Latest results from the Tevatron

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For the CDF and D0 collaborations

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- The Tevatron gave us a unique dataset: proton-antiproton collisions at 1.96 TeV
- Two experiments, CDF and D0, recorded 10 fb^{-1} each
- Highlights of the entire Tevatron program:
  - discovery of the top quark
  - observation of B_s oscillations
  - observation of single top
  - discovery of huge number of b hadrons
  - evidence for the Higgs
  - very precise W boson mass
- Finished operations in Sept 2011
- Still analyzing data almost five years later

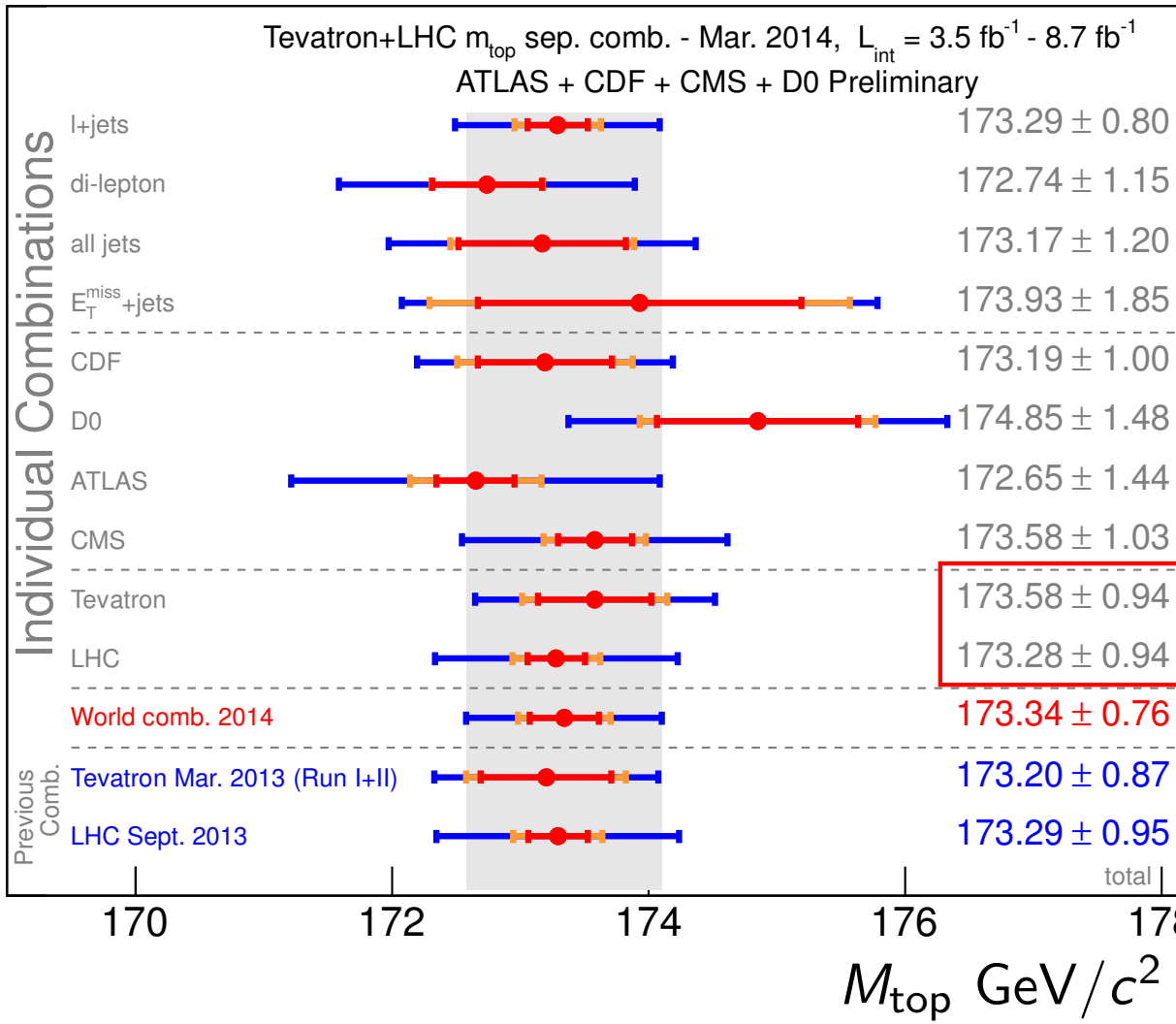
Since the last Users Meeting, 28 Tevatron analyses have been published, submitted, or released for the first time!

- Almost 400 physicists from 54 institutions in 13 countries
- Spokespersons Giorgio Bellettini and David Toback
- Recorded first collisions October 1985
- 544 PhD theses
- 697 publications
- Expect to surpass 700 publications by end of year

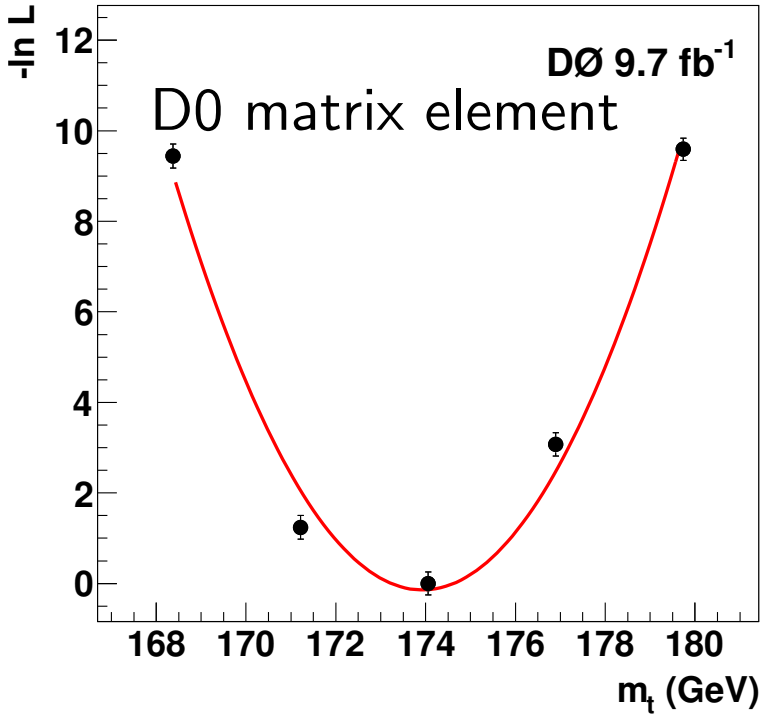
- Almost 400 physicists from 66 institutions in 19 countries
- Spokespersons Dmitri Denisov and Paul Grannis
- Recorded first collisions May 1992
- 478 PhD theses
- 489 publications
- Expect to surpass 500 publications by end of year

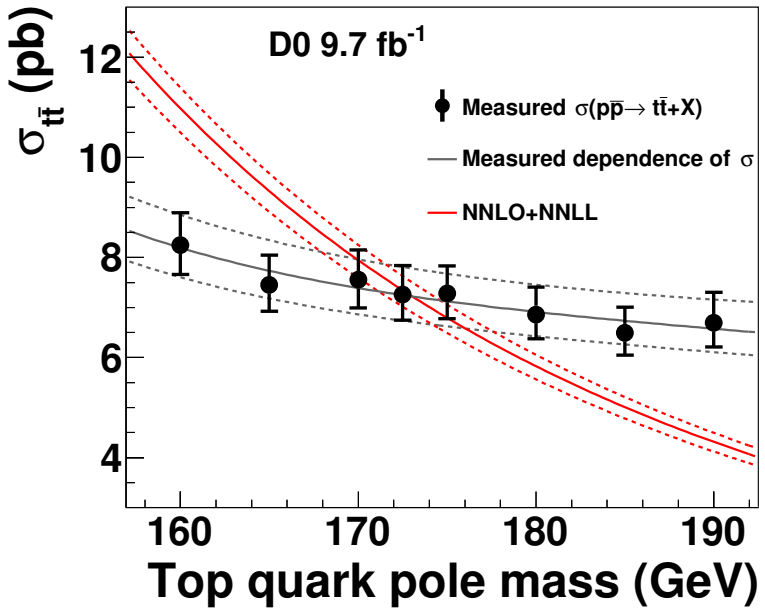
- What good can Tevatron data do today? Isn't the LHC all we need?
- No. The Tevatron data has some unique features
  - Lower instantaneous luminosity – reduced backgrounds for certain processes
  - Proton-antiproton collisions – anti-symmetric initial state and enhanced cross sections
  - Lower energy – different parton distributions, different region of QCD phase space
- So, using Tevatron data, we can
  - Perform high-precision measurements of standard model parameters
  - Measure forward-backward asymmetries
  - Constrain QCD and PDFs in unique phase space
  - We can even still find new particles / states

- Top quark discovered at the Tevatron in 1995
- Tevatron data still used for high-precision measurements of its properties – competitive with LHC
- LHC measurements in most sensitive channels limited by systematic uncertainties
- Direct measurements afflicted by definition difficulties: "PYTHIA mass", about 1 GeV/c^2 effect

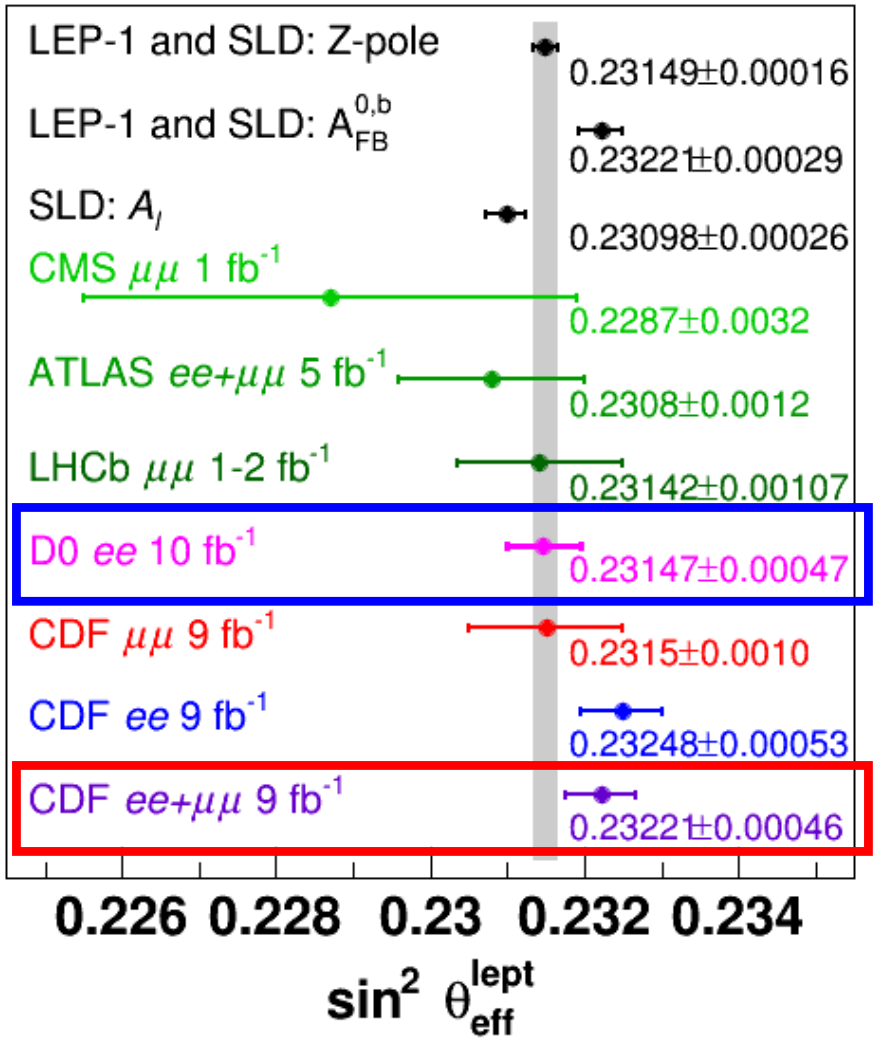


- D0 has had great success in controlling systematics
- 2015 D0 measurement in lepton+jets channel 174.98 ± 0.76 GeV c^{-2}
- Recent measurements in the dilepton final state from CDF and D0:
  - CDF neutrino ϕ weighting method: 171.46 ± 3.15 GeV c^{-2}
  - D0 matrix element method: 173.93 ± 1.84 GeV c^{-2}
- D0 also extracts top quark pole mass from cross section, avoiding theoretical issues
  - $172.8^{+3.4}_{-3.6}$ GeV c^{-2}
- Important piece of testing standard model consistency



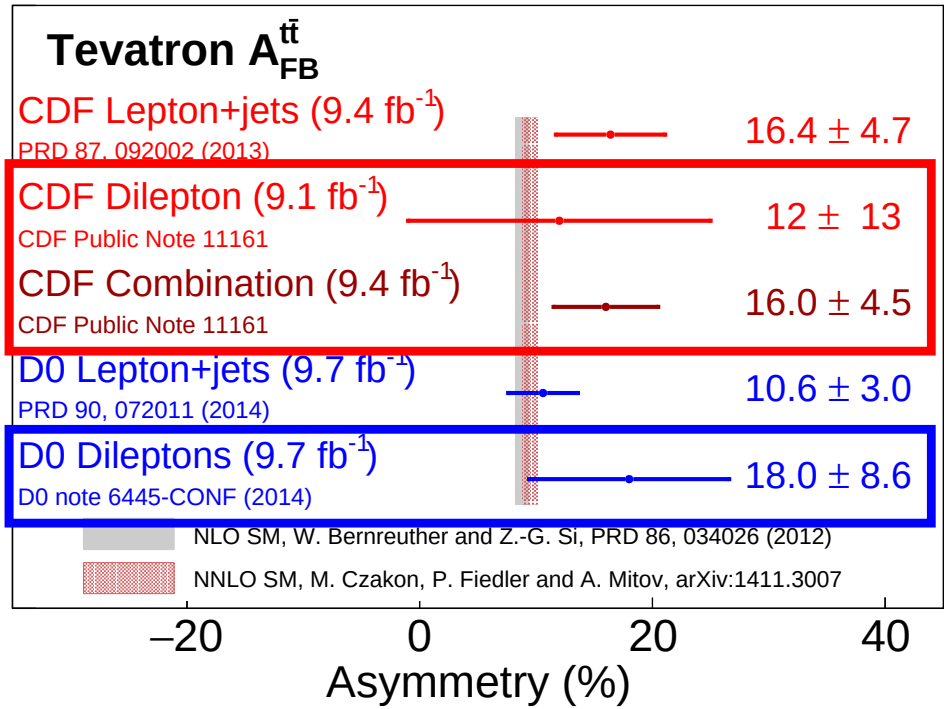


- D0 and CDF both measure weak mixing angle via forward-backward asymmetry of lepton pairs from Z/γ^* decay
- Made possible by $p\bar{p}$ initial state
- Most sensitive results from a hadron collider, and competitive with lepton colliders!
- Allow indirect measurements of W mass, precision 24 MeV/c^2
- Compare to precision of direct measurement, 15 MeV/c^2
- Also used to constrain PDFs, will aid direct W mass measurement



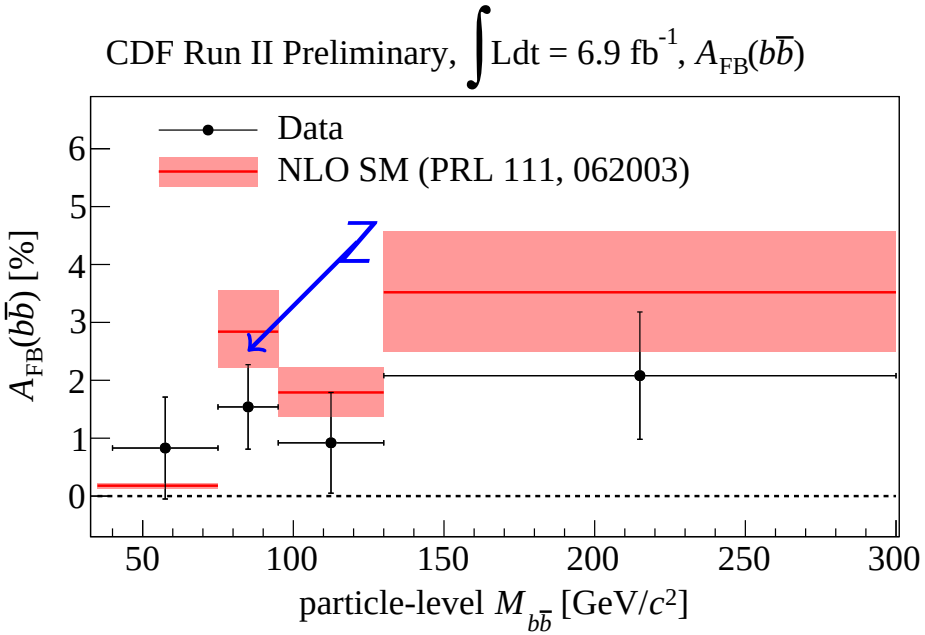
Definition:

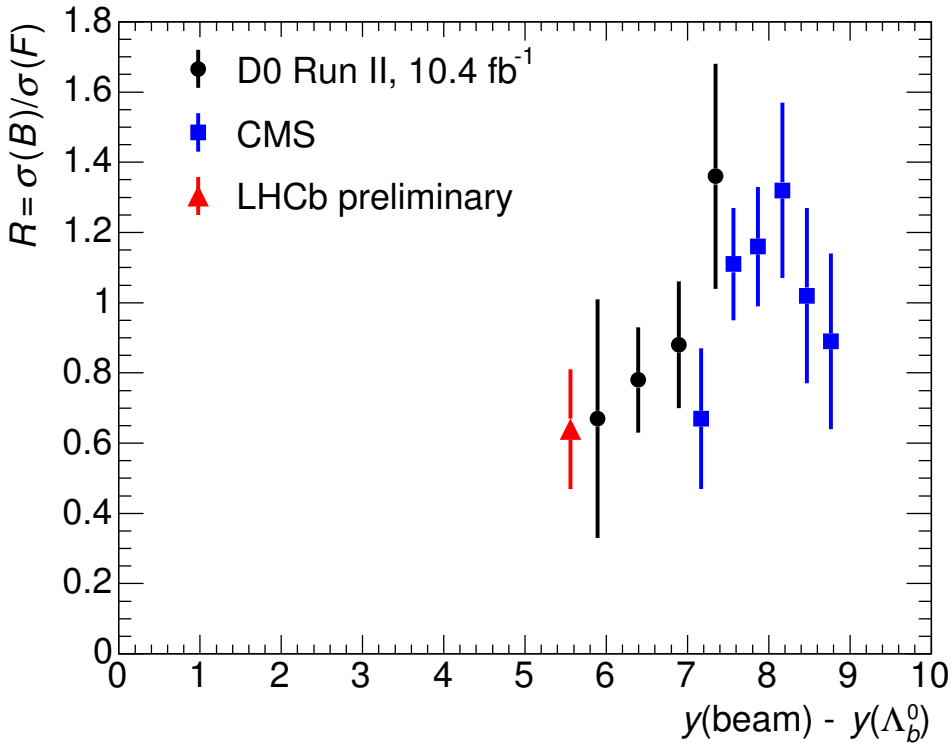
$$A_{FB} = \frac{N(\text{forward}) - N(\text{backward})}{N(\text{forward}) + N(\text{backward})}$$



- Wrapping up the top forward-backward asymmetry measurements
- Can only be measured at the Tevatron – LHC measures a related quantity A_C
- AFB in dilepton channel at CDF and D0 both recently published
- Top AFB at Tevatron used to show tension with predictions
- Many exotic explanations were proposed
- Standard model calculations improved (to NNLO+) and experiments got more data
- Tension now resolved

- CDF measures AFB of bottom quark pairs
- Complements top AFB
- Agreement with SM
- See AFB caused by $Z \to b\bar{b}$

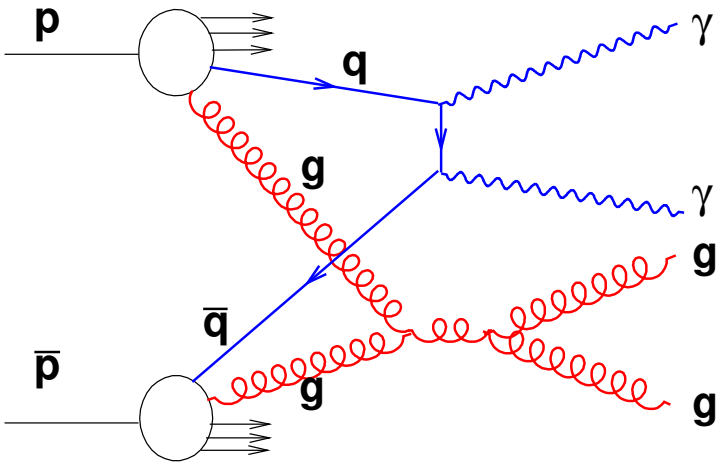


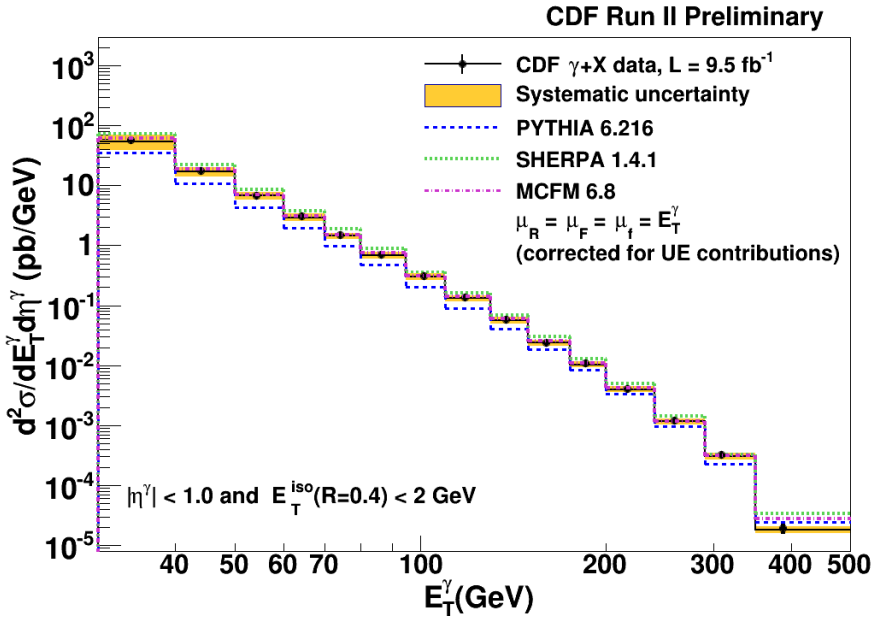


- D0 measures AFB of Λ_b, Ξ, and Ω baryons
- Ξ and Ω consistent with zero
- Λ_b AFB demonstrates "string drag" effect (Rosner)
- Universal function of rapidity loss independent of collider, energy, etc.

Variety of measurements allow us to constrain parton content of the proton at different scales

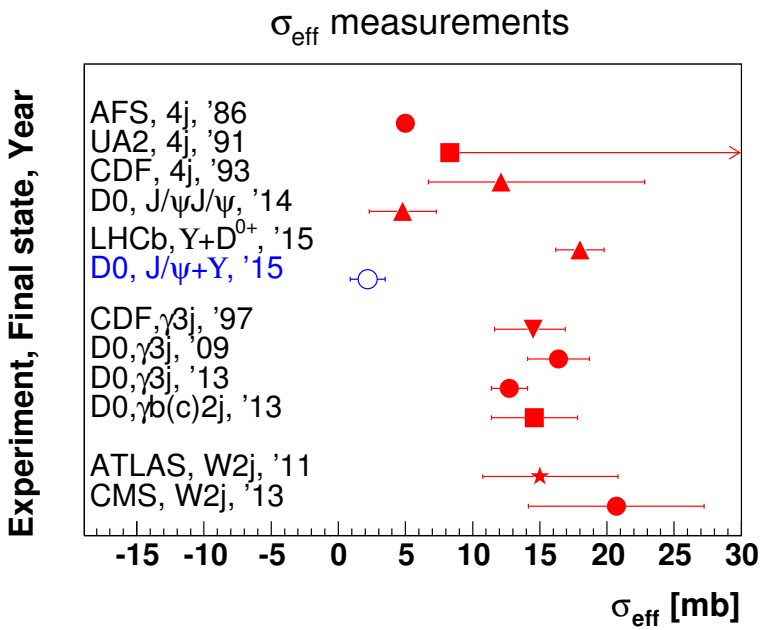
- CDF measures cross section for prompt, isolated photons
- Dominated by $q\bar{q}$ and gq initial states
- Good agreement with SHERPA and MCFM





- D0 measures cross section for diphoton+dijet events
- Sensitive to double-parton interaction and to gg and $q\bar{q}$ initial states
- Effective cross section shows "volume" occupied by quarks and gluons in the proton

- D0 sees simultaneous J/ψ with Υ
- Dominated by gg initial state and double-parton interactions
- Measure effective cross section
- Smaller than σ_{eff} in diphoton+dijet, indicating gluons occupy smaller "volume" in proton than quarks do

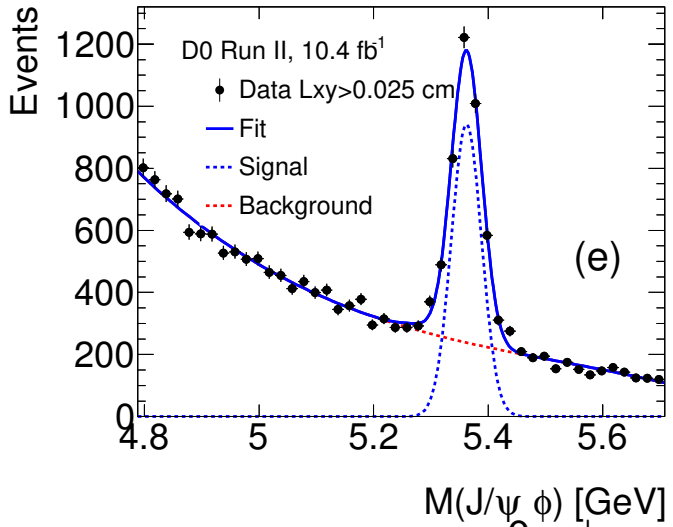


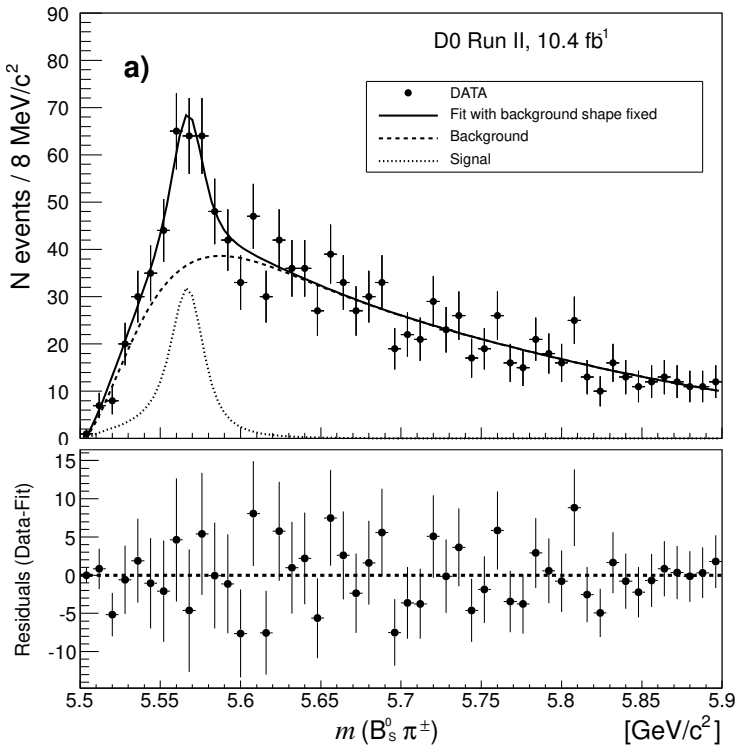
Production process	Fraction of $W(\to \ell\nu) + D^*$ signal
$s(d) + g \to W + c$	$14 \pm 6\%$
$q + \bar{q}' \to W + g(\to c\bar{c})$	$73 \pm 8\%$
$q + \bar{q}' \to W + g(\to b\bar{b})$	$13 \pm 5\%$

- CDF $W/Z + D^*$
- Sensitive to CKM matrix element V_{cs}
- Constrains strange quark PDF
- Refine hadronization models

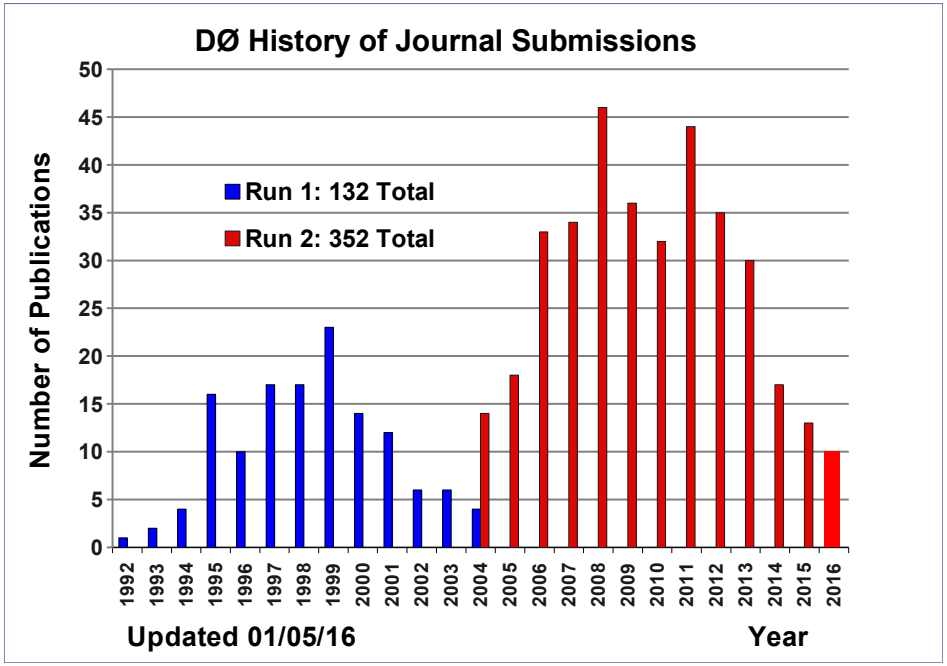
$X(4140)$ and $X(5568)$

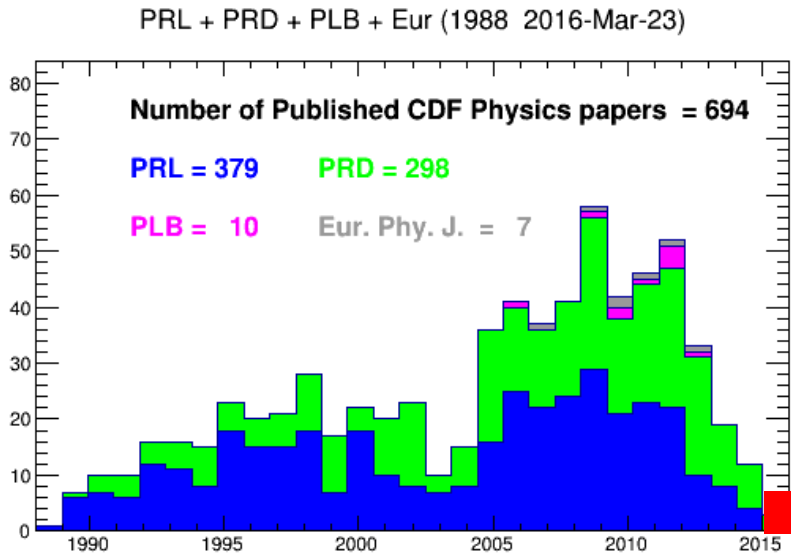
- D0 measures $X(4140)$ state, first observed by CDF in 2009
- Prompt vs non-prompt ratio measured for first time, $\sim 40\,\%$ non-prompt
- LHCb initially did not see this state, but now sees it (as of 2 weeks ago)





- D0 observes novel resonance in $B_s^0\pi^\pm$ final state
- Tetraquark candidate – first with four different quark flavors!
- $5567.8 \pm 2.9(\text{stat.})^{+0.9}_{-1.9}(\text{syst.})$ MeV c^{-2}
- Global significance 5.1σ
- arXiv:1602.07588, accepted by PRL
- LHCb reports not seeing $X(5568)$ – looking forward to other experiments' searches





- With 28 papers in last year, Tevatron still contributing great science
- In the next year or two, look forward to:
  - Tevatron and World combinations of top mass
  - Improvements to top pole mass
  - Direct W boson mass with entire data set
  - Final weak mixing angle and indirect W boson mass
  - Tetraquark $X(5568)$ studies
- Many papers had to be left out due to time – full list in backup slides
- Thanks to Accelerator Division, the spokespersons, the collaborations, and the Users Meeting organizers for making this talk possible!

- D0 dilepton top mass (matrix element) arXiv:1606.02814
- D0 top cross section and pole mass arXiv:1605.06168
- D0 B_s^0 lifetime arXiv:1603.01302
- D0 tetraquark arXiv:1602.07588
- D0 top spin correlation PLB 757 199
- D0 Ξ and Ω AFB PRD 93 112001
- D0 double parton PRD 93 052008
- D0 J/ψ Υ PRL 116 082002
- D0 Λ AFB PRD 93 032002
- D0 dilepton top mass (ν weighting) PLB 752 18
- D0 X(4140) PRL 115 232001
- D0 CPT and Lorentz violation in B_s^0 PRL 115 161601
- D0 dilepton top AFB and polarization PRD 92 052007
- D0 weak mixing angle PRL 115 041801

- CDF inclusive photon XS CDF note 11180
- CDF electroweak mixing arXiv:1605.02719
- CDF W+jets CDF note 11167
- CDF dilepton top AFB PRD 93 112005
- CDF bottom AFB low mass PRD 93 112003
- CDF Higgs in triphoton events arXiv:1601.04001
- CDF $W' \to tb$ PRL 115 061801
- CDF $W/Z + D^*$ PRD 93 052012
- CDF single top in MET+jets PRD 93 032011
- CDF bottom AFB high mass PRD 92 032006
- CDF WW+jets PRD 91 111101
- CDF B_c^+ relative cross section PRD 93 052001
- CDF dilepton top mass PRD 92 032003
- Tevatron combined single top PRL 115 152003