Latest Results on Bottom Spectroscopy and Production with CDF

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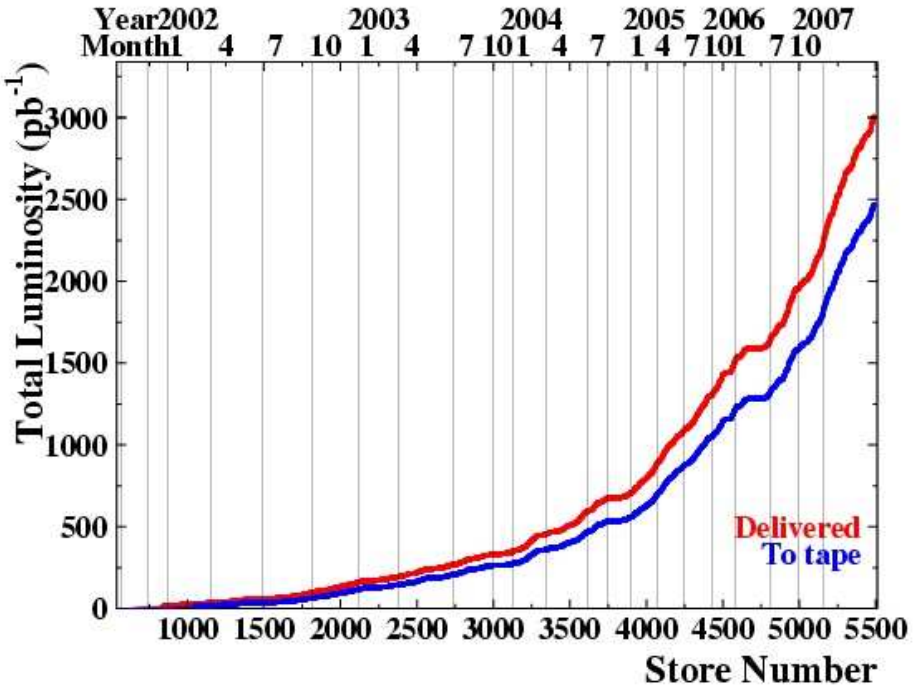
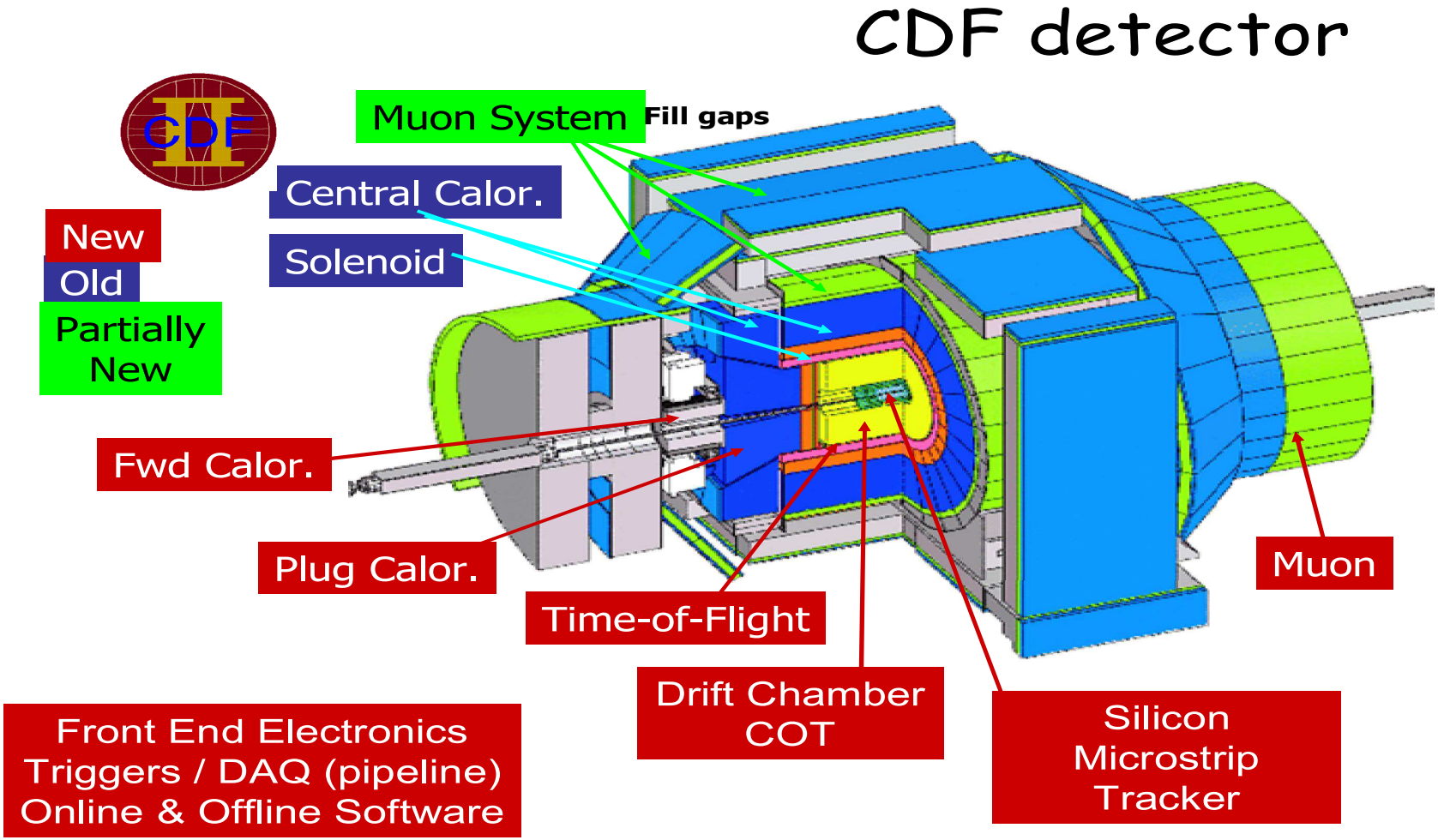
Outline



- Tevatron Accelerator at FERMILAB
- Integrated Luminosity now: $3.0\,\mathrm{fb}^{-1}$/ $2.5\,\mathrm{fb}^{-1}$ delivered / on tape

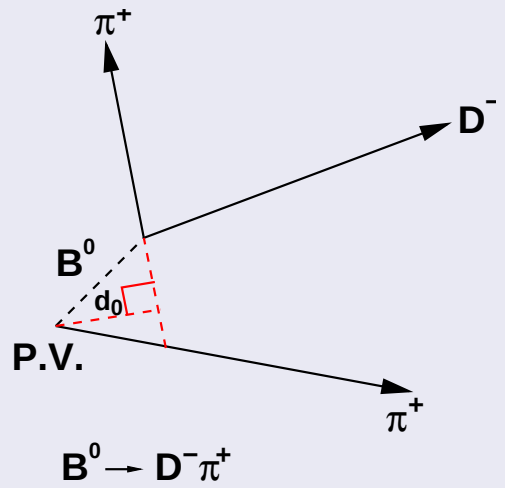
- Critical: COT (central tracker), Si vertex detector (SVX II)
- Muon system.



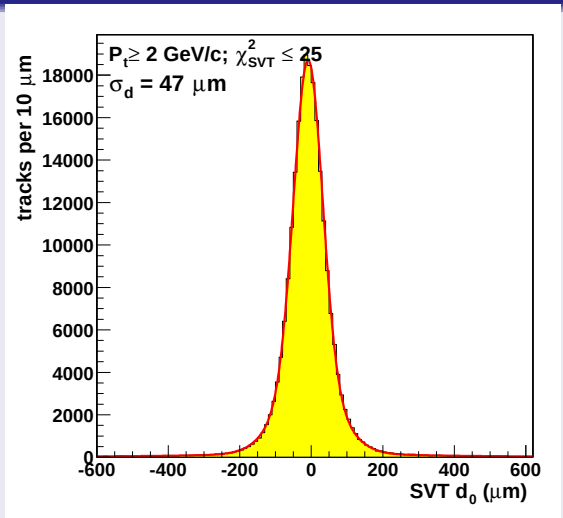
b- Triggers at @1.96 TeV

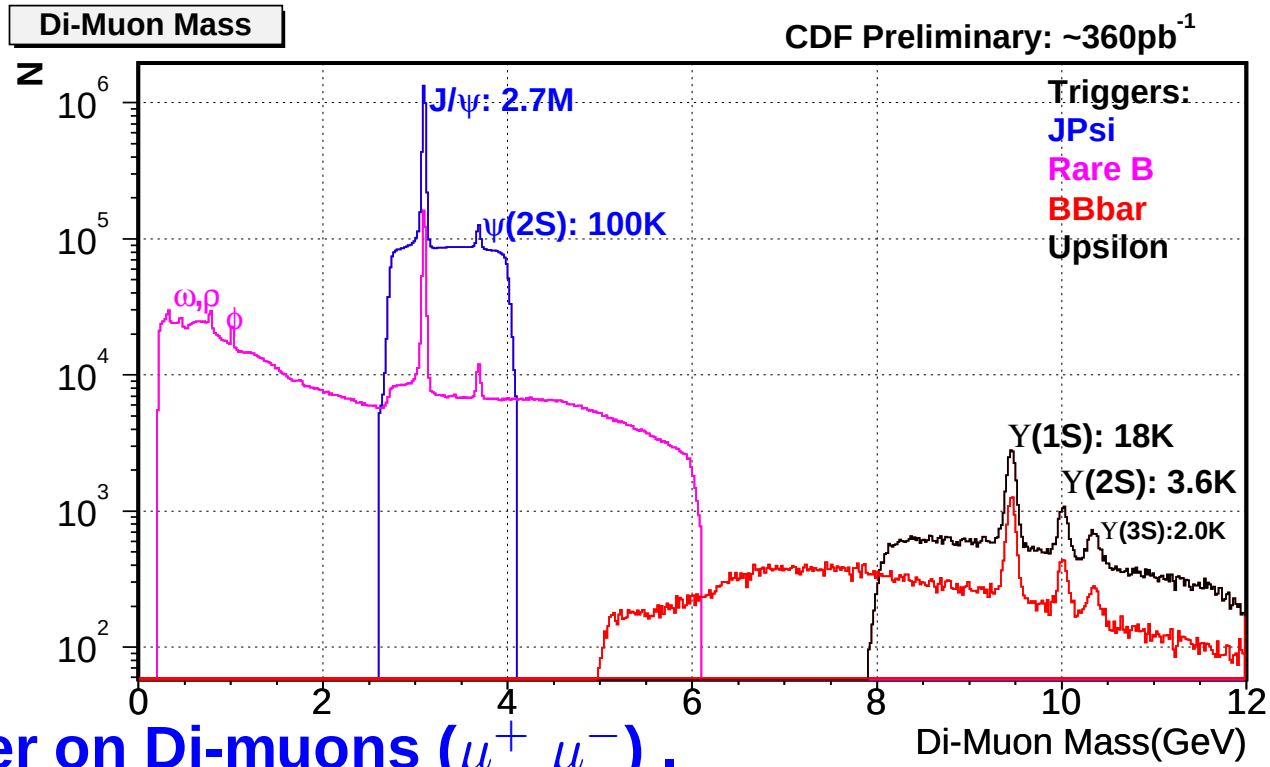
- Enormous inelastic total cross-section of $\sigma_{\mathbf{tot}}^{\mathbf{inel}} \sim \mathbf{60}\,\mathrm{mb}$ at Tevatron.
- $\sigma_{\mathbf{b}} \approx \mathbf{20}\,\mu\mathrm{b}\,(|\eta| < \mathbf{1.0})$, **@1.96 TeV** to compare with
  - $e^+e^- \to \Upsilon(4S) \approx 1$ nb (only B^0, B^+)
  - $e^+e^- \to Z^0 \approx 7$ nb
- Selective three-level triggers
- **Trigger on Hadron or Semileptonic Modes** .
  - Exploit "long" $c\tau$(b-hadrons)
  - Trigger on ≥ 2 tracks with large d_0.

Displaced Track: π^+



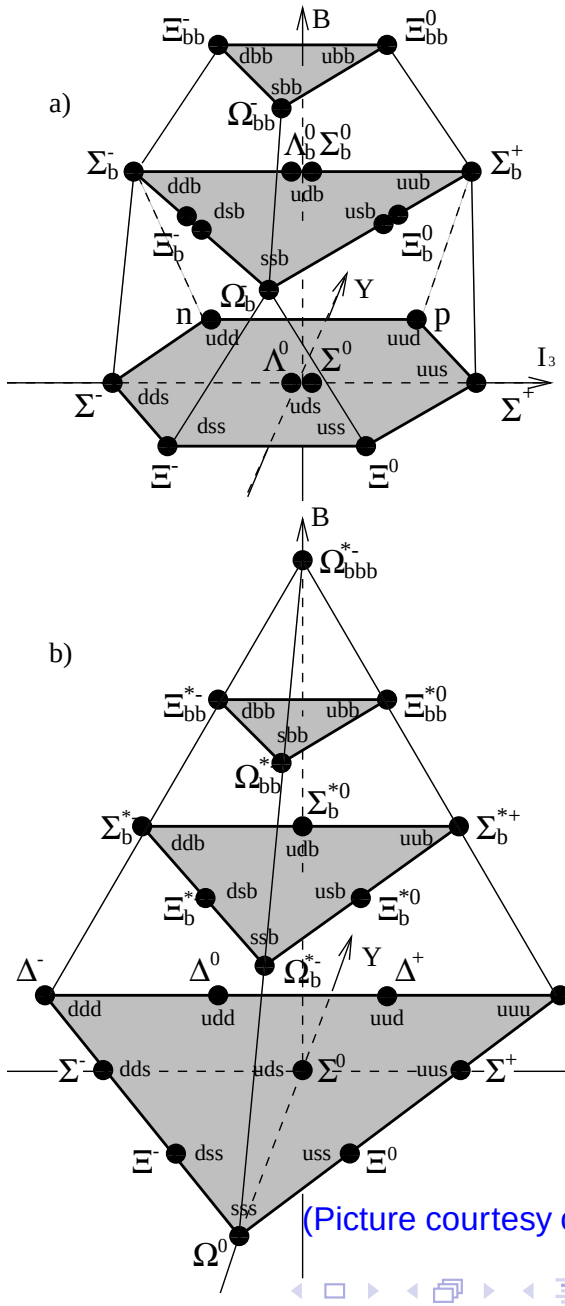
d_0 Resolution $\oplus$ beamline = 47 μm





- **Trigger on Di-muons ($\mu^+ \mu^-$) .**
- e.g. reach of $B^+ \rightarrow J/\psi K^+, J/\psi \rightarrow \mu^+\mu^-$ mode
- Level 1 eXtremely Fast Tracker (XFT) Trigger: tracks are reconstructed
  in the COT and matched to hits in the Muon Chambers.
- Level 2: transparent
- Level 3: full reconstruction

- Baryon: $q_{f_1}, q_{f_2}, q_{f_3}$
- Ordinary $SU_f(3)$ with $f_i \in u, d, s$
- Bottom $SU_f(5)$ with $f_i \in u, d, s, c, b$
- $Y \equiv \mathcal{B} + S - \frac{B}{3}$, hypercharge.
- $B = -1$, for b- quark.
  - to be discussed:
  - $b\,[u\,d] \rightarrow \Lambda_b^0\,(\frac{1^+}{2})$
  - $b\,\{q_{f_1}\,q_{f_2}\} \rightarrow \Sigma_b(\frac{1^+}{2}),\ \Sigma_b(\frac{3^+}{2})$
  - $b\,[s\,q_f] \rightarrow \Xi_b(\frac{1^+}{2})$
  - $q_f \in (u, d)$

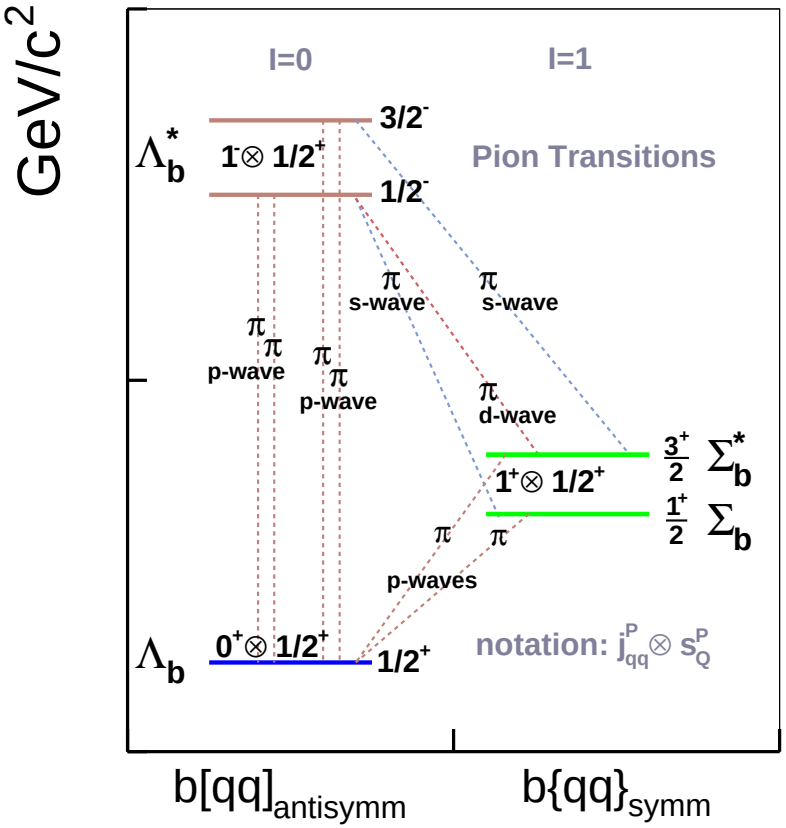


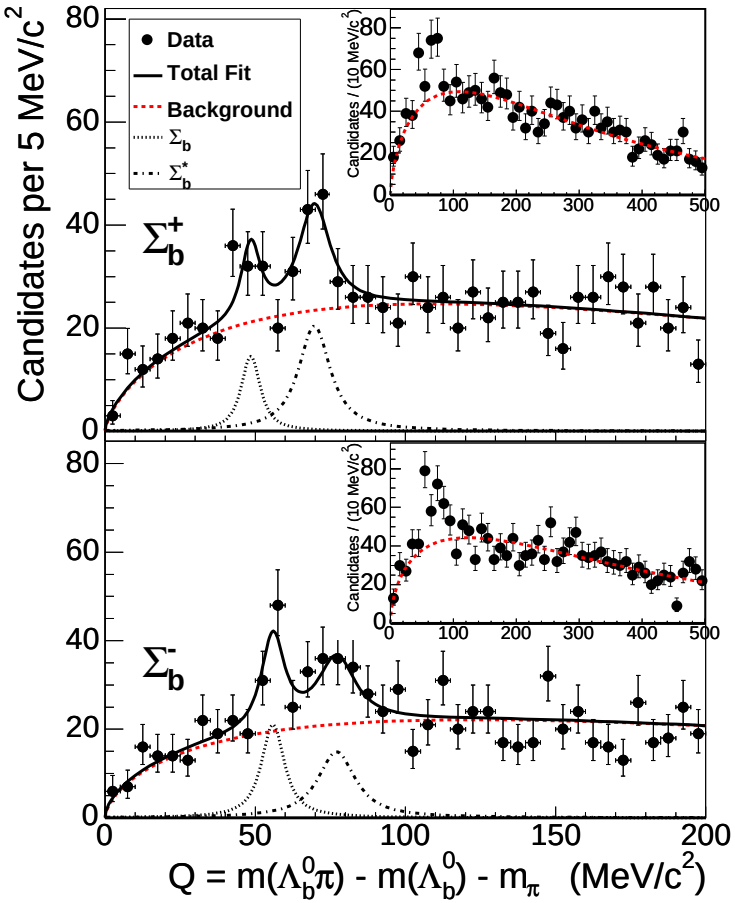
$J^P = \frac{1^+}{2}$

$J^P = \frac{3^+}{2}$

(Picture courtesy of Dr. D. Litvintsev)

First Observation of Heavy Baryons Σ_b and Σ_b^* in CDF





- Modes: $\Sigma_b^{(*)\pm} \to \Lambda_b^0 \pi^\pm_{soft}$, $\Lambda_b^0 \to \Lambda_c^+ \pi^-$, $\Lambda_c^+ \to pK^-\pi^+$

Total luminosity: $\mathcal{L} = 1.1\,\mathrm{fb}^{-1}$

- submitted to PRL recently: arXiv:0706.3868v1 [hep-ex]

Results on Mass Measurements and Yields

State	Yield	Q or $\Delta_{\Sigma_b^*}$ (MeV/c^2)	Mass (MeV/c^2)
Σ_b^+	32^{+13+5}_{-12-3}	$Q_{\Sigma_b^+} = 48.5^{+2.0+0.2}_{-2.2-0.3}$	$5807.8^{+2.0}_{-2.2} \pm 1.7$
Σ_b^-	59^{+15+9}_{-14-4}	$Q_{\Sigma_b^-} = 55.9 \pm 1.0 \pm 0.2$	$5815.2 \pm 1.0 \pm 1.7$
Σ_b^{*+}	77^{+17+10}_{-16-6}	$\Delta_{\Sigma_b^*} = 21.2^{+2.0+0.4}_{-1.9-0.3}$	$5829.0^{+1.6+1.7}_{-1.8-1.8}$
Σ_b^{*-}	69^{+18+16}_{-17-5}		$5836.4 \pm 2.0^{+1.8}_{-1.7}$

The combined 4-peak, $\Sigma_b^{(*)\pm}$, signal significance w.r.t. to null (no any peak, background only) hypothesis exceeds 5.2 gaussian σ.

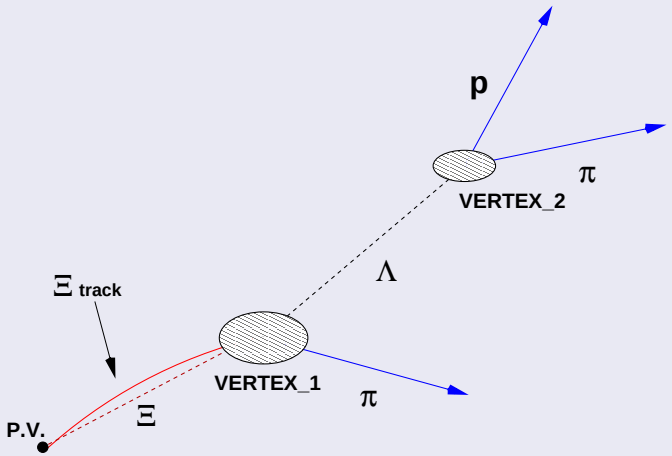
Observation of Cascade Bottom Baryon Ξ_b

Ξ_b Theoretical Predictions: Koerner *et al.*, arXiv:hep-ph/9406359v1

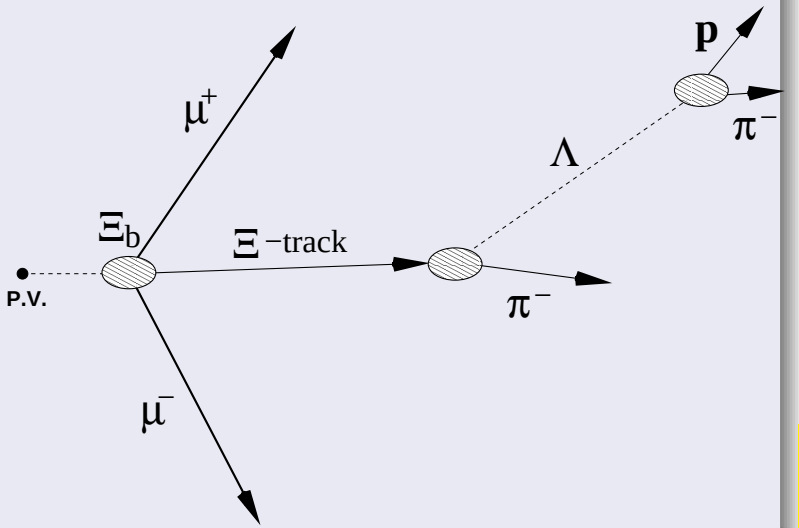
State	Quark	J^P	(I, I_3)	$S_{q_1 q_2}$	Mass
Λ_b	$b[ud]$	$1/2^+$	(0,0)	0	(5624 ± 9) MeV/c^2
Ξ_b^0	$b[su]$	$1/2^+$	(1/2,1/2)	0	5.80 GeV/c^2
Ξ_b^-	$b[sd]$	$1/2^+$	(1/2,-1/2)	0	5.80 GeV/c^2
$\Xi_b^{0\prime}$	$b\{su\}$	$1/2^+$	(1/2,1/2)	1	5.94 GeV/c^2
$\Xi_b^{-\prime}$	$b\{sd\}$	$1/2^+$	(1/2,-1/2)	1	5.94 GeV/c^2

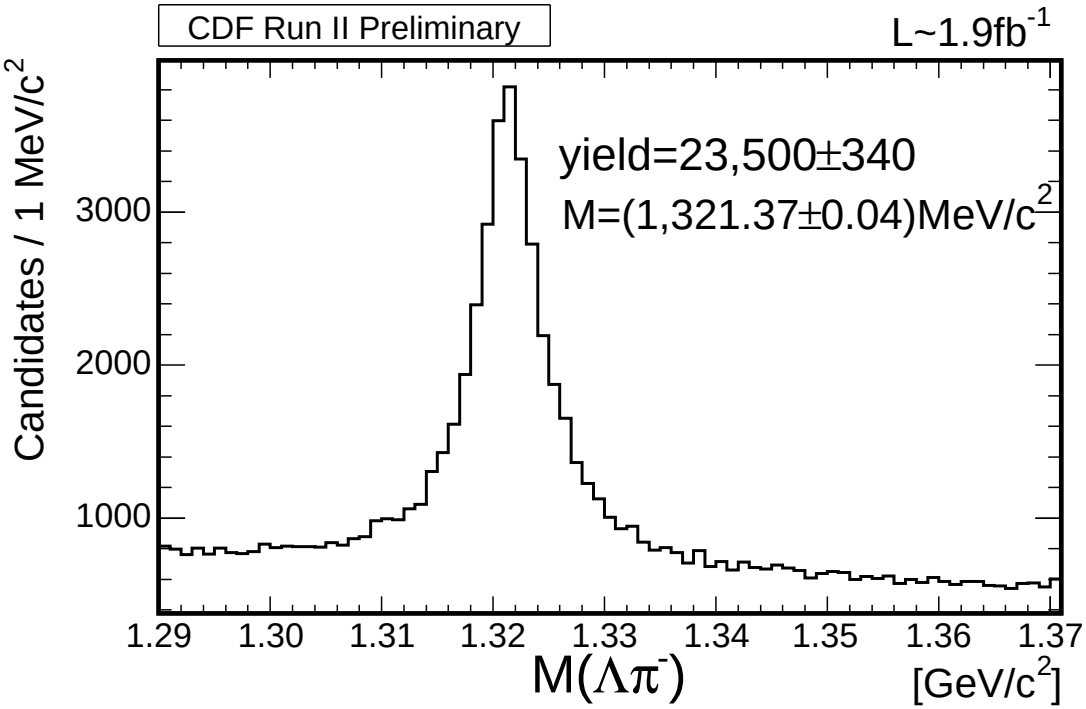
- We consider the lowest lying Ξ_b states decaying weakly
  - $\Xi_b^- \to J/\psi \Xi^-$ or
  - $\Xi_b^- \to \Xi_c^0 \pi^-$, $\Xi_b^0 \to \Xi_c^+ \pi^-$
- $\Xi_b^{\prime}$ is anticipated to decay radiatively or via single π emission

Topology: $\Xi^- \to \Lambda^0\pi^-$, $\Lambda^0 \to p\pi^-$



Topology: $\Xi_b^- \to J/\psi\,\Xi^-$



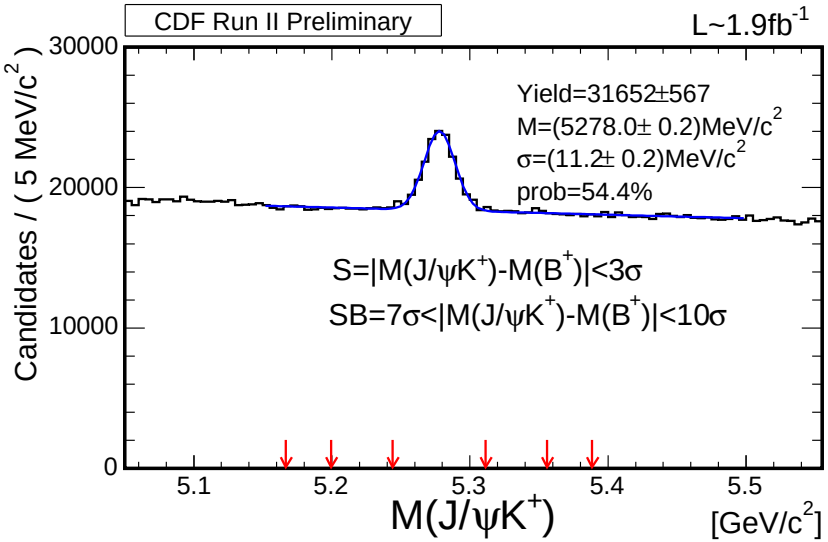


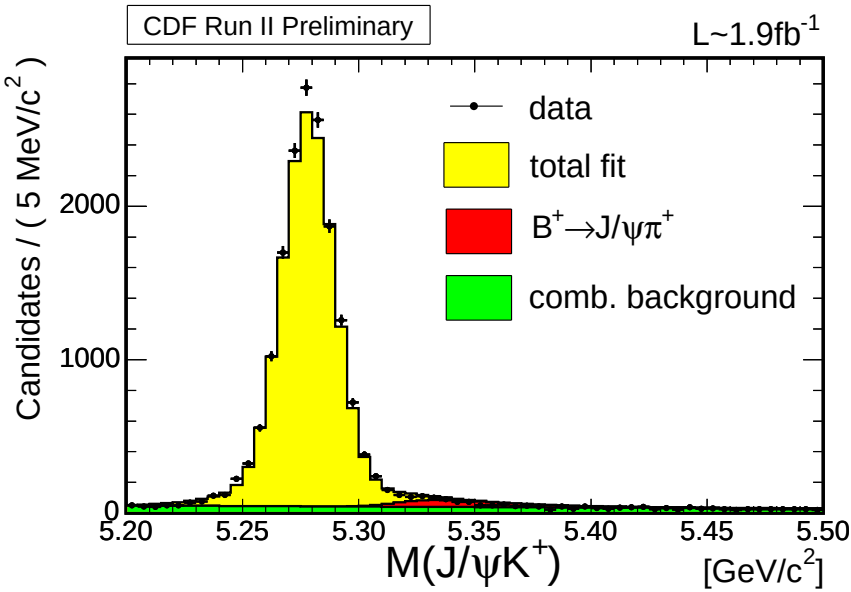
- Ξ^- charged and long-lived, $\tau = 4.91\,\mathrm{cm}$.
- **Ξ^- can be tracked in CDF Si tracker**
- Original tracking algorithm used.
- **Requiring ≥ 2 Si hits substantially reduced background**

Fitted mass: excellent agreement with PDG, method has no mass scale biases.

- The total statistics of $\mathcal{L} = 1.9\,\text{fb}^{-1}$
- Di-muon ("J/ψ ") trigger dataset yields
  - $N(J/\psi) \sim 15M$
  - $N(\Xi^-) \sim 23.5K$

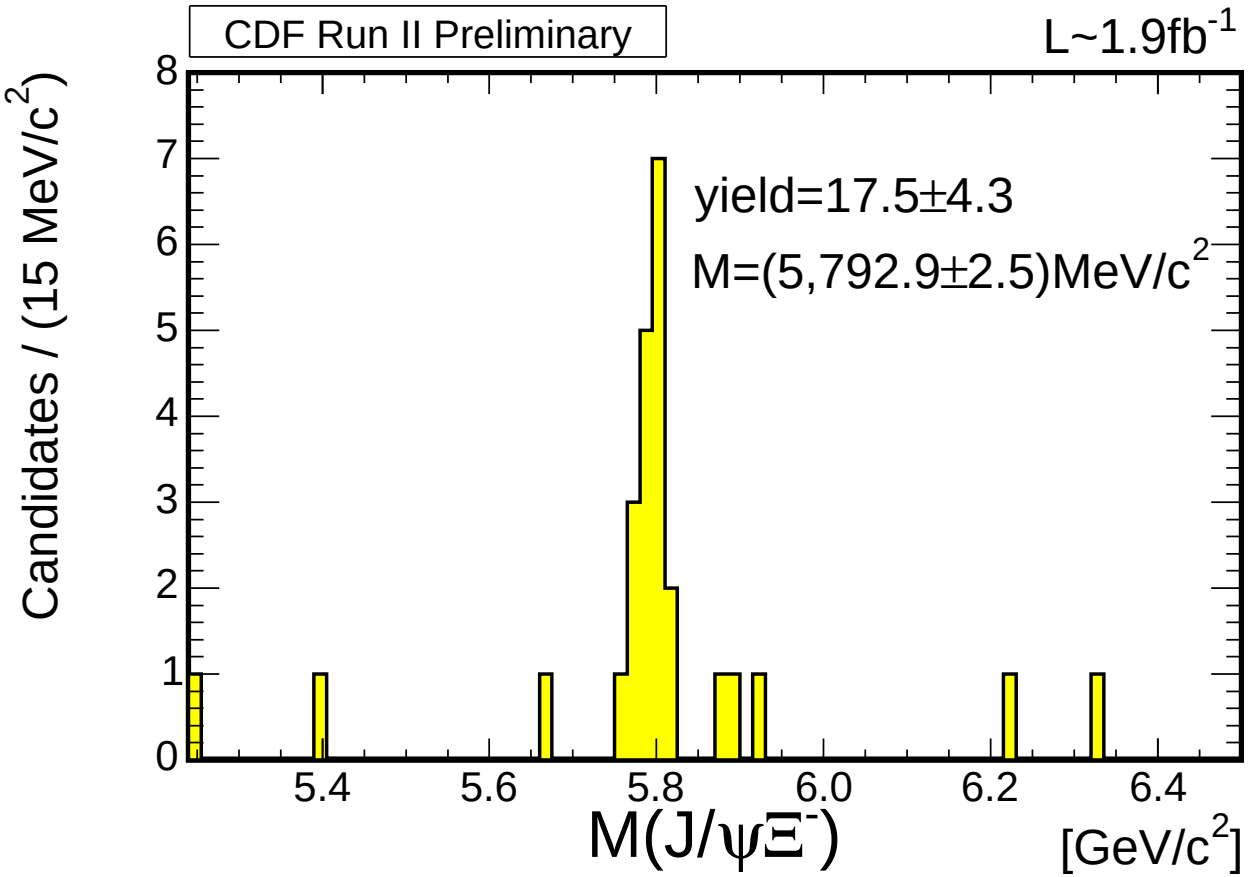
- Assume: $B^+ \to J/\psi\ K^+$ has topology and kinematics similar to $\Xi_b \to J/\psi\ \Xi^-$
- Use $B^+ \to J/\psi\ K^+$ as a control sample
- K^+ track emulates Ξ^- in $\Xi_b \to J/\psi\ \Xi^-$
- With loose non-optimal cuts: $N(B^+) \sim 31K$
- With optimal cuts: $N(B^+) \sim 16K$
- Background reduction factor: ~ 500
- Signal efficiency : $\sim 50\%$
- **Apply developed cuts to $J/\psi\ \Xi^-$ candidates**





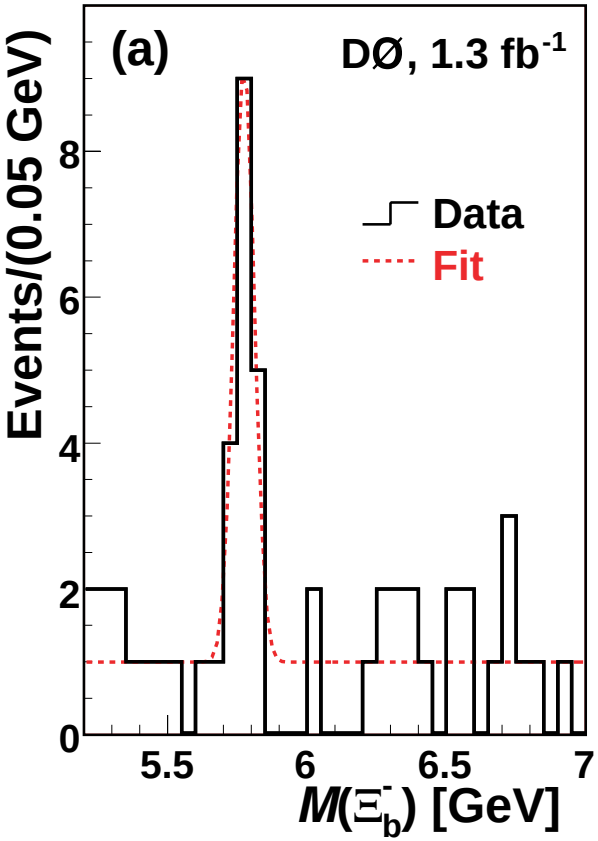
- effect of optimization

Cascade Bottom Baryon Ξ_b: Signal in CDF Detector

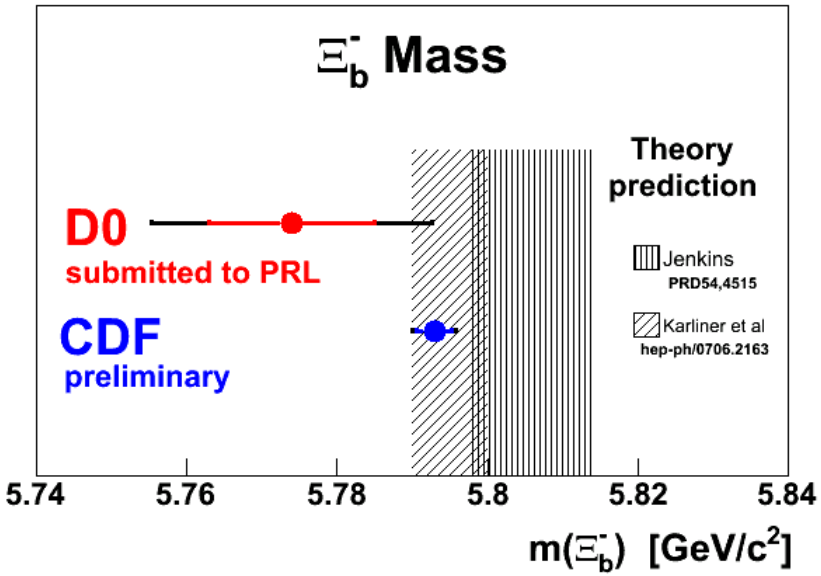


- **Yield** $= 17.5 \pm 4.3(\text{stat})$ with significance of 7.7σ
- **Mass** $= 5792.9 \pm 2.5(\text{stat}) \pm 1.7(\text{syst})\ \text{MeV}/c^2$

Comparison with a DØ result on "Direct observation..."



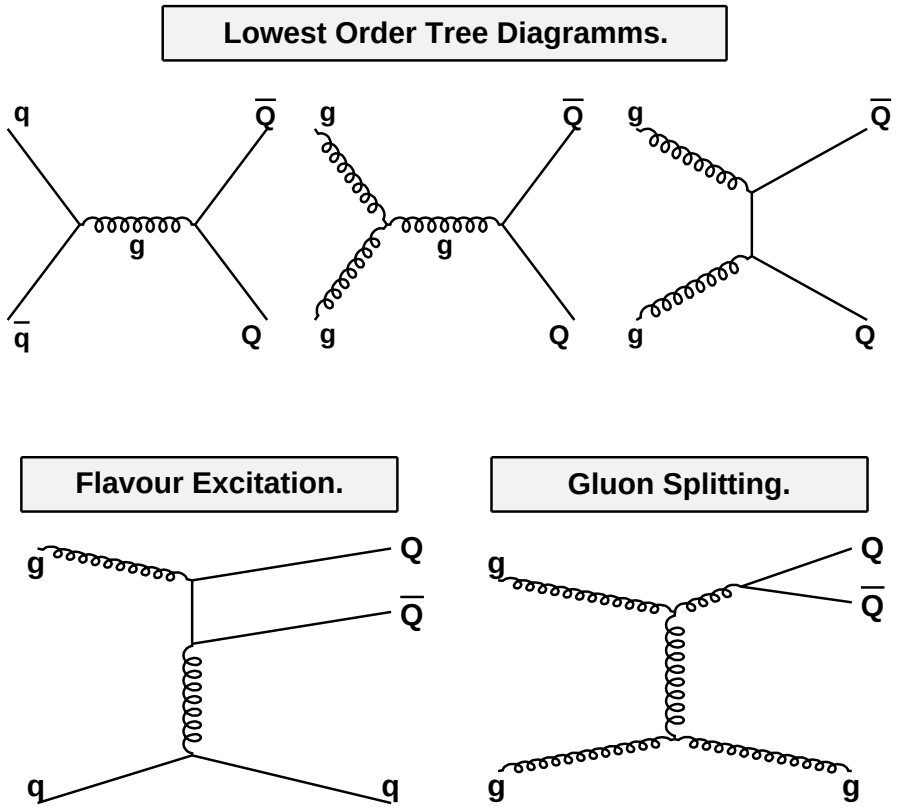
- DØ: arXiv:0706.1690v2 [hep-ex], submitted to PRL
- $\mathbf{M = 5774.0 \pm 11.0(\text{stat}) \pm 15.0(\text{syst})\ \text{MeV}/c^2}$
  $\mathbf{N = 15.2 \pm 4.4(\text{stat})^{+1.9}_{-0.4}(\text{syst})}$



- **CDF: arXiv:0707.0589v1 [hep-ex], submitted to PRL**
- **CDF result is consistent with DØ and both are consistent with theory predictions**

Bottom Production: Processes Involved

- LO and NLO contributions
- $m_Q \gg \Lambda_{QCD}$, where
- $\Lambda_{QCD} \simeq 400\,MeV$, typical scale of strong interactions.
- $m_Q \simeq 4.8\,GeV$, $Q \equiv b$.
- $\frac{d\sigma(p\bar{p} \to B + X, B \to J/\psi, \mu + X)}{dp_T(B)} = d\hat{\sigma}(gg, gq, qq \to b + X) \otimes \mathcal{F}^{p,\bar{p} \to q,g} \otimes \mathcal{D}^{b \to B} \otimes \mathcal{B}$
- LO dominate $b\bar{b}$ production. $\sigma_{b\bar{b}}$
- NLO is essential for inclusive σ_b



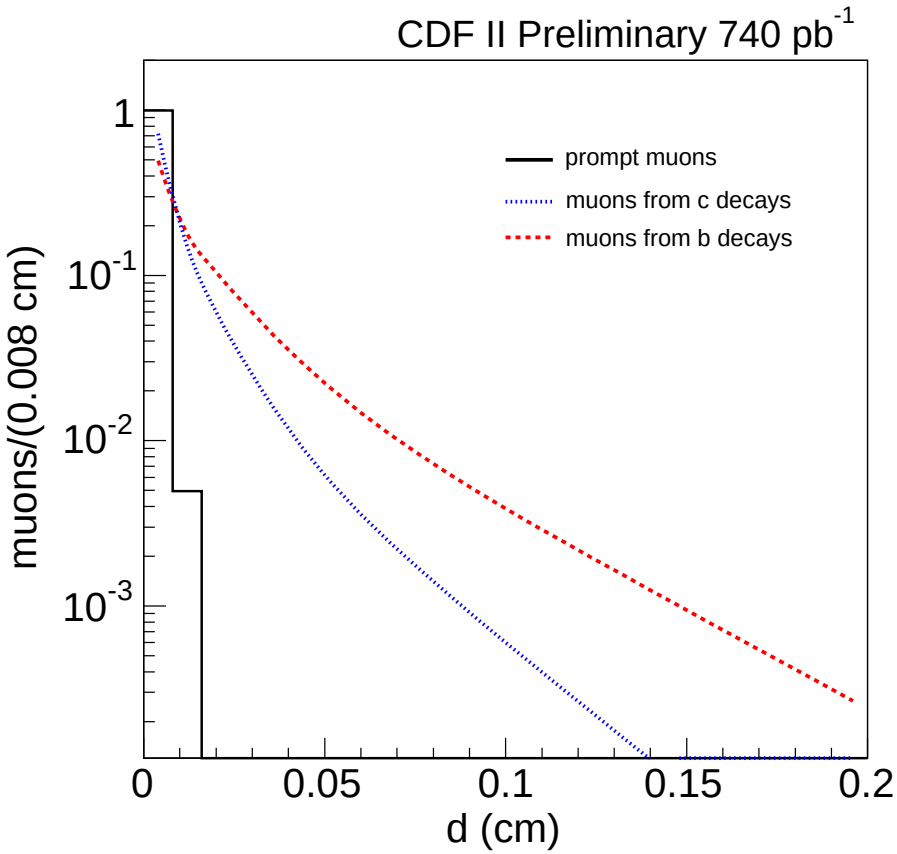
$b\bar{b}$ Production: Motivation and Method

- Mostly b from direct LO production contribute to the measurement.
- Measurement of $\sigma_{b\bar{b}}$ will help to disentangle LO and NLO contributions.
- Critical test of QCD calculations
- Solve the controversy of Run I DØ, CDF measurements
- In this analysis: use (μ_1, μ_2) events and measure $\sigma(b \to \mu^- + X, \bar{b} \to \mu^+ + X)$
- Other contributions to (μ_1, μ_2): $c\bar{c}$, prompt Drell-Yan, c- and b-onium prompt decays, π-, K-decays, fakes
- Physical fact: the shape of μ track impact parameter $d_0(\mu)$ distribution determined by the lifetime of its parent heavy hadron
- Fit the experimental 2-d $d_0(\mu_1, \mu_2)$ distributions to the expected composition
  - H.Q. templates from MC
  - prompt templates from $\Upsilon(1S)$ peak, data

Analysis

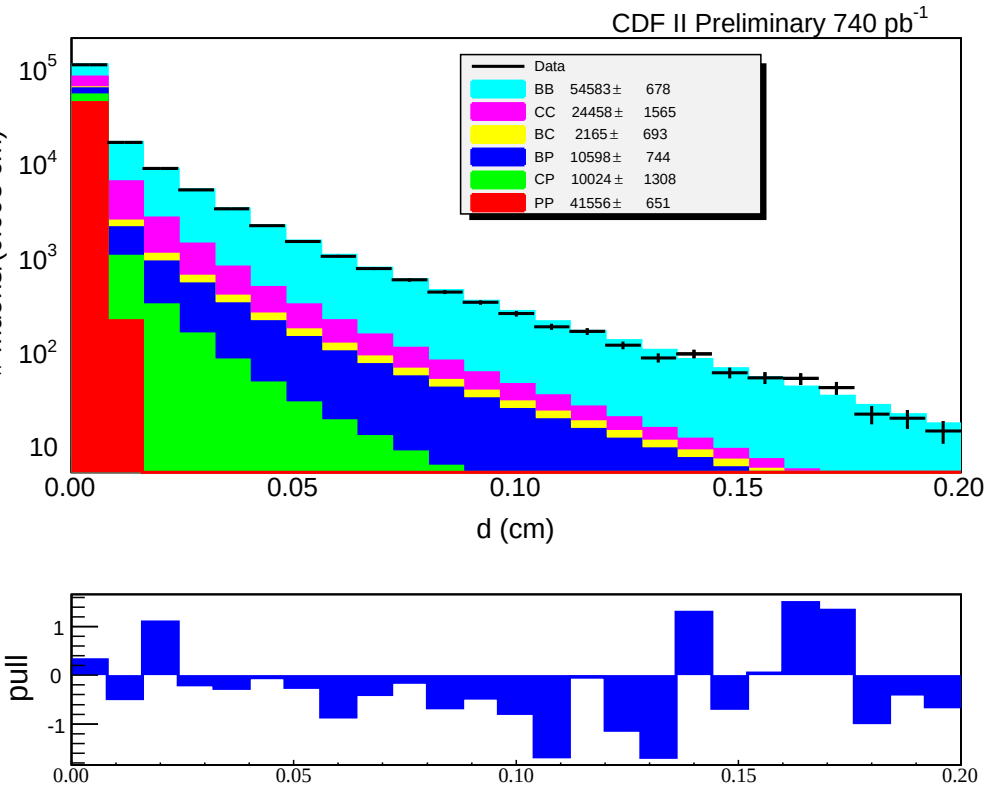
Total luminosity: $\mathcal{L} = 740\,\mathrm{pb}^{-1}$

- Dataset collected with Di-μ Trigger
- select $p_T(\mu) \geq 3\,\mathrm{GeV}/c$, $|\eta(\mu)| \leq 0.7$
- $5 < M(\mu_1\mu_2) < 80\,\mathrm{GeV}/c^2$
- $b \to \mu_1$, $\bar{b} \to \mu_2$: fit impact parameters in 2-d space
- impact parameters are uncorrelated
- Fitter: binned maximum log LH fit



⇒Templates for d_0 (μ) fits.
⇒Prompt template is based on
⇒data around $\Upsilon(1S)$ signal

Cross-Section: $\sigma(b \to \mu_1, b \to \mu_2)$



$\Rightarrow$The projection of 2-d fit of d_0 (μ) comprising several contributions and compared with data.

Experimental Results w.r.t. NLO MC ($\equiv$ MNR+MRSD0+Peterson+EvtGen)

- $\sigma = N_{\mu\mu}/(\mathcal{L} \cdot \mathcal{A})$
- $\sigma(b \to \mu_1, b \to \mu_2) = 1549 \pm 133\,\mathrm{pb}$
- $\sigma(c \to \mu_1, c \to \mu_2) = 624 \pm 104\,\mathrm{pb}$
- The data/NLO: $R2(b \to \mu_1, b \to \mu_2) = 1.20 \pm 0.21$
- The data/NLO: $R2(c \to \mu_1, c \to \mu_2) = 2.71 \pm 0.64$
- $\sigma_{NLO}(b\bar{b}, p_T \geq 6\,\mathrm{GeV}/c, |y| \leq 1) = 1348 \pm 209\,\mathrm{nb}$ leads to $\Rightarrow$
- $\sigma(b\bar{b}, p_T \geq 6\,\mathrm{GeV}/c, |y| \leq 1) = 1618 \pm 148\,\mathrm{nb}$

Summary

- CDF made a first observation of four bottom baryon $\Sigma_b^{(*)\pm}$ states. The result is submitted to PRL.
- CDF has observed a strange bottom cascade baryon Ξ_b^-. The CDF precise measurements are in agreement within errors with DØ observation and with theoretical predictions. Both results have been shortly submitted to PRL.
- CDF II has measured the correlated production cross-section of $(b\bar{b})$ pairs with b-quarks identified in their muon semileptonic modes. The measurement is consistent with theoretical expectations. Using NLO Monte-Carlo cross-section calculations the full $b\bar{b}$ production cross-section in a kinematic domain of $(p_T \geq 6\,\mathrm{GeV}/c, |y| \leq 1)$ has been deduced.

Backup Slides

4-peak, $\Sigma_b^{(*)\pm}$, signal significance w.r.t. to several alternative hypotheses

Hypothesis	p-value	Significance (σ)
No Signal	$< 8.3 \times 10^{-8}$	> 5.2
Two Σ_b States	9.2×10^{-5}	3.7
No Σ_b^- Signal	3.2×10^{-4}	3.4
No Σ_b^+ Signal	9.0×10^{-3}	2.4
No Σ_b^{*-} Signal	6.4×10^{-4}	3.2
No Σ_b^{*+} Signal	6.0×10^{-4}	3.2