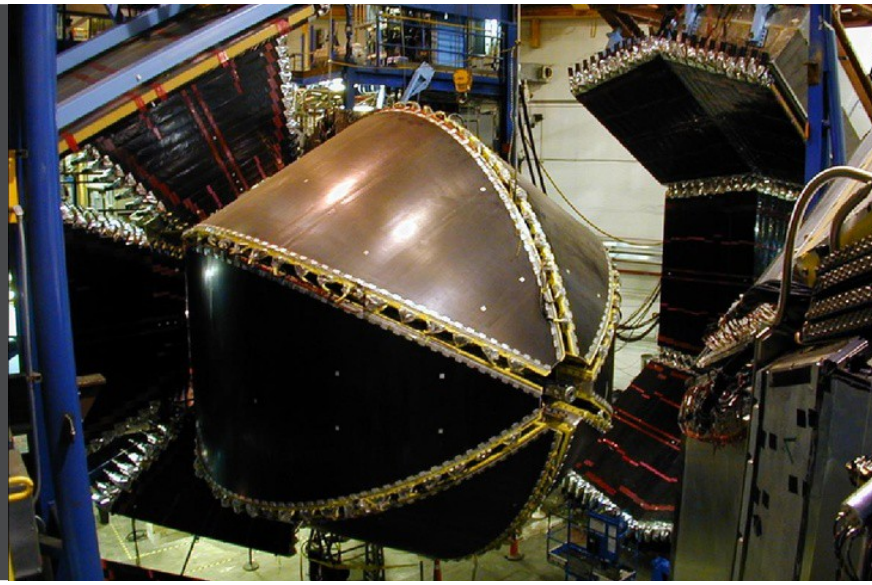
Fracture Functions from Λ Leptoproduction for Target Remnant Description



CEBAF Large Acceptance Spectrometer

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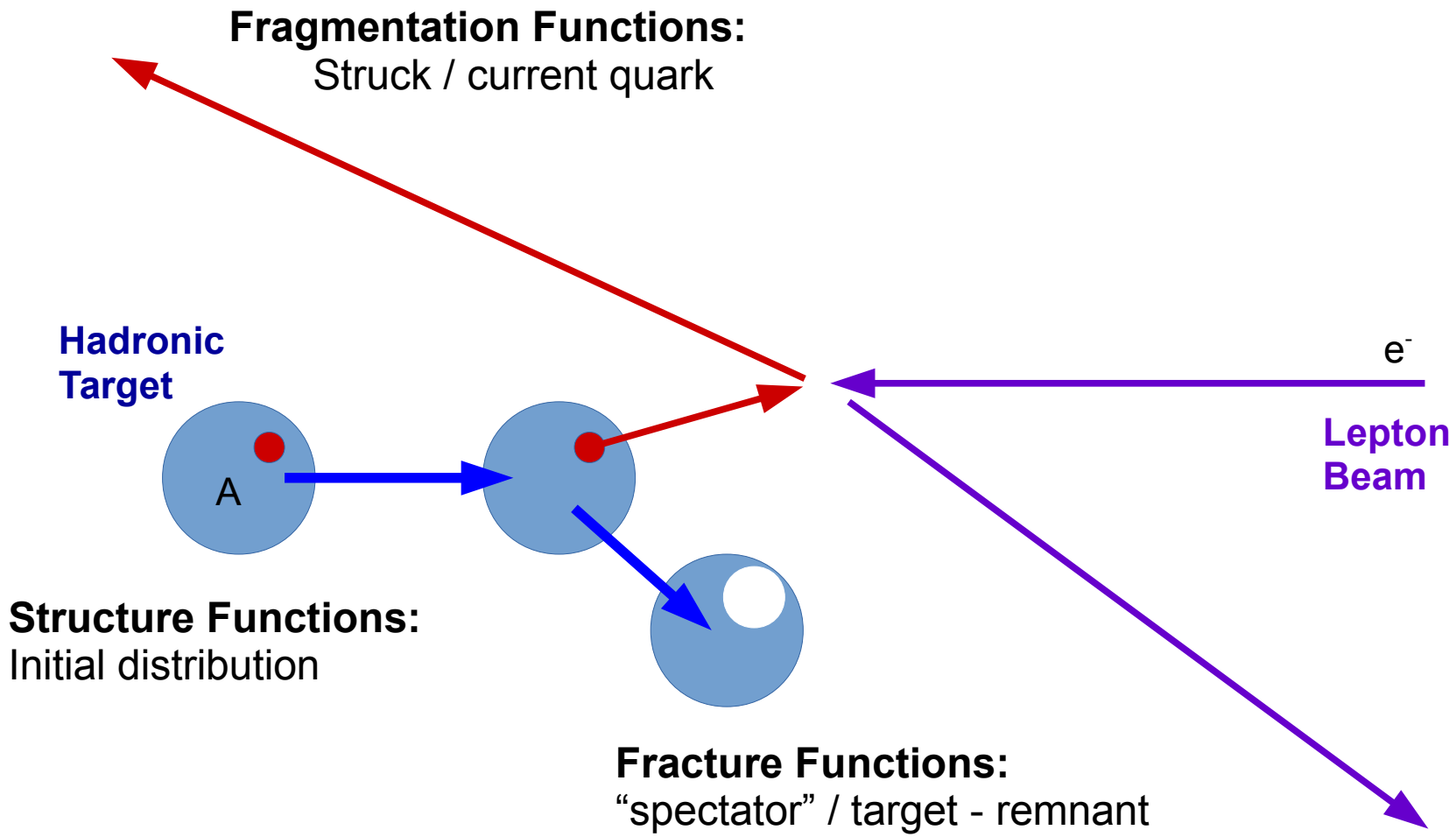
Lamiaa El Fassi
On behalf of the CLAS Collaboration

April 11, 2019

Fracture Functions: Context



Factorized QCD

Separate:

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

Example:

$$\sigma(l+N\to l'+H+X)=\sum_J \int_0^1 \frac{dx}{x} F^J_N(x,Q)\sigma^J_H(x,Q)$$

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

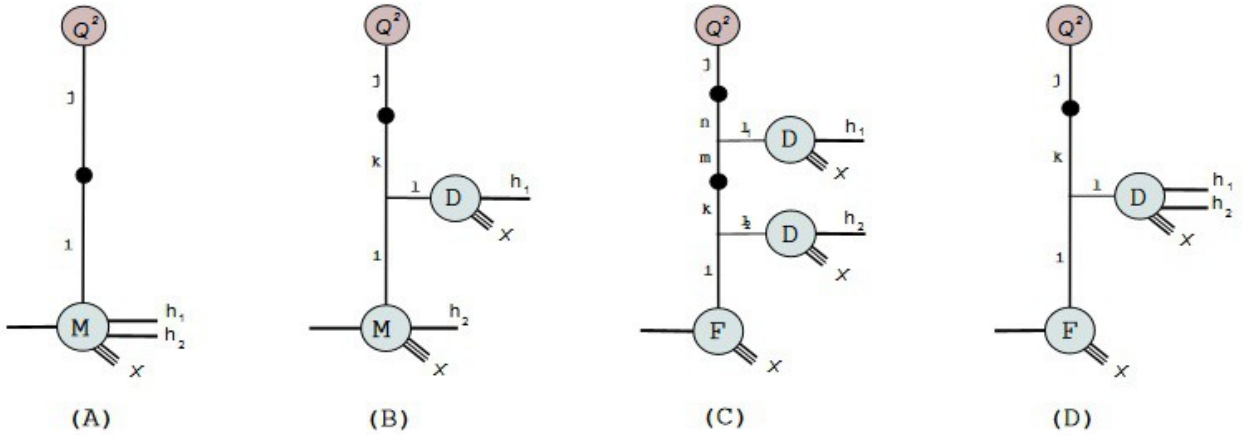


FIG. 2: The four terms of eq. (18). The black blob denotes the parton-to-parton evolution function E. Partons indices are shown and at each triple-line vertex is associated a real AP splitting functions $\hat{P}(u)$. The diagrams are at the amplitude square level. The top parton line enters the hard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

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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

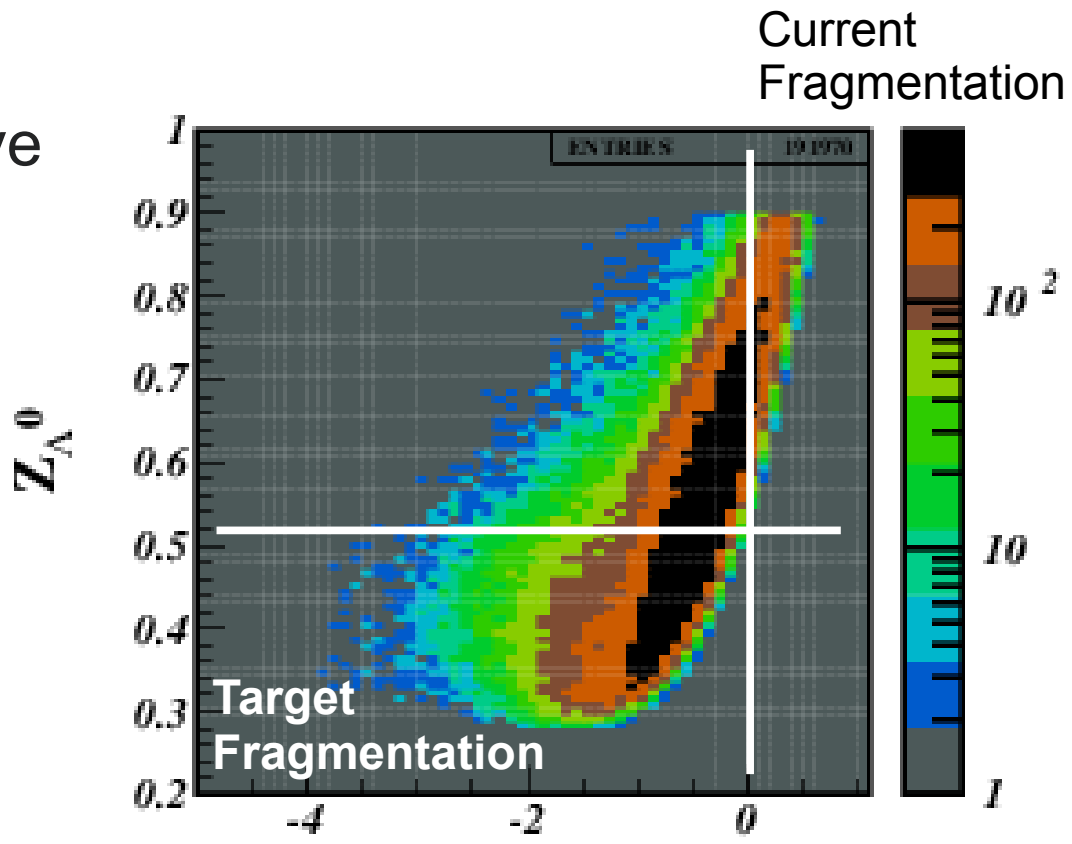
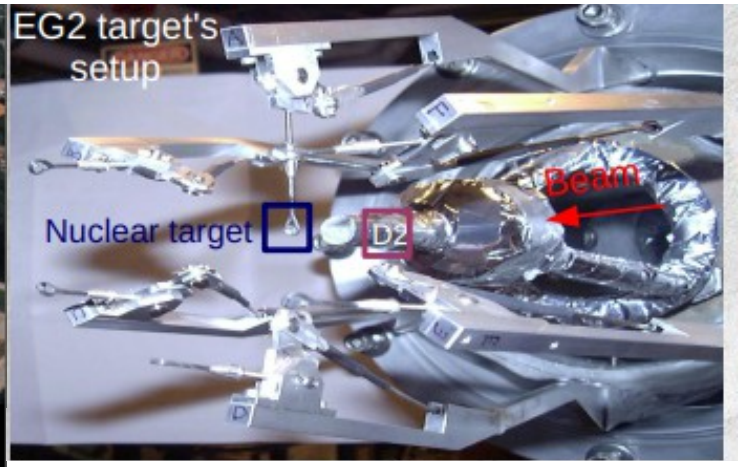
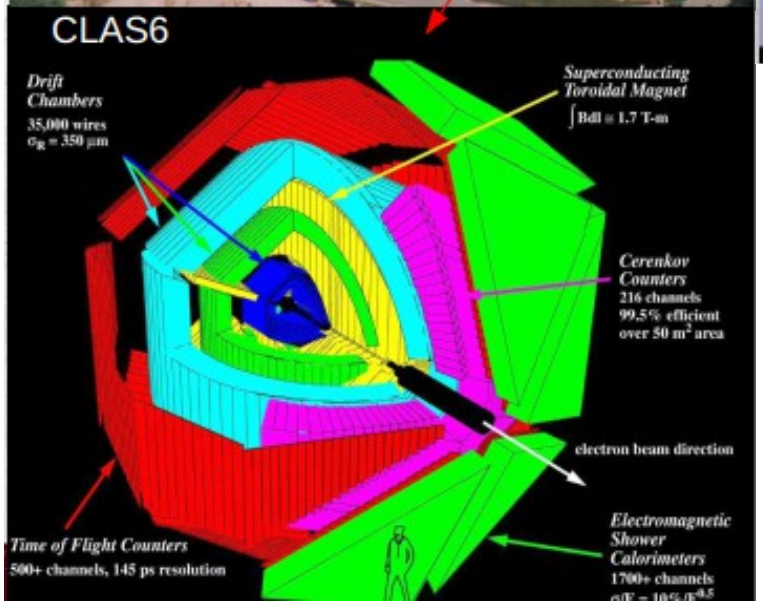
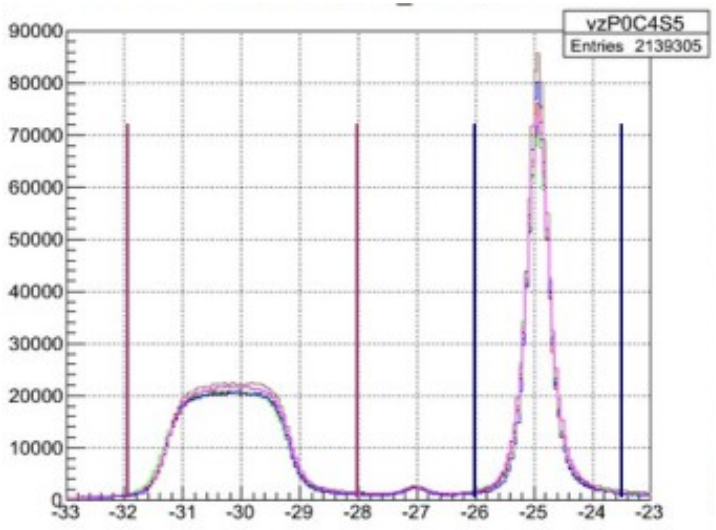


Fig. 1. D2: X_F

EG2 Experiment







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Hadronization Highlight

Compare nuclear and D2 target in super-ratio

Approach dual hadronization scales

Uniquely Λ^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 * 10^{34} (Hz cm^{-2})
- Pb Luminosity: 1.3 * 10^{34} (Hz cm^{-2})

Fracture Function Reaction Channel

- D(e,e'Λ^0)X
- Scattered electron and Λ^0 decay products detected

$\Lambda^0 \rightarrow \pi^-$ + proton

- (~64% branching ratio)

Electron Identification, pion Identification

- EM Calorimetry, Cherenkov Counter, Tracking
- Color Transparency: Phys. Lett. B 712 (2012) 326-330

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

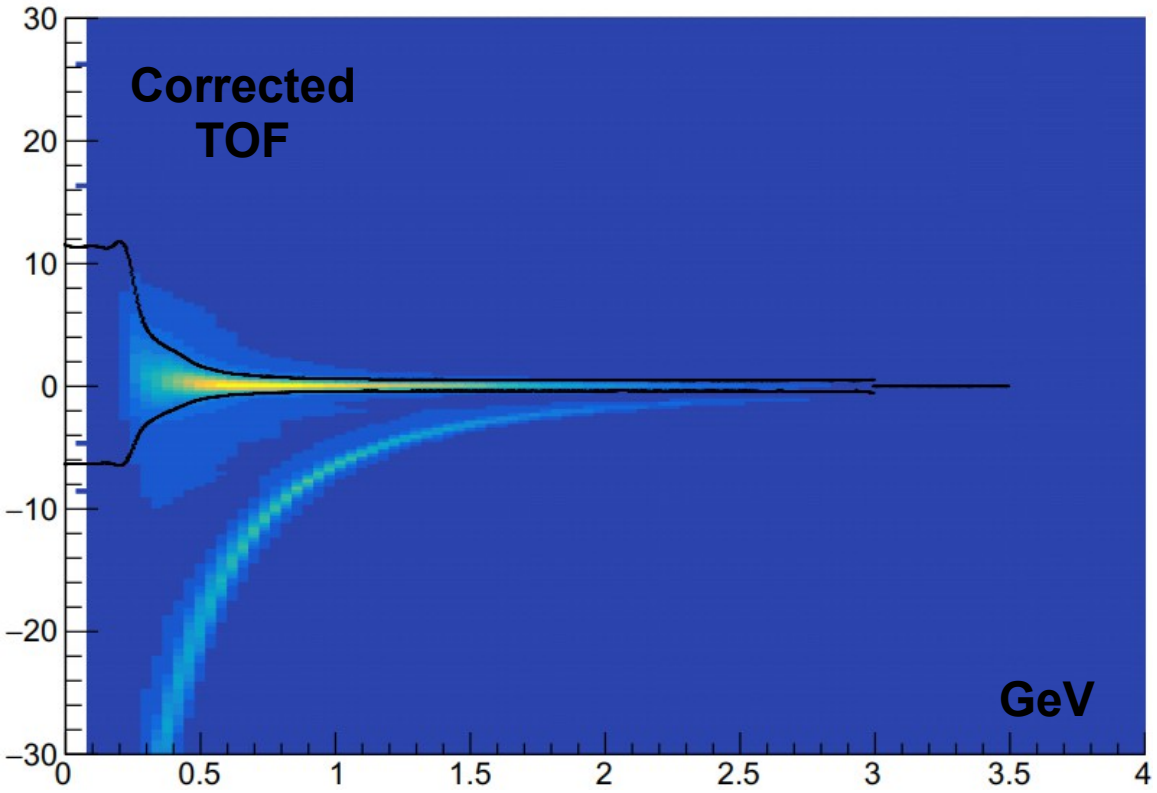
Fitted proton peak per bin

- Half-peak range

Smoothed between bins

- Spline function

Time of Flight Proton ID

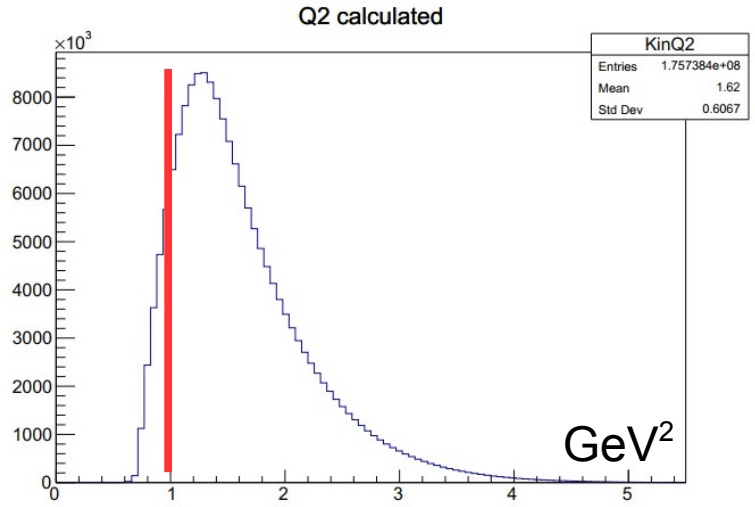


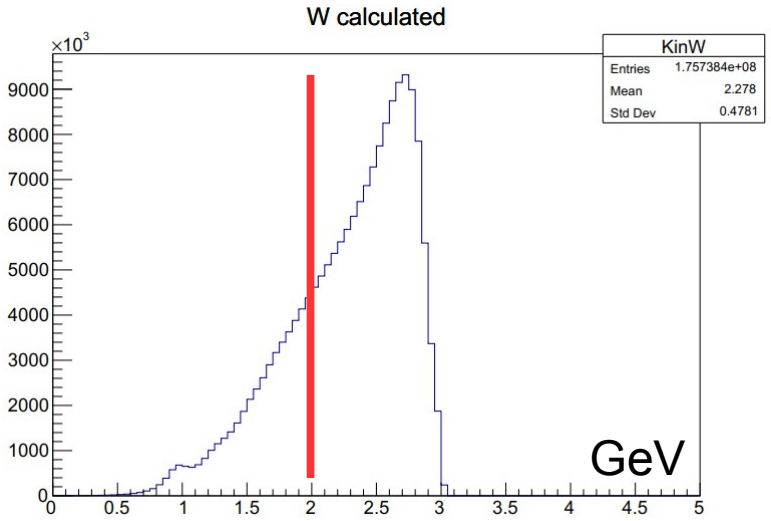
DIS Selection

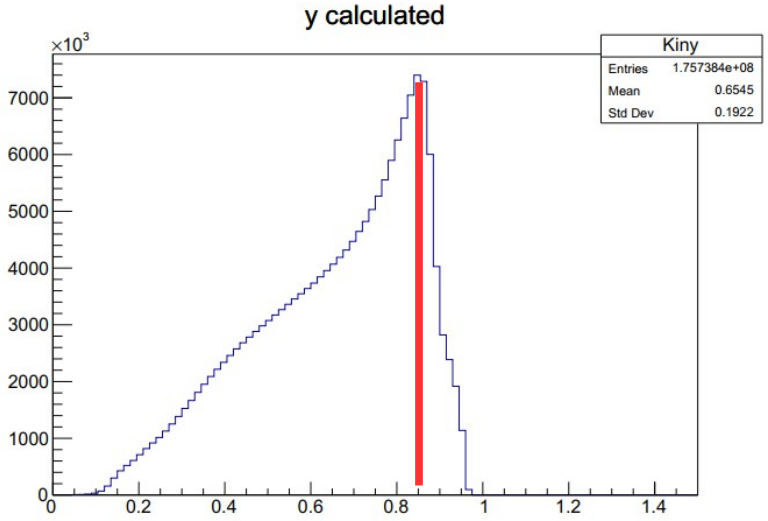
Kinematic cuts:

- $Q^2 > 1$ (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:

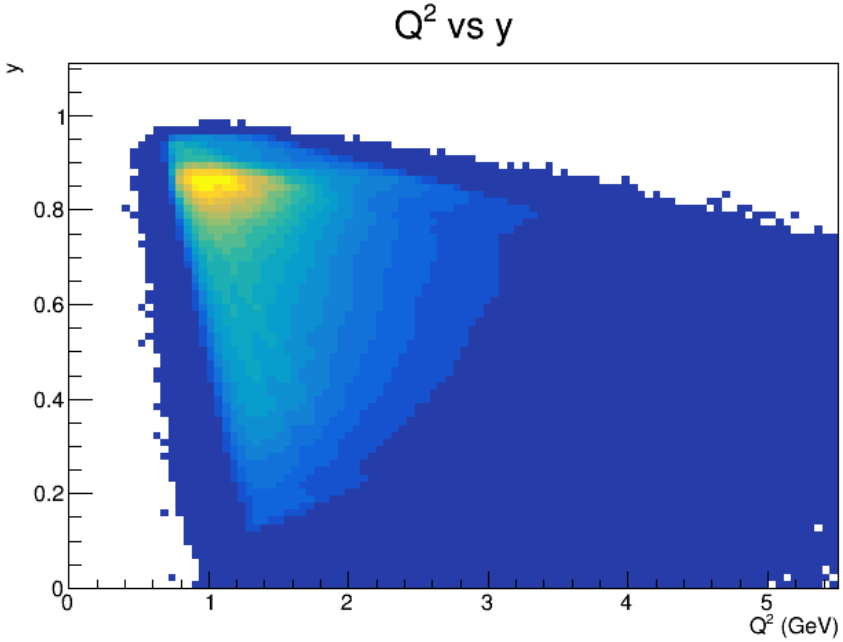
- Electron energy fraction transferred to quark

z variable:

- Fraction of transferred energy carried by observed hadron

Fracture Function

- $M(x_B,z,Q)$



Multivariate Binning

- ~900 Bins for π^+ analysis
- ~1/10th data for Λ^0 analysis

Lambda Yield Procedure

Event Selection:

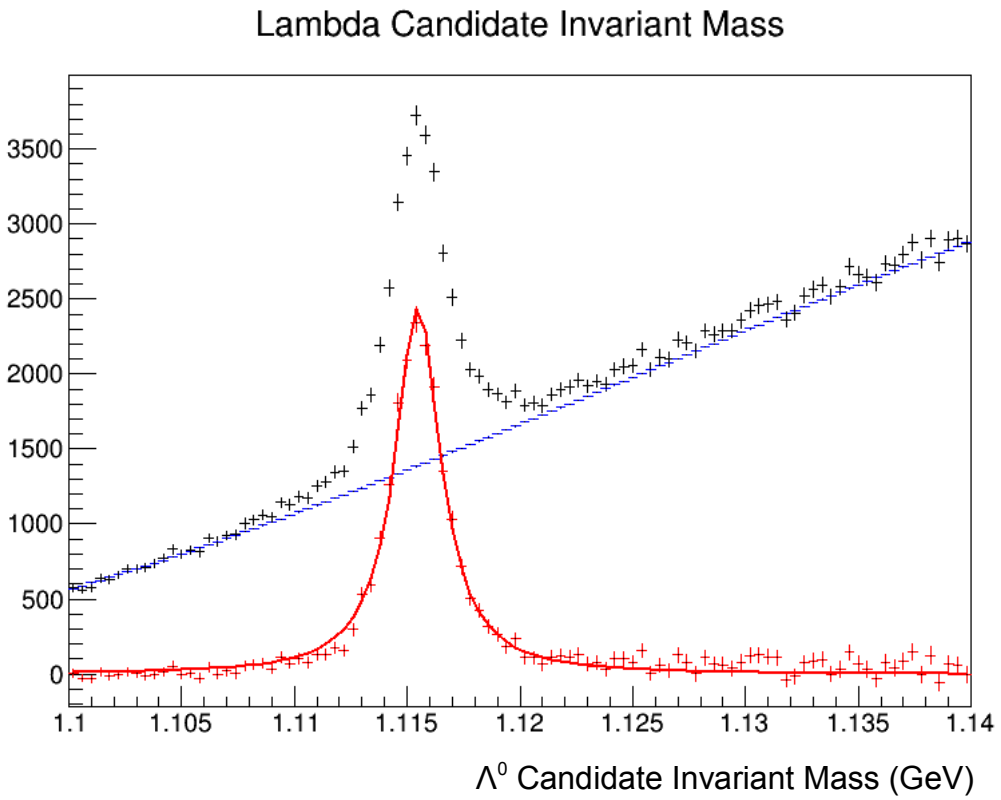
- DIS electron, π^-, proton
- Same Target

Reconstruct Λ^0 mass

Background Model:

- Mix π^-, proton (separate events)

Normalize background model to sideband region



Iron Dataset

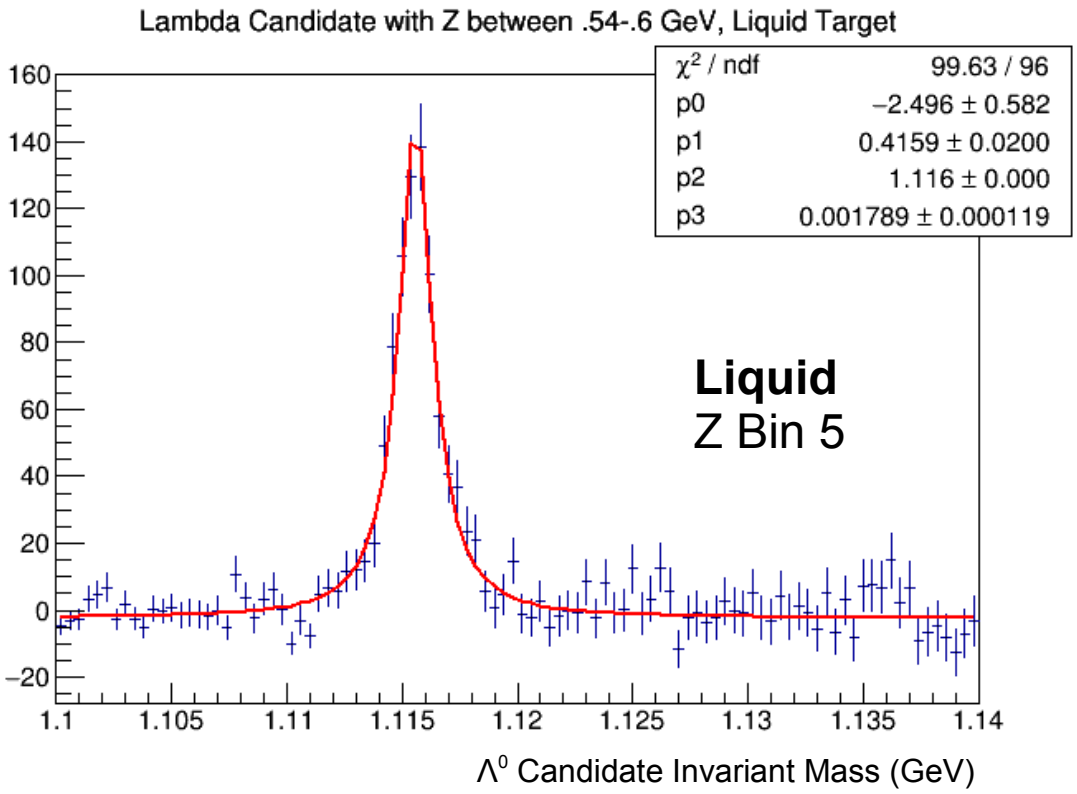
Black: Data
Blue: Background
Red: Subtracted

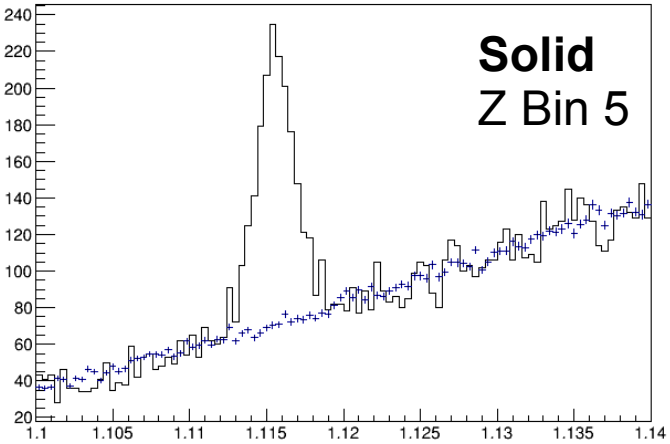
Lambda Yield Procedure

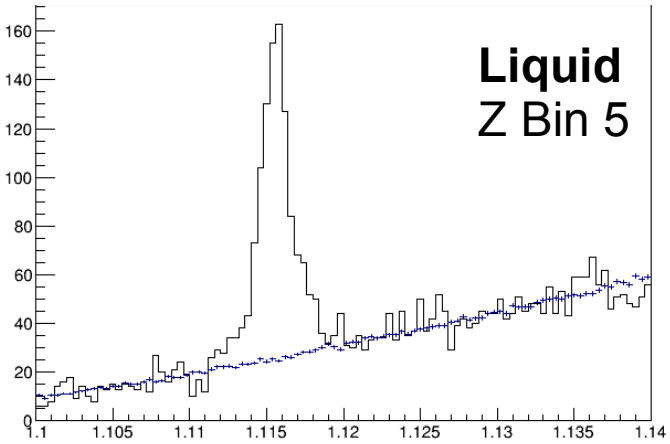
2 Side Bands

Subtract Background

Breit-Wigner + Constant



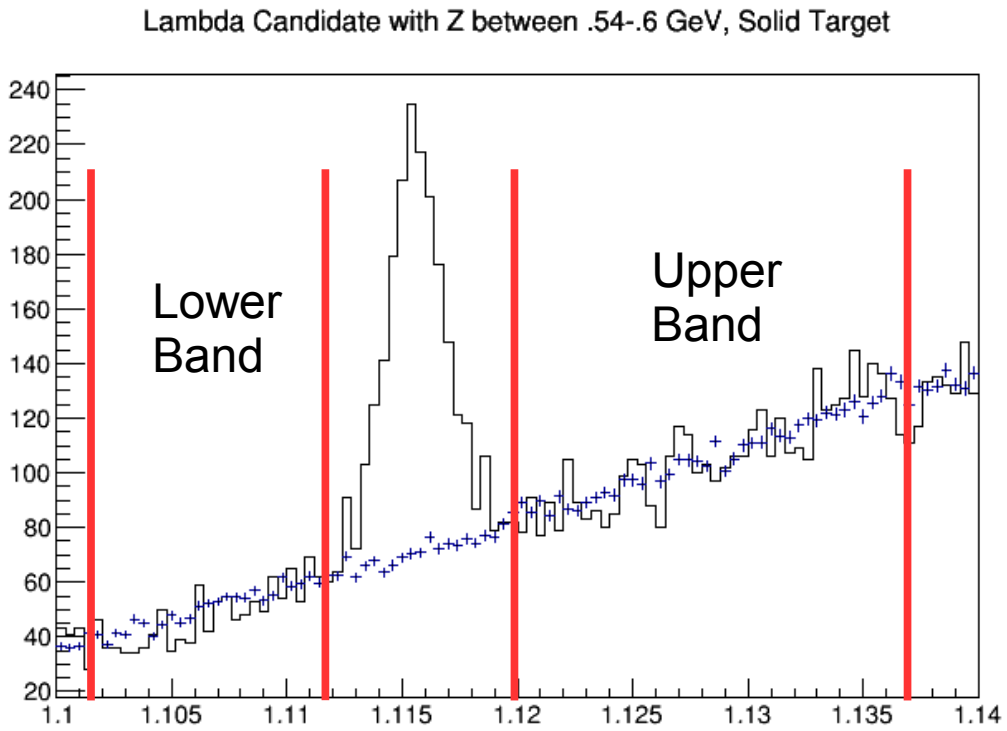




Nine Z Bins, Two Targets

Background Subtraction

- Side bands used to normalize background and signal
- Fit Quality Tests
  - 1) Combined χ^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

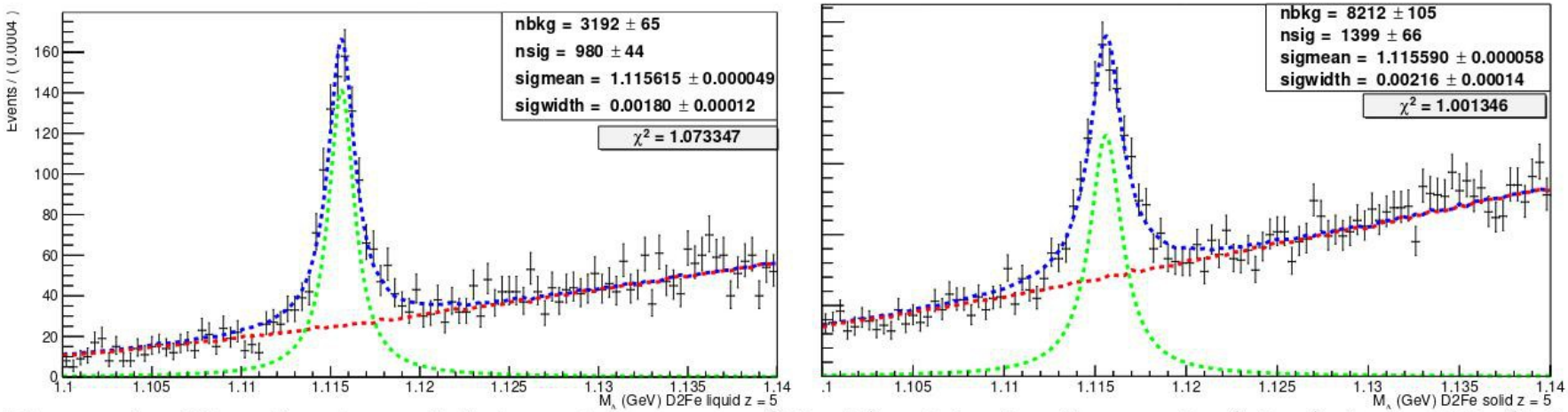


Figure 1: Distribution of Λ invariant mass (black) with the fit result (blue) from D2 (left) and Fe (right) for the 5th z-bin. The dot-dashed red curve is the combinatorial background, and the dashed green curve is the simple Breit-Wigner (BW) background-subtracted signal.

Finalizing Lambda Yields

Apply acceptance corrections

- Negative π^- inbending
- Positive p outbending

Combine Fe, C, Pb datasets

Determine Binning

Extract Yields per Bin

Fracture Function Extraction

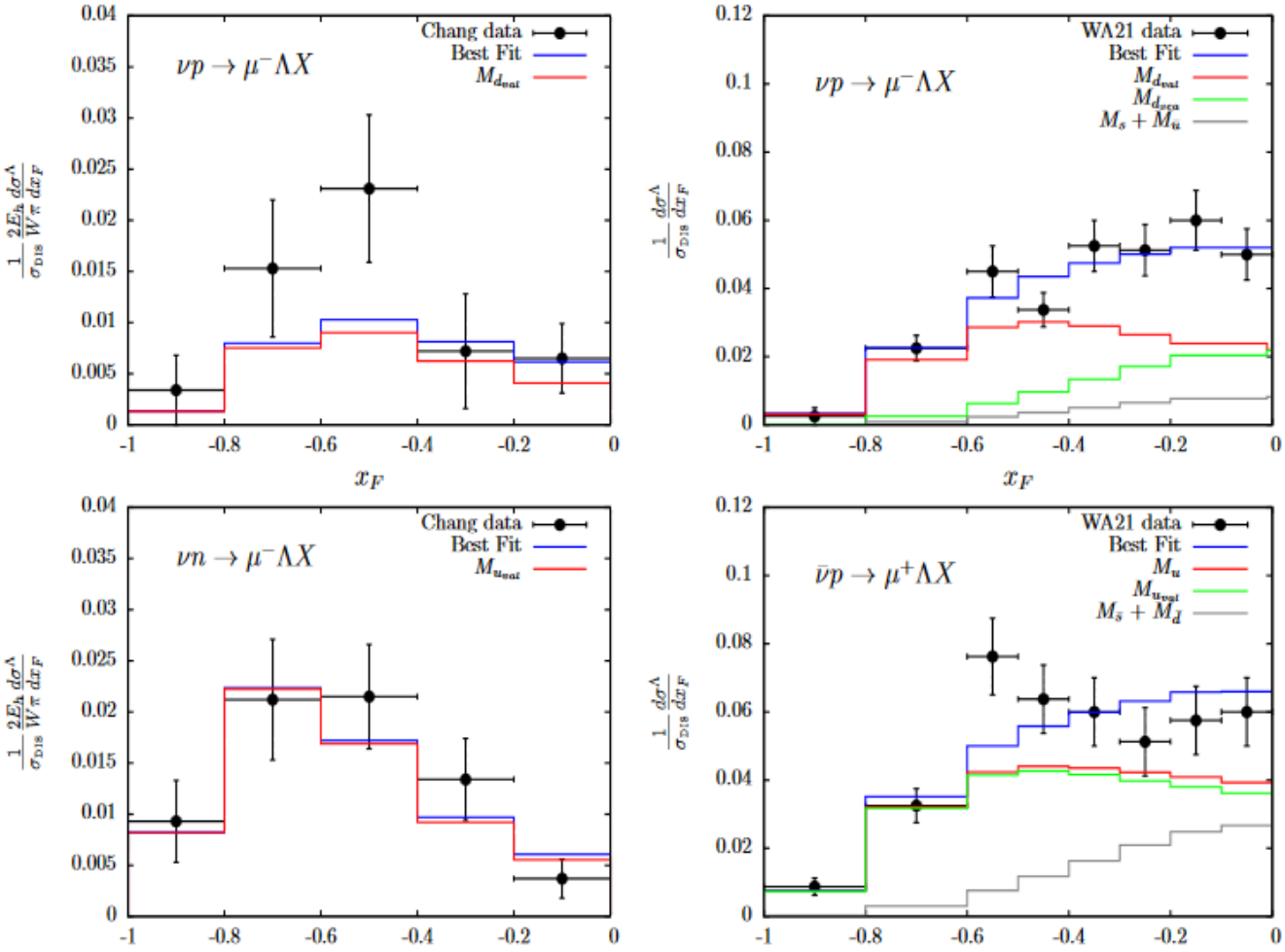


Figure 1: Best-fit predictions compared to normalised x_F distributions for charged current semi-inclusive Lambda cross-sections from Ref. [12] (left panels) and Ref. [13] (right panels). Various quark-flavour proton-to-Lambda fracture functions contributions are shown. Note the additional factor $2E_h/(\pi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

Ceccopieri, F.A. & Mancusi, D. Eur. Phys. J. C (2013) 73: 2435
https://doi.org/10.1140/epjc/s10052-013-2435-5

Fracture Function Extraction

Decompose: PDF & “Spectator Fragmentation”

- $M_i^{\Lambda/p}(x_B, z, Q_0^2) = f_{i/p}(x_B, Q_0^2)\widetilde{D}_i^{\Lambda/p}(z)\,,\ i = q, \bar{q}, g\,.$

Decompose: Sea vs. Valance

- $M_{q=u,d}^{\Lambda/p}(x_B, z, Q_0^2) = q_{val}(x_B, Q_0^2)\widetilde{D}_{q_{val}}^{\Lambda/p}(z) + q_{sea}(x_B, Q_0^2)\widetilde{D}_{q_{sea}}^{\Lambda/p}(z)\,.$

Assign Functional Form

- $\widetilde{D}_i^{\Lambda/p}(z) = \overline{N_i} z^{\alpha_i}(1-z)^{\beta_i}$

Normalize

- $\overline{N_i} = N_i\Big[\int_0^1 dz\, z^{\alpha_i}(1-z)^{\beta_i}\Big]^{-1}, \quad \alpha_i, \beta_i > -1\,,$

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 extraction
- Also used for hadronization studies

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