SELEX

SELEX (E781) is a fixed target experiment

The goal of the experiment was
charm hadro-production and charm spectroscopy

Fermi National Accelerator Laboratory (FNAL)
Batavia (Chicago) USA

Tevatron (E_p = 0.8 TeV)

Data taking in 1996-1997.

SELEX

The SELEX Collaboration

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SELEX

The SELEX collaboration: 20 institutes, 110 persons

PNPI participants:

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PNPI contribution:

1. **Detectors**: 14 multiwire proportional chambers 0.6*1.0 m^2,
   TRD-detectors: for beam and for scattered electrons,
   Fast scattering trigger.
2. **Electronics**: Readout system for RICH detector (11 000 channels),
   Readout system for vertex detector (70 000 channels),
   Front-end electronics for the drift chambers,
   Electronics for BTRD, ets.
   Software for electronics.
3. **Data taking**.
4. **Data analysis**.

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Main SELEX physics publications:

1. **Total cross section** measurements with π^-, Σ^- and protons on nuclei and nucleons around 600 GeV/c. Nucl.Phys. B579 (2000) 277.
2. Observation of the **Cabibbo-suppressed decay** $\Xi_c^+ \rightarrow p K^- \pi^+$. Phys.Rev.Lett. 84 (2000) 1857.
3. Precision measurements of the Λ_c^+ **and** D^0 **lifetimes**. Phys.Rev.Lett. 86 (2001) 5243.
4. Measurement of the Σ^- **charge radius** by Σ^- -electron elastic scattering. Phys.Lett. B 522 (2001) 233.
5. Measurement of the D_s **lifetime**. Phys.Lett. B 523 (2001) 22.
6. Radiative **decay width of the** $a_2(1320)^-$ meson. Phys.Lett. B 521 (2001) 171.
7. First measurement of $\pi^- e \rightarrow \pi^- e \gamma$ **pion virtual compton scattering**. Phys.Rev. C 66 (2002) 034613.
8. Hadronic **production of** Λ_c from 600 GeV/c π^-, Σ^- and p beams. Phys. Lett. B 528 (2002) 49.
9. **Production asymmetry of** D_s from 600 GeV/c Σ^- and π^- beam. Phys. Lett. B 558 (2003) 34.
10. First observation of the **doubly charmed baryon** Ξ^+_{cc}. Phys. Rev. Lett. 89 (2002) 112001.

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11. **Upper limit on the decay $\Sigma(1385) \rightarrow \Sigma^{-}\gamma$**, and cross section for $\gamma\Sigma^{-} \rightarrow \Lambda\pi^{-}$. Phys. Lett. B 590 (2004) 161.
12. **Polarization of Σ^{+} hyperons** produced by 800 GeV/c protons on Cu and Be. Phys. Rev. D 70 (2004) 112005.
13. **First observation of a narrow charm-strange meson $D_{sJ}^{+}(2632)$** $\rightarrow D_{s}^{+}\eta$ and $D^{0}K^{+}$. Phys. Rev. Lett. 93 (2004) 242001.
14. **Confirmation of the doubly charmed baryon** $\Xi_{cc}^{+}(3520)$ via its decay to $pD^{+}K^{-}$. Phys. Lett. B 628 (2005) 18.

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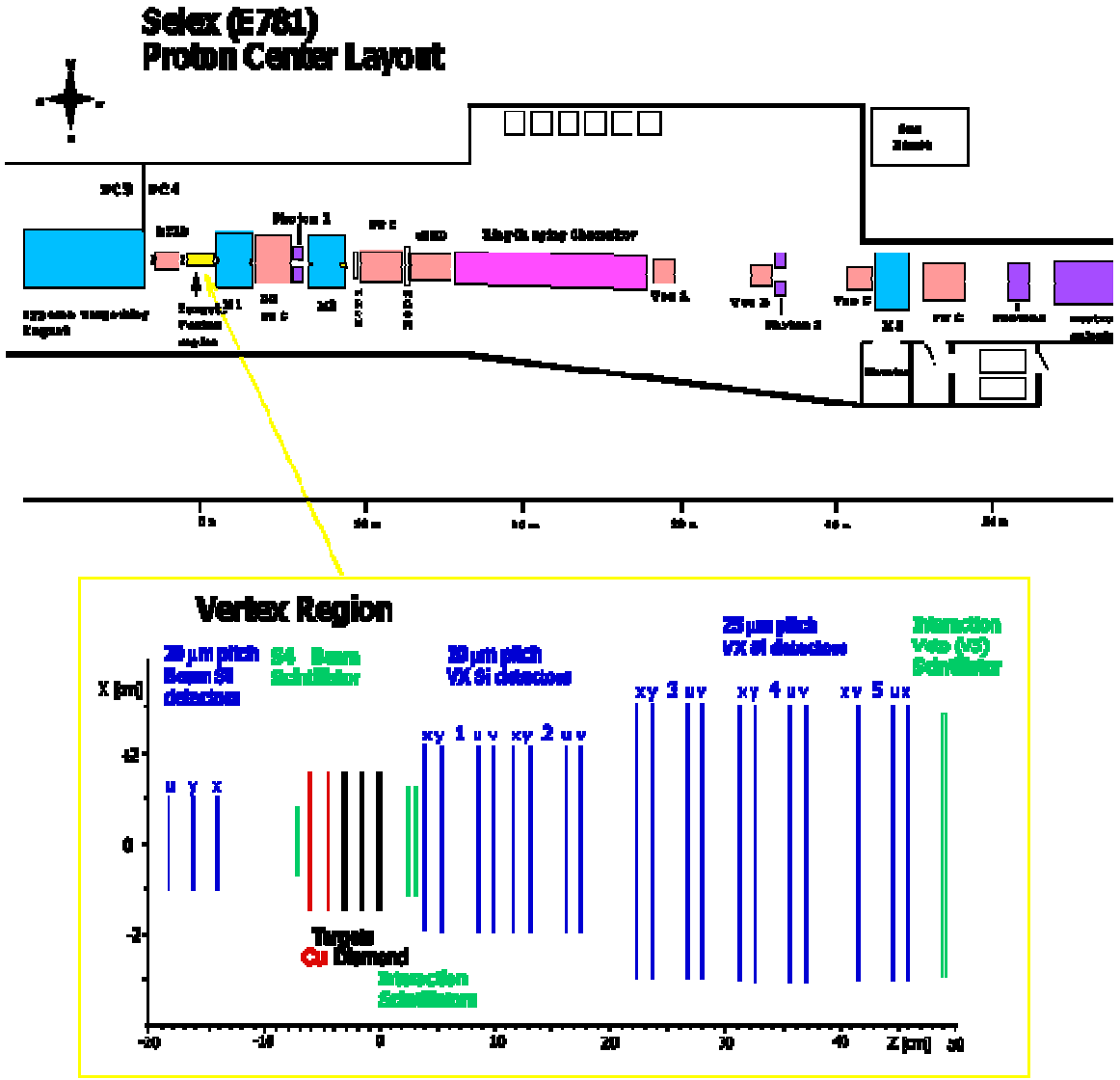
SELEX Apparatus Features

- Forward production: $p_t < 3$ GeV/c
- typical Lorentz Boost ~ 100
- π, Σ^-, p beams
- RICH identification above 25 GeV/c
- decay proper time resolution ~ 18 fs



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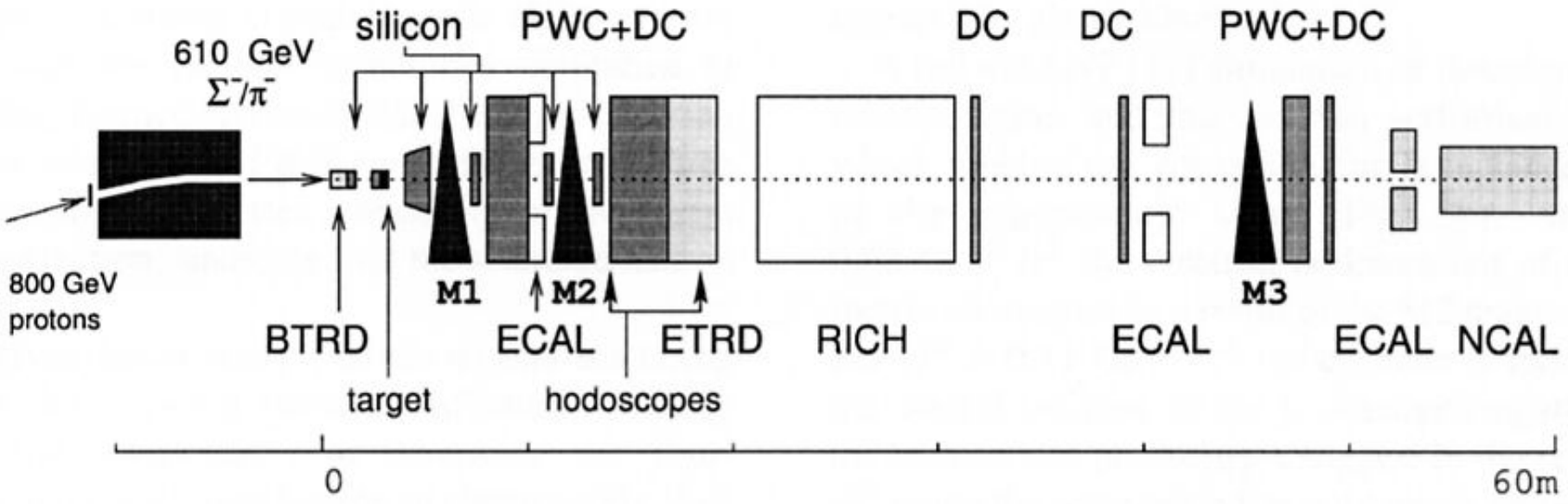

Schematic view of the SELEX detector.

SELEX

The SELEX spectrometer

- Segmented target: 2 Cu and 3 C
- Hyperon magnet + 3 analysis magnets: M1, M2, and M3

Vertex detectors:

- Beam silicon detectors
- High precision silicon vertex detectors

Tracking:

- 18 Large silicon detector planes ($\sigma \sim 14\ \mu m$)
- 28 PWC planes ($\sigma \sim 0.6$-1 mm)
- 72 Drift chamber planes ($\sigma \sim 100\ \mu m$)

Particle identification:

- Beam transition radiation detector, tagging Σ^-/π^-, p/π^+
- Ring imaging Cherenkov counter (3000 PMT)
- Electron TRD
- 3 Lead glass electromagnetic calorimeters

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Beams

Primary 800 GeV proton beam of $1.6*10^{10}$ s^{-1} on Be target

Secondary beams: negative – Σ^- (50%) or π^- (50%)
positive - protons (92%) and π^+

Charm trigger

Hardware: Valid beam track: BTRD
≥ 4 charged tracks in the forward direction
≥ 2 charged tracks in M2 with the momentum > 15 GeV/c

Software: (Online) Evidence for secondary vertex

Data

$15*10^9$ interactions studied: 10^9 events written on tape

Σ^- 67%, π^- 14%, p^+ 18%, π^+ 1%

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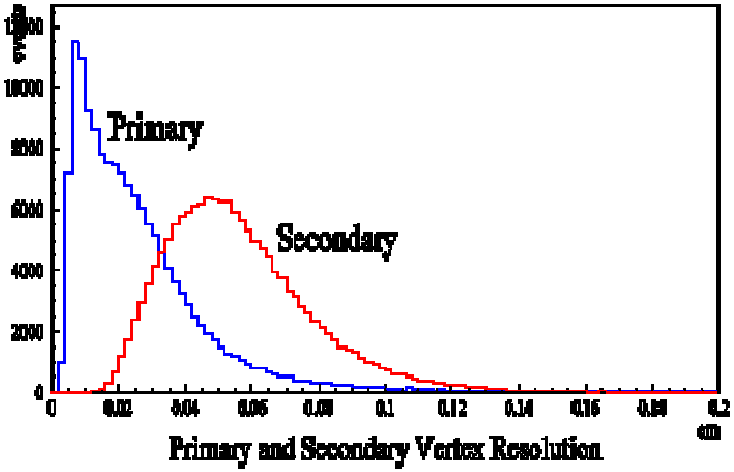
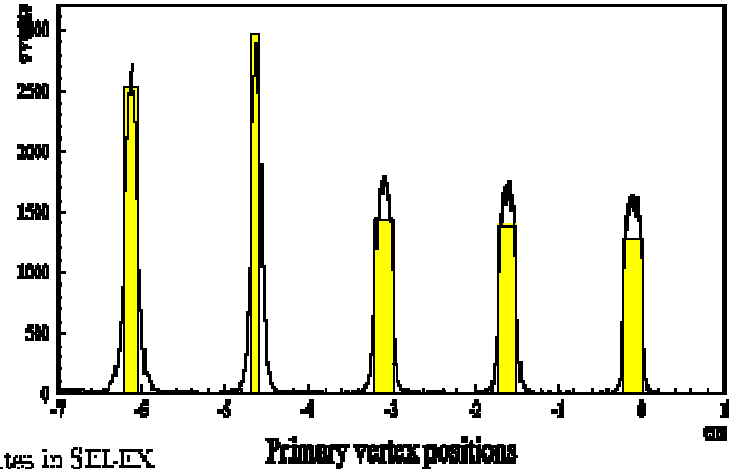
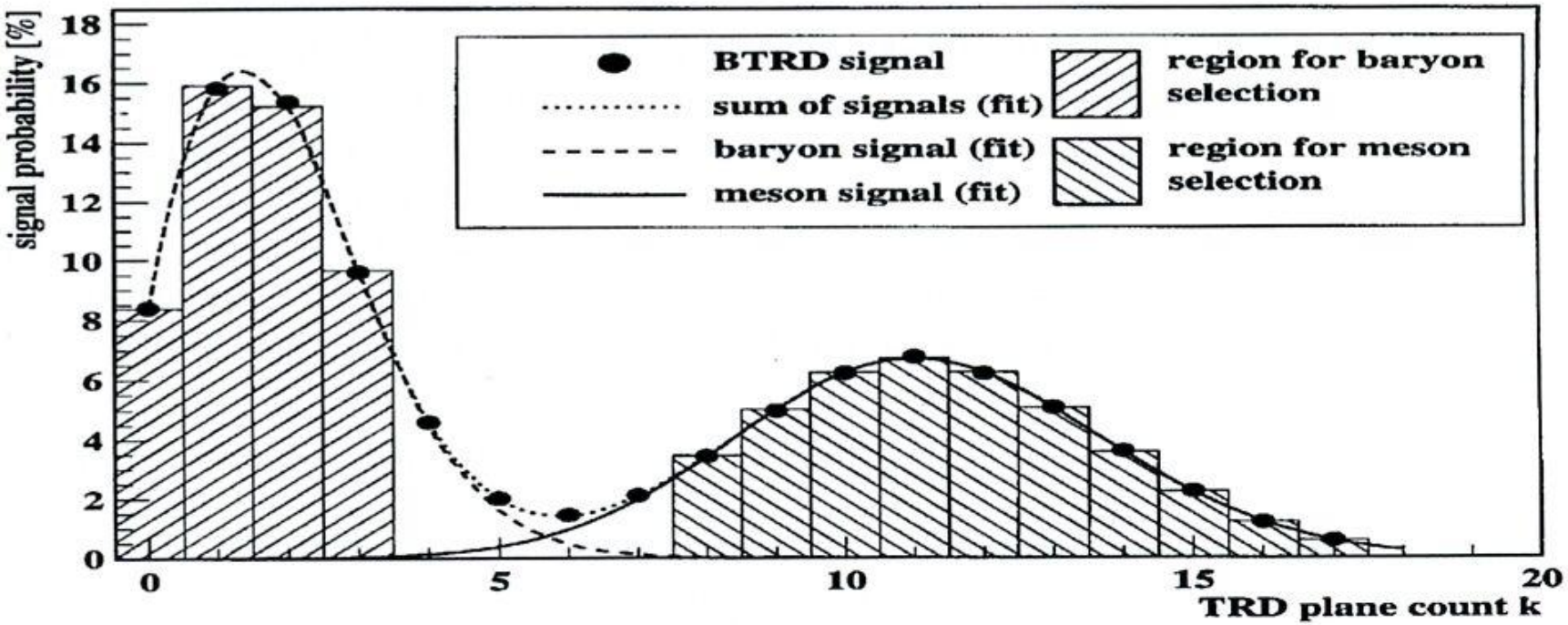
Vertex Spectrometer Performance





- transverse vtx resolution 8-15 μm
- 20 highly-efficient vertex planes overdetermine tracks, reduce tracking confusion in high-multiplicity events
- target foils 0.8-2.2 mm thick with 1.5 cm period to localize primary int

SELEX



18 planes of BTRD. Each plane is a stack of 200 polypropylene foils 17 μm thick spaced at 500 μm followed by 3 PWC (70% Xe, 30% CO_2).

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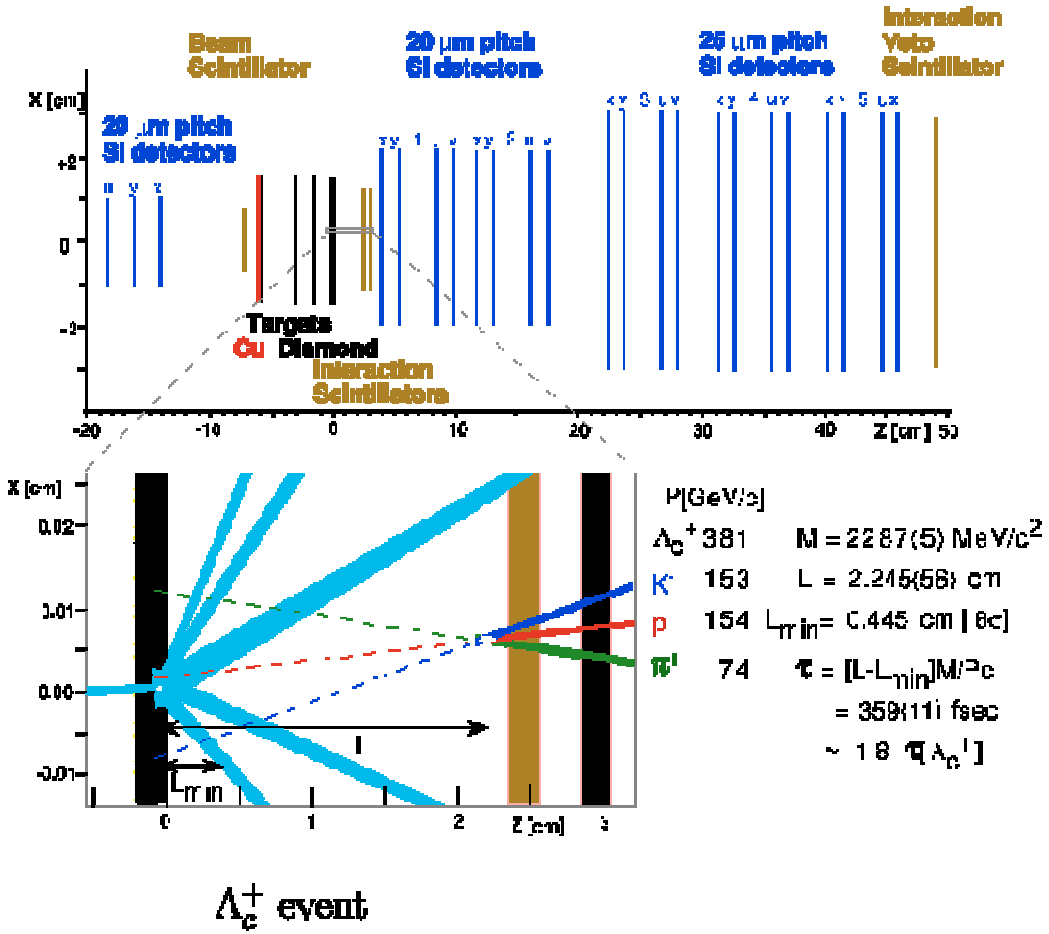
SELEX Charm Selection Criteria



Λ_c^+ event

- primary vertex tagged by beam track
- secondary vertex must lie outside material

Charm Selection Cuts for single charm studies:

- secondary vertex significance:
  - $L/\sigma \geq 1$ for short-lived states (Ξ_c^0, Ω_c^0)
  - $L/\sigma \geq 8$ for long-lived states $(\Lambda_c^+, \ldots)$
- Pointback ≤ 4 $(2\ \sigma_b)$
- *second*-largest miss significance among decay trks ≥ 4.

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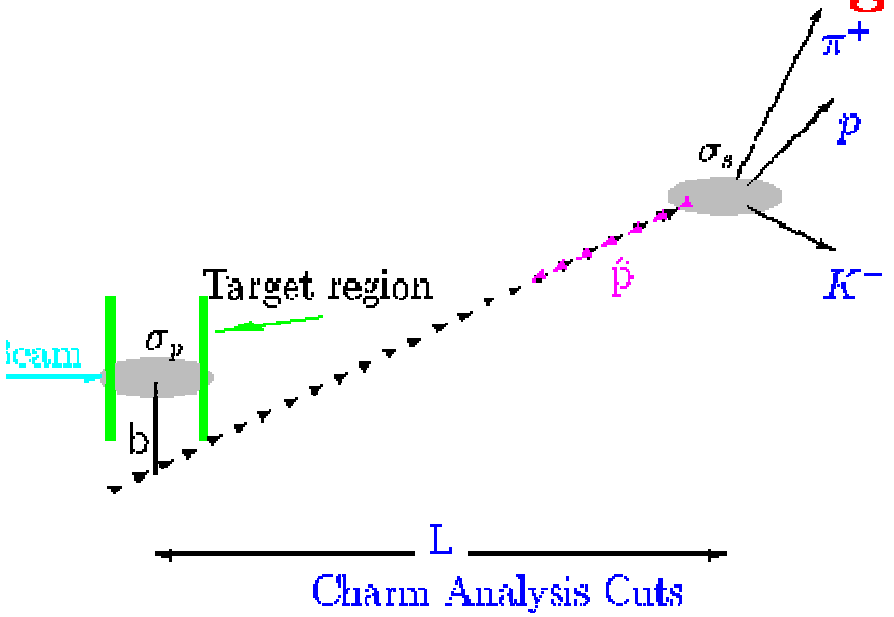
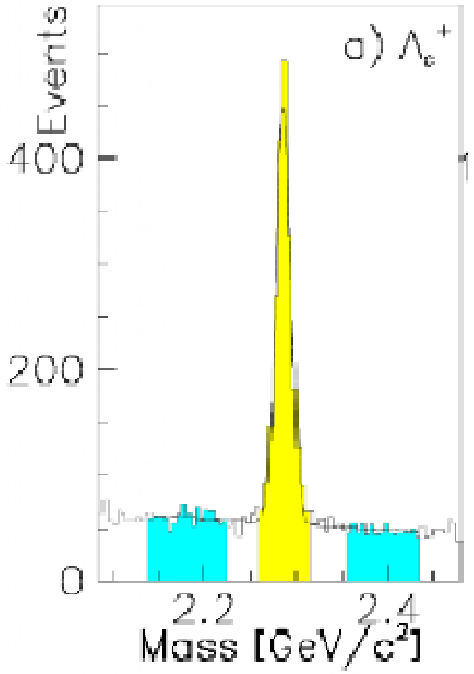
SELEX Single Charm Analysis





- Decay vertex separation significance L/σ
- Charm vector momentum points back to primary: cut on $(b/\sigma_b)^2$ (point-back cut)
- Decay vertex lies outside target material (space cut)
- $\Lambda_c^+ \to pK^-\pi^+$ sample used to search for double charm

STANDARD MODEL

(u d) (s c) (b t)

u, d, s - light, c, b, t - heavy

p - (uud) π^+ - (ud) K^- - (su) D^0 – (cu)

D^+ - (cd) D_s^- – (cs) Λ_c^+- (udc) Σ^- - (dds)

Ξ_{cc}^+ - (dcc)

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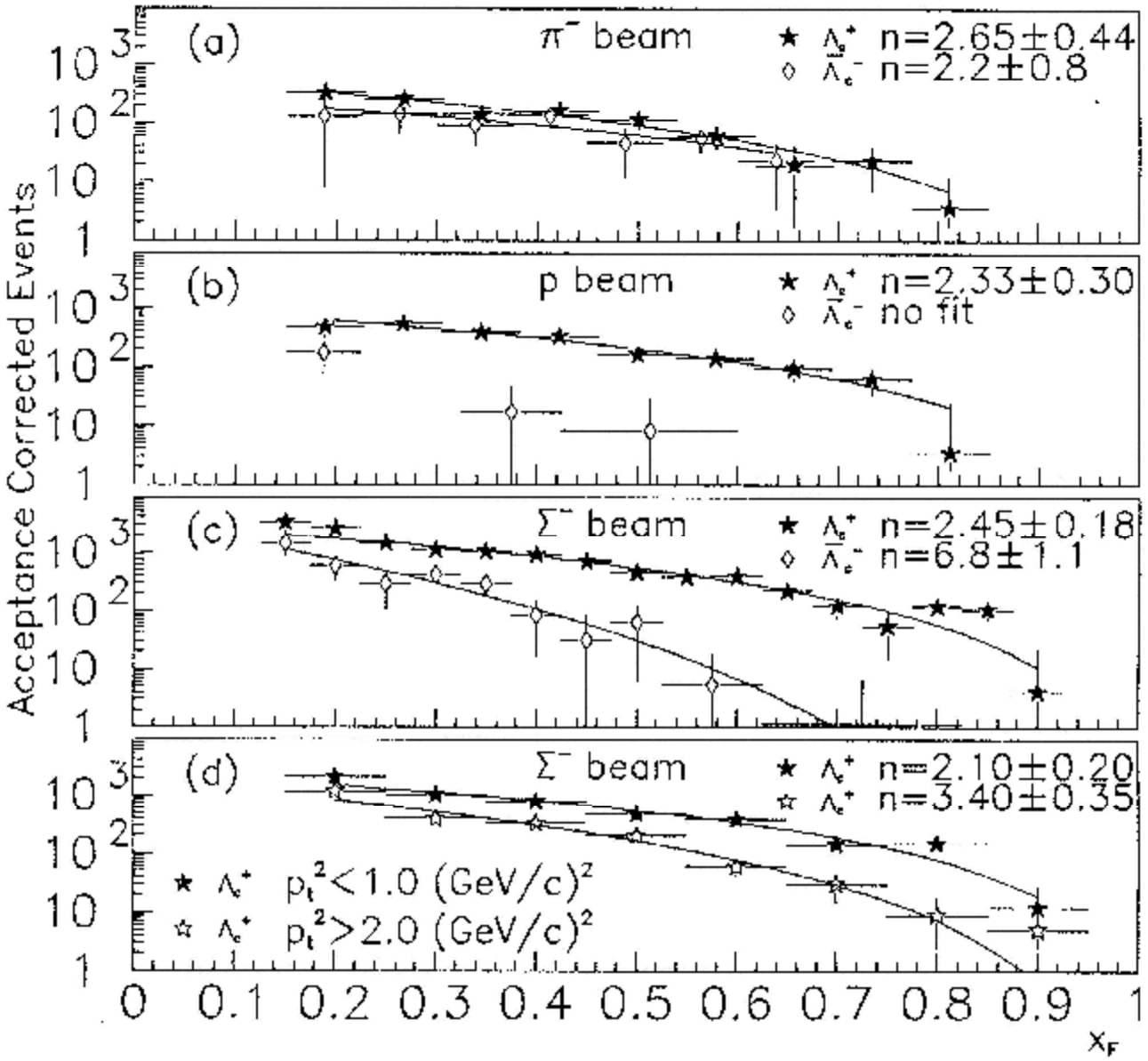
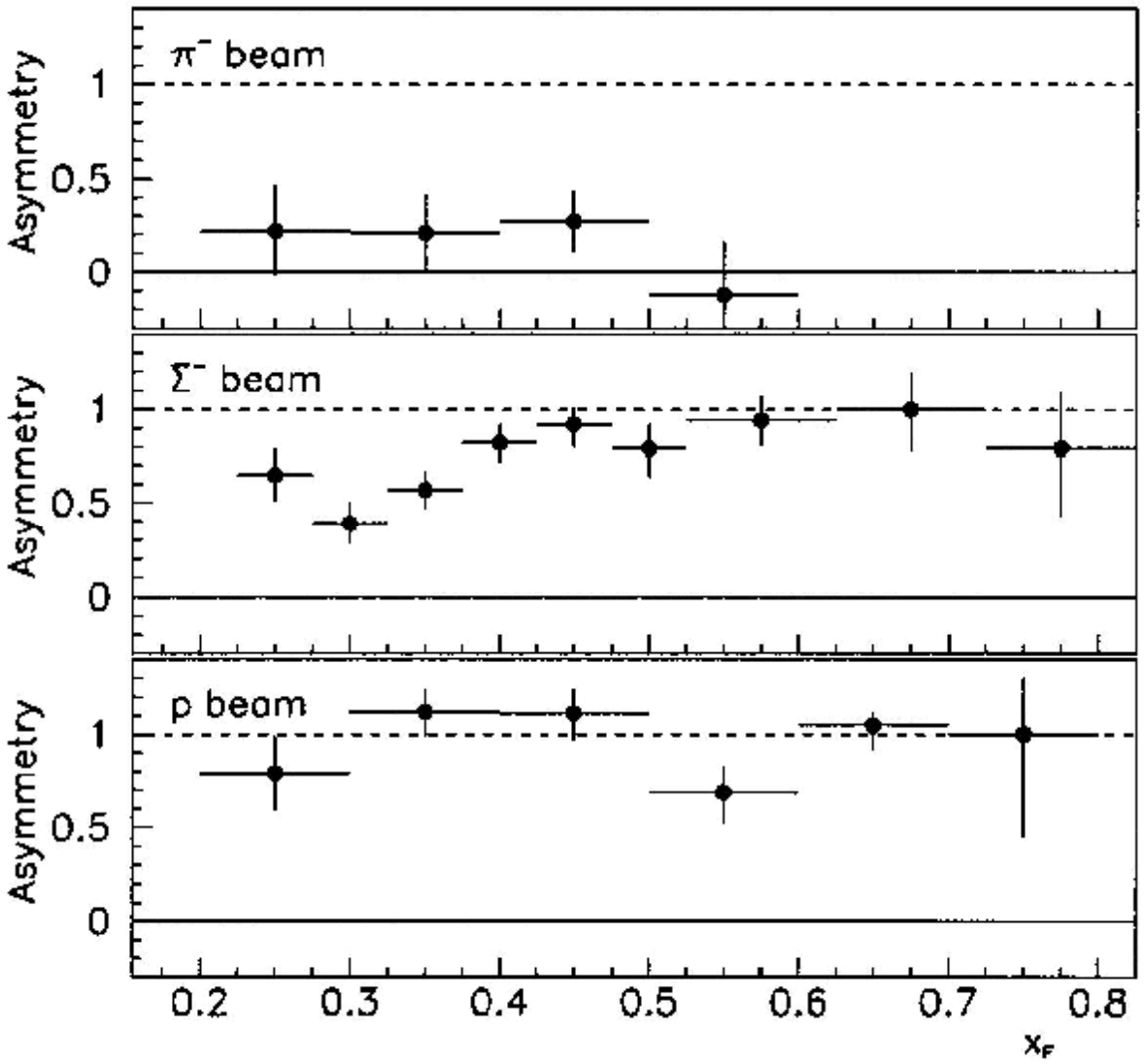


Λ_c x_F distribution at low and high p_t

$(1 - x_F)^n$

π^- (ud)
Σ^- (dds)
p (uud)
Λ^+_c (udc)
Λ^-_c (udc)

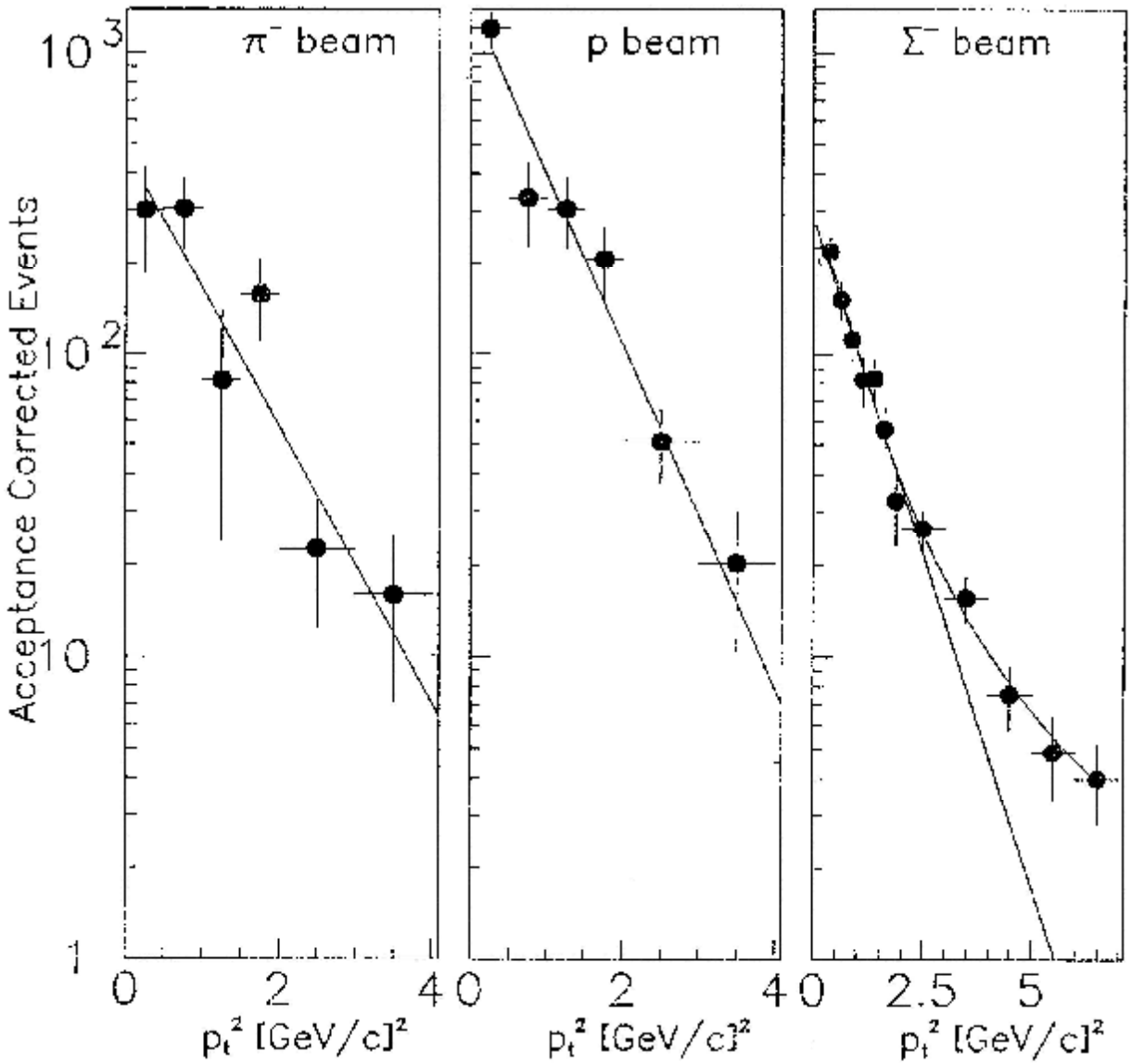
SELEX



Asymmetry for Λ_c production.

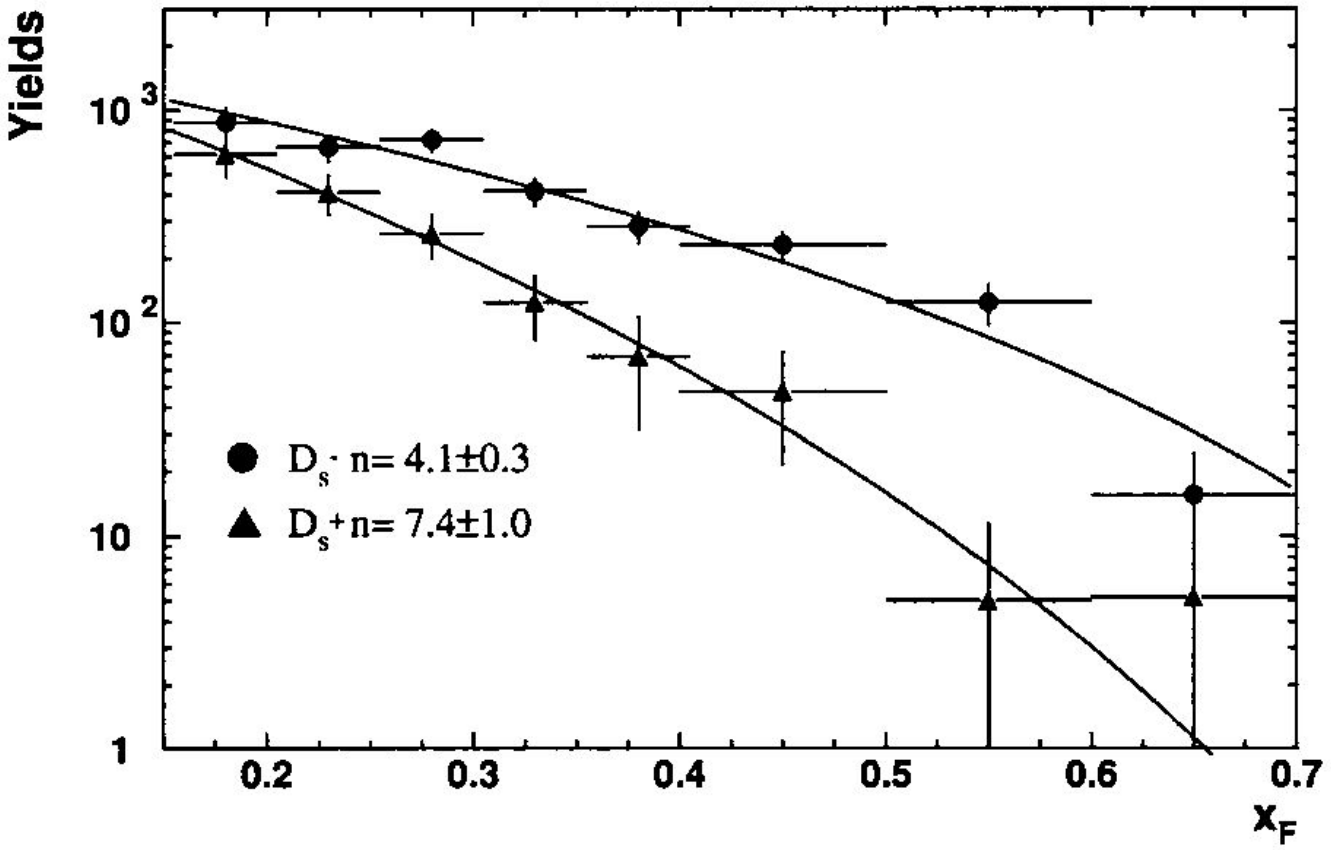
$$A=[\sigma(\Lambda_c^+) - \sigma(\Lambda_c^-)]/[\sigma(\Lambda_c^+) + \sigma(\Lambda_c^-)]$$

SELEX



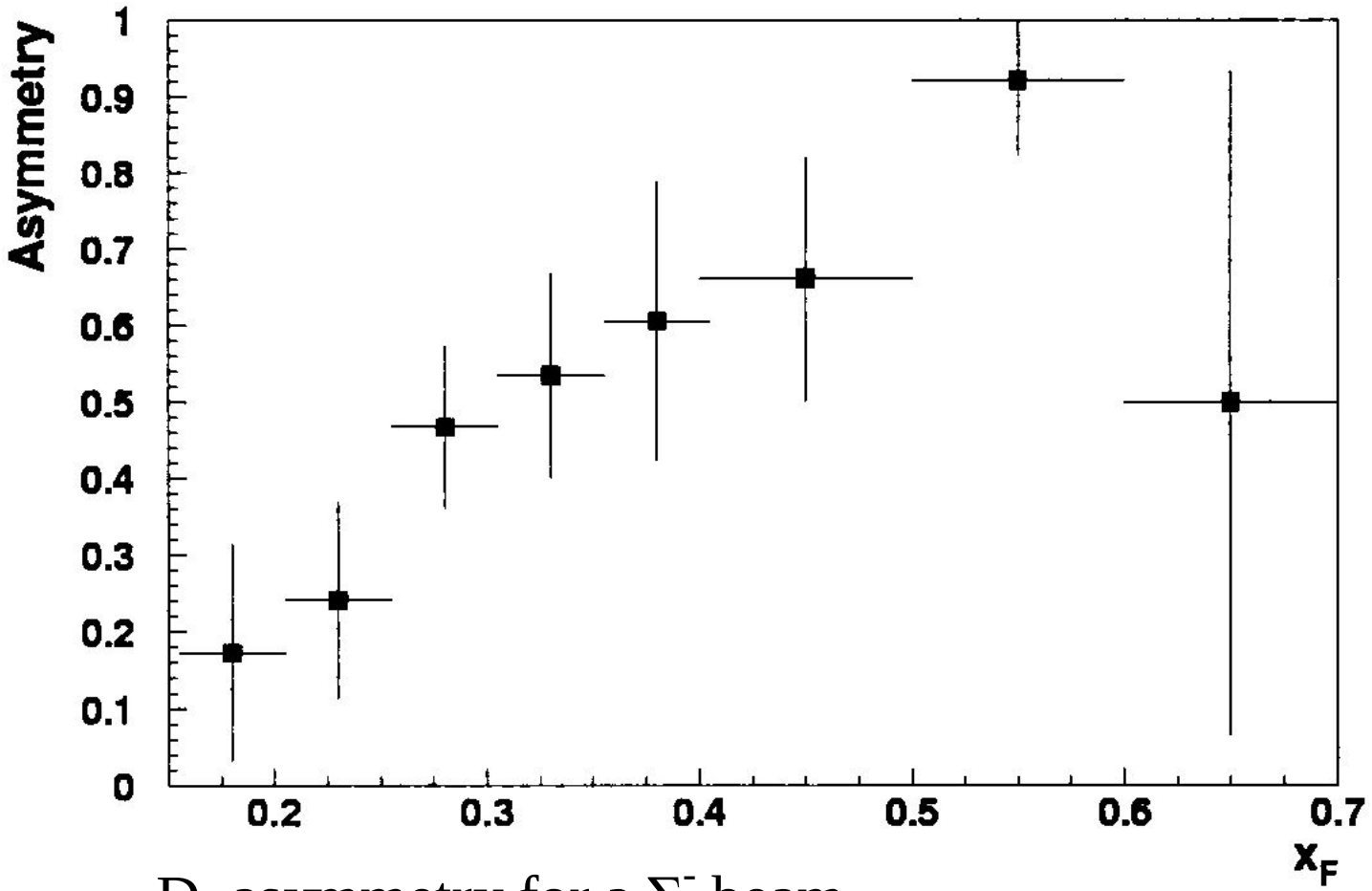
Λ_c p_t^2 distribution

SELEX



D_s x_F distributions for a Σ^- beam

SELEX



π^- (ud)
Σ^- (dds)
D_s^- (cs)
D_s^+ (cs)

D_s asymmetry for a Σ^- beam.
For a π^- beam, the asymmetry is A=0.06 +/- 0.11.

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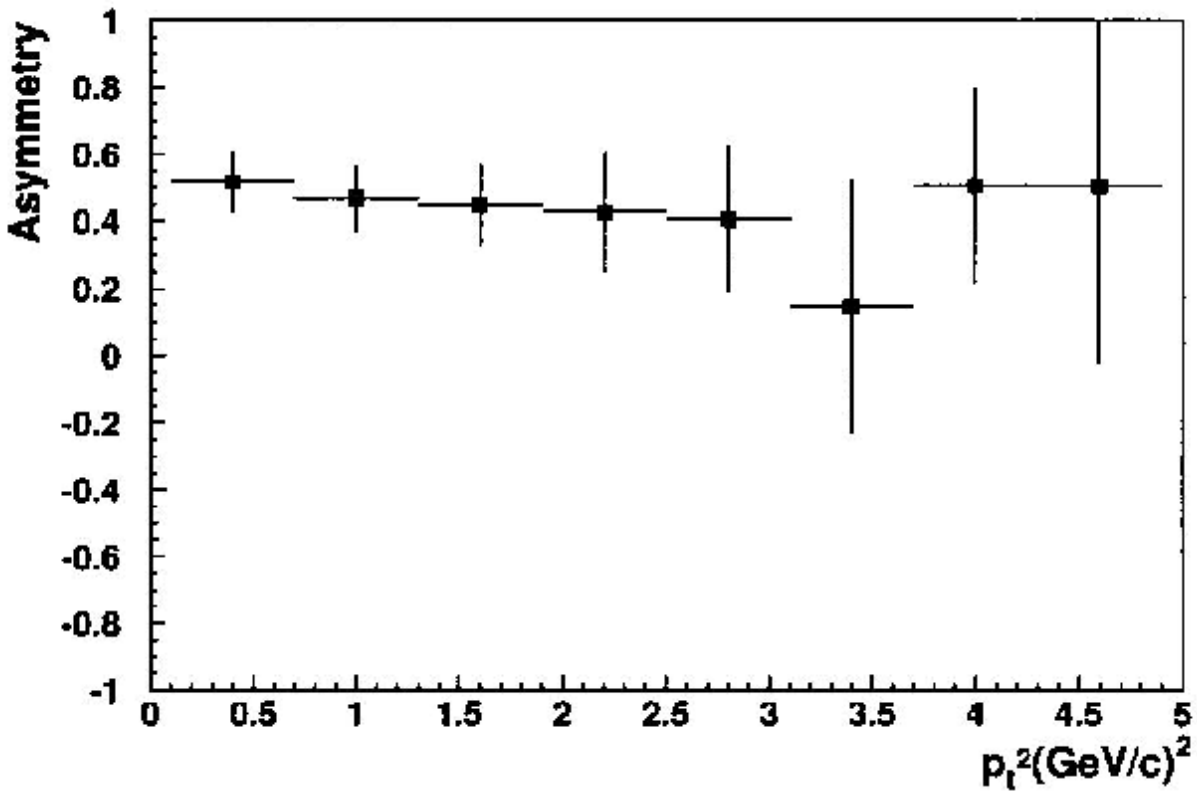
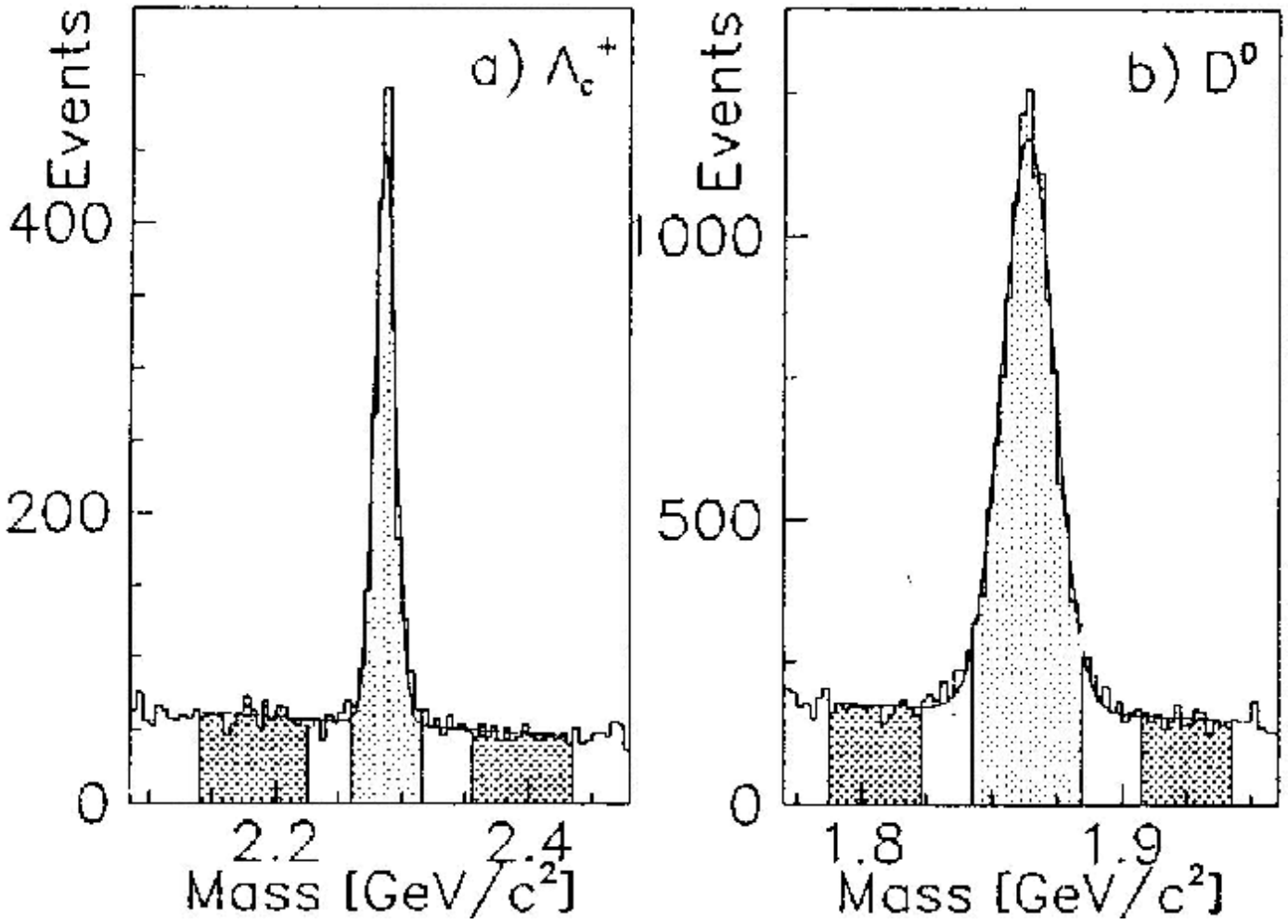


$$A=[\sigma(D_s^-) - \sigma(D_s^+)]/[\sigma(D_s^-) + \sigma(D_s^+)]$$

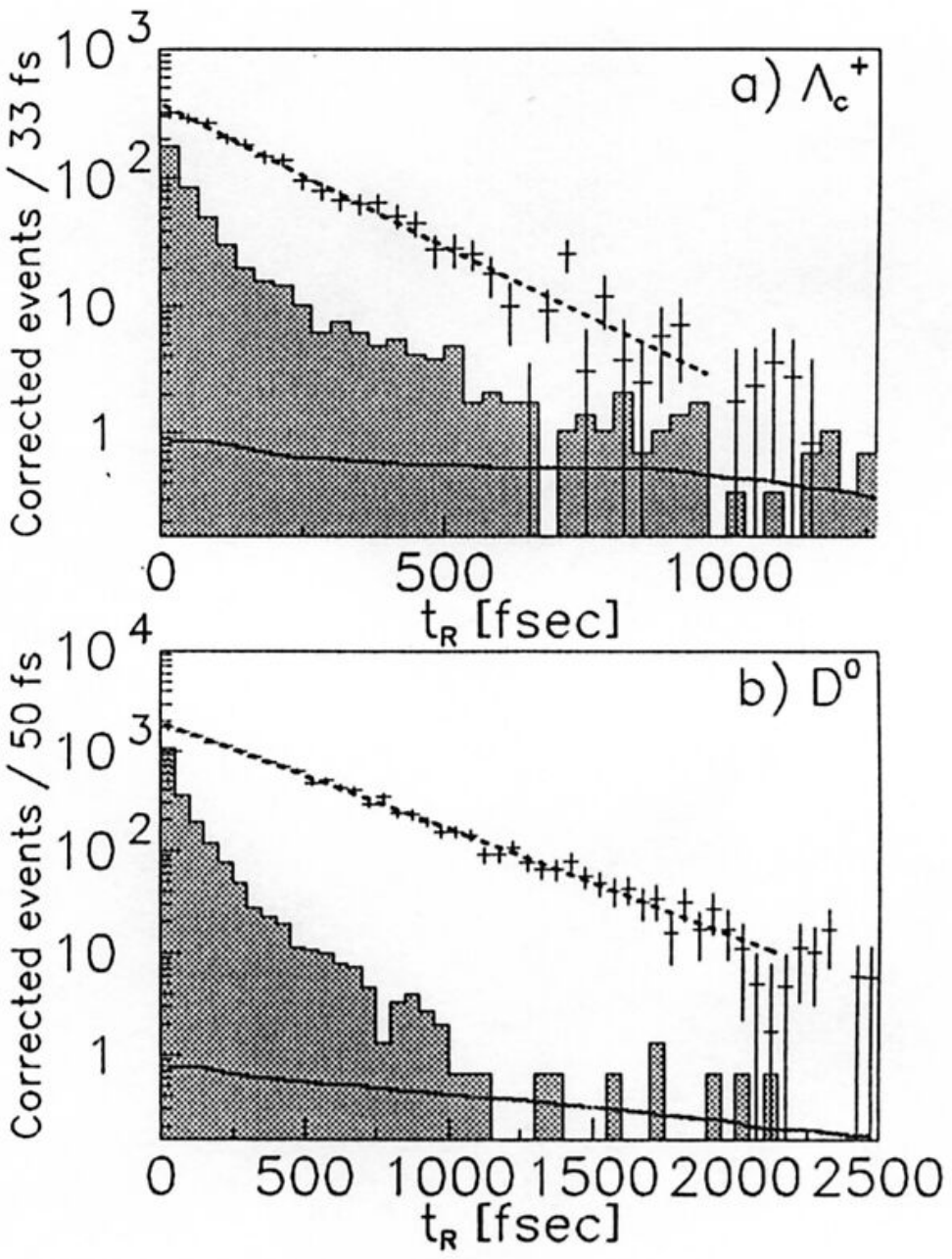
Colour-drag string model; intrinsic-charm model

SELEX



Reconstructed masses of Λ_c^+ and D^0.

SELEX



The acceptance-corrected reduced proper lifetime distributions for Λ_c^+ and D^0 events.

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	Lifetime, fs	Stat. error, fs	Syst. error, fs
Λ_c^+	198.1	7.0	5.6
D^0	407.9	6.0	4.3
$D^\pm$	1070	36	–
D_s	472.5	17.2	4.4

Results of the SELEX lifetime measurements.

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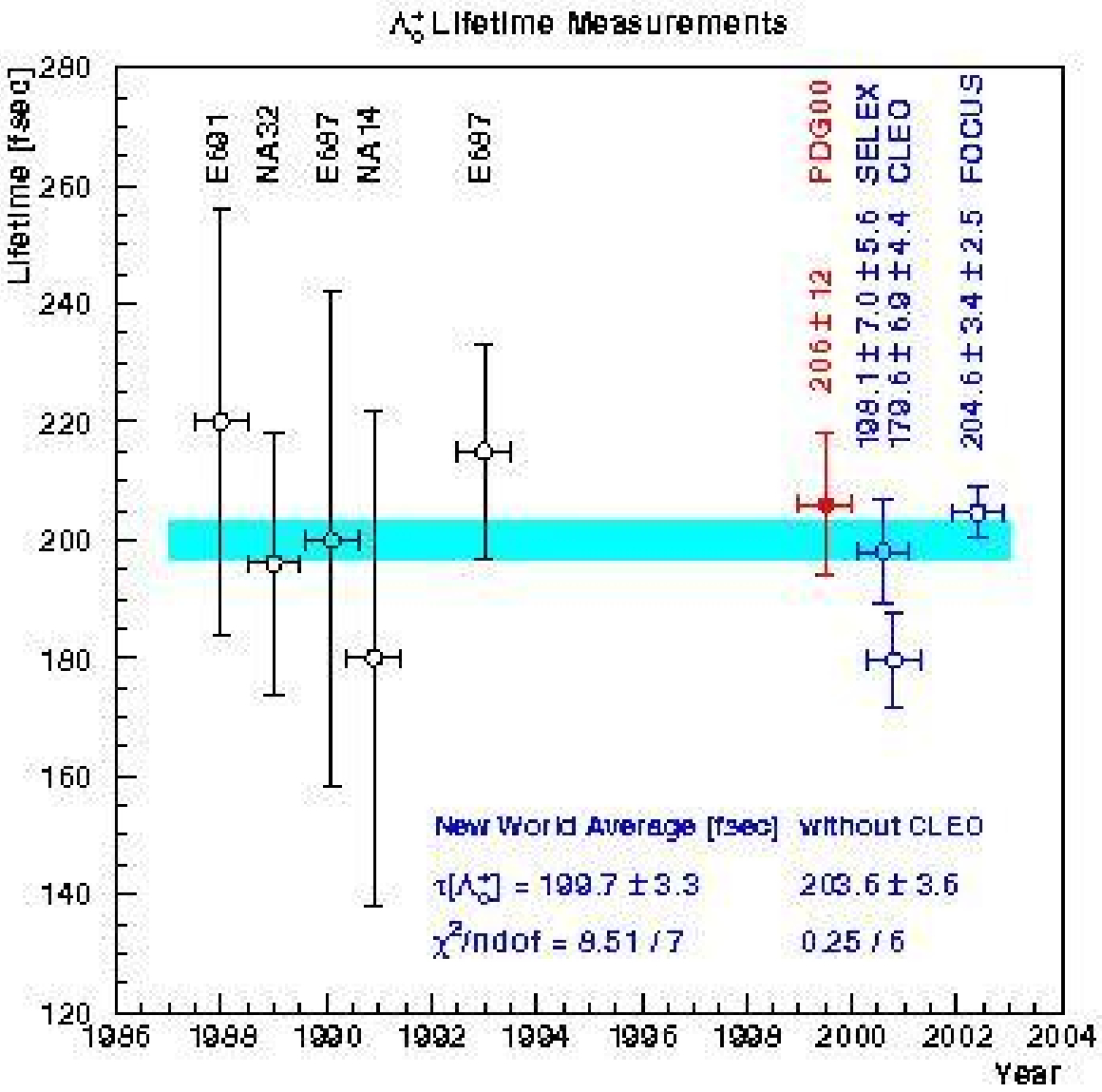
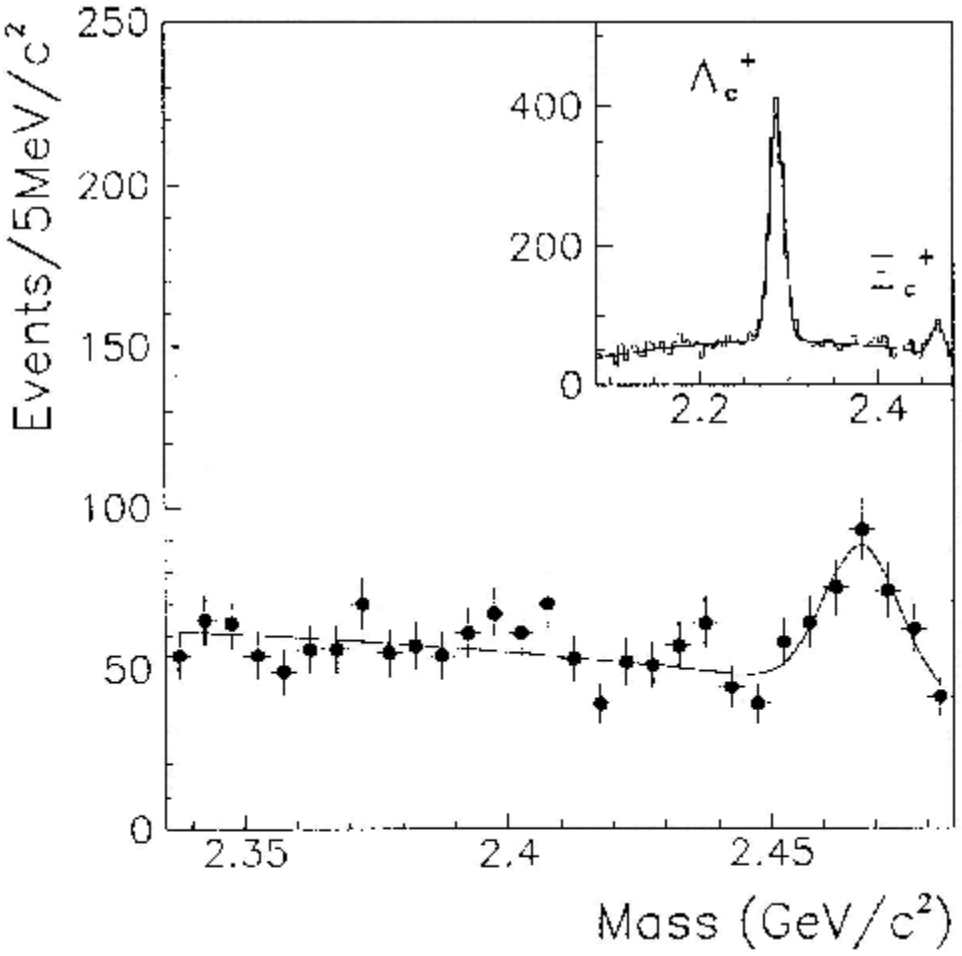
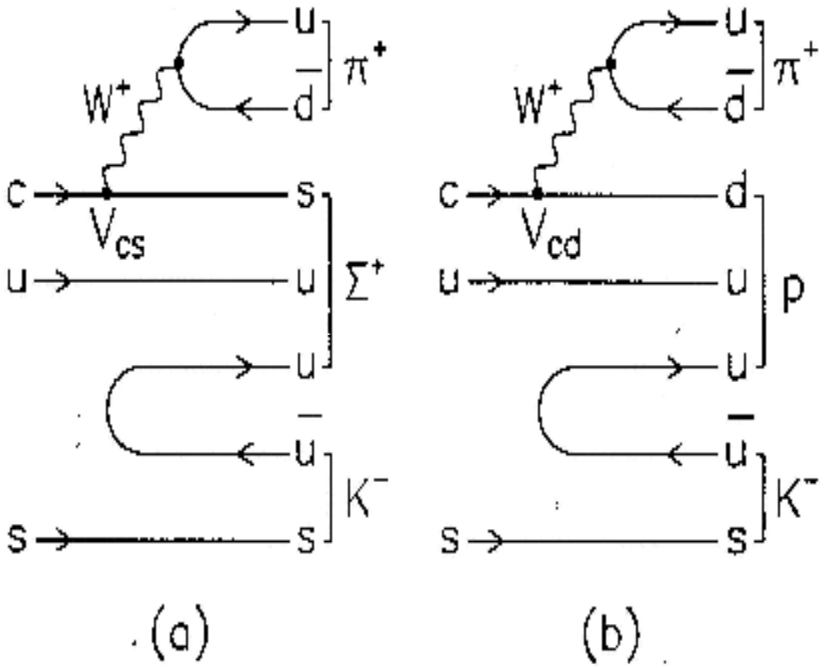


SELEX lifetime of Λ_c^+ in comparison with the results of other experiments.

SELEX



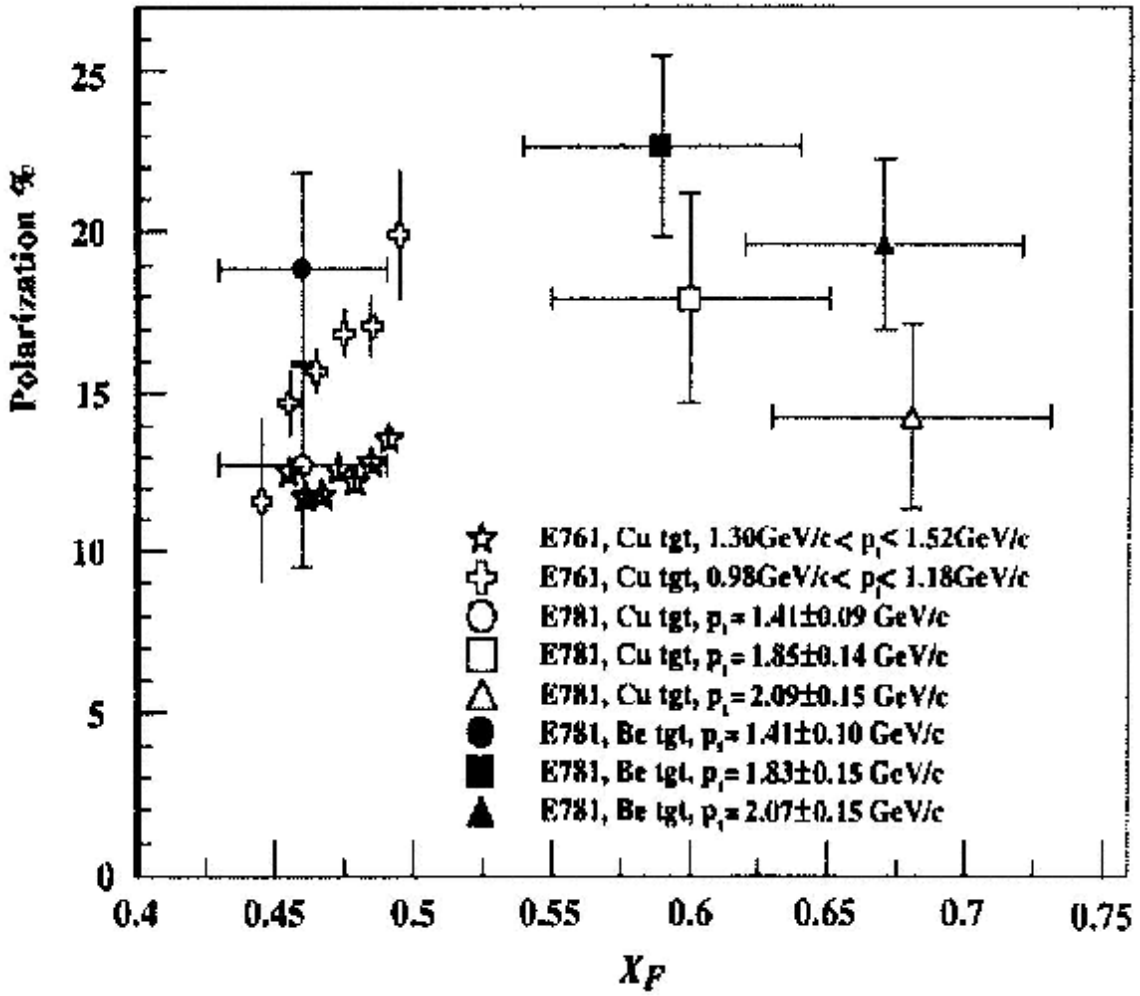
Ξ_c^+ CF decay; Ξ_c^+ CS decay



150 +/- 22 events. $B(\Xi_c^+ \rightarrow pK^-\pi^+)/B(\Xi_c^+ \rightarrow \Sigma^+K^-\pi^+) = 2.1\alpha \tan^2\theta_c$ α=2.0+/-0.5

S ≈ 7. $B(\Lambda_c^+ \rightarrow pK^-K^+)/B(\Lambda_c^+ \rightarrow pK^-\pi+)$ → α=2.5+/-0.6

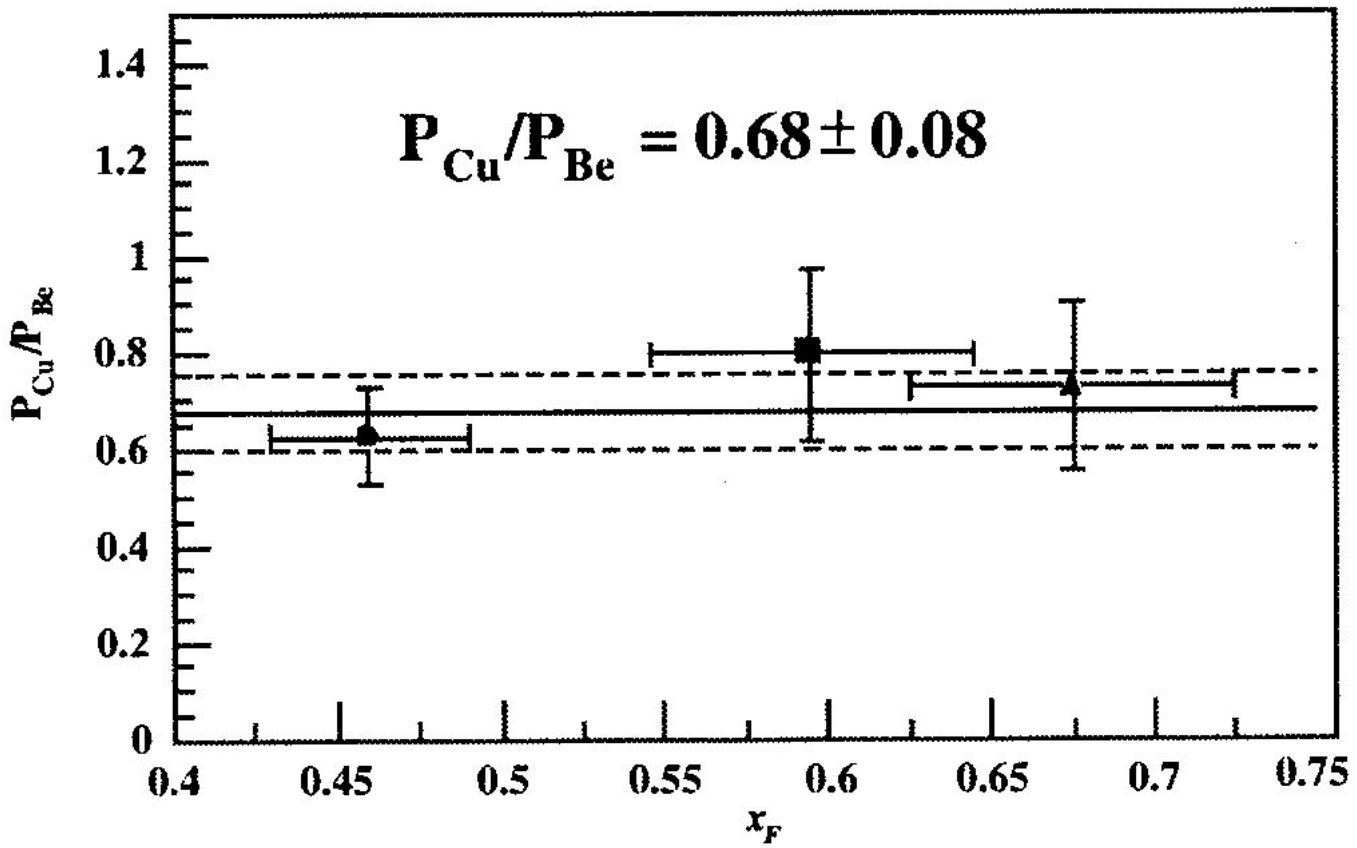
SELEX



Σ^+ polarization
as a function of x_F
for Cu and Be targets.

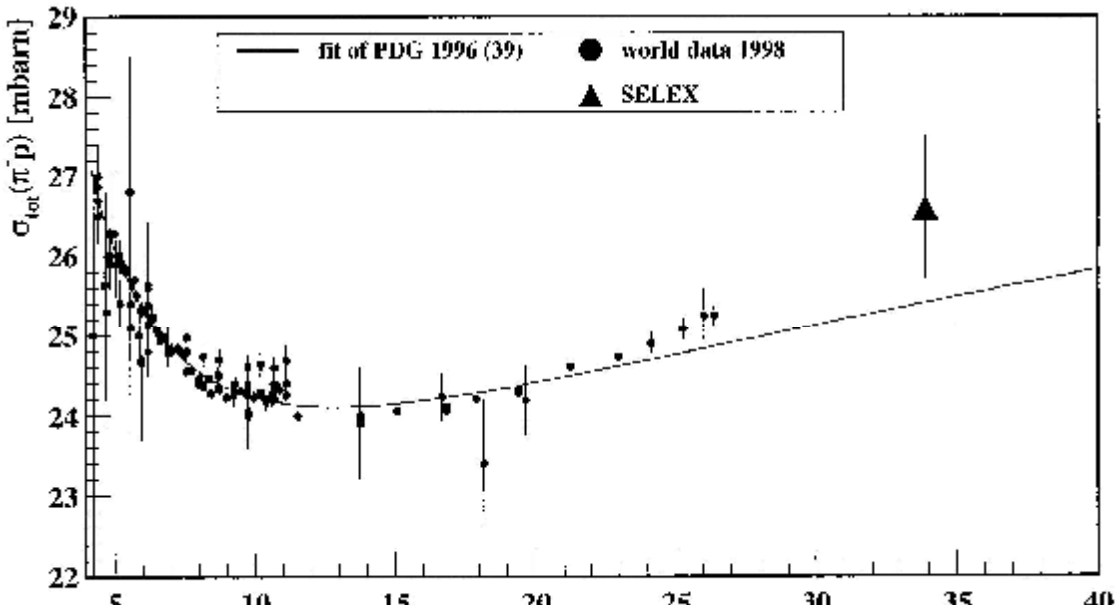
(The production angle
was 4 mrad; the polarization
is perpendicular to the
production plane)

SELEX



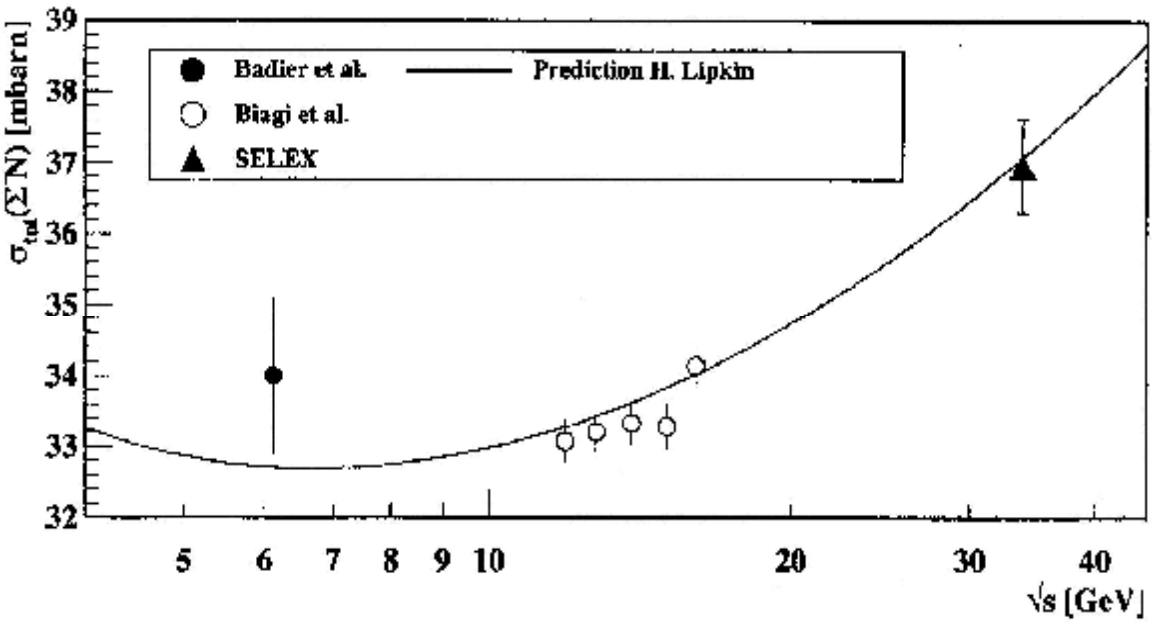
Σ^+ polarization ratio vs x_F.

SELEX



Total π^-p cross section

SELEX and other data

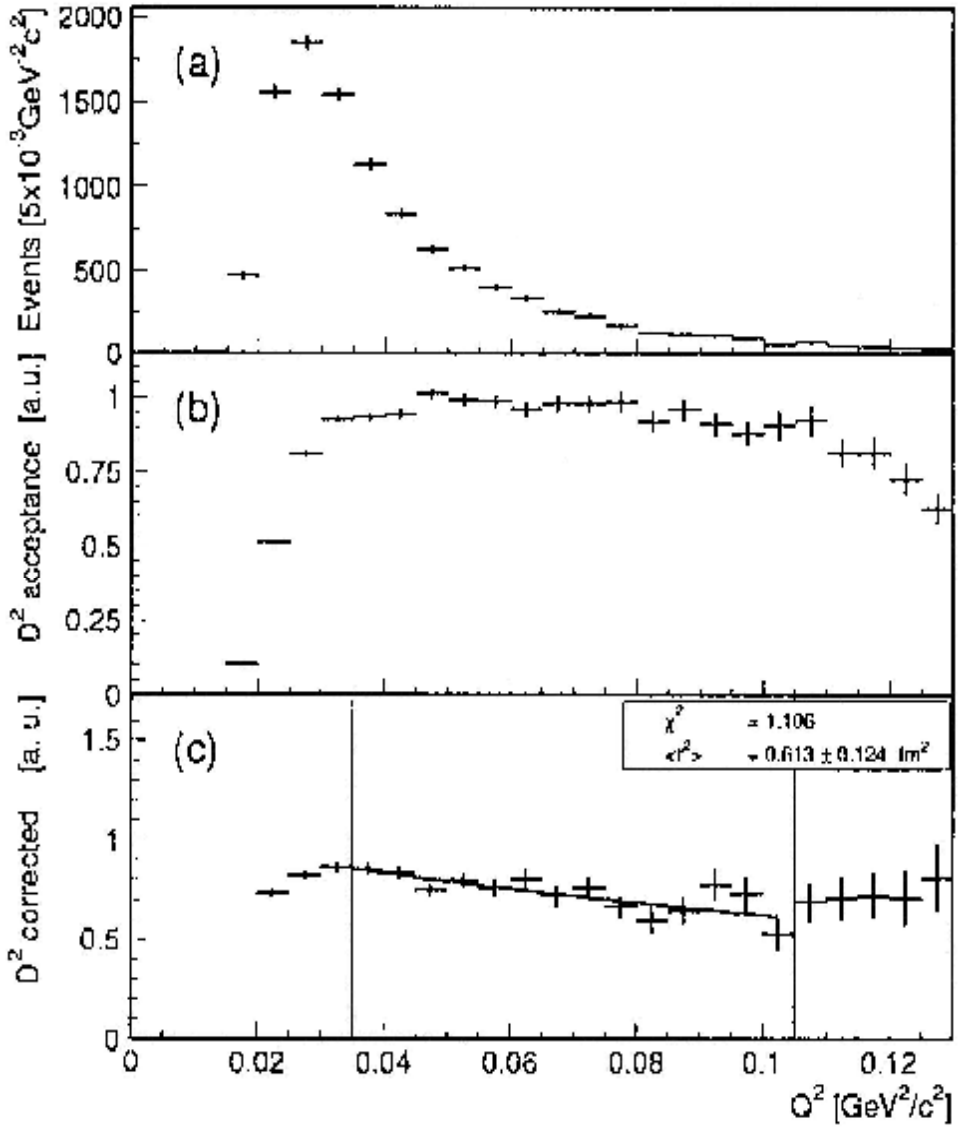


Total Σ^-p cross section

SELEX and other data

SELEX

Σ^-e elastic scattering



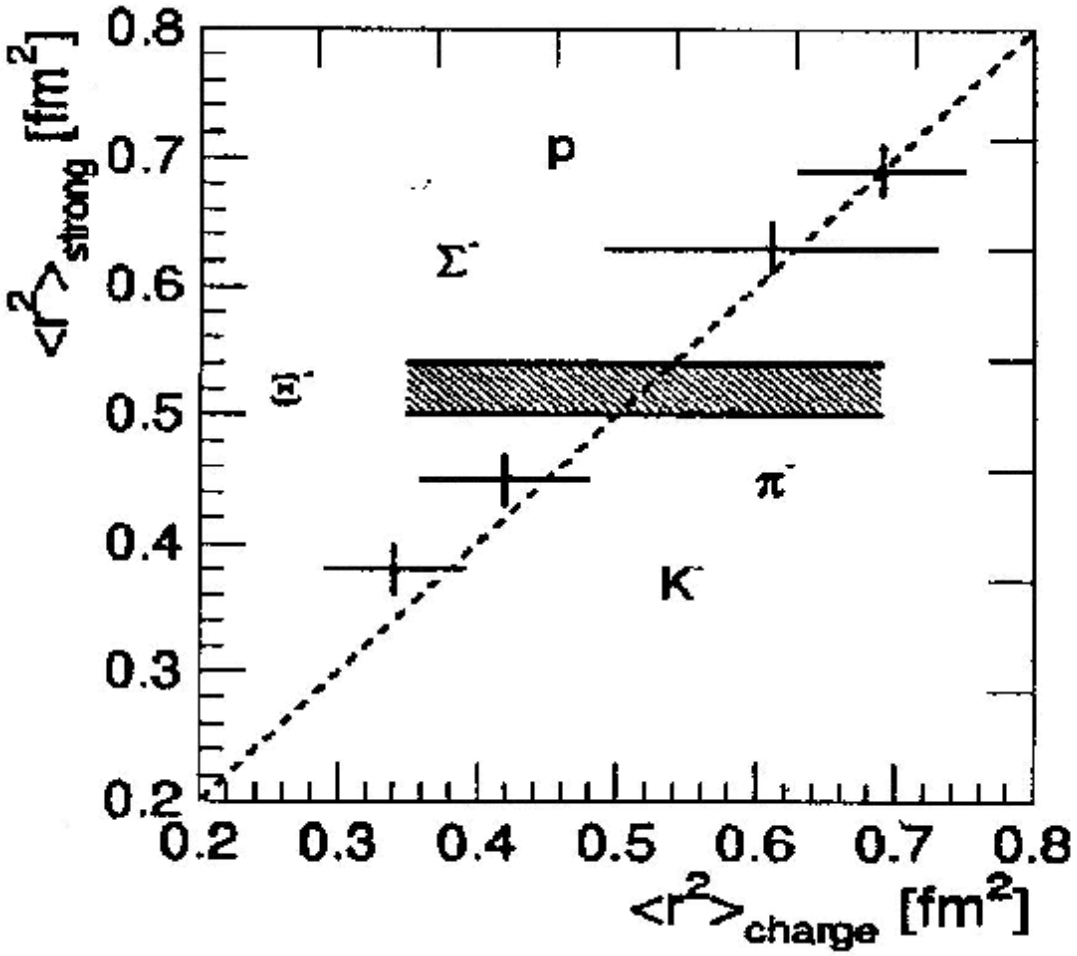
Q^2 Λ_c events distribution

Acceptance as a function of Q^2.

Formfactor squared.

$F(Q)=1 - Q^2\langle r^2\rangle/6$.

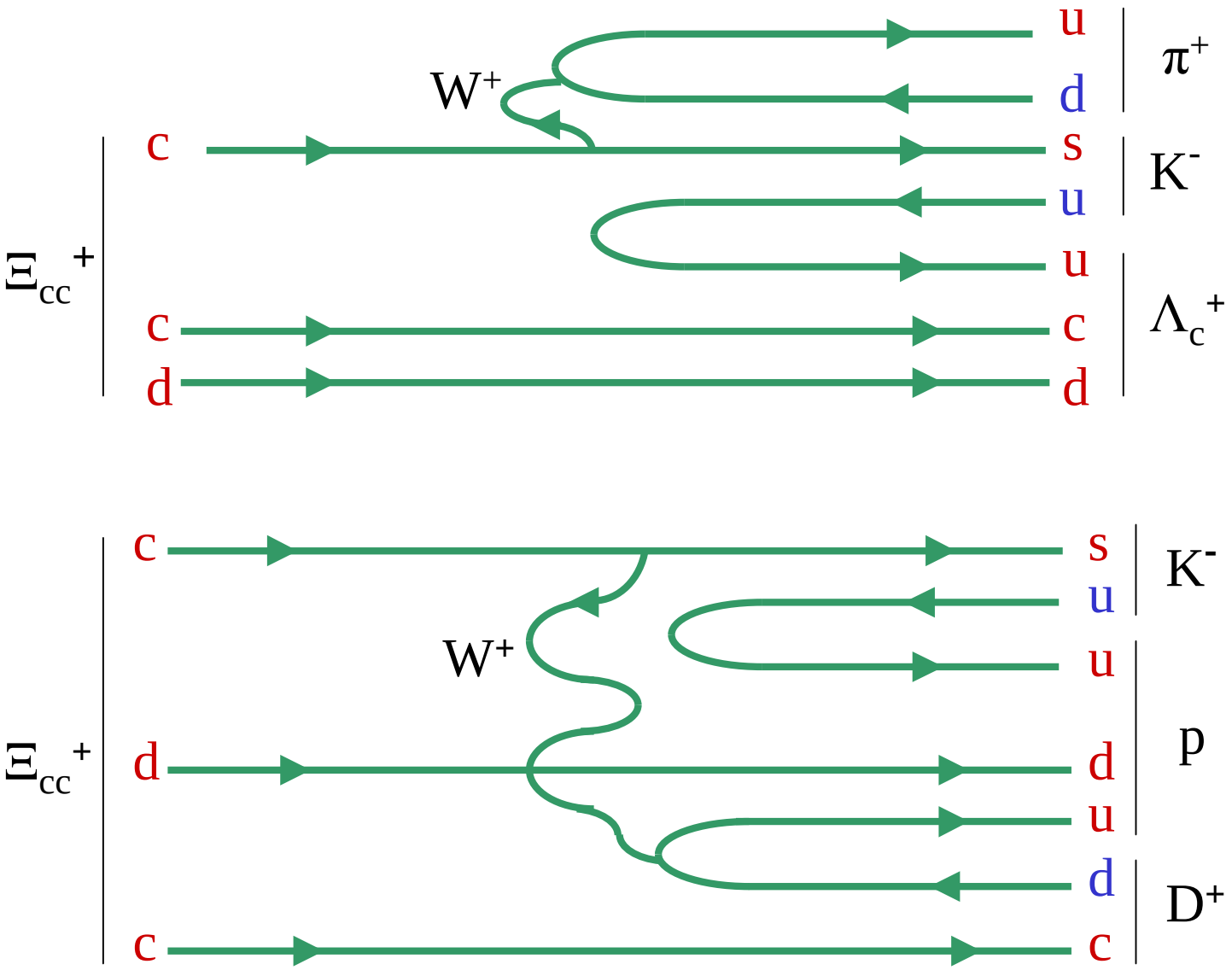
SELEX



Comparison of strong and electromagnetic mean squared radii for proton, Ξ^-, and π^- from SELEX data and for K^- and Ξ^- from other data.

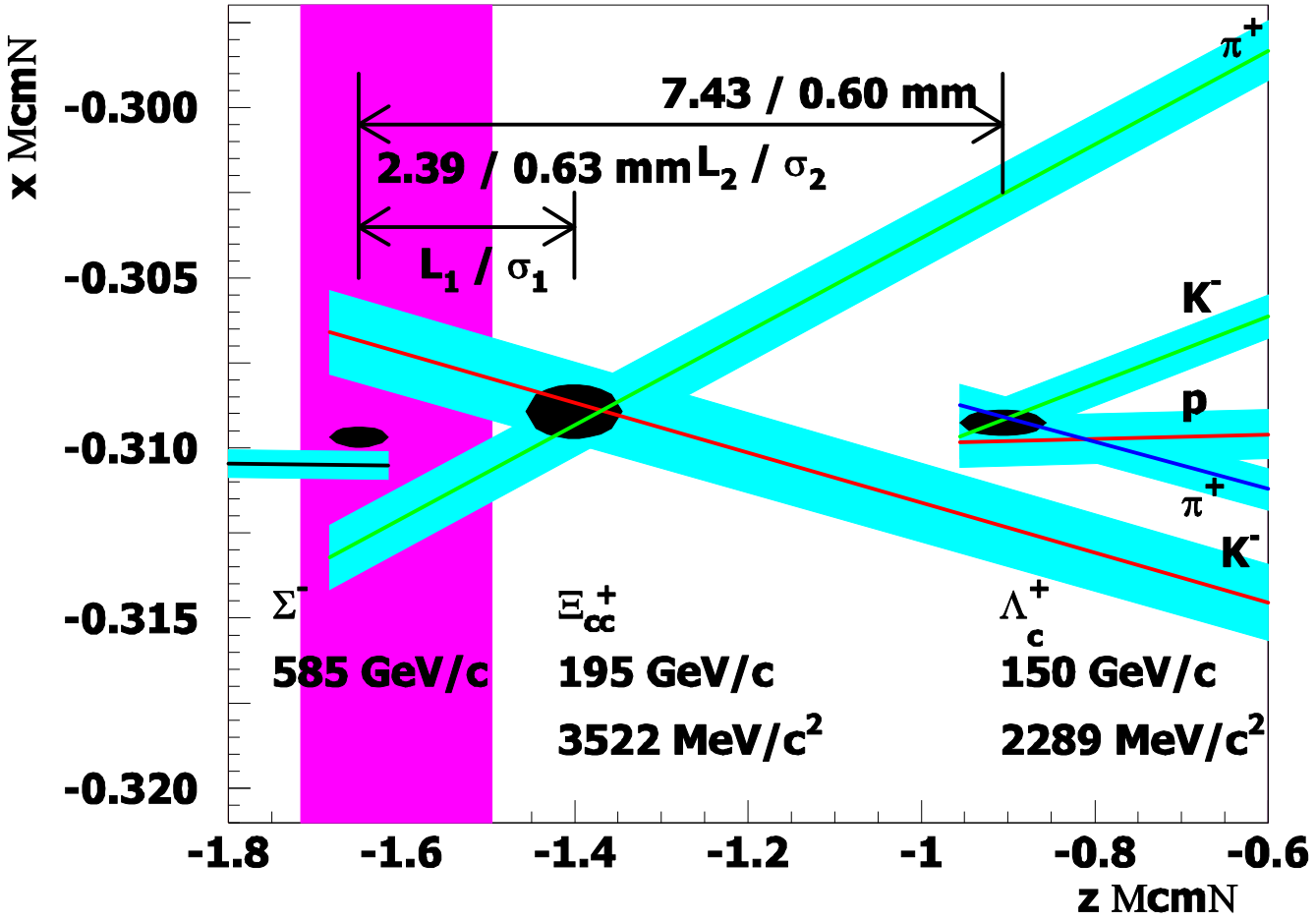
SELEX

Double charm baryon search strategy



$\Xi_{cc}^{+} \rightarrow \Lambda_c^{+} K^{-} \pi^{+}$

$\Lambda_c^{+} \rightarrow K^{-} p \pi^{+}$



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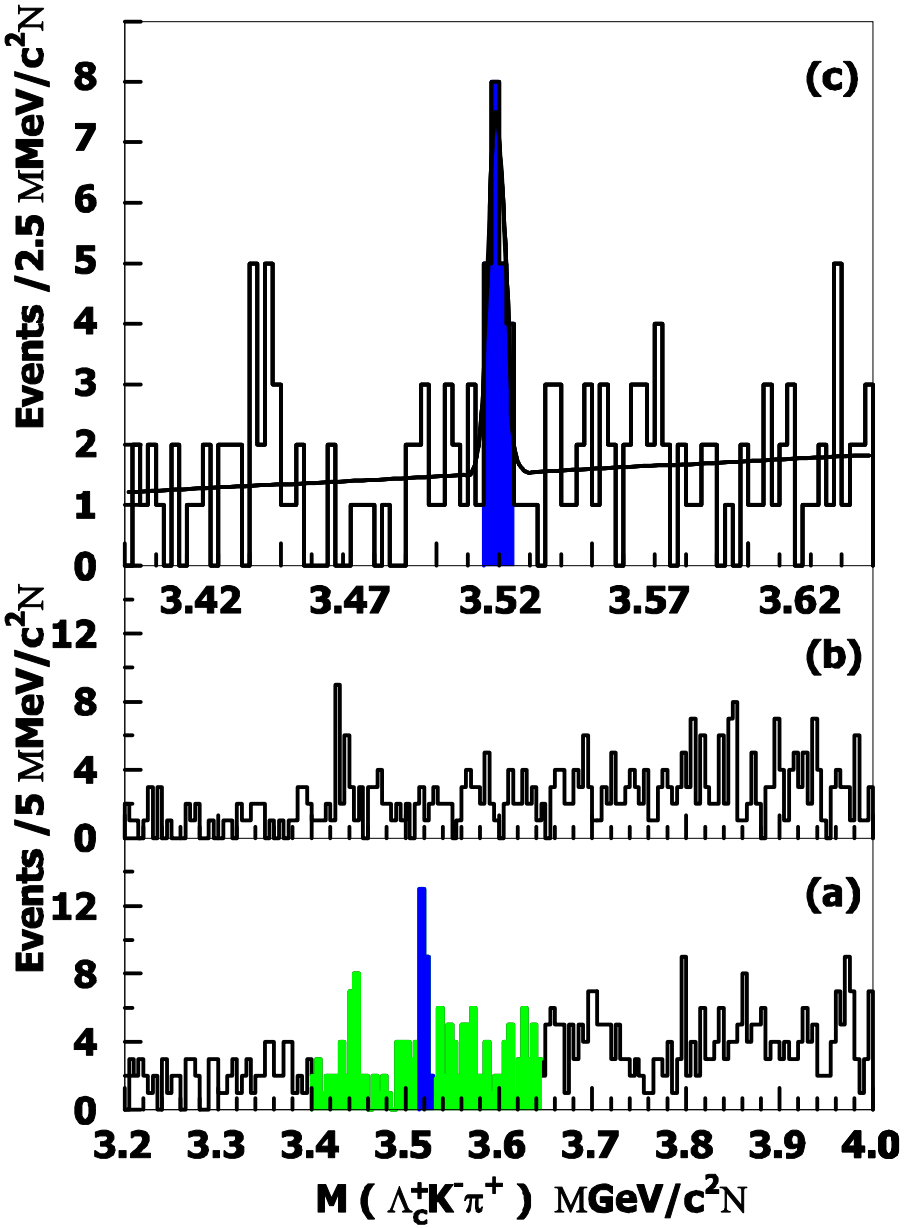


16 событий над фоном, равным 6.1+/-0.5.

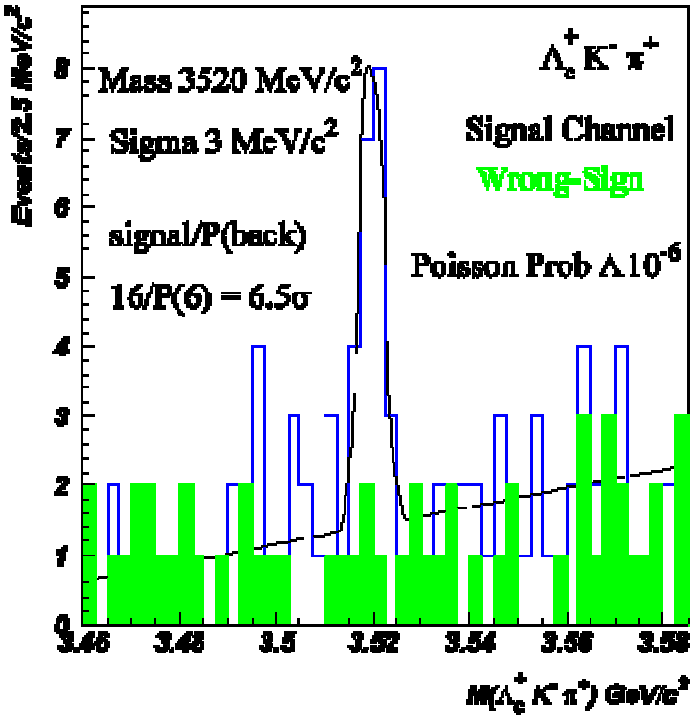
Статистическая значимость – 6.3σ.

Вероятность случайного выброса – 10^{-4}.

SELEX

Results from ccd^+ Search

$K^-\pi^+\Lambda_c^+$: Phys. Rev. Lett **89**,112001(2002)



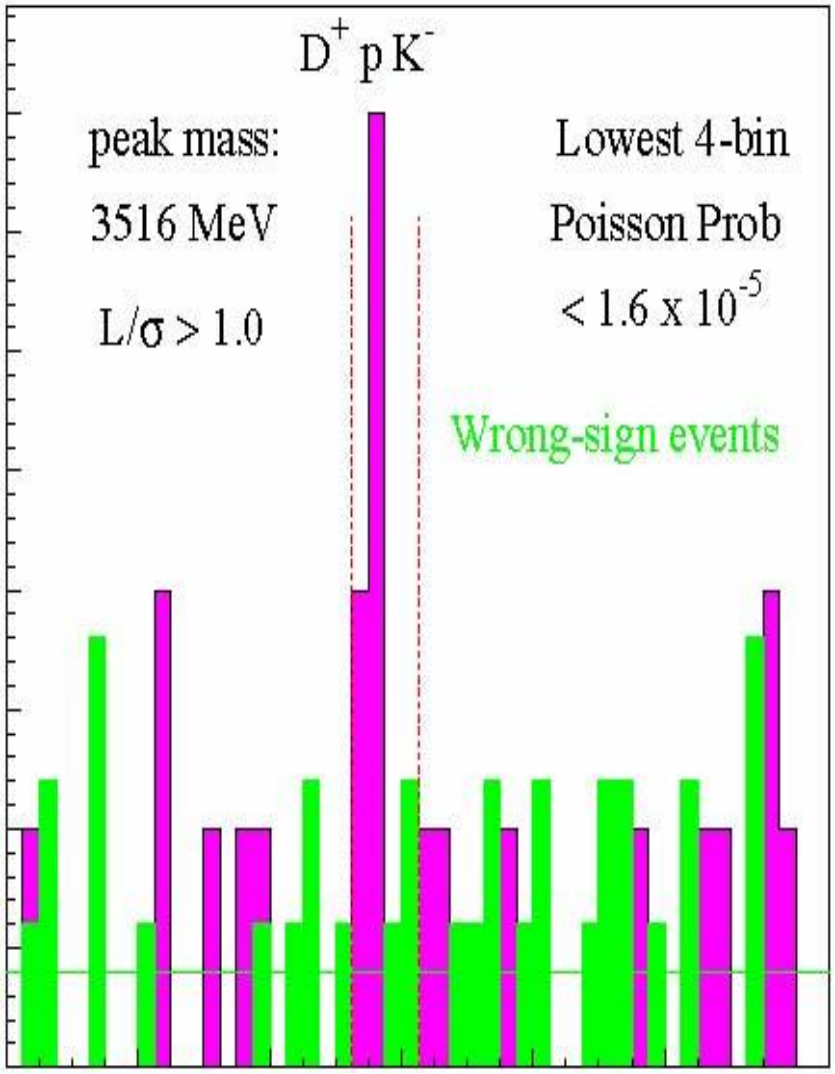
- look for extra vertex between primary and Λ_c^+ with vertex significance ≥ 1.
- If it's double charm, ccq decay has to make a K^-
- Results confirmed by two independent, different analysis methods

Right-sign channel has peak at 3520 MeV/c^2

Wrong-sign channel has no significant structure

Calculate m(ccd^+) using m(Λ_c^+) = 2.2849 GeV/c^2 Poisson Probability for peak anywhere on plot: 1.1×10^{-4}

SELEX



$\Xi^+_{cc} \rightarrow pD^+K^-$

Confirmation of the Double Charm Baryon $\Xi^+_{cc}(3520)$ via its decay to pD^+K^-

5.4 событий над фоном 1,6+/-0.35. Вероятность случайного выброса- $1.5*10^{-5}$.

Вероятность статистической флуктуации в двух экспериментах- $1.5*10^{-9}$.

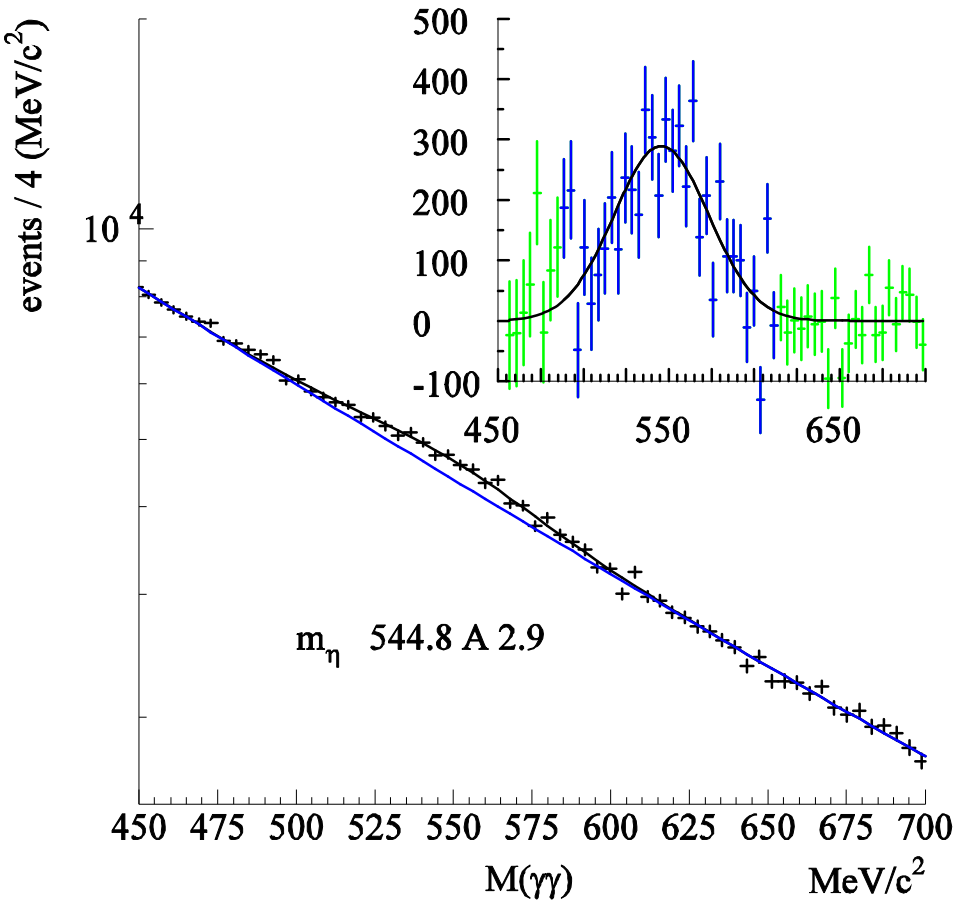
SELEX

$D^+_s(2632) \rightarrow D^+_s \eta$

$D^+_s \rightarrow K^+ K^- \pi^+$ $\qquad \eta \rightarrow \gamma + \gamma$

First observation of a Narrow Charm-Strange Meson $D^+_{sJ}(2632)$

In 2003, BaBar, Cleo, Belle $D_{sJ}(2317)$ and $D_{sJ}(2463)$



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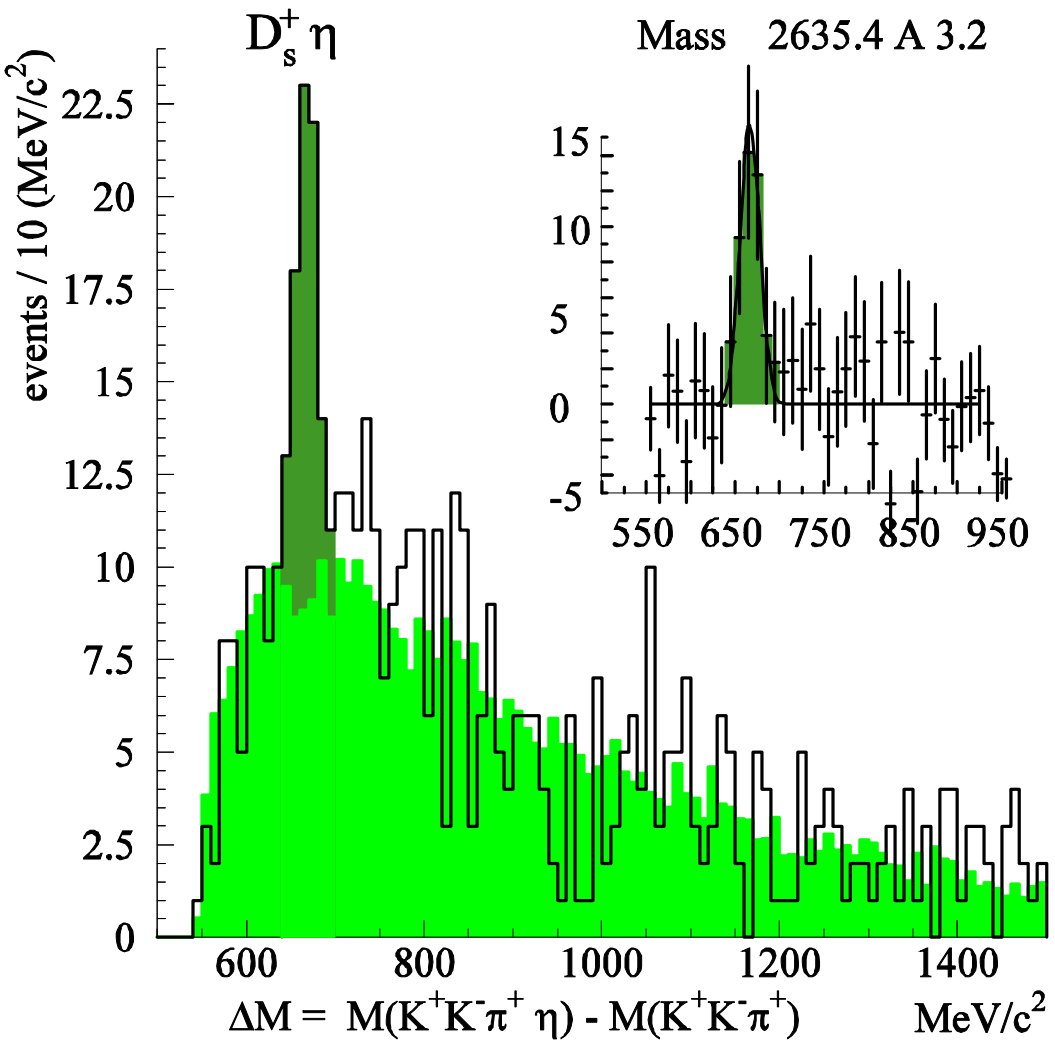

$D^+_s(2632) \rightarrow D^+_s \eta$

49 событий над фоном в 52 события.
Значимость – 7.2 σ.

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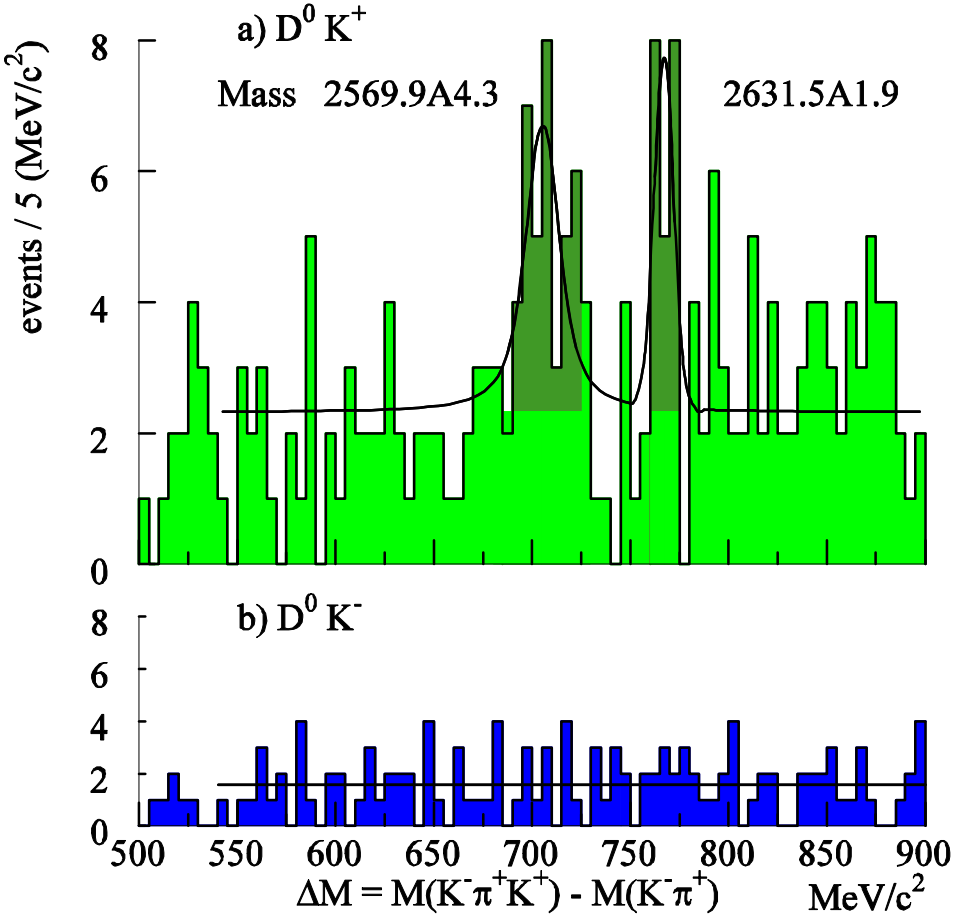
$D^+_s(2632) \rightarrow D^0 K^+$



$D^0 \rightarrow K^- \pi^+$ Q≈275 MeV

14 событий над фоном в 7 событий.
Значимость – 5.3 σ.

The relative branching ratio $\Gamma(D^0K^+)/\Gamma(D^+_s)$ = 0.16 +/- 0.06.

K. Chao Phys. Lett. B 599 (2004) 43,
Barnes et.al., hep-ph/0407120,
Beverin et al., hep-ph/0407281 :

$D^+_{sJ}(2632)$ → first radial excitation of the 1^- of $D_s^*(2112)$.

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CONCLUSION

SELEX has obtained a number of physical results.
The most interesting results are
The discovery of a doubly charmed baryon $\Xi_{cc}^{+}(3520)$ and
Observation of a heavy charm-strange meson $D_{sJ}(2632)$

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