Results on Charm Baryon Spectroscopy from Tevatron

Study of $\Lambda_c(2595)$, $\Lambda_c(2625)$, $\Sigma_c(2455)$ and $\Sigma_c(2520)$ Baryons

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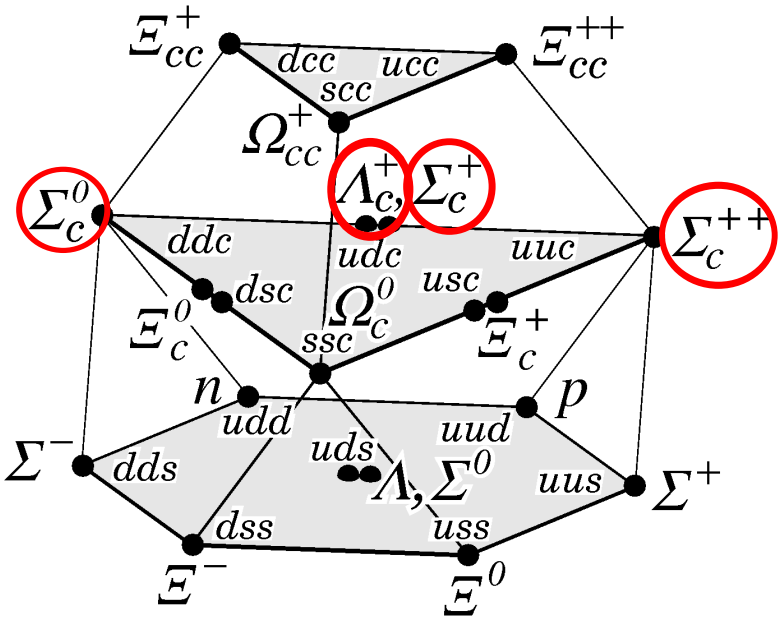
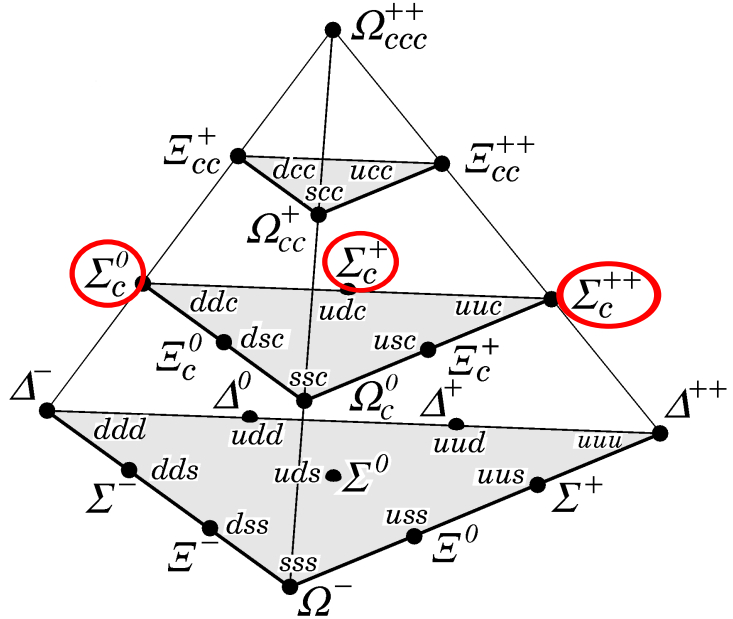
Charm Baryons



$J^P = \frac{1}{2}^+$

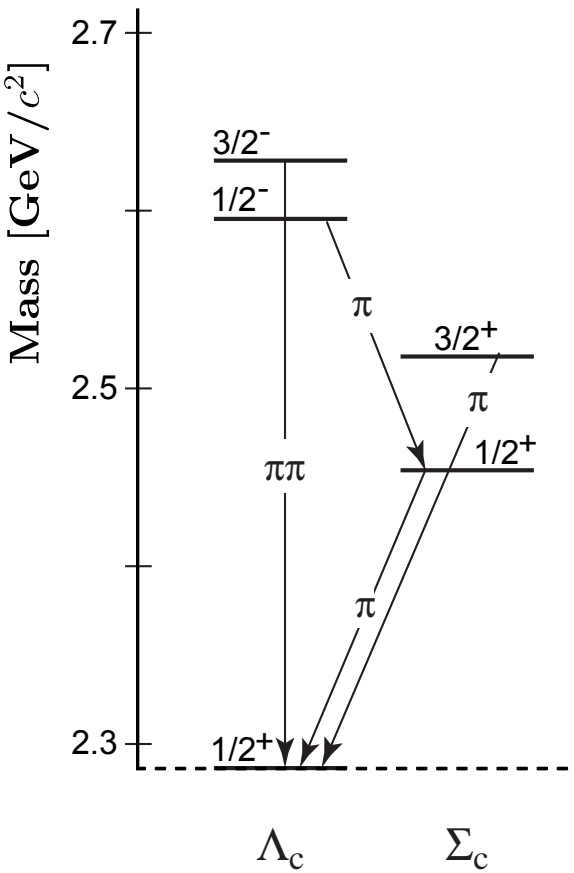


$J^P = \frac{3}{2}^+$

- Λ_c^+ ($J^P = \frac{1}{2}^+$) charm baryon with smallest mass $\rightarrow$ weak decay
- $\Sigma_c(2455)$ ($J^P = \frac{1}{2}^+$), $\Sigma_c(2520)$ ($J^P = \frac{3}{2}^+$)
  - Λ_c^+ spin excitations: spin-1 light diquark
  - isospin triplets Σ_c^0, Σ_c^+, Σ_c^{++}
  - strong decay to $\Lambda_c^+ \pi^{-,0,+}$

Λ_c^+ Orbital Excitations ($l = 1$)

$\Lambda_c(2595)^+$ ($J^P = \frac{1}{2}^-$) and $\Lambda_c(2625)^+$ ($J^P = \frac{3}{2}^-$)



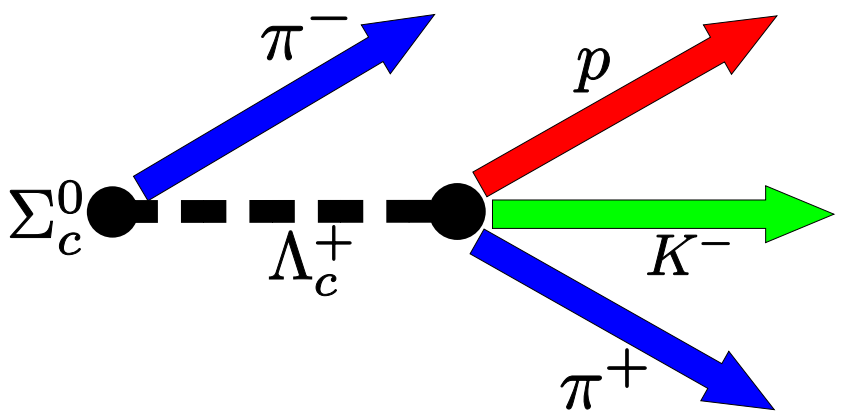
- isospin singlets $\rightarrow$ decay to $\Lambda_c^+ \pi^+ \pi^-$
- nonresonant decays via *P*-wave (parity conservation in strong interaction)
- resonant decays $\Lambda_c(2595) \rightarrow \Sigma_c(2455)\,\pi$ via *S*-wave
- resonant decays $\Lambda_c(2625) \rightarrow \Sigma_c(2455)\,\pi$ via *D*-wave (angular momentum and parity conservation)
- resonant decays to $\Sigma_c(2520)\,\pi$ kinematically disfavored

Motivations

- study of *P*-wave charm mesons pioneered by ARGUS and CLEO
- enough CDF data for analogous high statistics studies in charm baryon system
- charm baryon system testing ground for heavy quark symmetry
  - rich mass spectrum
  - relatively narrow widths of the resonances
- improvement of previous mass and decay width measurements of $\Sigma_c(2455)^{0,++}$, $\Sigma_c(2520)^{0,++}$, $\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$
- proper inclusion of kinematical threshold effects in $\Lambda_c(2595)^+ \to \Sigma_c(2455)^{0,++}\,\pi^{+,-}$
- direct experimental determination of pion coupling constant h_2 in chiral Lagrangian
  - knowledge of h_2 provides information about other excited charm and bottom baryons
  - up to now calculated using measured $\Gamma(\Lambda_c(2595)^+)$

Selection Method

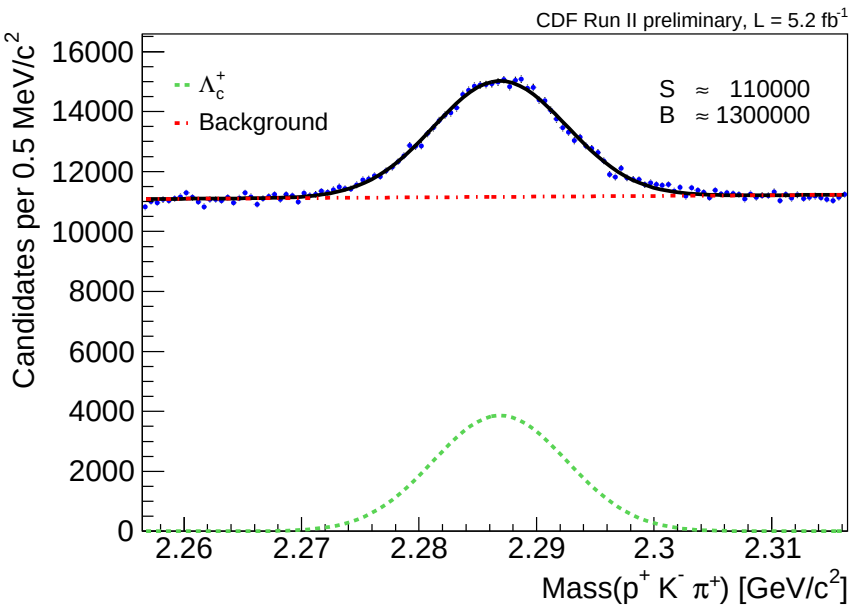
- Hadronic Trigger requires two displaced tracks with $p_T > 2\,\mathrm{GeV}/c$ (selection of secondary vertex decays)
- use integrated luminosity of $5.2\,\mathrm{fb}^{-1}$
- application of neural networks (NeuroBayes)
  - $\Lambda_c^+ \to p^+\,K^-\,\pi^+$
    lifetime, vertex fit, particle identification, Dalitz structure
  - $\Sigma_c^{0,++} \to \Lambda_c^+\,\pi^{-,+}$, $\Lambda_c^{*+} \to \Lambda_c^+\,\pi^+\,\pi^-$
    Λ_c^+ network output, vertex fits
- look at mass difference distributions to remove Λ_c^+ mass resolution



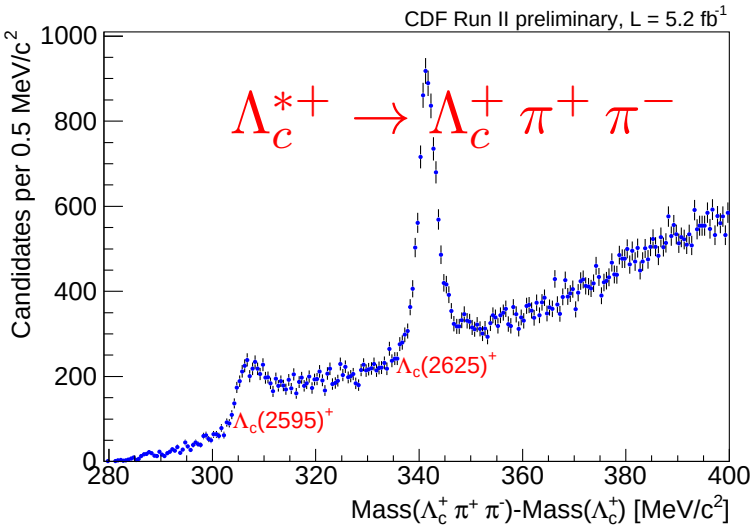
Network Trainings

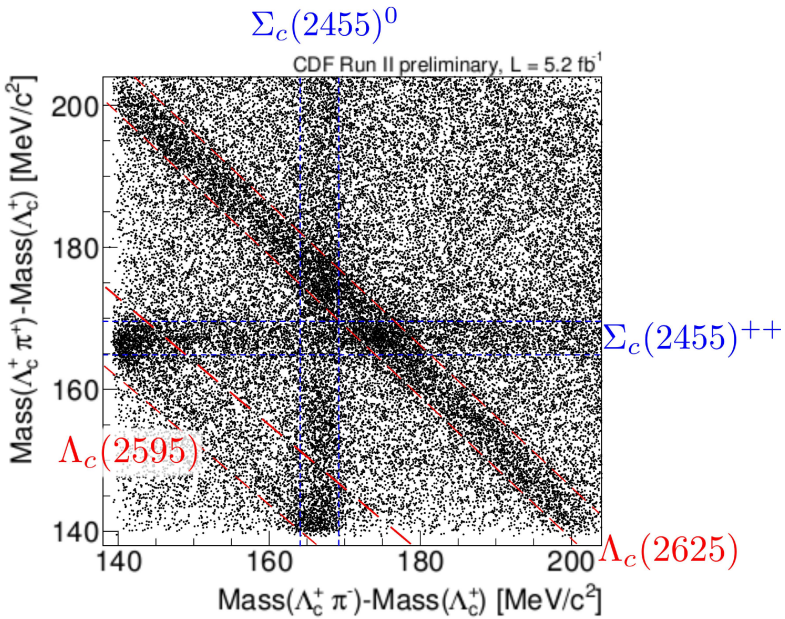
- trainings solely based upon real data by means of ${}_s\mathcal{P}lot$ weights $\rightarrow$ independent of simulated events
- ${}_s\mathcal{P}lot$ technique corresponds to advanced sideband subtraction
- invariant mass as discriminating variable between signal and background $\rightarrow$ requires significant signal in mass spectrum

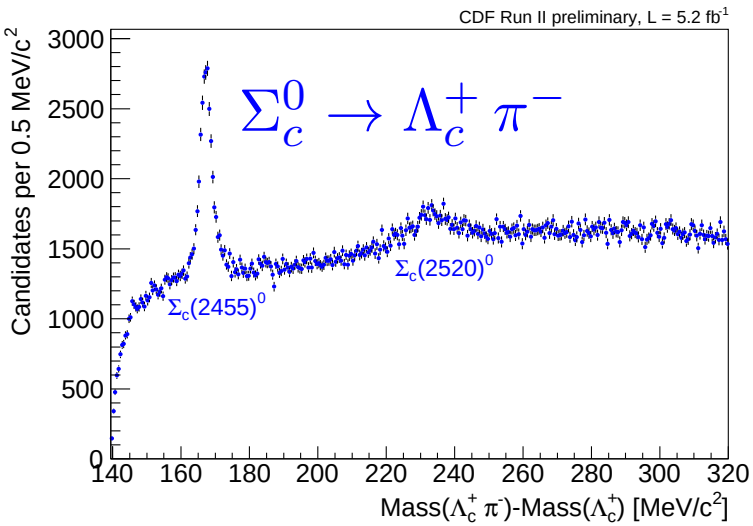
candidates used for Λ_c^+ training:

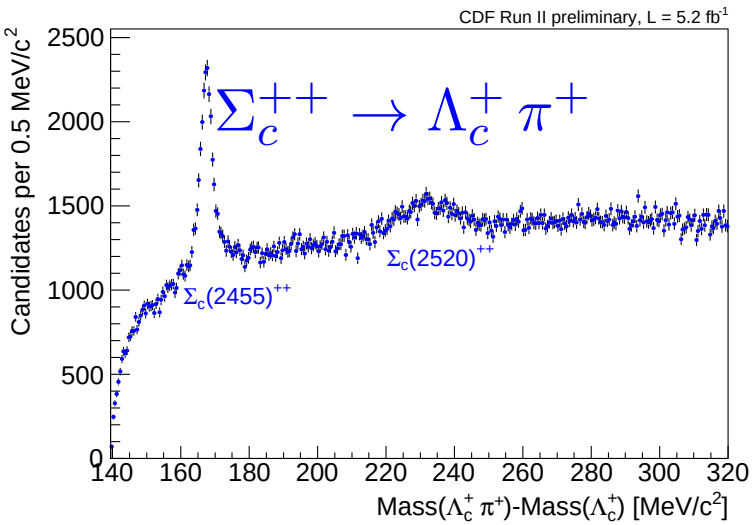


Resulting Spectra

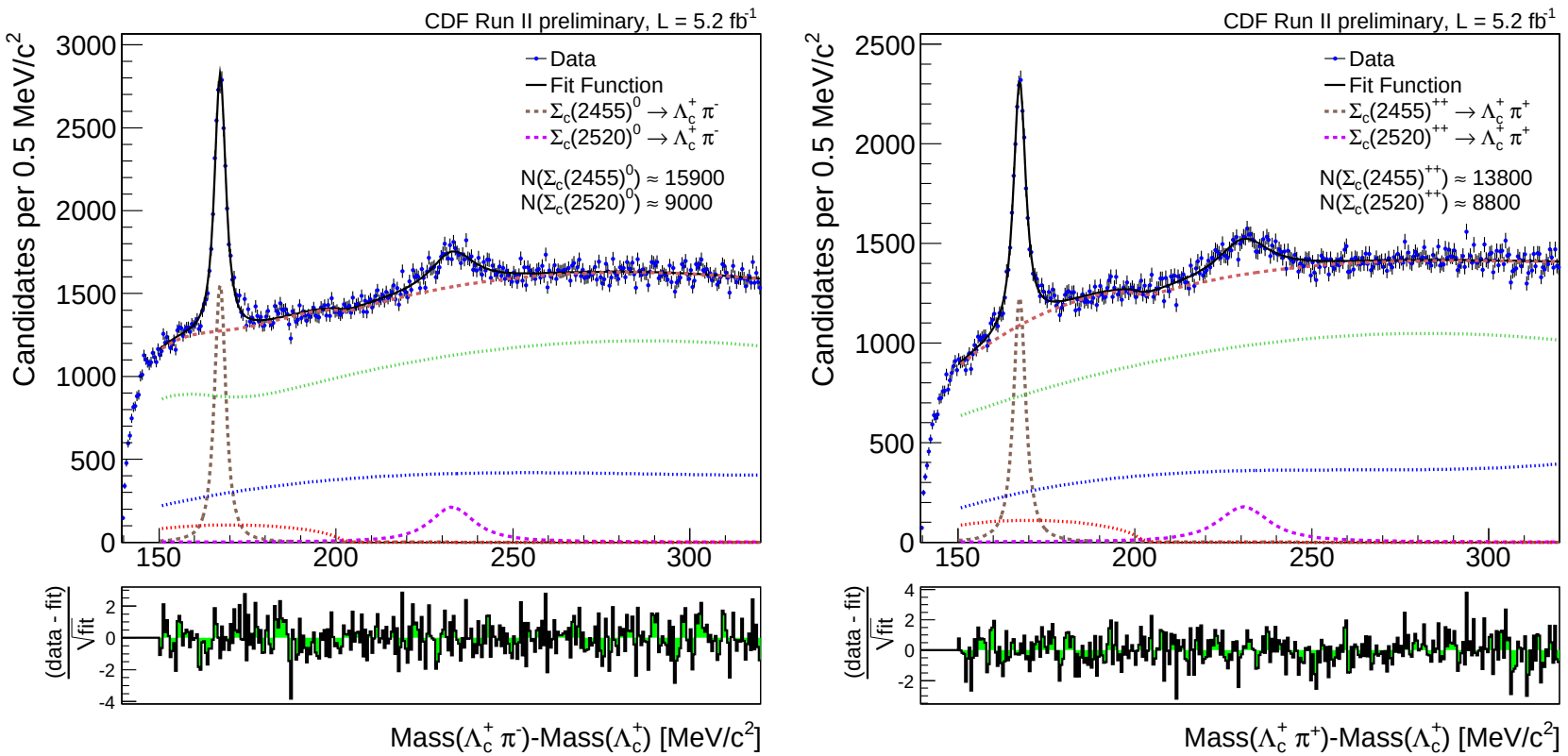






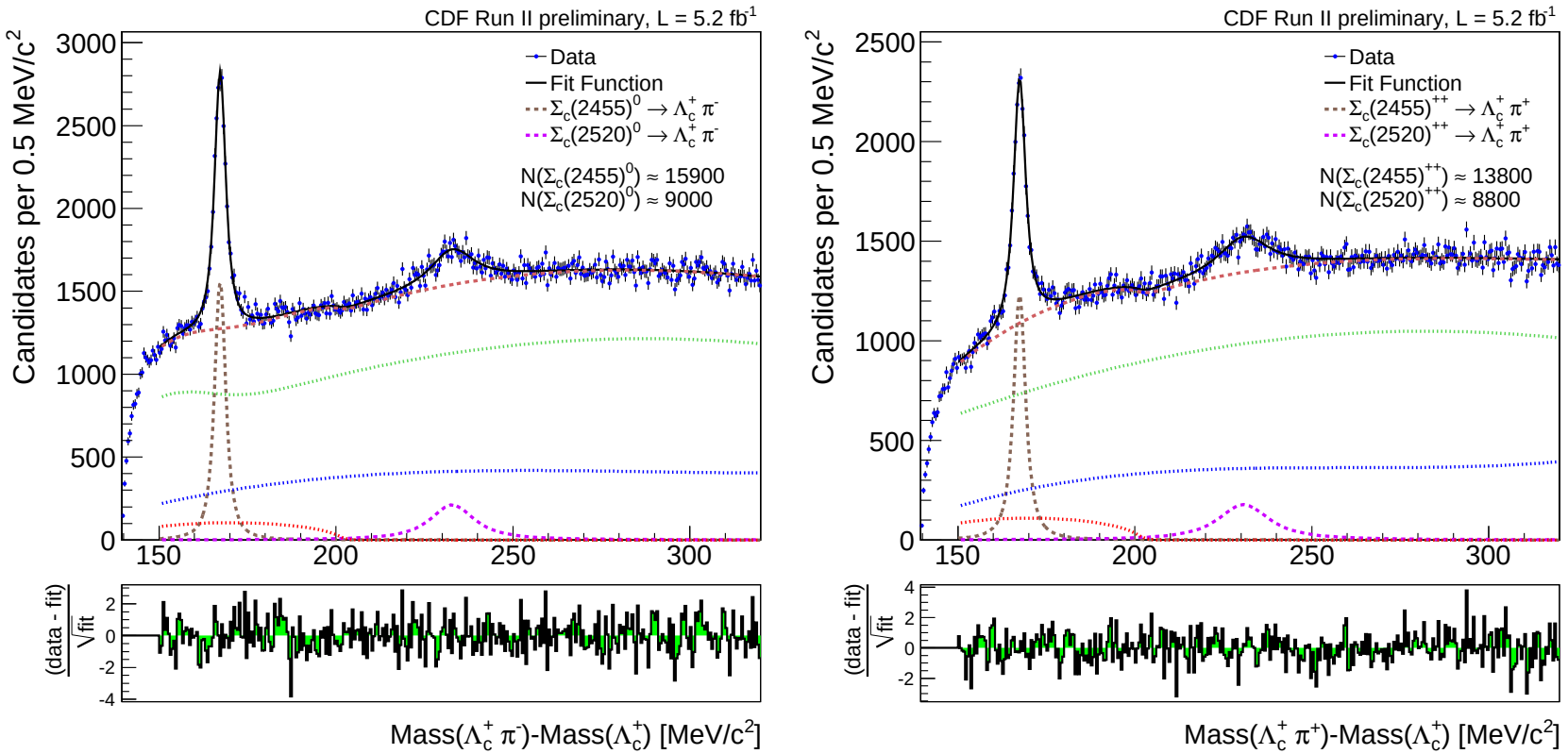


Fit Strategy



- binned maximum likelihood method
- signals: convolutions of nonrelativistic Breit-Wigner functions with detector resolutions ($\approx 2\,\mathrm{MeV}/c^2$)
- several background constituents

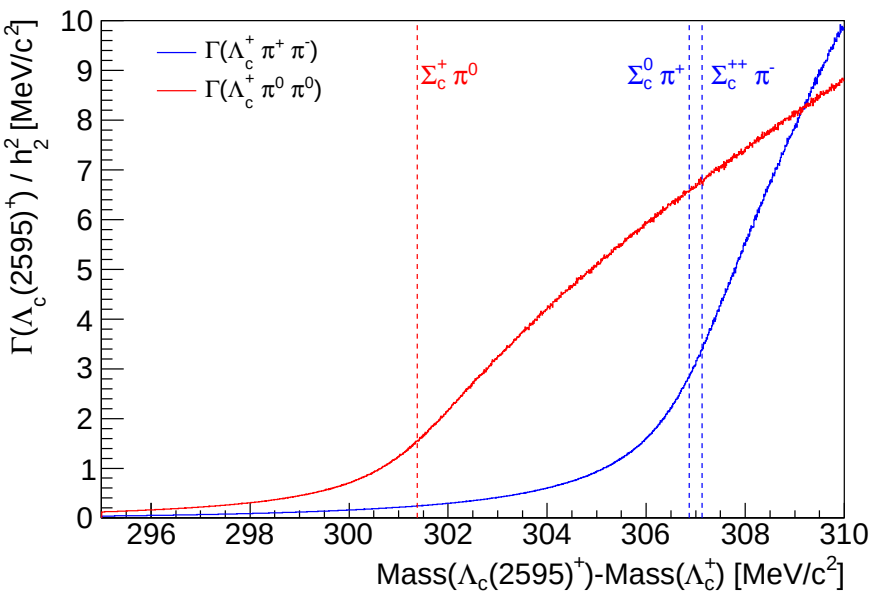
$\Sigma_c(2455)^{0,++}$ and $\Sigma_c(2520)^{0,++}$ Fits



- combinatorial background without real Λ_c^+
- real Λ_c^+ combined with random track
- feed-down from $\Lambda_c(2625)^+ \to \Lambda_c^+ \pi^+ \pi^-$

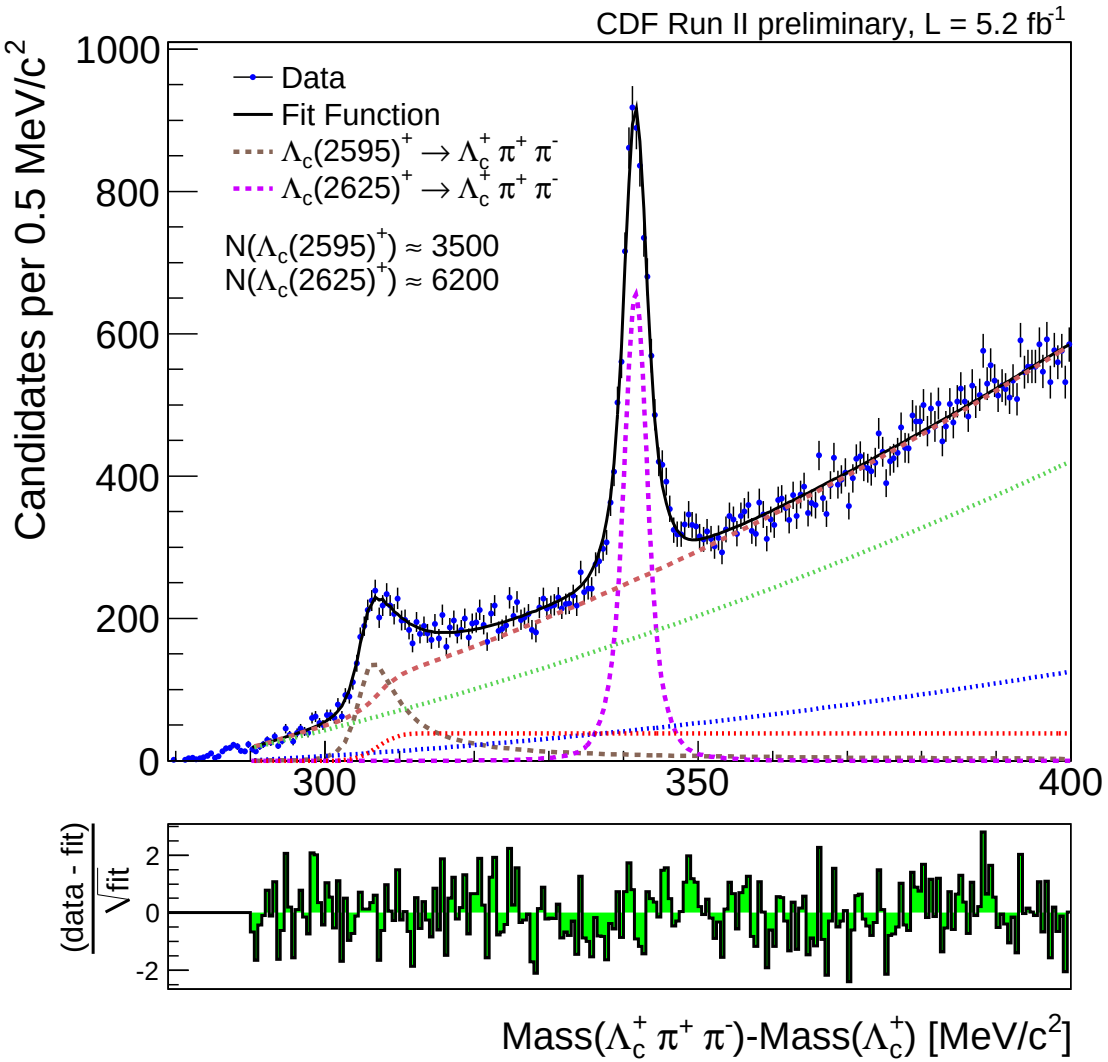
$\Lambda_c(2595)^+$ Line Shape

$\Lambda_c(2595)^+ \to \Sigma_c(2455)^{0,++}\,\pi^{+,-}$ right at kinematical threshold
$\Rightarrow$ Breit-Wigner shape strongly distorted by threshold effects
$\to$ calculation of mass-dependent width:



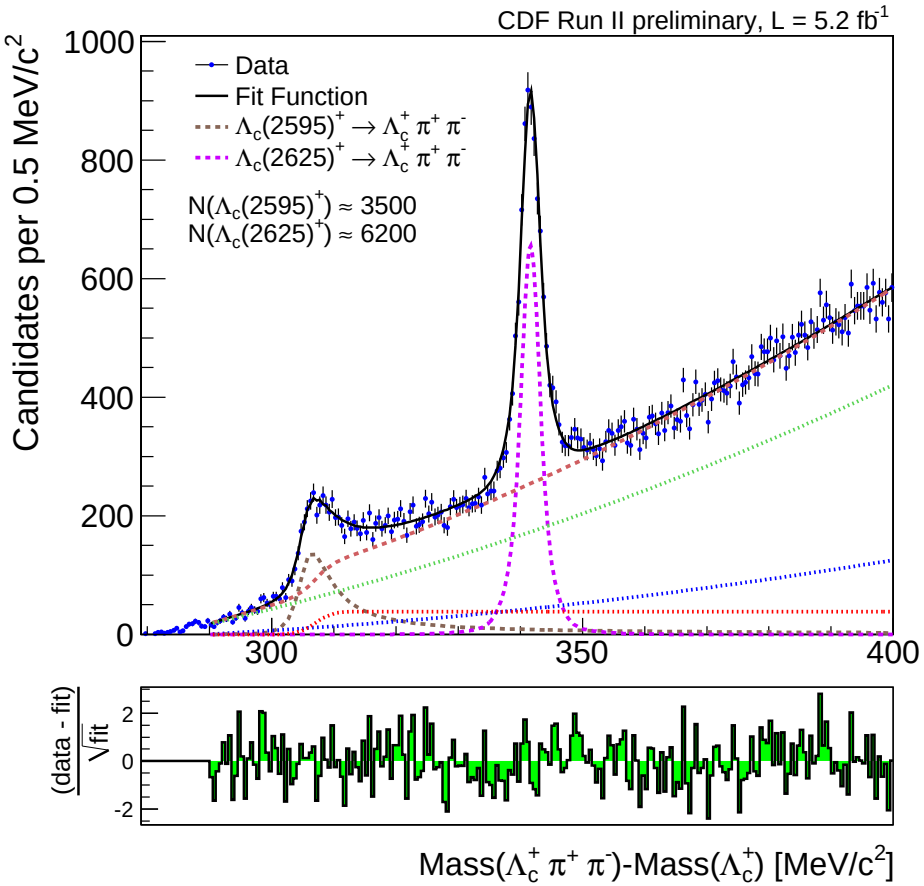
- Blechman *et al.*:
  Threshold effects in excited charmed baryon decays,
  Phys. Rev. D 67, 074033
- h_2: pion coupling constant in
  $\Lambda_c(2595) \to \Sigma_c(2455)\,\pi$
  $\to$ can be determined from data

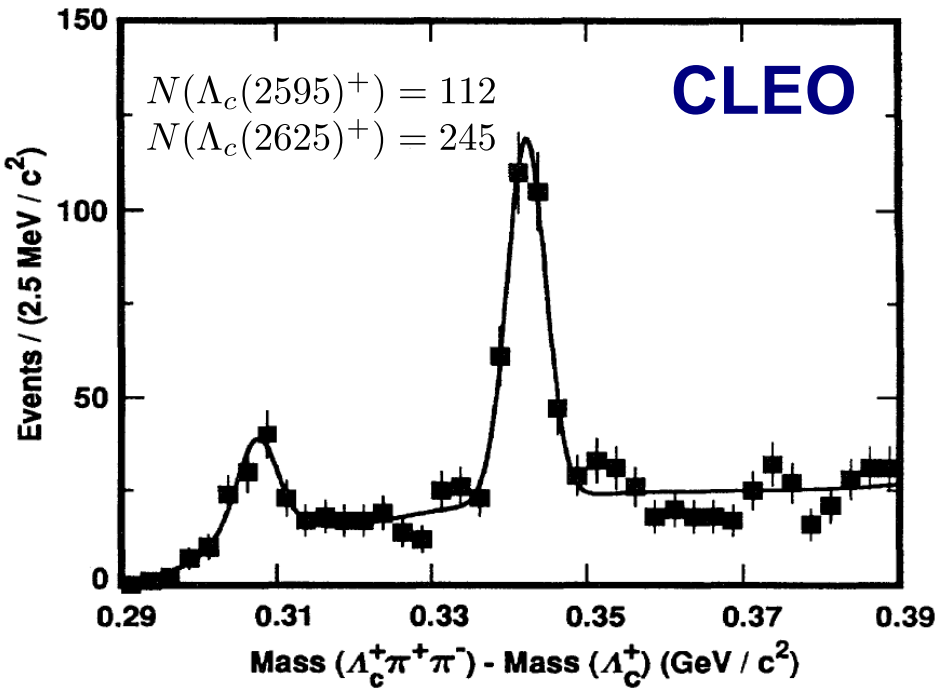
$\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$ Fits



- combinatorial background without real Λ_c^+
- real Λ_c^+ combined with two random tracks
- $\Sigma_c(2455)^{0,++}$ combined with random track

Comparison with CLEO Measurement





Systematic Uncertainties

- detector resolutions
  - uncertainties on the Monte Carlo simulations
  - affect all decay widths
- overall mass scale
  - magnetic field and energy loss uncertainties in momentum scale calibration
  - affect all masses and decay widths
- fit models
  - possible biases because of signal-background correlations
  - affect $\Sigma_c(2520)$ properties
- external input for $\Lambda_c(2595)$ signal shape
  - uncertainties on PDG values of $\Sigma_c(2455)$ mass differences and decay widths
  - affect $\Lambda_c(2595)$ properties

Results

analysis provides 12 measurements (PDG values in parentheses):

	$m - m(\Lambda_c^+)[\mathrm{MeV}/c^2]$		$\Gamma[\mathrm{MeV}/c^2]$	
$\Sigma_c(2455)^0$	167.28 ± 0.12	(167.30 ± 0.11)	1.65 ± 0.50	(2.2 ± 0.4)
$\Sigma_c(2455)^{++}$	167.44 ± 0.13	(167.56 ± 0.11)	2.34 ± 0.47	(2.23 ± 0.30)
$\Sigma_c(2520)^0$	232.88 ± 0.46	(231.6 ± 0.5)	12.51 ± 2.28	(16.1 ± 2.1)
$\Sigma_c(2520)^{++}$	230.73 ± 0.58	(231.9 ± 0.6)	15.03 ± 2.52	(14.9 ± 1.9)
$\Lambda_c(2595)^+$	305.79 ± 0.24	(308.9 ± 0.6)	2.59 ± 0.56	$(3.6^{+2.0}_{-1.3})$
$\Lambda_c(2625)^+$	341.65 ± 0.13	(341.7 ± 0.6)	$< 0.97\,(90\%CL)$	(< 1.9)

- $h_2^2 = 0.36 \pm 0.08$
- combined statistical and systematic uncertainties
- discrepancy in $\Lambda_c(2595)$ mass compared to previous measurements due to proper treatment of kinematical threshold effects, data consistent

Summary

- mass difference and decay width measurements of the charmed baryons $\Sigma_c(2455)^{0,++}$, $\Sigma_c(2520)^{0,++}$, $\Lambda_c(2595)^+$ and $\Lambda_c(2625)^+$
- analysis with highest number of signal events
- considerable improvements in precision of $\Lambda_c(2595)$ and $\Lambda_c(2625)$ properties
- proper inclusion of kinematical threshold effects in $\Lambda_c(2595)$ decay
  - significantly smaller measured value of the $\Lambda_c(2595)$ mass
  - direct measurement of the pion coupling constant h_2
- after bottom and charm mesons as well as bottom baryons CDF now also studies charm baryons

`http://www-cdf.fnal.gov/physics/new/bottom/100701.blessed-Charm_Baryons/cdf10260_CharmBaryons.pdf`

Backup

Systematic Uncertainties

Source	$\Delta m(\Sigma_c(2455)^0)$	$\Gamma(\Sigma_c(2455)^0)$	$\Delta m(\Sigma_c(2520)^0)$	$\Gamma(\Sigma_c(2520)^0)$
Resolution	-	$0.45\,\mathrm{MeV}/c^2$	-	$0.70\,\mathrm{MeV}/c^2$
Mass Scale	$0.12\,\mathrm{MeV}/c^2$	$0.20\,\mathrm{MeV}/c^2$	$0.12\,\mathrm{MeV}/c^2$	$0.20\,\mathrm{MeV}/c^2$
Fit Model	$0.02\,\mathrm{MeV}/c^2$	-	$0.11\,\mathrm{MeV}/c^2$	$1.16\,\mathrm{MeV}/c^2$
Sum	$0.12\,\mathrm{MeV}/c^2$	$0.49\,\mathrm{MeV}/c^2$	$0.16\,\mathrm{MeV}/c^2$	$1.37\,\mathrm{MeV}/c^2$
Statistical	$0.03\,\mathrm{MeV}/c^2$	$0.11\,\mathrm{MeV}/c^2$	$0.43\,\mathrm{MeV}/c^2$	$1.82\,\mathrm{MeV}/c^2$

Source	$\Delta m(\Sigma_c(2455)^{++})$	$\Gamma(\Sigma_c(2455)^{++})$	$\Delta m(\Sigma_c(2520)^{++})$	$\Gamma(\Sigma_c(2520)^{++})$
Resolution	-	$0.40\,\mathrm{MeV}/c^2$	-	$0.69\,\mathrm{MeV}/c^2$
Mass Scale	$0.12\,\mathrm{MeV}/c^2$	$0.20\,\mathrm{MeV}/c^2$	$0.12\,\mathrm{MeV}/c^2$	$0.20\,\mathrm{MeV}/c^2$
Fit Model	$0.02\,\mathrm{MeV}/c^2$	-	$0.11\,\mathrm{MeV}/c^2$	$1.16\,\mathrm{MeV}/c^2$
Sum	$0.12\,\mathrm{MeV}/c^2$	$0.45\,\mathrm{MeV}/c^2$	$0.16\,\mathrm{MeV}/c^2$	$1.36\,\mathrm{MeV}/c^2$
Statistical	$0.04\,\mathrm{MeV}/c^2$	$0.13\,\mathrm{MeV}/c^2$	$0.56\,\mathrm{MeV}/c^2$	$2.12\,\mathrm{MeV}/c^2$

Source	$\Delta m(\Lambda_c(2595)^+)$	h_2^2	$\Gamma(\Lambda_c(2595)^+)$	$\Delta m(\Lambda_c(2625)^+)$
Resolution	$0.06\,\mathrm{MeV}/c^2$	0.03	$0.22\,\mathrm{MeV}/c^2$	-
Mass Scale	$0.12\,\mathrm{MeV}/c^2$	0.03	$0.20\,\mathrm{MeV}/c^2$	$0.12\,\mathrm{MeV}/c^2$
Δm, Γ of $\Sigma_c(2455)$	$0.15\,\mathrm{MeV}/c^2$	0.06	$0.36\,\mathrm{MeV}/c^2$	-
Sum	$0.20\,\mathrm{MeV}/c^2$	0.07	$0.47\,\mathrm{MeV}/c^2$	$0.12\,\mathrm{MeV}/c^2$
Statistical	$0.14\,\mathrm{MeV}/c^2$	0.04	$0.30\,\mathrm{MeV}/c^2$	$0.04\,\mathrm{MeV}/c^2$