Elliptic azimuthal anisotropy and the distribution of linearly polarized gluons in DIS dijet production at high energy

Adrian Dumitru
Baruch College, CUNY

POETIC VI
7-11 Sept. 2015,
Palaiseau, France

based on: A.D., T. Lappi, V. Skokov, 1508.04438

WW gluon distribution, unpolarized target

(Mulders, Rodrigues, PRD 2001
Metz, Zhou, PRD 2011,
Dominguez, Qiu, Xiao, Yuan, PRD 2012)

$$\int d^2\xi \, d\xi^- e^{ixP^+\xi^- - i\vec{q}_\perp\cdot\vec{\xi}} \left\langle \mathrm{tr}\; F^{i+}(\xi) U_\xi^{[+]\dagger} F^{j+}(0) U_0^{[+]} \right\rangle$$

$$\sim \quad \delta^{ij}\; xG^{(1)}(x,q_\perp) + \left(\frac{2q_\perp^i q_\perp^j}{q_\perp^2} - \delta^{ij} \right)\; xh^{(1)}(x,q_\perp)$$

$$\delta^{ij} = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} = (e_x^i e_x^j + e_y^i e_y^j) = \left[\varepsilon_+^{*i}\varepsilon_+^j + \varepsilon_-^{*i}\varepsilon_-^j \right]$$

$$\left(\frac{2q_\perp^i q_\perp^j}{q_\perp^2} - \delta^{ij} \right) = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} = (e_x^i e_y^j + e_y^i e_x^j) = -i \left[\varepsilon_+^{*i}\varepsilon_-^j - \varepsilon_-^{*i}\varepsilon_+^j \right]$$

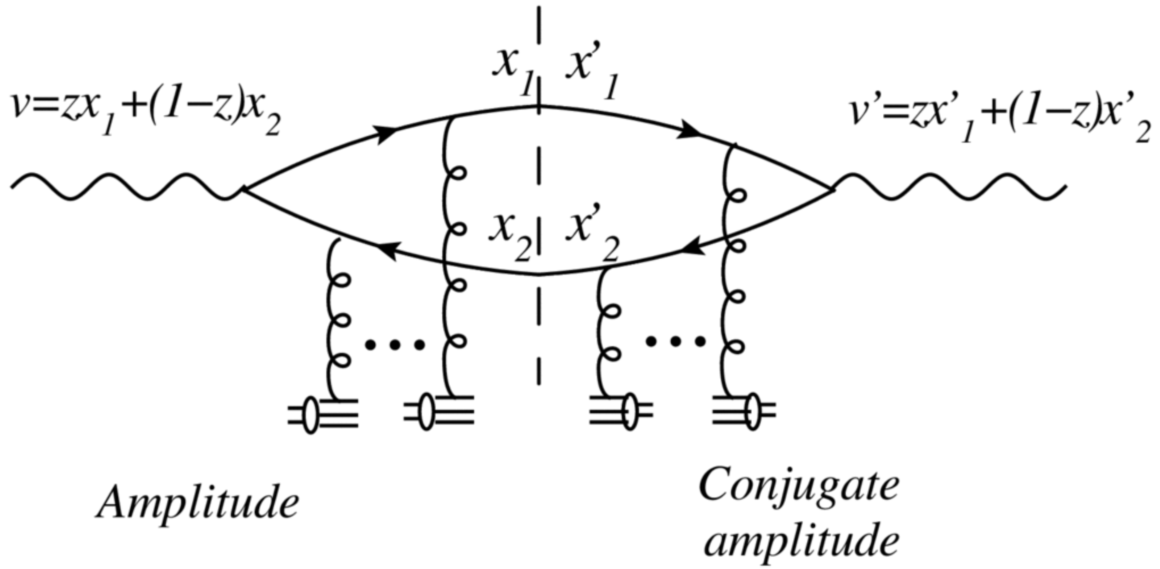
(in frame where $q_x = q_y$)

compare to gluon helicity distribution

$$i\epsilon^{ij} = \begin{pmatrix} 0 & i \\ -i & 0 \end{pmatrix} = i e_x^i e_y^j - e_y^i e_x^j = \varepsilon_+^{*i}\varepsilon_+^j - \varepsilon_-^{*i}\varepsilon_-^j$$

Dijets in γ*A :

(Dominguez, Marquet, Xiao, Yuan, PRD 2011)



Dijet total tr. momentum:

$$\vec{P} = \frac{1}{2}\left(\vec{k}_1 - \vec{k}_2\right) \quad \text{or} \quad \widetilde{P} = (1-z)\vec{k}_1 - z\vec{k}_2$$

and net momentum (imbalance): $\vec{q} = \vec{k}_1 + \vec{k}_2$

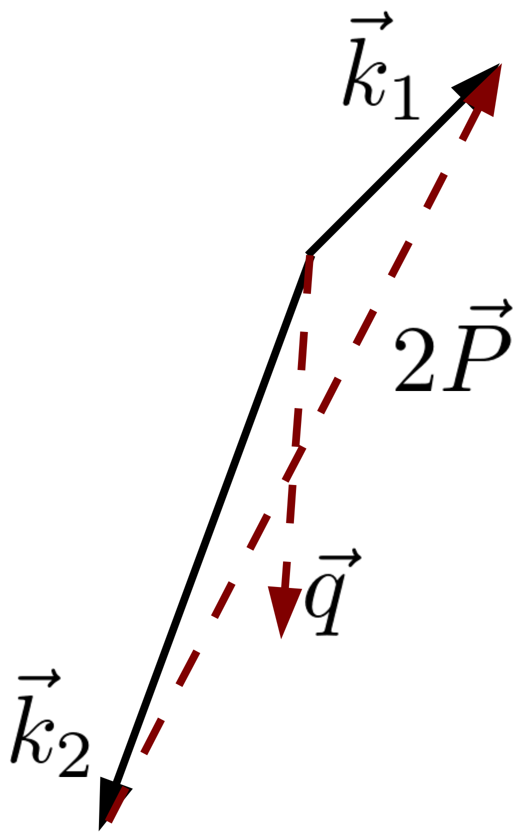
“correlation limit” $P \gg q$ involves only 2-point functions / TMDs, no quadrupole

Azimuthal anisotropy

(Dominguez, Qiu, Xiao, Yuan, PRD 2012)

$$d\sigma^{\gamma_L^* A\to q\bar{q}X} = e_q^2 \alpha\alpha_s z^2(1-z)^2 \frac{8\epsilon_f^2 \widetilde{P}^2}{(\widetilde{P}^2+\epsilon_f^2)^4} \left(xG^{(1)}(x,q) + \cos(2\phi)\, xh_\perp^{(1)}(x,q) \right)$$

ϕ = angle between $\vec{P}$ and $\vec{q}$



$\longrightarrow$ rotate net transverse momentum vector q around and measure amplitude of cos(2ϕ) modulation

$$v_2(q,x) = \langle \cos 2\phi \rangle = \frac{1}{2} \frac{h_\perp^{(1)}(x,q)}{G^{(1)}(x,q)}$$

The distribution of linearly polarized gluons

(in terms of L.C. gauge E-field correlator)

(Metz, Zhou: PRD 2011; Dominguez, Qiu, Xiao, Yuan, PRD 2012)

$$xG_\perp^{(1)}(x,k) = -\frac{2}{\alpha_s\, L^2}\delta^{ij}\left\langle \mathrm{Tr}\left[E_i(\vec{k})E_j(-\vec{k})\right]\right\rangle$$

$$xh_\perp^{(1)}(x,k) = \frac{2}{\alpha_s\, L^2}\left(\delta^{ij} - 2\frac{k^i k^j}{k^2}\right)\left\langle \mathrm{Tr}\left[E_i(\vec{k})E_j(-\vec{k})\right]\right\rangle$$

$$E_i(\vec{k}) = \int \frac{d^2y}{(2\pi)^2} e^{-i\vec{k}\cdot\vec{y}}\, U^\dagger(\vec{y})\partial_i U(\vec{y})$$

We have computed these functions at small x
by solving JIMWLK from MV model initial conditions

(A.D., T. Lappi, V. Skokov: 1508.04438)

Resummation of boost-invariant quantum fluctuations (JIMWLK):

classical ensemble at Y = log x_0/x = 0:

$$P[\rho] \sim e^{-S_{\rm cl}[\rho]} \ , \ S_{\rm MV} \quad = \quad \int d^2x_\perp \ dx^- \ \frac{1}{2\mu^2} \rho^a \rho^a \ ,$$

$$V(x_\perp) = \mathcal{P} \exp \ ig^2 \int dx^- \frac{1}{\nabla_\perp^2} \rho(x_\perp)$$

quantum evolution to Y>0: random walk in space of Wilson lines

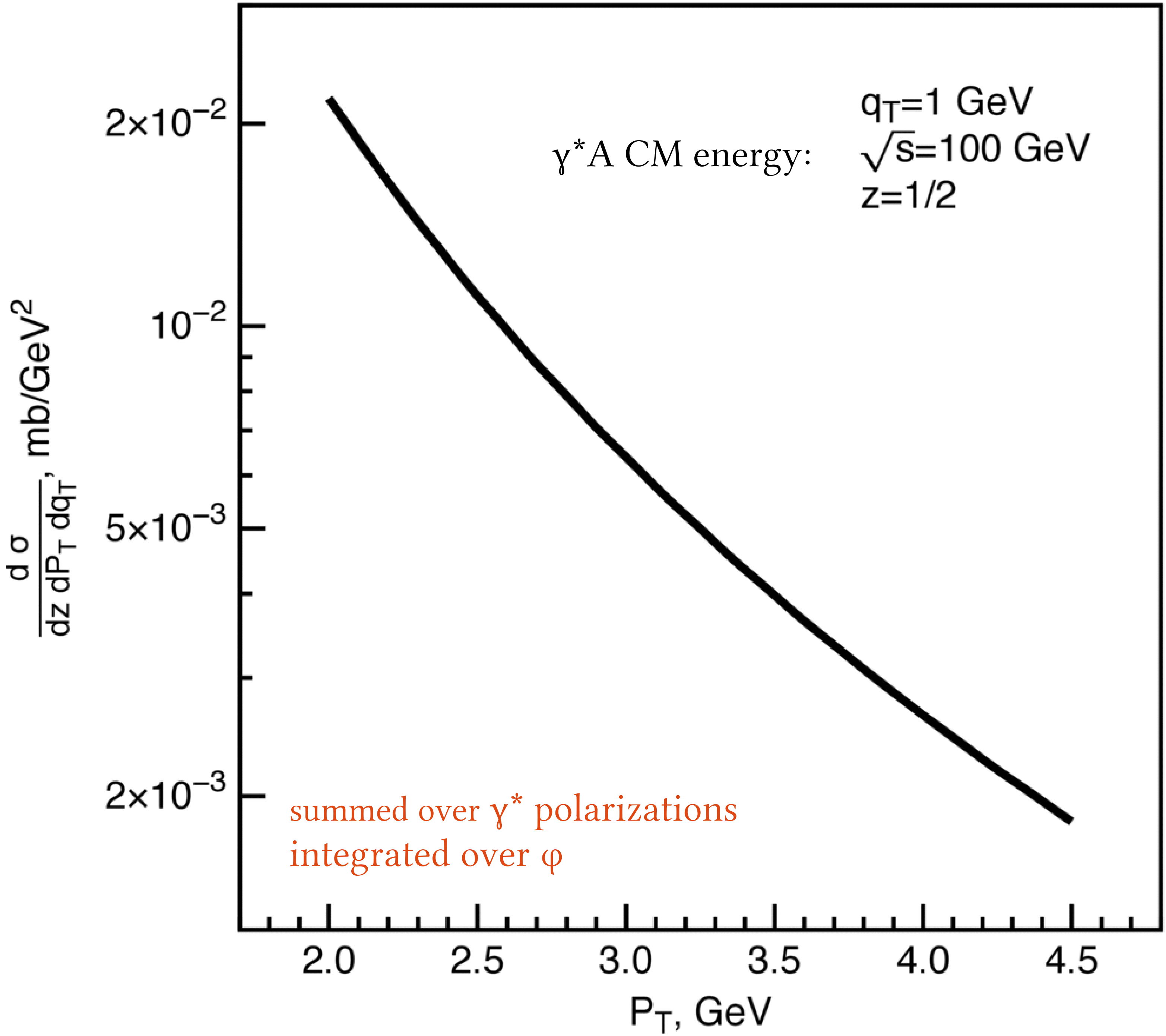
$$\partial_Y V(x_\perp) = V(x_\perp) \ it^a \left\{ \int d^2y_\perp \ \varepsilon_k^{ab}(x_\perp, y_\perp) \ \xi_k^b(y_\perp) + \sigma^a(x_\perp) \right\} \ .$$

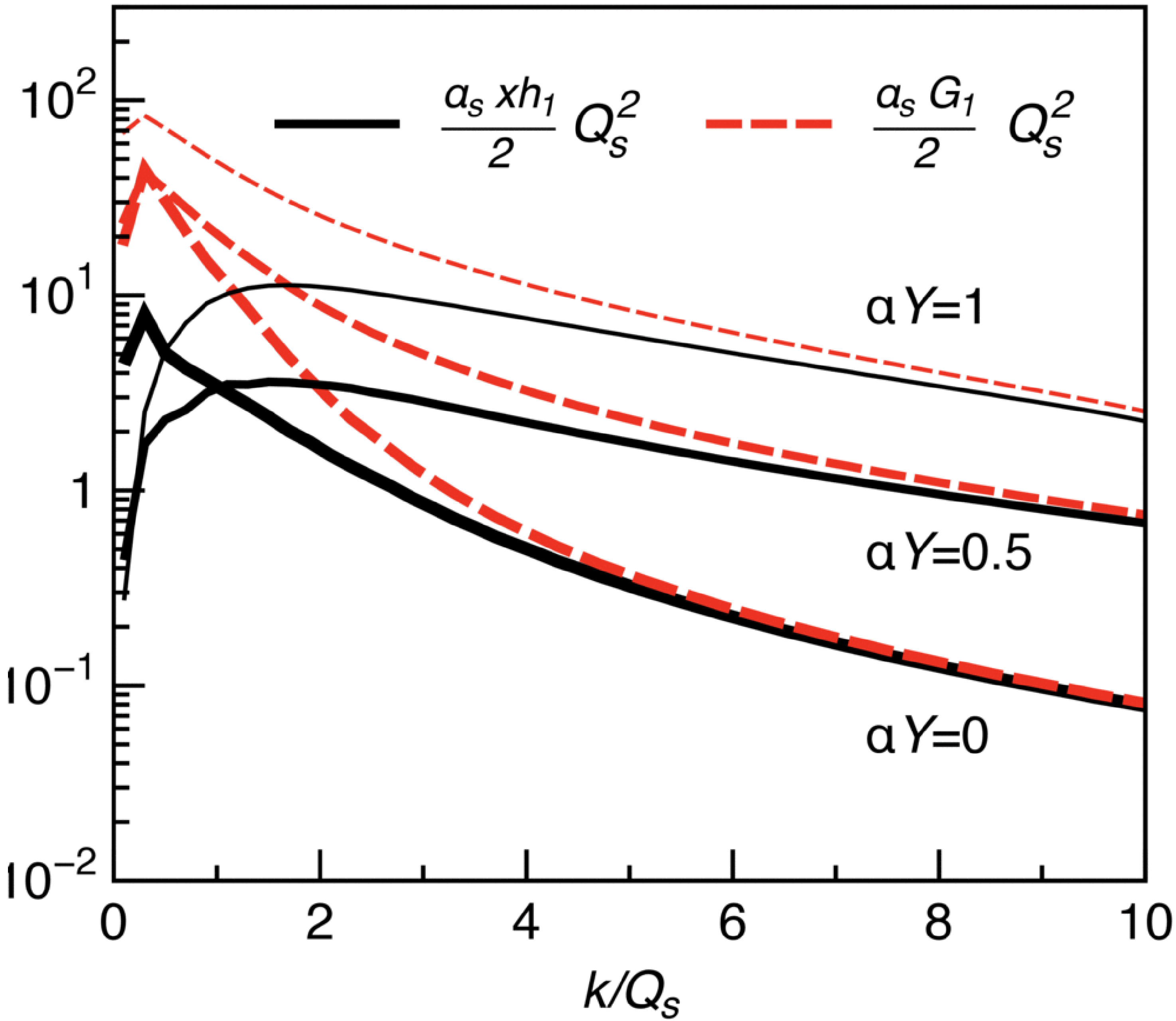
$$\varepsilon_k^{ab} = \left(\frac{\alpha_s}{\pi} \right)^{1/2} \ \frac{(x_\perp - y_\perp)_k}{(x_\perp - y_\perp)^2} \ \left[1 - U^\dagger(x_\perp) U(y_\perp)\right]^{ab}$$

$$\langle \xi_i^a(x_\perp) \ \xi_j^b(y_\perp) \rangle = \delta^{ab} \delta_{ij} \delta^{(2)}(x_\perp - y_\perp)$$

$$\sigma^a(x_\perp) = -i \frac{\alpha_{\rm s}}{2\pi^2} \int d^2 z_\perp \ \frac{1}{(x_\perp - z_\perp)^2} {\rm tr} \ \left(T^a U^\dagger(x_\perp) \, U(z_\perp) \right)$$

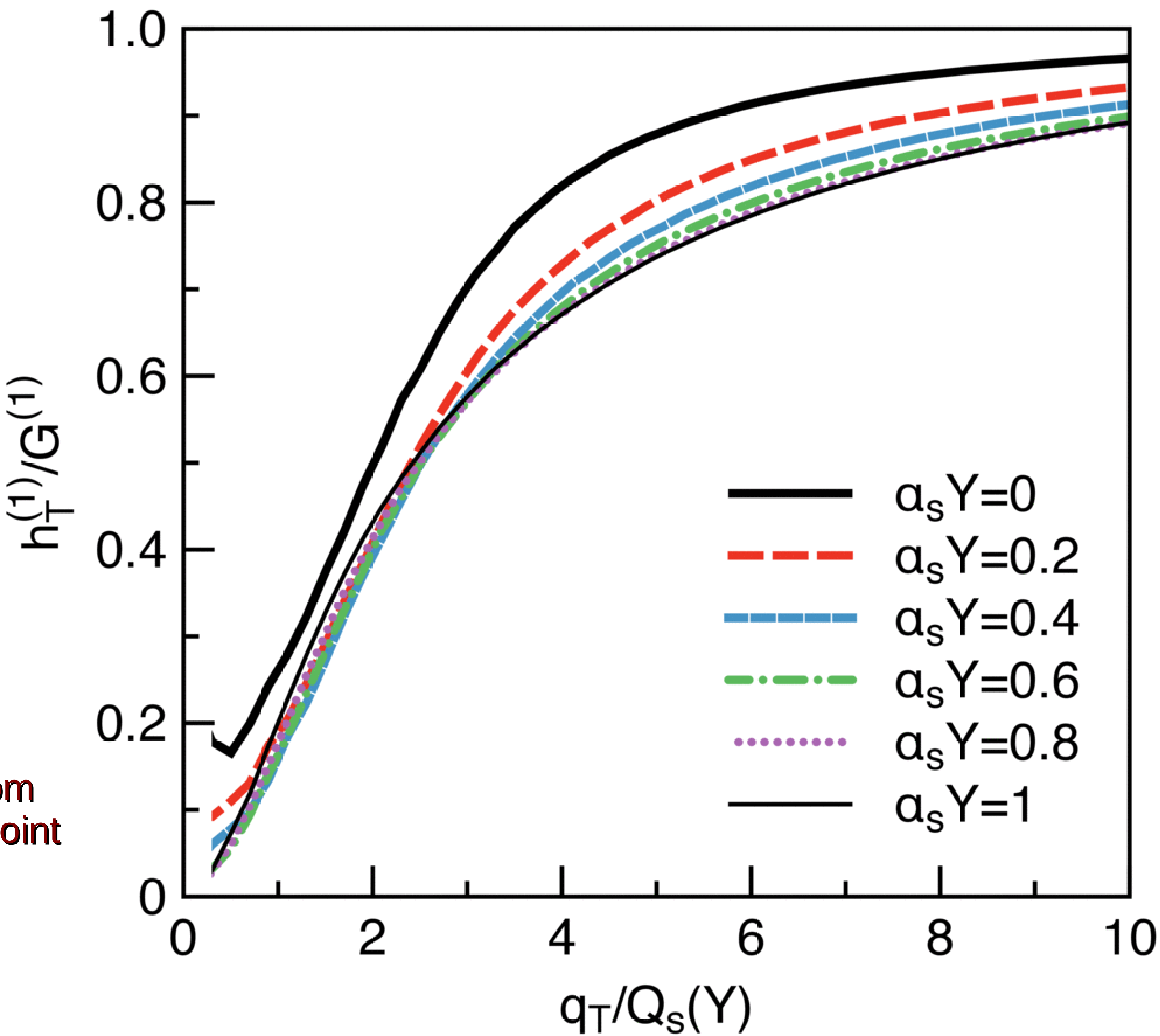
Magnitude of cross-section (angular integr.)





- $h^{(1)}_{\perp} / G^{(1)} \longrightarrow 0$ at low q
- but $h^{(1)}_{\perp} / G^{(1)} \longrightarrow 1$ at high transv. momentum:

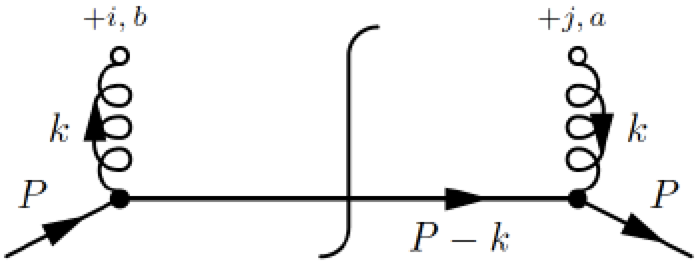
  $d\sigma(\gamma^* \longrightarrow q\bar{q}) \approx 0$ at $\Phi = \pm 90°$!



- rapid initial flow away from MV model → RG fixed point
- followed by rather slow small-x evolution

Gluon TMDs in Quark-Target Model

(Meißner, AM, Goeke, 2007)



- Results for f_1^g and $h_1^{\perp g}$

$$f_1^g = \frac{8\alpha_s}{3(2\pi)^2 x} \frac{(2(1-x)+x^2)\vec{k}_T^2 + x^4 m^2}{(\vec{k}_T^2 + m^2)^2}$$

$$h_1^{\perp g} = \frac{32\alpha_s}{3(2\pi)^2 x} \frac{(1-x)\vec{k}_T^2}{(\vec{k}_T^2 + m^2)^2}$$

- Limit of small x

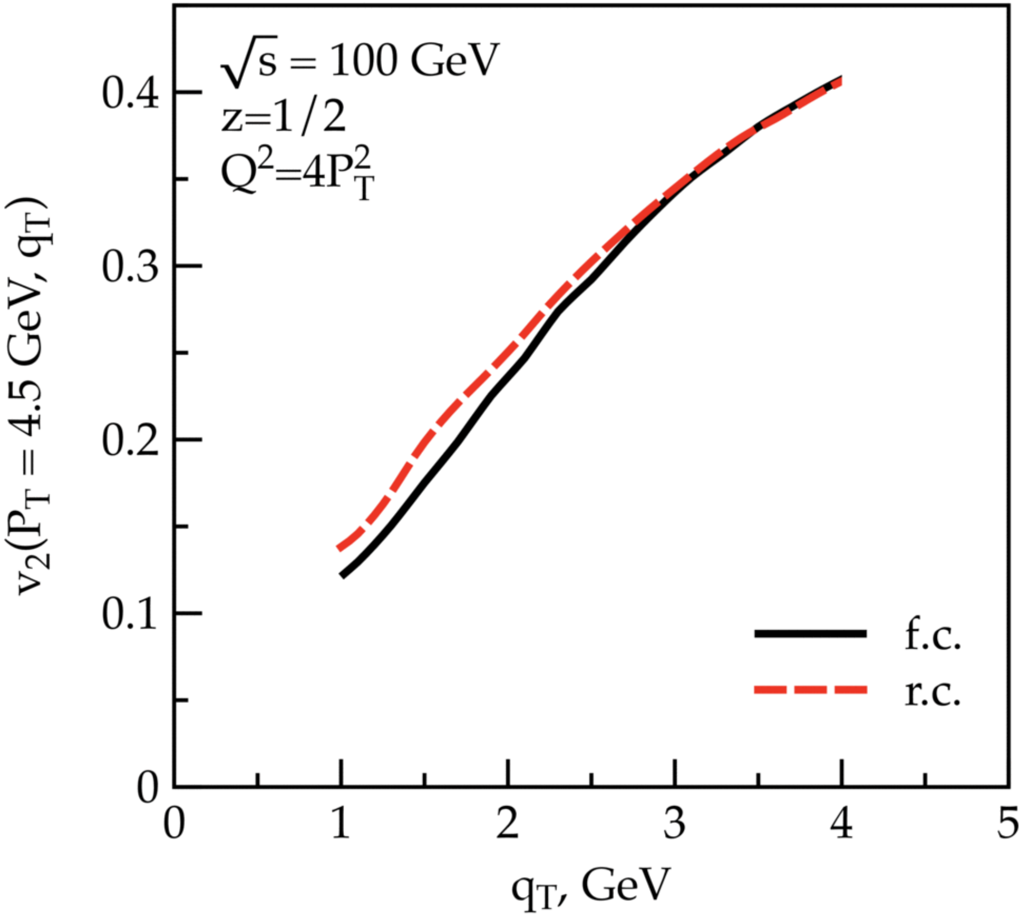
$$h_1^{\perp g}(x, \vec{k}_T^2) = 2\, f_1^g(x, \vec{k}_T^2)$$

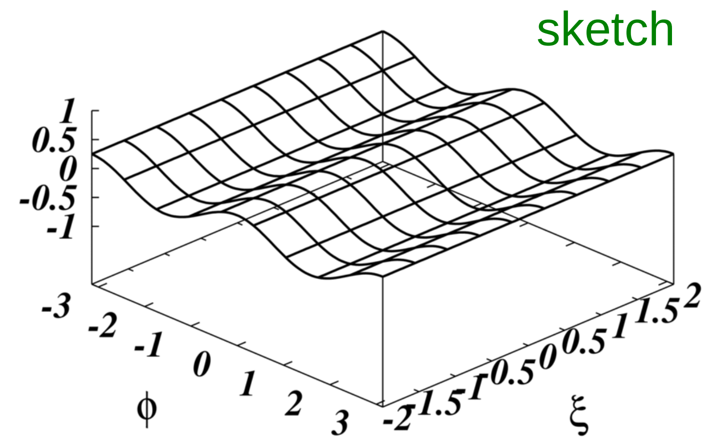
$\rightarrow$ saturation of positivity bound (Mulders, Rodrigues, 2000) $\rightarrow$ 100 % polarization

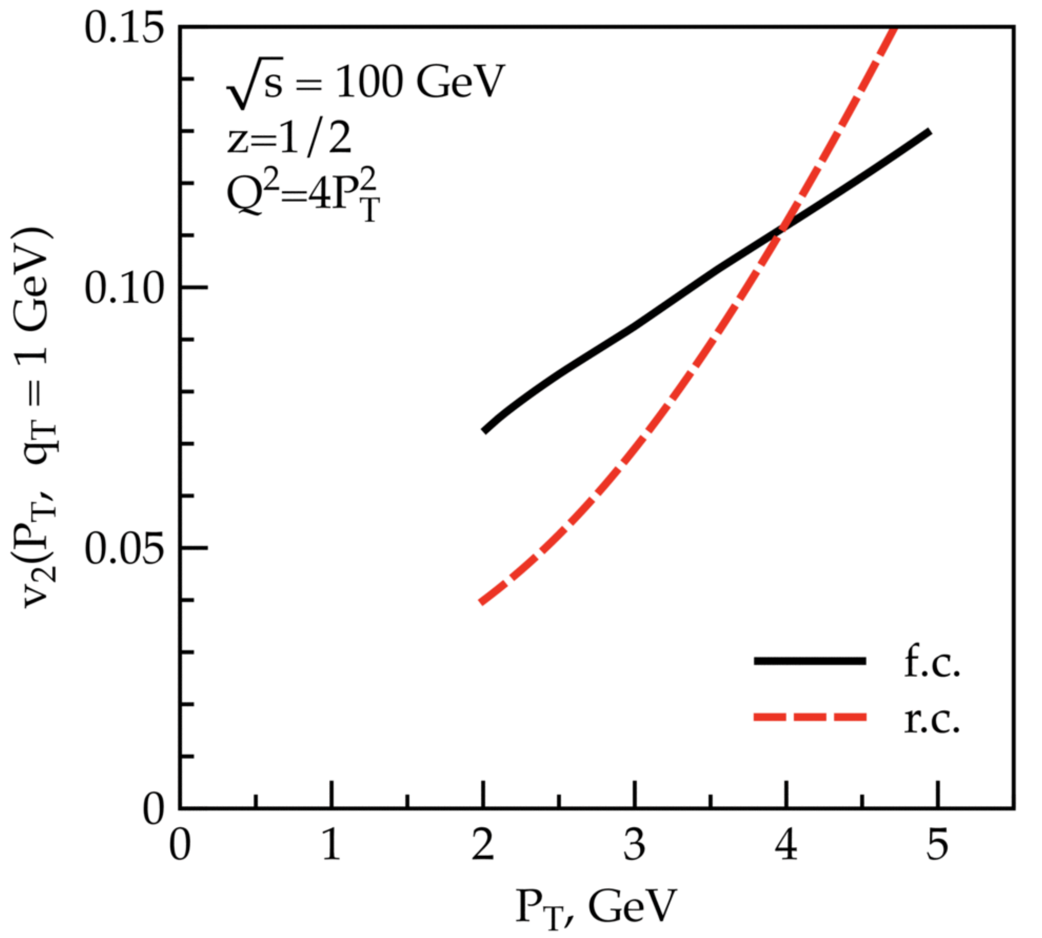
- Result for $h_1^{\perp g}$ can also be red off from higher order pQCD calculation of processes (Nadolsky, Balazs, Berger, Yuan, 2007 / Catani, Grazzini, 2010 / ...)

Slide by A. Metz, POETIC V, Yale, New Haven 2014

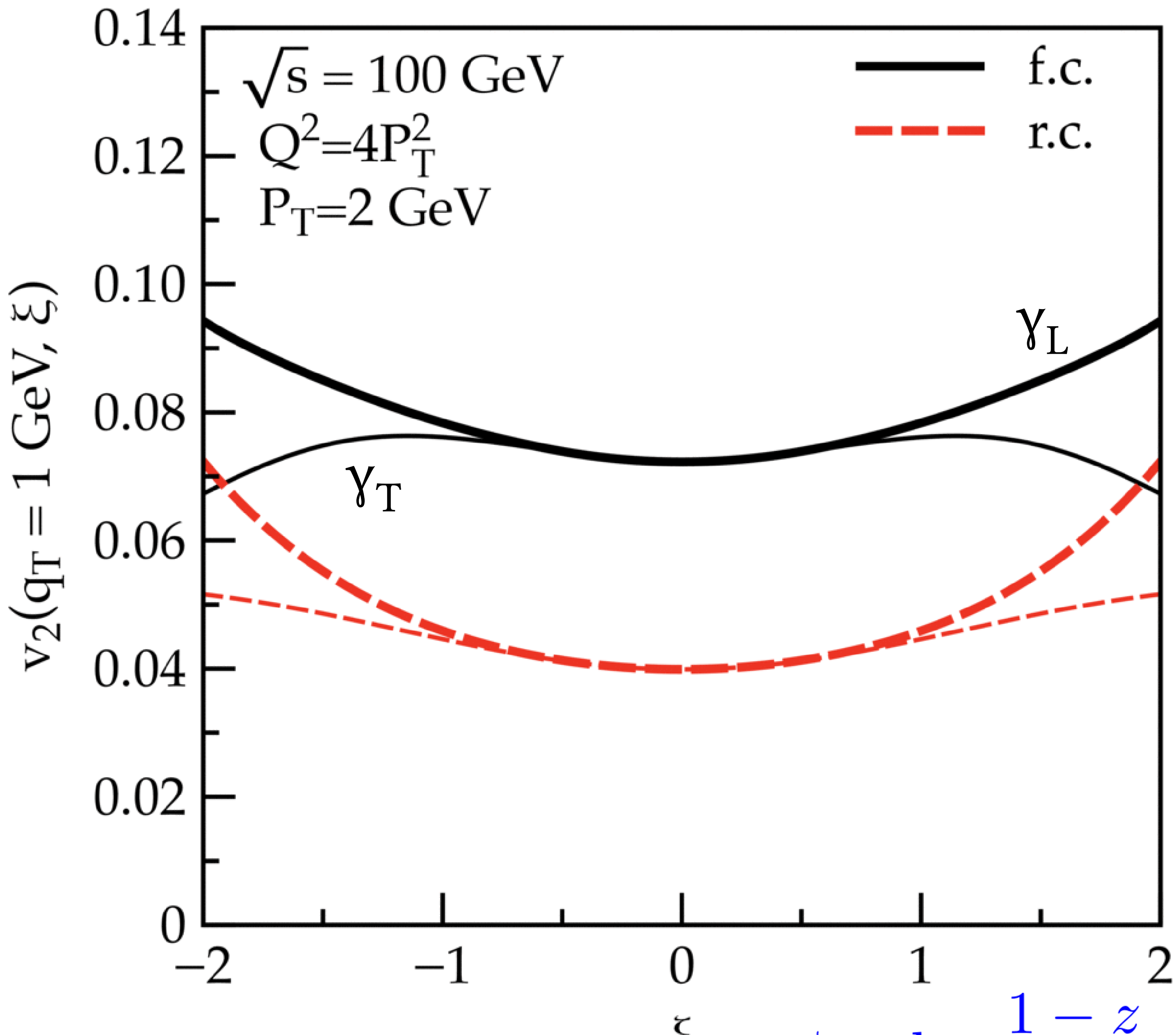
Large cos(2ϕ) amplitudes...







Amplitude of cos(2Φ) is long range in rapidity



$$\xi = \log \frac{1-z}{z}$$

Summary:

- Dijet production in eA probes WW gluon distribution ($P_T \gg q_T$ limit)

- WW distribution can be decomposed in **two** UGDs / TMDs
  i) isotropic gluon probability $xG^{(1)}(x,q_T)$
  ii) ~cos(2Φ) anisotropic distribution $xh^{(1)}(x,q_T)$ for orthogonal
  polarizations in amplitude vs. conjugate amplitude

- MV model gives large ~cos(2Φ) anisotropies at $q_T > Qs$

- JIMWLK small-x evolution: strong growth of both $xG^{(1)}(x,q_T)$ and $xh^{(1)}(x,q_T)$, their ratio drops slowly with Y

- this would result in "ridge"-like structure in terms of azimuthal angle of $\vec{q}_\perp$

- long-range in rapidity asymmetry $\xi = \log (1-z)/z$