Charm –
Recent Experimental Highlights

Reunion DPyC
July 2, 1999
Jürgen Engelfried, Instituto de Física
Universidad Autónoma de San Luis Potosí

Outline

- Physics Overview
- The “typical” experiment
- Production
- Spectroscopy
- Decays
- Conclusions

Selection is biased (but not totally...)
towards Fixed Target and Baryons.

(Preliminary) Results from:
CLEO, E687, E791, FOCUS, SELEX, WA89

E690: See talk by Marco Reyes

Charm

Production:

– Mass: 1.5 GeV/c^2 (or not?)

– Non-Pertubative QCD

– Intrinsic charm?

Spectroscopy:

– QCD Potential Models

Decays:

– CKM Matrix Elements: Unitary? New Physics?

– Wavefuncions of quarks

– Test of HQET

Important to know by their own rights
But also needed as input (B, Kaons)

Experimental Setup

To do a good job on charm, you need:

– High Statistic
(charm cross section small)

– Good Trigger or Software Filter
($\sigma_c \approx 10^{-3}\sigma_{tot}$)

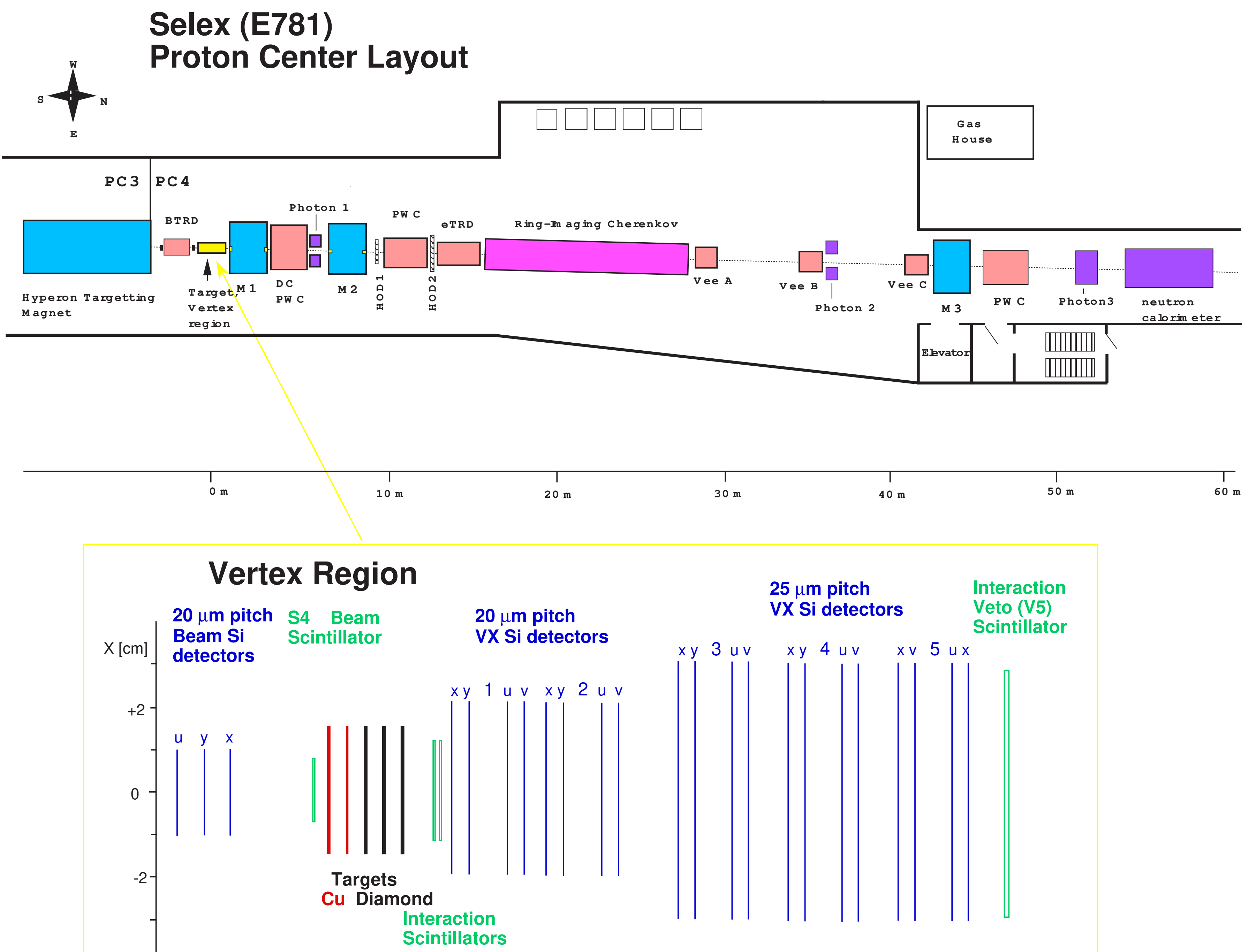
– Extremely good Silicon Detectors
(sec. vertex, lifetime)

– Extremely good Particle Identification
(proton, kaon)

Or even better: All of the above!

Fermilab View 1

Fermilab View 2



Selex (E781)
Proton Center Layout
W
S
N
E
Gas
House
PC3
PC4
BTRD
Photon 1
PW C
eTRD
Ring-Imaging Cherenkov
Hyperon Targetting
Magnet
Target,
Vertex
region
M1
DC
PW C
M2
HOD1
HOD2
Vee A
Vee B
Photon 2
Vee C
M3
PW C
Photon3
neutron
calorimeter
Elevator
0 m
10 m
20 m
30 m
40 m
50 m
60 m
Vertex Region
X [cm]
+2
0
-2
20 µm pitch
Beam Si
detectors
u y x
S4 Beam
Scintillator
Targets
Cu Diamond
Interaction
Scintillators
20 µm pitch
VX Si detectors
x y 1 u v x y 2 u v
25 µm pitch
VX Si detectors
x y 3 u v
x y 4 u v
x v 5 u x
Interaction
Veto (V5)
Scintillator

SELEX Apparatus

3 segment forward spectrometer ($x_F > 0.1$)

- 74000 strip silicon system, $4\mu m$ transverse position resolution at 600 GeV
- Beam tagging ($\Sigma^-/\pi^-, p/\pi^+$) with Beam TRD
- 3000 phototube RICH - K/π separation up to 165 GeV
- Secondary e^- with Electron TRD for semileptonic decays
- Precise downstream tracking
  - 18 large silicon planes ($\sigma \sim 8\mu m$)
  - 26 PWC planes ($\sigma \sim 0.6 - 1mm$)
  - 3×24 Vector Drift chambers ($\sigma \sim 100\mu m$)
- 3 lead glass photon detectors

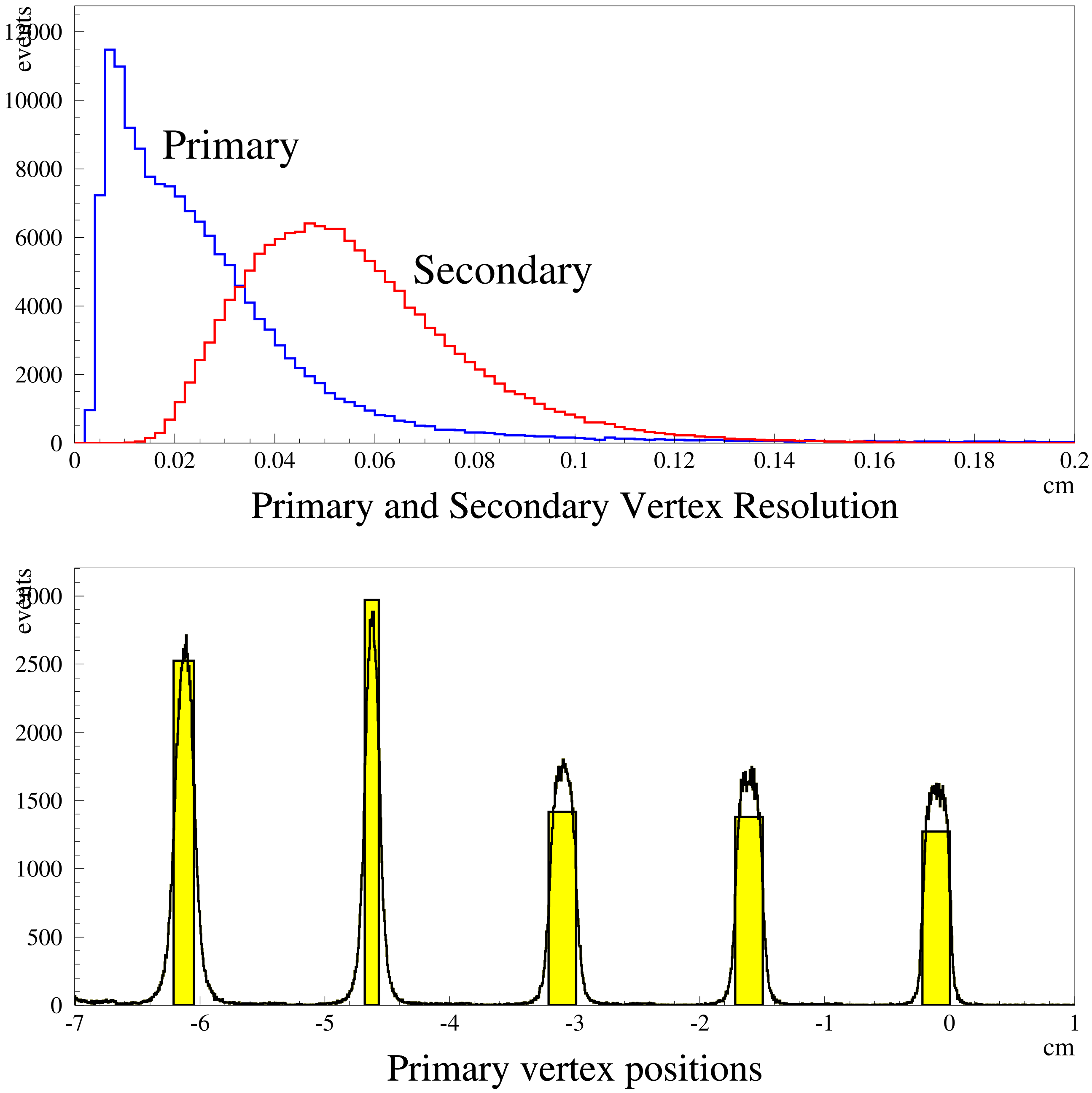
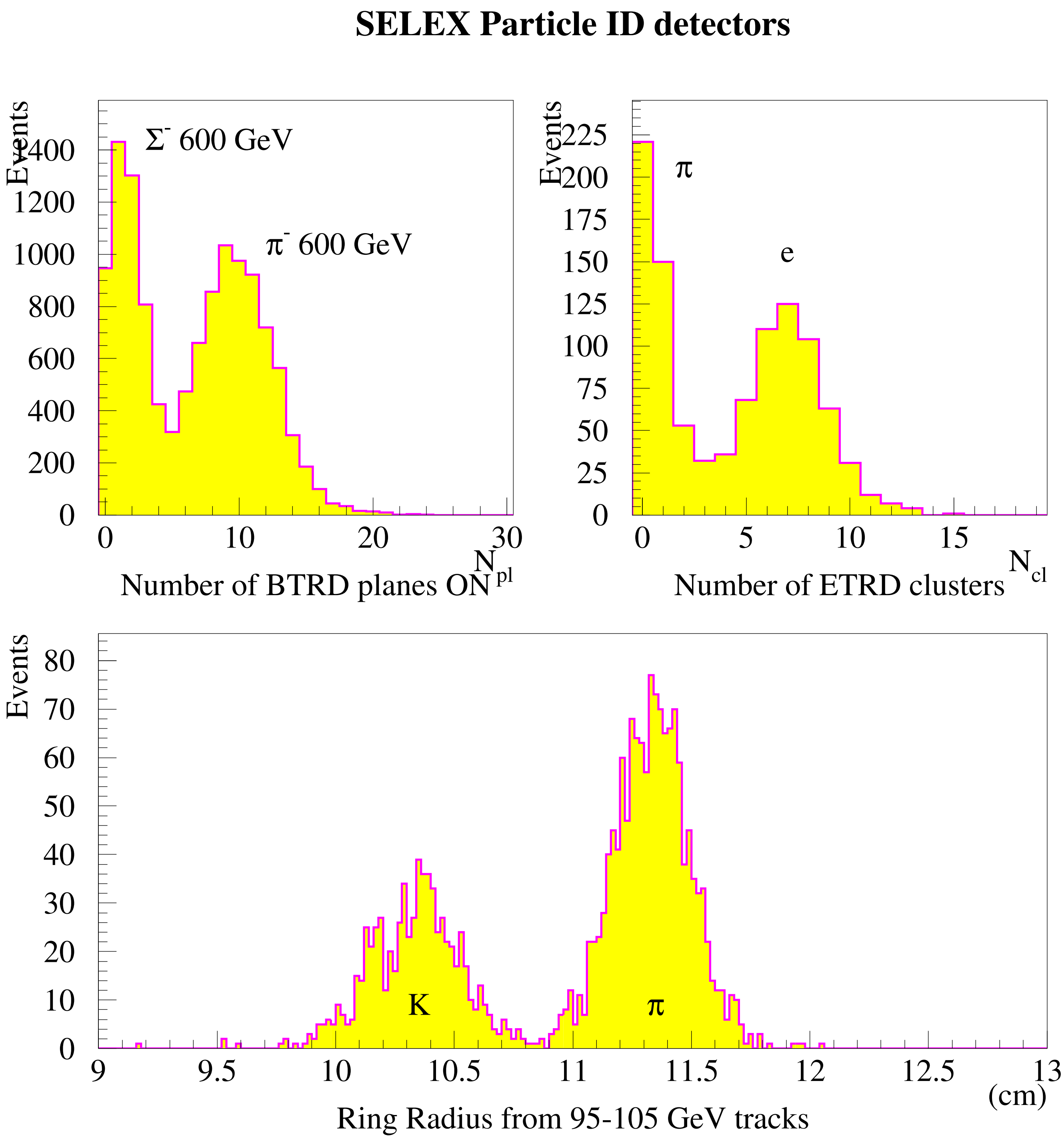


Fig. 3: Vertex resolution


SELEX Particle ID detectors
Events
Σ⁻ 600 GeV
π⁻ 600 GeV
Number of BTRD planes ON
N_pl
Events
π
e
Number of ETRD clusters
N_cl
Events
K
π
(cm)
Ring Radius from 95-105 GeV tracks

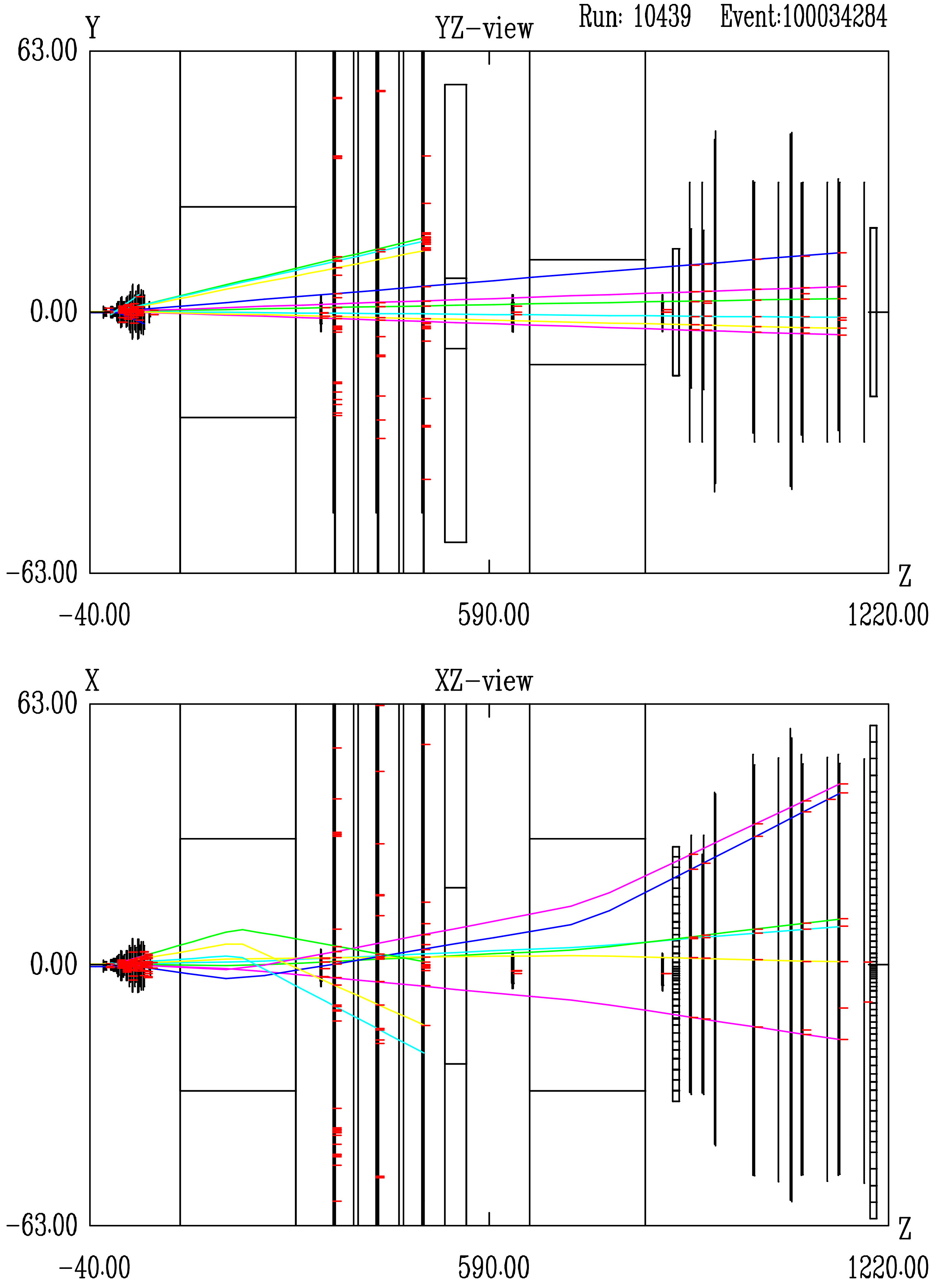
Online Filter

Filter is **Online Program** which select events that have evidence for a secondary vertex.

- Algorithm:
  - Start from downstream tracking to find high-momentum $(p > 20GeV)$ tracks in PWC chambers
  - extrapolate tracks back to vertex silicon within the roads predicted by downstream tracking
  - Reject events if tracks form just a primary vertex

- Charm efficiency about 50%, Rejection 8

- 4 times more charm per tape. 8 times faster to process.


Run: 10439
Event:100034284
YZ-view
Y
63.00
0.00
-63.00
-40.00
590.00
1220.00
Z
XZ-view
X
63.00
0.00
-63.00
-40.00
590.00
1220.00
Z

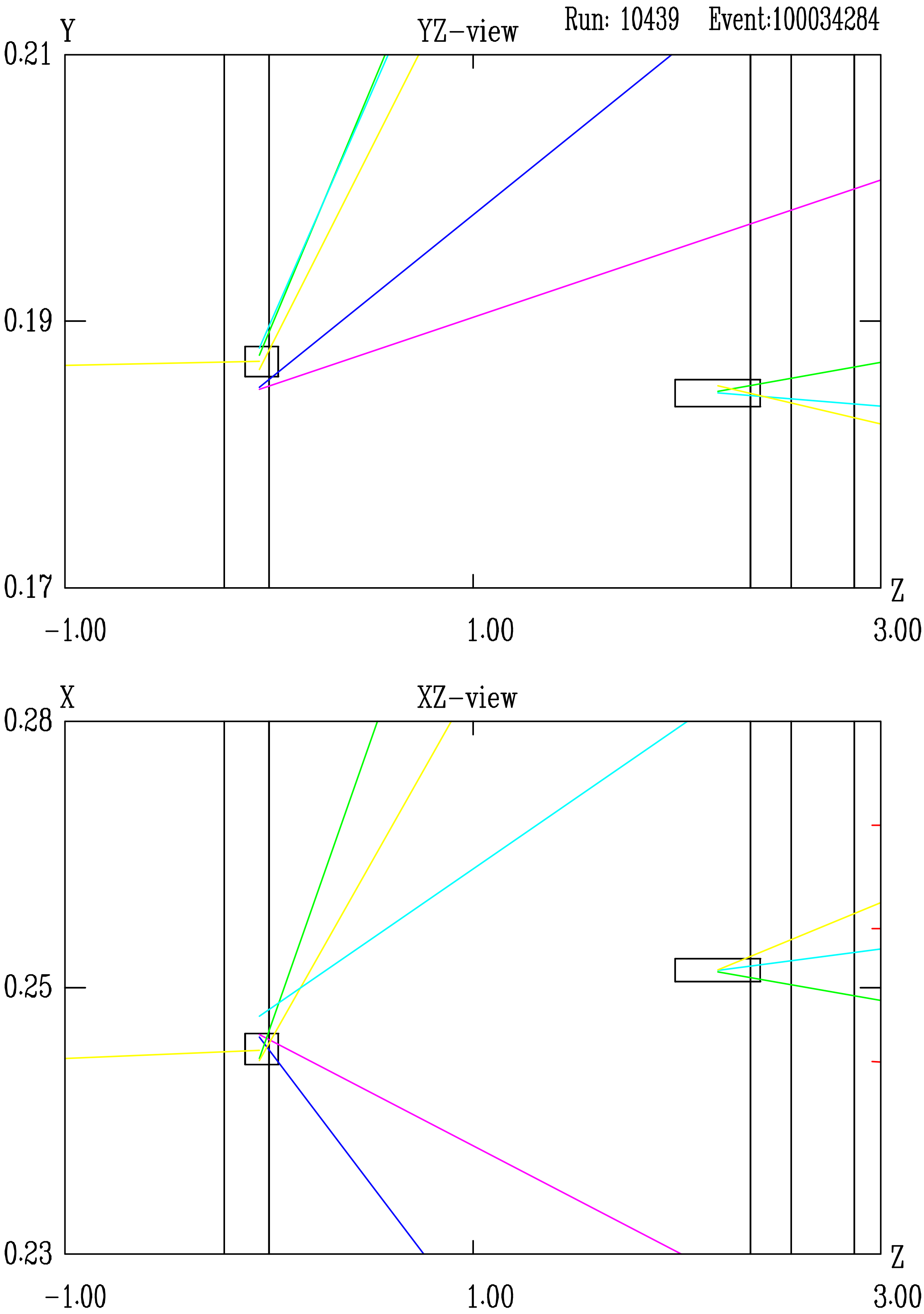
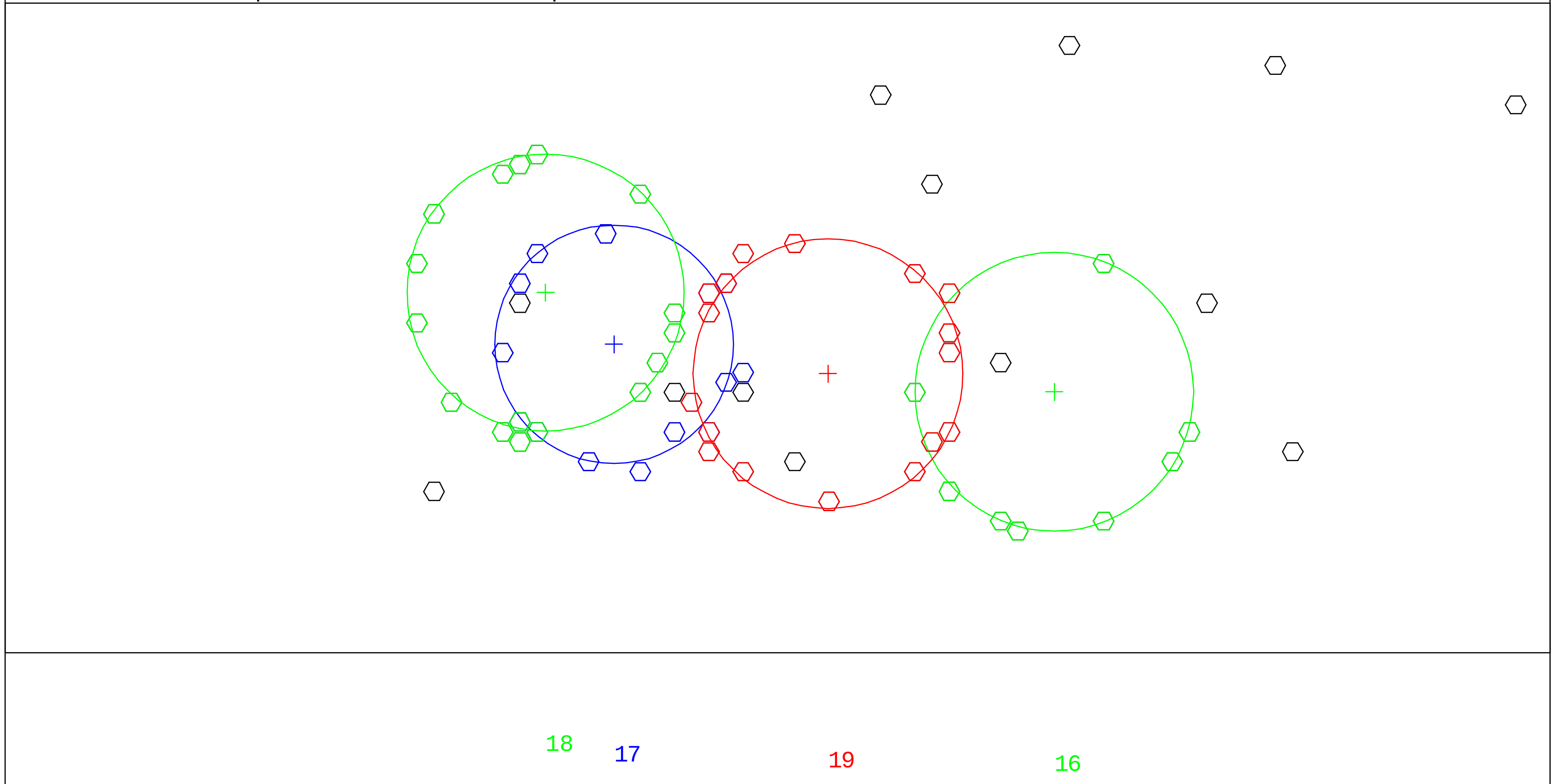


Fig. 8: $\Lambda_c^+ \to pK^-\pi^+$ event - vertex view

Date: 98/10/08 22.59.43
Run: 10439 Spill: 41 Event_in_Spill: 17156 Event: 100034284 Tubes: 63



Tracks : 16 17 18 19
Momenta: -095 +154 +074 -153

Masses: Sigma Proton Kaon Pion Muon Electron Backgrnd

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

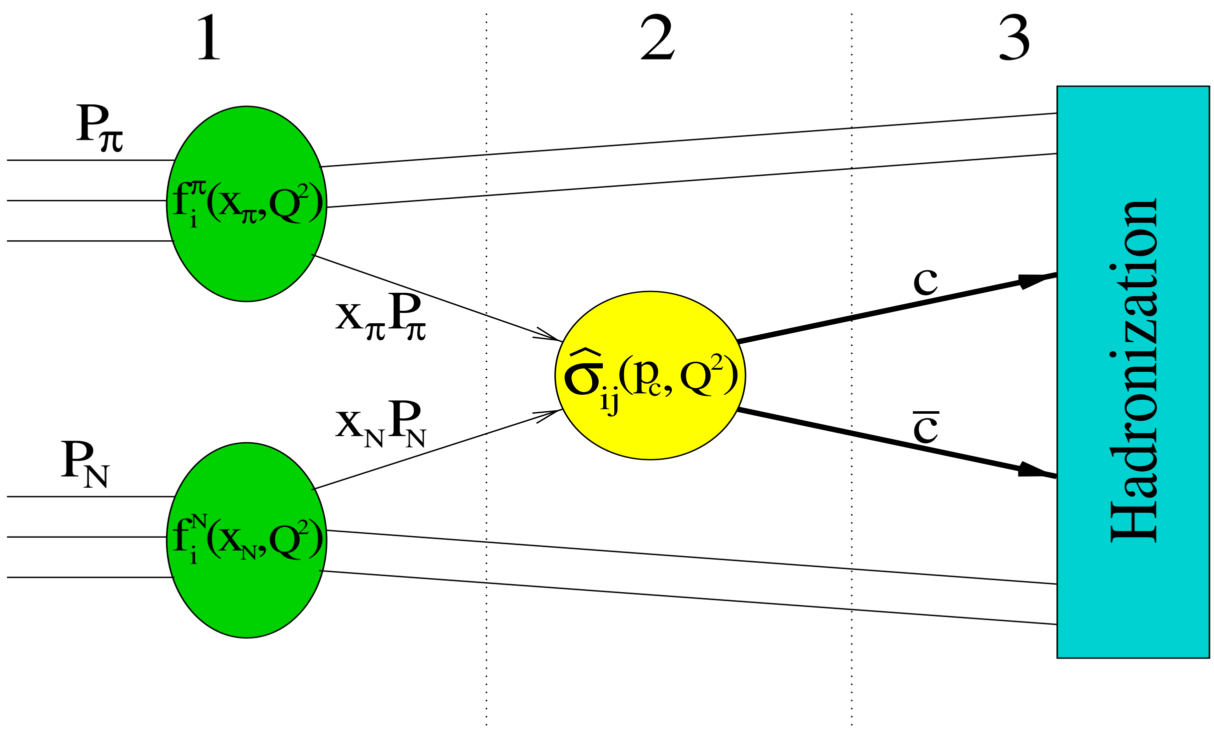
Calculable? by perturbative QCD — $\hat{\sigma}_{ij}(\mathrm{p_c}, Q^2)$.

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

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

Incalculable by perturbative QCD.

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



Asymmetries

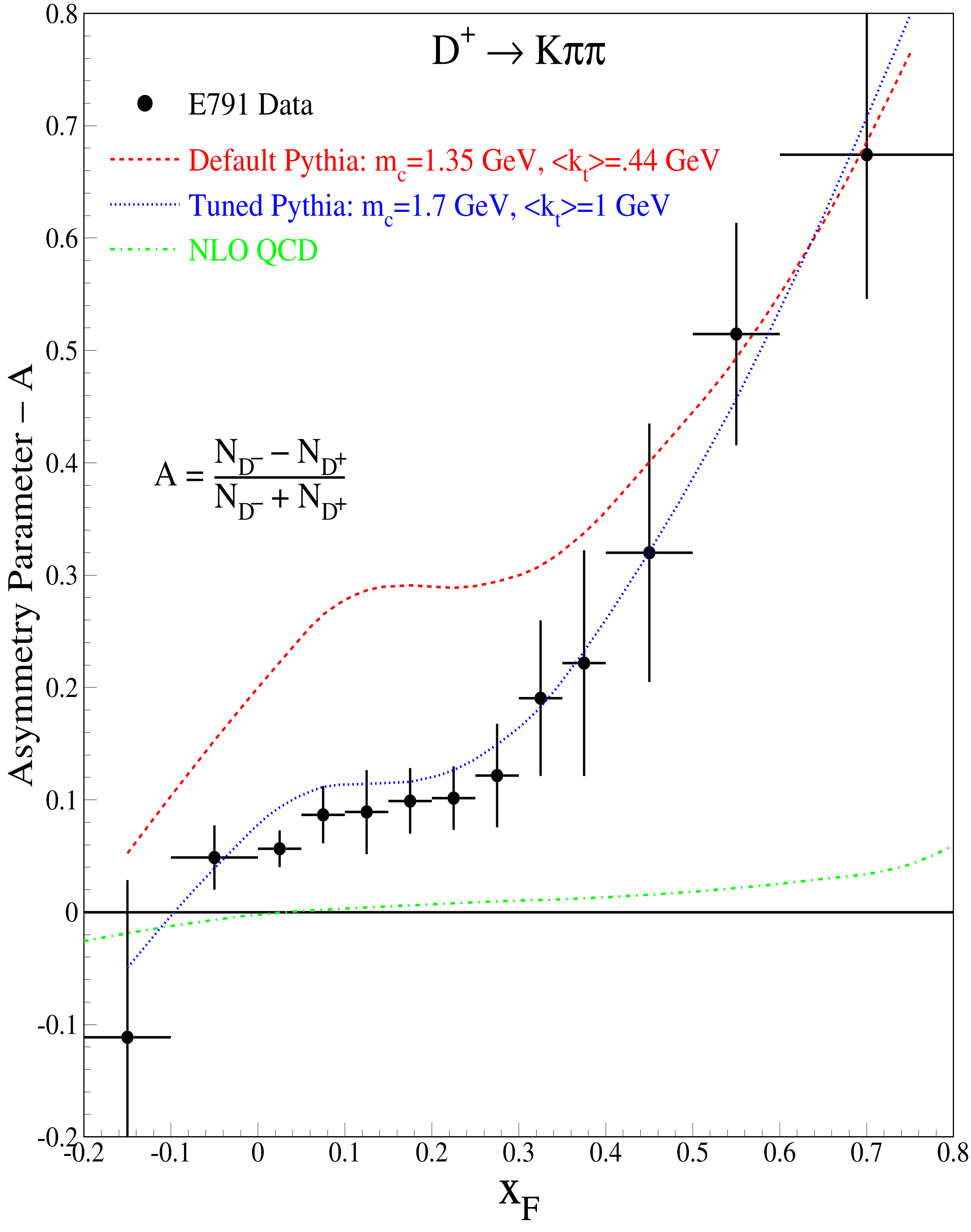
- Measure $A \equiv \frac{\sigma_X - \sigma_{\overline{X}}}{\sigma_X + \sigma_{\overline{X}}}$ vs p_T^2 and $x_F \equiv \frac{p_L^*}{p_{Lmax}^*}$.
- $A \approx 0$ in perturbative QCD.
- $\Longrightarrow$ asymmetry measurements reveal hadronization effects.
- Color string between c quarks and beam/target 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).

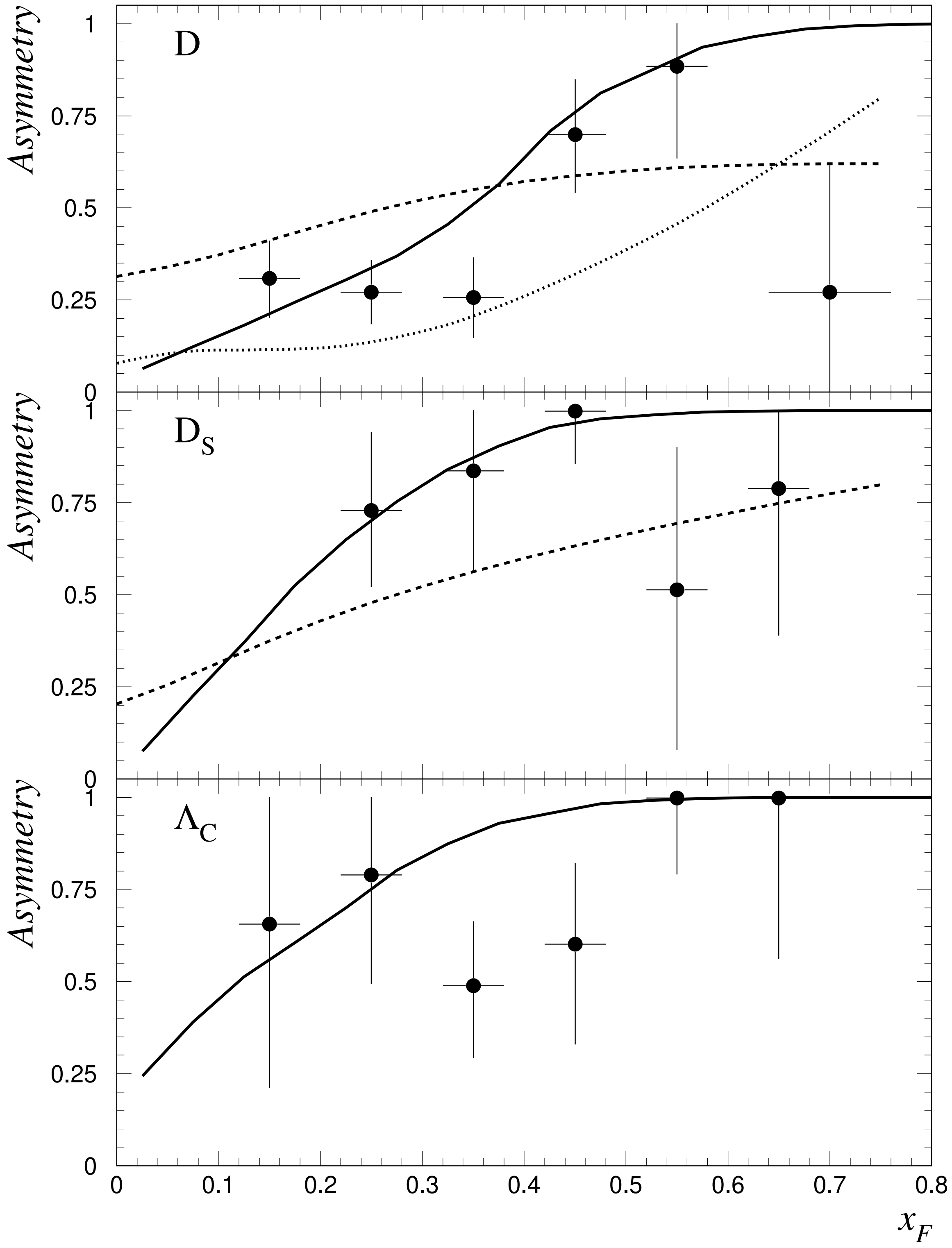
Projectile	Λ_c^+(cud)	Λ_c^-($\bar{c}\bar{u}\bar{d}$)	D^+($c\bar{d}$)	D^-($\bar{c}d$)
$\pi^-(\bar{u}d)$	d	$\bar{u}$	nonleading	d
$\Sigma^-(dds)$	d	nonleading	nonleading	d
$p(uud)$	ud	nonleading	nonleading	d

- 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



E791 Collaboration, Phys. Lett. B 371 (1996) 157

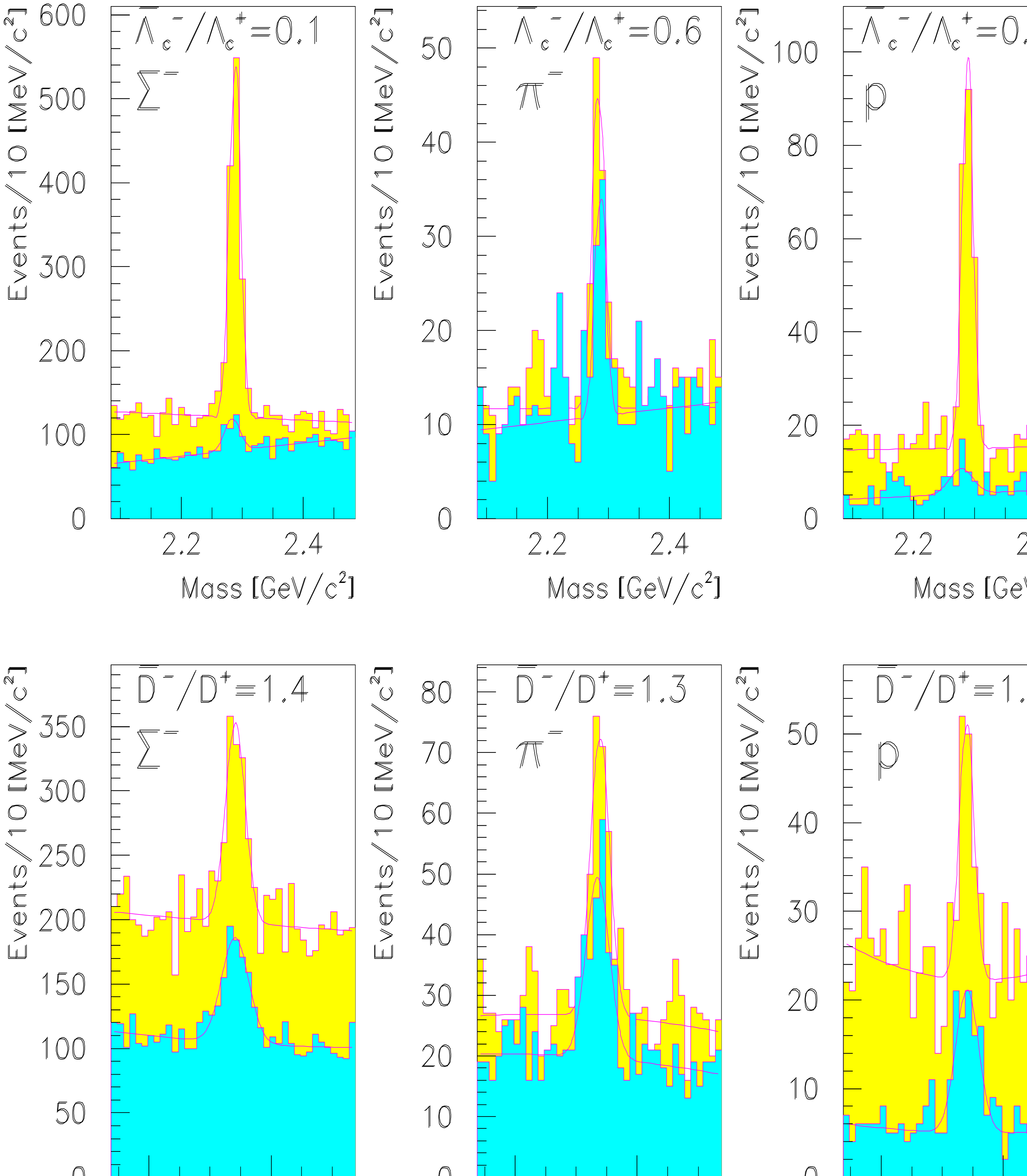
WA89: Σ^- Beam



WA89 Collaboration, Eur. Phys. J. C 8 (1999) 593

PRELIMINARY SELEX Production Comparison

Sample cuts: $x_F > 0.3$ and $L/\sigma > 8$

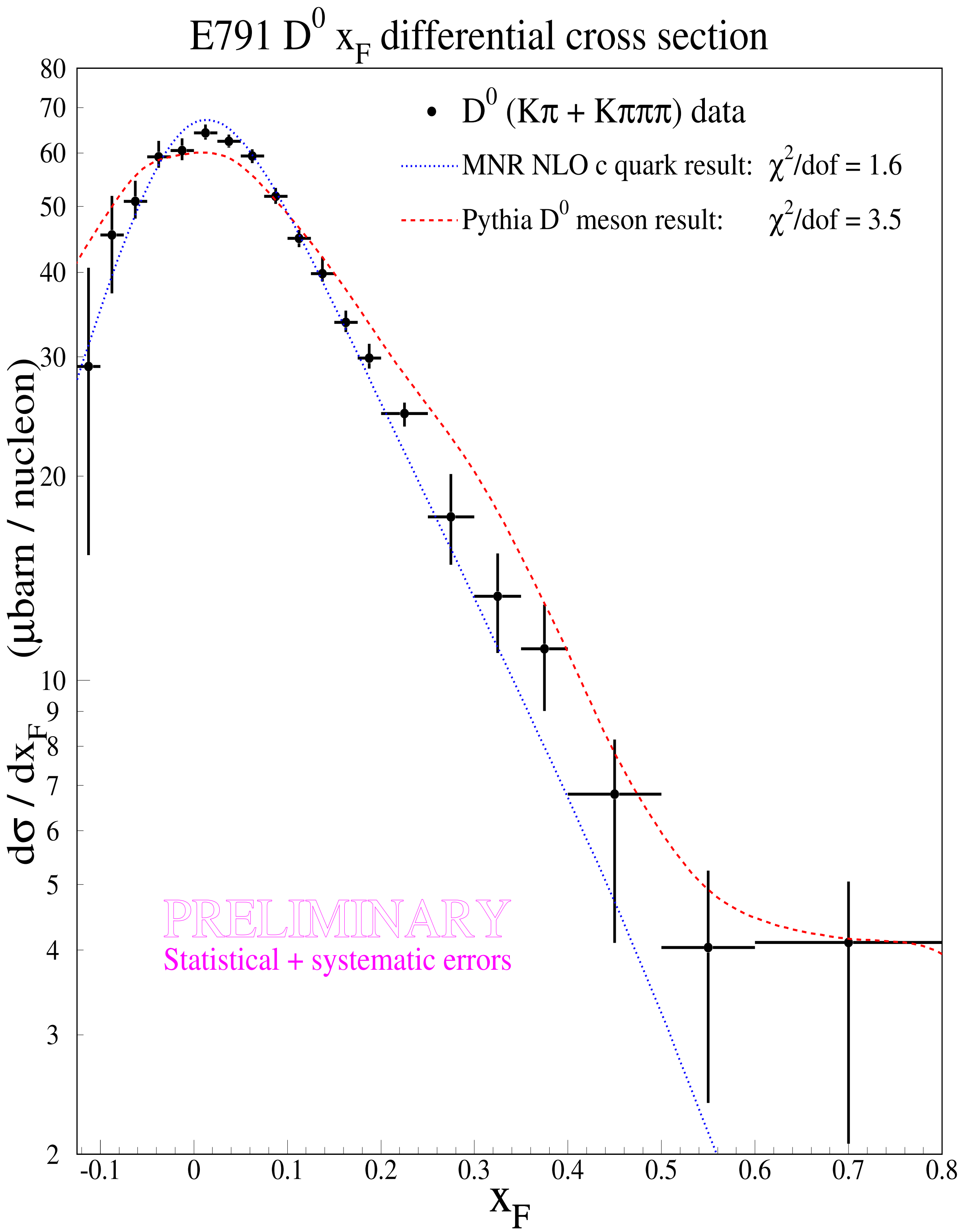


Differential Cross sections

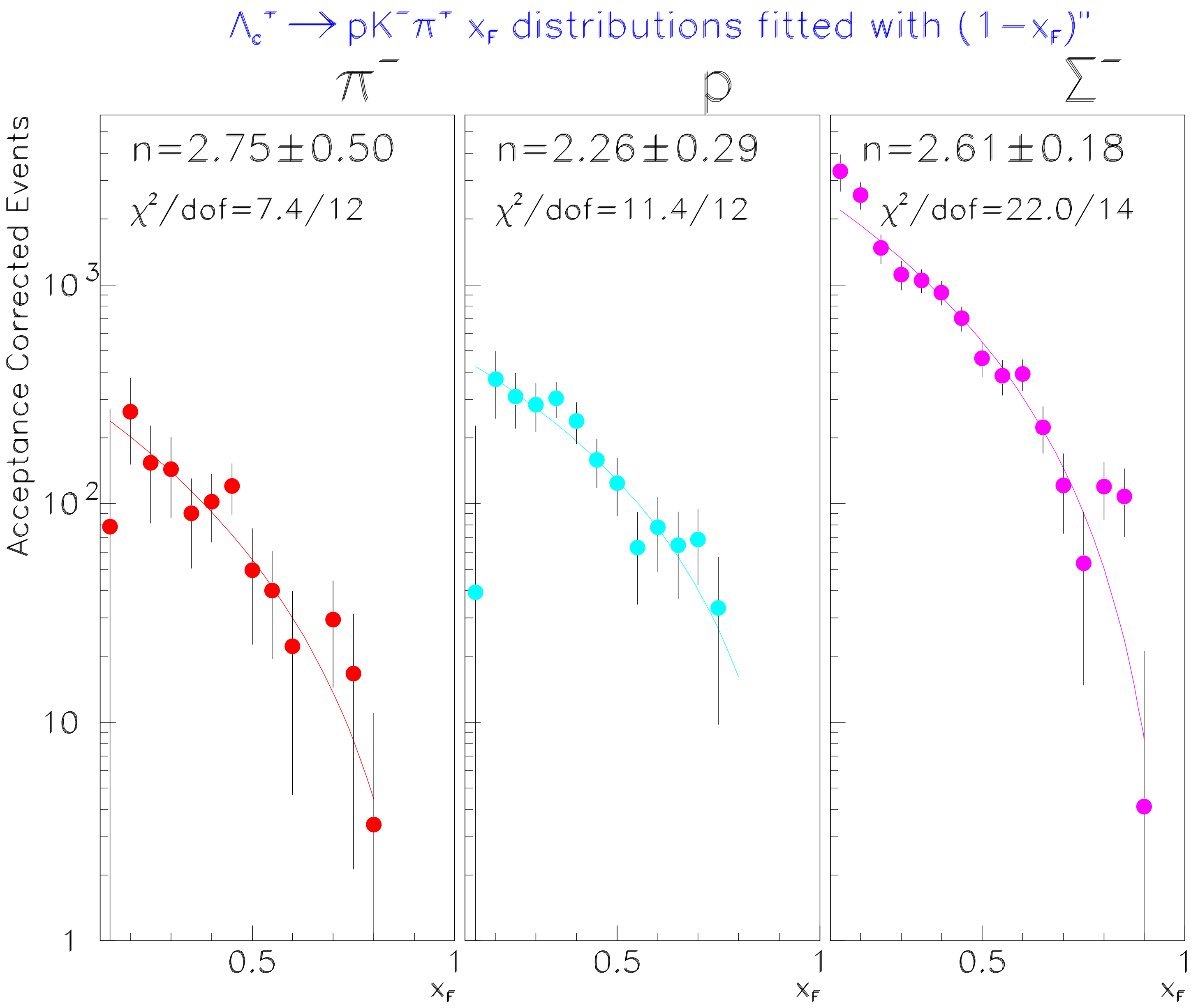
- x_F and p_T^2 distribution shapes are sensitive to c quark production and hadronization.

- 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 agrees with data. Implies cancelation of non-perturbative effects.
  - Default PYTHIA predicts too much dragging.

- 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 studies of D production.



E791 Collaboration, submitted to Phys. Lett. B, hep-ex/9906034

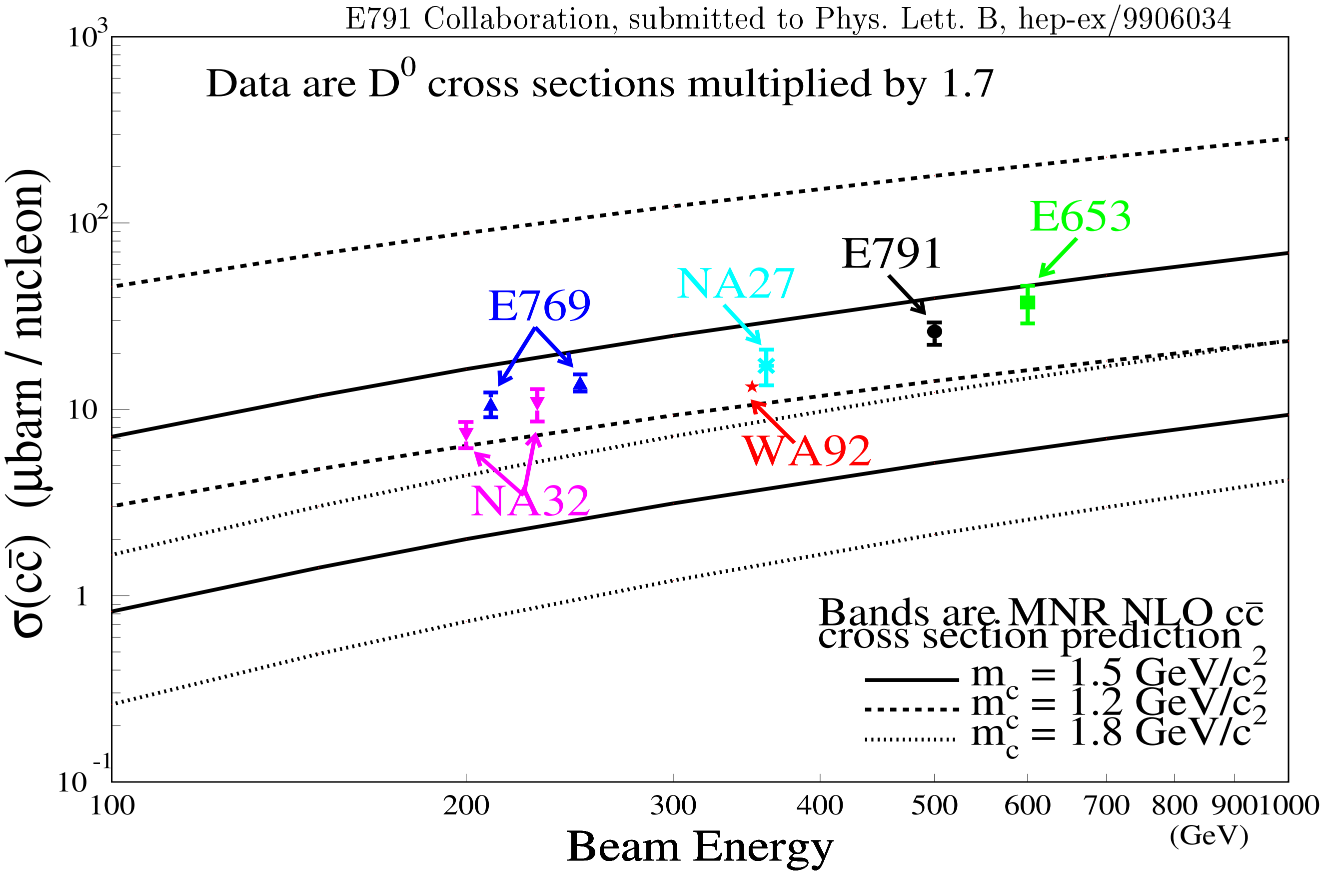


$\Lambda_c^+ \to pK^-\pi^+$ x_F distributions fitted with $(1-x_F)^n$
π^-
p
Σ^-
n=2.75±0.50
χ^2/dof=7.4/12
n=2.26±0.29
χ^2/dof=11.4/12
n=2.61±0.18
χ^2/dof=22.0/14
Acceptance Corrected Events
10^3
10^2
10
1
0.5
1
x_F

Total Cross sections

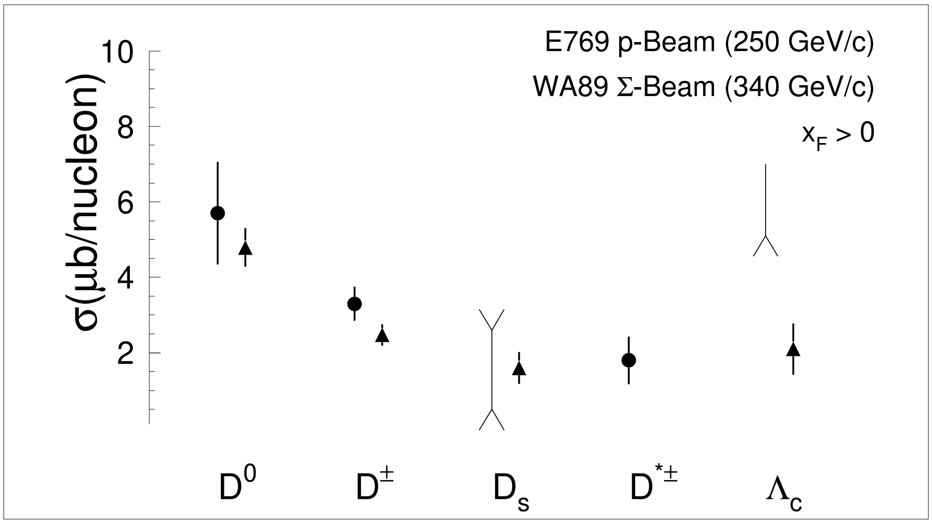
- E791 results from 79,000 D^0 ($K\pi$ & $K\pi\pi\pi$) events.
- Measure $\sigma(D^0 + \overline{D}^0\ ; x_F > 0)\ =\ 15.4\ ^{+1.8}_{-2.3}$ μbarns/nucleon for 500 GeV π^- beam on nuclear target (linear A dependence).
- Good agreement with previous D^0 results and theory.

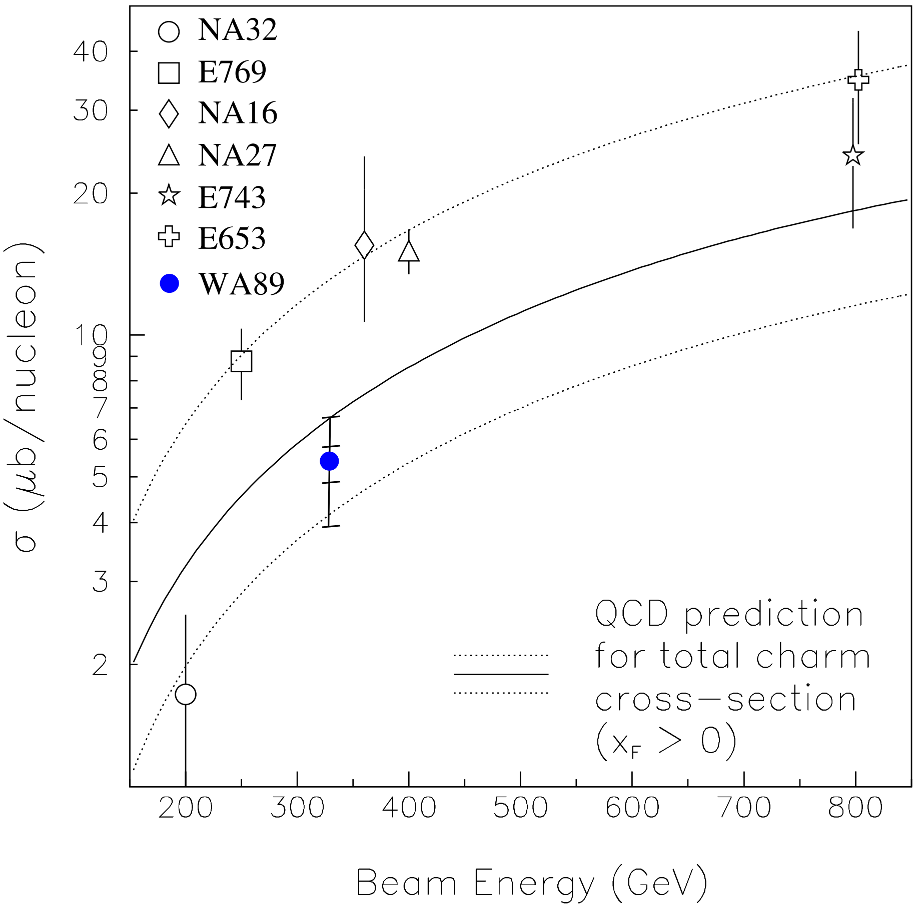
E791 Collaboration, submitted to Phys. Lett. B, hep-ex/9906034



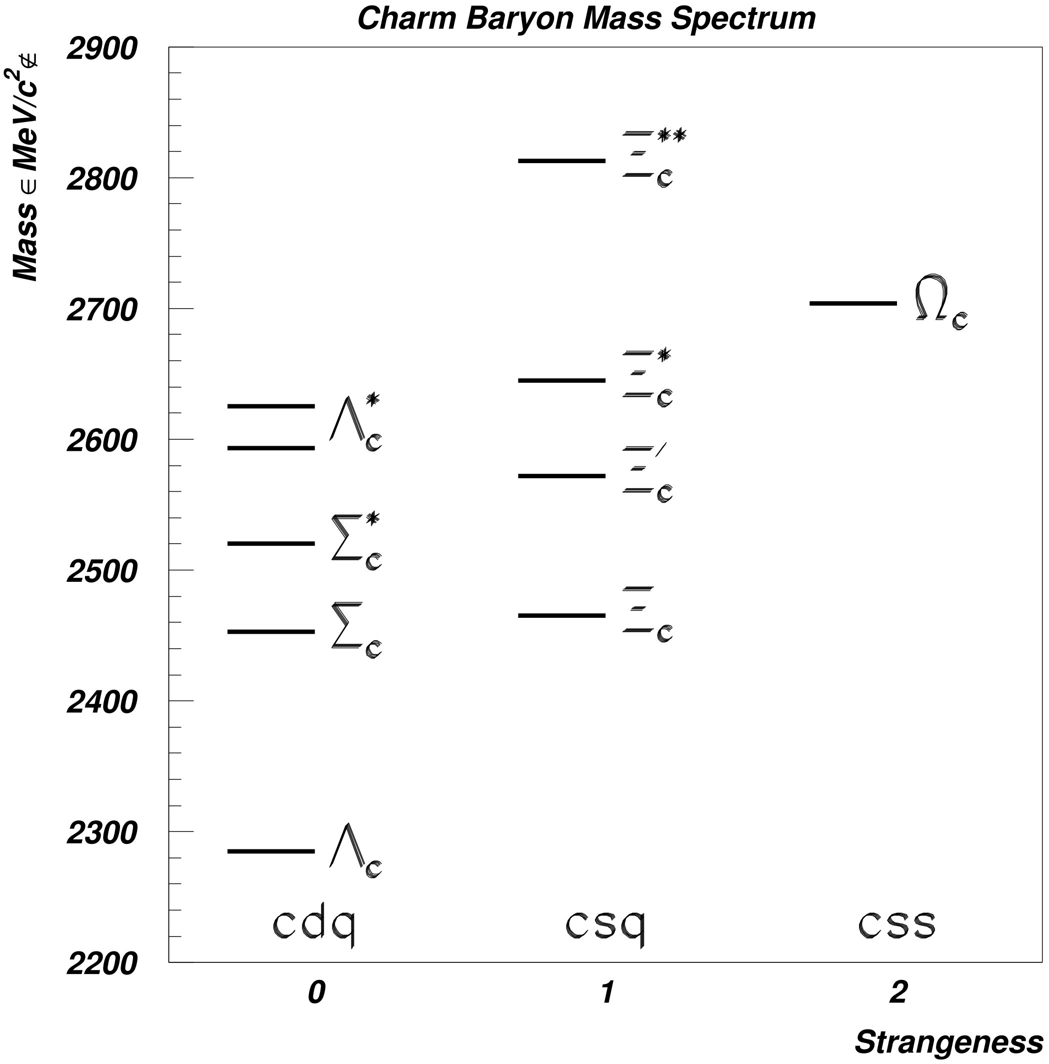
- FOCUS will be able to provide a high statistics measurement of both open and hidden charm cross sections.

- SELEX should provide interesting results on high x_F Λ_c and Ξ_c production (e.g. vs. beam type)


E769 p-Beam (250 GeV/c)
WA89 Σ-Beam (340 GeV/c)
$x_F > 0$
σ(μb/nucleon)
10
8
6
4
2
D^0
$D^\pm$
D_s
$D^{*\pm}$
Λ_c

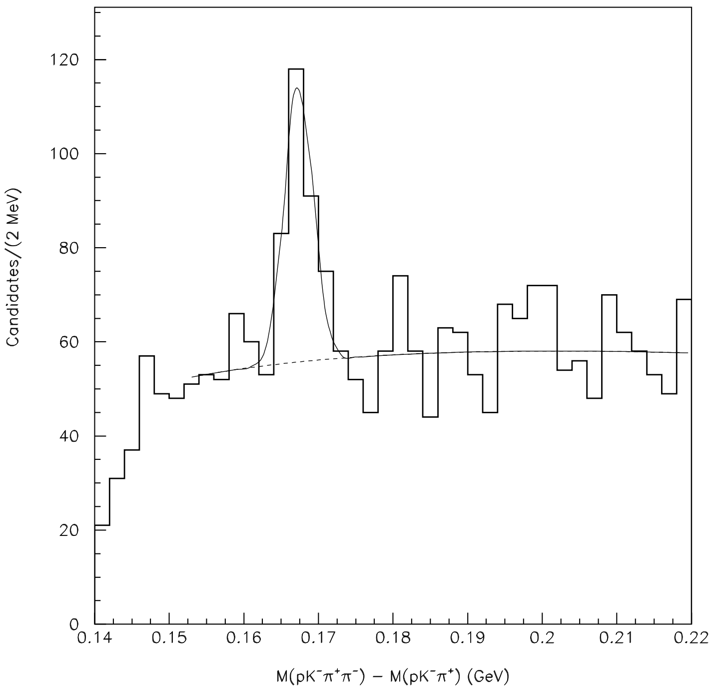

NA32
E769
NA16
NA27
E743
E653
WA89
σ (μb/nucleon)
Beam Energy (GeV)
QCD prediction
for total charm
cross−section
($x_F > 0$)

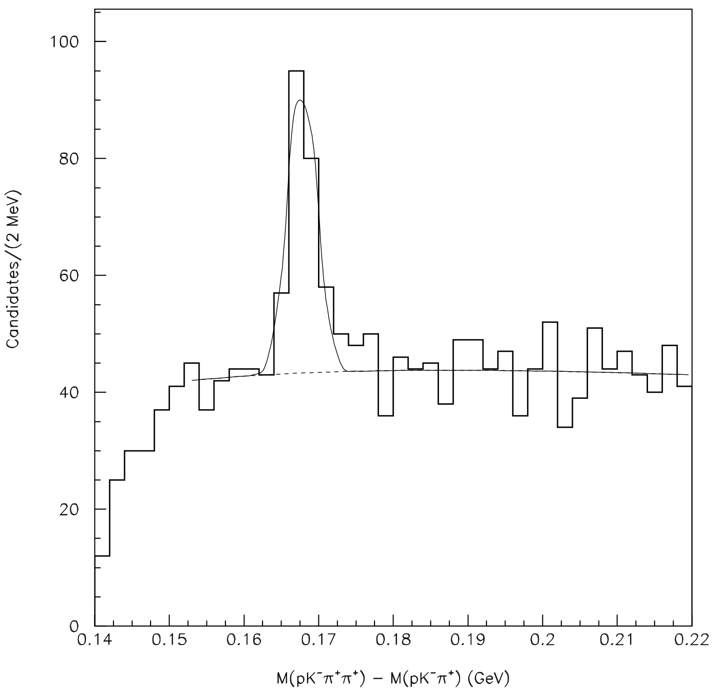
Spectroscopy



New: Ξ_c', Ξ_c^{**}, better Σ_c

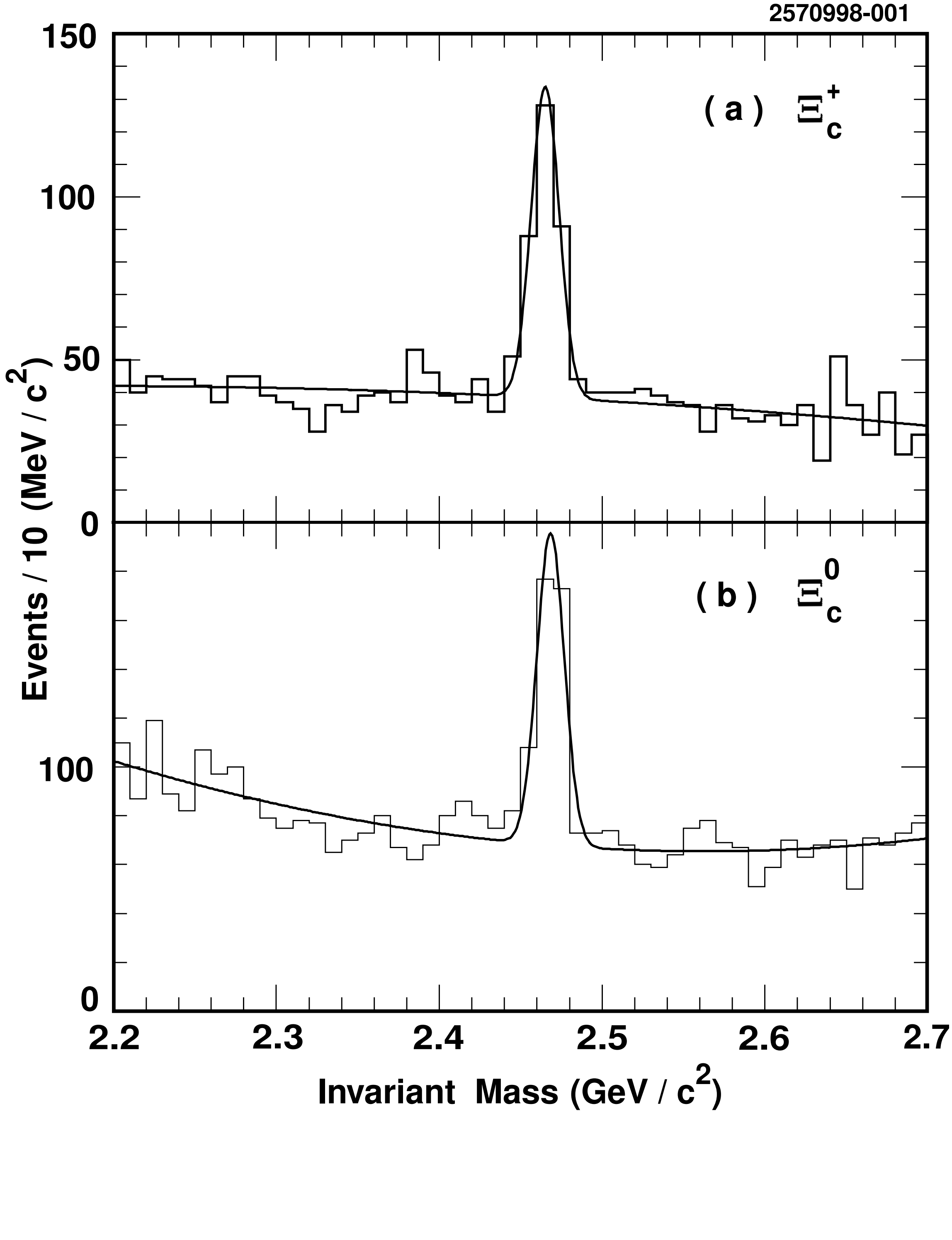
Usually measured: $\mathrm{Mass}(X+{}^{\pi}_{\gamma}) - \mathrm{Mass}(X)$



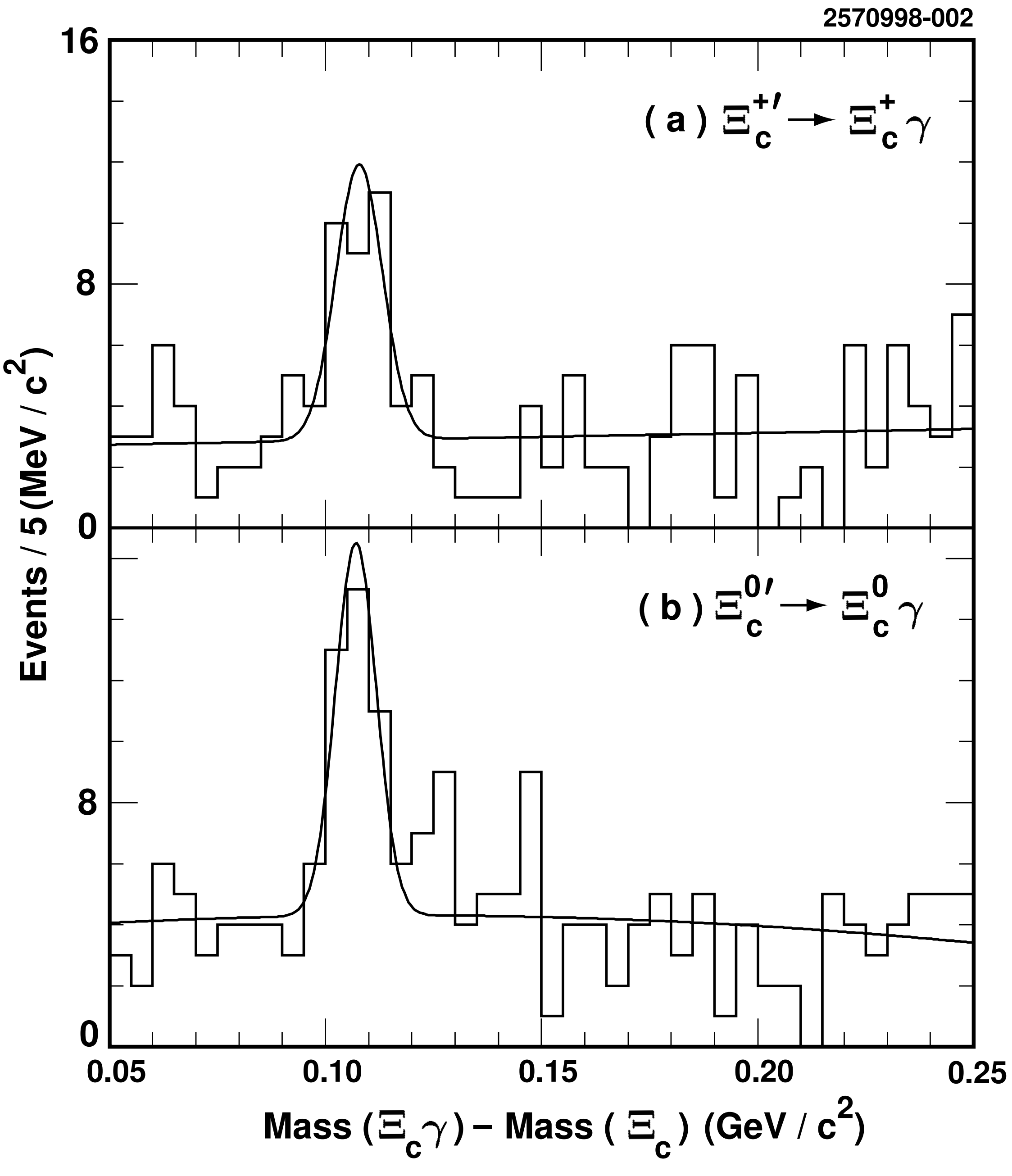


$$
\begin{aligned}
M(\Sigma_c^0) - M(\Lambda_c^+) &= (167.38 \pm 0.29 \pm 0.15)\,\mathrm{MeV/c^2} \\
M(\Sigma_c^{++}) - M(\Lambda_c^+) &= (167.76 \pm 0.29 \pm 0.15)\,\mathrm{MeV/c^2}
\end{aligned}
$$

E791 Collaboration, Phys. Lett. B379 (1996) 292



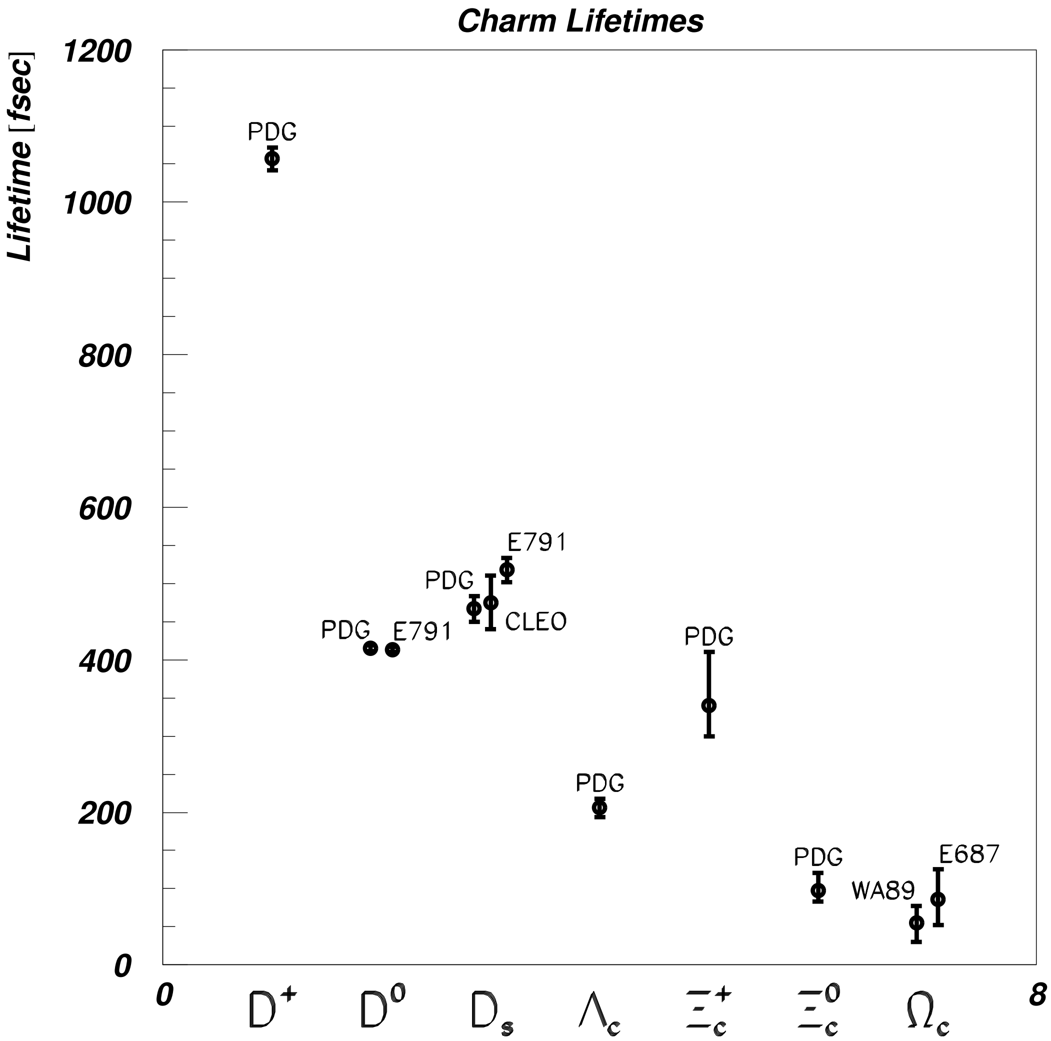
CLEO Collaboration, Phys. Rev. Lett. 82 (1999) 492



$$M(\Xi_c^{+\prime}) - M(\Xi_c^{+}) \;=\; (107.8 \pm 1.7 \pm 2.5)\,\mathrm{MeV/c^2}$$
$$M(\Xi_c^{0\prime}) - M(\Xi_c^{0}) \;=\; (107.0 \pm 1.4 \pm 2.5)\,\mathrm{MeV/c^2}$$

CLEO Collaboration, Phys. Rev. Lett. 82 (1999) 492

Decays



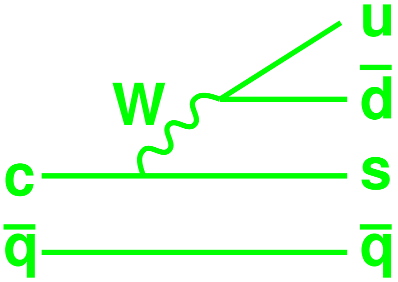
Most PDG98 values are dominated by E687

PDG, Eur. Phys. J. C 3 (1998) 1
E791 Collaboration, accepted in PRL, hep-ex/9903012
CLEO Collaboration, Proceedings Moriond 1998
E791 Collaboration, Phys. Lett. B 445 (1999) 449
WA89 Collaboration, Phys. Lett. B 358 (1995) 151
E687 Collaboration, Phys. Lett. B 357 (1995) 678

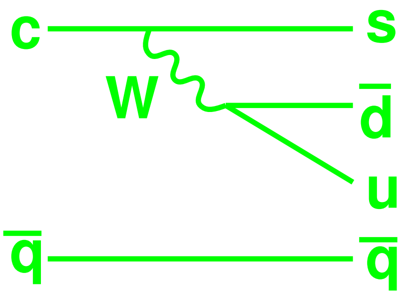
MOTIVATION
Decays Diagrams

$$\tau = \frac{\hbar}{\Gamma_{SL} + \Gamma_{NL} + \Gamma_{PL}}$$

$$\mathrm{PDG98}: \frac{\tau(D^+)}{\tau(D^0)} = 2.55 \pm 0.04$$



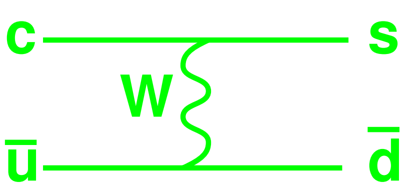
Spectator Decay
(Color Aligned)



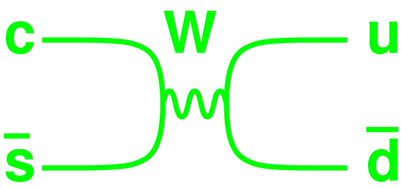
Internal Spectator
(Color Suppressed)

Spectator Decays

Coefficients modified by strong int.



W-exchange



W-annihilation

Annihilation Diagrams

Helicity and wavefunction suppressed

$$\Gamma_{SL}(D^+) = \frac{BR_{SL}}{\tau(D^+)} = (1.071 \pm 0.119) \times 10^{-13} GeV$$
$$\Gamma_{SL}(D^0) = \frac{BR_{SL}}{\tau(D^0)} = (1.067 \pm 0.041) \times 10^{-13} GeV$$

New Lifetime Measurements

– E791: *Measurements of Lifetimes and a Limit on the Lifetime Differences in the Neutral D-Meson System* (accepted in PRL)

Lifetime of $D^0 \rightarrow K^-K^+$ (CP-even final state) $\tau_{KK} = 0.410 \pm 0.011 \pm 0.006$ps

Lifetime of $D^0 \rightarrow K^-\pi^+$ (equal mixture of CP-odd and CP-even final states) $\tau_{K\pi} = 0.413 \pm 0.003 \pm 0.004$ps

Used to set a limit on decay width difference and mixing

– D_s Lifetimes

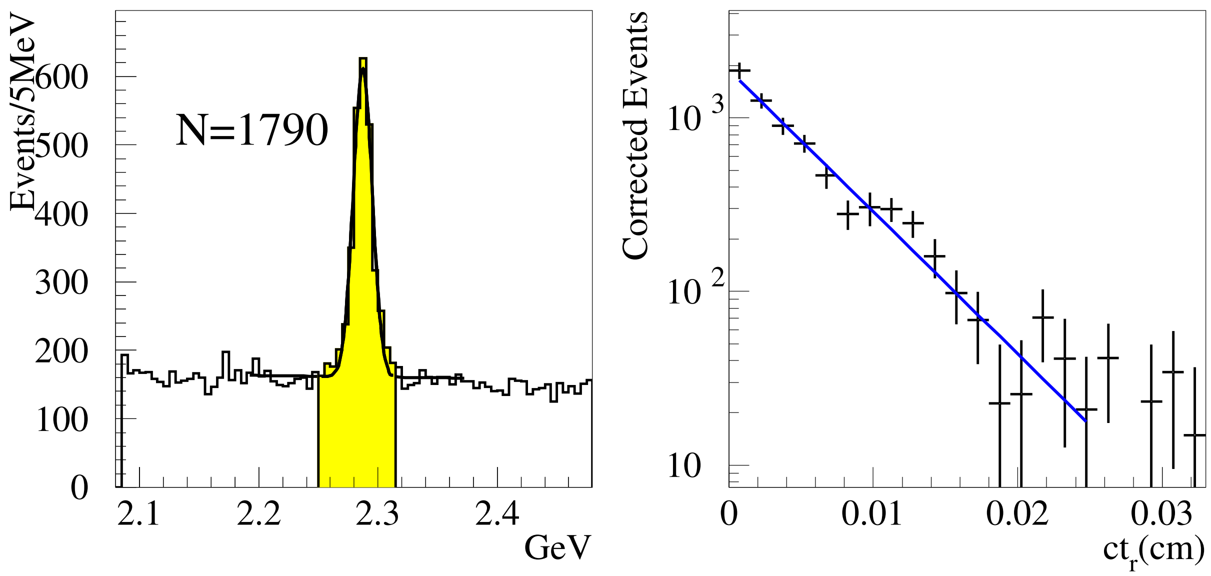
E791: $\tau = 0.518 \pm 0.014 \pm 0.007$ps (Phys. Lett. B 445 (1999) 449)

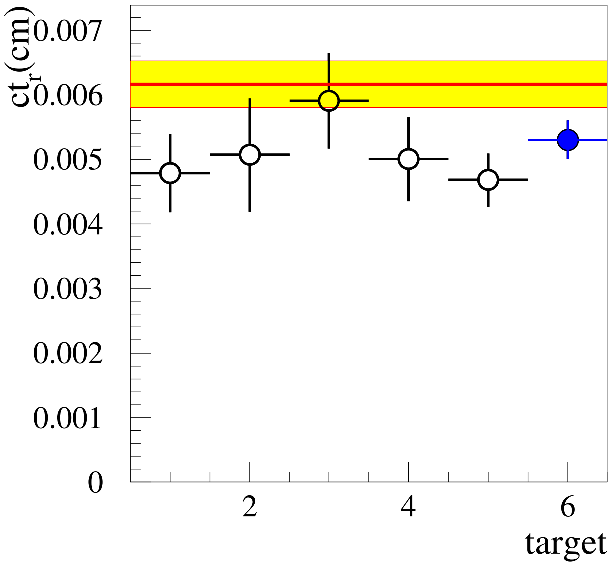
CLEO: $\tau = 0.475 \pm 0.024 \pm 0.025$ps (Proceedings Moriond 1998)

This, together with D_0 lifetime, is first significant measurement of lifetime difference: $\tau_{D_s}/\tau_{D^0} = 1.193 \pm 0.027$

SELEX

Very preliminary Λ_c lifetime using D^0 to measure efficiency





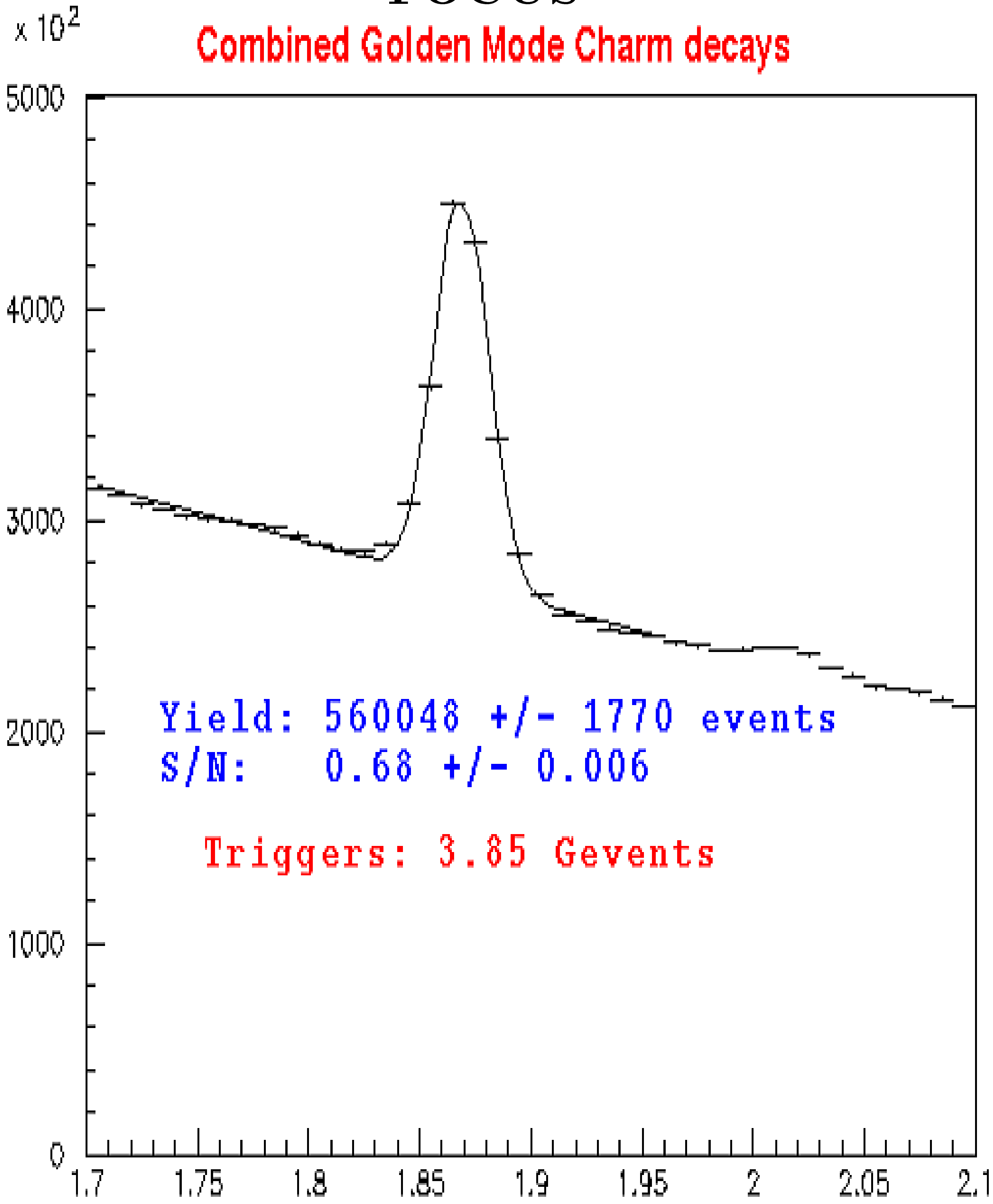
T=206 ± 12 (fs) PDG

T=177 ± 10 (fs) E781

Statistical error only

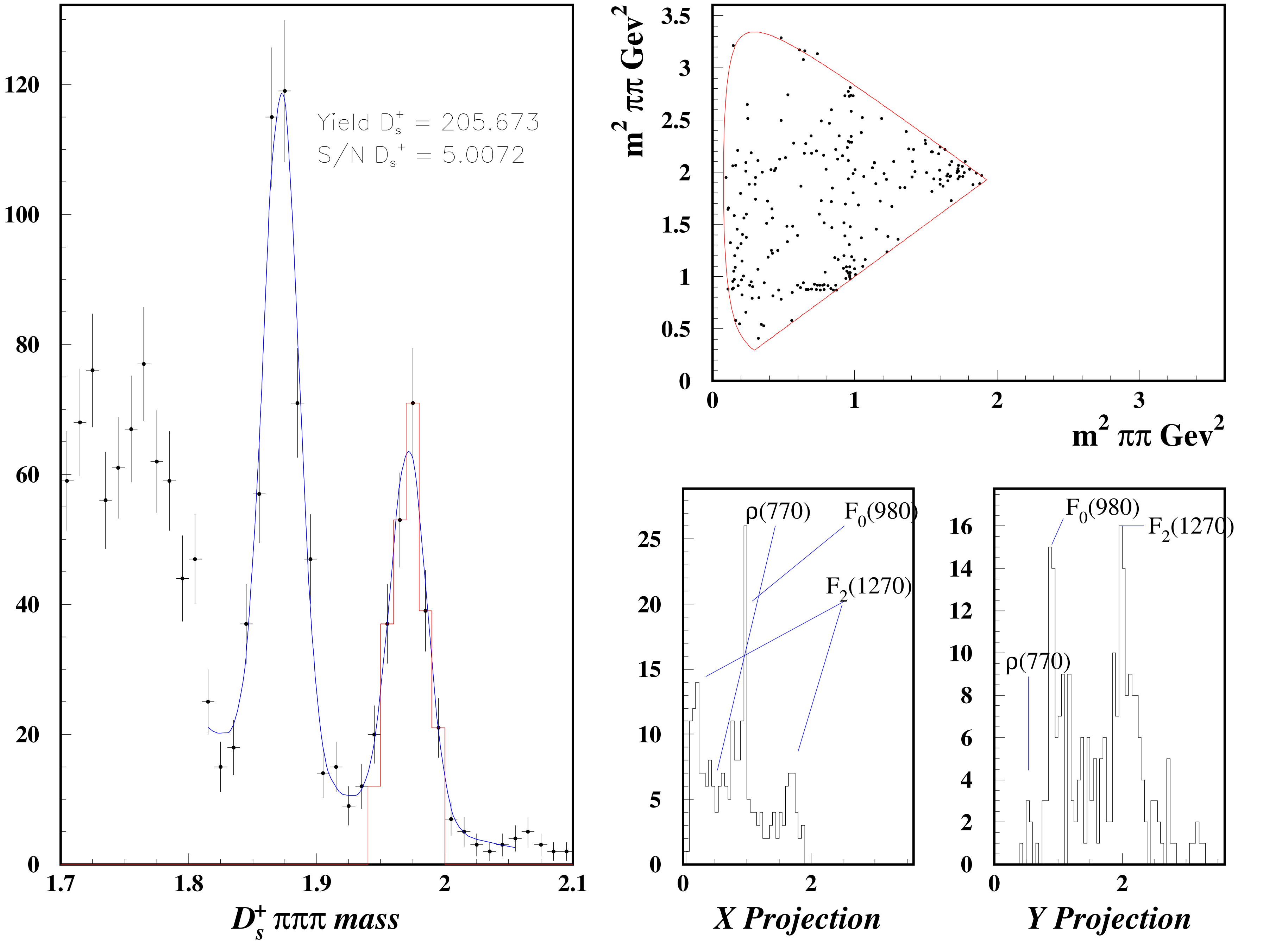
SELEX Collaboration, Publication in preparation

FOCUS



Will have $> 10^6$ reconstructed charm!

$D_s^+ \to \pi\pi\pi$ dalitz plot and projections

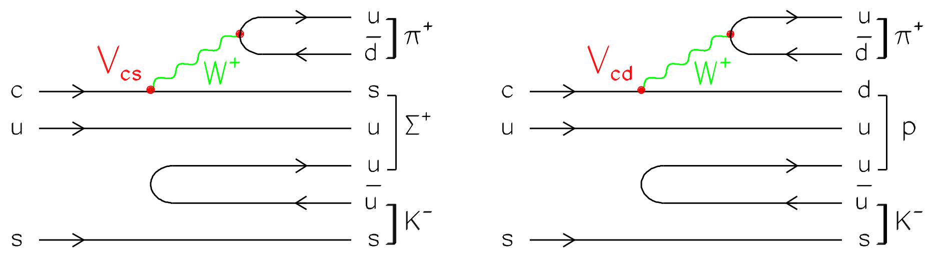


Introduction

- Charmed Baryon Studies at SELEX(E781)
  - Precision measurement of mass and lifetime
  - Search for new decay modes
  - Study of Cabibbo-suppressed(CS) modes

- Cabibbo-favored vs. Cabibbo-suppressed Mode

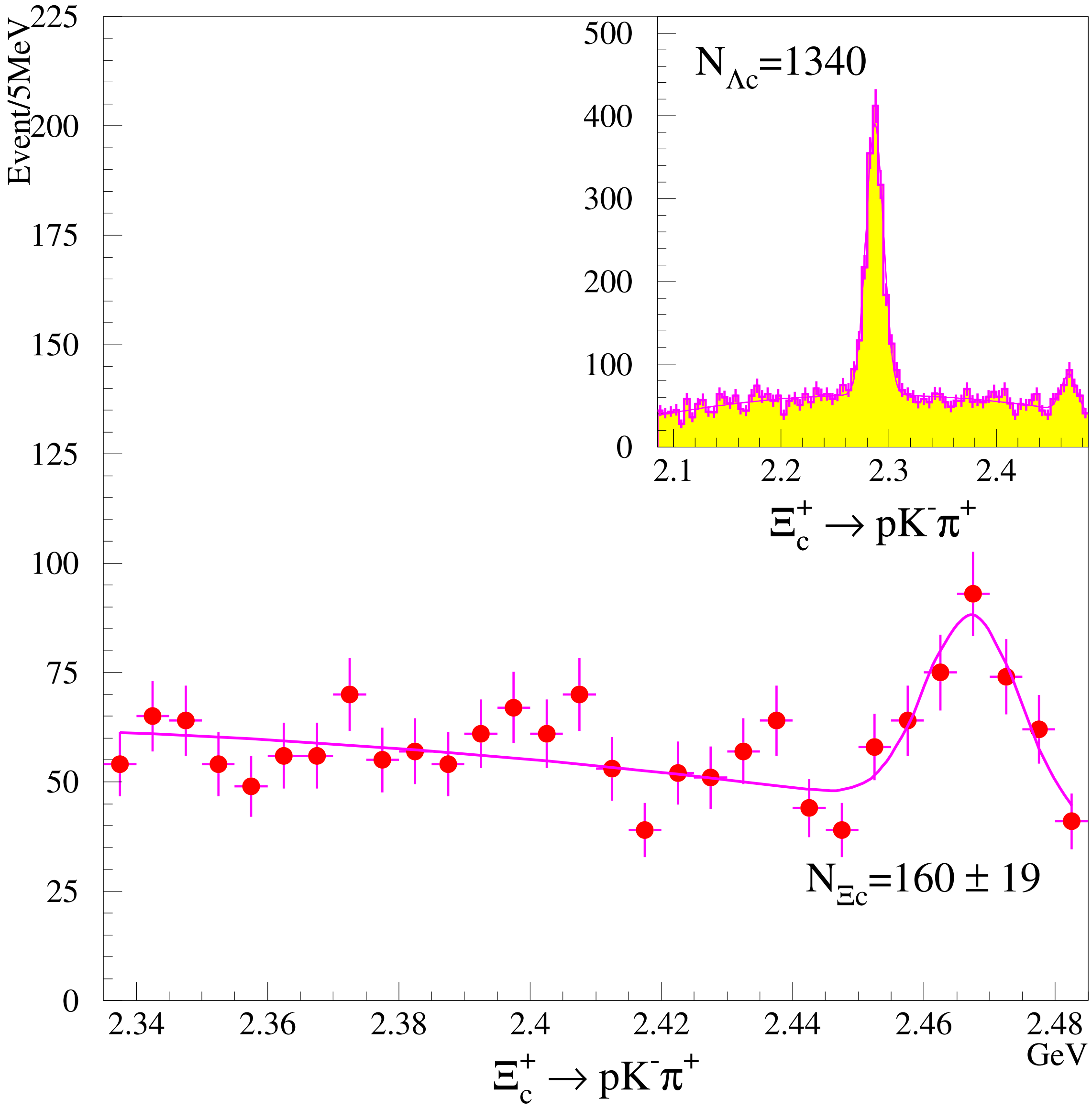
$$\Gamma \propto G_F^2 \sum_{q=d,s} |V_{uq} V_{cq}|^2 \mathcal{F}$$



$\Xi_c^+ \to \Sigma^+ K^- \pi^+$ $\Xi_c^+ \to p K^- \pi^+$

$$\frac{\Gamma_{CS}}{\Gamma_{CF}} \approx \mathcal{O}(\left|\frac{V_{cd}}{V_{cs}}\right|^2 = tan^2\theta_c \approx 0.053)$$

SELEX PRELIMINARY $\Xi_c^+ \to pK^-\pi^+$ (L/σ>8)



First Observation of Cabibbo-suppressed decay $\Xi_c^+ \to pK^-\pi^+$

Final Numbers:

Observed 150 ± 22 Events

$$\frac{B(\Xi_c^+ \to pK^-\pi^+)}{B(\Xi_c^+ \to \Sigma^+K^-\pi^+)} = 0.22 \pm 0.06 \pm 0.01$$

$$\frac{B(\Xi_c^+ \to pK^-\pi^+)}{B(\Xi_c^+ \to \Xi^-\pi^+\pi^+)} = 0.20 \pm 0.04 \pm 0.01$$

SELEX Collaboration, will be submitted to PRL next week

Conclusions

- Very active research going on
- I did not talk about most of the interesting results
- "Old" (E791, WA89, E789, E690, WA89, ...) and running experiments (CLEO, LEP, HERA, ...) are publishing
- "New" experiments (FOCUS, SELEX) are coming up
- Plans for future experiments (COMPASS, CLEO3, B-Factories)

SELEX Charm Program

- Compare Production by Σ^-, π^- and p beams:
  - X_f and P_t dependency
  - Charm - Anticharm production asymmetry
  - Production of excited states
  - Charm pair production
  - Search for polarization effects
  - ...
- Decay Physics:
  - Precision measurement of charm lifetimes
  - Search for new decay modes
  - Study of Cabibbo-suppressed modes
  - Charm barion semi-leptonic decay
  - ...
- Spectroscopy:
  - Measure excited state characteristics
  - Search for new excited states
  - ...

$D^+ \to \pi\pi\pi$ dalitz plot and projections