# The Role of Heavy Quarks in Light Hadron Fragmentation.

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**HUGS 2016**

**Jefferson Lab, Newport News, Virginia**

**June, 2016**

# Outline

Fragmentation Functions and Global Analyses

Heavy Quark Mass Effects and General Mass Schemes

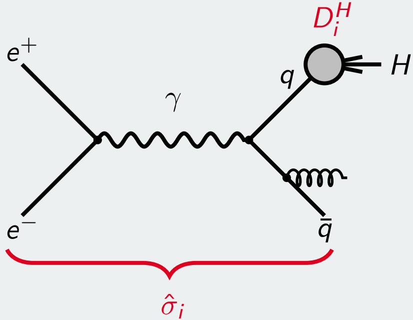
General Mass Global Analysis

Summary

# Fragmentation functions (FF) and Global Analyses

Hadroproduction in scattering processes begins with the excitation of free partonic states (quarks and gluons).

Fragmentation: excited partons group together into hadrons through a non perturbative mechanism.




First stages can be described in a perturbative theory (pQCD): partonic cross sections $\hat{\sigma}_i(x, Q)$.

- The final partonic state of the type $i$ is excited.
- $Q$ is the energy scale of the process.
- $x$ is center of mass momentum fraction carried by the parton

The probability of producing the hadron $H$ from a parton $i$ is measured by FFs: $D_i^H(y, Q)$.

- $y$ is the momentum fraction of the parton $i$ carried by the $H$ hadron

The QCD prediction for the cross section of production of $H$.

$$\frac{d\sigma}{dz}(Q) = \sum_{i=q,\bar{q},g} \hat{\sigma}_i(Q) \otimes D_i^H(Q)$$

→ Can be measured. ($\frac{d\sigma}{dz}$)

→ Convolution in the Mellin sense. ($\otimes$)

QCD tells us how fragmentation functions evolve in the energy scale: Altarelli - Parisi equations.

$$\frac{d}{d\ln(Q^2)} \begin{pmatrix} D_{q_i} \\ D_g \end{pmatrix} = \sum_j \begin{pmatrix} P_{q_i q_j} & P_{q_i g} \\ P_{g q_j} & P_{gg} \end{pmatrix} \otimes \begin{pmatrix} D_{q_j} \\ D_g \end{pmatrix} \quad (1)$$

Extraction of fragmentation functions by performing a QCD global analysis.

- Propose a parametrization for the fragmentation functions at an initial scale.
- Evolve to some experiment energy scale through the Altarelli - Parisi equations.
- Compute cross section predictions as a fucntion of the unknown parameters.
- Obtain best parameter values by minimizing a $\chi^2$ function.

Fragmentation functions are universal quantities. All available experimental data set types are used:

- semi inclusive electron-positron annihilation (SIA)
- semi inclusive deep inelastic scattering (SIDIS)
- proton-proton collisions

# Heavy Quark Mass Effects and General Mass Schemes

Cross section calculation at zero mass variable flavour number (ZMVFN) scheme:

$$\frac{d\sigma}{dz}^{\text{ZMVFN}} = \sum_{i=q,h,g} \hat{\sigma}_i^{\text{ZM}}(Q) \otimes D_i^{\text{ZM}}(Q) \qquad (2)$$

$D_i^{\text{ZM}}$ functions evolve through the standard zero mass evolution equations.

Cross section calculation at a massive (M) scheme:

$$\frac{d\sigma}{dz}^{\text{M}} = \sum_{i=q,g} \hat{\sigma}_i^{\text{M}}(Q, m_h) \otimes D_i^{\text{M}}(Q) + \hat{\sigma}_h^{\text{M}}(Q, m_h) \otimes D_h^{\text{M}} \qquad (3)$$

$\propto \alpha_S^n \, ln(Q/m_h)^k$

Light flavour $D_i^{\text{M}}$ functions evolve through the standard zero mass evolution equations.

$D_h^{\text{M}}$ are decoupled of the QCD evolution.

Large logarithmic contributions can be factorised systematically:

$$\hat{\sigma}_i^{\text{M}}(Q, m_h) \xrightarrow[m_h \to 0]{} \sum_{j=q,g,h} \hat{\sigma}_j^{\text{ZM}}(Q) \otimes \mathcal{A}_{ji}(Q/m_h) \qquad (4)$$

The best of the two worlds: general mass variable flavour number scheme (GMVFN).

$$\frac{d\sigma}{dz}^{\text{GMVFN}} = \sum_{i=q,g,h} \hat{\sigma}_j^{\text{GM}}(Q, m_h) \otimes D_j^{\text{GM}}(Q) \tag{5}$$

$$\hat{\sigma}_j^{\text{GM}} \rightarrow \sum_{i=q,g,h} \hat{\sigma}_i^{\text{M}}(Q, m_h) \otimes \mathcal{A}_{ij}^{-1}(Q/m_h)$$

$D_i^{GM}$ functions evolve through the standard zero mass evolution equations.

To ensure continuity across the threshold is necessary to impose matching condition:

$$D_j^{\text{GM}}(m_h) = \sum_{i=q,g,h} \mathcal{A}_{ji}(1) \otimes D_i^{\text{M}}(m_h)$$

The GMVFN scheme is not unique. We can emphasize massive-like behaviour if:

$$\hat{\sigma}_j^{\text{GM}} \longrightarrow \hat{\sigma}_j^{\text{GM}*} = (1 - f(Q))\ \hat{\sigma}_j^{\text{M}} + f(Q)\ \hat{\sigma}_j^{\text{GM}} \tag{6}$$

$$\begin{cases} f(Q) \xrightarrow[Q \to 2m_h]{} 0 \\ f(Q) \xrightarrow[Q \to \infty]{} 1 \end{cases}$$

Alternatively, we can emphasize massless-like behaviour if:

$$\hat{\sigma}_j^{\text{GM}} \longrightarrow \hat{\sigma}_j^{\text{GM}*} = (1 - f(Q))\ \hat{\sigma}_j^{\text{GM}} + f(Q)\ \hat{\sigma}_j^{\text{ZM}} \tag{7}$$

Any power-like choice for $f(Q)$ is equally valid.

# General Mass Global Analysis

Experimental data sets used:

- SIA (ALEPH, BABAR, BELLE, DELPHI, OPAL, SLD, TPC)
- SIDIS (COMPASS, HERMES)
- proton-proton collisions (PHENIX, STAR, ALICE)

Only SIA partonic cross section were computed in the GMVFN.

Best results were obtained with a mass dependent scheme, specifically:

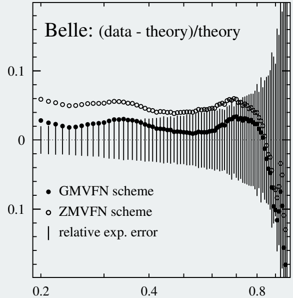
- emphasize the **massive** behaviour of the charm flavour
- emphasize the **massless** behaviour of the bottom flavour

| experiment | # data | ZMVFN | GMVFN |
|---|---|---|---|
| **TOTAL** $\chi^2$**:** | 924 | 966.4 | 875.8 |

No significant improvement with more sophisticated Q-dependence than $f(Q) = 1 - 2m_h/Q$.

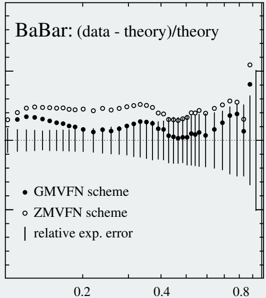
Better agreement between lower energy data sets (Belle, Babar) and theory is obtained for the general mass scheme.

| $Q \approx 10$ GeV | | | | | | |
|---|---|---|---|---|---|---|
| experiment | data type | # data in fit | ZMVFN $N_i$ | ZMVFN $\chi^2$ | GMVFN $N_i$ | GMVFN $\chi^2$ |
| BaBar | incl. | 39 | 1.019 | 76.7 | 1.002 | 58.2 |
| Belle | incl. | 78 | 1.044 | 19.5 | 1.019 | 11.0 |

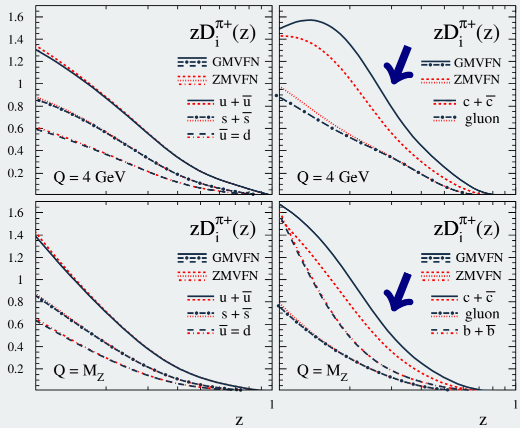



There is also a considerable improvement in the description of data from experiments at a higher energy scale.

| $Q = 91.2$ GeV | | | | | | |
|---|---|---|---|---|---|---|
| experiment | data type | # data in fit | ZMVFN $N_i$ | ZMVFN $\chi^2$ | GMVFN $N_i$ | GMVFN $\chi^2$ |
| Opal | incl. | 21 | 0.946 | 27.9 | 0.970 | 15.9 |
| Sld | 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 |



Extracted fragmentation functions:




Most noticeable difference in the charm distribution.

No change for the bottom: suppressed at Belle and Babar, no mass effects at $M_Z$.

No change in the light flavors: fixed mostly by SIDIS.

# Summary

A determination of the fragmentation probabilities required a scheme sensitive to the heavy flavour dynamics.

Heavy quark dependence is specially relevant in the single inclusive electron-positron annihilation into pions.

Impact of the mass correction in SIDIS and proton-proton corrections into pions is needed to be evaluated.