# Challenges and Perspectives in Quarkonium Polarization

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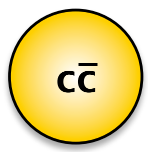
# Outline

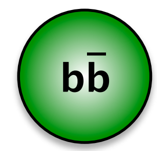
- Introduction to Quarkonium Physics
- Quarkonium Polarization Models
- New Perspectives on Quarkonium Polarization
- Recent Results on Quarkonium Polarization
- Challenges Related to the Measurement of Quarkonium Polarization

# Introduction

- Quarkonia are bound states of a heavy quark and its antiquark



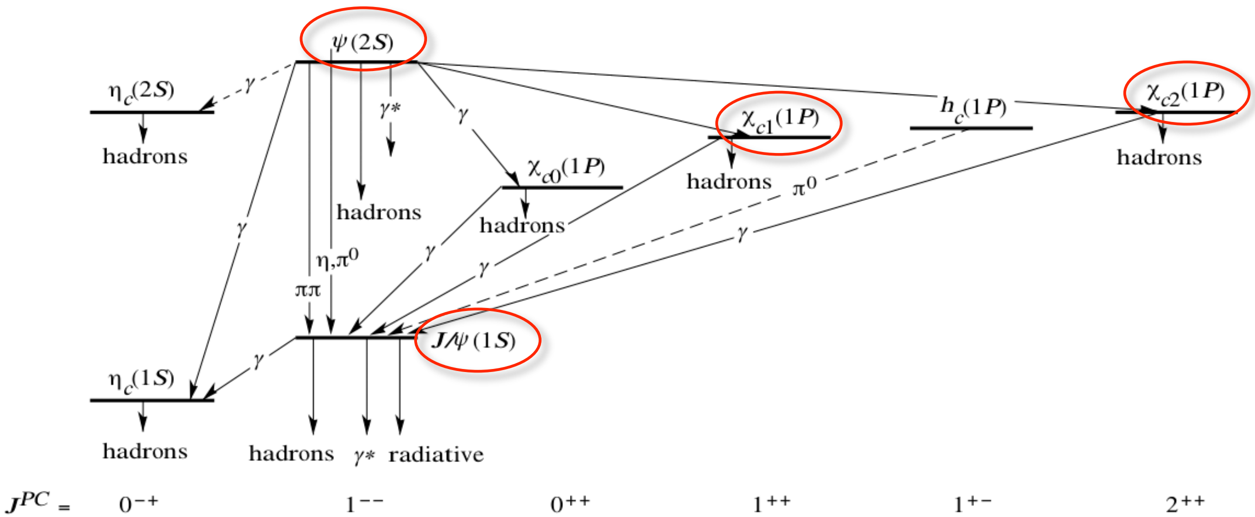

$m_{c\bar{c}} \sim 3 - 4$ GeV




$m_{b\bar{b}} \sim 9.5 - 10.5$ GeV

- Quarkonium production rate at LHC is very high ($\approx 10^8$ $J/\psi$'s for $L_{int} = 1\ fb^{-1}$ at $p_T(J/\psi) > 6.5$ GeV/c)
- Quarkonium production is studied in all four LHC experiments
- QCD can be probed through quarkonium production properties, in particular differential cross sections and spin alignments

# Quarkonium Spectrum

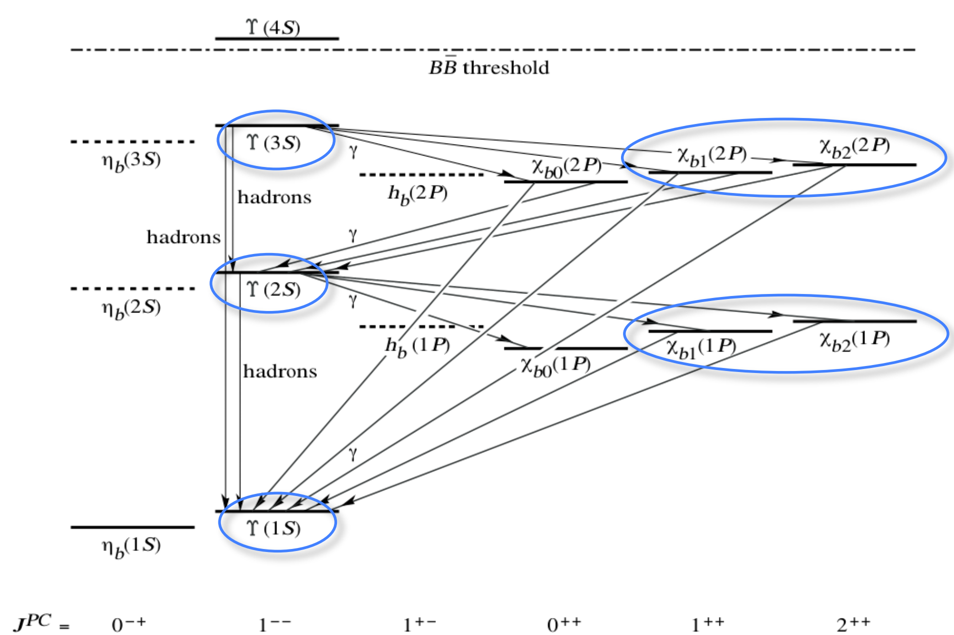



cc̄

Charmonium spectrum

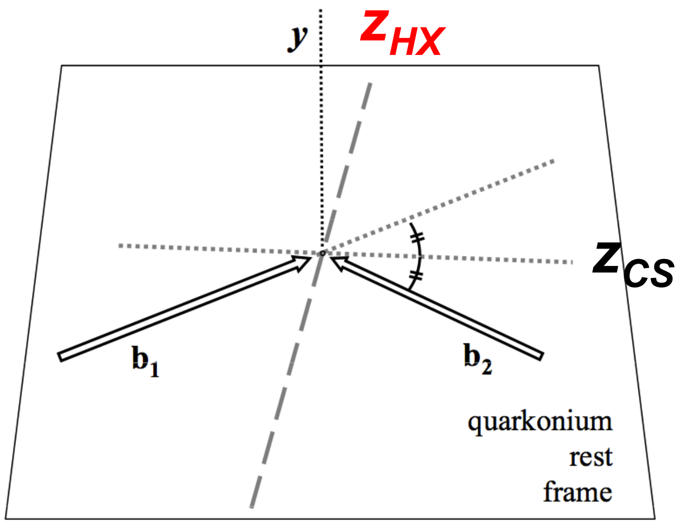
Bottomonium spectrum

bb̄



# Quarkonium Polarization

- Angular decay distribution measured with respect to a reference frame (Collins-Soper CS, helicity HX, etc.)




$z_{CS}$ ≈ direction of colliding partons

$z_{HX}$ = direction of quarkonium momentum

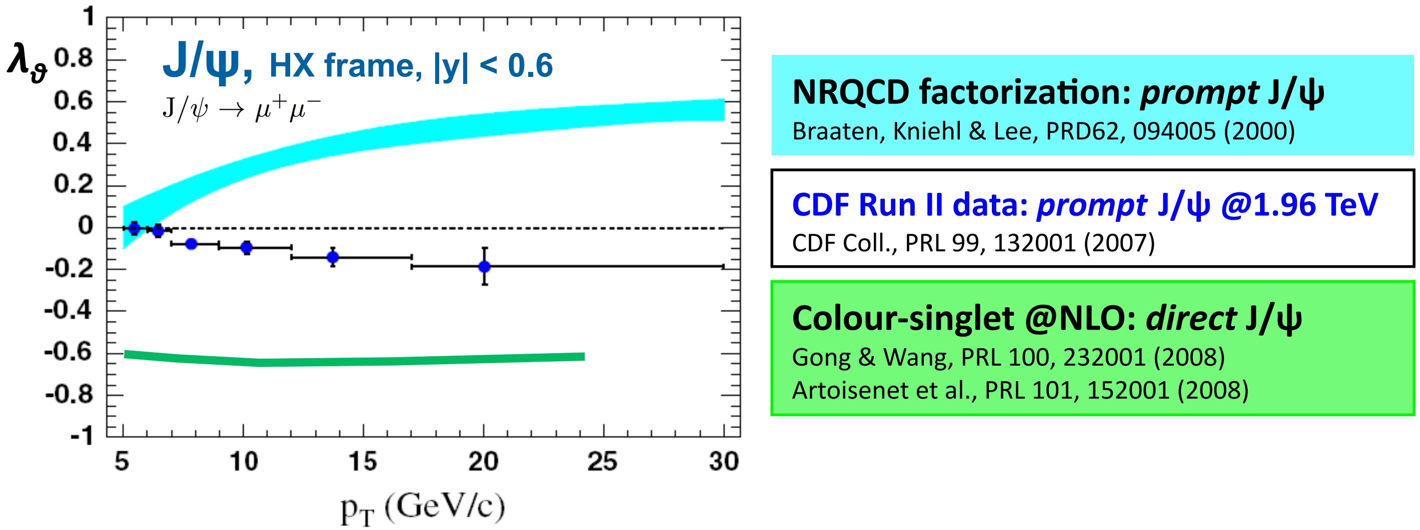
- Most general angular distribution:

$$\frac{dN}{d\cos\theta d\phi} \propto 1 + \lambda_\theta \cos^2\theta + \lambda_\phi \sin^2\theta \cos 2\phi + \lambda_{\theta\phi} \sin 2\theta \cos\phi$$

where $\lambda_\theta$, $\lambda_\Phi$, $\lambda_{\theta\Phi}$ are polarization parameters

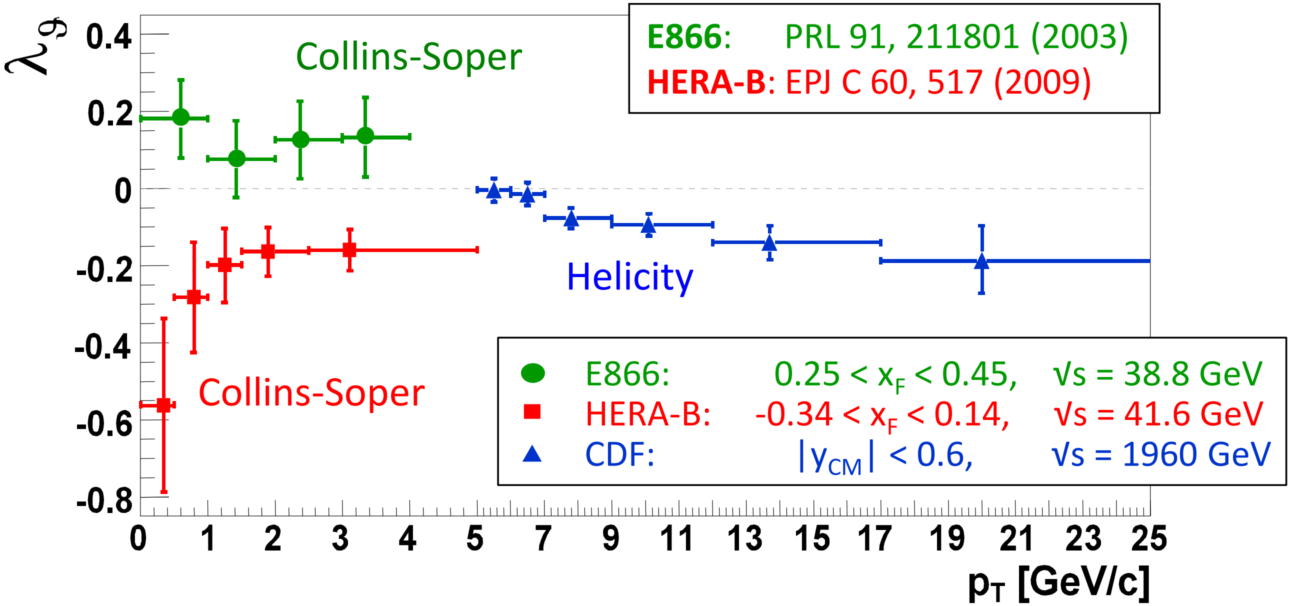
# Quarkonium Polarization

- Two approaches: Color Singlet Model (CSM), Non Relativistic QCD (NRQCD)



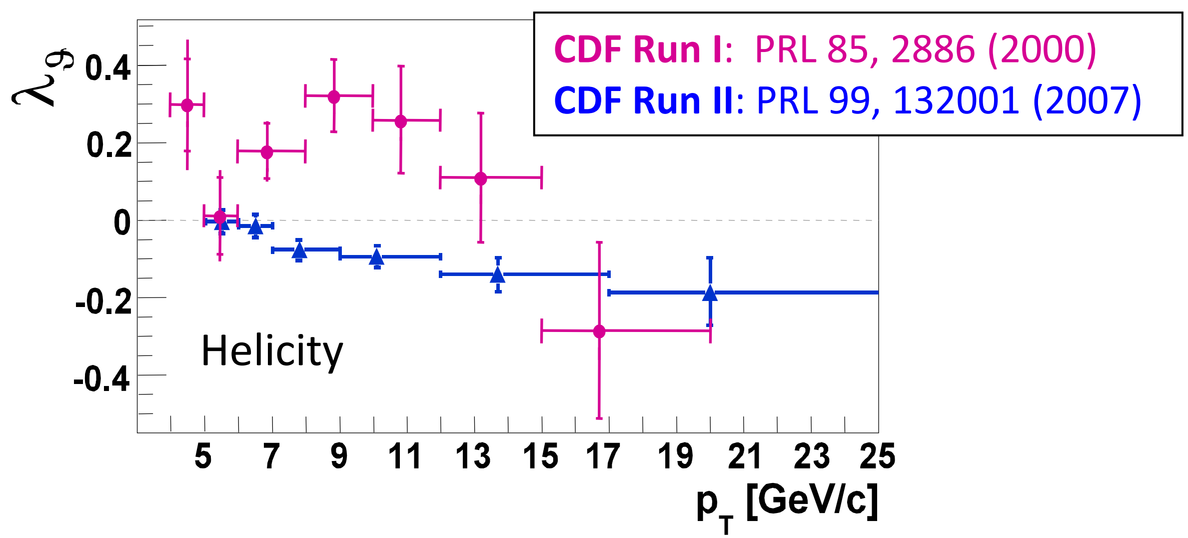

- CDF results seem to exclude both models
- Note: CDF only measured polar angle distribution which allows ambiguous interpretations

# Experimental Results for J/ψ Polarization



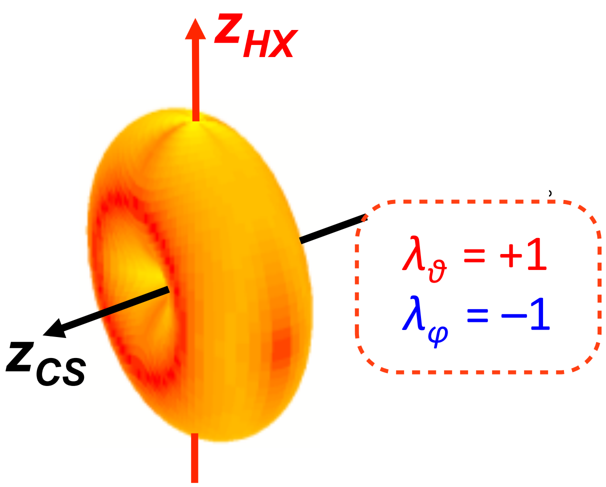

Apparent inconsistency of results between experiments ...

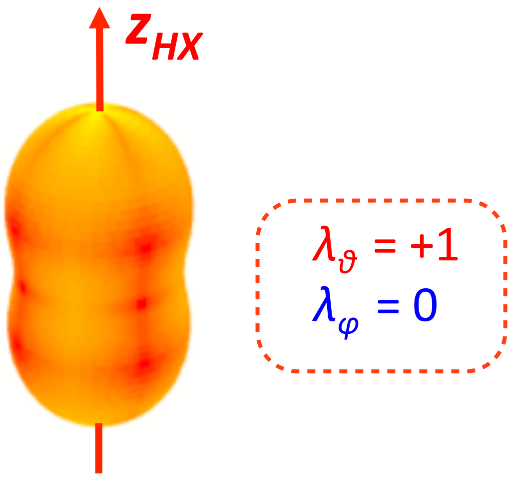
... and even within the same experiment!
Note: Only the polar angle distribution is shown!



# Need to Measure Full Angular Distribution

- Measure of the full angular decay distribution (three polarization parameters): Two very different physical cases are indistinguishable if only $\lambda_\theta$ is measured.
- Measure the polarization in at least two reference frames to be able to compare experimental results
- Observed polarization depends on frame

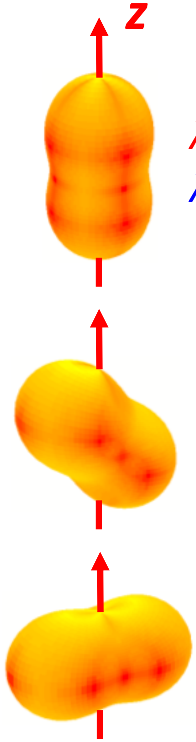


# Frame Independent Parameter

- Define frame invariant parameters such as $\tilde{\lambda}$ from the full angular distribution of a given frame

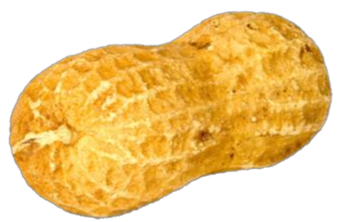
$$\tilde{\lambda} = \frac{\lambda_\theta + 3\lambda_\phi}{1 - \lambda_\phi}$$




$\lambda_\vartheta = +1$
$\lambda_\varphi = 0$

$\lambda_\vartheta = +1/5$
$\lambda_\varphi = +1/5$

$\lambda_\vartheta = -1/3$
$\lambda_\varphi = +1/3$



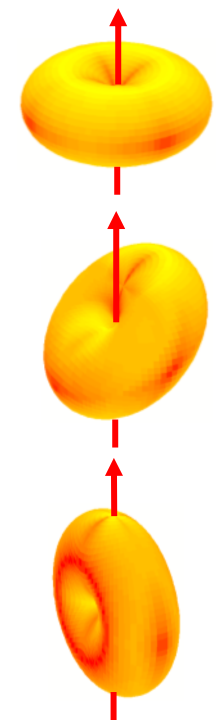
$$\tilde{\lambda} = +1$$

$$\tilde{\lambda} = -1$$

$\lambda_\vartheta = -1$
$\lambda_\varphi = 0$

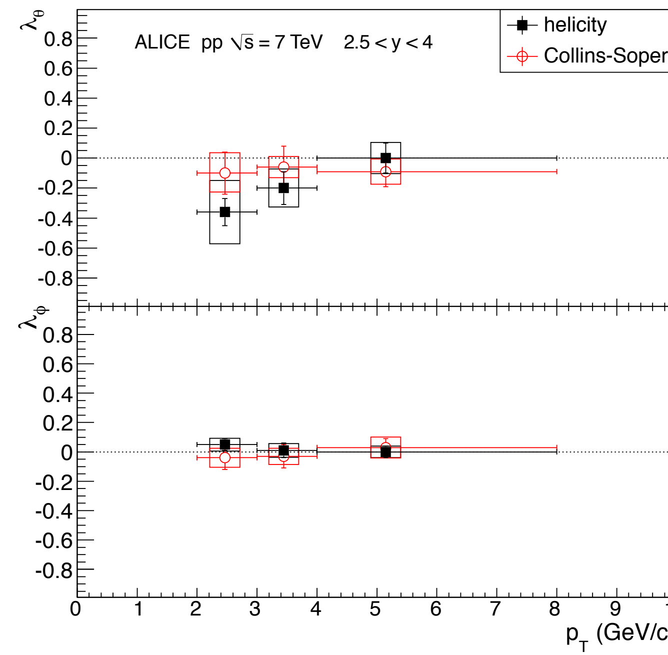
$\lambda_\vartheta = -1/3$
$\lambda_\varphi = -1/3$

$\lambda_\vartheta = +1$
$\lambda_\varphi = -1$



# Recent Results on Quarkonium Polarization

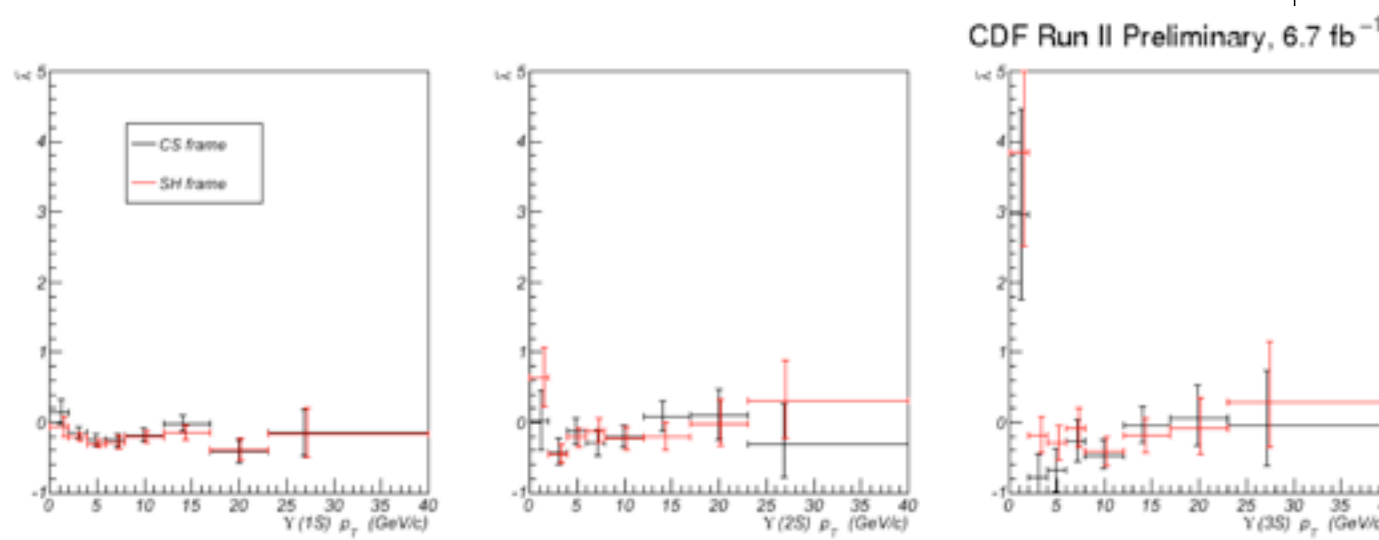
- ALICE:
  slightly longitudinal polarization at low $p_T$ in HX frame
  CS frame compatible with no polarization




arXiv:1111.1630

- CDF:
  Υ(1S) compatible with no polarization
  Υ(2S) and Υ(3S) large uncertainties

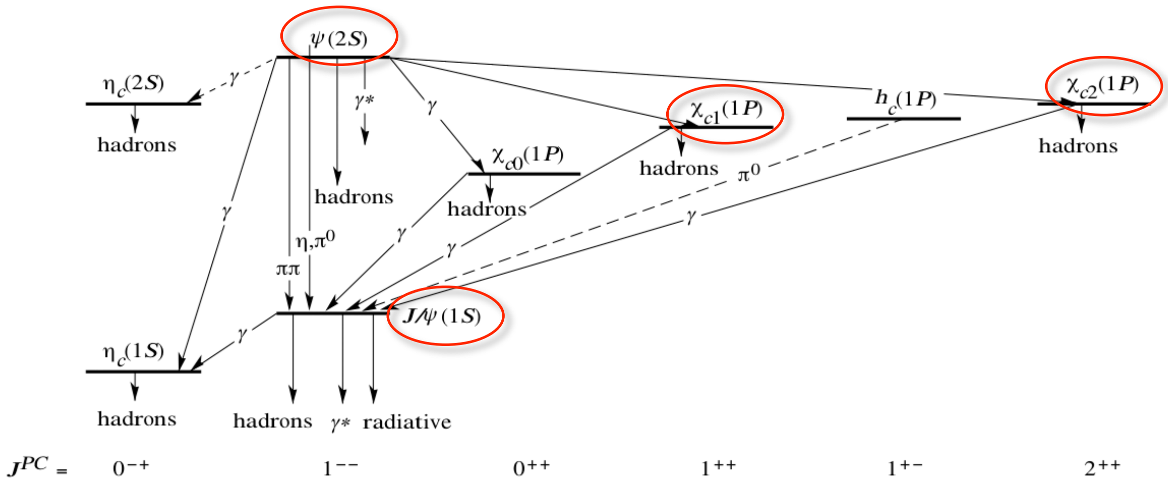
No evidence of polarization!




CDF Note 10665

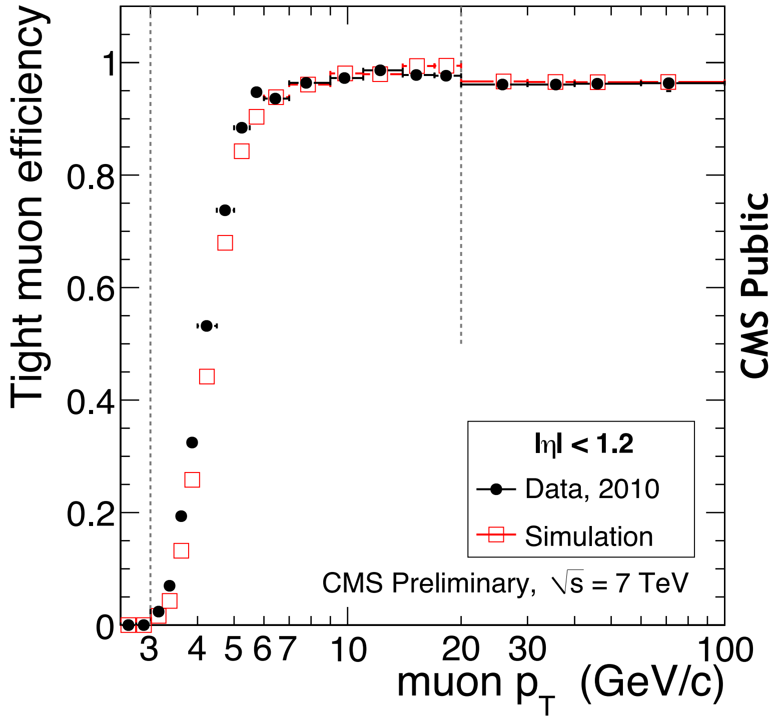
# Some More Challenges

- Since LHC is a "quarkonium production factory", statistics is not a problem. Trigger rate is very high.
- Systematic uncertainties prove difficult: Dimuon efficiency is the most important input for the extraction of polarization parameters.
- Feed-down from $\chi$-states will be difficult to identify because it requires a precise measurement and identification of low energy photons.

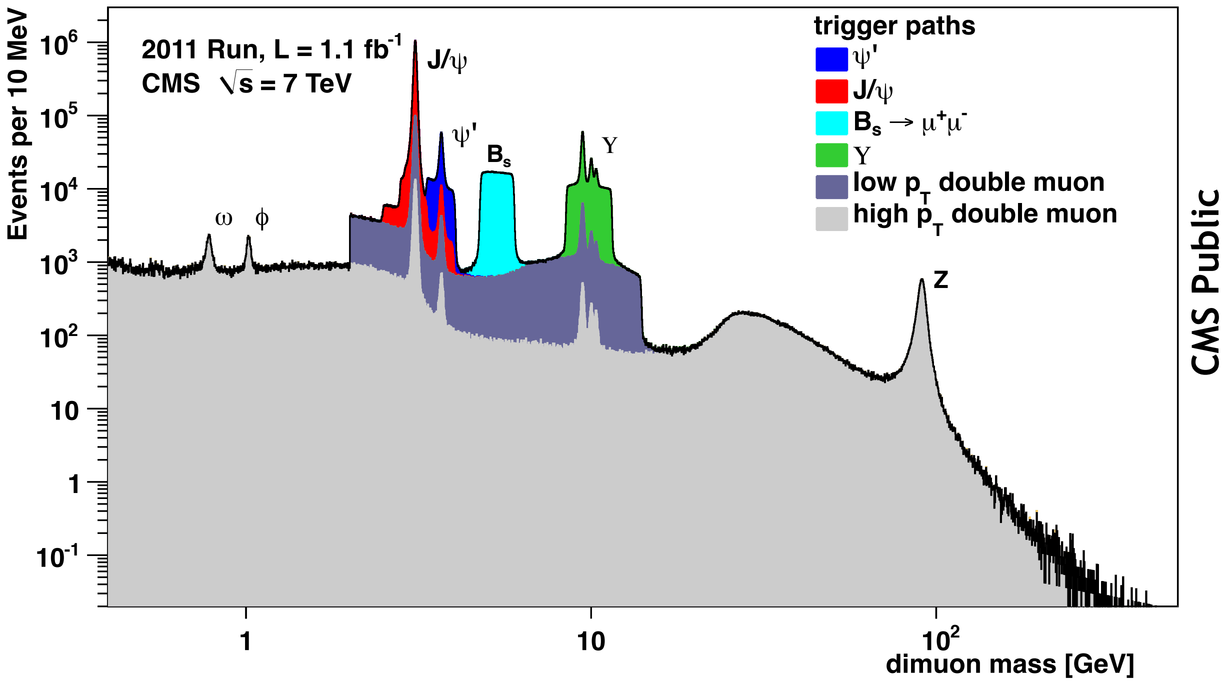


# Dimuon Efficiencies

- A very precise description of the dimuon efficiencies in the low $p_T$ region is needed.
- Efficiency corrections depend on the kinematical variable $p_T$, rapidity and also on the angular configuration of the two muons.
- Tag and Probe method is standard to extract single muon efficiencies: utilizes a known resonance to select particles. One muon (tag) satisfying all muon requirements is paired with another muon (probe) with looser selection criteria.



# Dimuon Efficiencies




- "Special" trigger paths to study efficiency are needed
- How to get dimuon efficiencies?
  Using the single muon efficiency and a correction factor for correlations between muons
  Directly using events collected without using muon information in the trigger

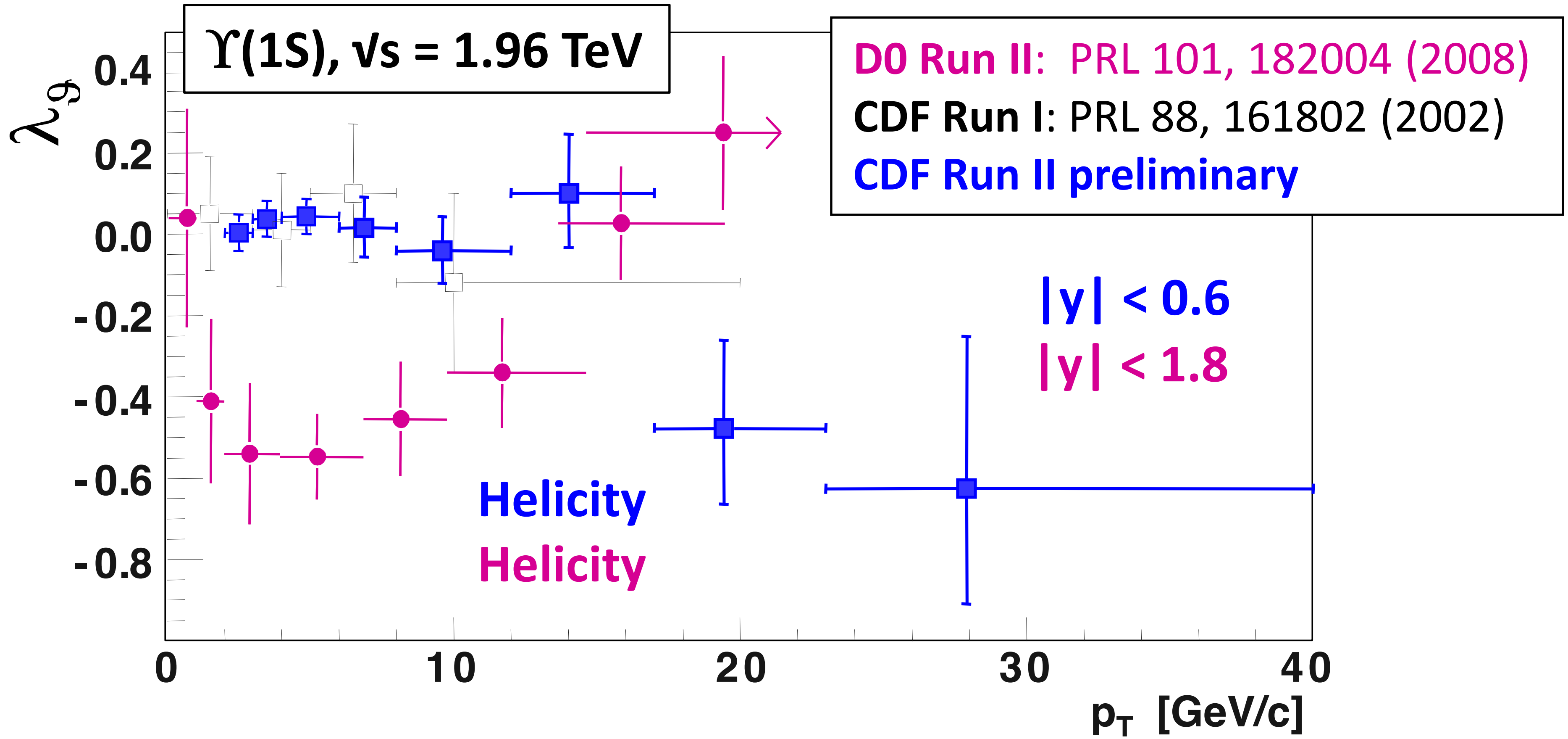
# Summary

- Quarkonium polarization has been an active field of research since some time.
- It is a very complex and sensitive measurement.
- Measurement of all polarization parameters in at least two reference frames is needed for an accurate result.
- Frame invariant parameters are important and can also be used as cross-checks.

**THANK YOU!**

# BACKUP

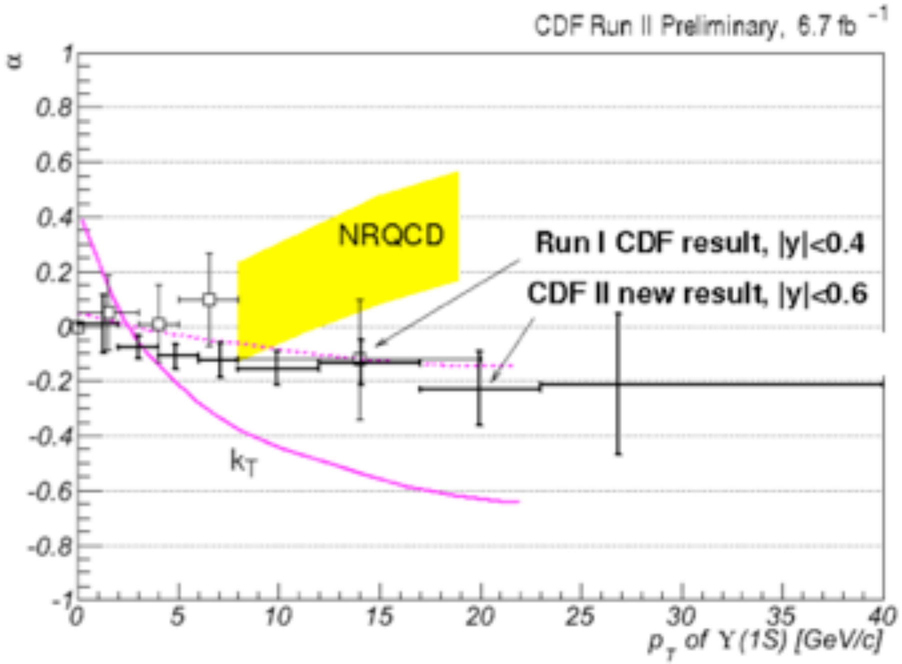
# Experimental Results for Υ(1S)

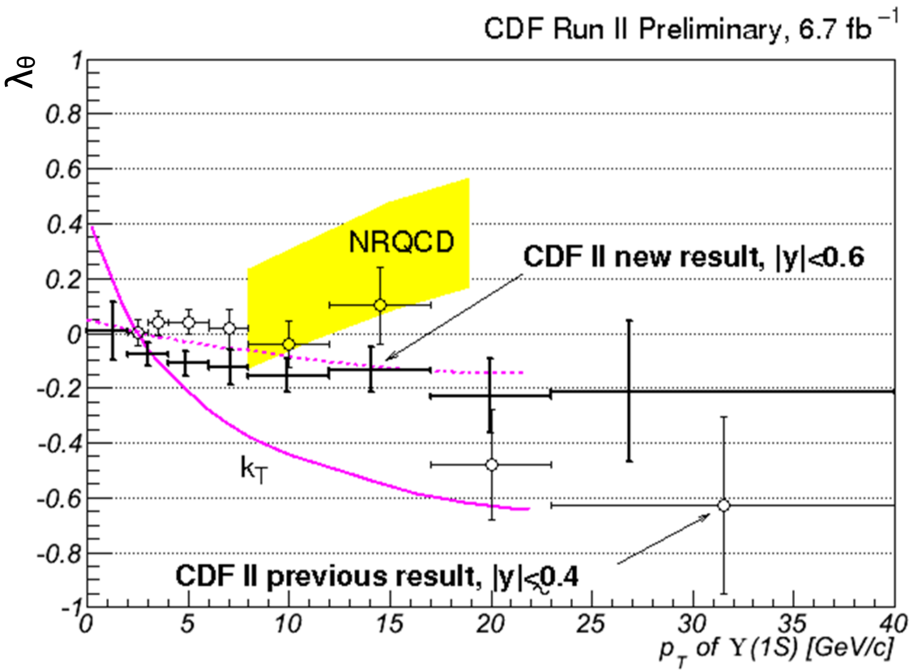


# New CDF Result Run II

- Measure all three parameters simultaneously
- Measure Collins-Soper and helicity frame

CDF Note 10665

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