Achievements and Open Issues in the Determination of Fragmentation Functions

XVI International Workshop on Hadron Structure and Spectroscopy

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MARIE CURIE ACTIONS

Foreword: the fragmentation realm [Prog.Part.Nucl.Phys. 91 (2016) 136]

- Integrated (collinear) FFs (possibly polarised)

$$\Delta^{h/q}(z;P_h,S_h)=\sum\!\!\!\!\!\!\!\int_X \int\frac{d\xi^+}{2\pi}e^{ik^-\xi^+}\langle 0|\mathcal{W}(\infty^+,\xi^+)\psi_q(\xi^+,0^-,\vec{0}_T|P_h,S_h;X\rangle \times\langle P_h,S_h;X|\bar{\psi}_q(0^+,0^-,\vec{0}_T)\mathcal{W}(0^+,\infty^+)|0\rangle$$

- Transverse momentum dependent (TMD) FFs

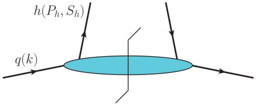
$$\Delta^{h/q}(z,\vec{k}_T;P_h,S_h)=\sum\!\!\!\!\!\!\!\int_X \sum\frac{d\xi^+d^2\vec{\xi}_T}{(2\pi)^3}e^{i(k^-\xi^+-\vec{k}_T\cdot\vec{\xi}_T)}\langle 0|\mathcal{W}_1(\infty,\xi)\psi_q(\xi^+,0^-,\vec{\xi}_T)|P_h,S_h;X\rangle \times\langle P_h,S_h;X|\bar{\psi}_q(0^+,0^-,\vec{0}_T)\mathcal{W}_2(0,\infty)|0\rangle$$

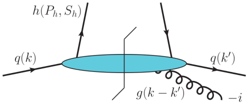
- Higher twist FFs

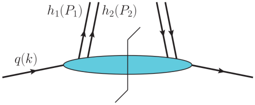
$$\Delta_F^{h/q;i}(z,z';P_h,S_h)=\frac{1}{P_h^-}\sum\!\!\!\!\!\!\!\int_X \sum\frac{d\xi^+d\zeta^+}{(2\pi)^2}e^{ik'^-\xi^+}e^{i(k^--k'^-)\zeta^+} \times\langle 0|\mathcal{W}(\infty^+,\zeta^+)igF^{-i}(\zeta^+,0^-,\vec{0}_T)\mathcal{W}(\zeta^+,\xi^+)\psi_q(\xi^+,0^-,\vec{0}_T)|P_h,S_h;X\rangle \times\langle P_h,S_h;X|\bar{\psi}_q(0^+,0^-,\vec{0}_T)\mathcal{W}(0^+,\infty^+)|0\rangle$$

- Di-hadron FFs

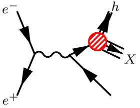
$$\Delta^{h_1h_2/q}(z,\vec{k}_T;P_1,P_2)=\sum\!\!\!\!\!\!\!\int_X \int\frac{d\xi^+d^2\vec{\xi}_T}{(2\pi)^3}e^{i(k^-\xi^--\vec{k}_T\cdot\vec{\xi}_T)}\langle 0|\mathcal{W}_1(\infty,\xi)\psi_q(\xi^+,0^-,\vec{\xi}_T)|P_1,P_2;X\rangle \times\langle P_1,P_2;X|\bar{\psi}_q(0^+,0^-,\vec{0}_T)\mathcal{W}_2(0,\infty)|0\rangle$$







Factorisation of physical observables [Adv.Ser.Direct.HEP 5 (1988) 1]

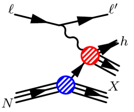


$e^+ + e^- \to h + X$
single-inclusive annihilation (SIA)

$$\frac{d\sigma^h}{dz} = F_T^h(z,Q^2) + F_L^h(z,Q^2) = F_2^h(x,Q^2)$$

$$F^h_{k=T,L,2} = \frac{4\pi\alpha_{\rm em}^2}{Q^2}\langle e^2\rangle \left\{ D_\Sigma^h \otimes C_{k,q}^{\rm S} + n_f D_g^h \otimes C_{k,g}^{\rm S} + D_{\rm NS}^h \otimes C_{k,q}^{\rm NS} \right\}$$

up to NNLO [PLB 386 (1996) 422; NPB 487 (1997) 233; PLB 392 (1997) 207]



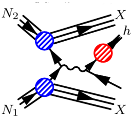
$\ell + N \to \ell' + h + X$
semi-inclusive deep-inelastic scattering (SIDIS)

$$\frac{d\sigma^h}{dx\,dy\,dz} = \frac{2\pi\alpha_{\rm em}^2}{Q^2}\left[\frac{1+(1-y)^2}{y}2F_1^h + \frac{2(1-y)}{y}F_L^h\right]$$

$$2F_1^h = e_q^2\left\{ q\otimes D_q^h + \frac{\alpha_s}{2\pi}\left[q\otimes C_{qq}^1 \otimes D_q^h + q \otimes C_{gq}^1 \otimes D_g^h + g\otimes C_{qg}^1 \otimes D_q^h \right]\right\}$$

$$F_L^h = \frac{\alpha_s}{2\pi}\sum_{q,\bar q} e_q^2 \left[q\otimes C_{qq}^L \otimes D_q^h + q \otimes C_{gq}^L \otimes D_g^h + g\otimes C_{qg}^L \otimes D_q^h \right]$$

up to NLO [NPB 160 (1979) 301; PRD 57 (1998) 5811]
partial NNLO [PRD 95 (2017) 034027]



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

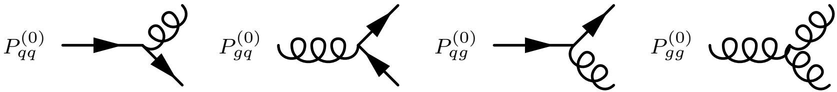
$$E_h\frac{d^3\sigma}{dp^3_{T,h}} = \sum_{a,b,c} f_a \otimes f_b \otimes \hat\sigma_{ab}^c \otimes D_c^h$$
$$=$$
$$\sum_{i,j,k}\int\frac{dx_a}{x_a}\int\frac{dx_b}{x_b}\int\frac{dz}{z^2} f^{i/p_a}(x_a) f^{j/p_b}(x_b) D^{h/k}(z)\hat\sigma^{ij\to k}\delta(\hat s + \hat t + \hat u)$$

up to NLO [PRD 67 (2003) 054004; PRD 67 (2003) 054005]

Evolution of FFs: DGLAP equations [NPB 126 (1977) 298]

A set of $(2n_f+1)$ integro-differential equations (n_f=number of active flavours)

$$\frac{\partial}{\partial \ln \mu^2} D_i(x,\mu^2) = \sum_j^{n_f} \int_x^1 \frac{dz}{z} P_{ji}\left(z, \alpha_s(\mu^2)\right) D_j\left(\frac{x}{z}, \mu^2\right)$$



LO [Sov. J. Nucl. Phys. 15 (1973) 438; NPB 126 (1977) 298; NPB 136 (1978) 445]
NLO [NPB 175 (1980) 27, PLB 97 (1980) 497, PRD 48 (1993) 116]
NNLO [PLB 638 (2006) 61, PLB 659 (2008) 290, NPB 854 (2012) 133]

Must be careful with fixed-order splitting functions as $z \to 0$ ($m = 1, \dots, 2k+1$)

SPACE-LIKE CASE

$$P_{ji} \propto \frac{\alpha_s^{k+1}}{x} \log^{k+1-m} \frac{1}{x}$$

TIME-LIKE CASE

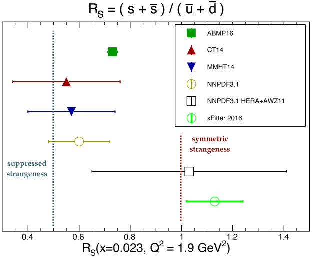
$$P_{ji} \propto \frac{\alpha_s^{k+1}}{z} \log^{2(k+1)-m-1} z$$

Soft gluon logarithms diverge more rapidly in the TL case than in the SL case: as z decreases, the unresummed SGLs spoil the convergence of the FO series for $P(z,\alpha_s)$ if $\log \frac{1}{z} \geq \mathcal{O}\left(\alpha_s^{-1/2}\right)$

1. Open issues

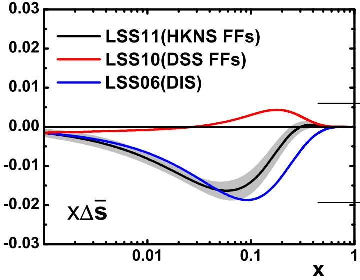
Fragmentation functions: why should we bother?

Example 1: The strange (polarised) parton distribution and SIDIS

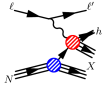


Can SIDIS data be used to determine s?
What is the bias induced by FFs onto PDFs?
$\longrightarrow$ How well do we know kaon FFs?

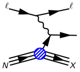
If SIDIS data is used to determine Δs, $K^\pm$ FFs for different sets lead to different results
Such results may differ significantly among them and w.r.t. the results obtained from DIS
$\longrightarrow$ How well do we know kaon FFs?



directly from SIDIS Kaon data



indirectly from DIS + SU(3)



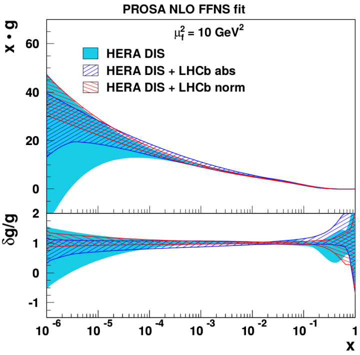
Fragmentation functions: why should we bother?

Example 2: Heavy quark fragmentation: the D^* case

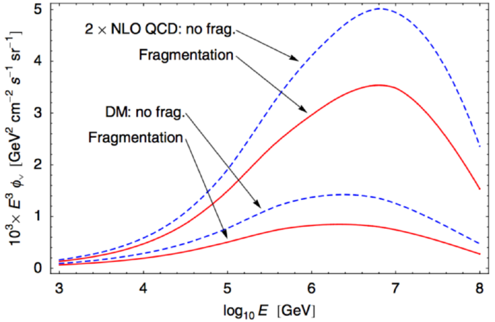
Constrain the low-x (gluon) PDFs through charm production in the forward region
[EPJ C75 (2015) 396; JHEP 1602 (2016) 130]

Compute the prompt atmospheric neutrino flux
[PRD 78 (2008) 043005; JHEP 1506 (2015) 110]

Extract information on the medium in heavy ion collisions
[JHEP 1703 (2017) 146]

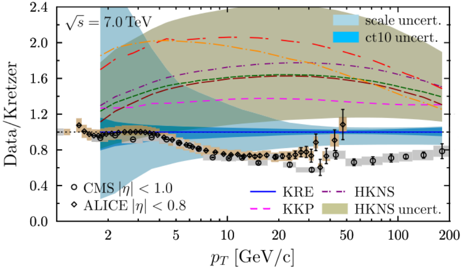


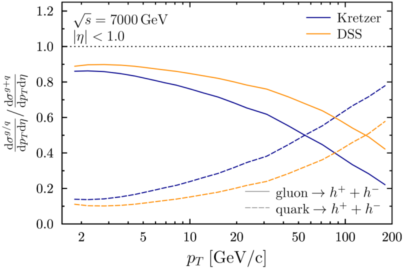
w or w/o considering $\frac{d\sigma(pp\to hX)}{dE_h} = \int_{E_h}^{\infty} \frac{dE_c}{E_c}\frac{d\sigma(pp\to cX)}{dE_c} D_c^h(E_h/E_c)$

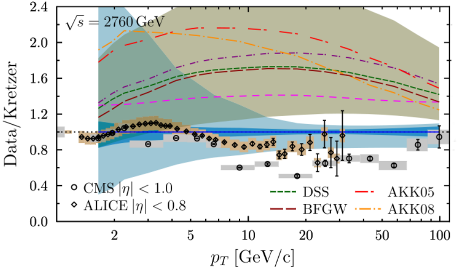


Fragmentation functions: why should we bother?

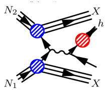
Example 3: Ratio of the inclusive charged-hadron spectra measured by CMS and ALICE







Figures taken from [NPB 883 (2014) 615]



$$E\frac{d^3\sigma}{dp_T^3} = \sum_{a,b,c} f_a \otimes f_b \otimes \hat{\sigma}_{ab}^c \otimes D_c^h$$

Predictions from all available FF sets are not compatible with CMS and ALICE data, not even within scale and PDF/FF uncertainties
$\longrightarrow$ How well do we know the gluon FF?

2. Achievements

Available fragmentation function sets (status 2019)

		DEHSS	HKNS	JAM	NNFF
DATA	SIA	☑	☑	☑	☑
	SIDIS	☑	☒	☑	☒
	PP	☑	☒	☒	☑ ($h^\pm$)
METH.	statistical treatment	Iterative Hessian 68% - 90%	Hessian $\Delta\chi^2 = 15.94$	Monte Carlo	Monte Carlo
	parametrisation	standard	standard	standard	neural network
THEORY	pert. order	(N)NLO	NLO	NLO	LO, NLO, NNLO
	HF scheme	ZM(GM)-VFN	ZM-VFN	ZM-VFN	ZM-VFN
	hadron species	$\pi^\pm$, $K^\pm$, $p/\bar{p}$, $h^\pm$	$\pi^\pm$, $K^\pm$, $p/\bar{p}$	$\pi^\pm$, $K^\pm$	$\pi^\pm$, $K^\pm$, $p/\bar{p}$, $h^\pm$
	latest update	PRD 91 (2015) 014035 PRD 95 (2017) 094019	PTEP 2016 (2016) 113B04	PRD 94 (2016) 114004 PRL 119 (2017) 132001	EPJ C77 (2017) 516 EPJ C78 (2018) 651

$+$ many others (including analyses for specific hadrons)

Focus on π and K which constitute the largest fraction in measured yields

BKK96 [PRD 53 (1996) 3553] K^0

DSV97 [PRD 57 (1998) 5811] Λ^0

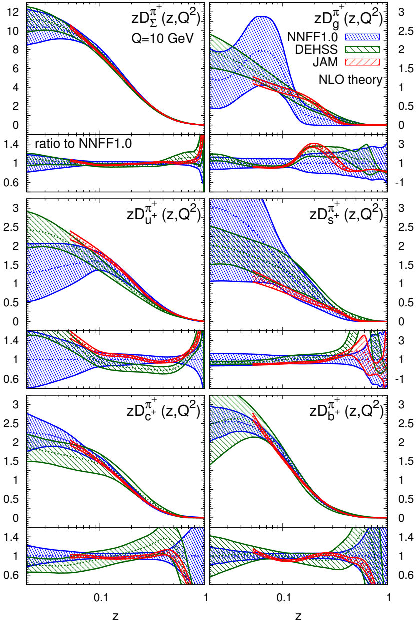
BFGW00 [EPJ C19 (2001) 89] $h^\pm$

AESS11 [PRD 83 (2011) 034002] η

AKSRV17 [PRD 96 (2017) 034028] D^*

LSS15 [PRD 96 (2016) 074026] SIDIS only

Comparison at NLO (π^+): NNFF1.0 - JAM - DEHSS



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

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

different cuts at small z

$D_\Sigma^{\pi^+}$: 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
slightly different shape w.r.t. DHESS (dataset)

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

Comparison at NLO (K^+): NNFF1.0 - JAM - DEHSS

DEHSS [PRD 95 (2017) 094019]
(+SIDIS +PP)

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

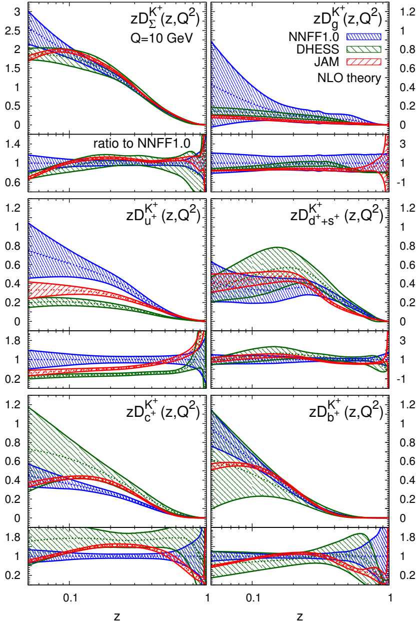
$D_\Sigma^{\pi^+}$: excellent agreement (both c.v. and unc.)
bulk of the dataset

$D_g^{\pi^+}$: 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

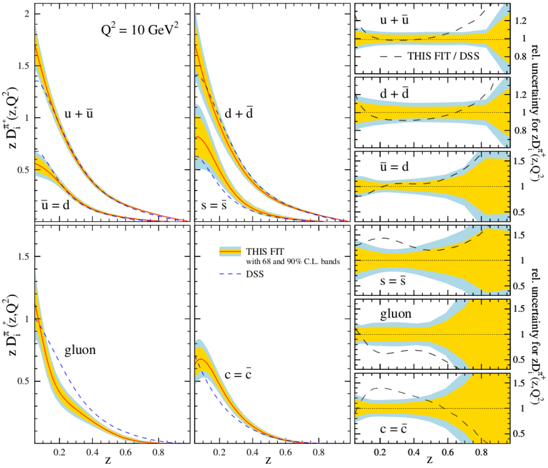
$D_{d^+}^{\pi^+} + D_{s^+}^{\pi^+}$: fair mutual agreement
differences in dataset and parametrisation
comparable uncertainties in the data region

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



Global fit of pion fragmentation functions [PRD 91 (2015) 014035]

experiment		data type	norm. N_i	# data in fit	χ^2
TPC [48]		incl.	1.043	17	17.3
		uds tag	1.043	9	2.1
		c tag	1.043	9	5.9
		b tag	1.043	9	9.2
TASSO [49]	34 GeV	incl.	1.043	11	30.2
	44 GeV	incl.	1.043	7	22.2
SLD [19]		incl.	0.986	28	15.3
		uds tag	0.986	17	18.5
		c tag	0.986	17	16.1
		b tag	0.986	17	5.8
ALEPH [16]		incl.	1.020	22	22.9
DELPHI [17]		incl.	1.000	17	28.3
		uds tag	1.000	17	33.3
		b tag	1.000	17	10.6
OPAL [18, 20]		incl.	1.000	21	14.0
		u tag	0.786	5	31.6
		d tag	0.786	5	33.0
		s tag	0.786	5	51.3
		c tag	0.786	5	30.4
		b tag	0.786	5	14.6
BABAR [28]		incl.	1.031	45	46.4
BELLE [29]		incl.	1.044	78	44.0
HERMES [30]		π^+ (p)	0.980	32	27.8
		π^- (p)	0.980	32	47.8
		π^+ (d)	0.981	32	40.3
		π^- (d)	0.981	32	59.1
COMPASS [31] prel.		π^+ (d)	0.946	199	174.2
		π^- (d)	0.946	199	229.0
PHENIX [21]		π^0	1.112	15	15.8
STAR [33–36]	$0 \leq \eta \leq 1$	π^0	1.161	7	5.7
	$0.8 \leq \eta \leq 2.0$	π^0	0.954	7	2.7
	$\lvert\eta\rvert < 0.5$	$\pi^\pm$	1.071	8	4.3
	$\lvert\eta\rvert < 0.5$	π^+,π^-/π^+	1.006	16	17.2
ALICE [32]	7 TeV	π^0	0.766	11	27.7
TOTAL:				973	1154.6



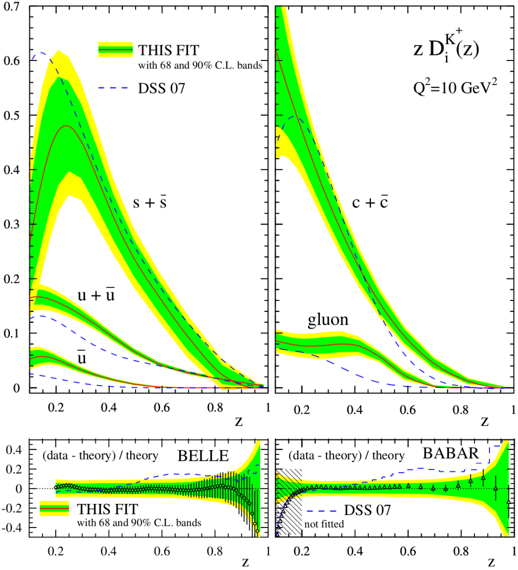
$D_{u+\bar{u}}$: most precise (B-factory SIA data)

Very little or no charge symmetry breaking (SIDIS)

D_g: significant shift of the central value (pp data)

Global fit of kaon fragmentation functions [PRD 95 (2017) 094019]

experiment	data type	norm. N_i	# data in fit	χ^2
TPC [37]	incl.	1.003	12	13.4
SLD [33]	incl.	1.014	18	17.2
	uds tag	1.014	10	31.5
	c tag	1.014	10	21.3
	b tag	1.014	10	11.9
ALEPH [30]	incl.	1.026	13	29.7
DELPHI [31]	incl.	1.000	12	6.9
	uds tag	1.000	12	13.1
	b tag	1.000	12	11.0
OPAL [34]	*u* tag	0.778	5	9.6
	d tag	0.778	5	7.7
	s tag	0.778	5	23.4
	c tag	0.778	5	42.5
	b tag	0.778	5	16.9
BABAR [17]	incl.	1.077	45	30.6
BELLE [18]	incl.	0.996	78	15.6
HERMES [19]	K^+ (p) Q^2	0.843	36	61.9
	K^- (p) Q^2	0.843	36	29.6
	K^+ (p) x	1.135	36	75.8
	K^- (p) x	1.135	36	42.1
	K^+ (d) Q^2	0.845	36	44.7
	K^- (d) Q^2	0.845	36	41.9
	K^+ (d) x	1.095	36	48.9
	K^- (d) x	1.095	36	44.4
COMPASS [22]	K^+ (d)	0.996	309	285.8
	K^- (d)	0.996	309	265.1
STAR [24]	K^+,K^-/K^+	1.088	16	7.6
ALICE [23] 2.76 TeV	K/π	0.985	15	21.6
TOTAL:			1194	1271.7



Good flavour separation (SIDIS data)

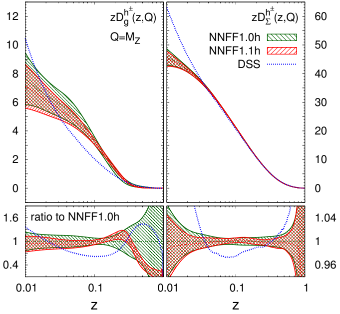
D_g: significant shift (pp data)

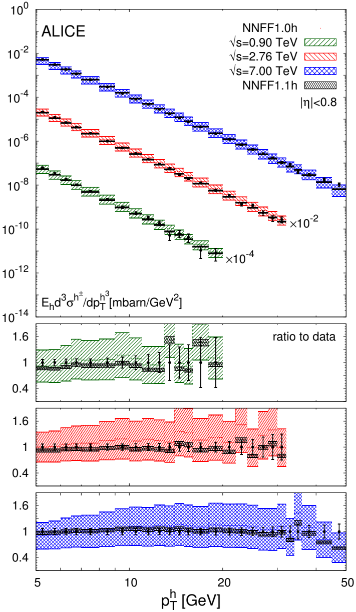
Caution with mass corrections

$D_{u+\bar{u}}$: most precise (B-factory SIA data)

Global fit of unidentified charged hadron FFs [EPJ C78 (2018) 651]

Experiment	$\sqrt{s}$ [TeV]	$N_{\rm dat}$		$\chi^2_{\rm b}/N_{\rm dat}$	$\chi^2_{\rm a}/N_{\rm dat}$	
e^+e^-	various	471	(527)	0.83	0.83	
ALICE	0.90	11	(54)	4.94	1.88	1012
	2.76	27	(60)	13.3	0.82	574
	7.00	22	(65)	6.03	0.53	779
CMS	0.90	7	(20)	4.20	0.70	1206
	2.76	9	(22)	10.6	1.24	579
	7.00	14	(27)	12.4	1.64	396
CDF	1.80	2	(49)	3.32	0.20	1420
	1.96	50	(230)	2.93	1.23	735
		603	(1054)	6.54	1.11	407





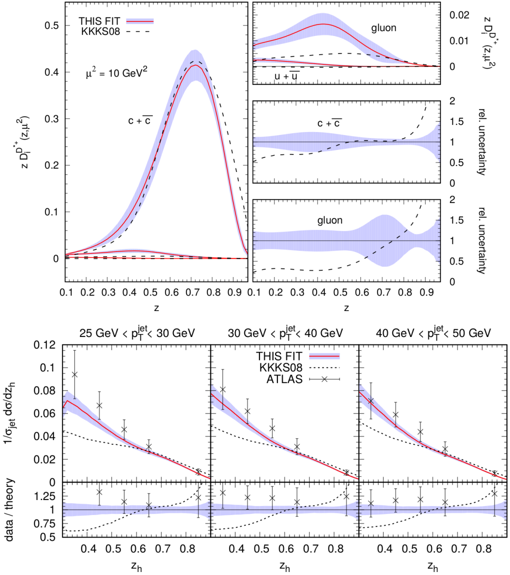
First global fit of D^* fragmentation functions [PRD 96 (2017) 034028]

Only g, c and b FFs parametrised

Use of ZM-VFN scheme

Kinematic cut $p_T^h > 10$ GeV

experiment		data type	#data in fit	χ^2
ALEPH [80]	*Eur. Phys. J. C 16, 597 (2000)*	incl.	17	33.738
OPAL [81]	*Z. Phys. C 67, 27 (1995)*	incl.	9	6.999
		c tag	9	8.388
		b tag	9	5.342
ATLAS [94]	*Nucl. Phys. B 907, 717 (2016).*	$D^{*\pm}$	5	3.598
ALICE [60, 61] *JHEP 1201, 128 (2012)*	$\sqrt{S} = 7$ TeV	D^{*+}	3	0.126
JHEP 1207, 191 (2012)	$\sqrt{S} = 2.76$ TeV	D^{*+}	1	0.007
CDF [62]	*Phys. Rev. Lett. 91, 241804 (2003)*	D^{*+}	2	1.289
LHCb [64]	$2 \leq \eta \leq 2.5$	$D^{*\pm}$	5	10.984
JHEP 1609, 013 (2016)	$2.5 \leq \eta \leq 3$	$D^{*\pm}$	5	2.607
	$3 \leq \eta \leq 3.5$	$D^{*\pm}$	5	8.229
	$3.5 \leq \eta \leq 4$	$D^{*\pm}$	2	10.411
ATLAS [68]	$25 \leq \frac{p_T^{\rm jet}}{\rm GeV} \leq 30$	(jet $D^{*\pm}$)	5	4.146
Phys. Rev. D 85, 052005 (2012)	$30 \leq \frac{p_T^{\rm jet}}{\rm GeV} \leq 40$	(jet $D^{*\pm}$)	5	1.977
	$40 \leq \frac{p_T^{\rm jet}}{\rm GeV} \leq 50$	(jet $D^{*\pm}$)	5	0.659
	$50 \leq \frac{p_T^{\rm jet}}{\rm GeV} \leq 60$	(jet $D^{*\pm}$)	5	0.791
	$60 \leq \frac{p_T^{\rm jet}}{\rm GeV} \leq 70$	(jet $D^{*\pm}$)	5	1.333
TOTAL:			97	100.980



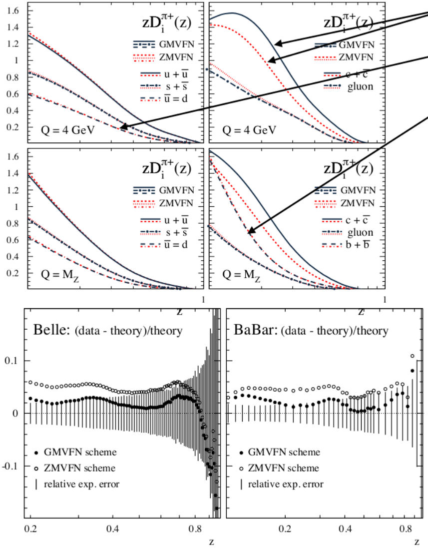
See also [JHEP 1605 (2016) 125]

Pion fragmentation functions in the GM-VFNs [PR D94 (2016) 034037]

charm changes significantly

light flavors constrained by sidis

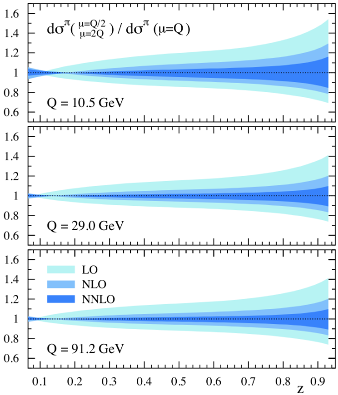
bottom constrained by high Q

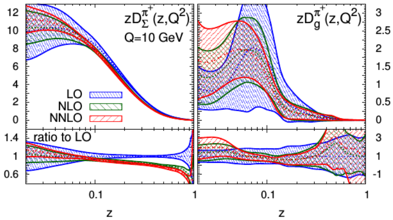


experiment	data type	# data in fit	ZMVFN N_i	ZMVFN χ^2	GMVFN N_i	GMVFN χ^2
ALEPH [23]	incl.	22	0.968	21.6	0.994	23.3
BABAR [13]	incl.	39	1.019	76.7	1.002	58.2
BELLE [14]	incl.	78	1.044	19.5	1.019	11.0
DELPHI [24]	incl.	17	0.978	6.7	1.003	9.3
	uds tag	17	0.978	20.8	1.003	9.5
	b tag	17	0.978	10.5	1.003	7.8
OPAL [25]	incl.	21	0.946	27.9	0.970	15.9
SLD [26]	incl.	28	0.938	28.0	0.963	9.5
	uds tag	17	0.938	21.3	0.963	11.3
	c tag	17	0.938	34.0	0.963	19.8
	b tag	17	0.938	11.1	0.963	9.9
TPC [27]	incl.	17	0.997	31.7	1.006	27.9
	uds tag	9	0.997	2.0	1.006	2.0
	c tag	9	0.997	5.9	1.006	4.3
	b tag	9	0.997	9.6	1.006	10.9
COMPASS [28]	$\pi^{\pm}$ (d)	398	1.003	378.7	1.008	382.9
HERMES [29]	$\pi^{\pm}$ (p)	64	0.981	74.0	0.986	69.9
	$\pi^{\pm}$ (d)	64	0.980	107.3	0.985	103.7
PHENIX [30]	π^0	15	1.174	14.3	1.167	14.4
STAR [31]	$\pi^{\pm}$, π^0	38	1.205	31.2	1.202	33.8
ALICE [32]	π^0	11	0.696	33.3	0.700	31.2
TOTAL:		924		966.4		875.8

Slide: courtesy of R. Sassot

Fragmentation functions at NNLO [PR D92 (2015) 114017; EPJ C77 (2017) 516]





Exp.	$N_{\rm dat}$	LO $\chi^2/N_{\rm dat}$	NLO $\chi^2/N_{\rm dat}$	NNLO $\chi^2/N_{\rm dat}$
BELLE	70	0.60	0.11	0.09
BABAR	40	1.91	1.77	0.78
TASSO12	4	0.70	0.85	0.87
TASSO14	9	1.55	1.67	1.70
TASSO22	8	1.64	1.91	1.91
TPC	13	0.46	0.65	0.85
TPC-UDS	6	0.78	0.55	0.49
TPC-C	6	0.55	0.53	0.52
TPC-B	6	1.44	1.43	1.43
TASSO34	9	1.16	0.98	1.00
TASSO44	6	2.01	2.24	2.34
TOPAZ	5	1.04	0.82	0.80
ALEPH	23	1.68	0.90	0.78
DELPHI	21	1.44	1.79	1.86
DELPHI-UDS	21	1.30	1.48	1.54
DELPHI-B	21	1.21	0.99	0.95
OPAL	24	2.29	1.88	1.84
SLD	34	2.33	1.14	0.83
SLD-UDS	34	0.95	0.65	0.52
SLD-C	34	3.33	1.33	1.06
SLD-B	34	0.45	0.38	0.36
TOTAL	428	1.44	1.02	0.87

Excellent perturbative convergence
FFs almost stable from NLO to NNLO
LO FF uncertainties larger than HO
Effects less evident for $K^\pm$ and $p/\bar{p}$

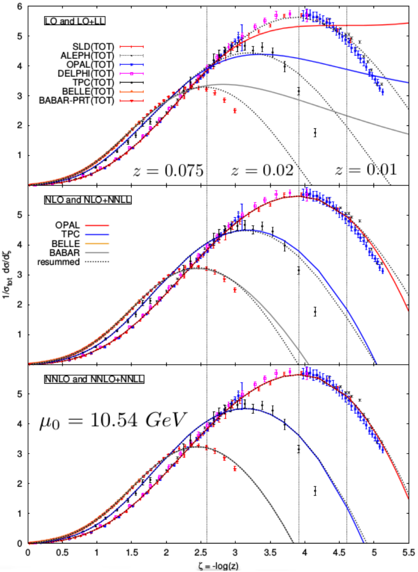
Small-z resummed fragmentation functions [PRD 95 (2017) 054003]

436 Total data Points:

- LEP cut (z = 0.01) due to inconsistency between OPAL and ALEPH

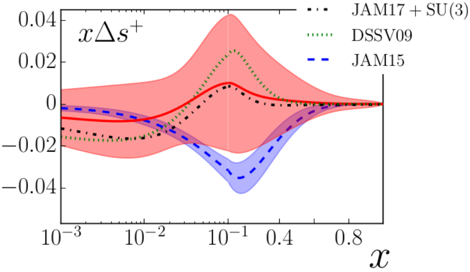
- TPC lower cut (z = 0.02) based on difference of energy fraction $z = 2\,E_h/Q$ and three momentum fraction $x_p = z - 2m_h^2/(zQ^2) + \mathcal{O}(1/Q^4)$ in c.m.s being less than at least 15%

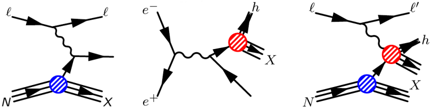
accuracy	χ^2	χ^2/dof
LO	1260.78	2.89
NLO	354.10	0.81
NNLO	330.08	0.76
LO+LL	405.54	0.93
NLO+NNLL	352.28	0.81
NNLO+NNLL	329.96	0.76

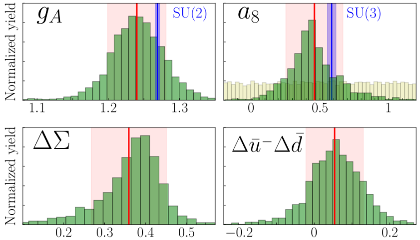


Slide: courtesy of D. P. Anderle

Simultaneous fits of (pol.) PDFs and FFs [PRL 119 (2017) 132001]







process	target	$N_{\rm dat}$	χ^2
DIS	$p, d, {}^3$He	854	854.8
SIA ($\pi^\pm, K^\pm$)		850	997.1
SIDIS ($\pi^\pm$)			
HERMES	d	18	28.1
HERMES	p	18	14.2
COMPASS	d	20	8.0
COMPASS	p	24	18.2
SIDIS ($K^\pm$)			
HERMES	d	27	18.3
COMPASS	d	20	18.7
COMPASS	p	24	12.3
Total:		**1855**	**1969.7**

$g_A = 1.24 \pm 0.04$ $\qquad$ $a_8 = 0.46 \pm 0.21$

confirmation of SU(2) symmetry to $\sim 2\%$

$\sim 20\%$ SU(3) breaking $\pm 20\%$

$$\Delta s^+ = -0.03 \pm 0.09$$

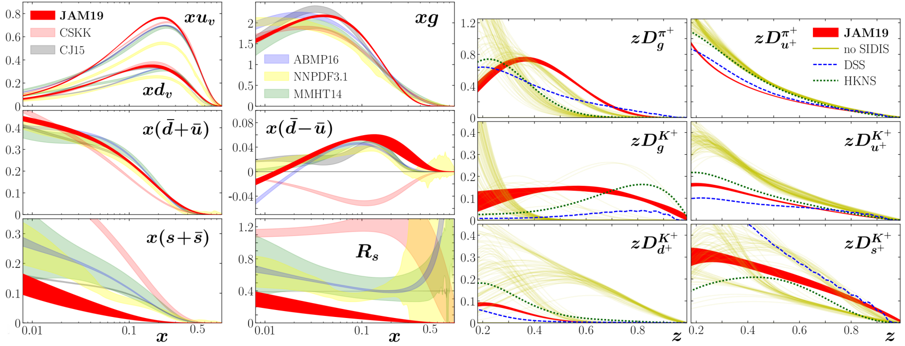
$\Delta\Sigma = 0.36 \pm 0.09$ $\qquad$ $\Delta u - \Delta d = 0.05 \pm 0.08$

Simultaneous fits of (unp.) PDFs and FFs [arXiv:1905.03788]

Multi-step procedure

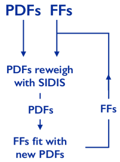
- sampling the posterior distributions from flat priors for fixed-target DIS data (BCDMS, SLAC, NMC)
- update these posteriors with collider DIS data (HERA I-II)
- update the resulting posteriors with DY data (E866)
- sampling the posterior distributions from flat priors for SIA data (DESY, SLAC, CERN, KEK)
- update the FF/PDF posteriors with SIDIS data (COMPASS)

Process	$N_{\rm dat}$	$\chi^2/N_{\rm dat}$
DIS	2680	1.28
SIDIS	992	1.25
DY	250	1.67
SIA	444	1.27
Total	4366	1.30

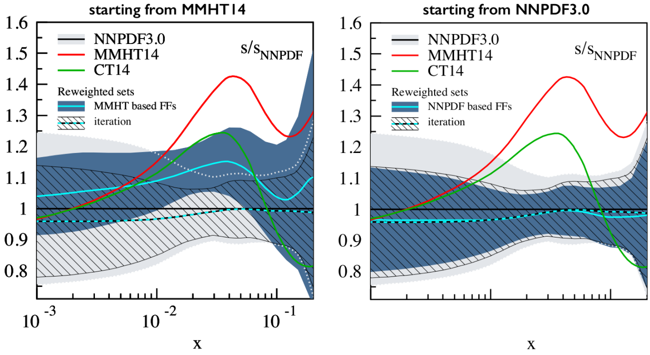


Simultaneous fits of (unp.) PDFs and FFs [PRD 96 (2017) 094020]

IDEA:
iterative reweighting of PDFs and fit of FFs
with kaon SIDIS data ($N_{\rm dat} = 906$)
HERMES [PRD 87 (2013) 074029]
COMPASS [PLB 767 (2017) 133]



convergence?
and very fast!
robust!



χ^2_{FF} = 1271.7 | 1041.3 | 1002.3   1017.2 | 1005.3 | 1000.6

similar results with CT14 replicas

3. Conclusions

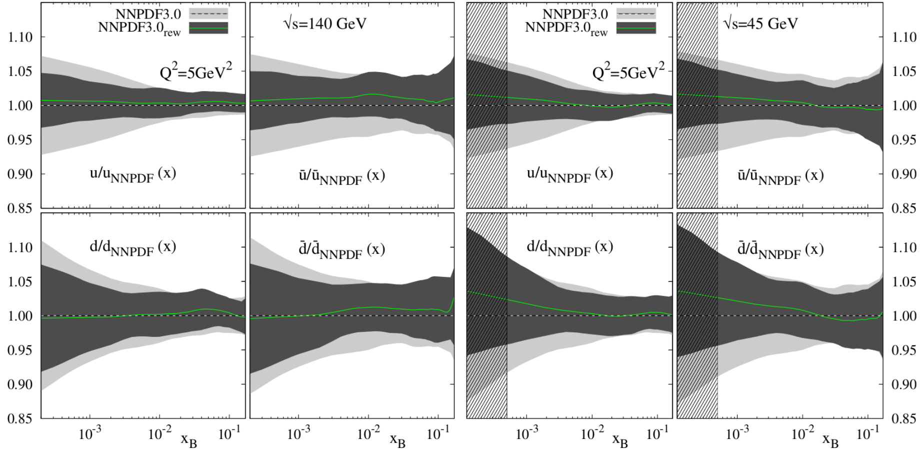
Fragmentation Functions at a future EIC [PRD 99 (2019) 094004]

Assess the quantitative impact of simulated $\pi^{\pm}$ and $K^{\pm}$ DIS data at an EIC

Consider two kinematic scenarios for the EIC ($\sqrt{s}$=45 GeV, $\sqrt{s}$=140 GeV)

Use an iterative procedure based on reweighting

Appreciate the significant impact on sea quark PDFs and on all FFs



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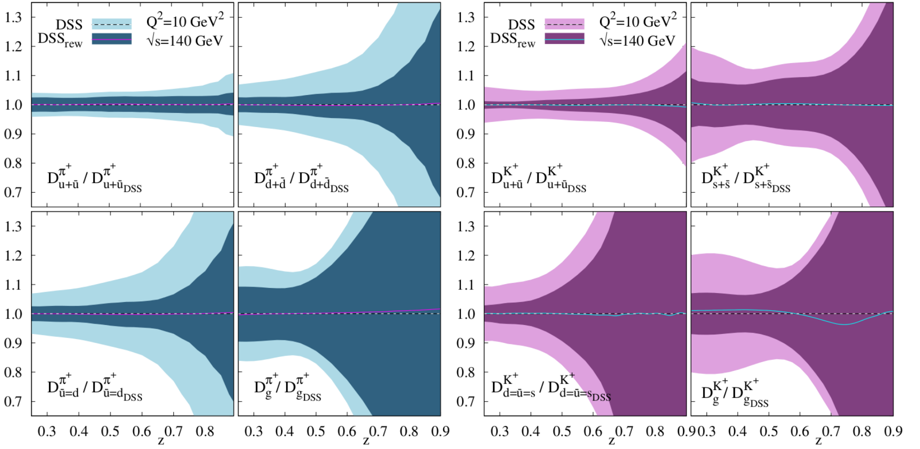

Summary

1. A number of hard-scattering processes require an appropriate knowledge of FFs
   - probing nucleon momentum, spin and flavour
   - studying the prompt atmospheric neutrino flux
   - understanding spatial distributions and the dynamics of nuclear matter
2. Significant role of new data, including LHC data
   - increased accuracy of fragmentation functions
   - increased precision of fragmentation functions
3. Increasing sophistication of the QCD theory
   - needed to catch most of the features of the data
   - includes NNLO, heavy quark mass schemes, resummation
4. Exploit the full potential of SIDIS to improve our knowledge of PDFs
   - simultaneous fits challenging, but feasible
   - combine simultaneous and global fits to make the most from the data

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Thank you

Dependence on α_s