Charm Production from Fermilab Fixed-Target Programs

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Talk presented at the XXXIVth Rencontres de Moriond
(QCD and High Energy Hadronic Interactions)
Les Arcs 1800,
March 20-27, 1999

OUTLINE

I. Overview of Charm Production

II. Experiments

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B. SELEX (600 GeV hadron beams)
C. FOCUS (200 GeV photon beam)

III. Results

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B. Charm-Pair Correlations
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D. Total Cross Sections

IV. Conclusions

Charm Production

1 Incoming hadron parton distributions

$f_i^A(x_A, Q^2)$ = probability of finding parton type i inside hadron A with momentum fraction x_A.

For unresolved photons, this is simply the photon

2 $c\bar{c}$ production from partons

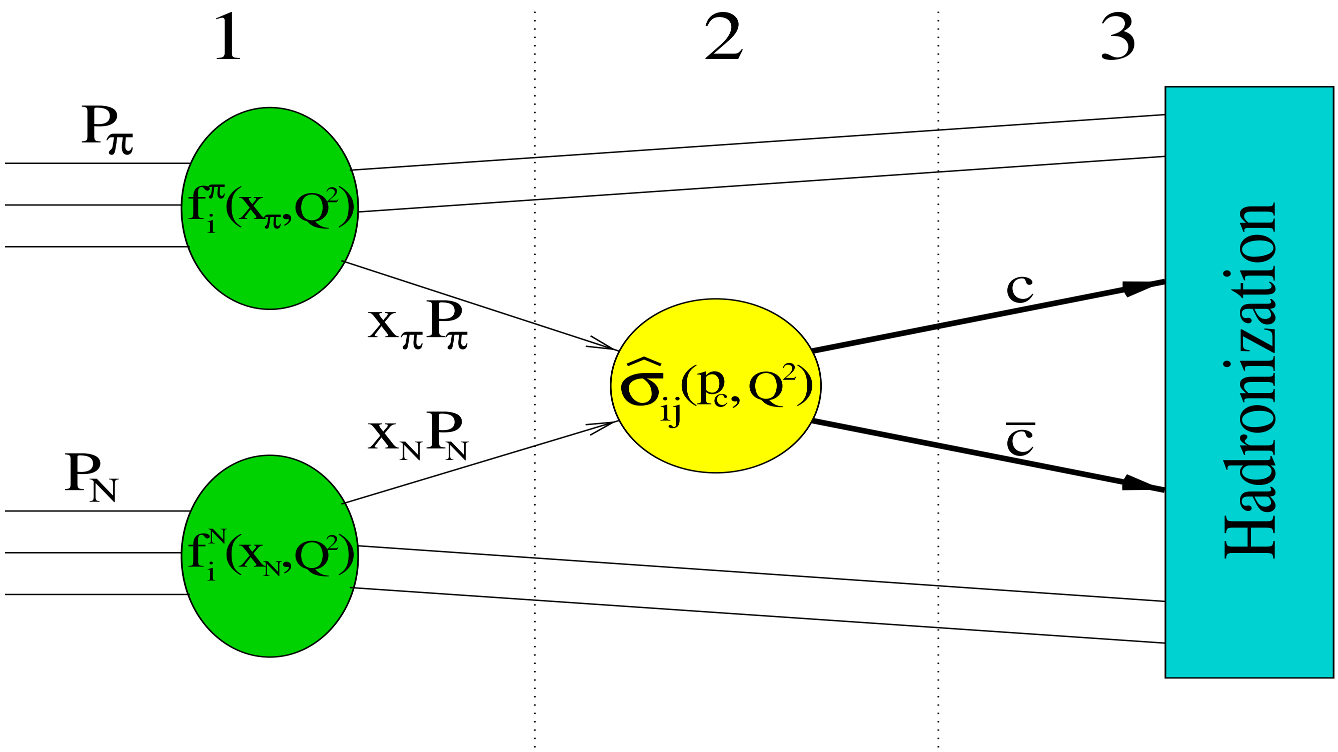
Calculable? by perturbative QCD — $\hat{\sigma}_{ij}(\mathbf{p_c}, Q^2)$.

Scale $= Q^2 \gtrsim m_c^2 \sim (1.5 \text{ GeV})^2$.

3 $c\bar{c}$ hadronization (fragmentation) into hadrons

Incalculable by perturbative QCD.

Scale $= Q^2 \sim \Lambda_{QCD}^2 \sim (0.3 \text{ GeV})^2$.



The Experiments

Fermilab: E791, SELEX, FOCUS

- Beams
  - E791: 500 GeV π^- beam
  - SELEX: 540 GeV p and 600 GeV Σ^- and π^- beams
  - FOCUS: $<$180$>$ GeV photon beam
- E791 ran in 1991, SELEX and FOCUS in 1996/7
- All used segmented targets
- E791, FOCUS, and SELEX used 17, 16, and 38 Si planes, respectively, for downstream vertexing and tracking
- Many wire chambers and 2-3 magnets for tracking and momentum measurement
- 2(3) threshold Čerenkov counters for E791 (FOCUS); SELEX used a RICH
- E791 and FOCUS used EM and hadronic calorimeters to loosely trigger on hadronic events slightly enriched with charm. Goal is charm production and decays.
- SELEX used online vertex trigger based on miss distance. Goal is high-x_F baryons; especially charm-strange baryons.
- E791 and FOCUS also had muon systems

The Results

Asymmetries

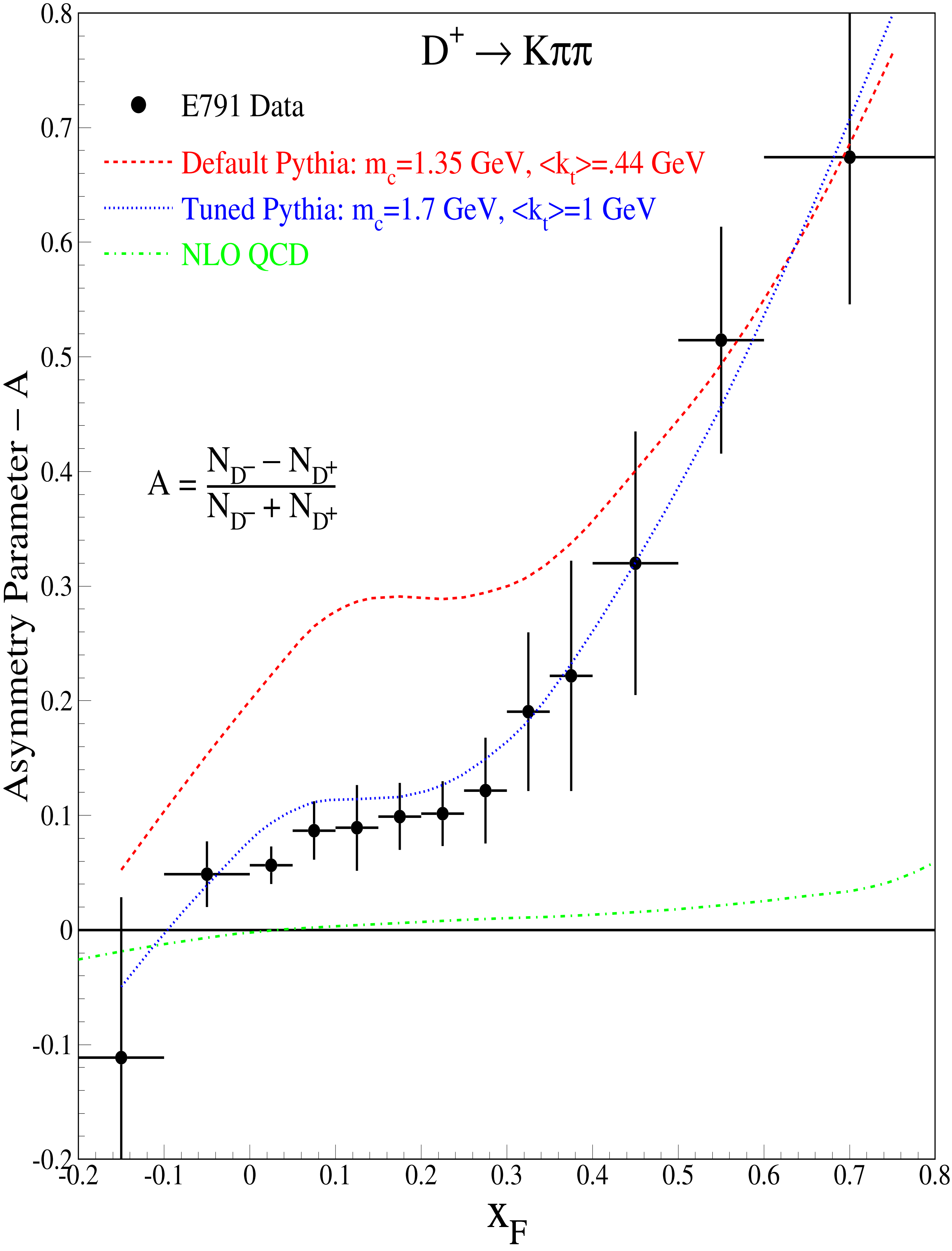
- Measure $A \equiv \frac{\sigma_X - \sigma_{\overline{X}}}{\sigma_X + \sigma_{\overline{X}}}$ vs p_T^2 and $x_F \equiv \frac{p_L^*}{p_{L max}^*}$.
- $A \approx 0$ in perturbative QCD.
- $\Longrightarrow$ asymmetry measurements reveal hadronization effects.
- Color string between c quarks and beam/target fragments affects hadron flavor and momentum; non-perturbative

Hadroproduction hadronization: leading particle effect

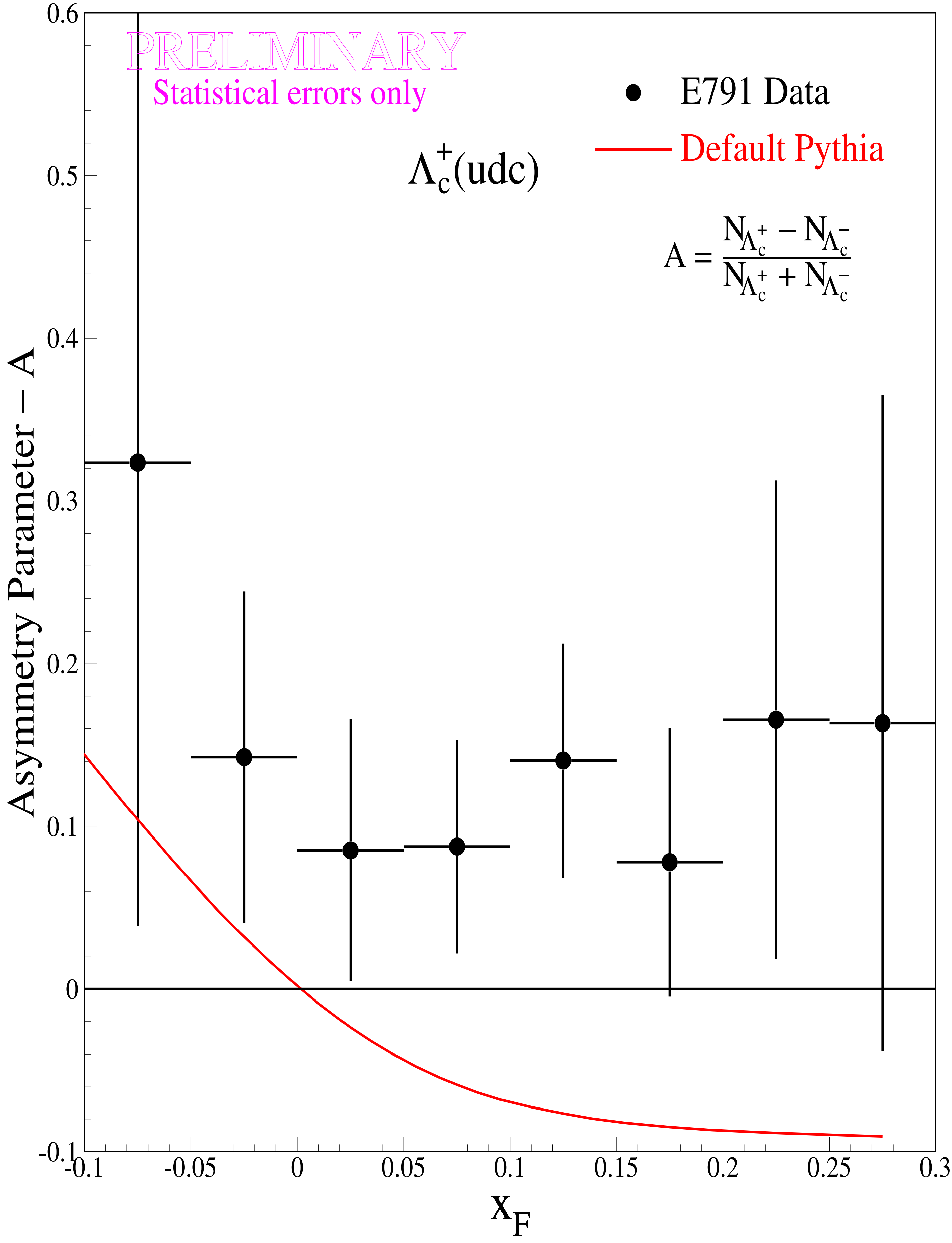
Beam(target) quark or quarks coalesce with charm or anticharm quark dragging the resulting hadron forward(backward).

Beam	$\Lambda_c^+(\mathrm{cud})$	$\Lambda_c^-(\bar{\mathrm{c}}\bar{\mathrm{u}}\bar{\mathrm{d}})$	$\mathrm{D}^+(\mathrm{c}\bar{\mathrm{d}})$	$\mathrm{D}^-(\bar{\mathrm{c}}\mathrm{d})$
$\pi^-(\bar{u}d)$	d	$\bar{u}$	nonleading	d
$\Sigma^-(dds)$	d	nonleading	nonleading	d
$p(uud)$	ud	nonleading	nonleading	d

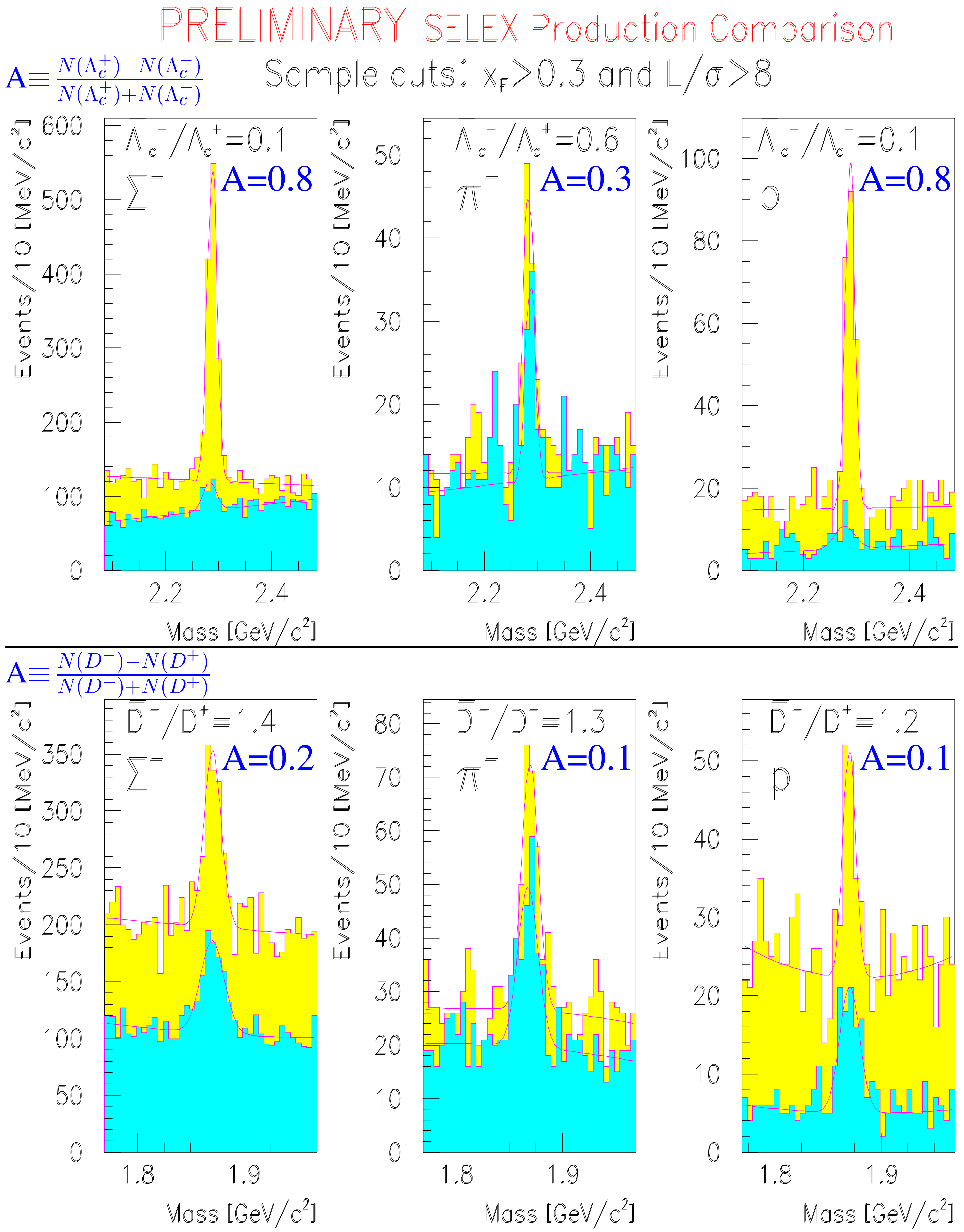
- E791 sees leading particle effect evidence from $D^\pm$ asymmetry versus x_F with a $\pi^-(\bar{u}d)$ beam; SELEX confirms.
- E791 $\Lambda_c^+(udc)$ asymmetry shows slight target dragging?
- SELEX shows clear asymmetry in high-x_F data



D+ → Kππ
E791 Data
Default Pythia: m_c=1.35 GeV, <k_t>=.44 GeV
Tuned Pythia: m_c=1.7 GeV, <k_t>=1 GeV
NLO QCD
A = (N_D− − N_D+) / (N_D− + N_D+)
Asymmetry Parameter − A
x_F
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8



PRELIMINARY
Statistical errors only
E791 Data
Default Pythia
$\Lambda_c^+(udc)$
$A = \frac{N_{\Lambda_c^+} - N_{\Lambda_c^-}}{N_{\Lambda_c^+} + N_{\Lambda_c^-}}$
Asymmetry Parameter – A
x_F
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.05
0.05
0.15
0.25

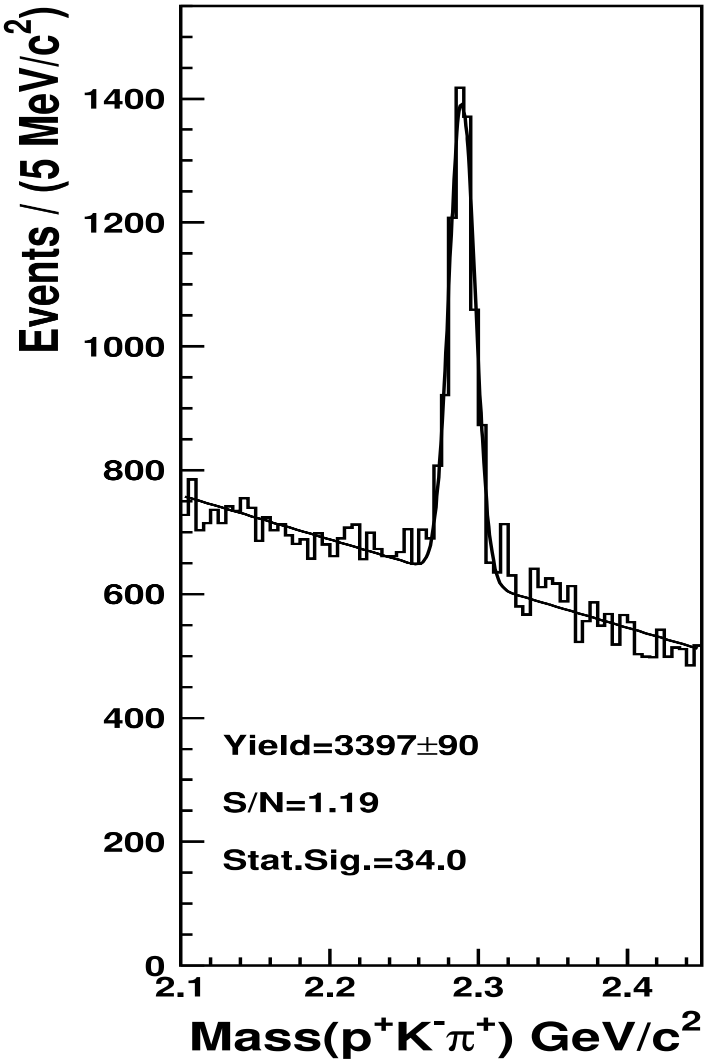

PRELIMINARY SELEX Production Comparison
Sample cuts: $x_F > 0.3$ and $L/\sigma > 8$
$A \equiv \frac{N(\Lambda_c^+) - N(\Lambda_c^-)}{N(\Lambda_c^+) + N(\Lambda_c^-)}$
$\bar{\Lambda}_c^- / \Lambda_c^+ = 0.1$
Σ^-
A=0.8
$\bar{\Lambda}_c^- / \Lambda_c^+ = 0.6$
π^-
A=0.3
$\bar{\Lambda}_c^- / \Lambda_c^+ = 0.1$
p
A=0.8
Events/10 [MeV/c^2]
Mass [GeV/c^2]
$A \equiv \frac{N(D^-) - N(D^+)}{N(D^-) + N(D^+)}$
$\bar{D}^- / D^+ = 1.4$
Σ^-
A=0.2
$\bar{D}^- / D^+ = 1.3$
π^-
A=0.1
$\bar{D}^- / D^+ = 1.2$
p
A=0.1
Events/10 [MeV/c^2]
Mass [GeV/c^2]

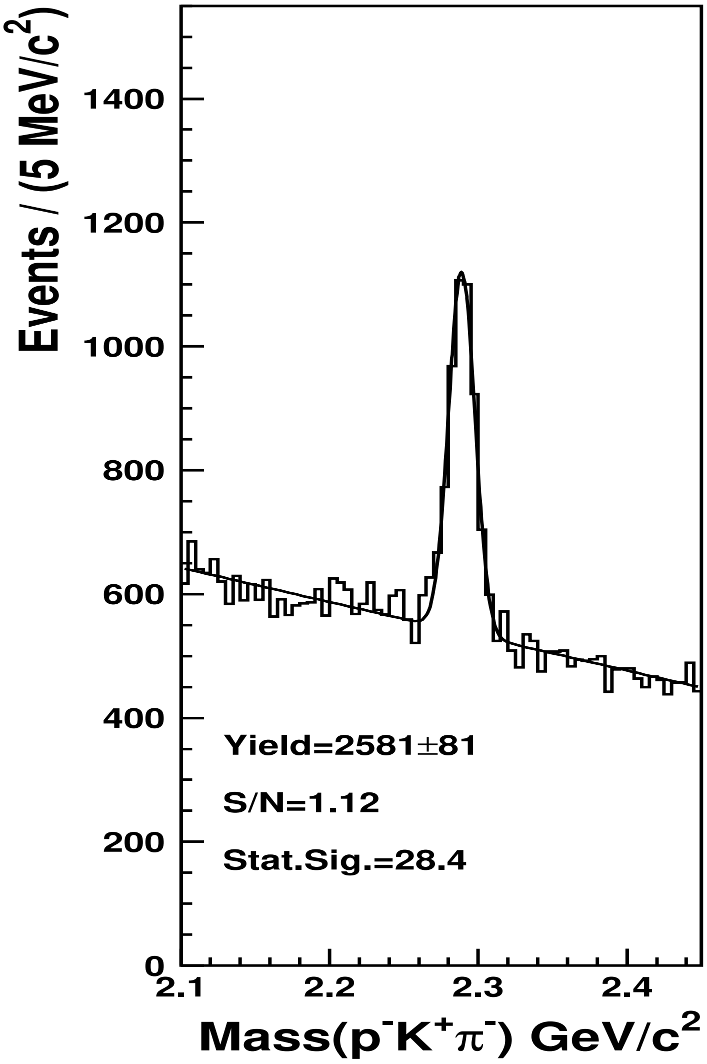
Photoproduction Hadronization

- Beam is neutral so asymmetries come from target.
- $\Lambda_c(cud)$ should be produced more often and at lower momentum than $\overline{\Lambda_c}(\bar{c}\bar{u}\bar{d})$.
- Preliminary FOCUS results from 30% of data shows first evidence for Λ_c asymmetry in photoproduction.

E691	$A = 0.11 \pm 0.09$	
E687	$A = 0.04 \pm 0.08$	
FOCUS	$A = 0.14 \pm 0.02$	(Preliminary)

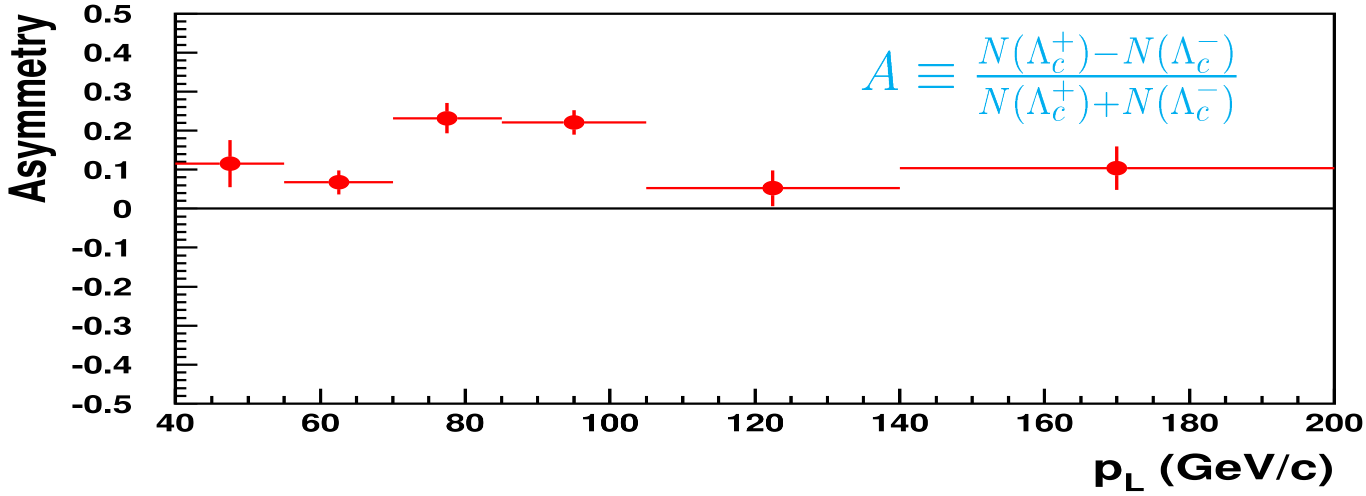
$$A \equiv \frac{N(\Lambda_c^+)-N(\Lambda_c^-)}{N(\Lambda_c^+)+N(\Lambda_c^-)}$$

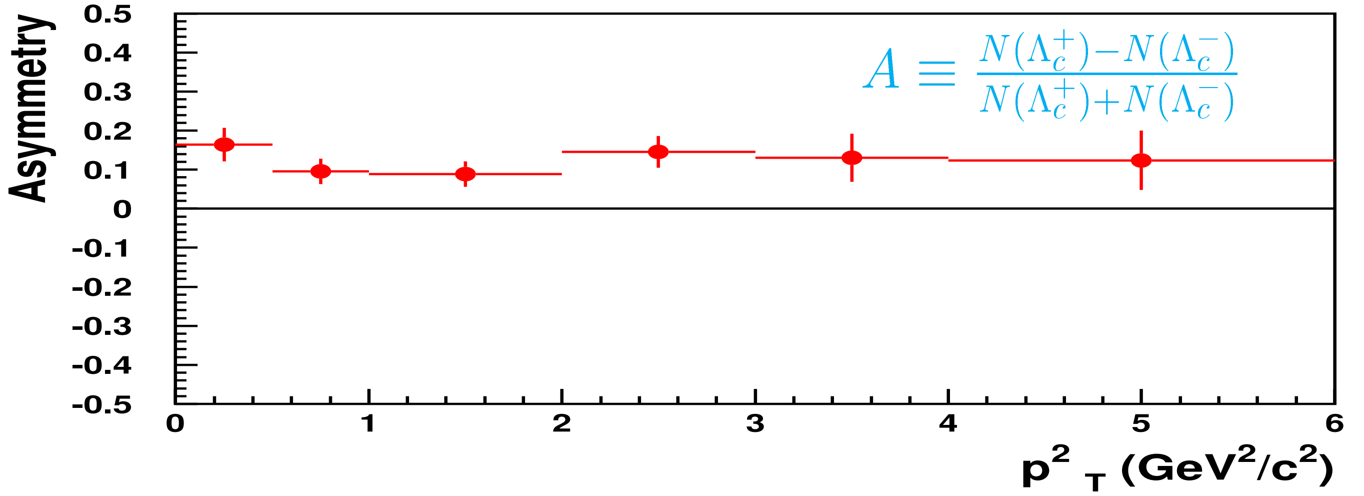


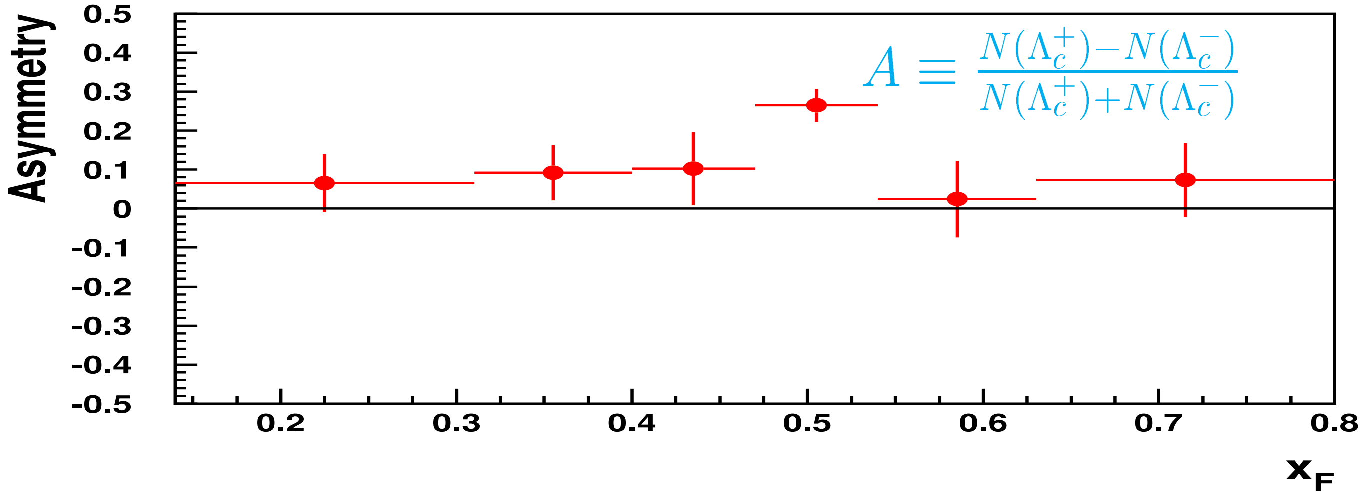


$A(\Lambda_c)$ vs. Kinematic Variables

- 30% of FOCUS data
- No clear dependence yet on p_ℓ, p_T^2, or x_F.







Charm-Pair Correlations

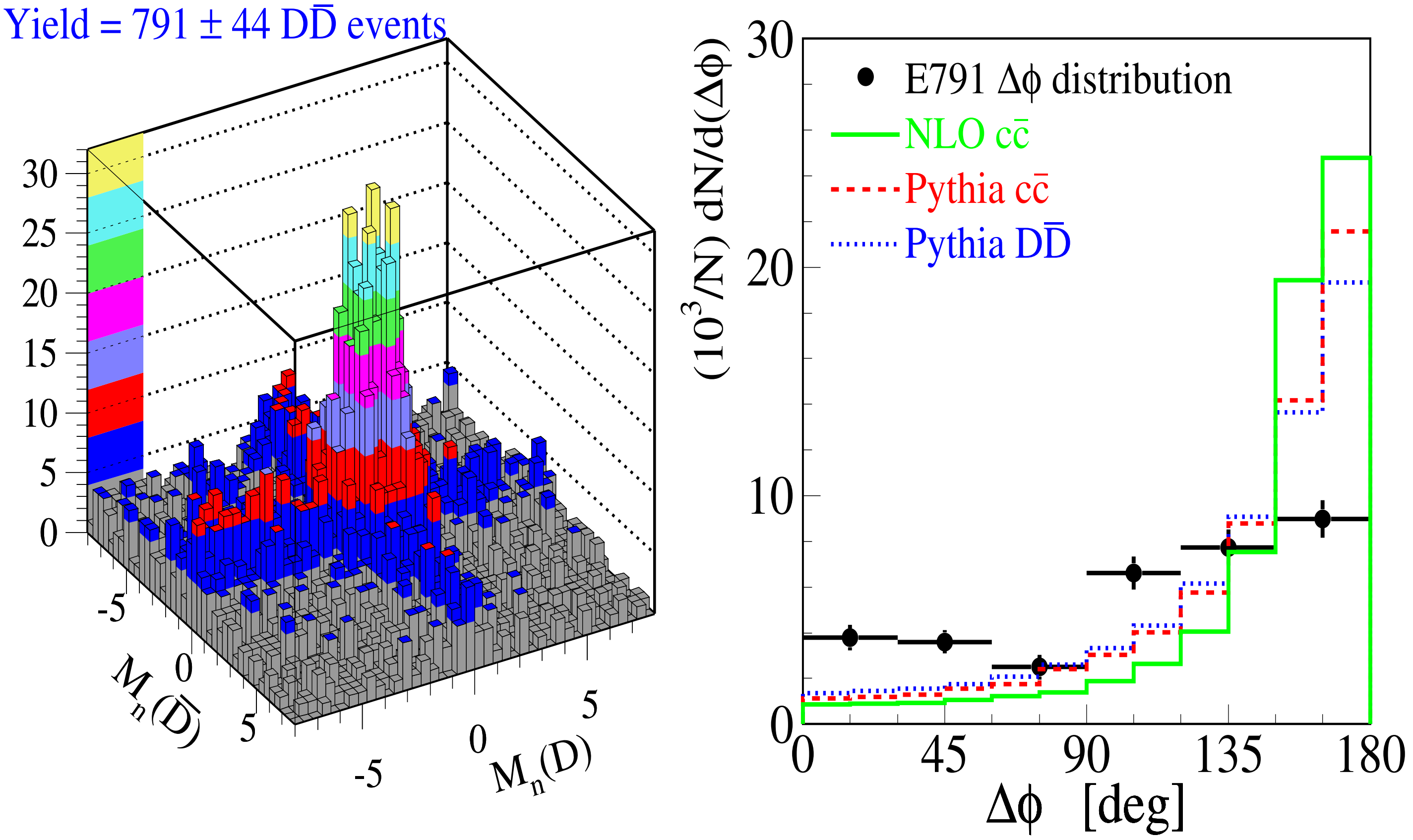
E791 (π^-–N)

- E791 charm-pair analysis fully reconstructs 791±44 D meson pairs to investigate correlations between the pairs.
- Transverse correlations (*e.g.* $\Delta\phi$, $\Delta p_t^2 \equiv |p_{t,D}^2 - p_{t,\overline{D}}^2|$, and $p_{t,D\overline{D}}^2 \equiv |\vec{p}_{t,D} + \vec{p}_{t,\overline{D}}|^2$) are sensitive to c quark production.
- Longitudinal correlations (e.g.Δx_F) are sensitive to hadronization.
- We show here just the $\Delta\phi$ distribution.

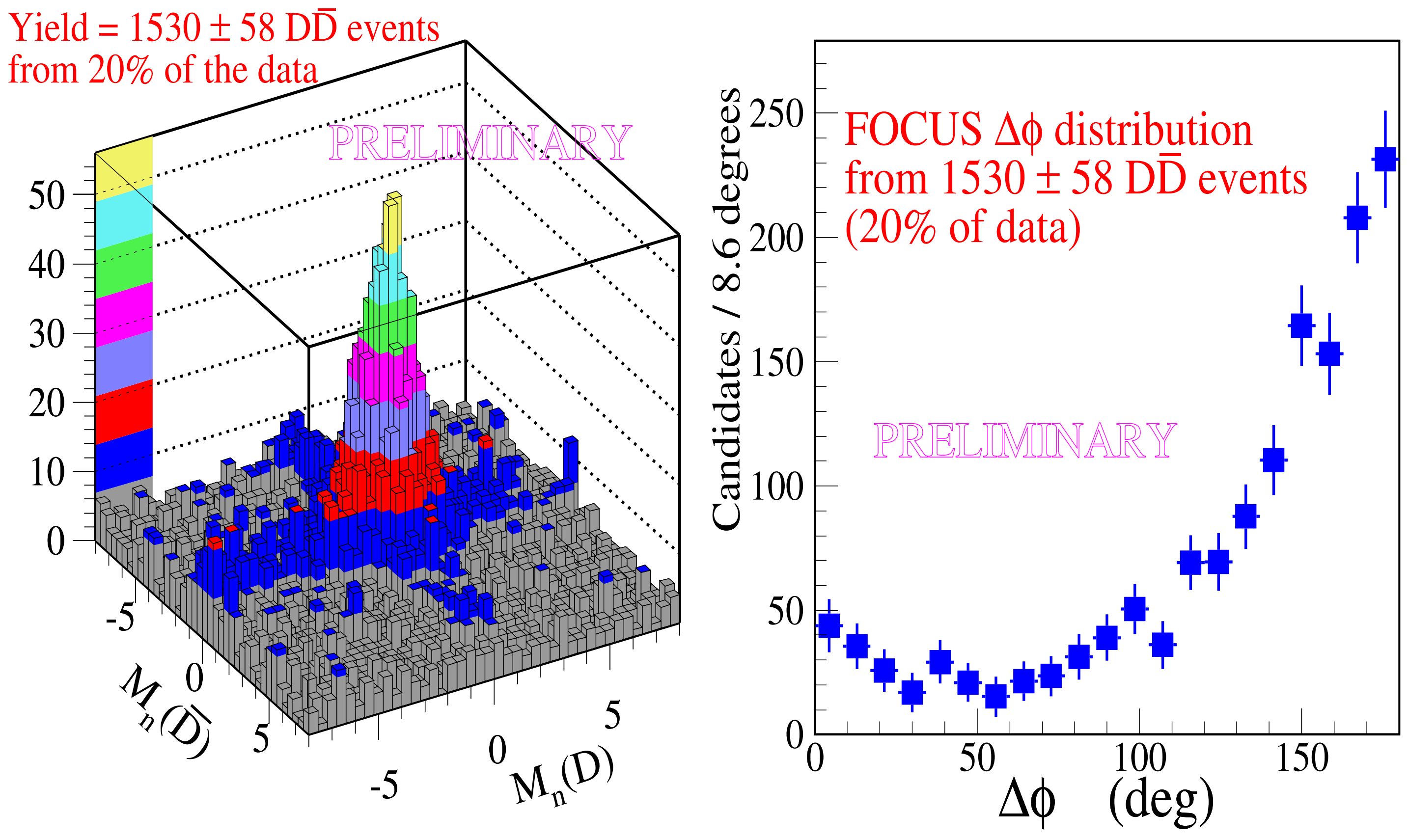
FOCUS (γ–N)

- FOCUS expects $\gtrsim$7500 fully reconstructed charm-pairs.
- Preliminary 20% sample and $\Delta\phi$ distribution shown.
- More peaked at high $\Delta\phi$ (than E791) and interesting turn-up at low $\Delta\phi$.
- Also working on partially reconstructed (D^* tag) pairs.
- Will be including Λ_c's as well.

E791 (π^-–N)



FOCUS (γ–N)

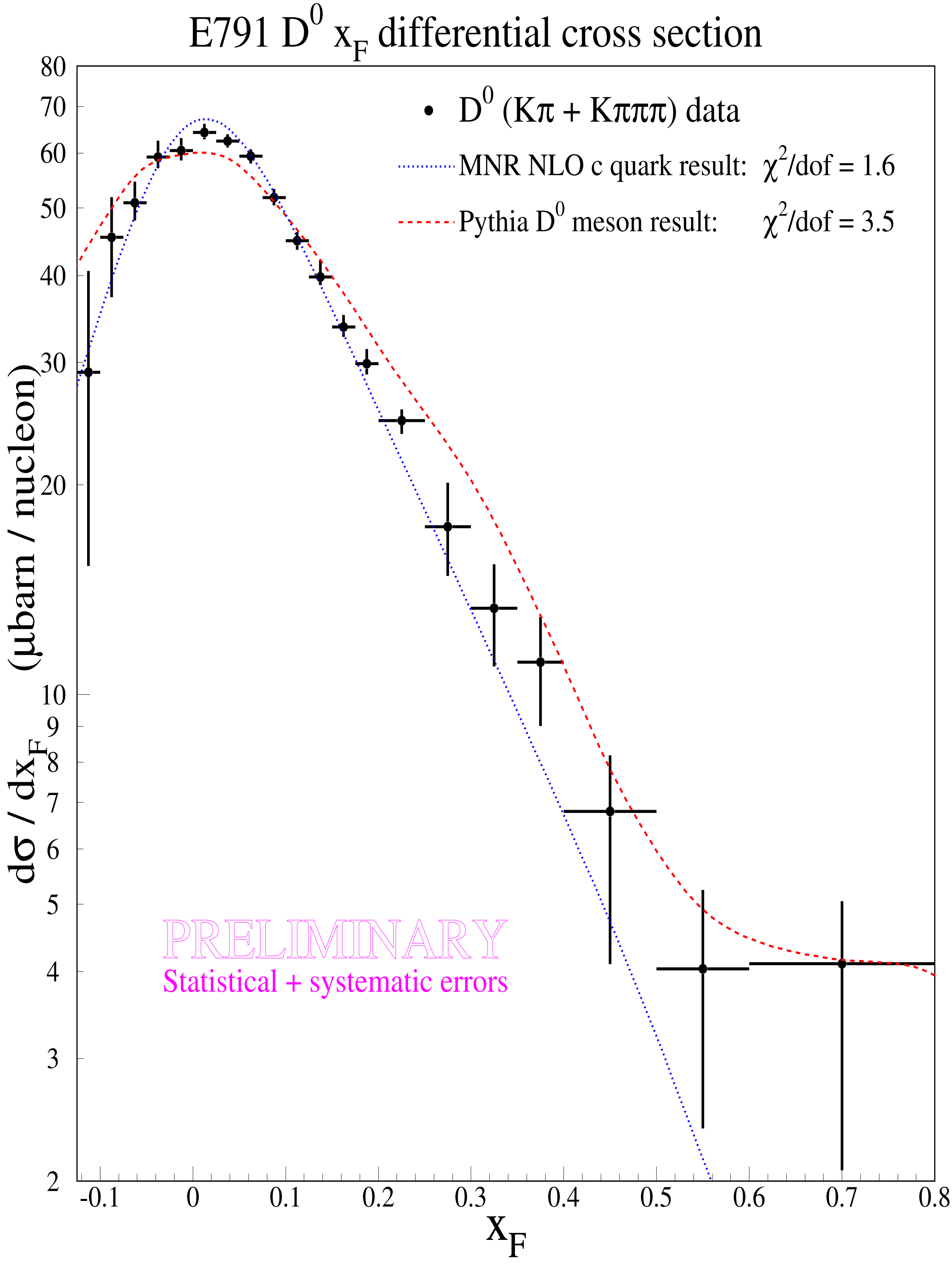


Differential Cross Sections

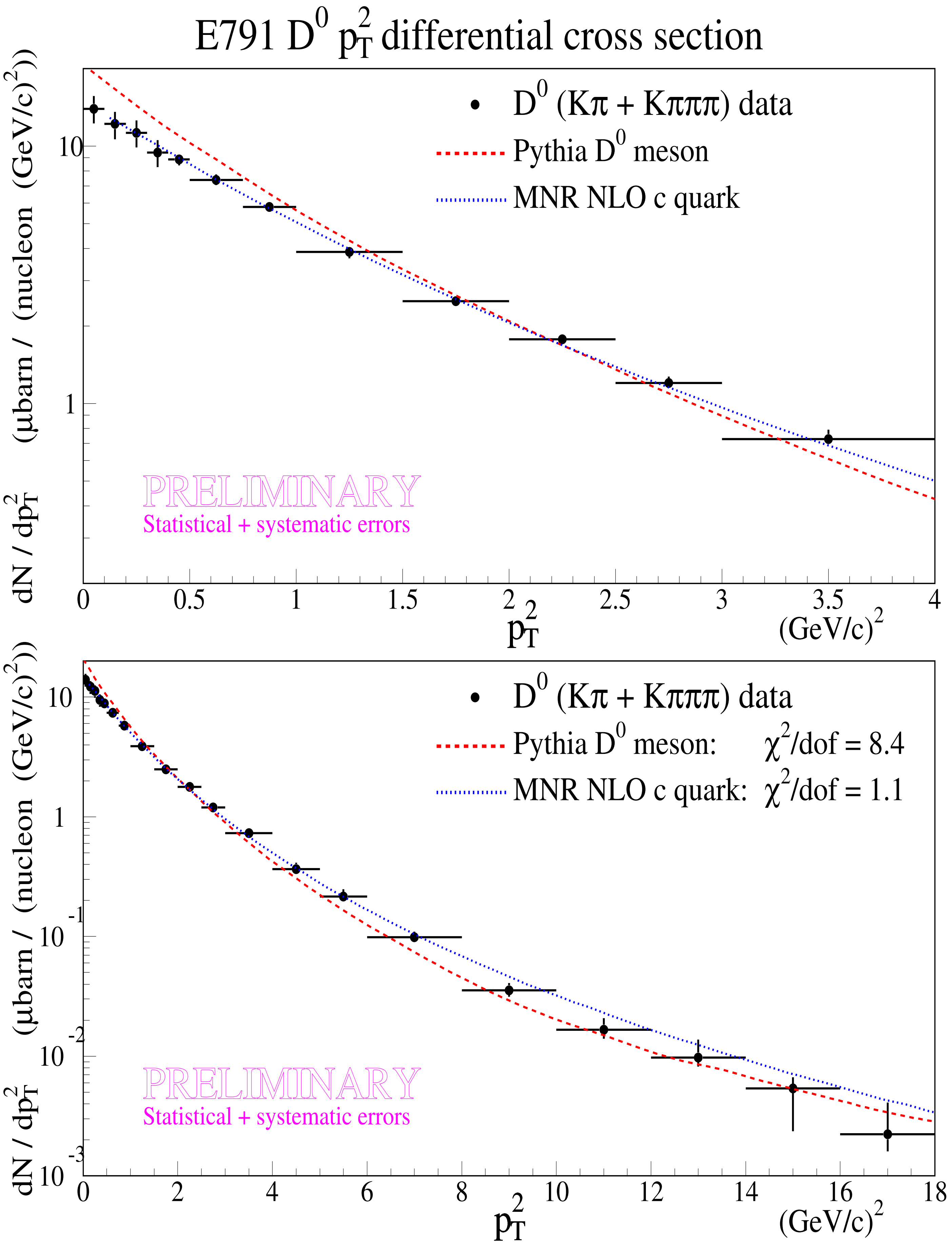
- x_F and p_T^2 distribution shapes are sensitive to c quark production and hadronization.

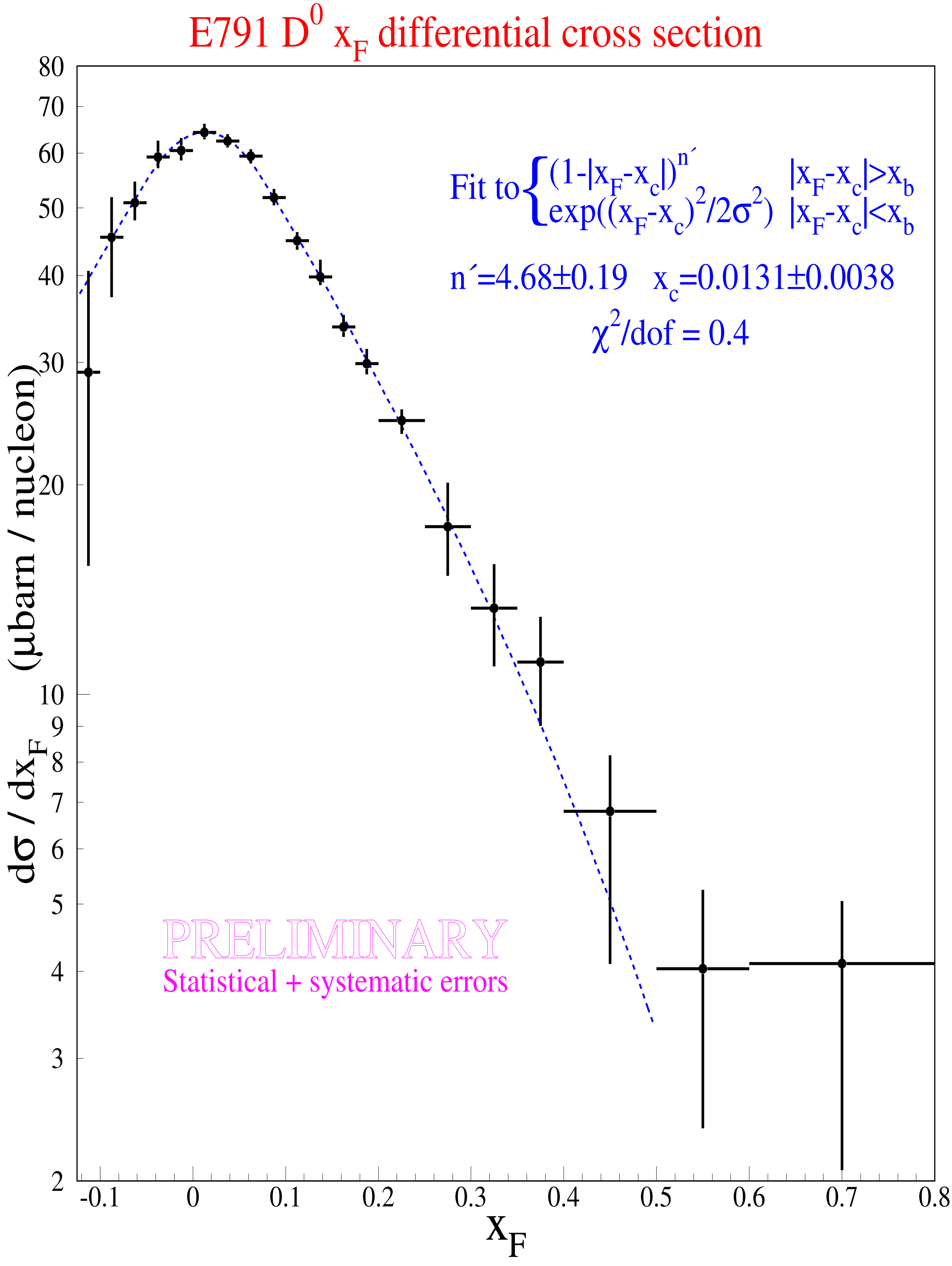
- E791 results for x_F and p_T^2 differential cross sections from 89,000 D^0 ($K\pi$ & $K\pi\pi\pi$) events.
  - High statistics show x_F turnover point clearly.
  - p_T^2 data out to 18 (GeV/c)^2.
  - Default NLO QCD c quark prediction not too bad. Implies cancellation of non-perturbative effects.
  - Default PYTHIA predicts too much dragging in the central region.

- Preliminary SELEX results on Λ_c^+ x_F distributions from π^-, p, and Σ^- beams.
  - n values generally lower than for D mesons.
  - No clear indication yet of beam type dependence.
  - Will complement E769 study of π, K, p production of D mesons.



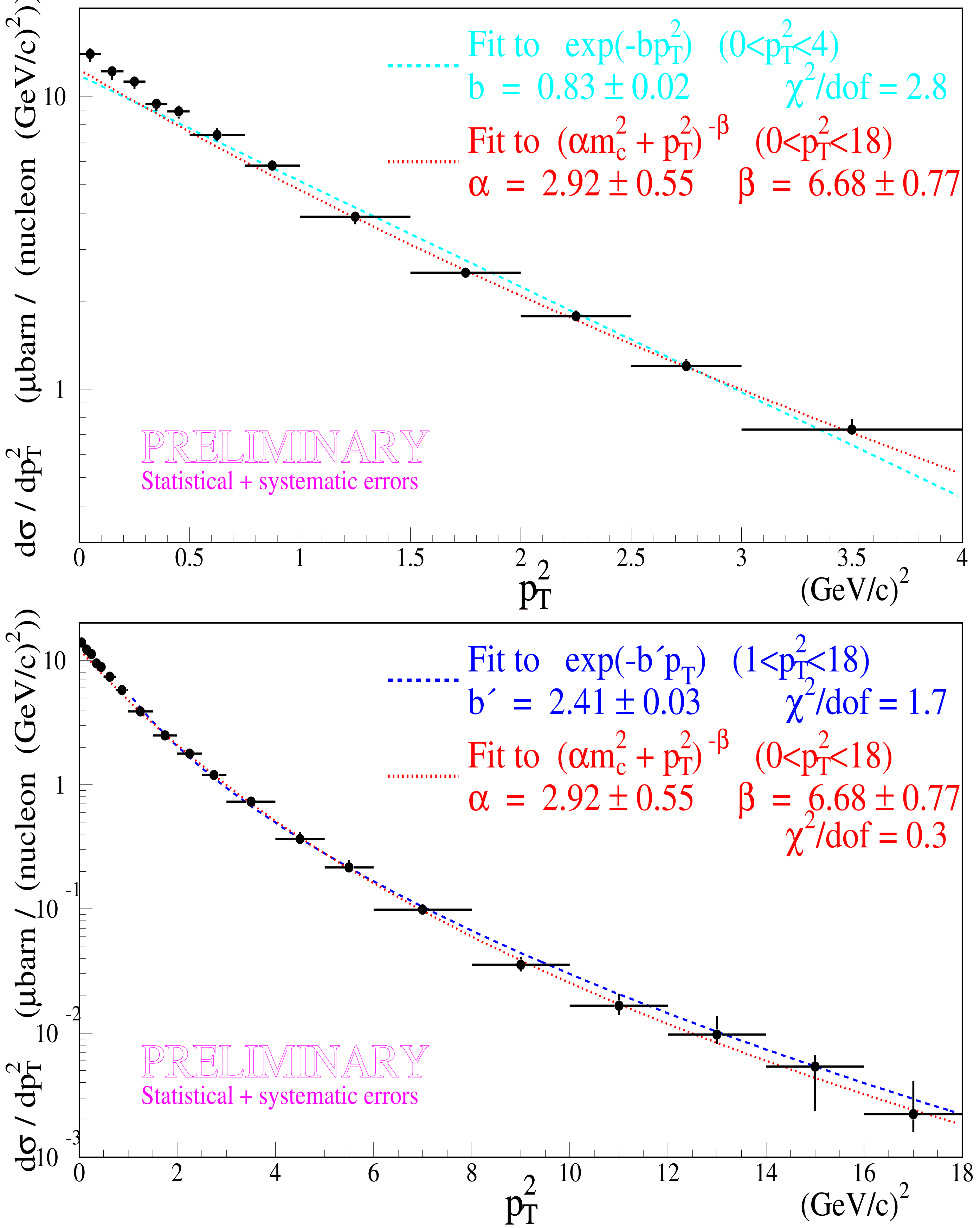
E791 D^0 x_F differential cross section
D^0 ($K\pi + K\pi\pi\pi$) data
MNR NLO c quark result: χ^2/dof = 1.6
Pythia D^0 meson result: χ^2/dof = 3.5
PRELIMINARY
Statistical + systematic errors
$d\sigma / dx_F$ (μbarn / nucleon)
x_F

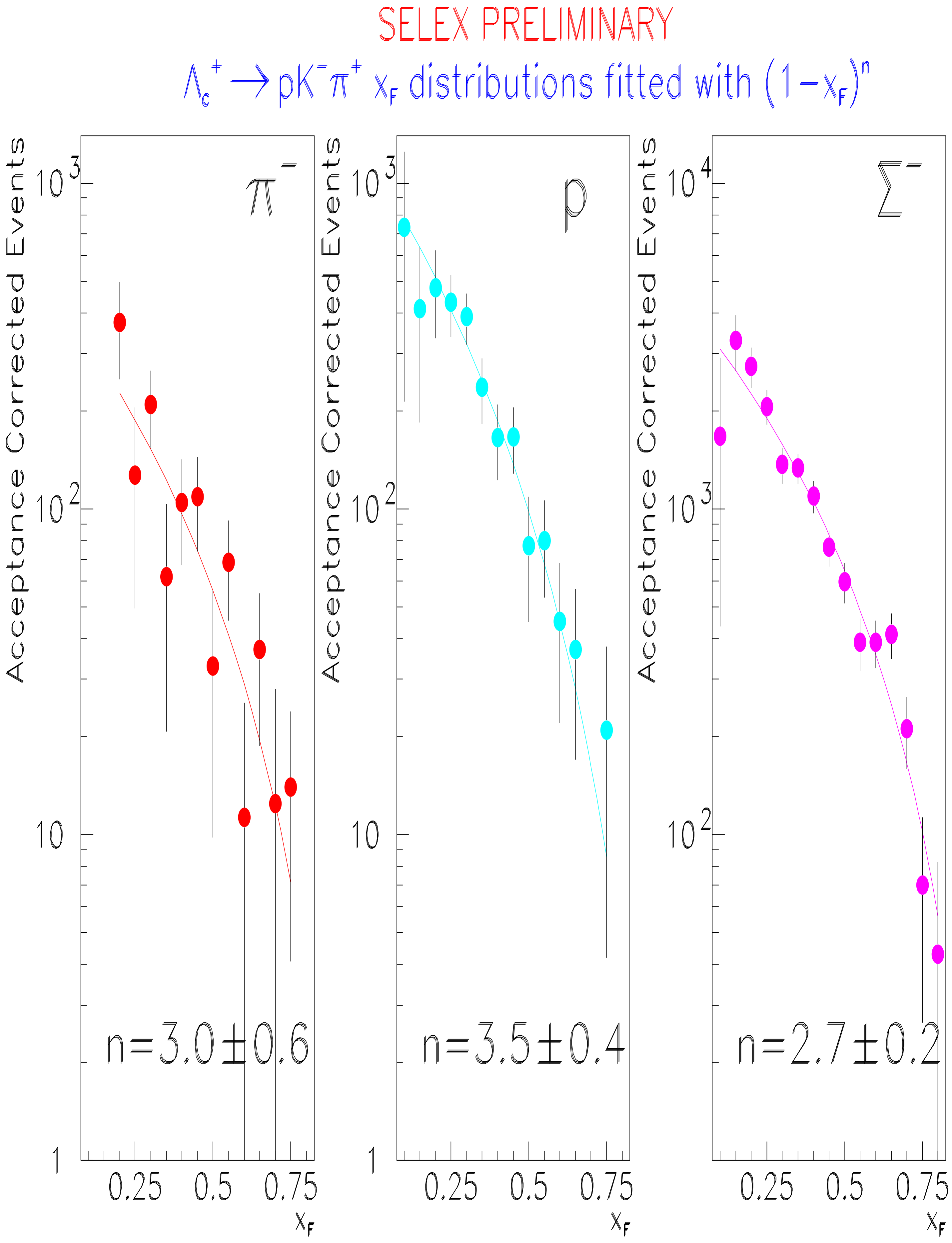

E791 D0 pT2 differential cross section
D0 (Kπ + Kπππ) data
Pythia D0 meson
MNR NLO c quark
PRELIMINARY
Statistical + systematic errors
dN / dpT2 (μbarn / (nucleon (GeV/c)2))
pT2 (GeV/c)2
D0 (Kπ + Kπππ) data
Pythia D0 meson: χ2/dof = 8.4
MNR NLO c quark: χ2/dof = 1.1
PRELIMINARY
Statistical + systematic errors
dN / dpT2 (μbarn / (nucleon (GeV/c)2))
pT2 (GeV/c)2



E791 D^0 x_F differential cross section
Fit to $\begin{cases}(1-|x_F-x_c|)^{n'} & |x_F-x_c|>x_b \\ \exp((x_F-x_c)^2/2\sigma^2) & |x_F-x_c|<x_b\end{cases}$
$n'=4.68\pm0.19$ $x_c=0.0131\pm0.0038$
$\chi^2/dof = 0.4$
PRELIMINARY
Statistical + systematic errors
$d\sigma / dx_F$ (μbarn / nucleon)
x_F

E791 D^0 p_T^2 differential cross section

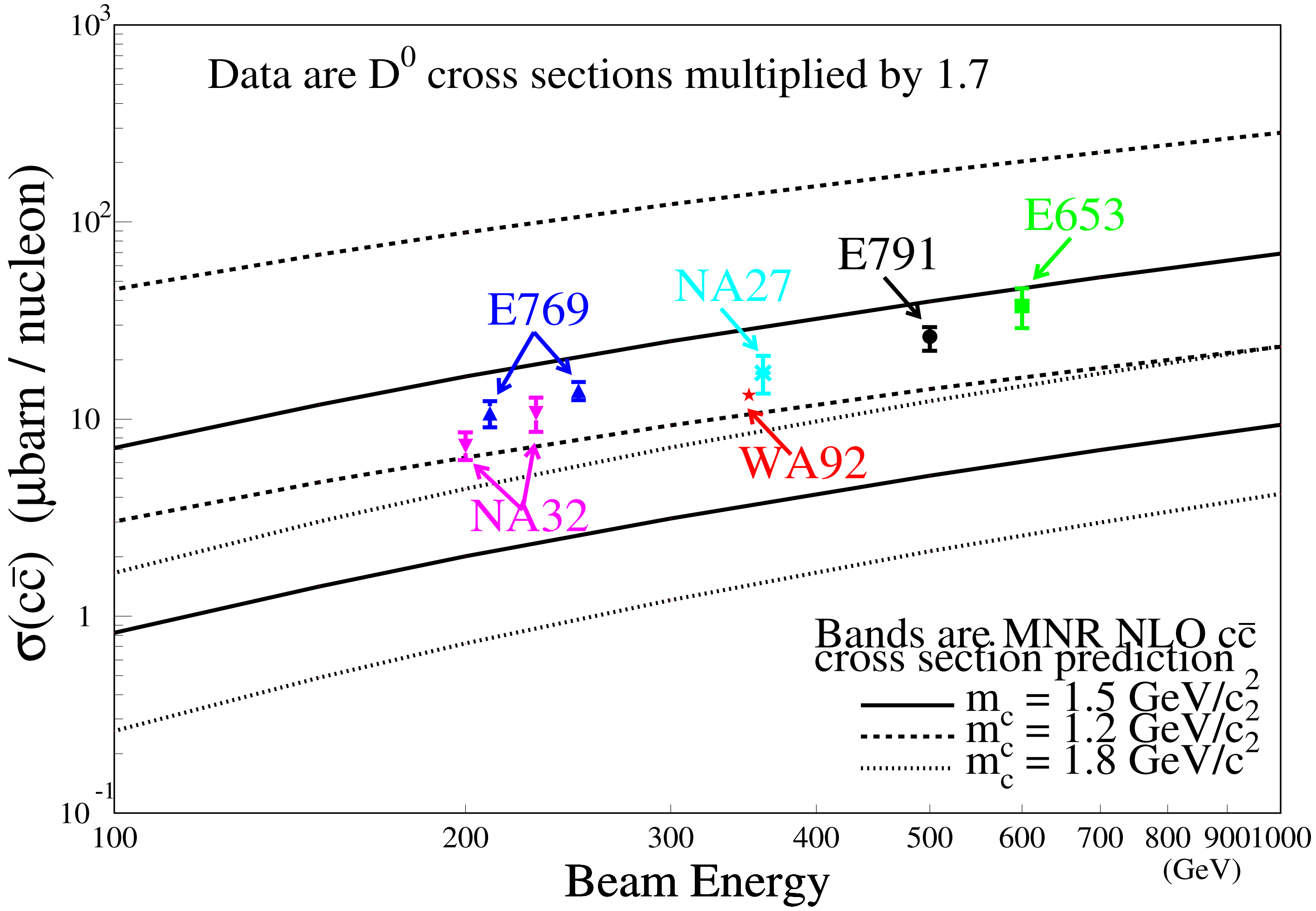




SELEX PRELIMINARY
$\Lambda_c^+ \rightarrow pK^-\pi^+$ x_F distributions fitted with $(1-x_F)^n$
Acceptance Corrected Events
π^-
p
Σ^-
$n=3.0\pm0.6$
$n=3.5\pm0.4$
$n=2.7\pm0.2$
x_F

Total Cross Sections

- E791 results from 79,000 D^0 ($K\pi$ & $K\pi\pi\pi$) events.
- Measure $\sigma(D^0 + \overline{D}^0; x_F > 0) = 15.4\,^{+1.8}_{-2.3}$ μbarns/nucleon for 500 GeV π^- beam on nuclear target assuming a linear A dependence.
- Good agreement with previous D^0 results and theory.



- FOCUS will be able to provide high statistics measurements of both open and hidden charm production.
- SELEX should provide interesting results on high x_F Λ_c and Ξ_c production (e.g. vs. beam type)

Conclusions

- E791 has provided, and will continue to provide, many results on charm hadroproduction.
- FOCUS and SELEX have great potential to increase our knowledge of charm photoproduction and high-x_F charm baryon hadroproduction.
- Large theoretical uncertainties imply no single result, or even single experiment, can uniquely determine the physics of charm production.
- Combining results of E791, FOCUS, and SELEX along with other past experiments may provide a coherent picture.

These talk transparencies can be found at:
http://fnphyx-www.fnal.gov/experiments/e791/stenson/moriond_talk.ps or
http://fnphyx-www.fnal.gov/experiments/e791/stenson/moriond_talk.ps.gz