Results from the CDF Experiment at Tevatron Run II

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KEK

Hadron Collider Roles

Higher energy than e^+e^- colliders.

Larger production rates : strong interactions.

Important discoveries made at hadron colliders :

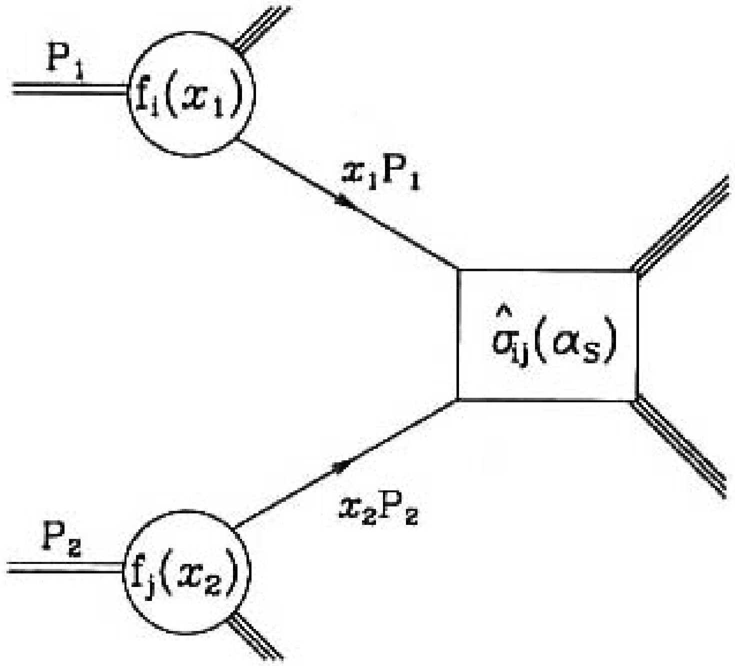
Where	Name	beams	When	$\sqrt{s}$ (GeV)
CERN	ISR	pp	1970's	50
CERN	SPS	$p\bar{p}$	1980's	540 - 630
FNAL	Tevatron	$p\bar{p}$	1985 -	1800 - 2000
CERN	LHC	pp	2007 -	14000

- CERN ISR : rising pp cross section
- CERN SPS : $W^{\pm}$, Z^0 bosons
- Tevatron : top quark

Future :
- Tevatron/LHC : higgs?

Not just new particle searches, but also precision measurements.

$\bar{p}p$ collisions at 1.8 - 2.0 TeV



beam energy $= 900$ GeV, $\sqrt{s} = 1.8$ TeV

luminosity $\mathcal{L}$, cross section σ :

$$\text{Rate} \quad \frac{dN}{dt} = \mathcal{L}\,\sigma$$

Process	Approx. σ	rate at 10^{31}	$N_{\rm ev}/10^7$ s
inel. coll.	50 mb	0.5 MHz	∞
jets	1 mb	10 kHz	many many
b quarks	20 μb	200 Hz	2×10^9
$W^+ \to \ell^+ \nu$	1 nb	0.01 Hz	10^5
top quarks	5 pb	10^{-4} Hz	2000

Rates at inst. luminosity $\mathcal{L} = 1 \times 10^{31}$ cm^{-2} s^{-1}.

Tevatron accelerator history

1970's	400 GeV Main Ring
1980's	800 GeV Tevatron
1985	collider at $\sqrt{s} = 1.6$ TeV
1987	collider at $\sqrt{s} = 1.8$ TeV
1999	150 GeV Main Injector replaces Main Ring
2000 -	collider at $\sqrt{s} = 1.96$ TeV

Collider Detector at Fermilab : CDF

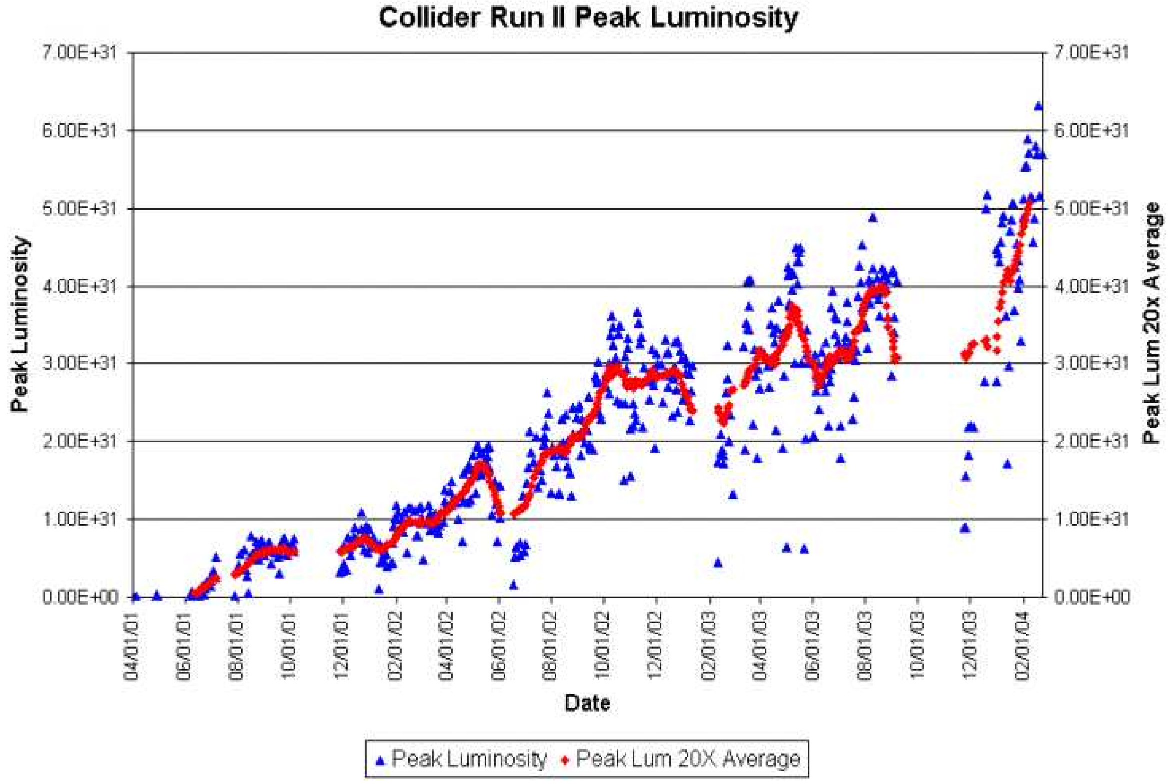
1979	Conceptual Design Report
1985	Central Calorimeters, Vertex TPC
	First collisions, $\sim$ 20 events recorded.
1986	CDF detector construction complete.
1987	First run. 25 nb^{-1} (some results)
1988-89	Physics run. 4.5 pb^{-1}.
1992-93	Run Ia. 20 pb^{-1}.
1994-96	Run Ib. 90 pb^{-1}.
1996-00	Upgrade to CDF Run-II detector.
2001-05	Run IIa. 2 fb^{-1} expected.
2005-09?	Run IIb. 5 - 9 fb^{-1} in total.

Run II started in March 2001

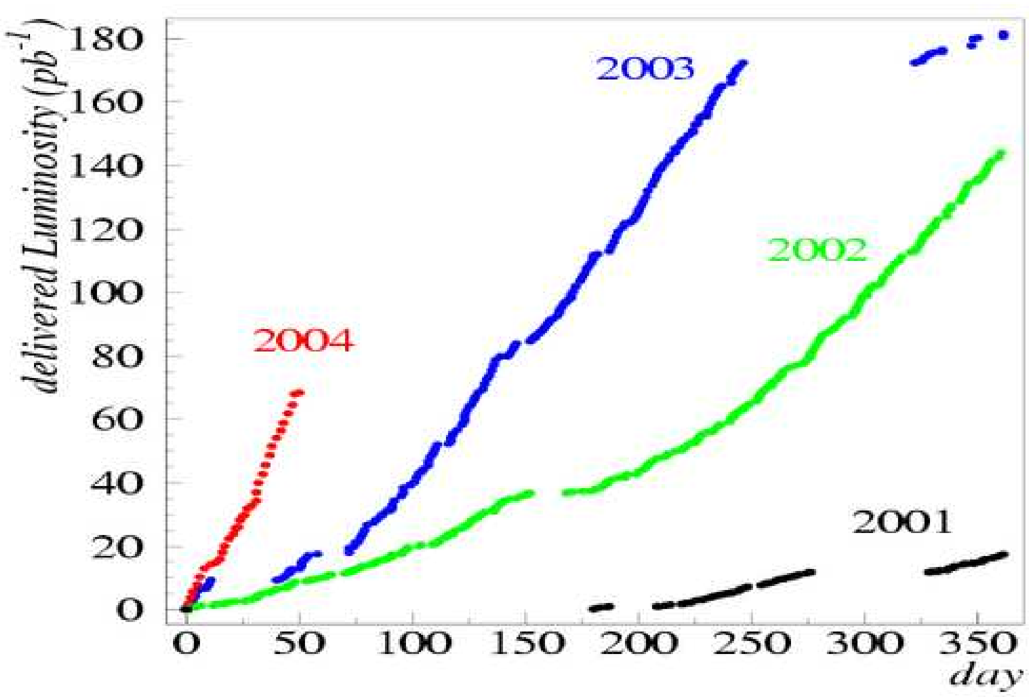
- Increased CM energy : 1.8 $\rightarrow$ 1.96 TeV
- 36 $\times$ 36 bunches of p's and $\bar{p}$'s
  $\Rightarrow$ Beam crossing every 400 ns (was 3600 ns).
- New 150 GeV Main Injector
  $\Rightarrow$ Higher $\bar{p}$ production rate. More p's and $\bar{p}$'s to Tevatron.

Record luminosity : 7.2×10^{31} cm^{-2} s^{-1} (Feb 27, 2004). Design is 8×10^{31}, so almost there !

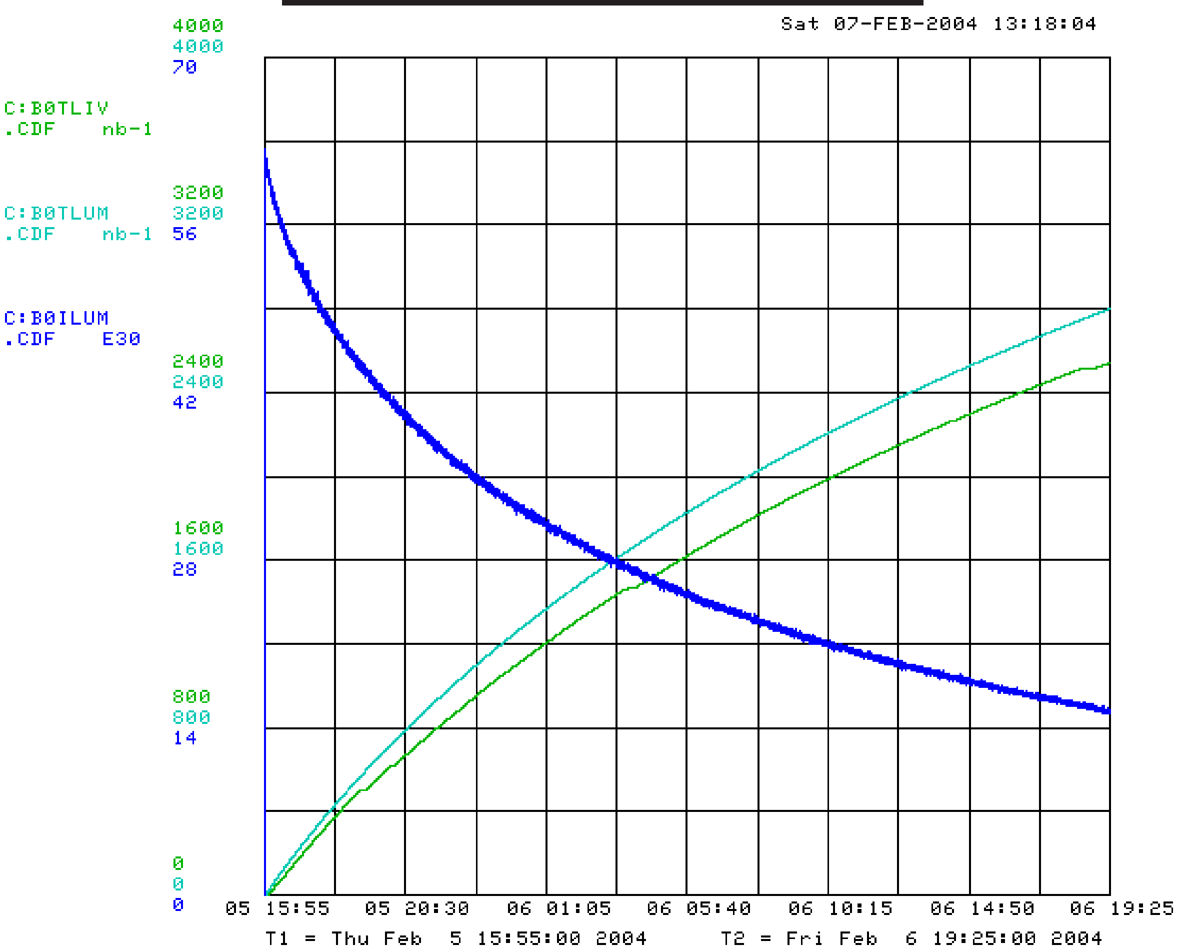
Luminosity : now consistently above 5×10^{31} cm^{-2} s^{-1}, $\geq 3\times$ best in Run I.



So far 400 pb^{-1} delivered, 320 pb^{-1} recorded.



Store : # 3219



Initial luminosity : 5.8×10^{31} cm^{-2} s^{-1}.

Duration : 27.5 hours.

Integrated luminosity delivered : 2.8 pb^{-1}.

Integrated luminosity recorded : 2.5 pb^{-1}.

Store # 3219 setup efficiency

Shot Summary, store 3219, Thu Feb 05 13:29:26 CST 2004, Initial Stack Size = 173.7875 E10

	Proton Intensity E9	Step Efficiency %	Cumulative Efficiency %	Pbar Intensity E9	Step Efficiency %	Cumulative Efficiency %
Accumulator				1474.00		
MI 8Gev	10412.23			1421.52	96.44	96.44
MI 150Gev	10391.72	99.80	99.80	1425.68	100.29	96.72
Coalescing				1343.31	94.22	91.13
Inject Protons	9578.31		91.99			
Pbar Injection porch	9492.01	99.10	91.16			
Inject Pbars	9169.07	96.60	88.06	1306.81	97.28	88.66
Before Ramp	9163.90	99.94	88.01	1266.24	96.90	85.91
Flattop	8741.13	95.39	83.95	1194.42	94.33	81.03
Squeeze	8678.48	99.28	83.35	1208.24	101.16	81.97
Initiate Collisions	8658.93	99.77	83.16	1194.96	98.90	81.07
Remove Halo	8518.28	98.38	81.81	1175.89	98.40	79.78
HEP	8516.58	99.98	81.79	1176.60	100.06	79.82
Initial Luminosity	61.89	CDF		55.60	DZero	
Shot Setup Time	146.20	min				

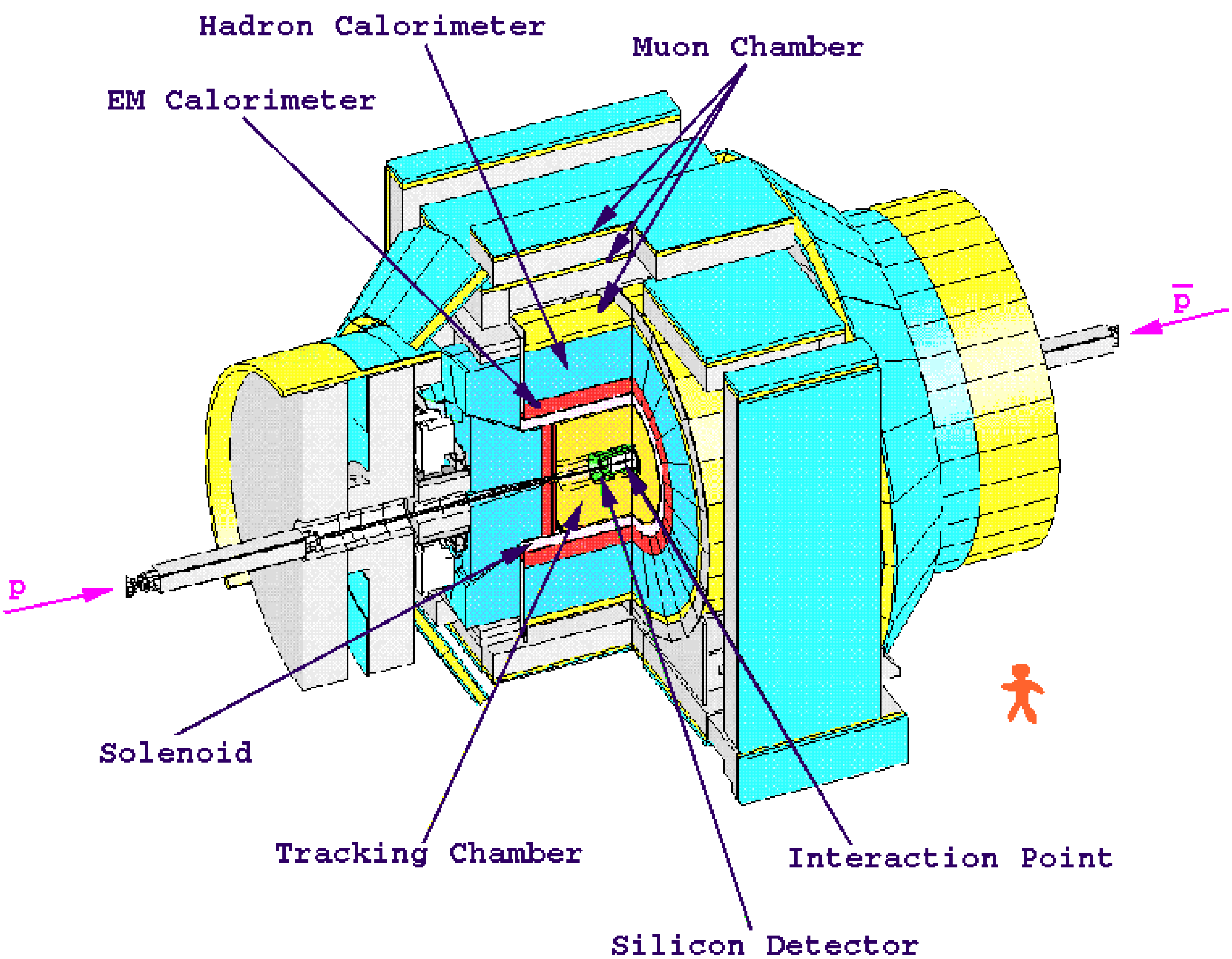
8.5×10^{12} protons, 1.2×10^{12} antiprotons.

80% efficiency for transferring antiprotons from the Accumulator to the Tevatron for collisions !

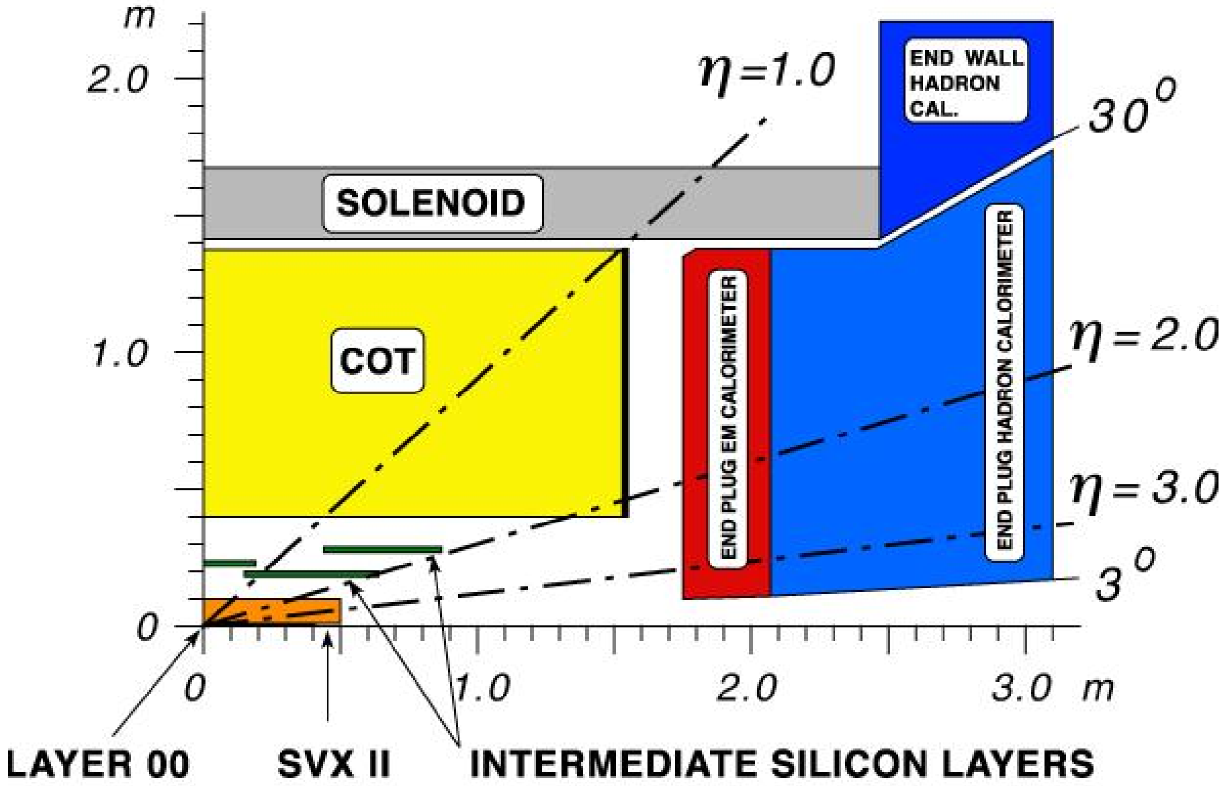
Also :
Much improved stability/reliability in recent weeks.

2004 goal is $230 - 310$ pb^{-1} delivered.
Thus far we are doing better than that.

Run-II CDF Detector



CDF-II Detector 1/4 slice



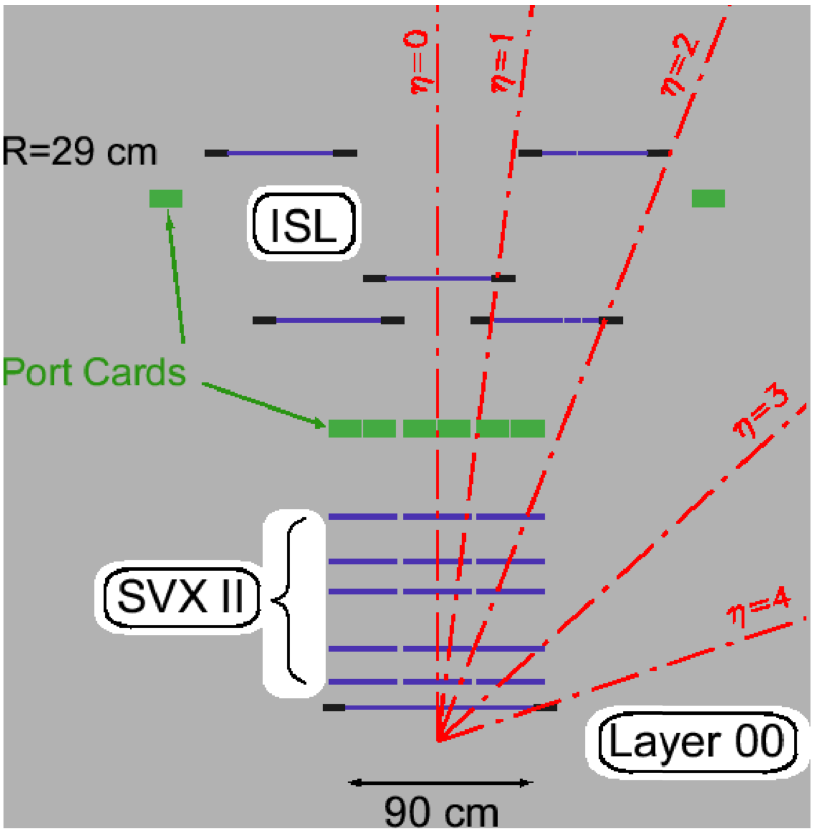
Everything inside the solenoid is new.

- Charged particle tracking

  Central Outer Tracker : 30 k sense wires.
  - $\sigma(p_T)/p_T = 0.0008\, p_T$ for $|\eta| < 1$.
  - Relativistic rise dE/dx.

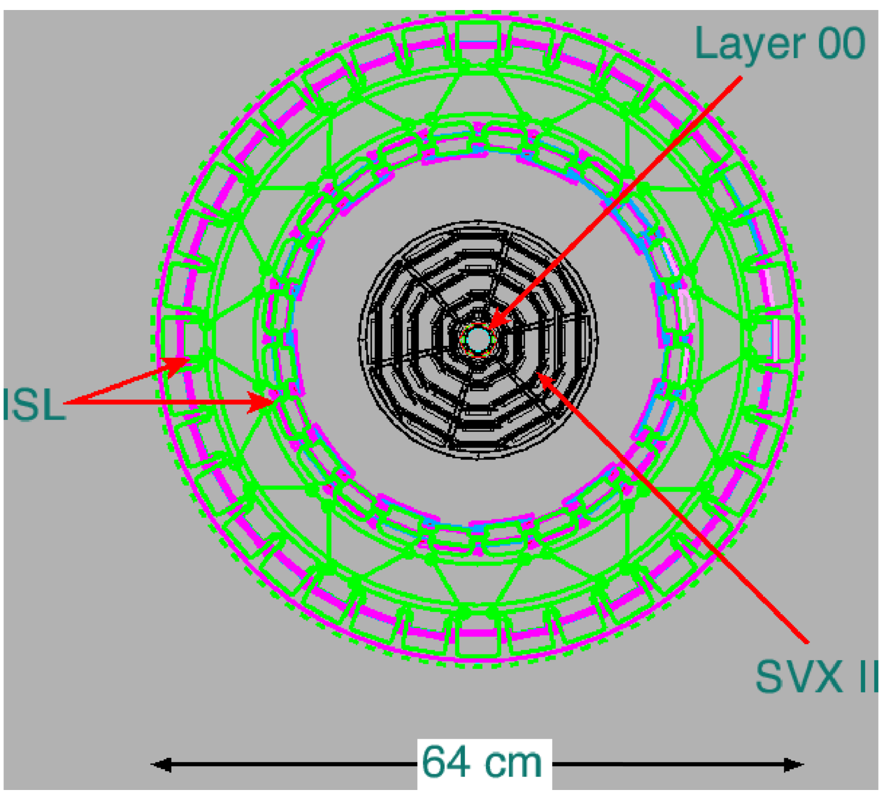
  SVX : 700 k channels (r-φ-z), 15 readouts per track.
  - $\sigma(P_T)/p_T = 0.004\, p_T$ for $1 < |\eta| < 2$.
- New scintillating plug calorimeter to $|\eta| < 3.6$.
  - electron ID.
- TOF particle ID, $|\eta| < 1$.
- Muon coverage increased by $\times 1.7$.
  - $p_T > 1.4$ GeV/c, $|\eta| < 1.5$.

Run-II silicon detector

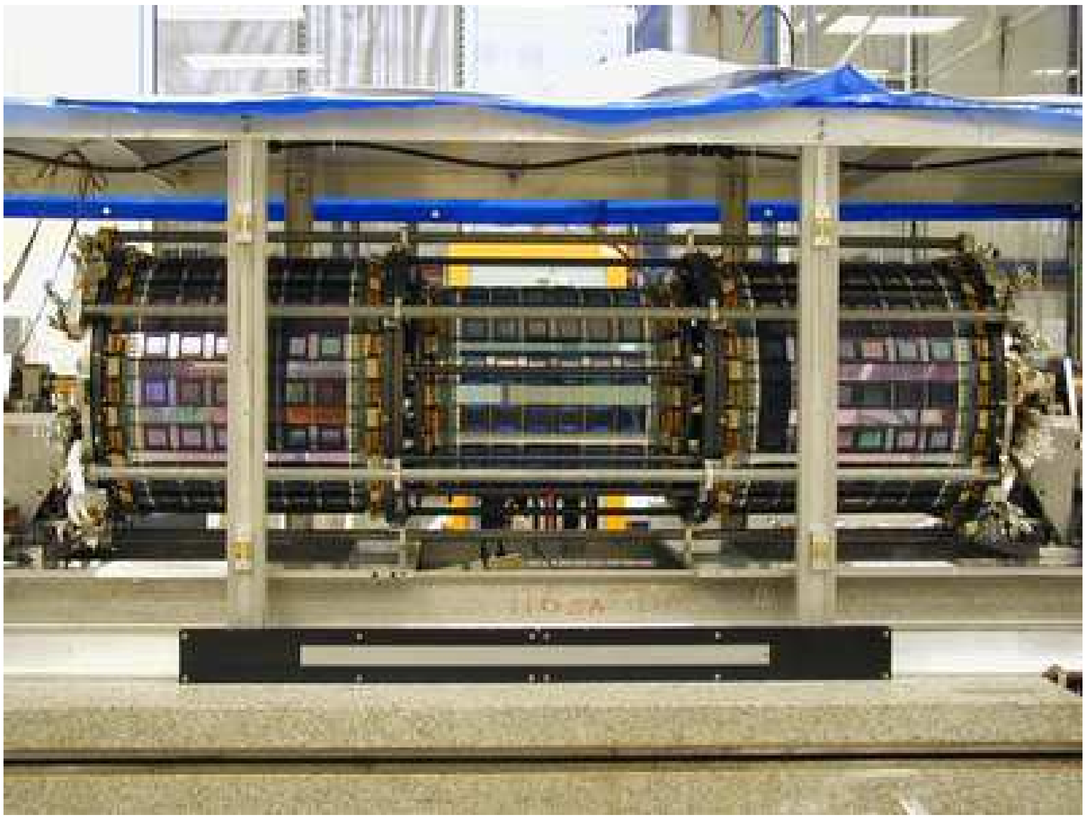


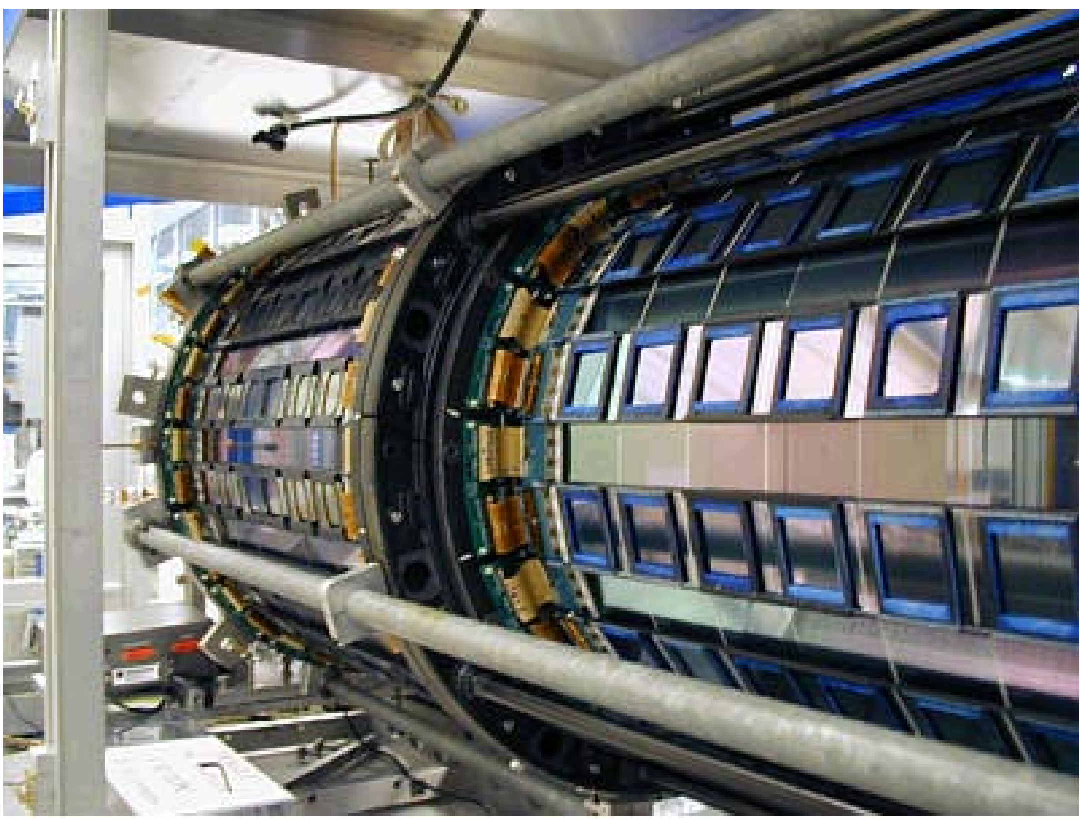
SVX :
Radii 2 cm to 11 cm:
5 layers
Double-sided,
90° and 1.2° stereo

ISL :
Radii 20 cm to 28 cm:
3 layers
sensor similar to SVX
$|\eta| < 2$

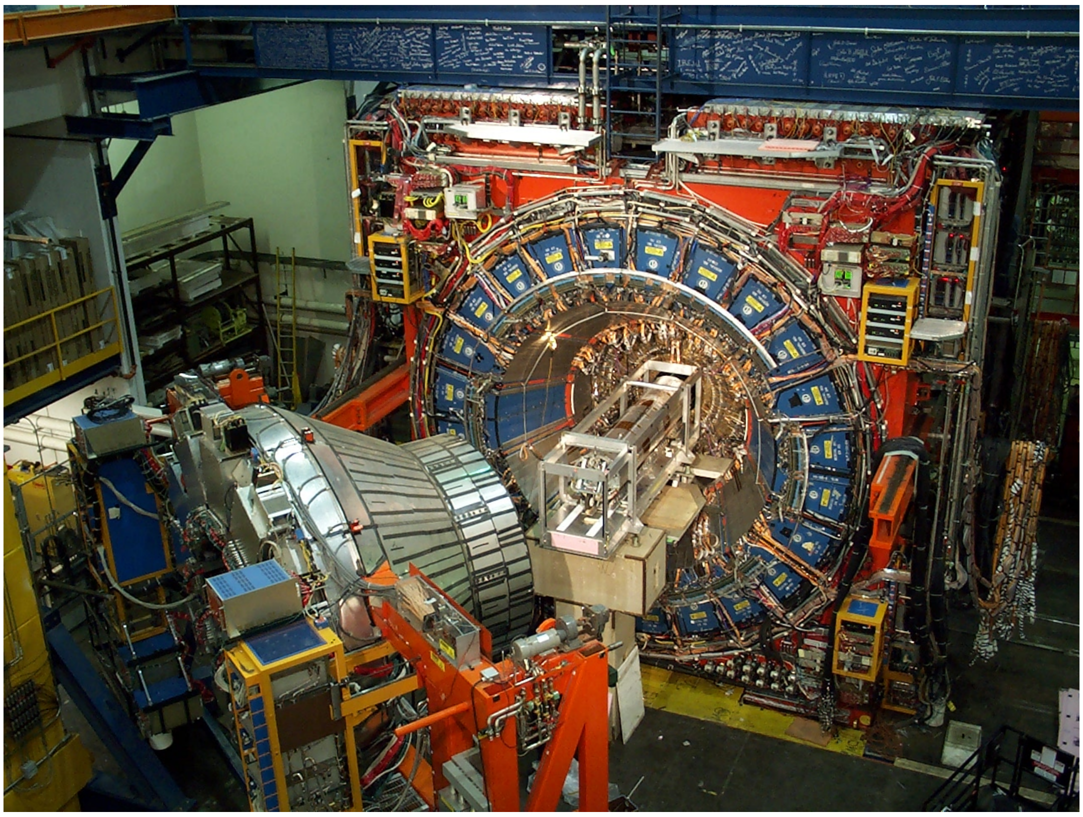


ISL detector

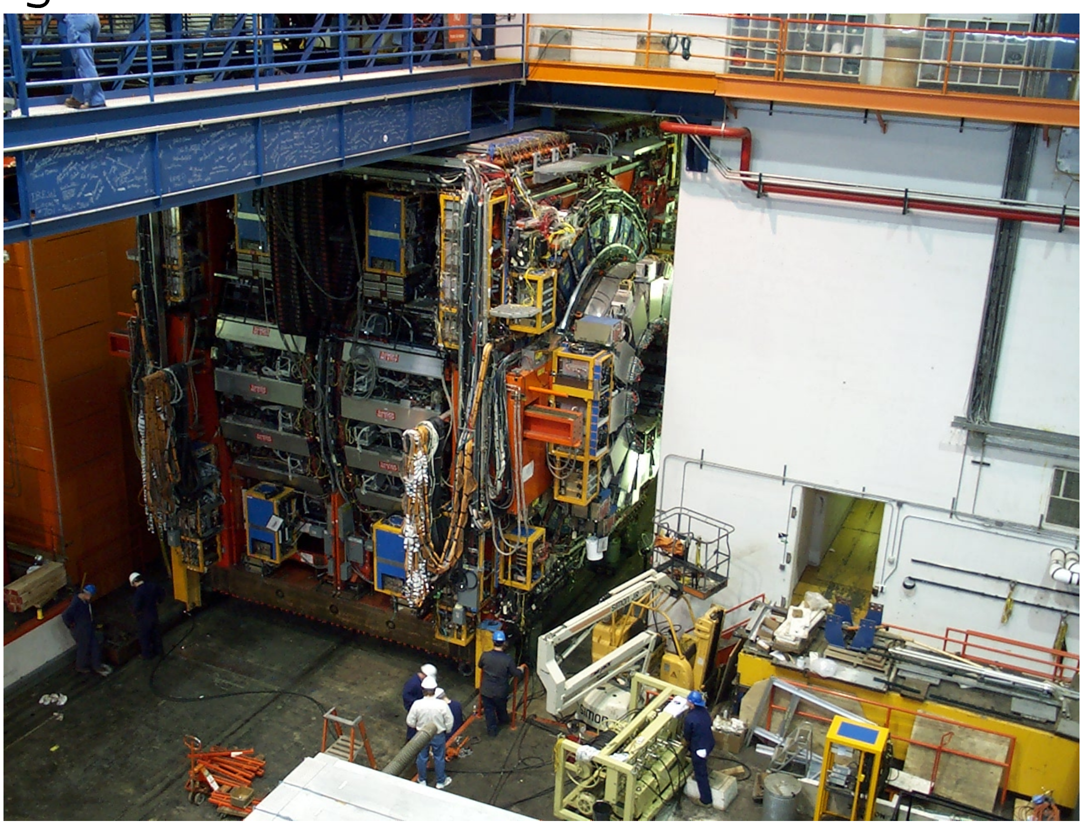




Installing the silicon detectors.



Rolling into the collision hall.



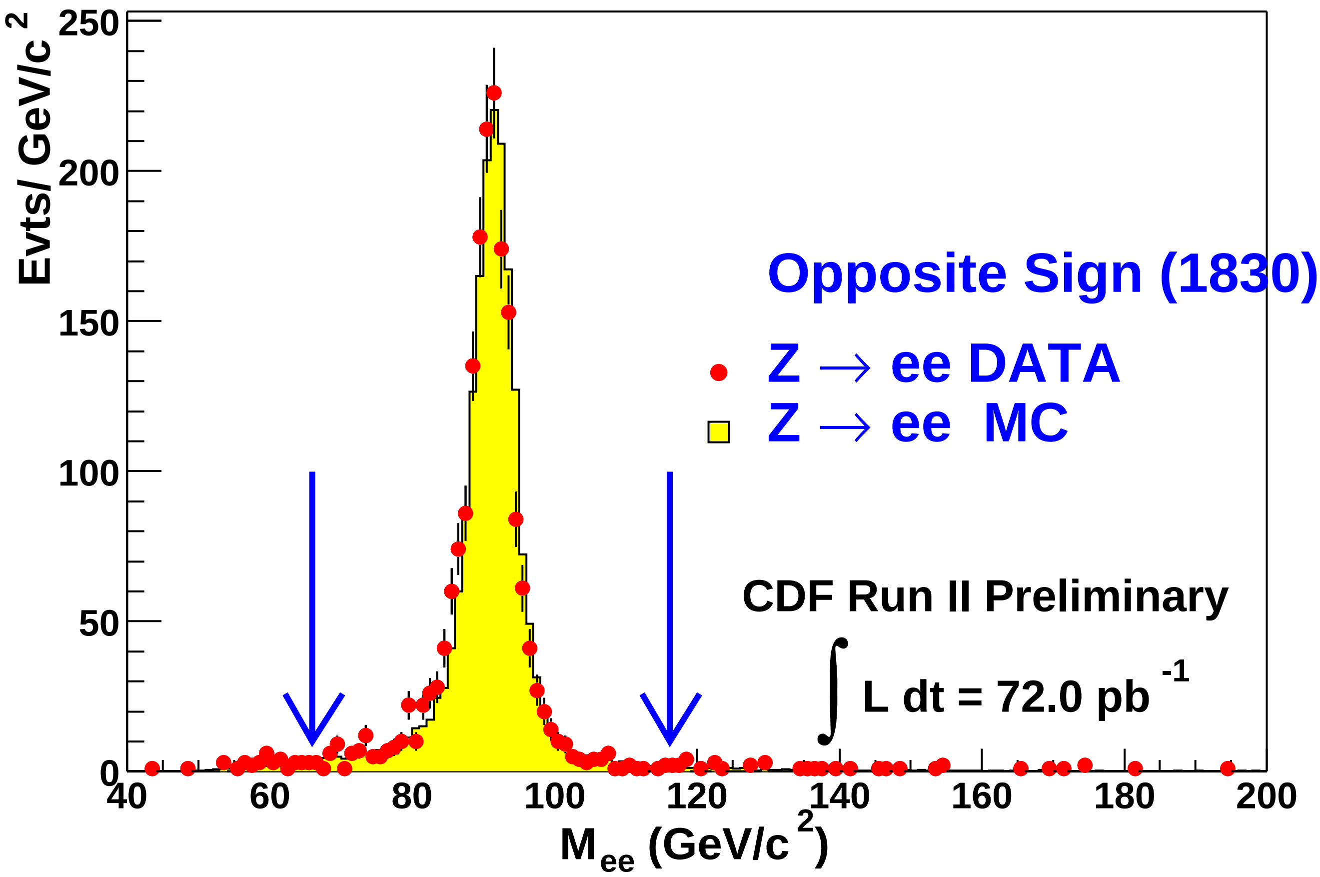
CDF Physics Program

Covers broad range of particle physics :

- Top quark
- Bottom and charm physics
- Electroweak physics
- QCD (jets, photons, heavy quarks ...)
- New particle searches (Higgs, SUSY, ...)

Today I cover only selected topics.

Run-II $Z^0 \to e^+e^-$



Production cross section :

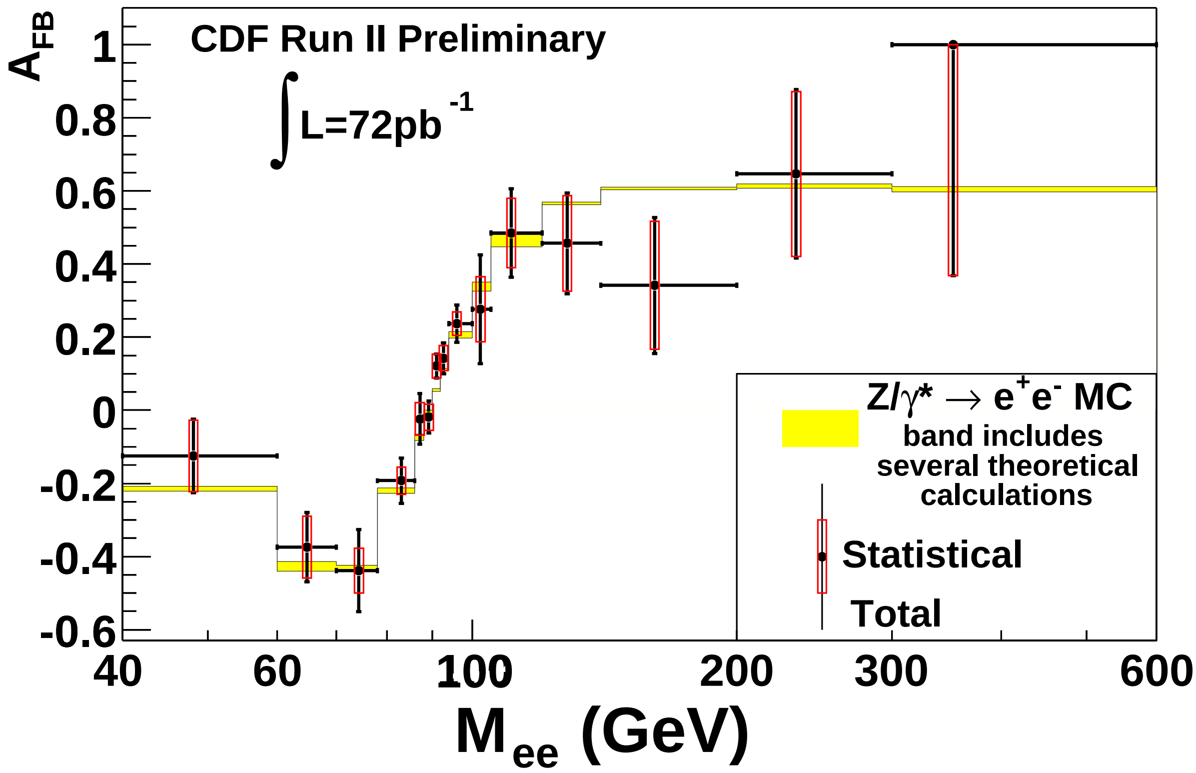
$$\sigma(\bar{p}p \to Z^0 X) \cdot \mathcal{B}(Z^0 \to e^+e^-)$$
$$= \; 267.0 \pm 6.3 \pm 15.2 \pm 16.0 \text{ pb}$$

Similarly from the muon channel :

$$\sigma(\bar{p}p \to Z^0 X) \cdot \mathcal{B}(Z^0 \to \mu^+\mu^-)$$
$$= \; 246 \pm 6 \pm 12 \pm 15 \text{ pb}$$

Z^0 and Drell-Yan $\ell^+\ell^-$ Production

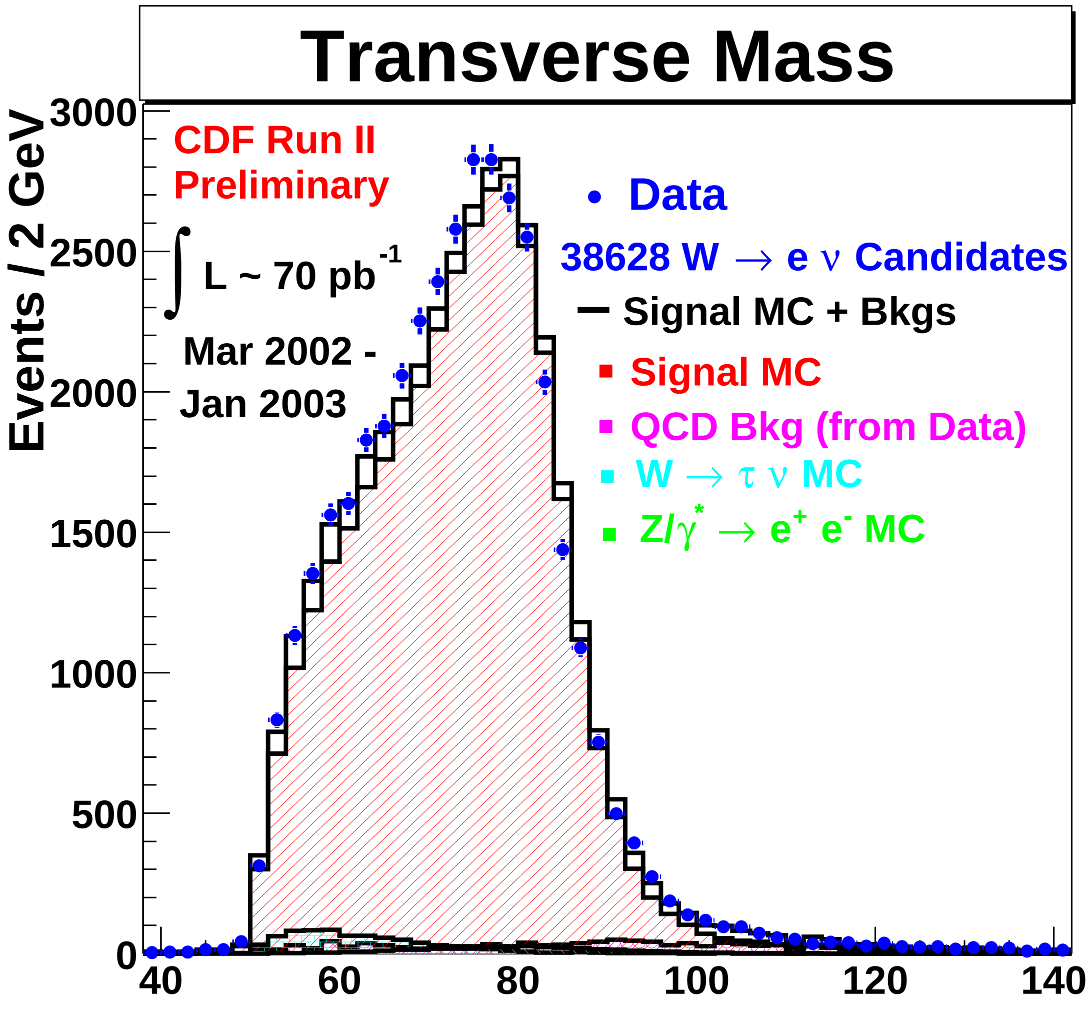
Interference of V and A couplings gives forward-backward asymmetry in lepton angular distribution.



SM gives a definite prediction.

Sensitive to new physics effects, e.g. Z' boson.

Run-II $W \to e\nu$



Cross section result:

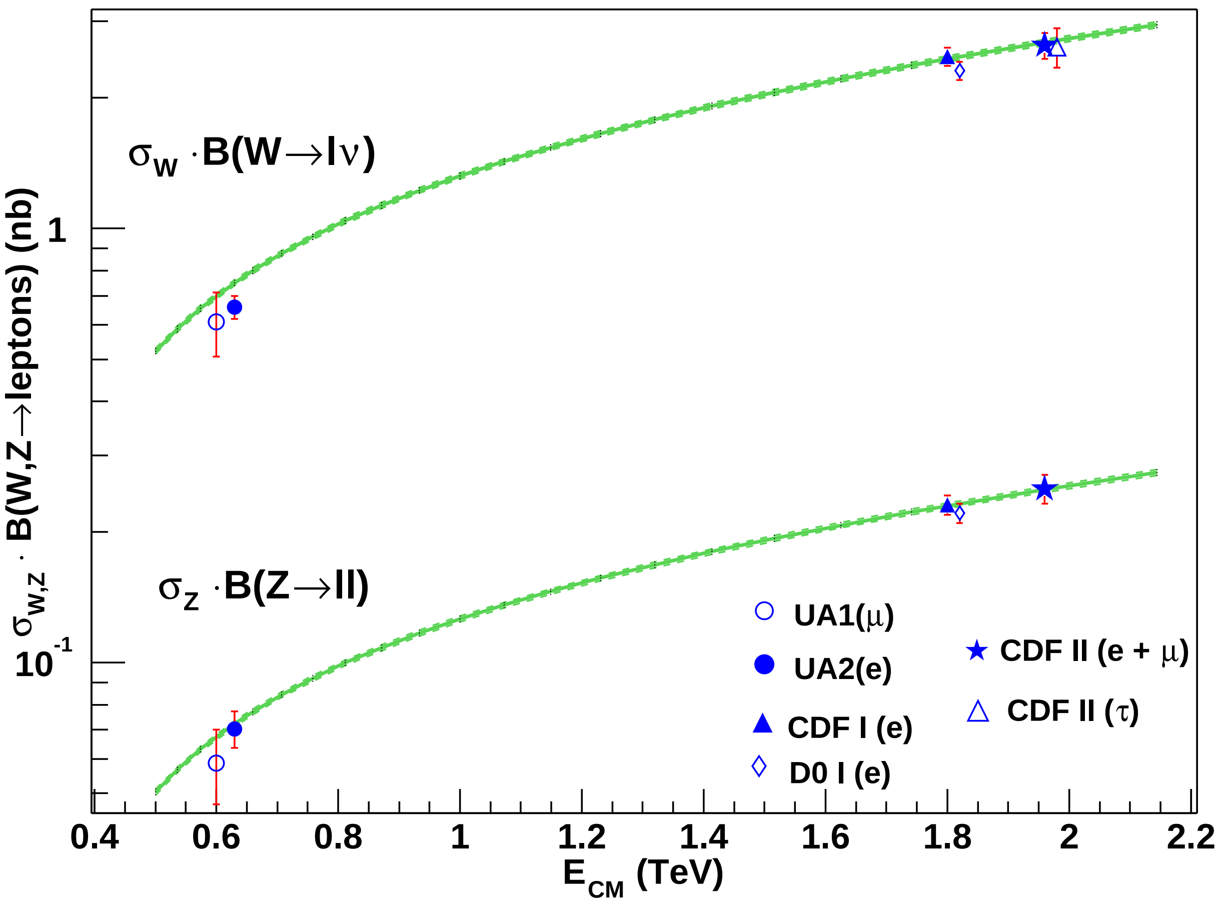
$$\begin{aligned}&\sigma(\bar{p}p \to W^{\pm}X) \cdot \mathcal{B}(W \to e\nu)\\ = \;& 2.64 \pm 0.01 \pm 0.09 \pm 0.16 \text{ nb}\end{aligned}$$

Similarly from the muon channel :

$$\begin{aligned}&\sigma(\bar{p}p \to W^{\pm}X) \cdot \mathcal{B}(W \to \mu\nu)\\ = \;& 2.69 \pm 0.02 \pm 0.12 \pm 0.16 \text{ nb}\end{aligned}$$

Next step : Accumulate stats, measure the mass.

W/Z boson production cross sections



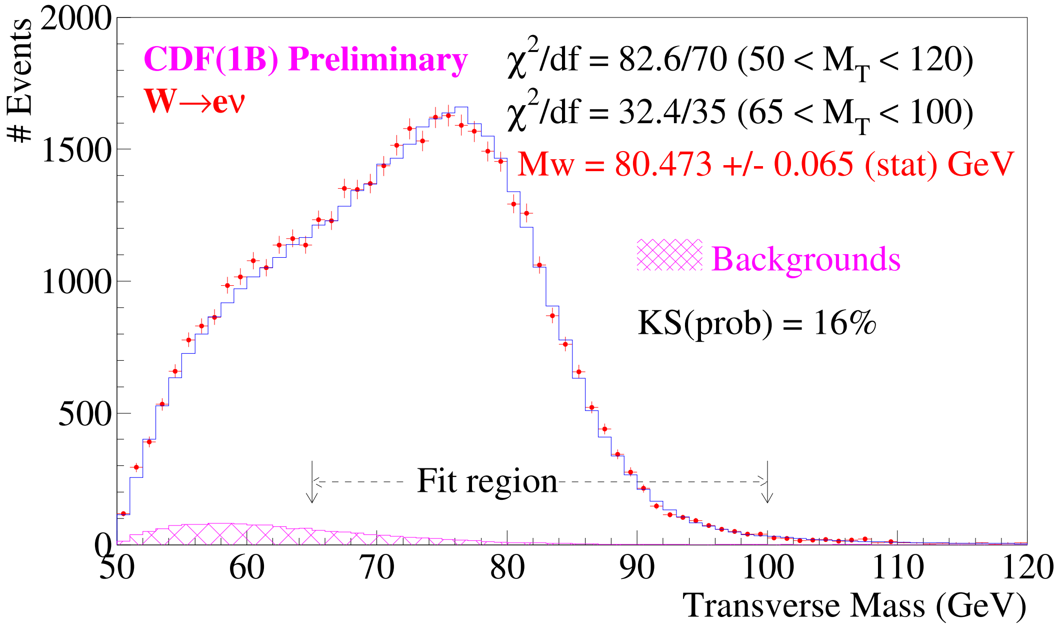
$$\frac{\sigma(\bar{p}p \to W^{\pm}X) \cdot \mathcal{B}(W \to \ell\nu)}{\sigma(\bar{p}p \to Z^0X) \cdot \mathcal{B}(Z^0 \to \ell^+\ell^-)} = 10.54 \pm 0.18 \pm 0.33$$

$\Rightarrow$ extract $\Gamma(W \to \text{all})$ to be

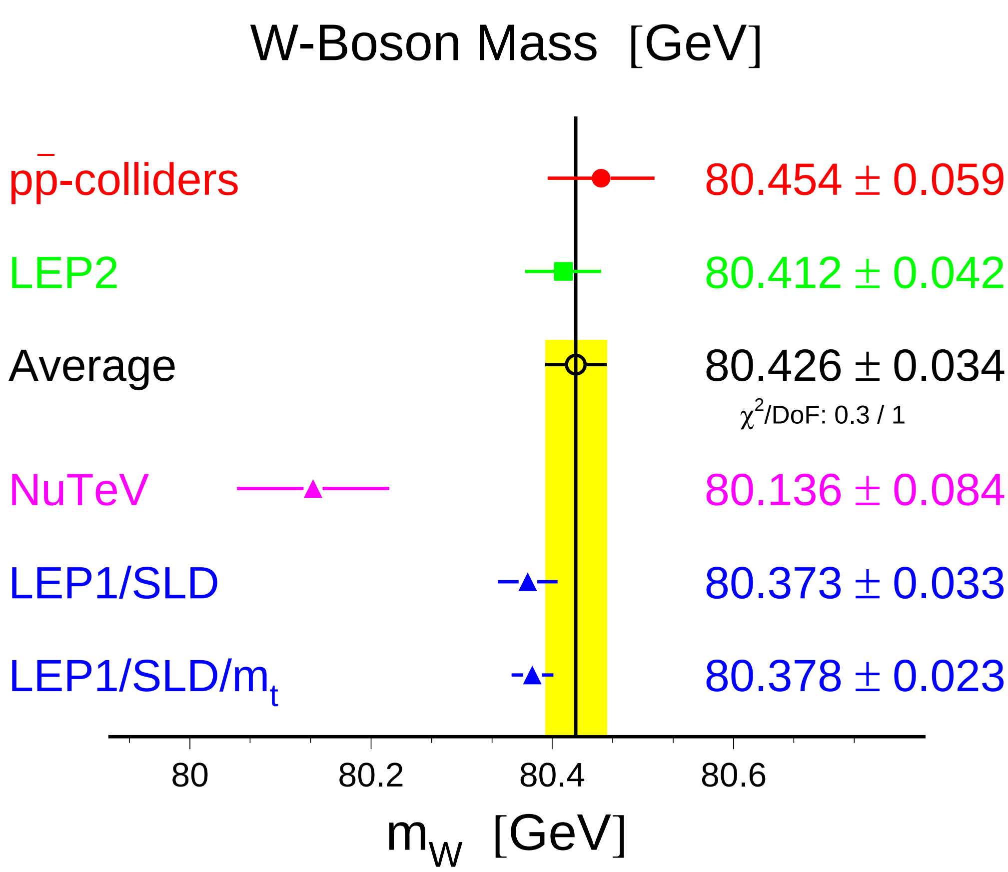
$$\Gamma_W = 2.146 \pm 0.078 \text{ GeV}/c^2$$

$W^{\pm}$ boson mass measurements

Run Ib (90 pb^{-1}), electron channel.

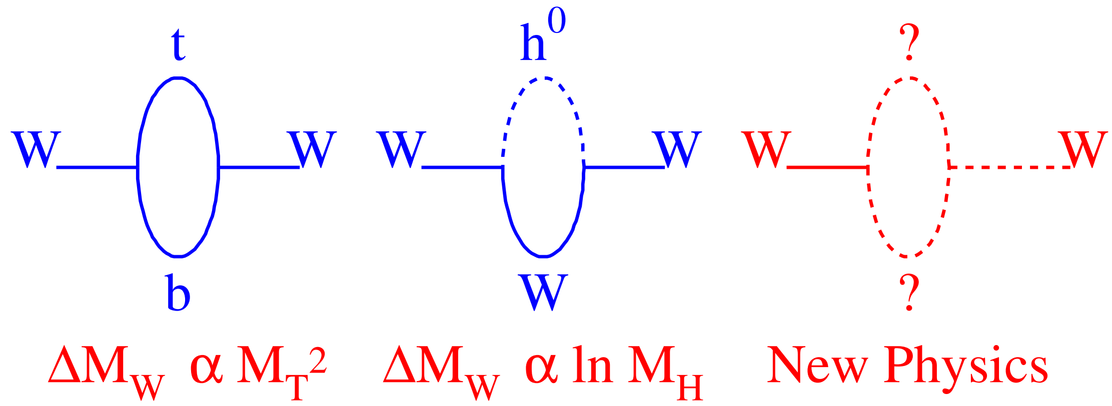


$\Rightarrow M_W = 80.443 \pm 0.079$ GeV$/c^2$ (CDF combined).

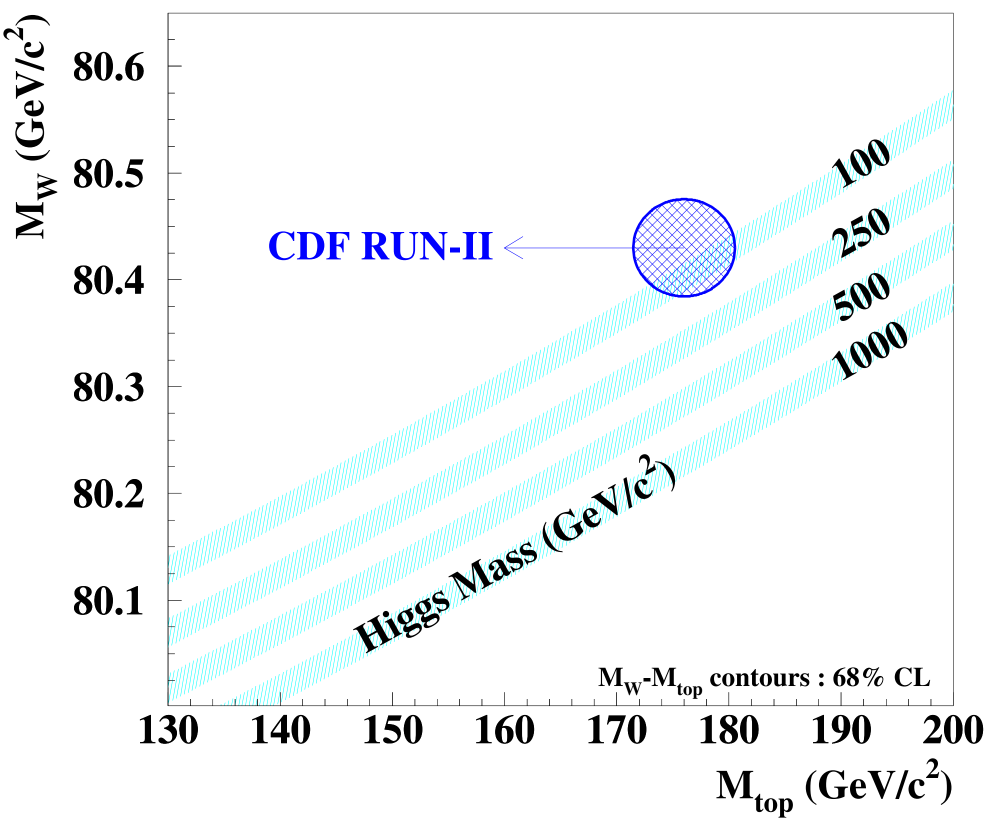


Higgs?

m_W, m_t somewhat sensitive to the Higgs mass through radiative corrections.



Constraints on the Higgs mass :
CDF Run-II projecctions (2 fb^{-1}).
m_W to 40 MeV/c^2, m_t to 3 GeV/c^2.



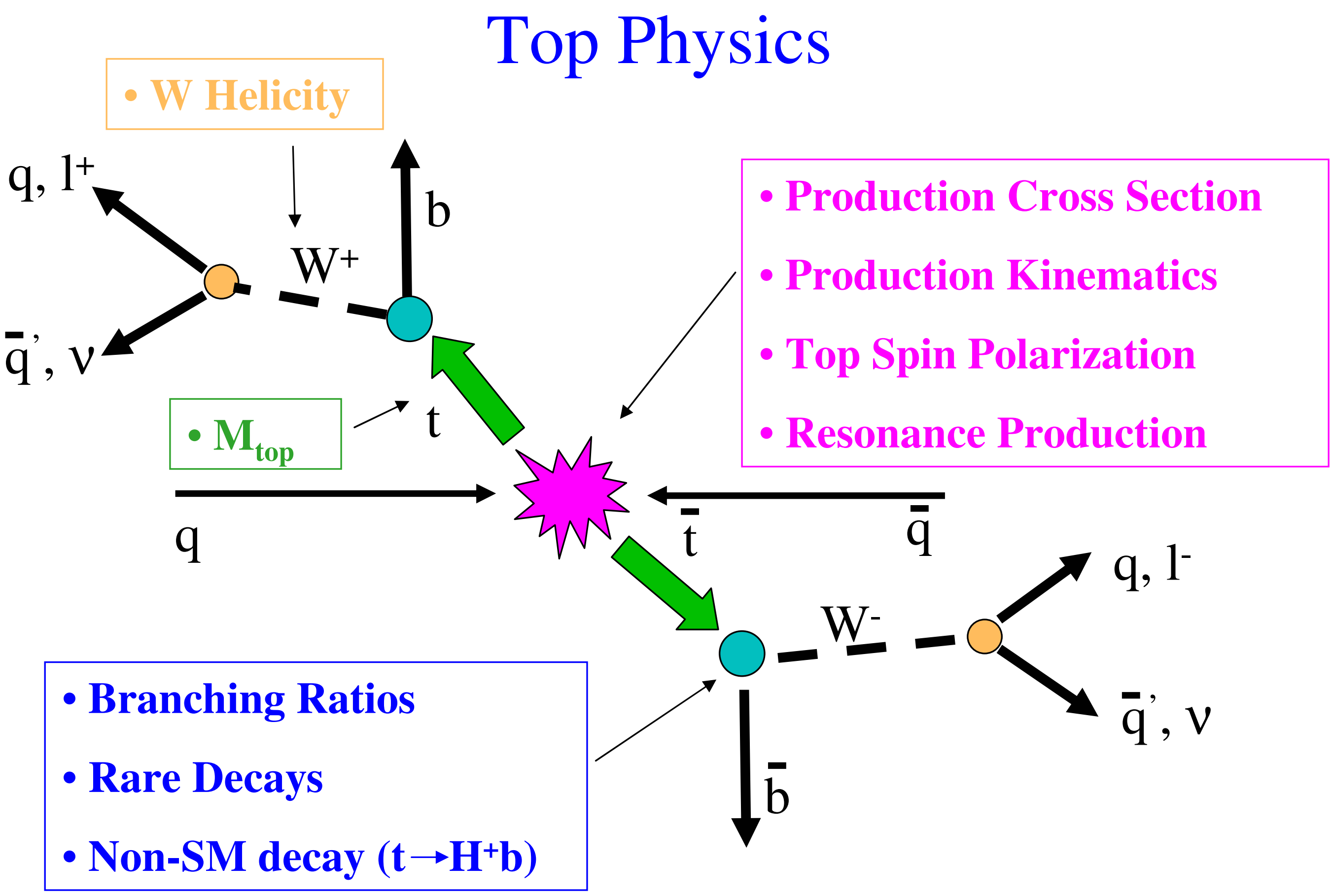
And $\Delta m_h/m_h \sim 0.3$.

Top quark

Discovered in Run I, among ~ 100 pb^{-1}.

Tens of events reconstructed.
All measurements statistics-limited.

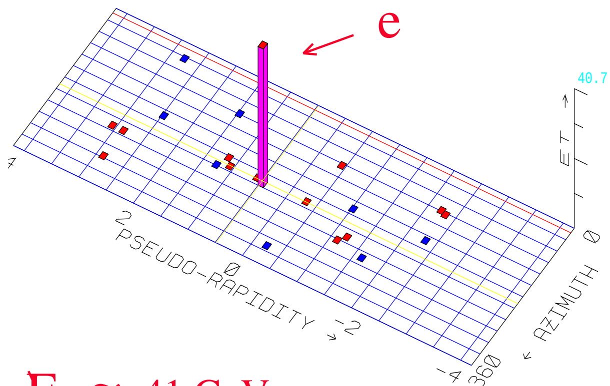
Run-II data (2 fb^{-1}) should allow more detailed studies.



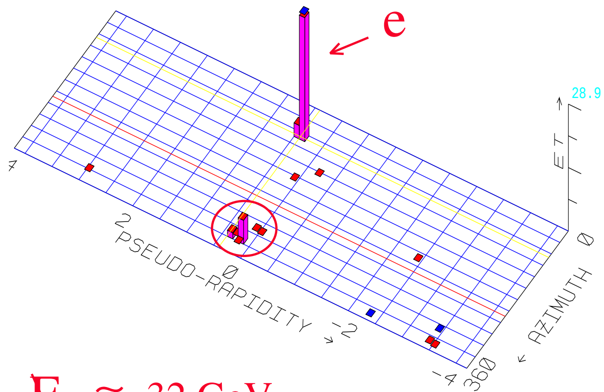
W + jets Production

CDF

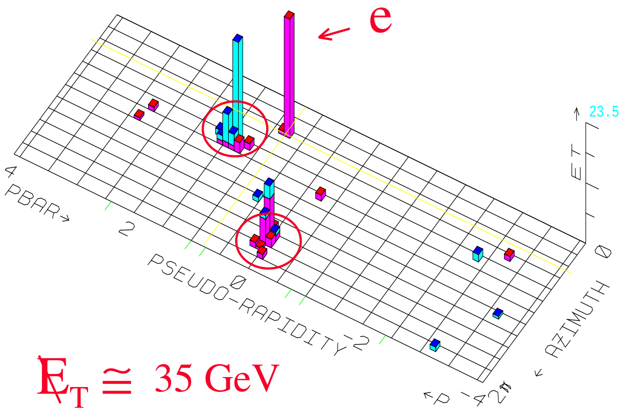
W + 0,1,2,3 jet(s) Events



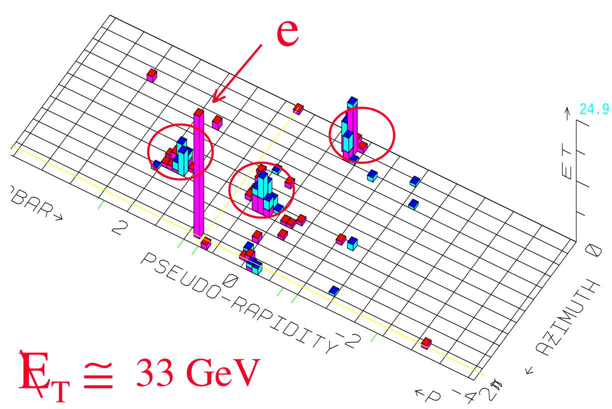
$\not{E}_T \cong$ 41 GeV



$\not{E}_T \cong$ 32 GeV



$\not{E}_T \cong$ 35 GeV



$\not{E}_T \cong$ 33 GeV

Top candidate event (Run I)

$W^+ \to e^+\nu$,
$W^- \to$ jets $\#2$ and $\#3$.

e + 4 jet event

40758_44414

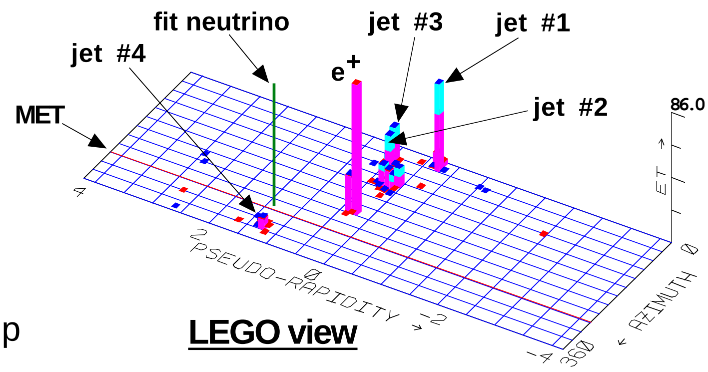
24-September, 1992

TWO jets tagged by SVX

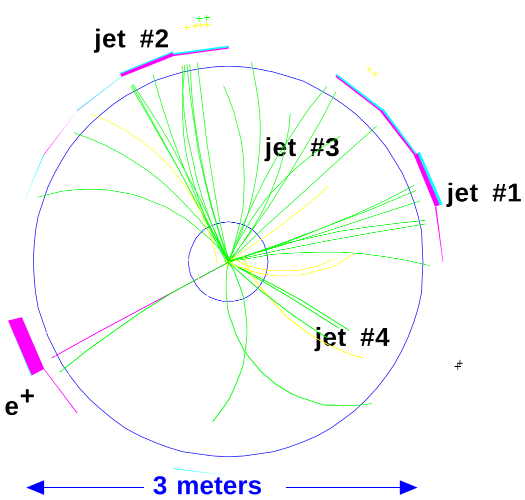
fit top mass is 170 +- 10 GeV

e^+, Missing E_t, jet #4 from top

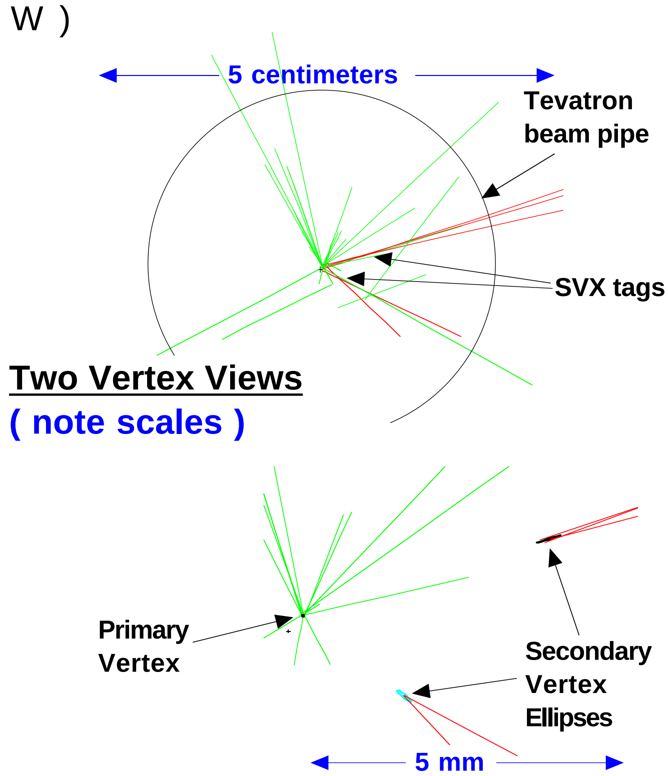
jets 1,2,3 from top (2&3 from W)



LEGO view



Tracking View



Two Vertex Views

(note scales)

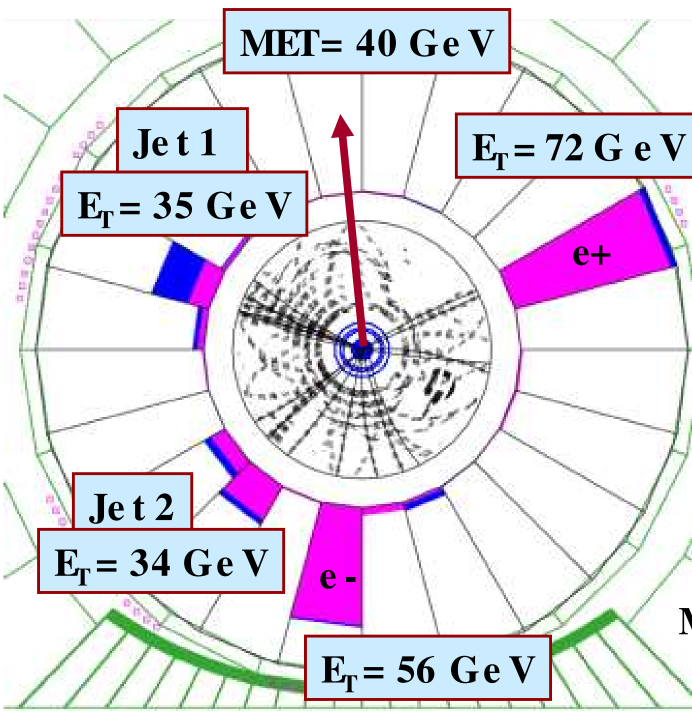
Jets $\#1$ and $\#2$ are from $b/\bar{b}$.

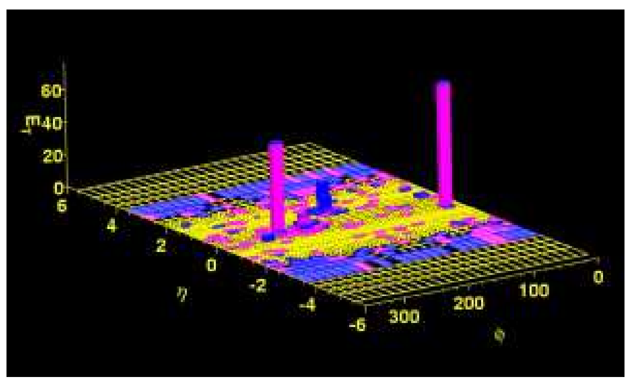
Expected Yield in Run II

Decay Channel	Event Yield (2 fb^{-1})	
Produced $t\bar{t}$	13,600	525
Dilepton (ee,μμ,eμ)	160	8
Tau Dileptons (eτ,μτ)	20	-
e,μ + >=3 jets	1500	80
e,μ + >=3 jets+>=1 b-tag	1000	25
mass sample w/ >=1 b-tag	800	15
mass sample w/ >=2 b-tags	250	5

Approx #'s from Run I and in current 70 pb^{-1} Run IIA

Top di-lepton candidate event (Run II)





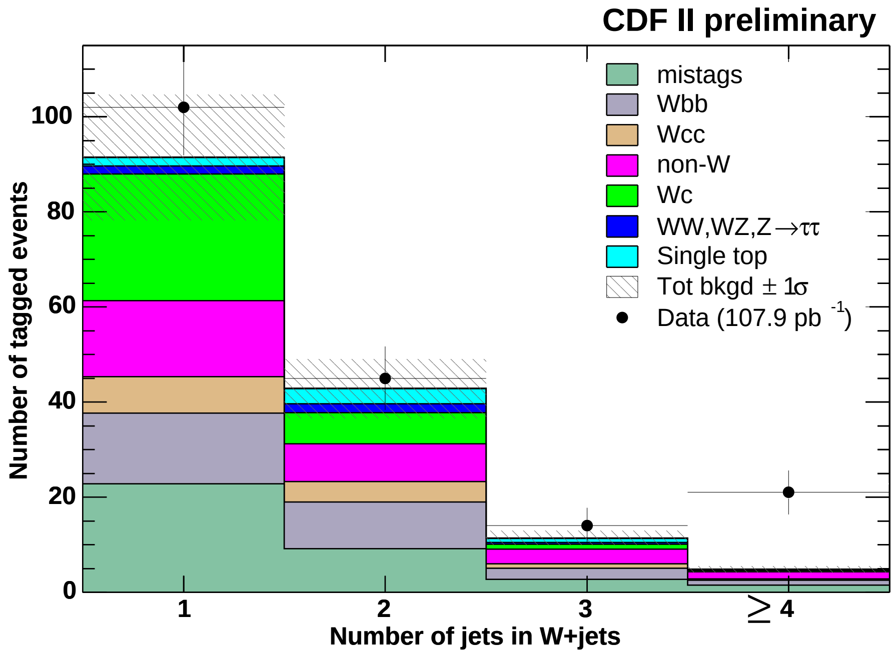
CDF Top Dilepton Candidate

M_{ee} = 118 GeV/c^2 and H_T = 255 GeV

CDF Run 2 Preliminary

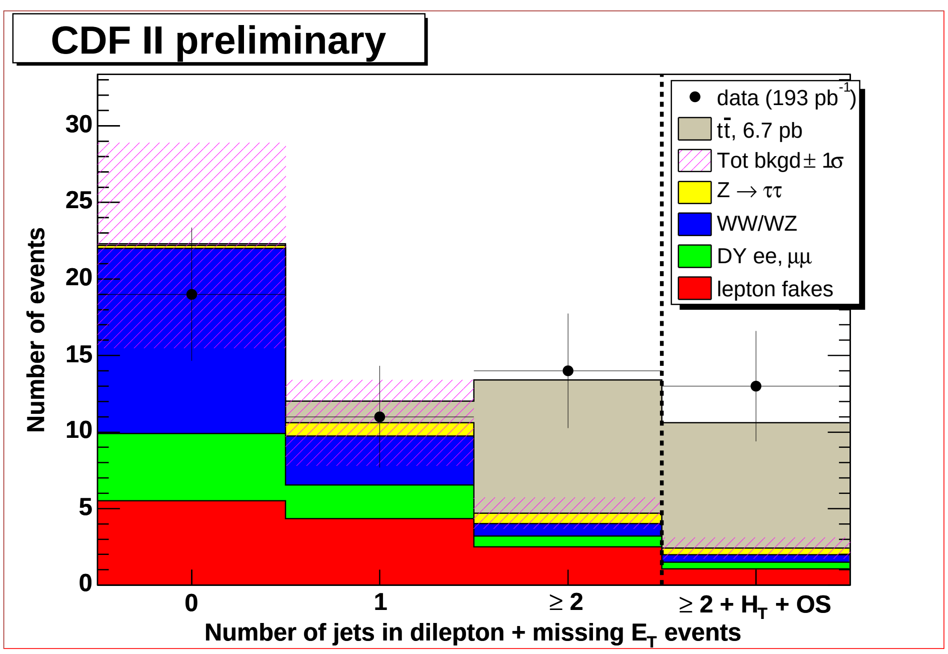
Top Production Cross Section

Lepton + jet mode, b tag by secondary vertices.



$$\sigma(\bar{p}p \to t\bar{t}X) = 4.5 \pm 1.4 \pm 0.8 \text{ pb}$$

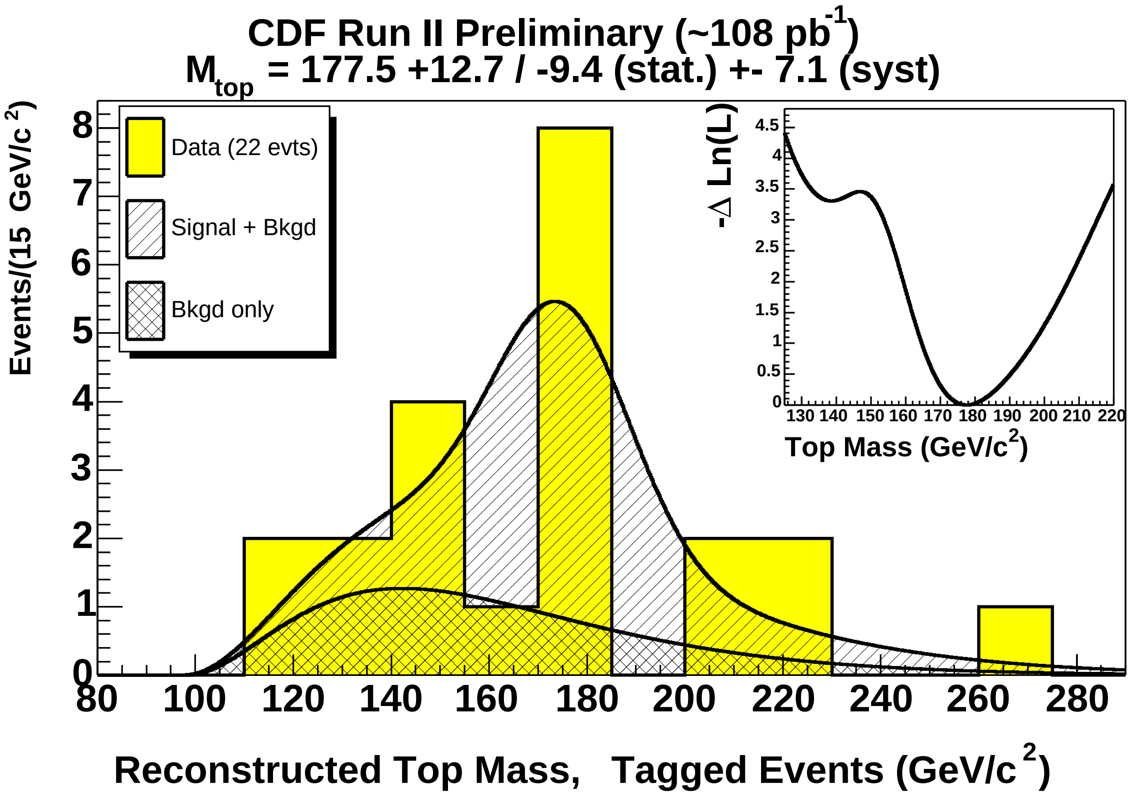
Dilepton mode



$$\sigma(\bar{p}p \to t\bar{t}X) = 8.7^{+3.9}_{-2.6} \pm 1.5 \text{ pb}$$

Top Mass : CDF Run II

Lepton + jets mode :



$$m_t = 177.5\,^{+12.7}_{-\;9.4} \pm 7.1 \;\; \mathrm{GeV}/c^2$$

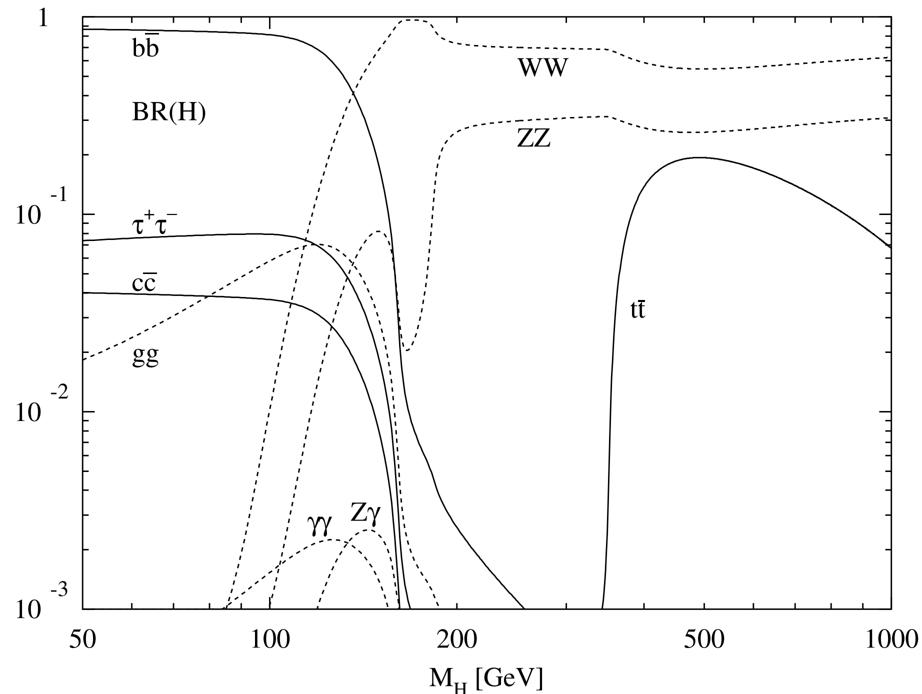
Dilepton mode :

$$m_t = 175 \pm 17 \pm 8 \;\; \mathrm{GeV}/c^2$$

$\sigma(m_t) \sim 3$ GeV/c^2 expected with 2 fb^{-1}.

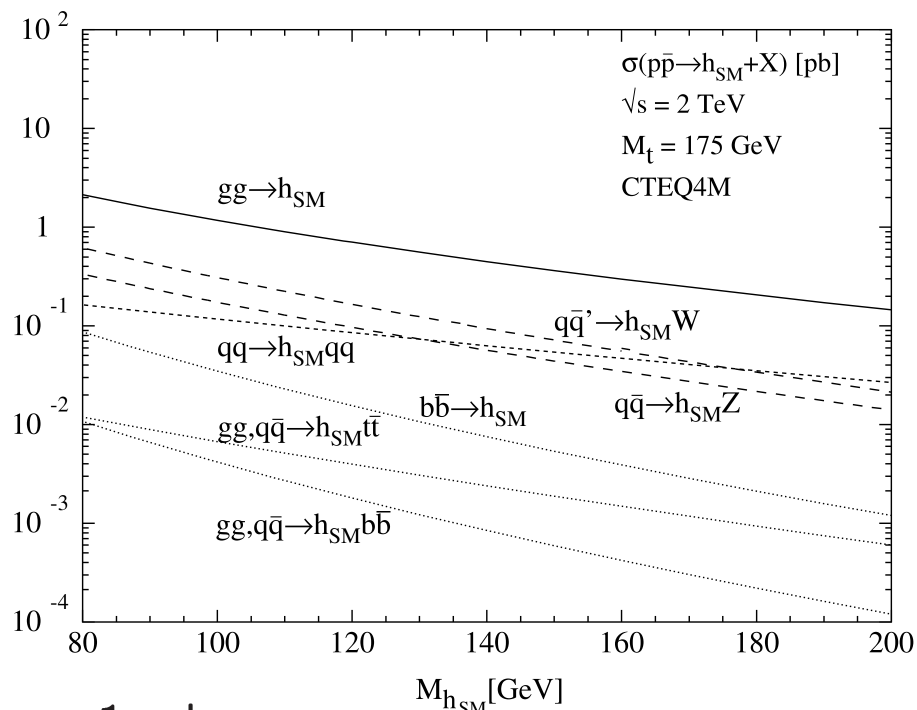
Search for the Higgs boson

Branching Fractions



$b\bar{b}$ dominant for $m_h < 120$ GeV/c^2, VV if heavy.

Production cross section at $\sqrt{s} = 2$ TeV :



At most $\sim$ 1 pb.
Single production largest, but swamped by BG.

Use associated production $p\bar{p} \to Vh$

$V \equiv W^{\pm}$ or Z^0. Subprocess is $q\bar{q} \to V^* \to Vh$.

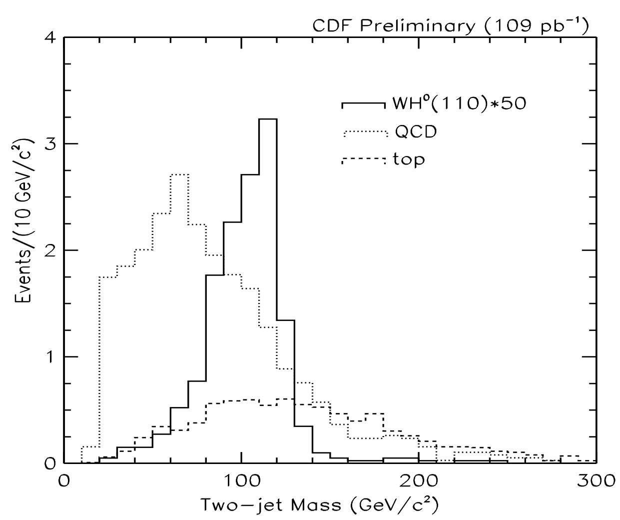
Use $W^+ \to \ell^+\nu$, $Z^0 \to \ell^+\ell^-$ $(\nu\bar{\nu})$, and $h \to b\bar{b}$.

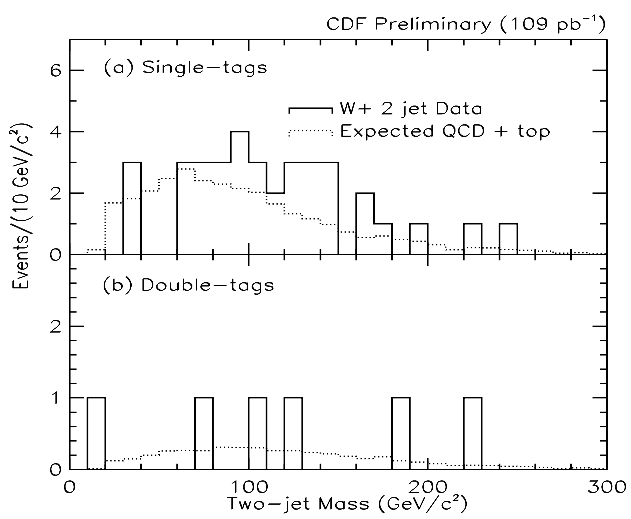
Examine $b\bar{b}$ invariant mass, look for a peak at m_h.

BG:
$V + b\bar{b}$ ($b\bar{b}$ mass continuum)
VZ^0, $Z^0 \to b\bar{b}$ ($b\bar{b}$ mass $= Z^0 = 91$ GeV$/c^2$)
Top

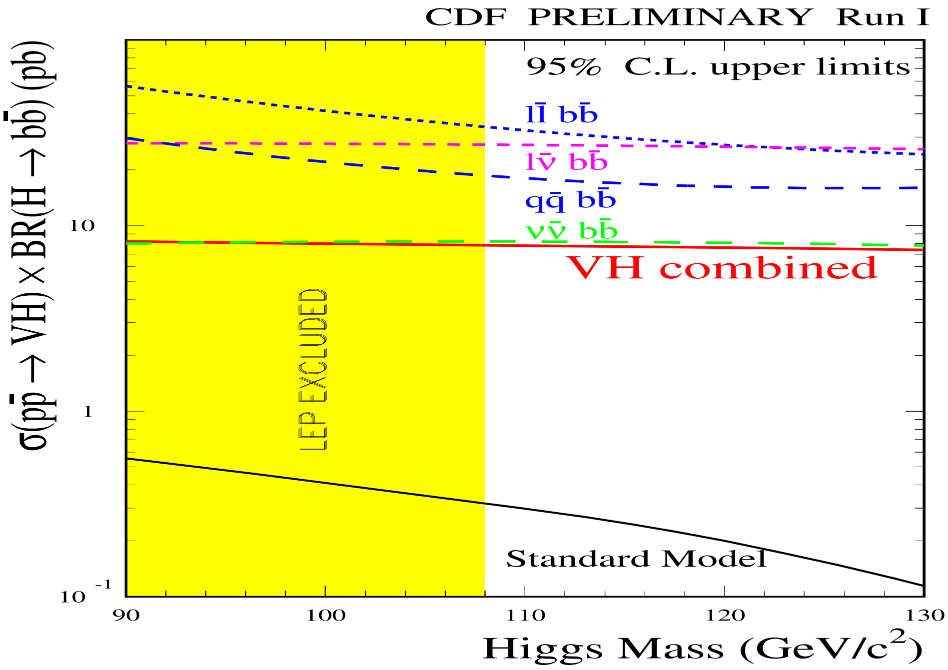
Looking for $WH \to \ell\nu b\bar{b}$, more like top analysis.

Expectations for signal and BG

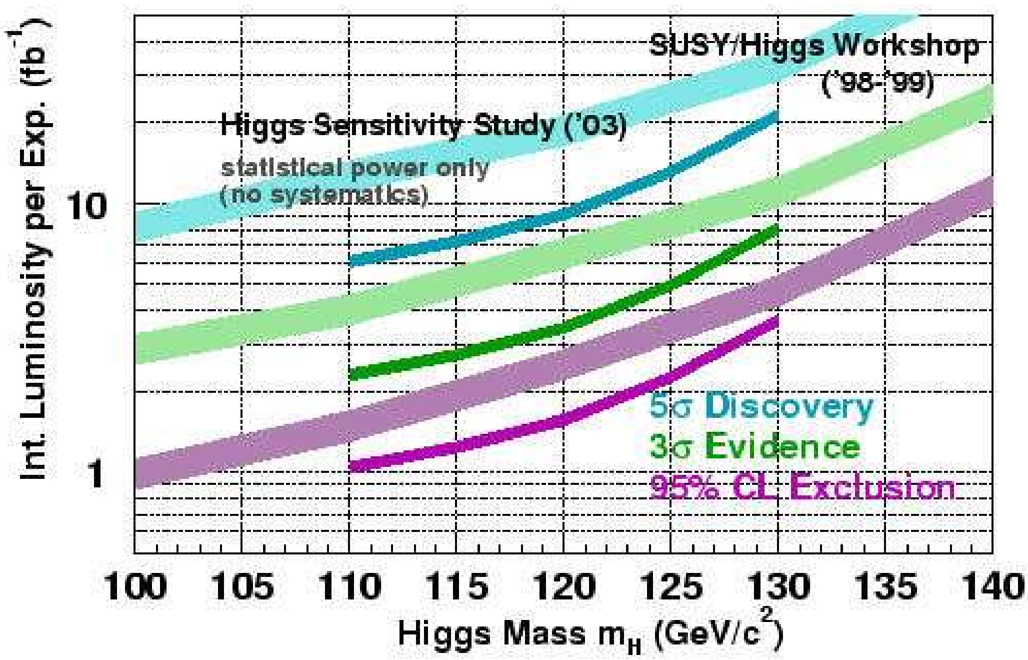




CDF Higgs Search : Run I / Run II



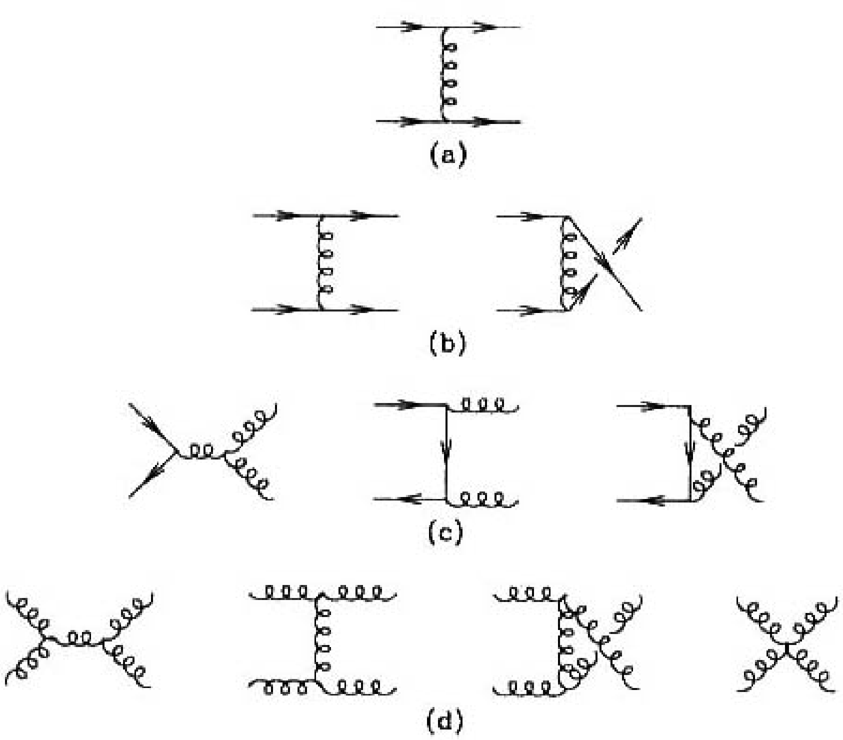
Need more data!



$m_H < 123$ GeV/c^2 can be excluded with 2 fb^{-1}, if not there.

Jet Production

Jets are the most common events in hard hadron-hadron collisions.



$qq' \to qq'$

$qq \to qq$

$q\bar{q} \to gg$

$gg \to gg$

Initial parton composition vs. final state jet E_T

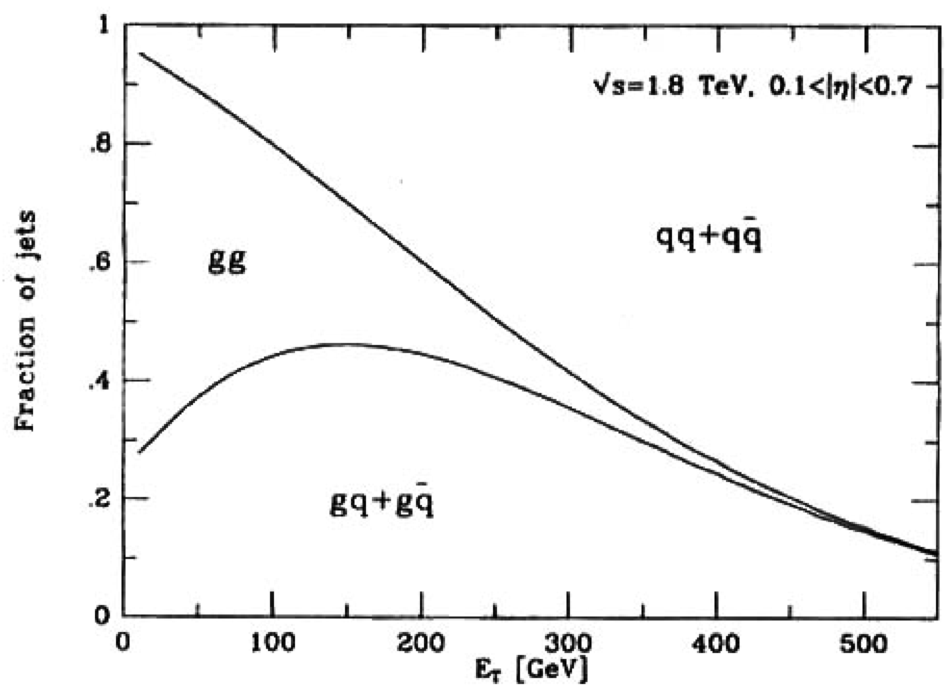
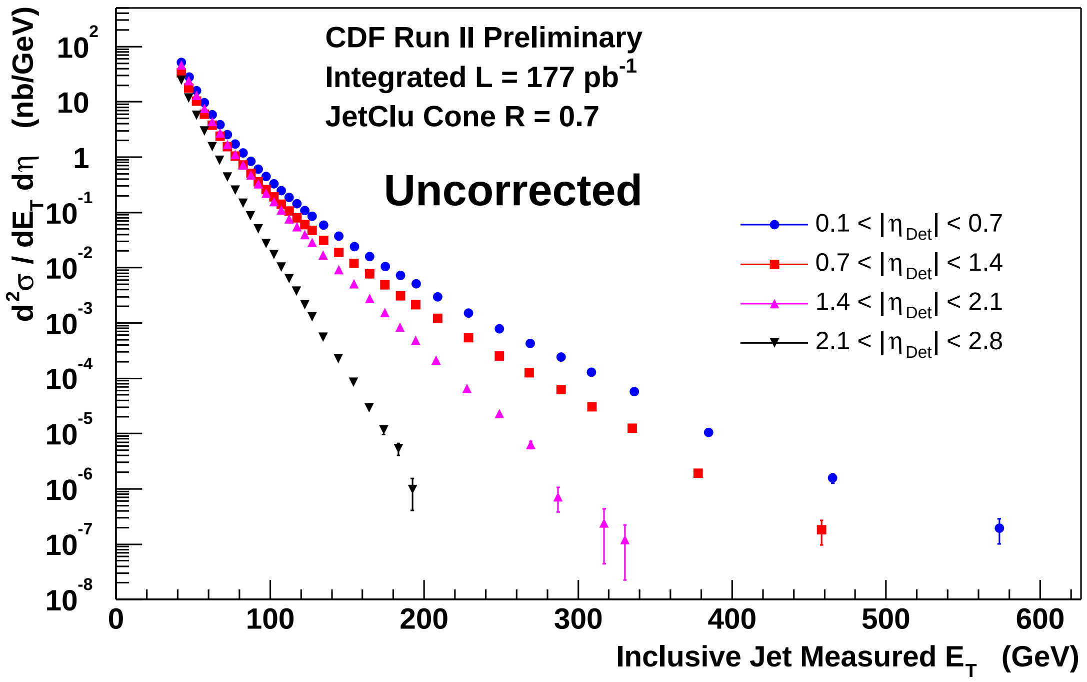


Fig. 7.8. Plot showing the fraction of the jet E_T distribution initiated by different parton combinations.

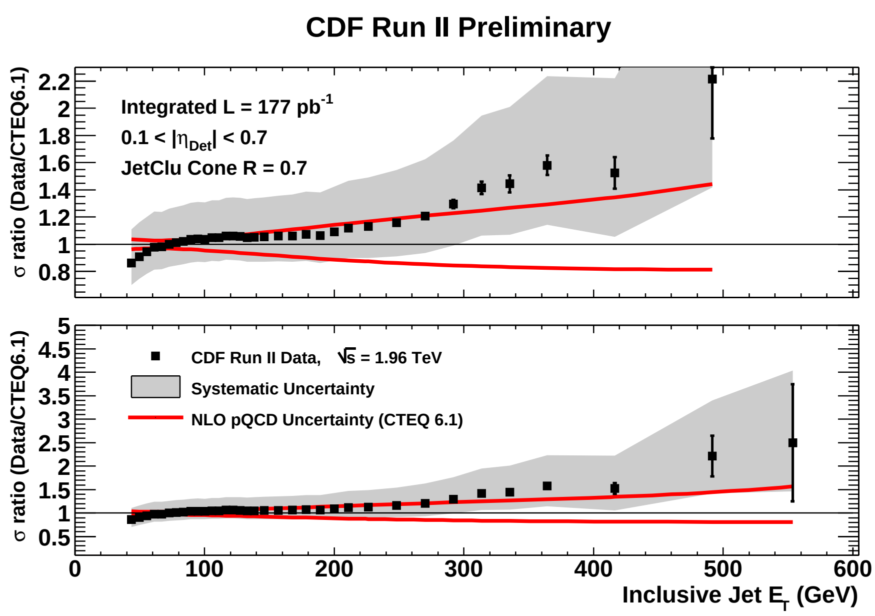
Inclusive Jet Cross Section (Run II)



Covers nine orders of magnitudes.

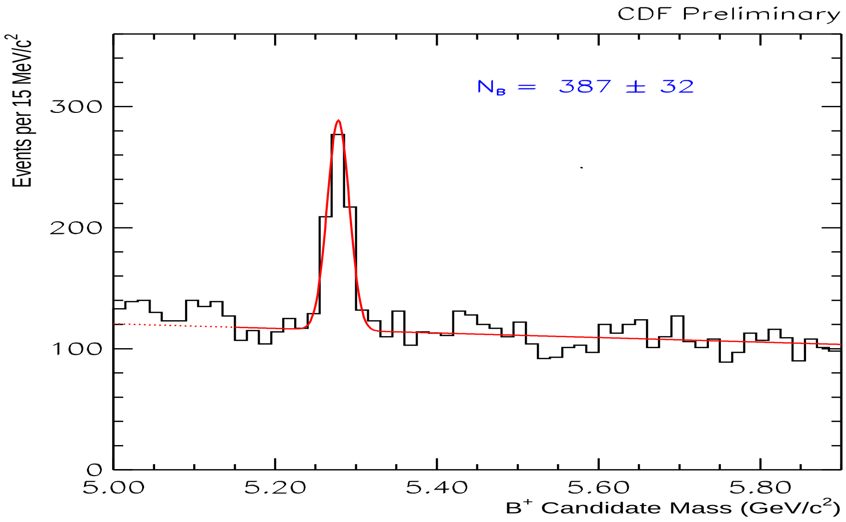
Overall, impressive agreement with theory.

Excess at the high end?

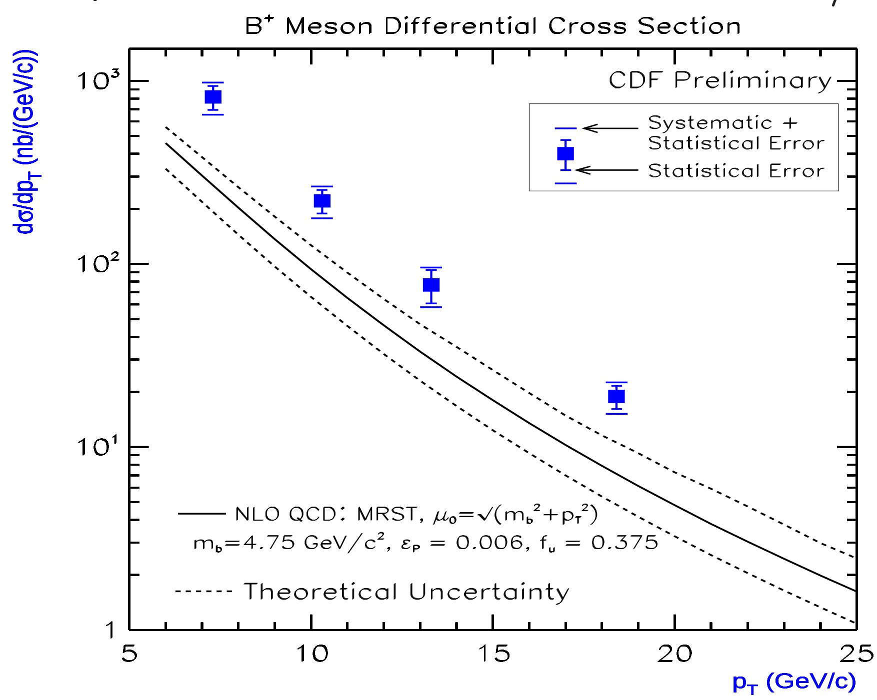


Bottom Quark Production : Run I

Fully reconstructed $B^+ \to J/\psi\, K^+$ decays



B^+ meson production cross section $d\sigma/dp_T$



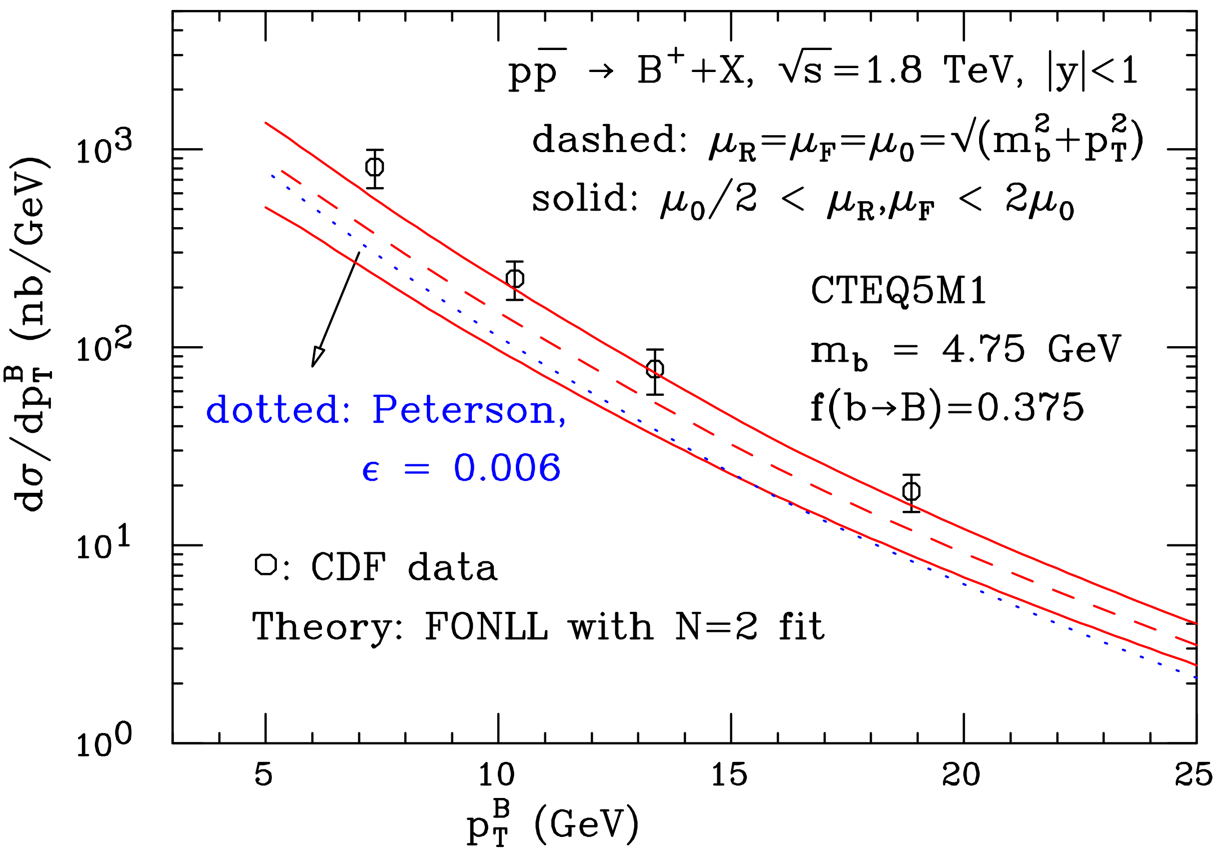
$\sigma(\bar{p}p \to B^+X) = 3.51 \pm 0.42 \pm 0.53$ μb for $p_T > 6$ GeV/c and $|y| < 1.0$.

PRD 65, 052005 (2002)

Data / Theory $= 2.9 \pm 0.5$

Or, is it the Fragmentation?

Same data points, but with proper treatment of fragmentation function and perturbative calculations.

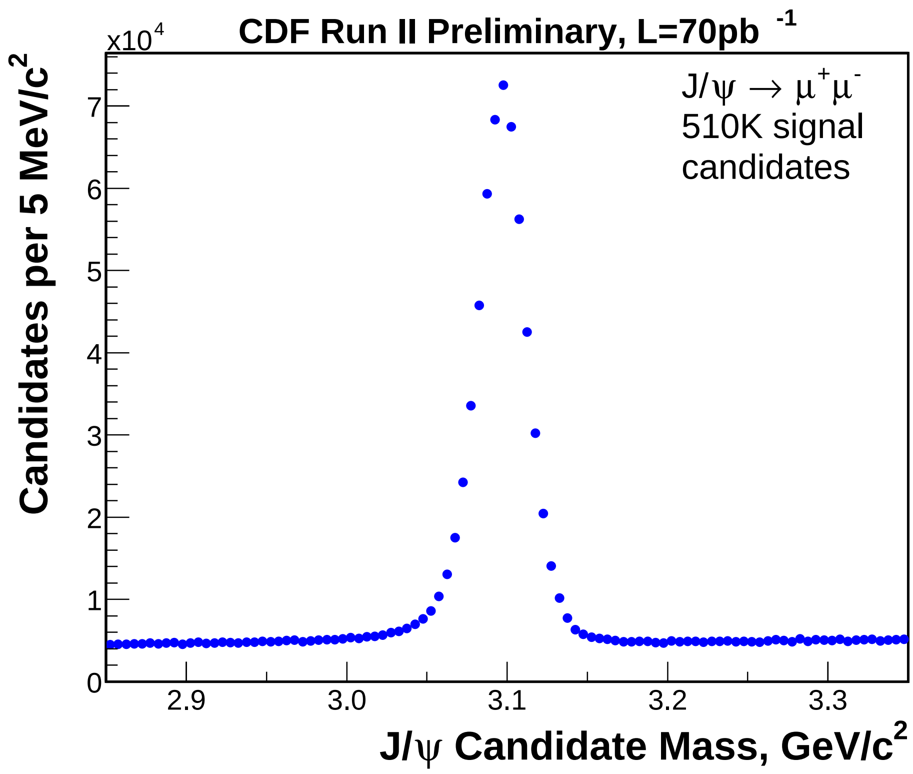


Change rates in different p_T ranges, but total is the same.

Brings Data / Theory to ~ 1.7. "Acceptable". Cacciari and Nason, PRL 89, 122003 (2002).

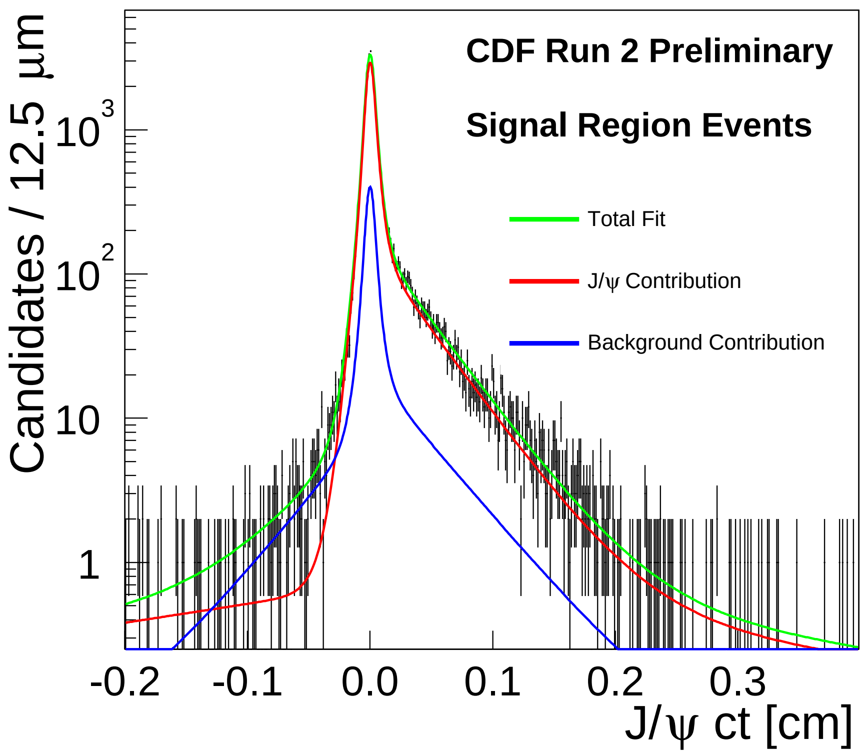
Can tell if we measure down to $p_T^b = 0$.

Run-II using $B \to J/\psi X \to \mu^+\mu^- X$



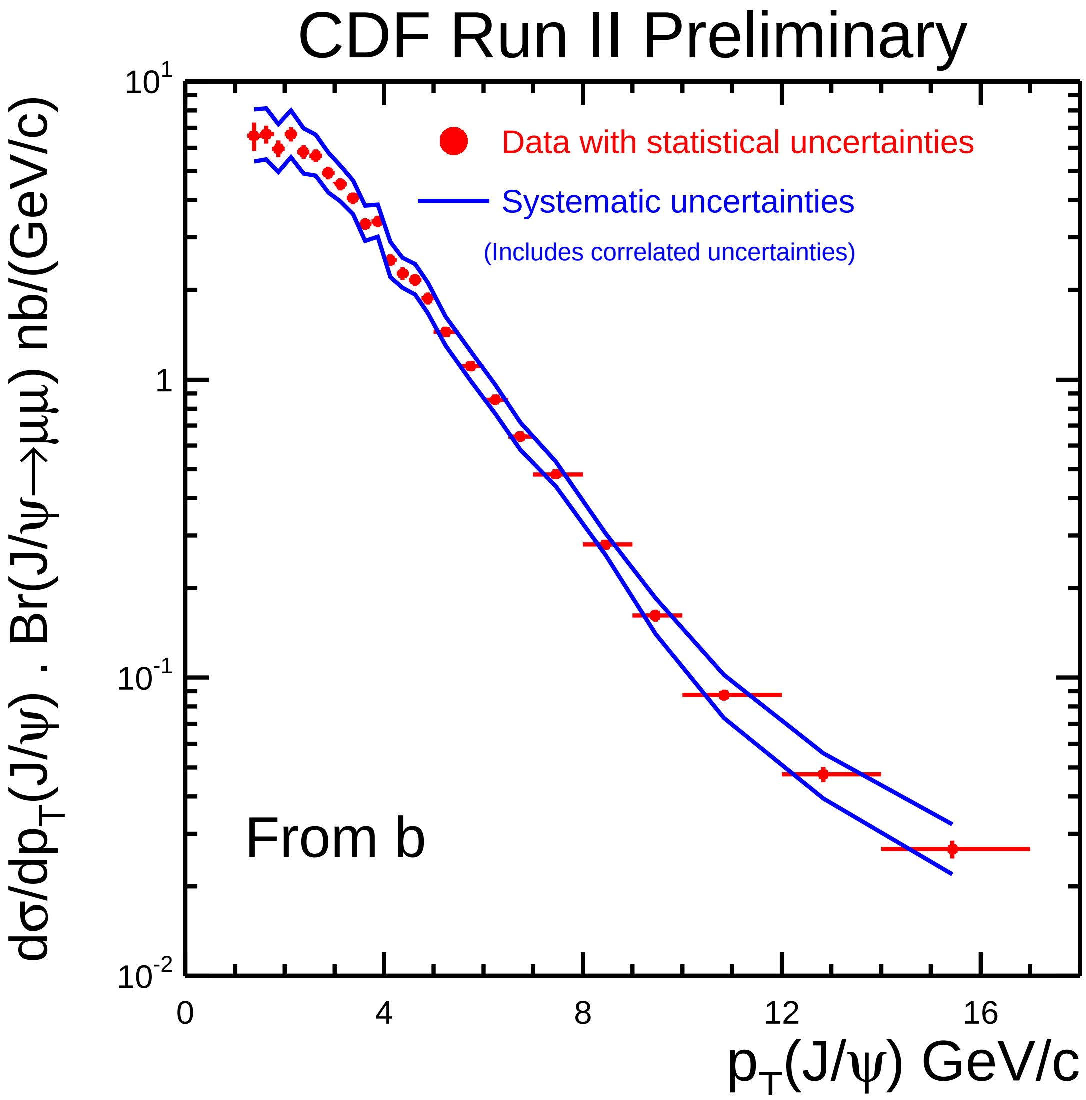
p_T threshold : 2 GeV/$c \Rightarrow$ 1.5 GeV/c.

Lifetime distribution



Inclusive B Hadron Production

Lower $p_T(\mu)$ threshold gives reasonable acceptance down to $p_T(J/\psi) \simeq 0$:



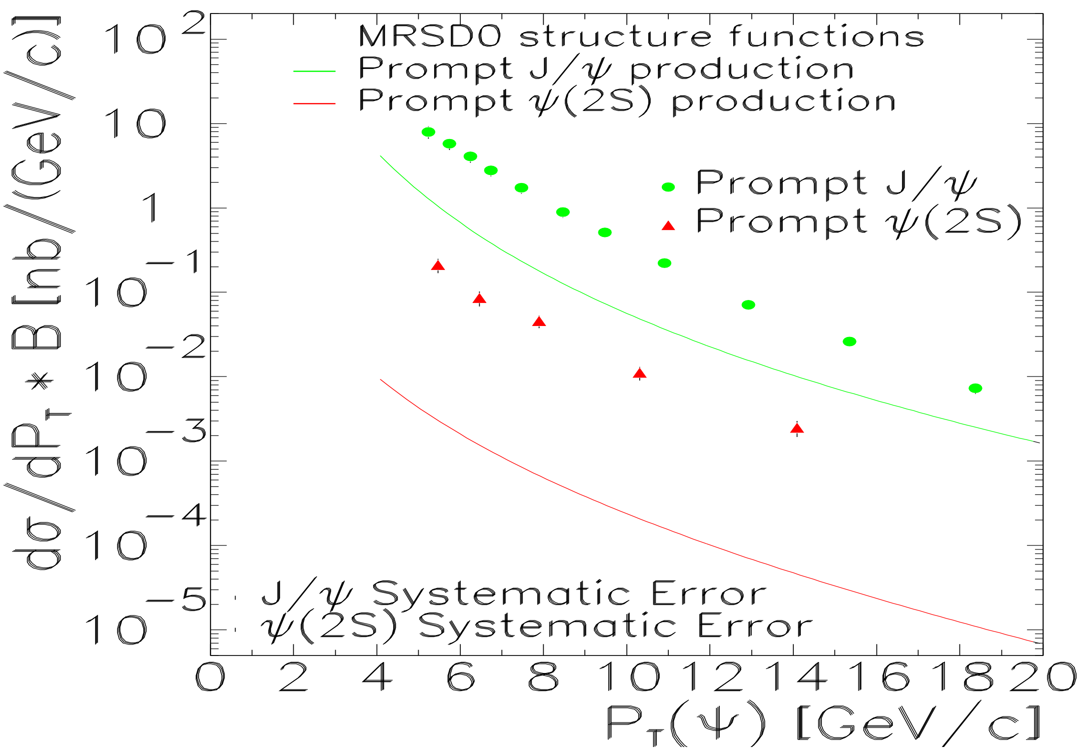
$$\begin{aligned} & \sigma(\bar{p}p \to bX) \cdot \mathcal{B}(b \to J/\psi X) \cdot \mathcal{B}(J/\psi \to \mu^+\mu^-) \\ = \; & 24.5 \pm 0.5 \pm 4.7 \text{ nb} \quad (|y| < 0.6,\ p_T > 1.25 \text{ GeV}/c) \end{aligned}$$

$$\begin{aligned} & \sigma(\bar{p}p \to bX; \quad p_T^b > 0,\ |y^b| < 1.0) \\ = \; & 29.4 \pm 0.6 \pm 6.2 \ \mu\text{b} \end{aligned}$$

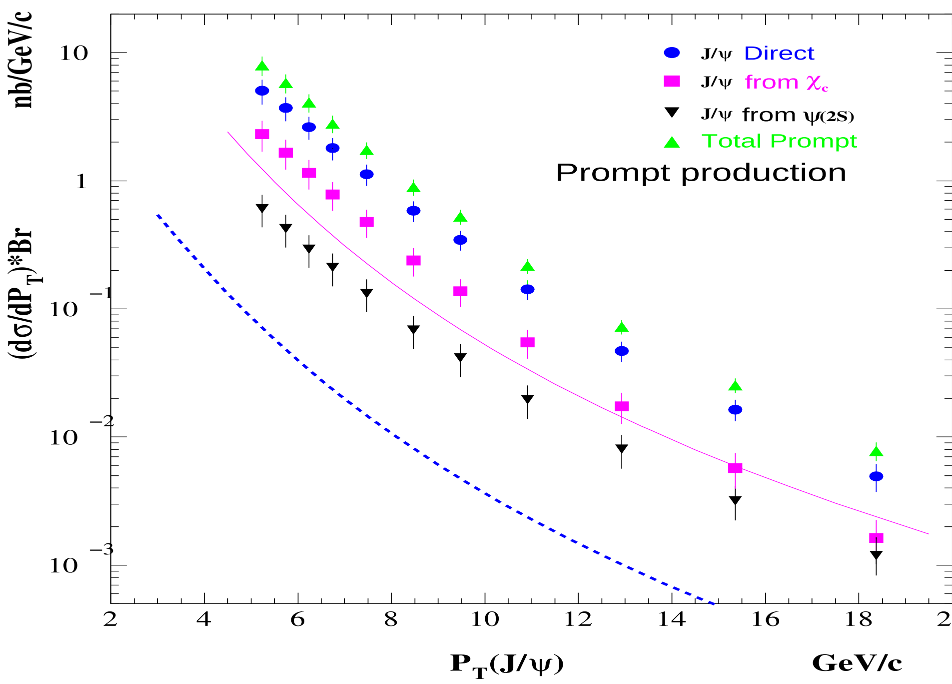
Theory : $23.5\,^{+11.6}_{-\ 7.6}\ \mu$b

Direct ψ Production (Run I)

"Prompt" $=$ zero lifetime $=$ Not from B



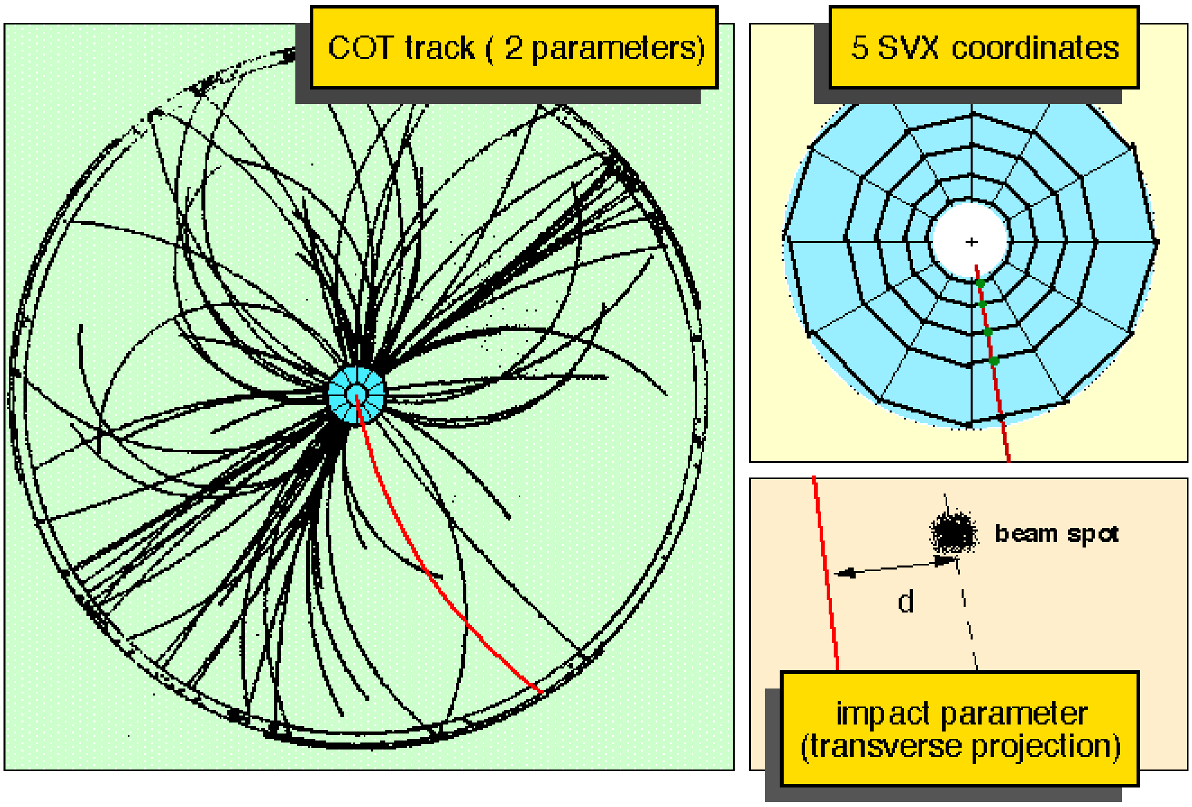
"Direct J/ψ" $=$ Not from χ_c or $\psi(2S)$



Both $\sim 50\times$ theory. Still unsolved mystery.

Run-II Silicon Vertex Trigger : SVT

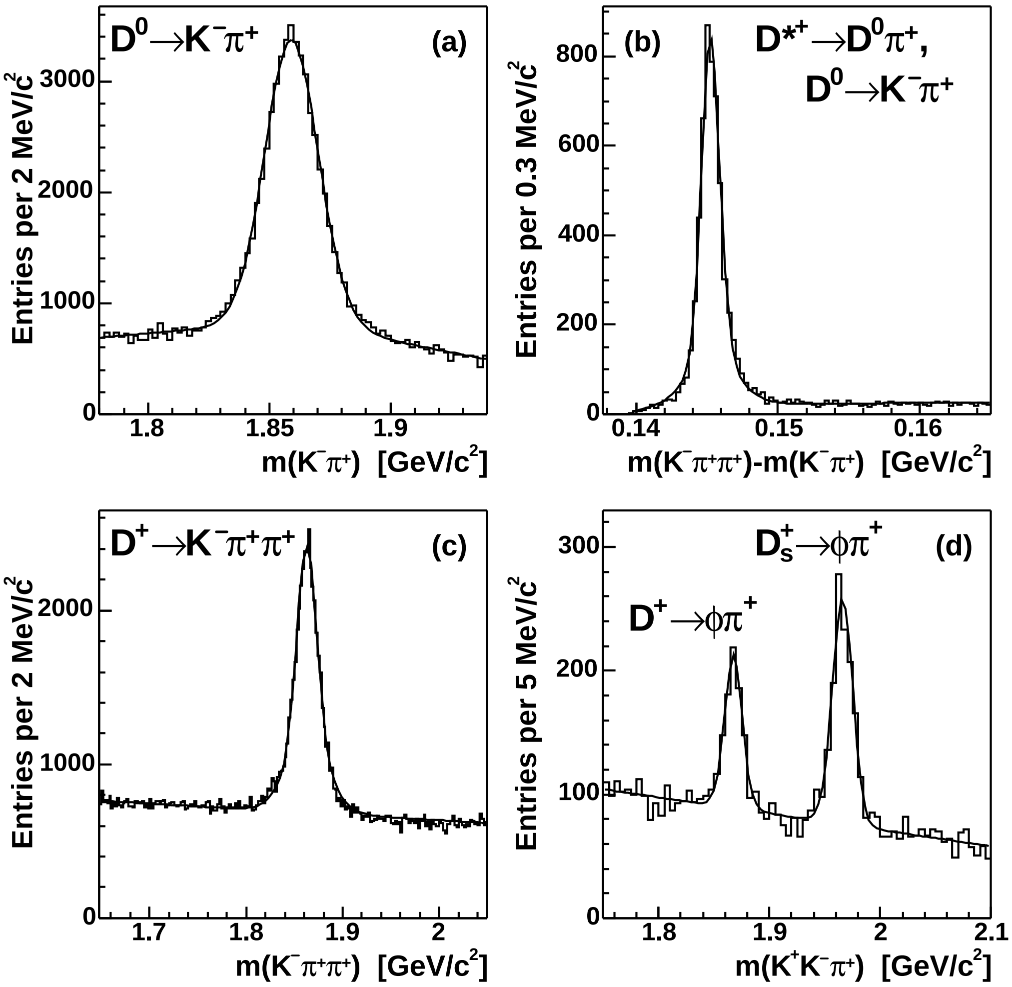
Use silicon information at 2nd level of trigger.

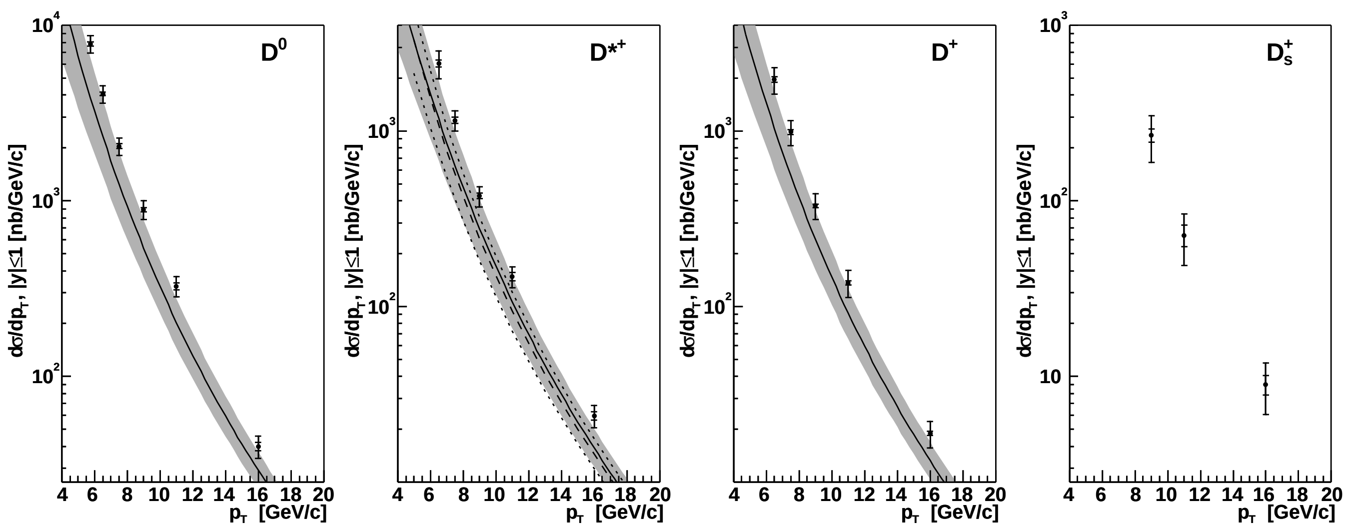


- Find a track in the main tracker COT.
- Extrapolate inwards to Si detector.
- Find Si hits along the road.
- Calculate impact parameter d with respect to the primary vertex (beam spot, $\sim$ 20 μm).

Resolution $\sigma_d \sim 50\ \mu$m for $p_T > 2$ GeV$/c$.

Open charm prod. : D^0, $D^{(*)+}$, D_s^+

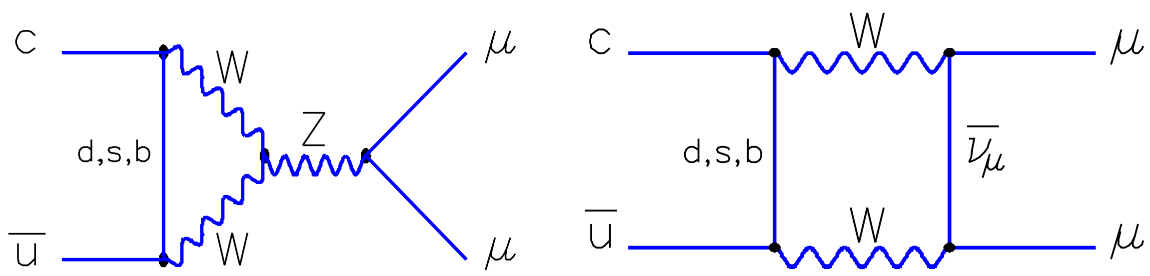




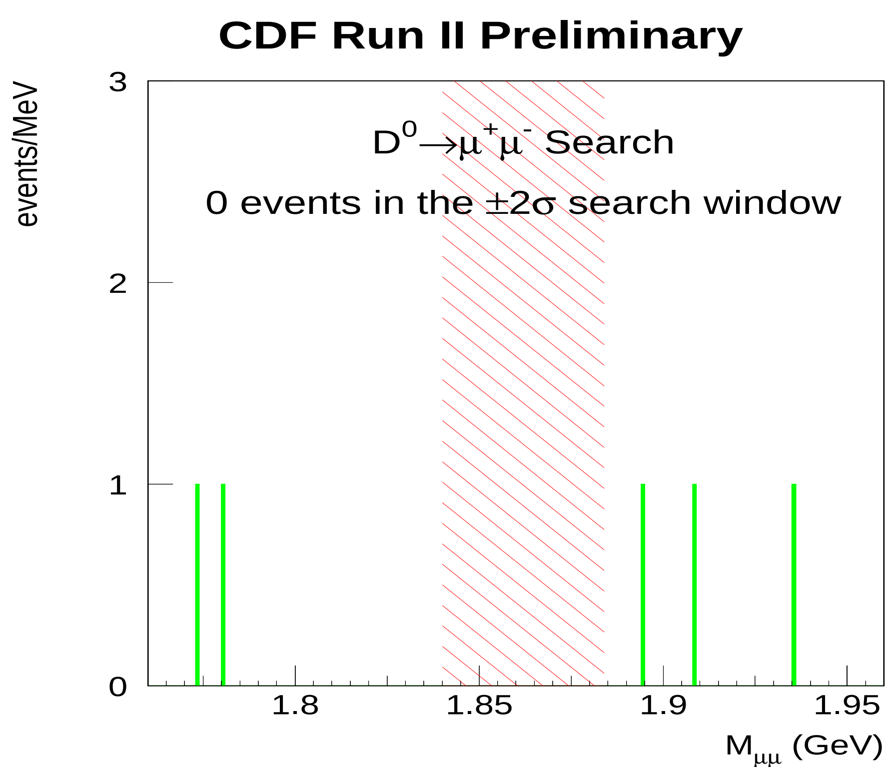
Data / Theory $\sim 1.5 - 2$.
PRL 91, 241804 (2003).

Search for $D^0 \to \mu^+\mu^-$: FCNC

Proceed via loop and box diagrams in SM



Also helicity suppressed $\Rightarrow$ $\mathcal{B} \sim 10^{-13}$.
So a good place to look for new physics effects.



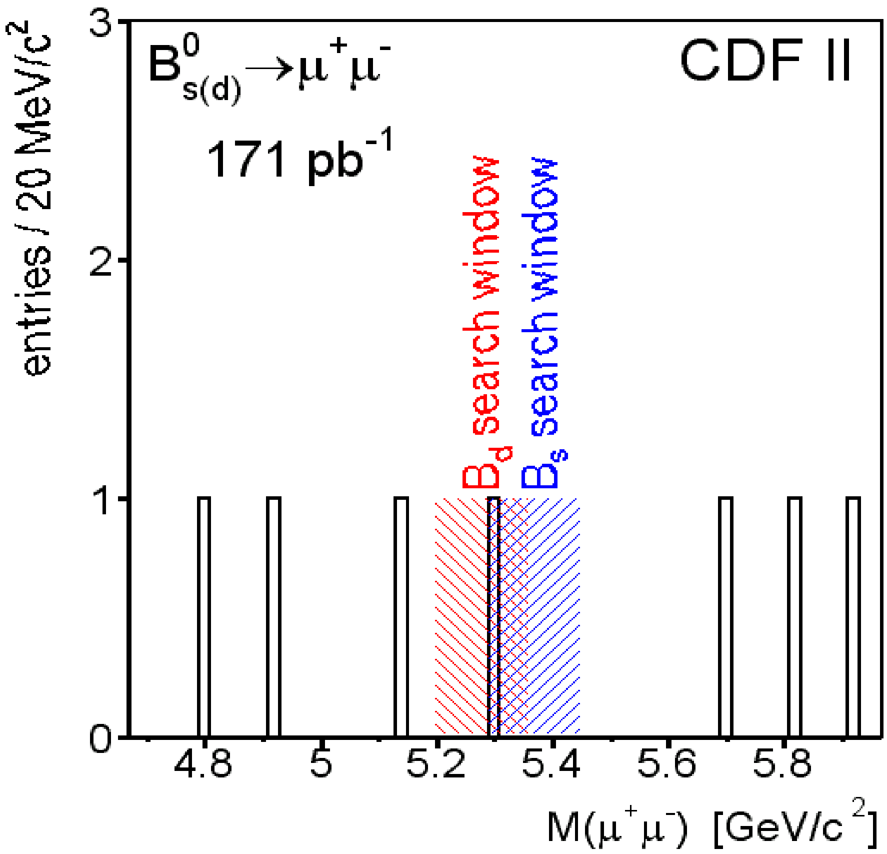
0 candidate observed, 1.7 ± 0.7 BG expected.

$\Rightarrow \mathcal{B}(D^0 \to \mu^+\mu^-) < 2.5 \times 10^{-6}$ (90% CL),
PRD 68, 091101 (2003)

Better than PDG 2002 : $\mathcal{B} < 4.1 \times 10^{-6}$,
but still long way to go.

Search for B_d^0, $B_s^0 \to \mu^+\mu^-$

SM prediction :
$\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.5 \pm 1.4) \times 10^{-10}$
$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.5 \pm 1.0) \times 10^{-9}$



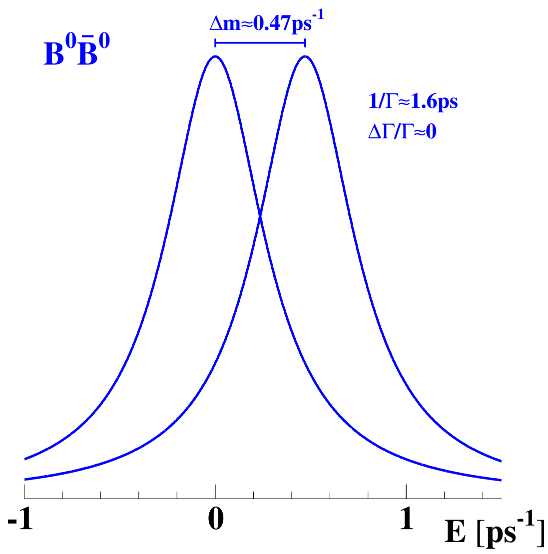
One candidate observed in the overlap region of B^0 and B_s^0.

$\Rightarrow \mathcal{B}(B^0 \to \mu^+\mu^-) < 1.9 \times 10^{-7}$ (95% CL)
$\Rightarrow \mathcal{B}(B_s^0 \to \mu^+\mu^-) < 7.5 \times 10^{-7}$ (95% CL)
To be submitted to PRL.

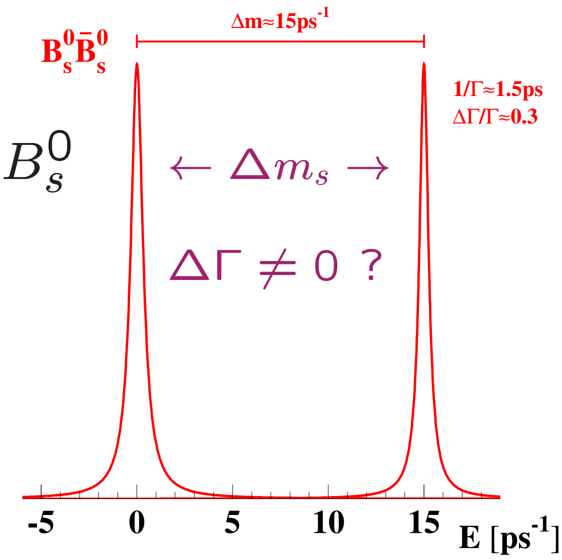
A factor of ~ 3 better than previous result :
PRD 57, 3811 (1998)

Neutral meson mass eigenstates

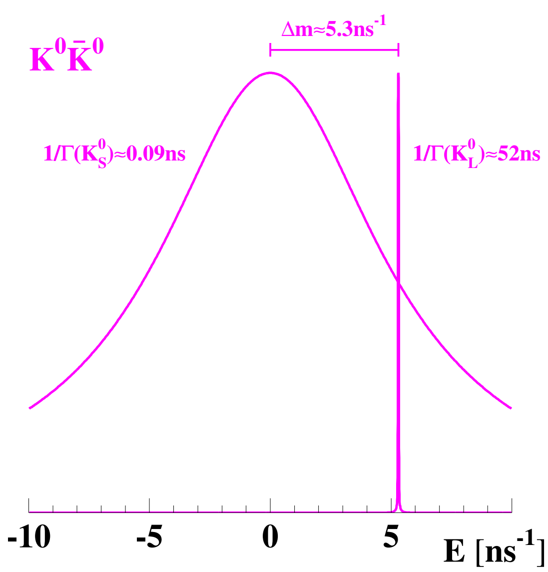
B_d^0



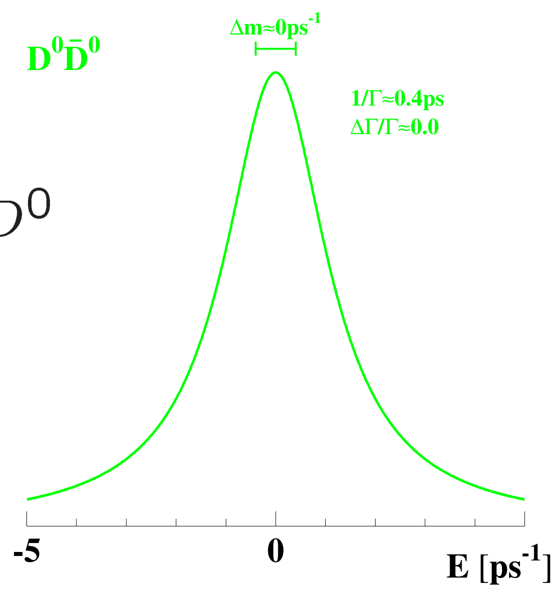
B_s^0



K^0

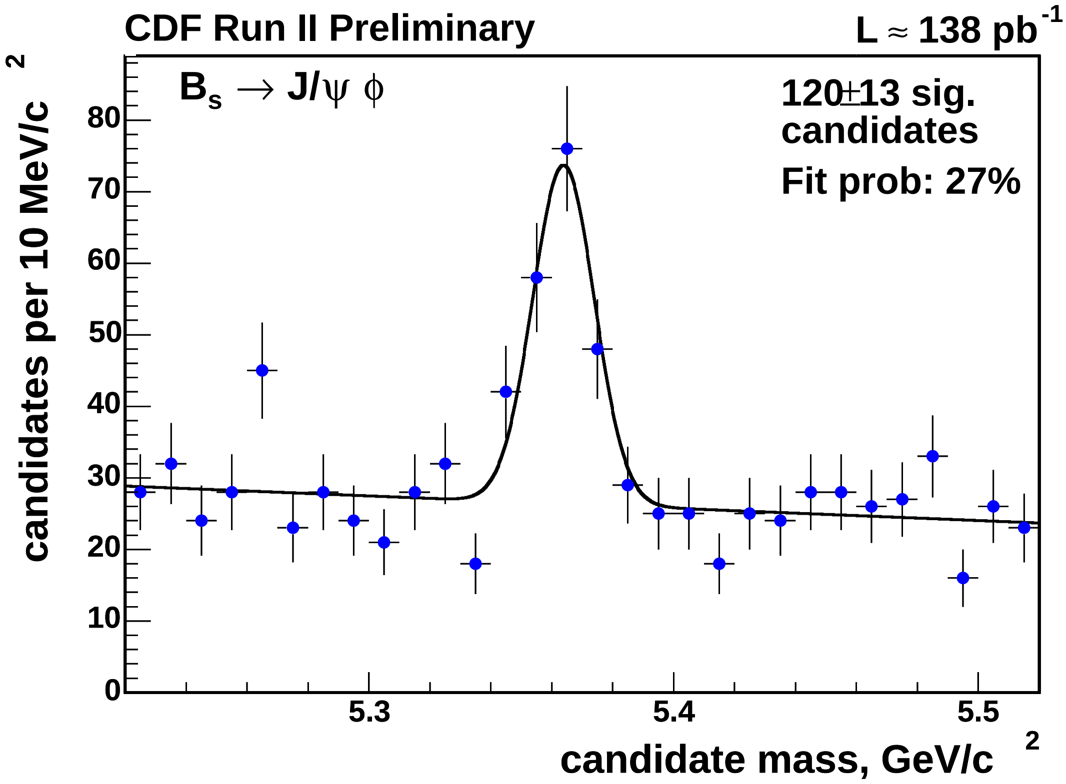


D^0



B_s^0 meson : unique to CDF

$B_s^0 \to J/\psi\, \phi \to \mu^+\mu^-\, K^+K^-$



$\Rightarrow m(B_s^0) = 5365.5 \pm 1.3 \pm 0.9$ MeV$/c^2$.

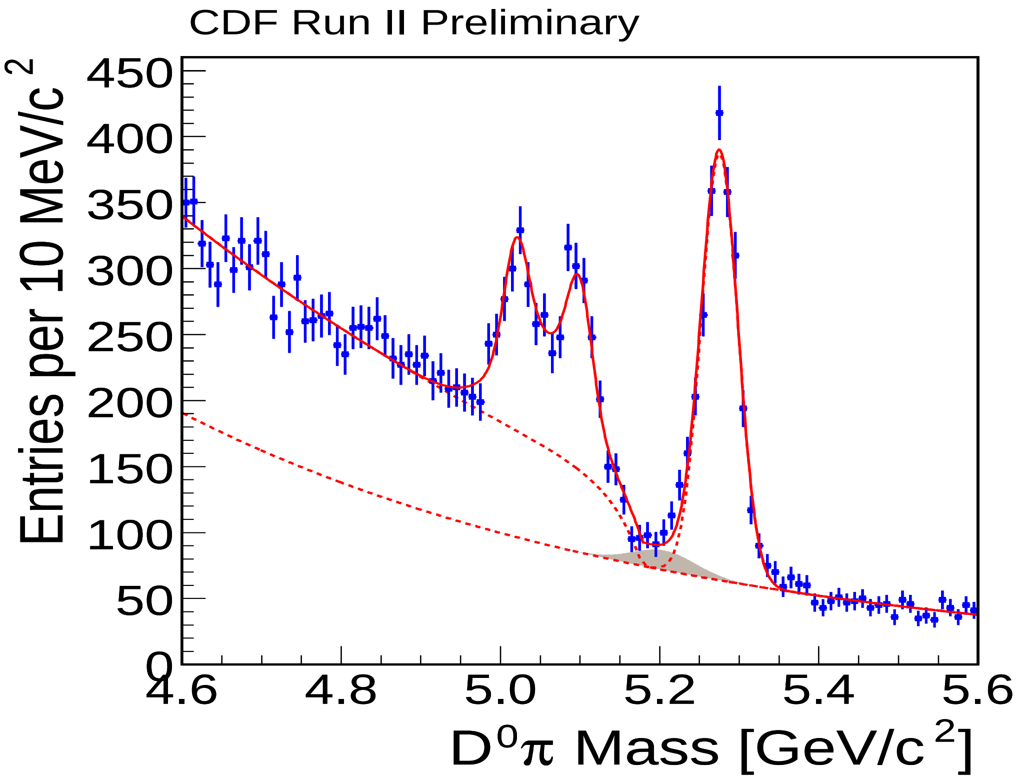
$\Rightarrow \tau(B_s^0) = 1.33 \pm 0.14 \pm 0.02$ ps

Expect $\tau(B_s^0)/\tau(B^0) = 1.0 \pm \mathcal{O}(1\%)$.
The mode is dominated by CP-even eigenstate.
Can exhibit different τ than flavor eigenstates, such as $\ell^-\bar{\nu}D_s^+$ and $D_s^+\pi^-$.

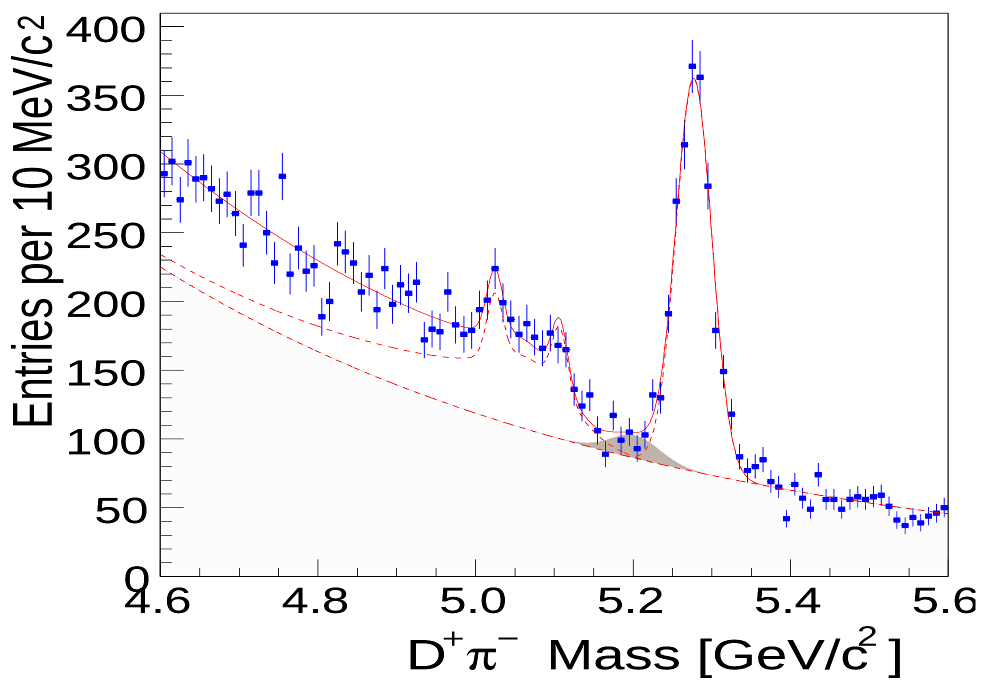
Future : look for CP violation.
$\sim$ zero expected in SM (phase of V_{ts})

B signals from SVT triggers

$B^- \to D^0\pi^- \to (K^-\pi^+)\pi^-$: 1873 ± 55

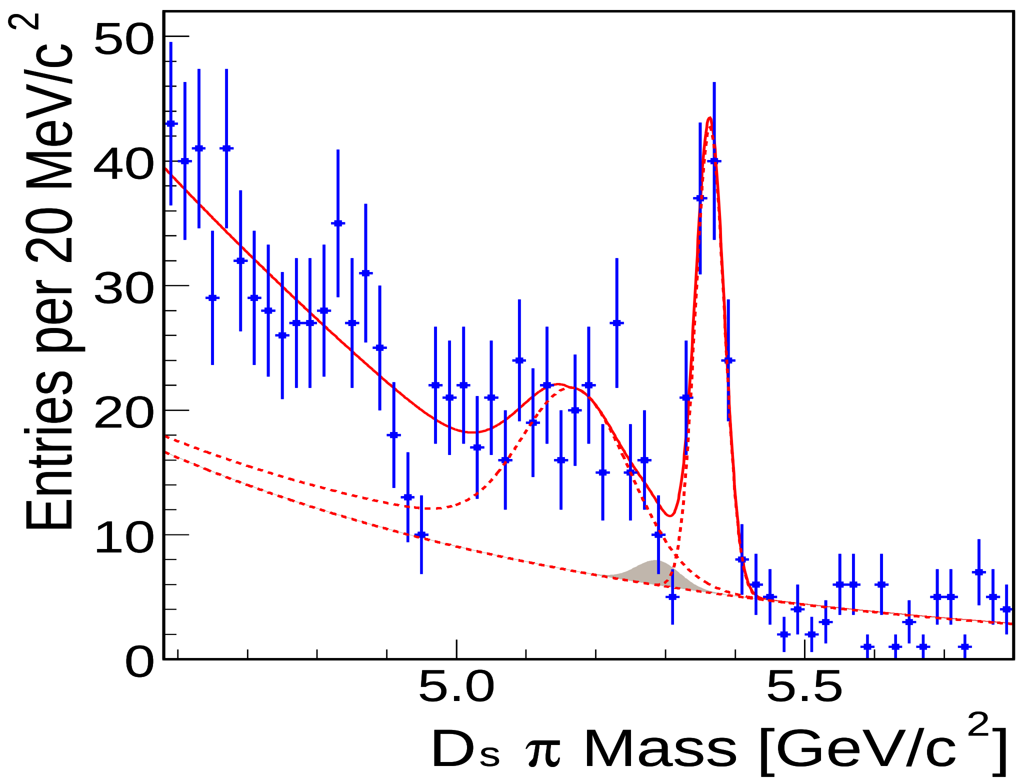


$\bar{B}^0 \to D^+\pi^- \to (K^-\pi^+\pi^+)\pi^-$: 1639 ± 56



Measure Δm_d, calibrate/optimize flavor tagging. Exercise for the B_s^0-$\bar{B}_s^0$ oscillations.

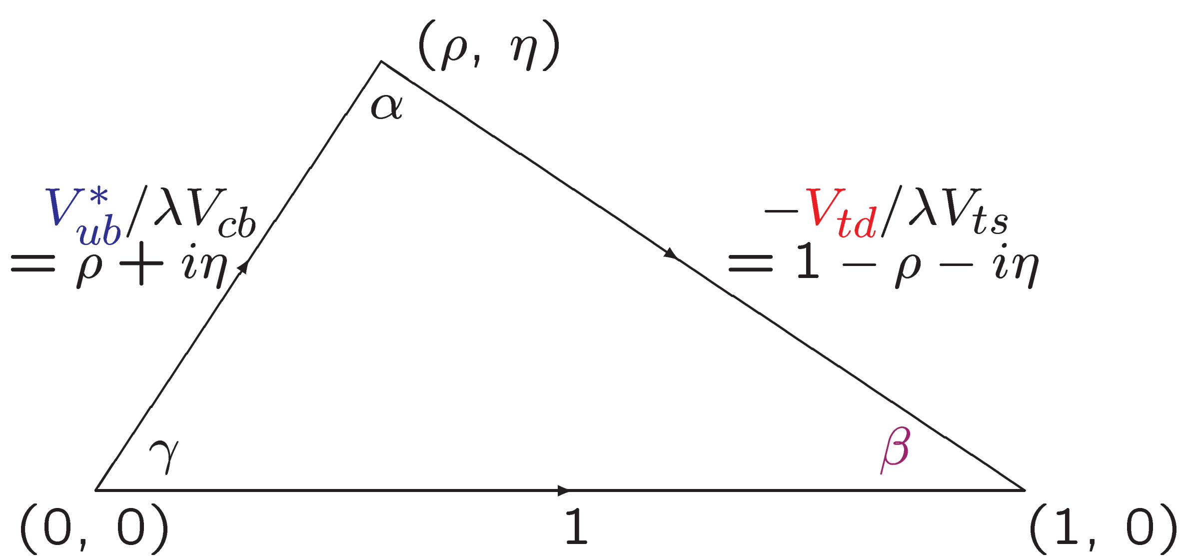
What we wanted : $\bar{B}_s^0 \to D_s^+ \pi^-$



$\sim$ 100 signal events observed in 120 pb^{-1}.

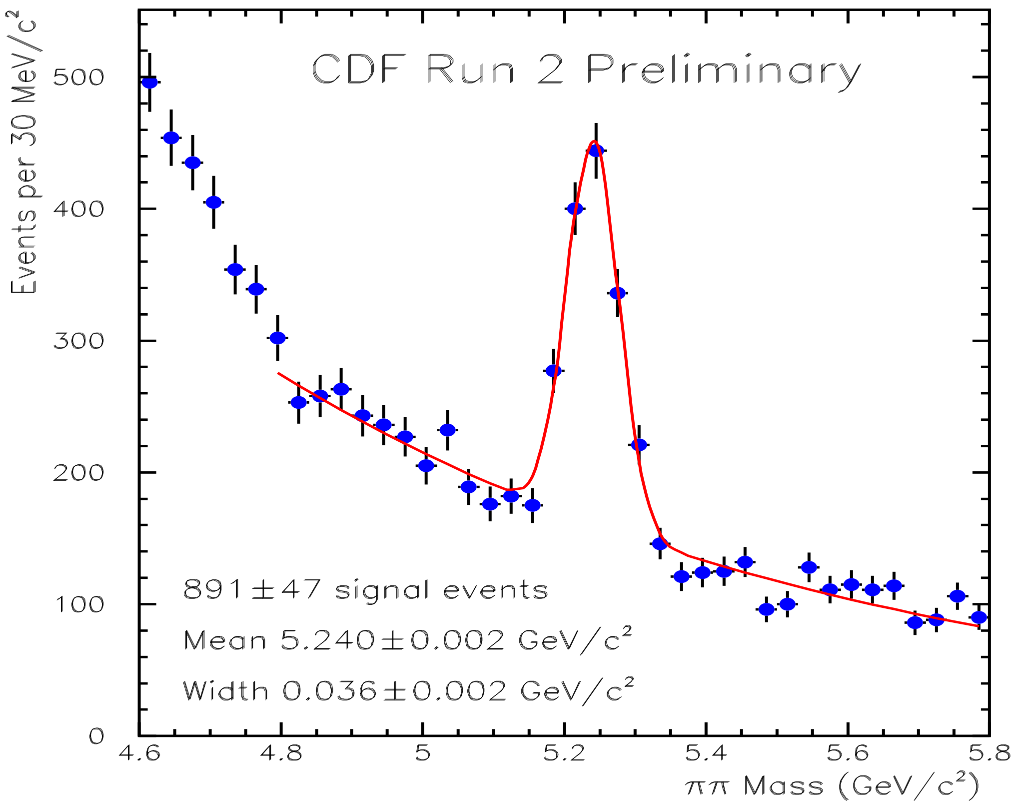
Next step : accumulate stats, look for oscillations.

$\Delta m_s \Rightarrow$ Crucial for $|V_{td}/V_{ts}|$.

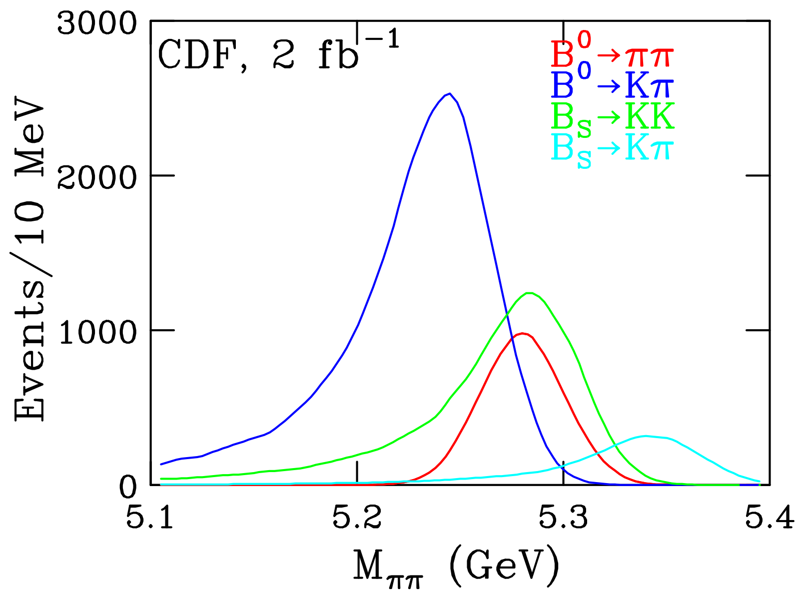


$B_d^0,\ B_s^0 \to h^+h'^-$

900 events / 190 pb^{-1}

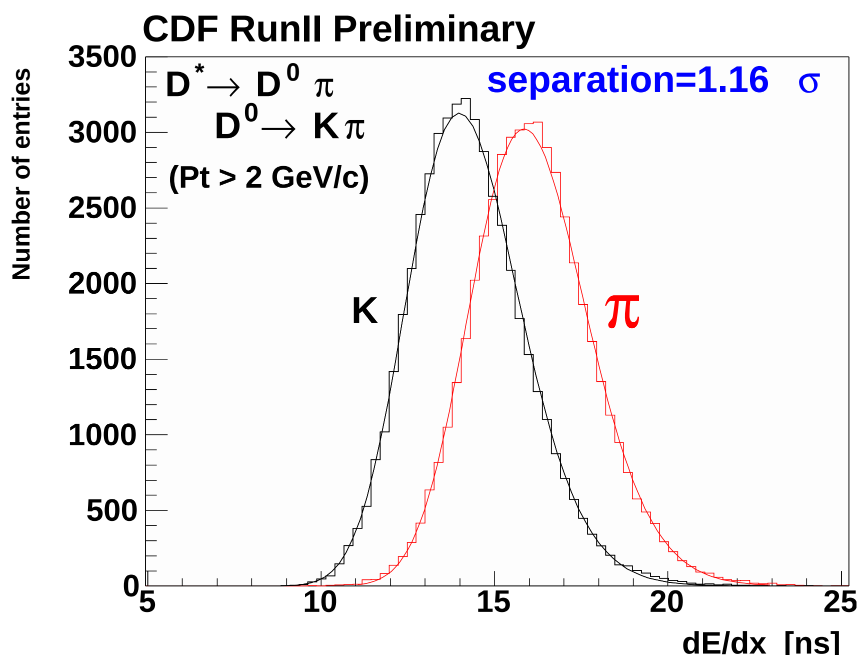


Peak : mixture of $B_d^0 \to \pi^+\pi^-$, $K^+\pi^-$ and $B_s^0 \to K^+K^-$, $K^-\pi^+$.



Composition determined using COT dE/dx.

B_d^0, $B_s^0 \to h^+h'^-$ cont'd



Mode	Yield (65 pb^{-1})
$\bar{B}^0 \to K^-\pi^+$	$148 \pm 17 \pm 17$
$\bar{B}^0 \to \pi^+\pi^-$	$39 \pm 14 \pm 17$
$\bar{B}_s^0 \to K^+K^-$	$90 \pm 17 \pm 17$
$\bar{B}_s^0 \to K^+\pi^+$	$3 \pm 11 \pm 17$

First observation of $B_s^0 \to K^+K^-$:

$$\frac{f(b \to \bar{B}_s^0) \cdot \mathcal{B}(\bar{B}_s^0 \to K^+K^-)}{f(b \to \bar{B}_d^0) \cdot \mathcal{B}(\bar{B}_d^0 \to K^-\pi^+)} = 0.74 \pm 0.20 \pm 0.22$$

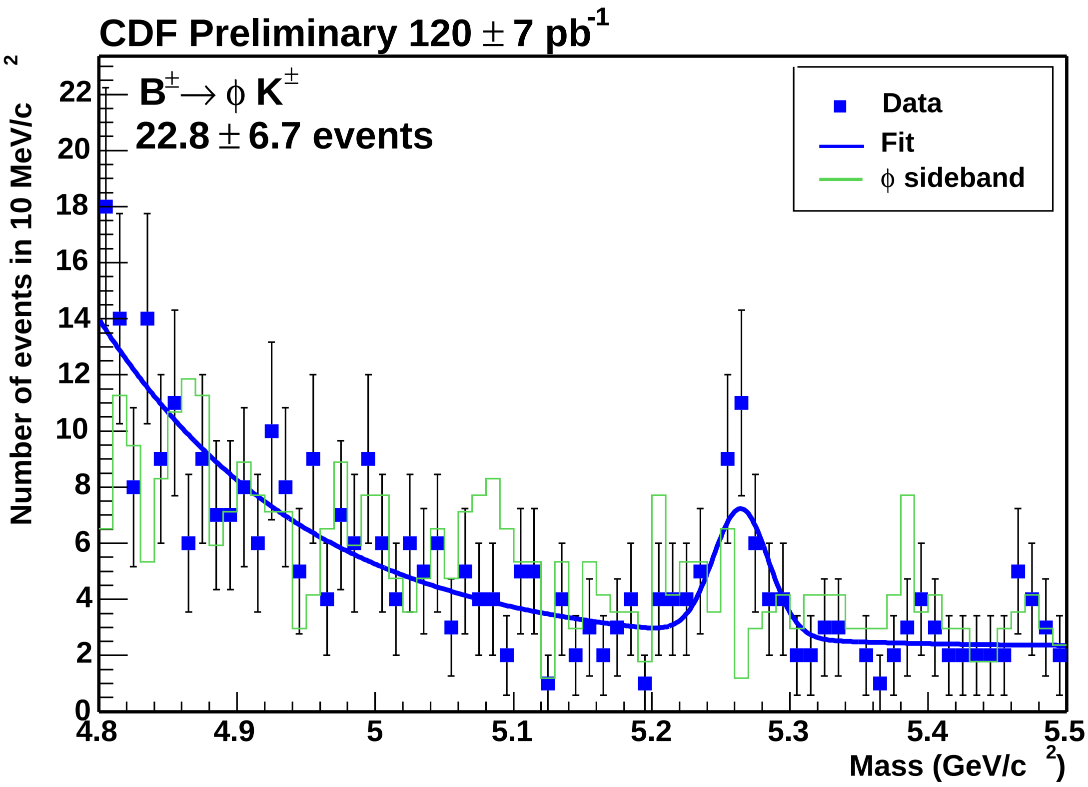
Also :

$\mathcal{B}(\bar{B}^0 \to \pi^+\pi^-)/\mathcal{B}(\bar{B}^0 \to K^-\pi^+) = 0.26 \pm 0.11 \pm 0.06$

$\mathcal{A}_{\mathrm{CP}}^{\mathrm{DIR}}(B^0 \to K^-\pi^+) = 0.02 \pm 0.15 \pm 0.02$

Future : CP asymmetry and then angle γ from $B^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$,
R. Fleischer, Phys. Lett. B459, 306 (1999).

Even $B^+ \to \phi K^+$ is seen.



$$\frac{\mathcal{B}(B^+ \to \phi K^+)}{\mathcal{B}(B^+ \to J/\psi K^+)} = (0.68 \pm 0.21 \pm 0.07) \times 10^{-2}$$

Try neutral : $B^0 \to \phi K_S^0$,

$\sin 2\beta$ really different from $J/\psi K_S^0$?

Summary

Run-II CDF has been running since 2001.

We have accumulated ~ 3 times more data than Run I.

- CDF-II detector is working very well.

  Machine luminosity is greatly improving in recent months.
  We are ready to accumulate 2 fb^{-1} in ~ 2 years.

- Already some physics results are coming out.

  Important measurements to follow, e.g. :
  Top mass, W mass, Δm_s ...

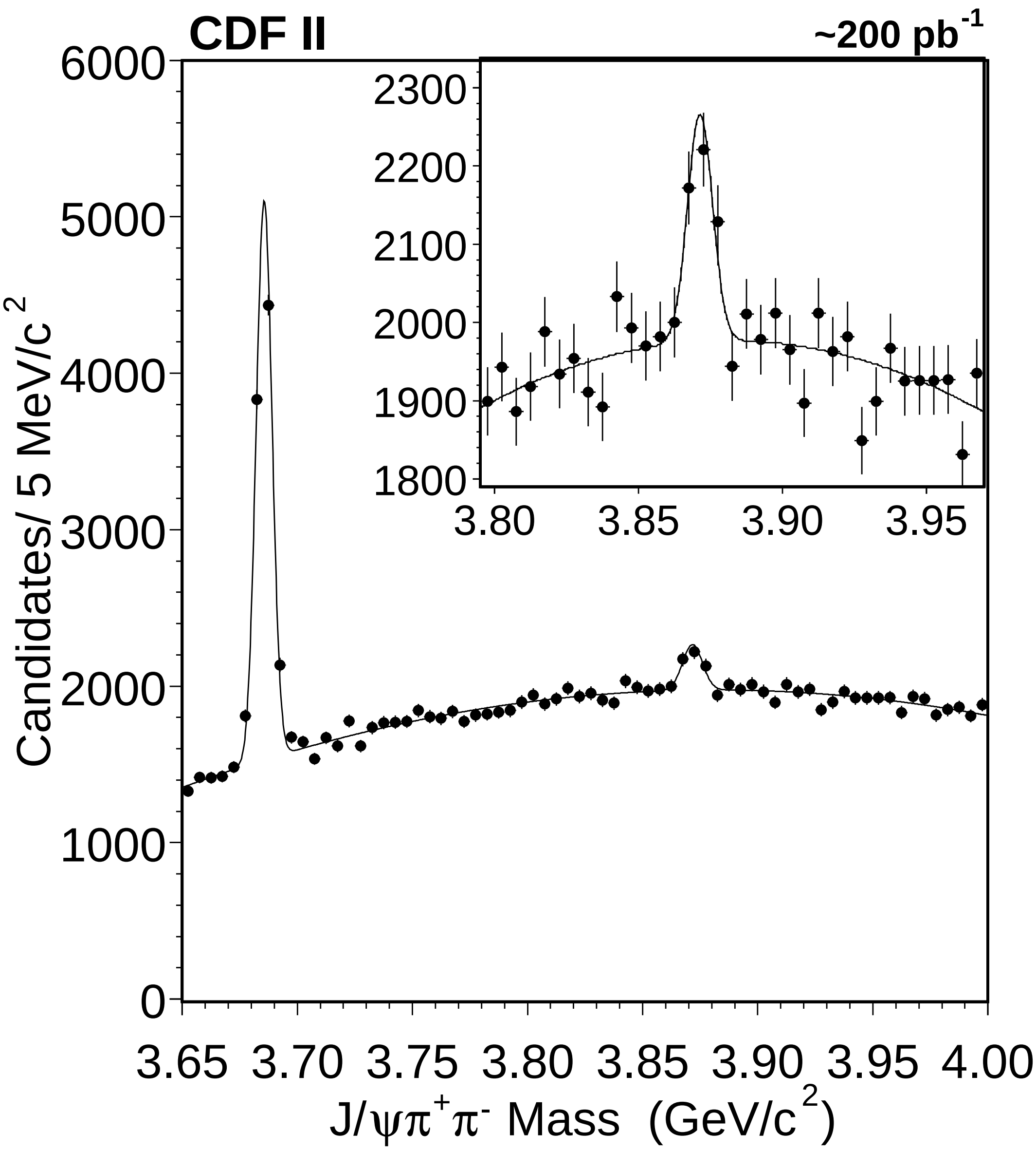
CDF will continue through 2009. Expect to collect a total of $5 - 9$ fb^{-1}.

- Hopefully some kind of discovery before LHC.

  Supersymmetry? Light Higgs?
  Or, totally unexpected?

State $X(3872) \to J/\psi\,\pi^+\pi^-$

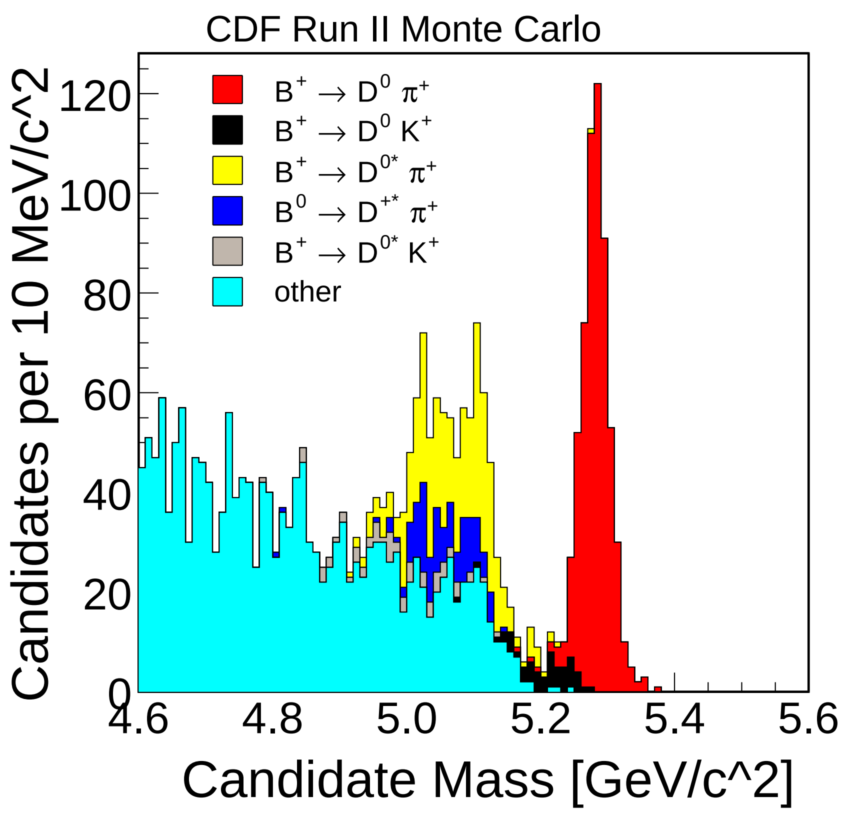
CDF confirms Belle discovery.

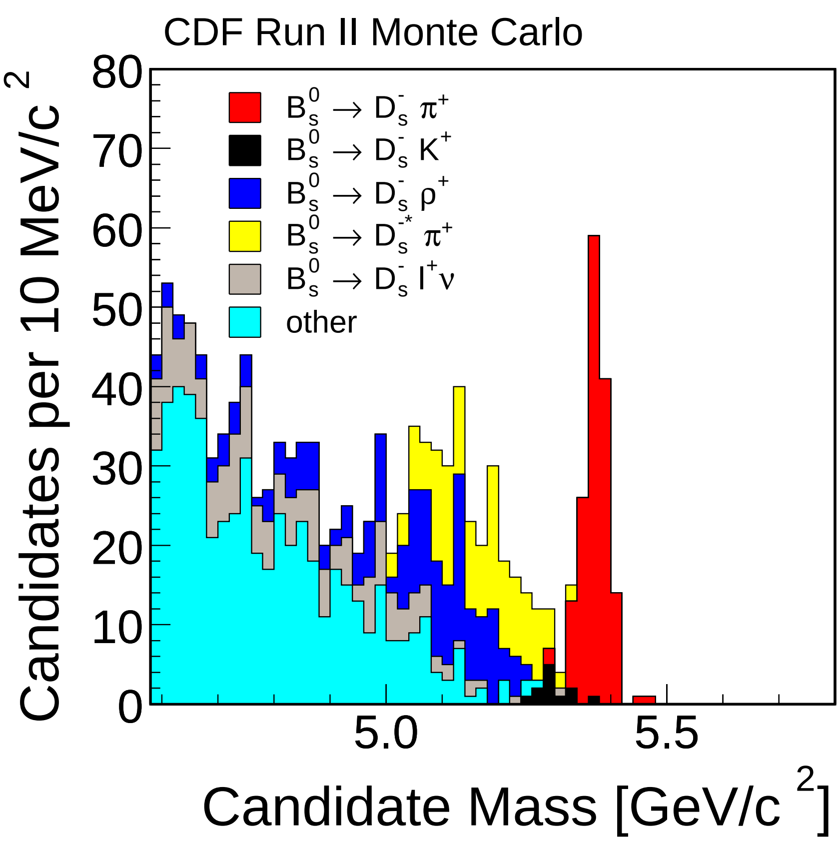


Mass : $3871.3 \pm 0.7 \pm 0.4$ MeV/c^2
Width : narrow (detector resolution)

Submitted to PRL.

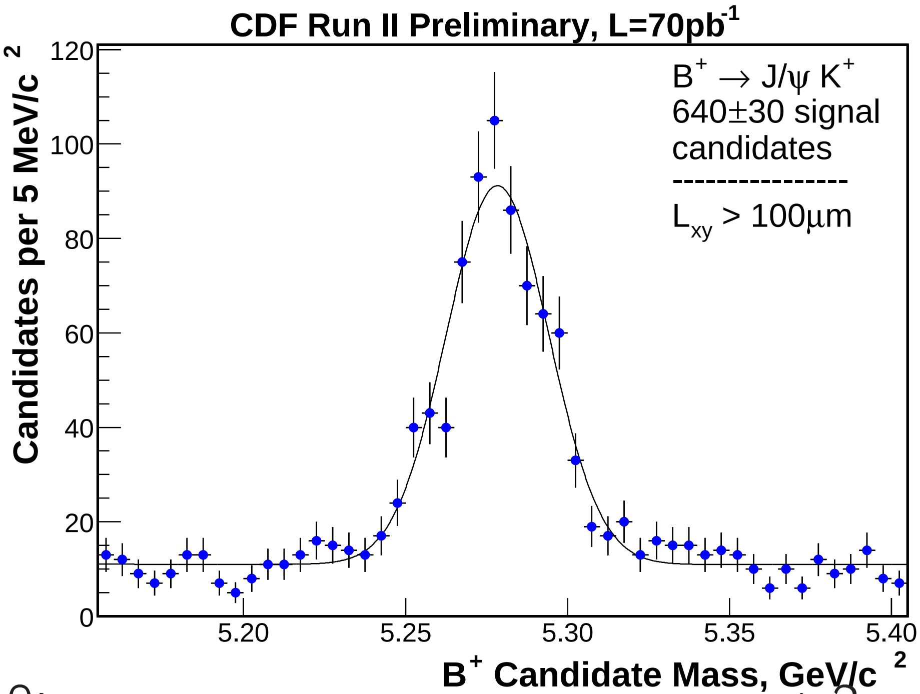
$\bar{B} \to D\pi^-$ Mass from MC



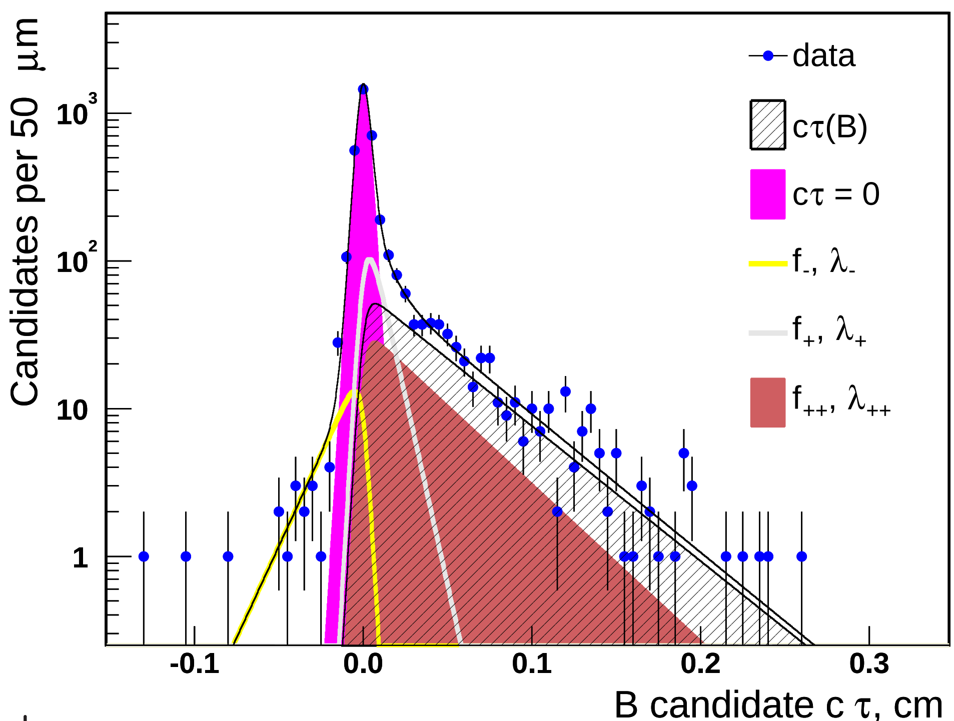


Structure understood as missing neutrals.

Run-II $B^+ \to J/\psi\, K^+$

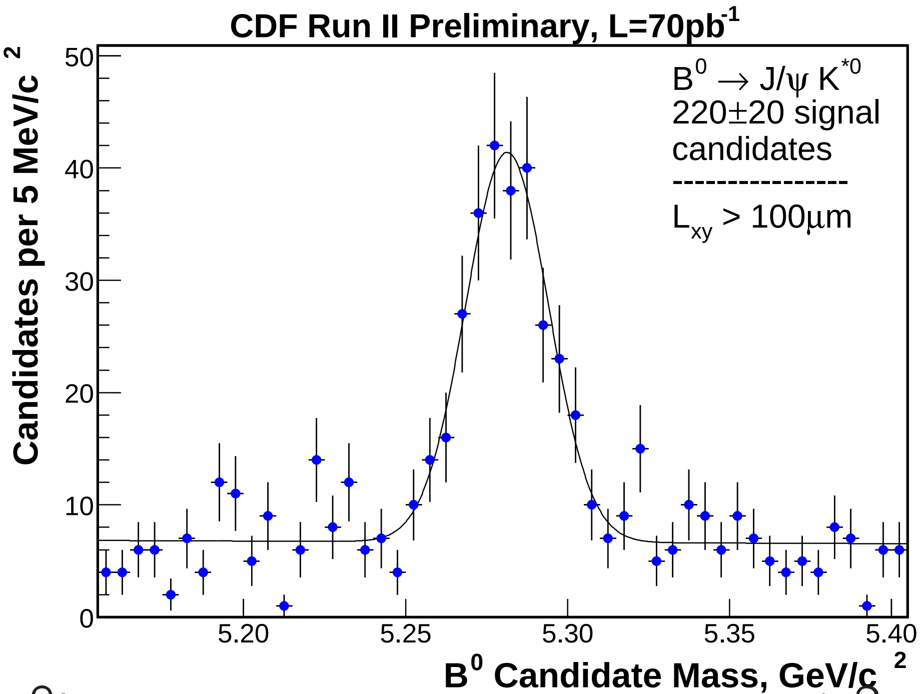


$$\Rightarrow m(B_s^0) = 5280.6 \pm 1.7 \pm 1.1\ \text{MeV}/c^2.$$



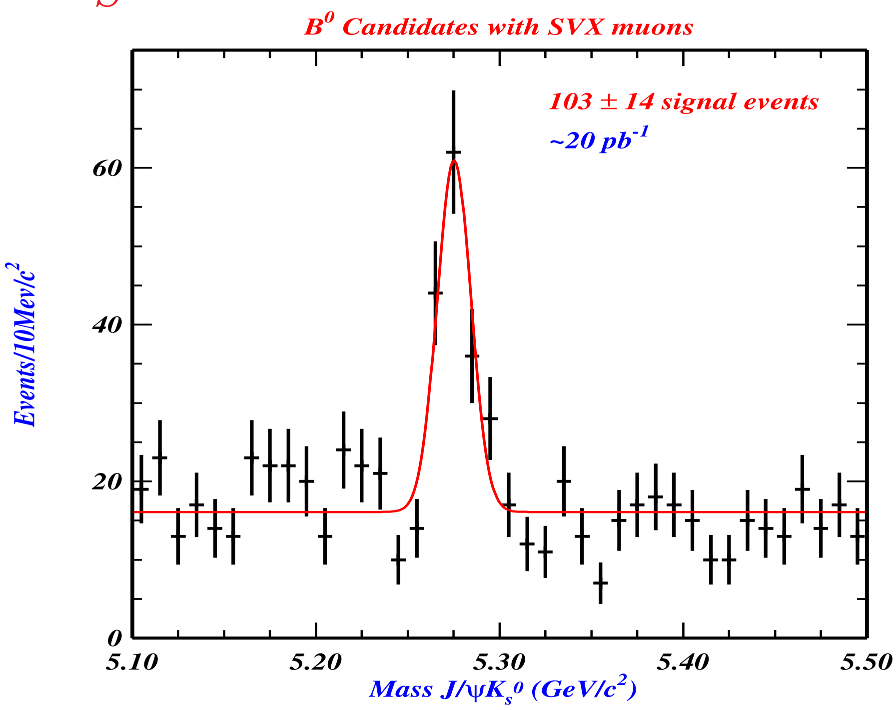
$$\Rightarrow \tau(B^+) = 1.57 \pm 0.07 \pm 0.02\ \text{ps}.$$

$B^0 \to J/\psi\, K^{*0} \to \mu^+\mu^-\, K^+\pi^-$



$\Rightarrow m(B^0) = 5279.8 \pm 1.9 \pm 1.4$ MeV$/c^2$.

$B^0 \to J/\psi\, K^0_S \to \mu^+\mu^-\, \pi^+\pi^-$



Mode for $\sin 2\beta$. Yield $\sim 2.5 \times$ Run-I.

$\bar{B} \to \ell^- \bar{\nu} D X$ signals