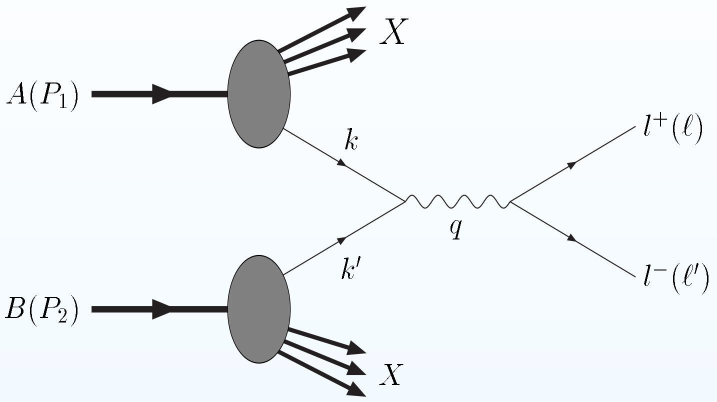
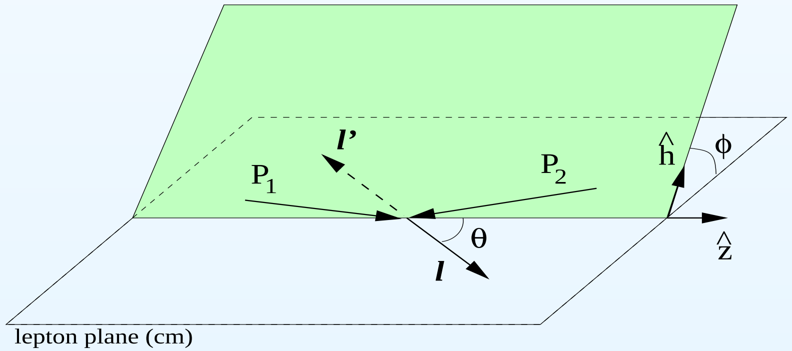
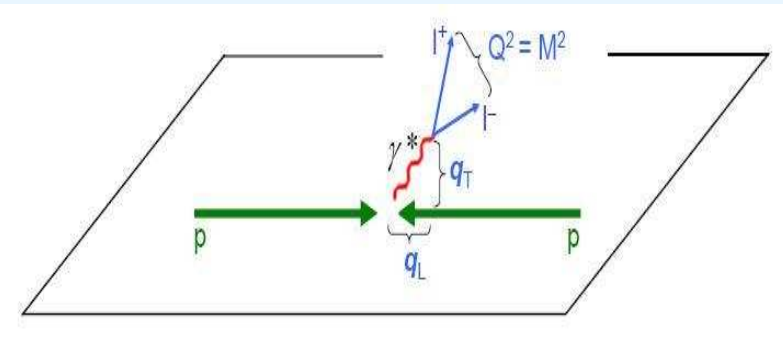
Research on Drell-Yan and J/Ψ physcis at J-PARC and COMPASS

O. Shevchenko

Kinematics







- $x_1 = \frac{Q^2}{2p_1 q}, \quad x_2 = \frac{Q^2}{2p_2 q}$ **– fractions of the longitudinal momentum of the hadrons A and B carried by the quark and antiquark which annihilate into virtual photon**
- $s = (p_1 + p_2)^2 \simeq 2p_1 p_2$ **– the center of mass energy squared**

  $Q^2 = M^2 \simeq x_1 x_2 s \equiv \tau s$

  $y = \frac{1}{2} \ln \frac{x_1}{x_2}$

  $x_F = x_1 - x_2$

  $x_1 = \frac{\sqrt{x_F^2 + 4\tau} + x_F}{2} = \sqrt{\tau} e^{y}$

  $x_2 = \frac{\sqrt{x_F^2 + 4\tau} - x_F}{2} = \sqrt{\tau} e^{-y}$
- θ **– production angle in the dilepton rest frame – polar angle of the lepton pair in the dilepton rest frame**
- ϕ **– azimuthal angle of lepton pair**
- ϕ_S **– azimuthal angle of the hadron polarization measured with respect to lepton plane**

DY with $pp^{\uparrow}$ collisions

$$A_{UT}^{\sin(\phi\pm\phi_S)\frac{q_T}{M_N}} = \frac{\int d\Omega d\phi_{S_2} \int d^2\mathbf{q}_T (|\mathbf{q}_T|/M_p) \sin(\phi\pm\phi_{S_2})[d\sigma(\mathbf{S}_{2T})-d\sigma(-\mathbf{S}_{2T})]}{\frac{1}{2}\int d\Omega d\phi_{S_2} \int d^2\mathbf{q}_T [d\sigma(\mathbf{S}_{2T})+d\sigma(-\mathbf{S}_{2T})]},$$

Access to Sivers function

$$A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}} = 2\frac{\sum_q e_q^2[\bar{f}_{1T}^{\perp(1)q}(x_{p^\uparrow})f_{1q}(x_p) + (q \longrightarrow \bar{q})]}{\sum_q e_q^2[\bar{f}_{1q}(x_{p^\uparrow})f_{1q}(x_p) + (q \longrightarrow \bar{q})]},$$

Access to transversity

$$A_{UT}^{\sin(\phi+\phi_S)\frac{q_T}{M_N}} = 2\hat{A}_h = -\frac{\sum_q e_q^2[\bar{h}_{1q}^{\perp(1)}(x_p)h_{1q}(x_{p^\uparrow}) + (q \longrightarrow \bar{q})]}{\sum_q e_q^2[\bar{f}_{1q}(x_p)f_{1q}(x_{p^\uparrow}) + (q \longrightarrow \bar{q})]}.$$

Limiting cases $x_p \gg x_{p^\uparrow}$ and $x_p \ll x_{p^\uparrow}$

$$x_p \gg x_{p^\uparrow}$$

$$A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}}\Big|_{x_p \gg x_{p^\uparrow}} \simeq 2\frac{\bar{f}_{1T}^{\perp(1)u}(x_{p^\uparrow})f_{1u}(x_p)}{\bar{f}_{1u}(x_{p^\uparrow})f_{1u}(x_p)} = 2\frac{\bar{f}_{1T}^{\perp(1)u}(x_{p^\uparrow})}{\bar{f}_{1u}(x_{p^\uparrow})}$$

$$A_{UT}^{\sin(\phi+\phi_S)\frac{q_T}{M_N}}\Big|_{x_p \gg x_{p^\uparrow}} \simeq -\frac{h_{1u}^{\perp(1)}(x_p)\bar{h}_{1u}(x_{p^\uparrow})}{f_{1u}(x_p)\bar{f}_{1u}(x_{p^\uparrow})}$$

$$x_p \ll x_{p^\uparrow}$$

$$A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}}\Big|_{x_p \ll x_{p^\uparrow}} \simeq 2\frac{f_{1T}^{\perp(1)u}(x_{p^\uparrow})\bar{f}_{1u}(x_p)}{f_{1u}(x_{p^\uparrow})\bar{f}_{1u}(x_p)} = 2\frac{f_{1T}^{\perp(1)u}(x_{p^\uparrow})}{f_{1u}(x_{p^\uparrow})}$$

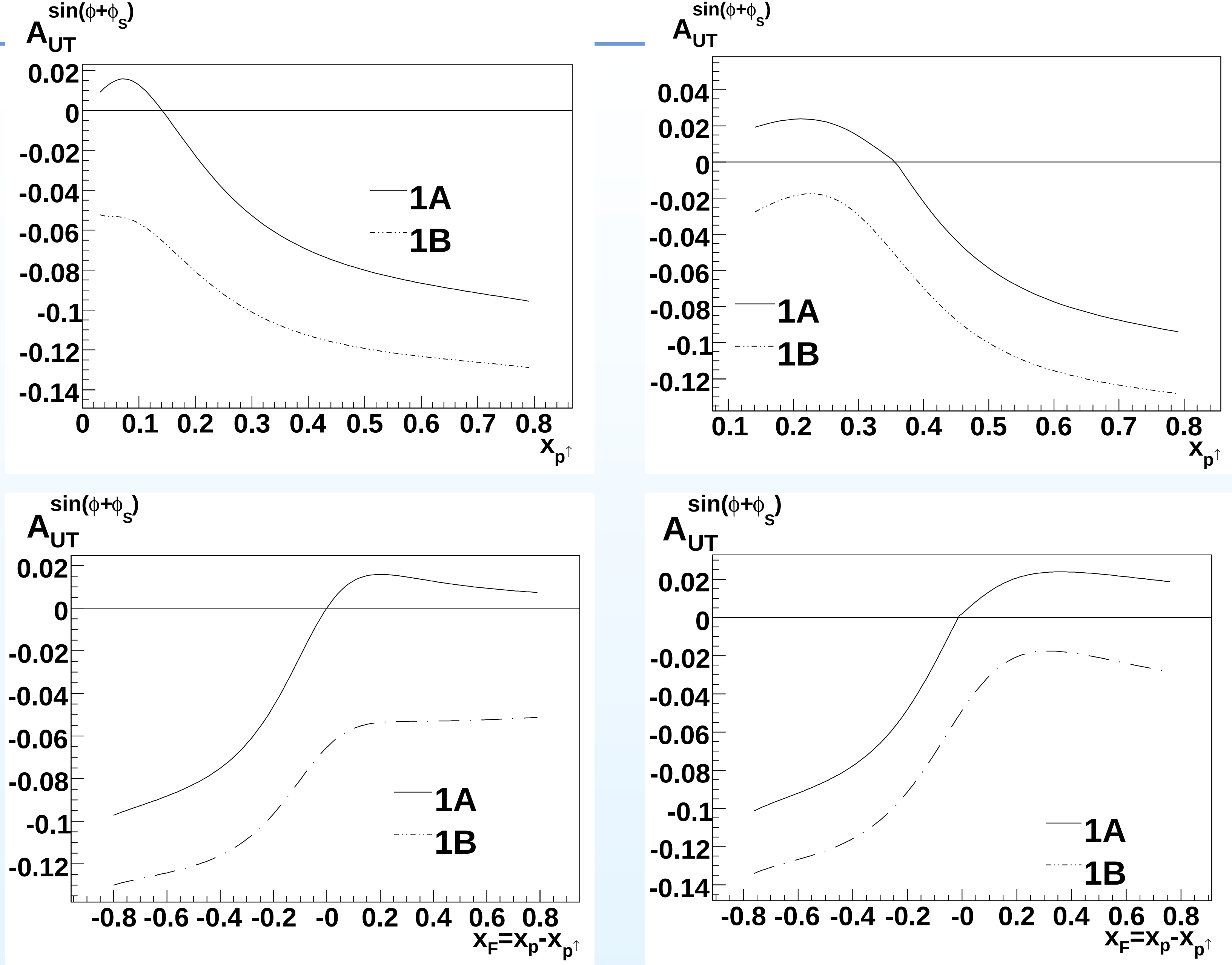
$$A_{UT}^{\sin(\phi+\phi_S)\frac{q_T}{M_N}}\Big|_{x_p \ll x_{p^\uparrow}} \simeq -\frac{\bar{h}_{1u}^{\perp(1)}(x_p)h_{1u}(x_{p^\uparrow})}{\bar{f}_{1u}(x_p)f_{1u}(x_{p^\uparrow})}$$

Acceptance restriction:

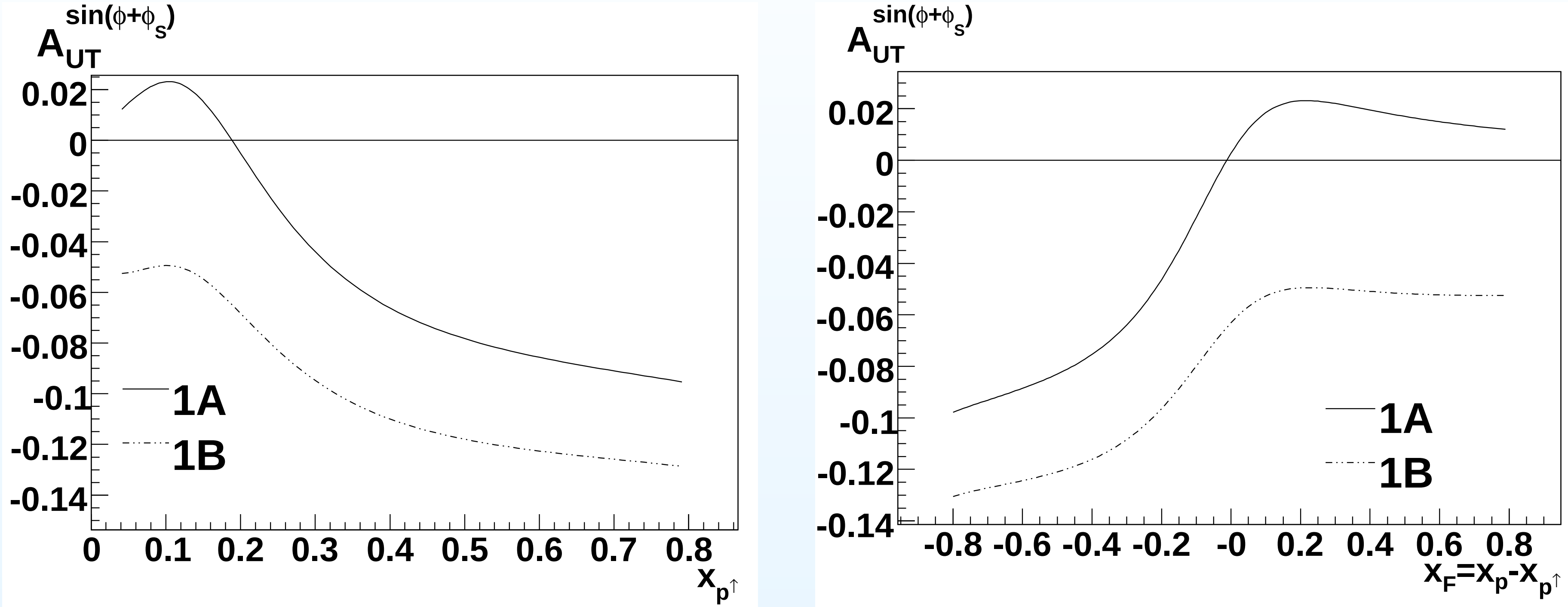
$$x_F \equiv x_{beam} - x_{target} \gtrsim 0$$

$A_{UT}^{\sin(\phi-\phi_S)} \neq 0$ if only $x_p - x_{p^\uparrow} > 0$

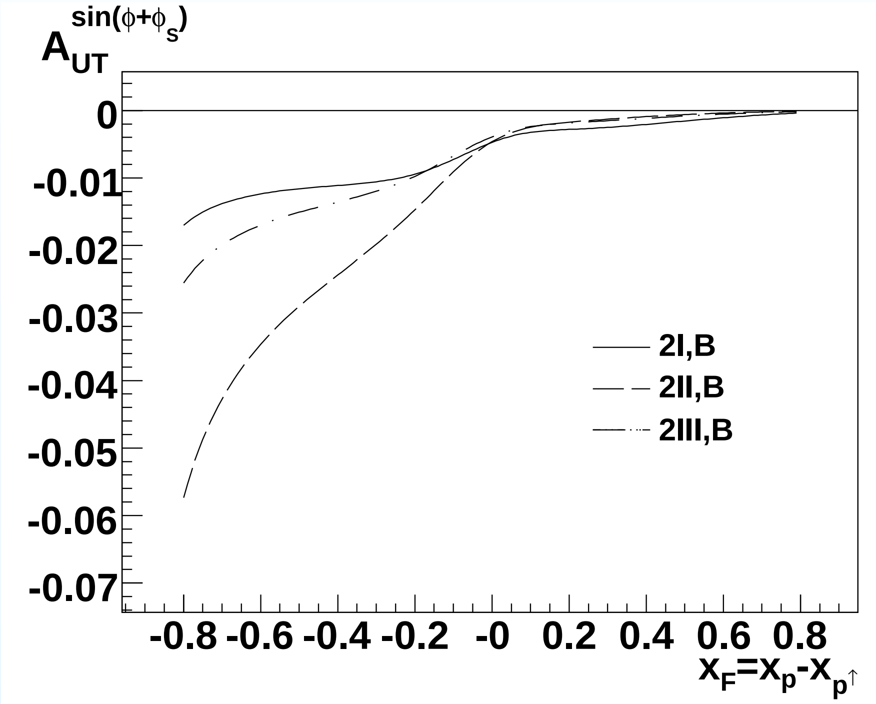
$A_{UT}^{\sin(\phi+\phi_S)} \neq 0$ if only $x_p - x_{p^\uparrow} < 0$

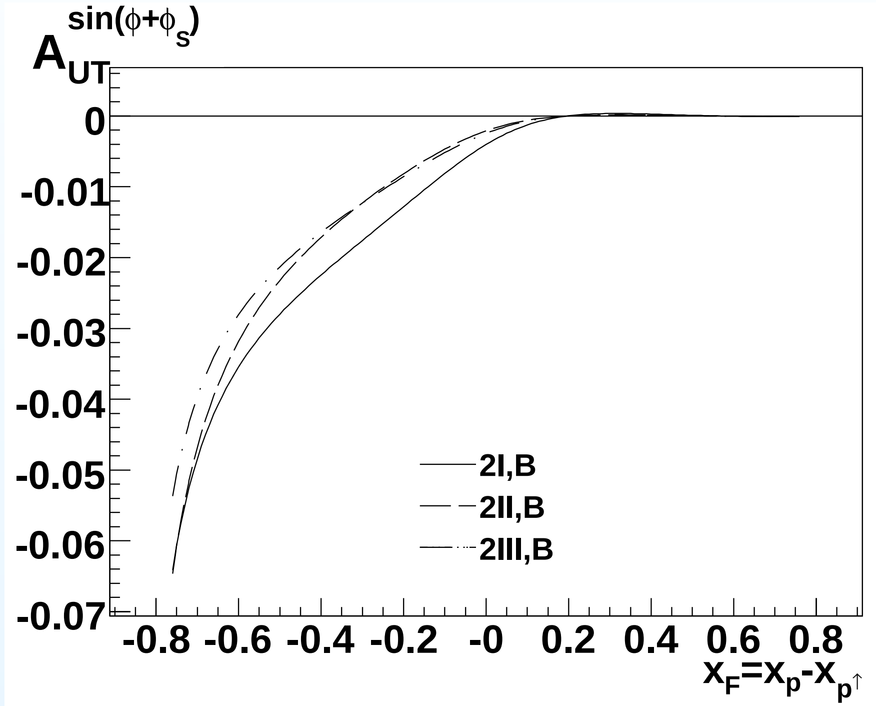


$s = 100\,GeV^2$. $Q^2 = 2GeV^2$ (left) and $Q^2 = 3.5^2 GeV^2$ (right). A: $h_{1q,\bar{q}} = \Delta q, \Delta\bar{q}$; B: $h_{1q} = (\Delta q + q)/2$. $h_{1\bar{q}} = (\Delta\bar{q} + \bar{q})/2$. at $Q_0^2 = 0.23 GeV^2$.

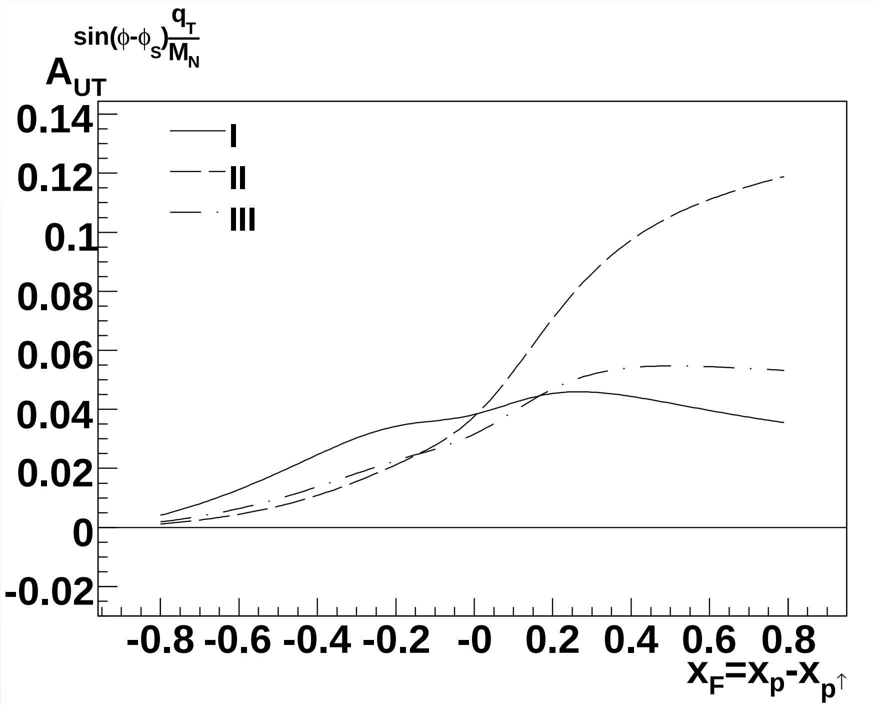


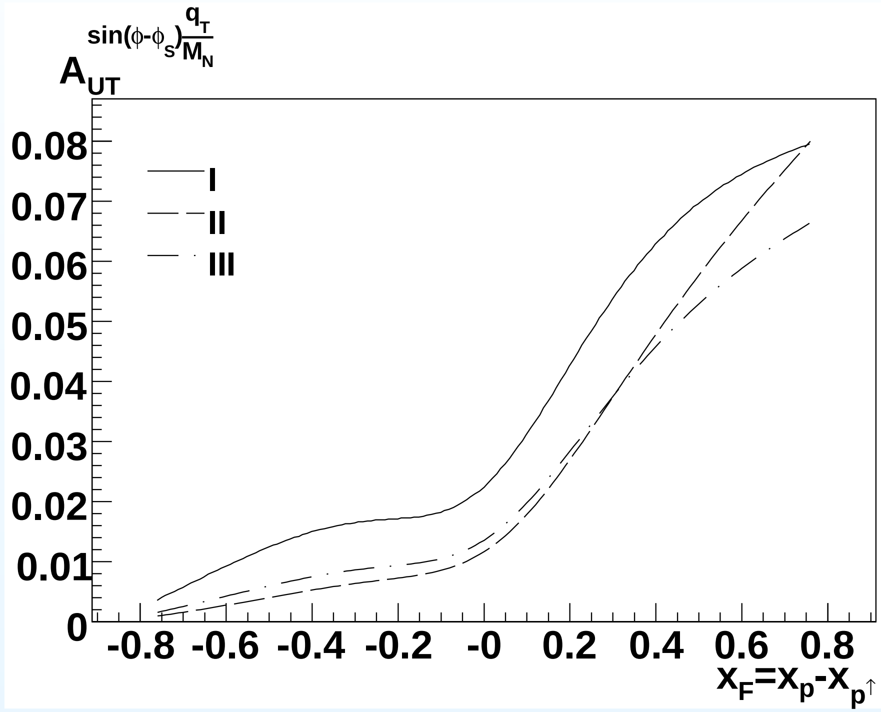
$s = 60\,GeV^2$. $Q^2 = 2GeV^2$. A: $h_{1q,\bar{q}} = \Delta q, \Delta\bar{q}$; B: $h_{1q} = (\Delta q + q)/2$.
$h_{1\bar{q}} = (\Delta\bar{q} + \bar{q})/2$. at $Q_0^2 = 0.23GeV^2$.



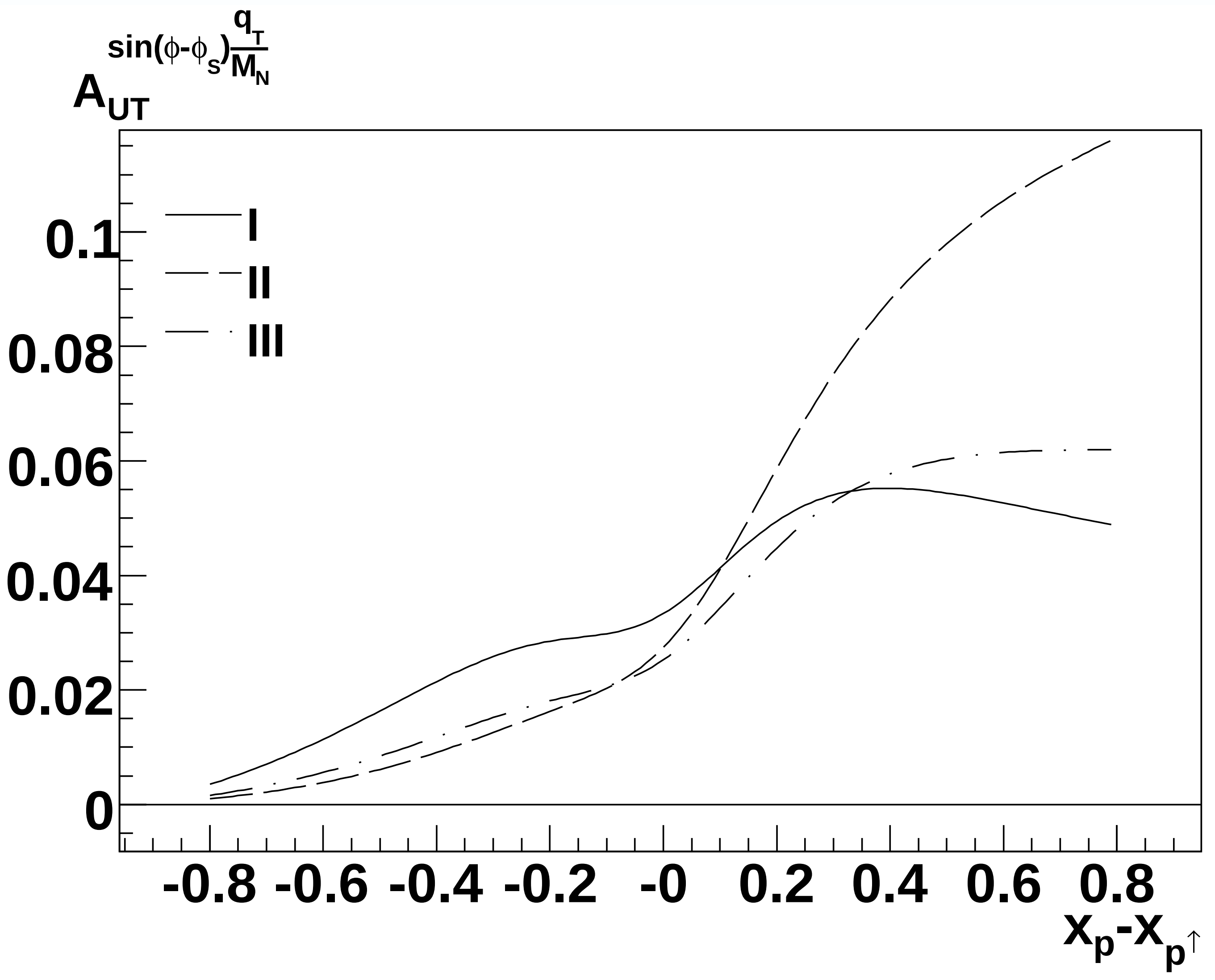


$s = 100\,GeV^2$; $Q^2 = 2GeV^2$ (left) and $Q^2 = 3.5^2GeV^2$ (right). B: $h_1^{\perp(1)} = f_{1T}^{(1)}$. We use three fits for the Sivers function I, II and III (from papers by Efremov et al; Collins, Efremov et al).



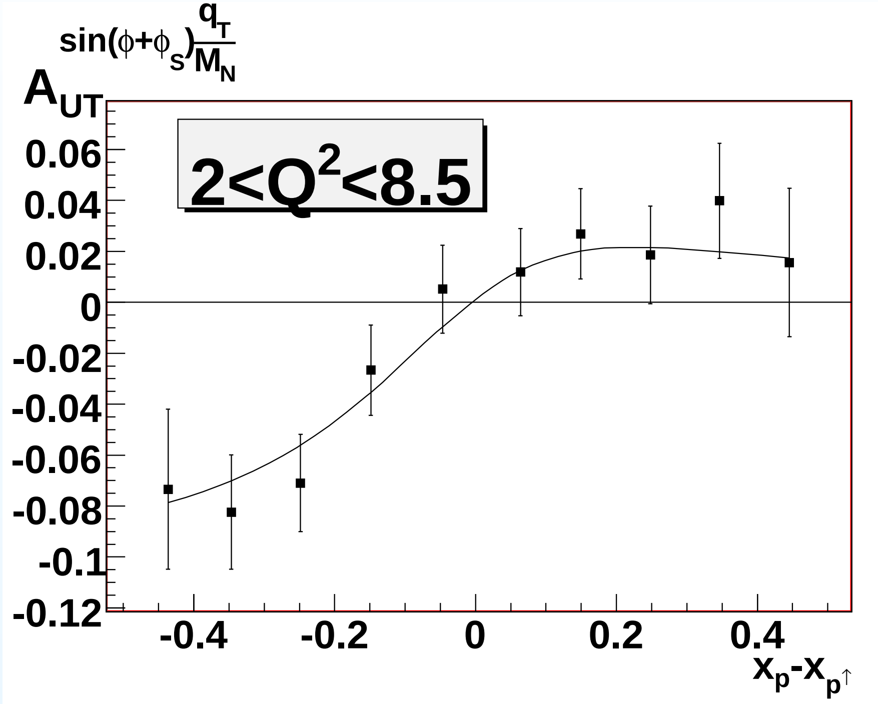


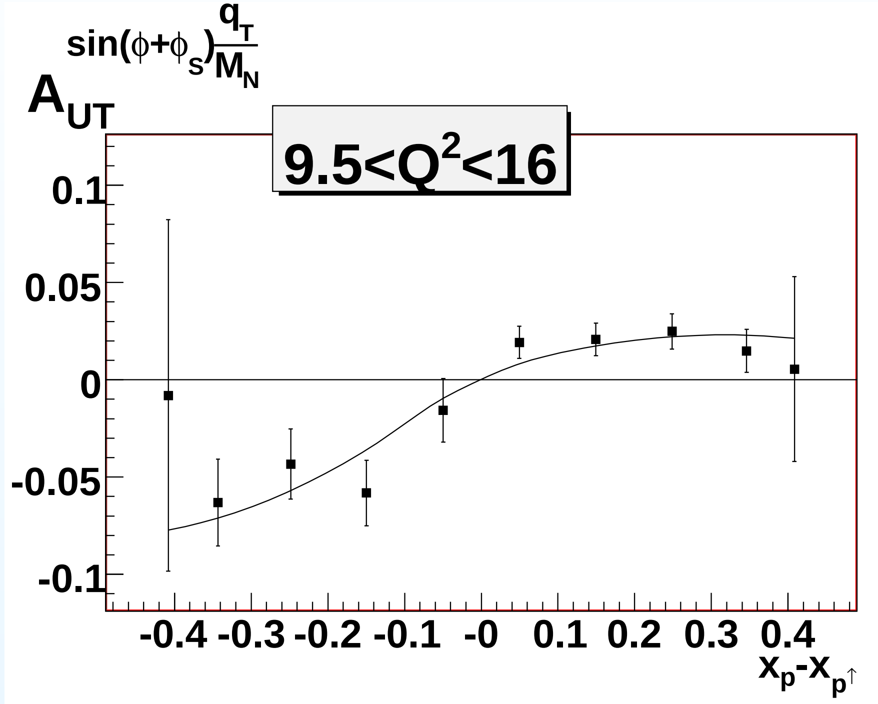
s=100GeV^2; $Q^2 = 2GeV^2$ (left) and $Q^2 = 3.5^2GeV^2$ (right). Rome numbers I, II, III denote different fits from papers by Efremov et al and Collins, Efremov et al.



s=60GeV^2; $Q^2 = 2GeV^2$. Rome numbers I, II, III denote different fits from papers by Efremov et al and Collins, Efremov et al.

Statistical errors (100k pure Drell-Yan events)





J-PARC, s=100GeV^2. Evolution model with $h_{1q,\bar{q}} = \Delta q, \Delta\bar{q}$ at initial scale $Q_0^2 = 0.23 GeV^2$.

Points with error bars are obtained with PYTHIA applying the special Monte-Carlo weighting procedure.

$w_{1,2} = 1 \pm p_B p_T A$, $p_B = p_T = 1$

$A_{bin} = \frac{\sum_{bin} w_1 - \sum_{bin} w_2}{\sum_{bin} w_1 + \sum_{bin} w_2}$.

Test on approximation validity

Values of $A_{UT}^{sin(\phi+\phi_S)}$ for two approximations in comparison with the “exact” values

$s = 100GeV^2, Q^2 = 2GeV^2$			
x_F	I	II	III
-0.4000	-0.0751	-0.0874	-0.0913
-0.5000	-0.0828	-0.0925	-0.0943
-0.6000	-0.0882	-0.0959	-0.0967
-0.7000	-0.0927	-0.0985	-0.0988
-0.8000	-0.0972	-0.1013	-0.1013
0.4000	0.0126	0.0125	0.0135
0.5000	0.0108	0.0108	0.0112
0.6000	0.0093	0.0093	0.0095
0.7000	0.0082	0.0082	0.0083
0.8000	0.0072	0.0072	0.0073

I,II,III correspond to $A_{UT}^{sin(\phi+\phi_S)}$ calculated respectively with all contributions, without d quark contribution and without both d quark and contributions containing sea quarks at large x.

Test on approximation validity

Values of $A_{UT}^{sin(\phi+\phi_S)}$ for two approximations in comparison with the “exact” values

$s = 100 GeV^2, Q^2 = 3.5^2 GeV^2$			
x_F	I	II	III
-0.4000	-0.0777	-0.0902	-0.0967
-0.5000	-0.0859	-0.0958	-0.0985
-0.6000	-0.0920	-0.0995	-0.1004
-0.7000	-0.0975	-0.1026	-0.1029
0.4000	0.0238	0.0246	0.0275
0.5000	0.0228	0.0234	0.0246
0.6000	0.0213	0.0217	0.0221
0.7000	0.0197	0.0199	0.0200

I,II,III correspond to $A_{UT}^{sin(\phi+\phi_S)}$ calculated respectively with all contributions, without d quark contribution and without both d quark and contributions containing sea quarks at large x.

Extraction of $h_1/h_1^{\perp(1)}$ and $f_{1T}^{\perp(1)}/\bar{f}_{1T}^{\perp(1)}$ from J-PARC data

Fixed target mode with unpolarized beam and polarized target. Acceptance restrictions means

$$x_p > x_{p\uparrow}$$

$A_{UT}^{\sin(\phi-\phi_S)} \neq 0$ while $A_{UT}^{\sin(\phi+\phi_S)} \simeq 0$

$$A_{UT}^{\sin(\phi-\phi_S)\frac{q_T}{M_N}}\Big|_{x_p \gg x_{p\uparrow}} \simeq 2\frac{\bar{f}_{1T}^{\perp(1)u}(x_{p\uparrow})f_{1u}(x_p)}{\bar{f}_{1u}(x_{p\uparrow})f_{1u}(x_p)} = 2\frac{\bar{f}_{1T}^{\perp(1)u}(x_{p\uparrow})}{\bar{f}_{1u}(x_{p\uparrow})},$$

Fixed target mode with polarized beam and unpolarized target. Acceptance restrictions means

$$x_{p\uparrow} \equiv x_1 > x_p \equiv x_2$$

$A_{UT}^{\sin(\phi+\phi_S)} \neq 0$ while $A_{UT}^{\sin(\phi-\phi_S)} \simeq 0$

$$A_{UT}^{\sin(\phi+\phi_S)\frac{q_T}{M_N}}\Big|_{x_p \ll x_{p\uparrow}} \simeq -\frac{\bar{h}_{1u}^{\perp(1)}(x_p)h_{1u}(x_{p\uparrow})}{\bar{f}_{1u}(x_p)f_{1u}(x_{p\uparrow})},$$

Unpolarized case with $x_1 = x_{p\uparrow}$, $x_2 = x_p$

$$\hat{k}\Big|_{x_1 \gg x_2} \simeq 8\frac{h_{1u}^{\perp(1)}(x_1)\bar{h}_{1u}^{\perp(1)}(x_2)}{f_{1u}(x_1)\bar{f}_{1u}(x_2)}$$

Thus

$$\frac{h_{1u}(x_1)}{h_{1u}^{\perp(1)}(x_1)} \simeq -8\frac{\hat{A}_{UT}^{\sin(\phi+\phi_S)}}{\hat{k}}\Bigg|_{x_1 \gg x_2}$$

J/ψ and DY

E. Leader and E. Predazzi, “An introduction . . . ”, Cambridge Univ. Press. 1982
N. Anselmino, V. Barone, A. Drago, N. Nikolaev, Phys. Lett. B594 (2004) 1997
V. Barone, Z. Lu, B. Ma, Eur. Phys. J. C49 (2007) 967

Since J/ψ is a vector particle like γ and the same helicity structure of $(q\bar{q})(J/\psi)$ coupling and $(q\bar{q})\gamma^*$ coupling one can apply the replacement

$$16\pi^2\alpha^2 e_q^2 \to (g_q^V)^2\,(g_\ell^V)^2,\ \frac{1}{M^4} \to \frac{1}{(M^2-M_{J/\psi}^2)^2+M_{J/\psi}^2\Gamma_{J/\psi}^2}\,.$$

“The crucial point is now that, because of the identical helicity and vector structure of the γ^* and J/ψ elementary channels (all γ^μ couplings) the same replacements hold for the single-polarized and double polarized cross-sections.”

For example $A_{UT}^{\frac{q_T}{M_N}\sin(\phi+\phi_S)} \simeq \frac{\bar{h}_{1u}^{\perp(1)}(x_1)h_{1u}(x_2)+(u\leftrightarrow\bar{u})}{\bar{f}_{1u}(x_1)f_{1u}(x_2)+(u\leftrightarrow\bar{u})}$

J/ψ and DY

"Drell-Yan model"

$$\frac{d^2\sigma/dx_F dQ^2\Big|_{(AB\to J/\psi\to l^+l^-)}}{d^2\sigma/dx_F dQ^2\Big|_{(A'B'\to J/\psi\to l^+l^-)}} = \frac{\sum_q[\bar{q}(x_A)q(x_B)+q(x_A)\bar{q}(x_B)]}{\sum_q[\bar{q}(x_{A'})q(x_{B'})+q(x_{A'})\bar{q}(x_{B'})]},$$

$$x_{A,B} = \frac{1}{2}\left[\pm x_F + \sqrt{x_F^2 + 4Q^2/s}\right]$$

$$\mathrm{Q}^2/s - 1 < x_F < 1 - Q^2/s$$

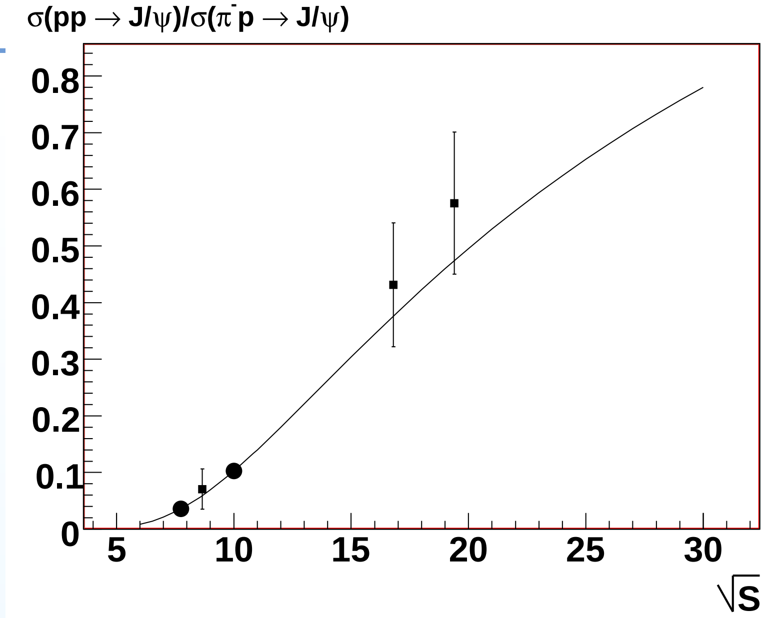
Gluon evaporation model

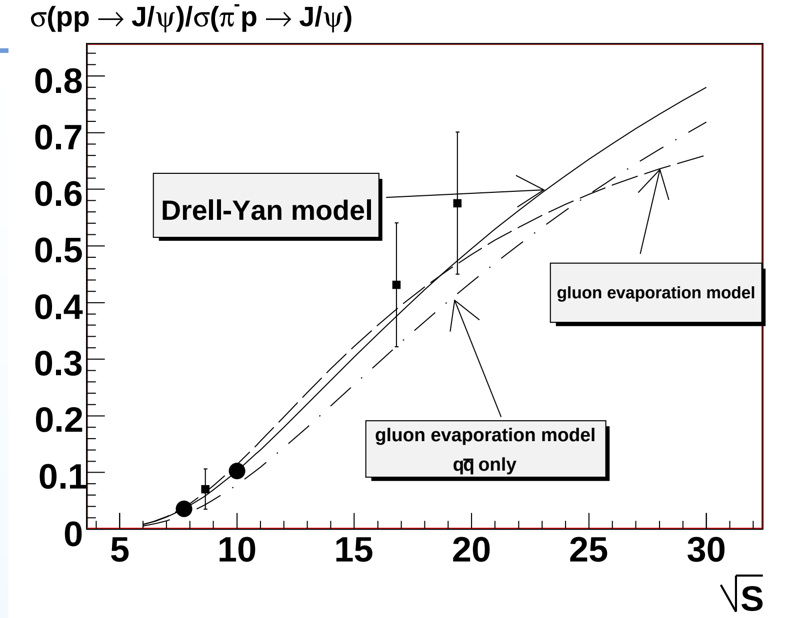
$$\frac{d^2\sigma/dx_F\Big|_{(AB\to J/\psi\to l^+l^-)}}{d^2\sigma/dx_F\Big|_{(A'B'\to J/\psi\to l^+l^-)}} = \frac{d^2(\sigma_{q\bar{q}}+\sigma_{gg})/dx_F\Big|_{(AB\to J/\psi\to l^+l^-)}}{d^2(\sigma_{q\bar{q}}+\sigma_{gg})/dx_F\Big|_{(A'B'\to J/\psi\to l^+l^-)}},$$

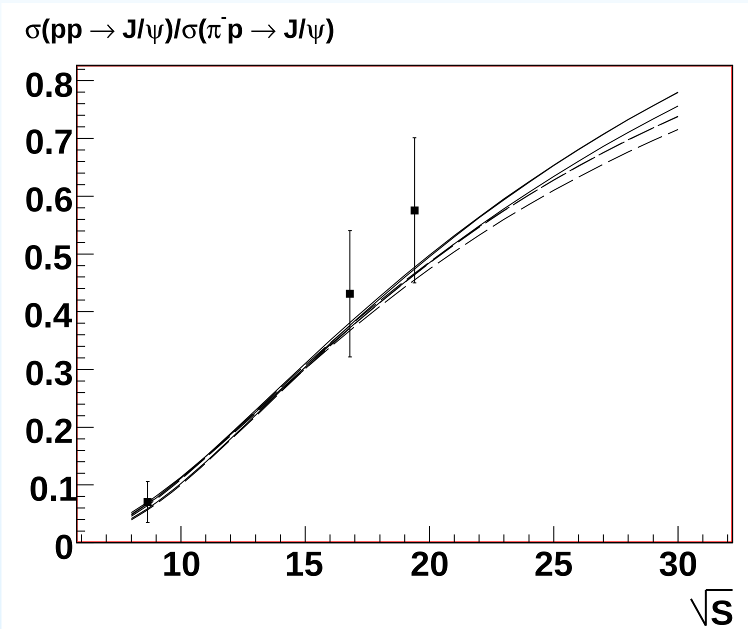
$$d\sigma_{q\bar{q}}^{AB}/dx_F = \int_{4m_c^2}^{4m_d^2} dQ^2 \sigma^{q\bar{q}\to c\bar{c}}(Q^2)\frac{x_A x_B}{Q^2(x_A+x_B)}[q^A(x_A)\bar{q}^B(x_B + \bar{q}^A(x_A)q^B(x_B))]$$

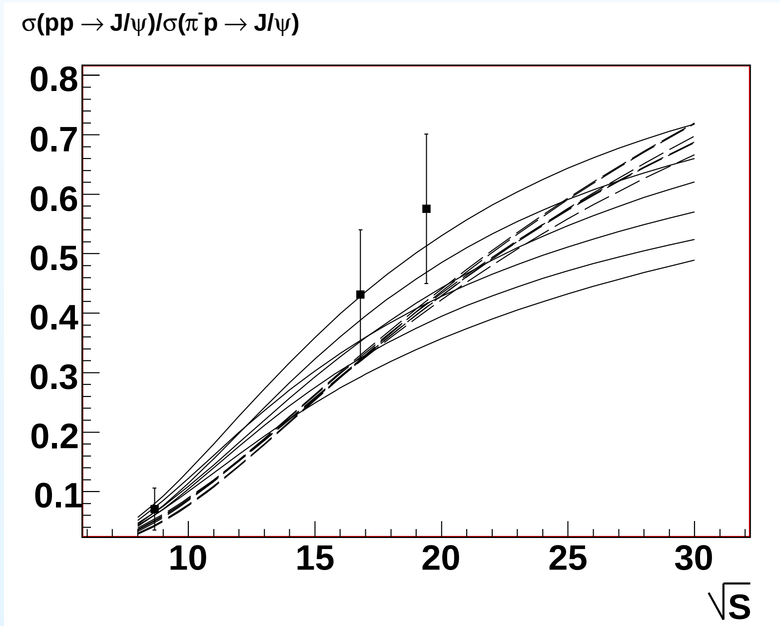
$$d\sigma_{gg}^{AB}/dx_F = \int_{4m_c^2}^{4m_d^2} dQ^2 \sigma^{gg\to c\bar{c}}(Q^2)\frac{x_A x_B}{Q^2(x_A+x_B)}G^A(x_A)G^B(x_B)$$

$$\sigma^{q\bar{q}\to c\bar{c}}(Q^2) \sim \frac{\alpha_s(Q^2)}{Q^2},\ \sigma^{gg\to c\bar{c}}(Q^2) \sim \frac{\alpha_s(Q^2)}{Q^2}.$$

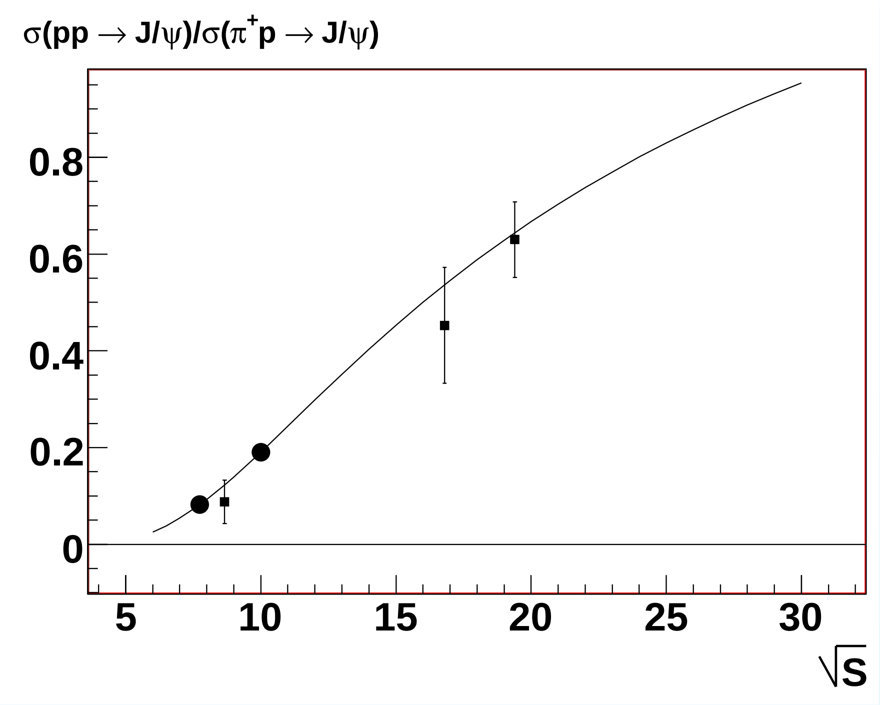


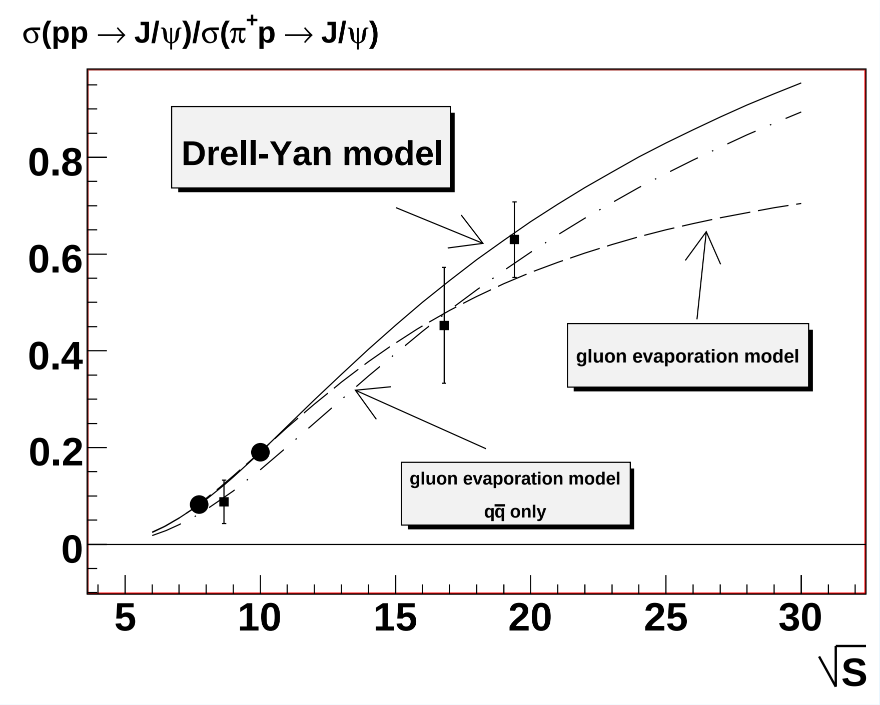




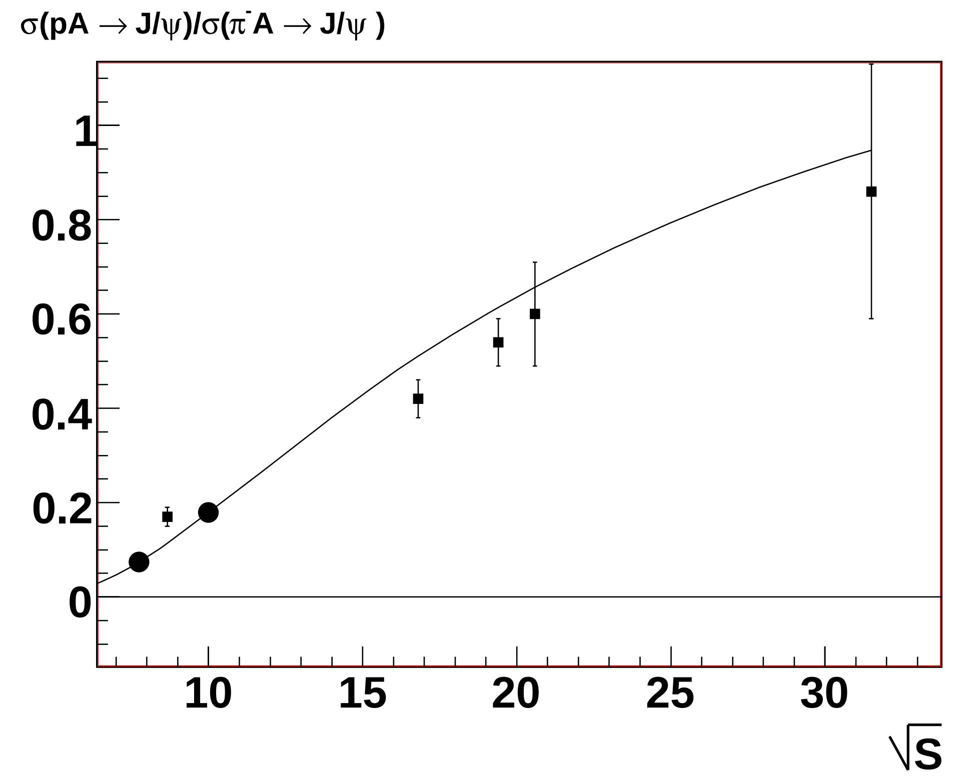


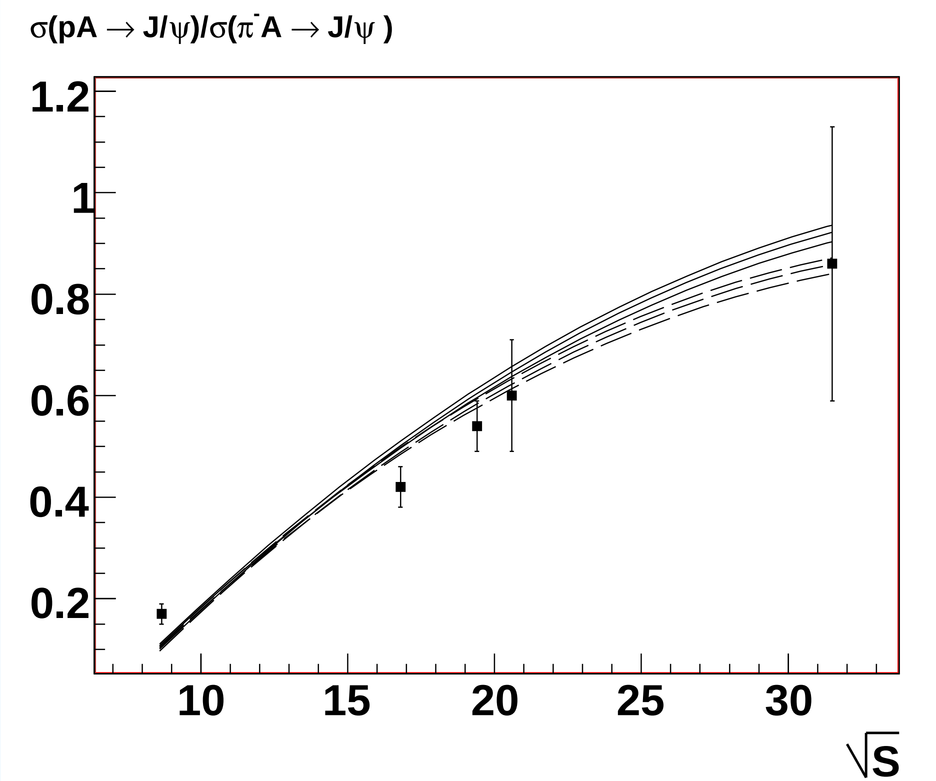
Hydrogen (H_2) target. Data of WA39 and NA3 collaborations are used.



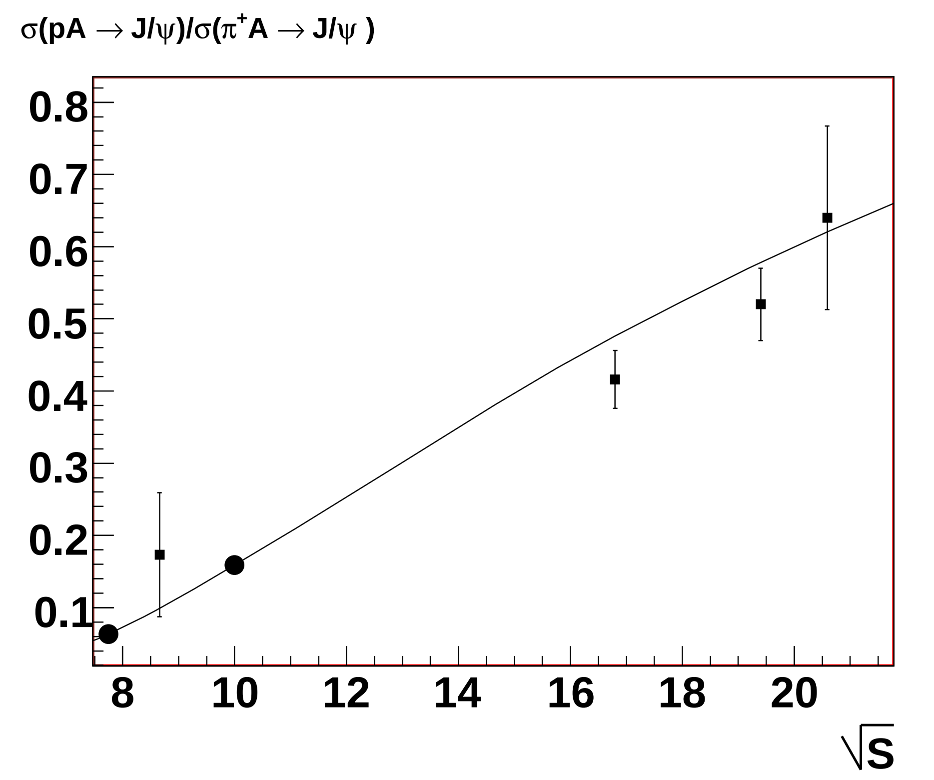


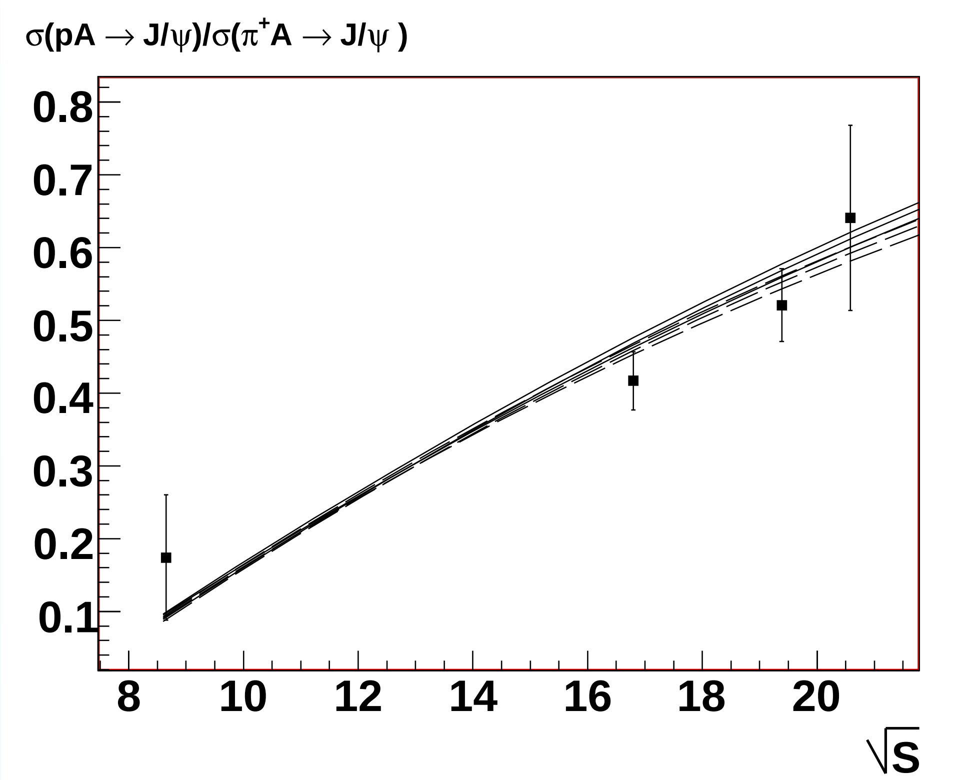
Hydrogen (H_2) target. Data of WA39 and NA3 collaborations are used.



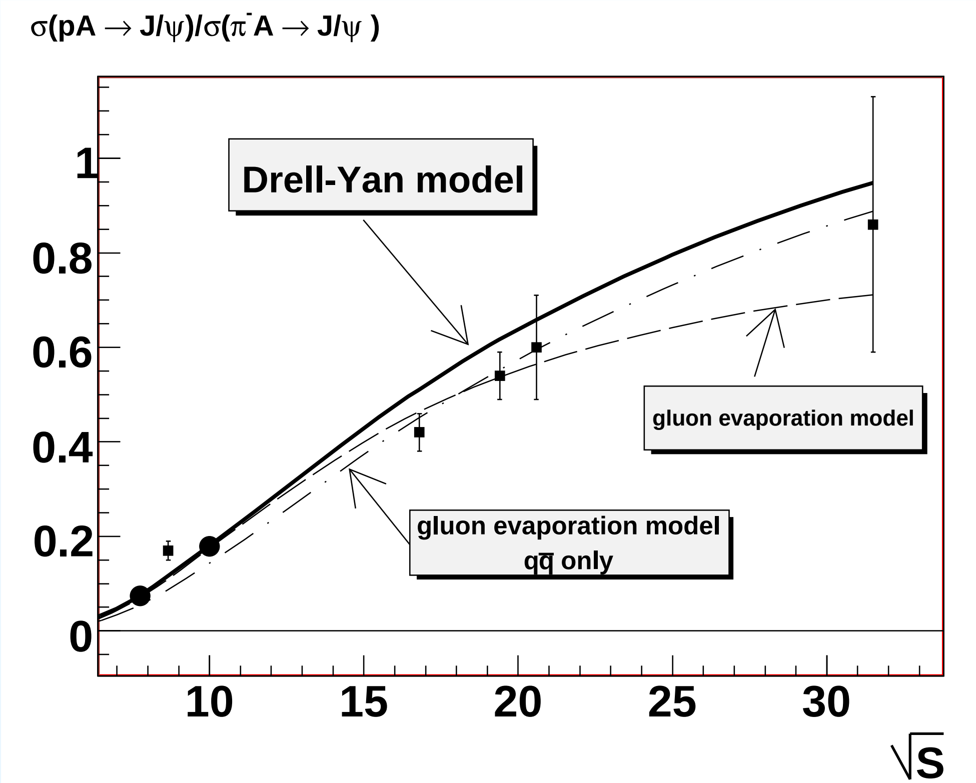


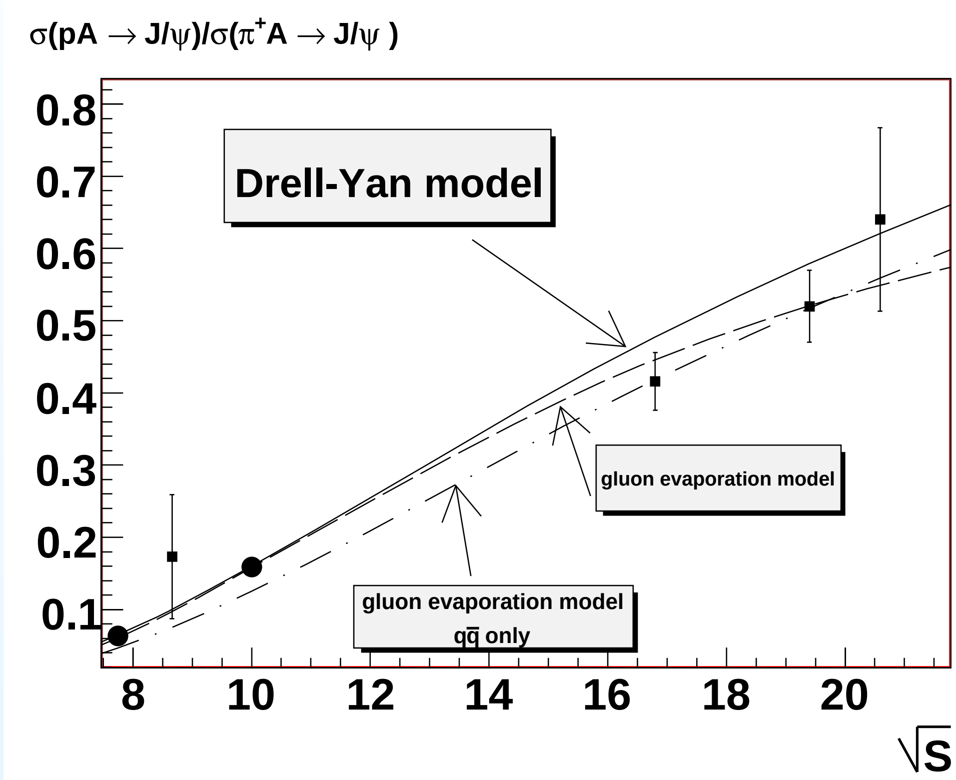
First point: W, Z/A=0.40 (WA39 coll.); second and third points: Pt, Z/A=0.40 (NA3 coll.); fourth point: C, Z/A=0.5 (UA6 coll.); fifth point: Be, Z/A=0.44 (E672/E706 coll.).



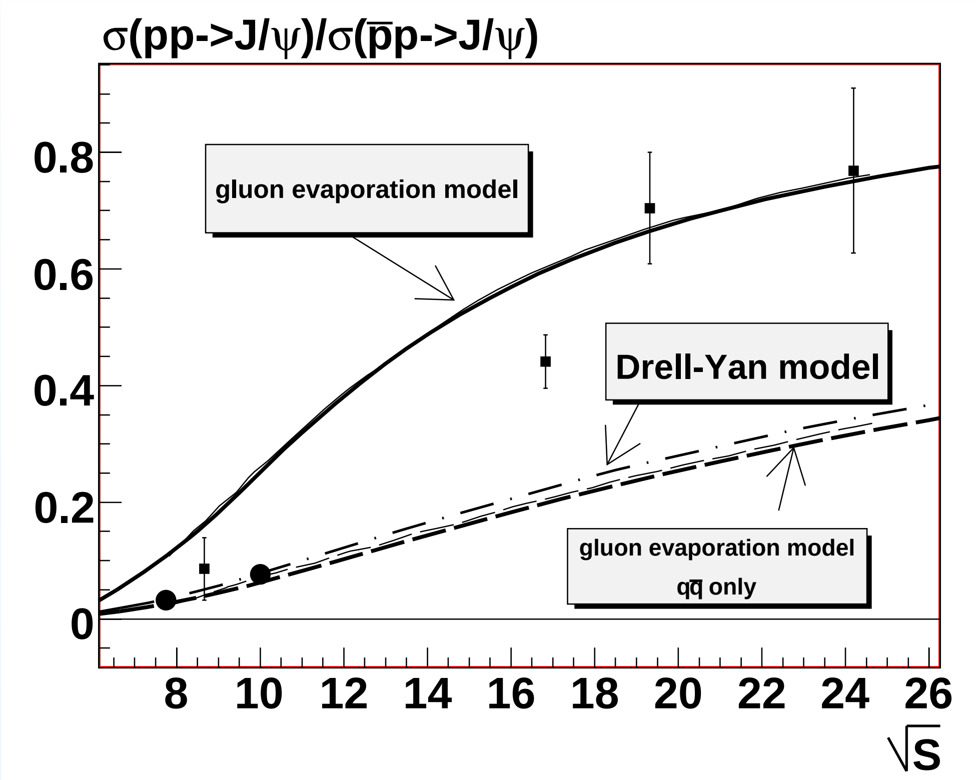


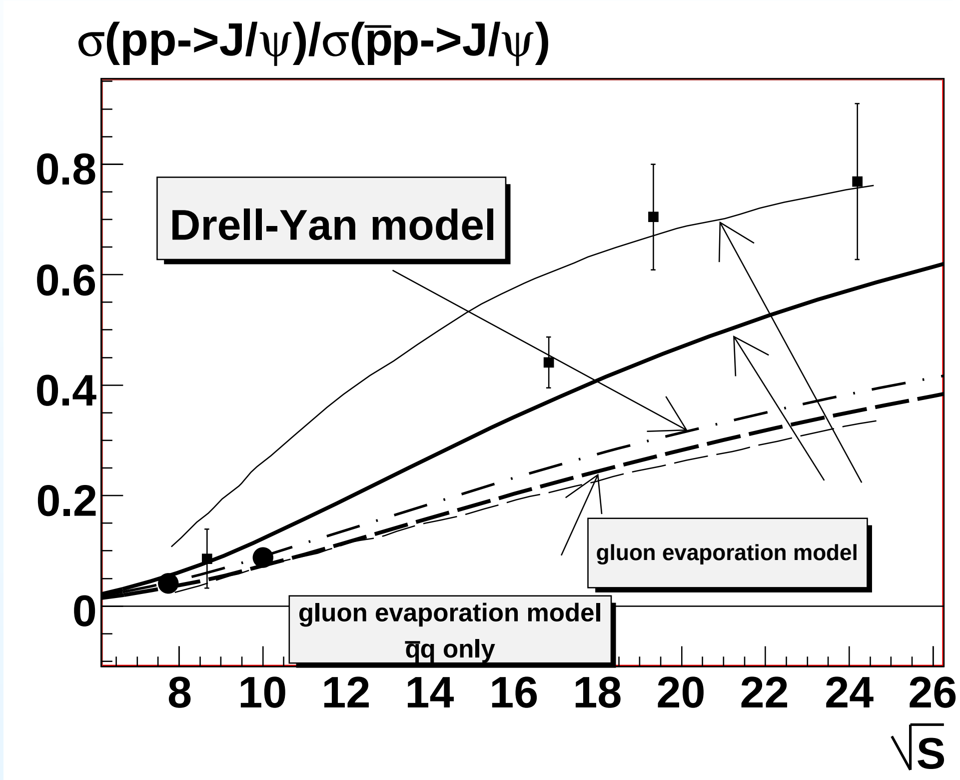
First point: W, Z/A=0.40 (WA39 coll.); second and third points: Pt, Z/A=0.40 (NA3 coll.); fourth point: C, Z/A=0.5 (UA6 coll.).





First point: W, Z/A=0.40 (WA39 coll.); second and third points: Pt, Z/A=0.40 (NA3 coll.); fourth point: C, Z/A=0.5 (UA6 coll.); fifth point: Be, Z/A=0.44 (E672/E706 coll.). Comparison of "Drell-Yan" and gluon evaporation models.





Hydrogen (H_2) target. Data of the different collaborations were collected by UA6 collaboration. Left: old parametrisation by Duke-Owens (1984) is used. Right: recent (widely used) parametrisation GRV98 is used.

Summary

DY

- Presumably transversity as well as Boer-Mulders and Sivers PDFs can be measured by J-PARC
- In the fixed target mode (J-PARC) the polarized beam and unpolarized target gives the access to transversity and Boer-Mulders PDFs. On the contrary, the unpolarized beam and polarized target is necessary to measure Sivers PDF.

J/ψ

- It is argued that "Drell-Yan" model for J/ψ production works well at least for J-PARC energies.
- We've got surprise at large energies !

. . . **Still a lot of work to be done . . .**