CDF Run II 実験の現状報告2

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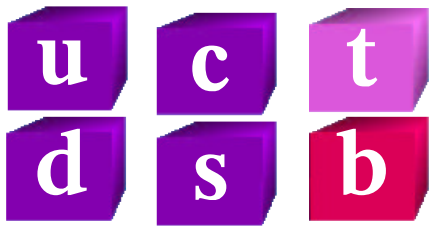
Outline

- Top Quark Physics
- Bottom/Charm Quark Physics
- Summary

Top Quark Overview

- Partner of b-quark in SU(2) doublet of weak isospin in the third generation.



- Experimentlly established by CDF and D$\varnothing$ in 1995

  CDF : F. Abe *et al.* Phys. Rev. Lett. 74 (1995) 2626

  D$\varnothing$: S. Abachi *et al.* Phys. Rev. Lett. 74 (1995) 2632

- Mass: $M_t \approx 175\,\mathrm{GeV}/c^2$
  Width: $\Gamma_t \simeq 1.42\,\mathrm{GeV}$
- Top quark decays before it's hadronized.
- Yukawa coupling $\sqrt{2}\dfrac{m_t}{v} \approx 1$

  $\rightarrow$ Special role in electroweak symmetry breaking?

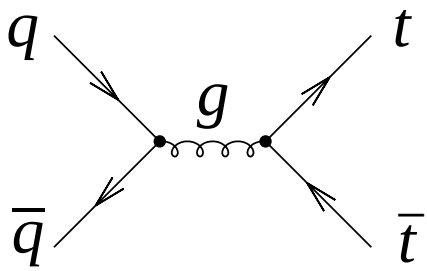
Top Quark Production at Tevatron

- $t\bar{t}$ pair production thru. strong interaction

$$\sigma(t\bar{t}) \sim 5\,\mathrm{pb} \text{ at } \sqrt{s} = 1.8\,\mathrm{TeV} \text{ (Run I)}$$
$$\sim 7\mathrm{pb} \text{ at } \sqrt{s} = 1.96\,\mathrm{TeV} \text{ (Run II)}$$

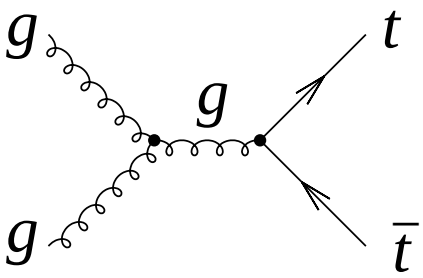
  - $q\bar{q}$ annihilation

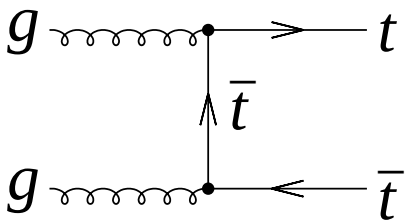
    $\sim 90\%$(Run I) $\sim 85\%$(Run II)



  - gluon fusion

    $\sim 10\%$(Run I) $\sim 15\%$(Run II)





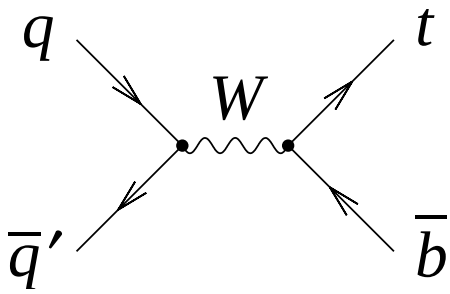
- Single-top production via EW interaction

$\sigma(\text{single}-t) \sim 2.4\,\text{pb}$ at $\sqrt{s} = 1.8\,\text{TeV}$

$\sim 3\,\text{pb}$ at $\sqrt{s} = 1.96\,\text{TeV}$

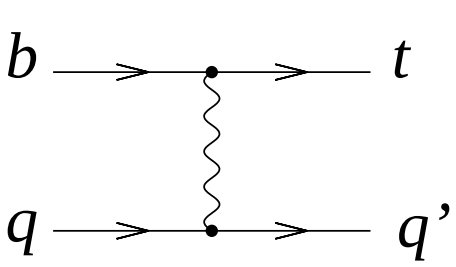
  - s-channel W^*

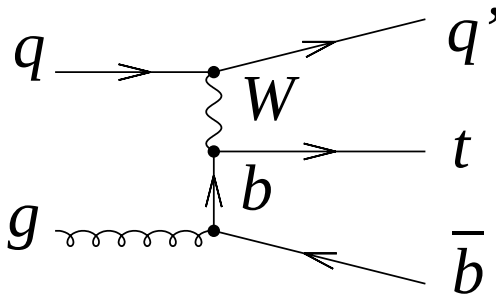
    $\sim 32\%$(Run I)



  - t-channel

    $\sim 62\%$(Run I)





W-gluon fusion

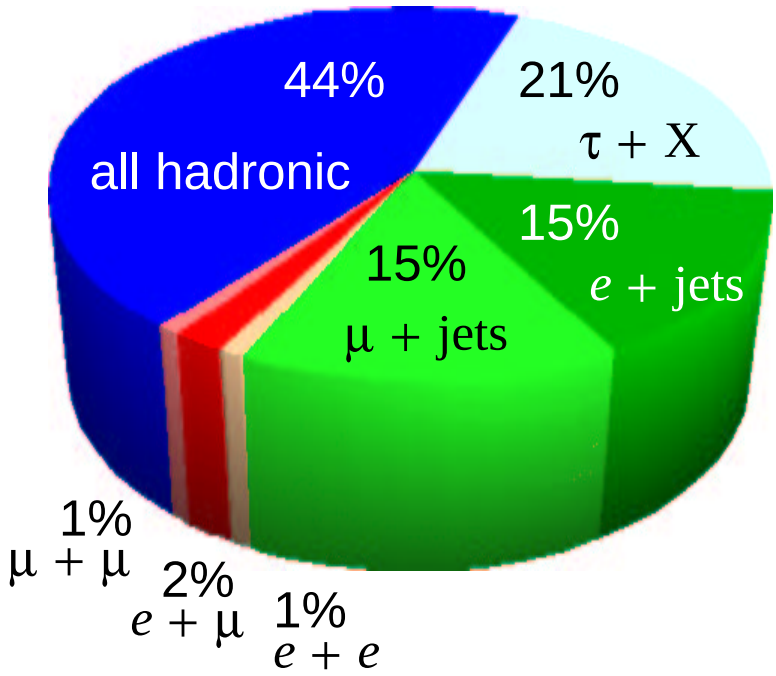
  - Dominant contributions:
    s-channel and W-gluon fusion

3 classes of signal in $t\bar{t}$ production

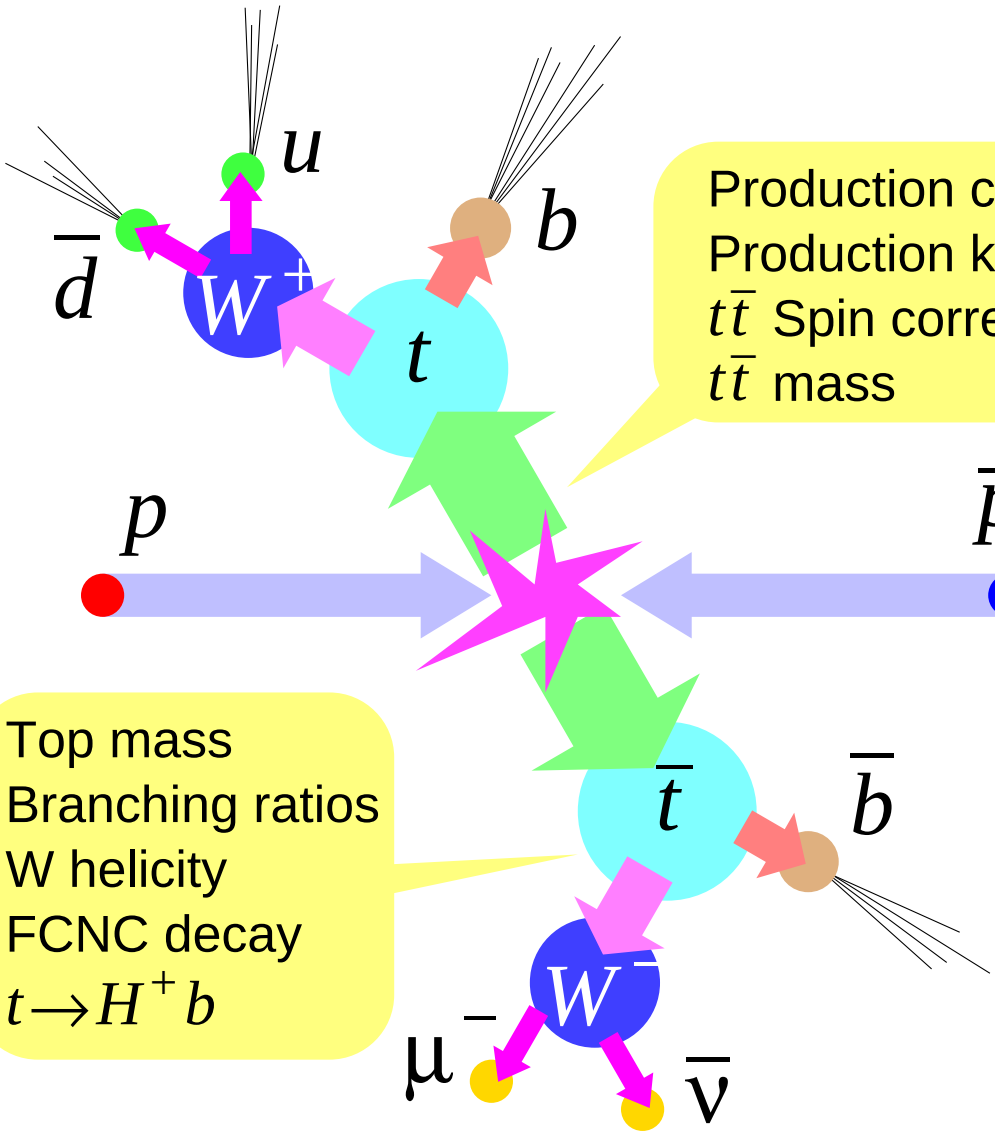
- Top quark goes W+b at a rate of $\sim$100%:
  $\mathrm{Br}(t \to W^+ b) \simeq 1$
- Decay channels of $t\bar{t}$ pair

$t \to W^+ b$	b	b	b	b
$\hookrightarrow$	$\ell^+\nu$	$q\bar{q}'$	$\ell^+\nu$	$q\bar{q}'$
$\bar{t} \to W^- \bar{b}$	$\bar{b}$	$\bar{b}$	$\bar{b}$	$\bar{b}$
$\hookrightarrow$	$\ell^-\bar{\nu}$	$\ell^-\bar{\nu}$	$q\bar{q}'$	$q\bar{q}'$

  - dilepton channel
  - lepton+jets channel
  - all hadronic channel
- Fraction of decay channels of $t\bar{t}$



Topics on Top Physics at Tevatron



Production cross section
Production kinematics
$t\bar{t}$ Spin correlations
$t\bar{t}$ mass

Top mass
Branching ratios
W helicity
FCNC decay
$t \to H^+ b$

Results from Run IIa

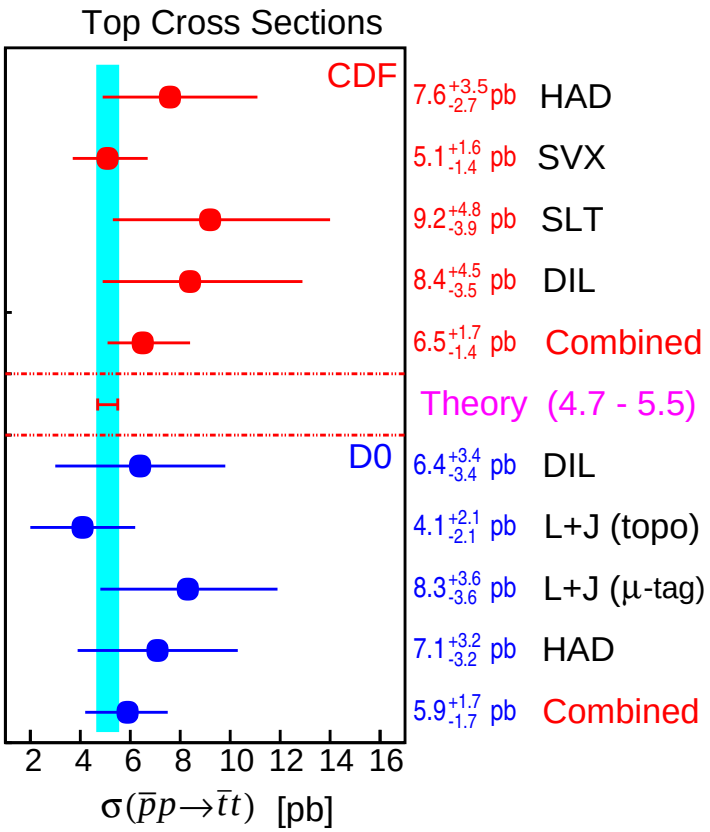
- ✓ $\sigma_{t\bar{t}}$ in dilepton channel
- ✓ $\sigma_{t\bar{t}}$ in ℓ + jets channel
- ✓ Top mass measurement in ℓ + jets channel

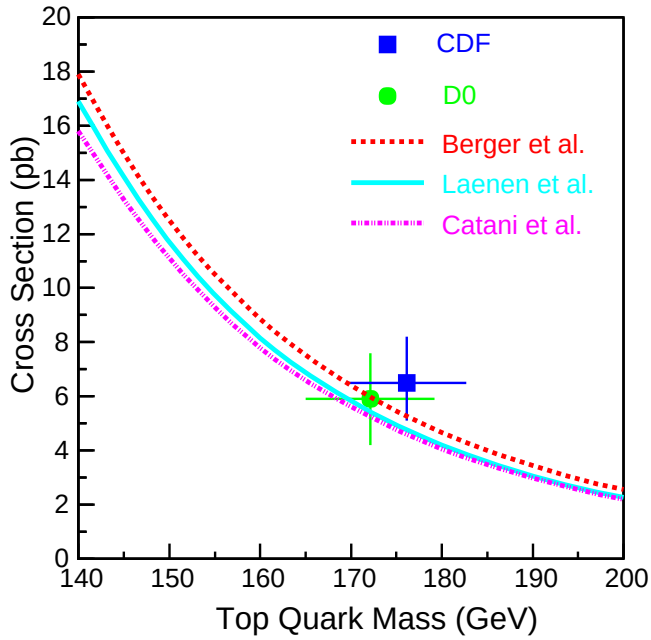
$\sigma_{t\bar{t}}$

- Test of perturbative QCD predictions.

  $\rightarrow$ NLO($\mathcal{O}(\alpha_s^3)$)

- Run I results



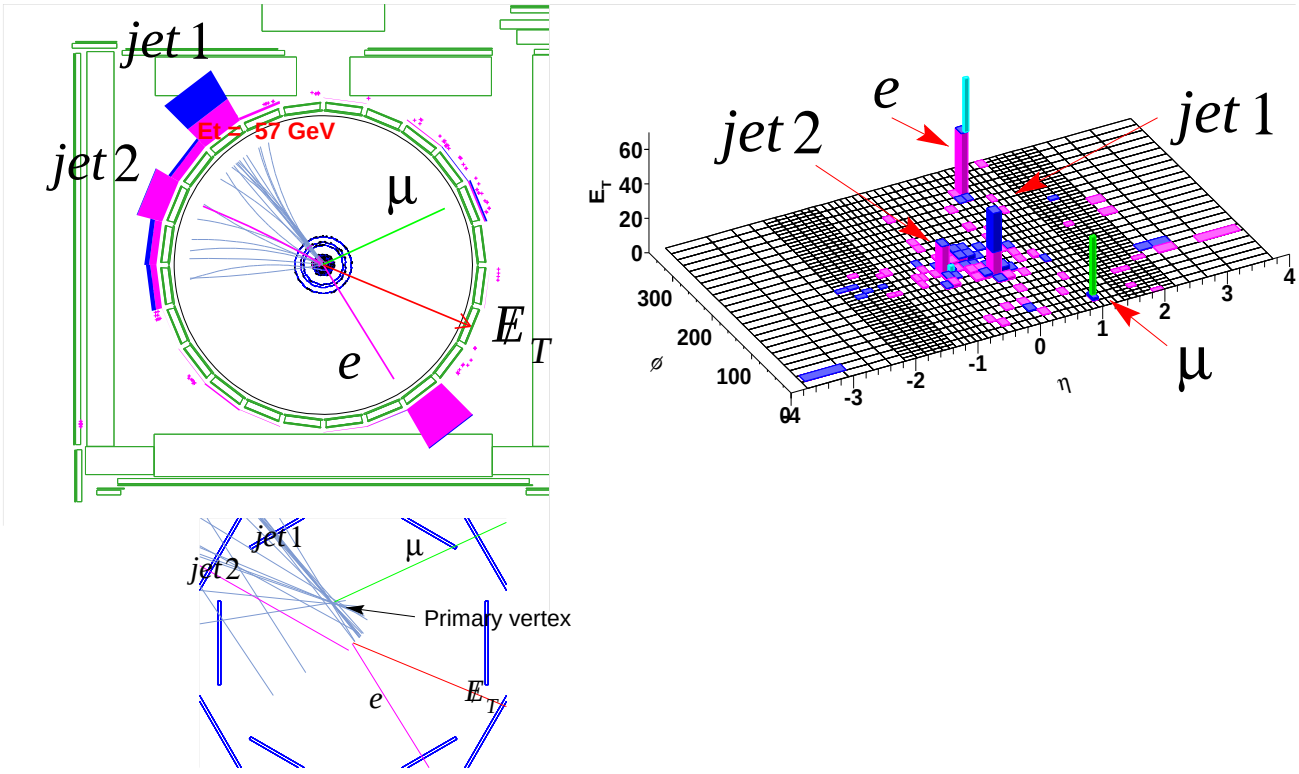


$$\sigma_{t\bar{t}} = 6.5^{+1.7}_{-1.4}\,\mathrm{pb} \;@\; \sqrt{s} = 1.8\,\mathrm{TeV}\ \text{(CDF Run I)}$$

In good agreement with theory

$\sigma_{t\bar{t}}$ in dilepton channel (Run II)

- Event selection
  - 2 leptons(e/μ)
    - isolated and high p_T w/ opposite charge
    - Veto Z, cosimics
  - $\not\!\!E_T > 25\,\mathrm{GeV}$
  - At least 2 jets w/ $E_T > 10\,\mathrm{GeV}$
- A dilepton candidate ($e\mu$ event)



Run 156484 Event 3099305

$E_T(e) = 34\,\mathrm{GeV}$ $P_T(\mu) = 36\,\mathrm{GeV}$

$E_T(\mathrm{jets}) = 57, 28\,\mathrm{GeV}$

$\not\!\!E_T = 55\,\mathrm{GeV}$ $M_{e\mu} = 47\,\mathrm{GeV}$ $H_T = 227\,\mathrm{GeV}$

- Counting experiment: $\sigma_{t\bar{t}} = \dfrac{N_{\rm obs} - B}{\epsilon_{\rm tot} \int \mathcal{L} dt}$

$\int \mathcal{L} dt$: Integrated luminosity (Mar,2002-Dec,2002)

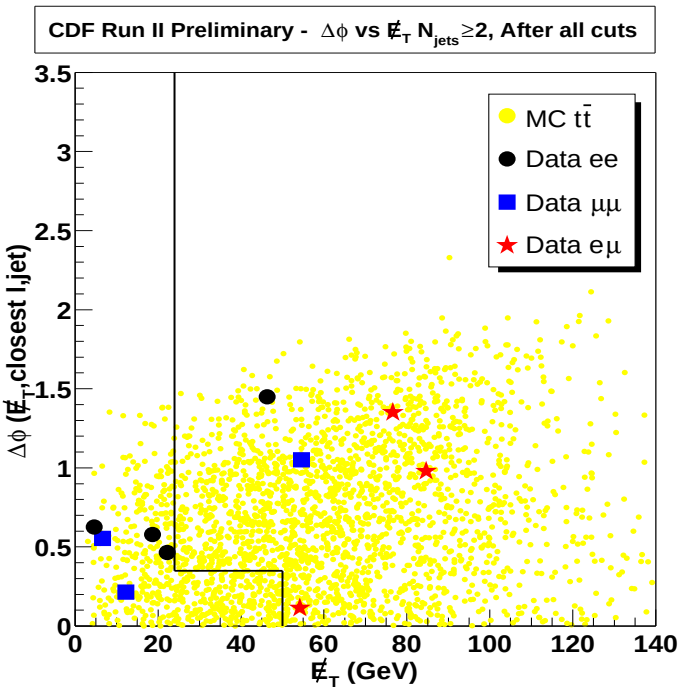
$72 \pm 4\,{\rm pb}^{-1}$

B : BG estimate (WW/WZ, DY, $Z \to \tau\tau$, fake)

0.30 ± 0.12

$N_{\rm obs}$: # of observed candidates

5 ($\Leftrightarrow$ MC sig+bg expectation 2.8 ± 0.3)



$$\sigma_{t\bar{t}} = 13.2 \pm 5.9_{\rm stat} \pm 1.5_{\rm syst}\,{\rm pb}$$

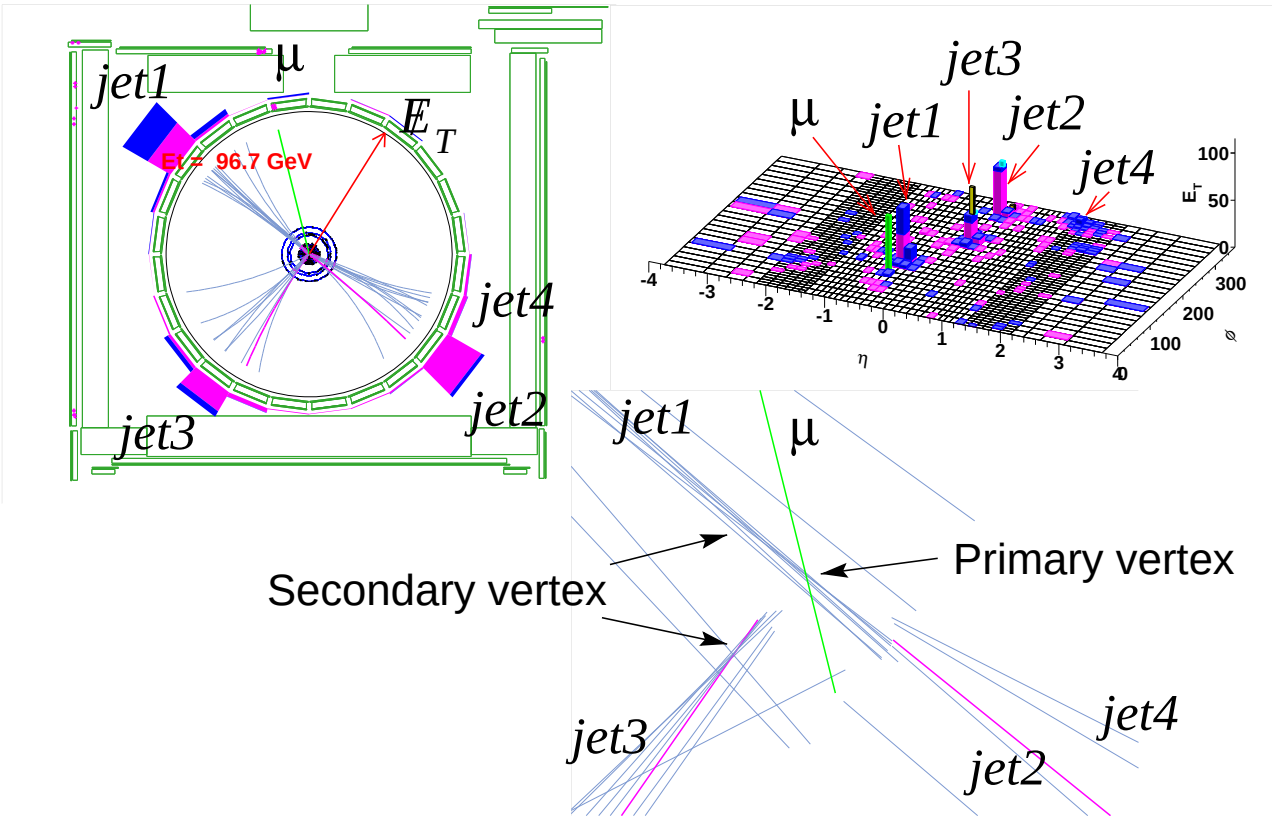
$\Updownarrow$ (CDF II preliminary)

$6.70^{+0.71}_{-0.88}\,{\rm pb}$ (NLO @ $\sqrt{s} = 1.96\,{\rm TeV}$)

In agreement with theory && (Run I) x 1.4

$\sigma_{t\bar{t}}$ in ℓ+jets channel (Run II)

- Event selection
  - 1 lepton(e/μ)
    - isolated and high p_T
    - Veto Z, cosimics
  - $\not\!\!E_T > 20\,\mathrm{GeV}$
  - $N_{\mathrm{jets}} \geqslant 3$ ($E_T > 15\,\mathrm{GeV}$)
    - At least 1 jet w/ B-tag(SECondary VerTeX)
- A lepton+jets candidate



Run 153693 Event 799494

$P_T(\mu) = 54.4\,\mathrm{GeV}$ $E_T(\mathrm{jets}) = 96.7, 65.8, 54.8, 33.8\,\mathrm{GeV}$

$\not\!\!E_T = 40.8\,\mathrm{GeV}$ $H_T = 227\,\mathrm{GeV}$

$L_{xy}/\sigma = 10.8(\mathrm{jet1}), 21.9(\mathrm{jet3})$

- $\sigma_{t\bar{t}}$ in lepton+jets

$\int \mathcal{L} dt$: Integrated luminosity (silicon required)

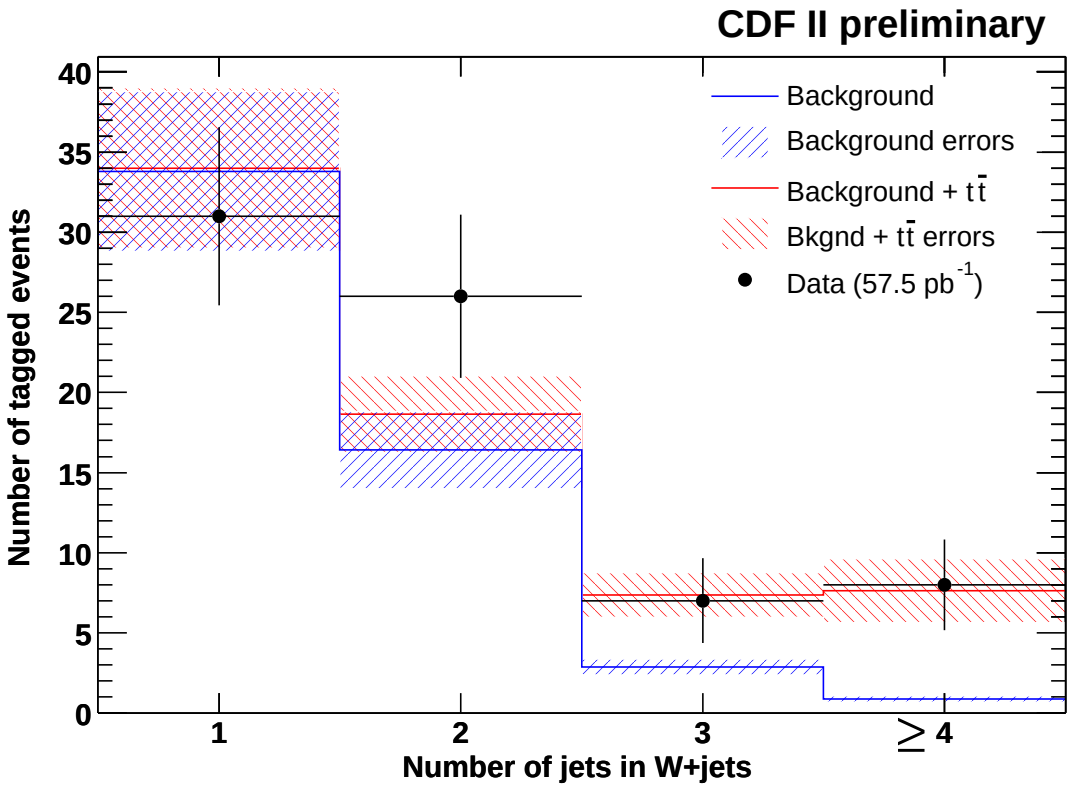
$57.5\,\mathrm{pb}^{-1}$

B : BG estimate ($Wb\bar{b}$, $Wc\bar{c}$, Wc, non-W, ...)

3.8 ± 0.5

N_{obs} : # of observed candidates

15 ($\Leftrightarrow$ sig+bg expectation 15.0 ± 2.4)



← signal →

$\sigma_{t\bar{t}} = 5.3 \pm 1.9_{\mathrm{stat}} \pm 0.8_{\mathrm{syst}}\,\mathrm{pb}$ (CDF II preliminary)

In agreement with theory && (Run I) x 1.4

$M_{\rm top}$

- CDF Run I result

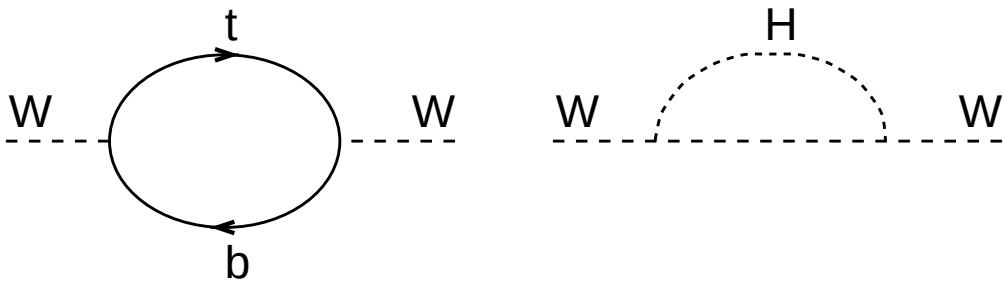
$$M_t = 176.0 \pm 6.5\,\mathrm{GeV}/c^2$$

- What is the top quark mass for?

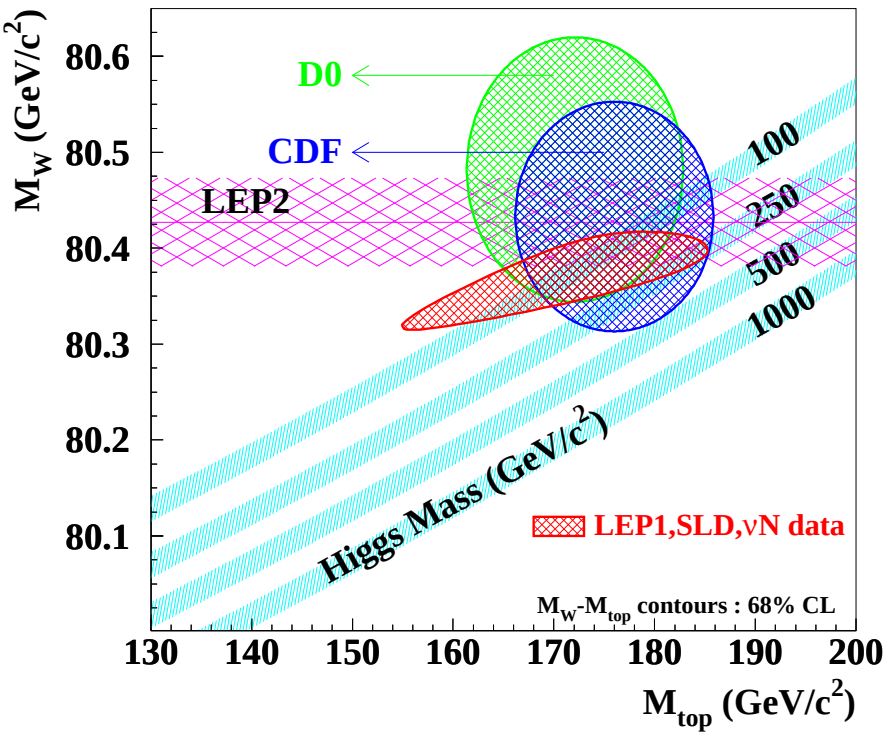
  → Important parameter for radiative corrections in SM predictions.

  → Measurements of M_W and M_t constrain M_H.

$$\delta M_W = F(M_t^2, \log M_H)$$



Constraint on Higgs mass (Tevatron Run I)



$M_{\rm top}$ in ℓ+jets channel (Run II)

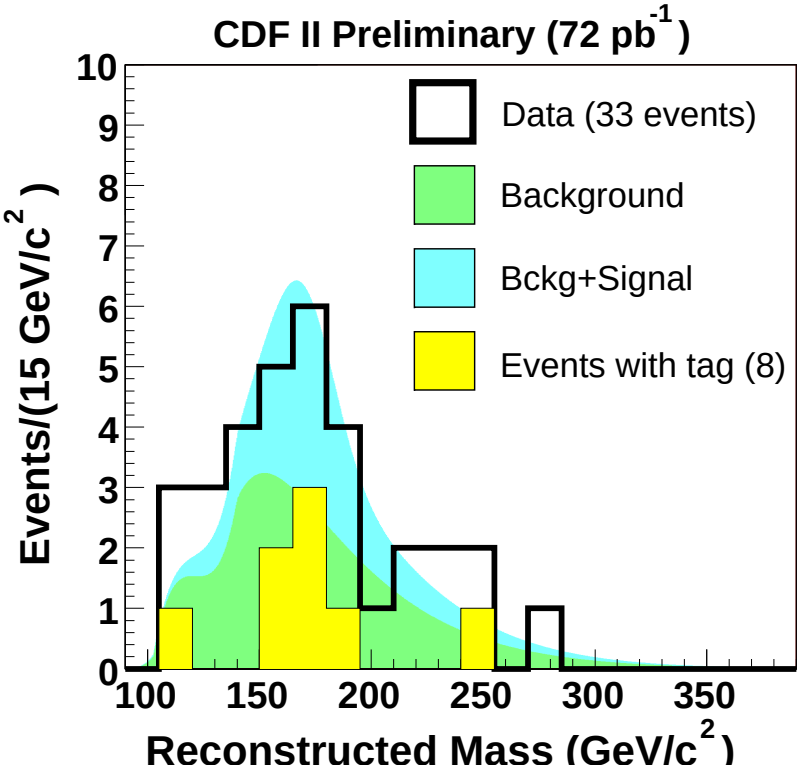
- Use pre-SECVTX-tagged $\ell + 4\mathrm{jets}$ sample.
  - Similar event selection to $\sigma_{t\bar{t}}$, but w/o b-tagging.
  - 33 candidates
- How do we extract M_t in a $\ell + 4\mathrm{jets}$ event?

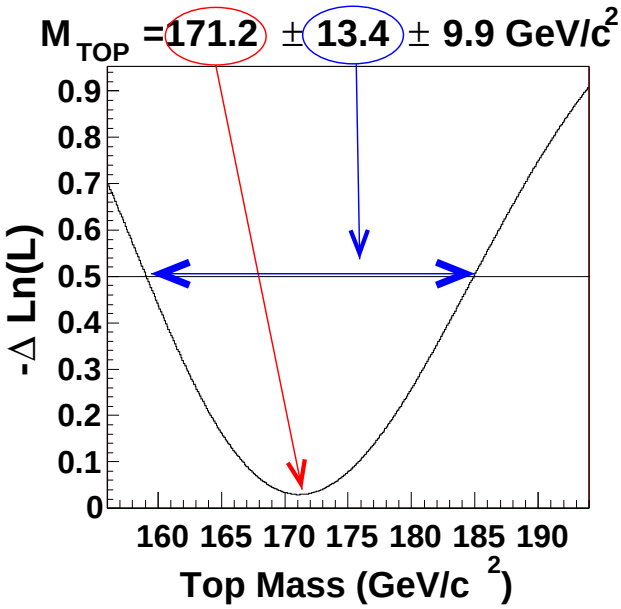
  $\rightarrow$ Use kinematical χ^2 fitting

  $\rightarrow$ over 2 constraint system:

  2 unknowns: M_t, p_z^ν

  4 constraints: $M_{\ell\nu} = M_{jj'} = M_W$, $M_{\ell\nu b} = M_{bjj'} = M_t$





- Compare DATA to MC with M_t as a parameter.

  $\rightarrow$ Likelihood as a function of M_t

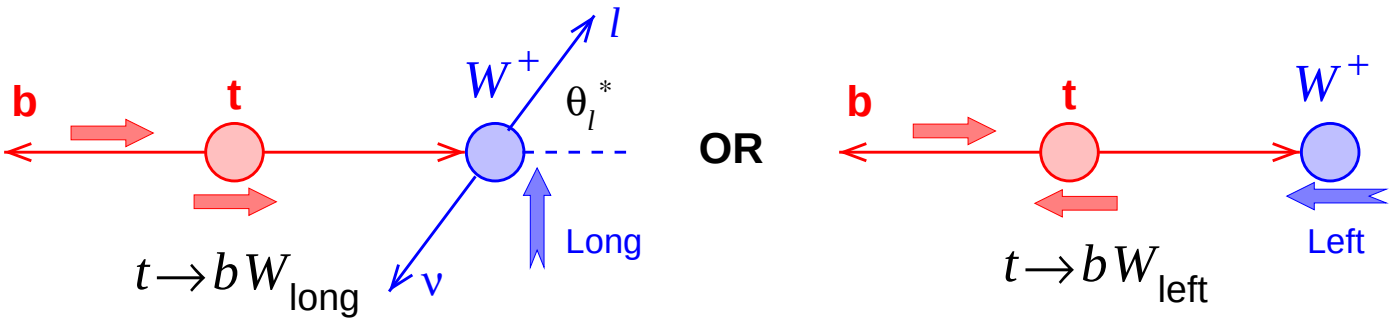
$$M_{\rm top} = 171.2 \pm 13.4 \pm 9.9\ \mathrm{GeV}/c^2$$ (CDF II preliminary)

Other Topics expected in Run II

- W helicity in top decays

  $\rightarrow$ In SM(V-A), top quark decays only to longitudinally polarized or left-handed W.
  $h_W = 0$ or -1

  $\rightarrow$ V+A or anomalous coupling in $t-W-b$?



$$\frac{\mathrm{Br}(t \rightarrow b W_{\text{long}})}{\mathrm{Br}(t \rightarrow b W_{\text{left}})} = \frac{1}{2}\left(\frac{m_t}{m_W}\right)^2 = \frac{0.70}{0.30} \quad \text{(SM)}$$

$\rightarrow$ Run I result

CDF Run I Results		SM
$\mathcal{F}_{\text{long}} = 0.91 \pm 0.37_{\text{stat}} \pm 0.12_{\text{syst}}$	$\Longleftrightarrow$	~ 0.7
$\mathcal{F}_{\text{right}} = 0.11 \pm 0.15_{\text{stat}} \pm 0.06_{\text{syst}}$		0

- Single top production

  $\rightarrow$ Direct measurement of $|V_{\mathrm{tb}}|$

  $\rightarrow$ Run I result

N_{obs}		SM expectation	
		$W-g$	3.0
		W^*	1.3
65	$\Leftrightarrow$	$t\bar{t}$	8.4
		non-top(QCD)	54
		total	67 ± 12

$\sigma(Wg + W^*) < 14\,\mathrm{pb}$ (CDF Run I)

- Search for FCNC top quark decays

  $\rightarrow$ strongly GIM suppressed in SM

  $\mathrm{Br} < 10^{-10}$

  If observe $\Rightarrow$ New physics!

  $\rightarrow$ Run I results

  - $p\bar{p} \rightarrow t\bar{t} + X$ with $t \rightarrow W + b$ and $\bar{t} \rightarrow \bar{u}/\bar{c} + \gamma$

    $\mathrm{Br}(t \rightarrow u/c + \gamma) < 3.2\%$ (95%CL)

  - $p\bar{p} \rightarrow t\bar{t} + X$ with $t \rightarrow W + b$ and $\bar{t} \rightarrow \bar{u}/\bar{c} + Z^0$

    $\mathrm{Br}(t \rightarrow u/c + Z^0) < 33\%$ (95%CL)

- Branching ratio $R = \frac{\mathrm{Br}(t \to Wb)}{\mathrm{Br}(t \to Wq)}$

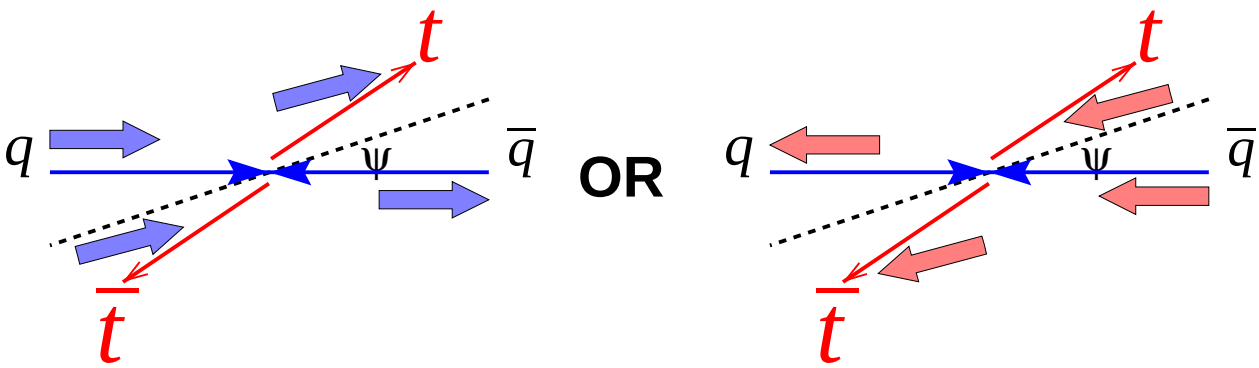
  $\to$ CDF Run I result

  $$R = 0.94^{+0.31}_{-0.24} \quad \Rightarrow \quad |V_{\mathrm{tb}}| = 0.97^{+0.16}_{-0.12}$$

  (assuming 3 generations)

- $t\bar{t}$ spin correlations

  $\to$ If $t\bar{t}$ pairs produced via $q\bar{q}$ annihilation 100% correlation between t and $\bar{t}$ spins in "Off-diagonal basis".



  $\to$ Experimental proof of $1/\Gamma_t \ll$ spin flip time

  $\to$ No result from CDF Run I

  Only DØ Run I result based on 6 dilepton candidates

  $$\kappa > -0.25 \ (68\%\mathrm{CL}) \quad \Leftrightarrow \quad \kappa \simeq 0.9(\mathrm{SM})$$

  κ: correlation parameter

  $0 \to 0\%$ correlated

  $1 \to 100\%$ correlated

Run II Prospects on Top Quark

Run IIa luminosity goal is $2\,\mathrm{fb}^{-1}$.
At least 20x higher statistics.

- δM_t
  $6.5\,\mathrm{GeV}/c^2$(Run I) $\longrightarrow 2\text{–}3\,\mathrm{GeV}/c^2(2\,\mathrm{fb}^{-1})$
  Constraint on higgs mass: $\delta M_h/M_h \sim 40\%$
- $\delta\sigma_{t\bar{t}}$
  25% (CDF Run I) $\longrightarrow$ 10% $(2\,\mathrm{fb}^{-1})$
- Single top production cross-section
  Observe 100-150 single top events $(2\,\mathrm{fb}^{-1})$.
  $\rightarrow \delta|V_{\mathrm{tb}}| \approx$ 10-15%
- W helicity in top decay
  - $\delta\mathcal{F}_{\mathrm{long}}$: 0.4 (Run I) $\longrightarrow$ 0.09 $(2\,\mathrm{fb}^{-1})$
  - $\delta\mathcal{F}_{\mathrm{right}}$: 0.15 (Run I) $\longrightarrow$ 0.03 $(2\,\mathrm{fb}^{-1})$
- Search for FCNC top decay
  - $\mathrm{Br}(t \to u/c + \gamma) < 0.032 \longrightarrow 3 \times 10^{-3}(2\,\mathrm{fb}^{-1})$
  - $\mathrm{Br}(t \to u/c + Z^0) < 0.33 \longrightarrow 0.02(2\,\mathrm{fb}^{-1})$

Bottom/Charm Quark Physics

- Why B physics at Hadron Colliders?

  Advantage:

  - $\sigma(b\bar{b})$: $\mathcal{O}(10^5)$ larger

    $\sim 1\,\mathrm{nb}$ e^+e^- @ $\Upsilon(4S)$

    $\sim 7\,\mathrm{nb}$ e^+e^- @ Z^0

    $\sim 100\,\mu b$ $p\bar{p}$ @$\sqrt{s} = 2\,\mathrm{TeV}$

  - All B species: $B^{\pm}$, B^0, B_s, $B_c^{\pm}$, Λ_b, ...

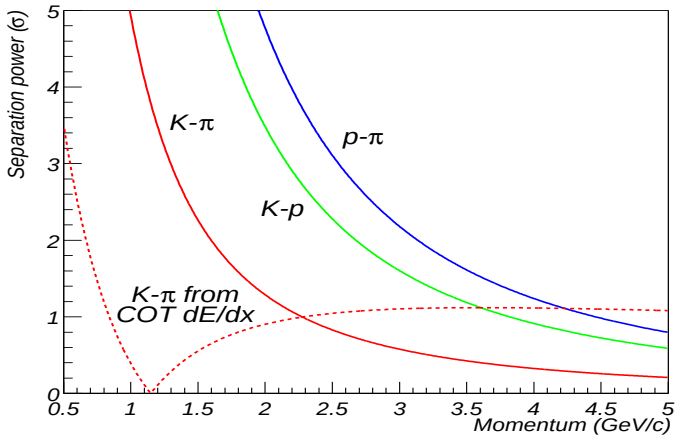
  Disadvantage:

  - Total inelastic cross section 10^3 bigger
  - Multiple event

- New tools for B physics in CDF II

  SVT Triggering on track impact parameters

  TOF PID for $\pi/K/p$



Separate K/π by
$> 2\sigma$ up to $1.6\,\mathrm{GeV}/c$

B Triggers and data samples

- Di-Muon
  - $p_T^\mu > 1.5\,\mathrm{GeV}/c$ (was 2.2 GeV in Run I)
    $\Rightarrow$ $\sim 2\times$ yield for J/ψ in Run II

  ✓ $B_s \to J/\psi\,\phi \to [\mu\mu][KK]$

  ✓ $\Lambda_b \to J/\psi\,\Lambda \to [\mu\mu][p\pi]$

- Displaced track + lepton ($\ell + D$)
  - SVT: $d_0 > 120\,\mu m$ w/ $p_T > 2\,\mathrm{GeV}/c$
    $\mu^\pm$: $p_T > 1.5\,\mathrm{GeV}/c$
    $e^\pm$: $p_T > 4\,\mathrm{GeV}/c$

  ✓ $B_s \to D_s\ell\nu \to [\phi\pi]\ell\nu \to [[KK]\pi]\ell\nu$

  ✓ $\Lambda_b \to \Lambda_c\ell\nu \to [pK\pi]\ell\nu$

- Two-track trigger
  - SVT: $d_0 > 100\,\mu m$ w/ $p_T > 2\,\mathrm{GeV}/c$

  ✓ $D^0 \to KK, K\pi, \pi\pi$

  ✓ $D_s^\pm \to \phi\pi \to [KK]\pi$

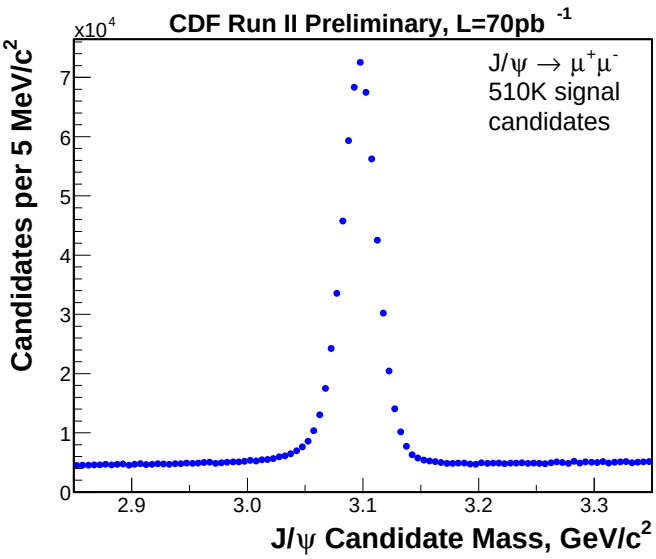
  ✓ $B^0 \to \pi\pi, K\pi$ $B_s \to KK, K\pi$ $\Lambda_b \to p\pi(K)$

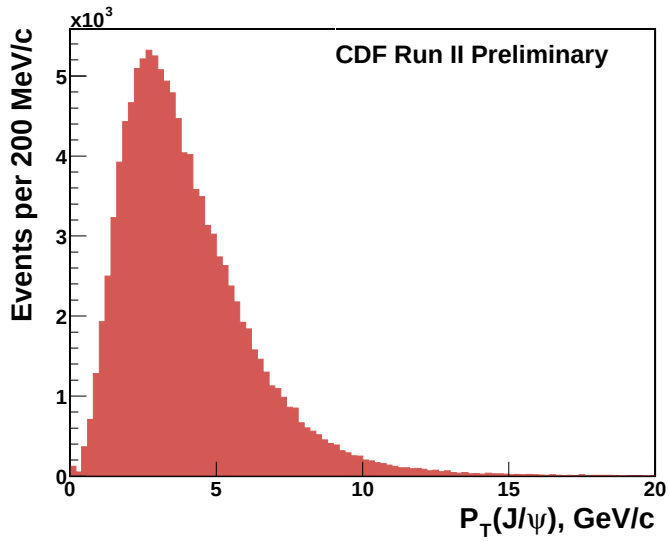
  ✓ $B_s \to D_s\pi \to [\phi\pi]\pi \to [[KK]\pi]\pi$

  ✓ $\Lambda_b \to \Lambda_c\pi \to [pK\pi]\pi$

Di-Muon sample

- J/ψ, $\psi(2S)$, Υ, ...
  - J/ψ production





  - $\sim 0.5M$ $J/\psi \to \mu\mu$ in $70\,\mathrm{pb}^{-1}$
  - all $p_T(J/\psi)$ range now

    $\to$ detector studies

    $\to$ $\mathrm{d}\sigma(\text{direct } J/\psi)/\mathrm{d}p_T$

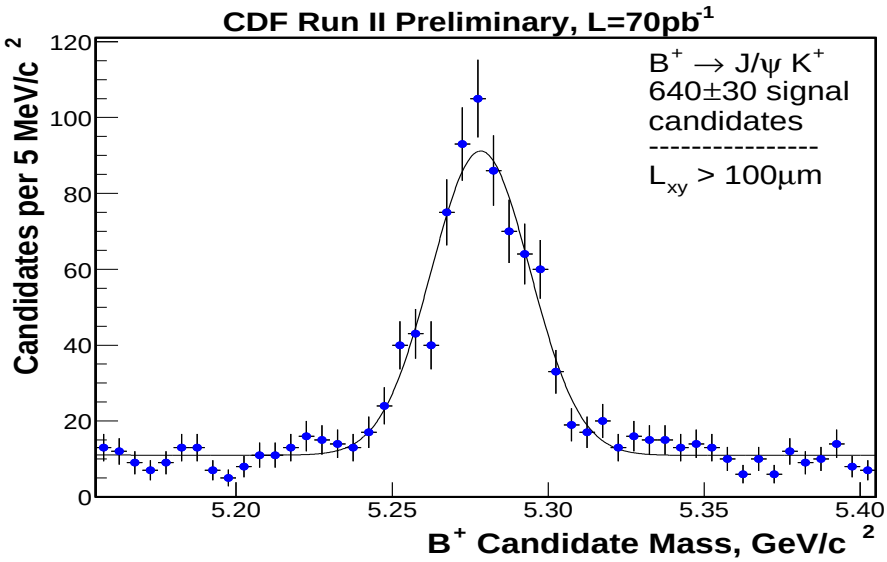
    $\times 50$ higher than prediction (Run I)

    $\to$ J/ψ polarization

    $> 2\sigma$ discrepancy between prediction and Run I data

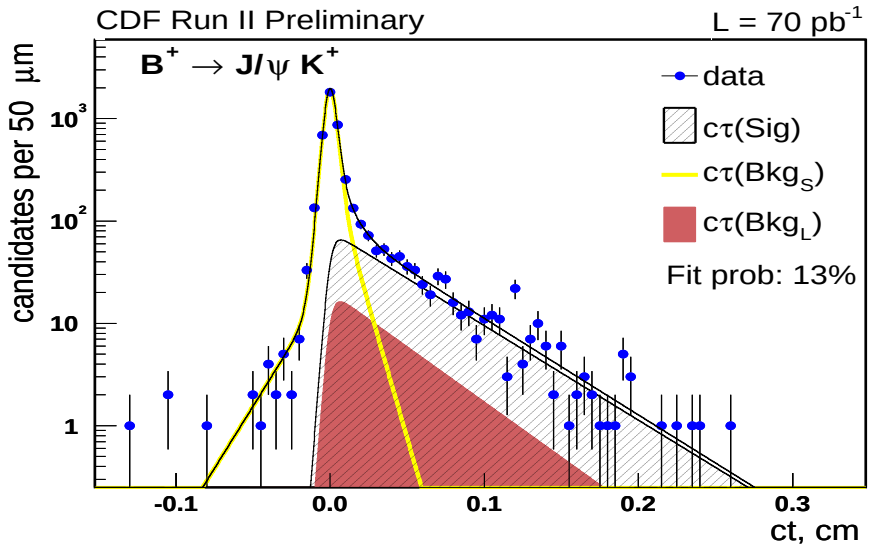
Exclusive B^+, B^0, B_s sample from di-muon

- $B^+ \to J/\psi\, K^+ \to [\mu\mu] K^+$
  - 1st. steps towards $B_c^+ \to J/\psi\, \pi^+$



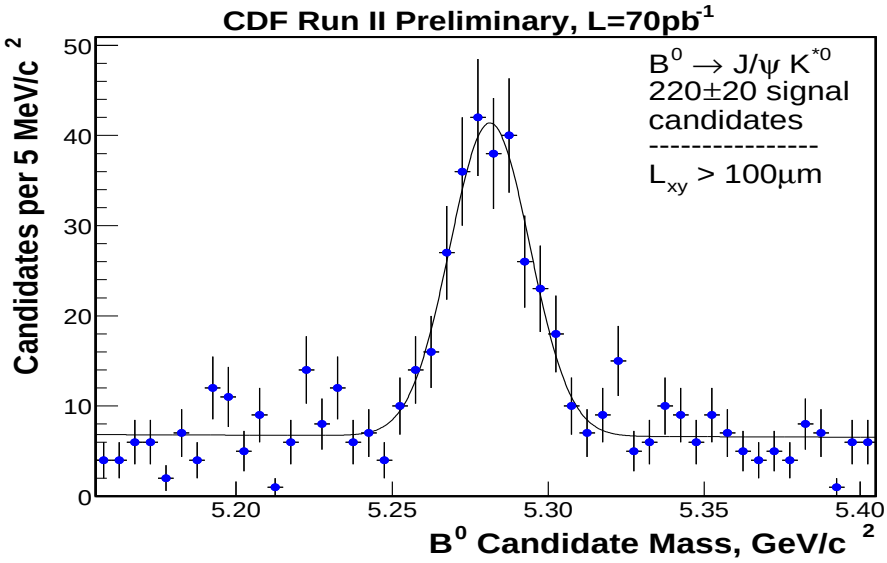
~640 in $70\,\mathrm{pb}^{-1}$

$\to\ m(B^+) = 5280.6 \pm 1.7 \pm 1.1\,\mathrm{MeV}$ (Preliminary $\sim 18\,\mathrm{pb}^{-1}$)



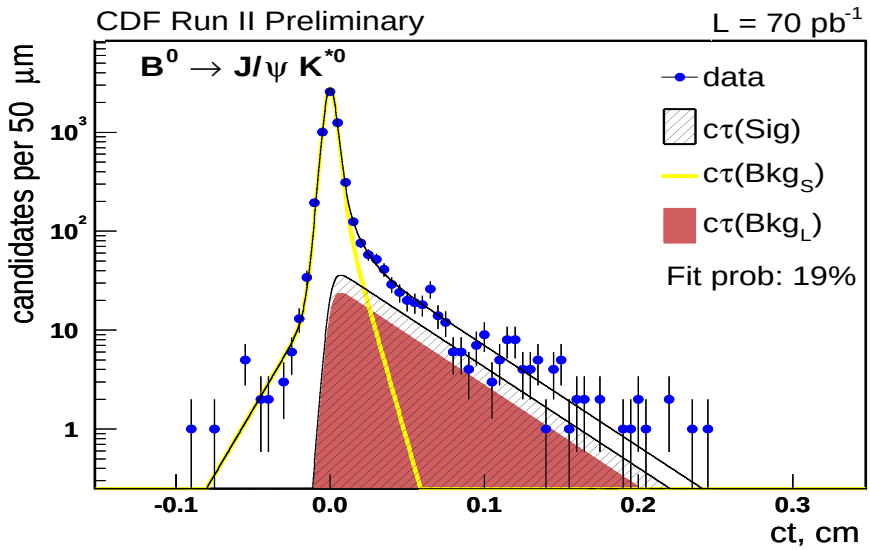
$\to\ \tau(B^+) = 1.57 \pm 0.07 \pm 0.02\,\mathrm{ps}$ (CDF II preliminary)

- $B^0 \to J/\psi\, K^{*0} \to [\mu\mu][K\pi]$
  - control for $B^0 \to J/\psi\, K_S$, $B_s^0 \to J/\psi\, \phi$



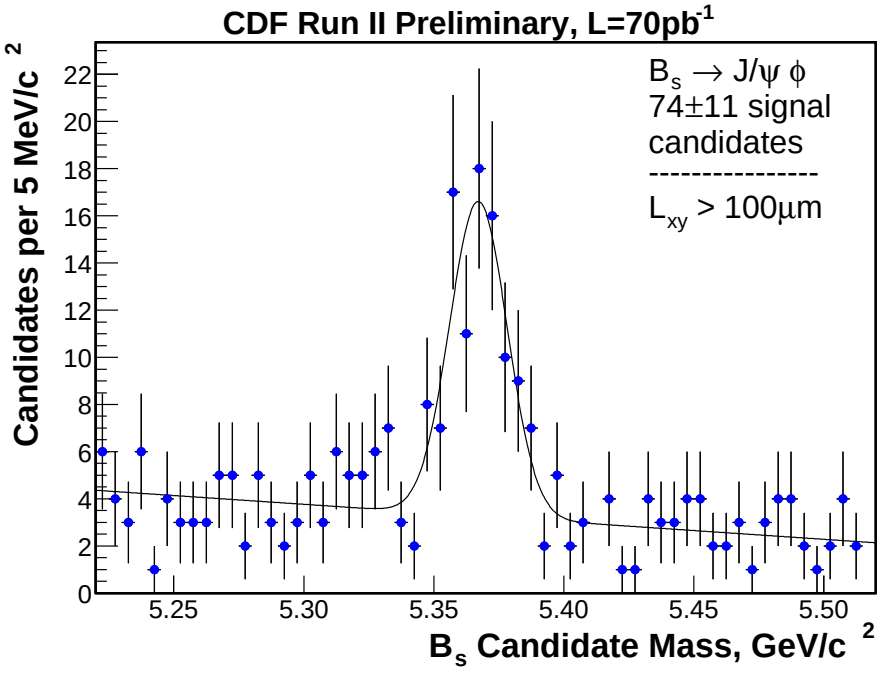
~220 in $70\,\mathrm{pb}^{-1}$

$\to\ m(B^0) = 5279.8 \pm 1.9 \pm 1.4\,\mathrm{MeV}$ (Preliminary $\sim 18\,\mathrm{pb}^{-1}$)



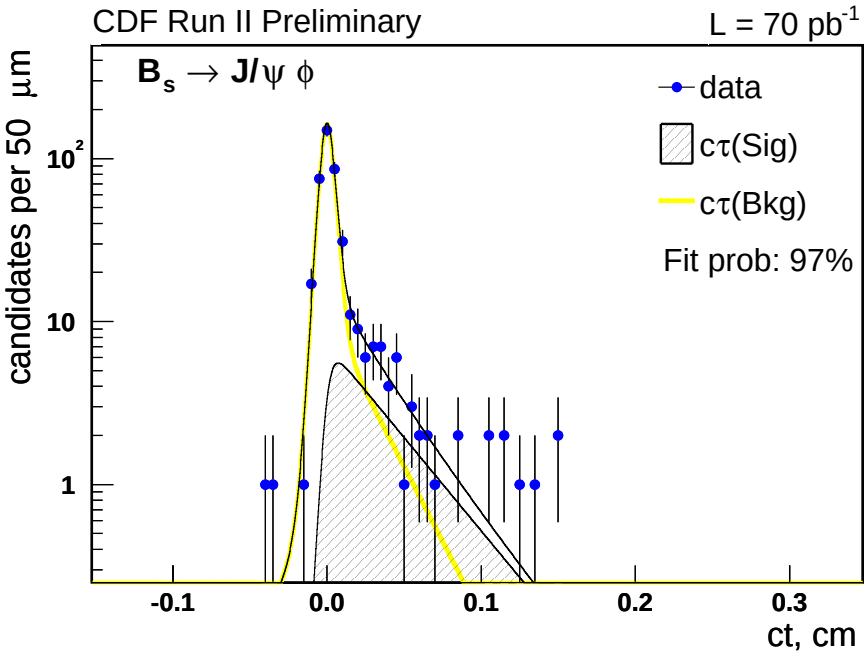
$\to\ \tau(B^0) = 1.42 \pm 0.09 \pm 0.02\,\mathrm{ps}$ (CDF II preliminary)

- $B_s \to J/\psi\,\phi \to [\mu\mu][KK]$
  - Golden sample for $\Delta\Gamma_s$ measurement



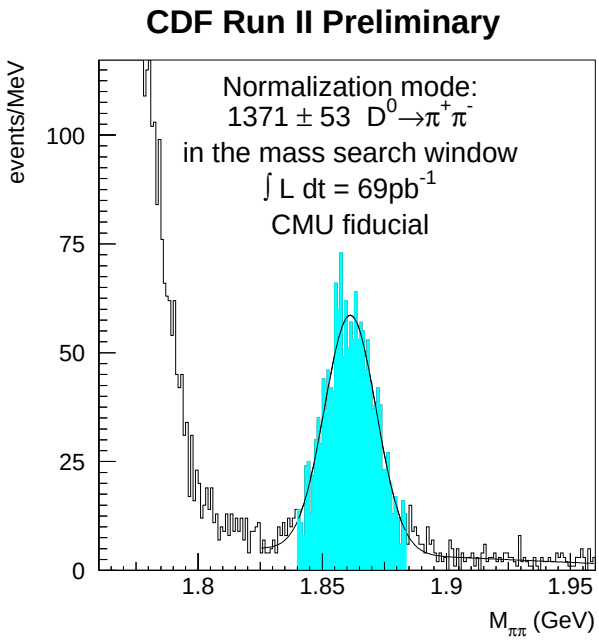
~74 in $70\,\mathrm{pb}^{-1}$

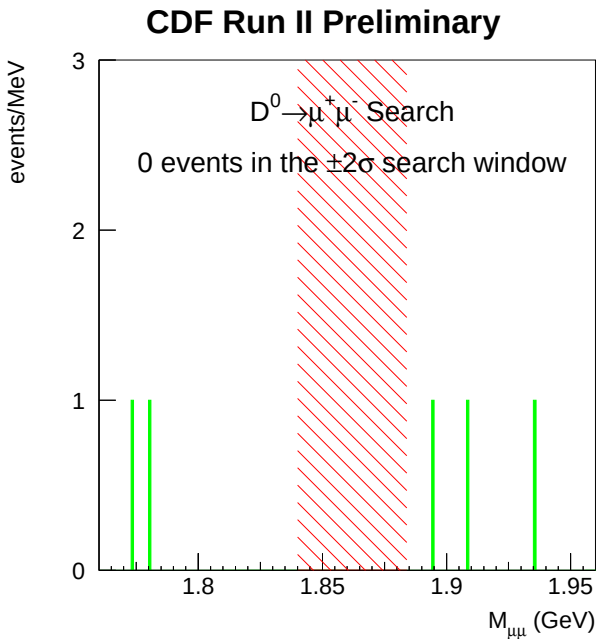
$\to\ m(B_s) = 5360.3 \pm 3.8^{+2.1}_{-2.9}\,\mathrm{MeV}$ (Preliminary $\sim 18\,\mathrm{pb}^{-1}$)



$\to\ \tau(B_s) = 1.26 \pm 0.20 \pm 0.02\,\mathrm{ps}$ (CDF II preliminary)

- Search for the FCNC Decay $D^0 \to \mu\mu$
  - Strongly supressed in SM: $\mathrm{Br} \sim 10^{-13}$

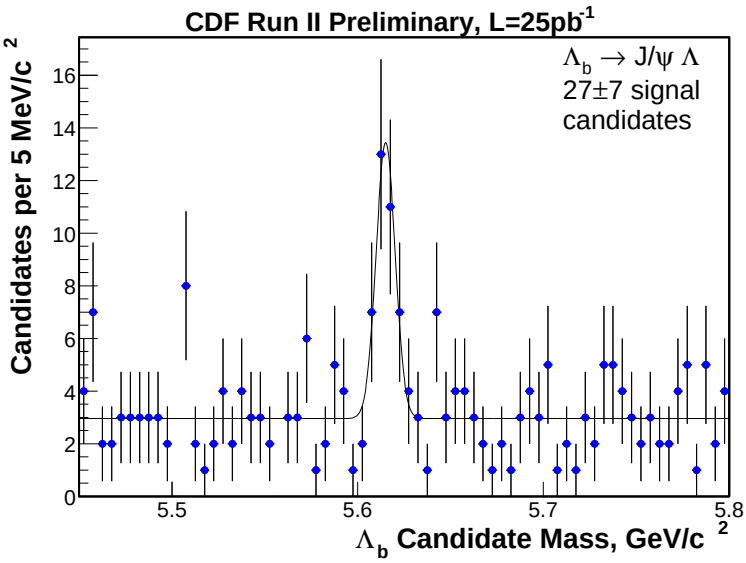




$\to \mathrm{Br}(D^0 \to \mu\mu) < 2.4 \times 10^{-6}$(90%CL) (CDF II preliminary)

$\Leftrightarrow$ best limit: $\mathrm{Br} < 4.1 \times 10^{-6}$(90%CL)

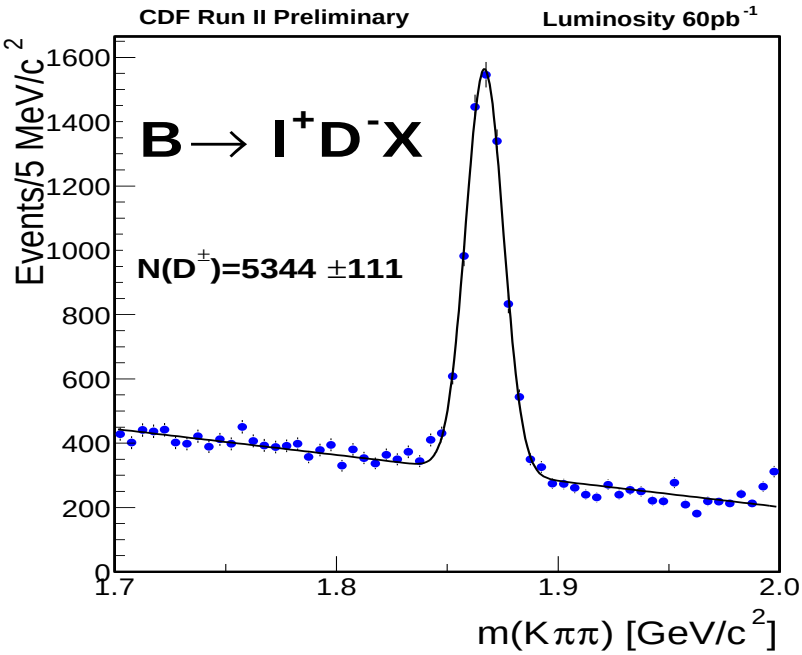
- $\Lambda_b \to J/\psi\Lambda \to [\mu\mu][p\pi]$



~27 in $25\,\mathrm{pb}^{-1}$

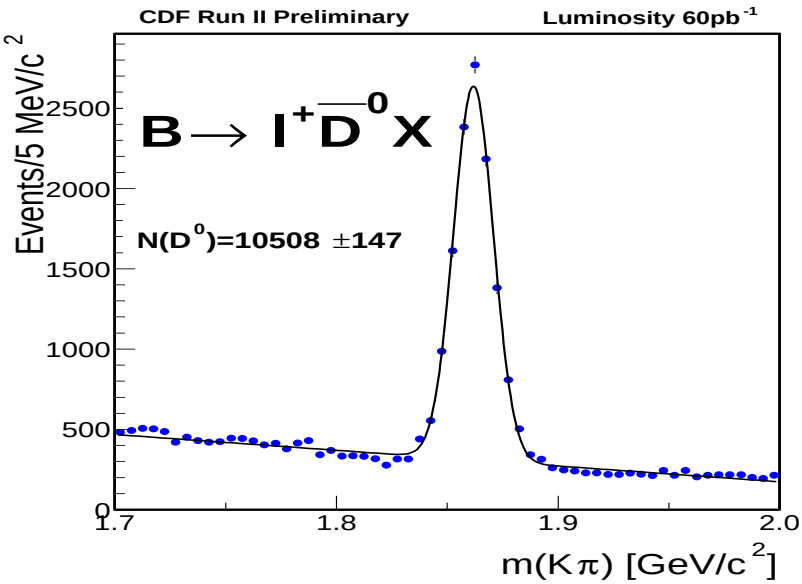
Displaced track + lepton ($\ell + D$)

- B samples from lepton+displaced track
  - $\rightarrow$ Higher statistics sample
  - $\rightarrow$ Lifetime measurement
    - Inclusive $B \rightarrow \ell^{\pm} D^{\mp} X$



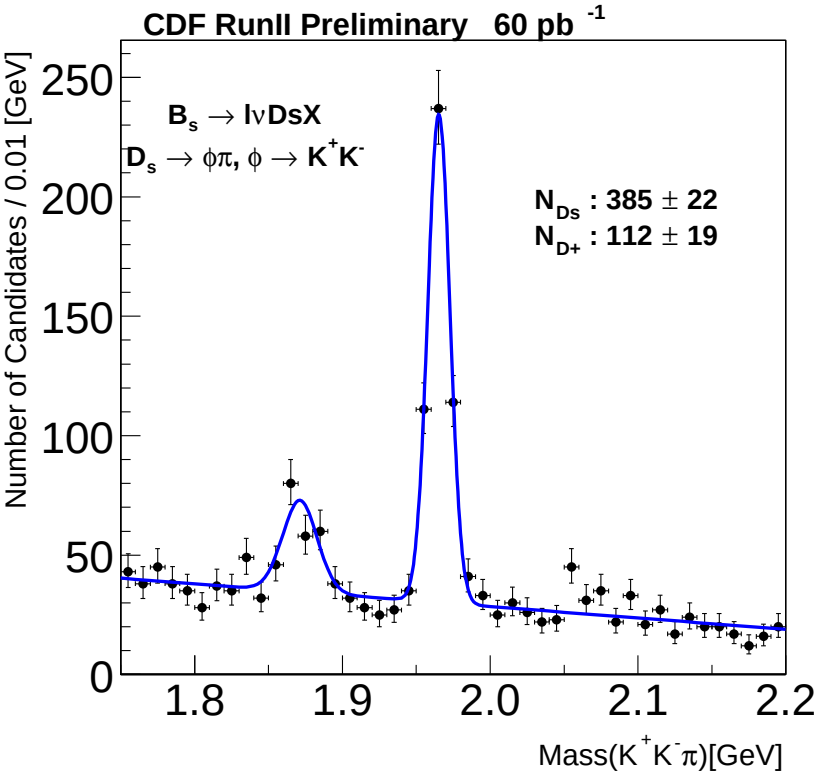
~5K $D^{\pm}$ in 60 pb^{-1}

- Inclusive $B \rightarrow \ell D^0 X$



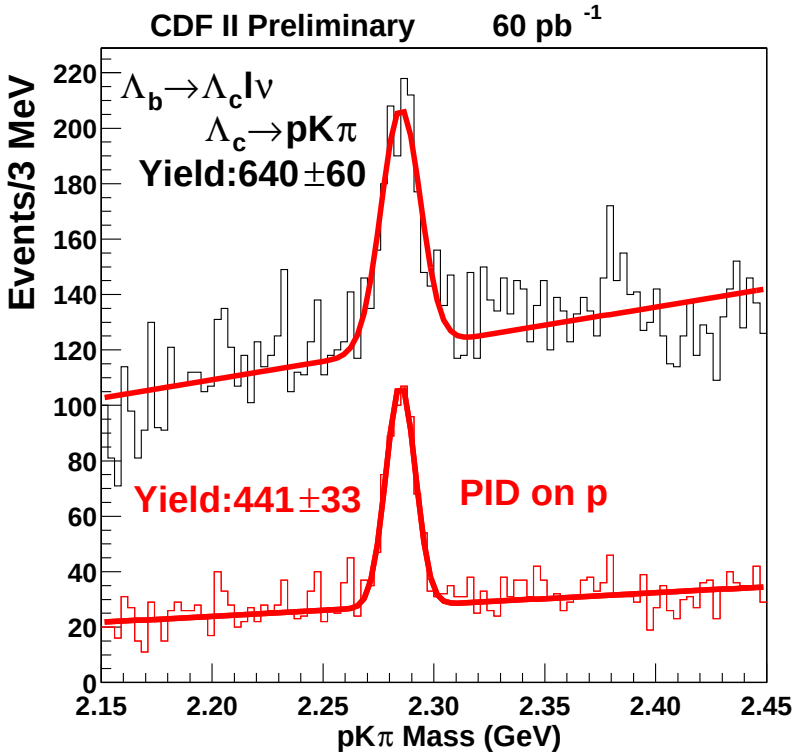
~10K D^0 in 60 pb^{-1}

- $B_s \to D_s \ell\nu \to [\phi\pi]\ell\nu \to [[KK]\pi]\ell\nu$



~385 D_s
~112 D^+ in 60 pb^{-1}

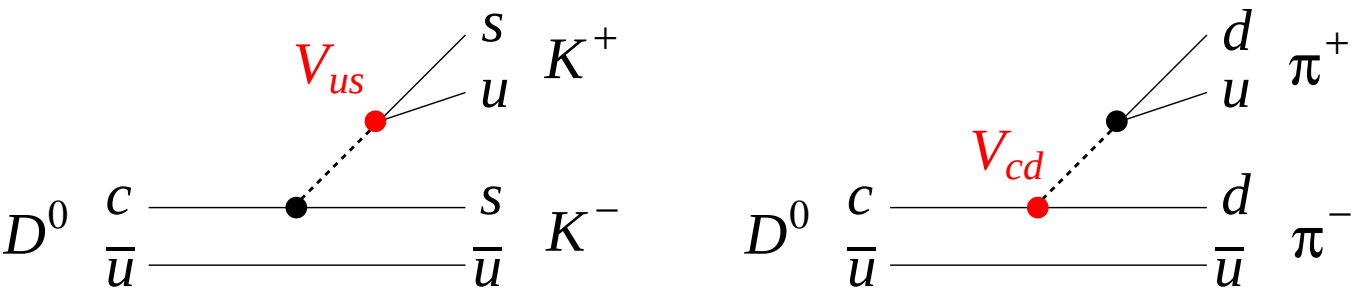
- $\Lambda_b \to \Lambda_c \ell\nu \to [pK\pi]\ell\nu$



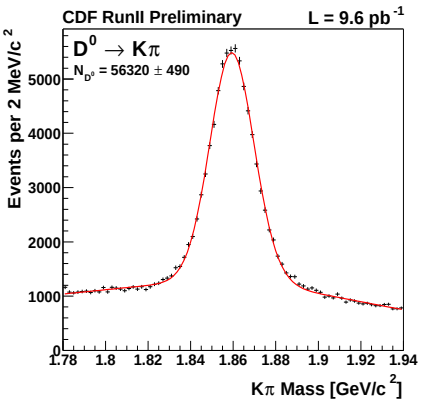
~441 Λ_c in 60 pb^{-1}

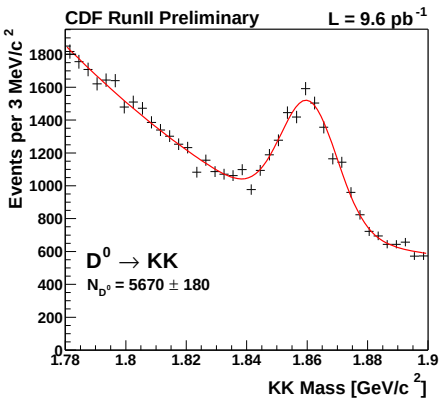
Two-track trigger

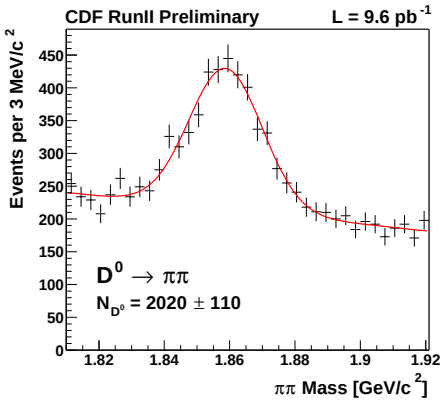
- Charm Mesons from two-track trigger sample
  - Cabibbo suppressed D^0 decays



$D^0 \to K\pi$ $D^0 \to KK$ $D^0 \to \pi\pi$







~56K ~6K ~2K

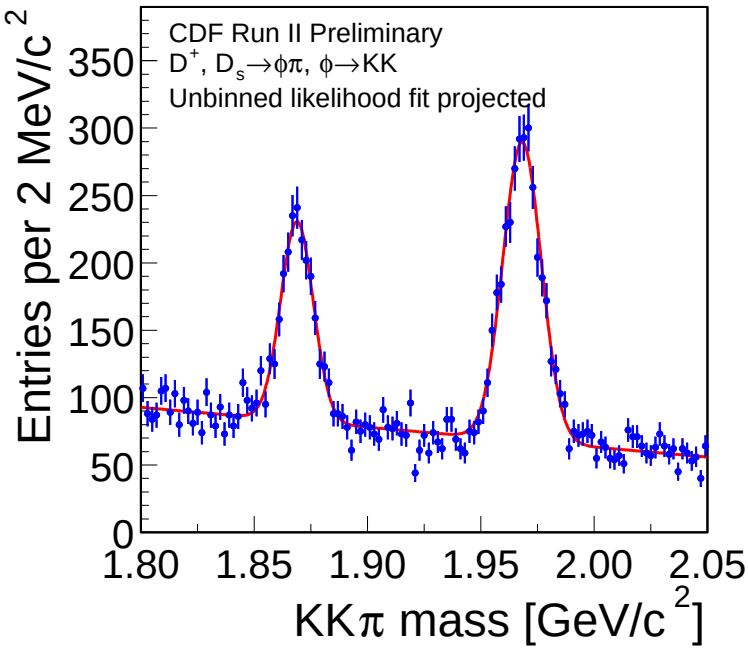
in 9.6pb^{-1}

$$\to \frac{\mathrm{Br}(D^0 \to K^+K^-)}{\mathrm{Br}(D^0 \to K^-\pi^+)} = 11.17 \pm 0.48 \pm 0.98\%$$

$$\to \frac{\mathrm{Br}(D^0 \to \pi^+\pi^-)}{\mathrm{Br}(D^0 \to K^-\pi^+)} = 3.37 \pm 0.20 \pm 0.16\%$$

- Results from only $9.6\,\mathrm{pb}^{-1}$
- competitive with the best measurements

- $D_s^{\pm} - D^{\pm}$ mass difference
  - $D_s/D^+ \to \phi\pi \to [KK]\pi$
  - same final state, same trigger



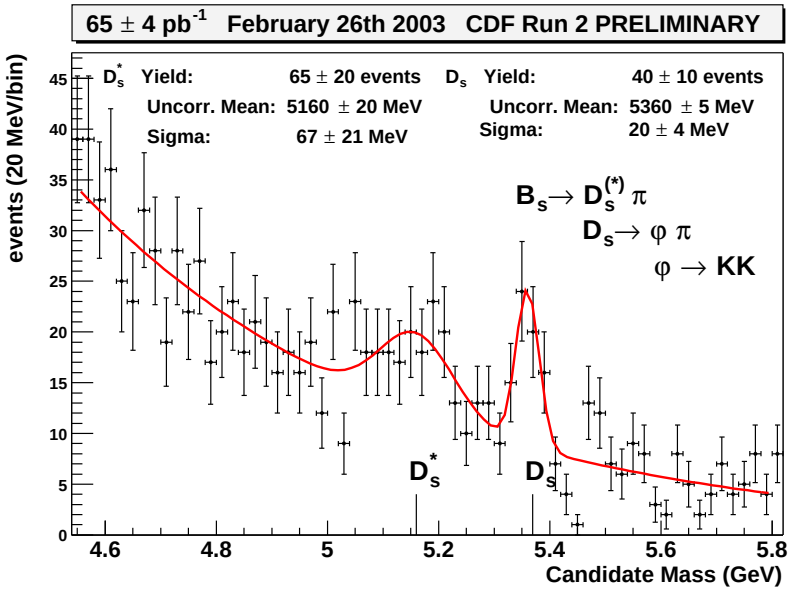
only $11.6\,\mathrm{pb}^{-1}$

~2400 D_s
~1400 $D^{\pm}$

$$M(D_s^{\pm}) - M(D^{\pm}) = 99.28 \pm 0.43_{\mathrm{stat}} \pm 0.27_{\mathrm{syst}}\ \mathrm{MeV}$$
$$\Leftrightarrow (\mathrm{PDG}: 99.2 \pm 0.5\ \mathrm{MeV})$$

- Competitive with PDG average
- First CDF II paper!!

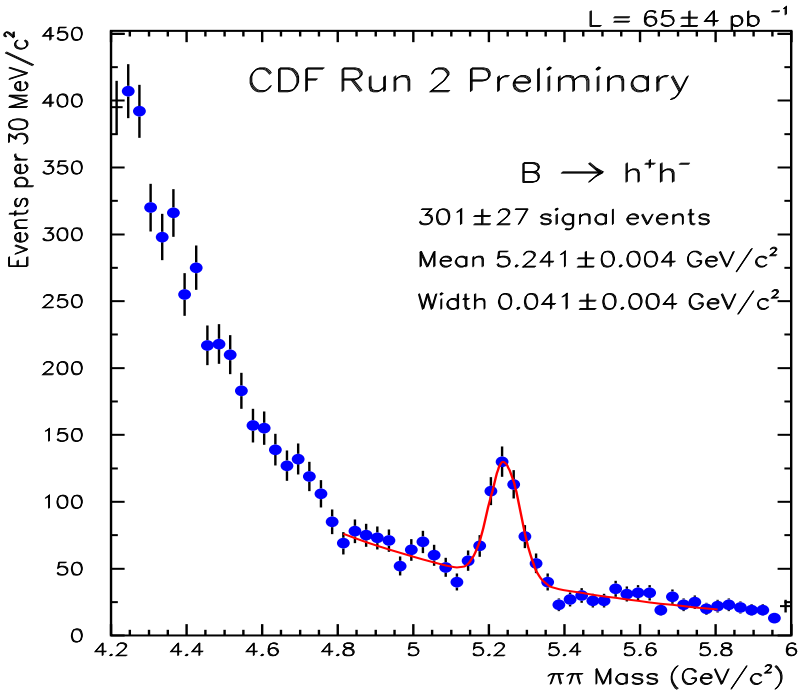
- B sample from 2-track trigger
  - $B_s \to D_s^{(*)-}\pi^+$ w/ $D_s \to \phi\pi \to [KK]\pi$
    - Golden sample for B_s oscillation



~40 $B_s \to D_s\pi$
~65 $B_s \to D_s^*\pi$

in $65\,\mathrm{pb}^{-1}$

- $B \to h^+h^-$ $[B_d(B_s) \to K\pi, \pi\pi(KK, K\pi)]$
  - $\sin 2\alpha$ in $B^0 \to \pi^+\pi^-$



~300 in $65\,\mathrm{pb}^{-1}$

Good S/N~1

Summary

- Top physics in Run IIa is at the process of reestablishing measurements of basic physics:
  - $t\bar{t}$ Cross Section
  - Top quark mass

  and ready for extensions Run I top physics with larger samples.
- Displaced track trigger at CDF
  - a great success!
  - access to $B_S - \bar{B}_S$ oscillations via B_S hadronic decay
- Lots of Charm, Bottom, and Top at CDF in the next years!!

Seven years after the conclusion of Run I,
CDF is back!