# Fragmentation Functions and their uncertainties

with V. Bertone, S. Carrazza, N.P. Hartland and J.Rojo

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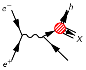
# Foreword

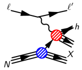
Fragmentation functions encode the information on how partons produced in a hard-scattering process are turned into an observed colorless hadronic bound final-state [PRD 15 (1977) 2590]

Starting point: (leading-twist) QCD factorization

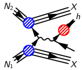
$$d\sigma^h(x,Q^2) = \sum_{i=-n_f}^{n_f} \int_x^1 dz\, d\sigma^i \left( \frac{x}{z}, \frac{Q^2}{\mu^2}, \frac{m_i^2}{Q^2}, \alpha_s(\mu^2) \right) D_i^h(z,\mu^2)$$




$e^+ + e^- \to h + X$
single-inclusive annihilation (SIA)




$\ell + N \to \ell' + h + X$
semi-inclusive deep-inelastic scattering (SIDIS)




$N_1 + N_2 \to h + X$
high-$p_T$ hadron production in $pp$ collisions (PP)

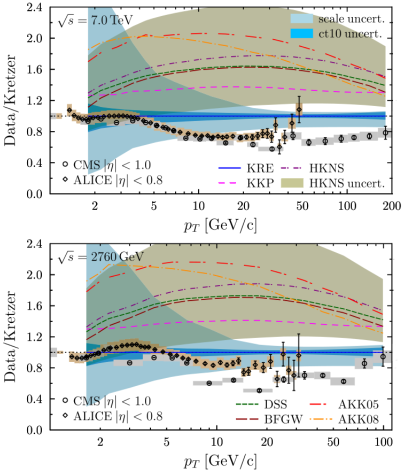
| | DHESS | HKNS | JAM | NNFF1.0 |
|---|---|---|---|---|
| SIA<br>SIDIS<br>PP | ☑<br>☑<br>☑ | ☑<br>☒<br>☒ | ☑<br>☒<br>☒ | ☑<br>☒<br>☑ |
| statistical treatment | Iterative Hessian<br>68% - 90% | Hessian<br>$\Delta\chi^2 = 15.94$ | Monte Carlo | Monte Carlo |
| hadron species | $\pi^\pm$, $K^\pm$, $p/\bar{p}$, $h^\pm$ | $\pi^\pm$, $K^\pm$, $p/\bar{p}$ | $\pi^\pm$, $K^\pm$ | $\pi^\pm$, $K^\pm$, $p/\bar{p}$ |
| latest update | PRD 91 (2015) 014035; 1702.06353 | PTEP 2016 (2016) 113B04 | PRD 94 (2016) 114004 | in preparation |

New data: BELLE [PRL 11 (2013) 062002], BABAR [PRD 88 (2013) 032001] (SIA)
HERMES [PRD 87 (2013) 074029], COMPASS [PLB 764 (2017) 1; PLB 767 (2017) 133] (SIDIS)

Improved methodological sophistication, improved SIA theory: NNLO [PRD 92 (2015) 114017], low-$z$ resummation [PRD 95 (2017) 054003], HQ [PRD 94 (2016) 034037]

# Fragmentation functions: why should we bother?

Example 1: Ratio of the inclusive charged-hadron spectra measured by CMS and ALICE




Figures taken from [NPB 883 (2014) 615]

Example 2: The strange polarised parton distribution at $Q^2 = 2.5$ GeV$^2$ ($\Delta s = \Delta \bar{s}$)

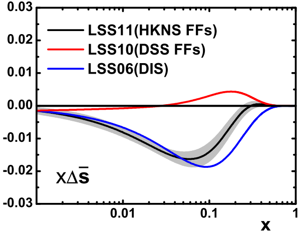



Figure taken from [PRD D84 (2011) 014002]

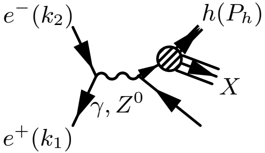
1 Predictions from all available FF sets are not compatible with CMS and ALICE data, not even within scale and PDF/FF uncertainties
$\longrightarrow$ input for nuclear medium modifications

2 If SIDIS data are used to determine $\Delta s$, $K^{\pm}$ FFs for different sets lead to different results. Such results may differ significantly among them and w.r.t. the results obtained from DIS
$\longrightarrow$ input for polarised PDFs and TMDs

# Towards NNFF1.0

A first determination of fragmentation functions à la NNPDF

1. Data:
   - all untagged and tagged SIA data for $\pi^\pm$, $K^\pm$, $p/\bar{p}$




$$e^+(k_1) + e^-(k_2) \xrightarrow{\gamma, Z^0} h(P_h) + X$$

$$q = k_1 + k_2 \qquad q^2 = Q^2 > 0 \qquad z = \frac{2 P_h \cdot q}{Q^2}$$

2. Theory:
   - LO, NLO, NNLO (will be the only NNLO fit together with [PRD 92 (2015) 114017]), $\overline{\text{MS}}$
3. Fit methodology/technology:
   - à la NNPDF, successfully used for the determination of unpolarised/polarised PDFs

     Monte Carlo sampling of experimental data + neural network parametrisation

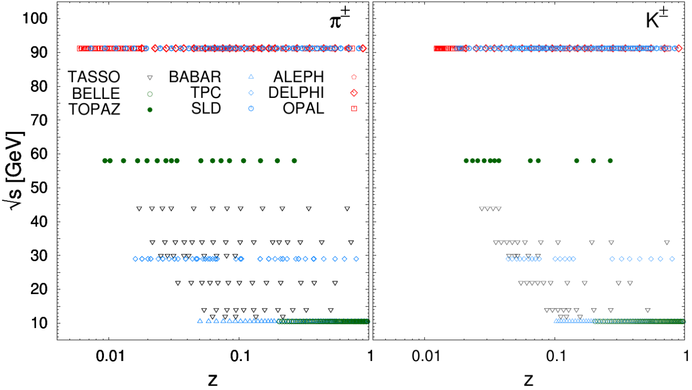
     Genetic algorithm minimisation + determination of the best fit by cross-validation

     closure tests for a full characterisation of procedural uncertainties
   - use of `APFEL` [CPC 185 (2014) 1647] for the calculation of SIA observables (FK tables)
   - keep mutual consistency with NNPDF unpolarised/polarised PDF sets

Results presented in this talk refer to $\pi^+$ and $K^+$ fragmentation functions

$\pi$ and $K$ constitute the largest fraction in measured yields, work in progress for $p/\bar{p}$

# The dataset




**CERN-LEP:** ALEPH [ZP C66 (1995) 353] DELPHI [EPJ C18 (2000) 203] OPAL [ZP C63 (1994) 181]

**KEK:** BELLE ($n_f = 4$) [PRL 111 (2013) 062002] TOPAZ [PL B345 (1995) 335]

**DESY-PETRA:** TASSO [PL B94 (1980) 444, ZP C17 (1983) 5, ZP C42 (1989) 189]

**SLAC:** BABAR ($n_f = 4$) [PR D88 (2013) 032011] SLD [PR D58 (1999) 052001] TPC [PRL 61 (1988) 1263]

$$\frac{d\sigma^h}{dz} = \frac{4\pi\alpha^2(Q^2)}{Q^2} F_2^h(z, Q^2) \quad h = \pi^+ + \pi^-,\, K^+ + K^-; \quad \text{possibly normalised to } \sigma_{\text{tot}}$$

# From observables to fragmentation functions

$$\boxed{\mathcal{F}_2^h = \langle e^2 \rangle \left\{ C_{2,q}^{\rm S} \otimes D_\Sigma^h + n_f \mathcal{C}_{2,g}^{\rm S} \otimes D_g^h + \mathcal{C}_{2,q}^{\rm NS} \otimes D_{\rm NS}^h \right\}}$$

$$\langle e^2 \rangle = \frac{1}{n_f} \sum_{q=1}^{n_f} \hat{e}_q^2 \qquad D_\Sigma^h = \sum_{q=1}^{n_f} D_{q^+}^h \qquad D_{\rm NS}^h = \sum_{q=1}^{n_f} \left( \frac{\hat{e}_q^2}{\langle e^2 \rangle} - 1 \right) D_{q^+}^h \qquad D_{q^+}^h = D_q^h + D_{\bar{q}}^h$$

Coefficient functions and splitting functions known up to NNLO

[NPB 751 (2006) 18; NPB 749 (2006) 1; PLB 638 (2006) 61; NPB 845 (2012) 133]

---

$$\begin{aligned} F_2^{h,n_f=5} =& \frac{1}{5}\left[\left(2\hat{e}_u^2 + 3\hat{e}_d^2\right) C_{2,q}^{\rm S} + 3\left(\hat{e}_u^2 - \hat{e}_d^2\right) C_{2,q}^{\rm NS}\right] \otimes \left(D_{u^+}^h + D_{c^+}^h\right) \\ &+ \frac{1}{5}\left[\left(2\hat{e}_u^2 + 3\hat{e}_d^2\right) C_{2,q}^{\rm S} - 2\left(\hat{e}_u^2 - \hat{e}_d^2\right) C_{2,q}^{\rm NS}\right] \otimes \left(D_{d^+}^h + D_{s^+}^h + D_{b^+}^h\right) \\ &+ \left(2\hat{e}_u^2 + 3\hat{e}_d^2\right) C_{2,g}^{\rm S} \otimes D_g^h \end{aligned}$$

No sensitivity to individual quark and antiquark FFs

Limited sensitivity to flavour separation via the variation of $\hat{e}_q$ with $Q^2$

$\hat{e}_u^2/\hat{e}_d^2(Q^2 = 10\,{\rm GeV}) \sim 4 \Rightarrow D_{u^+}^h,\ D_{d^+}^h + D_{s^+}^h;\quad \hat{e}_u^2/\hat{e}_d^2(Q^2 = M_Z) \sim 0.8 \Rightarrow D_\Sigma^h$

Flavor separation between $uds$ and $c$, $b$ quarks achieved thanks to tagged data

Direct sensitivity to $D_g^h$ only beyond LO, as $C_{2,g}^{\rm S}$ is $\mathcal{O}(\alpha_s^2)$, and tenous

Indirect sensitivity to $D_g^h$ via scale violations in the time-like DGLAP evolution

# Fit settings

Physical parameters: consistent with the upcoming `NNPDF3.1` PDF set

$$\alpha_s(M_Z) = 0.118,\ \alpha(M_Z) = 1/127,\ m_c = 1.51 \text{ GeV},\ m_b = 4.92 \text{ GeV}$$

Solution of DGLAP equations: numerical solution in $z$-space as implemented in `APFEL`

extensive benchmark performed up to NNLO [JHEP 1503 (2015) 046]

Parametrisation: each FF is parametrised with a feed-forward neural network (2-5-3-1)

$$D_i^h(Q_0, z) = \text{NN}(x) - \text{NN}(1),\ \ Q_0 = 5 \text{ GeV}$$

PIONS

$h = \pi^+ + \pi^-$, $i = u^+, s^+, c^+, b^+, g$

$D_{u^+}^{\pi^\pm} = D_{d^+}^{\pi^\pm}$ (isospin symmetry)

KAONS

$h = K^+ + K^-$, $i = u^+, d^+ + s^+, c^+, b^+, g$

no further theoretical assumptions

we assume charge conjugation, from which $D_{q^+}^{\pi^+} = D_{q^+}^{\pi^-}$

we enforce positivity by construction, assuming quadratic NNs

initial scale above $m_b$, but below the lowest c.m. energy of the data, avoid threshold crossing

Heavy flavours: heavy-quark FFs are parametrised independently at the initial scale $Q_0$

a matched GM-VFNS (like FONLL) may be required if $Q_0 < m_c$ [PRD 94 (2016) 034037]

Kinematic cuts: $z \to 0$: contributions $\propto \ln z$; $z \to 1$: contributions $\propto \ln(1-z)$

PIONS

$z_{\text{min}} = 0.1$, $z_{\text{min}} = 0.05$ ($\sqrt{s} = M_Z$); $z_{\text{max}} = 0.90$

$z_{\text{min}} = 0.075$, $z_{\text{min}} = 0.01$ ($\sqrt{s} = M_Z$); $z_{\text{max}} = 0.90$

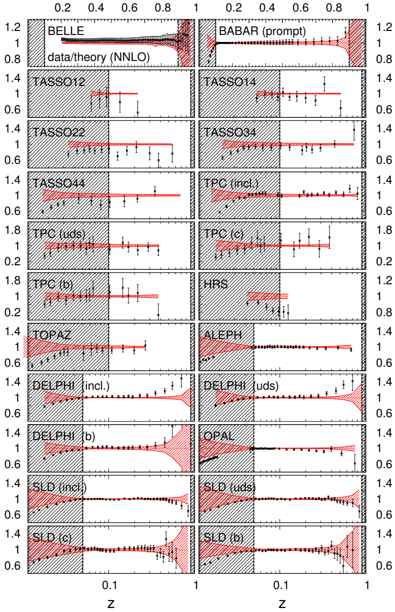
KAONS

$z_{\text{min}} = 0.2$, $z_{\text{min}} = 0.1$ ($\sqrt{s} = M_Z$); $z_{\text{max}} = 0.90$

$z_{\text{min}} = 0.1$, $z_{\text{min}} = 0.05$ ($\sqrt{s} = M_Z$); $z_{\text{max}} = 0.90$

kinematic corrections $\propto M_h/(sz^2)$ included exactly in the cross sections [PRD 73 (2006) 054020]

# Fit quality: $\pi^+$

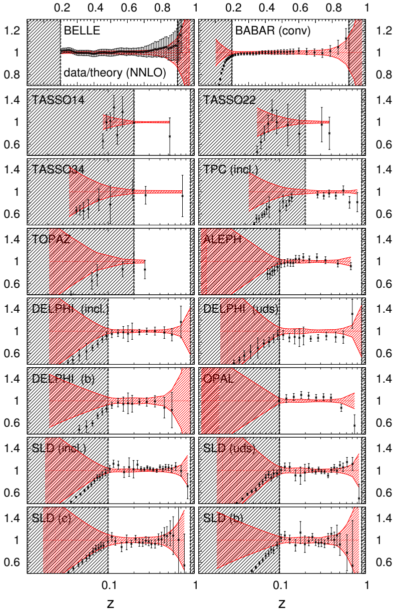



| Exp. | $N_{\rm dat}$ | NNLO theory $\chi^2/N_{\rm dat}$ | remarks |
|---|---|---|---|
| BELLE | 70 | 0.08 | lack of correlations |
| BABAR | 37 | 1.17 | ☑ |
| TASSO12 | 2 | 1.61 | small sample |
| TASSO14 | 7 | 1.83 | } data fluctuations |
| TASSO22 | 7 | 2.16 | |
| TASSO34 | 8 | 1.09 | ☑ |
| TASSO44 | 5 | 1.95 | data fluctuations |
| TPC | 12 | 0.98 | ☑ |
| TPC-UDS | 6 | 0.45 | ☑ |
| TPC-C | 6 | 0.50 | ☑ |
| TPC-B | 6 | 1.41 | ☑ |
| TOPAZ | 4 | 0.66 | ☑ |
| ALEPH | 22 | 0.88 | ☑ |
| DELPHI | 16 | 2.32 | tension with OPAL |
| DELPHI-UDS | 16 | 1.90 | tension with OPAL |
| DELPHI-B | 16 | 1.09 | ☑ |
| OPAL | 22 | 2.05 | tension with DELPHI |
| SLD | 29 | 1.09 | ☑ |
| SLD-UDS | 29 | 0.80 | ☑ |
| SLD-C | 29 | 0.97 | ☑ |
| SLD-B | 29 | 0.44 | ☑ |
| TOTAL | 378 | 0.99 | ☑ |

Overall good description of the dataset
Signs of tension OPAL vs DELPHI (inclusive)
Anomalously small $\chi^2/N_{\rm dat}$ for BELLE

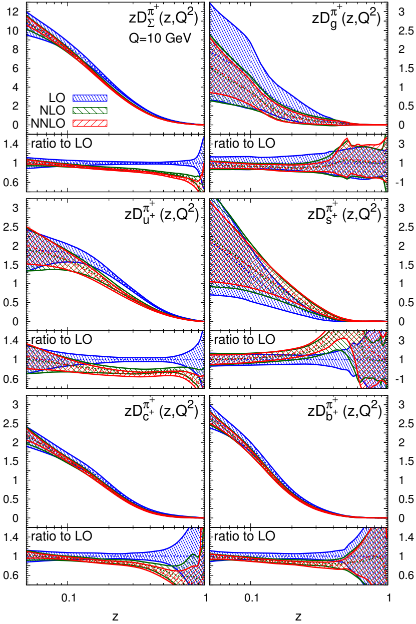
# Fit quality: $K^+$

| Exp. | $N_{\rm dat}$ | NNLO theory $\chi^2/N_{\rm dat}$ | remarks |
|---|---|---|---|
| BELLE | 70 | 0.19 | lack of correlations |
| BABAR | 28 | 0.77 | ☑ |
| TASSO14 | 3 | 1.30 | } small sample |
| TASSO22 | 2 | 0.29 | } small sample |
| TASSO34 | 2 | 0.09 | } small sample |
| TPC | 7 | 1.19 | ☑ |
| ALEPH | 13 | 0.72 | ☑ |
| DELPHI | 11 | 0.17 | ☑ |
| DELPHI-UDS | 11 | 1.97 | ☑ |
| DELPHI-B | 11 | 0.41 | ☑ |
| OPAL | 9 | 2.10 | tension with other $M_Z$ data |
| SLD | 21 | 0.77 | ☑ |
| SLD-UDS | 21 | 1.11 | ☑ |
| SLD-C | 20 | 0.42 | ☑ |
| SLD-B | 21 | 0.71 | ☑ |
| TOTAL | 250 | 0.67 | ☑ |




Overall good description of the dataset
Excellent BELLE/BABAR consistency
Signs of tension OPAL vs DELPHI (inclusive)
Anomalously small $\chi^2/N_{\rm dat}$ for BELLE
Data description rapidly deteriorates at low $z$
Prediction uncertainties blow up at low $z$

# Dependence upon perturbative order: $\pi^+$




| Exp. | $N_{\rm dat}$ | LO $\chi^2/N_{\rm dat}$ | NLO $\chi^2/N_{\rm dat}$ | NNLO $\chi^2/N_{\rm dat}$ |
|---|---|---|---|---|
| BELLE | 70 | 0.67 | 0.12 | 0.08 |
| BABAR | 37 | 1.64 | 1.26 | 1.17 |
| TASSO12 | 2 | 1.19 | 1.57 | 1.61 |
| TASSO14 | 7 | 1.60 | 1.81 | 1.83 |
| TASSO22 | 7 | 1.81 | 2.19 | 2.16 |
| TASSO34 | 8 | 1.26 | 1.11 | 1.09 |
| TASSO44 | 5 | 2.05 | 2.00 | 1.95 |
| TPC | 12 | 0.51 | 0.69 | 0.98 |
| TPC-UDS | 6 | 0.79 | 0.52 | 0.45 |
| TPC-C | 6 | 0.54 | 0.51 | 0.50 |
| TPC-B | 6 | 1.45 | 1.41 | 1.41 |
| TOPAZ | 4 | 1.25 | 0.75 | 0.66 |
| ALEPH | 22 | 2.25 | 1.10 | 0.88 |
| DELPHI | 16 | 1.63 | 2.17 | 2.32 |
| DELPHI-UDS | 16 | 1.40 | 1.75 | 1.90 |
| DELPHI-B | 16 | 1.45 | 1.18 | 1.09 |
| OPAL | 22 | 2.68 | 2.19 | 2.05 |
| SLD | 29 | 2.66 | 1.35 | 1.09 |
| SLD-UDS | 29 | 1.63 | 0.98 | 0.80 |
| SLD-C | 29 | 2.39 | 1.15 | 0.97 |
| SLD-B | 29 | 0.45 | 0.43 | 0.44 |
| TOTAL | 378 | 1.50 | 1.05 | 0.99 |

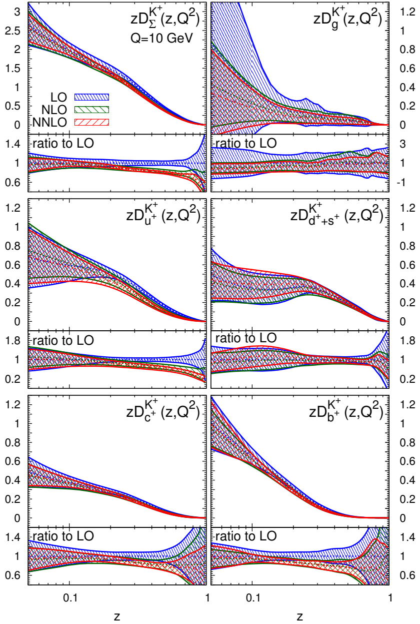
Excellent perturbative convergence
FFs almost stable from NLO to NNLO
LO FF uncertainties larger than HO

# Dependence upon perturbative order: $K^+$

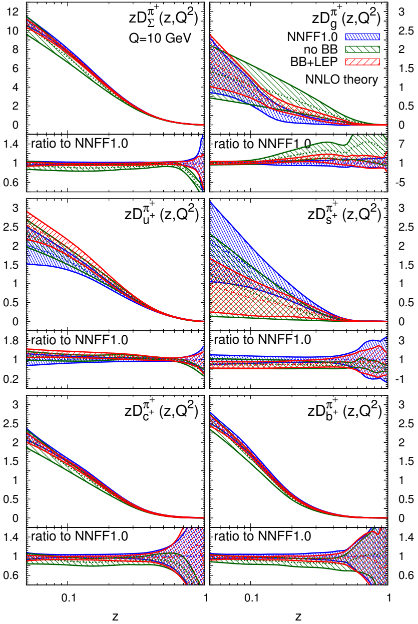
| Exp. | $N_{\rm dat}$ | LO $\chi^2/N_{\rm dat}$ | NLO $\chi^2/N_{\rm dat}$ | NNLO $\chi^2/N_{\rm dat}$ |
|---|---|---|---|---|
| BELLE | 70 | 0.37 | 0.34 | 0.19 |
| BABAR | 28 | 1.02 | 0.96 | 0.77 |
| TASSO14 | 3 | 1.23 | 1.24 | 1.30 |
| TASSO22 | 2 | 0.29 | 0.32 | 0.29 |
| TASSO34 | 2 | 0.02 | 0.03 | 0.09 |
| TPC | 7 | 0.41 | 0.49 | 1.19 |
| ALEPH | 13 | 0.66 | 0.71 | 0.72 |
| DELPHI | 11 | 0.17 | 0.16 | 0.17 |
| DELPHI-UDS | 11 | 2.01 | 1.94 | 1.97 |
| DELPHI-B | 11 | 0.51 | 0.44 | 0.41 |
| OPAL | 9 | 2.02 | 2.08 | 2.10 |
| SLD | 21 | 0.81 | 0.80 | 0.77 |
| SLD-UDS | 21 | 1.16 | 1.19 | 1.11 |
| SLD-C | 20 | 0.49 | 0.46 | 0.42 |
| SLD-B | 21 | 0.71 | 0.68 | 0.71 |
| TOTAL | 250 | 0.73 | 0.72 | 0.67 |

Excellent perturbative convergence
FFs almost stable from NLO to NNLO
LO FF uncertainties larger than HO

| i | N$^{i+1}$LO/N$^i$LO | $D_g$ | $D_\Sigma$ | $D_{c^+}$ | $D_{b^+}$ |
|---|---|---|---|---|---|
| 0 | NLO/LO [%] | 95-300 | 70-80 | 65-80 | 70-85 |
| 1 | NNLO/NLO [%] | 70-130 | 90-100 | 90-110 | 95-115 |



# Dependence upon the dataset: $\pi^+$




| NNLO theory Exp. | $N_{\rm dat}$ | NNFF1.0 $\chi^2/N_{\rm dat}$ | no BB $\chi^2/N_{\rm dat}$ | BB+LEP $\chi^2/N_{\rm dat}$ |
|---|---|---|---|---|
| BELLE | 70 | 0.08 | (5.95) | 0.08 |
| BABAR | 37 | 1.17 | (82.2) | 1.22 |
| TASSO12 | 2 | 1.61 | 0.84 | (1.61) |
| TASSO14 | 7 | 1.83 | 1.77 | (1.85) |
| TASSO22 | 7 | 2.16 | 1.55 | (2.48) |
| TASSO34 | 8 | 1.09 | 1.35 | (1.55) |
| TASSO44 | 5 | 1.95 | 2.22 | (2.60) |
| TPC | 12 | 0.98 | 1.94 | (0.87) |
| TPC-UDS | 6 | 0.45 | 0.56 | (0.79) |
| TPC-C | 6 | 0.50 | 0.73 | (0.57) |
| TPC-B | 6 | 1.41 | 1.59 | (1.47) |
| TOPAZ | 4 | 0.66 | 0.75 | (1.50) |
| ALEPH | 22 | 0.88 | 0.69 | 0.71 |
| DELPHI | 16 | 2.32 | 2.50 | 2.38 |
| DELPHI-UDS | 16 | 1.90 | 1.98 | 1.91 |
| DELPHI-B | 16 | 1.09 | 1.10 | 1.13 |
| OPAL | 22 | 2.05 | 1.87 | 1.98 |
| SLD | 29 | 1.09 | 0.72 | 1.07 |
| SLD-UDS | 29 | 0.80 | 0.60 | 0.73 |
| SLD-C | 29 | 0.97 | 0.80 | 1.10 |
| SLD-B | 29 | 0.44 | 0.43 | 0.43 |
| TOTAL | 378 | 0.99 | 1.14 | 0.93 |

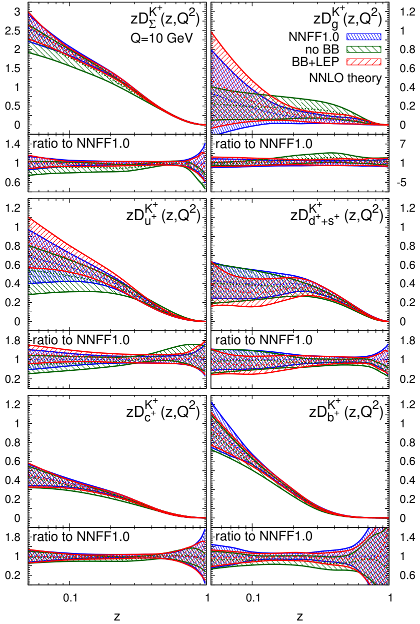
no BB: larger uncertainties; different gluon shape and different light flavour separation
BB+LEP: comparable uncertainties; slightly different size of gluon and light flavoured quarks

# Dependence upon the dataset: $K^+$

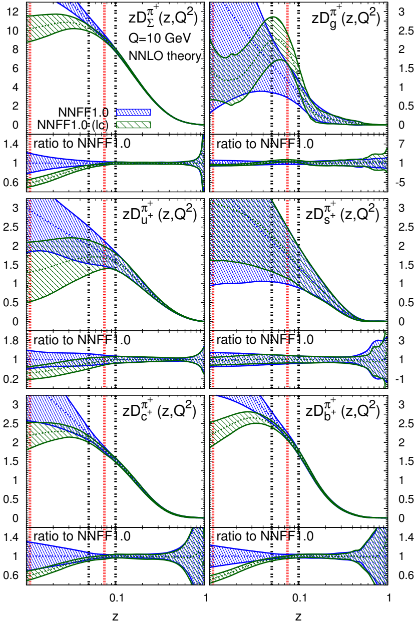
| NNLO theory Exp. | $N_{\rm dat}$ | NNFF1.0 $\chi^2/N_{\rm dat}$ | no BB $\chi^2/N_{\rm dat}$ | BB+LEP $\chi^2/N_{\rm dat}$ |
|---|---|---|---|---|
| BELLE | 70 | 0.19 | (16.3) | 0.37 |
| BABAR | 28 | 0.77 | (190) | 0.99 |
| TASSO14 | 3 | 1.30 | 1.80 | (1.23) |
| TASSO22 | 2 | 0.29 | 0.23 | (0.33) |
| TASSO34 | 2 | 0.09 | 0.02 | (0.04) |
| TPC | 7 | 1.19 | 0.61 | (0.45) |
| ALEPH | 13 | 0.72 | 0.75 | 0.63 |
| DELPHI | 11 | 0.17 | 0.23 | 0.16 |
| DELPHI-UDS | 11 | 1.97 | 2.05 | 2.00 |
| DELPHI-B | 11 | 0.41 | 0.45 | 0.48 |
| OPAL | 9 | 2.10 | 2.01 | 2.01 |
| SLD | 21 | 0.77 | 0.76 | 0.77 |
| SLD-UDS | 21 | 1.11 | 1.12 | 1.19 |
| SLD-C | 20 | 0.42 | 0.36 | 0.47 |
| SLD-B | 21 | 0.71 | 0.76 | 0.70 |
| TOTAL | 250 | 0.67 | 0.86 | 0.74 |

no BB: larger uncertainties; different gluon shape and different light flavour separation; significant degradation in the description of BELLE and BABAR data

BB+LEP: comparable uncertainties; FFs stable; no significant degradation in fit quality; fair description of the data not included in the fit



# Dependence upon kinematic cuts: $\pi^+$



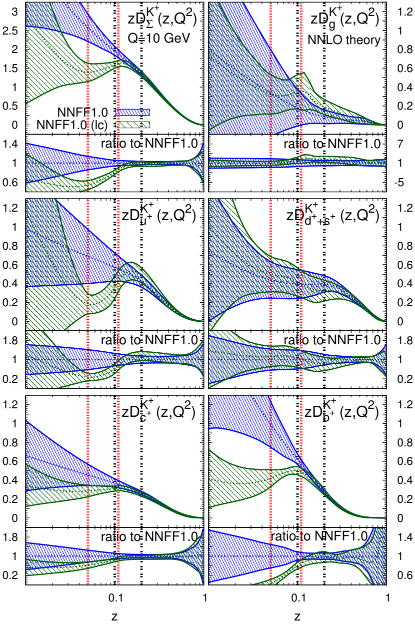

| NNLO theory Exp. | NNFF1.0 $N_{\rm dat}$ | NNFF1.0 $\chi^2/N_{\rm dat}$ | NNFF1.0 (lc) $N_{\rm dat}$ | NNFF1.0 (lc) $\chi^2/N_{\rm dat}$ |
|---|---|---|---|---|
| BELLE | 70 | 0.08 | 70 | 0.09 |
| BABAR | 37 | 1.17 | 40 | 0.82 |
| TASSO12 | 2 | 1.61 | 4 | 0.87 |
| TASSO14 | 7 | 1.83 | 9 | 1.69 |
| TASSO22 | 7 | 2.16 | 8 | 1.88 |
| TASSO34 | 8 | 1.09 | 9 | 0.97 |
| TASSO44 | 5 | 1.95 | 6 | 2.32 |
| TPC | 12 | 0.98 | 13 | 0.88 |
| TPC-UDS | 6 | 0.45 | 6 | 0.47 |
| TPC-C | 6 | 0.50 | 6 | 0.52 |
| TPC-B | 6 | 1.41 | 6 | 1.42 |
| TOPAZ | 4 | 0.66 | 5 | 0.75 |
| ALEPH | 22 | 0.88 | 30 | 2.39 |
| DELPHI | 16 | 2.32 | 22 | 1.70 |
| DELPHI-UDS | 16 | 1.90 | 22 | 1.43 |
| DELPHI-B | 16 | 1.09 | 22 | 0.85 |
| OPAL | 22 | 2.05 | 38 | 1.31 |
| SLD | 29 | 1.09 | 38 | 0.97 |
| SLD-UDS | 29 | 0.80 | 38 | 0.61 |
| SLD-C | 29 | 0.97 | 38 | 0.84 |
| SLD-B | 29 | 0.44 | 38 | 0.41 |
| TOTAL | 378 | 0.99 | 468 | 0.94 |

Slight improvement of the overall fit quality
Excellent consistency in the overlapping region
Significantly varied FF shapes at low $z$
Possible tensions with ALEPH at small $z$

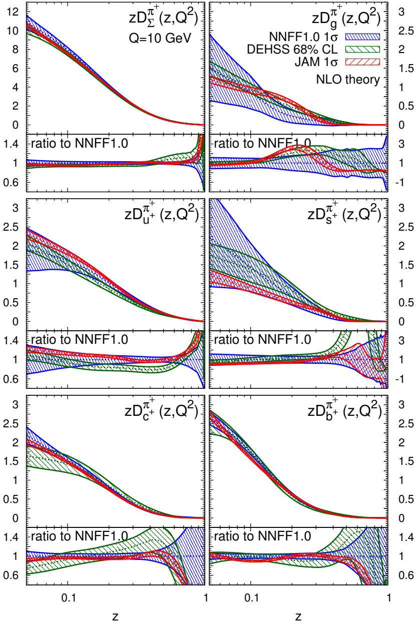
# Dependence upon kinematic cuts: $K^+$

| NNLO theory | NNFF1.0 | | NNFF1.0 (lc) | |
|---|---|---|---|---|
| Exp. | $N_{\rm dat}$ | $\chi^2/N_{\rm dat}$ | $N_{\rm dat}$ | $\chi^2/N_{\rm dat}$ |
| BELLE | 70 | 0.19 | 70 | 0.32 |
| BABAR | 28 | 0.77 | 43 | 1.12 |
| TASSO12 | — | — | 3 | 1.02 |
| TASSO14 | 3 | 1.30 | 7 | 2.03 |
| TASSO22 | 2 | 0.29 | 4 | 0.33 |
| TASSO34 | 2 | 0.09 | 4 | 0.04 |
| TPC | 7 | 1.19 | 12 | 0.72 |
| TOPAZ | — | — | 3 | 0.73 |
| ALEPH | 13 | 0.72 | 18 | 0.48 |
| DELPHI | 11 | 0.17 | 16 | 0.23 |
| DELPHI-UDS | 11 | 1.97 | 16 | 1.63 |
| DELPHI-B | 11 | 0.41 | 16 | 0.33 |
| OPAL | 9 | 2.10 | 10 | 1.68 |
| SLD | 21 | 0.77 | 29 | 0.71 |
| SLD-UDS | 21 | 1.11 | 29 | 1.02 |
| SLD-C | 20 | 0.42 | 29 | 0.41 |
| SLD-B | 21 | 0.71 | 29 | 0.84 |
| TOTAL | 250 | 0.67 | 338 | 0.73 |

Slight deterioration of the overall fit quality
Excellent consistency in the overlapping region
Significantly varied FF shapes at low $z$



# Comparison with other FF sets: $\pi^+$




DEHSS [arXiv:1702.06353]
(+SIDIS +PP)

JAM [PRD 94 (2016) 114004]
(almost same dataset as NNFF1.0)

$D_\Sigma^{\pi^+}$: excellent mutual agreement
both c.v. and unc. (bulk of the dataset)

$D_g^{\pi^+}$: slight disagreement
different shapes, larger uncertainties
DEHSS: data; JAM: parametrisation

$D_{u^+}^{\pi^+}$, $D_{s^+}^{\pi^+}$: good overall agreement
excellent with JAM, though larger uncertainties
slight different shape w.r.t. DHESS (dataset)

$D_{c^+}^{\pi^+}$, $D_{b^+}^{\pi^+}$: good overall agreement
excellent with JAM, same uncertainties
slight different shape w.r.t. DHESS (dataset)

# Comparison with other FF sets: $K^+$

DEHSS [PRD 91 (2015) 014035]
(+SIDIS +PP)

JAM [PRD 94 (2016) 114004]
(almost same dataset as NNFF1.0)

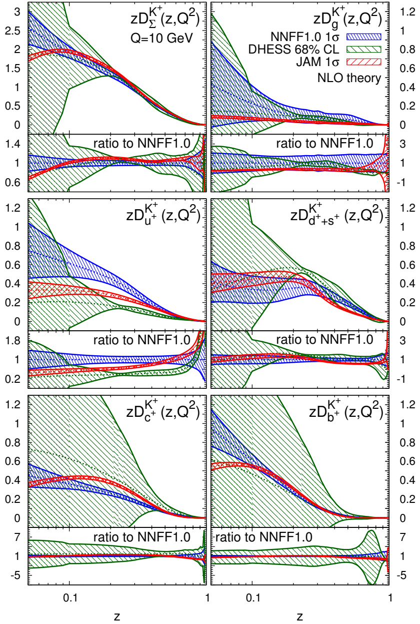
$D_\Sigma^{\pi^+}$: excellent agreement (both c.v. and unc.)
bulk of the dataset

$D_g^{\pi^+}$: good mutual agreement
similar shapes, larger uncertainties
DEHSS: data; JAM: parametrisation

$D_{u^+}^{\pi^+}$: mutual sizable disagreement
differences in dataset and parametrisation
comparable uncertainties in the data region

$D_{d^+}^{\pi^+} + D_{s^+}^{\pi^+}$: fair mutual agreement
differences in dataset and parametrisation
comparable uncertainties in the data region

$D_{c^+}^{\pi^+}$, $D_{b^+}^{\pi^+}$: excellent mutual agreement
uncertainties similar to JAM
DHESS shows inflated uncertainties



# Summary and outlook

1. NNFF1.0 is the first determination of fragmentation functions à la NNPDF
   - based on SIA data only (still limited phenomenological usefulness)
   - provided at LO, NLO and NNLO
2. Preliminary results for $\pi^+$ and $K^+$ fragmentation functions were presented
   - good description of all untagged and tagged SIA data
   - inclusion of higher-order corrections up to NNLO, good perturbative convergence
   - substantial impact of $B$-factory data (shape and reduction of uncertainties)
   - significant stability under removal of the least precise data
   - good fit quality as $z$ cuts are lowered, modified FF shapes
   - shape and size of the uncertainties of $D_{\Sigma}^{\pi^+,K^+}$ comparable to other sets
   - uncertainties larger than other sets for $D_g^{\pi^+,K^+}$ (with different shapes for $\pi^+$)
   - slight different light flavour separation, especially for $K^+$, w.r.t. other sets
   - overall good agreement for $D_{c^+}^{\pi^+,K^+}$ and $D_{b^+}^{\pi^+,K^+}$ with other sets
3. The NNFF1.0 release will include fragmentation functions of $\pi^\pm$, $K^\pm$ and $p/\bar{p}$
   - they will be made available for each hadron species through the LHAPDF interface
4. Beyond NNFF1.0: inclusion of SIDIS and PP data, GM-VFNS, resummation(s), ...

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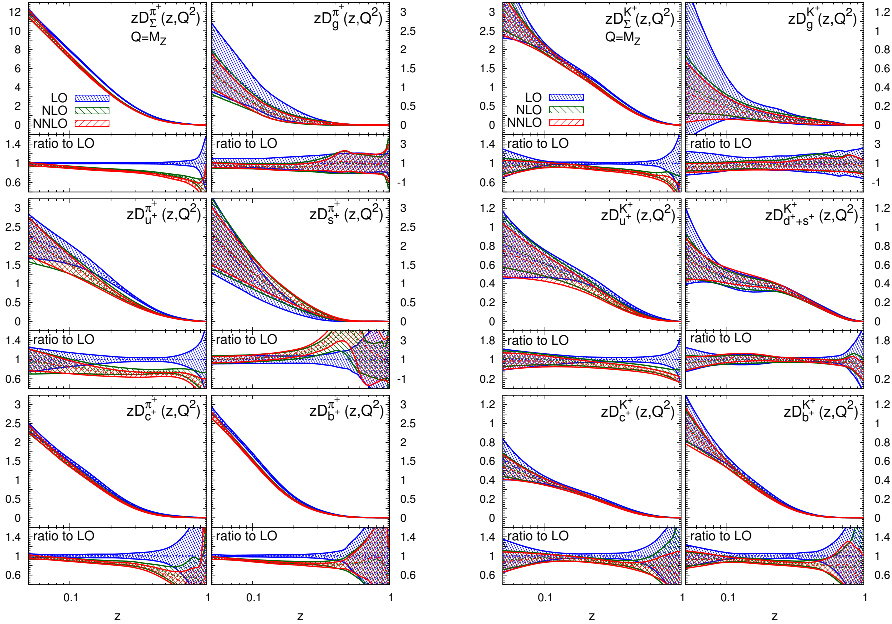
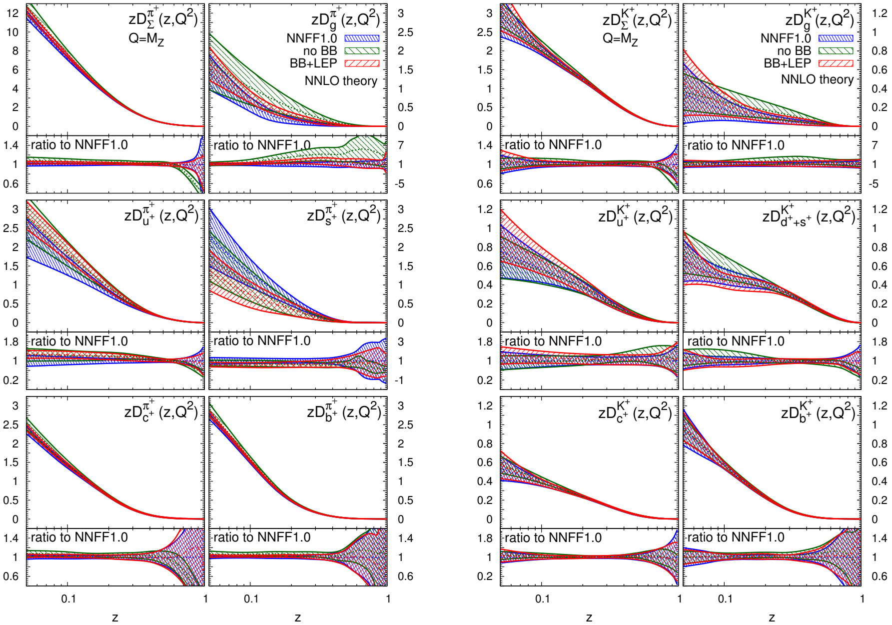
**Thank you**

# Extra material

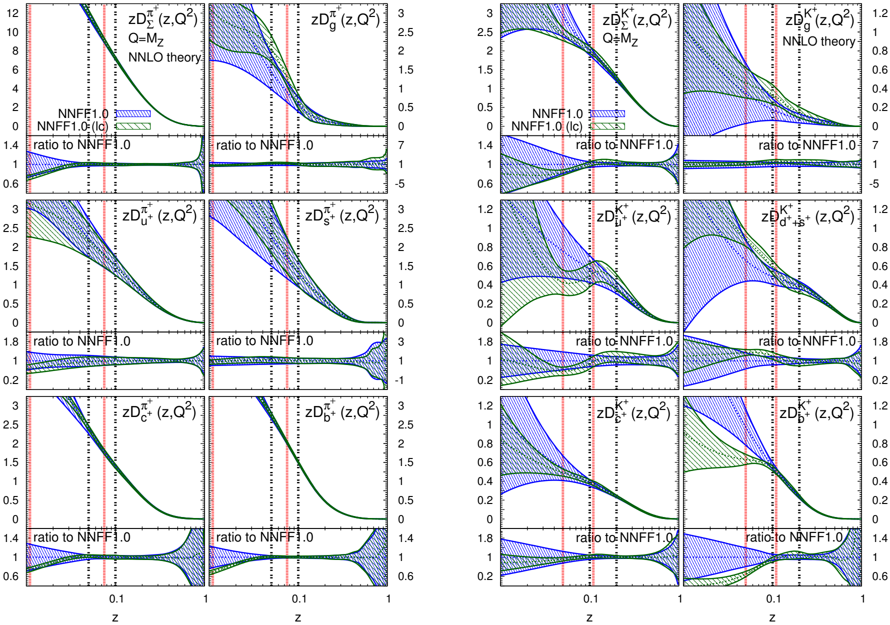
# Dependence upon perturbative order



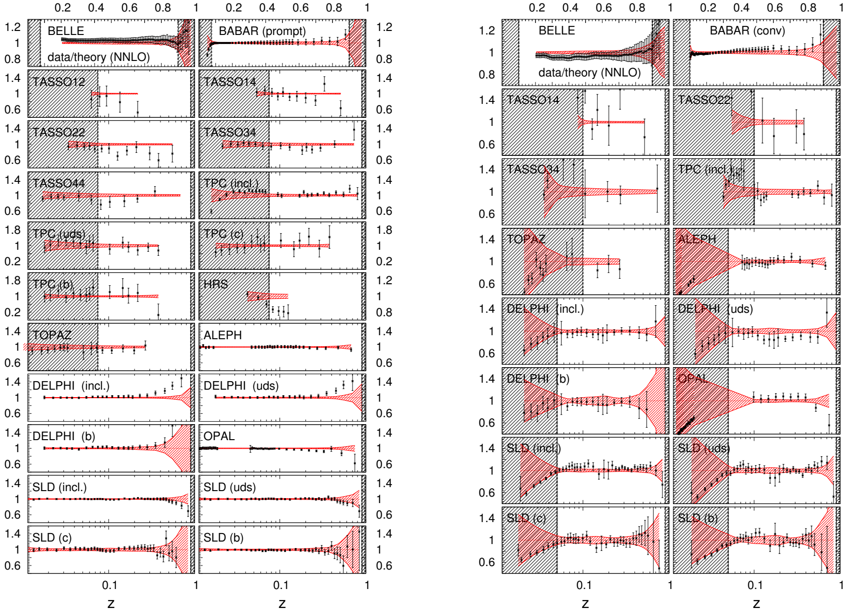
# Dependence upon the dataset



# Dependence upon kinematic cuts



# Data/theory comparison



# Comparison with other sets