Fragmentation Function Studies at BESIII

Christoph Florian Redmer for the BESIII collaboration

The 11th International Workshop on Chiral Dynamics

August 27, 2024











Puzzles of QCD at Long Distances

Confinement



Nucleon Structure

August 27, 2024



How do mass and spin of the nucleon emerge?

CD2024

0.04

10

100

IGL

Q [GeV]

1000

Fragmentation Functions $D_q^h(z)$

Probability density of a parton \mathbf{q} to fragment into a specific hadron \mathbf{h}

Depending on fraction z of final hadron's momentum of initial parton's momentum



Access to Fragmentation Functions in Experiment





 $pp: \sigma = \sum_{q} PDF \otimes PDF \otimes \sigma(q_1q_2 \to q'_1q'_2) \otimes FF$

- Depends on unpolarized PDFs
- Parton momenta not directly known
- Leading access to gluon FF
- $\begin{array}{l} {\sf SIDIS}: \sigma = \sum_q PDF \otimes \sigma(eq \rightarrow e'q') \otimes FF \\ \bullet \ \, {\sf Depends \ on \ unpolarized \ PDFs} \end{array}$
- Flavor structure directly accessible



August 27, 2024

$$e^+e^-: \sigma = \sum_q \sigma(e^+e^- \to q\bar{q}) \otimes FF$$

- PDFs not involved
- Calculations known at NNLO
- Flavor structure not directly accessible
- Cleanest access to Fragmentation Functions

CD2024

IGI

Access to Fragmentation Functions in Experiment





 $pp: \sigma = \sum_{q} PDF \otimes PDF \otimes \sigma(q_1q_2 \to q'_1q'_2) \otimes FF$

- Depends on unpolarized PDFs
- Parton momenta not directly known
- Leading access to gluon FF
- $\begin{array}{l} {\sf SIDIS}: \sigma = \sum_q PDF \otimes \sigma(eq \rightarrow e'q') \otimes FF \\ {\scriptstyle \bullet} \end{array} \\ \begin{array}{l} {\sf Depends \ on \ unpolarized \ PDFs} \end{array}$
- Flavor structure directly accessible

Experimental observable:

1 d $\sigma_{\rm h}$ $\sigma_{had,tot} dz$

At leading order:

CD2024

 $e^+e^- \rightarrow hX \sim \sum_a e_a^2 D_1^{h/q}(z)$

IGL



August 27, 2024

$$e^+e^-: \sigma = \sum_q \sigma(e^+e^- \to q\bar{q}) \otimes FF$$

- PDFs not involved
- Calculations known at NNLO
- Flavor structure not directly accessible
- Cleanest access to Fragmentation Functions

Available World Data



August 27, 2024

Fragmentation Functions at BESIII

- Most information at high energies (SLAC, CERN, DESY)
- Lack of data below 10 GeV

CD2024

• Unique opportunity for BESIII: $2 \le \sqrt{s} \, [\text{GeV}] \le 5$

JGU

Available World Data



Lack of precise data at low energies, where BESIII can contribute!

CD2024

IGU

Fragmentation Functions at BESIII

August 27, 2024

Beijing e⁺e⁻**Collider** – **BEPCII**

Fragmentation Functions at BESIII





August 27, 2024

Center-of-mass energies from 2 – 5 GeV

Design luminosity exceeded: 1.1×10³³ cm⁻²s⁻¹ at 3.77 GeV

World's largest e+e- data sets at τ -charm energies

- 10^{10} J/ ψ and 2.7×10⁹ ψ (2s) directly produced
- 20 fb⁻¹ collected at 3.773 GeV
- More than 40 fb⁻¹ collected between 3.773 and 5 GeV
- More than 170 scan points

This work:

- 6(8) R scan data points
- 2.23 GeV 3.67 GeV

CD2024

IGL

Beijing Spectrometer – BESIII



Normalized Hadronic Cross Section



Results for π^0 and K^0_S



- Hadrons reconstructed from daughters
- Background suppression:

August 27, 2024

- Helicity angle cut
- Secondary vertex fit



CD2024

IGU

Disagreement with existing fits of Fragmentation Functions

- Depending on \sqrt{s} and p_h
- Problem in extrapolation of Fragmentation Functions to lower energies?

Results for η



August 27, 2024

- Hadrons reconstructed from daughters
- Helicity angle cut for background suppression



CD2024

JG U

- Disagreement with fit of Fragmentation Functions in Phys. Rev. D83 (2011) 034002
- Agreement with new fit by Li, Anderle, Xiao, Zhang (arXiv:2404.11527)
 - Includes NNLO accuracy, higher-twist effects, and hadron mass correction

Further Measurements at BESIII

Large amounts of additional data already collected

Fragmentation Functions at BESIII

170 energy scan points with >10⁵ hadrons



August 27, 2024

Continuum region (2.00 – 3.67 GeV):

- Inclusive production of charged particles (p vs. p_t) $e^+e^- \rightarrow \pi^{\pm}, K^{\pm} + X$
- Spin-alignment effects of vector mesons $e^+e^- \rightarrow \phi, K^* + X$

Higher energies

Access to heavier mesons and hyperons

 $e^+e^- \to \eta', \Lambda/\Sigma + X$

CD2024

IGL

Summary

- Fragmentation Functions important ingredient to understanding of non-perturbative QCD
- Cleanest access in e⁺e⁻ annihilation experiments

BESIII provides valuable information at $\sqrt{s} < 5 \,\text{GeV}$

August 27, 2024

Normalized differential cross sections of inclusive $\pi^0/K_S^0/\eta$ production published RPL 130 (2023) 231901

CD2024

IG

- Excellent z-coverage $(0.1 \le z \le 0.9)$ and precision $(3\% \text{ at } z \sim 0.4)$
- Large discrepancies with existing fits/predictions of Fragmentation Functions observed

• More results in preparation for $\pi^{\pm}, K^{\pm}, \phi, K^{*}$ and η', Λ, Σ