J/ψ exclusive photoproduction off protons and nuclei near threshold

Mark Strikman, PSU

Application of VDM: $\sigma_{tot}^{VDM}(J/\psi N) \sim 1\,mb$, $\frac{\sigma_{tot}^{VDM}(\Psi' N)}{\sigma_{tot}^{VDM}(J/\psi N)} \sim \frac{m_{J/\psi}^2}{m_{\Psi'}^2}$

though $\frac{r_{\Psi'}^2}{r_{J/\psi}^2} \sim 4$

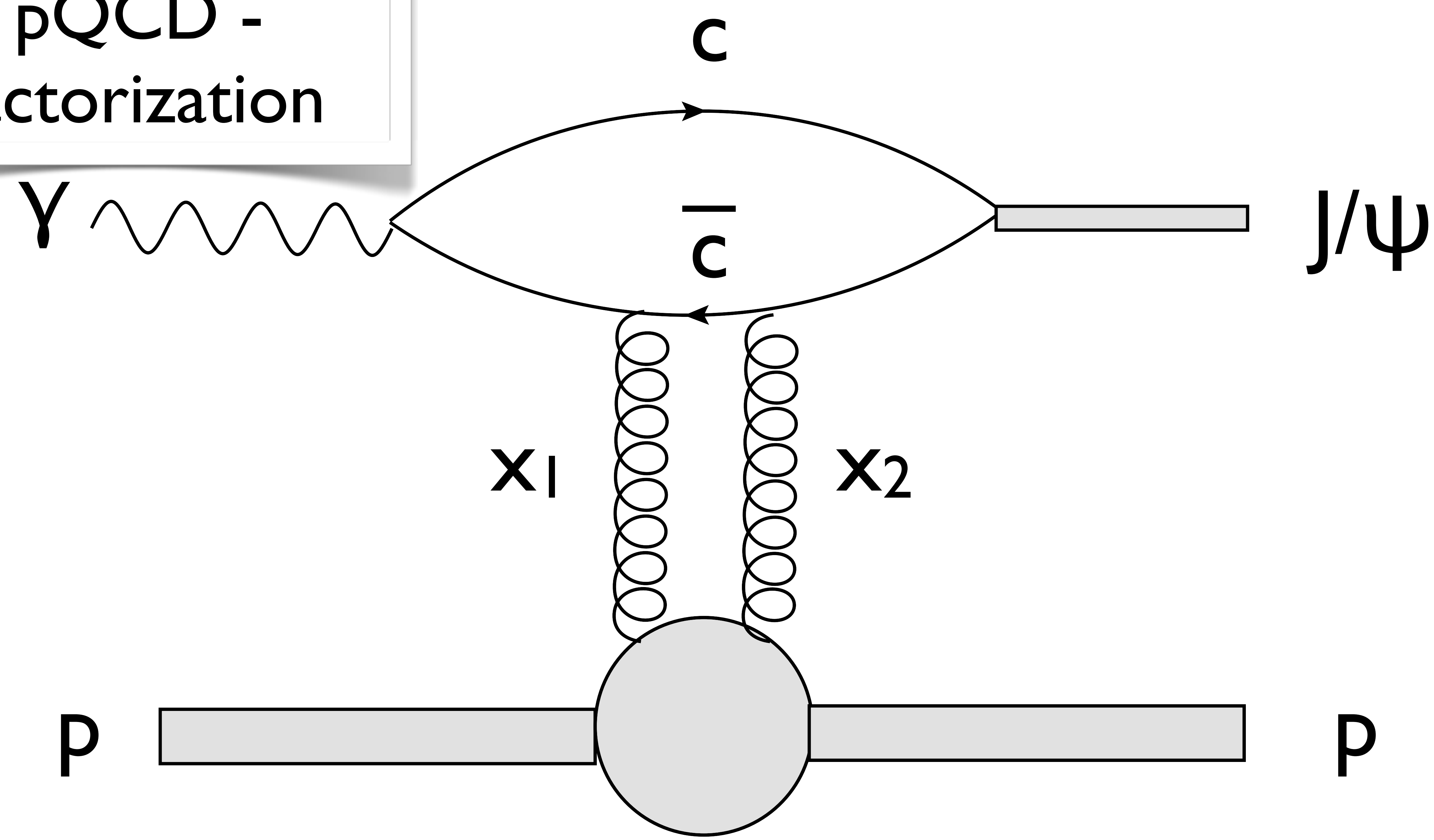
QCD: what enters in the cross section is cross section of small "c$\bar{c}$ pair" -N interaction

Hence VDM underestimates genuine J/ψ-N cross section, due to production of J/ψ in small size configurations ~1/m_c FS85

Consistent with nuclear data $\sigma_{tot}(J/\psi N) \sim 3 \div 4\,mb$

Jlab, March 26, 2011

pQCD - factorization



DGLAP region: $x_2 > 0$ ERBL region: $x_2 < 0$

Im A Re A

$$\alpha_p = (1-x)$$

$$x_1 - x_2 = x \approx \frac{Q^2 + m^2_{J/\psi}}{W^2}$$

$$-t_{min} = \frac{x^2}{1-x} m_p^2$$

Threshold

$$x_{thr} = \frac{1}{1 + m_N/m_{J/\psi}} = 0.77$$

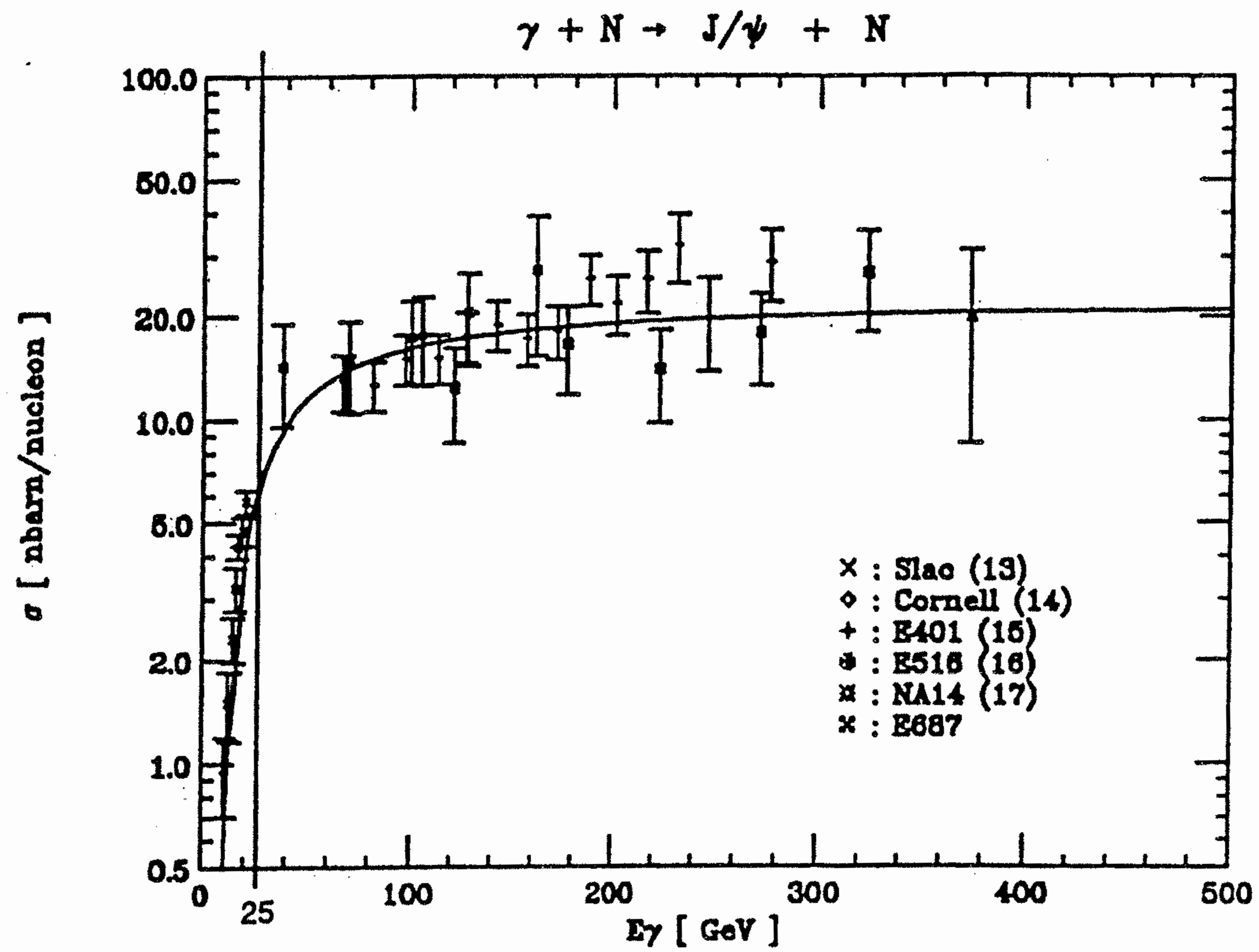
$$x_{thr-naive} = \frac{1}{1 + m_N^2/m_{J/\psi}^2} = 0.92$$

Analysis of the overlapping integral including Fermi motion of quarks in J/ψ (Koepf et al)

$$x_1/x_2 \sim 2$$

pQCD motivated analysis - dipole cross section + realistic charmonium wave functions - a reasonable description of the HERA data - momenta of charm quarks are large: $p_c \sim 1$ GeV/c

Energy dependence



Naive expectation - color evaporation model (in contradiction with QCD)

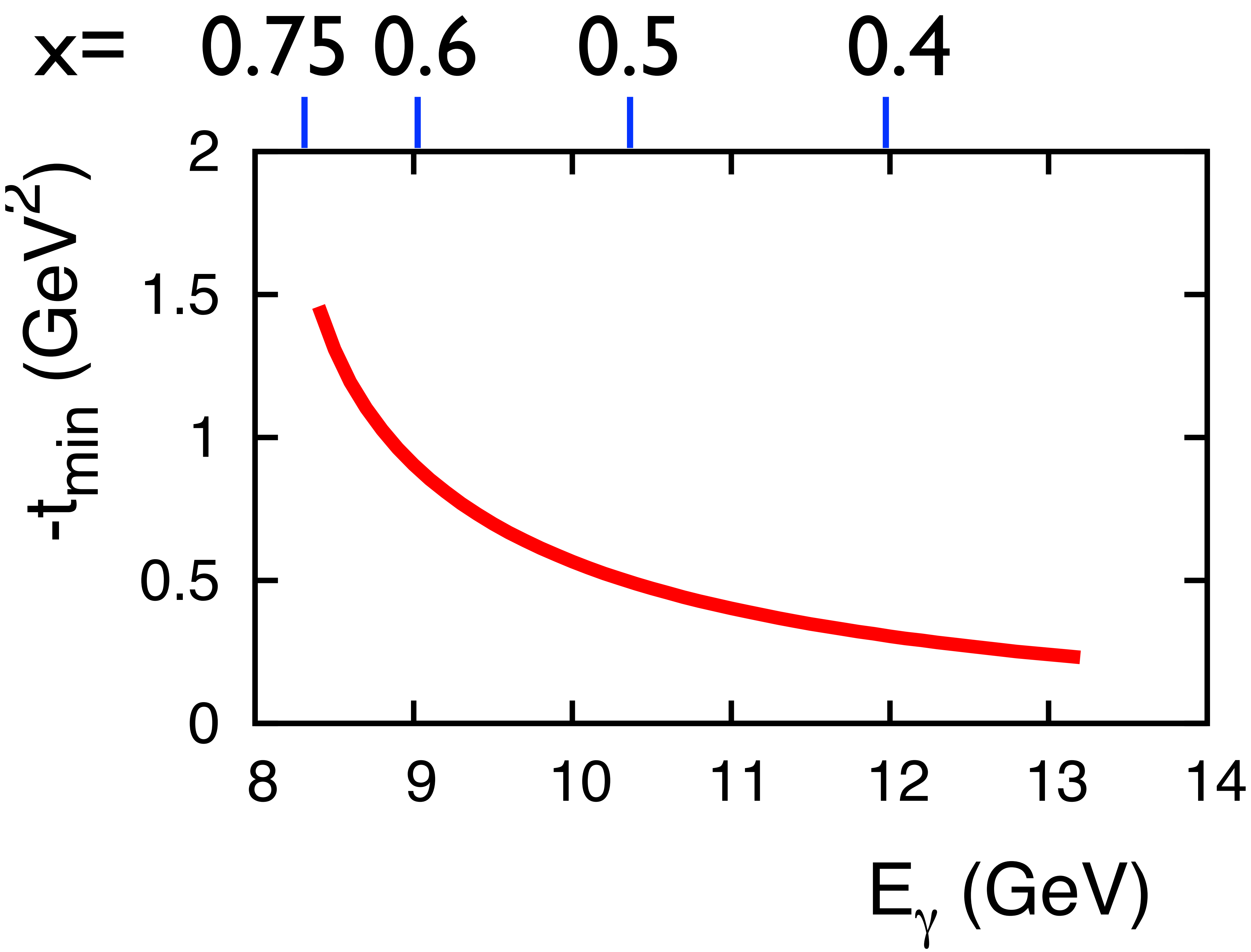
$$\sigma \propto xG_N(x, Q_0^2) \propto (1-x)^5$$ a reasonable fit

At high energies $\sigma \propto xG_N^2(x, Q_0^2)$ ⟹ $[xG(x_1, x_2)] \propto xG_N^2(x, Q_0^2)$???

maybe rather natural if one considers lowest order large x diagrams (MS 98)

Threshold is not kinematic limit for GPDs - $x_{thr} < 1$.

Amplitude for fixed t → const near threshold. However a pretty strong effect due to variation of t_{min} with E_γ



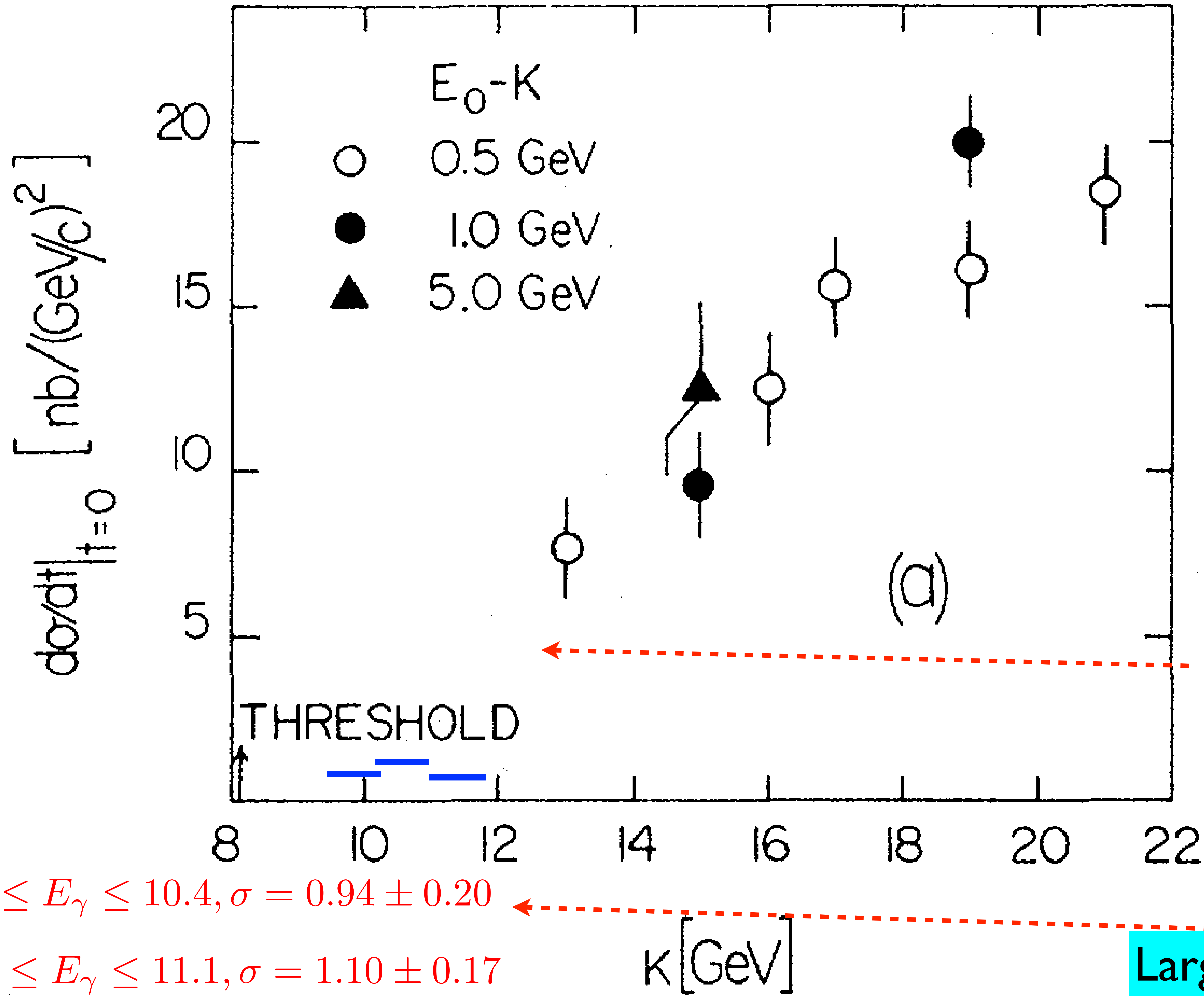
$x=0.6$ - should be much easier to reach for $x_2 < 0$, than for $x_2 > 0$ as in this case $x_1 \sim 1$

$\Downarrow$

Re/Im large in Jlab kinematics???

Is study of interference with BH doable?

Near threshold Data



Tension between SLAC and Cornell data

Wrong extrapolation - could give a factor of 3 up

$9.3 \leq E_\gamma \leq 10.4, \sigma = 0.94 \pm 0.20$

Large extrapolation in t

$10.4 \leq E_\gamma \leq 11.1, \sigma = 1.10 \pm 0.17$

$11.1 \leq E_\gamma \leq 11.8, \sigma = 0.60 \pm 0.12$

Photoproduction of the $\psi(3100)$ Meson at 11 GeV

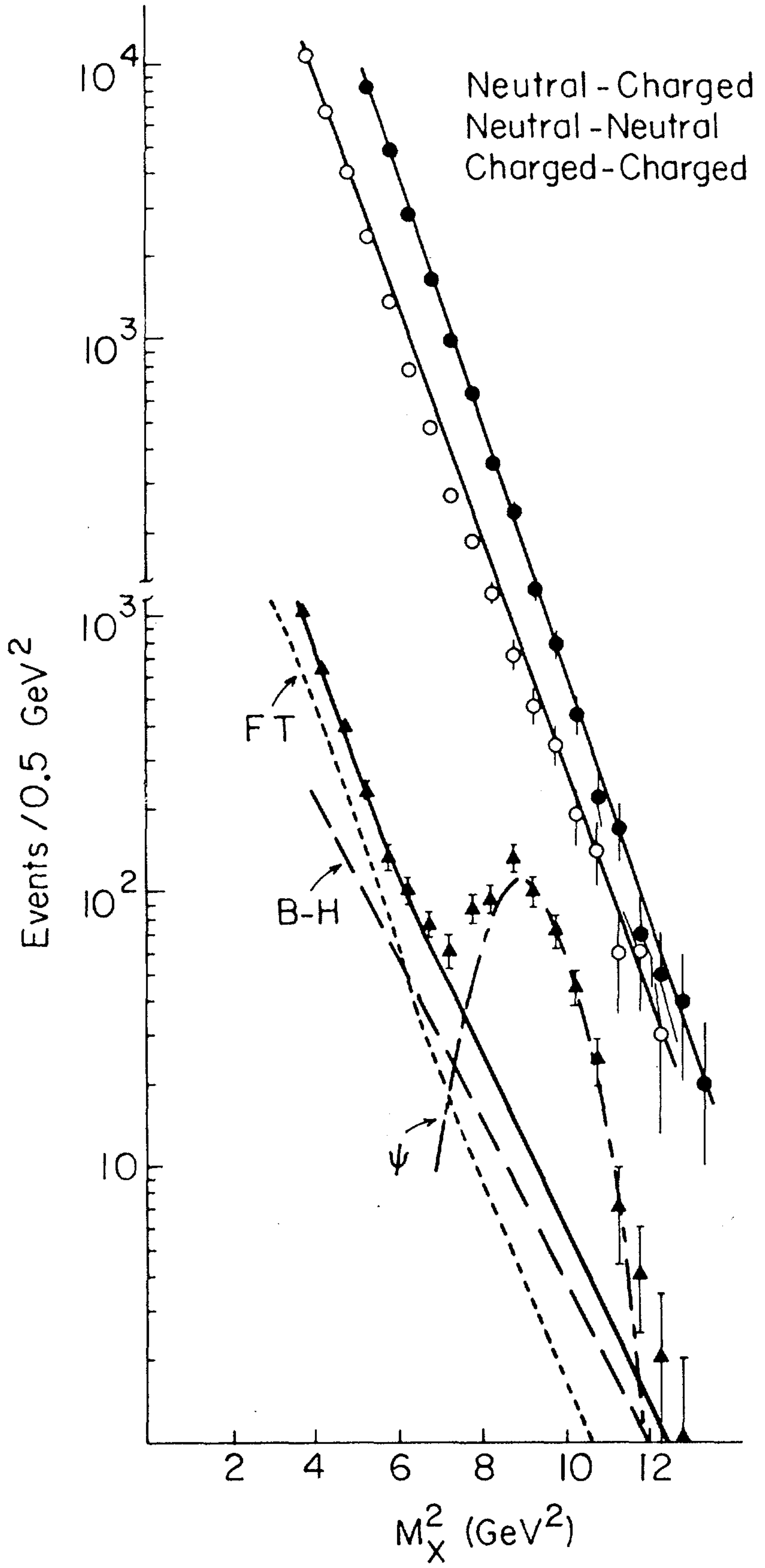


FIG. 1. The two-particle M_x^2 spectra for each of the three charge states. The curves drawn through the n-n and n-c data points are merely to guide the eye. The expected resolution function is drawn through the c-c data points at the ψ mass. The solid line associated with the c-c spectrum is the background arising from Bethe-Heitler pairs (B-H) and experimental feed-through (FT) of n-n and n-c events.

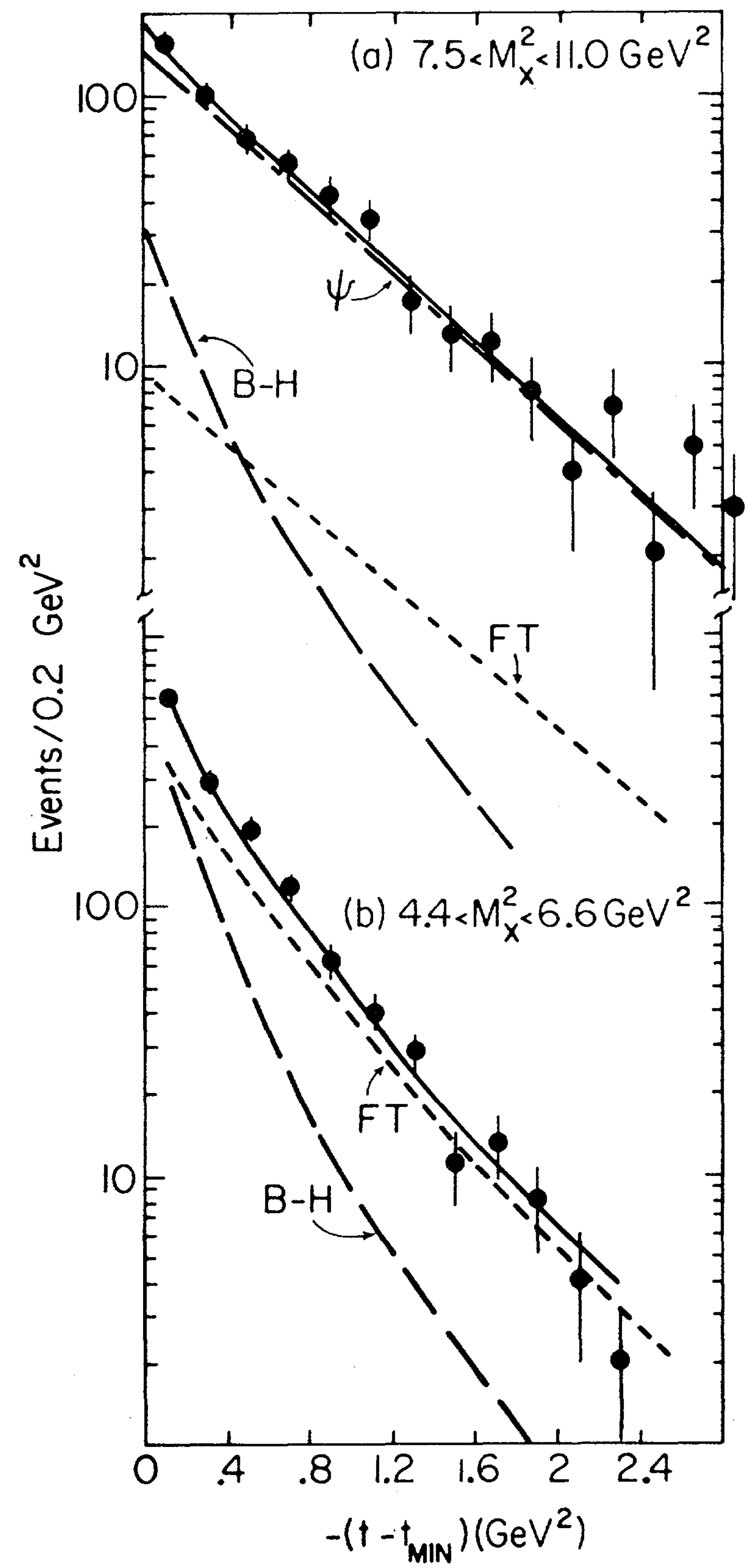


FIG. 2. $t-t_{\min}$ distributions for c-c events in two ıass regions. The solid curves represent the sum of ıe contributions from Bethe-Heitler pairs (B-H), n-n nd n-c feedthrough (FT), and for (a) the fit to the ψ ross section described in the text.

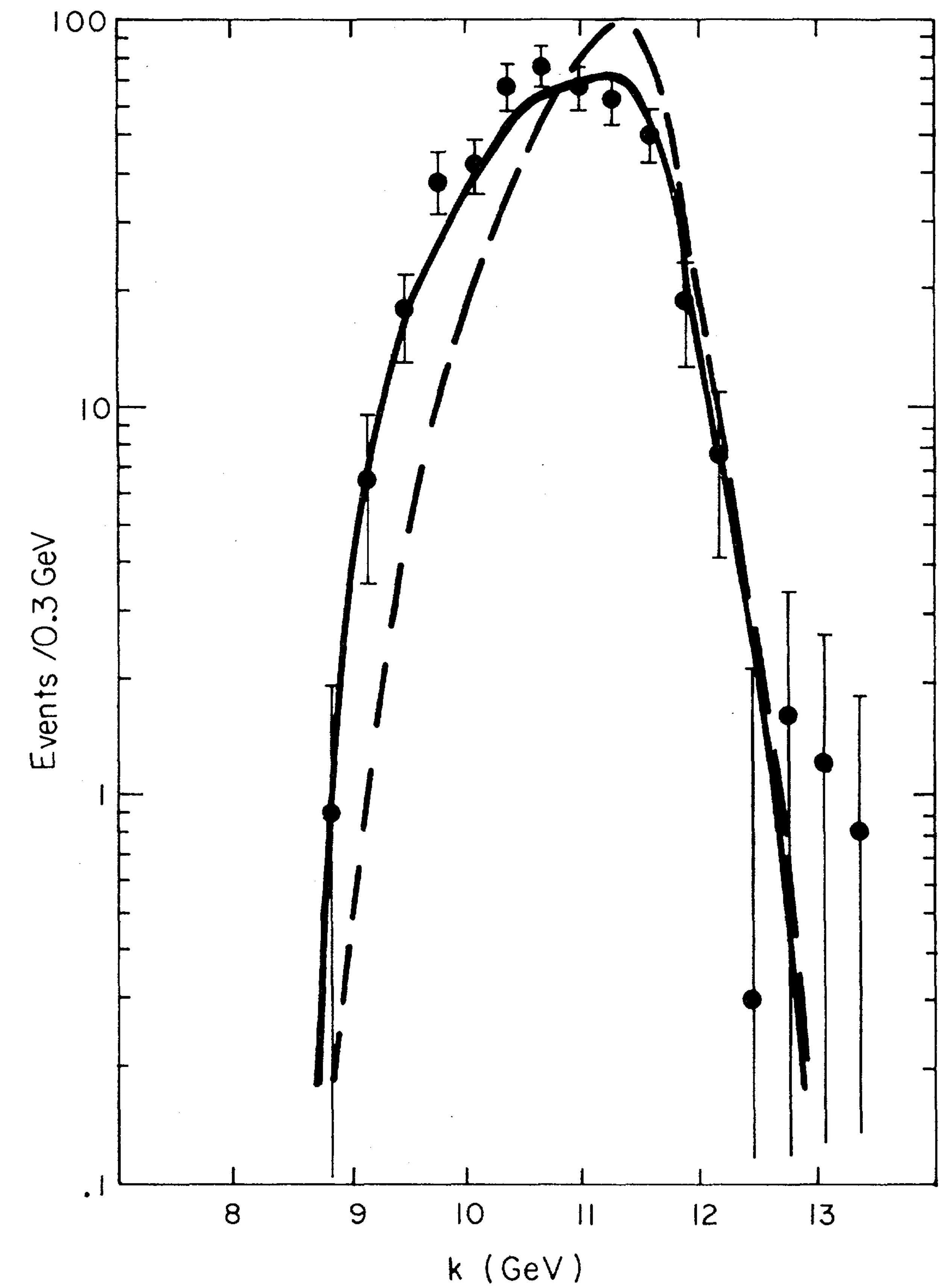
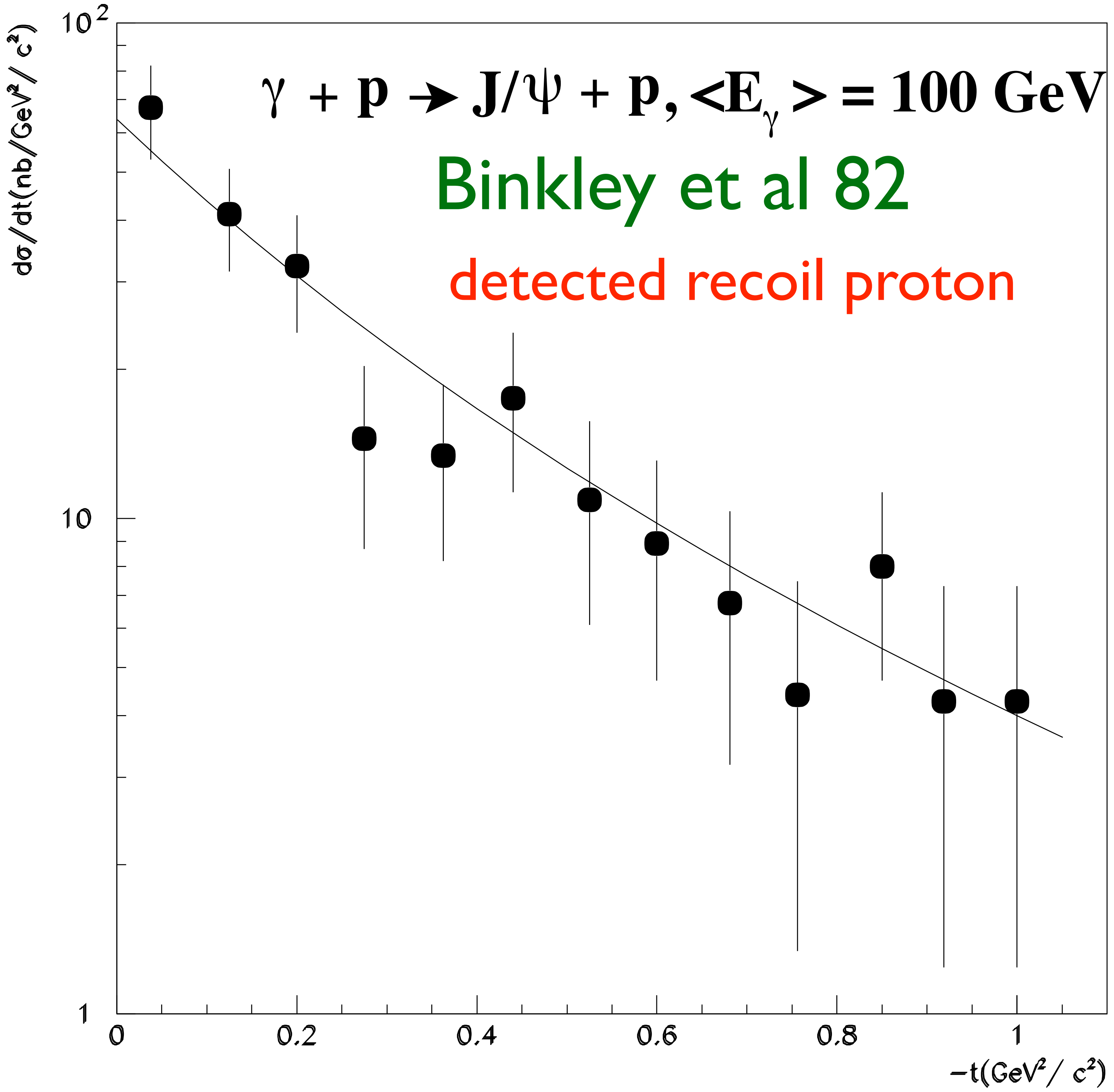


FIG. 3. The reconstructed photon energy distribution for the ψ events with Bethe-Heitler pairs and feed-throughs subtracted. The solid line is the expected distribution for a cross section $d\sigma/dt = 0.9\exp(1.2t)$. The dashed line is for $d\sigma/dt = 0.144(k-8.2)^2\exp(1.2t)$ nb/GeV^2.

Data require slow E dependence?



Theoretical analysis of J/ψ photoproduction at corresponds to the two-gluon form factor of the nucleon for $100\ GeV \geq E_\gamma \geq 10\ GeV$

$$0.03 \leq x \leq 0.4,\ \ Q_0^2 \sim\ 3\ GeV^2, -t \leq 2\ GeV^2$$

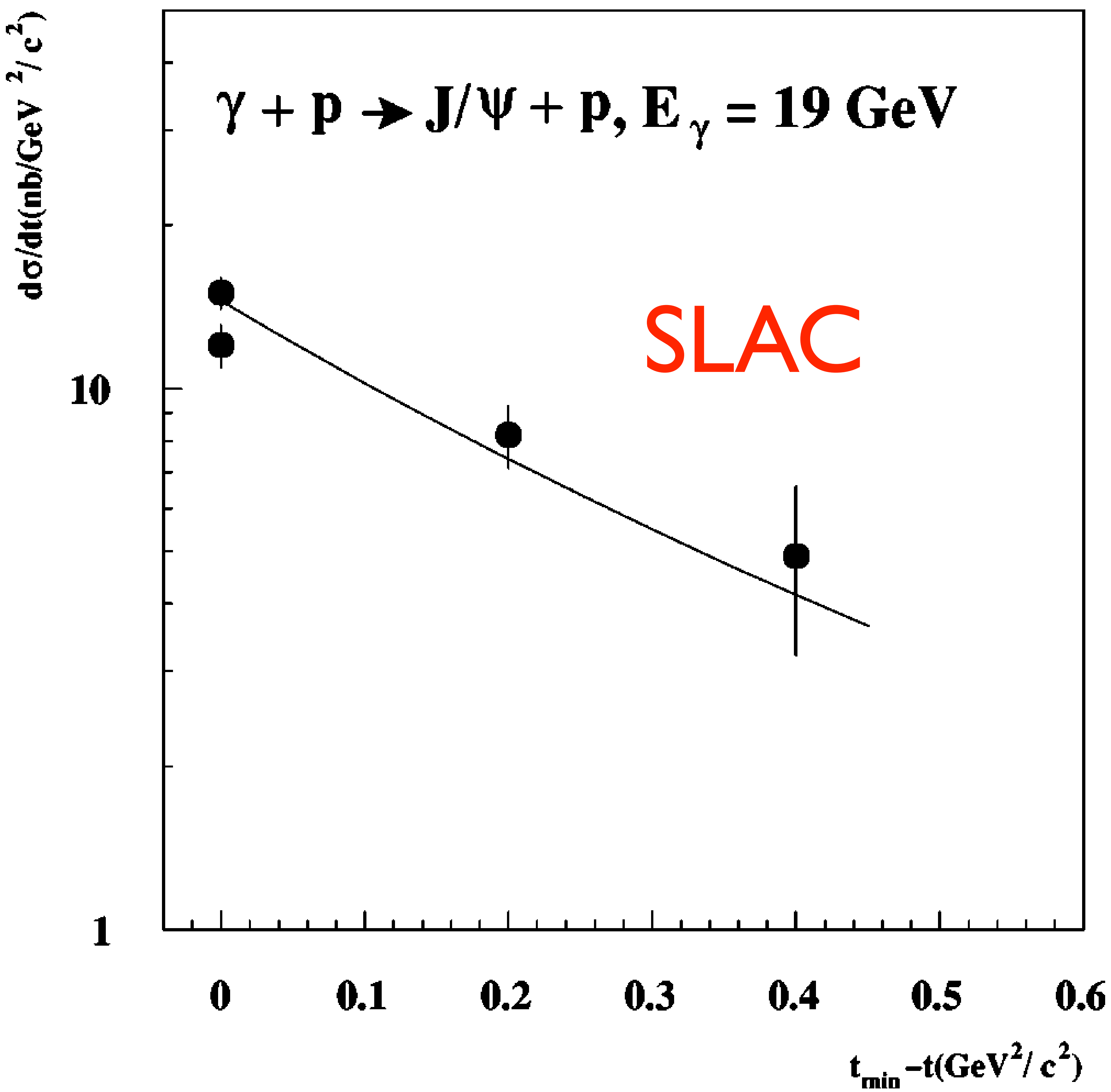
$$F_g(x, Q^2, t) = (1 - t/m_g^2)^{-2}.\ m_g^2 = 1.1\ GeV^2$$

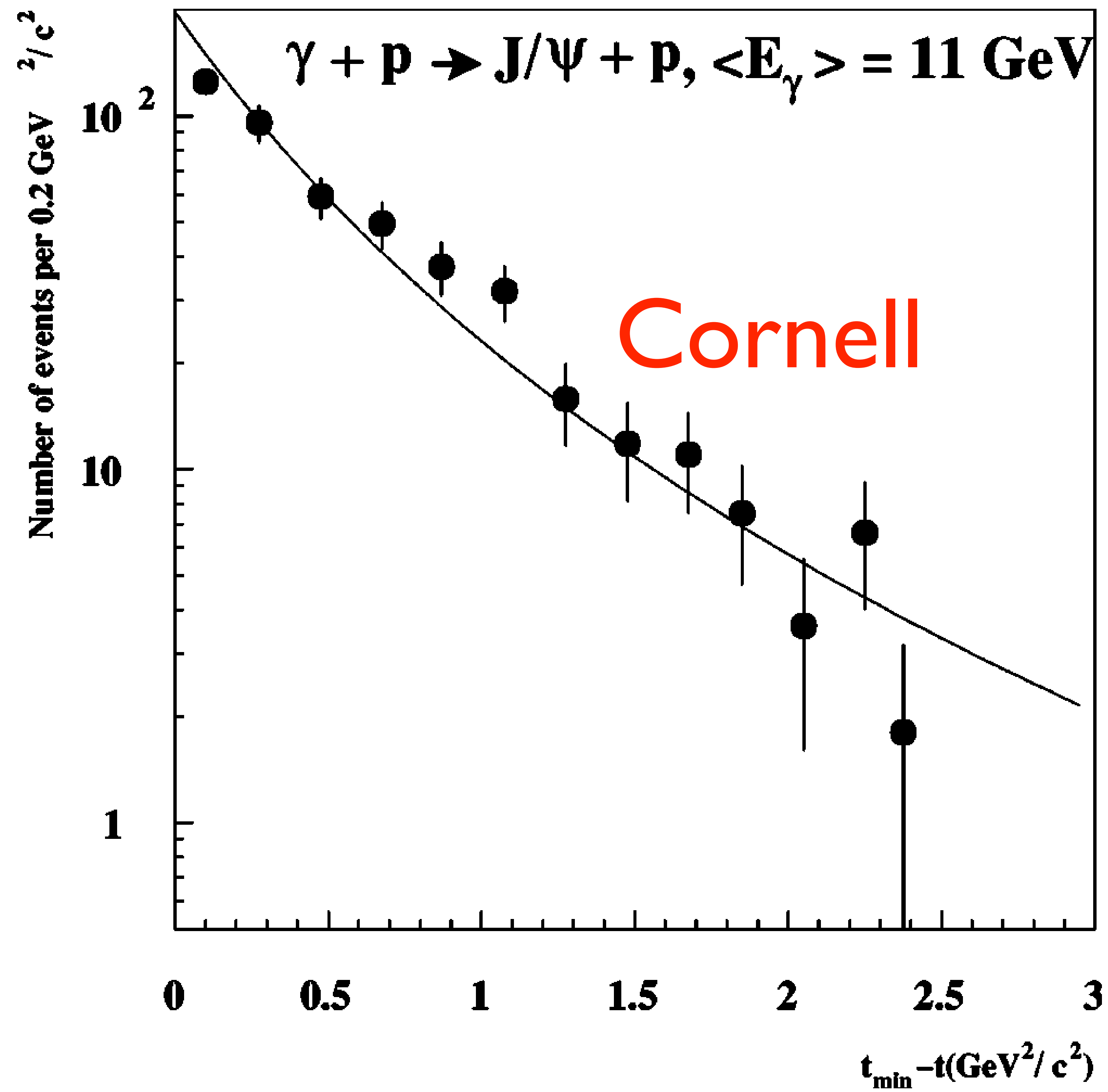
which is larger than e.m. dipole mass

$$m_{e.m.}^2 = 0.7\ GeV^2.$$ (FS02)

Note - fit to the data uses $F(t) = (1 - t/M^2)^{-2},\ \ M^2 = 1.0\ GeV^2$

$m_g^2 - M^2 \approx 0.1\ GeV^2$ correction due to the finite size of J/ψ



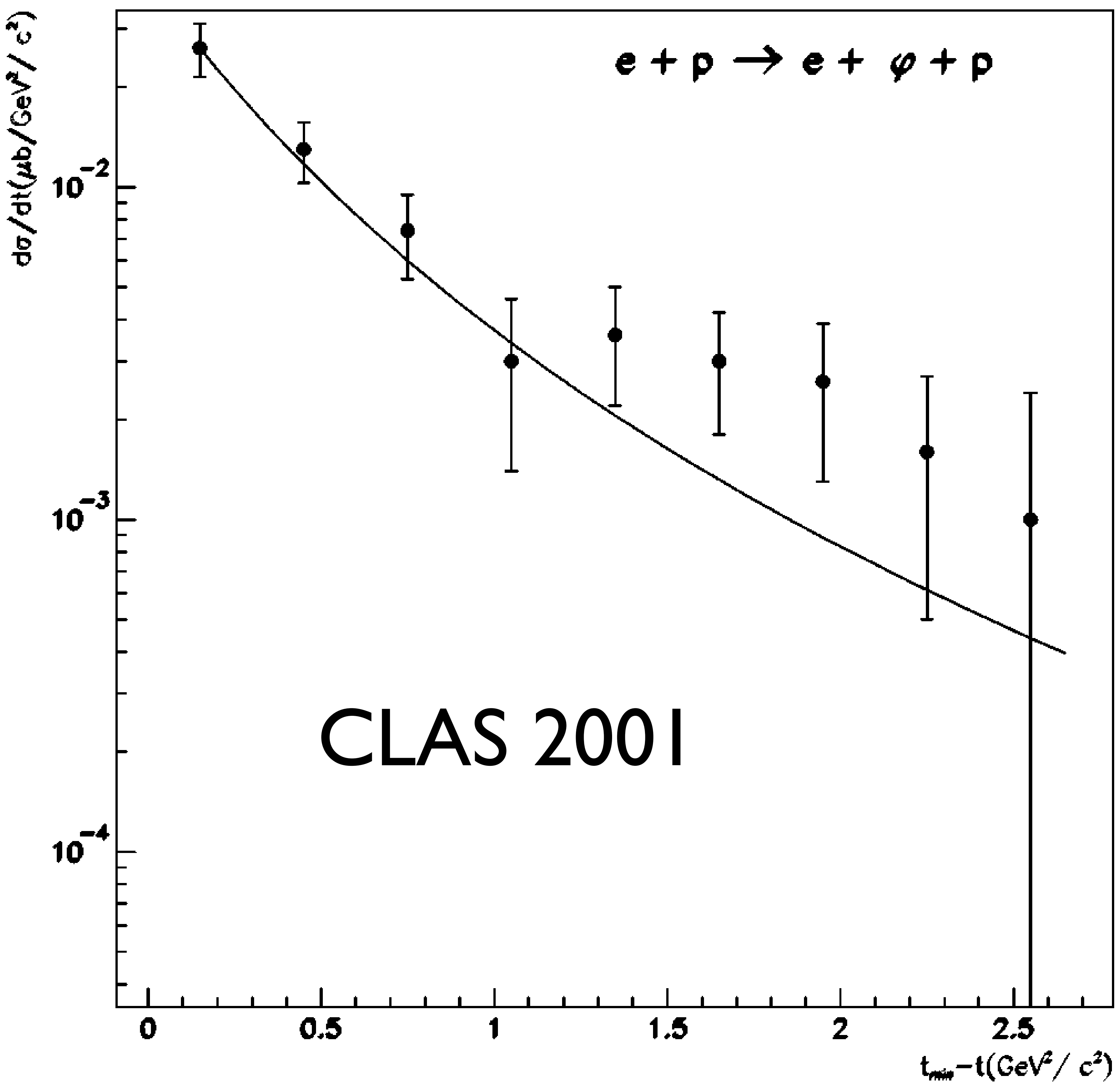


Curves are the dipole parametrization - the same as for E=100 GeV

For exp fit B is a very strong function of energy

Warning: Cornell analysis cited B inconsistent with their plot of t-dependence

Use of the dipole extrapolation to t=0 would increase $d\sigma/dt(t=0)$ by a factor ~ 3!!



$-t$ (GeV^2)	$d\sigma/dt$ (nb/GeV^2)	
0.6	10.7 ± 3.1	normaliz. point
1.0	0.8 ± 1.0	4.4
1.4	3.4 ± 1.0	2.1
1.8	1.0 ± 0.5	1.1
2.2	1.4 ± 0.5	0.67
3.0	0.5 ± 0.2	0.3

CLAS 2008

Comparison of the dipole parametrization with M^2= 1GeV^2 with the ϕ electroproduction data of CLAS.

Easier to squeeze near threshold?

Production of J/ψ's off nuclei

Space -time picture of J/ψ production for scattering off nuclei

$$l_{coh} = \frac{2P}{m^2_{\Psi'} - m^2_{J/\psi}} \approx 0.3fm \cdot P/m_{J/\psi}$$

At Jlab 12 energies J/ψ produced in the interaction point

Expansion effect is very small up to ~ 50 GeV (Farrar et al 1990)

SLAC A-dependence

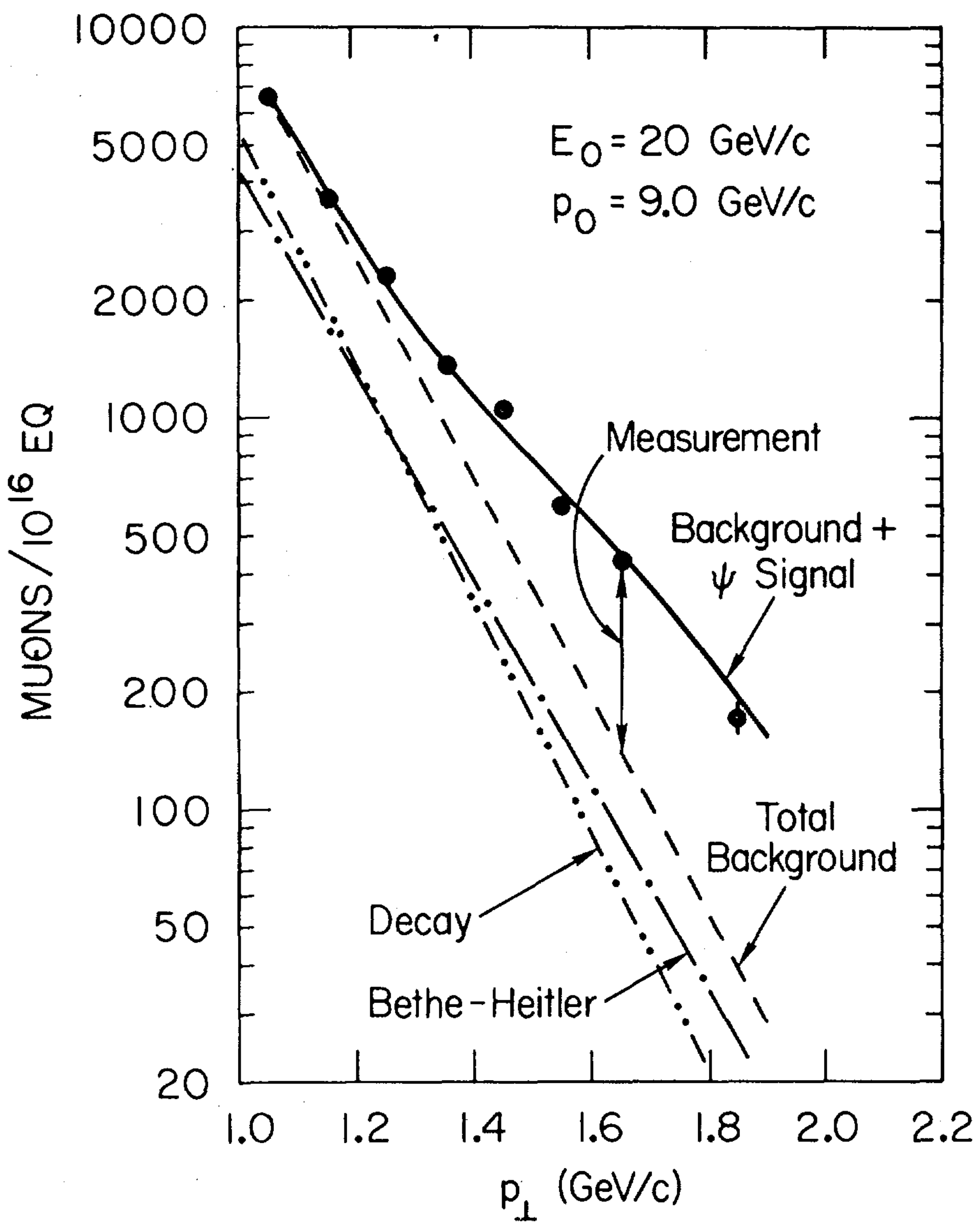


FIG. 2. Muon yield as a function of transverse momentum obtained with a beryllium target. The dashed lines indicate the calculated background contributions and the solid line shows the fitted total muon yield including the J/ψ-production contribution. The transverse momentum is varied by changing the spectrometer angle.

$$[\sigma(\mathrm{Be})/\sigma(\mathrm{Ta})]_{\psi\,\mathrm{corrected}} = 1.21 \pm 0.07$$

$$\sigma_{\psi N} = 3.5 \pm 0.8 \text{ mb}$$

Are errors bars realistic?

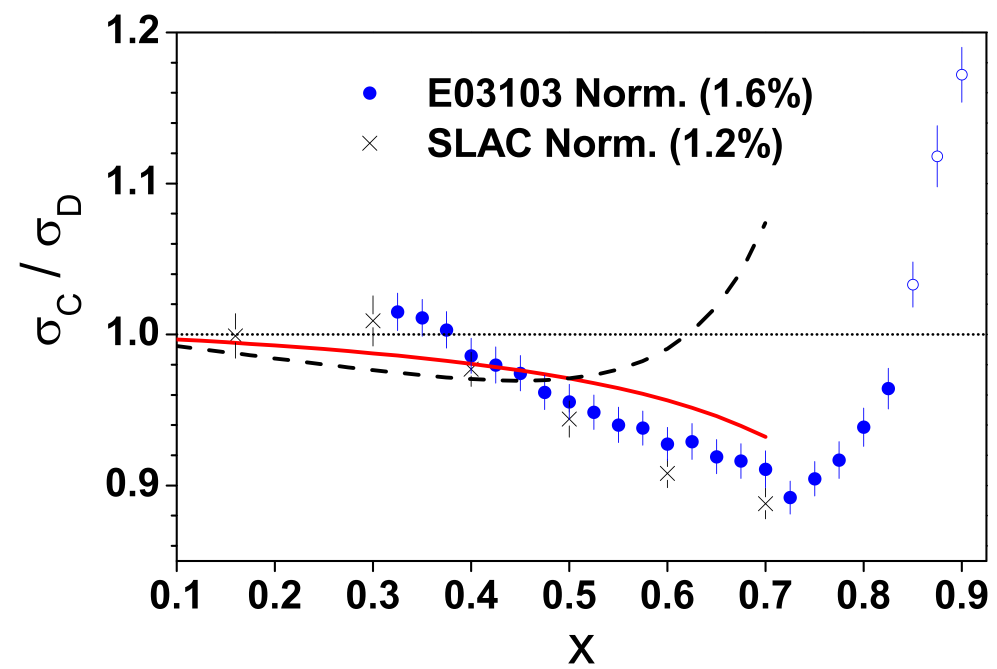
Jlab12

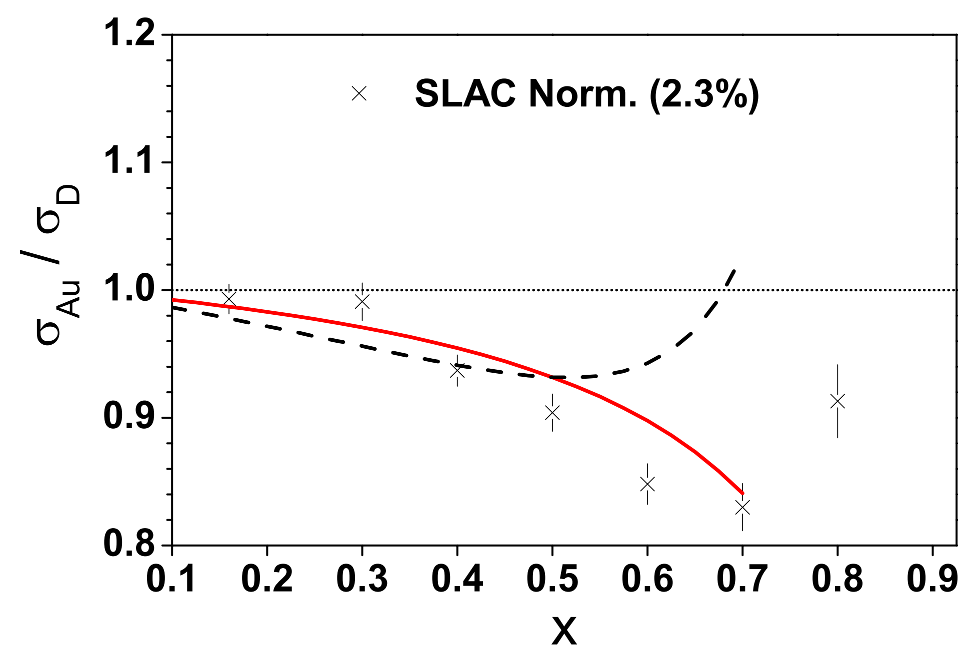
Complication as compared to SLAC 20 GeV (x~ 0.25)

Effects related to nuclear parton structure (like EMC effect)

Bound nucleon gluon GPD at large x ∊ 0.5 ÷ 0.75

Recent development (Frankfurt & MS10) - practically no hadronic EMC effect at x < 0.55 - practically all effect is due to need to use correct Bj x and presence of Coulomb field in nuclei which carries finite fraction of the nucleus light cone momentum. Large x effect is proportional to <k^2> mostly short-range correlations.





red curves= Bj x + Coulomb

dashed curves= Bj x + Coulomb +Fermi motion

Whether the same effects dominate for gluons for x < 0.55 is not clear. In any case likely very different dynamics for ERBL and DGLAP regions.

Is “coherent” (“collective”) production off light nuclei is possible / has a clear signature?

<u>Example</u> E_γ= 8.2 GeV

$x(\gamma p)=0.77$, $p_{J/\psi}=6.2$ GeV/c

$x(\gamma^2H)=0.6$, $p_{J/\psi}=7.4$ GeV/c

→ Sensitivity to Fermi motion and recoil

Thresholds for scattering involving N nucleons

$E_\gamma^{(1)}$= 8.2 GeV

$E_\gamma^{(2)}$= 5.66 GeV

$E_\gamma^{(3)}$= 4.8 GeV

To observe J/ψ in the Jlab experiment of P.Bosted et al, N=3 was necessary

More work is necessary to figure out how to separate FSI and initial wave function (Fermi motion and nucleon deformation) effects

Worth exploring study of FSI through final states

- $J/\psi + N \rightarrow J/\psi + X$ $\Rightarrow$ slower J/ψ
- $J/\psi + N \rightarrow \bar{D} + \Lambda_c$
- $J/\psi + N \rightarrow \psi' + N$ $\sim 10^{-3}$ J/ψ for A=200???

☀ Shift of the J/ψ momentum due to Fermi nucleon momentum/ coherent recoil

Conclusions

Jlab 12 is in a unique position to study near threshold dynamics for J/ψ .

Hard dynamics seems to dominate for J/ψ - window to gluon GPDs in extreme large x limit

Hard dynamics seems to be relevant for ϕ at $Q^2 \sim 2GeV^2$

J/ψ photoproduction off nuclei

☛use open geometry to probe momentum of struck nucleon - try to learn from this more about nuclear effects in the initial state (light nuclei)

☛ use heavy nuclei to look at modifications of J/ψ spectrum, production of ψ'

Worth doing in parallel φ electroproduction off nuclei

Complementary studies planned by PANDA