Search for Pentaquark states at CDF

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for CDF collaboration

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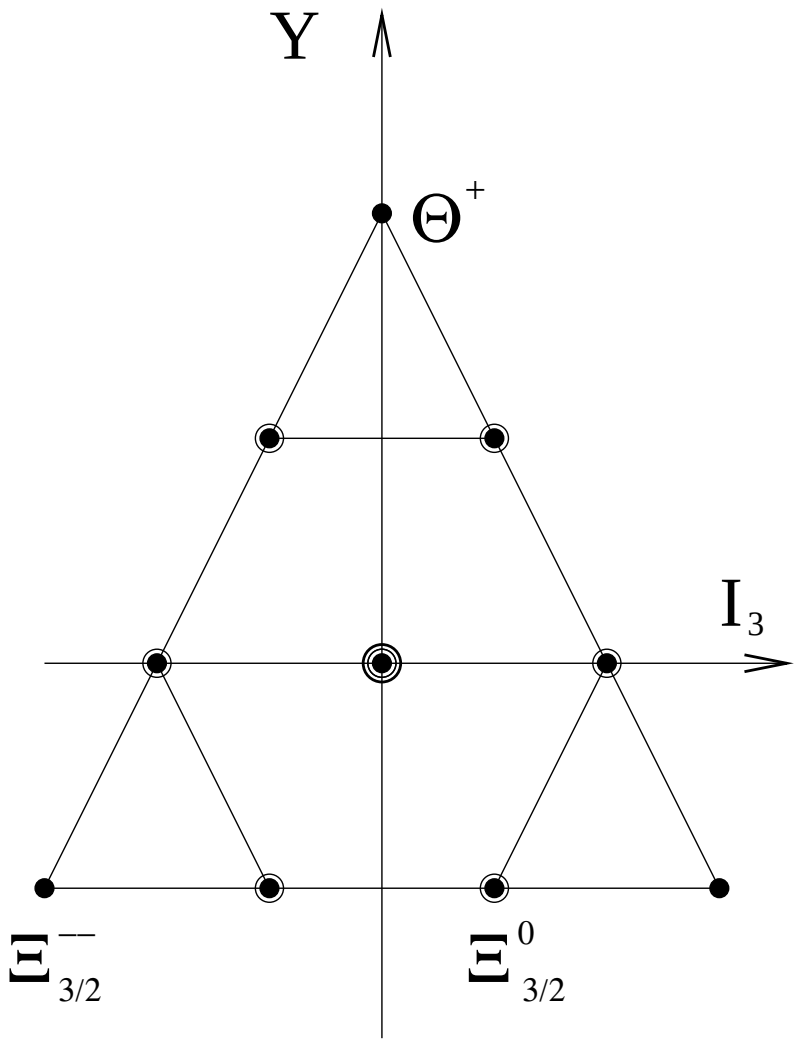
Motivation

* Recent flurry of reports of experimental evidences for a narrow exotic baryon state decaying to nK^+, pK^0_S at the mass of $\sim 1540\ MeV/c^2$, interpreted as 5-quark, ($uudd\bar{s}$), Θ^+ 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 Ξ^{--}, Ξ^0, $M \sim 1860\ MeV/c^2$, decaying to $\Xi^-\pi^-, \Xi^-\pi^+$, by NA49 Experiment. Members of $S = -2$ ($qqss\bar{q}, q = u, d$) quadruplet of the SU(3) $\overline{10}$ of pentaquarks. (cf. Phys.Rev.Lett.92:042003,2004)
* Recently H1 Experiment reported anti-charmed analogue ($uudd\bar{c}$) of the Θ^+ state decaying to $D^{*+}\bar{p}$. $M(\Theta^0_c) = (3,099 \pm 3 \pm 5)\ MeV/c^2$ (cf. hep-ex/0403017)
* All reported resonances are narrow with witdhs compatible with the apparatus resolutions.



Search strategy

* **search for the following states - new searches highlighted blue**

Notation	Quark content	Decay channel	Reference Channel(s)
Θ^+	$\bar{s}uudd$	pK^0_S	$\Lambda(1520) \to pK^-$, $K^{*+} \to K^0_S\pi^+$
$\Xi^{--}_{3/2}$	$\bar{u}ddss$	$\Xi^-\pi^-$	
$\Xi^0_{3/2}$	$\bar{d}udss$	$\Xi^-\pi^+$	$\Xi^0(1530) \to \Xi^-\pi^+$
Θ^0_c	$\bar{c}dudu$	$D^{*-}p$	$D^{**} \to D^{*+}\pi^-$
Θ^0_c	$\bar{c}dudu$	D^-p	$D^{**} \to D^+\pi^-$
Θ^+_c	$\bar{c}uudu$	$\bar{D}^0p$	$D^{**} \to D^0\pi^+$
R^+_s	$\bar{b}uuds$	$J/\psi p$	$B^+ \to J/\psi K^+$

* **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 (Ξ^-, Ω^-) 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 events 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/ψ)

Particle identification

* **combine ToF and dE/dx information for a given track into common χ^2_i :**

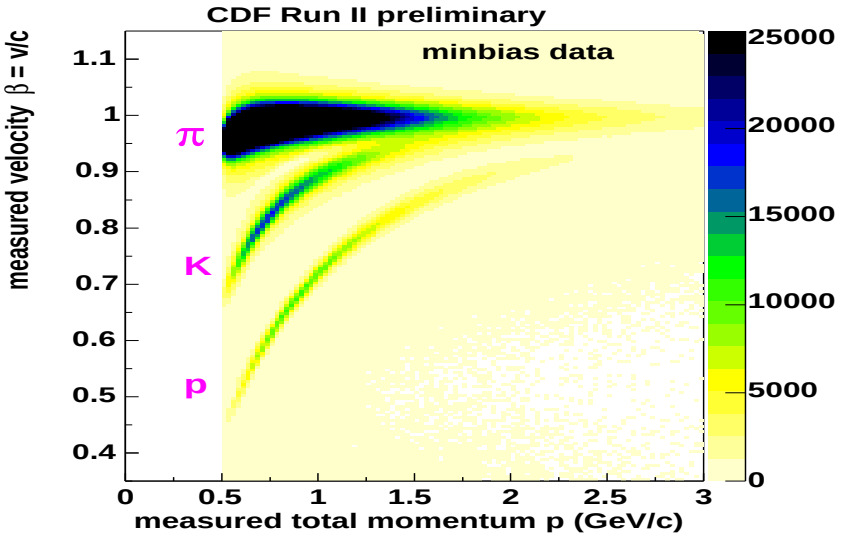
$$\chi^2_i = \chi^2_{\mathrm{i}}(\mathrm{ToF}) + \chi^2_{\mathrm{i}}(\mathrm{dE/dx})(\mathrm{COT}),$$

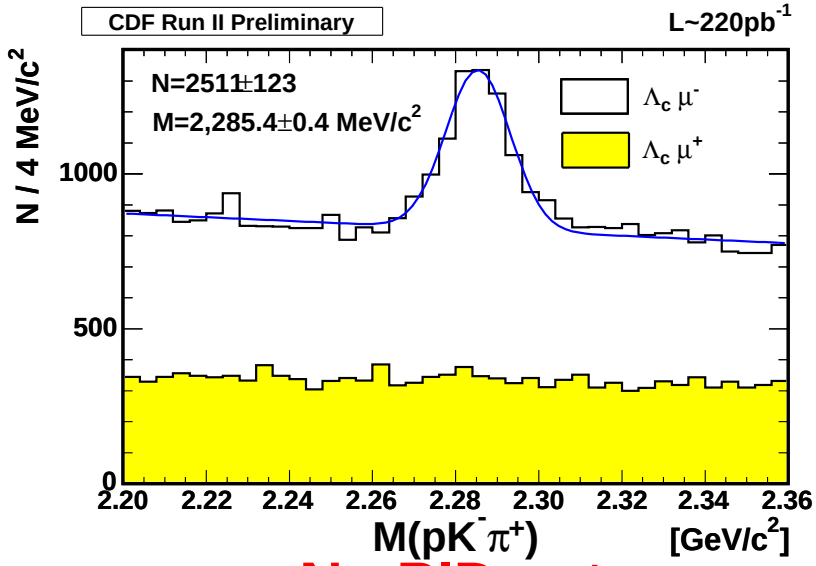
where $\mathrm{i} = \mathrm{p}, \mathrm{K}, \pi, \mathrm{e}, \mu$

* **form normalized likelihood discriminant:**

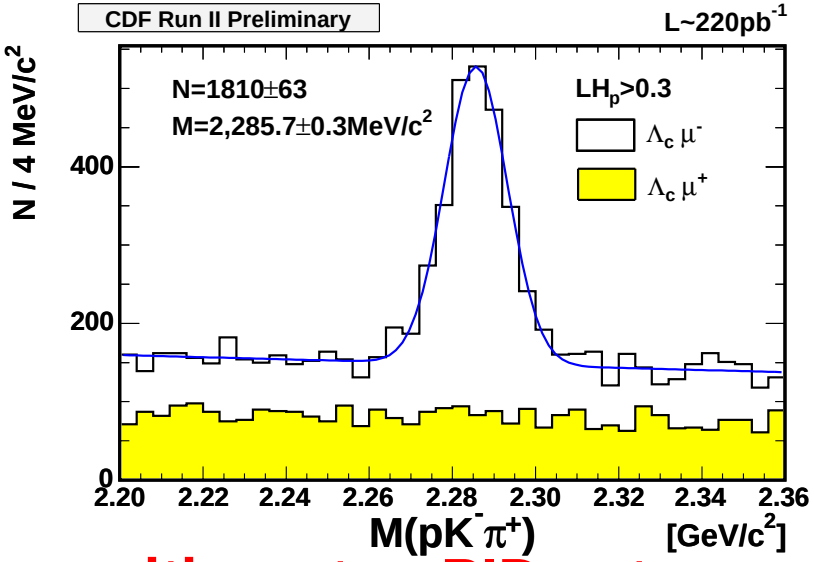
$$\mathrm{LH_i} = \frac{\mathrm{lh(i)}}{\mathrm{lh(p)} + \mathrm{lh(K)} + \mathrm{lh(e)} + \mathrm{lh}(\mu) + \mathrm{lh}(\pi)}$$

where $\mathrm{lh(i)} = \exp(-\chi^2_{\mathrm{i}}/2)$





No PID cut



with proton PID cut

Search for Θ^+

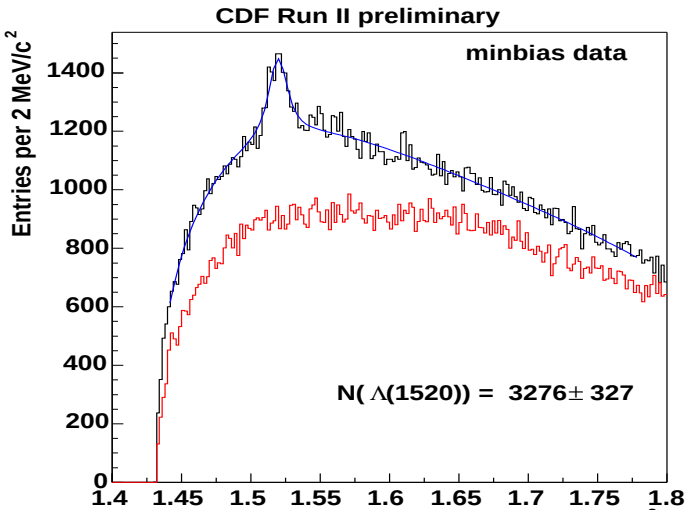
*

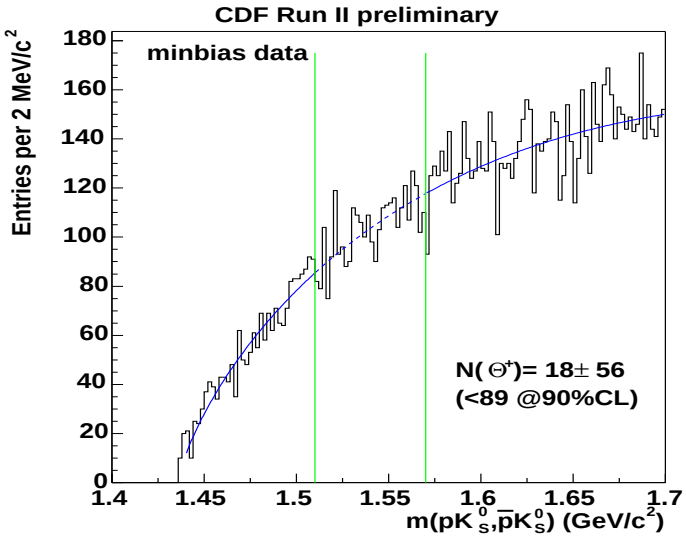
$$\Theta^+ \rightarrow K^0_S p$$
$$\hookrightarrow \pi^+\pi^-$$

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

Resonance	Minbias data	Jet20 data
$\phi \rightarrow K^+K^-$	$19,721 \pm 273$	$26,658 \pm 385$
$\Lambda \rightarrow pK^-$	$3,276 \pm 327$	$4,915 \pm 702$
$K^{*+} \rightarrow K^0_S\pi^+$	$15,695 \pm 775$	$37,769 \pm 1,390$
$\Theta^+ \rightarrow pK^0_S$	18 ± 56	-56 ± 103
90% CL limit on Θ^+	< 89	< 76

* **Calculation of relative yields is underway**





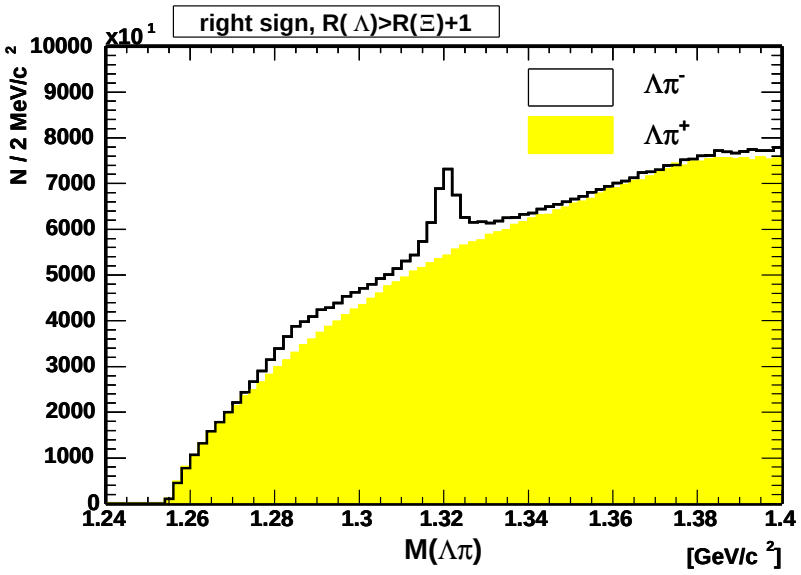
no signal observed !

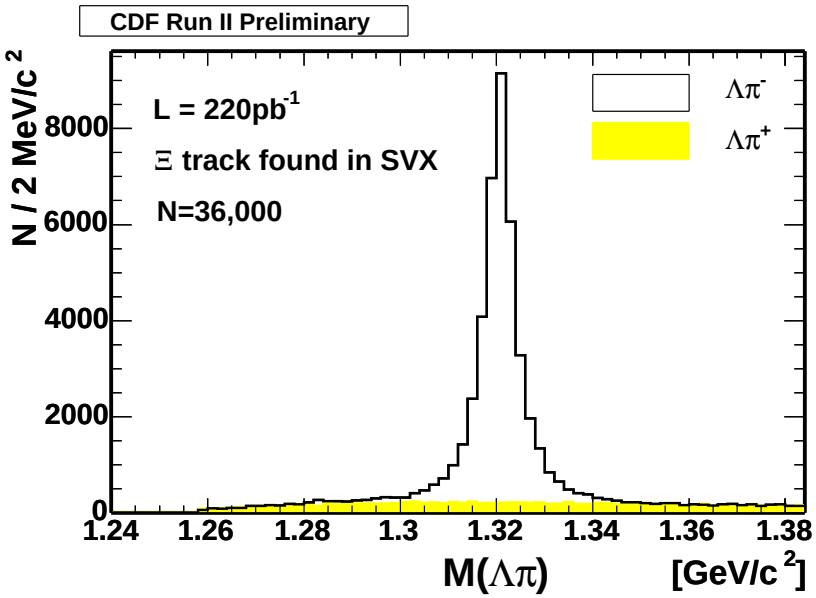
Search for Exotic Cascades

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

Hyperon Are Tracked in Silicon

* $\Xi^- \rightarrow \Lambda^0\pi^-$ is a long lived particle $c\tau = 4.91cm$. It leaves hits in SVX detector. CDF developed dedicated tracking Ξ 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 $\Xi\pi^{-,+}$ spectra

* **fit function:**

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

* **fit yielded:**

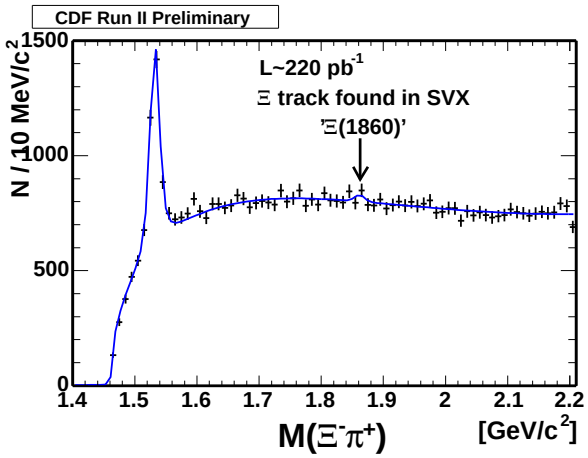
$$N(\Xi(1530)) = 2,182 \pm 92$$
$$M = (1,5320 \pm 0.4)\ \mathrm{MeV/c^2}$$

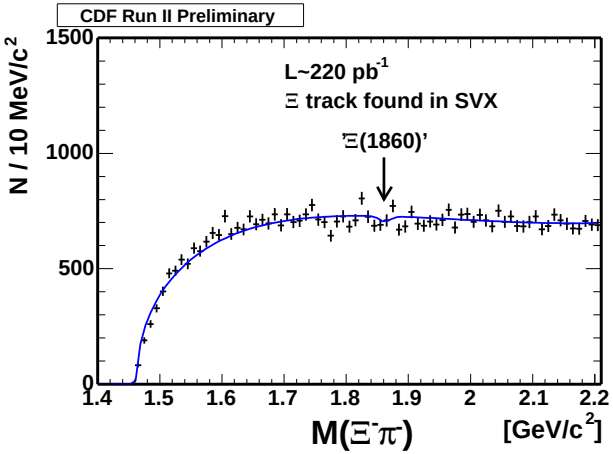
$$\frac{\sigma(pp \to \Xi(1530)) \cdot a(\Xi(1530))}{\sigma(pp \to \Xi) \cdot a(\Xi)} \sim 0.061$$

Channel	# of events	90 % CL	relative yield
$\Xi^-\pi^+$	57±51	126	0.06
$\Xi^-\pi^-$	-54±47	51	0.03

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

hadronic trigger sample





no signal observed !

CDF $\Xi\pi^{-,+}$ spectra

* $E_T > 20$ GeV **jet trigger data, SVX tracked** $\Xi^{\pm}$

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

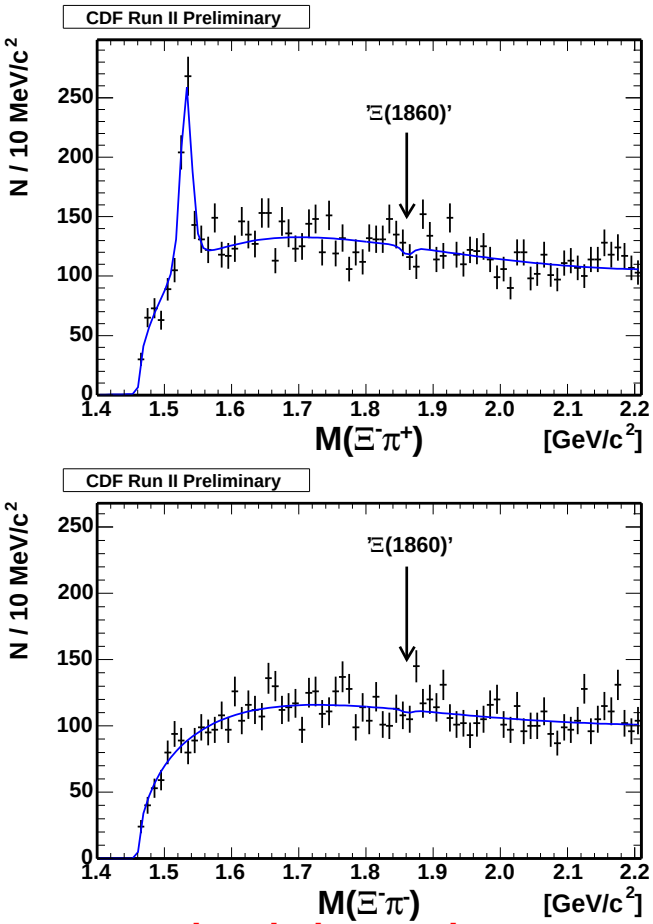
$$\frac{\sigma(pp \to \Xi(1530)) \cdot a(\Xi(1530))}{\sigma(pp \to \Xi) \cdot a(\Xi)} \sim 0.08$$

(similar to TTT sample and similar to NA49)

Channel	# of events	90 % CL	relative yield
$\Xi^-\pi^+$	-14±19	25	0.08
$\Xi^-\pi^-$	-4±18	28	0.09

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

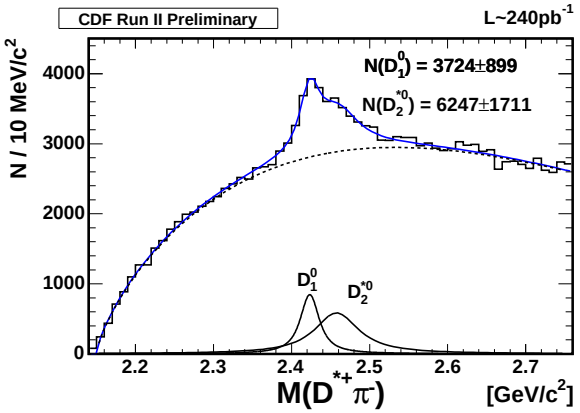
Jet20 sample



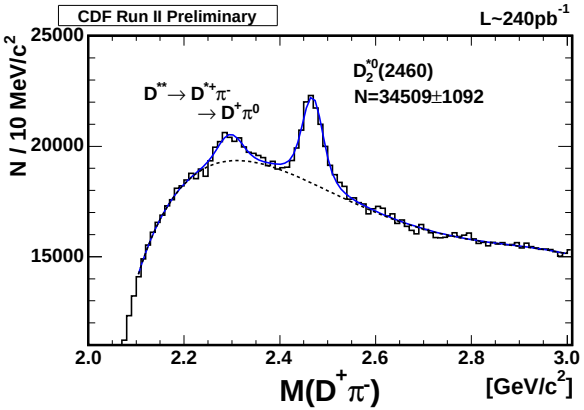
no signal observed !

Search for Θ_c

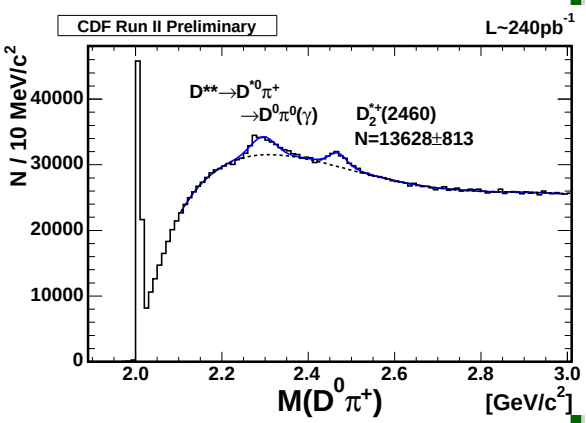
Reference channels



$$D^{**} \rightarrow D^{*+}\pi^-$$
$$\hookrightarrow D^0\pi^+$$
$$\hookrightarrow K^-\pi^+$$



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

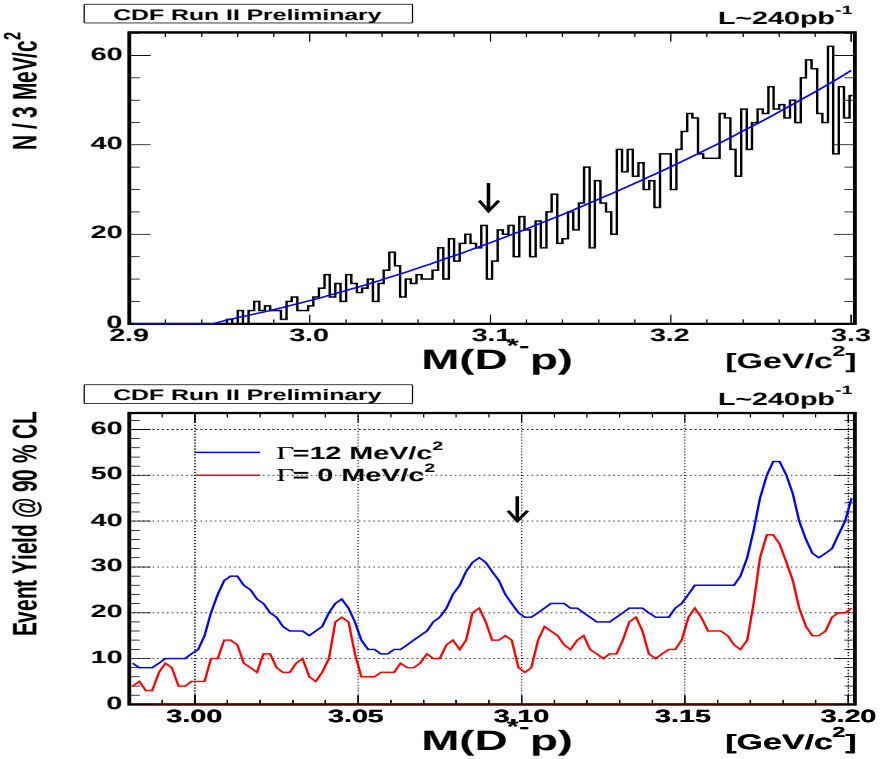


$$D^{**} \rightarrow D^0\pi^+$$
$$\hookrightarrow K^-\pi^+$$

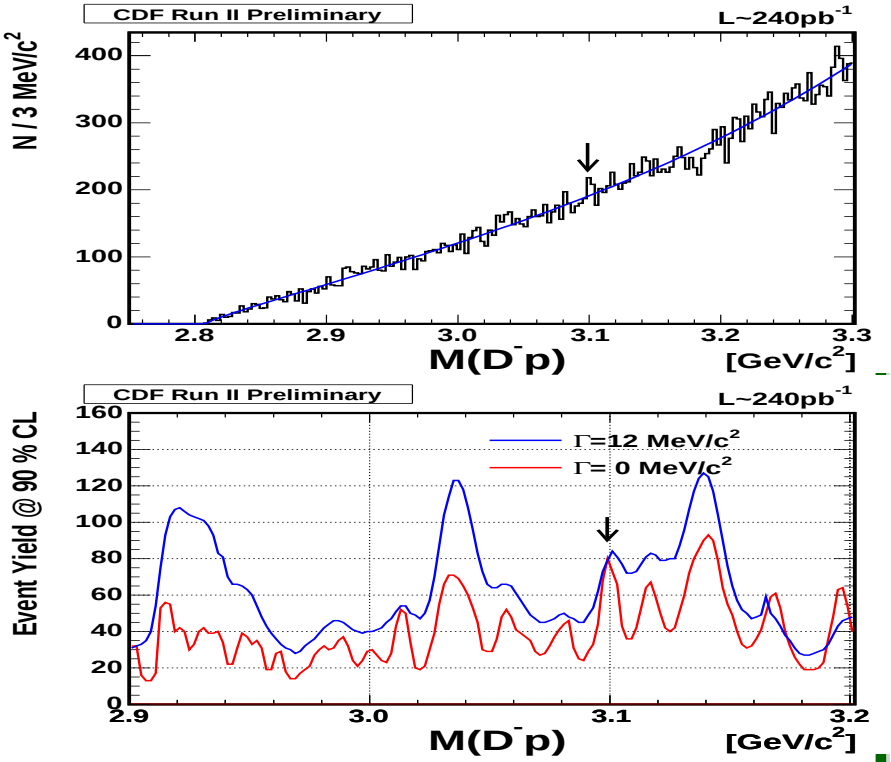
Search for Θ_c^0

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

$D^{*-}p$

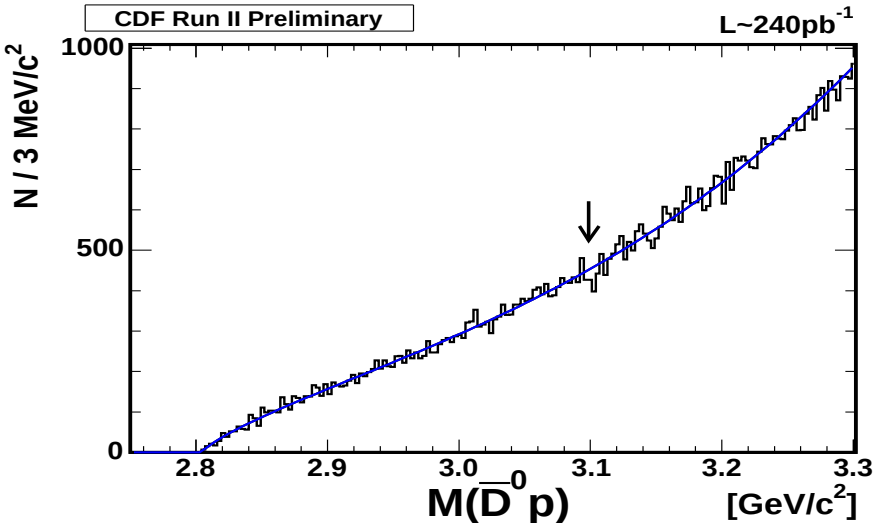


$D^{-}p$

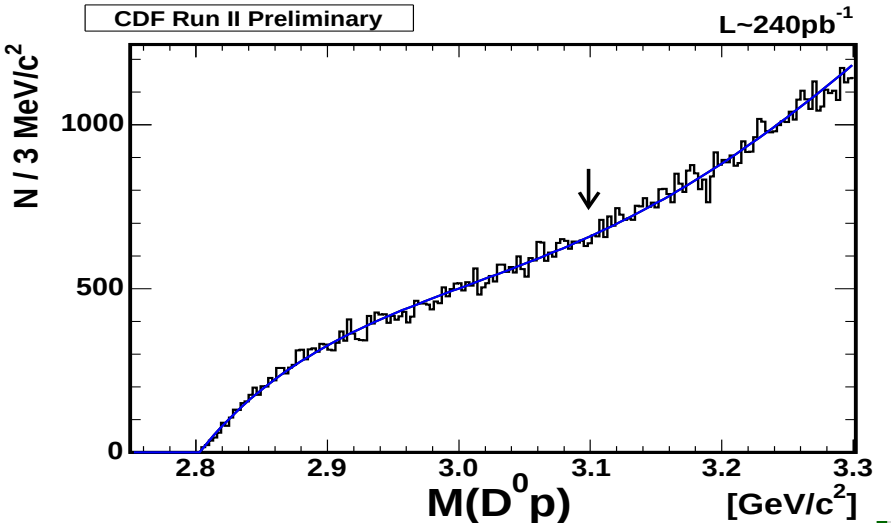


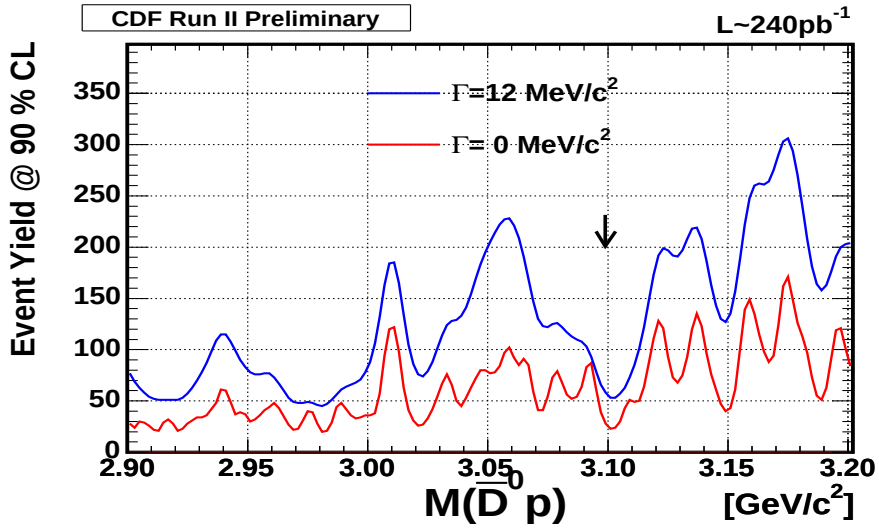
Search for Θ_c^+

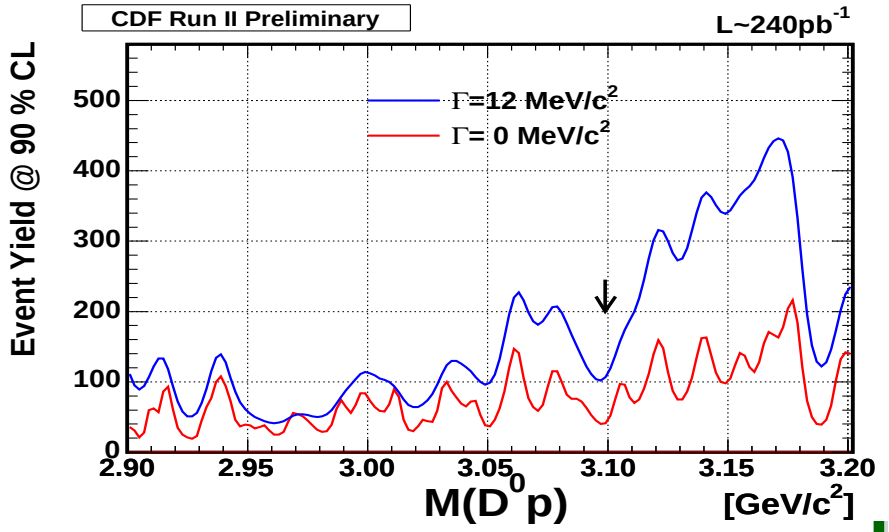
$\bar{D}^0 p$



$D^0 p$







Limits on Θ_c

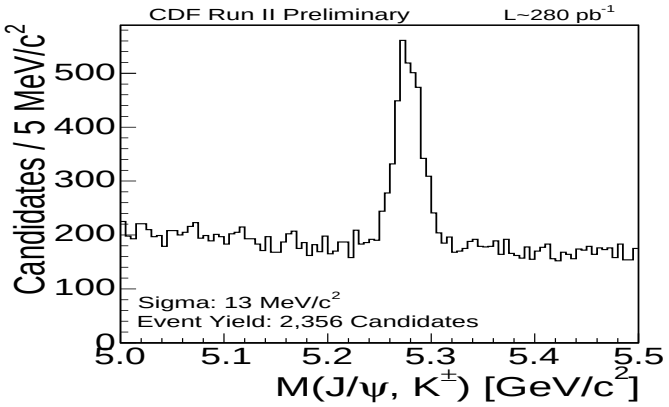
* search window $3.099 \pm 18\ \mathrm{MeV}/c^2$ - as measured by H1
* take worst point from the limit vs mass inside the window

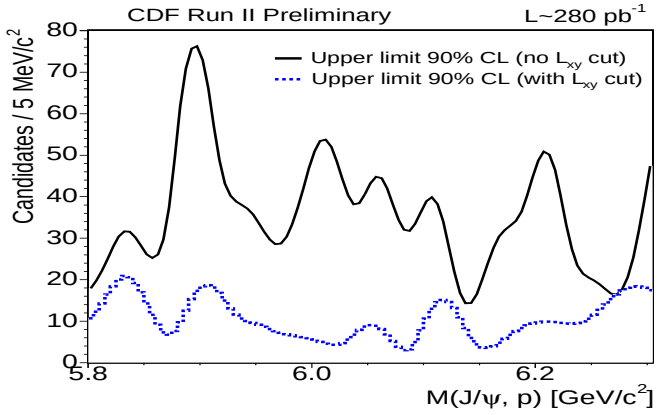
Reference channel		Search channel	
$D_2^{*0} \to D^+\pi^-$	6247 ± 1711	$\Theta_c^0 \to D^{*-}p$	< 21 @ 90% CL
$D_2^{*0} \to D^+\pi^-$	34509 ± 1092	$\Theta_c^0 \to D^-p$	< 89 @ 90% CL
$D_2^{*+} \to D^0\pi^+$	13628 ± 813	$\Theta_c^+ \to \bar{D}^0p$	< 87 @ 90% CL
		$\Theta_c^+ \to D^0p$	< 97 @ 90% CL

Search for R_s^+

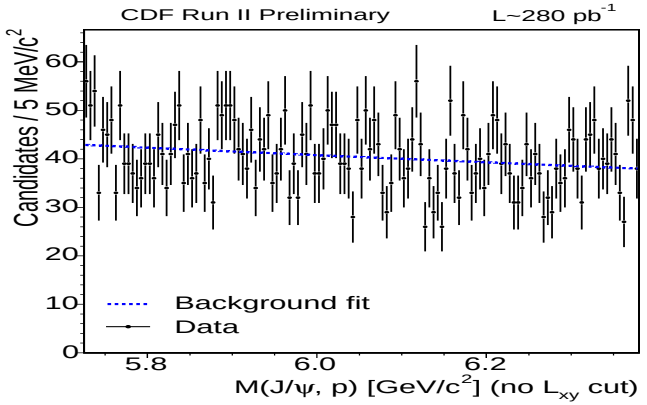
* $R_s^+ \to J/\psi p$ **on dimuon data 282** pb^{-1} **- ref. channel** $B^+ \to J/\psi K^+$
* **measurable** R_s^+ **lifetimes considered:** $L_{xy} > 100\ \mu m$ **and no** L_{xy} **cut**
* **unbinned likelihood fits varying mass in wide range => calculate mass dependent limits**

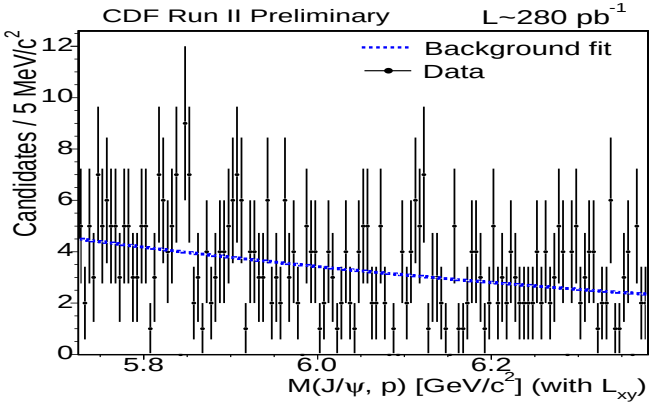
Ref. channel





$J/\psi p$





no signal found!

Conclusions

* CDF has found no evidence for pentaquark states Θ, Θ_c, R_s, and $\Xi_{3/2}$ in several decay modes
* production of exotic baryons in fragmentation may be severely supperessed with respect to normal baryon production
* CDF continues studies of weak and strong decay signatures of exotic charmed and bottom baryons