Testing BFKL using high-t vector meson production

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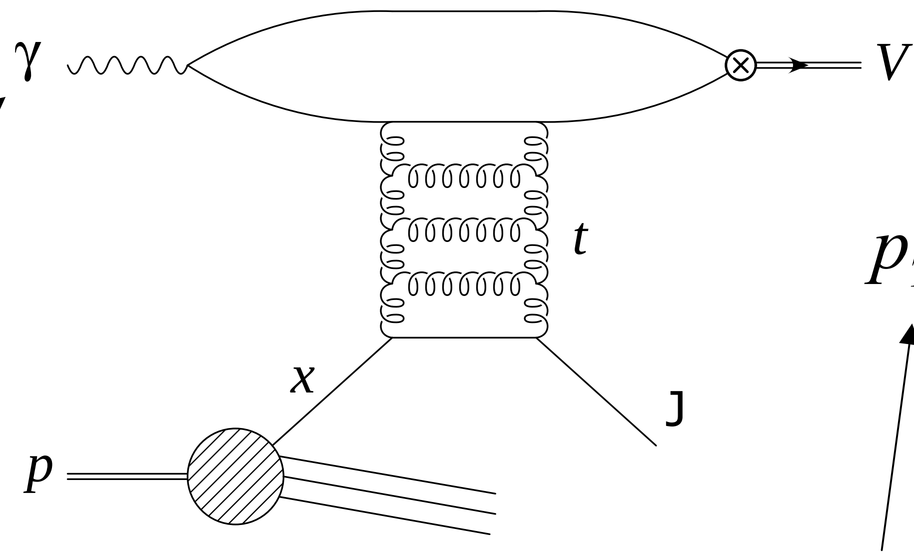
High-t Meson Production



Real (or virtual) photon.

$$p_T^2 \approx -t$$

Transverse momentum of jet J and meson V.

$$xW^2 >> -t >> \Lambda^2$$

There is a rapidity gap between the meson V and the jet, J.

Motivation

- ✓ Large momentum transfer: an excellent opportunity to elucidate our understanding of rapidity gap processes in a perturbative environment.

- ✓ No need to measure the dissociating proton: obvious experimental advantage; can reach high rapidity gaps (<6 units) and therefore probe QCD in a region where fixed order PT breaks down (BFKL).

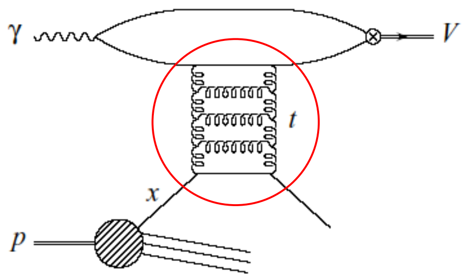
- ✓ Relatively rare, means we are only recently getting high quality data from HERA.

- ✓ No "gap survival" problems. Variety of mesons to measure (and photons).

Lowest order BFKL

Asymptotically:

$$\frac{d\sigma}{dt}(\gamma q \to Vq) \sim \frac{\alpha_s^{\ 4}}{t^4}\left(\frac{s}{s_0}\right)^{2\omega_0}$$



$$\omega_0 = 12 \ln 2 \frac{\alpha_s}{\pi}$$

Regge cut

BFKL = summing logarithms in energy:

$$\sum_n \left(c_n^0 \alpha_s^{\ n} \ln^n (s/s_0) + c_n^1 \alpha_s^{\ n} \ln^{n-1}(s/s_0) + ...\right)$$

LL

Balitsky, Fadin, Kuraev, Lipatov

- ✓ Complete LL calculations do go beyond the asymptotic approximation

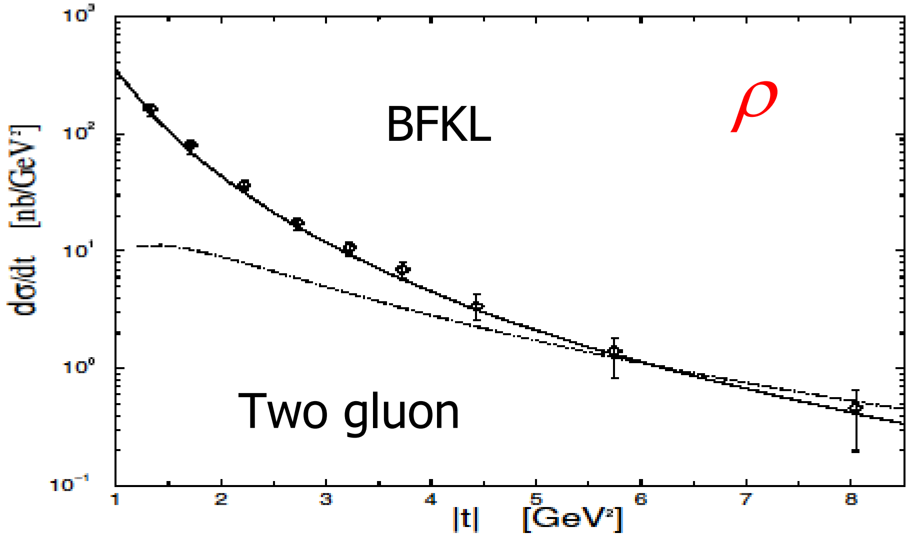
- ✓ But they treat the vector meson in a non-relativistic limit i.e. the quark and antiquark have no relative transverse momentum and share equally the meson's longitudinal momentum.

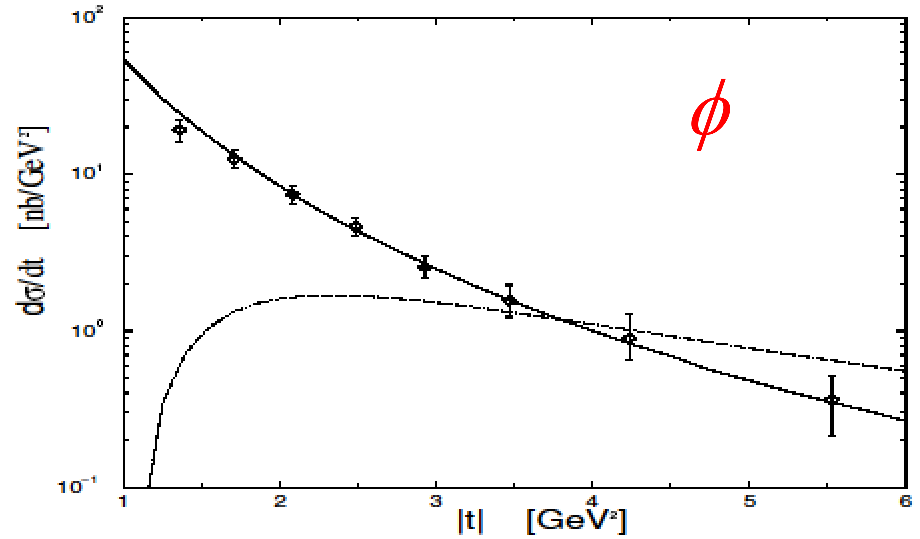
- ✓ And they keep only lowest conformal spin "n=0" (BFKL amplitude can be written as a sum over functions labelled by the way they transform under the conformal group, n=0 dominates at large enough centre-of-mass energy)

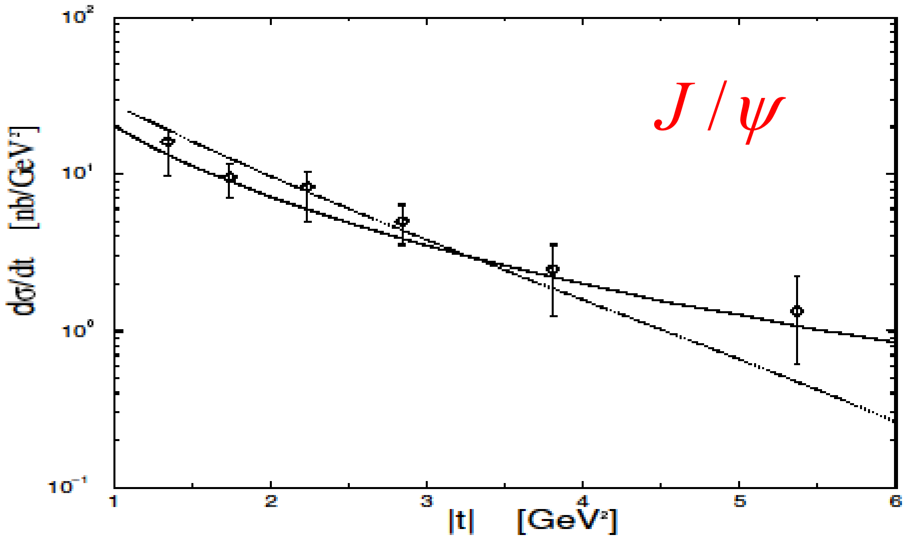
- ✓ Even so, LL seems to work very well indeed…

[Forshaw & Ryskin; Bartels, Forshaw, Lotter, Wüsthoff]

Comparison to ZEUS data







- LO BFKL works remarkably well: Three parameter fit
  α_s and $s_0 = \beta M_V^2 - \gamma t$
  Fit prefers
  $\alpha_s \approx 0.20$ and $s_0 \approx M_V^2$
- Two-gluon exchange fails

Forshaw & Poludniowski

Fixed order perturbation theory

✓ Two-gluon exchange calculations (and fixed order calculations in general) miss some essential physics They predict that one gluon should carry all the momentum transfer whilst the other carries none

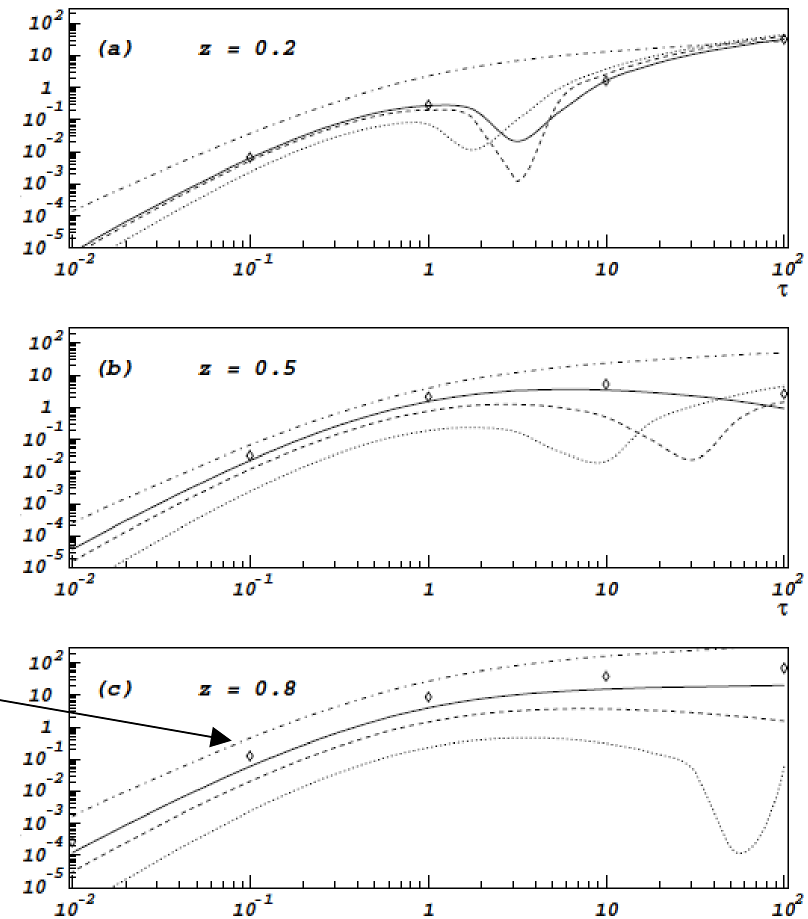
✓ Need to resum double logs:

$$\exp[\sim \alpha_s \ln(k^2 (k-q)^2 / q^2) \ln s]$$

✓ And also single logs:

$$\sim \alpha_s \ln s$$

Poor convergence of perturbation series (even after resumming double logs – it is much worse if one does not resum them)



Forshaw & Ryskin

Improving the original calculations I: Relativistic Corrections

- Original calculations of D.Ivanov et al implement full lightcone wavefunctions of the vector mesons but in a two-gluon exchange model

  Two-gluon exchange is IR divergent due to endpoint singularities in the integral over the quark/antiquark momentum fractions. This divergence is not present after BFKL summation.

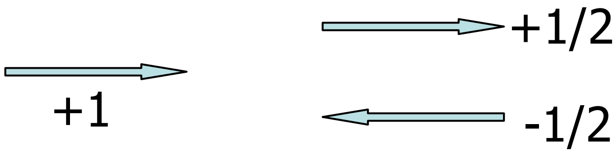
- For light mesons naïvely expect “chiral even” term to dominate

  Ivanov et al argued that although the chiral even term dominates at asymptotically high momentum transfers, there should be a significant chiral odd component at HERA energies.

D.Ivanov, Kirschner, Schäfer, Szymanowski
Ball, Braun, Koike, Tanaka

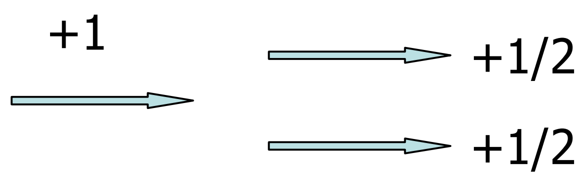
Chiral Even

Naively expect light mesons to be be predominantly **longitudinal**



But longitudinal amplitude should vanish if the quark and antiquark are collinear and share equally the meson's momentum

Chiral Odd



Expect meson to be predominantly **same helicity** as photon

HERA data

But the amplitude should be suppressed by $m^2 / |t|$

Condensate? Current mass? Constituent mass?

Nb: Chiral odd is the only contribution in the non-relativistic approximation used in the original calculations.

Closed analytic expressions have now been obtained for all amplitudes:

$$M_{++}^{\rm odd} = \frac{C_V f_V^T}{4|q|} \int_0^1 du\, 6\, u(1-u)$$
$$\times \sum_{n=-\infty}^{n=+\infty} \int_{-\infty}^{\infty} d\nu \frac{\nu^2+n^2}{[\nu^2+(n-1/2)^2][\nu^2+(n+1/2)^2]} \frac{\exp[\chi_{2n}(\nu) z]}{\sin(i\pi\nu)} I_{-\frac{1}{2}\,-\frac{1}{2}}(\nu, 2n, q, u; 0)$$

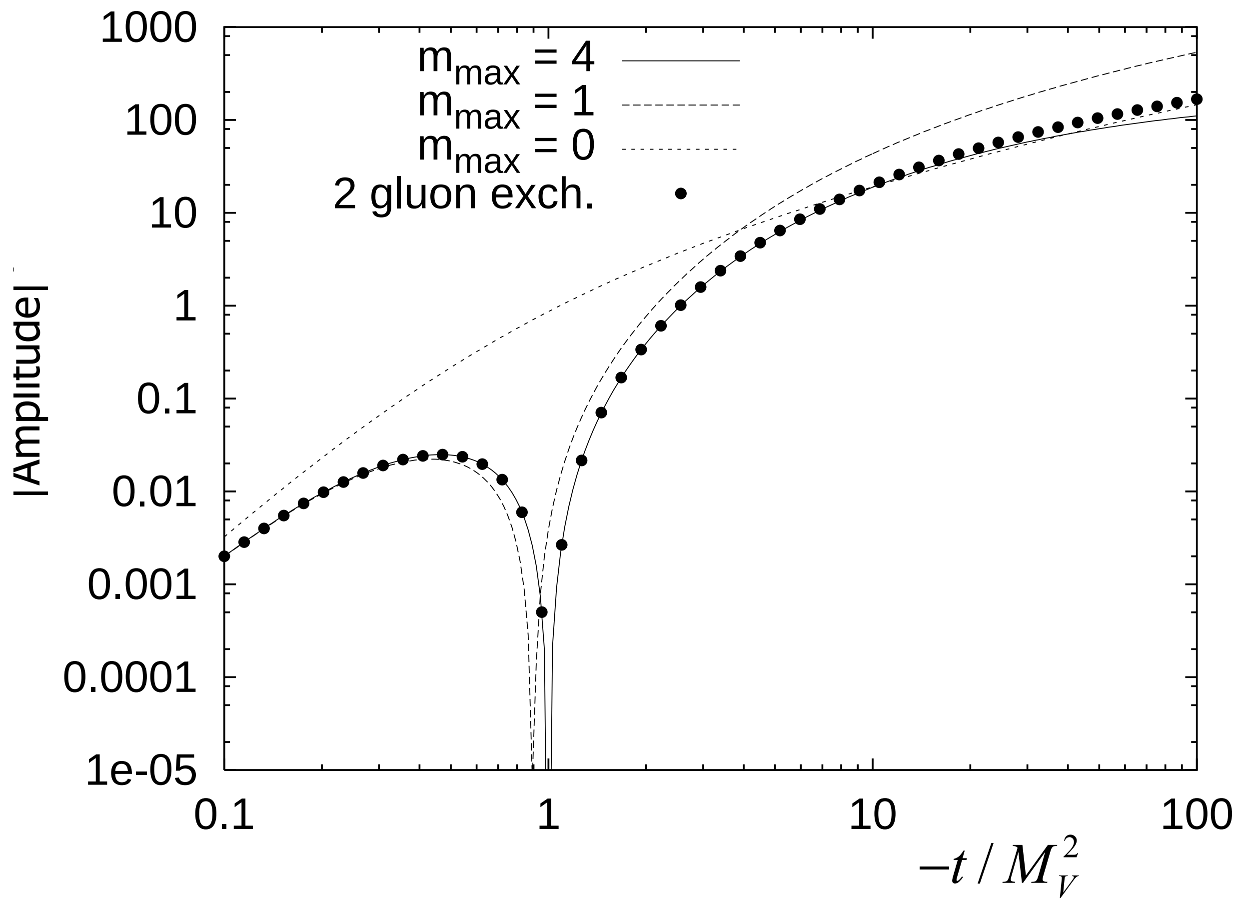
$$I_{\alpha\beta}(\nu,n,q,u;a) = -\frac{m}{2} \int_{C'-i\infty}^{C'+i\infty} \frac{d\zeta}{2\pi i} \Gamma(a/2-\zeta)\Gamma(-a/2-\zeta)\,\tau_q^{\zeta}\,(i\,{\rm sign}\,(2u-1))^{\alpha-\beta+n}$$
$$\times \left(\frac{4}{|q|}\right)^4 [\sin\pi(\alpha+\mu+\zeta)\;\; B(\alpha,\mu,q^*,u,\zeta)\, B(\beta,\widetilde{\mu},q,u^*,\zeta)$$
$$-\;(-1)^n \sin\pi(\alpha-\mu+\zeta)\; B(\alpha,-\mu,q^*,u,\zeta)\, B(\beta,-\widetilde{\mu},q,u^*,\zeta)\;]$$

$$B(\alpha,\mu,q^*,u,\zeta) = (-4u\bar{u})^{-(\mu+2+\alpha+\zeta)/2} \left(\frac{4}{q^*}\right)^{\alpha} 2^{-\mu} \frac{\Gamma(\mu+2+\alpha+\zeta)}{\Gamma(\mu+1)}$$
$${}_2F_1\left(\frac{\mu+2+\alpha+\zeta}{2}, \frac{\mu-1-\alpha-\zeta}{2}; \mu+1; \frac{1}{4u\bar{u}}\right).$$

Enberg, Forshaw, Motyka, Poludniowski

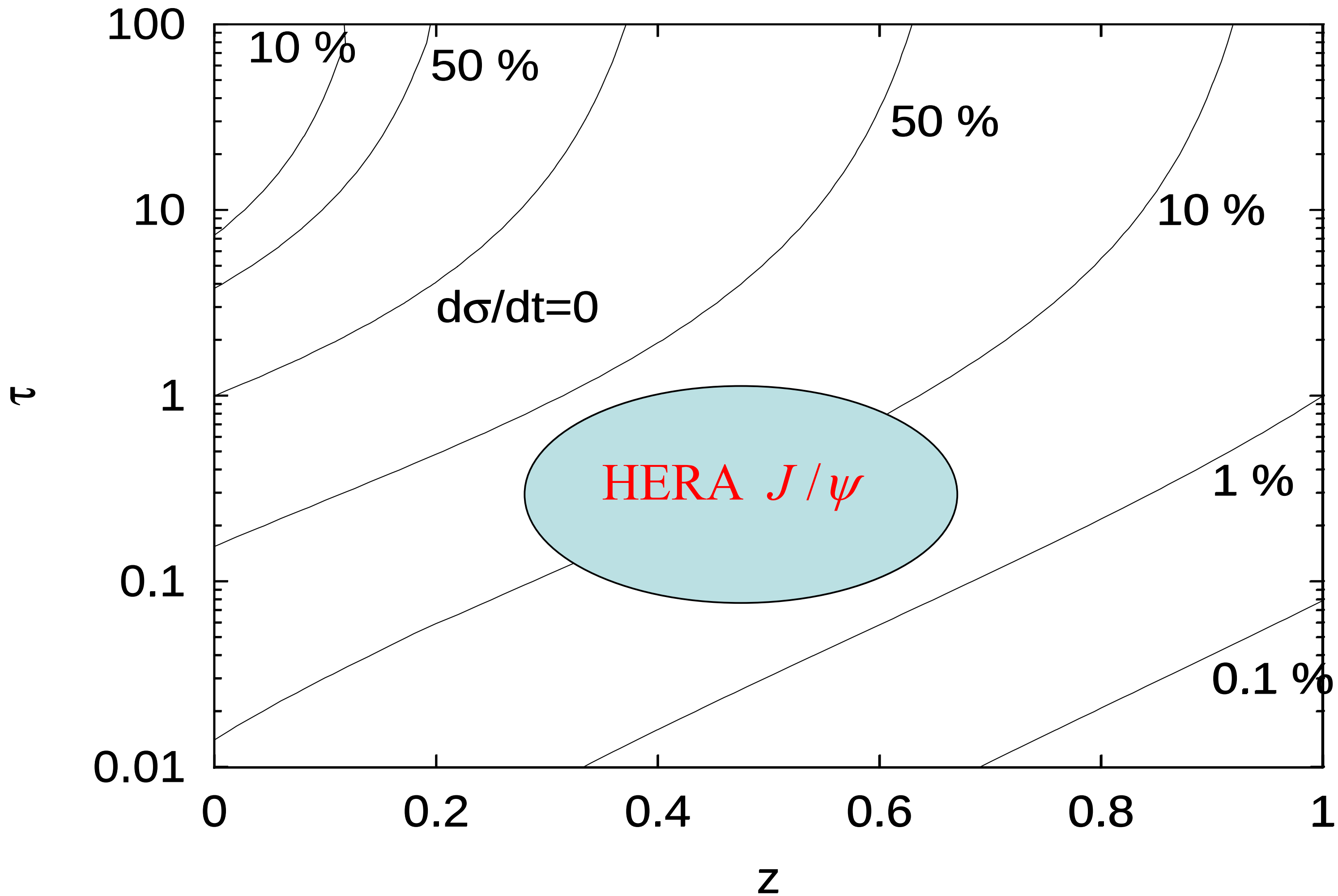
Improving the original calculations II: Conformal Spin

Higher conformal spin is necessary to match BFKL to the two-gluon approximation at zero rapidity.



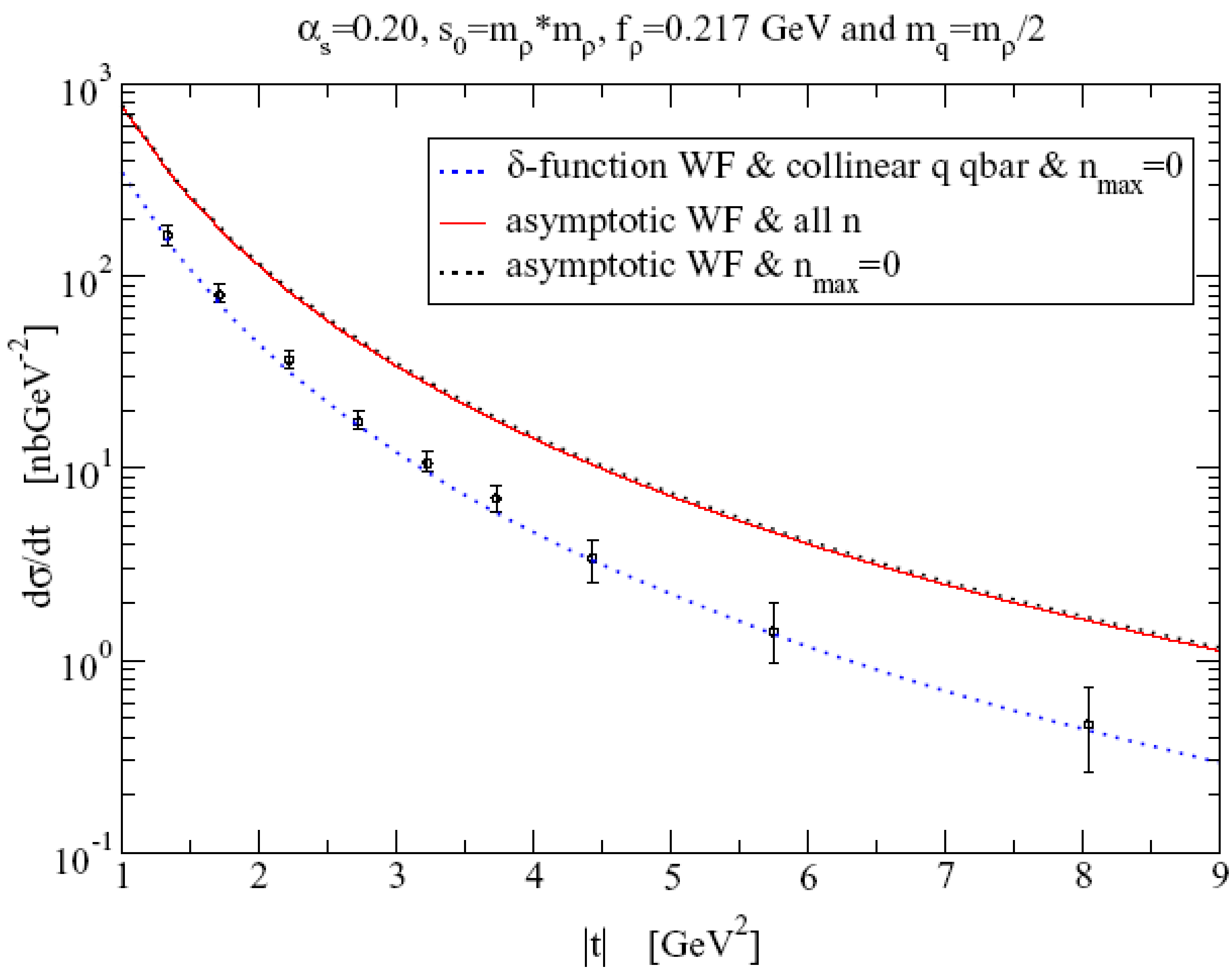
Enberg, Motyka, Poludniowski

Higher conformal spin is a modest effect at HERA

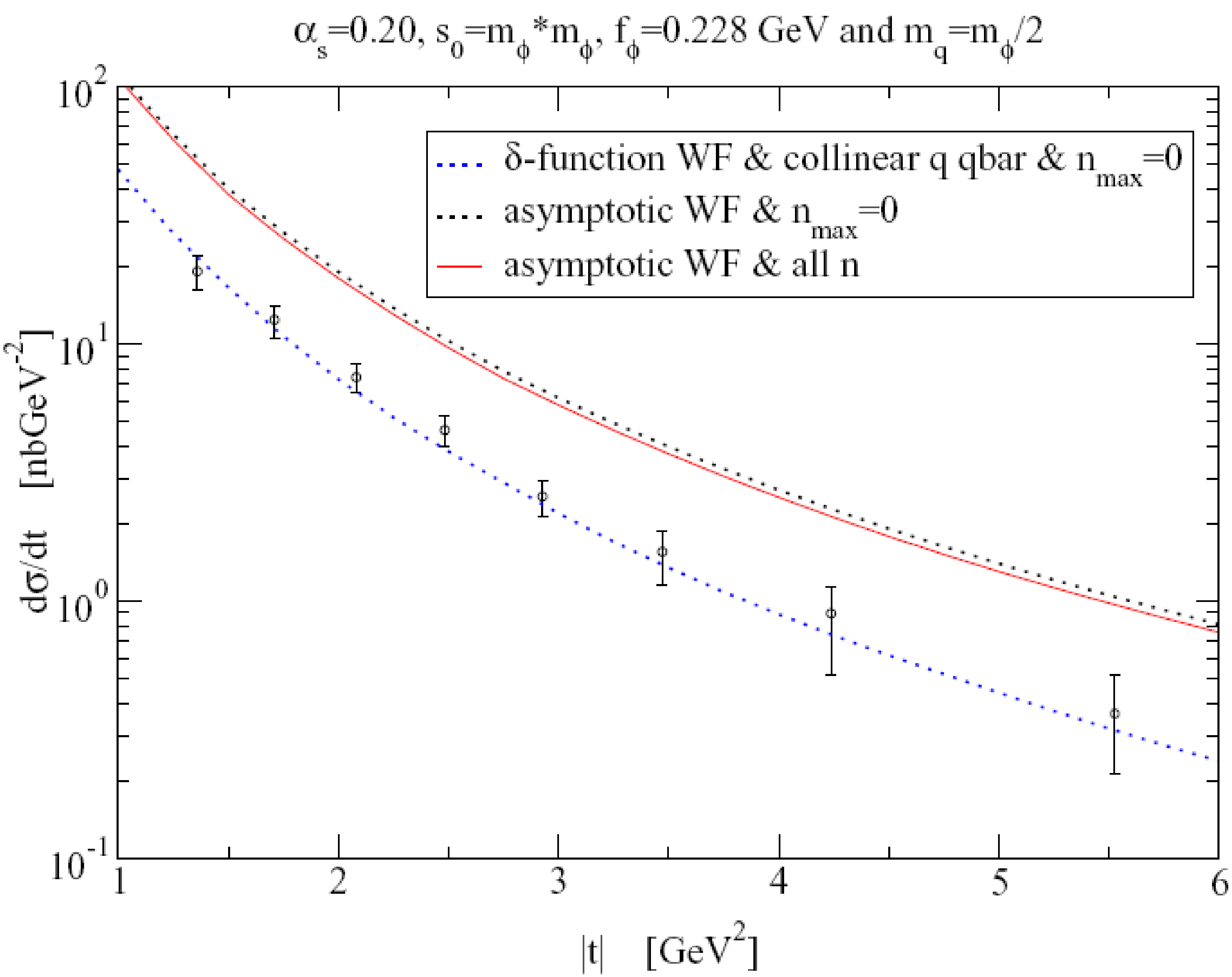


Contours of fixed $\frac{|\sigma(\mathrm{all\ n}) - \sigma(\mathrm{n}=0)|}{\sigma(\mathrm{n}=0)}$

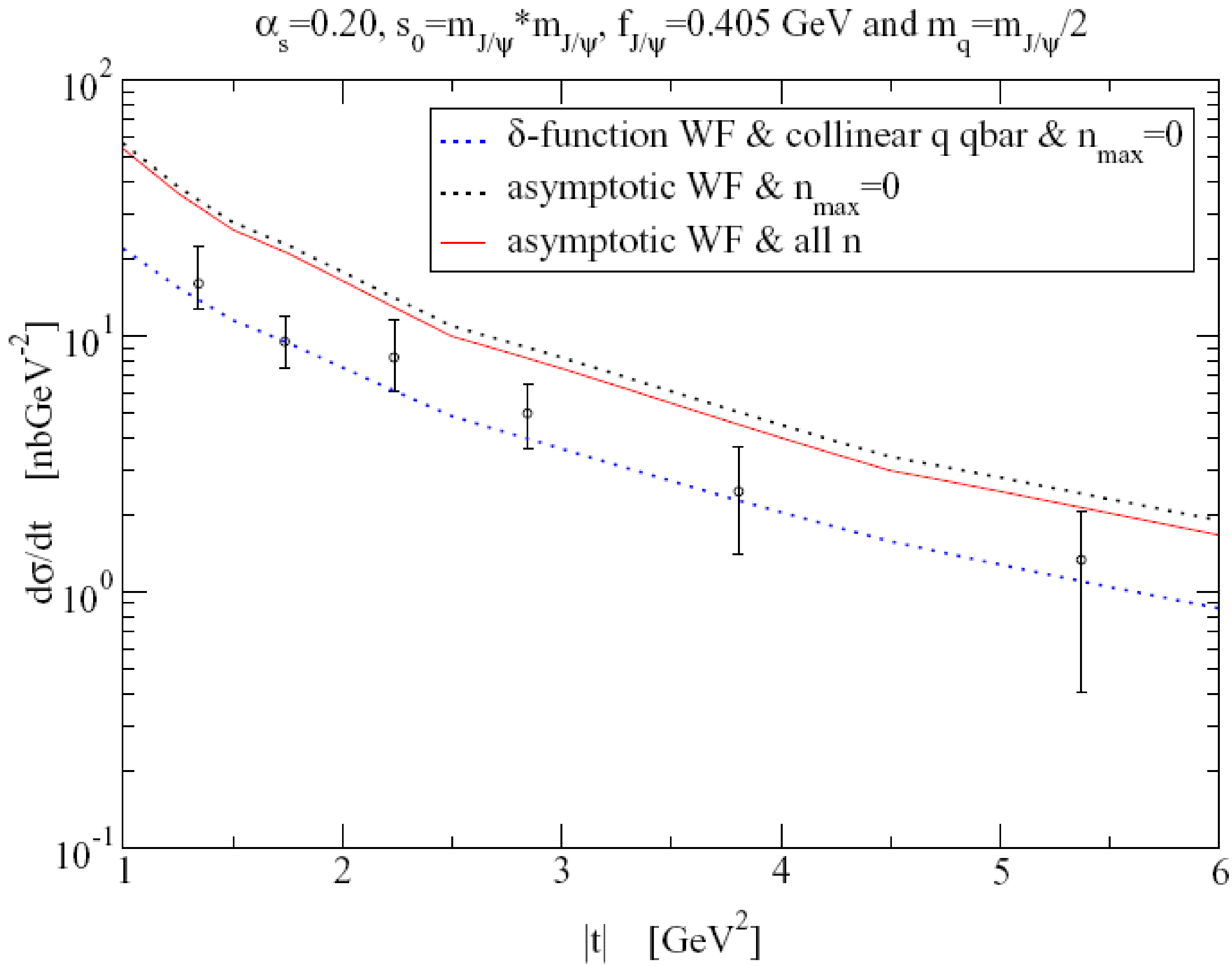
Enberg, Motyka, Poludniowski



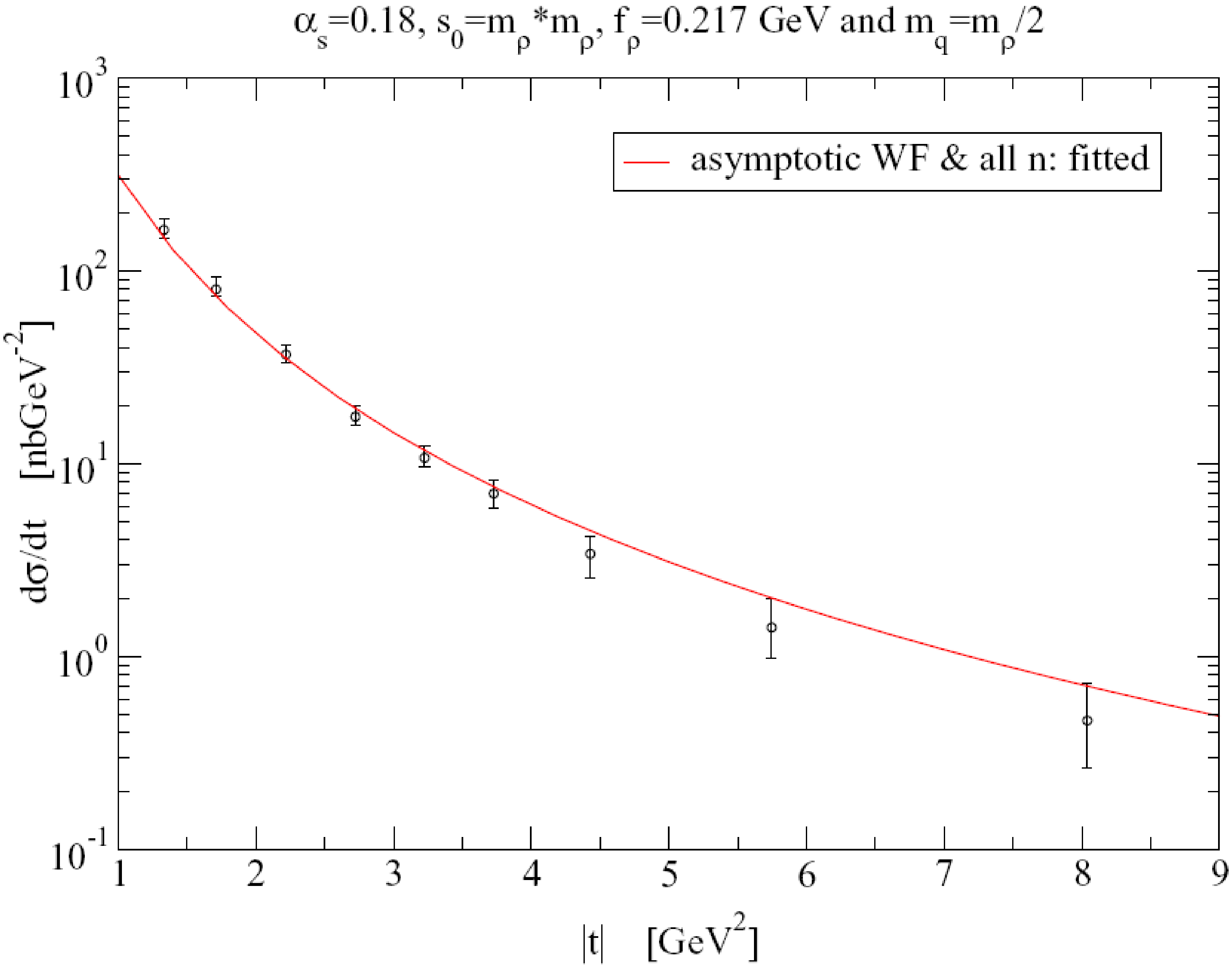
α_s=0.20, s_0=m_ρ*m_ρ, f_ρ=0.217 GeV and m_q=m_ρ/2
δ-function WF & collinear q qbar & n_{max}=0
asymptotic WF & all n
asymptotic WF & n_{max}=0
dσ/dt [nbGeV^{-2}]
|t| [GeV^2]

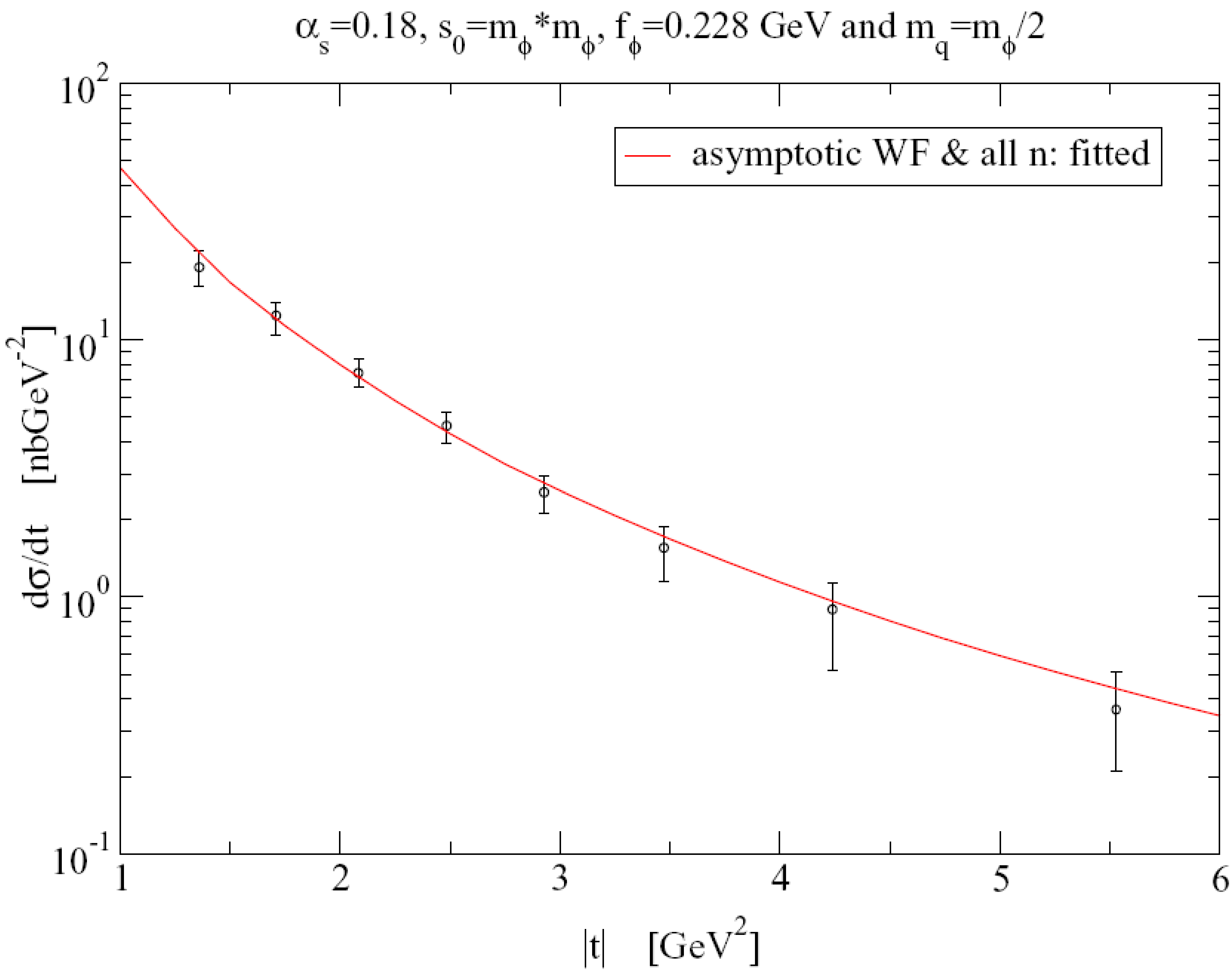


α_s=0.20, $s_0=m_\phi * m_\phi$, f_ϕ=0.228 GeV and $m_q=m_\phi/2$
δ-function WF & collinear q qbar & n_{max}=0
asymptotic WF & n_{max}=0
asymptotic WF & all n
dσ/dt [nbGeV^{-2}]
10^2
10^1
10^0
10^{-1}
1
2
3
4
5
6
|t| [GeV^2]

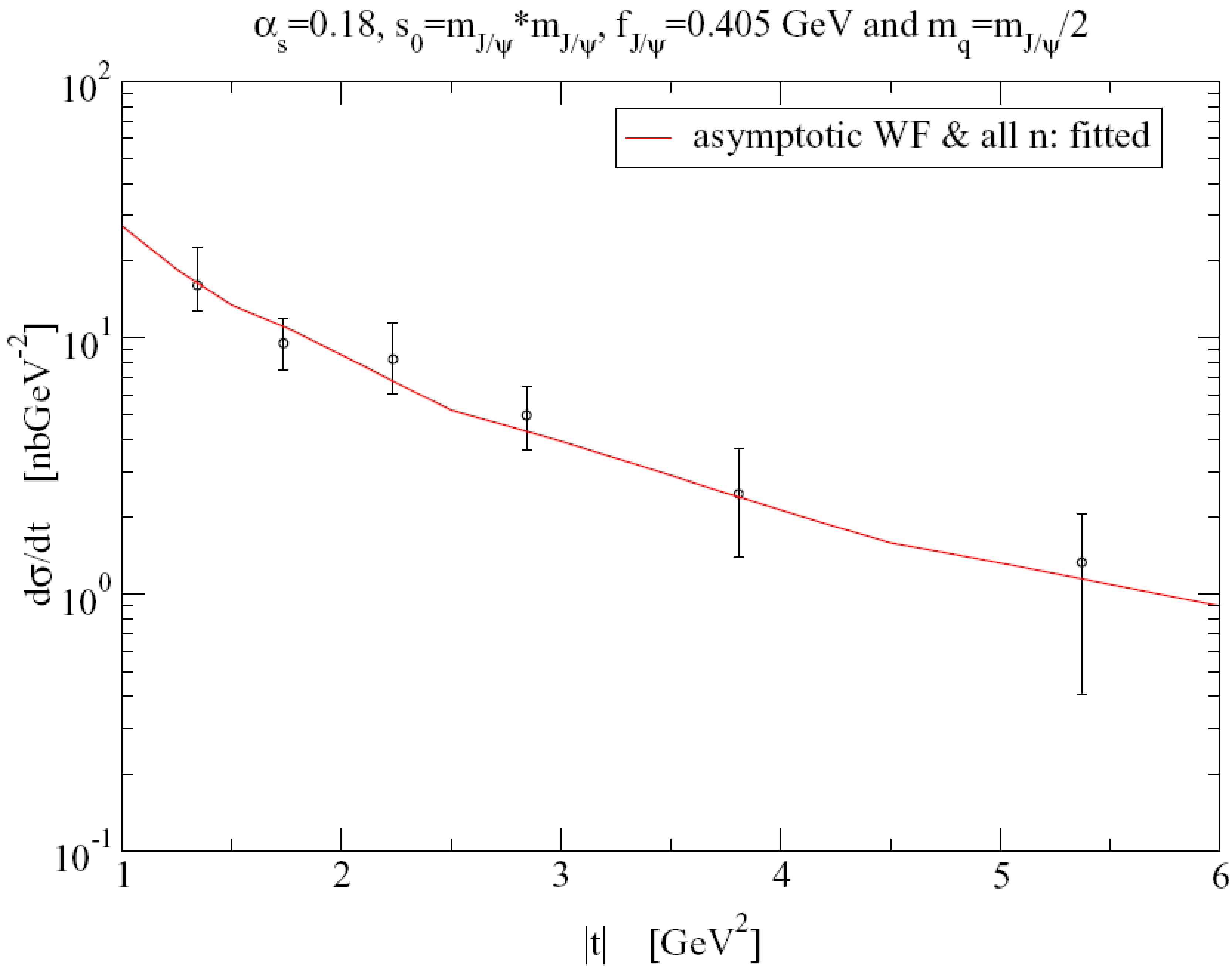


α_s=0.20, s_0=$m_{J/\psi}$*$m_{J/\psi}$, $f_{J/\psi}$=0.405 GeV and m_q=$m_{J/\psi}$/2
δ-function WF & collinear q qbar & n_{max}=0
asymptotic WF & n_{max}=0
asymptotic WF & all n
dσ/dt [nbGeV^{-2}]
|t| [GeV^2]
10^2
10^1
10^0
10^{-1}
1
2
3
4
5
6


αs=0.18, s0=mρ*mρ, fρ=0.217 GeV and mq=mρ/2
asymptotic WF & all n: fitted
dσ/dt [nbGeV-2]
|t| [GeV2]
10-1
100
101
102
103
1
2
3
4
5
6
7
8
9



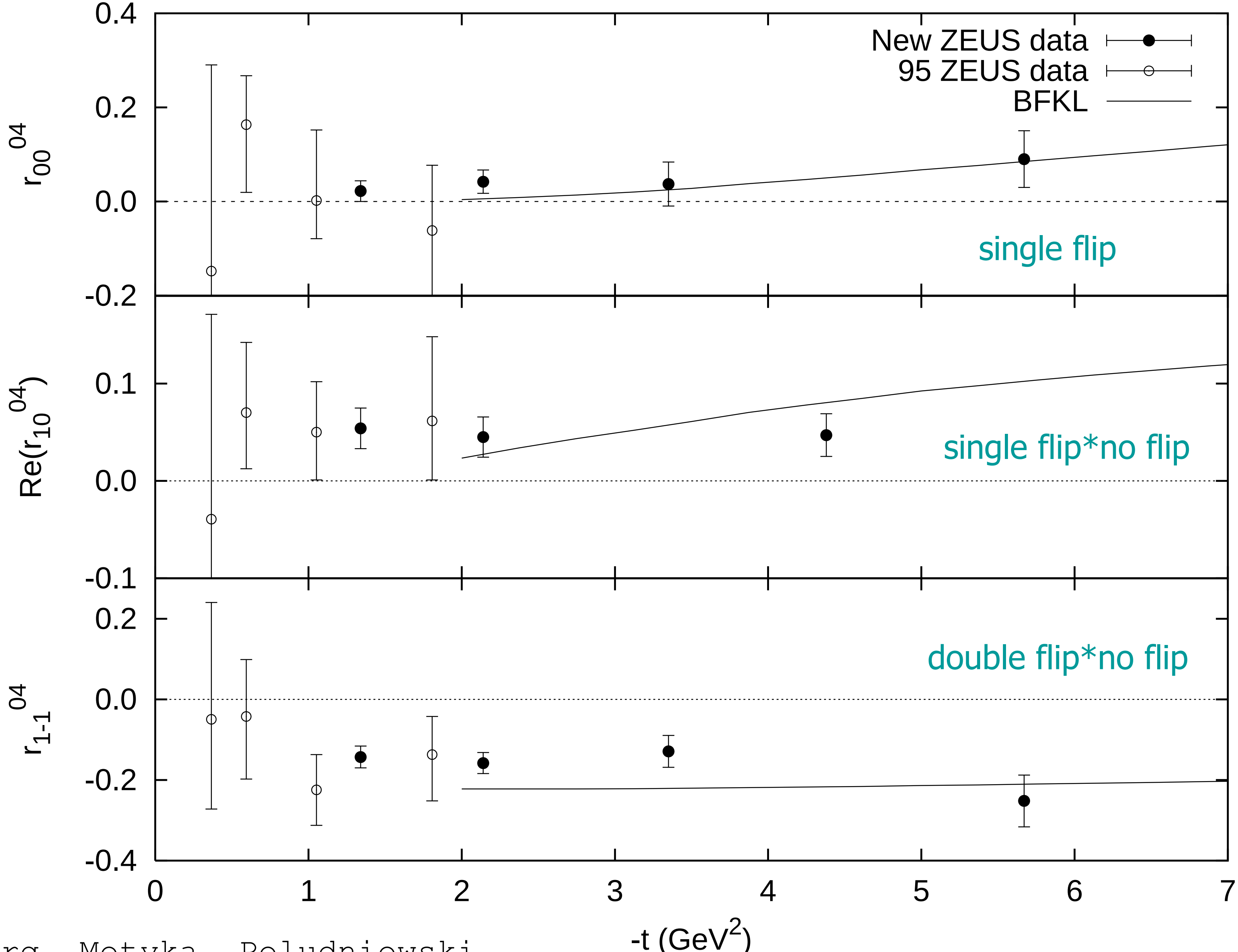
α_s=0.18, s_0=m_ϕ*m_ϕ, f_ϕ=0.228 GeV and m_q=m_ϕ/2
asymptotic WF & all n: fitted
dσ/dt [nbGeV^{-2}]
|t| [GeV^2]
10^2
10^1
10^0
10^{-1}
1
2
3
4
5
6



α_s=0.18, s_0=$m_{J/\psi}$*$m_{J/\psi}$, $f_{J/\psi}$=0.405 GeV and m_q=$m_{J/\psi}$/2
asymptotic WF & all n: fitted
dσ/dt [nbGeV^{-2}]
|t| [GeV^2]
10^2
10^1
10^0
10^{-1}
1
2
3
4
5
6

Spin density matrix elements

[All these vanish in the non-relativistic approximation]



Enberg, Motyka, Poludniowski

Conclusions

- ✓ Vector meson production is proving an effective process in which to explore BFKL dynamics
  Two-gluon/fixed order exchange calculations do not do a good job

- ✓ Data require a large chiral odd contribution even for the rho meson can be generated in QCD either by using the constituent quark mass or by invoking the quark condensate – this explains in part the success of the "non-relativistic" model

- ✓ A full NLL calculation is desirable to get a handle on the normalization uncertainty and the treatment of the strong coupling

- ✓ Future: W-dependence, more accurate information on helicity structure (sensitive to meson wavefunctions), photons, omegas and upsilons.