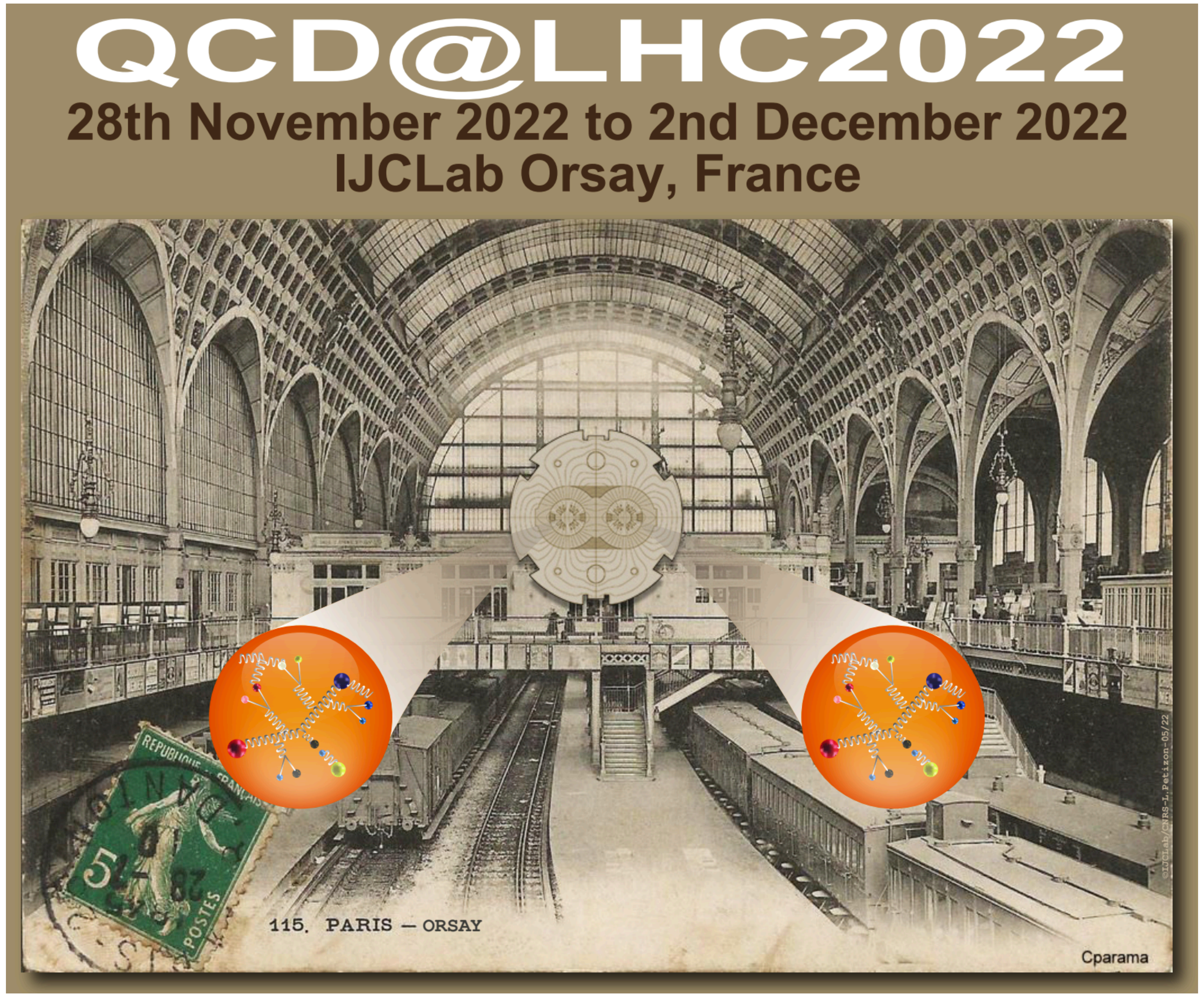

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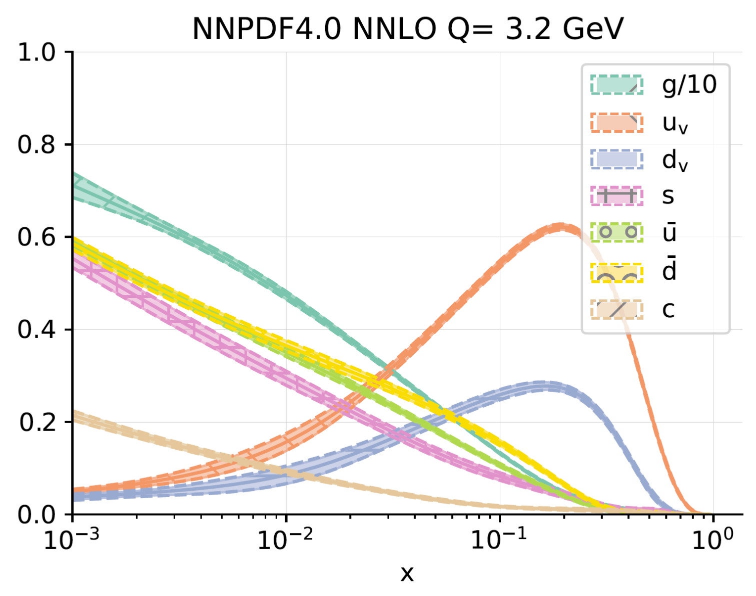
PBSP

THE DGLAP-SMEFT INTERPLAY

MANUEL MORALES ALVARADO

OUTLINE



$$+ \quad \frac{c_i}{\Lambda^2}$$

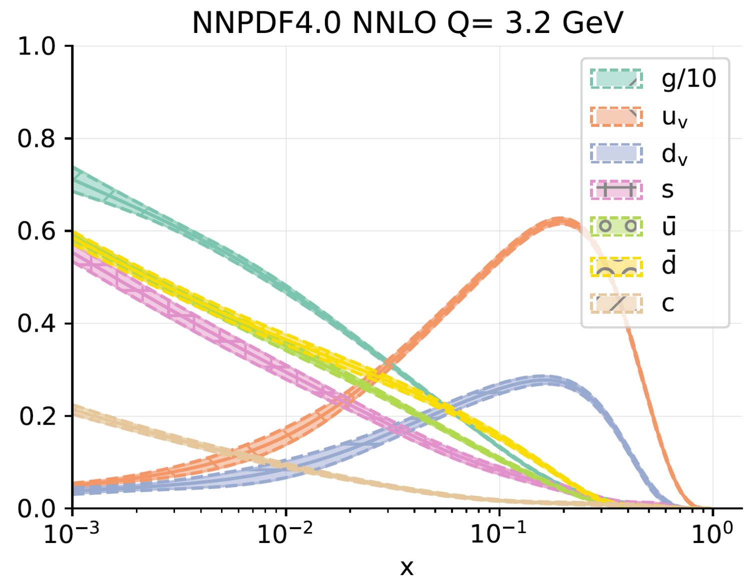
Background: PDFs and SMEFT

$$P_{ij}^{SM} \to P_{ij}^{SMEFT}$$

SMEFT corrections to the DGLAP equations

Conclusions and outlook

OUTLINE



$$+ \quad \frac{c_i}{\Lambda^2}$$

Background: PDFs and SMEFT

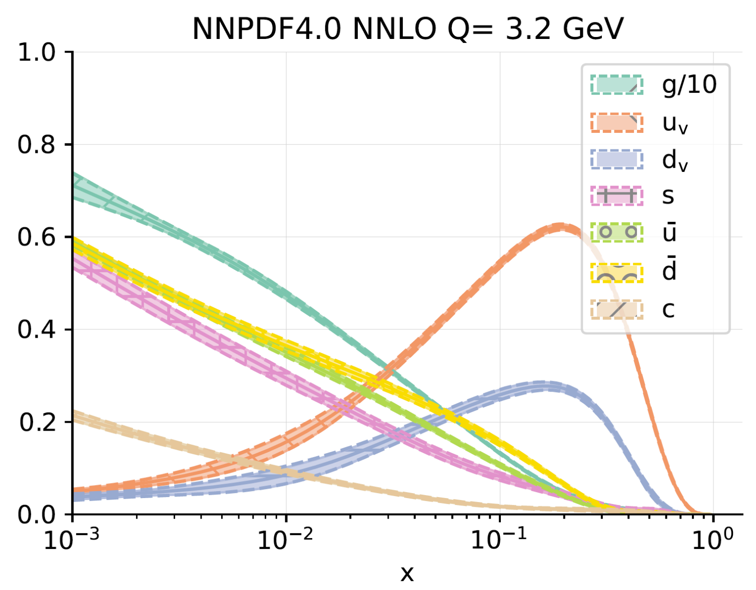
$$P_{ij}^{SM} \to P_{ij}^{SMEFT}$$

SMEFT corrections to DGLAP equations

Based on ongoing work with L. Mantani and M. Ubiali @ PBSP group

Conclusions and outlook

OUTLINE



$+ \frac{c_i}{\Lambda^2}$

Background: PDFs and SMEFT

$P_{ij}^{SM} \rightarrow P_{ij}^{SMEFT}$

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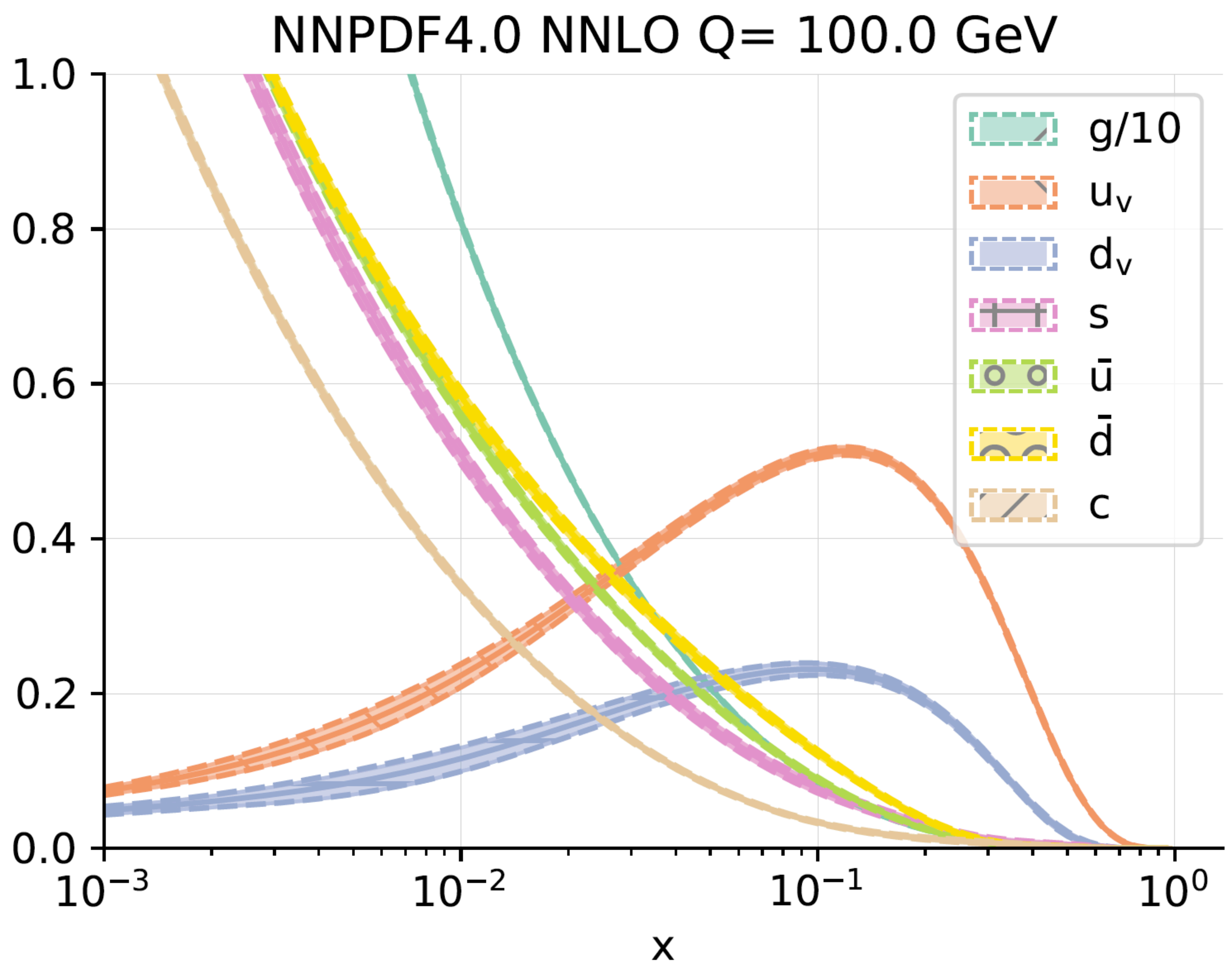
Conclusions and outlook

PARTON DISTRIBUTION FUNCTIONS

Parton distribution functions (PDFs) are important ingredients in LHC phenomenology

$$f(x, Q^2)$$



Ball et al. arXiv: 2109.02653

Recent global PDF fits include:

- NNPDF 4.0: Ball et al., 2109.02653
- CT18: Hou et al., 1912.10053
- MSHT20aN3LO: McGowan et al., 2207.04739

PDF EVOLUTION

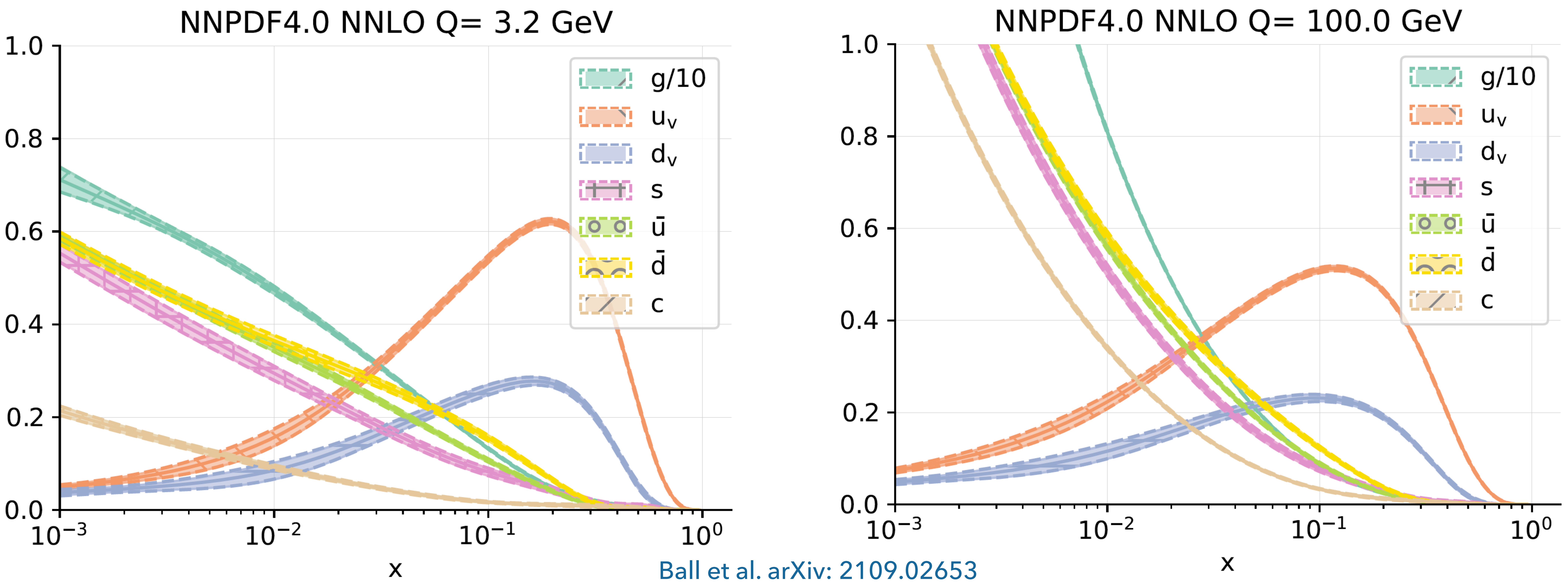
The evolution of the PDFs in Q^2 is described by the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi (DGLAP) equations

Gripov, Lipatov, Sov.J.Nucl.Phys. 15 (1972)

Dokshitzer, Sov.Phys.JETP 46 (1977)

Altarelli, Parisi, Nucl.Phys.B 126 (1977)

$$f(x, Q_0^2) \;\rightarrow\; f(x, Q_f^2)$$



Ball et al. arXiv: 2109.02653

DGLAP EQUATIONS

Gripov, Lipatov,
Sov.J.Nucl.Phys. 15 (1972)

Dokshitzer, Sov.Phys.JETP 46 (1977)

Altarelli, Parisi, Nucl.Phys.B
126 (1977)

For PDFs $f = q, g$ the DGLAP equations in QCD are given by

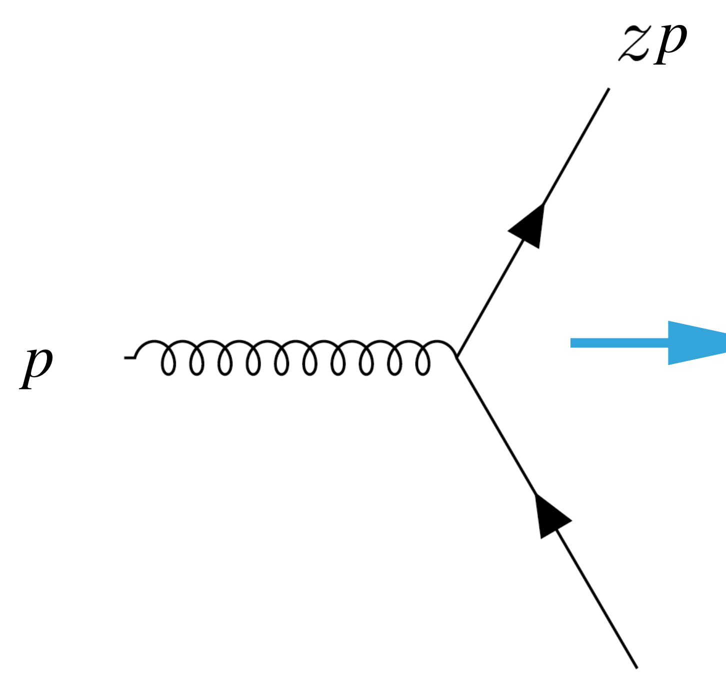
$$\frac{\partial}{\partial \log(\mu^2)} \begin{pmatrix} q(x,\mu^2) \\ g(x,\mu^2) \end{pmatrix} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dz}{z} \begin{pmatrix} P_{qq} & P_{qg} \\ P_{gq} & P_{gg} \end{pmatrix} \begin{pmatrix} q(x/z,\mu^2) \\ g(x/z,\mu^2) \end{pmatrix}$$

splitting functions

$$P_{ij} := P_{ij}(z, \alpha_S)$$

At LO QCD

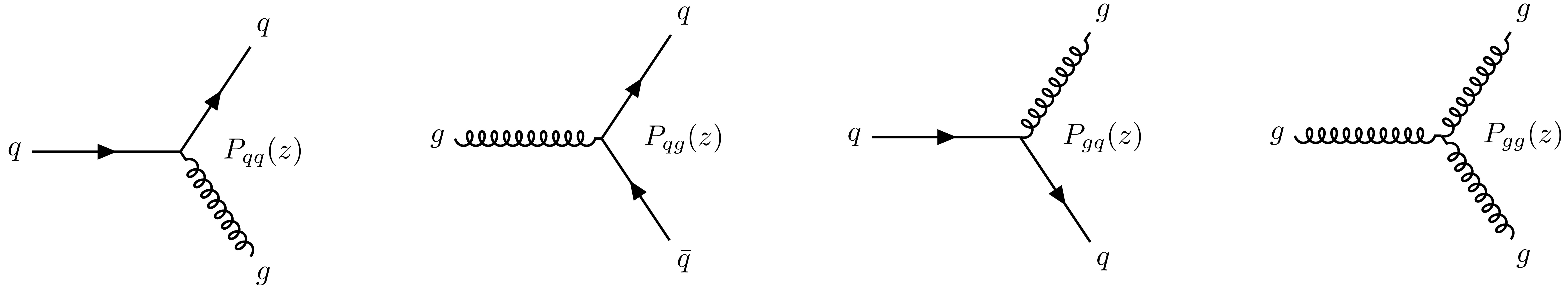
$$\frac{\partial}{\partial \log(\mu^2)} \begin{pmatrix} q(x,\mu^2) \\ g(x,\mu^2) \end{pmatrix} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dz}{z} \begin{pmatrix} P_{qq}(z) & P_{qg}(z) \\ P_{gq}(z) & P_{gg}(z) \end{pmatrix} \begin{pmatrix} q(x/z,\mu^2) \\ g(x/z,\mu^2) \end{pmatrix}$$



$\rightarrow P_{qg}(z)$

SPLITTING FUNCTIONS

In the SM, LO QCD, the splitting functions are given by



Gripov, Lipatov, Sov.J.Nucl.Phys. 15 (1972)

Dokshitzer, Sov.Phys.JETP 46 (1977)

Altarelli, Parisi, Nucl.Phys.B 126 (1977)

$$P_{qq}(z) = C_F \left(\frac{1+z^2}{(1-z)_+} + \frac{3}{2}\delta(1-z) \right)$$

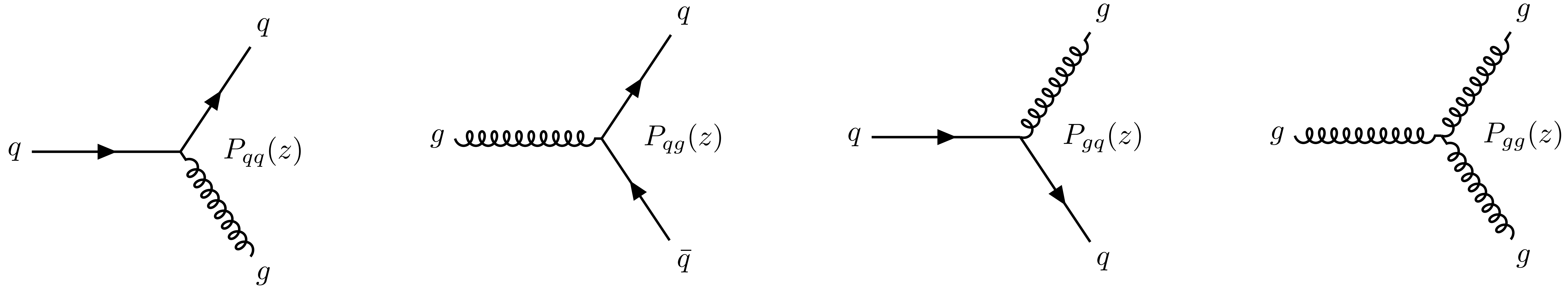
$$P_{qg}(z) = T_F(z^2 + (1-z)^2)$$

$$P_{gq}(z) = C_F \left(\frac{1+(1-z)^2}{z} \right)$$

$$P_{gg}(z) = 2C_A \left(\frac{z}{(1-z)_+} + \frac{1-z}{z} + z(1-z) \right) + \left(\frac{11C_A}{6} - \frac{3}{2}T_F n_f \right) \delta(1-z)$$

SPLITTING FUNCTIONS

In the SM, LO QCD, the splitting functions are given by



Gripov, Lipatov, Sov.J.Nucl.Phys. 15 (1972)

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$$P_{qq}(z) = C_F\left(\frac{1+z^2}{(1-z)_+} + \frac{3}{2}\delta(1-z)\right) \qquad P_{qg}(z) = T_F(z^2 + (1-z)^2)$$

$$P_{gq}(z) = C_F\left(\frac{1+(1-z)^2}{z}\right) \qquad P_{gg}(z) = 2C_A\left(\frac{z}{(1-z)_+} + \frac{1-z}{z} + z(1-z)\right) + \left(\frac{11C_A}{6} - \frac{3}{2}T_F n_f\right)\delta(1-z)$$

Could the DGLAP evolution be affected by SMEFT contributions?

STANDARD MODEL EFFECTIVE FIELD THEORY (SMEFT)

In the SMEFT we supplement the SM Lagrangian with towers of higher dimensional operators

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} Q_i^{(6)} + \cdots$$

We will parametrise the SMEFT using the Warsaw basis (59 operators without generation indices)

B. Grzadkowski et al.
arXiv:1008.4884

X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar l_p e_r \varphi)$
$Q_{\widetilde G}$	$f^{ABC} \widetilde G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p u_r \widetilde\varphi)$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar q_p d_r \varphi)$
$Q_{\widetilde W}$	$\varepsilon^{IJK} \widetilde W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar l_p \sigma^{\mu\nu} e_r)\tau^I \varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar l_p \gamma^\mu l_r)$
$Q_{\varphi\widetilde G}$	$\varphi^\dagger\varphi\, \widetilde G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar l_p \sigma^{\mu\nu} e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar l_p \tau^I \gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar q_p \sigma^{\mu\nu} T^A u_r)\widetilde\varphi\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar e_p \gamma^\mu e_r)$
$Q_{\varphi\widetilde W}$	$\varphi^\dagger\varphi\, \widetilde W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar q_p \sigma^{\mu\nu} u_r)\tau^I \widetilde\varphi\, W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar q_p \gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar q_p \sigma^{\mu\nu} u_r)\widetilde\varphi\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu \varphi)(\bar q_p \tau^I \gamma^\mu q_r)$
$Q_{\varphi\widetilde B}$	$\varphi^\dagger\varphi\, \widetilde B_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar q_p \sigma^{\mu\nu} T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar u_p \gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar q_p \sigma^{\mu\nu} d_r)\tau^I \varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu \varphi)(\bar d_p \gamma^\mu d_r)$
$Q_{\varphi\widetilde WB}$	$\varphi^\dagger\tau^I\varphi\, \widetilde W^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar q_p \sigma^{\mu\nu} d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde\varphi^\dagger D_\mu \varphi)(\bar u_p \gamma^\mu d_r)$

$(\bar LL)(\bar LL)$		$(\bar RR)(\bar RR)$		$(\bar LL)(\bar RR)$	
Q_{ll}	$(\bar l_p \gamma_\mu l_r)(\bar l_s \gamma^\mu l_t)$	Q_{ee}	$(\bar e_p \gamma_\mu e_r)(\bar e_s \gamma^\mu e_t)$	Q_{le}	$(\bar l_p \gamma_\mu l_r)(\bar e_s \gamma^\mu e_t)$
$Q_{qq}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar q_s \gamma^\mu q_t)$	Q_{uu}	$(\bar u_p \gamma_\mu u_r)(\bar u_s \gamma^\mu u_t)$	Q_{lu}	$(\bar l_p \gamma_\mu l_r)(\bar u_s \gamma^\mu u_t)$
$Q_{qq}^{(3)}$	$(\bar q_p \gamma_\mu \tau^I q_r)(\bar q_s \gamma^\mu \tau^I q_t)$	Q_{dd}	$(\bar d_p \gamma_\mu d_r)(\bar d_s \gamma^\mu d_t)$	Q_{ld}	$(\bar l_p \gamma_\mu l_r)(\bar d_s \gamma^\mu d_t)$
$Q_{lq}^{(1)}$	$(\bar l_p \gamma_\mu l_r)(\bar q_s \gamma^\mu q_t)$	Q_{eu}	$(\bar e_p \gamma_\mu e_r)(\bar u_s \gamma^\mu u_t)$	Q_{qe}	$(\bar q_p \gamma_\mu q_r)(\bar e_s \gamma^\mu e_t)$
$Q_{lq}^{(3)}$	$(\bar l_p \gamma_\mu \tau^I l_r)(\bar q_s \gamma^\mu \tau^I q_t)$	Q_{ed}	$(\bar e_p \gamma_\mu e_r)(\bar d_s \gamma^\mu d_t)$	$Q_{qu}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar u_s \gamma^\mu u_t)$
		$Q_{ud}^{(1)}$	$(\bar u_p \gamma_\mu u_r)(\bar d_s \gamma^\mu d_t)$	$Q_{qu}^{(8)}$	$(\bar q_p \gamma_\mu T^A q_r)(\bar u_s \gamma^\mu T^A u_t)$
		$Q_{ud}^{(8)}$	$(\bar u_p \gamma_\mu T^A u_r)(\bar d_s \gamma^\mu T^A d_t)$	$Q_{qd}^{(1)}$	$(\bar q_p \gamma_\mu q_r)(\bar d_s \gamma^\mu d_t)$
				$Q_{qd}^{(8)}$	$(\bar q_p \gamma_\mu T^A q_r)(\bar d_s \gamma^\mu T^A d_t)$

$(\bar LR)(\bar RL)$ and $(\bar LR)(\bar LR)$		B-violating	
Q_{ledq}	$(\bar l_p^j e_r)(\bar d_s q_t^j)$	Q_{duq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(q_s^{\gamma j})^T C l_t^k\right]$
$Q_{quqd}^{(1)}$	$(\bar q_p^j u_r)\varepsilon_{jk}(\bar q_s^k d_t)$	Q_{qqu}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jk}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{quqd}^{(8)}$	$(\bar q_p^j T^A u_r)\varepsilon_{jk}(\bar q_s^k T^A d_t)$	Q_{qqq}	$\varepsilon^{\alpha\beta\gamma}\varepsilon_{jn}\varepsilon_{km}\left[(q_p^{\alpha j})^T C q_r^{\beta k}\right]\left[(q_s^{\gamma m})^T C l_t^n\right]$
$Q_{lequ}^{(1)}$	$(\bar l_p^j e_r)\varepsilon_{jk}(\bar q_s^k u_t)$	Q_{duu}	$\varepsilon^{\alpha\beta\gamma}\left[(d_p^\alpha)^T C u_r^\beta\right]\left[(u_s^\gamma)^T C e_t\right]$
$Q_{lequ}^{(3)}$	$(\bar l_p^j \sigma_{\mu\nu} e_r)\varepsilon_{jk}(\bar q_s^k \sigma^{\mu\nu} u_t)$		

OUTLINE

$$+ \frac{c_i}{\Lambda^2}$$

Background: PDFs and SMEFT

$$P_{ij}^{SM} \rightarrow P_{ij}^{SMEFT}$$

SMEFT corrections to DGLAP equations

Conclusions and outlook

SMEFT CORRECTIONS TO THE DGLAP EQUATIONS

Remember that DGLAP at LO QCD is given by

$$\frac{\partial}{\partial \log(\mu^2)} \begin{pmatrix} q(x,\mu^2) \\ g(x,\mu^2) \end{pmatrix} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dz}{z} \begin{pmatrix} P_{qq}(z) & P_{qg}(z) \\ P_{gq}(z) & P_{gg}(z) \end{pmatrix} \begin{pmatrix} q(x/z,\mu^2) \\ g(x/z,\mu^2) \end{pmatrix}$$

We find 3 ways in which new physics can affect the DGLAP evolution equations:

1) New particles (for general BSM models)
2) Modification of the splitting functions P_{ij}
3) Modification of the running of α_S

SMEFT CORRECTIONS TO THE DGLAP EQUATIONS

1) New particles

A new particle X will induce new splitting functions P_{iX} and P_{Xi}

$$\frac{\partial}{\partial \log(\mu^2)} \begin{pmatrix} q(x,\mu^2) \\ g(x,\mu^2) \end{pmatrix} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dz}{z} \begin{pmatrix} P_{qq}(z) & P_{qg}(z) \\ P_{gq}(z) & P_{gg}(z) \end{pmatrix} \begin{pmatrix} q(x/z,\mu^2) \\ g(x/z,\mu^2) \end{pmatrix}$$

↓

$$\frac{\partial}{\partial \log(\mu^2)} \begin{pmatrix} q(x,\mu^2) \\ g(x,\mu^2) \\ X(x,\mu^2) \end{pmatrix} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dz}{z} \begin{pmatrix} P_{qq} & P_{qg} & P_{qX} \\ P_{gq} & P_{gg} & P_{gX} \\ P_{Xq} & P_{Xg} & P_{XX} \end{pmatrix} \begin{pmatrix} q(x/z,\mu^2) \\ g(x/z,\mu^2) \\ X(x/z,\mu^2) \end{pmatrix}$$

Berger et al., 1010.4315

Becciolini et al., 1403.7411

McCullough, Moore, Ubiali, 2203.12628

The DGLAP equations are coupled. The inclusion of X *can* change the way in which PDFs evolve.

In the SMEFT, however, there are no additional degrees of freedom apart from the SM ones

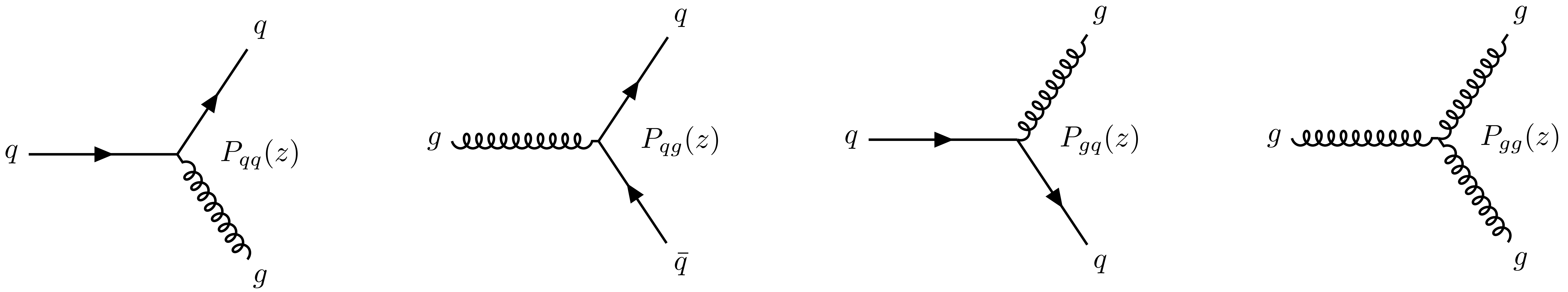
SMEFT CORRECTIONS TO THE DGLAP EQUATIONS

2) Modifications of the splitting functions P_{ij}

The evolution of the PDFs is characterised by the splitting functions P_{ij}, the coefficients of the evolution matrix

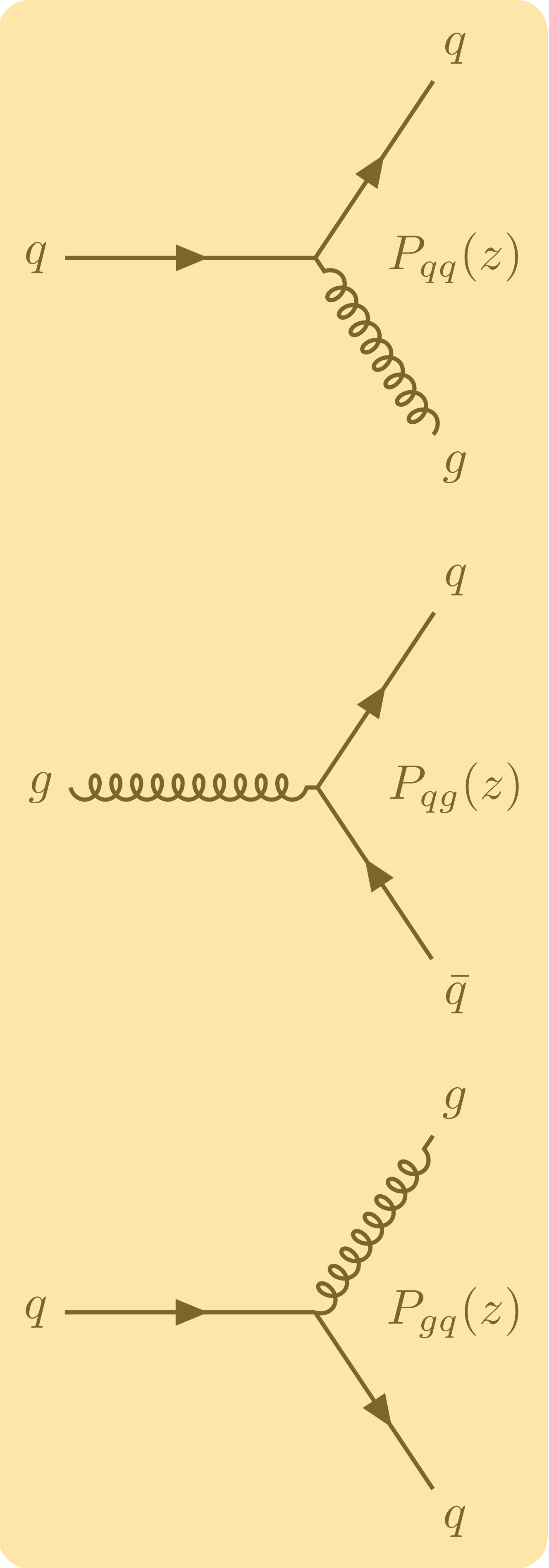
$$\frac{\partial}{\partial \log(\mu^2)} \begin{pmatrix} q(x,\mu^2) \\ g(x,\mu^2) \end{pmatrix} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dz}{z} \begin{pmatrix} P_{qq}(z) & P_{qg}(z) \\ P_{gq}(z) & P_{gg}(z) \end{pmatrix} \begin{pmatrix} q(x/z,\mu^2) \\ g(x/z,\mu^2) \end{pmatrix}$$

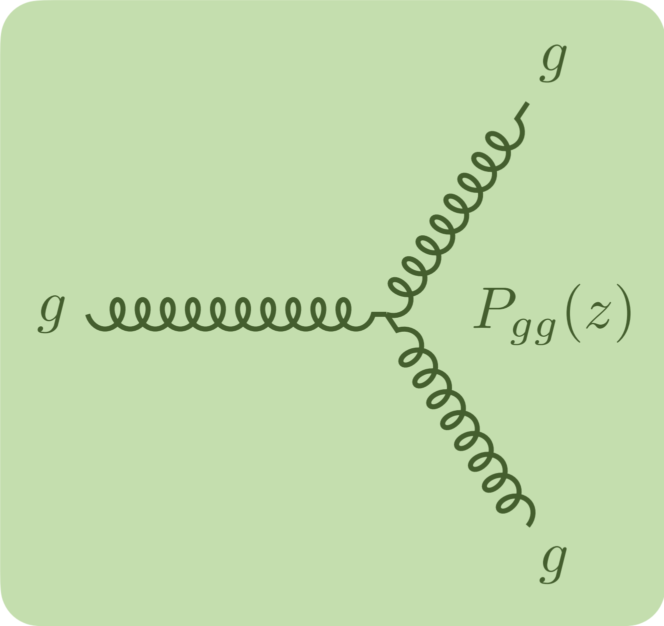
The P_{ij} splittings are related to SM matrix elements in the collinear limit:



SMEFT CORRECTIONS TO THE DGLAP EQUATIONS

We wonder what SMEFT operators could affect P_{ij}





X^3		φ^6 and $\varphi^4 D^2$		$\psi^2\varphi^3$	
Q_G	$f^{ABC} G_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	Q_φ	$(\varphi^\dagger\varphi)^3$	$Q_{e\varphi}$	$(\varphi^\dagger\varphi)(\bar{l}_p e_r \varphi)$
$Q_{\widetilde{G}}$	$f^{ABC} \widetilde{G}_\mu^{A\nu} G_\nu^{B\rho} G_\rho^{C\mu}$	$Q_{\varphi\Box}$	$(\varphi^\dagger\varphi)\Box(\varphi^\dagger\varphi)$	$Q_{u\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p u_r \widetilde{\varphi})$
Q_W	$\varepsilon^{IJK} W_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$	$Q_{\varphi D}$	$\left(\varphi^\dagger D^\mu\varphi\right)^\star \left(\varphi^\dagger D_\mu\varphi\right)$	$Q_{d\varphi}$	$(\varphi^\dagger\varphi)(\bar{q}_p d_r \varphi)$
$Q_{\widetilde{W}}$	$\varepsilon^{IJK} \widetilde{W}_\mu^{I\nu} W_\nu^{J\rho} W_\rho^{K\mu}$				

$X^2\varphi^2$		$\psi^2 X\varphi$		$\psi^2\varphi^2 D$	
$Q_{\varphi G}$	$\varphi^\dagger\varphi\, G^A_{\mu\nu} G^{A\mu\nu}$	Q_{eW}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\tau^I\varphi W^I_{\mu\nu}$	$Q_{\varphi l}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{l}_p\gamma^\mu l_r)$
$Q_{\varphi\widetilde{G}}$	$\varphi^\dagger\varphi\, \widetilde{G}^A_{\mu\nu} G^{A\mu\nu}$	Q_{eB}	$(\bar{l}_p\sigma^{\mu\nu}e_r)\varphi B_{\mu\nu}$	$Q_{\varphi l}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{l}_p\tau^I\gamma^\mu l_r)$
$Q_{\varphi W}$	$\varphi^\dagger\varphi\, W^I_{\mu\nu} W^{I\mu\nu}$	Q_{uG}	$(\bar{q}_p\sigma^{\mu\nu}T^A u_r)\widetilde{\varphi}\, G^A_{\mu\nu}$	$Q_{\varphi e}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{e}_p\gamma^\mu e_r)$
$Q_{\varphi\widetilde{W}}$	$\varphi^\dagger\varphi\, \widetilde{W}^I_{\mu\nu} W^{I\mu\nu}$	Q_{uW}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\tau^I\widetilde{\varphi}\, W^I_{\mu\nu}$	$Q_{\varphi q}^{(1)}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{q}_p\gamma^\mu q_r)$
$Q_{\varphi B}$	$\varphi^\dagger\varphi\, B_{\mu\nu} B^{\mu\nu}$	Q_{uB}	$(\bar{q}_p\sigma^{\mu\nu}u_r)\widetilde{\varphi}\, B_{\mu\nu}$	$Q_{\varphi q}^{(3)}$	$(\varphi^\dagger i\overleftrightarrow{D}^I_\mu\varphi)(\bar{q}_p\tau^I\gamma^\mu q_r)$
$Q_{\varphi\widetilde{B}}$	$\varphi^\dagger\varphi\, \widetilde{B}_{\mu\nu} B^{\mu\nu}$	Q_{dG}	$(\bar{q}_p\sigma^{\mu\nu}T^A d_r)\varphi\, G^A_{\mu\nu}$	$Q_{\varphi u}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{u}_p\gamma^\mu u_r)$
$Q_{\varphi WB}$	$\varphi^\dagger\tau^I\varphi\, W^I_{\mu\nu} B^{\mu\nu}$	Q_{dW}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\tau^I\varphi\, W^I_{\mu\nu}$	$Q_{\varphi d}$	$(\varphi^\dagger i\overleftrightarrow{D}_\mu\varphi)(\bar{d}_p\gamma^\mu d_r)$
$Q_{\varphi\widetilde{W}B}$	$\varphi^\dagger\tau^I\varphi\, \widetilde{W}^I_{\mu\nu} B^{\mu\nu}$	Q_{dB}	$(\bar{q}_p\sigma^{\mu\nu}d_r)\varphi\, B_{\mu\nu}$	$Q_{\varphi ud}$	$i(\widetilde{\varphi}^\dagger D_\mu\varphi)(\bar{u}_p\gamma^\mu d_r)$

SMEFT CORRECTIONS TO THE SPLITTING FUNCTIONS

The relevant operator are

$$Q_{uG} = (\overline{q}\sigma^{\mu\nu}T^A u)\tilde{H}G^A_{\mu\nu}$$

$$Q_{dG} = (\overline{q}\sigma^{\mu\nu}T^A d)HG^A_{\mu\nu}$$

$$Q_{HG} = H^\dagger H G^A_{\mu\nu}G^{A\mu\nu}$$

$$Q_G = g_s f^{ABC} G^{A\nu}_{\mu} G^{B\rho}_{\nu} G^{C\mu}_{\rho}$$

$q :$ LH doublets

$u, d :$ RH singlets

$H :$ Higgs doublet

$G^A_{\mu\nu} :$ $SU(3)$ field strength

How can we assess if they change the matrix elements?

SMEFT CORRECTIONS TO THE SPLITTING FUNCTIONS

It is instructive to define an expression $\hat{P}_{ij}$ to study the matrix element before we take the collinear limit

$$\lim_{k_T \to 0} \left(\hat{P}_{\mathrm{ij}}(z) \right) = P_{\mathrm{ij}}(z)$$

For example, in the SMEFT P_{qq} calculation we have

$$\hat{P}_{qq}(z) = \frac{\alpha_S}{2\pi} \left(C_F \left(\frac{1+z^2}{1-z} \right) + 4 \frac{c_{uG}^2}{\Lambda^4} p_T^2 v^2 \frac{1}{(1-z)} \right)$$

$$Q_{uG} = (\bar{q}\sigma^{\mu\nu} T^A u)\tilde{H} G^A_{\mu\nu}$$

We see that

$$\lim_{k_T \to 0} \left(\hat{P}_{\mathrm{qq}}(z) \right) = P_{\mathrm{qq}}(z)$$

and therefore the higher dimensionality of the operator keeps the collinear limit safe

SMEFT CORRECTIONS TO THE SPLITTING FUNCTIONS

What we have seen far:

- This argument based on dimensionality is also observed in the other dimension 6 operators
- Some SMEFT operators have effective dimension-4 parts (v^2/Λ^2) $Q_{HG} = H^\dagger H G^A_{\mu\nu} G^{A\mu\nu}$
- We are exploring higher order splitting functions, and assessing loop effects

SMEFT CORRECTIONS TO THE DGLAP EQUATIONS

3) SMEFT modifications of the running of α_S

$$\frac{\partial}{\partial \log(\mu^2)} \begin{pmatrix} q(x,\mu^2) \\ g(x,\mu^2) \end{pmatrix} = \frac{\alpha_S(\mu^2)}{2\pi} \int_x^1 \frac{dz}{z} \begin{pmatrix} P_{qq}(z) & P_{qg}(z) \\ P_{gq}(z) & P_{gg}(z) \end{pmatrix} \begin{pmatrix} q(x/z,\mu^2) \\ g(x/z,\mu^2) \end{pmatrix}$$

The running of α_S is calculated from the vacuum polarisation of the gluon

At 1-loop in the SM

$$\mu^2 \frac{d\alpha_S}{d\mu^2} = \beta(\alpha_S) = -b\alpha_S^2 + \mathcal{O}(\alpha_S^3)$$

$$b = \frac{33 - 2n_f}{12\pi}$$

$$\alpha_S(\mu^2) = \frac{\alpha_S(Q^2)}{1 + \alpha_S(Q^2)\, b \log\left(\frac{\mu^2}{Q^2}\right)}$$

Q : reference scale

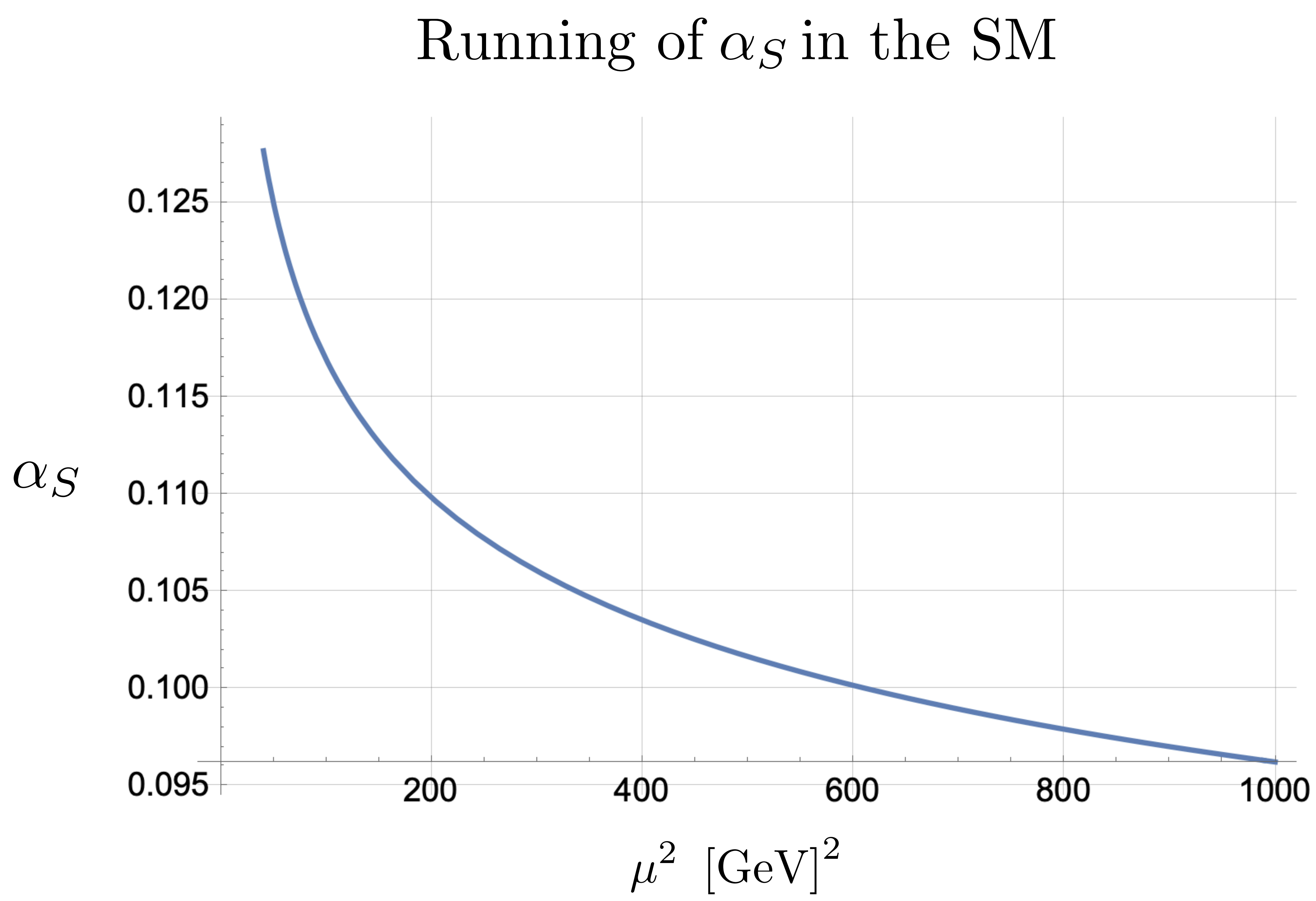
SMEFT CORRECTIONS TO THE DGLAP EQUATIONS

The running of α_S is therefore described by

$$\alpha_S(\mu^2) = \frac{\alpha_S(Q^2)}{1 + \alpha_S(Q^2) b \log\left(\frac{\mu^2}{Q^2}\right)}$$

$$Q = m_Z \approx 91.2 \ \ \text{GeV}$$

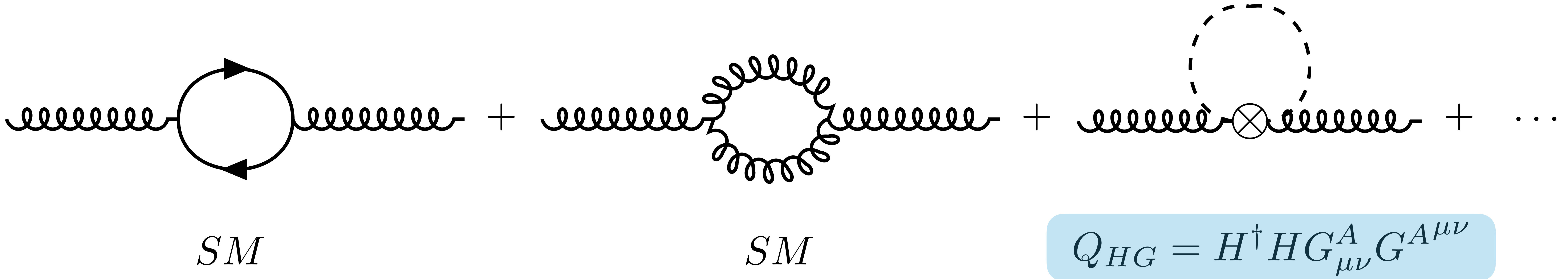
$$\alpha_S(m_Z) \approx 0.118$$



What happens if we include SMEFT corrections?

SMEFT CORRECTIONS TO THE DGLAP EQUATIONS

The running of α_S is now calculated from



$$Q_{HG} = H^\dagger H G^A_{\mu\nu} G^{A\mu\nu}$$

The β function changes:

(retaining only leading contribution)

$$\mu^2 \frac{d\alpha_S}{d\mu^2} = \beta(\alpha_S) = -\frac{8m_H^2}{16\pi^2}\frac{C_{HG}}{\Lambda^2}\alpha_S - b\alpha_S^2 + \mathcal{O}(\alpha_S^3)$$

$$\alpha_S(\mu^2) = \alpha_S(Q^2)\left(\frac{Q^2}{\mu^2}\right)^{-\frac{8m_H^2}{16\pi^2}\frac{C_{HG}}{\Lambda^2}}$$

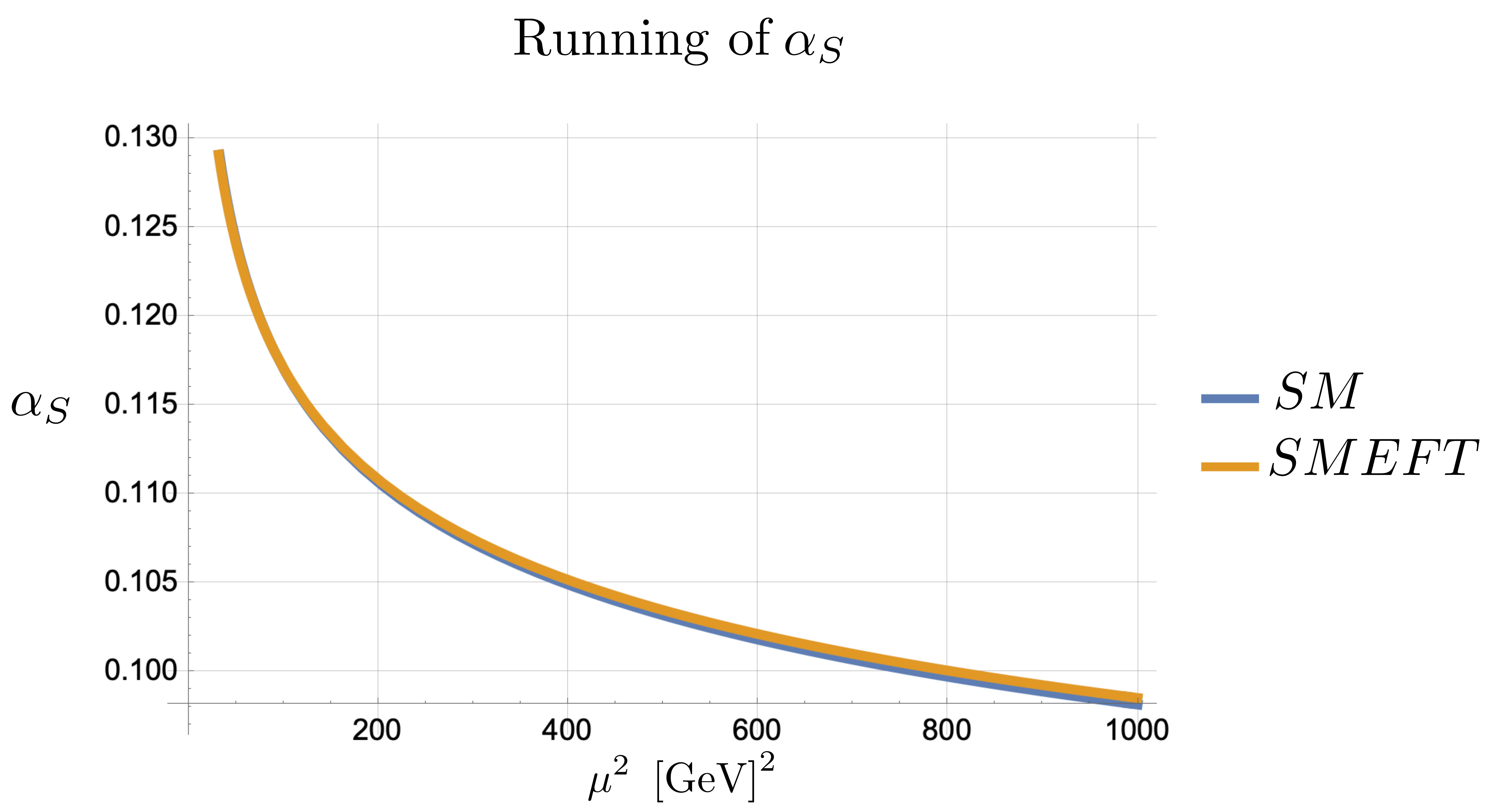
$$b = \frac{33 - 2n_f}{12\pi}$$

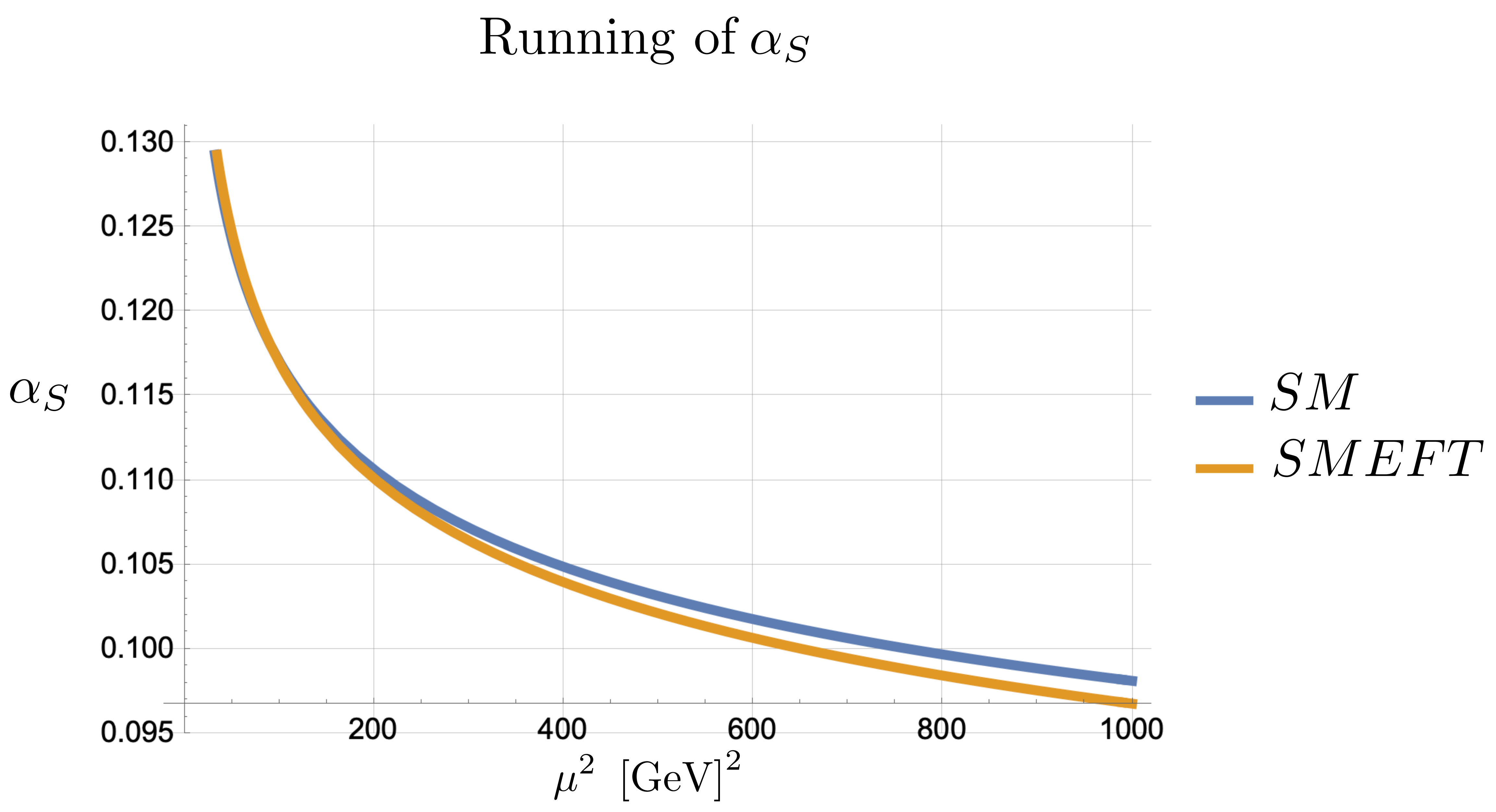
Jenkins, Manohar, Trott, 1308.2627

Q : reference scale

SMEFT CORRECTIONS TO THE DGLAP EQUATIONS

The running of α_S is modified by SMEFT corrections





$$C_{HG} = 0.01$$

$$\Lambda = 1 \ \text{TeV}$$

Ellis et al., 2012.02779
Ethier at al., 2105, 00006

$$C_{HG}^{ext} = 100 \cdot C_{HG}$$

$$\Lambda = 1 \ \text{TeV}$$

OUTLINE

$+ \quad \frac{c_i}{\Lambda^2}$

Background: PDFs and SMEFT

$$P_{ij}^{SM} \to P_{ij}^{SMEFT}$$

SMEFT corrections to DGLAP equations

Conclusions and outlook

CONCLUSIONS AND OUTLOOK

- The SMEFT can affect the DGLAP evolution equations through

  - [x] New particles (for general BSM models)
  - [x] Modification of the splitting functions P_{ij}
  - [x] Modification of the running of α_S

- Work being carried to determine

  - [ ] How to address these calculations at higher orders
  - [ ] How field redefinitions can help
  - [ ] Possible UV models to compare and contrast

Thank you for your attention!