B_s and Λ_b Decays at the Tevatron

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Fermilab

2004 Particle Data Group Summary (B_s)

B_s Summary

- 5 decay modes observed
- 3 Branching fractions
- 18 Upper limits on BR

B_s Physics

- CP violation
- CKM physics
- penguins
- New Physics (beyond Standard Model)

Tevatron produces

~2 B_s/min/η/experiment

BOTTOM, STRANGE MESONS
($B = \pm 1$, $S = \mp 1$)

$B_s^0 = s\overline{b}$, $\overline{B}_s^0 = \overline{s}b$, similarly for B_s^*'s

B_s^0 $I(J^P) = 0(0^-)$

I, J, P need confirmation. Quantum numbers shown are quark-model predictions.

Mass $m_{B_s^0} = 5369.6 \pm 2.4$ MeV

Mean life $\tau = (1.461 \pm 0.057) \times 10^{-12}$ s

$c\tau = 438\ \mu$m

B_s^0-$\overline{B}_s^0$ mixing parameters

$\Delta m_{B_s^0} = m_{B_{sH}^0} - m_{B_{sL}^0} > 14.4 \times 10^{12}\ \hbar\ s^{-1}$, CL = 95%

$> 94.8 \times 10^{-10}$ MeV, CL = 95%

$x_s = \Delta m_{B_s^0}/\Gamma_{B_s^0} > 20.6$, CL = 95%

$\chi_s > 0.49883$, CL = 95%

These branching fractions all scale with B($\overline{b} \to B_s^0$), the LEP B_s^0 production fraction. The first four were evaluated using B($\overline{b} \to B_s^0$) = (10.7 ± 1.4)% and the rest assume B($\overline{b} \to B_s^0$) = 12%.

The branching fraction B($B_s^0 \to D_s^- \ell^+ \nu_\ell$ anything) is not a pure measurement since the measured product branching fraction B($\overline{b} \to B_s^0$) × B($B_s^0 \to D_s^- \ell^+ \nu_\ell$ anything) was used to determine B($\overline{b} \to B_s^0$), as described in the note on "Production and Decay of b-Flavored Hadrons."

For inclusive branching fractions, *e.g.*, $B \to D^\pm$ anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

B_s^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
D_s^- anything		(94 ±30) %		–
$D_s^- \ell^+ \nu_\ell$ anything	[kkk]	(7.9 ± 2.4) %		–
$D_s^- \pi^+$		< 13 %		2322
$D_s^{(*)+} D_s^{(*)-}$		$(23\ ^{+21}_{-13})$ %		–
$J/\psi(1S)\phi$		(9.3 ± 3.3) $\times 10^{-4}$		1590
$J/\psi(1S)\pi^0$		< 1.2 $\times 10^{-3}$	90%	1788
$J/\psi(1S)\eta$		< 3.8 $\times 10^{-3}$	90%	1735
$\psi(2S)\phi$		seen		1123
$\pi^+\pi^-$		< 1.7 $\times 10^{-4}$	90%	2681
$\pi^0\pi^0$		< 2.1 $\times 10^{-4}$	90%	2681
$\eta\pi^0$		< 1.0 $\times 10^{-3}$	90%	2655
$\eta\eta$		< 1.5 $\times 10^{-3}$	90%	2628
$\rho^0\rho^0$		< 3.20 $\times 10^{-4}$	90%	2570
$\phi\rho^0$		< 6.17 $\times 10^{-4}$	90%	2528
$\phi\phi$		< 1.183 $\times 10^{-3}$	90%	2484
π^+K^-		< 2.1 $\times 10^{-4}$	90%	2660
K^+K^-		< 5.9 $\times 10^{-5}$	90%	2639
$\overline{K}^*(892)^0\rho^0$		< 7.67 $\times 10^{-4}$	90%	2551
$\overline{K}^*(892)^0 K^*(892)^0$		< 1.681 $\times 10^{-3}$	90%	2532
$\phi K^*(892)^0$		< 1.013 $\times 10^{-3}$	90%	2508
$p\overline{p}$		< 5.9 $\times 10^{-5}$	90%	2516
$\gamma\gamma$		< 1.48 $\times 10^{-4}$	90%	2685
$\phi\gamma$		< 1.2 $\times 10^{-4}$	90%	2588

Lepton Family number (*LF*) violating modes or
$\Delta B = 1$ weak neutral current (*B1*) modes

$\mu^+\mu^-$	B1		< 2.0 $\times 10^{-6}$	90%	2683
e^+e^-	B1		< 5.4 $\times 10^{-5}$	90%	2685
$e^\pm\mu^\mp$	LF	[gg]	< 6.1 $\times 10^{-6}$	90%	2684
$\phi(1020)\mu^+\mu^-$	B1		< 4.7 $\times 10^{-5}$	90%	2584
$\phi\nu\overline{\nu}$	B1		< 5.4 $\times 10^{-3}$	90%	2588

2004 Particle Data Group Summary (Λ_b)

Λ_b Summary

- 4 decay modes seen
- 2 Branching Fractions
- 3 Upper limits on BR

Λ_b Physics

- Test HQET/SCET
- CKM physics
- CP violation
- Form Factors

Tevatron produces ~2 Λ_b/min/η/experiment

BOTTOM BARYONS ($B = -1$)

$\Lambda_b^0 = udb$, $\Xi_b^0 = usb$, $\Xi_b^- = dsb$

Λ_b^0 $I(J^P) = 0(\frac{1}{2}^+)$

$I(J^P)$ not yet measured; $0(\frac{1}{2}^+)$ is the quark model prediction.

Mass $m = 5624 \pm 9$ MeV (S = 1.8)

Mean life $\tau = (1.229 \pm 0.080) \times 10^{-12}$ s

$c\tau = 368$ μm

These branching fractions are actually an average over weakly decaying b-baryons weighted by their production rates in Z decay (or high-energy $p\overline{p}$), branching ratios, and detection efficiencies. They scale with the LEP b-baryon production fraction B($b \to$ b-baryon) and are evaluated for our value B($b \to$ b-baryon) = $(9.9 \pm 1.7)\%$.

The branching fractions B(b-baryon $\to$ $\Lambda\ell^-\overline{\nu}_\ell$anything) and B($\Lambda_b^0 \to \Lambda_c^+\ell^-\overline{\nu}_\ell$anything) are not pure measurements because the underlying measured products of these with B($b \to$ b-baryon) were used to determine B($b \to$ b-baryon), as described in the note "Production and Decay of b-Flavored Hadrons."

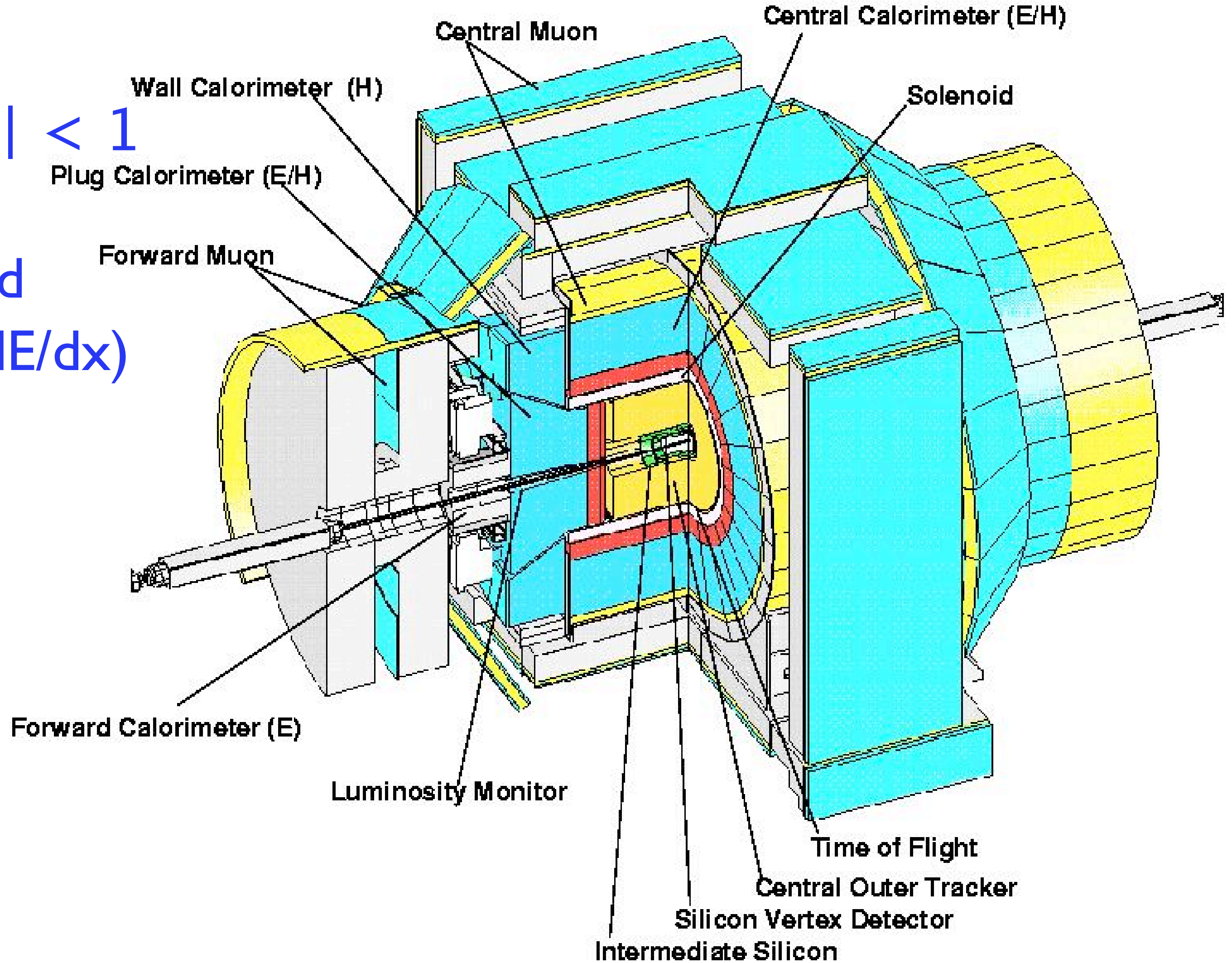
For inclusive branching fractions, *e.g.*, $B \to D^\pm$anything, the values usually are multiplicities, not branching fractions. They can be greater than one.

Λ_b^0 DECAY MODES		Fraction (Γ_i/Γ)	Confidence level	p (MeV/c)
$J/\psi(1S)\Lambda$		$(4.7\pm2.8) \times 10^{-4}$		1744
$\Lambda_c^+\pi^-$		seen		2345
$\Lambda_c^+ a_1(1260)^-$		seen		2156
$\Lambda_c^+\ell^-\overline{\nu}_\ell$anything	[t]	(9.2 ± 2.1) %		–
$p\pi^-$		$< 5.0 \times 10^{-5}$	90%	2732
pK^-		$< 5.0 \times 10^{-5}$	90%	2711
$\Lambda\gamma$		$< 1.3 \times 10^{-3}$	90%	2701

CDF Experiment

Detector

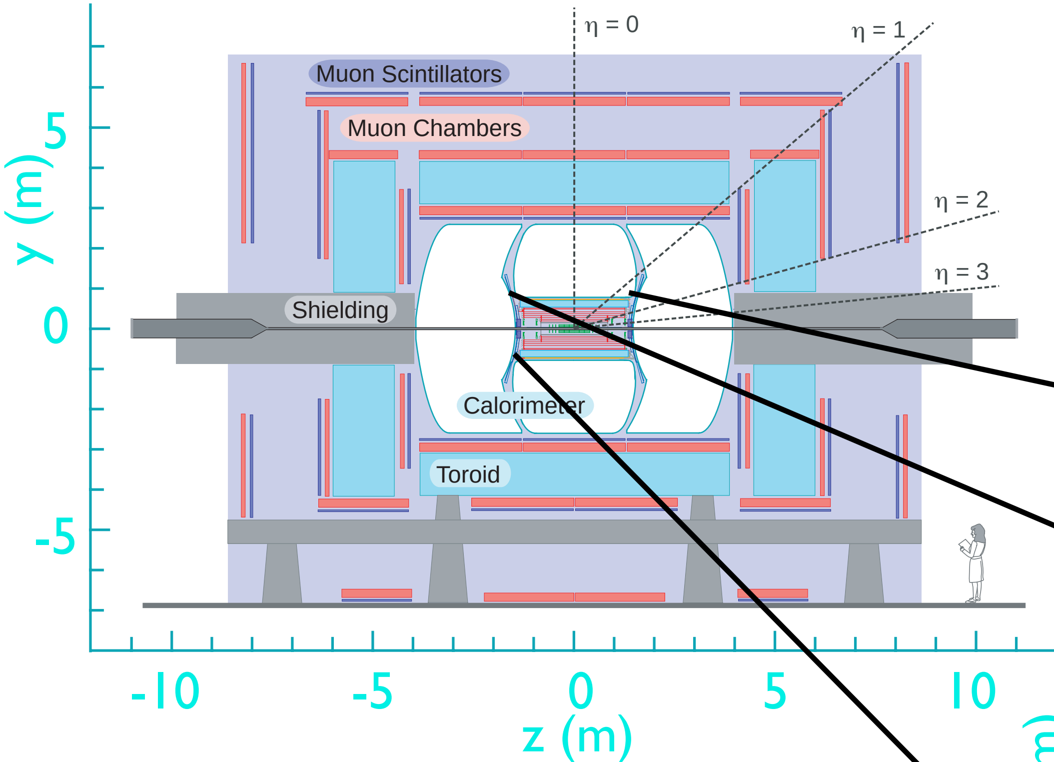
- Tracking/muon $|\eta| < 1$
- Silicon $|\eta| < 2$
- 1.4 T magnetic field
- Particle ID (TOF, dE/dx)



Trigger

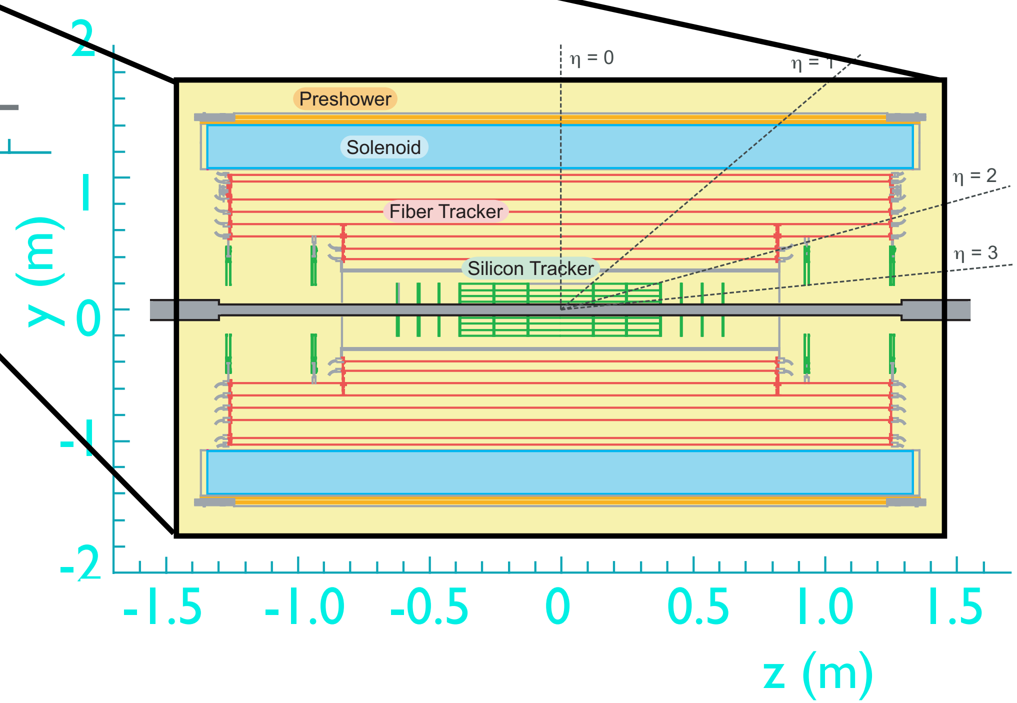
- Tracks
- Leptons
- Displaced vertices
- Impact parameter

D0 Experiment



Detector

- Muon/tracking coverage |η|< 2
- Silicon coverage |η|<3
- 2 T magnetic field



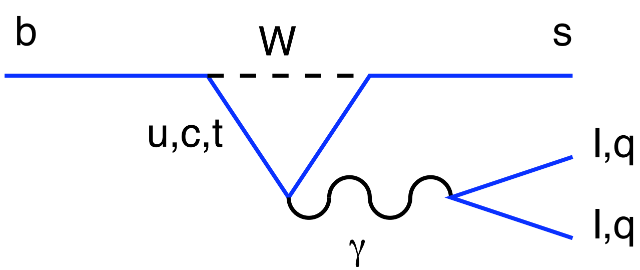
Trigger

- Tracks
- Leptons

B_s Decays

Rare B_s Decays

$B_s \rightarrow \varphi\gamma^{(*)}$:

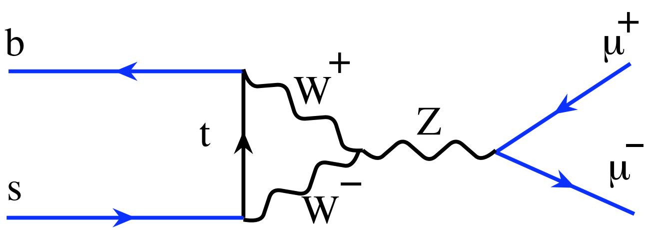


- $B_s \rightarrow \varphi\mu\mu$
- $B_s \rightarrow \varphi\varphi$ (+strong penguin)
- $B_s \rightarrow \psi(2s)\varphi$

Similar physics as $B^0 \rightarrow X_s\,\gamma$, (Martin Gorbahn's talk)

Observation at Tevatron in reach

$B_s \rightarrow \mu\mu$:



Standard Model Prediction small

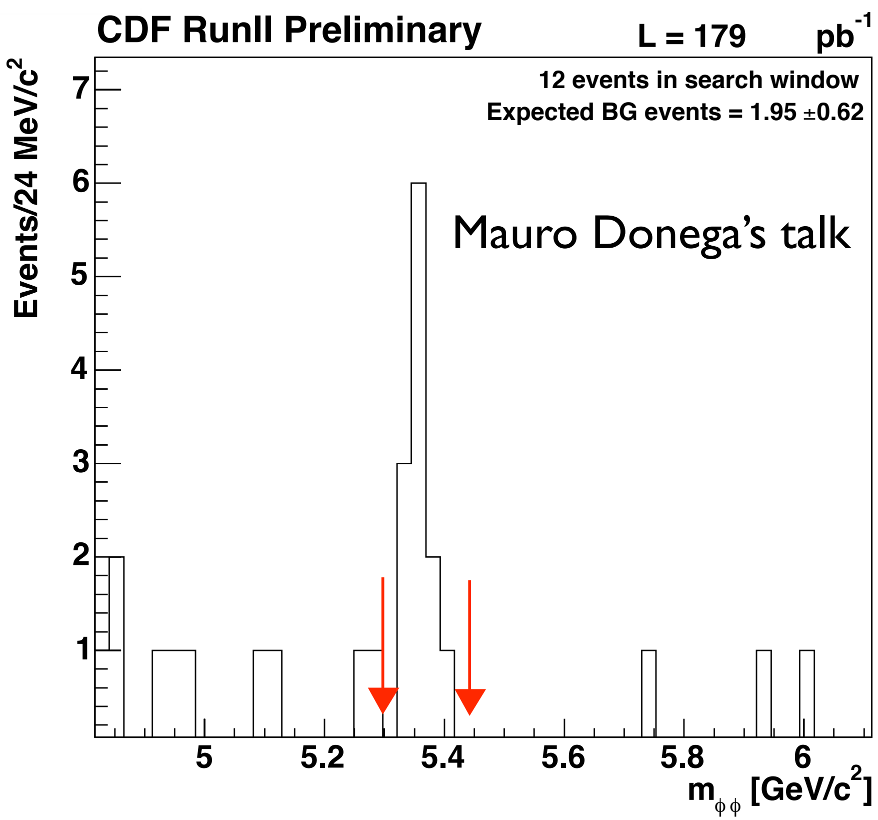
$$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) = (3.5 \pm 0.9) \times 10^{-9}$$

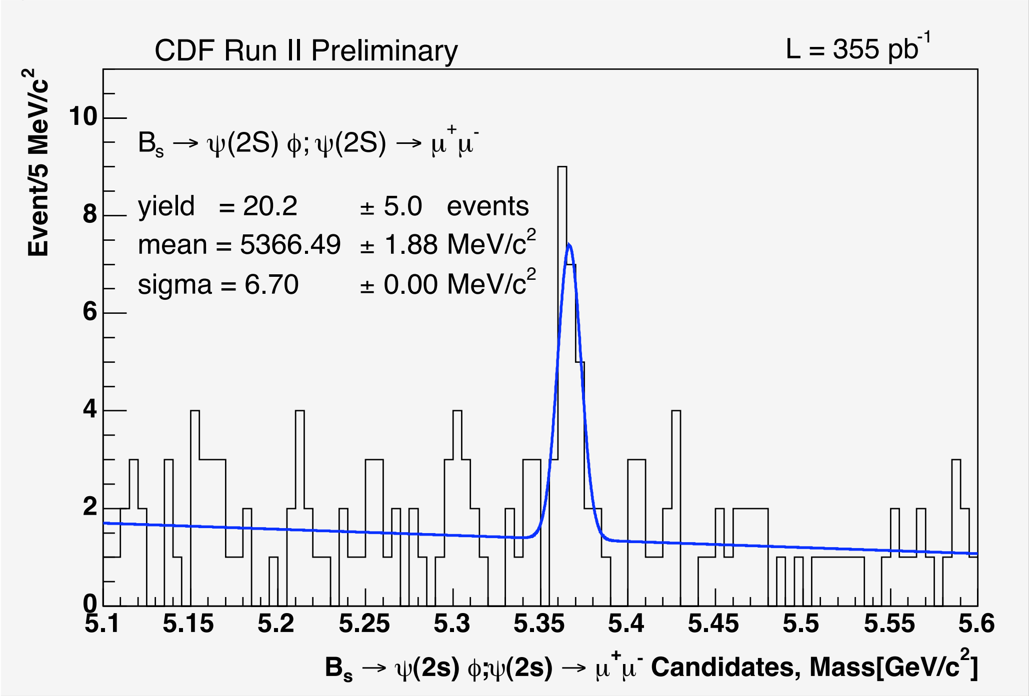
Buchalla, Buras; Misiak, Urban

Observation at Tevatron implies new physics

$B_s \rightarrow \phi\phi$, $\psi(2S)\phi$

Both modes normalized using Bs → J/ψφ





$$\frac{\mathcal{B}(B_s^0 \rightarrow \psi(2S)\phi)}{\mathcal{B}(B_s^0 \rightarrow J/\psi\phi)} = 0.52 \pm 0.13(stat) \pm 0.04(syst) \pm 0.06(BR)$$

$$\mathcal{B}(B_s^0 \rightarrow \phi\phi) = (1.4 \pm 0.6(stat.) \pm 0.2(syst.) \pm 0.5(BR)) \times 10^{-5}$$

12 events in

$\psi(2S) \rightarrow J/\psi\pi^+\pi^-$

$B_s \to \varphi\mu^+\mu^-$ Sensitivity

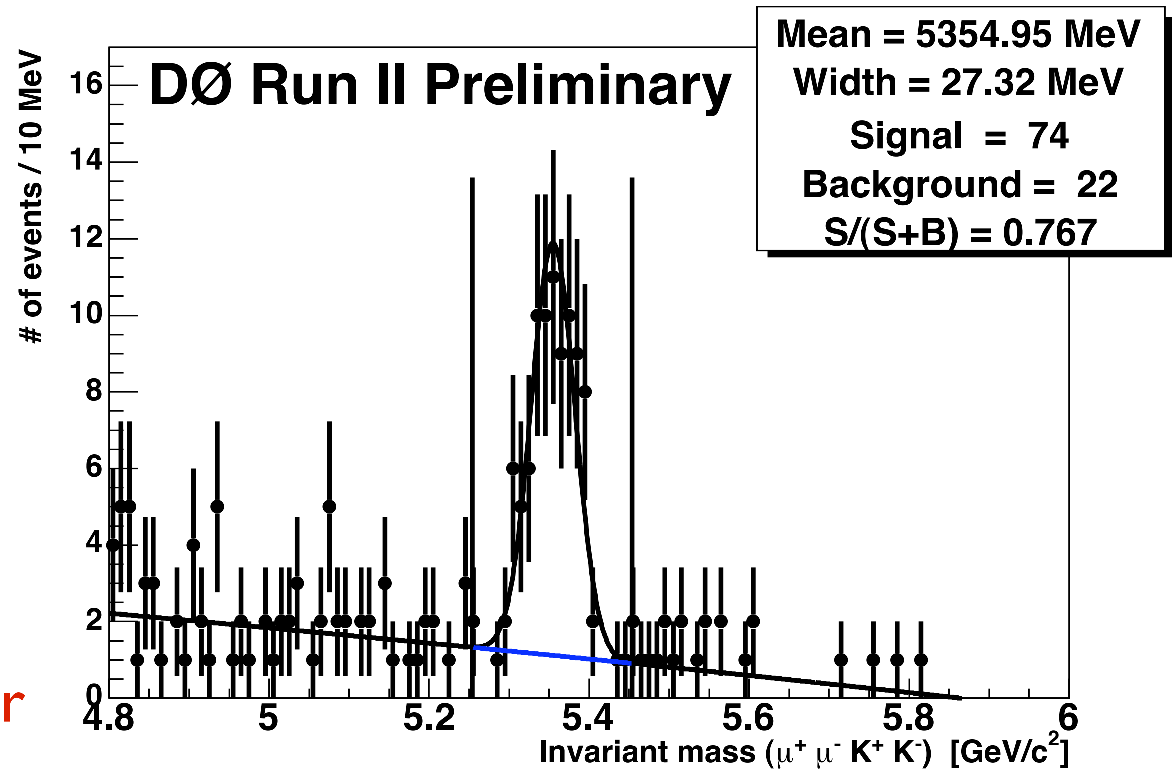
Sensitivity projection

- $B_s \to J/\psi\ \varphi$; $J/\psi \to \mu^+\mu^-$
- 300 pb^{-1} data analyzed

Frank Lehner's talk

D0 sensitivity (95% CL upper limit)

$$\mathcal{B}(B_s^0 \to \phi\mu^+\mu^-) = 1.2 \times 10^{-5}$$

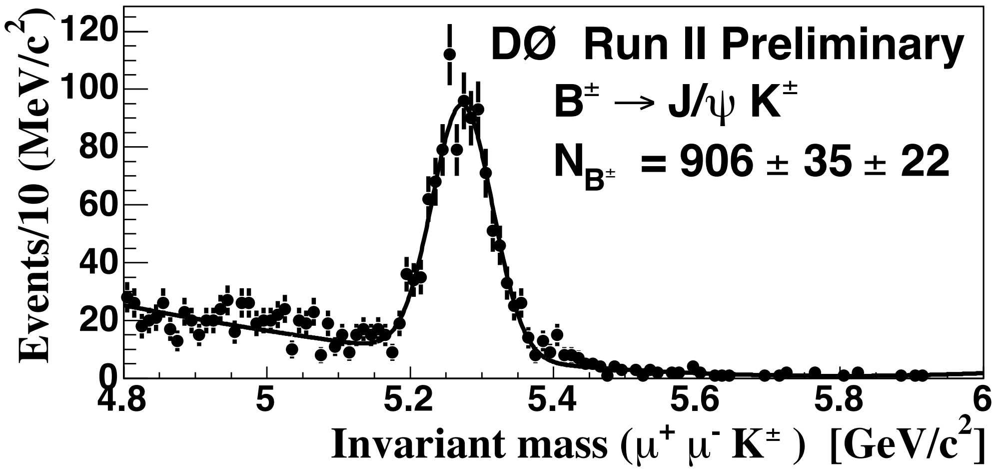


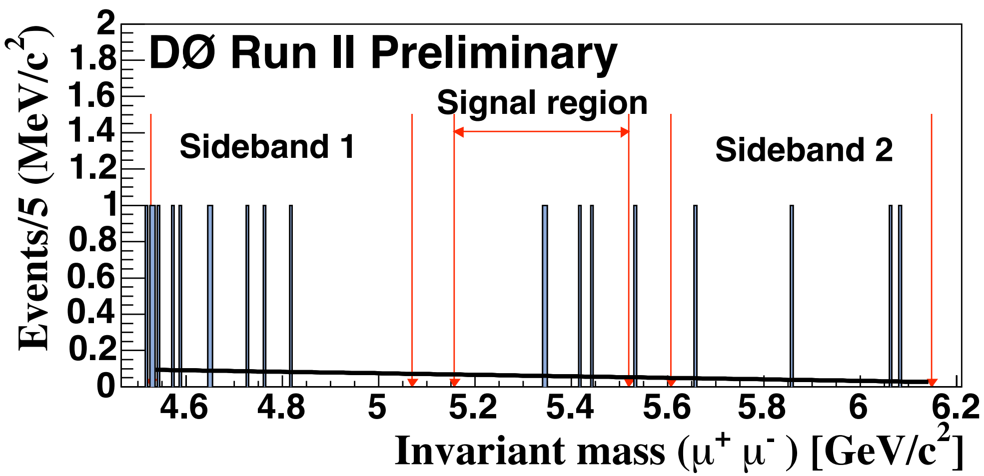
Similar analysis at CDF is underway

Look forward to results in near future.

Rare Decays: $B_s \to \mu^+\mu^-$

300 pb^{-1}

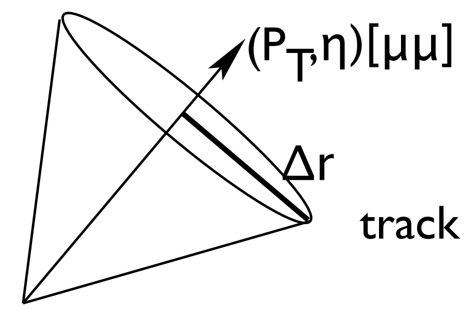




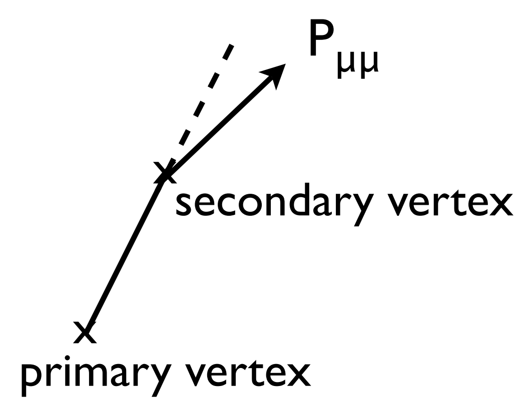
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 3.7 \times 10^{-7} (95\% \text{ CL})$$

Cut based analysis

- o Transverse decay length (Lxy)
- o Isolation $\Delta r = (\Delta P_T^2 + \Delta\eta^2)^{1/2}$



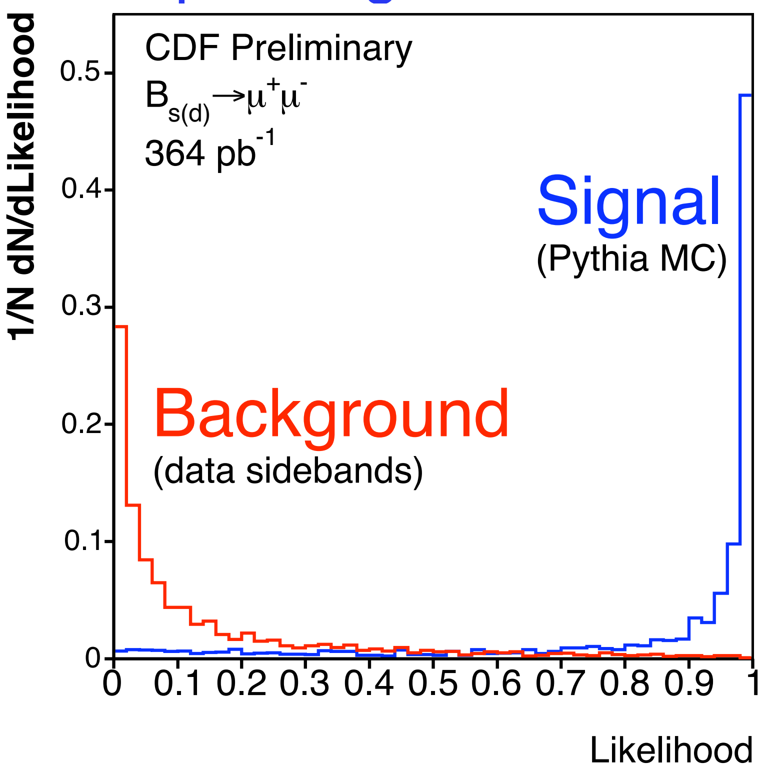
- o Vertex pointing(transverse plane)

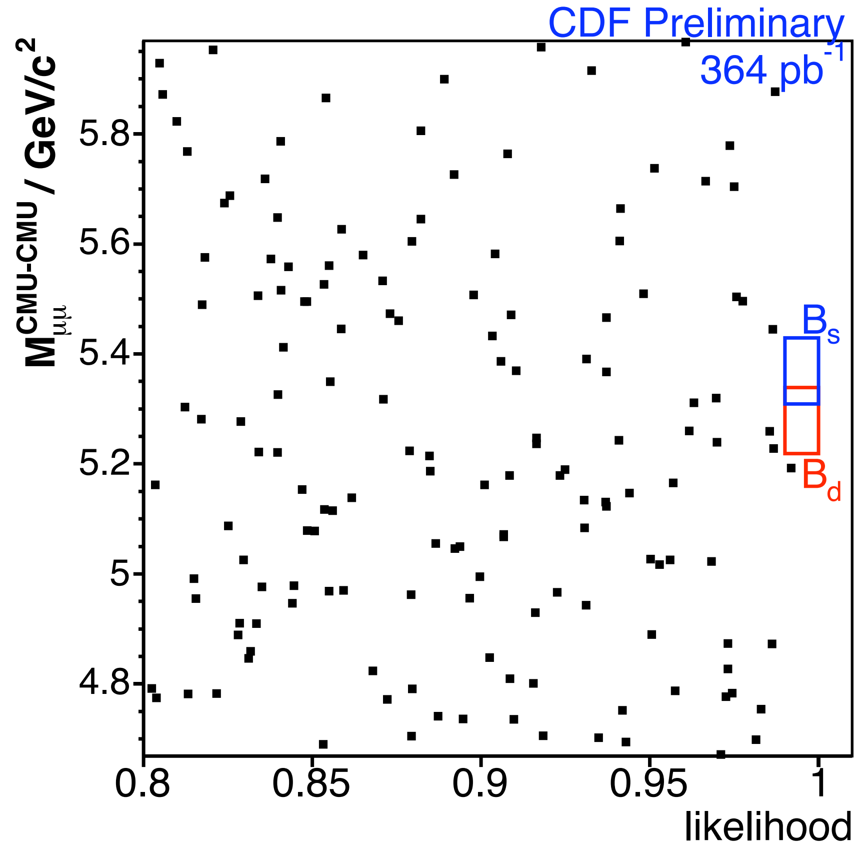


Rare Decays: Bs → μμ

Use discriminating variables to form liklihood.

- transverse decay length
- Isolation
- pointing





$$\mathcal{B}(B^0 \rightarrow \mu^+\mu^-) < 4.9 \times 10^{-8} (95\% \text{ CL})$$

$$\mathcal{B}(B_s^0 \rightarrow \mu^+\mu^-) < 2.0 \times 10^{-7} (95\% \text{ CL})$$

Rare Decays: $B_s \to \mu^+\mu^-$

mSUGRA

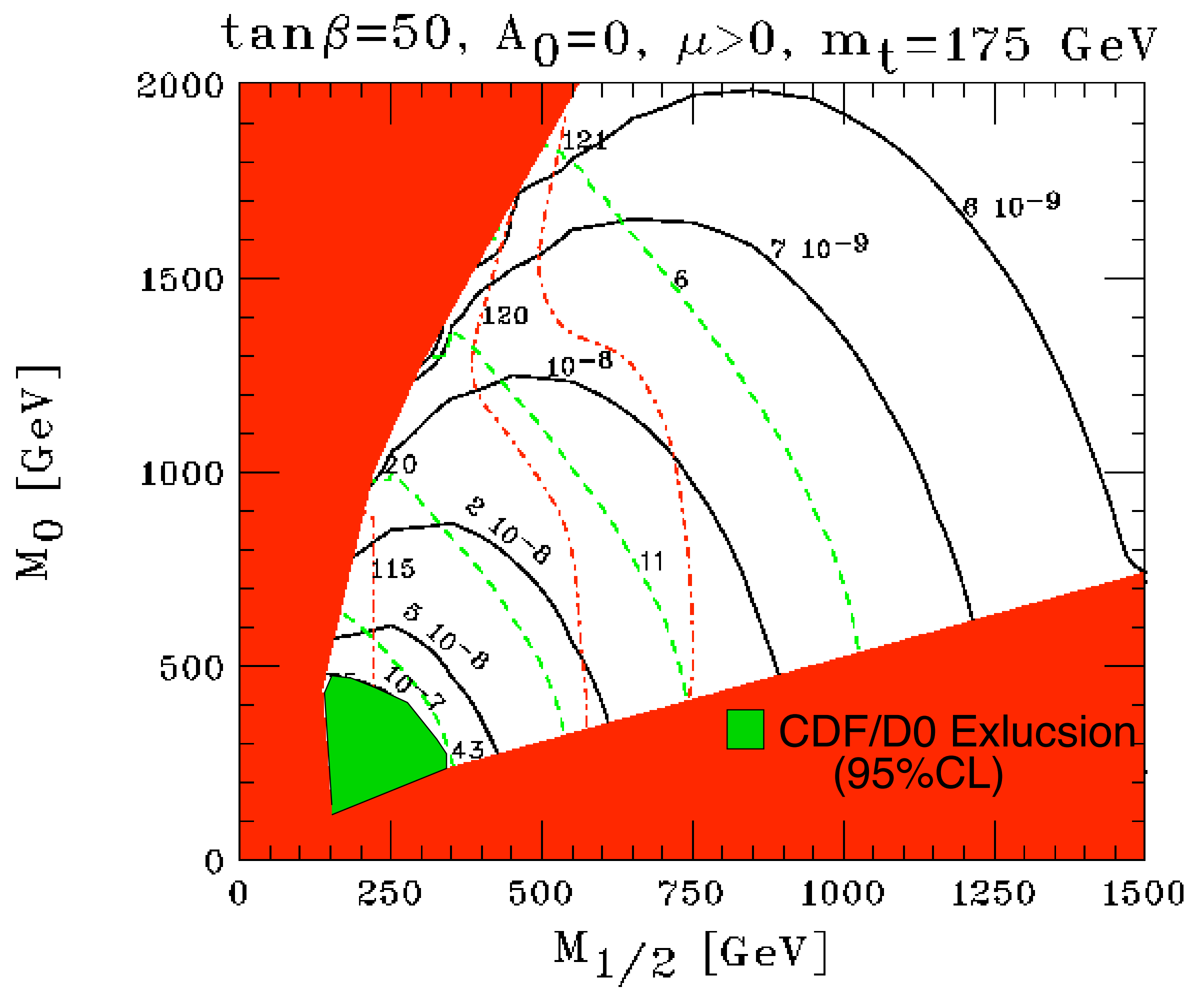
Dedes, Dreiner, Nierste, PRL (2001) 251804

solid red: excluded by theory or previous experiments.

Dashed red line: light higgs mass (m_h)

Dashed green line: SUSY δa_μ (10^{-10} units)

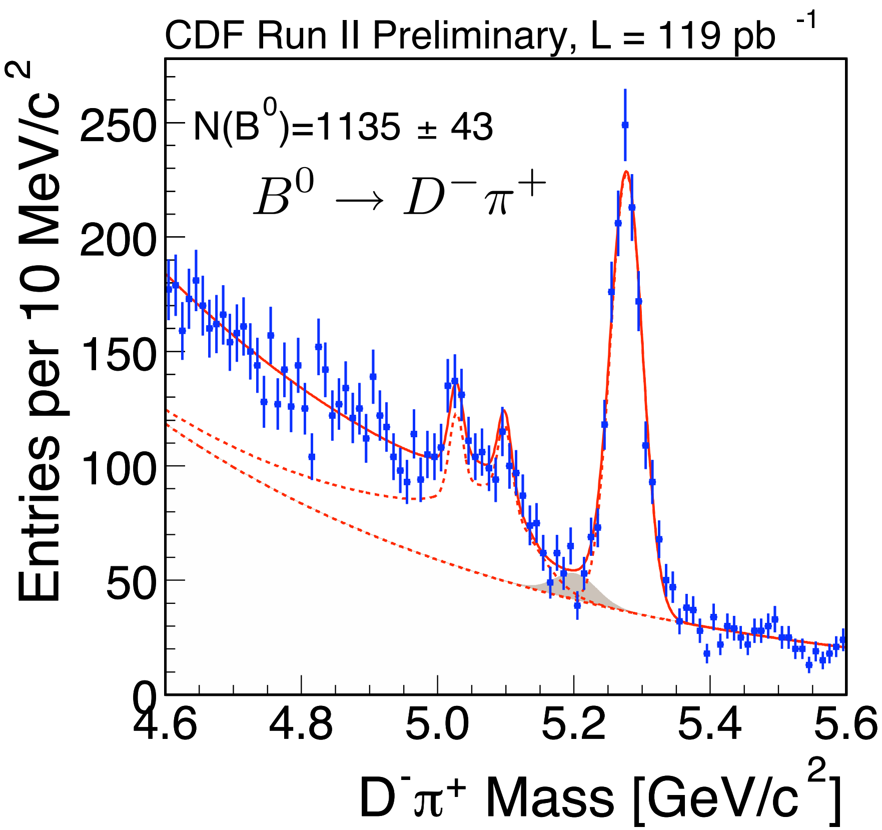
Black Line: $BR(B_s \to \mu\mu)$

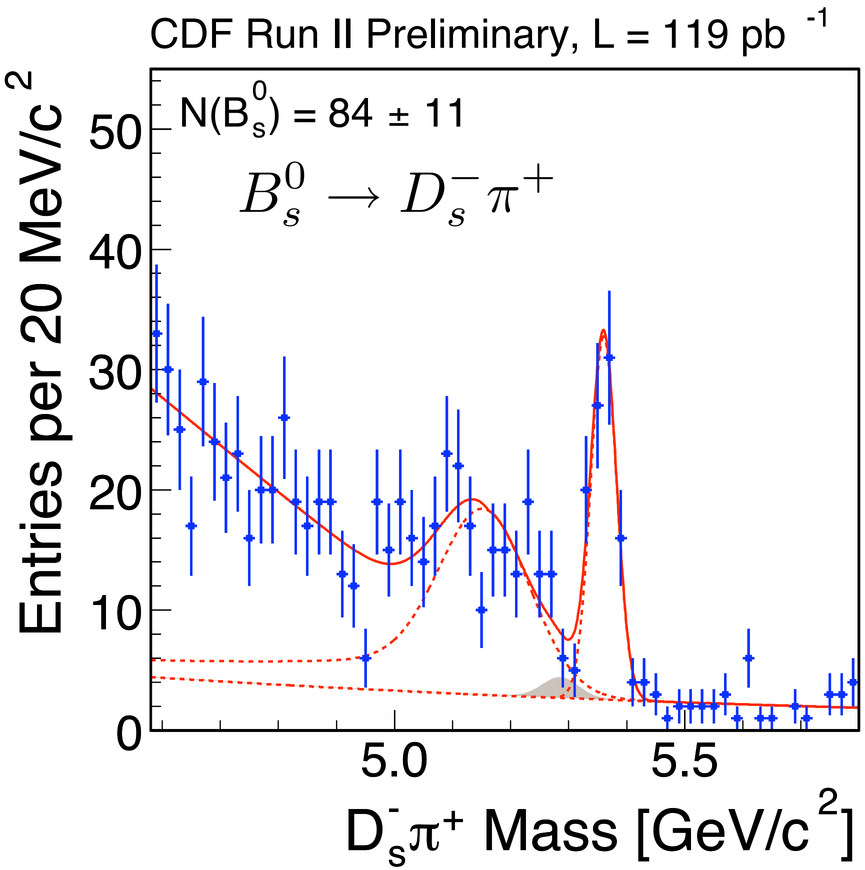


$B_s \to D_s \pi$

B_s mixing "golden mode"

Normalization

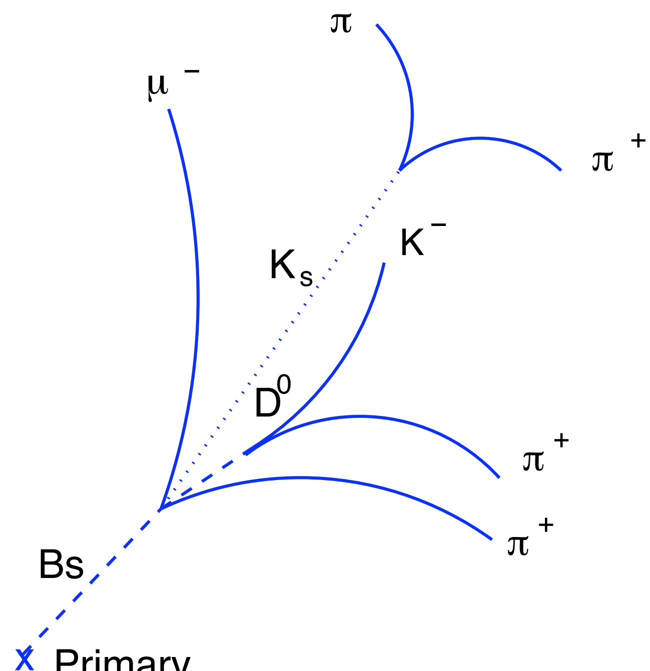




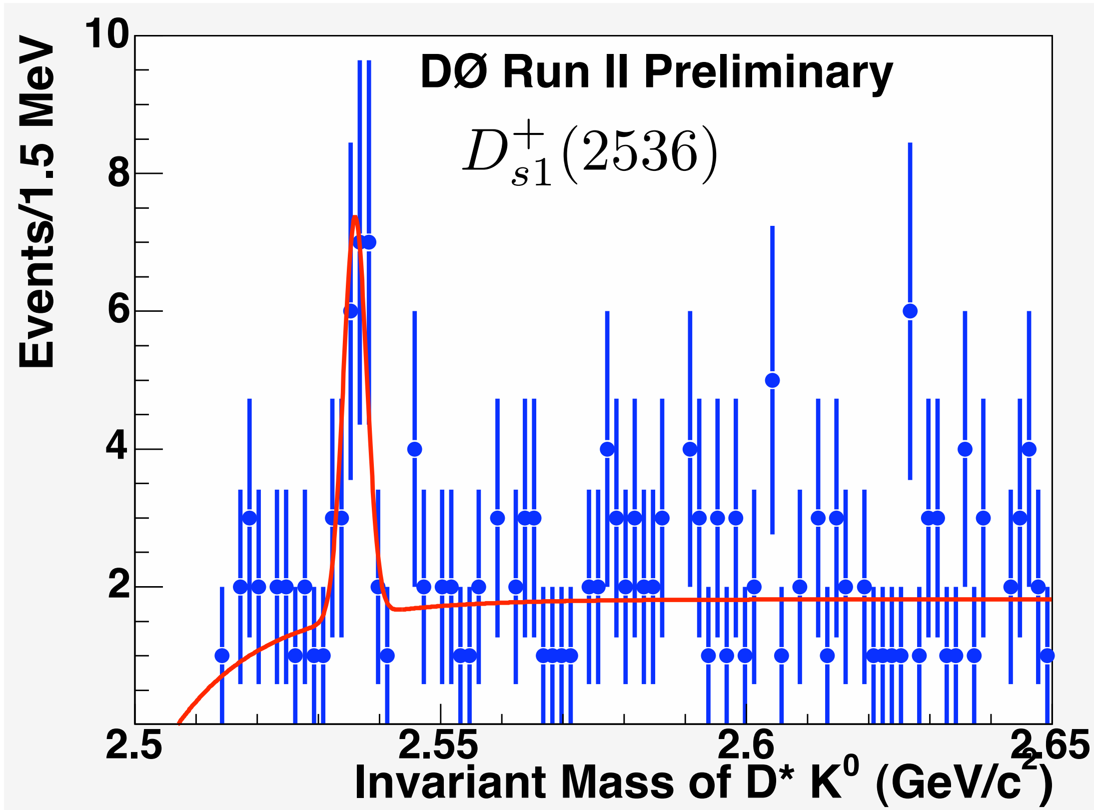
$$\frac{f_d \mathcal{B}(B_s^0 \to D_s^- \pi^+)}{f_s \mathcal{B}(B^0 \to D^- \pi^+)} = 0.35 \pm 0.05(stat.) \pm 0.04(syst.) \pm 0.09(BR)$$

1st Evidence: $B_s \rightarrow D_{s1}^* \mu\nu X$

6 track (complex) final state



$$B_s^0 \rightarrow D_{s1}^+(2536)\mu^-\overline{\nu}_\mu$$
$$\hookrightarrow D^{*+}K_s^0$$
$$\hookrightarrow \pi^+\pi^-$$
$$\hookrightarrow D^0\pi^+$$
$$\hookrightarrow K^-\pi^+$$



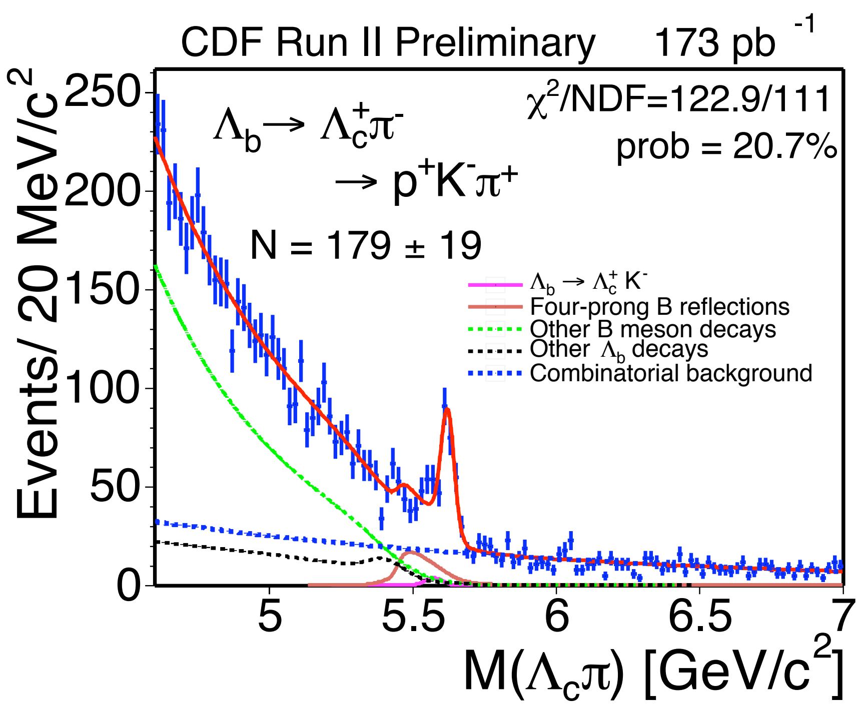
- HQET
- $D_{s1}^+(2536)$ properties

Λ_b Decays

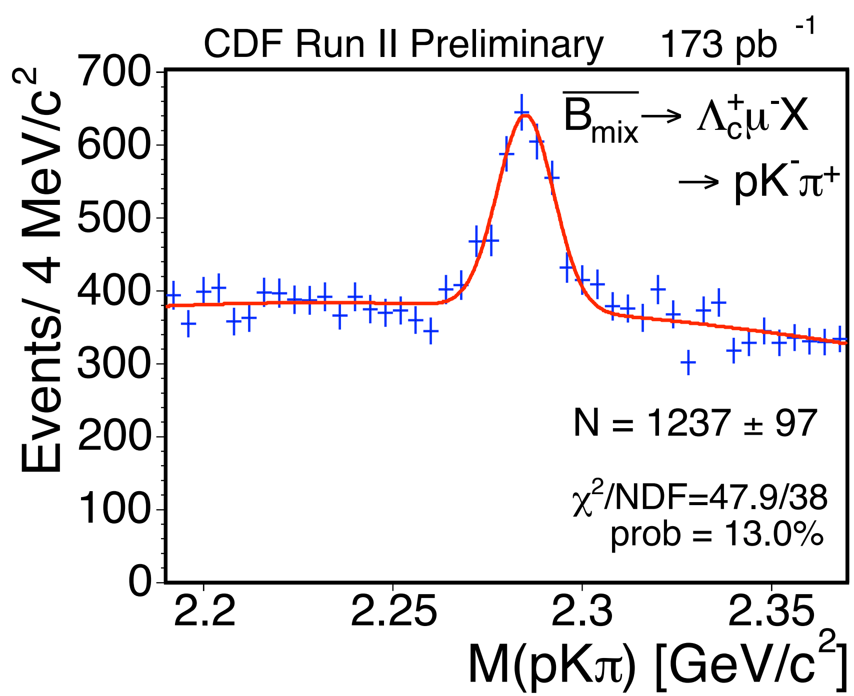
Semileptonic Decay: $\Lambda_b^0 \to \Lambda_c^+ \mu^- \nu$

Goal: Exclusive semileptonic decays!

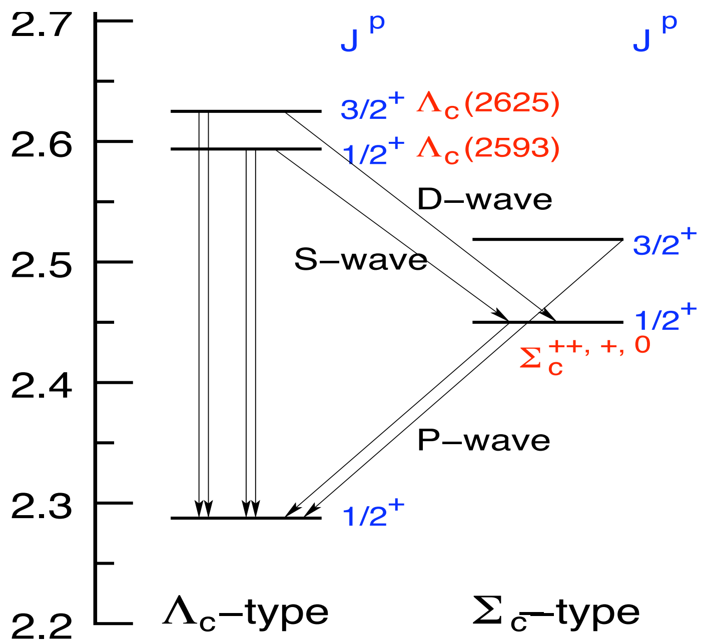
- Can it be done in a hadron collider environment?
- Test HQET
- prelude to other measurements

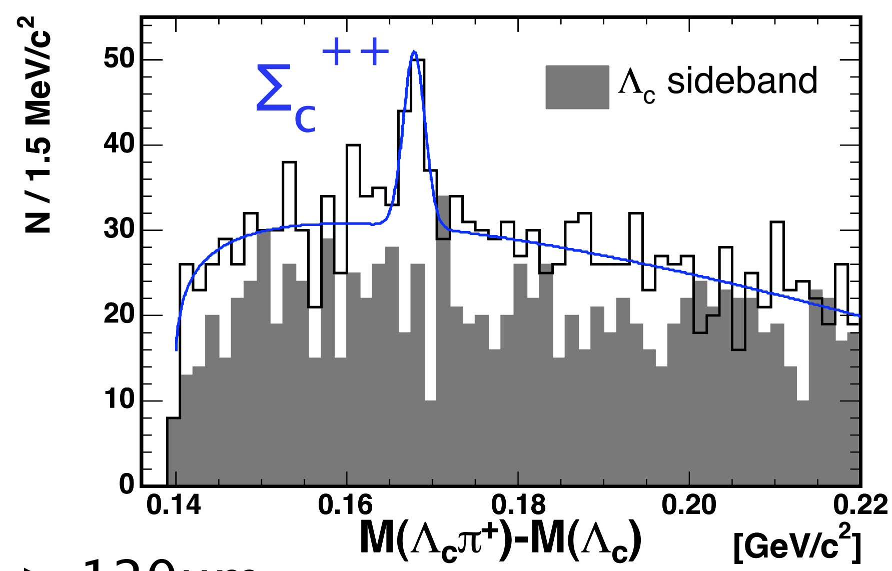


$|d_0|$ (μ) > 120μm

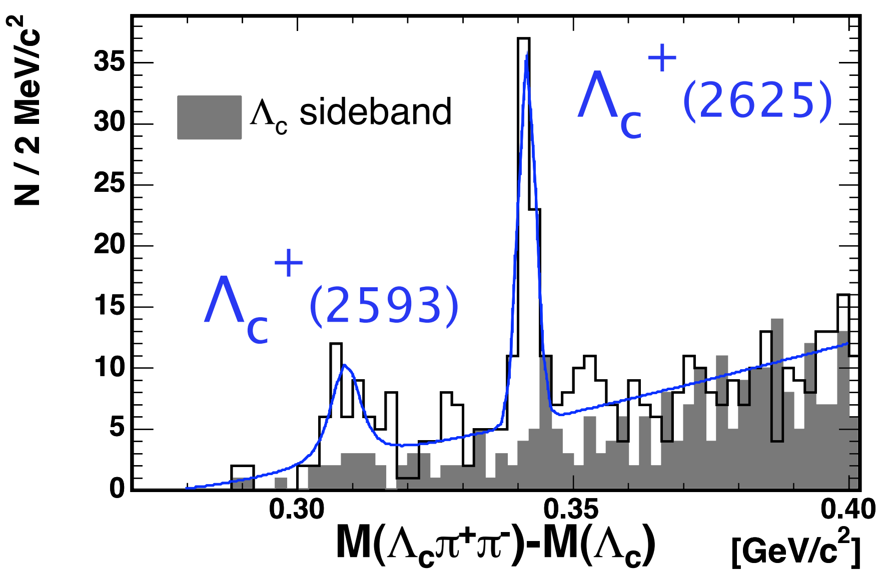


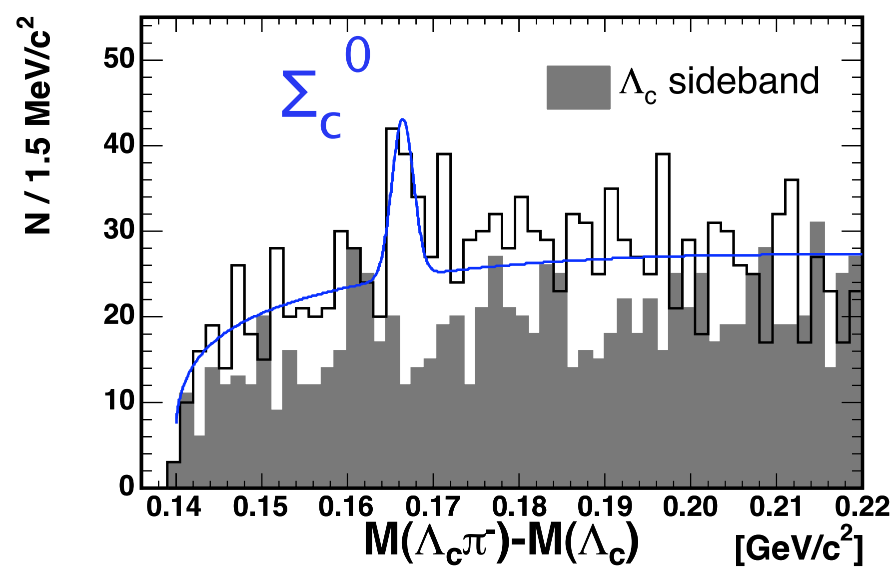
1st Observation: $\Lambda_b^0 \to \Lambda_c^{*+} \mu^- \nu$, $\Sigma_c \pi \mu$





$|d_0|$ (μ) > 120μm





Exclusive semileptonic BR

Subtract backgrounds to get exclusive ratio of BR

$$\frac{\mathcal{B}(B_{semileptonic})}{\mathcal{B}(B_{hadronic})} = \frac{N_{semi.-incl.} - N_{background}}{N_{hadr.}} \cdot \frac{\epsilon_{hadr.}}{\epsilon_{semi.-excl.}}$$

Test method with control samples

8 physics background modes

CDF Preliminary	$\frac{\mathcal{B}(\overline{B}^0 \to D^+\mu^-\overline{\nu}_\mu)}{\mathcal{B}(\overline{B}^0 \to D^+\pi^-)} = 9.8 \pm 1.0(stat.) \pm 0.6(syst.) \pm 0.8(BR) \pm 0.9(UBR)$	
2004 PDG Average	$\frac{\mathcal{B}(\overline{B}^0 \to D^+\mu^-\overline{\nu}_\mu)}{\mathcal{B}(\overline{B}^0 \to D^+\pi^-)} = 7.8 \pm 1.0$	1.2σ

7 physics background modes

CDF Preliminary	$\frac{\mathcal{B}(\overline{B}^0 \to D^{*+}\mu^-\overline{\nu}_\mu)}{\mathcal{B}(\overline{B}^0 \to D^{*+}\pi^-)} = 17.7 \pm 2.3(stat.) \pm 0.6(syst.) \pm 0.4(BR) \pm 1.1(UBR)$	
2004 PDG Average	$\frac{\mathcal{B}(\overline{B}^0 \to D^{*+}\mu^-\overline{\nu}_\mu)}{\mathcal{B}(\overline{B}^0 \to D^{*+}\pi^-)} = 19.7 \pm 1.7$	0.3σ

Signal

5 physics background modes

CDF Preliminary	$\frac{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\mu^-\overline{\nu}_\mu)}{\mathcal{B}(\Lambda_b^0 \to \Lambda_c^+\pi^-)} = 20.0 \pm 3.0(stat.) \pm 1.2(syst.)^{+0.7}_{-2.1}(BR) \pm 0.5(UBR)$

Ratio of Branching Fractions: HQET Test

Experimental Uncertainties:

- Data Sample size (15%)
- External (10%)
  $(BR(\Lambda_c \to pK\pi) + f_{baryon}/f_d)$

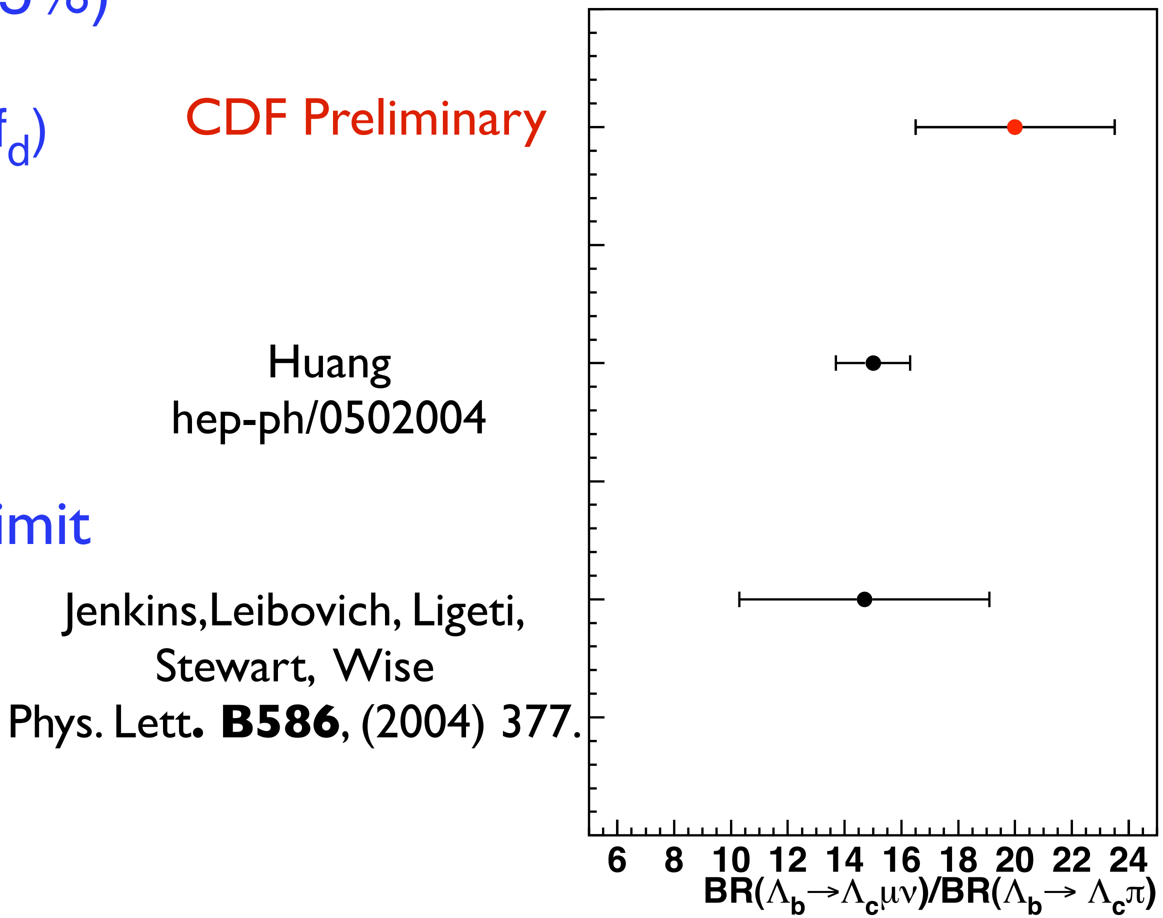
Theory:

Huang: QCD Sum rule

Jenkins, *et al.*: Large Nc limit

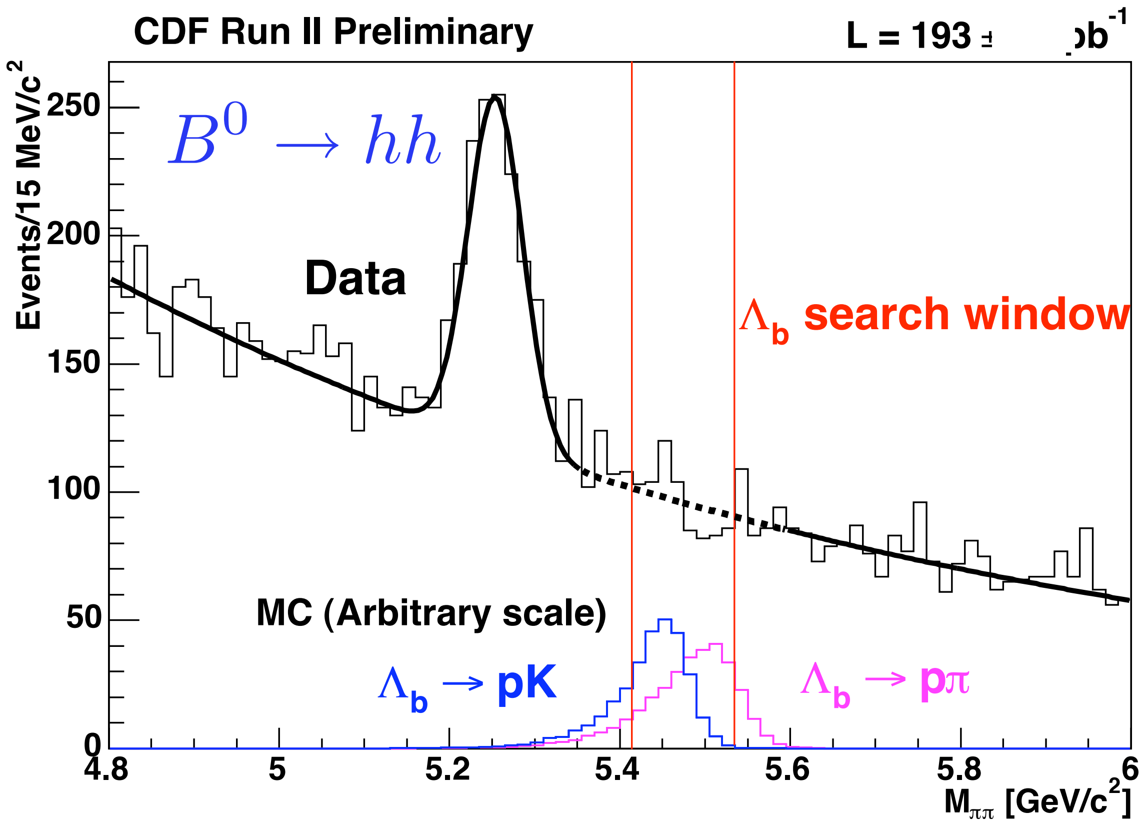
Future:

- Form factors
- Polarization
- $|V_{cb}|$



$\Lambda_b \to hh$ (pK^-, $p\pi^-$)

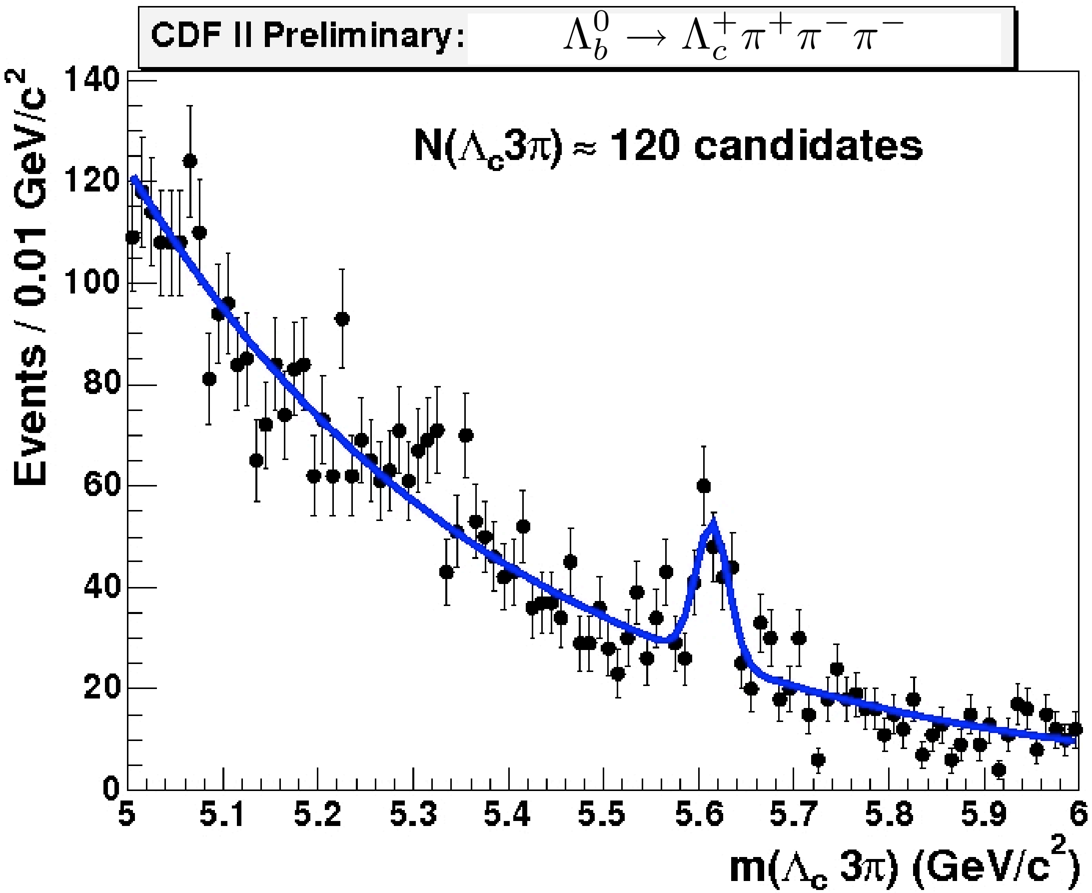
- Expect large CP asymmetry (10-20%)



$$\mathcal{B}(\Lambda_b^0 \to h^+h^-) < 2.2 \times 10^{-5} \text{ (90\% C.L.)}$$

1st Observation: $\Lambda_b \to \Lambda_c^+ \pi^+ \pi^- \pi^-$

- Expect rich resonance structure (Λ_c^*, $\Sigma_c^{++, +, 0}$)
- Study charm baryons



Summary

B_s Decays:

- Observation and BR for 3 decays
  $\varphi\varphi$, $\Psi(2S)\varphi$, $D_s\pi$
- Limits on SUSY mSUGRA ($B_s \rightarrow \mu\mu$)
- Observation of new semileptonic decay ($B_s \rightarrow D_{s1}\ \mu\nu X$)

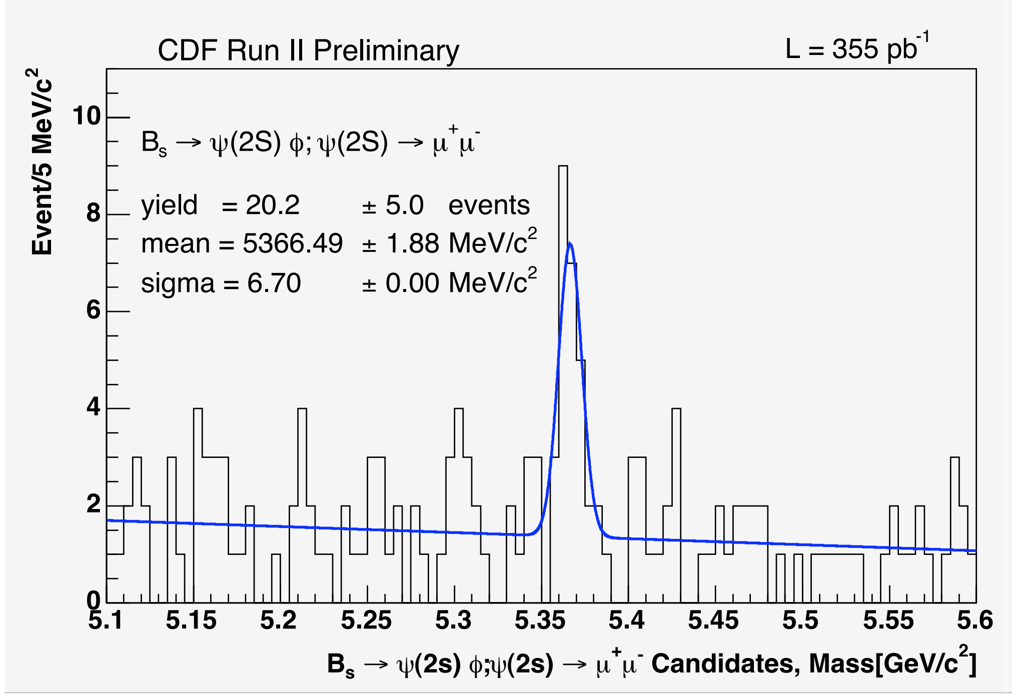
Λ_b Decays:

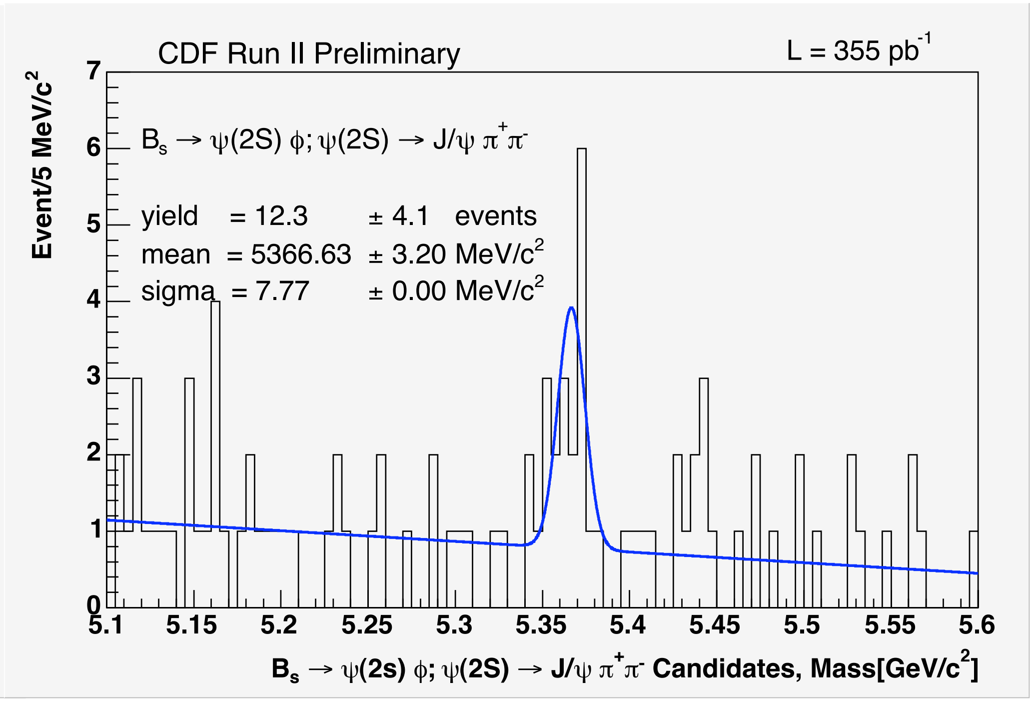
- Observation of 5 new decay modes
  $\Lambda_c^*(2593)\mu\nu$, $\Lambda_c^*(2625)\mu\nu$, $\Sigma_c^{++}\mu\nu$, $\Sigma_c^{0}\mu\nu$, $\Lambda_c 3\pi$
- Exclusive semileptonic BR
- Upper limit for BR rare decay ($\Lambda_b \rightarrow hh$)

Just the beginning...

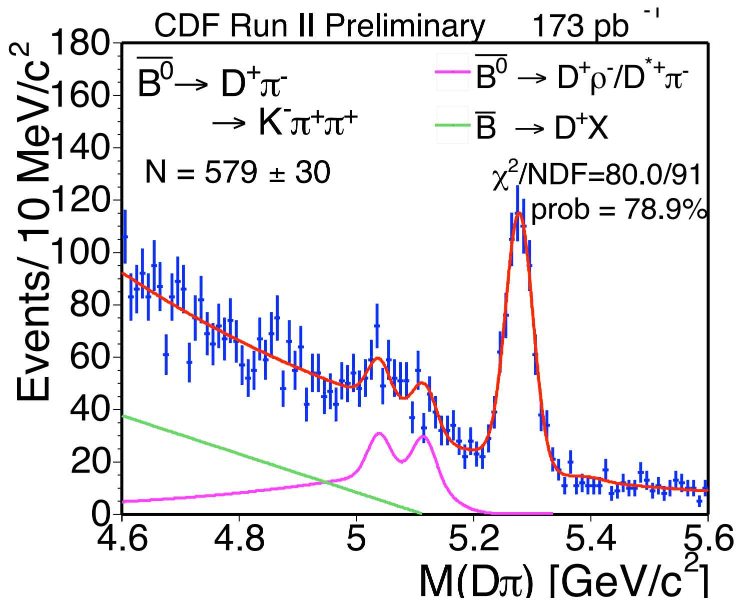
Backup Slides

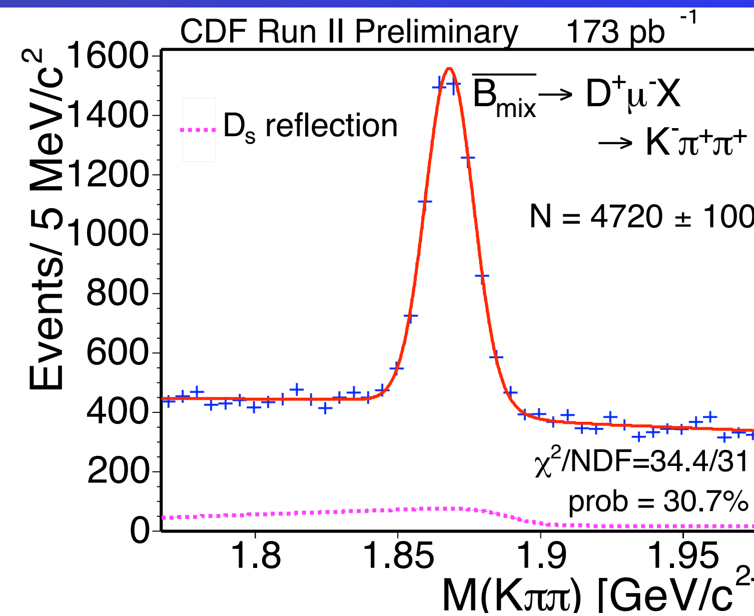
$B_s \rightarrow \psi(2S)\ \varphi$

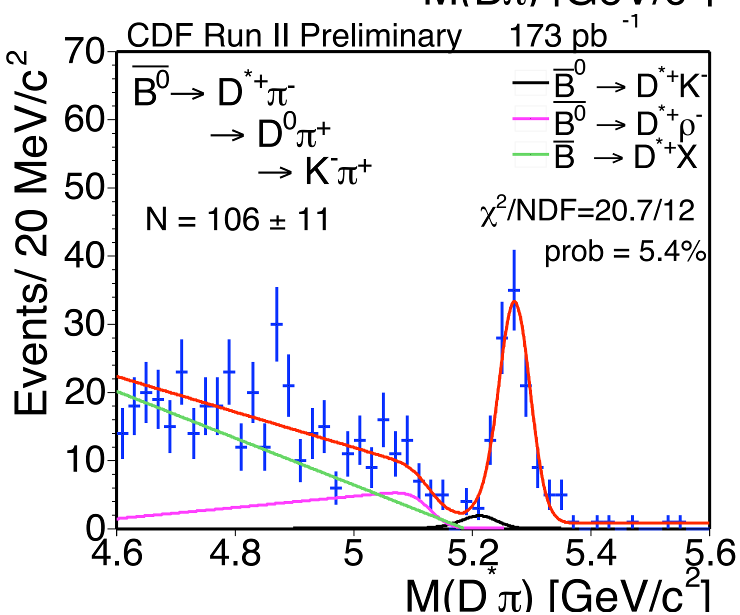


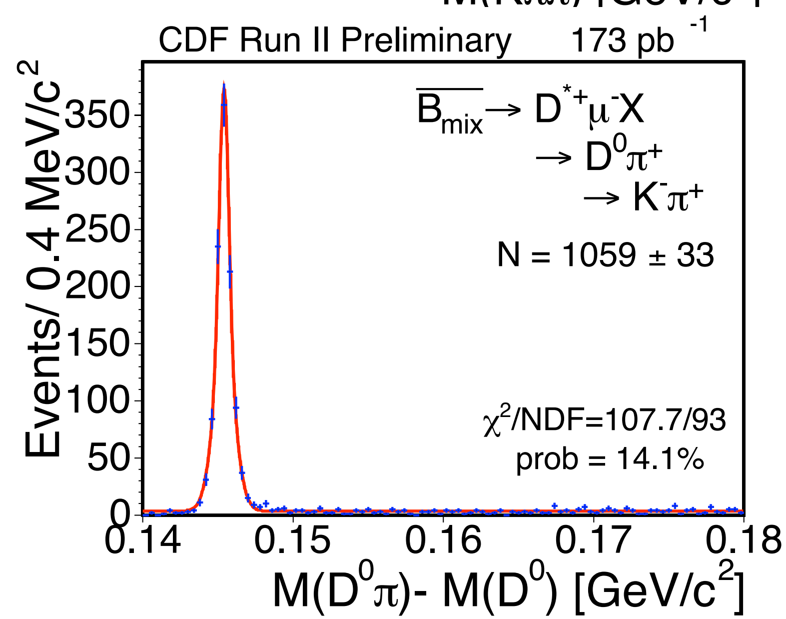


$B^0 \rightarrow D^{(*)} \mu\nu$

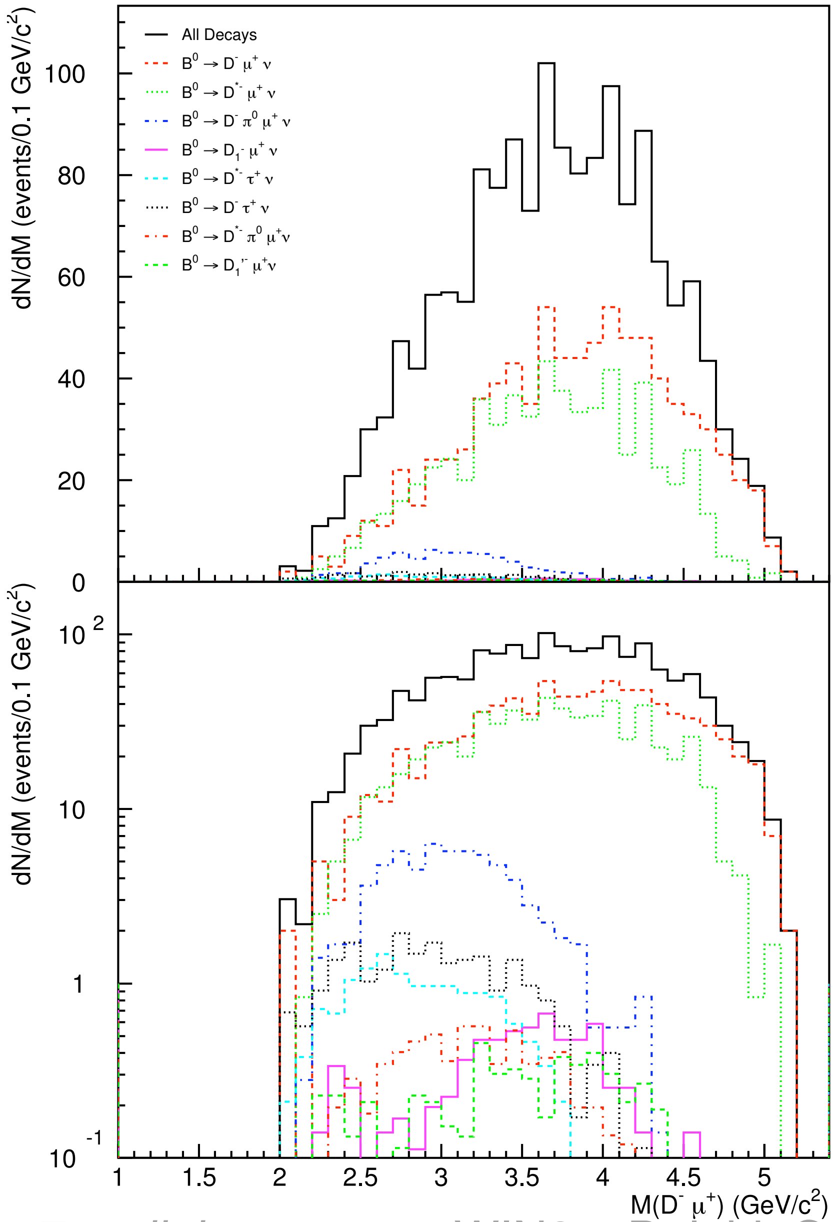








B^0, Λ_b backgrounds



B^0, Λ_b backgrounds