CDF Run II 実験の現状報告 1

電弱相互作用，Bの物理

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CDF collaboration

2003年9月10日

日本物理学会

アウトライン

１．はじめに

　１．１．**TEVATRON**

　１．２．**CDF**

２．電弱相互作用

　２．１．$W / Z \to \ell\ell$

　２．２．$W / Z\gamma$

　２．３．WW

３．**B** の物理

　３．１．寿　命

　３．２．質　量

　３．３．分岐比

４．まとめ

1. はじめに

1. 1. Tevatron

Main Injector

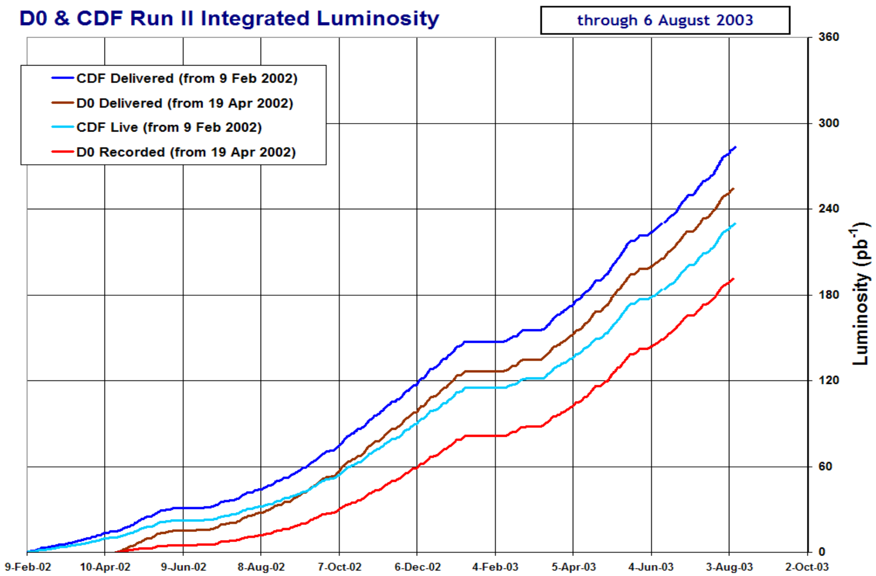
反陽子生成率の向上

ビーム強度の増加

Recycler

反陽子の再利用

今後



Run IIa

２００１年３月より稼動

6×6@900GeV ⇒ 36×36@980GeV

$5.2\times10^{31}cm^{-2}\,sec^{-1}$　2003年８月１１日

$(4.1\times10^{31}cm^{-2}\,sec^{-1}$　2003年３月　春の学会)

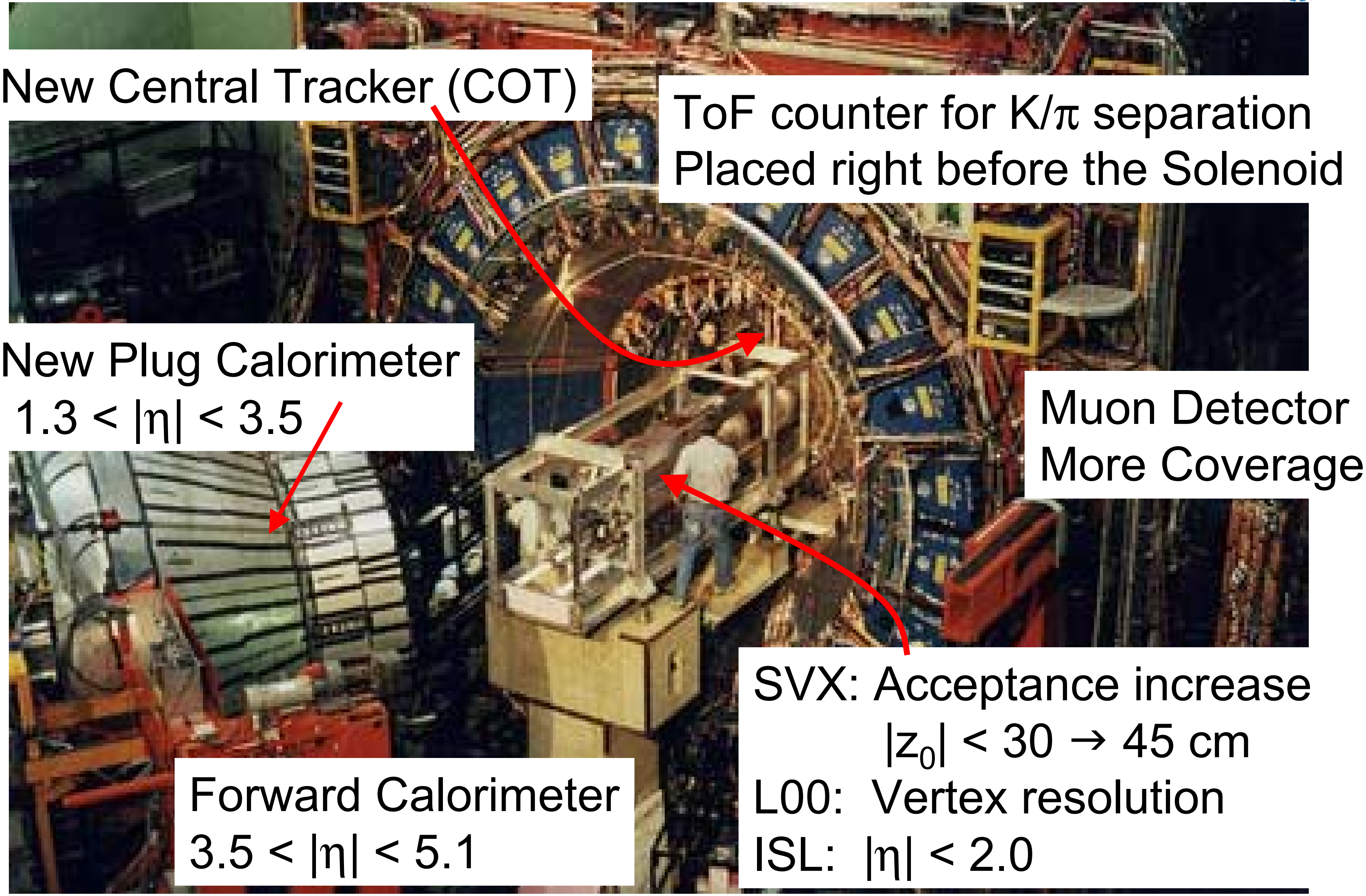
$(1.6\times10^{31}cm^{-2}\,sec^{-1}$　Run 1b)

$300pb^{-1}$　Delivered

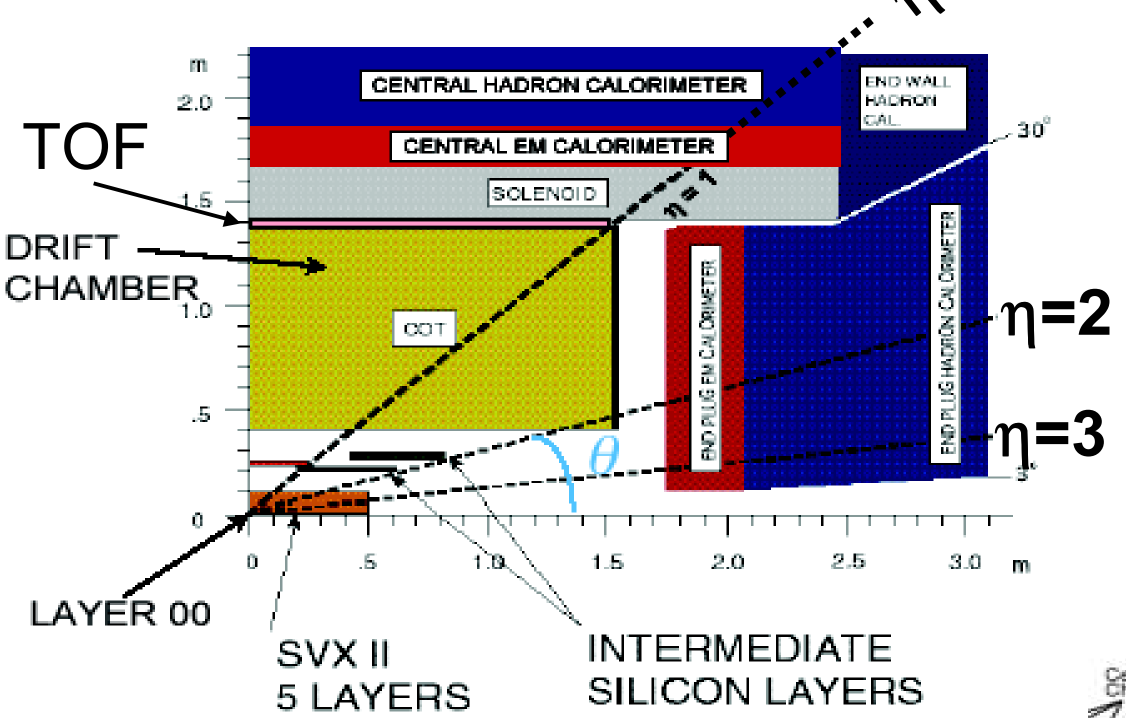
$250pb^{-1}$　On Tape

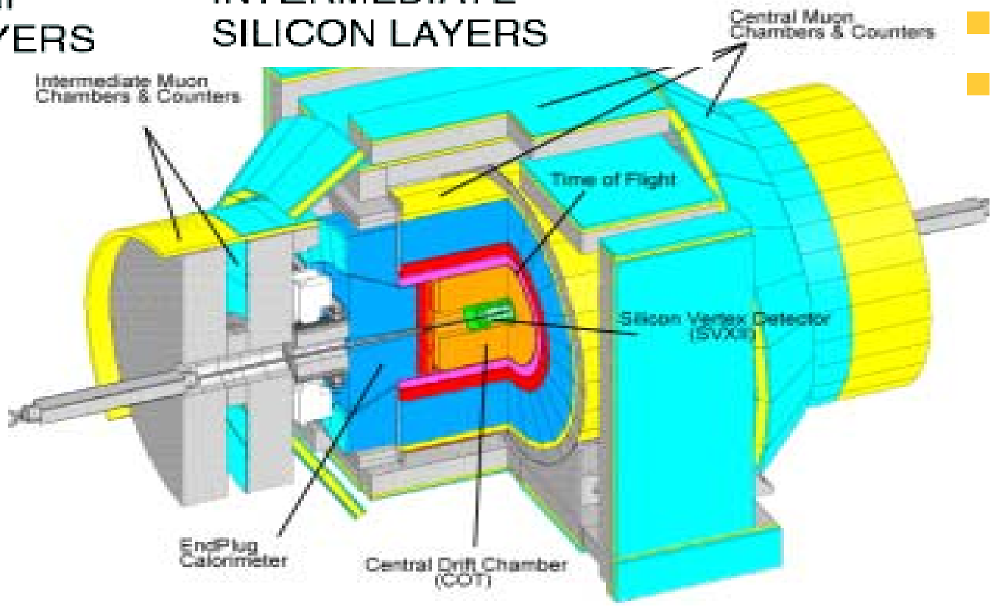
$130pb^{-1}$　Analysis

1.2. CDF(その1)
CDF Detector Overview



1.2. CDF(その2)

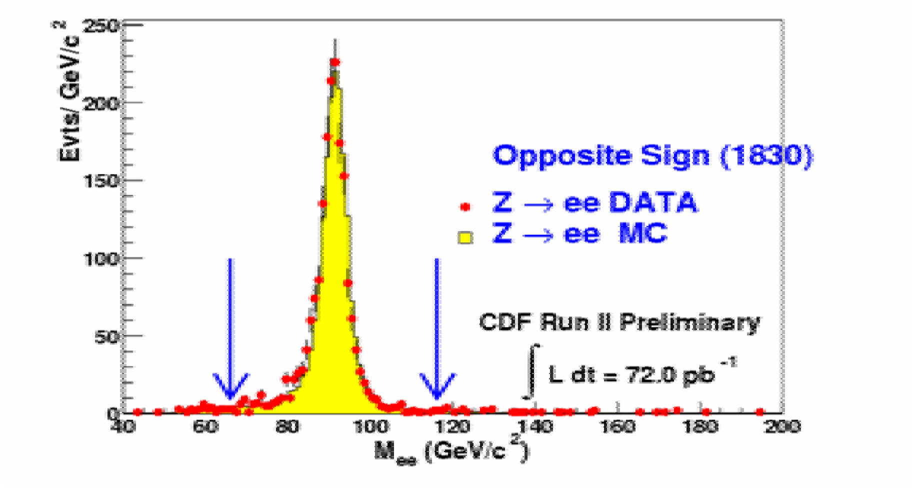


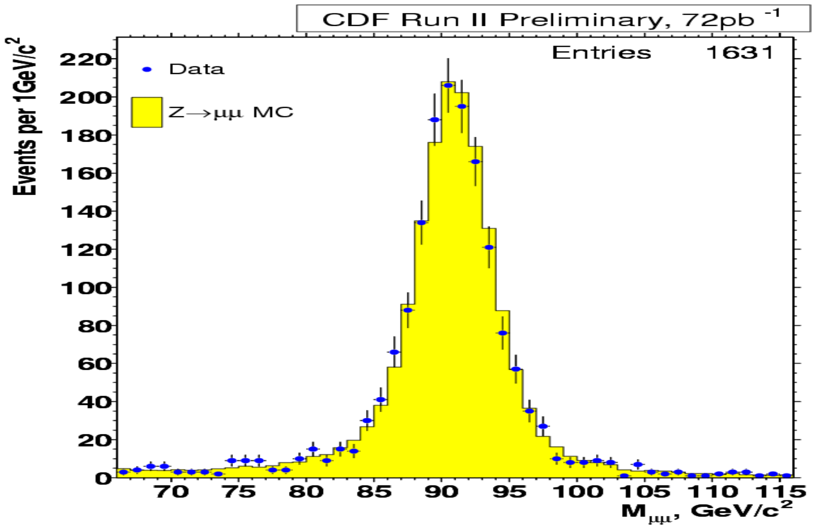


- Improved Si coverage
  - |η| < 2
  - 8 layers
- Central Drift Chamber
  - 96 layers
- Time of Flight
- Expanded μ coverage
- Forward Calorimeter
- Trigger
  - COT tracks at L1
  - Silicon tracks at L2

2. 電弱相互作用

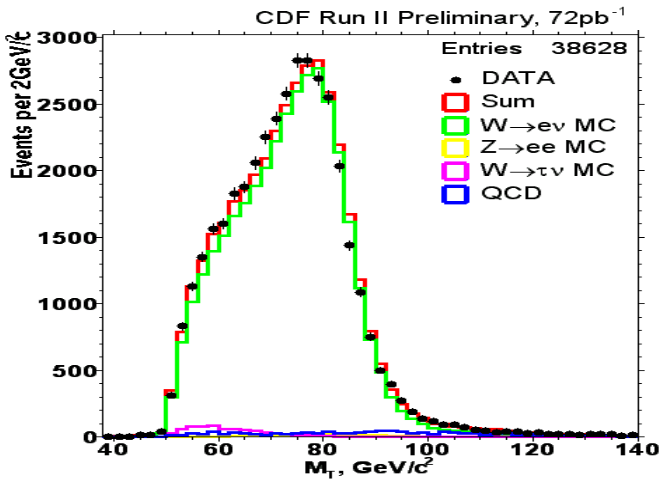
2.1. $W/Z \to \ell\ell$(その1)

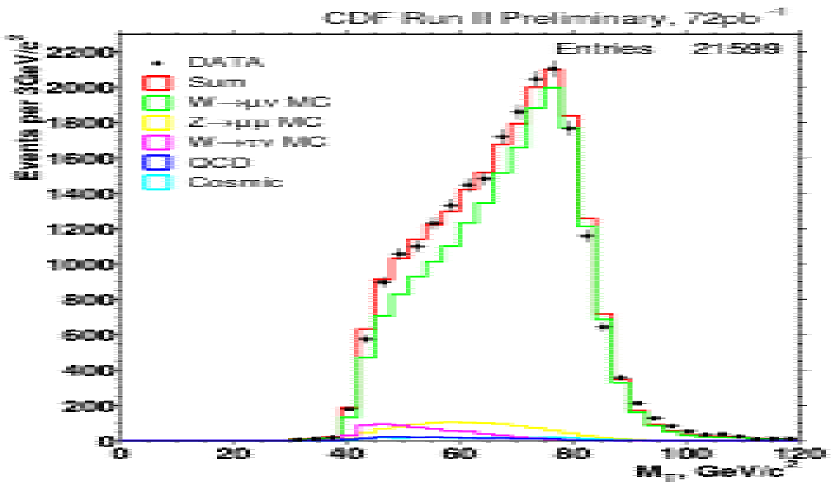




$\sigma_Z \cdot Br(Z \to e^+e^-) = 267.0 \pm 6.3 \pm 15.2 \pm 16.0$ pb
stat. syst. lumi.

$\sigma_Z \cdot Br(Z \to \mu^+\mu^-) = 246 \pm 6 \pm 12 \pm 15$ pb
stat. syst. lumi.





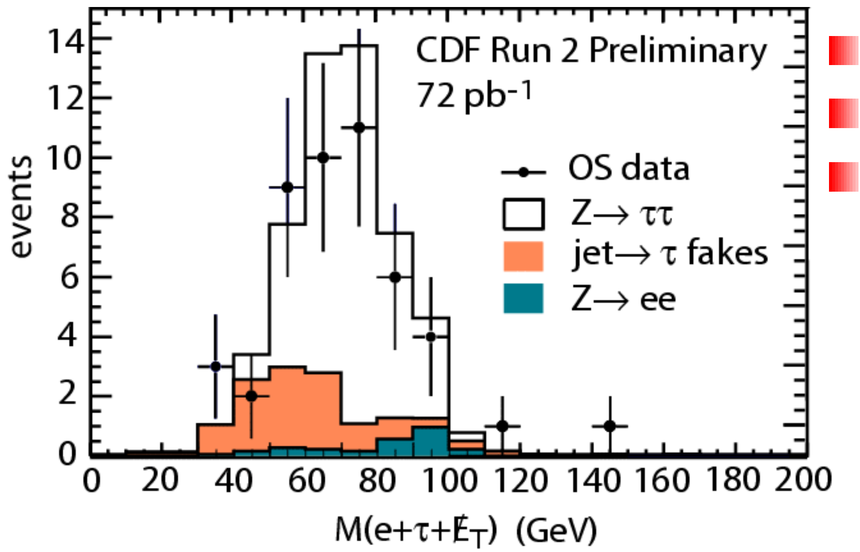
$\sigma_W \cdot Br(W \to e\nu) = 2.64 \pm 0.01 \pm 0.09 \pm 0.16$ nb
stat. syst. lumi.

$\sigma_W \cdot B(W \to \mu\nu) = 2.64 \pm 0.02 \pm 0.12 \pm 0.16$ nb
stat syst lum

2.1. $W/Z \to \ell\ell$ (その2)

$Z^0 \to \tau_e \tau_h$

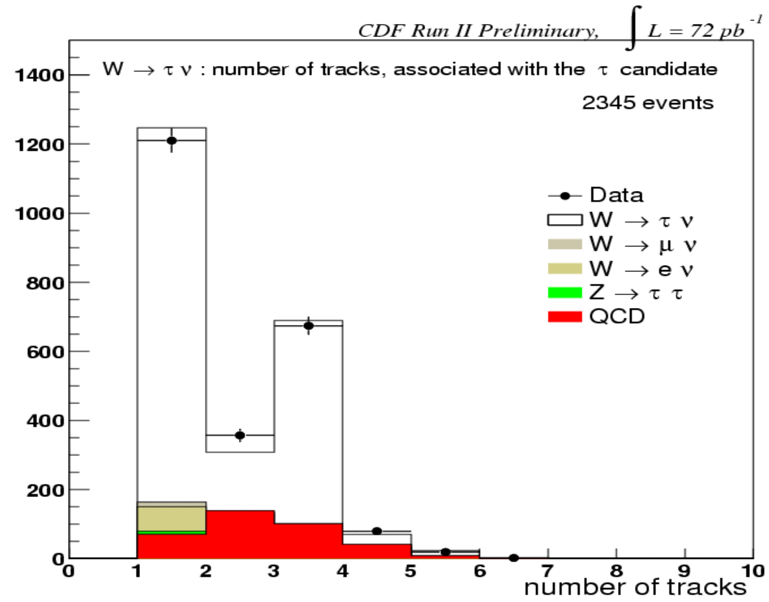
- We have a clear $Z^0 \to \tau_e \tau_h$ signal.
- Further study of backgrounds is underway.



Not only interesting as an EWK measurement, it is important for Higgs and SUSYsearches.

W→ τ ν

- Look for jet within narrow 10 degree cone
- Isolated within wider 30 degree cone
- $p_T(\tau)$ > 25 GeV
- E_T^{miss} > 25 GeV
- N_{cand} = 2345

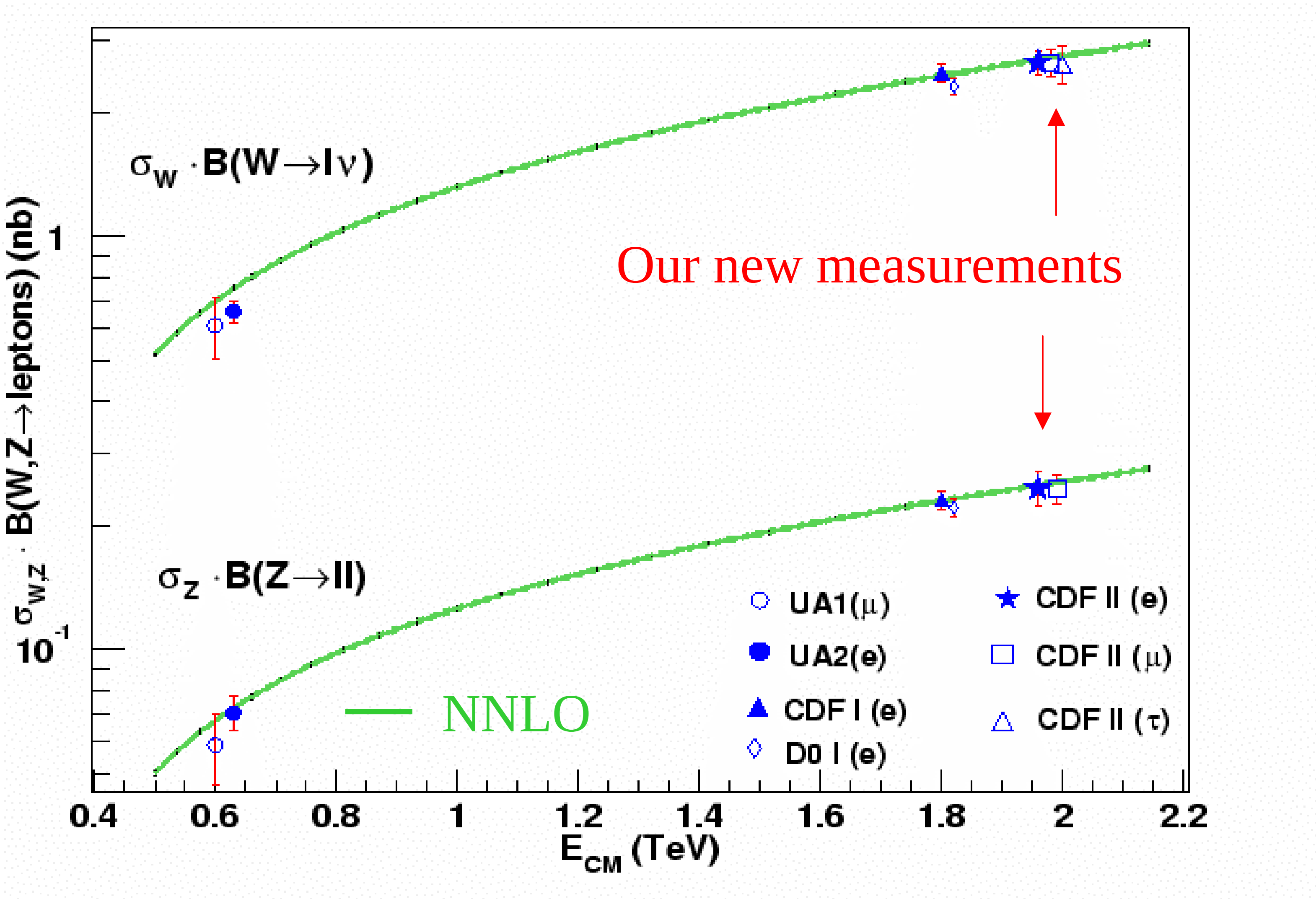


$\sigma_W \cdot Br(W \to \tau\nu) = 2.62 \pm 0.07 \pm 0.21 \pm 0.16$ nb

stat. syst. lumi.

2.1. $W/Z \to \ell\ell$ (その3)

W & Z Cross Sections vs. E_{CM}

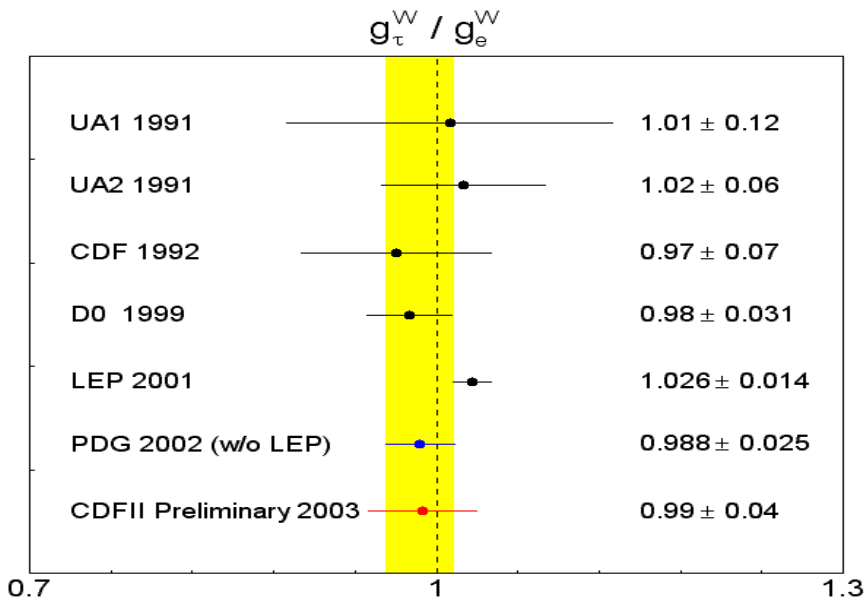


2.1. $W/Z \to \ell\ell$ (その4)
Lepton Universality in W Decay

τ -e

$$\frac{\mathrm{BR}(W \to \tau\nu)}{\mathrm{BR}(W \to e\nu)} = 0.99 \pm 0.04_{\mathrm{stat}} \pm 0.07_{\mathrm{syst}}$$

$$\frac{g_\tau}{g_e} = 0.99 \pm 0.02_{\mathrm{stat}} \pm 0.04_{\mathrm{sys}}$$



μ -e

$$U = \frac{\Gamma(W \to \mu\nu)}{\Gamma(W \to e\nu)}$$

$$= \frac{(N_{W\mu} - B_{W\mu})(N_{Ze} - B_{Ze})}{(N_{We} - B_{We})(N_{Z\mu} - B_{Z\mu})} \times \frac{A_{We} A_{Z\mu}}{A_{W\mu} A_{Ze}} \times \frac{\varepsilon_{Z\mu} \varepsilon_{We}}{\varepsilon_{W\mu} \varepsilon_{Ze}}$$

$N_{W\mu}$ = Number of $W \to \mu\nu$ candidates

$B_{W\mu}$ = Number of $W \to \mu\nu$ background events

$A_{W\mu}$ = Acceptance for $W \to \mu\nu$

$\varepsilon_{W\mu}$ = Efficiency for $W \to \mu\nu$

$$= 1.082 \pm 0.039 \pm 0.050$$

$$R = \frac{\sigma(pp \to W)}{\sigma(pp \to Z)} \; \frac{\Gamma(Z)}{\Gamma(Z \to ll)} \; \frac{\Gamma(W \to l\nu_l)}{\Gamma(W)}$$

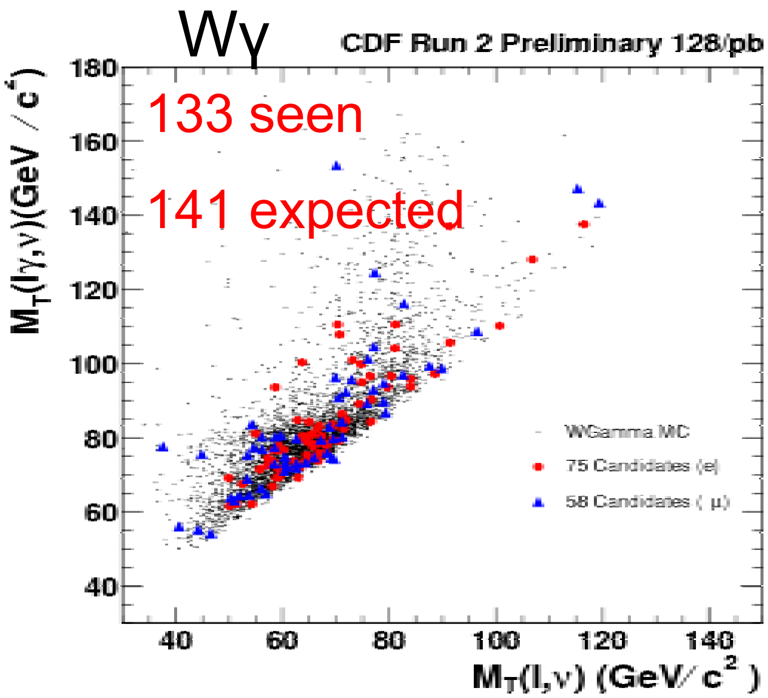
2.2. W/ Zγ (その1)

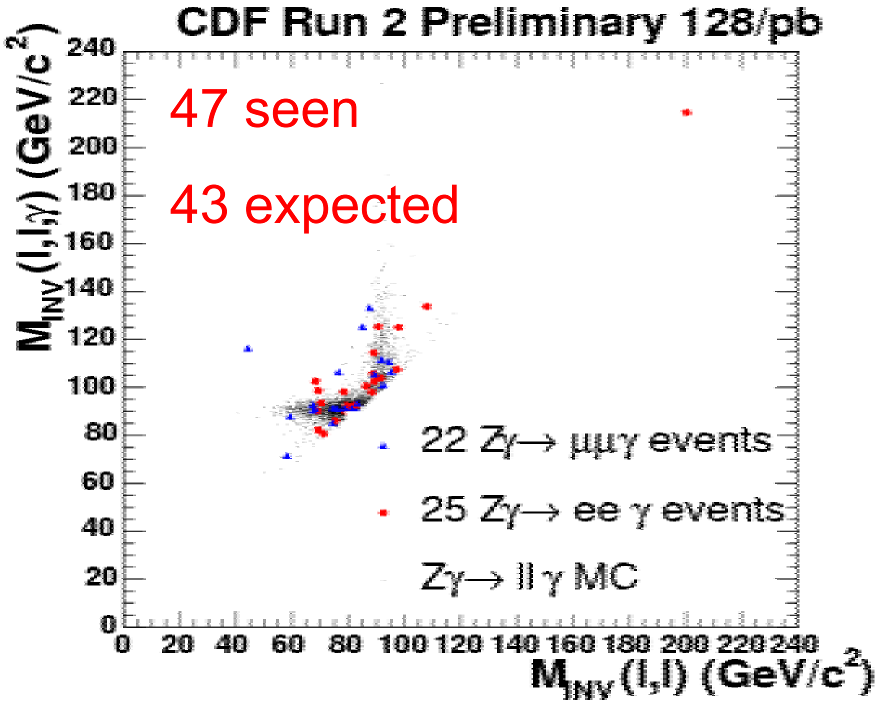
10aSE 岡山大 谷本

Study of Wγ production with W→μν at CDF in Run II

- Require central γ
- $E_T(\gamma) > 7$ GeV
- $\Delta R(l\text{-}\gamma) = \sqrt{(\Delta\eta^2+\Delta\Phi^2)} > 0.7$

Zγ



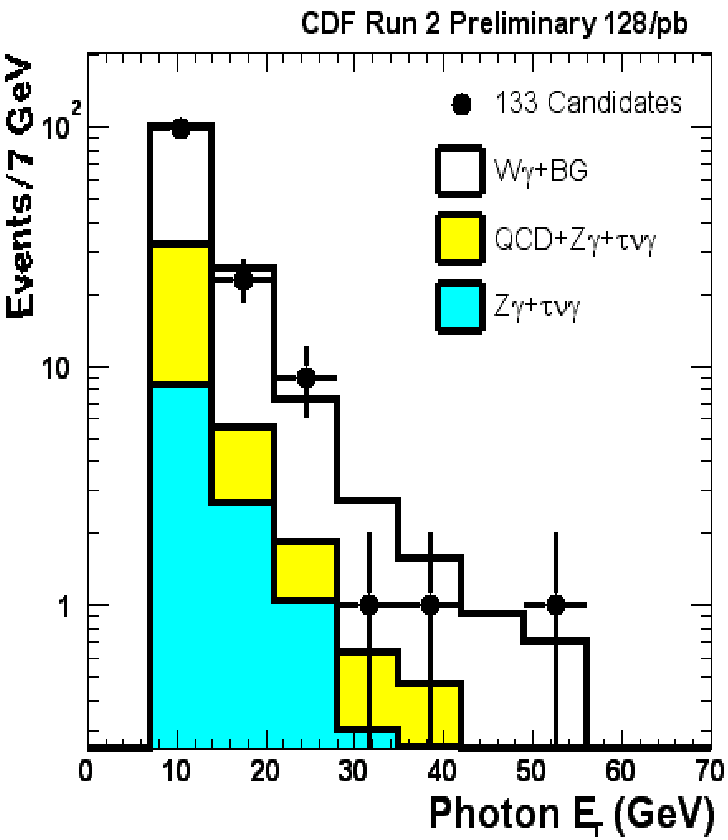


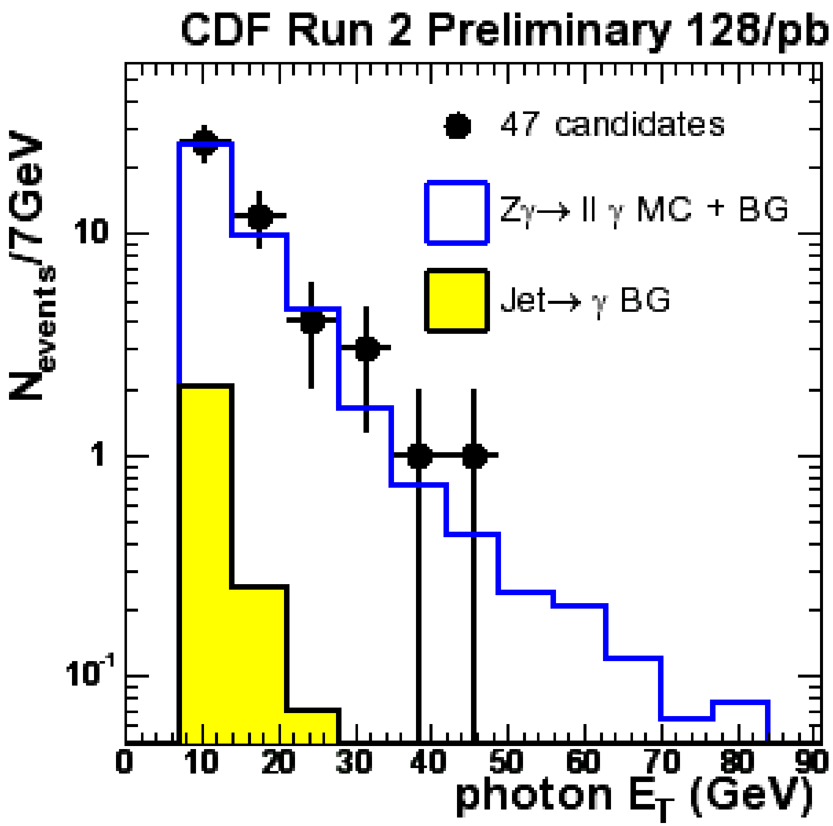
σ • Br = 17.2 ± 2.2 (stat.) ± 2.0 (syst.) ± 1.1(lumi.) pb

σ • Br = 5.8 ± 1.0 (stat.) ± 0.4 (syst.) ± 0.4 (lumi.) pb

2.2. W/ Zγ (その2)

Wγ and Zγ couplings

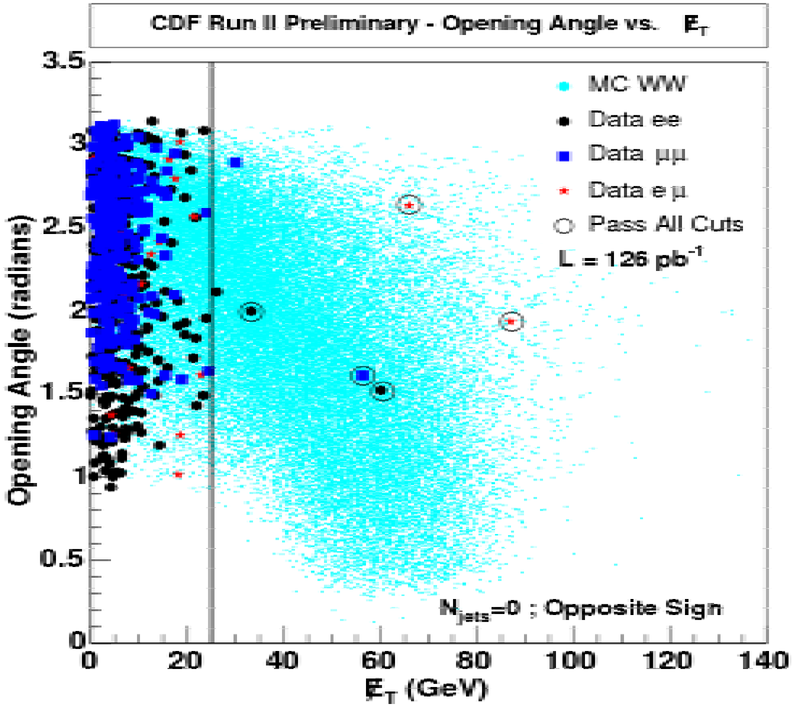




Cross sections and mass spectra are consistent with SM

2.3. W W

Higgs, SUSY Search



- isolated lepton pair
- opposite-charge, high p_T
- E_T^{miss}
- Z veto
- veto events with jets
- $\int L$ = 126 pb^{-1}
- 5 events seen
  (5 with 1.2 ±0.3 BG events
  in Run I @ $\int L$ = 108 pb^{-1})
- 9.2 events expected
  (2.3 background, 6.9 ± 1.5 W W → lν l'ν')

$$\sigma_{meas}^{p\bar{p}\to WW} = 5.1^{+5.4}_{-3.6} \;(\mathrm{stat}) \;\pm\; 1.3 \;(\mathrm{syst}) \;\pm\; 0.3 \;(\mathrm{lumi}) \;\mathrm{pb} \;.$$

$$\sigma_{theo:NLO}^{p\bar{p}\to WW} = 13.25\pm0.25 \;\;\mathrm{pb} \quad \mathrm{J.M.Campbell, R.K.Ellis} \;\; \mathrm{hep-ph/9905386}$$

3. Bの物理

B Physics at Hadron Machines

b's produced by strong interaction, decay by weak interaction

- Enormous cross-section
  - ~100 μbarn total
  - ~3-5 μbarn "reconstructable"
  - **At $4 \times 10^{31} cm^{-2}s^{-1} \Rightarrow$ ~150Hz of reconstructable *BB*!!**
- All *B* species produced
  - $B_u, B_d, \mathbf{B_s}, \mathbf{B_c}, \Lambda_b, \ldots$
- Large inelastic background
  - Triggering and reconstruction are challenging

3.1. 寿　命（その1）
B Hadron Lifetimes

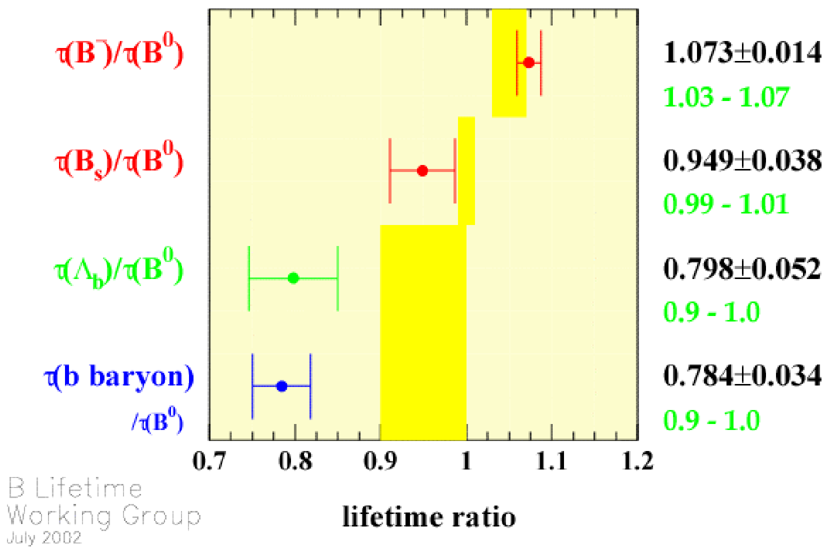
- All lifetimes equal in spectator model.
  - Differences from interference & other nonspectator effects
- Heavy Quark Expansion predicts the lifetimes for different B hadron species

$$\tau(B^+) \geq \tau(B^0) \approx \tau(B_S) > \tau(\Lambda_b) \gg \tau(B_c)$$

- Measurements:
  - B^0,B^+ lifetimes measured to better than 1%!
  - B_s known to about 4%
  - LEP/CDF (Run I) Λ_b lifetime lower than HQE prediction
- Tevatron can contribute to B_s,B_c and Λ_b (and other *b*-baryon) lifetimes.

Heavy Flavor Averaging Group
http://www.slac.stanford.edu/xorg/hfag/index.html

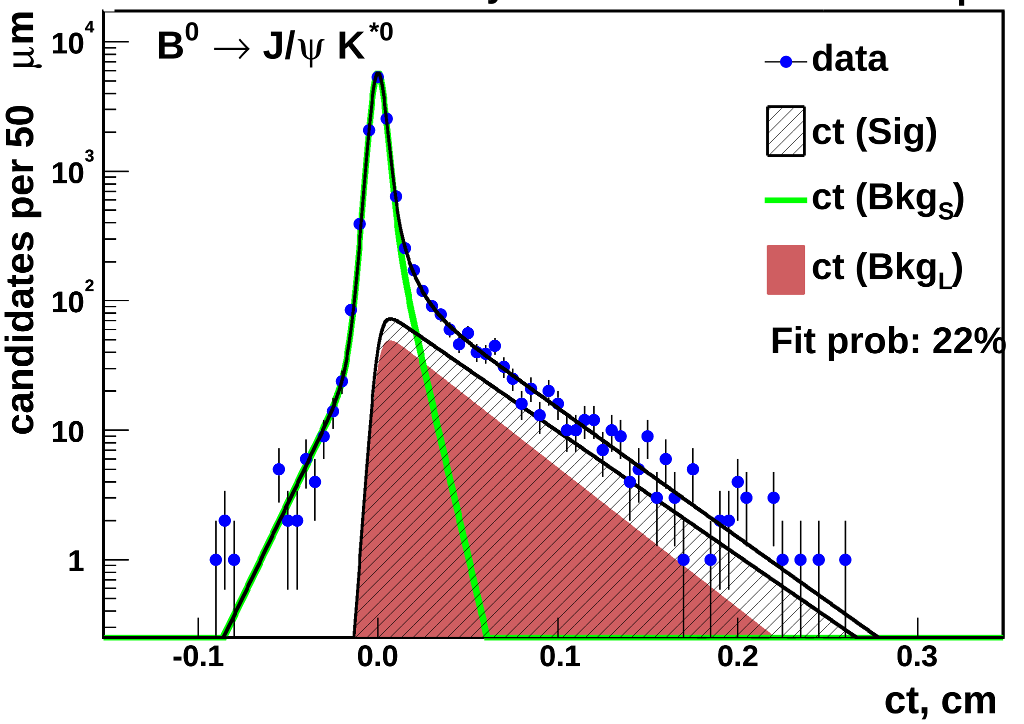
B hadron	Average lifetime (ps)
B^0	1.534±0.013
B^+	1.653±0.014
B_s	1.439±0.053
B_c	$0.46^{+0.18}_{-0.16}$
Λ_b	$1.233^{+0.078}_{-0.076}$



3.1. 寿　命(その2)
B^+, B^0 Lifetimes in J/ψ Modes

$\tau(B^0)$ **1.51 ± 0.06(*stat.*) ± 0.02 (*syst.*) ps**

$\tau(B^+)$ **1.63 ± 0.05(*stat.*) ± 0.04 (*syst.*) ps**



- Trigger on low p_T dimuons (1.5-2GeV/μ)
- Fully reconstruct
  - ✓ J/ψ, $\psi(2s) \to \mu^+\mu^-$
  - ✓ $B^+ \to J/\psi K^+$
  - ✓ $B^0 \to J/\psi K^*$, $J/\psi K_S$
  - ✓ $B_s \to J/\psi\phi$
  - ✓ $\Lambda_b \to J/\psi\Lambda$

Proper decay length:

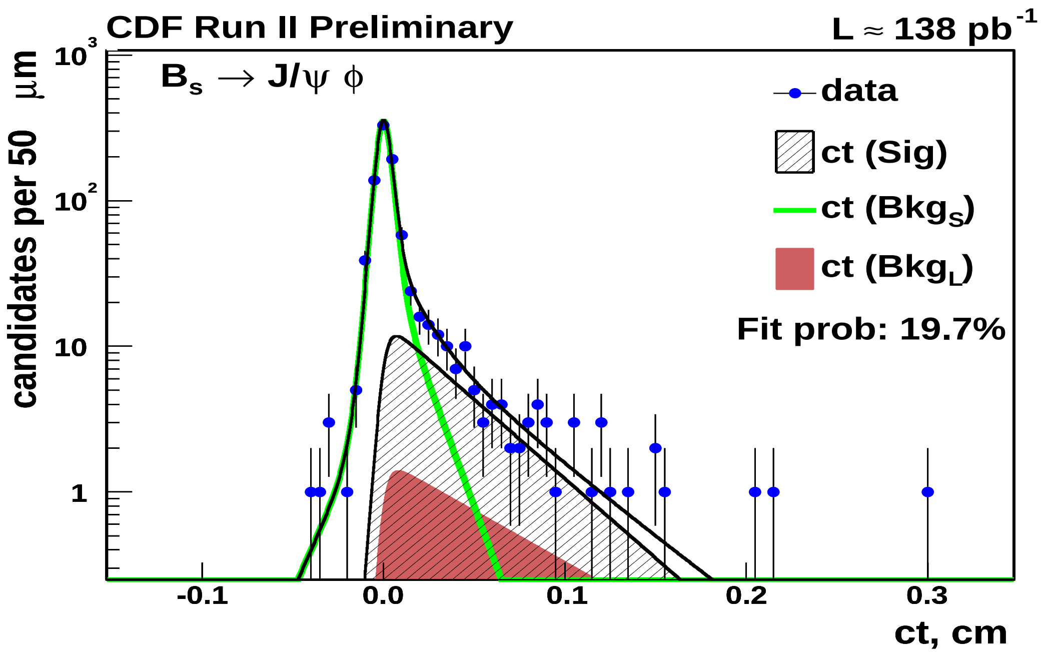
$$ct = \frac{L_{xy}}{\beta\gamma} = \frac{L_{xy} m_B}{p_T}$$

3.1. 寿　命（その3）
B_s Meson Lifetime

$B_s \rightarrow J/\psi\ \Phi$ with $J/\psi \rightarrow \mu^+ \mu^-$ and $\Phi \rightarrow K^+K^-$
$B^+ \rightarrow J/\Psi K^+$, $B^0 \rightarrow J/\Psi K^{*0}$ check technique, systematics

$$ct = L_{xy} \frac{m_B}{p_T^B}$$

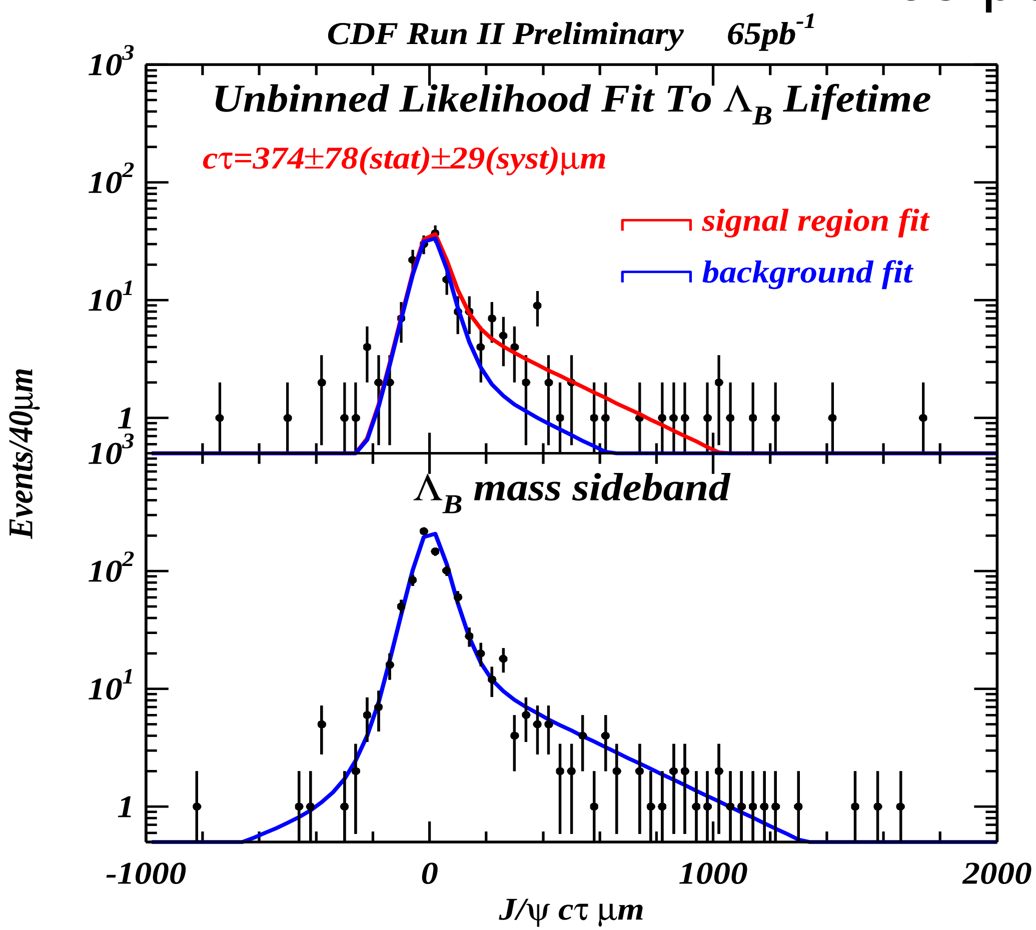
B_s lifetime - PDG 1.461 ± 0.057 ps
$1.33 \pm 0.14_{(stat)} \pm 0.02_{(sys)}$ ps

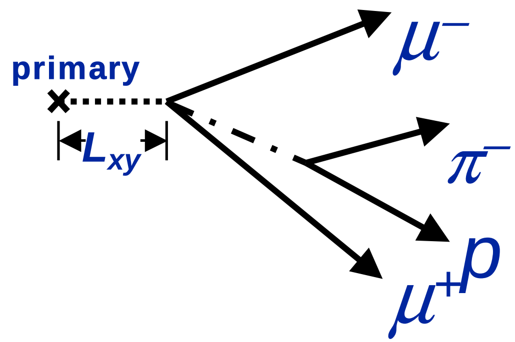


3.1. 寿　命（その4）
Λ_b Lifetime

- *Use fully reconstructed* $\Lambda_b \to J/\psi \Lambda$ *with* $J/\psi \to \mu^+\mu^-$ and $\Lambda \to p\pi^-$
  - *Previous LEP/CDF measurements used semileptonic* $\Lambda_b \to \Lambda_c l \nu$
    - *Systematics different*

65 pb^{-1}





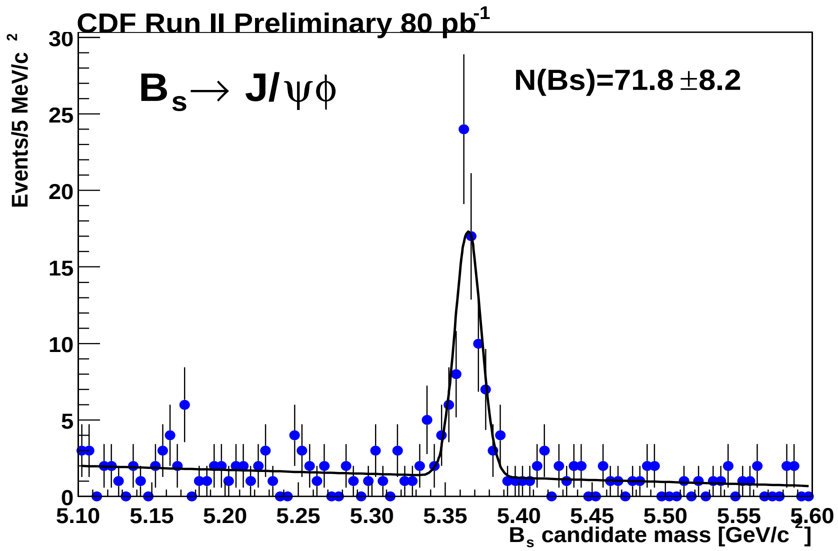
46±9 signal

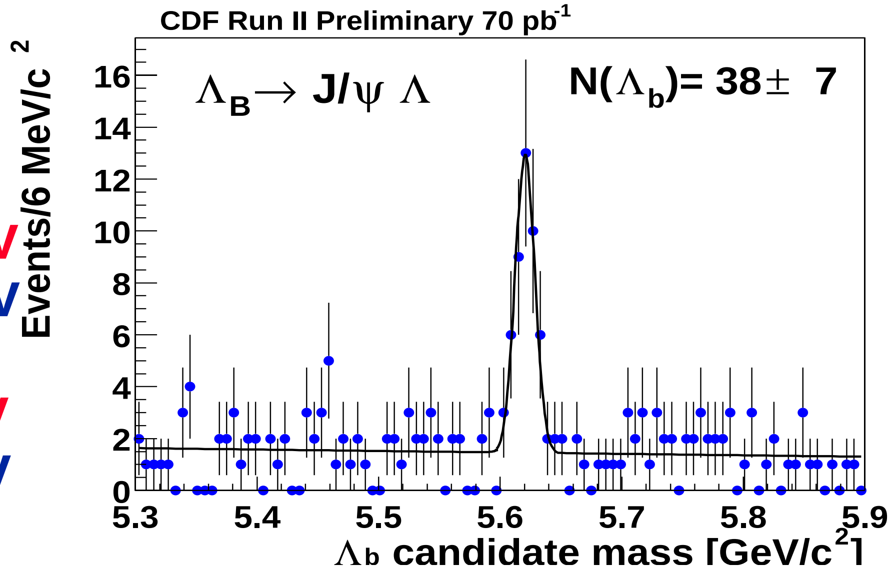
$$\tau(\Lambda_b) = 1.25 \pm 0.26(stat.) \pm 0.10(syst.)\ \text{ps}$$

First lifetime from fully reconstructed Λ_b decay!

B Hadron Masses

- Measure masses using fully reconstructed $B \rightarrow J/\psi X$ modes
- High statistics $J/\psi \rightarrow \mu^+\mu^-$ and $\psi(2s) \rightarrow J/\psi \pi^+\pi^-$ for calibration.
- Systematic uncertainty from tracking momentum scale
  - *Magnetic field*
  - *Material (energy loss)*
- *B^+ and B^0 consistent with world average.*
- ***B_s and Λ_b*** **measurements are world's best.**





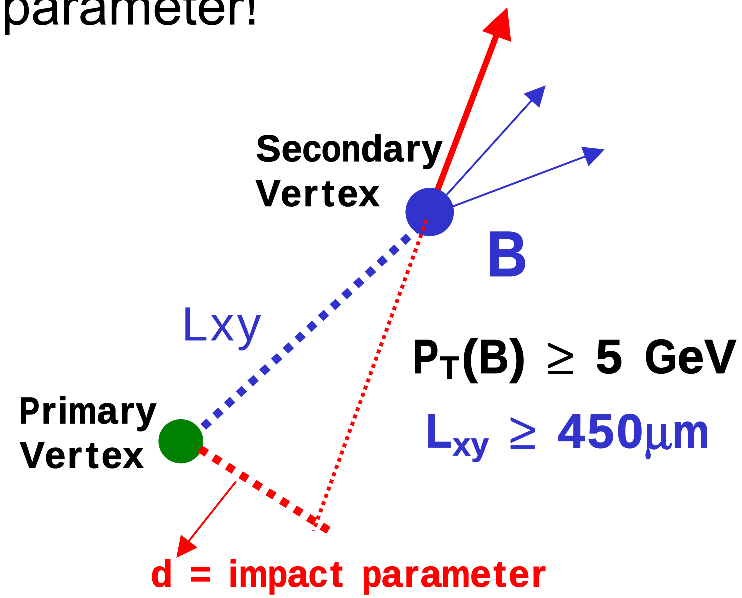
CDF result: $M(B_s)=5365.50 \pm 1.60$ **MeV**
World average: $M(B_s)=5369.6 \pm 2.4$ **MeV**

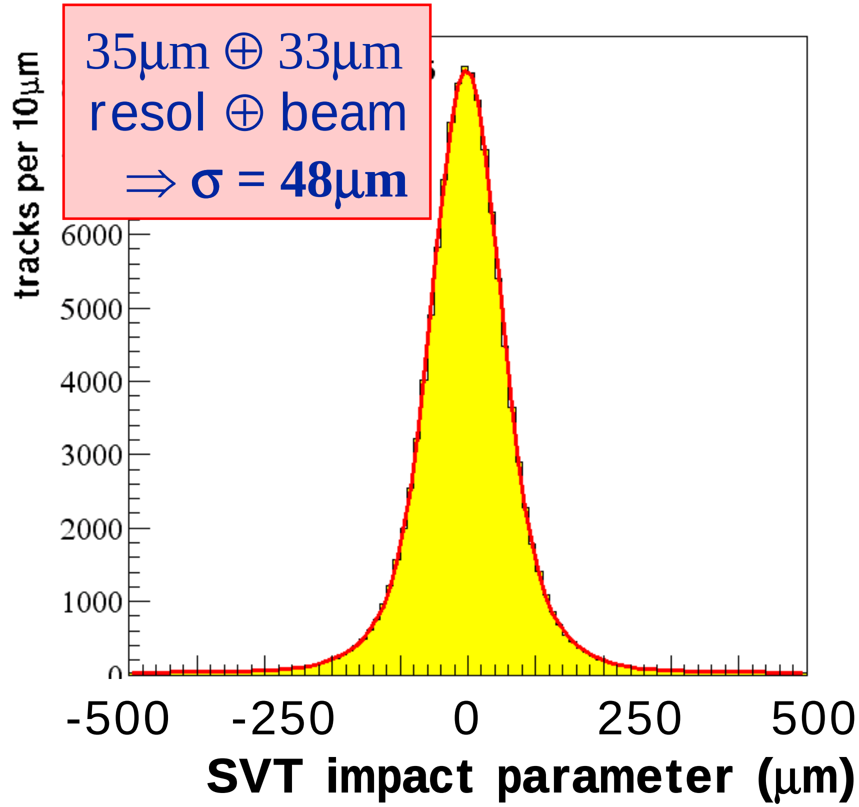
CDF result: $M(\Lambda_b)=5620.4 \pm 2.0$ **MeV**
World average: $M(\Lambda_b)=5624 \pm 9$ **MeV**

3.3. 分岐比（その1）

Silicon Vertex Tracker (SVT)

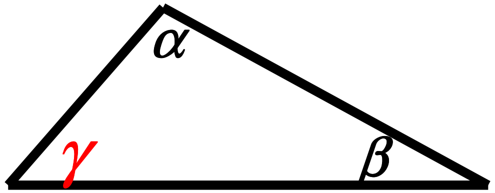
- SVT incorporates silicon info in the Level 2 trigger… select events with large impact parameter!



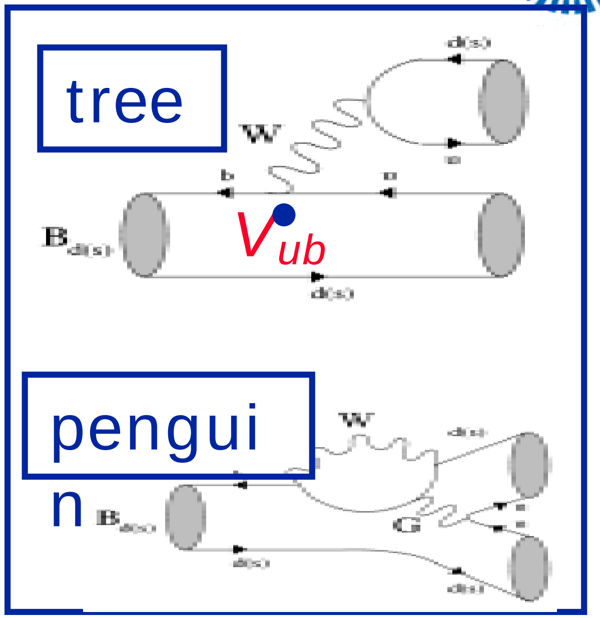


- Uses fitted beamline
- impact parameter per track
- System is deadtimeless:
  - ~25 µsec/event for readout + clustering + track fitting

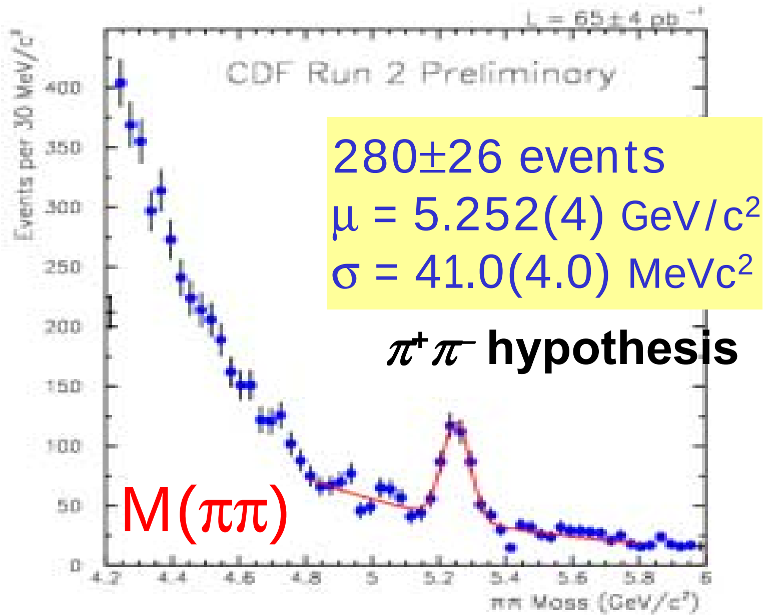
3.3. 分岐比（その2）



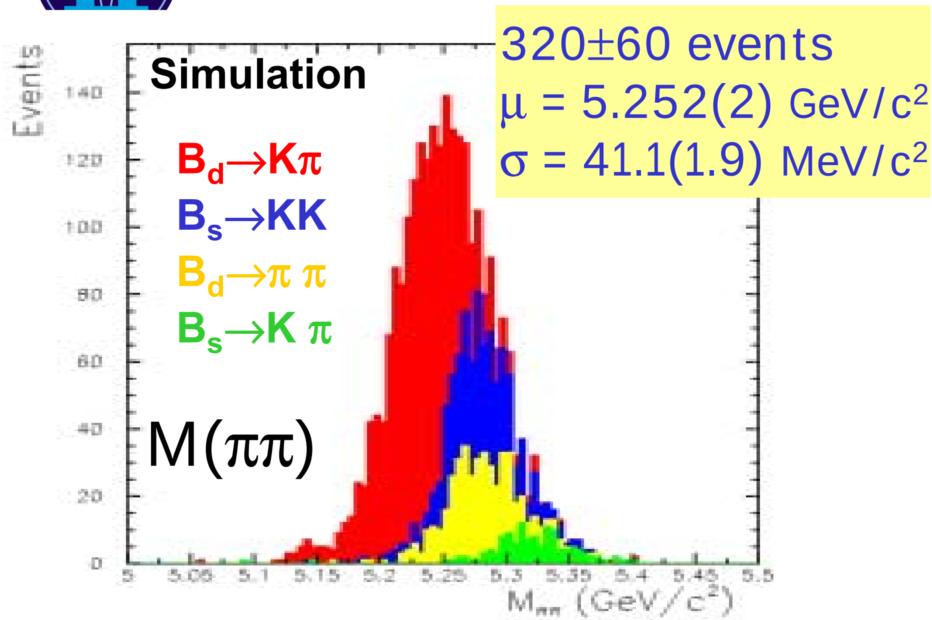
$B \to h^+ h^-$



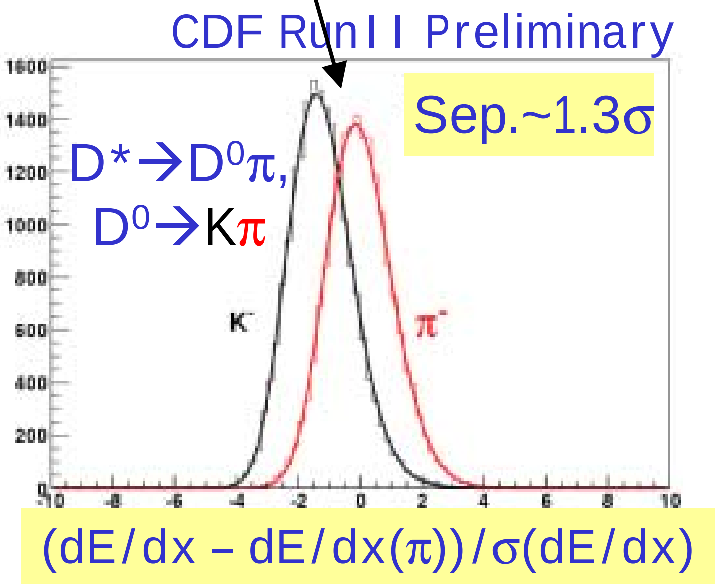
- charmless two-body decays
  - longer term B_s modes help extract unitarity angle γ
- Signal is a combination of:
  - $B^0 \to \pi^+\pi^-$ $BR\sim5x10^{-6}$
  - $B^0 \to K^+\pi^-$ $BR\sim2x10^{-5}$ } $\Upsilon(4s)$,Tevatron
  - $B_s \to K^+K^-$ $BR\sim5x10^{-5}$
  - $B_s \to \pi^+K^-$ $BR\sim1x10^{-5}$ } Tevatron
- Requirements
  - Displaced track trigger
  - Good mass resolution
  - Particle ID (*dE/dx*)



3.3. 分岐比（その3）



kinematics & *dE/dx* to separate contributions



$BR(B_s \to K^+K^-)$

Fitted contributions:

mode	Yield (65 pb^{-1})
$B^0 \to K\pi$	148±17(stat.)±17(syst)
$B^0 \to \pi\pi$	39±14(stat.)±17(syst)
$B_s \to KK$	90±17(stat.) ±17(syst)
$B_s \to K\pi$	3±11(stat.) ±17(syst)

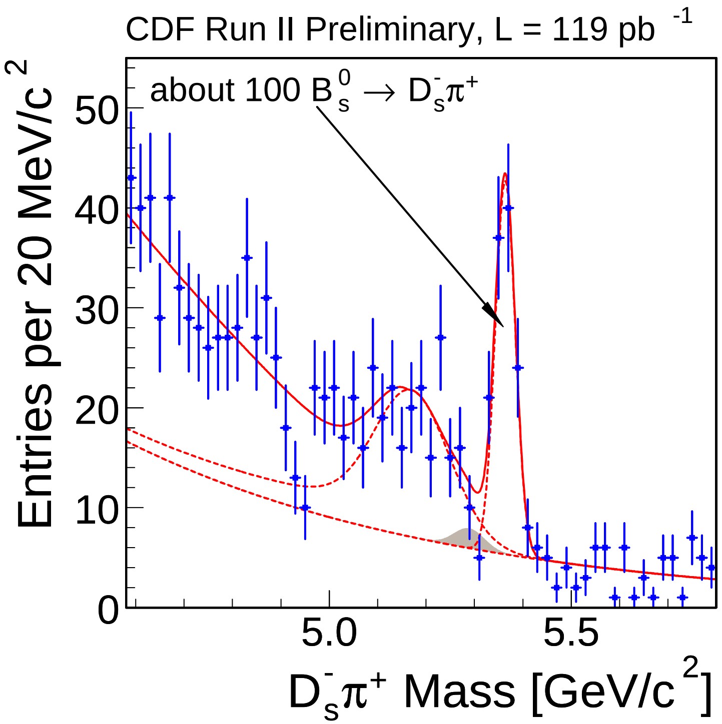
First observation of $B_s \to K^+K^-$!!

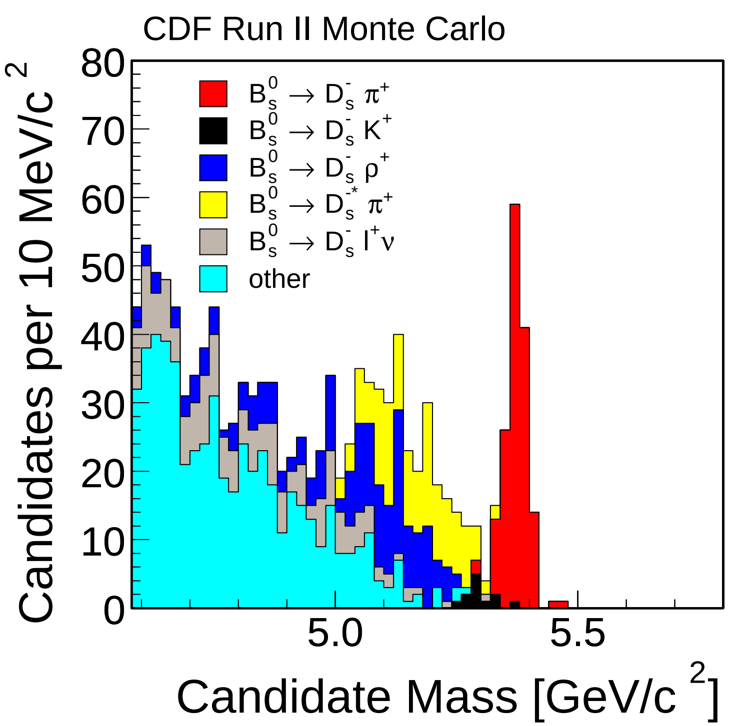
Result: $$\frac{BR(B_s \to K^{\pm}K^{\mp})}{BR(B_d \to K^{\pm}\pi^{\mp})} = 2.71 \pm 1.15$$

3.3. 分岐比（その4）

$B_s \to D_s \pi^+$

Golden mode for B_s mixing





$B_s \to D_s \pi^-$ with $D_s \to \phi\pi^+$ and $\phi \to K^- K^+$

$$BR(B_s \to D_s \pi^\pm) = (4.8 \pm 1.2 \pm 1.8 \pm 0.8 \pm 0.6) \times 10^{-3}$$

(Stat) (BR) (sys) (f_s/f_d)

New measurement !

Previous limit set by OPAL: BR ($B_s \to D_s \pi^\pm$) < 13%

BR result uses less data than shown in plot.

3.3. 分岐比(その5)
B_s Sensitivity Estimate

hadronic mode only

- Current performance:
  - S=1600 events/fb^{-1} (*i.e.* $\sigma_{effective}$ for produce+trigger+recon)
  - S/B = 2/1
  - εD^2 = 4%
  - σ_t = 67fs

2σ sensitivity for Δm_s =15ps^{-1} with ~0.5fb^{-1} of data

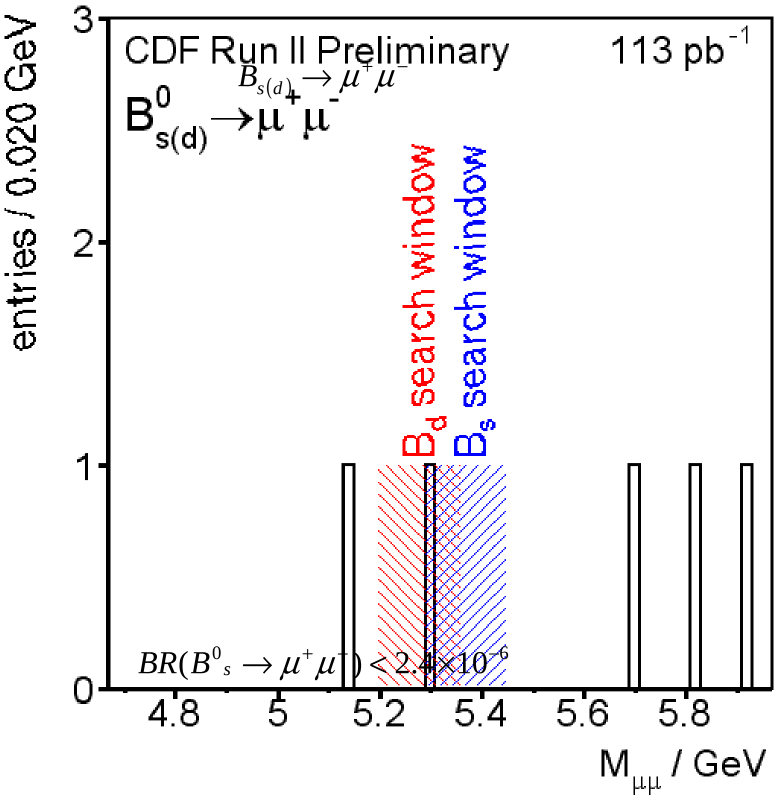
  - surpass the current world average
- With "modest" improvements
  - S=2000 fb (improve trigger, reconstruct more modes)
  - S/B = 2/1 (unchanged)
  - εD^2 = 5% (kaon tagging)
  - σ_t = 50fs (event-by-event vertex + L00)

5σ sensitivity for Δm_s =18ps^{-1} with ~1.7fb^{-1} of data
5σ sensitivity for Δm_s =24ps^{-1} with ~3.2fb^{-1} of data

  - ✓ Δm_s=24ps^{-1} "covers" the expected region based upon indirect fits.
- *This is a difficult measurement.*

3.3. 分岐比（その6）

$$B_{s(d)} \to \mu^+\mu^-$$



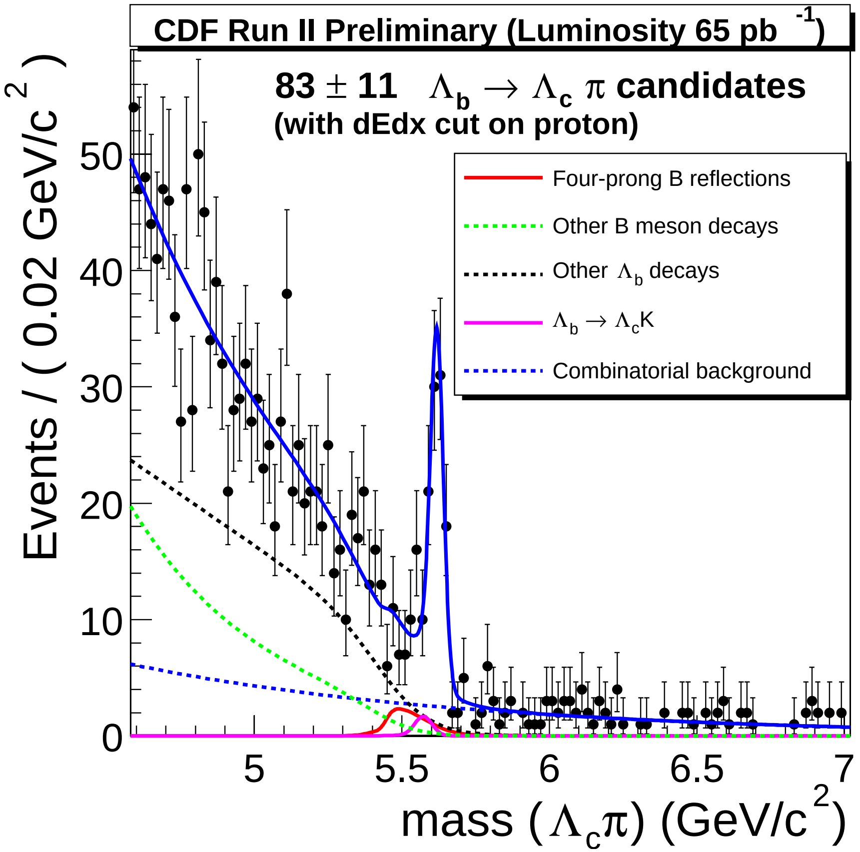
CDF
1 event in B_s and B_d search window

Expected bkg
0.54 ±0.20 (for B_s)
0.59 ±0.22 (for B_d)

$$BR(B^0{}_s \to \mu^+\mu^-) < 2.4\times10^{-6}$$ @95% CL

3.3. 分岐比(その7)

$\Lambda_b \to \Lambda_c \pi$ with $\Lambda_c \to pK\pi$



Backgrounds: real *B* decays

Reconstruct π as *p*: $B_d \to D^- \pi^+ \to K^+ \pi^- \pi^- \pi^+$

- Use MC to parametrize the shape.
- Data to normalize the amplitude
- Dominant backgrounds are real heavy flavor
- proton particle ID (*dE/dx*) improves S/B

Fitted signal:

$$N_{\Lambda_b} = 96 \pm 13(stat.)^{+6}_{-7}(syst.)$$

Measure: $$\frac{\sigma_b \times f_{baryon} \times BR(\Lambda_b \to \Lambda^+_c \pi^-)}{\sigma_b \times f_d \times BR(B^0 \to D^- \pi^+)}$$

New Result !

$BR(\Lambda_b \to \Lambda_c \pi^\pm) = (6.0 \pm 1.0(\text{stat}) \pm 0.8(\text{sys}) \pm 2.1(\text{BR})) 10^{-3}$

3.3. 分岐比（その8）

$Br(\Lambda_b \to \Lambda J/\psi)$

In progress

11pSJ6 岡山大 山下

Study of

$$\frac{\sigma\left(p\bar{p} \to \Lambda_b X\right) Br\left(\Lambda_b \to J/\psi\Lambda\right)}{\sigma\left(p\bar{p} \to B^0 X\right) Br\left(B^0 \to J/\psi K^0{}_s\right)}$$

4. まとめ

- 最大5．2×$10^{31}cm^{-2}sec^{-1}$を達成した。
- Tevatron Luminosityは順調に増加している。
- 検出器増強も成果を出している。
- 検出器/トリガー/シミュレーションの理解も深まりつつある。
- 解析に使用可能な積分Luminosityが130pb^{-1}に達しRun Iの結果を統計精度を上げながら再現。
- 新しい物理結果が出はじめた。

断面積、寿命、分岐比等