CEA - Saclay

Top mass standard reconstruction at the Tevatron

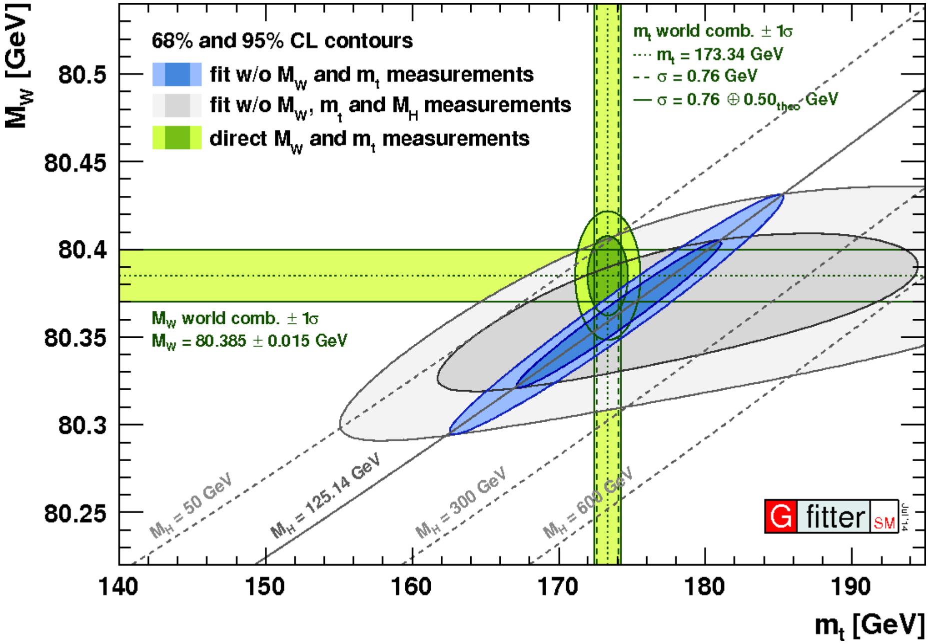
Viatcheslav Sharyy

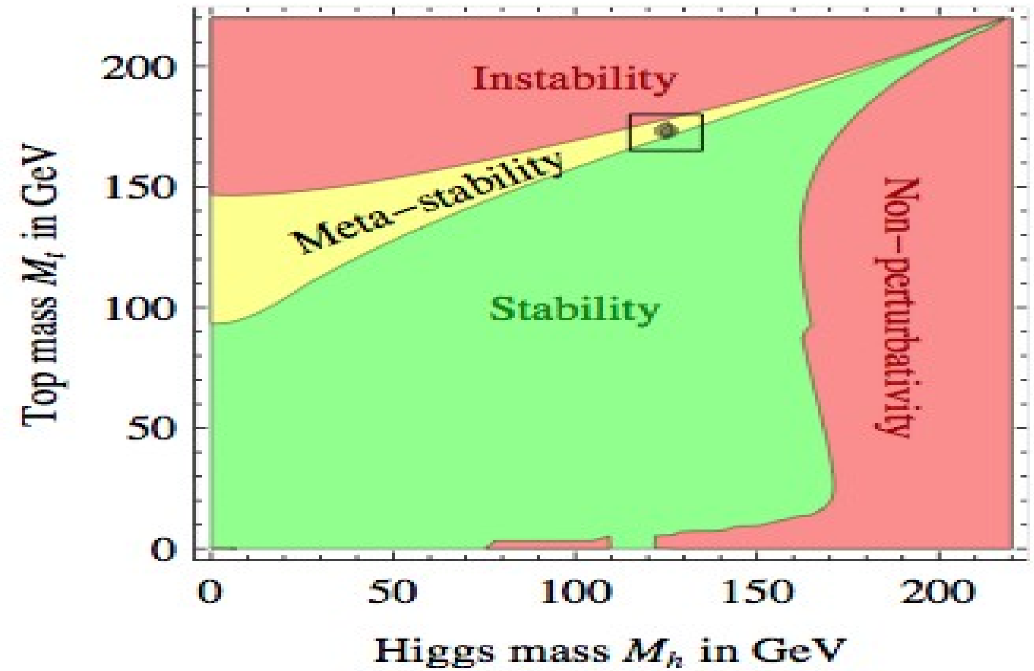
for the D0 and CDF collaborations

7th International Workshop on Top Quark Physics
September 30, 2013

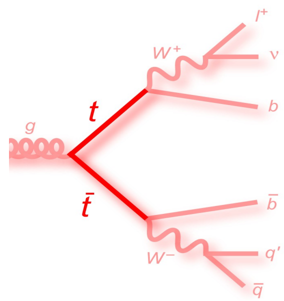
Why?

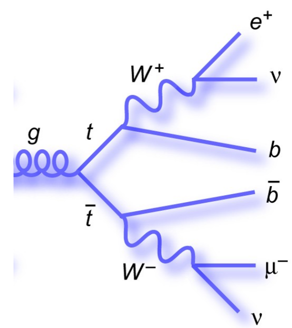
- Theoretician answers:
  - Standard Model self-consistency
  - Higgs potential ⇒ Universe Stability
- Experimentalist answer
  - Because we can measure with high precision!

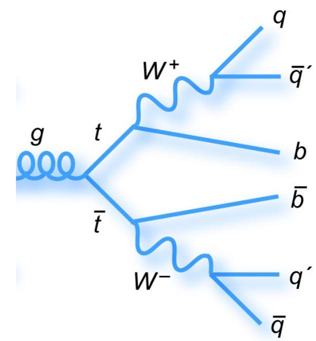


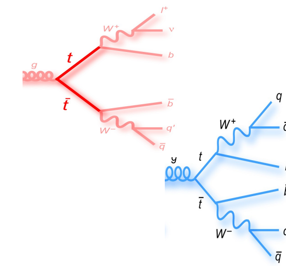


How?



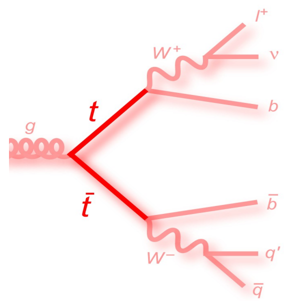


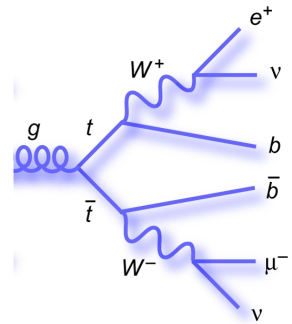


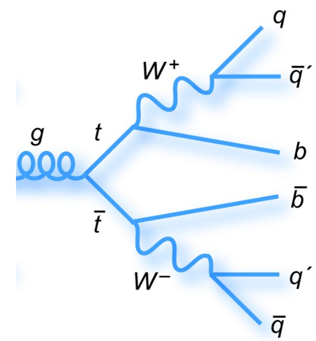


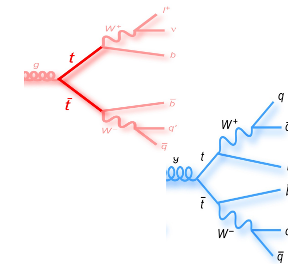
	Lepton + jets	Dileptons	All-jets	MET+jets
Templates	CDF, 8.7 fb^{-1}	CDF: 9.1 fb^{-1} D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}	CDF, 9.3 fb^{-1} Soon: D0, 9.7 fb^{-1}	CDF, 8.7 fb^{-1}
Matrix Element	D0, 9.7 fb^{-1}	D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}		
From cross-section	D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}	D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}		
Lepton pT	CDF 2.7 fb^{-1}	CDF 2.8 fb^{-1}		

How?









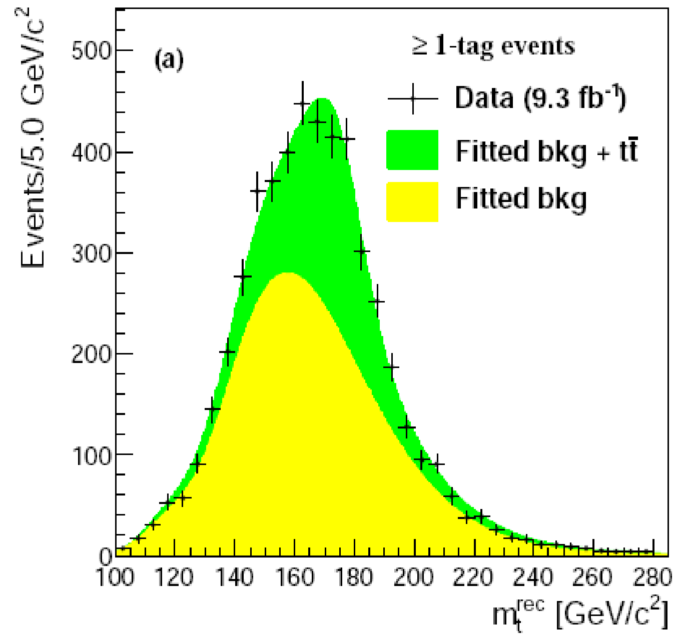
	Lepton + jets	Dileptons	All-jets	MET+jets
Templates	CDF, 8.7 fb^{-1}	CDF: 9.1 fb^{-1} D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}	CDF, 9.3 fb^{-1} Soon: D0, 9.7 fb^{-1}	CDF, 8.7 fb^{-1}
Matrix Element	D0, 9.7 fb^{-1}	D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}		
From cross-section	D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}	D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}		
Lepton pT	CDF 2.7 fb^{-1}	CDF 2.8 fb^{-1}		

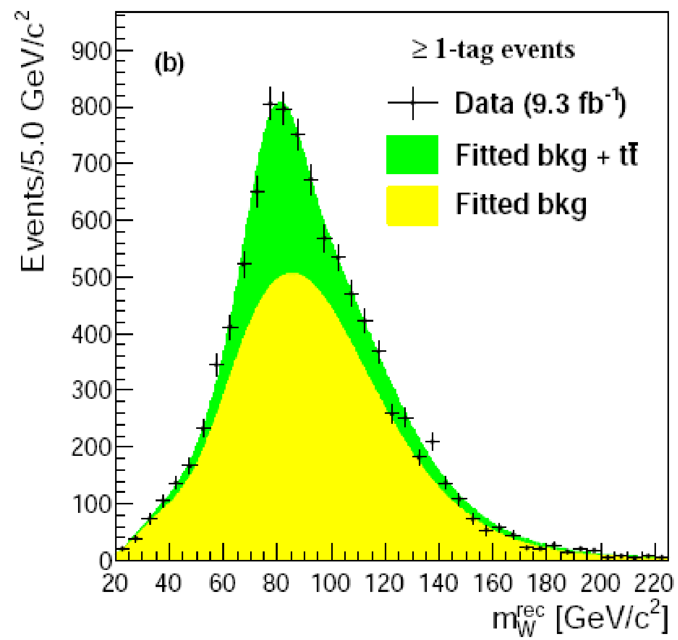
For the top mass combinations see Yvon Peter's talk on Wednesday

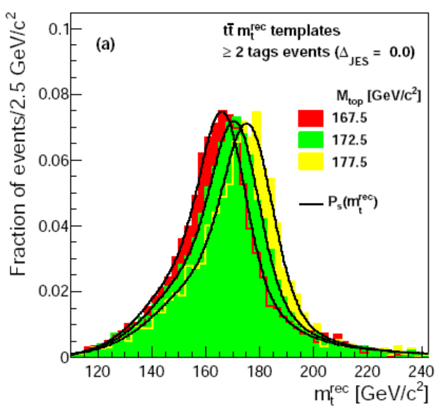
CDF alljet measurement, 9.3 fb^{-1}

arXiv:1409.4906

- $t\bar{t}$ simulation: Poweg+Pythia
- Selection
  - 6 – 8 jets with p_T > 15 GeV, $|\eta| \leq 2.0$
  - MET significance cut + NN discrimination
  - 1—3 b-tags in the event
- Background model:
  - Pretag sample times b-tagging rate
  - Evaluate probability to tag background jet from the sample with 5 jets
  - Use correction factors for multiple b-quarks per events from background dominated samples (inverse NN cut)
- All possible combination are taken into account
- m^{rec} and m_W^{rec} are reconstructed by the χ^2 minimization and fitted simultaneously



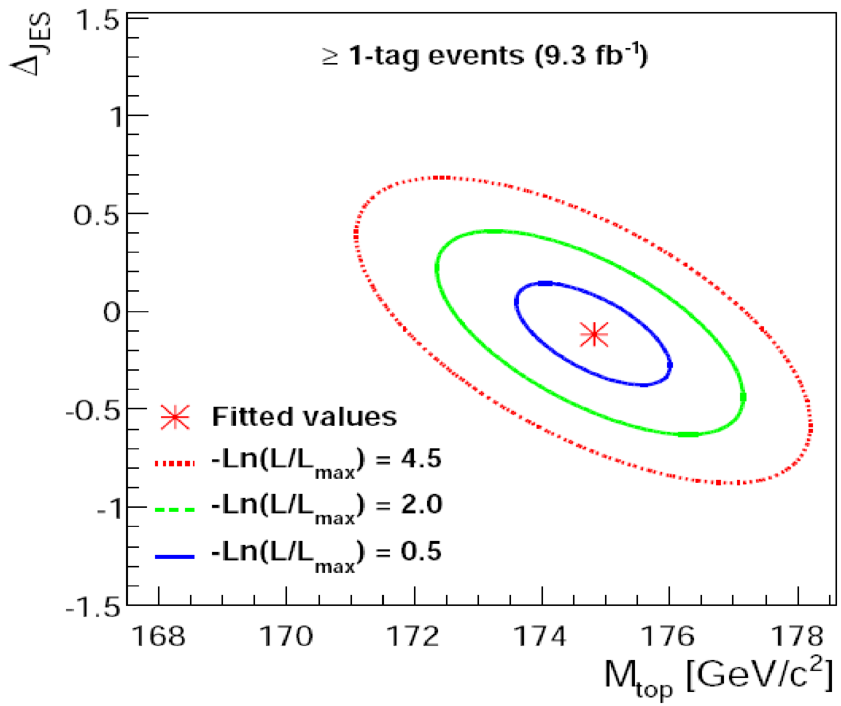




CDF alljet measurement, 9.3 fb^{-1}

Source	$\sigma_{M_{top}}$ (GeV/c^2)	$\sigma_{\Delta_{JES}}$
Generator (hadronization)	0.29	0.273
Parton distribution functions	$^{+0.18}_{-0.36}$	$^{+0.096}_{-0.052}$
Initial / Final state radiation	0.13	0.232
Color reconnection	0.32	0.101
Δ_{JES} fit	0.97	−−
M_{top} fit	−−	0.207
Other free parameters of the fit	0.41	0.040
Templates sample size	0.34	0.071
$t\bar{t}$ cross section	0.15	0.034
Integrated luminosity	0.15	0.032
Trigger	0.61	0.188
Background shape	0.15	0.014
b-tagging	0.04	0.018
b-jets energy scale	0.20	0.035
Pileup	0.22	0
Residual JES	0.57	−−
Residual bias / Calibration	$^{+0.27}_{-0.24}$	$^{+0.077}_{-0.096}$
Total	$^{+1.55}_{-1.58}$	$^{+0.492}_{-0.488}$

Herwig – Pythia



$$m_{top} = 175.07 \pm 1.19\,(\mathrm{stat})\,^{+1.55}_{-1.58}\,(\mathrm{syst})\ \mathrm{GeV}$$

Precision: 1.1%

CDF dilepton measurement, 9.1 fb^{-1}

CDF Public note: 11072

- Selection:
  - 2 x electron or muon with p_T > 20 GeV
  - 2 or more jets with p_T > 15 GeV, $|\eta| \leq 2.5$
  - MET > 25 GeV, H_T > 200 GeV
  - Z veto in ee and mumu + topological cuts
- Template based analysis with “hybrid” variable:

$$M_t^{eff} = w \cdot M_t^{reco} + (1-w) \cdot M_t^{alt}$$

  - w is a free parameter (weight) in the range 0 – 1 ⇒ choose w = 0.7
  - M^{reco} is a top quark mass reconstructed with the “neutrino weighting”
  - Alternative variable

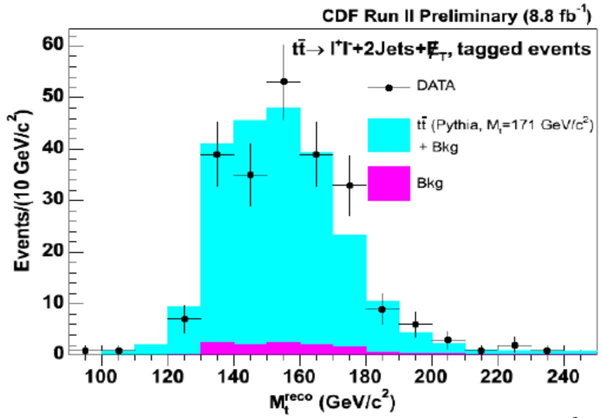
$$M_t^{alt} \equiv \sqrt{\langle l_1, c_{b_1}\rangle \cdot \langle l_2, c_{b_2}\rangle} + 120 \text{ GeV}$$

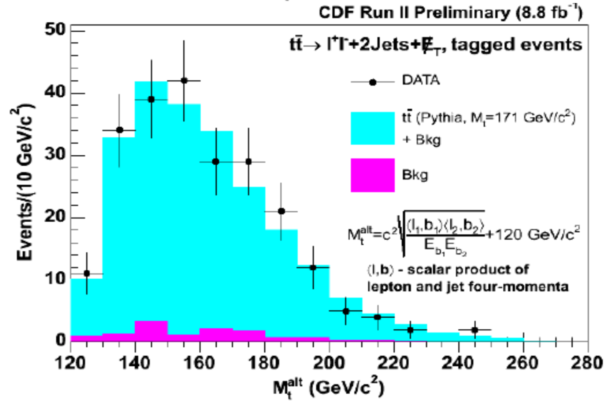
Lepton 4-momenta, jet directions

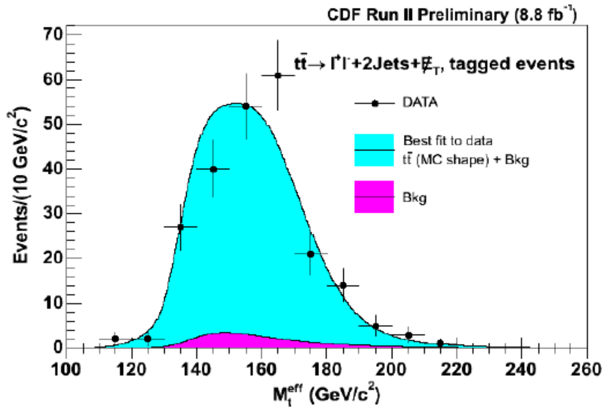
JES dominated

$$\boxed{m_{top} = 170.80 \pm 1.83(\text{stat.}) \pm 2.69(\text{syst.}) \text{ GeV}}$$

Precision: 1.9%



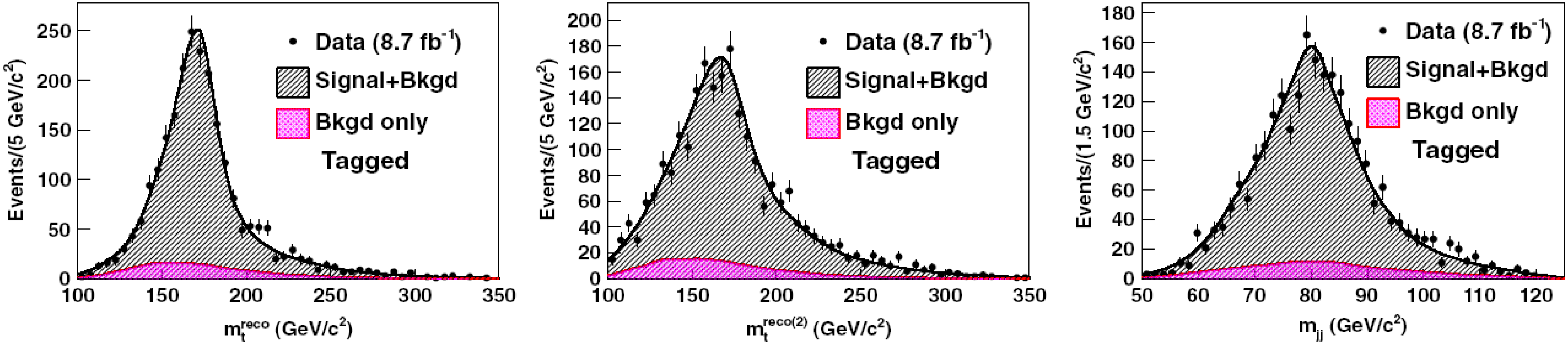




D0, 5.3 fb^{-1}, PRD(R) 86, 051103 (2012)
173.9 ± 1.9 (stat) ± 1.6 (syst) GeV

CDF l+jet measurement, 8.7 fb^{-1}

PRL 109 152003 (2012)



- $t\bar{t}$ simulation: Pythia
- Selection: electron or muon with p_T> 20 GeV, $|\eta|$ < 1.1, 4 and more jets p_T> 20 GeV, $|\eta|$ < 2.0, MET > 20 GeV
- Separate in n b-tag samples
- Use kernel density estimation method for three variables: m^{reco} for the best and next-to-best assignment + m_{jj} – inv. mass for tho W jets.

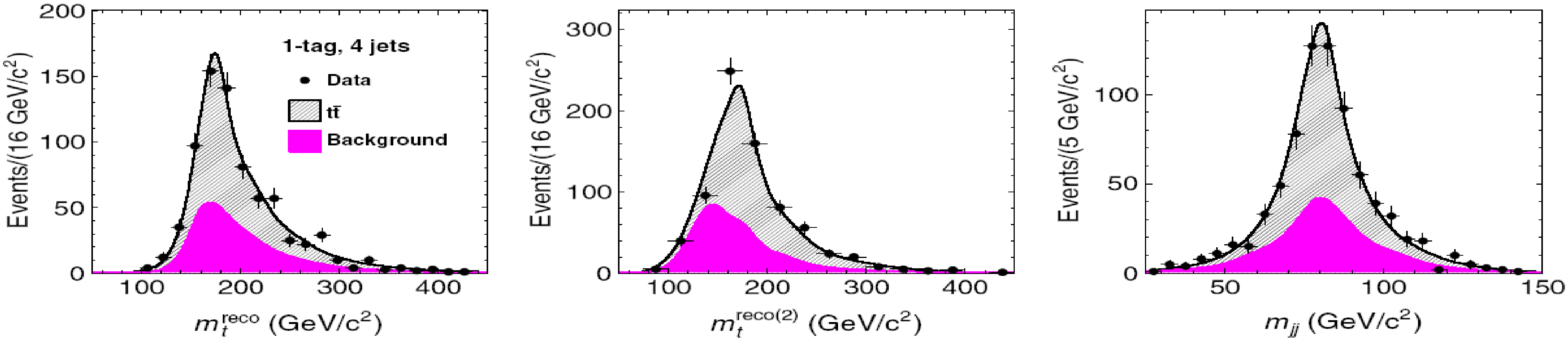
Source	Systematic ur
Residual jet energy scale	0.52
Signal modeling	0.56
Higher-order corrections	0.09
b jet energy scale	0.18
b-tagging efficiency	0.03
Initial and final state radiation	0.06
Parton distribution functions	0.08
Gluon fusion fraction	0.03
Lepton energy scale	0.03
Background shape	0.20
Multiple hadron interaction	0.07
Color reconnection	0.21
MC statistics	0.05

m_{top} = 172.85 ± 0.71 (stat+JES) ± 0.84 (syst) GeV

Precision: 0.6%

CDF MET+jet channel, 8.7 fb^{-1}

PRD (R) 88 011101 (2013)



- $t\bar{t}$ simulation: Pythia
- Selection ~ l+jets:
  - NO identified leptons, MET significance > 3 GeV$^{1/2}$
  - 4 – 6 jets with p_T > 15 GeV, $|\eta|$ < 2.0
  - topological cuts + NN discriminant cut
  - Use b-tagging to classify events
- Reconstruction procedure is similar to the l+jets

Source	Uncertainty (GeV/c^2)
Residual jet-energy scale	0.44
MC generator	0.36
Color reconnection	0.28
gg fraction	0.27
Radiation	0.28
PDFs	0.16
b-jet energy scale	0.19
Background	0.15
Calibration	0.21
Multiple hadron interaction	0.18
Trigger modeling	0.13

M_{top} = 173.93 ± 1.64 (stat+JES) ± 0.87 (syst) GeV

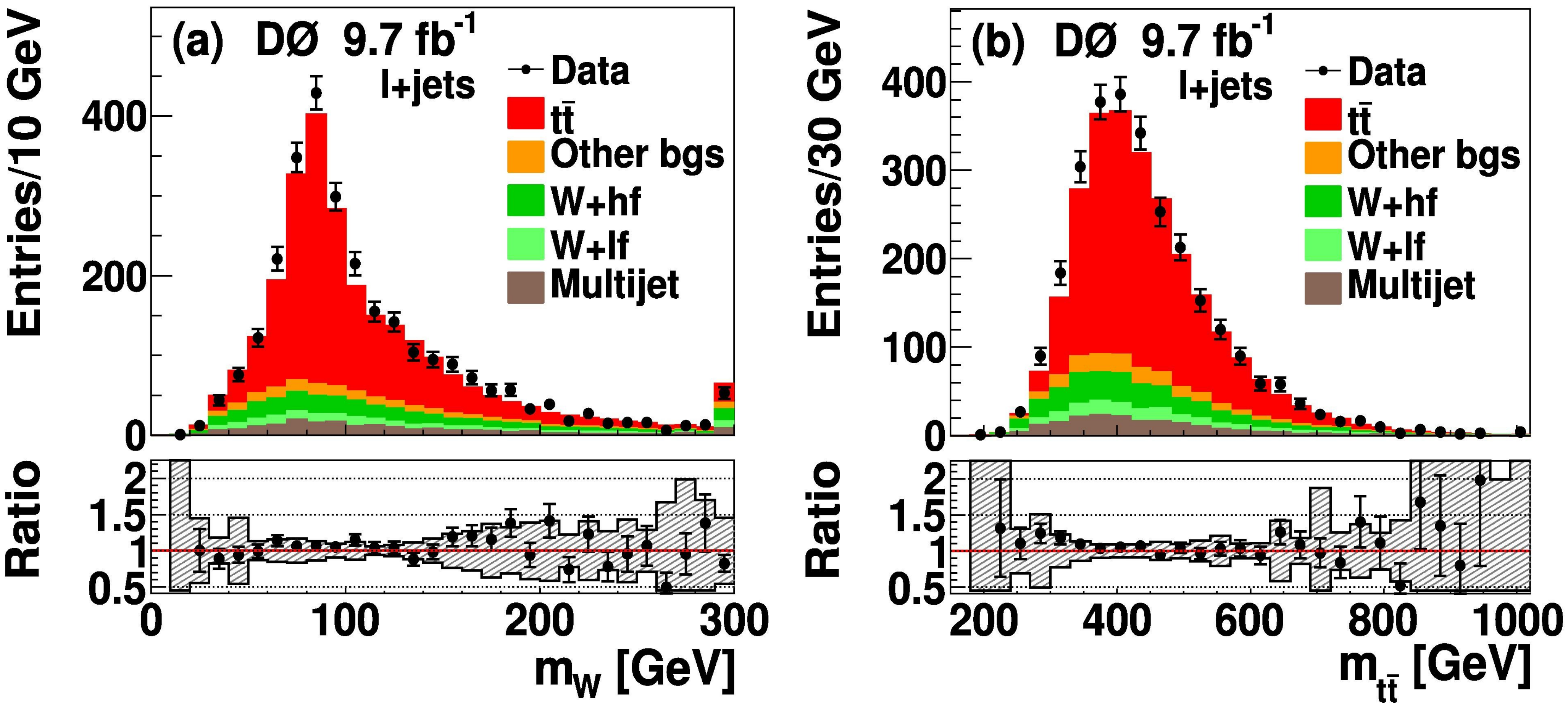
Precision: 1.1%

D0 l+jet measurements, 9.7 fb^{-1}

- Full D0 data set.
- Selections
  - Exactly one electron or muon with p_T> 20 GeV, $|\eta_e|$ < 1.1, $|\eta_\mu|$ < 2.0
  - Exactly four jets $p_T^{leading}$ > 40 GeV, p_T> 20 GeV
  - One or more b-tagged jets (efficiency ~ 65%, mistag rate ~5%)
  - MET < 20 GeV + topological cuts
- Simulation
  - $t\bar{t}$: Alpgen +Pythia (D0 modified tune A), CTEQ 6L1 PDFs
  - W+jets : Alpgen+Pythia
  - W+cc, W+bb: Alpgen+Pythia
  - Multijets events : from data

Contribution	e+jets			μ+jets		
$t\bar{t}$	918.11	±	3.63	824.88	±	3.48
W + jets	77.85	±	2.13	101.03	±	2.93
W + HF	125.98	±	2.12	162.21	±	2.81
Multijet	144.41	±	24.19	48.17	±	16.11
Other backgrounds	97.75	±	0.51	79.24	±	0.94
Expected	1364.10	±	24.65	1215.53	±	17.00
Observed	**1502**			**1286**		

Expected signal fraction ~68%


(a) DØ 9.7 fb-1
l+jets
Data
tt̄
Other bgs
W+hf
W+lf
Multijet
Entries/10 GeV
Ratio
m_W [GeV]
(b) DØ 9.7 fb-1
l+jets
Data
tt̄
Other bgs
W+hf
W+lf
Multijet
Entries/30 GeV
Ratio
m_tt̄ [GeV]

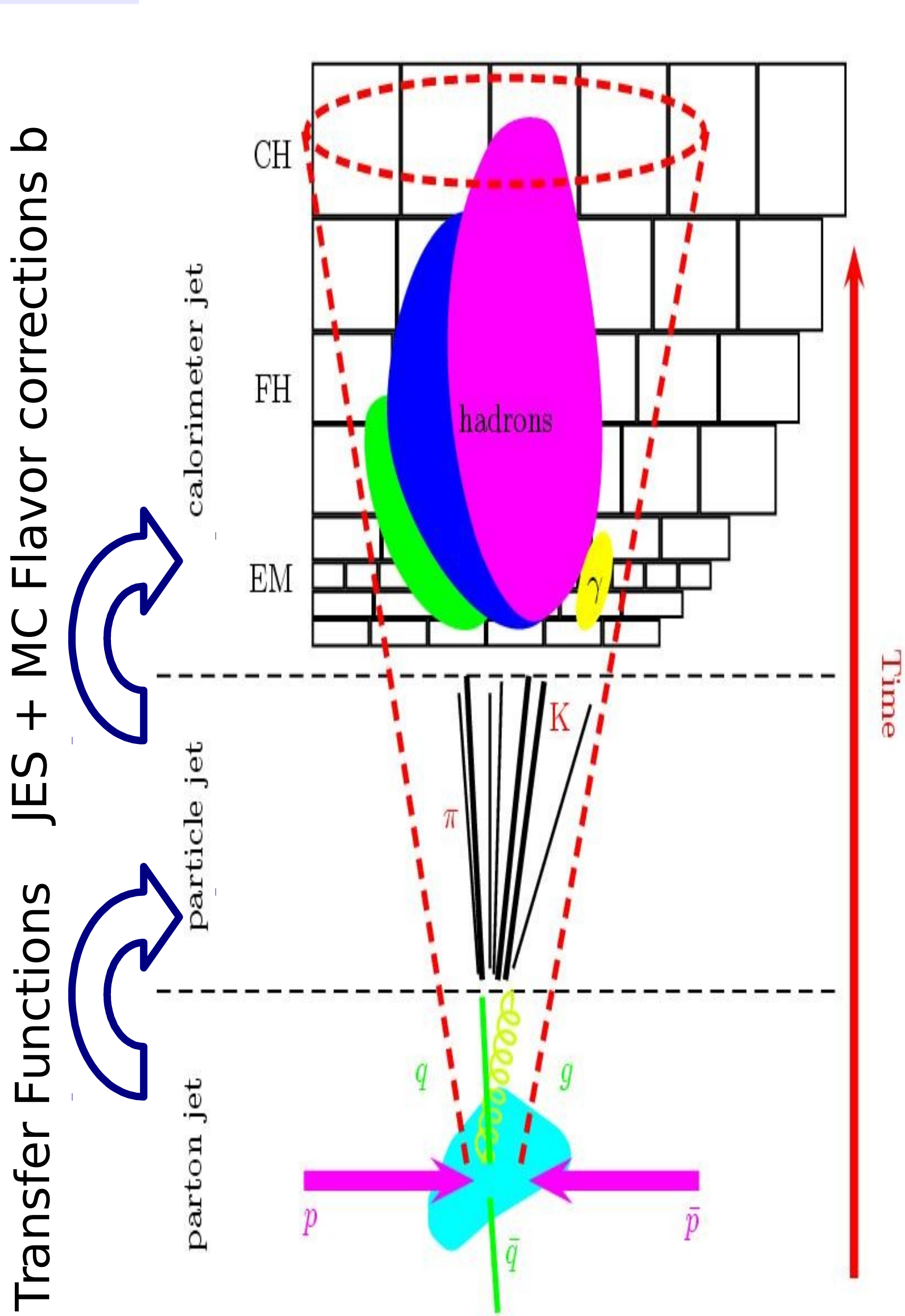
JES at D0

- Jet Energy Scale: correct reconstructed jet energy to the particle level
  - Absolute JES
  - Separately measured for data and MC

$$E_{jet} = \frac{E_{meas} - E_{offset}}{R_{esponse} \cdot S_{howring}}$$

- Flavor dependent correction : different response correction for gluon, light quark, b-quarks (b-JES)
  - Tune the single particle response difference between data and MC in γ+jets and dijets events

$$F_{corr} = \frac{1}{<F>_{\gamma+jet}} \frac{\Sigma_i E_i R_i^{data}}{\Sigma_i E_i R_i^{MC}}$$



- Jet Energy Scale: correct reconstructed jet energy to the particle level
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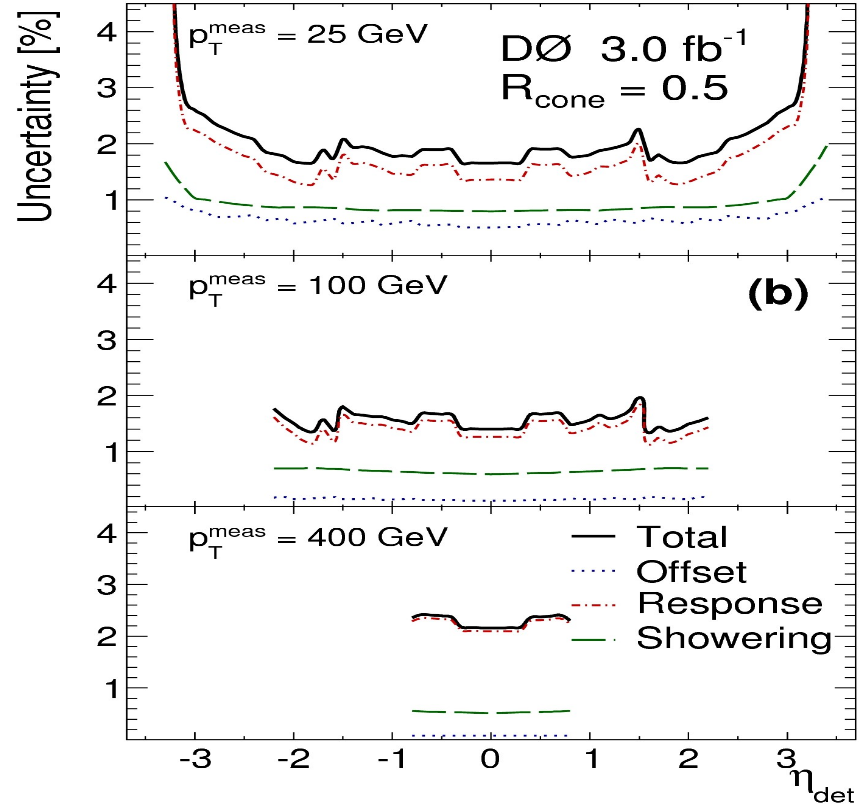
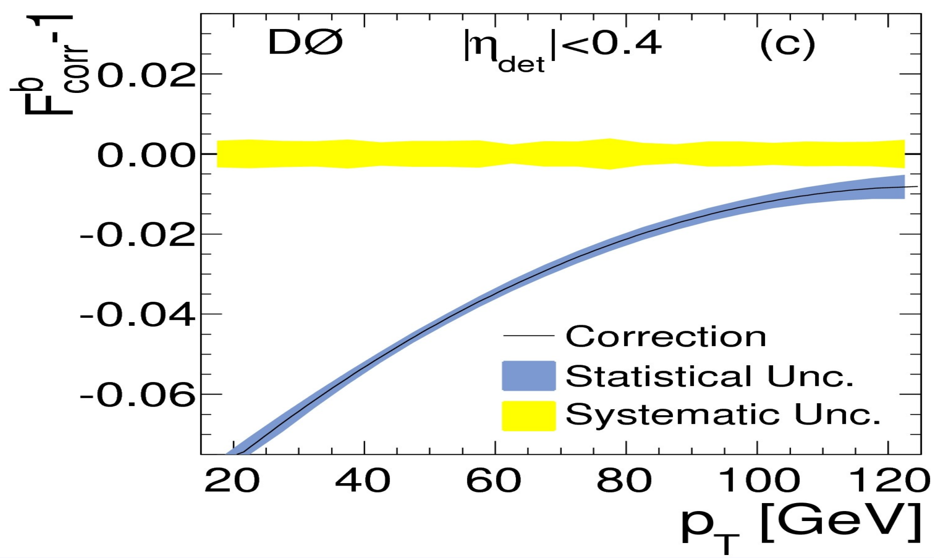
$$F_{corr} = \frac{1}{<F>_{\gamma+jet}} \frac{\Sigma_i E_i R_i^{data}}{\Sigma_i E_i R_i^{MC}}$$





Matrix Element Technique

$$P(x,H) \sim \int d^6\sigma(y,H) W(x,y) f_{PDF}(q_1) f_{PDF}(q_2) dq_1 dq_2$$

Diff. xsection with LO ME — Detector response (Transfer Function) — PDFs

- Sum over 24 possible jet-parton assignments with b-tag dependent weights
- Integrate over 10 variables using MC integration
- Use W-boson mass as an additional constrains for the JES correction factor
- Multiply probabilities for all events -> likelihood as a function of top quark mass and JES correction. $P_{\mathrm{evt}}(m_{\mathrm{top}}) \propto f P_{\mathrm{sig}}(m_{\mathrm{top}}) + (1-f) P_{\mathrm{bgr}}$
- Iimprovement since previous publication (*PRD 84, 032004, 2011*):

Accelerate integration by a factor of ~100

- low-discrepancy sequences for the MC integration
- Factorise the JES correction factor from the ME calculation

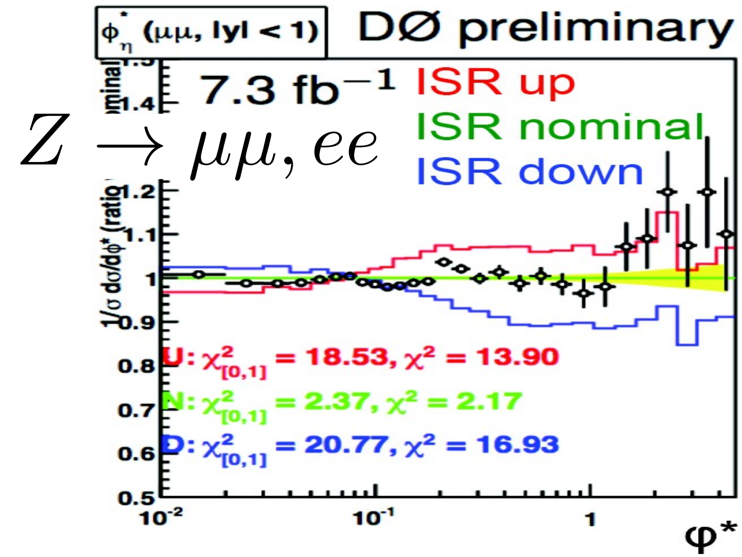
Integrate many more MC events ⇒ reduce statistical component in the systematic uncertainties estimation from ~0.25 GeV to **0.05 GeV**

Systematic Uncertainties Estimation

Source of uncertainty	Effect on m_t (GeV)
Signal and background modeling:	
Higher order corrections	$+0.15$
Initial/final state radiation	± 0.09
Hadronization and underlying event	$+0.26$
Color reconnection	$+0.10$
Multiple $p\bar{p}$ interactions	-0.06
Heavy flavor scale factor	± 0.06
b quark jet modeling	$+0.09$
Parton distribution functions	± 0.11
Detector modeling:	
Residual jet energy scale	± 0.21
Flavor-dependent response to jets	± 0.16
b tagging	± 0.10
Trigger	± 0.01
Lepton momentum scale	± 0.01
Jet energy resolution	± 0.07
Jet identification efficiency	-0.01
Method:	
Modeling of multijet events	$+0.04$
Signal fraction	± 0.08
MC calibration	± 0.07
Total systematic uncertainty	± 0.49
Total statistical uncertainty	± 0.58
Total uncertainty	± 0.76

MC@NLO +Herwig – Alpgen + Herwig

Vary renormalisation scale in Alpgen by 1.5

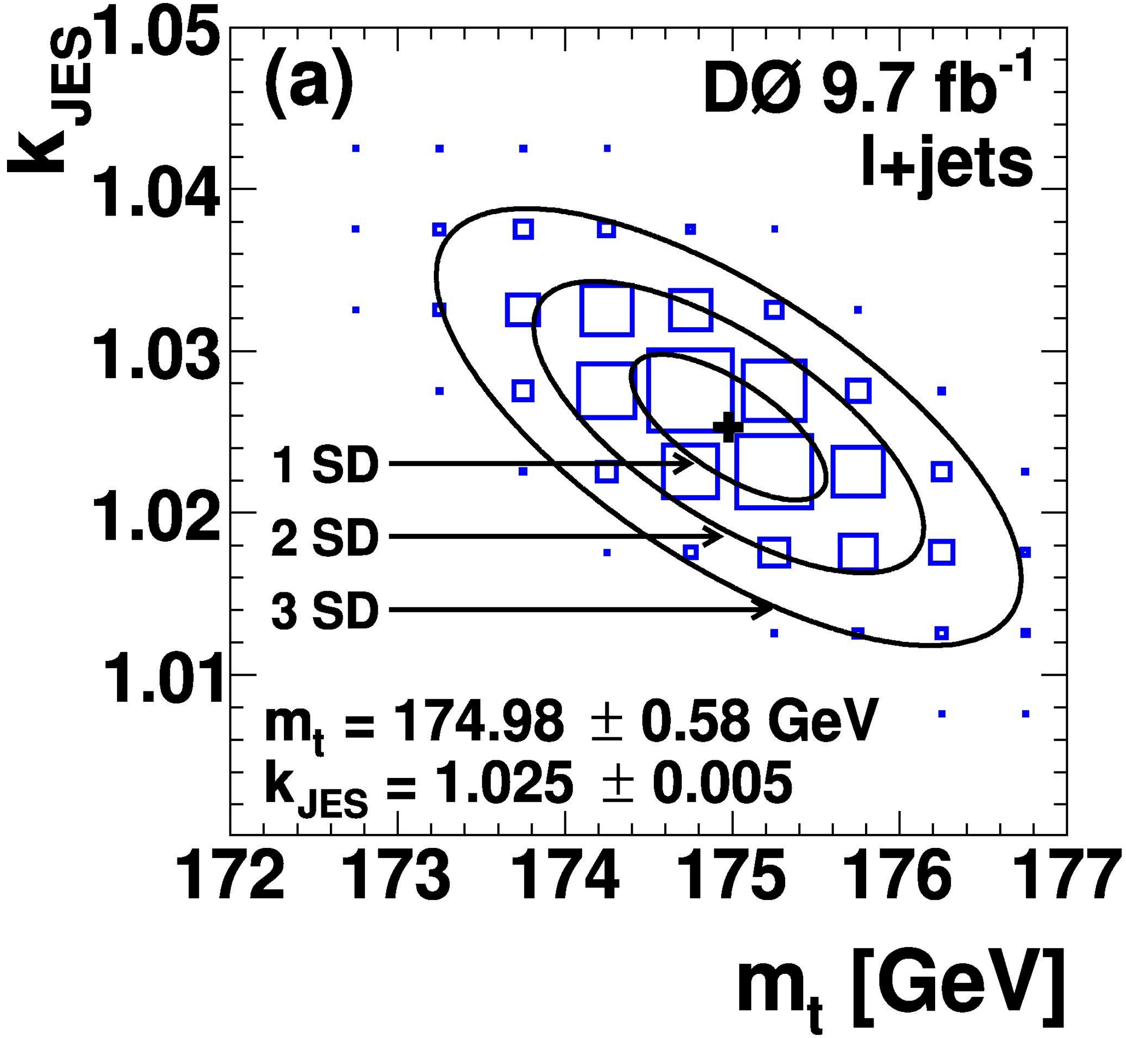


Alpgen +Herwig – Alpgen + Pythia
for particle-level jets

Pythia, Perugia 2011 – Perugia 2001NOCR

Phys. Rev. Lett. 113, 032002 (2014)
PRD with more details is in preparation

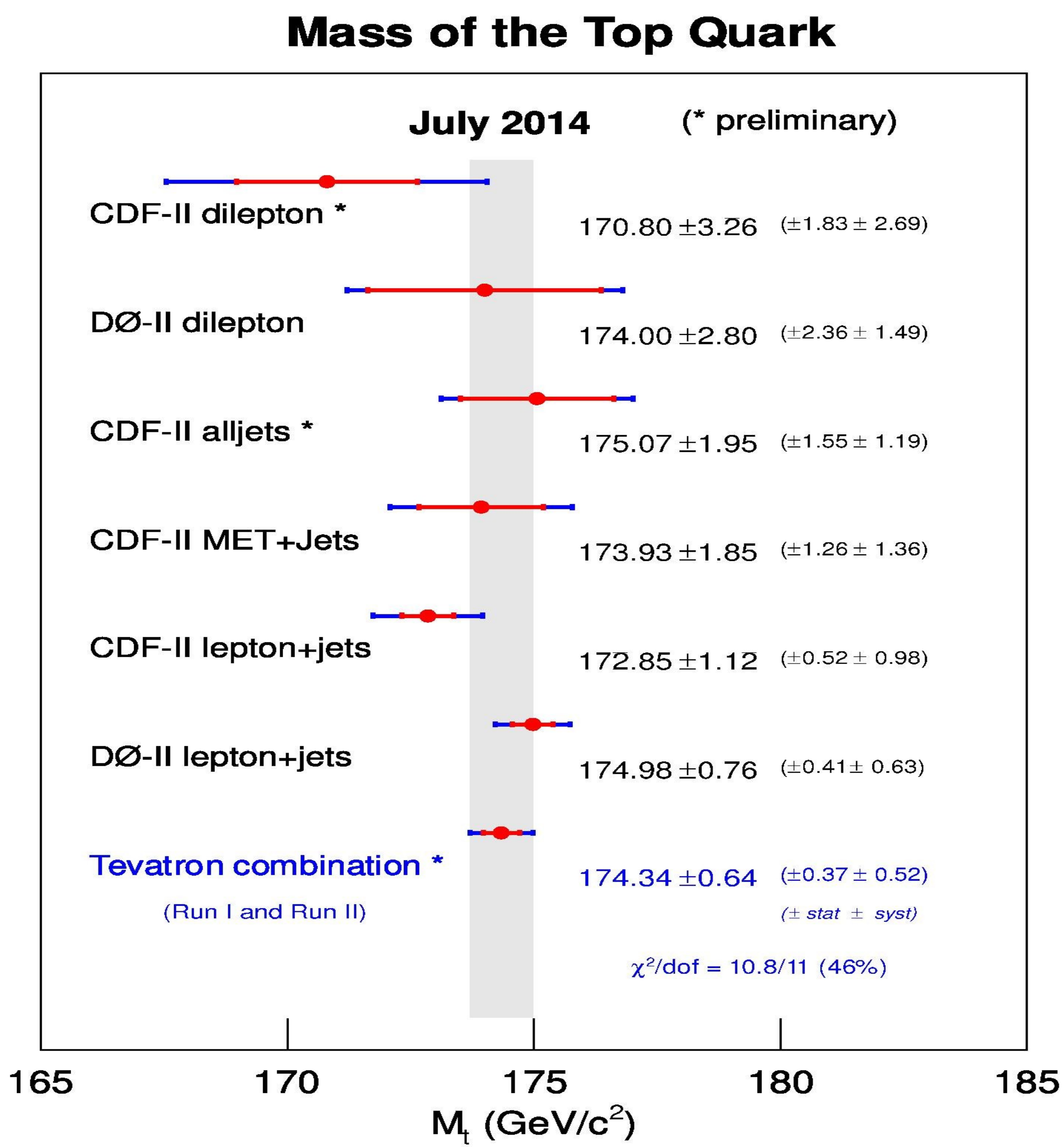
Results



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

Precision: 0.44%

Summary of the results



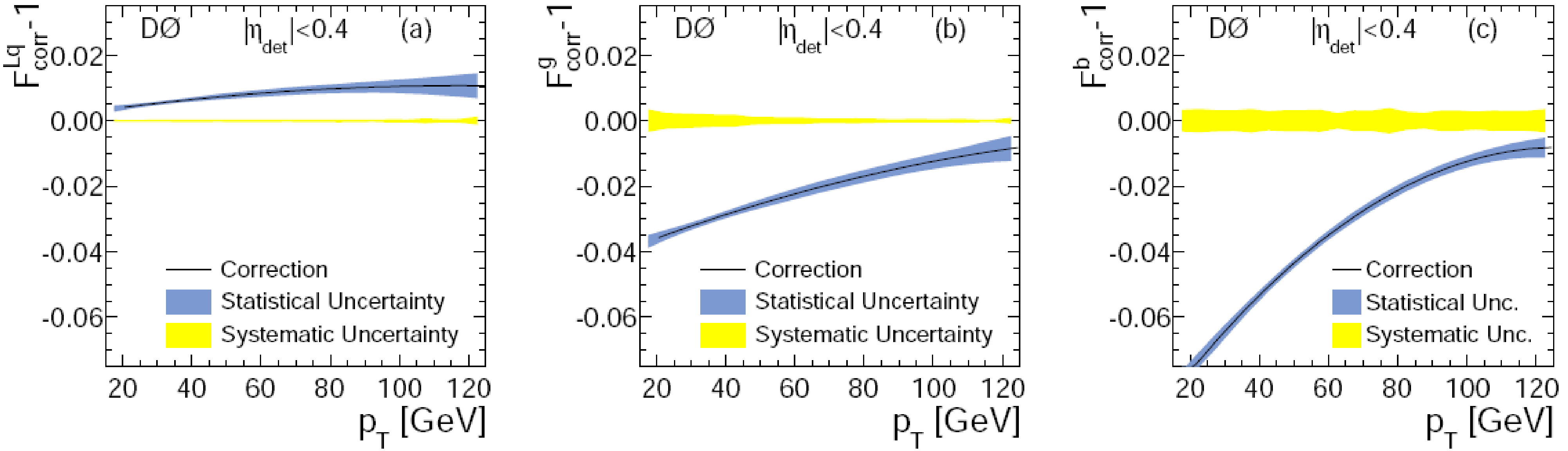
Conclusion

- The most precise channels from the Tevatron with all statistics are done.
- Several more results are coming in dilepton and alljets channels

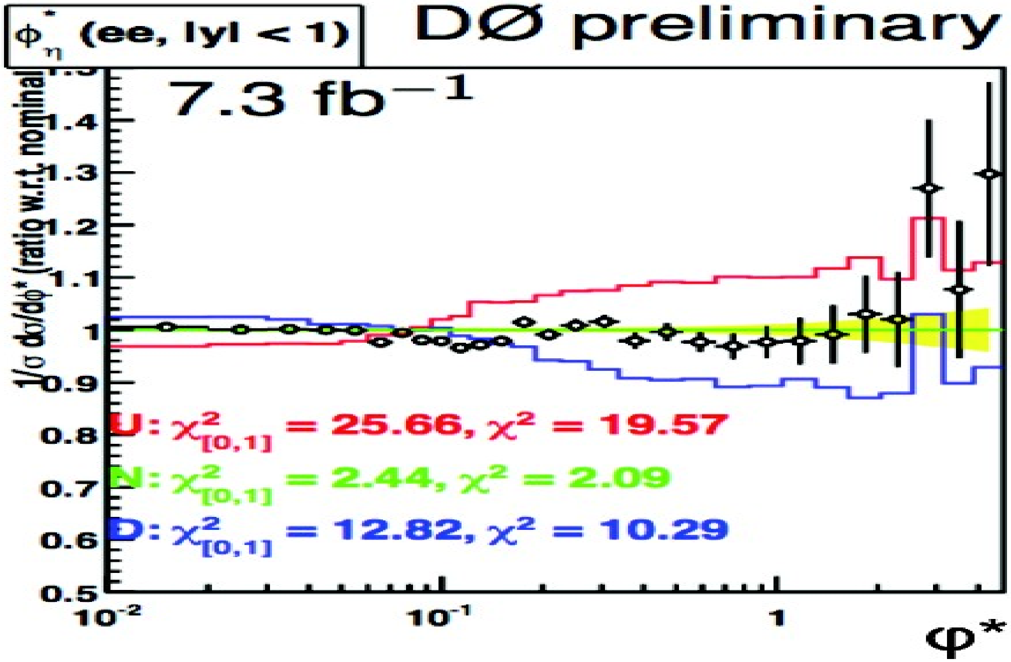
	Lepton + jets	Dileptons	All-jets	MET+jets
Templates	CDF, 8.7 fb^{-1}	CDF: 9.1 fb^{-1} D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}	CDF, 9.3 fb^{-1} Soon: D0, 9.7 fb^{-1}	CDF, 8.7 fb^{-1}
Matrix Element	D0, 9.7 fb^{-1}	D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}		
From cross-section	D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}	D0, 5.4 fb^{-1} Soon: D0, 9.7 fb^{-1}		
Lepton pT	CDF 2.7 fb^{-1}	CDF 2.8 fb^{-1}		

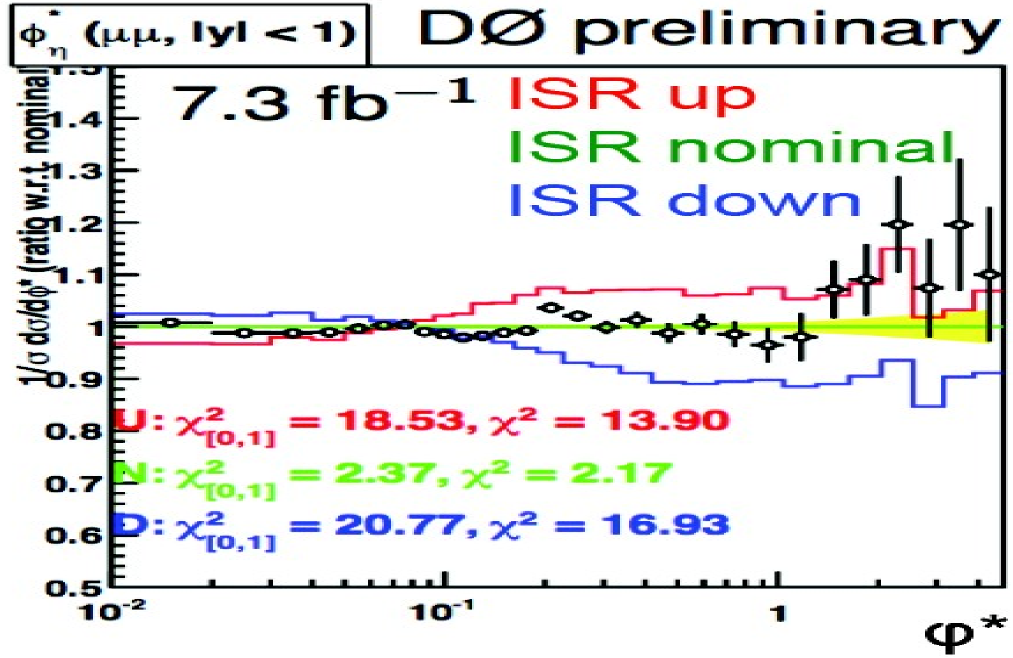
Additional Materials

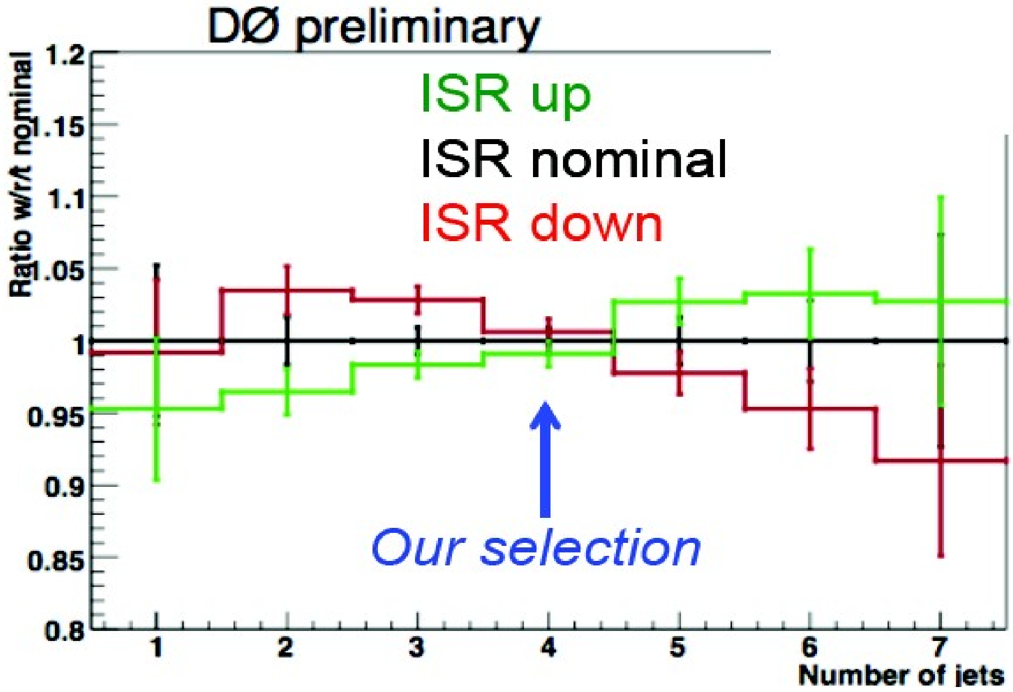
D0 b-JES

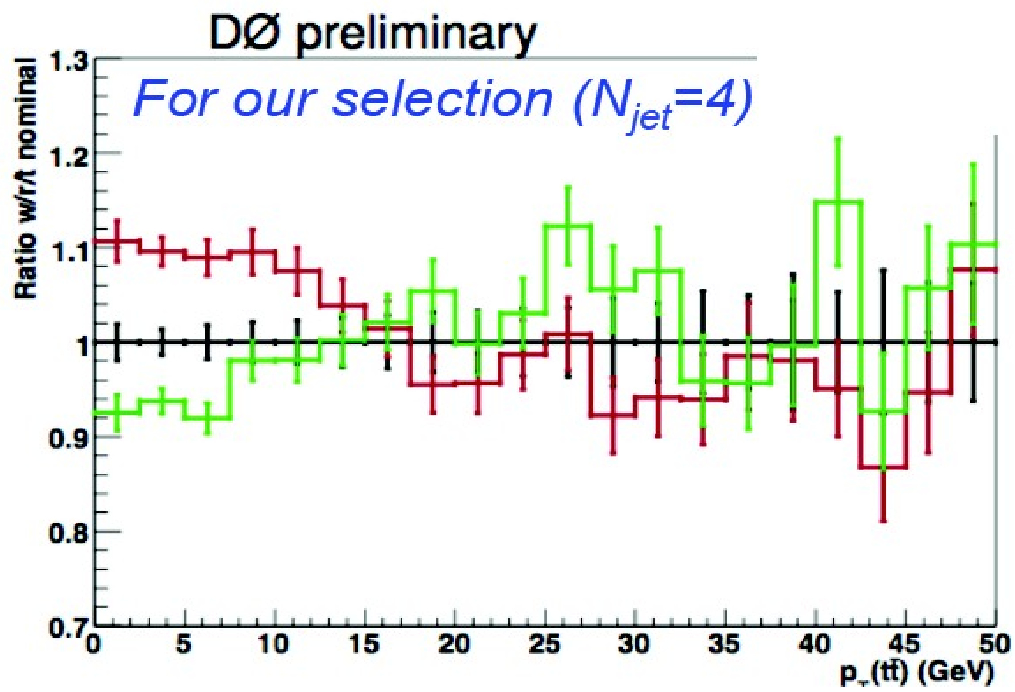

DØ
$|\eta_{det}|<0.4$
(a)
$F^{Lq}_{corr}-1$
0.02
0.00
-0.02
-0.04
-0.06
Correction
Statistical Uncertainty
Systematic Uncertainty
20
40
60
80
100
120
p_T [GeV]
DØ
$|\eta_{det}|<0.4$
(b)
$F^{g}_{corr}-1$
Correction
Statistical Uncertainty
Systematic Uncertainty
p_T [GeV]
DØ
$|\eta_{det}|<0.4$
(c)
$F^{b}_{corr}-1$
Correction
Statistical Unc.
Systematic Unc.
p_T [GeV]

D0 ISR/FSR variation









D0 measurement: systematic uncertainties comparison

3.6 fb^{-1}

Source	Uncertainty (GeV)
Modeling of production:	
Modeling of signal:	
Higher-order effects	±0.25
ISR/FSR	±0.26
Hadronization and UE	±0.58
Color reconnection	±0.28
Multiple $p\bar{p}$ interactions	±0.07
Modeling of background	±0.16
W+jets heavy-flavor scale factor	±0.07
Modeling of b jets	±0.09
Choice of PDF	±0.24
Modeling of detector:	
Residual jet energy scale	±0.21
Data-MC jet response difference	±0.28
b-tagging efficiency	±0.08
Trigger efficiency	±0.01
Lepton momentum scale	±0.17
Jet energy resolution	±0.32
Jet ID efficiency	±0.26
Method:	
Multijet contamination	±0.14
Signal fraction	±0.10
MC calibration	±0.20
Total	±1.02

9.7 fb^{-1}

Source of uncertainty	Effect on m_t (GeV)
Signal and background modeling:	
Higher order corrections	+0.15
Initial/final state radiation	±0.09
Hadronization and underlying event	+0.26
Color reconnection	+0.10
Multiple $p\bar{p}$ interactions	−0.06
Heavy flavor scale factor	±0.06
b quark jet modeling	+0.09
Parton distribution functions	±0.11
Detector modeling:	
Residual jet energy scale	±0.21
Flavor-dependent response to jets	±0.16
b tagging	±0.10
Trigger	±0.01
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Jet identification efficiency	−0.01
Method:	
Modeling of multijet events	+0.04
Signal fraction	±0.08
MC calibration	±0.07
Total systematic uncertainty	±0.49
Total statistical uncertainty	±0.58
Total uncertainty	±0.76