

# FONLL official code usage development

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- ▶ **FONLL** calculation: **NLO+NLL**
- ▶  $d\sigma_I^{FONLL} = d\sigma_Q^{FONLL} \otimes D_{Q \rightarrow H_Q}^{NP} \otimes g_{H_Q \rightarrow I}^{\text{weak}}$
- ▶ predict to bottom and charm production by default;

bottom:

$$D_{Q \rightarrow H_Q}^{NP} = (\alpha + 1)(\alpha + 2)x^\alpha(1 - x) \quad (\text{Kartvelishvili})$$

with one parameter  $\alpha = 24.2$  ( $m_b = 4.75$  [GeV]) for all B mesons

charm:

use BCFY<sup>†</sup> for each  $D_{c \rightarrow D^*}^{NP}$ ,  $D_{c \rightarrow D^+}^{NP}$  and  $D_{c \rightarrow D^0}^{NP}$

- ▶ uncertainty:  $\Delta_{\pm} = \sqrt{\Delta_{\pm, \text{scales}}^2 + \Delta_{\pm, \text{mass}}^2 + \Delta_{\pm, \text{PDF}}^2}$

<sup>||</sup>Cacciari, M., Frixione, S., Houdeau, N. et al. Theoretical predictions for charm and bottom production at the LHC. J. High Energ. Phys. 2012, 137 (2012)

<sup>†</sup>M. Cacciari, P. Nason, JHEP 0309 (2003) 006

# Why not the FONLL web<sup>§</sup>

Grid is fixed in the web; collider type, PDF sets, quark masses are fixed.

The screenshot shows the FONLL web interface with the following settings:

- Collider:** LHC (pp, 13 TeV) [ptmax ≤ 300 GeV]
- PDFs:** CTEQ6.6
- Perturbative order:** FONLL
- Heavy quark:** bottom
- Hadronic final state:** bare quark
- Further decay:** -
- Cross section type:**  $d\sigma/dpt$
- ptmin (GeV):** 5
- ptmax (GeV):** 20
- y(eta)min:** -1
- y(eta)max:** 1
- Use y** (radio button selected)
- npoints:** 2
- central prediction only** (checkbox checked)
- Output all scales** (checkbox unchecked)
- Include PDFs uncertainties** (checkbox unchecked)
- Non-pert. Fragm. Funct.:** default
- Non-pert. parameter =** default
- Use default N=5 moment** (checkbox checked)
- Fragmentation Fraction  $c \rightarrow D$ :** 1
- Fragmentation Fraction  $b \rightarrow B$ :** 1
- BR( $D \rightarrow l$ )**: 0.103
- BR( $B \rightarrow l$ )**: 0.1086
- BR( $B \rightarrow D \rightarrow l$ )**: 0.096
- BR( $B \rightarrow D$ )**: 0.823
- BR( $B \rightarrow D^*$ )**: 0.173
- BR( $B \rightarrow J/\psi$ )**: 0.0116
- BR( $B \rightarrow \psi(2S)$ )**: 0.00307

Below the form, there is a note: "Set your inputs, click submit, and be patient. The run time may be as long as a few minutes depending on your choices (e.g. a total cross section with full uncertainty band, or many points of a differential cross section.)."

At the bottom, there are two radio buttons: **Display results** (selected) and **Email results to**, followed by a text input field "Enter email address". There are also "Submit" and "Reset" buttons.

→ use the **FONLL official code<sup>¶</sup>**; user need to **create grid and convolute them with proper non-perturbative fragmentation functions(NFF)**

<sup>§</sup><http://www.lpthe.jussieu.fr/~cacciari/fonll/fonllform.html>

<sup>¶</sup><https://cacciari.web.cern.ch/cacciari/fonll/>

# Bare Quark Production - grid creation

Grid example:

	Bottom ( $m_b = 4.75$ GeV)		Charm ( $m_c = 1.5$ GeV)	
Collider	7 TeV (LHC)			
Scale	$\mu_F = \mu_R = m_b$			$\mu_F = \mu_R = m_c$
PDF set	CTEQ6.6	PROSA_2019_VFNS	CTEQ6.6	PROSA_2019_VFNS
Phase space	$2 \leq p_T \leq 50, 0 \leq y \leq 2.6$			$1 \leq p_T \leq 15, 0 \leq y \leq 2.6$
Grid size	$(n_{p_T} = 25) \times (n_y = 27) = 675$			$(n_{p_T} = 15) \times (n_y = 27) = 405$

→ **relatively time consuming process** (the FONLL web uses pre-created grid) but once it is properly created fit to user's purpose, **this grid can be re-used** to every hadronic productions of same hard scattering process

# Bare Quark Production - grid creation

Charm quark pair production:

$p_T$ [GeV]	FONLL web [pb]		FONLL code <sup>†</sup> [pb]	difference [%]
	original result ( $\frac{1}{\pi} \frac{d\sigma}{dp_T^2 dy}  _{y=0}$ )	$\frac{d\sigma}{dp_T^2 dy}  _{y=0}$	$\frac{d\sigma}{dp_T^2 dy}  _{y=0}$	
1.00	$1.8949 \times 10^7$	$5.95300 \times 10^7$	$5.95373 \times 10^7$	0.01
2.00	$1.3488 \times 10^7$	$4.23738 \times 10^7$	$4.23804 \times 10^7$	0.02
3.00	$5.9135 \times 10^6$	$1.85778 \times 10^7$	$1.85826 \times 10^7$	0.03
4.00	$2.4596 \times 10^6$	$7.72706 \times 10^6$	$7.73305 \times 10^6$	0.08
5.00	$1.0733 \times 10^6$	$3.37187 \times 10^6$	$3.37100 \times 10^6$	0.03
6.00	$5.0342 \times 10^5$	$1.58154 \times 10^6$	$1.58248 \times 10^6$	0.06
7.00	$2.5406 \times 10^5$	$7.98153 \times 10^5$	$7.98244 \times 10^5$	0.01
8.00	$1.3614 \times 10^5$	$4.27696 \times 10^5$	$4.27816 \times 10^5$	0.03
9.00	$7.6848 \times 10^4$	$2.41425 \times 10^5$	$2.41439 \times 10^5$	0.01
10.00	$4.5349 \times 10^4$	$1.42468 \times 10^5$	$1.42511 \times 10^5$	0.03
11.00	$2.7812 \times 10^4$	$8.73740 \times 10^4$	$8.73979 \times 10^4$	0.03
12.00	$1.7637 \times 10^4$	$5.54083 \times 10^4$	$5.54283 \times 10^4$	0.04

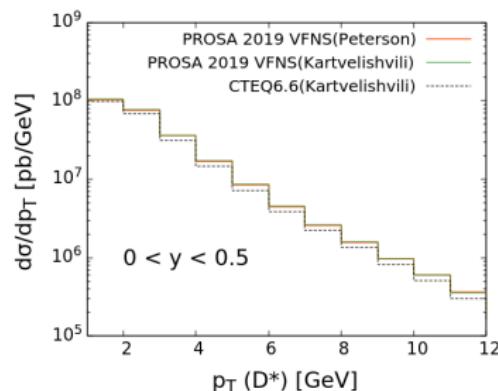
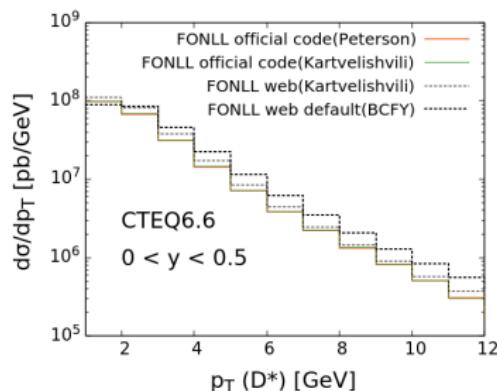
$\Lambda_5 = 0.226$   
PDF set: CTEQ6.6

<sup>†</sup>matched cross section

# D Meson Production - convolution with NFF

Non-perturbative fragmentation function: **Peterson** (which is given by parameter: 0.035\*), **Kartvelishvili** (is given by parameter: 4.2\*) and **BCFY** (which is default of the FONLL web)

PDF sets: CTEQ6.6 (which is available in the FONLL web) and **PROSA\_2019\_VFNS**



→ need to distinguish between matched cross section and hadronic massive cross section

\* R. Akerset al.(OPAL), Z. Phys.C67, 27 (1995)

## Next plan

- ▶ So far only central predictions considered → next obtain predictions also with the uncertainty
- ▶ Obtain predictions for other D mesons besides  $D^*$  and for B hadron productions
- ▶ Collect results to interface for decay productions