Deciphering QCD:

From PDFs to the underlying QCD characteristics

Fred Olness SMU

Thanks for substantial input from my friends & colleagues



xFitter



EIC opportunities for Snowmass

25 January 2021

Landscape of the Physics Frontier



F. Olness PDF uncertainties are among the leading uncertainties in the first LHC precision measurements by CMS" Jan Kretzschmar

arXiv:hep-ph/9907340

/9907340 "QCD is our most perfect physical theory" Frank Wilczek

Electro-Weak Strong Gravitation magnetism Interaction Interaction **PDFs & nPDFs Generalized PDFs Spin Structure Lattice QCD Quark-Gluon Plasma** $\mathcal{L}_{QCD} = \overline{\psi}_q \left(i \gamma_\mu D^\mu - m_q
ight) \psi_q$ – $G^a_{\mu\nu}G^{\mu\nu}_a$ **QCD** is our most perfect physical theory What QCD Tells Us About Nature - and Why We Should Listen. Frank Wilczek In many respects, our most complex asymptotic freedom strong color confinement ... associated manifestations **Lessons: The Nature of Nature Combines HEP + NUC** "... alien, simple, beautiful, weird, & comprehensible" *interdisciplinary*

4 From Parameterization to a Deep Understanding ... LHC + EIC



F. Olness

... the motivation for nCTEQ



The

Physics

nCTEQ Wish List



F

www.ncteq.org

CTEQ

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www.cteq.org
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PDF General Issues:

• Proton PDF; nuclear corrections for interpreting heavy target DIS (Ar, Fe, Pb).

Strange quark PDF: *s*(*x*)

• Resolve tension between fixed-target (νN , ℓN) and collider expectations (W^{\pm} ,Z)

Charm & Bottom: c(x) & b(x)

- Multi-scale & resummation issues: $Log(m_{cb}/Q)$
- "Fitted" charm: $c(x) \neq 0$ at m_c
- Intrinsic heavy flavors: $c(x) \neq 0$ at $Q < m_c$

Neutrino cross sections on heavy targets (Ar, Fe, Pb)

• Universality of Neutral Current (γ) and Charged Current (W^{\pm}) processes

Expanded {x,Q²} Kinematic Regime

- Small-x saturation, resummation: Log[1/x]
- Large-x higher twist: (M^2/Q^2)
- Low Q² non-perturbative effects

Compilation by Fred Olness with helpful feedback from: Alberto Accardi, Tim Hobbs, Tomas Jezo, Thia Keppel, Michael Klasen, Karol Kovarik, Aleksander Kusina, Jorge Morfin, Pavel Nadolsky, Jeff Owens, Ingo Schienbein, Efrain Segarra, Steve Sekula, Ji-Young Yu

nPDFs: Extend Kinematic Reach in {x,Q²} **nC**

nCTEQ15HIX



8

W/Z Production at LHC and the strange PDF

nCTEQ15WZ

Eur.Phys.J.C 80 (2020) 10, 968

9

nuclear PDFs for lead (Pb)



Challenging problems require good ideas & tools





nCTEQ++ ... *modular* w/ standard interfaces

- A complete rewrite of the nCTEQ FORTRAN fitting code in C++
- Changed the code to allow for modules when building a PDF





Strategy: use case studies to validate new nCTEQ++ framework

Grid Technology: ... to NLO and Beyond: ApplGrid, FastNLO, ...

12



MCFM Processes Library (v6.8)

MCFM: Vector boson pair production at the LHC, J. M.Campbell, R. K.Ellis and C.Williams, JHEP 1107, 018 (2011)

The APPLGRID Project: Tancredi Carli, Dan Clements, Amanda Cooper-Sarkar, Claire Gwenlan, Gavin P. Salam,
Frank Siegert, Pavel Starovoitov, Mark Sutton.Eur.Phys.J. C66 (2010) 503-524

nproc $f(p_1) + f(p_2) \rightarrow .$			Order	$\begin{array}{c} \mid H(\gamma(p_3) + \gamma(p_4)) + f(p_5) + f(p_6) [\text{in heavy top limit]} \\ \mid H(b(p_4) + \delta(p_4)) + f(p_5) + f(p_6) [\text{in heavy top limit]} \\ \mid H(\gamma^-(p_4) + \tau^+(p_6)) + f(p_5) + f(p_6) [\text{in heavy top limit]} \end{array}$	NLO NLO NLO	$\begin{array}{l} 540 & H(b(p_1) + b(p_1)) + t(p_5) + q(p_6) \\ 541 & H(b(p_1) + \overline{b}(p_1)) + \overline{t}(p_5) + q(p_6) \\ \end{array} \qquad \qquad$
$\frac{1}{1} \qquad W^+ (\rightarrow \nu(n_0) + e^{-1})$	$+(n_{1}))$		NLO	$ = I H(\rightarrow W^+(\nu(p_k), e^+(p_k))W^-(e^-(p_k), \bar{\nu}(p_k))) + f(p_l) + \bar{f}(p_k) $ $ = I H(\rightarrow Z(e^-(p_k), e^+(p_k))Z(\mu^-(p_k), \mu^+(p_k))) + f(p_l) + f(p_k) $ $ = I H(0, p_l) + \bar{h}(p_k) + \bar{h}(p_$	NLO NLO	544 $H(b(p_3) + \tilde{b}(p_4)) + t(\nu(p_5) + e^+(p_6) + b(p_7)) + q(p_9)$ NLO 547 $H(b(p_3) + \tilde{b}(p_4)) + \tilde{t}(e^-(p_5) + \tilde{\nu}(p_6) + b(p_7)) + q(p_9)$ NLO
$\begin{array}{c c} 1 & W & (7 \nu (p_3) + c) \\ 0 & W - ($	$(P_4))$		NLO	$ \begin{array}{c} & H(r_{1}(p_{3}) + g_{4}(p_{1}) + f(p_{3}) + f(p_{4}) + f(p_{7}) + f(p_{7}) + g_{7}(p_{1}) + g_{7}(p_{1}) \\ & H(r_{1}(p_{3}) + g_{7}^{+}(p_{4})) + f(p_{3}) + f(p_{3}) + f(p_{7}) + f(p_{7}) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) W^{-}(e^{-}(p_{3}), p(p_{3}))) + f(p_{7}) + f(p_{5}) + f(p_{5}) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) W^{-}(e^{-}(p_{3}), p(p_{3}))) + f(p_{7}) + f(p_{5}) + f(p_{5}) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) W^{-}(e^{-}(p_{3}), p(p_{3}))) + f(p_{7}) + f(p_{5}) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) W^{-}(e^{-}(p_{3}), p(p_{3}))) + f(p_{7}) + f(p_{5}) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) W^{-}(e^{-}(p_{3}), p(p_{3}))) + f(p_{7}) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) W^{-}(e^{-}(p_{3}), p(p_{3})) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) W^{-}(p_{3}) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) W^{-}(p_{3}) \\ & H(r_{1}(p_{3}) + g_{7}(p_{3})) \\ & H(r_{1}(p_{3}) +$	0.0	$\frac{550}{551} \frac{H(\gamma(p_3) + \gamma(p_4)) + t(p_5) + q(p_6)}{H(\gamma(p_3) + \gamma(p_4)) + t(p_5) + q(p_6)} \frac{NLO}{NLO}$
$0 \qquad W (\rightarrow e (p_3) + i)$	$\nu(p_4))$		NLO	$\frac{1}{p_1} \frac{H(-Z(e^-(p_5), e^+(p_4))Z(\mu^-(p_5), \mu^+(p_6))] + f(p_7) + f(p_6) + f(p_6)}{1}$ $\frac{1}{p_1} \frac{f(p_3) + f(p_3)}{p_2} + f(p_3) +$	NLO+F	554 $H(\gamma(p_3) + \gamma(p_4)) + t(\nu(p_5) + e^+(p_5) + b(p_7)) + q(p_3)$ NLO
11 $W^+(\rightarrow \nu(p_2) + e^-)$	$(p_{4}) + f(p_{5})$		NLO	$ \begin{array}{c} : & f(p_1) + f(p_2) \rightarrow \gamma(p_3) + f(p_4) + f(p_5) \\ \downarrow & f(p_1) + f(p_2) \rightarrow \gamma(p_3) + b(p_4) \\ \downarrow & f(p_1) + f(p_2) \rightarrow \gamma(p_3) + b(p_4) \end{array} $.0	$\frac{1557}{560} \frac{H(\gamma(p_3) + \gamma(p_4)) + t(e^-(p_5) + \bar{\nu}(p_6) + b(p_7)) + q(p_9)}{1560} \frac{NLO}{2(e^-(p_3) + e^+(p_4)) + t(p_5) + q(p_6)} \frac{NLO}{NLO}$
$10 \qquad \qquad$	(P4) + $J(P3)$		NLO	$f(p_1) + f(p_2) \rightarrow \gamma(p_3) + \gamma(p_4)$ $f(p_1) + f(p_2) \rightarrow \gamma(p_5) + \gamma(p_4)$ $f(p_6) + f(p_2) \rightarrow \gamma(p_5) + \gamma(p_4) + f(p_5)$	NLO+F NLO+F	561 $Z[e - (p_3] + e + (p_1)] + \overline{\ell}(p_5) + q(p_6)$ NLO
$ 12 W (\rightarrow \nu(p_3) + e)$	$(p_4)) + b(p_5)$		NLO	$\frac{\gamma}{F(p_1) + f(p_2) \rightarrow \gamma(p_3) + \gamma(p_4) + \gamma(p_5)}$ $\frac{\gamma}{F(p_1) + f(p_2) \rightarrow \gamma(p_3) + e^+(p_4)) + \gamma(p_5)}$ 1	NLO+F NLO+F	$\begin{array}{c c c c c c c c c c c c c c c c c c c $
13 $W^+(\rightarrow \nu(n_2) + e^-)$	$(p_{4}) + \bar{c}(p_{5})$		NLO	$\begin{array}{l} : & W^+(\rightarrow\nu(p_3)+e^+(p_4))+\gamma(p_5)+f(p_6)\\ \\ : & W^-(\rightarrow e^-(p_3)+\bar{\nu}(p_4))+\gamma(p_5) \end{array} \end{array}$.0 NLO+F	$\begin{array}{l} 564 \\ S66 \\$
10 11 11 11	(P_4) + (P_5)		LO	$\frac{f}{P} \frac{W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_4)) + \gamma(p_5) + f(p_6)}{2^0(\rightarrow e^-(p_3) + e^+(p_4)) + \gamma(p_5)} = 1$	NLO+F	$\begin{array}{ll} 500 & \mathcal{L}(e - (p_3) + e + (p_4)) + i(\rightarrow v(p_5) + e^-(p_6) + 4(p_7)) + q(p_8) + f(p_9) & \text{IA} \\ 567 & \mathcal{Z}(e - (p_3) + e + (p_4)) + \bar{t}(\rightarrow e^-(p_5) + \bar{v}(p_9) + \bar{t}(p_7)) + q(p_8) & \text{NLO} \end{array}$
$ 14 W^{+}(\rightarrow \nu(p_3) + e^{-}) $	$(p_4) + c(p_5)$ [massless]		LO	$Z^{\nu}(\rightarrow e^{-}(p_{5}) + e^{-}(p_{4})) + \gamma(p_{5}) + \gamma(p_{6})$ $Z^{0}(\rightarrow e^{-}(p_{5}) + e^{+}(p_{4})) + \gamma(p_{5}) + f(p_{6})$ $Z^{0}(\rightarrow e^{-}(p_{1}) + e^{+}(p_{1})) + \gamma(p_{5}) + f(p_{6})$ $Z^{0}(\rightarrow e^{-}(p_{1}) + e^{+}(p_{1})) + \gamma(p_{5}) + f(p_{6})$	NLO + F NLO + F	$\frac{569}{601} \frac{Z(e - (p_3) + e + (p_4)) + \bar{\ell}(\rightarrow e^-(p_5) + \bar{\nu}(p_6) + \bar{\ell}(p_7)) + q(p_6) + f(p_6)}{LO} = \frac{LO}{1001} \frac{LO}{LO}$
$16 \qquad W^{-}(\rightarrow e^{-}(n_2) + i)$	$\bar{\nu}(n_{4})) + f(n_{E})$		NLO	$\begin{array}{c} 1 & Z & (\rightarrow e^{-}(p_{3}) + e^{-}(p_{4})) + \gamma(p_{5}) + \gamma(p_{6}) + f(p_{7}) \\ 1 & Z^{0}(\rightarrow e^{-}(p_{4}) + e^{+}(p_{4})) + \gamma(p_{5}) + f(p_{6}) + f(p_{7}) \\ 1 & Z^{0}(\rightarrow 3(\nu(p_{6}) + \bar{\nu}(p_{7}))) + \gamma(p_{5}) \end{array}$.0 NLO + F	$\begin{array}{l} 001 & H(q_{B_{1}}) + b(p_{1})) + H(\gamma(p_{5}) + \gamma(p_{6})) \\ 002 & H(b(p_{1}) + \bar{b}(p_{1})) + H(\gamma(p_{5}) + \gamma(p_{6})) \\ \end{array}$
10 11 117 117	-(P4) + J(P5) - (P4) + J(P5)		NLO	$i Z^{0}(\rightarrow 3(\nu(p_{3}) + \bar{\nu}(p_{4}))) + \gamma(p_{5}) + \gamma(p_{6})$ $\cdot Z^{0}(\rightarrow 3(\nu(p_{3}) + \bar{\nu}(p_{4}))) + \gamma(p_{3}) + f(p_{6})$	NLO + F NLO + F	$\begin{array}{c} 640 & t(p_3) + \bar{t}(p_4) + H(p_5) \\ 641 & t(\rightarrow \nu(n_c) + e^+(n_c) + \bar{t}(n_c)) + \bar{t}(\rightarrow \bar{\nu}(n_c) + e^-(n_c) + \bar{\bar{\lambda}}(n_c)) + H(\bar{h}(n_c) + \bar{\bar{\lambda}}(n_c)) \end{array} \\ \begin{array}{c} LO \\ IO \end{array}$
$ 17 \qquad W (\rightarrow e^{-}(p_3) + i)$	$\nu(p_4)) + b(p_5)$		NLO	$ \begin{array}{l} : Z^{0}(\rightarrow 3(\nu(p_{3}) + \bar{\nu}(p_{4}))) + \gamma(p_{5}) + \gamma(p_{6}) + f(p_{7}) \\ + Z^{0}(\rightarrow 3(\nu(p_{3}) + \bar{\nu}(p_{4}))) + \gamma(p_{5}) + f(p_{6}) + f(p_{7}) \end{array} $.0	$ \begin{array}{c} 644 \\ t(\rightarrow \nu(p_5) + e^+(p_4) + b(p_5)) + t(\rightarrow \bar{q}(p_1) + q(p_5) + \bar{b}(p_6)) + H(b(p_9) + \bar{b}(p_10)) \\ \end{array} \\ \begin{array}{c} LO \\ LO \end{array} $
$18 \qquad W^{-}(\rightarrow e^{-}(p_2) + i)$	$\bar{\nu}(n_{4})) + c(n_{5})$		NLO	$\begin{array}{c} f(p_1) + b(p_2) \rightarrow W^+(\rightarrow \nu(p_3) + e^+(p_3)) + b(p_5) + f(p_6) \\ i - f(p_1) + b(p_3) \rightarrow W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_3)) + b(p_5) + f(p_6) \end{array}$	0.0	$\begin{array}{c} 647 & t(\rightarrow q(p_3) + \bar{q}(p_4) + b(p_5)) + t(\rightarrow \bar{\nu}(p_7) + e^-(p_8) + b(p_6)) + H(b(p_9) + b(p_{10})) \\ 651 & t(\rightarrow \nu(p_4) + e^+(p_4) + b(p_5)) + \bar{t}(\rightarrow \bar{\nu}(p_7) + e^-(p_8) + \bar{b}(p_6)) + H(\gamma(p_9) + \gamma(p_{10})) \\ \end{array}$
$10 \qquad \qquad$	$=(p_4)) + c(p_5)$		TO	$f(p_1) + c(p_2) \rightarrow W^-(\rightarrow v(p_3) + e^-(p_4)) + c(p_5) + f(p_6)$ $i - f(p_1) + c(p_2) \rightarrow W^-(\rightarrow e^-(p_3) + v(p_3)) + c(p_5) + f(p_6)$ 1 $f(p_1) - c(p_2) \rightarrow W^-(\rightarrow e^-(p_3) + v(p_3)) + c(p_5) + f(p_6)$ 1	.0	$ \begin{array}{c} 654 \\ t(\rightarrow v(p_{5})+e^{+}(p_{1})+b(p_{5}))+\bar{t}(\rightarrow \bar{q}(p_{7})+q(p_{8})+\bar{b}(p_{5}))+H(\gamma(p_{0})+\gamma(p_{10})) \end{array} \\ \end{array} \\ \begin{array}{c} \text{LO} \\ \end{array}$
$ 19 W^-(\rightarrow e^-(p_3) + i)$	$\overline{\nu}(p_4)) + c(p_5)[\text{massless}]$		LO	$W^{-}(\rightarrow \nu(p_3) + e^{-}(p_4)) + c(p_5) + f(p_6)[cs interaction]$ $W^{-}(\rightarrow e^{-}(p_3) + \bar{\nu}(p_4)) + c(p_5) + f(p_6)[cs interaction]$ $I^{-}(p_6) + f(p_6) - 2^{O_6}(p_6) + c^{O_6}(p_6) + c^{O_6}(p_6) + f(p_6)) + f(p_6) $	0.0	$\begin{array}{l} 657 & t(\rightarrow q p_3 + \bar{q} p_4) + b(p_3)) + t(\rightarrow \bar{\nu} p_7 + e^-(p_8 + b p_6) + H(\gamma(p_8 + \gamma(p_{10})) \\ 661 & t(\rightarrow \nu(p_8)e^+(p_4)b(p_8)) + \bar{t}(\rightarrow \bar{\nu} p_7)e^-(p_8)\bar{b}(p_8)) + H(W^+(p_8, p_{20})W^-(p_{11}, p_{12})) \\ \end{array}$
$ \begin{array}{ccc} 12 & W^+(\rightarrow \nu(p_3) \stackrel{+}{+} e^+(p_4)) + b(p_3) \\ 13 & W^+(\rightarrow \nu(p_3) + e^+(p_4)) + \bar{v}(p_3) \end{array} \end{array} $ NLO NLO	$\begin{array}{c} 107 \\ 107 \\ 2^{0}(\neg 3 \times (\nu(p_{3}) + \bar{\nu}(q_{4})) + H(\neg W^{+}(\nu(p_{5}), e^{+}(p_{6}))W^{-}(e^{-}(p_{7}), \bar{\nu}(p_{6}))) \\ 108 \\ 2^{0}(\neg 3 \times (\nu(p_{3}) + \bar{\nu}(p_{3})) + H(\neg W^{+}(\nu(p_{5}), e^{+}(p_{6}))W^{-}(e^{-}(p_{7}), \bar{\nu}(p_{6}))) \\ 108 \\$	129 $H(\rightarrow Z^*(e^+(p0) + e^+(p0)) + Z^*(e^-(p6) + \mu^-(p6)))$ [only H, gg $\rightarrow ZZ$ 130 $H(\rightarrow Z^*(e^-(p1) + e^+(p1)) + Z^*(e^-(p5) + \mu^+(p6)))$ $ H ^2$ and H gg \rightarrow	ZZ inf. LO	$\begin{array}{c} 1 & - [\gamma_{P_1}) + \gamma_{P_2} = 2 & (-e^{-1}(q_1) + e^{-1}(p_1)) + b(p_2) + \gamma_{P_2} + \gamma_{P_2} + \gamma_{P_2} + (p_1) \\ 342 & f(p_1) + b(p_2) = 2^{0} (-e^{-1}(p_1) + e^{+1}(p_1)) + b(p_2) + f(p_2) + \bar{b}(p_1) \\ 345 & f(p_1) + b(p_2) = Z^0 (-e^{-1}(p_1) + e^{+1}(p_2)) + b(p_2) + f(p_2) + \bar{b}(p_2) \end{array}$	REAL]	$\begin{array}{c} 664 \\ t(\rightarrow \nu(p_3)e^+(p_4)b(p_3)) + \bar{t}(\rightarrow \bar{q}(p_1)q(p_3)\bar{b}(p_3)) + H(W^+(p_3,p_{10})W^-(p_{11},p_{12})) \\ \end{array} \text{LO} \end{array}$
14 $W^+(\rightarrow \nu(p_3) + e^+(p_4)) + \bar{c}(p_4)[massless]$ LO 16 $W^-(\rightarrow e^-(p_4) + \bar{\nu}(p_4)) + f(p_5)$ NLO	$\frac{109}{2^{0}} \frac{Z^{0} - (-p_{0}) + \gamma(q_{1}) + R(-r)}{Z^{0} - e^{-}(p_{1}) + R(q_{2}) + R(-r)} \frac{(-p_{1}) + (-p_{1}) + R(-r)}{(-p_{2}) + (-p_{1}) + (-p_{2}) + R(q_{2}) + (-p_{2}) + (-p_{$	151 $Z = (c_0(q)) + c_0(q)) + Z = (p_0(p_0) + p_0(p_0)) (g_0 - g_0 - g_0)$ 152 $Z^{(0)}(c^{-1}(q)) + c^{(0)}(q) + Z^{(0)}(c^{-1}(q)) + \mu^{+}(q)) [(g_0 - g_0) - g_0 - g_0)]$ 1281 $H(\rightarrow e^{-1}(q)) + e^{+1}(q) + c_0(q) (q) = h^{+1}(q)$ [top, horizon longe, exact]	LO LO	$347 f(p_1) + b(p_2) \rightarrow Z^0(\rightarrow e^-(p_3) \; 84e^+(p_4)) + b(p_5) + f(p_6) + b(p_7) \qquad 1$.0	$\begin{array}{c c c c c c c c c c c c c c c c c c c $
17 $W^-(\rightarrow e^-(p_5) + \theta(p_4)) + b(p_5)$ NLO 18 $W^-(\rightarrow e^-(p_5) + \theta(p_4)) + c(p_5)$ NLO	$\begin{array}{ c c c c c c c c c c c c c c c c c c c$	$\begin{array}{c} 1311 & e^{-}(p3) + e^{+}(p4) + v_{e}(p5) + \bar{\nu}_{e}(p6) & [gg \ only, \ [H + gg - ZZ] \ squared] \\ 1321 & e^{-}(p3) + e^{+}(p4) + v_{e}(p5) + e_{+}(p6) & [gg - ZZ] \ squared] \\ 1331 & e^{-}(p3) + e^{+}(p4) + v_{e}(p5) + e^{-}(p4) & [gg - ZZ] & [gg - ZZ] \\ 1331 & e^{-}(p3) + e^{-}(p4) + e^{-}(p4) & [gg - ZZ] & [gg - ZZ] \\ 1331 & e^{-}(p3) + e^{-}(p4) + e^{-}(p4) & [gg - ZZ] & [gg - ZZ] \\ 1331 & e^{-}(p3) + e^{-}(p4) + e^{-}(p4) & [gg - ZZ] & [gg - ZZ] \\ 1331 & e^{-}(p4) + e^{-}(p4) + e^{-}(p4) & [gg - ZZ] & [gg - ZZ] \\ 1331 & e^{-}(p4) + e^{-}(p4) + e^{-}(p4) & [gg - ZZ] & [gg - ZZ] & [gg - ZZ] \\ 1331 & e^{-}(p4) + e^{-}(p4) + e^{-}(p4) & [gg - ZZ] & [gg - ZZ] & [gg - ZZ] \\ 1331 & e^{-}(p4) + e^{-}(p4) + e^{-}(p4) & [gg - ZZ] & [gg - ZZ] & [gg - ZZ] & [gg - ZZ] \\ 1331 & e^{-}(p4) + e^{-}(p4) + e^{-}(p4) & [gg - ZZ] &$	LO 3 LO 3	$\frac{351}{52} \left[\frac{f(p_1 + c(p_2 \rightarrow Z^0(\rightarrow e^-(p_1) + e^+(p_2)) + c(p_1 + f(p_2) + f(p_2))}{522} \right] \frac{f(p_1 + c(p_2 \rightarrow Z^0(\rightarrow e^-(p_1) + e^+(p_1)) + c(p_1 + f(p_2) + f(p_2))}{522} \right]$	(REAL)	800 $V \rightarrow (\chi(p_3) + \tilde{\chi}(p_4)) + f(p_5)$ [Vector Mediator] NLO 801 $A \rightarrow (\chi(p_3) + \tilde{\chi}(p_5)) + f(p_5)$ [Avial Vector Mediator] NLO
$\begin{array}{c c c c c c c c c c c c c c c c c c c $	114 $H(\rightarrow W^+(\nu(p_3) + e^+(p_4)) + W^-(q(p_5) + \tilde{q}(p_6)))$ NLO 115 $H(\rightarrow W^+(\nu(p_3) + e^+(p_4)) + W^-(q(p_5) + \tilde{q}(p_6)))[rad.in.dk]$ NLO NLO	1312 $ \mathbf{n}(\rightarrow e_{-} \mathbf{p}\mathbf{a}) + e_{-} \mathbf{p}\mathbf{a}\rangle + e_{+} \mathbf{p}\mathbf{a}\rangle + e_{+} \mathbf{p}\mathbf{a}\rangle + e_{+} \mathbf{p}\mathbf{a}\rangle$ [1312 $ \mathbf{e}^{-} \mathbf{p}\mathbf{a}\rangle + e_{-} \mathbf{p}\mathbf{a} + e_{+} \mathbf{p}\mathbf{a}\rangle + e_{+} \mathbf{p}\mathbf{a}\rangle$ [322 $ \mathbf{e}^{-} \mathbf{p}\mathbf{a}\rangle$ squared]	LO LO	$\frac{356}{f(p_1) + c(p_2)} \rightarrow Z^0 (\rightarrow e^-(p_1) + e^+(p_1)) + c(p_1) + f(p_1) + f(p_1)$ $\frac{357}{f(p_1) + c(p_2)} \rightarrow Z^0 (\rightarrow e^-(p_1) + e^+(p_1)) + c(p_2) + f(p_1) + \bar{c}(p_7)$	LO	802 $S \rightarrow (\chi(p_3) + \bar{\chi}(p_4)) + f(p_5)$ [Scalar Mediator] NLO
21 $W^+(-\nu(p_3) + e^+(p_4)) + f(p_5) + b(p_6)$ NLO 22 $W^+(-\nu(p_3) + e^+(p_4)) + f(p_5) + f(p_6)$ NLO	$\begin{array}{ccc} 116 & H(\rightarrow Z^0(c^-(p_1) + c^+(p_4)) + Z^0(\mu^-(p_5) + \mu^+(p_6)) \\ 117 & H(\rightarrow Z^0(3 \times \{\nu(p_3) + \bar{\nu}(p_4)\}) + Z^0(\mu^-(p_3) + \mu^+(p_6)) \\ 118 & H(\rightarrow Z^0(c^-(p_3) + \mu^+(p_3)) + Z^0(\mu^-(p_3) + \mu^+(p_6)) \\ \end{array} \end{array}$ NLO	$\begin{array}{ccc} 133 & H(\rightarrow Z^{0}(e^{-}(p3)+e^{+}(p4))+Z^{0}(e^{-}(p5)+\mu^{+}(p6)+f(p7)) \mbox{ [intf,no]} \\ 136 & H(\rightarrow b(p_{3})+b(p_{3}))+b(p_{3})(+g(p_{6})) \end{array}$	v cut LO 3 NLO 5	361 $ c(p_1) + \bar{v}(p_2) \rightarrow W^+(\rightarrow v(p_2) + e^+(p_2)) mc=0 \text{ in NLO} $ 362 $ c(p_1) + \bar{v}(p_2) \rightarrow W^+(\rightarrow v(p_1) + e^+(p_1)) massless corrections only $	NLO NLO	$\begin{array}{l} 803 PS \rightarrow (\chi(p_1) + \chi(p_4)) + f(p_5) \ [Pseudo Scalar Meinator] \\ 804 GG \rightarrow (\chi(p_1) + \bar{\chi}(p_4)) + f(p_5) \ [Ghuonic DM operator] \\ \end{array}$ NLO
25 $W' (\rightarrow \nu(p_3) + e^{-(p_4)}) + b(p_3) + f(p_7) + D(p_1) + D(p_1) + D(p_2) + D(p_3) + D(p_1) + D(p_2) + D(p_3) + D(p_3$	$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	(REAL) 3	$363 c(p_1) + \delta(p_2) \rightarrow W^+(\rightarrow \nu(p_1) + e^+(p_1))$ (massive charm in real) $370 W^+(\rightarrow \delta(p_1) + e^+(p_1)) + \gamma(p_2) + \gamma(p_1)$	NLO LO	$\frac{805}{890} \frac{S(\chi(p_3) + \bar{\chi}(p_4)) + f(p_5)}{Scalar Mediator, mt loops} \frac{NLO}{NLO + F}$
26 $W^-(\rightarrow e^-(p_1) + b(p_2)) + b(p_3) + b(p_4) \text{Indexival}$ 26 $W^-(\rightarrow e^-(p_3) + b(p_4)) + b(p_3) + b(p_4)$ NLO 27 $W^-(\rightarrow e^-(p_3) + b(p_3)) + b(p_3) + b(p_4) + b(p_4)$ NLO	121 $H \rightarrow Z^0(3 \times (\nu(p_3) + \nu(p_4))) + \gamma(p_5))$ NLO	$\begin{array}{ccc} 141 & t(\rightarrow \nu(p_3) + e^+(p_3) + b(p_5)) + \bar{t}(\rightarrow b \ (p_5) + e^-(p_7) + \bar{v}(p_5)) \\ 142 & t(\rightarrow \nu(p_3) + e^+(p_3) + b(p_5)) + \bar{t}(\rightarrow b \ (p_5) + e^-(p_7) + \bar{v}(p_5)) \ (\text{rad}. \end{array}$	in.dk] NLO 3	$\frac{871}{10} \frac{W^{-1}(\rightarrow a^{-1}(p_{1}) + b(p_{1})) + \gamma(p_{3}) + \gamma(p_{4})}{101} \frac{W^{-1}(\rightarrow a(p_{1}) + b(p_{1})) + \gamma(p_{3}) + \gamma(p_{4})}{12 \text{ ar } 3 \text{ yets } 4FNS}$	1.0	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$
28 $W^-(\rightarrow e^-(p_1) + \bar{\nu}(p_1)) + f(p_2) + f(p_3) + f(p_7)$ LO 29 $W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_4)) + f(p_3) + f(p_3) + f(p_7)$ LO	$\frac{56}{61} \frac{Z^9(\rightarrow e^-(p_3) + e^+(p_4)) + e(p_5) + \bar{e}(p_4)}{W^+(\rightarrow \nu(p_3) + e^+(p_4)) + W^-(\rightarrow e^-(p_5) + \bar{\nu}(p_6))} \qquad \text{NLO}$	143 $t(\rightarrow \nu(p_3) + e^+(p_3) + b(p_5)) + \bar{t}(\rightarrow b(p_5) + e^-(p_7) + \bar{v}(p_8)) + f(-144)$ 144 $t(\rightarrow \nu(p_3) + e^+(p_3) + b(p_5)) + \bar{t}(\rightarrow b(p_6) + e^-(p_7) + \bar{v}(p_8))$ (unc	pg) LO orr) NLO	402 $W^+(\rightarrow p_1) + e^+(p_1)) + (b + b)(p_2) [1 or 2 jets, 4FNS]$ 403 $W^+(\rightarrow p_1) + e^+(p_1)) + (b + b)(p_2) [2 or 2 jets, 4FNS]$	NLO NLO	$ \begin{array}{ll} 822 & S \rightarrow (\chi(p_3) + \bar{\chi}(p_4)) + \gamma(p_5) [\text{Scalar Mediator}] & \text{NLO} + F \\ 823 & PS \rightarrow (\chi(p_3) + \bar{\chi}(p_4)) + \gamma(p_5) [\text{Pseudo Scalar Mediator}] & \text{NLO} + F \\ \end{array} $
$\frac{20}{31} = \frac{20}{2} (- e^{-(p_1) + v(p_1) + v(p_2) + v(p_1) + v(p_2) + v(p_1) + v(p_2)}) = \frac{20}{31} = \frac{20}{2} (-e^{-(p_1) + e^{+(p_2)} + v(p_1) + v(p_2) + v(p_2) + v(p_1) + v(p_2) + v(p_2$	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	in.dk],uncorr NLO NLO	$\begin{array}{l} w_{-}(-e^{-}\rho_{0}) + e^{-}(p_{0}) + e^{-}(p_{0}) + e^{-}(p_{0}) \\ w_{-}(-e^{-}(p_{0}) + \bar{\nu}(p_{0})) + b(\rho_{0}) \\ \end{array} \\ \left[1, 2 \text{ or } 3 \text{ jets. 4FNS} \right] \end{array}$	NLO	840 $V \rightarrow \langle \chi(p_3) + \bar{\chi}(p_3) \rangle + f(p_3) + f(p_4)$ [Vector Mediator] LO
$\begin{array}{cccc} 3z & Z^{(-)} \rightarrow S \land (r_{0}(y_{1}) + \bar{v}(y_{1}))) \\ 33 & Z^{(0)} \rightarrow (p_{3}) + \bar{b}(p_{3})) \\ 24 & Z^{(0)} \rightarrow (y_{2}) \land (\bar{d}(y_{1}))) \\ \end{array}$ NLO	$\begin{array}{l} 64 & W^{-}(\rightarrow e^{-}(p_{3}) + \bar{\nu}(p_{4}))W^{+}(\rightarrow q(p_{5}) + \bar{q}(p_{6})) \\ 65 & W^{-}(\rightarrow e^{-}(p_{3}) + \bar{\nu}(p_{4}))W^{+}(\rightarrow q(p_{5}) + \bar{q}(p_{6}))[rad \operatorname{in} dk] \end{array} $ NLO	147 $t(\rightarrow \nu(p_3) + e^+(p_3) + b(p_5)) + \tilde{t}(\rightarrow b(p_5) + q(p_7) + \tilde{q}(p_5))$ [rad in 148 $t(\rightarrow \nu(p_3) + e^+(p_3) + b(p_5)) + \tilde{t}(\rightarrow b(p_5) + q(p_7) + \tilde{q}(p_5))$] [rad in	Ltop.dk] NLO 4 LW.dk] NLO 4	$\frac{407}{W} = \frac{e^{-}(p_1) + v(p_1)) + (b + b)(p_2)}{1 \text{ or } 2 \text{ pes. 4FNS}}$ $\frac{408}{W} = \frac{W^-(\rightarrow e^-(p_1) + \tilde{v}(p_1)) + b(p_1) + b(p_2)}{1 \text{ or } 3 \text{ jets. 4FNS}}$	NLO	811 $A \rightarrow (\chi(p_3) + \chi(p_4)) + f(p_3) + f(p_6)$ [AXIA Vector Jaconator] LO 842 $S \rightarrow (\chi(p_3) + \bar{\chi}(p_4)) + f(p_8) + f(p_6)$ [Scalar Mediator] LO
$\begin{array}{cccc} 37 & Z & (-3 \times (u(p_0) + \bar{u}(p_0))) \\ 35 & Z^0 (-2 \times (u(p_0) + \bar{u}(p_0))) \\ 26 & Z & (u(p_0) + \bar{u}(p_0)) + \bar{v}(-1) + \bar{v}(-1) + \bar{v}(-1) + \bar{v}(-1) \\ \end{array}$ NLO	$\begin{array}{ccc} 66 & W^+(\rightarrow \nu(p_3) + e^+(p_4)) + W^-(\rightarrow e^-(p_5) + \bar{\nu}(p_5)) + f(p_7) & \text{LO} \\ 69 & W^+(\rightarrow \nu(p_3) + e^+(p_4)) + W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_6)) [\text{no pol}] & \text{LO} \end{array}$	149 $t \mapsto q(p_3) + q(p_4) + b(p_5) + t \mapsto b(p_5) + e^-(p_7) + b(p_8)$ 150 $t \mapsto q(p_4) + \tilde{q}(p_4) + b(p_5) + \tilde{t} \mapsto b(p_5) + e^-(p_7) + b(p_8)$ [rad in 151 $t \mapsto q(p_4) + \tilde{q}(p_4) + \tilde{q}(p_4) + \tilde{t} \mapsto b(p_5) + e^-(p_7) + b(p_8)$] [rad in	top.dk] NLO	$\begin{array}{l} 411 & f(p_1) + b(p_2) \rightarrow W^+(\rightarrow \nu(p_1) + e^+(p_4)) + b(p_5) + f(p_6) & [5FNS] \\ 416 & f(p_1) + b(p_2) \rightarrow W^-(\rightarrow e^-(p_6) + \bar{\nu}(p_6)) + b(p_5) + f(p_6) & [5FNS] \end{array}$	NLO NLO	843 $PS \rightarrow (\chi(p_i) + \bar{\chi}(p_i)) + f(p_i) + f(p_i)$ [Pseudo Scalar Modiator] LO 844 $GG \rightarrow (\chi(p_i) + \bar{\chi}(p_i)) + f(p_i) + f(p_i)$ [Chaonic DM operator] LO
$\begin{array}{cccc} 0 & Z & = (-z_1 - z_1) + (-z_1 - z_2) + ($	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$	157 [f[for total Xseet] 158 [a][for total Xseet]	NLO 4	421 $W^+(\rightarrow \phi(p_3) + e^+(p_4)) + b(p_5)$ [1,2 or 3 jets, 4FNS+5FNS] 426 $W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_5)) + b(p_5)$ [1,2 or 3 jets, 4FNS+5FNS]	NLO NLO	845 $V \rightarrow (\chi(p_3) + \bar{\chi}(p_1)) + \gamma(p_5) + f(p_6)$ [Vector Mediator] LO
43 $Z^0(\rightarrow b(p_1) + b(p_2)) + f(p_3)$ NLO 44 $Z^0(\rightarrow b(p_1) + b(p_1)) + f(p_3)$ NLO	$\begin{array}{l} 73 & W^+(\rightarrow \nu(p_3) + \mu^+(p_4)) + Z^0(\rightarrow b(p_5) + \bar{b}(p_6)) \\ 74 & W^+(\rightarrow \nu(p_3) + \mu^+(p_4)) + Z^0(\rightarrow 3 \times (d(p_3) + \bar{d}(p_6))) \end{array} \end{array} \qquad $	159 c^2 [for total Xsect] 160 ff + g[for total Xsect]	NLO 4 LO 4	$\frac{131}{W^+(\rightarrow s(p_i) + e^+(p_i)) + b(p_i) + b(p_i) + f(p_i)} \max interve$ $\frac{136}{W^-(\rightarrow e^+(p_i) + b(p_i)) + b(p_i) + b(p_i) + f(p_i)} \max interve$	10	846 $A \rightarrow (\chi(p_3) + \chi(p_4)) + \gamma(p_5) + f(p_6)$ [Axial Vector Mediator] LO 847 $S \rightarrow (\chi(p_3) + \bar{\chi}(p_4)) + \gamma(p_5) + f(p_6)$ [Scalar Mediator] LO
45 $Z^{(-)} \rightarrow c^{-}(p_{3}) + c^{-}(p_{4}) + f(p_{5}) + f(p_{6}) + f(p_{7})$ 46 $Z^{(0)} \rightarrow c^{-}(p_{3}) + c^{+}(p_{4}) + f(p_{5}) + f(p_{5}) + f(p_{7})$ 46 $Z^{(0)} \rightarrow 3 \times (q(p_{3}) + \tilde{q}(p_{3})) + f(p_{5}) + f(p_{7})$	$\begin{array}{ccc} 75 & W^+(\rightarrow \nu(p_3) + \mu^+(p_4)) + Z^0(\rightarrow 2 \times (u(p_5) + \bar{u}(p_6))) & \text{NLO} \\ \hline 76 & W^-(\rightarrow \mu^-(p_5) + \bar{\nu}(p_4)) + Z^0(\rightarrow e^-(p_5) + e^+(p_6)) & \text{NLO} \end{array}$	$\begin{array}{ccc} 161 & t(\rightarrow \nu \langle p_3 \rangle + e^+ \langle p_4 \rangle + b \langle p_5 \rangle \rangle + q \langle p_4 \rangle [t-channel] \\ 162 & t(\rightarrow \nu \langle p_3 \rangle + e^+ \langle p_4 \rangle + b \langle p_5 \rangle \rangle + q \langle p_6 \rangle [decay] \end{array}$	NLO NLO	500 $W^+(\rightarrow u[p_1] + v[p_1]) + t[p_2] + t[p_3] + t[p_3] + t[p_3]$ (massive) + $t^{-1}(p_1) + t^{-1}(p_1) + t^{-1}(p_2) + t^{-1}(p_3) + t^{-1}($	NLO NLO	848 $PS \rightarrow (\chi(p_3) + \bar{\chi}(p_4)) + \gamma(p_5) + f(p_6)$ [Pseudo Scalar Mediator] LO 1002 Check of Vidence of 2 norticle where space
47 $Z^{(-)} \rightarrow S \times (\nu(p_3) + \nu(p_4)) + f(p_3) + f(p_6) + f(p_7)$ LO 50 $Z^{(0)} \rightarrow S \times (\nu(p_3) + \nu(p_4)) + f(p_6) + f(p_6) + f(p_7)$ LO	$\begin{array}{l} 77 W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_4)) + Z^0(\rightarrow 3 \times (\nu_e(p_3) + \bar{\nu}_e(p_6))) \\ 78 W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_4)) + Z^0(\rightarrow b(p_3) + \bar{b}(p_6)) \\ & \text{NLO} \end{array}$	$\begin{array}{c} 163 & t(\rightarrow \nu(p_3) + e^+(p_3) + b(p_3)) + q(p_3)[e-channel]wb > 0\\ 166 & t(\rightarrow e^-(p_3) + b(p_3) + b(p_3)) + q(p_3)[e-channel] \end{array}$	NLO NLO	$\frac{1}{1(-\nu)p_0} + e^{-(p_0)} + a(p_0) + u(-\nu)p_0 + e^{-(p_0)} + e^{-(p_0)} + u^{-(p_0)}p_0), \mu^{-(p_0)}$ (some as process 501 but with radiation in decay)	NLO	903 Check of Volume of 3 particle phase space
$\begin{array}{cccc} 50 & Z^{*}(\rightarrow e^{-}(y_{4}) + e^{+}(y_{4})) + b(y_{5}) + b(y_{6}) (\text{massive}) & \text{LO} \\ 51 & Z^{0}(\rightarrow e^{-}(y_{5}) + e^{+}(y_{4})) + b(y_{5}) + b(y_{6}) & \text{NLO} \\ \end{array}$	$\begin{array}{ll} 79 & W^-(\rightarrow e^-(p_5) + \bar{\nu}(p_4)) + Z^0(\rightarrow 3 \times (d(p_5) + d(p_6))) & \text{NLO} \\ 80 & W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_4)) + Z^0(\rightarrow 2 \times (u(p_5) + \bar{u}(p_6))) & \text{NLO} \end{array}$	167 $[(-e^{-}(p_1) + \delta(p_3) + \delta(p_5)) + q(p_5)]$ rad.in.dk] 168 $[(-e^{-}(p_3) + \delta(p_3) + \delta(p_5)) + q(p_5)]$ (e-channel] $mb > 0$ 171 $[(-e^{-}(p_3) + \delta(p_3) + \delta(p_5)) + q(p_5)]$ (e-channel] $mb > 0$	NLO NLO	$\begin{array}{l} 503 & t(\rightarrow \nu(p_{3}) + e^{+}(p_{4}) + 0(p_{3})) + t(\rightarrow b^{-}(p_{6}) + q^{-}(p_{7}) + q^{-}(p_{6})) + W^{+}(\nu(p_{3}), \mu^{+}(p_{10})) \\ 506 & 1(\rightarrow q(p_{2}) + q^{-}(p_{4}) + b(p_{5})) + b^{-} \rightarrow b^{-}(p_{7}) + e^{-}(p_{7}) + \nu^{-}(\nu(p_{3}), \mu^{+}(p_{10})) \end{array}$	NLO NLO	904 Check of Volume of 4 particle phase space 905 Check of Volume of 5 particle phase space
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	$\begin{array}{lll} \$1 & \mathbb{Z}^{9}(\rightarrow e^{-}(p_{3}) + e^{+}(p_{4})) + \mathbb{Z}^{0}(\rightarrow \mu^{-}(p_{5}) + \mu^{+}(p_{6})) & \text{NLO} \\ \$2 & \mathbb{Z}^{9}(\rightarrow e^{-}(p_{3}) + e^{+}(p_{4})) + \mathbb{Z}^{0}(\rightarrow 3 \times (\nu(p_{5}) + \bar{\nu}(p_{6}))) & \text{NLO} \end{array}$	171 $t(\rightarrow \nu(p_3) + e^+(p_4) + o(p_5)) + o(p_6))$ [s-manne] 172 $t(\rightarrow \nu(p_3) + e^+(p_3) + b(p_5)) + \bar{b}(p_6))$ [decay] 176 $(\bar{t}(\rightarrow \nu(p_3) + b(p_3) + b(p_5)) + \bar{b}(p_5))$ [decay]	NLO NLO	510 $W^-(\rightarrow e^-(p_1) + \bar{\nu}(p_1)) + t(p_2) + t(p_3)$ massive 511 $t(\rightarrow \nu p_1) + e^+(p_3) + t(p_3) + \bar{v}(\rightarrow b p_4) + e^-(p_2) + \bar{\nu}(p_3)) + W^-(\mu^-(p_4), \bar{\nu}(p_3))$	NLO NLO	906 Check of Volume of 6 particle phase space
04 $Z (\rightarrow v (03) + v (04)) + v(03) + v(04) + f(05)$ πc	$\begin{array}{llllllllllllllllllllllllllllllllllll$	$\frac{116}{110} = \frac{1}{10} \left[-\epsilon - \left(p_0 \right) + \phi(p_0) + \phi(p_0) \right] + b(p_0) \right] = \min[k] = \frac{1}{100} \left[177 - \left[\left(-\epsilon - \left(p_0 \right) + \phi(p_0) + b(p_0) \right) + b(p_0) \right] \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + b(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + \phi(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + b(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + b(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + b(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + b(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + b(p_0) + b(p_0) \right] = \frac{1}{100} \left[180 - W^- (p_0) + b(p_0) + b(p_0) \right]$	NLO	512 (same as process 511 but with radiation in decay) 513 $t(\rightarrow \nu(p_1) + e^+(p_2) + b(p_2)) + t(\rightarrow b(p_1) + \rho(p_2) + a(p_2)) + W^-(\mu^-(p_1), \rho(p_2))$	NLO NLO	908 Check of Volume of 8 particle massive phase space 909 Check of Volume of 4 particle massive phase space
	$\begin{array}{c c c c c c c c c c c c c c c c c c c $	181 $W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_4)) + t(\nu(p_5) + e^+(p_6) + b(p_7))$ 182 $W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_4)) + t(\nu(p_5) + e^+(p_6) + b(p_7))$ [rad.in.db]	NLO NLO	516 $1(\rightarrow q(p_1) + q(p_1) + b(p_1)) + \hat{1}(\rightarrow b(p_k) + e^-(p_1) + b(p_k)) + W^-(\mu^-(p_2), b(p_{1k}))$ (29) $2^{Q_{1,2}} = (-m_1 + e^-(m_1)) + b(p_1) + \hat{1}(m_1)$	NLO	910 Check of Volume of 3 particle (2 massive) phase space 911 Check of Volume of 5 particle W14 (with durin) marries absorber
	87 $Z^{q}(\rightarrow e^{-}(p_{3}) + e^{+}(p_{4})) + Z^{0}(\rightarrow 3 \times (\nu(p_{5}) + \bar{\nu}(p_{6})))[\text{no gamma}^{*}]$ NLO 88 $Z^{q}(\rightarrow e^{-}(p_{3}) + e^{+}(p_{4})) + Z^{0}(\rightarrow b(p_{5}) + \bar{b}(p_{6}))[\text{no gamma}^{*}]$ NLO	$\begin{array}{c} 183 & W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_4)) + t(\nu(p_b) + e^+(p_b) + b(p_7)) + b(p_8) \\ 184 & W^-(\rightarrow e^-(p_3) + \bar{\nu}(p_4)) + t(p_5) + b(p_6) \\ \end{array}$	LO LO	$\begin{array}{l} z_{1} \rightarrow z_{1} (p_{1}) + c_{1} p_{2} (p_{1}) + c_{1} p_{3} (p_{1}) + c_{1} p_{3} (p_{1}) \\ z_{1} = z_{1} (p_{2}) + c_{1} (p_{1}) + c_{1} (p_{2}) + c_{1} (p_{2}) + s_{1} (p_{2}) + s_{1} (p_{3}) + b_{1} (p_{3}) + 2(c_{1} (p_{3}), c_{1} (p_{3})) \\ z_{1} = z_{1} (p_{2}) + c_{2} (p_{3}) + c_{1} (p_{3}) + c_{2} (p_{3}) + c_{3} (p_{3}) + c_{3} (p_{3}) + c_{3} (p_{3}) + c_{3} (p_{3}) \\ z_{1} = z_{1} (p_{3}) + c_{3} (p_{3}) \\ z_{2} = z_{1} (p_{3}) + c_{3} (p_{3$	LO	911 Check of Volume of 5 particle W+4 (no decay) massive phase space 912 Check of Volume of 5 particle W+4 (no decay) massive phase space
	89 $Z^{\gamma}(\rightarrow b(p_{h}) + b(p_{1})) + Z^{\nu}(\rightarrow 3 \times (\nu(p_{5}) + b(p_{6}))) [\text{no gamma}^{*}]$ NLO 90 $Z^{0}(\rightarrow e^{-}(p_{3}) + e^{-}(p_{4})) + Z^{0}(\rightarrow e^{-}(p_{5}) + e^{+}(p_{5}))$ NLO 91 $Z^{0}(\rightarrow e^{-}(p_{3}) + e^{-}(p_{4})) + Z^{0}(\rightarrow e^{-}(p_{5}) + e^{+}(p_{5}))$ NLO	$\begin{array}{ccc} 185 & W^+(\rightarrow \nu(p_3) + e^+(p_4)) + \bar{\nu}(p_b) \\ 186 & W^+(\rightarrow \nu(p_3) + e^+(p_4)) + \bar{\ell}(e^-(p_3) + \bar{\nu}(p_6) + \bar{b}(p_7) \\ \dots & \dots \\ \mu^+(e^+,e^+) + e^+(p_4)) + \bar{\mu}(e^-(p_3) + e^+(p_6)) + \bar{\nu}(e^-(p_7)) \\ \dots & \dots \\ \mu^+(e^+,e^+) + e^+(p_4) + e^+(p_4) + e^+(p_6) \\ \dots & \dots \\ \mu^+(e^+,e^+) + e^+(p_4) + e^+(p_6) \\ \dots & \dots \\ \mu^+(e^+,e^+) + e^+(p_6) + e^+(p_6) \\ \dots & \dots \\ \mu^+(e^+,e^+) + e^+(p_6) + e^+(p_6) \\ \dots & \dots \\ \mu^+(e^+,e^+) + e^+(p_6) + e^+(p_6) \\ \dots & \dots \\ \mu^+(e^+,e^+) + e^+(p_6) + e^+(p_6) \\ \dots & \dots \\ \mu^+(e^+,e^+) \\ \dots & \mu^+($	NLO NLO	$\begin{array}{l} \sin i & (-v_1p_1) + v_2p_2) + a(p_2) + a(p_2) + b(-v_1p_2) + b(p_2) + b(p_2) + 2(o(p_1), k(p_2)) \\ \sin 2 & (-v_1p_2) + c^+(p_1) + b(p_2)) + b(-v_1p_2) + b(p_2) + b(p_3)) + 2(c^-(p_2), c^+(p_1)) \end{array}$	1.0	913 Check of Volume of 5 particle W+t+g (in decay) massive phase space 914 Check of Volume of 5 particle W+t+g (in production) massive phase space
	91 $W^+(\rightarrow \nu(p_3) + e^+(p_4)) + H(\rightarrow b(p_5) + b(p_6))$ NLO 92 $W^+(\rightarrow \nu(p_3) + e^+(p_4)) + H(\rightarrow W^+(\nu(p_5), e^+(p_6))W^-(e^-(p_7), \theta(p_5)))$ NLO 93 $W^+(\rightarrow \nu(p_3) + e^+(p_4)) + H(\rightarrow W^+(\nu(p_5), e^+(p_6)))W^-(e^-(p_7), \theta(p_5)))$ NLO	$[187]$ $W^{-}(\rightarrow \nu(p_3) + e^{-}(p_4)) + t(e^{-}(p_5) + \theta(p_7) + \theta(p_7)]$ rad.in.dk]	NLO	$333 1(\rightarrow q(p_1) + q(p_1) + b(p_2)) + t(\rightarrow e^-(p_1) + b(p_2) + b^-(p_3)) + Z(e^-(p_3), e^+(p_{10}))$	1/0	· · · · · · · · · · · · · · · · · · ·
	$\begin{array}{ll} 93 & W^+(\rightarrow\nu\mu_3) + e^+(p_1)) + H(\rightarrow Z(e^-(p_5), e^+(p_6)) + Z(\mu^-(p_7), \mu(p_5))) \\ 94 & W^+(\rightarrow\nu(p_3) + e^+(p_1)) + H(\rightarrow\gamma(p_5) + \gamma(p_6) \\ 0e^+ W^+(\rightarrow\nu(p_3) + e^+(p_1)) + H(\rightarrow\gamma(p_5) + \gamma(p_6) \\ W^+(\rightarrow\nu(p_3) + e^+(p_1)) + H(\rightarrow\nu(p_5) + \gamma(p_6) \\ W^+(\rightarrow\nu(p_3) + e^+(p_1)) + H(\rightarrow\nu(p_3) + \gamma(p_6) \\ W^+(\rightarrow\nu(p_3) + e^+(p_1)) + H(\rightarrow\nu(p_5) + \gamma(p_6) \\ W^+(\rightarrow\nu(p_3) + e^+(p_1)) + H(\rightarrow\nu(p_3) + \varphi(p_3) \\ W^+(\rightarrow\nu(p_3) + e^+(p_1)) + H(\rightarrow\nu(p_3) + \varphi(p_3) \\ W^+(\rightarrow\nu(p_3) + e^+(p_1)) + H(\rightarrow\nu(p_3) + \varphi(p_3) \\ W^+(\rightarrow\nu(p_3) + e^+(p_3) \\ W^+(\rightarrow\nu(p_3) + e^+(p_$					
F. Olness	$\begin{array}{l} 96\\ 97\\ W^-(\rightarrow e^-(p_3) + \bar{v}(p_4)) + H(\rightarrow b(p_5) + u(p_6))\\ 97\\ W^-(\rightarrow e^-(p_5) + v(p_4)) + H(\rightarrow W^+(\nu(p_5), e^+(p_6))W^-(e^-(p_7), \bar{\nu}(p_5)))\\ n_0\\ W^-(\rightarrow e^-(p_5) + v(p_4)) + H(\rightarrow W^+(\nu(p_5), e^+(p_5))) + 2(-e^-(p_5) + v(p_5))\\ NLO\\ n_0\\ W^-(\rho_5) + (\rho_5) + (\rho_5) + (\rho_5) + 2(-e^-(p_5)) + 2(-e^-(p_5)) + 2(-e^-(p_5)) \\ NLO\\ NLO\\ NLO\\ NLO\\ NLO\\ NLO\\ NLO\\ NL$					
	$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$					



www.xFitter.org

Sample data files: LHC: ATLAS, CMS, LHCb Tevatron: CDF, D0 HERA: H1, ZEUS, Combined Fixed Target: ... User Supplied: ...

Theoretical costs sections
 Comparisons to other PDFs (LHAPDF)

Features & Recent Updates:

Photon PDF & QED Pole & MS-bar masses Profiling and Re-Weighting Heavy Quark Variable Treshold Improvements in χ^2 and correlations TMD PDFs (uPDFs) ... and many other

xFitter 2.0.1 Old Fashioned

14

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Charged Current Charm Production Constrains Strange PDF₁₅



New Tools

PDFSense & & ... borrowing from AI

TensorFlow Embedding Projector

https://metapdf.hepforge.org/PDFSense/

Reads 2 .tsv files with vectors and metadata (descriptions of data points)



Principal Component Analysis (PCA) visualizes the 56-dim. manifold by reducing it to 10 dimensions (à la META PDFs)

http://projector.tensorflow.org

t-distributed stochastic neighbor embedding (t-SNE) sorts vectors according to their similarity

$$r_i(\vec{a}) = \frac{1}{s_i} \left(T_i(\vec{a}) - D_{i,sh}(\vec{a}) \right)$$

Conclusion

One accurate measurement is worth monomous a thousand expert opinions



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