Experimental studies of the nuclear dependence of charm production

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AFTER @ LHC Workshop, Trento
7 February 2013

Outline

Introduction

Hadro-Production of Charm

- Usual parametrization of material dependent cross section: $\sigma \propto A^{\alpha}$
- From Λ-Production: $\alpha = \alpha(x_F, p_t)$
- Charm: Published α vary between 2/3 and 1, different(?) for open and hidden charm.
- Usually experiments only give one α averaged over their (x_F, p_t) acceptance
- No model on first principle exists, even less for double charm
- Still problems calculating double-double-charm production in $e^+e^- \rightarrow J/\Psi\eta_c$!!!
- Important input for other fields like Heavy-Ion Collisions

Hadro-Production of Charm in SELEX

- SELEX has charm signals with decent statistics in 14 particles and modes, in several x_F and p_t bins.
- D^+, D^0, D_s^+, $D^+(2010)$, Λ_c^+, and charge-conjugate
- 2 Copper and 3 Carbon Targets
- 4 different beam particles: Σ^-, π^-, p, π^+
- Cross check results with Λ and K^0 production

PhD Thesis E. Alejandro Blanco-Covarrubias
European Physical Journal C, Vol.64, 637-644 (2009)
arXiv:0902.0355 [hep-ex]

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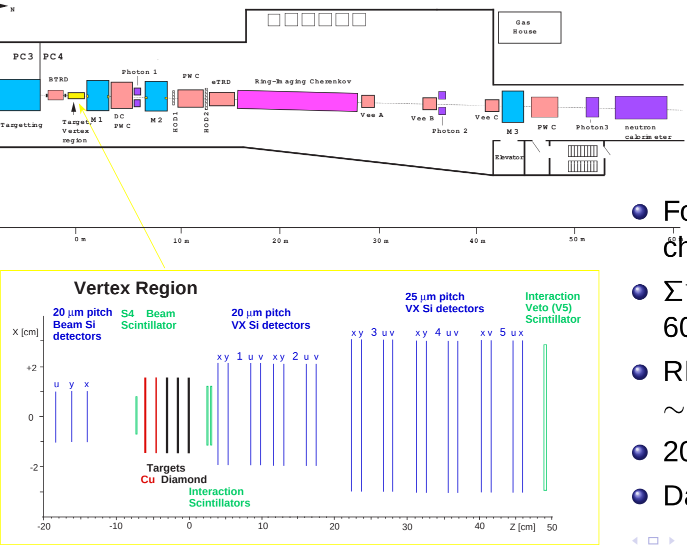
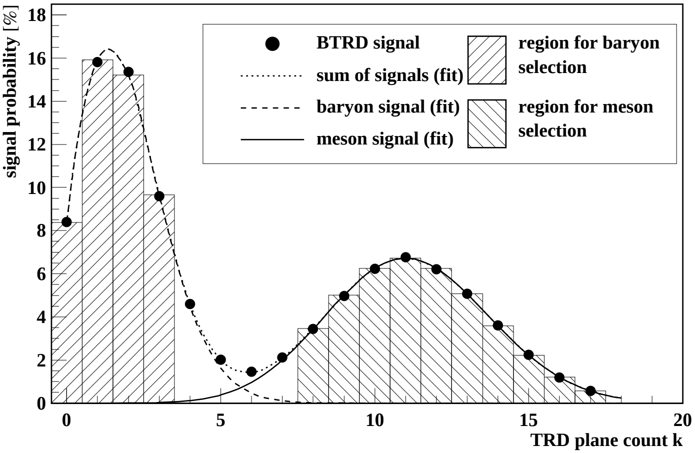
Selex (E781)
Proton Center Layout

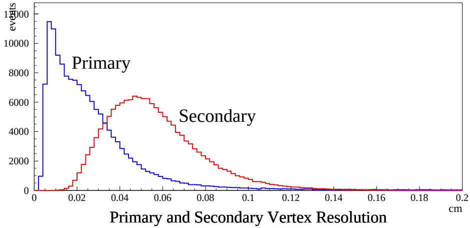


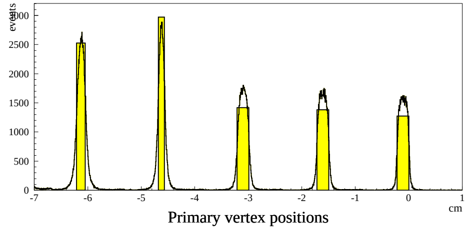
- Forward ($x_F > 0.1$) charm production
- Σ^-, $\pi^\pm$, p beam at 600 GeV$/c$
- RICH PID above $\sim$ 22 GeV$/c$
- 20 plane Si-Vertex.
- Data taken 1996/7

Beam tagging: TRD



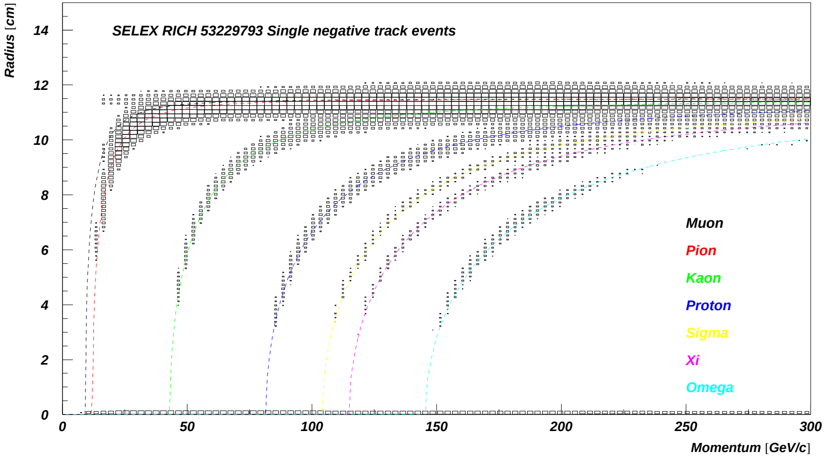
Vertex Spectrometer Performance



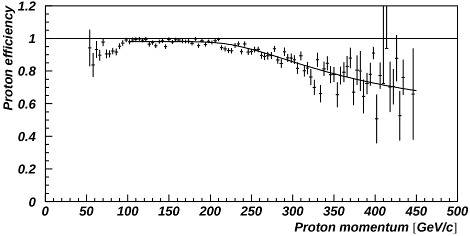


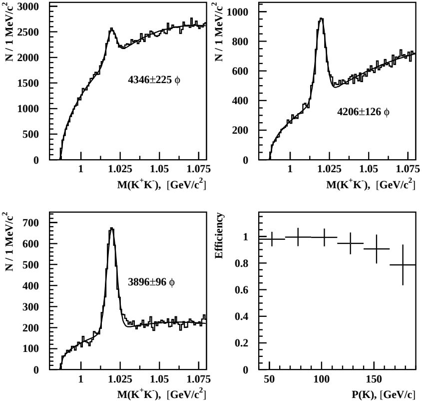
- transverse vtx resolution 8-15 μm
- 20 highly-efficient vertex planes over-determine tracks, reduce tracking confusion in high-multiplicity events
- target foils 0.8-2.2 mm thick with 1.5 cm spacing to localize primary interaction
- Lifetime resolution 20 – 40 fs depending on particle/mode

Ring Imaging Cherenkov Counter Performance (1)

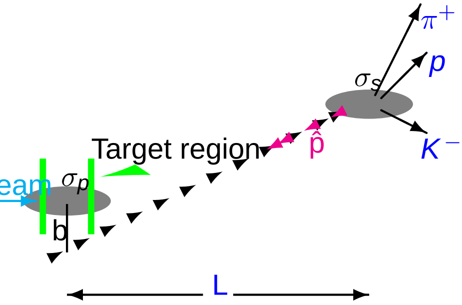


Ring Imaging Cherenkov Counter Performance (2)





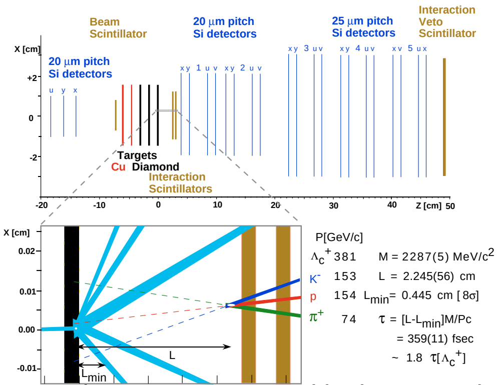
SELEX Single Charm Analysis



Charm Analysis Cuts

- 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
- Proton and Kaon identified in RICH detector

SELEX Charm Selection Criteria



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

Charm Selection Cuts for single charm studies:

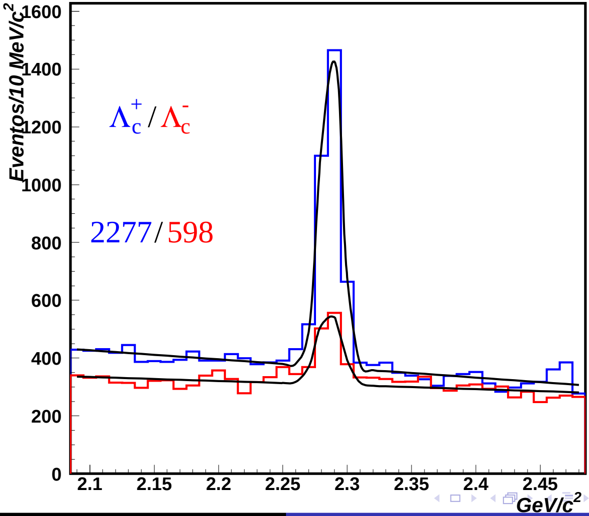
- secondary vertex significance:
  - $L/\sigma \geq 1$ short-lived states (Ξ_c^0, Ω_c^0)
  - $L/\sigma \geq 8$ long-lived states (Λ_c^+, D^+)
- Pointback $\leq$ 4 ($2\sigma_b$)
- *second*-largest miss significance among decay tracks $\geq$ 4.

Charm Particles and Decay modes

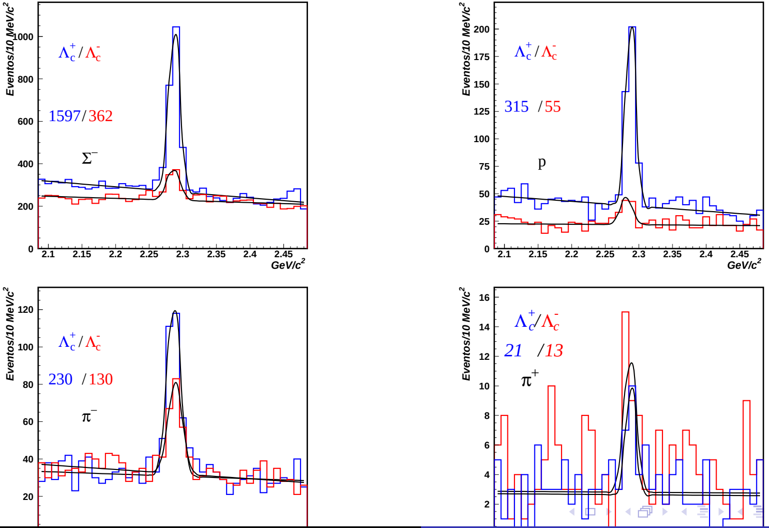
- $\Lambda_c^+ \rightarrow pK^-\pi^+$
- $D_s^+ \rightarrow K^-K^+\pi^+$
- $D^+ \rightarrow K^-\pi^+\pi^+$
- $D^0 \rightarrow K^+\pi^-$
- $D^0 \rightarrow K^+\pi^-\pi^-\pi^+$
- $D^{\star+} \rightarrow D^0\pi^+, D^0 \rightarrow K^+\pi^-$
- $D^{\star+} \rightarrow D^0\pi^+, D^0 \rightarrow K^+\pi^-\pi^-\pi^+$

All modes also with corresponding anti-particles

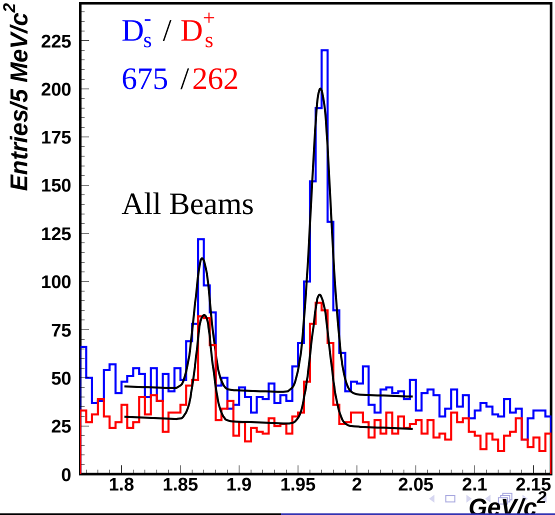
$\Lambda_c^+ \rightarrow pK^-\pi^+ + c.c.$



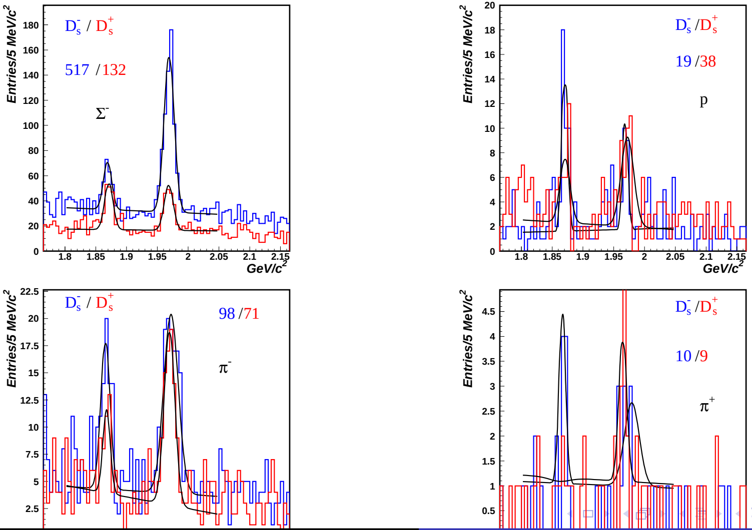
$\Lambda_c^+ \to pK^-\pi^+ + c.c.$



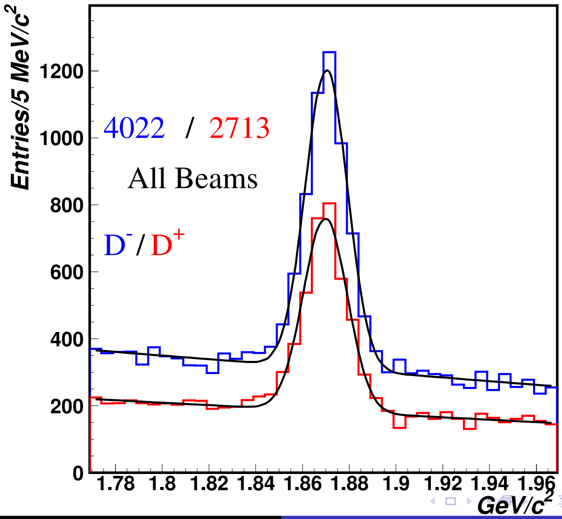
$D_s^+ \rightarrow K^- K^+ \pi^+ + c.c.$



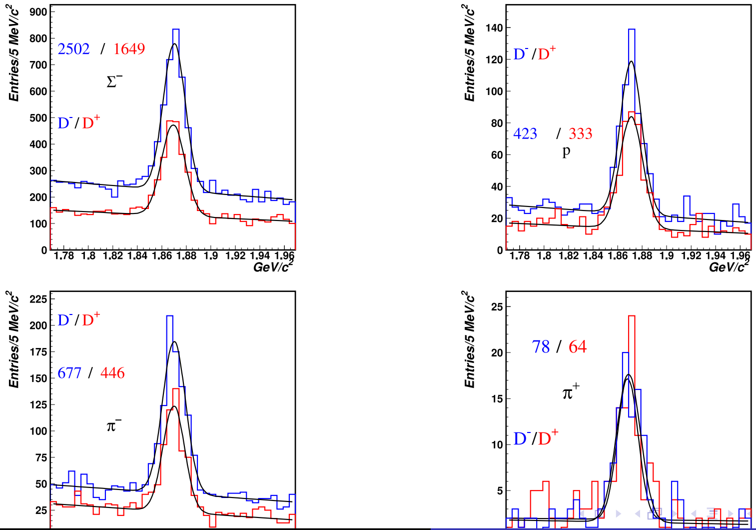
$D_s^+ \rightarrow K^-K^+\pi^+ + c.c.$



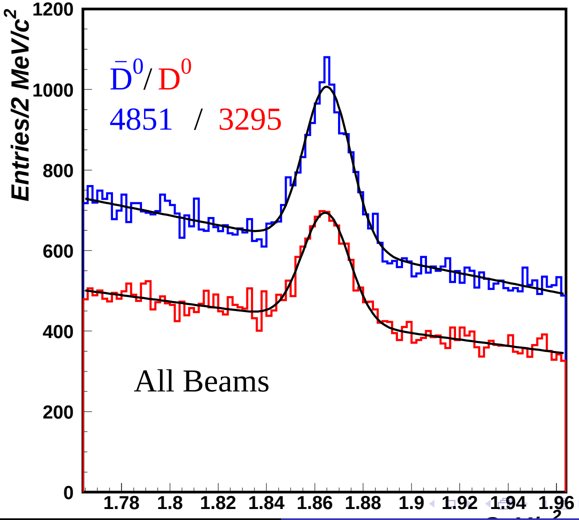
$D^+ \to K^-\pi^+\pi^+ + c.c.$


Entries/5 MeV/c^2
1200
1000
800
600
400
200
0
4022 / 2713
All Beams
D$^-$ / D$^+$
1.78 1.8 1.82 1.84 1.86 1.88 1.9 1.92 1.94 1.96
GeV/c^2

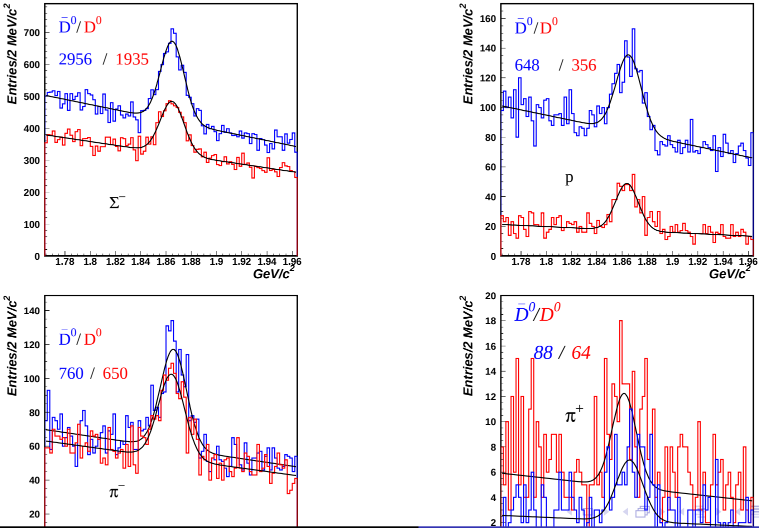
$D^+ \to K^-\pi^+\pi^+ + c.c.$


Entries/5 MeV/c²
2502 / 1649
Σ⁻
D⁻/D⁺
GeV/c²
Entries/5 MeV/c²
D⁻/D⁺
423 / 333
p
GeV/c²
Entries/5 MeV/c²
D⁻/D⁺
677 / 446
π⁻
Entries/5 MeV/c²
78 / 64
π⁺
D⁻/D⁺

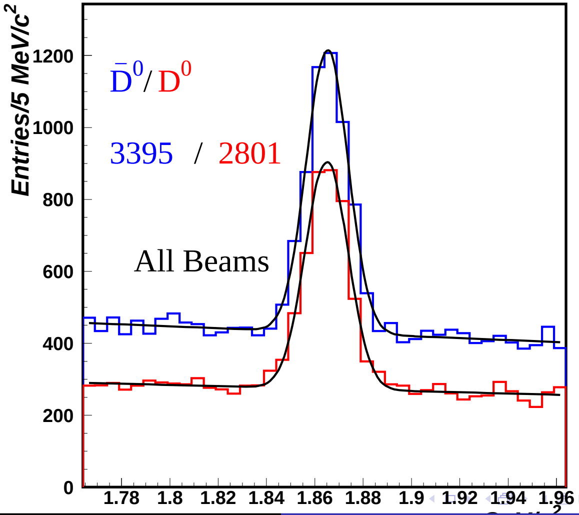
$D^0 \to K^+\pi^- + c.c.$


$\bar{D}^0$/ D^0
4851 / 3295
All Beams
Entries/2 MeV/c^2
1200
1000
800
600
400
200
0
1.78
1.8
1.82
1.84
1.86
1.88
1.9
1.92
1.94
1.96

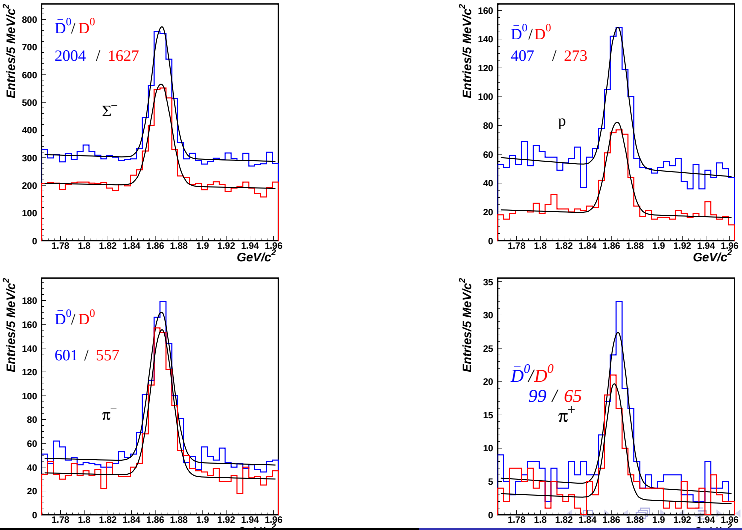
$D^0 \to K^+\pi^- + c.c.$


$\bar{D}^0$/D^0
2956 / 1935
Σ^-
Entries/2 MeV/c²
GeV/c²
$\bar{D}^0$/D^0
648 / 356
p
Entries/2 MeV/c²
GeV/c²
$\bar{D}^0$/D^0
760 / 650
π^-
Entries/2 MeV/c²
$\bar{D}^0$/D^0
88 / 64
π^+
Entries/2 MeV/c²

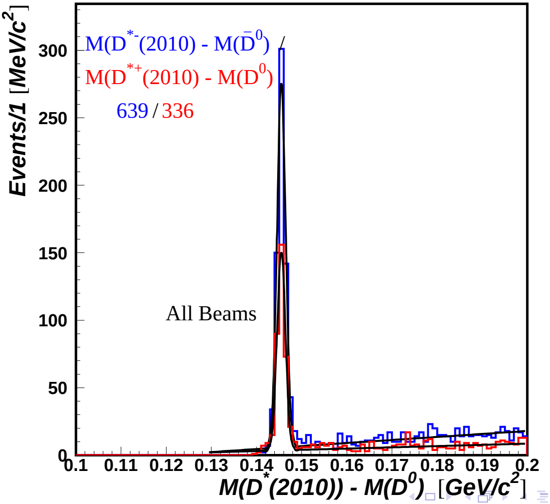
$D^0 \rightarrow K^+\pi^-\pi^-\pi^+ + c.c.$



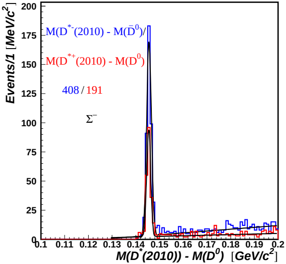
$D^0 \to K^+\pi^-\pi^-\pi^+ + c.c.$

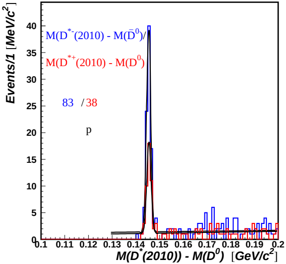


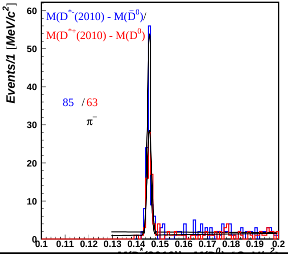
$D^{\star +} \rightarrow D^0\pi^+, D^0 \rightarrow K^+\pi^- + c.c.$



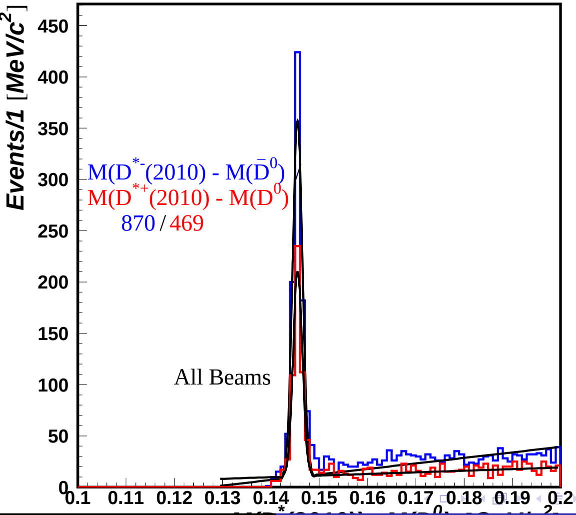
$D^{\star+} \to D^0\pi^+, D^0 \to K^+\pi^- + c.c.$



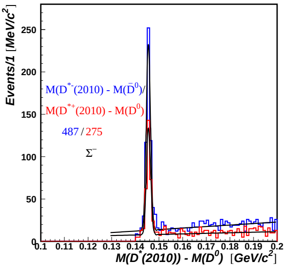


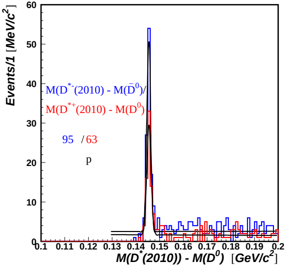


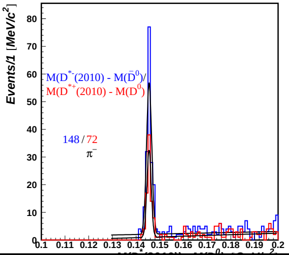
$D^{\star +} \rightarrow D^0 \pi^+, D^0 \rightarrow K^+ \pi^- \pi^- \pi^+ + c.c.$



$D^{\star +} \to D^0\pi^+, D^0 \to K^+\pi^-\pi^-\pi^+ + c.c.$







Further Analysis

- Subdivide the 14 particles/modes into
  - 4 different beam particles (for most modes)
  - 5 different target foils
  - 4 x_F bins

  $\Rightarrow$ 736 different numbers of observed particle yields (via sideband subtraction)
- Correct for acceptance and reconstruction efficiencies as a function of x_F, p_t^2, and target foil
- Study systematics by comparing the corrected yields for 2 copper and 3 diamond targets
  $\Rightarrow$ Systematic problem for the first copper target
- Cross check analysis procedure with $\Lambda^0 \rightarrow p\pi^-$

Measuring α

Summing the corrected yields for the 3 diamond targets and the copper target:

$$\alpha = \frac{\ln\left(\frac{N_{\mathrm{Cu}}}{N_{\mathrm{C}}}\frac{\rho_{\mathrm{C}}}{\rho_{\mathrm{Cu}}}\frac{L_{\mathrm{C}}}{L_{\mathrm{Cu}}}\frac{A_{\mathrm{Cu}}}{A_{\mathrm{C}}}\right)}{\ln\left(\frac{A_{\mathrm{Cu}}}{A_{\mathrm{C}}}\right)} = \frac{\ln\frac{N_{\mathrm{Cu}}}{N_{\mathrm{C}}}}{\ln\frac{A_{\mathrm{Cu}}}{A_{\mathrm{C}}}} + \frac{\ln\left(\frac{\rho_{\mathrm{C}}}{\rho_{\mathrm{Cu}}}\frac{L_{\mathrm{C}}}{L_{\mathrm{Cu}}}\frac{A_{\mathrm{Cu}}}{A_{\mathrm{C}}}\right)}{\ln\frac{A_{\mathrm{Cu}}}{A_{\mathrm{C}}}}$$

$A_{\mathrm{C}}, A_{\mathrm{Cu}}$	Atomic masses
$L_{\mathrm{C}}, L_{\mathrm{Cu}}$	Total thickness of the targets
$\rho_{\mathrm{C}}, \rho_{\mathrm{Cu}}$	Densities
$N_{\mathrm{C}}, N_{\mathrm{Cu}}$	Acceptance corrected yields

Measuring α requires knowledge of yields AND target material

148 α-values

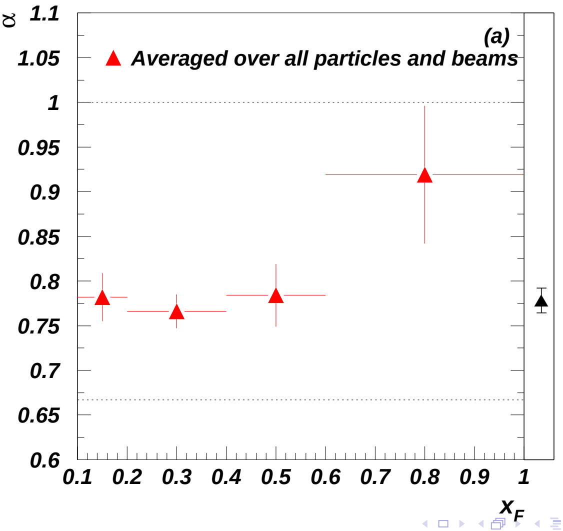
Beam	Mode	α $0.1 < x_F < 0.2$	α $0.2 < x_F < 0.4$	α $0.4 < x_F < 0.6$	$x_F >$
Σ^-	1	0.75 ± 0.07	0.72 ± 0.07	0.48 ± 0.25	–
Σ^-	2	0.80 ± 0.05	0.70 ± 0.06	0.98 ± 0.18	0.71
Σ^-	3	0.52 ± 0.18	0.66 ± 0.09	0.57 ± 0.22	0.67
Σ^-	4	0.47 ± 0.19	0.67 ± 0.09	0.80 ± 0.17	1.23
Σ^-	5	0.75 ± 0.09	0.68 ± 0.07	0.33 ± 0.27	–
Σ^-	6	0.80 ± 0.08	0.79 ± 0.06	0.74 ± 0.13	0.84
Σ^-	7	0.86 ± 0.24	0.89 ± 0.15	0.57 ± 0.31	–
Σ^-	8	0.63 ± 0.19	0.73 ± 0.11	0.74 ± 0.20	–
Σ^-	9	0.43 ± 0.45	0.41 ± 0.17	0.88 ± 0.17	–
Σ^-	10	0.80 ± 0.21	0.80 ± 0.10	0.84 ± 0.14	0.47
Σ^-	11	1.10 ± 0.38	1.07 ± 0.19	–	–
Σ^-	12	0.99 ± 0.35	0.79 ± 0.12	0.87 ± 0.16	–
Σ^-	13	0.70 ± 0.20	0.95 ± 0.08	0.90 ± 0.10	0.83
Σ^-	14	1.32 ± 0.25	0.74 ± 0.24	–	

Results

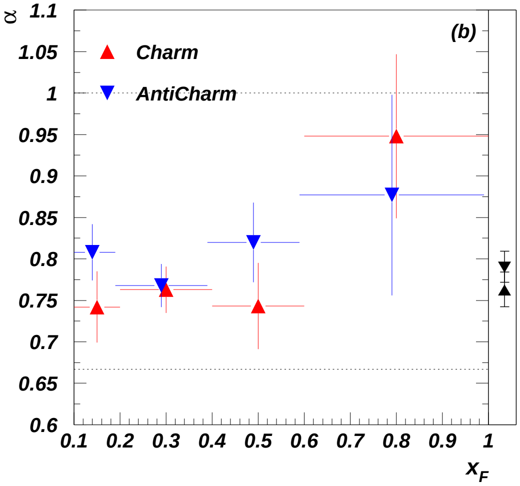
Every single value has large errors
$\Rightarrow$ Average the values for different combinations

- All particles and beams
- charm / anti-charm
- baryon / meson beams
- leading / non-leading particles
- In modes/beams with enough statistics: High / low p_t^2

α: All beams all particles

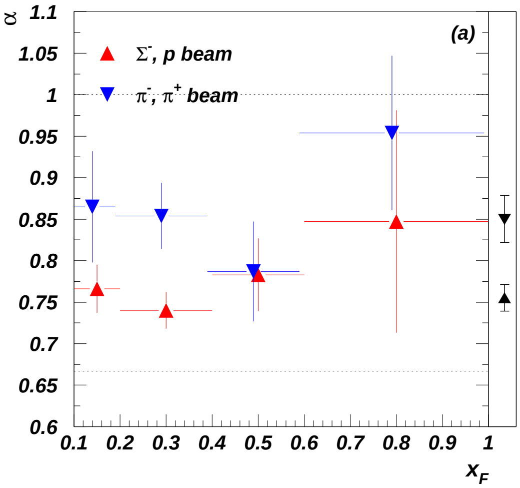


α: Charm / Anti-Charm



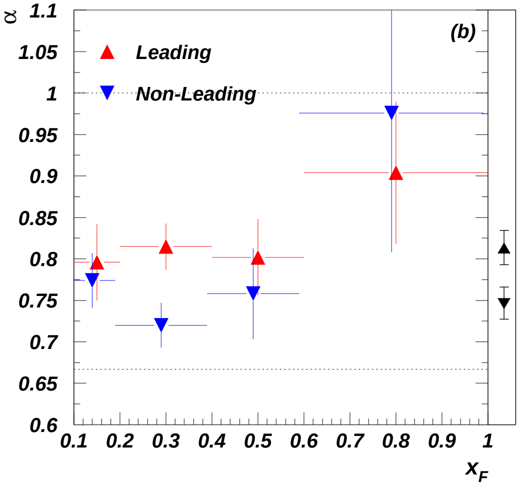
No difference when separating in charm and anti-charm final

α: Baryon / Meson Beam



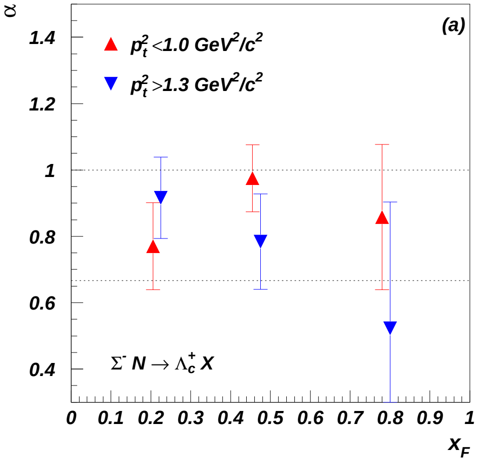
3 σ difference in production by baryon and meson beams

α: Leading / Non-leading particles



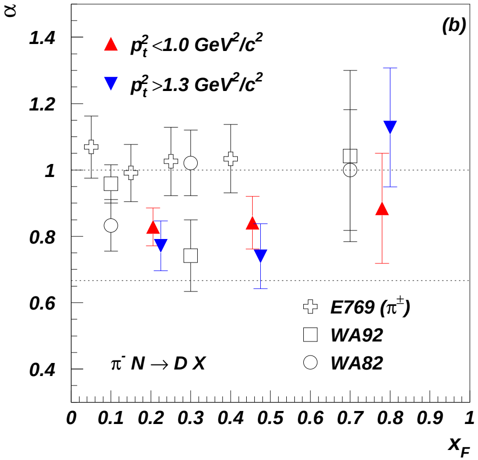
2.3 σ difference when separating in leading and non-leading

α: Low/High p_t^2: Λ_c with Σ^- beam



No difference for low/high p_t^2 production

α: Low/High p_t^2: all D's with π^- beam



No difference for low/high p_t^2 production

After our publication....

After we published these results:
Contact with Boris Kopeliovich via Stan Brodsky

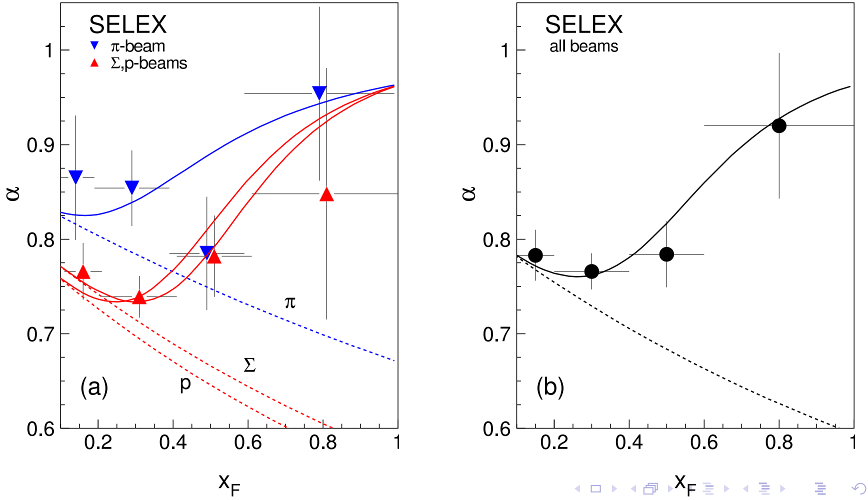
Boris requested more combinations:

- Mesons / Baryons with different beams

Penetrating Intrinsic Charm: Evidence in Data
by B.Z. Kopeliovich, I.K. Potashnikova, Ivan Schmidt
arXiv:1003.3673 [hep-ph]

Unfortunately, Boris did not publish this paper.

Figures from arXiv:1003.3673 [hep-ph]



Conclusions

- SELEX studied the A dependence of Charm Hadro-Production for
  - different charm particles
  - different beams
  - several x_F and p_t^2 bins