Λ production in the DIS target fragmentation region

Federico A. Ceccopieri

Scientific Collaborator @ IFPA, AGO Department Bàt 5a,

Université de Liège, 4000 Liège, Belgium

F.Ceccopieri and D.Mancusi, EPJC73 (2012)
F.Ceccopieri, arXiv:1508.07459

Outline

- Theoretical overview
- Brief discussion of CM12 Lambda fracture functions fit
- Predictions for CLAS@12 GeV

Theoretical status : factorisation and fragmentation in DIS

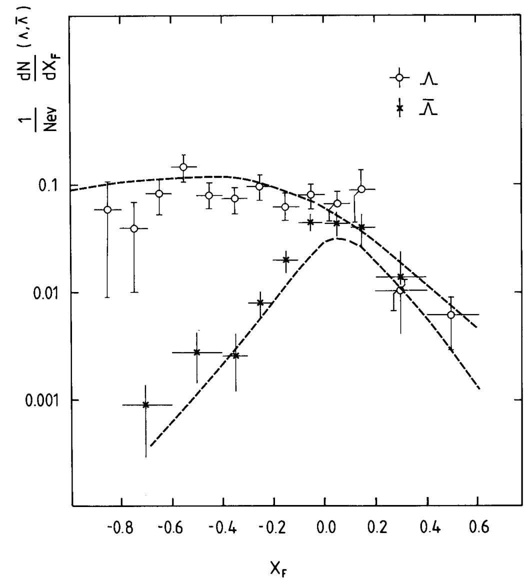
- Backward Particle production described by Fracture Functions M (Trentadue, Veneziano, '94)

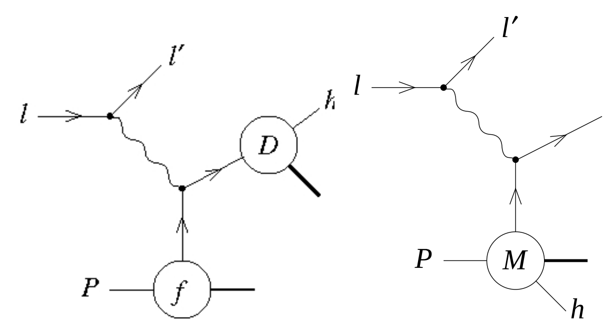
- Factorization for M in SIDIS proven at collinear and soft level (Graudenz '94, Grazzini, Trentadue, Veneziano '98; Collins '98)

- Factorization theorem: decoupling of short distance ($d\hat{\sigma}$) from long distance (f, D, M) physics

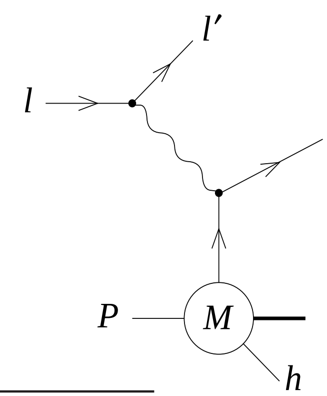
- f, D, M are not calculable from first principles but their evolution predictable in pQCD

- To lowest order:
  current region $(x_F > 0)$: $d\sigma \propto f_{i/N} \otimes D_j^h \otimes d\hat{\sigma}^{ij}$
  target region $(x_F < 0)$: $d\sigma \propto M_{i/N}^h \otimes d\hat{\sigma}^i$





SIDIS variables and cross section



- $M^h_{i/N}(x,\zeta)$ give the conditional probability that a parton i with a fractional momentum x of the incoming nucleon momentum P initiates the hard scattering while an hadron h with fractional momentum ζ is detected in the TFR of N

- hadron variables in $\gamma^* N$ c.o.m. frame:

$$z = \frac{E_h^*}{E_p^*(1-x_B)}, \quad E_p^*(1-x_B) = W/2, \quad \zeta = \frac{E_h^*}{E_p^*}, \quad x_F = \pm\sqrt{z^2 - \frac{4m_T^2}{W^2}}$$

- The Lambda leptoproduction cross section in term of these variables reads

$$\frac{d\sigma^{\Lambda/N}}{dx_B\, dy\, dz} = \frac{z}{|x_F|} \sum_i c_i \left[f_{i/N}(x_B, Q^2)\, D_i^\Lambda(z, Q^2) + (1-x_B)\, M^\Lambda_{i/N}(x_B, (1-x_B)z, Q^2) \right]$$

- Similar cross sections are derived for charged current neutrino DIS

Data set used in the fit

- $lN \to l'\Lambda X$, $l = \mu, \nu, \bar{\nu}$
- $E_l =$ from 38 to 490 GeV + neutrino fluxes
- SKAT collaboration reported sizeable A-dependence of backward Λ production, $\langle n_\Lambda \rangle \propto A^\delta$
- Temptative explanation : secondary interactions, $\pi N \to \Lambda X$, inside nuclear medium
- fit data only light targets : $N = p$,D,n $\to$ quark-flavour separation
- observable : $d\sigma^\Lambda / dx_F$
- Inclusive Λ sample : Λ coming from higher mass resonance decays included in the sample

SKAT '07

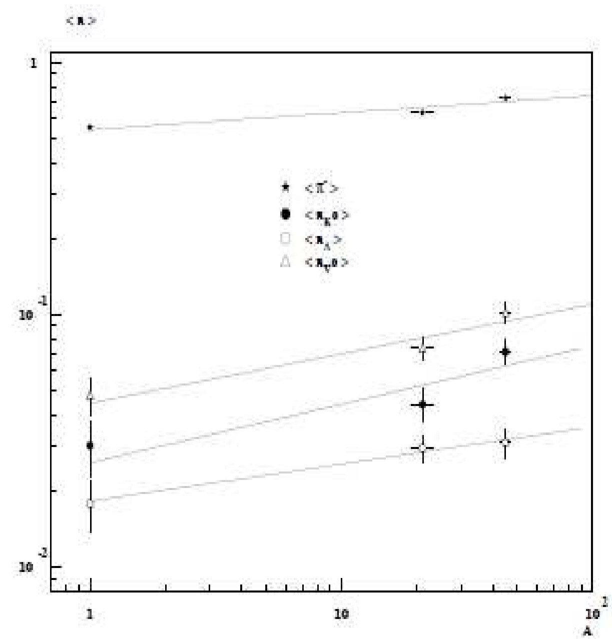
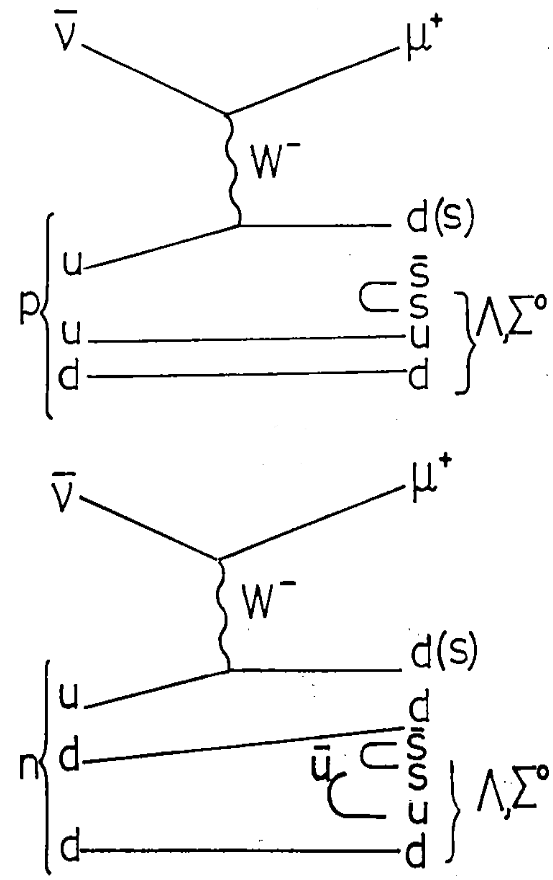


Figure 1: The A- dependence of the total yields of K^0, Λ, V^0 and π^-. The curves are the result of the exponential fit.

Initial conditions for Λ fracture functions (1)

- The electroweak current probes the "struck quark" on very short "time scale", $\sim 1/Q_0$
- A parton with flavour i and momentum x is then removed from the proton with probability $f_{i/P}(x_B, Q_0^2)$
- The leftover coloured system reassembles to give colourless Λ with fractional momentum z on much longer "time scale", $\sim 1/\Lambda_{QCD}$, with probability $\widetilde{D}_i^{\Lambda}(z)$
- Phenomenological factorisation: $M \propto f \times \widetilde{D}$



Initial conditions for Λ fracture functions (2)

- Assumption : fracture functions can be factorized, at some low and arbitrary $Q_0^2 \sim 1$ GeV^2 scale, in the form

$$(1-x_B)M_{i/p}^{\Lambda}(x_B,\,\zeta,Q_0^2) = M_{i/p}^{\Lambda}(x_B,\,z,Q_0^2) = f_{i/p}(x_B,Q_0^2)\widetilde{D}_i^{\Lambda}(z)$$

- $f_{i/p}(x,Q_0^2)$ are standard parton distribution functions (GRV'94)
- $\widetilde{D}_i^{\Lambda}(z)$ are unknown spectator fragmentation functions
- The input distributions are then evolved to arbitrary scales via FF evolution equations.

Initial conditions for Λ fracture functions (3)

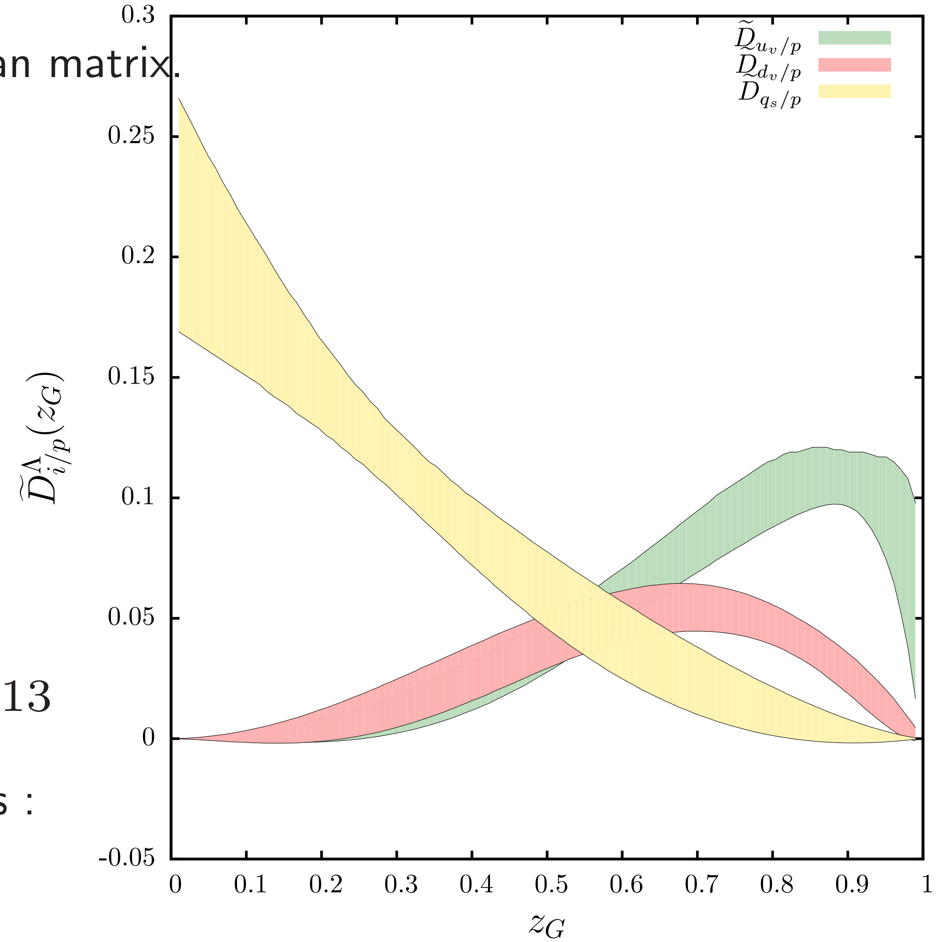
- Exploit GRV'94 valence/sea decomposition $\oplus$ simplied flavour and energy dependence

$$
\begin{aligned}
(1-x_B)M^{\Lambda}_{u/p}(x_B,z,Q_0^2) &= u_v(x_B,Q_0^2)N_u z^{\alpha_u}(1-z)^{\beta_u} + u_s(x,Q_0^2)N_s z^{\alpha_s}(1-z)^{\beta_s} \\
(1-x_B)M^{\Lambda}_{d/p}(x_B,z,Q_0^2) &= d_v(x_B,Q_0^2)N_d z^{\alpha_d}(1-z)^{\beta_d} + d_s(x,Q_0^2)N_s z^{\alpha_s}(1-z)^{\beta_s} \\
(1-x_B)M^{\Lambda}_{g/p}(x_B,z,Q_0^2) &= g(x,Q_0^2)N_s z^{\alpha_s}(1-z)^{\beta_s} \\
(1-x_B)^{\Lambda}_{q_s/p}(x_B,z,Q_0^2) &= q_s(x_B,Q_0^2)N_s z^{\alpha_s}(1-z)^{\beta_s}
\end{aligned}
$$

- In case of scattering on a sea quark, the spectator fragments independtly of the flavour of the latter: $N_s z^{\alpha_s}(1-z)^{\beta_s}$
- x_B dependence driven by pdfs. 12 free pars
- Gluon spectator fragmentation unconstraind, set $\widetilde{D}^{\Lambda}_{g} = \widetilde{D}^{\Lambda}_{q_s}$, $\rightarrow$ 9 free pars

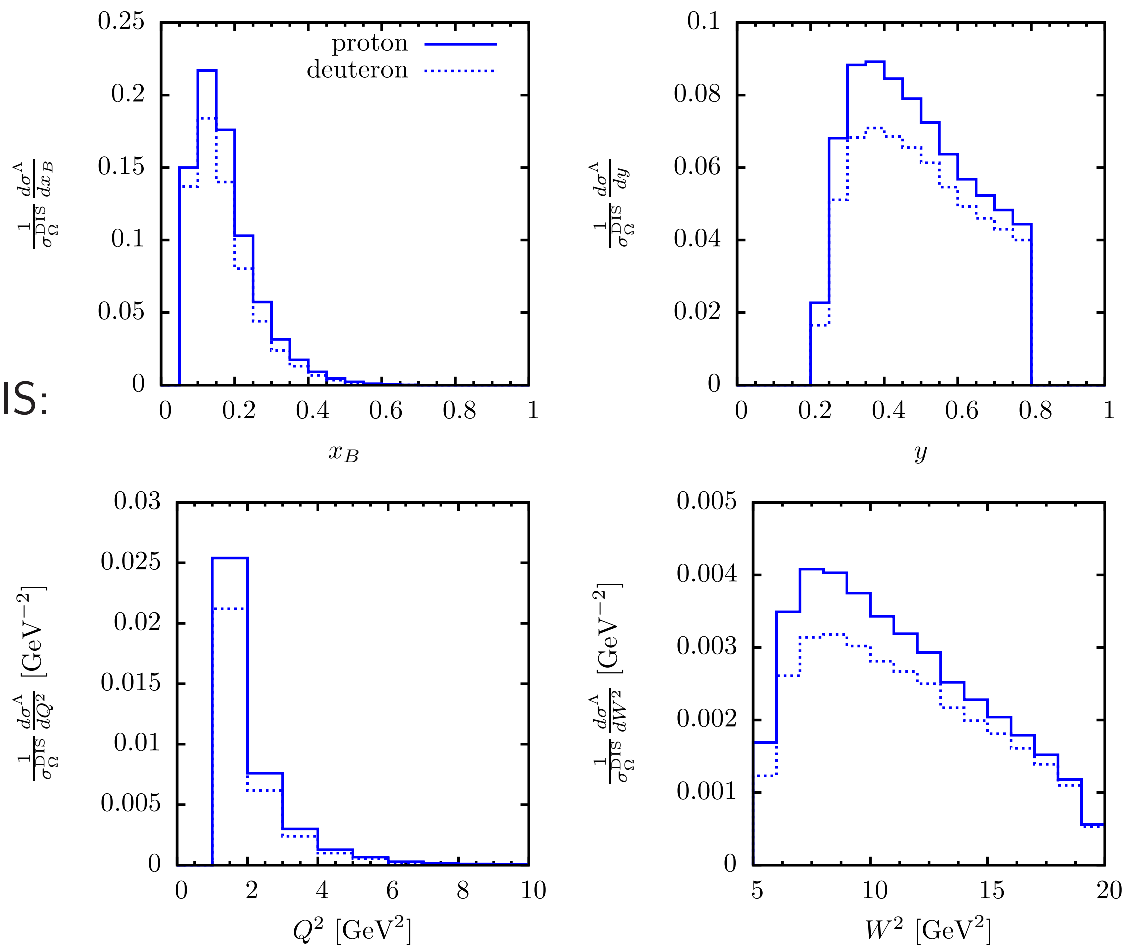
Fit result and error propagation

- Study of the eigenvalues of the Hessian matrix. parameter reduction : 7 free pars
- $\widetilde{D}_i^{\Lambda} = N_i z^{\alpha_i}(1-z)^{\beta_i}$
- 3 normalization N_i are OK
- β_i determined with acceptable errors
- α_i mostly unconstrained: $\alpha_u = \alpha_d$ and $\alpha_{qs} = 0$
- $\chi^2/d.o.f. = 44.14/(46-7) = 1.13$
- propagation experimental uncertanties : 14 additional ΛFF set corresponding to $\Delta\chi^2 = 1$

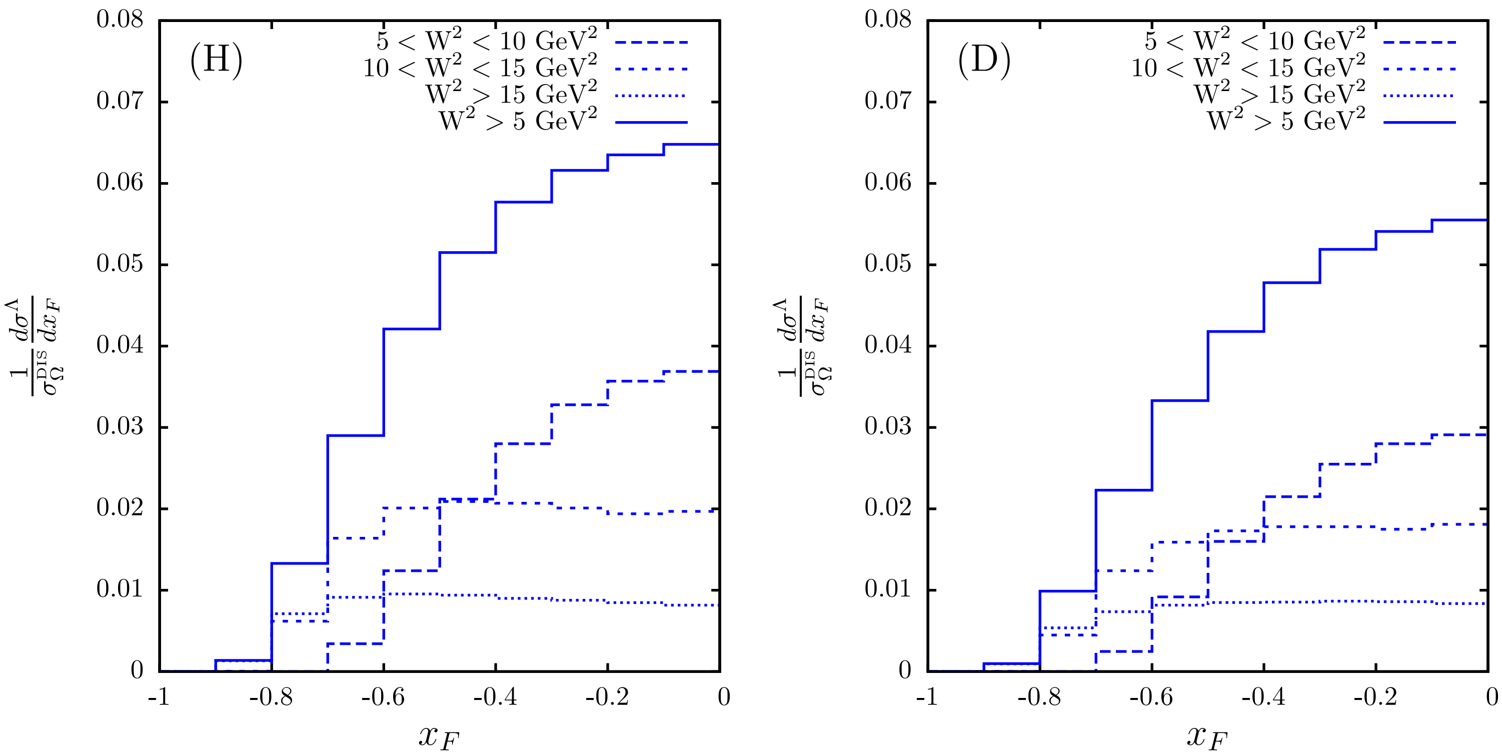


Predictions for CLAS12 (1)

- $0.2 < y < 0.8$
  $Q^2 > 1$ GeV^2,
  $W^2 > 5$ GeV^2
- target Λ has $x_F < 0$
- comparison with inclusive DIS:
  correlation between
  hard scattering
  and target Λ production
- Λ yields for $x_F < 0$:
  $\langle n_p(\Lambda) \rangle = 0.039$
  $\langle n_D(\Lambda) \rangle = 0.032$

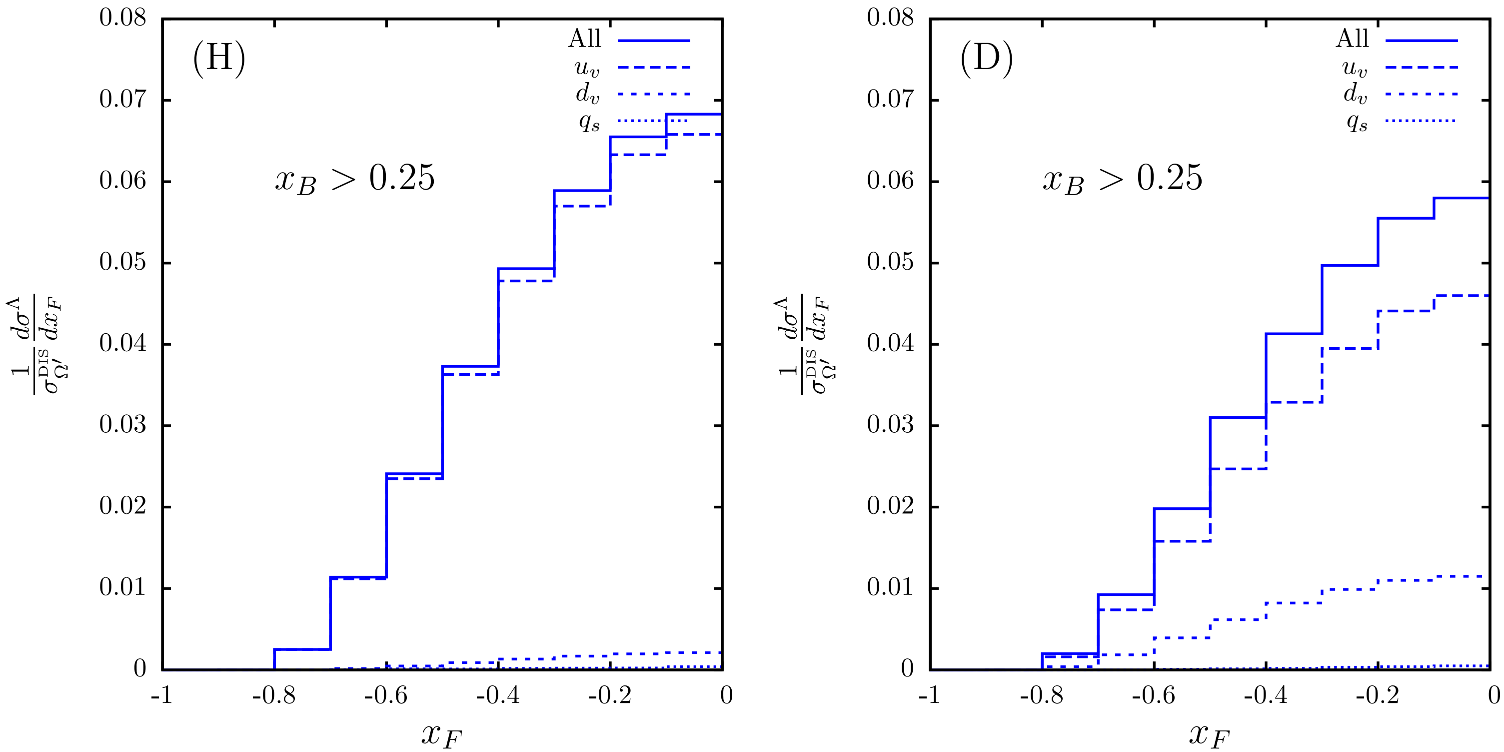


Predictions for CLAS12 (2)



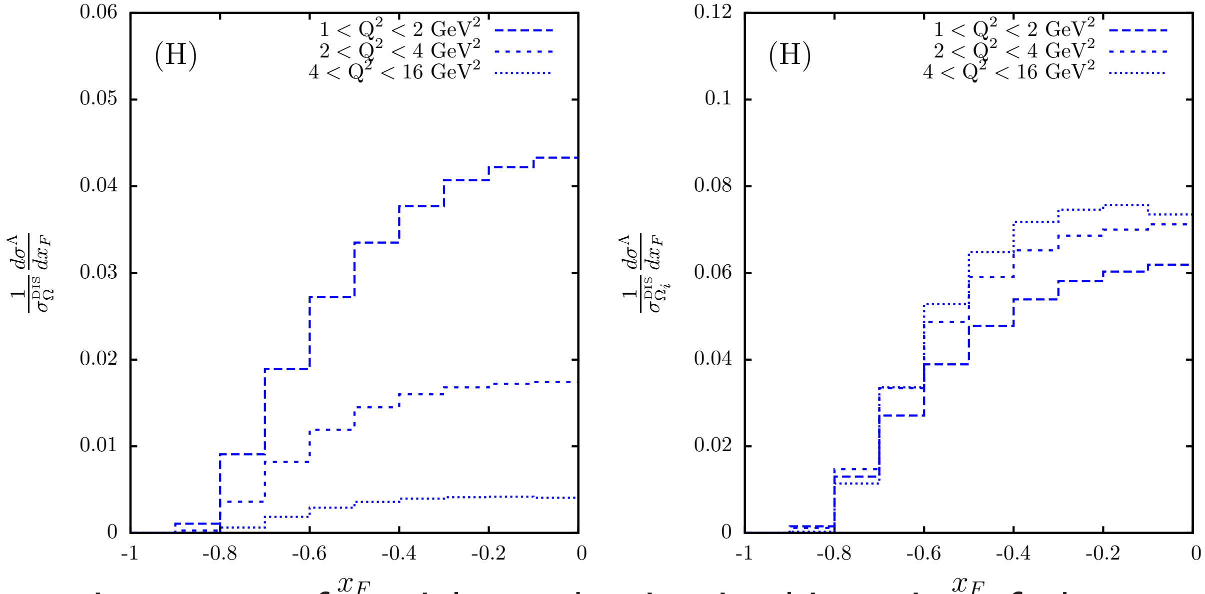
- Very backward production regime accessed only at highest values of W^2.
- Combined effect of hadron mass corrections and the energy spectrum of $\widetilde{D}_{i/p}^{\Lambda}$

Predictions for CLAS12 (3)



- proton and deuteron targets $\oplus$ $x_B > 0.25$: good valence quark-flavour sensitivity to disentangle M_{u_v} from M_{d_v} (plus generalised isospin relations)

Predictions for CLAS12 (4)

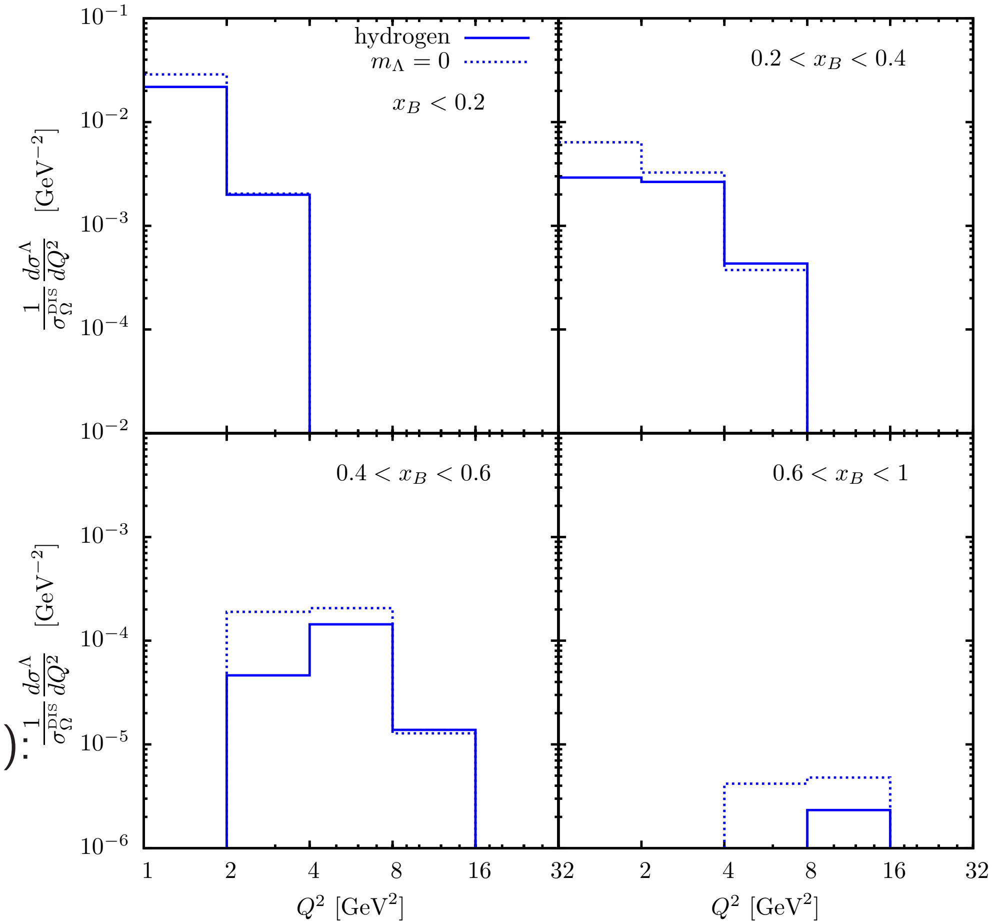


- Test leading twist nature of particle production in this region of phase space, as assumed by fracture functions formalism
- mild rise of Λ multiplicity with Q^2: test pQCD evolution of fracture functions
- compare spectra in DIS and PHP regime: determine to which extent the transition to the non-perturbative regime in Q^2 affects the Lambda spectrum in the target region.

Predictions for CLAS12 (5)

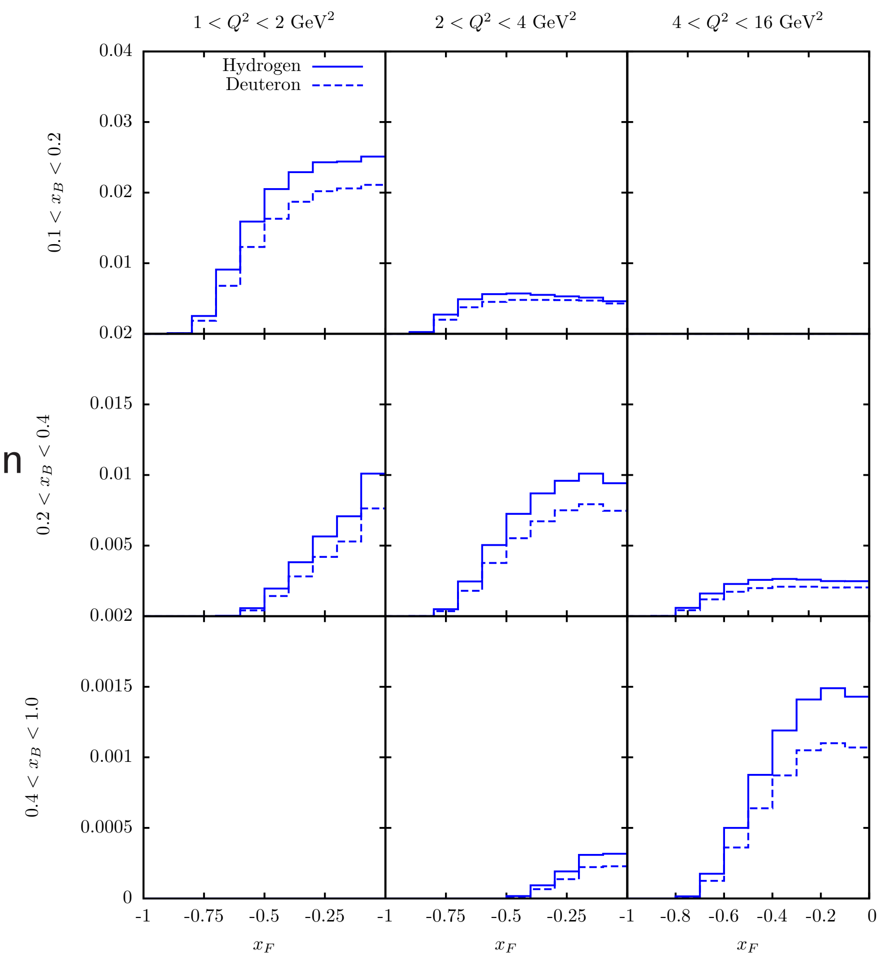
- The Q^2-differential cross section deserve special attention
- it may provide crucial test for the predicted evolution of FFs
- BUT : low values of W^2 accessed by the experiment
- the Q^2 spectrum receives significant hadron mass corrections
- They suppress the cross section as x_B increases.
- to spot Q^2 scaling violations from FF evolution use reduced cross section (all Q^2-dep. from M):

$$\frac{1}{\sigma_0}\frac{d\sigma^{\Lambda/N}}{dx_B\,dy\,dz} = \frac{z}{|x_F|}\sum_i e_i^2\, M_{i/N}^{\Lambda}$$



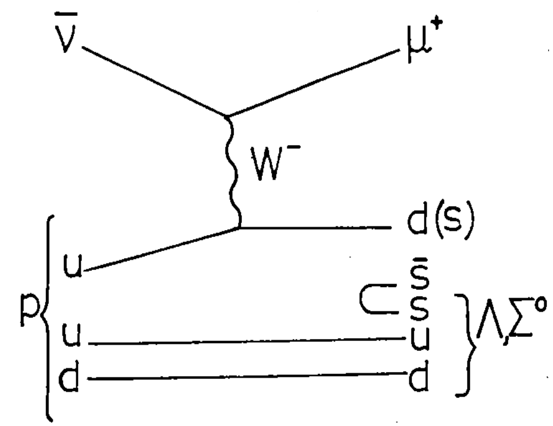
Predictions for CLAS12 (6)

- $\frac{1}{\sigma^{\text{DIS}}} \frac{d\sigma^{\Lambda}}{dx_F}$ in (x_B, Q^2) ranges for both proton and deuteron targets
- This way of presenting the data is probably the more exhaustive and it might be valuable for the determination of Lambda fracture functions in forthcoming global fit analyses:
- maximal sensitivity to $\widetilde{D}$'s parameters



Strange sea correlations

- Consider double inclusive cross section:
  $lN \to \Lambda K^+ X$, in DIS regime



- Trigger on very backward Lambdas (uds),
  $-1 < x_F < -0.5$ and K^+ $(u\bar{s})$ for all x_F

- Measure cross section (or related distributions)
  as a function of the rapidity difference $\Delta y = y_{K^+} - y_\Lambda$

- for forward K^+ we can predict this cross section:
  it has the form : $d\sigma/d\Delta y \propto M^{\Lambda}_{i/N} \times D^{K^+}_i$

- Observable sensitive to strangeness propagation (and conservation) accross final state, (*i.e.* hadron rank in hadronisation model...)
  - small Δy, ΛK^+ close in phase space, short range correlation
  - large Δy, ΛK^+ distant in phase space, long range correlation

Conclusions

- A model for the description of backward Λ production has been constructed in the fracture functions framework (CM12)
- The non-perturbative spectator fragmention functions have been obtained through a combined fit to a variety of Lambda leptoproduction DIS cross sections
- The model can be used to predict other cross sections not included in the fit, with full experimental error propagation
- Predictions for a number of observables in CLAS@12 GeV have been presented
- Good agreement with re-processed (old) NOMAD multiplicities: preliminar fit ready, compatible with CM12 (ongoing collaboration with D.Naumov & al. @JINR)
- `federico@laptop$ input data: ■`