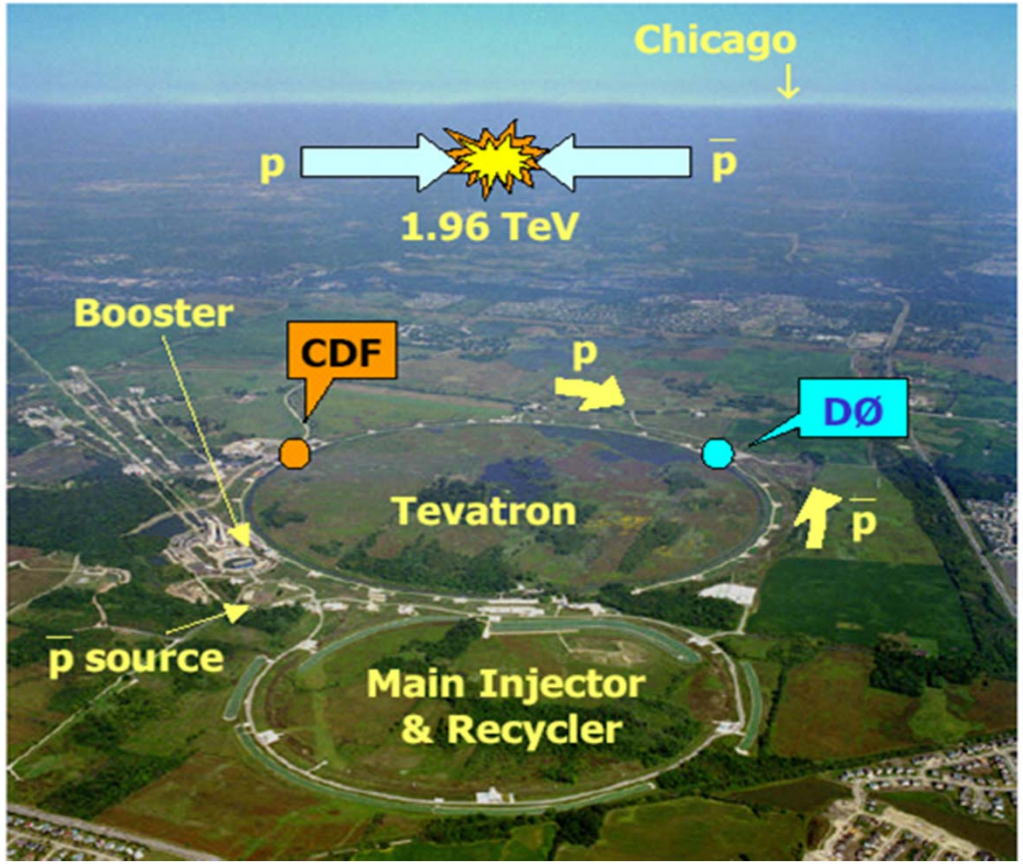
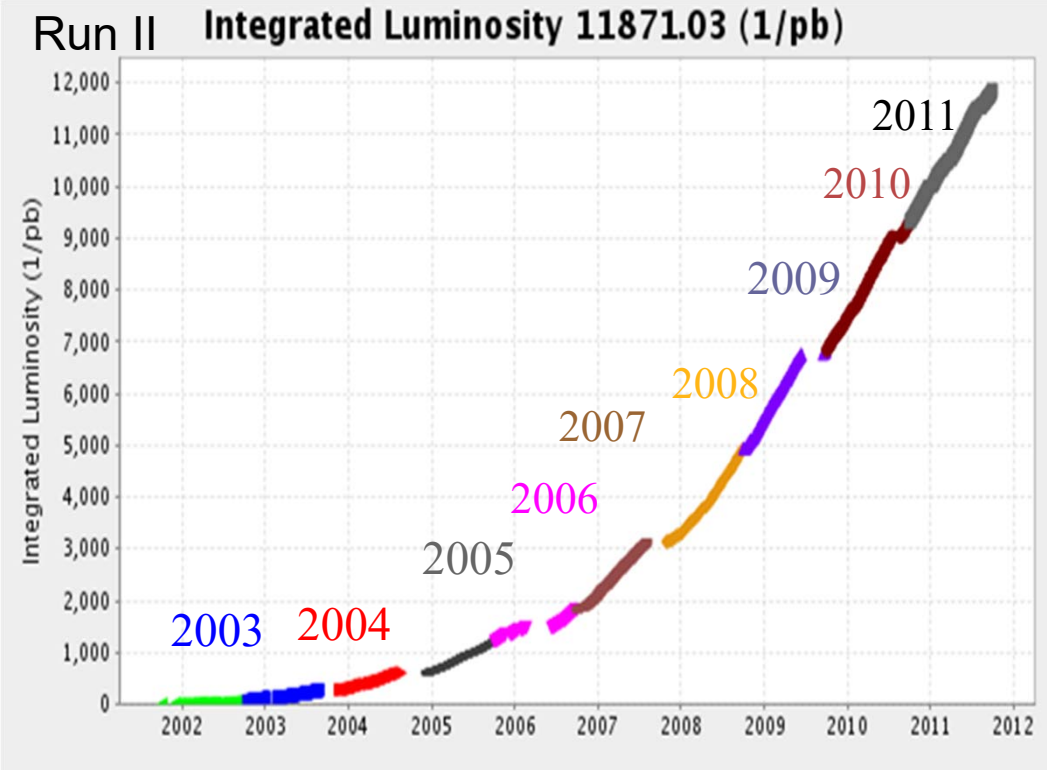
Direct Top mass measurements from DØ

Gregorio Bernardi, LPNHE-Paris, IN2P3
on behalf of the
DØ collaboration



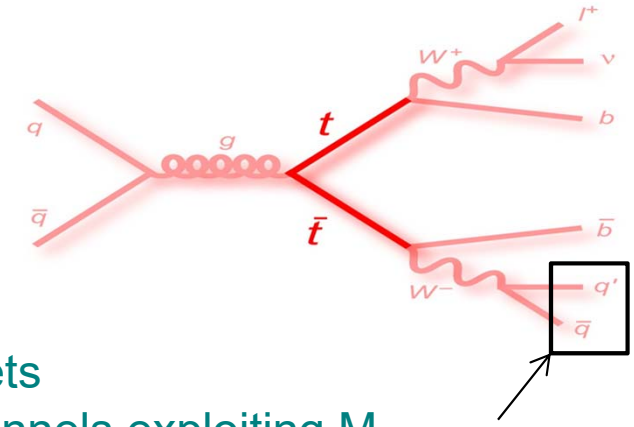


Tevatron Run I: (1993-1996)
Discovery of the top quark
~120 pb^{-1} per experiment
@ sqrt(s) = 1.8 TeV

Tevatron Run II: (2001-2011)
A decade of successful running
Improved performance over time
~12 fb^{-1} delivered per experiment
~10 fb^{-1} for analysis @ 1.96 TeV

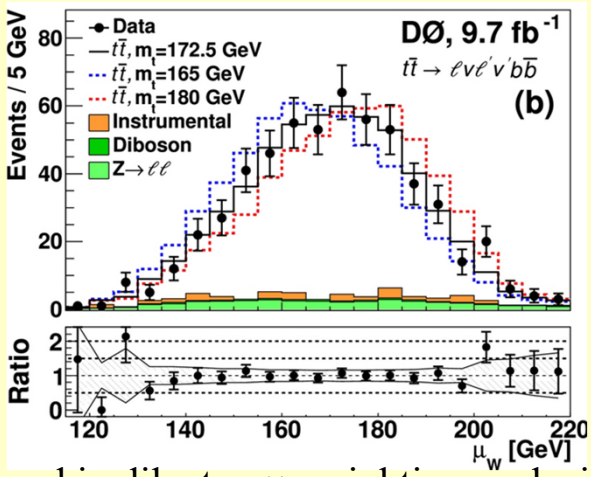
Top quark mass measurements

- Different analyses at D0 depending on Channel
  - mainly ℓ+jets and dilepton channels
  - Different methods to extract top mass
- Consistency check
  - Not sensitive to same systematics
- Reduction of systematic uncertainties
- Jet Energy Scale from in situ calibration in ℓ+jets channels exploiting M_{jj} ~ 80.4 GeV



Template method

- Choose kinematic observable(s)
- Create MC templates at different m_{top}
- Likelihood fit to best template



Template method used in dilepton ν-weighting analysis

Matrix Element (ME) method

- Define likelihood from matrix elements, PDF,
- transfer functions (parton $p_T \leftrightarrow$ jet p_T).

$$P(\vec{x}, m_t, JES) = \frac{1}{\sigma}\int d\sigma(\vec{y}, m_t) f(\tilde{q}_1) f(\tilde{q}_2) W(\vec{x}, \vec{y}, JES) d\tilde{q}_1 d\tilde{q}_2$$

$$P_{\rm evt} = f_{\rm sig} P_{\rm sig}(\vec{x}, m_t) + (1 - f_{\rm sig}) P_{\rm bkg}(\vec{x})$$

- Integrate over unmeasured quantities or quantities with a significant measurement uncertainty ➔ CPU demanding

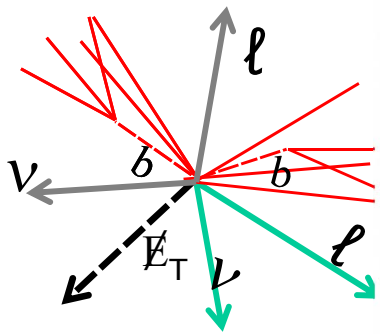
Cross-section method: derive top mass from measured cross section (see A. Jung's talk !)

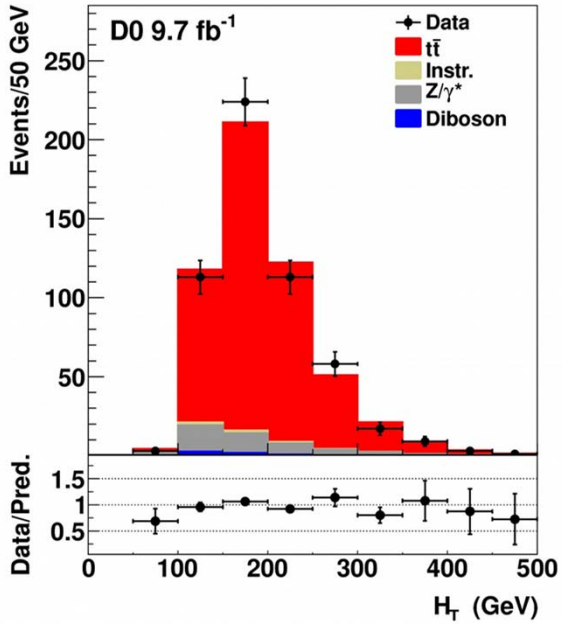
Top mass in dilepton channel using ME

Very pure channel with low background

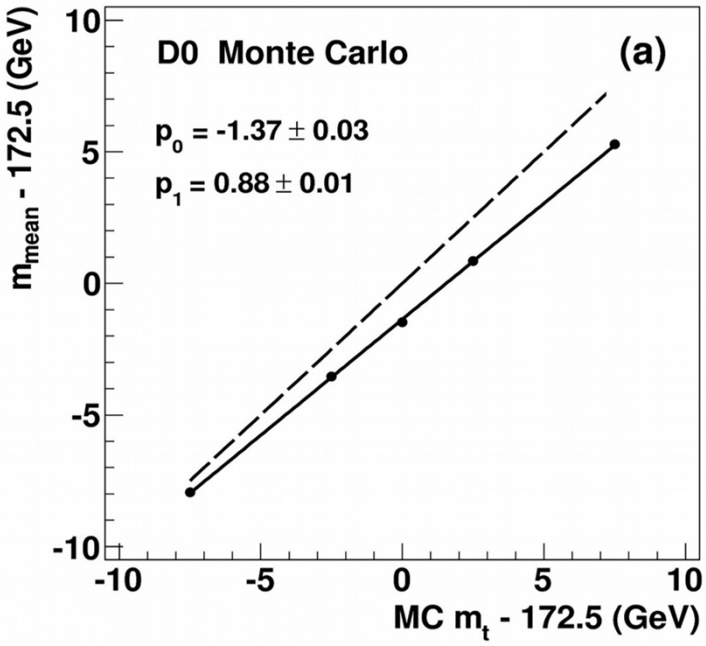
Kinematic underconstrained because of two neutrinos

Extract maximum information with ME method or Neutrino Weighting method. Separate analyses then combined

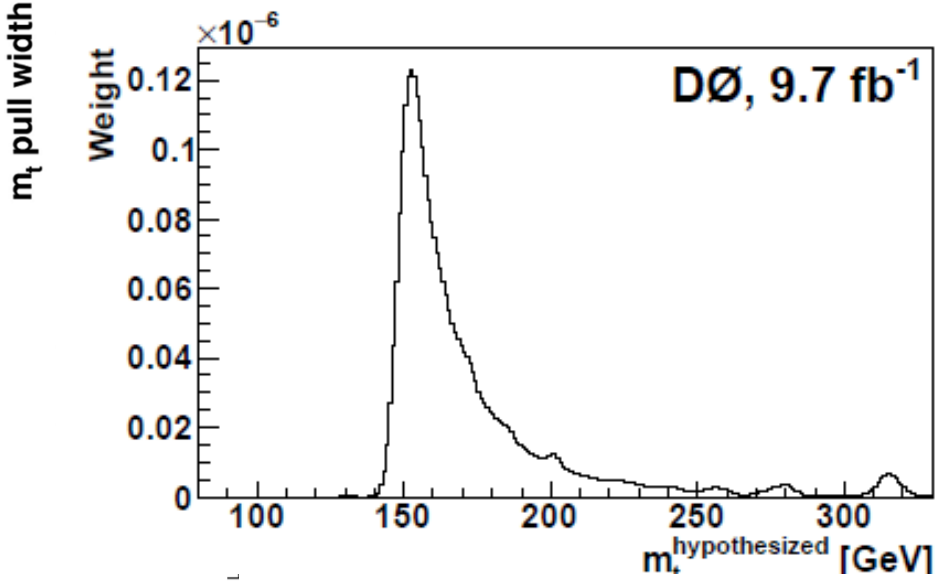




Calibration of mass and uncertainty using MC ensembles



Event Weight in the neutrino weighting method



The weight as a function of $m_t^{hypothesized}$

Top mass in dilepton events

- Mass extraction with ME method

  Use JES calibration from D0 ℓ+jets measurement

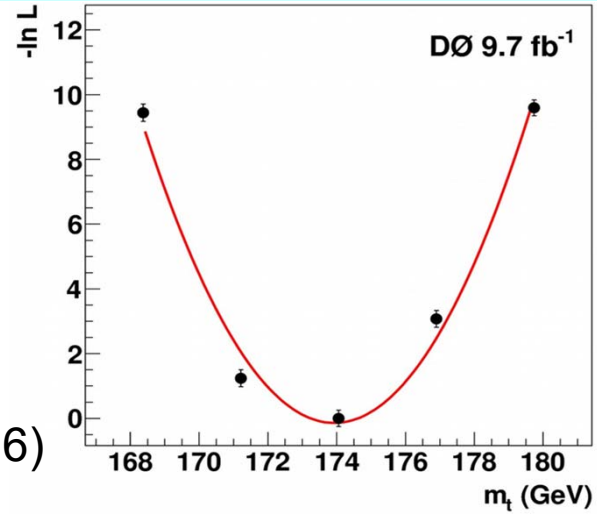
  [PRL 113, 032002 (2014), PRD 91, 112003 (2015)]

  to reduce by ~3 the JES uncertainty

  → Maximization of ME-based likelihood

m_t = 173.93 ± 1.61 (stat) ± 0.88 (syst) GeV

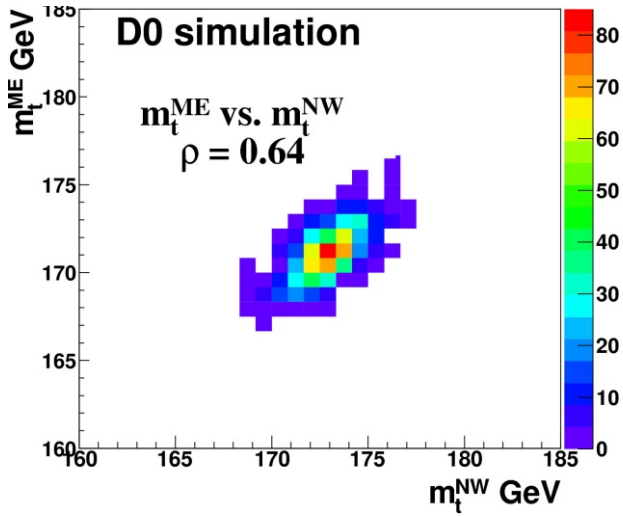
$\delta m_t/m_t = 1.1\%$ PRD 94, 032004 (2016)



- Dilepton measurement using templates and neutrino-weighting technique

m_t = 173.32 ± 1.32 (stat) ± 0.85 (syst) GeV

$\delta m_t/m_t = 0.9\%$ PLB 752, 18 (2016)



- Statistical correlation 64 ± 2 % between the two meas.

- **Combined Run II dilepton measurement**

m_t = 173.50 ± 1.31 (stat) ± 0.84 (syst) GeV

$\delta m_t/m_t = 0.9\%$ Phys. Rev. D 95, 112004 (2017)

Dominant uncertainties

- JES (stat) uncertainty from ℓ+jets calibration
- Signal model
- Statistical uncertainty

D0 final top mass combination

- D0 combination
  - Combine Run I and Run II direct measurements in

    ℓ+jets and dilepton channels

  - Since last combination (2011):
    → updated measurements in ℓ+jets and dilepton channel using full Run II data

- Combination accounts for all uncertainties and their correlation
  - Use BLUE (Best Linear Unbiased Estimate)
  - χ2 /ndof = 2.5/3, prob = 47 %: good consistency between the measurements

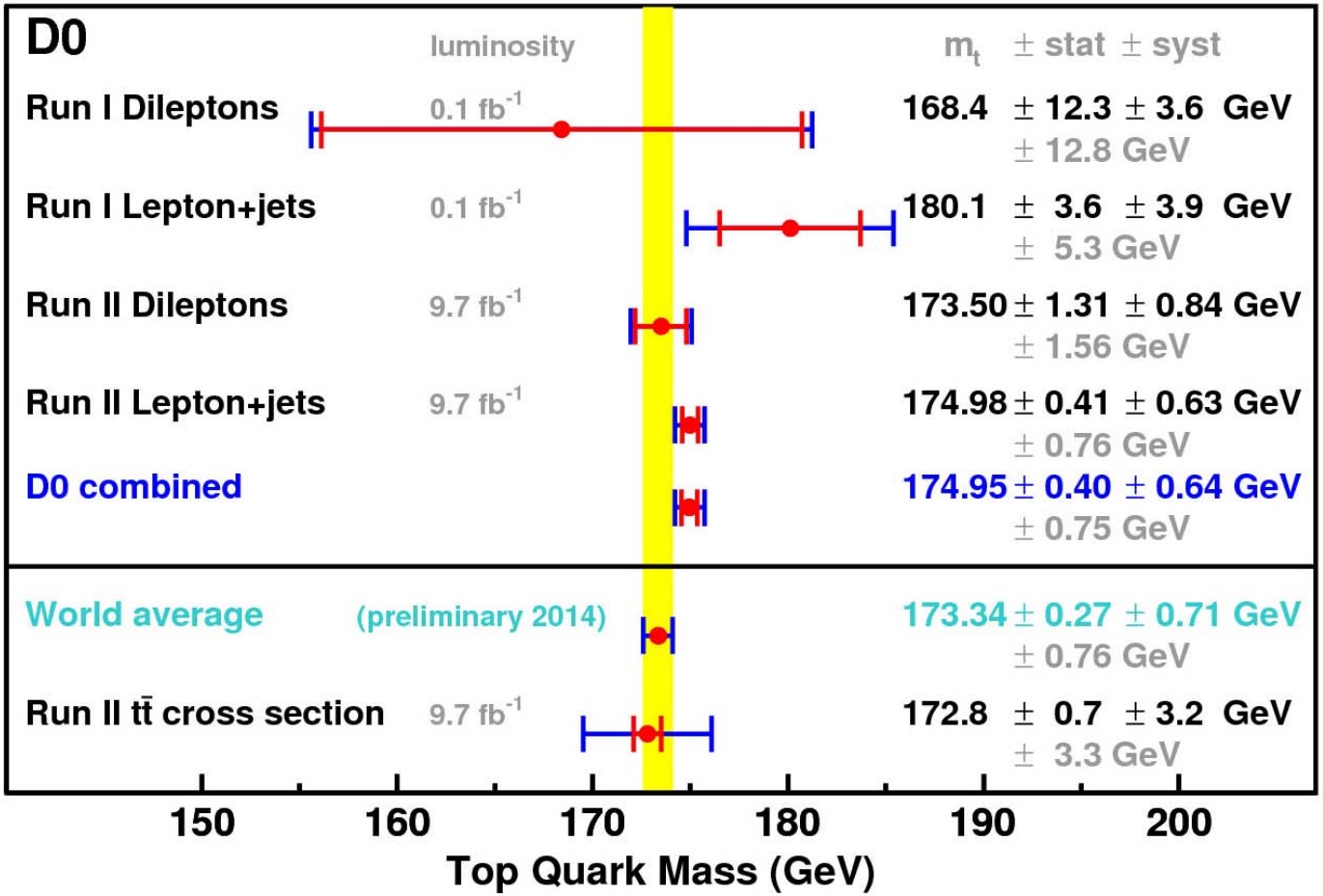
	Run I		Run II	
	$\ell+$jets	$\ell\ell'$	$\ell+$jets	$\ell\ell'$
In situ light-jet calibration	n/a	n/a	×	×
response to b, q, and g jets	n/a	n/a	×	×
Model for b jets	×	×	×	×
Light-jet response	⊗	⊗	×	×
Out-of-cone correction	×	×	n/a	n/a
Offset	×	×	n/a	n/a
Jet modeling	n/a	n/a	×	×
Multiple interactions model	n/a	n/a	×	×
b tag modeling	n/a	n/a	×	×
Lepton modeling	n/a	n/a	×	×
Signal modeling	×	×	×	×
Background from theory	×	⊗	×	⊗
Background based on data	n/a	n/a	0	0
Calibration method	0	0	0	0
Statistical	0	0	0	0

correlation table

	Run I, $\ell+$jets	Run I, $\ell\ell'$	Run II, $\ell+$jets	Run II, $\ell\ell'$
Run I, $\ell+$jets	1.00			
Run I, $\ell\ell'$	0.16	1.00		
Run II, $\ell+$jets	0.13	0.07	1.00	
Run II, $\ell\ell'$	0.07	0.05	0.43	1.00

	D0 Run I		D0 Run II	
	$\ell+$jets	$\ell\ell'$	$\ell+$jets	$\ell\ell'$
Pull	0.98	−0.51	0.63	−1.06
Weight	0.002	−0.003	0.964	0.035

D0 final top mass combination



	Combined value (GeV)
In situ light-jet calibration	0.41
Response to b, q, and g jets	0.16
Model for b jets	0.09
Light-jet response	0.21
Out-of-cone correction	< 0.01
Offset	< 0.01
Jet modeling	0.07
Multiple interaction model	0.06
b tag modeling	0.10
Lepton modeling	0.01
Signal modeling	0.35
Background from theory	0.06
Background based on data	0.09
Calibration method	0.07
Systematic uncertainty	0.64
Statistical uncertainty	0.40
Total uncertainty	0.75

m_t = 174.95 ± 0.75 GeV (± 0.40(stat) ± 0.64 (syst))

Phys. Rev. D 95, 112004 (2017)

$\delta m_t/m_t = 0.43\%$

Dominant uncertainties

- JES uncertainty from ℓ+jets calibration (statistical origin)
- Statistical uncertainty
- Signal model

Tevatron top mass (Summer 16)

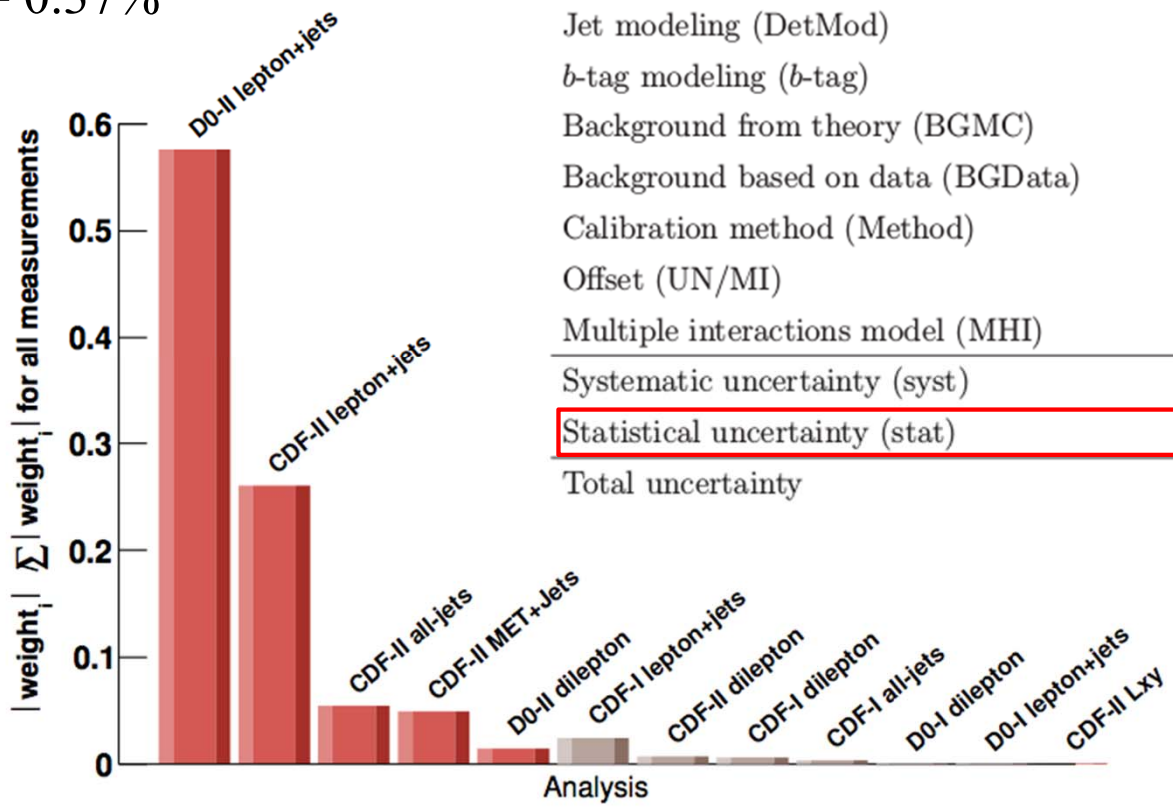
- All D0 and CDF inputs are published.
- Perform BLUE combination
  - $\chi 2$ /ndof = 10.8/11, prob = 46 %
  - Good consistency between measurements
- Combination dominated by ℓ+jets
- channels

m_t = 174.30 ± 0.65 GeV (± 0.35 (stat) ± 0.54 (syst))

$$\delta m_t/m_t = 0.37\%$$

	Combined value (GeV)
M_t	174.30
In situ light-jet calibration (iJES)	0.31
Response to $b/q/g$ jets (aJES)	0.11
Model for b-jets (bJES)	0.10
Out-of-cone correction (cJES)	0.03
Light-jet response (1) (rJES)	0.05
Light-jet response (2) (dJES)	0.14
Lepton modeling (LepPt)	0.01
Signal modeling (Signal)	0.36
Jet modeling (DetMod)	0.05
b-tag modeling (b-tag)	0.07
Background from theory (BGMC)	0.04
Background based on data (BGData)	0.07
Calibration method (Method)	0.07
Offset (UN/MI)	0.00
Multiple interactions model (MHI)	0.06
Systematic uncertainty (syst)	0.54
Statistical uncertainty (stat)	0.35
Total uncertainty	0.65

Dominant uncertainties
- JES uncertainty from ℓ+jets calibration (statistical origin)
- Statistical uncertainty
- Signal model



Tevatron top mass results

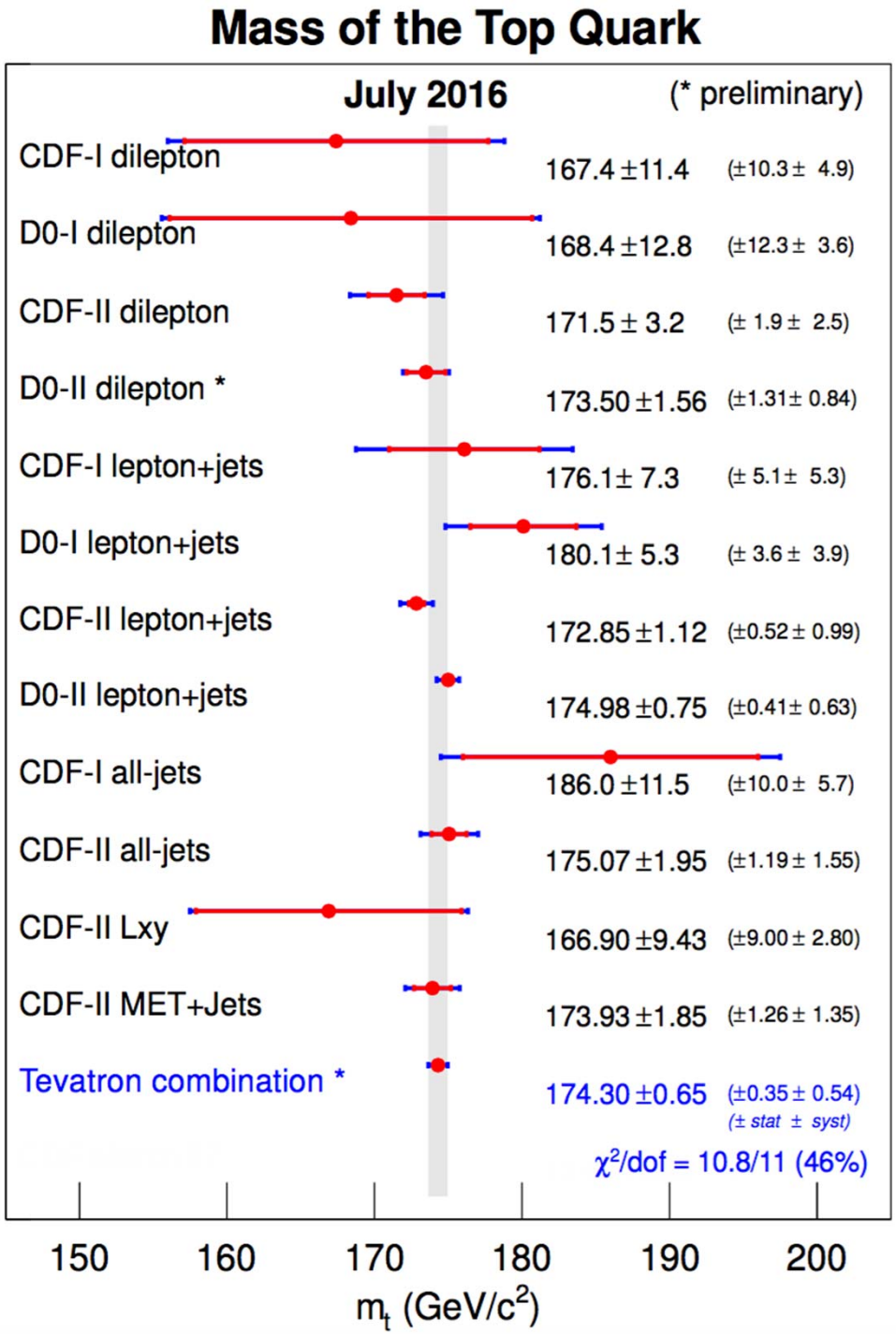
$$m_t = 174.30 \pm 0.65 \text{ GeV}$$

$\delta m_t / m_t = 0.37\%$

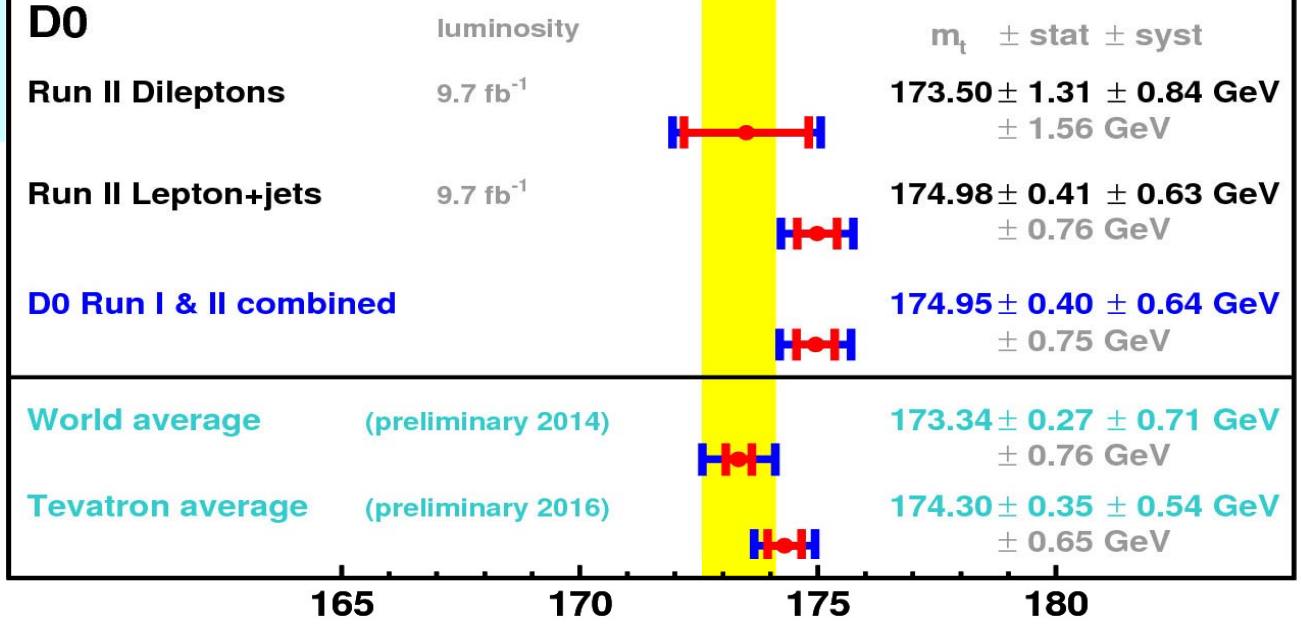
Not final:

expecting an improved

CDF ℓ+jets measurement



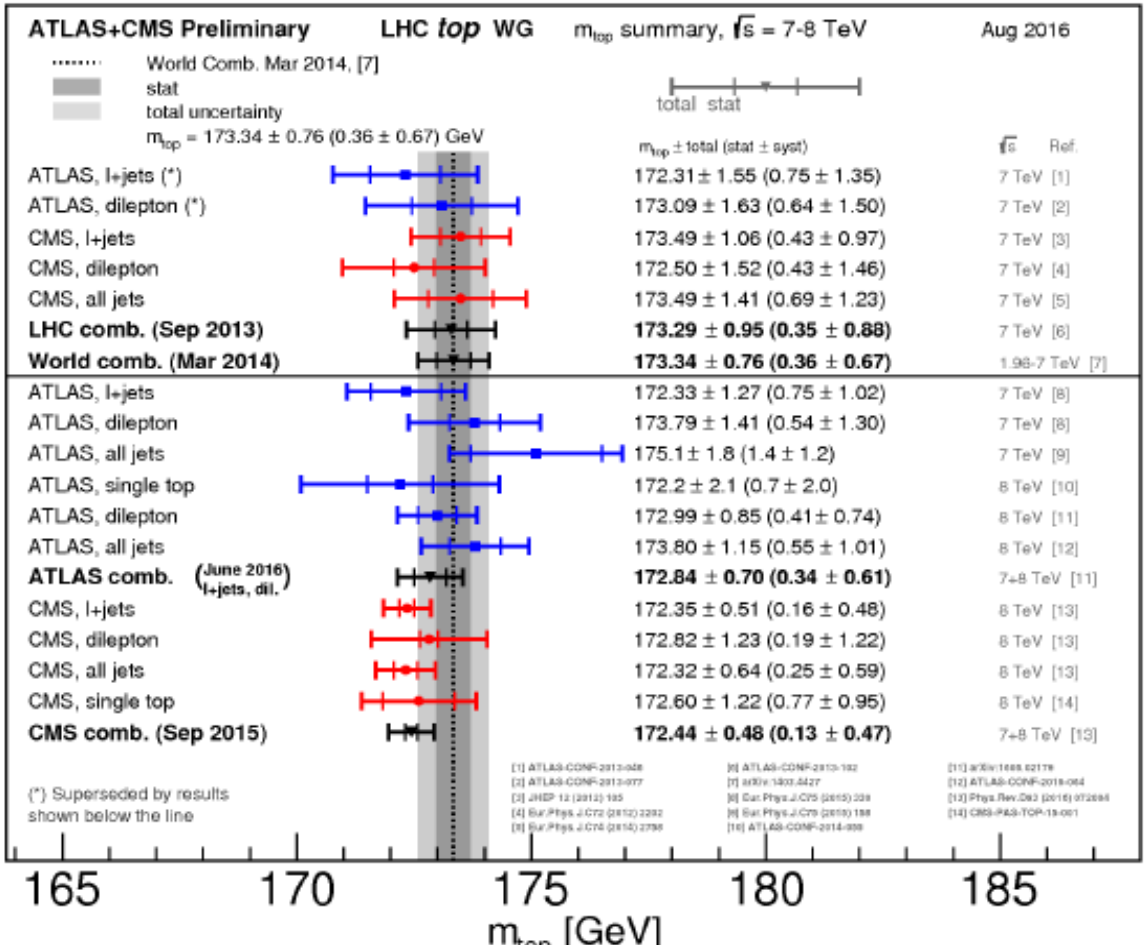
Comparison



Tevatron

vs.

LHC



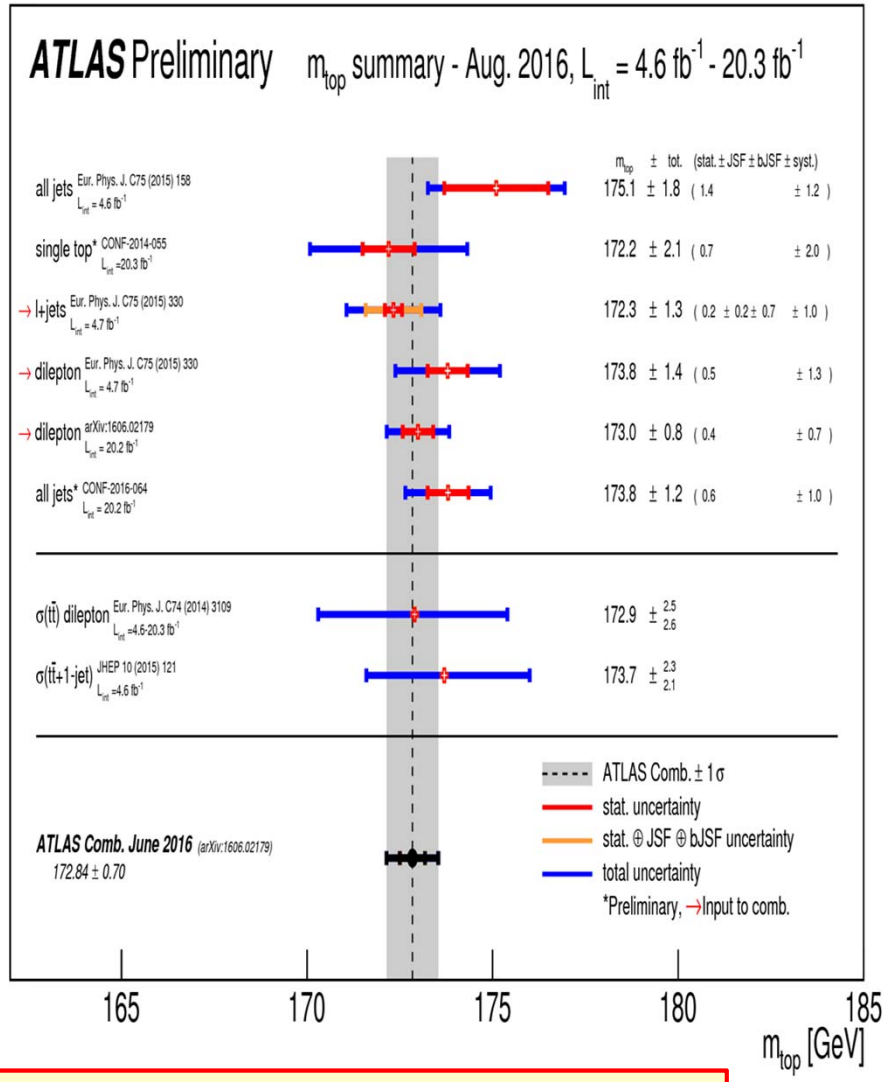
Summary

- New results still appearing 5 years after Tevatron shutdown
- Top quark mass measurements
  - Latest measurements and combinations to finalize Tevatron legacy
    - Mass measured in a variety of modes
    - Top quark mass measured with 0.43% accuracy at D0
    - Top quark mass measured with 0.37% accuracy at Tevatron
    - Expect CDF l+jets update

Support slides

LHC (direct) measurements

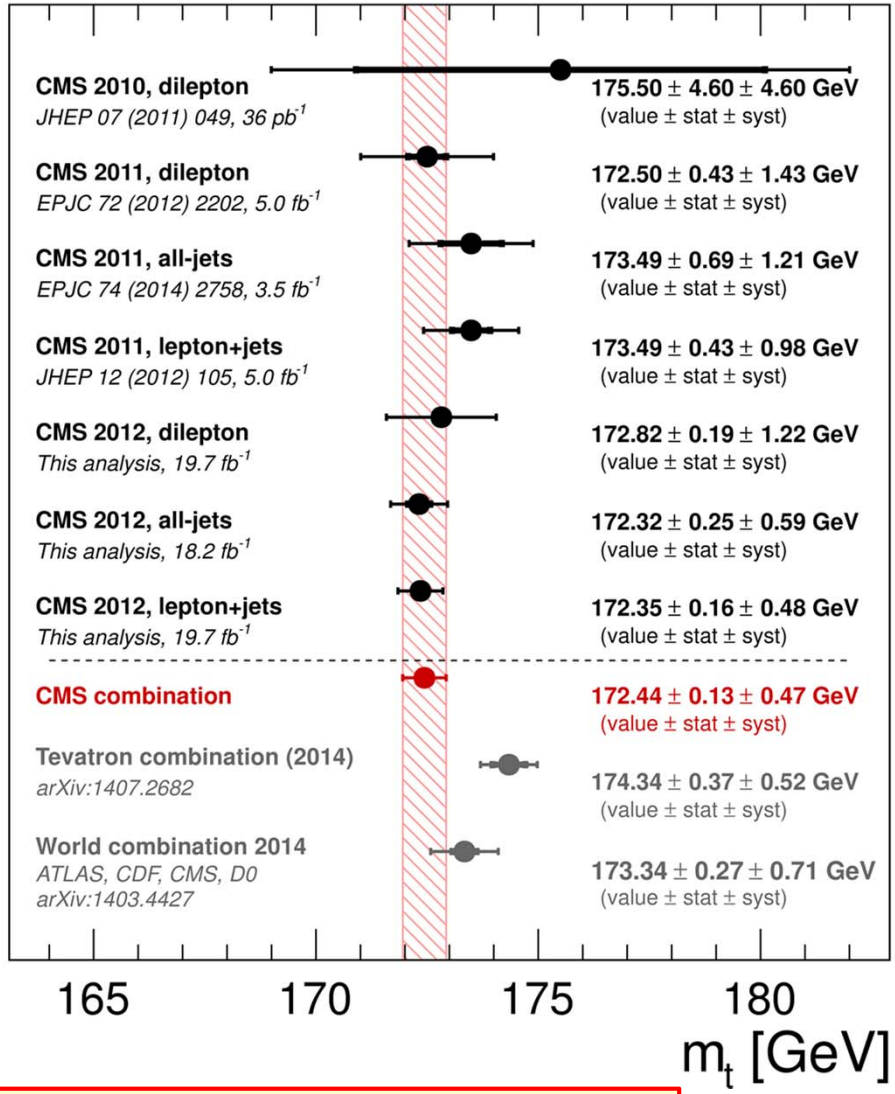
August 2016



m_t = 172.84 ± 0.70 (total) GeV

$\delta m_t/m_t = 0.40\%$

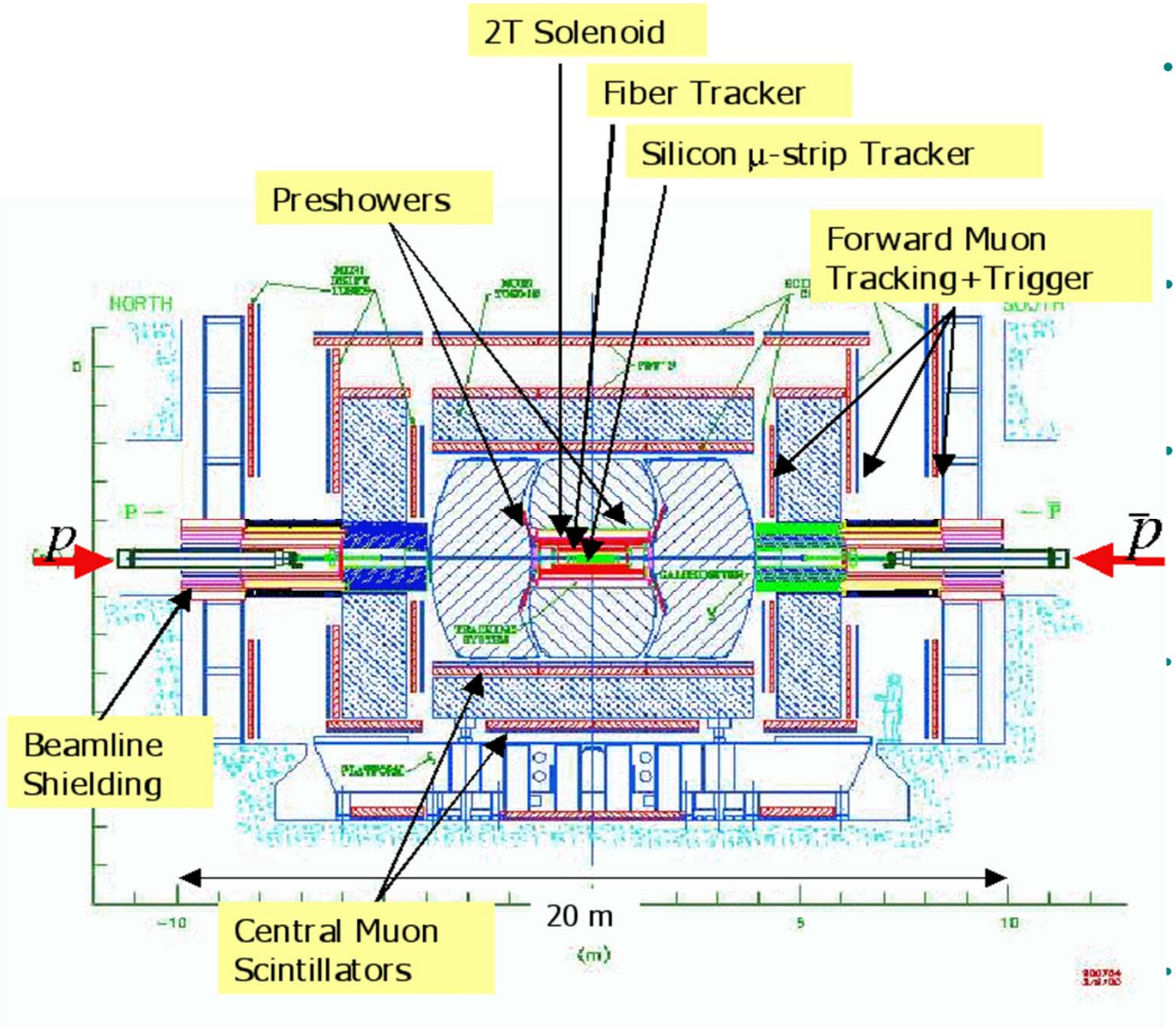
September 2015



m_t = 172.35 ± 0.51 (total) GeV

$\delta m_t/m_t = 0.29\%$

D0 detector in Run II



- Tracking and vertexing
  - 2 Tesla Solenoid
  - Silicon ($|\eta| < 3.0$, r~10cm)
  - Fiber ($|\eta| < 1.7$, r~50 cm)
- Calorimetry
  - LAr/U
  - $|\eta|<4.0$
- Muons:
  - Toroid
  - Drift chambers/Scintillators
  - $|\eta| <2.0$
- Typical coverage
  - Muons $|\eta| < 2$
  - Electrons
    - $|\eta|<1.1$
    - $1.5<|\eta|<2.5$
  - Jets $|\eta|< 2.5$
- Magnet polarities
  - Reverse toroid and solenoid polarities regularly to cancel detector asymmetries for charged track reconstruction.