Linearly polarized gluons and the Higgs transverse momentum distribution

Wilco den Dunnen
Daniël Boer, Cristian Pisano, Marc Schlegel, Werner Vogelsang

Phys.Rev.Lett. 108 (2012) 032002

Higgs boson status update

December 2011:

Big news!

and then?

- is it the SM Higgs?
- to what particles does it couple?
- with what strength?
- what is its spin?
- is it a scalar or pseudoscalar boson?

scalar vs pseudoscalar

scalar Higgs:

$$\mathcal{L} \ni m_q H^0\, \overline{\Psi}\Psi$$

$$H^0 \xrightarrow{\mathcal{P}} H^0$$

$$H^0 \xrightarrow{\mathcal{C}P} H^0$$

pseudoscalar Higgs:

$$\mathcal{L} \ni m_q A^0\, \overline{\Psi}\gamma^5\Psi$$

$$A^0 \xrightarrow{\mathcal{P}} -A^0$$

$$A^0 \xrightarrow{\mathcal{C}P} -A^0$$

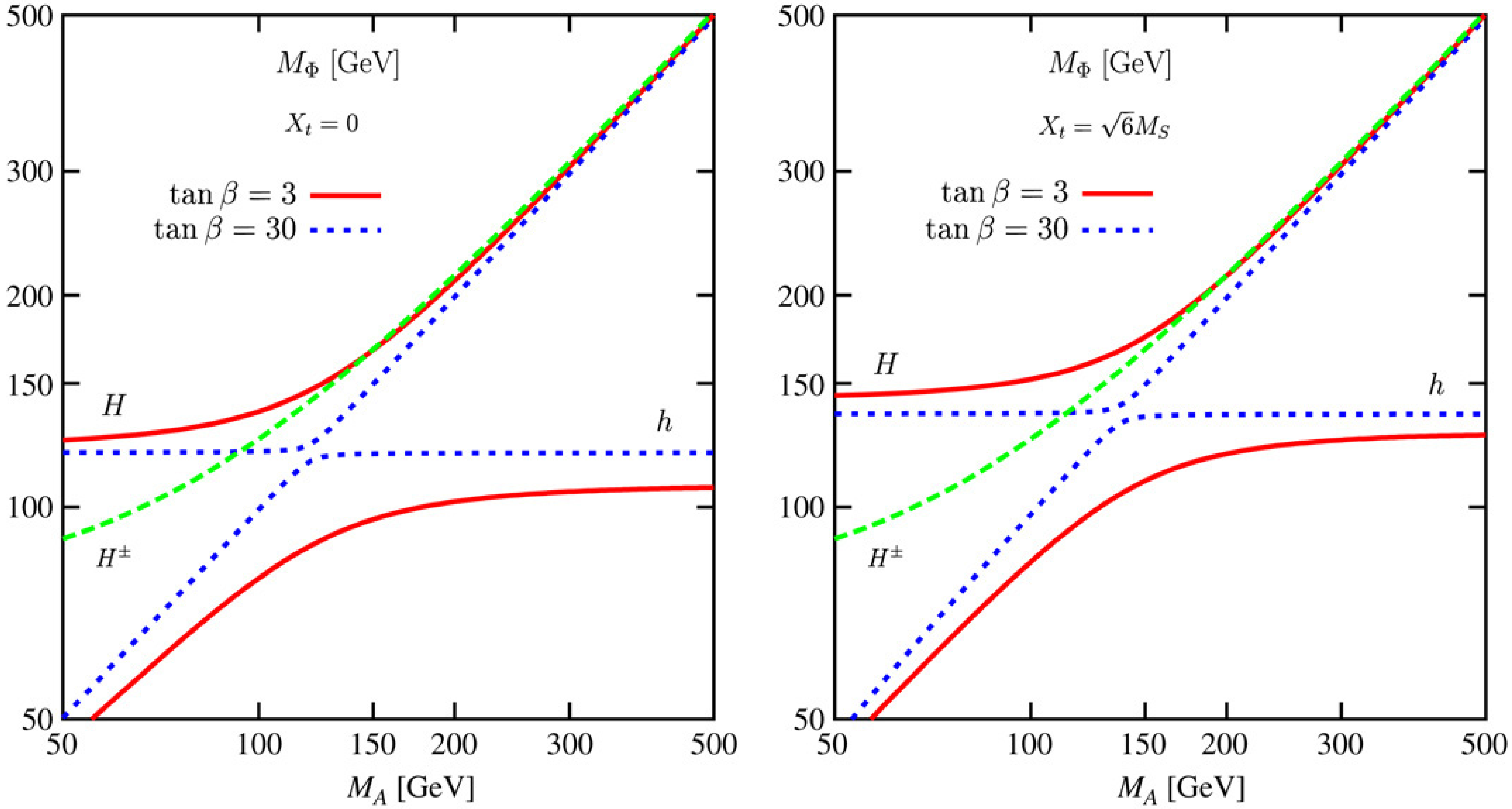
	$\overline{\Psi}\Psi$	$\overline{\Psi}\gamma^5\Psi$
$\mathcal{P}$	$+$	$-$
$\mathcal{C}$	$+$	$+$
$\mathcal{CP}$	$+$	$-$

SM extensions

	scalar	pseudoscalar	charged
SM	h		
MSSM/2HDM	h, H	A	$H^{\pm}$
NMSSM	H_1, H_2, H_3	A_1, A_2	$H^{\pm}$
MWT	8	7	2
...			

Djouadi, Phys.Rept. 459 (2008) 1-241
Vasquez et al., arXiv:1203.3446
Foadi et al., Phys.Rev. D76, 055005 (2007)

MSSM



Djouadi, Phys.Rept. 459 (2008) 1-241

how to distinguish?

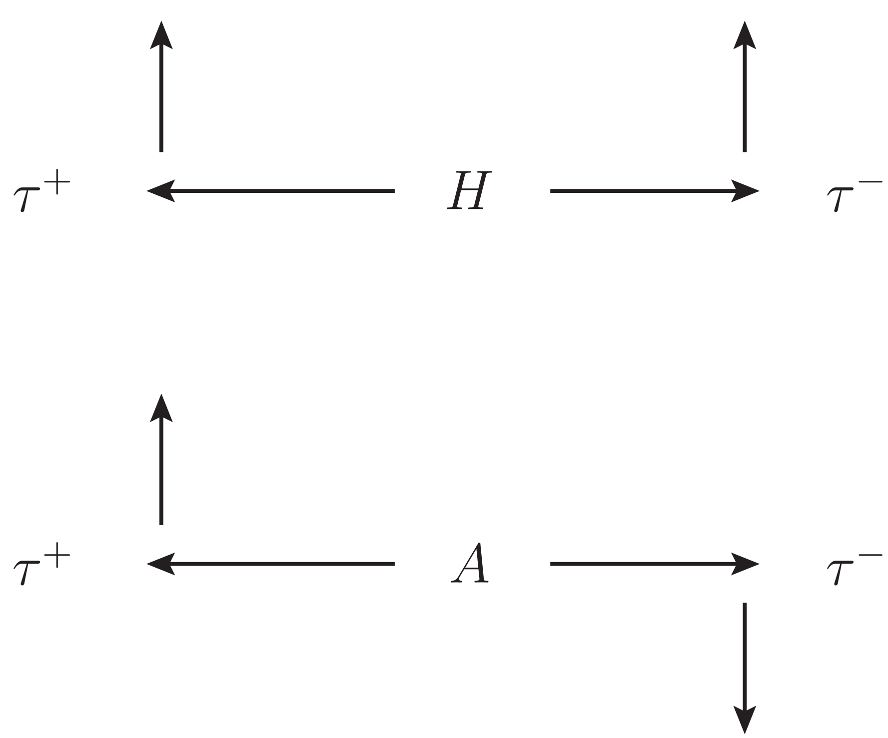
pseudoscalar	scalar
$$\frac{\mathrm{BR}(A \to WW^*)}{\mathrm{BR}(A \to \gamma\gamma)} \ll 1$$ e.g. MSSM *A*	$$\frac{\mathrm{BR}(H \to WW^*)}{\mathrm{BR}(H \to \gamma\gamma)} \sim 10^2$$ e.g. SM Higgs
$$\frac{\mathrm{BR}(A \to WW^*)}{\mathrm{BR}(A \to \gamma\gamma)} \sim 10^2$$ e.g. CP violating MSSM	$$\frac{\mathrm{BR}(H \to WW^*)}{\mathrm{BR}(H \to \gamma\gamma)} \ll 1$$ e.g. - MSSM *H* (decoupling regime) - MSSM *h* (anti decoupl. reg.)

Williams et al. Eur. Phys. J. C71:1669

Fransden & Sannino, arXiv:1203.3988

how to distinguish?

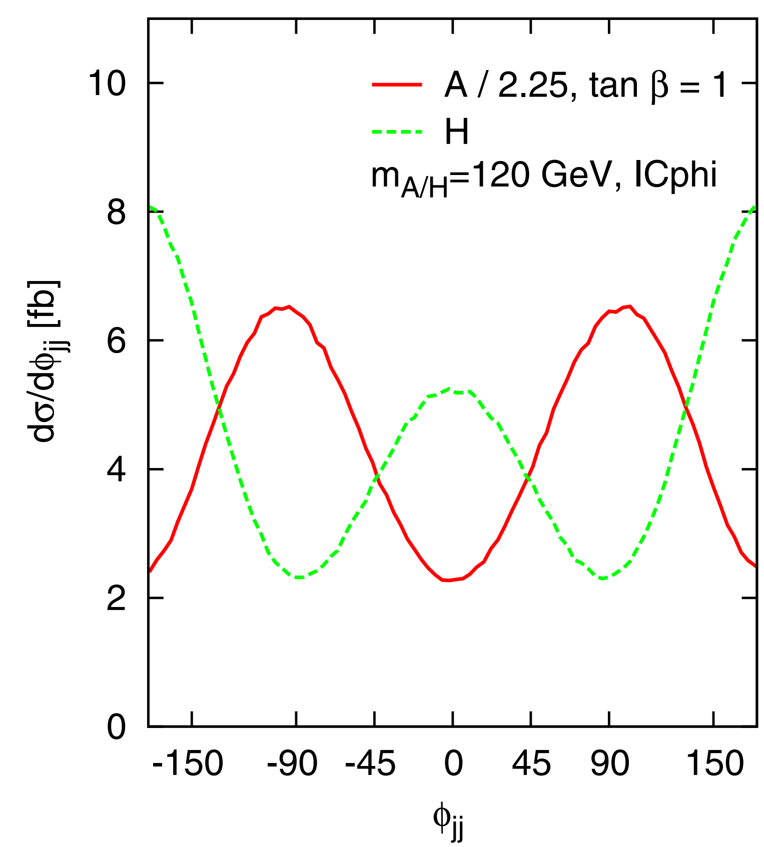
$\Phi \to \tau^+\tau^-$



Berge et al., Phys.Lett. B671, 470 (2009)
Berge et al., Phys.Rev. D84, 116003 (2011)

$\Phi = H, A$

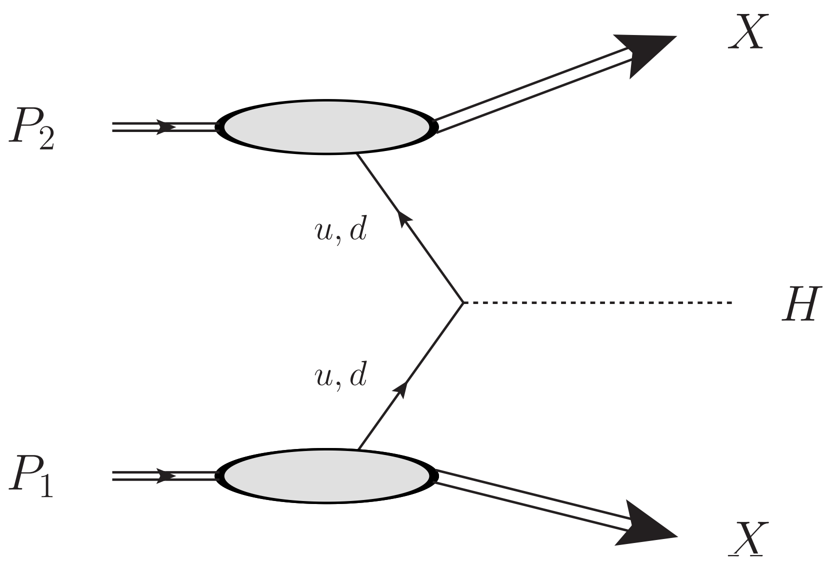
Φjj production

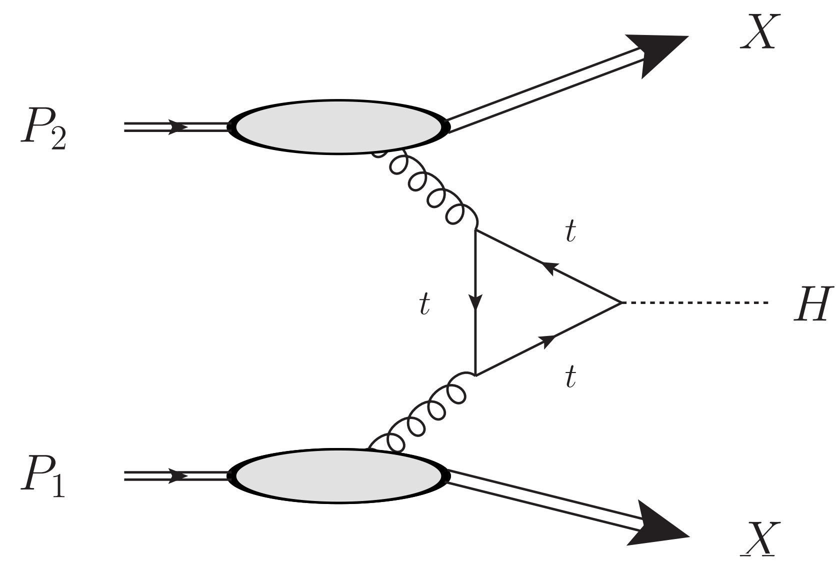


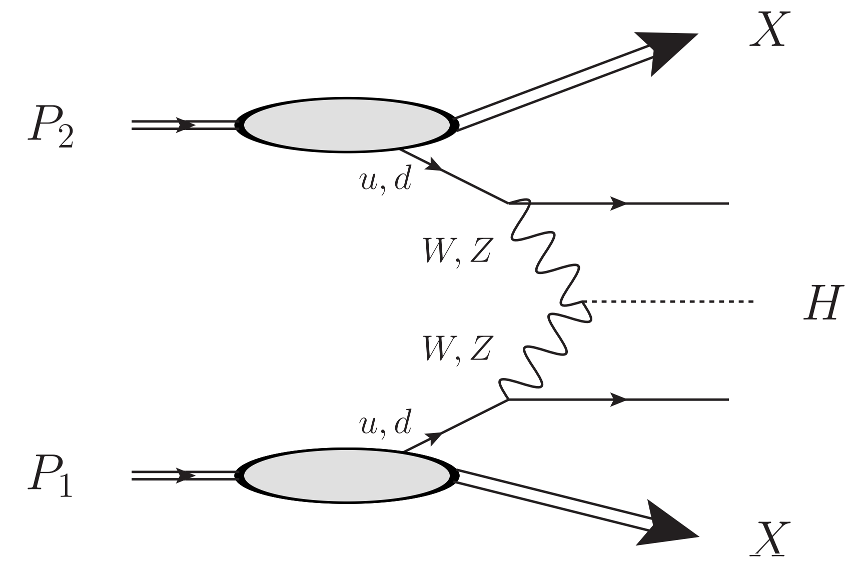
Plehn et al., Phys.Rev.Lett. 88, 051801
Camparino et al., Phys. Rev. D84, 095025 (2011)

transverse momentum distribution?

Higgs production at the LHC





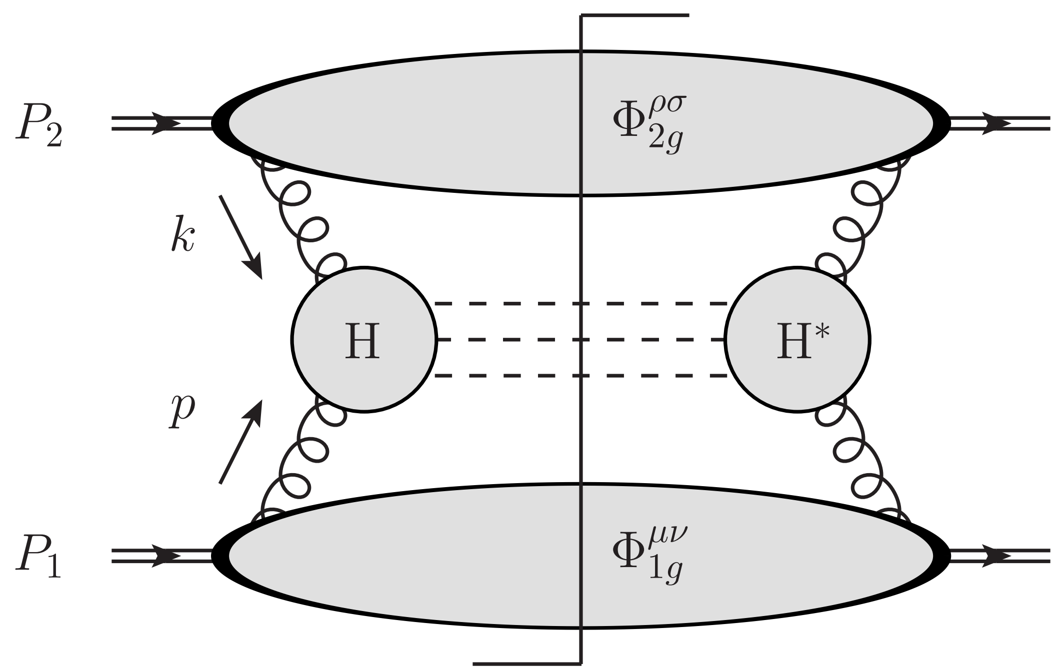


'direct'
≈0 pb

gluon fusion
≈20-60 pb

weak boson fusion
≈3-5 pb

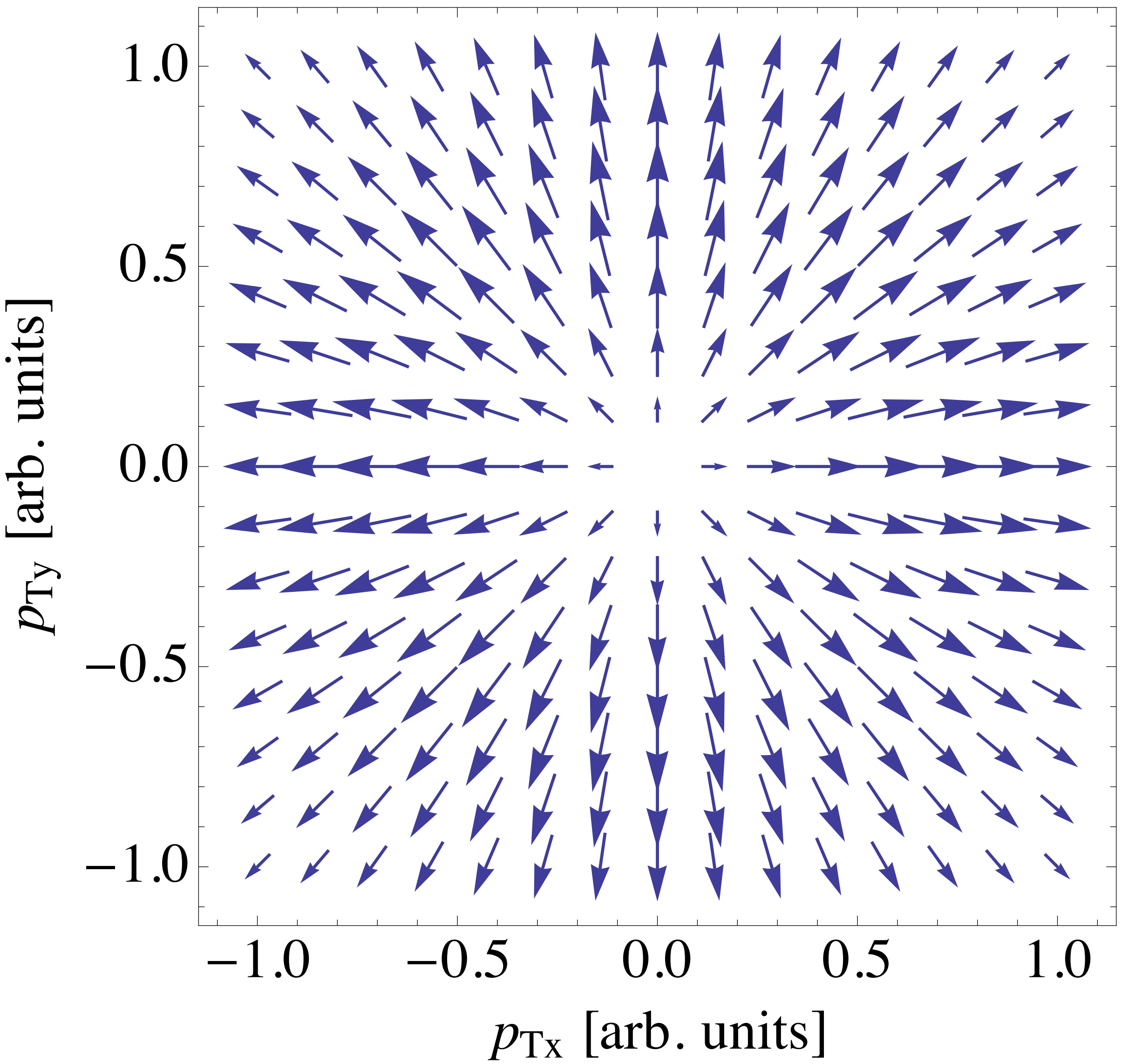
TMD factorization for gluons



$$= \int d^2\mathbf{p}_T\, d^2\mathbf{k}_T\, \delta^2(\mathbf{p}_T + \mathbf{k}_T - \mathbf{q}_T)\Phi_{1g}^{\mu\nu}(x_1, \mathbf{p}_T)\Phi_{1g}^{\rho\sigma}(x_2, \mathbf{k}_T)\mathrm{H}_{\mu\rho}\mathrm{H}^*_{\nu\sigma}$$

$$\Phi_g^{\mu\nu}(x, \vec{p}_T) = -\frac{1}{2x}\left\{ \underbrace{g_T^{\mu\nu} f_1^g(x, \vec{p}_T)}_{\text{gluon TMD PDF}} - \left(\frac{p_T^\mu p_T^\nu}{M^2} + g_T^{\mu\nu}\frac{\vec{p}_T^{\,2}}{2M^2} \right) \underbrace{h_1^{\perp g}(x, \vec{p}_T)}_{\text{gluon BM function}} \right\} + \ldots$$

Boer-Mulders function



$$\sigma \propto f_1^g(x_1, p_T) f_1^g(x_2, k_T) \sigma_p^{\mathrm{unpol}} + h_1^{g\perp}(x_1, p_T) h_1^{g\perp}(x_2, k_T) \times \left[\sigma_p^{\parallel\parallel} - \sigma_p^{\parallel\perp} - \sigma_p^{\perp\parallel} + \sigma_p^{\perp\perp}\right]$$

gluon polarization inside proton

Boer-Mulders function

positivity bound

$$\frac{\boldsymbol{p}_T^2}{2M^2}\,|h_1^{\perp g}(x,\boldsymbol{p}_T^2)| \le f_1^g(x,\boldsymbol{p}_T^2),$$

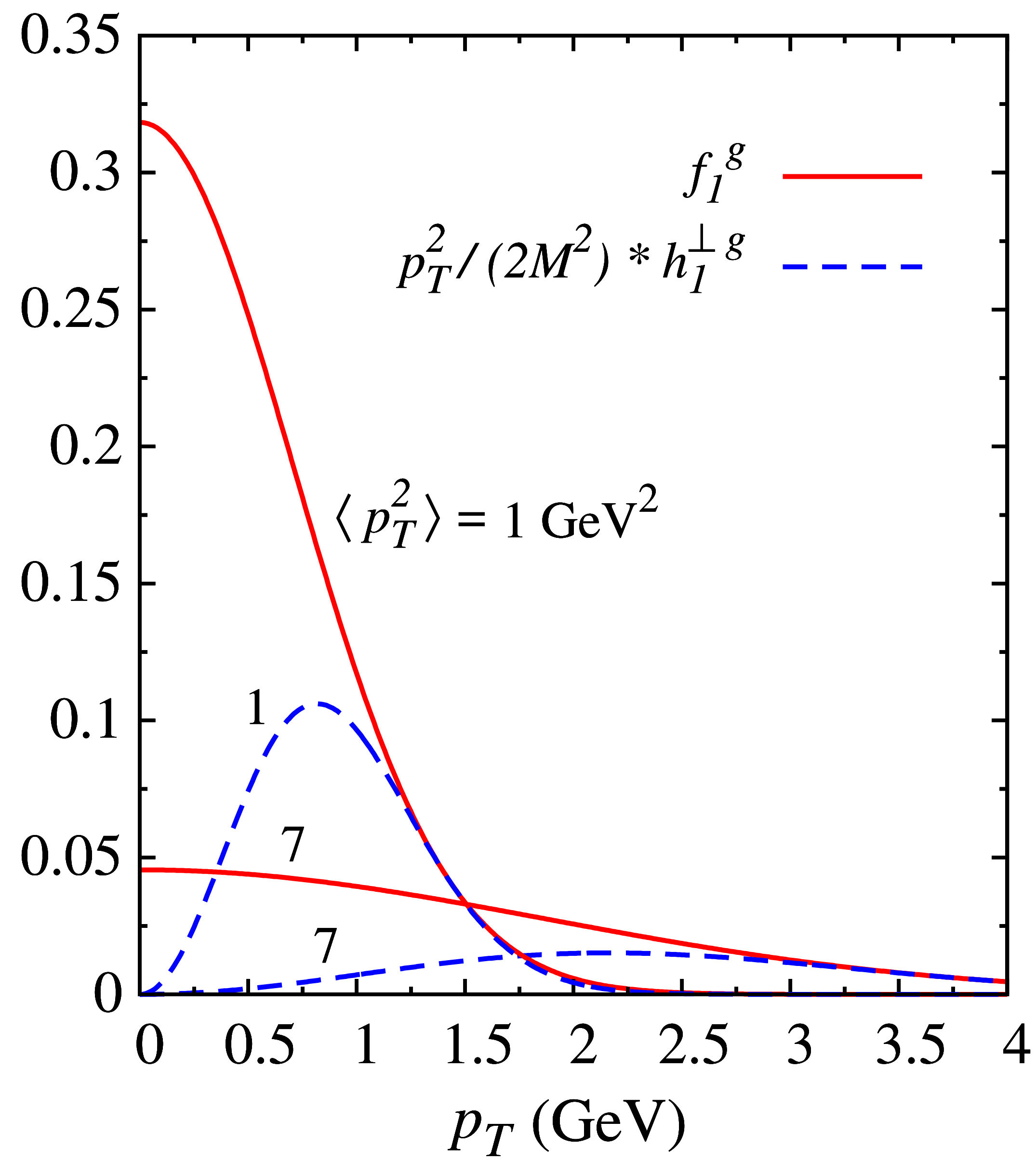
Mulders, Rodrigues, Phys.Rev. D63 094021 (2001)

Gaussian TMD ansatz

$$f_1^g(x,\boldsymbol{p}_T^2) = \frac{G(x)}{\pi\langle p_T^2\rangle}\exp\left(-\frac{\boldsymbol{p}_T^2}{\langle p_T^2\rangle}\right),$$

$$h_1^{\perp g}(x,\boldsymbol{p}_T^2) = \frac{M^2 G(x)}{\pi\langle p_T^2\rangle^2}\,\frac{2e(1-r)}{r}\exp\left(-\frac{\boldsymbol{p}_T^2}{r\langle p_T^2\rangle}\right).$$

$$r = 2/3.$$



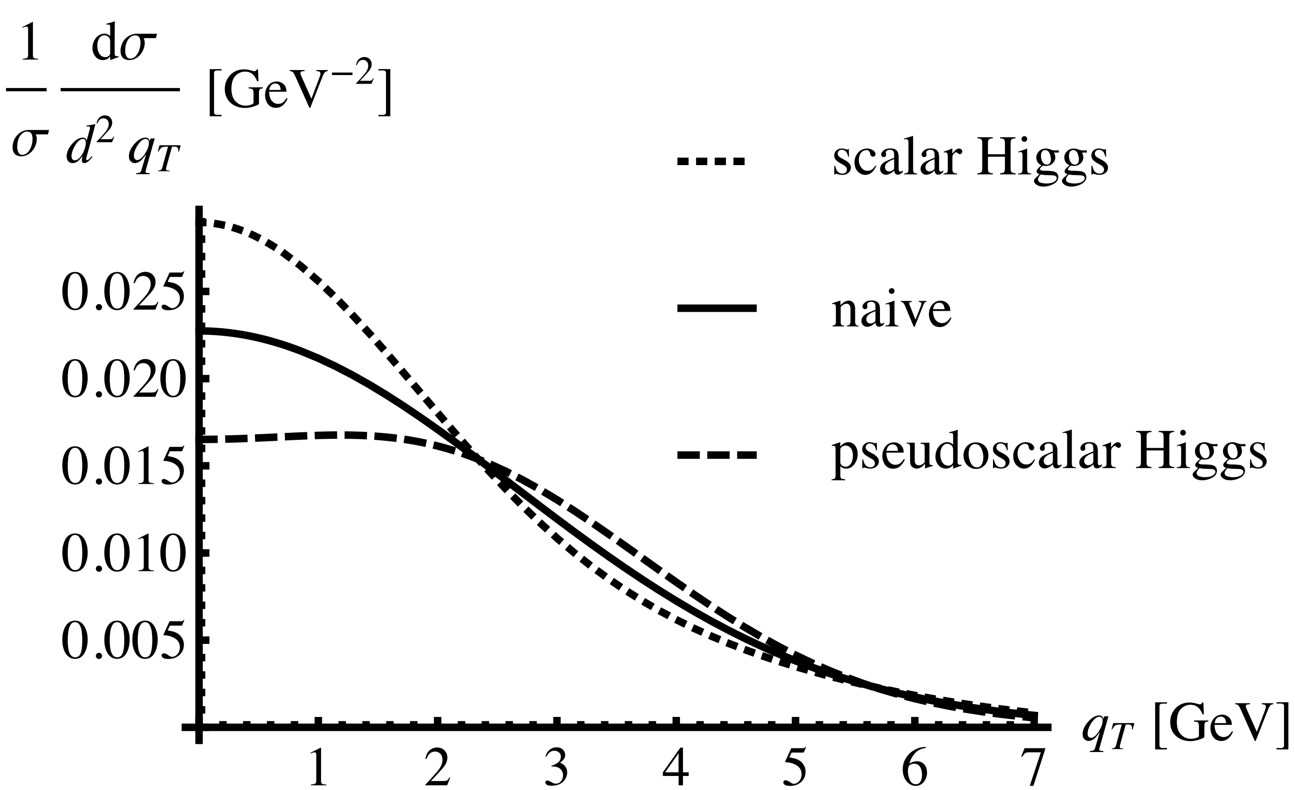
model calculations: bound saturated for all pT
Color Glass Codensate: Metz and Zhou, Phys. Rev. D 84 (2011) 051503
Color Dipole Model: Dominguez et al., Phys.Rev. D85 (2012) 045003

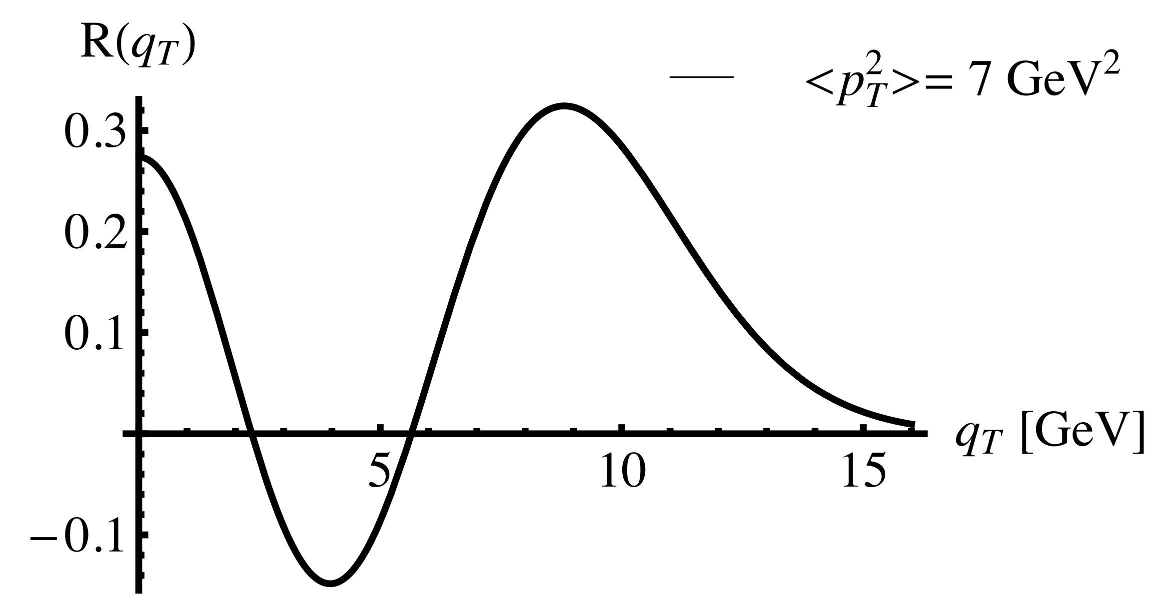
$$\langle p_T^2\rangle = 7\ \mathrm{GeV}^2$$

Aybat, Rogers, Phys. Rev. D 83, 114042 (2011)

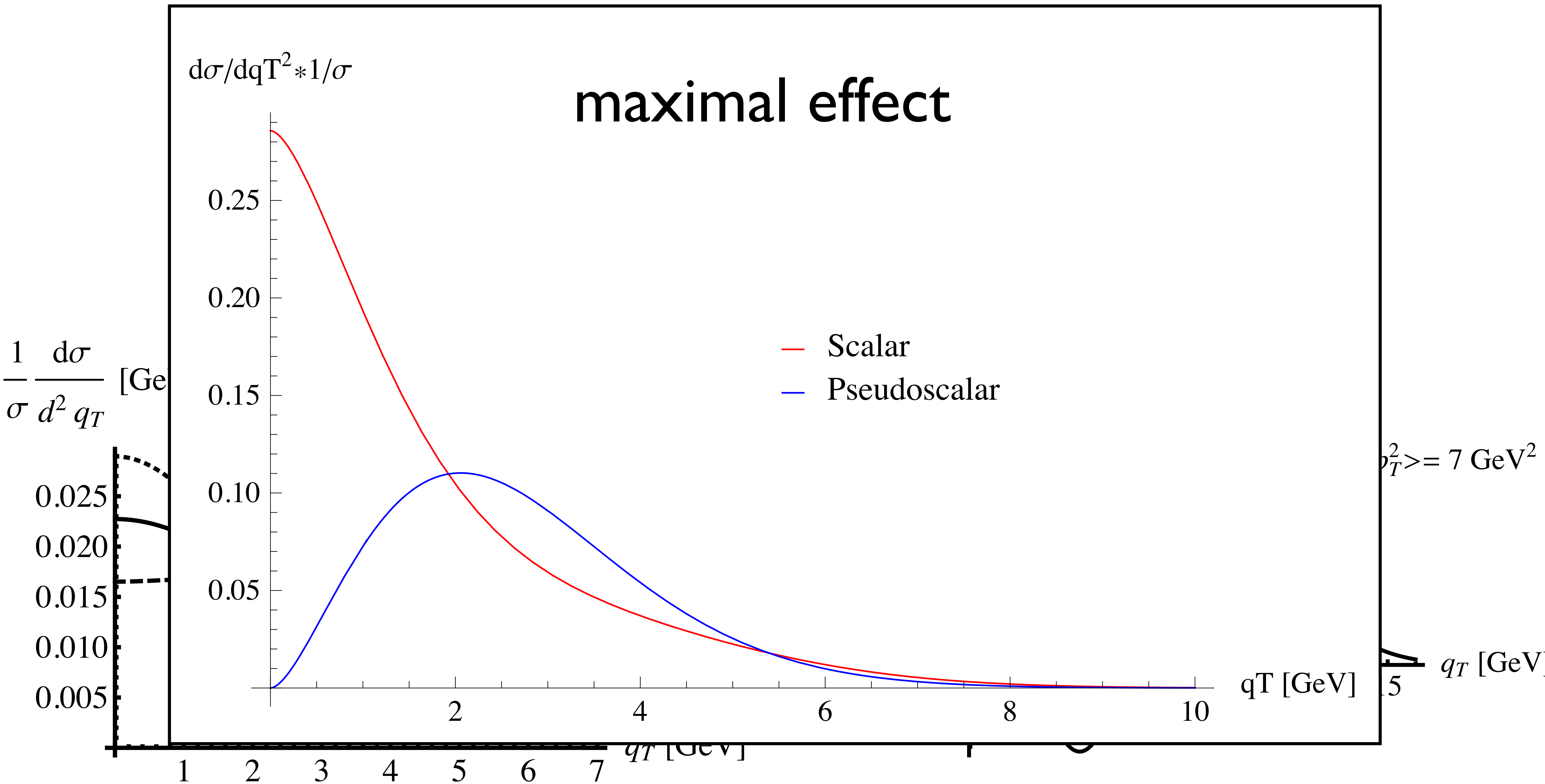
gg → H/A

$$\frac{1}{\sigma}\frac{d\sigma}{d^2\vec{q}_T} = \left[1 \pm R(q_T)\right]\frac{1}{2\pi\langle p_T^2\rangle}e^{-q_T^2/2\langle p_T^2\rangle}$$



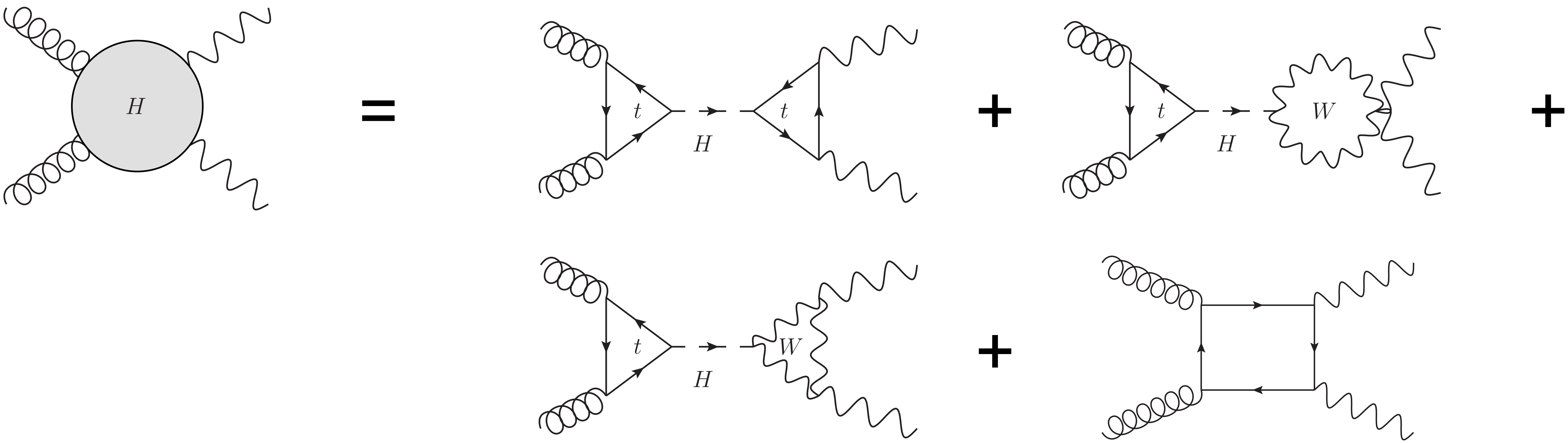


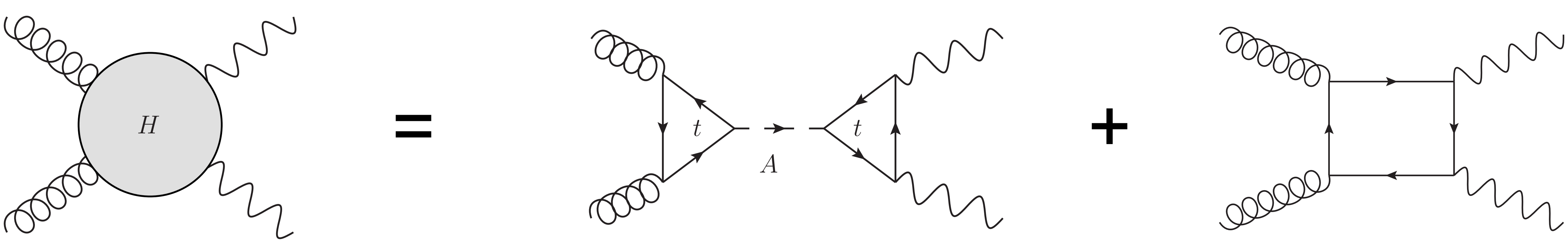
gg → H/A



maximal effect
dσ/dqT²∗1/σ
0.25
0.20
0.15
0.10
0.05
Scalar
Pseudoscalar
qT [GeV]
2
4
6
8
10
$\frac{1}{\sigma}\frac{d\sigma}{d^2 q_T}$ [Ge
0.025
0.020
0.015
0.010
0.005
1
2
3
4
5
6
7
q_T [GeV]
$>= 7$ GeV^2

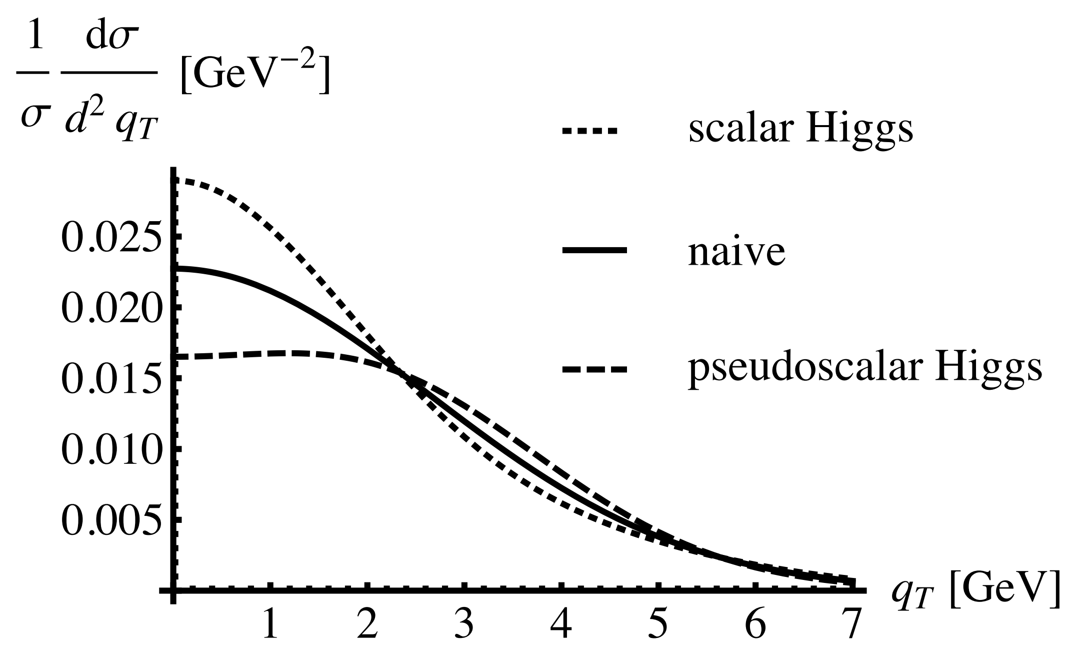
include the decay H/A → γγ



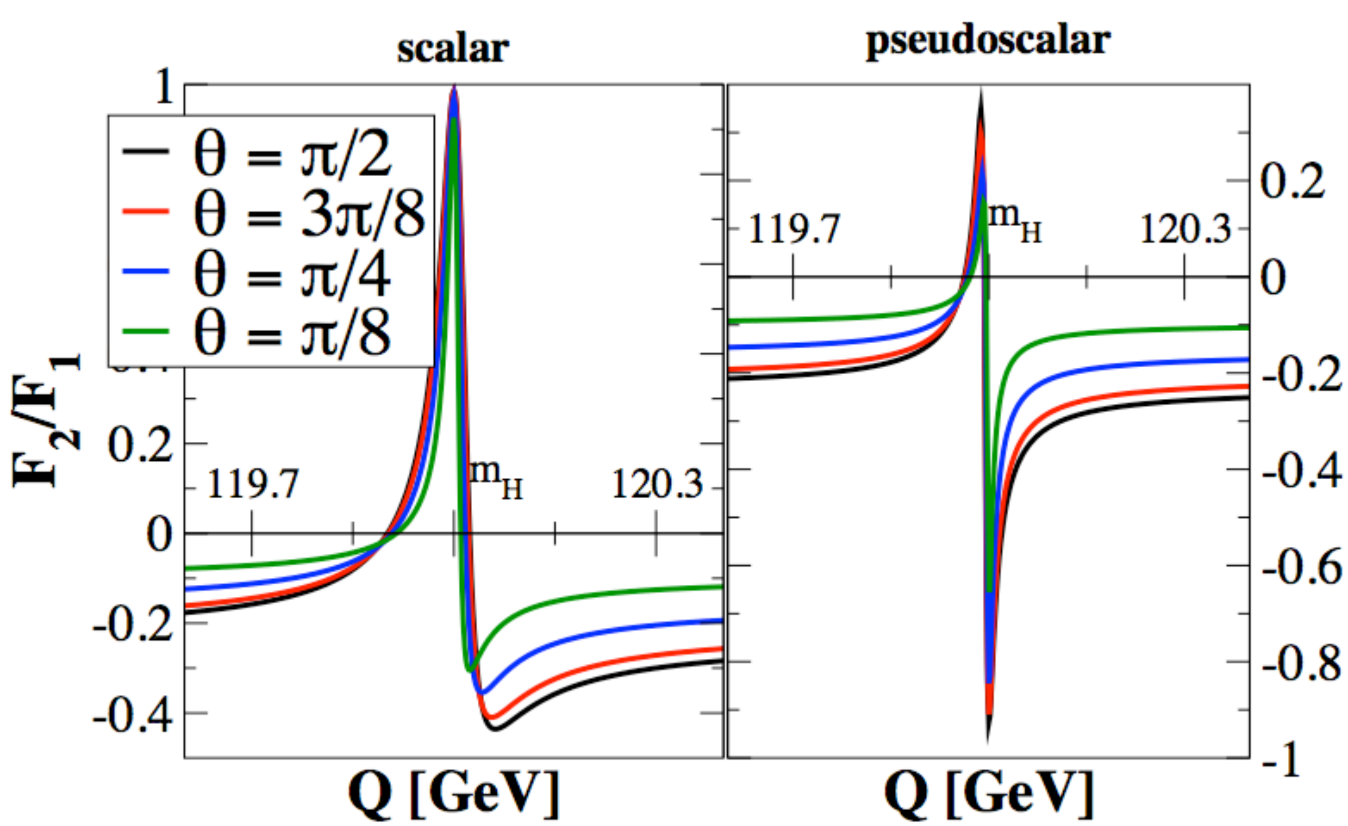


gg → H/A vs. gg → γγ

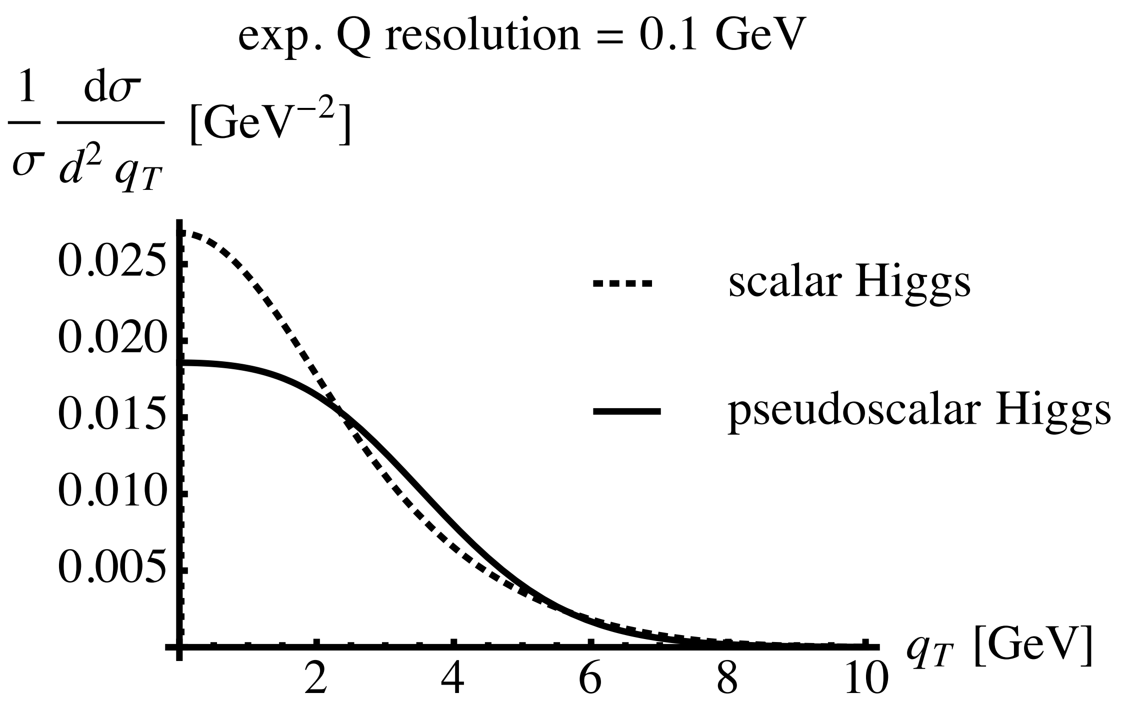
$$\frac{1}{\sigma}\frac{d\sigma}{d^2\vec{q}_T} = [1 \pm R(q_T)]\,\frac{1}{2\pi\langle p_T^2\rangle}e^{-q_T^2/2\langle p_T^2\rangle}$$

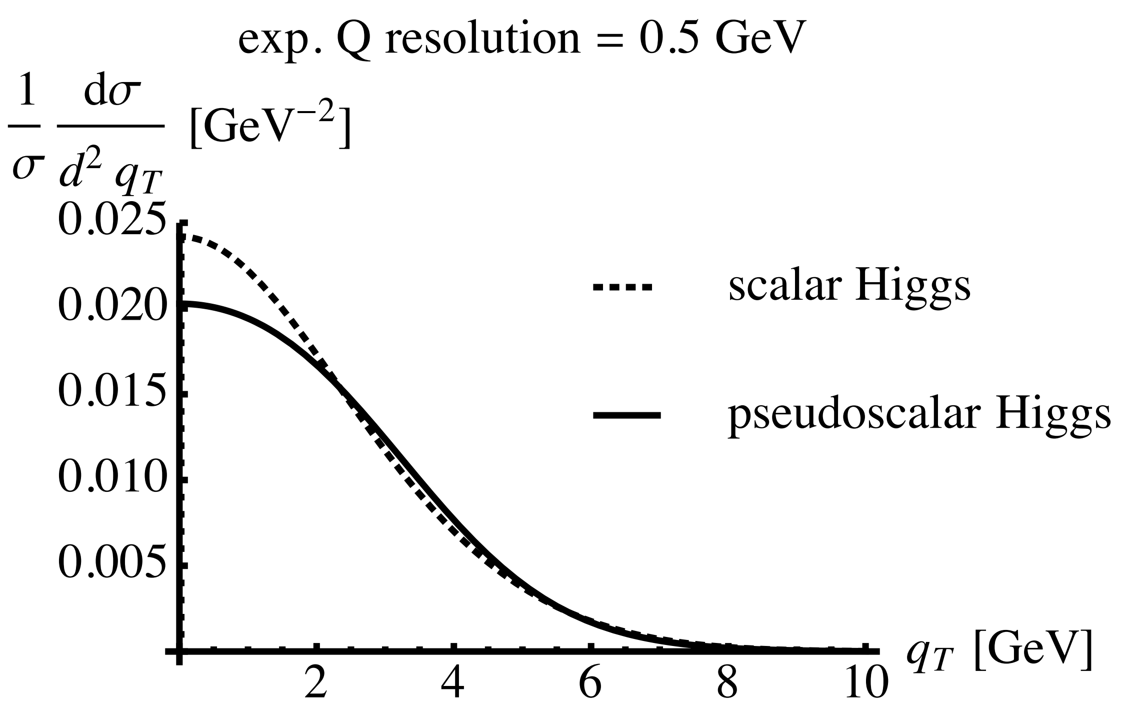


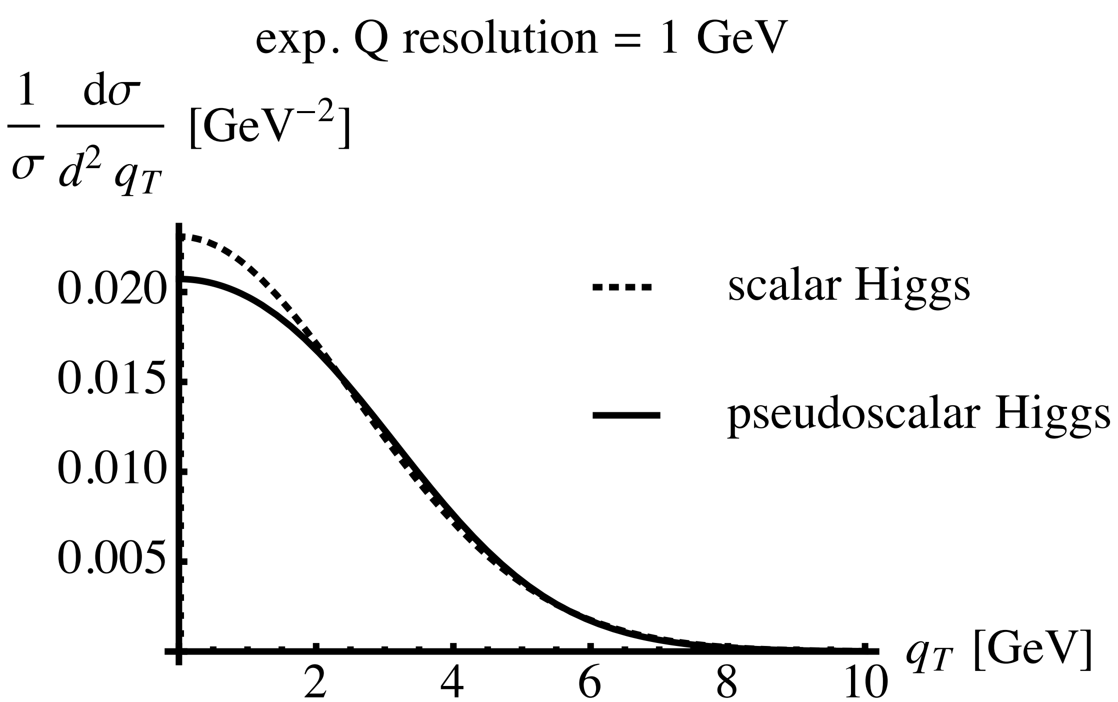
$$\frac{1}{\sigma}\frac{d\sigma}{d^2\vec{q}_T} = \left[1 + \frac{F_2}{F_1}R(q_T)\right]\frac{1}{2\pi\langle p_T^2\rangle}e^{-q_T^2/2\langle p_T^2\rangle}$$



exp. resolution in $gg \to \gamma\gamma$







summary

- gluon transverse momentum → polarized gluons
- polarization modifies q_T distribution
- different modification for scalar & pseudoscalar
- next: ZZ^*, WW^*, $Z\gamma$ final states, NLO & evolution

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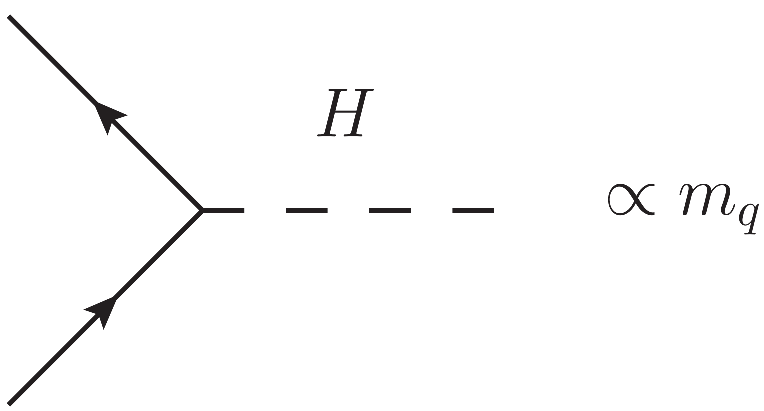
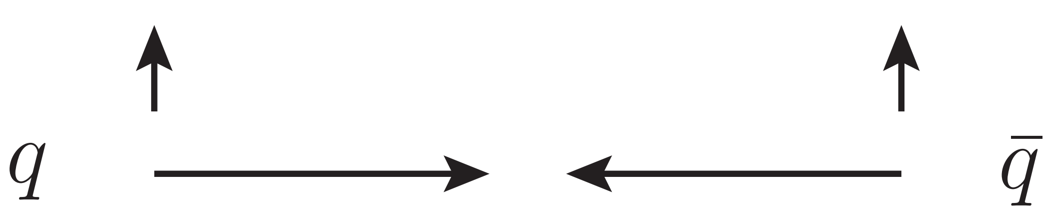
scalar/pseudoscalar Higgs

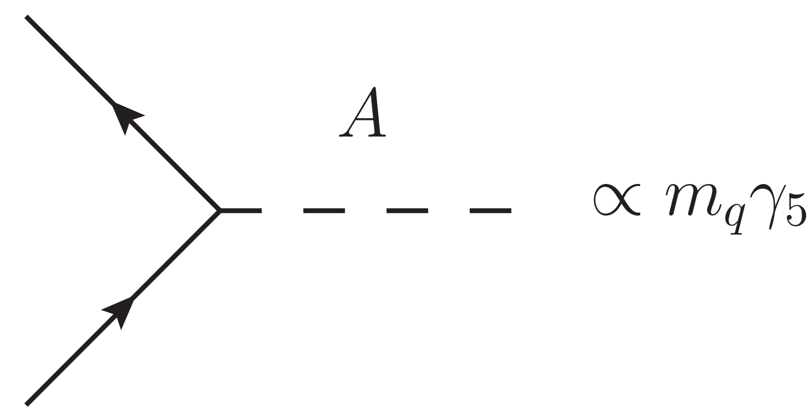
scalar Higgs



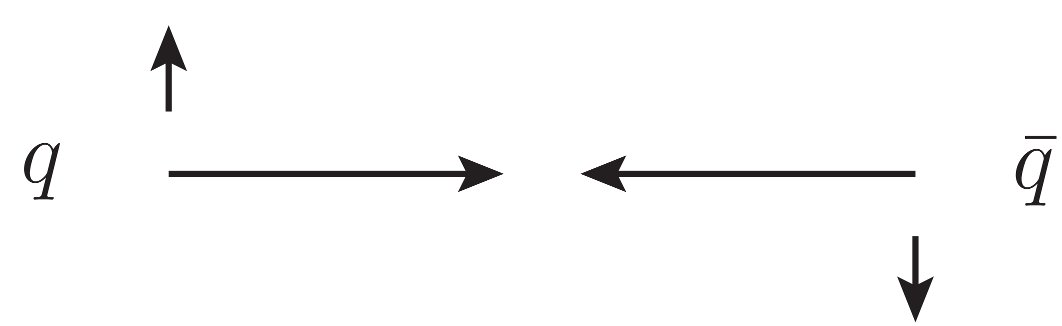
$$q\bar{q} \rightarrow H^0$$



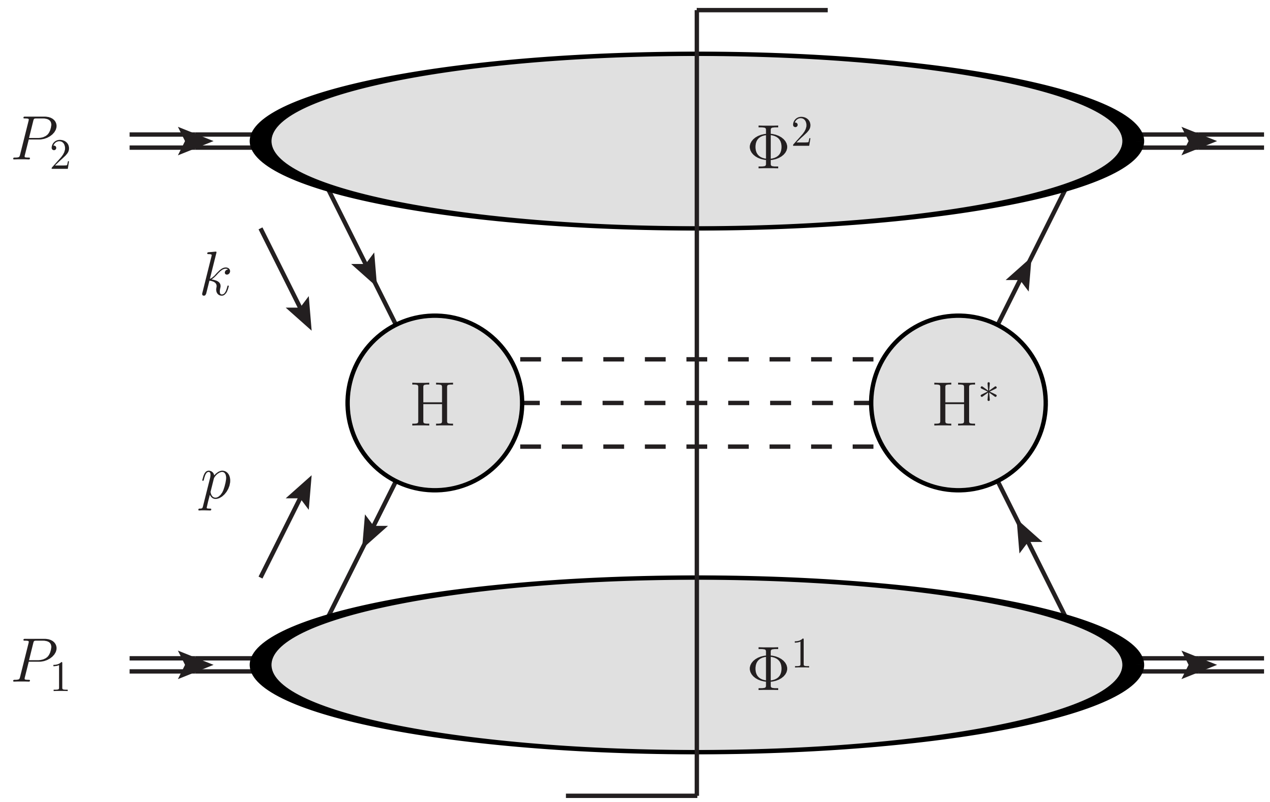
pseudoscalar Higgs



$$q\bar{q} \rightarrow A^0$$



diagrammatic factorization

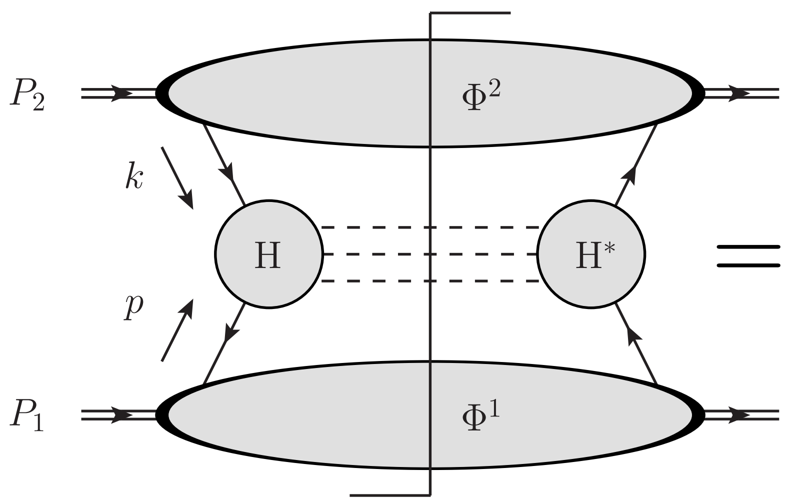


$$= \int d^4p\, d^4k\, \mathrm{Tr}\Big[\Phi^1(p)\mathrm{H}\,\Phi^2(k)\mathrm{H}^*\Big]\delta^4(p+k-q)$$

quark correlator

$$\Phi^1_{ij}(p) = \frac{1}{(2\pi)^4}\int d^4\xi\, e^{ip\cdot\xi}\,\langle P_1|\overline{\Psi}_j(0)\Psi_i(\xi)|P_1\rangle$$

diagrammatic factorization



$$= \int d^4p\, d^4k\, \mathrm{Tr}\Big[\Phi^1(p)\mathrm{H}\,\Phi^2(k)\mathrm{H}^*\Big]\delta^4(p+k-q)$$

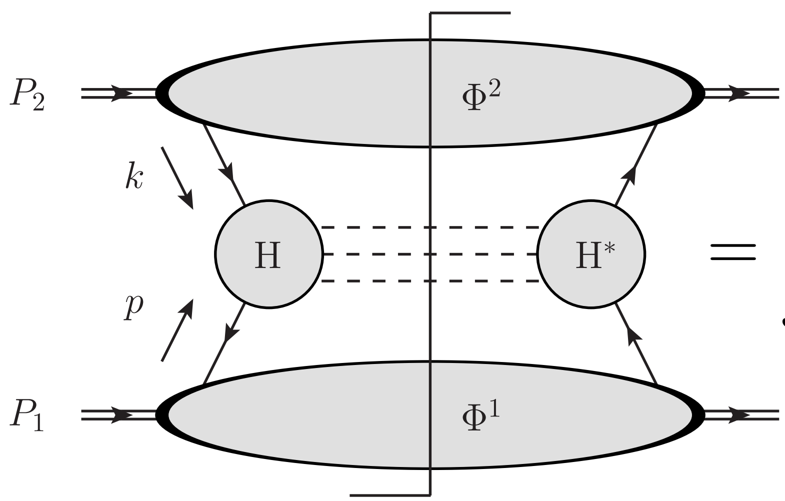
$$\delta^4(p+k-q) \approx \delta(p^+ - q^+)\delta(k^- - q^-)\delta^2(\mathbf{p}_T + \mathbf{k}_T - \mathbf{q}_T)$$

$$= \int d^2\mathbf{p}_T\, d^2\mathbf{k}_T\, \delta^2(\mathbf{p}_T + \mathbf{k}_T - \mathbf{q}_T)\mathrm{Tr}\Big[\Phi^1(x_1, \mathbf{p}_T)\mathrm{H}\,\Phi^2(x_2, \mathbf{k}_T)\mathrm{H}^*\Big]$$

TMD correlator

$$\Phi^1_{ij}(x, \mathbf{p}_T) \equiv \int dp^-\, \Phi^1_{ij}(p)\Big|_{p^+ = xP_1^+}$$

diagrammatic factorization



$$= \int d^2\mathbf{p}_T\, d^2\mathbf{k}_T\, \delta^2(\mathbf{p}_T + \mathbf{k}_T - \mathbf{q}_T)\mathrm{Tr}\Big[\Phi^1(x_1, \mathbf{p}_T)\mathrm{H}\,\Phi^2(x_2, \mathbf{k}_T)\mathrm{H}^*\Big]$$

TMD correlator

$$\Phi^1_{ij}(x, \mathbf{p}_T) \equiv \int dp^- \, \Phi^1_{ij}(p)\Big|_{p^+ = xP_1^+}$$

Collinear correlator

$$\Phi^1_{ij}(x) \equiv \int d^2\mathbf{p}_T \, dp^- \, \Phi^1_{ij}(p)\Big|_{p^+ = xP_1^+}$$

diagrammatic factorization

Collinear correlator

Parton Distribution Function

$$\Phi(x) = \frac{1}{2} f_1(x) \not{n}_+ + \frac{M}{2P^+} \left(e(x) + h(x) \frac{i[\not{n}_+, \not{n}_-]}{2} \right) + \mathcal{O}\left(\frac{M^2}{P^{+2}} \right)$$

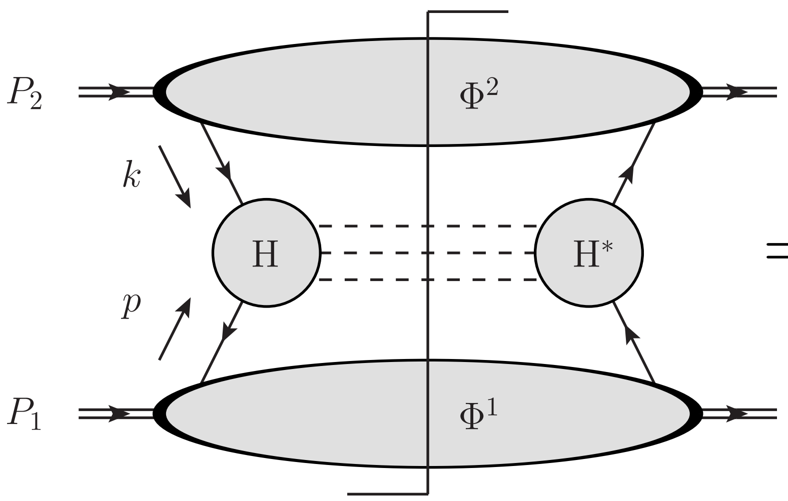
TMD correlator

TMD PDF

Boer-Mulders function

$$\Phi(x, \mathbf{p}_T) = \frac{1}{2} f_1(x, p_T) \not{n}_+ + h_1^\perp(x, p_T) \frac{i[\not{p}_T, \not{n}_+]}{2M}$$
$$+ \frac{M}{2P^+} \left(e(x, p_T) + f^\perp(x, p_T) \frac{\not{p}_T}{M} + h(x, p_T) \frac{i[\not{n}_+, \not{n}_-]}{2} \right) + \mathcal{O}\left(\frac{M^2}{P^{+2}} \right)$$

diagrammatic factorization



$$= \int d^2\mathbf{p}_T\, d^2\mathbf{k}_T\, \delta^2(\mathbf{p}_T + \mathbf{k}_T - \mathbf{q}_T)\mathrm{Tr}\Big[\Phi^1(x_1, \mathbf{p}_T) H\, \Phi^2(x_2, \mathbf{k}_T) H^*\Big]$$

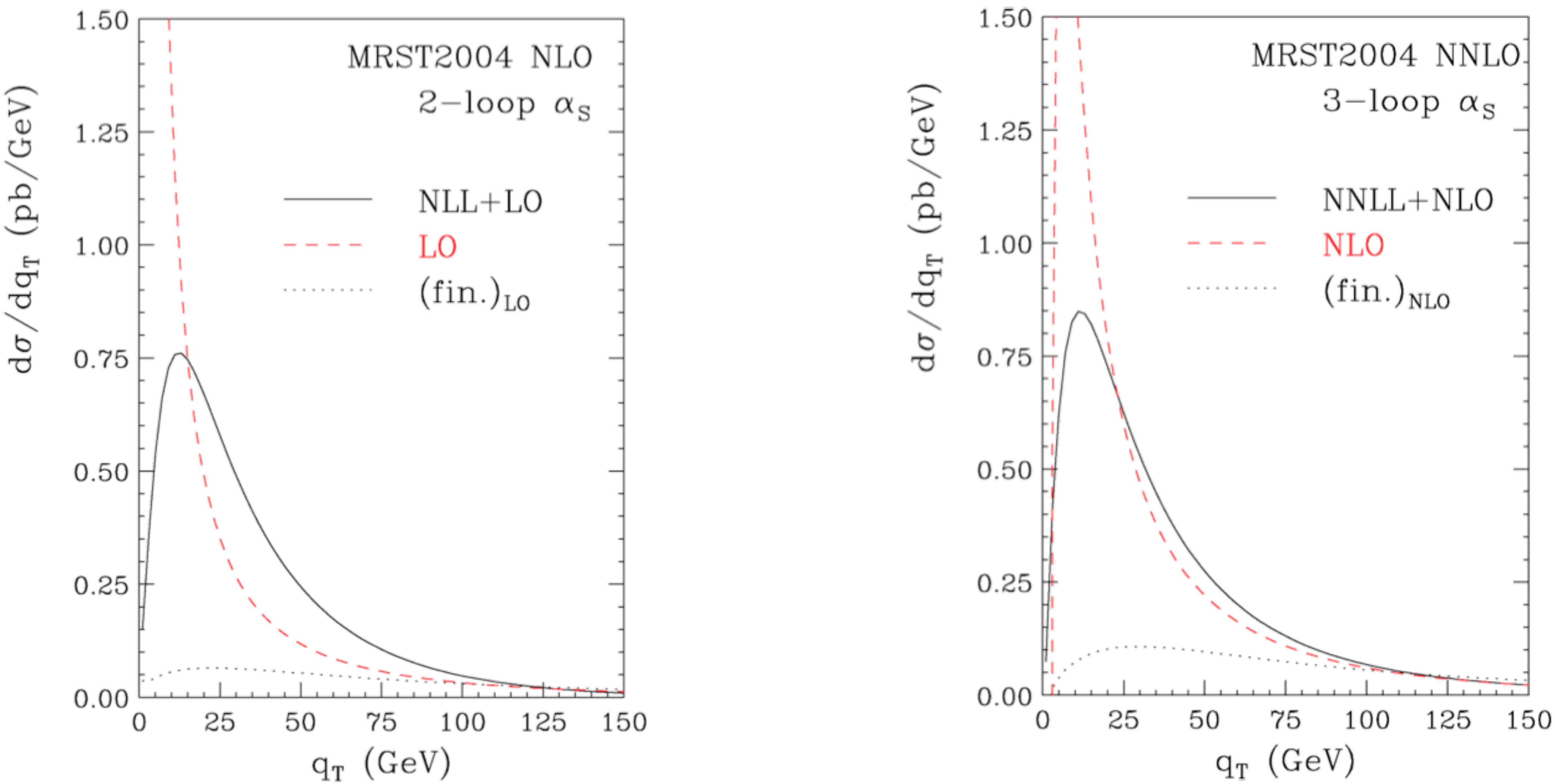
Collinear factorization

$$\sigma \propto f_1(x_1) f_1(x_2) \sigma_p^{\mathrm{unpol}}$$

TMD factorization

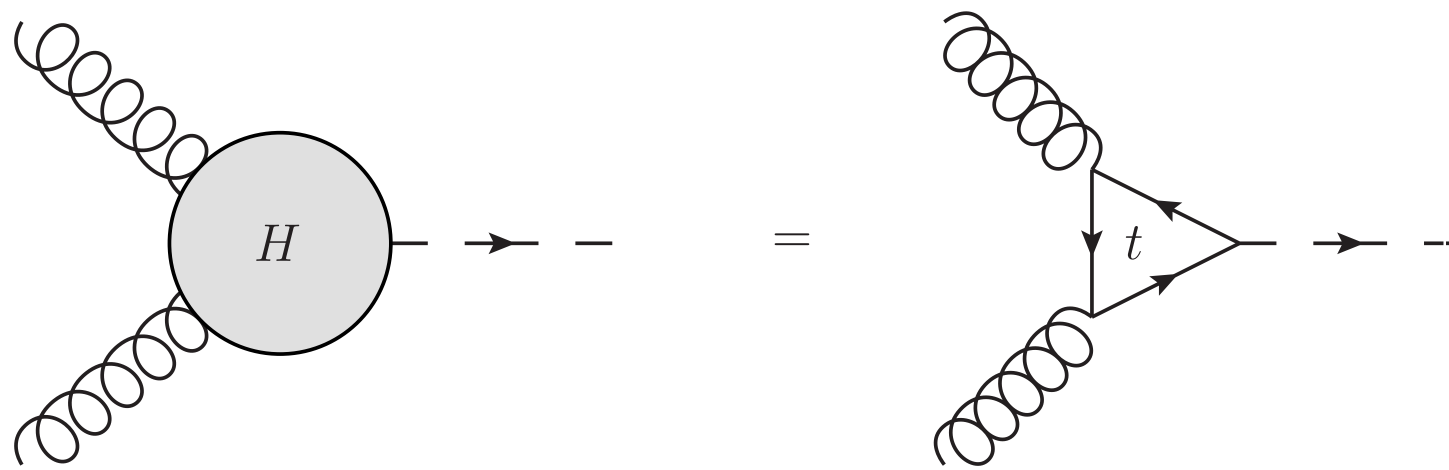
$$\sigma \propto f_1(x_1, p_T) f_1(x_2, k_T) \sigma_p^{\mathrm{unpol}} + h_1^{\perp}(x_1, p_T) h_1^{\perp}(x_2, k_T)\Big[\sigma_p^{\uparrow\uparrow} - \sigma_p^{\uparrow\downarrow} - \sigma_p^{\downarrow\uparrow} + \sigma_p^{\downarrow\downarrow}\Big]$$

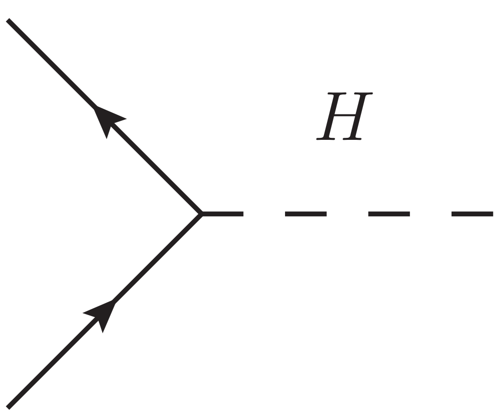
transverse momentum distribution (collinear factorization)



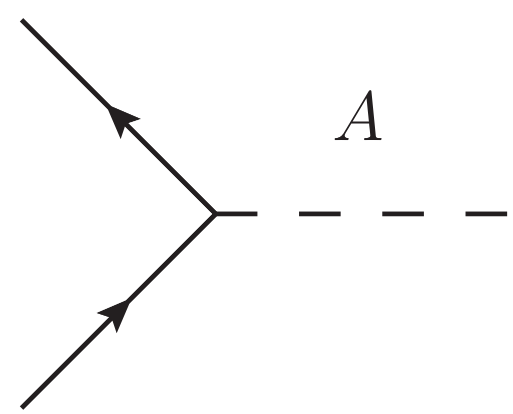
G. Bozzi et al. / Nuclear Physics B 737 (2006) 73–120

$gg \rightarrow H^0/A^0$





$\propto m_q$

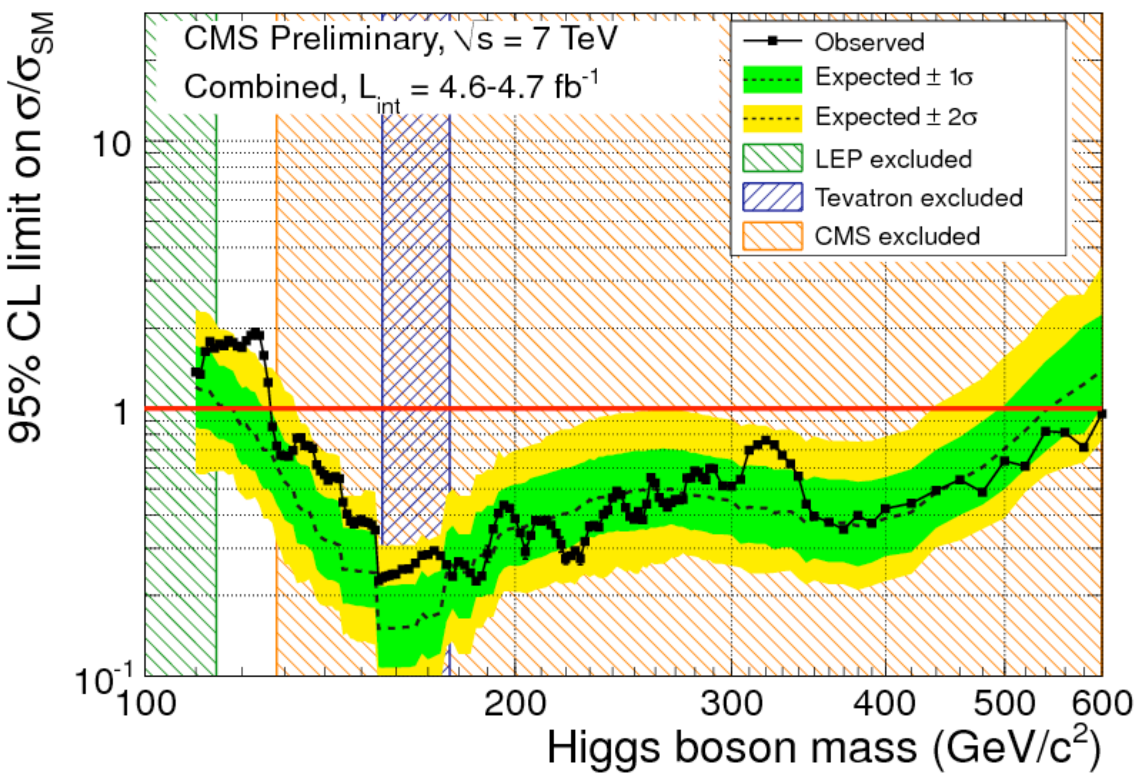


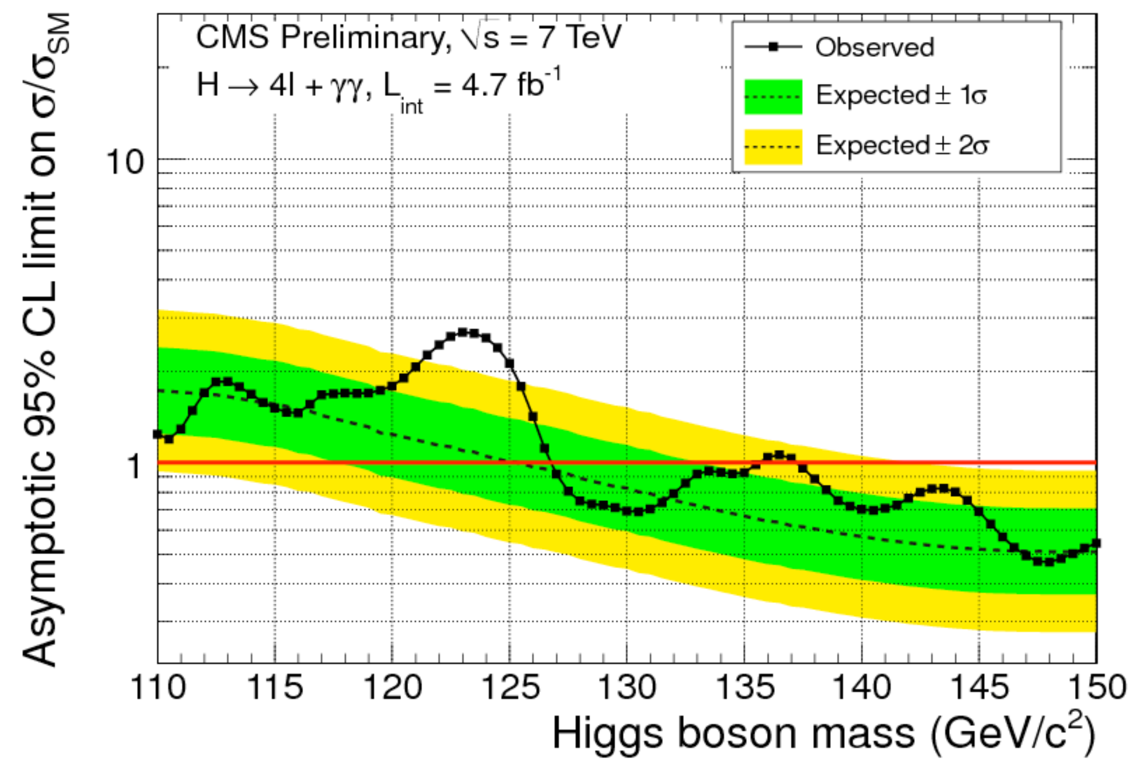
$\propto m_q \gamma_5$

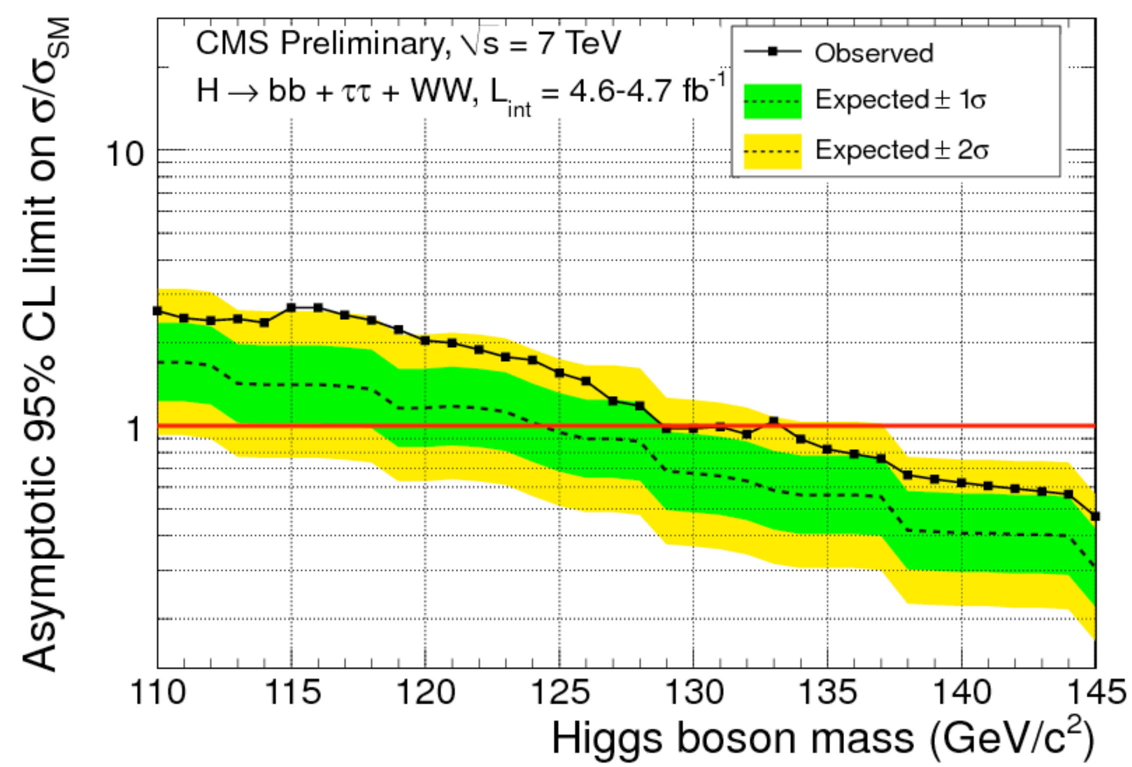
scalar Higgs

pseudoscalar Higgs

Higgs boson status update: CMS

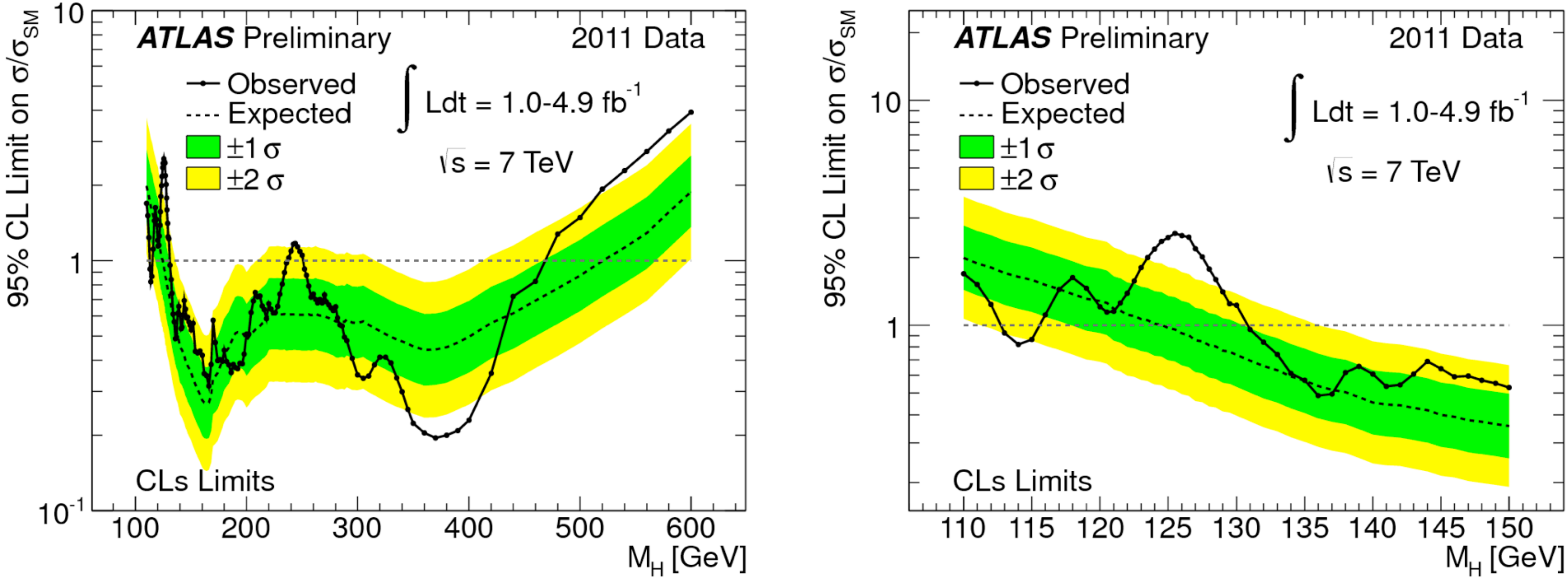






CMS-PAS-HIG-11-032

Higgs boson status update: ATLAS



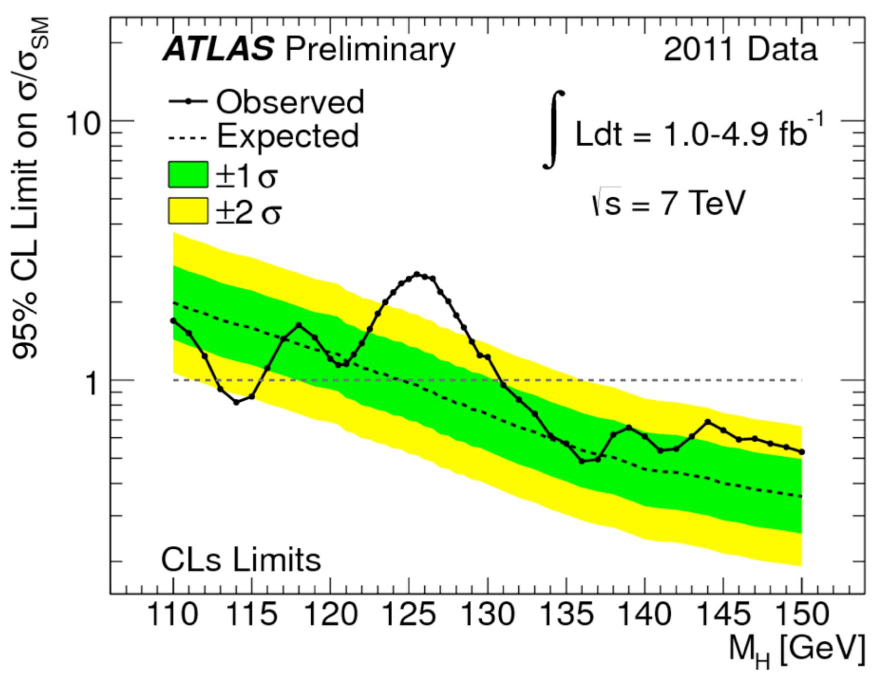
ATLAS-CONF-2011-163

Higgs boson status update

December 2011:
hints for a scalar particle
between 116-127 GeV
seen by both
CMS & ATLAS

ATLAS

ATLAS-CONF-2011-163



CMS

CMS-PAS-HIG-11-032