DETERMINING THE HIGGS SPIN AND PARITY USING GLUON POLARIZATION

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arXiv:1304.2654

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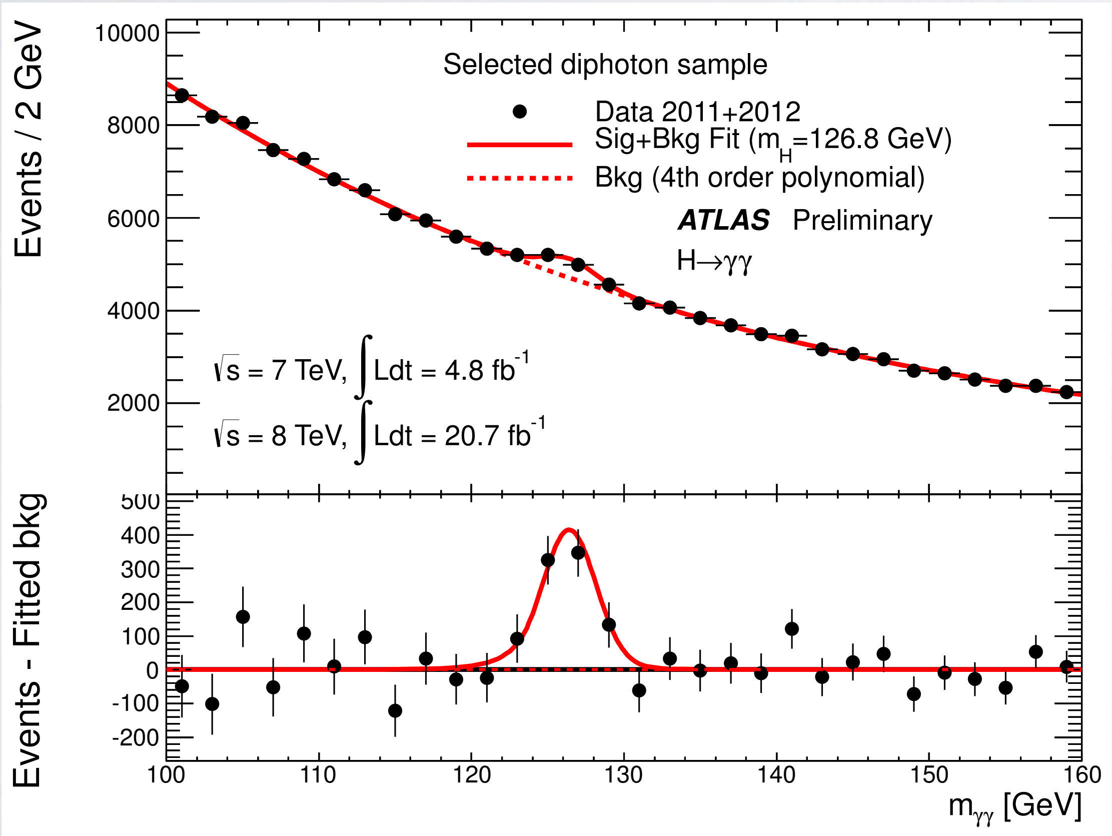
HIGGS J^P DETERMINATION

	postive parity	negative parity
spin-0	0^+	0^-
spin-1	✗	✗
spin-2	2^+_m 2^+_h $2^+_{h'}$ $2^+_{h''}$	2^-_h

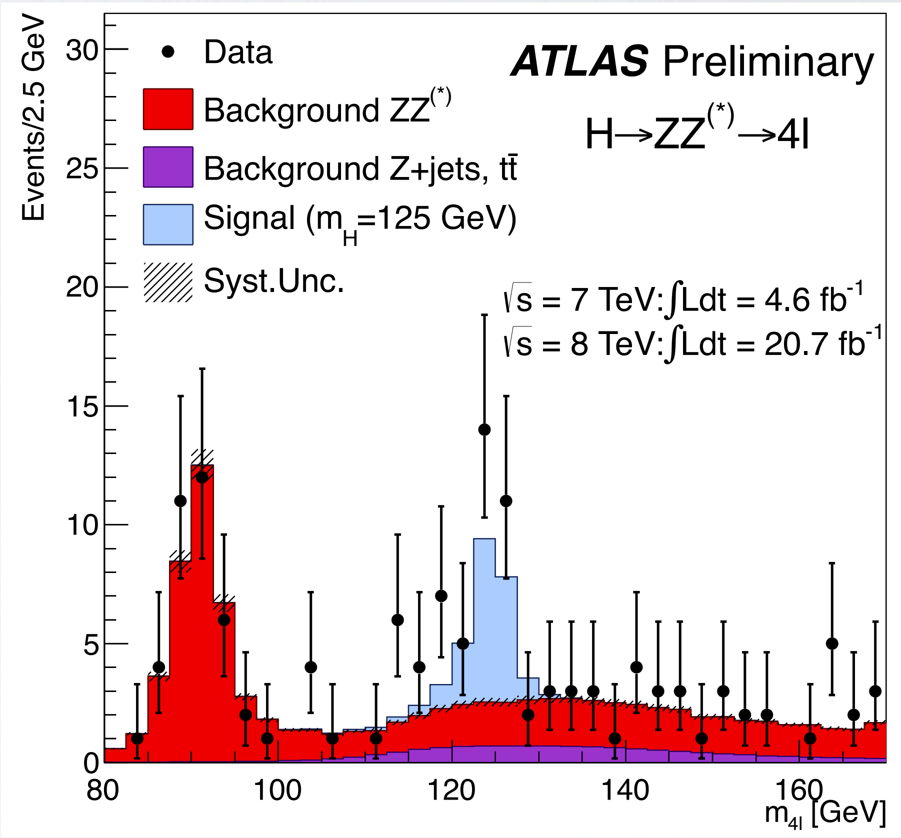
HIGGS J^P DETERMINATION

di-photon



ATLAS-CONF-2013-012

$ZZ^* \rightarrow 4l$

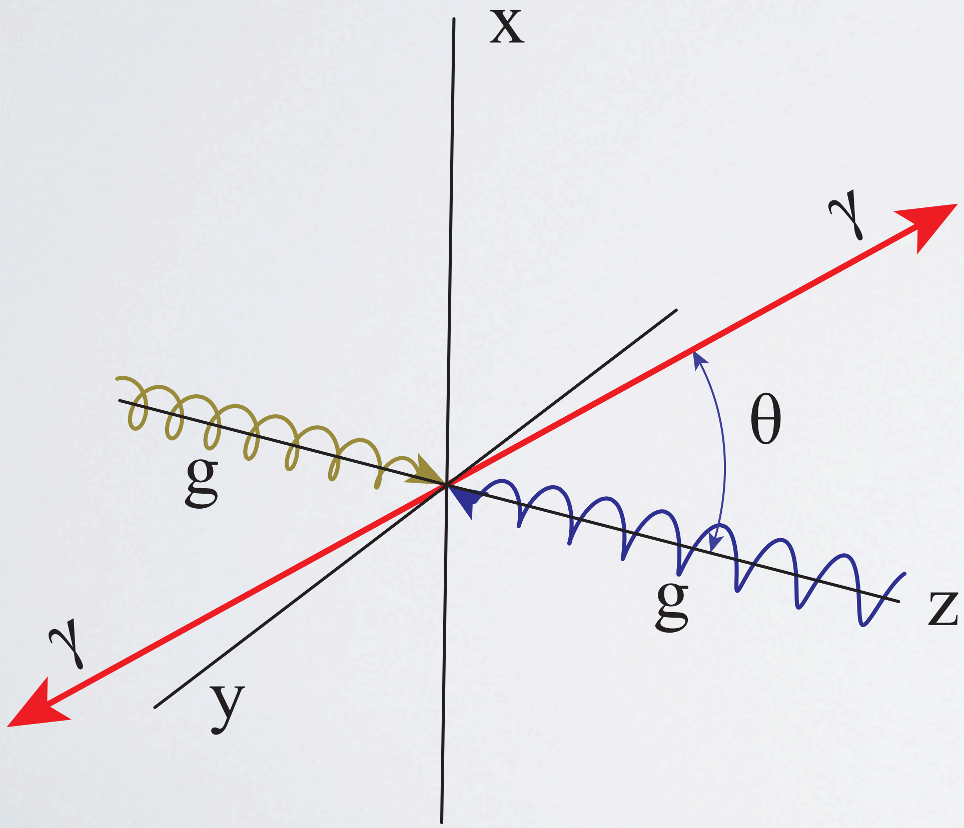


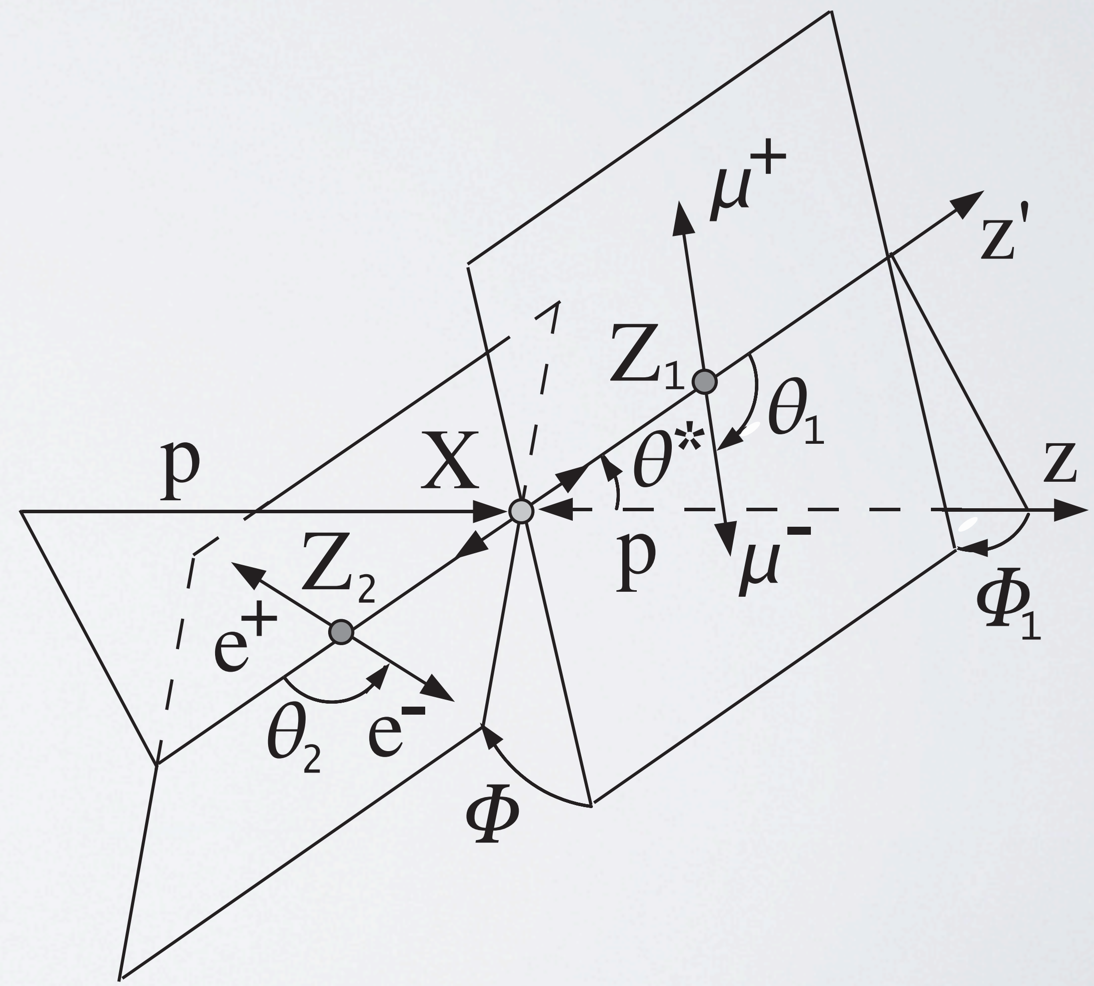
ATLAS-CONF-2013-013

HIGGS J^P DETERMINATION

di-photon

$ZZ^* \rightarrow 4l$

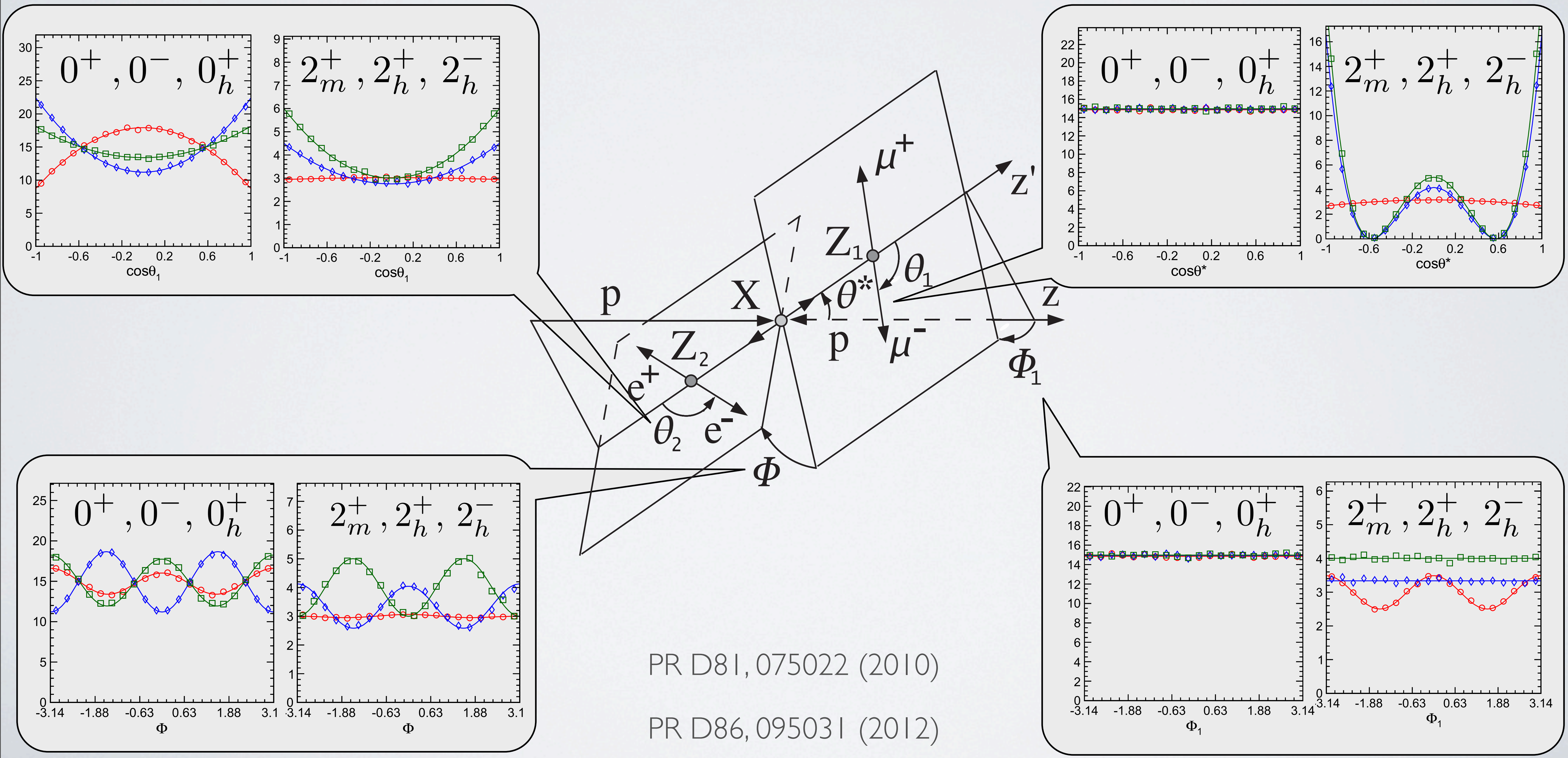




PR D81, 075022 (2010)

HIGGS J^P DETERMINATION

$ZZ^* \rightarrow 4l$

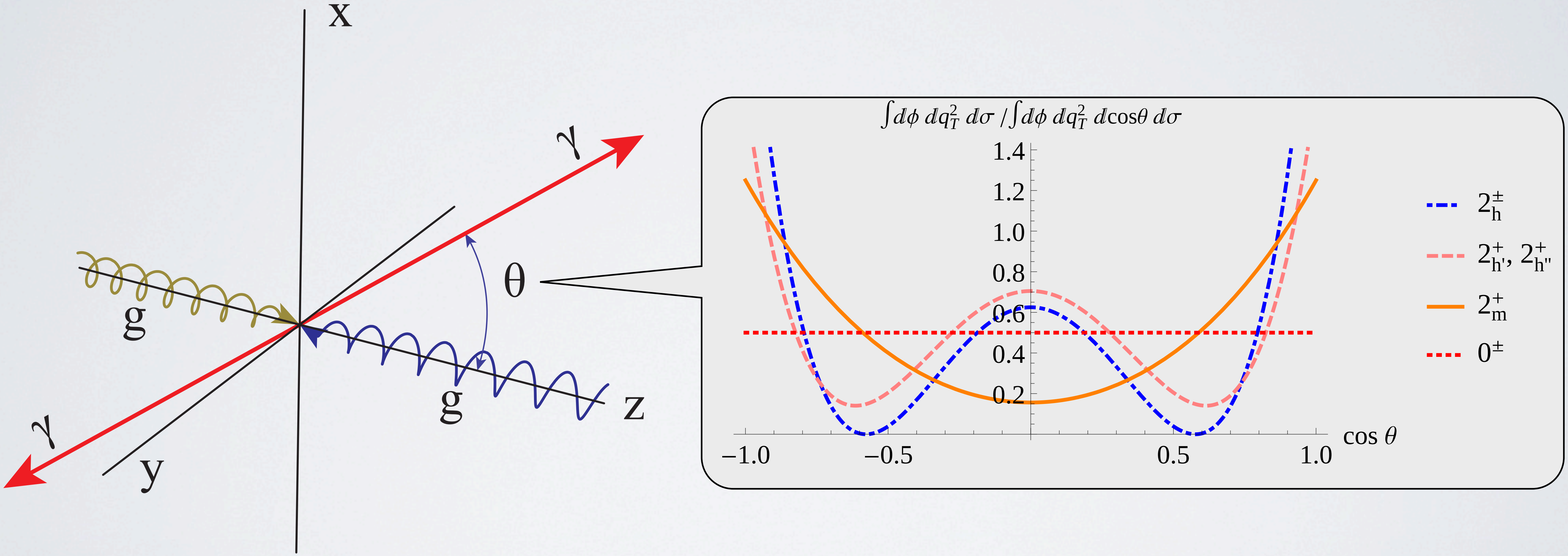


PR D81, 075022 (2010)

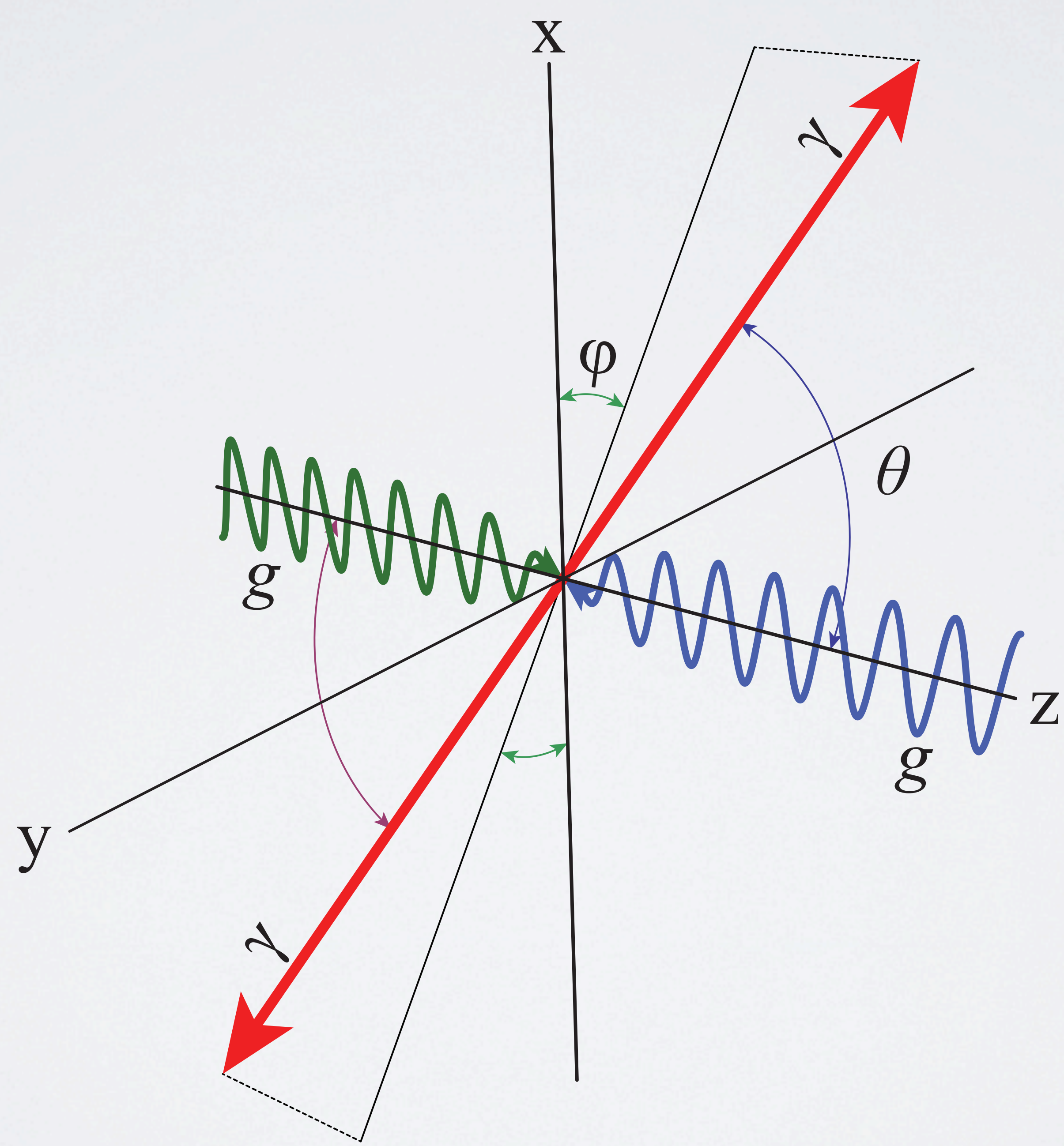
PR D86, 095031 (2012)

HIGGS J^P DETERMINATION

di-photon



WITH GLUON POLARIZATION



TMD FACTORIZATION

$$\frac{\mathrm{d}\sigma}{\mathrm{d}^4q\mathrm{d}\Omega} \propto \int \mathrm{d}^2\boldsymbol{p}_T \mathrm{d}^2\boldsymbol{k}_T \delta^2(\boldsymbol{p}_T + \boldsymbol{k}_T - \boldsymbol{q}_T)\mathcal{M}_{\mu\rho\kappa\lambda}\left(\mathcal{M}_{\nu\sigma}{}^{\kappa\lambda}\right)^* \Phi_g^{\mu\nu}(x_1, \boldsymbol{p}_T, \zeta_1, \mu)\, \Phi_g^{\rho\sigma}(x_2, \boldsymbol{k}_T, \zeta_2, \mu),$$

Hard scattering matrix element

Transverse Momentum Dependent (TMD) correlator

Ji, Ma, Yuan, JHEP07 (2005) 020

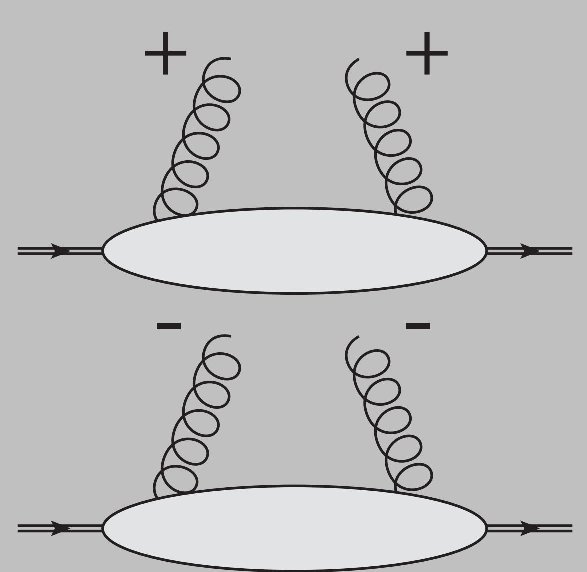
in principle also soft factor,
but vanishes (up to NLO) for $\zeta_{1,2} \to 3/2\sqrt{S}$

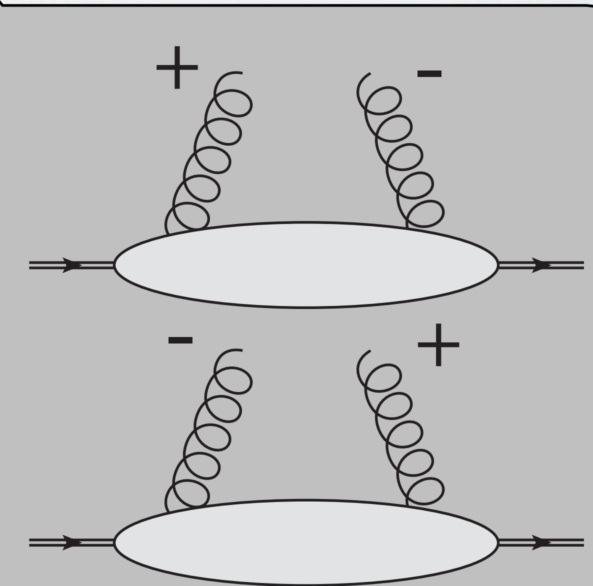
TMD FACTORIZATION

$$\frac{\mathrm{d}\sigma}{\mathrm{d}^4q\,\mathrm{d}\Omega} \propto \int \mathrm{d}^2\boldsymbol{p}_{\scriptscriptstyle T}\mathrm{d}^2\boldsymbol{k}_{\scriptscriptstyle T}\delta^2(\boldsymbol{p}_{\scriptscriptstyle T}+\boldsymbol{k}_{\scriptscriptstyle T}-\boldsymbol{q}_{\scriptscriptstyle T})\mathcal{M}_{\mu\rho\kappa\lambda}\left(\mathcal{M}_{\nu\sigma}{}^{\kappa\lambda}\right)^*\Phi_g^{\mu\nu}(x_1,\boldsymbol{p}_{\scriptscriptstyle T},\zeta_1,\mu)\,\Phi_g^{\rho\sigma}(x_2,\boldsymbol{k}_{\scriptscriptstyle T},\zeta_2,\mu),$$

$$\Phi_g^{\mu\nu}(x,\boldsymbol{p}_{\scriptscriptstyle T},\zeta,\mu) \equiv 2\int \frac{\mathrm{d}(\xi\cdot P)\,\mathrm{d}^2\xi_T}{(xP\cdot n)^2(2\pi)^3}\,e^{i(xP+p_T)\cdot\xi}\,\mathrm{Tr}_c\Big[\langle P|F^{n\nu}(0)\,\mathcal{U}^{n[-]}_{[0,\xi]}\,F^{n\mu}(\xi)\,\mathcal{U}^{n[-]}_{[\xi,0]}|P\rangle\Big]_{\xi\cdot P'=0}$$

$$= -\frac{1}{2x}\left\{g_{\scriptscriptstyle T}^{\mu\nu}f_1^g - \left(\frac{p_{\scriptscriptstyle T}^\mu p_{\scriptscriptstyle T}^\nu}{M_p^2}+g_{\scriptscriptstyle T}^{\mu\nu}\frac{\boldsymbol{p}_{\scriptscriptstyle T}^2}{2M_p^2}\right)h_1^{\perp\,g}\right\} + \text{higher twist},$$

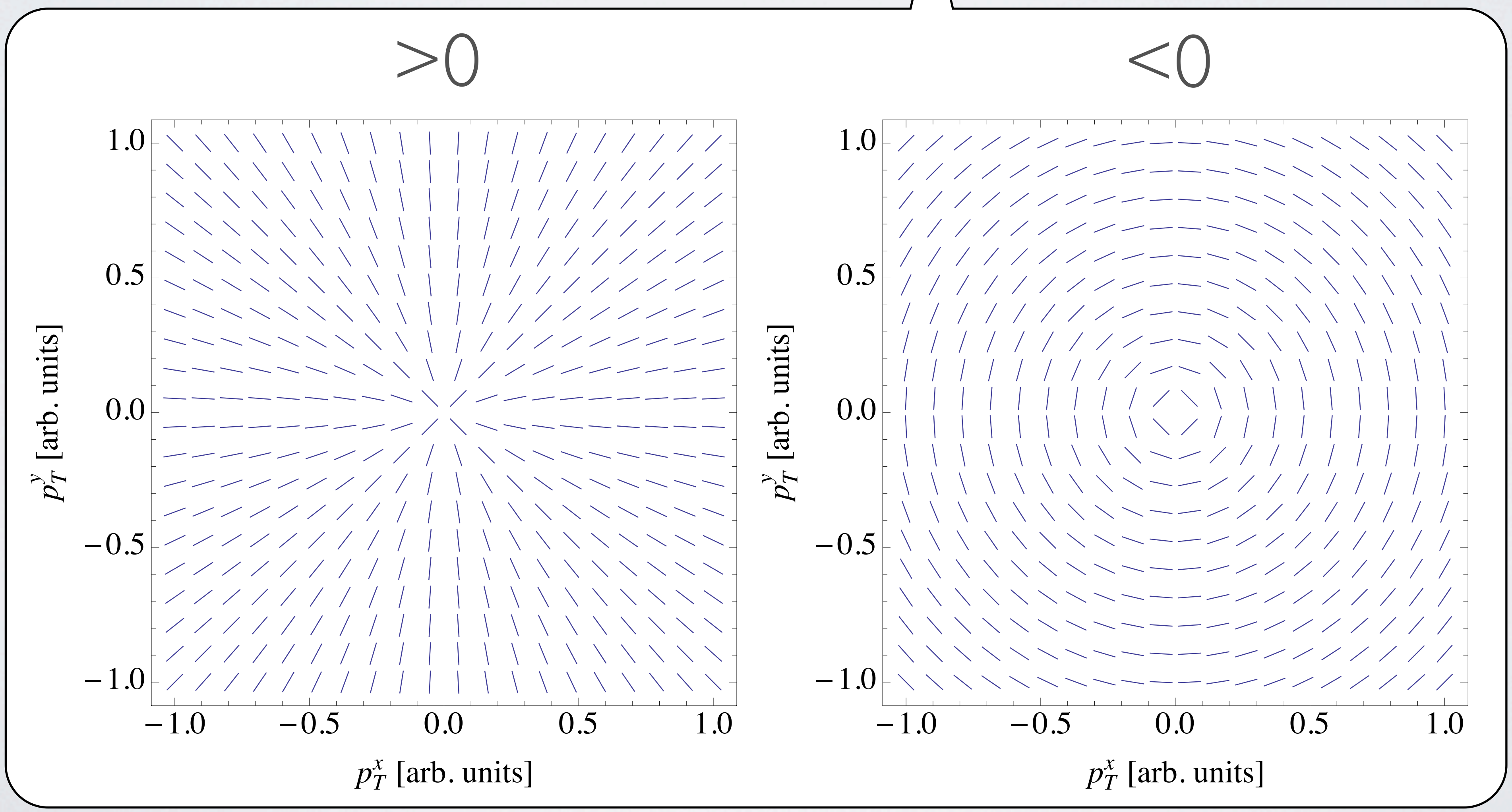




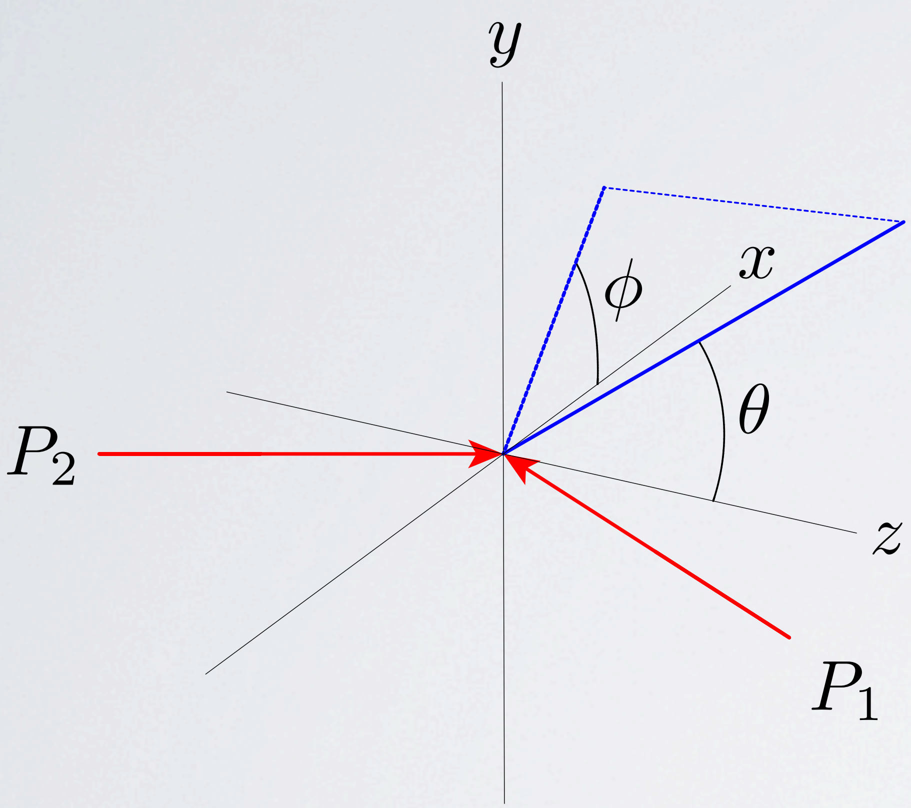
LINEARLY POLARIZED GLUON DISTRIBUTION

$$\Phi_g^{\mu\nu}(x, \boldsymbol{p}_T, \zeta, \mu) \equiv 2 \int \frac{\mathrm{d}(\xi \cdot P)\, \mathrm{d}^2\xi_T}{(xP \cdot n)^2 (2\pi)^3}\, e^{i(xP+p_T)\cdot\xi}\, \mathrm{Tr}_c \Big[\langle P | F^{n\nu}(0)\, \mathcal{U}^{n[-]}_{[0,\xi]}\, F^{n\mu}(\xi)\, \mathcal{U}^{n[-]}_{[\xi,0]} | P \rangle \Big]_{\xi\cdot P'=0}$$

$$= -\frac{1}{2x} \left\{ g_T^{\mu\nu} f_1^g - \left(\frac{p_T^\mu p_T^\nu}{M_p^2} + g_T^{\mu\nu} \frac{\boldsymbol{p}_T^2}{2M_p^2} \right) h_1^{\perp\, g} \right\} + \text{higher twist},$$



GENERAL STRUCTURE

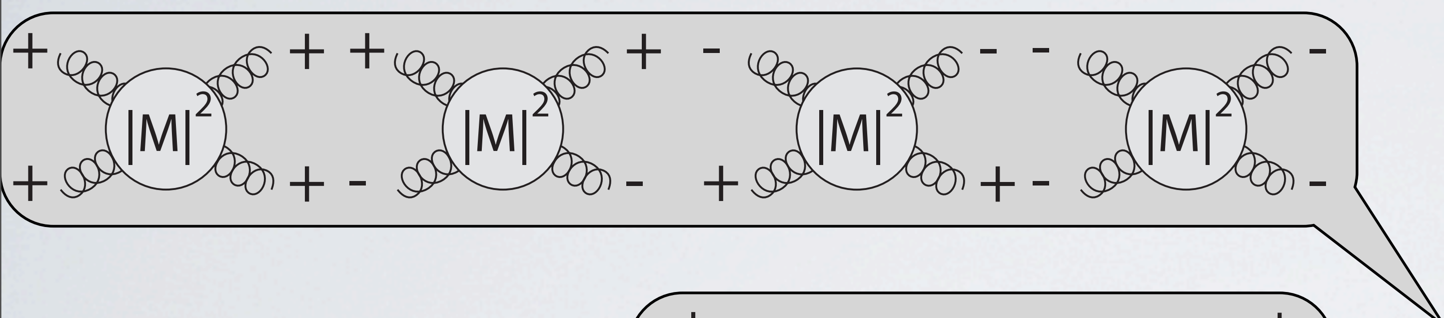


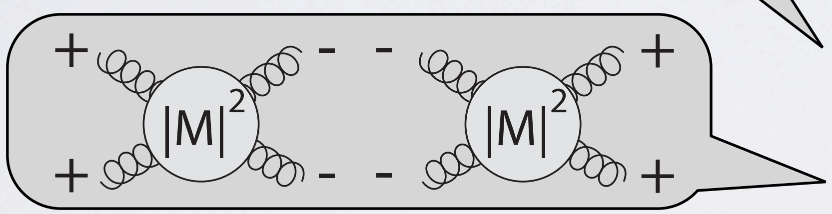
Collins-Soper frame

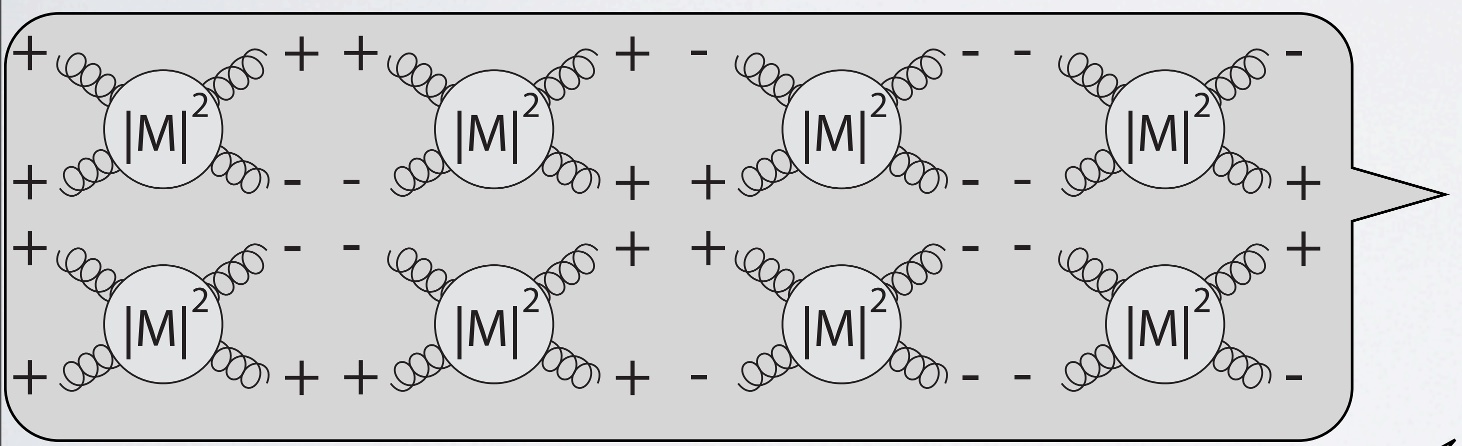
$$
\begin{aligned}
&\frac{d\sigma}{d^4q\,d\Omega} \propto \\
&F_1(Q,\theta)\,\mathcal{C}\left[f_1^g f_1^g\right] + \\
&F_2(Q,\theta)\,\mathcal{C}\left[w_2\, h_1^{\perp g} h_1^{\perp g}\right] + \\
&F_3(Q,\theta)\,\mathcal{C}\left[w_3 (f_1^g h_1^{\perp g} + h_1^{\perp g} f_1^g)\right] \cos(2\phi) + \\
&F_3'(Q,\theta)\,\mathcal{C}\left[w_3 (f_1^g h_1^{\perp g} - h_1^{\perp g} f_1^g)\right] \sin(2\phi) + \\
&F_4(Q,\theta)\,\mathcal{C}\left[w_4\, h_1^{\perp g} h_1^{\perp g}\right] \cos(4\phi) + \\
&\mathcal{O}\left(q_T/Q\right)
\end{aligned}
$$

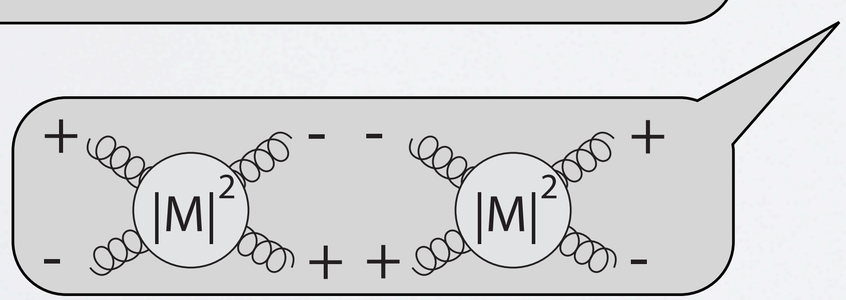
ϕ azimuthal Collins-Soper angle

GENERAL STRUCTURE









$$\frac{\mathrm{d}\sigma}{\mathrm{d}^4 q \mathrm{d}\Omega} \propto$$

$$F_1(Q,\theta)\,\mathcal{C}\left[f_1^g f_1^g\right] +$$

$$F_2(Q,\theta)\,\mathcal{C}\left[w_2\, h_1^{\perp g} h_1^{\perp g}\right] +$$

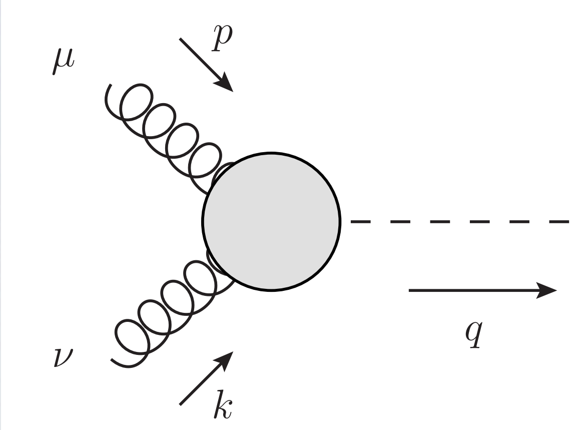
$$F_3(Q,\theta)\,\mathcal{C}\left[w_3 (f_1^g h_1^{\perp g} + h_1^{\perp g} f_1^g)\right] \cos(2\phi) +$$

$$F_3'(Q,\theta)\,\mathcal{C}\left[w_3 (f_1^g h_1^{\perp g} - h_1^{\perp g} f_1^g)\right] \sin(2\phi) +$$

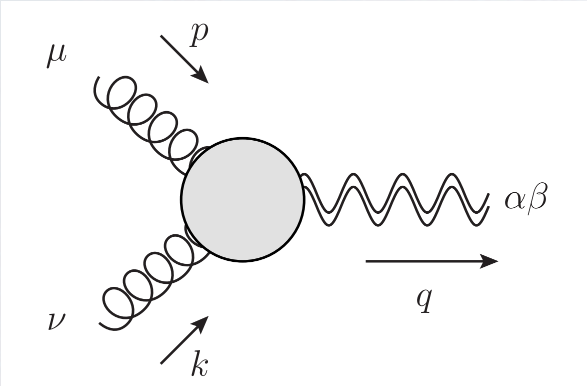
$$F_4(Q,\theta)\,\mathcal{C}\left[w_4\, h_1^{\perp g} h_1^{\perp g}\right] \cos(4\phi) +$$

$$\mathcal{O}\left(q_T/Q\right)$$

PARTONIC AMPLITUDES



$$= a_1\, q^2 g^{\mu\nu} + a_3\, \epsilon^{pk\mu\nu}$$



$$= \frac{1}{2} c_1\, q^2 g^{\mu\alpha} g^{\nu\beta} + \left[c_2\, q^2 g^{\mu\nu} + c_5\, \epsilon^{pk\mu\nu}\right] \frac{(p-k)^\alpha (p-k)^\beta}{q^2}$$

scenario	0^+	0^-	2^+_m	2^+_h	$2^+_{h'}$	$2^+_{h''}$	2^-_h
a_1	1	0	-	-	-	-	-
a_3	0	1	-	-	-	-	-
c_1	-	-	1	0	1	1	0
c_2	-	-	$-\frac{1}{4}$	1	1	$-\frac{3}{2}$	0
c_5	-	-	0	0	0	0	1

GENERAL STRUCTURE

$$\frac{\mathrm{d}\sigma}{\mathrm{d}^4 q \mathrm{d}\Omega} \propto$$

$$F_1(Q,\theta)\,\mathcal{C}\,[f_1^g f_1^g] +$$

$$F_2(Q,\theta)\,\mathcal{C}\left[w_2\, h_1^{\perp g} h_1^{\perp g}\right] +$$

$$F_3(Q,\theta)\,\mathcal{C}\left[w_3 (f_1^g h_1^{\perp g} + h_1^{\perp g} f_1^g)\right] \cos(2\phi) +$$

$$F_3'(Q,\theta)\,\mathcal{C}\left[w_3 (f_1^g h_1^{\perp g} - h_1^{\perp g} f_1^g)\right] \sin(2\phi) +$$

$$F_4(Q,\theta)\,\mathcal{C}\left[w_4\, h_1^{\perp g} h_1^{\perp g}\right] \cos(4\phi) +$$

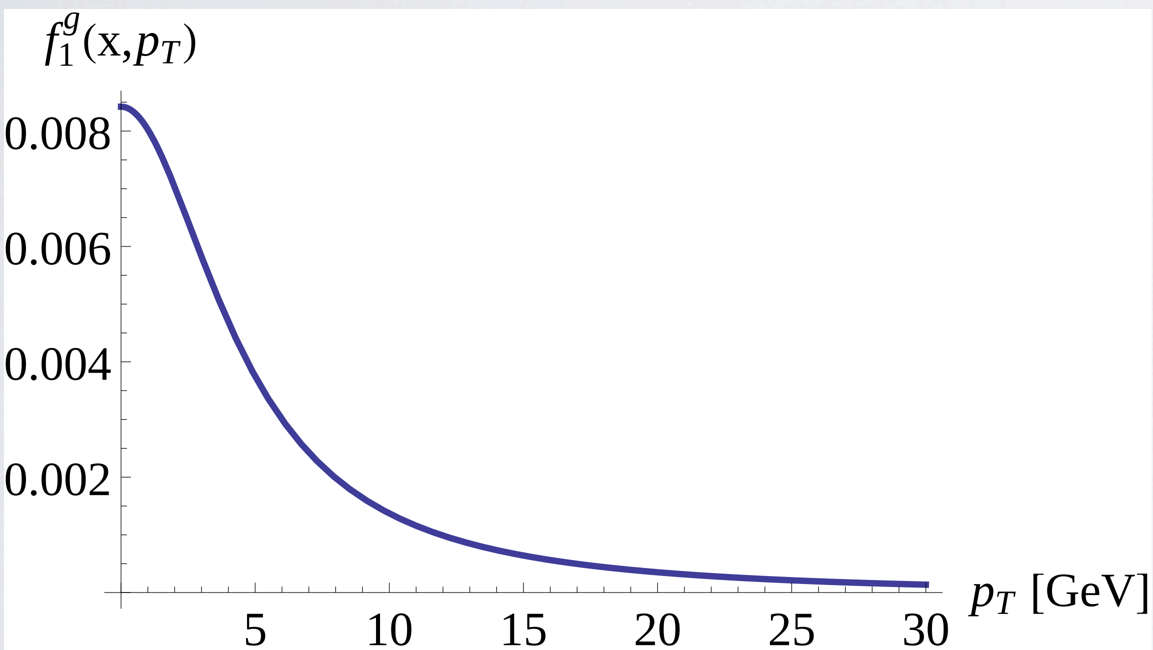
$$\mathcal{O}\left(q_T/Q\right)$$

- Unpolarized distribution
- gluon TMD
- f_1^g

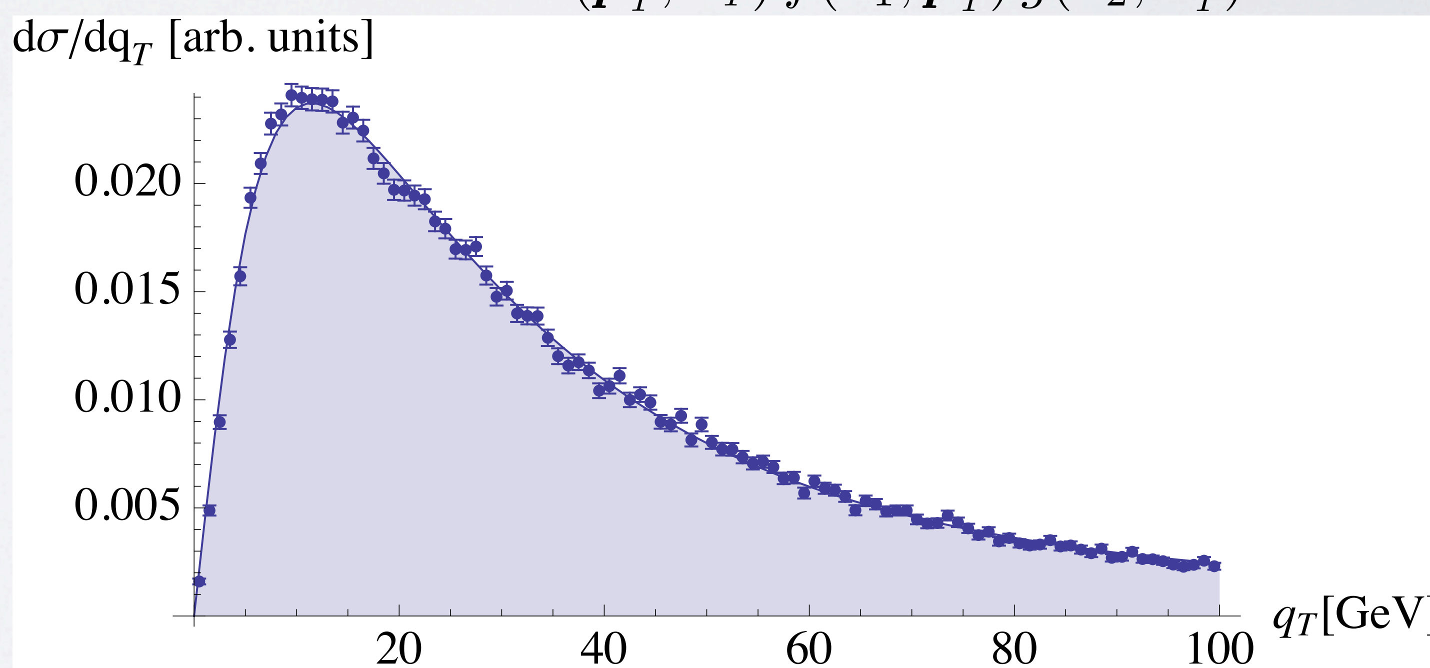
- Polarized distribution
- linearly polarized gluon distribution
- $h_1^{\perp g}$

UNPOLARIZED DISTRIBUTION

$$f_1^g(x, \boldsymbol{p}_T^2, \frac{3}{2}\sqrt{s}, M_h) = \frac{A_0\, M_0^2}{M_0^2 + \boldsymbol{p}_T^2} \exp\left[-\frac{\boldsymbol{p}_T^2}{a\boldsymbol{p}_T^2 + 2\sigma^2}\right]$$



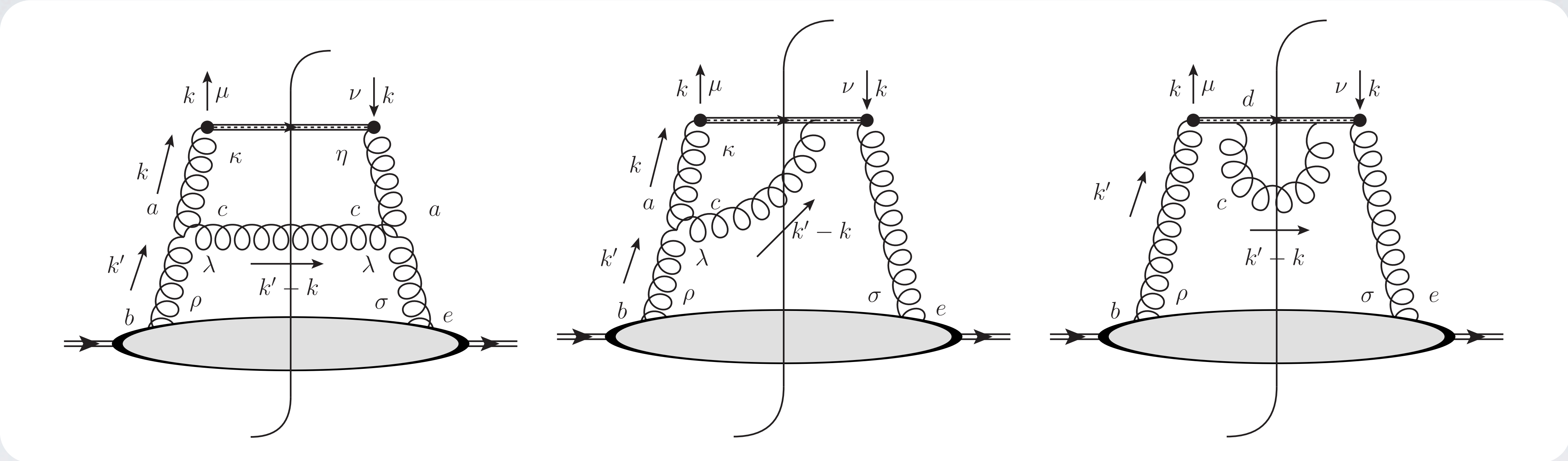
$$\mathcal{C}[w\, f\, g] \equiv \int d^2\boldsymbol{p}_T \int d^2\boldsymbol{k}_T\, \delta^2(\boldsymbol{p}_T + \boldsymbol{k}_T - \boldsymbol{q}_T)$$
$$w(\boldsymbol{p}_T, \boldsymbol{k}_T)\, f(x_1, \boldsymbol{p}_T^2)\, g(x_2, \boldsymbol{k}_T^2)$$

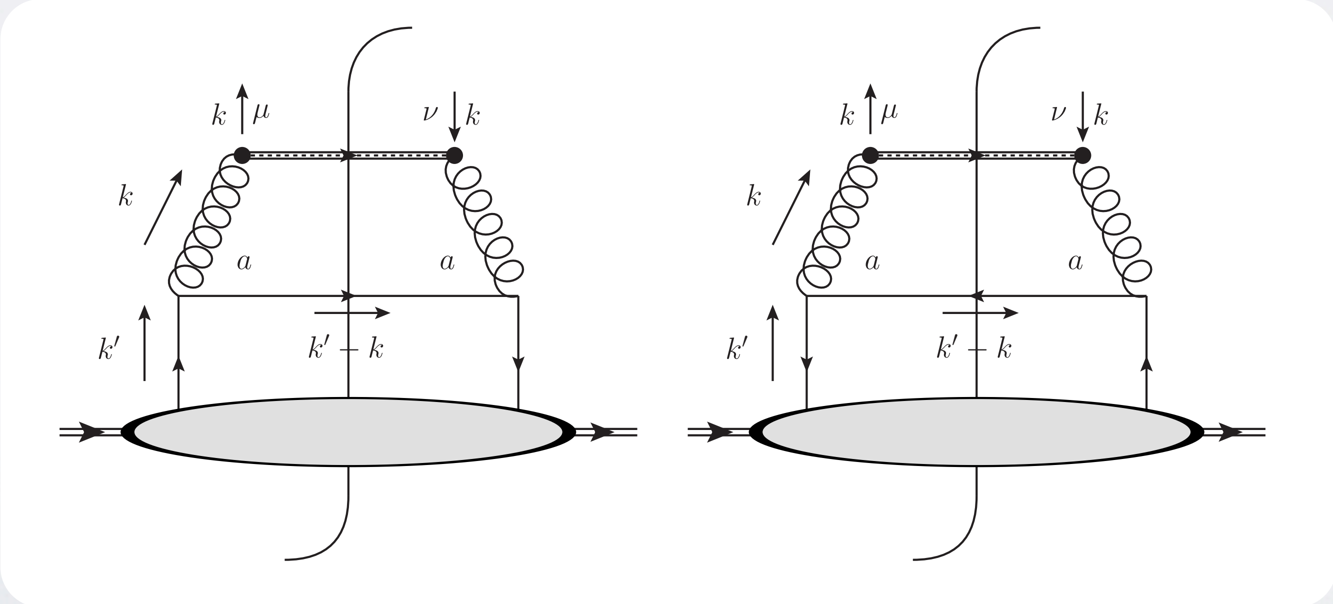


POWHEG+Pythia 8 Higgs qT distribution

POLARIZED DISTRIBUTION

$$\Phi_g^{\mu\nu}(x, \boldsymbol{p}_T, \zeta, \mu) \equiv 2 \int \frac{\mathrm{d}(\xi \cdot P)\,\mathrm{d}^2\xi_T}{(xP\cdot n)^2(2\pi)^3}\, e^{i(xP+p_T)\cdot\xi}\, \mathrm{Tr}_c\Big[\langle P|F^{n\nu}(0)\,\mathcal{U}^{n[-]}_{[0,\xi]}\,F^{n\mu}(\xi)\,\mathcal{U}^{n[-]}_{[\xi,0]}|P\rangle\Big]_{\xi\cdot P'=0}$$

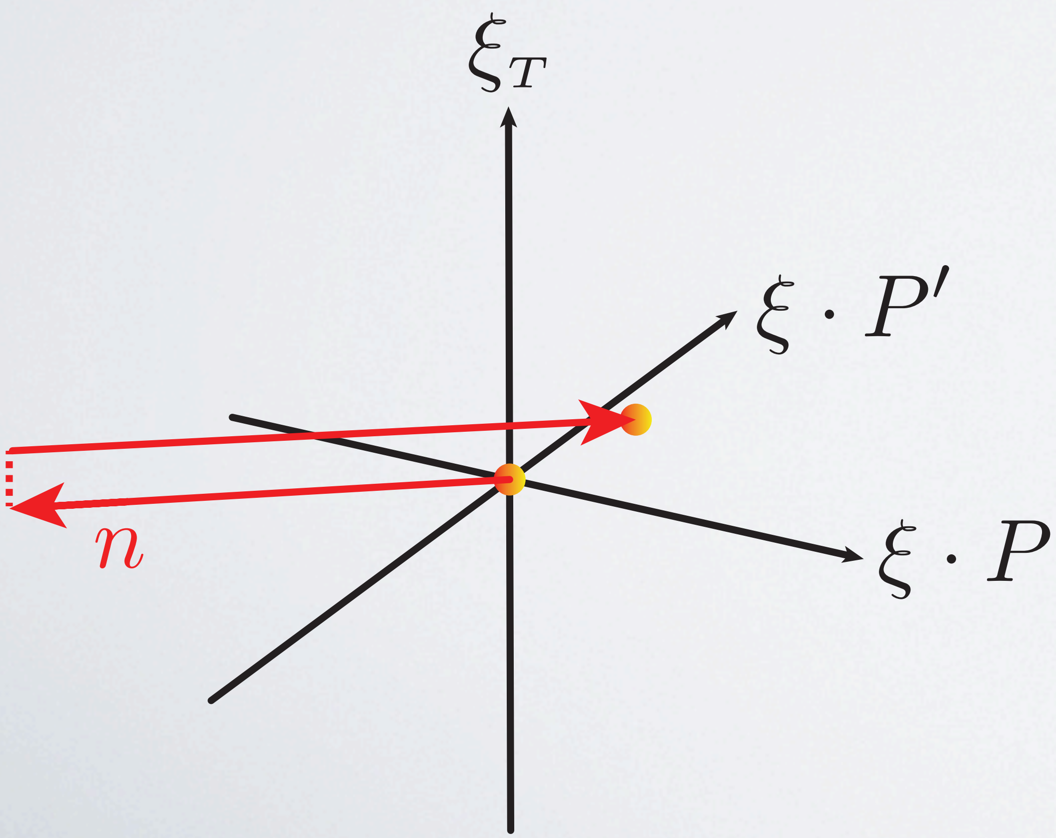




POLARIZED DISTRIBUTION

$$\Phi_g^{\mu\nu}(x,\boldsymbol{p}_T,\zeta,\mu) \equiv 2\int \frac{\mathrm{d}(\xi\cdot P)\,\mathrm{d}^2\xi_T}{(xP\cdot n)^2(2\pi)^3}\, e^{i(xP+p_T)\cdot\xi}\,\mathrm{Tr}_c\Big[\langle P|F^{n\nu}(0)\,\mathcal{U}^{n[-]}_{[0,\xi]}\,F^{n\mu}(\xi)\,\mathcal{U}^{n[-]}_{[\xi,0]}|P\rangle\Big]_{\xi\cdot P'=0}$$

$$\mathcal{U}^{n[-]}_{[0,\xi]} \equiv \mathcal{U}^n_{[0,-\infty]}\,\mathcal{U}^n_{[-\infty,\xi]} = \mathcal{P}e^{-ig\int_0^{-\infty} dy A^n(0+ny)}\mathcal{P}e^{-ig\int_{-\infty}^0 dy A^n(\xi+ny)}$$

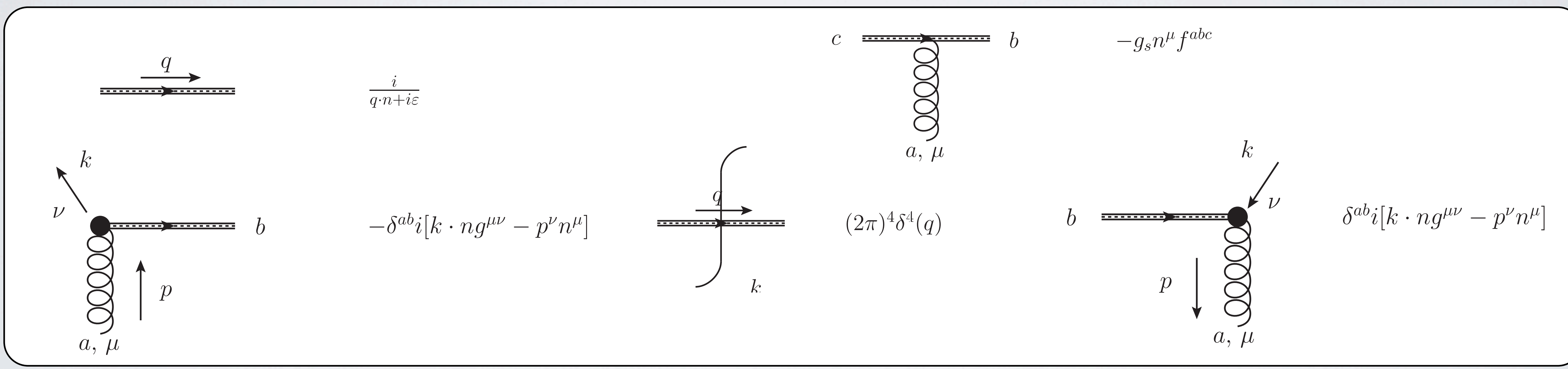


$$n \propto \frac{1}{\zeta}\,P + \frac{\zeta}{P\cdot P'}\,P'$$

$$\zeta \equiv \frac{2(n\cdot P)}{\sqrt{n^2}}$$

POLARIZED DISTRIBUTION

$$\Phi_g^{\mu\nu}(x, \boldsymbol{p}_T, \zeta, \mu) \equiv 2 \int \frac{\mathrm{d}(\xi \cdot P)\, \mathrm{d}^2\xi_T}{(xP \cdot n)^2 (2\pi)^3}\, e^{i(xP+p_T)\cdot\xi}\, \mathrm{Tr}_c \Big[\langle P | F^{n\nu}(0)\, \mathcal{U}^{n[-]}_{[0,\xi]}\, F^{n\mu}(\xi)\, \mathcal{U}^{n[-]}_{[\xi,0]} | P \rangle \Big]_{\xi\cdot P'=0}$$



POLARIZED DISTRIBUTION

in $\zeta \to \infty$ limit results compatible with the literature

$$f^g_{1\text{tail}}(x, \boldsymbol{k}_T) = -\frac{4g_s^2}{(2\pi)^3 k_T^2} \int_x^1 \frac{\mathrm{d}z}{z} \Bigg[C_A \Bigg\{ \frac{1-z}{z} + z(1-z) + \frac{z}{(1-z)^+} - \frac{1}{2}\delta(z-1) \left[1 + \log\left(\frac{-k_T^2}{\zeta^2}\right) - \log x^2 (1-x)^2 \right] \Bigg\} f_1^g\left(\frac{x}{z}\right) + C_F \frac{1+(1-z)^2}{2z} \sum_{q,\bar{q}} f_1^q \left(\frac{x}{z}\right) \Bigg]$$

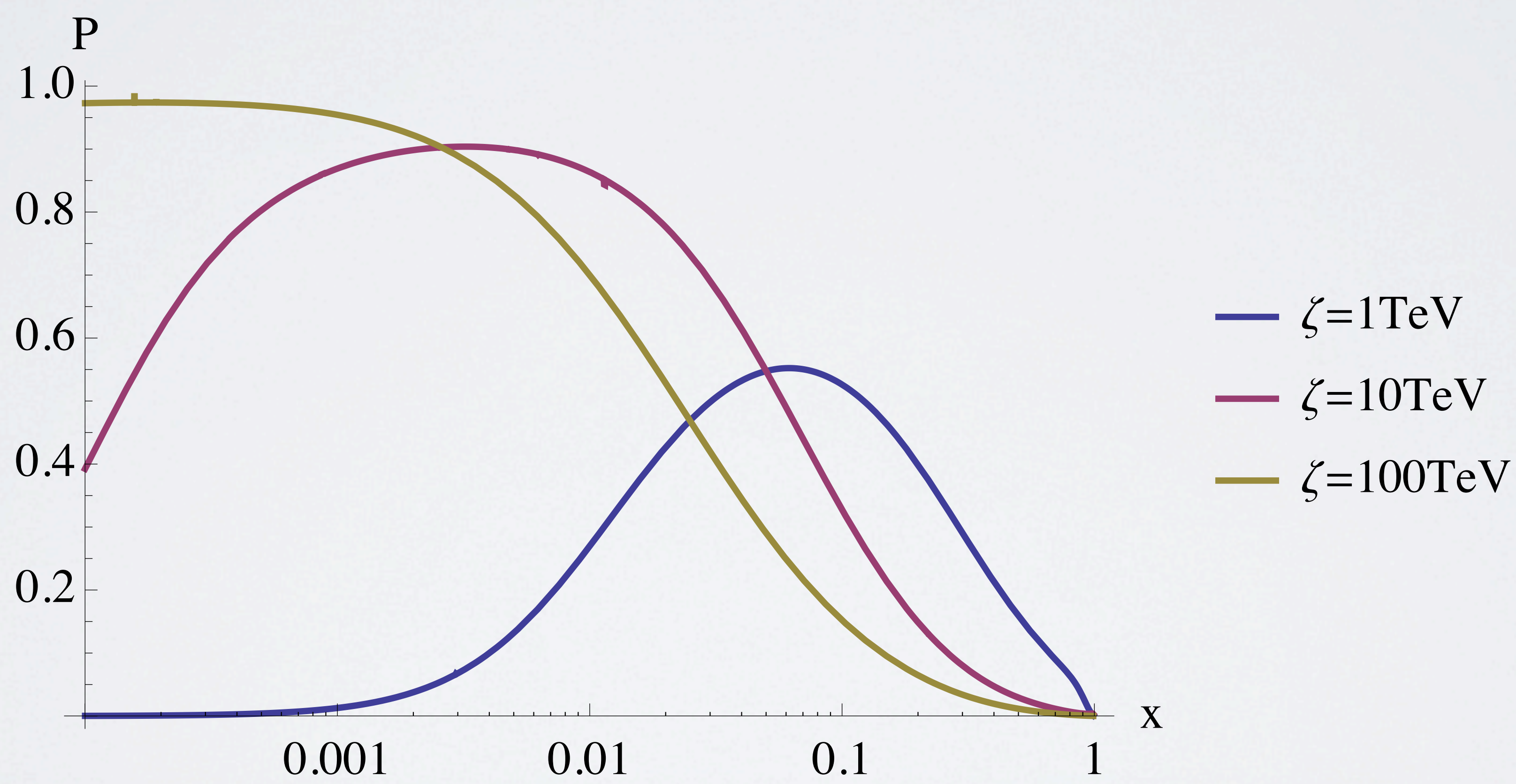
cf. Ji, Ma, Yuan
JHEP07 (2005) 020

$$h^{\perp g}_{1\text{tail}}(x, \boldsymbol{k}_T) = \frac{4g_s^2}{(2\pi)^3 k_T^2} \frac{2M^2}{k_T^2} \int_x^1 \frac{\mathrm{d}z}{z} \frac{1-z}{z} \left[C_A f_1^g\left(\frac{x}{z}\right) + C_F \sum_{q,\bar{q}} f_1^q\left(\frac{x}{z}\right) \right]$$

cf. Sun, Xiao, Yuan
PR D84, 094005 (2011)

DEGREE OF POLARIZATION

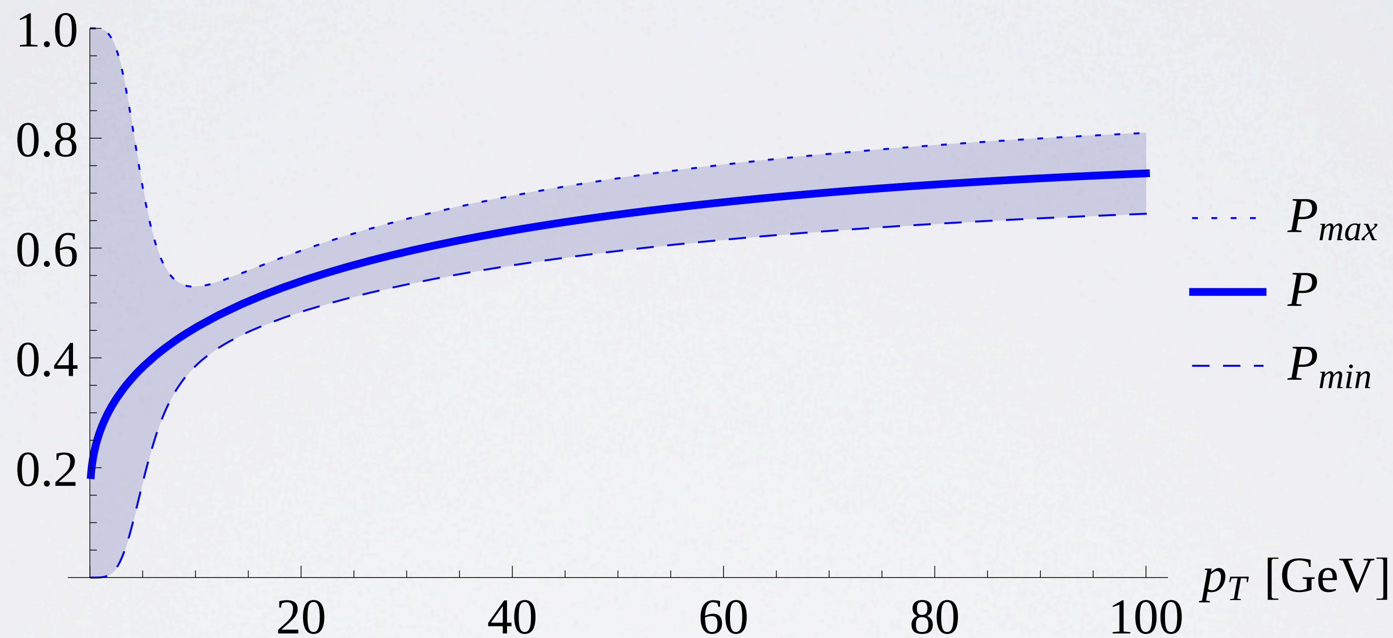
$$h_1^{\perp g}(x, \boldsymbol{p}_T, \zeta, \mu) = \mathcal{P}(x, \boldsymbol{p}_T^2, \zeta) \frac{2M_p^2}{\boldsymbol{p}_T^2} f_1^g(x, \boldsymbol{p}_T, \zeta, \mu),$$



CGC model predicts full polarization at small x:
A. Metz and J. Zhou, Phys. Rev. D 84, 051503 (2011)

DEGREE OF POLARIZATION

$$h_1^{\perp g}(x, \boldsymbol{p}_T, \zeta, \mu) = \mathcal{P}(x, \boldsymbol{p}_T^2, \zeta)\,\frac{2M_p^2}{\boldsymbol{p}_T^2}\,f_1^g(x, \boldsymbol{p}_T, \zeta, \mu),$$

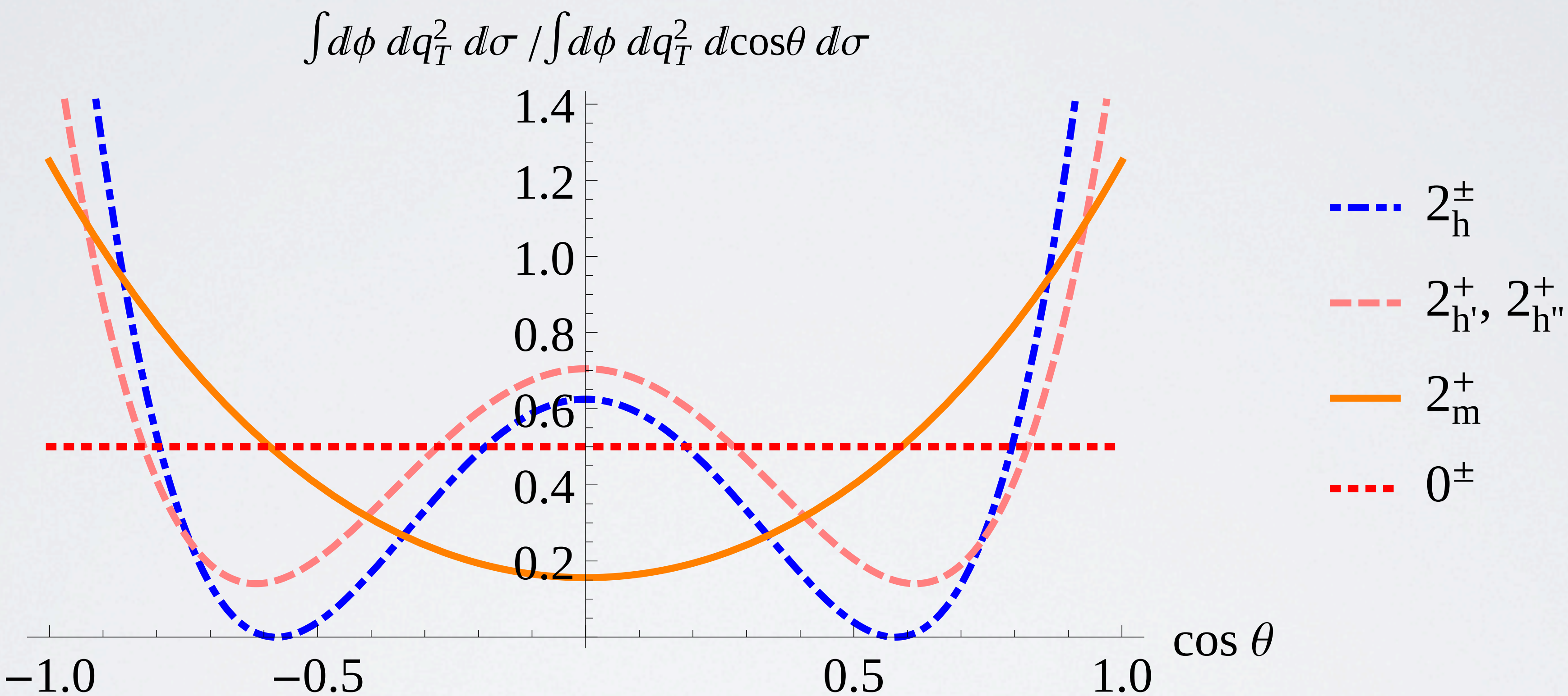


$$\mathcal{P}_{min} \equiv \frac{\boldsymbol{p}_T^4}{p_0^4 + \boldsymbol{p}_T^4}\,0.9\,\mathcal{P}_{\mathrm{pQCD}}(x, \boldsymbol{p}_T^2),$$

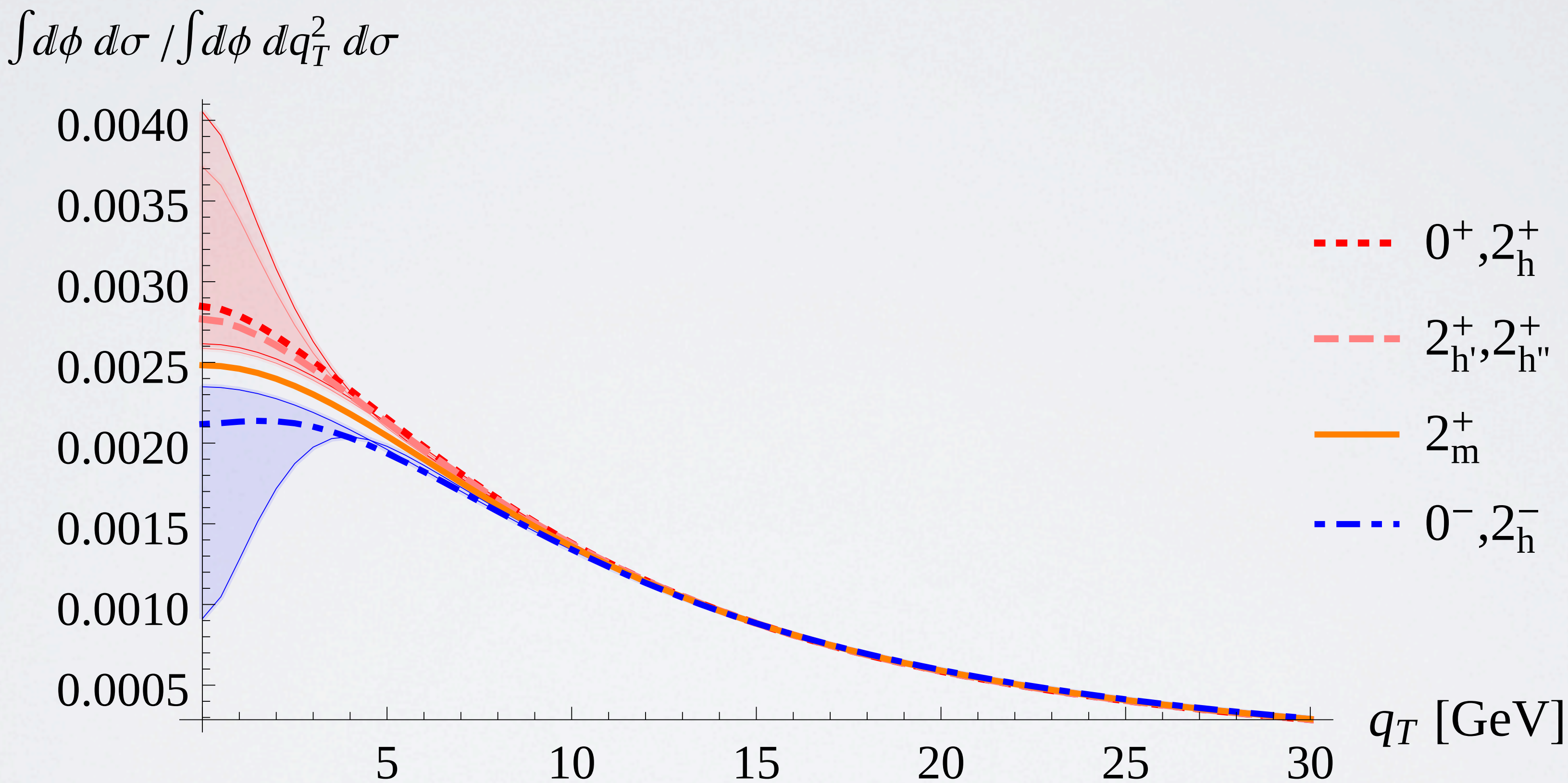
$$\mathcal{P} \equiv \mathcal{P}_{\mathrm{pQCD}}(x, \boldsymbol{p}_T^2),$$

$$\mathcal{P}_{max} \equiv 1 - \frac{\boldsymbol{p}_T^4}{p_0^4 + \boldsymbol{p}_T^4}\left[1 - 1.1\,\mathcal{P}_{\mathrm{pQCD}}(x, \boldsymbol{p}_T^2)\right],$$

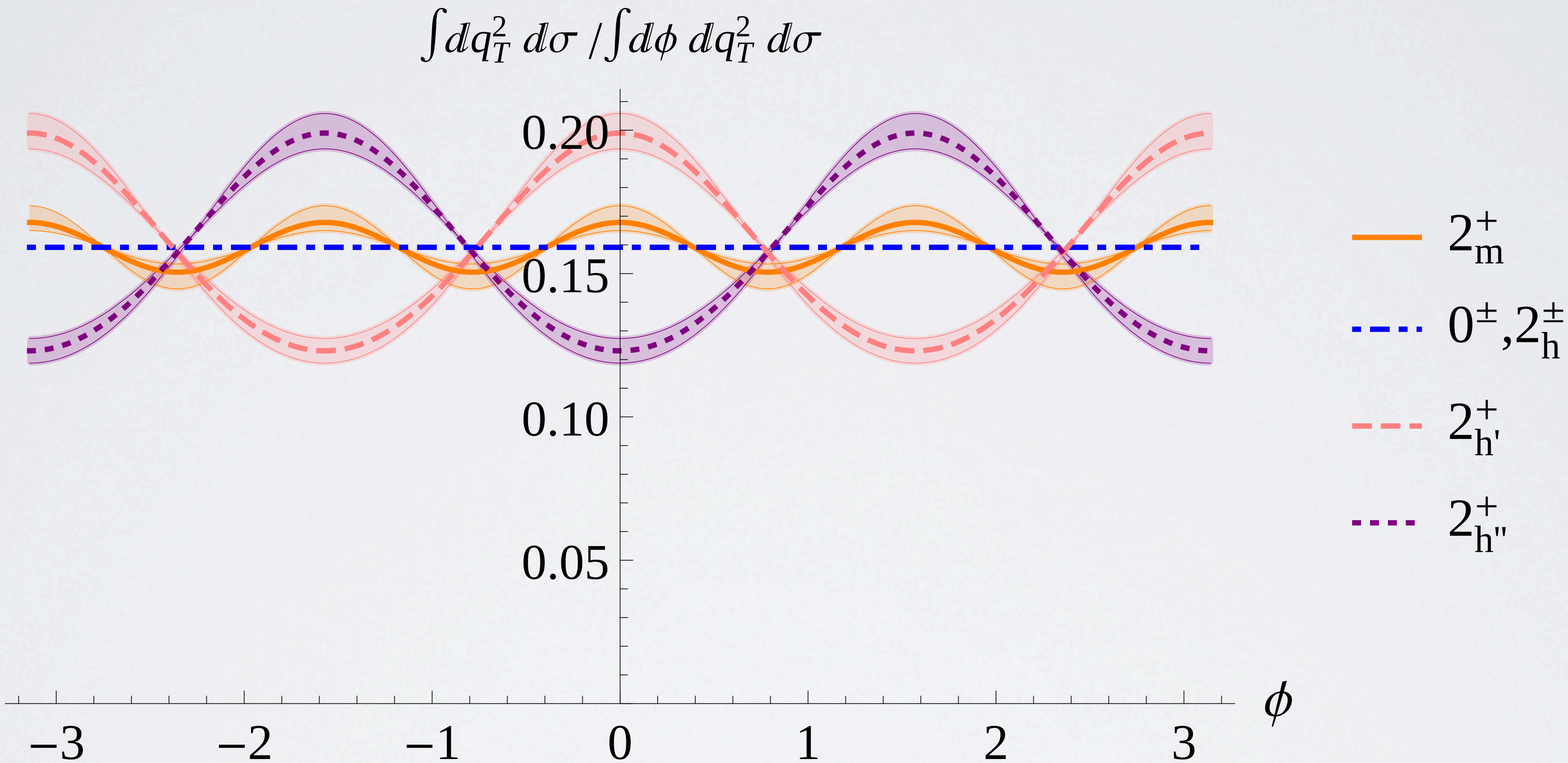
COSθ DISTRIBUTION



TRANSVERSE MOMENTUM DISTRIBUTION



Φ DISTRIBUTION



REMARKS

- spin-2 with CP violating coupling ↔ sin2ϕ dependence
- gg → box → $\gamma\gamma$ background also ϕ dependent
- same can be done in the $H \to ZZ^*$ channel

for gg → box → $\gamma\gamma$ see also
J. -W. Qiu, M. Schlegel and W. Vogelsang,
Phys. Rev. Lett. 107, 062001 (2011)
[arXiv:1103.3861 [hep-ph]]

CONCLUSIONS

- gluon polarization modifies both Higgs q_T and ϕ distribution
- q_T distribution modification different for positive/negative parity states
- ϕ distribution modification different for various spin-0 and spin-2 coupling scenarios

for more info see:
arXiv:1304.2654

SPIN STATUS

May 15, 2013

0^+ vs 2_m^+	ATLAS	CMS
γγ	99.3% CLs (2.7 σ)	-
WW*	94.7% CLs (1.9 σ)	86% CLs (1.5 σ)
ZZ*	83.4% CLs (1.4 σ)	98.5% CLs (2.4 σ)

PARITY STATUS

May 15, 2013

0^+ vs 0^-	ATLAS	CMS
$\gamma\gamma$	-	-
WW^*	-	-
ZZ^*	99.6% CLs (2.9 σ)	99.84% CLs (3.2 σ)