Pentaquark Results from CDF

International Workshop Pentaquark04

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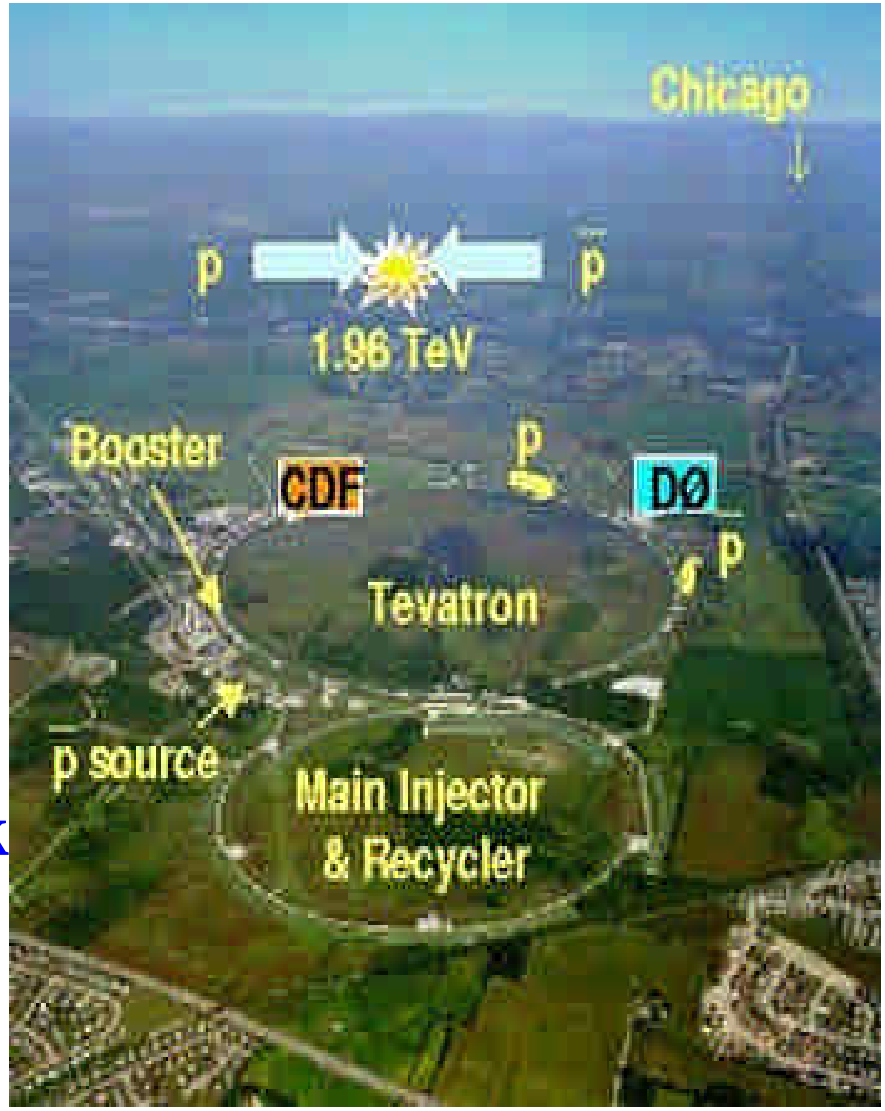
For the CDF collaboration

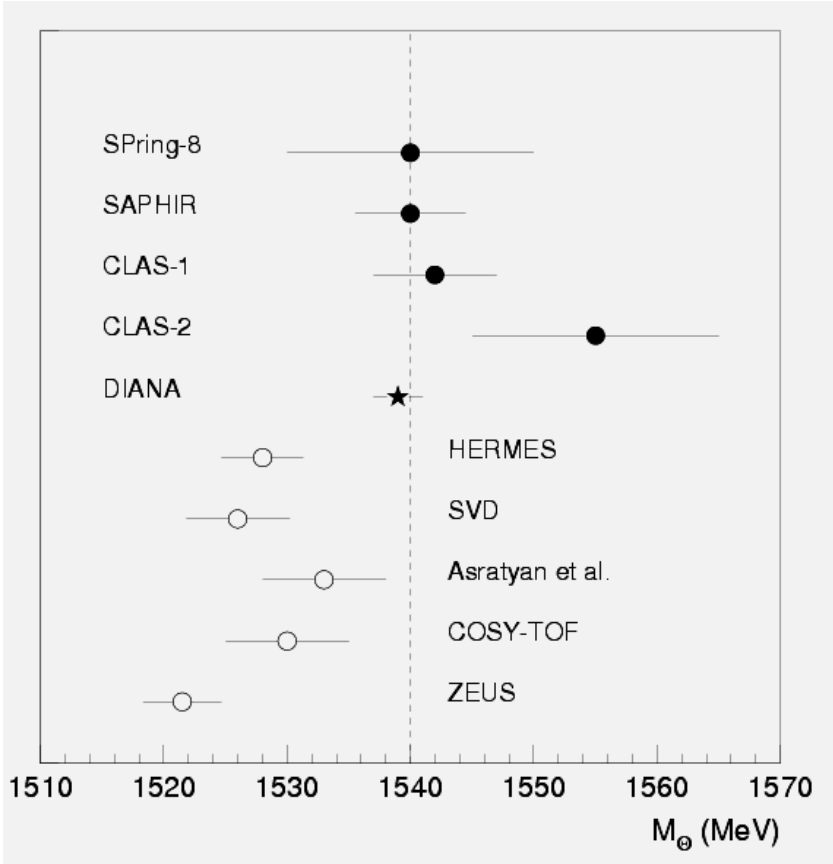
Outline

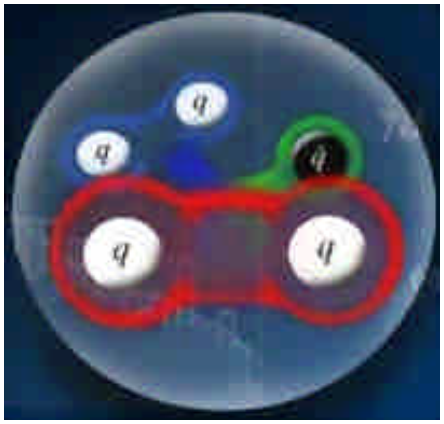
- **Motivations**
- **CDF Detector**
- **Search Strategy**
- **Θ_c^0 ($uudd\bar{c}$) Search**
- **Θ^+ ($uudd\bar{s}$) Search**
- **$\Xi_{3/2}$ ($qsqs\bar{q}$) Search**
- **Ongoing Searches**
- **Summary & Outlook**



Motivation for Pentaquark Search

- *5 quark state predicted by*
- *Diakonov, Petrov, Polyakov(1997)*:
- 4 quarks + 1 antiquark
- Q+ : u u d d s(bar)
- Mass ~ 1530 MeV/c2
- Width ~ 15 MeV/c2
- Decays equally to nK+ and pK0





10 experiments report evidence
3 experiments report no observation
(HERA-B, PHENIX, BES)

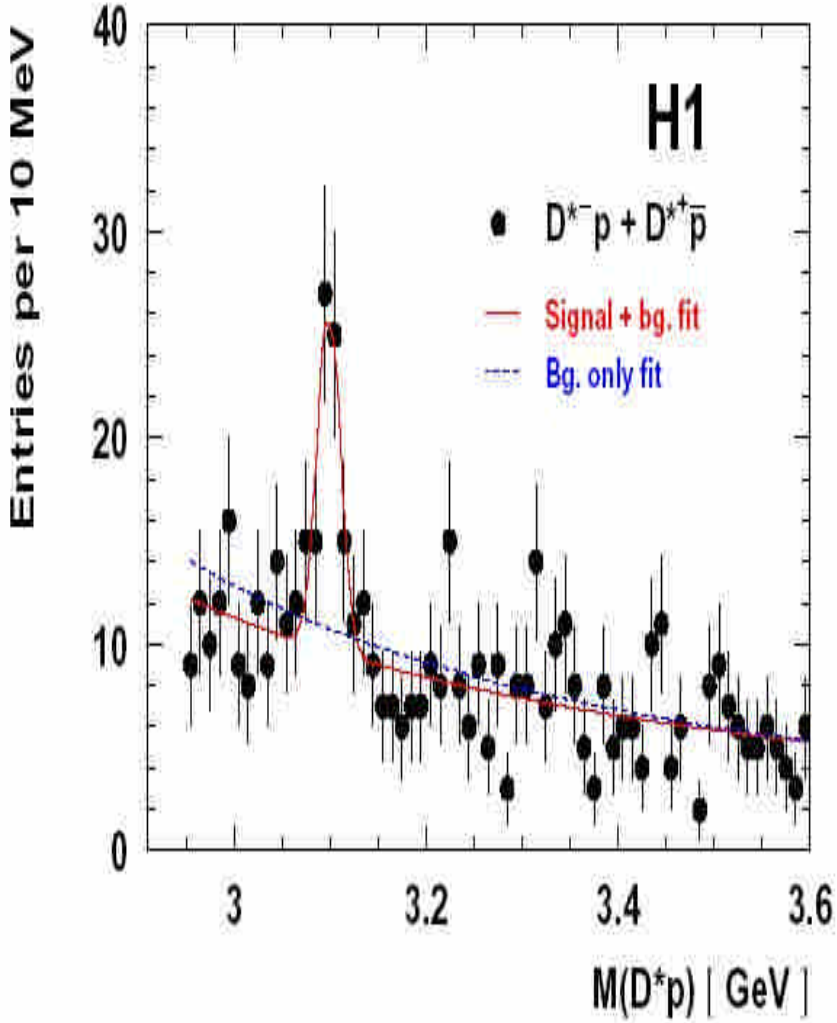
Motivation for forming a PQ Task Force

- H1 claimed to have found a peak and interpreted it as the Θ_c(3099) state
  - -looked into the D*p decay channel
  - -a narrow resonance in D*p mass combination is observed
  - -mass of 3099+/-3(stat.)+/-5(syst.) MeV
  - -a measured Gaussian width of 12+/-3 (stat.) MeV

- A CDF pentaquark task force was formed to do comprehensive pentaquark states search after 4 simultaneous search

  presentations by Y.S. Chung, K. Rinnert, Ming-Jer Wang, D. Litvintsev of this state on 15-Mar-2004 at the B hadronic meeting

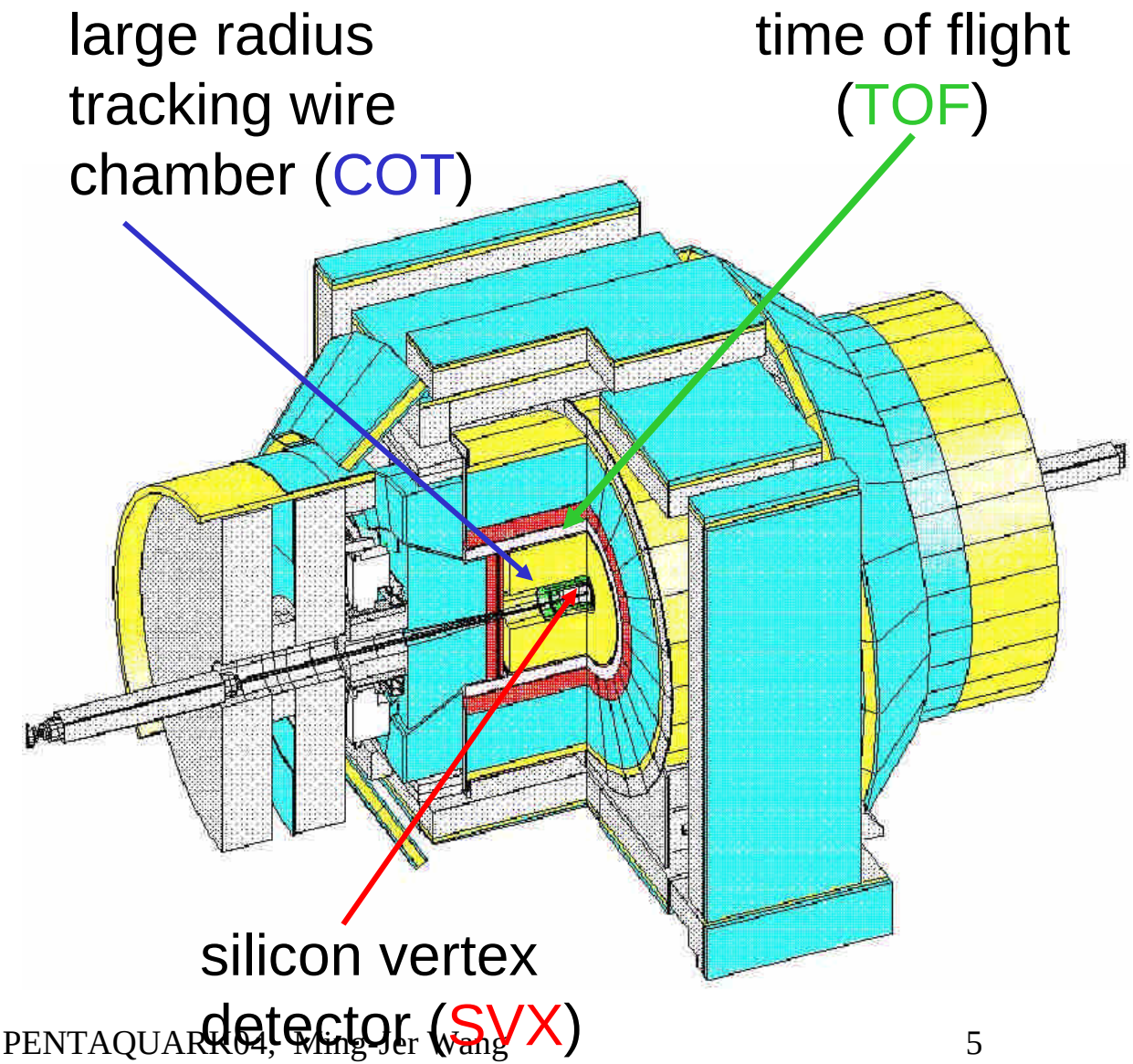
- Two searches have been performed by E.Gerchtein, D. Litvintsev, F. Curbis, and R. Oldeman before this CDF task force was formed



Pentaquark Searches with CDF Detector

Search Modes:

- Θc^0
  - ↳ $D^{*+} p(bar)$
    - ↳ $D^0 \pi^+$
      - ↳ $K^- \pi^+$
- $\Theta^+ \rightarrow Ks^0 p$
  - ↳ $\pi^+ \pi^-$
- Ξ^{--}
  - ↳ $\Xi^- \pi^-$
    - ↳ $\Lambda \pi^-$
      - ↳ $\pi^- p$



General Search Strategy

- **Unknown factors about Pentaquarks @ $p\bar{p}$ Collider & sqrt(s) = 1.96 TeV:**
  - Production cross section? -> Which PQ is the best to look for?
  - Production mechanism? -> Which data set is the best to use?
  - Decay properties? -> Which kinematic region is the best to look for?
- **Difficulty in Reconstruction:**
  - High track multiplicities -> Large combinatory background! -> Do we have the sensitivity in searching for PQ?
- **General Search Strategy:**
  -> Start with claimed PQ's
  -> Choose all possible data sets for each search
  -> Select known resonances with similar decay products and multiplicity
  -> Use these known resonances as guidelines for PQ search
  - Advantages:
    - A quick starting point for selection cuts
    - Make sure we are able to reconstruct & see the known resonances
    - We could calculate the relative yields
  - Limitations:
    - We did not exhaust the search for all the kinematic regions
    - The cuts are not optimized for the PQ search

Θ_c^0 search: Strategy & Samples

Data Sample

CDF II Detector at Fermilab

- $p\bar{p}$ collisions, $\sqrt{s}$ = 1.96 TeV
- Integrated Luminosity ~ 240 pb^{-1}
- Use Two Track Trigger sample

✓ 2 oppositely-charged tracks with impact parameter>0.012cm
✓ We have about 3 million of D0->$K^-\pi^+$ reconstructed events

Search Mode

$\Theta_c^0 \rightarrow D^{*+}\bar{p}$+ c.c.

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

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

Calibration Mode

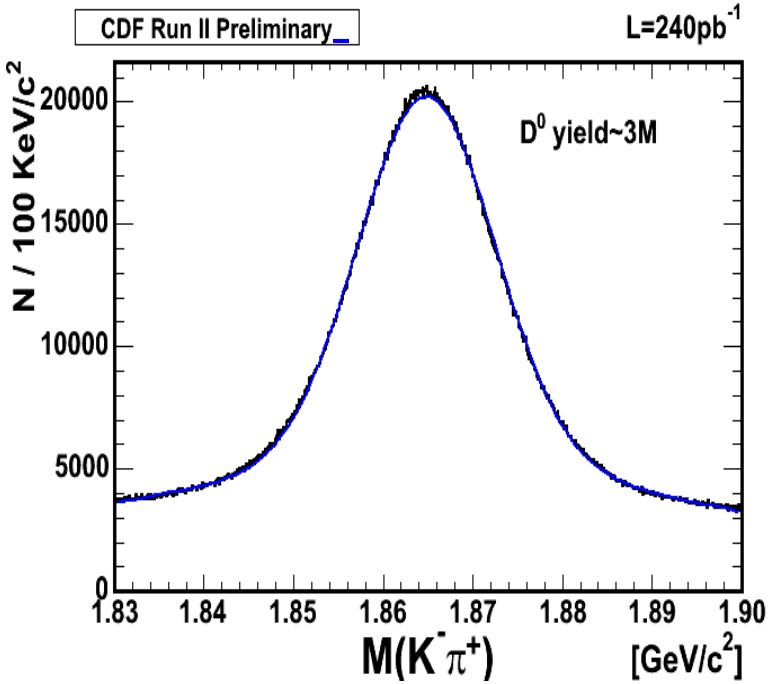
$D_1(2420), D^*_2(2460) \rightarrow D^{*+}\pi^-$+c.c.

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

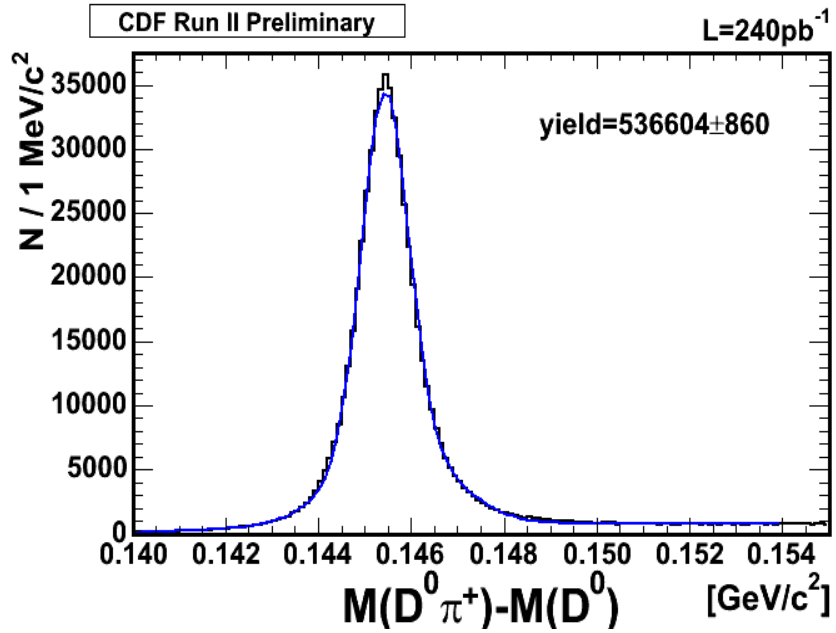
$D^0 \rightarrow K^-\pi^+$

Θc^0 search: D & D* reconstructions

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



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

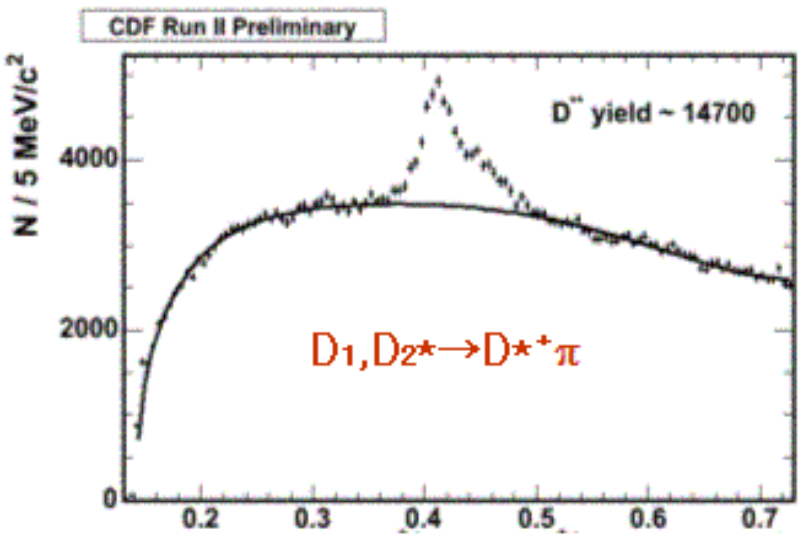


K and π pass all tracking cuts
K and π form a good vertex with vertex $\chi^2 < 30$
$N(D^0) \sim$ 3 M events
$\sigma(D^0) \sim 8$ MeV/c^2

Pion pass all tracking cuts
$Pt(\pi) > 400$ MeV
D^0 and pion form a good vertex with vertex $\chi^2 < 30$
$1.845 < M(D^0) < 1.885$ GeV/c^2
$N(D^*) \sim$0.5 M events,
$\sigma(D^*) \sim 1.2$ MeV /c^2

Θc^0 search: D1 & D2 reconstructions

$D_1(2420)$ & $D_2^*(2460)$



Reference signal

Pion pass all tracking cuts

$Pt(\pi) > 500$ MeV/c

D^* and pion form a good vertex

with vertex $\chi^2 < 30$

$143.6 < M(D^*) - M(D^0) < 147.2$ MeV/c²

N(D1(2420), D2*(2460)) ~ 15k events

$M(D^{*+}\pi^-) - M(D^{*+})$ [GeV/c2]

Θ_c^0 search: Proton Pt Distribution

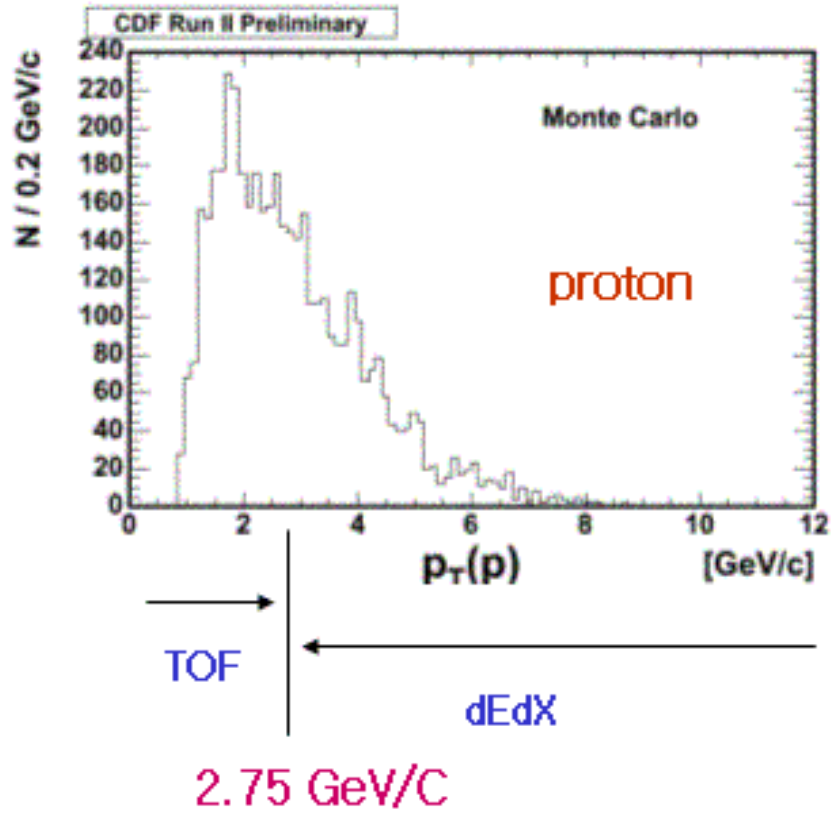
Θ_c^0 Monte Carlo

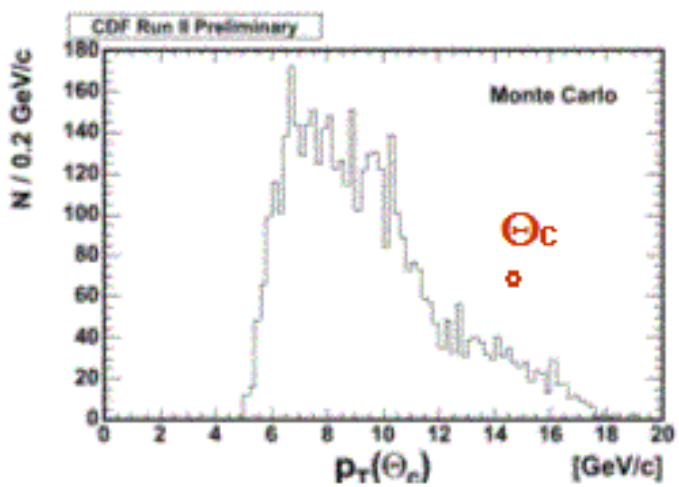
Input Parameters

- M=3.1 GeV/c²
- Γ=0.0 MeV/c²

Zero Width MC Mass Resolution ~ 2.5 MeV/c²

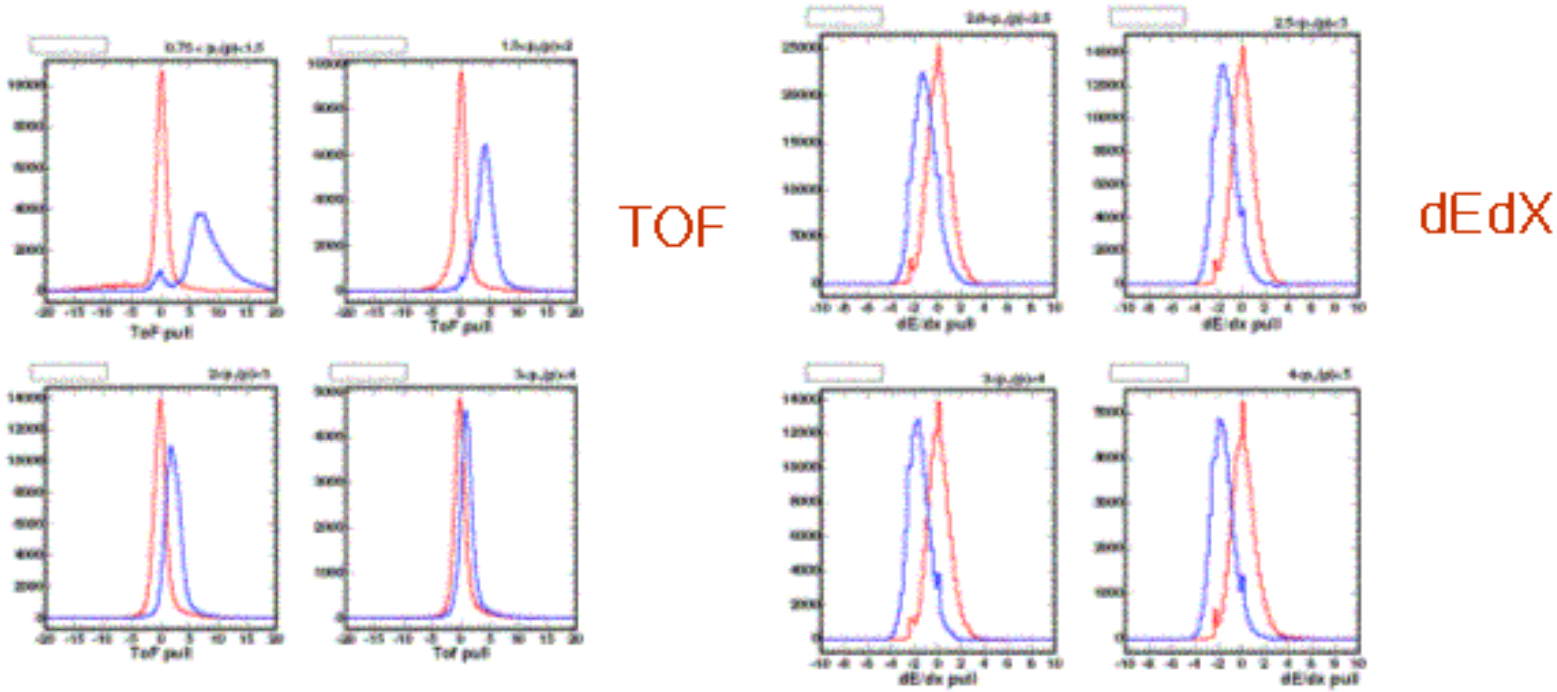
→ should be able to resolve Θ_c^0 that H1 claims





Θc^0 search: Proton Identification

Proton PID – TOF and dEdX



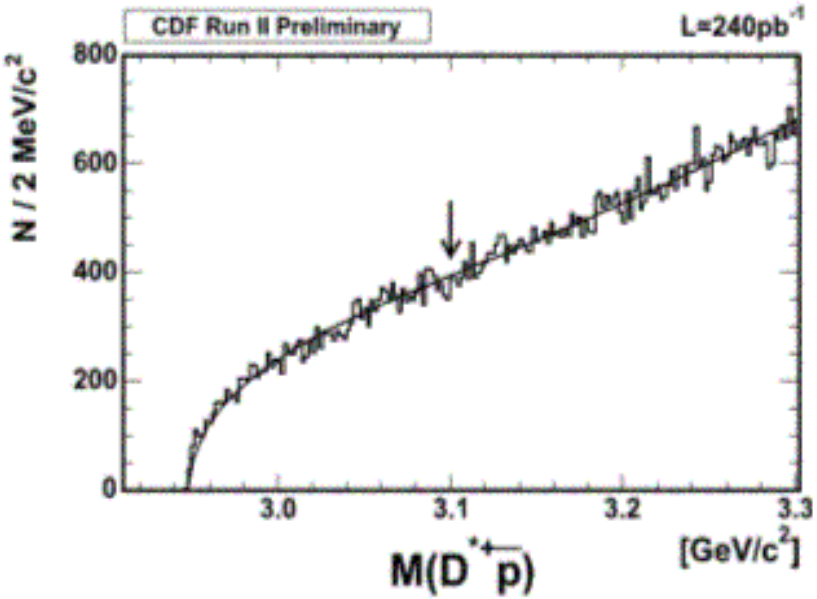
PID studies with D*, Λ, and Ks

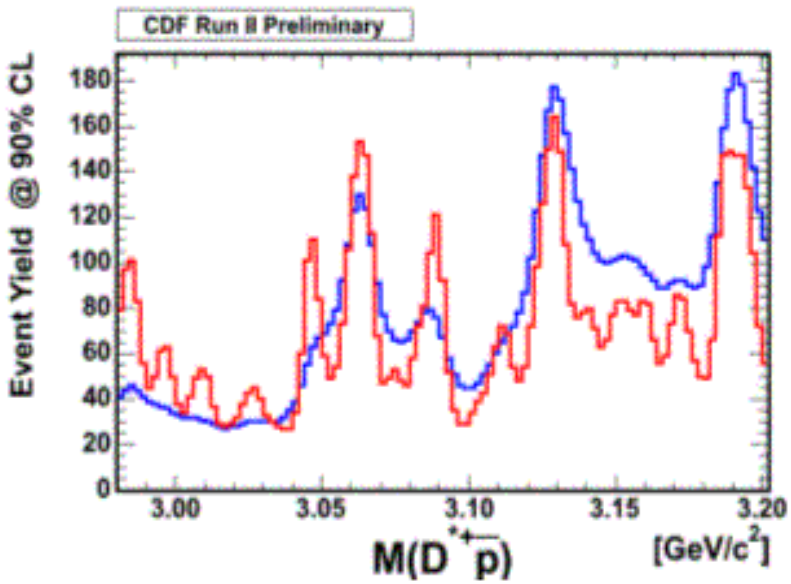
TOF : >2σ separation between protons and pions p_T<~2.75 GeV/c

dEdX : >1.3σ separation between protons and pions p_T>~2.75 GeV/c

Θc^0 search: D*p Mass Spectrum

D*proton mass – No PID





- Proton pass all tracking cuts
- Pt(proton) > 500 MeV/c
- D± and proton form a good vertex with vertex χ^2 < 30
- 142.5 <M(D±)–M(D*) < 148.5 MeV/c²
- No PID cut

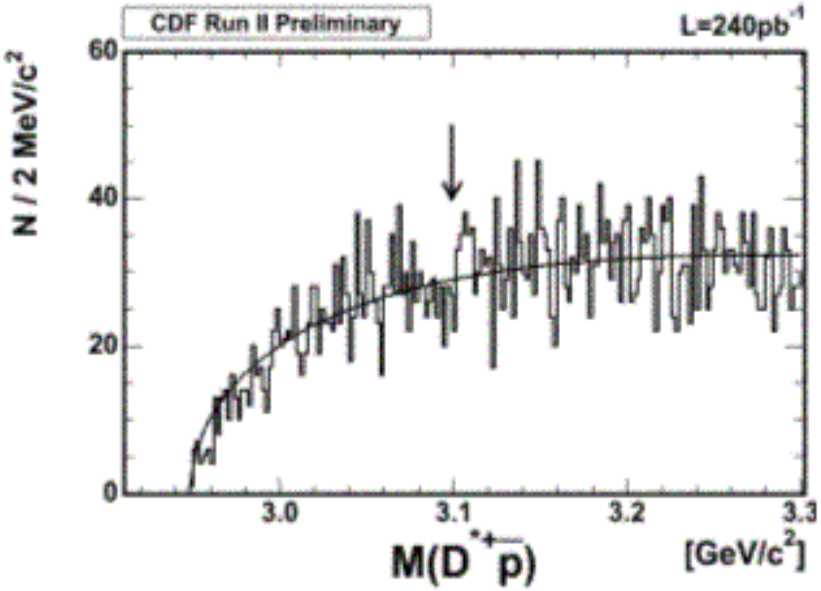
For M=3.099 GeV/c²,

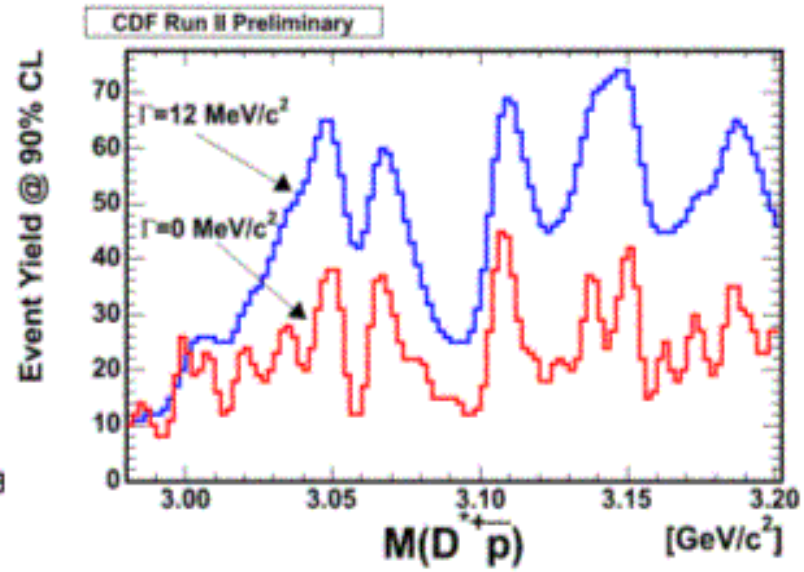
<29 events for Γ=0.0 MeV/c² @90% C.L.

<44 events for Γ=12.0 MeV/c² @90% C.L.

Θc^0 search: D*p Mass Spectrum

D*proton mass with TOF



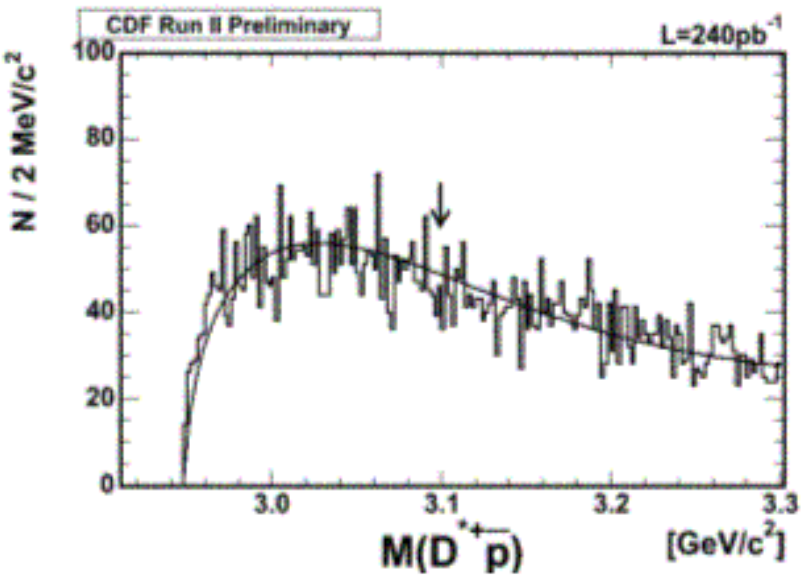


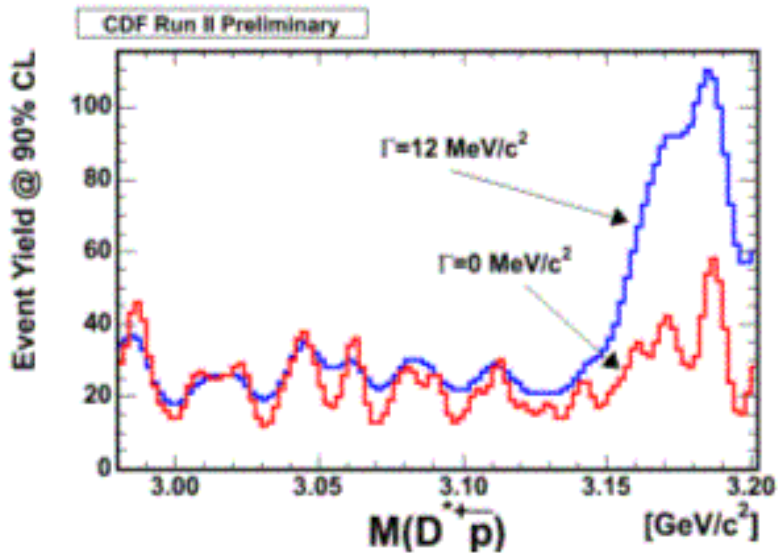
- Proton pass all tracking cuts
- 0.5 GeV/c < Pt(proton) <2.75 GeV/c
- D± and proton form a good vertex with vertex χ^2 < 30
- 142.5 <M(D±)-M(D*) < 148.5 MeV/c²
- TOF : (measured-expected)/error <2.0

For M=3.099 GeV/c²,
<12 events for Γ=0.0 MeV/c² @90% C.L.
<25 events for Γ=12.0 MeV/c² @90% C.L.

Θc^0 search: D*p Mass Spectrum

D*proton mass with dEdX





- Proton pass all tracking cuts
- 2.75 GeV/c < Pt(proton)
- D* and proton form a good vertex with vertex χ^2 < 30
- 142.5 <M(D*)−M(D°) < 148.5 MeV/c²
- dEdX : (measured−expected)/error <1.3

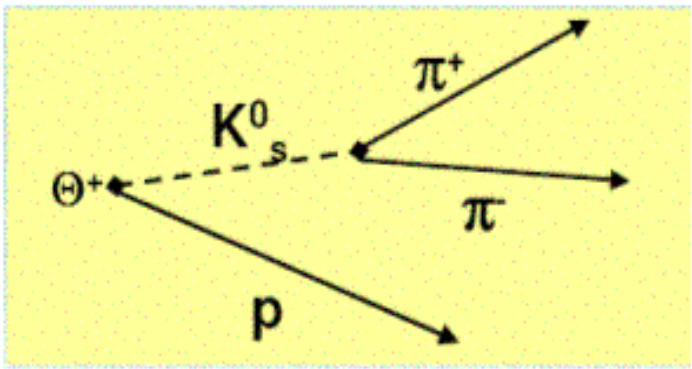
For M=3.099 GeV/c²,
<19 events for Γ=0.0 MeV/c² @90% C.L.
<30 events for Γ=12.0 MeV/c² @90% C.L.

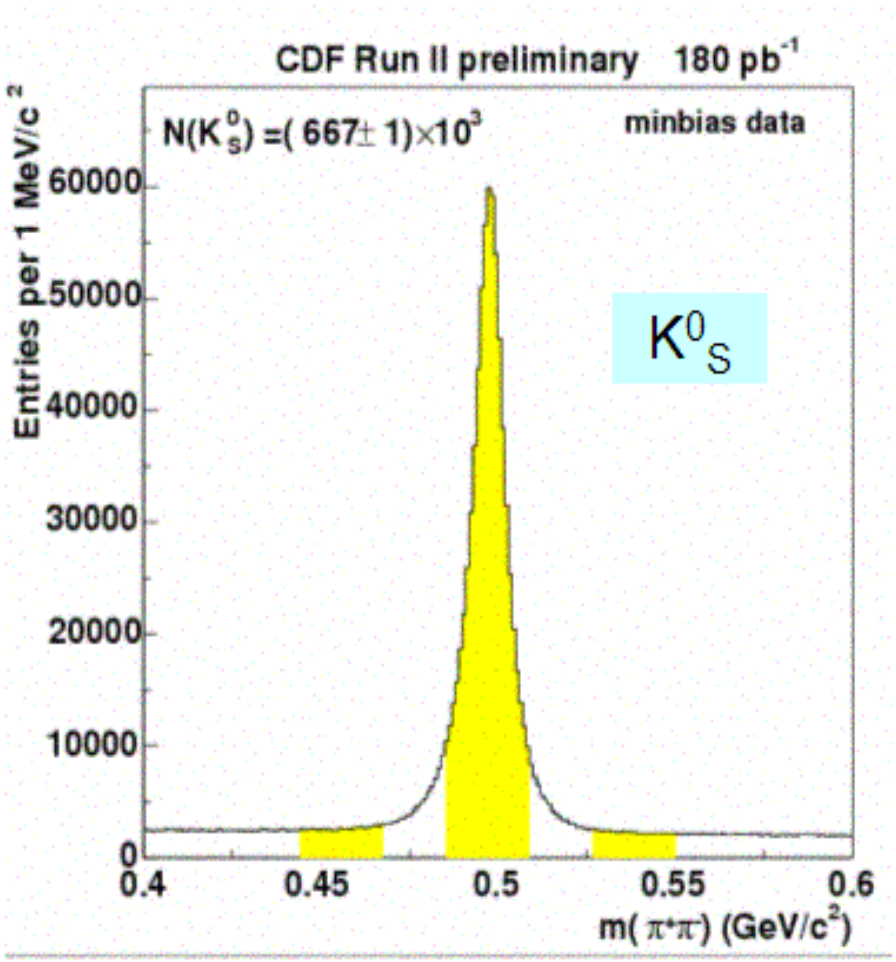
Summary of Θc^0 search

- Reference signals D** are clearly reconstructed
  - with 14.7 K events
  - the combinatory BKG underneath is large
- PID are used for the proton
- With the selection cuts for D** & PID for proton, no evidence was found for Θc^0
- Need more inputs from theorists on both the production mechanism & decay properties in order to design Θc^0-specific cuts

Θ^+ Search: Strategy & Samples

$p\,K^0_S \rightarrow p\,\pi^+\,\pi^-$



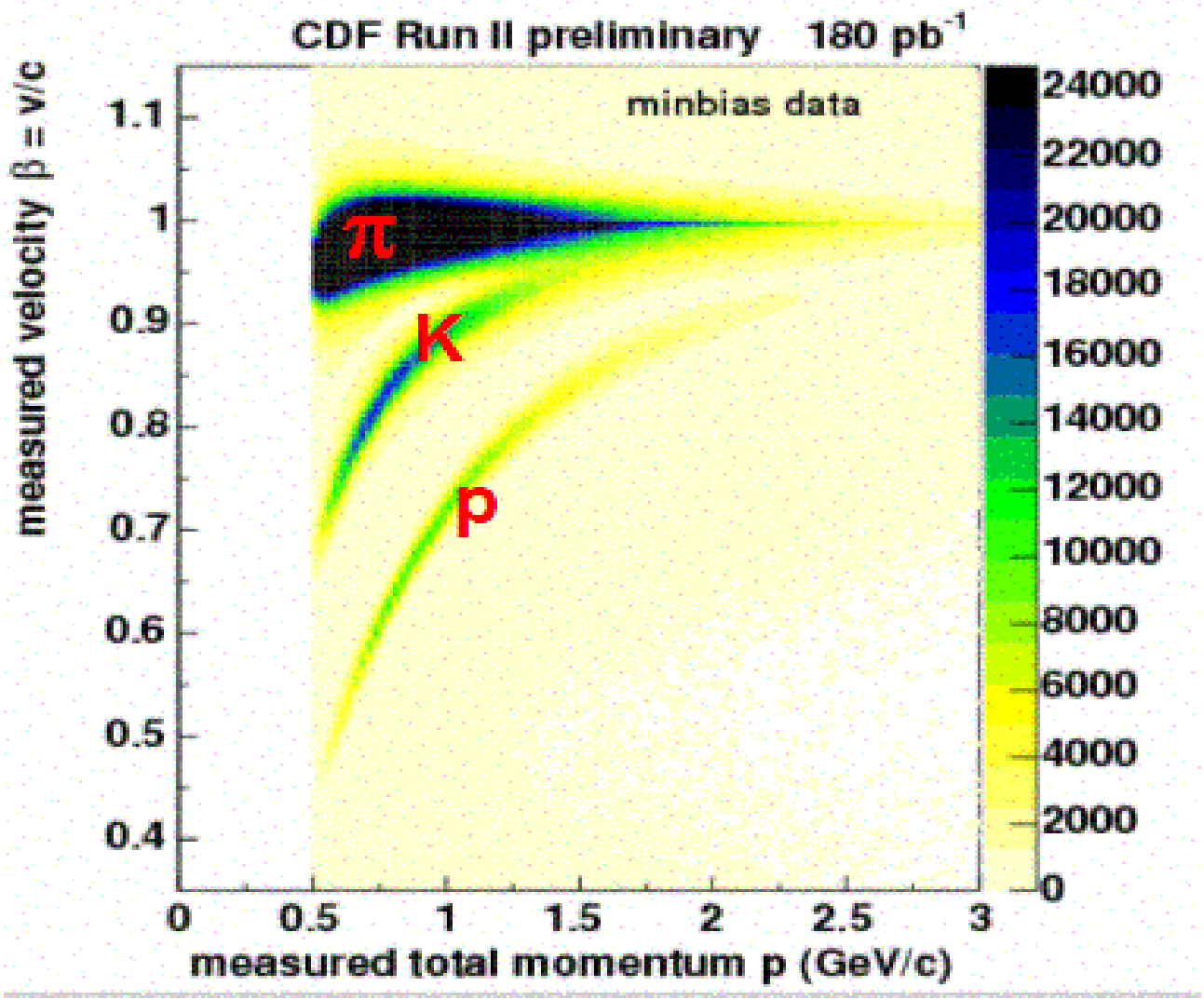


Two energy ranges:

- ***minbias***! 23£10^6 events
- ***jet20***! 16£10^6 events

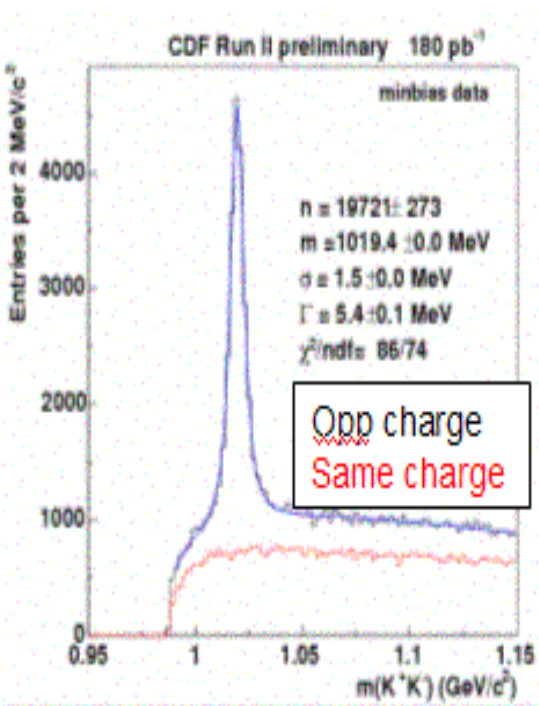
to remove $\Lambda \rightarrow p\pi^-$: m($\pi$p) and m(p$\pi$), 1.13 GeV

Θ^+ Search: Proton ID with TOF

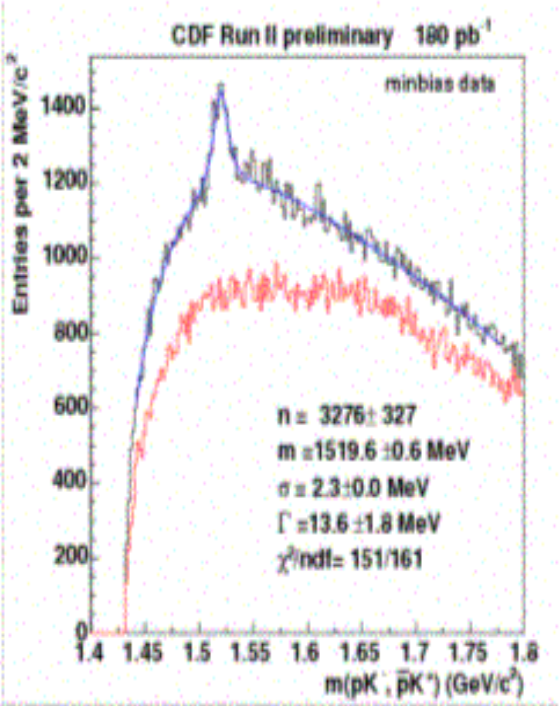


Θ^+ Search: Known Resonances

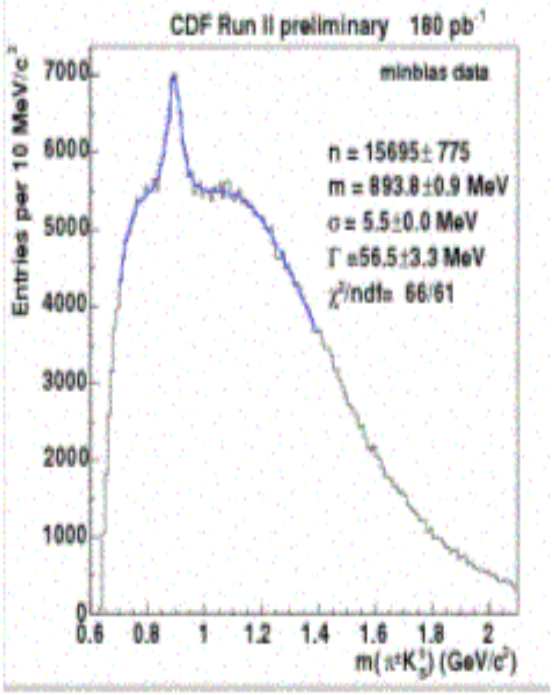
$\phi \rightarrow K^+K^-$



$\Lambda(1520) \rightarrow pK^-$

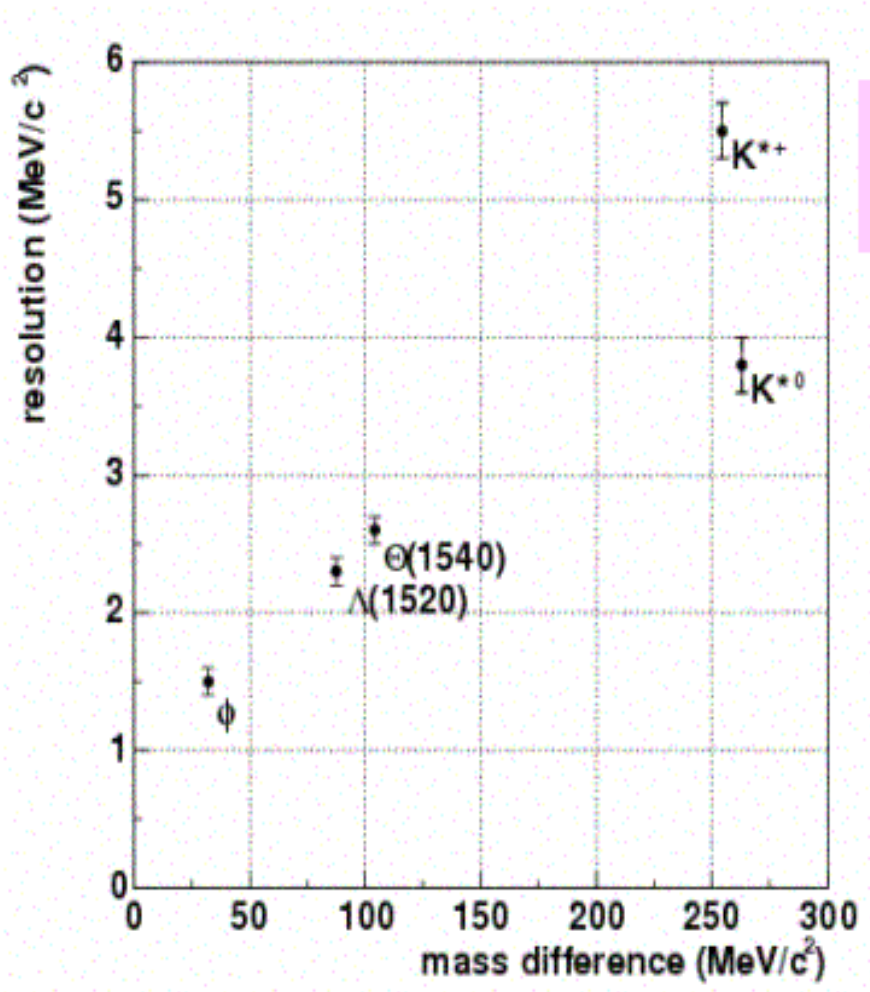


$K^{*+} \rightarrow K^0_S\pi^+$



Acceptance limited by TOF cuts: *(determined with MC)*

Θ^+ Search: Mass Resolutions

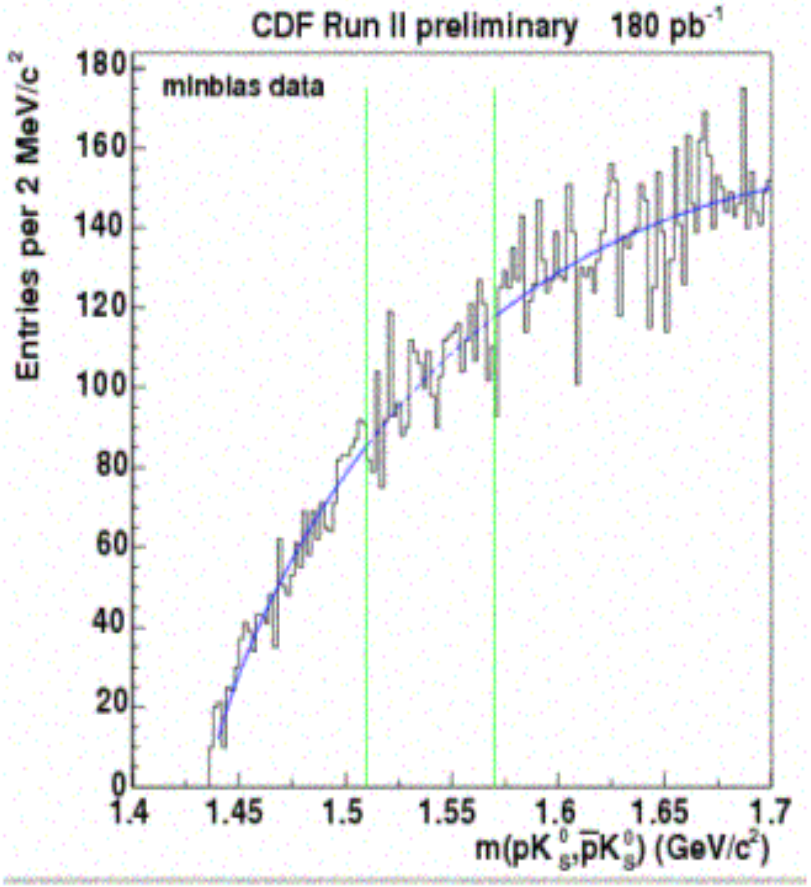


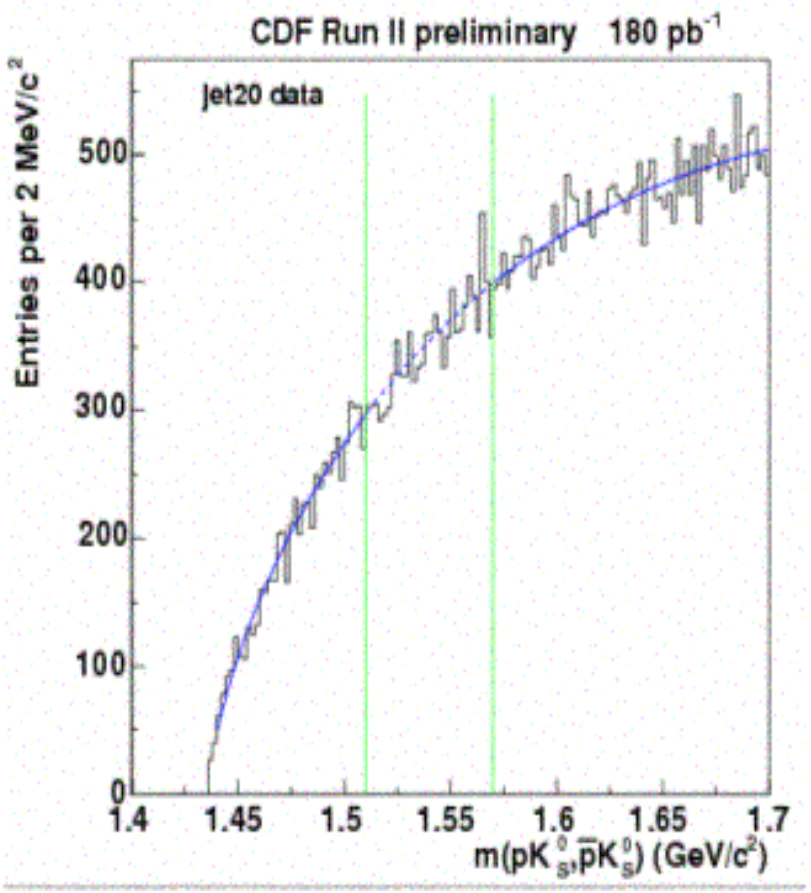
$\sigma(\Theta^+)<3$MeV,

compare with 15MeV expected width

MC resolution validated with K^0_S

Θ^+ Search: pK^0_S Mass Spectrum





No evidence of narrow resonance

Summary of Θ^+ search

- Reference signals K*+, $\Lambda(1520)$, Φ are clearly reconstructed

  -we have sensitivity to these known resonances

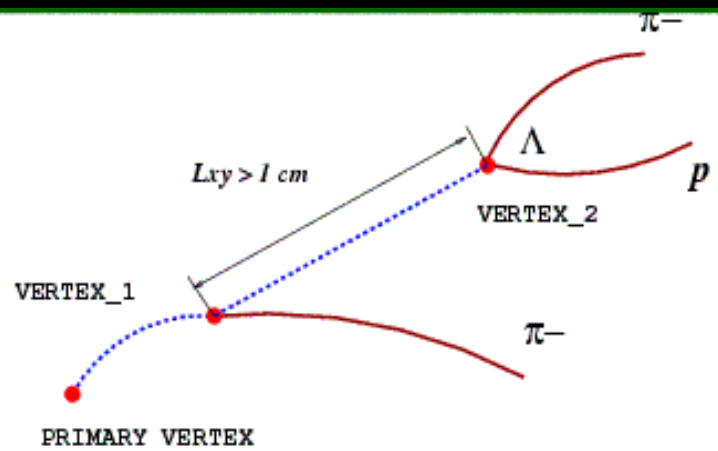
  -the combinatory BKGs underneath are large
- TOF is used for the proton ID
- With the present selection cuts, no evidence was found for Θ^+
- Need more inputs from theorists on both the production mechanism & decay properties in order to do further search

$\Xi_{3/2}$ Search : Strategy & Samples

- Displaced track trigger data - large hadronic sample enriched with charm and bottom
  QCD inclusive jet data with $E_t > 20\ GeV$ threshold - smaller, trigger unbiased sample.
- $\mathscr{L} = 220\ \mathrm{pb}^{-1}$
- Decay modes : $\Xi^0_{3/2} \to \Xi^-\pi^+$; $\Xi^{--}_{3/2} \to \Xi^-\pi^-$
- A well established $J^P = 3/2^+$ resonance $\Xi(1530)^0 \to \Xi^-\pi^+$ can serve as a calibrating signal

  $$\mathrm{M_{PDG}}(\Xi(1530)^0) = 1531.80 \pm 0.32\ \mathrm{MeV/c^2}$$
  $$\Gamma(\Xi(1530)^0) = 9.1 \pm 0.5\ \mathrm{MeV/c^2}$$
- A novel tracking technique of a long lived cascade hyperon Ξ^- in the CDF Si vertex detector
  - improved momentum and vertex resolution
  - significant reduction of combinatorial background

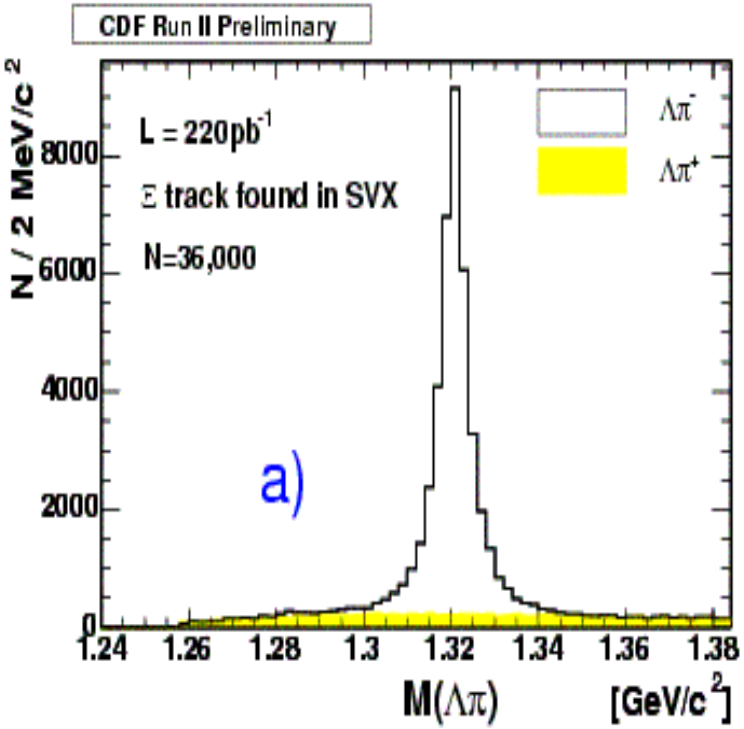
$\Xi_{3/2}$ Search : Ξ reconstruction

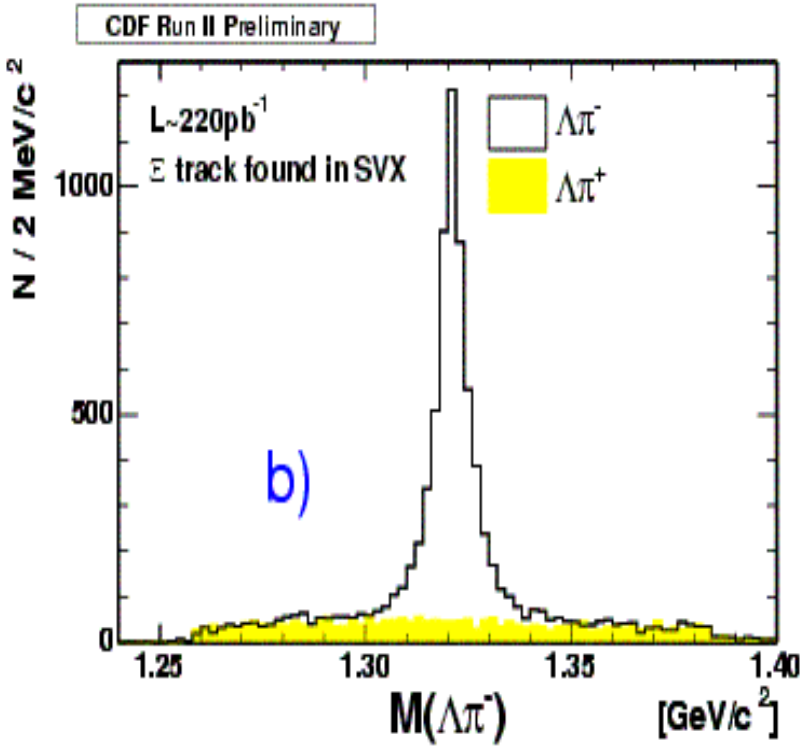


- $\Xi^- \rightarrow \Lambda\pi^-$ reconstruction.
- Fit a vertex formed by $\Lambda^0 \rightarrow p\pi^-$
- Fit Λ^0 and π^- to a common vertex
- Ξ^- is a long lived particle $(c\tau = 4.91\ cm)$ and it makes hits in Si Detector. Ξ 4-momentum and its decay vertex are used to seed specialized silicon tracking.
- Ξ^-'s produced by this specialized tracking have very low background and greatly improved momentum and vertex resolution.

$\Xi_{3/2}$ Search : Ξ Mass Spectra

Cascade reconstructed with specialized silicon tracking



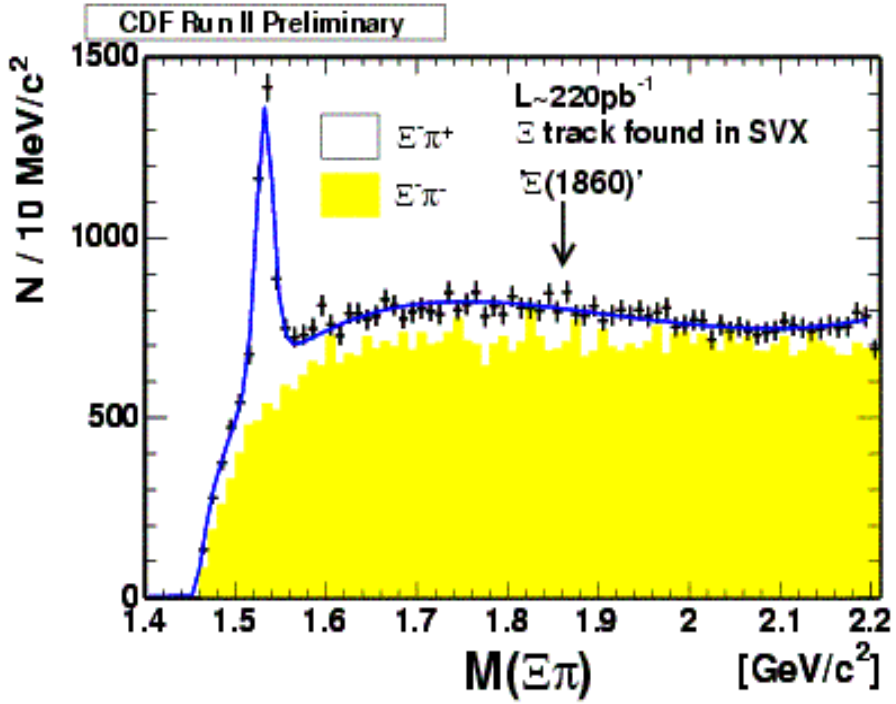


a) Displaced Track Trigger sample

b) Inclusive Jet Trigger sample

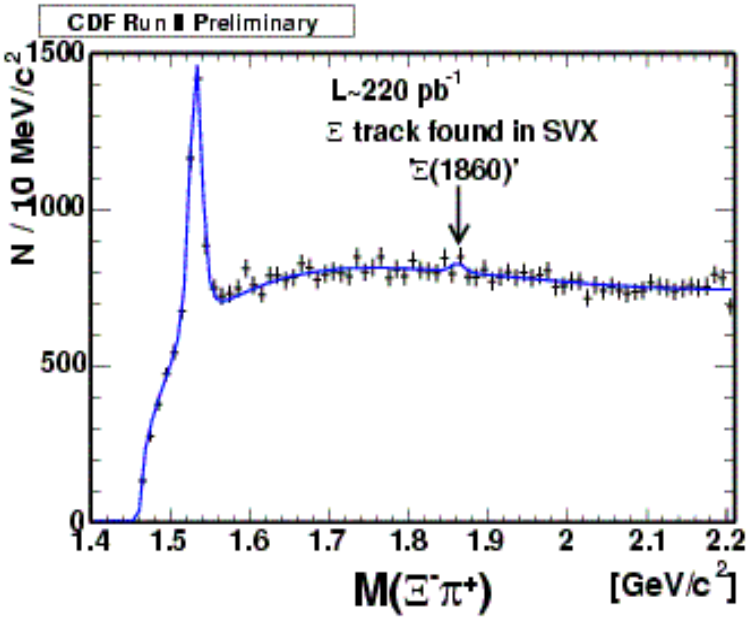
$\Xi_{3/2}$ Search : Two-Track Trigger

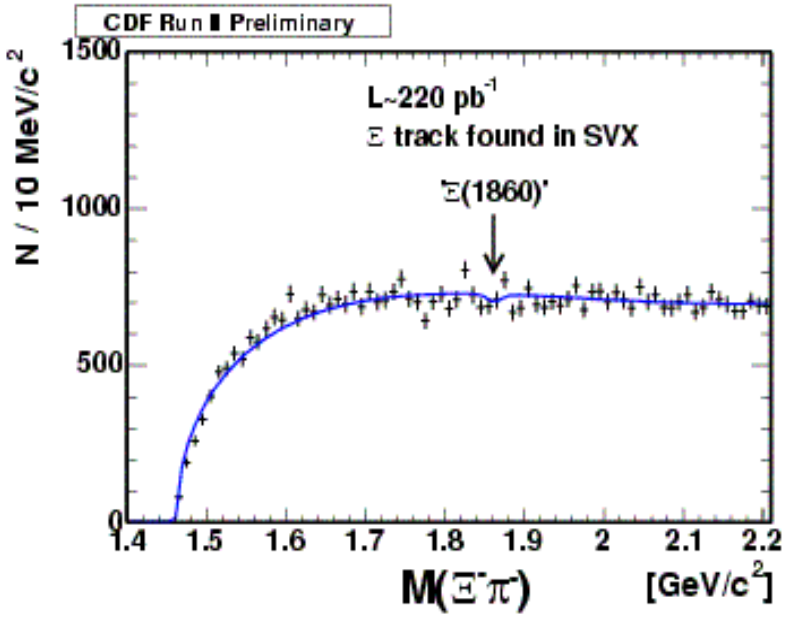
- Invariant mass spectra $M(\Xi^-\pi^\pm)$
- fit function $\mathscr{BW} \otimes \mathscr{G}$
- $\Gamma_{PDG} = 9.1\ \mathrm{MeV}/c^2$
- $\sigma_{res} = 5.8 \pm 0.5 MeV/c^2$
- $\mathrm{N}(\Xi(1530)) = 2,182 \pm 92$
- $\mathrm{M}(\Xi(1530)) = 1,5320 \pm 0.5\mathrm{MeV}/c^2$



$\Xi_{3/2}$ Search : Two-Track Trigger

Separately $\Xi^-\pi^+$ and $\Xi^-\pi^-$

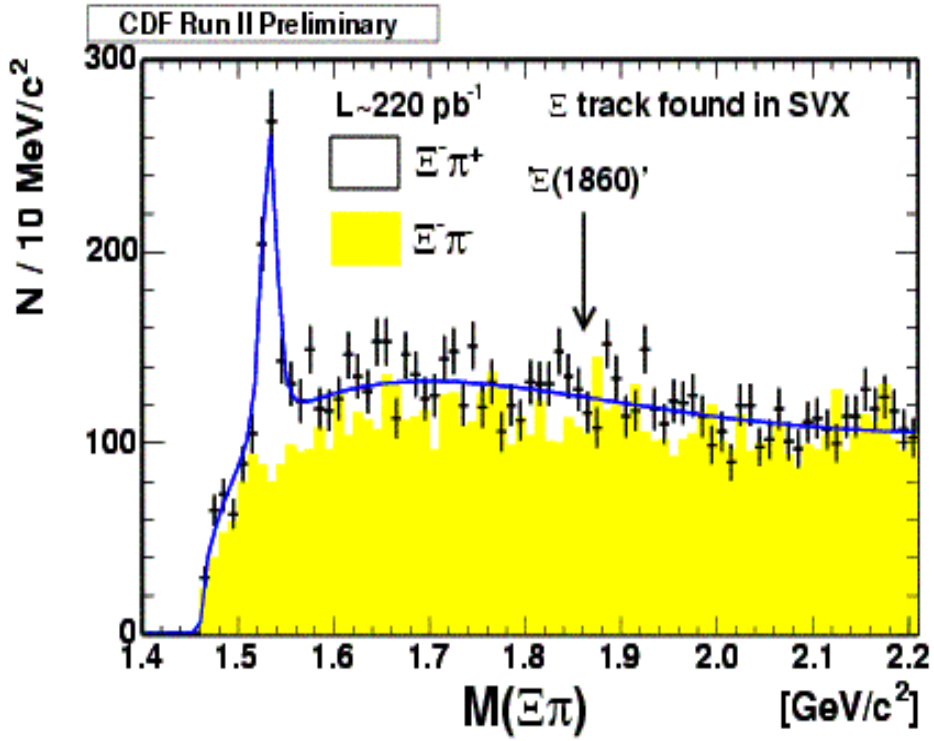




Channel	# of events	UL 90 % CL	UL 95 % CL
$\Xi^-\pi^+$	57±51	126	144
$\Xi^-\pi^-$	-54±47	51	63

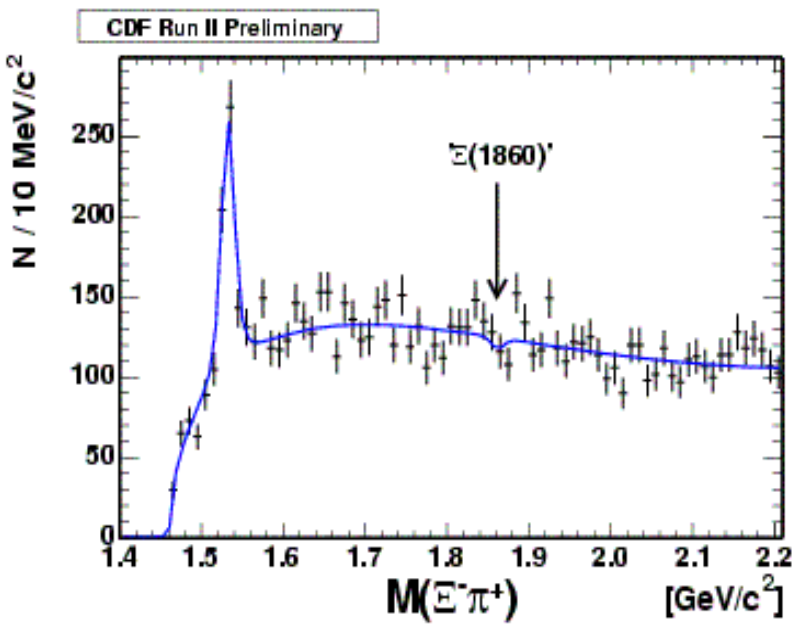
$\Xi_{3/2}$ Search : Inclusive Jet Trigger

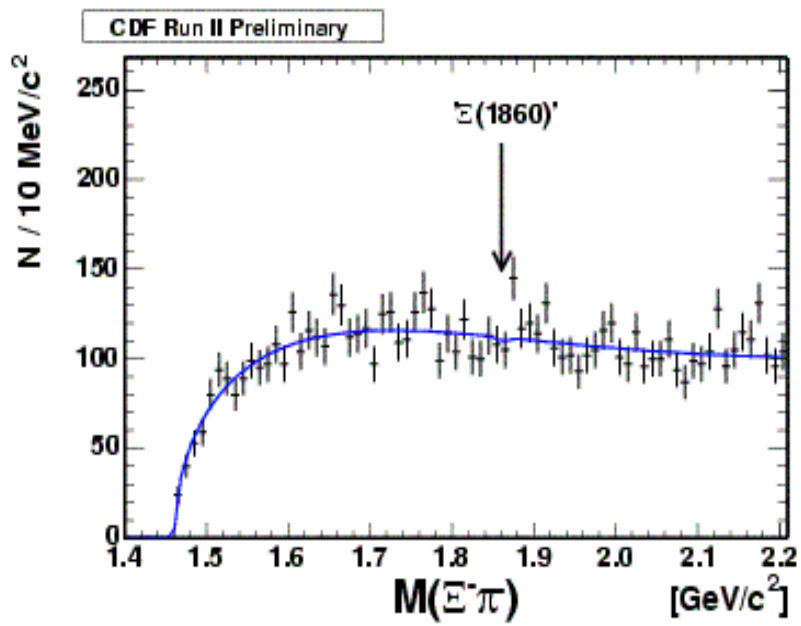
- Invariant mass spectra $M(\Xi^-\pi^\pm)$
- fit function $\mathscr{BW} \otimes \mathscr{G}$
- $\Gamma_{PDG} = 9.1\ \mathrm{MeV}/c^2$
- $\sigma_{res} = 5.8 \pm 0.5 MeV/c^2$
- $N(\Xi(1530)) = 387 \pm 34$
- $M(\Xi(1530)) = 1,532.3 \pm 0.8\ \mathrm{MeV}/c^2$



$\Xi_{3/2}$ Search : Inclusive Jet Trigger

Separately $\Xi^-\pi^+$ and $\Xi^-\pi^-$





Channel	# of events	UL 90 % CL	UL 95 % CL
$\Xi^-\pi^+$	-14±19	25	30
$\Xi^-\pi^-$	-4±18	28	33

Summary of Ξ Search

- Reference signal $\Xi(1530)$ is clearly reconstructed in both data sets
- With the present selection cuts, no evidence was found for $\Xi_{3/2}$
- Need more inputs from theorists on both the production mechanism & decay properties

Ongoing Searches

- PQ(**uudc$\bar{c}$)** -> J/Psi proton
- PQ(**uuds$\bar{c}$)** -> Ds- proton
- PQ(**uuud$\bar{c}$)** -> D0 proton
- PQ(**uudd$\bar{c}$)** -> D- proton

Summary & Outlook

- CDF Collaboration have searched for Θ_c^0, Θ^+, $\Xi_{3/2}$ states
- With no application of knowledge for pentaquark production mechanisms and decay properties in all analyses, no evidences of these states have been found
- We are vigorously searching for another 4 pentaquark states