

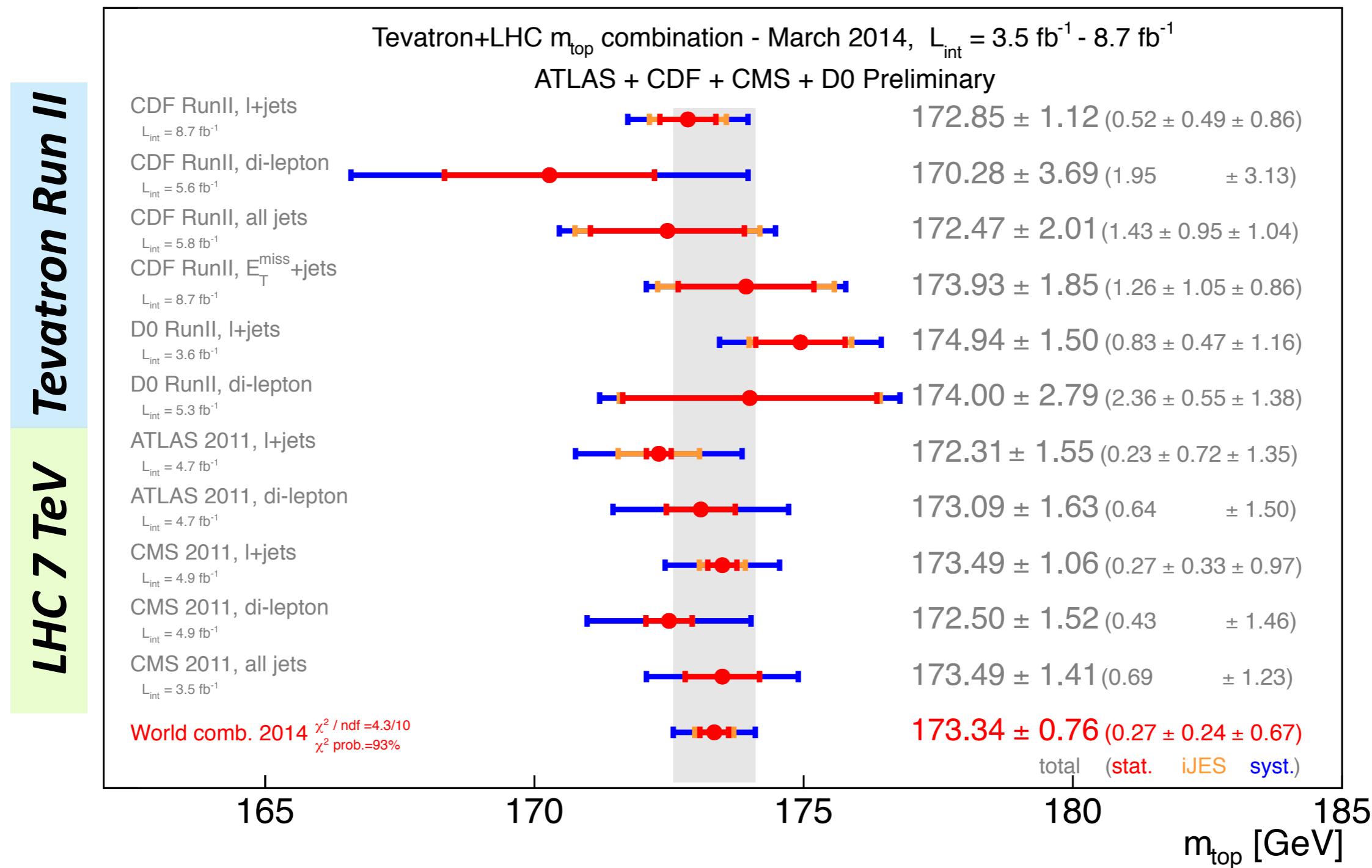
Towards a new top mass world combination

Benjamin Stieger (CERN)

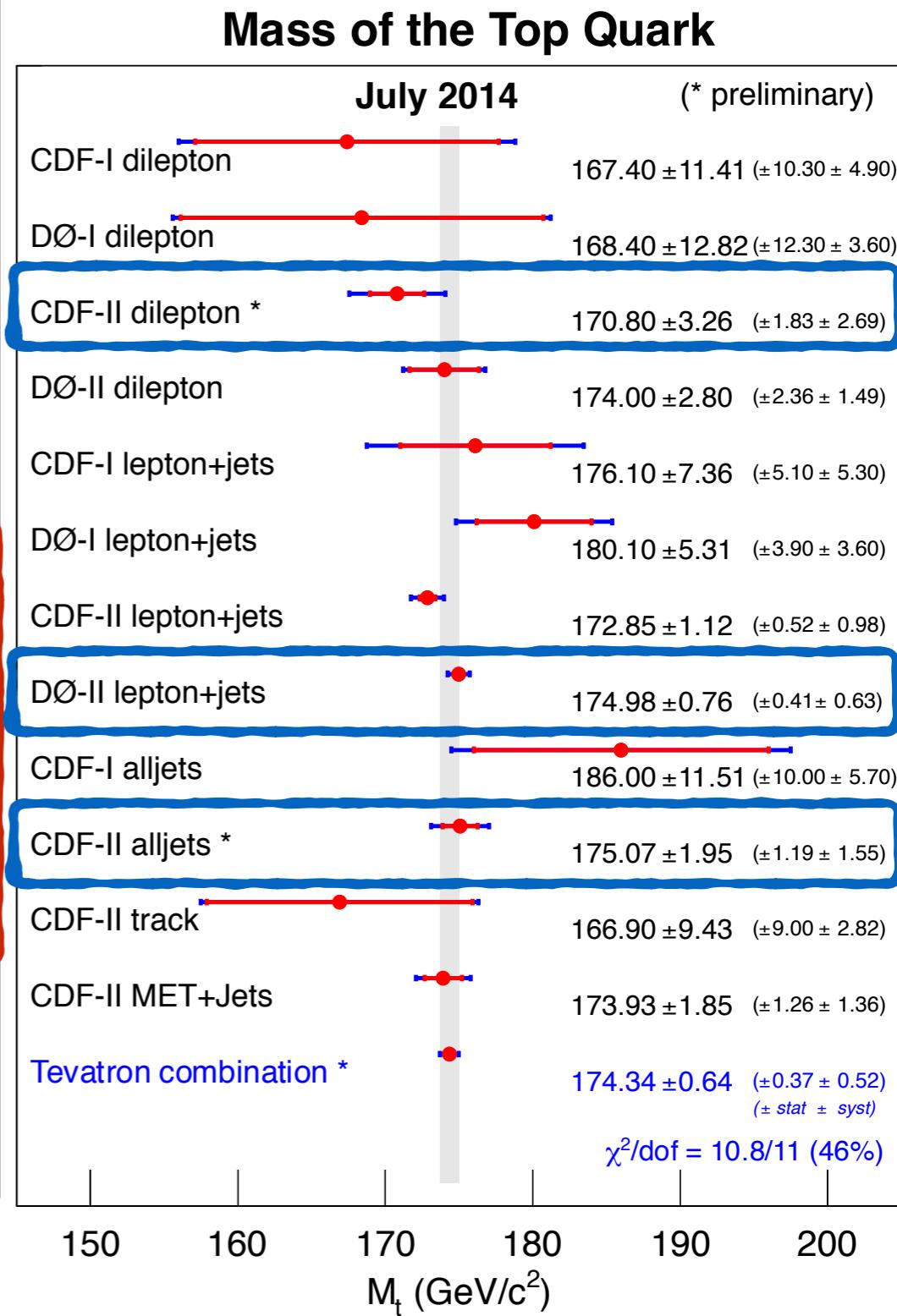
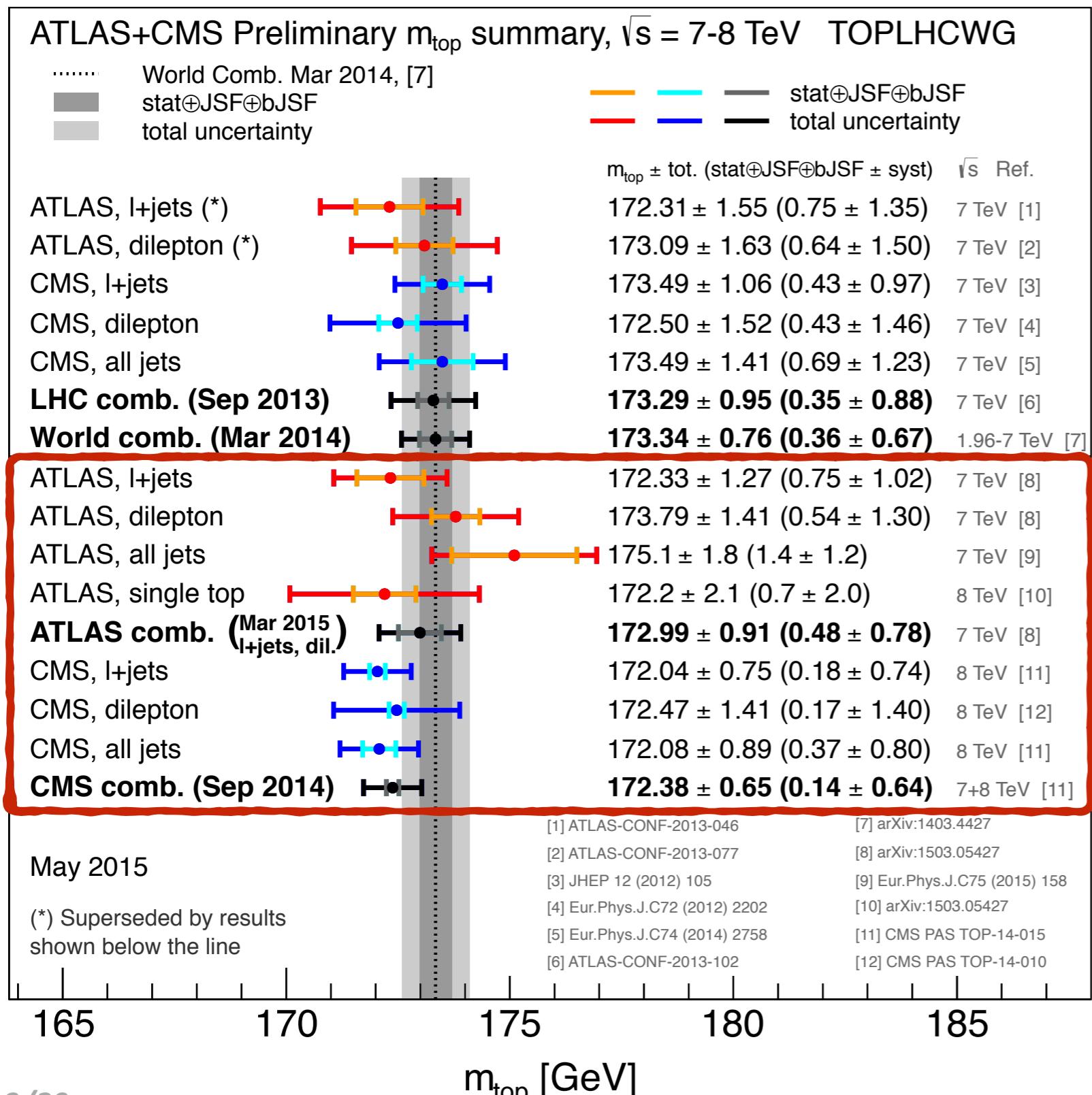
*Top LHC Working Group
May 21st 2015*

Previous World Combination

- First ever combination of LHC/Tevatron data!
- Great forum to discuss common issues



Several updated or new results from each experiment are waiting to be included, more expected soon.



Which results to include?

- Can only combine things that measure the same:
 - Standard template methods extracting a MC parameter
 - Include **single top** measurements or not?
- What about '**alternative**' measurements?
 - Could provide gain from different systematics profiles
 - Will require evaluation of statistical overlaps
- Could consider a separate **combination of pole-mass measurements**
 - Possibly separate values for each center-of-mass point

Difference between very precise individual results triggered additional investigations

- Most precise measurements from CMS and D0 **spread by almost 3 GeV**, with individual uncertainties of ~800 MeV:

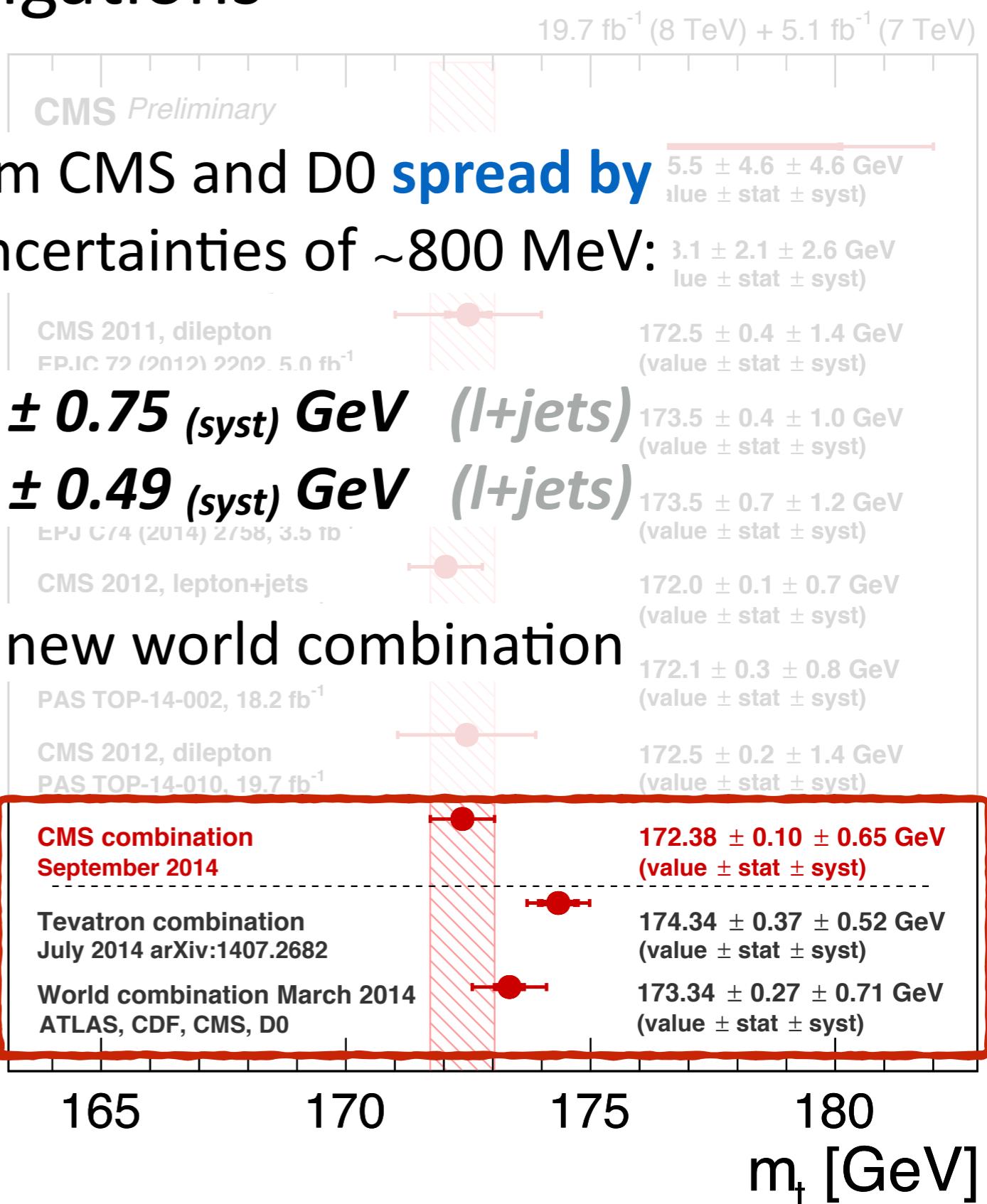
CMS: 172.04 ± 0.19 (stat+JSF) ± 0.75 (svst) GeV (l+jets)

D0: $174.98 \pm 0.58_{\text{(stat+JES)}} \pm 0.49_{\text{(syst)}} \text{ GeV}$ (l+jets)

- Would play an important role in new world combination

- Initiated **fruitful discussions** and exchange of ideas between D0 and CMS

- Performed many **cross-checks**, some still ongoing



Considering all the results, there is no serious statistical incompatibility in the combination.

- Combining **only the two l+jets results**:

$$X^2/N_{dof} = 9.8 / 1, \text{Probability } 0.2\%$$

- **Maximum bias!**
 - Similar weight for both results
 - Depending on assumed correlations: 2-3 sigma significance
-
- Adding those results to the **previous world combination**:

$$X^2/N_{dof} = 17.1 / 13, \text{Probability } 19\%$$

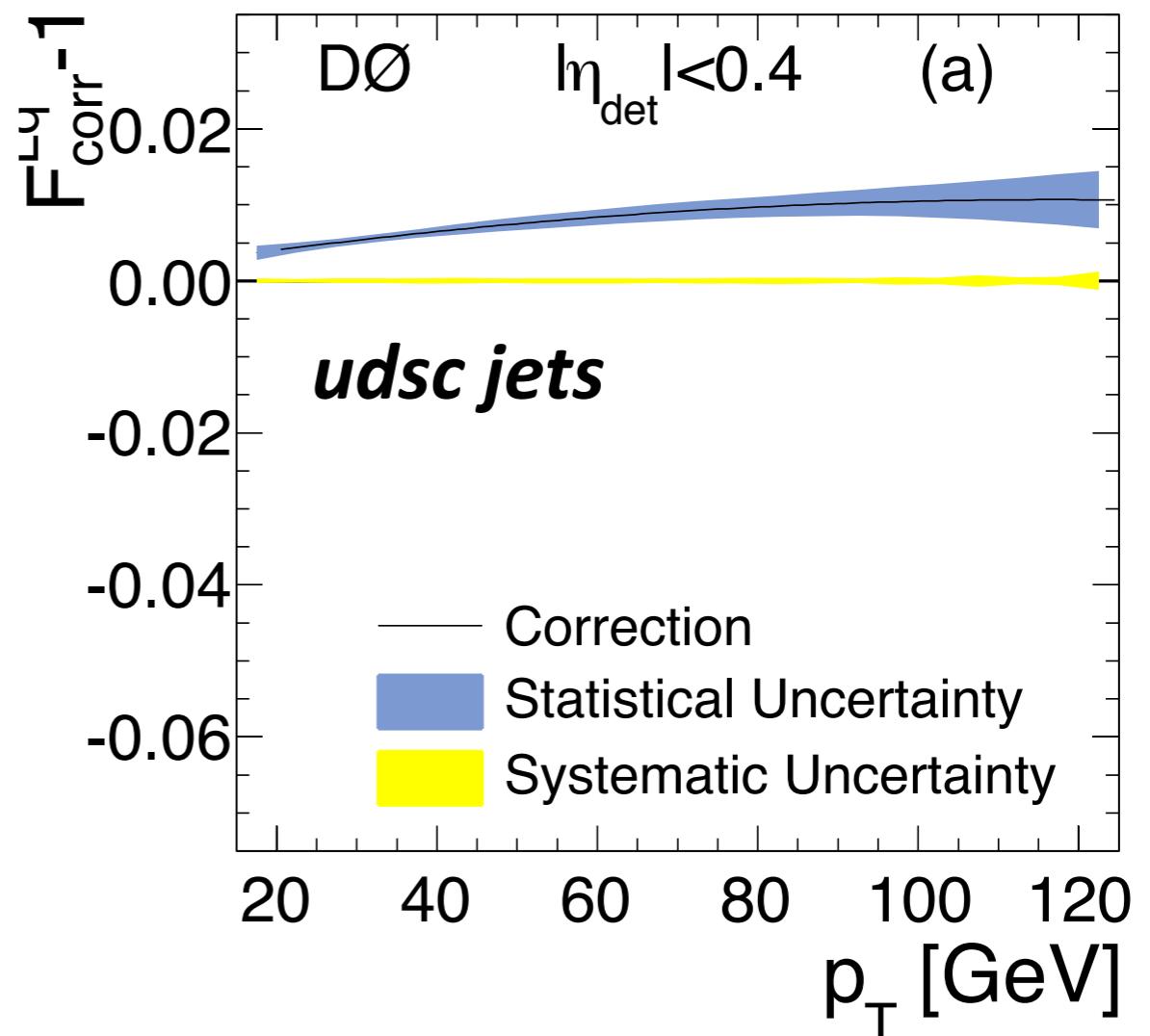
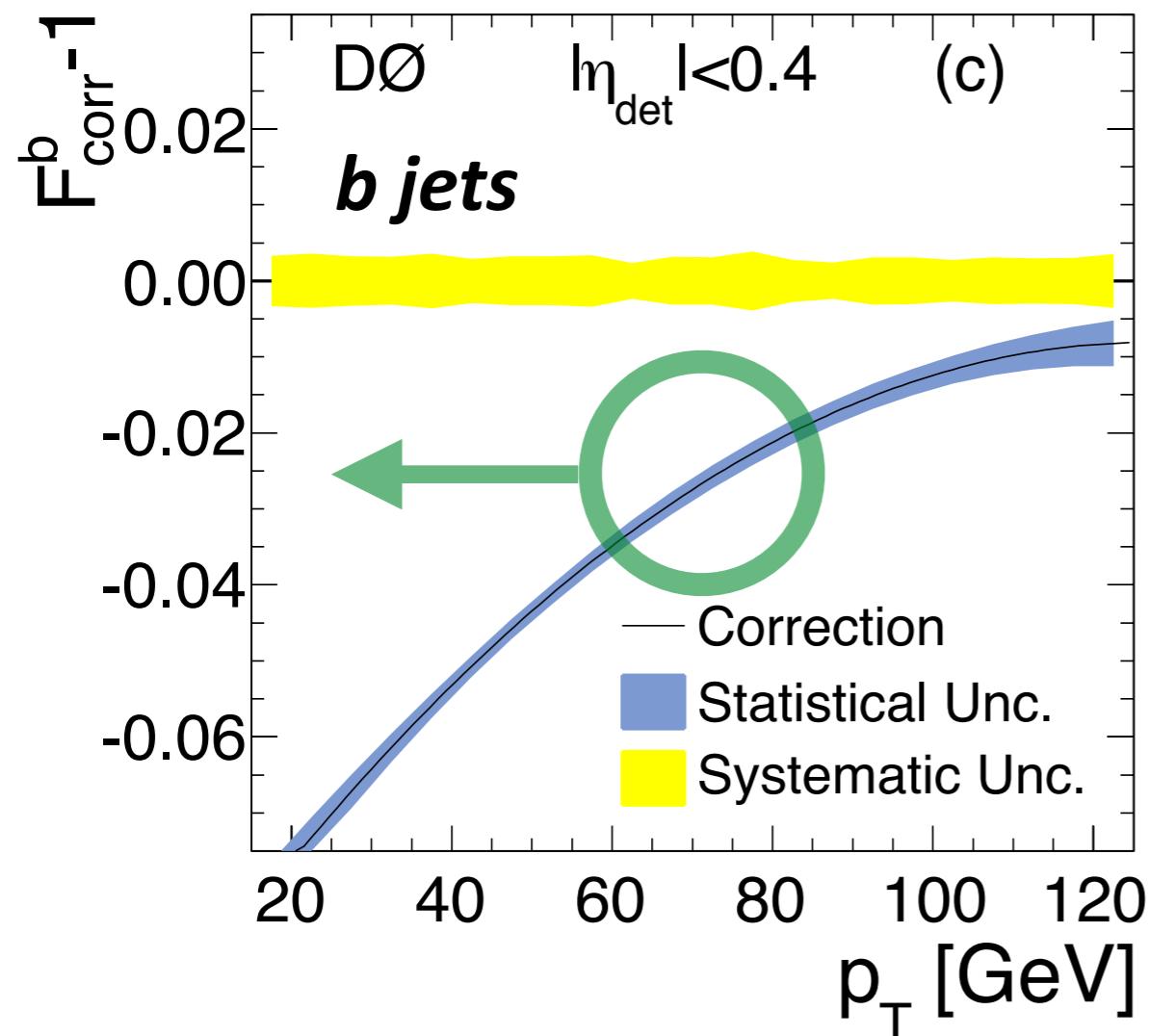
(2014 WA + public CMS 8 TeV + D0 l+jets results)

- **Not a real issue from statistical point of view**
- Investigate whether there is a **reason for the difference?**

- Some studies documented by D0 in PRD: [arXiv:1501.07912](https://arxiv.org/abs/1501.07912)

D0: b-Jet Energy Scale

- **Large correction with high impact:** 2 % shift \rightarrow 1 GeV shift in m_t



- **Dominant systematics** on correction:

- Variation of **functional shapes of single particle response**
 - Calorimeter with zero suppression on/off
 - Very conservative estimate

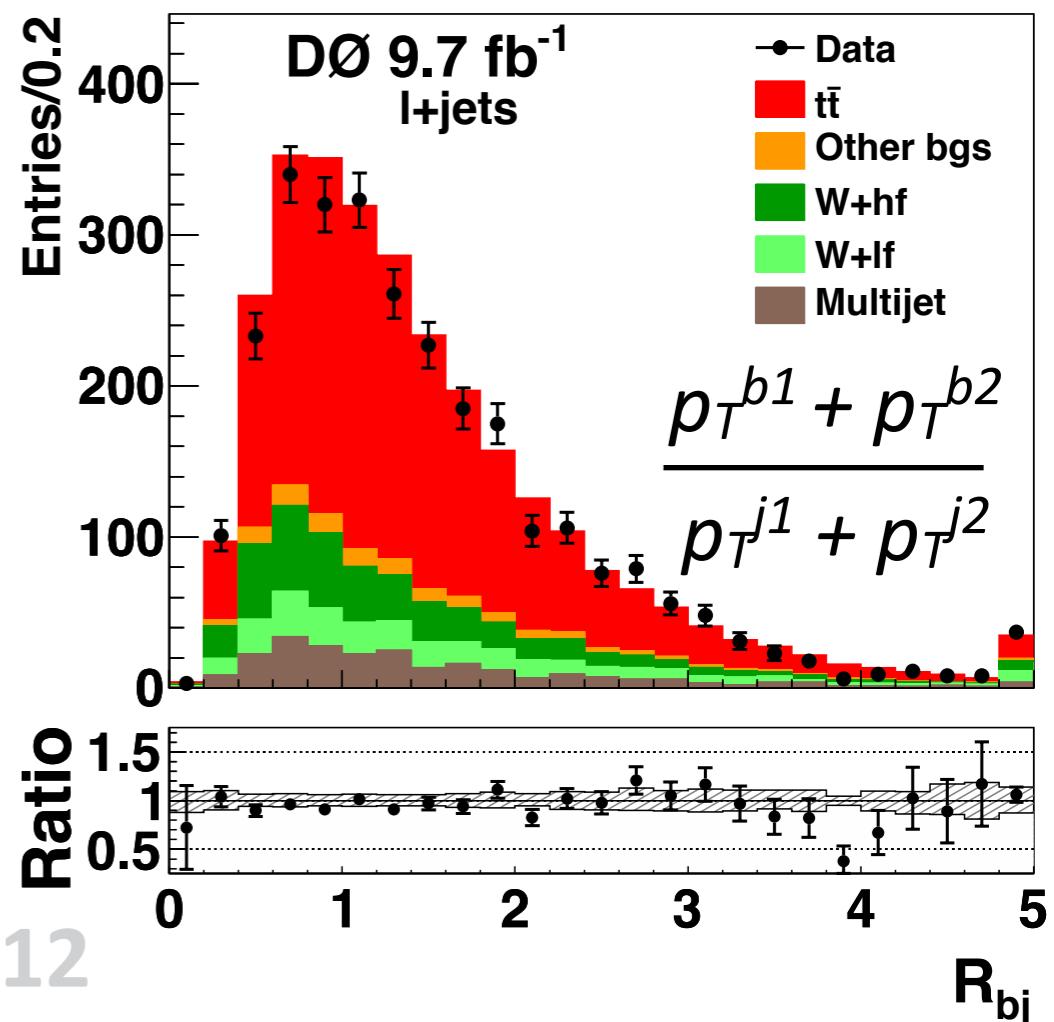
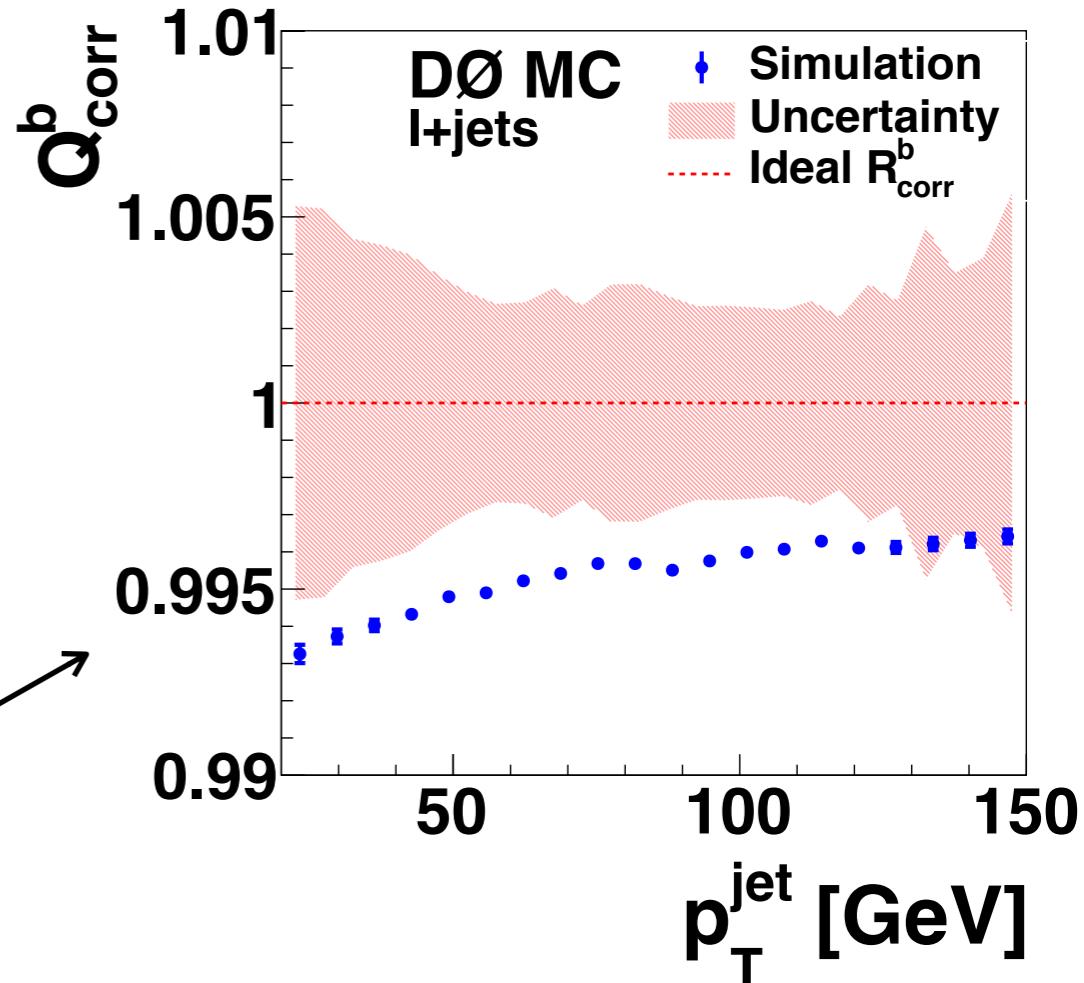
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D0: b-JES Checks

- Jet flavor composition in γ +jet and dijet samples
 - Comparing them independently
→ consistent within uncertainty

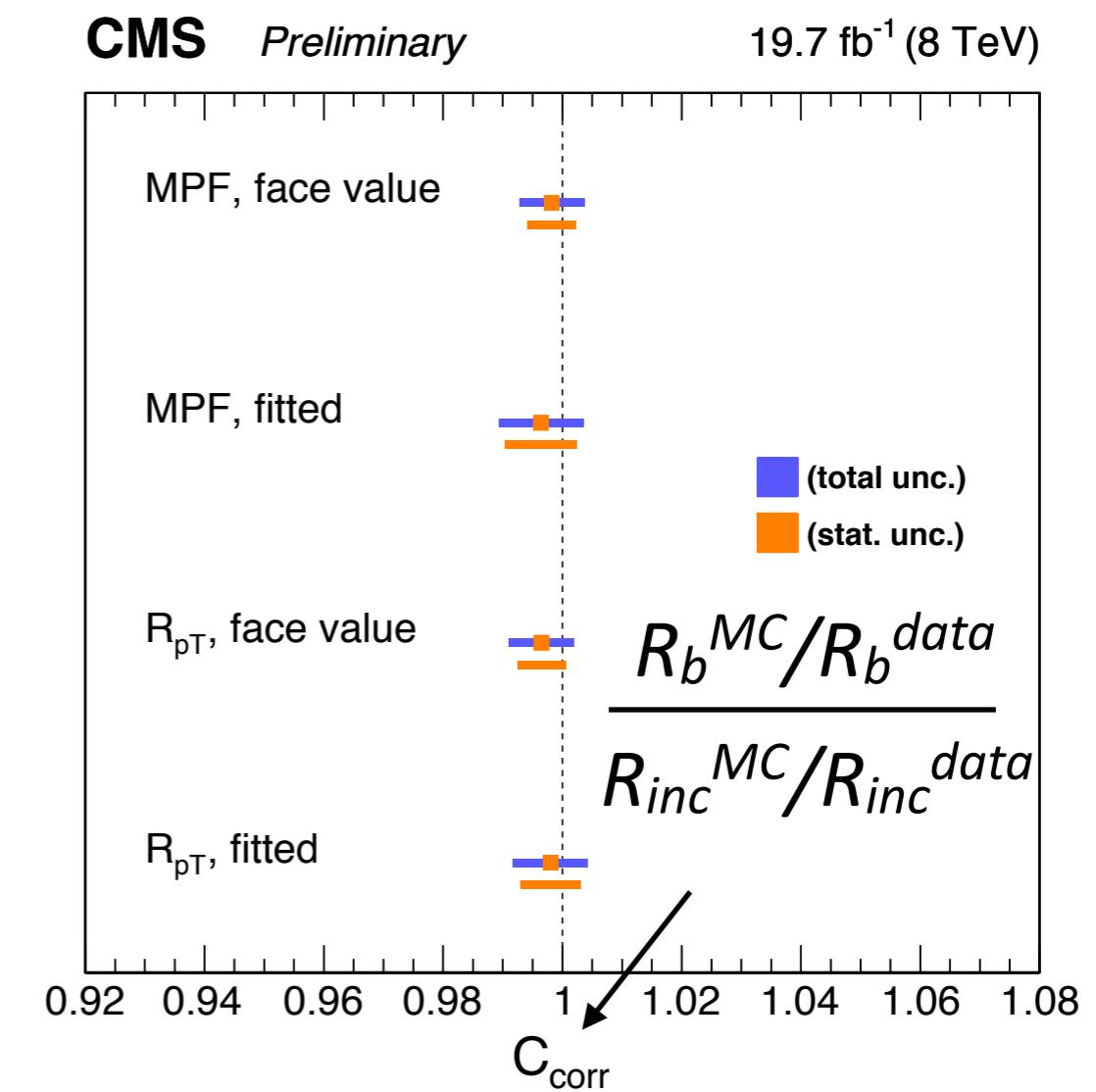
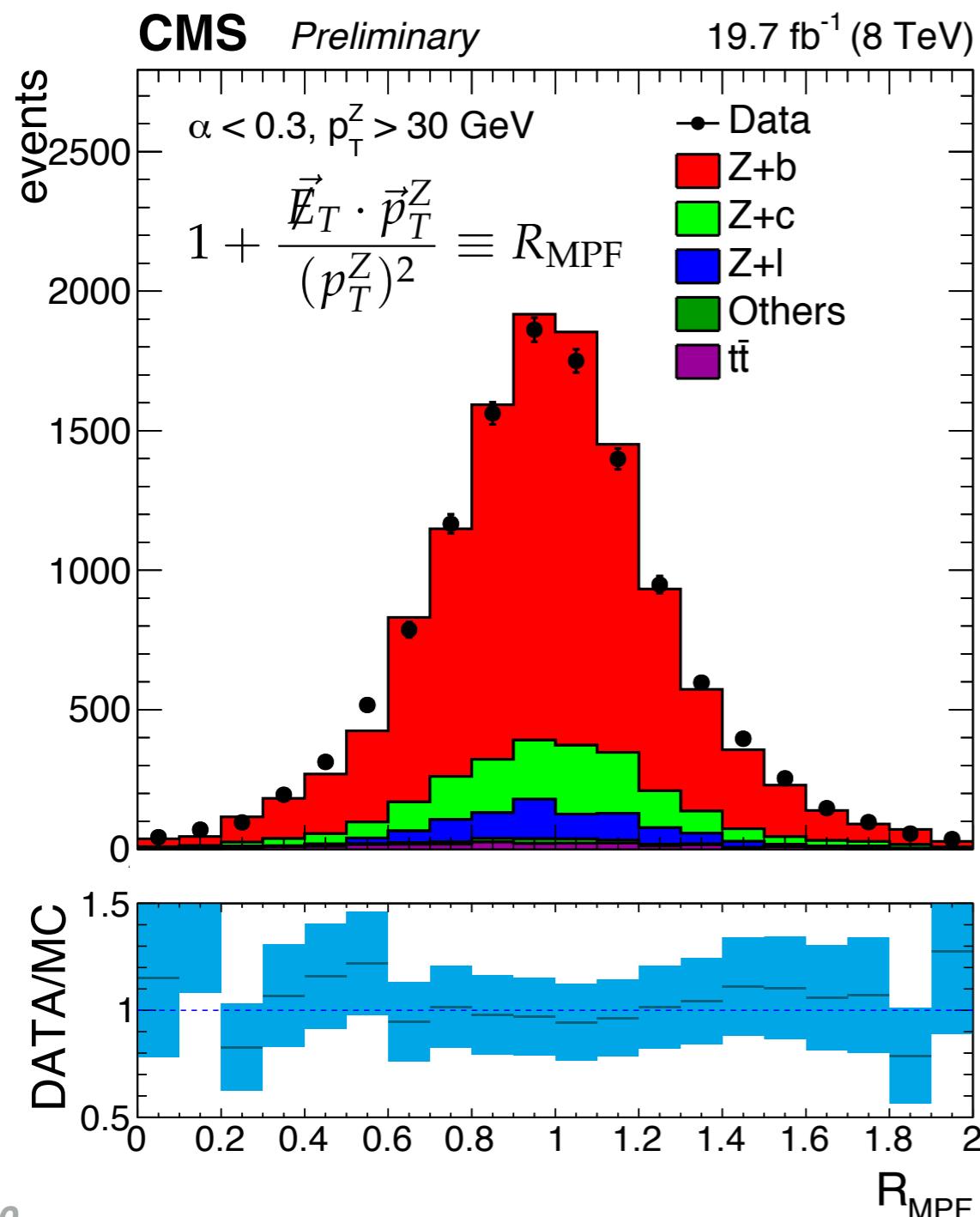
$$Q^b_{\text{corr}} = \frac{F^b_{\text{corr,Alpgen+Herwig}}}{F^b_{\text{corr,Alpgen+Pythia}}}$$

- Verify bJES directly using **R_{bj}** observable (similar to ATLAS 3D)
 - Consistent with 1 within large uncertainties (3% syst., 2% stat.)



CMS: b-Jet Energy Scale

- Independent result using **Z+b events in the data**
- Confirms bJSF consistent with 1

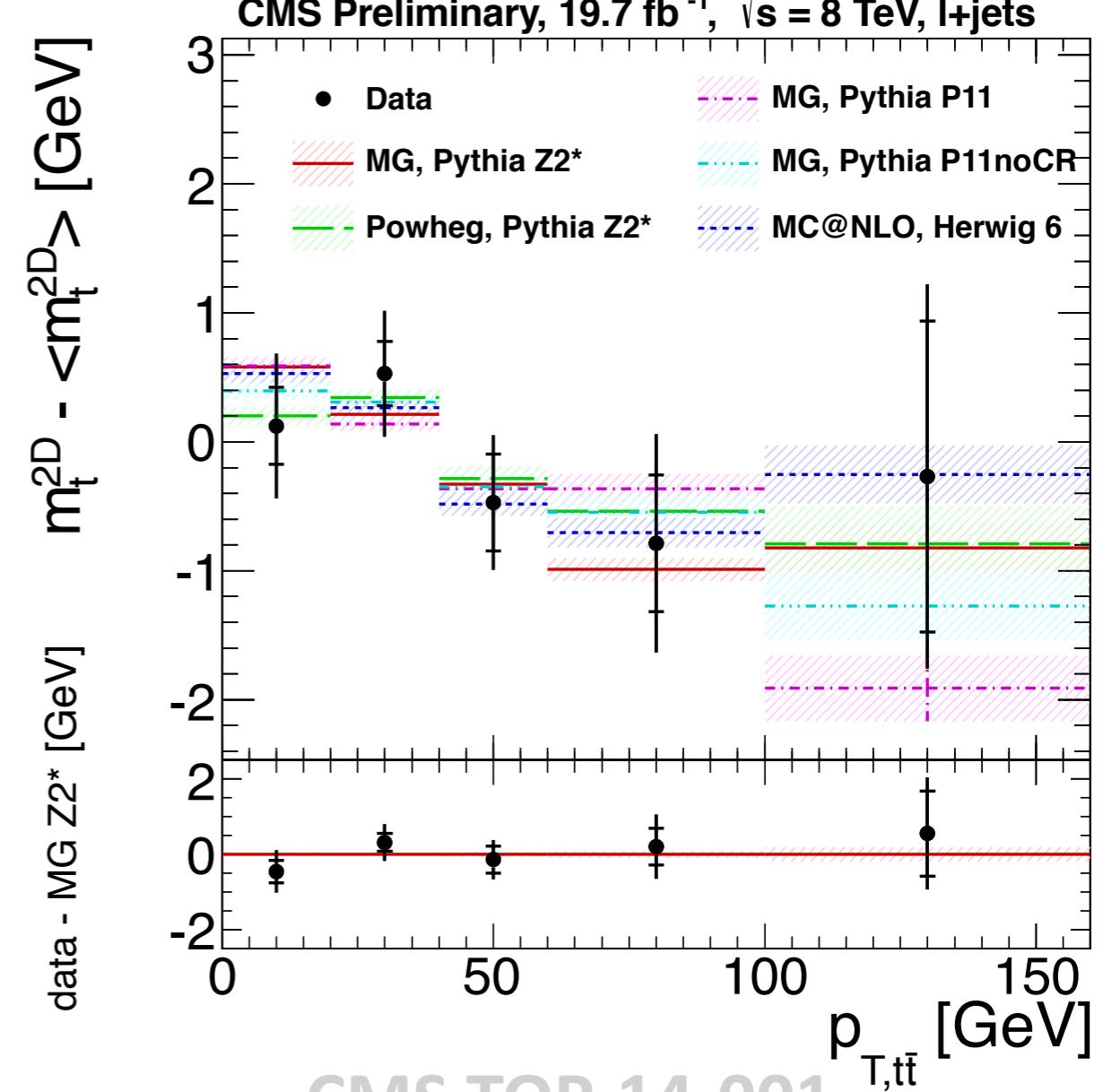
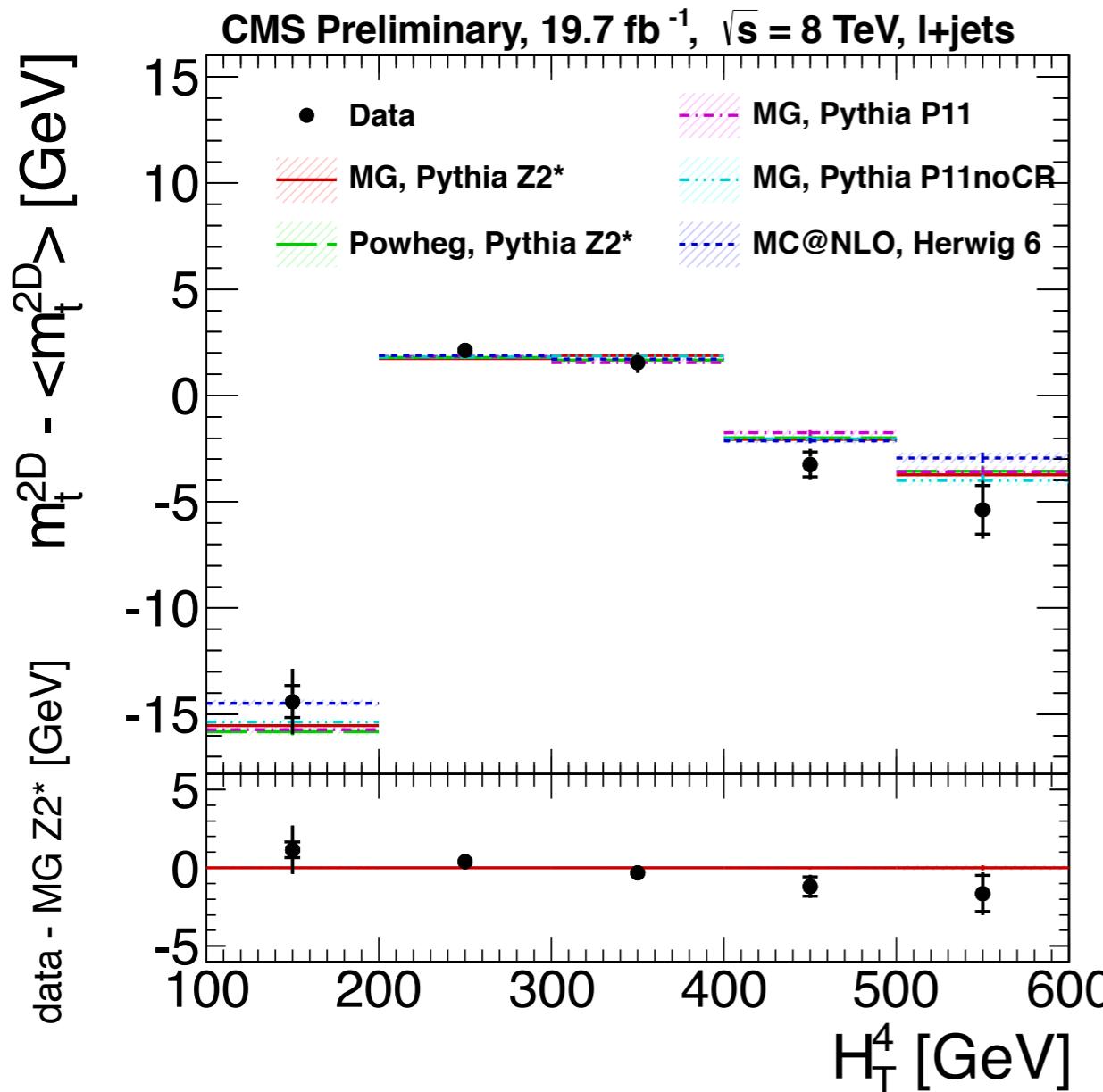


$$C_{\text{corr}} = 0.998 \pm 0.004(\text{stat}) \pm 0.004(\text{sys})$$

Measure m_{top} as a function of event kinematics to check whether they would induce a shift

- Data is **well-described** by various different MC setups
- **D0-like selection** gives insignificant shift ($-0.15 \pm 0.30 \text{ GeV}$)

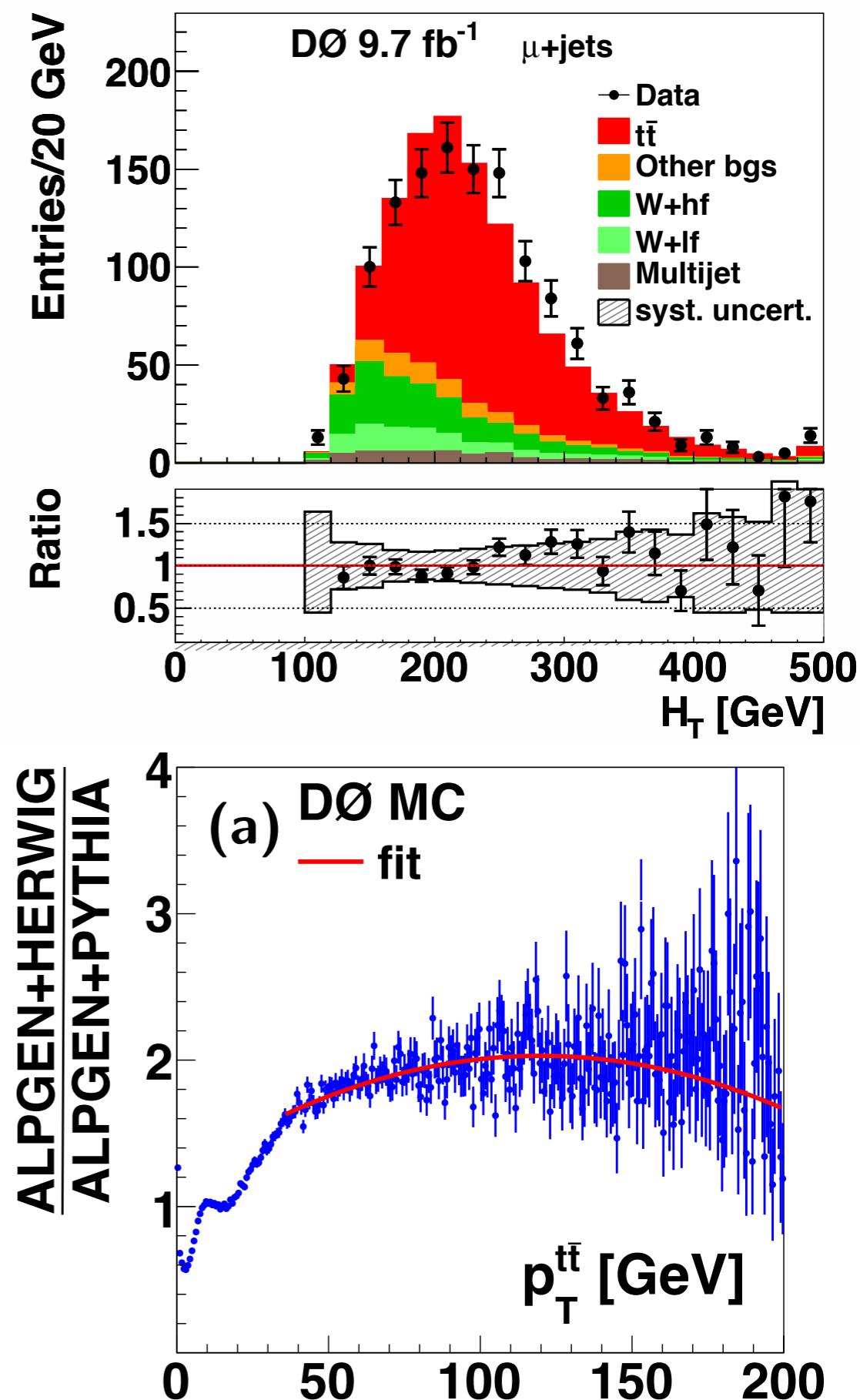
(=4 jets, $p_T(t\bar{t}) < 30 \text{ GeV}$)



CMS TOP-14-001

m_{top} vs event kinematics at D0

- H_T (scalar sum of Jet E_T)
 - Only two bins due to **lack of statistics**
 - Exclude large effect on m_{top} extraction
 - **Reweighting HT to data** has effect on the order of **100 MeV** (JSF compensates)
- p_T of the $t\bar{t}$ system
 - Reweight MC to data (included as systematic uncertainty)
 - Compare when reweighting spectrum of Pythia to Herwig
 - JSF compensates: impact **at level of 100 MeV**



The remaining question is whether we are all measuring the same thing.

- Technically: standard methods measure a **MC parameter**
 - Does that mean the same thing for the different generators?

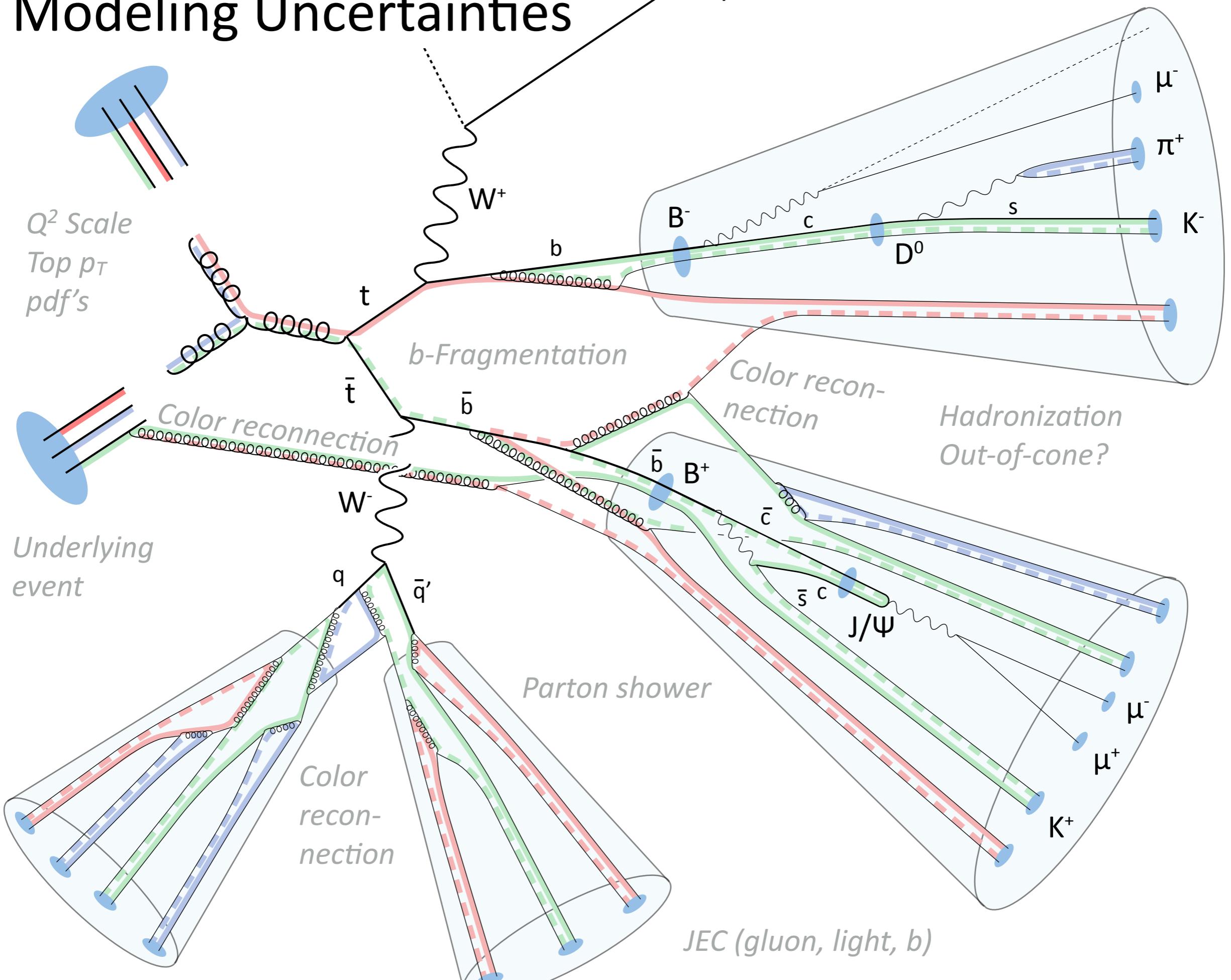
Experiment	Matrix Element	Parton shower / hadronisation	PDF	Tune
CDF	PYTHIA	PYTHIA	CTEQ5L	Tune A
D0	ALPGEN	PYTHIA	CTEQ6L1	Mod. Tune A
ATLAS	POWHEG	PYTHIA	CT10	Perugia2011C
CMS	MADGRAPH	PYTHIA	CTEQ6.6L	Z2

- **Checks with different ME generators give small shifts:**
 - E.g.: **120 MeV** between *MadGraph+PY* and *Powheg+PY* (*CMS*)
220 MeV between *MC@NLO+HW* and *Powheg+HW* (*ATLAS*)
150 MeV between *Alpgen+HW* and *MC@NLO+HW* (*D0*)
- As far as we can tell, **we are measuring the same**
- Ultimate test will be a **common generator setup**

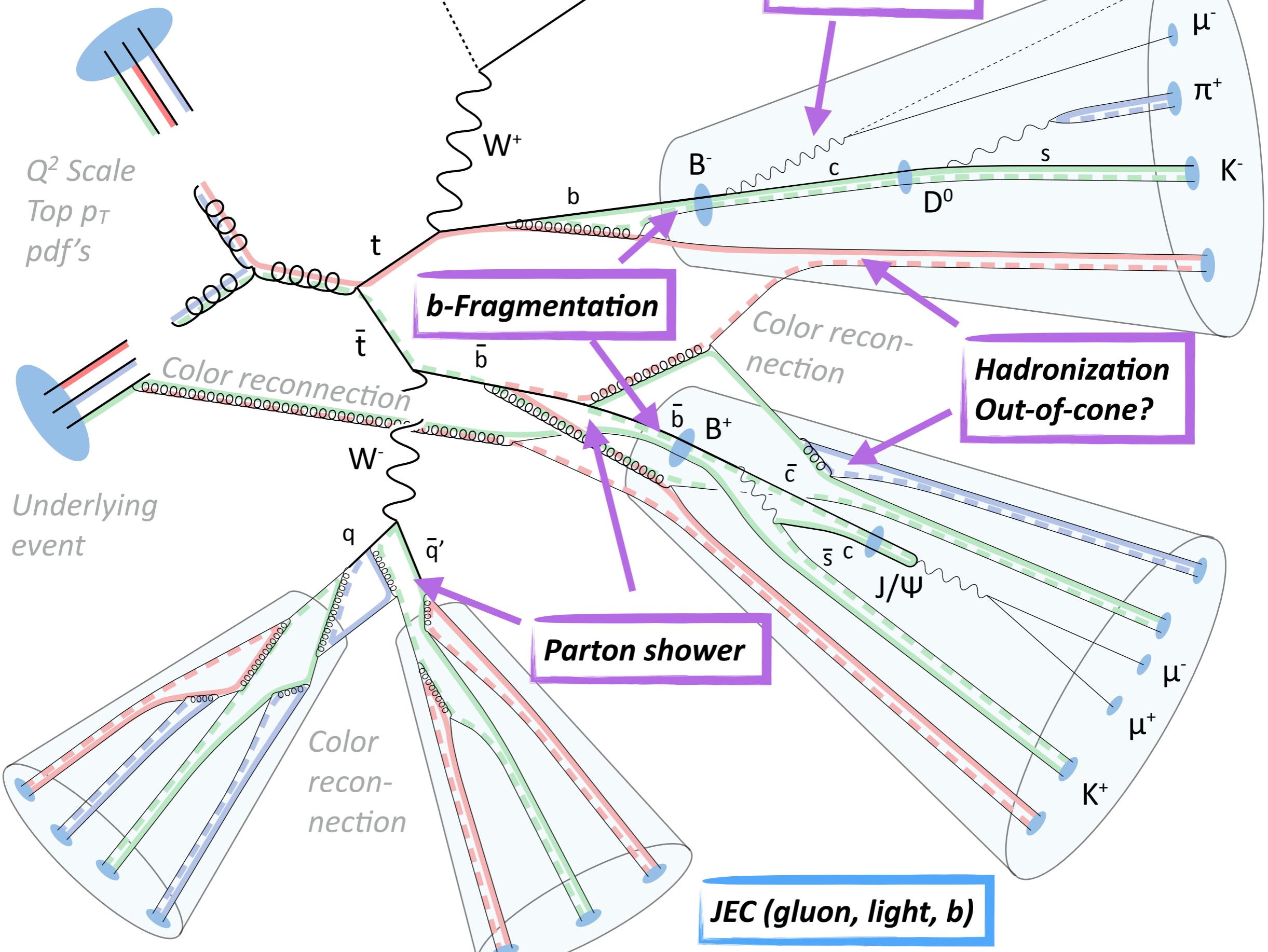
Additional and ongoing checks

- **Common MC setup** (*ongoing*)
 - Generate Powheg+Pythia(P11C)
 - Started by CMS/D0, but should also include ATLAS/CDF
- Consistency of **directions of systematic shifts**
 - Agree wherever significant → no sign of anti-correlations
- **Particle-level studies** (*ongoing*)
 - Factor out detector response effects
 - Compare different MC setups
- Considering to write a **common public document**

$t\bar{t}$ Modeling Uncertainties



$t\bar{t}$ Modeling Uncertainties



In last world combination, modeling of hadronization was evaluated almost universally by comparing Pythia and Herwig

- Combination of many **different and overlapping effects**:
 - Different parton showers (p_T -ordered vs. angular-ordered)
 - Fragmentation functions
 - Particle compositions, decay tables
 - Hadronization model (string vs. cluster fragmentation)
 - Underlying event / color reconnections
 - Tunes
- **How do they all add up** in a difference for m_{top} ?
 - Some already accounted for in dedicated systematics
 - **Crude and (probably) conservative** approach

CMS approach of breaking down the hadronization modeling in 8 TeV analyses:

- **Hard scattering → partons → showering**
 - Q^2 scale variations (μ_F , μ_R)
 - ME/PS matching scale variation
 - P.d.f's, top p_T , etc.
- **Partons after showering → stable particles**
 - Cluster vs string fragmentation
- **Stable particles → reconstructed jets**
 - Neutrino fraction (semi-leptonic B branching fractions)
 - b-fragmentation (hardness of B hadrons, hardness of neutrinos)
 - Flavor-dependent jet energy scale:
 - gluon, light (uds), charm, bottom

Hadronization modeling

In the new 8 TeV results, CMS attempted to split the hadronization modeling into separate effects

Experimental uncertainties

Fit calibration

p_T - and η -dependent JES

Lepton energy scale

MET

Jet energy resolution

b tagging

Pileup

Non- $t\bar{t}$ background

Modeling of hadronization

Flavor-dependent JSF

b fragmentation

Semi-leptonic B hadron decays

Modeling of the hard scattering process

PDF

Renormalization and factorization scales

ME-PS matching threshold

ME generator

Modeling of non-perturbative QCD

Underlying event

Color reconnection modeling

- **Flavor-dependent JSF:**

- Separate **PY/HW** variation for each flavor (gluon, light, charm, b)
- Signed sum of differences
- Cross-check with **Z+b data**

- **b fragmentation:**

- Retune **Pythia Z2*** to **ALEPH data**
- Compare difference

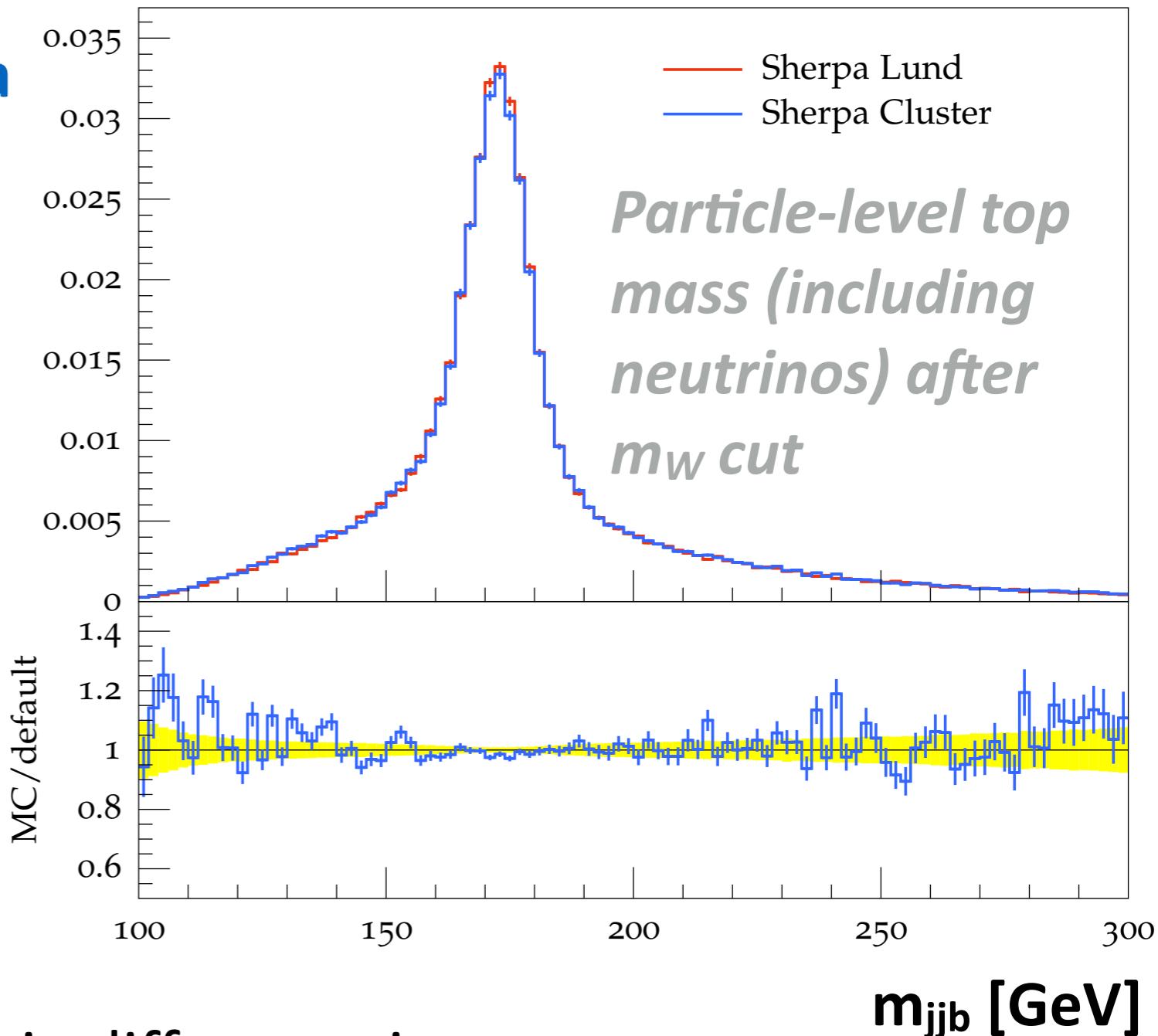
- **Neutrino fraction:**

- Vary semi-leptonic B-hadron **branching fractions** within uncertainty

- Vary ME/PS matching threshold

Varying hadronization models with fixed parton showering shows almost no effects on the top mass

- Particle-level study in **Sherpa**
 - Same p_T -ordered parton showering
 - Switch **cluster fragmentation** to **Lund string fragmentation**
- **No evidence for out-of-cone effects**
- Effect on jet directions is very small as well
- Suggests bulk of Pythia/Herwig difference is due to other effects



Conclusions

- All four experiments have presented **new or updated results** since the last world combination
 - Should start **preparing for an update** of standard combination
 - Could consider separate combination of pole-mass measurements
- CMS/D0 discussion
 - Statistically not very significant: **fluctuation after all?**
 - Cross checks of most important effects are all consistent
- Refined treatment of **hadronization uncertainties**
 - Could use some consolidation



Additional material

ATLAS |+jets, dilep

1503.05427v1

	$t\bar{t} \rightarrow \text{lepton+jets}$			$t\bar{t} \rightarrow \text{dilepton}$	Combination	
	$m_{\text{top}}^{\ell+\text{jets}}$ [GeV]	JSF	bJSF	$m_{\text{top}}^{\text{dil}}$ [GeV]	$m_{\text{top}}^{\text{comb}}$ [GeV]	ρ
Results	172.33	1.019	1.003	173.79	172.99	
Statistics	0.75	0.003	0.008	0.54	0.48	0
– Stat. comp. (m_{top})	0.23	n/a	n/a	0.54		
– Stat. comp. (JSF)	0.25	0.003	n/a	n/a		
– Stat. comp. (bJSF)	0.67	0.000	0.008	n/a		
Method	0.11 ± 0.10	0.001	0.001	0.09 ± 0.07	0.07	0
Signal MC	0.22 ± 0.21	0.004	0.002	0.26 ± 0.16	0.24	+1.00
Hadronisation	0.18 ± 0.12	0.007	0.013	0.53 ± 0.09	0.34	+1.00
ISR/FSR	0.32 ± 0.06	0.017	0.007	0.47 ± 0.05	0.04	-1.00
Underlying event	0.15 ± 0.07	0.001	0.003	0.05 ± 0.05	0.06	-1.00
Colour reconnection	0.11 ± 0.07	0.001	0.002	0.14 ± 0.05	0.01	-1.00
PDF	0.25 ± 0.00	0.001	0.002	0.11 ± 0.00	0.17	+0.57
W/Z+jets norm	0.02 ± 0.00	0.000	0.000	0.01 ± 0.00	0.02	+1.00
W/Z+jets shape	0.29 ± 0.00	0.000	0.004	0.00 ± 0.00	0.16	0
NP/fake-lepton norm.	0.10 ± 0.00	0.000	0.001	0.04 ± 0.00	0.07	+1.00
NP/fake-lepton shape	0.05 ± 0.00	0.000	0.001	0.01 ± 0.00	0.03	+0.23
Jet energy scale	0.58 ± 0.11	0.018	0.009	0.75 ± 0.08	0.41	-0.23
b -jet energy scale	0.06 ± 0.03	0.000	0.010	0.68 ± 0.02	0.34	+1.00
Jet resolution	0.22 ± 0.11	0.007	0.001	0.19 ± 0.04	0.03	-1.00
Jet efficiency	0.12 ± 0.00	0.000	0.002	0.07 ± 0.00	0.10	+1.00
Jet vertex fraction	0.01 ± 0.00	0.000	0.000	0.00 ± 0.00	0.00	-1.00
b -tagging	0.50 ± 0.00	0.001	0.007	0.07 ± 0.00	0.25	-0.77
$E_{\text{T}}^{\text{miss}}$	0.15 ± 0.04	0.000	0.001	0.04 ± 0.03	0.08	-0.15
Leptons	0.04 ± 0.00	0.001	0.001	0.13 ± 0.00	0.05	-0.34
Pile-up	0.02 ± 0.01	0.000	0.000	0.01 ± 0.00	0.01	0
Total	1.27 ± 0.33	0.027	0.024	1.41 ± 0.24	0.91	-0.07

CMS Combination (September 2014)

CMS TOP-14-015

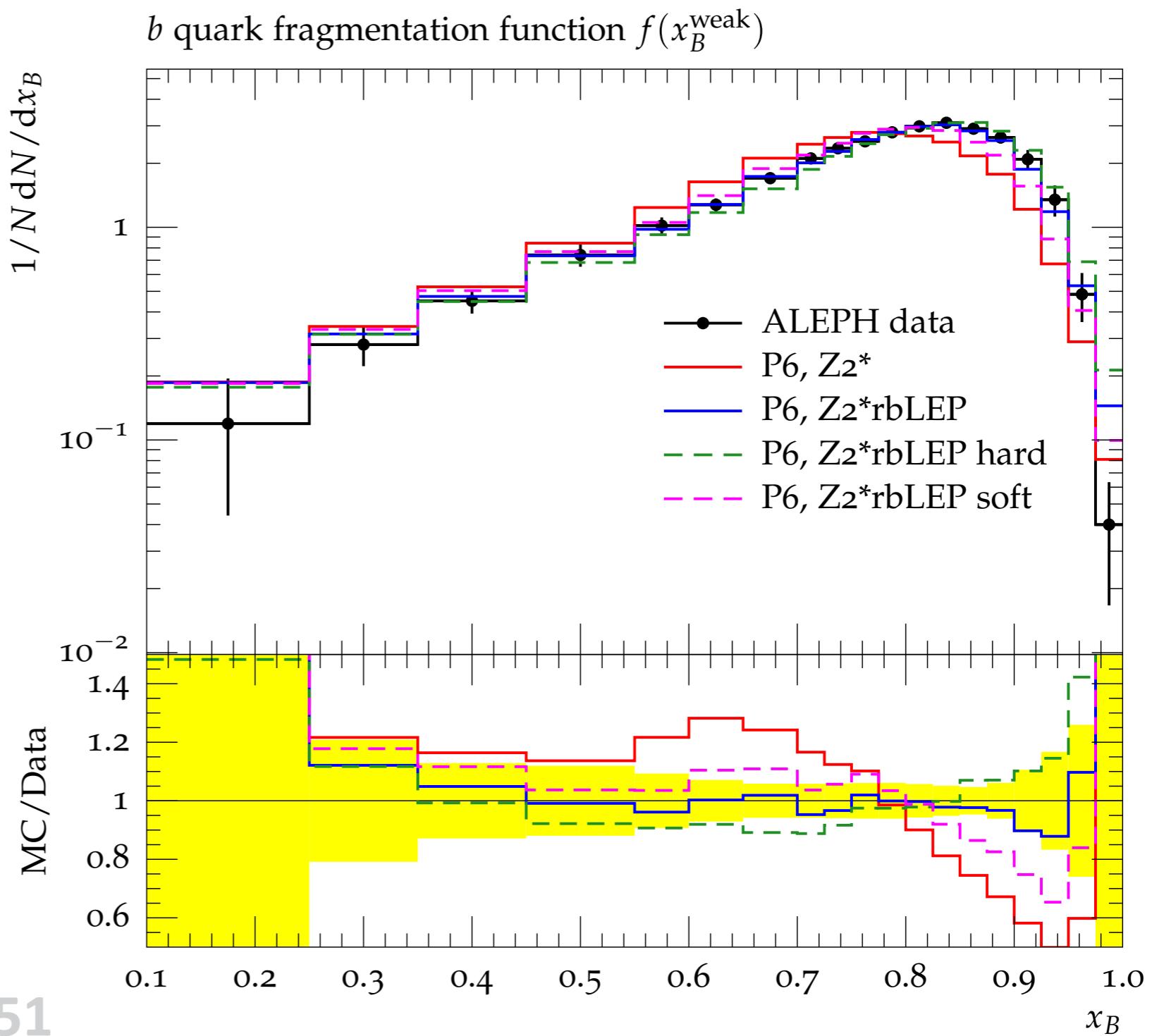
	2010		2011			2012		
	di- l	$l + \text{jets}$	di- l	$l + \text{jets}$	all-jets	di- l	$l + \text{jets}$	all-jets
Measured m_t	175.50	173.10	172.50	173.49	173.49	172.47	172.04	172.08
Experimental uncertainties								
<i>In-situ</i> JSF factor	n/a	n/a	n/a	0.33	n/a	n/a	0.15	0.24
Inter-calibration JES component	0.17	0.08	0.08	0.01	0.08	0.03	0.01	0.01
MPF <i>in-situ</i> JES component	0.76	0.16	0.35	0.02	0.35	0.31	0.01	0.01
Uncorrelated JES component	1.48	1.90	0.69	0.24	0.69	0.53	0.12	0.25
Other JES uncertainties	3.28	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Lepton energy scale	0.30	n/a	0.14	0.02	n/a	0.12	0.03	n/a
E_T^{miss} scale	0.10	0.40	0.12	0.06	n/a	0.07	0.09	n/a
Jet energy resolution	0.50	0.10	0.14	0.23	0.15	0.09	0.26	0.10
b -tagging	0.40	0.10	0.09	0.12	0.06	0.04	0.02	0.02
Trigger	n/a	n/a	n/a	n/a	0.24	n/a	n/a	0.18
MHI (Pileup)	1.00	0.10	0.11	0.07	0.06	0.15	0.27	0.31
Background Data	n/a	0.40	n/a	n/a	0.13	0.02	n/a	0.22
Background MC	0.10	0.20	0.05	0.13	n/a	0.01	0.11	n/a
Fit calibration	0.20	0.10	0.40	0.06	0.13	0.01	0.10	0.06
Modeling of hadronization								
Flavor JES component	1.21	0.87	0.58	0.11	0.58	n/a	n/a	n/a
Flavor-dependent hadronization uncertainty	0.90	0.90	0.76	0.61	0.49	0.28	0.39	0.31
b fragmentation and B branching fractions	n/e	n/e	n/e	n/e	n/e	0.69	0.17	0.14
Modeling of the hard scattering process and radiation								
Parton distribution functions	0.50	0.10	0.09	0.07	0.06	0.18	0.09	0.02
Renormalization and factorization scales	0.63	1.12	0.55	0.24	0.22	0.87	0.13	0.19
ME-PS matching threshold	0.70	0.40	0.19	0.18	0.24	0.13	0.15	0.20
ME generator	0.50	n/e	0.04	0.02	0.19	0.24	0.14	0.21
Top quark p_T	n/e	n/e	n/e	n/e	n/e	0.27	0.20	0.08
Modeling of non-perturbative QCD								
Underlying event	1.30	0.20	0.05	0.15	0.20	0.04	0.17	0.28
Color reconnection	n/e	n/e	0.13	0.54	0.15	0.16	0.15	0.25
Statistical uncertainty	4.60	2.10	0.43	0.27	0.69	0.17	0.11	0.27
Total systematic uncertainty	4.52	2.66	1.46	1.03	1.23	1.40	0.74	0.84
Total uncertainty	6.45	3.39	1.52	1.06	1.41	1.41	0.75	0.89

World Combination (March 2014)

Uncertainty	Input measurements and uncertainties in GeV											World Combination	
	CDF				D0		ATLAS		CMS				
	$l+$ jets	di- l	all jets	E_T^{miss}	$l+$ jets	di- l	$l+$ jets	di- l	$l+$ jets	di- l	all jets		
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	
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	

b-fragmentation was measured at LEP to be significantly harder than our default (Pythia Z2*)

- Retune Z2* to describe b-fragmentation in ALEPH data
- Quote difference as uncertainty



ALEPH data:
arXiv:hep-ex/0106051