Double diffractive production of mesons and spin effects

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DSPIN-07

Dubna, September 3 - 7, 2007

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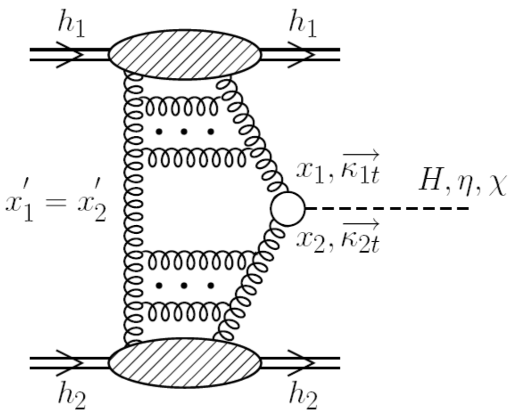
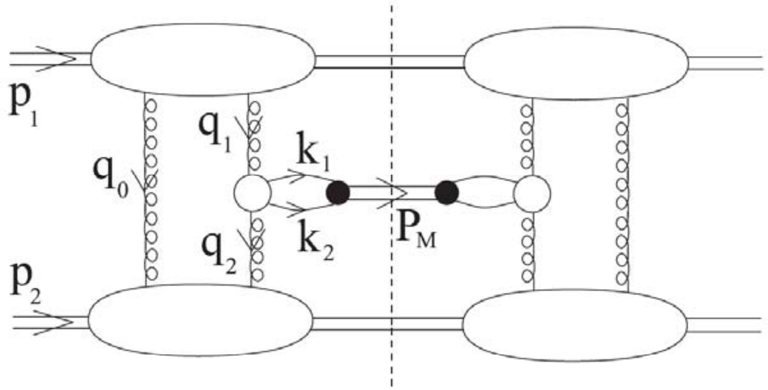
Exclusive double-diffractive production





KMR approach

$$\mathcal{M} = N \int \frac{d^2 q_{0,t} P[\chi_c(0^+)]}{q_{0,t}^2 q_{1,t}^2 q_{2,t}^2} f_g^{KMR}(x_1, x_1', Q_{1,t}^2, \mu^2; t_1) f_g^{KMR}(x_2, x_2', Q_{2,t}^2, \mu^2; t_2)$$

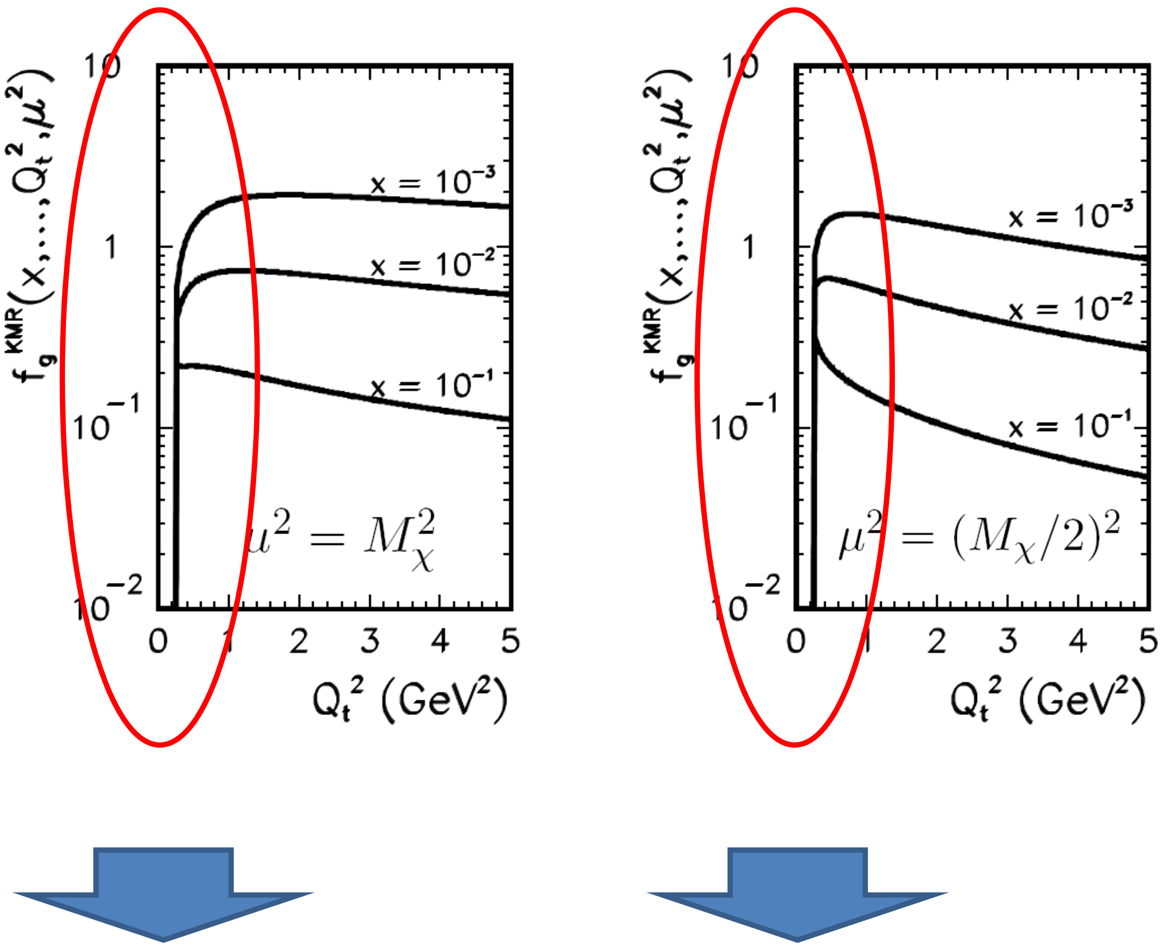
$$Q_{1,t}^2 = \min\{q_{0,t}^2, q_{1,t}^2\}, \qquad Q_{2,t}^2 = \min\{q_{0,t}^2, q_{2,t}^2\} \qquad P[\chi_c(0^+)] \simeq (q_{1,t} q_{2,t})$$

$$f_g^{KMR}(x, x', Q_t^2, \mu^2; t) = f_g^{KMR}(x, x', Q_t^2, \mu^2) \exp(b_0 t) \qquad b_0 = 2 \text{ GeV}^{-2}$$

$$f_g^{KMR}(x, x', Q_t^2, \mu^2) = R_g \frac{\partial}{\partial \ln Q_t^2} \left[\sqrt{T(Q_t^2, \mu^2)} x g(x, Q_t^2) \right]$$

$$T(Q_t^2, \mu^2) = \exp\left(- \int_{Q_t^2}^{\mu^2} \frac{\alpha_s(k_t^2)}{2\pi} \frac{dk_t^2}{k_t^2} \int_0^{1-\Delta} [z P_{gg}(z) + \sum_q P_{qg}(z)] dz \right) \qquad \Delta = k_t/(\mu + k_t)$$

KMR Unintegrated Gluon Distribution Functions (UGDFs)



huge unpredictable sensitivity of results to details in nonperturbative region !!!

Uncertainties in KMR approach

mainly appear

- *due to KMR UGDF cut-off uncertainties (Sudakov f.f. does not work at* $Q_t^2 < Q_{cut}^2$ *and* $|x_F| > 0.2$*)*

- *due to effective gluon transverse momentum uncertainties*

- *due to off-shellness of gluons*

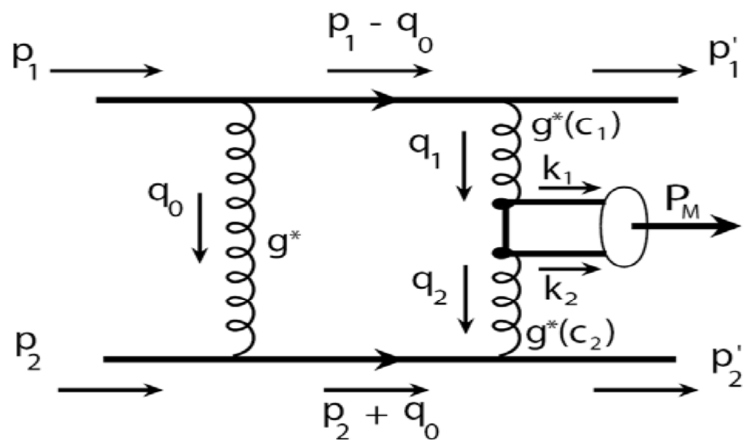
- *due to uncertainties in hard scale* μ^2

Our approach

$$\mathcal{M}^{g^* g^*} = \frac{s}{2} \cdot \pi^2 \frac{1}{2} \frac{\delta_{c_1 c_2}}{N_c^2 - 1} \Im \int d^2 q_{0,t} V_J^{c_1 c_2} \frac{f_{g,1}^{off}(x_1, x_1', q_{0,t}^2, q_{1,t}^2, t_1) f_{g,2}^{off}(x_2, x_2', q_{0,t}^2, q_{2,t}^2, t_2)}{q_{0,t}^2 \, q_{1,t}^2 \, q_{2,t}^2}$$

NRQCD vertex

$$V_{J,\mu\nu}^{c_1 c_2}(q_1, q_2) = \mathcal{P}(q\bar{q} \to \chi_{cJ}) \bullet \Psi_{ik,\mu\nu}^{c_1 c_2}(k_1, k_2) = 2\pi \cdot \sum_{i,k} \sum_{L_z, S_z} \frac{1}{\sqrt{m}} \int \frac{d^4 q}{(2\pi)^4} \delta\left(q^0 - \frac{\mathbf{q}^2}{M}\right) \times$$
$$\times \Phi_{L=1,L_z}(\mathbf{q}) \cdot \langle L=1, L_z; S=1, S_z | J, J_z \rangle \langle 3i, \bar{3}k | 1 \rangle \, \mathrm{Tr}\left\{ \Psi_{ik,\mu\nu}^{c_1 c_2} \mathcal{P}_{S=1,S_z} \right\},$$
$$\Psi_{ik,\mu\nu}^{c_1 c_2} = -g^2 \left[t_{ij}^{c_1} t_{jk}^{c_2} \cdot \left\{ \gamma_\nu \frac{\hat{q}_1 - \hat{k}_1 - m}{(q_1 - k_1)^2 - m^2} \gamma_\mu \right\} - t_{kj}^{c_2} t_{ji}^{c_1} \cdot \left\{ \gamma_\mu \frac{\hat{q}_1 - \hat{k}_2 + m}{(q_1 - k_2)^2 - m^2} \gamma_\nu \right\} \right].$$



$$V_{J=0}^{c_1 c_2}(q_1, q_2) = 8 i g^2 \frac{\delta^{c_1 c_2}}{M} \frac{\mathcal{R}'(0)}{\sqrt{\pi M N_c}} \frac{3M^2 (q_{1,t} q_{2,t}) + 2 q_{1,t}^2 q_{2,t}^2 - (q_{1,t} q_{2,t})(q_{1,t}^2 + q_{2,t}^2)}{(M^2 - q_{1,t}^2 - q_{2,t}^2)^2}$$

Our choice of skewed UGDFs

- **GBW** K. Golec-Biernat and M. Wüsthoff, Phys. Rev. D **60** (1999) 114023-1
- **KL** D. Kharzeev and E. Levin, Phys. Lett. B **523** (2001) 79
- **BFKL** E.A. Kuraev, L.N. Lipatov and V.S. Fadin, Sov. Phys. JETP **45** (1977) 199; Ya.Ya. Balitskij and L.N. Lipatov, Sov. J. Nucl. Phys. **28** (1978) 822.
- **two-scale Gaussian**

$$f_{g,1}^{off} = \sqrt{f_g^{(1)}(x_1', q_{0,t}^2, \mu_0^2) \cdot f_g^{(1)}(x_1, q_{1,t}^2, \mu^2)} \cdot F_1(t_1)$$

$$f_{g,2}^{off} = \sqrt{f_g^{(2)}(x_2', q_{0,t}^2, \mu_0^2) \cdot f_g^{(2)}(x_2, q_{2,t}^2, \mu^2)} \cdot F_1(t_2)$$

$$F_1(t_{1,2}) = \frac{4m_p^2 - 2.79\, t_{1,2}}{(4m_p^2 - t_{1,2})(1 - t_{1,2}/071)^2}$$

modified dipole model nucleon f.f.

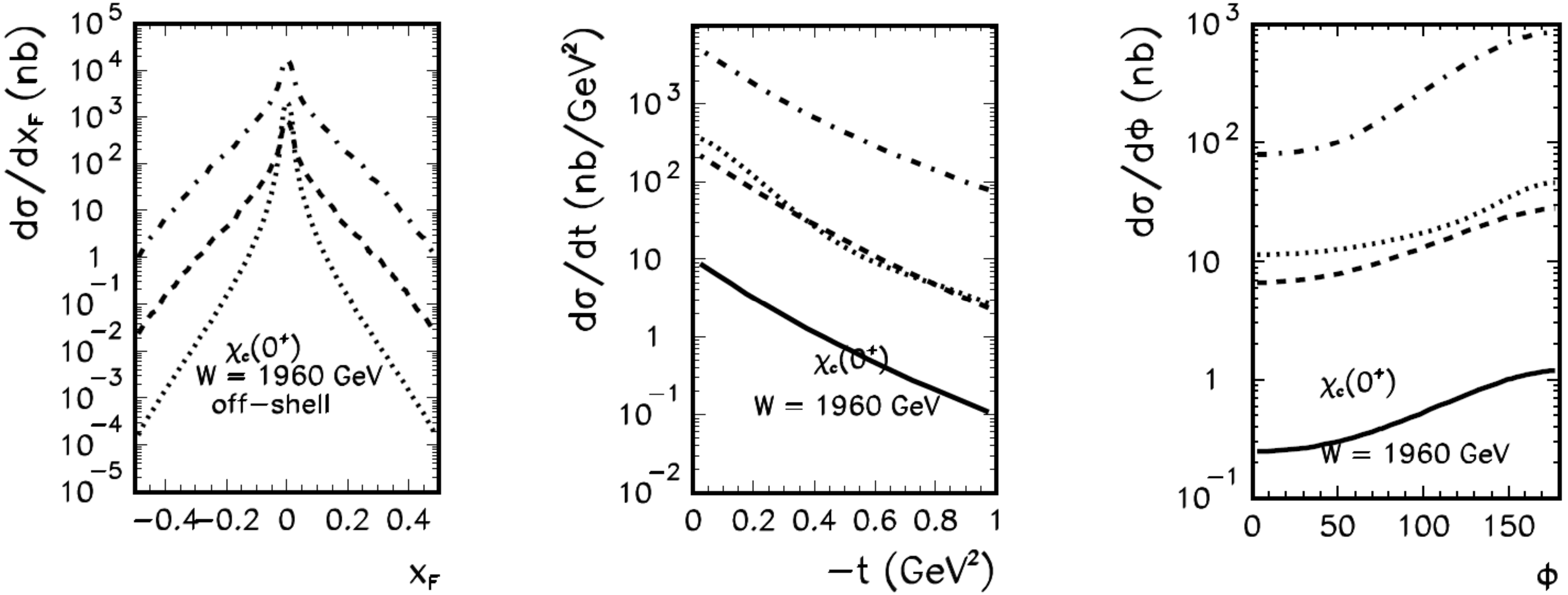
factorization scales

$$(1) \quad \mu_0^2 = M^2, \qquad \mu^2 = M^2,$$

$$(2) \quad \mu_0^2 = Q_0^2, \qquad \mu^2 = M^2,$$

$$(3) \quad \mu_0^2 = q_{0,t}^2 \ (+\text{freezing at } q_{0,t}^2 < Q_0^2), \quad \mu^2 = M^2 \ .$$

Results for χc(0+)-production



UGDF	RHIC	Tevatron	LHC
Kl	0.6430(+1)	0.5231(+2)	0.1090(+3)
GBW	0.2830(+1)	0.1590(+3)	0.1413(+3)
BFKl	0.6140(+1)	0.1125(+4)	0.6306(+5)
Gauss, $\sigma_0 = 1.0$ GeV, scales (2)	0.7126(-1)	0.1811(+1)	0.1428(+2)

Results for χc(1+)-production

- **Can NOT be produced in the fusion of REAL gluons (Landau-Yang theorem) -> off-shellness is crucial**

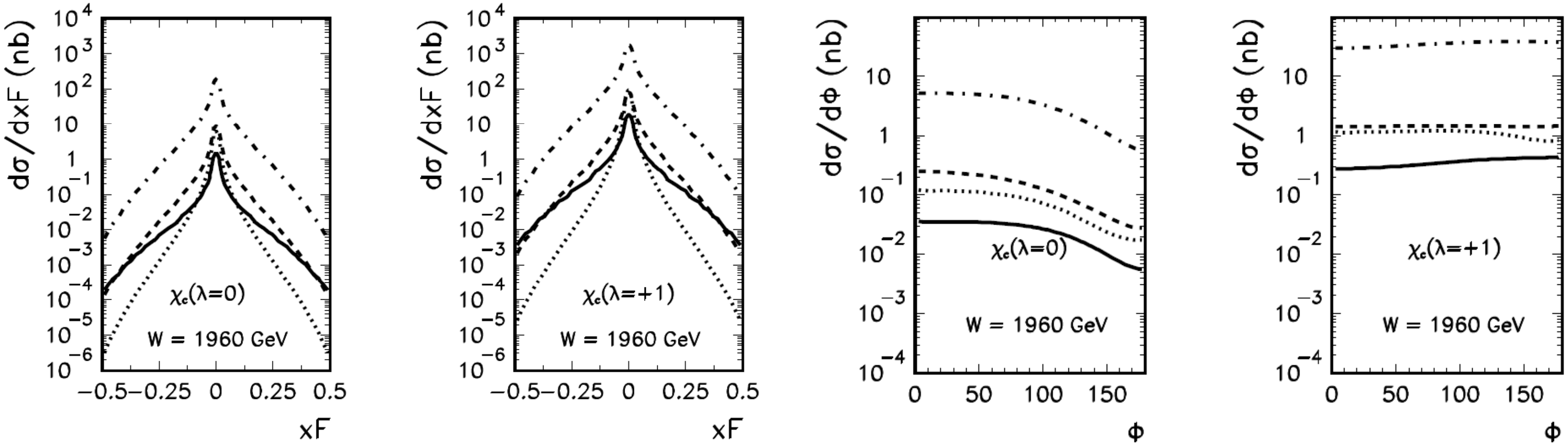
$$V_{J=1}^{c_1 c_2} = 2g^2 \delta^{c_1 c_2} \sqrt{\frac{6}{M\pi N_c}} \frac{\mathcal{R}'(0)}{M^2 (q_1 q_2)^2} \varepsilon_{\sigma\rho\alpha\beta} \epsilon^{\beta}(J_z) \Big[q_{1,t}^{\sigma} q_{2,t}^{\rho} (x_1 p_1^{\alpha} - x_2 p_2^{\alpha})(q_{1,t}^2 + q_{2,t}^2) -$$
$$- \frac{2}{s} p_1^{\sigma} p_2^{\rho} \Big(q_{1,t}^{\alpha} (2 q_{2,t}^2 (q_1 q_2) - (q_{1,t} q_{2,t})(q_{1,t}^2 + q_{2,t}^2)) + q_{2,t}^{\alpha} (2 q_{1,t}^2 (q_1 q_2) - (q_{1,t} q_{2,t})(q_{1,t}^2 + q_{2,t}^2)) \Big) \Big].$$

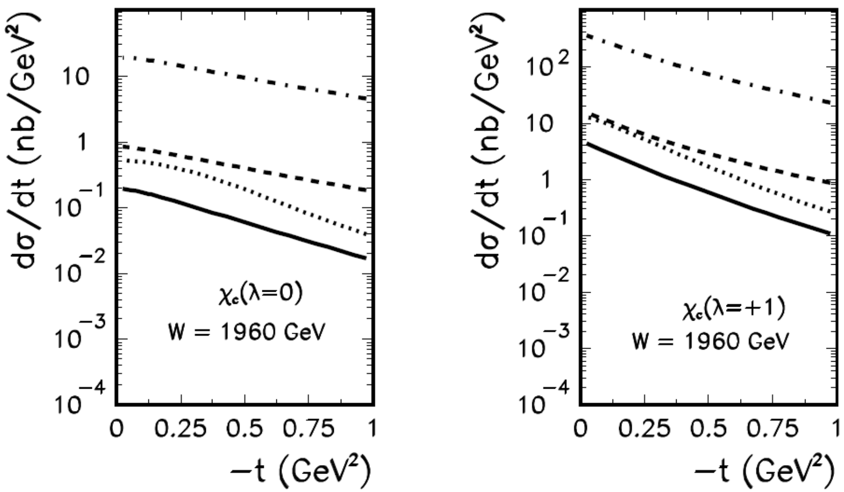
- **Helicity amplitudes are defined in protons c.m. frame**

$$\epsilon^{\beta}(P,\lambda) = (1 - |\lambda|) n_3^{\beta} - \frac{1}{\sqrt{2}} (\lambda n_1^{\beta} + i|\lambda| n_2^{\beta}), \quad n_0^{\mu} = \frac{P_{\mu}}{M}, \quad n_{\alpha}^{\mu} n_{\beta}^{\nu} g_{\mu\nu} = g_{\alpha\beta}, \quad \epsilon^{\mu}(\lambda) \epsilon_{\mu}^{*}(\lambda') = -\delta^{\lambda\lambda'}$$

$$V_{J=1,\lambda}^{c_1 c_2} = -8 g^2 \delta^{c_1 c_2} \sqrt{\frac{6}{M\pi N_c}} \frac{\mathcal{R}'(0)}{|\mathbf{P}_t| (M^2 - q_{1,t}^2 - q_{2,t}^2)^2} \Big\{ (1 - |\lambda|)(q_{1,t}^2 + q_{2,t}^2) \, |[\mathbf{q}_{1,t} \times \mathbf{q}_{2,t}] \times \mathbf{n}_3| -$$
$$- \frac{1}{\sqrt{2}} \Big[\lambda (q_{1,t}^2 + q_{2,t}^2) \, |[\mathbf{q}_{1,t} \times \mathbf{q}_{2,t}] \times \mathbf{n}_1| + i|\lambda| (q_{1,t}^2 - q_{2,t}^2)(q_{1,t} q_{2,t}) \Big] \Big\}, \qquad \lambda = 0, \pm 1$$

Results for χc(1+)-production





UGDF	$\lambda = 0$	$\lambda = \pm 1$	ρ_{00}
KL	0.4452(+0)	0.4492(+1)	0.050
GBW	0.2345(+0)	0.3409(+1)	0.034
BFKL	0.1051(+2)	0.1114(+3)	0.047
Gauss, $\sigma_0 = 0.5$ GeV, scales (2)	0.7800(-1)	0.1103(+1)	0.035
Gauss, $\sigma_0 = 1.0$ GeV, scales (2)	0.1757(-1)	0.1819(+0)	0.048
Gauss, $\sigma_0 = 2.0$ GeV, scales (2)	0.8924(-3)	0.8628(-2)	0.052

Conclusions

- Uncertainties in KMR approach is discussed. Our approach with NRQCD hard part is checked for $\chi_c(0+)$-production.

- We get purely off-shell effect in $\chi_c(1+)$-production amplitude.

- Spin polarization $\lambda = \pm 1$ is approximately an order of magnitude greater than $\lambda = 0$ polarization for any UGDF –> strong tensor polarization about 5 %