# Upsilon Polarization at CDF

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# High Energy Vector Meson Production Mechanisms

- Long history of theoretical models to try to match vector meson data from Tevatron and HERA
  - cross section *problem* $\Rightarrow$ CSM $\rightarrow$ NRQCD
  - polarization problems with NRQCD $\Rightarrow$ multi-gluon models
  - recent theoretical considerations raise questions about $k_T$ factorization approach, Q fragmentation effects at Tevatron energies
- See recent review by J.-P. Lansberg for summary of theoretical situation (arXiv:0811.4005)

# CDF Experimental Results

- This talk's focus: Features of CDF results on vector meson polarization
  - **Υ(1S) polarization from 2.9 fb$^{-1}$ integrated luminosity**
  - **Update plans from 4.8 fb$^{-1}$ integrated luminosity**
- Future developments and request for theoretical input

# Measuring Polarization

- Polarization produces an angular asymmetry:

$$dN/d(\cos\theta) \propto 1 + \alpha \cos^2\theta$$

  - what axis? The size of $\alpha$ depends on frame.

    (aside: think of electron polarized along z-axis. If you measure spin along some other direction with direction cosine $\gamma$, the maximum polarization is $\gamma$.)

  - **historically, low $p_T$ fixed target experiments have analyzed in Collins-Soper frame.**

  - **high $p_T$ collider experiments have used s-channel helicity frame**

# Example: Prompt J/ψ Polarization

- Prompt polarization in s-channel helicity frame more longitudinal as $p_T(\psi)$ increases

- Consistent with multi-gluon models but not NRQCD

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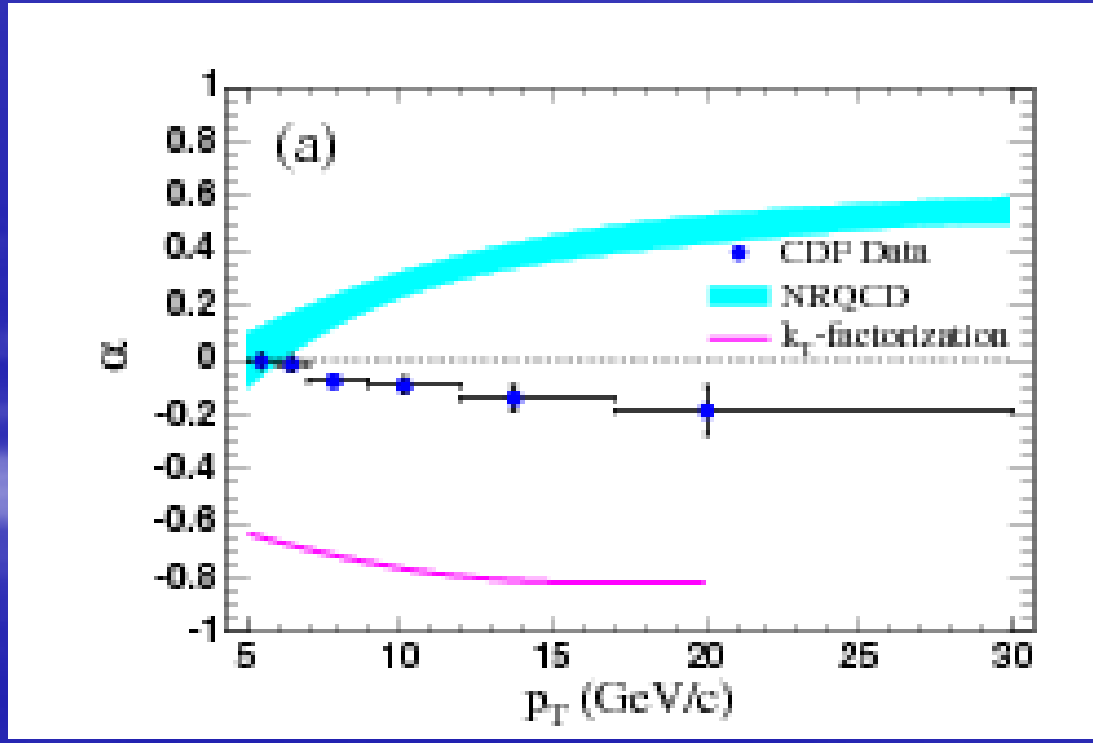
0.8 $fb^{-1}$



# What About Y Polarization?

- Is c quark is too light for factorization?
- Consensus:  Y(ns) polarization at high $m_T$ is acid test for NRQCD.
- CDF Run I Y(1S) polarization does not show T polarization, but limited $m_T$ range.
- D0: trend toward T polarization?

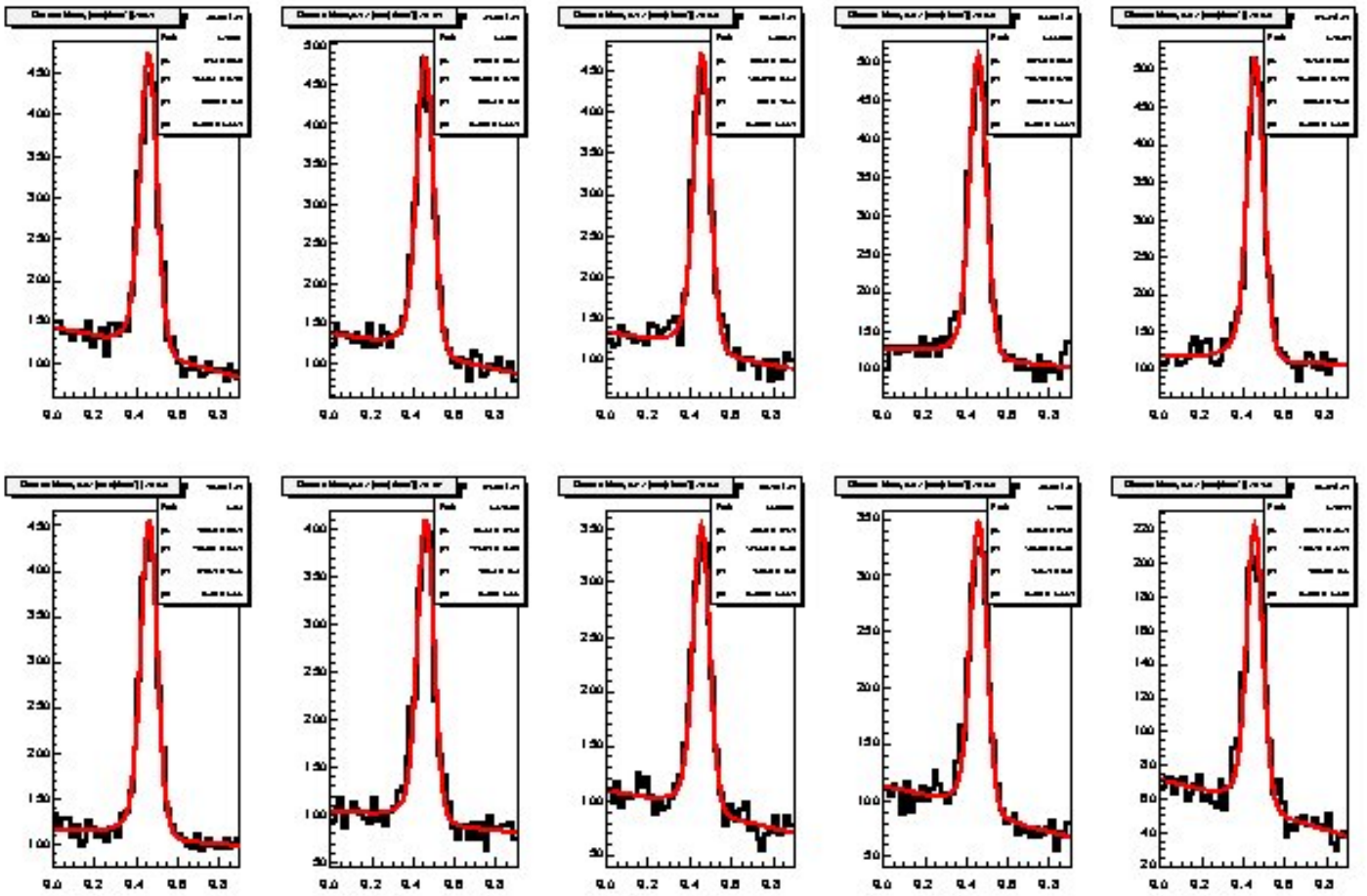
# CDF Y Analysis - I

- For Y(1S) analysis with 2.9 $fb^{-1}$
  - 82K Y(1S) signal events after sideband subtraction
  - S/B ~ 2:1 in all angular bins
- CDF cos θ and $p_T$ resolutions are good:
  - $\Delta(\cos\theta)/\cos\theta$ = .011 for $p_T$ ~ 2 GeV/c
    .006 for $p_T$ > 8 GeV/c
    $\Delta p_T / p_T$ < .015 for $p_T$ ~ 2 GeV/c
    < .010 for $p_T$ ~ 20 GeV/c

# Typical Mass Fits in Angle Bins

Y(1S) mass fits using Double Gaussian fit to MC for $2<p_T<3$ GeV/c:

- bkg is small but not simple
- fit for mass peak and bkg in each angular bin
- Fit determines signal region to count $\mathbf{D_i}$ and determine the backgnd $\mathbf{B_i}$ .



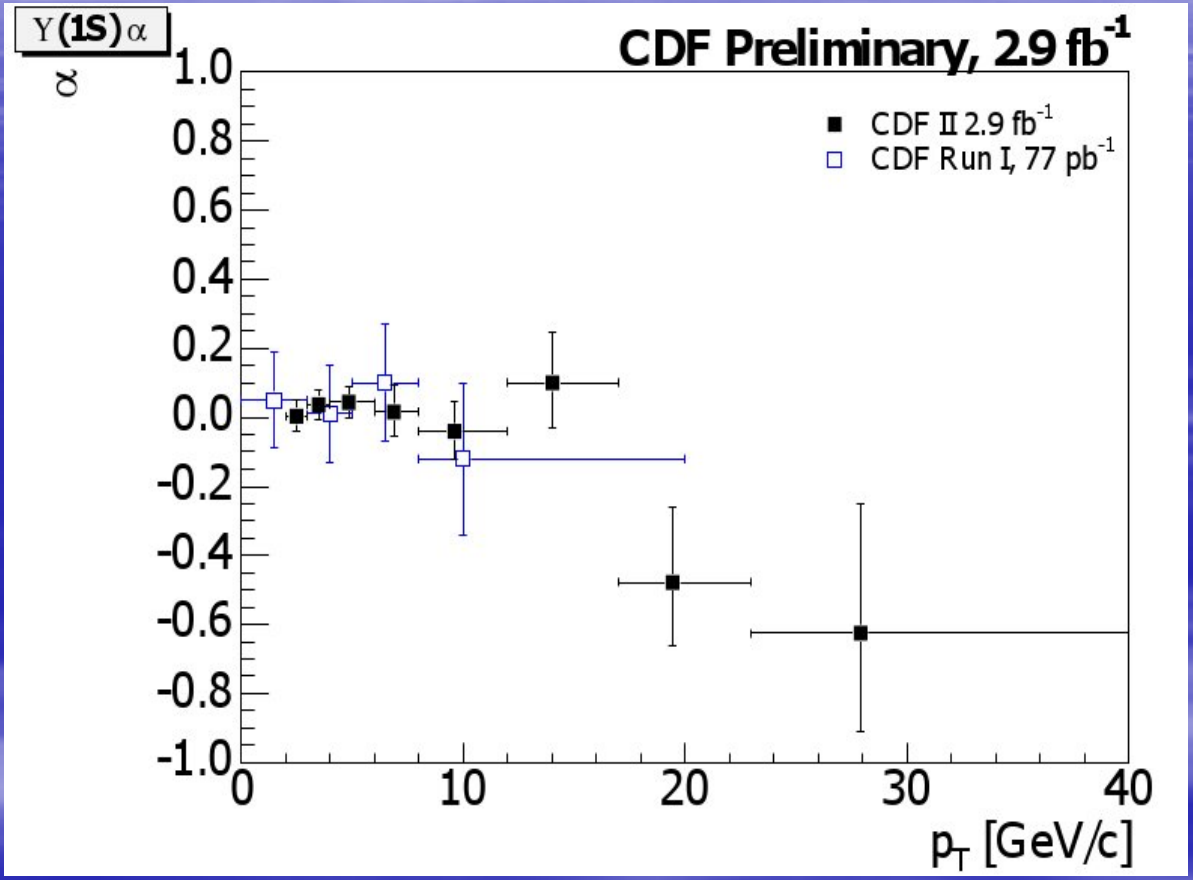
# CDF Y Analysis - II

- **Follow methodology of J/$\psi$ analysis:**
  - **make templates for L, T polarization to incorporate trigger, acceptance conditions: $E = \eta L + (1-\eta)T$**
  - **Use sideband angular distribution $B_i$ to estimate signal angular distribution for polarization analysis.**
  - **Make simultaneous fit to polarization parameter $\eta$ and background $\beta_i$ in cos $\theta$ bins – *improves background estimate by using bin-to-bin correlations***
- $\chi^2 = \Sigma\, [(D_i - \beta_i - E_i(\eta))^2 / D_i + (B_i - \beta_i)^2 / B_i]$
- $D_i$ is the total data in the signal region, not just the signal

# Run II and CDF-I Polarization

- Polarization is small for $p_T < 20$ GeV/c

- New data show trend toward L polarization at large $p_T$

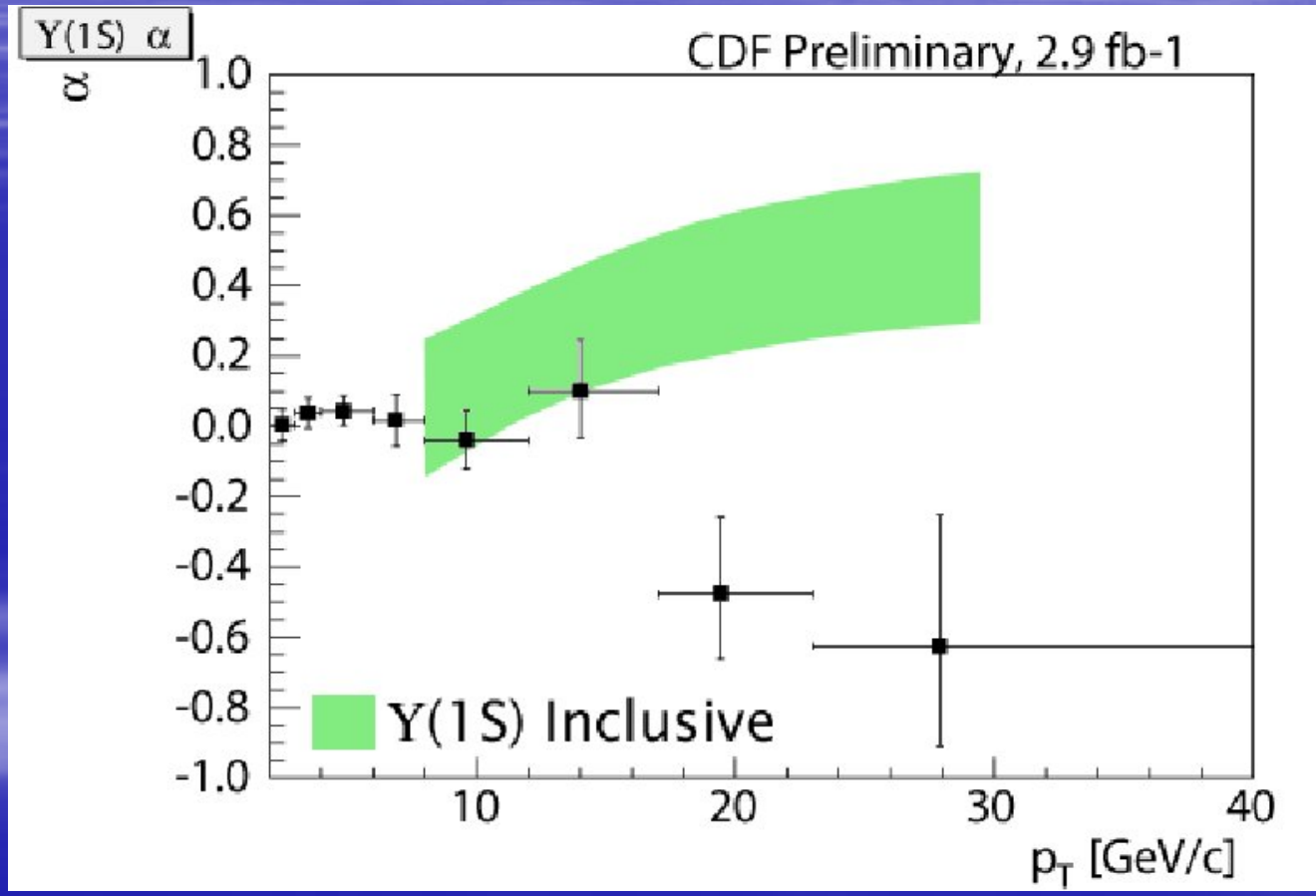



Difference in |y| coverage (0.4 vs 0.6) doesn't have big effect

# NRQCD Y(1S) Polarization

- Y(1S) prompt polarization, including feed-down from $\chi_b$, Y(nS).

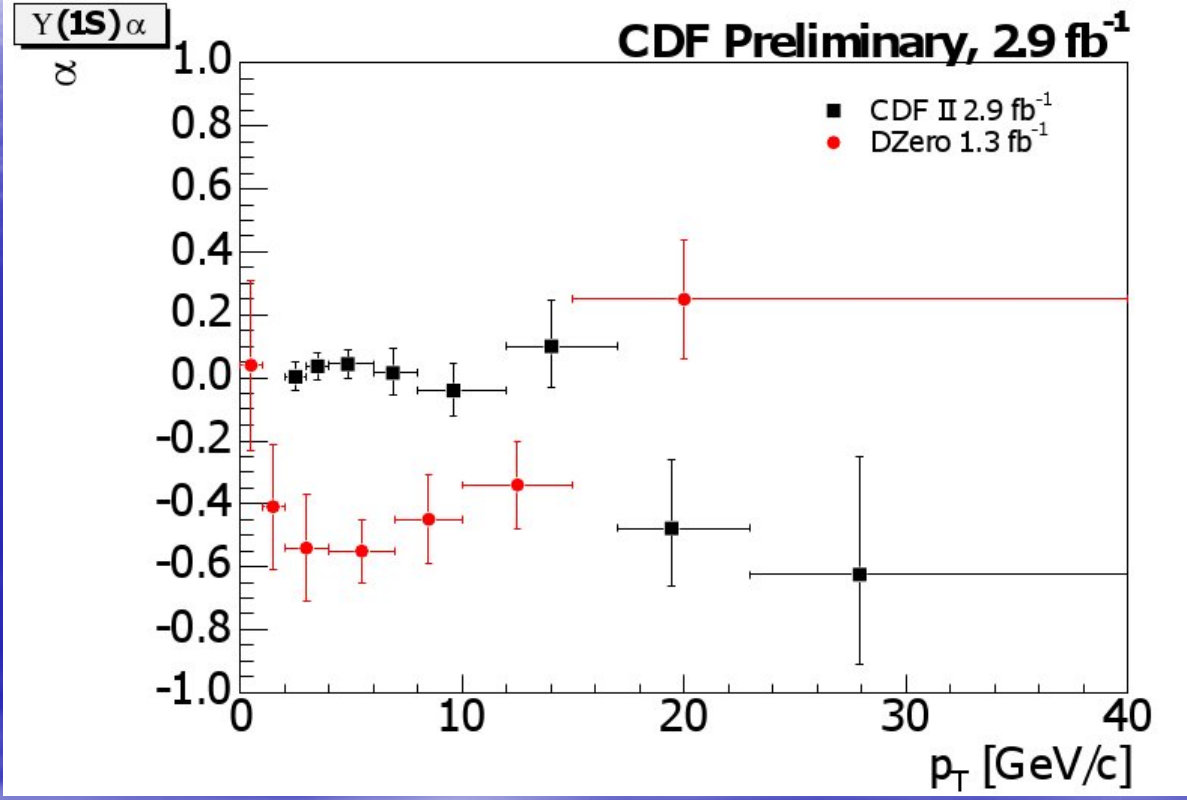
- Green is NRQCD including feeddown (Braaten and Lee, PRD 63, 071501 (2000))



# CDF Disagrees with D0

Trends are totally different.

Does |y| matter?
D0: |y|< 1.8
CDF: |y|<0.6

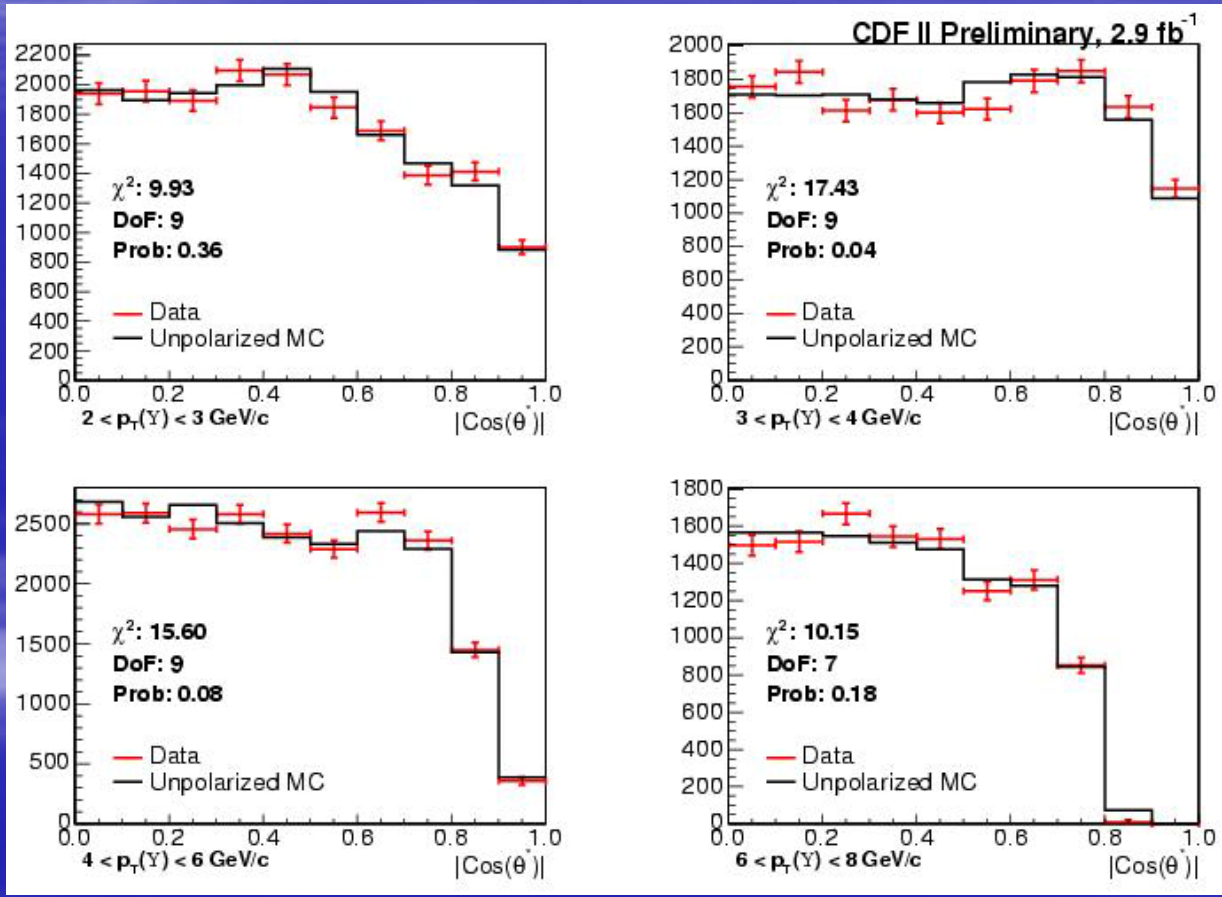



D0 paper: " We expect the CDF and D0 results to be similar and have no explanation for the observed difference." Same remarks apply here – no explanation.

# Trying to Understand CDF/D0 Difference

## Can we tell if low pT Y(1S) data are polarized?

- **Generate unpolarized decays with Monte Carlo:**
  - **Processed in same way as data**
  - **Normalize to number of events in data and overlay – <u>no fitting involved</u>.**
- **See good agreement**
- **CDF data do not support D0 claim of longitudinal polarization at low $p_T$**



# CDF/ D0 Differences

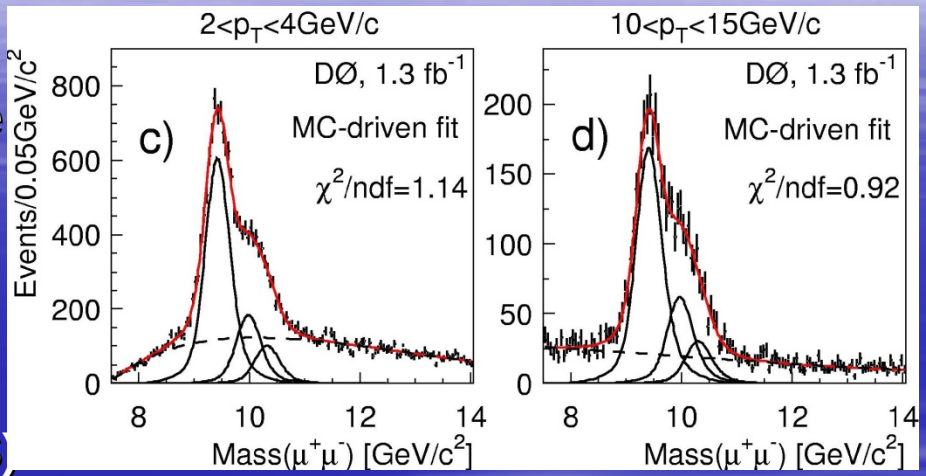
D0: Smooth data-driven backgnd shape under all mass peaks for each angle, $p_T$ bin.

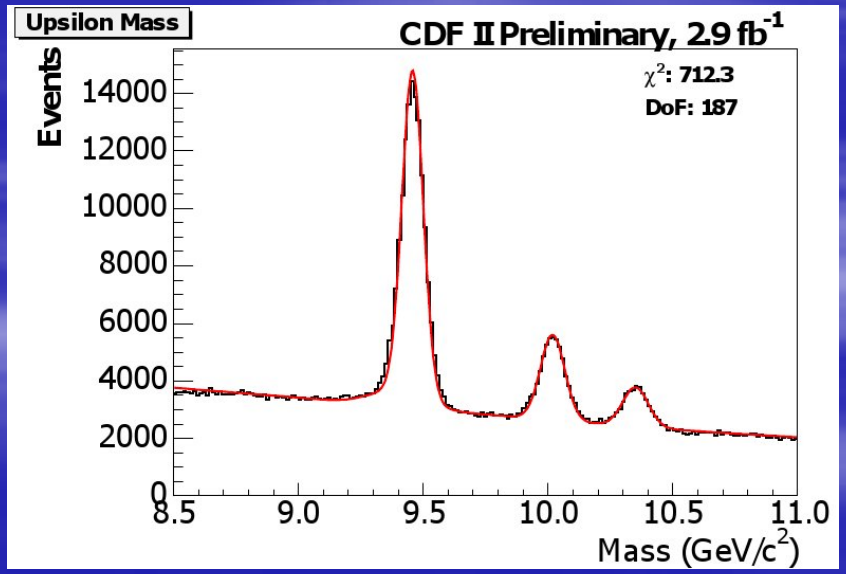
CDF: Two independent analyses:

make mass fits, backgnd for each Y(nS) peak ; or define mass peak and plot angular distribution.

Use sideband background subtraction in each case.

Polarization results are consistent between the two methods.



# Polarization Summary

- CDF prompt vector meson polarizations show trend toward L polarization at high $p_T$ in s-channel helicity frame
- Multi-gluon models predict this kind of behavior, but
  - models go L at lower $p_T$ than data
  - models are for *direct* production – data are prompt
- Backgrounds have angular structure. How much is due to Drell-Yan?

# Near-Term CDF Plans

- Nearly done doubling CDF data set - the plan:
- Update Y(nS) polarization measurements in helicity, frame
- Make first high energy collider analysis in Collins-Soper frame for Y(nS) state.
- Measure $\chi_b$, feed-down fractions for Y(1S)

# Summary

- Vector Meson polarization studies at hadron colliders benefit from excellent mass resolution because of complicated background angular behavior.
- Prompt production is readily measured. Determining the direct production fraction is much harder but was done in Run I. It's important for comparing to theory.
- These methods can extend the $p_T$ reach of such measurements toward 100 GeV/c at LHC.

# Questions for theorists:

- Looking past polarization to cross-section work:
  - What is the prediction for Y production isolation in multi-gluon models?
    - What cone size? What track $p_T$? Measure $p_T$ relative to Y or proton?
  - Is there physics interest to identify DY component of dimuon continuum and measure polarization ?
  - What is the predicted high $p_T$ differential cross section shape? Models undershoot present data.