Ξ_b observation at CDF

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for CDF

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Special seminar

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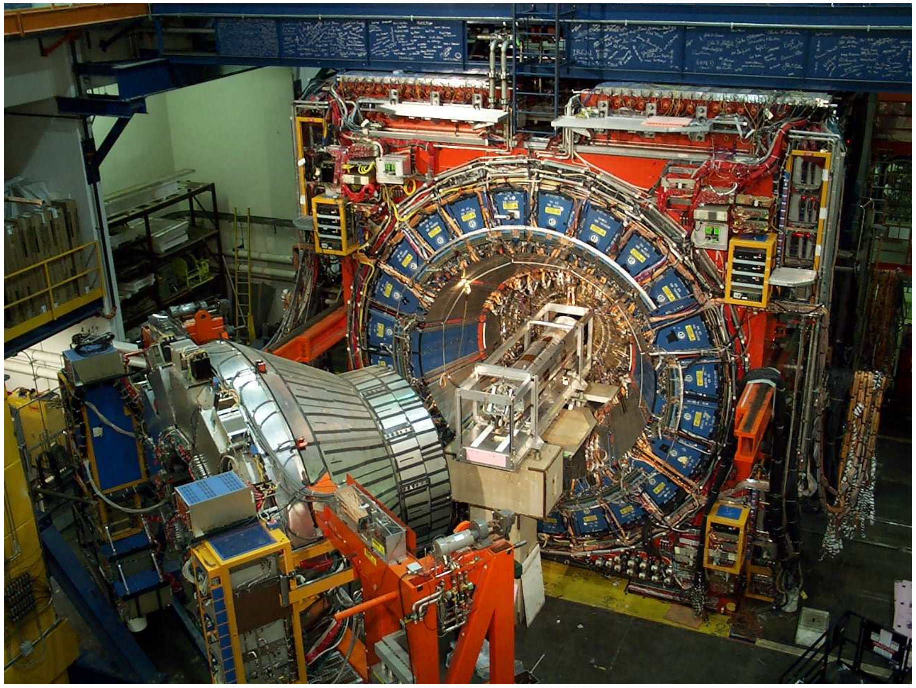
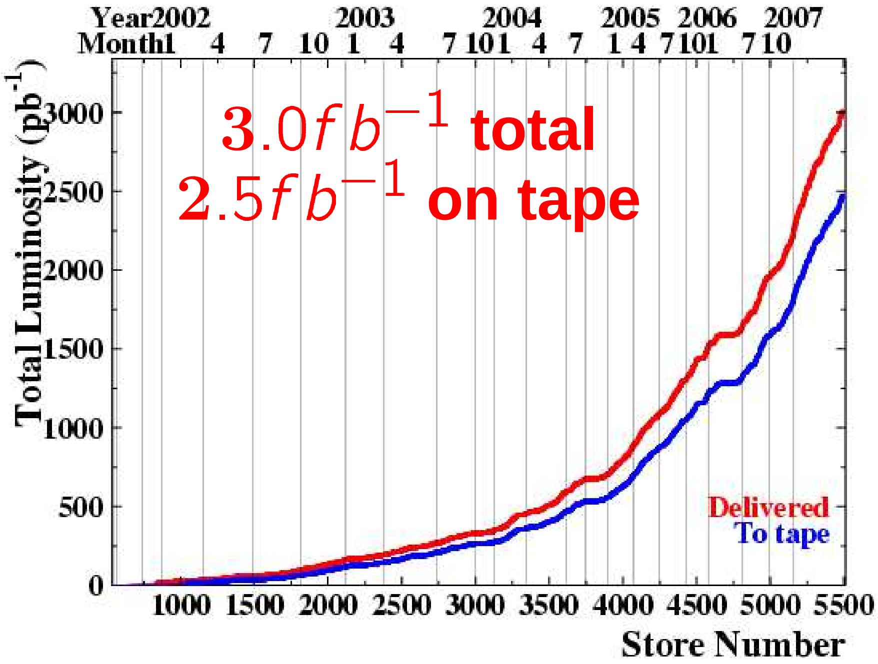
- Introduction
- Charged hyperons at CDF
- Analysis Strategy
- Mass measurement
- Other channels and plans
- Conclusion

Introduction

- Happy to show another observation in a string of discoveries of new bottom hadrons in Run 2
- We showed this result at the P5 review last week
- First $2\ fb^{-1}$ level CDF analysis
- We appreciate this opportunity to share our result
- Congratulations to DØ on their success!
- This talk will be short.

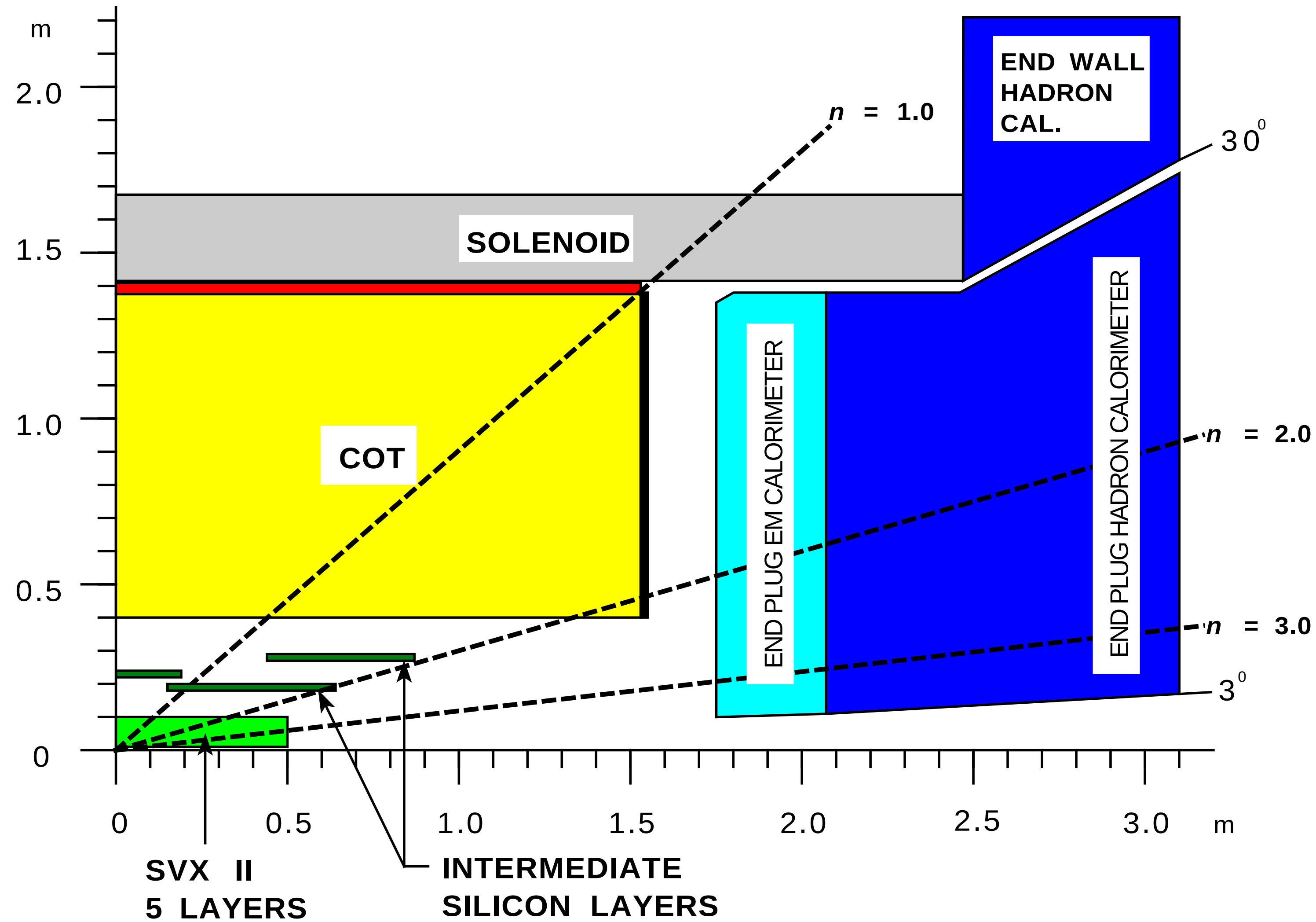
Source of data: CDF II





Analysis uses data collected up to January 2007, $L \sim 1.9 fb^{-1}$

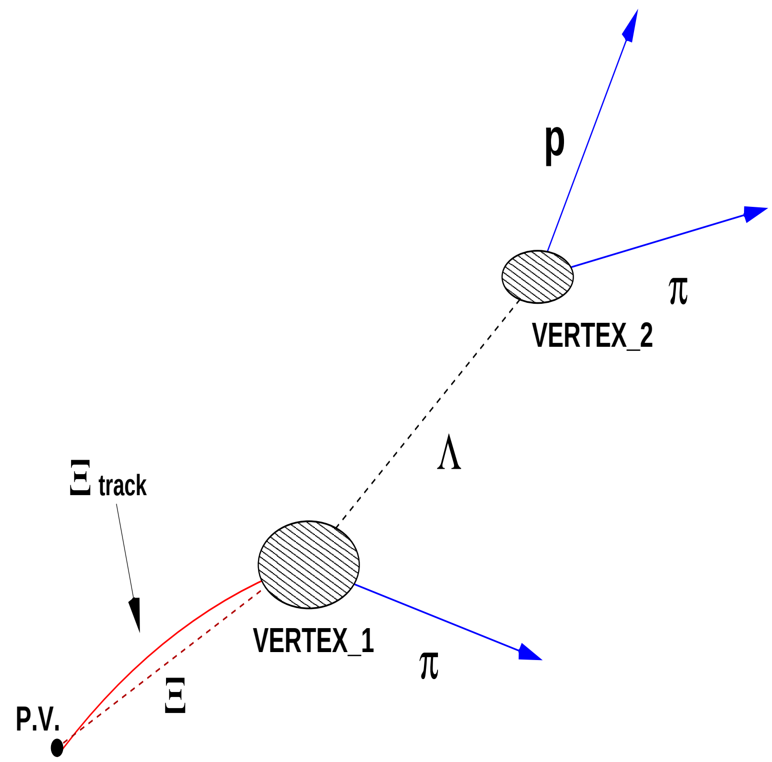
Tracking System



- CDF can do wonderful things with this tracking system

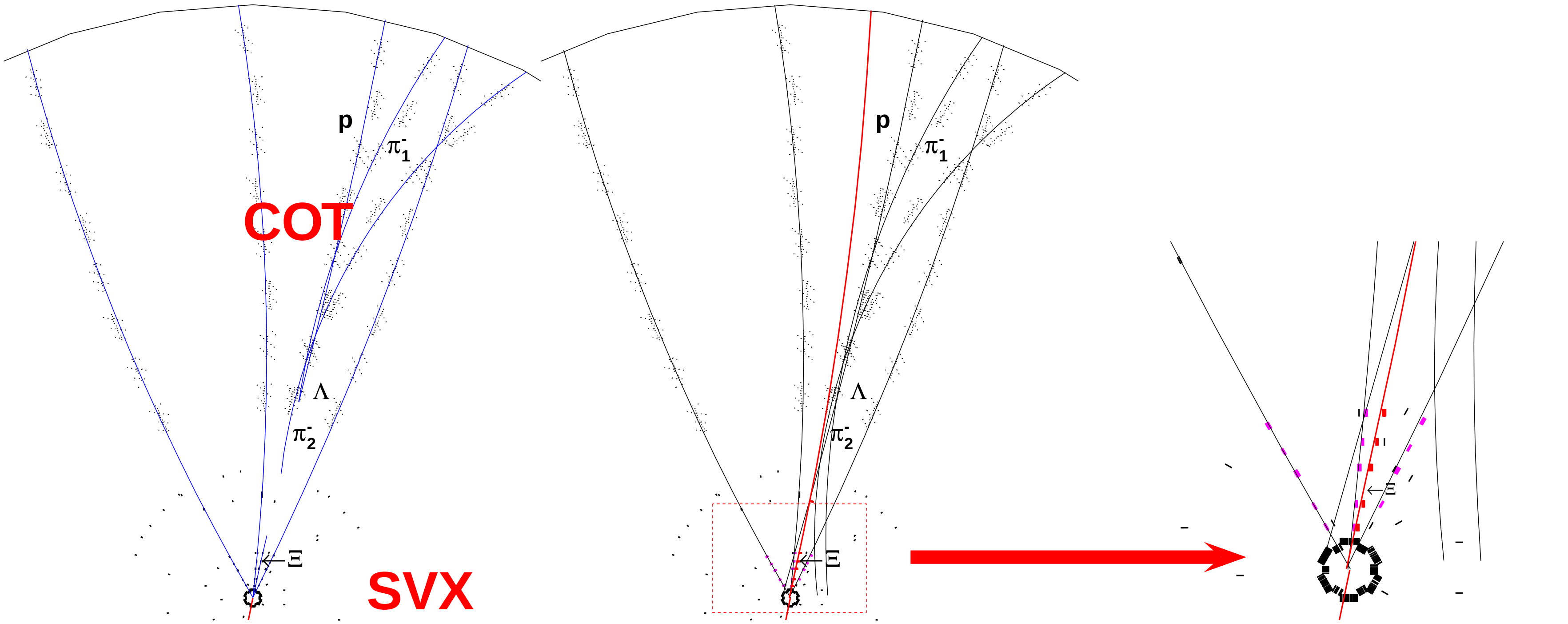
Cascades at CDF

- Ξ^- long lived & charged
- Can be tracked in the SVX (technique previously used at LEP)
- CDF developed tracking of Ξ. 1st in hadron collider experiment.
  - Form of a Ξ candidate using standard decay chain $\Xi \to \Lambda\pi,\ \Lambda \to p\pi^-$
  - Convert Ξ momentum and vertex position into helix in CDF track parameter $(cu, \phi_0, d_0, \lambda, z_0)$ basis and convert elements of Vertex fit error matrix into track 5×5 error matrix
  - Use this track to seed Outside In (OI)Z tracking
  - Attach silicon hits starting from vertex point and going to PV
  - Store SVX Ξ tracks in the event record on the file for subsequent analysis.
- Φ pentaquarks search was based on this technique (Phys.Rev.D75:032003,2007)



Cascade Tracked!

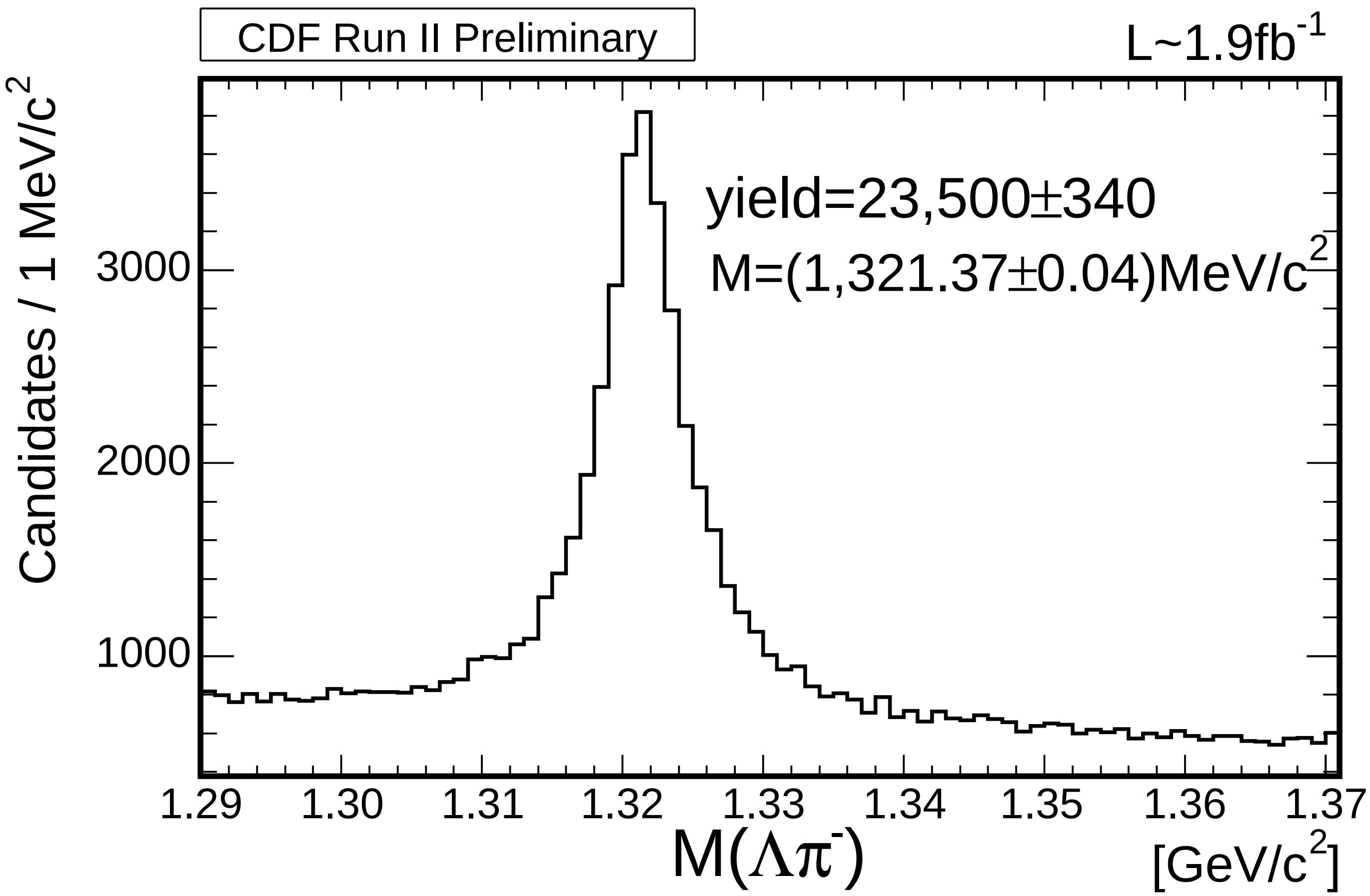
Event Display of generated Hyperons Tracked in Silicon



$$\Xi_b \to \Xi_c^+ \pi^- \quad \Xi_c^+ \to \Xi^- \pi^+ \pi^+ \quad \Xi^- \to \Lambda \pi_2^- \quad \Lambda \to p \pi_1^-$$

- Reduce random background - clean Ξ samples
- Improvement in Ξ impact parameter resolution

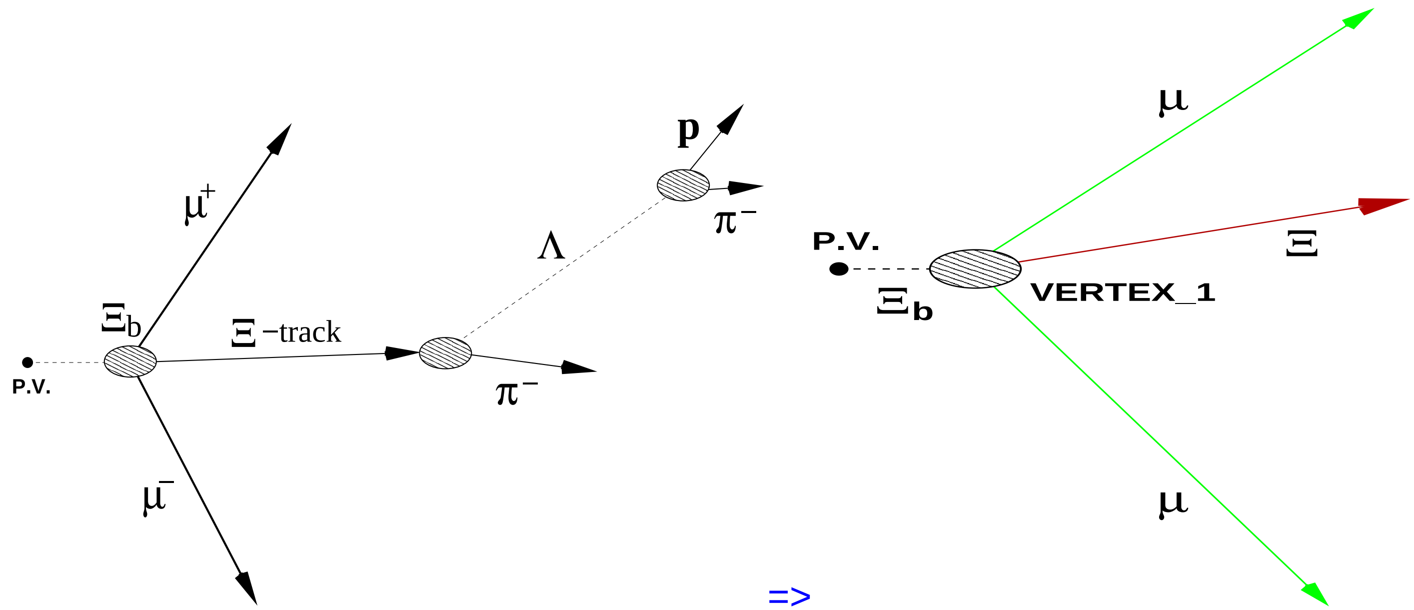
Cascade Yield in J/ψ trigger



- 23.5K events
- Mass is consistent with PDG
- Almost no cuts, just minimum of 2 $r - \phi$ SVX hits

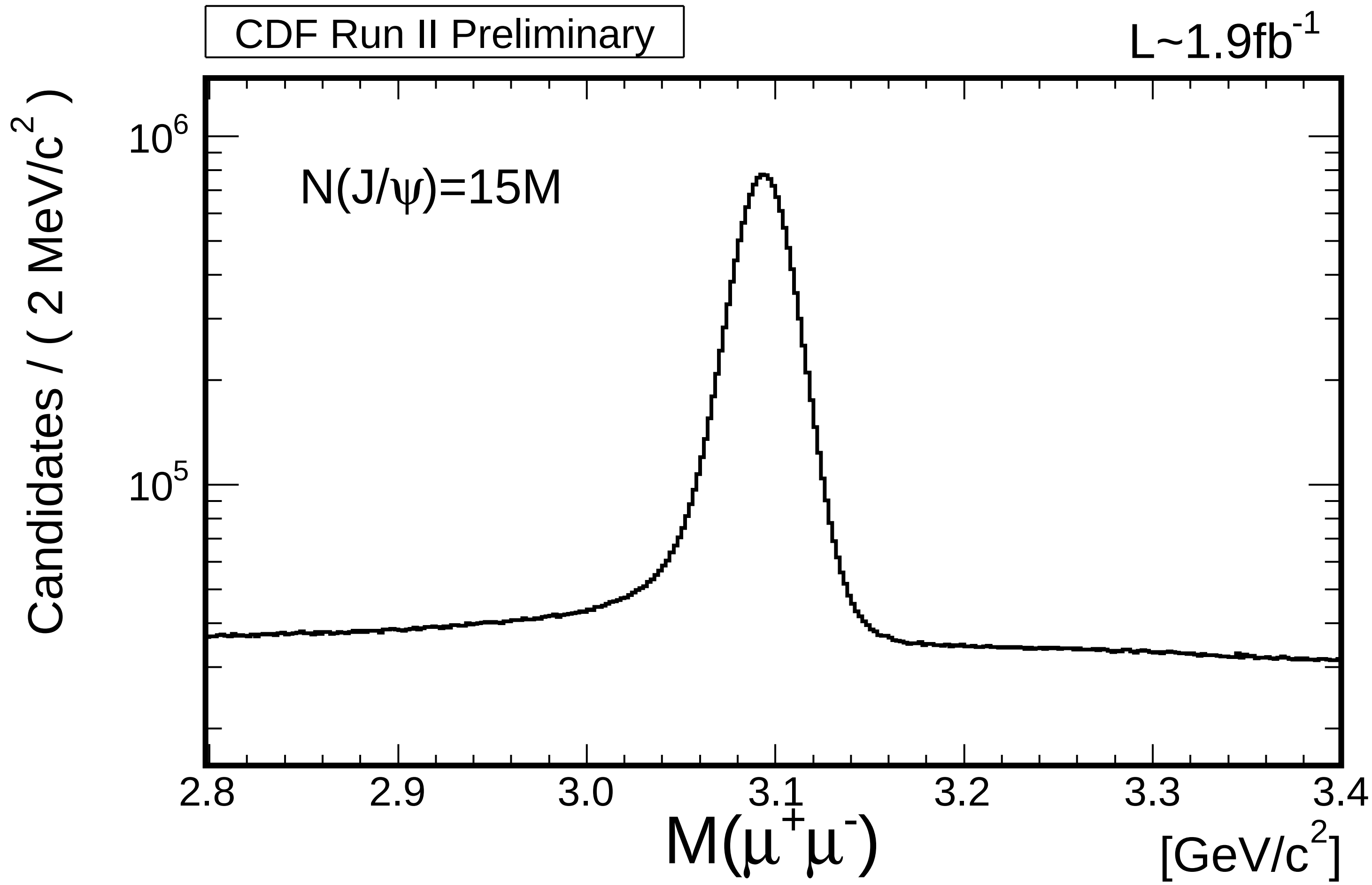
Analysis Strategy

- Use silicon Ξ tracks to look for $\Xi_b \to J/\psi \Xi$



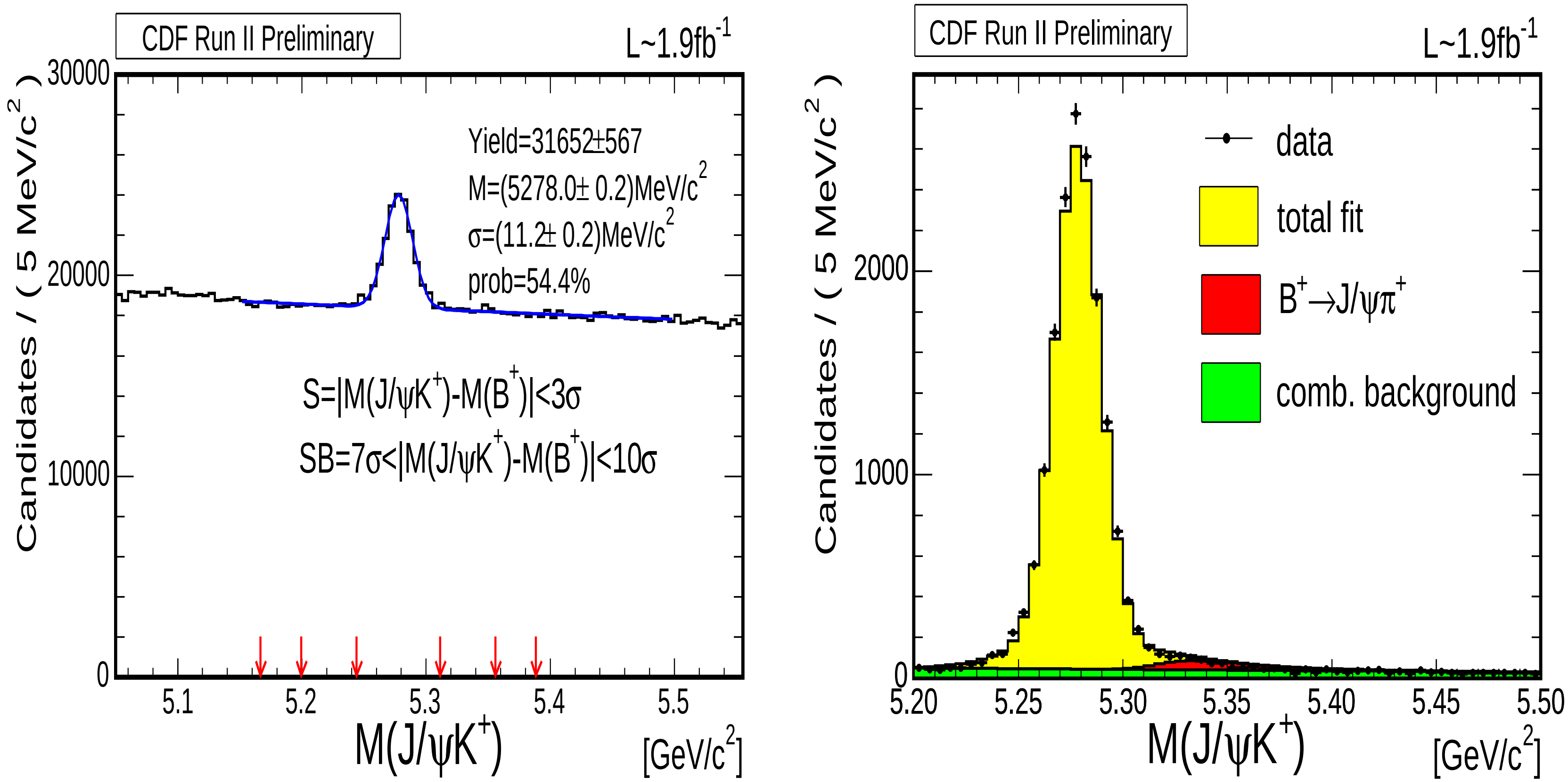
- Collapse 3-track Ξ candidate to 1-track.
- Ξ_b becomes like $B^+ \to J/\psi K^+$. Use $B^+ \to J/\psi K^+$ as control sample.
- Selection is data driven & independent of signal under study.
- Optimized cuts for best $B^+ \to J/\psi K^+$ signal. Applied same cuts to $\Xi_b \to J/\psi \Xi$ candidates.
- Approach is based on assumption "$B^+ \to J/\psi K^+$ look similar to $\Xi_b \to J/\psi \Xi$". Validated assumption with Simulation.
- Same approach used to discover $B_c \to J/\psi \pi$. Should work even better for $\Xi_b \to J/\psi \Xi$.

$J/\psi \to \mu\mu$



15M J/ψs using sideband subtraction counting

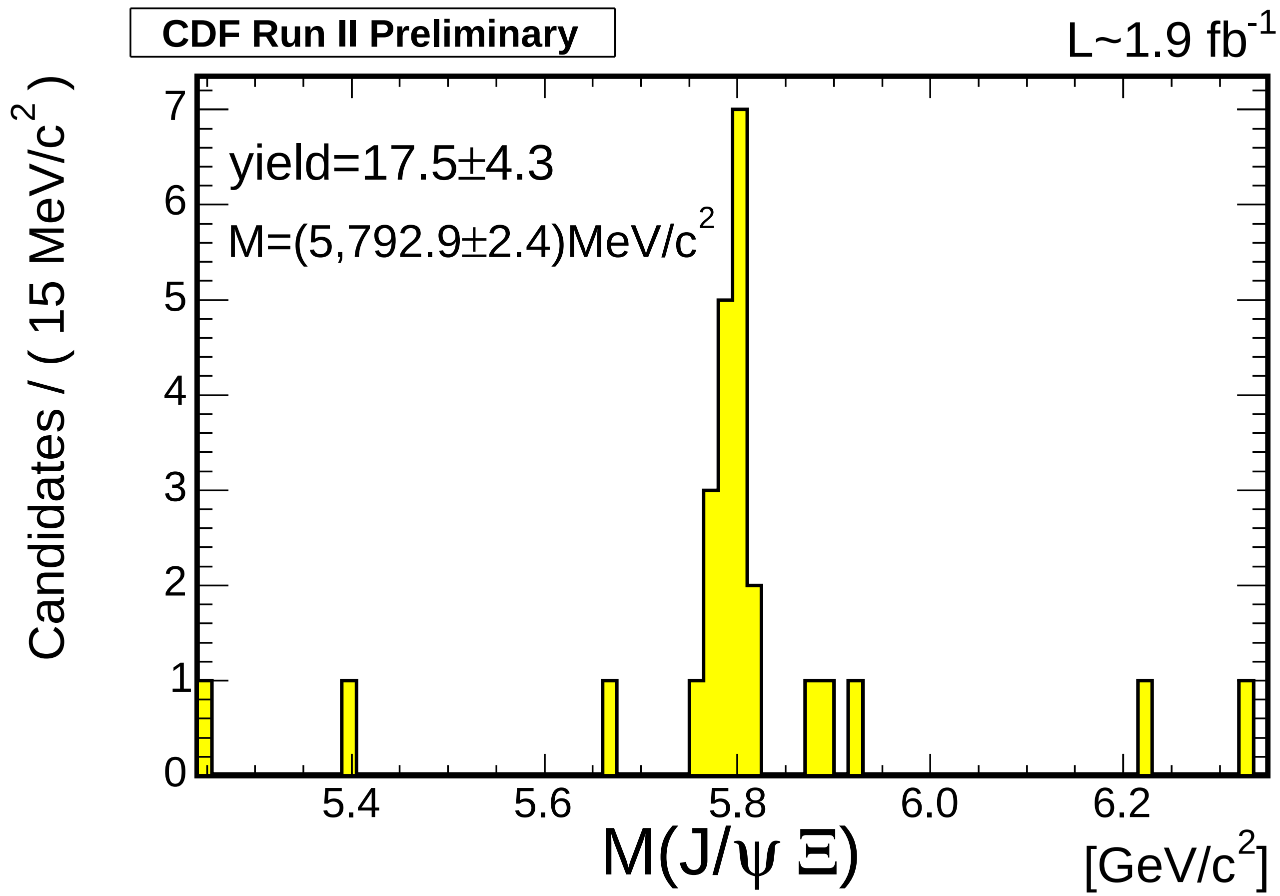
$B^+ \to J/\psi K^+$



- Loose cuts – 31K B^+
- Optimized cuts 16K B^+.
- Signal effi ciency 52%, background reduced by factor of 500

The Ξ_b

Unbinned fit uses estimate of mass uncertainty of each candidate to improve mass resolution. Linear background



Yield	Mass
17.5 ± 4.3	$(5,792.9 \pm 2.4)$ MeV$/c^2$

Ξ_b^- Significance

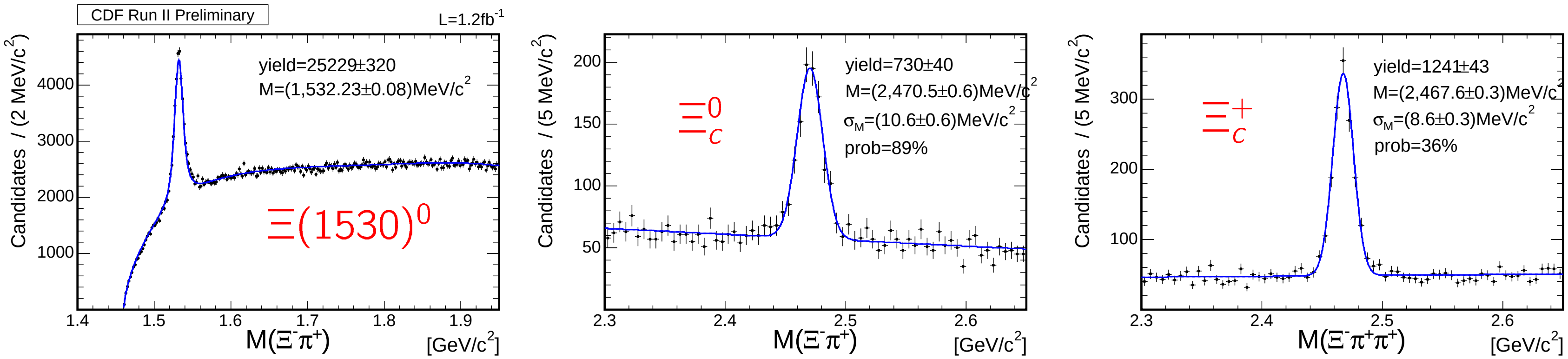
- Assume flat distribution of events in the mass region $[5.7-6.5]$ GeV$/c^2$
- The p-value is defined as probability to toss $N_{total} = 23$ events contained in this interval, so that there are $N_{signal} = 17$ observed events in 60 MeV$/c^2$ signal range ($\pm 2\sigma$).

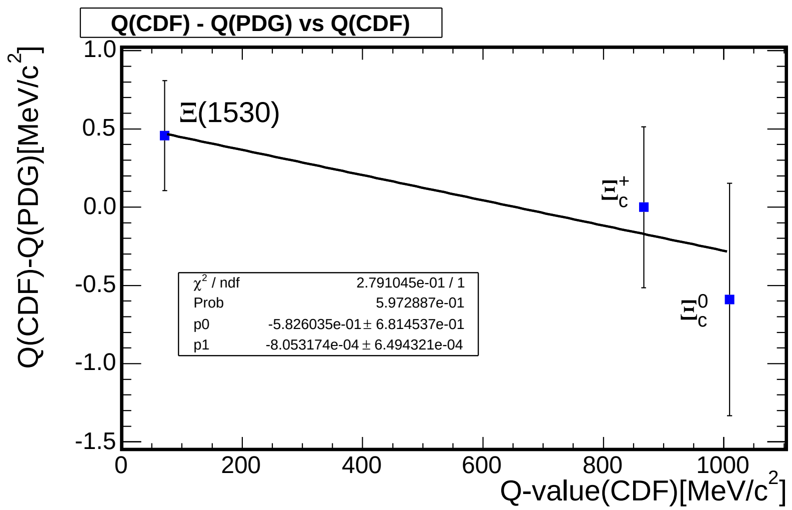
$$p = 1 - \sum_{i=0}^{N_{signal}-1} \mathcal{B}(i, N_{total}, \frac{60}{800})$$

- putting in the numbers we get $4.1 \cdot 10^{-15}$ which corresponds to 7.8σ Gaussian significance.

Mass Systematics

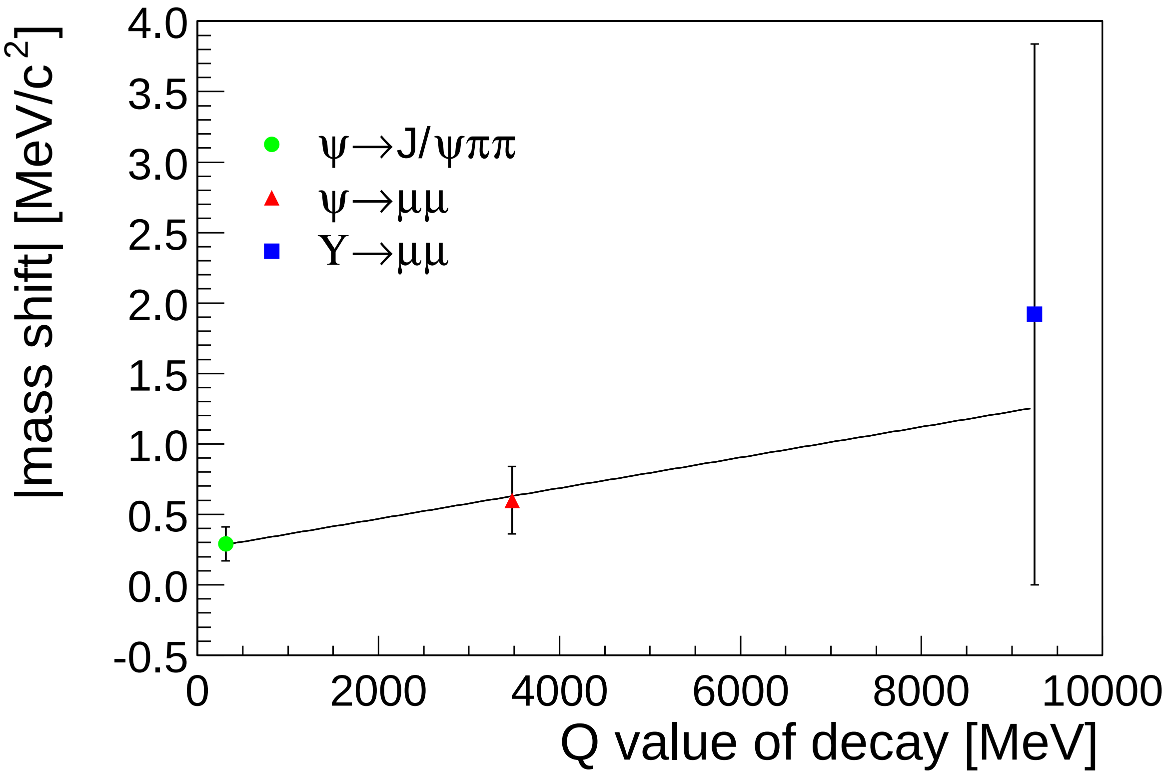
- check on large samples in TTT that Ξ tracking does not introduce any additional tracking systematics





- projected shift at Ξ_b mass is $\delta m = (-1.69 \pm 1.54)$ MeV/c^2. Not significant.

Tracking Momentum Scale



$$\delta m = 1.09 \cdot 10^{-4} \cdot Q + 0.25[MeV]$$

Phys.Rev.Lett.96:202001,2006.

Fit model variation

Fit	yield	mass
base	17.5	$(5,792.9)$ MeV$/c^2$
free sigma	17.4	$(5,791.8)$ MeV$/c^2$
double Gaussian	18.1	$(5,794.4)$ MeV$/c^2$

- Reasonable variation of background function and fit range does not change parameters of the peak appreciably
- Take maximum deviation as ± 1.5 MeV$/c^2$

Summary Systematics

Error source	value
Tracking Momentum scale	$\delta m = \pm 0.4$ MeV/c^2
PDG Masses(J/ψ, Ξ, Λ)	$\delta m = \pm 0.14$ MeV/c^2
Mass scale calibration	$\delta m = \pm 0.6$ MeV/c^2
Fit model/resolution	$\delta m = \pm 1.5$ MeV/c^2
Total	$\delta m = \pm 1.7$ MeV/c^2

$$\boxed{M(\Xi_b^-) = (5,792.9 \pm 2.4(stat.) \pm 1.7(syst.))\ \mathrm{MeV/c^2}}$$

Accessible channels at CDF

- J/ψ trigger:

$$\Xi_b \to \boxed{J/\psi}\, \Xi^- + n\pi \quad , \Omega_b \to \boxed{J/\psi}\, \Omega^- + n\pi$$
$$\hookrightarrow \Lambda\pi^- \qquad\qquad \hookrightarrow \Lambda K^-$$

- TTT trigger:

$$\Xi_b \to \Xi_c + n\boxed{\pi} \quad , \Omega_b \to \Omega_c + n\boxed{\pi}$$
$$\hookrightarrow \Xi^- + n\boxed{\pi} \qquad \hookrightarrow \Omega^- + n\boxed{\pi}$$
$$\hookrightarrow \Lambda\pi^- \qquad\qquad \hookrightarrow \Lambda K^-$$

$$\Xi_b \to D^0\Lambda \,, \Omega_b \to D^0\Xi^-$$

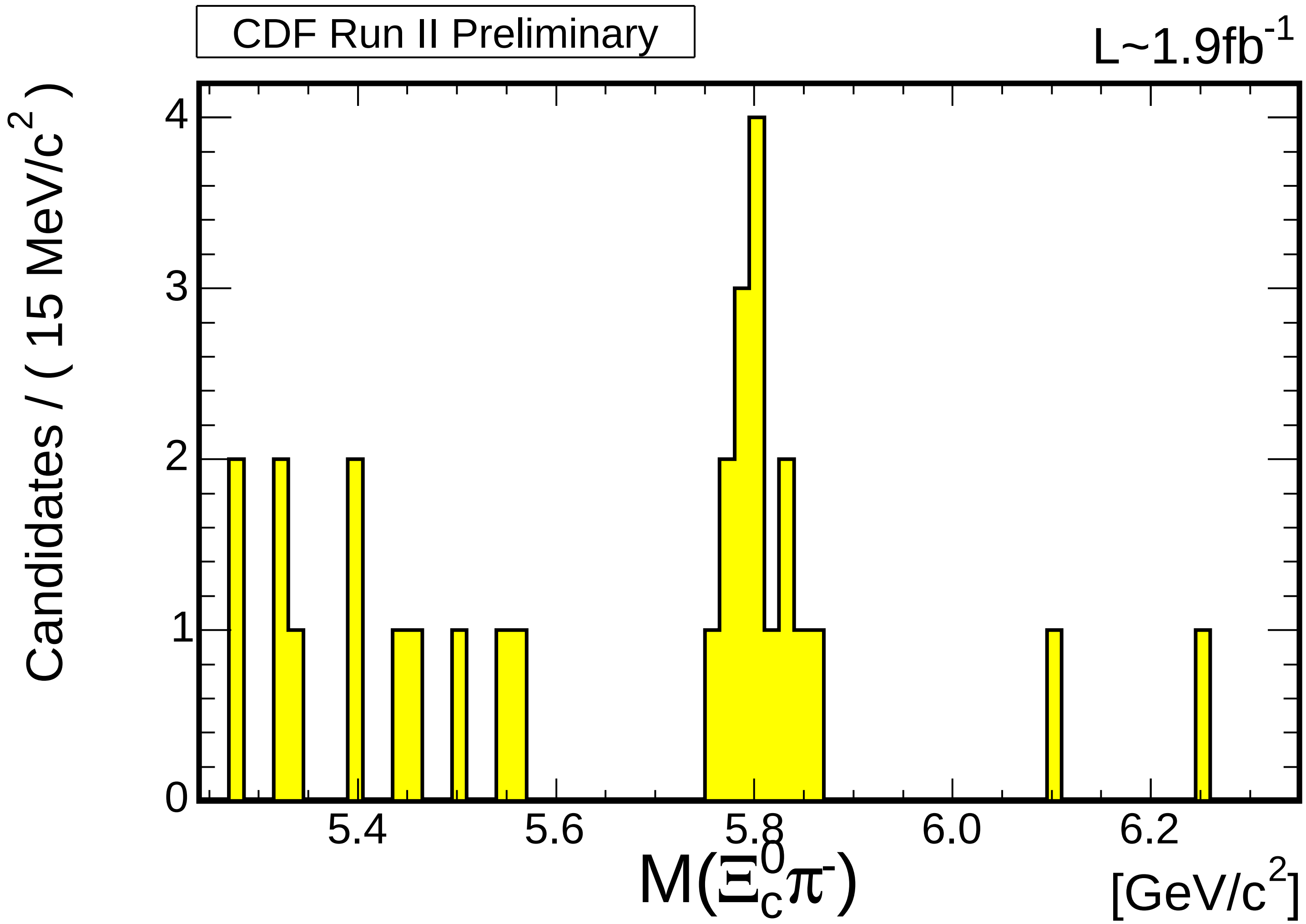
$$\Xi_b \to \Lambda_c K + n\pi \,, \Omega_b \to \Xi_c K + n\pi$$

- SVT+lepton trigger:

$$\Xi_b \to \Xi_c + \boxed{\ell^-}X \quad , \Omega_b \to \Omega_c + \boxed{\ell^-}X$$
$$\hookrightarrow \Xi^- + n\boxed{\pi} \qquad \hookrightarrow \Omega^- + n\boxed{\pi}$$
$$\hookrightarrow \Lambda\pi^- \qquad\qquad \hookrightarrow \Lambda K^-$$

Hadronic Channel

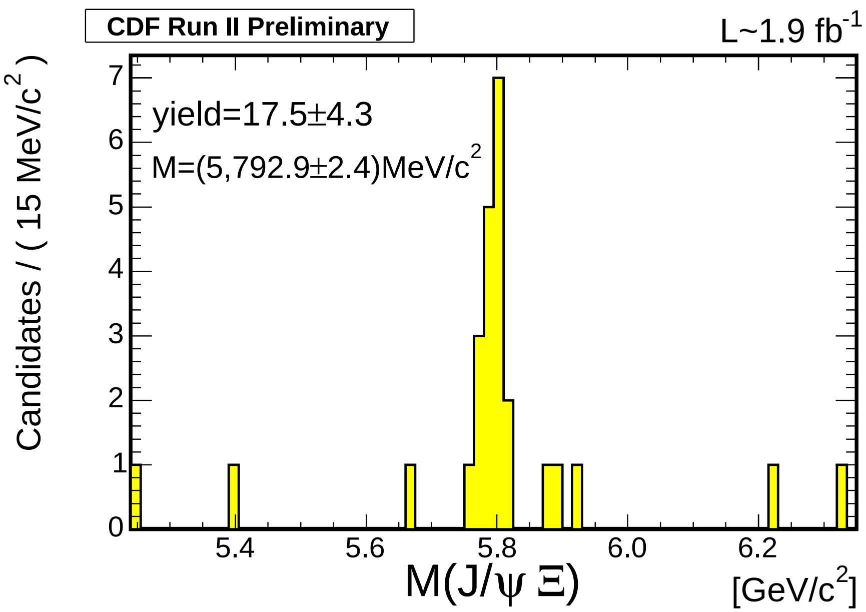
Displaced track trigger (a.k.a. TTT)

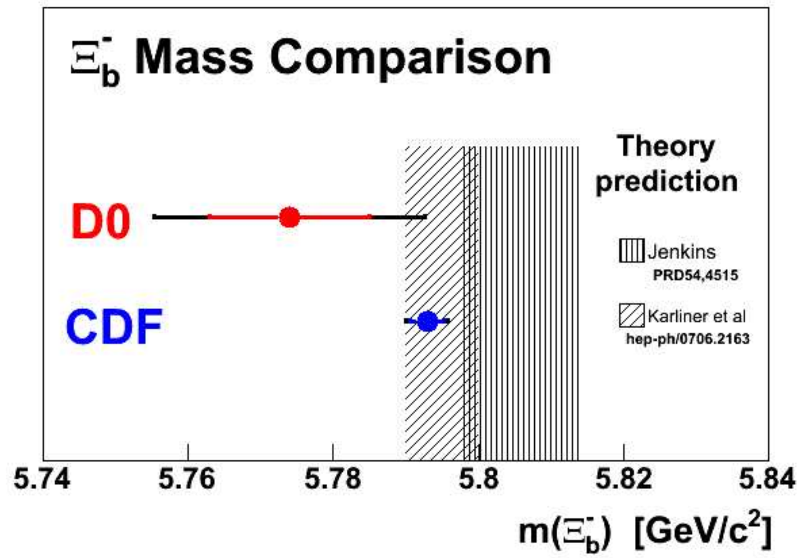


Conclusion

- CDF observes Ξ_b. Significance is 7.8σ
- The Ξ_b mass is measured to be

$$\boxed{M(\Xi_b^-) = (5,792.9 \pm 2.4(stat.) \pm 1.7(syst.))\ \mathrm{MeV}/c^2}$$

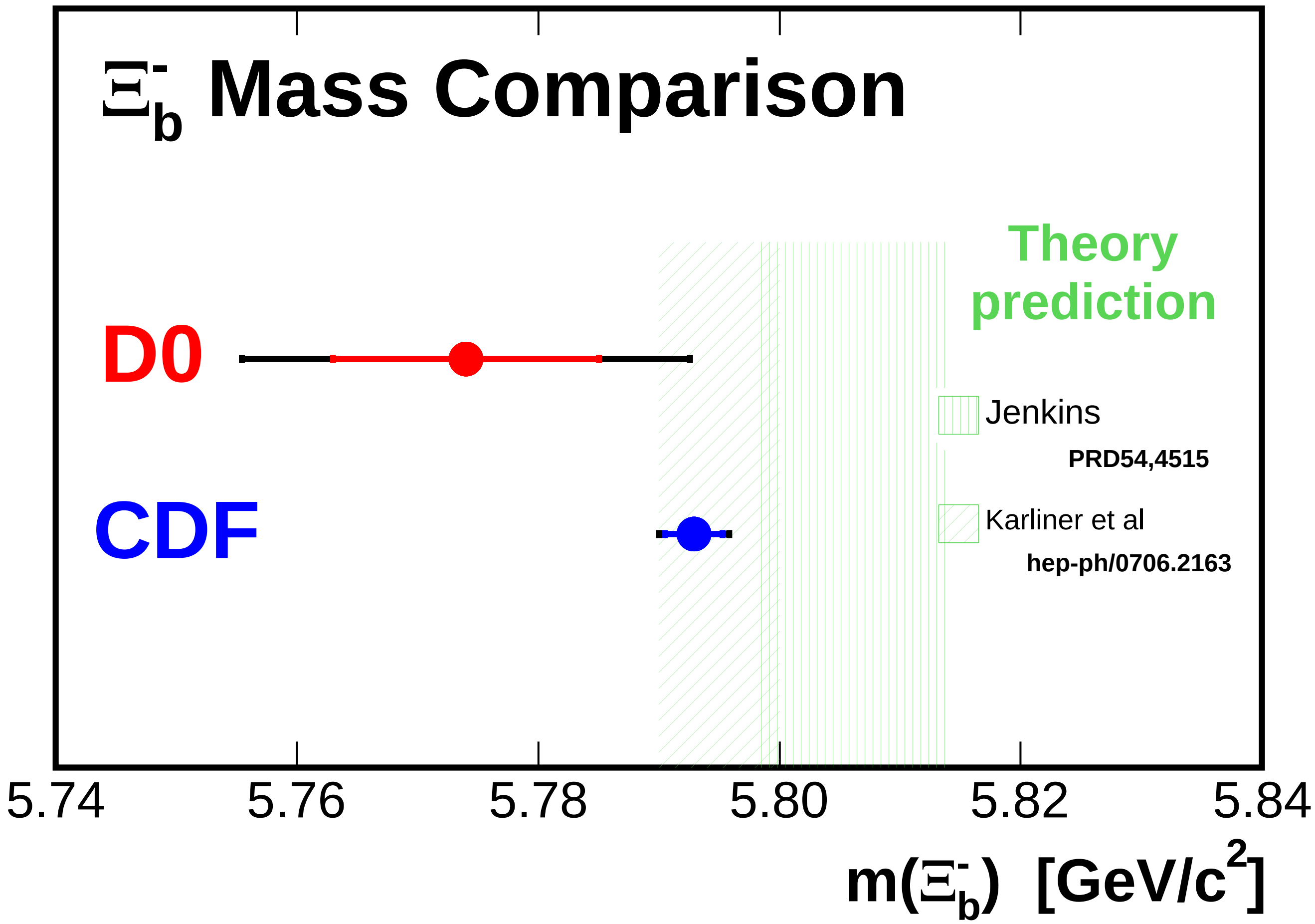




- PRL in preparation. There is much more to come from us.

Backup Slides

Ξ_b masses



Ξ_b^- Mass Comparison
Theory prediction
D0
CDF
Jenkins
PRD54,4515
Karliner et al
hep-ph/0706.2163
5.74
5.76
5.78
5.80
5.82
5.84
m(Ξ_b^-) [GeV/c^2]

$B^+ \to J/\psi K^+/\Xi$ pre-cuts

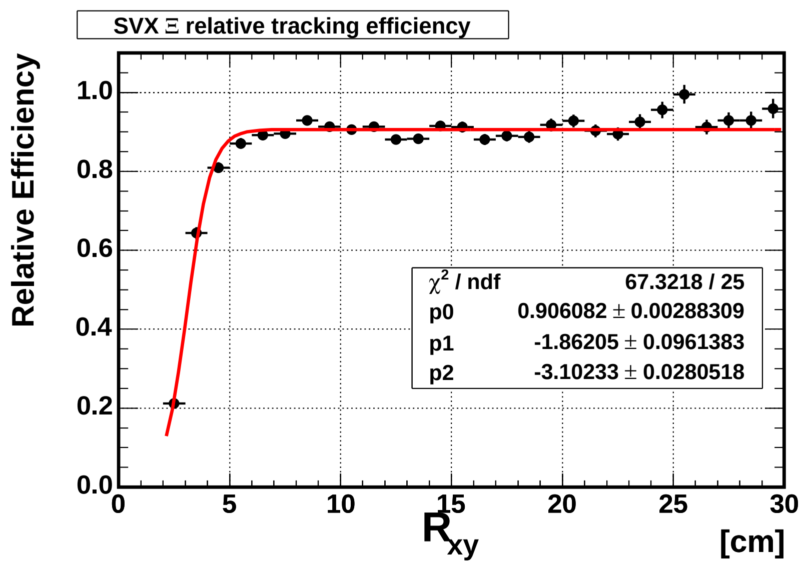
- pre-selection cuts:
  - All three track have >= 3 $r - \phi$ silicon hits (Ξ have >=2 hits)
  - $p_T(\mu) > 1.5$ GeV/c
  - $p_T(K/\Xi) > 1.$ GeV/c
  - if CMU muon $\chi^2 < 9$ (of track-stub match)
  - if CMX muon $\chi^2 < 9$ (of track-stub match)
  - form 2-track J/ψ vertex, do vertex fit with $prob(\chi^2(3D)) > 10^{-3}$.
  - require $|M(\mu\mu) - M(J/\psi)| < 0.08$ MeV/c^2
  - Attach K/Ξ-track to J/ψ vertex, perform vertex fit. Require $prob(\chi^2(3D)) > 10^{-4}$.

$B^+ \to J/\psi K/\Xi$ **Cuts**

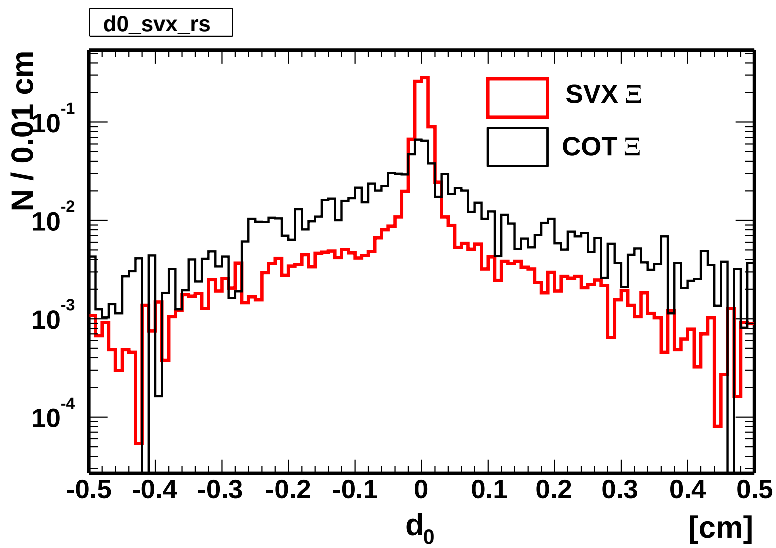
Selection variable	Optimization A	Optimization B
$p_T(K/\Xi)$ [GeV/c]	> 1.7	> 2.5
$p_T(J/\psi K/\Xi)$ [GeV/c]	$> 5.$	$> 6.$
$ct(J/\psi K/\Xi)$ [cm]	> 0.008	> 0.01
$\delta[ct(J/\psi K/\Xi)]$ [cm]	< 0.003	< 0.0025
Pointing angle	< 0.4 radians	< 0.3 radians
$prob(\chi^2(3D))$	$> 10^{-3}$	$> 10^{-2}$
$\|d_0(K/\Xi)\|$ [cm] (w.r.t sec. vtx.)	< 0.01	< 0.008
$\|d_0(J/\psi K/\Xi)\|$ [cm] (w.r.t p.v.)	< 0.0075	< 0.006
$\|d_0(K/\Xi)_{sig}\|$ (w.r.t p. v.)	$> 2.5\sigma$	$> 3.0\sigma$

- Apply Optimization A. If candidate fails just one cut, apply Optimization B. Accept if it does not fail any other cuts in Optimization B.
- Any single cut has almost 90% signal efficiency

PR: Ξ track features

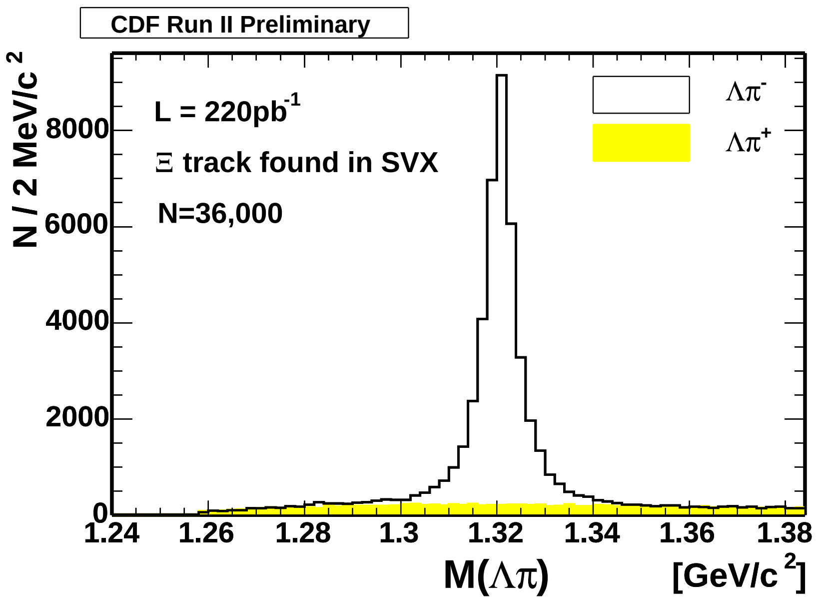


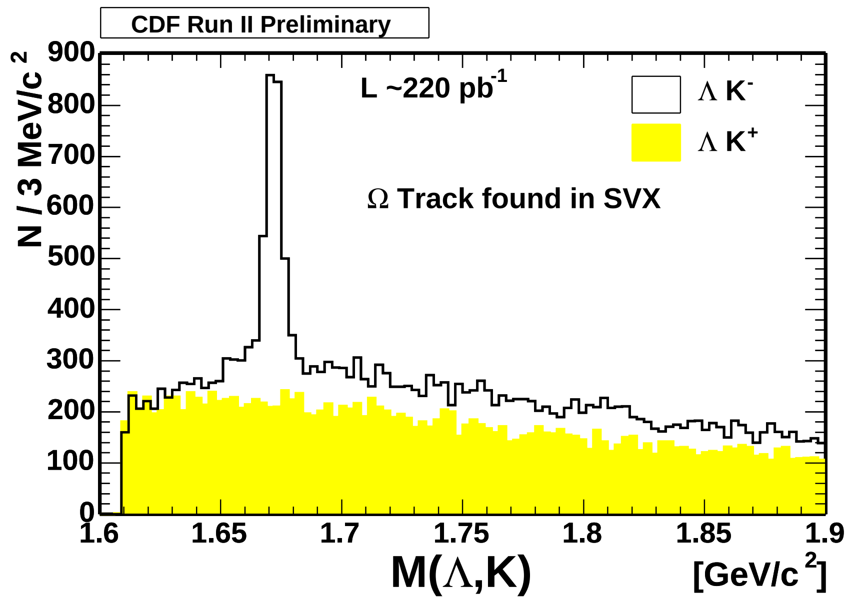
Relative SVX tracking efficiency as a function of Ξ decay vertex position



Ξ track impact parameter resolution (black - failed SVX tracking) (red - SVX Ξ tracks)

PR: Tracked Hyperon signals





Two Track trigger data

- Can see Ω too!