Study of Heavy Quark and Quarkonium Production in Polarized p-p Collisions

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(PHENIX Collaboration)

–Physics Motivation

–Expectations from Run3 (PHENIX)

–Ideas for New Physics Search

Physics with Heavy Quarks

- Gluon Polarization
  - proton spin puzzle
- pQCD with Heavy Quarks
  - J/Psi production and polarization
  - Spin transfer in heavy quark production
- New Physics beyond the Standard Model
  - light gluino
  - graviton and extradimension

Gluon Polarization?

- Proton Spin Puzzle and ΔG

$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta G + \Delta L_{G+q}$$
$$= J_q + J_G$$

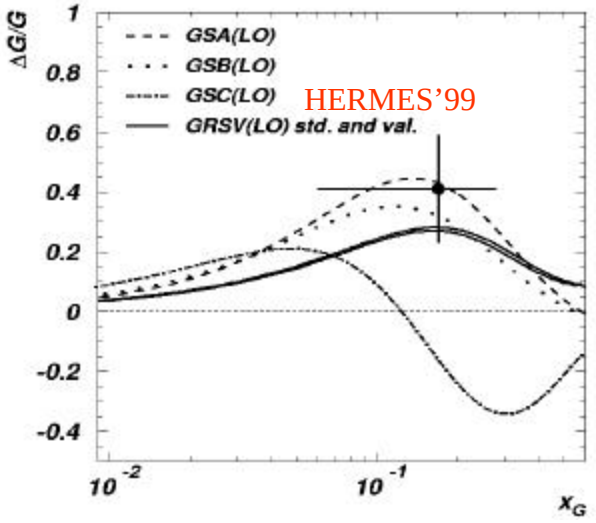
Experimentally

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s = 0.31 \pm 0.04$$
$$\Delta s = -0.10 \pm 0.02$$
$$\left\langle \frac{\Delta G(x)}{G(x)} \right\rangle = 0.41 \pm 0.18 \pm 0.03; \quad \langle x_G \rangle = 0.17$$

- Asymptotic limit $Q^2 \to \infty$

$$J_q(Q^2) = \frac{1}{2}\Delta\Sigma + \Delta L_q \to \frac{1}{2}\frac{3n_f}{16 + 3n_f}$$
$$J_G(Q^2) = \Delta G + \Delta L_G \to \frac{1}{2}\frac{16}{16 + 3n_f}$$

Gluons may play a significant role !



NASA Los Alamos

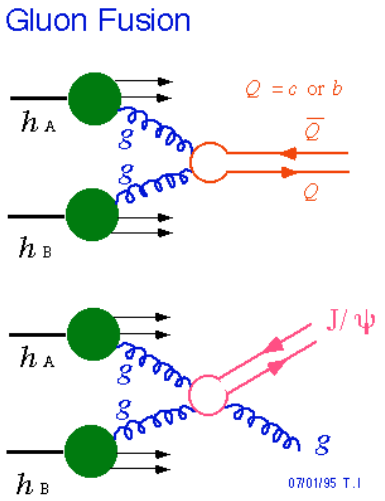
Why Heavy Quarks?

- Heavy Quark production at 200 GeV

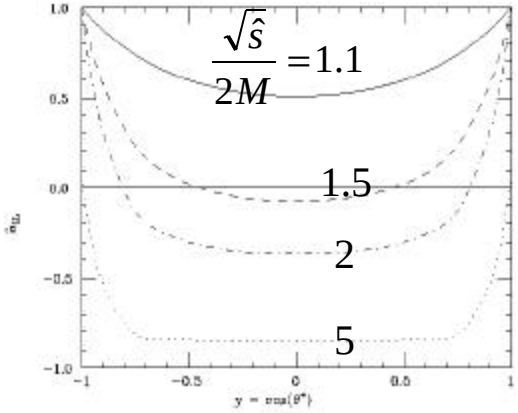
$$c\bar{c}: \; gg \to c\bar{c} \quad 95\%$$
$$b\bar{b}: \; gg \to b\bar{b} \quad 85\%$$

- distinct experimental signatures
  - high Pt lepton
  - 2nd vertex
- pQCD - theoretical advantage
  - $M_Q >> \Lambda_{QCD}$
  - $E\frac{d^3 s_X}{dp^3} \propto F_A^a(x_a,Q^2) \otimes F_B^b(x_b,Q^2) \otimes \frac{ds_{ab}^{cd}}{dt} \otimes D_X(z)$

$$A_{LL} = \frac{\Delta s}{s} \approx \Delta G(x_1) \cdot \Delta G(x_2) \frac{\Delta \hat{s}_{parton}}{\hat{s}}$$

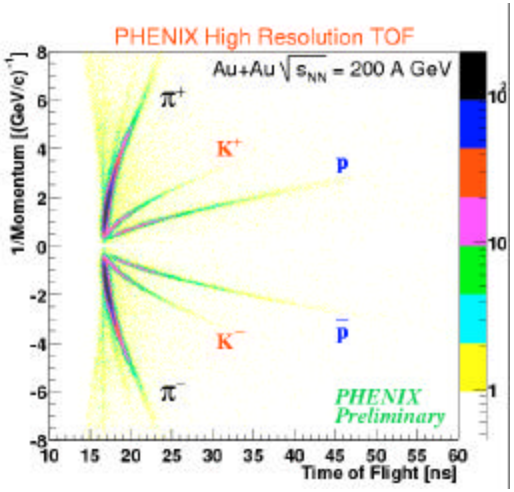


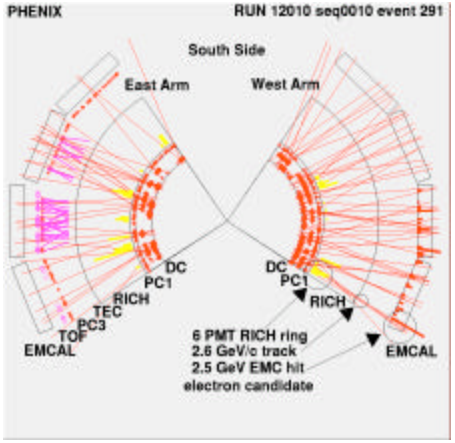
Hep-ph/9310346 M. Karliner &R.Robinet

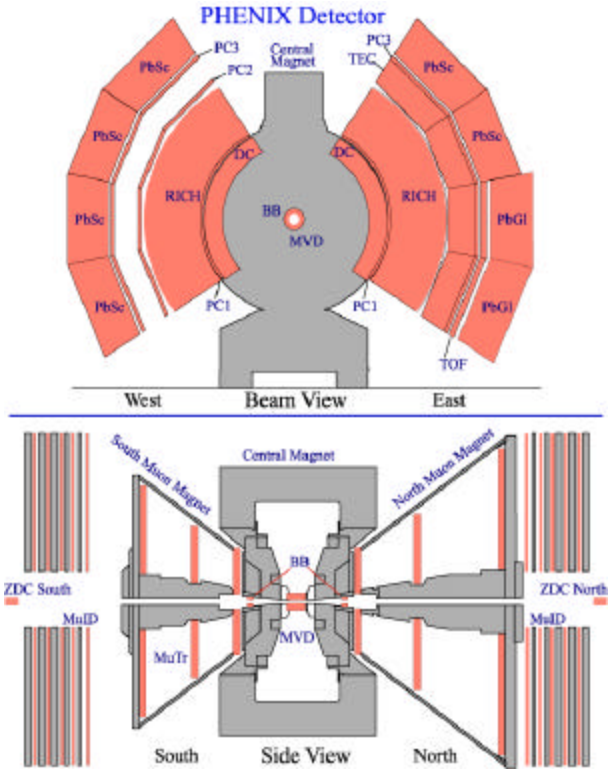


PHENIX Detectors

- Central & Forward
  - Tracking
  - EMCal
  - PID: γ, μ, π, e, K

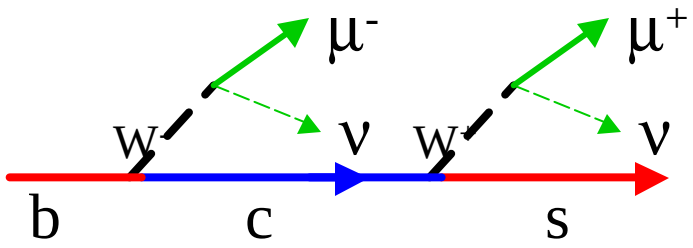


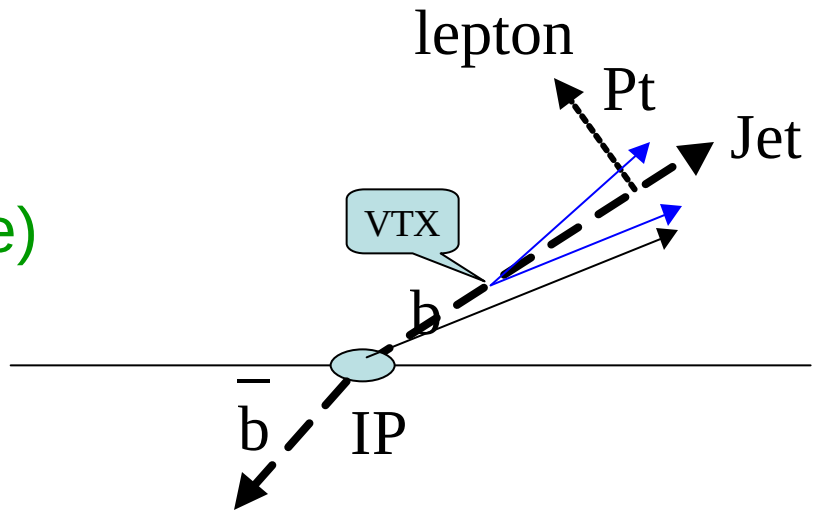




Heavy Quarks@PHENIX

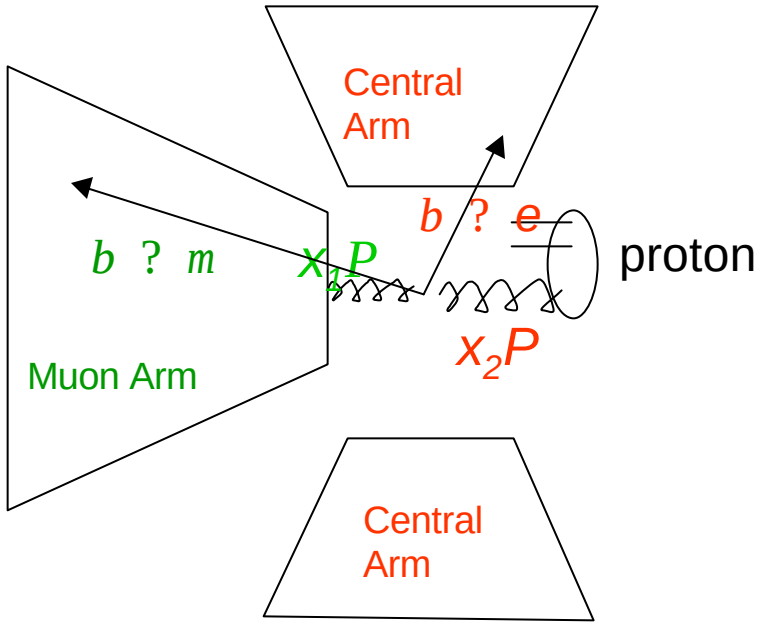
- Exp. Signatures
  - full reconstruction
    - D->pi+K
    - J/Psi->di-leptons
  - semileptonic decay
    - BR ~10%
  - Long lifetimes*(upgrade)
    - 2nd VTX

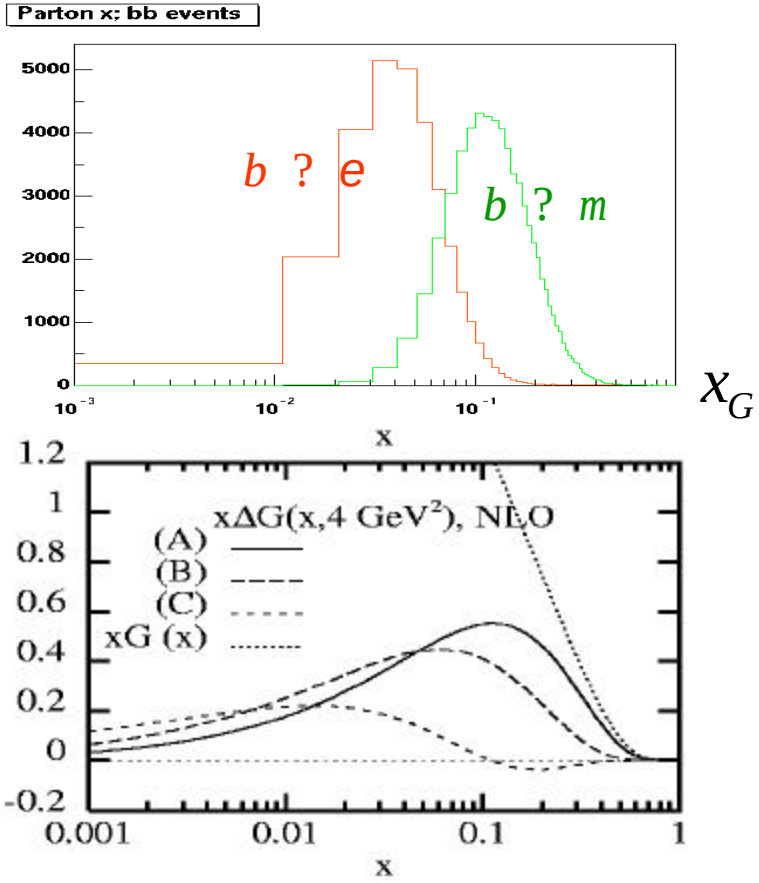




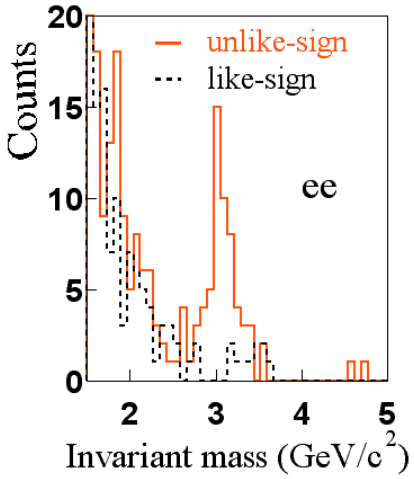
Heavy Quark Production and G(x)

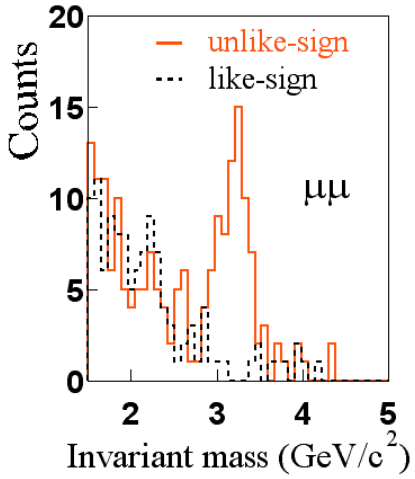
- Gluon's x range

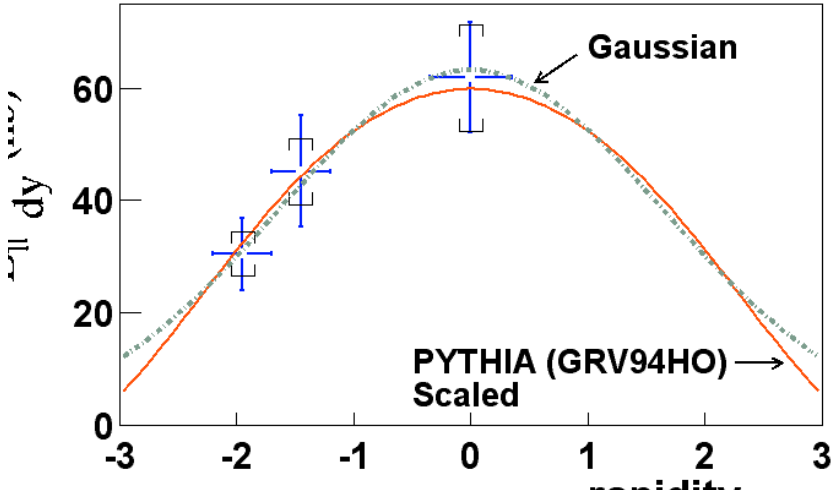


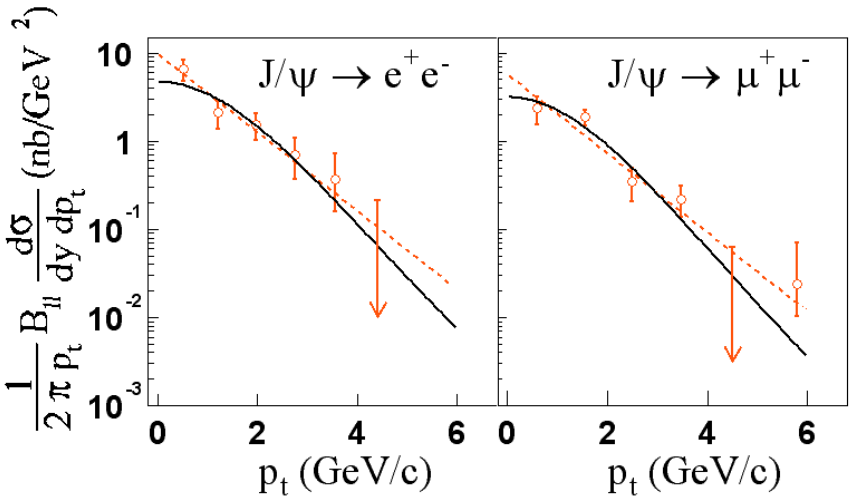


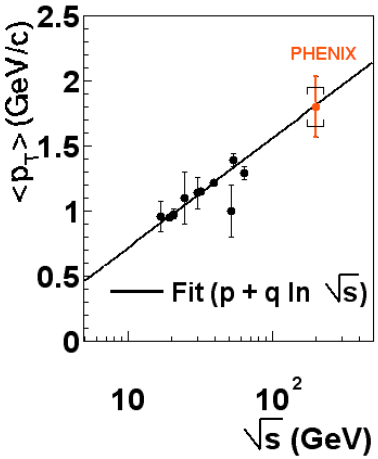
J/Psi from pp in Run-02

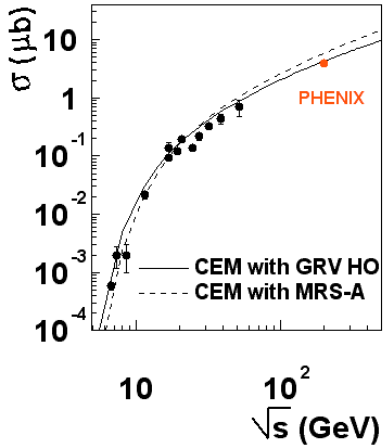












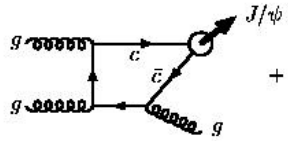
J/ψ Production in Polarized p-p collisions

- J/Psi production mechanism
- J/Psi polarization - a key probe?
- Spin dynamics in pQCD

$$\frac{d\,s}{d\cos q^{*}} \propto 1 + a\cos^{2} q^{*}$$

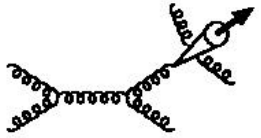
a = +1: transversely polarized
a = -1: longitudinally polarized
a = 0: no polarization

(a) leading-order colour-singlet: $g + g \to c\bar{c}[^1S_1^{(1)}] + g$

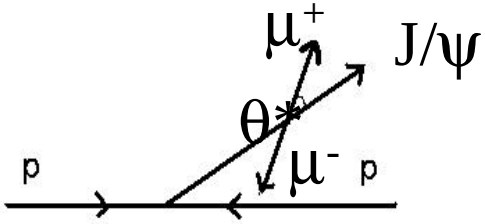


$+\ldots \qquad \sim \alpha_s^3 \frac{(2m_c)^4}{p_t^8}$

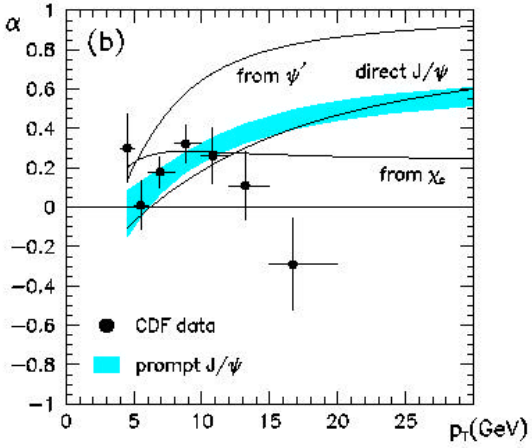
(b) colour-singlet fragmentation: $g + g \to [c\bar{c}[^1S_1^{(1)}] + gg] + g$

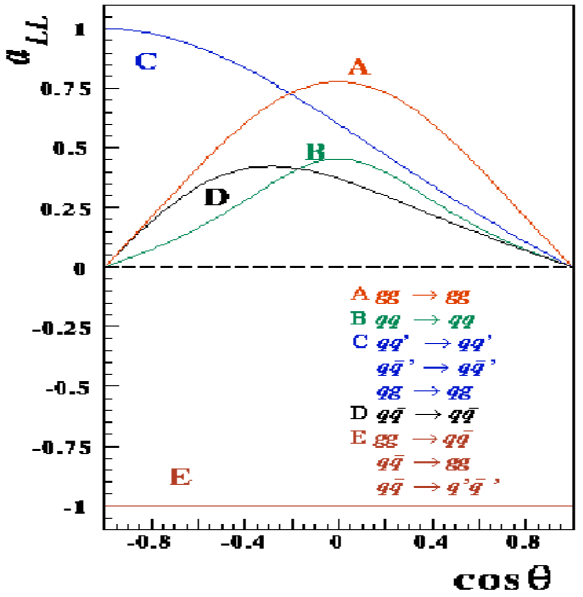


$+\ldots \qquad \sim \alpha_s^5 \frac{1}{p_t^4}$



hep-ph/0106120 M. Kramer



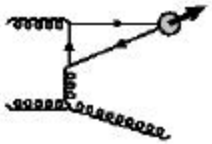


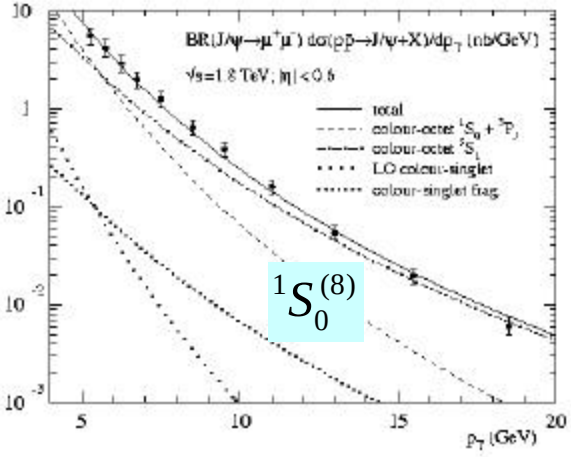
J/Psi production in K_T factorization

Collinear parton model

(c) colour-octet fragmentation: $g + g \to c\bar{c}[^3S_1^{[8]}] + g$

(d) colour-octet t-channel gluon exchange: $g + g \to c\bar{c}[^1S_0^{[8]}, {}^3P_J^{[8]}] + g$





Color octet K_T - factorization

- small x
- high energy collisions
- "intrinsic Pt" contribution

$$s_{J/\Psi} = f(x_1, k_{T1}) \otimes f(x_2, k_{T2}) \hat{s}(x_1 x_2 \to c\bar{c} \to J/\Psi)$$

PRL 87 (2001) F.Yuan & K. Chao

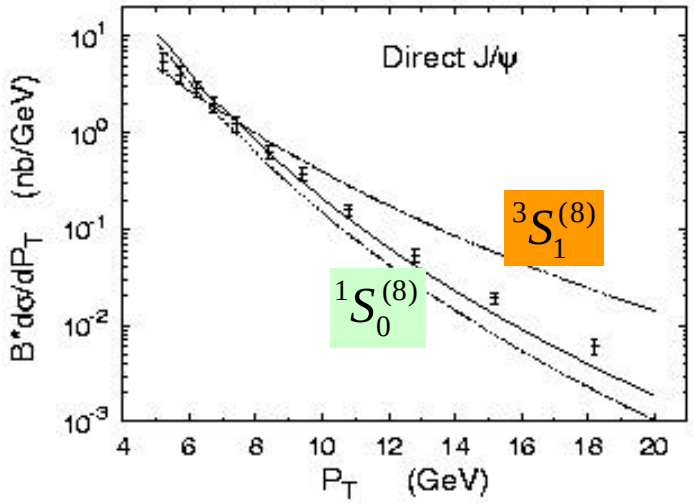


FIG. 1. The p_T distribution of direct J/ψ production cross section at the Tevatron in the k_t-factorization approach. The solid line is for $^1S_0^{(8)}$ contribution, the dashed line for $^3P_J^{(8)}$, and the dot-dashed line for $^3S_1^{(8)}$.

More on J/Psi production

Gluon fragmentation or fusion?

open $c\bar{c}$, $b\bar{b}$:

frag : $a_{LL} \sim +1$

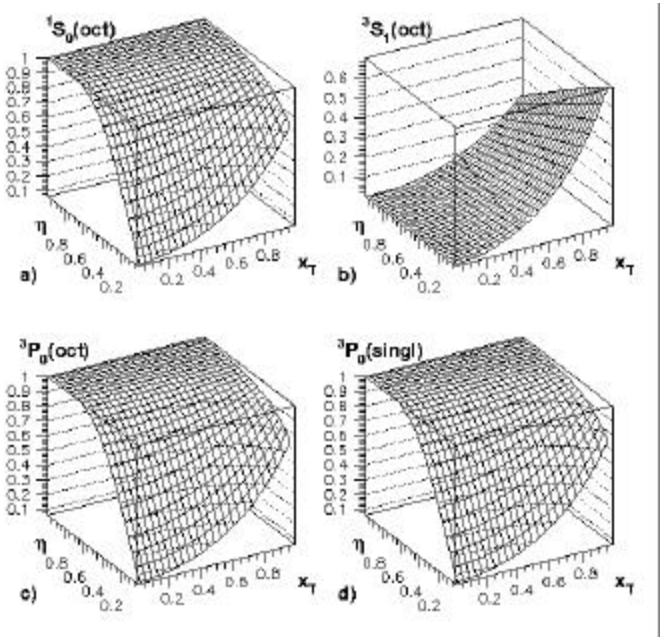
fusion : $a_{LL} \sim -1$

J/Ψ :

a_{LL} *process dep* .

$a(\Psi' \to m^+ m^-) = \{+1, 0, -1\}$

$\Delta G(x)$?



PRD 56 (1997)A. Tkabladze &O. Teryaev

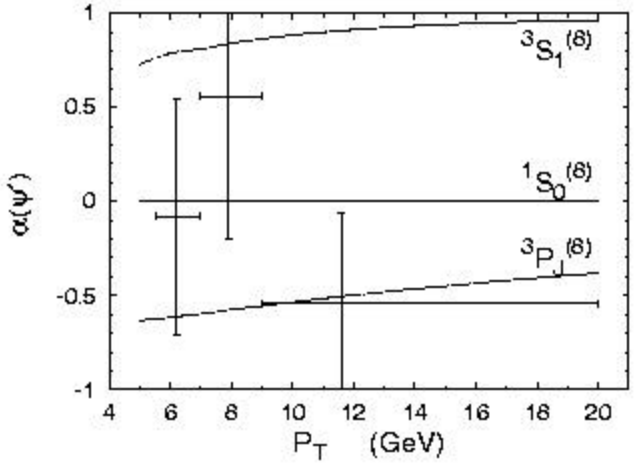


FIG. 3. Prompt ψ' polarization at the Tevatron.

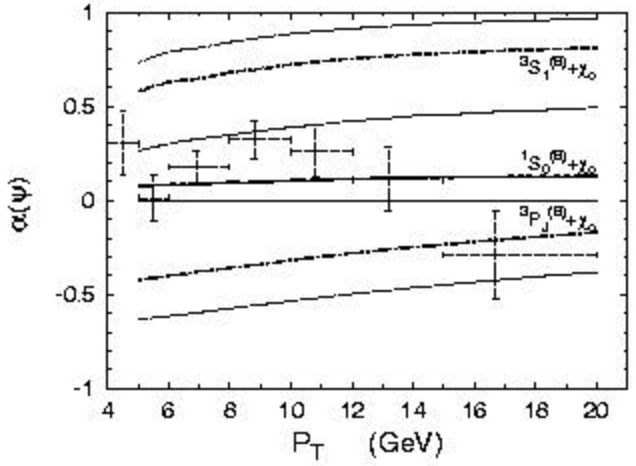
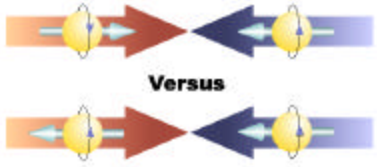


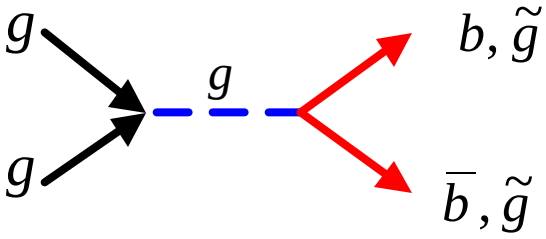
FIG. 4. Prompt J/ψ polarization at the Tevatron. The thinner lines are for the direct polarizations, and the thicker lines for the prompt polarizations.

Physics Beyond the SM with Polarized Beams

Novel ideas for new physics search

- Asymmetry - advantage over traditional unpolarized beams
- SUSY search
  - light gluino

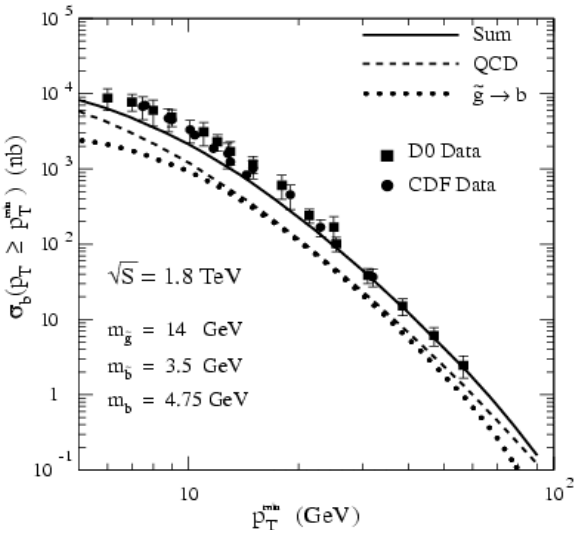


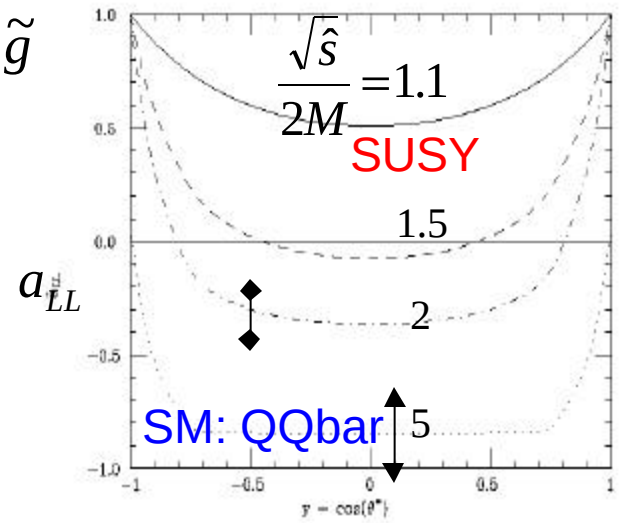


$$A_{LL} = -\frac{\{s(++)+s(--)\}-\{s(+-)+s(-+)\}}{\{s(++)+s(--)\}+\{s(+-)+s(-+)\}}$$

$$SM: a_{LL}(gg \to q\bar{q}) = -1$$

$$SUSY: a_{LL}(gg \to Q\bar{Q}, \tilde{g}\tilde{g}) = F(\frac{\sqrt{\hat{s}}}{M}): [-1,+1]$$



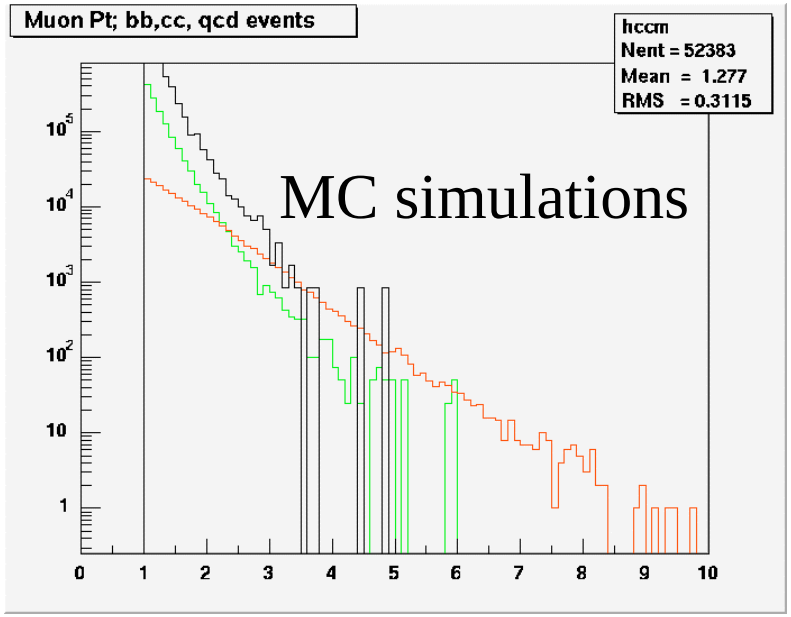


Heavy Quarks in Run-03

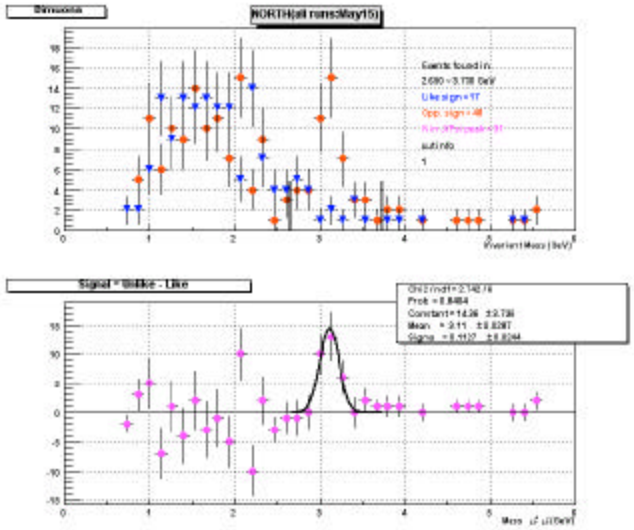
- Some Numbers
  - **L=2.5/pb (7.5 optimal)**
  - σ(bb) ~ **2ub =>5 M/bb**
  - σ(cc) ~**200ub =>500M/cc**
  - **J/Psi ~ 1k (muon arms)**

$$A_{LL}^{pp\to Q\bar{Q}X}(x_1,x_2)=\frac{s_{+-}-s_{++}}{s_{+-}+s_{++}}$$

$$=\frac{\Delta G(x_1)}{G(x_1)}\frac{\Delta G(x_2)}{G(x_2)}a_{LL}^{gg\to Q\bar{Q}}$$

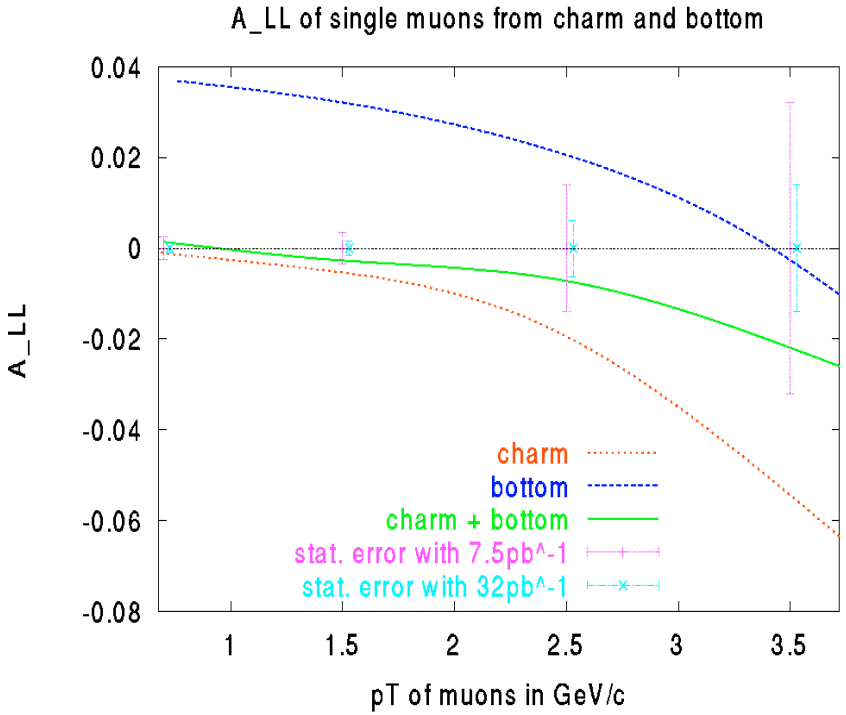


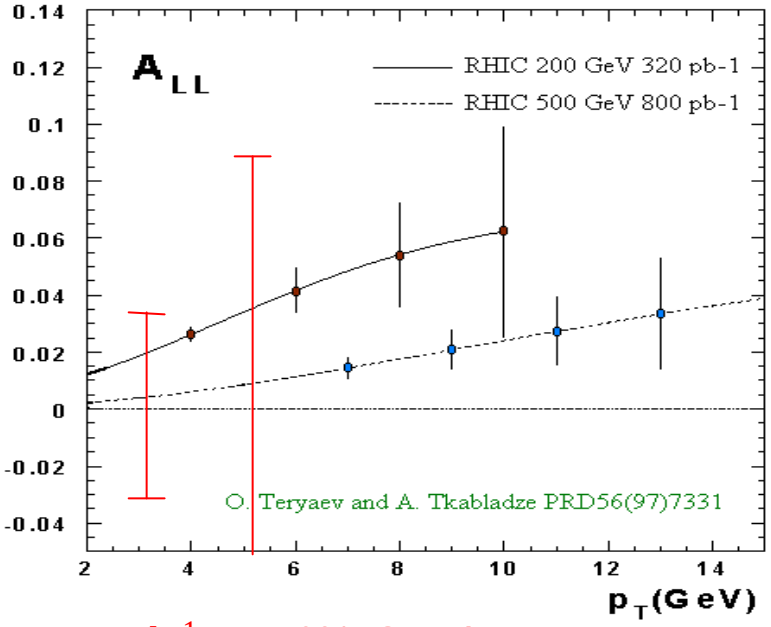
from Online Monitor



Expectations from Run-03

- Data taking is ongoing …
- Simulations from 7.5/pb and pol=50%(very optimistic:-)





$7.5pb^{-1}$,P_B=50%, One Arm

Summary

- Heavy quarks from polarized p-p collisions
  - A unique tool for
    - polarized gluon distribution
    - pQCD/NRQCD factorization theory
    - heavy quarkonium production mechanism
      - a probe for QGP?
  - a new window for searching physics beyond the Standard Model
- Very rich physics program in coming years
  - Polarization

$$a = f(P_T, X_F \mid J/Psi, \Psi', ... \langle Q\overline{Q} \rangle_{bound})$$

  - Spin asymmetry

$$A_{LL} = f(P_T, X_F \mid J/Psi, \Psi', ... \langle Q\overline{Q} \rangle_{bound})$$
$$A_{LL} = f(P_T, X_F \mid c, b, ..)$$
$$A_{LL} = f(P_T, X_F, M^2/\hat{s} \mid c\overline{c}, b\overline{b})$$

$$\frac{d^2 s}{dP_T dy}(J/\Psi; \Psi'; Q; Q\overline{Q} ...)$$