



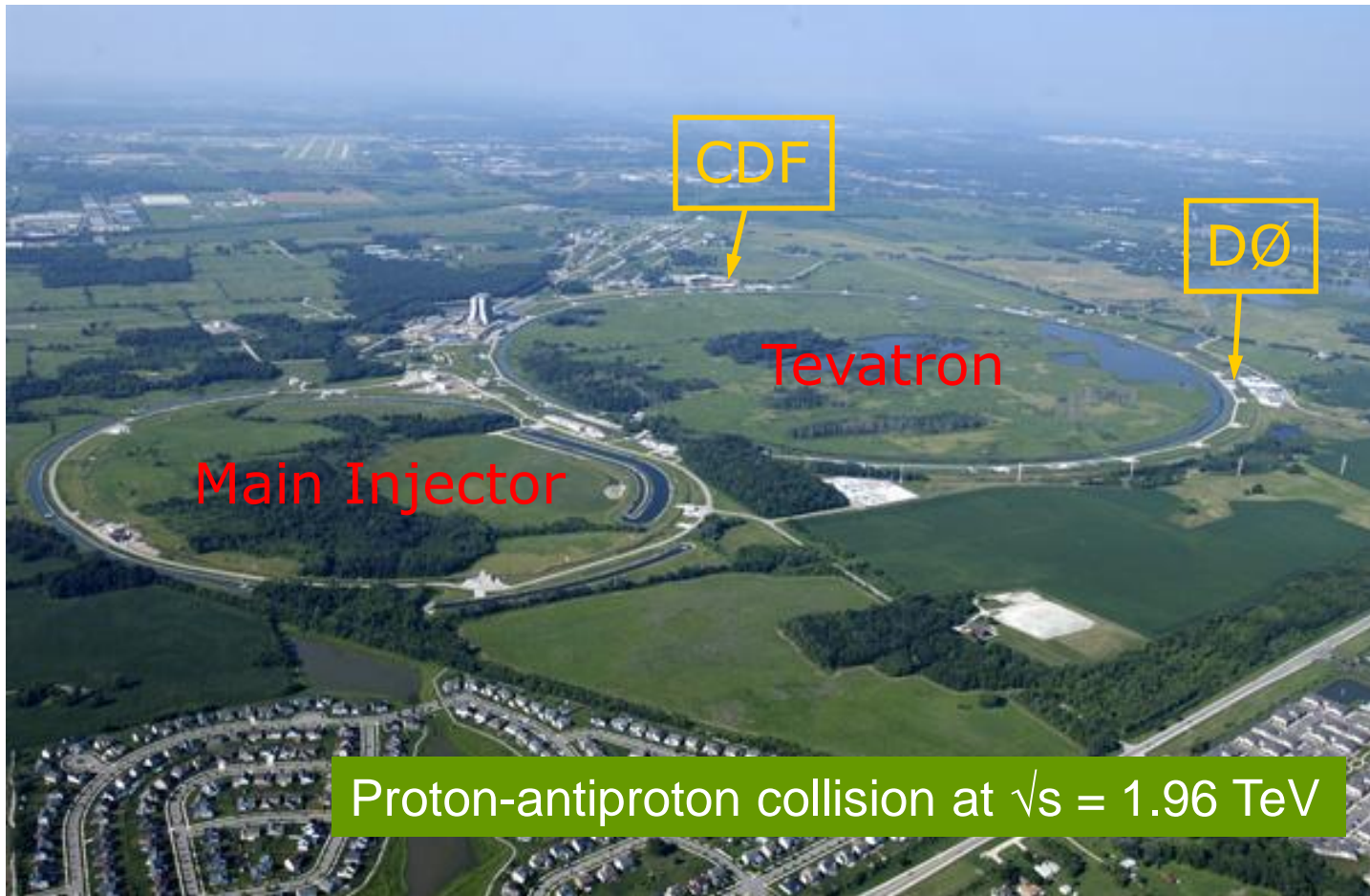
Heavy Hadron Studies at the Tevatron

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for the CDF Collaboration

1. Tevatron and CDF
2. X(3872)
3. Pentaquark
4. New b-baryons

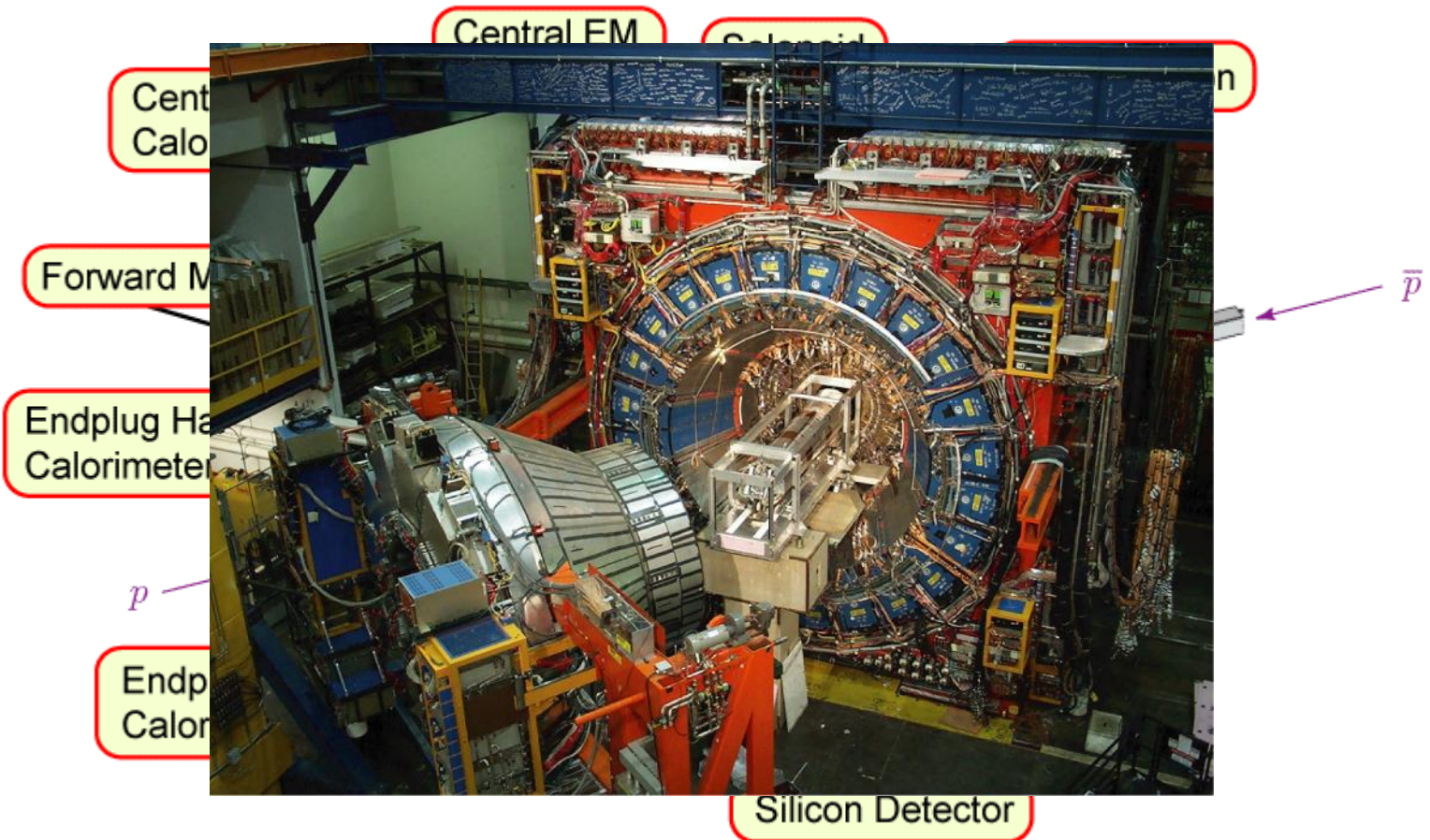


Tevatron at Fermilab





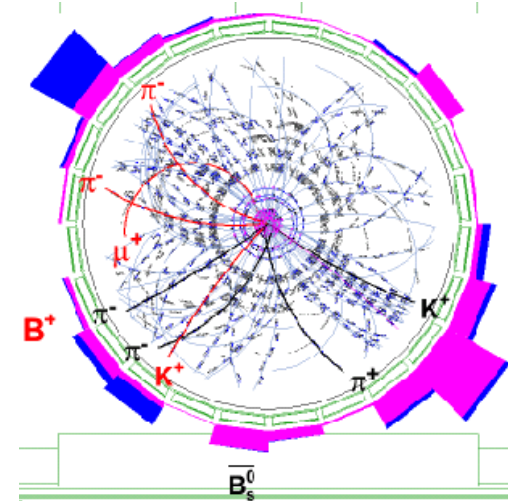
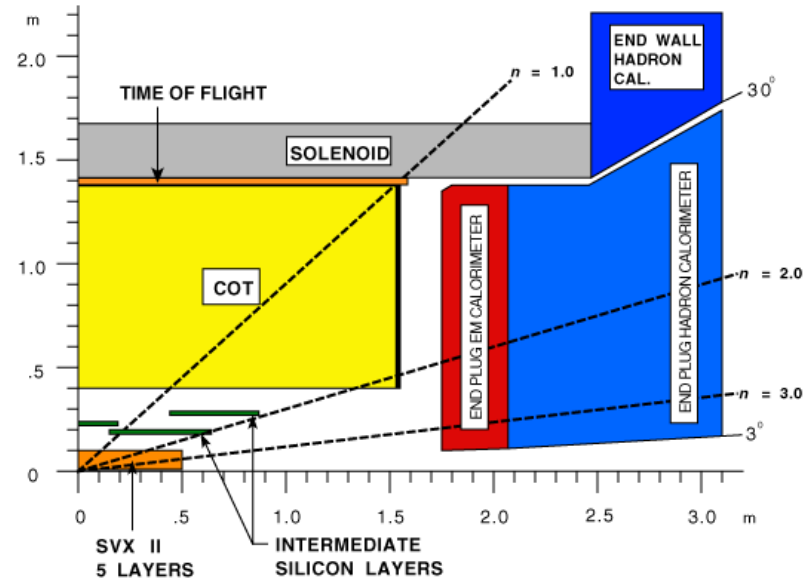
CDF II Detector





Particle tracking and ID at CDF

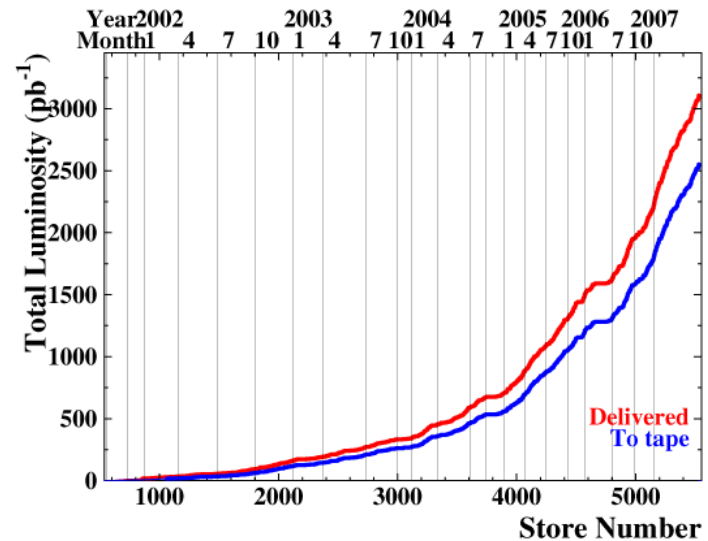
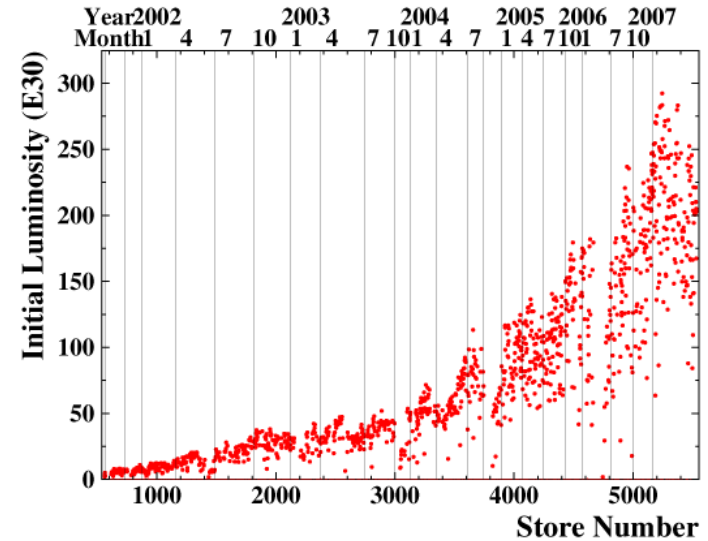
- Central drift chamber in B field
 - $\sigma(p_T)/p_T^2 \sim 0.1\% \text{ GeV}/c^{-1}$
 - dE/dx measurement
- Silicon vertex detector
 - I.P. resolution: $35\mu\text{m} @ 2\text{GeV}/c$
- Time-of-flight detector
- Muon coverage: $|\eta| < 1$
- Triggers for heavy flavor physics
 - Di-muon trigger
 - Displaced track trigger





Tevatron Status

- Accelerator performance
 - Growing year by year
- Typical parameters
 - Peak luminosity
 - $2.0 \sim 2.5 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1}$
 - Weekly integrated lum.
 - $40 \text{ pb}^{-1}/\text{wk}$
- Expect the integrated lum. of $6 \sim 8 \text{ fb}^{-1}$ by the end of FY2009

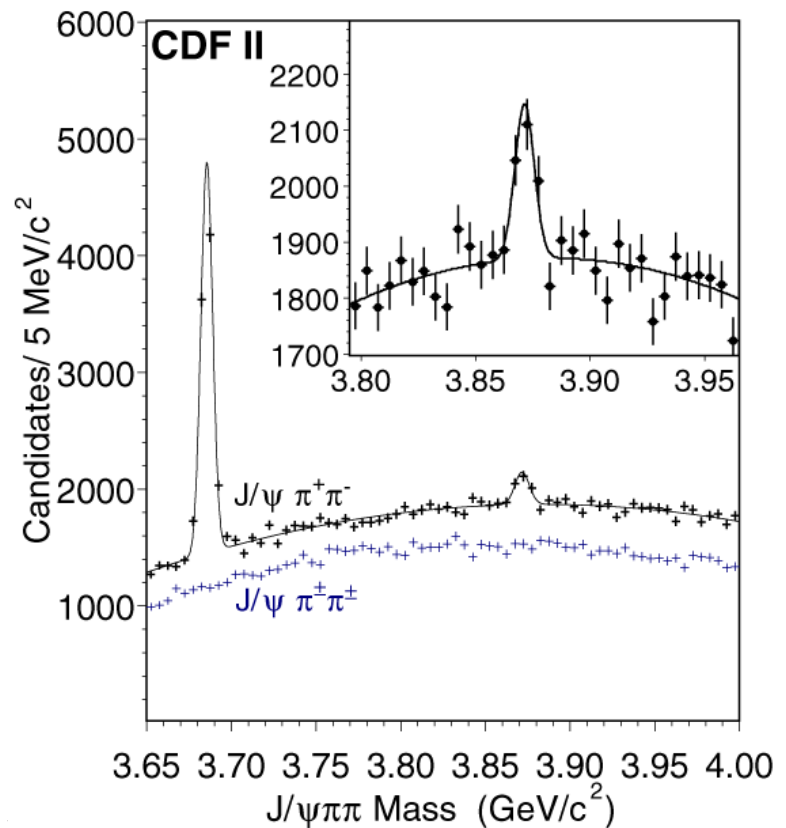




X(3872)

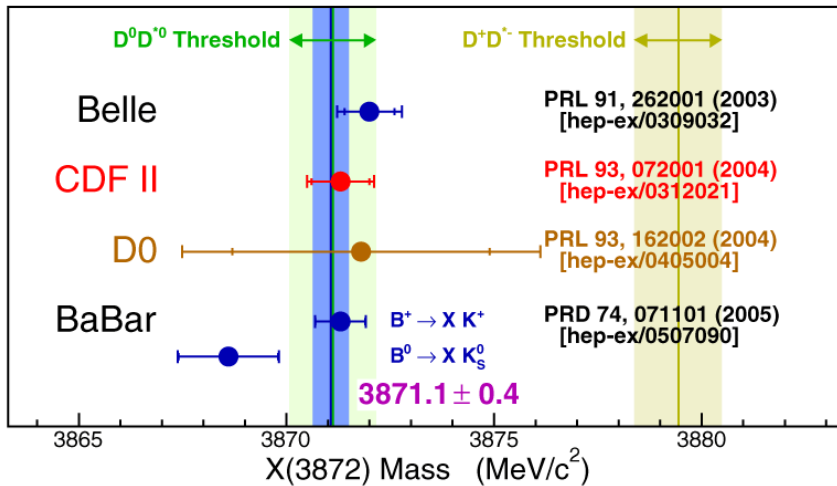
- First observation at Belle
 - PRL 91 262001 (2003)
 - Charmoniumlike state decaying to $J/\psi \pi^+ \pi^-$
- Confirmation at CDF
 - PRL93 072001 (2004)
- Also in DØ and BABAR
 - PRL93 162002 (2004), DØ
 - PRD71 071103 (2005), BABAR

Belle Collaboration





X(3872) - 2 -



- Mass
 - $M_x = 3871.1 \pm 0.4 \text{ MeV}/c^2$
 - X(3872) right in $D^0 D^{*0}$ threshold region.
- Width
 - Compatible with or smaller than the detector resolution.

- Not easily explained as a conventional $1D \text{ } c\bar{c}$ state.
- Possible $D^0 \bar{D}^{*0}$ molecule-like bound state ?

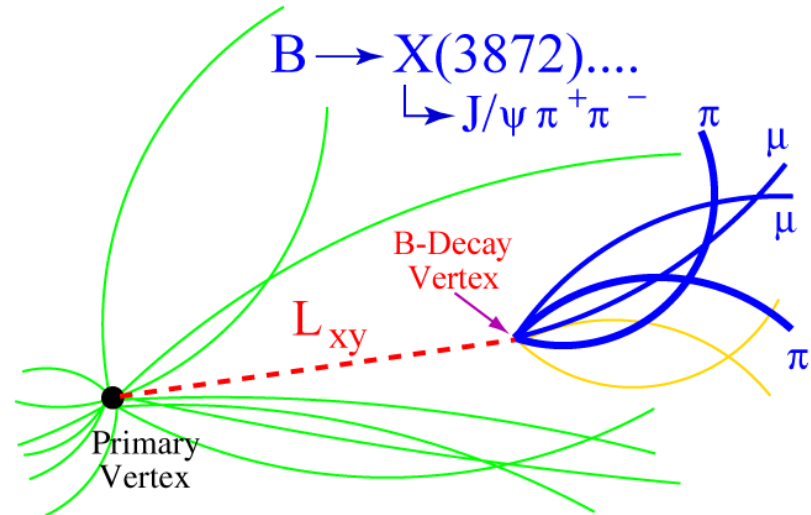


X(3872) - 3 -

- Production fraction from B decays
 - Proper decay time

$$ct \equiv \frac{M(J/\psi \pi^+ \pi^-)}{p_T(J/\psi \pi^+ \pi^-)} L_{xy}$$

- Fit “prompt” and “displaced” fractions
- Comparison with $\psi(2S)$





X(3872) - 4 -

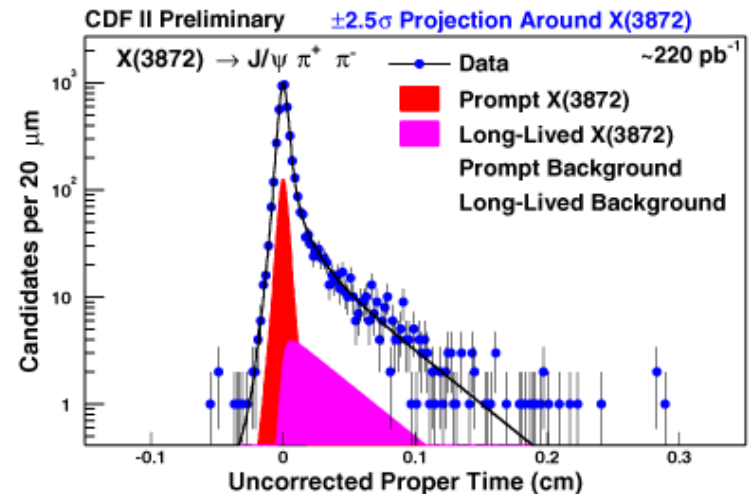
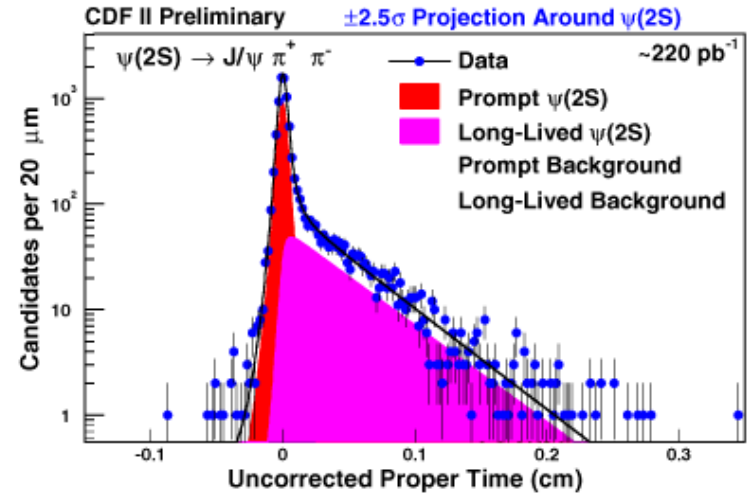
- Fraction from B decays
 - Long-lived fraction

$\psi(2S)$:
 $28.3 \pm 1.0(\text{stat.}) \pm 0.7(\text{syst.}) \%$

X(3872) :
 $16.1 \pm 4.9(\text{stat.}) \pm 1.0(\text{syst.}) \%$

X(3872) behaves similarly to $\psi(2S)$.

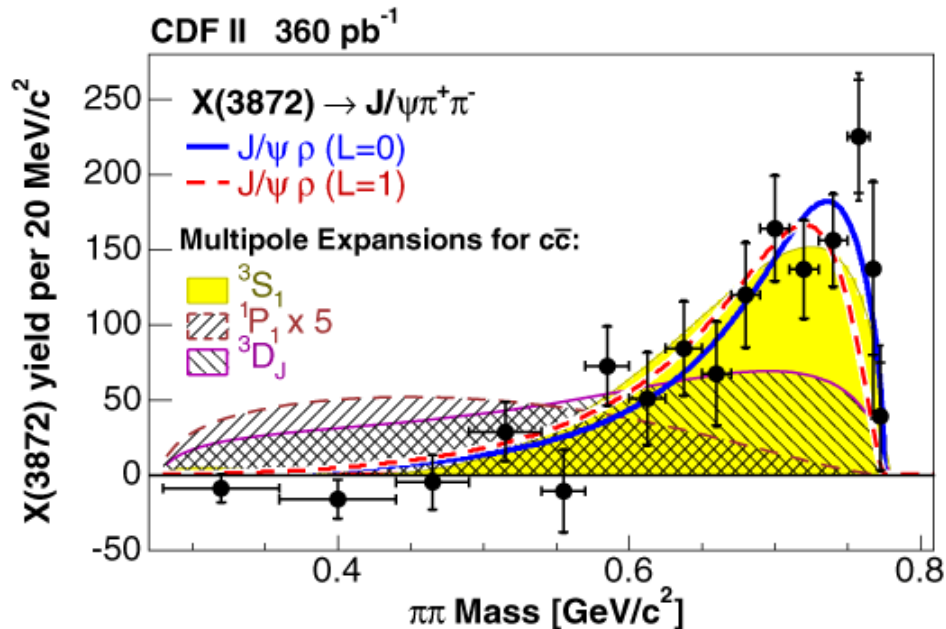
X(3872) mostly prompt.





X(3872) - 5 -

- Determination of J^{PC} of X(3872)
 - Looked at di-pion mass spectrum.
 - **Belle**: Found high $\pi\pi$ masses favored.
 - **CDF**: Observed the same tendency. Tried fits for possible cases.

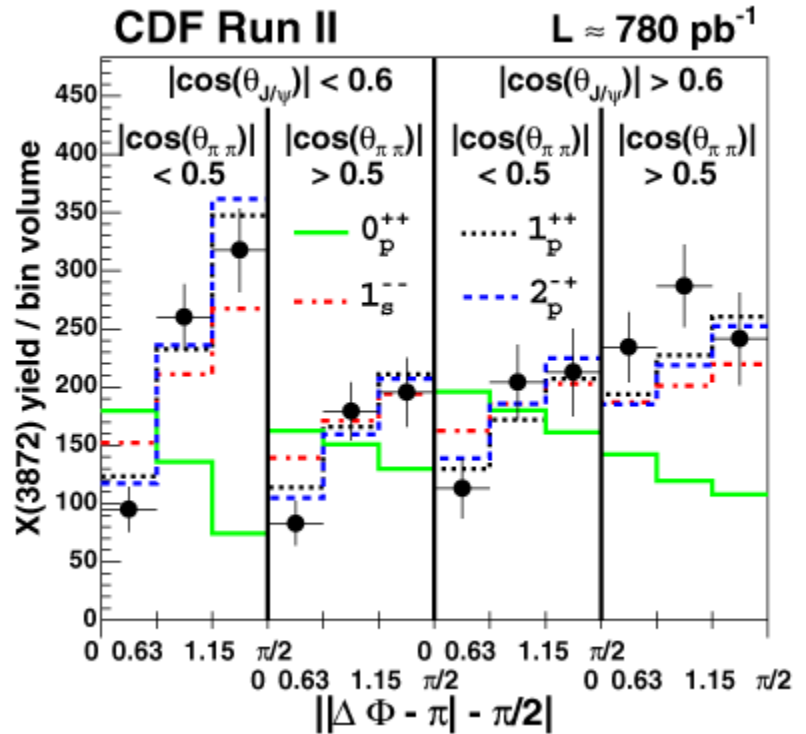
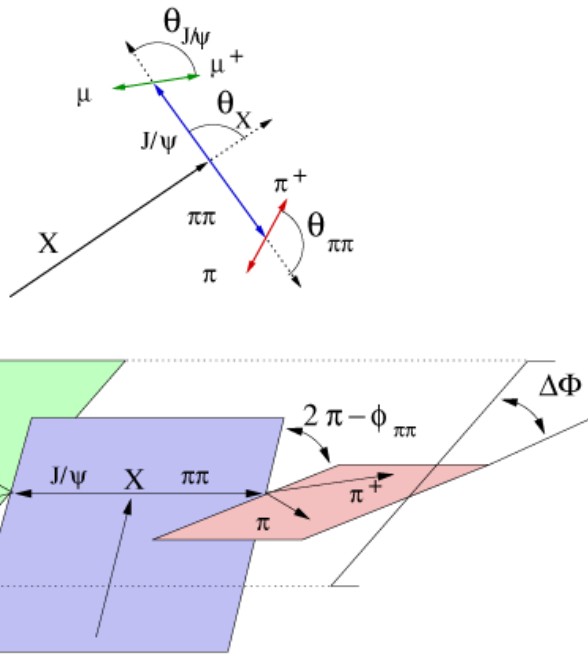


- Compatible with intermediate $\rho^0 \rightarrow \pi\pi$ resonances. (1^{++} , 2^{++})
- 3S_1 multipole expansion for $c\bar{c}$ also possible. (1^-)
 - But, no charmonium candidates at that mass.



X(3872) - 6 -

- Determination of J^{PC} of X(3872)
 - Looked at angular correlations b/w (π, π) and (μ, μ) .



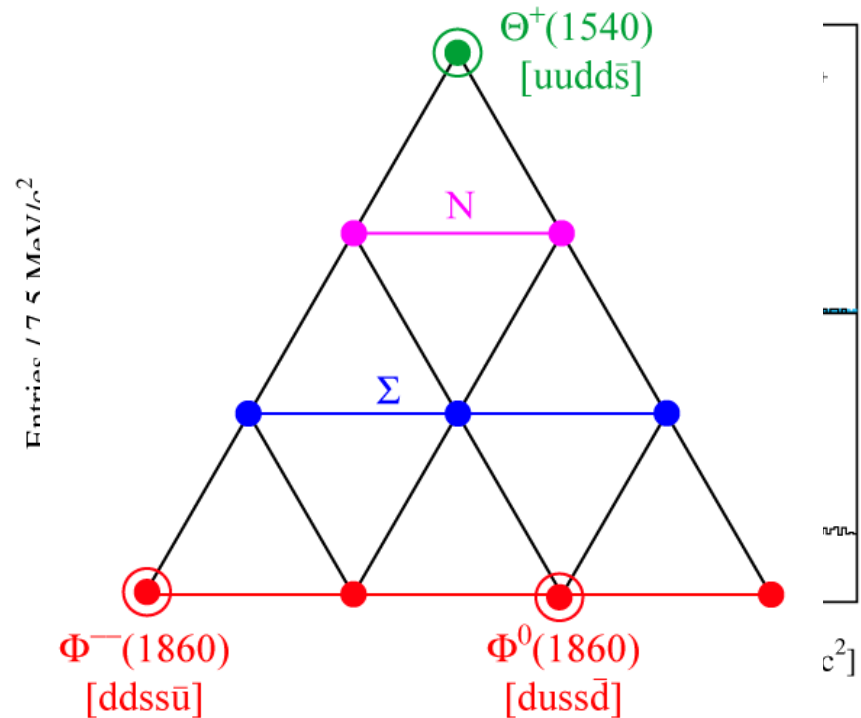
- $J^{PC} = 1^{++}$ and 2^{-+}
- All other assignments are ruled out by more than 3σ .



Pentaquark

- Search for $\Phi^{--}(1860) \rightarrow \Xi^{-}\pi^{-}$ and $\Phi^0(1860) \rightarrow \Xi^{-}\pi^{+}$
 - Reported by NA49 at CERN

- In hadron-collider,
 - Displaced vertex resulting from weak decay of Ξ^{-}
 - Accessible by discriminating candidates out of the huge number of tracks in QCD events.





Pentaquark - 2 -

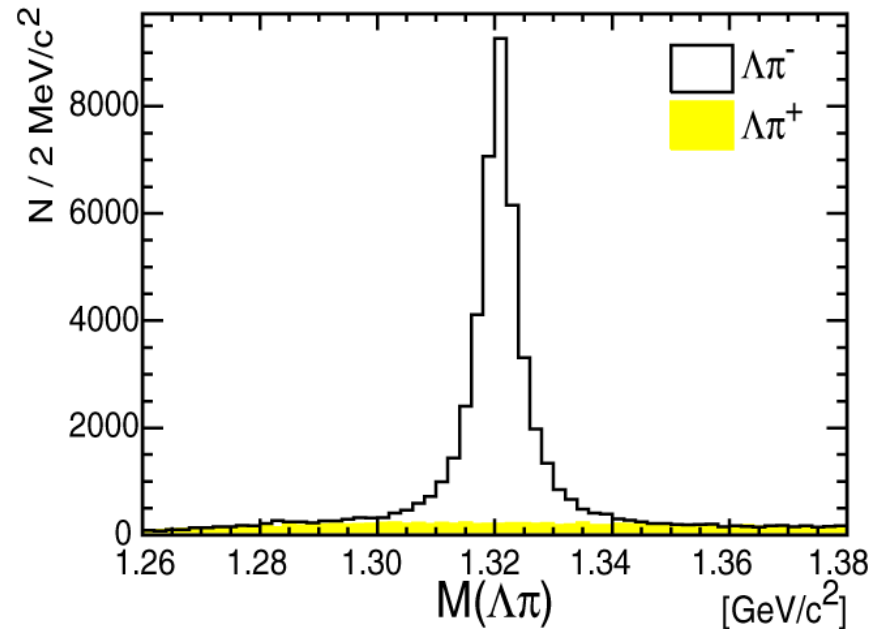
- Summary of $\Phi(1860)$ searches

Experiment	Initial state	Energy [GeV]	Result
NA49	pp	$Ep = 158$	$N(\Phi(1860)) = 69$
ALEPH	Z^0	$\sqrt{s} = MZ^0$	$N(\Phi^-(1860) \rightarrow \Xi^- \pi^-) / N(\Xi(1530) \rightarrow \Xi^- \pi^-) < 0.082$
BABAR	e^+e^-	$\sqrt{s} = 10.58$	$N(\Phi^-(1860) \rightarrow \Xi^- \pi^-) < 0.74 \times 10^{-5} / q\bar{q}$
FNAL-E690	pp	$Ep = 800$	$N(\Phi^-(1860) \rightarrow \Xi^- \pi^-) / N(\Xi(1530) \rightarrow \Xi^- \pi^-) < 0.3\%$
FOCUS	γp	$E\gamma \leq 300$	$\sigma(\Phi^-(1860)) \cdot Br(\Phi^-(1860) \rightarrow \Xi^- \pi^-) < 0.25\%$
HERA-B	pA	$Ep = 920$	$N(\Phi^-(1860) \rightarrow \Xi^- \pi^-) / N(\Xi(1530) \rightarrow \Xi^- \pi^-) < 4\%$
HERMES	e^+D	$Ee = 27.6$	$\sigma(\Phi^-(1860) \text{ photoproduction}) < 2.1 \text{ nb}$
WA89	Σ^-A	$E_{\Sigma^-} = 340$	$\sigma(\Sigma^-A \rightarrow \Phi^-(1860)X) \cdot Br(\Phi^-(1860) \rightarrow \Xi^- \pi^-) < 3.5 \mu\text{b}$
ZEUS	ep	$\sqrt{s} = 300, 318$	$N(\Phi^-(1860) \rightarrow \Xi^- \pi^-) / N(\Xi(1530) \rightarrow \Xi^- \pi^-) \leq 0.3$
COMPASS	μ^+A	$E\mu = 160$	$N(\Phi^-(1860) \rightarrow \Xi^- \pi^-) / N(\Xi(1530) \rightarrow \Xi^- \pi^-) < 4.6\%$



Pentaquark - 3 -

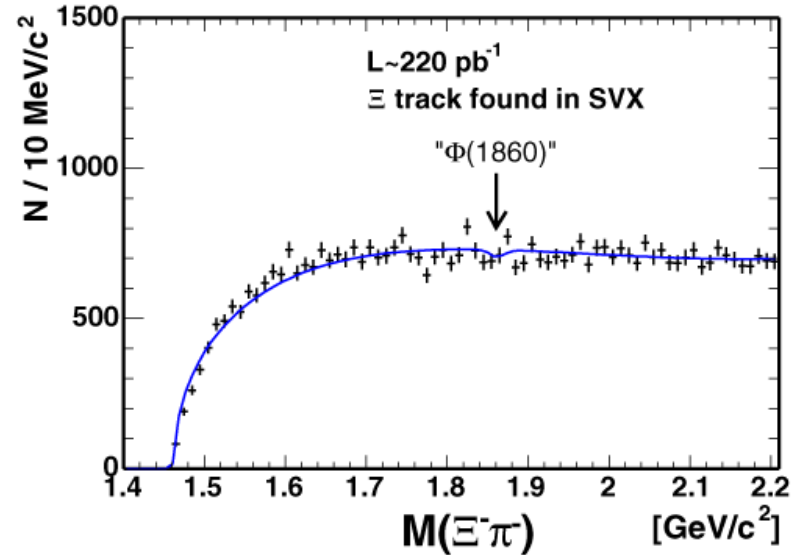
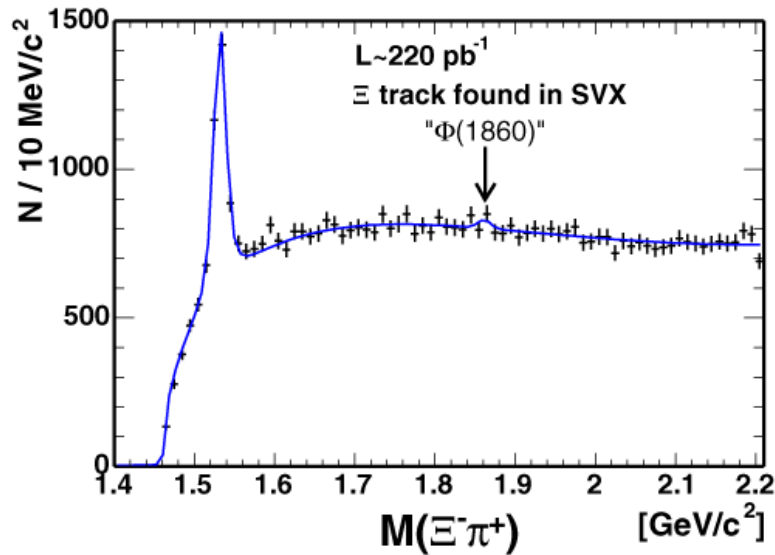
- $\Phi(1860)$ search at CDF
 - Proton-antiproton collision
 - $\sqrt{s} = 1.96$ TeV
 - Reconstruction of
 - $\Lambda \rightarrow p\pi^-$
 - $\Xi^- \rightarrow \Lambda\pi^-$
 - $\Phi(1860) \rightarrow \Xi^-\pi$
 with tracking detectors





Pentaquark - 4 -

- Invariant mass spectra of $\Xi^- \pi$

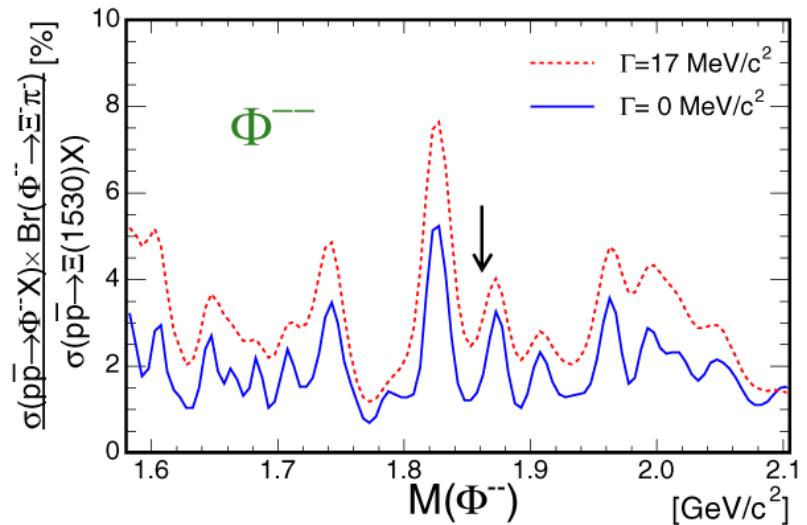
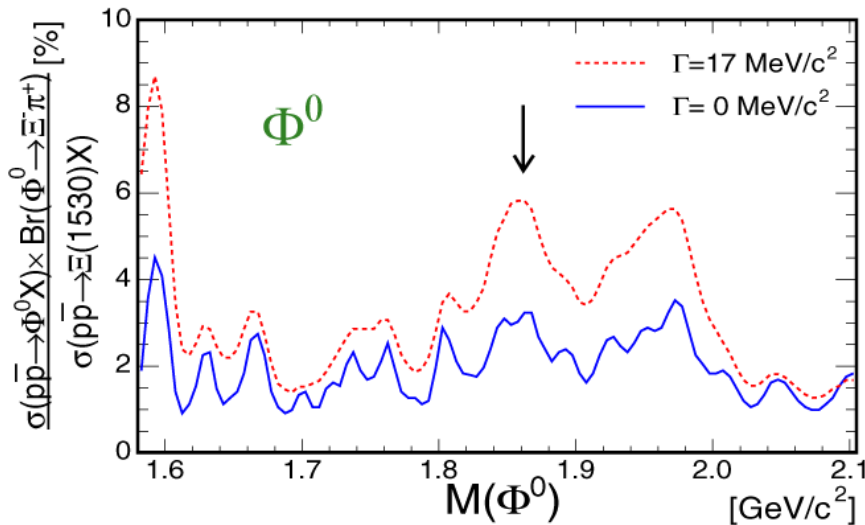


No peaks around $M(\Xi\pi) = 1820 \text{ MeV}/c^2$ for $\Xi^- \pi^+$ and $\Xi^- \pi^-$



Pentaquark - 5 -

- Upper limits for $\Phi(1820)$ production
 - Cross section ratio to $\Xi(1530)$ production



$$\frac{\sigma(p\bar{p} \rightarrow \Phi(1860) X) \cdot Br(\Phi(1860) \rightarrow \Xi^- \pi)}{\sigma(p\bar{p} \rightarrow \Xi(1530) X)} < 2 \sim 3\% \quad (90\% \text{ C.L.})$$



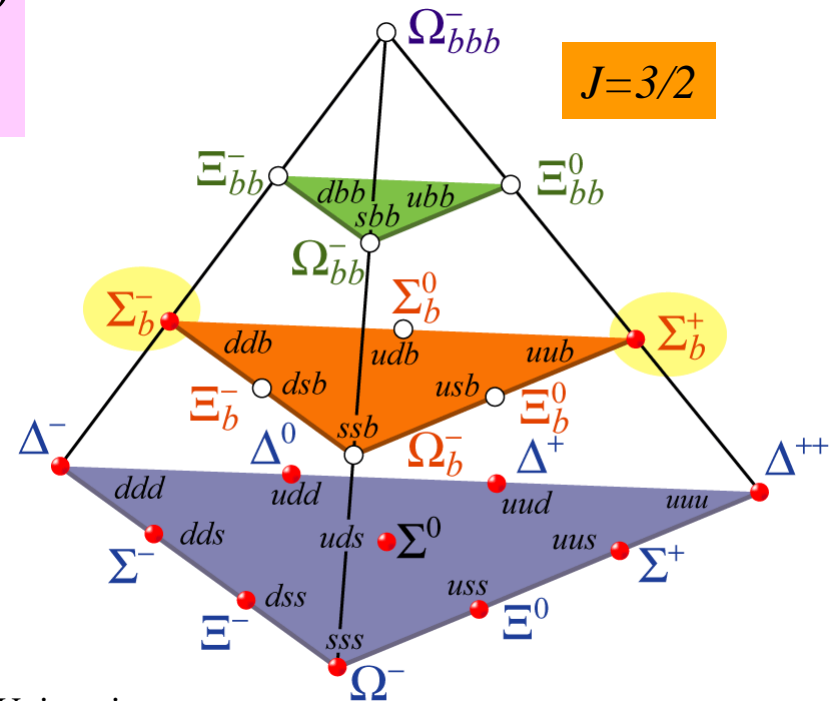
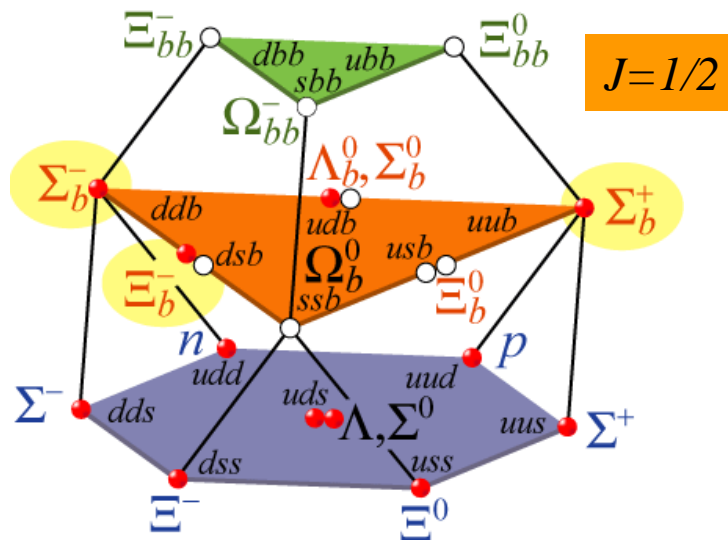
New b -Baryons

- So far, $\Lambda_b^0(udb, I(J^P)=0(1/2^+))$ was the only established b -baryon.
- Newly observed b -baryons :

$$\Sigma_b^+(uub), \Sigma_b^-(ddb) : I(J^P)=1(1/2^+)$$

$$\Sigma_b^{*+}(uub), \Sigma_b^{*-}(ddb) : I(J^P)=1(3/2^+)$$

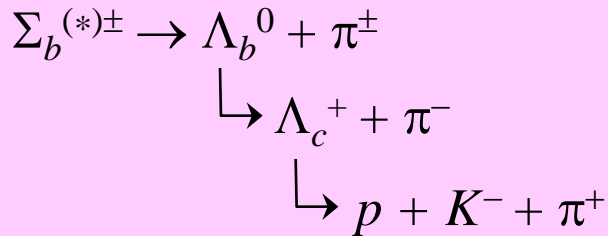
$$\Xi_b^-(dsb) : I(J^P)=1/2(1/2^+)$$





Observation of Σ_b^\pm and $\Sigma_b^{*\pm}$

- Reconstruction of the decay chain:



- Signals consistent with lowest lying Σ_b^\pm states at $> 5\sigma$ significant level.

$$m(\Sigma_b^+) = 5808^{+2.0}_{-2.3}(\text{stat.}) \pm 1.7(\text{syst.}) \text{ MeV}/c^2$$

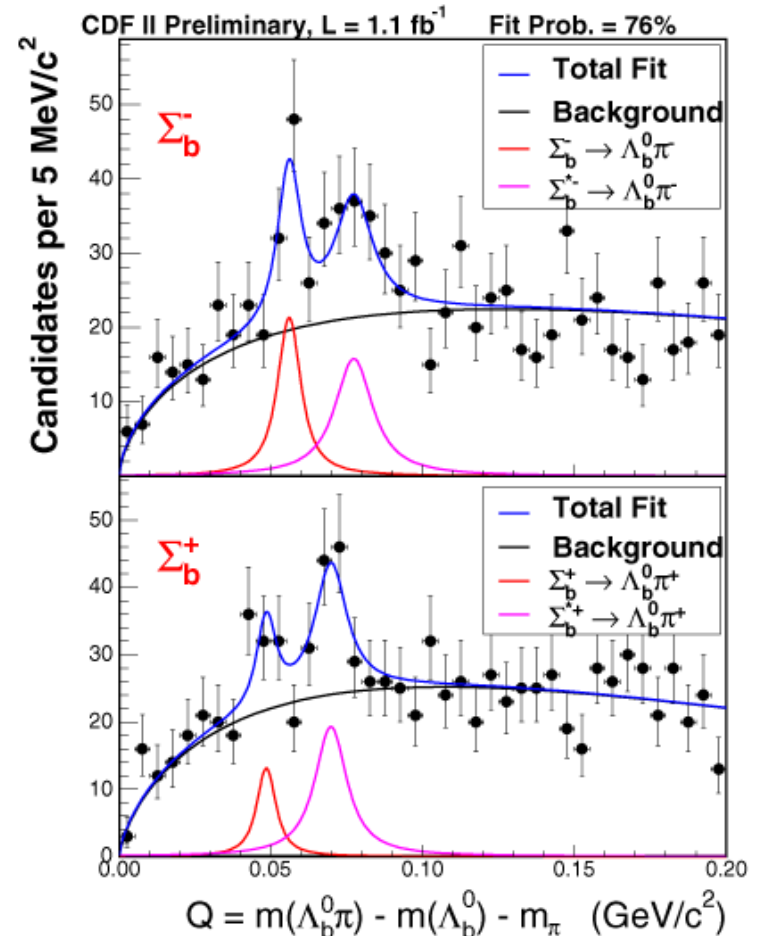
$$m(\Sigma_b^-) = 5816^{+1.0}_{-1.0}(\text{stat.}) \pm 1.7(\text{syst.}) \text{ MeV}/c^2$$

$$m(\Sigma_b^{*+}) = 5829^{+1.6}_{-1.8}(\text{stat.}) \pm 1.7(\text{syst.}) \text{ MeV}/c^2$$

$$m(\Sigma_b^{*-}) = 5837^{+2.1}_{-1.9}(\text{stat.}) \pm 1.7(\text{syst.}) \text{ MeV}/c^2$$

July 7 – 8, 2007

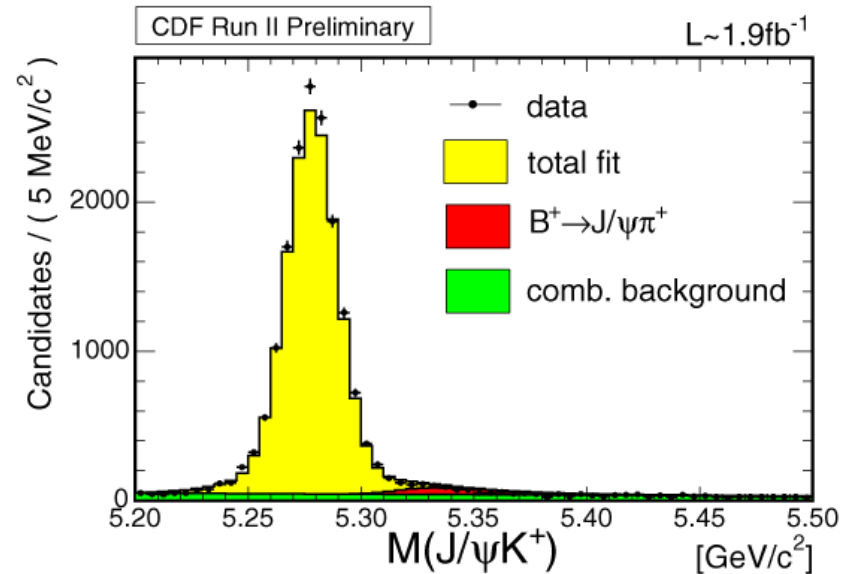
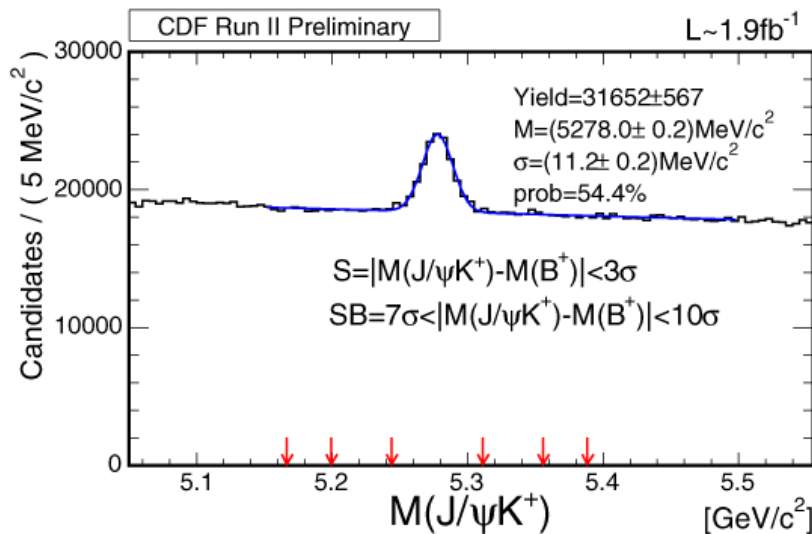
RCNP, Osaka University





Observation of Ξ_b^- - 2 -

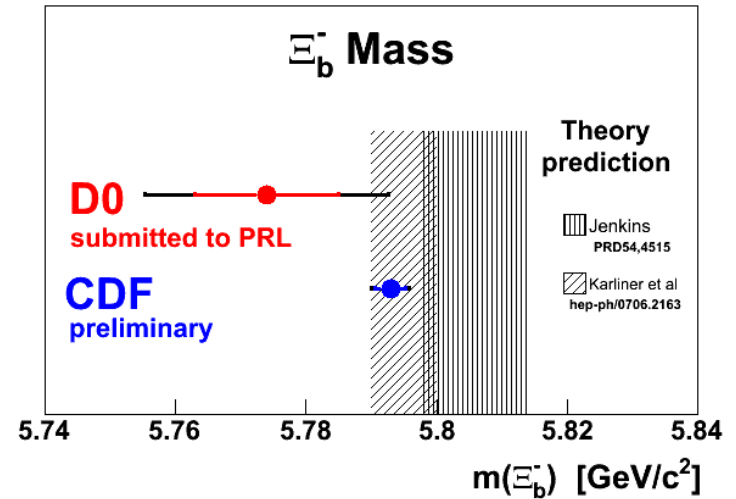
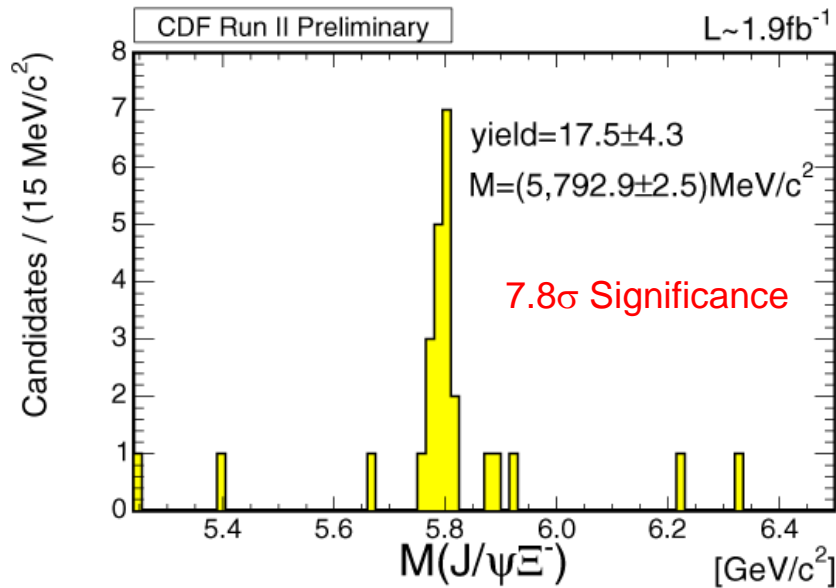
- $B^+ \rightarrow J/\psi K^+$ was used for the control channel of $\Xi_b^- \rightarrow J/\psi \Xi^-$
 - Optimized cuts for best $B^+ \rightarrow J/\psi K^+$ signal. Applied the same cuts to $\Xi_b^- \rightarrow J/\psi \Xi^-$ candidates.
 - This assumption was validated with the simulation .





Observation of Ξ_b^- - 3 -

- Invariant mass of Ξ_b^-

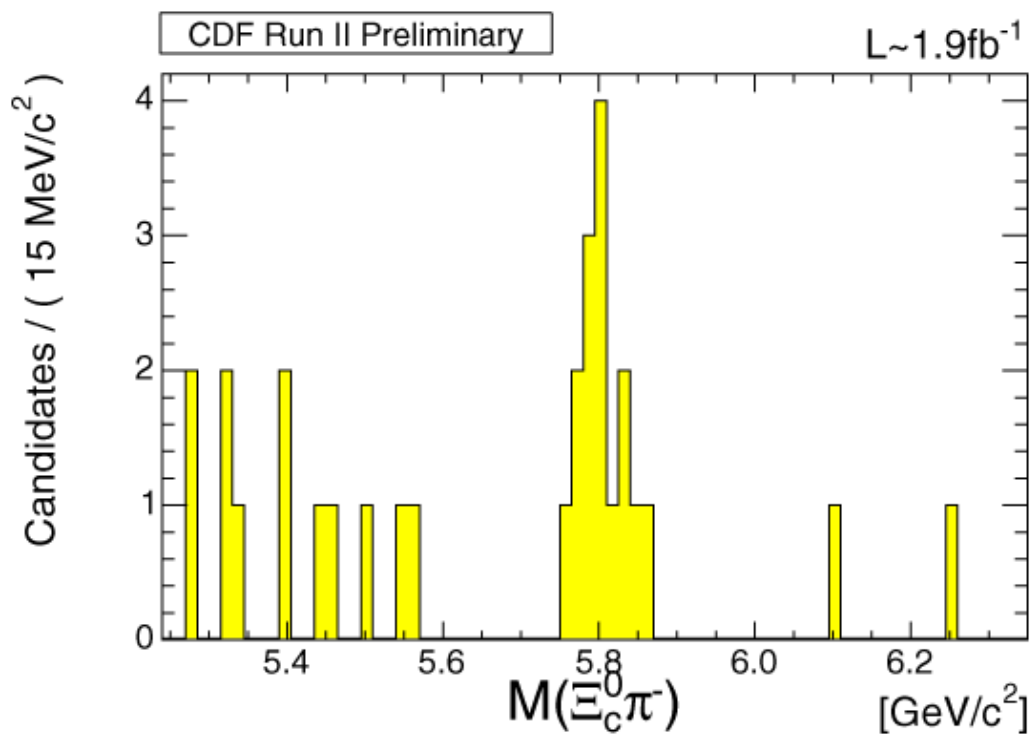


$$m(\Xi_b^-) = 5792.9 \pm 2.5 \text{ (stat.)} \pm 1.7 \text{ (syst.) MeV}/c^2$$



Observation of Ξ_b^- - 4 -

- Candidates for $\Xi_b^- \rightarrow \Xi_c^0 \pi^-$
 - Hadronic decay of Ξ_b^-





Summary

- Heavy flavor hadron studies in progress at the Tevatron
- CDF and DØ observed $X(3872)$.
 - $M_X = 3871.1 \pm 0.4 \text{ MeV}/c^2$
 - $J^{PC} = 1^{++}$ and 2^{-+} favorable
 - Needs more investigation to solve of the mystery of $X(3872)$.
- Negative result for existence of pentaquark $\Phi(1860)$.
- CDF and DØ observed new b -baryons $\Sigma_b^{\pm(*)}$ and Ξ_b^- .