E791: High-Statistics Charm Production with a π^- Beam

Kevin Stenson
University of Wisconsin - Madison

for the E791 Collaboration
(http://fnphyx-www.fnal.gov/experiments/e791/welcome.html)

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Outline

I. Overview of Charm Hadroproduction

II. The E791 Experiment

III. The E791 Results

- A. Asymmetries
- B. Charm-Pair Correlations
- C. Differential Cross Sections

IV. Conclusions

I. Production of Charm from π–N Interactions

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

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

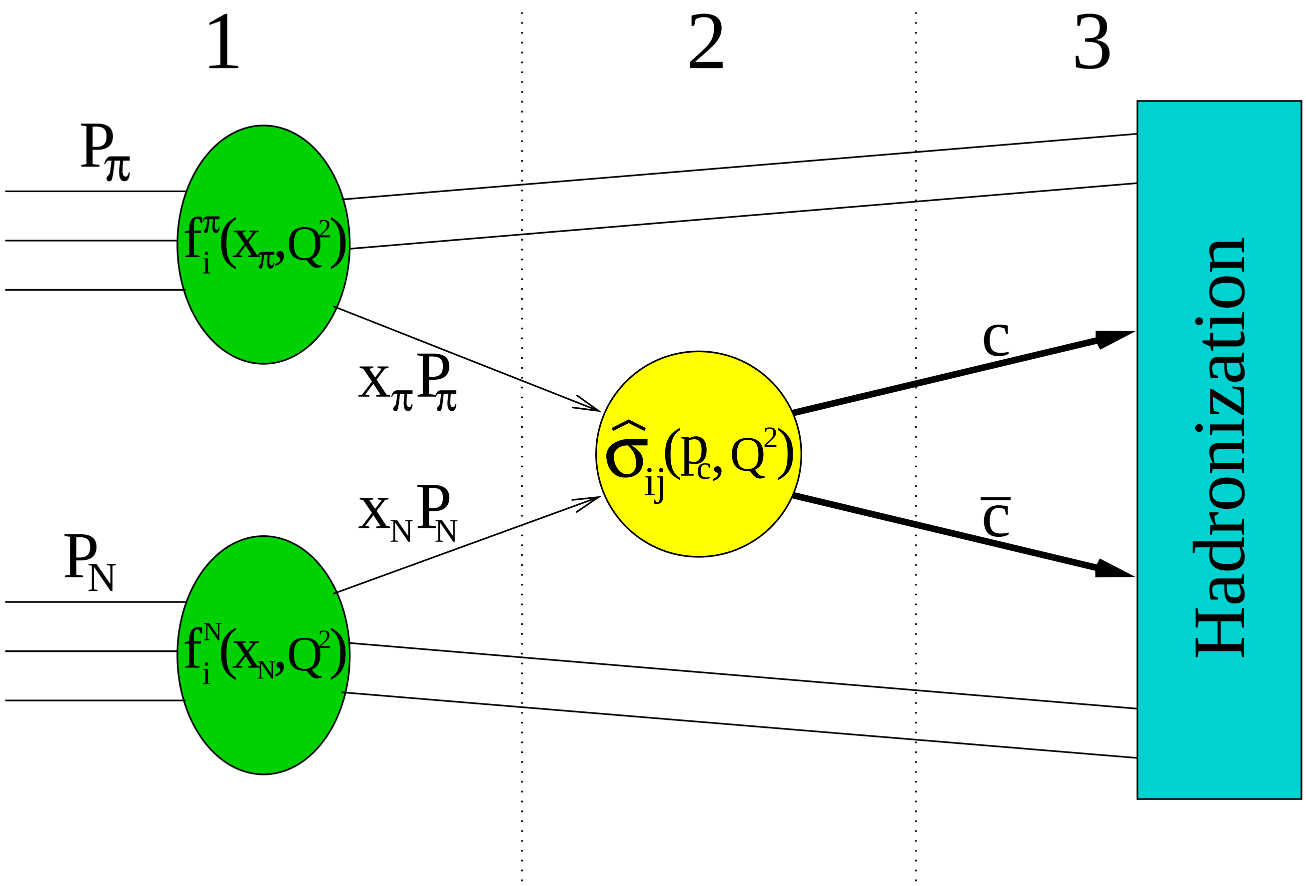
Calculable? by perturbative QCD — $\hat{\sigma}_{ij}(\mathbf{p_c}, Q^2)$

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 $= Q^2 \sim \Lambda^2_{QCD} \sim (0.3 \text{ GeV})^2$



II. The E791 Experiment

The Spectrometer

- Located in Fermilab's Tagged Photon Laboratory
- Upgrade of photoproduction experiments E516 and E691 and hadroproduction experiment E769
- 6 (17) planes of beam (vertex) silicon strip detectors
- 8 (2) planes of beam (tracking) PWC's
- 35 drift chamber planes
- 2 Čerenkov counters
- 2 analysis magnets (same polarity)
- Electromagnetic and hadronic calorimeters
- Muon system (scintillators behind steel)

Data Sample

- 500 GeV π^- beam on platinum & diamond targets
- Collected 20 billion events during 6 months in 1991
- Loose transverse energy requirement in trigger
- Fully reconstructed more than 200,000 charm mesons

III. The E791 Results

A. Asymmetries

- We 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.

- Therefore, asymmetry measurements are able to reveal hadronization effects.

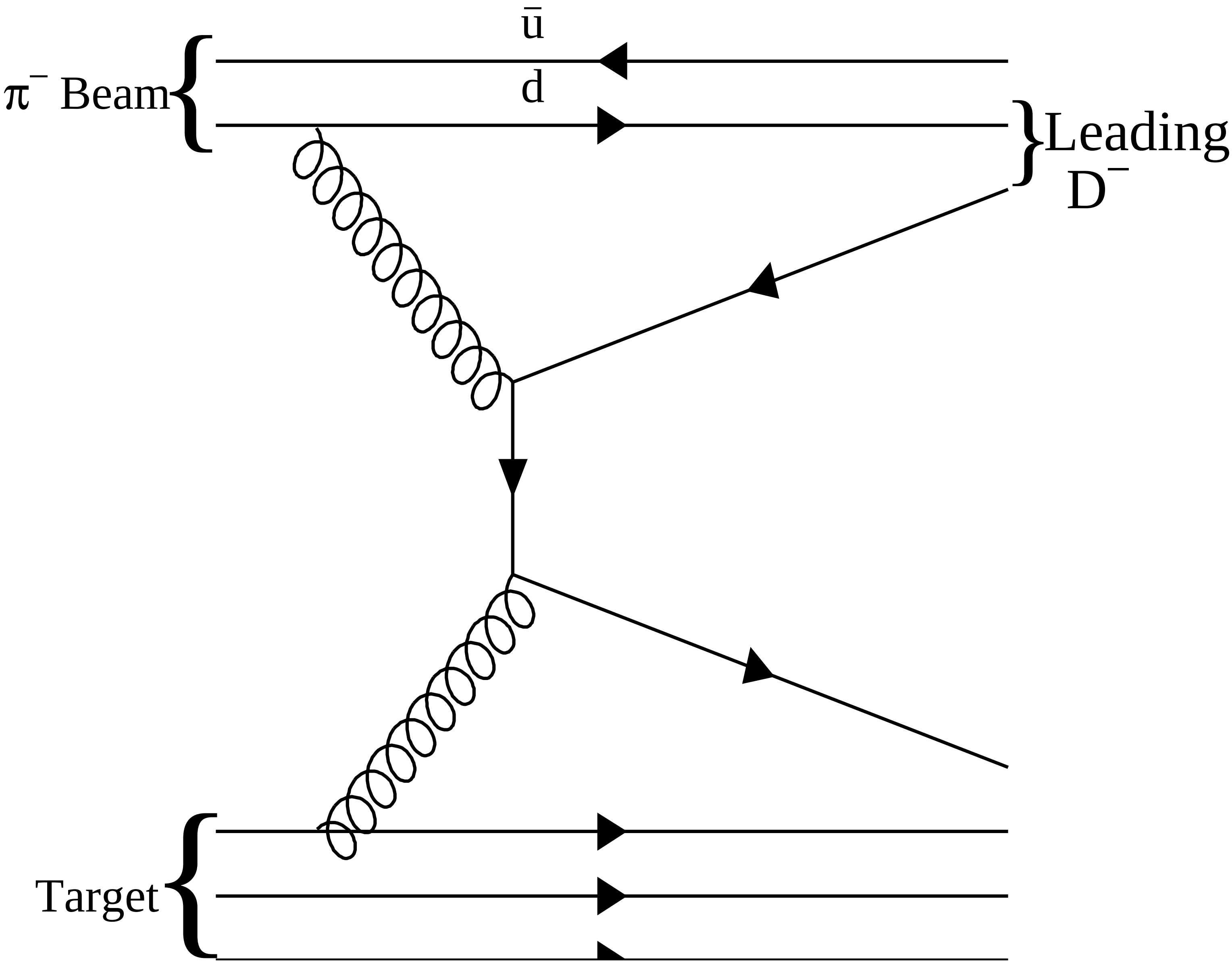
- Color string between c quarks and beam/target fragments affects hadron flavor and momentum; perhaps PYTHIA can model.

- $D^-(\bar{c}d)$ has a quark in common with $\pi^-(\bar{u}d)$ beam; $D^+(c\bar{d})$ doesn't. Coalescence seen — $D^\pm$ asymmetry increases as x_F increases. In Phys. Lett. B371:157,1996.

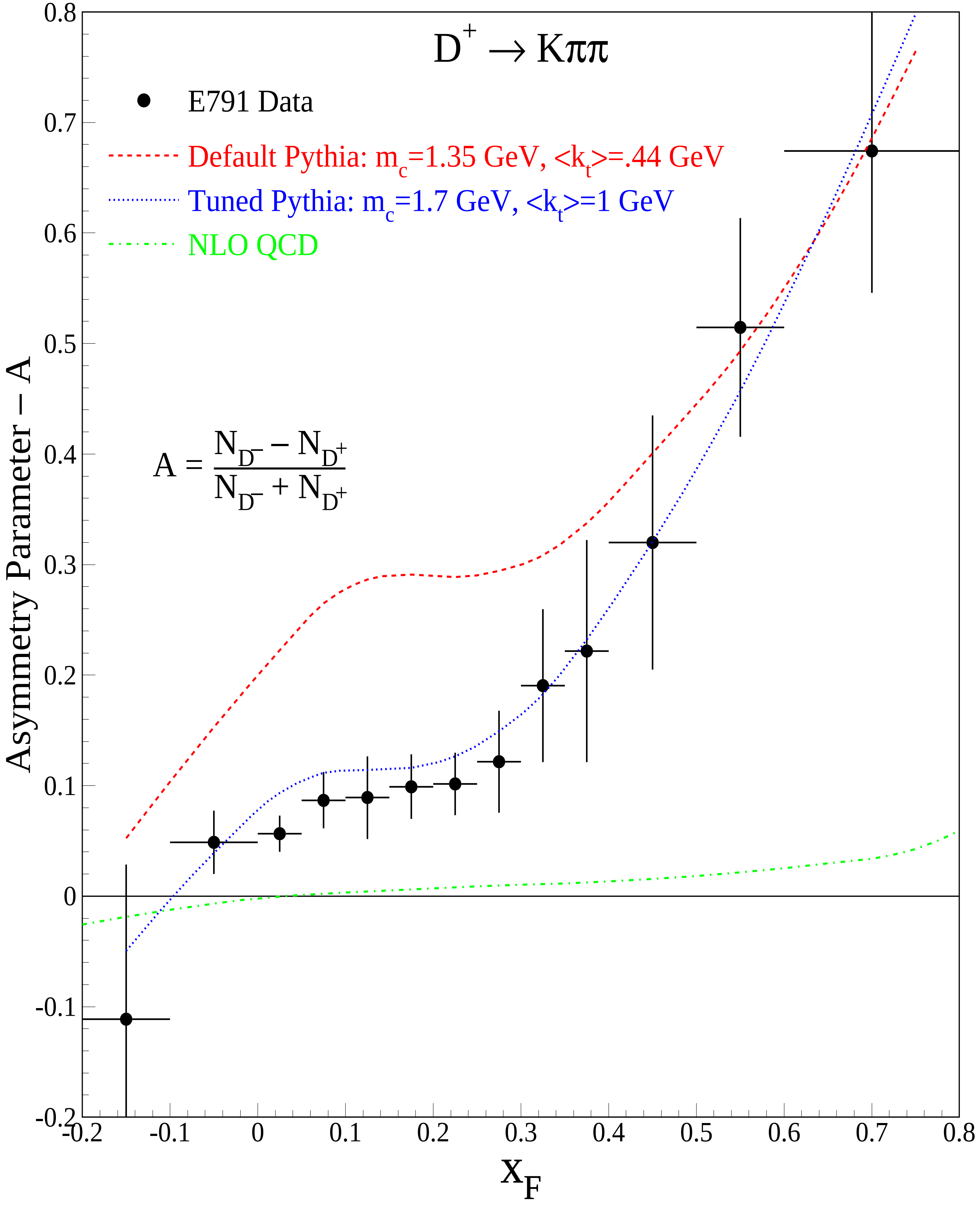
- No $D_s^\pm$ asymmetry where neither state contains a quark in common with the beam. In Phys. Lett. B411:230,1997.

- $\Lambda_c^+(udc)$ asymmetry should increase as x_F decreases because it shares a diquark with the target.

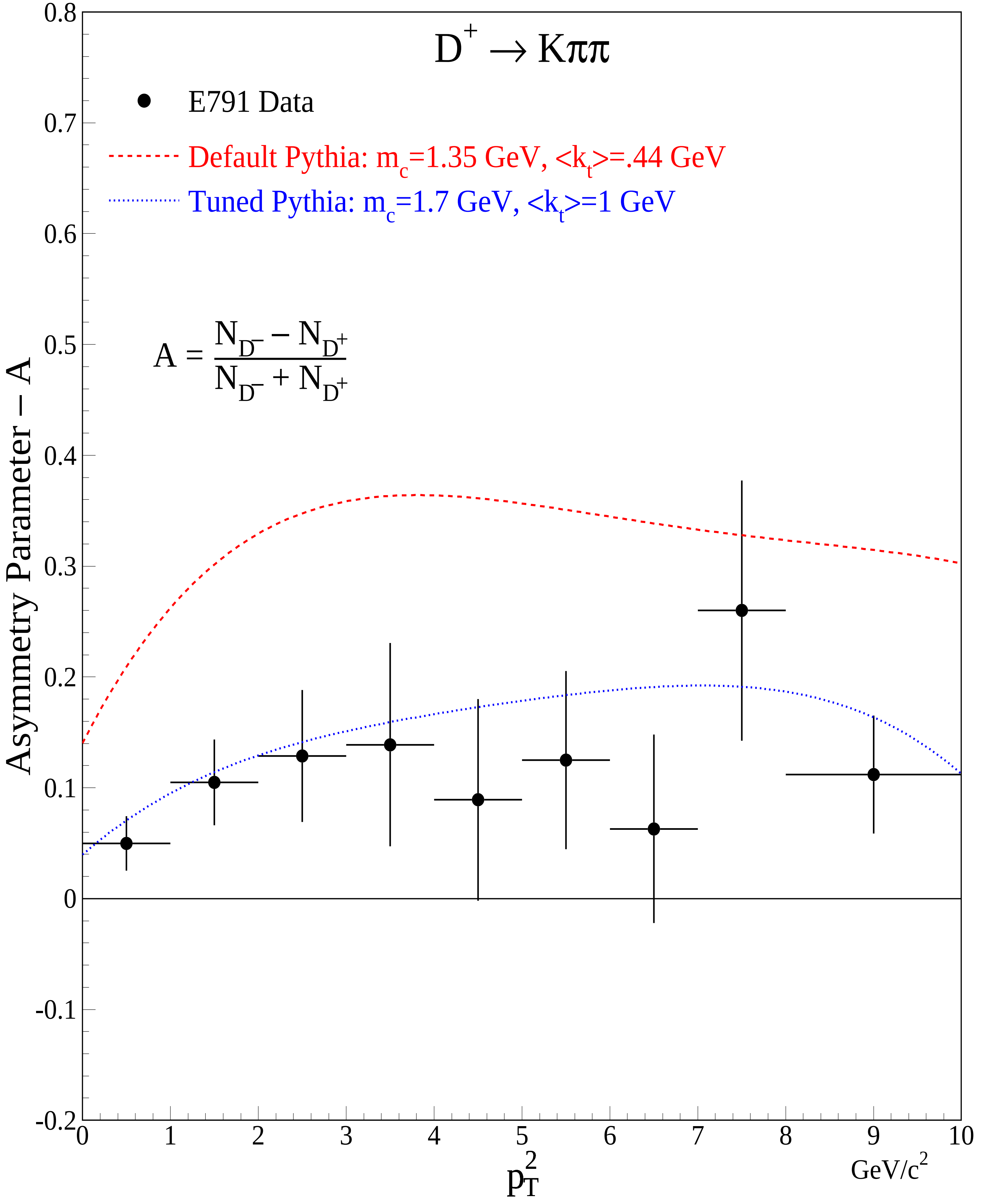
- This asymmetry is clearly seen for *strange* baryons (hyperons). Asymmetry at low x_F depends on number of quarks in common with the target.



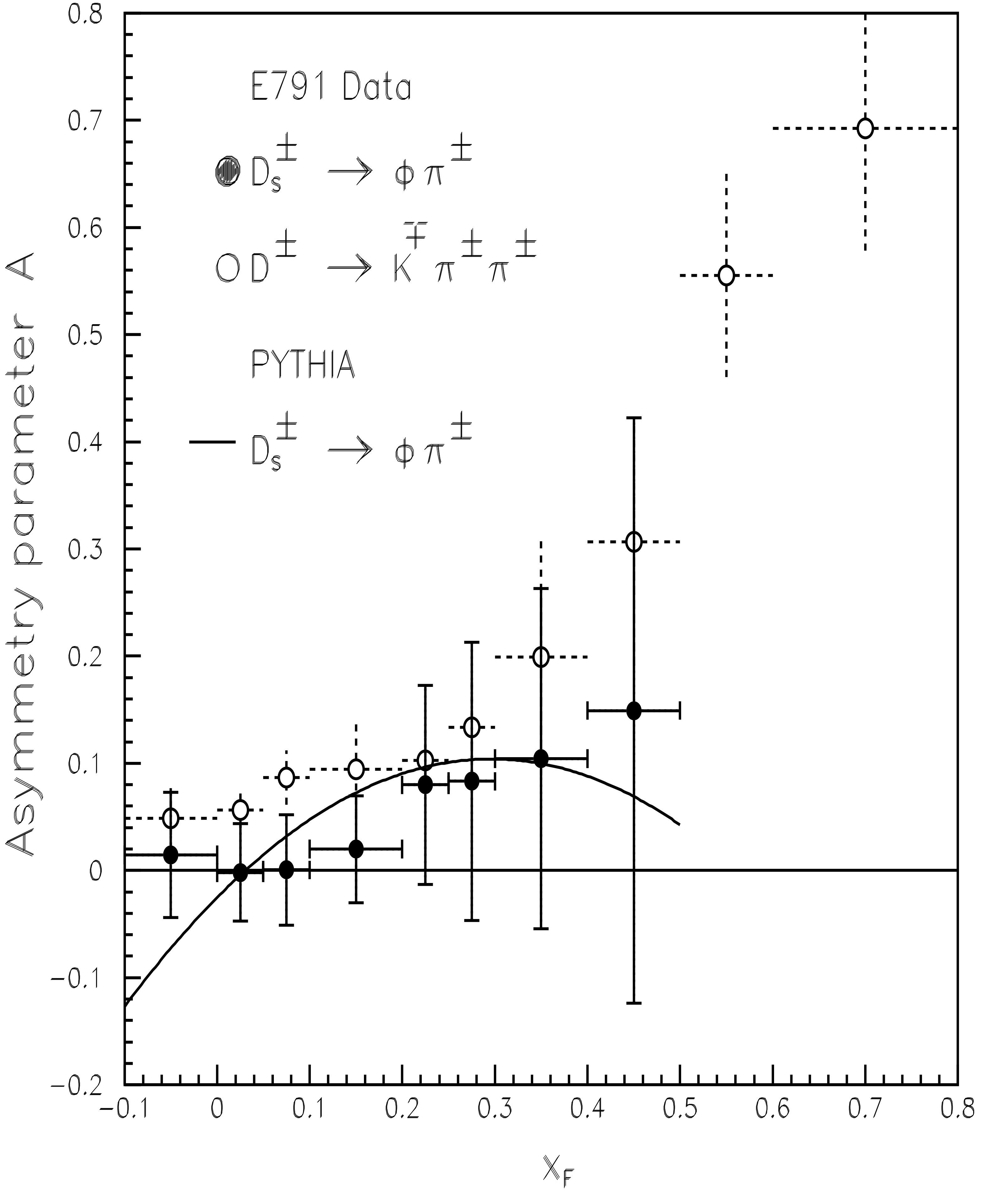
π⁻ Beam
ū
d
Leading D⁻
Target



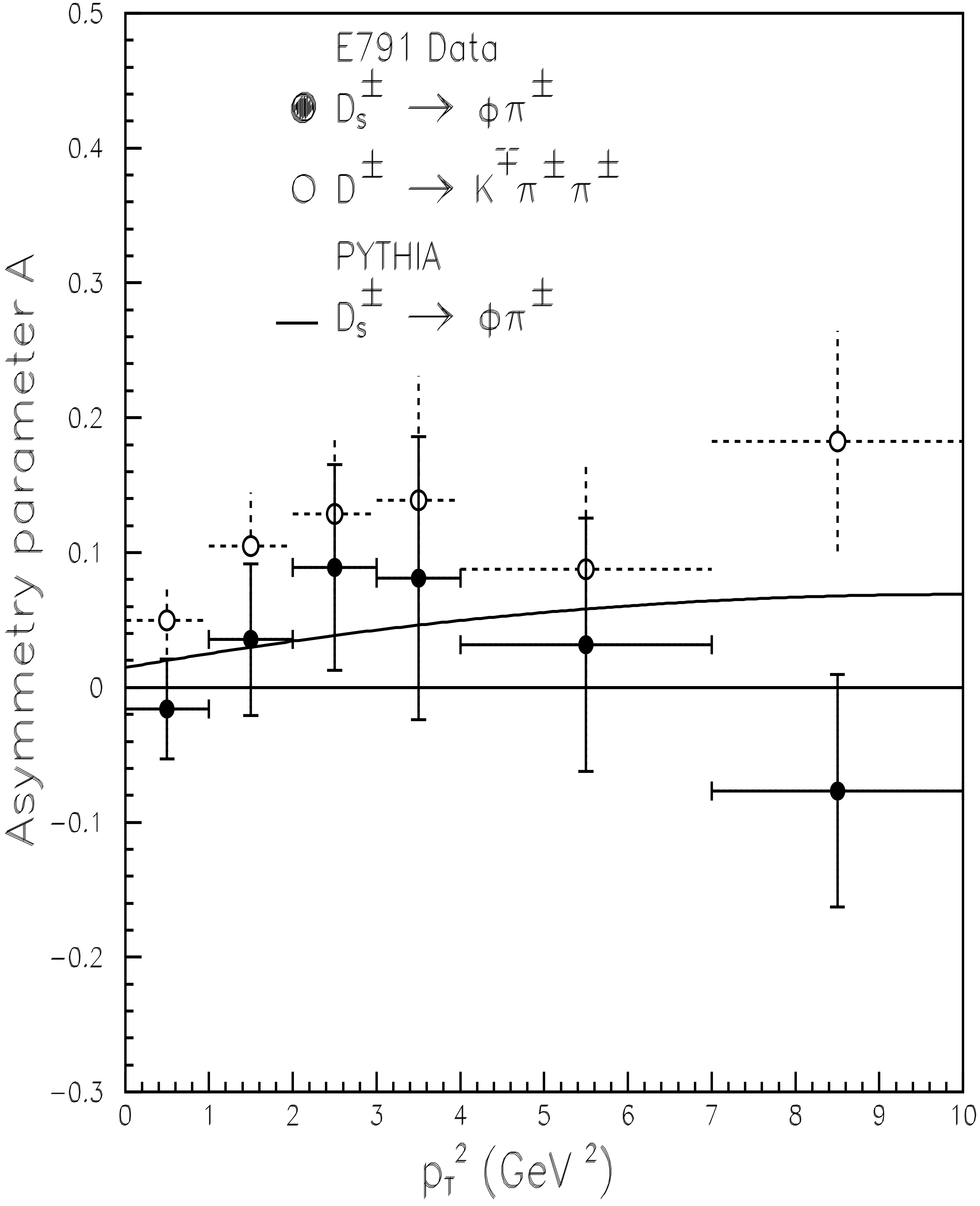
D+ → Kππ
E791 Data
Default Pythia: m_c=1.35 GeV, <k_t>=.44 GeV
Tuned Pythia: m_c=1.7 GeV, <k_t>=1 GeV
NLO QCD
A = (N_D− − N_D+) / (N_D− + N_D+)
Asymmetry Parameter – A
x_F
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8



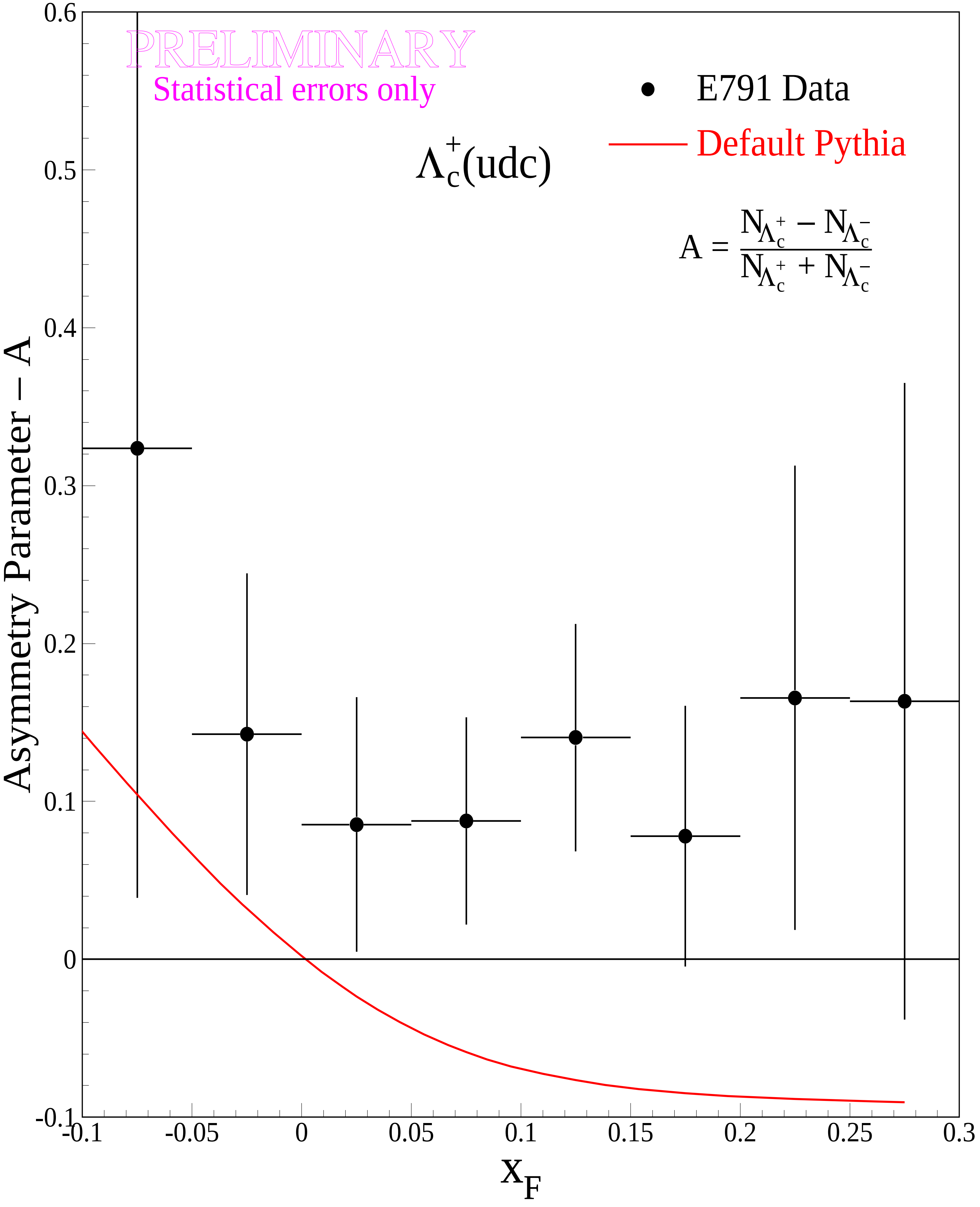
$D^+ \rightarrow K\pi\pi$
E791 Data
Default Pythia: m_c=1.35 GeV, $<k_t>$=.44 GeV
Tuned Pythia: m_c=1.7 GeV, $<k_t>$=1 GeV
$A = \frac{N_{D^-} - N_{D^+}}{N_{D^-} + N_{D^+}}$
Asymmetry Parameter – A
p_T^2
GeV/c^2



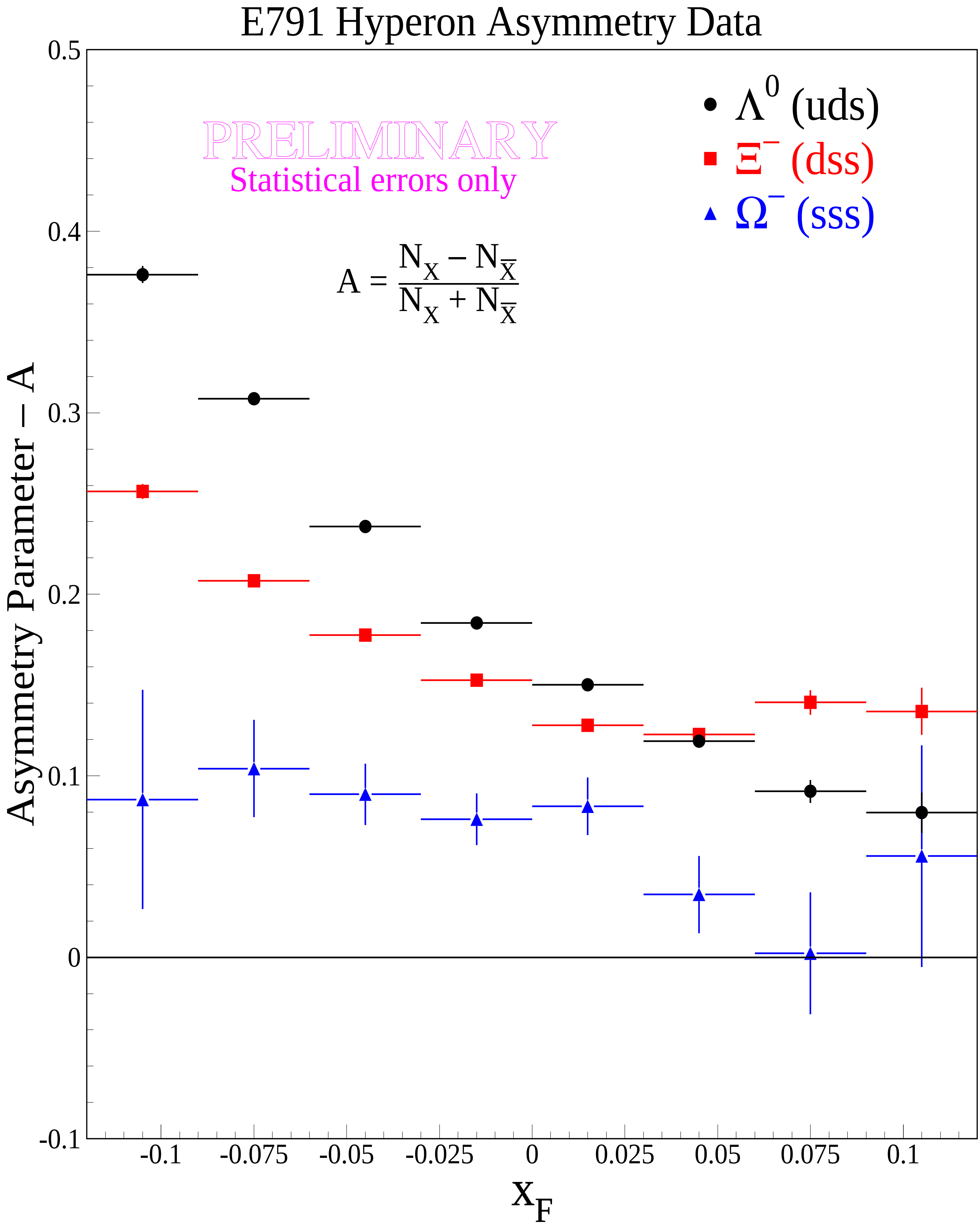
E791 Data
$D_s^{\pm} \rightarrow \phi\pi^{\pm}$
$D^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}$
PYTHIA
$D_s^{\pm} \rightarrow \phi\pi^{\pm}$
Asymmetry parameter A
x_F
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

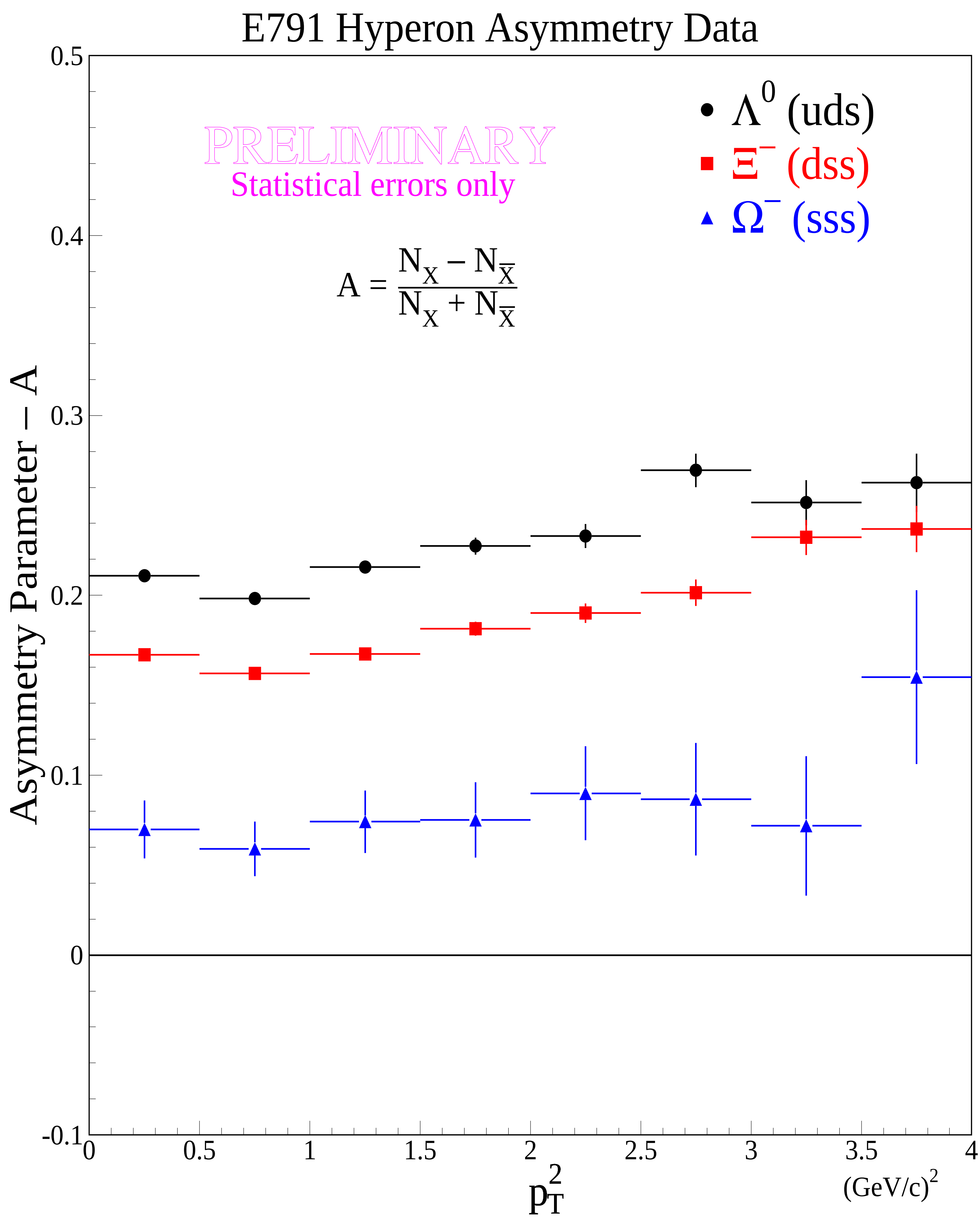


E791 Data
$D_s^{\pm} \rightarrow \phi\pi^{\pm}$
$D^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}$
PYTHIA
$D_s^{\pm} \rightarrow \phi\pi^{\pm}$
Asymmetry parameter A
p_T^2 (GeV ^{2})
0.5
0.4
0.3
0.2
0.1
0
−0.1
−0.2
−0.3
0
1
2
3
4
5
6
7
8
9
10



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
-0.1
-0.05
0
0.05
0.1
0.15
0.2
0.25
0.3

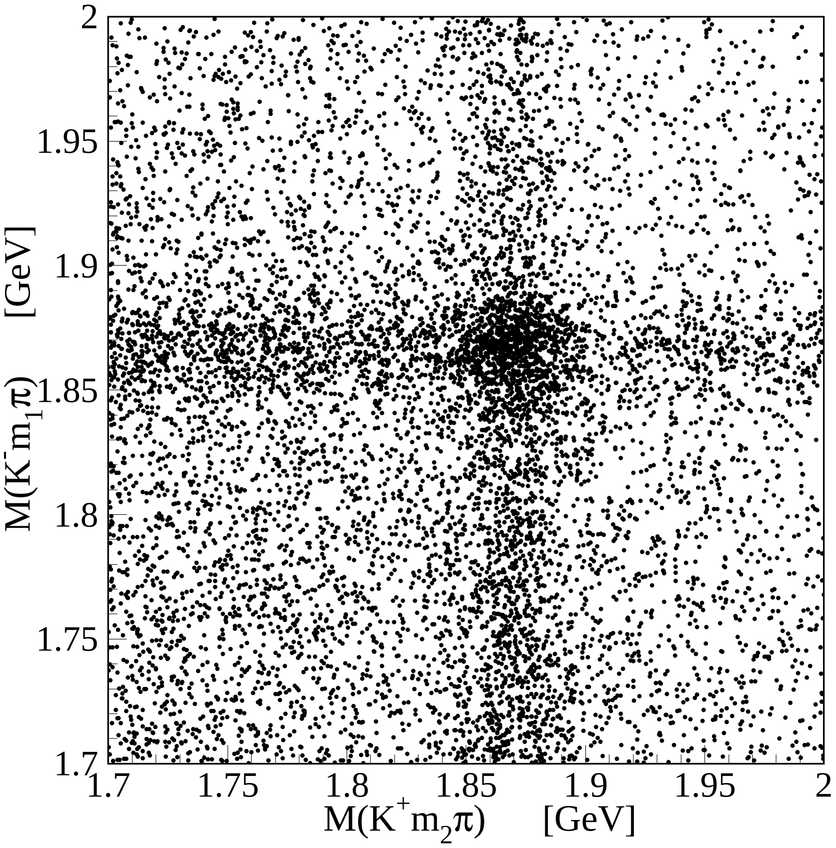

E791 Hyperon Asymmetry Data
PRELIMINARY
Statistical errors only
$A = \frac{N_X - N_{\overline{X}}}{N_X + N_{\overline{X}}}$
Λ^0 (uds)
Ξ^- (dss)
Ω^- (sss)
Asymmetry Parameter – A
x_F
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.075
-0.05
-0.025
0.025
0.05
0.075


E791 Hyperon Asymmetry Data
PRELIMINARY
Statistical errors only
$A = \frac{N_X - N_{\overline{X}}}{N_X + N_{\overline{X}}}$
Λ^0 (uds)
Ξ^- (dss)
Ω^- (sss)
Asymmetry Parameter – A
0.5
0.4
0.3
0.2
0.1
0
-0.1
0
0.5
1
1.5
2
2.5
3
3.5
4
p_T^2
$(\mathrm{GeV/c})^2$

B. Charm-pair correlations

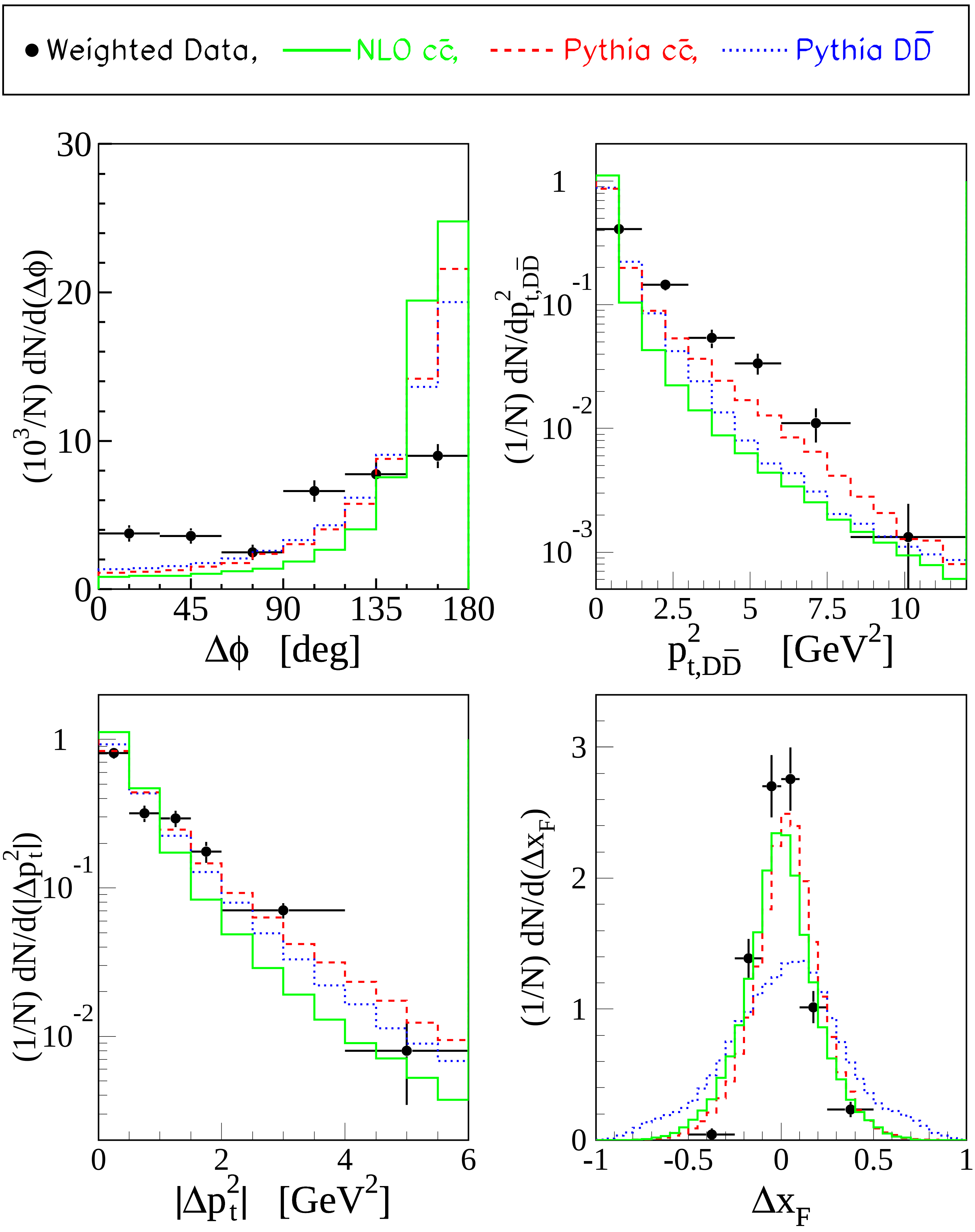
- E791 charm-pair analysis fully reconstructs 791±44 D meson pairs to investigate correlations between the pairs.
- Transverse correlations (*e.g.* $\Delta\phi$, $\Delta p_t^2 \equiv |p_{t,D}^2 - p_{t,\overline{D}}^2|$, and $p_{t,D\overline{D}}^2 \equiv |\vec{p}_{t,D} + \vec{p}_{t,\overline{D}}|^2$) are sensitive to the c quark production.
- Longitudinal correlations, such as Δx_F, are sensitive to hadronization.
- Recent paper (hep-ex/9809029) has full details.

Expt	Energy	Beam	Target	Number of Pairs			
E791	500 GeV	π^-	Pt, C	791	fully		
NA27	360 GeV	π^-	H_2	12	fully	53	partially
WA92	350 GeV	π^-	Cu			475	partially
WA75	350 GeV	π^-	emulsion			177	partially
NA32	230 GeV	π^-	Cu	20	fully	642	partially
E653	800 GeV	p	emulsion			35	partially
NA27	400 GeV	p	H_2	17	fully	107	partially
E687	200 GeV	γ	Be	325	fully	4534	partially
NA14	100 GeV	γ	Si	22	fully		



E791 charm-pair data.

Unbinned maximum likelihood fit to the E791 charm-pair data.



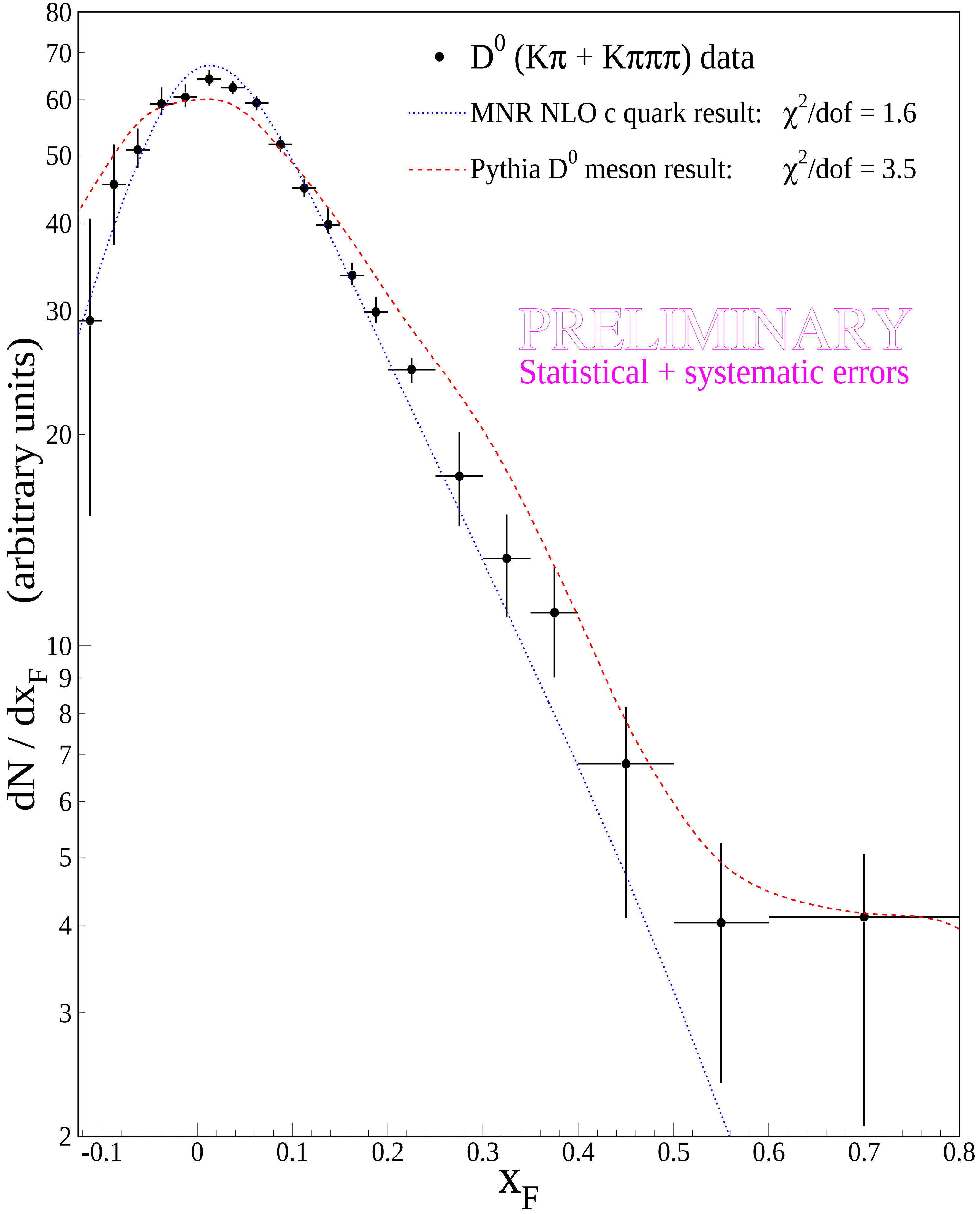
Weighted Data,
NLO $c\bar{c}$,
Pythia $c\bar{c}$,
Pythia $D\bar{D}$
$(10^3/N)$ dN/d($\Delta\phi$)
$\Delta\phi$ [deg]
(1/N) dN/d$p^2_{t,D\bar{D}}$
$p^2_{t,D\bar{D}}$ [GeV^2]
(1/N) dN/d($|\Delta p_t^2|$)
$|\Delta p_t^2|$ [GeV^2]
(1/N) dN/d(Δx_F)
Δx_F

C. Differential Cross sections

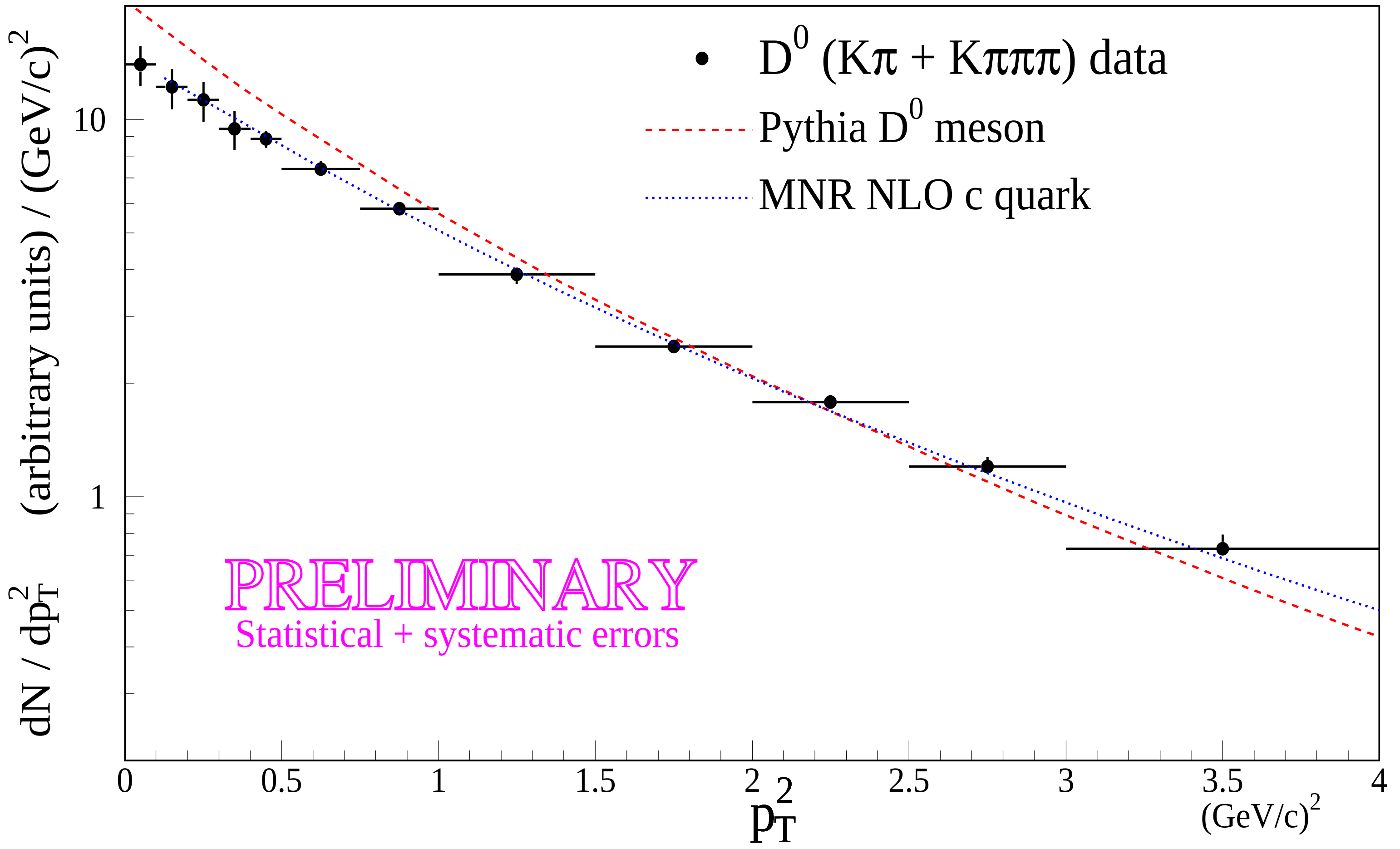
- Shapes of the x_F and p_T^2 distributions are sensitive to c quark production and hadronization.

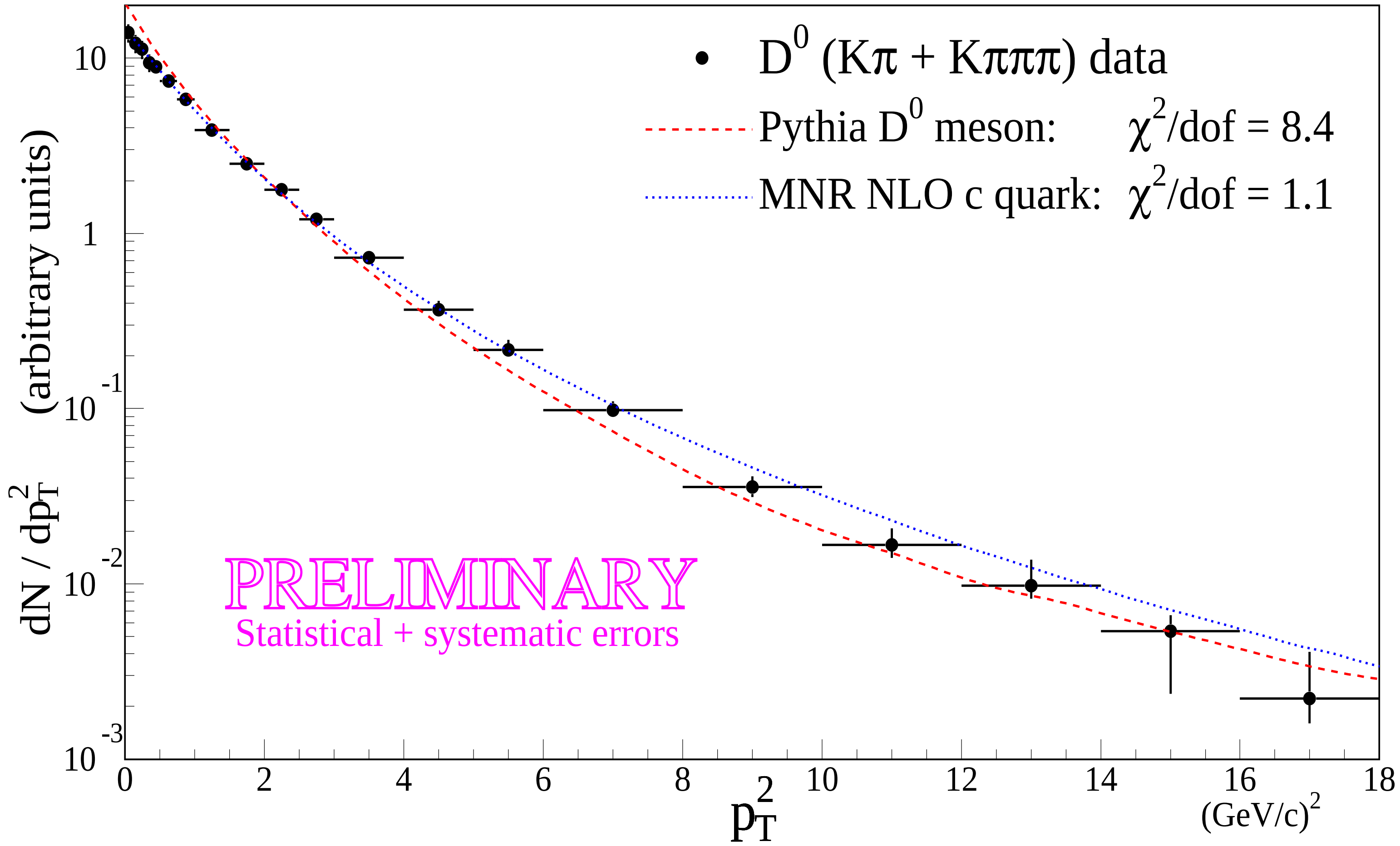
- The total cross section is insensitive to hadronization but suffers from large theoretical errors.

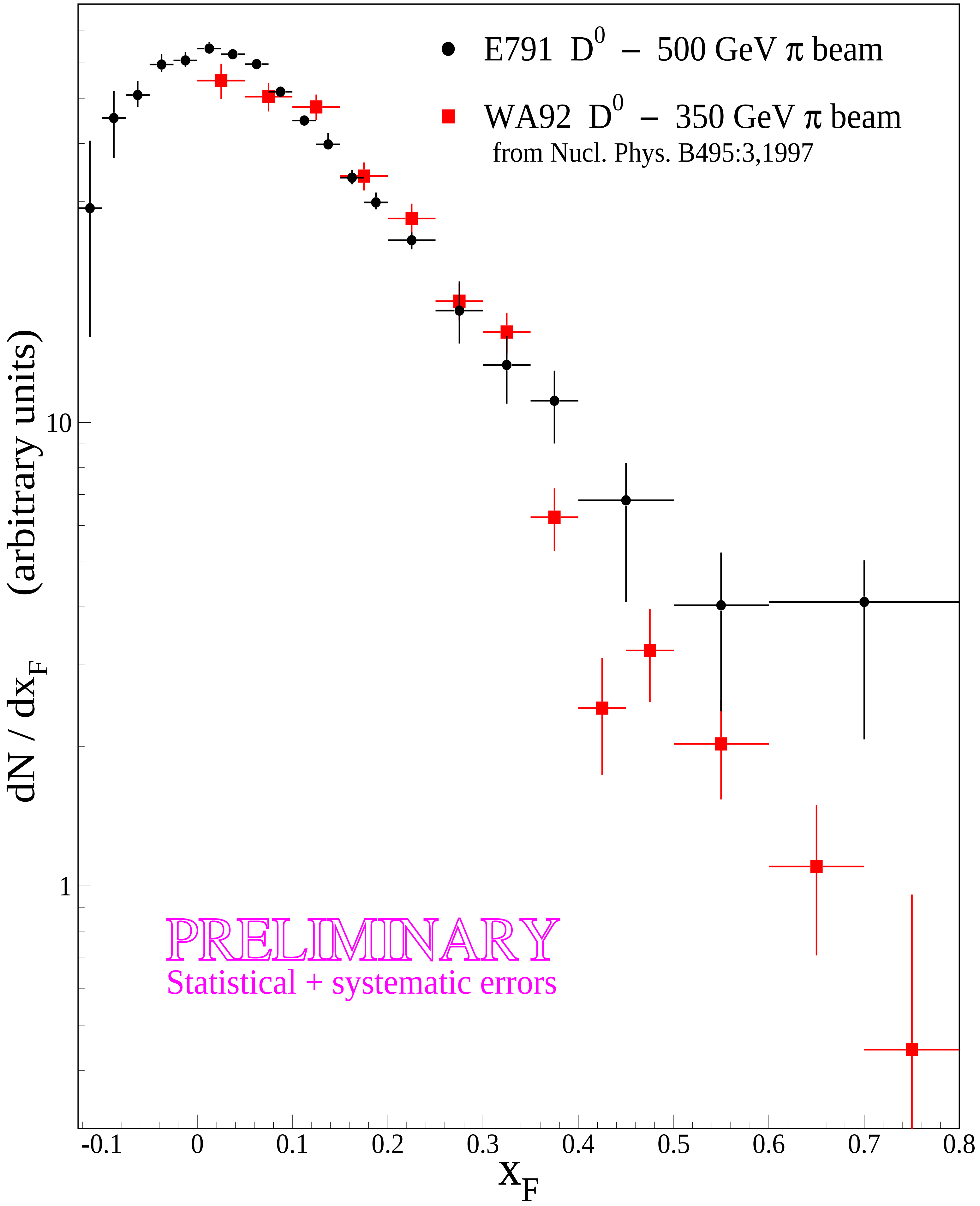
- Preliminary results for x_F and p_T^2 distributions from $\sim$100,000 D^0 ($K\pi$ & $K\pi\pi\pi$) events.
  - High statistics show x_F turnover point clearly.
  - p_T^2 data out to 18 (GeV/c)^2.
  - Default NLO QCD c quark prediction agrees with data. Implies cancelation of non-perturbative effects.
  - Default PYTHIA predicts too much dragging.
  - Qualitative agreement with recent 350 GeV WA92 data.
  - Differential and total cross sections are forthcoming.



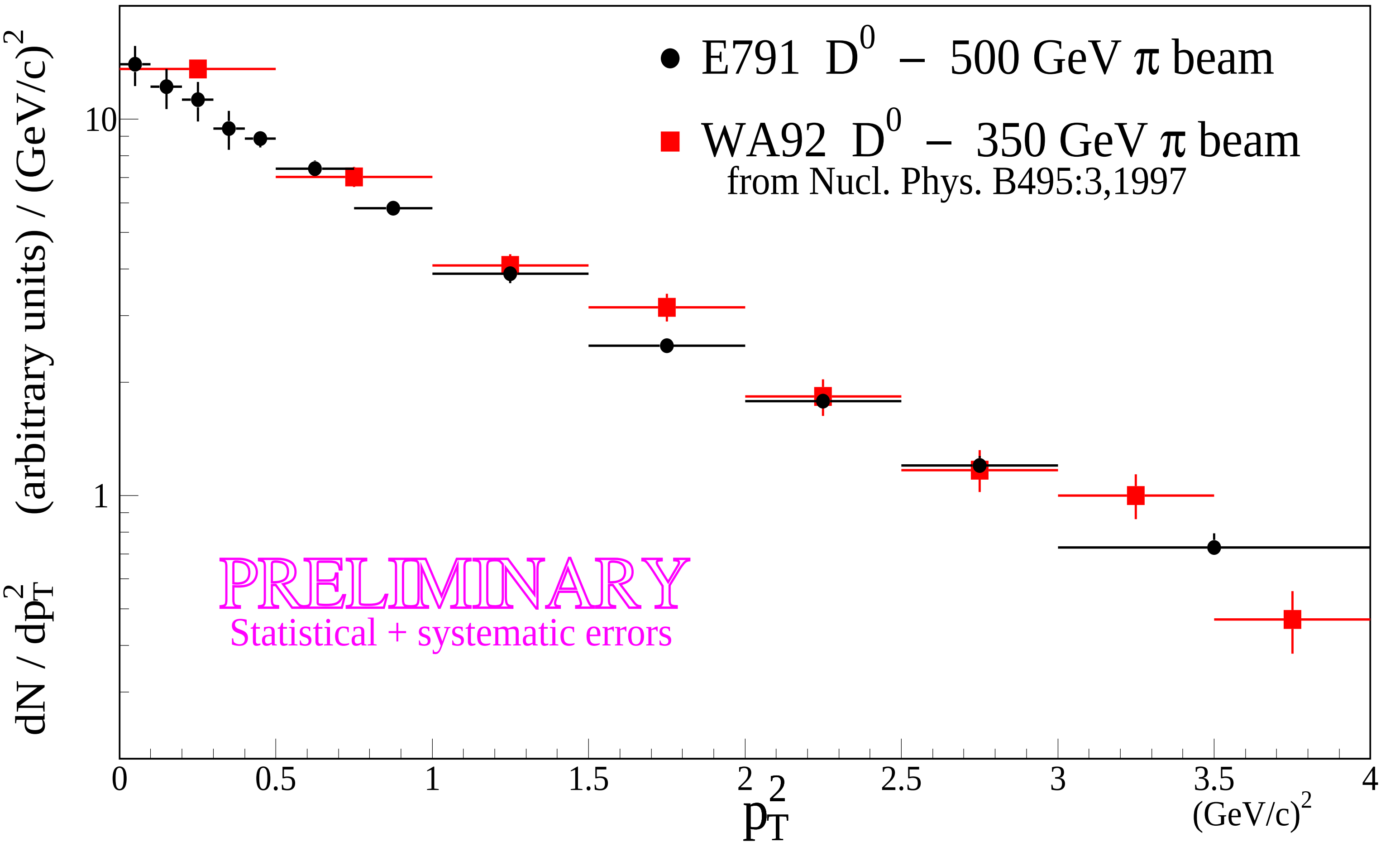
D^0 (Kπ + Kπππ) data
MNR NLO c quark result: χ^2/dof = 1.6
Pythia D^0 meson result: χ^2/dof = 3.5
PRELIMINARY
Statistical + systematic errors
dN / dx$_F$ (arbitrary units)
x$_F$
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8

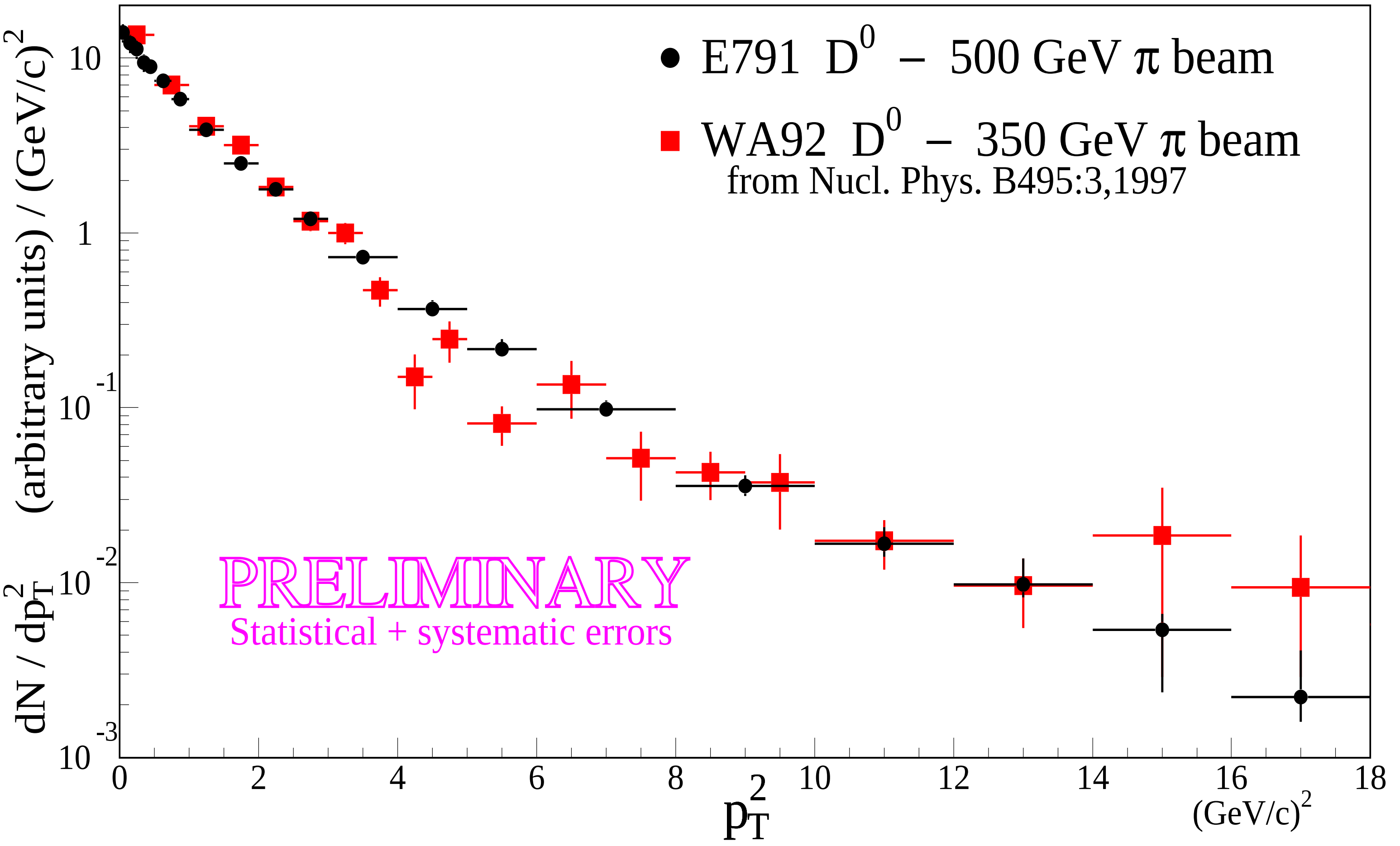

D0 (Kπ + Kπππ) data
Pythia D0 meson
MNR NLO c quark
PRELIMINARY
Statistical + systematic errors
dN / dpT2 (arbitrary units) / (GeV/c)2
pT2
(GeV/c)2
0
0.5
1
1.5
2
2.5
3
3.5
4
1
10


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 (arbitrary units)
pT2
(GeV/c)2
0
2
4
6
8
10
12
14
16
18
10-3
10-2
10-1
1
10



E791 D^0 – 500 GeV π beam
WA92 D^0 – 350 GeV π beam
from Nucl. Phys. B495:3,1997
PRELIMINARY
Statistical + systematic errors
dN / dx$_F$ (arbitrary units)
x$_F$
10
1
-0.1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8


E791 D^0 – 500 GeV π beam
WA92 D^0 – 350 GeV π beam
from Nucl. Phys. B495:3,1997
PRELIMINARY
Statistical + systematic errors
dN / dp$_T^2$ (arbitrary units) / (GeV/c)^2
p_T^2
(GeV/c)^2


E791 D^0 – 500 GeV π beam
WA92 D^0 – 350 GeV π beam
from Nucl. Phys. B495:3,1997
PRELIMINARY
Statistical + systematic errors
dN / dp$_T^2$ (arbitrary units) / (GeV/c)^2
p_T^2
(GeV/c)^2

IV. Conclusions

- E791 has provided, and will continue to provide, many results on charm hadroproduction.
- Large theoretical uncertainties imply no single result, or even single experiment, can uniquely determine the physics of charm production.
- Synthesizing all the E791 results and results from other experiments might provide a coherent picture.

These talk transparencies and referenced papers can be found at
http://fnphyx-www.fnal.gov/experiments/e791/welcome.html