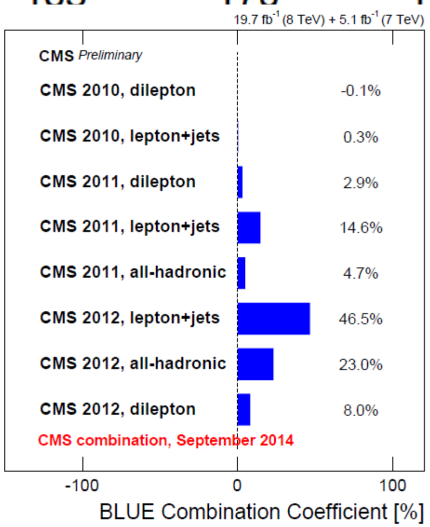
CMS-PAS-TOP-14-014 Fit to m(ℓb)

CMS combination

CMS PAS TOP-14-015

- Make sure to combine only consistent measurements
  - ➢ Only direct reconstruction techniques used





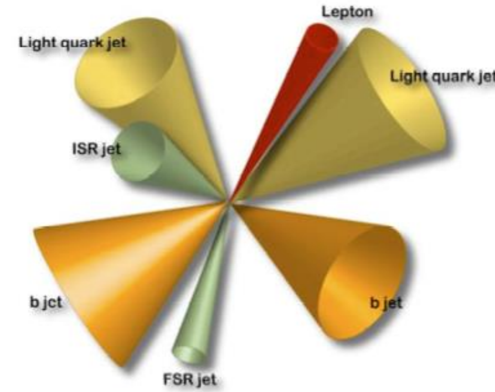
	Correlations ρ_{year}	Correlations ρ_{chan}	Combined uncertainty
Experimental uncertainties			
In-situ JSF factor	0	0	0.10
Inter-calibration JES component	1	1	0.01
MPF *in-situ* JES component	1	1	0.05
Uncorrelated JES component	0	1	0.14
Other JES uncertainties	0	0	0.00
Lepton energy scale	1	1	0.02
$E_{\mathrm{T}}^{\mathrm{miss}}$ scale	1	1	0.06
Jet energy resolution	1	1	0.17
b-tagging	1	1	0.03
Trigger	0	0	0.04
MHI(Pileup)	0	1	0.20
Background Data	0	0	0.05
Background MC	1	1	0.07
Fit calibration	0	0	0.05
Modeling of hadronization			
Flavor JES component	1	1	0.05
Flavor-dependent hadronization uncertainty	1	1	0.36
b fragmentation and B branching fractions	1	1	0.14
Modeling of the hard scattering process and radiation			
Parton distribution functions	1	1	0.06
Renormalization and factorization scales	1	1	0.17
ME-PS matching threshold	1	1	0.16
ME generator	1	1	0.13
Top quark p_T	1	1	0.12
Modeling of non-perturbative QCD			
Underlying event	1	1	0.16
Color reconnection	1	1	0.18
Statistical uncertainty			0.10
Total systematic uncertainty			0.65
Total uncertainty			0.65

$$m_{\mathrm{t}} = 172.38 \pm 0.10\,(\text{stat.}) \pm 0.65\,(\text{syst.})\ \text{GeV}$$

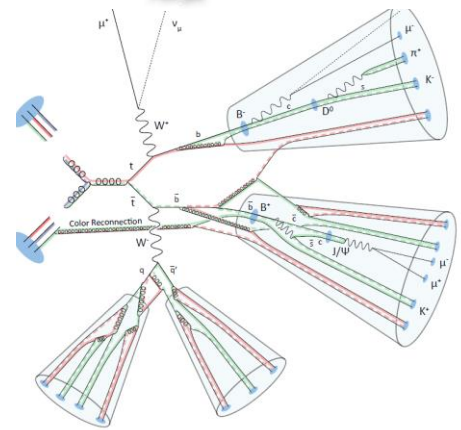
TOP PAIRS FOR CONSTRAINING SYSTEMATIC UNCERTAINTIES

m_t modelling systematics(*)

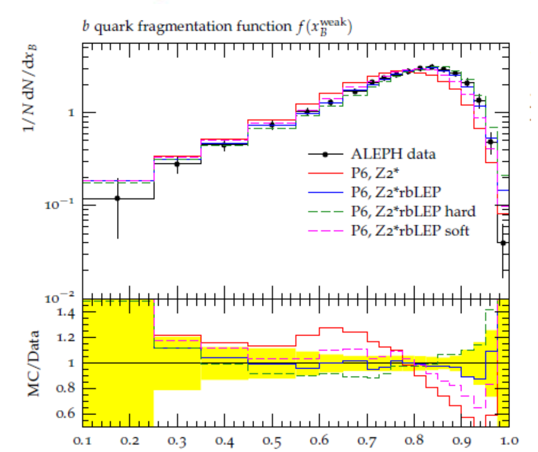
- **Radiation:** at the LHC top quark are often produced with extra jets from the initial (or final) state
  - ➢ Higher energy, gluons from initial state (more colour)
  - ➢ About half of the event with an extra jet with p_T >50 GeV!
  - ➢ Impact on jet pairing, systematic errors due to radiation description in MC can be dominant



- **Colour connection:** the issue of the decay of an unstable coloured particle before hadronization
  - ➢ One of the decay products is connected to the rest of the event. In MCs the effect is driven by shower evolution and the specific connection model, steered by parameters.
  - ➢ Impact on different soft particle/jet emission between jets and mass reconstruction via the decay products



- **Fragmentation function/model** of the b quark
  - ➢ Impact on analyses exploiting (semi)exclusive b decays
  - ➢ Blindly use LEP/SLD tunes for now

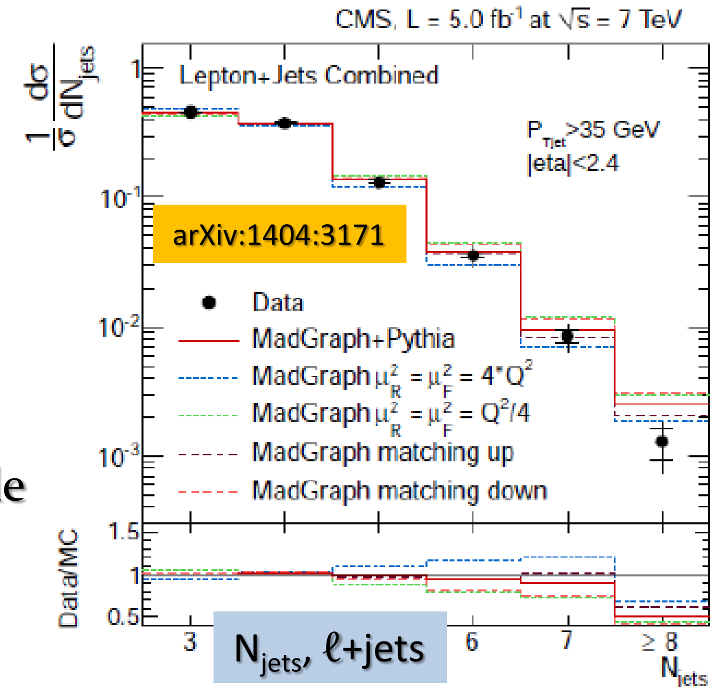


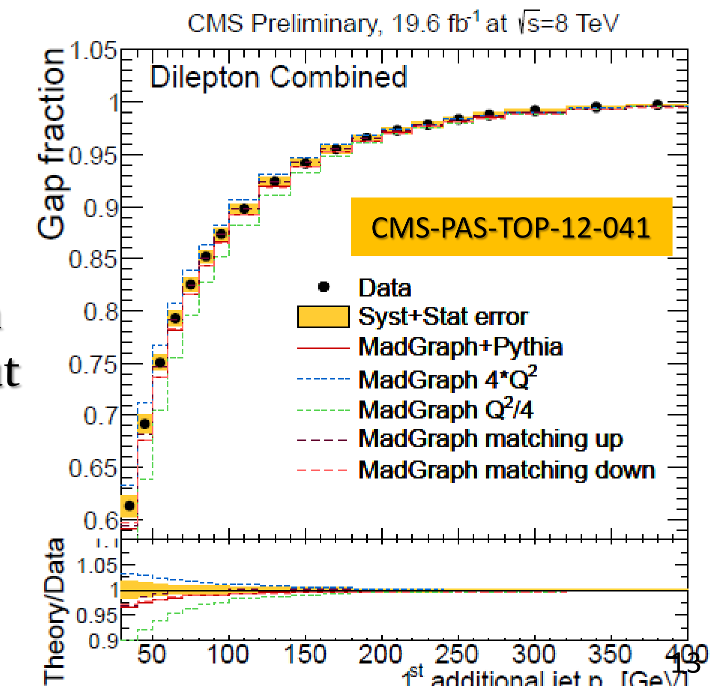
ALEPH data: arXiv:hep-ex/0106051

(*) Non exhaustive list, but most important modelling systematic sources for top mass reconstruction. CMS approaches used, ATLAS have similar techniques.

Constraining radiation

- Use observables which are maximally sensitive to radiation to constrain Monte Carlos
  - In MCs: change by a factor two the renormalization and factorization scales in the ME MC. Shower emission scale in the PS is changed accordingly. Also vary the matching scale for multi-leg generators
- Inclusive jet multiplicity
  - Consistent agreement across channels and energies
- Jet gap fraction
  - Fraction of events that do not have a jet emission (in a defined angular range) above a certain p_T cut
  - TH uncertainties typically bracket the data. Central CMS tuning also describes well ATLAS data
  - CMS data able to exclude extreme variations

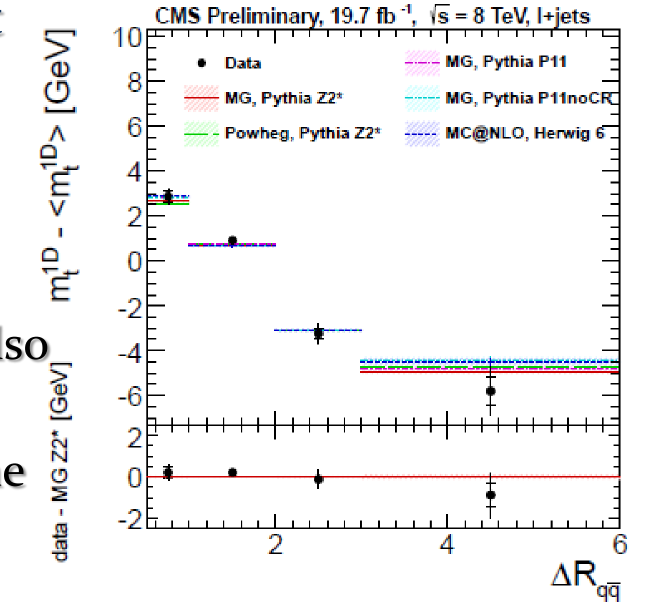


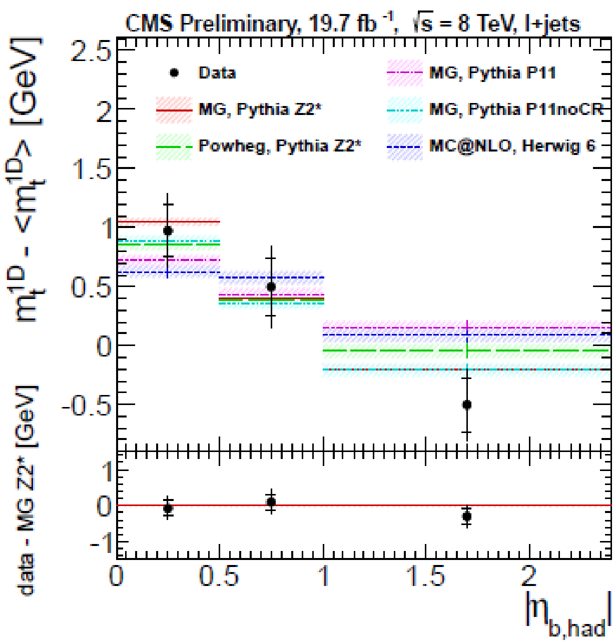


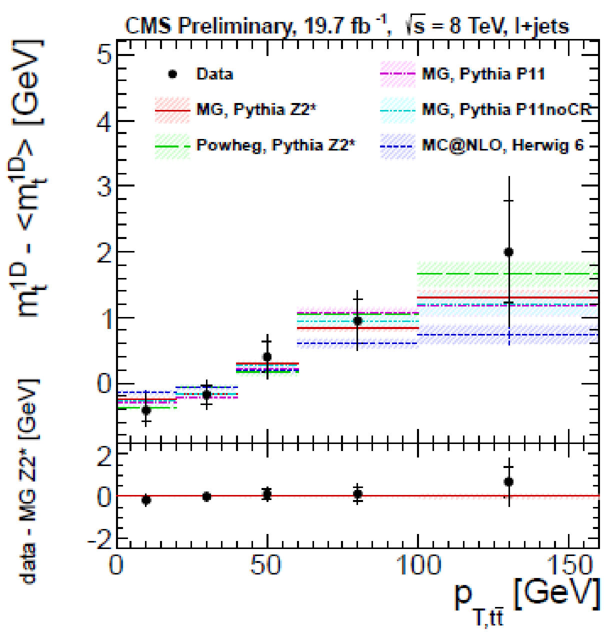
Reconstructed top mass as a function of kinematics

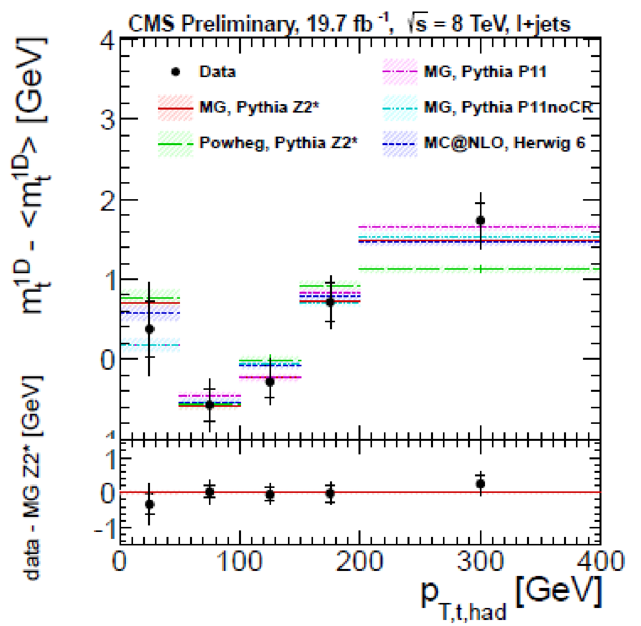
CMS-PAS-TOP-14-001

- CMS expands the top mass reference measurement as a function of ΔR_{qq}, η_b, $p_T(t)$, $p_T(tt)$. Check observables sensitive to radiation and CR effects
  - ➢ Use semileptonic events and choose the two best jet permutations after a kinematic fit.
  - ➢ The 1D mass determination are shown. Agreement also for the 2D analyses
  - ➢ Data not sufficient yet for a discrimination among the models (also agreeing among each other)





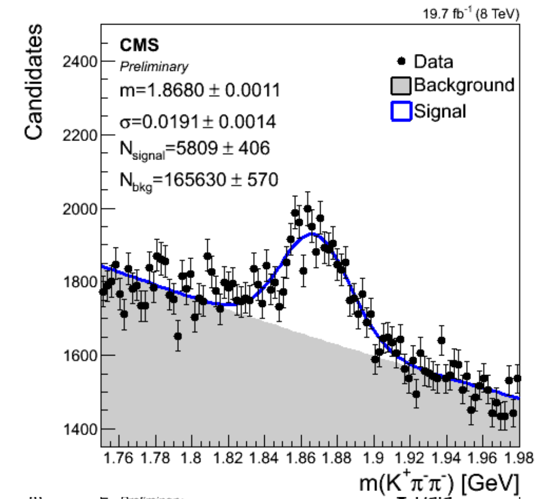


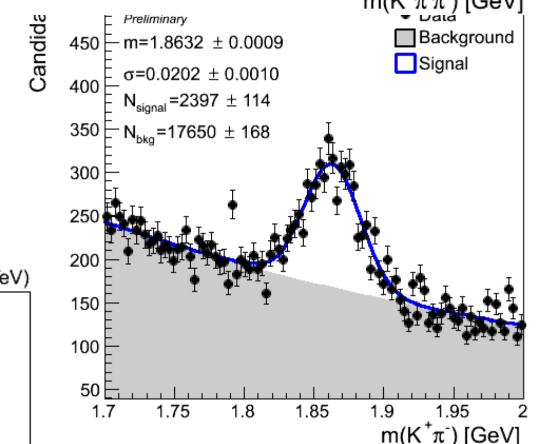


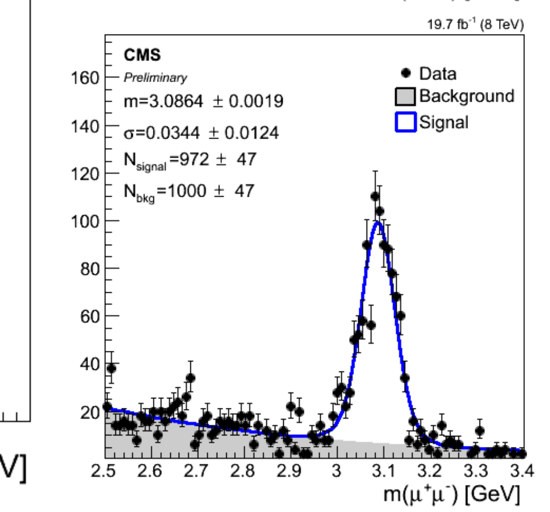
A closer look to b fragmentation

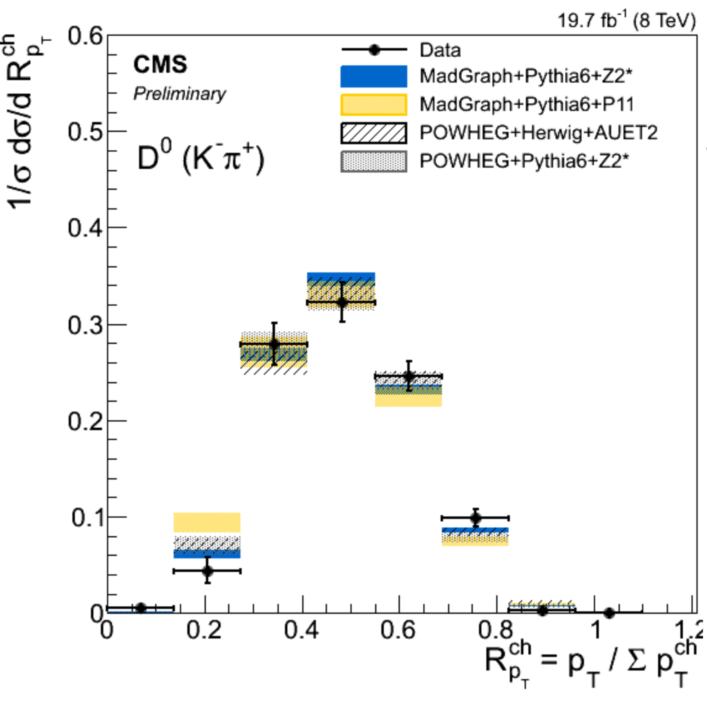
CMS PAS TOP-13-007

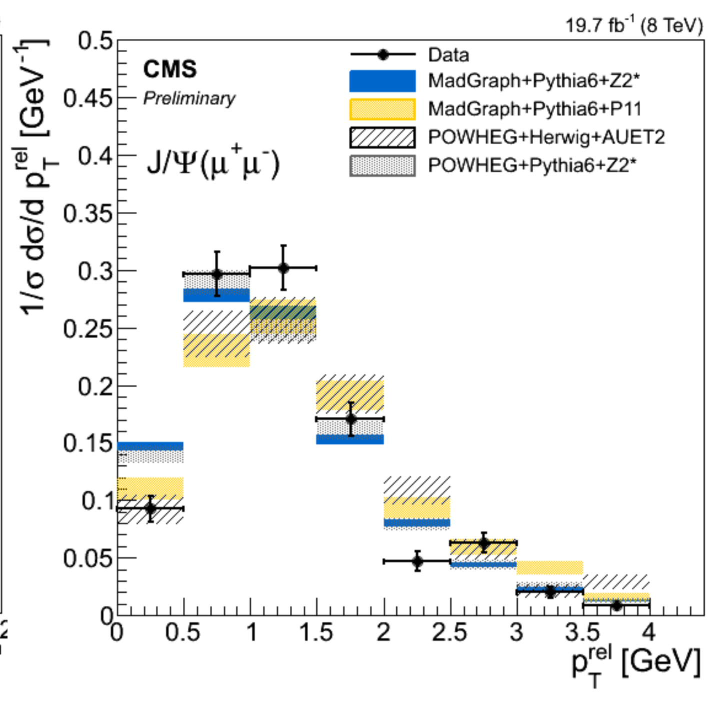
- We have so much statistics that we can envisage a bottom physics program by using only top pair events
- In situ constraining of b fragmentation may be possible
  - ➢ Exclusive decays can be reconstructed
  - ➢ Work ongoing in finding the best variables helping in testing and constraining the b fragmentation



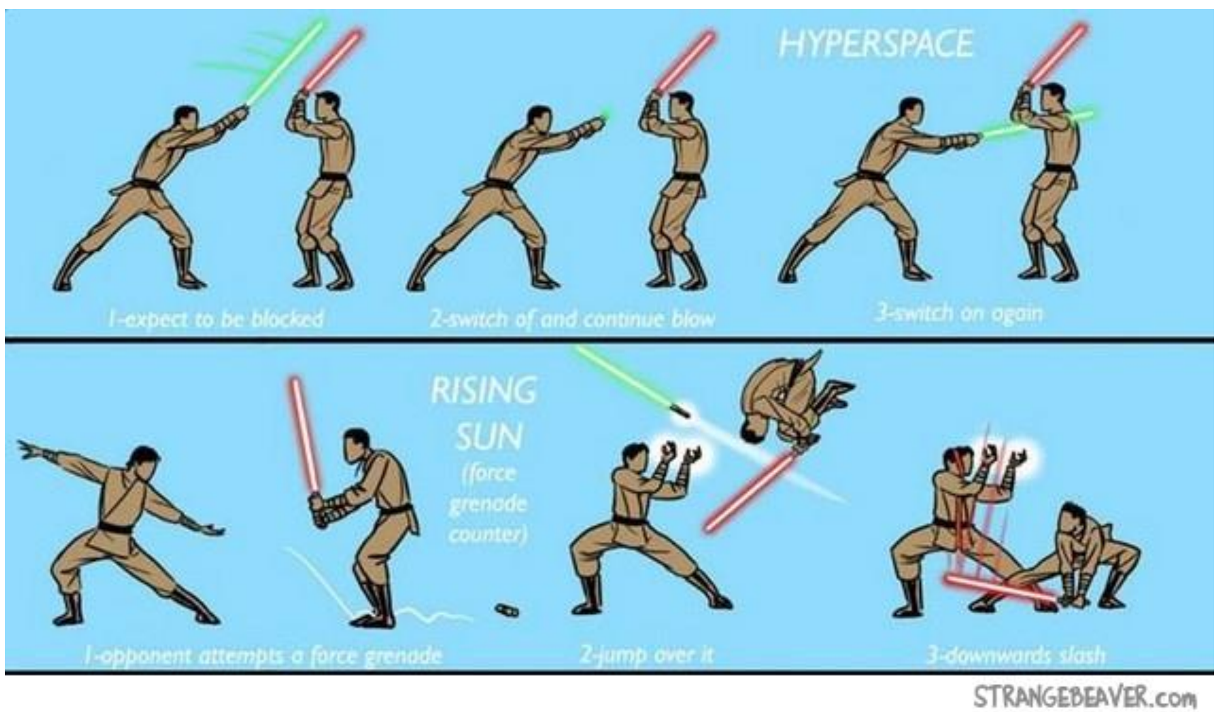








TOP MASS: ALTERNATIVE TECHNIQUES IN CMS



Why bother?

- Precision measurements can become an increasingly important task at the LHC RunII. Maybe the only available task at all.

- Issue #1 for m_t: the classical measurements are dominated by systematic errors
  - Most of which are fully correlated across channels, methods and experiments (even at different accelerators)

- Issue #2 for m_t: connect convincingly what experimentalists measure/infer with what should enter the fits to the SM (a properly defined short distance mass)

- It becomes essential to perform and envisage alternative measurements of the top mass, and attack both issues whenever possible:
  - Reduce the total error by combining estimators of the top mass which present as much as possible uncorrelated systematic uncertainties
  - Construct analyses that are explicitly sensitive to the top pole mass (see also Marina's talk)

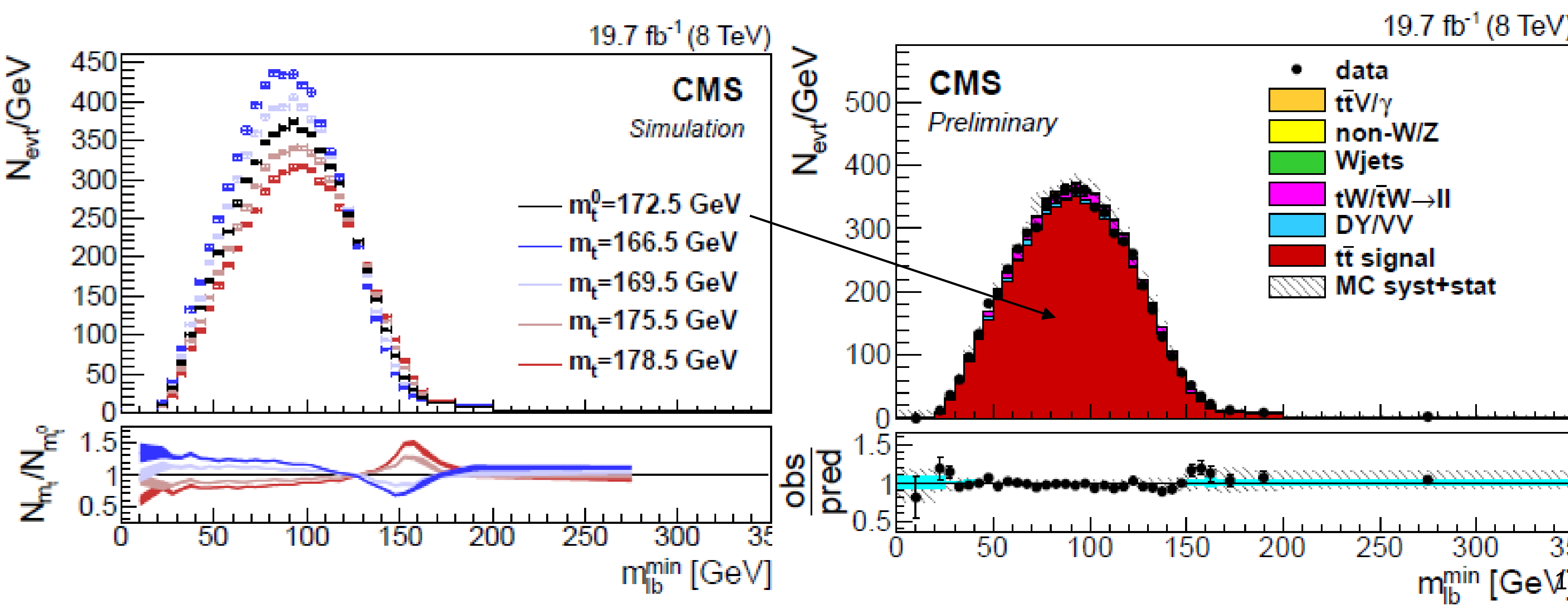
The $m_{\ell b}$ method

CMS PAS TOP-14-014

- Look for visible masses (as $m_{\ell b}$) as proxies of the top mass.

$$m_{lb}^2 = \frac{m_t^2 - m_W^2}{2}(1 - \cos\theta_{lb})$$

- Use fully leptonic eμ events to favour a very “clean” environment
  - By choosing the highest p_T b-jet and taking only the pairing minimizing $m_{\ell b}$ the correct combination is found 85% of the time
  - Perform a χ^2 fit to the shape of the $m_{\ell b}$ distribution



The $m_{\ell b}$ method

- Experimental systematic uncertainties dominated by radiation (±0.6 GeV), b-fragmentation (±0.6 GeV) and the description of the top p_T. (±0.7 GeV)

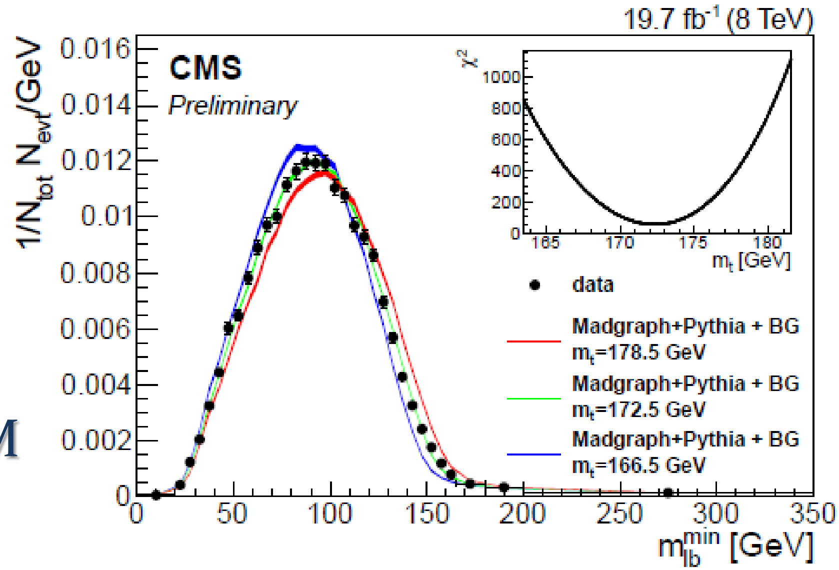
$$\boxed{m_t = 172.3 \pm 1.3 \text{ GeV}}$$

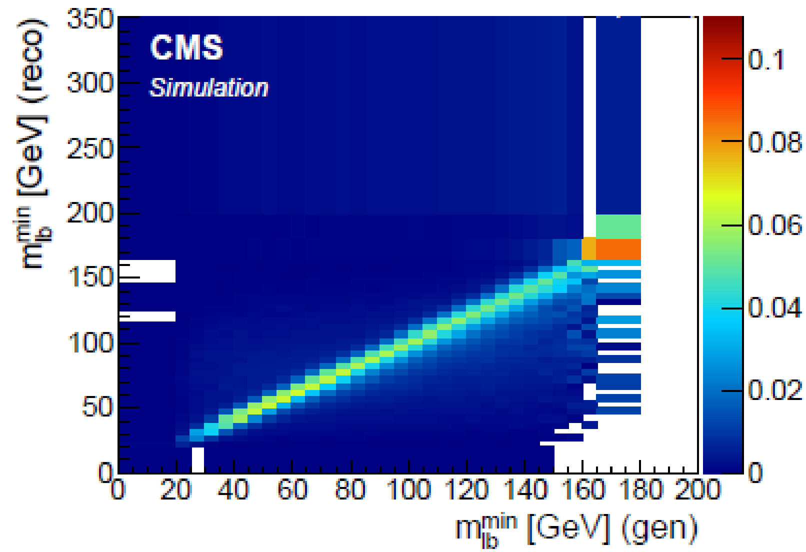
- Can also compare data directly with MCFM (NLO only in production) after a detector folding by using a response matrix
  - Use phase space definition matching the one used in the analysis

- Directly compare distributions with the pole mass

- TH uncertainties now derived on MCFM: scales, PDFs, value of the b mass.

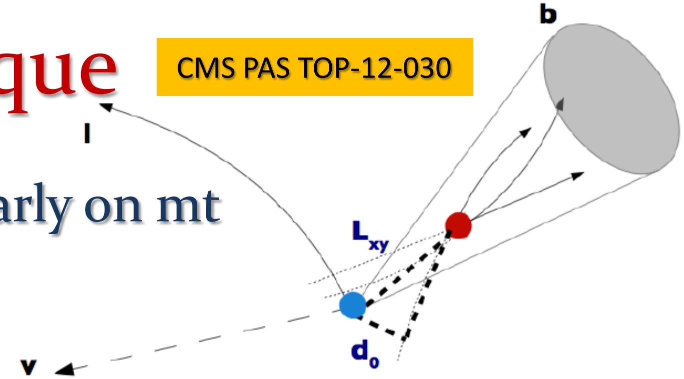
$$\boxed{m_t = 171.4\ ^{+1.0}_{-1.1} \text{ GeV}}$$





The B hadron lifetime technique

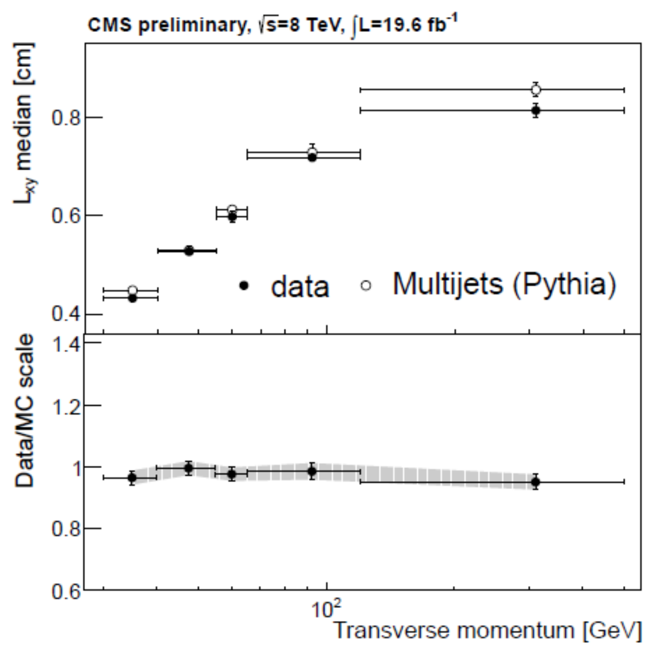
CMS PAS TOP-12-030

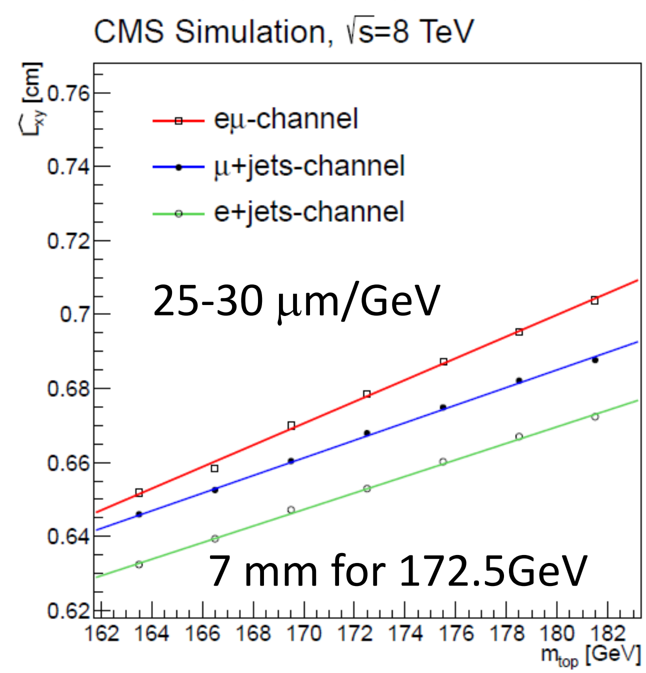


- The relativistic boost of the b quark depends linearly on mt
  - ➢ Get rid of the energy scale uncertainties in the jet
- Semileptonic and dilepton final states are used

$$L_{xy} = \gamma_b \beta_B \tau_B \approx 0.4 \cdot \frac{m_t}{m_B} \beta_B \tau_B$$

- In each selected event, the secondary vertex with largest Lxy is chosen, and the median of the distribution of these Lxy is used to extract mt
- Important to subtract the backgrounds by using data driven distributions from control regions
  - ➢ Lxy reconstruction tested on bb events (tight b tag on one side), excellent agreement DT/MC in all the p_T range



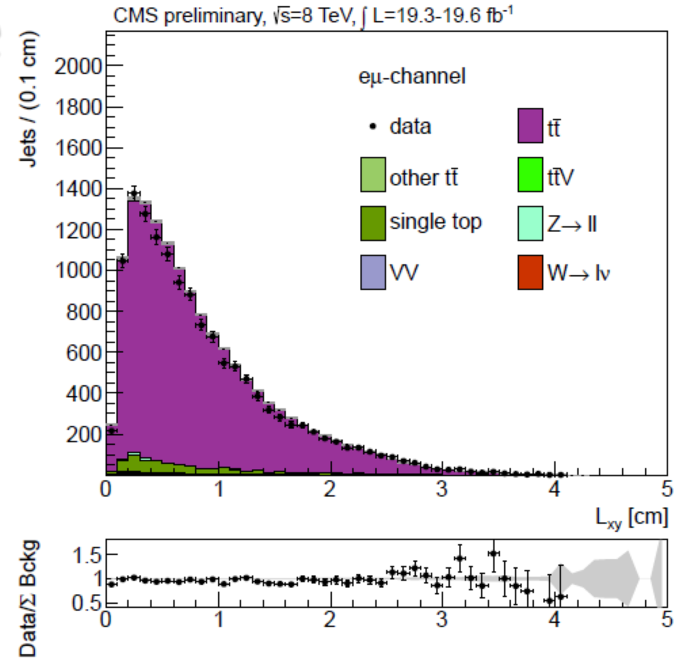


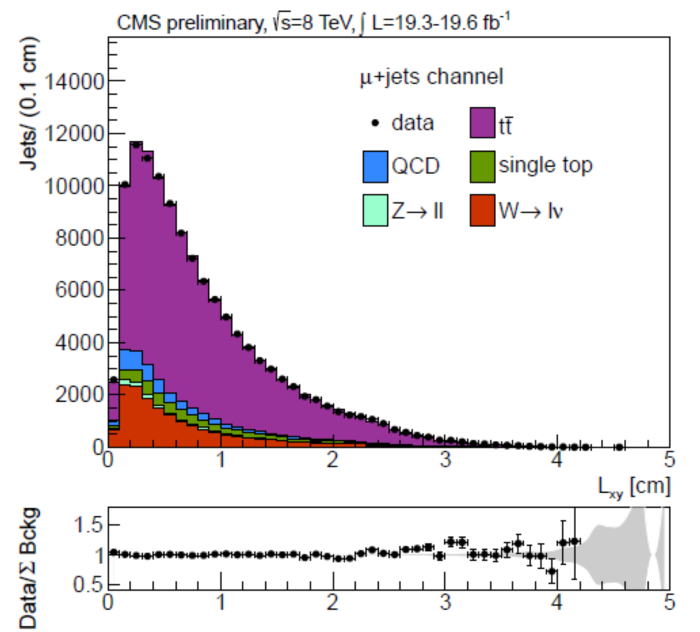
The B hadron lifetime technique

- The analysis is calibrated on MC
- The dominant systematic uncertainties are expected to come from hadronisation
- Conservative approach to also quote all difference MC/DT on the top p_T as extra systematic error

Source		Δm_t[GeV]		
		μ+jets	e+jets	$e\mu$
Statistical		1.0	1.0	2.0
Experimental	Jet energy scale	0.30 ± 0.01	0.30 ± 0.01	0.30 ± 0.01
	Multijet normalization (ℓ+jets)	0.50 ± 0.01	0.67 ± 0.01	-
	W+jets normalization (ℓ+jets)	1.42 ± 0.01	1.33 ± 0.01	-
	DY normalization ($\ell\ell$)	-	-	0.38 ± 0.06
	Other backgrounds normalization	0.05 ± 0.01	0.05 ± 0.01	0.15 ± 0.07
	W+jets background shapes (ℓ+jets)	0.40 ± 0.01	0.20 ± 0.01	-
	Single top background shapes	0.20 ± 0.01	0.20 ± 0.01	0.30 ± 0.06
	DY background shapes ($\ell\ell$)	-	-	0.04 ± 0.06
	Calibration	0.42 ± 0.01	0.50 ± 0.01	0.21 ± 0.01
Theory	Q^2-scale	0.47 ± 0.13	0.20 ± 0.03	0.11 ± 0.08
	ME-PS matching scale	0.73 ± 0.01	0.87 ± 0.03	0.44 ± 0.08
	PDF	0.26 ± 0.15	0.26 ± 0.15	0.26 ± 0.15
	Hadronization model	0.95 ± 0.13	0.95 ± 0.13	0.67 ± 0.10
	B hadron composition	0.39 ± 0.01	0.39 ± 0.01	0.39 ± 0.01
	B hadron lifetime	0.29 ± 0.18	0.29 ± 0.18	0.29 ± 0.18
	Top quark p_T modeling	3.27 ± 0.48	3.07 ± 0.45	2.36 ± 0.35
	Underlying event	0.27 ± 0.51	0.25 ± 0.48	0.19 ± 0.37
	Colour reconnection	0.36 ± 0.51	0.34 ± 0.48	0.26 ± 0.37

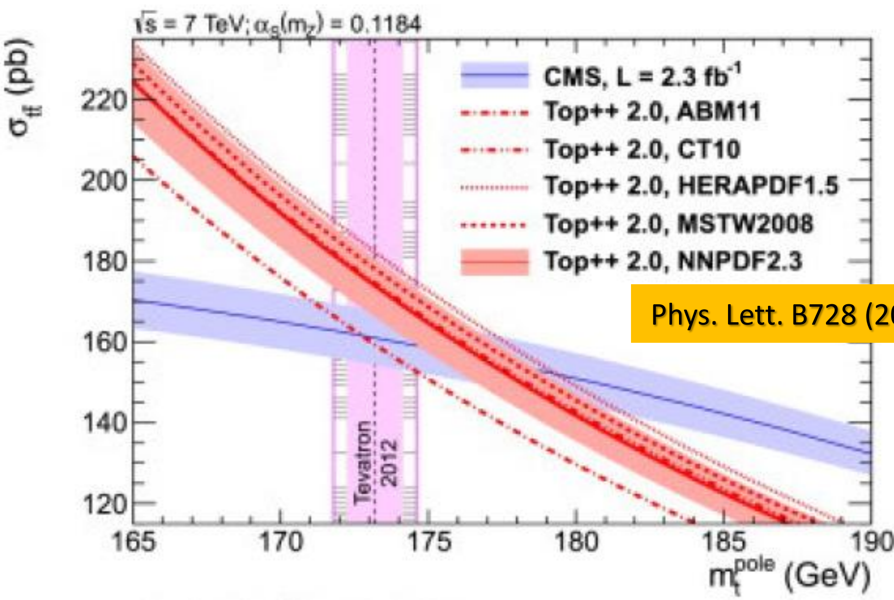
$$m_t = 173.5 \pm 1.5_{\text{stat}} \pm 1.3_{\text{syst}} \pm 2.6_{p_T(t)} \text{ GeV}$$



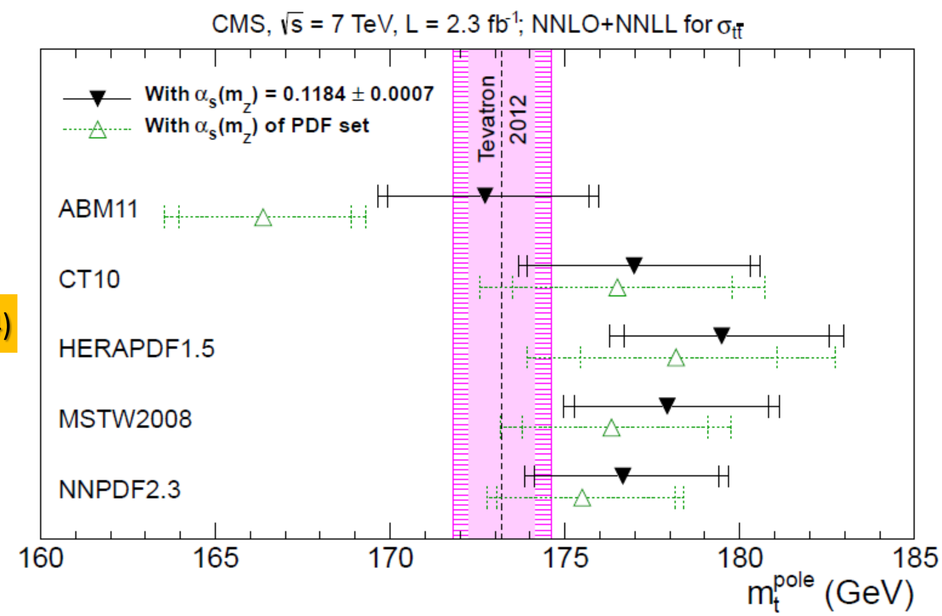


Extraction of m_t from the cross section

- Exploit the dependence of σ_{tt} on m_t and α_S
  - ➢ Parametrize measured and predicted cross section as a function of the top mass
    - o Need the full dependence of analyses' acceptances on m_t.
    - o Extract m_t by using a joint likelihood approach
  - ➢ Method to directly access the pole mass (even though not competitive)



Phys. Lett. B728 (2014)



▷ fixed $\alpha_S(m_Z) = 0.1184 \pm 0.0007$

$m_t^{\text{pole}} = 176.7^{+3.0}_{-2.8}\ \text{GeV}$

$\sigma_{t\bar{t}}^{meas}$: $^{+2.1}_{-2.0}$

LHC beam energy: $^{+0.9}_{-0.9}$

PDF: $^{+1.5}_{-1.3}$, $\mu_{R,F}$: $^{+0.9}_{-0.9}$, α_S: $^{+0.7}_{-0.7}$

m_t^{MC}: $^{+0.5}_{-0.4}$

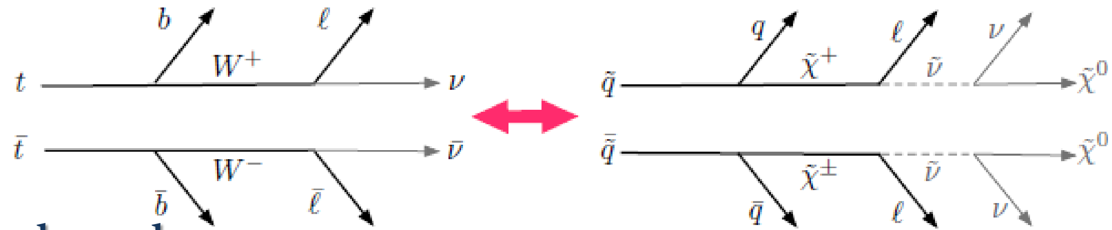
▷ fixed $m_t = 173.2 \pm 1.4$ GeV:

$\alpha_S(m_Z) = 0.1151^{+0.0028}_{-0.0027}$

Kinematic end point method in di-leptons

Eur. Phys. J. C73 (2013) 2494

- Exploit the same procedure as for hypothetical NP signature where none of the masses is known and can be determined in isolation from the others



  - ➢ First determine together the W, top and neutrino mass
  - ➢ Then apply a constrain to the W and the neutrino to get the known masses

- Knowing p(t), p(tbar) (hence the top rest frames) one could exploit kinematics to link distribution endpoints to the masses into play. Focus on dilepton decays

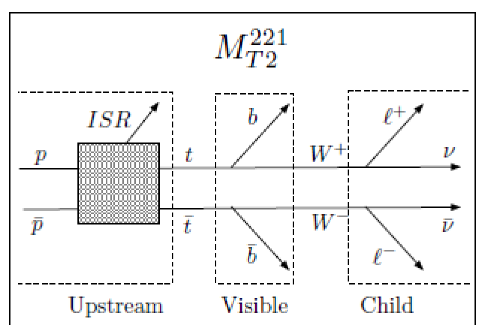
- Use variables which are least sensitive to the event and top p_Ts: $M_{T2\perp}^{210}$, $M_{T2\perp}^{221}$, $M_{b\ell}$

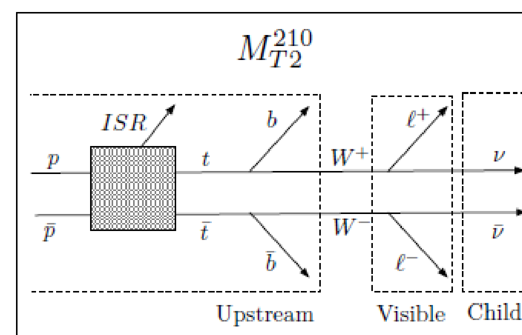
$$M_T^2 \equiv m_\nu^2 + m_\ell^2 + 2(E_T^\nu E_T^\ell - \mathbf{p}_T^\nu \cdot \mathbf{p}_T^\ell)$$

$$M_{T2} \equiv \min_{\mathbf{p}_T^{\nu a} + \mathbf{p}_T^{\nu b} = \mathbf{p}_T^{\text{miss}}} \{\max(m_T^a, m_T^b)\}$$

M_T2 is the min parent mass consistent with two identical decay chains (a, b) terminating in a missing particle.

$M_T2\perp$ is M_T2 where all transverse quantities are defined w.r.t. the direction of the two-parents system





Kinematic end point method in di-leptons

- Selection requires two isolated leptons (non-Z-like) and two b-tagged jets. Use largest mass $b\ell$ pairings
- Use data to model backgrounds with contribution beyond the endpoints (typically mistagged jets)
  - ➢ Use control regions with anti-b-tags
- Likelihood fit to the endpoint regions $a \in \{210, 221, M_{b\ell}\}$

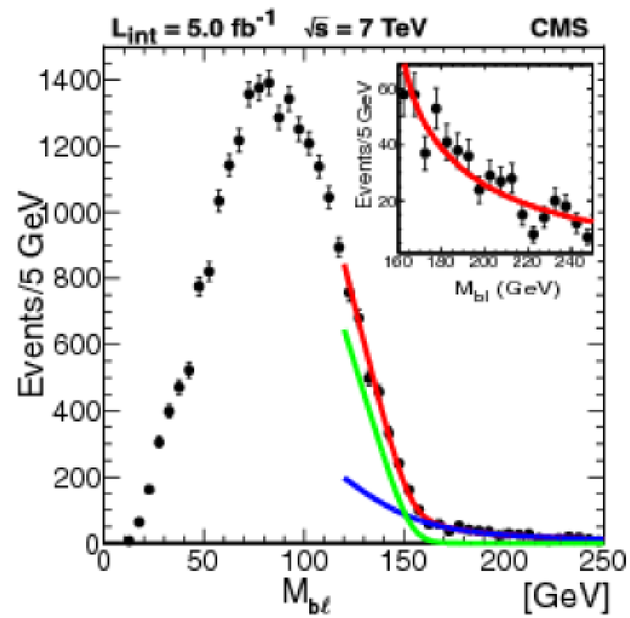
$$\mathcal{L}_i^a(x_i|x_{\max}) = \alpha \int S^a(y|x_{\max})\mathcal{R}_i^a(x_i - y)\,dy + (1-\alpha)B^a(x_i)$$

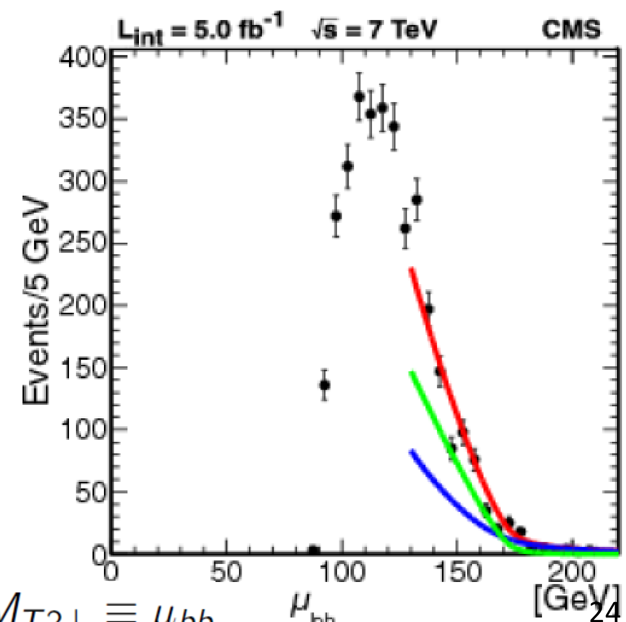
$$S(x|x_{\max}) \equiv \begin{cases} \mathcal{N}(x_{\max} - x) & x_{lo} \le x \le x_{\max} \\ 0 & x_{\max} \le x \le x_{hi} \end{cases}$$

  - ➢ The x_{max} linked to the masses via analytic functions
  - ➢ Systematic error dominated by JES

Fit Quantity	Constraint		
	None	$m_\nu = 0$	$m_\nu = 0$ and $M_W = 80.4$
m_ν^2 (GeV^2)	$-556 \pm 473 \pm 600$	(0)	(0)
M_W (GeV)	$72 \pm 7 \pm 9$	$80.7 \pm 1.1 \pm 1$	(80.4)
M_t (GeV)	$163 \pm 10 \pm 11$	$174.0 \pm 0.9 \pm 2$	$173.9 \pm 0.9^{+1.2}_{-1.8}$

$$\boxed{M_t = 173.9 \pm 0.9\ (\text{stat})\ ^{+1.2}_{-1.8}\ (\text{syst})\quad \text{GeV}}$$





$M_{T2} \to M_{T2\perp} \equiv \mu_{bb}$

TOP MASS COMBINATIONS

AKA: how to deal with 1001 systematic errors

Combining may be tricky

- Combining results from different analyses and experiments is a necessity for precision measurements
  - ➢ In general a very difficult task (different conventions, error splitting, information in the documentation, missing or non-recoverable information,…)
  - ➢ Communication among the experts is of the essence but…

- …assumptions are sometime needed
  - ➢ Categories of systematics
  - ➢ Correlations of systematics (often difficult to assess)

- For the top mass need to combine a consistent and unambiguous set of measurements
  - ➢ Just measurements performed via direct reconstruction for now
  - ➢ Use a simple method like the Best Linear Unbiased Estimate

BLUE primer

- Method universally used so far for combining measurements
  - ➢ Very practical when a more detailed combination is not feasible (different experiments/time, no likelihoods,…)
- Given a linear combination of measurements: $\hat{Y} = \tilde{\boldsymbol{\lambda}}\mathbf{y} = \sum_{i=1}^{n} \lambda_i \, y_i$

$$\tilde{\mathbf{U}}\boldsymbol{\lambda} = \sum_{i=1}^{n} \lambda_i = 1$$

- The Best Linear Unbiased Estimate simply finds the vector of coefficients minimizing the total variance:

$$\lambda_i = \frac{\left(\mathcal{M}^{-1}\mathbf{U}\right)_i}{\left(\tilde{\mathbf{U}}\mathcal{M}^{-1}\mathbf{U}\right)} \qquad \mathrm{var}(\hat{Y}) = \sigma_{\hat{Y}}^2 = \sum_{i=1}^{n}\sum_{j=1}^{n} \lambda_i \, \mathcal{M}_{ij} \, \lambda_j = \frac{1}{\left(\tilde{\mathbf{U}}\mathcal{M}^{-1}\mathbf{U}\right)}$$

  - ➢ Y is the combined value, λ the vector of linear coefficients
  - ➢ M is the (NxN) covariance of the n measurements
  - ➢ U is a vector of all 1's (i.e. contraction by U means summing all indexes)

Comments about high correlation regimes

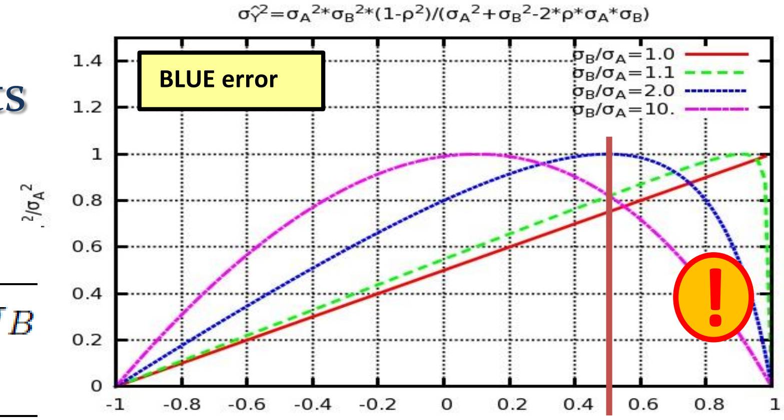
- Best understood with only two measurements A and B with errors $\sigma_A < \sigma_B$ and correlation ρ

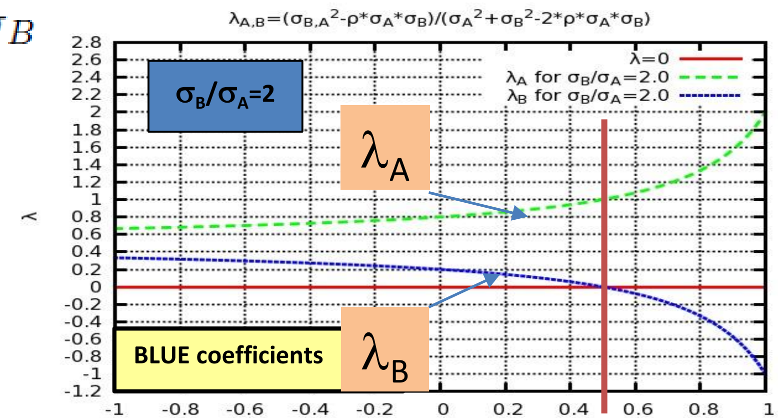
$$\hat{Y} = \lambda_A y_A + \lambda_B y_B \qquad \lambda_A = \frac{\sigma_B^2 - \rho\sigma_A\sigma_B}{\sigma_A^2 + \sigma_B^2 - 2\rho\sigma_A\sigma_B}$$

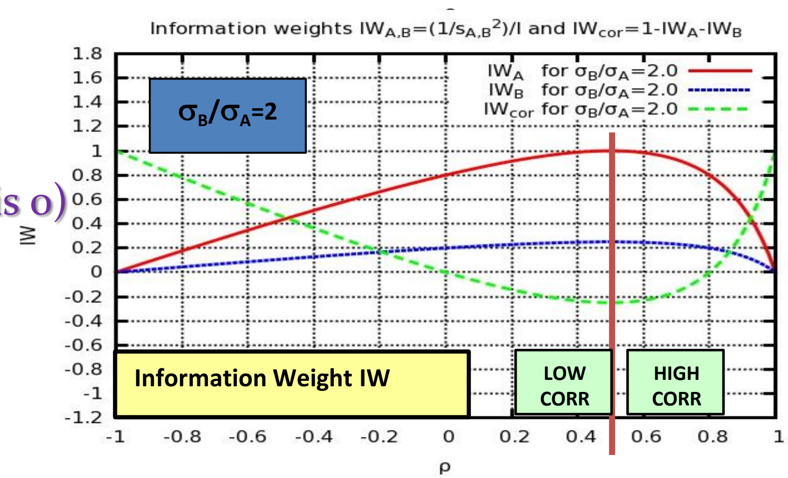
$$\sigma_{\hat{Y}}^2 = \frac{\sigma_A^2\sigma_B^2(1-\rho^2)}{\sigma_A^2 + \sigma_B^2 - 2\rho\sigma_A\sigma_B} = \frac{1}{I} \qquad \lambda_B = \frac{\sigma_A^2 - \rho\sigma_A\sigma_B}{\sigma_A^2 + \sigma_B^2 - 2\rho\sigma_A\sigma_B}$$

!

- Varying ρ, the combined error is maximum (equal to σ_A) for $\rho=\sigma_A/\sigma_B$, where λ_B flips sign
  - ➢ Low correlation region – $\rho<\sigma_A/\sigma_B$
    - Both λ_A and λ_B are > 0
    - Info decreases (error increases) as ρ increases
  - ➢ High correlation region – $\rho>\sigma_A/\sigma_B$
    - One coefficient λ_B is < 0
    - Info increases (error decreases) as ρ increases
  - ➢ Boundary – $\rho=\sigma_A/\sigma_B$ (max correlation)
    - One coefficient λ_B is = 0
    - Error is maximum = σ_A (marginal info from B is 0)
- Introduce information weights (IW: A, B, ρ)
  - ➢ Sum is equal to 1 by construction
  - ➢ IW from ρ is minimum (negative) for λ_B=0







March 2013: first ever top mass World Average

- Big effort for reaching common conventions in the splitting of systematic unc.s
  - Across the LHC experiments, but also talking with the Tevatron.
- Most notably (but not only) on the JES uncertainties
  - iJES: in situ calibration, statistical origin
  - stdJES: light jet calibration with data, only correlated within the same exp
  - flavourJES : from different jet energy responses (gluon vs quarks)
  - bJES : modelling of the response for b jets. TH uncertainties correlate it among exp.s

arXiv:1403.4427

ATLAS CONF 2014-008

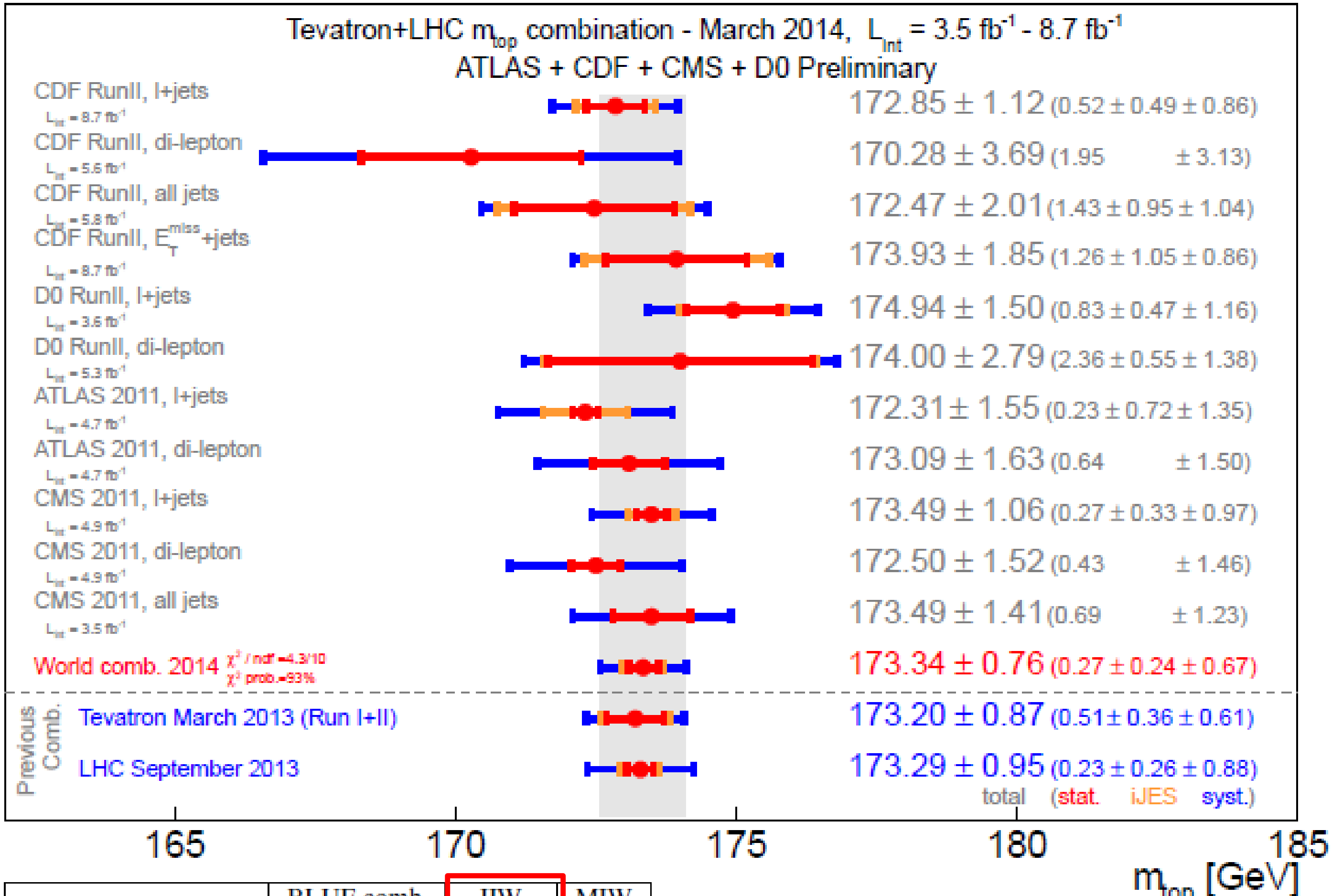
CMS PAS TOP-13-014

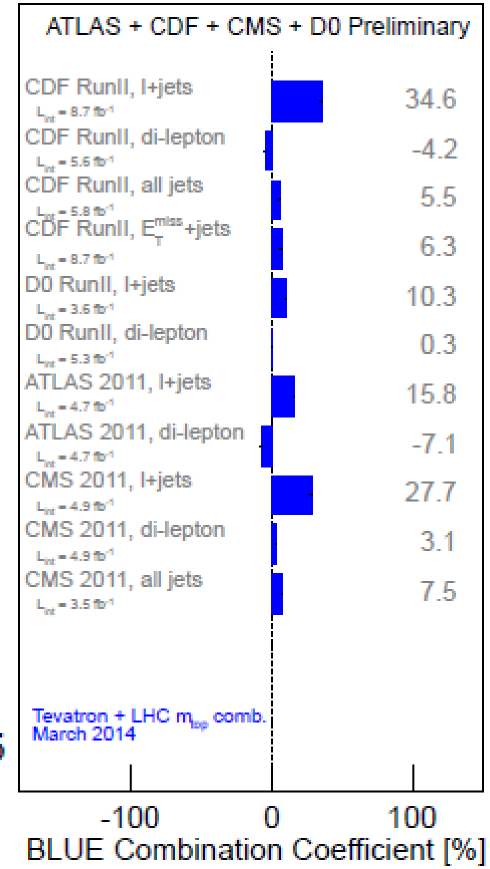
CDF-NOTE-11071

D0-NOTE-6416

	Input measurements and uncertainties in GeV													
	CDF				D0		ATLAS		CMS			World		
Uncertainty	l+jets	di-l	all jets	E_T^{miss}	l+jets	di-l	l+jets	di-l	l+jets	di-l	all jets	Combination	ρ_{LHC}	ρ_{TEV}
m_{top}	172.85	170.28	172.47	173.93	174.94	174.00	172.31	173.09	173.49	172.50	173.49	173.34		
Stat	0.52	1.95	1.43	1.26	0.83	2.36	0.23	0.64	0.27	0.43	0.69	0.27	0.0	0.0
iJES	0.49	n.a.	0.95	1.05	0.47	0.55	0.72	n.a.	0.33	n.a.	n.a.	0.24	0.0	0.0
stdJES	0.53	2.99	0.45	0.44	0.63	0.56	0.70	0.89	0.24	0.78	0.78	0.20	0.0	0.0
flavourJES	0.09	0.14	0.03	0.10	0.26	0.40	0.36	0.02	0.11	0.58	0.58	0.12	0.0	0.0
bJES	0.16	0.33	0.15	0.17	0.07	0.20	0.08	0.71	0.61	0.76	0.49	0.25	0.5	1.0
MC	0.56	0.36	0.49	0.48	0.63	0.50	0.35	0.64	0.15	0.06	0.28	0.38	1.0	1.0
Rad	0.06	0.22	0.10	0.28	0.26	0.30	0.45	0.37	0.30	0.58	0.33	0.21	1.0	1.0
CR	0.21	0.51	0.32	0.28	0.28	0.55	0.32	0.29	0.54	0.13	0.15	0.31	1.0	1.0
PDF	0.08	0.31	0.19	0.16	0.21	0.30	0.17	0.12	0.07	0.09	0.06	0.09	1.0	1.0
DetMod	<0.01	<0.01	<0.01	<0.01	0.36	0.50	0.23	0.22	0.24	0.18	0.28	0.10	0.0	0.0
b-tag	0.03	n.e.	0.10	n.e.	0.10	<0.01	0.81	0.46	0.12	0.09	0.06	0.11	0.0	0.0
LepPt	0.03	0.27	n.a.	n.a.	0.18	0.35	0.04	0.12	0.02	0.14	n.a.	0.02	0.0	0.0
BGMC	0.12	0.24	n.a.	n.a.	0.18	n.a.	n.a.	0.14	0.13	0.05	n.a.	0.10	1.0	1.0
BGData	0.16	0.14	0.56	0.15	0.21	0.20	0.10	n.a.	n.a.	n.a.	0.13	0.07	0.0	0.0
Meth	0.05	0.12	0.38	0.21	0.16	0.51	0.13	0.07	0.06	0.40	0.13	0.05	0.0	0.0
MHI	0.07	0.23	0.08	0.18	0.05	<0.01	0.03	0.01	0.07	0.11	0.06	0.04	1.0	0.0
Total Syst	0.99	3.13	1.41	1.36	1.25	1.49	1.53	1.50	1.03	1.46	1.23	0.71		
Total	1.12	3.69	2.01	1.85	1.50	2.79	1.55	1.63	1.06	1.52	1.41	0.76		

Summary



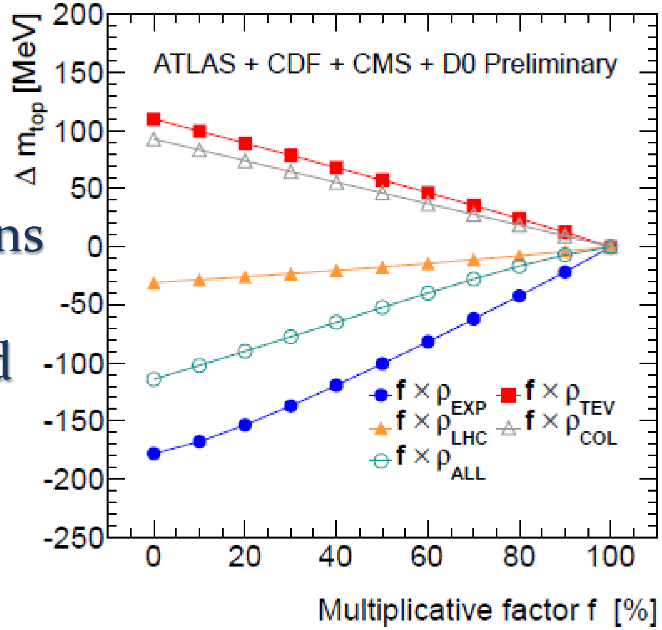


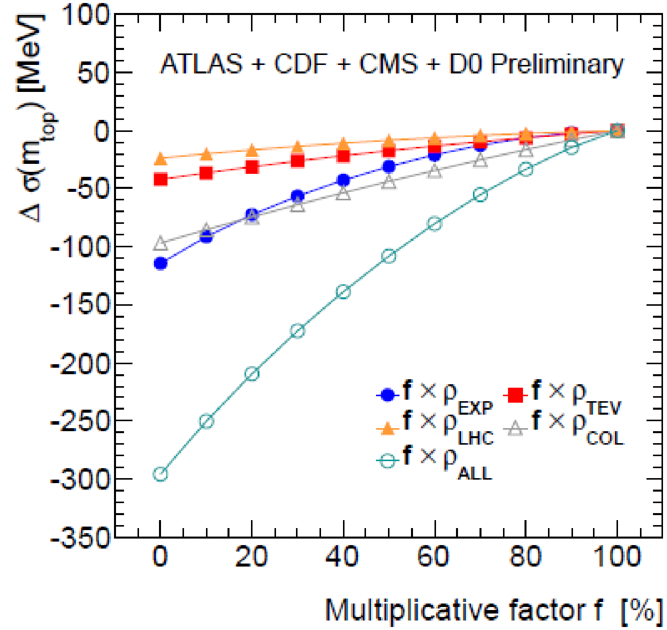
Measurements		BLUE comb. coeff. [%]	IIW [%]	MIW [%]
CDF	l+jets	34.6	46.6	16.1
	di-l	−4.2	4.3	3.0
	all jets	5.5	14.4	1.9
	E_T^{miss}	6.3	16.9	2.1
D0	l+jets	10.3	25.8	3.2
	di-l	0.3	7.5	0.0
ATLAS	l+jets	15.8	24.2	6.1
	di-l	−7.1	21.9	1.2
CMS	l+jets	27.7	51.3	7.6
	di-l	3.1	25.1	0.1
	all jets	7.5	29.2	0.8
Correlations (IIW_{corr})		—	−167.3	—

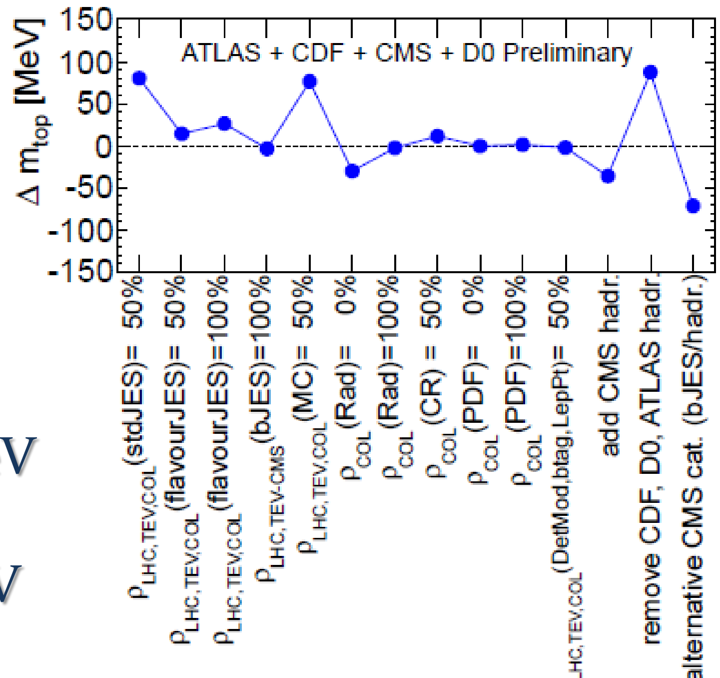
- Most precise individual results are CDF and CMS in lepton+jets
- The ensemble of correlations gives an impact way more important that any individual measurement

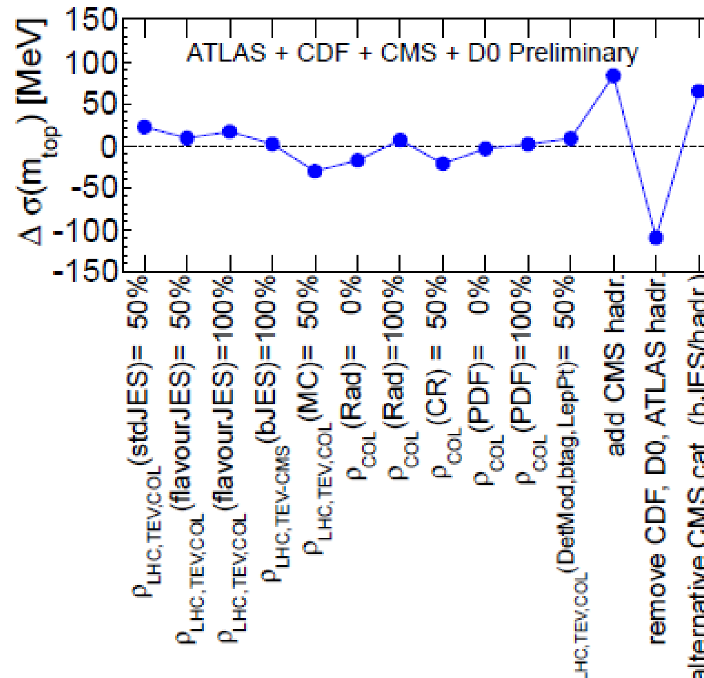
Testing the stability

- Different correlations are tested, varying them separately and even in a correlated way



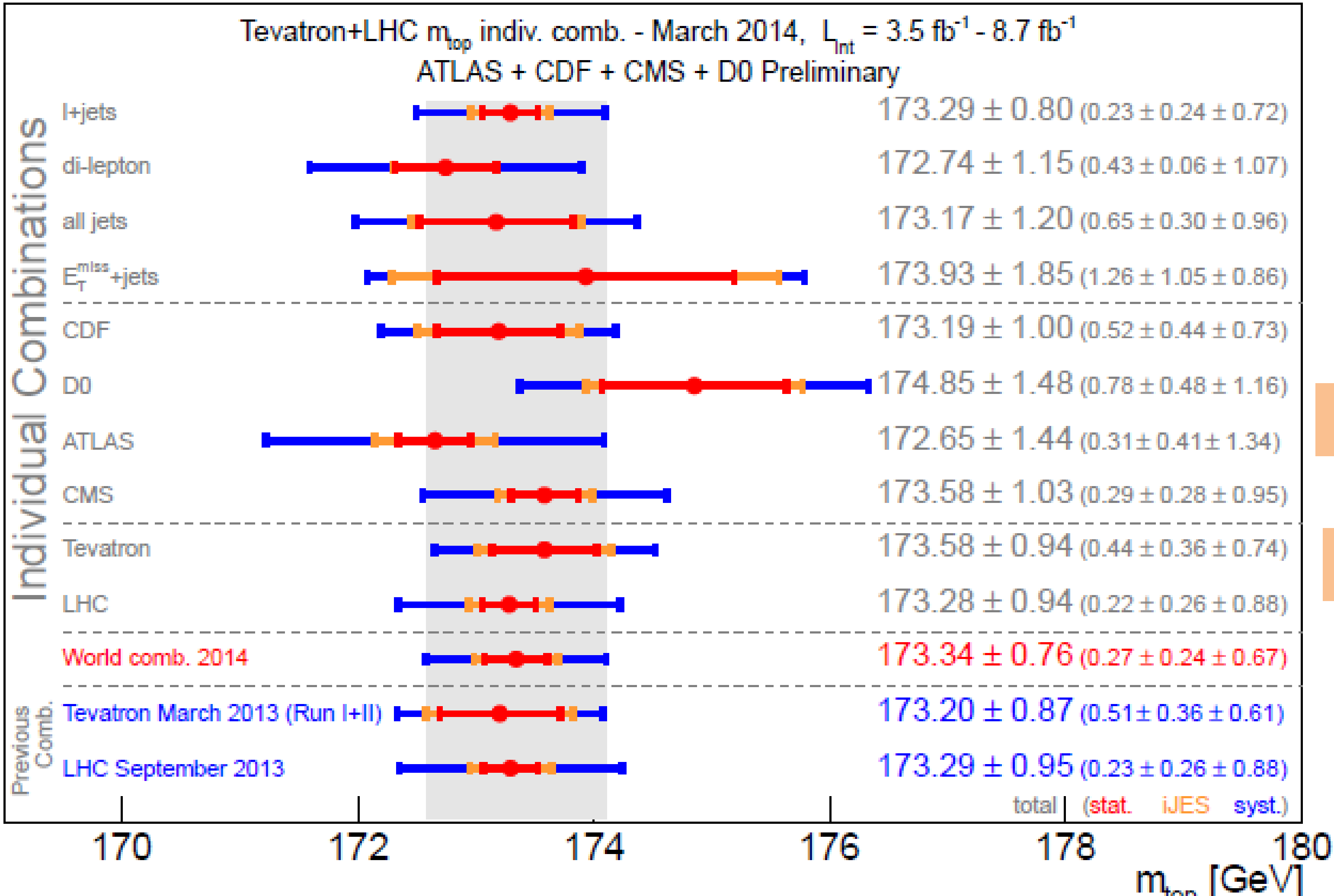






- Results stable within 200 MeV for the central value, 300 MeV for the error

Yet another summary



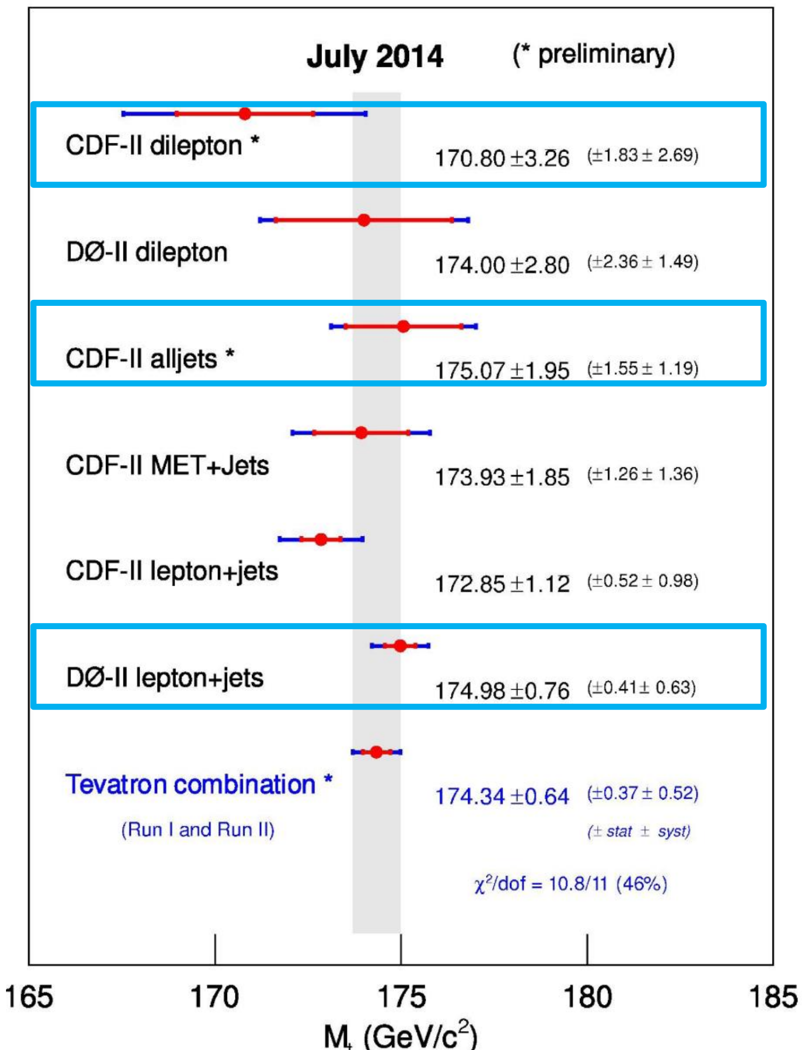
Per channel

Per experiment

Per accelerator

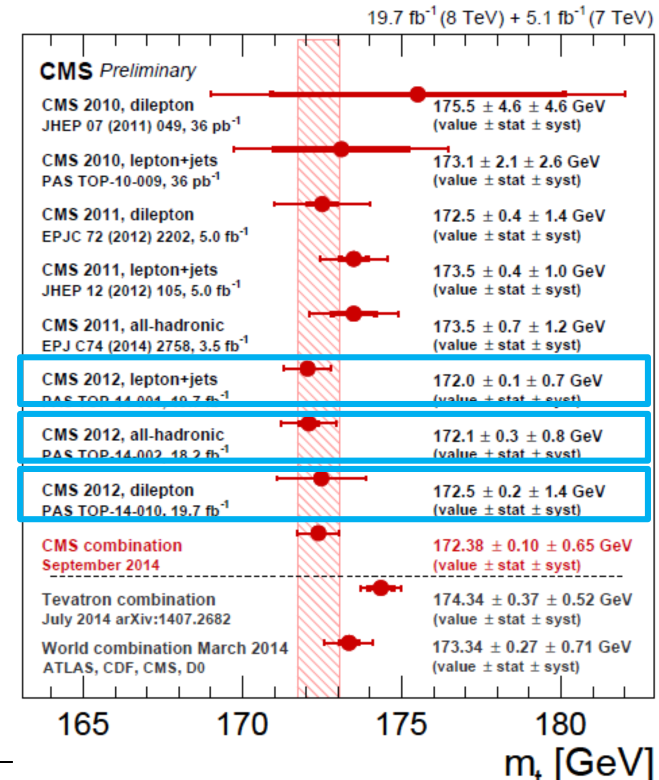
Many things happened since…

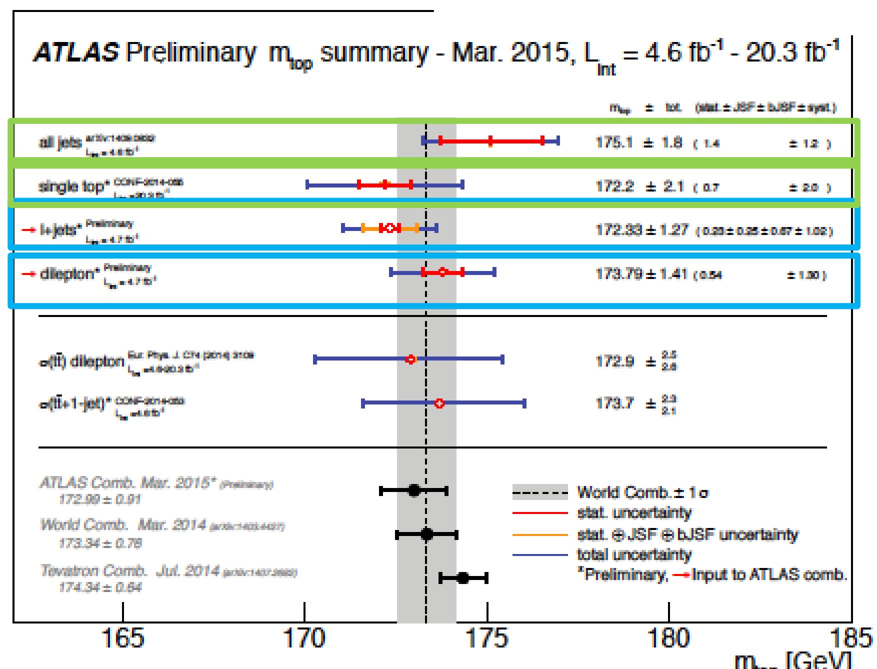
- Very dynamic field, making a combination soon obsolete



NEW

UPDATED





Speculations and work about D0-CMS

- A new combination is in the works, but still on hold for an apparent tension among the measurements

- Several crosschecks have been performed to assess whether the two most apart measurements (D0 and CMS) are compatible with each other
  - This is a potentially biasing procedure
  - Worried about the assessment of correlations of systematic errors, and the fact that the difference be due to something treated differently in the two analyses

- Comparing methods and results (on MCs)
  - Consistent sensitivity of the methods to a bJES variation
  - Check size and sign of systematic variations, looking for unexpected anti-correlations. Major systematics are found to be OK: JEC, ME generator, b-fragmentation, colour reconnection

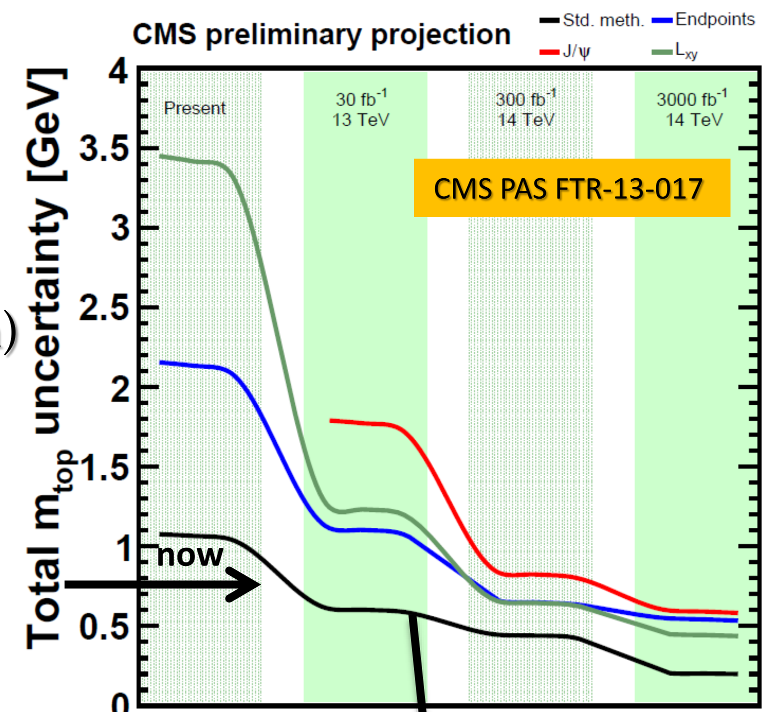
- Work is still ongoing before moving to an update of the World Average
  - Next (final) test: use common events to determine the correlations or biases (compared to errors in play)

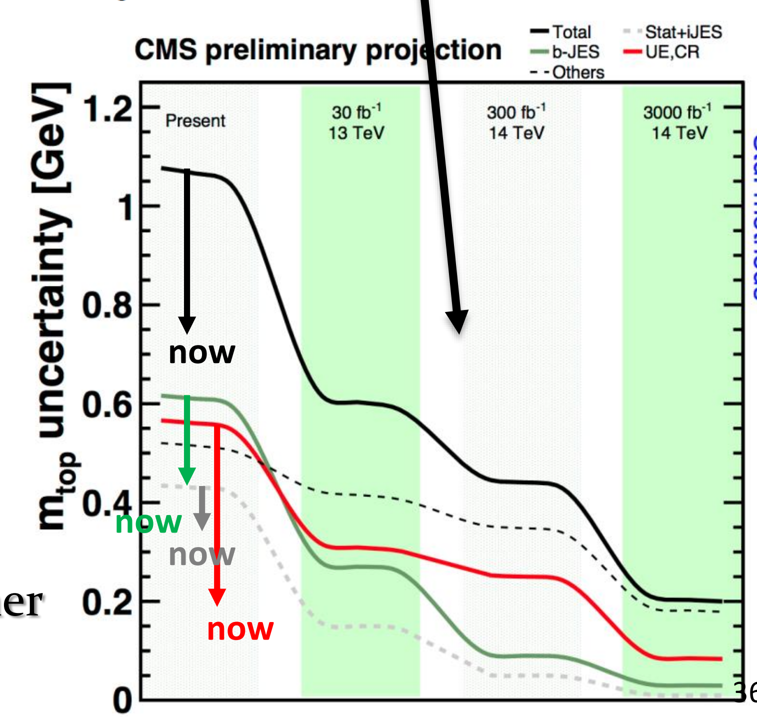
OUTLOOK AND CONCLUSIONS

Perspectives for the new runs

- Many assumptions: take with grain of salt
  - ➢ Increase of cross section compensates larger inefficiencies from triggering (+reconstruction)
  - ➢ Detector improvements after LSII should help keeping the assumption above true also in tremendous PU conditions as for 3000/fb
  - ➢ Data itself will be used to constrain systematic sources, especially those due to MC modelling (light- and b-JES will be fitted in situ when possible)

- Typical reduction of systematic errors:
  - ➢ Light-JES: factor 2 (30/fb) to 4 (3000/fb)
  - ➢ b-JES: factor 2 (30/fb) to 10 (3000/fb)
  - ➢ Radiation: factor 2 (30/fb) to 4 (3000/fb)
  - ➢ b-tagging: factor 2
  - ➢ CR: factor 2 (30/fb) to 10 (3000/fb)
  - ➢ Lepton ES, PU, PDFs, UE, background and other TH errors stay constant





Conclusions

- Experimentalists have measured the (MC!) top mass with direct reconstruction techniques at the level of 750 MeV, or better by now (likely below 600 MeV)
- We should determine how this mass relates to a well defined short distance mass, and quantify an extra possible error on it
- We have experimental methods more sensitive to a short distance mass to be studied, and methods largely uncorrelated to the present ones to be exploited
- We have plenty more data to be taken in the next years, with which systematics effect can be constrained even further.
- In the long run it does not look impossible to reach, in practice, an error on the (MC) top mass of the order of Λ_{QCD}. That would also likely correspond to the end of this game (?).