Quarkonium Production at J-PARC

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Outline

- Quarkonium Production at J-PARC with Unpolarized Proton Beam
- Quarkonium Production at J-PARC with Polarized Beam and Target

Physics with quarkonium production at J-PARC

J/Ψ production with unpolarized proton beam :

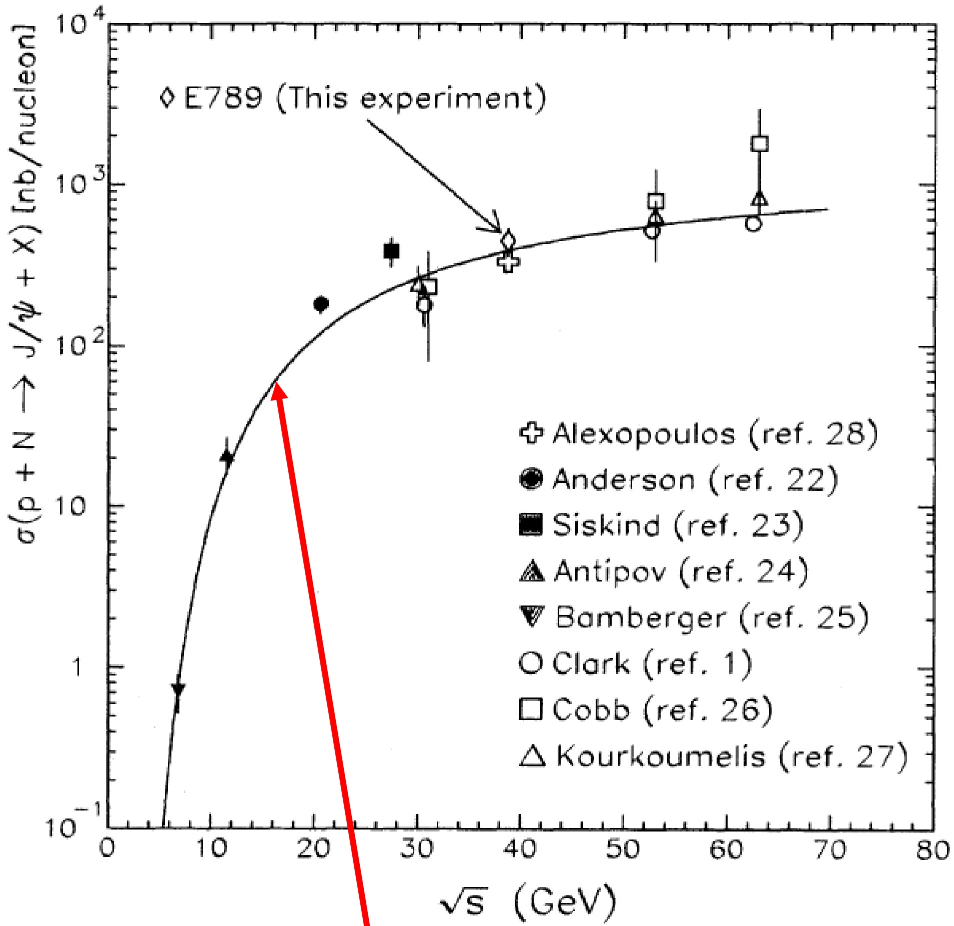
- J/Ψ production mechanism at J-PARC energies -- is it dominated by quark-antiquark annihilation or gluon-gluon fusion?
- Nuclear dependence of J/Ψ production
- Antiquark distributions in nucleons and nuclei
- Polarization of J/Ψ and Ψ'

J/Ψ Production with polarized beam/target:

- Sivers quark distribution with single-spin asymmetry A_N
- Sea-quark polarization with double-spin asymmetry A_{LL}
- Quark transversity distributions with double-spin asymmetry A_{TT}

J/Ψ Production at J-PARC Energies

Very few data for J/Ψ production at 30-50 GeV



- 24 GeV/c at CERN-PS
- 70 GeV/c at IHEP

Schub et al., Fermilab E789, PR D52 (1995) 1307

$$\sigma(p + N \rightarrow J/\Psi + x) = Ae^{-B\sqrt{\tau}}; \text{ where } \tau = M^2/s$$

Color-Evaporation Model for J/Ψ Production

$$d\sigma / dx_F (J/\psi) = F \int_{\tau_1}^{\tau_2} 2\tau d\tau H_{PT}(x_1, x_2; m^2) / (x_F^2 + 4\tau^2)^{1/2}$$

where $\tau^2 = m^2 / s$ and $x_F = x_1 - x_2$

τ_1 : $Q\bar{Q}$ threshold,

τ_2 : open charm threshold

$$H_{PT}(x_1, x_2; m^2) =$$

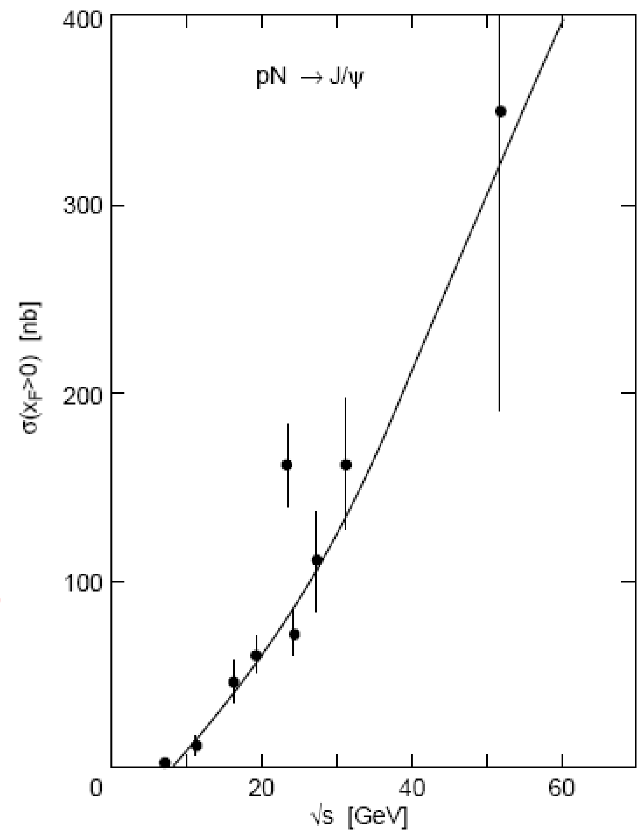
$$G_P(x_1) G_T(x_2) \sigma(gg \to Q\bar{Q}; m^2)$$

$$+ \sum_{i=u,d,s} \{q_P^i(x_1)\bar{q}_T^i(x_2) + \bar{q}_P^i(x_1) q_T^i(x_2)\} \sigma(q\bar{q} \to Q\bar{Q}; m^2)$$

Gluon-gluon fusion

Quark-antiquark annihilation

CEM calculations versus data

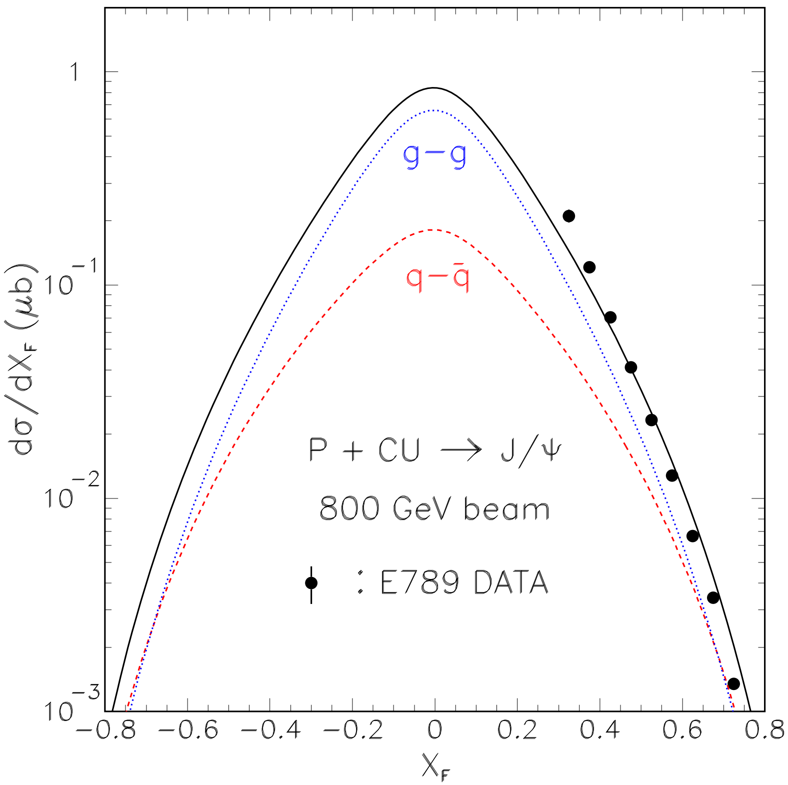


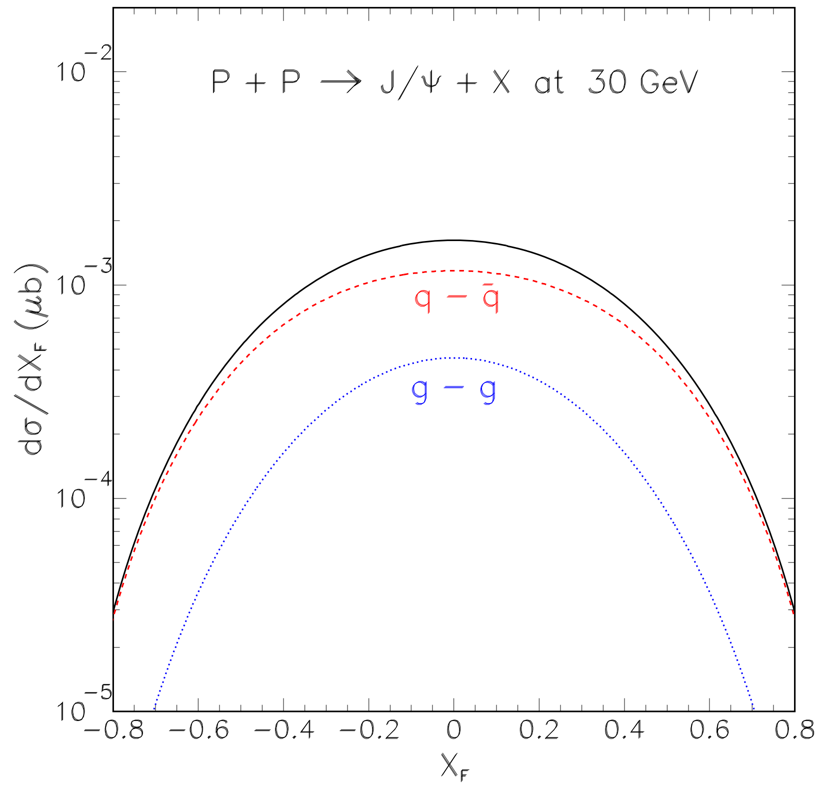
Schuler, Vogt, PL B 387(1996)181

J/Ψ Production at 30 GeV

At 800 GeV, J/Ψ production is dominated by gluon-gluon fusion

At 30 GeV J/Ψ production is dominated by quark-antiquark annihilation

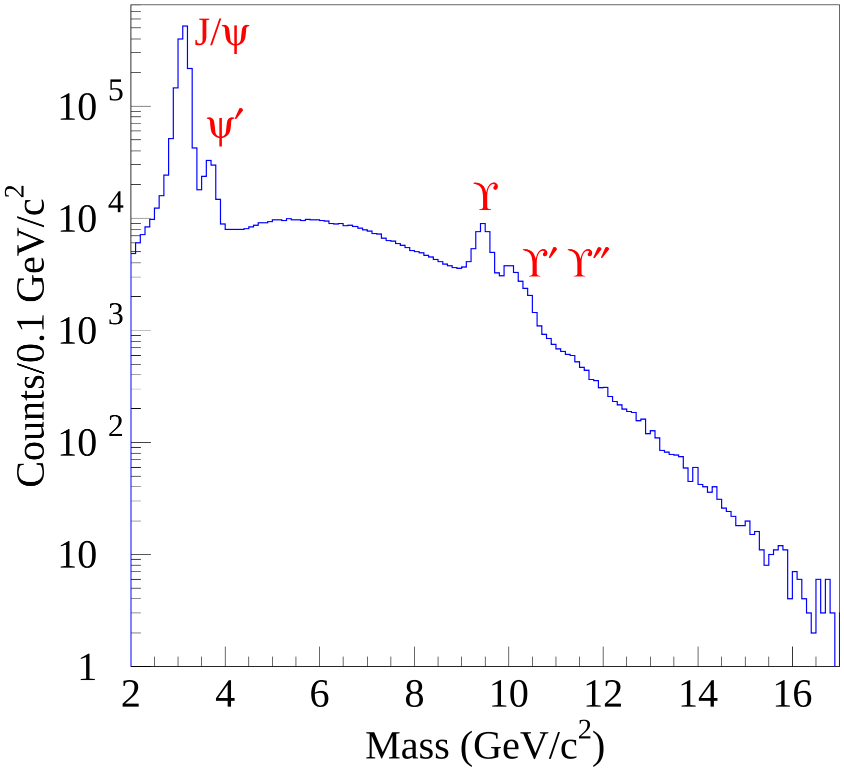


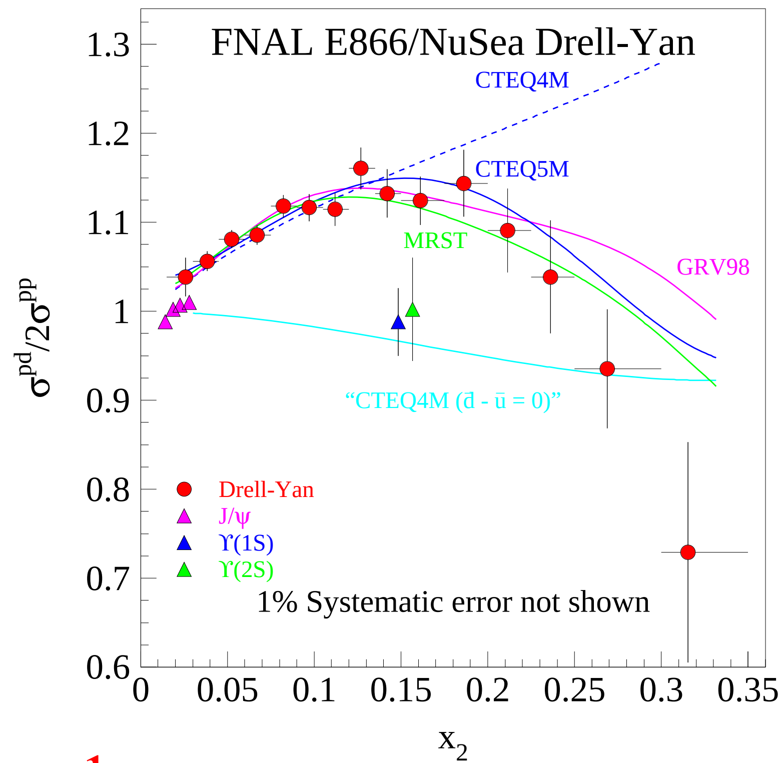


J/Ψ production at 30 GeV is sensitive to quark and antiquark distributions

Evidence that gluon-gluon fusion is the dominant mechanism at 800 GeV

$$800\ GeV\ \ \sigma(p+d \rightarrow \mu^{+}\mu^{-}X)/\sigma(p+p \rightarrow \mu^{+}\mu^{-}X)$$



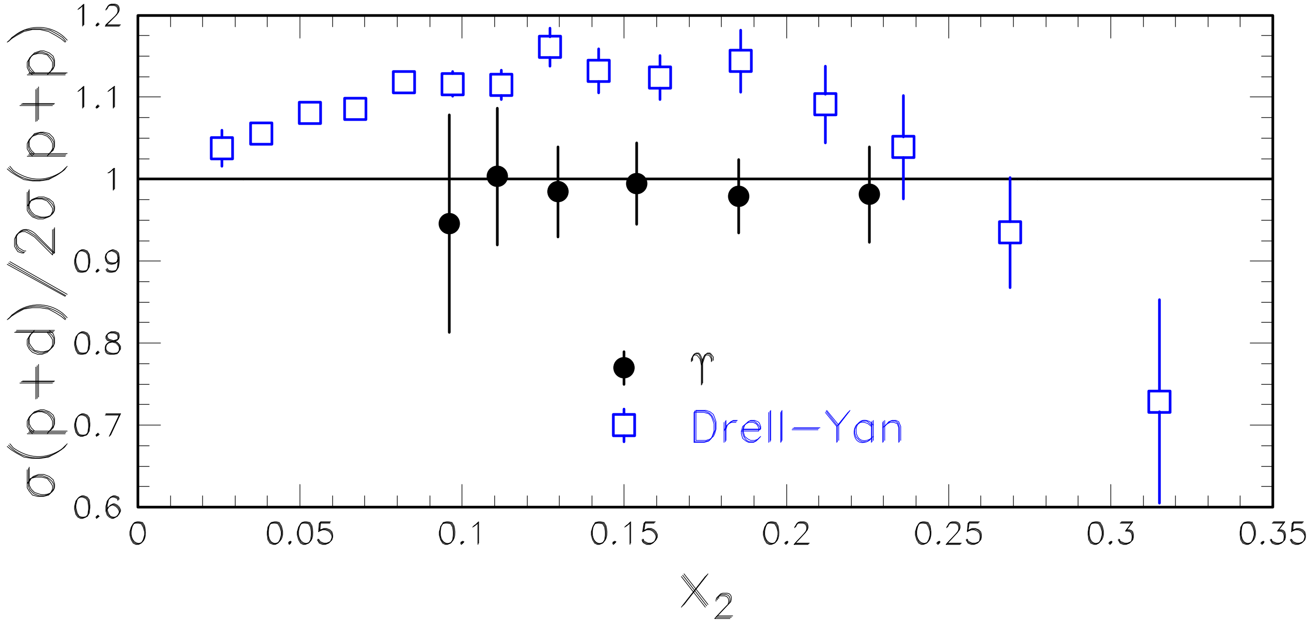


$$Drell-Yan:\quad \sigma^{pd}/2\sigma^{pp} \approx \frac{1}{2}[1+\bar{d}(x)/\bar{u}(x)]$$

$$J/\Psi,\Upsilon:\quad \sigma^{pd}/2\sigma^{pp} \approx \frac{1}{2}[1+g_n(x)/g_p(x)]$$

Evidence that gluon-gluon fusion is the dominant mechanism at 800 GeV

$$800\ GeV\ \sigma(p+d\to\mu^+\mu^-X)/\sigma(p+p\to\mu^+\mu^-X)$$

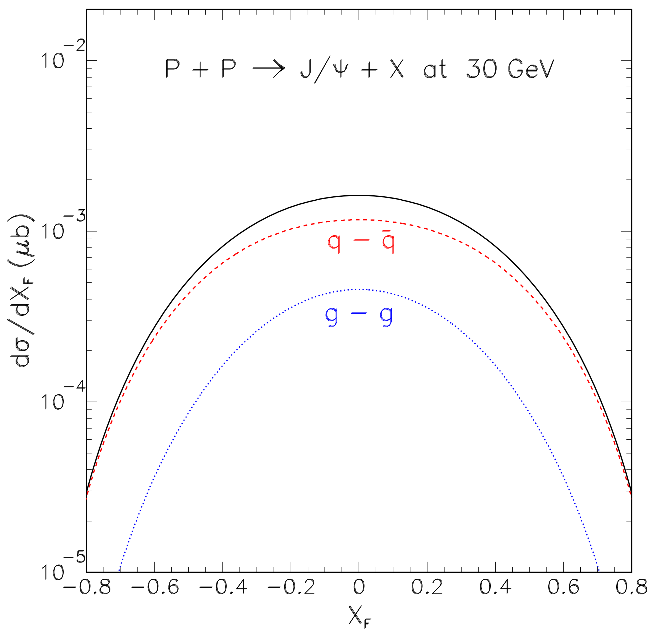


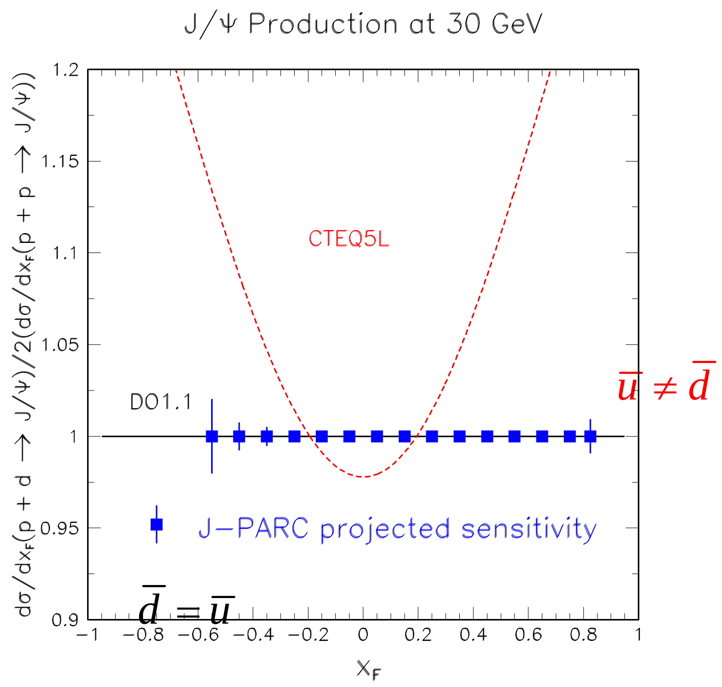
E866 collaboration: PRL 100 (2008) 062301

$$Drell-Yan:\quad \sigma^{pd}/2\sigma^{pp} \approx \frac{1}{2}[1+\bar{d}(x)/\bar{u}(x)]$$

$$J/\Psi,\Upsilon:\quad \sigma^{pd}/2\sigma^{pp} \approx \frac{1}{2}[1+g_n(x)/g_p(x)]$$

Is quark-antiquark annihilation the dominant mechanism at 30 GeV ?



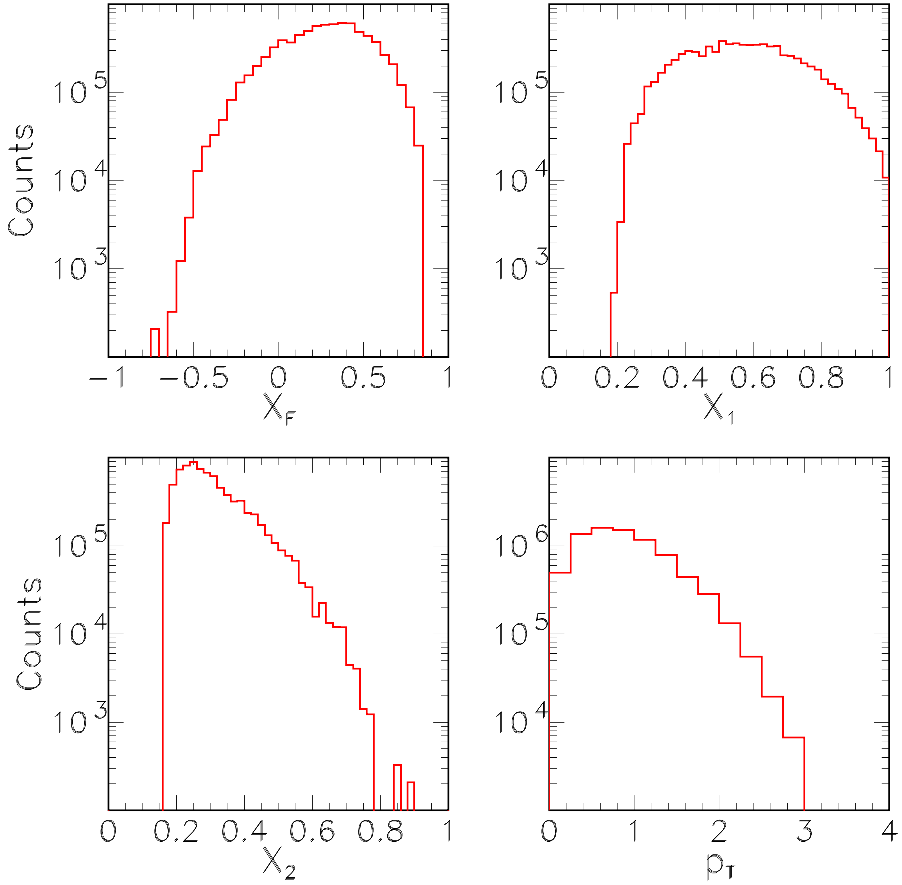


$\sigma(p+d \rightarrow J/\Psi)/\sigma(p+p \rightarrow J/\Psi)$ is a sensitive test for the production mechanism

J/Ψ production at J-PARC could be sensitive to quark/antiquark distributions!

Expected J/Ψ yields and kinematic coverage

J/Ψ yields for a two-month p+d run at 30 GeV



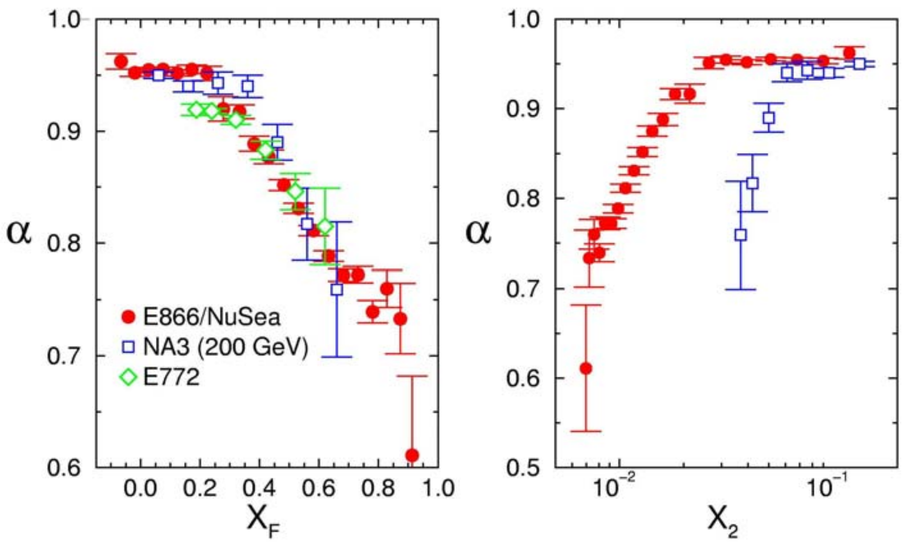
Broad coverage in x_F, x_1, x_2, p_T

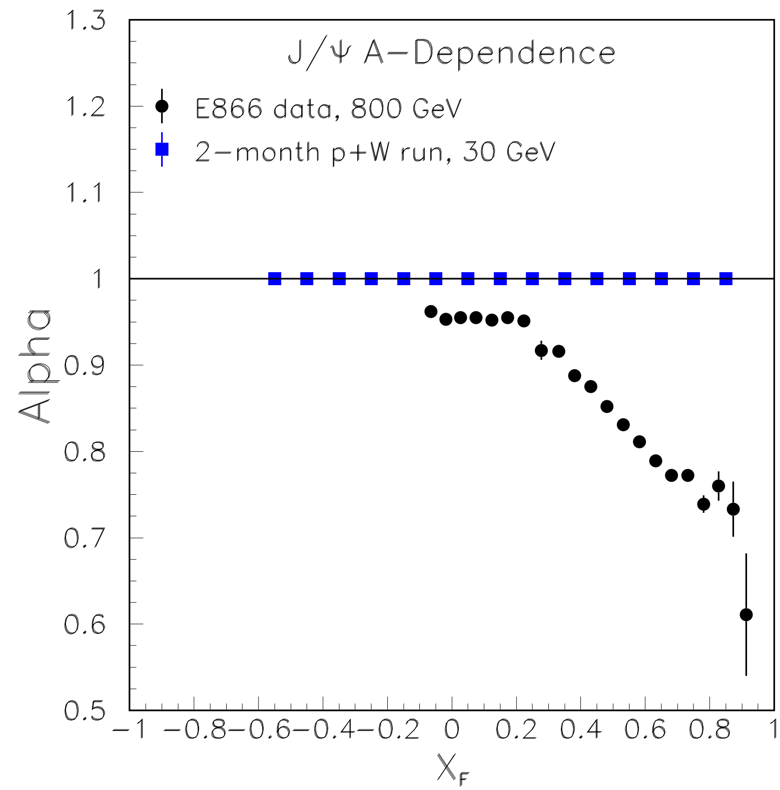
Expected total number of J/Ψ events: ~ $8x10^6$

- 10^{12} protons/spill
- 50-cm long liquid deuterium target
- Assume 50 percent efficiency

Nuclear Dependence of J/Ψ Production at 30 GeV

$$\sigma(p+A) = A^{\alpha}\sigma(p+N)$$





- 30 GeV data would provide an interesting test for the x_F-scaling in J/ψ production
- Very few data exist for negative x_F region

Polarization of J/Ψ and Ψ′

- Decay angular distribution in the quarkonium rest frame

$$\frac{d\sigma}{d\Omega} \propto 1+\lambda\cos^2\theta$$

  - * Transverse : σ_T ; helicity: ± 1; $\lambda = 1$
  - * Longitudinal : σ_L ; helicity: 0; $\lambda = -1$
  - * Unpolarized : $\sigma_T = 2\sigma_L$; helicity: $0, \pm 1$; $\lambda = 0$

- $\lambda = \dfrac{\sigma_T - 2\sigma_L}{\sigma_T + 2\sigma_L} = (1-2\sigma_L/\sigma_T)/(1+2\sigma_L/\sigma_T)$
- σ_L/σ_T depends on the color - spin states of the $Q\bar{Q}$ pair :

State:	${}^3S_1^{(1)}$	${}^1S_0^{(8)}$	${}^3P_J^{(8)}$	${}^3S_1^{(8)}$
σ_L/σ_T :	$1/3.4$	$1/2$	$1/6$	$0/1$

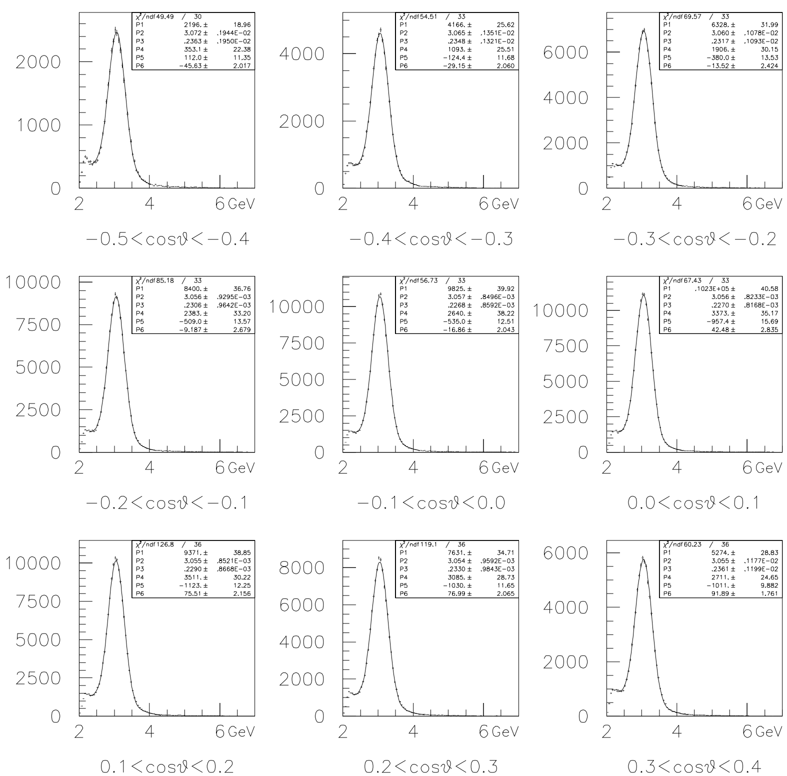
- Polarization of $Q\bar{Q}$ is sensitive to the production mechanism

Polarization of J/Ψ

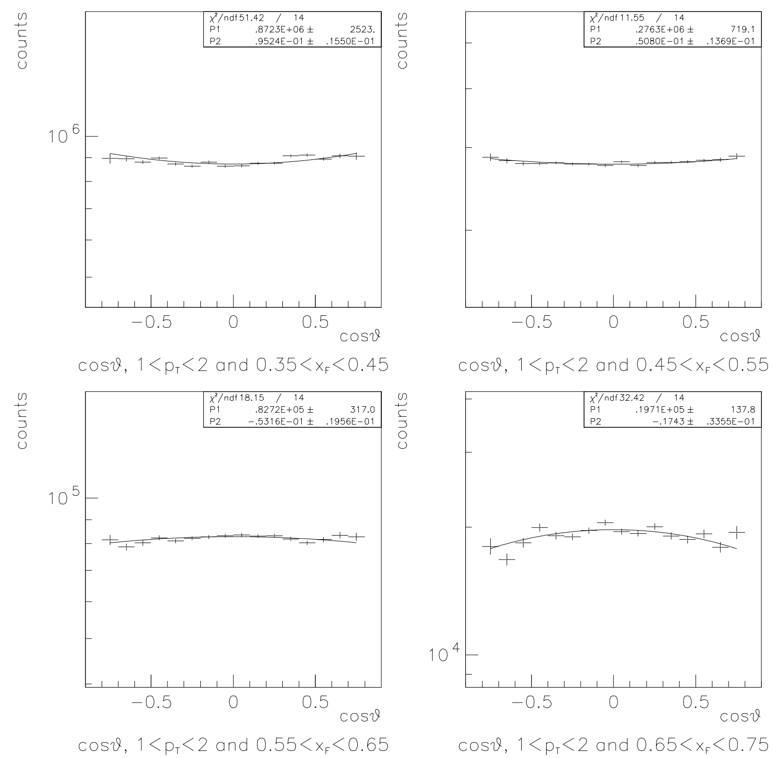
E866 p + Cu → J/Ψ + x (beam dump) $s^{1/2} = 38.8$ GeV

(PRL 91 (2003) 21180,hep-ex/030801, T. Chang et al.)

Typical dimuon mass spectrum for various xF, pT, cosθ bins



$d\sigma/d\Omega \sim 1 + \lambda\cos^2\theta$ (extraction of λ for various x_F, p_T bins)

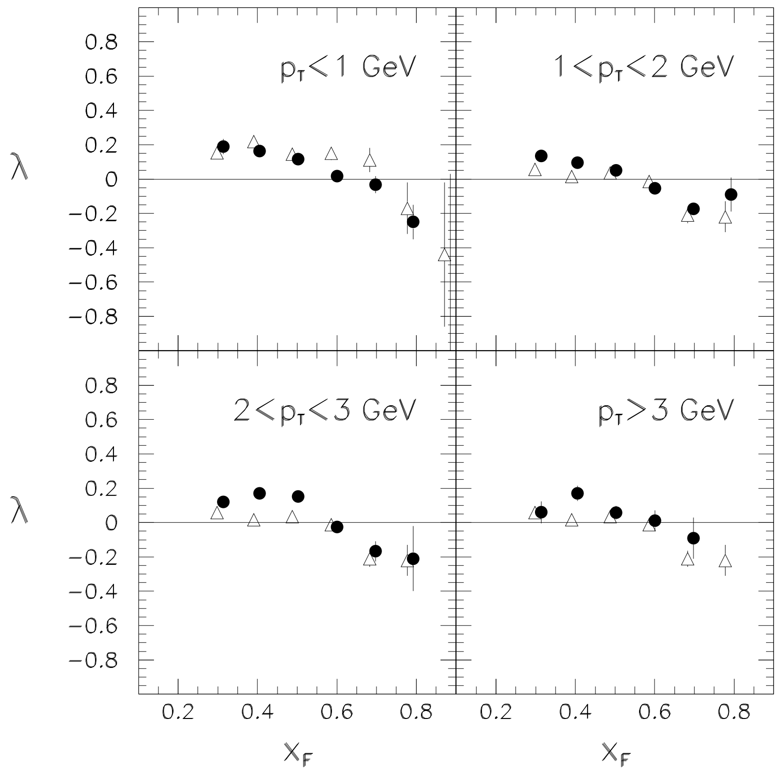


Polarization of J/Ψ in p + Cu Collision

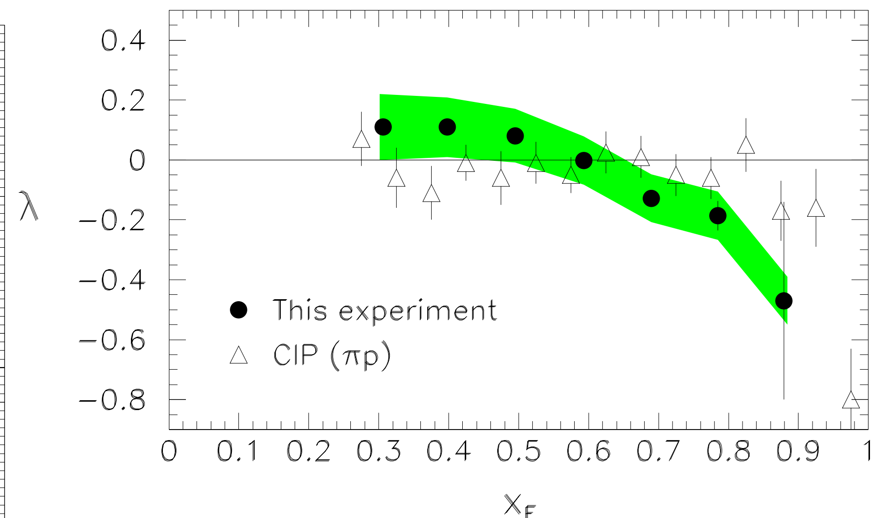
$$d\sigma/d\Omega \sim 1 + \lambda \cos^2\theta$$

(λ=1: transversely polarized, λ = -1: longitudinally polarized
λ = 0, unpolarized)

E866 data



hep-ex/030801



- λ is small, but nonzero
- λ becomes negative at large x_F
- No strong p_T dependence for λ

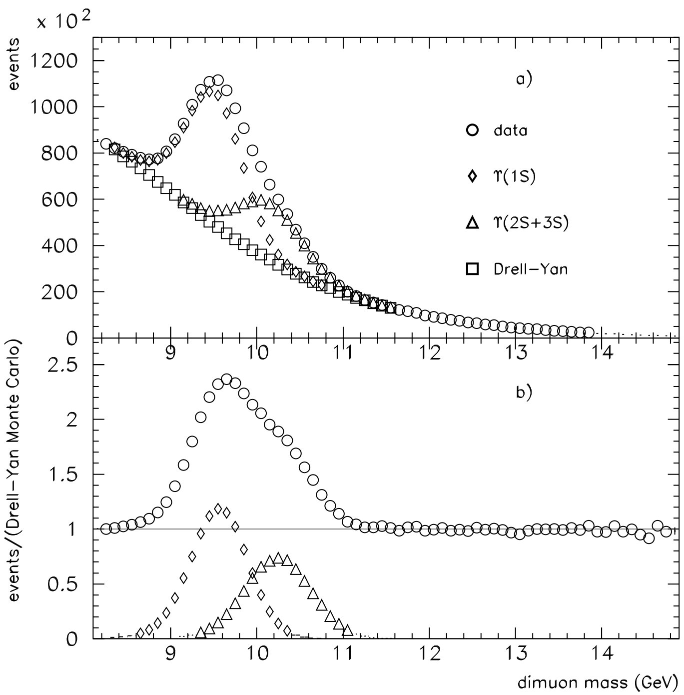
Polarization of Ψ' has never been measured

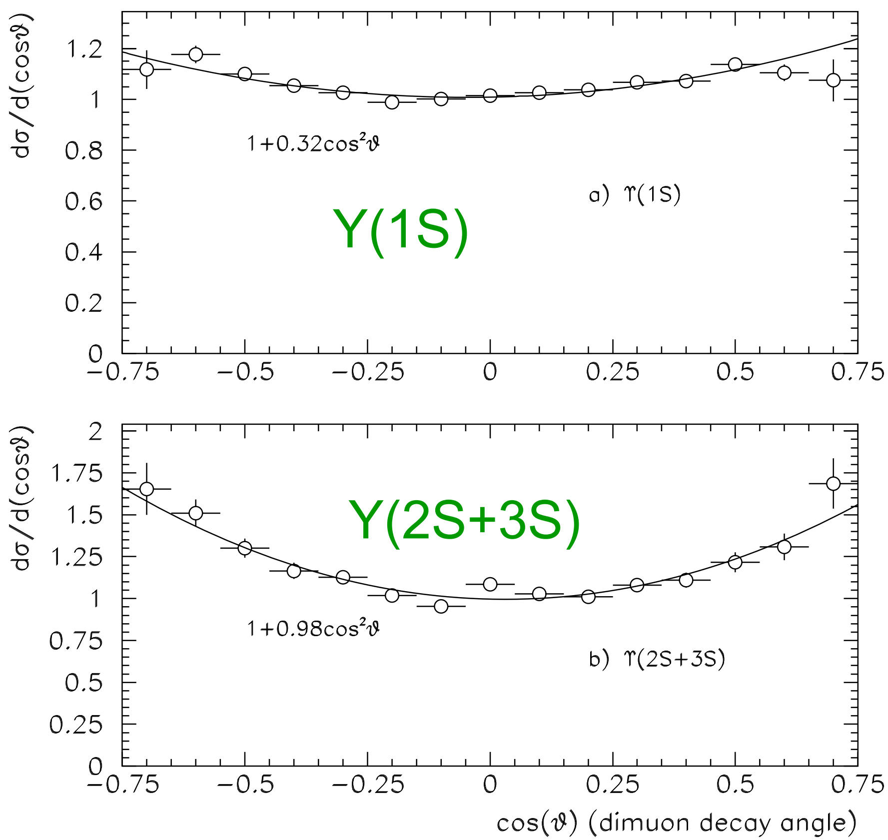
Polarization of Y(1S),Y(2S+3S)

p + Cu →Y + x (E866 beam-dump data)

Dimuon mass spectrum

Decay angular distributions



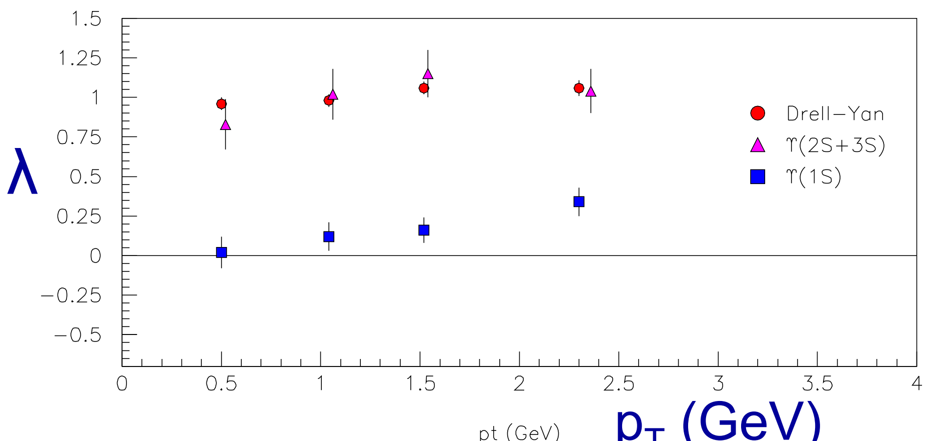


Brown et al. PRL 86, 2529 (2001)

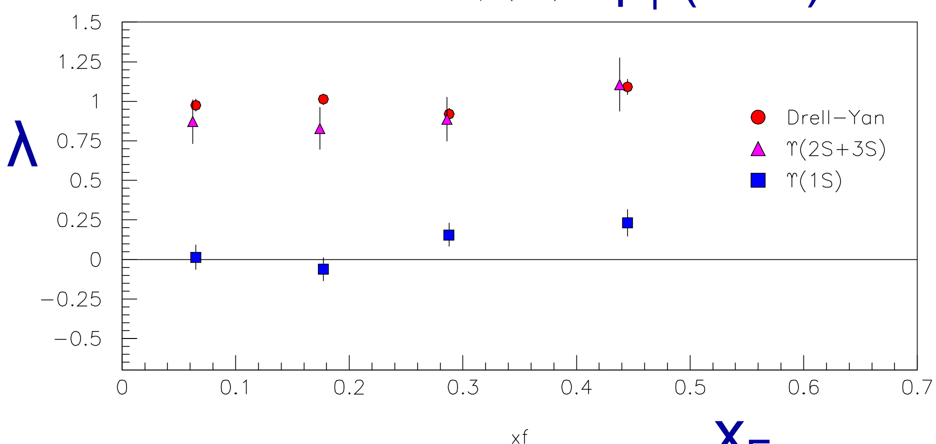
Polarization of Υ(1S),Υ(2S+3S)

p + Cu →Υ + x (E866 beam-dump data)

λ for D-Y, Υ(1S), Υ(2S+3S)



p_T (GeV)



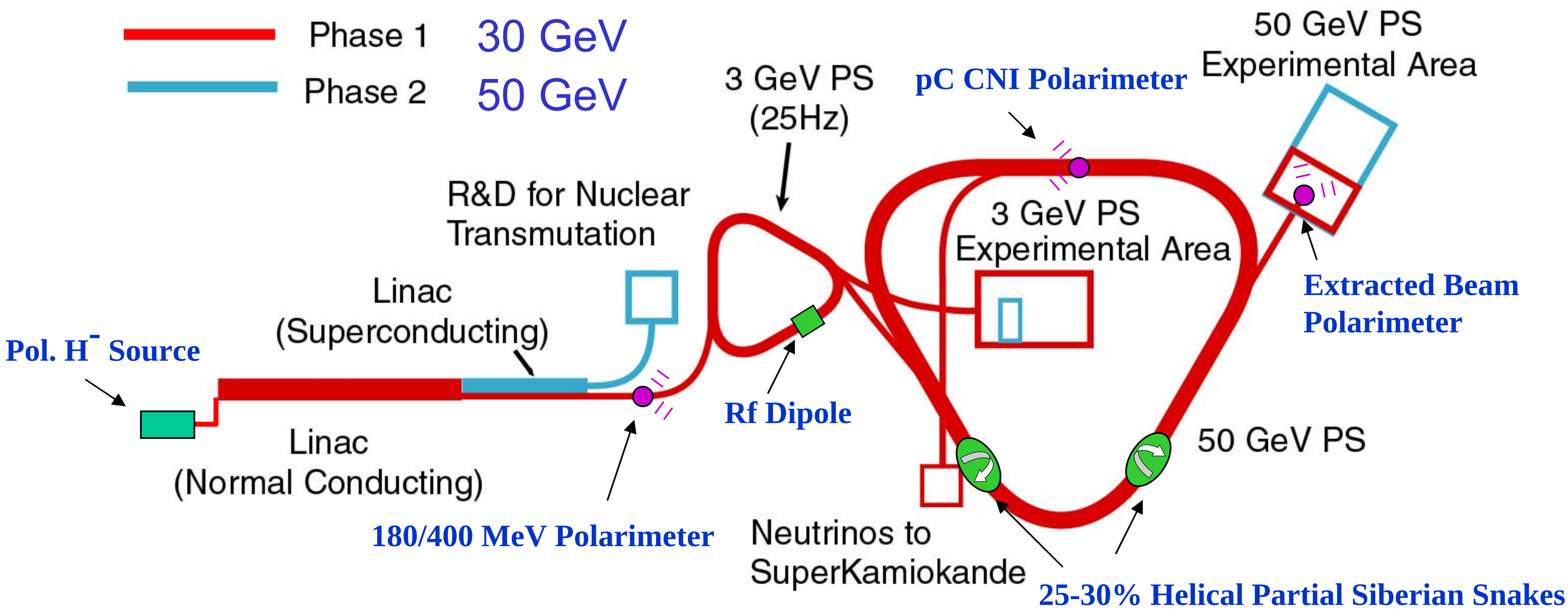
x_F

Brown et al. PRL 86, 2529 (2001)

- D-Y is transversely polarized
- Υ(1S) is slightly polarized (like J/Ψ)
- Υ(2S+3S) is transversely polarized!
- Analysis of Υ polarization in p+p and p+d is underway (nuclear dependence?)
- Preliminary result shows ψ’ is also transversely polarized!

Polarized proton beam at J-PARC ?

- **Polarized proton beam at J-PARC with**
  - **Polarized H^- source**
  - **RF dipole at 3 GeV RCS**
  - **Two 30% partial snakes at 50 GeV Main Ring**

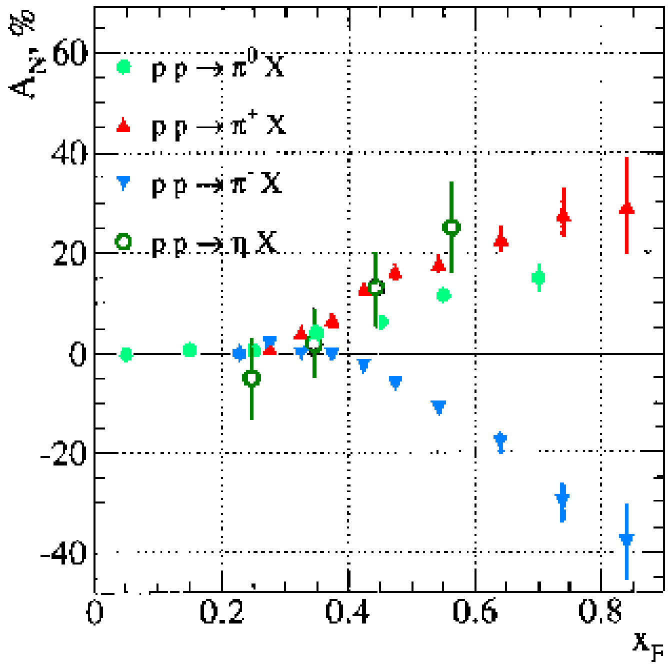


Single-spin asymmetry in polarized p-p collision

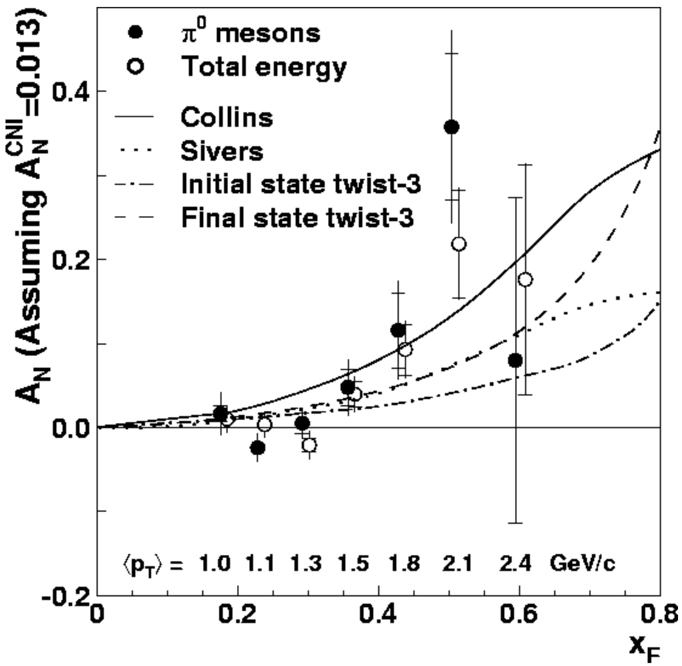
Large single-spin asymmetry in light meson production in polarized p-p:

Sivers, Collins, and/or higher-twist effect?

FNAL-E704 E_{lab} = 200 GeV



RHIC-STAR $\sqrt{s}$ = 200 GeV

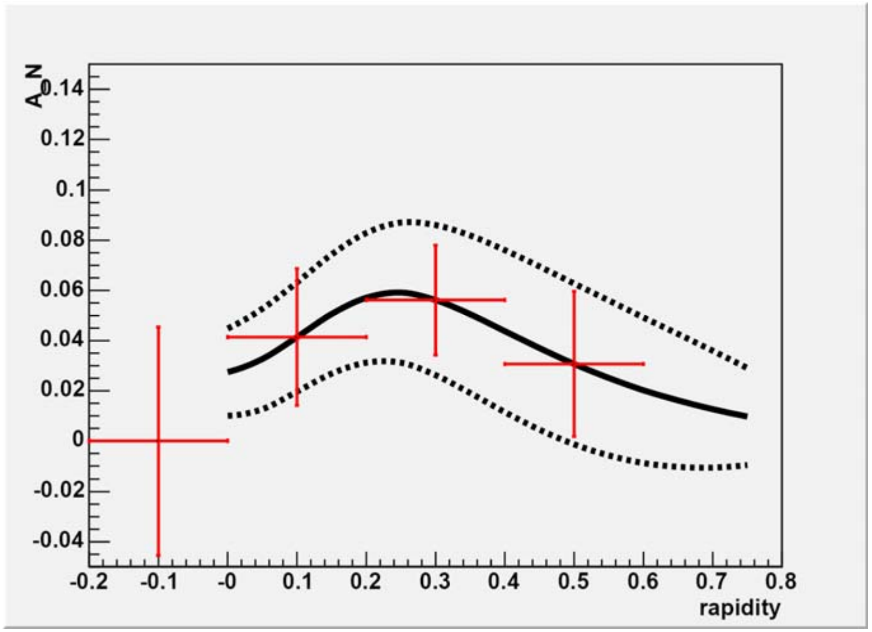


What is the single-spin asymmetry for J/Ψ production?

Single-spin asymmetry in polarized p-p at J-PARC

Single-spin asymmetry (A_N) can probe Sivers function

– Sivers function in Drell-Yan is expected to have a sign opposite to that in DIS



$$A_N^{DY} = \frac{\sum_q e_q^2 f_{1T}^{\perp}(x_q) f_{\bar{q}}(x_{\bar{q}})}{\sum_q e_q^2 f_q(x_q) f_{\bar{q}}(x_{\bar{q}})}$$

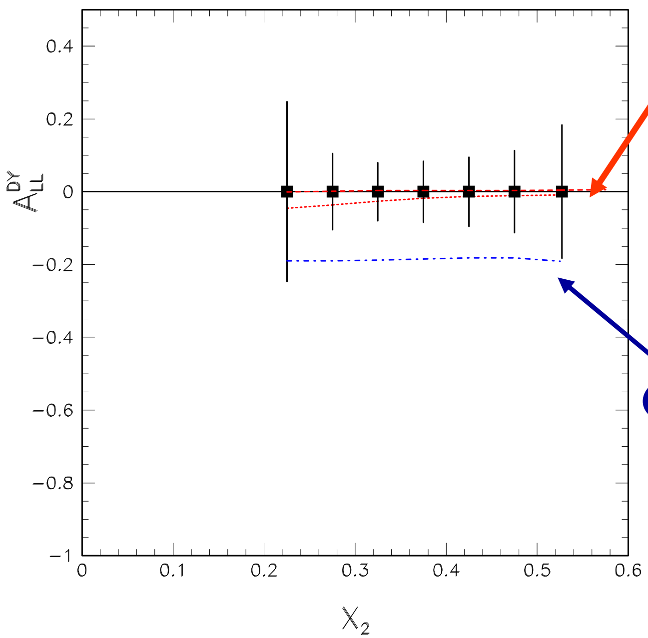
- J/Ψ production could also probe the Sivers function

- Much higher statistics could be obtained in J/Ψ production

Double-spin asymmetry in polarized p-p at J-PARC

Double-spin asymmetry (A_{LL}) with longitudinally polarized beam/target in Drell-Yan (and J/Ψ) probe Sea-Quark polarization

D-Y A_{LL} at 50 GeV



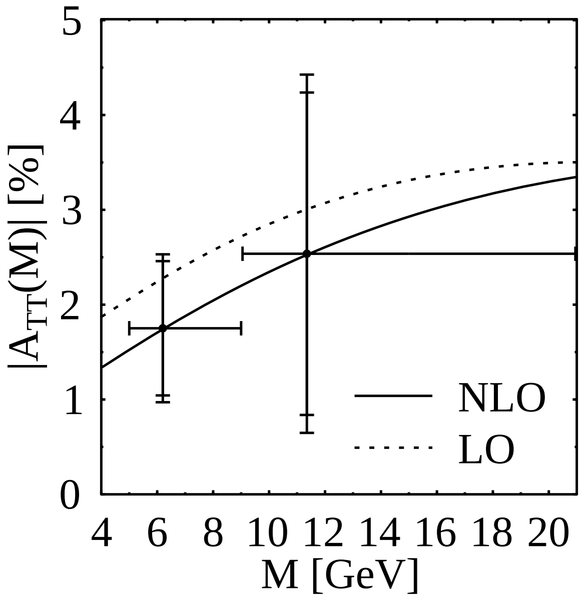
$$A_{LL}^{DY} = \frac{\sum_a e_a^2[\Delta q_a(x_1)\Delta\bar{q}_a(x_2) + \Delta\bar{q}_a(x_1)\Delta q_a(x_2)]}{\sum_a e_a^2[q_a(x_1)\bar{q}_a(x_2) + \bar{q}_a(x_1)q_a(x_2)]}$$

- J/Ψ production could also probe the Sea-Quark polarization
- Much higher statistics could be obtained in J/Ψ production

Double-spin asymmetry in polarized p-p at J-PARC

Double-spin asymmetry (A_{TT}) with transversely polarized beam/target in Drell-Yan (and J/Ψ) probe quark transversity distribution

PHENIX, $s^{1/2}$=200GeV, 320 pb^{-1}



$$A_{TT} = \hat{a}_{TT} \frac{\sum_q e_q^2 h_1^q(x_1, M^2) h_1^{\bar{q}}(x_2, M^2)}{\sum_q e_q^2 q(x_1, M^2) \bar{q}(x_2, M^2)}$$

- J/Ψ production could also probe the transversity distribution

- Much higher statistics could be obtained in J/Ψ production

Summary

- A rich physics program in J/Ψ production can be carried out at the J-PARC using primary proton beam.
- J/Ψ production at J-PARC energies is expected to be dominated by quark-antiquark annihilation, similar to Drell-Yan but with much larger cross sections.
- An extensive and exciting program in spin physics can be pursued if polarized proton and polarized targets are available at J-PARC.