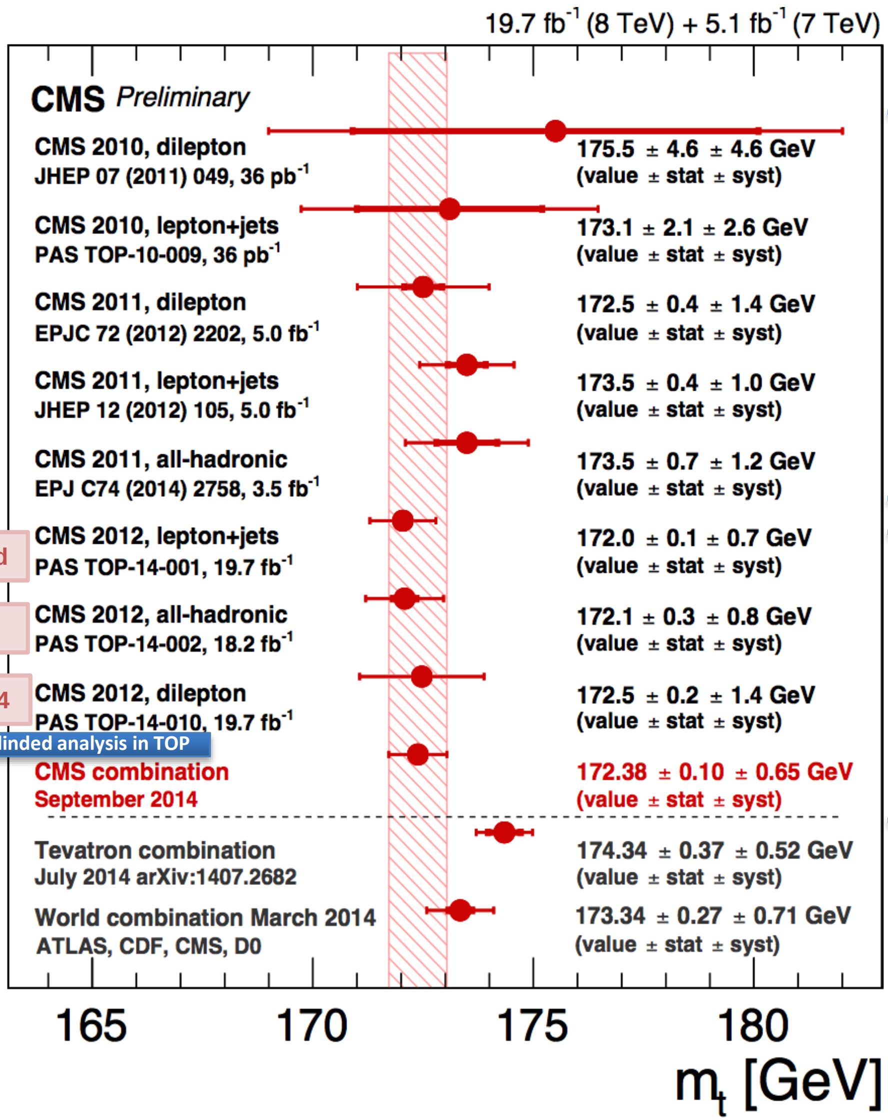
New results on Top Mass in CMS

Martijn Mulders (CERN)

for CMS

TOPLHCWG open meeting, January 13, 2015

CMS Top Mass results in 2014 (standard methods)

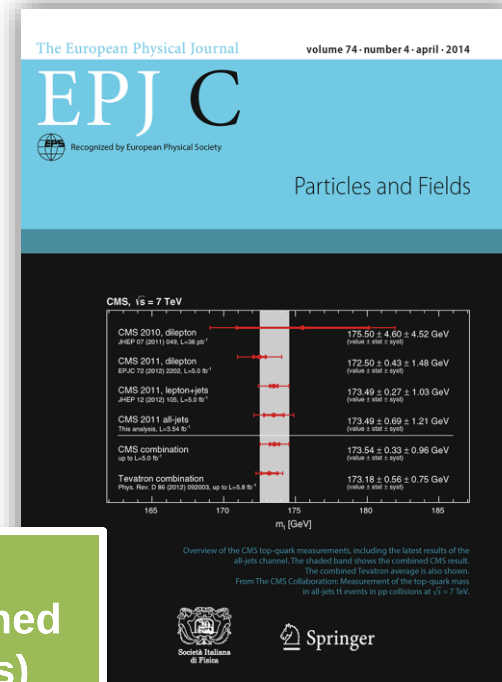


Moriond

ICHEP

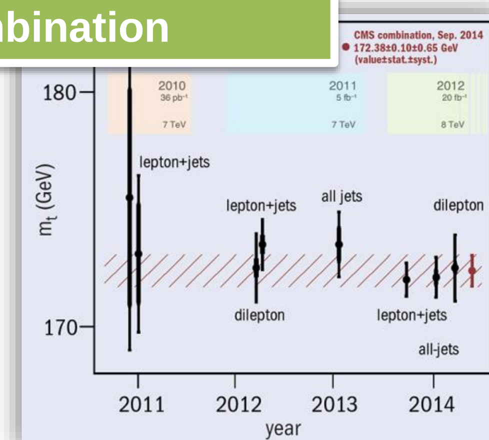
TOP2014

First blinded analysis in TOP



7 TeV:
All published
(4 papers)

8 TeV:
Preliminary results in all channels and 7+8 TeV combination



http://cerncourier.com/cws/article/cern/59318

CMS Top Mass combination

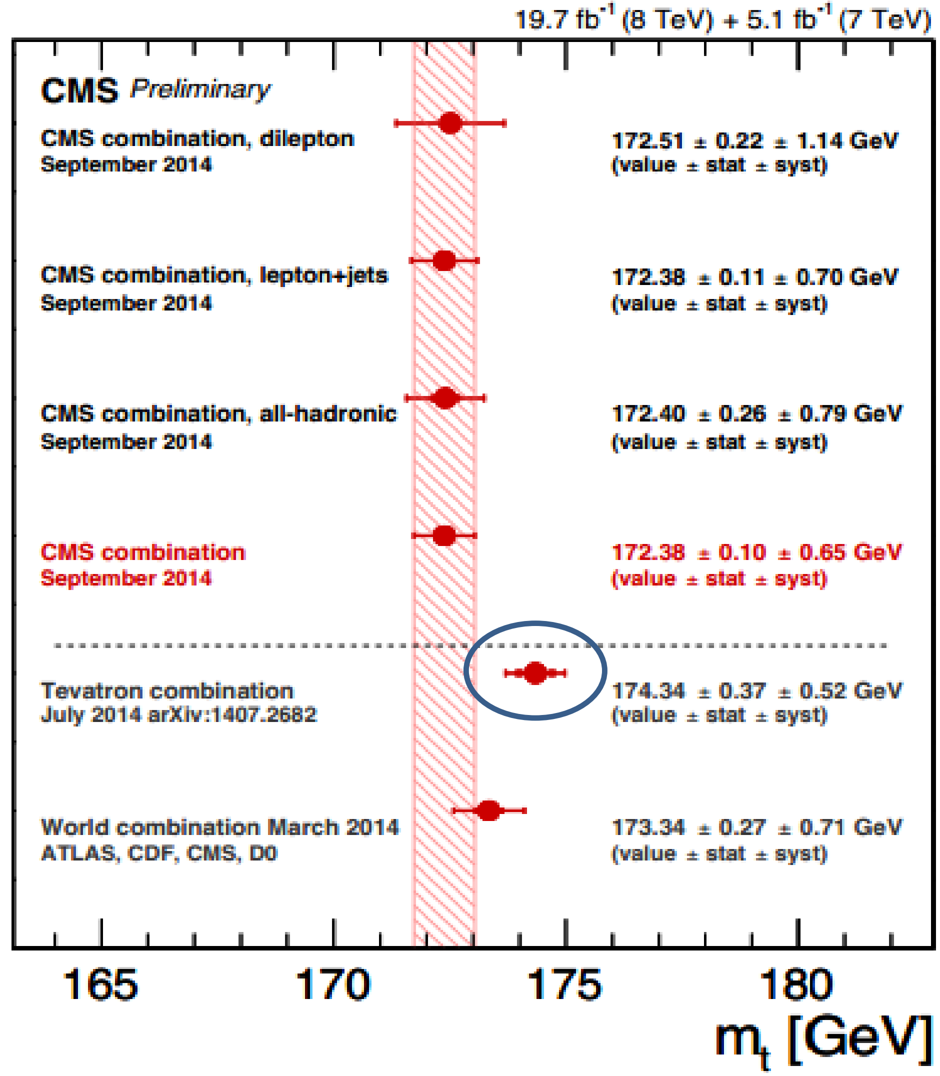
TOP-14-015

- Excellent consistency across channels in CMS
- Some tension with the latest Tevatron combination, which includes the new DØ lepton+jets measurement:

m_{top} = 174.98 ± 0.41(stat) ±0.41(JES) ±0.49(syst) GeV

D0 collaboration: PRL 113 (2014) 032002

- Dedicated discussion ongoing between CMS and DØ experts:
  - additional cross-checks
  - (anti)correlations ?
  - check with same generator Powheg2+Pythia6 P11C



m_t = 172.38 ± 0.65 GeV (0.38%)

Top mass in lepton+jets channel 8 TeV

TOP-14-001

Signature

– e/μ + 4 jets, 2 b-tags (high purity selection)

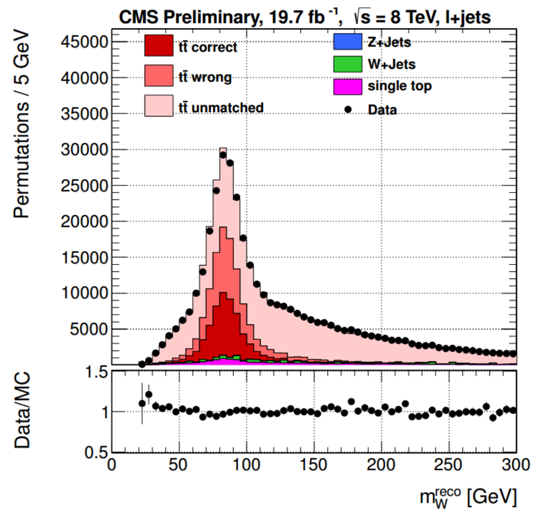
Analysis using 'Ideogram' technique

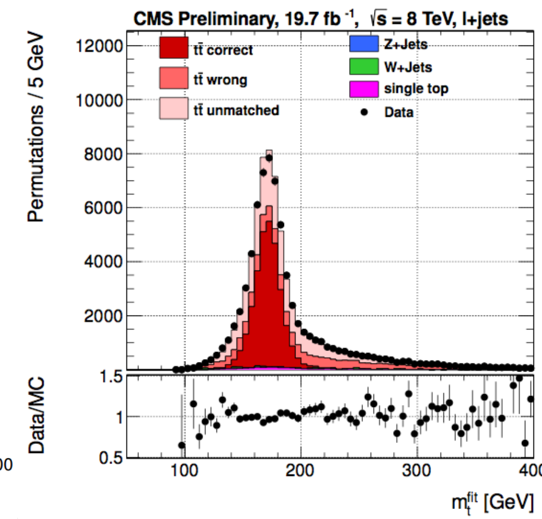
– Apply kinematic fit ($P_{gof} > 0.2$)
– 2D-fit of mass and jet energy scale (JSF) using W-mass constraint
– Weight each fit solution by P_{gof}
– Measurement from max.likelihood in mass-JES plane

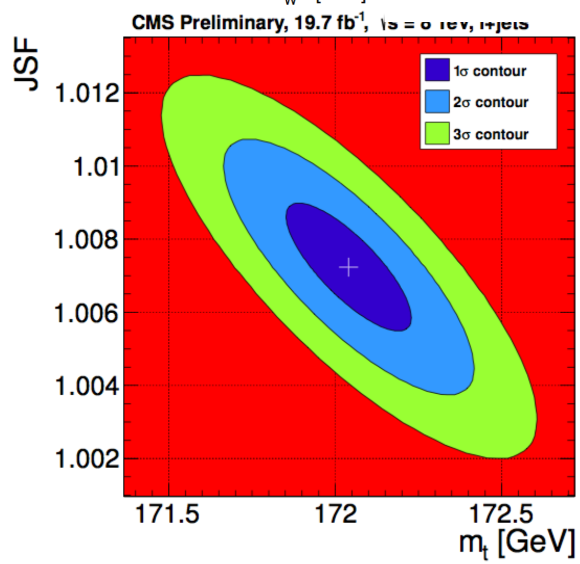
Dominant Uncertainties

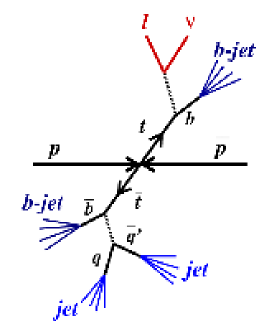
– Jet energy resolution: 0.26 GeV
– Pile-up: 0.27 GeV
– Flavor-dependent jet energy scale, includes hadronization (PYTHIA vs HERWIG) 0.41 GeV
– ME-generator: 0.23 GeV

As precise as World Average









$m_{top} = 172.04 \pm 0.19_{stat+JES} \pm 0.75_{syst}$ GeV

$JSF = 1.007 \pm 0.002_{stat} \pm 0.012_{syst}$

Top mass in all-hadronic channel 8 TeV

TOP-14-002

Signature

– 6 jets, 2 b-tags (high purity selection)

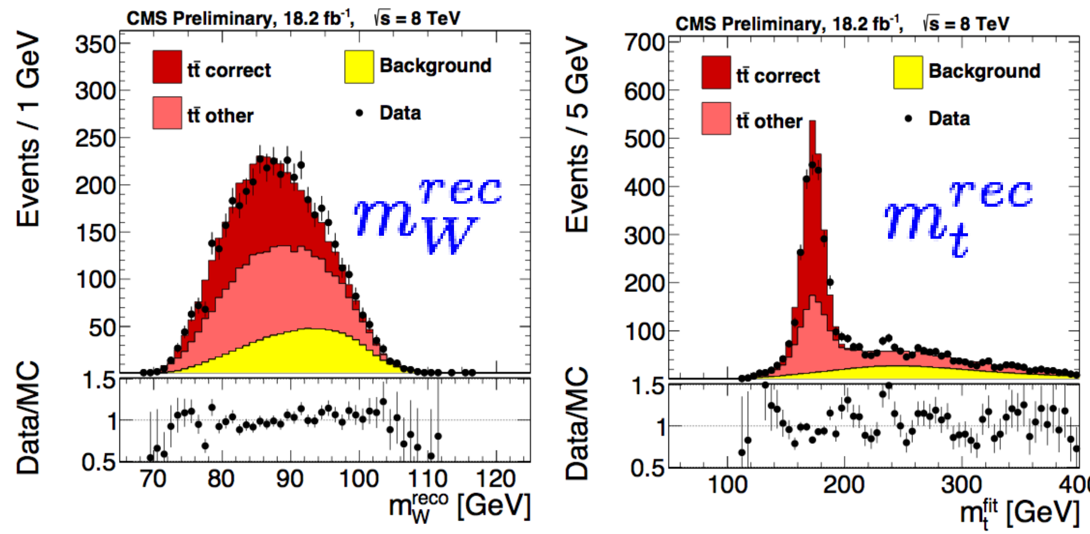
Analysis using 'Ideogram' technique

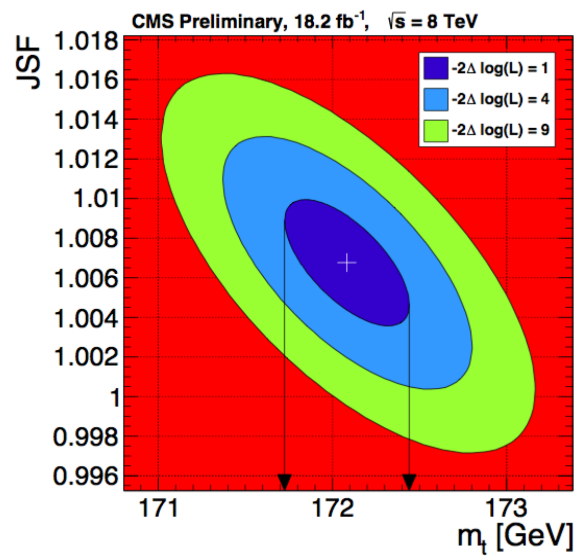
– Apply kinematic fit ($P_{gof} > 0.1$)
– 2D-fit of mass and jet energy scale (JSF) using W-mass constraint
– Include one fit solution per event
– Measurement from max.likelihood in mass-JES plane

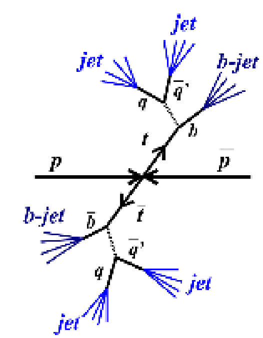
Dominant Uncertainties

– p_T and η-dependent JES: 0.28 GeV
– Pile-up: 0.31 GeV
– Flavour-dependent jet energy scale, includes hadronization (PYTHIA vs HERWIG) 0.36 GeV
– ME-generator: 0.21 GeV

As precise as World Average



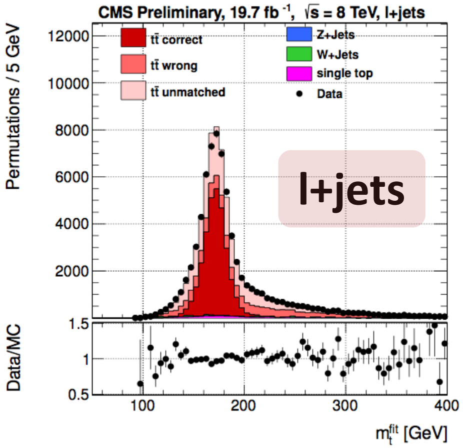




m_{top} = 172.08 ± $0.36_{stat+JES}$ ± 0.83_{syst} GeV

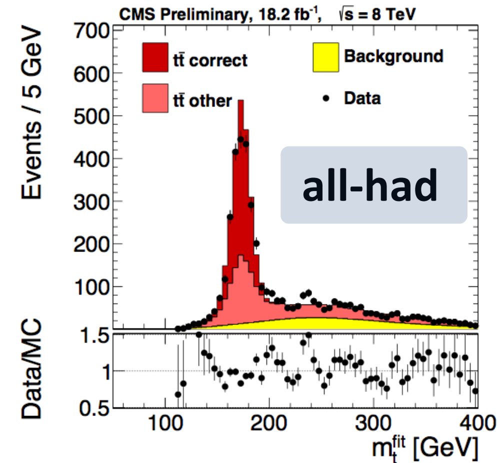
JSF = 1.007 ± 0.003_{stat} ± 0.011_{syst}

Systematics l+jets / all-hadronic



all-hadronic channel competitive with lepton+jets channel

- Higher branching ratio
- No neutrinos
- Full kinematics available
- Higher jet p_T cuts (trigger)
- Lower purity



2D JSF 1D

	δm_t^{2D} (GeV)	δJSF	δm_t^{1D} (GeV)
Experimental uncertainties			
Fit calibration	0.10	0.001	0.06
p_T- and η-dependent JES	0.18	0.007	1.17
Lepton energy scale	0.03	<0.001	0.03
MET	0.09	0.001	0.01
Jet energy resolution	0.26	0.004	0.07
b tagging	0.02	<0.001	0.01
Pileup	0.27	0.005	0.17
Non-tt̄ background	0.11	0.001	0.01
Modeling of hadronization			
Flavor-dependent JSF	0.41	0.004	0.32
b fragmentation	0.06	0.001	0.04
Semi-leptonic B hadron decays	0.16	<0.001	0.15
Modeling of the hard scattering process			
PDF	0.09	0.001	0.05
Renormalization and factorization scales	0.12±0.13	0.004±0.001	0.25±0.08
ME-PS matching threshold	0.15±0.13	0.003±0.001	0.07±0.08
ME generator	0.23±0.14	0.003±0.001	0.20±0.08
Modeling of non-perturbative QCD			
Underlying event	0.14±0.17	0.002±0.002	0.06±0.10
Color reconnection modeling	0.08±0.15	0.002±0.001	0.07±0.09
Total	0.75	0.012	1.29

2D JSF 1D

	δm_t^{2D} (GeV)	δJSF	δm_t^{1D} (GeV)
Experimental uncertainties			
Fit calibration	0.06	<0.001	0.06
p_T- and η-dependent JES	0.28	0.006	0.86
Jet energy resolution	0.10	0.001	0.01
b tagging	0.02	<0.001	<0.01
Pileup	0.31	0.001	0.30
Calorimeter JES of trigger confirmation	0.18	0.003	0.07
Non-tt̄ background	0.22	0.002	0.08
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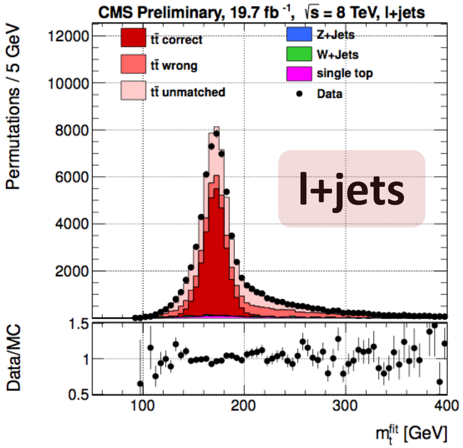
Systematics l+jets / all-hadronic



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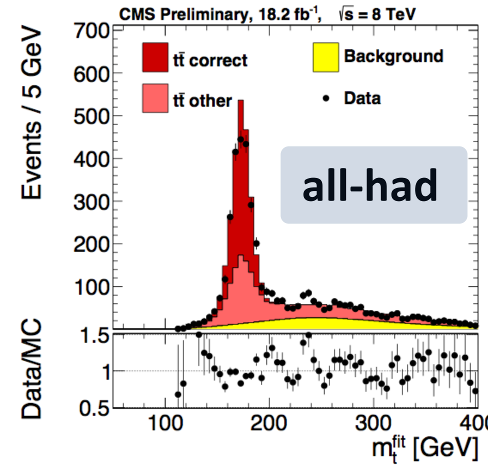

jet reconstruction / pile-up	δm_t^{2D} (GeV) l+jets	δm_t^{2D} (GeV) all-had
p_T- and η-dependent JES	0.18	0.28
Jet energy resolution	0.26	0.10
Pileup	0.27	0.31

hadronization modeling	δm_t^{2D} (GeV) l+jets	δm_t^{2D} (GeV) all-had
Flavor-dependent JSF	0.41	0.36
b fragmentation	0.06	0.07
Semi-leptonic B hadron decays	0.16	0.12

	δm_t^{2D} (GeV) l+jets	δm_t^{2D} (GeV) all-had
Total	0.75	0.83

Experimental uncertainties			
Fit calibration			
p_T- and η-dependent JES			
Lepton energy scale			
MET			
Jet energy resolution			
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Color reconnection modeling			
Total	0.75	0.012	1.29

			δm_t^{1D} (GeV)
			0.06
			0.86
			0.01
			<0.01
			0.30
			0.07
			0.08
			0.30
			0.03
			0.12
			0.01
			0.18±0.14
			0.09±0.14
			0.17±0.15
			0.11±0.20
			0.03±0.18
Total	0.83	0.011	1.05

Most other (QCD) uncertainties appear to be small

- Invariant mass observable: small sensitivity to most of the modeling effects
  - PDF4LHC, factorization and renormalization scales, ME-PS matching threshold
  - ME generator: (LO) MG+Pythia6 vs (NLO) Powheg+Pythia6 + 100% of pt(top) modeling discrepancy
  - Underlying Event: Perugia11 default vs “mpiHi” vs “Tevatron”
  - Color reconnection model: Perugia11 default (CR) vs NoCR – conservative?

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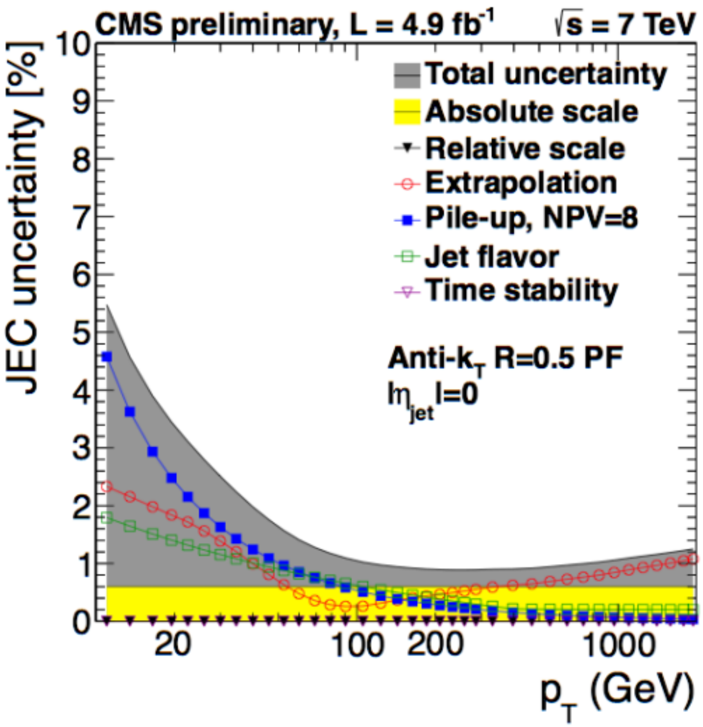
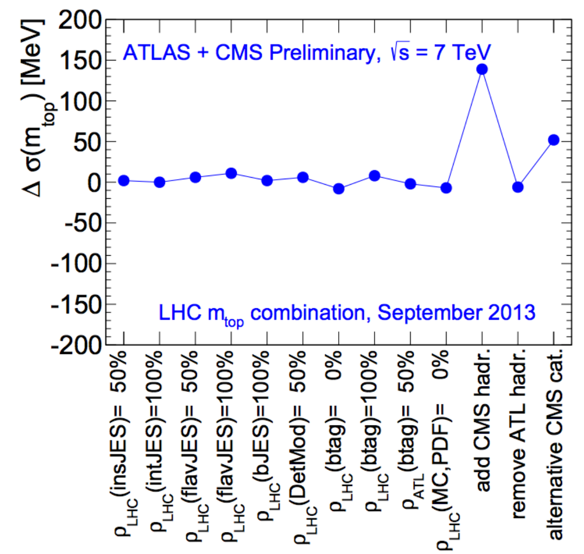
Jet Energy Scale: Flavour Dependence at 7 TeV

- Light-quark jet energy scale (JES) constrained in-situ in ttbar with 2D fit based on W→jj decay
- **B-quark jets:** Rely on MC to describe the relative difference compared to light jets
  - Requires correct modeling of **jet hadronization** differences
- CMS 7 TeV: For uncertainty on ratio of b-JES vs light-quark-JES, using centrally provided "Jet Flavor" uncertainty in
- Determined from difference between Herwig++ and Pythia6 Z2 predictions for the JES ratios for different jet flavors
- "Jet Flavor" = envelope of all jet flavors = ~2x larger than estimate for b-jet vs light-jet = believed to be conservative for TOP analysis



7 TeV top mass, l+jets

2012 LHC Top mass



- Pythia vs Herwig++ in JES:
  Δmtop = 0.61 GeV (published)

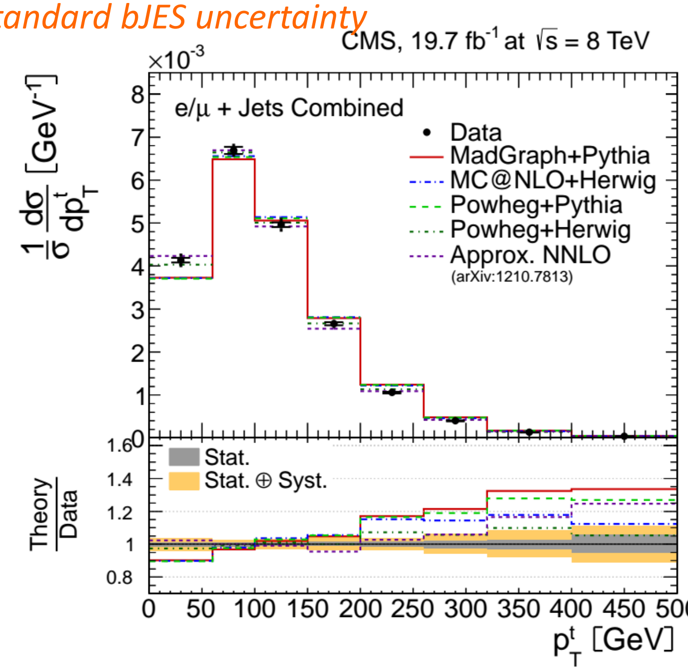
- Pythia vs Herwig AUET2 <u>in ttbar</u>:
  Δmtop = 0.58 GeV (*)
  add also semi-leptonic BR
  Δmtop = 0.10 GeV
  and b-fragmentation functions
  Δmtop = 0.15 GeV

alternative CMS proposal: use combination of these 3 instead of standard bJES uncertainty

- (*) Some doubts about the CMS ttbar POWHEG + Herwig AUET2 sample
  - Not tuned to CMS data
  - Unexpected b-tagging performance
  - Different UE? (double counting?)
  - Unexpected top p_T distribution

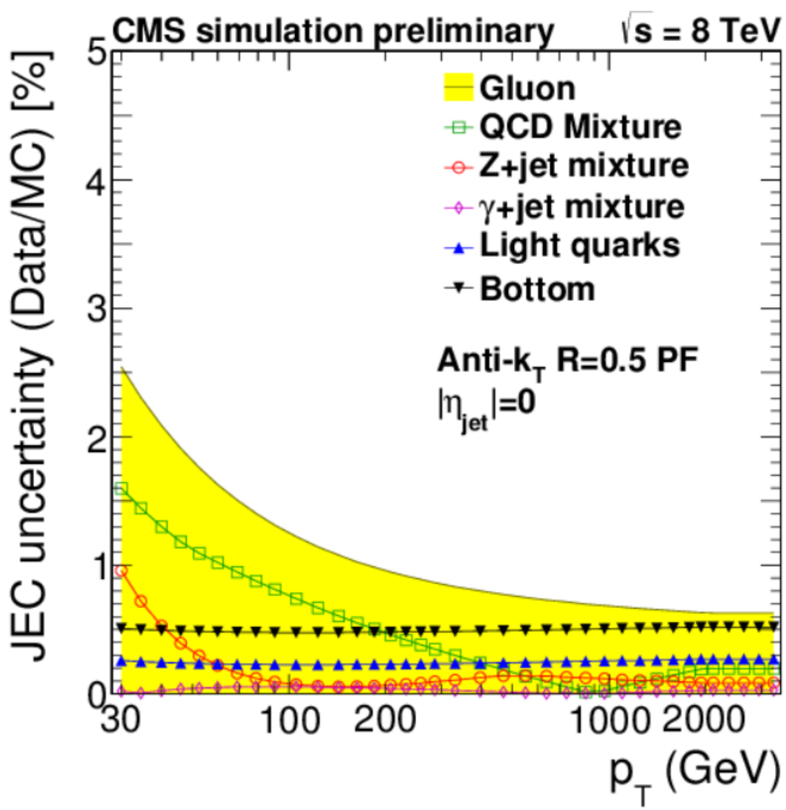
  … related to “parton re-shuffling issue”

→ prefer to treat top p_T as separate uncertainty



Jet Energy Scale: Flavour dependence at 8 TeV

- NEW: JES Flavour uncertainty (Pythia vs Herwig++) now available for individual jet flavours → allows proper propagation to final analysis
- Typical size of uncertainty for Δmtop : 0.4 GeV (Preliminary)

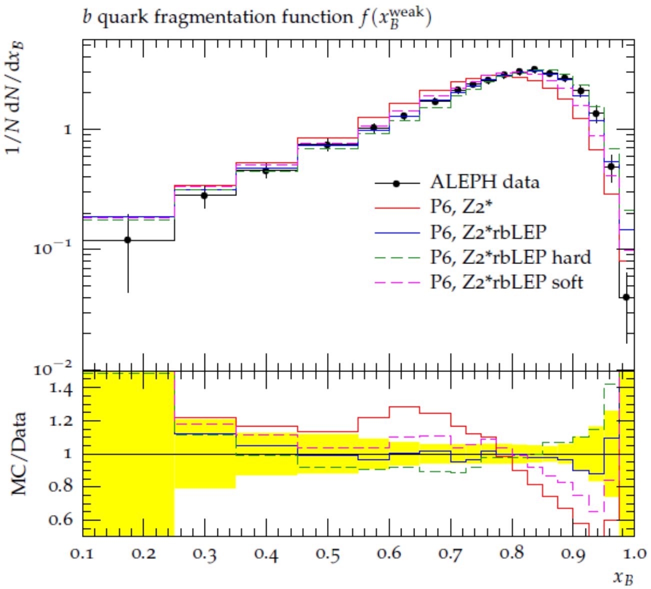


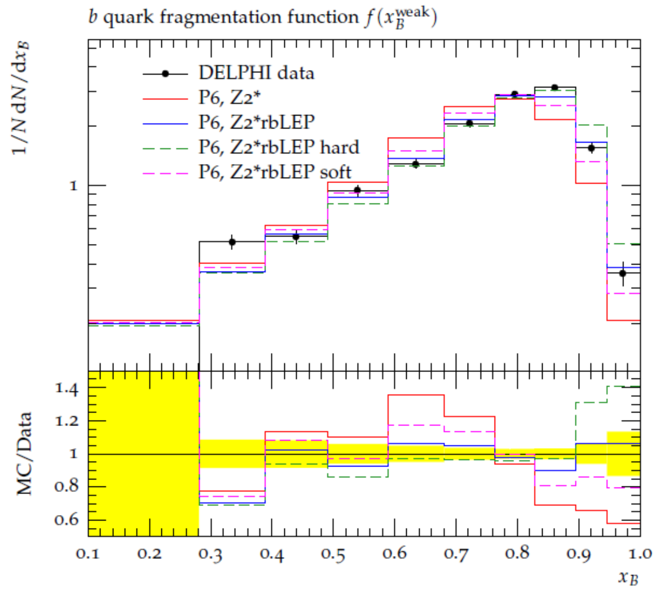
- Add uncertainty semi-leptonic BRs for B^0 and B^{+-} hadrons
  (fraction of neutrinos in b jets…)
  -0.45% +0.77% [from PDG]
  Δmtop = 0.16 GeV
- and b-fragmentation functions
  Δmtop = 0.06 GeV

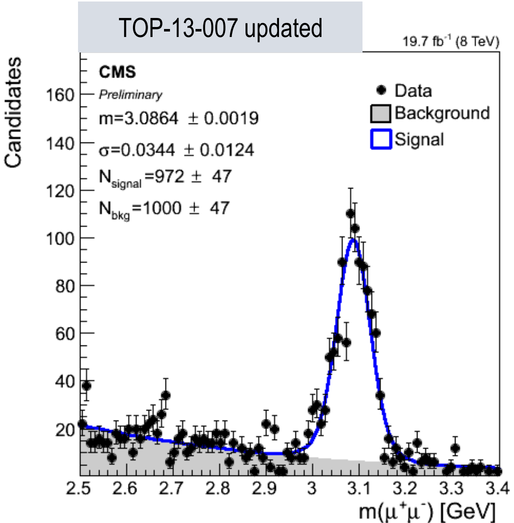
(preliminary TOP-14-001)

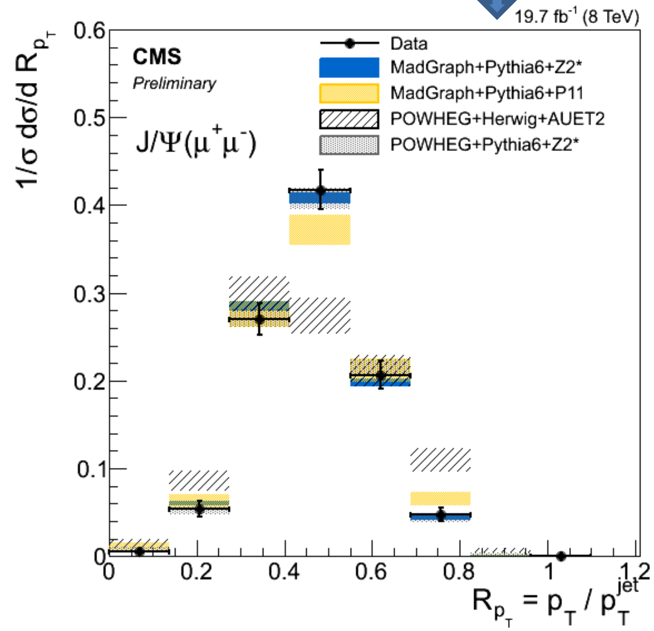
B-jet fragmentation

$$f(z) \propto \frac{1}{z^{1+r \cdot bm_\perp^2}} (1-z)^a \exp\left(\frac{-bm_\perp^2}{z}\right)$$









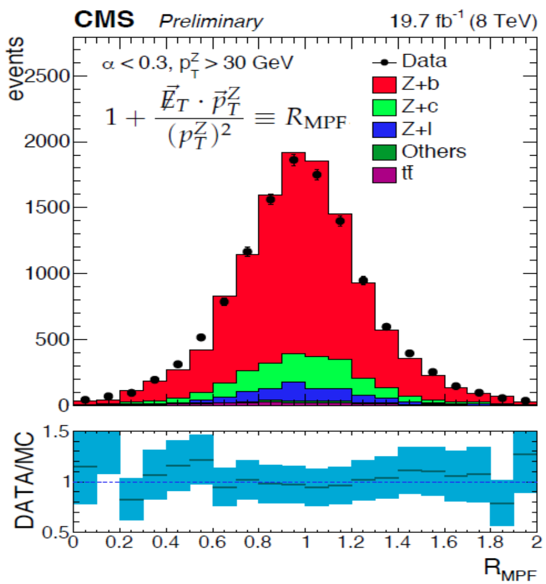
Tune r_b parameter (= r for b-jets only) to LEP data in RIVET using Professor tool

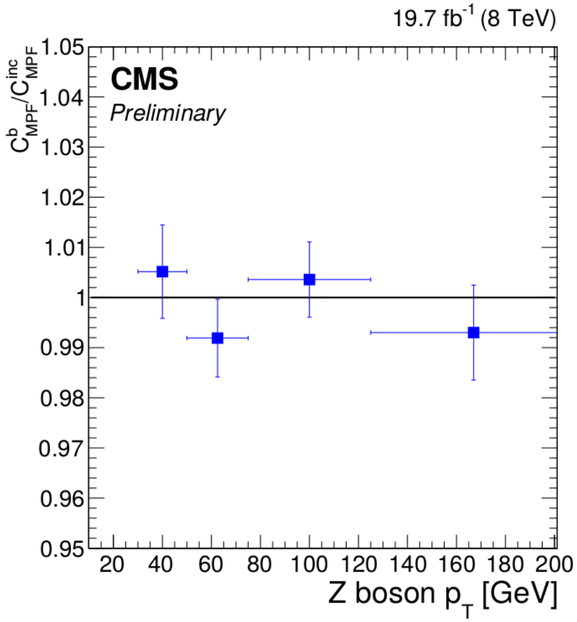
→ default Z2* value outside range (P8 default is OK)

→ Quote full difference Z2* vs Z2*rbLEP

Tune	r_b	χ^2	Ndf
Z2*rbLEP	$0.591^{+0.216}_{-0.275}$	69.0	28
– soft	0.807	138.0	28
– hard	0.316	138.0	28
Z2*	1.0		
PYTHIA 8 default	0.67		

New: b-jet calibration with b+Z events in data





JME-13-001

Source of systematic uncertainty	Systematic uncertainty
Lepton flavor	0.09%
Purity (b-tagging)	0.07%
Alpha variation	0.07%
B-tagging efficiency/mistag rate	0.05%
Neutrinos	0.32%
Fragmentation	0.04%
Jet multiplicity	0.15%
TOTAL	0.38%
TOTAL (without neutrinos)	0.21%

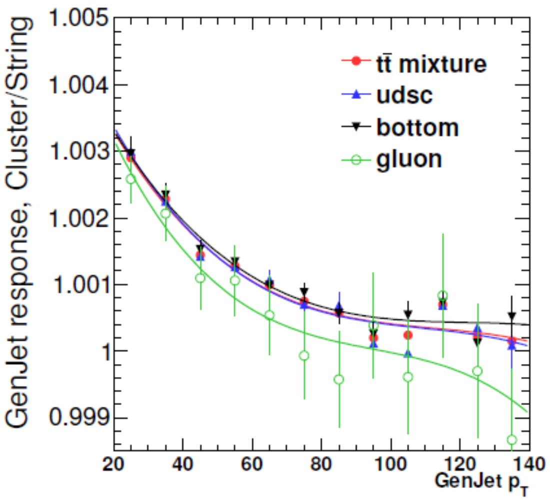
- Use p_T balance between b-jet and a well-measured object Z (→2 leptons)
- Interested in relative calibration wrt flavor-inclusive sample, compared to the MC prediction $(R_b / R_{inclusive})_{MC} / (R_b / R_{inclusive})_{data}$
- Conclusion: flavor-dependent differences are well reproduced by MC – the additional average correction factor would be:

  0.998 ± 0.004 (stat) ± 0.002 (syst)
- **Strong data-based confirmation of b-jet energy scale! (only used as cross-check)**

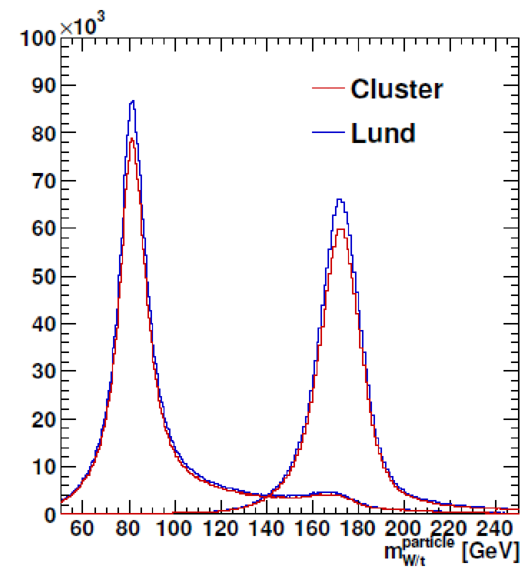
Cluster vs string fragmentation in Sherpa

M. Seidel

- Very challenging to compare different hadronisation models on equal footing…
- Here: particle-level study using Sherpa 2.1
  - Use same parton shower (CSShower++)
  - Exchange:
    - Built-in sherpa cluster fragmentation (AHADIC++, HADRONS ++)
    - Pythia 6.4.18 lund string fragmentation



- Check effect on particle jet response (particle jet energy *inc. neutrinos** vs matched parton)
  - Differences cluster/string are extremely small
  - Limits possible out-of-jet effects
- For events with m_W in 70-90 GeV range, reconstructed top mass agrees < 10 MeV



(normalization adapted for improved visibility)

(*) larger effect seen when neutrinos are excluded, due to high semi-leptonic BR in cluster model, outside PDG range

Intermediate conclusion JES + hadronization

- Hadronization uncertainty (Herwig vs Pythia) accounted for in flavour-dependent JES component
- Are there any outside-Jet effects that have not yet been taken into account?
- A number of cross-checks and additional studies performed:
  - MC@NLO+Herwig vs POWHEG+Pythia6 : Δmtop = 0.33 GeV
  - Sherpa 2.1 Cluster vs String: Δmtop < 0.01 GeV
  - B fragmentation, BRs, pt(top) treated separately

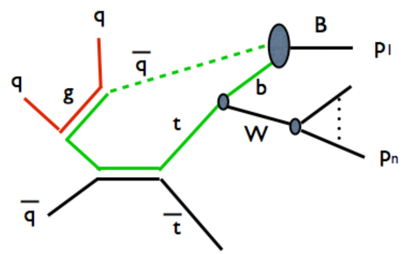
  ➔ VERY difficult to do proper comparison of modeling uncertainties! In principle requires full re-tuning and re-calibration of alternative model AND excellent statistical precision
- So far picture is consistent with NO sizeable additional effects, that are not already taken into account
- Further refinement of these studies will require detailed understanding (or active removal) of double-counting… one study planned is D0 approach: *evaluate Herwig vs Pythia difference using particle-level jet energies after applying reco-level selection*

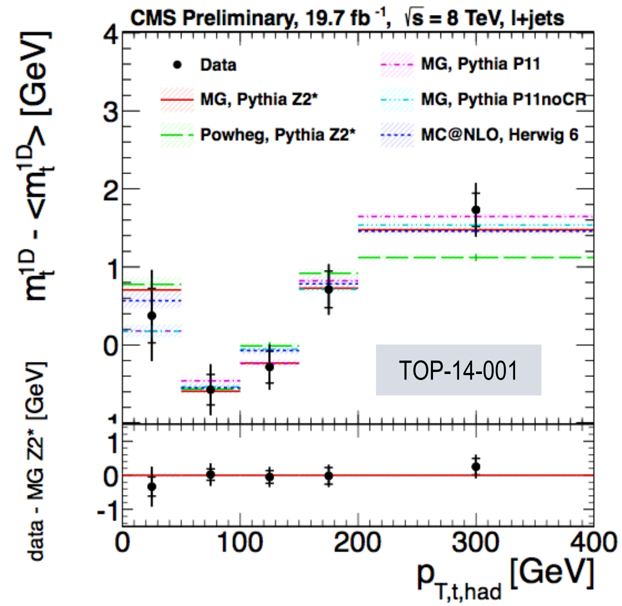
What about the mass interpretation?

- We can validate the modeling of perturbative and non-perturbative QCD effects in our MC programs, with ever increasing precision
- The question remains: what is the exact (QField-Theoretical) meaning of the mass parameter that is extracted? – mostly a theoretical question
- See dedicated talk later today (A. Hoang)
- Contribution from experimental side:
  - Study dependence of extracted mass on event kinematics
  - Use alternative mass extraction methods

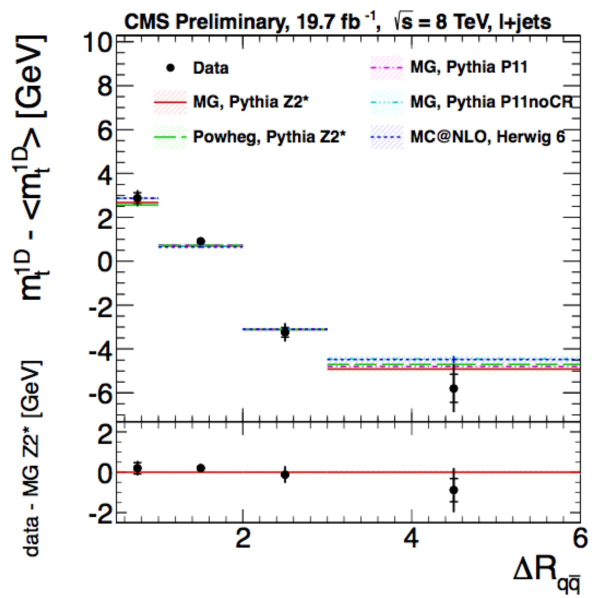
Top Mass: Kinematic Dependence

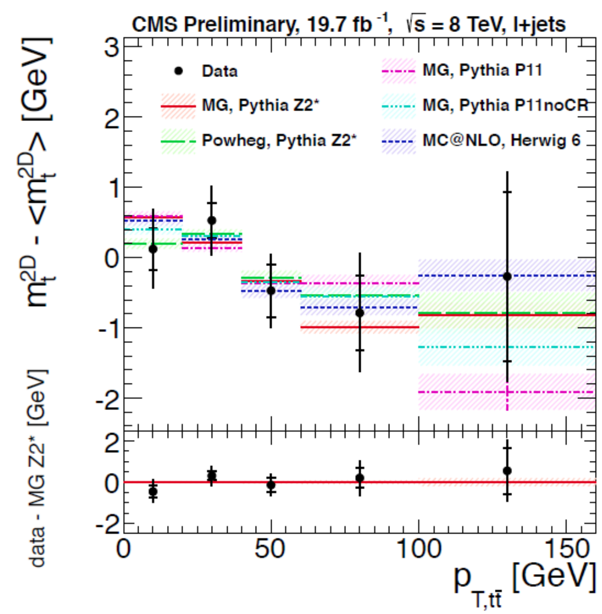
- Probe for issues with QCD modeling or Mass Definition by looking for kinematic dependence in extracted top mass
- Investigate distributions with sensitivity to
  - Color reconnection
  - ISR/FSR
  - b-quark kinematics
- Figures: $m_{top} - \langle m_{top} \rangle$
- Check 14 variables; ≈ 50 total bins





Observable	m_t^{1D} χ^2	JSF χ^2	m_t^{2D} χ^2	Ndf
$\Delta R_{q\bar{q}}$	2.87	3.66	0.83	3
$p_{T,t,had}$	0.89	12.03	5.76	4
$\lvert\eta_{t,had}\rvert$	5.56	1.22	1.14	3
H_T^4	6.19	9.18	7.54	4
$m_{t\bar{t}}$	2.16	4.69	4.22	5
$p_{T,t\bar{t}}$	1.02	1.22	1.33	4
Jet multiplicity	4.24	0.10	1.16	2
$p_{T,b,had}$	2.57	5.80	2.17	4
$\lvert\eta_{b,had}\rvert$	1.15	0.08	0.72	2
$\Delta R_{b\bar{b}}$	0.37	1.63	1.77	3
$p^1_{T,q,had}$	4.04	8.39	1.28	4
$\lvert\eta^1_{q,had}\rvert$	3.36	3.79	6.27	2
$p_{T,W,had}$	1.59	8.06	1.60	4
$\lvert\eta_{W,had}\rvert$	1.41	1.09	1.35	3
Total	37.43	60.94	37.15	47



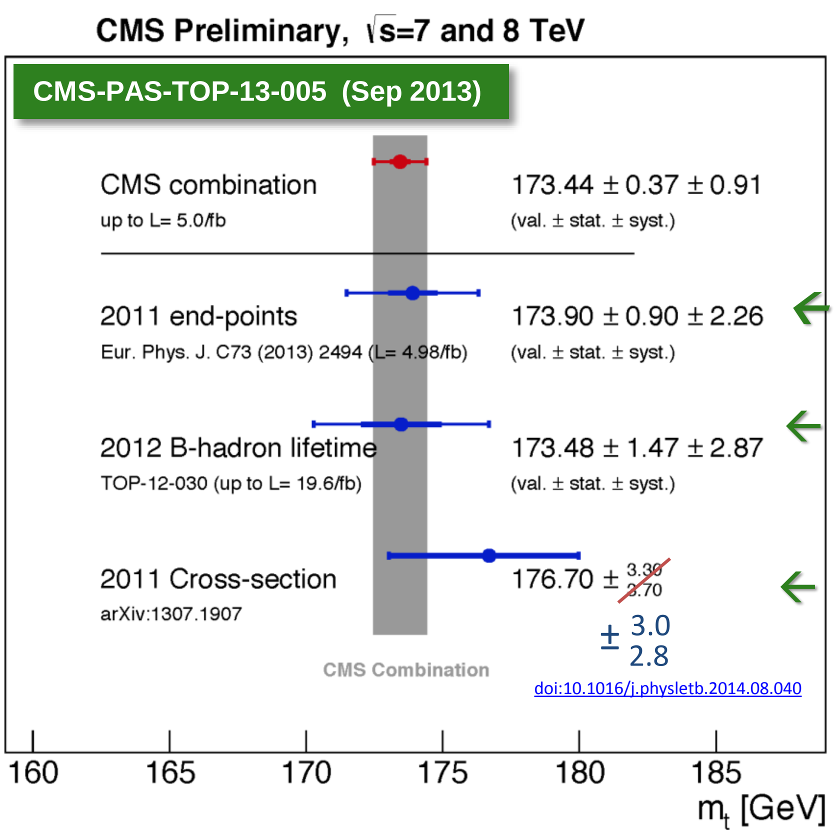


No significant deviations between data and various models w.r.t their kinematic dependence

CMS Top Mass with alternative techniques

Alternative methods with different systematic uncertainties or mass definition

- For example: m^{pole}_{top} from the inclusive cross-section
- <u>NEW</u>: use differential distribution of observable that can be calculated perturbatively
- Other measurements in preparation



← *No MC used … endpoint using kinematics only (no QCD)*

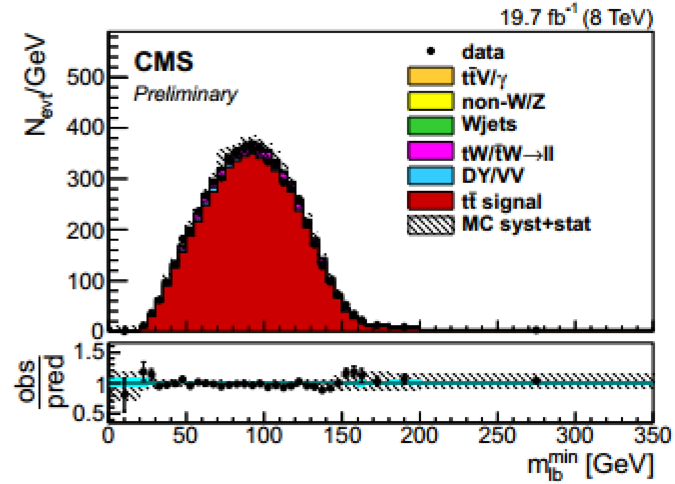
← *B hadron lifetime (Lxy) method… no jets, only uses tracking. Limitation: depends on correct modeling of top production (top pT)*

← *well-defined top 'pole mass' using NNLO prediction*

Other method proposed: peak position of energy spectrum of b-jets, less sensitive to top production modeling (talk by R. Franceschini later today)

New: use m_{lb} distribution and forward folding

- Signature di-lepton channel
  - 2 leptons, ≥ 2 jets, ≥1 b-tags
  - Plot mass of b-jet (highest p_T) and lepton that gives lowest m_{lb} → correct in 85%



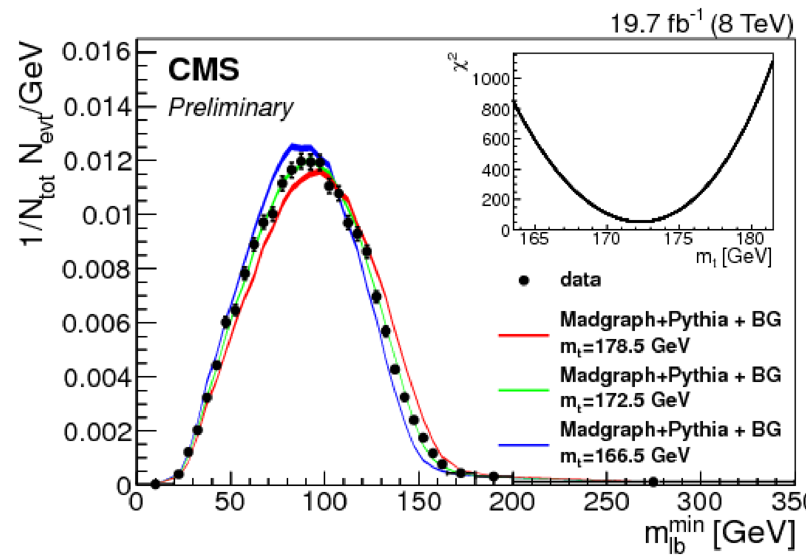
- Introduces "Forward Folding Matrix"
  - Encodes detector efficiency and resolution
  - Forward folding matrices to be provided for all systematic variations

- Can be used with any theoretical calculation that gives m_{lb} in fiducial volume
  - Here: use Madgraph+Pythia as input
  - blinded analysis
  - Extraction also performed with MCFM (NLO pole mass): yields **171.4 ± 1.1 GeV**

    … using NLO production + LO decay

    (LO prod and decay): 171.5

    (full NLO prod and decay) 172.3

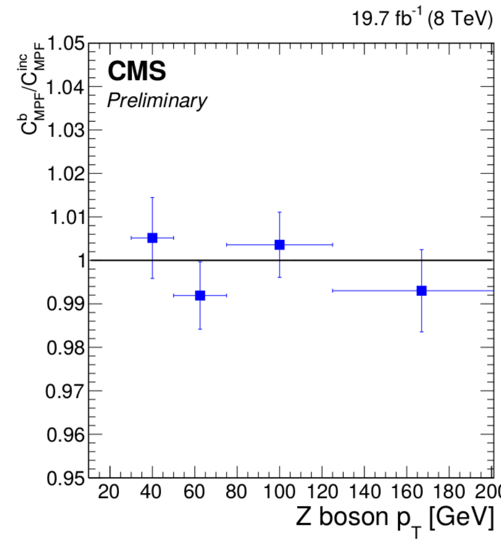


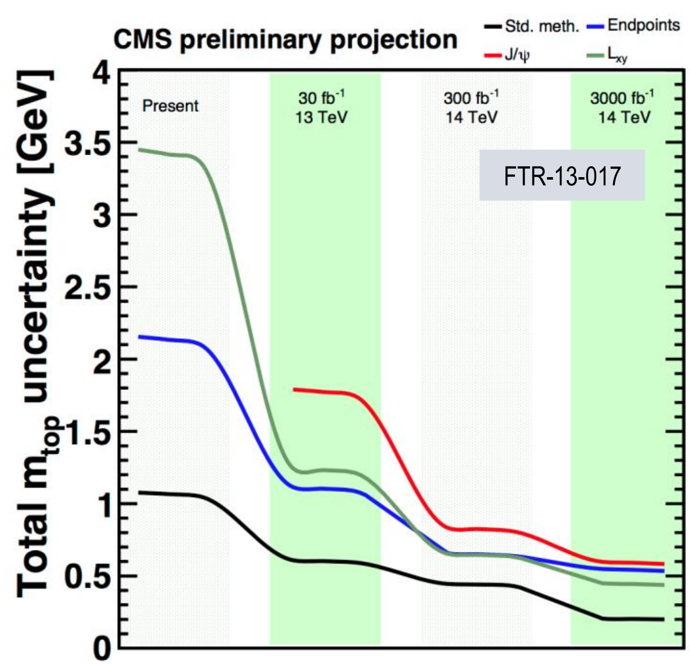
m_t = 172.3 ± 1.33 GeV (0.77%)

CERN X-talk on this topic Thu next week, Jan 22

Top mass in CMS: outlook

- Finalize Run1 publications
- We can still learn from 8 TeV data to further tune and constrain MC models and variations
- For Run2: implement and validate new (NLO+PS, multi-leg) MC Tools
- Large potential for enhanced precision, from improved MC tools and understanding, new analysis techniques, and huge statistics in Run2 and beyond

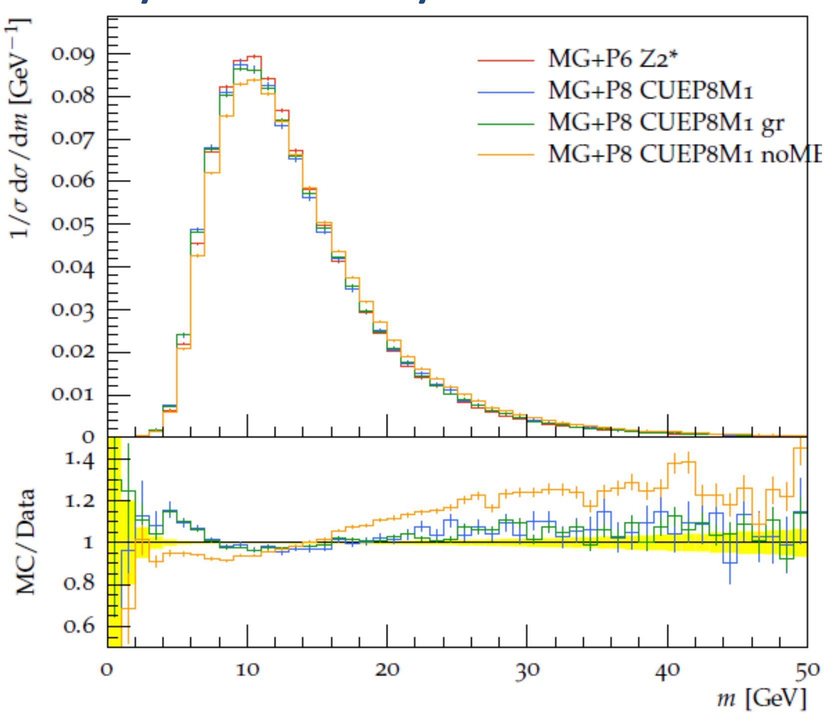




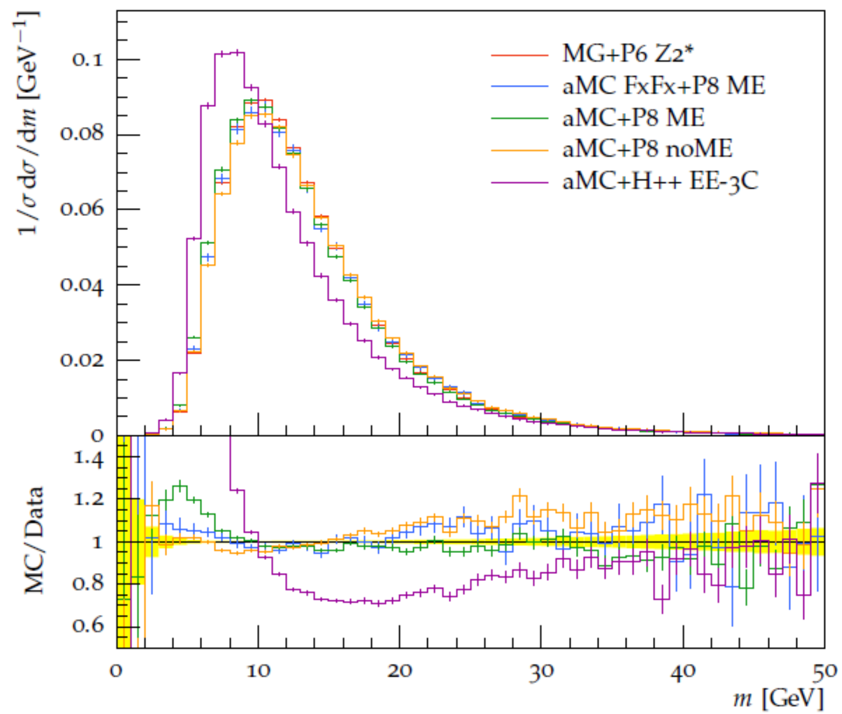
Preview of new MC Tools for Run2

Invariant mass of leading b-jet
in ttbar, lepton+jets selection, using RIVET, simulation only
*Ratio = comparison to MG+Pythia6 Z2**

Pythia6 vs Pythia8



aMC@NLO

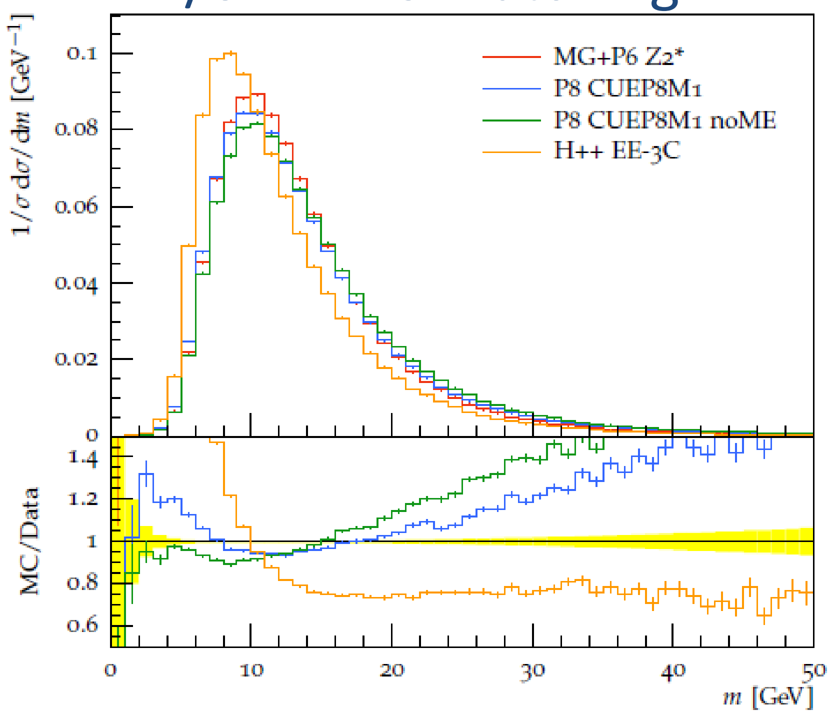


P8 CUEP8M1 tune looks promising (based on Monash + UE tune CMS/CDF data)

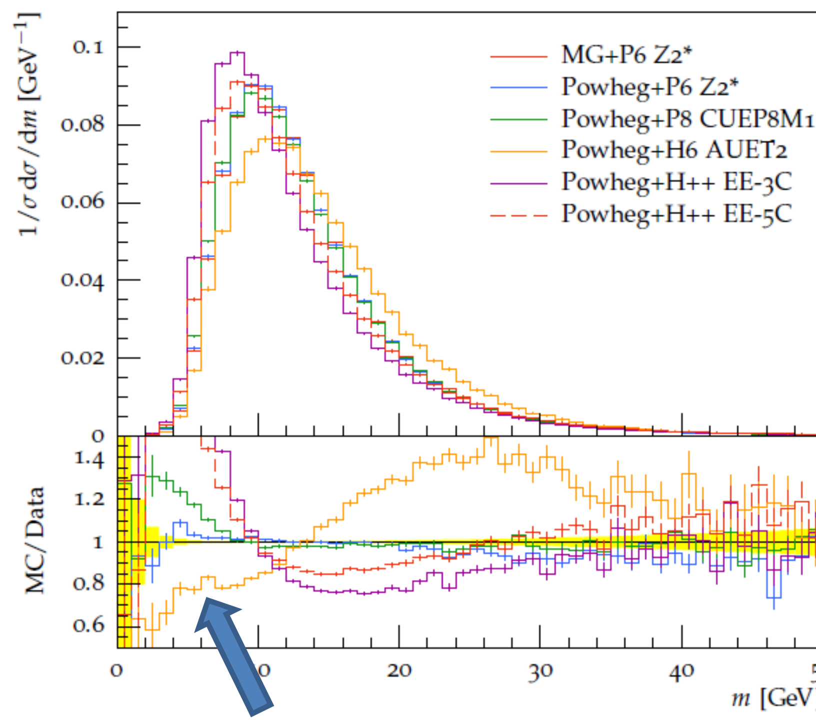
Preview of new MC Tools for Run2

Invariant mass of leading b-jet
in ttbar, lepton+jets selection, using RIVET, simulation only
*Ratio = comparison to MG+Pythia6 Z2**

P8 and H++ w/o ME-PS matching



POWHEG



Why is H6 so different from H++?

Conclusions

- Complete set of (standard) 8 TeV top mass results available
  - Systematic uncertainties refined and improved wrt 7 TeV
- New analysis approach: m_{lb} spectrum with forward folding matrix
  - and a number of other alternative methods in preparation
- Overall good consistency between all measurements
- Hadronization uncertainty included in JES, confirmed by new b-JES measurement in b+Z events
  - so far studies confirm picture that out-of-jet effects are negligible or accounted separately (MC tune, radiation, pt(top))
- Validating new MC Tools for Run 2 !