Polarization of J/ψ and $\psi(2S)$ at CDF

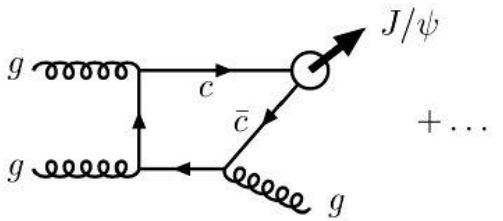
Kwangzoo Chung
Carnegie Mellon University

DPF 2006
October 30

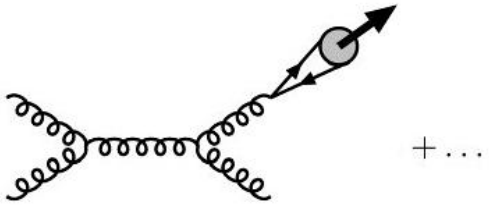
$p\bar{p}$ Collisions at $\sqrt{s} = 1.96\ \mathrm{TeV}/c^2$

Physics Motivation

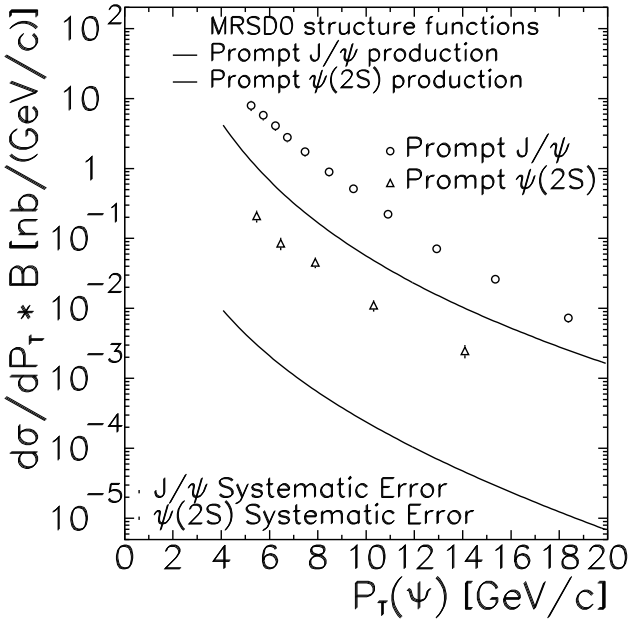
- Heavy quarkonia systems
  $\rightarrow$ A useful test stand for QCD.
- Early pQCD(CSM): Failed to explain the large production cross section of charmonium states.
- NRQCD:
  - includes color-octet mechanisms.
  - Consequently predicted a large transverse polarization at high p_T.



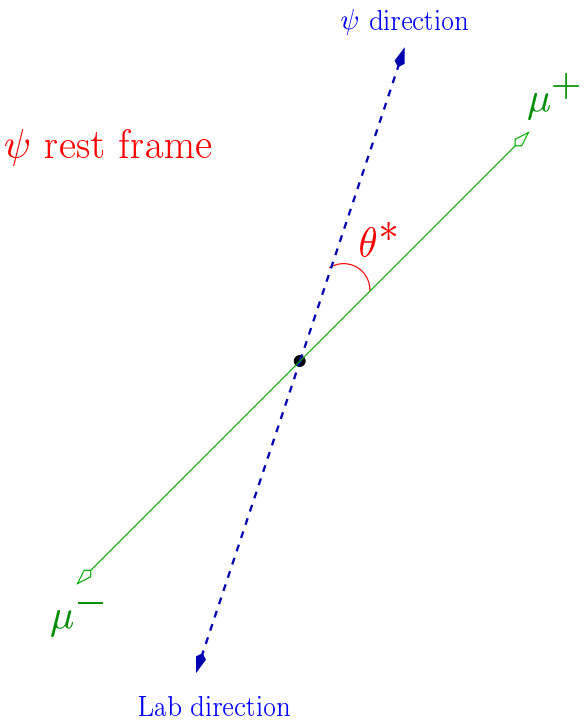
leading-order color-singlet



color-octet fragmentation



Polarization Measurement in $V \rightarrow \mu^+\mu^-$



Decay angle distribution

- The angle between the μ^+ direction in the vector meson V ($V \rightarrow J/\psi, \psi(2S)$) rest frame and the V direction in the lab frame.

$$\frac{d\Gamma}{d\cos\theta^*} \propto \frac{3}{2(\alpha+3)}\left(1+\alpha\cos^2\theta^*\right)$$

- The polarization parameter α
  - $\alpha = +1$: helicity ± 1 or fully transverse.
  - $\alpha = -1$: helicity 0 or fully longitudinal.

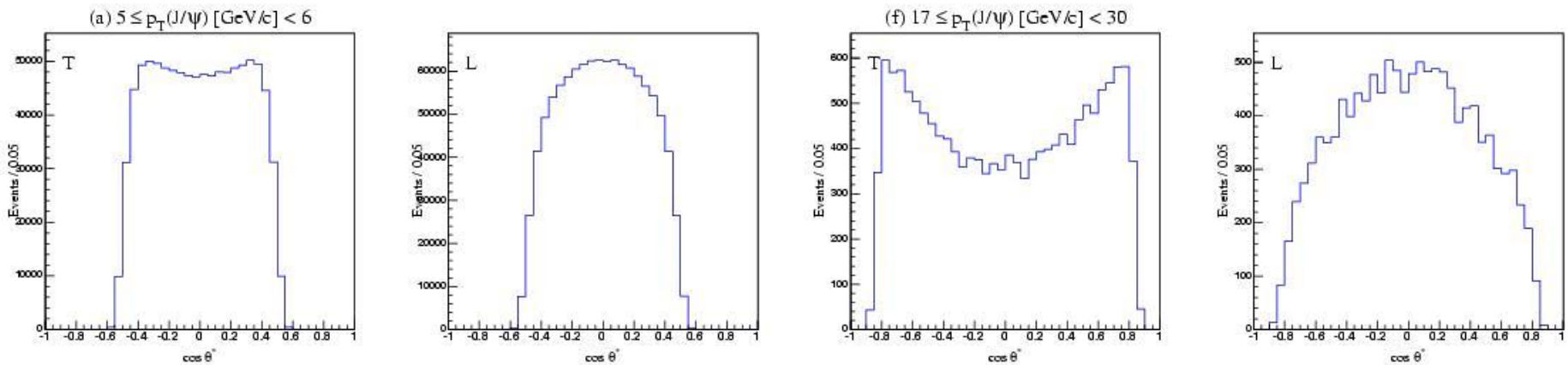
* This is a very challenging measurement since the detector behavior needs to be understood very well.
* Both the prompt V meson polarization and the polarization of V meson from B-decay are measured.

Polarization Measurement in $V \rightarrow \mu^+\mu^-$

Template method

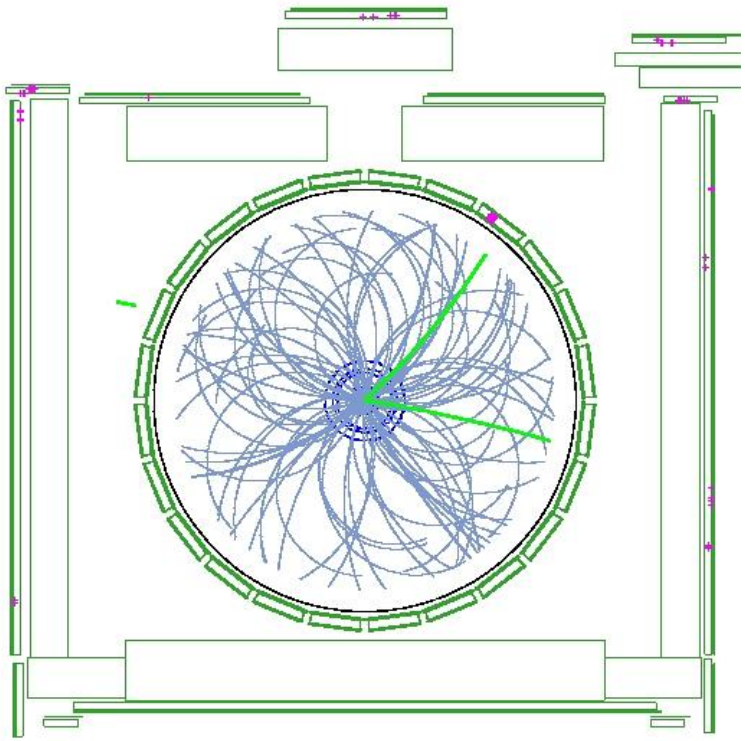
Main idea: Compare the observed $cos\theta^*$ distribution with fully polarized(transverse/longitudinal) $cos\theta^*$ distribution from Monte Carlo samples.

- Realistic MC samples are corrected for the detector acceptance, efficiency, and the trigger efficiencies.
- The polarization is obtained using a χ^2 fit of the data to a weighted sum of T & L templates.



Event Selection

- $800 pb^{-1}$ CDF Run II data collected by the track based dimuon trigger.
- $V \rightarrow \mu^+\mu^-$, $5 \leq p_T(\mu^+\mu^-) < 30\ \mathrm{GeV}/c, |y| < 0.6$.



- Muon candidates reconstructed in the Central Outer Tracker(COT) and Central Muon detectors(CMU,CMUP). Additionally, the Silicon Vertex Detector(SVX II) information is used.

- Minimum $p_T(\mu)$ 1.75 GeV/c to avoid trigger turn-on.

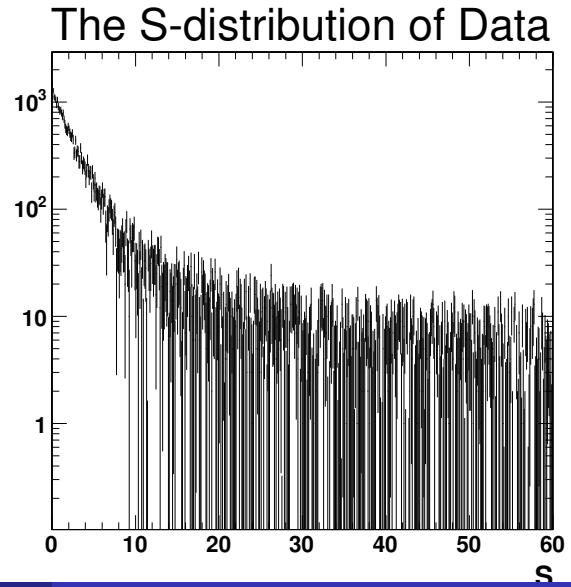
Prompt Vs. B-decay

Impact parameter significance cut

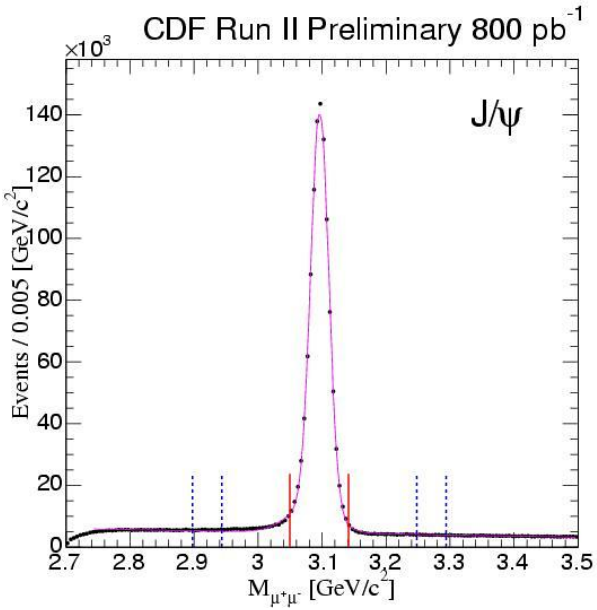
- V mesons from decays of B-hadrons have a different average polarization than prompt V mesons.
- The long B lifetime $\Rightarrow$ V mesons from B decay lead to muons that don't point to the primary vertex and can be separated by an impact parameter significance cut.

$$S = \left(\frac{d_0(\mu^-)}{\sigma_{d_0(\mu^-)}}\right)^2 + \left(\frac{d_0(\mu^+)}{\sigma_{d_0(\mu^+)}}\right)^2$$

- $S \leq 8$ for the prompt and $S > 16$ for the B-decay: based on the S - distribution of the data and a Monte Carlo sample.



J/ψ & $\psi(2S)$ Candidates

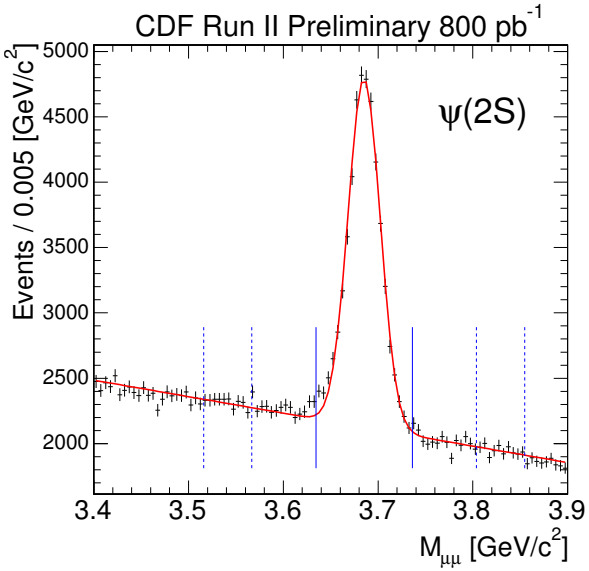


J/ψ candidates

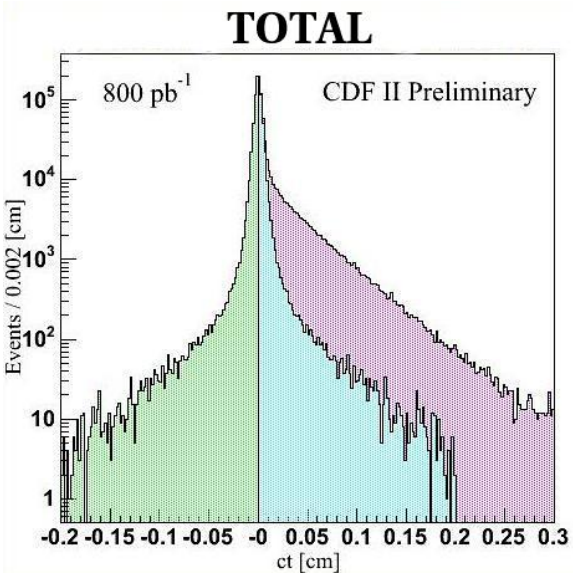
- A double Gaussian + a linear background.
- 6 p_T bins: 5-6, 6-7, 7-9, 9-12, 12-17, and 17-30.

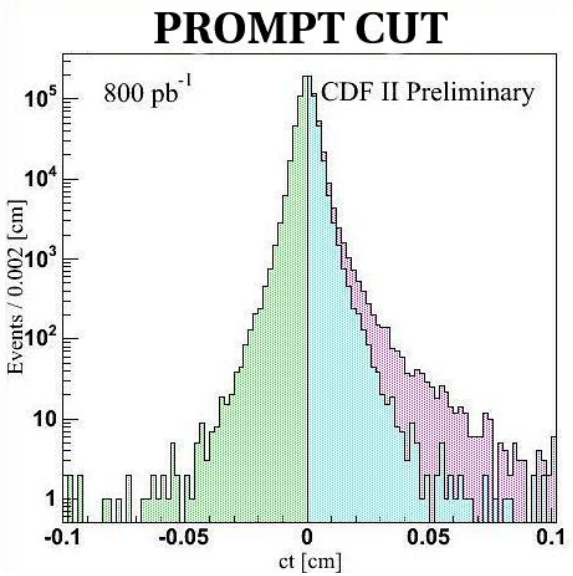
$\psi(2S)$ candidates

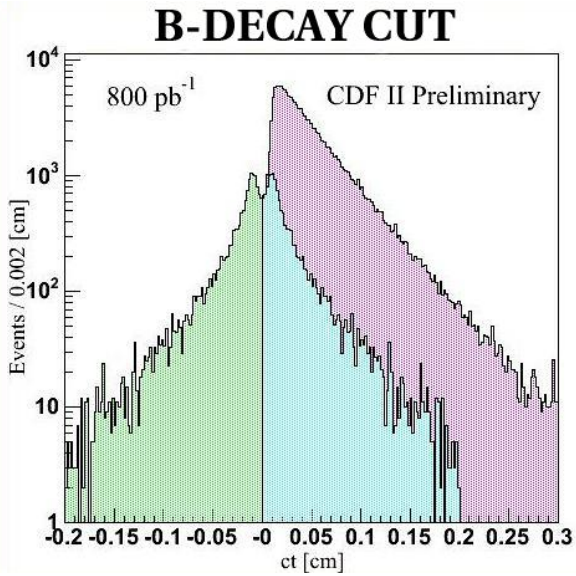
- A single Gaussian + a linear background.
- 3 p_T bins: 5-7, 7-10, and 10-30.



Signal Purity

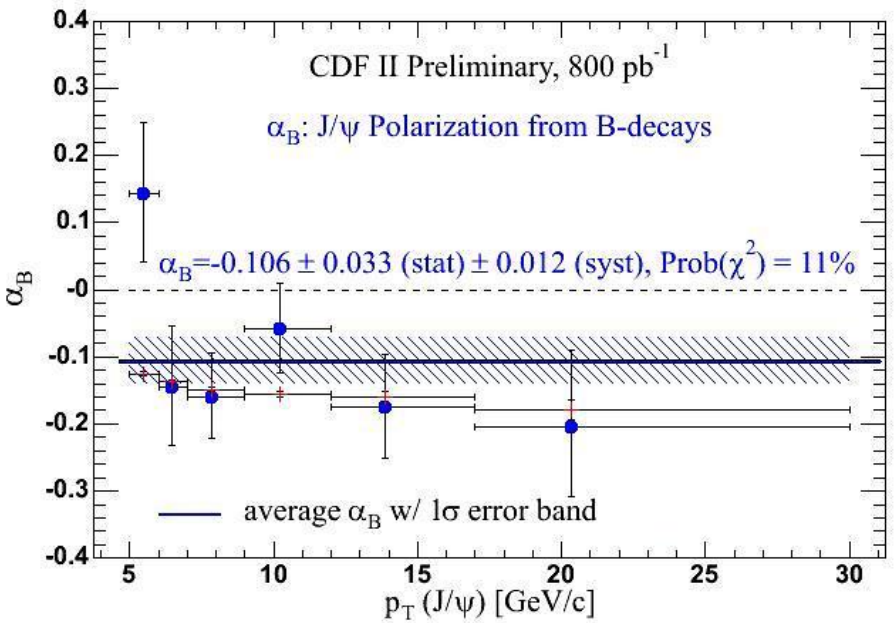






- plot proper time distribution of sideband-subtracted data.
- Prompt events: Gaussian centered at $ct = 0$.
- Mis-measured events: exponential tail visible at negative ct.
- B-decay events with $ct > 0$ purified by requiring $ct > 0.03$
- Residual background correction: $\alpha_{prompt} = \frac{\alpha_{fit} - F_B \cdot \alpha_B}{1 - F_B}$

Polarization of J/ψ from B-decay

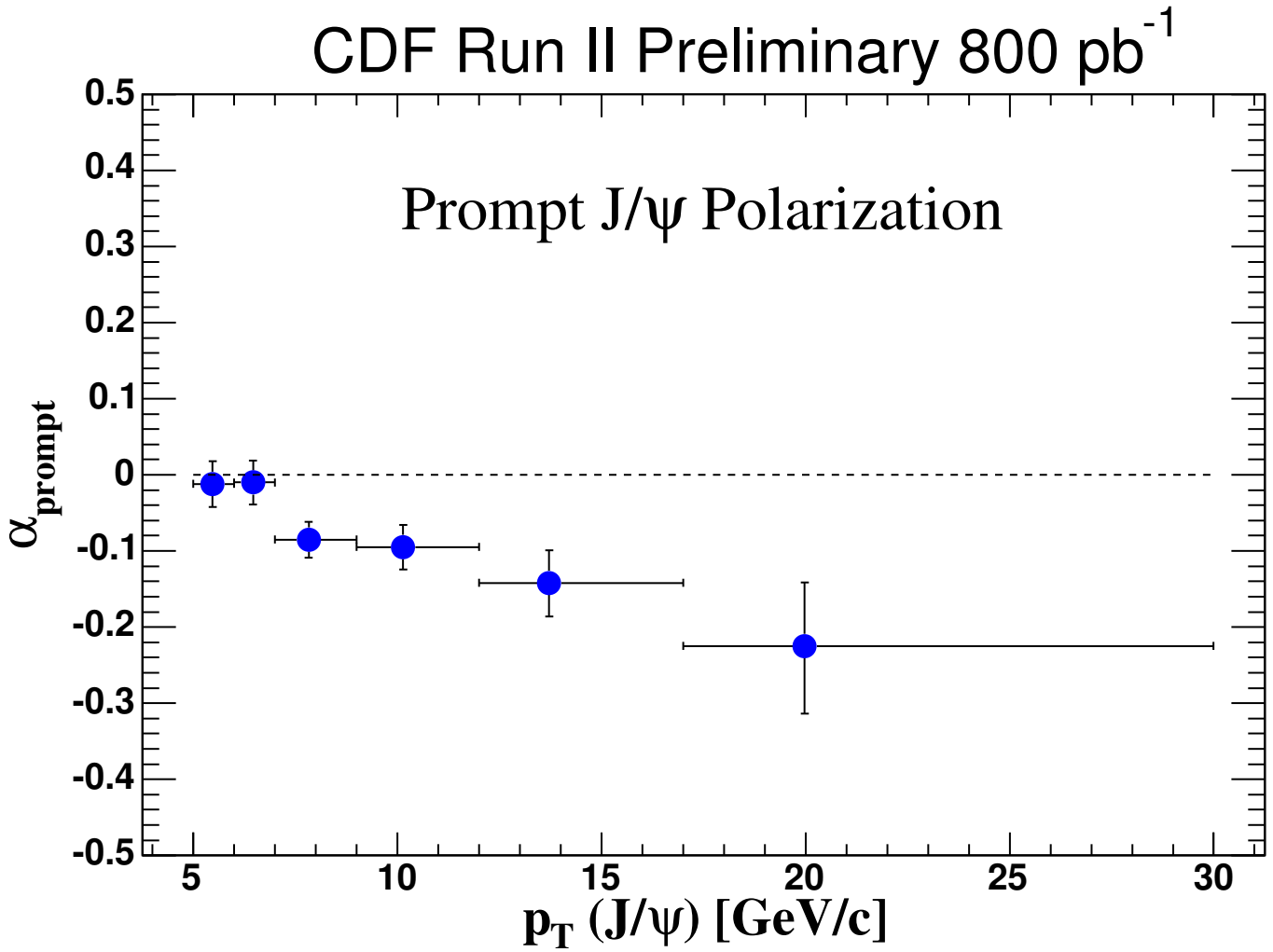


Polarization of J/ψ from B-decay

- All bins combined by a χ^2 average:
  $\alpha_B = -0.106 \pm 0.033 \pm 0.012$
  $Prob(\chi^2) = 11\%$

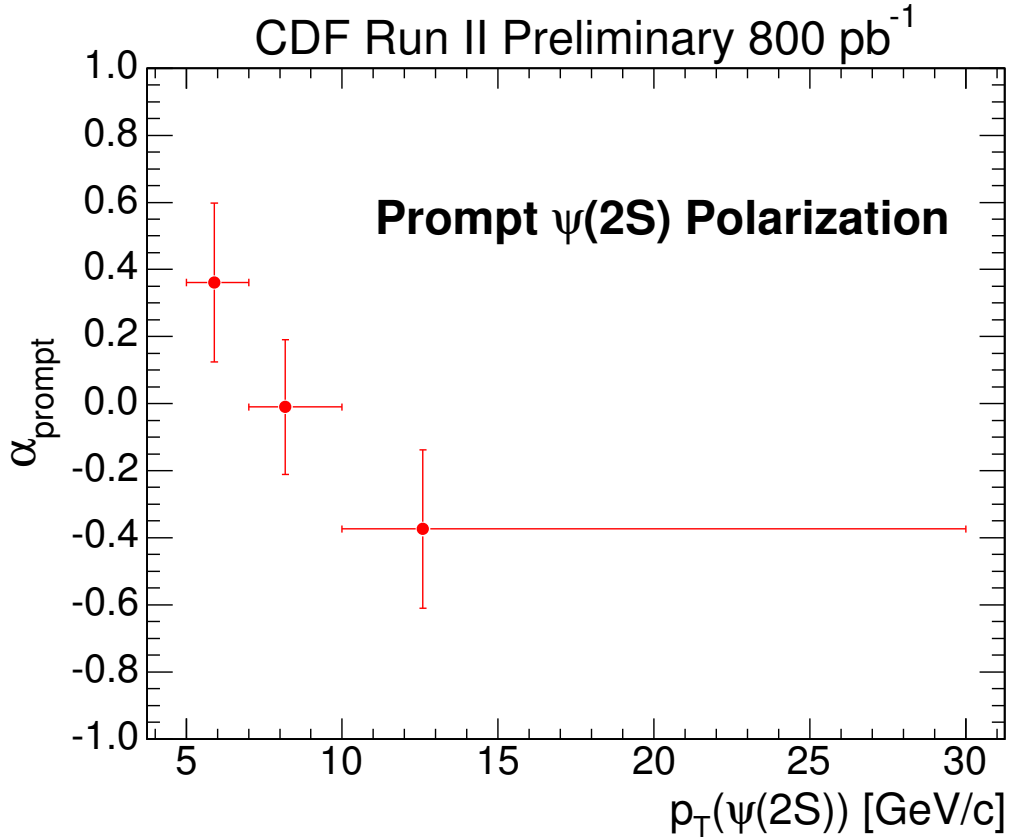
- CDF Simuilation study based on BaBar B meson decay measurement shows
  - polarization for daughter J/ψ mesons is flat in J/ψ $p_T > 5\ \mathrm{GeV}/c$.
  - average value from simulation is $\alpha_{eff} = -0.145 \pm 0.015$.
- CDF Run II measurement doesn't have enough statistics to determine any possible polarization influence from B_S or b-baryon decays.

Prompt J/ψ Polarization



- The polarization is longitudinal at all p_T.

Prompt $\psi(2S)$ Polarization



- The same experimental technique for both J/ψ & $\psi(2S)$.
- no feeddown contamination in $\psi(2S)$ decays.
- $\psi(2S)$ alignment is also longitudinal at high p_T.

Summary

Polarization of J/ψ & $\psi(2S)$ at CDF

- Both prompt J/ψ and $\psi(2S)$ have longitudinal polarization at high p_T.
- This results completely disagree with NRQCD predictions.
- Recent theory models predict longitudinal polarization at high p_T.
  - k_T-factorization approach: PRD,**66**, 11403(2002).
  - pomeron idea: Eur. Phys. J. C **39**, 163(2005).

- *Data on cross section, p_T spectra and polarization p_T dependence for both J/ψ and $\psi(2S)$ mesons over wide p_T range provide the basis for a critical re-examination of our understanding of the production of vector mesons in $p\bar{p}$ collision.*

Back Up

Back Up

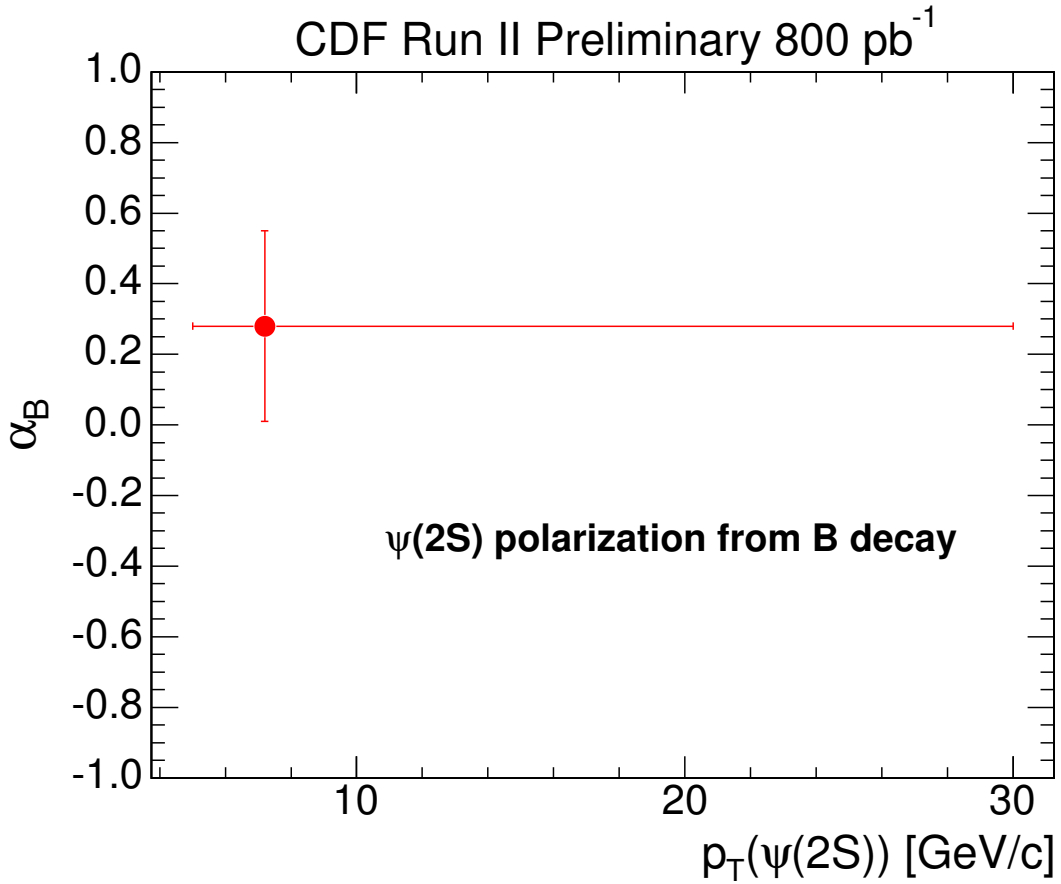
$p_T(J/\psi)$ [GeV/c]	Mean $p_T(J/\psi)$ [GeV/c]	α_{prompt}	χ^2/d.o.f
$5-6$	5.48	$-0.012 \pm 0.029 \pm 0.007$	21.4/22
$6-7$	6.47	$-0.010 \pm 0.028 \pm 0.007$	31.0/24
$7-9$	7.86	$-0.085 \pm 0.023 \pm 0.007$	46.7/27
$9-12$	10.22	$-0.095 \pm 0.028 \pm 0.007$	34.2/30
$12-17$	13.88	$-0.142 \pm 0.043 \pm 0.007$	38.3/32
$17-30$	20.33	$-0.225 \pm 0.089 \pm 0.007$	33.9/34

Table: Prompt J/ψ polarization in each p_T bin.

$p_T(\psi(2S))$ [GeV/c]	Mean $p_T(\psi(2S))$ [GeV/c]	α_{prompt}	χ^2/d.o.f
$5-7$	5.9	$+0.361 \pm 0.237 \pm 0.028$	13.8/12
$7-10$	8.2	$-0.010 \pm 0.201 \pm 0.022$	19.6/14
$10-30$	12.6	$-0.374 \pm 0.236 \pm 0.017$	26.8/16

Table: Prompt $\psi(2S)$ polarization in each p_T bin.

Back Up



- The first measurement of α_B for $\psi(2S)$: $\alpha_B = 0.28 \pm 0.27 \pm 0.03$