Fracture Functions from $\Lambda$ Leptoproduction for Target Remnant Description

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Fracture Functions: Context

Fragmentation Functions:
Struck / current quark

Structure Functions:
Initial distribution

Fracture Functions:
“spectator” / target - remnant

Hadronic Target

Lepton Beam
Factorized QCD

Separate:
- Non-Perturbative, Measurable, Universal
- Perturbatively Calculable, Process-Specific

Example:
\[
\sigma(l+N \rightarrow l'+H+X) = \sum_j \int_0^1 \frac{dx}{x} F^j_N(x, Q) \sigma^j_H(x, Q)
\]

Structure Function: \( F^j_N(x, Q) \)

Cross section: \( \sigma^j_H(x, Q) \)
- Specific hard lepton-parton process of interest
Measurable, Universal Functions

Structure Functions (F): Initial hadron configuration
Fragmentation Functions (D): Struck quark evolution to hadron
Fracture Function (M): Evolution of target spectators to hadron

FIG. 2: The four terms of eq. (18). The black blob denotes the parton-to-parton evolution function $\tilde{E}$. Partons indices are shown and at each triple-line vertex is associated a real AP splitting functions $\tilde{P}(u)$. The diagrams are at the amplitude square level. The top parton line enters the hard ($Q^2$) scattering indicated by the bright blob.

Current / Target Separation

Expect distinct behavior from $X_F$ positive vs negative

Positive = Forward
- Direction of virtual photon

Negative = Backward
- Direction of proton

$Z = 0.5$
- Separates target fragmentation from leading quark

*Fig. 1. D2: $X_F$*
EG2 Experiment
Hadronization Highlight

Compare nuclear and D2 target in super-ratio
Approach dual hadronization scales

Uniquely $\Lambda^0$:

Strange content, compare to strange meson production
Baryon # conserved, requires higher production energy

See talk by Taya Chetry, April 10th
EG2 Experiment

Data: 5.014 GeV, 50 days in 2004
- C, Fe Luminosity: $2.0 \times 10^{34}$ (Hz cm$^{-2}$)
- Pb Luminosity: $1.3 \times 10^{34}$ (Hz cm$^{-2}$)

Fracture Function Reaction Channel
- $D(e,e'\Lambda^0)X$
  - Scattered electron and $\Lambda^0$ decay products detected

$\Lambda^0 \rightarrow \pi^- +\text{proton}$
- (~64% branching ratio)

Electron Identification, pion Identification
- EM Calorimetry, Cherenkov Counter, Tracking
Proton Identification

Corrected Time of Flight Variable Identifies Protons
Time to Scintillator from Target
Path Length to Scintillator
  - Converted to time with measured momentum, assumed proton mass
Protons cluster near zero
Momentum binning
  - 0.05 GeV bins
Fitted proton peak per bin
  - Half-peak range
Smoothed between bins
  - Spline function
DIS Selection

Kinematic cuts:
- $Q^2 > 1$ (4-momentum transfer)
- $W > 2$ (Hadronic mass)
- $y < 0.85$ (Struck Quark Energy Fraction)

• Iron Dataset
  - Deuterium and nuclear targets
  - Single good electron events
CLAS Dataset

Total DIS electrons
- Fe run, D target: ~42 million
- C, Pb run: expect similar

y variable:
- Electron energy fraction transferred to quark

z variable:
- Fraction of transferred energy carried by observed hadron

Fracture Function
- $M(x_B, z, Q)$

Multivariate Binning
- ~900 Bins for $\pi^+$ analysis
- ~1/10$^{th}$ data for $\Lambda^0$ analysis
Lambda Yield Procedure

Event Selection:
- DIS electron, $\pi^-$, proton
- Same Target

Reconstruct $\Lambda^0$ mass

Background Model:
- Mix $\pi^-$, proton (separate events)

Normalize background model to sideband region

Iron Dataset

![Graph showing Lambda Candidate Invariant Mass](image-url)

**Legend:**
- Black: Data
- Blue: Background
- Red: Subtracted
Lambda Yield Procedure

2 Side Bands
Subtract Background
Breit-Wigner + Constant

Lambda Candidate with Z between .54-.6 GeV, Liquid Target

$\chi^2 / \text{ndf} = 99.63 / 96$
$p_0 = -2.496 \pm 0.582$
$p_1 = 0.4159 \pm 0.0200$
$p_2 = 1.116 \pm 0.000$
$p_3 = 0.001789 \pm 0.000119$

Lambda $^0$ Candidate Invariant Mass (GeV)

Nine Z Bins, Two Targets

Solid Z Bin 5
Liquid Z Bin 5
Background Subtraction

- Side bands used to normalize background and signal
- Fit Quality Tests
  - 1) Combined $\chi^2$ difference from one for all bins
  - 2) Combined linear offset for all bins
- Band limits varied independently
- Lower Band Only
  - Improves test 2
- Upper Band Only
  - Improves test 1
- New method Needed
  - Floating fit
Fitted Yields

- **Data Model Includes:**
  - Combinatorial background shape for each bin
  - Breit-Wigner signal

- **Allow normalization of both shapes to float**
  - Use RooFit Minuit Minimization procedure

- See Taya Chetry's talk: April 10th

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**Figure 1:** Distribution of $\Lambda$ invariant mass (black) with the fit result (blue) from D2 (left) and Fe (right) for the 5th $z$-bin. The dot-dashed red curve is the combinatorial background, and the dashed green curve is the simple Breit-Wigner (BW) background-subtracted signal.
Finalizing Lambda Yields

Apply acceptance corrections
- Negative $\pi^-$ inbending
- Positive $p$ outbending

Combine Fe, C, Pb datasets

Determine Binning

Extract Yields per Bin
Fracture Function Extraction

Figure 1: Best-fit predictions compared to normalised $x_F$ distributions for charged current semi-inclusive Lambda cross-sections from Ref. [12] (left panels) and Ref. [13] (right panels). Various quark-flavour proton-to-Lambda fracture functions contributions are shown. Note the additional factor $2E_h/(\pi W)$ which multiplies the normalised cross-sections from Ref. [12].
Fracture Function Extraction

Decompose: PDF & “Spectator Fragmentation”
- \[ M_i^{A/p}(x_B, z, Q_0^2) = f_{i/p}(x_B, Q_0^2) \tilde{D}_i^{A/p}(z), \quad i = q, \bar{q}, g. \]

Decompose: Sea vs. Valance
- \[ M_{q=u,d}^{A/p}(x_B, z, Q_0^2) = q_{val}(x_B, Q_0^2) \tilde{D}_{q_{val}}^{A/p}(z) + q_{sea}(x_B, Q_0^2) \tilde{D}_{q_{sea}}^{A/p}(z). \]

Assign Functional Form
- \[ \tilde{D}_i^{A/p}(z) = N_i z^{\alpha_i} (1 - z)^{\beta_i} \]

Normalize
- \[ N_i = N_i \left[ \int_0^1 dz z^{\alpha_i} (1 - z)^{\beta_i} \right]^{-1}, \quad \alpha_i, \beta_i > -1, \]

Fit with Free Parameters:
- \[ N_i \]

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Summary

Fracture Functions
- Universal, measurable, target remnant
- Parameterize soft nonperturbative QCD behavior

Large EG2 Dataset
- $M(x_B,z,Q)$

Lambda Yields
- Recent analysis progress
- Fracture function function extraction
- Also used for hadronization studies

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