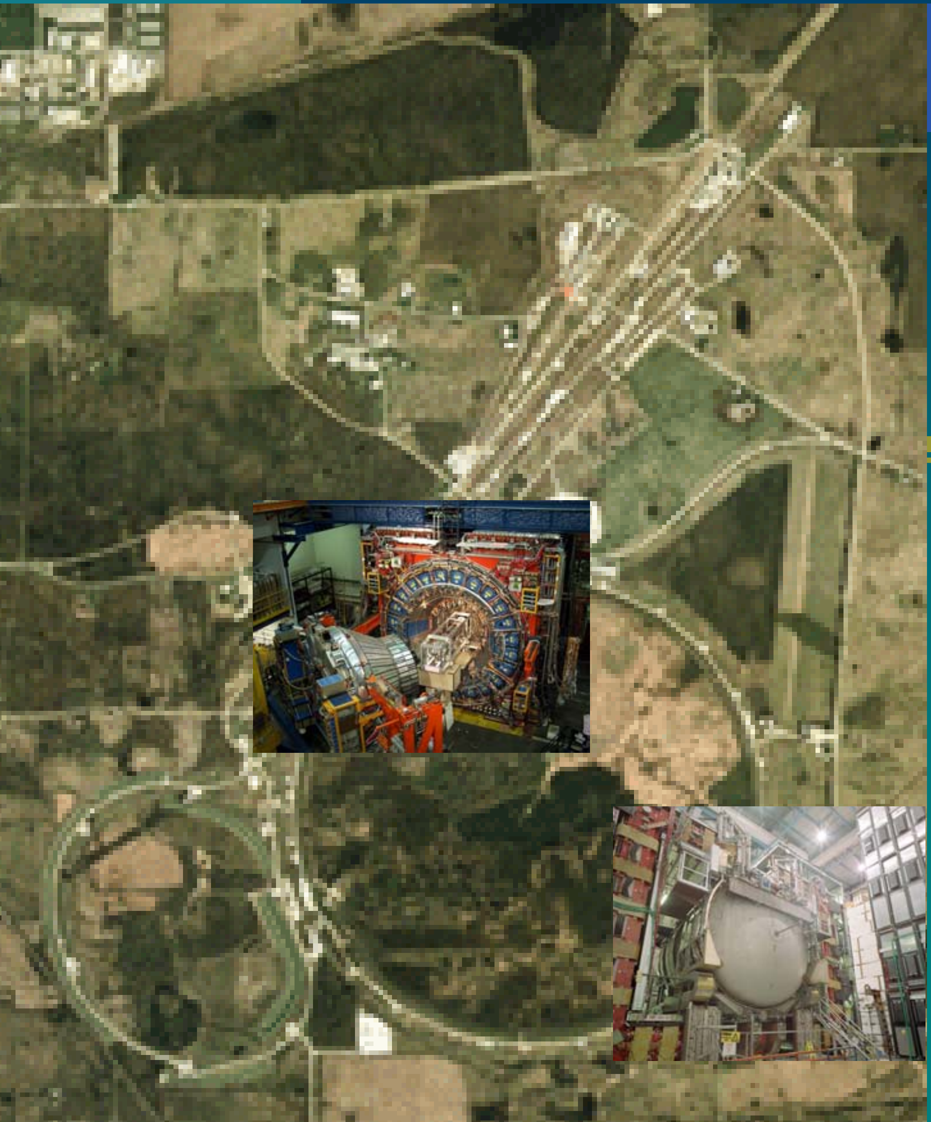
Charm physics at the Tevatron Run II



Mario Campanelli

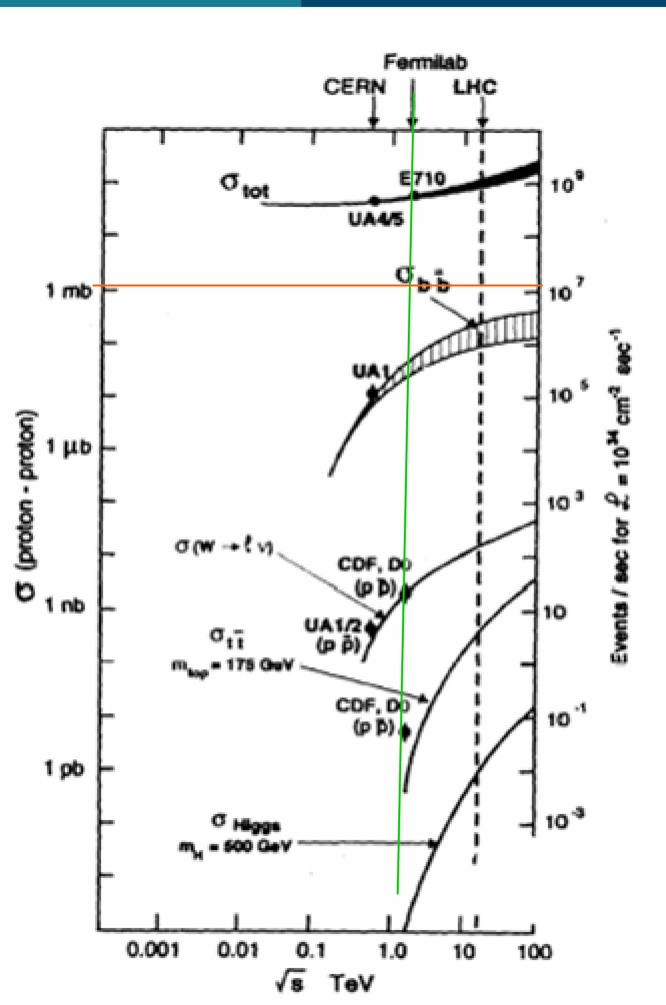
DPNC Université de Genève

Introduction: why?

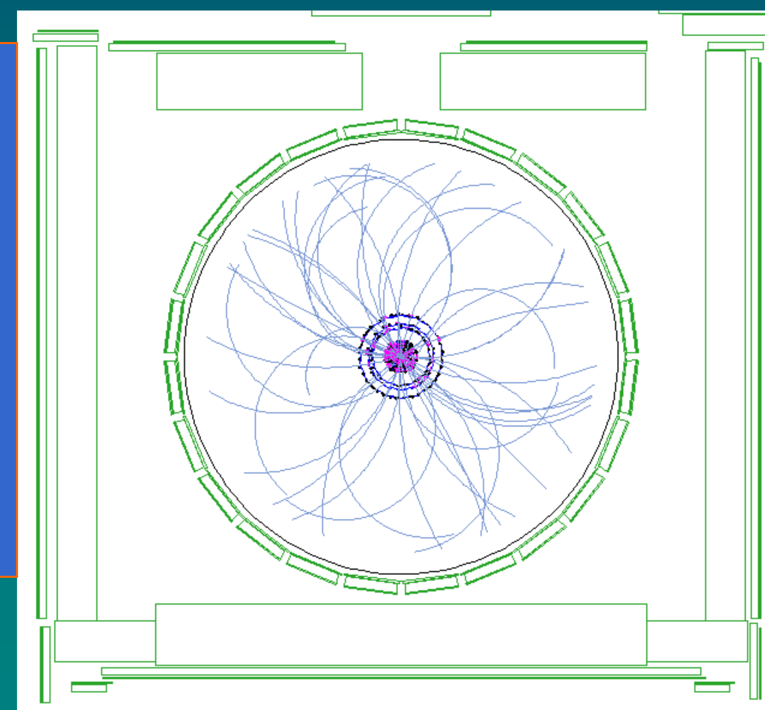
- CDF and D0 are known in the physics community for having discovered the top quark, and running at the world's largest energy accelerator
- Does it make sense to study low-energy events, a field dominated by dedicated experiments (b factories, FOCUS, CLEO III)?

Introduction: why c physics at Tevatron

- Extremely high cross section
- $\sigma(bb)$: TeV $\approx 50\ \mu b$, cc $\times 10$
- $\Upsilon(4S) \approx 1$ nb, Z0 ≈ 7 nb
- Relatively “clean” events



But:
- •Luminosity 1000x less than b-factories
- •Non optimal calorimetry-PID
- •Large combinatorics

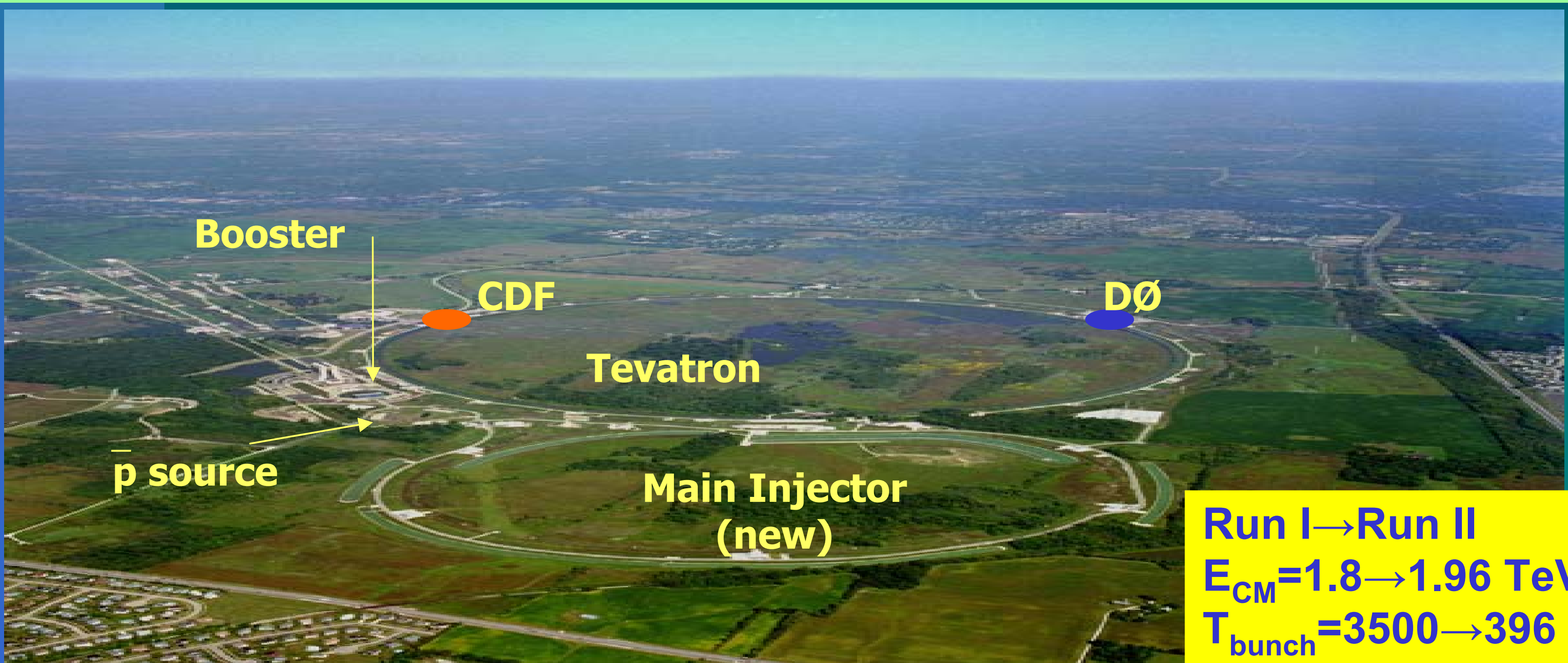


Outline

- The accelerator
- CDF II
- Triggering on charm
- Basic properties
- Spectroscopy
- New physics

The accelerator

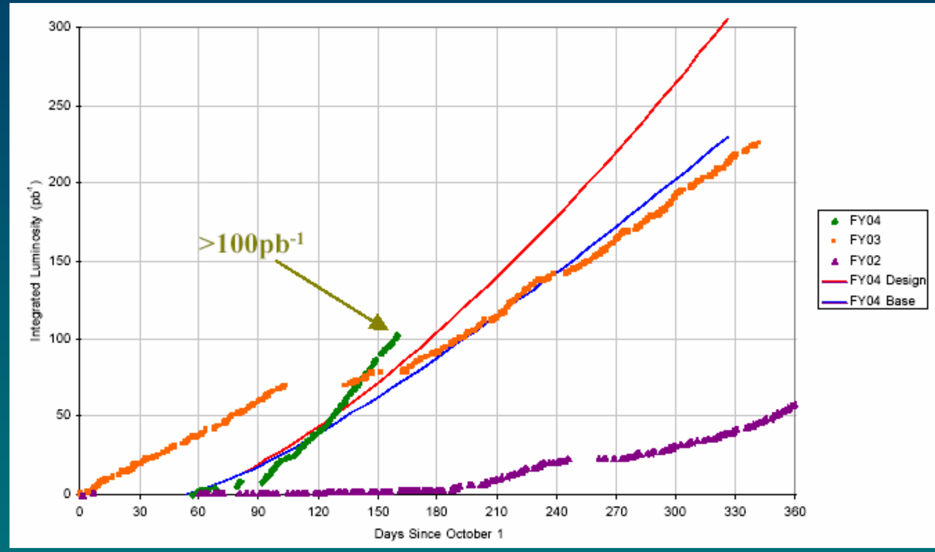
- The Tevatron is the largest-energy accelerator ever built.
- It serves two collider experiments (CDF and D0), plus several fixed targets (KTeV, NuTeV, DoNuT etc.)
- From 2001 it started phase 2 to increase collider luminosity

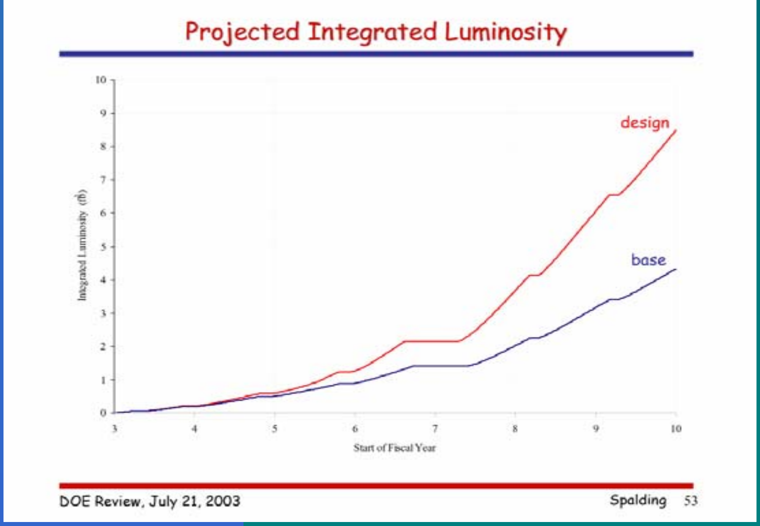


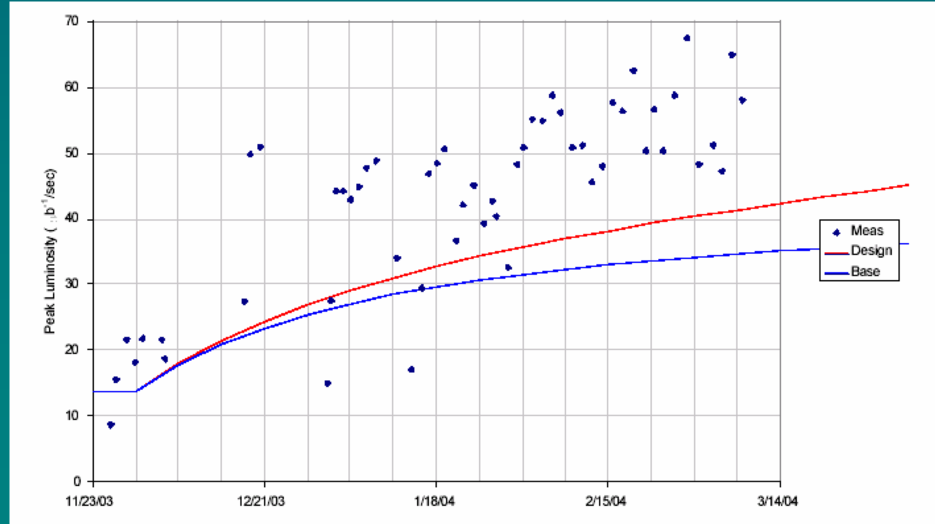
Run I→Run II
E_{CM}=1.8→1.96 TeV
T_{bunch}=3500→396 ns

The progress of Tevatron luminosity

- First Tevatron goals (2×10^{32}, for an integrated luminosity of 2 fb^{-1} over a 2-3 year period and 15 fb^{-1} before LHC) had to be revised. Now the accelerator is much better understood, performances exceed (revised) expectations, keeps improving

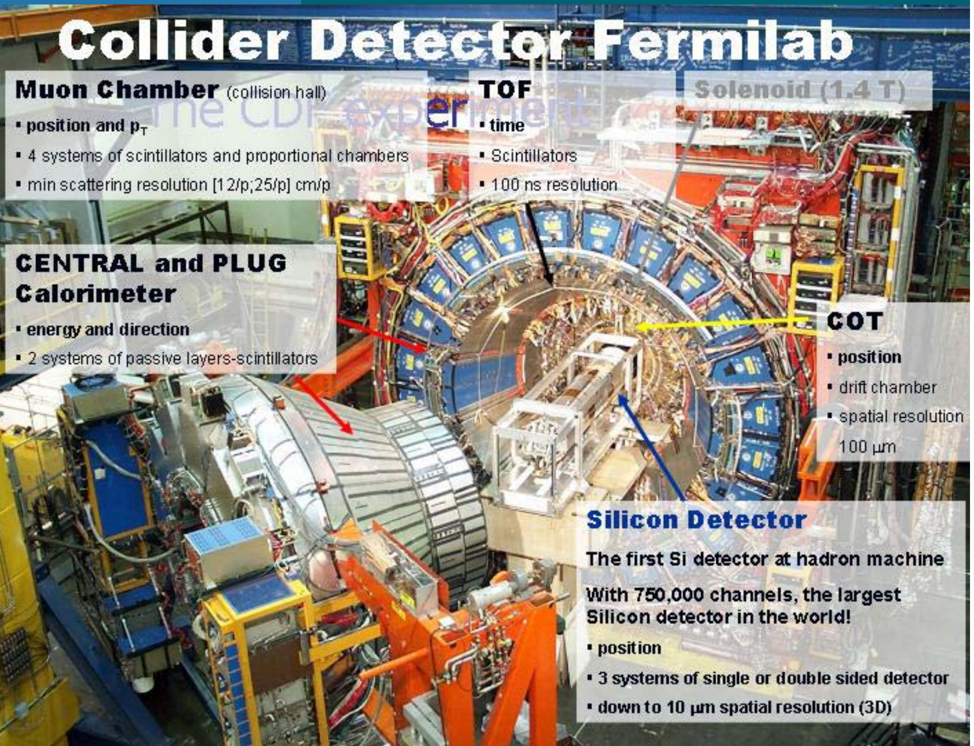


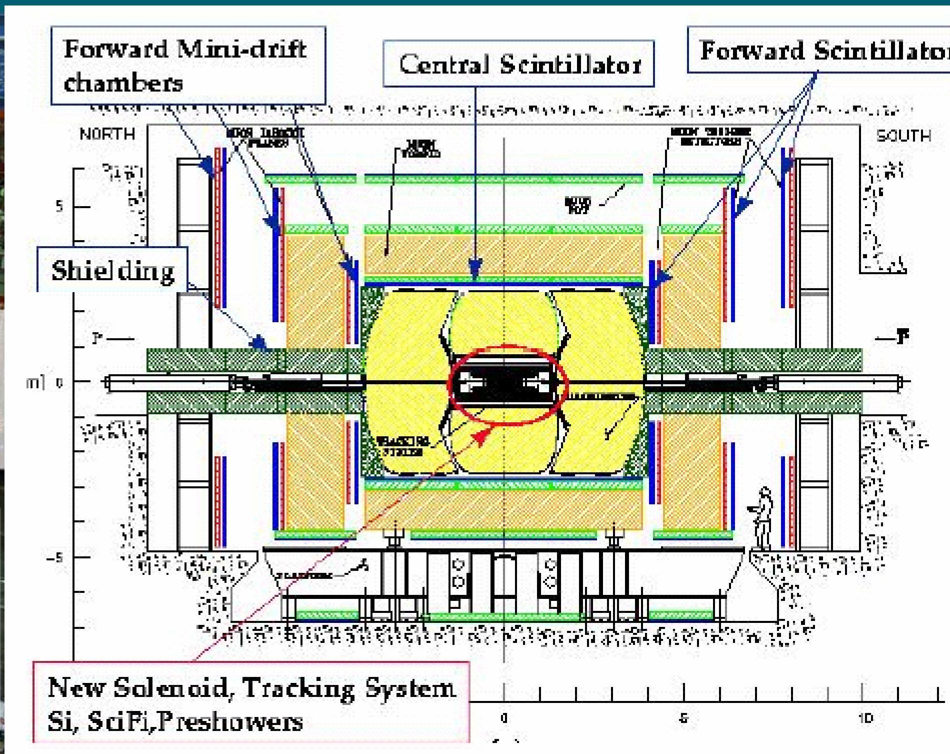




Detector hardware upgrades for Run II

- Both detectors underwent major upgrades for RunII, involving full DAQ system and tracking (all relevant to low-Pt physics) to cope with increased event rate. D0 added solenoid in tracking region.





Trigger issues

1.7 MHz events in central region
Only 70 Hz can be stored on tape

Process	Cross-section	Event Rate
Inelastic pp	60 mb	6 MHz
pp→bb (b p_T>6 GeV, $\|\eta\|$<1)	10 μb	1 kHz
pp→WX→ℓνX	5 nb	0.4 Hz
pp→ZX→ℓℓX	0.5 nb	0.04 Hz
pp→tt→WWbb→ℓν bbX	2 pb	0.0002 Hz
pp→WH→ℓνbb (M_H=120GeV)	15 fb	15 10-7 Hz

Assume L =100x10^{30} cm^{-2}s^{-1}, ℓ=electron or muon

Strategies to trigger on Heavy Flavors

Traditional (CDF, D0)

- Di-lepton - dilepton sample
  - pT(μ/e)>1.5/4.0 GeV/c
  - J/ψ modes, masses, lifetime, x-section
  - Yield 2x Run I (low Pt threshold, increased acceptance)

New (CDF)

- lepton + displaced track - semileptonic sample
  - pT(e/μ)>4 GeV/c 120 μm<d0(Trk)<1mm, pT(Trk)>2 GeV/c
  - Semileptonic decays ($B \rightarrow \ell \nu X$) , Lifetimes, flavor tagging.
  - B Yields 3x Run I

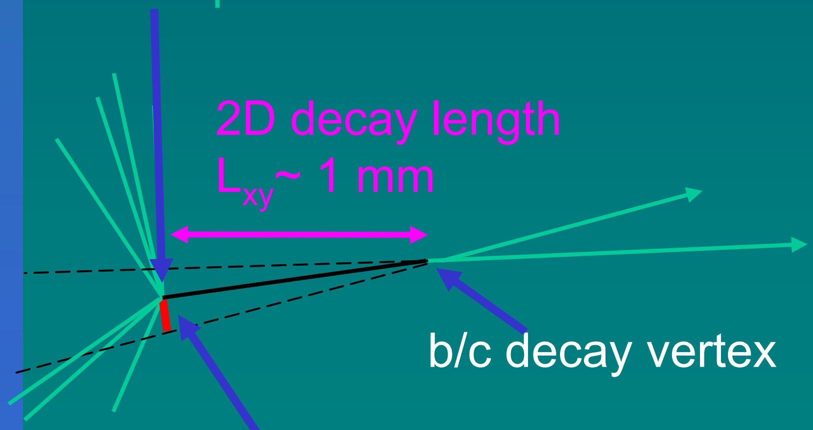
New (CDF)

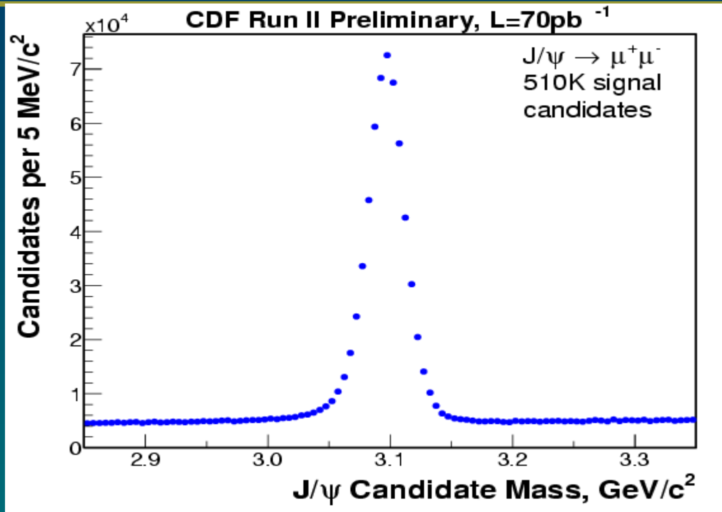
- Two displaced vertex tracks - hadronic sample
  - pT(Trk)>2 GeV/c, 120 μm<d0(Trk)<1mm, S pT>5.5 GeV/c
  - **Fully hadronic B decays ($B \rightarrow hh'$, $Bs \rightarrow Ds\pi$, $D \rightarrow K\pi$ …)**
  - Branching ratios, Bs mixing, …

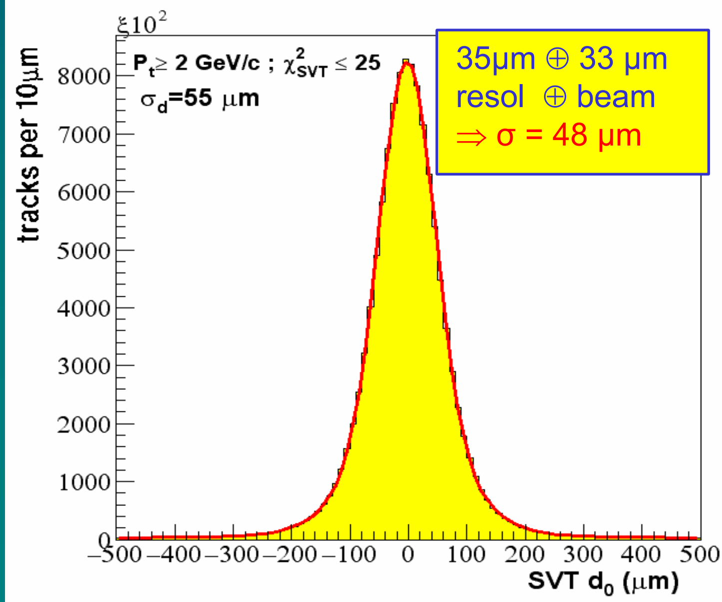
CDF track trigger

Exploit long b, c lifetimes in Trigger
L1 track + Si hits = Impact parameter @L2
A first at a hadron collider
CDF is a charm/Factory!

XFT (Level 1) measures curvature for tracks with Pt>1.5 GeV with $\sigma(p_T)=(1.74\ p_T)\%$
(directly used for J/Ψ dimuon trigger)
XFT information is passed to SVT, where it is merged with silicon hits and allows reconstruction (and trigger on) of impact parameter



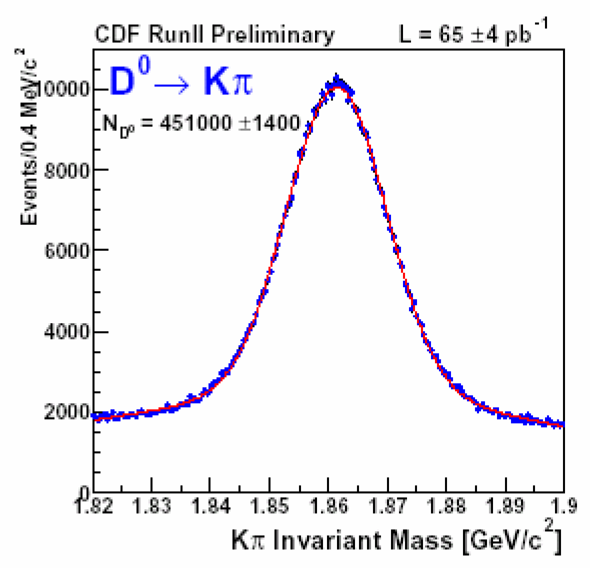


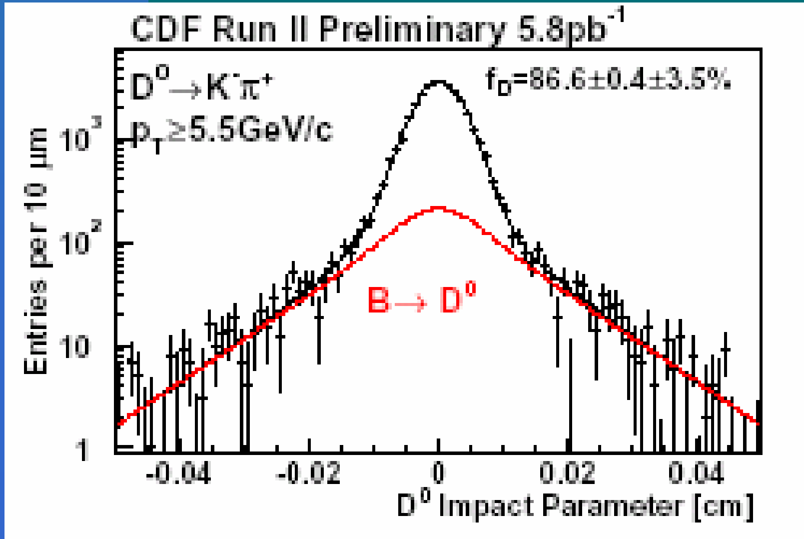


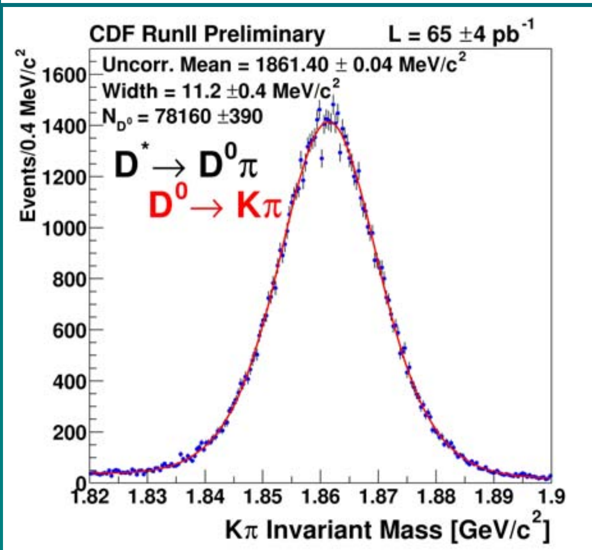
Basic properties: CDF measurements from two-track trigger

Huge samples of D^0 and D^* from TTT
(p_T>2 GeV, d_0>100m, Σp_t>5.5 GeV)
high purity from the decay $D^* \to D^0\pi_{slow}$

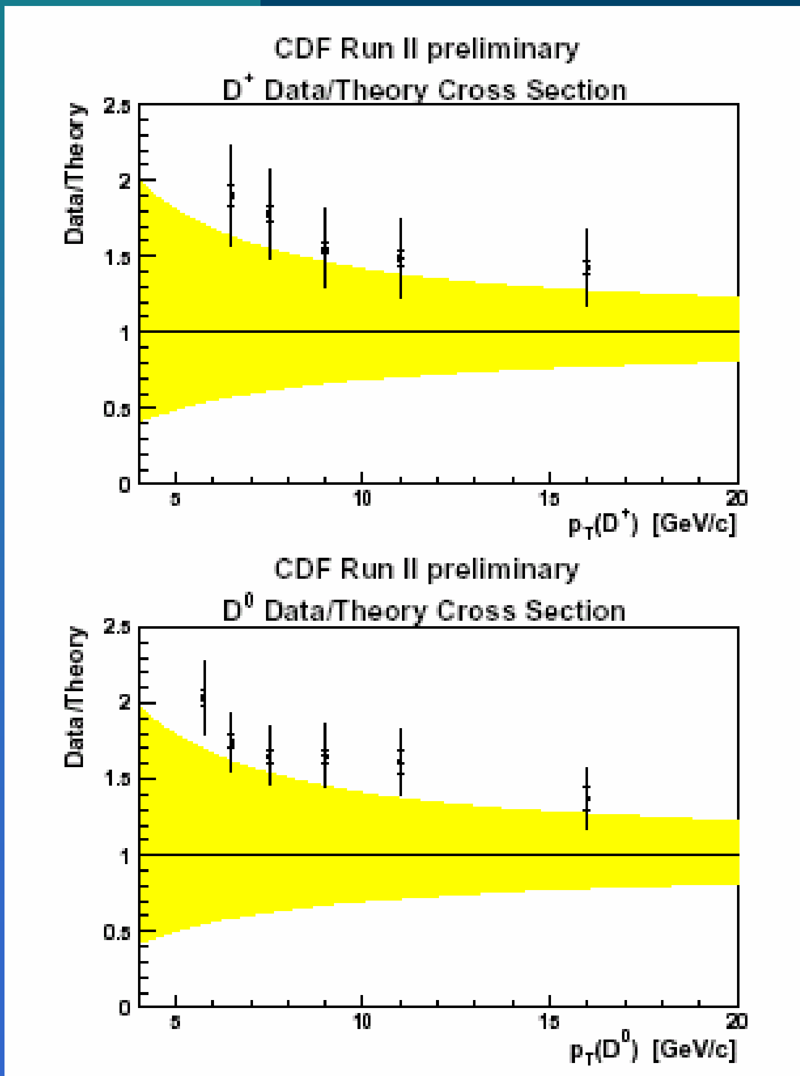
Distinction between prompt and b decay possible from D^0 impact parameter







Basic properties: Charm cross section



Done with few runs (limited by systematics)

- $\sigma(D^0)$pT>5.5 GeV =13.3 ± 0.2 ±1.5 μb
- $\sigma(D^*)$pT>6.0 GeV =5.2 ± 0.1 ± 0.8 μb
- $\sigma(D^+)$pT>6.0 GeV =4.3 ± 0.1 ± 0.7 μb
- $\sigma(D^+_s)$pT>8 GeV =0.75 ± 0.05±0.22 μb

Published in **Phys.Rev.Lett.91:241804,2003**

Agrees with Cacciari Nason JHEP 0309, 006 (2003), but on the high side

Basic properties: branching ratios of Cabibbo-suppressed decays and asymmetries

D0 decays other than Kπ seen in mass plot.

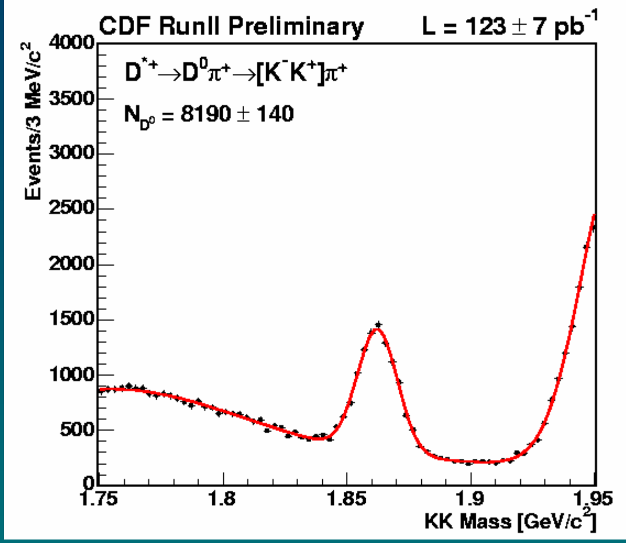
$\Gamma(D^0\text{->}KK)/\Gamma(D^0\text{->}K\pi)=9.96\pm0.11\pm0.12\%$

$\Gamma(D^0\text{->}\pi\pi)/\Gamma(D^0\text{->}K\pi)=3.608\pm0.054\pm0.040\%$

compare with FOCUS (2003)

$\Gamma(D^0\text{->}KK)/\Gamma(D^0\text{->}K\pi)=9.93\pm0.14\pm0.14\%$

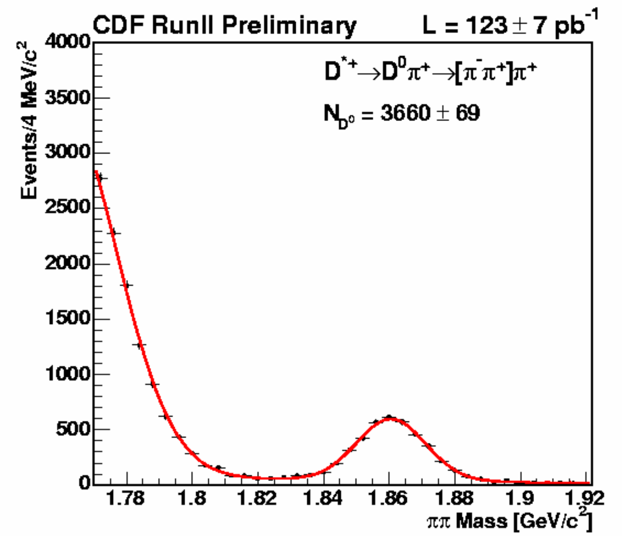
$\Gamma(D^0\text{->}\pi\pi)/\Gamma(D^0\text{->}K\pi)=3.53\pm0.12\pm0.06\%$



CP asymmetry: tagging the soft π from D* decays.

$A(D^0\text{->}KK) = 2.0 \pm 1.2 \pm 0.6\ \%$

$A(D^0\text{->}\pi\pi) = 1.0 \pm 1.3 \pm 0.6\ \%$



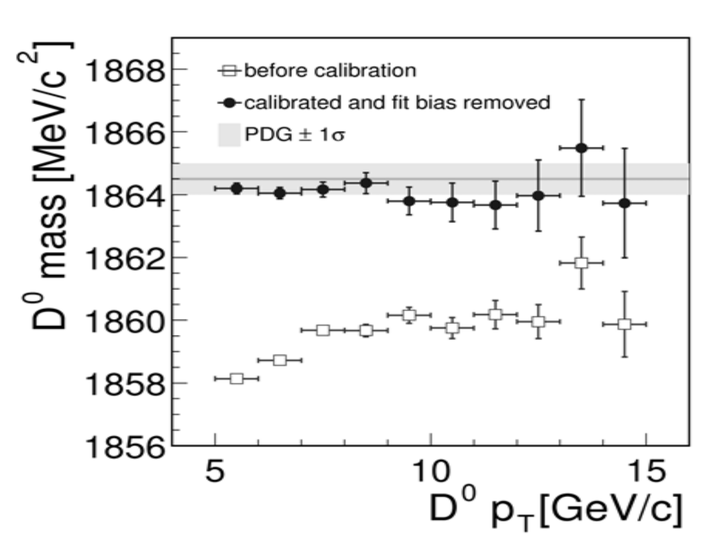
Spectroscopy: D_s^+ D^+ mass difference

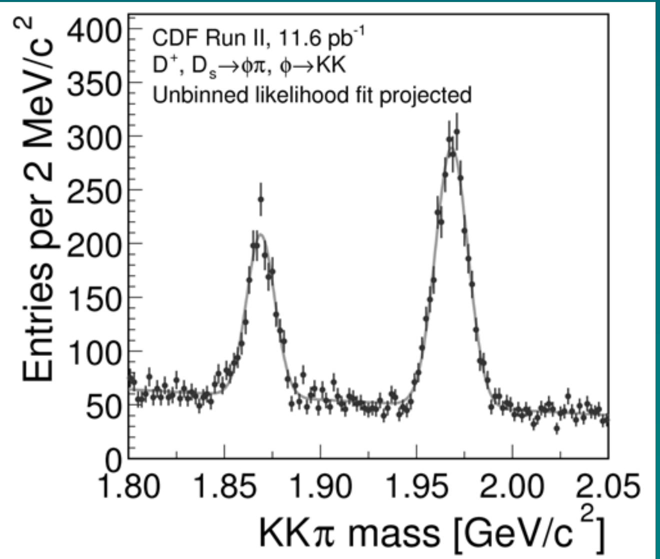
- First CDF RunII paper

(Phys. Rev. D68,072004,2003)

Careful tracker calibration using D^0 control sample needed

Best world measurement obtained with limited luminosity





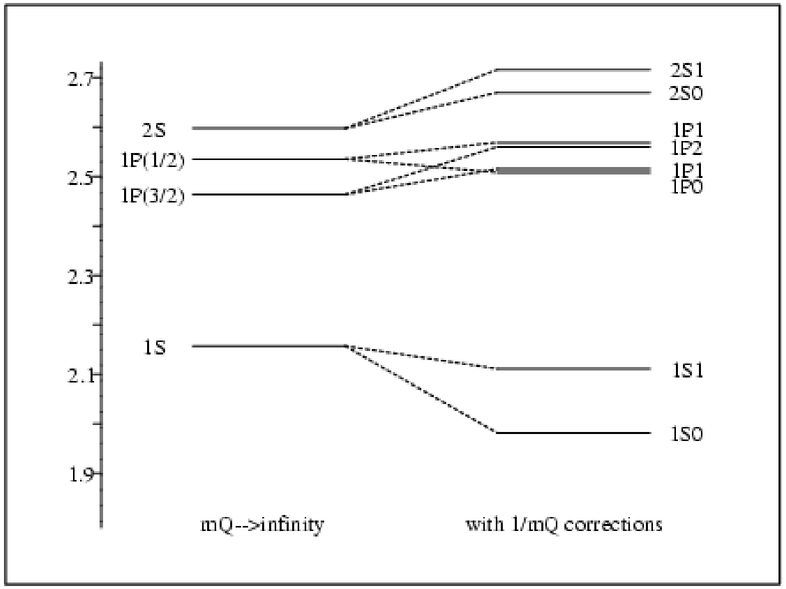
$M(D_s^+)-M(D^+)=$

99.41±0.38(stat.)±0.21(syst.) MeV

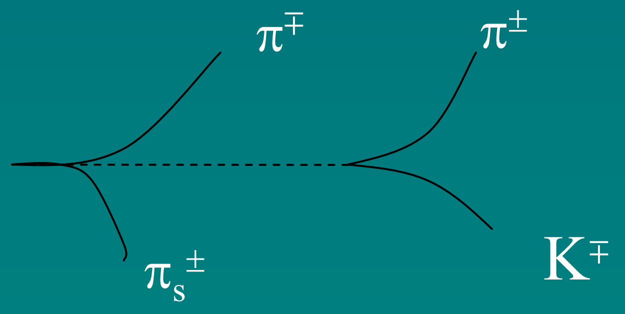
Spectroscopy: orbitally-excited charm mesons

Total angular momentum of a meson: $J=s_q+s_Q+L$. Depending on relative spin orientation, 4 P-wave mesons (L=1)

In heavy quark limit, masses of mesons with same $j_q=s_q+L$ are degenerate. $1/m_Q$ corrections introduce hyperfine splitting, particularly visible for $j_q=3/2$ states, decaying via a suppressed D-wave, (width ≅ 20 MeV). Width of $j_q=1/2$ states is about 200 MeV.



$D^{**} \to D^* \pi$
$\to D^0 \pi\pi$
$\to K \pi\pi\pi$



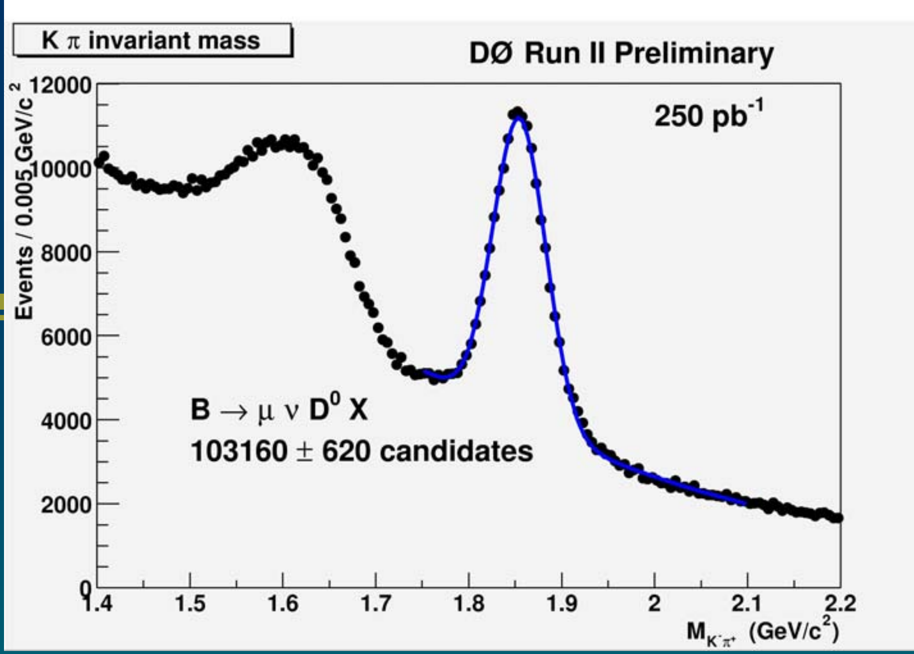
BR B->D**

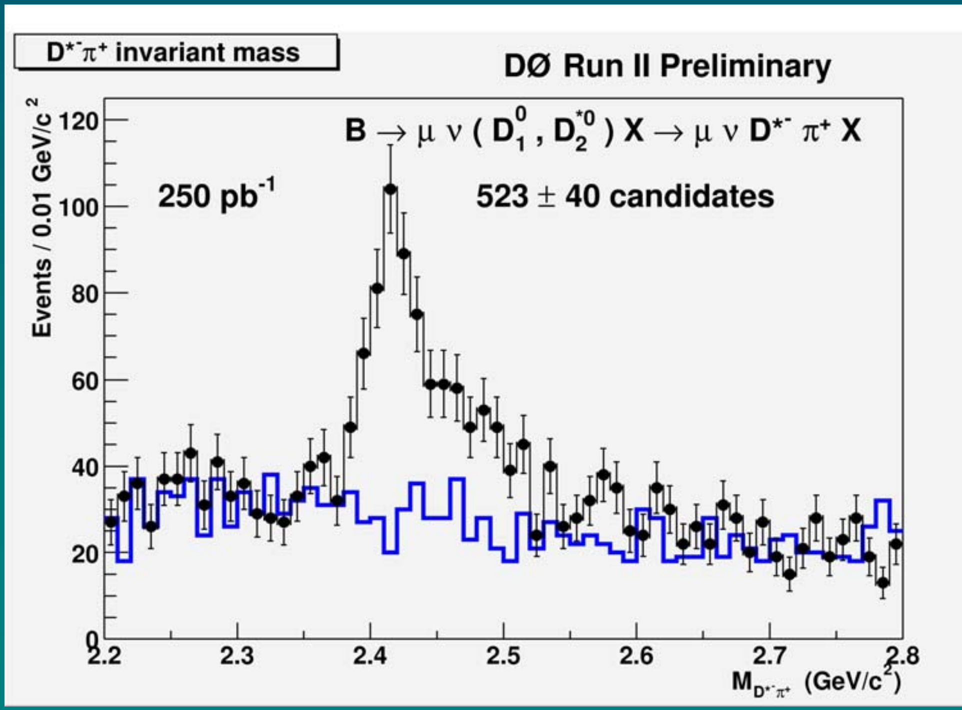
D0 has observed these states in the semileptonic B decay B->μν D** X followed by D** decay.

Measure Br(B->μν D** X)*BR(D**->D*π)=

(0.280 ± 0.021 ± 0.088)%

CDF has thousands of events from TTT, aim for a mass measurement with 1 MeV accuracy





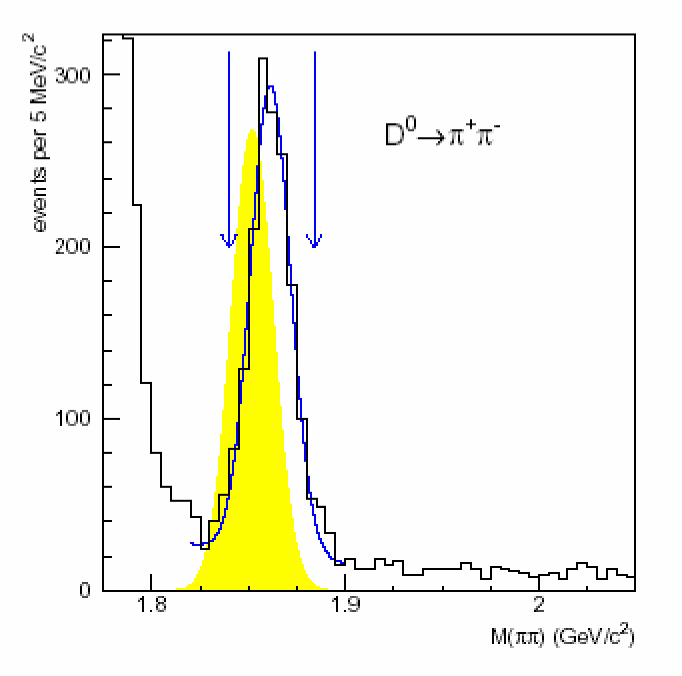
New Physics: FCNC $D^0 \to \mu\,\mu$ decays

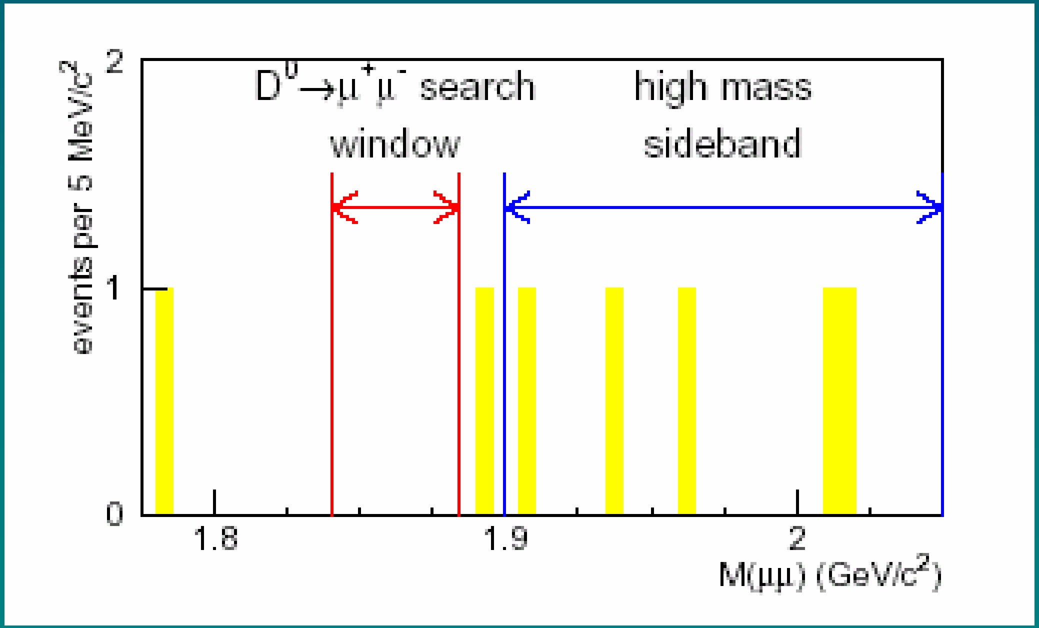
SM Br is 3×10^{-13}, can grow by 10^7 in R-violating SUSY

D0->ππ used as reference sample

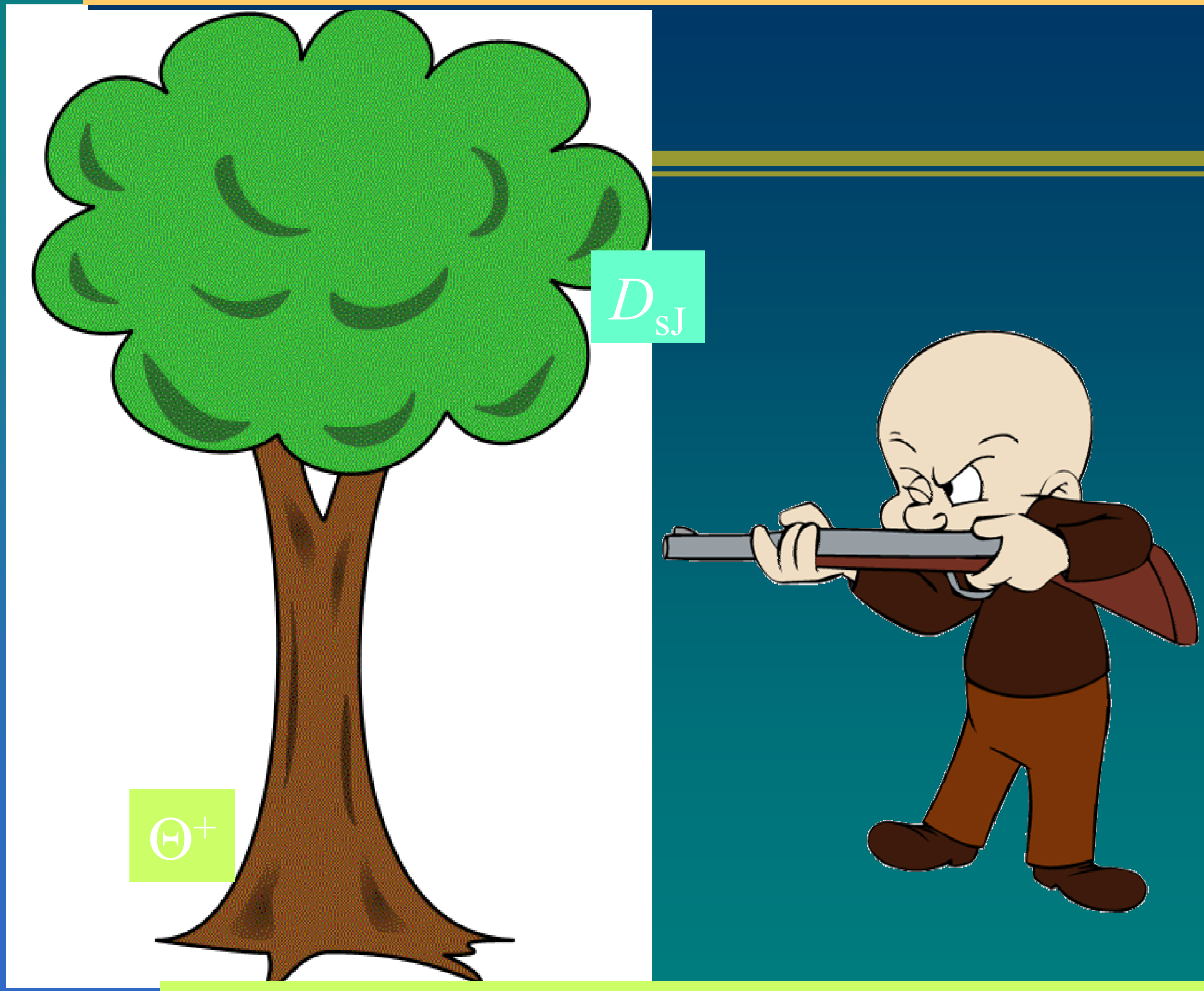
0 events observed, 1.6±0.7 from BG

BR($D^0 \to \mu\mu$)< 2.5 (3.3)x 10^{-6} at 90% (95%) CL (improves PDG by a factor 2)





Hunting For New States

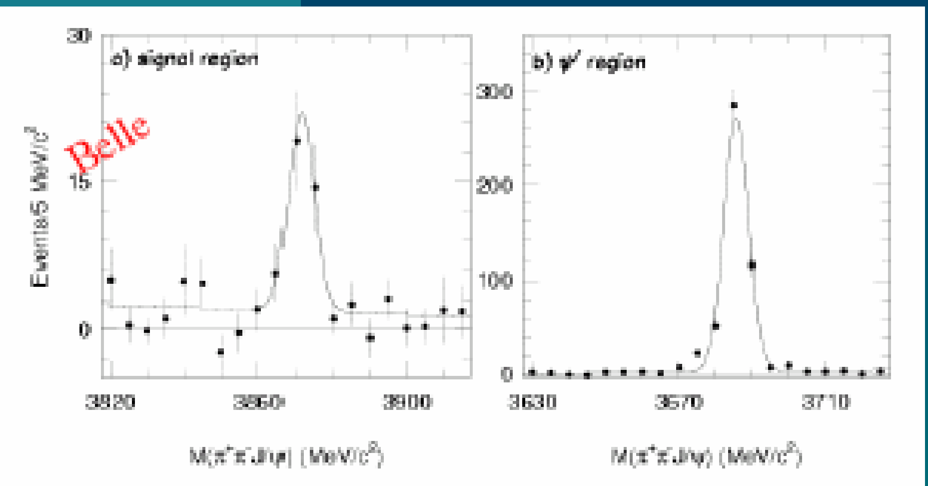


- Ssssshhhh........

Hunting For New States

- Ssssshhhh……..Wabbit hunting.

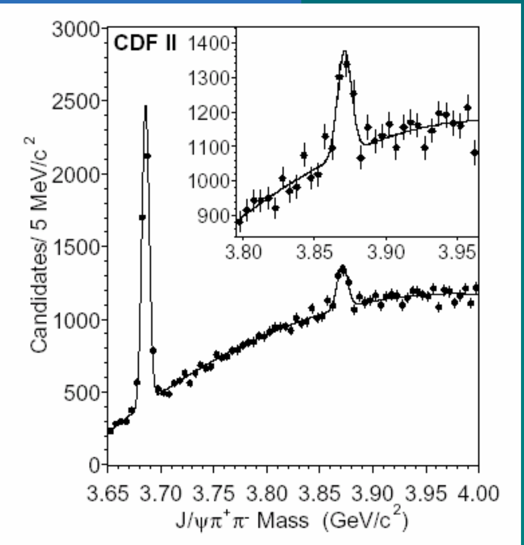
New physics: observation of X(3872)

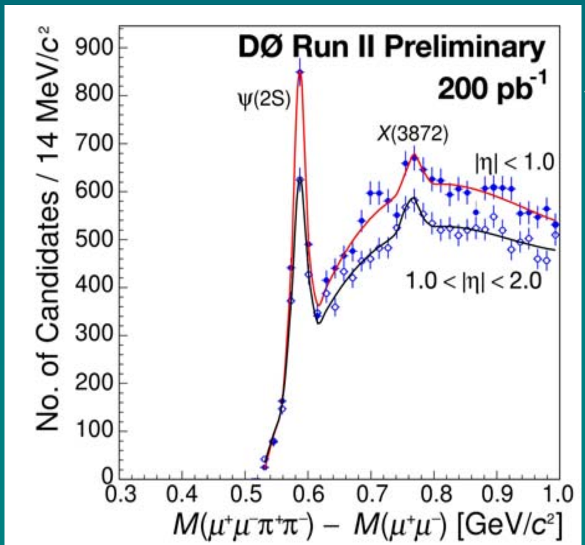


- New unexpected narrow state observed by Belle in J/Ψππ

M(X) = 3872.0 ± 0.6 ± 0.5 MeV

Confirmed by both Tevatron detectors
CDF observes 11 σ signal with mass (hep-ex/0312021)
M(X) = 3871.3 ± 0.7 ± 0.4 MeV
D0 has 4.4 σ with
ΔM(X-Ψ(2S)) = 766.4 ± 3.5 ± 3.9 MeV





What is it?

•Charmonium?

•DD molecule?

What is X(3872)?

- Two leading candidates:
  1. A ccbar state ⇒ like the 1 $^3D_2$ state
  2. D*D molecule (suggested by Belle)
     - Observed mass is a few MeV below threshold
     - $X \to \chi_c \gamma$ is not yet observed by Belle
     - $X \to J/\psi\ \rho$ forbidden for $^3D_2$ state
- Additional measurements to pin down the quantum numbers:
  - Helicity angles
  - $M_{\pi\pi}$ distribution (resonance structure)

Final remarks

- Despite non-dedicated, experiments at Fermilab play a major role in the field of charm physics due to huge cross section and dedicated triggers
- In particular, CDF SVT proved to be a huge success (so far, all papers published by CDF are on charm!), D0 about to install a similar system very soon
- Tevatron started to work closer to expectations, there is an even larger sample ahead of us