Measurements of the properties of $\Lambda_c(2595)$, $\Lambda_c(2625)$, $\Sigma_c(2455)$, $\Sigma_c(2520)$ baryons by CDF – contents analysis

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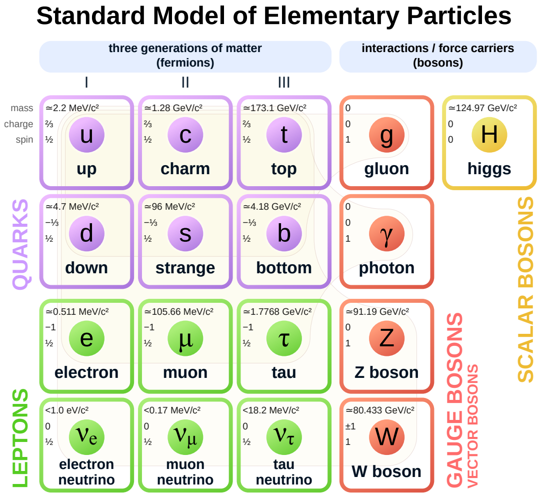
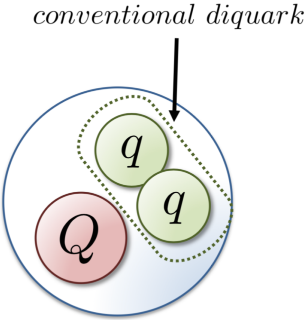
Introduction & motivation





$\Sigma_c(2455)^{++}$ $\Sigma_c(2455)^{0}$

$\Sigma_c(2520)^{++}$ $\Sigma_c(2520)^{0}$

$\Lambda_c(2595)^{+}$ $\Lambda_c(2625)^{+}$

World average values at the time of this analysis

TABLE II: World average values of the mass differences between the charmed baryon resonances and the Λ_c^+ mass, ΔM, and their natural widths, Γ [18].

Hadron	ΔM [MeV/c^2]	Γ [MeV/c^2]
$\Sigma_c(2455)^{++}$	167.56 ± 0.11	2.23 ± 0.30
$\Sigma_c(2455)^0$	167.30 ± 0.11	2.2 ± 0.4
$\Sigma_c(2520)^{++}$	231.9 ± 0.6	14.9 ± 1.9
$\Sigma_c(2520)^0$	231.6 ± 0.5	16.1 ± 2.1
$\Lambda_c(2595)^+$	308.9 ± 0.6	$3.6^{+2.0}_{-1.3}$
$\Lambda_c(2625)^+$	341.7 ± 0.6	< 1.9 at 90% C.L.

Experimental data selection

- Based on data from CDF II detector at Tevatron.
  Collected from 2002 to 2009: 5.2 fb^{-1} of integrated luminosity.
- Tracking system,
  Momentum measurement,
  Energy measurement,
  Time-of-flight sensor.
  Combined, they also provide particle identification.
- Event selection in several steps using neural networks at each one.
  - Selection of Λ_c^+ (ground state) candidates in $pK^-\pi^+$ spectrum.
  - Selection of $\Sigma_c(2455)$ candidates in $\Lambda_c^+\pi^\pm$ mass spectra.
  - Selection of $\Lambda_c(2625)^+$ candidates in $\Lambda_c^+\pi^+\pi^-$ spectrum.

Selection of Λ_c^+ candidates

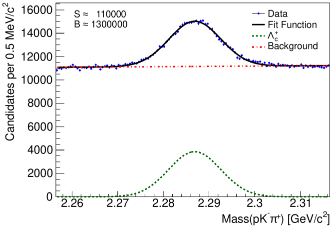


FIG. 1: (color online) The mass distribution of Λ_c^+ candidates used to train one of the two neural networks for the Λ_c^+ selection.

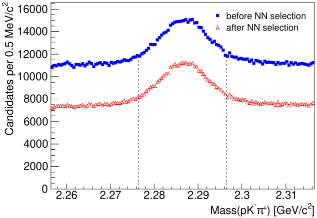
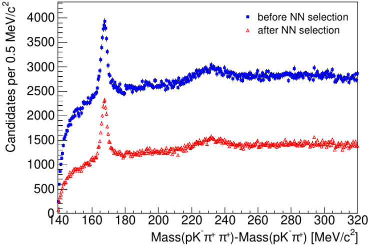


FIG. 2: (color online) The mass distributions of Λ_c^+ candidates before (blue full squares) and after (red open triangles) requiring their neural network output to correspond to an *a posteriori* signal probability greater than 2.5%. The vertical dashed lines indicate a $\pm 10\,\mathrm{MeV}/c^2$ region around the nominal Λ_c^+ mass [18] used for the selection of the Σ_c and Λ_c^{*+} states.

Event selection in $\Lambda_c^+\pi^\pm$ spectra



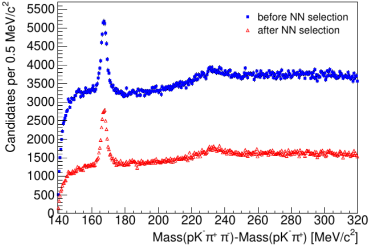


FIG. 3: (color online) The mass difference distributions of the $\Lambda_c^+\pi^+$ (left) and $\Lambda_c^+\pi^-$ (right) candidates before (blue full squares) and after (red open triangles) applying the neural network selection.

Event selection in $\Lambda_c^+\pi^+\pi^-$ spectrum

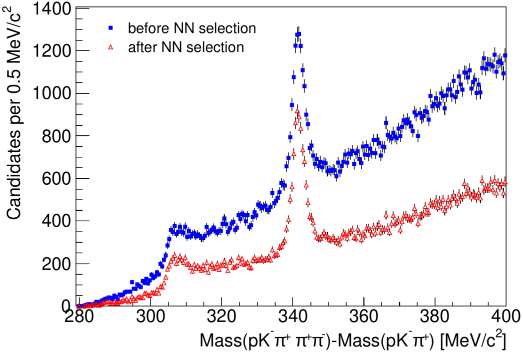


FIG. 4: (color online) The mass difference distribution of the $\Lambda_c^+\pi^+\pi^-$ candidates before (blue full squares) and after (red open triangles) applying the neural network selection.

Models and approximation of $\Lambda_c^+\pi^\pm$ spectra

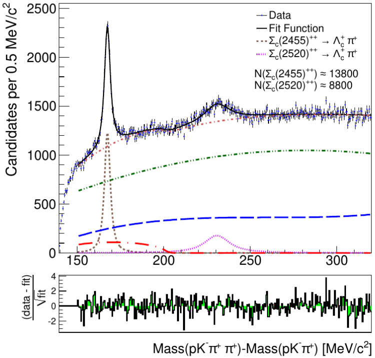


FIG. 7: (color online) The $M(pK^-\pi^+\pi^+) - M(pK^-\pi^+)$ (left) and $M(pK^-\pi^+\pi^-) - M(pK^-\pi^+)$ (right) distributions obtained from data (points with error bars) together with the fits (black solid line). The brown dashed and purple dotted lines correspond to the two signal contributions, the green dash-double-dotted line represents the combinatorial background without real Λ_c^+, the blue long-dashed line shows real Λ_c^+ combined with a random pion and the red long-dash-dotted line represents a reflection from Λ_c^{*+} decays. The red dash-dotted line corresponds to the sum of all three background contributions.

Model and approximation of $\Lambda_c^+\pi^+\pi^-$ spectrum

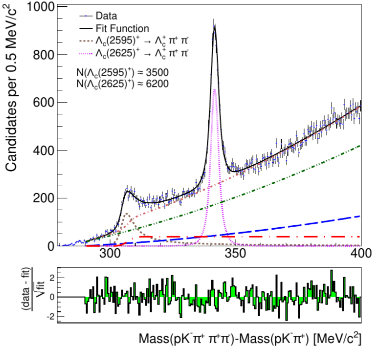


FIG. 11: (color online) The $M(pK^-\pi^+\pi^+\pi^-) - M(pK^-\pi^+)$ distribution obtained from data (points with error bars) together with the fit (black solid line). The brown dashed and purple dotted lines correspond to the two signal contributions, the green dash-double-dotted line represents the combinatorial background without real Λ_c^+, the blue long-dashed line shows real Λ_c^+ combined with two random pions and the red long-dash-dotted line represents real Σ_c combined with a random pion. The red dash-dotted line corresponds to the sum of all three background contributions.

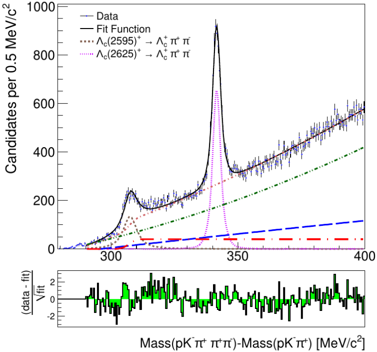


FIG. 12: (color online) The $M(pK^-\pi^+\pi^+\pi^-) - M(pK^-\pi^+)$ distribution obtained from data (points with error bars) together with the fit (black solid line), where a Breit-Wigner function with a mass-independent decay width is used to model the $\Lambda_c(2595)^+$ line shape. Explanations of the various background contributions can be found in the caption of Fig. 11.

Systematic uncertainties

TABLE IV: Systematic uncertainties on the measurements of the mass differences and decay widths of the Σ_c^{++} resonances. The corresponding statistical uncertainties are listed for comparison.

Source	$\Delta M(\Sigma_c(2455)^{++})$ [MeV/c^2]	$\Gamma(\Sigma_c(2455)^{++})$ [MeV/c^2]	$\Delta M(\Sigma_c(2520)^{++})$ [MeV/c^2]	$\Gamma(\Sigma_c(2520)^{++})$ [MeV/c^2]
Resolution model	...	0.40	...	0.69
Momentum scale	0.12	0.20	0.12	0.20
Fit model	0.02	...	0.11	1.16
External inputs	...	...	...	...
Sum	0.12	0.45	0.16	1.36
Statistical	0.04	0.13	0.56	2.12

TABLE V: Systematic uncertainties on the measurements of the mass differences and decay widths of the Σ_c^0 resonances. The corresponding statistical uncertainties are listed for comparison.

Source	$\Delta M(\Sigma_c(2455)^0)$ [MeV/c^2]	$\Gamma(\Sigma_c(2455)^0)$ [MeV/c^2]	$\Delta M(\Sigma_c(2520)^0)$ [MeV/c^2]	$\Gamma(\Sigma_c(2520)^0)$ [MeV/c^2]
Resolution model	...	0.45	...	0.70
Momentum scale	0.12	0.20	0.12	0.20
Fit model	0.02	...	0.11	1.16
External inputs	...	...	...	...
Sum	0.12	0.49	0.16	1.37
Statistical	0.03	0.11	0.43	1.82

TABLE VI: Systematic uncertainties on the measurements of the mass differences of the Λ_c^{*+} resonances and the pion coupling constant h_2^2 ($\Gamma(\Lambda_c(2595)^+)$). The corresponding statistical uncertainties are listed for comparison.

Source	$\Delta M(\Lambda_c(2595)^+)$ [MeV/c^2]	h_2^2	$\Gamma(\Lambda_c(2595)^+)$ [MeV/c^2]	$\Delta M(\Lambda_c(2625)^+)$ [MeV/c^2]
Resolution model	0.06	0.03	0.22	...
Momentum scale	0.12	0.03	0.20	0.12
Fit model	...	...	...	...
External inputs	0.15	0.06	0.36	...
Sum	0.20	0.07	0.47	0.12
Statistical	0.14	0.04	0.30	0.04

Results

TABLE VIII: Measured resonance parameters, where the first uncertainty is statistical and the second is systematic.

Hadron	ΔM [MeV/c^2]	Γ [MeV/c^2]
$\Sigma_c(2455)^{++}$	$167.44 \pm 0.04 \pm 0.12$	$2.34 \pm 0.13 \pm 0.45$
$\Sigma_c(2455)^{0}$	$167.28 \pm 0.03 \pm 0.12$	$1.65 \pm 0.11 \pm 0.49$
$\Sigma_c(2520)^{++}$	$230.73 \pm 0.56 \pm 0.16$	$15.03 \pm 2.12 \pm 1.36$
$\Sigma_c(2520)^{0}$	$232.88 \pm 0.43 \pm 0.16$	$12.51 \pm 1.82 \pm 1.37$
$\Lambda_c(2595)^{+}$	$305.79 \pm 0.14 \pm 0.20$	$h_2^2 = 0.36 \pm 0.04 \pm 0.07$
$\Lambda_c(2625)^{+}$	$341.65 \pm 0.04 \pm 0.12$	

$$\Gamma(\Lambda_c(2595)^+) = 2.59 \pm 0.30 \pm 0.47 \text{ MeV}$$