Combination of the top-quark measurements from the Tevatron

mostly the combination of the Tevatron top-quark mass measurements

Frédéric Déliot for the top-TevEWWG
CEA/Irfu-Saclay

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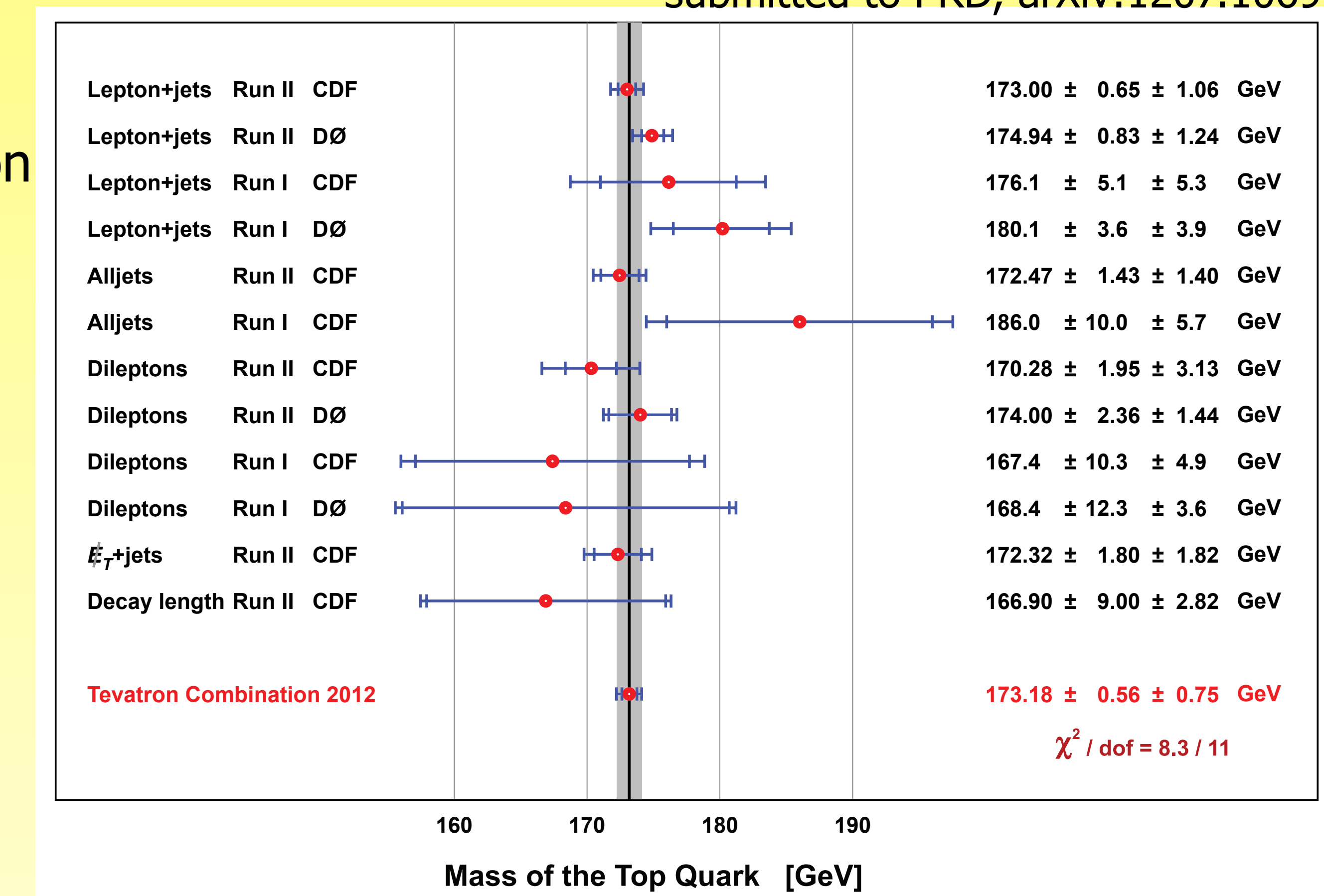
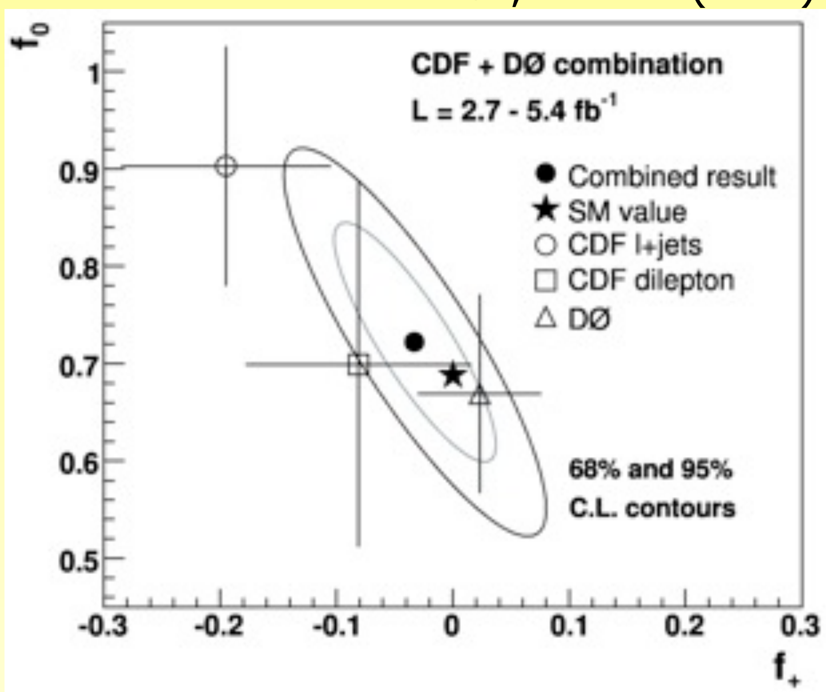
What and how did CDF and D0 combine ?

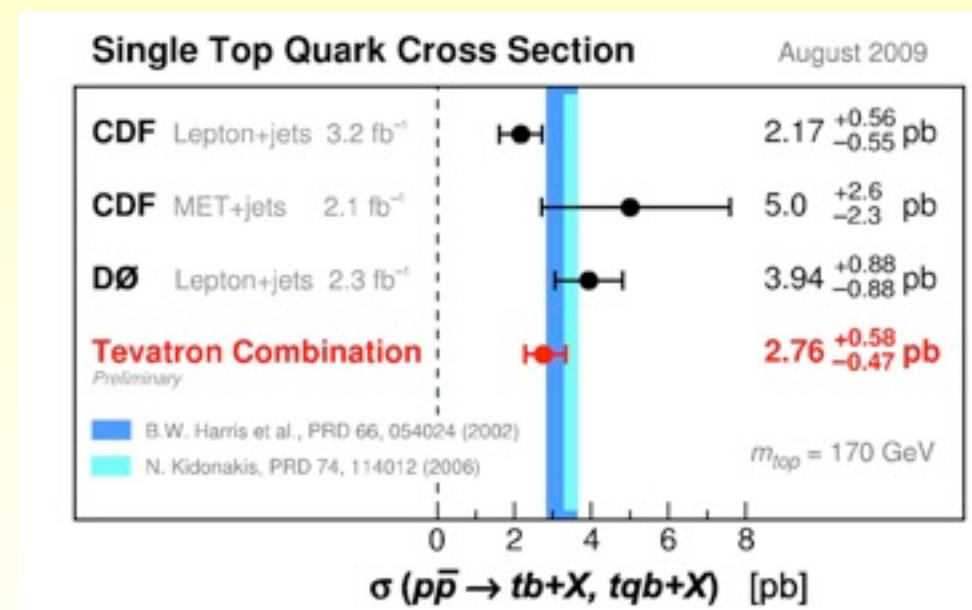
- CDF/D0 measurements :
  - top mass (since 1999, ~ one update every year)
  - single top cross section in 2009 after the observation
  - W helicity in 2011, published in 2012

submitted to PRD, arXiv:1207.1069



PRD 85, 091104 (2012)



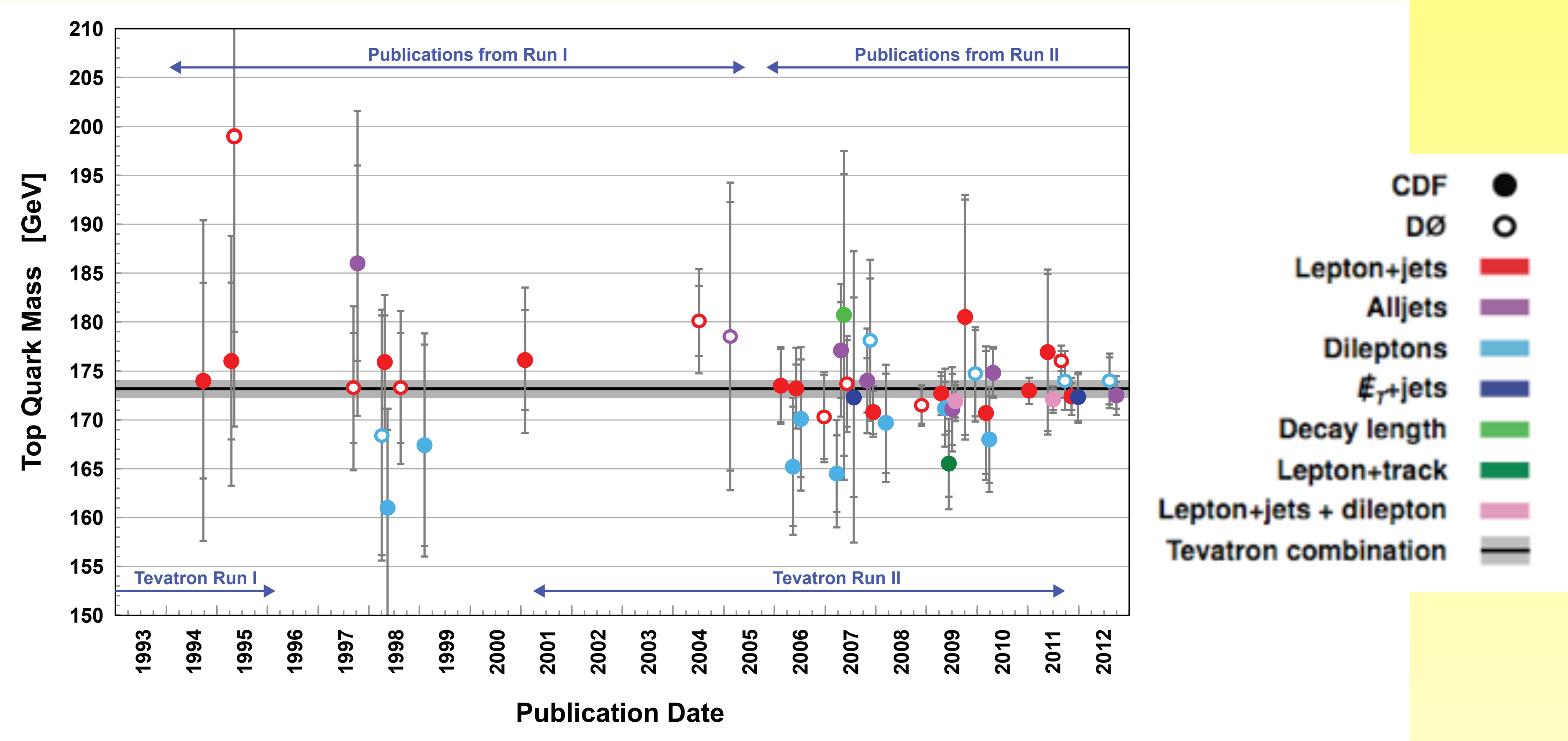


- currently working on:
  - ttbar cross sections

- possibly other properties:
  - ttbar charge asymmetry, ttbar spin correlation

- combination methods:
  - BLUE (Best Linear Unbiased Estimate): mass, W helicity
  - Bayesian statistical analysis: single top

Top-quark mass measurements at the Tevatron



- Tevatron combination (using up to 5.8 fb^{-1})

➔ choose the best (independent) measurement per channel in each experiment

Decay channel or method	Tevatron period	Experiment	Integrated luminosity [fb^{-1}]	Number of events	Background [%]	m_t [GeV]	Uncertainty on m_t [%]
Lepton+jets	Run II	CDF	5.6	1087	17	173.00 ± 0.65 ± 1.06	0.72
Lepton+jets	Run II	D0	3.6	615	27	174.94 ± 0.83 ± 1.24	0.85
Lepton+jets	Run I	CDF	0.1	76	54	176.1 ± 5.1 ± 5.3	4.2
Lepton+jets	Run I	D0	0.1	22	22	180.1 ± 3.6 ± 3.9	2.9
Alljets	Run II	CDF	5.8	2856	71	172.47 ± 1.43 ± 1.40	1.2
Alljets	Run I	CDF	0.1	136	79	186.0 ± 10.0 ± 5.7	6.2
Dileptons	Run II	CDF	5.6	392	23	170.28 ± 1.95 ± 3.13	2.2
Dileptons	Run II	D0	5.3	415	21	174.00 ± 2.36 ± 1.44	1.6
Dileptons	Run I	CDF	0.1	8	16	167.4 ± 10.3 ± 4.9	6.8
Dileptons	Run I	D0	0.1	6	25	168.4 ± 12.3 ± 3.6	7.6
$\not{E}_T$+jets	Run II	CDF	5.7	1432	32	172.32 ± 1.80 ± 1.82	1.5
Decay length	Run II	CDF	1.9	375	30	166.90 ± 9.00 ± 2.82	5.7

Agreements between the collaborations

- re-start extensive discussions in 2008:
  - CDF/D0 are using different MC for ttbar/single top:
    Alpgen+Pythia vs Pythia, CompHep vs MadEvent
    still possible to combine them as soon as the systematics are coherent
  - agree on the default top mass to quote the results (172.5 GeV)
  - try to agree on the list of systematics and the way to assess them
  - agree on how to symmetrize the uncertainties (BLUE with symmetric errors)

2 types of uncertainties:

1) result from the +/- 1 sigma variation of a certain quantity

3 types of treatment: M_{nom} = central value, σ_M = quoted uncertainty

1.a) +/- shift leads to M_+/M_- where $M_+<M_{nom}<M_-$ or $M_-<M_{nom}<M_+$

$\sigma_M = | M_- - M_+ |/2$

1.b) +/- shift when $M_+ - M_{nom}$ and $M_- - M_{nom}$ have the same sign

$\sigma_M = \max(|M_+ - M_{nom}|/2, |M_- - M_{nom}|/2)$

JES, residual JES, b-JES, PDF, ISR/FSR, detector modeling, method , bkg

1.c) only one sided variation allowed:

quote full difference as one sided systematic (asymmetric)

sample dependence JES, sometimes trigger, lepton momentum scale

2) difference between 2 (more) models

full maximal difference as σ_M (symmetrized)

b-fragmentation, hadronization modeling, higher order effects, UE and CR

Combination of the top-quark mass at the Tevatron

- Systematics
  - ➔ separated into 14 parts to get the correct pattern of correlation between channels, run periods and experiments

Channel	Run	Exp.	Light-jet response (1)	Light-jet response (2)	Out-of-cone correction	Offset	Model for b jets	Response to $b/q/g$ jets	*In-situ* light-jet calibration	Jet modeling	Lepton modeling	Signal modeling	Multiple interactions model	Background from theory	Background based on data	Calibration method	**Statistical uncertainty**	**Total JES uncertainty**	**Other systematic uncertainty**	**Total uncertainty**
			Jet energy scale systematics							Other systematics										
Lepton+jets	II	CDF	0.41	0.01	0.27	n/a	0.23	0.13	0.58	0.00	0.14	0.56	0.10	0.27	0.06	0.10	0.65	0.80	0.67	1.23
Lepton+jets	II	D0	n/a	0.63	n/a	n/a	0.07	0.26	0.46	0.36	0.18	0.77	0.05	0.19	0.23	0.16	0.83	0.83	0.94	1.50
Lepton+jets	I	CDF	3.4	0.7	2.7	n/a	0.6	n/e	n/a	n/e	n/e	2.7	n/e	1.3	n/e	0.0	5.1	4.4	2.8	7.3
Lepton+jets	I	D0	n/a	2.5	2.0	1.3	0.7	n/e	n/a	n/e	n/e	1.3	n/e	1.0	n/e	0.6	3.6	3.5	1.6	5.3
Alljets	II	CDF	0.38	0.04	0.24	n/a	0.15	0.03	0.95	0.00	n/a	0.64	0.08	0.00	0.56	0.38	1.43	1.06	0.91	2.00
Alljets	I	CDF	4.0	0.3	3.0	n/a	0.6	n/e	n/a	n/e	n/a	2.1	n/e	1.7	n/e	0.6	10.0	5.0	2.6	11.5
Dileptons	II	CDF	2.01	0.58	2.13	n/a	0.33	0.14	n/a	0.00	0.27	0.80	0.23	0.24	0.14	0.12	1.95	3.01	0.88	3.69
Dileptons	II	D0	n/a	0.56	n/a	n/a	0.20	0.40	0.55	0.50	0.35	0.86	0.00	0.00	0.20	0.51	2.36	0.90	1.11	2.76
Dileptons	I	CDF	2.7	0.6	2.6	n/a	0.8	n/e	n/a	n/e	n/e	3.0	n/e	0.3	n/e	0.7	10.3	3.9	3.0	11.4
Dileptons	I	D0	n/a	1.1	2.0	1.3	0.7	n/e	n/a	n/e	n/e	1.9	n/e	1.1	n/e	1.1	12.3	2.7	2.3	12.8
$\not\!\!E_T$+jets	II	CDF	0.45	0.05	0.20	n/a	0.00	0.12	1.54	0.00	n/a	0.78	0.16	0.00	0.12	0.14	1.80	1.64	0.78	2.56
Decay length	II	CDF	0.24	0.06	n/a	n/a	0.15	n/e	n/a	0.00	n/a	0.90	0.00	0.80	0.20	2.50	9.00	0.25	2.80	9.43

Jet energy scale systematics

- Large source of systematic uncertainties: splitted in 7 parts

  * Light-jet response (1) (rJES): specific to CDF measurements, calibration of JES using single-pion response in data and in MC by tuning the simulation

    100% correlated only within CDF

  * Light-jet response (2) (dJES): absolute and relative (η-dependent) calibration of JES using γ+jets events in D0, η-dependent calibration in CDF

    100% correlated within the same experiment and the same run period

  * Out-of-cone corrections (cJES): out-of-cone corrections to MC showers for CDF and D0 Run I

    100% correlated between all measurements

  * Offset (UN/MI): noise from uranium decay, only for D0 Run I

    100% correlated within D0 Run I

  * Model for b jets (bJES): from difference between models of b-jet hadronization

    100% correlated between all measurements

  * Response for b/q/g jets (aJES): difference in response between b, quark and gluon jets

    100% correlated within the same experiment and the same run period

  * in-situ light-jet calibration (iJES): for channel with at least one W decaying hadronically, calibrate the jet energy scale constraining M_{jj} to M_W (scaling with statistics)

    uncorrelated

Other systematics

- 7 non-JES uncertainty sources:

  * Jet modeling: from uncertainties in jet identification efficiency and jet smearing at D0

    100% correlated within D0 Run II

  * Lepton modeling: electron and muon pt scale uncertainties (+ muon smearing for D0)

    100% correlated within the same experiment and the same run period

  * Signal modeling: PDF, $q\bar{q}$/gg fraction, higher-order QCD corrections, ISR/FSR, hadronization model, color reconnection

    100% correlated between all measurements

  * Multiple interaction model: from modeling of pile-up in the MC

    100% correlated within the same experiment and the same run period

  * Background from theory: NLO fraction of heavy flavor jets in W+jets, factorization/renormalization scales in W+jets simulation, theoretical cross sections used for MC normalization

    100% correlated between all measurements in the same channel

  * Background based on data: MC/data difference in background distributions, signal/bkg fraction

    100% correlated within the same experiment and the same run period in the same channel

  * Calibration method: uncertainty from the calibration curve

    uncorrelated between all measurements

Signal Modeling Systematics

- include several effects : evaluated on ttbar MC
  - hadronization modeling
  - higher order effects
  - PDF
  - ISR/FSR
  - color reconnection

  describe one by one in the next slides

- correlated between the measurements and experiments

Higher Order Effects

- default ttbar MC : LO (Alpgen+Pythia or Pythia)
- method
  - difference between Alpgen+Herwig and MC@NLO
- also include the effects of variation in gg fraction

generator	gg (%)	qq (%)	qg (%)
PYTHIA (CTEQ6L1)	4.9 ± 0.2	95.1 ± 0.2	0
ALPGEN+PYTHIA (CTEQ6L1)	3.7 ± 0.1	93.0 ± 0.1	3.3 ± 0.1
MC@NLO (CTEQ6M)	18.6 ± 0.4	81.5 ± 0.4	-0.1 ± 0.1
MCFM [7] (CTEQ6M)	15.3 ± 0.05	84.1 ± 0.05	0.5 ± 0.05

Hadronization and Underlying Event

- difficult to disentangle these two effects
- method :
  - difference between Pythia and Herwig (Alpgen+Pythia and Alpgen+Herwig)
  - some statistical component

PDF Systematics

- default ttbar samples :
  - D0: CTEQ6.1, CDF: CTEQ5L
- 2 sources :
  - PDF errors:
    - reweight to CTEQ6M according to the parton momentum fraction used in the hard process
    - quadratic sum of the 2 × 20 PDF errors from CTEQ6M
  - difference between CTEQ and MRST

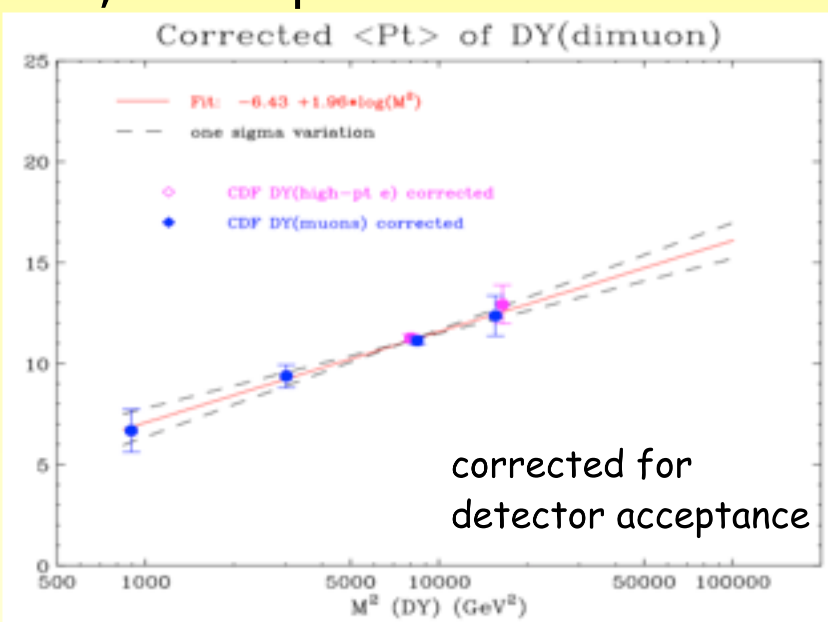
- differences between experiments :
  - CDF also adds in quadrature the difference between MRST with two different values of Λ_{QCD} (e.g. MRST72 Λ_{QCD}=228 MeV vs. MRST75 Λ_{QCD}=300 MeV)
    D0: not easily doable inside LHAPDF
  - CDF adds effect of reweighting gg contribution from 5% (LO) to 20%
    not needed at D0 since it is included in the higher order effects

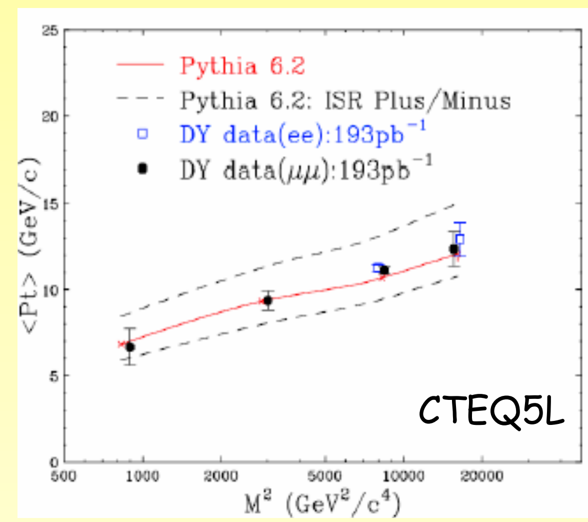
ISR/FSR Systematics

very different methods initially (D0 used the difference in the number of events vs jet bins in MC and data)
had also to compare carefully all the pythia parameters used in the two collaborations

- current method :
  - we can use Z events to constraint ISR systematics in top events
  - measure the Z pt in data and compare it with MC with varied tune parameters

CDF, ~ 200 pb-1





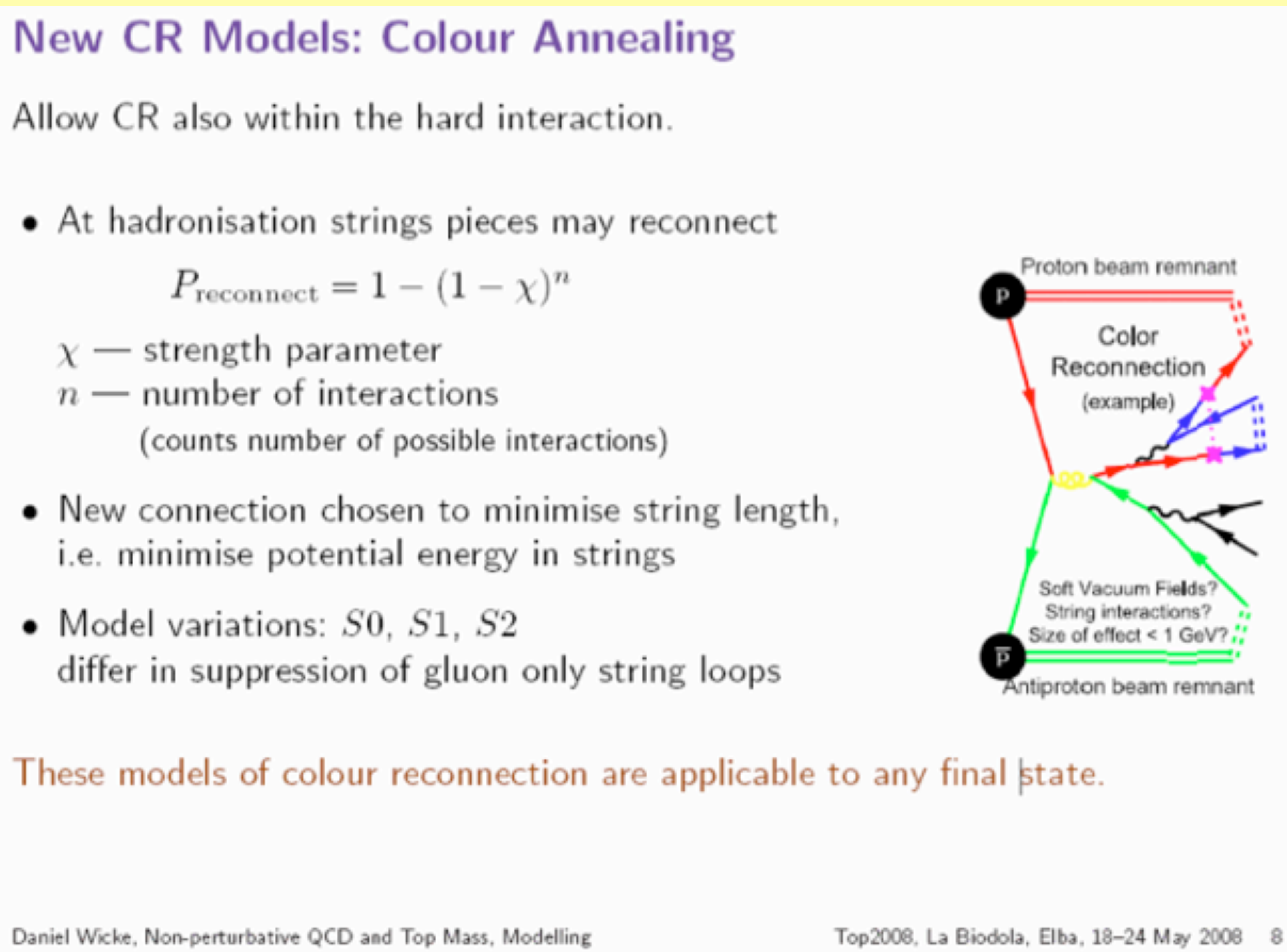
Parameter	ISR up	ISR down
PARP(61) (0.192 MeV)	0.384	0.100
PARP(64) (D=1.0)	0.50	2.0

- limitations :
  - study done in the early age of RunII: would try to reproduce with more statistics
  - modeling of the Z pt: try to use other variables
  - double counting with systematics from higher order effects
  - could also be studied with Madgraph to address the influence of extra hard radiations

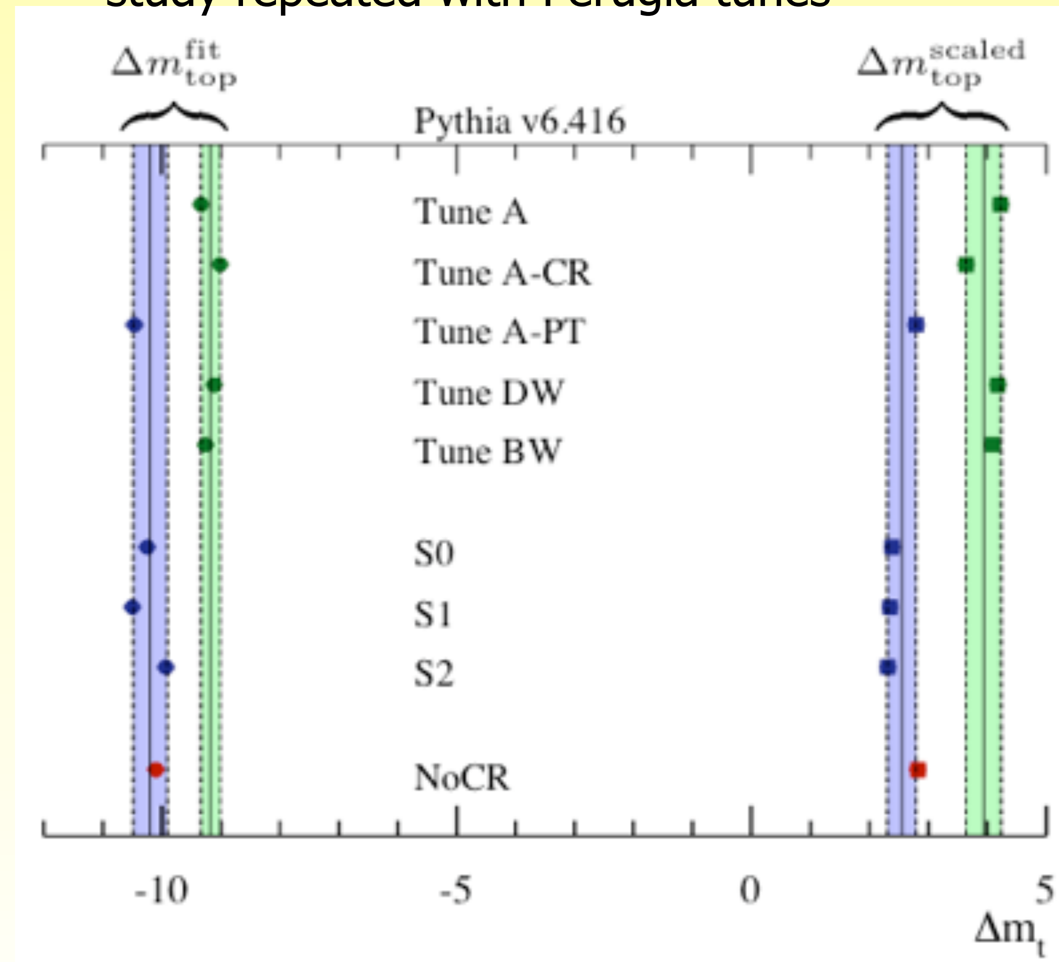
Color Reconnection Systematics

Added recently. Triggered by developments for tunning pythia v6.4 (~ oct 2008):
inclusion of explicit color reconnection model, pt ordered showering

- studies of the initial tunes :
  - show that:
    * new shower effects: Δ(mt) ~ 0.7 GeV
    * color reconnection effects: Δ(mt) ~ 0.5 GeV



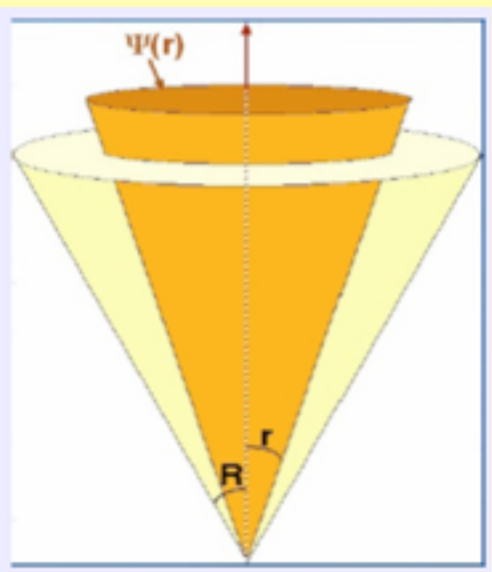
D. Wicke, P. Skands, arxiv: 0807.3248
using toy model
study repeated with Perugia tunes



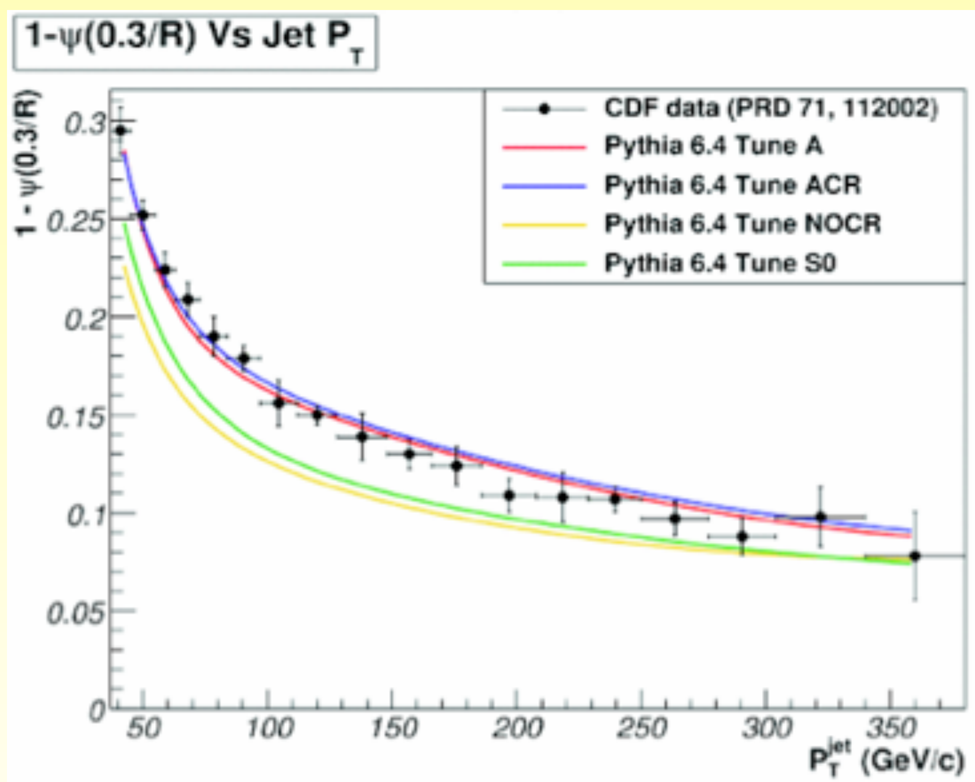
Color Reconnection Systematics

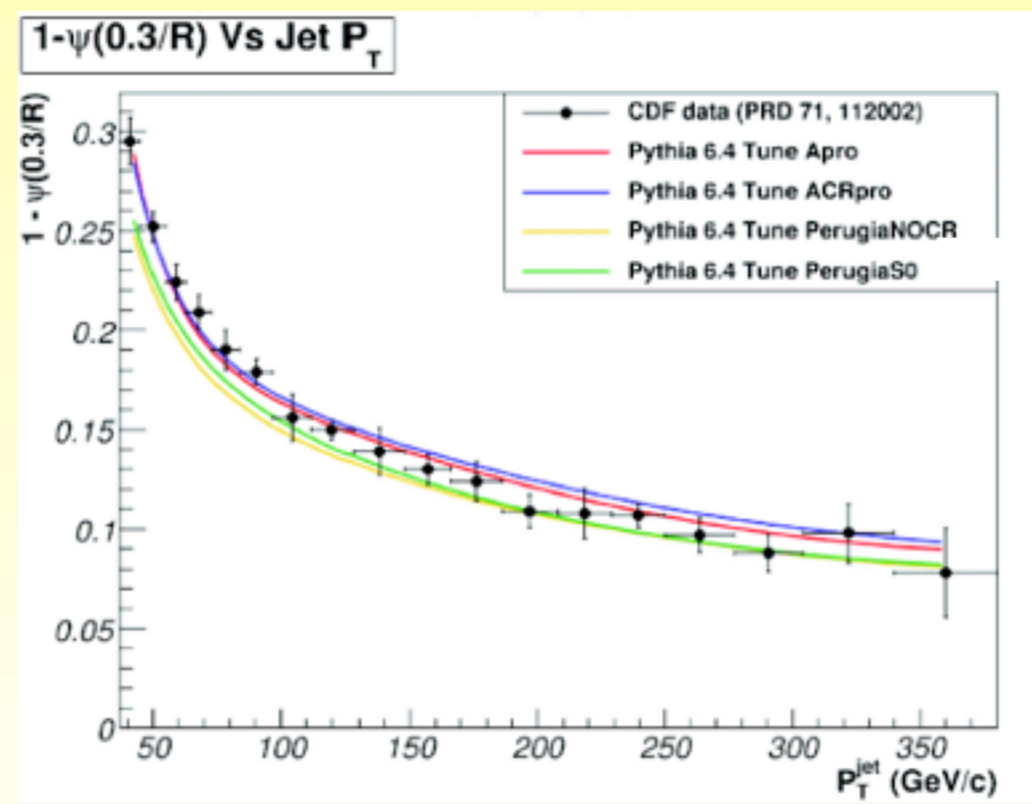
- method :
  - chosen after the studies of the different new tunes
  - compare measurement using different tune of Pythia: tune Apro vs tune ACRpro
  - initial pt ordered showered tunes didn't describe the jet cone in data properly: jets in tune S0 were wider leading to a shift in the b-jets energy

jet shapes in CDF di-jet events



MC4LHC readiness in 2010 (Lina Galtieri)

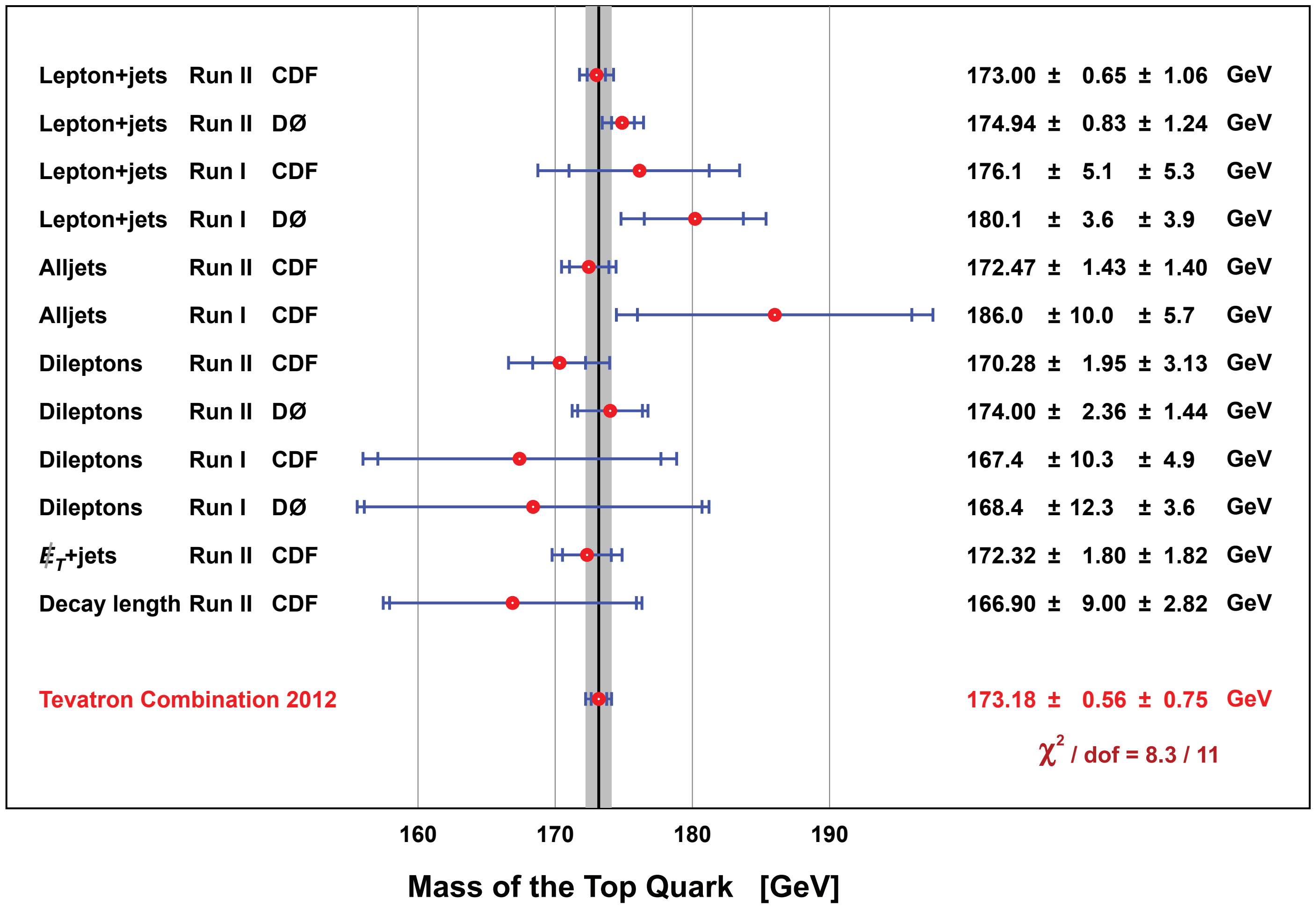




These studies should be reproduced with the latest Perugia tunes.
Measurements of color reconnection in W events from ttbar by D0 show that ACRpro is probably too extreme.

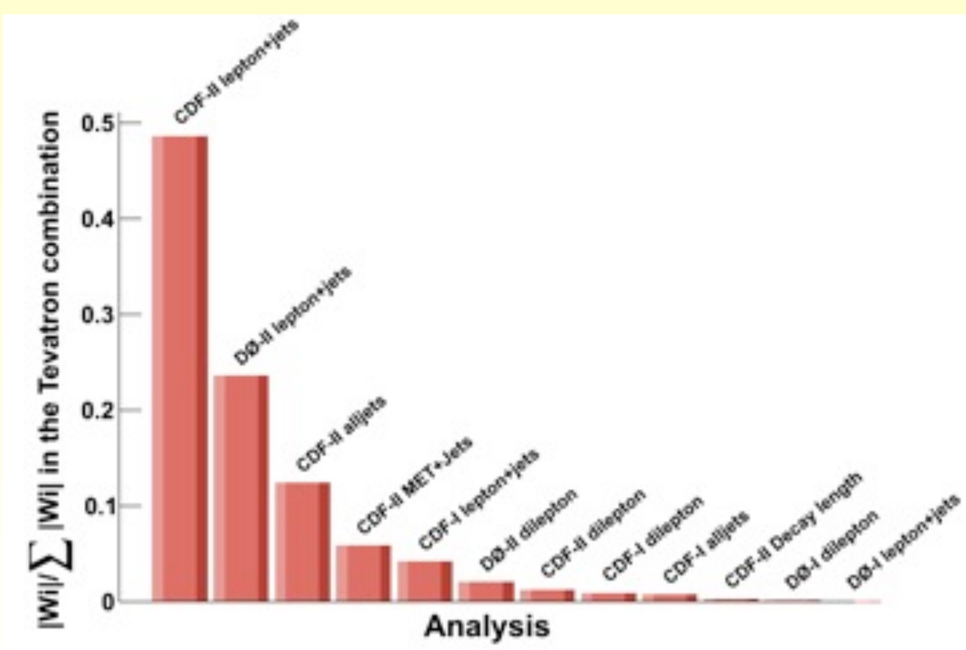
Tevatron top mass combination results

submitted to PRD, arXiv:1207.1069



$$m_t^{\rm comb} = 173.18 \pm 0.56\,({\rm stat}) \pm 0.75\,({\rm syst})\ \ {\rm GeV}$$
$$= 173.18 \pm 0.94\ {\rm GeV}$$

Source of uncertainty	Combination uncertainty (GeV)
Jet energy scale systematics	
Light-jet response (1)	0.12
Light-jet response (2)	0.19
Out-of-cone correction	0.04
Offset	0.00
Model for b jets	0.15
Response to $b/q/g$ jets	0.12
in-situ light-jet calibration	0.39
Other systematics	
Jet modeling	0.11
Lepton modeling	0.10
Signal modeling	0.51
Multiple interactions model	0.00
Background from theory	0.14
Background based on theory	0.11
Calibration method	0.09
Statistical uncertainty	0.56
Total JES uncertainty	0.49
Other systematic uncertainty	0.57
Total uncertainty	0.94



Cross checks of the Tevatron combination

- Combinations
  - ➔ for each tt decay mode
  - ➔ for each run period
  - ➔ for each experiment

Subset	m_t^{comb}	Consistency χ^2 (Degrees of freedom = 1)						χ^2 probability					
		Lepton+jets	Alljets	Dileptons	$\not\!\!E_T$+jets	Run II – Run I	CDF – D0	Lepton+jets	Alljets	Dileptons	$\not\!\!E_T$+jets	Run II – Run I	CDF – D0
Lepton+jets	173.4 ± 1.0	—	0.14	1.51	0.28			—	71%	22%	60%		
Alljets	172.7 ± 1.9	0.14	—	0.40	0.04			71%	—	53%	85%		
Dileptons	171.1 ± 2.1	1.51	0.40	—	0.12			22%	53%	—	73%		
$\not\!\!E_T$+jets	172.1 ± 2.5	0.28	0.04	0.12	—			60%	85%	73%	—		
Run II	173.6 ± 1.0					2.89						9%	
Run I	180.0 ± 4.1												
CDF	172.5 ± 1.0						2.56						11%
D0	174.9 ± 1.4												

Conclusion

- Tevatron top combinations :
  - a lot of discussions/studies over the past years (mainly for the mass combination) to agree on a common list of systematics and a common way of evaluating them (if possible)

first top mass combination submitted for combination, arXiv:1207.1069:

$$m_t^{\rm comb} = 173.18 \pm 0.56\,({\rm stat}) \pm 0.75\,({\rm syst})\ \ {\rm GeV}$$
$$= 173.18 \pm 0.94\ {\rm GeV}$$

- still some work in progress :
  - evaluation/removing of the possible double counting
  - limit the statistical component of the systematics
  - studies that might be possible with 10 fb^{-1} of statistics: use of data to constraint more the signal modeling systematics