Recent results from DØ and Recent Tevatron Combinations

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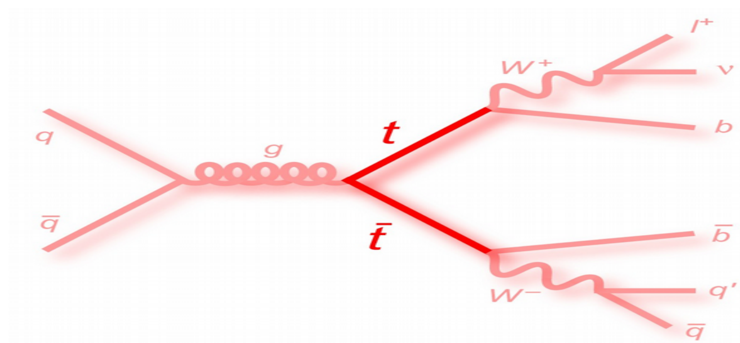
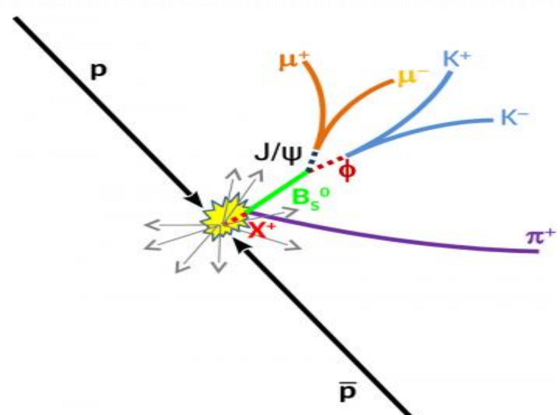
on behalf of the
DØ and CDF collaborations





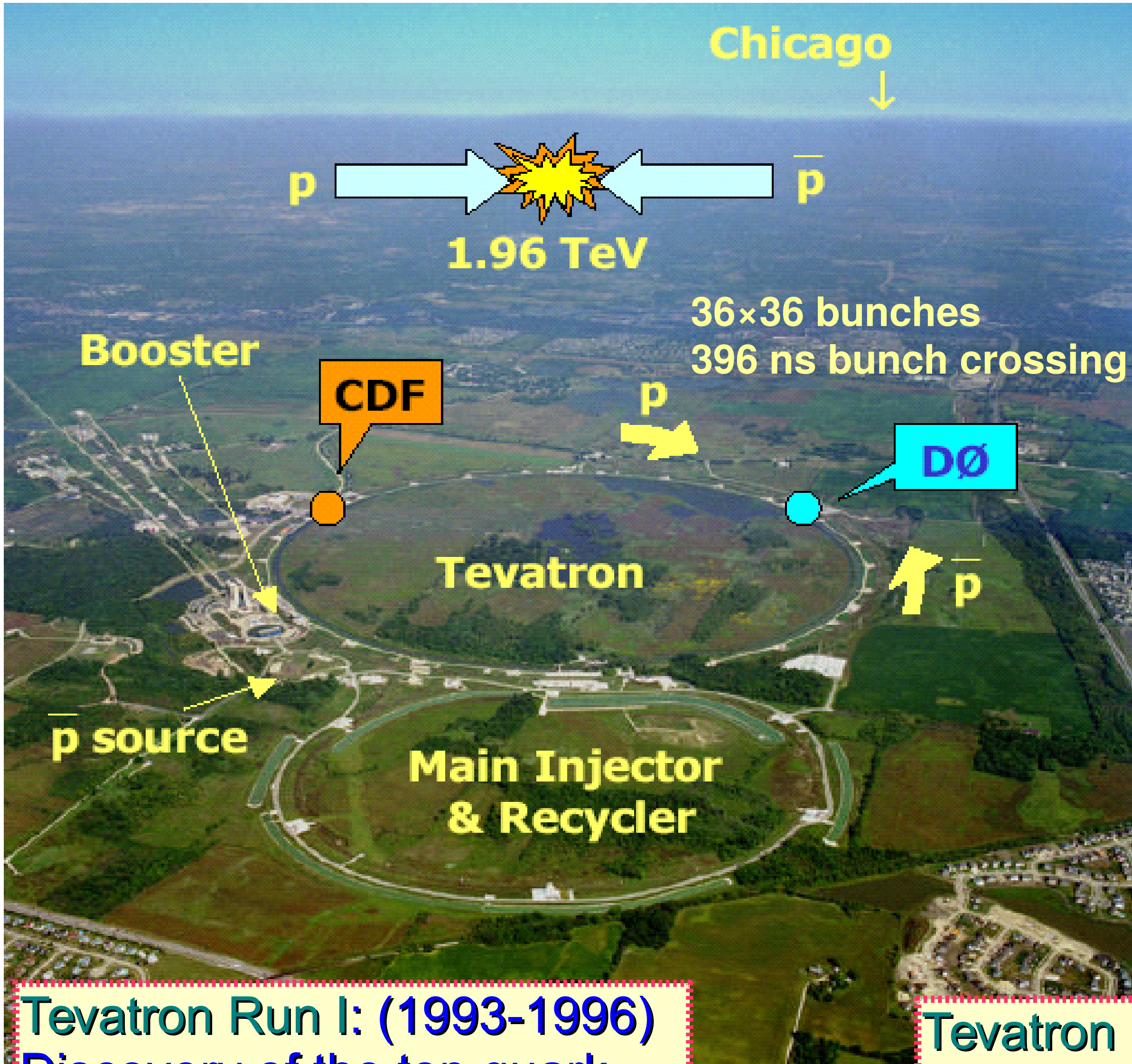
Outline

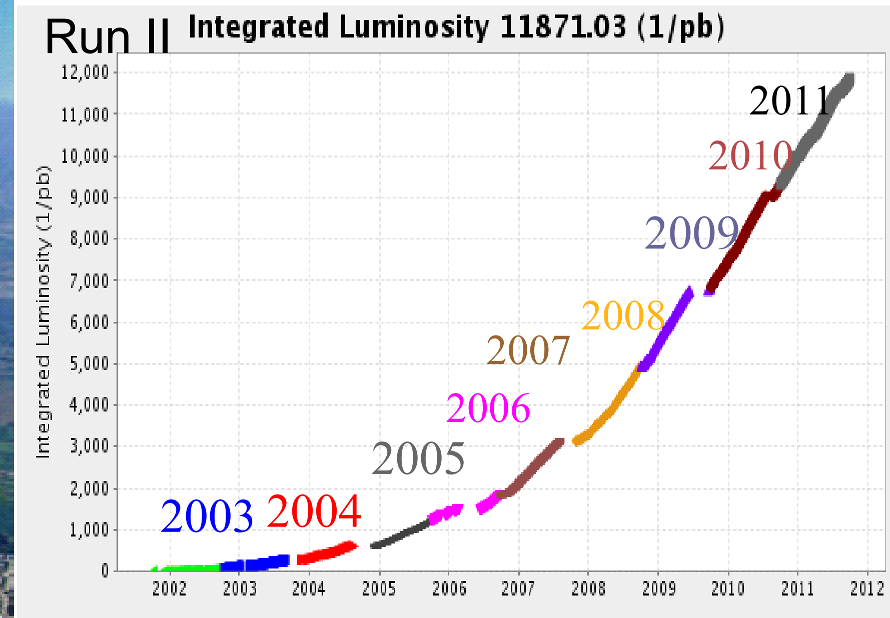
In this talk

- Recent results from D0
- Some recent CDF+D0 combinations
- See talk by Donatella Lucchesi for recent CDF results and more Tevatron combinations

- Top quark physics
  - Top quark mass
  - $t\bar{t}$ production asymmetries
- Search for CP violating asymmetry in B^+ production
- $X(5568) \to B_s\pi$

The Tevatron proton-antiproton collider

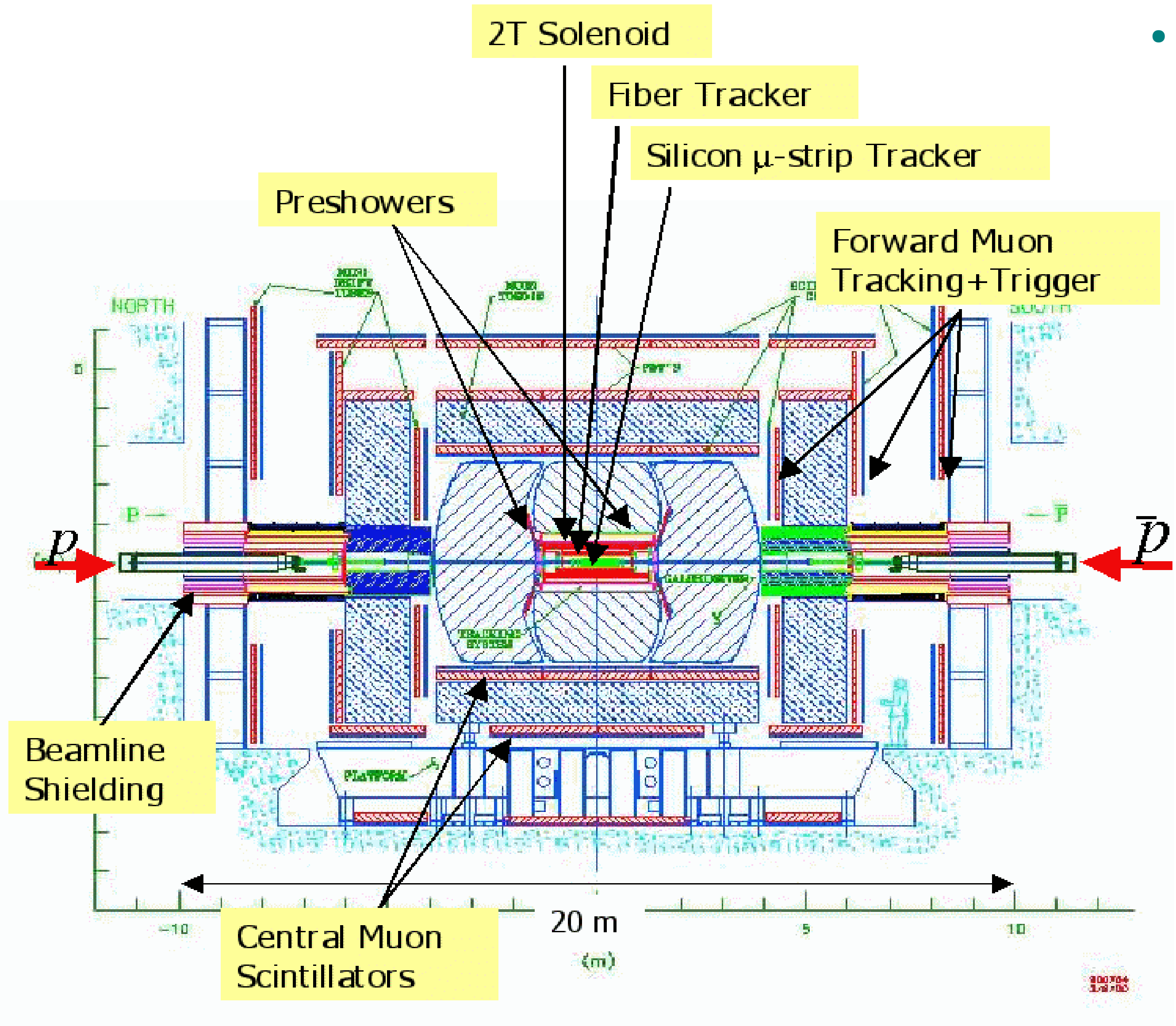




Tevatron Run I: (1993-1996)
Discovery of the top quark
~120 pb^{-1} per experiment

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

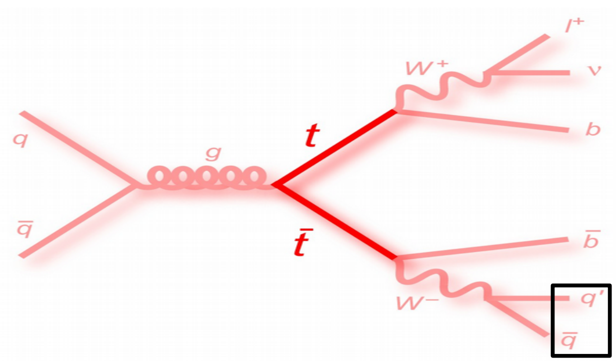
D0 detector in Run II



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

Top quark mass measurements

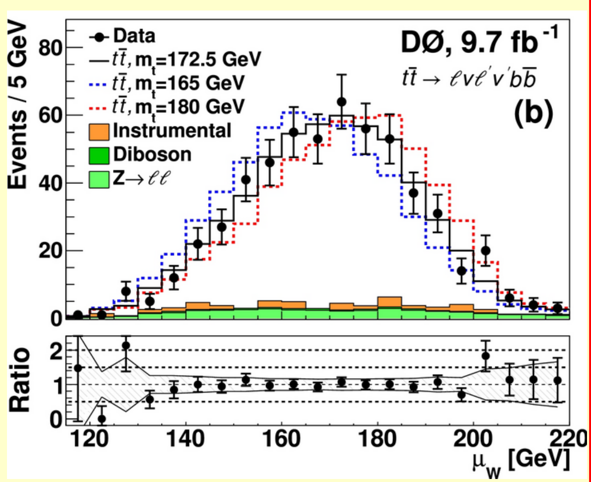
- Different analyses at D0 depending on
  - Channel: mainly ℓ+jets and dilepton
  - Method to extract top mass
- Consistency check
  - Not sensitive to same systematics
- Reduction of systematic uncertainties
  - Jet Energy Scale from in situ calibration in ℓ+jets channels exploiting M_{jj} ~ 80.4 GeV



M ~ 80.4 GeV

Template method

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



templates in dilepton ν-weight analysis

Matrix Element (ME) method

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

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

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

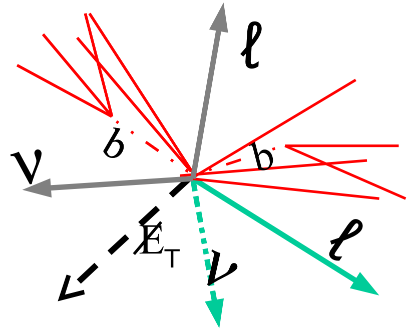
- Integrate over unmeasured quantities or quantities with a significant measurement uncertainty
- CPU demanding

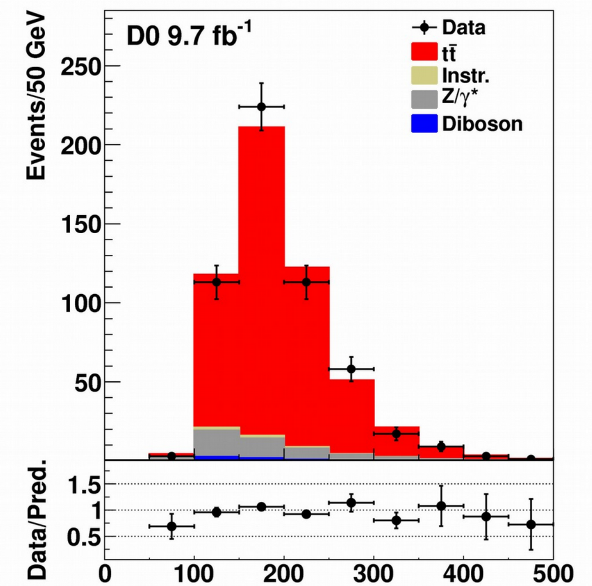
Cross-section method

Derive top mass from measured cross section

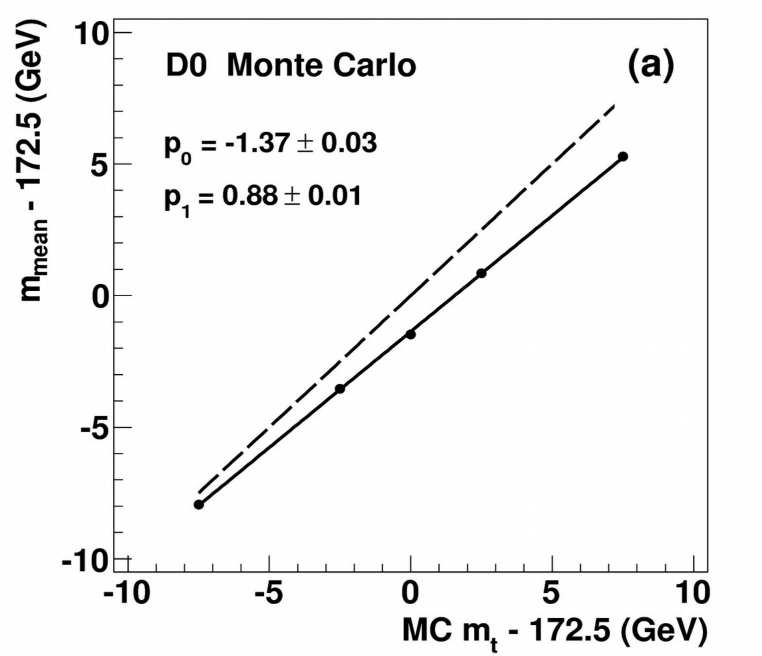
Top mass in dilepton channel using ME

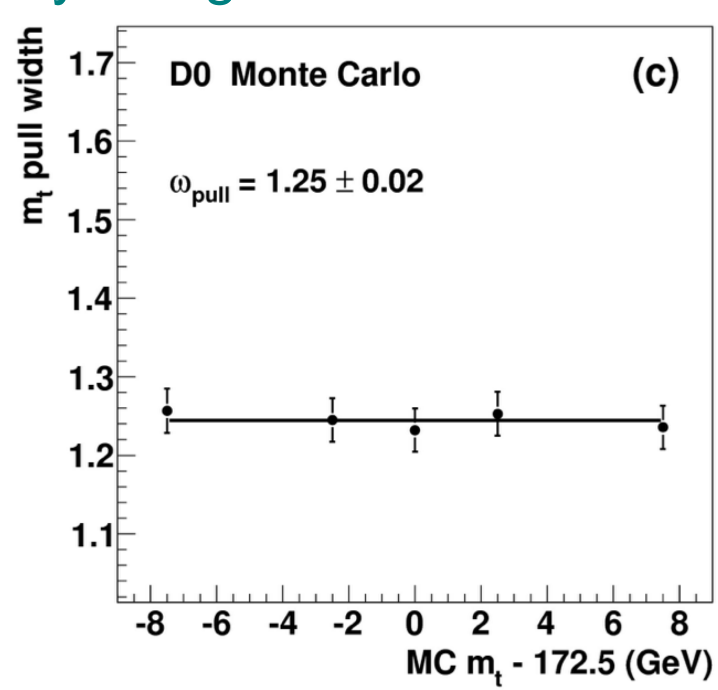
- Very pure channel with low background
- Kinematic underconstrained because of two neutrinos
- Extract maximum information with ME method





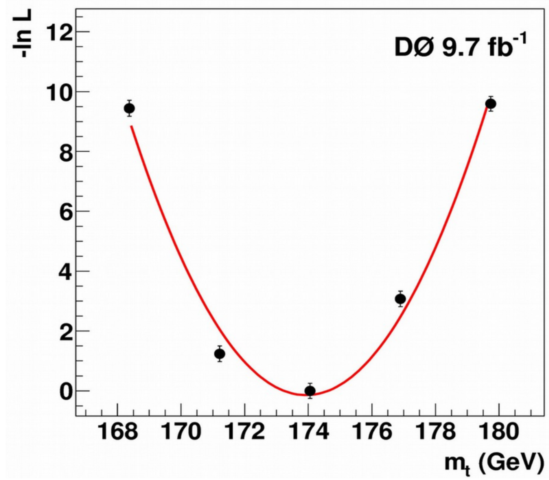
- Calibration of mass and uncertainty using MC ensembles





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)

- Previously published 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 measurements.
- Combined Run II dilepton measurement

$\boxed{m_t = 173.50 \pm 1.31\ (\text{stat}) \pm 0.84\ (\text{syst})\ \text{GeV}}$

D0-Conf-6485 (2016)
to be submitted to PRD

$\delta m_t/m_t = 0.9\%$

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

Top mass from inclusive cross-section

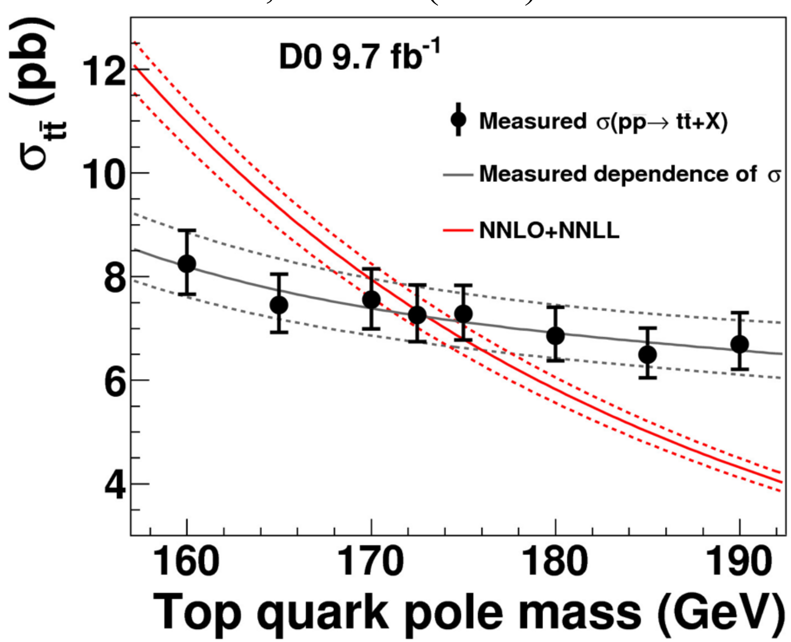
- Exploit dependence as a function of top mass
  - Measure cross-section for different top mass hypotheses
    - Dependence due to variation of acceptance
  - The theoretical prediction depends on the top "pole mass"
    - Use NNLO+NNLL pQCD calculation top++
- Construct a Bayesian posterior probability of the top mass
  - Flat prior on top mass
- Extract top mass
  - Advantage: well defined "pole mass", as opposed to "MC mass" obtained in direct measurements

$$m_t = 172.8 \pm 1.1(\text{theo})^{+3.3}_{-3.1}(\text{exp})\ \text{GeV}$$
$$m_t = 172.8 \pm 3.3\ \text{GeV}$$

$\delta m_t/m_t = 1.9\%$

  - Improvement over the 5.3 fb^{-1} result $167.5^{+5.2}_{-4.7}$ GeV (PLB 703, 422 (2011)) due to reduced dependence of measurement vs mass

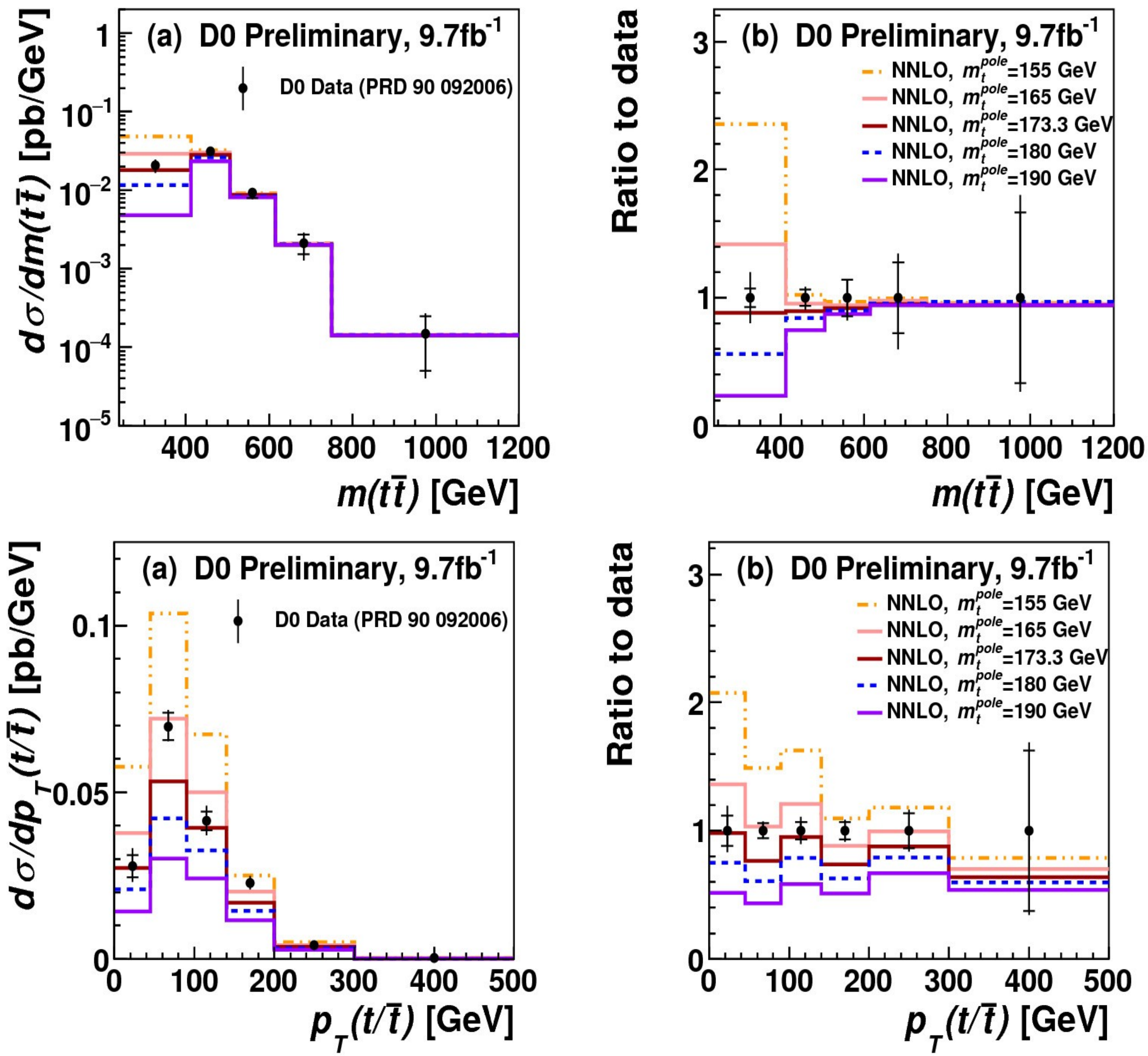
PRD 94, 092004 (2016)



Top mass from differential cross-section

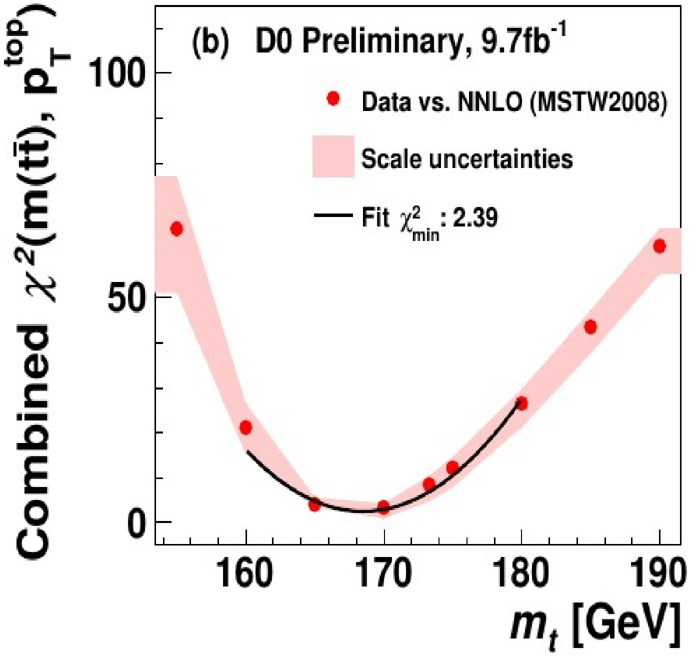
Differential cross-sections as a function of relevant kinematical quantities are sensitive to top pole mass

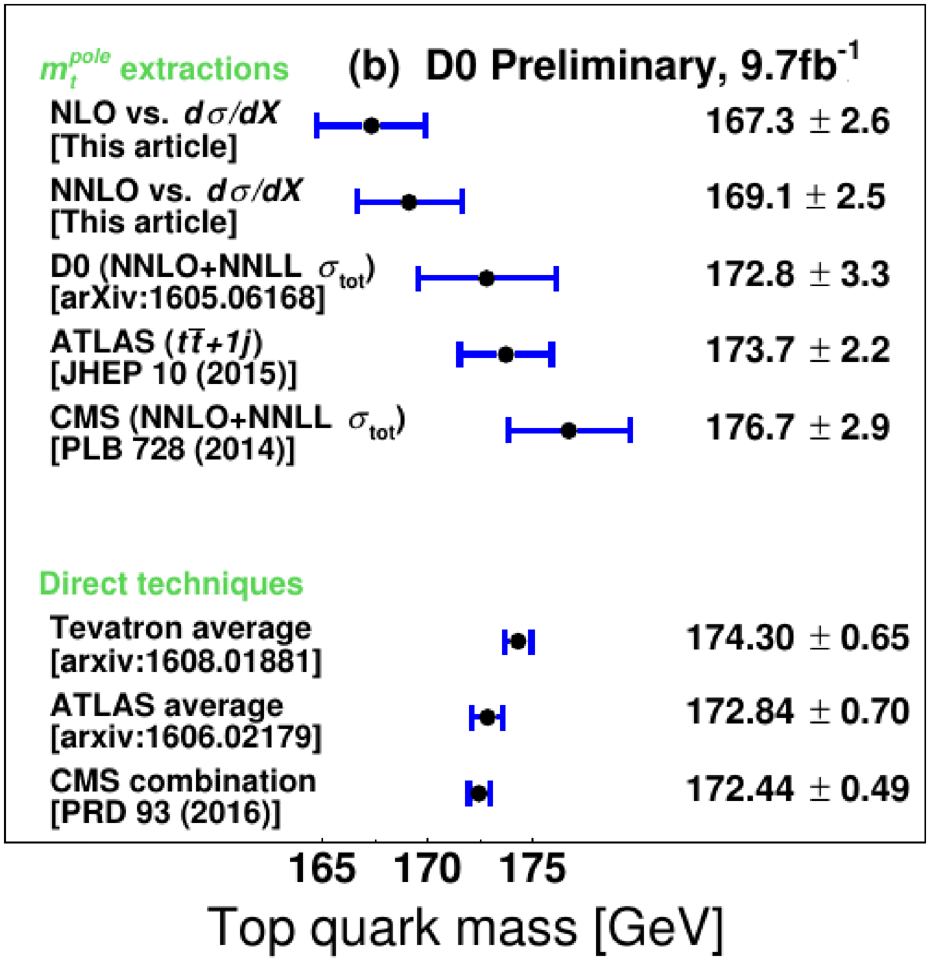
- Use $m(t\bar{t})$ and $p_T(t/\bar{t})$ as variable of interest
- Exploit D0 ℓ+jets measurements (PRD 90; 092006 (2014))
- Compare with NNLO QCD calculations
  (Czakon, Fiedler, Heymes, and Mitov JHEP 1605, 034 (2016))



Mass from differential cross-section : result

- Mass extracted from fit to unfolded data
  - Determine correlation matrix for unfolded data
  - $\chi 2$(Data- theory) minimized to determine mass and experimental uncertainty
  - Extract mass assuming different scale/PDF to obtain theory uncertainty.





m_t = 169.1±1.1 (theo) ±2.2 (exp) GeV

$\delta m_t/m_t = 1.5\%$

D0 conf 6473 (2016)

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

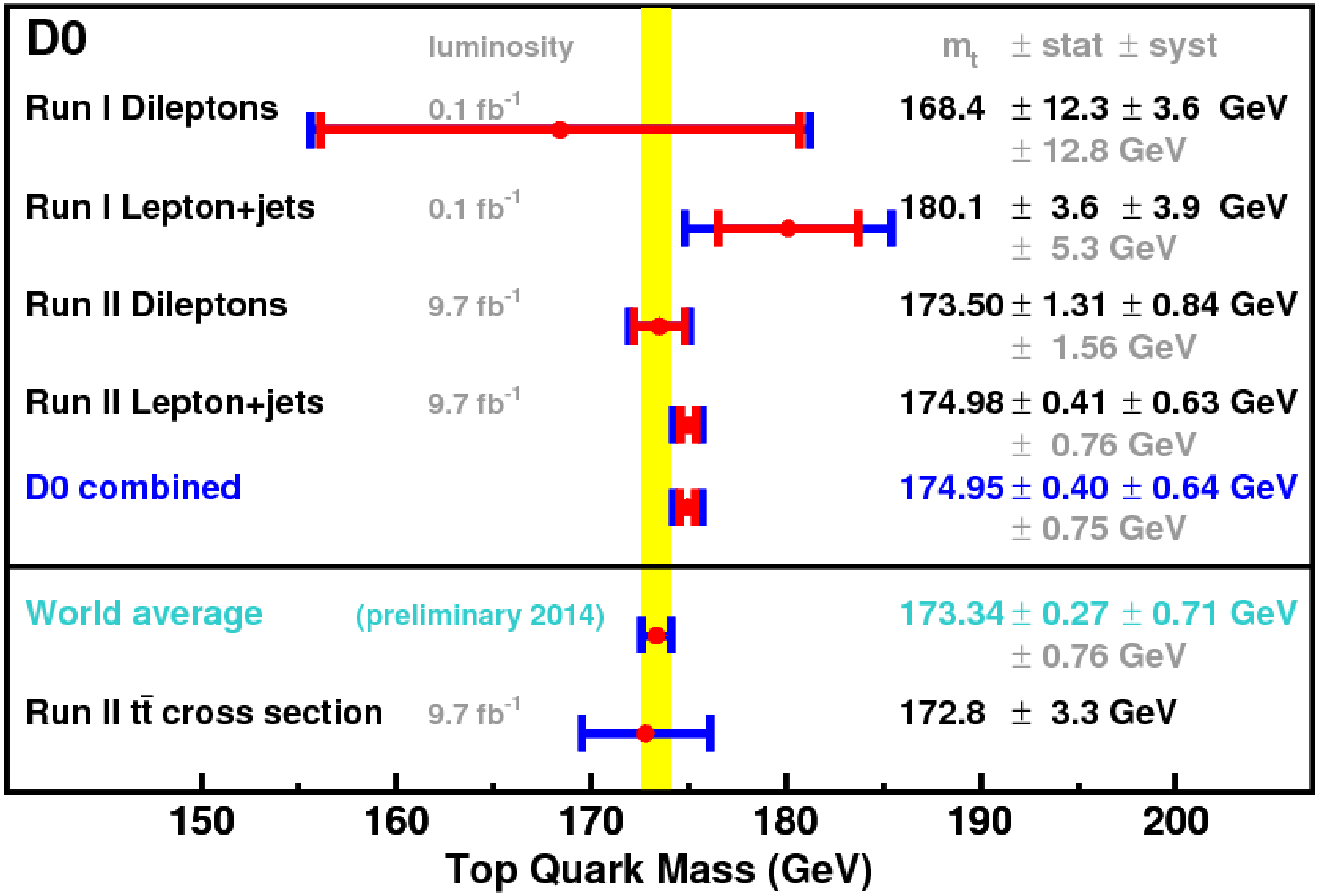
- Combination accounts for all uncertainties and their correlation
  - Use BLUE (Best Linear Unbiased Estimate)
  - χ2 /ndof = 2.5/3, prob = 47 %: good consistency between the measurements

D0-Conf-6485 (2016)
to be submitted to PRD

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

correlation table

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

$$m_t = 174.95 \pm 0.40(\text{stat}) \pm 0.64\ (\text{syst})\ \text{GeV}$$

$$\delta m_t/m_t = 0.43\%$$

Dominant uncertainties

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

D0-Conf-6485 (2016)
to be submitted to PRD

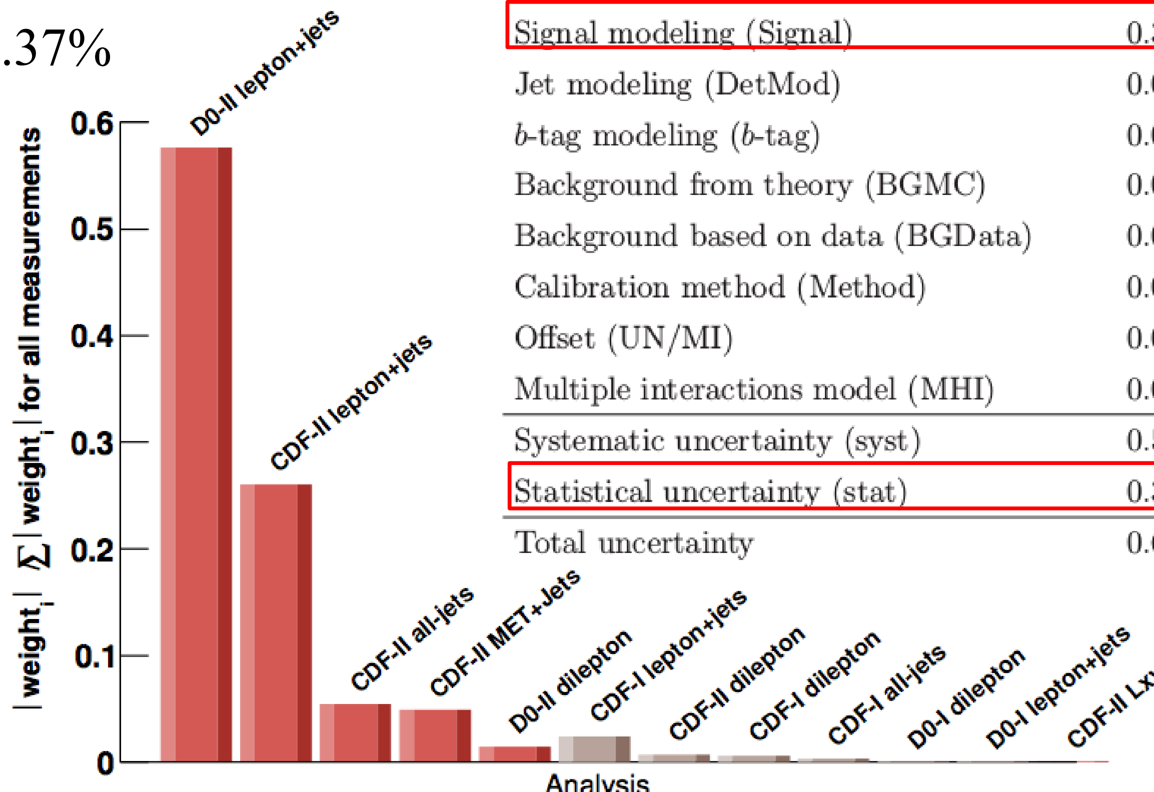
Tevatron top mass (Summer 16)

- All D0 and CDF inputs are published.
- Perform BLUE combination
  - $\chi2$ /ndof = 10.8/11, prob = 46 %
  - Good consistency between measurements
- Combination dominated by ℓ+jets channels

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

$\delta m_t/m_t = 0.37\%$

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



	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

Tevatron top mass summary

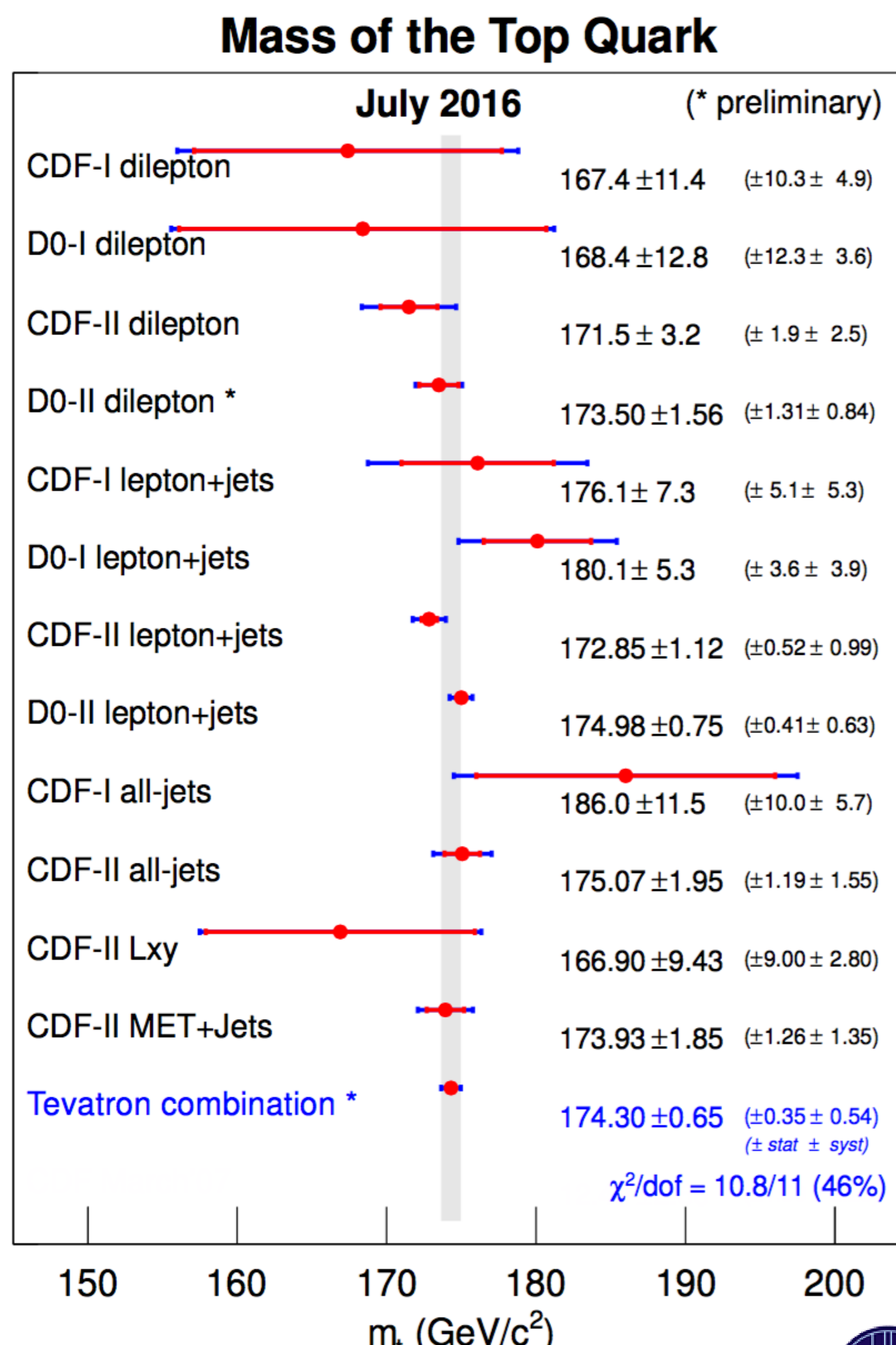
arXiv:1608.01881, D0 Note 6486, CDF Note 11204

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

$\delta m_t/m_t = 0.37\%$

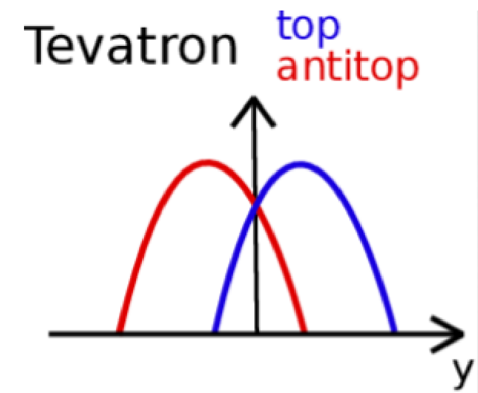
Not final:

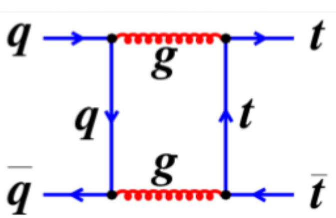
Expect an improved CDF ℓ+jets measurement in a few months

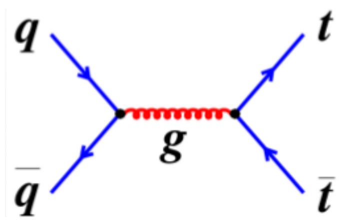


Tevatron $t\bar{t}$ forward-backward asymmetry (A_{FB})

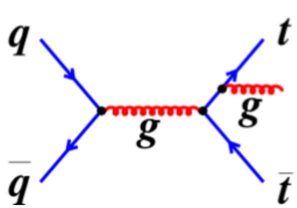
- QCD + EW theory predicts positive asymmetry in $t\bar{t}$ production: top quark tend to go in the same direction as incoming proton at Tevatron

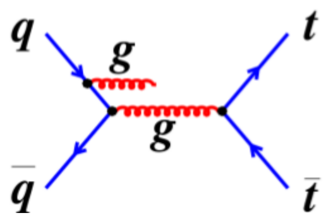




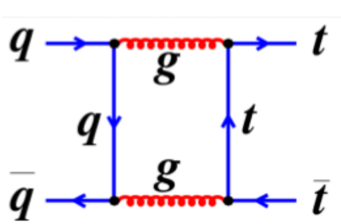


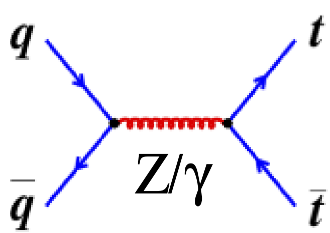
- Main positive contribution due to interference between born and box diagrams



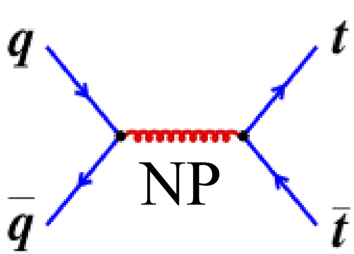


- Negative contribution in ISR/FSR interferences





- Also non negligible impact of interferences between QCD box and electroweak diagrams



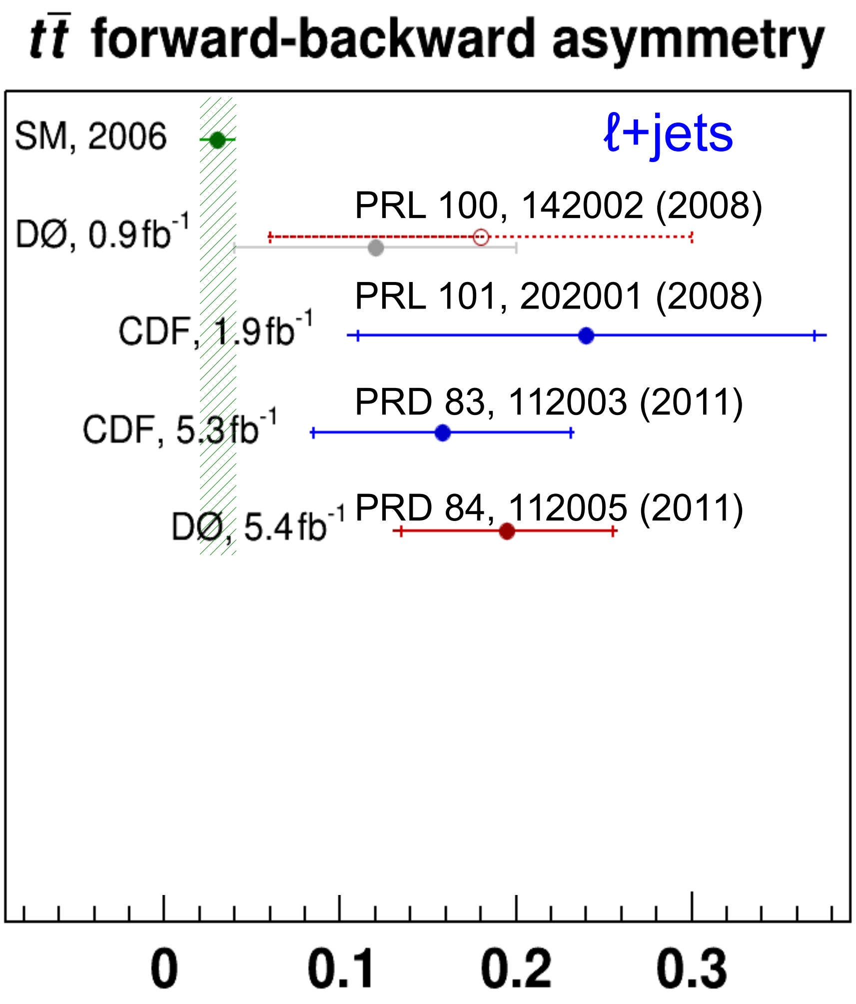
- New Physics could affect quantitatively the asymmetry
  - Eg axigluon models

A_{FB} History (1)

- Observable: $A_{FB} = \frac{N(\Delta y>0)-N(\Delta y<0)}{N(\Delta y>0)+N(\Delta y<0)}$

$$\Delta y = y_t - y_{\bar{t}}$$

- A lot of excitement in the past years:
  - Tevatron ℓ+jets analyses were showing departure from SM expectations

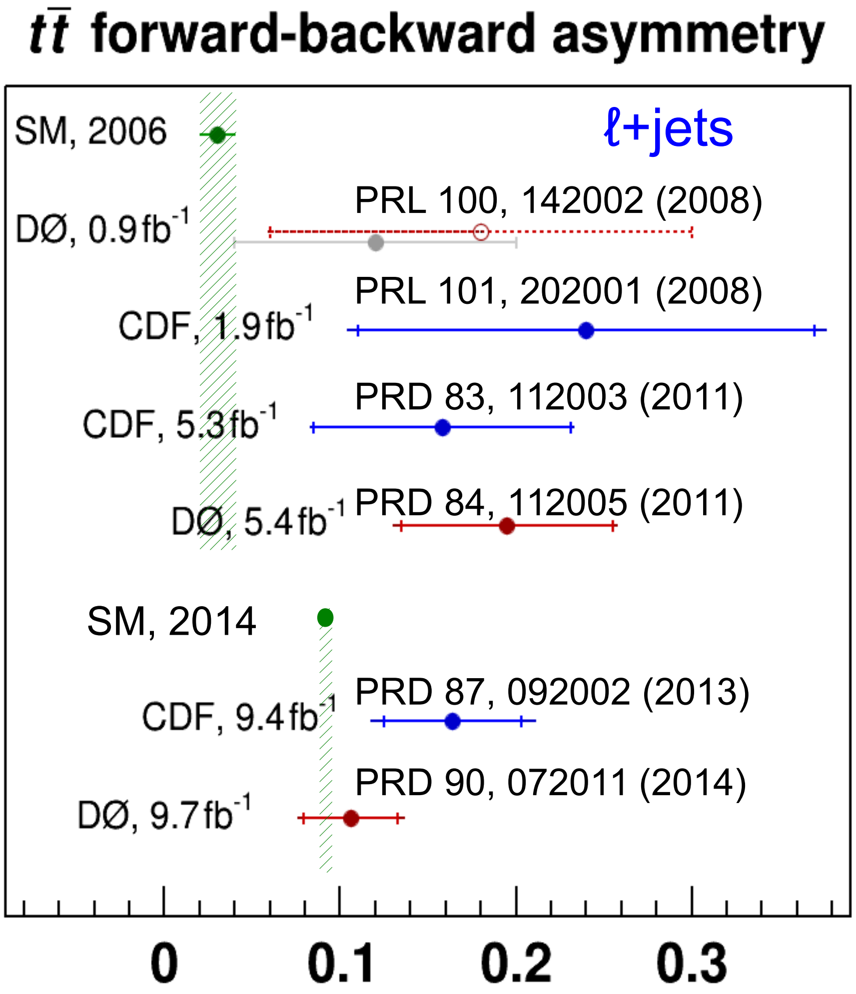


A_{FB} History (2)

- Observable: $A_{FB} = \frac{N(\Delta y>0) - N(\Delta y<0)}{N(\Delta y>0) + N(\Delta y<0)}$

$$\Delta y = y_t - y_{\bar{t}}$$

- A lot of excitement in the past years:
  - Tevatron ℓ+jets analyses were showing departure from NLO SM expectations
- More recent publications:
  - NNLO+EW SM expectations evaluated to be higher: ~9.5±0.5% (PRL 115, 052001 (2015))
  - More data, more refined analysis:
    - Latest experimental results are lower
    - More compatible with SM
- In 2015-2016 D0 and CDF also published latest measurements in dilepton channels



Tevatron combination: inclusive A_{FB}

- Use BLUE method to combine CDF and D0
  - large statistical uncorrelated uncertainties
  - main correlation from signal model ~ 10%
- $t\bar{t}$ asymmetry

$$A_{FB} = \frac{N(\Delta y > 0) - N(\Delta y < 0)}{N(\Delta y > 0) + N(\Delta y < 0)} \quad \Delta y = y_t - y_{\bar{t}}$$

  1.3 s.d. higher than NNLO prediction

- lepton qη asymmetry

$$A^{\ell}_{\rm FB} = \frac{N_\ell(q\times\eta > 0) - N_\ell(q\times\eta < 0)}{N_\ell(q\times\eta > 0) + N_\ell(q\times\eta < 0)}$$

  1.6 s.d. higher than NNLO prediction

- dilepton asymmetry

$$A^{\ell\ell}_{\rm FB} = \frac{N(\Delta\eta > 0) - N(\Delta\eta < 0)}{N(\Delta\eta > 0) + N(\Delta\eta < 0)} \quad \Delta\eta = \eta_{\ell+} - \eta_{\ell-}$$

  1.3 s.d. higher than NNLO prediction

- Note: the 3 results are correlated
- Conclusion: results compatible with SM

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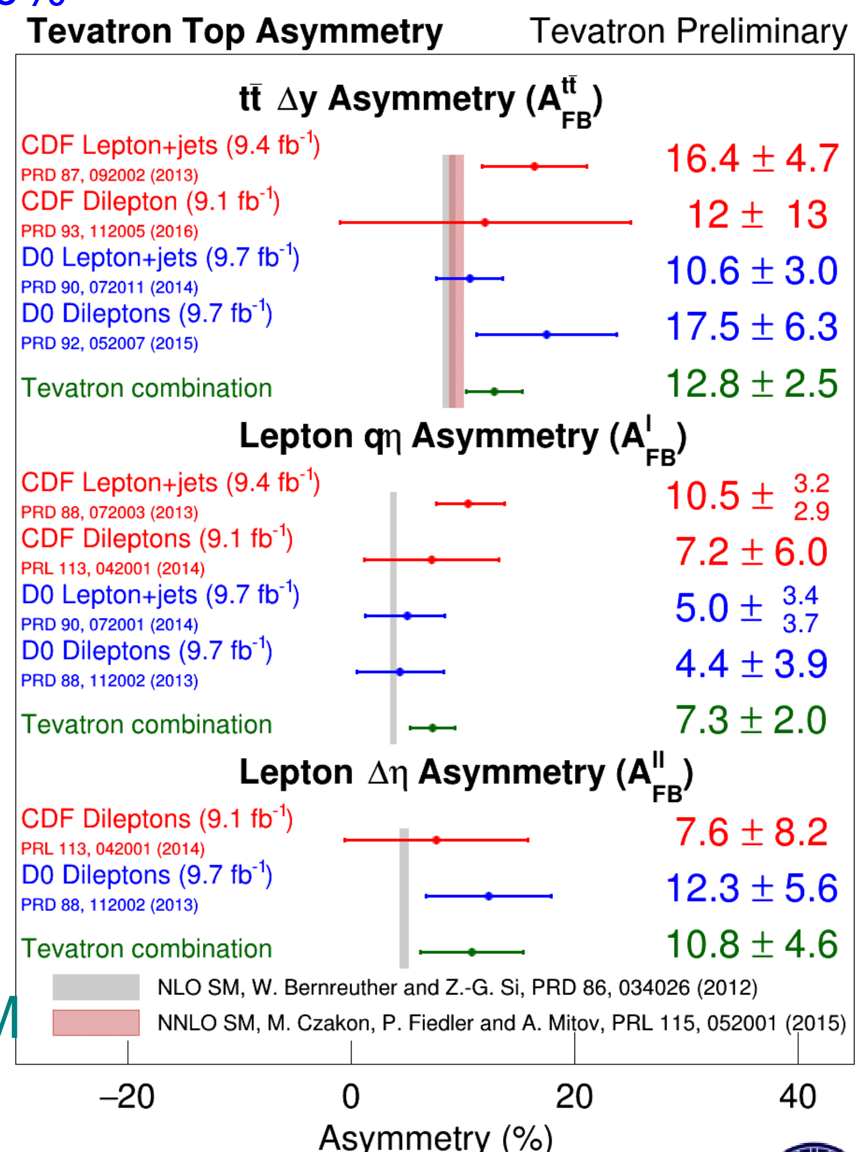
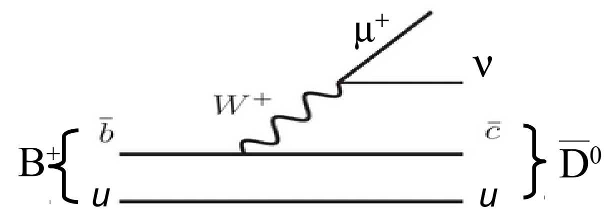


CPV asymmetry in $B^+ \to \mu\nu\overline{D}^0$

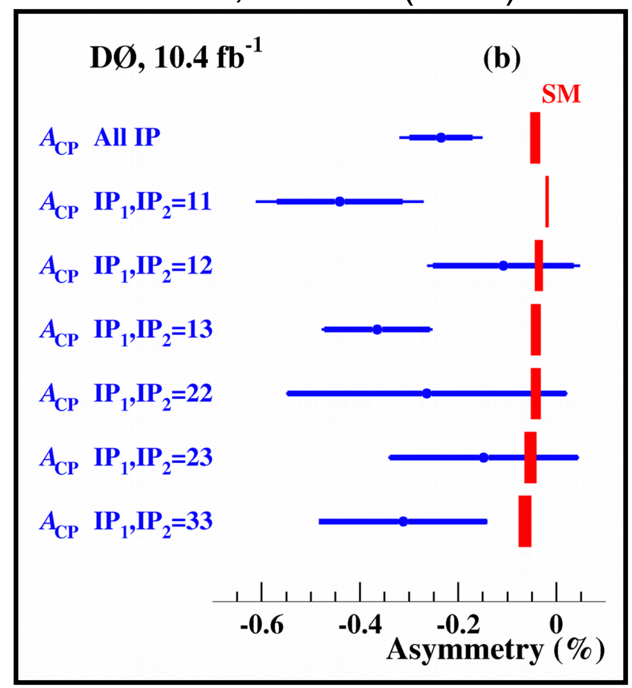
- Direct CP violating asymmetry defined as

$$A^{\mu D^0} = \frac{\Gamma(B^- \to \mu^-\overline{\nu_\mu}D^0) - \Gamma(B^+ \to \mu^+\nu_\mu\overline{D}^0)}{\Gamma(B^- \to \mu^-\bar{\nu_\mu}D^0) + \Gamma(B^+ \to \mu^+\nu_\mu\overline{D}^0)}$$

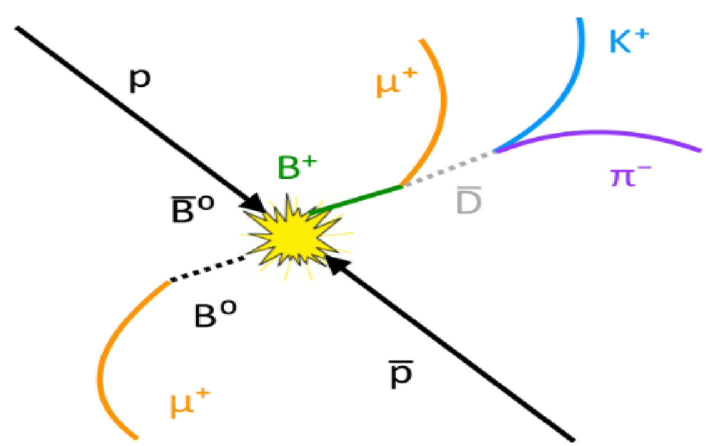


- Motivation
  - Never measured before
  - $A^{\mu D}$ Expected to be 0 in Standard Model
  - Try to explain like-sign dimuon asymmetry
    - D0 measured like-sign dimuon asymmetry with significance of 3.6 sd
    - CPV asymmetry in $B^+ \to \mu\nu\overline{D}^0$ could be a source of like-sign dimuon asymmetry
    - Would require $f_{B^+_{SL}} \times A^{\mu D} = 0.5\%$ $\to A^{\mu D^0} \sim 0.8\%$

PRD D89, 012002 (2014)



$$A_{CP} = \frac{N^{++} - N^{--}}{N^{++} + N^{--}}$$



Raw asymmetry measurement

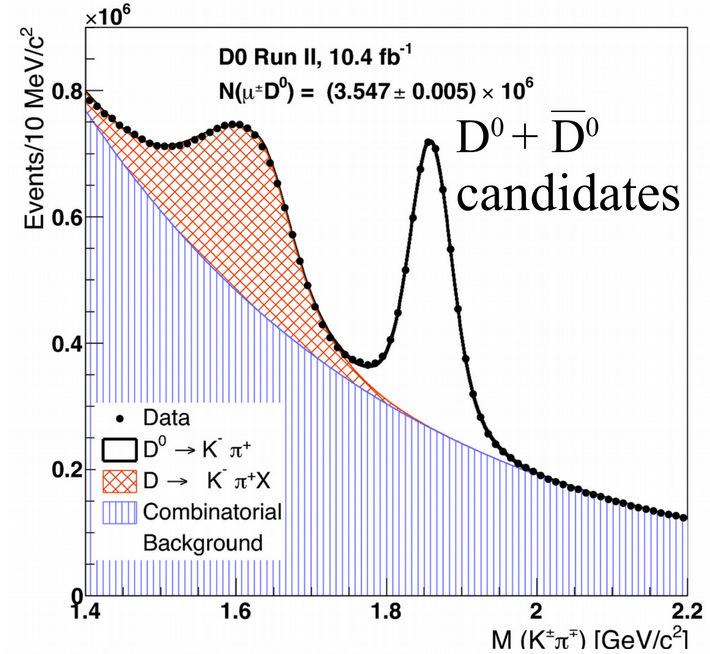
Selection:

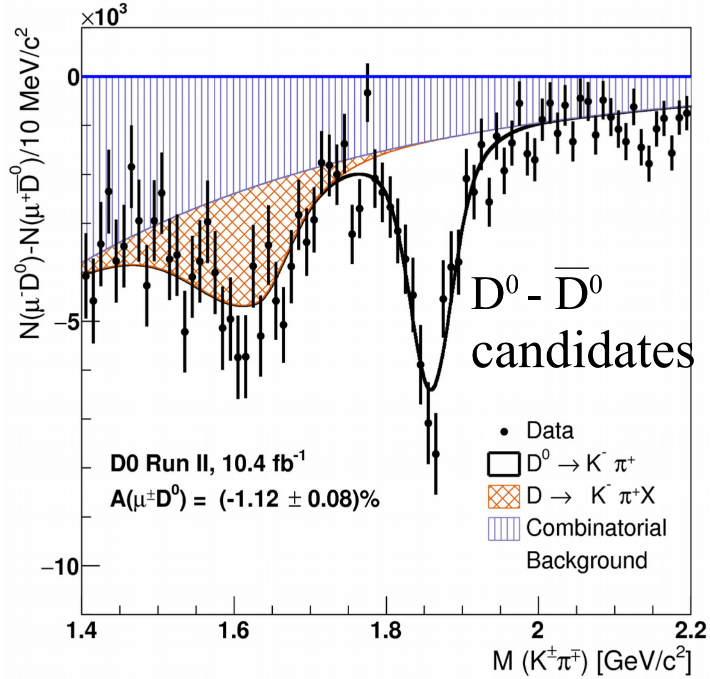
- Select D^0 candidates ($D^0 \to K^-\pi^+$)
- Mass range 1.40 <M(Kπ)<2.20 GeV

- Simultaneous fit of sum ($B^+ + B^-$) and difference ($B^+ - B^-$) to disentangle signal from backgrounds

  - Measure $$A_{\rm raw} = \frac{N_{\mu^- D^0} - N_{\mu^+\overline{D}^0}}{N_{\mu^- D^0} + N_{\mu^+\overline{D}^0}}$$

  - A_{raw}=[-1.12± 0.08 (stat) ± 0.008 (syst)]%





CPV Asymmetry extraction

- Correct for dilution, detector and physics effects:

$$A^{\mu D^0} = \frac{1}{f_B}(A_{\rm raw} - A_{\rm det} - A_{\rm phys})$$

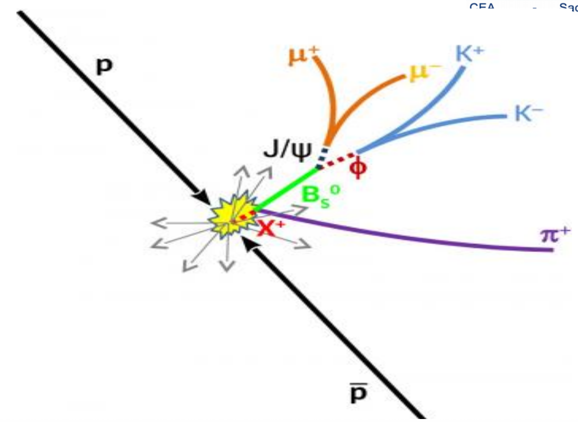
- Determine detector asymmetry using well established methods
  - As done in like-sign dimuon asymmetry or B_d semileptonic asymmetry (PRD 86, 072009 (2012))
  - A_{det}=-A_μ-A_K+A_{track}=[-1.02 ± 0.08 (syst)]%
- MC to determine
  - Dilution of signal in other sources of $D^0\mu X$ events
    - f_B=56±0.2%
  - Fraction of B_d (35.2±0.2%) and B_s (1.8±0.1%) contributing to $D^0\mu X$ final state and yielding possible physics asymmetry
    - A_{phys}=[-0.02±0.02]%
- Result in agreement with SM value of 0

PRD 95, 031101(R) (2017)

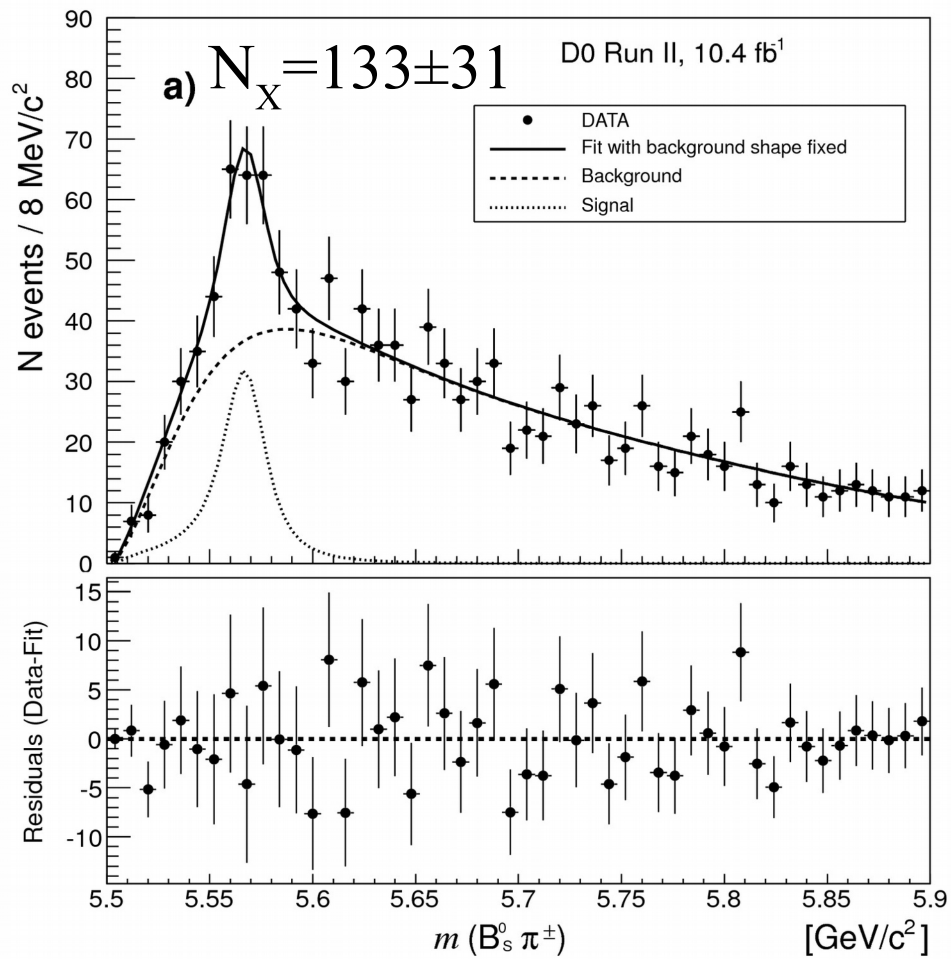
$$\boxed{A^{\mu D^0} = [-0.14 \pm 0.14(\text{stat}) \ \pm 0.14(\text{syst})]\%}$$

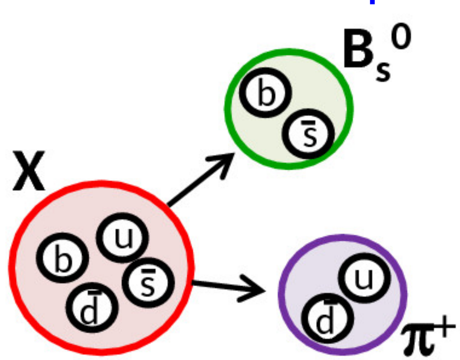
  - too small to explain like-sign dimuon asymmetry

New state X(5568) in $B_s + \pi^{\pm}$ final states



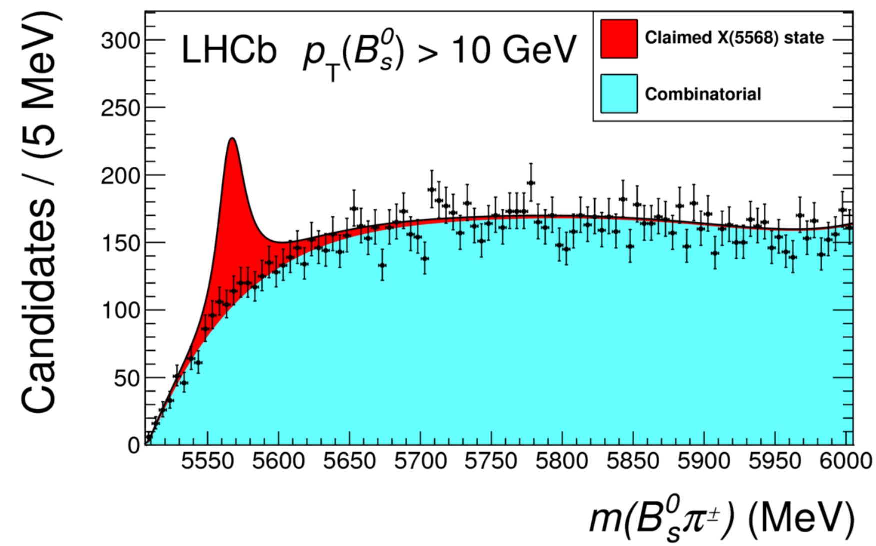
- Last year we published evidence for a new states decaying into $B_s + \pi^{\pm}$
  (Phys. Rev. Lett. 117, 022003 (2016))
  - $X \to B_s \pi^{\pm}$, $B_s \to J/\psi\, \phi$ ($J/\psi \to \mu^+\mu^-$, $\phi \to K^+K^-$)
- 5.1 sigma or 3.9 sigma excess depending on the cut
  - $M_X = 5567.8 \pm 2.9$ MeV
  - $\Gamma_X = 21.9 \pm 6.4$ MeV
- Relatively large width
  - cannot be a weak decay
  - 4 flavors are in the final state → 4 flavors are present in the initial state.
  - Evidence for a tetraquark ???

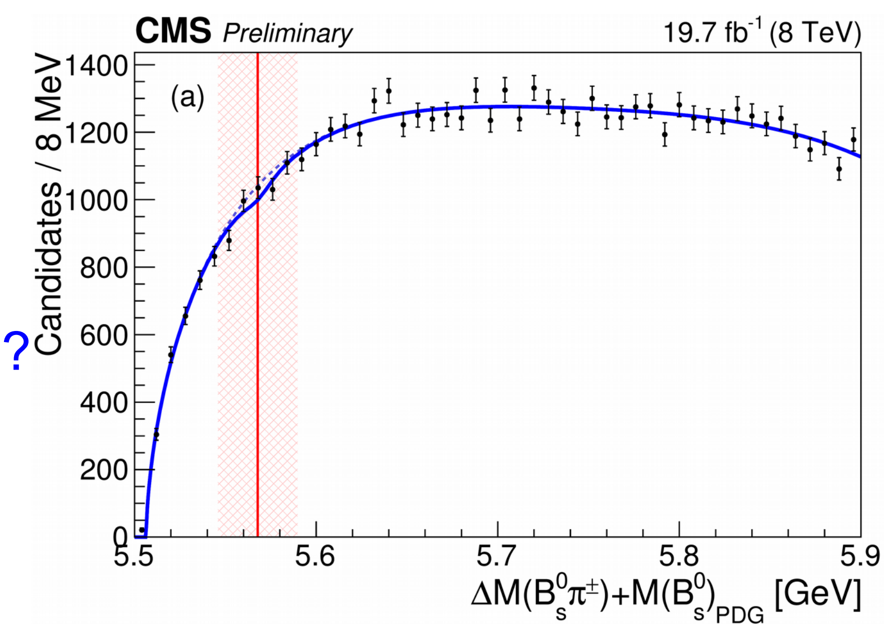




Since first claim

- LHCb produced similar analysis (Phys. Rev. Lett. 117 152003 (2016))
  - First (quick) analysis performed for Moriond QCD 2016
  - Final analysis for ICHEP
  - $J/\psi\ \phi$ and $D_s\pi$ channels
  - No signal observed
  - Yield relative to B_s smaller than 2.4% at 95% CL (to be compared to D0 measurement of 8%)
- CMS has produced similar analysis for ICHEP (CMS-PAS-BPH-16-002)
  - No signal observed
  - Yield relative to B_s smaller than 3.9% at 95%CL
- Mystery why nothing is seen at LHC
  - Problem in D0 analysis ?
  - Different production modes for X and/or B_s ?
    - 2 TeV vs 8 TeV
    - $p\bar{p}$ vs pp





$B_s + \pi^\pm$ state in semi-leptonic channel at D0

- D0 had a look at a semi-leptonic channel for ICHEP16
  - $X \rightarrow B_s^0 \pi^\pm$

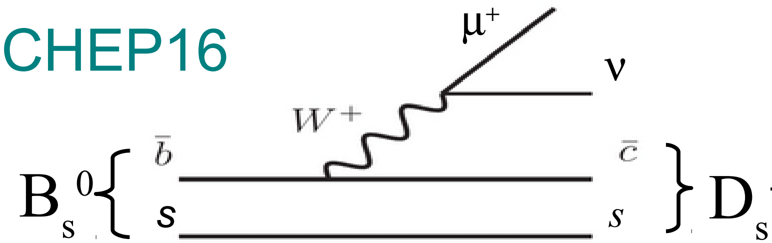
    $B_s^0 \rightarrow D_s^- \mu^+ \nu$

    $D_s^- \rightarrow \phi \pi^-$

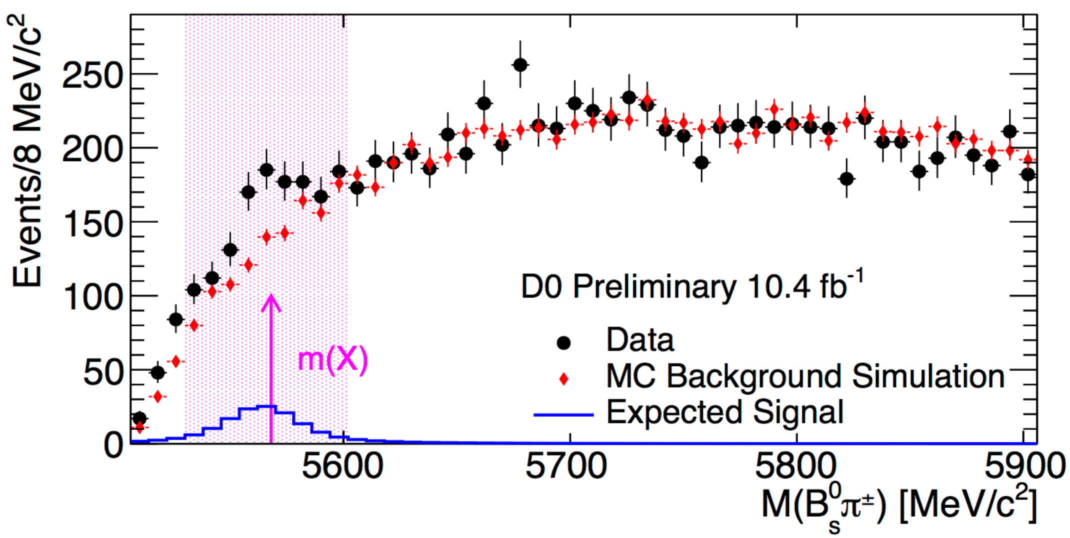
    $\phi \rightarrow K^+ K^-$

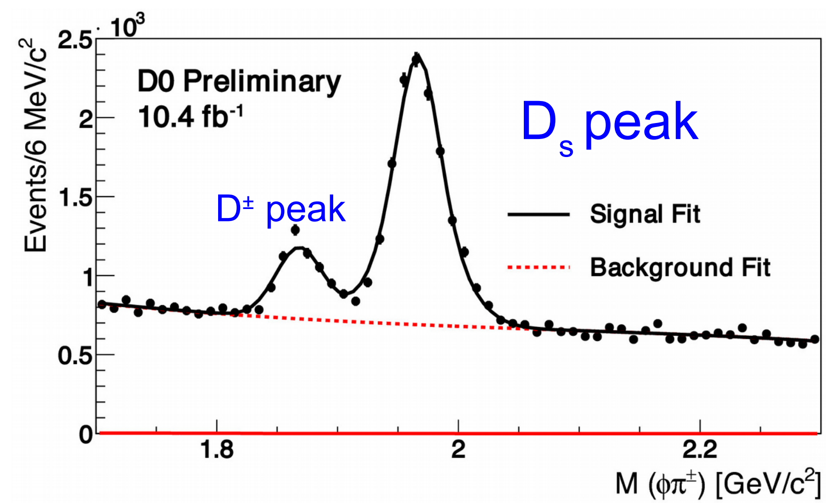
    ~ 90% of $D_s\mu$ arise from B_s

    ~8000 B_s observed. Expect ~150 X events



- Enhancement seen in data ~ as expected





D0-Conf-6488

- Now working on proper modeling of signal and background to assess significance of the excess. We expect an update in the next couple of weeks.. Stay tuned

Summary

- Still new results appearing 5 years after Tevatron shutdown
- Top quark physics.
  - Precise measurements of top quark mass
  - Latest measurements and combinations to finalize Tevatron legacy
    - Top quark mass measured with 0.43% accuracy at D0
    - Top quark mass measured with 0.37% accuracy at Tevatron
    - $t\bar{t}$ A_{FB} in agreement with Standard Model
- New ideas and new measurements in the heavy quark sector
  - CP violation test using B^+ semileptonic decays
  - Evidence for new state $X(5568) \rightarrow B_s \pi^\pm$
- Also electroweak analyses to appear soon
  - $\sin^2\theta_W$ from $Z \rightarrow \mu\mu$ A_{FB}
  - W mass measurement using full data set

Support slides

Summary of this X(5568) D0 paper

Phys. Rev. Lett. 117, 022003 (2016)
arXiv:1602.07588

- A new state X(5568) produced in $p\bar{p}$ collisions

  The significance is 5.1σ / 3.9σ with/without the cut ΔR<0.3

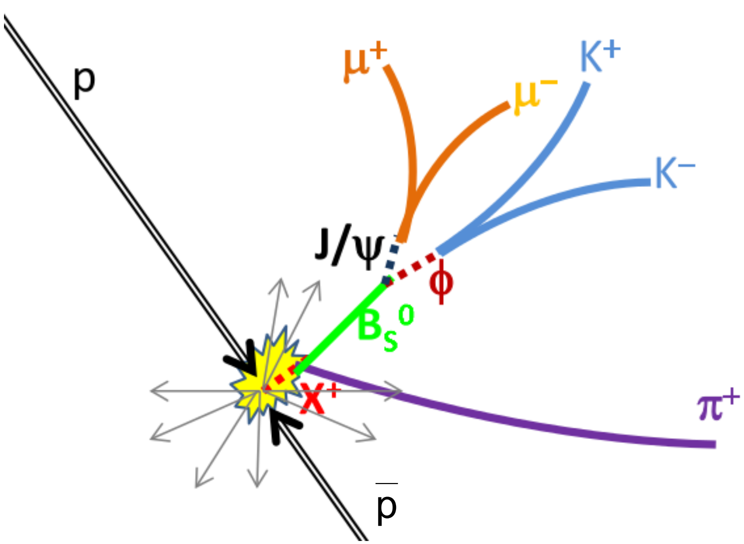
$$\mathrm{m}{=}5567.8{\pm}2.9\,(\mathrm{stat})\,{}^{+0.9}_{-1.9}(\mathrm{syst})\,\mathrm{MeV}$$

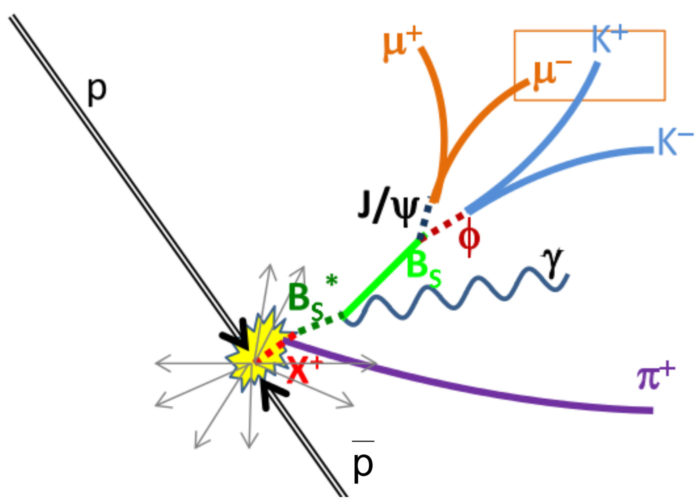
$$(\mathrm{m}{=}5568{+}48\,\mathrm{MeV}\ \text{if}\ \ \mathrm{X}\rightarrow\ B_s^*\pi^\pm)$$

$$\Gamma = 21.0 \pm 6.4\,(\mathrm{stat})\,{}^{+5.0}_{-2.5}(\mathrm{syst})\,\mathrm{MeV}$$

$$R = \frac{\sigma(X(5568)) \times Br(X \rightarrow\ B_s^0\pi^\pm)}{\sigma(B_s^0)} = (8.6 \pm 1.9 \pm 1.4)\%$$

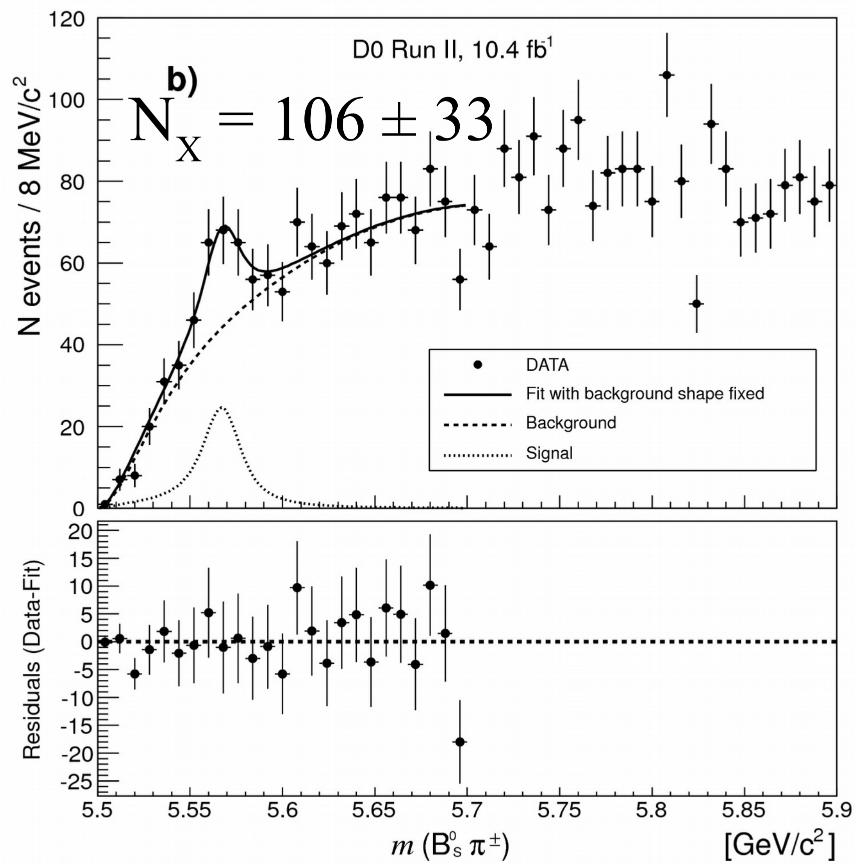
- $X \rightarrow B_s\,\pi^\pm$ JP = 0^+ or $X \rightarrow B_s^*\,\pi^\pm$ JP = 1^+



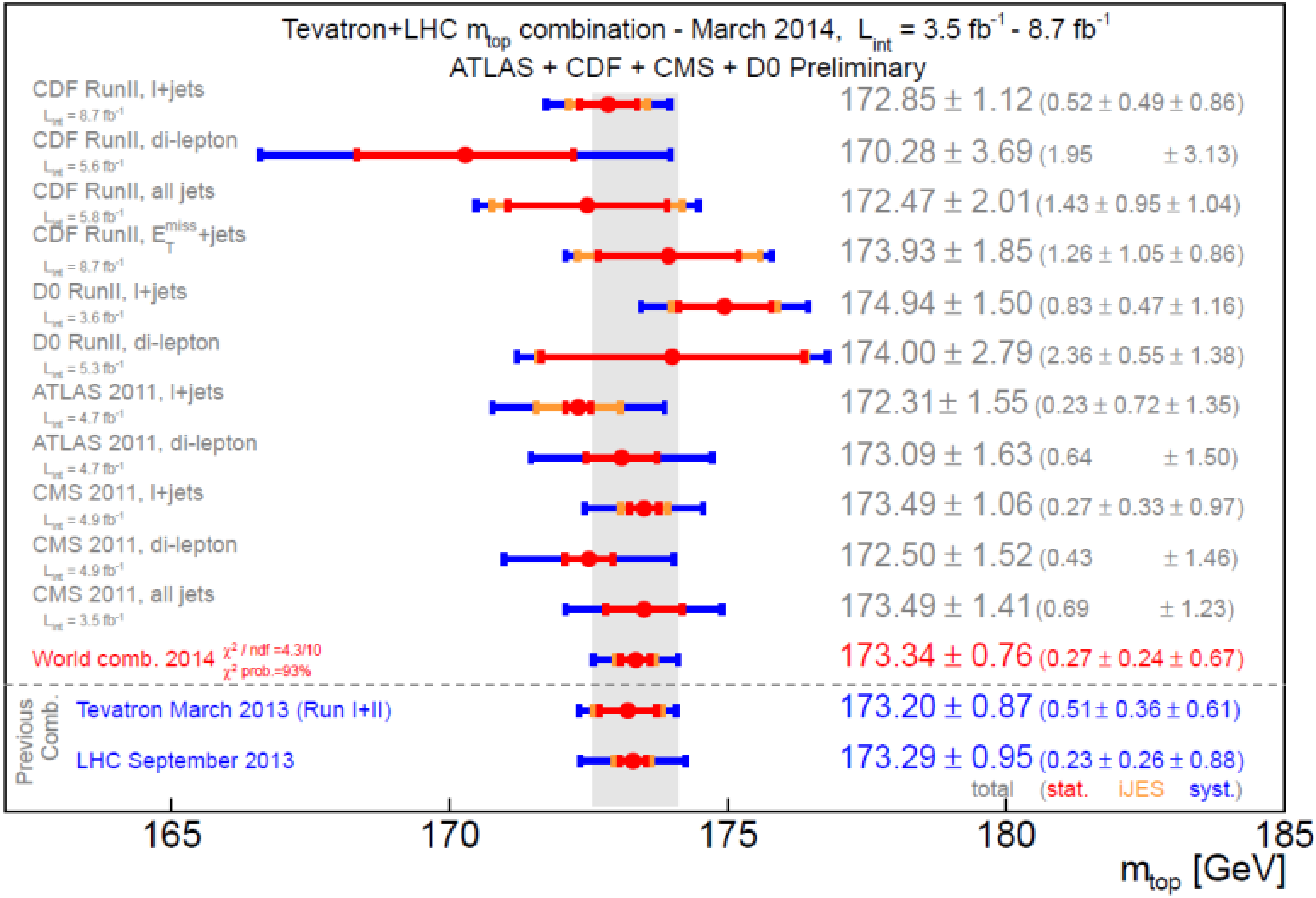


with/without ΔR cut

- Submitted paper in February
  - Main result obtain with $\Delta R<0.3$, 5.1 sigma significance
  - Analysis without cut performed as a cross-check
- However $\Delta R<0.3$ cut modifies the mass spectrum
  - Hint that some backgrounds (may be $B_c^\pm \rightarrow B_s\ \pi^0\pi^\pm$ (not in simulation)) are removed by this cut.
  - This was motivation to keep this cut
  - We believe we control the change in mass spectrum for signal due to this cut
  - PRL feedback
    - Keep the analysis as it is, but use significance as obtained without cone cut
    - 5.1 sigma $\rightarrow$ 3.9 sigma
- Published version: "Evidence of a new state"
  - Phys. Rev. Lett. 117, 022003 (2016)



World combination March 2014



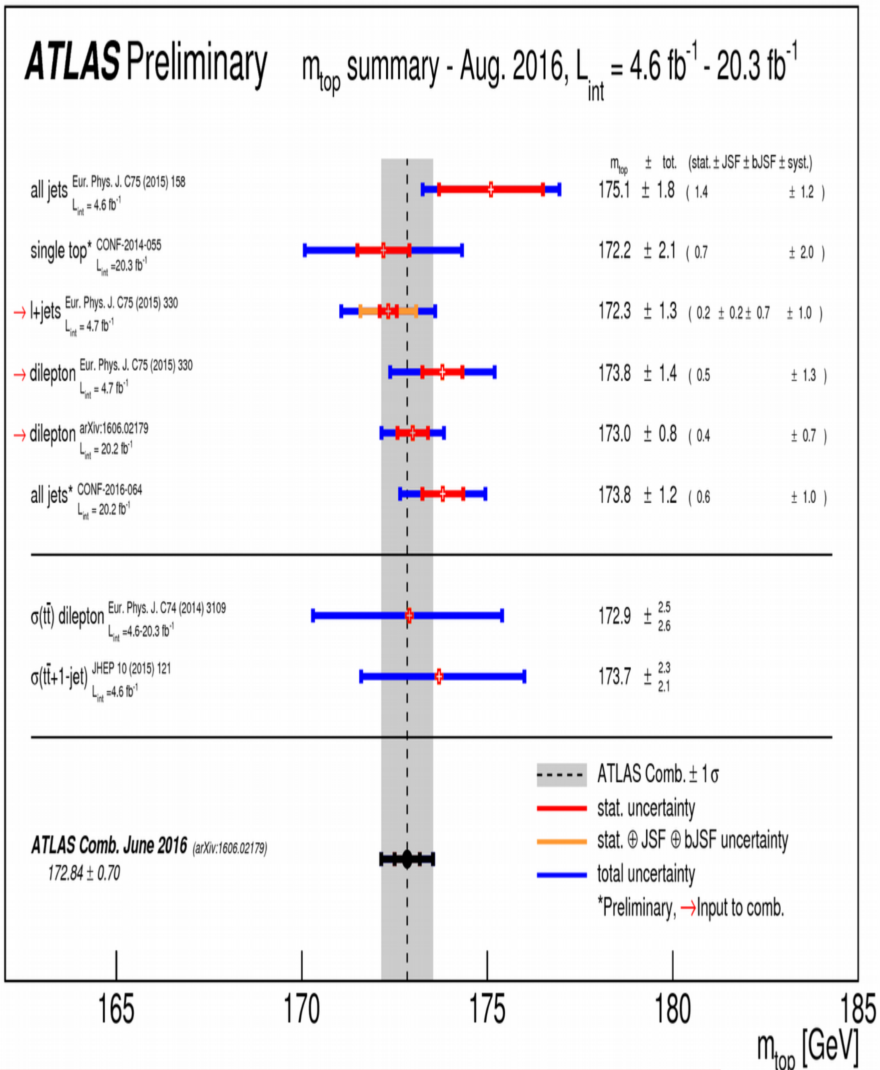
m_t = 173.34 ± 0.76 (total) GeV

arXiv:1403.4427

$\delta m_t / m_t = 0.43\%$

LHC (direct) measurements

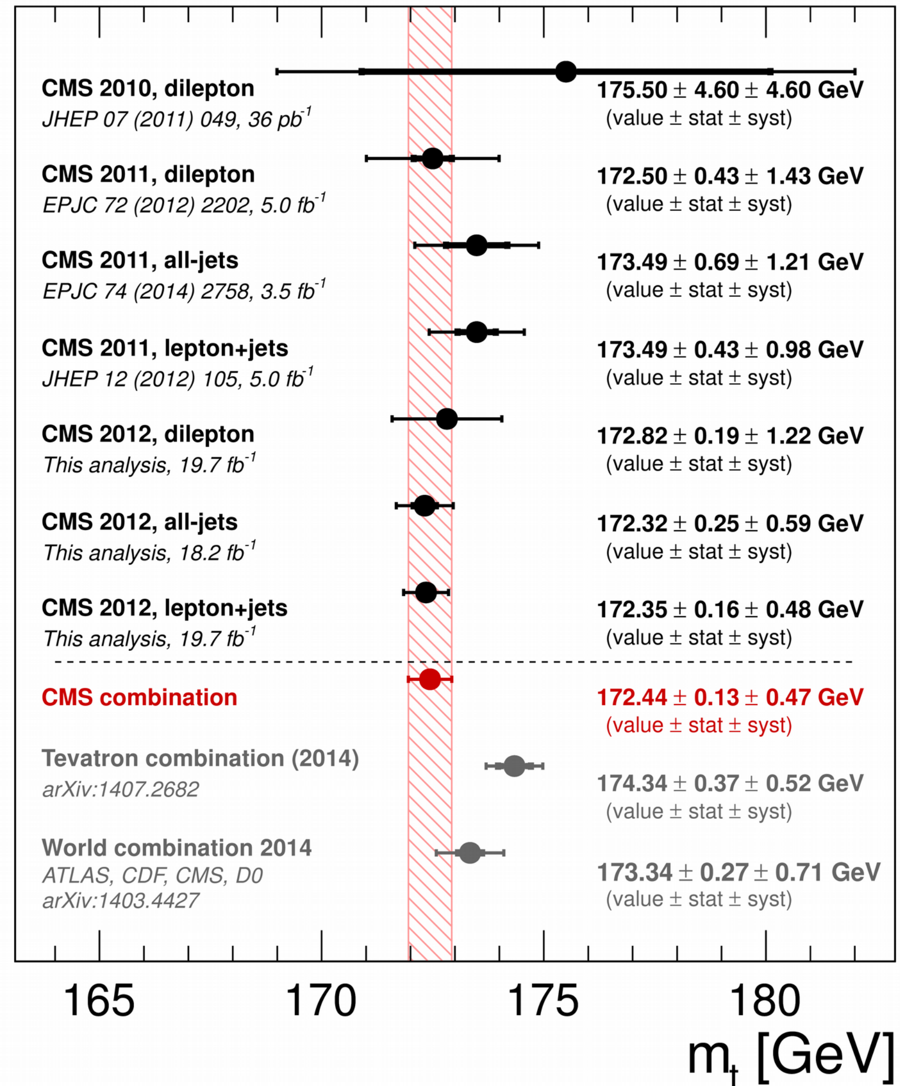
August 2016



m_t = 172.84 ± 0.70 (total) GeV

$\delta m_t/m_t = 0.40\%$

September 2015

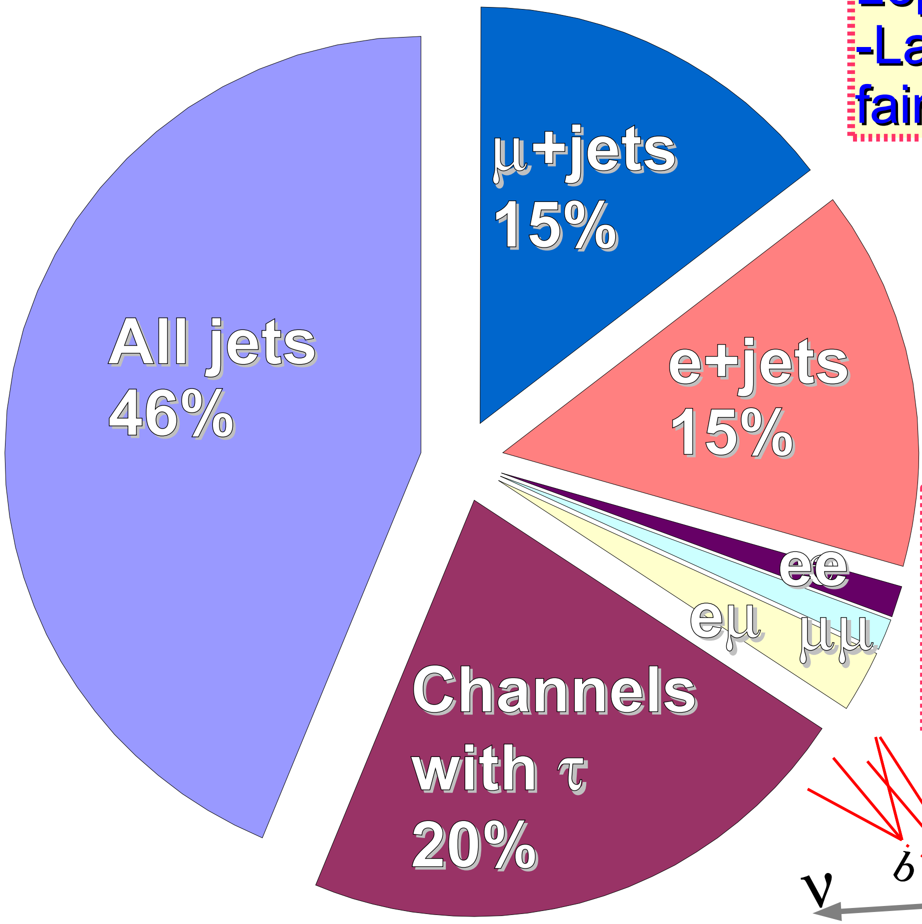


m_t = 172.35 ± 0.51 (total) GeV

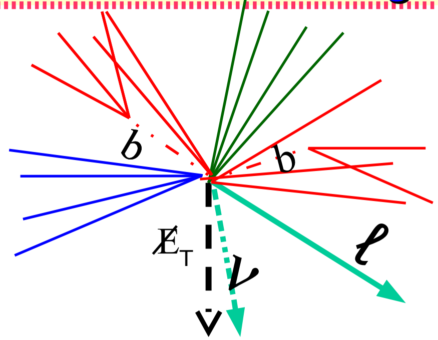
$\delta m_t/m_t = 0.29\%$

Top pair production signature

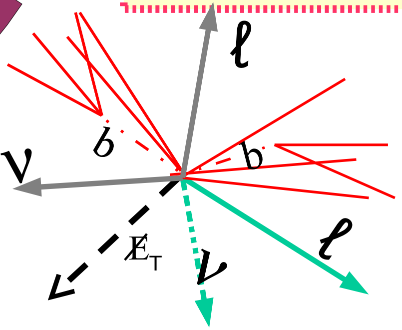
- Top decays into Wb (99.82%). Then W→ eν or μν or τν or jets.
  - Decay products with high momenta, large angular separation
  - Expect to reconstruct energetic objects: e, μ, jets, $E_{T\ miss}$
  - Tagging of b-quark jets to improve purity



Lepton+jets channels:
-Large yield but
fair amount of background



Dileptons channels:
- Pure, but low yield (4.5%).
- Kinematic underconstrained
because of 2 neutrinos



D0 top mass combination

- Run I and Run II measurements in l+jets and dilepton channels.

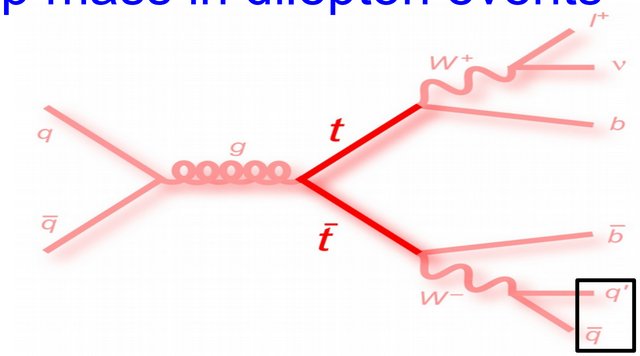
m_t = 174.95 ± 0.40(stat) ± 0.64 (syst) GeV

	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

	D0 Run I		D0 Run II	
	$\ell+$jets	$\ell\ell'$	$\ell+$jets	$\ell\ell'$
$\int \mathcal{L}\, dt$	0.1	0.1	9.7	9.7
m_t	180.10	168.40	174.98	173.50
In situ light-jet calibration	n/a	n/a	0.41	0.47
Response to b, q, and g jets	n/e	n/e	0.16	0.28
Model for b jets	0.71	0.71	0.09	0.13
Light-jet response	2.53	1.12	0.21	0.31
Out-of-cone correction	2.00	2.00	n/a	n/a
Offset	1.30	1.30	n/a	n/a
Jet modeling	n/e	n/e	0.07	0.14
Multiple interaction model	n/e	n/e	0.06	0.07
b tag modeling	n/e	n/e	0.10	0.22
Lepton modeling	n/e	n/e	0.01	0.08
Signal modeling	1.10	1.80	0.35	0.43
Background from theory	1.00	1.10	0.06	0.05
Background based on data	n/e	n/e	0.09	0.06
Calibration method	0.58	1.14	0.07	0.14
Systematic uncertainty	3.89	3.63	0.63	0.84
Statistical uncertainty	3.60	12.30	0.41	1.31
Total uncertainty	5.30	12.83	0.76	1.56

Optimization of systematic uncertainties

- A dominant uncertainty due to the scale of the jet energies: JES
  - JES calibrated in γ+jet events has ~ 2% uncertainty
  - A 2% shift on JES yields ~1% shift on the top mass in dilepton events



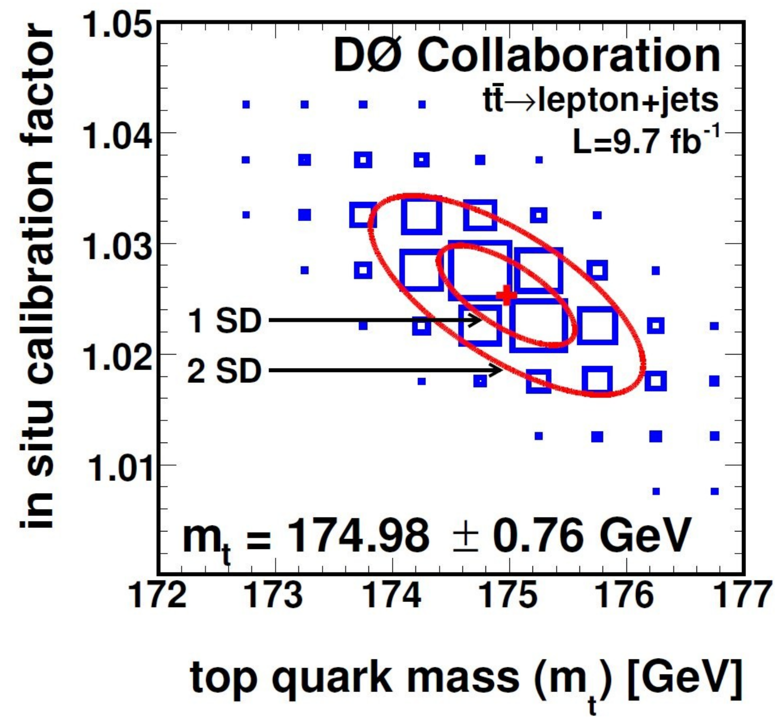
M ~ 80 GeV

- Simultaneous measurement of top mass and JES scale factor kJES and in ℓ+jets channel
  - JES constrained in-situ using dijet mass from W → qq' decay

m_t= 174.98 ± 0.76 GeV
kJES= 1.025 ± 0.005

$\delta m_t/m_t = 0.43\%$

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



- kJES factor propagated to the dilepton channel
- Reduce by ~ 3 the JES uncertainty