Selected New Heavy Flavor, QCD and Electroweak Results from the Tevatron

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On behalf of DØ and CDF
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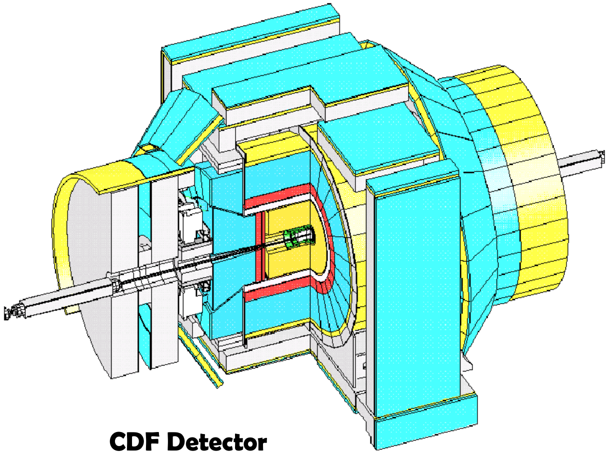
Overview

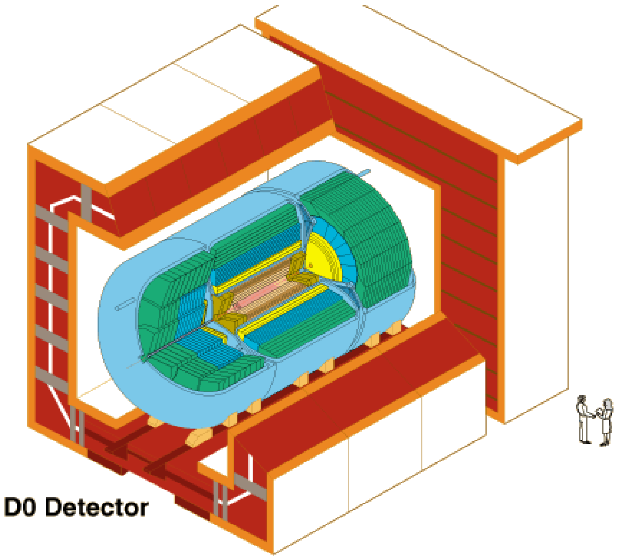
- Wide range of topics today, including:
  - CP violation parameters in $B^{\pm}\rightarrow J/\psi K^{\pm}$ and $B^{\pm}\rightarrow J/\psi\pi^{\pm}$
  - D^0-$\overline{D}^0$ mixing
  - Photon plus heavy flavor production
  - Anomalous quartic gauge coupling search
- Caveat: these are speaker's choice of topics, are many other interesting analyses not covered

Tevatron and Experiments

- Tevatron is 2π km with 1.96 TeV p-$\overline{\text{p}}$ collisions
  - Operation ended September 2011
- DØ and CDF analyses use full data set, ranging from 8.7 to 10.4 fb^{-1} depending on data quality requirements
- Both have inner tracker, magnet, calorimeter and muon system
  - DØ also regularly reverses magnet polarity
- p-$\overline{\text{p}}$ collisions mean CP symmetric initial states, which benefits certain analyses
- Different center of mass energy complements other experiments



CDF Detector



D0 Detector

Direct CP Violation Parameters in $B^\pm \to J/\psi K^\pm$ and $B^\pm \to J/\psi \pi^\pm$

- Clean test of CP violation
  - Expect ~0.3% asymmetry from penguin loops in $B^\pm \to J/\psi K^\pm$, up to a few percent allowed for $B^\pm \to J/\psi \pi^\pm$ in SM*

$$A^{J/\psi K} = \frac{\Gamma\left(B^- \to J/\psi K^-\right) - \Gamma\left(B^+ \to J/\psi K^+\right)}{\Gamma\left(B^- \to J/\psi K^-\right) + \Gamma\left(B^+ \to J/\psi K^+\right)}$$

$$A^{J/\psi \pi} = \frac{\Gamma\left(B^- \to J/\psi \pi^-\right) - \Gamma\left(B^+ \to J/\psi \pi^+\right)}{\Gamma\left(B^- \to J/\psi \pi^-\right) + \Gamma\left(B^+ \to J/\psi \pi^+\right)}$$

- Measure raw asymmetry, then correct for reconstruction asymmetry of K^+ K^- in the detector
  - Kaon asymmetry because K^- can interact with detector to form hyperons, no equivalent for K^+
  - Because of DØ detector magnet polarity reversals and symmetric detector, no track or pion asymmetry corrections are needed

* W.S. Hou, M. Nagashima, A. Soddu, arXiv:hep-ph/0605080 (2006); I. Dunietz, J.M. Soares, Phys. Rev. D 49, 5904 (1994); W. S. Hou, arXiv:hep-ph/9905541 (1999)

Direct CP Violation Parameters in $B^\pm \to J/\psi K^\pm$ and $B^\pm \to J/\psi \pi^\pm$

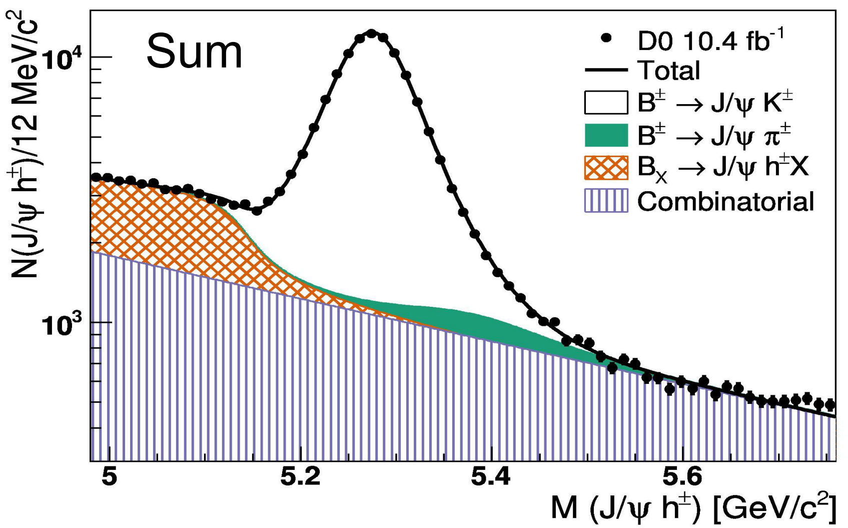
- Maximum likelihood fit used to extract raw $A^{J/\psi K}$ asymmetry
- Kaon asymmetry from fit to $M(K\pi)$ in $K^{*0}(\overline{K}^{*0}) \to K^+\pi^-(K^-\pi^+)$

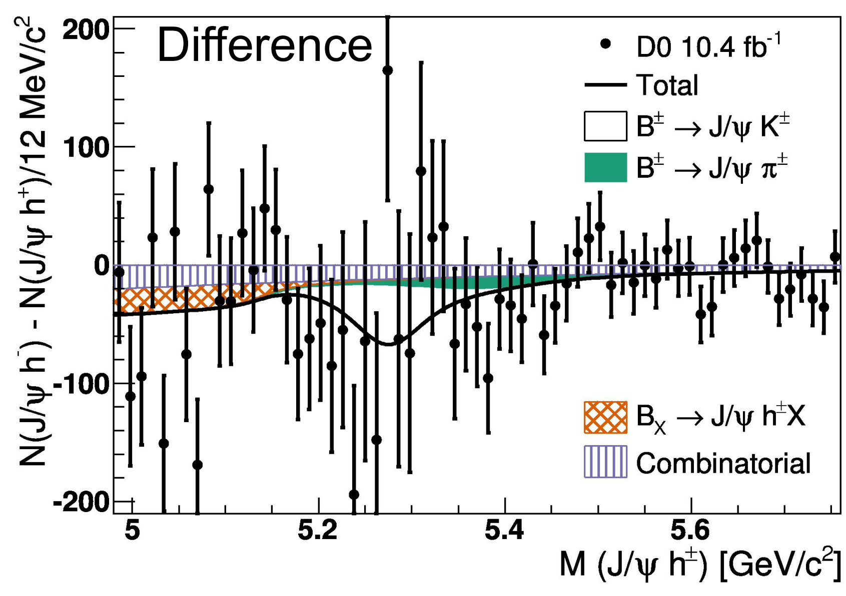
$$A_K = [1.046 \pm 0.043\,(\mathrm{syst})]\,\%$$

- Dominant uncertainties statistical and Kaon asymmetry estimate

$$A^{J/\psi K} = [0.59 \pm 0.36\,(\mathrm{stat}) \pm 0.08\,(\mathrm{syst})]\,\%$$
$$A^{J/\psi \pi} = [-4.2 \pm 4.4\,(\mathrm{stat}) \pm 1.8\,(\mathrm{syst})]\,\%$$

- Results consistent with prediction
- $A^{J/\psi K}$ most precise to date

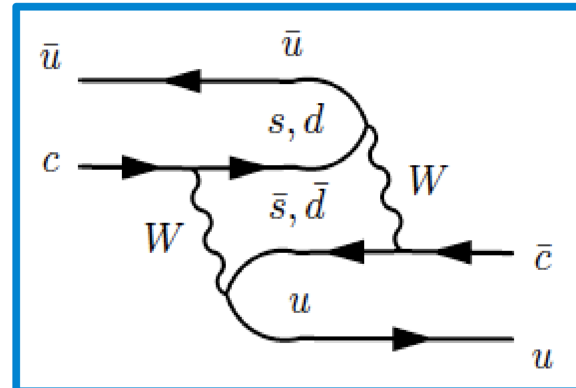


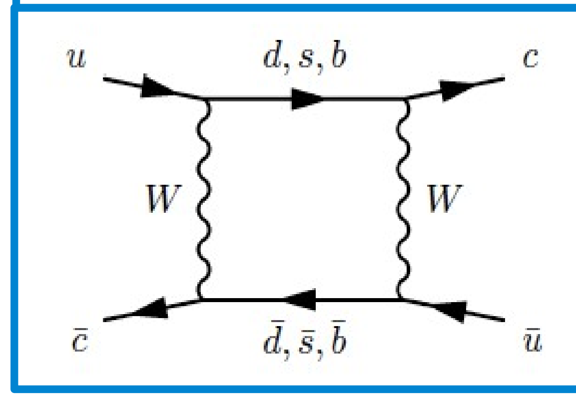


Fermilab-Pub-13-088-E, Accepted by Phys. Rev. Lett.

D^0-$\bar{D}^0$ Mixing

- Mixing slower than for B or K
- Occurs primarily through long range intermediate states but rate has large theoretical uncertainties (top)
- New physics could enhance short range rate, which is suppressed in SM (bottom)





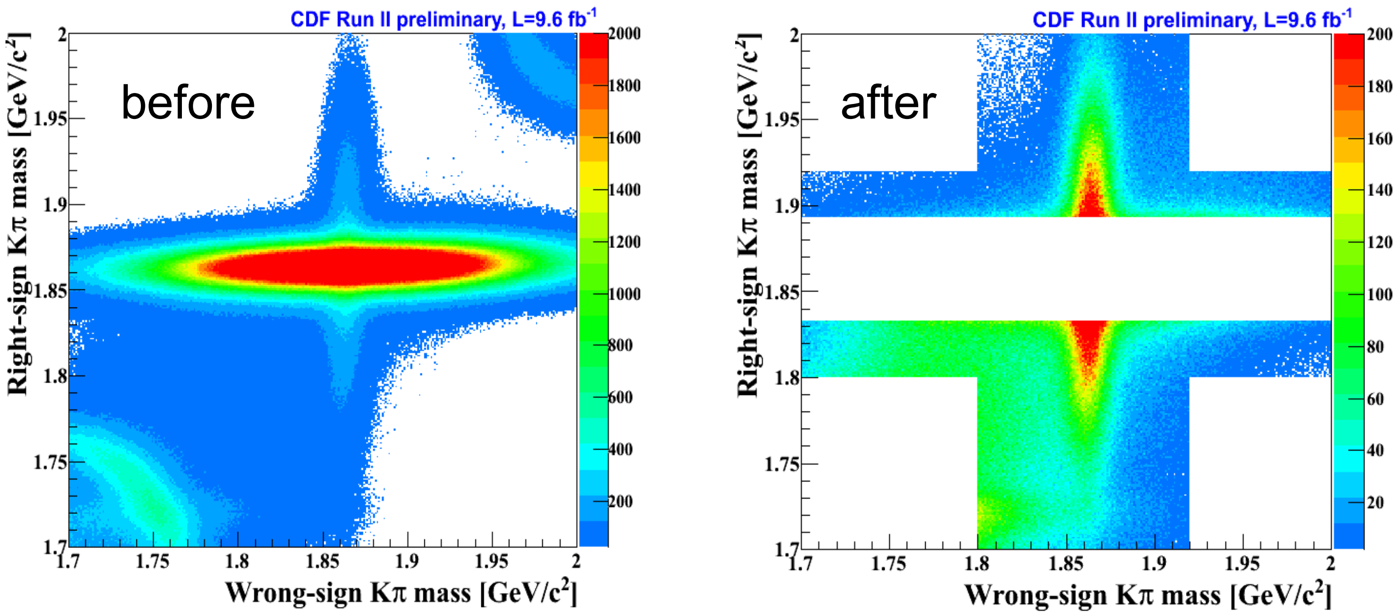
- Study the ratio of the $D^0 \to K^+\pi^-$ (WS) and $D^0 \to K^-\pi^+$ (RS) decay rates, where $D^* \to D^0\pi^+$. If no mixing, $x'=y'=0$

$$R(t/\tau) = R_D + \sqrt{R_D}y'\,(t/\tau) + \frac{x'^2 + y'^2}{4}\,(t/\tau)^2$$

- Using world averages for m_{D0} and τ in $t/\tau = m_{D^0}L_{xy}/(p_T\tau)$

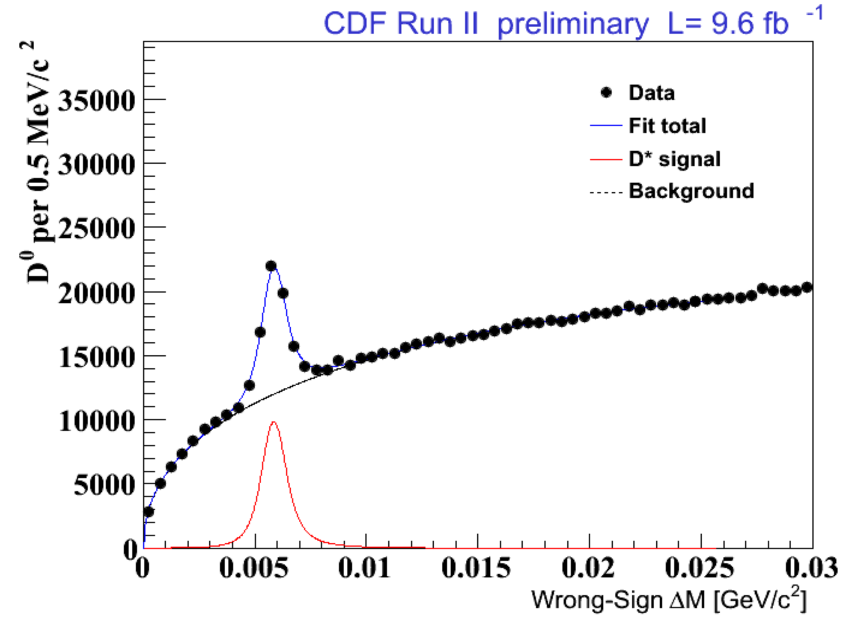
D^0-$\bar{D}^0$ Mixing

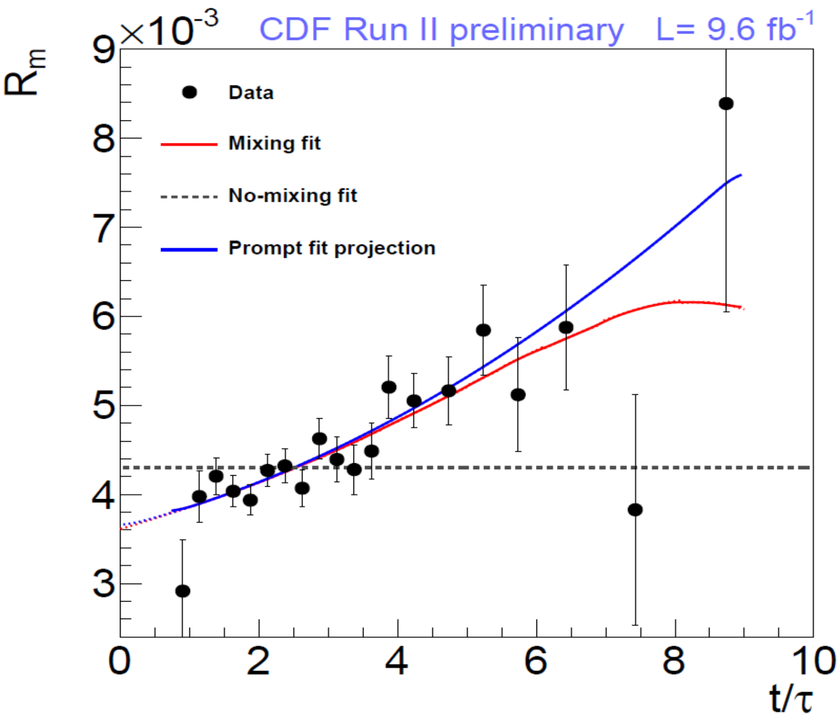
- Same selection applied to both RS and WS decay chains, chosen to optimize WS significance based on expected events and sideband information
  - $M(K\pi)$ selection (20 MeV around D^0 mass peak) strongly reduces background to WS from RW due to D^0 decay track mis-ID
  - Additional selections for particle ID, decay topology



D^0-$\bar{D}^0$ Mixing

- RS and WS separated into *t/τ* bins and $\Delta M = M(K^+\pi^-\pi^+) - M(K^+\pi^-) - M(\pi^+)$ bins
  - $M(K\pi)$ used to find D^0 yield, the ΔM is fit to get D* yield





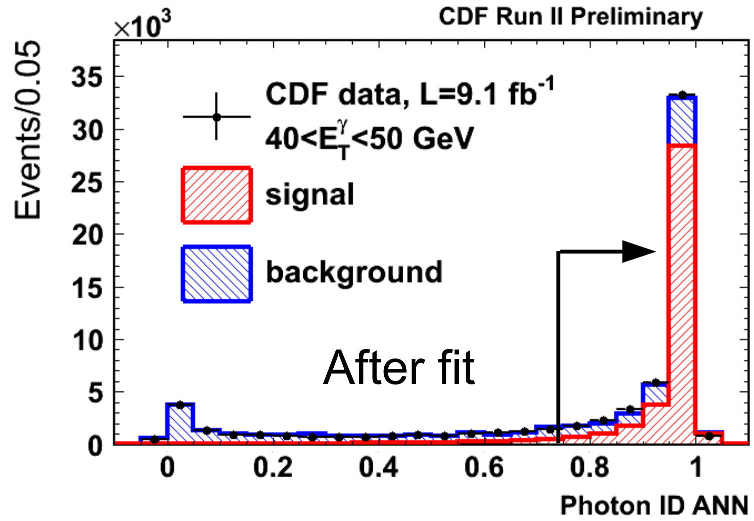
- Measured WS to RS D* decay ratio diverges from no mixing hypothesis
  - *No mixing excluded at 6.1 std. dev.*

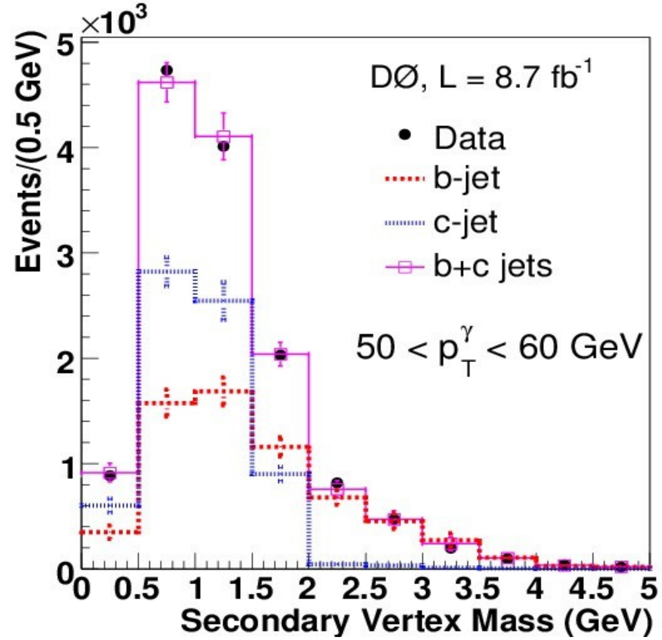
$$y' = (4.3\pm4.3)\times10^{-3} \quad x'^2 = (0.08 \pm 0.18) \times 10^{-3}$$
$$R_D = (3.51\pm0.35)\times10^{-3}$$

CDF Public Note 10990

Photon plus Heavy Flavor

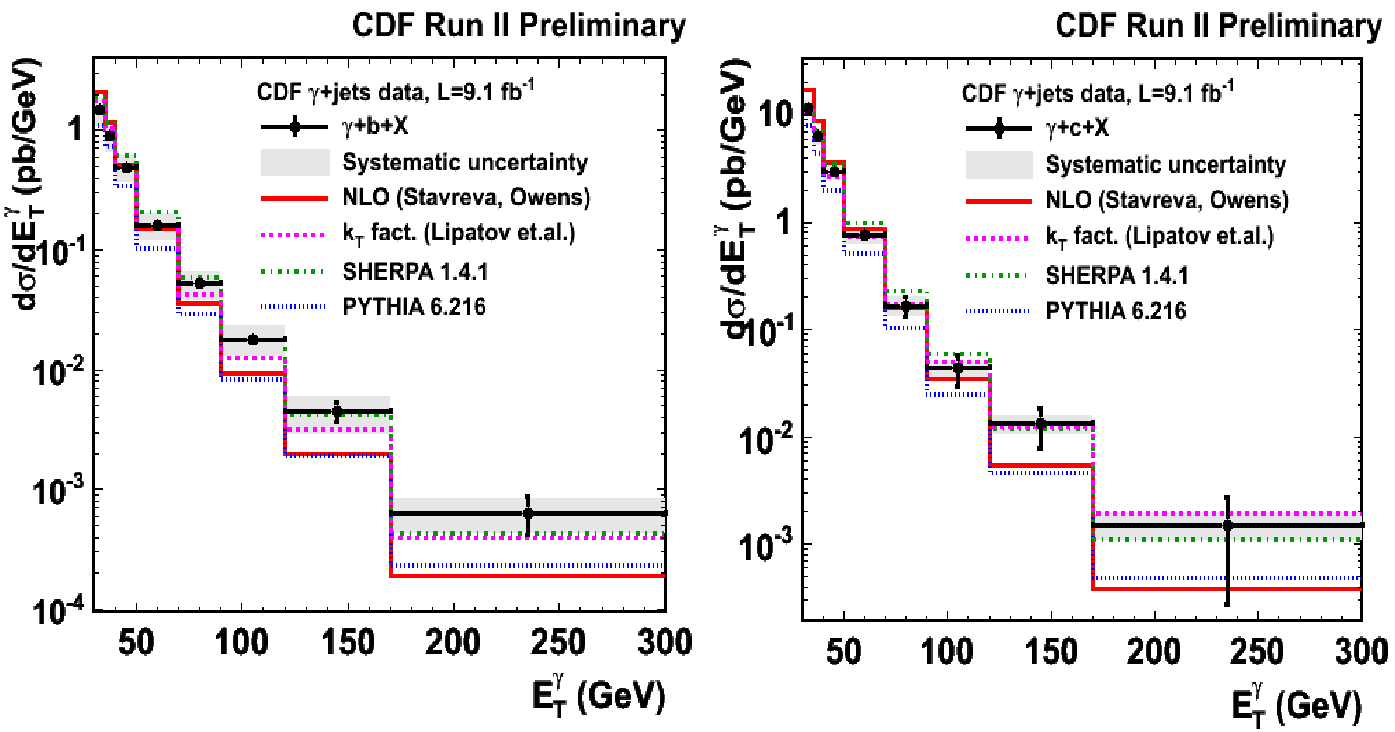
- "Clean" process to study quark PDFs and rate of gluon splitting to quarks
- Compton-like scattering at low γ Et (< ~100GeV), $p\bar{p}$ annihilation with gluon splitting otherwise
- Selections require a central γ, using a NN to help to identify the γ. NN is also used in template fit to determine rate of jets faking γ.
- Secondary vertex mass is used with a template fit to determine b and c quark fractions





Photon plus Heavy Flavor

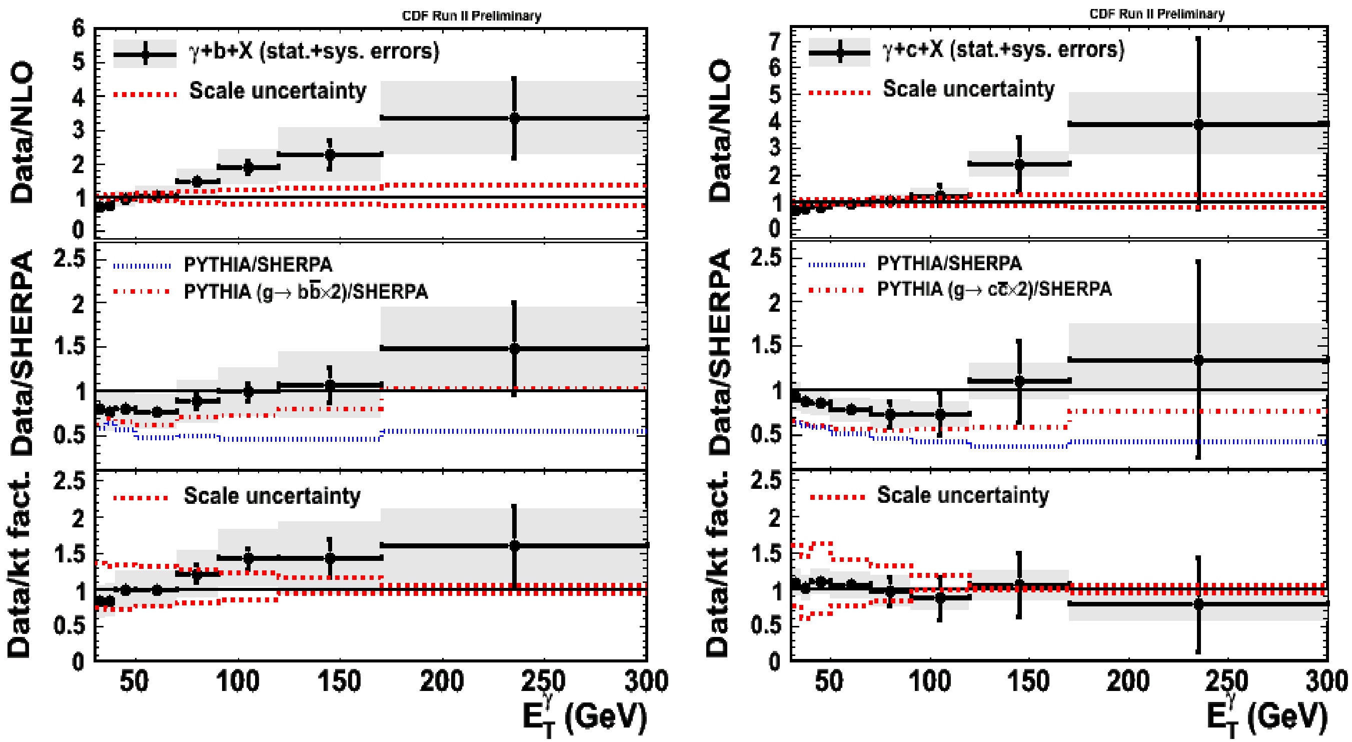
- Sherpa or kT fact. closest to data for γ plus b for high E_T
  - Uncertainties higher for γ plus c but similar preference
- NLO disagrees for E_T > 70 GeV



CDF Public Note 10818

Photon plus Heavy Flavor

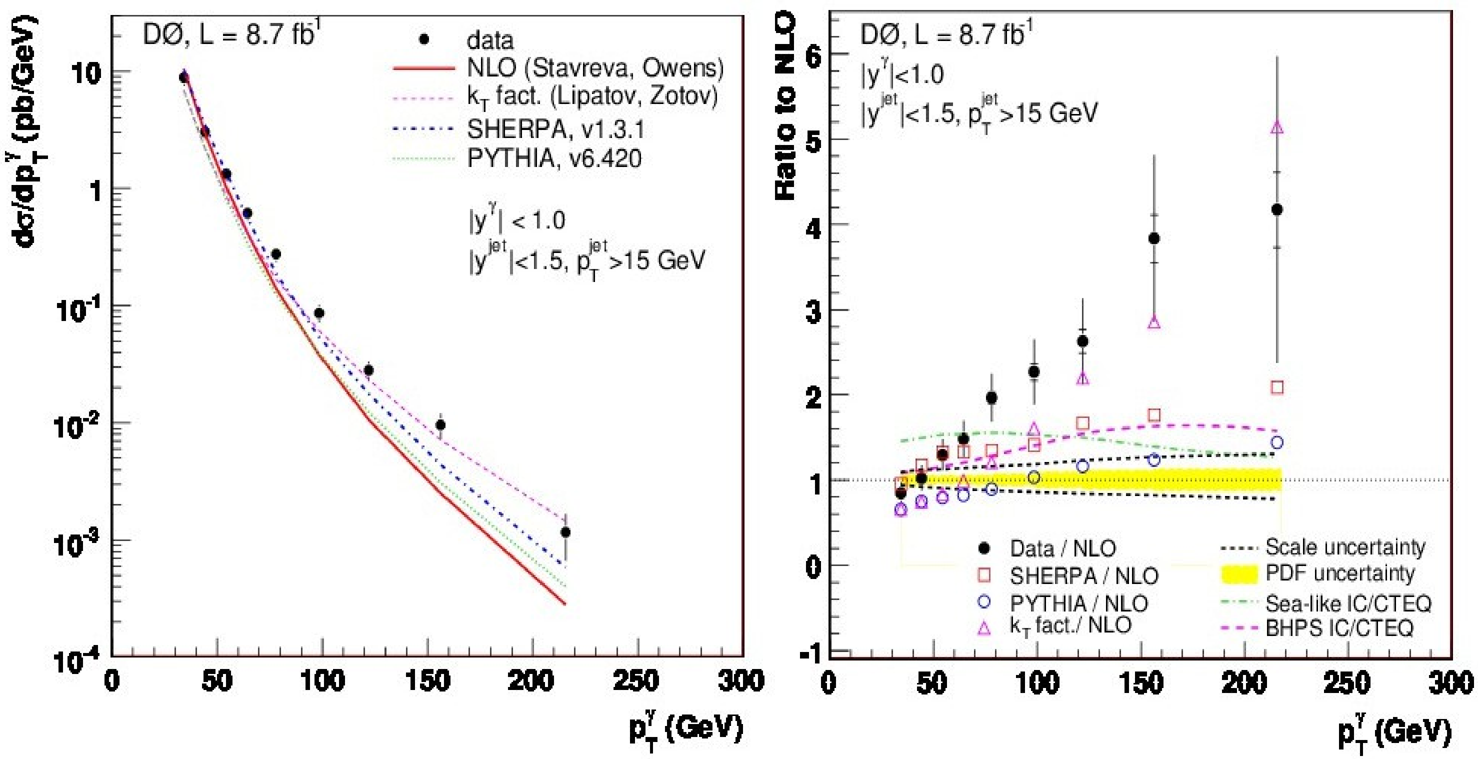
- Sherpa or kT fact. closest to data for γ plus b for high E_T
  - Uncertainties higher for γ plus c but similar preference
- NLO disagrees for E_T > 70 GeV
- Pythia agrees better with x2 gluon splitting to heavy flavor



CDF Public Note 10818

Photon plus Heavy Flavor

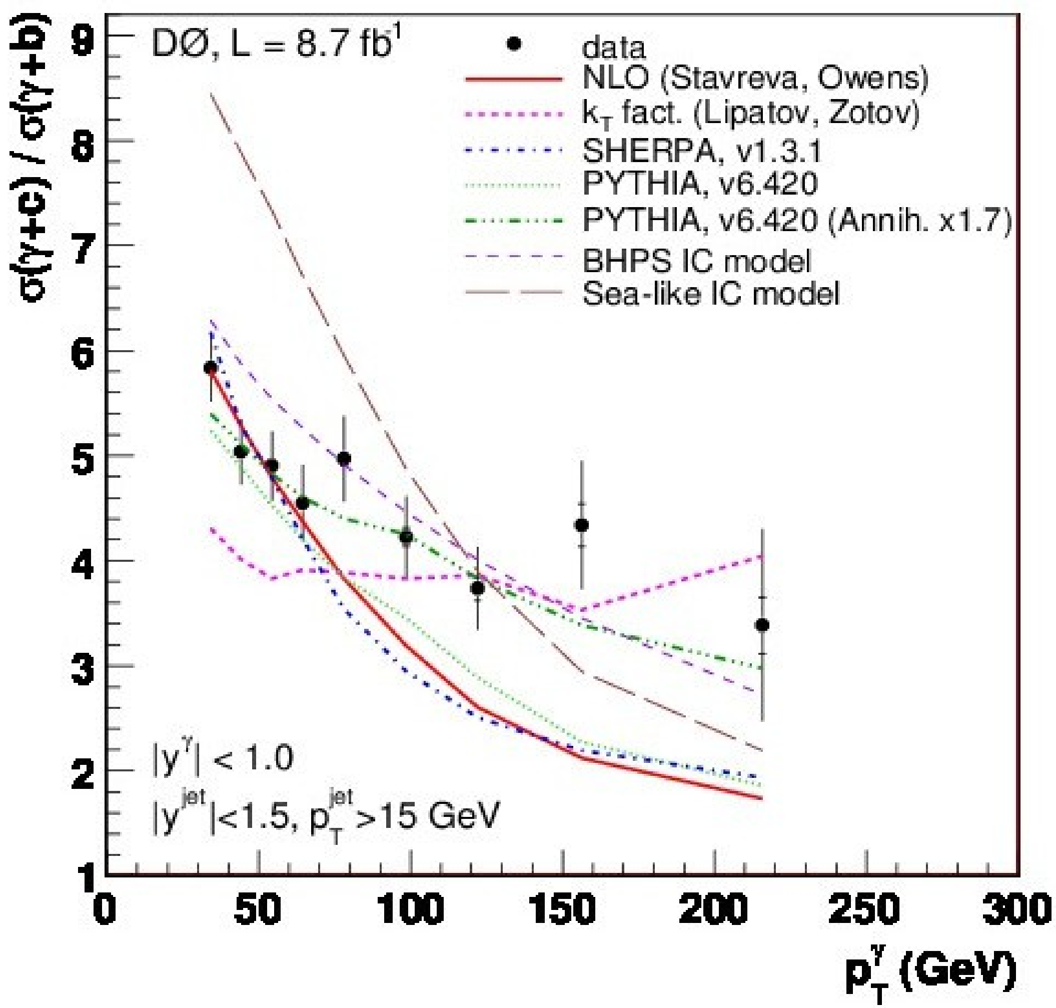
- Also see γ plus c agrees best with k_T fact or sherpa for larger p_T values for > 70 GeV, k_T underestimates for low p_T



Phys. Lett. B 719, 354 (2013)

Photon plus Heavy Flavor

- Also see γ plus c agrees best with k_T fact or sherpa for larger p_T values for > 70 GeV, k_T underestimates for low p_T
- Pythia agrees better with 1.7 enhancement factor for cross-section ratio



Phys. Lett. B 719, 354 (2013)

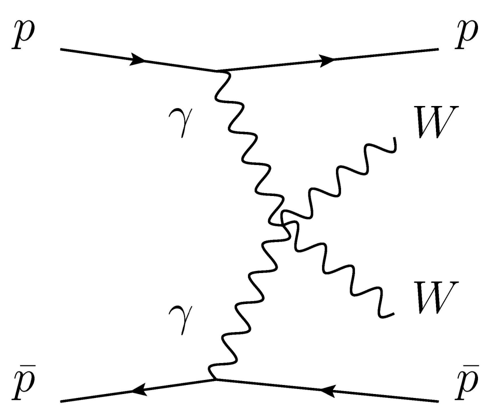
Anomalous Quartic Gauge Couplings with WWγγ

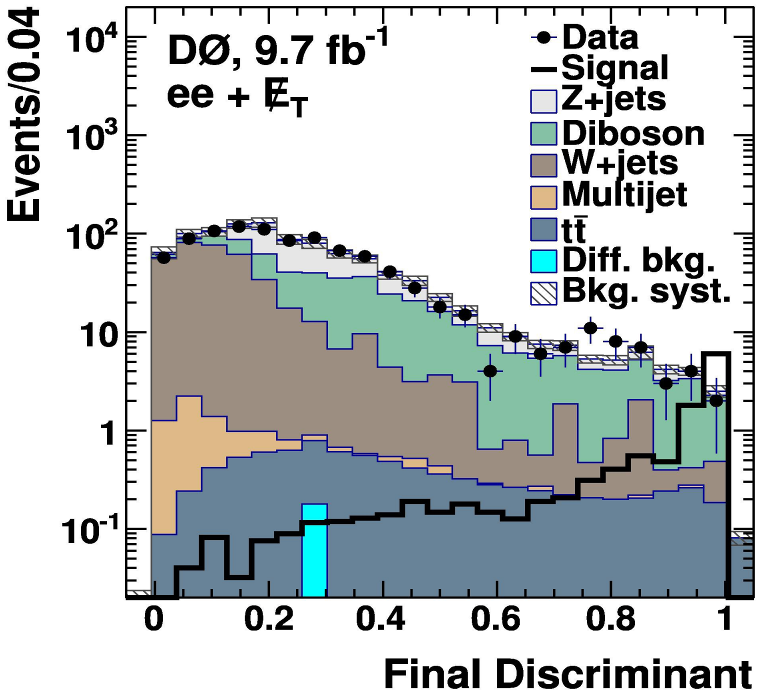
- WWγγ study extension of higgs search with same final state
  - Look for anomalous quartic gauge couplings, SM too small to see
- Dimension 6 operator for Lagrangian, a_0 and a_C = 0 in SM:

$$\mathcal{L}_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2} F_{\mu\nu}F^{\mu\nu}W^{+\alpha}W^-_\alpha$$

$$\mathcal{L}_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2} F_{\mu\alpha}F^{\mu\beta}(W^{+\alpha}W^-_\beta + W^{-\alpha}W^+_\beta)$$

- Selection same as for Higgs but with extra jet veto
  - BDT trained for AQGC signal
  - Same BDT used for both a_0 and a_C



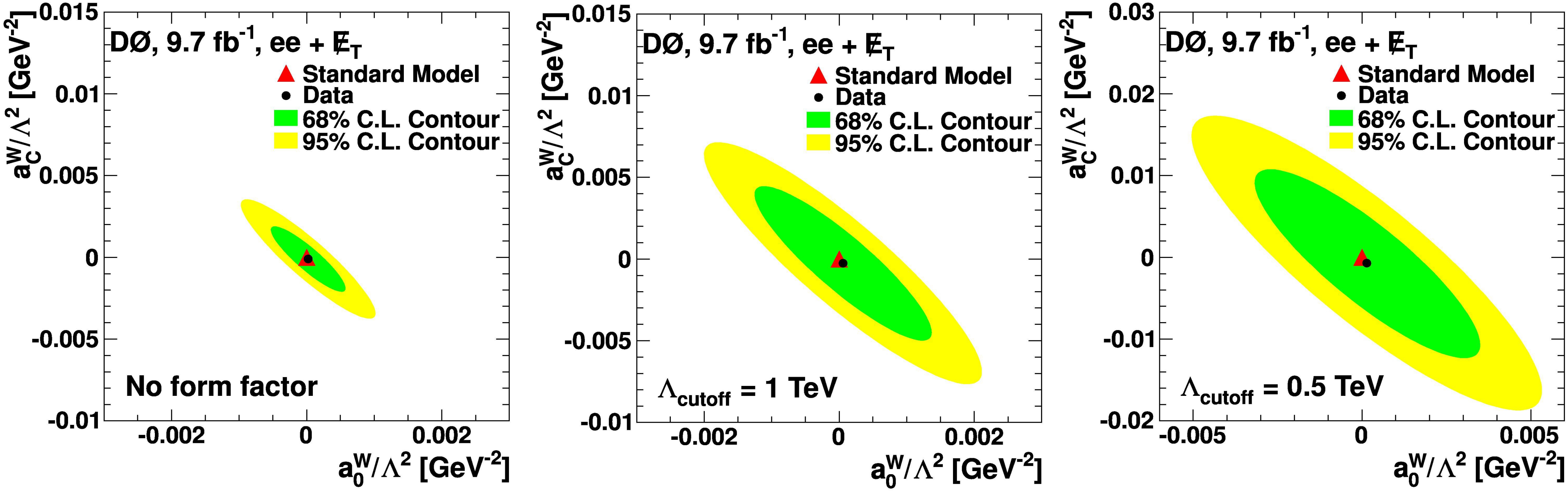


Anomalous Quartic Gauge Couplings with WWγγ

- With cutoff scale of 0.5 TeV, limits are

$$|a_0^W/\Lambda^2| < 0.0025\ \text{GeV}^{-2} \text{ and } |a_C^W/\Lambda^2| < 0.0092\ \text{GeV}^{-2}$$

- Factor of 4-8 better than best published results (OPAL)
  - For CMS result, see Jonatan's talk tomorrow afternoon



Fermilab-Pub-13-133-E, Submitted to Phys. Rev. D

Summary

- **Full data set analyses are ongoing at the Tevatron**
  - Precise $B^{\pm} \rightarrow J/\psi K^{\pm}$ and $J/\psi\pi^{\pm}$ CP violation measurements with DØ
  - Observation of D^0-$\overline{D}^0$ mixing with CDF
  - Photon plus heavy flavor cross-sections have been measured by both experiments
    - NLO in particular disagrees with data at high E_T values
  - AQCG search with DØ
- **Overall, there is agreement with the standard model**

Many topics not covered today, please see following pages for more results and more information about today's results

http://www-cdf.fnal.gov/physics/preprints/index.html
http://www-d0.fnal.gov/d0_publications/d0_pubs_list_runII_bytopic_byyear.html

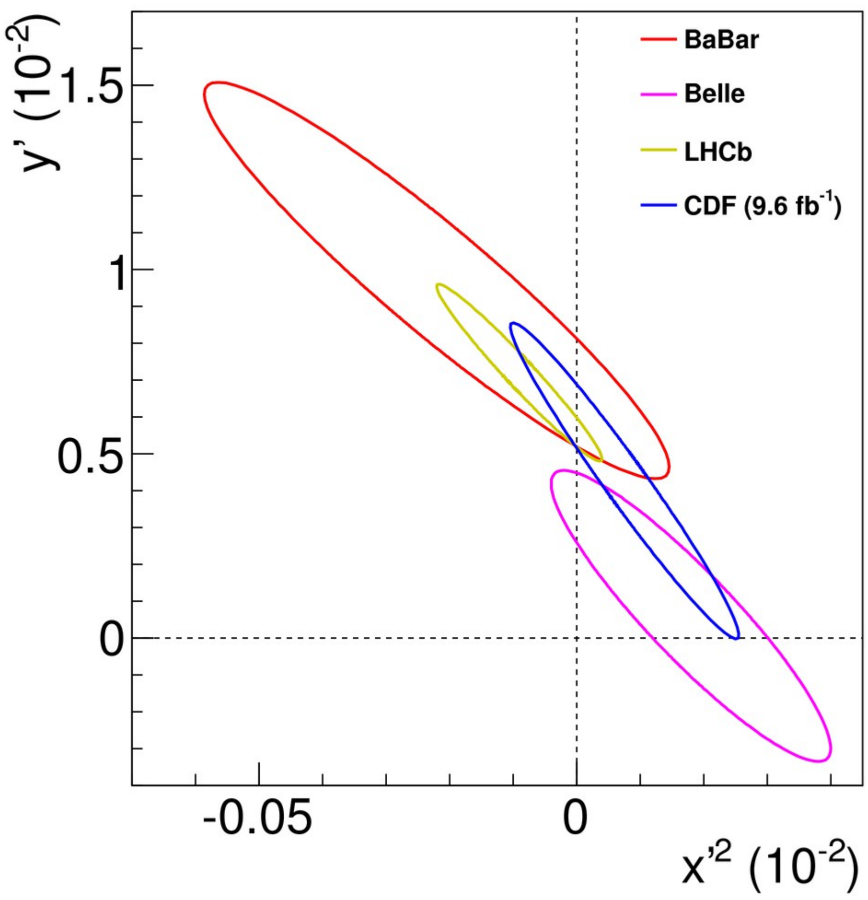
Other Recent Results and Papers (2013)

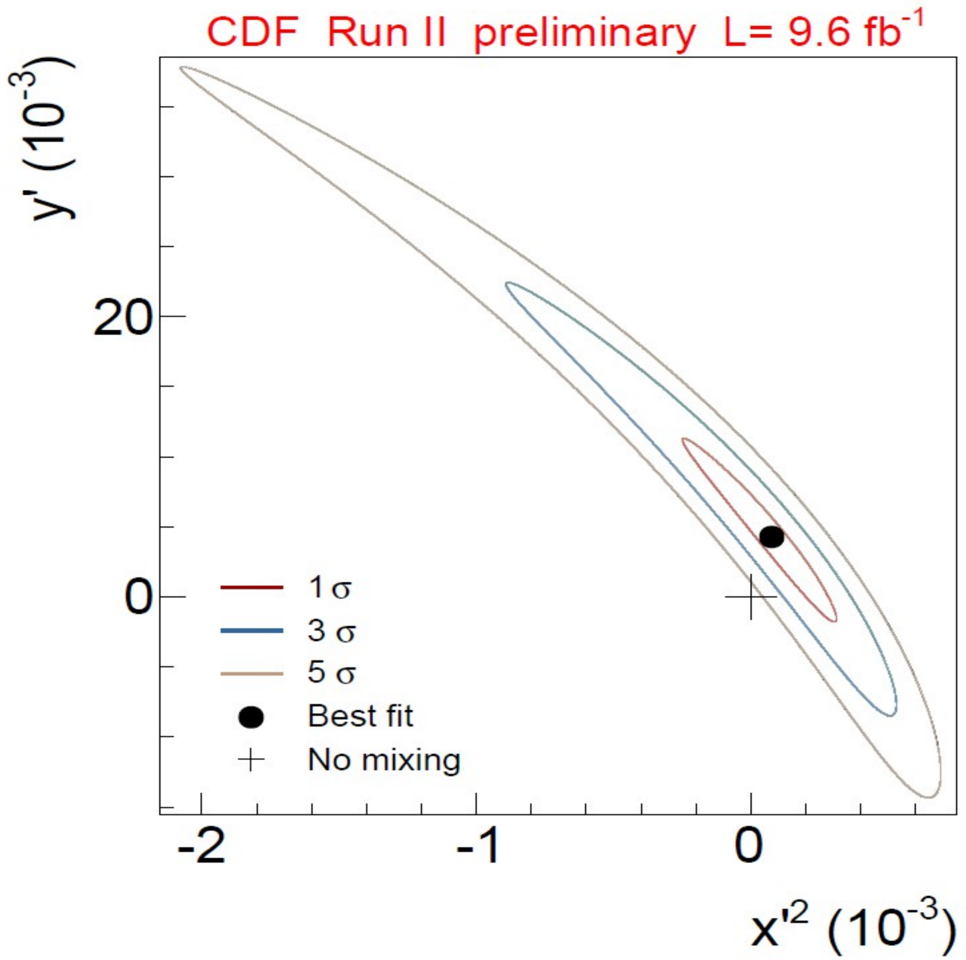
- Prompt Diphoton Production (CDF), Phys. Rev. Lett. 110, 101801 (2013)
- Photon Pair Production Differential Cross-section (DØ), Sub. Phys. Lett. B, arXiv:1301.4536
- W plus Charm Production (CDF), Phys.Rev.Lett 110, 071801 (2013)
- Differential Cross-section for Z+bjet/Z+jets (DØ), Accepted Phys. Rev. D, arXiv:1301.2233
- Measurement of $\sin^2\theta_W$ (or indirect M_W) (CDF), CDF Public Note 10952
- ZZ Cross Section (lll'l'+llvv) (CDF), CDF Public Note 10957
- W+jets Production (DØ), Sub. Phys. Rev. D, arXiv:1302.6508

Other Recent Results and Papers (2013)

- ZZ Cross Section (DØ), Sub. Phys. Rev. D, arXiv:1304.5422
- Search for the Rare Decay $B_s^0 \rightarrow \mu^+\mu^-$, (DØ), Phys. Rev. D 87, 072006 (2013)
- Measurement of the combined rapidity and p_T dependence of dijet azimuthal decorrelations (DØ), Phys. Lett. B 721, 212(2013)
- Measurement of the ratio of three-jet to two-jet cross section (DØ), Phys. Lett. B 720, 6 (2013)
- Measurement of the pp to W + b + X production cross section, (DØ), Phys. Lett. B 718, 1314 (2013)
- Measurement of the Semileptonic Charge Asymmetry using $B_s^0 \rightarrow D_s \mu X$ Decays (DØ), Phys. Rev. Lett., 110, 011801 (2013)

D^0 Mixing (CDF)





AQGC, Other Cut Off Values

TABLE II: Expected and observed 95% C.L upper limits on $|a_0^W/\Lambda^2|$, assuming a_C^W is zero and for different assumptions about the form factor.

Cutoff	Expected upper limit [GeV^{-2}]	Observed upper limit [GeV^{-2}]
No form factor	0.00043	0.00043
$\Lambda_{\mathrm{cutoff}} = 1\,\mathrm{TeV}$	0.00092	0.00089
$\Lambda_{\mathrm{cutoff}} = 0.5\,\mathrm{TeV}$	0.0025	0.0025

TABLE III: Expected and observed 95% C.L upper limits on $|a_C^W/\Lambda^2|$, assuming a_0^W is zero and for different assumptions about the form factor.

Cutoff	Expected upper limit [GeV^{-2}]	Observed upper limit [GeV^{-2}]
No form factor	0.0016	0.0015
$\Lambda_{\mathrm{cutoff}} = 1\,\mathrm{TeV}$	0.0033	0.0033
$\Lambda_{\mathrm{cutoff}} = 0.5\,\mathrm{TeV}$	0.0090	0.0092

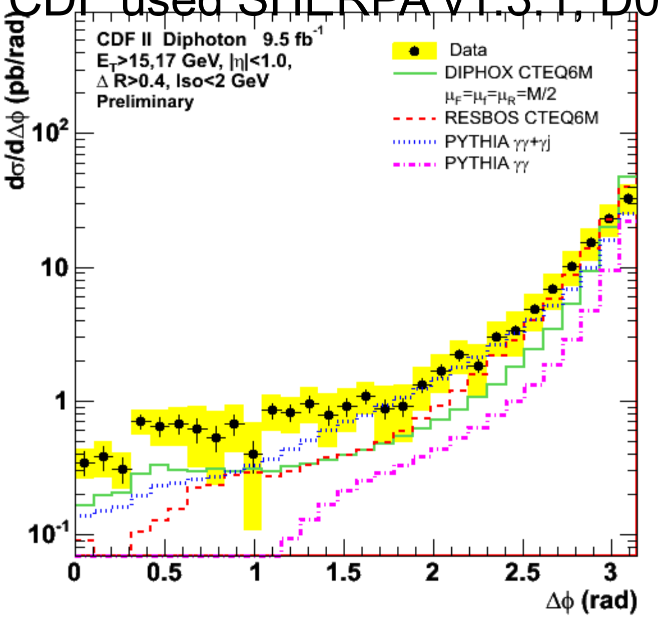
Direct Diphoton Cross-section

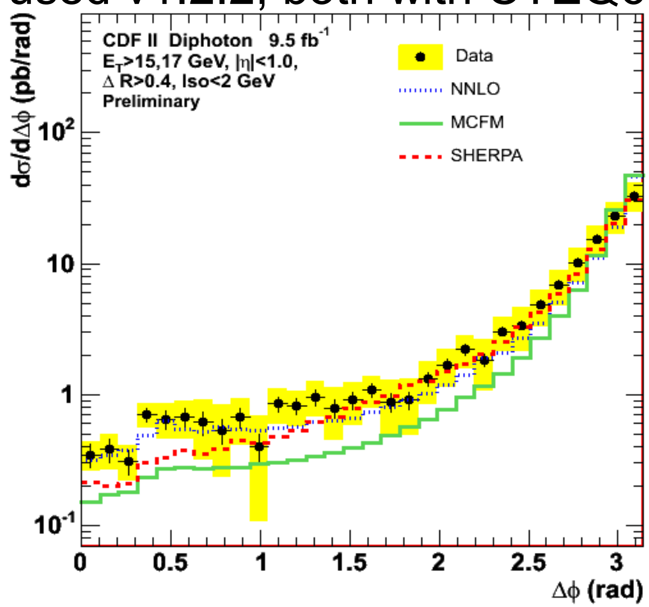
- Major background for Higgs production and new physics processes, also implications for QCD, PDFs
- At Tevatron, dominant production is $p\bar{p} \rightarrow \gamma\gamma$ with gluon production as well
- Photons required to be central
- Backgrounds include gamma jet and jet jet production
  - CDF reduces this using matrix method, D0 uses a 2-D fit to NN

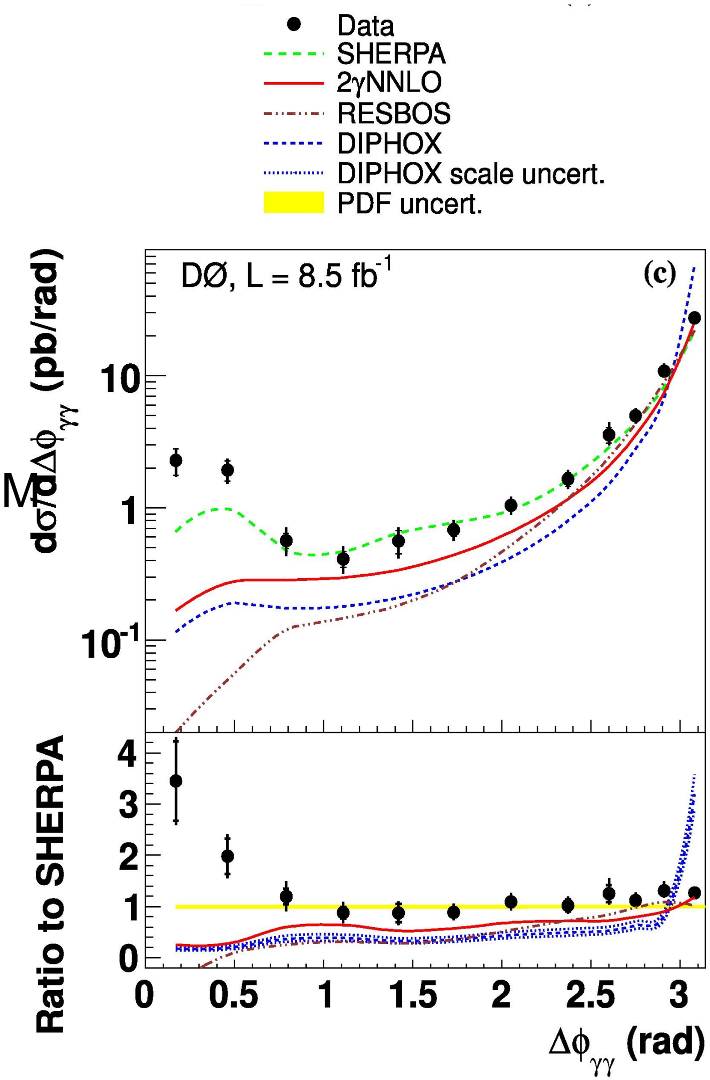
Diphoton Results

- Both groups see similar results, disagreement in the low delta phi region, best agreement with Sherpa
- Agreement in Higgs mass region, but disagreements for low mass (not shown)

NNLO is Catani et al PRL 108 , 072011 (2012)
NNLO is Catani & Grazzini, PRL 98, 222002 (2007)
CDF used SHERPA v1.3.1; D0 used v1.2.2; both with CTEQ6.6M







Phys. Rev. Lett. 110, 101801 (2013)
Fermilab-Pub-13-022-E, sub. Phys. Lett. B