Tevatron Combinations and World Top Quark Mass Combination

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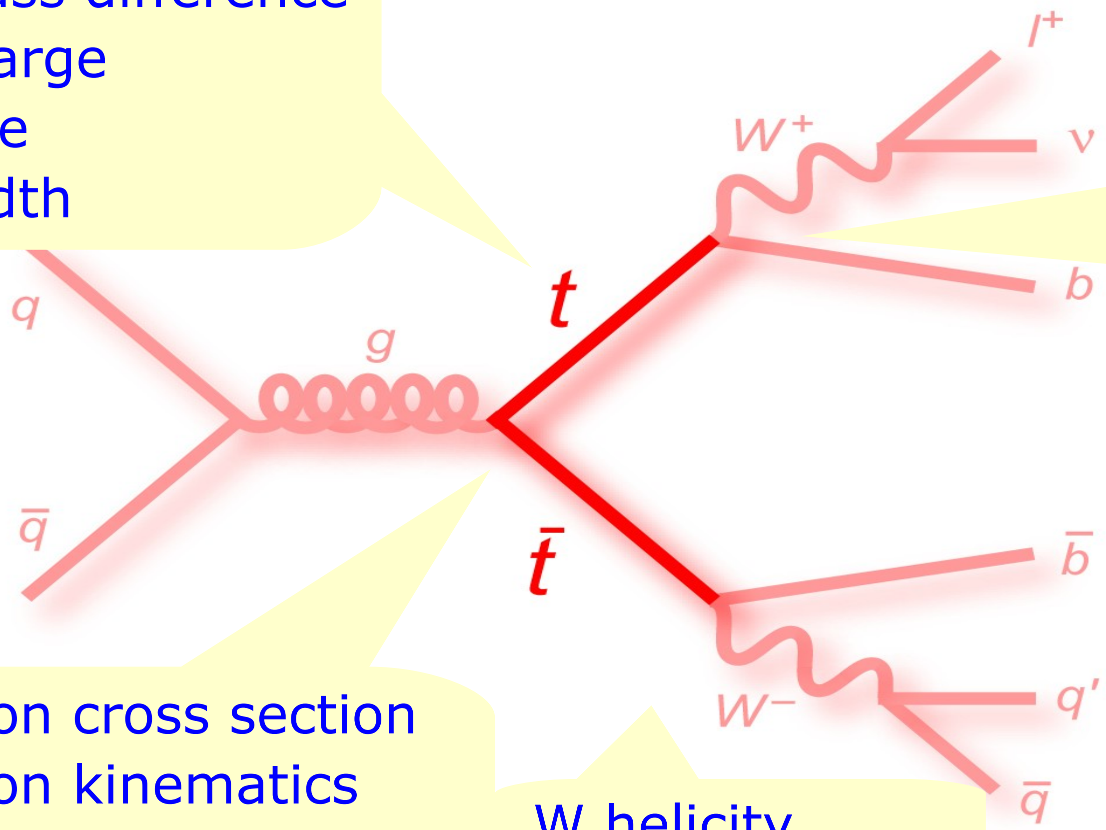
The University of Manchester, also at DESY

on behalf of the Tevatron and LHC experiments

Top Studies

Top mass
Top mass difference
Top charge
Lifetime
Top width

Branching ratios
$|V_{tb}|$
Anomalous coupling
New/Rare decays



Spin correlation
Charge asymmetry
Color Flow

Production cross section
Production kinematics
Production via resonance
New particles

W helicity

s- & t- channel production, properties and searches in single top events

Top Combinations

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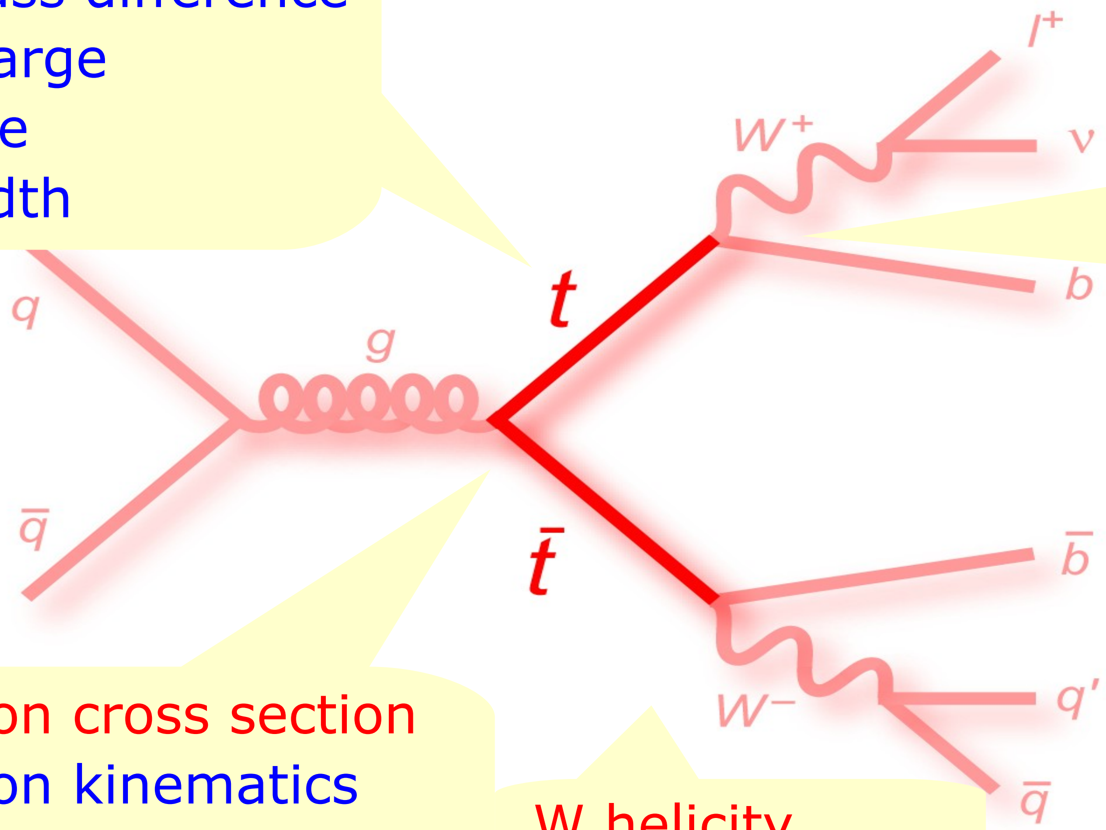

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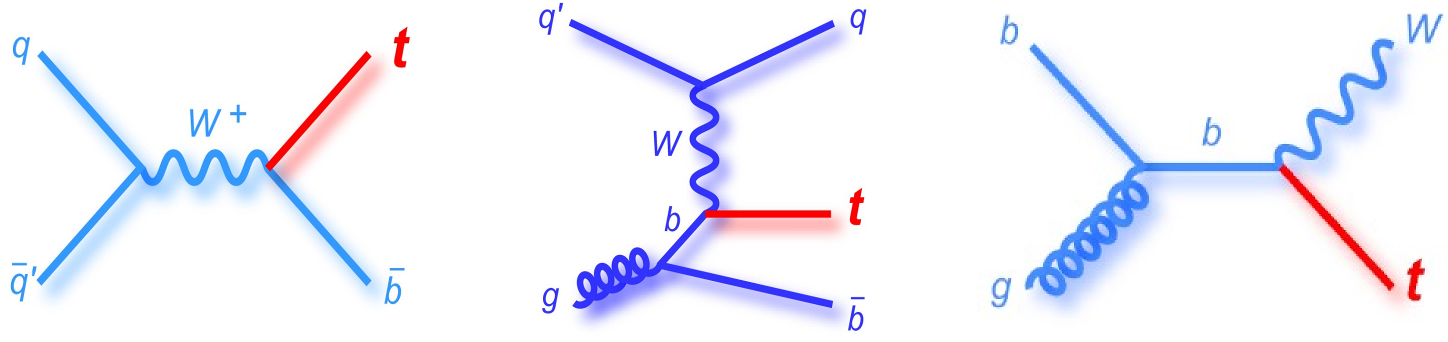
Single Top: Cross Sections

- Single top quark production via electroweak interaction



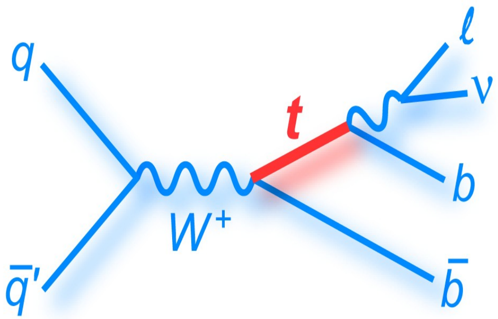
Collider	s-channel: σ_{tb}	t-channel: σ_{tqb}	Wt-channel: σ_{tW}
Tevatron: $p\bar{p}$ (1.96 TeV)	1.04 pb	2.26 pb	0.28 pb
LHC: pp (7 TeV)	4.6 pb	64.6 pb	15.7 pb

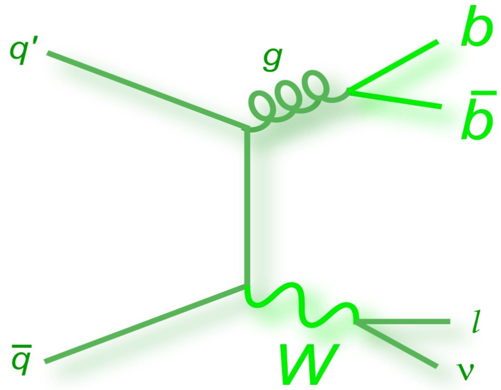
- Wt-channel: negligible at the Tevatron
- s-channel: challenging at the LHC

Single Top: Analysis

- Main background to single top: W+jets → very challenging

Simulated with Comphep (DØ) or POWHEG (CDF) +Pythia





Modeled using Alpgen+Pythia/ Herwig

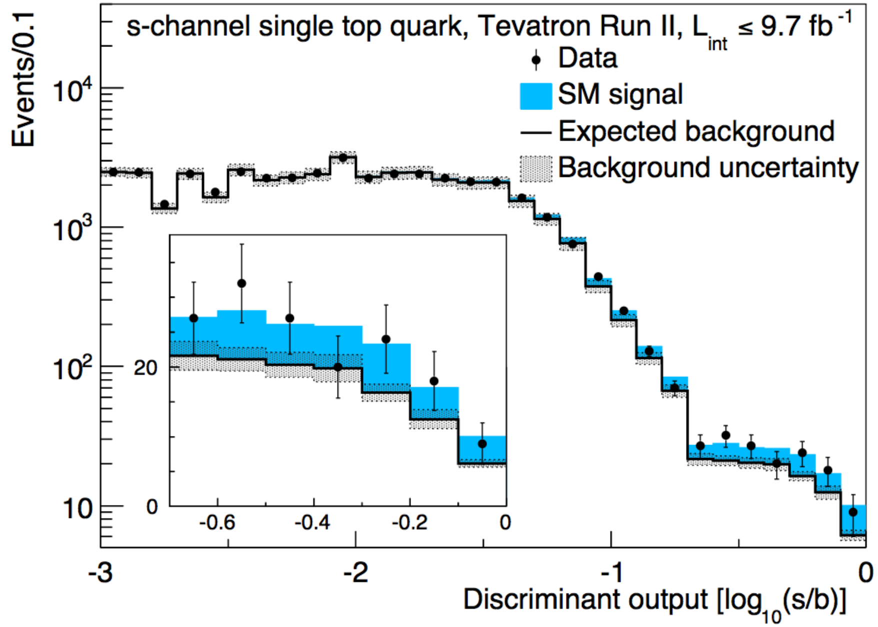
Normalized to Data

- Select l+jets & $\not{E}_T$+jets signature
  - High p_T lepton (l+jets) & high $\not{E}_T$
  - 2 jets (CDF) or 2&3 jets (D0)
    - 1 or 2 b-jets
  - $\not{E}_T$+jets: increase acceptance
    - Not-reconstructed electrons/muons from W
    - Events with hadronically decaying tau-lepton from W

Single Top: Combination

- Build multivariate discriminants, optimized to separate s-channel signal from backgrounds
- Extract combined cross section using Bayesian statistical analysis
  - Systematic uncertainties: categorized in classes; correlation taken into account

Systematic uncertainty	CDF Norm	CDF Dist	D0 Norm	D0 Dist	Correlated
Lumi from detector	4.5%		4.5%		No
Lumi from cross section	4.0%		4.0%		Yes
Signal modeling	2–10%	•	3–8%		Yes
Background (simulation)	2–12%	•	2–11%	•	Yes
Background (data)	15–40%	•	19–50%	•	No
Detector modeling	2–10%	•	1–5%	•	No
b-jet-tagging	10–30%		5–40%	•	No
JES	0–20%	•	0–40%	•	No

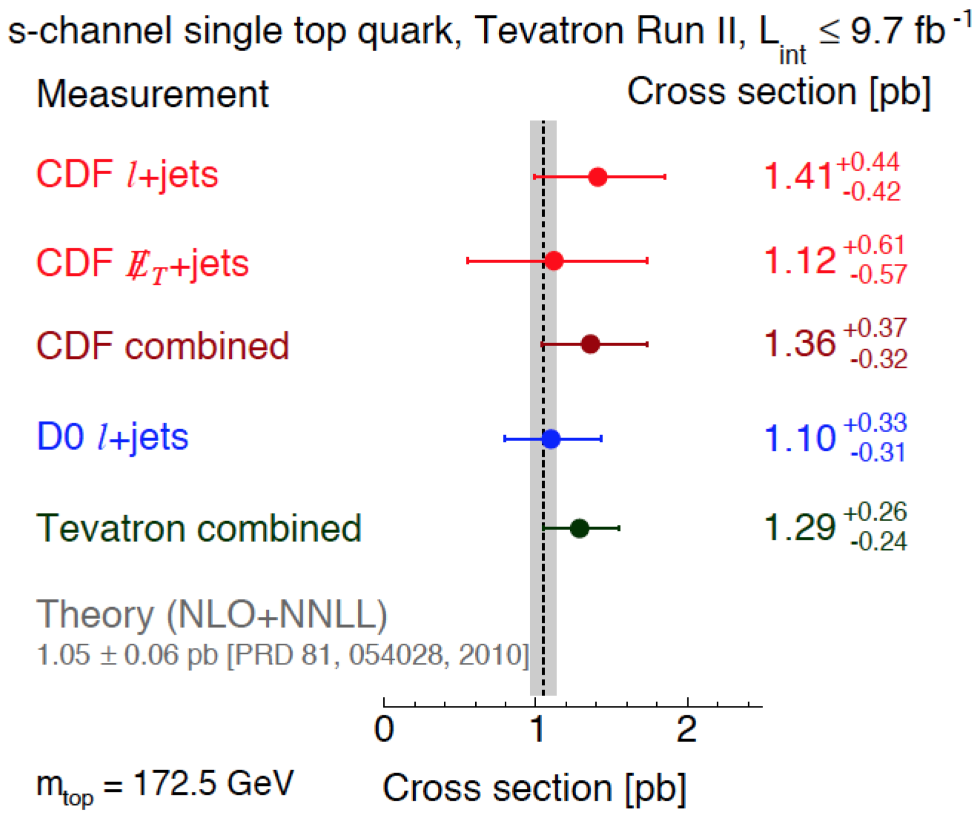


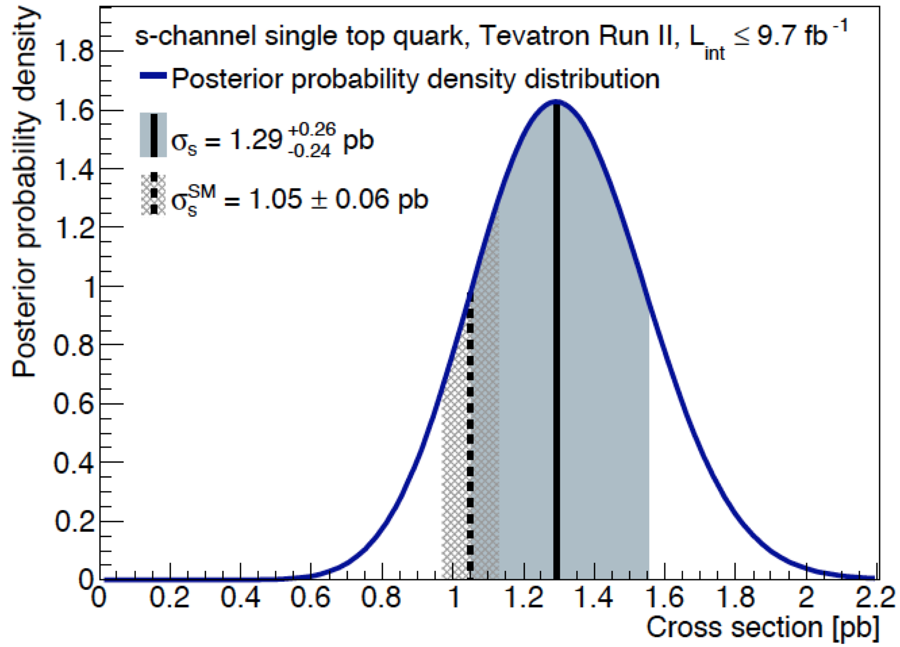
Single Top: s-channel Combination

- Central result: maximum of posterior

Phys. Rev. Lett. 112, 231803 (2014)

- P-value: $1.8 \times 10^{-10} \rightarrow$ 6.3. S.D. observed significance

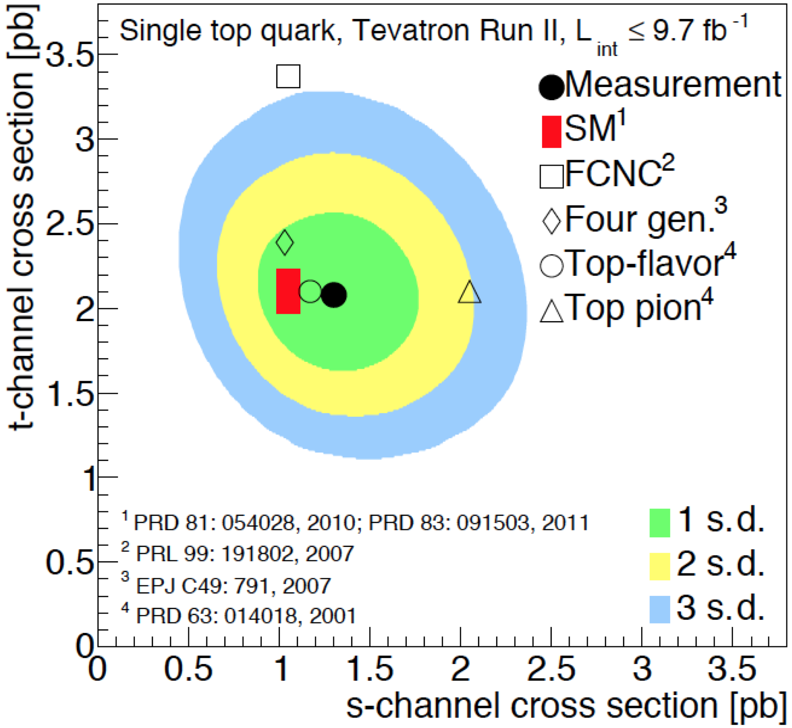




- First observation of s-channel single top production!

Single Top: s+t and t-channel Combinations

- Same combination method (& input analyses): also used for s+t-channel and t-channel combinations
  - Discriminants trained on s-channel or t-channel → both discriminants used simultaneously
- Construction of 2D posterior probability density
  - Function of σ_s and σ_t
- Combined σ_{s+t}: measured by forming 2D posterior for σ_{s+t} versus σ_t → integrate out σ_t



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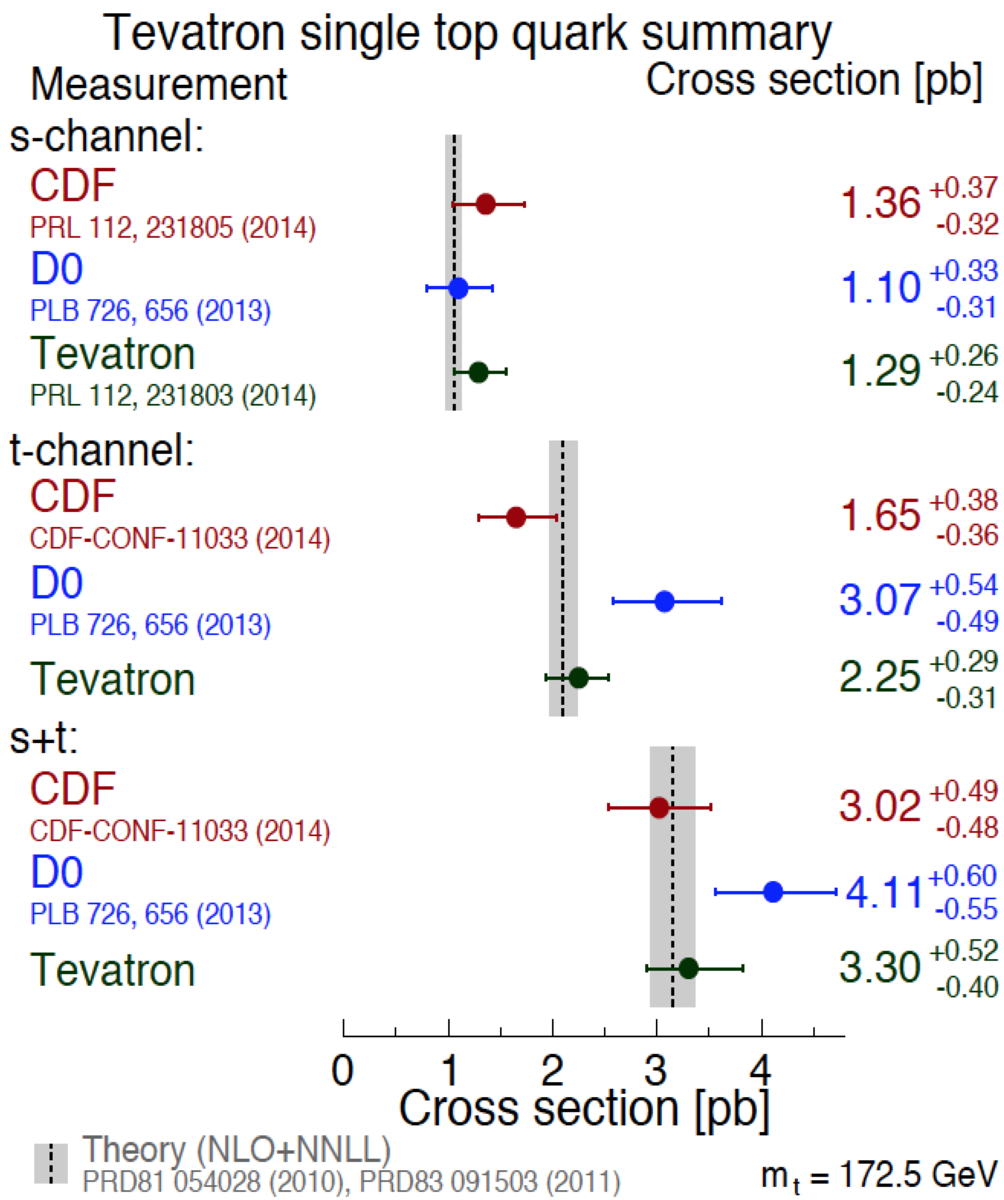
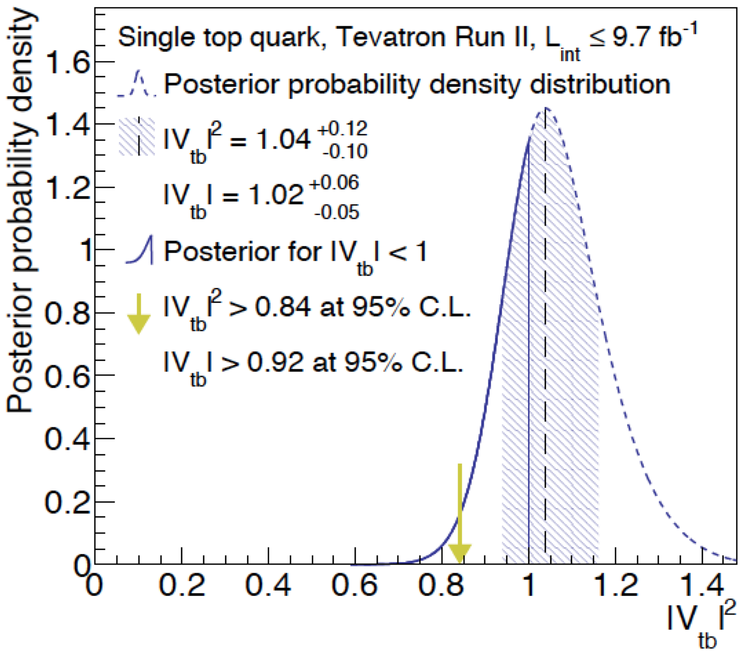
Single Top: s+t and t-channel Combinations

- Table of individual channels and combinations:



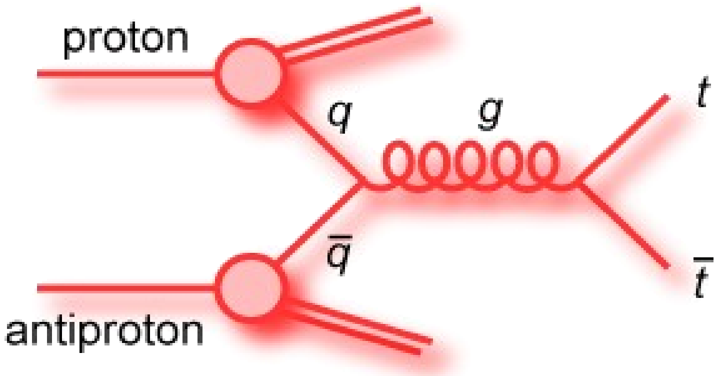
Single Top: $|V_{tb}|^2$

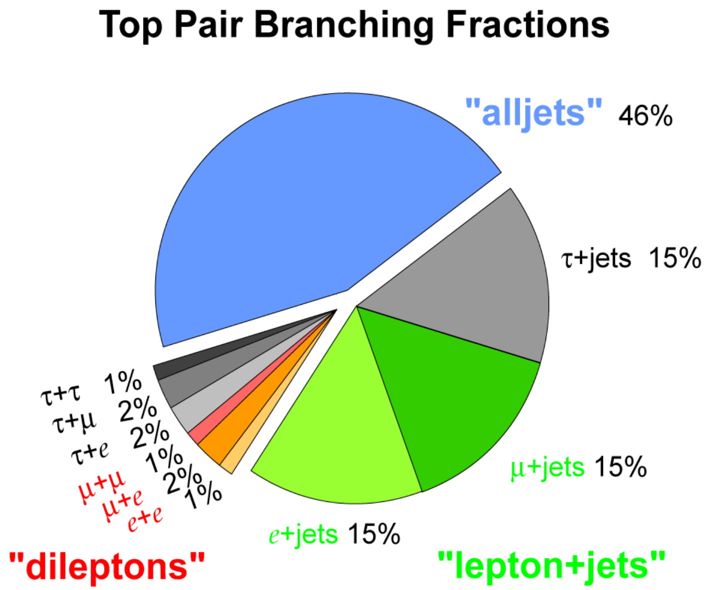
- Extraction of V_{tb}: use same discriminants as for s- and t-channel cross sections
  - Bayesian posterior probability density formed for $|V_{tb}|^2$
    - Assumption: flat prior in $|V_{tb}|^2$
    - No assumption on ratio σ_s/σ_t



$t\bar{t}$ Cross Section: Analysis

- At Tevatron: 85% $q\bar{q}$ annihilation + 15% gg fusion
- $t\bar{t} \rightarrow W^+bW^-\bar{b}$: Final states are classified according to W decay
  - Combination of $t\bar{t}$ cross section from CDF and D0 in dilepton and l+jets final states
    - 4 analyses from CDF, 2 from D0





$t\bar{t}$ Cross Section: CDF input

- 4 CDF measurements:
  - 2 l+jets
  - 1 dliepton
  - 1 allhadronic

  Constructed mutually exclusive
- Dilepton: counting events with >=1 b-tagged jets
- l+jets:
  - Analysis 1: Construct NN discriminant based on kinematic variables
    - No b-tagging
  - Analysis 2: counting events with >=1 b-tagged jets
- Allhadronic: fit to reconstructed top quark mass in events with ==1 and >1 b-tagged jets (in events containing 6-8 jets)

Intermezzo: BLUE Method

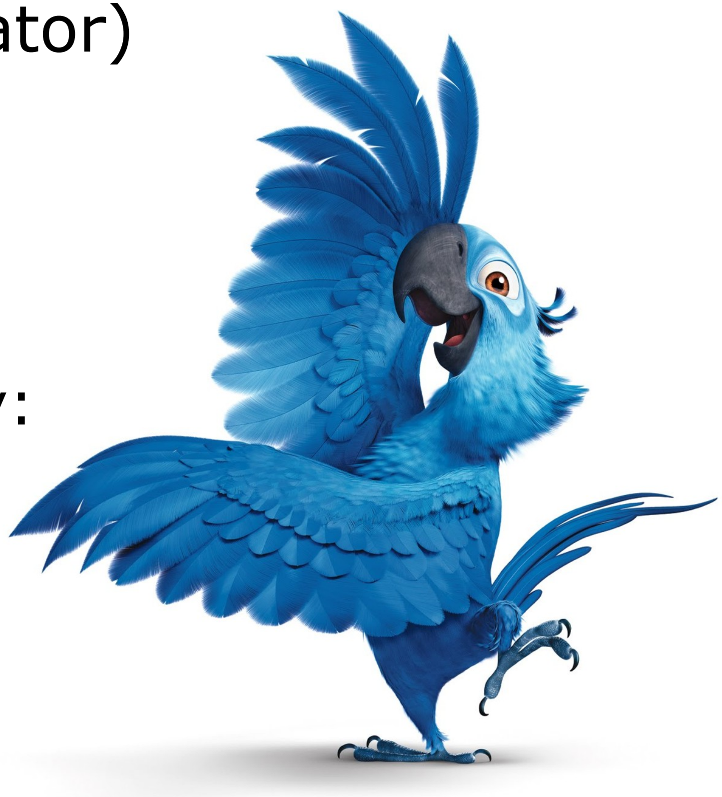
- BLUE Method (Best Linear Unbiased Estimator)
  - Use weighted mean of all measurements y_i:

$$\hat{\theta} = \sum_i w_i y_i$$

  - The weights are set to minimize uncertainty:

$$w_i = \frac{\sum_j V_{ij}^{-1}}{\sum_k \sum_l V_{kl}^{-1}}$$

    with V: covariance matrix (of all uncertainties: statistical and all systematics)



  - Error squared on the weighted mean: $Var(\hat{\theta}) = \vec{w}^T V \vec{w}$
- For high correlations: some weights can get negative

$t\bar{t}$ Cross Section: CDF input cont.

- CDF analyses are first combined to one CDF cross section
  - Using BLUE
  - Systematic uncertainty on $t\bar{t}$ selection efficiency directly proportional to measured $\sigma_{t\bar{t}}$ → three iterations of BLUE combination to remove this bias

Correlation	LJ-ANN	LJ-SVX	DIL	HAD
LJ-ANN	1	0.50	0.25	0.34
LJ-SVX		1	0.44	0.47
DIL			1	0.51
HAD				1

- CDF combination:

$$\sigma_{t\bar{t}} = 7.63 \pm 0.31(\text{stat}) \pm 0.36(\text{syst}) \pm 0.15(\text{lumi})\ \text{pb}$$

$t\bar{t}$ Cross Section: D0 input

- 2 D0 measurements
  - 1 dilepton
  - 1 l+jets
- Dilepton: likelihood fit to discriminant based on NN b-jet identification algorithm (using smallest NN output value from 2 highest-pT jets)
- l+jets: events with 3 & >3 jets, split into 0, 1 or >1 b-tagged jets
  - In background dominated samples: use random forest discriminant
  - Likelihood fit to all subsamples simultaneously
- Combination with likelihood fit, systematics treated as nuisance parameters
- D0 combination: $\sigma_{t\bar{t}}$= 7.56±0.20(stat)±0.32(syst)±0.46(lumi) pb

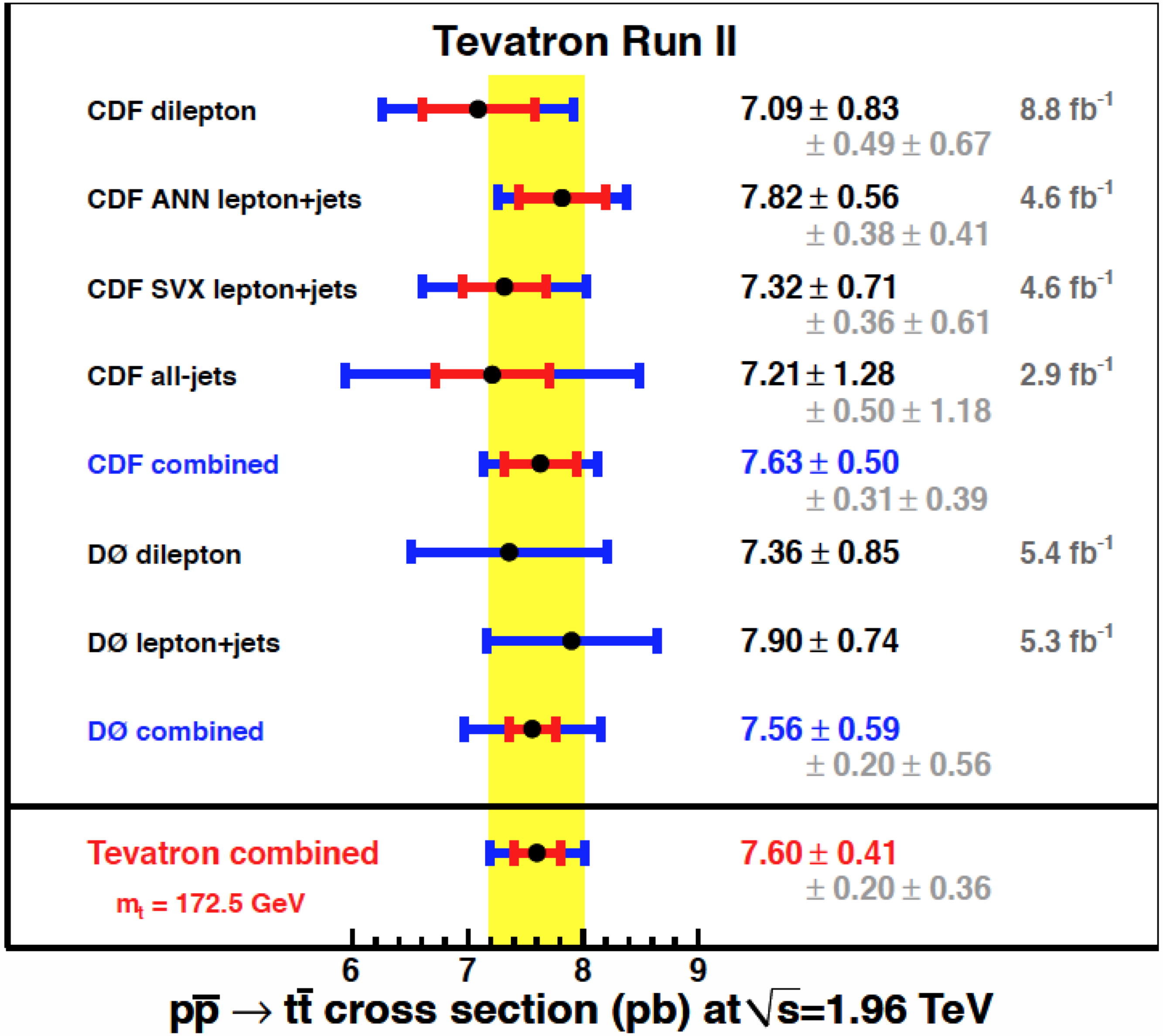
$t\bar{t}$ Cross Section: Tevatron Combination

- BLUE combination of CDF and D0 input combinations
  - Split systematics into classes according to correlation

	CDF	D0		Tevatron
Central value of $\sigma_{\bar{t}t}$	7.63	7.56		7.60
Sources of systematic uncertainty			Correlation	
Modeling of the detector	0.17	0.22	NO	0.13
Modeling of signal	0.21	0.13	YES	0.18
Modeling of jets	0.21	0.11	NO	0.13
Method of extracting $\sigma_{t\bar{t}}$	0.01	0.07	NO	0.03
Background modeled from theory	0.10	0.08	YES	0.10
Background based on data	0.08	0.06	NO	0.05
Normalization of Z/γ^* prediction	0.13	–	NO	0.08
Luminosity: inelastic $p\bar{p}$ cross section	0.05	0.30	YES	0.15
Luminosity: detector	0.06	0.35	NO	0.14
Total systematic uncertainty	0.39	0.56		0.36
Statistical uncertainty	0.31	0.20		0.20
Total uncertainty	0.50	0.59		0.41

$t\bar{t}$ Cross Section: Tevatron Combination

- Correlation between measurements from CDF and D0: 17%
- CDF measurement: weight 60%; D0: 40%

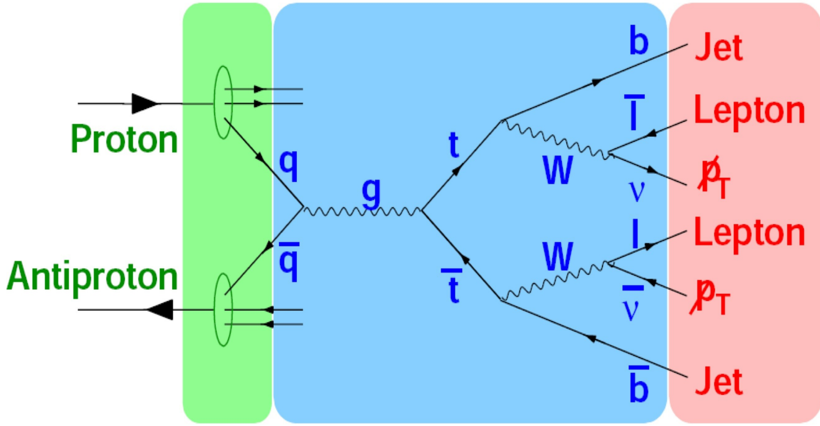


- All channels compatible with each other and SM value

Phys.Rev. D 89, 072001 (2014)

Top Quark Mass: Analyses

- Top quark mass: important free parameter in SM
- Tevatron combination uses
  - 5 Run I measurements
  - 5 published Run II measurements and 2 preliminary CDF results
- Update since march 2013:
  - CDF analyses in dilepton and alljets
  - D0 l+jets measurement using matrix elements



- Combination: using BLUE
  - Systematics split into classes according to source and correlations
    - Main challenge!

Top Quark Mass: Combination

- Matrix of total correlation coefficients:

	Run I published					Run II published					Run II prel.	
	CDF			DØ		CDF			DØ		CDF	
	ℓ+jets	$\ell\ell$	all-jets	ℓ+jets	$\ell\ell$	ℓ+jets	L_{XY}	MEt	ℓ+jets	$\ell\ell$	$\ell\ell$	all-jets
CDF-I ℓ+jets	1.00	0.29	0.32	0.26	0.11	0.49	0.07	0.26	0.19	0.12	0.54	0.27
CDF-I $\ell\ell$	0.29	1.00	0.19	0.15	0.08	0.29	0.04	0.16	0.12	0.08	0.32	0.17
CDF-I all-jets	0.32	0.19	1.00	0.14	0.07	0.30	0.04	0.16	0.08	0.06	0.37	0.18
DØ-I ℓ+jets	0.26	0.15	0.14	1.00	0.16	0.22	0.05	0.12	0.13	0.07	0.26	0.14
DØ-I $\ell\ell$	0.11	0.08	0.07	0.16	1.00	0.11	0.02	0.07	0.07	0.05	0.13	0.07
CDF-II ℓ+jets	0.49	0.29	0.30	0.22	0.11	1.00	0.08	0.32	0.28	0.18	0.52	0.30
CDF-II L_{XY}	0.07	0.04	0.04	0.05	0.02	0.08	1.00	0.04	0.05	0.03	0.06	0.04
CDF-II MEt	0.26	0.16	0.16	0.12	0.07	0.32	0.04	1.00	0.17	0.11	0.29	0.18
DØ-II ℓ+jets	0.19	0.12	0.08	0.13	0.07	0.28	0.05	0.17	1.00	0.36	0.15	0.14
DØ-II $\ell\ell$	0.12	0.08	0.06	0.07	0.05	0.18	0.03	0.11	0.36	1.00	0.10	0.09
CDF-II $\ell\ell$	0.54	0.32	0.37	0.26	0.13	0.52	0.06	0.29	0.15	0.10	1.00	0.32
CDF-II all-jets	0.27	0.17	0.18	0.14	0.07	0.30	0.04	0.18	0.14	0.09	0.32	1.00

Top Quark Mass: Combination

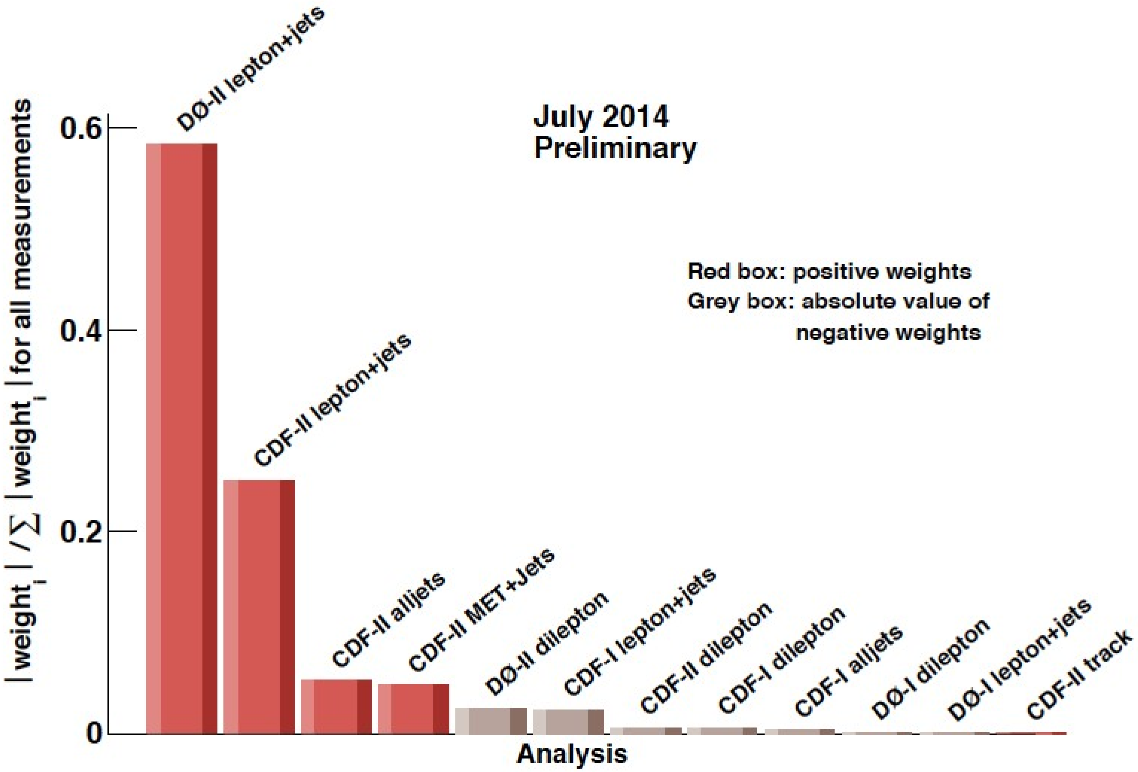
- Uncertainties on combined top quark mass:

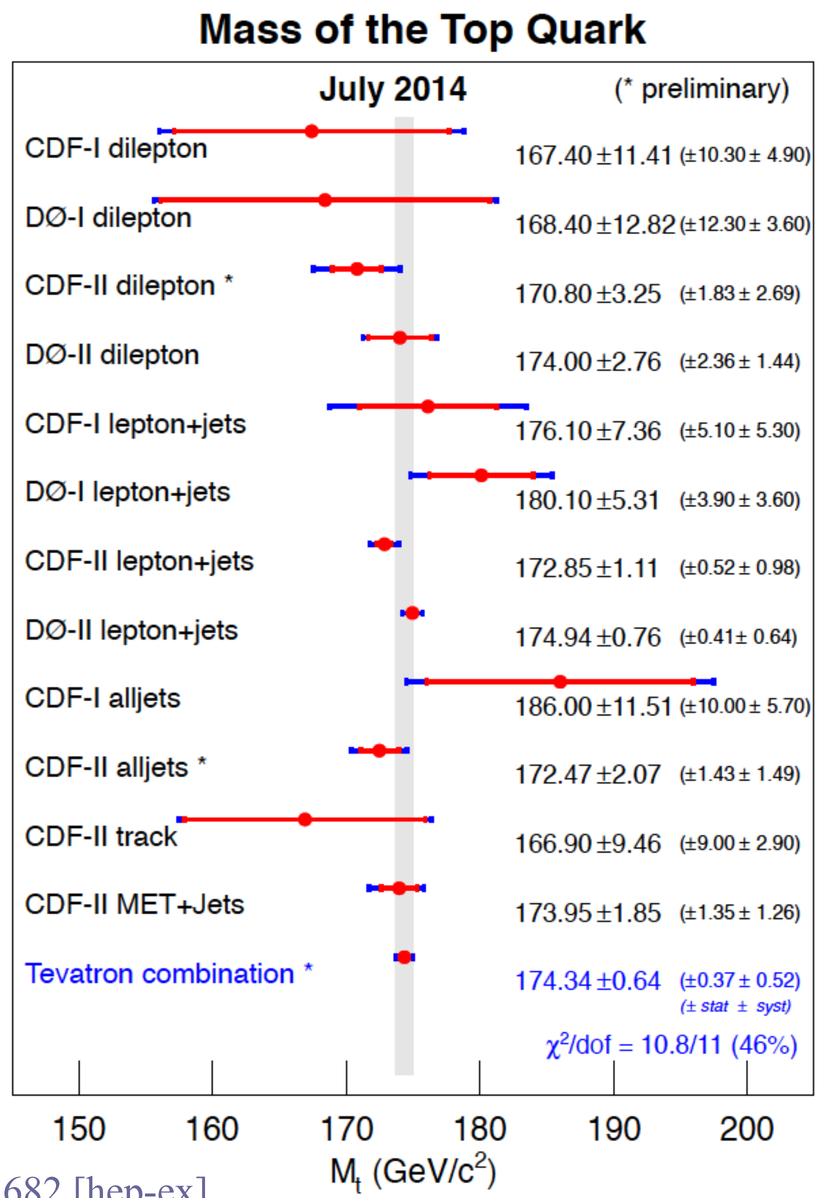
	Tevatron combined values (GeV/c^2)
M_t	174.34
In situ light-jet calibration (iJES)	0.31
Response to $b/q/g$ jets (aJES)	0.10
Model for b jets (bJES)	0.10
Out-of-cone correction (cJES)	0.02
Light-jet response (1) (rJES)	0.05
Light-jet response (2) (dJES)	0.13
Lepton modeling (LepPt)	0.07
Signal modeling (Signal)	0.34
Jet modeling (DetMod)	0.03
b-tag modeling (b-tag)	0.07
Background from theory (BGMC)	0.04
Background based on data (BGData)	0.08
Calibration method (Method)	0.07
Offset (UN/MI)	0.00
Multiple interactions model (MHI)	0.06
Systematic uncertainty (syst)	0.52
Statistical uncertainty (stat)	0.37
Total uncertainty	0.64

Top Quark Mass: Combination

- New Tevatron top mass combination
  - Results using up to $9.7 fb^{-1}$

$$m_t = 174.34 \pm 0.37\,(\mathrm{stat}) \pm 0.52\,(\mathrm{syst})\ \mathrm{GeV}$$





arXiv:1407.2682 [hep-ex]

Top Quark Mass: World Combination

- March 2014: First world combination of top quark mass
- Inputs: best measurement per channel per experiment (as of March 2014!)
  - 6 input measurements from Tevatron (Run II)
  - 5 input measurements from LHC (7 TeV data sample)
  - All input measurements are "classical" top mass measurements:
    - CDF: template methods; dilepton: neutrino weighting
    - D0: ME method in l+jets, neutrino weighting in dilepton
      - JES calibration transferred from l+jets to dilepton
    - ATLAS: 3D template method in l+jets, m_{lb} observable in dilepton
    - CMS: ideogram method; dilepton analytic matrix-weighting
- Combination performed using BLUE

Top Quark Mass: World Combination

- Main challenge: systematic uncertainties!
  - Correlation between measurements and experiments?
    - In contrast to Tevatron-only: also between colliders
  - (Partially) different treatment at different experiments
    - Different MC programs for central mass measurement: MadGraph at CMS, Alpgen at D0, Pythia at CDF, Powheg at ATLAS
- Solution:
  - 1. classify systematic in "logical" classes with the same correlation
    - Get central result
  - 2. vary the correlations to check the influence on the result!

Top Quark Mass: World Combination

- Step 1: correlations between systematics and experiments

	$\rho_{\rm EXP}$				$\rho_{\rm LHC}$	$\rho_{\rm TEV}$	$\rho_{\rm COL}$	
	$\rho_{\rm CDF}$	$\rho_{\rm D0}$	$\rho_{\rm ATL}$	$\rho_{\rm CMS}$			$\rho_{\rm ATL-TEV}$	$\rho_{\rm CMS-TEV}$
Stat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
iJES	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
stdJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
flavourJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
bJES	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5
MC	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Rad	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
CR	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PDF	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
DetMod	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
b-tag	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
LepPt	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
BGMC†	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BGData	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Meth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MHI	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0

Top Quark Mass: World Combination

- Step 1: correlations between systematics and experiments

Step 2
(examples)

Change:
0 → 0.5

	$\rho_{\rm EXP}$				$\rho_{\rm LHC}$	$\rho_{\rm TEV}$	$\rho_{\rm COL}$	
	$\rho_{\rm CDF}$	$\rho_{\rm D0}$	$\rho_{\rm ATL}$	$\rho_{\rm CMS}$			$\rho_{\rm ATL-TEV}$	$\rho_{\rm CMS-TEV}$
Stat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
iJES	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
stdJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
flavourJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
bJES	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5
MC	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Rad	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
CR	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PDF	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
DetMod	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
b-tag	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
LepPt	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
BGMC†	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BGData	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Meth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MHI	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0

Top Quark Mass: World Combination

- Step 1: correlations between systematics and experiments

Step 2
(examples)

Change:
0 → 0.5

Change:
1 → 0.5

	ρ_{EXP}				ρ_{LHC}	ρ_{TEV}	ρ_{COL}	
	ρ_{CDF}	ρ_{D0}	ρ_{ATL}	ρ_{CMS}			$\rho_{\mathrm{ATL-TEV}}$	$\rho_{\mathrm{CMS-TEV}}$
Stat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
iJES	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
stdJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
flavourJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
bJES	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5
MC	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Rad	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
CR	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PDF	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
DetMod	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
b-tag	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
LepPt	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
BGMC†	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BGData	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Meth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MHI	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0

Top Quark Mass: World Combination

- Step 1: correlations between systematics and experiments

Step 2
(examples)

Change:
0 → 0.5

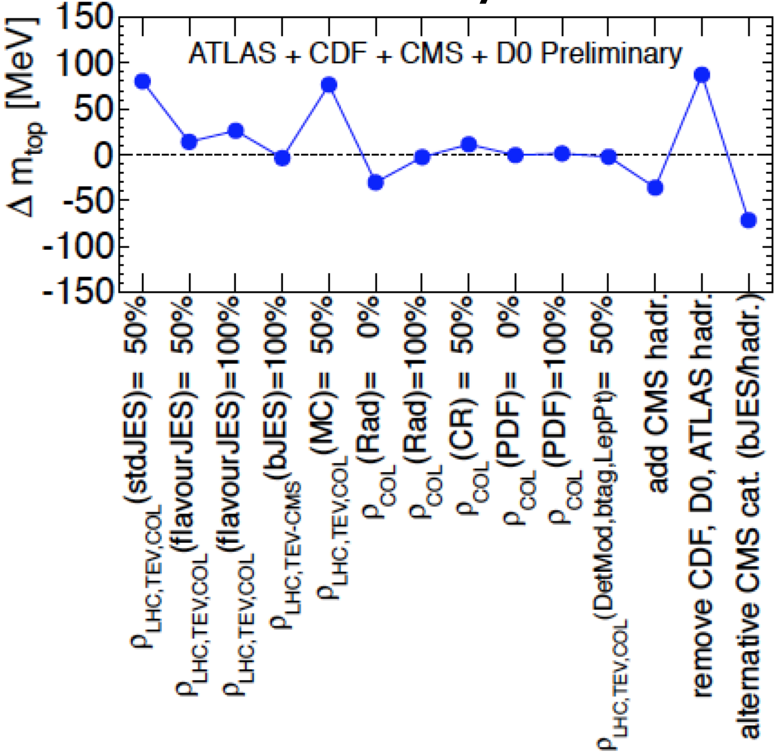
Change:
1 → 0.5

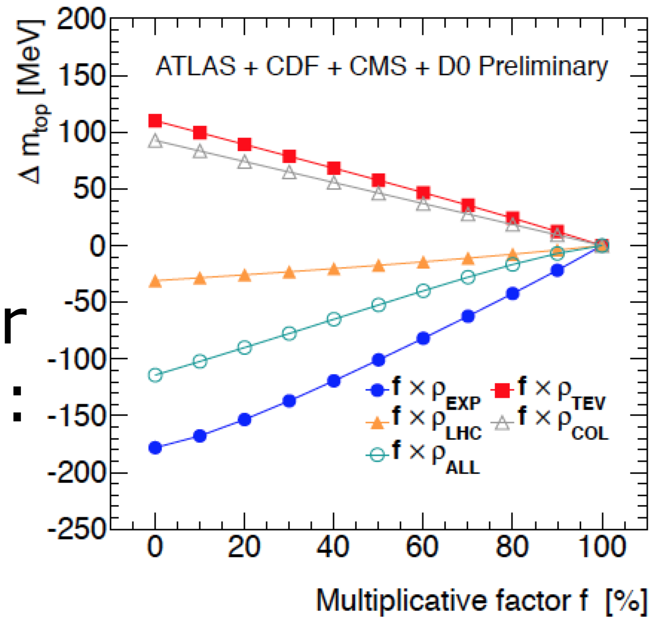
Change:
0 → 0.5

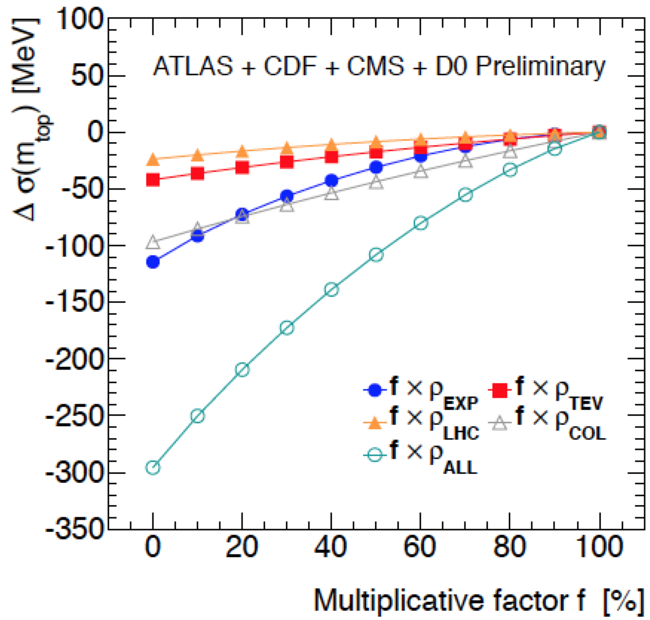
	ρ_{EXP}				ρ_{LHC}	ρ_{TEV}	ρ_{COL}	
	ρ_{CDF}	ρ_{D0}	ρ_{ATL}	ρ_{CMS}			$\rho_{\text{ATL-TEV}}$	$\rho_{\text{CMS-TEV}}$
Stat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
iJES	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
stdJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
flavourJES	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
bJES	1.0	1.0	1.0	1.0	0.5	1.0	1.0	0.5
MC	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Rad	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
CR	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
PDF	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.5
DetMod	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
b-tag	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
LepPt	1.0	1.0	1.0	1.0	0.0	0.0	0.0	0.0
BGMC†	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BGData	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Meth	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MHI	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.0

Top Quark Mass: World Combination

- Step 2: variations to check stability
- Global factor: →
- Change correlation factor of individual systematics:



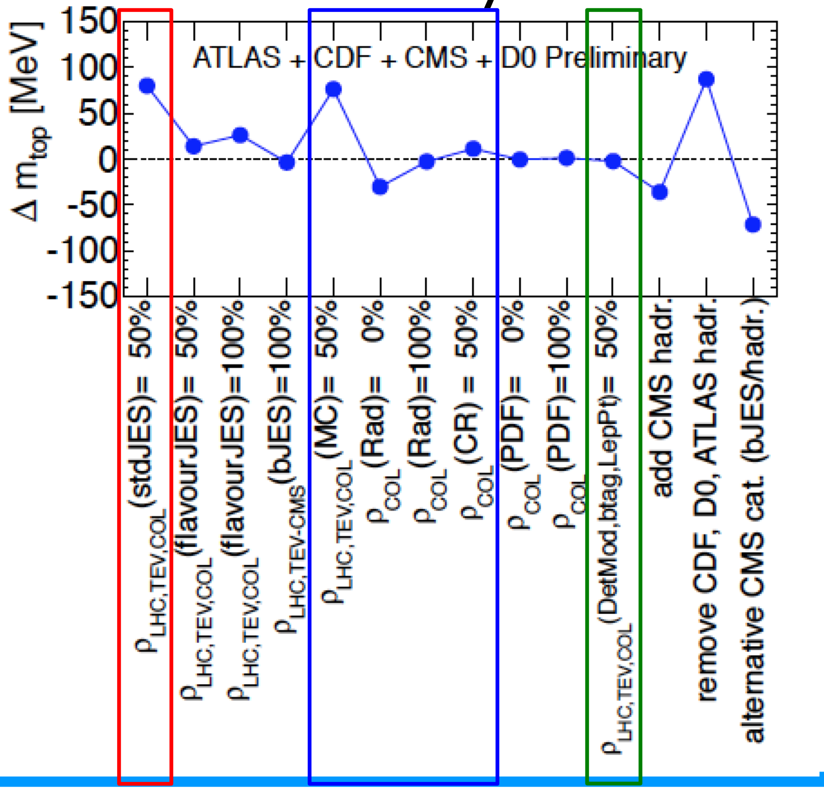


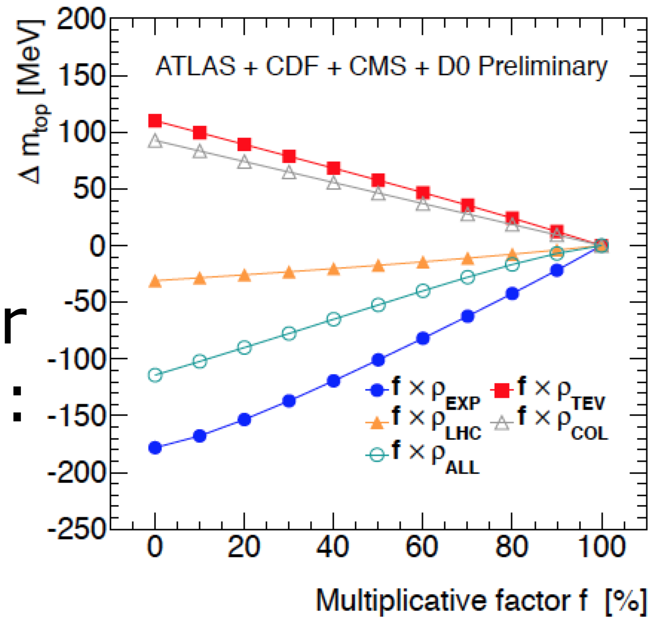


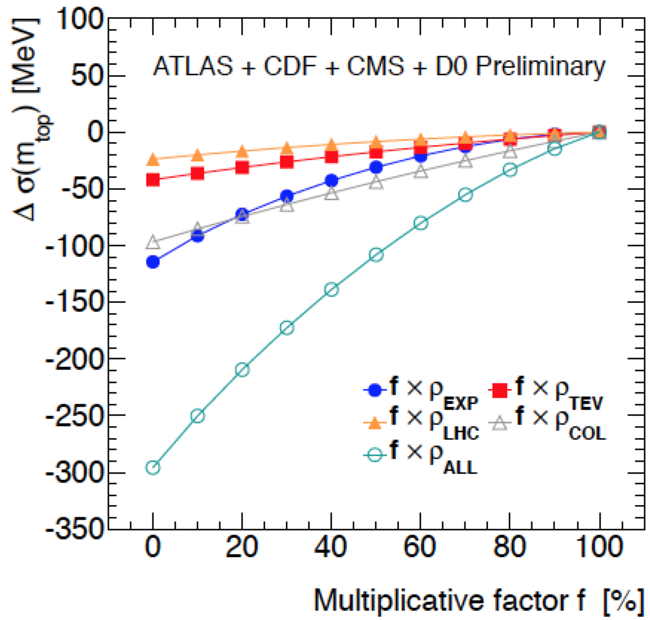
- Small size of effects → no additional uncertainty assigned for the choice of correlation factors

Top Quark Mass: World Combination

- Step 2: variations to check stability
- Global factor: →
- Change correlation factor of individual systematics:







- Small size of effects → no additional uncertainty assigned for the choice of correlation factors

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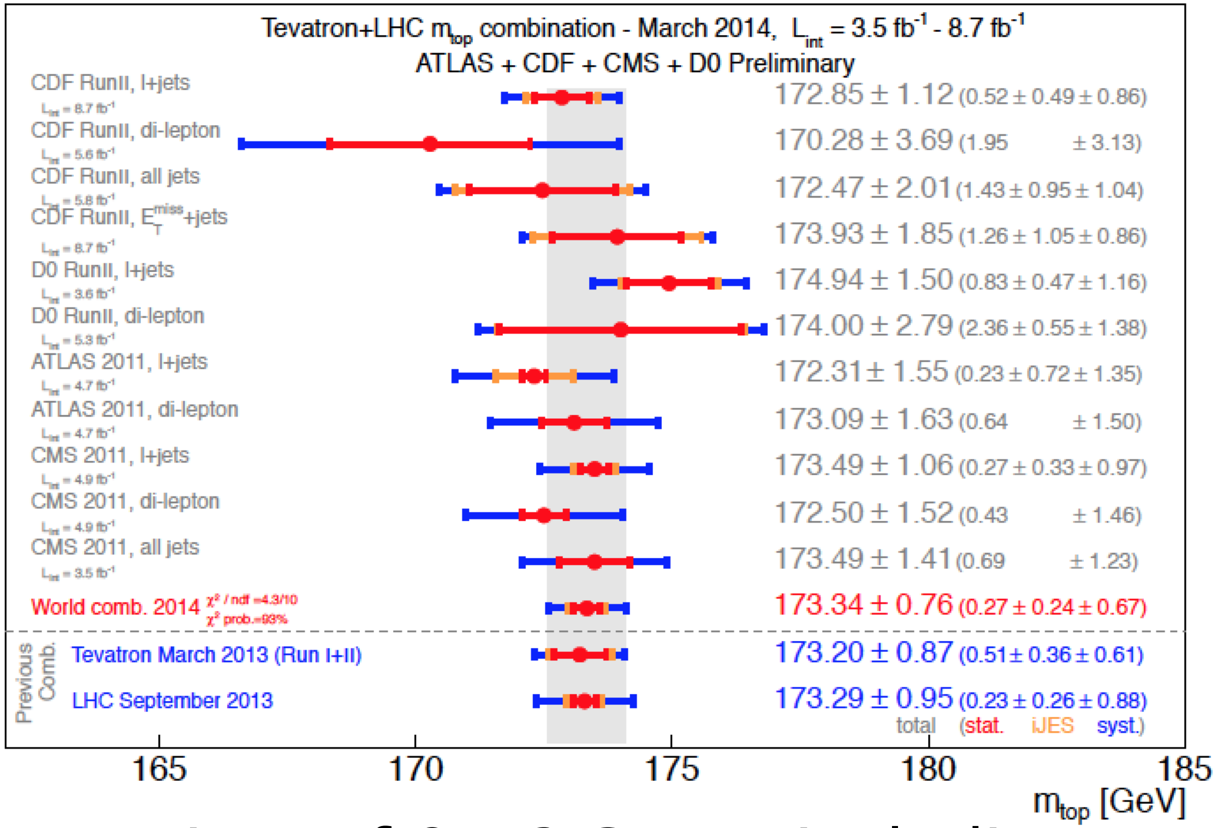
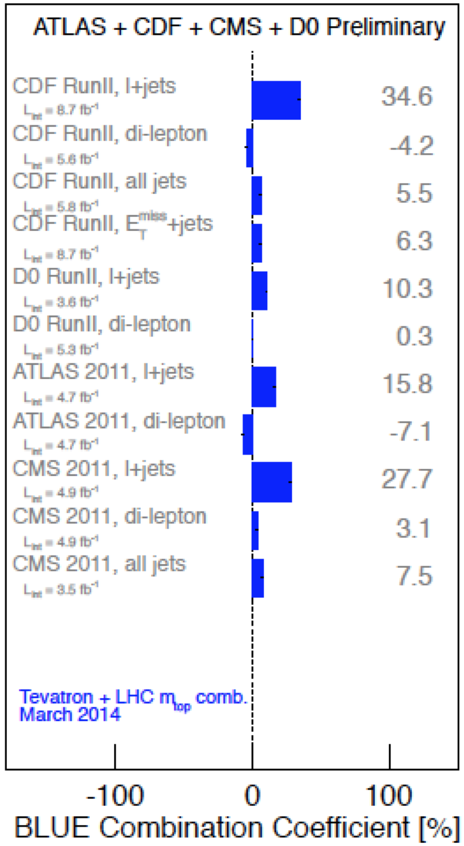
Top Quark Mass: World Combination

- Combined result:



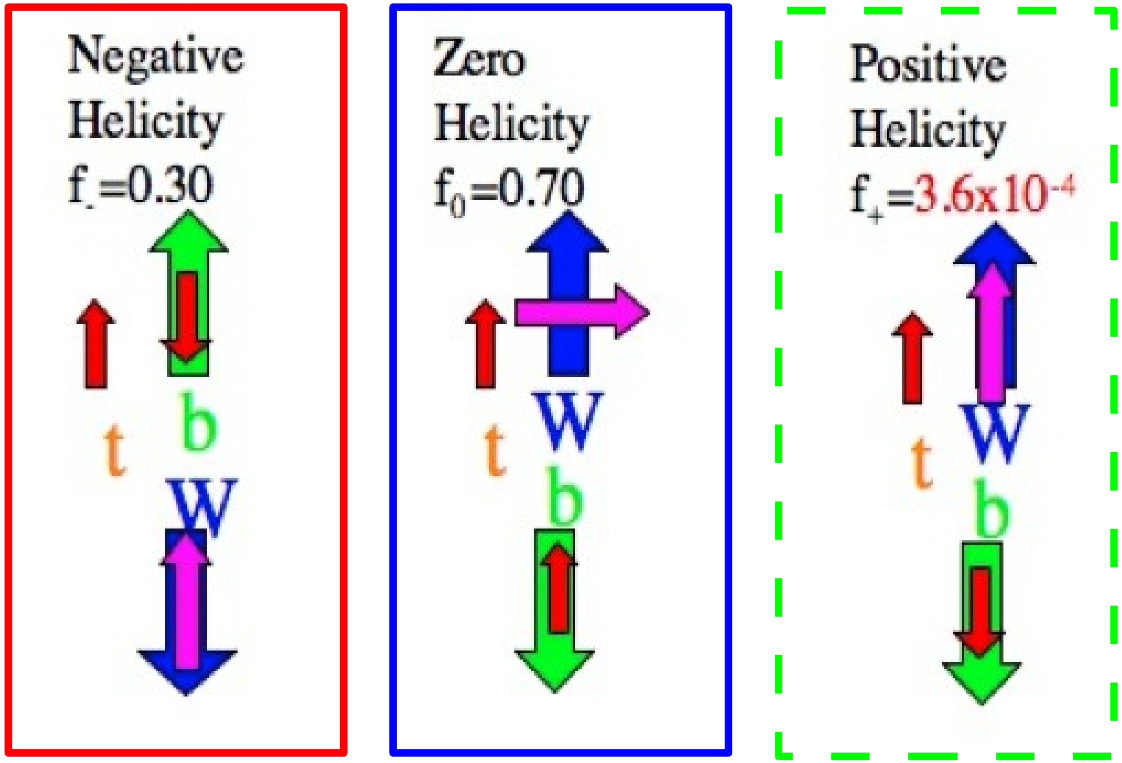


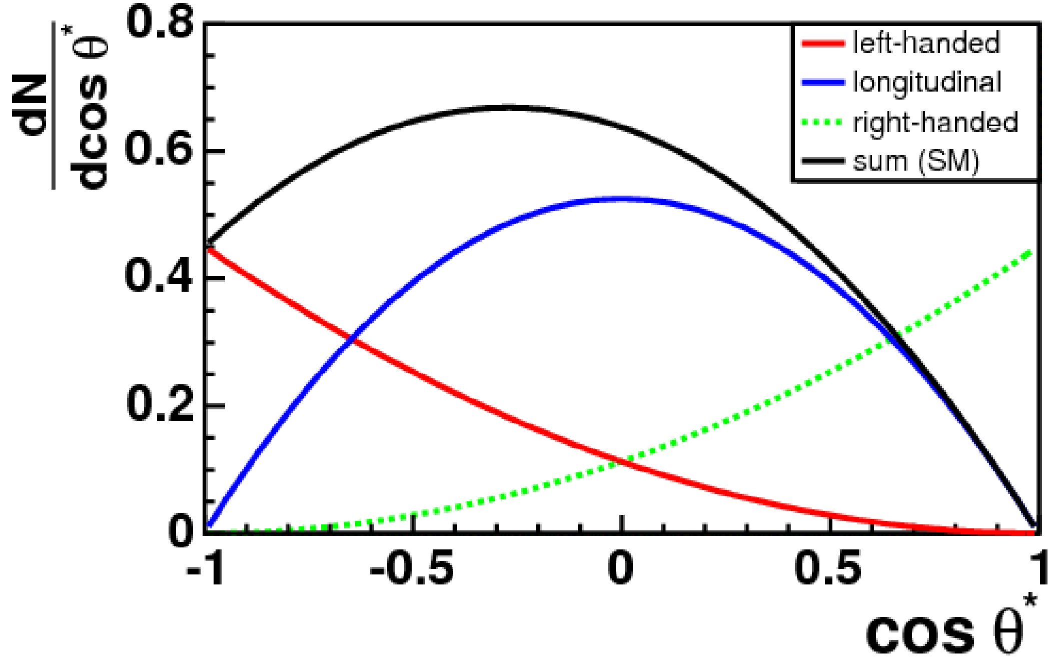
- Uncertainty of 0.76 GeV → including newest results from Tevatron and LHC should be reduced even further!
  - compatibility between input results will need careful consideration

arXiv:1403.4427

W Helicity in Top Quark Decays

- Left-handed coupling of W-boson to fermions:
  Not every combination of spin for W and b-quark is allowed

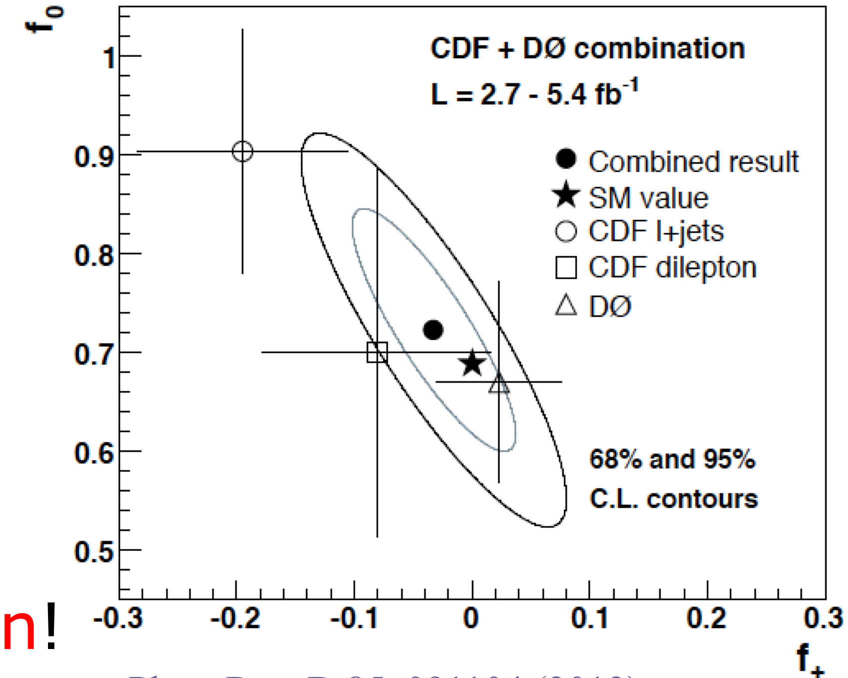




- Measure angle θ^* between down-type decay product (lepton, d-, s-quark) of W and top quark in W rest frame

W Helicity: Tevatron Results

- Input measurements combined with BLUE:
  - 1 CDF l+jets using matrix element method
    - Same method as for mass, but replace m_T with f_0 & f_+
  - 1 CDF dilepton analysis and D0 l+jets and dilepton analysis using a template method: fitting fraction of $\cos\theta^*$ templates to data
- Tevatron Combination:
  - Model independent (fit f_+, f_-, f_0 with $f_-+f_0+f_+=1$):
    $f_0=0.722\pm0.062(\text{stat})\pm0.052(\text{syst})$
    $f_+=-0.033\pm0.034(\text{stat})\pm0.031(\text{syst})$
- Good agreement with SM values
- First published Tevatron top combination!



Phys. Rev. D 85, 091104 (2012)

Summary

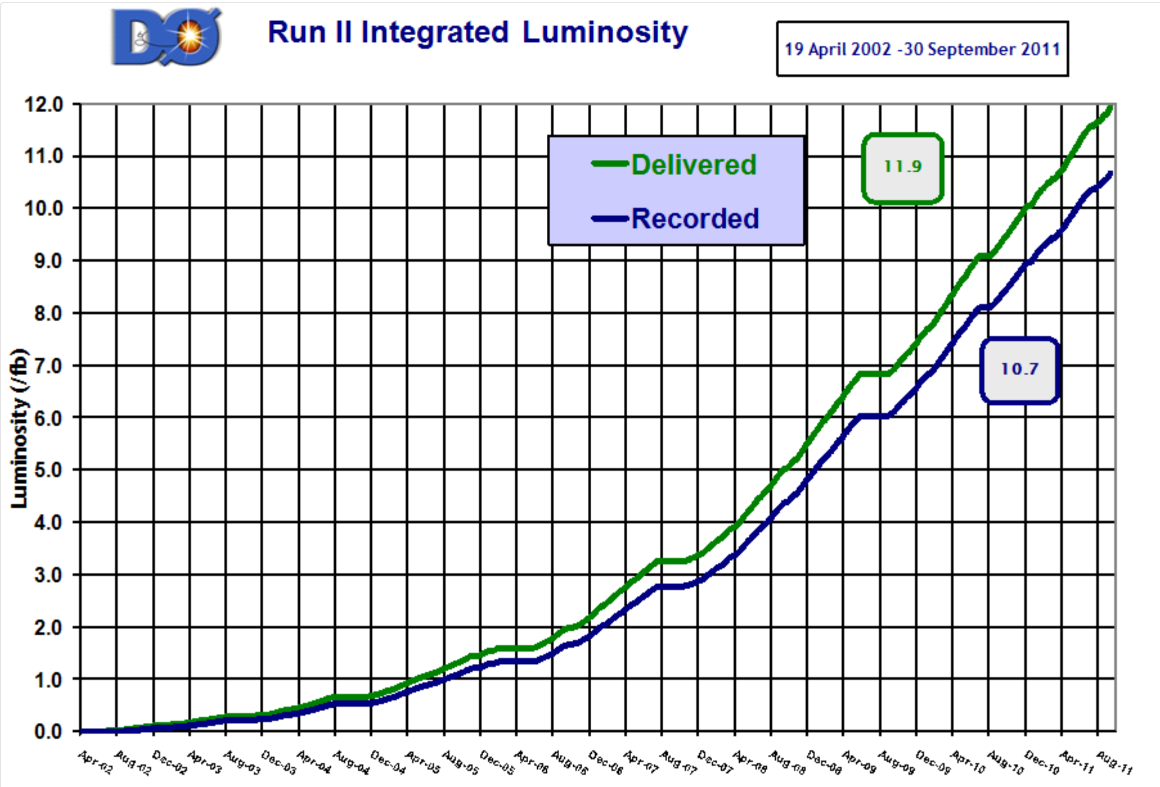
- Legacies of the Tevatron are being written
  - s-channel observation from CDF+D0 combination
  - New combinations of top quark mass!

- Work on more combinations ongoing
  - Tevatron, LHC and world combinations!

    → stay tuned!

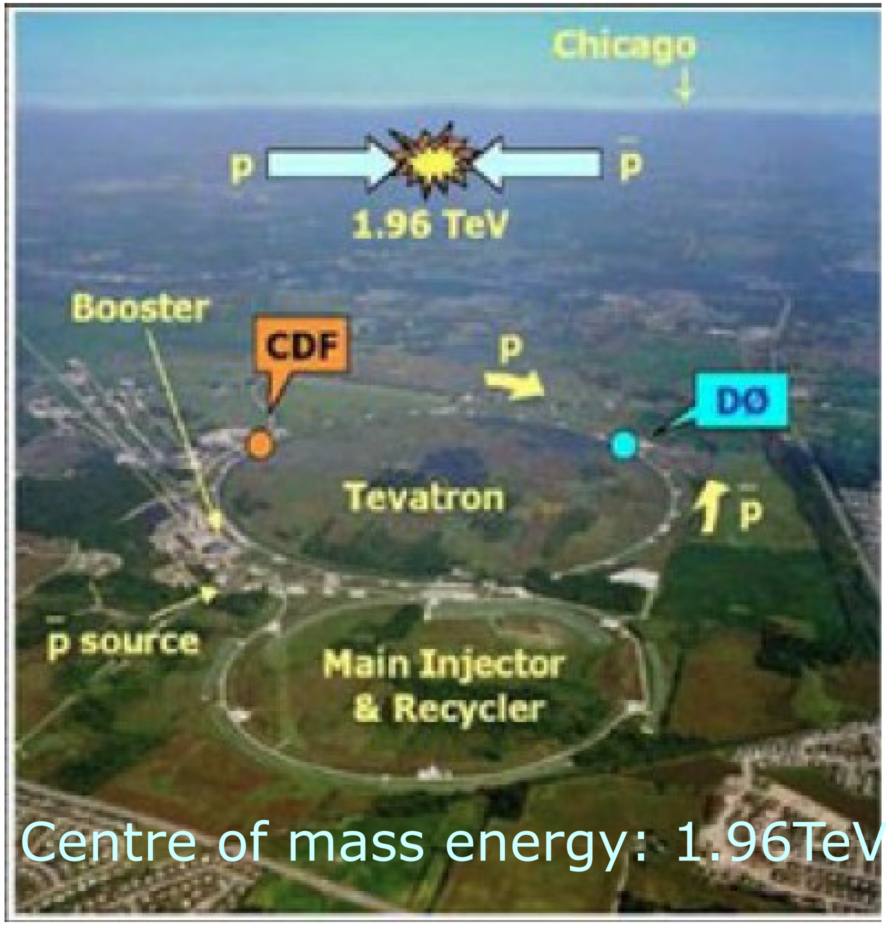
BACKUP

The Tevatron



~11.5fb^{-1} delivered

>10fb^{-1} on disk per experiment



Tevatron ended operation on 30.9.2011

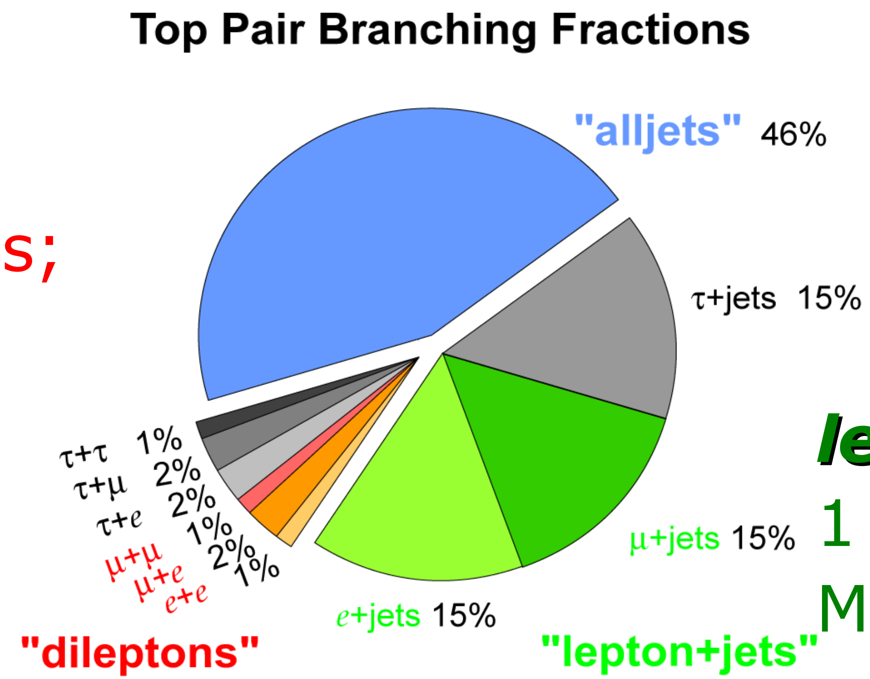
$t\bar{t}$ Final States

$t\bar{t}$ $W^+bW^-\bar{b}$: Final states are classified according to W decay

$B(t\ \ W^+b)=100\%$

pure hadronic:
≥6 jets (2 b-jets)

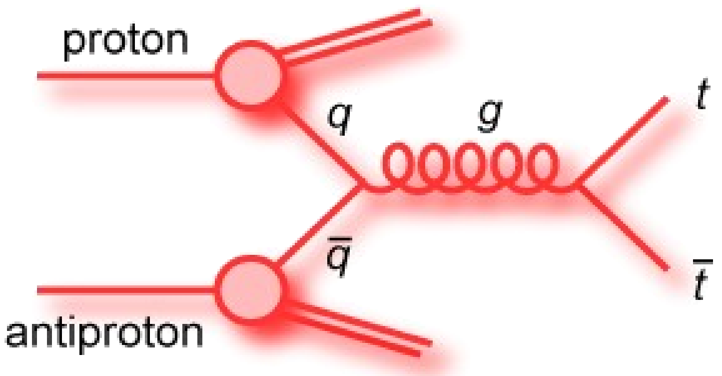
dilepton:
2 isolated leptons;
High missing E_T from neutrinos;
2 b-jets



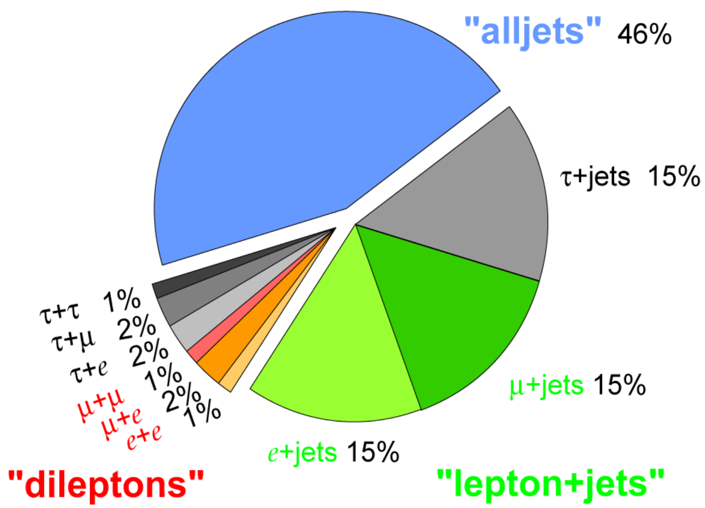
lepton+jets:
1 isolated lepton;
Missing E_T from neutrino;
≥4 jets (2 b-jets)

Reminder of some Basics: Production and Final States

- Most properties measured in $t\bar{t}$ events
- At Tevatron: 85% $q\bar{q}$ annihilation + 15% gg fusion
  - At LHC (7 TeV): 15% $q\bar{q}$ annihilation + 85% gg fusion
- $t\bar{t}$ $W^+bW^-\bar{b}$: Final states are classified according to W decay
  - Most properties measured in dilepton & l+jets final states



Top Pair Branching Fractions

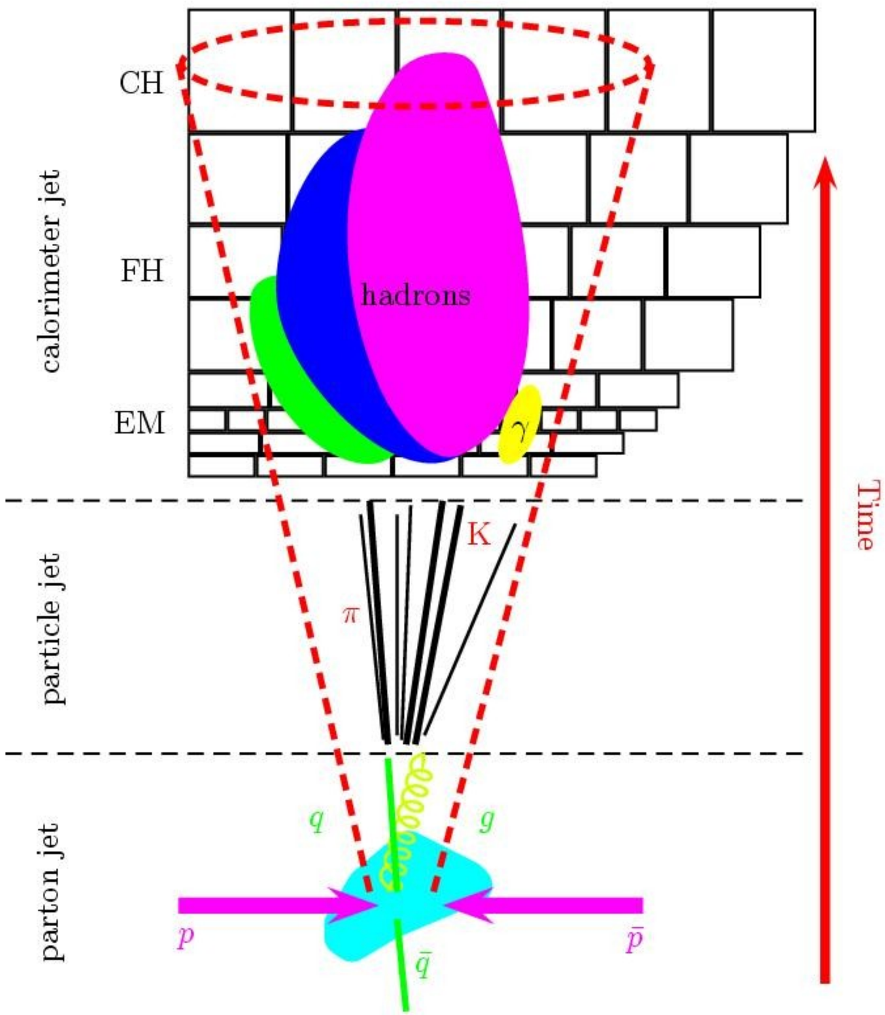


Top Quark Mass: Uncertainties

- l+jets:
  Systematic uncertainties

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 UE	$+0.26$
Color reconnection	$+0.10$
Multiple $p\bar{p}$ interactions	-0.06
Heavy flavor scale factor	± 0.06
b-jet modeling	$+0.09$
PDF uncertainty	± 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 ID 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

Jet Energy Scale



Top Quark Mass World Combination: Inputs

- Input measurements for world combination

Experiment	$t\bar{t}$ final state	$\mathcal{L}_{\text{int}}$ [fb^{-1}]	$m_{\text{top}} \pm$ (stat.) $\pm$ (syst.) [GeV]	Total uncertainty on m_{top} [GeV] ([%])	Reference
CDF	l+jets	8.7	$172.85 \pm 0.52 \pm 0.99$	1.12 (0.65)	[8]
	dilepton	5.6	$170.28 \pm 1.95 \pm 3.13$	3.69 (2.17)	[9]
	all jets	5.8	$172.47 \pm 1.43 \pm 1.41$	2.01 (1.16)	[10]
	$E_{\text{T}}^{\text{miss}}$+jets	8.7	$173.93 \pm 1.26 \pm 1.36$	1.85 (1.07)	[11]
D0	l+jets	3.6	$174.94 \pm 0.83 \pm 1.25$	1.50 (0.86)	[12]
	dilepton	5.3	$174.00 \pm 2.36 \pm 1.49$	2.79 (1.60)	[13]
ATLAS	l+jets	4.7	$172.31 \pm 0.23 \pm 1.53$	1.55 (0.90)	[14]
	dilepton	4.7	$173.09 \pm 0.64 \pm 1.50$	1.63 (0.94)	[15]
CMS	l+jets	4.9	$173.49 \pm 0.27 \pm 1.03$	1.06 (0.61)	[16]
	dilepton	4.9	$172.50 \pm 0.43 \pm 1.46$	1.52 (0.88)	[17]
	all jets	3.5	$173.49 \pm 0.69 \pm 1.23$	1.41 (0.81)	[18]

Table 2: Overview of the 11 input measurements used in this m_{top} combination.

Top Quark Mass World Combination: Naming Convention

- Naming convention of systematic uncertainties

WA	LHC comb [7]	TEV comb. [6] ([39])	
Stat	Statistics	Statistics	(Statistical uncertainty)
iJES	iJES	iJES	(*in situ* light-jet calibration)
stdJES	uncorrJES⊕insituγ/ZJES⊕intercalibJES	dJES⊕cJES⊕rJES	(Light-jet response 1⊕2)⊕Out-of-cone correction
flavourJES	flavourJES	aJES	(Response to $b/q/g$ jets)
bJES	bJES	bJES	(Model for b jets)
MC	MC⊕UE	part of Signal	(part of Signal modelling)
Rad	Rad	part of Signal	(part of Signal modelling)
CR	CR	part of Signal	(part of Signal modelling)
PDF	PDF	part of Signal	(part of Signal modelling)
DetMod	DetMod	DetMod	(Jet modelling)
b-tag	b-tagging	part of BGData	(part of background based on data)
LepPt	Lepton reconstruction	LepPt	(Lepton modelling)
BGMC	Background from MC	BGMC	(Background from theory)
BGData	Background from Data	BGData	(Background based on data)
Meth	Method	Method	(Calibration Method)
MHI	Multiple Hadronic Interactions	MHI	(Multiple interaction model)