CDFは走ってます!

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実験・観測にもとづく素粒子統一描像の構築
– 21 世紀の情報発信基地としての日本 –

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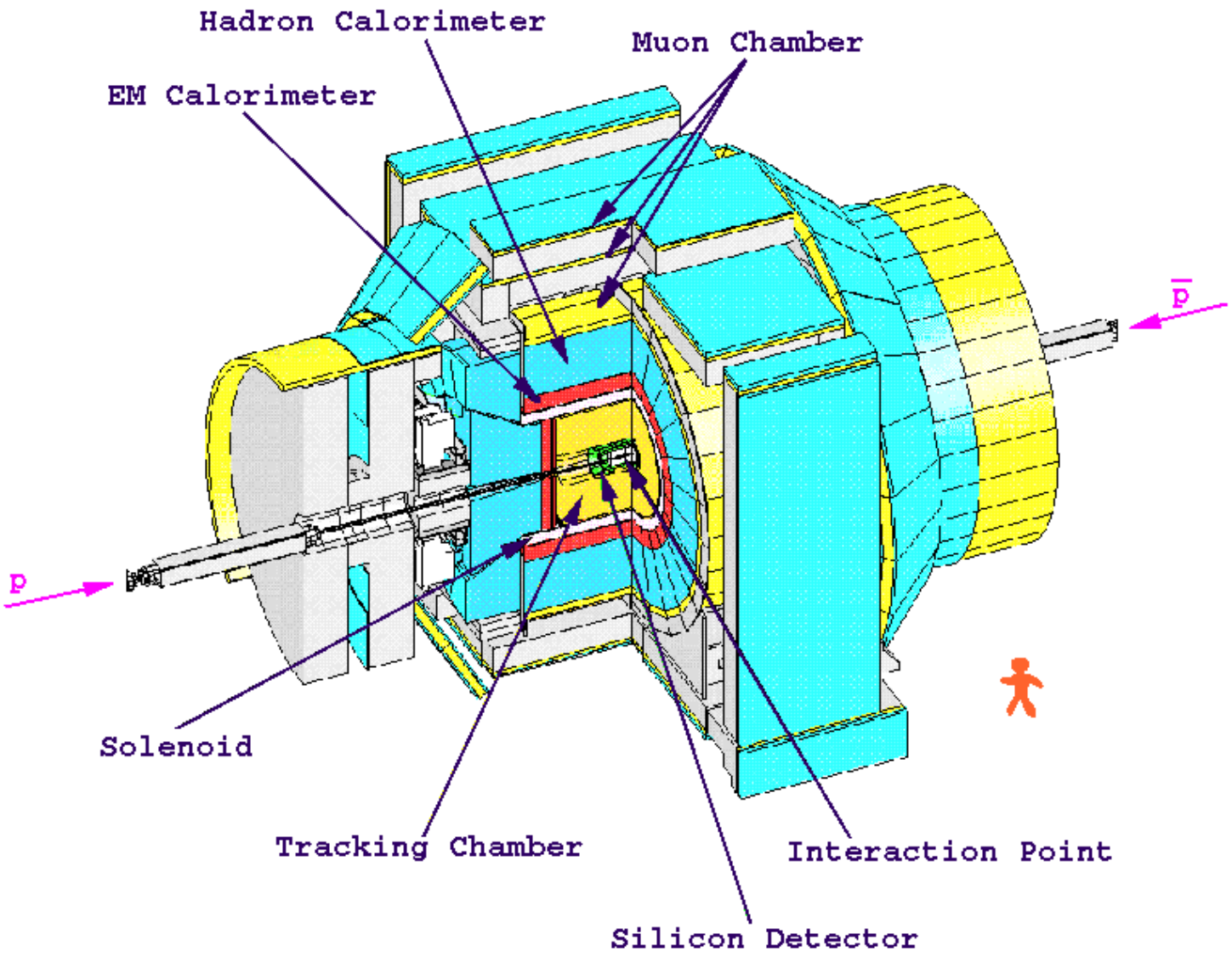
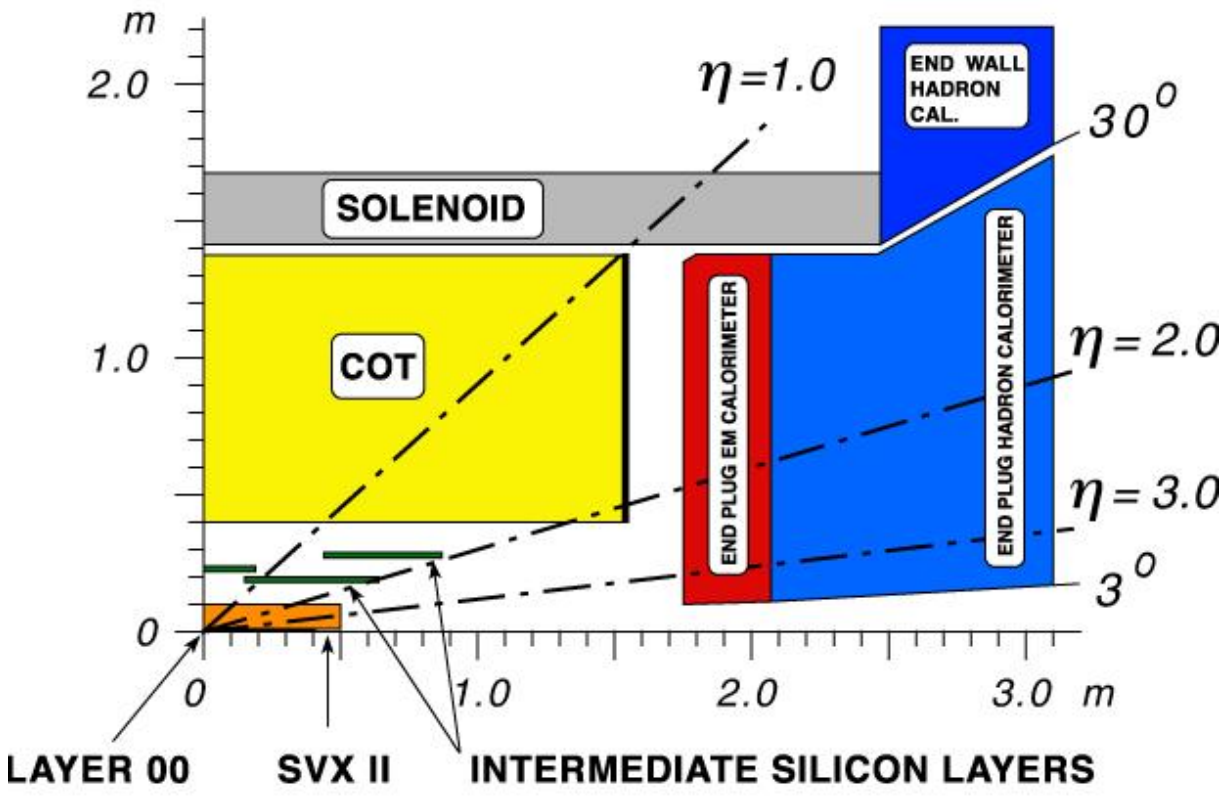
京都大学基礎物理学研究所

Run-II CDF Detector



CDF-II Detector



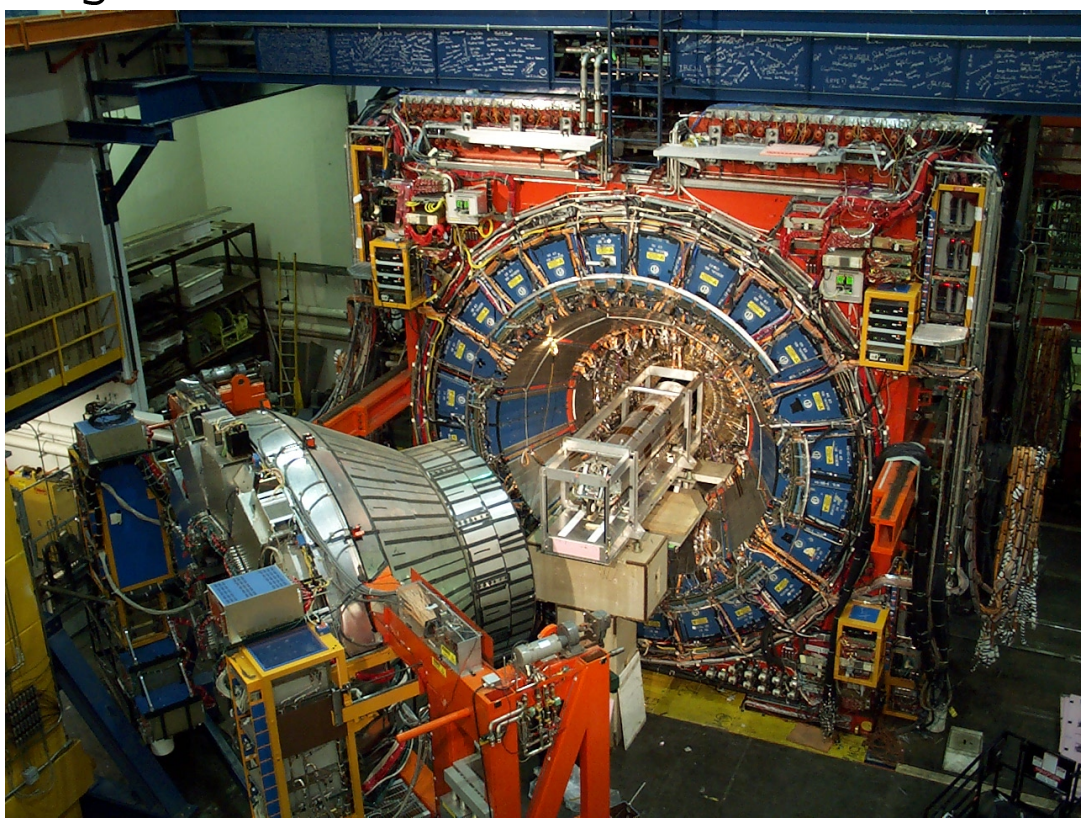
Everything inside the solenoid is new.

- Charged particle tracking

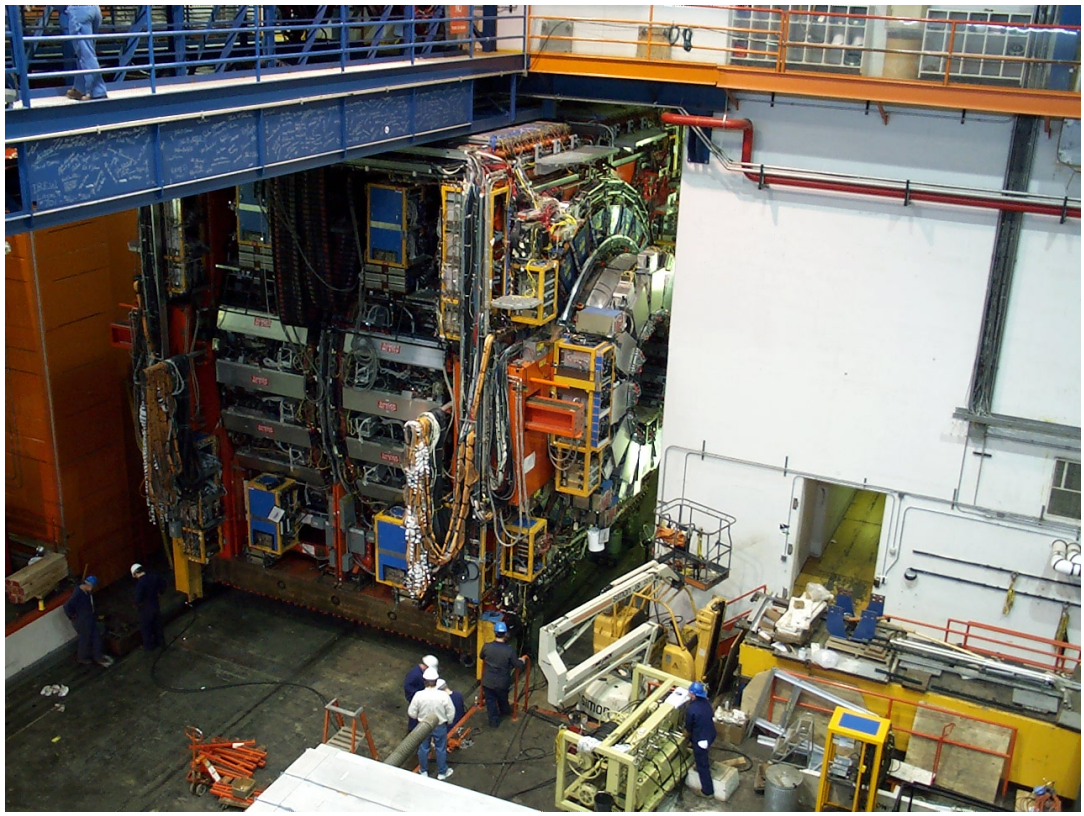
  Central Outer Tracker : 30 k sense wires.
  - $\sigma(p_T)/p_T = 0.0008\, p_T$ for $|\eta| < 1$.
  - Relativistic rise dE/dx.

  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, $|\eta| < 1.5$.

Installing the silicon detectors.



Rolling into the collision hall.



Tevatron Run-II Program

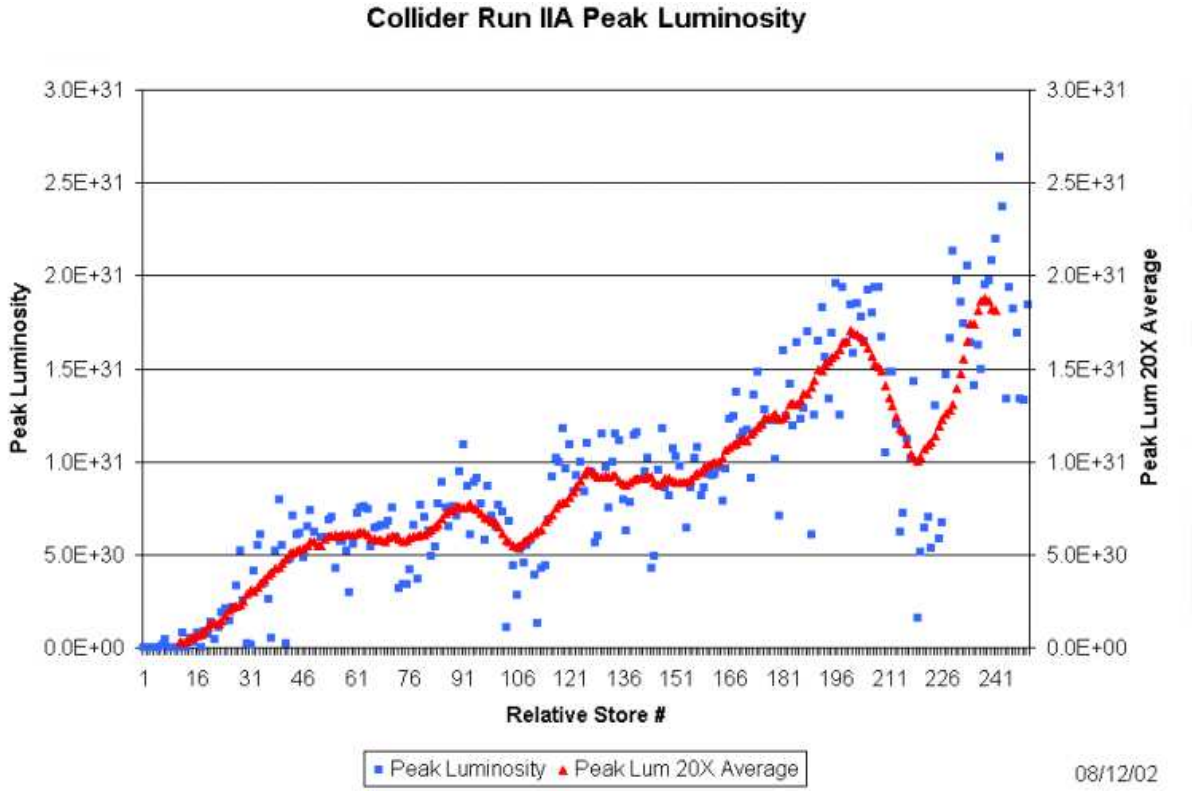
Run II started in March 2001

Increased CM energy : 1.8 $\rightarrow$ 2 TeV

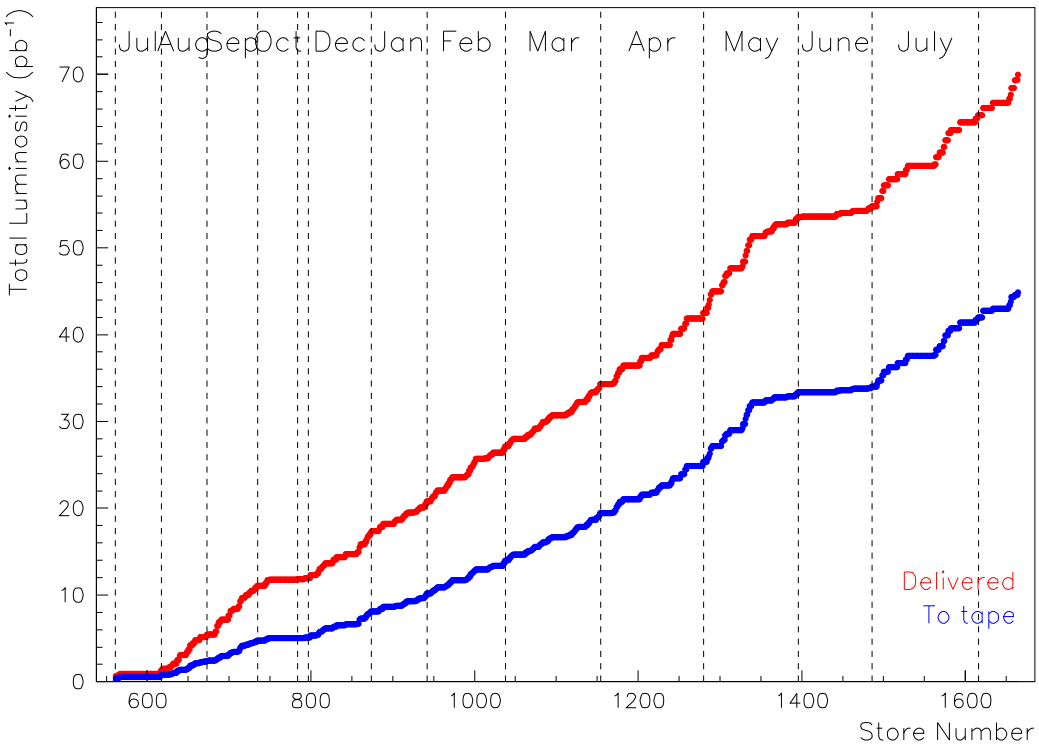
36 $\times$ 36 bunches of p's and $\bar{p}$'s
$\Rightarrow$ Beam crossing every 400 ns (was 3600 ns).

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

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



So far 70 pb^{-1} delivered, 40 pb^{-1} recorded.



Luminosity not as high as we hoped for :

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

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

  Hope to get a factor of two in lum.

- 6-week shutdown maybe in Jan 2003, to work on Recycler and others.

  Hope to get another factor of two then.

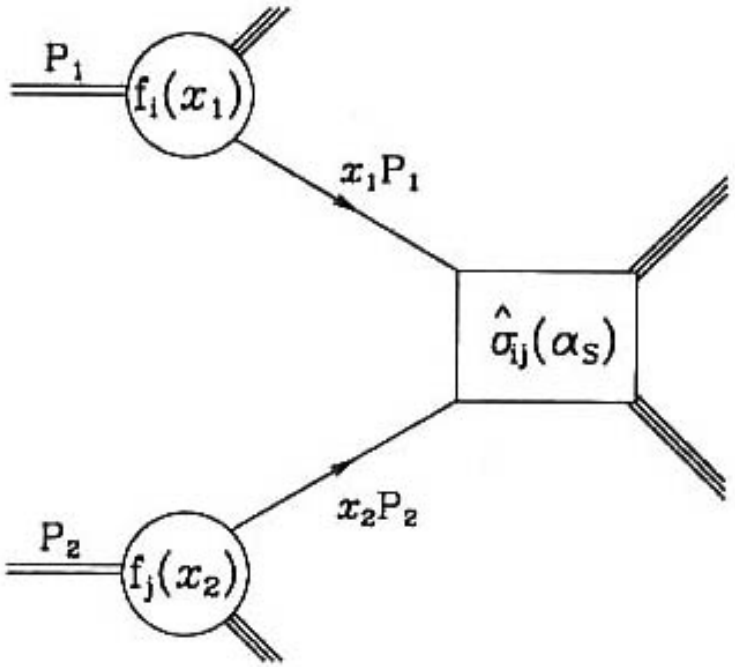
  $\Rightarrow 8 \times 10^{31}$ cm^{-2} s^{-1} $\sim$ Run-IIa goal.

Plans :

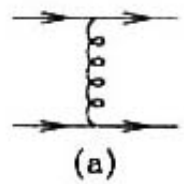
- $100 - 200$ pb^{-1} by end of 2002.
- ~ 1 fb^{-1} by end of 2003.
- ~ 2.5 fb^{-1} in Run-IIa total (end of 2004).
- 2005 : 6-month shutdown to replace silicon.
- After that, Run IIb continues thru 2008, 15 fb^{-1}.

Jet Production

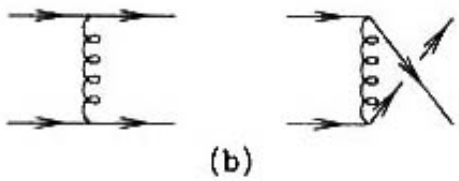
Jets are the most common events in hard hadron-hadron collisions.



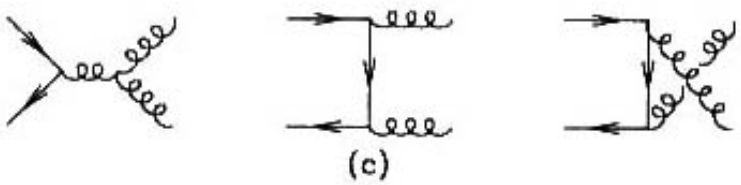
Lowest order sub-processes for jet production:


(a)

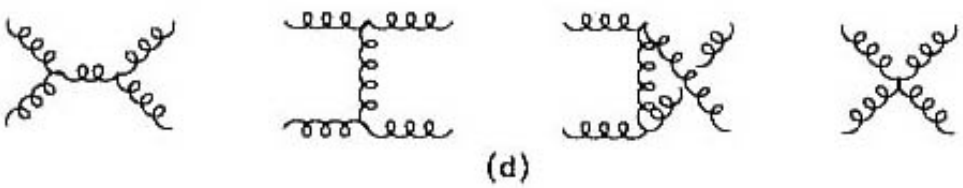
$qq' \to qq'$


(b)

$qq \to qq$


(c)

$q\bar{q} \to gg$


(d)

$gg \to gg$

Initial parton composition vs. final state jet E_T

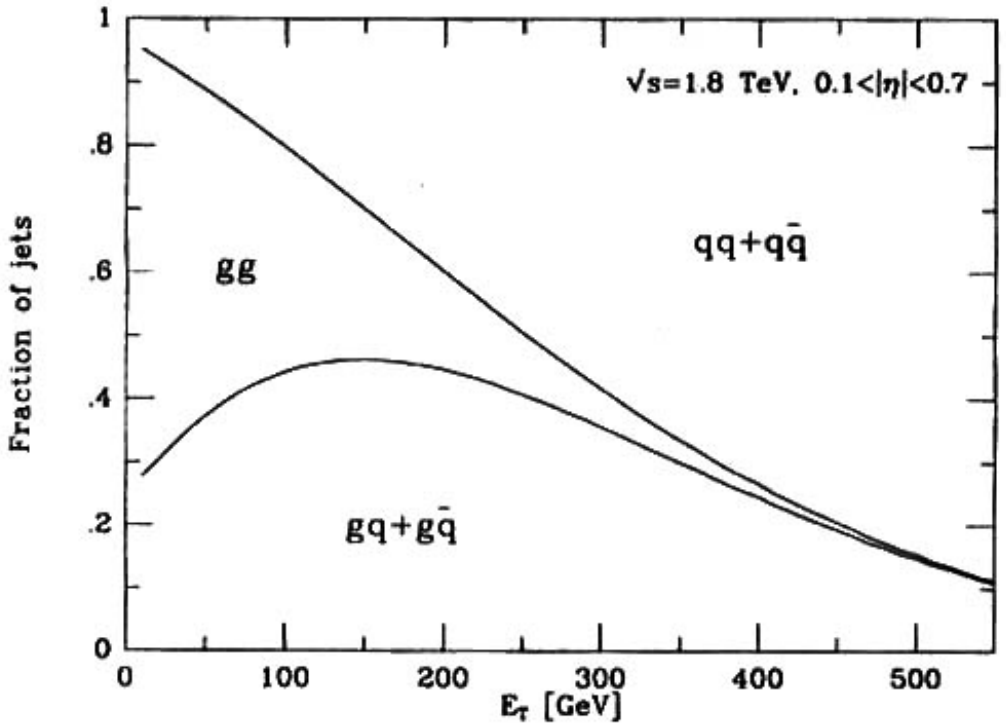
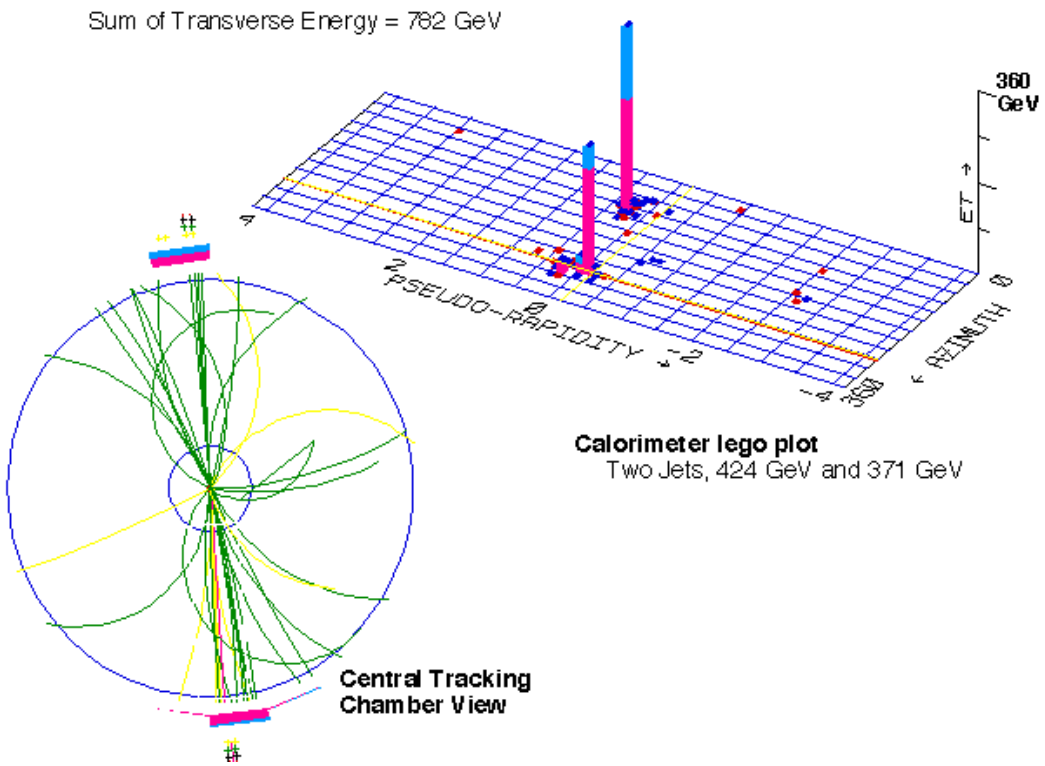


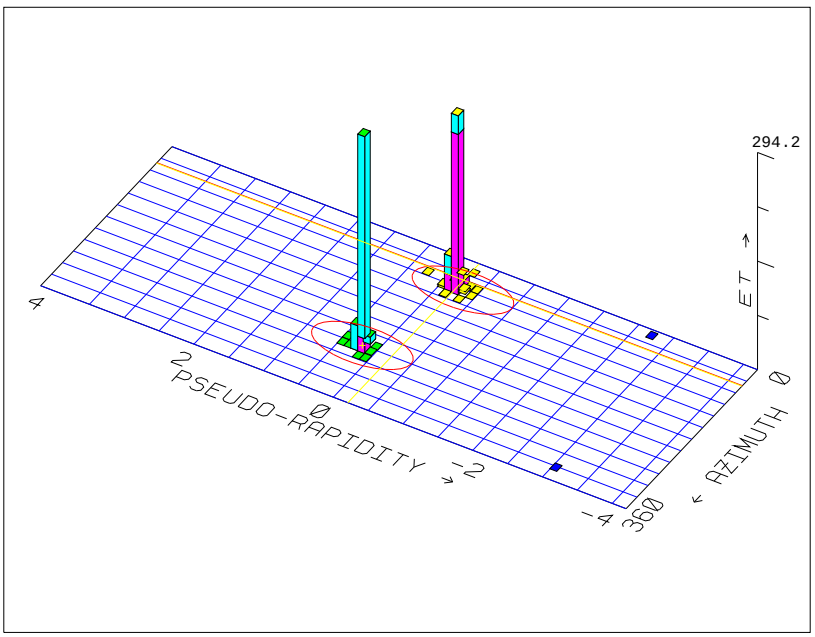
Fig. 7.8. Plot showing the fraction of the jet E_T distribution initiated by different parton combinations.

CDF: Highest Transverse Energy Event from the 1988-89 Collider Run

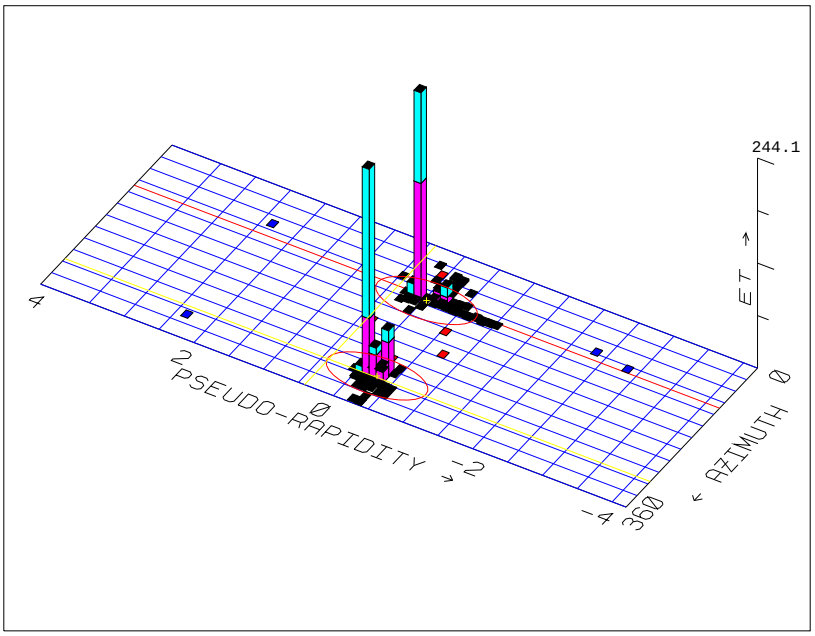


How you define jets?

CDF has used cone algorithm.
Cone in η-ϕ space, radius $R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$.
Add all calorimeter tower energies inside the cone.
Cone size : $R =$ 0.7 usual, sometimes 0.4, 1.0.

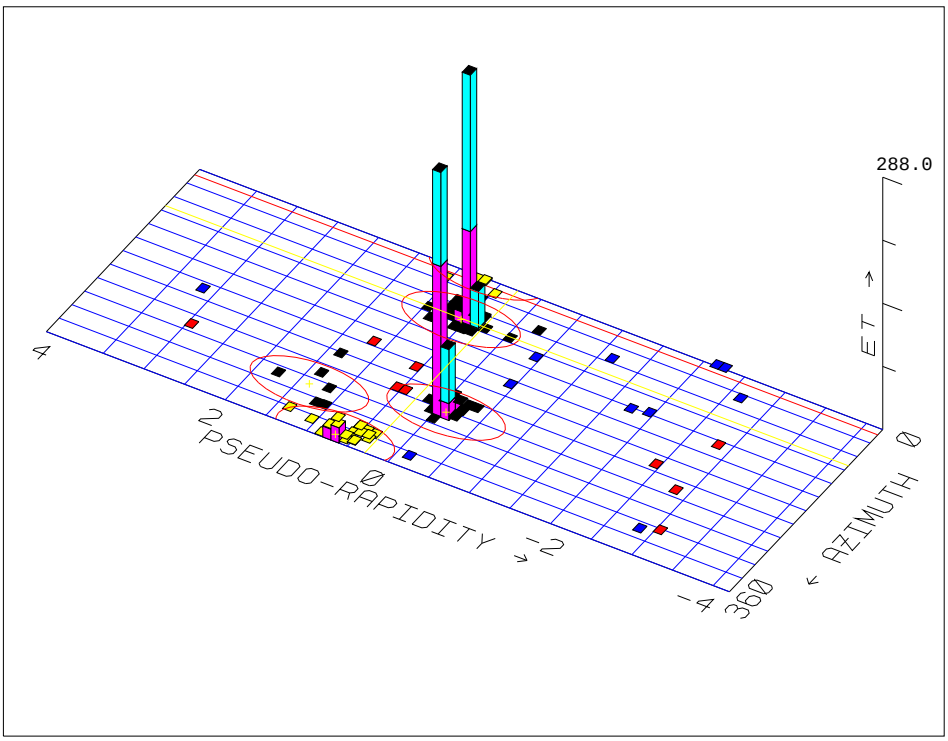


Two jets

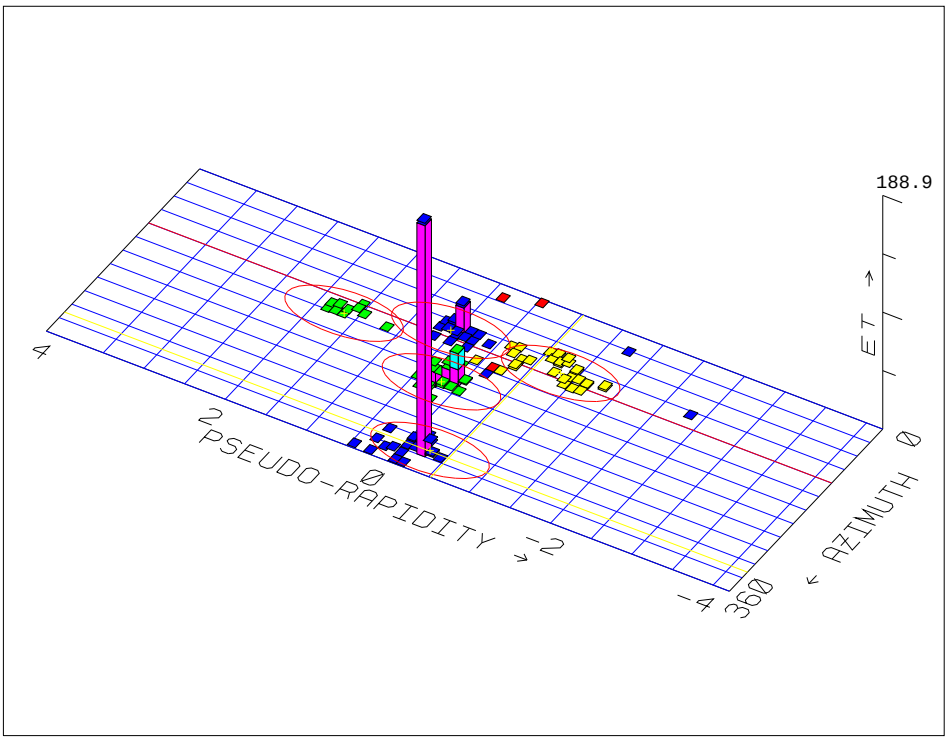


Two jets

Four jets



Five jets

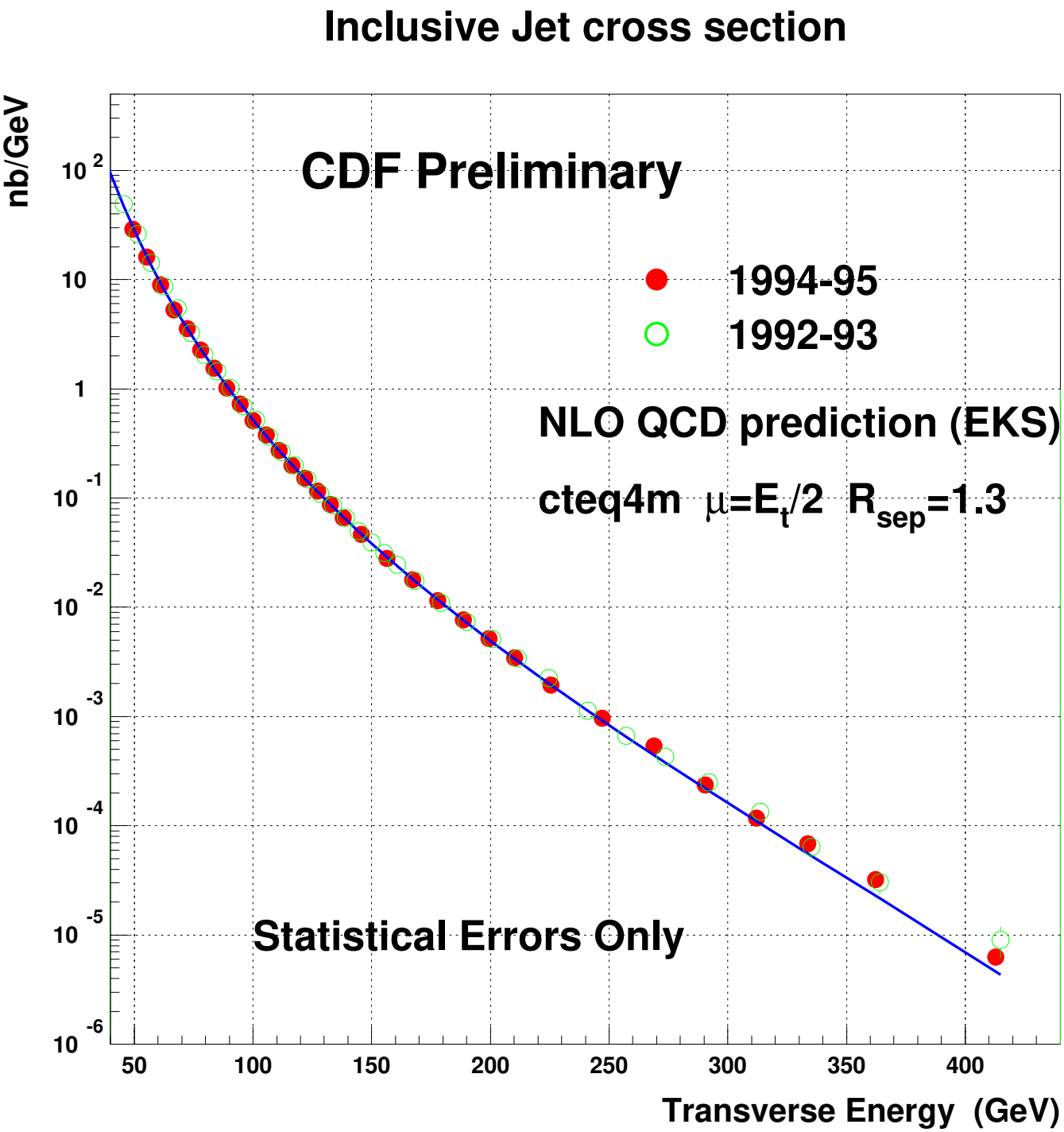


Red : EM cal energy

Blue : Hadron cal energy

Inclusive Jet Cross Section

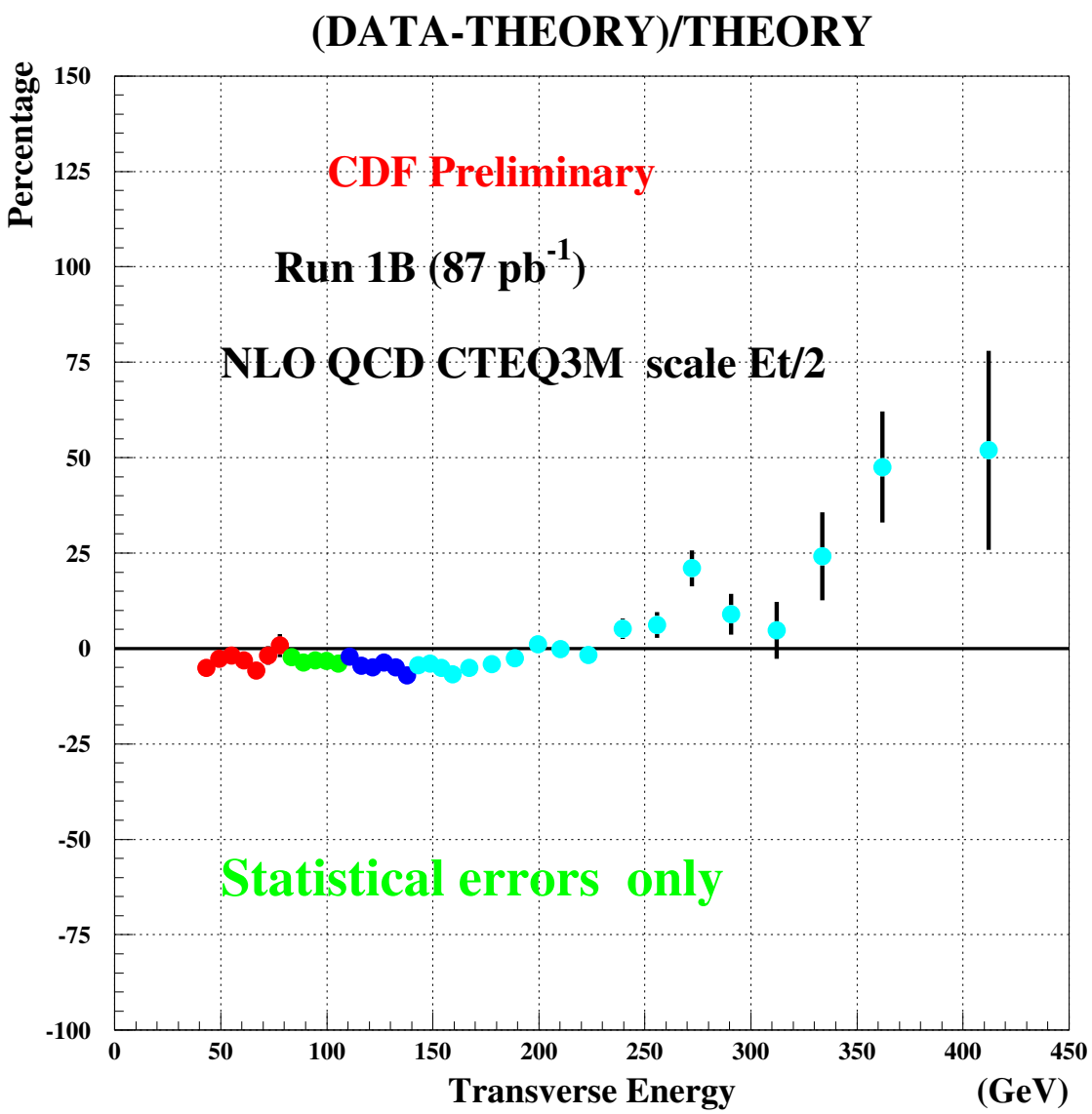
PRD 64, 032001 (2001)



Covers seven orders of magnitudes.

Overall, impressive agreement with theory.

Data-Theory Comparison

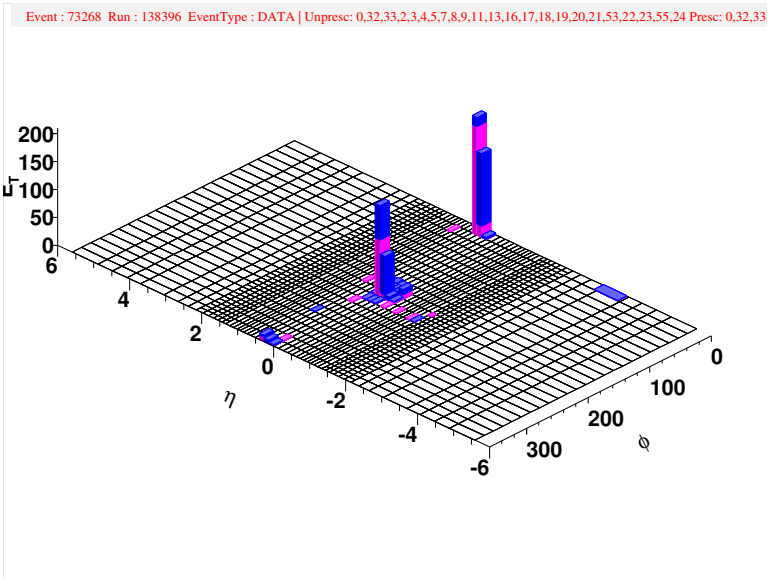


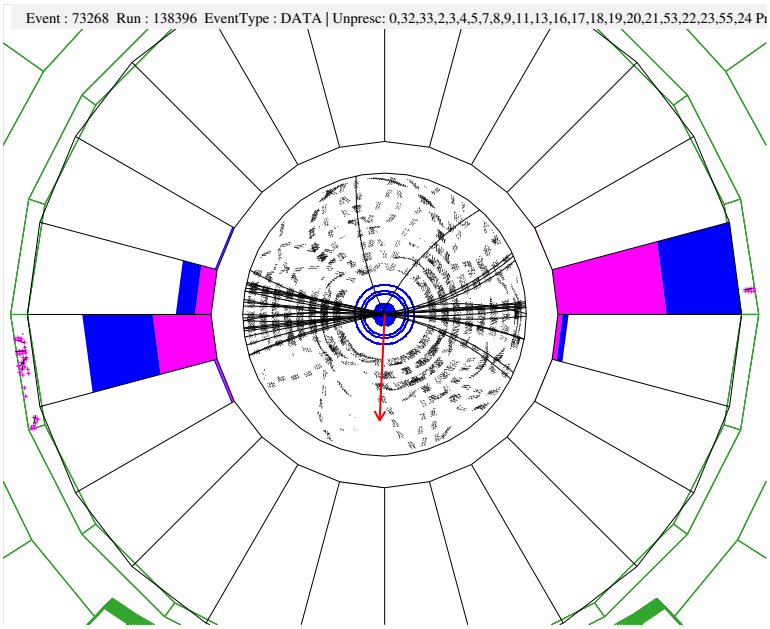
Excess at the high end? Need more stat.

Run-II examples :

CDF Highest E_T Dijet Event

- Jet E_{T1} = 403.3 GeV, η_1 = 0.037 (uncorrected)
- Jet E_{T2} = 322.0 GeV, η_2 = -0.364 (uncorrected)
- Vertex z = 39.0 cm
- Missing E_T Significance = 1.93

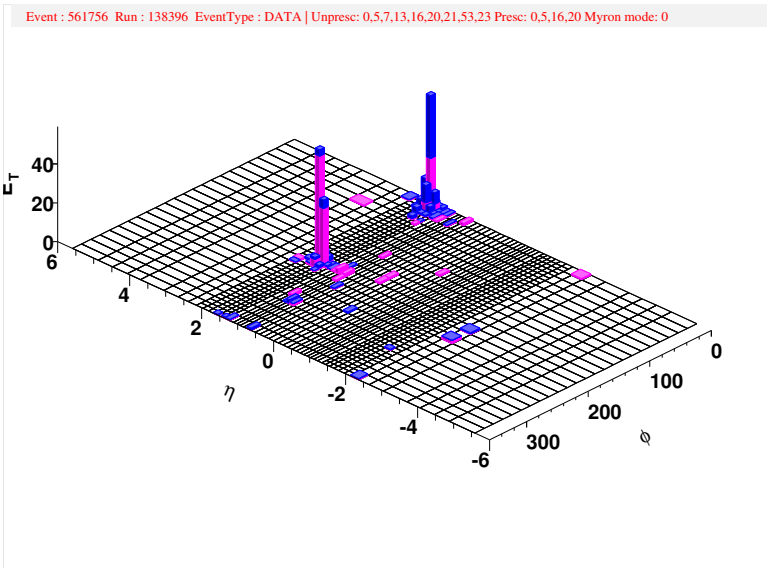


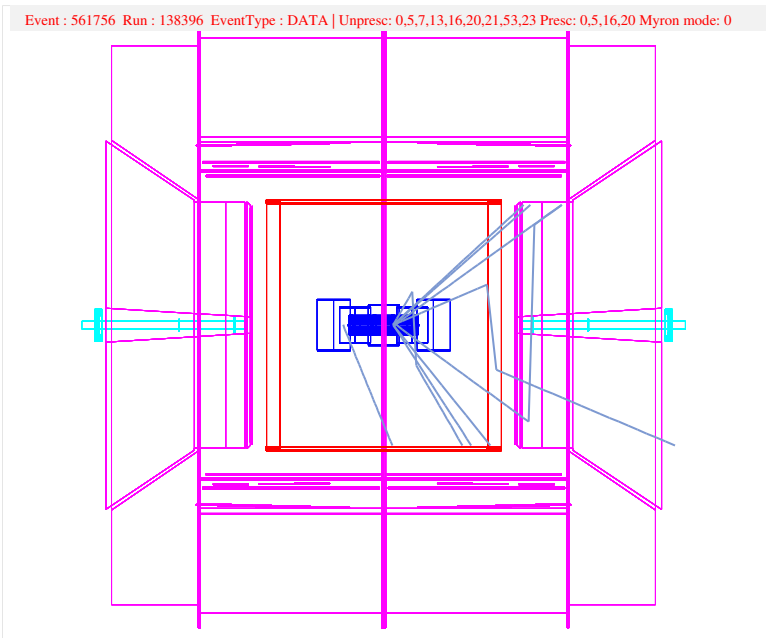


Run-II forward jets :

CDF Forward Dijet Event

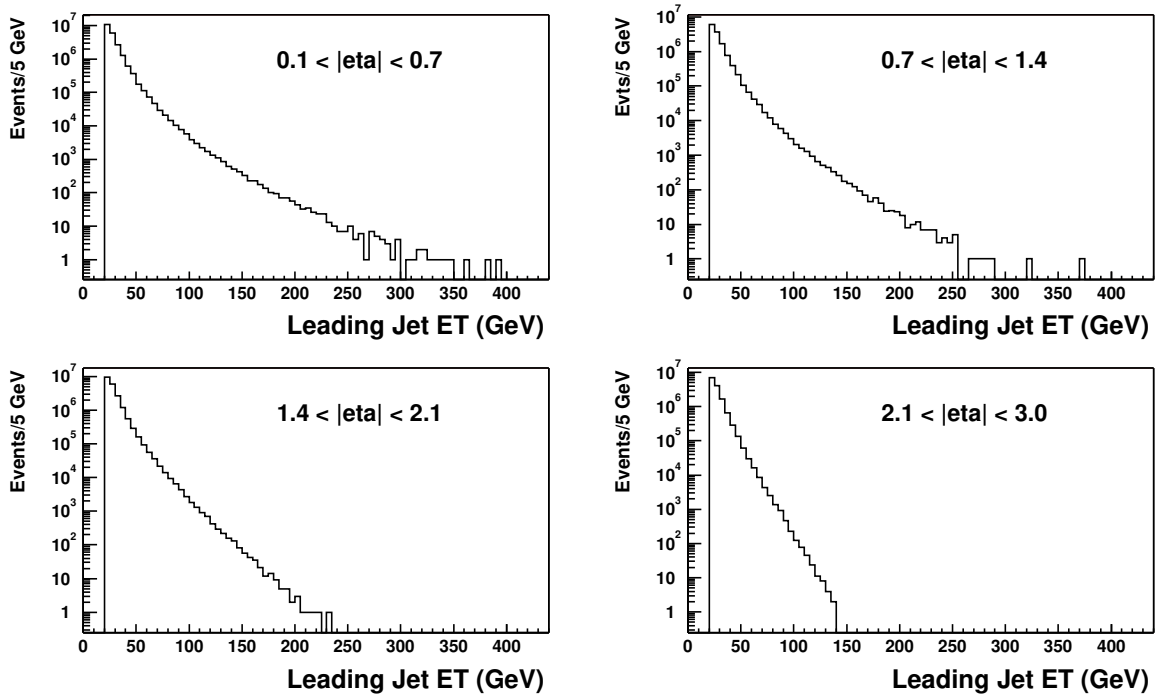
- Jet E_{T1} = 153.9 GeV, η_1 = 1.48 (uncorrected)
- Jet E_{T2} = 146.8 GeV, η_2 = 1.45 (uncorrected)
- Vertex z = 14.1 cm
- Missing E_T Significance = 0.08





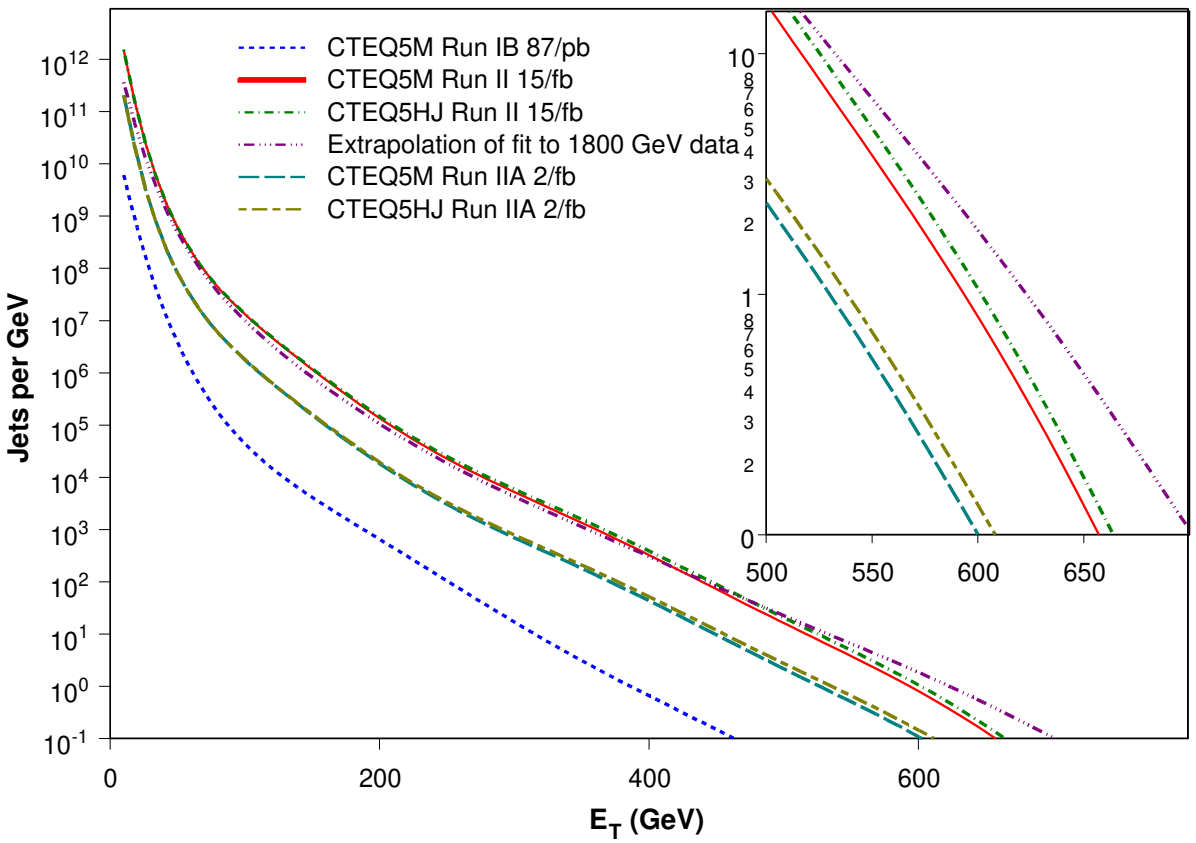
Leading Jet ET in CDF Jet Events

CDF Run 2 Preliminary (12/14/2001 - 2/18/2002) 4.4 pb-1



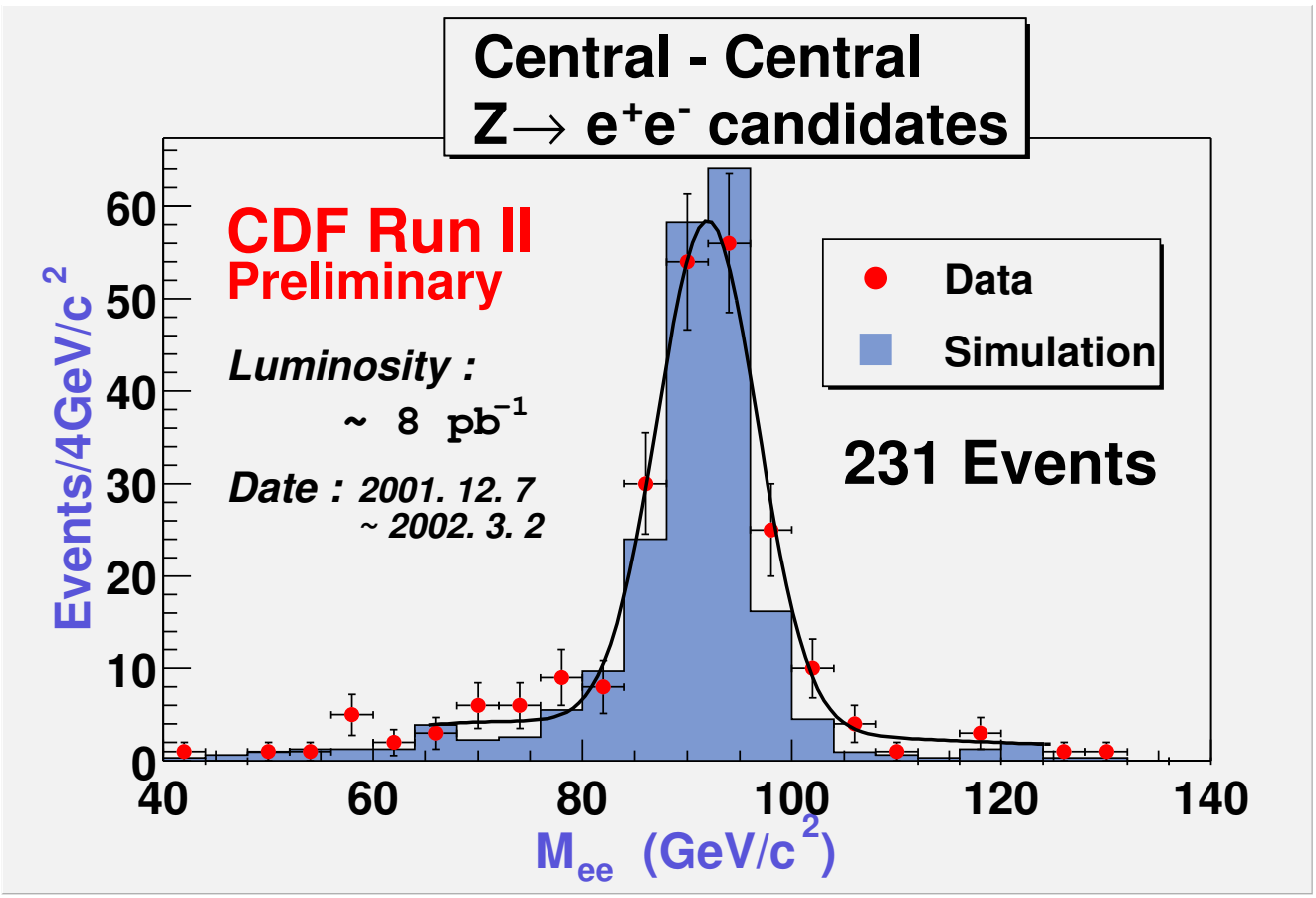
Run-II reach

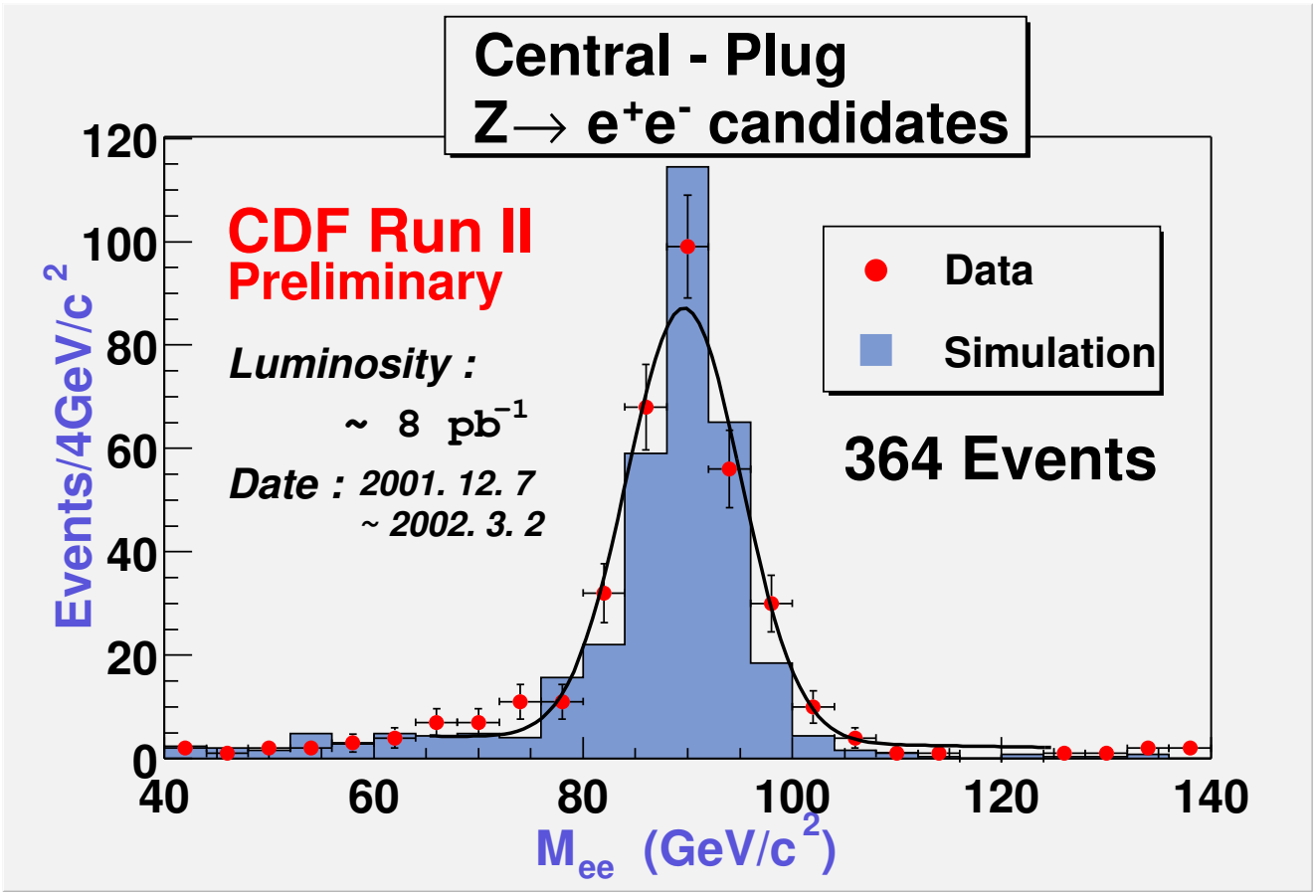
Jet Yields Bin 1 - 0.1 < |y| < 0.7



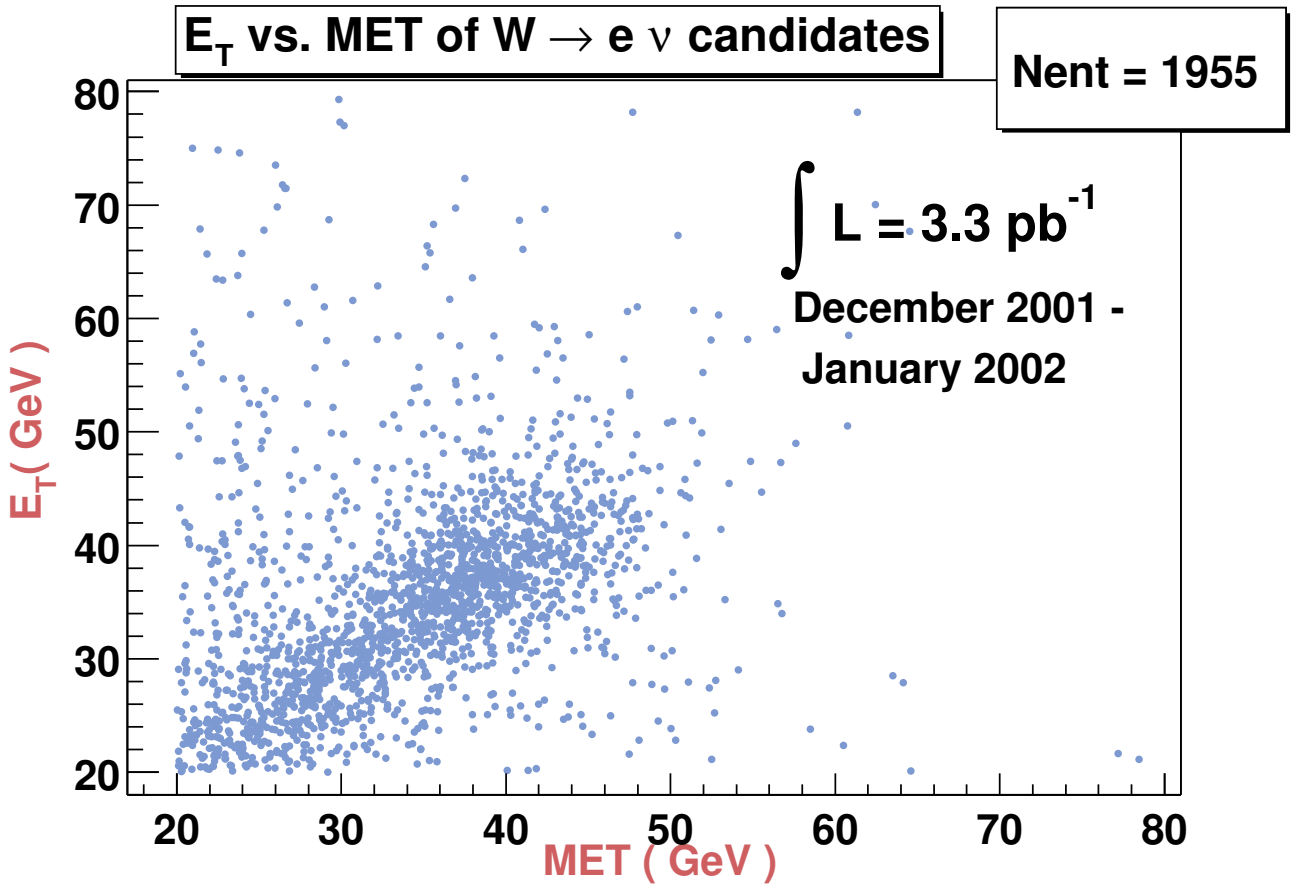
Up to 550 GeV with 2 fb^{-1}, 600 GeV with 15 fb^{-1}.

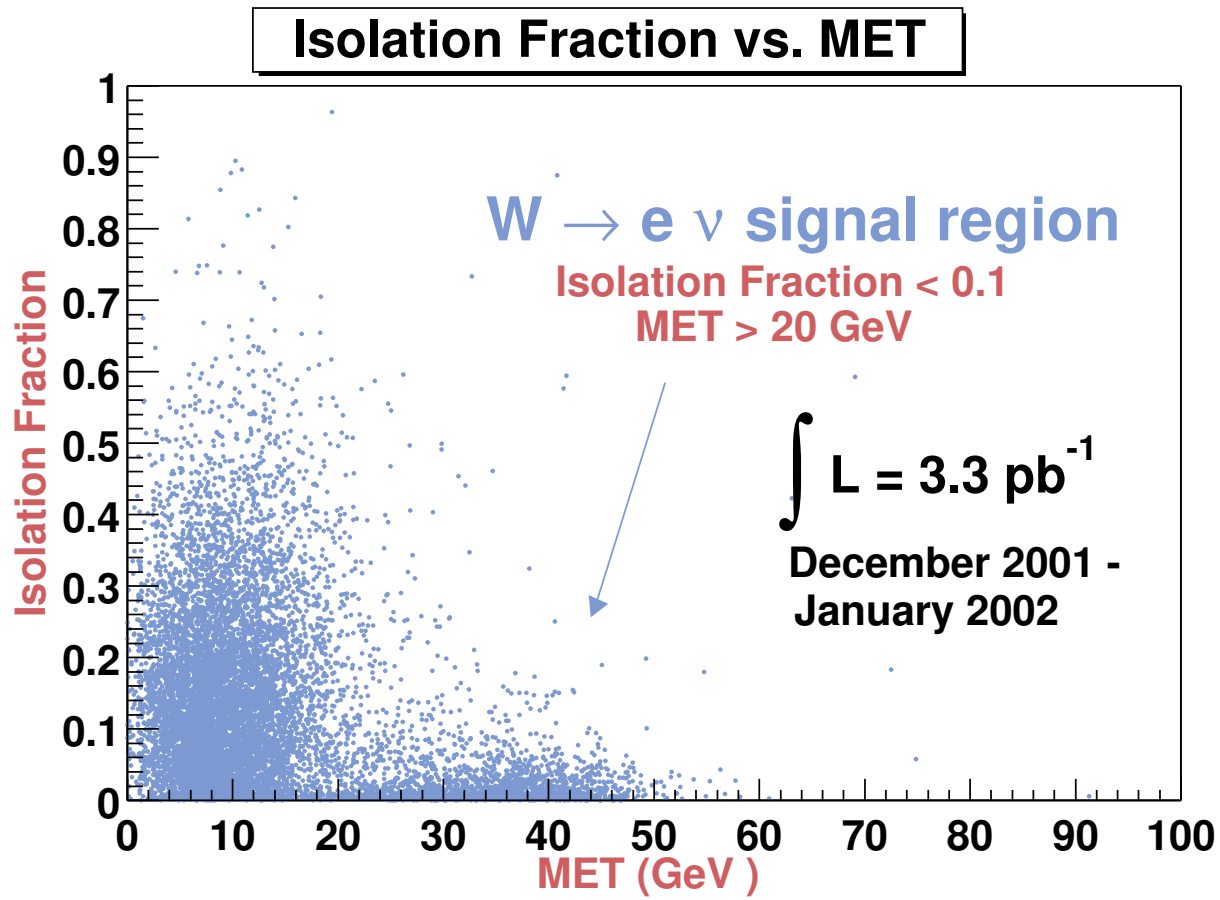
Run-II $Z^0 \to e^+e^-$ candidates :



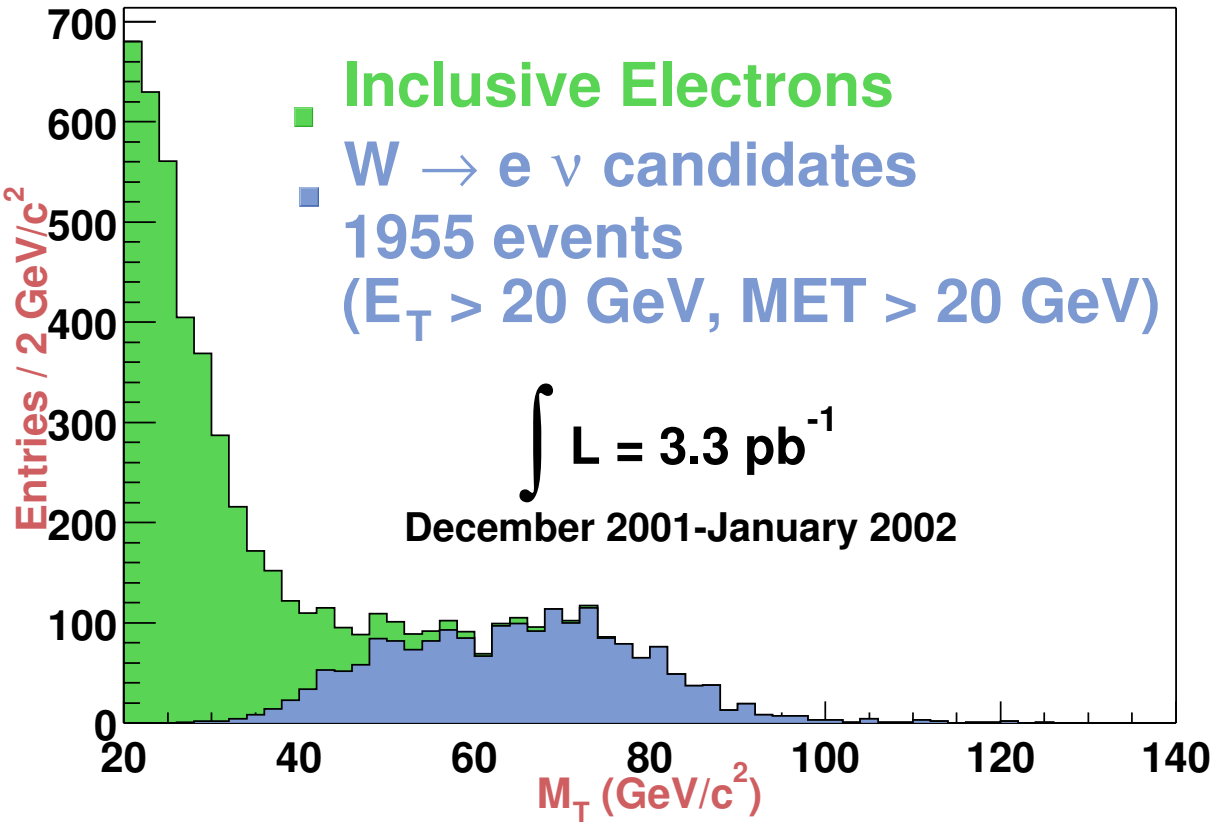


Run-II $W \to e\nu$ candidates



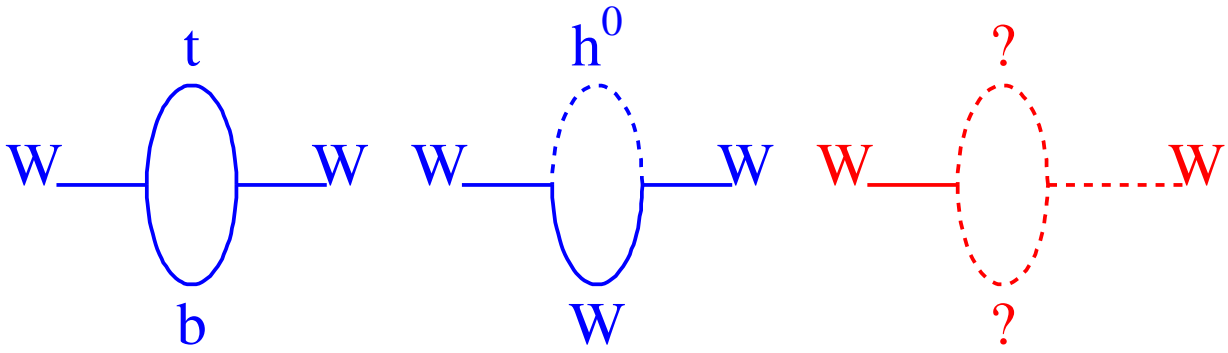


$W \to e\nu$ transverse mass distribution

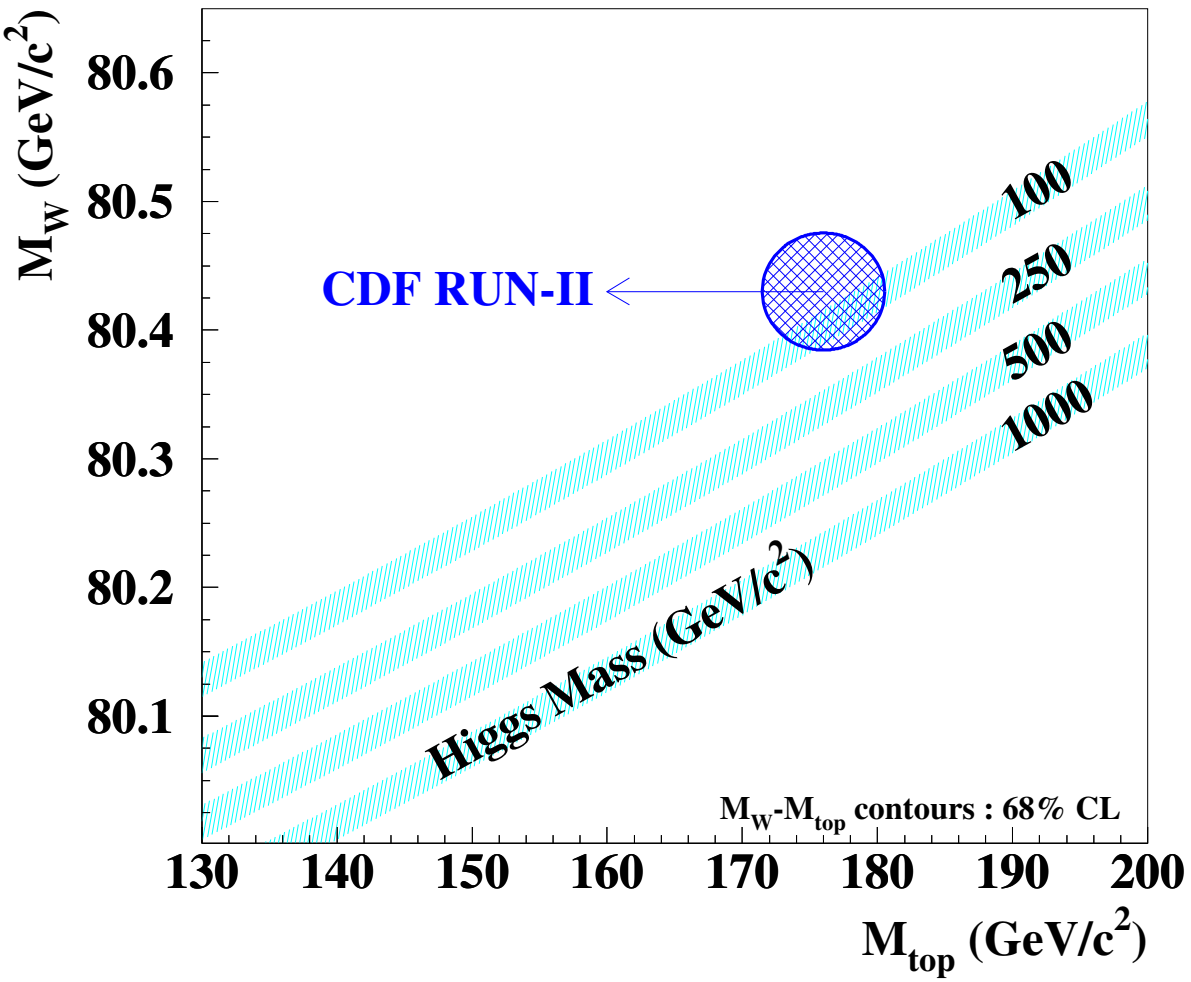


Next step : Accumulate stats, measure $W^{\pm}$ mass.

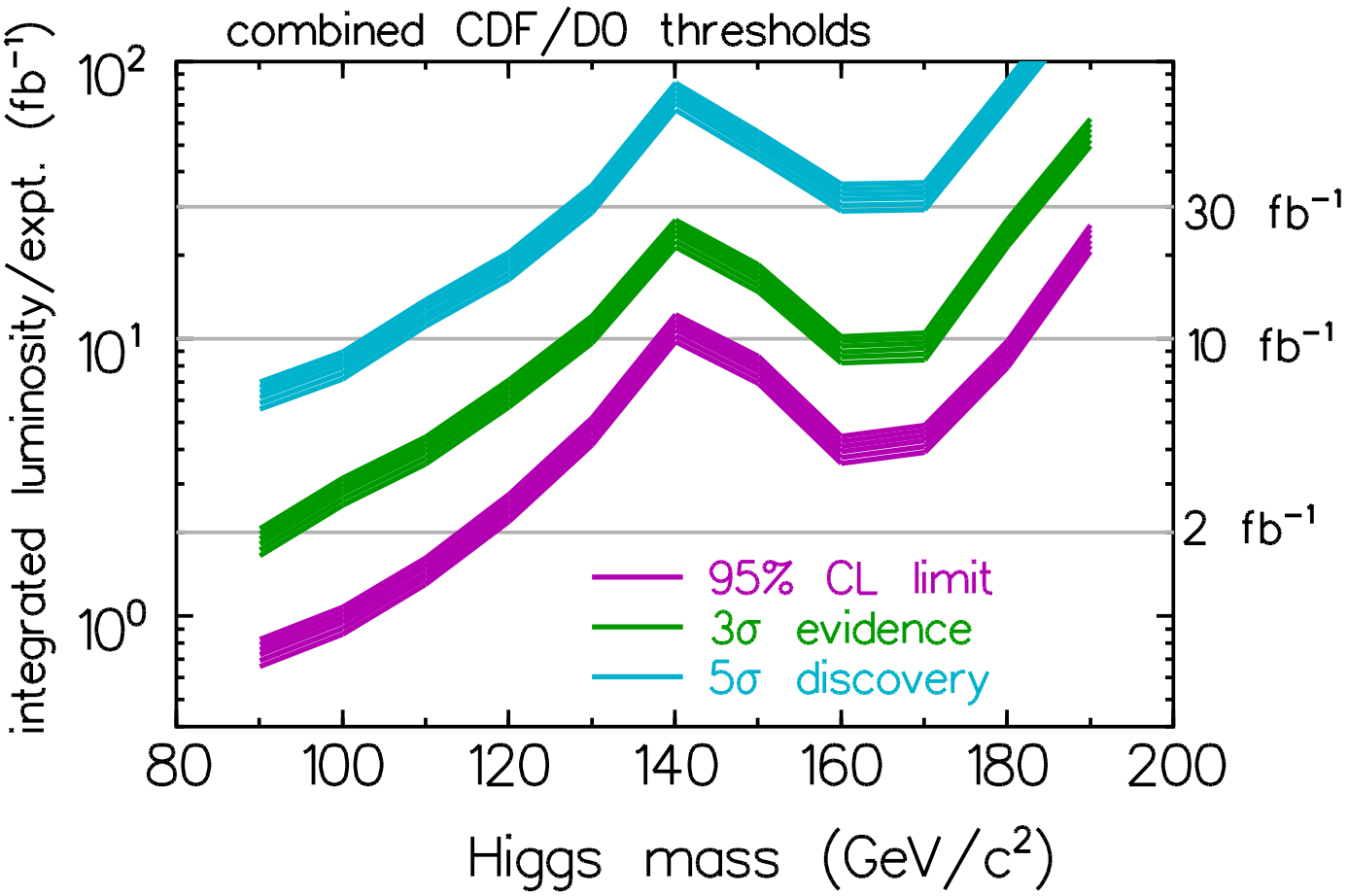
Somewhat sensitive to the Higgs mass thru radiative corrections.



Constraints on the Higgs mass :
CDF Run-II projections.



Run-II SM Higgs Reach

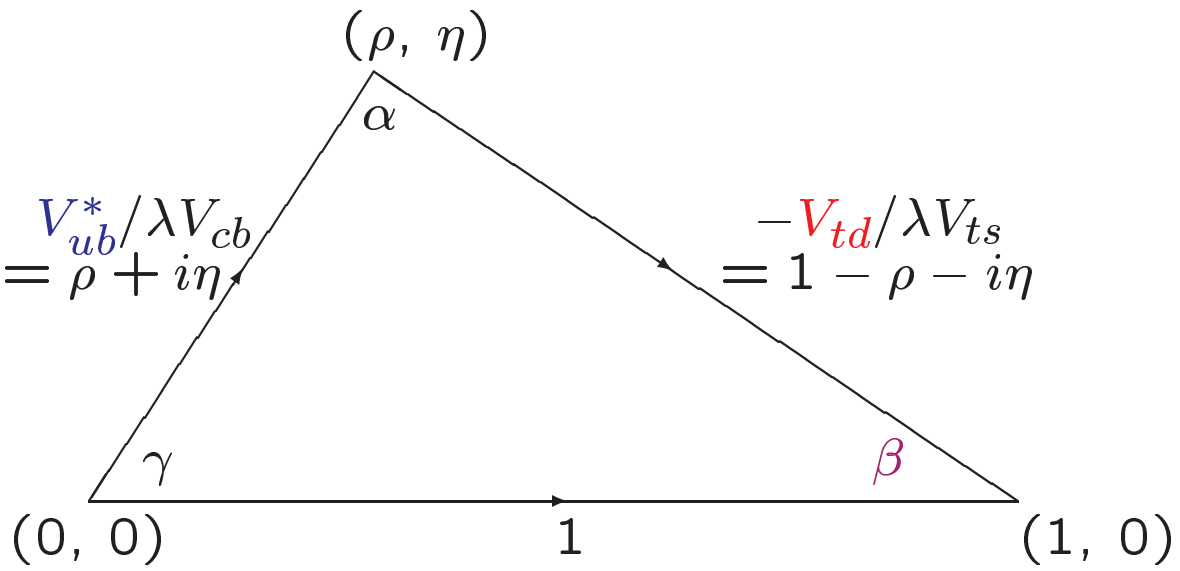


For $m_H < 120$ GeV/c^2 :

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

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:

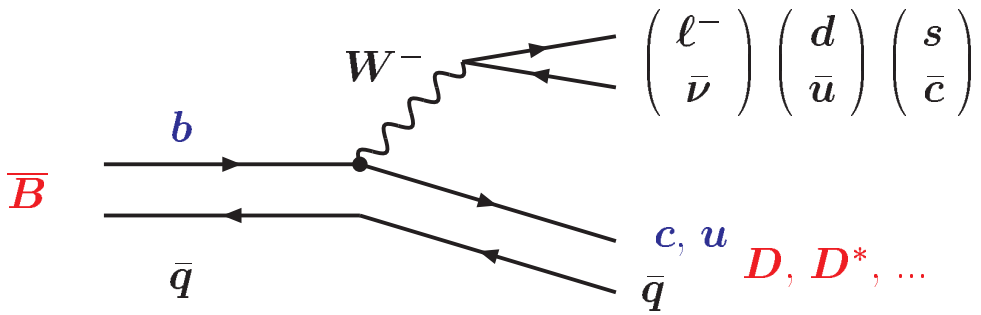
$$\frac{\Delta m_s}{\Delta m_d} = \left|\frac{V_{ts}}{V_{td}}\right|^2 \frac{M_{B_s}}{M_{B_d}} \xi^2 \quad (\xi = 1.17 \pm 0.06, \text{Aoki 1999})$$

- 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.

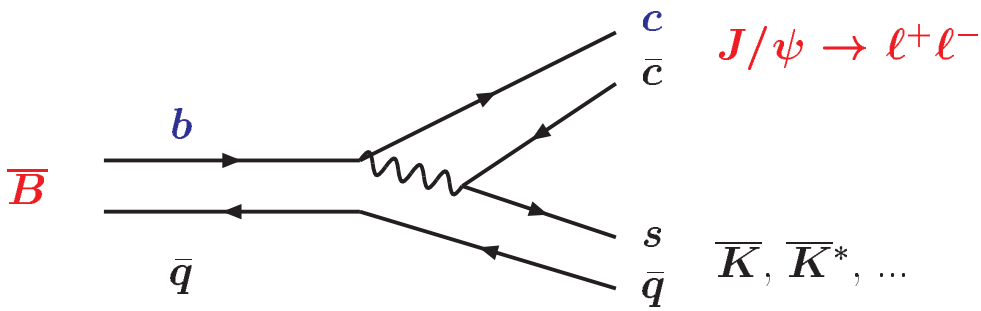
A: use leptons.

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

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

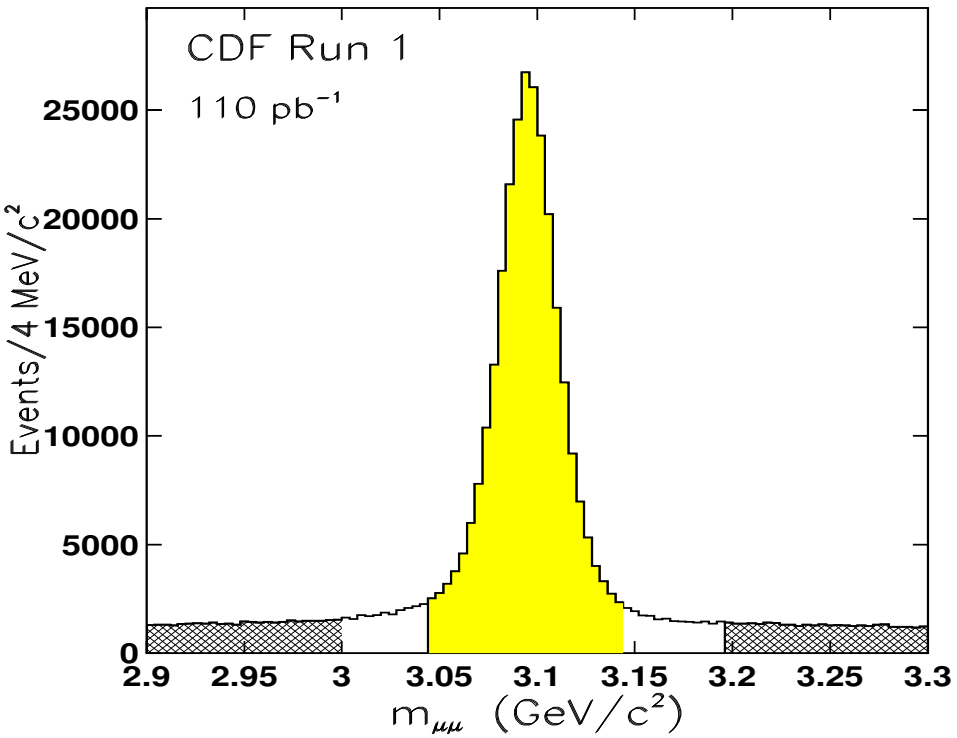
  Main source of single leptons at low p_T (below $W^\pm$ and Z^0).

- 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 $J/\psi \to \ell^+ \ell^-$.

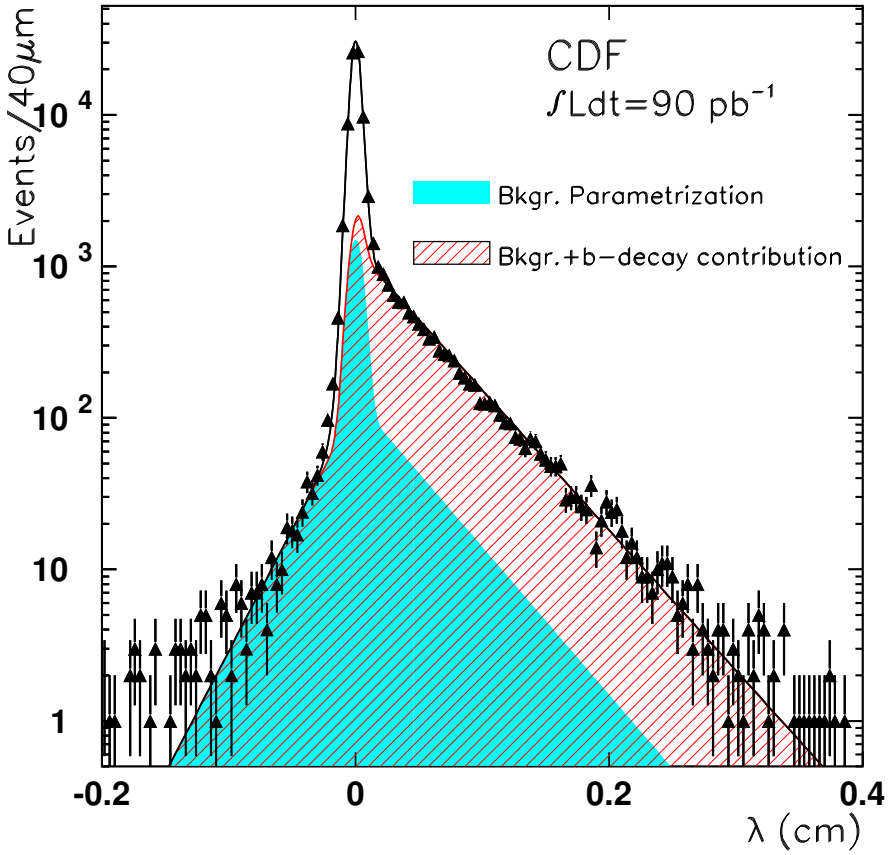


$$\mathcal{B}(\overline{B} \to J/\psi\, X) \simeq 1\%, \;\; \mathcal{B}(J/\psi \to \ell^+\ell^-) = 7\%.$$

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

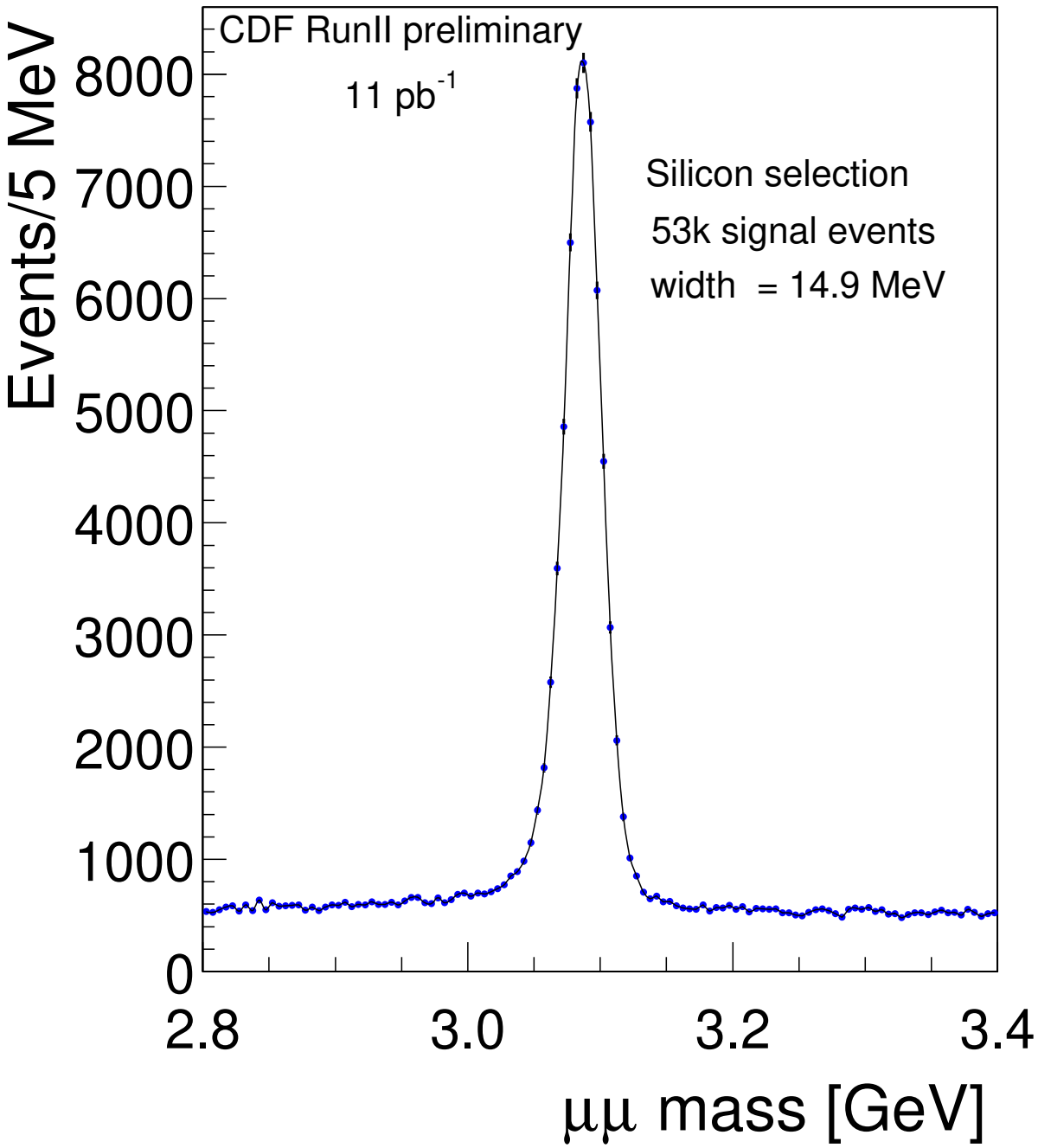


Decay length distribution



$\sim$ 20% of J/ψ's from B decays.

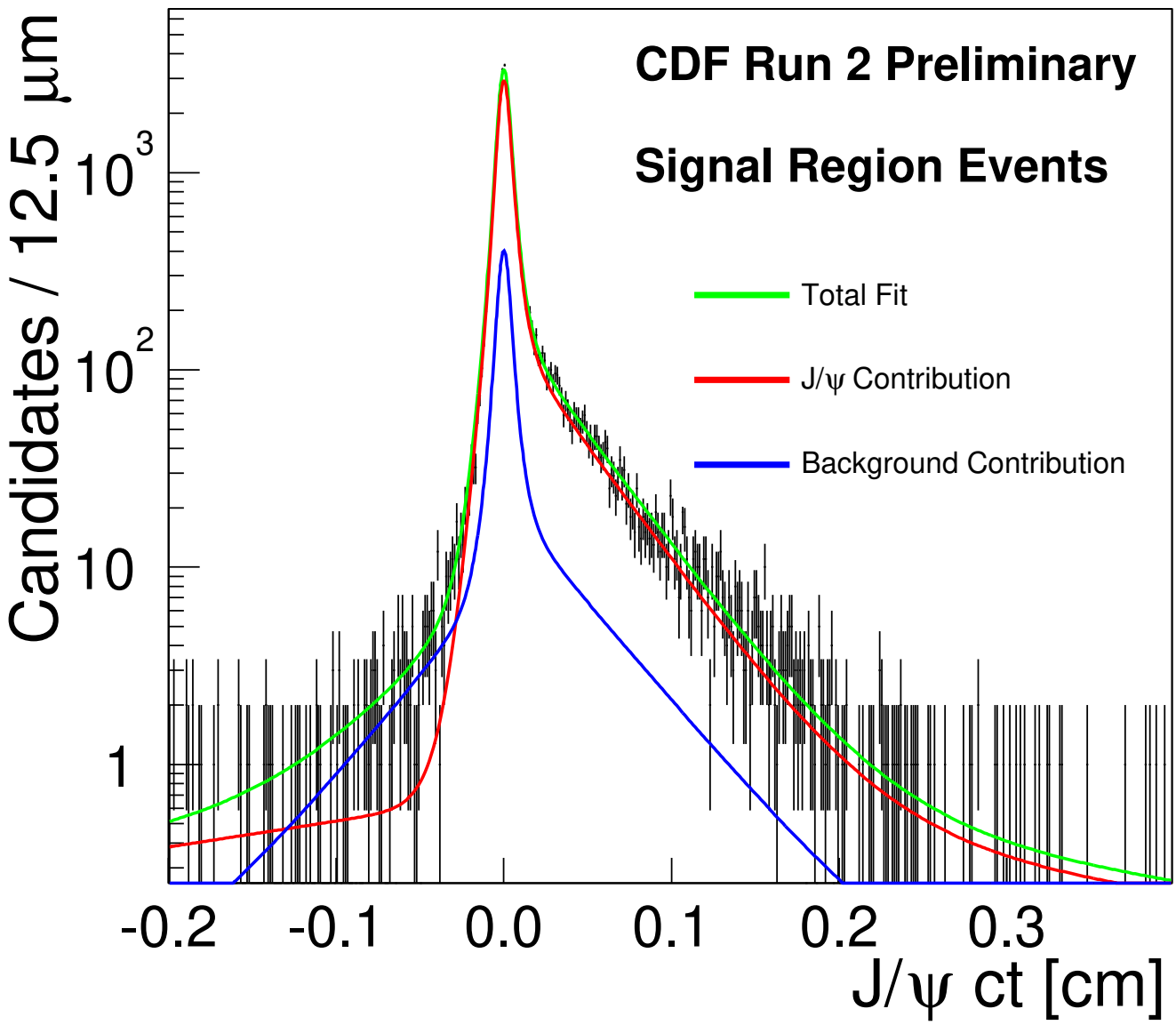
Run-II Dimuon Data



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

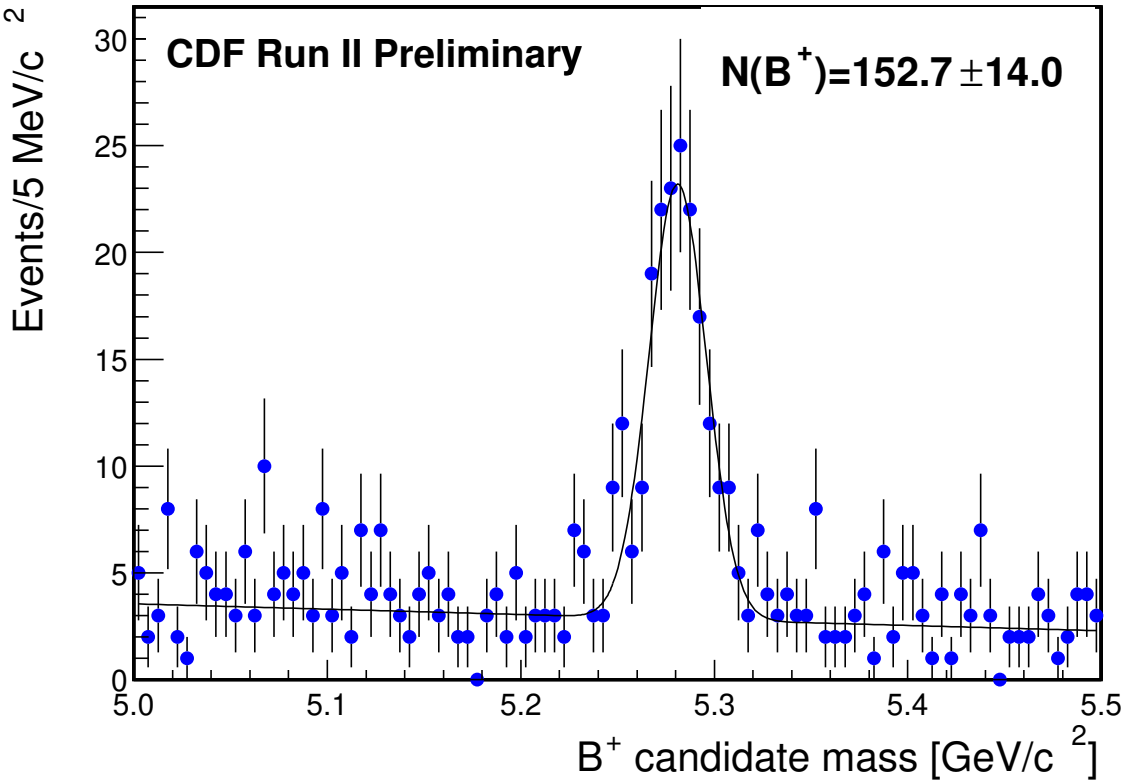
Yield $\sim 2 \times$ Run-I.

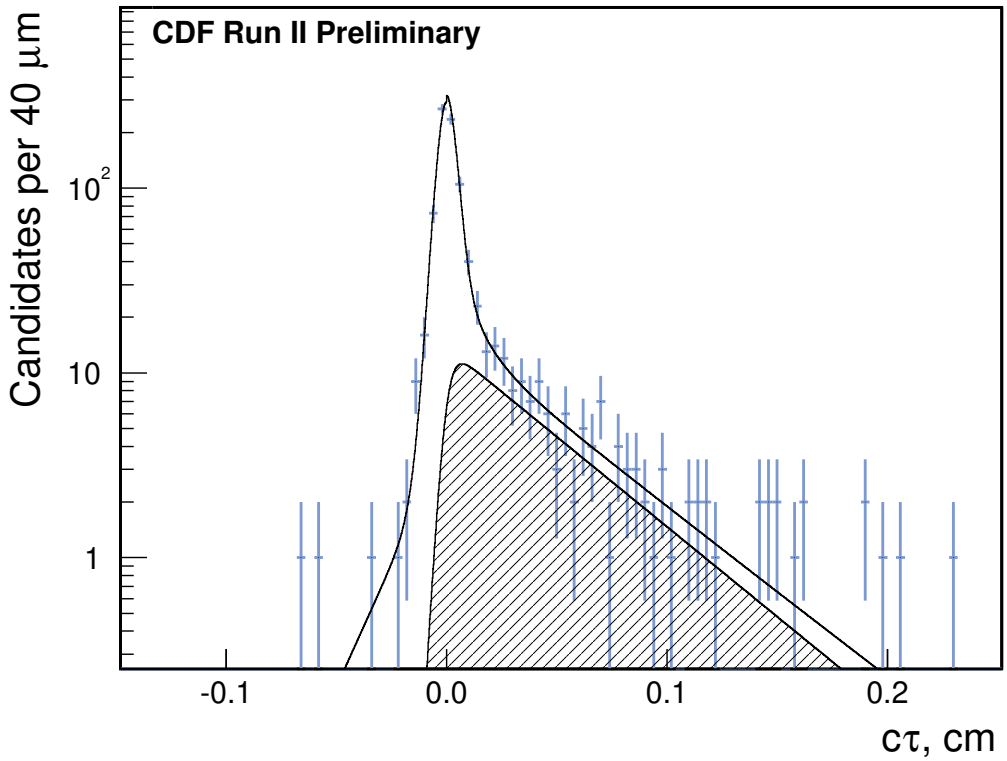
Inclusive J/ψ Lifetime



$\Rightarrow c\tau(B) = 458 \pm 10 \pm 11\ \mu\text{m}.$

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

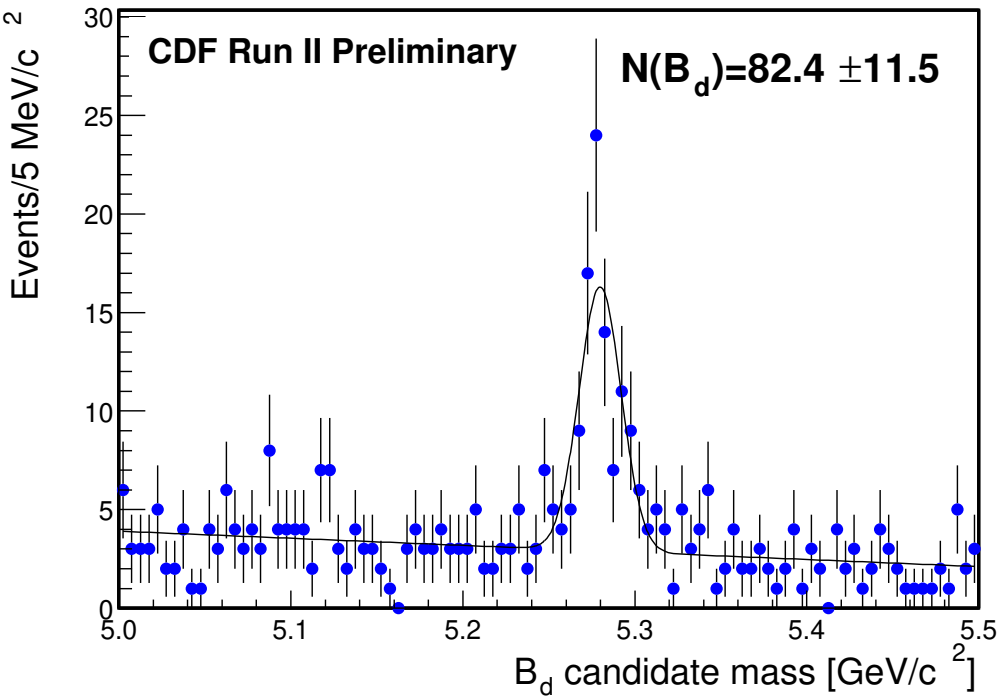




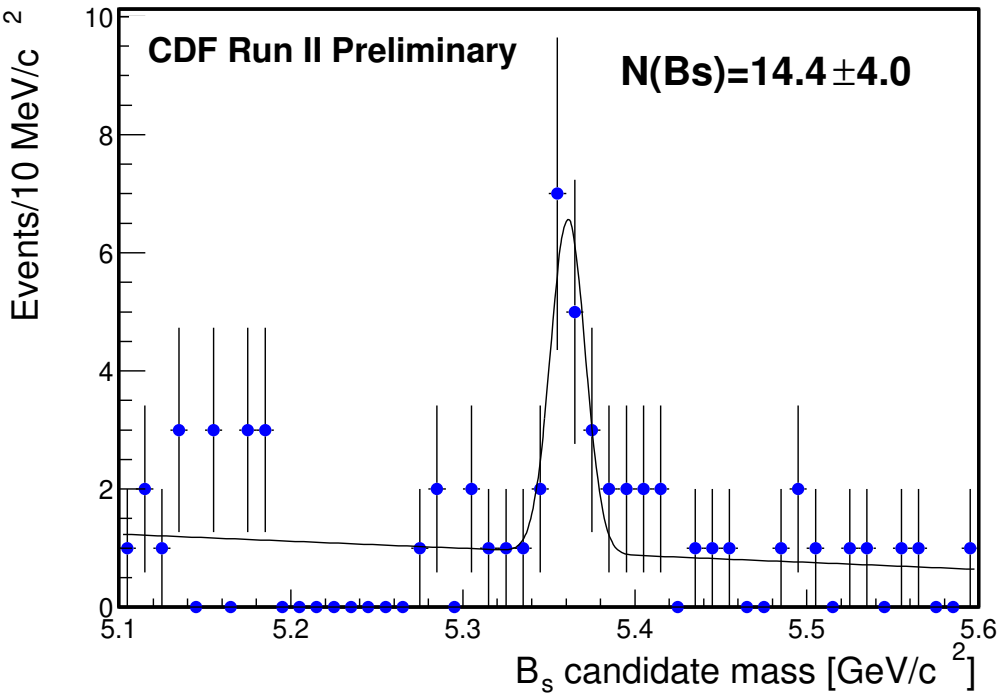
$\Rightarrow c\tau(B^+) = 446 \pm 43 \pm 13\ \mu\text{m}.$

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

$B^0 \to J/\psi\, K^{*0}$

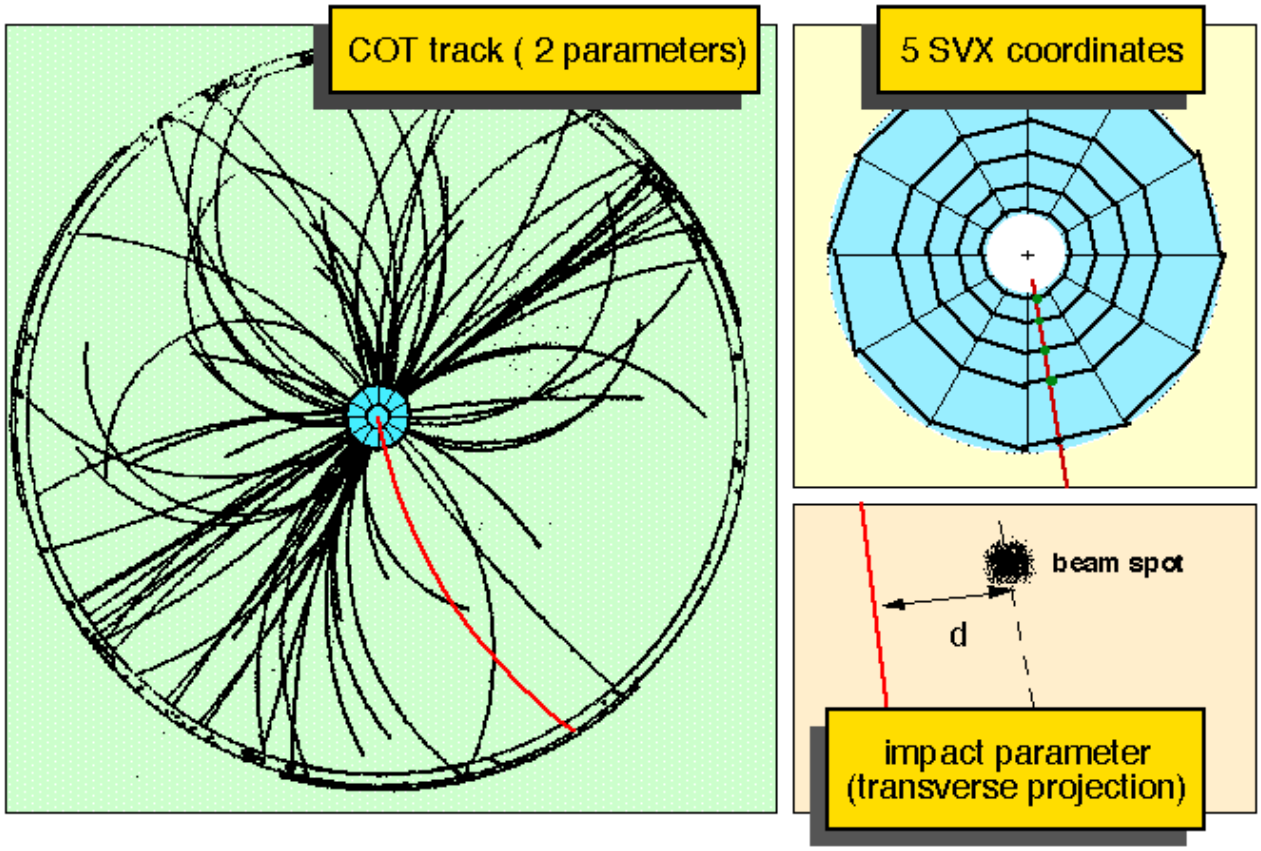


$B_s^0 \to J/\psi\, \phi$



Run-II Silicon Vertex Trigger : SVT

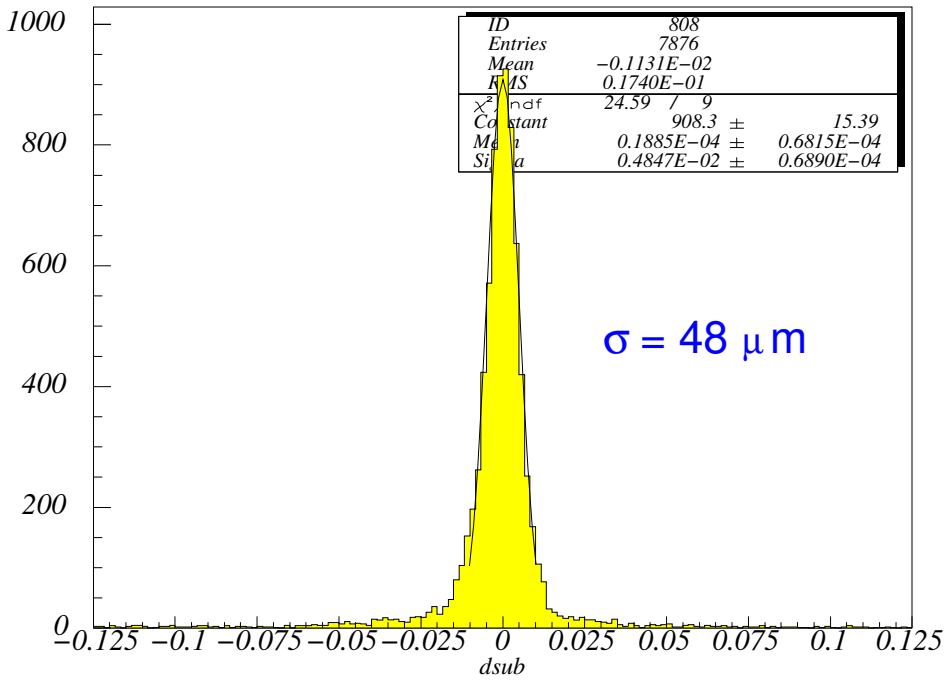
Use silicon information at 2nd level of trigger.



- 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).

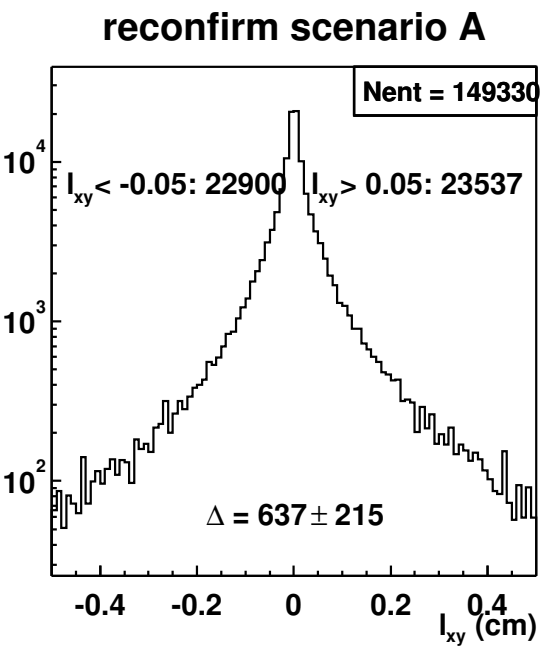
Resolution $\sigma_d \sim 50$ μm for $p_T > 2$ GeV/c.

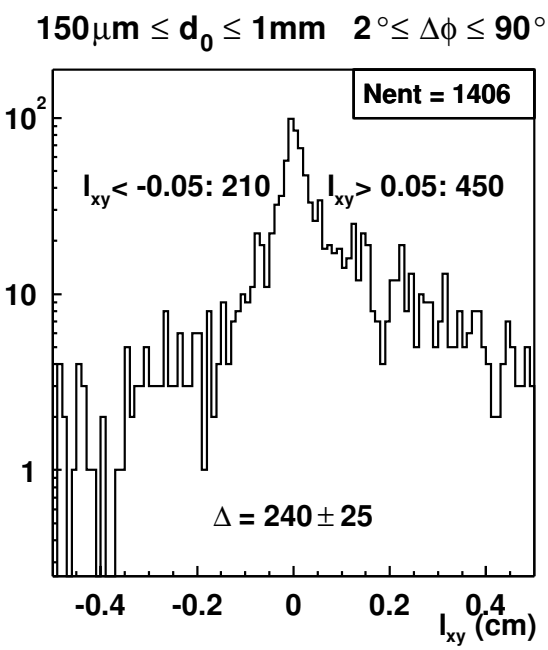
SVT Performance



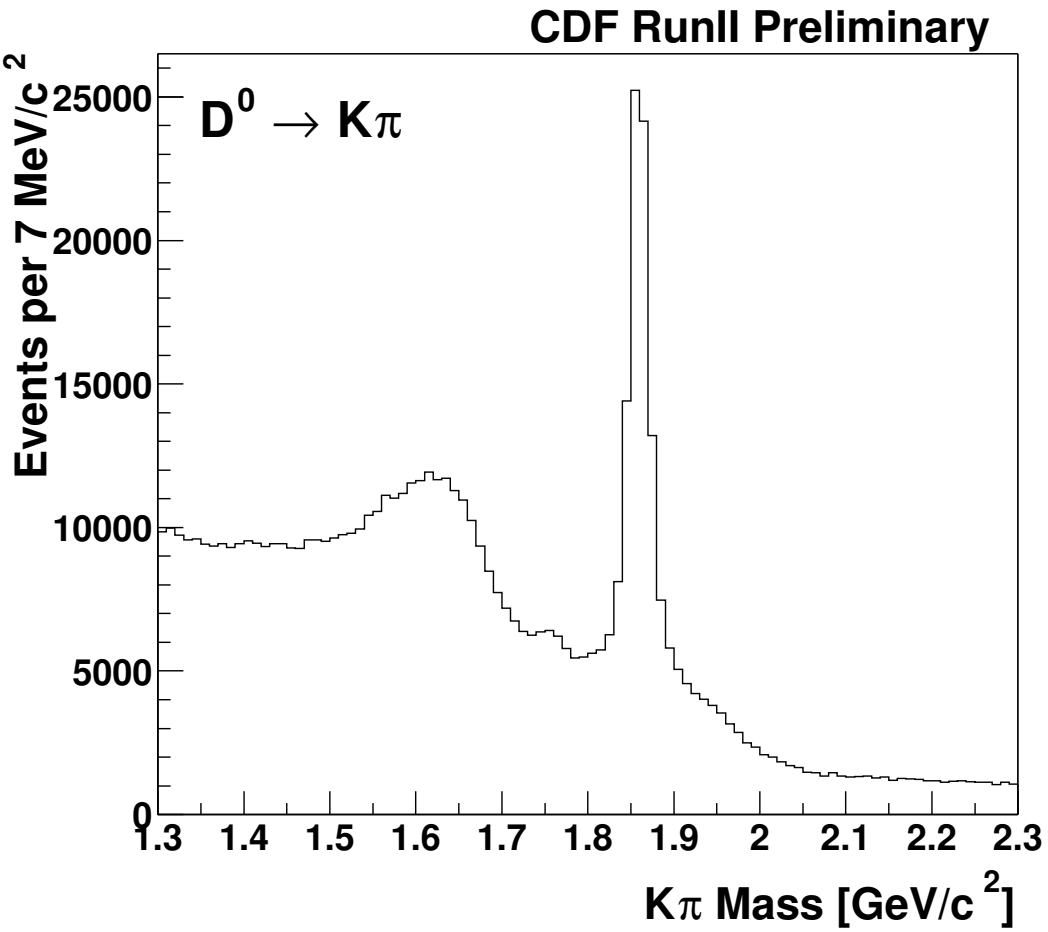
Trigger on tracks ($p_T > 2$ GeV/c) with
100 μm $< |d| <$ 1000 μm.

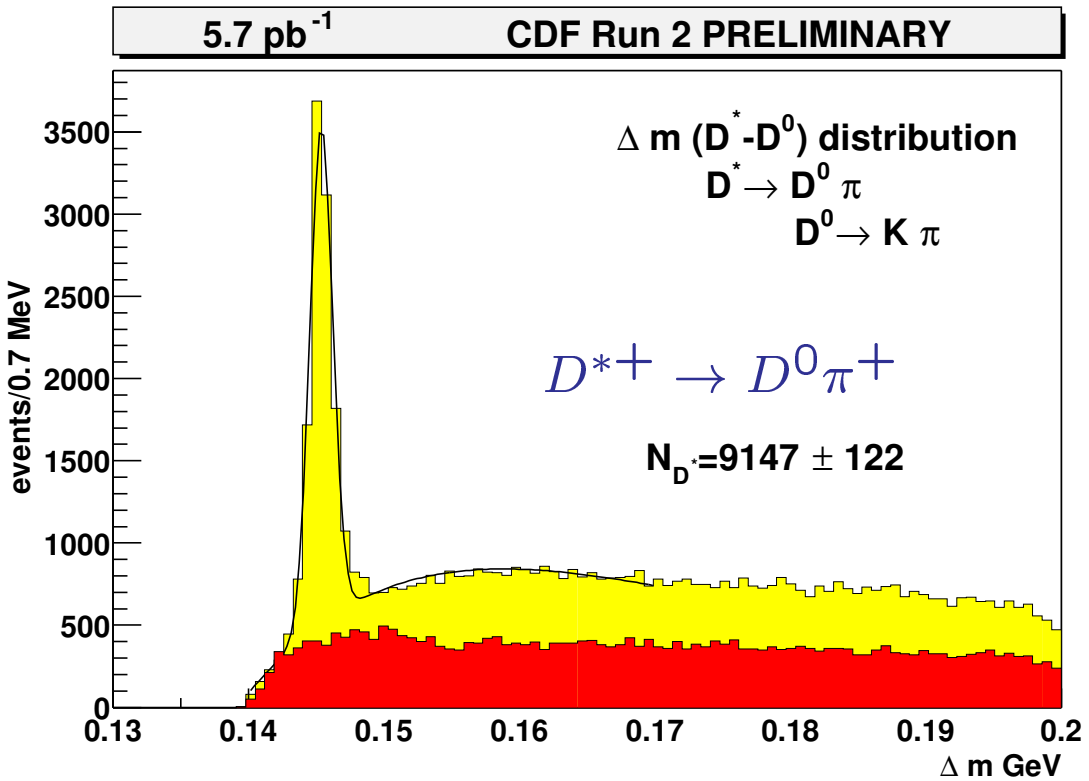
Calculate decay length L_{xy}, require $L_{xy} > 500$ μm.



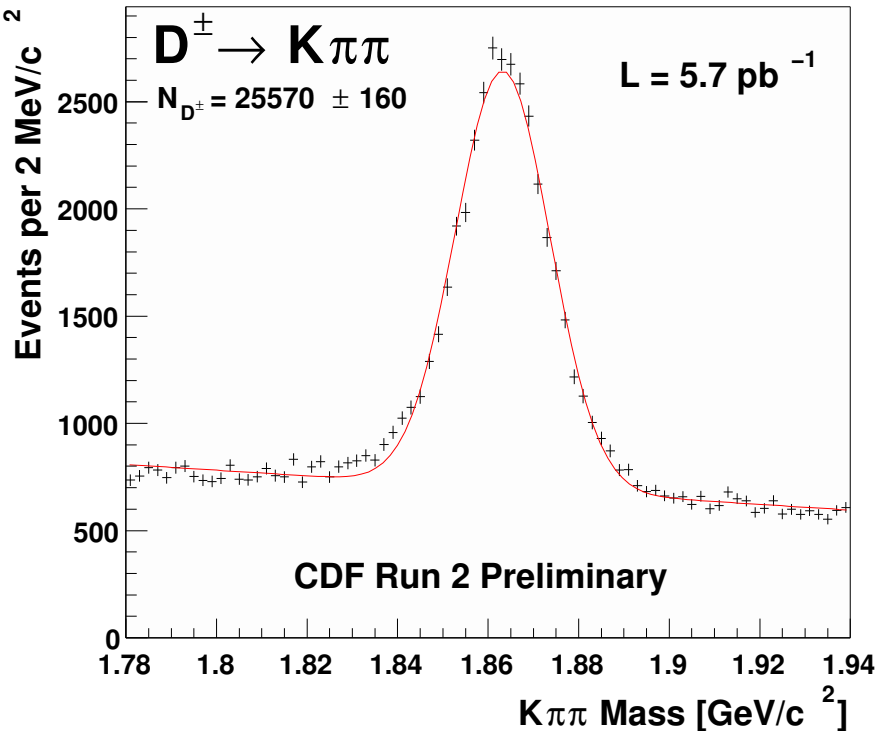


Run-II $D^0 \to K^-\pi^+$ from SVT trigger

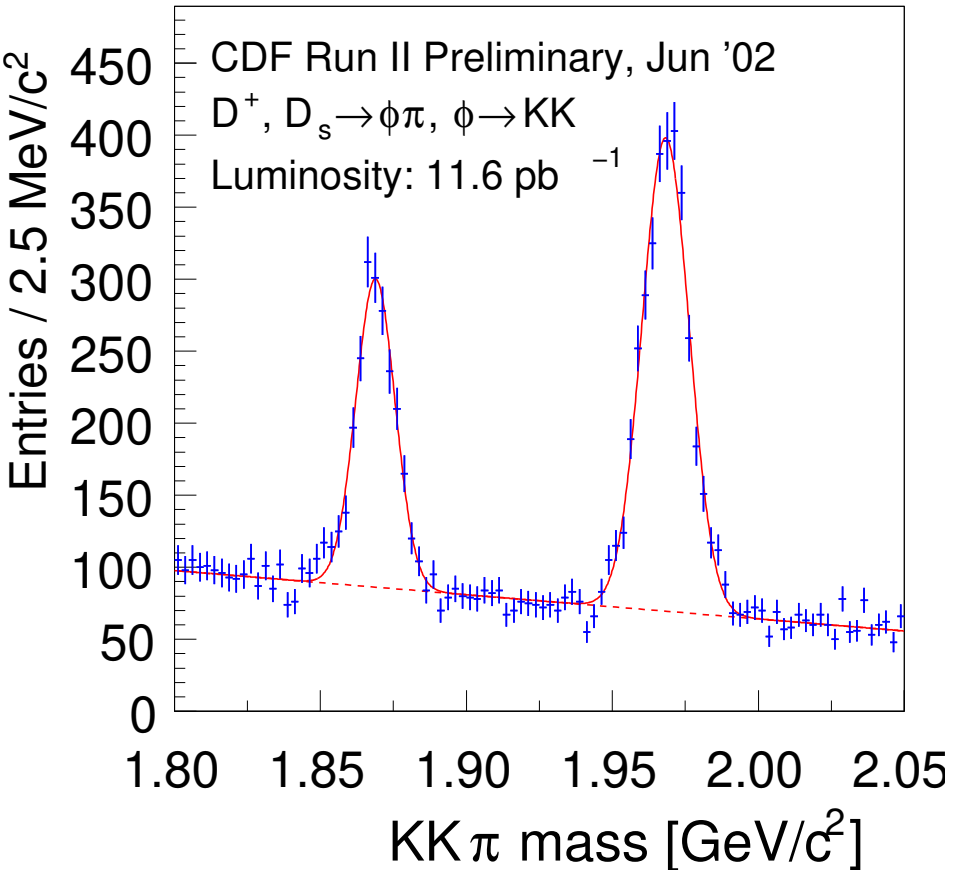




More charm : $D^+ \to K^-\pi^+\pi^+$

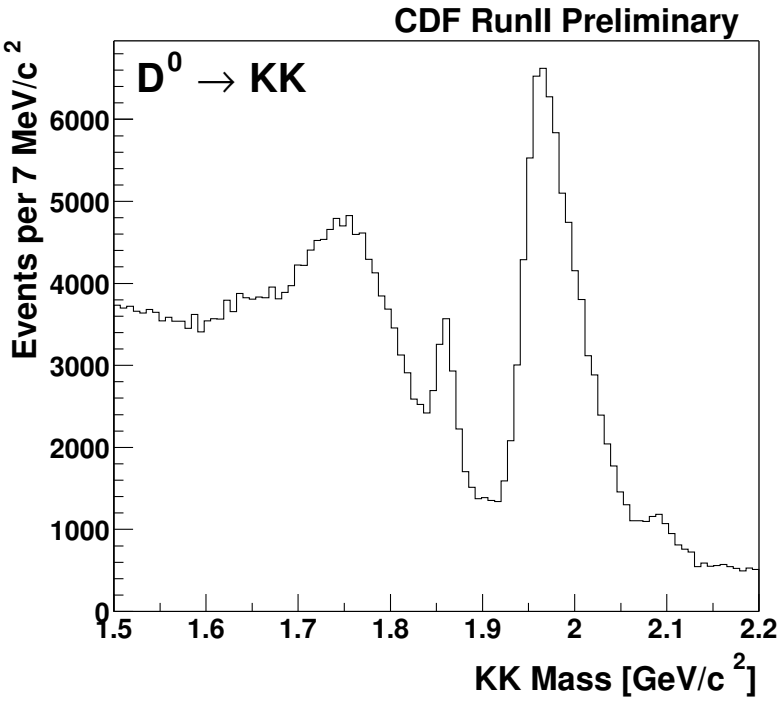


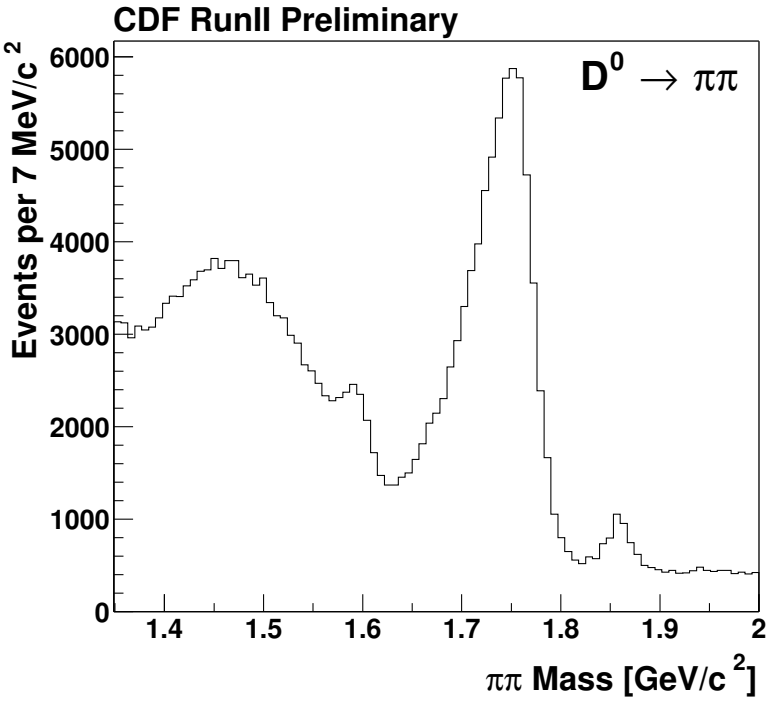
$D^+,\ D_s^+ \to \phi\pi^+,\ \phi \to K^+K^-$



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

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

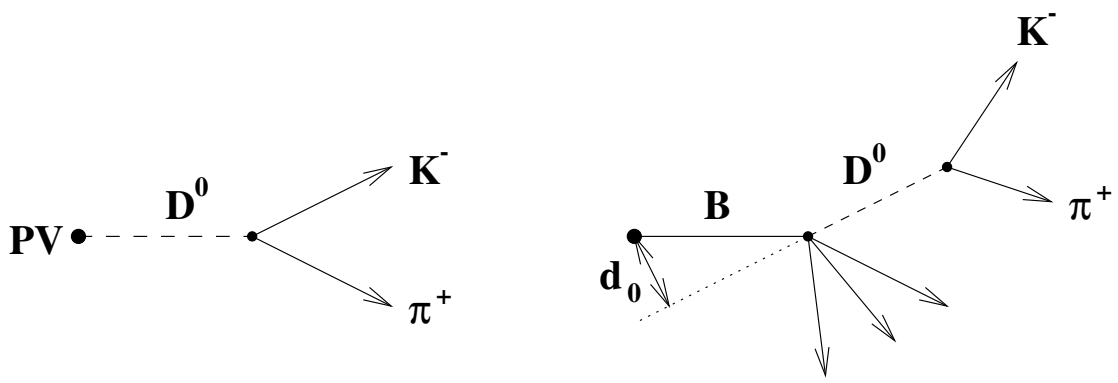
Sources of D mesons :

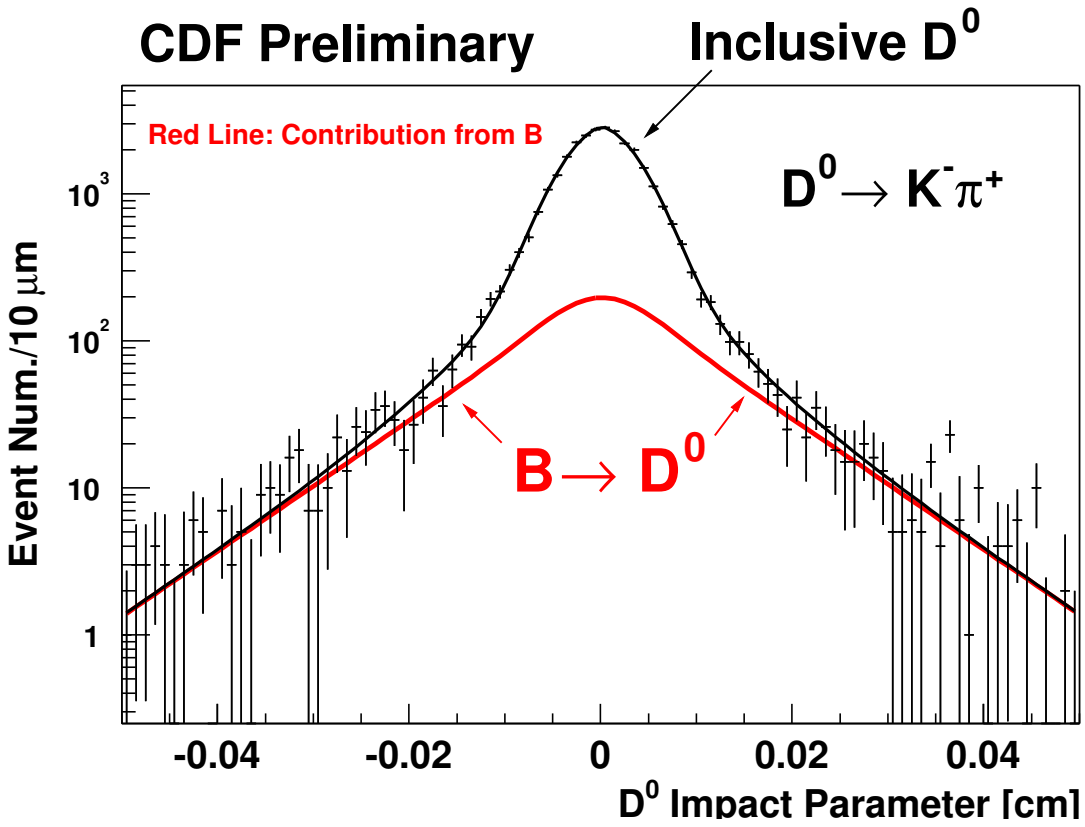
$\bar{p}p \to c \to D$ (Direct) vs.

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

Examine impact parameter wrt primary vertex :

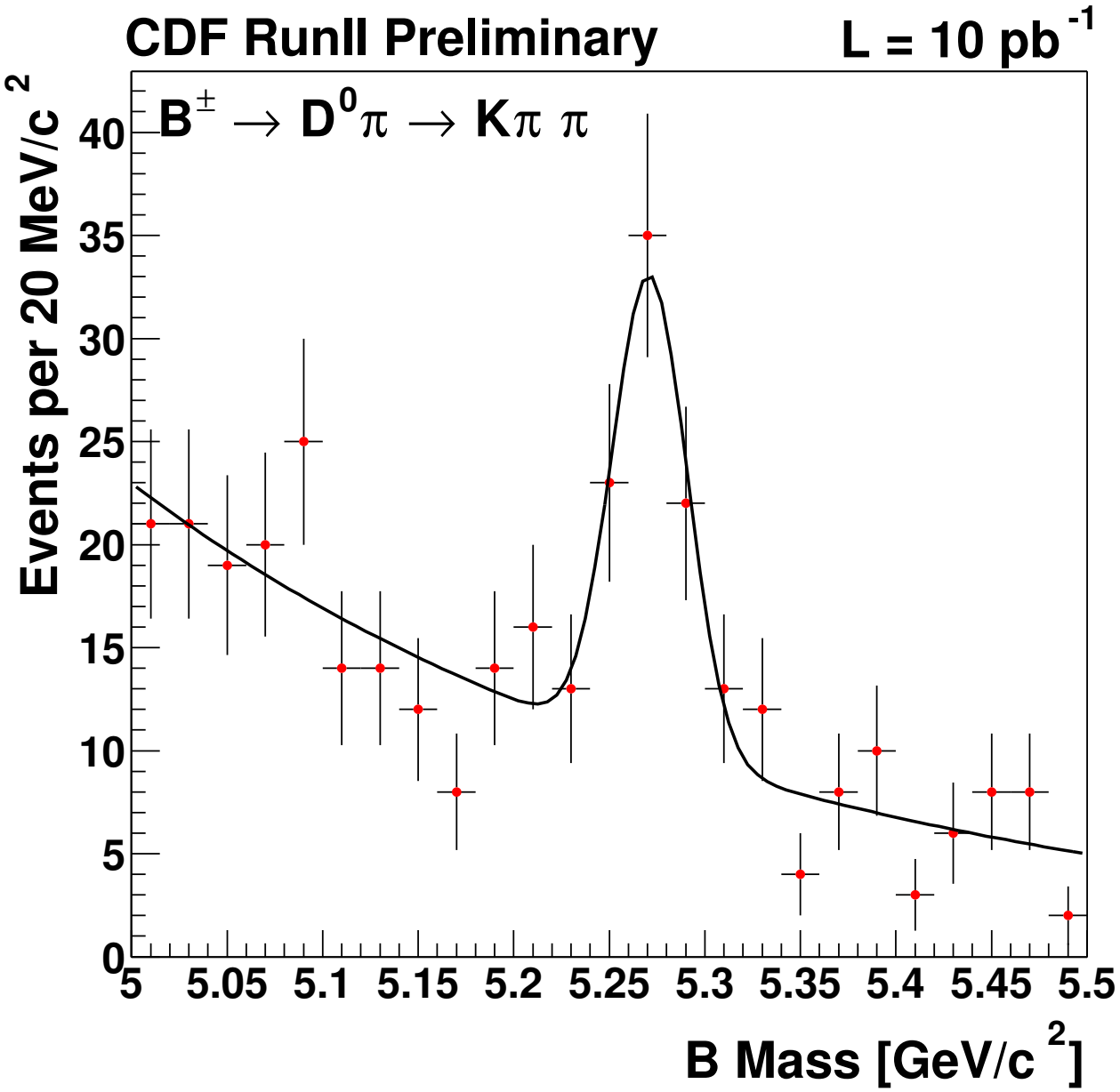
Direct Production	**Secondary Production**
D points back to PV	**D has finite impact parameter**





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

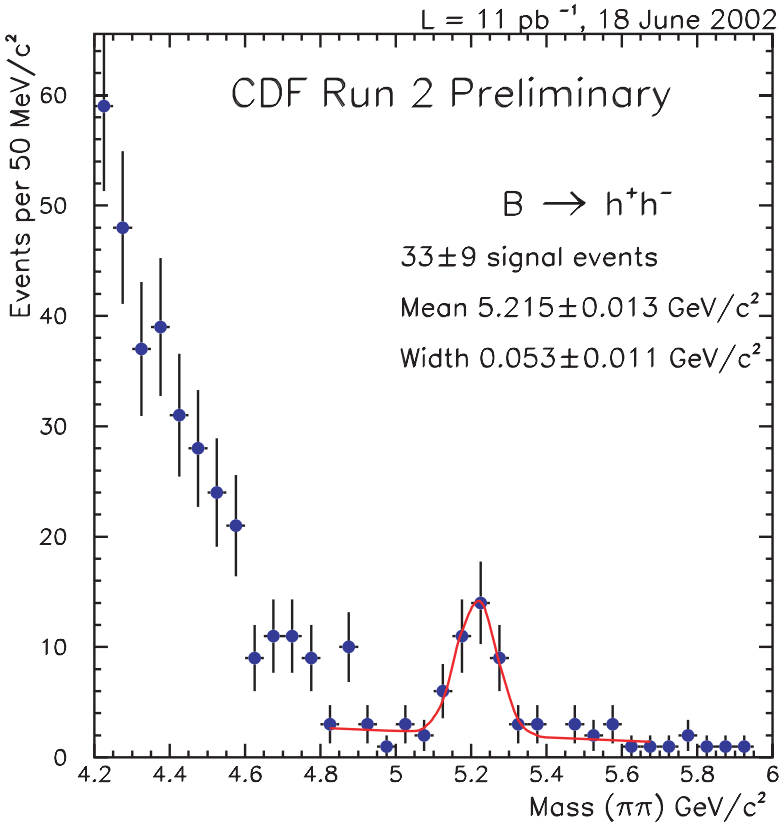
What we wanted : $\bar{B} \to D\,(n\pi)$



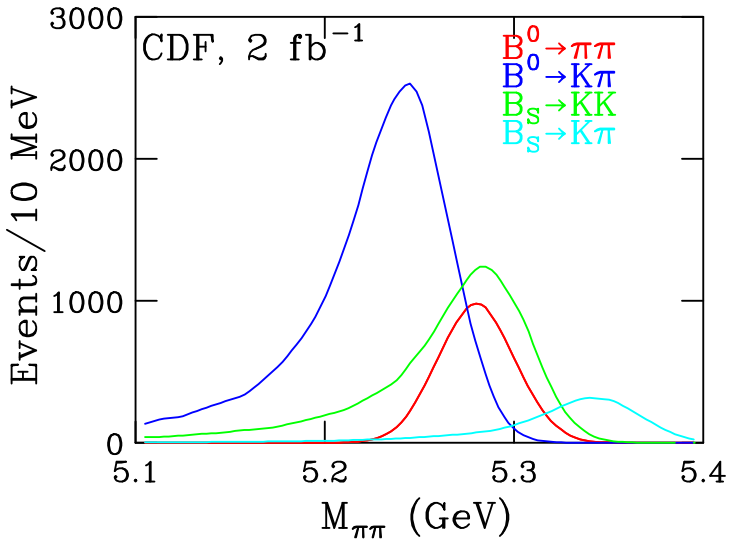
Next step : $\bar{B}_s^0 \to D_s^+ \pi^-$ for Δm_s.

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

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



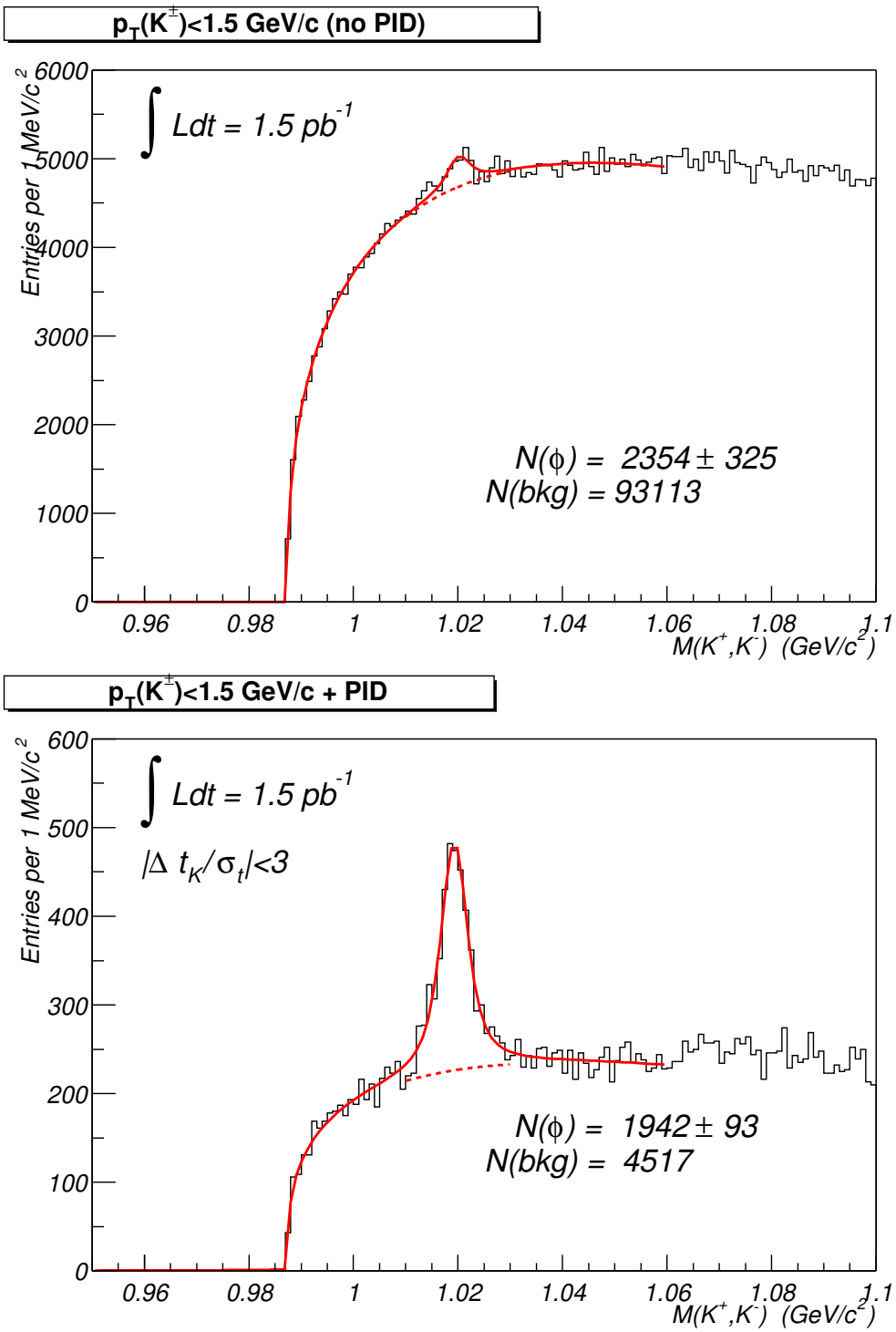
Peak : mixture of $B^0 \to \pi^+\pi^-$, $K^+\pi^-$ and $B_s^0 \to K^+K^-$, $K^-\pi^+$.



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).

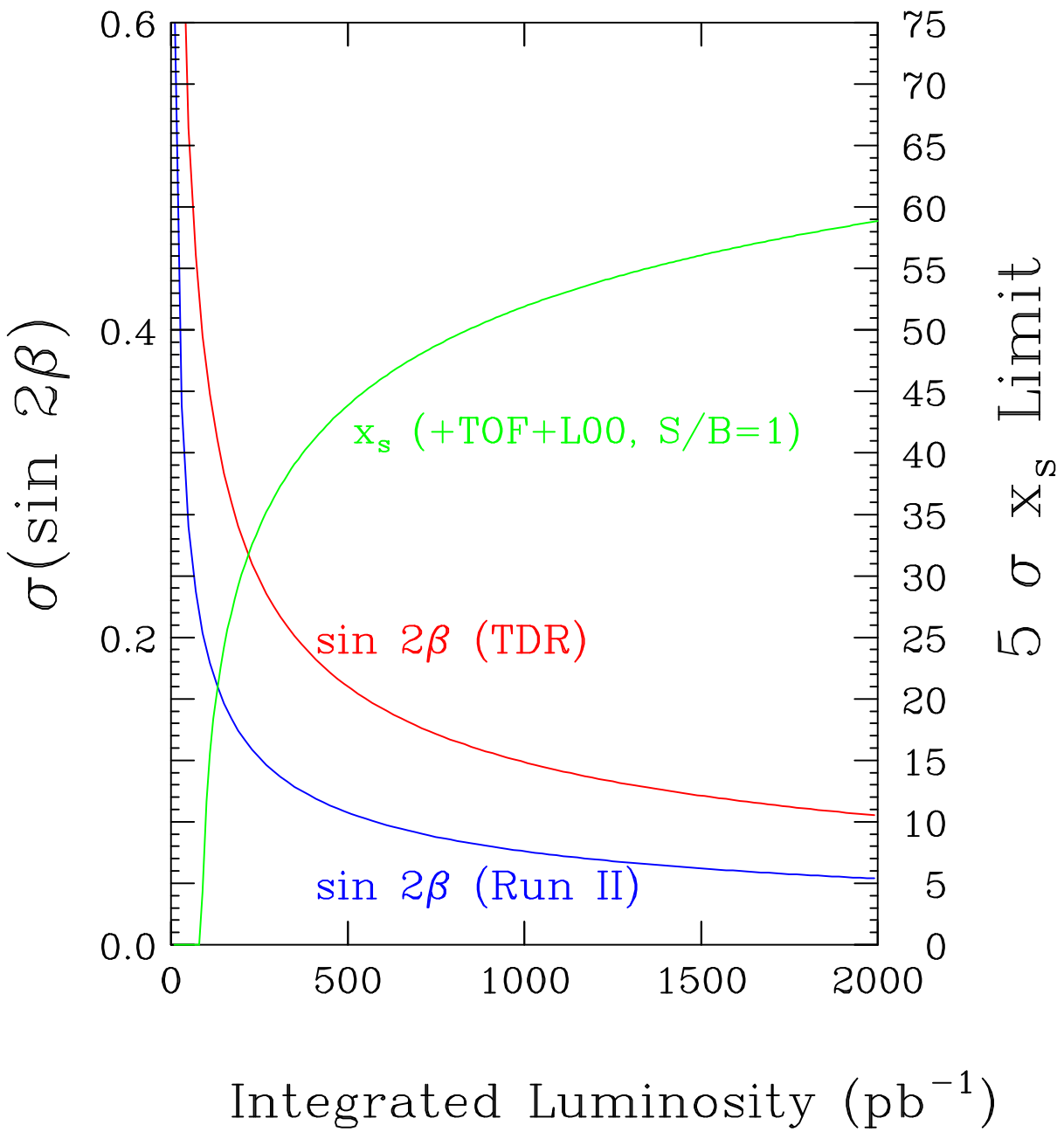
Toward B Flavor Tagging : TOF

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



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

CDF Run-II Projections



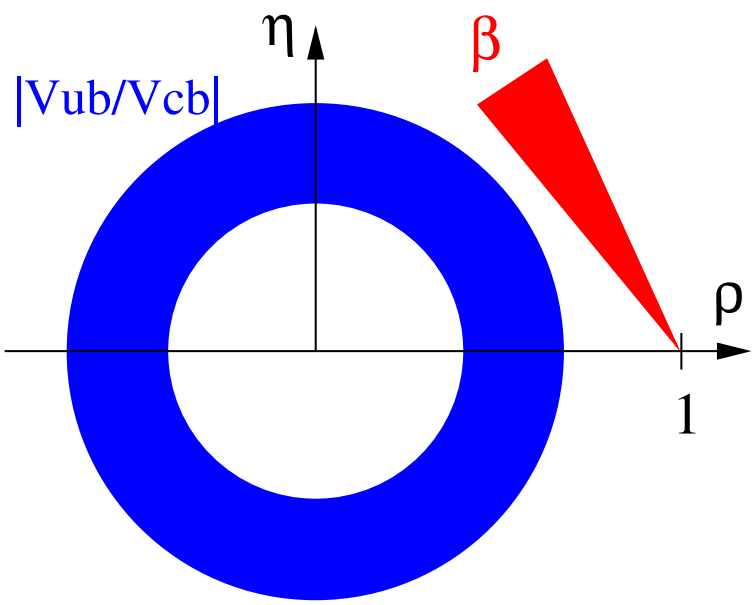
Left axis: $\sin 2\beta$ precision.

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

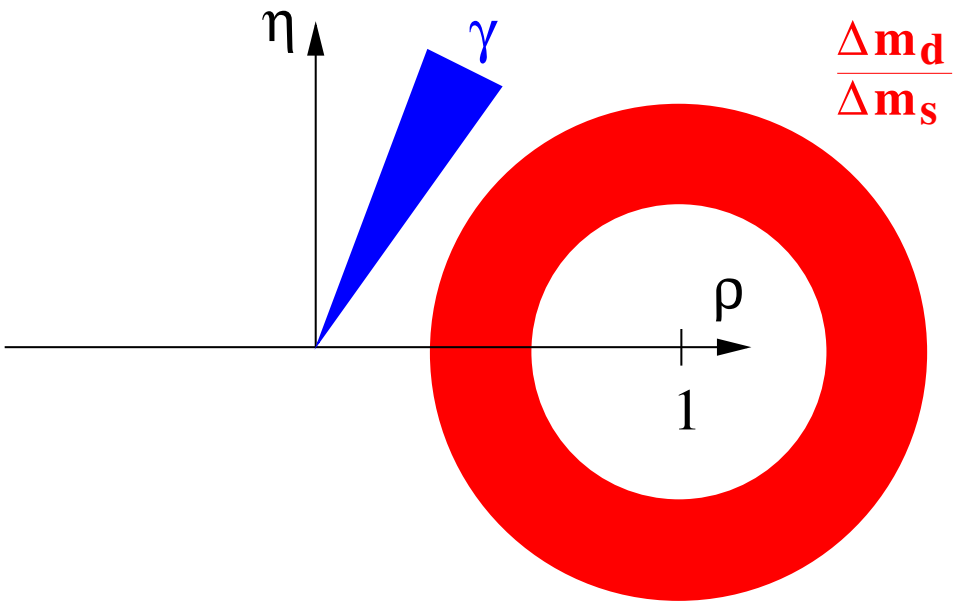
Maybe optimistic here, but ...

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

CDF *has* been running.

Maybe not as fast as we wanted to be. But...

- CDF-II detector is working very well.
  We are ready to accumulate statistics.
- 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.

Not all results covered in this talk.
See R. Tanaka's presentation later this afternoon.