Tevatron CDF実験の現状

受川 史彦
(CDF Collaboration)

筑波大学 物理学系 素粒子実験研究室

京都大学理学部 物理学第二教室 談話会

February 27, 2003

京都大学理学部

Disclaimer and Advertisement

- Winter Conferences : La Thuile, Moriond next month.

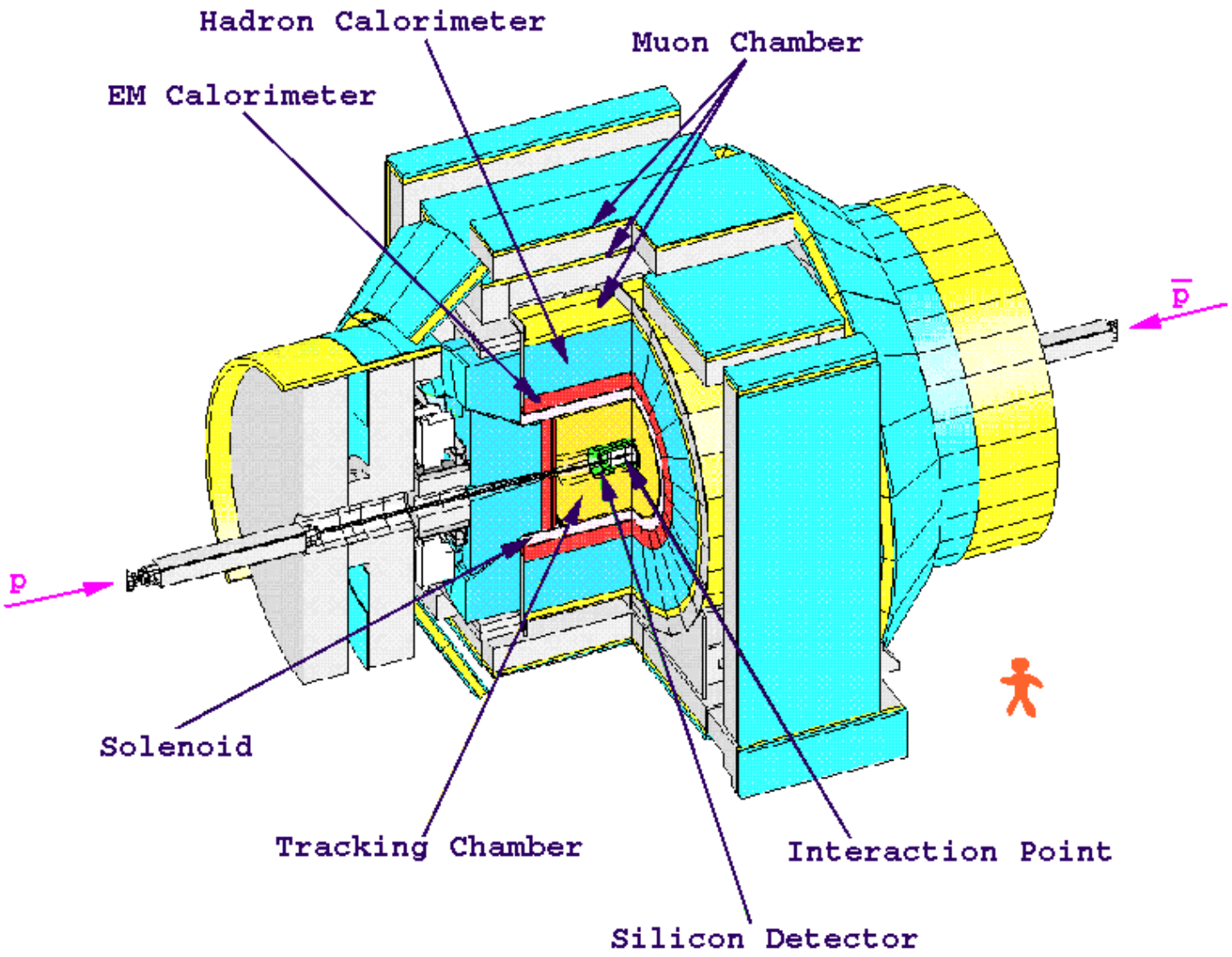
  We are preparing some physics results for them, but not quite finished yet.

- 基礎物理学研究所研究会「素粒子高エネルギーフロンティアでの物理」3月17日(月)- 18日(火)

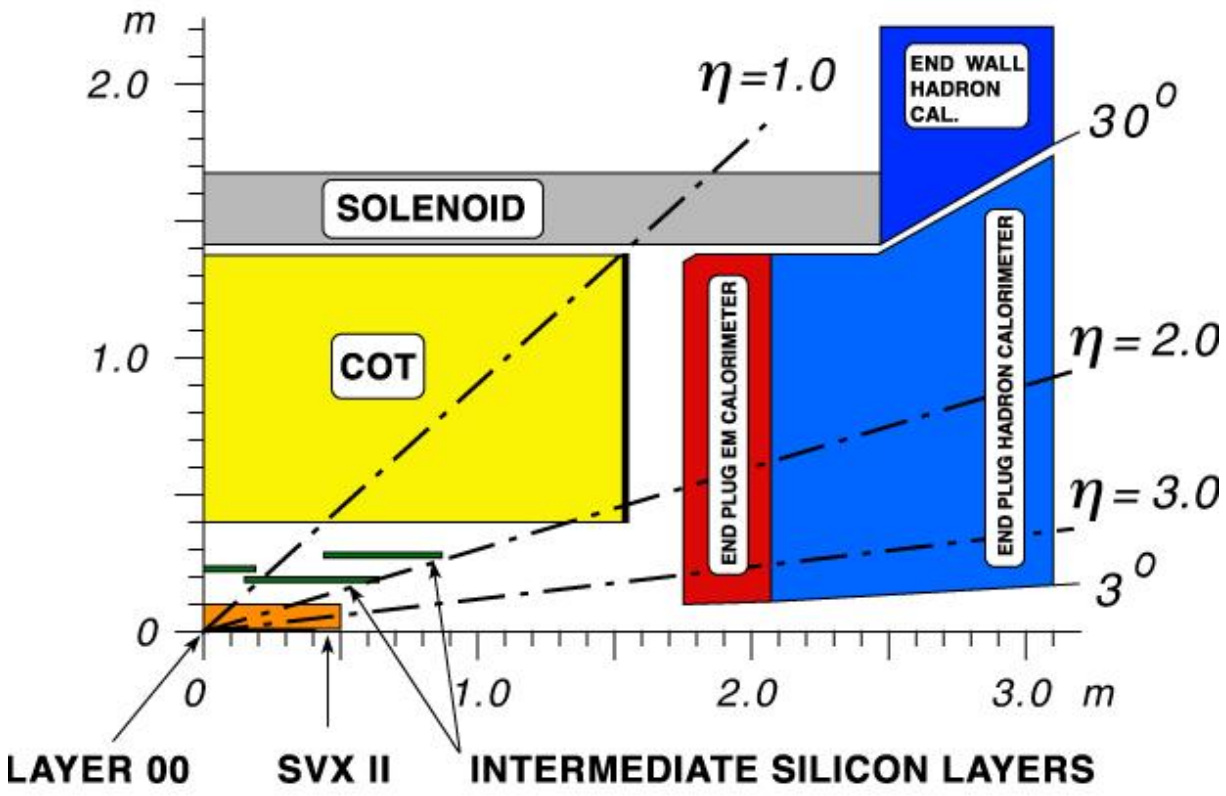
  Five CDF talked assigned.

  Please come and join us.

Run-II CDF Detector



CDF-II Detector



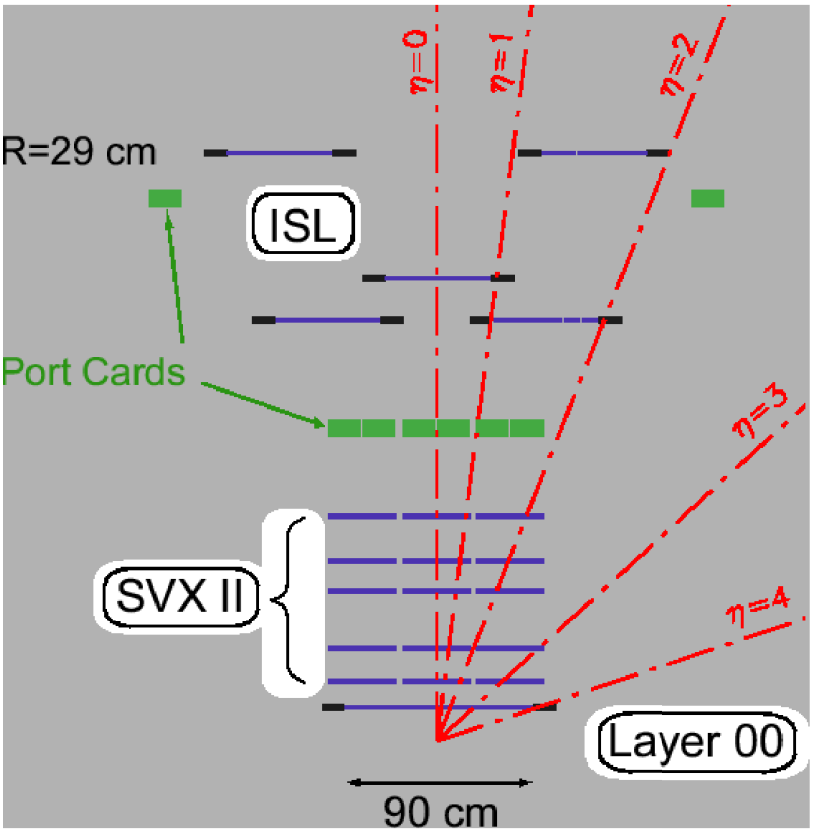
Everything inside the solenoid is new.

- 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.

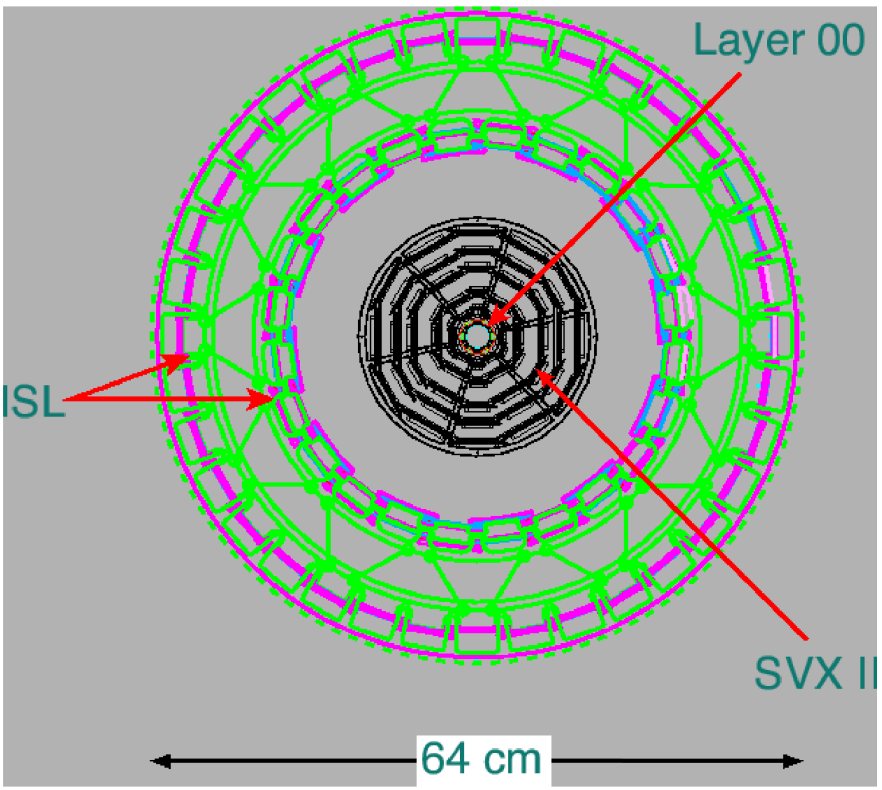
  SVX : 700 k channels (r-φ-z), 15 readouts per track.
  - $\sigma(P_T)/p_T = 0.004\, p_T$ for $1 < |\eta| < 2$.
- New scintillating plug calorimeter to $|\eta| < 3.6$.
  - electron ID.
- TOF particle ID, $|\eta| < 1$.
- Muon coverage increased by $\times 1.7$.
  - $p_T > 1.4$ GeV/c, $|\eta| < 1.5$.

Run-II silicon detector

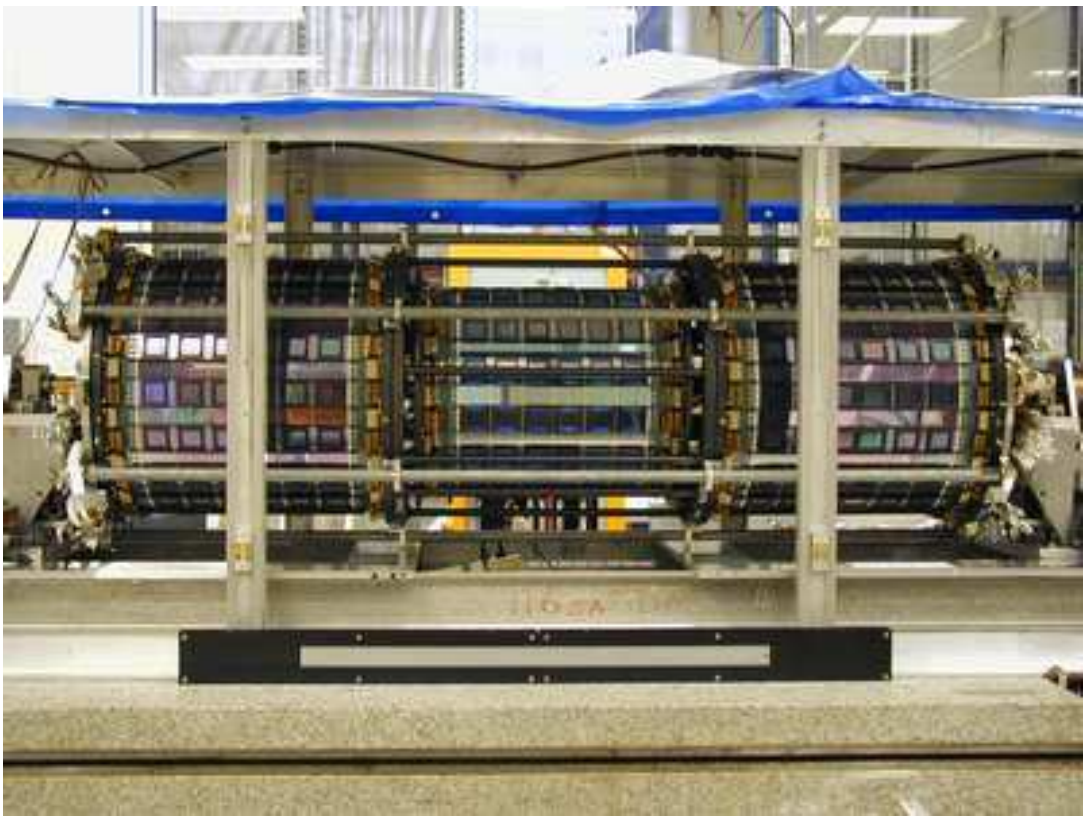


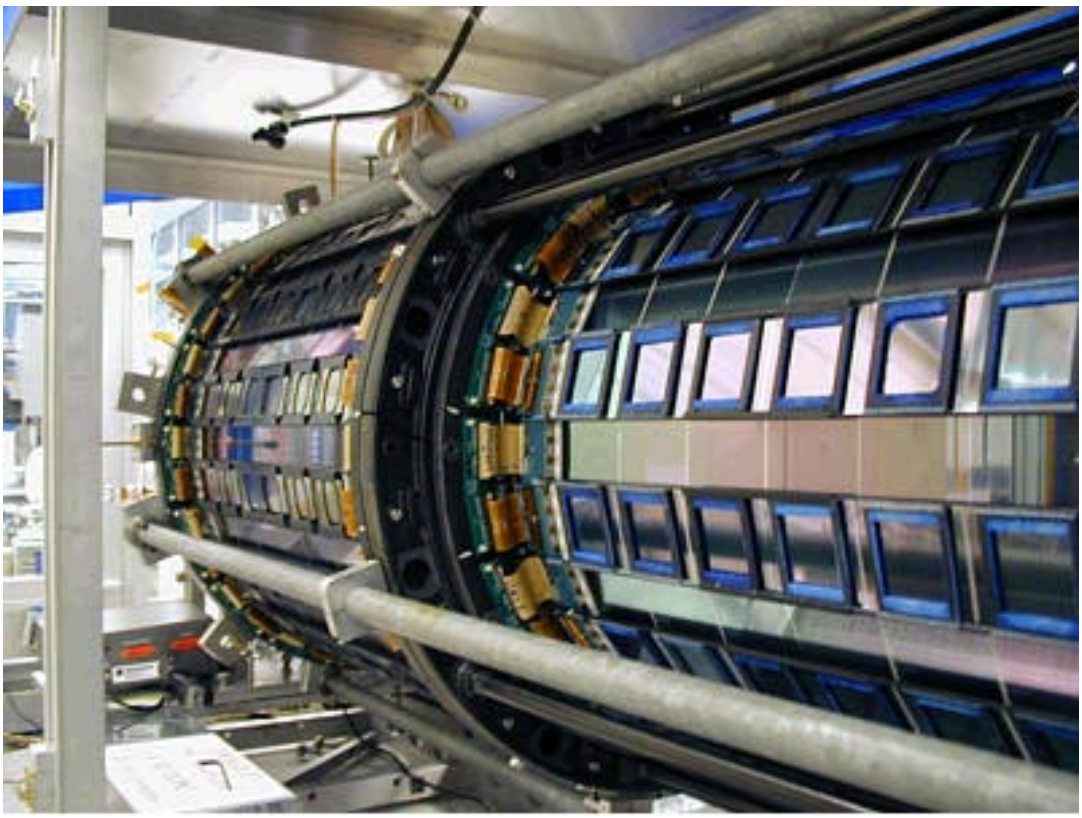
SVX :
Radii 2 cm to 11 cm:
5 layers
Double-sided,
90° and 1.2° stereo

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

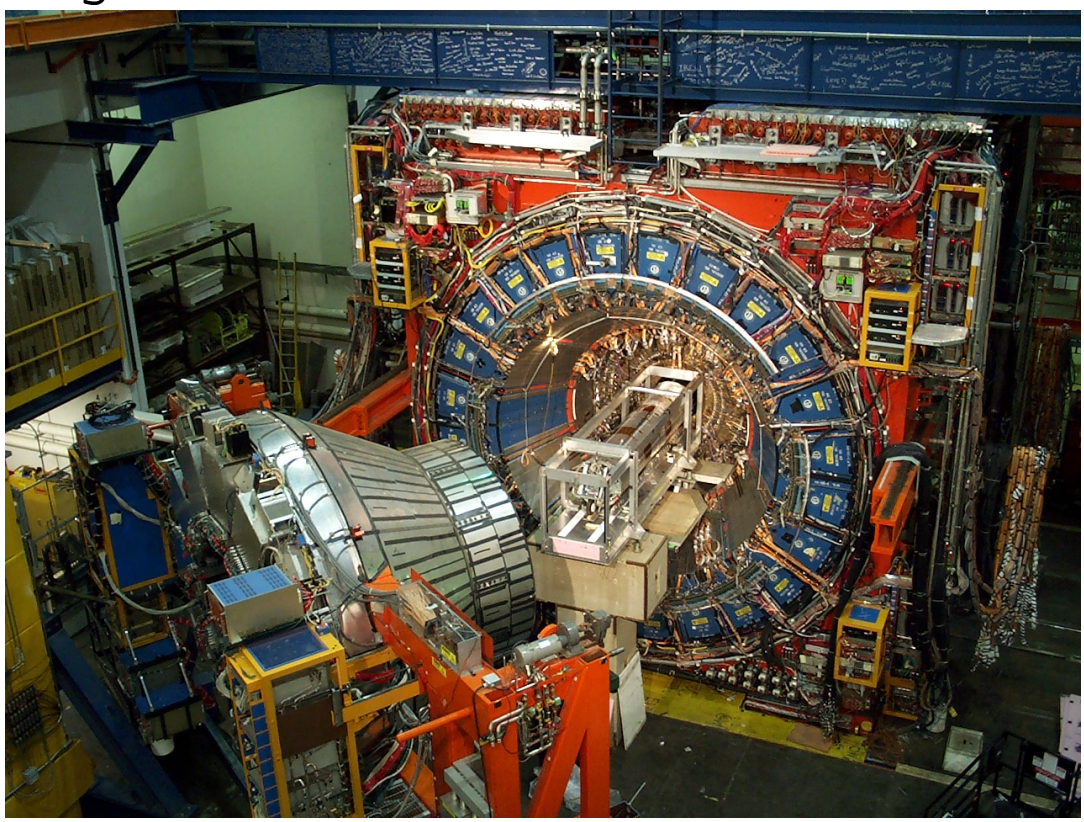


ISL detector

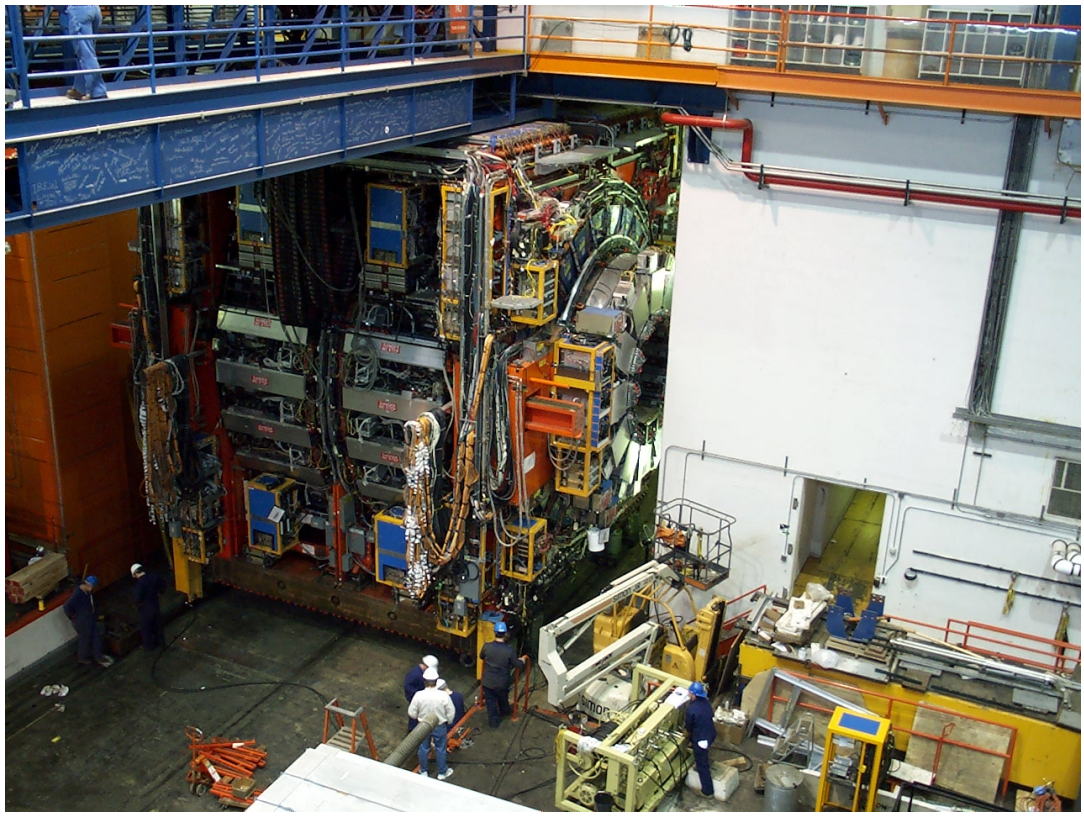




Installing the silicon detectors.



Rolling into the collision hall.



Tevatron Run-II Program

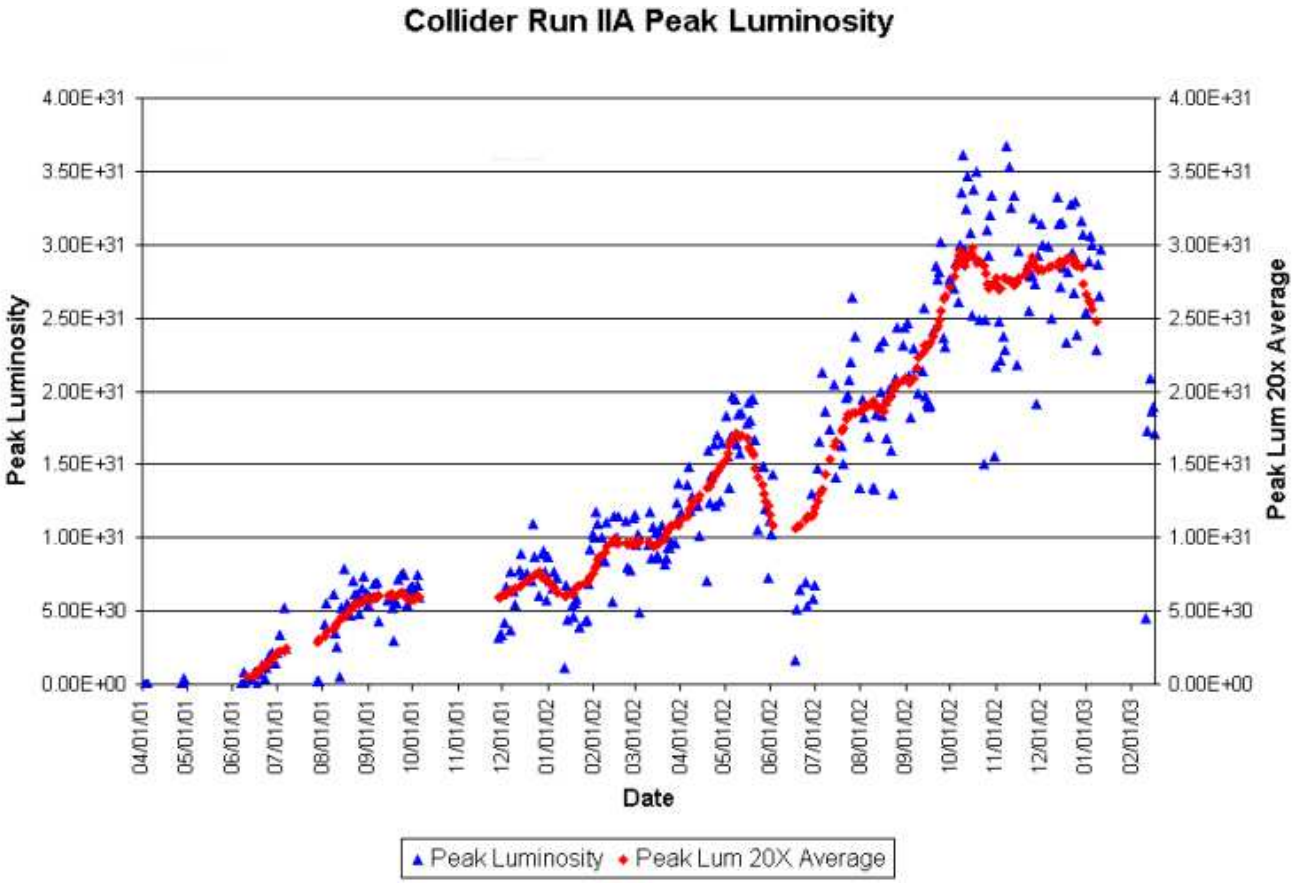
Run II started in March 2001

Increased CM energy : 1.8 $\rightarrow$ 2 TeV

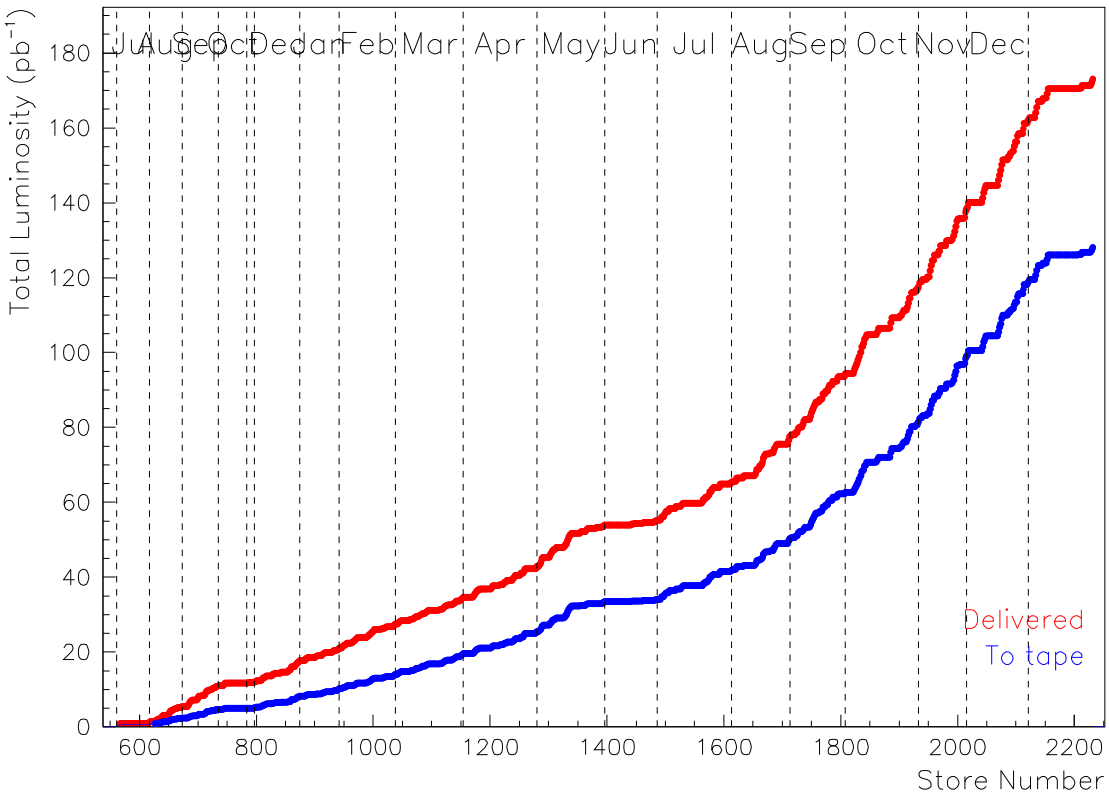
36 $\times$ 36 bunches of p's and $\bar{p}$'s
$\Rightarrow$ Beam crossing every 400 ns (was 3600 ns).

New 150 GeV Main Injector
$\Rightarrow$ Higher $\bar{p}$ production rate. More p's and $\bar{p}$'s to Tevatron.

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



So far 170 pb^{-1} delivered, 120 pb^{-1} recorded.



Luminosity

We started slowly, but it is getting better.

- $\bar{p}$ transfer efficiency (Acc. to MI to TeV) was low. Emittance was large.

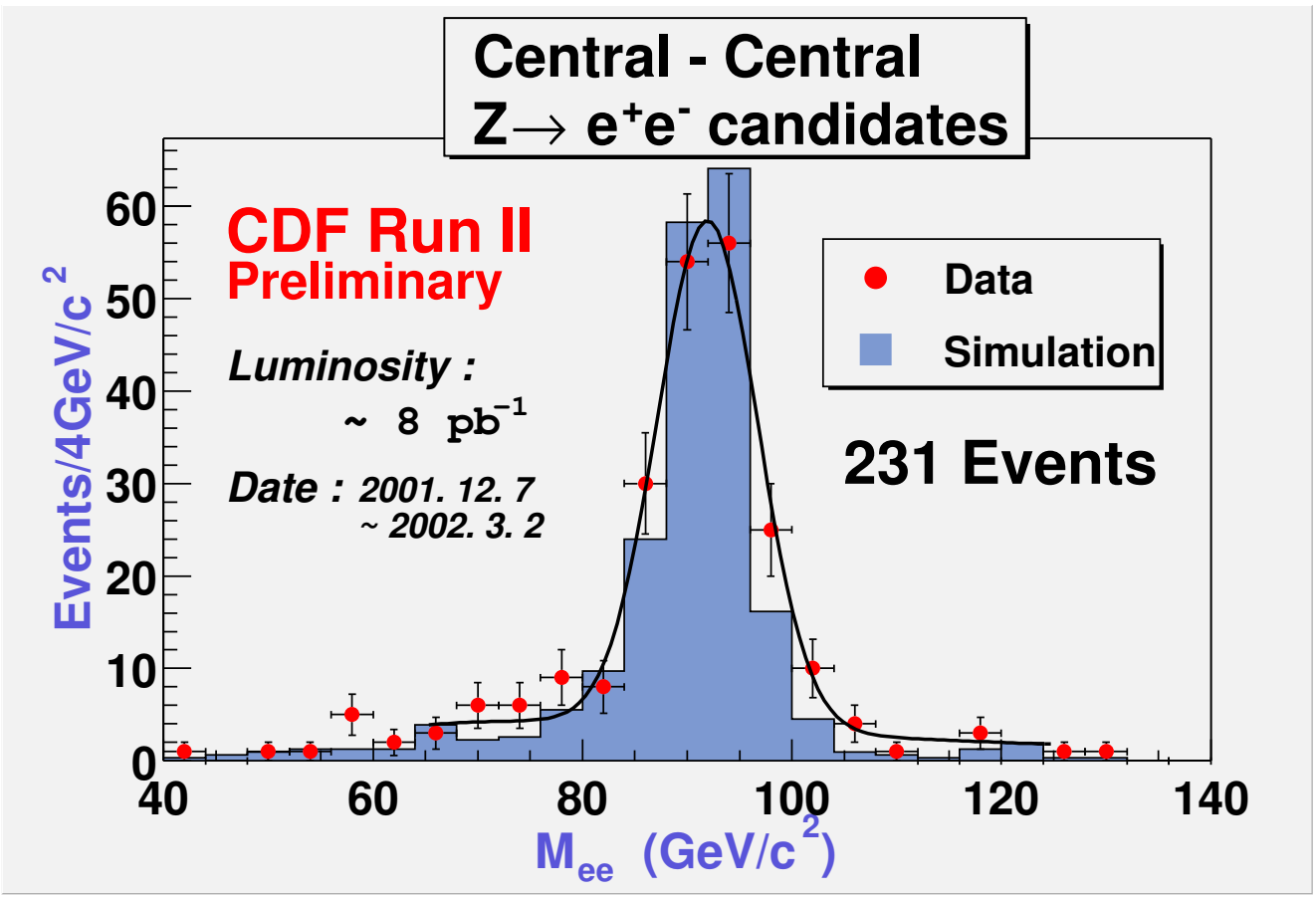
  Had 2-week shutdown in June 2002 to improve stochastic cooling (Accumulator).

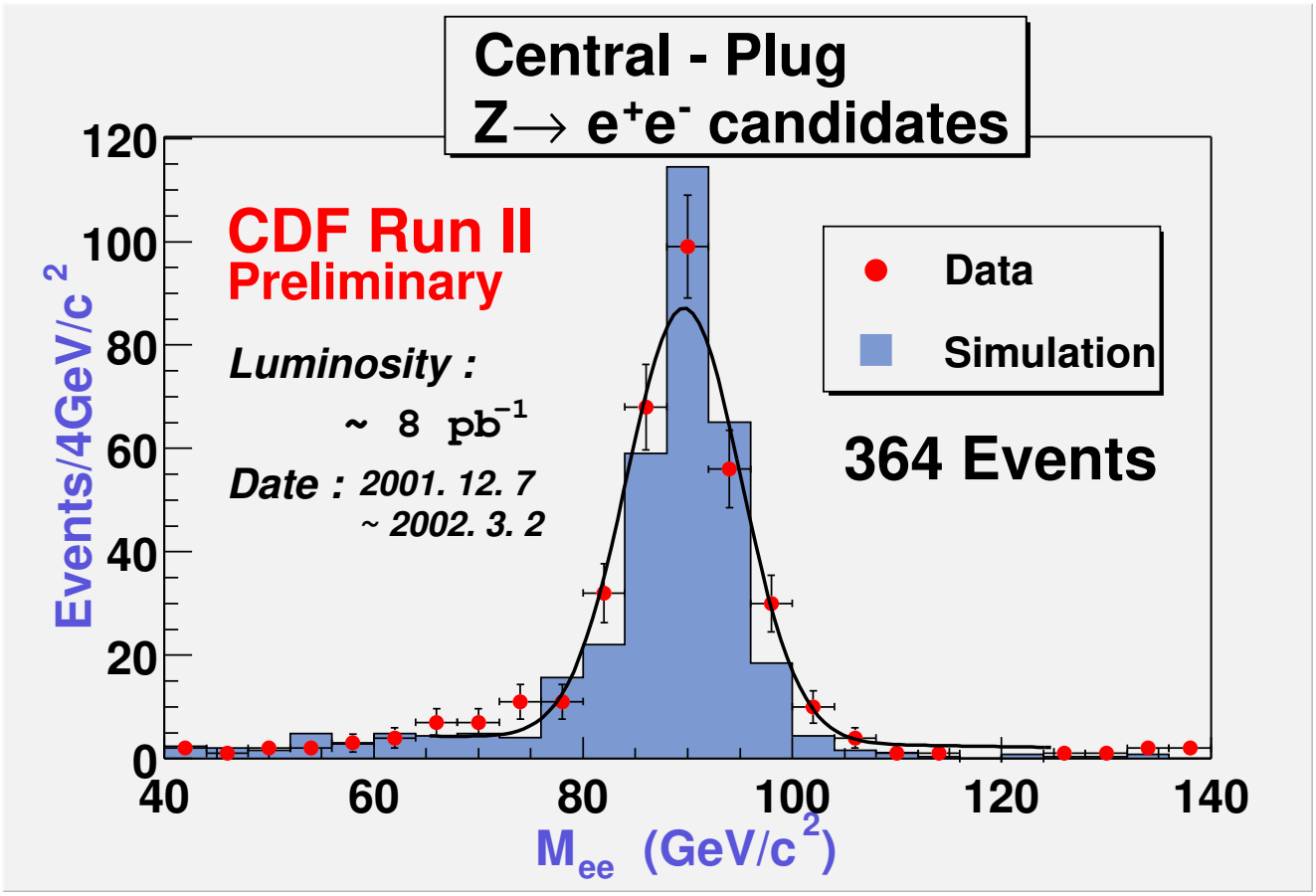
  Got almost a factor of two improvement.
- Had 3-week shutdown in Jan 2003, to remove an obsolete optics at C0 in Tevatron.
- Need recycler working in order to get to : 8×10^{31} cm^{-2} s^{-1} $\sim$ Run-IIa goal.

Plans :

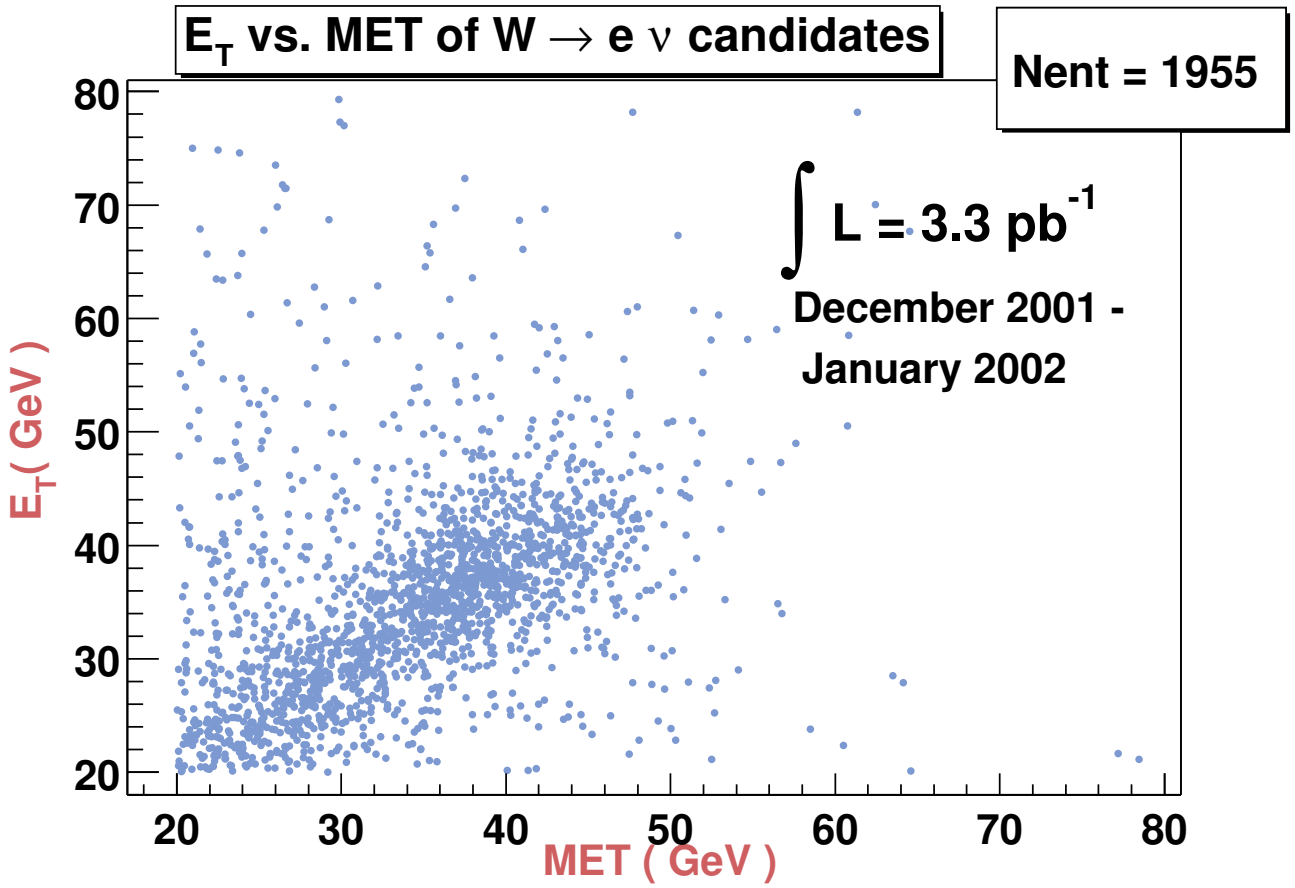
- A few fundred pb^{-1} by end of 2003.
- ~ 2 fb^{-1} in Run-IIa total (end of 2004?).
- 2005 : 6-month shutdown to replace silicon etc.
- After that, Run IIb continues thru 2008, 15 fb^{-1}.

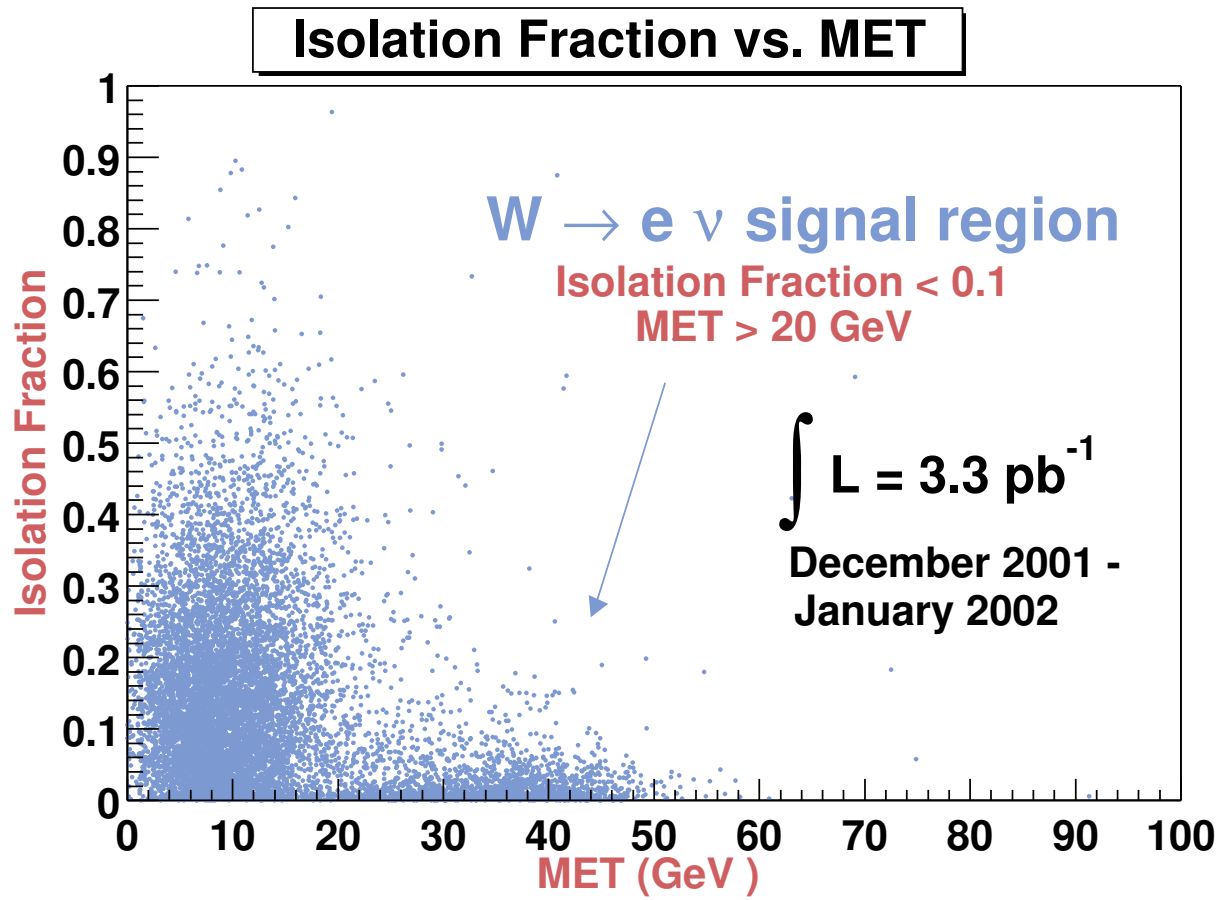
Run-II $Z^0 \to e^+e^-$ candidates :



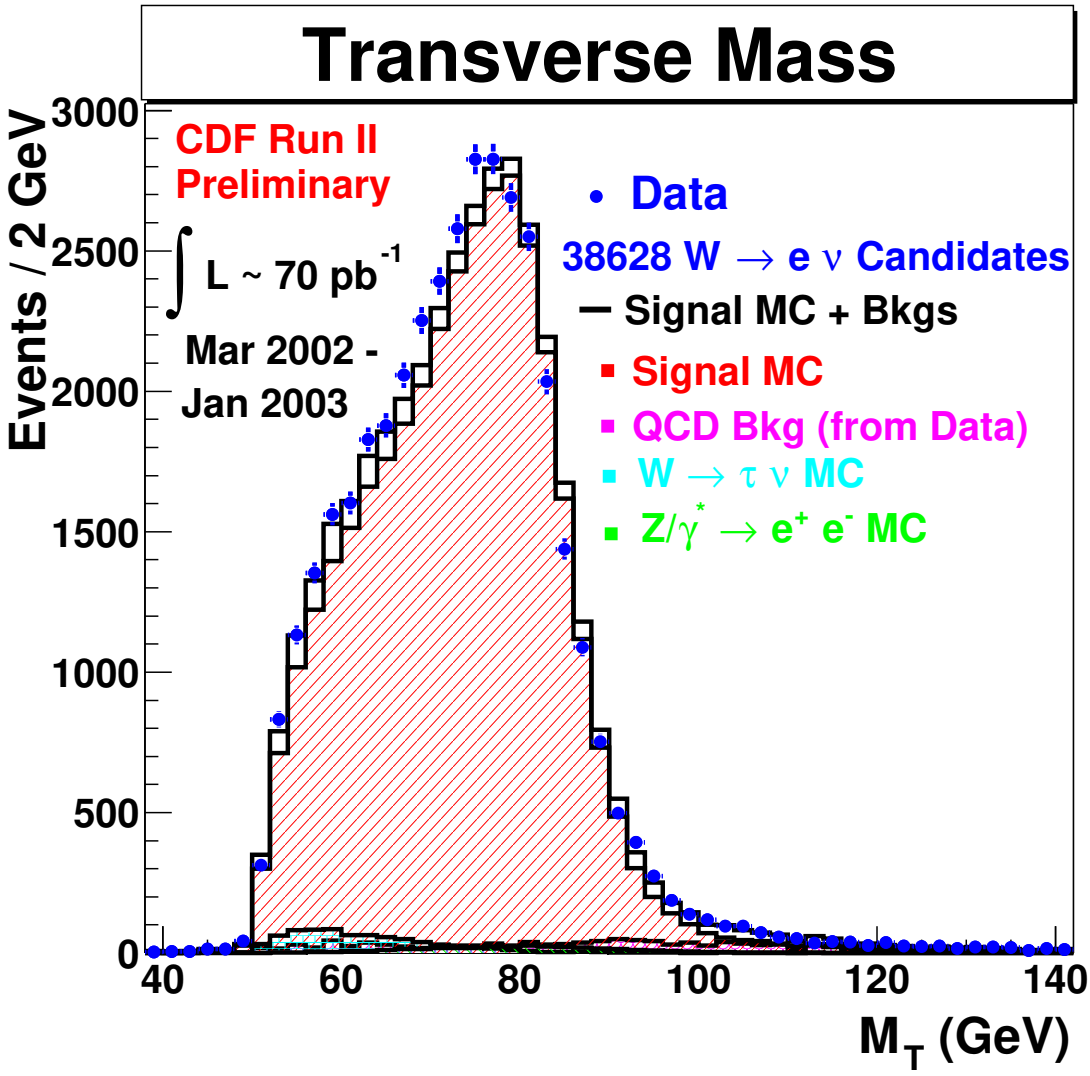


Run-II $W \to e\nu$ candidates





Run-II $W \to e\nu$



$$\sigma(\bar{p}p \to W^+X) \cdot \mathcal{B}(W^+ \to e^+\nu)$$
$$= \quad 2.69 \pm 0.01 \pm 0.09 \pm 0.27 \text{ nb}$$

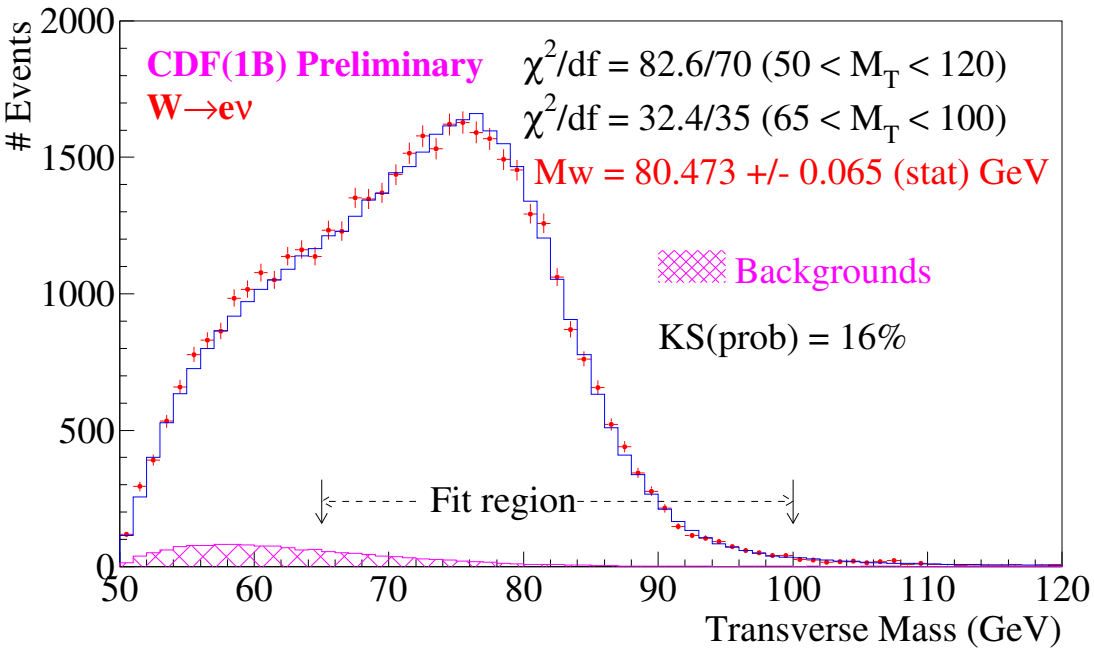
Similarly from the muon channel :

$$\sigma(\bar{p}p \to W^+X) \cdot \mathcal{B}(W^+ \to \mu^+\nu)$$
$$= \quad 2.70 \pm 0.04 \pm 0.19 \pm 0.27 \text{ nb}$$

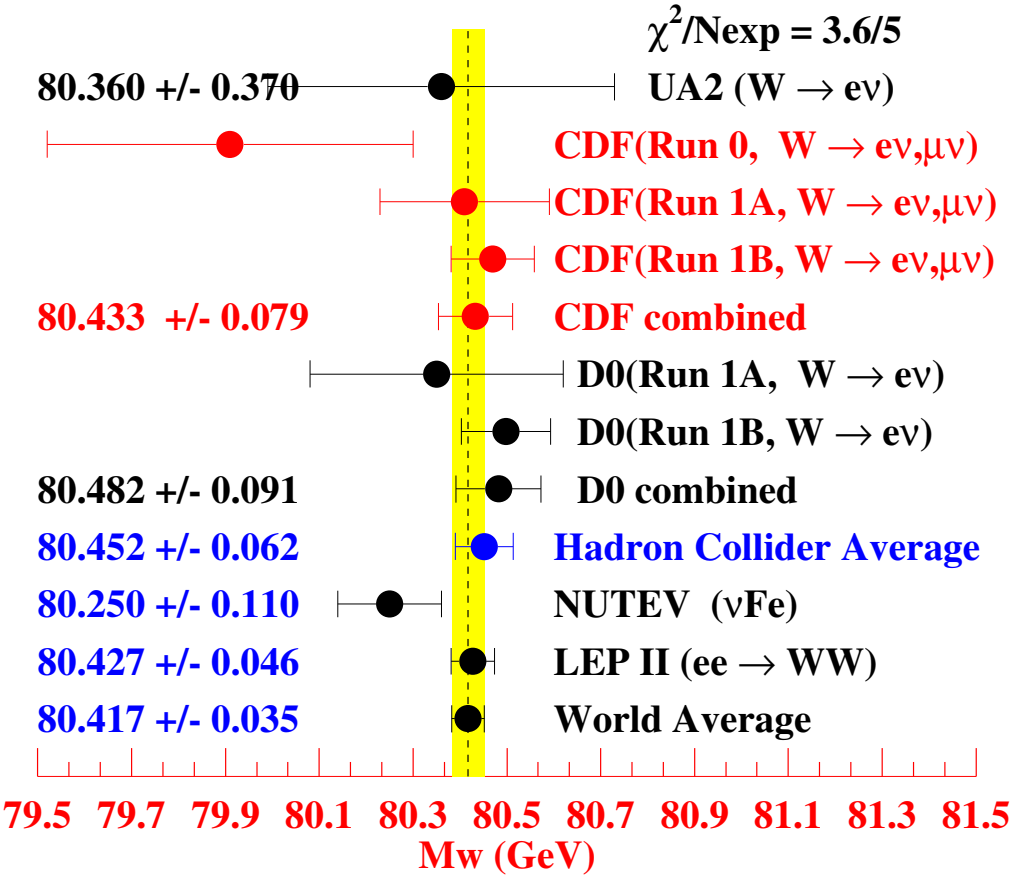
Next step : Accumulate stats, measure $W^{\pm}$ mass.

$W^{\pm}$ boson mass measurements

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

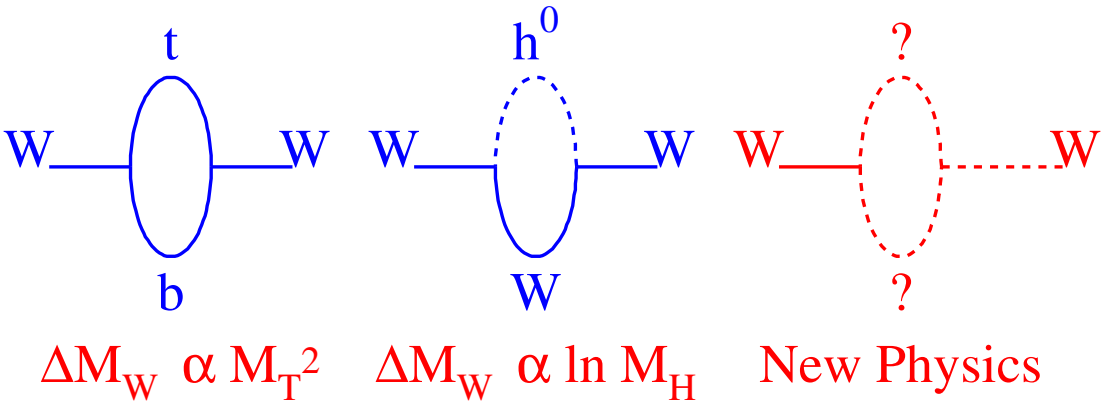


$\Rightarrow M_W = 80.443 \pm 0.079$ GeV/c^2 (CDF combined).

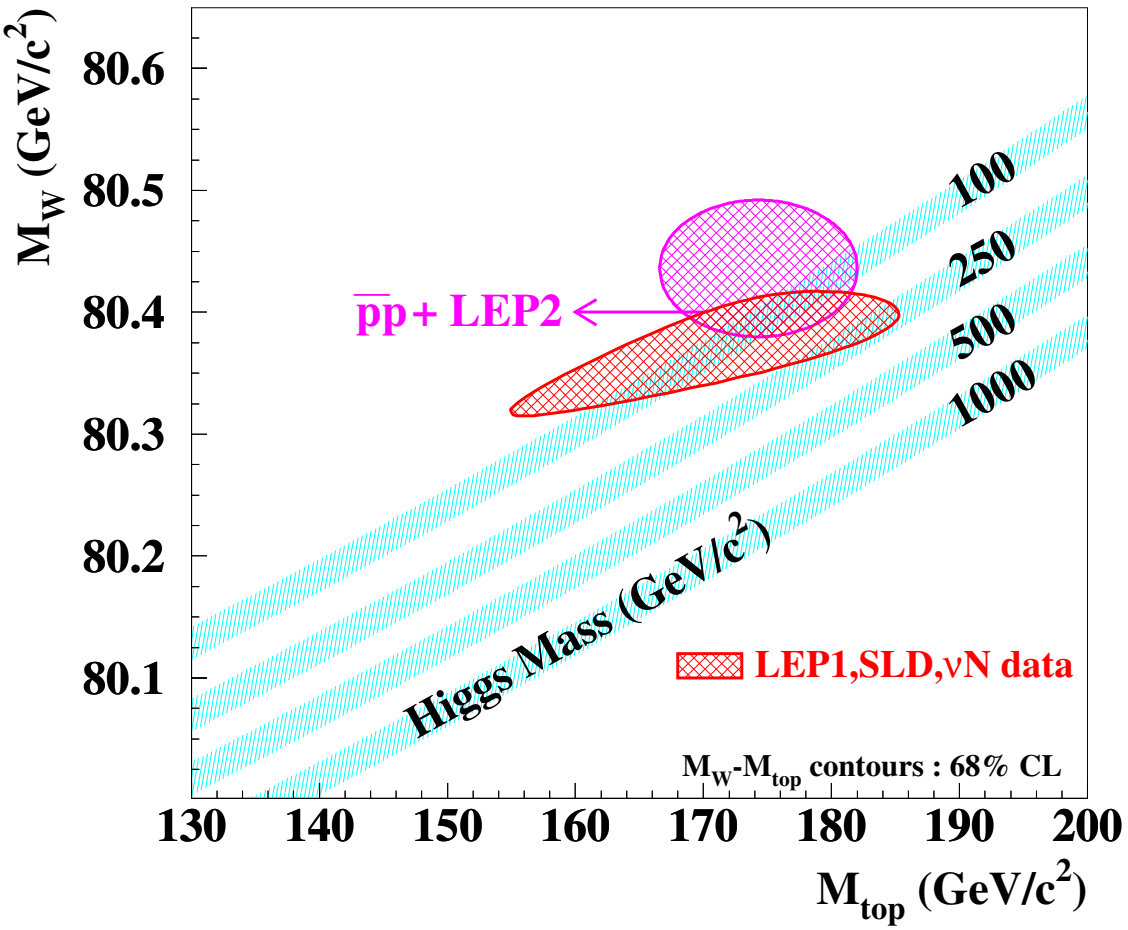


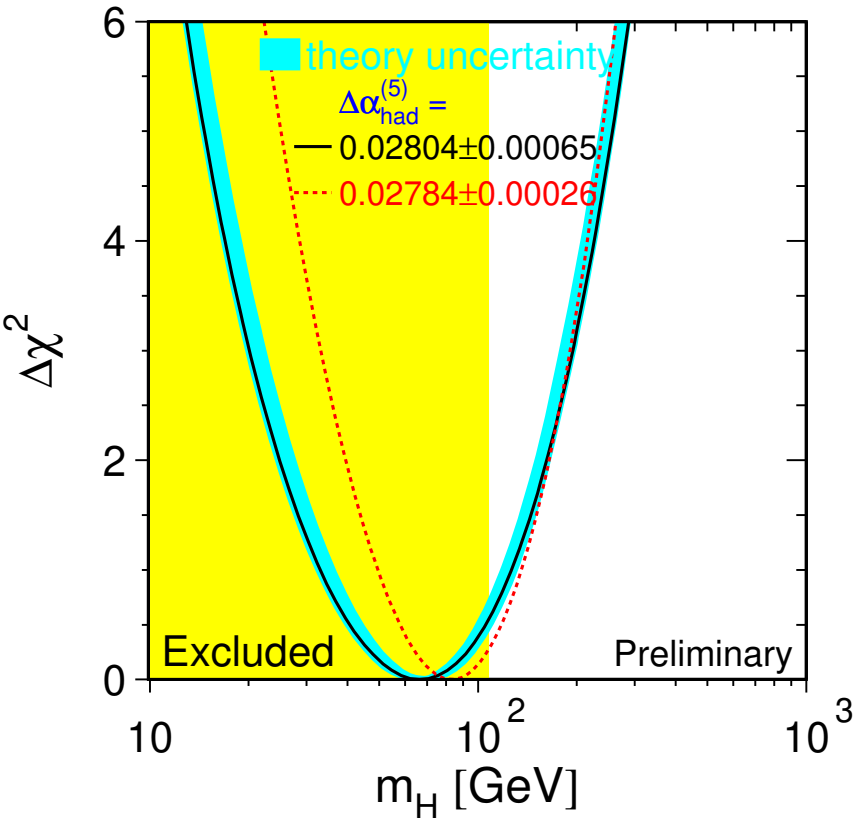
Higgs?

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

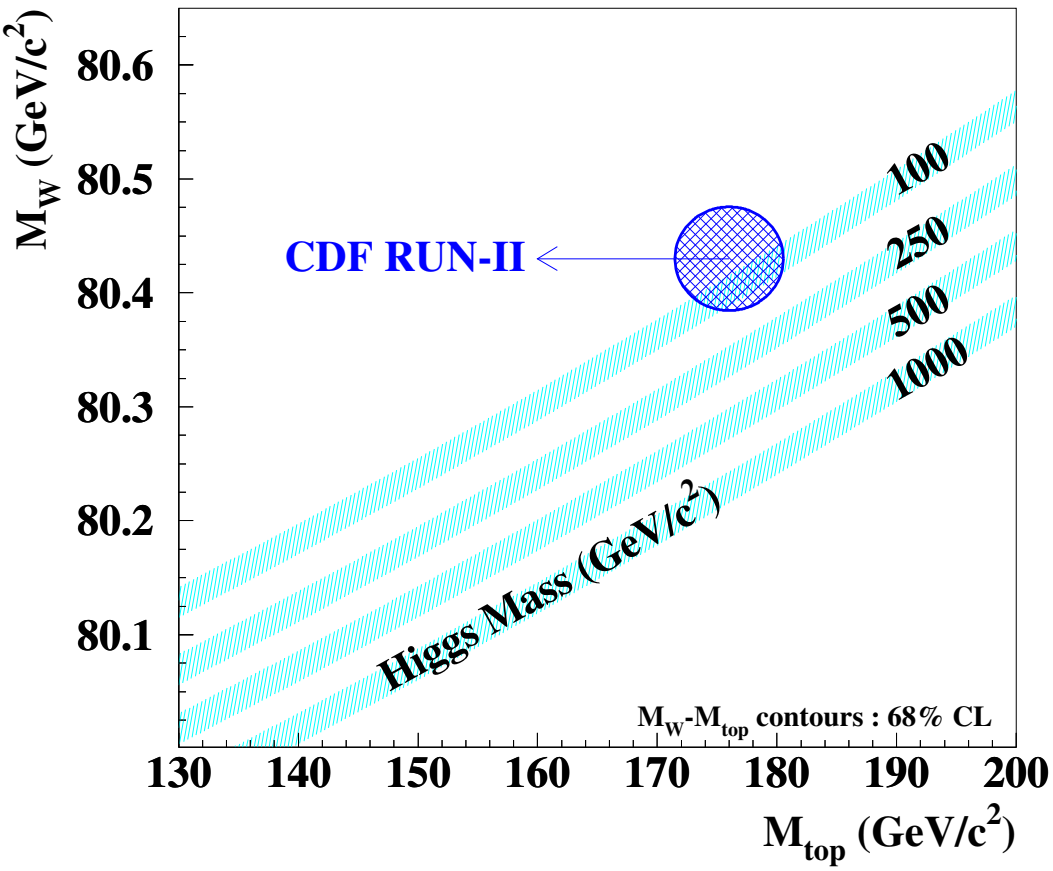


Constraints on the Higgs mass :





CDF Run-II projecctions.
m_W to 40 MeV/c^2, m_t to 3 GeV/c^2.



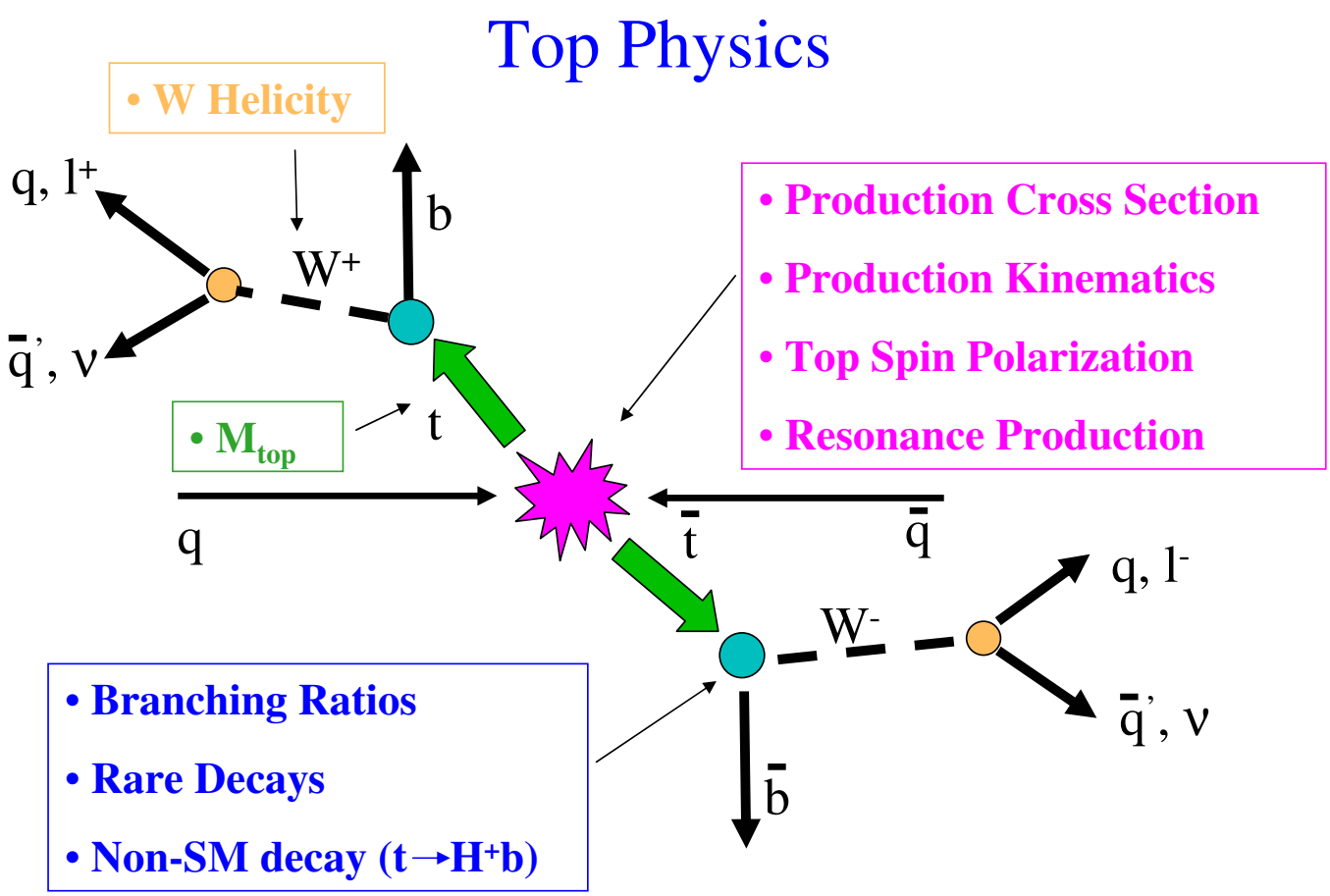
And $\Delta m_h/m_h \sim 0.3$.

Top quark

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

Tens of events. Measurements statistics-limited.

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

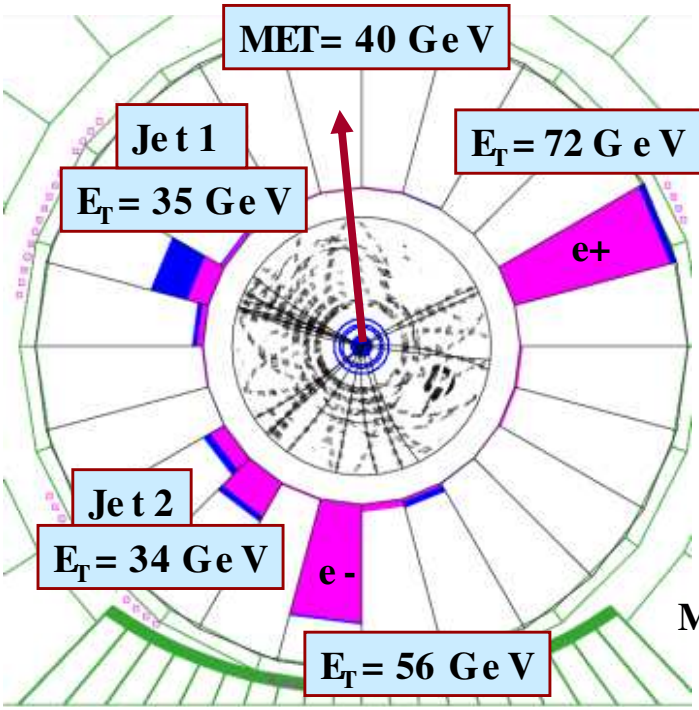


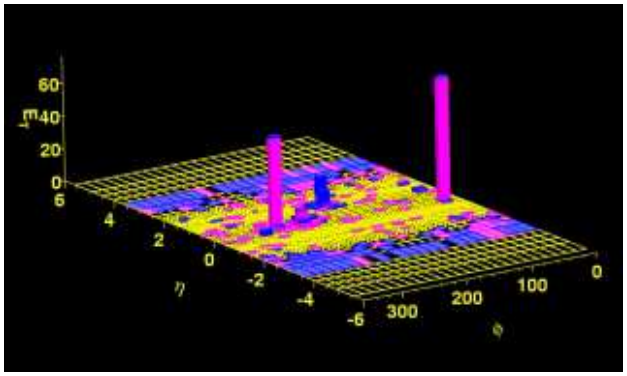
Expected Yield

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 candidate event (Run I)

$W^+ \rightarrow e^+\nu$,

$W^- \rightarrow$ jets #2 and #3.

e + 4 jet event

40758_44414

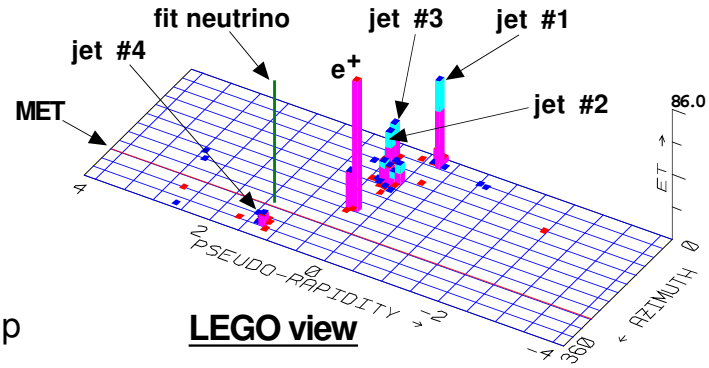
24-September, 1992

TWO jets tagged by SVX

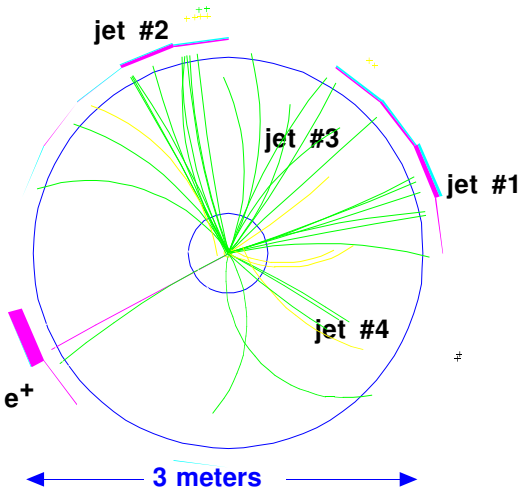
fit top mass is 170 +- 10 GeV

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

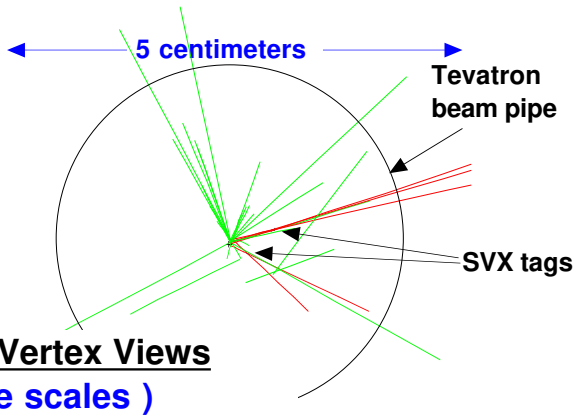
jets 1,2,3 from top (2&3 from W)



LEGO view

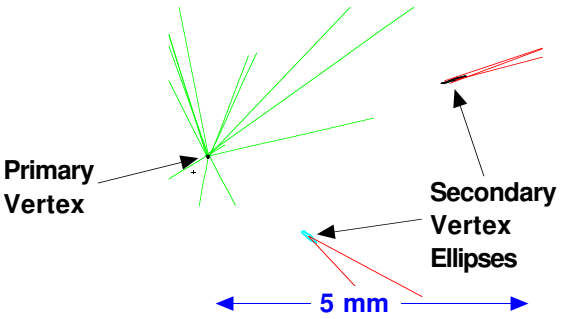


Tracking View



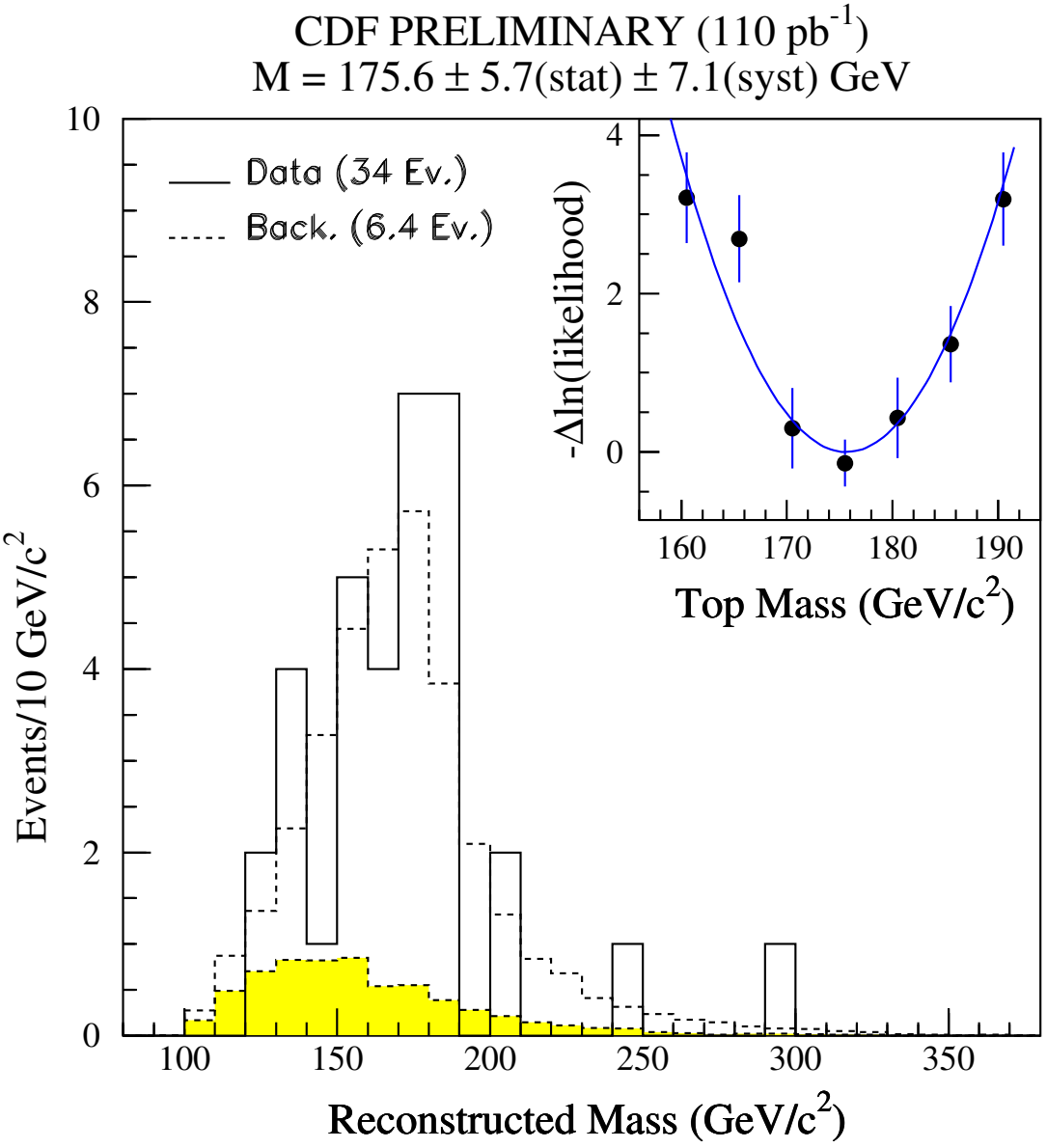
Two Vertex Views

(note scales)



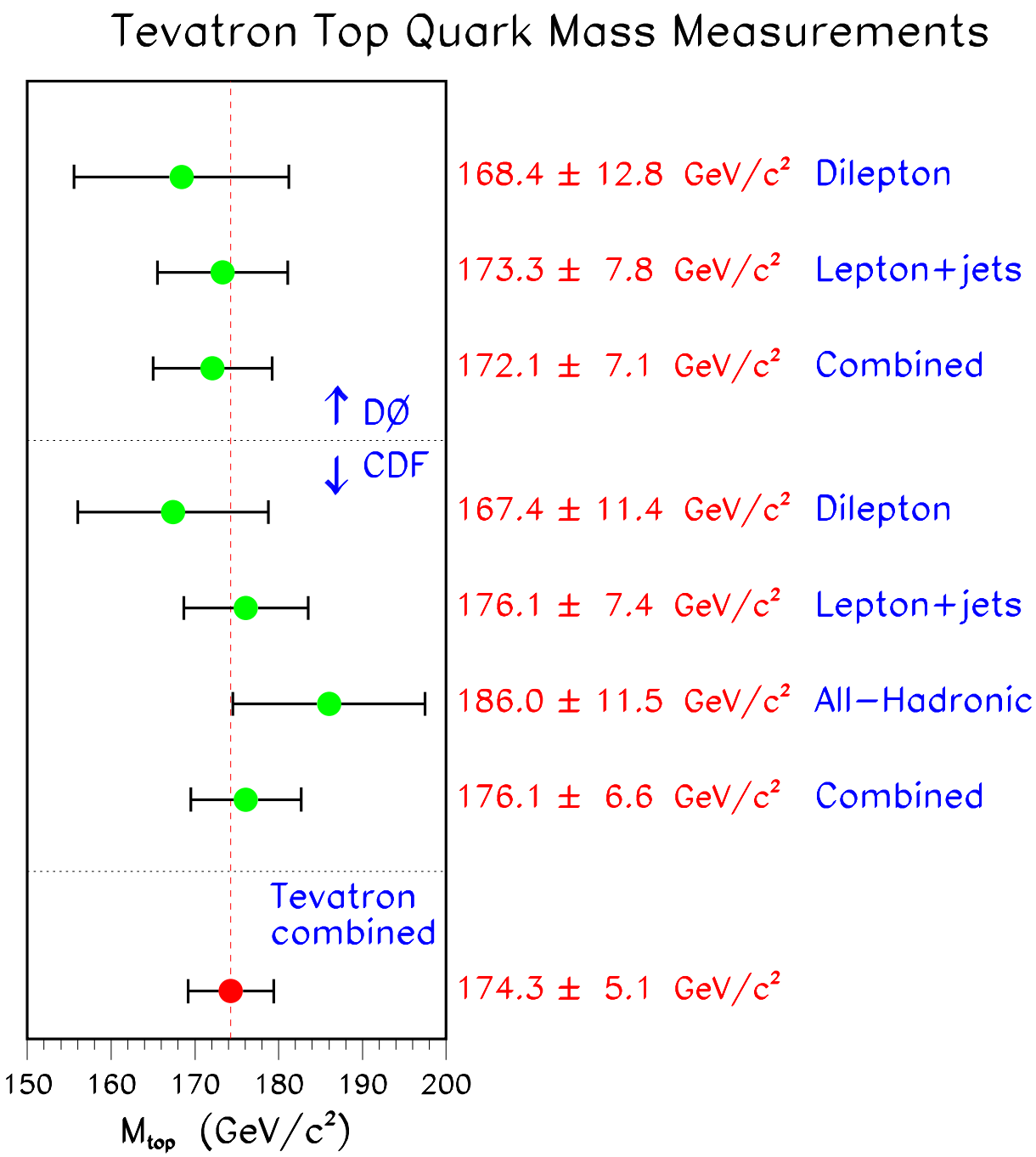
Jets #1 and #2 are from $b/\bar{b}$.

m_{top} from ℓ + jets mode (Run I)



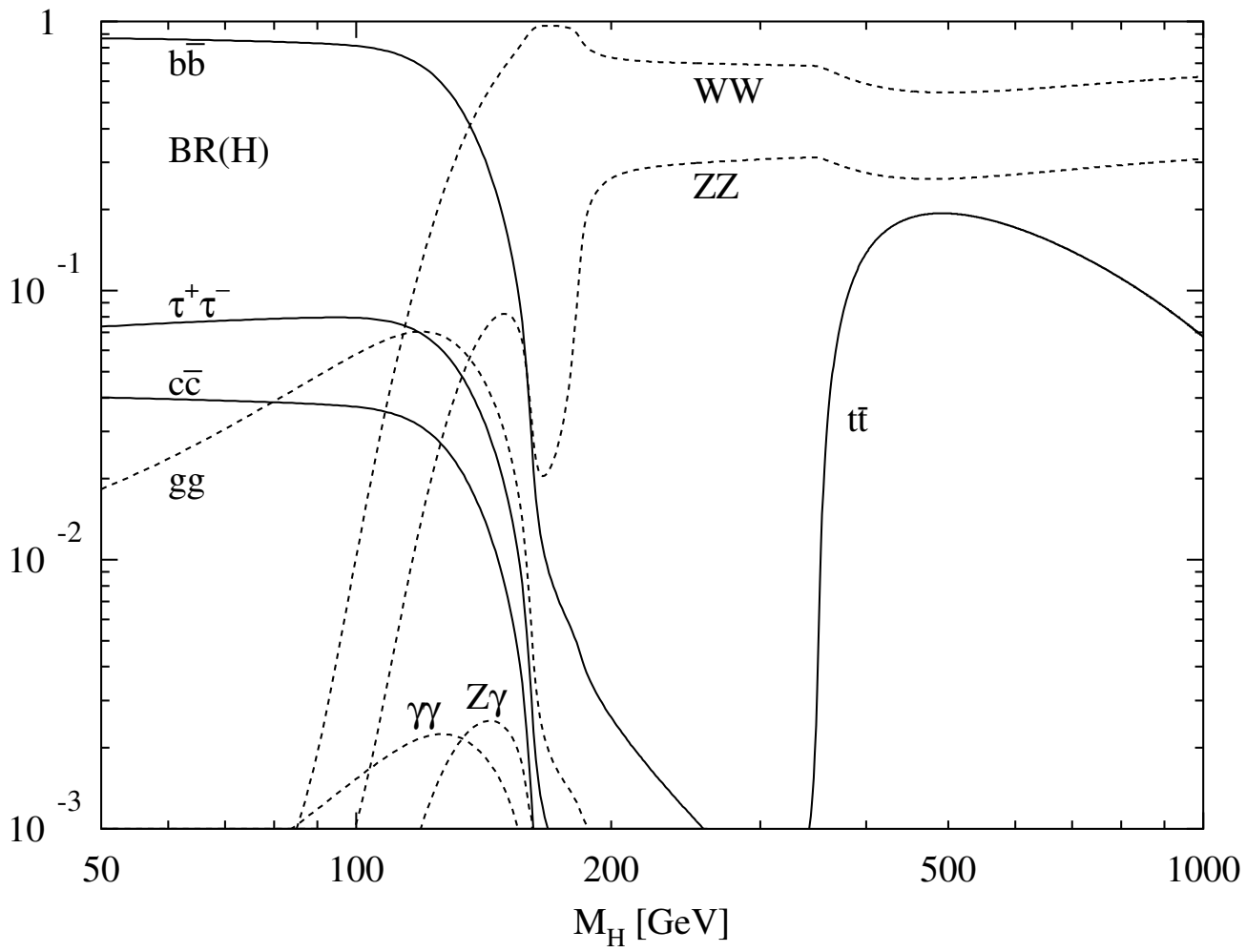
$$m_{\mathrm{top}} = 175.6 \pm 5.7 \pm 7.1 \ \mathrm{GeV}/c^2.$$

Top Mass : CDF + D0 (Run I)



Higgs直接探索

Branching Fractions

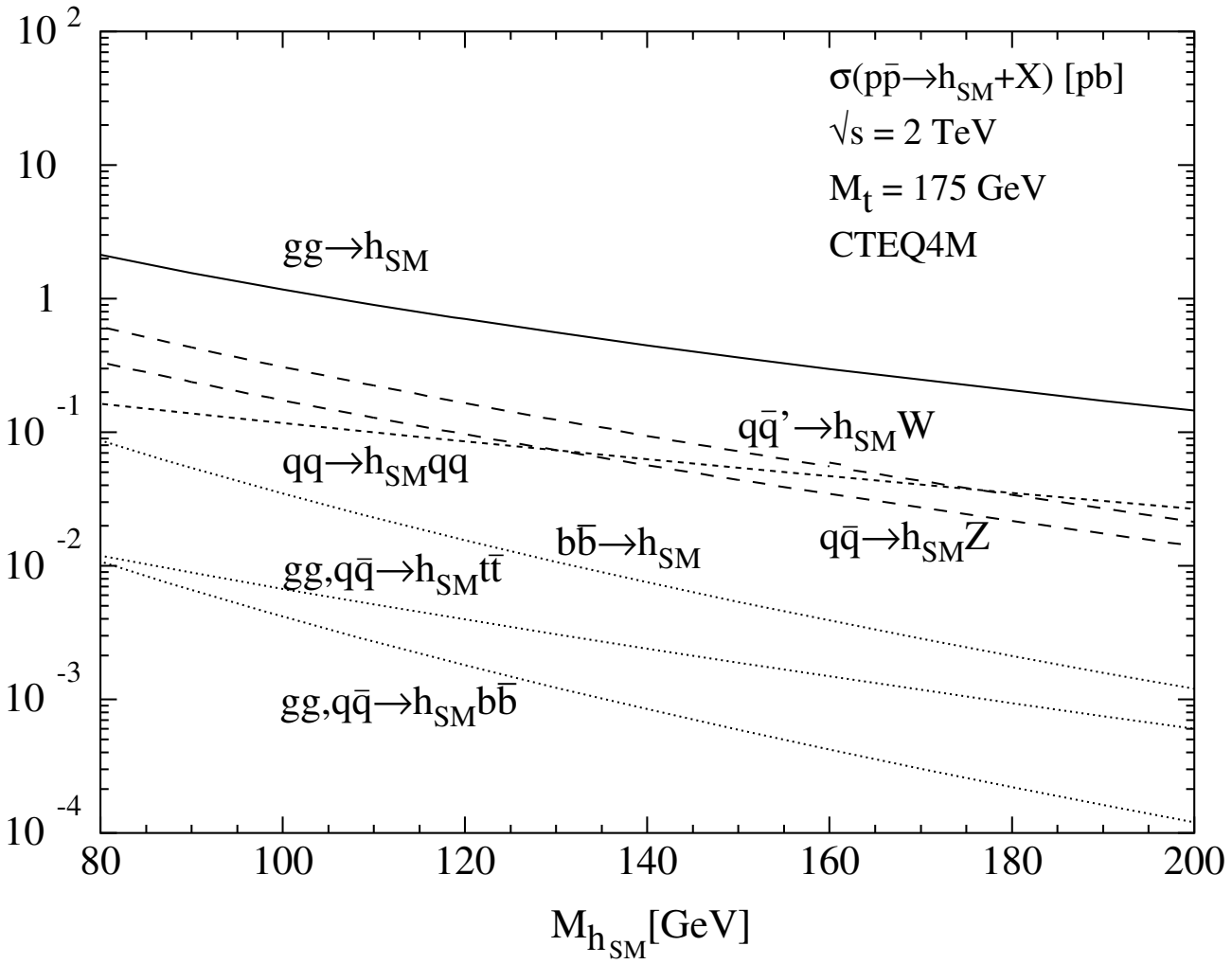


Wants to couple to the heaviest particles accessible:

$h \to b\bar{b}$ dominant at $m_h < 120$ GeV/c^2.
$h \to W^+W^-, Z^0Z^0$ dominant at $m_h > 160$ GeV/c^2.

Higgs production at $\sqrt{s} = 2.0$ TeV

Production cross sections for various subprocesses:



At most $\sim$ 1 pb.

Single production ($gg \to h$) largest,
but the final sates ($b\bar{b}$, $\gamma\gamma$) swamped by QCD BG,
except for $h \to W^+W^-/Z^0Z^0$ at large m_h.

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

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

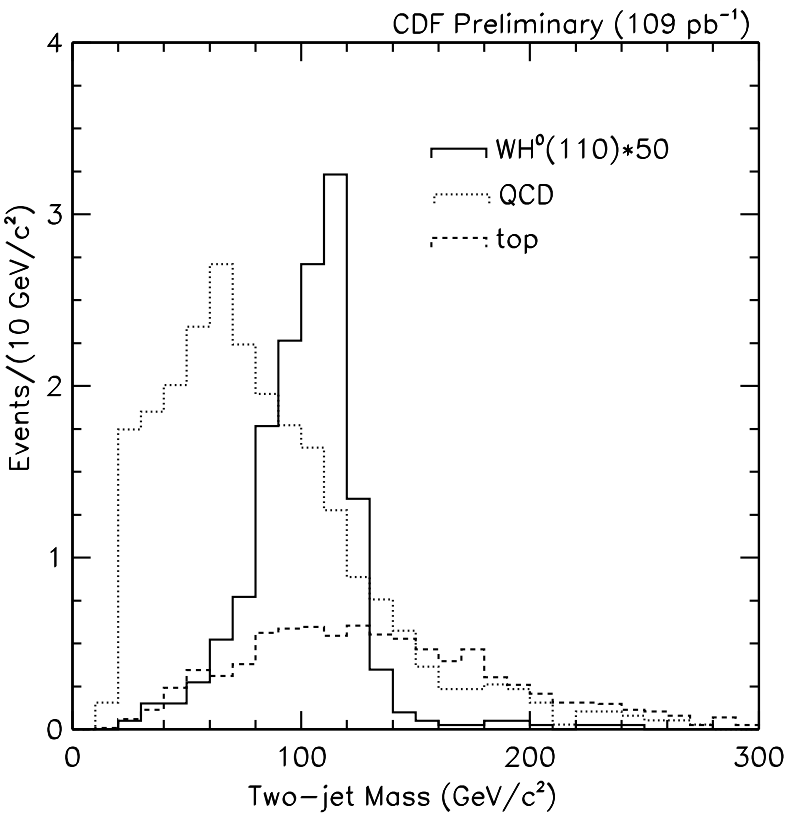
Use $W^+ \to \ell^+\nu$, $Z^0 \to \ell^+\ell^-$ $(\nu\bar{\nu})$,
and $h \to b\bar{b}$.

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

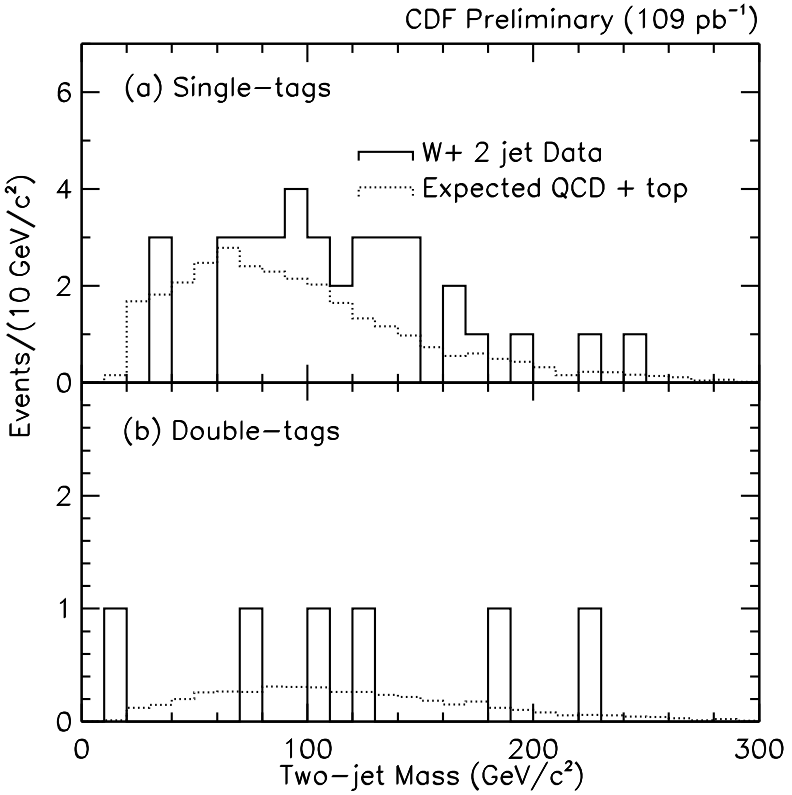
BG:
$V + b\bar{b}$ ($b\bar{b}$ mass continuum)
VZ^0, $Z^0 \to b\bar{b}$ ($b\bar{b}$ mass $= Z^0 = 91$ GeV/c^2)
Top

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

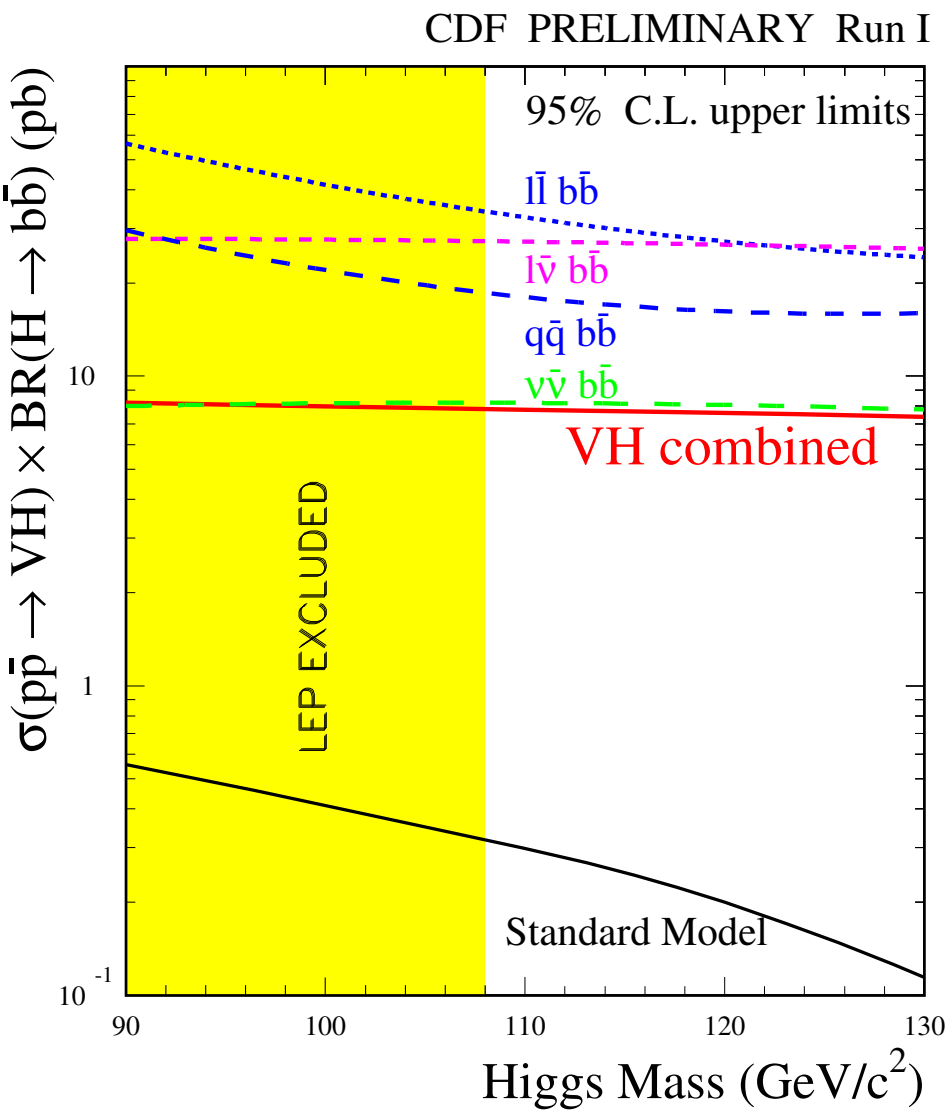
Expectations for signal and BG



One b-jet or two b-jets tagged



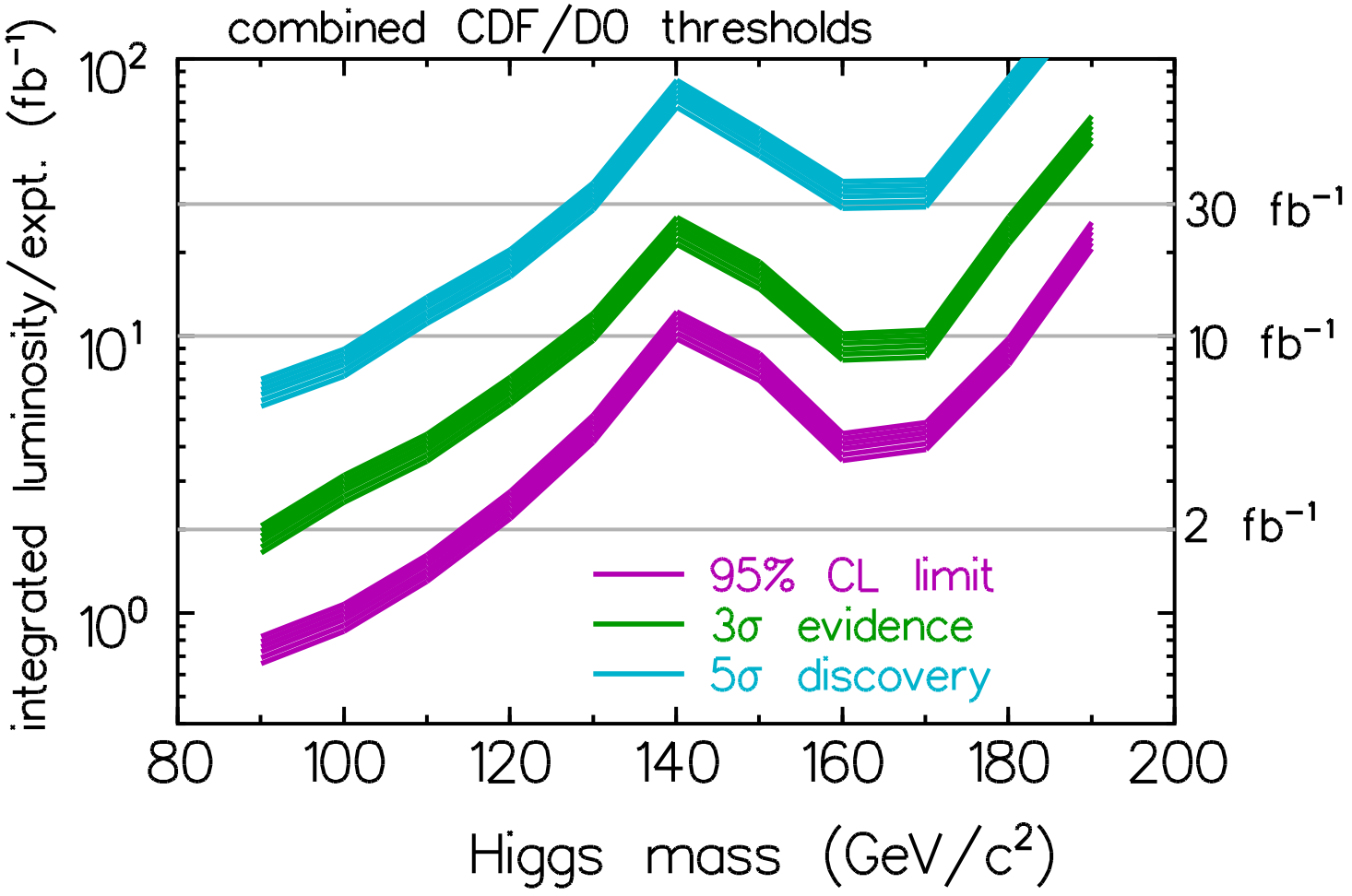
CDF Vh Search : Run I



Theory $\sigma \times \mathcal{B} =$ a few tenths of pb,
so could not really discover/exclude anything.

Need more data!

Run-II SM Higgs Reach

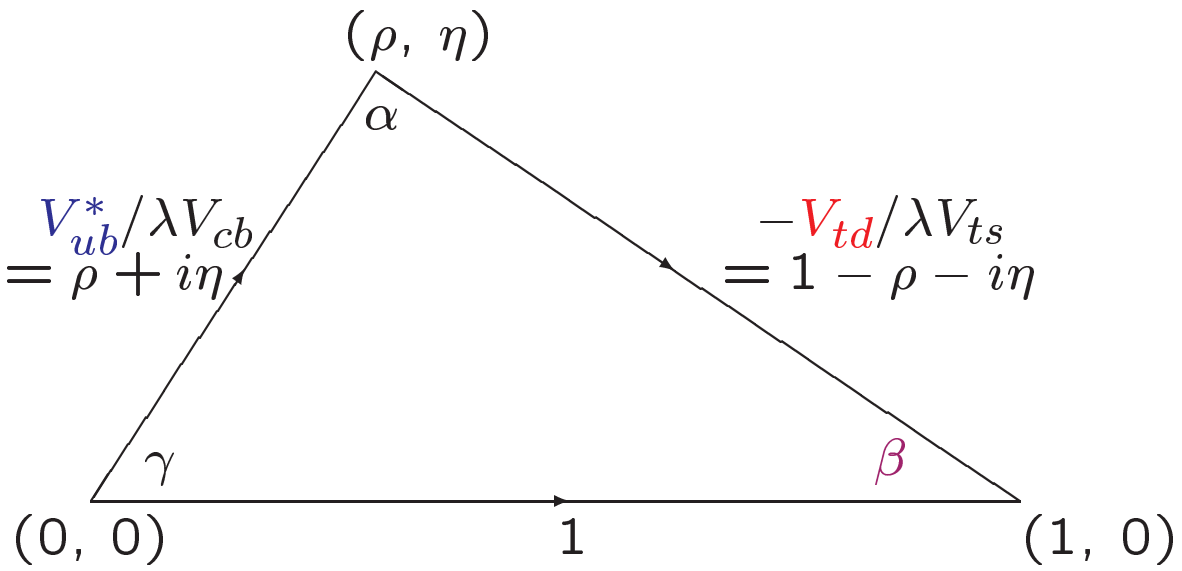


For $m_H < 120$ GeV/c^2 :

- can be excluded with 2 fb^{-1} if not there.
- 3-σ evidence with 7 fb^{-1}.
- 5-σ discovery with 15 fb^{-1}.

B Physics : ユニタリ三角形は閉じるか?

It may or may not, but Belle/BaBar alone cannot tell you the answer.
You need a CDF measurement, or two.



- $|V_{cb}|$ from $b \to c\ell\nu$, $|V_{ub}|$ from $b \to u\ell\nu$.
- $|V_{td}|$ from Δm_d, but large QCD uncertainties.
- Use ratio to partially cancel the uncertainties:

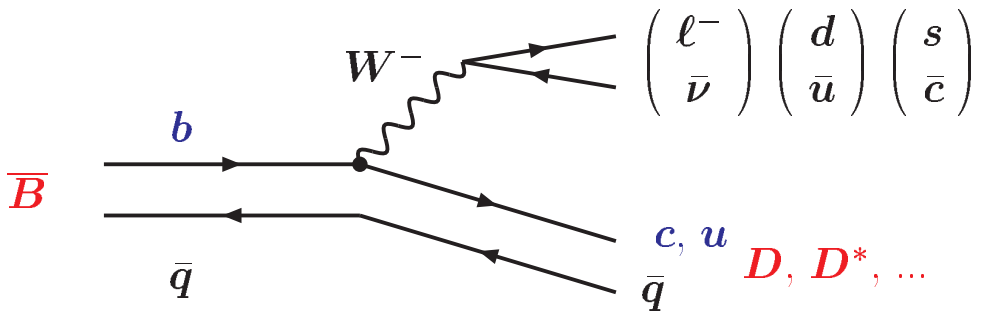
$$\frac{\Delta m_s}{\Delta m_d} = \left|\frac{V_{ts}}{V_{td}}\right|^2 \frac{M_{B_s}}{M_{B_d}} \xi^2 \quad (\xi = 1.17 \pm 0.06, \text{Aoki 1999})$$

- Present limit on Δm_s (95% C.L.)

$$\frac{\Delta m_s}{\Delta m_d} > \frac{15.0}{0.487} \implies \frac{V_{td}}{\lambda V_{ts}} < 0.97 \pm 0.06.$$

- Angle β from $B^0/\bar{B}^0 \to J/\psi K_S^0$.

Q: How you collect B-hadron decays at CDF?



- b quark decays to c or u quark.

  $b \to c$ decay dominant, because $|V_{cb}| \gg |V_{ub}|$.

- Have to isolate among BG of q and g jets.

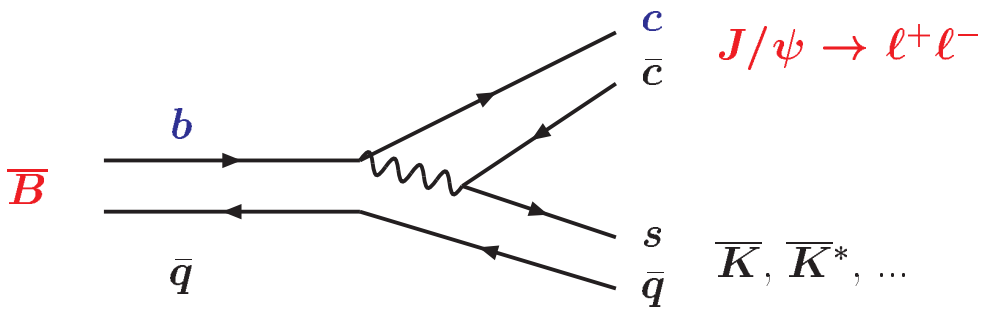
A: use leptons.

- Semileptonic decay $\Rightarrow$ single leptons (e, μ).

  Rate sizable : $\mathcal{B}(\overline{B} \to \ell^- \bar{\nu} X) = 10\%$.

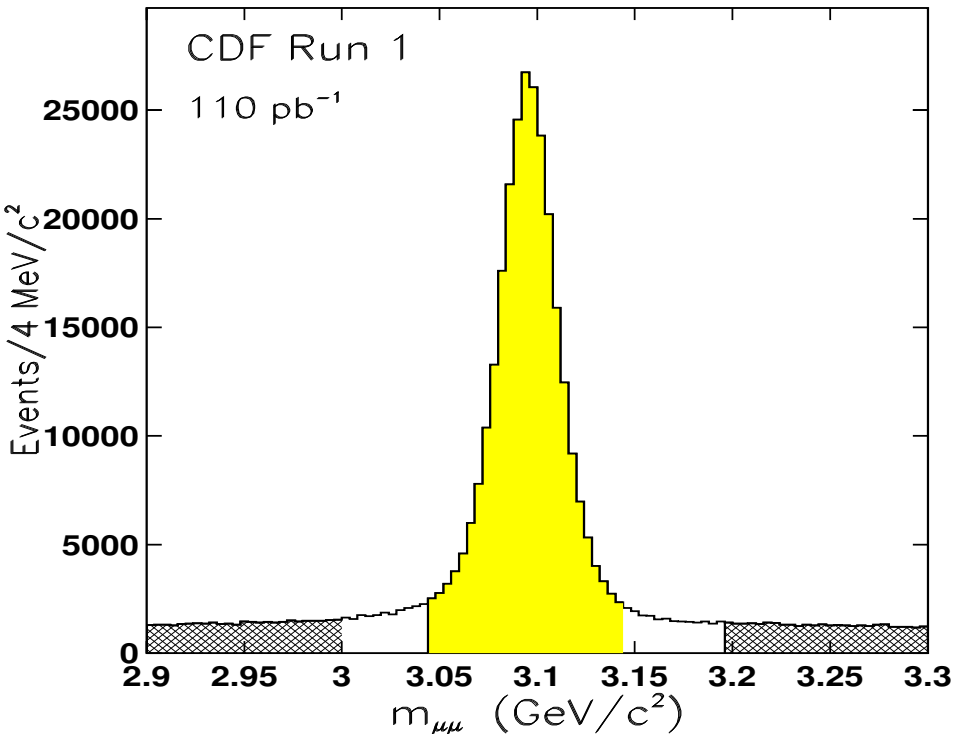
  Main source of single leptons at low p_T (below $W^\pm$ and Z^0).

- B decays can also produce two leptons :
  - Sequential decays : $b \to \ell^- \bar{\nu} c$, $c \to \ell^+ \nu s$.
  - $\overline{B} \to J/\psi\, X$ via $b \to c\, \bar{c} s$, and $J/\psi \to \ell^+ \ell^-$.

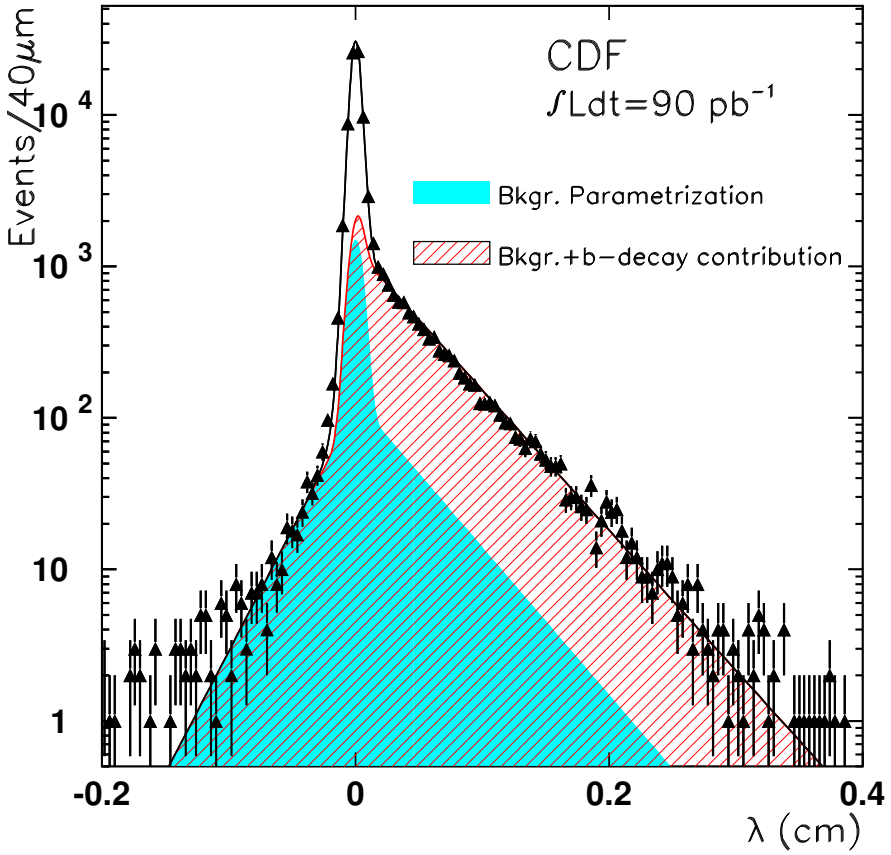


$$\mathcal{B}(\overline{B} \to J/\psi\, X) \simeq 1\%, \;\; \mathcal{B}(J/\psi \to \ell^+\ell^-) = 7\%.$$

Run-I $J/\psi \to \mu^+\mu^-$: 250 k events / 110 pb^{-1}.

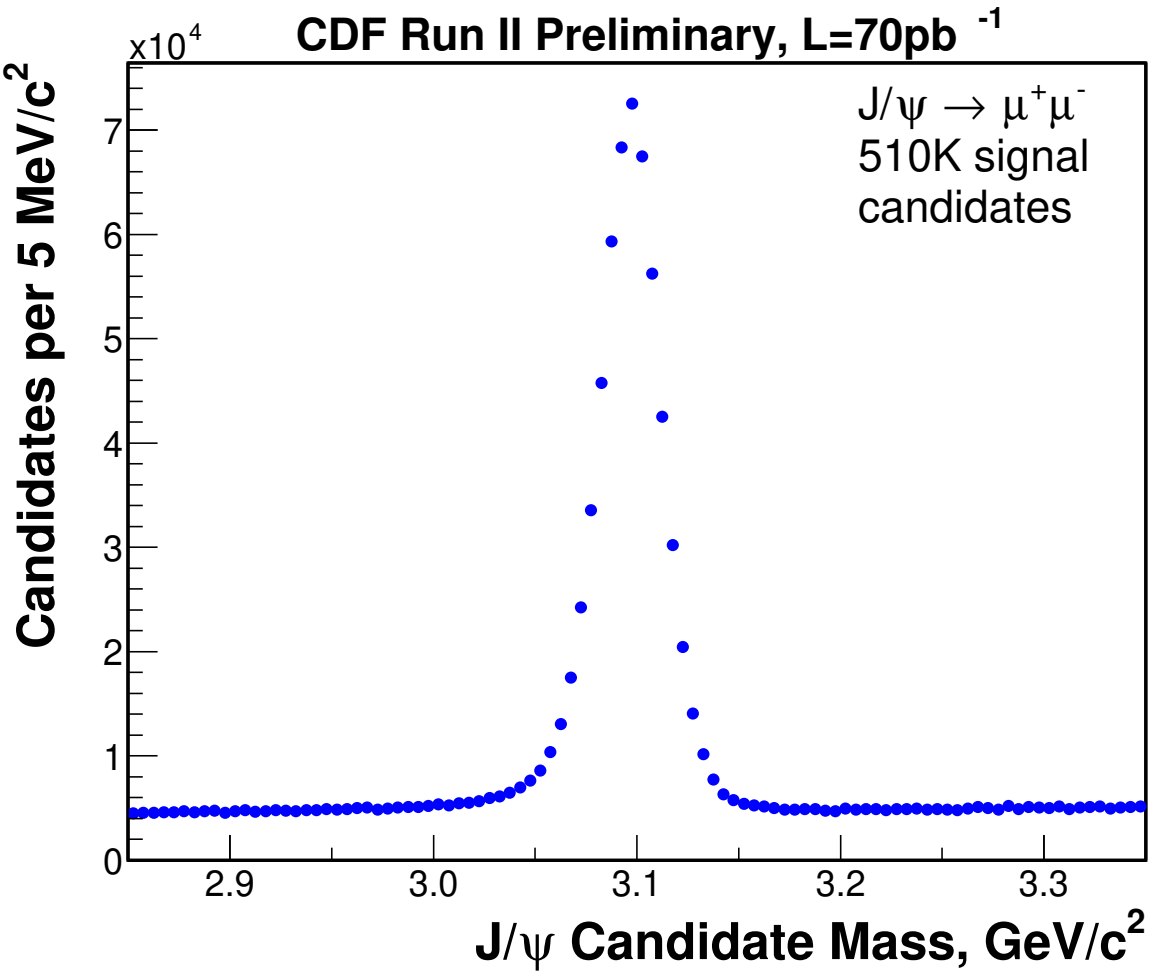


Decay length distribution



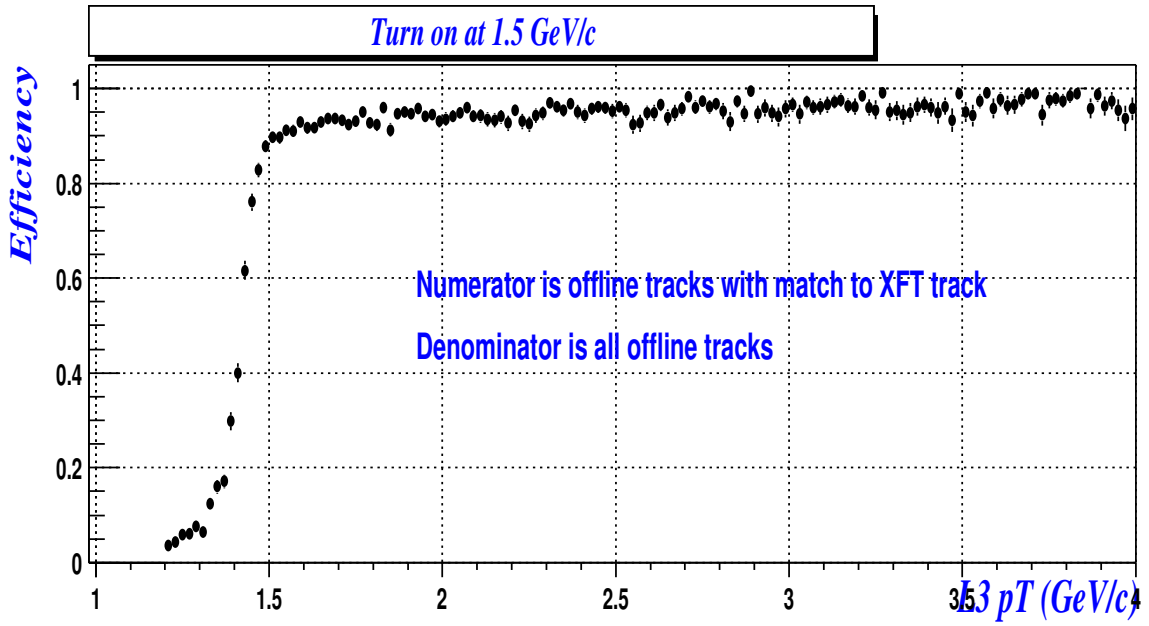
$\sim$ 20% of J/ψ's from B decays.

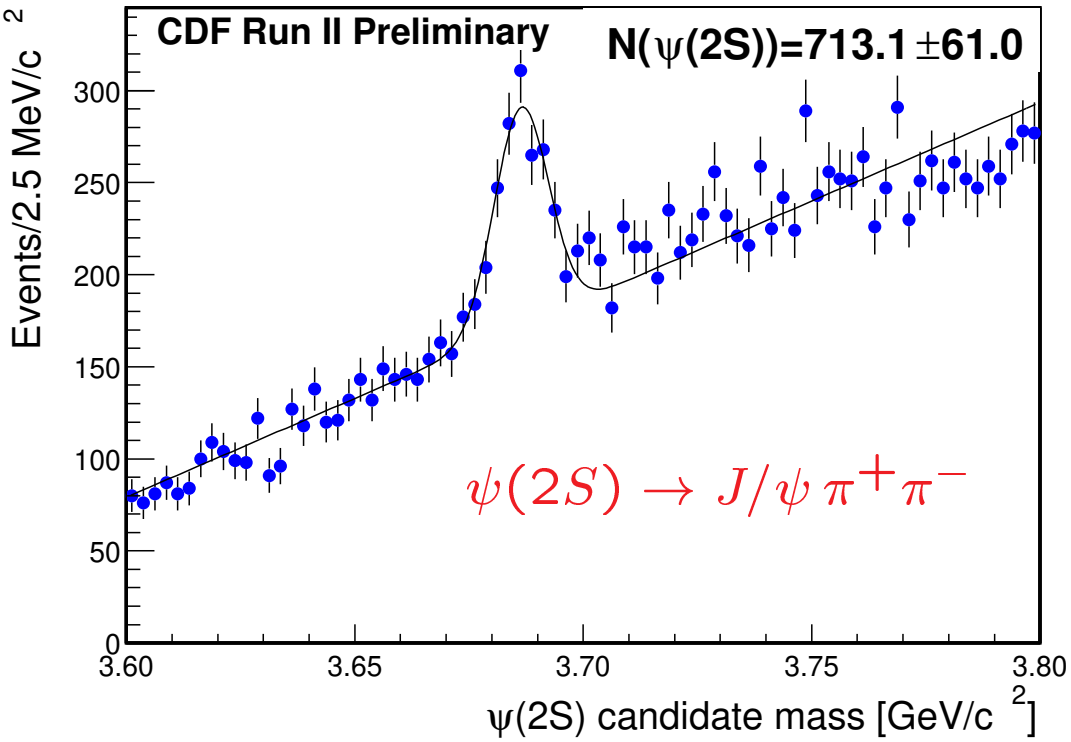
Run-II Dimuon Data



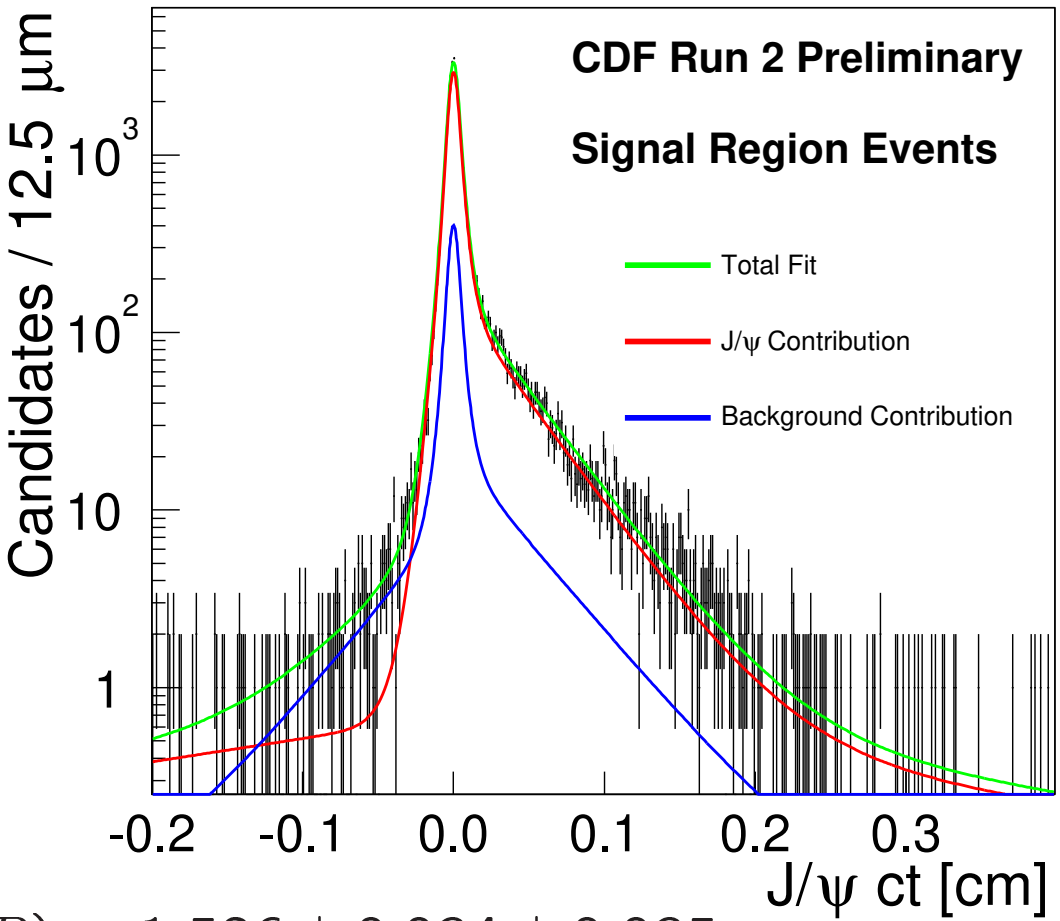
p_T threshold : 2 GeV/c $\Rightarrow$ 1.5 GeV/c.

Yield $\sim 2 \times$ Run-I.



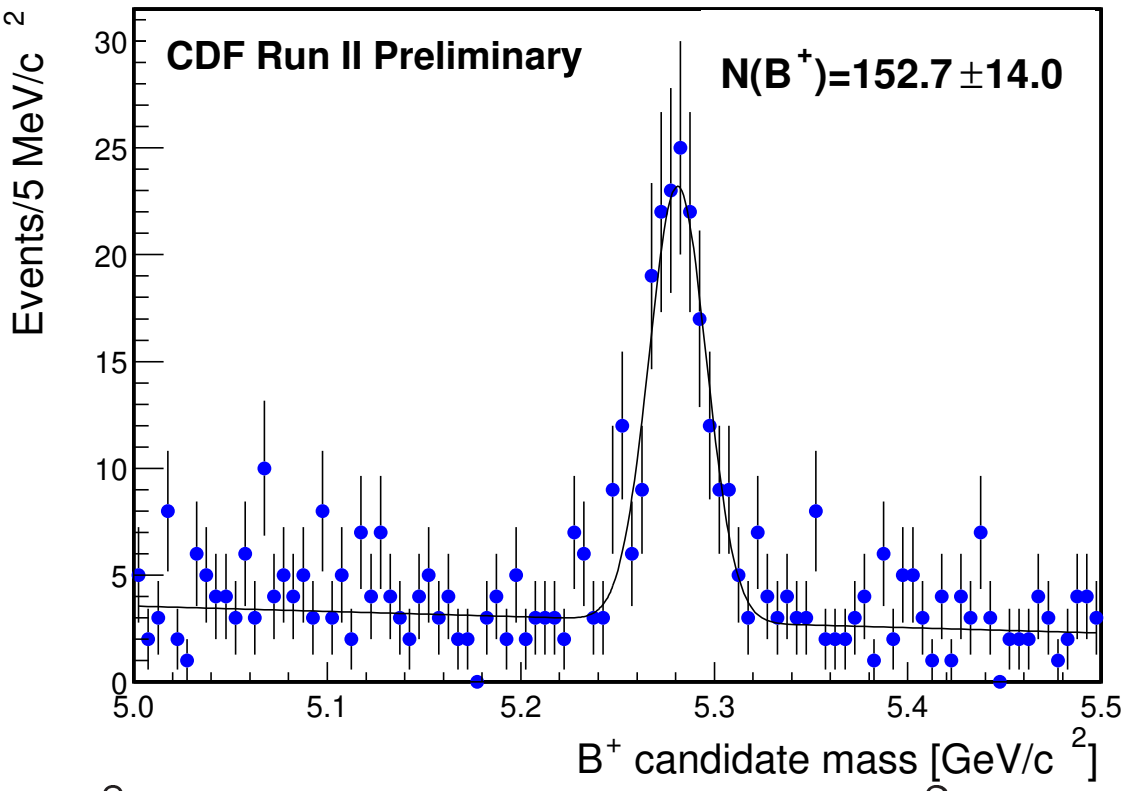


Average B-hadron Lifetime from $B \to J/\psi X$

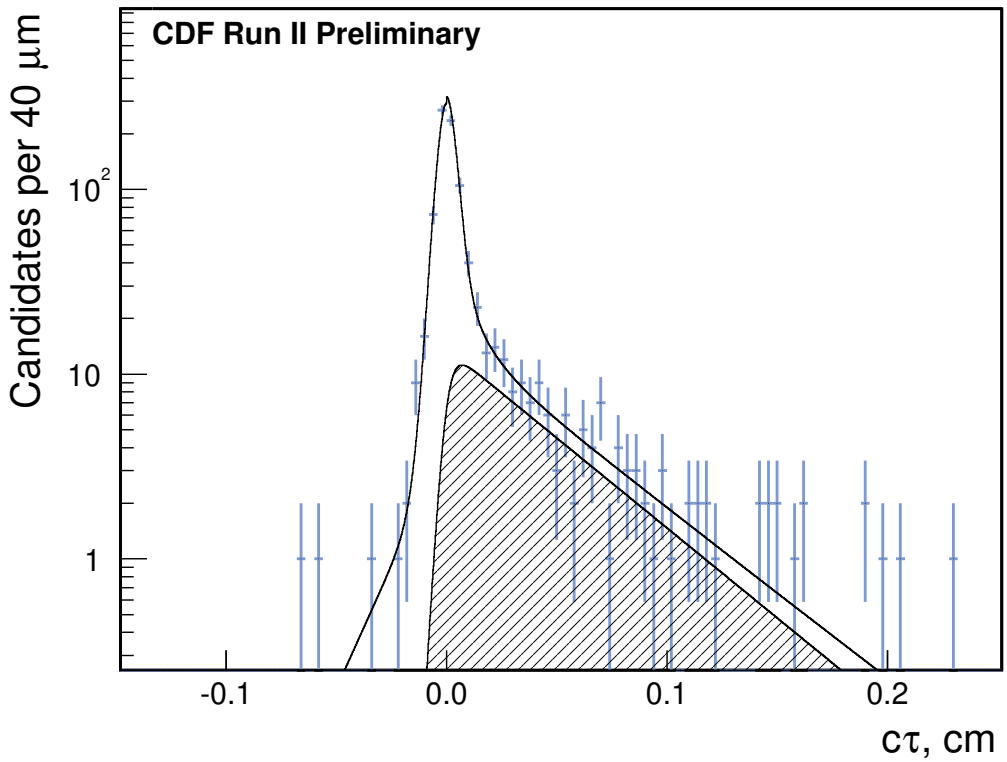


$\Rightarrow \tau(B) = 1.526 \pm 0.034 \pm 0.035$ ps.

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



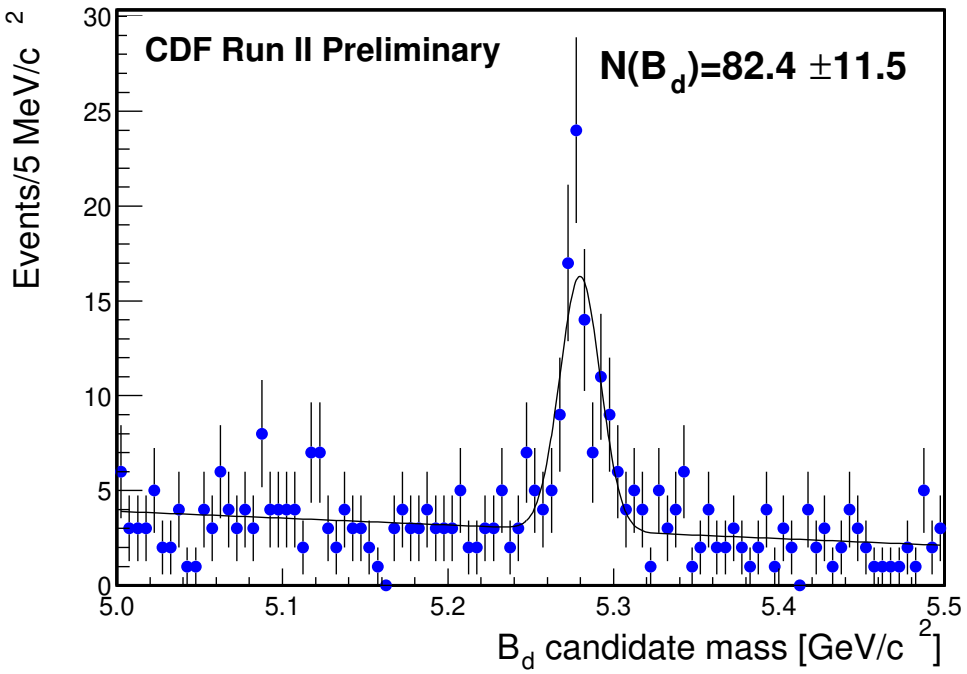
$\Rightarrow m(B_s^0) = 5280.6 \pm 1.7 \pm 1.1$ MeV/c^2.



$\Rightarrow \tau(B^+) = 1.49 \pm 0.14 \pm 0.04$ ps.

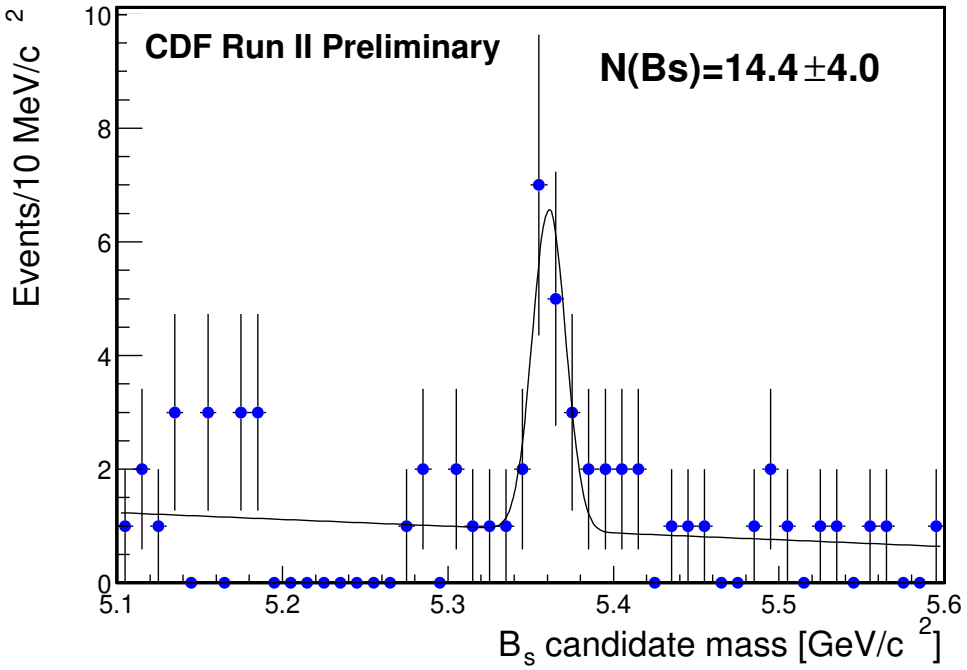
More $B \to J/\psi\, K$

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



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

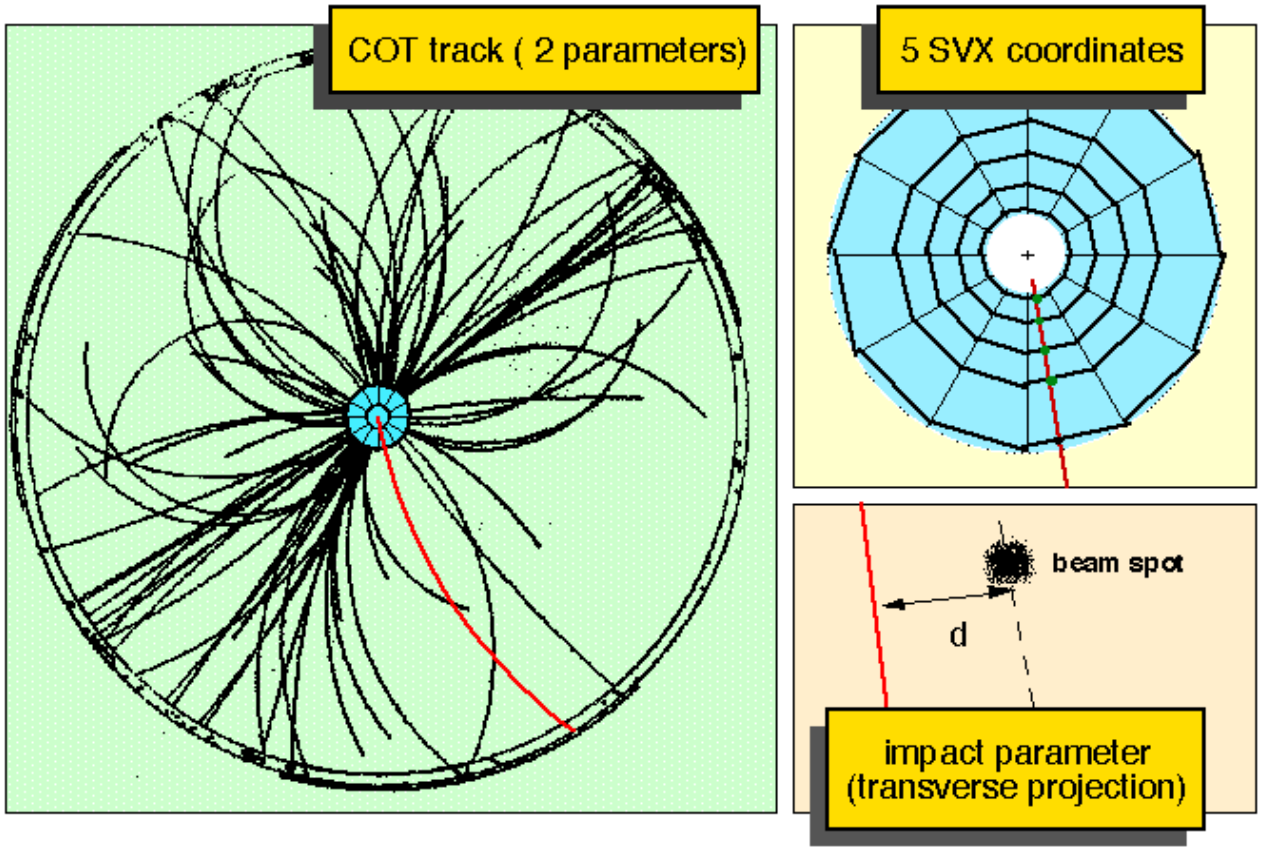
$B_s^0 \to J/\psi\, \phi \to \mu^+\mu^-\, K^+K^-$



$\Rightarrow m(B_s^0) = 5360.3 \pm 3.8\, ^{+2.1}_{-2.9}$ MeV/c^2.

Run-II Silicon Vertex Trigger : SVT

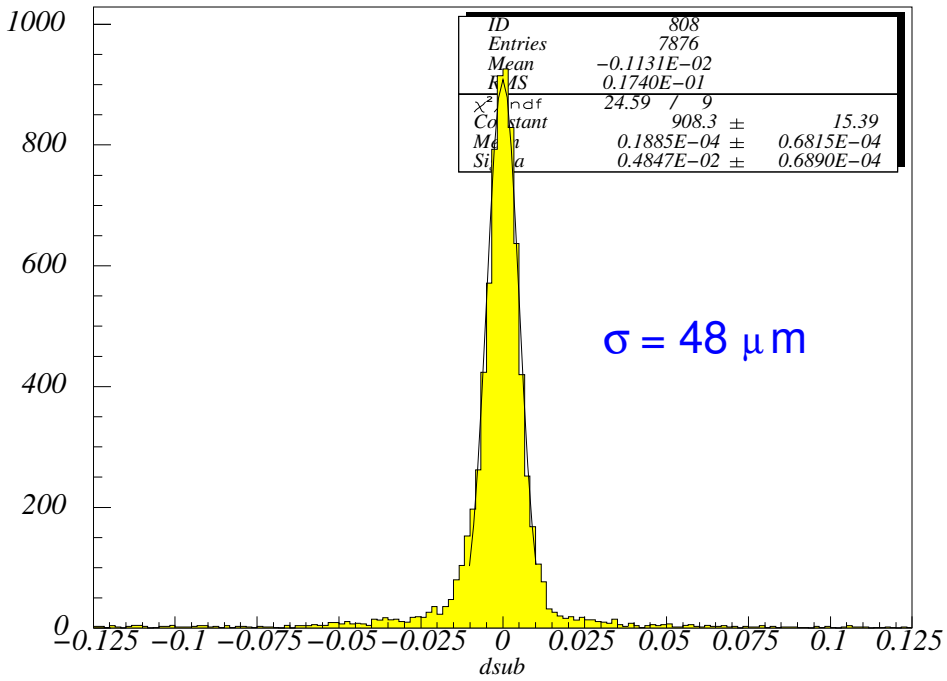
Use silicon information at 2nd level of trigger.



- 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).

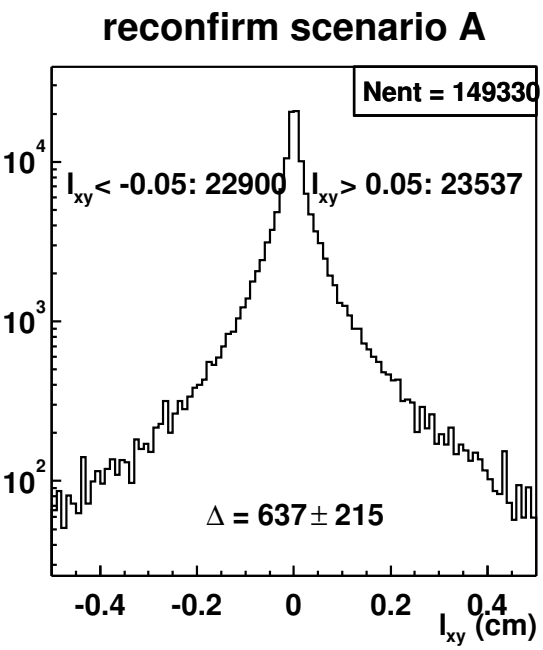
Resolution $\sigma_d \sim 50$ μm for $p_T > 2$ GeV/c.

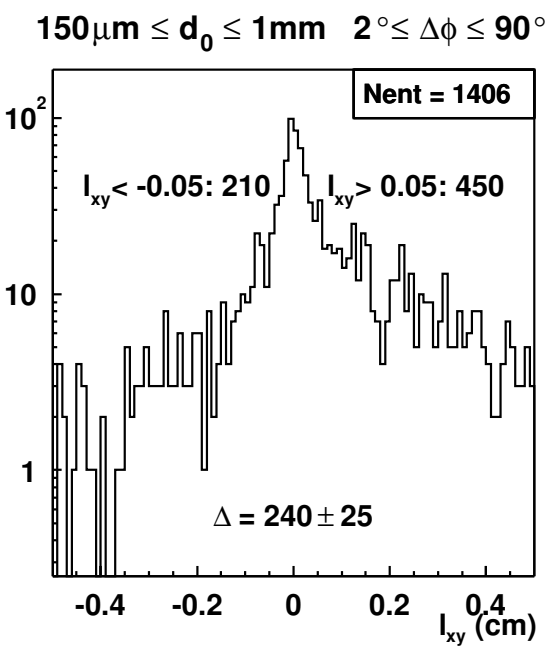
SVT Performance



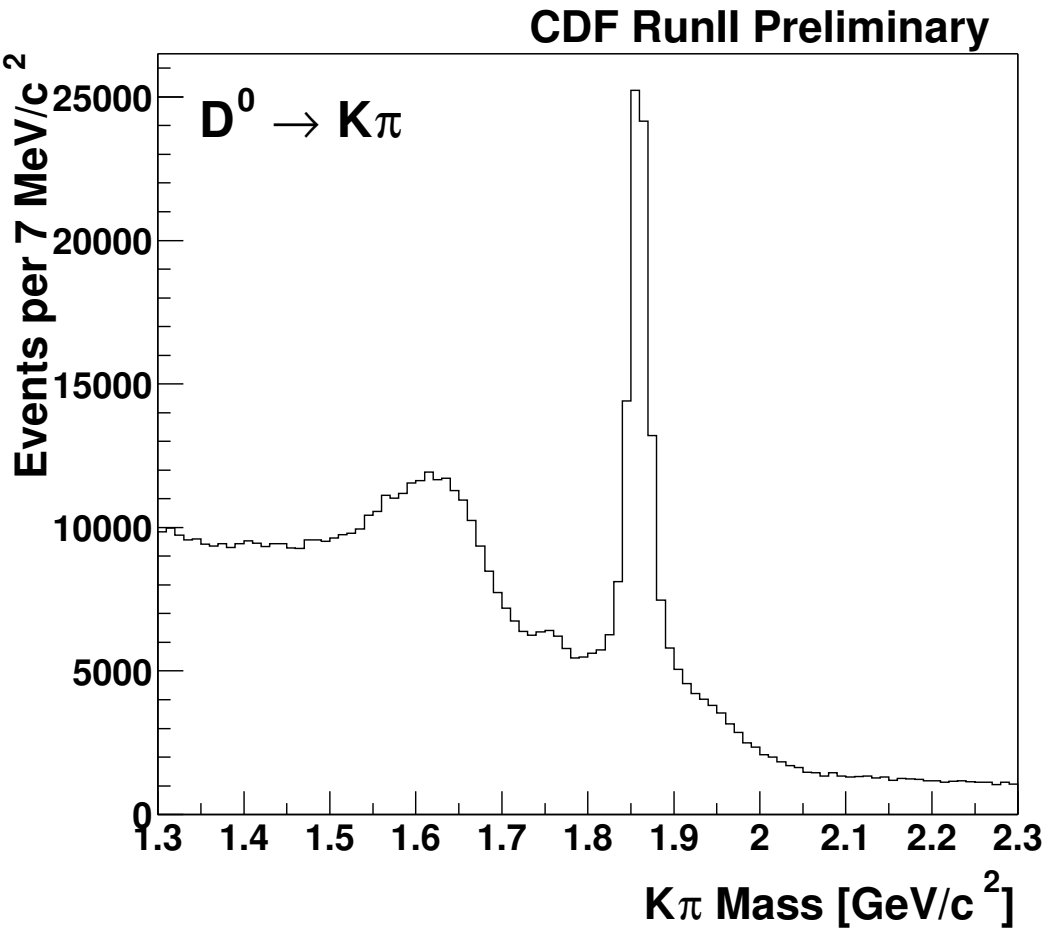
Trigger on tracks ($p_T > 2$ GeV/c) with
100 μm $< |d| <$ 1000 μm.

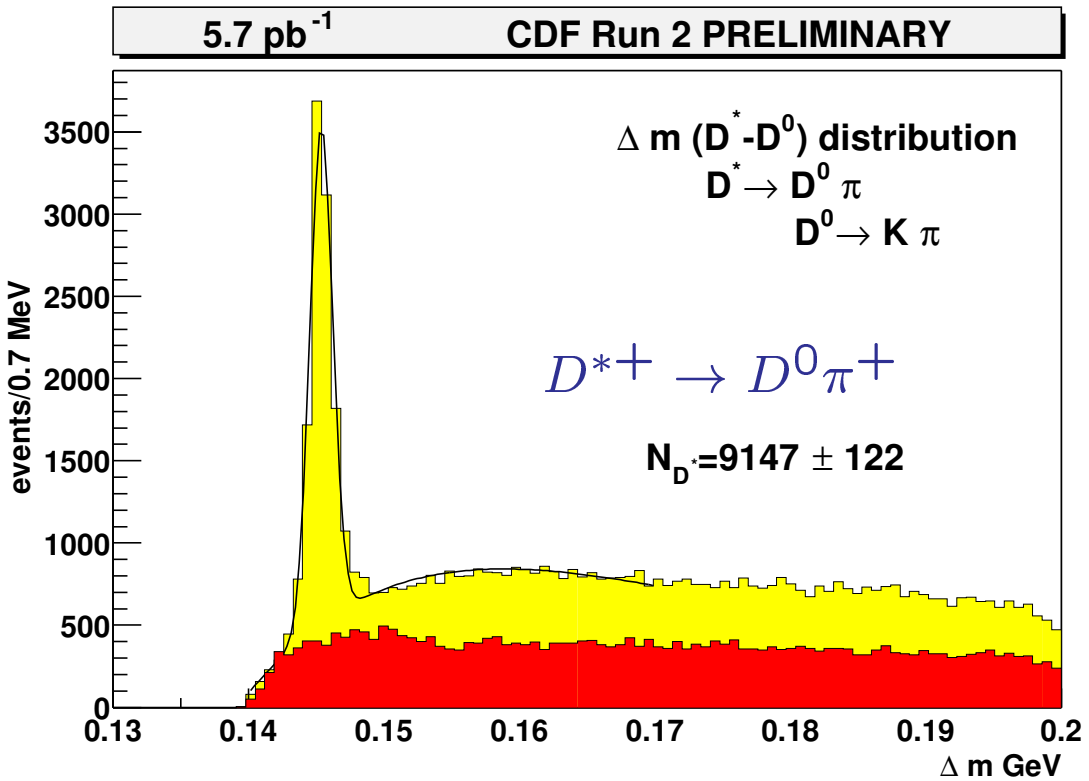
Calculate decay length L_{xy}, require $L_{xy} > 500$ μm.



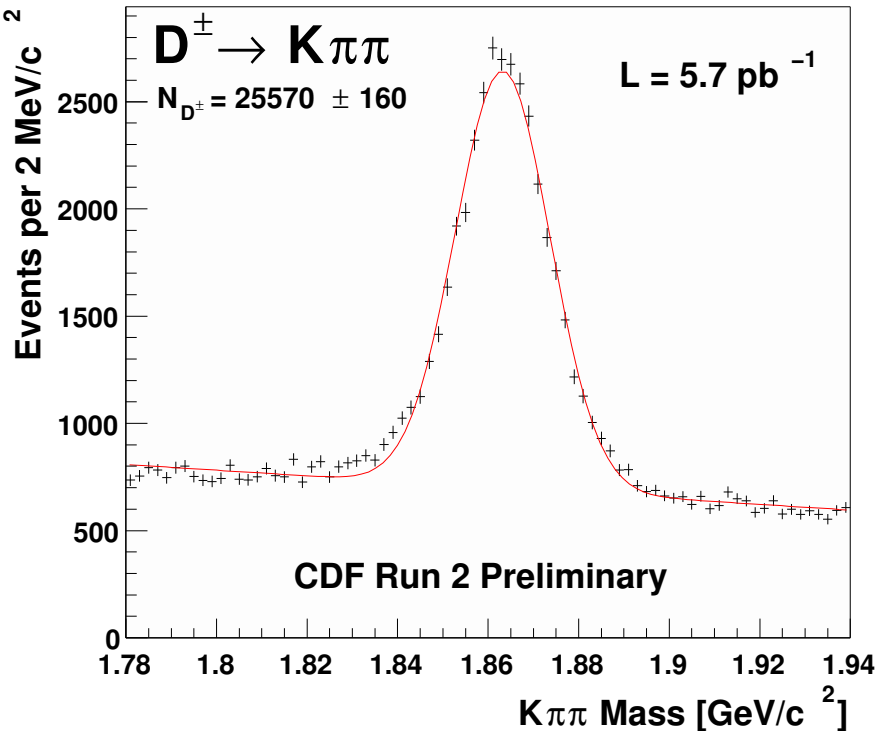


Run-II $D^0 \to K^-\pi^+$ from SVT trigger

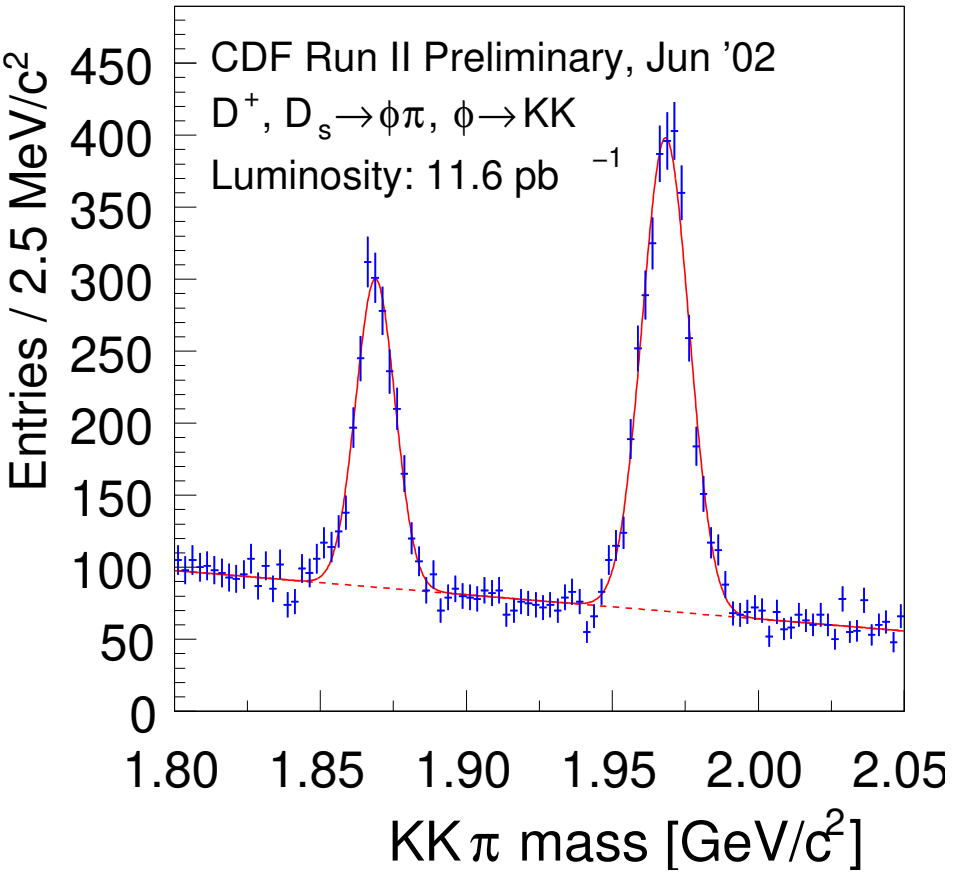




More charm : $D^+ \to K^-\pi^+\pi^+$

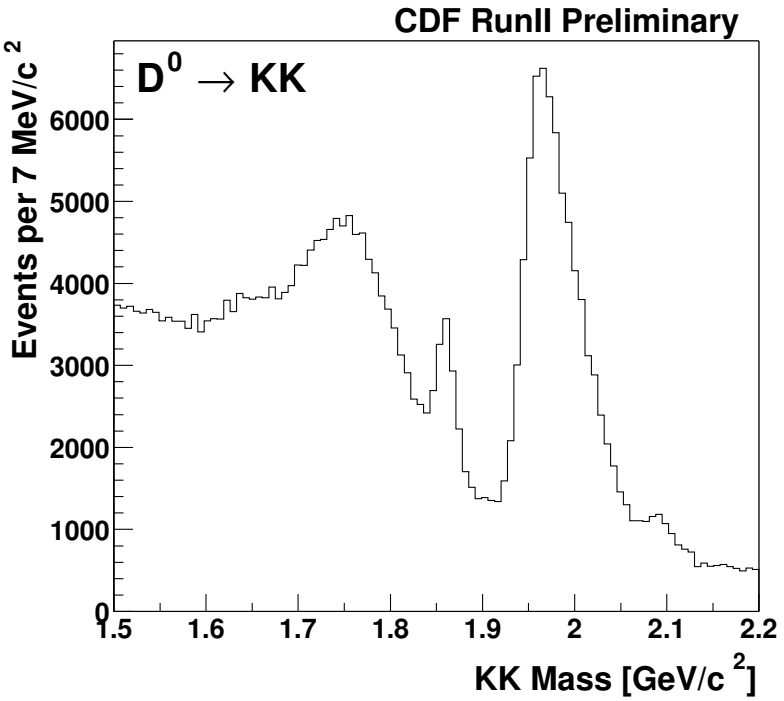


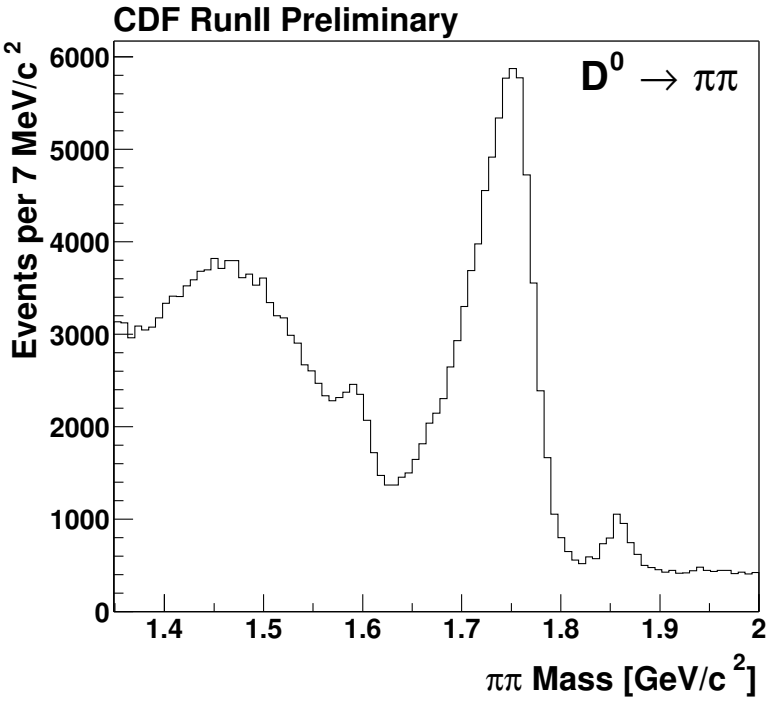
$D^+,\ D_s^+ \to \phi\pi^+,\ \phi \to K^+K^-$



$\Rightarrow m(D_s^+) - m(D^+) = 99.28 \pm 0.43 \pm 0.27\ \text{MeV}/c^2.$

$D^0 \to K^+K^-$ and $\pi^+\pi^-$:





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

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

Toward measurement of charm cross sections :

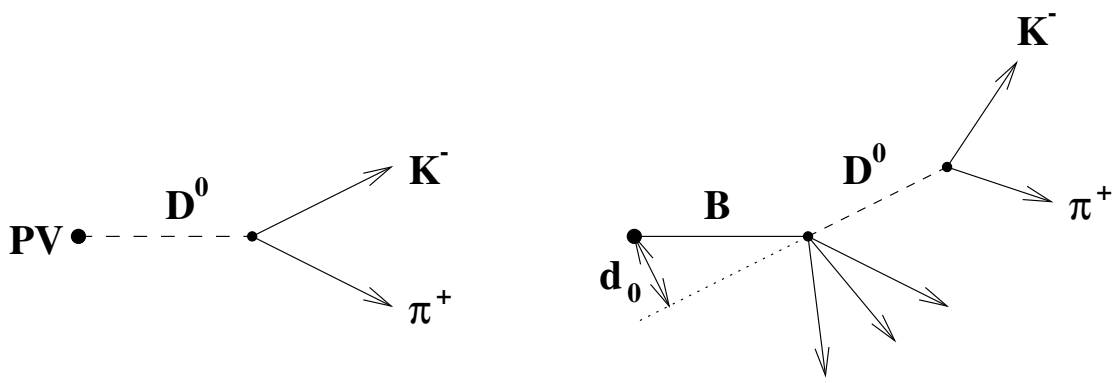
Sources of D mesons :

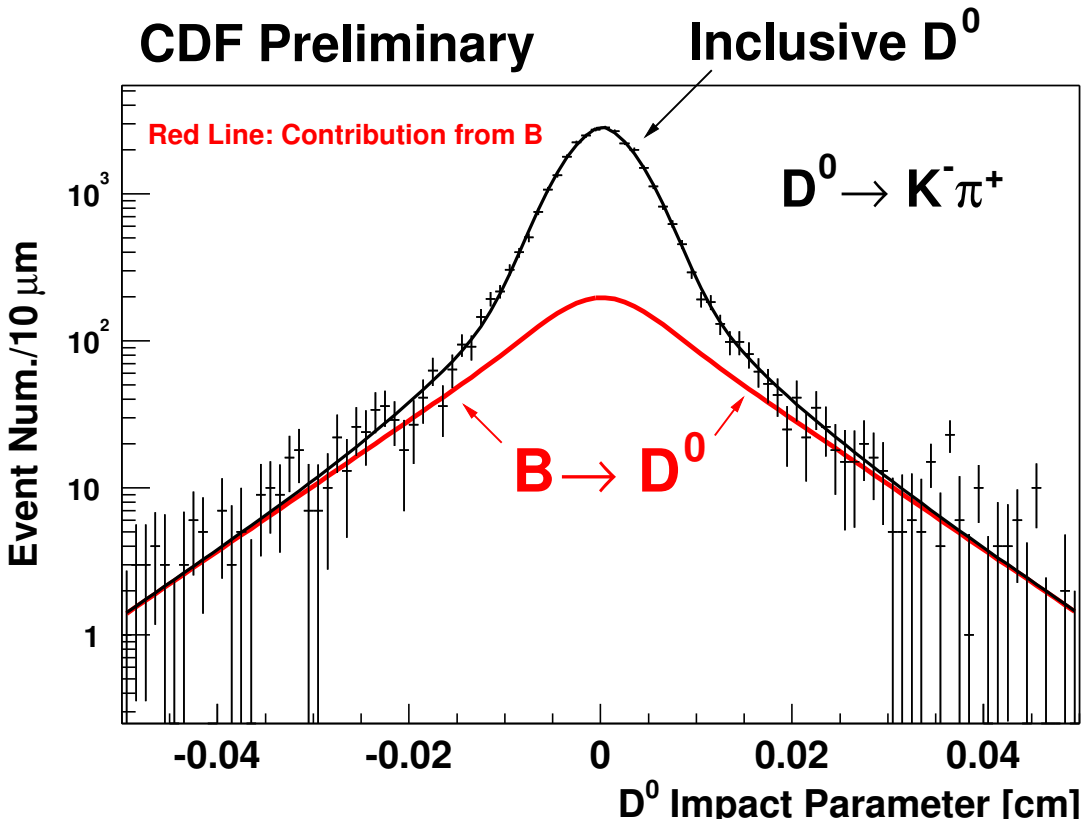
$\bar{p}p \to c \to D$ (Direct) vs.

$\bar{p}p \to b \to \bar{B} \to D$ (Secondary).

Examine impact parameter wrt primary vertex :

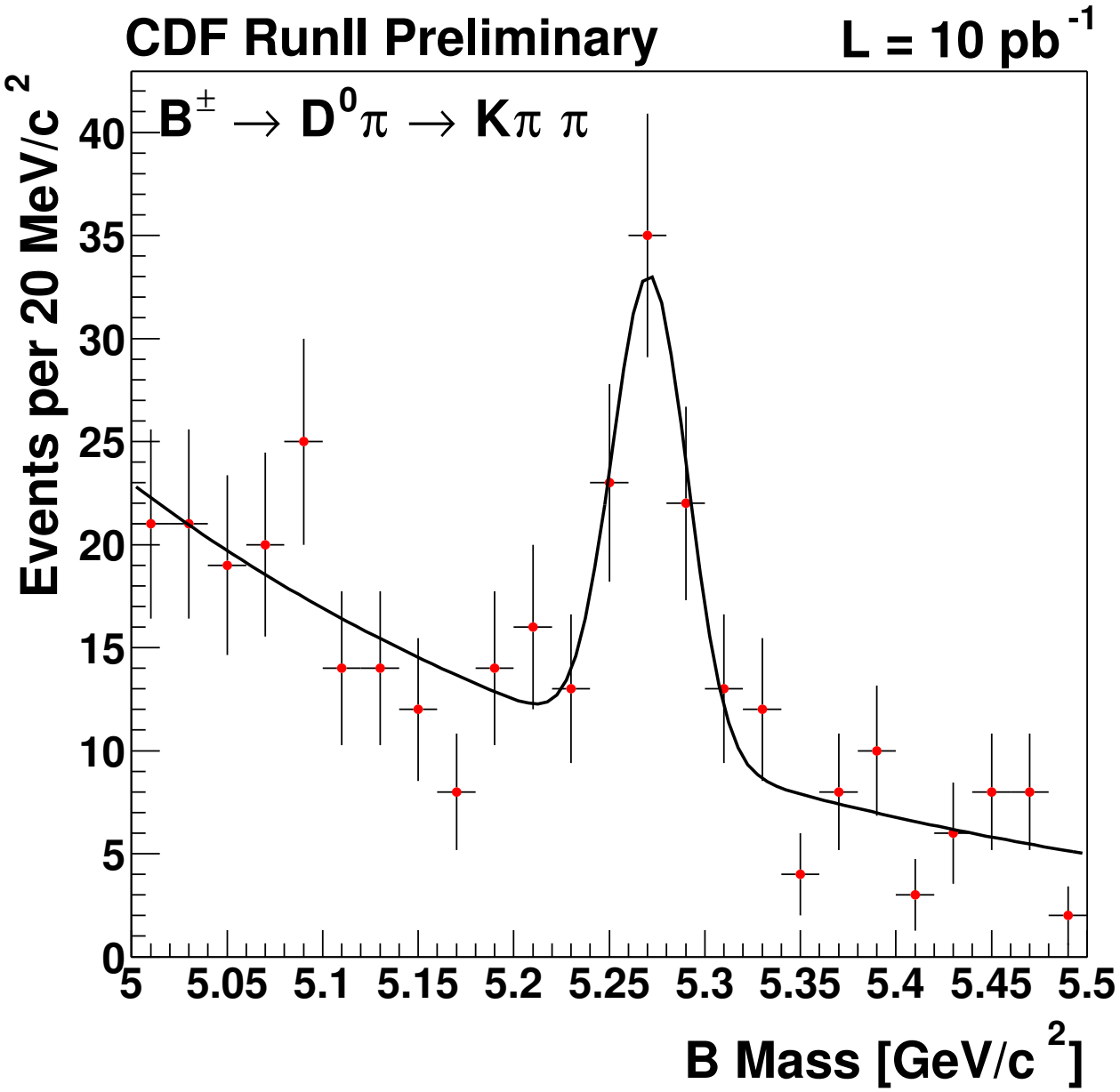
Direct Production	**Secondary Production**
D points back to PV	**D has finite impact parameter**





Find B fraction to be $10 - 30\%$

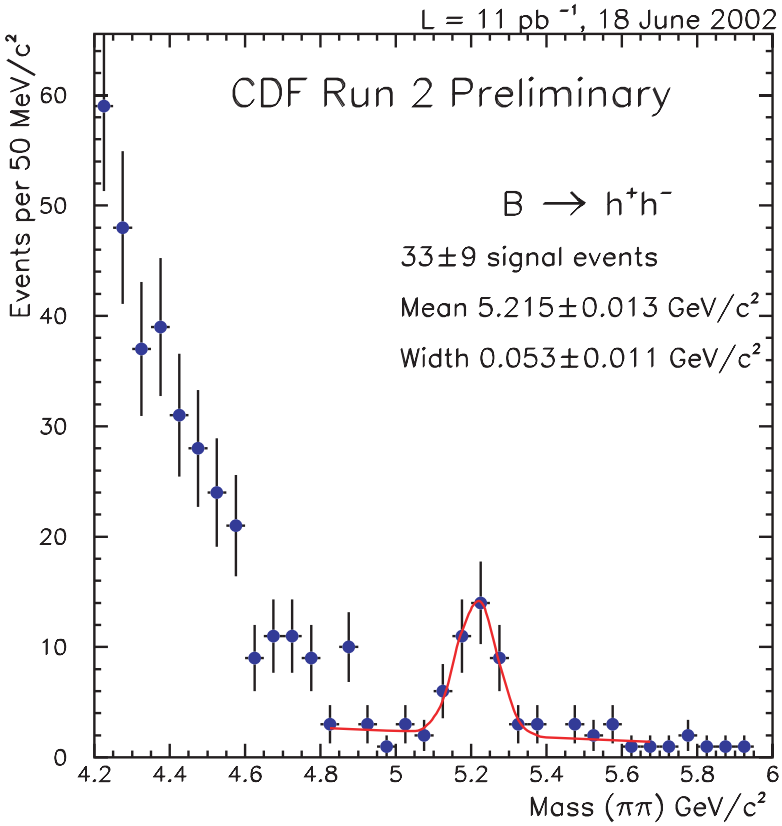
What we wanted : $\bar{B} \to D\,(n\pi)$



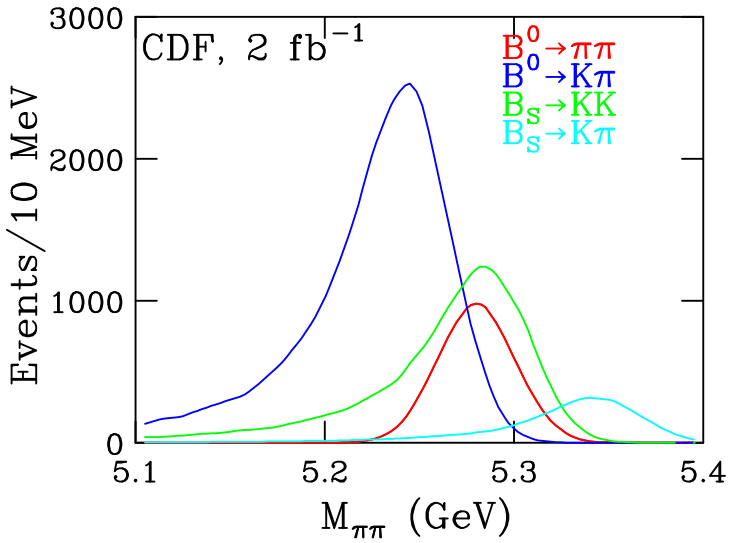
Next step : $\bar{B}_s^0 \to D_s^+ \pi^-$ for Δm_s.

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

What we wanted II : $B^0/B_s^0 \to h^+h^-$



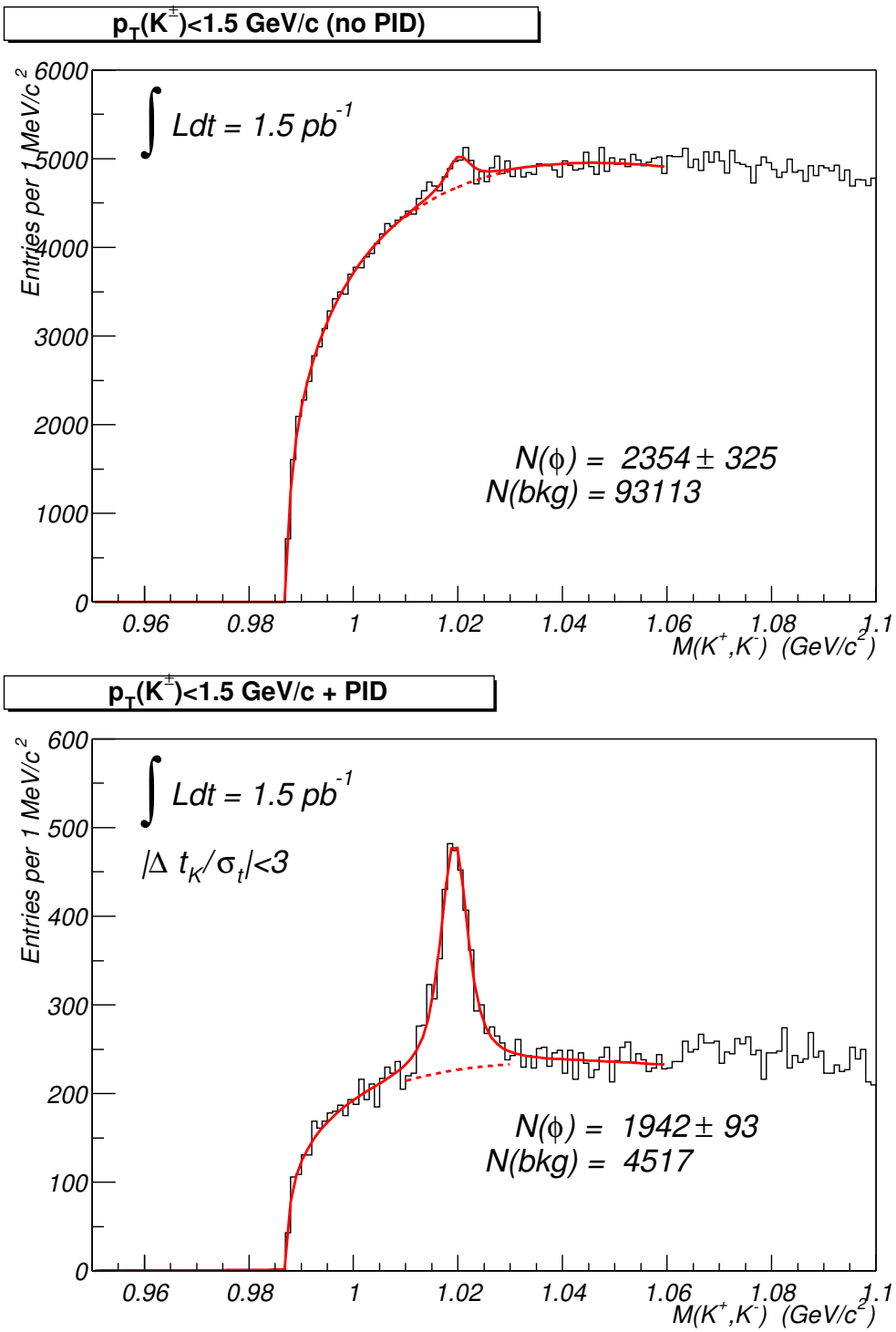
Peak : mixture of $B^0 \to \pi^+\pi^-$, $K^+\pi^-$ and $B_s^0 \to K^+K^-$, $K^-\pi^+$.



Next step : measure composition using dE/dx.
Future : Angle γ from $B^0 \to \pi^+\pi^-$, $B_s^0 \to K^+K^-$, R. Fleischer, Phys. Lett. B459, 306 (1999).

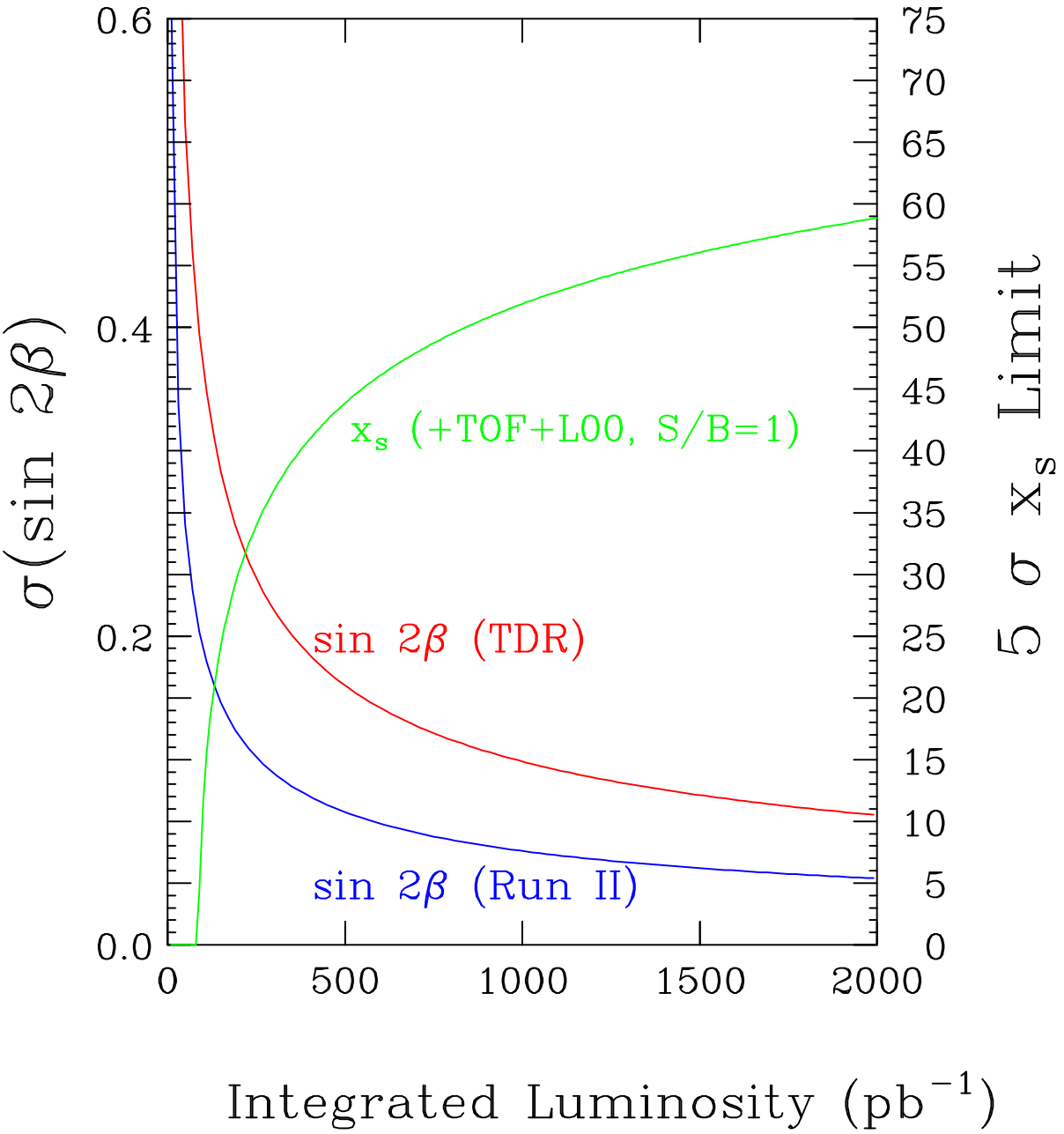
Toward B Flavor Tagging : TOF

$\phi \to K^+K^-$ before and after TOF cuts.



Next step : measure flavor tagging efficiencty $\epsilon \mathcal{D}^2$

CDF Run-II Projections



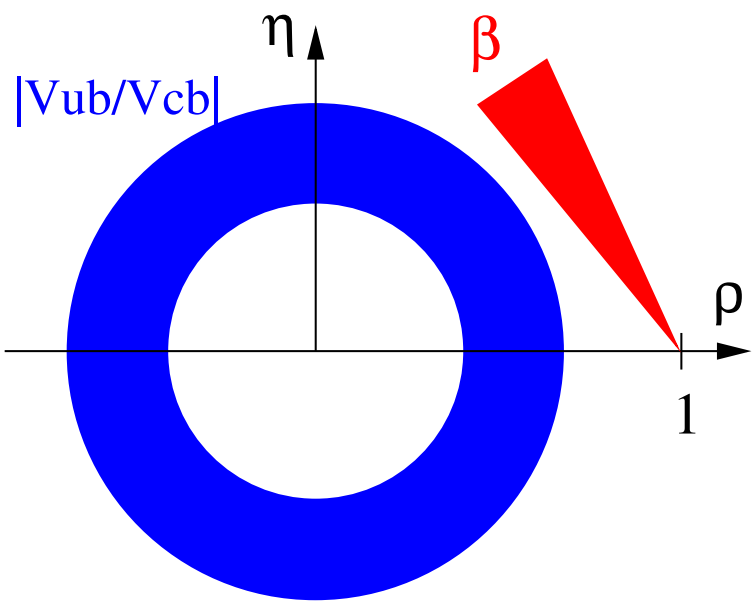
Left axis: Expected $\sin 2\beta$ precision.

Right axis: $B_s^0 \overline{B}_s^0$ oscillation discovery limit.

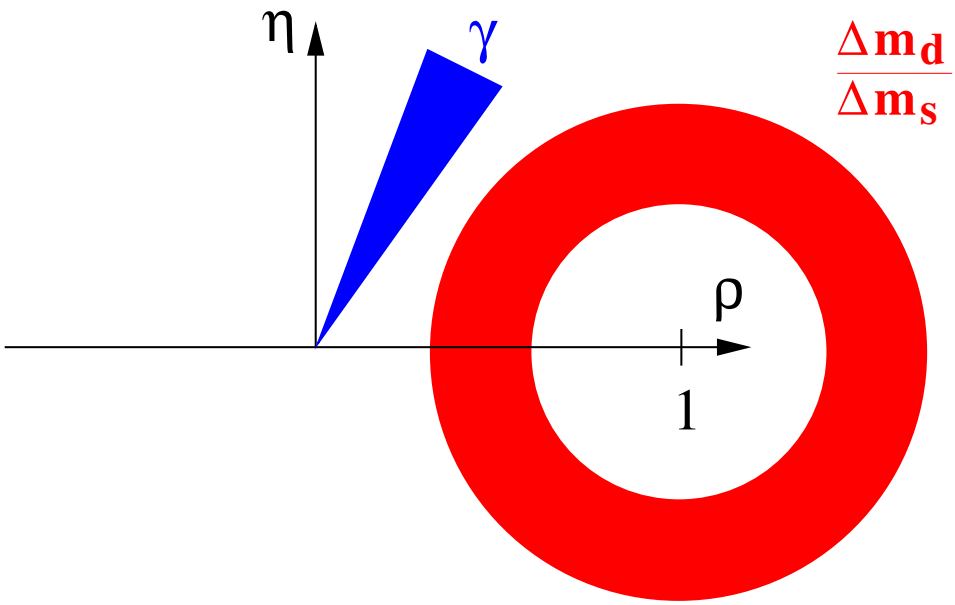
Maybe overly optimistic here, but ...

Will New Physics Show Up?

When you will have measured angles β and γ, and sides $|V_{td}/V_{ts}|$ and $|V_{ub}/V_{cb}|$ precisely enough, things may turn out to be like this:



CP violating New Physics in mixing



CP conserving New Physics in mixing

Other B Physics Topics

- Search for CP-violation in $B_s^0/\bar{B}_s^0 \to J/\psi\phi$

  A_{CP} to $\sim \pm 0.1$. Expect ~ 0 in SM, new physics if substantial.

- Width difference $\Delta\Gamma$ in $B_s^0\bar{B}_s^0$ system

  Potential for CP studies with untagged B_s^0 decays.

  $\sigma(\Delta\Gamma/\Gamma) \simeq 0.024$ from $J/\psi\,\phi$ vs. $D_s^+\pi^-$.

  Also, direct check with $D_s^{(*)+}D_s^{(*)-}$.

- Rare decays :

  $B \to \mu^+\mu^- K^{(*)}$, ~ 60 events in 2 fb^{-1}.

  Need more data for forward/backward asymmetry.

  Also $(B^0 \to K^{*0}\gamma)$ / $(B^0 \to \rho^0\gamma)$

  and $(B_s^0 \to \phi\gamma)$ / $(B_s^0 \to K^{*0}\gamma) \Rightarrow |V_{ts}/V_{td}|$.

- Angle γ from $B_s^0 \to D_s^{\mp}K^{\pm}$?

  Theoretically clean, but BG from $D_s^-\pi^+$ tough.

  Hope to see signal in 2 fb^{-1}.

- Precision lifetime ratios : B_s^0/B^0, B_c^+/B^0, Λ_b/B^0
- Full reconstruction of $B_c^+ \to J/\psi\pi^+$, $B_s^0\pi^+$ ...
- QCD b and c production, onium polarization.

Much of them pretty complementary to $\Upsilon(4S)$.

Summary

Run-II CDF has been running since 2001.

We have accumulated data comparable to Run I.

- CDF-II detector is working very well.
  We are ready to accumulate 2 fb^{-1}.
- Machine luminosity is getting better.
- Already some physics results are coming out.
- Important measurements to follow soon.
- Hopefully some kind of discovery before LHC era.

来月またお目にかかりましょう .