Search for Pentaquark states at CDF

Elena Gerchtein, CMU
for CDF collaboration

DPF, August 26-31, 2004
Recent flurry of reports of experimental evidences for a narrow exotic baryon state decaying to $nK^+$, $pK_S^0$ at the mass of $\sim 1540$ MeV/c$^2$, interpreted as 5-quark, $(uudd\bar{s})$, $\Theta^+$ state originally predicted in chiral soliton model of baryons by Diakonov, Petrov, Polyakov (cf. hep-ph/9703373) revitalized interest in baryon spectroscopy.

Followed by observation of $\Xi^-, \Xi^0$, $M \sim 1860$ MeV/c$^2$, decaying to $\Xi^-\pi^-, \Xi^-\pi^+$, by NA49 Experiment. Members of $S=-2$ ($qqss\bar{q}, q = u, d$) quardruplet of the SU(3) $\Gamma\bar{0}$ of pentaquarks. (cf. Phys.Rev.Lett.92:042003,2004)

Recently H1 Experiment reported anti-charmed analogue $(uudd\bar{c})$ of the $\Theta^+$ state decaying to $D^{*+}\bar{p}$. $M(\Theta^0) = (3,099 \pm 3 \pm 5)$ MeV/c$^2$ (cf. hep-ex/0403017)

All reported resonances are narrow with widths compatible with the apparatus resolutions.
Search strategy

* search for the following states - new searches highlighted blue

<table>
<thead>
<tr>
<th>Notation</th>
<th>Quark content</th>
<th>Decay channel</th>
<th>Reference Channel(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Theta^+$</td>
<td>$\bar{s}uudd$</td>
<td>$pK_S^0$</td>
<td>$\Lambda(1520) \rightarrow pK^-, K^{*+} \rightarrow K_S^0\pi^+$</td>
</tr>
<tr>
<td>$\Xi_{3/2}^{--}$</td>
<td>$\bar{u}dss$</td>
<td>$\Xi^-\pi^-$</td>
<td></td>
</tr>
<tr>
<td>$\Xi_{3/2}^0$</td>
<td>$\bar{d}udss$</td>
<td>$\Xi^-\pi^+$</td>
<td>$\Xi^0(1530) \rightarrow \Xi^-\pi^+$</td>
</tr>
<tr>
<td>$\Theta_c^0$</td>
<td>$\bar{c}dudu$</td>
<td>$D^*-p$</td>
<td>$D^{**} \rightarrow D^{*-}\pi^-$</td>
</tr>
<tr>
<td>$\Theta_c^0$</td>
<td>$\bar{c}dudu$</td>
<td>$D^-p$</td>
<td>$D^{**} \rightarrow D^+\pi^-$</td>
</tr>
<tr>
<td>$\Theta_c^+$</td>
<td>$\bar{c}uudu$</td>
<td>$\bar{D}^0p$</td>
<td>$D^{**} \rightarrow D^0\pi^+$</td>
</tr>
<tr>
<td>$R_s^+$</td>
<td>$\bar{b}uuds$</td>
<td>$J/\psi p$</td>
<td>$B^+ \rightarrow J/\psi K^+$</td>
</tr>
</tbody>
</table>

* Currently we present raw yields, calculation of the relative yields is under way.

CDF advantages

* high statistics samples
* excellent tracking:
  * good 3D vertexing reduces background
  * excellent mass resolution
  * ability to track long lived hyperons ($\Xi^-, \Omega^-$) in SVX
* decent PID capabilities based on ToF and dE/dx to identify protons, kaons.
Datasets

* Tevatron: $p\bar{p}$ collisions @ 1.96 TeV
  * hadronic trigger data
    - events with at least 2 displaced tracks
    - hard scattering events
    - sample enriched with decay products of charmed and bottom hadrons
  * Jet20 trigger
    - each event has at least one jet with 20 GeV/c, generic QCD
    - prescaled trigger – lower statistics
  * Min-bias and zero-bias trigger
    - soft inelastic scattering
  * Dimuon data ($J/\psi$)
Particle identification

* combine ToF and dE/dx information for a given track into common $\chi_i^2$:

$$\chi_i^2 = \chi_i^2(\text{ToF}) + \chi_i^2(\text{dE/dx})(\text{COT}),$$

where $i = p, K, \pi, e, \mu$

* form normalized likelihood discriminant:

$$LH_i = \frac{\text{lh}(i)}{\text{lh}(p) + \text{lh}(K) + \text{lh}(e) + \text{lh}(\mu) + \text{lh}(\pi)}$$

where $\text{lh}(i) = \exp(-\chi_i^2/2)$

---

CDF Run II preliminary

No PID cut

with proton PID cut
Search for $\Theta^+$

* $\Theta^+ \to K_S^0 p$
  $\leftrightarrow \pi^+ \pi^-$

* apply PID cuts to identify protons
* measure yield relative to known resonances

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Minbias data</th>
<th>Jet20 data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi \to K^+K^-$</td>
<td>$19,721 \pm 273$</td>
<td>$26,658 \pm 385$</td>
</tr>
<tr>
<td>$\Lambda \to pK^-$</td>
<td>$3,276 \pm 327$</td>
<td>$4,915 \pm 702$</td>
</tr>
<tr>
<td>$K^{*+} \to K_S^0 \pi^+$</td>
<td>$15,695 \pm 775$</td>
<td>$37,769 \pm 1,390$</td>
</tr>
<tr>
<td>$\Theta^+ \to pK_S^0$</td>
<td>$18 \pm 56$</td>
<td>$-56 \pm 103$</td>
</tr>
</tbody>
</table>

90% CL limit on $\Theta^+$

90% CL limit on $\Theta^+$

* Calculation of relative yields is underway

no signal observed!
Search for Exotic Cascades

* Reconstruction of $\Xi^{-}, 0 \rightarrow \Xi\pi^{-},^{+}$

Hyperon Are Tracked in Silicon

* $\Xi^{-} \rightarrow \Lambda^{0}\pi^{-}$ is a long lived particle $c\tau = 4.91 cm$. It leaves hits in SVX detector. CDF developed dedicated tracking $\Xi$ in Silicon. Momentum and vertex of $\Lambda\pi^{-}$ are used to seed silicon tracking algorithm.

* silicon tracking of hyperons improves momentum and impact parameter resolution as well as results in excellent background suppression
CDF $\Xi\pi^-,\pi^+$ spectra

* fit function:

$$\mathcal{F} = BW \otimes Gauss + Gauss = (\sum_{n=0}^{3} a_n \cdot x^n) \cdot \sqrt{x - M_\Xi - M_\pi}$$

* fit yielded:

$$N(\Xi(1530)) = 2,182 \pm 92$$
$$M = (1,5320 \pm 0.4) \text{ MeV}/c^2$$

$$\frac{\sigma(pp \rightarrow \Xi(1530)) \cdot a(\Xi(1530))}{\sigma(pp \rightarrow \Xi) \cdot a(\Xi)} \sim 0.061$$

<table>
<thead>
<tr>
<th>Channel</th>
<th># of events</th>
<th>90 % CL</th>
<th>relative yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Xi^-\pi^+$</td>
<td>57±51</td>
<td>126</td>
<td>0.06</td>
</tr>
<tr>
<td>$\Xi^-\pi^-$</td>
<td>-54±47</td>
<td>51</td>
<td>0.03</td>
</tr>
</tbody>
</table>

(Relative yields of $\Xi(1860)/\Xi(1530)$ assuming equal detector efficiency)

hadronic trigger sample

no signal observed!
* $E_T > 20$ GeV jet trigger data, SVX tracked $\Xi^\pm$

$$N(\Xi(1530)) = 387 \pm 34$$
$$M(\Xi(1530)) = (1,532.3 \pm 0.8) \text{ MeV}/c^2$$

$$\frac{\sigma(pp \to \Xi(1530)) \cdot a(\Xi(1530))}{\sigma(pp \to \Xi) \cdot a(\Xi)} \sim 0.08$$

(similar to TTT sample and similar to NA49)

<table>
<thead>
<tr>
<th>Channel</th>
<th># of events</th>
<th>90 % CL</th>
<th>relative yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Xi^- \pi^+$</td>
<td>-14$\pm$19</td>
<td>25</td>
<td>0.08</td>
</tr>
<tr>
<td>$\Xi^- \pi^-$</td>
<td>-4$\pm$18</td>
<td>28</td>
<td>0.09</td>
</tr>
</tbody>
</table>

(Relative yields of $\Xi(1860)/\Xi(1530)$ assuming equal detector efficiency)

no signal observed!
Search for $\Theta_c$

Reference channels

$D^{**} \rightarrow D^{*+} \pi^-$

$\leftrightarrow D^0 \pi^+$

$\leftrightarrow K^- \pi^+$

$D^{**} \rightarrow D^+ \pi^-$

$\leftrightarrow K^- \pi^+ \pi^+$

$D^{**} \rightarrow D^0 \pi^+$

$\leftrightarrow K^- \pi^+$

CDF Run II Preliminary

$N(D^0) = 37241 \pm 899$

$N(D^*_{J/P}) = 6247 \pm 1711$

CDF Run II Preliminary

$N(D^*_{J/P}) = 34509 \pm 1092$

CDF Run II Preliminary

$N(D^*_{J/P}) = 13628 \pm 813$
Search for $\Omega_c^0$

* $LH_p > 0.4$ (optimized using $\Lambda_c$ signal)
* require prompt decays
* no signal found!
* unbinned likelihood fits varying mass in wide range => calculate mass dependent limits

CDF Run II Preliminary

$D^* - p$

$D^- p$

Event Yield @ 90% CL

CDF Run II Preliminary

Elena Gerchtein, Carnegie-Mellon University/CDF
Search for $\Theta^+_c$

CDF Run II Preliminary 

N / 3 MeV/c$^2$

$M(D^0 p)$

[GeV/c$^2$]

Event Yield @ 90% CL

CDF Run II Preliminary 

L~240pb$^{-1}$

Elena Gerchtein, Carnegie-Mellon University/CDF

August 26, 2004
Limits on $\Theta_c$

- search window $3.099 \pm 18 \text{ MeV}/c^2$ - as measured by H1
- take worst point from the limit vs mass inside the window

<table>
<thead>
<tr>
<th>Reference channel</th>
<th>Search channel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_2^* \to D^+\pi^-$</td>
<td>$\Theta_c^0 \to D^*^-p &lt; 21 , @ , 90% , \text{CL}$</td>
</tr>
<tr>
<td>$D_2^* \to D^+\pi^-$</td>
<td>$\Theta_c^0 \to D^-p &lt; 89 , @ , 90% , \text{CL}$</td>
</tr>
<tr>
<td>$D_2^{*+} \to D^0\pi^+$</td>
<td>$\Theta_c^+ \to \bar{D}^0p &lt; 87 , @ , 90% , \text{CL}$</td>
</tr>
<tr>
<td>$D_2^+ \to D^0\pi^+$</td>
<td>$\Theta_c^+ \to D^0p &lt; 97 , @ , 90% , \text{CL}$</td>
</tr>
</tbody>
</table>
Search for $R^+_s$

* $R^+_s \rightarrow J/\psi p$ on dimuon data 282 pb$^{-1}$ - ref. channel $B^+ \rightarrow J/\psi K^+$
* measurable $R^+_s$ lifetimes considered: $L_{xy} > 100 \mu m$ and no $L_{xy}$ cut
* unbinned likelihood fits varying mass in wide range => calculate mass dependent limits

no signal found!

CDF Run II Preliminary $L \sim 280$ pb$^{-1}$

Reference channel $J/\psi p$

CDF Run II Preliminary $L \sim 280$ pb$^{-1}$

August 26, 2004

Elena Gerchtein, Carnegie-Mellon University/CDF
Conclusions

* CDF has found no evidence for pentaquark states $\Theta$, $\Theta_c$, $R_s$, and $\Xi_{3/2}$ in several decay modes

* production of exotic baryons in fragmentation may be severely suppressed with respect to normal baryon production

* CDF continues studies of weak and strong decay signatures of exotic charmed and bottom baryons