Review of Tevatron Results

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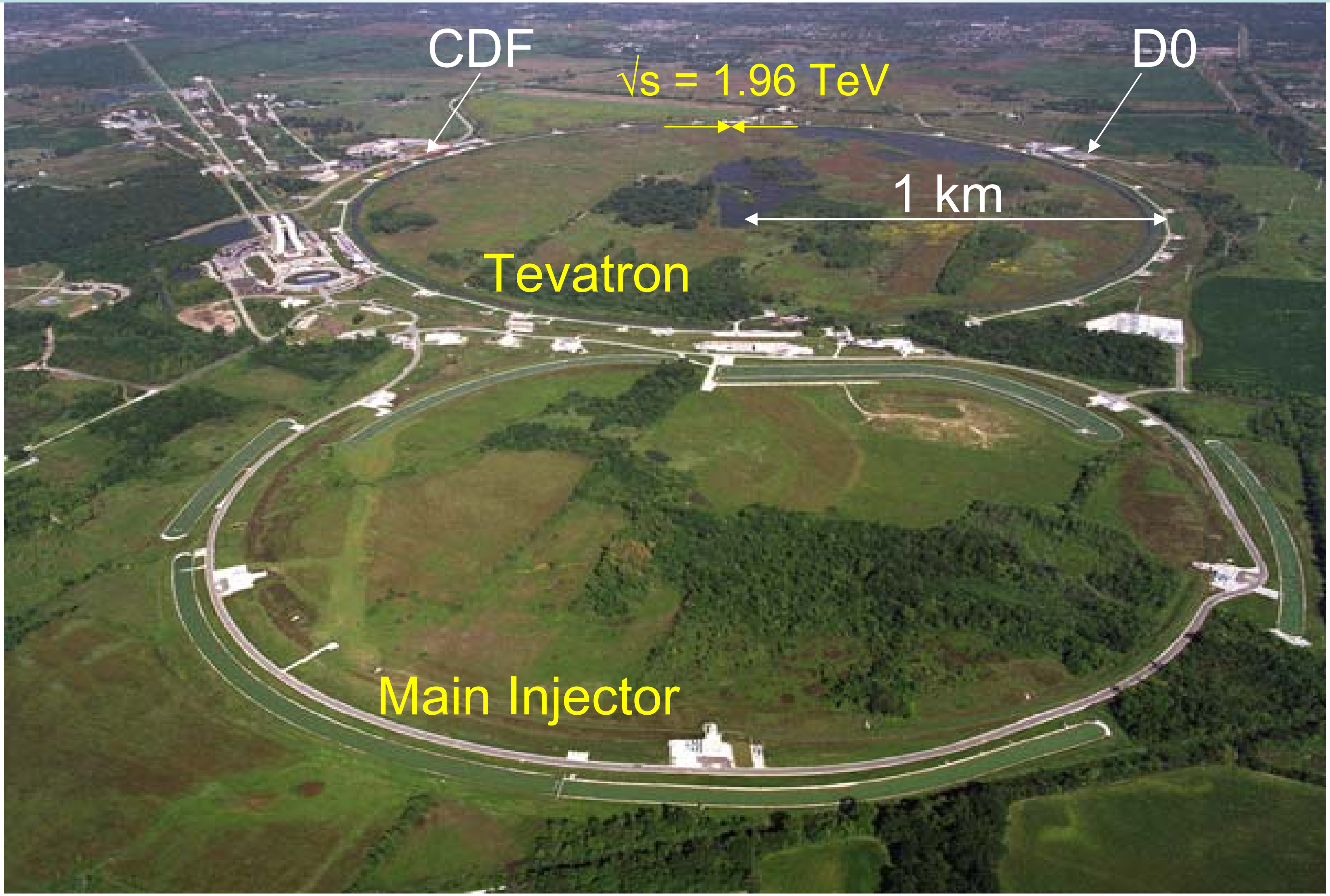
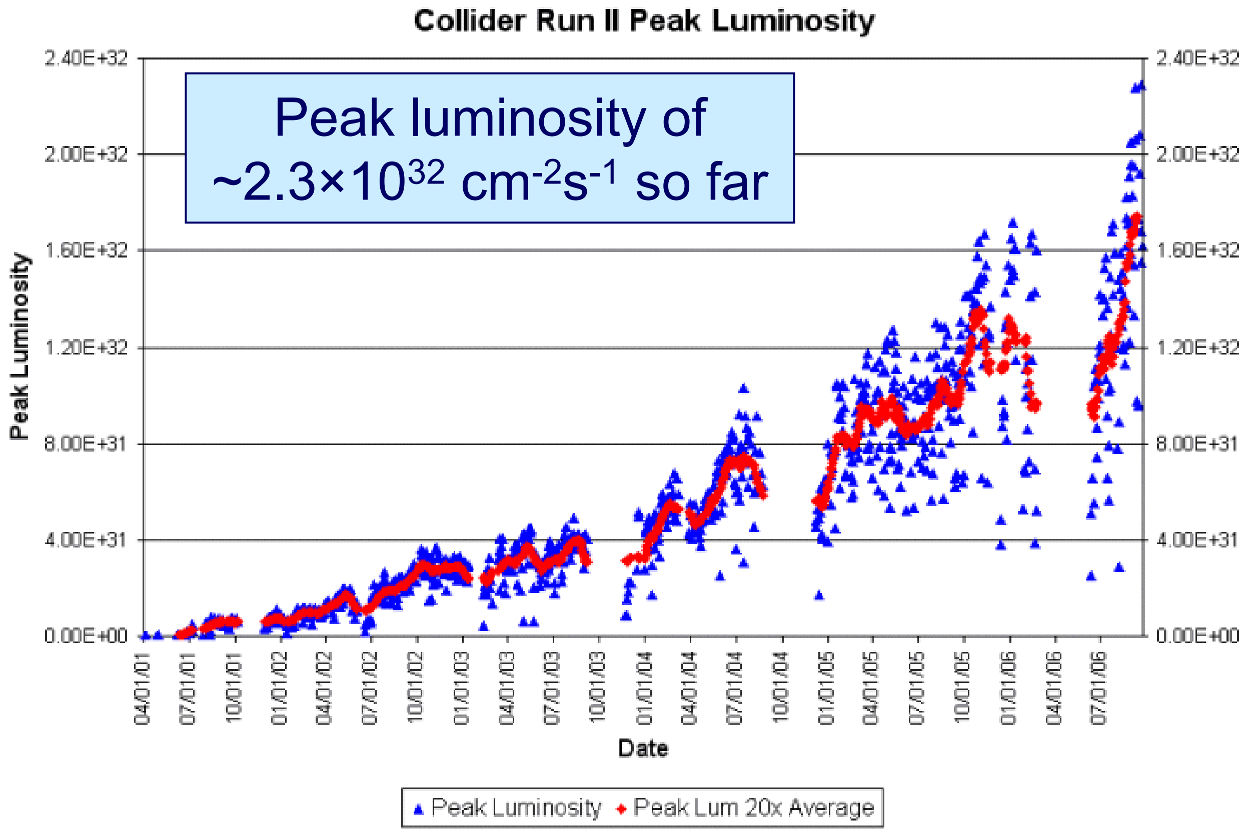
Overview

- Quantum Chromodynamics
  - jet cross section measurements
- Searches for New Phenomena
  - chargino – neutralino searches
  - Search for di-electron / di-photon resonances
- B Physics
  - Observation of B_s Oscillations
- Top, Higgs and EWK a little later this afternoon

Tevatron Collider

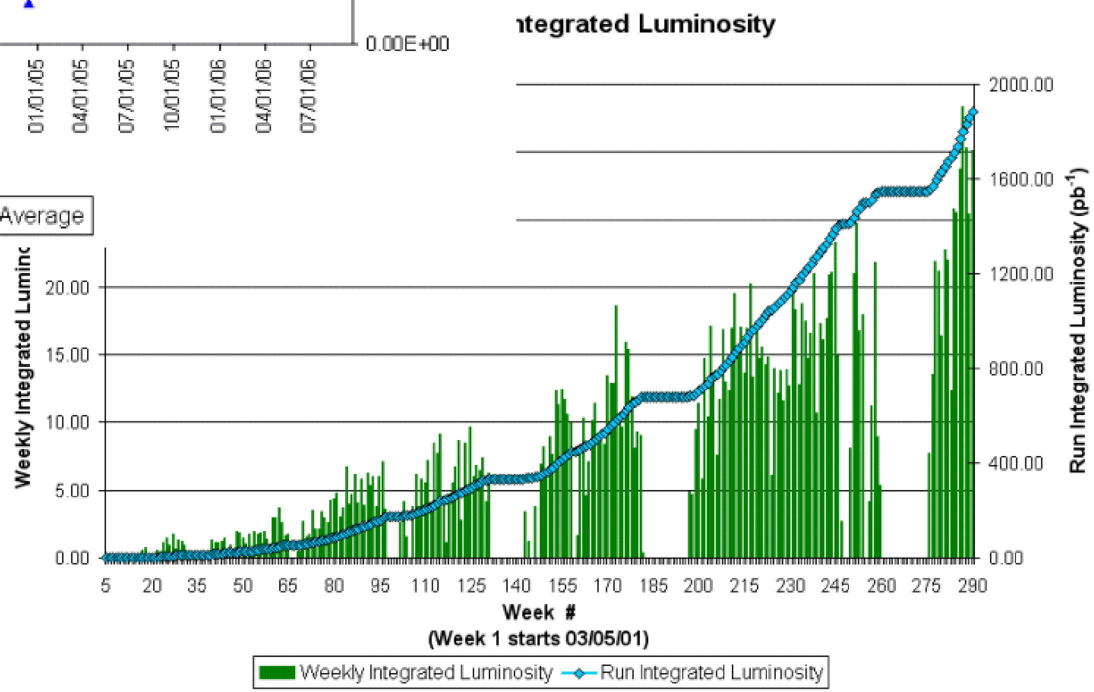


Tevatron luminosity



Peak luminosity of ~2.3×10^{32} $cm^{-2}s^{-1}$ so far

- Delivered integrated luminosity ~2 fb^{-1}
- Data set has doubled every year
- Expect 4 – 8 fb^{-1} by the end of 2009



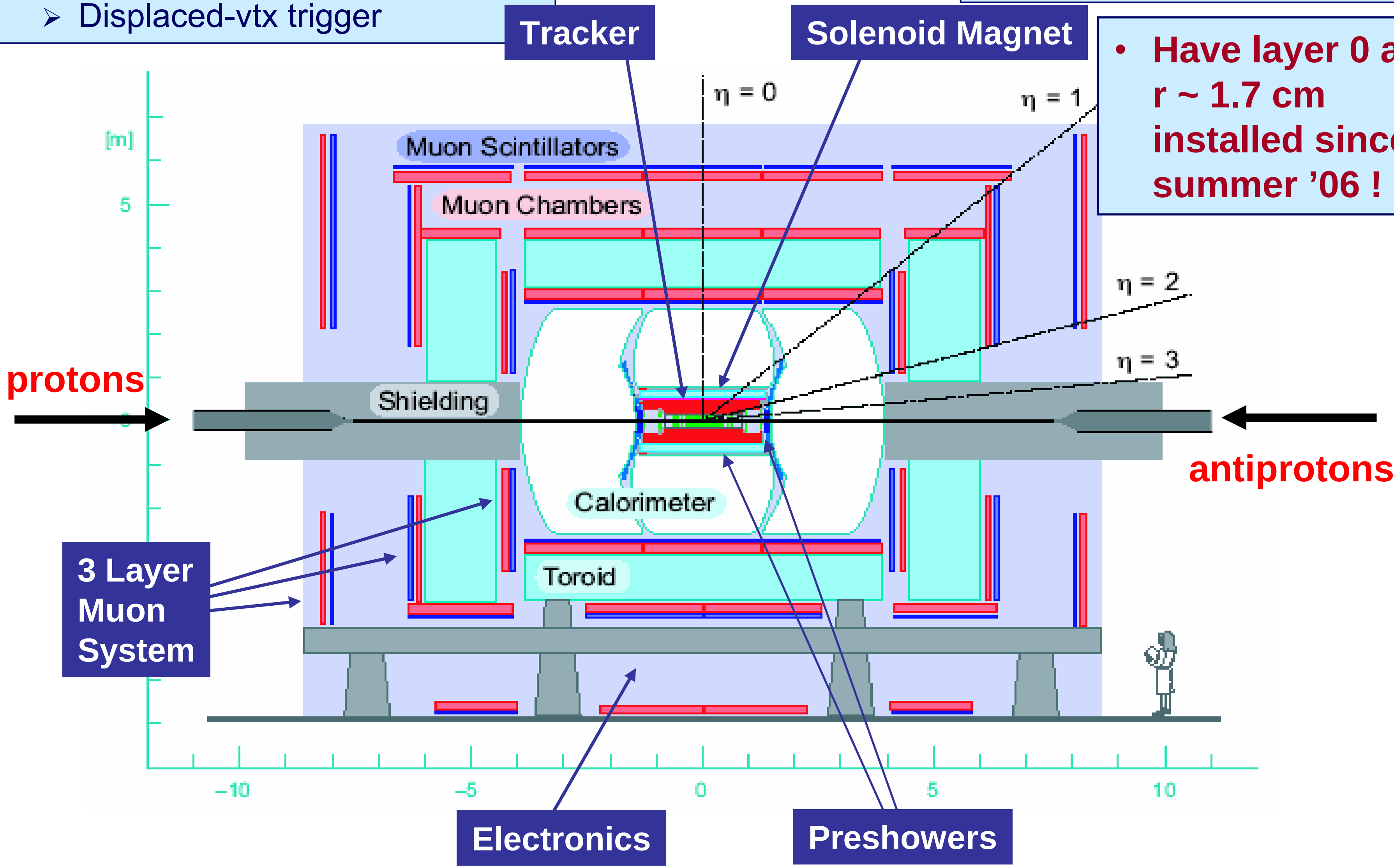
- CDF/DØ operate at ~85% efficiency
- Results in the following are based on 0.3 – 1 fb^{-1} of data

The upgraded DØ detector

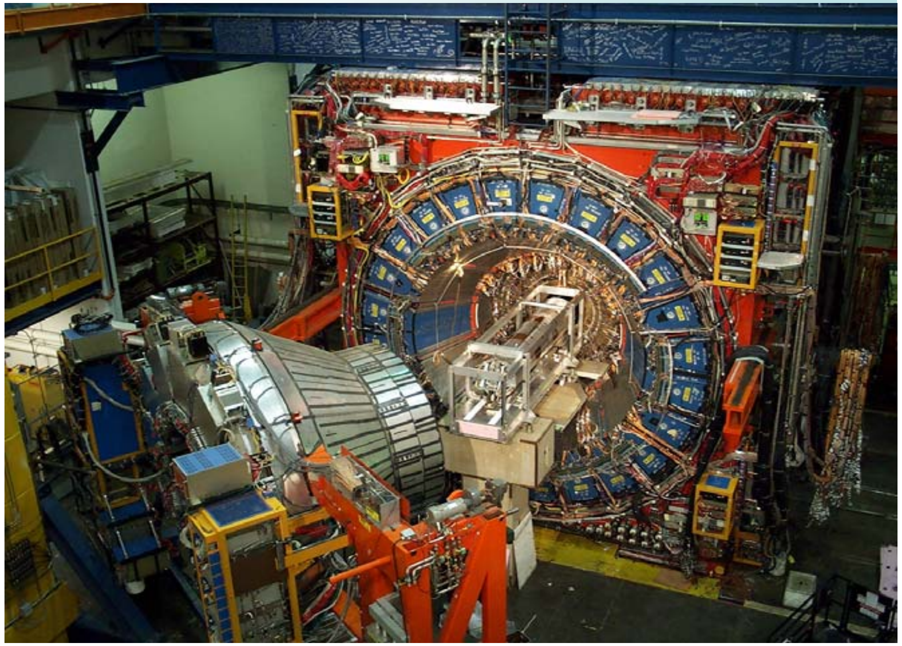
- Upgraded
  - Muon system, cal. electronics
  - DAQ, (track) trigger system
  - Displaced-vtx trigger

- New (tracking in B-field)
  - Silicon detector
  - Fiber tracker

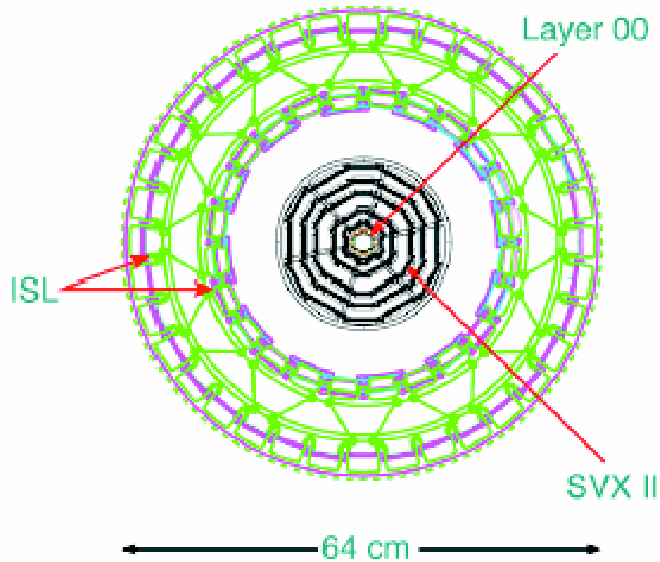
- **Have layer 0 at r ~ 1.7 cm installed since summer '06 !**



The upgraded CDF II Detector



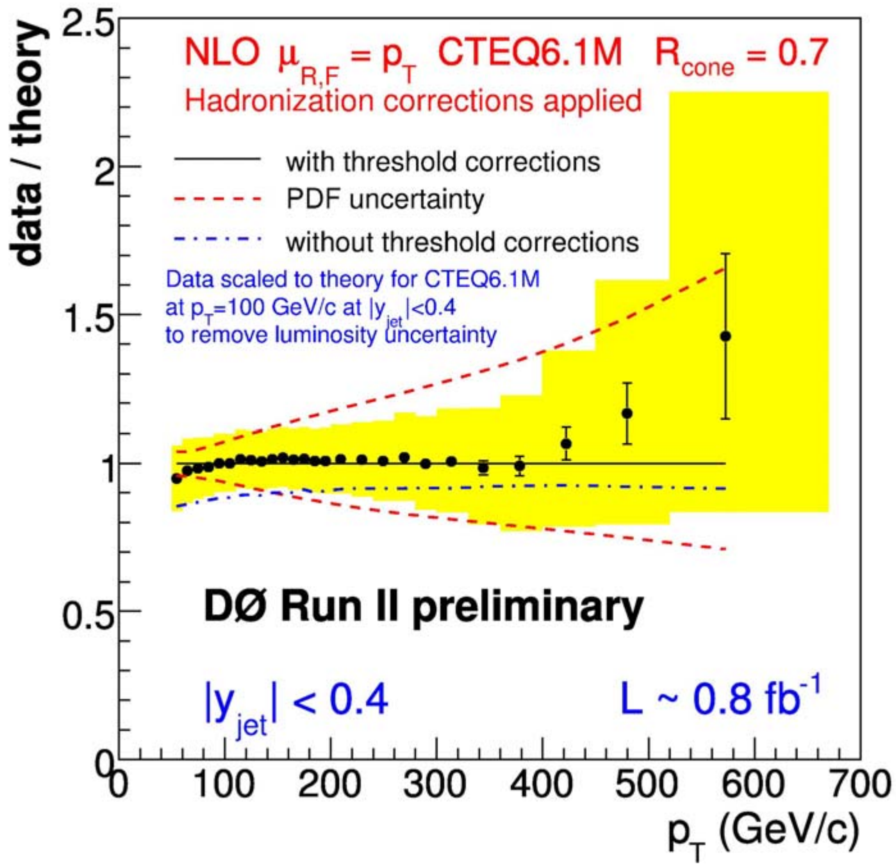
- Major upgrades for Run II:
  - Drift chamber: COT
  - Silicon: SVX, ISL, L00 at r ~ 1.5 cm
    - 8 layers
    - 700 k readout channels
    - 6 m^2
    - material:15% X_0
  - Forward calorimeters
  - Forward muon system
    - Improved central muon system
  - Time-of-flight
  - Preshower detector
  - Timing in EM calorimeter
  - Trigger and DAQ

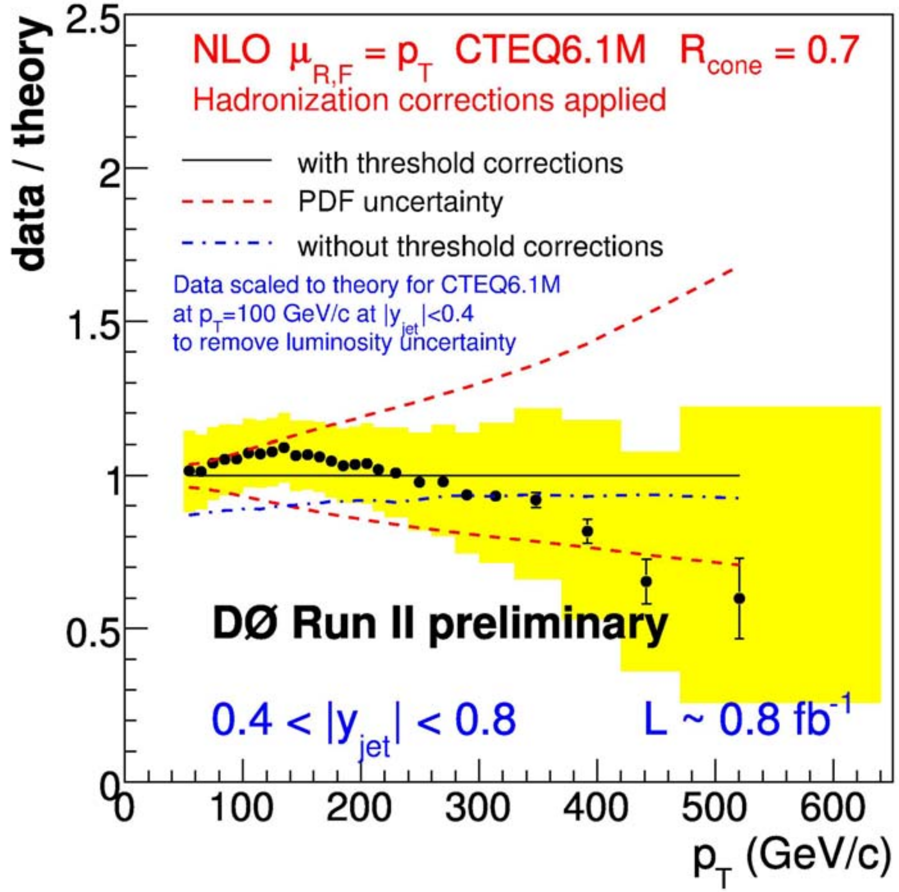


Quantum Chromodynamics

Jet Cross Sections from D0

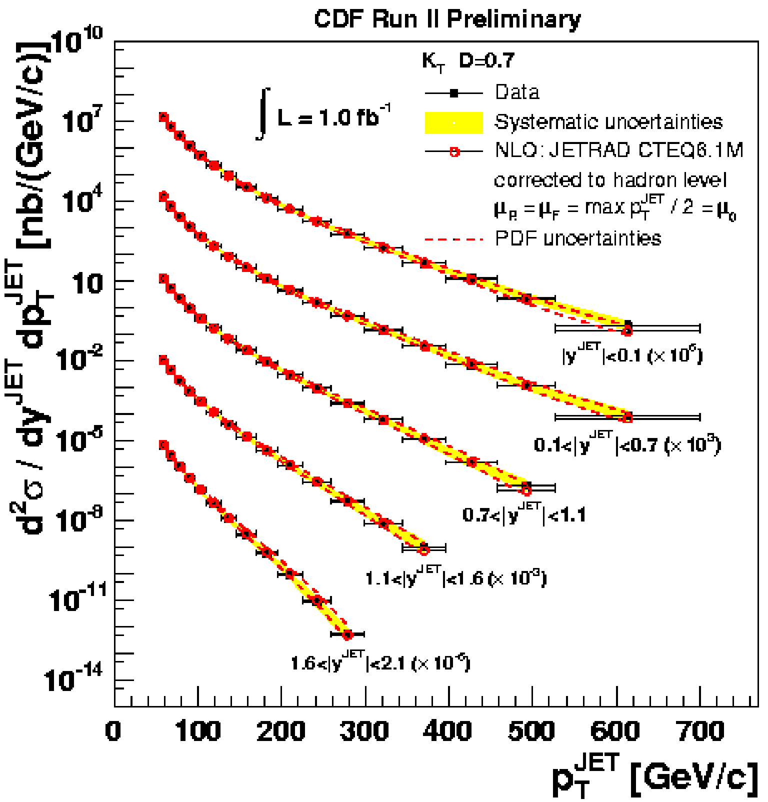
Cone clustering aglorithm, R_{cone} = 0.7



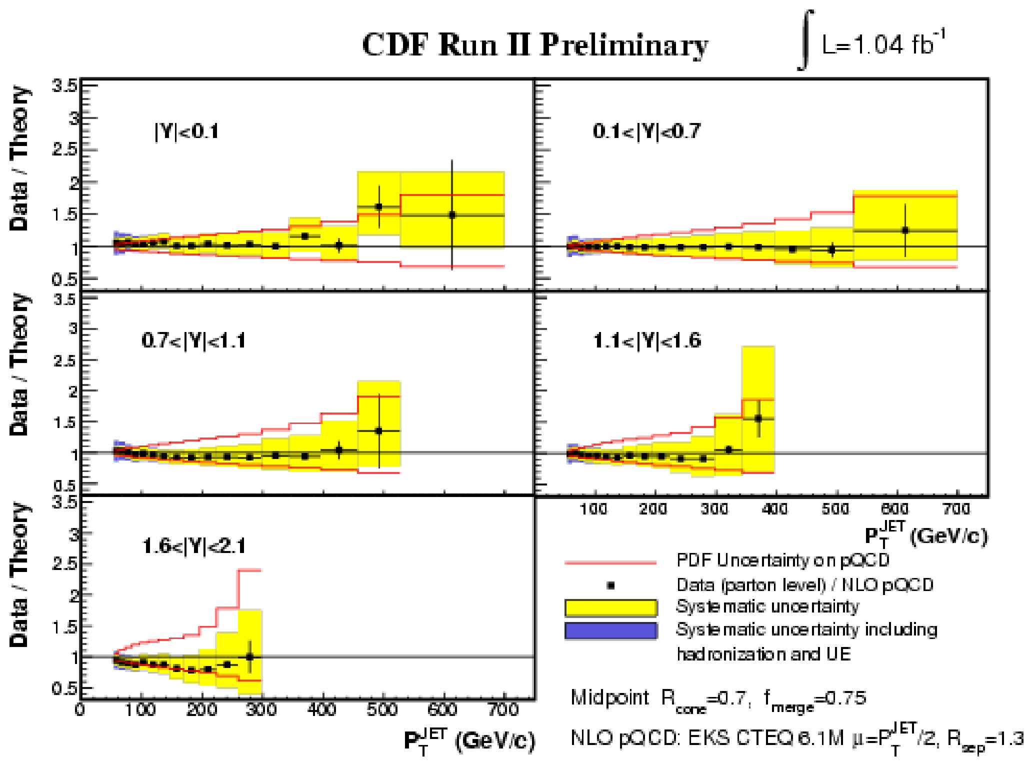


Jet Cross Sections from CDF

K_T clustering algorithm

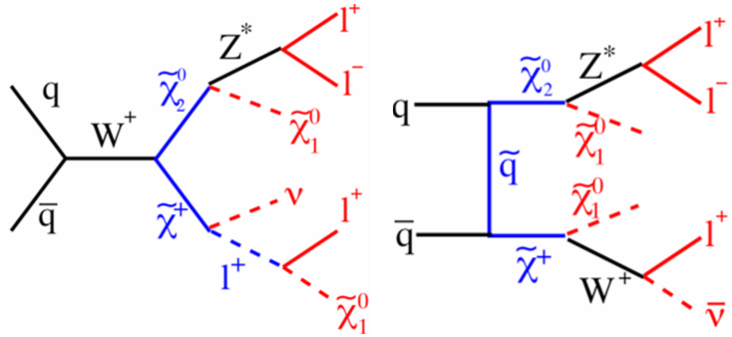


Midpoint clustering algorithm



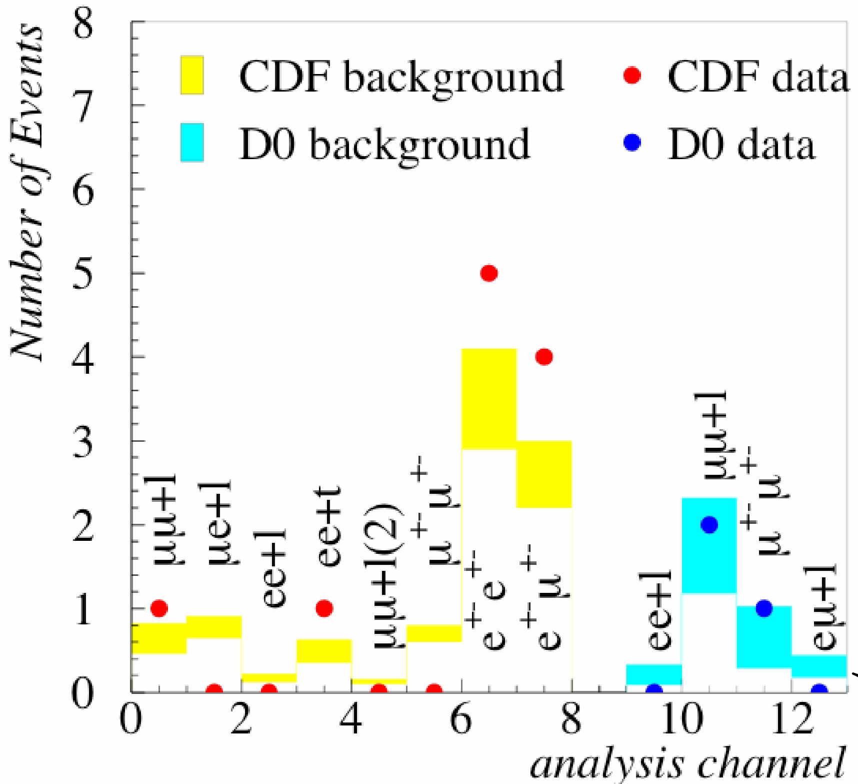
New Phenomena

Chargino-Neutralino Searches



- 3 leptons + $\not{E}_T$ (from ν and neutralino)
  - Very small SM background
  - Same sign dilepton channel adds acceptance at the expense of background

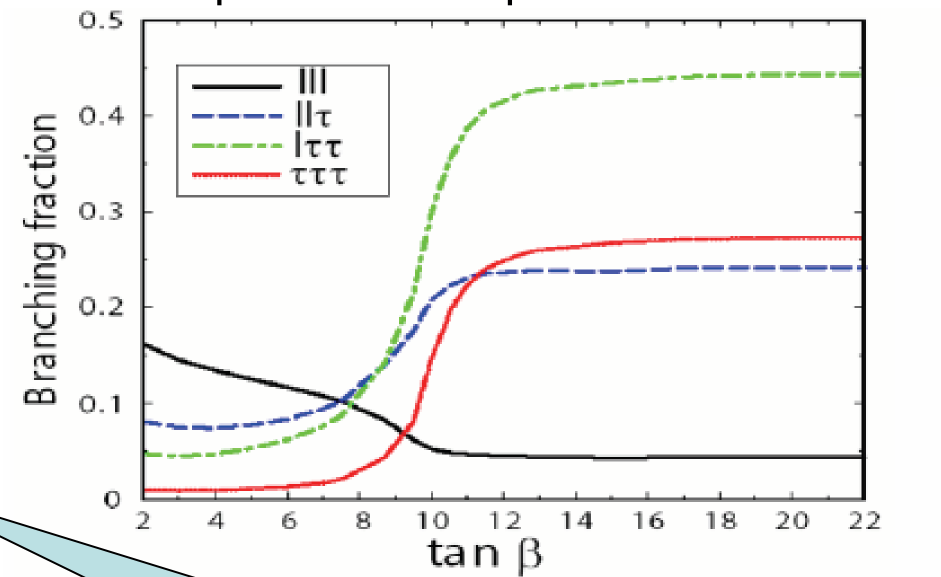
Golden mode for SUSY discovery at the Tevatron



Poisson uncertainty on the predicted number of events not shown

2 more D0 analyses involving taus

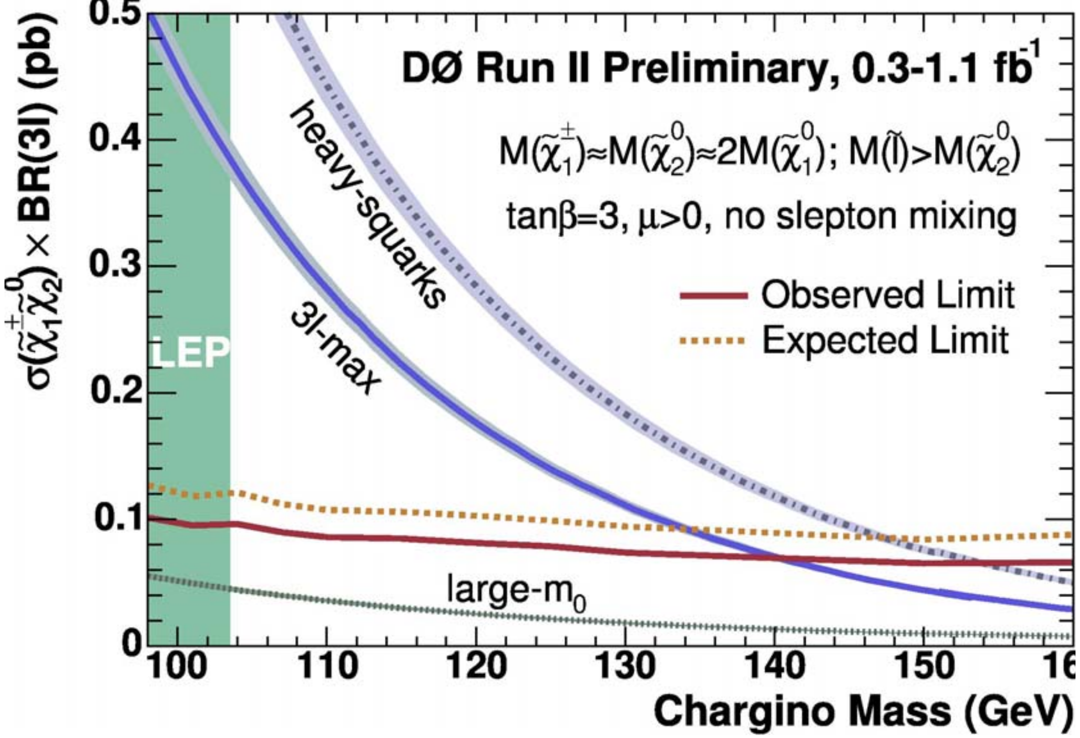
Decays to leptons:
- depends on slepton masses
- lepton flavor depends on tanbeta



Chargino-Neutralino limits

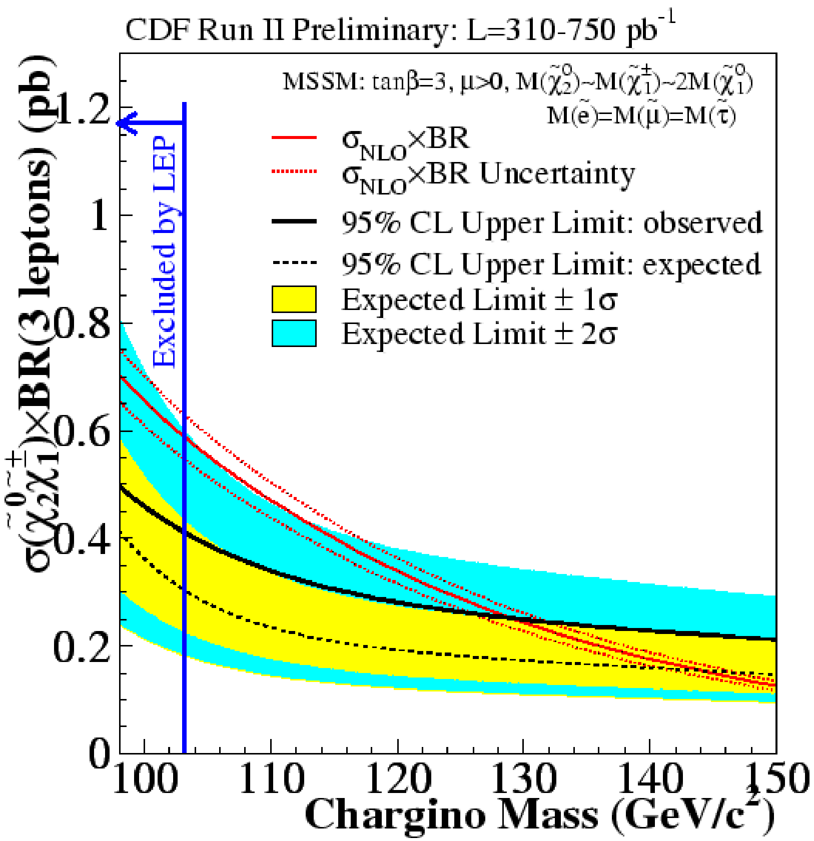
Choose an mSUGRA-inspired low tan beta scenario

no slepton mixing



$M_{\tilde{\chi}_1^{\pm}}$ > 140GeV(D0)

slepton mass degenerate



$M_{\tilde{\chi}_1^{\pm}}$ > 127GeV (CDF)

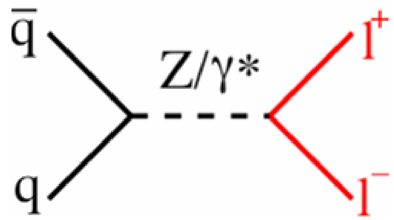
Results are model dependent

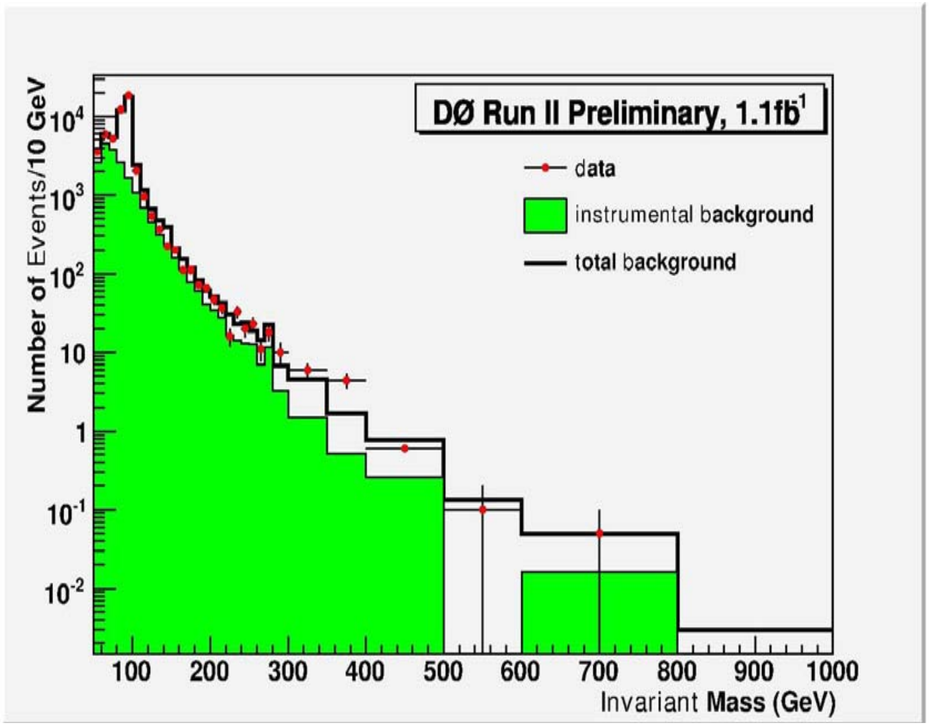
Beyond LEP in these scenarios

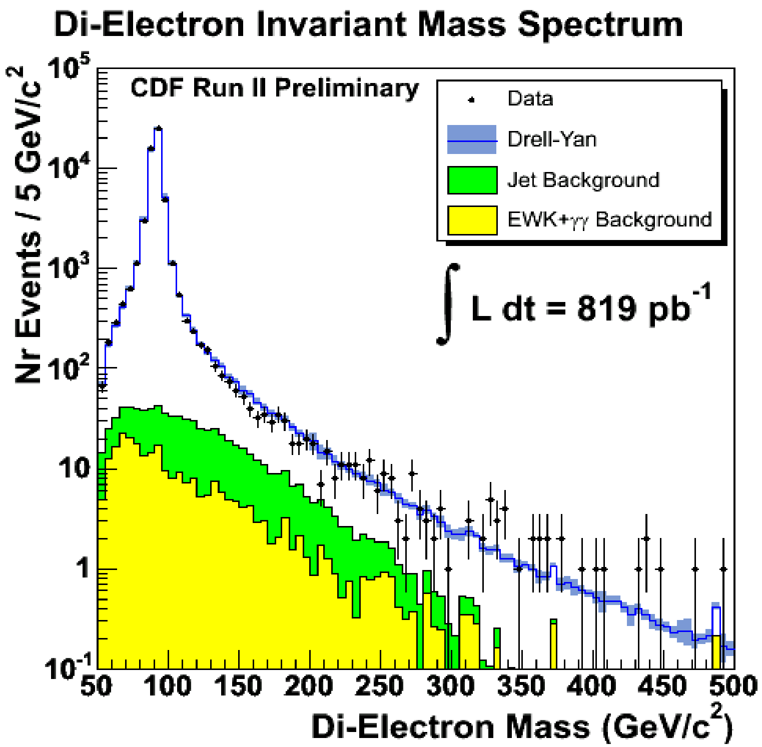
Di-lepton / di-photon resonances

- Backgrounds:
  - Mainly Drell-Yan
  - WW, diphoton, jets faking leptons
- Calculate probability of data vs SM prediction at each mass
  - Mass window size adapted to mass resolution (~3%)

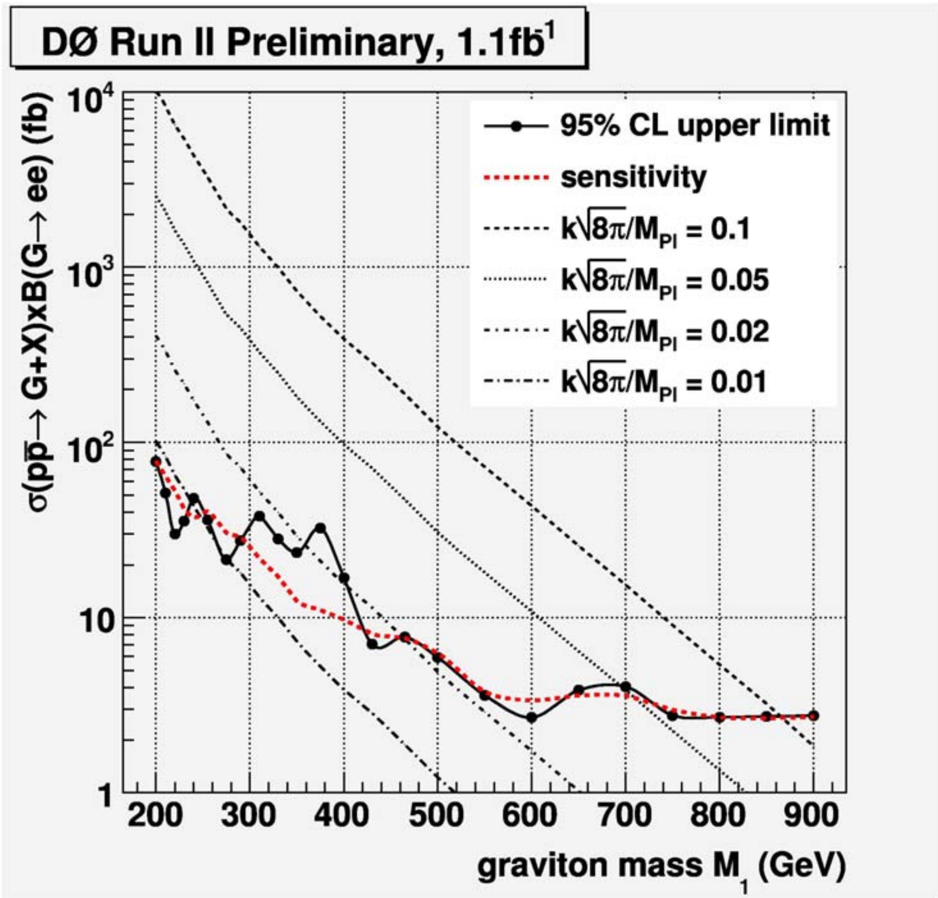
Model independent measurement

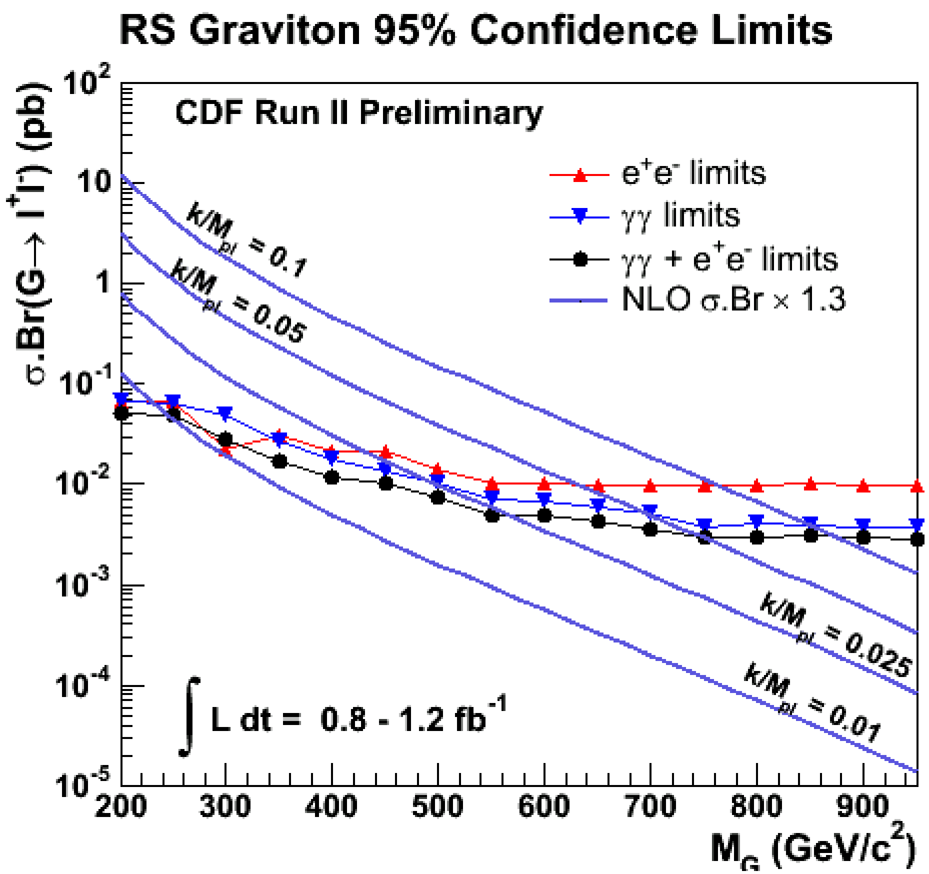






Interpretation: RS Graviton





B Physics

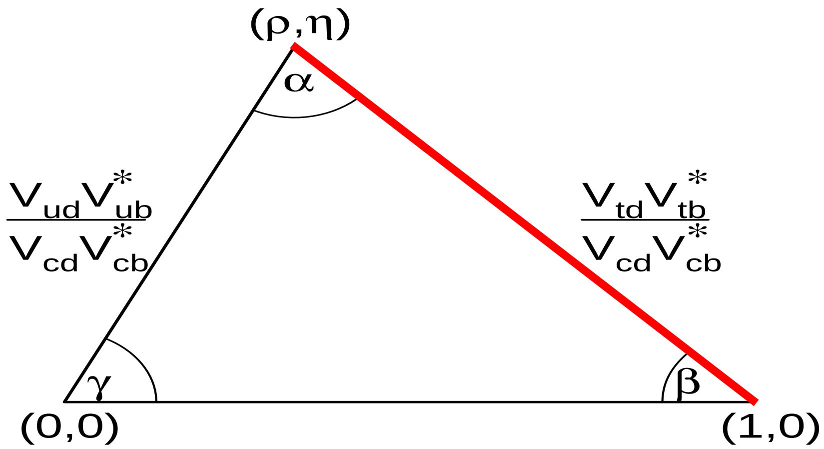
Unitarity Triangle

- CKM Matrix (Wolfenstein parameterization)

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

- Unitarity of CKM Matrix

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



- $|V_{cb}|=|V_{ts}|$

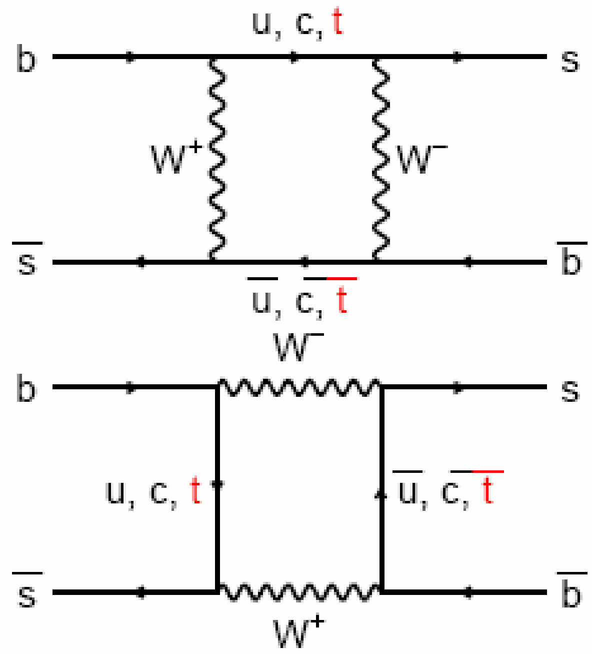
$$\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| = \frac{|V_{td}|}{|V_{ts}|} \times \frac{1}{|V_{cd}|}$$

- $|V_{cd}|$ is known to ~5% precision
  - 0.224 ± 0.012

B Mixing in the Standard Model

- B_s mixing: box diagram

$$\Delta m_q = \frac{G_F^2 m_W^2 \eta S(m_t^2 / m_W^2)}{6\pi^2} m_{Bq} f_{Bq}^2 B_{Bq} \left| V_{tq}^* V_{tb} \right|^2$$

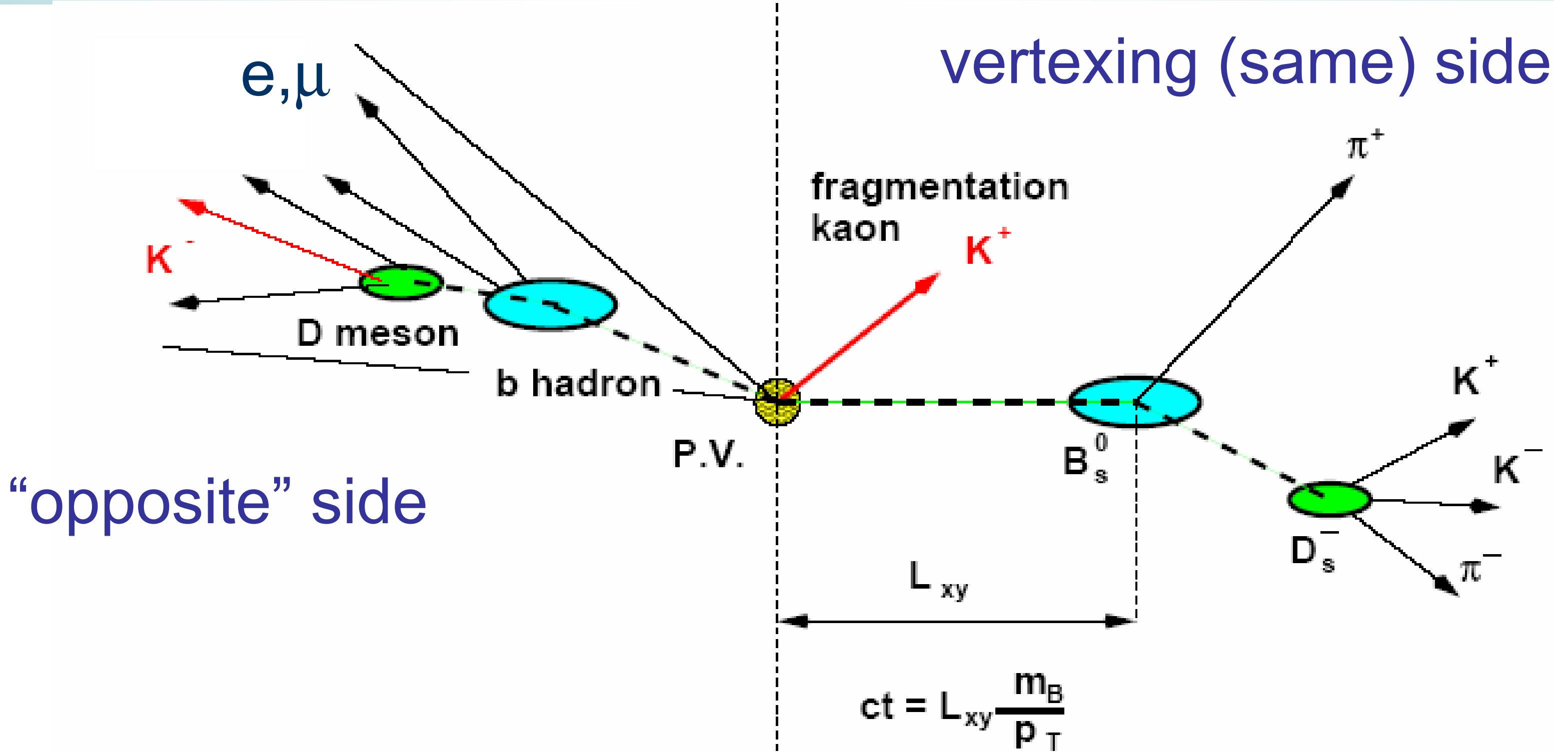


- $m_d = 0.510 \pm 0.005\ ps^{-1}$ (HFAG 2005)
  - lattice QCD calculation: $f^2_{Bd} B_{Bd} = (246 \pm 25 \pm 11\ MeV)^2$
  - $|V_{td}|$ determination limited at ~13%
- Ratio between Δm_s and Δm_d

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \frac{f_{Bs}^2 B_{Bs}}{f_{Bd}^2 B_{Bd}} \frac{\left|V_{ts}\right|^2}{\left|V_{td}\right|^2} = \frac{m_{Bs}}{m_{Bd}} \xi^2 \frac{\left|V_{ts}\right|^2}{\left|V_{td}\right|^2}$$

- theoretical uncertainties cancel in the ratio:
  - $\xi = 1.21^{+0.047}_{-0.035}$
  - determine $|V_{ts}|/|V_{td}|$ ~3.4% precision

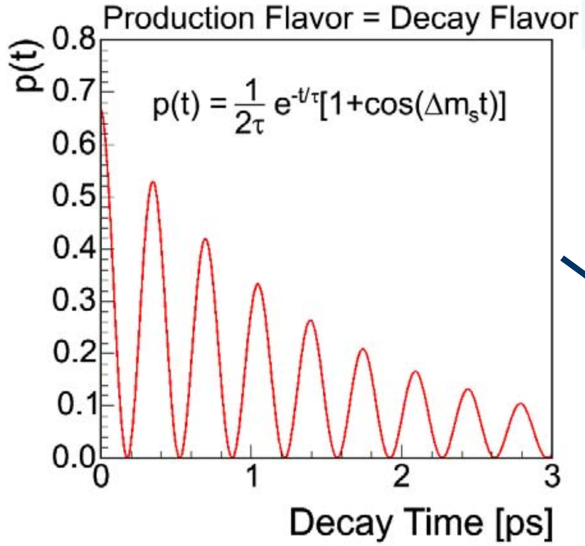
B_s Mixing Measurement Technique



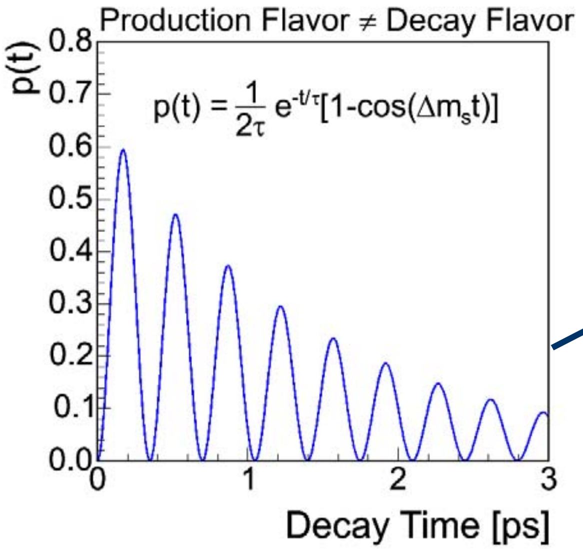
- "opposite side" : look for other B meson in event, if it was matter, the B_s was antimatter!
- "same side": fragmentation remnants

Asymmetry – a useful quantity

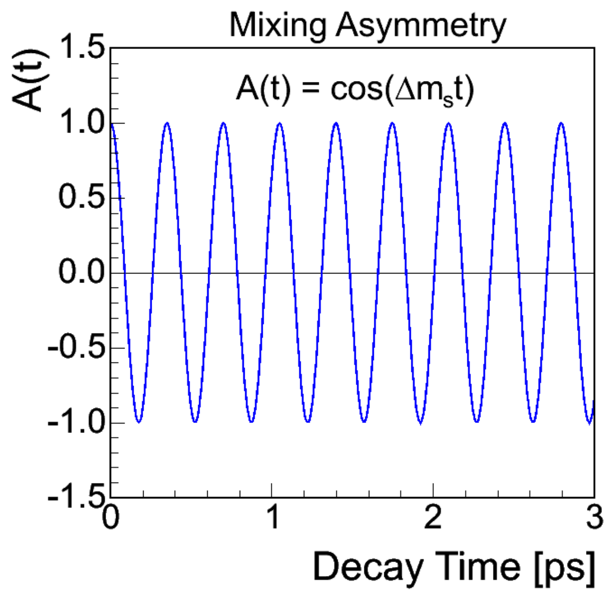
“Right Sign”



“Wrong Sign”



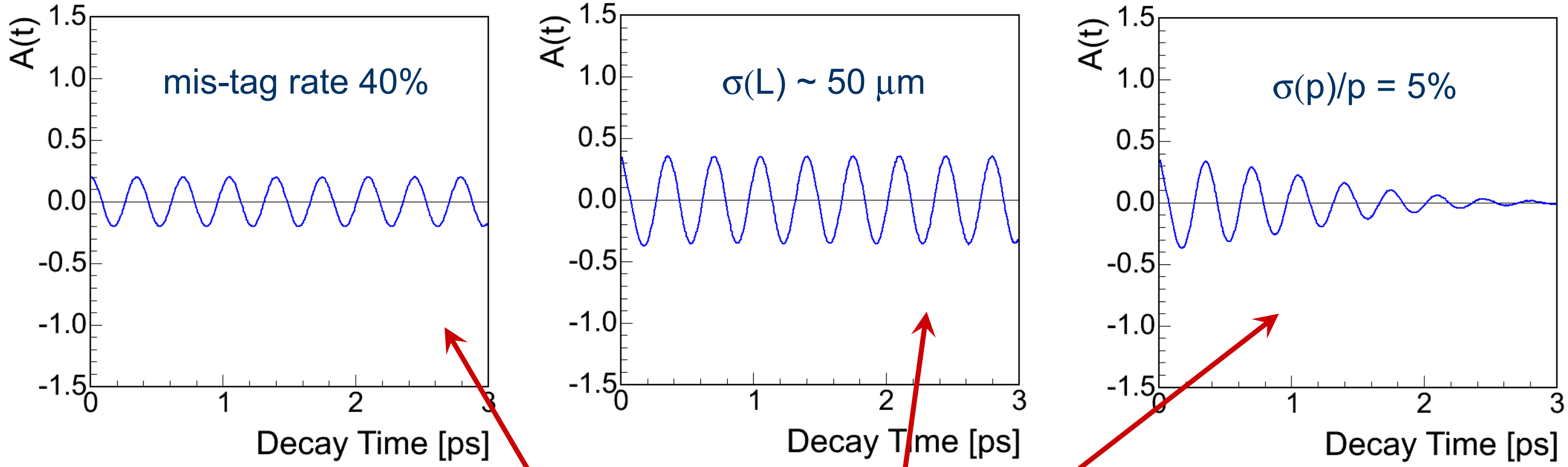
$$A(t) = \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}}$$



what about detector effects?

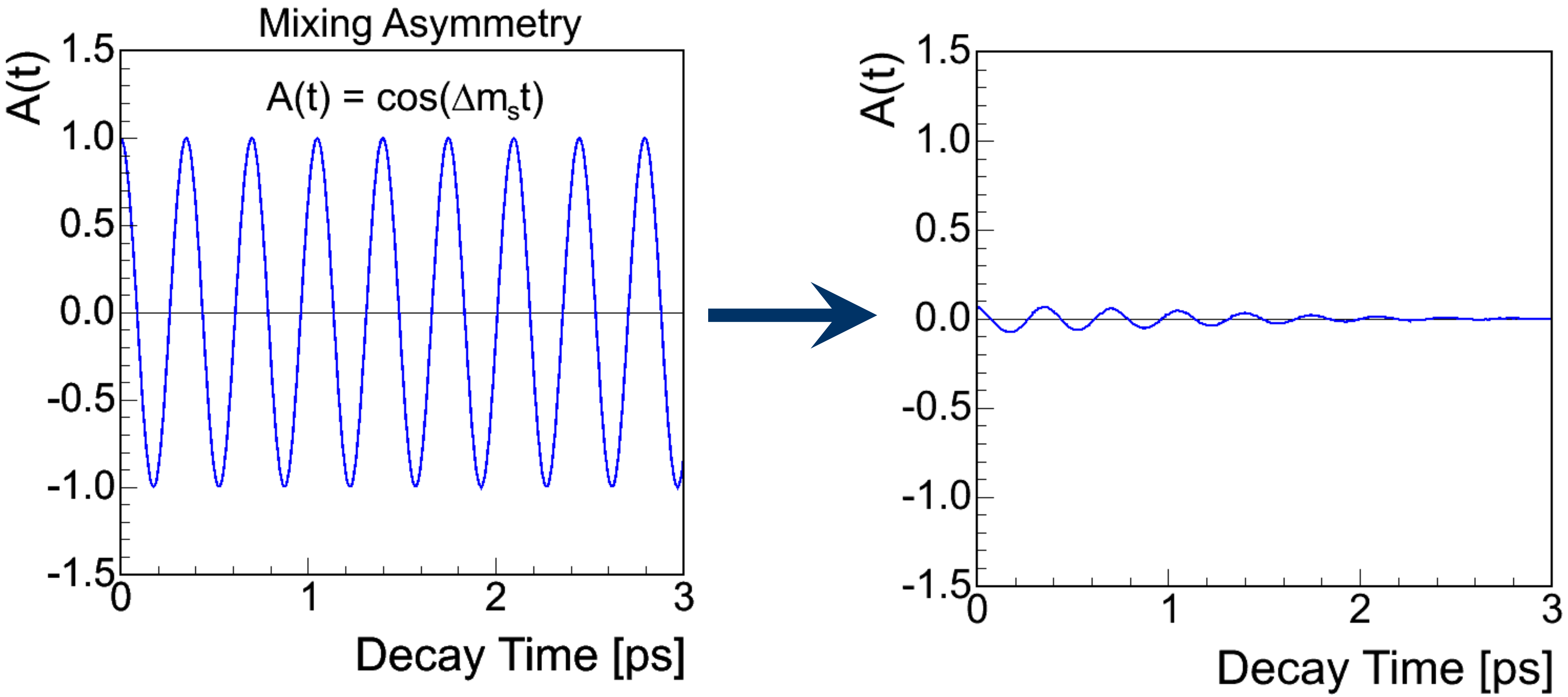
Realistic Detector Effects

flavor tagging power, background | displacement resolution | momentum resolution



$$\frac{1}{\sigma} = \sqrt{\frac{S\epsilon D^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

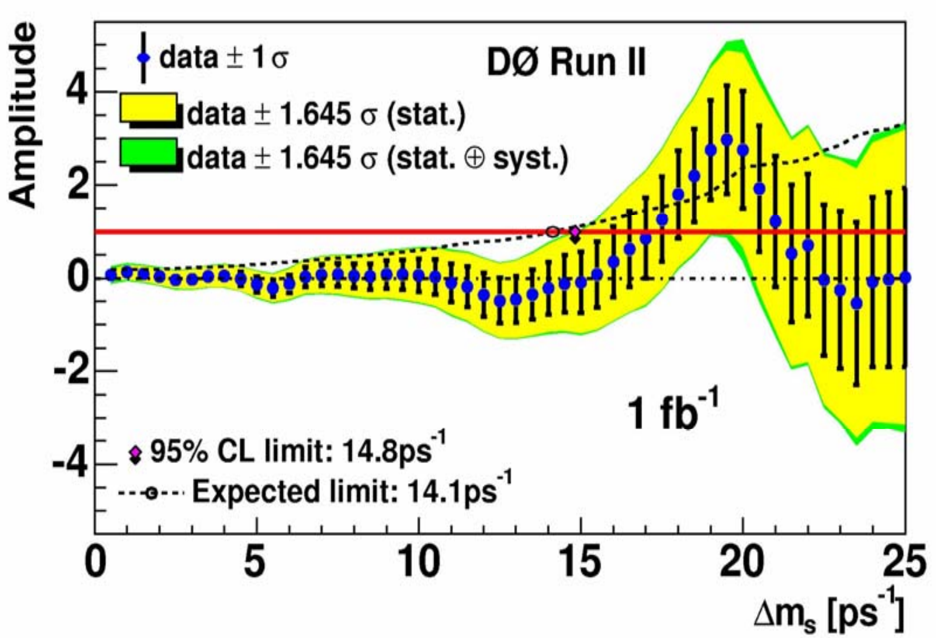
All Effects Together

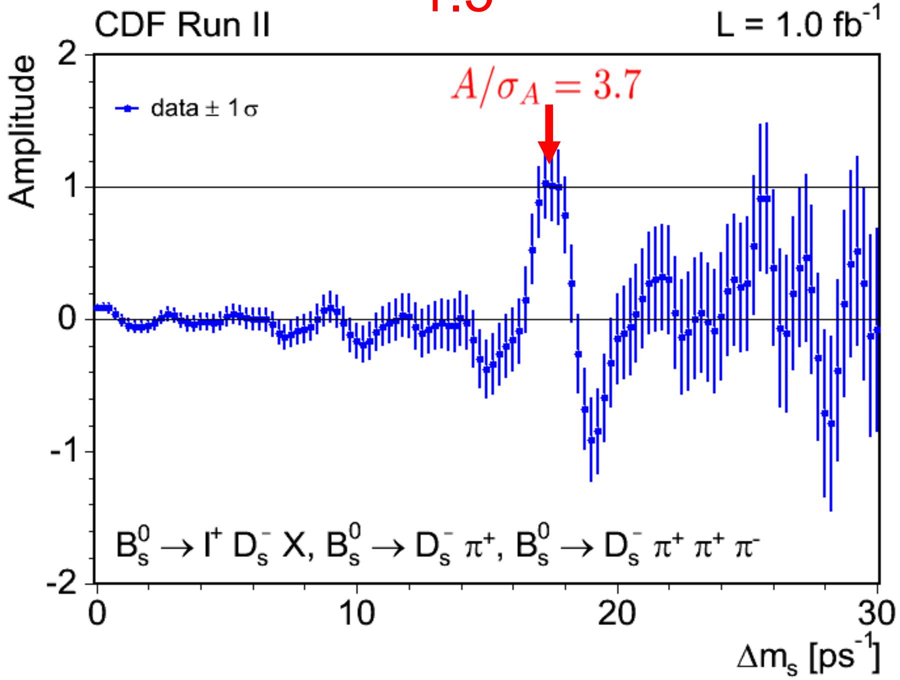


This is why previous measurements have not been able to observe B_s mixing!

Previous Results

- CKM fit, EPS 2005: $\Delta m_s = 18.3^{+6.5}_{-1.5}\ \mathrm{ps}^{-1}$





D0, March 2006: $p = 5\%$

$17\ \mathrm{ps}^{-1} < \Delta m_s < 21\ \mathrm{ps}^{-1}$

PRL 97, 021802 (2006)

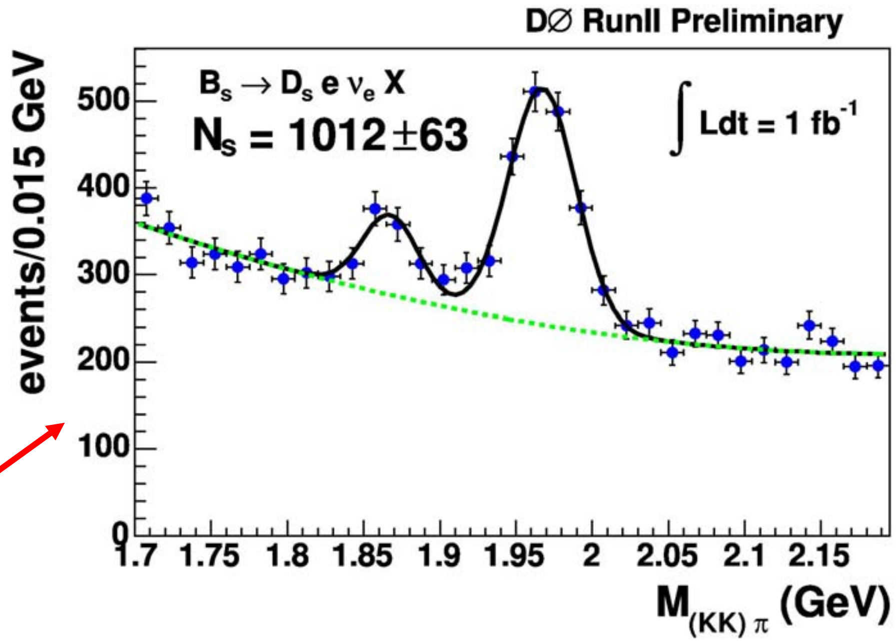
CDF, April 2006: $p = 0.2\%$

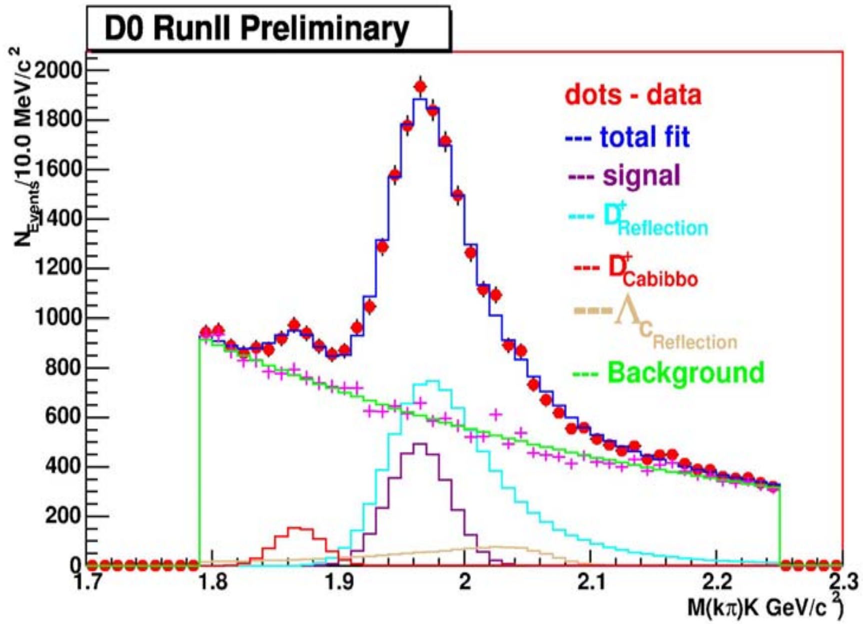
$\Delta m_s = 17.31^{+0.33}_{-0.18}(\mathrm{stat}) \pm 0.07(\mathrm{syst})\ \mathrm{ps}^{-1}$

PRL 97, 062003 (2006)

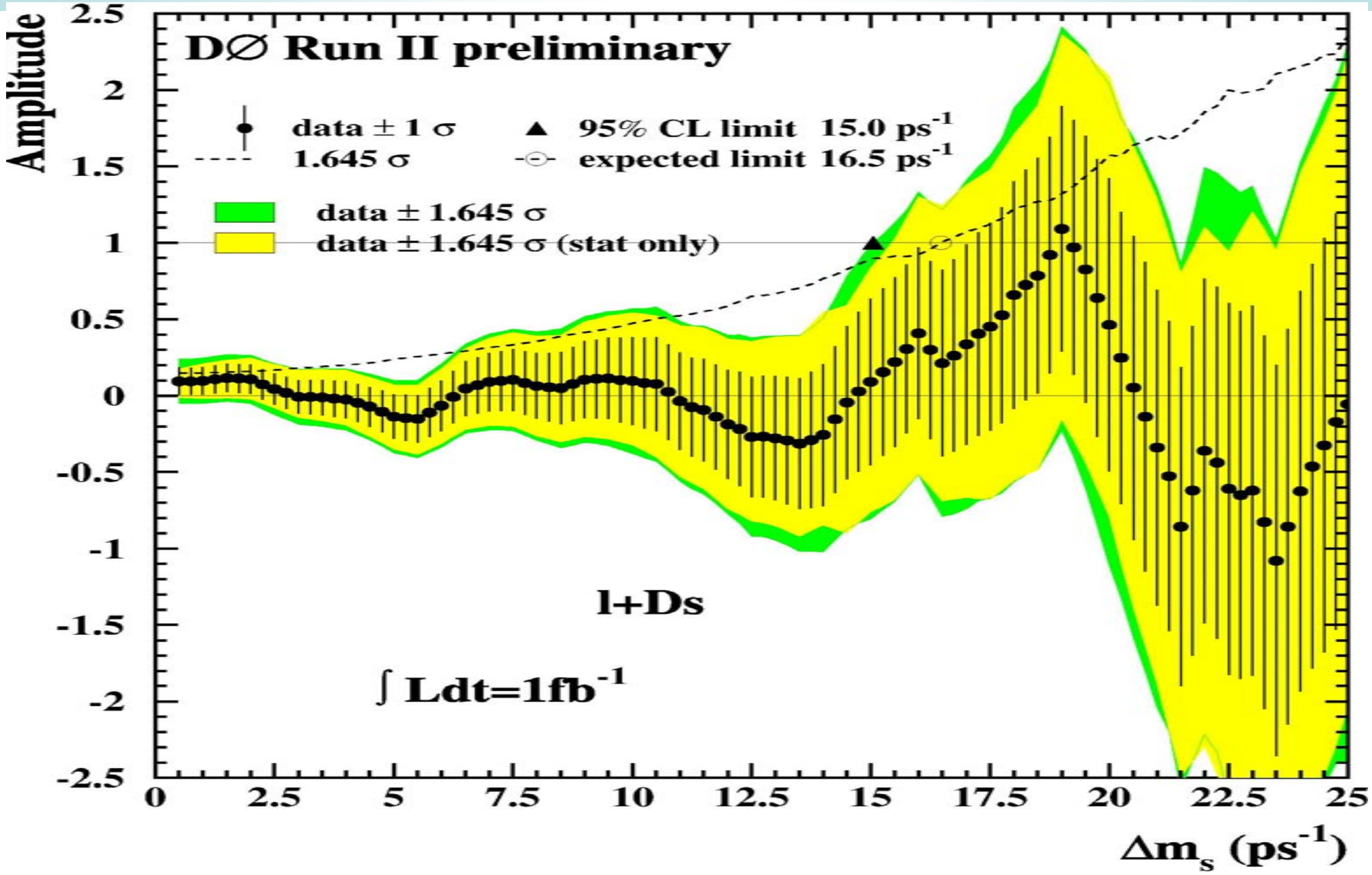
D0 Yield Upgrades

- previous analysis used $\mu + D_s(\phi\pi)$ (5600 events)
- new: $e + D_s(\phi\pi)$ (+ 1000 events)
- new: $\mu + D_s(K^*K)$ (+13 000 events)
- opposite side tagging unchanged





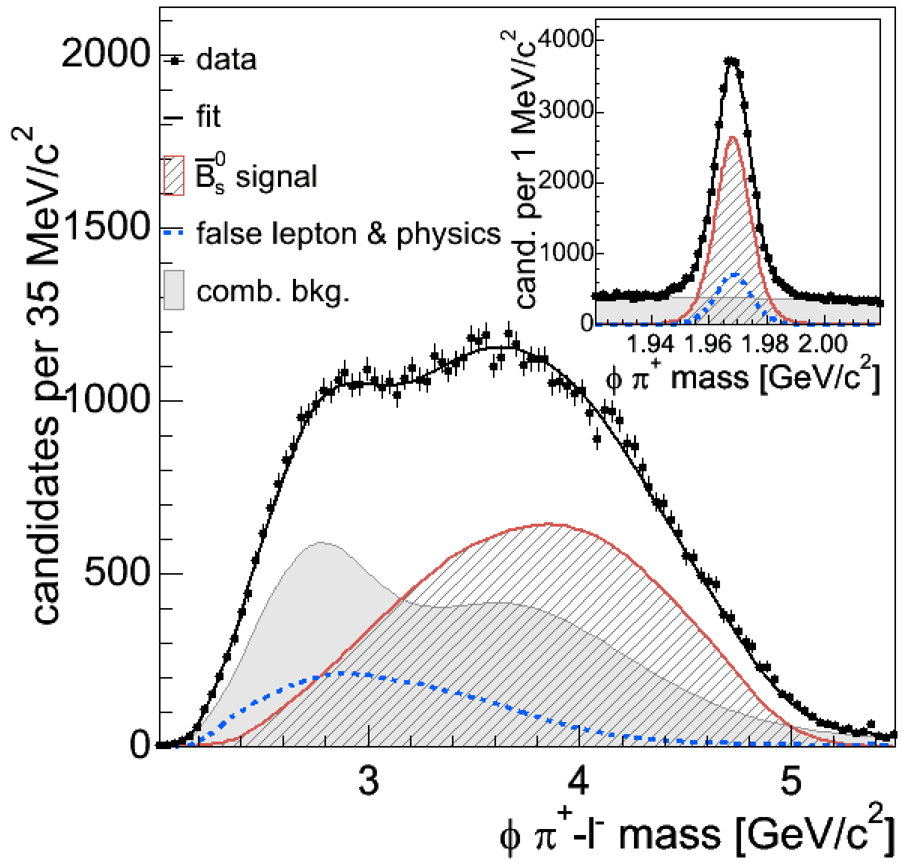
Combined D0 Amplitude Scan



- prob of stat. fluctuation 8%; 17 $ps^{-1} < \Delta m_s < 21\ ps^{-1}$

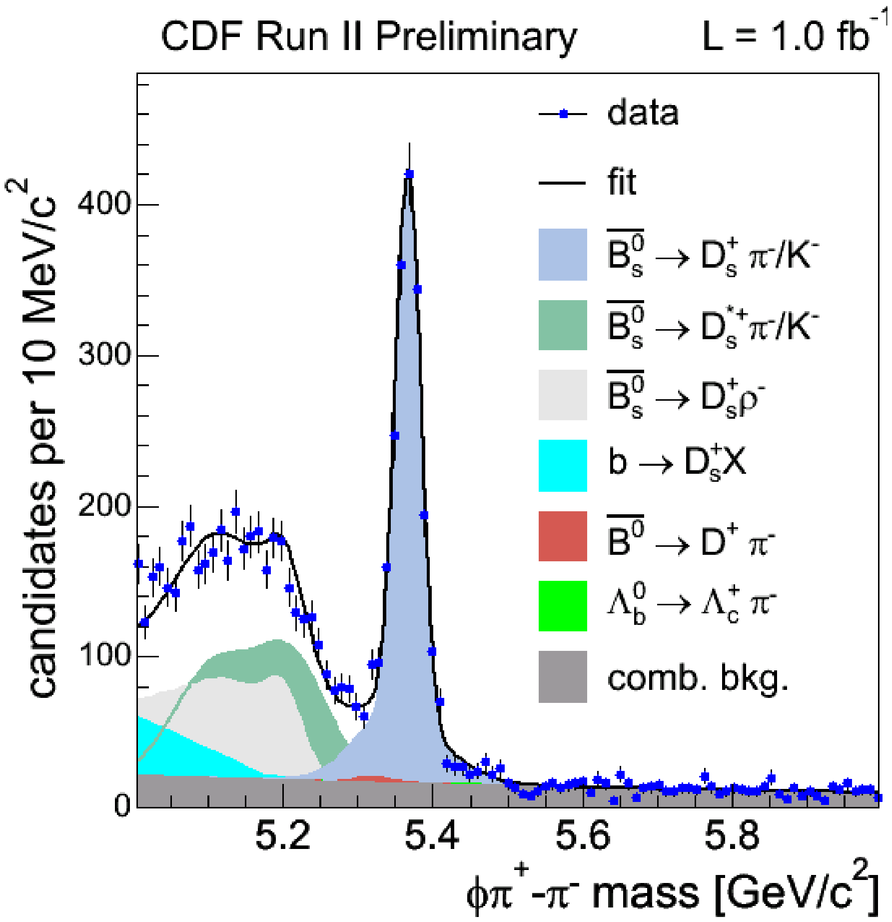
CDF Yield Upgrades: Semileptonic

- use of particle identification
- combined TOF and energy loss in tracker
- most improvement in $D_s \rightarrow K^*K$ (+35%)
- rejects $D^- \rightarrow K^*\pi$
- π in comb. background
- yield: 62k (was 37k)
- S/Bx2 for $D_s \rightarrow K^*K$, $\phi\pi$
- added new trigger paths



CDF Yield Upgrades: Hadronic

B Mode	Signal	S/B
(ϕπ)π	2000 (1600)	+13%
partial	3100 (-)	-
(K*K)π	1400 (800)	+35%
(3π)π	700 (600)	+22%
(ϕπ)3π	700 (500)	+92%
(K*K)3π	600 (200)	+110%
(3π)3π	200 (-)	-
Total	8700 (3700)	-



- partial reconstruction, particle ID, NN selection

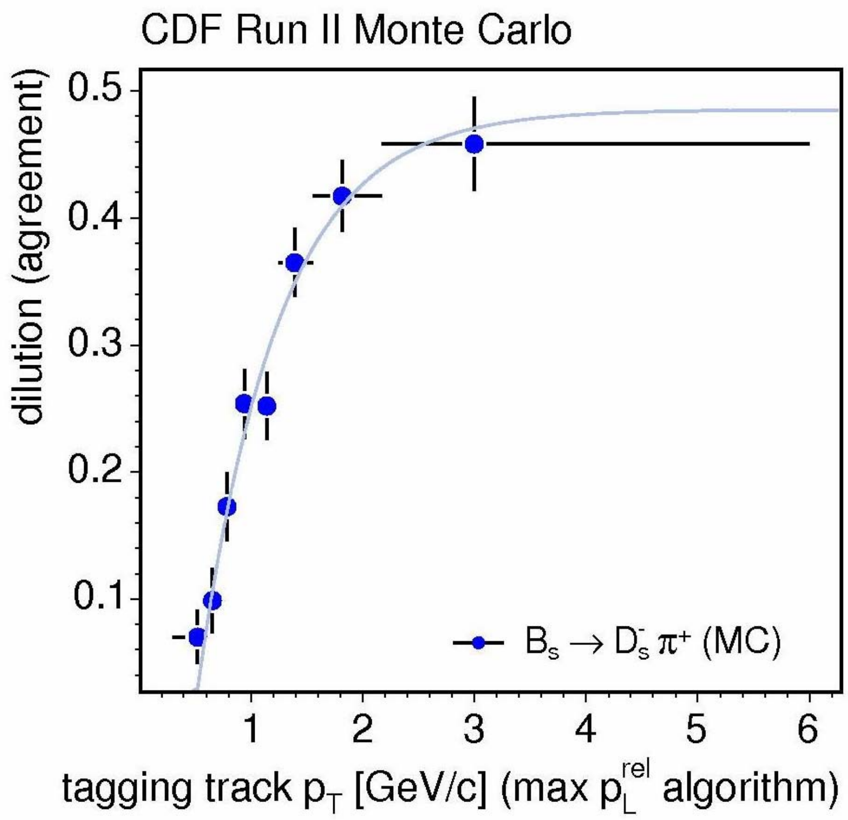
CDF Tagging Upgrades: Opposite Side Tagger

tagger	efficiency	dilution	εD^2
Muon	4.6±0.0	34.7±0.5	0.58±0.02
Electron	3.2±0.0	30.3±0.7	0.29±0.01
JQT	95.5±0.1	9.7±0.2	0.90±0.03
Kaon	18.1±0.1	11.1±0.9	0.23±0.02
OST Old	95.6±0.1	11.9±0.1	1.34±0.03
OST NN	95.8±0.1	12.7±0.2	1.54±0.04

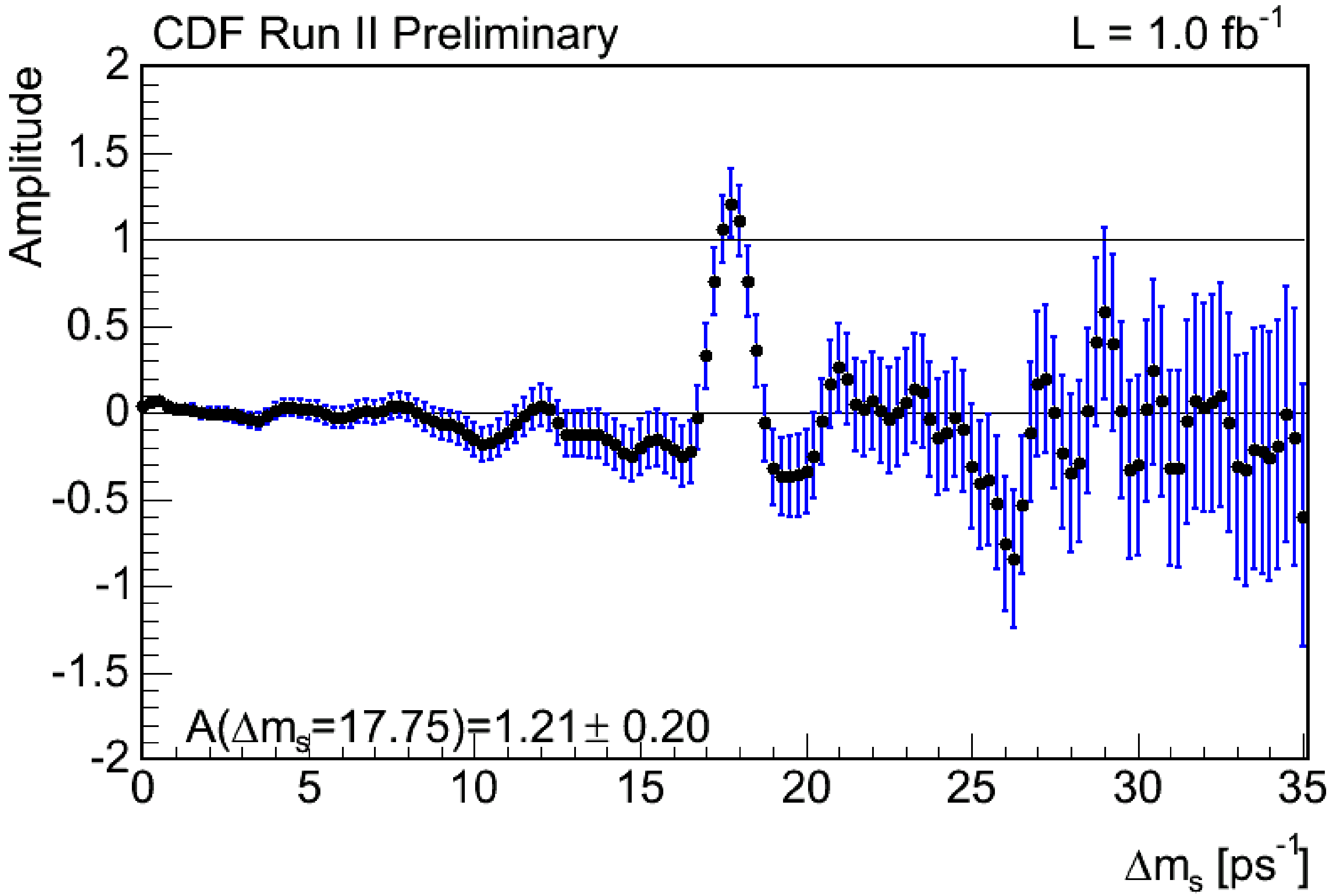
- new opposite side kaon tagger
- combination of opposite side tags: NN vs hierarchy

CDF Tagging Upgrades: Same Side Tagger

- old SSKT used only particle id information
- dilution is found to depend on several kinematic variables
- NN with PID, kinematic input
- hadronic: $\varepsilon D^2 = 3.5\%$ (+0% relative improvement)
- semilept: $\varepsilon D^2 = 4.8\%$ (+8% relative improvement)

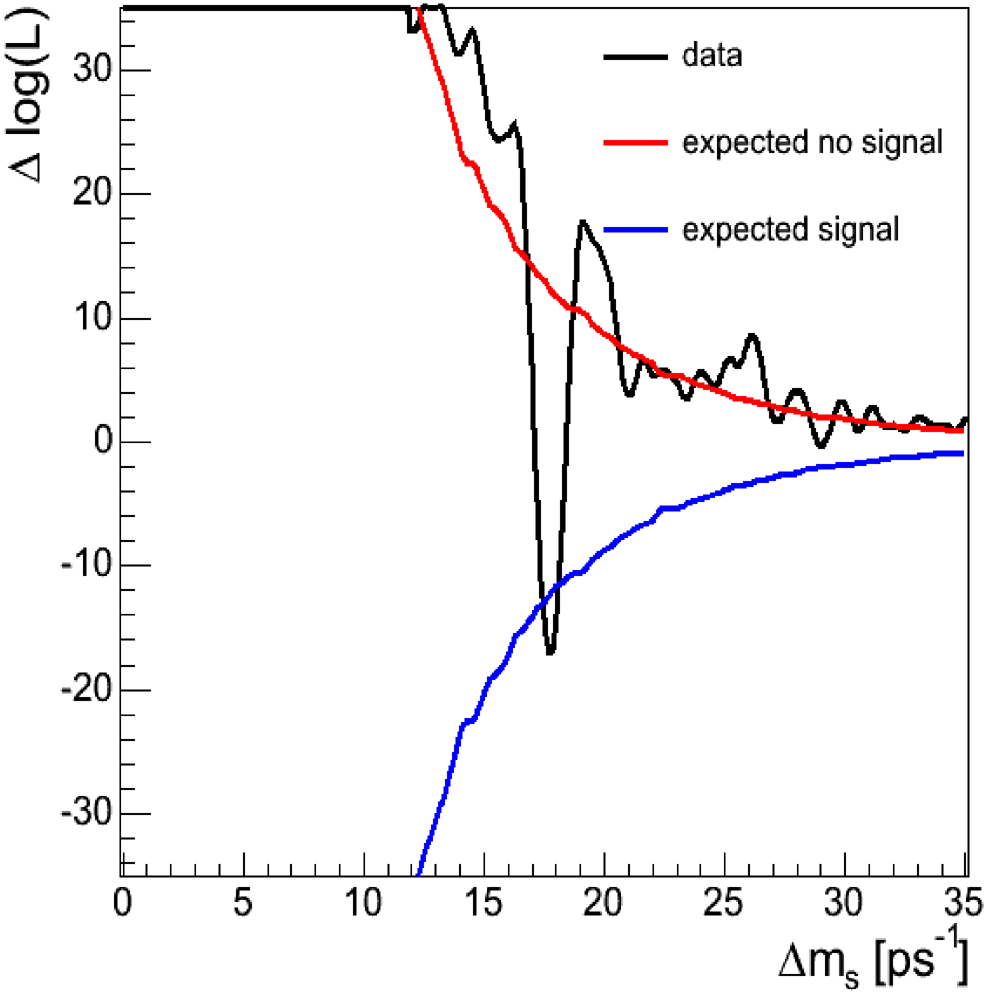


CDF Combined Amplitude Scan

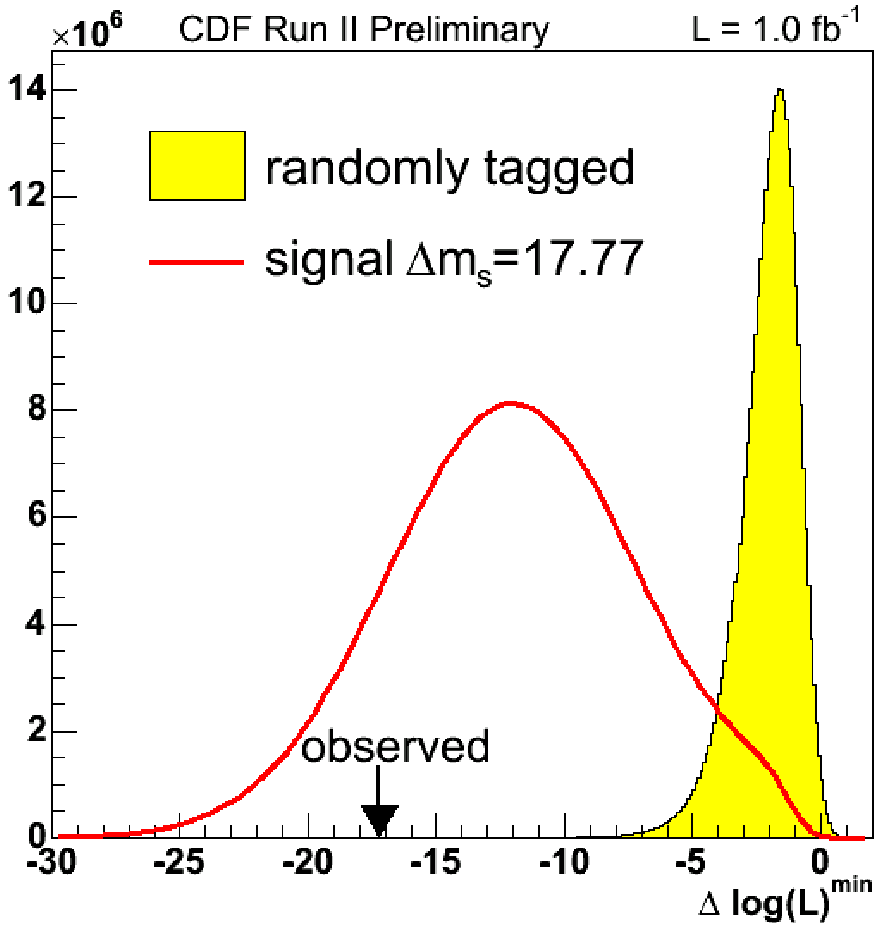


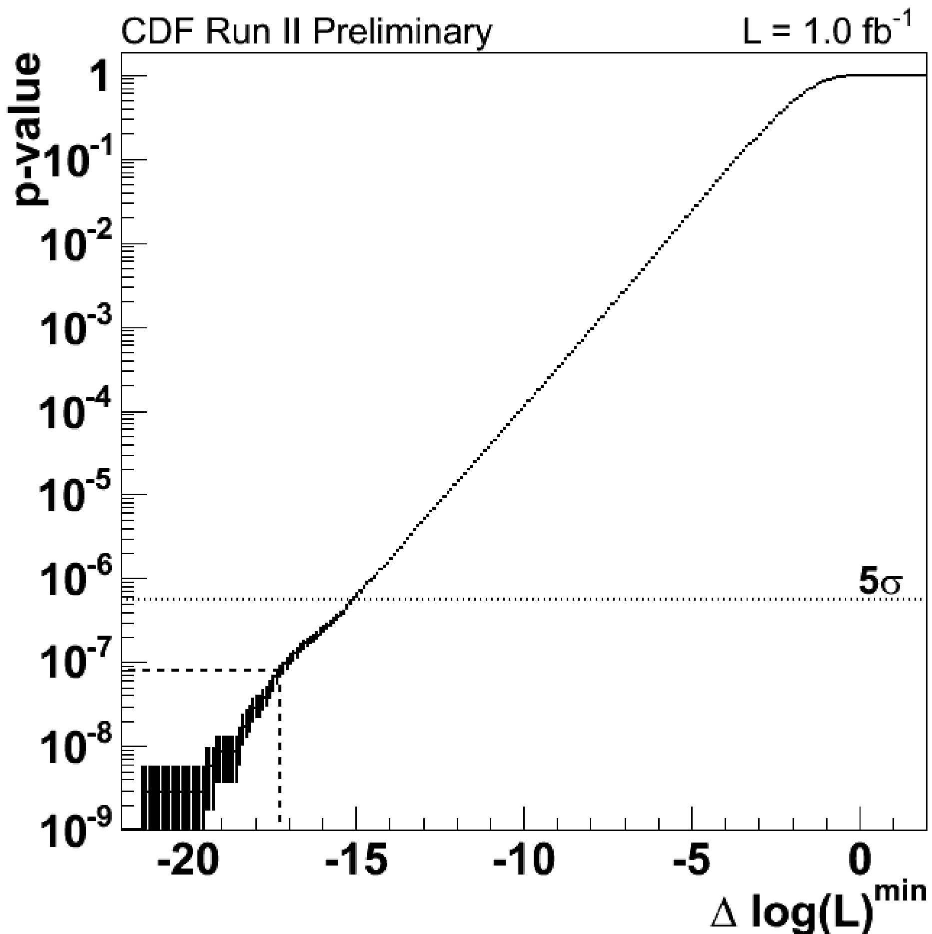
CDF Likelihood Shape

- log [L(A=0) / L(A=1)]
- min Δlog(L) = -17.26
- probability of random tags conspiring to produce a likelihood this deep?



Probability of a Statistical Fluctuation





28 trials out of 350 million p = 8×10^{-8}

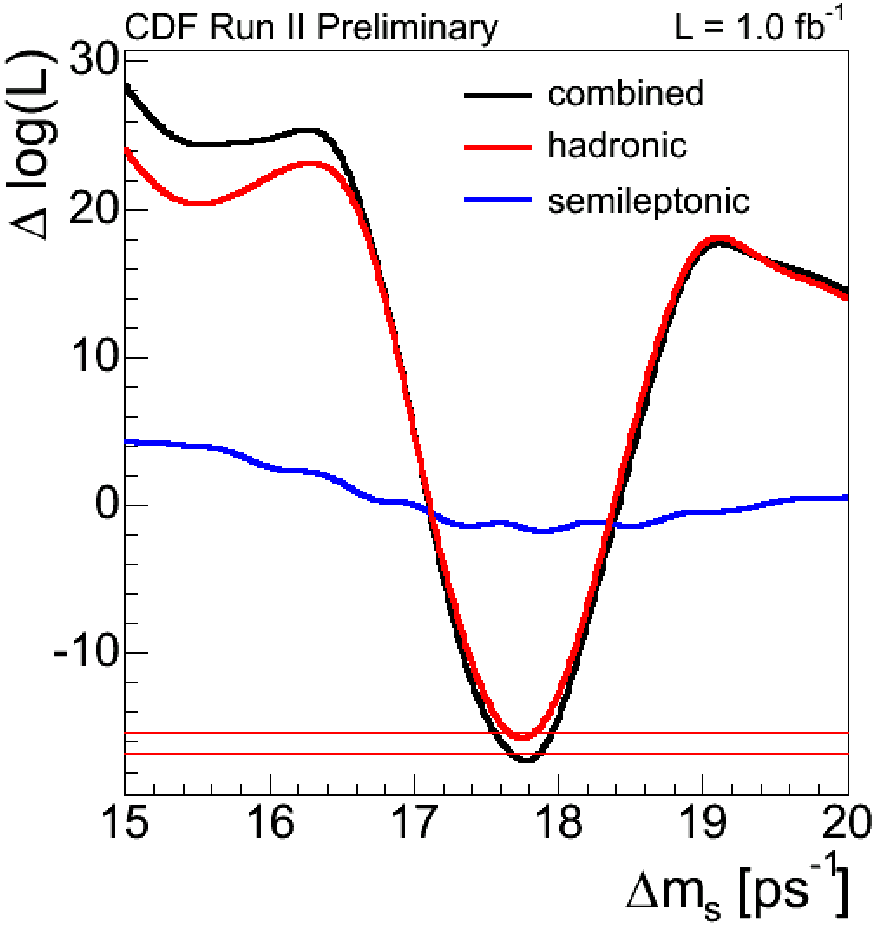
5 std. deviations = 5.7×10^{-7} → OBSERVATION

Frequency Measurement

$\Delta m_s = 17.77 \pm 0.10(\text{stat}) \pm 0.07(\text{syst})\ \text{ps}^{-1}$

- submitted to PRL last Monday
- ArXiv: hep/ex 0609040
- systematic:
  - Decay time scale
  - Other effects are small

- agrees with SM: $18.3^{+6.5}_{-1.5}$ ps^{-1}
- agrees with previous measurement:
- $17.31^{+0.33}_{-0.18}$ (stat) §0.07 (syst) ps^{-1}



Measurement of V_{td}/V_{ts}

- relation between $\Delta\, m_q$ and V_{tq}:

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m(B_s)}{m(B_d)}\xi^2 \left|\frac{V_{ts}}{V_{td}}\right|^2$$

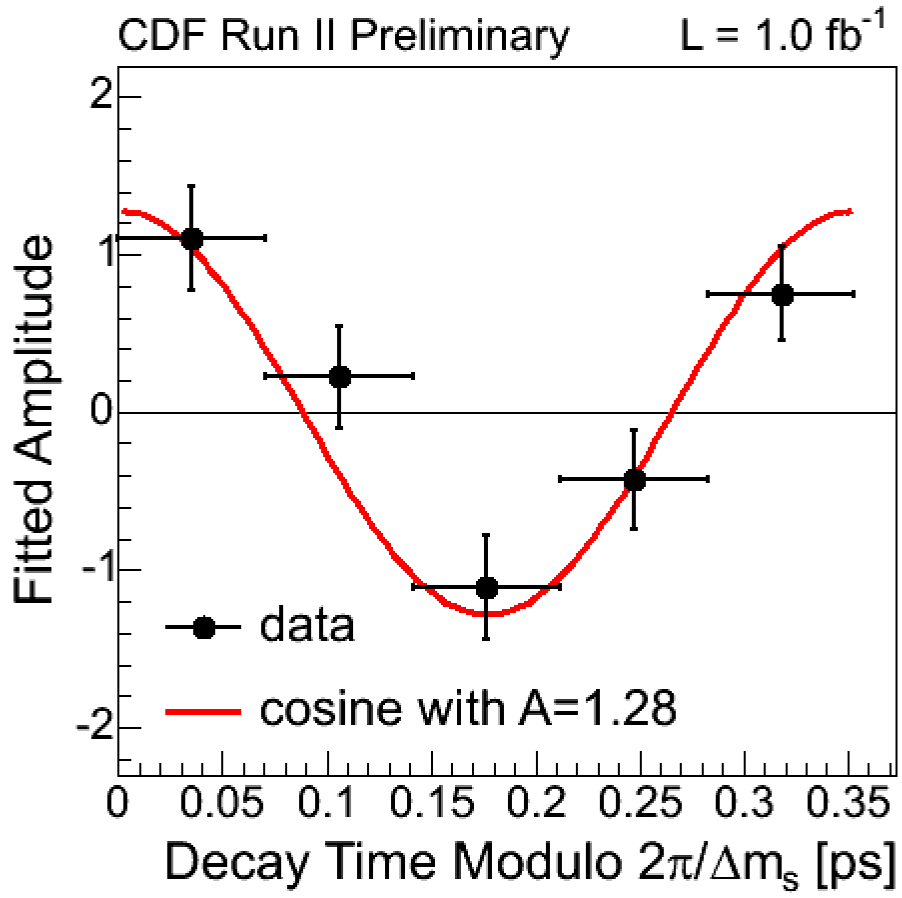
- inputs:
- $m(B_d)/m(B_s) = 0.98390$
- $\xi = 1.21^{+0.047}_{-0.035}$
- $\Delta\, m_D = 0.507$ § $0.005\ ps^{-1}$
- $|V_{td}/V_{ts}| = 0.2060 \pm 0.0007(exp)\ ^{+0.0081}_{-0.0060}\ (theo)$
- Belle PRL 96 221601 (2006):
- $|V_{td}/V_{ts}| = 0.199\ ^{+0.026}_{-0.025}(exp)\ ^{+0.018}_{-0.016}\ (theo)$

Conclusions

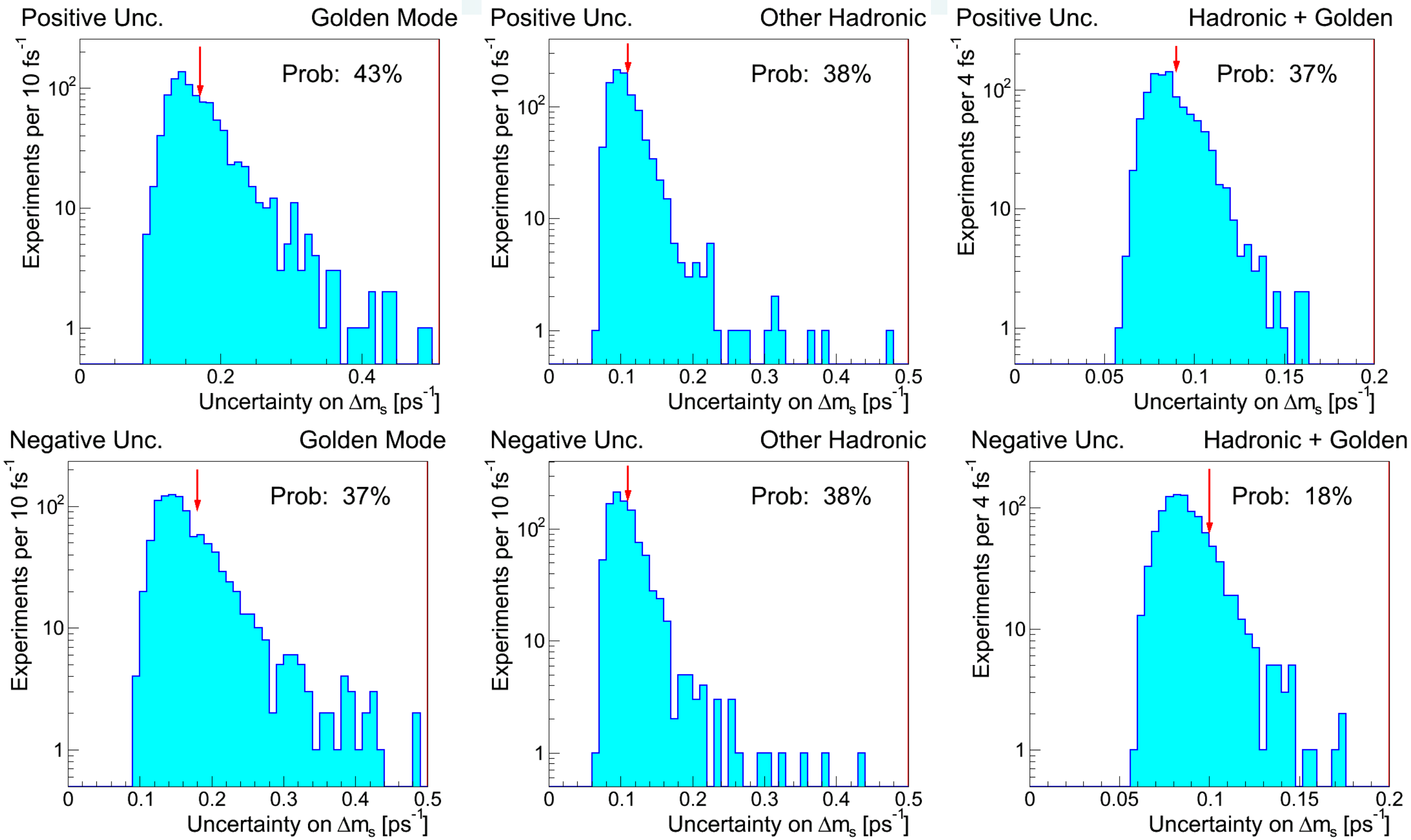
- many results from both detectors with 1 fb^{-1}
- updated jet cross sections
- searches for chargino-neutralino and RS graviton/Z'
- after 20 years of searching, B_s oscillations finally observed at the Tevatron!
- frequency consistent with Standard Model prediction
- extraction of V_{td}/V_{ts} now theory limited (x10)

Time Domain Plot

- time folded modulo oscillation period
- only hadronic decays participate
- A=1.28 from hadronic-only scan



Uncertainty on Δm_s



B_s Meson Decays

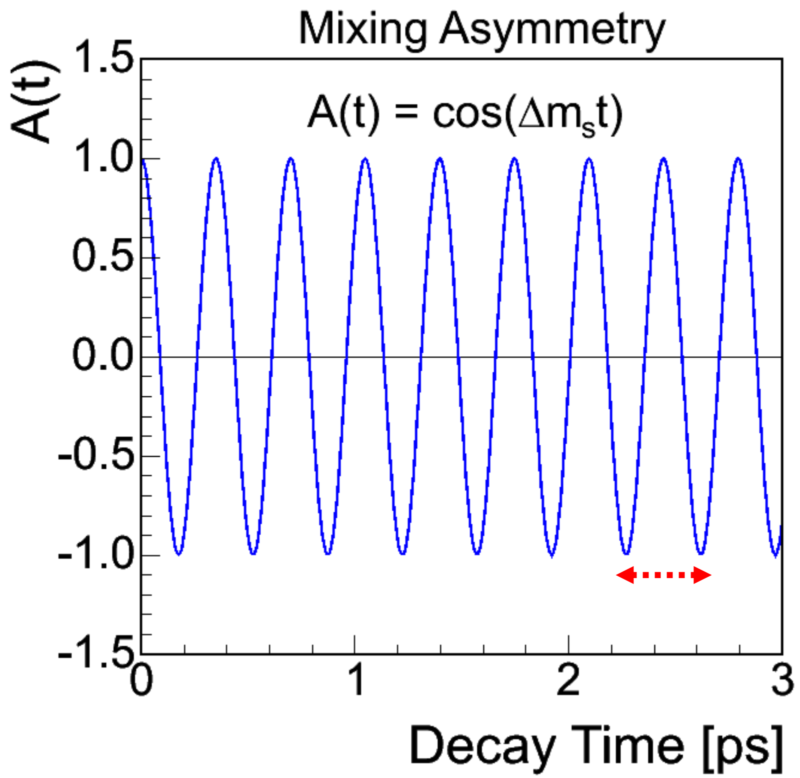
Hadronic Decays

- $B_s!D_s\pi$, $D_s3\pi$
- $D_s!\phi\pi$, K^*K, $\pi\pi\pi$
- small branching fraction
- excellent momentum resolution
- excellent decay time resolution

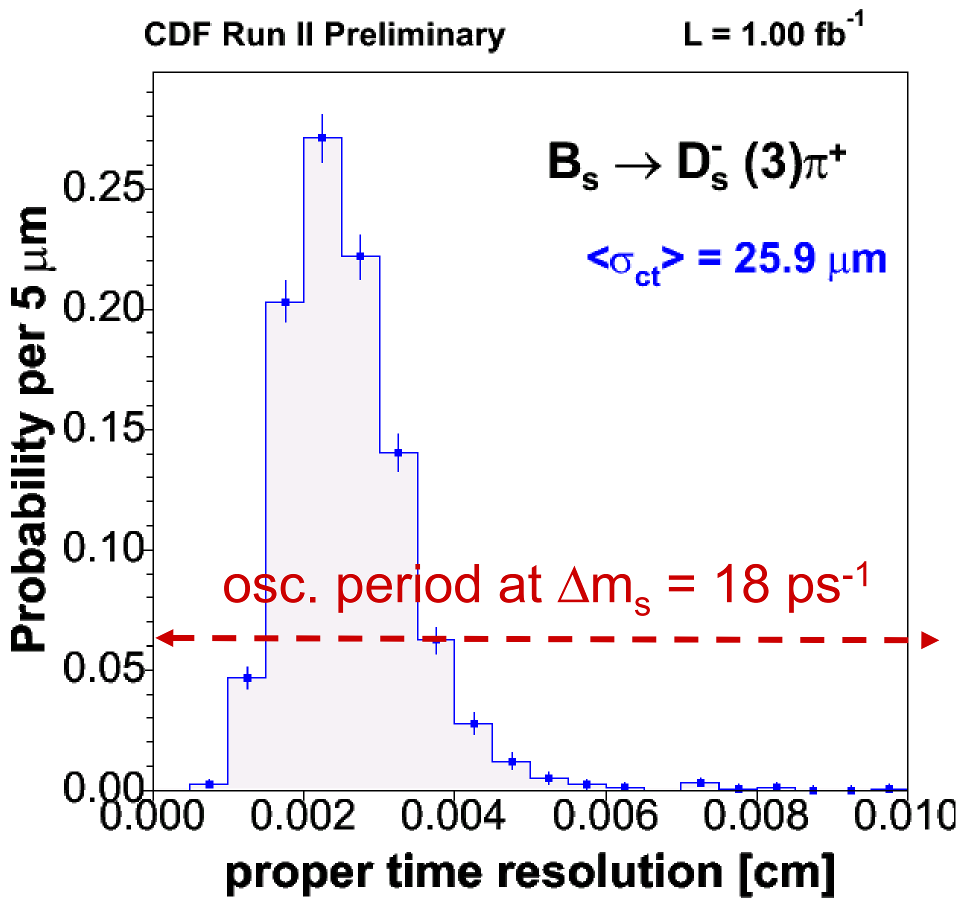
Semileptonic Decays

- B_s ! D_s l ν
- D_s ! $\phi\pi$, K^*K, $\pi\pi\pi$
- large branching fraction
- missing momentum
- corrected on average (K factor)
- inferior decay time resolution

Decay Time Resolution

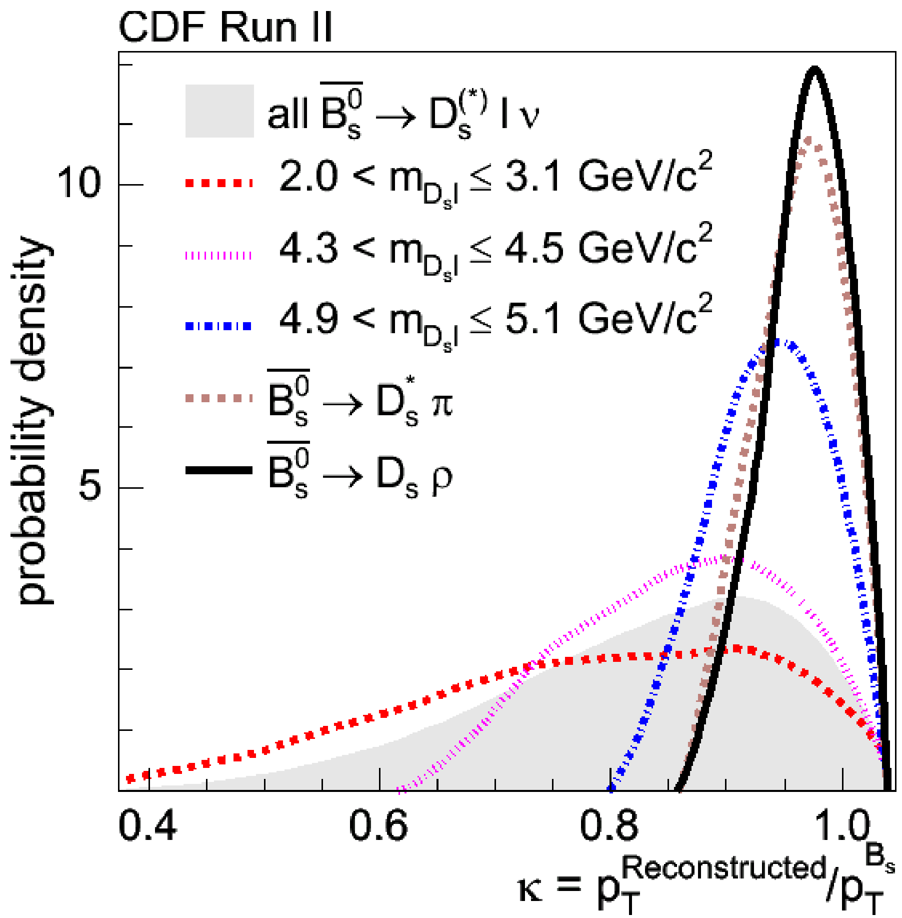


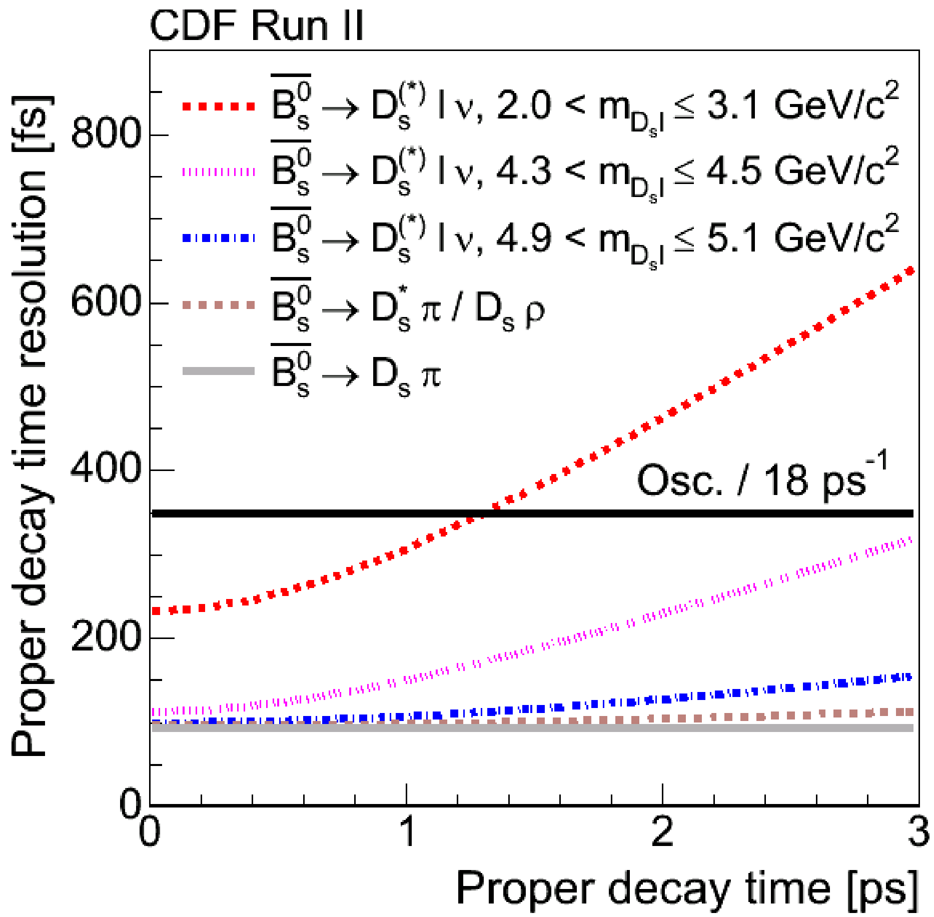
Avg resolution ~¼ period at $\Delta m_s = 18\ ps^{-1}$



superior decay time resolution gives CDF sensitivity at larger values of Δm_s than previous experiments

Semileptonic vs Hadronic vs Partial





Fourier Transform of Asymmetry

$$\mathcal{A}(\Delta m) = \int_0^{T_{max}} \mathcal{A}(t)\cos(\Delta m \cdot t)dt$$

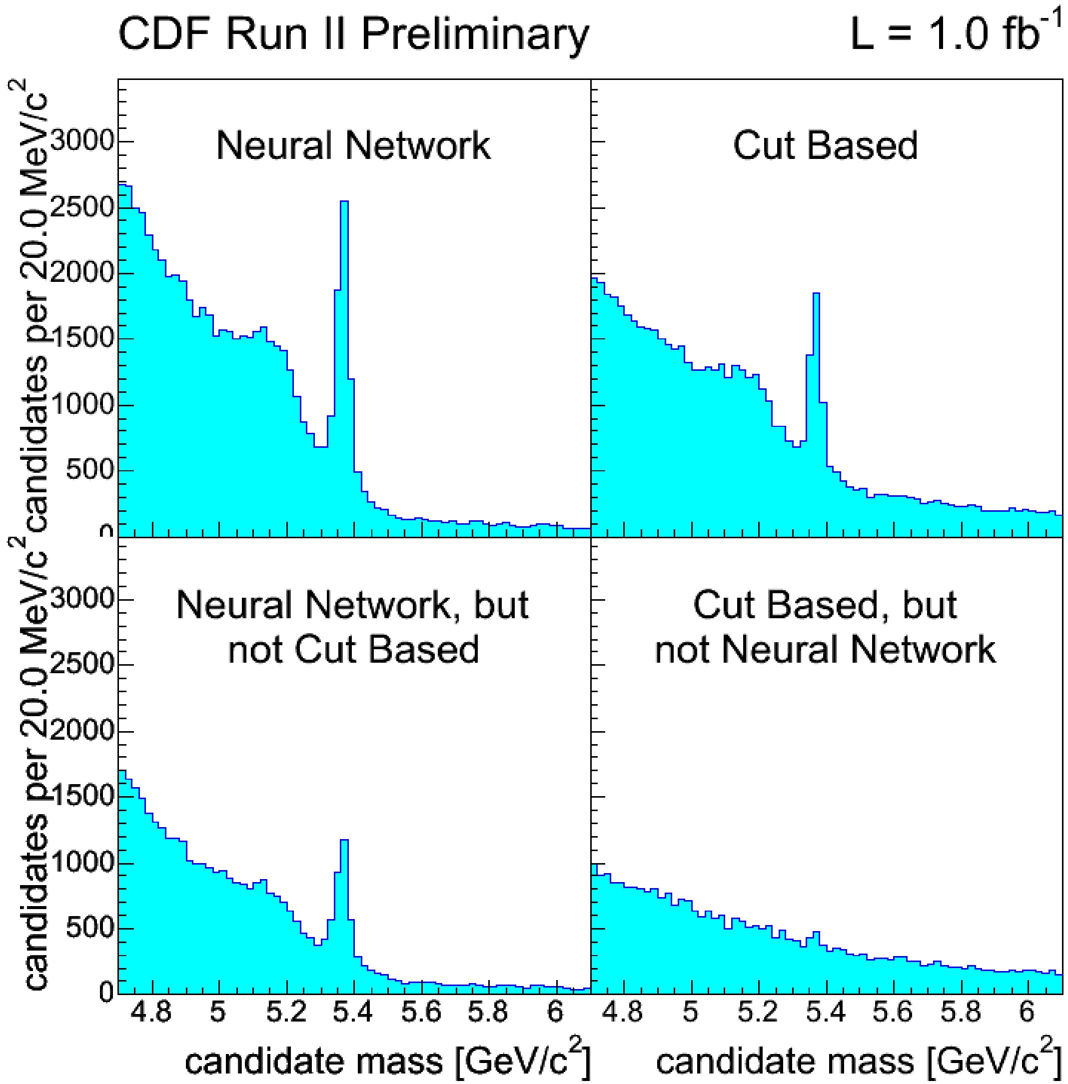
- Useful properties:

A(Δm) ¼ 0 if no mixing at Δm

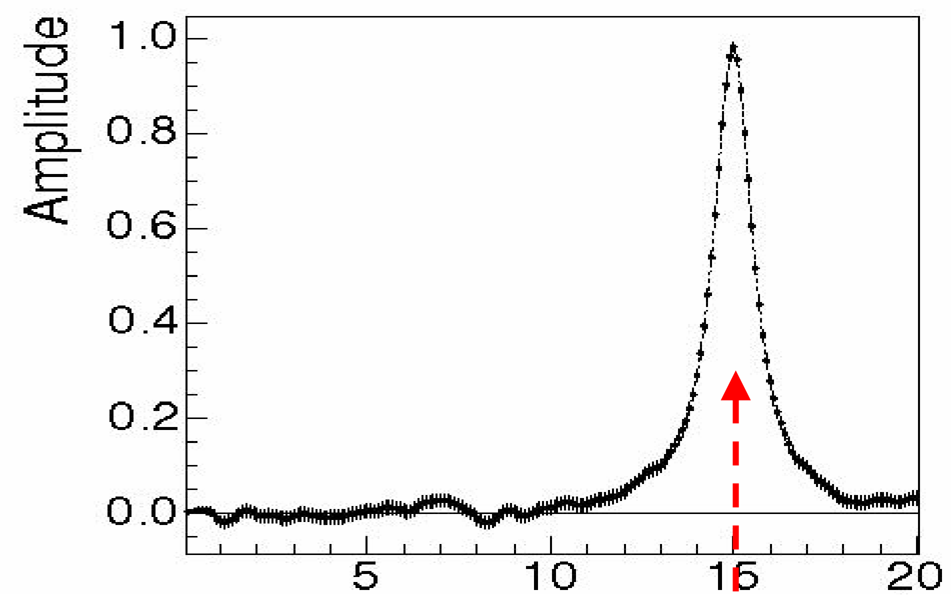
A(Δm) ¼ 1 if mixing at Δm

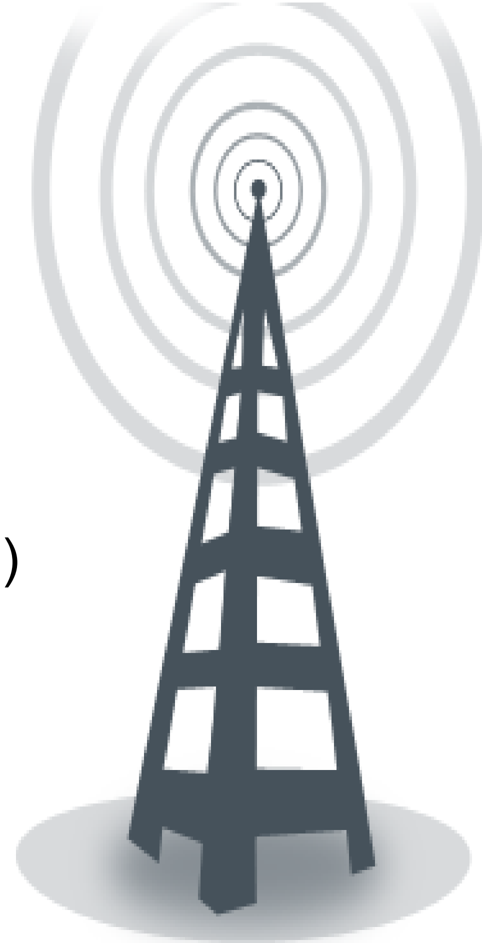
“calibrated for detector effects”

Neural Network Selection

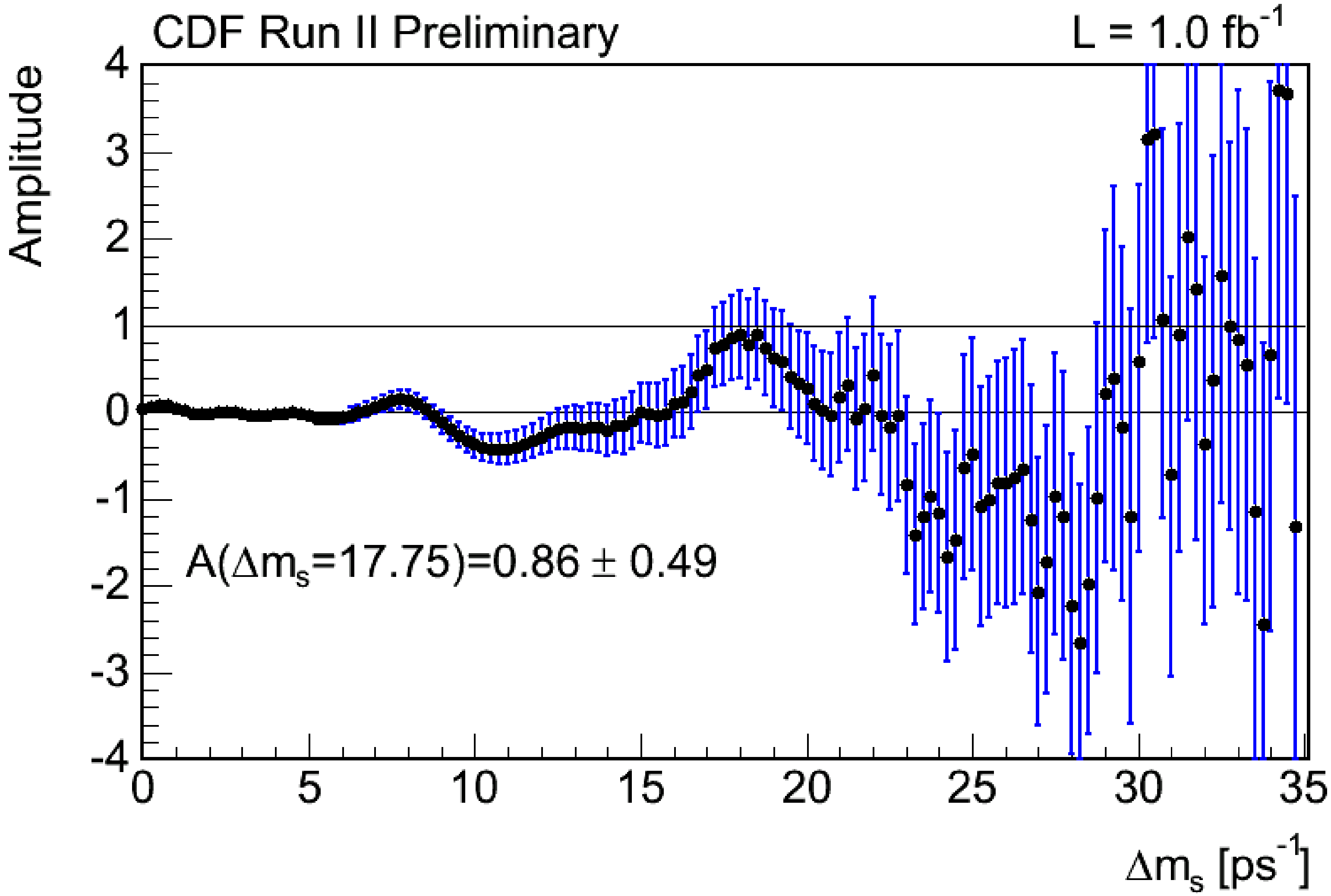


Amplitude “Scanning”

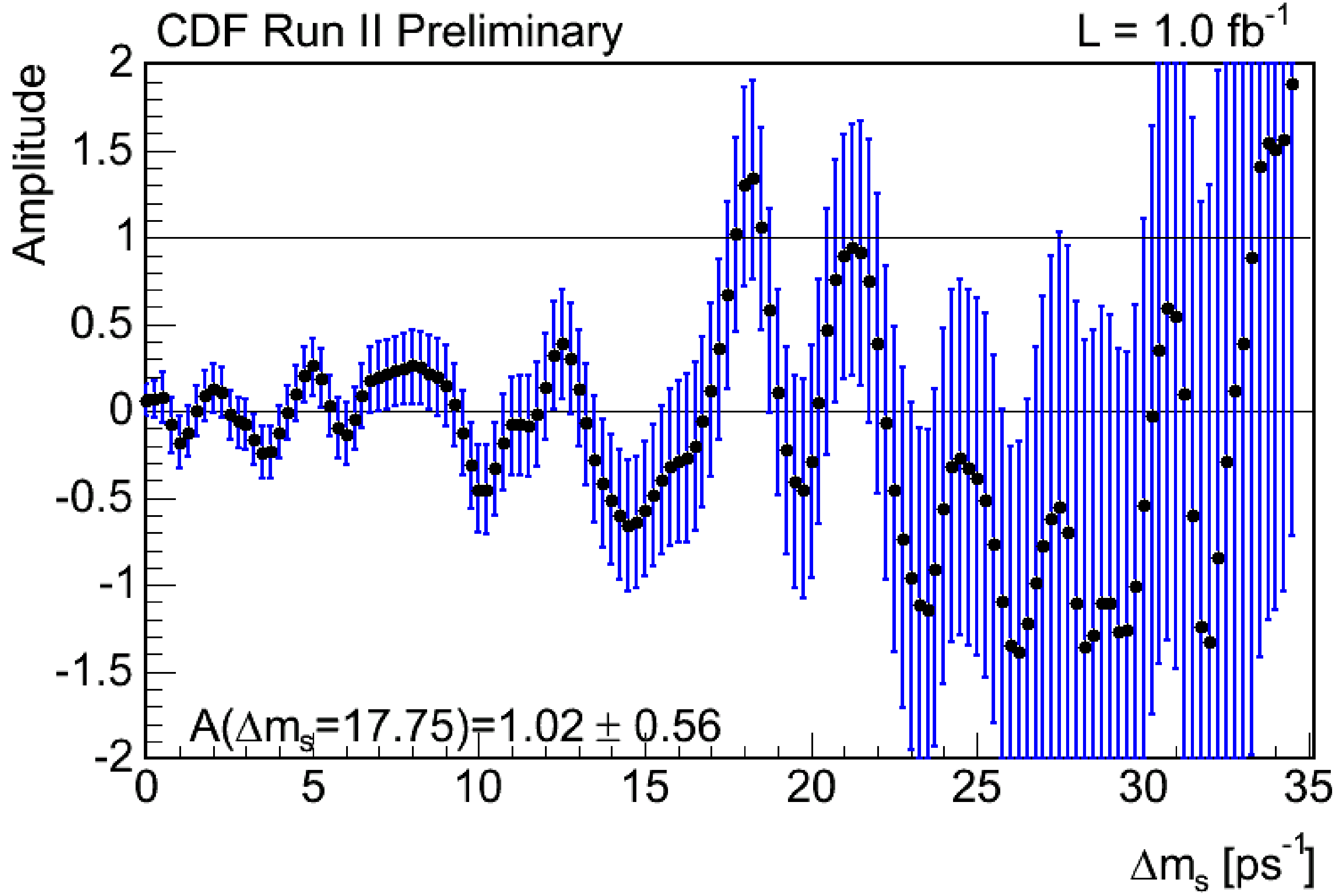




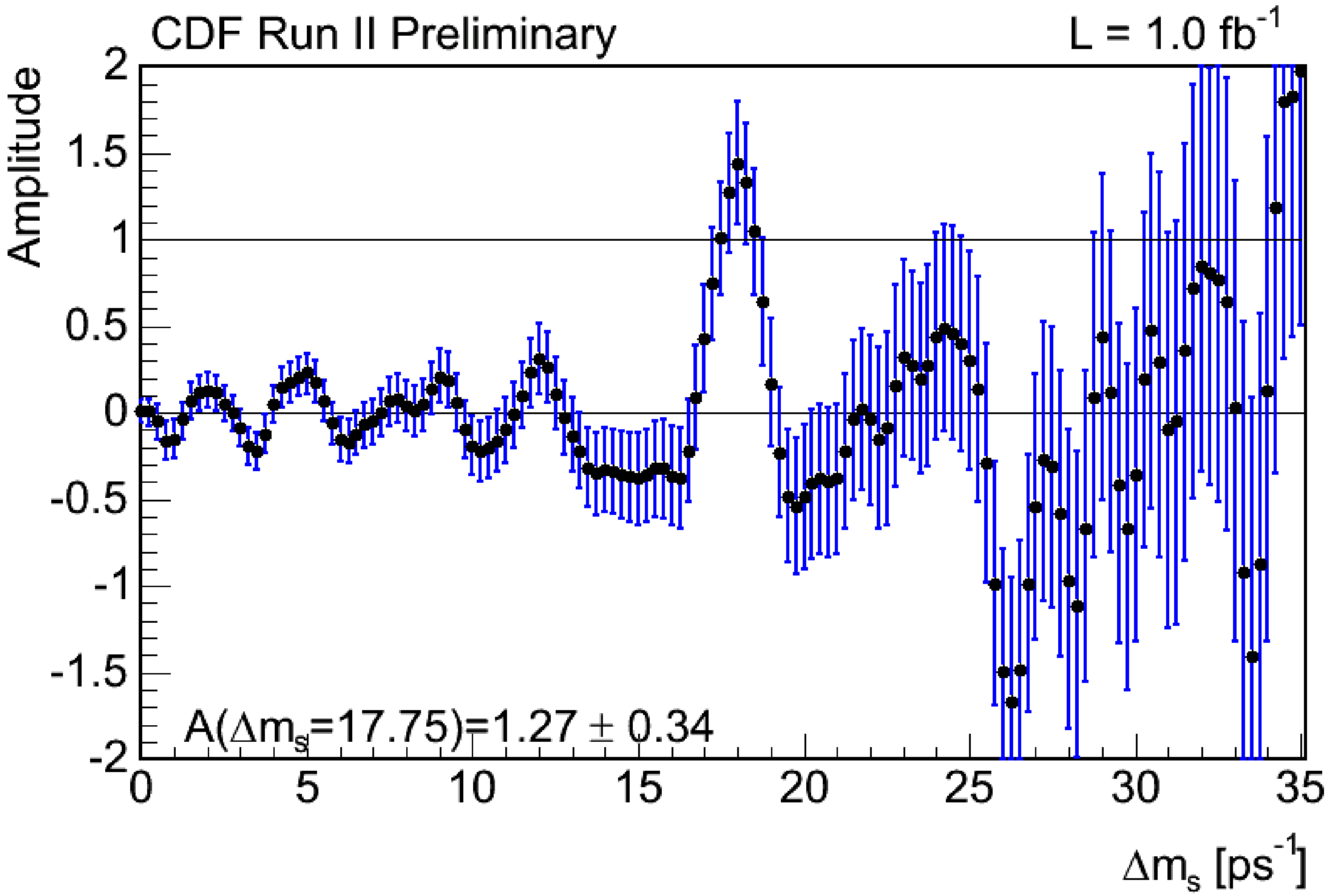
Amplitude Scan: Semileptonic Modes



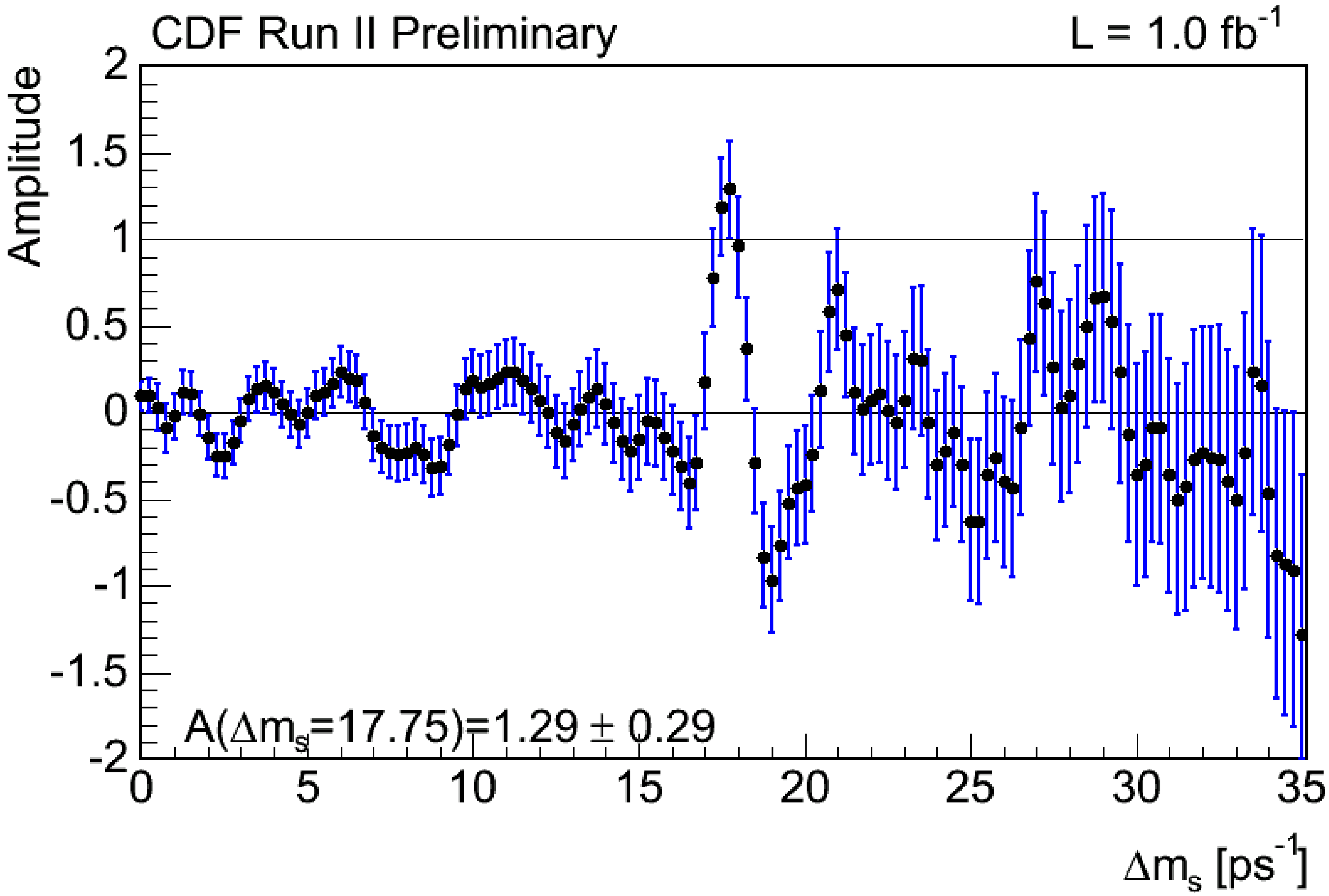
Amplitude Scan: Partially Reconstructed Decays



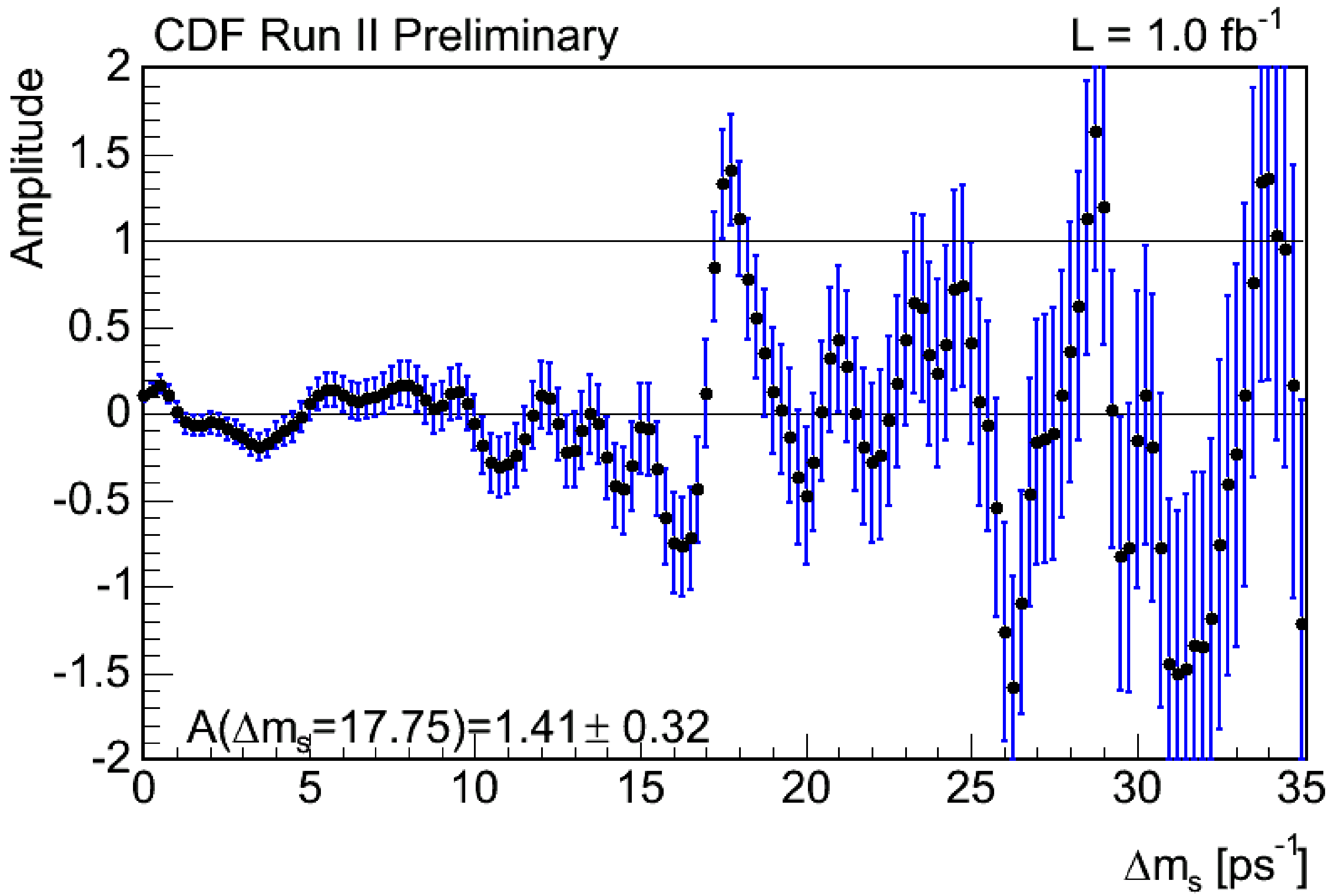
Amplitude Scan: "Golden Mode"



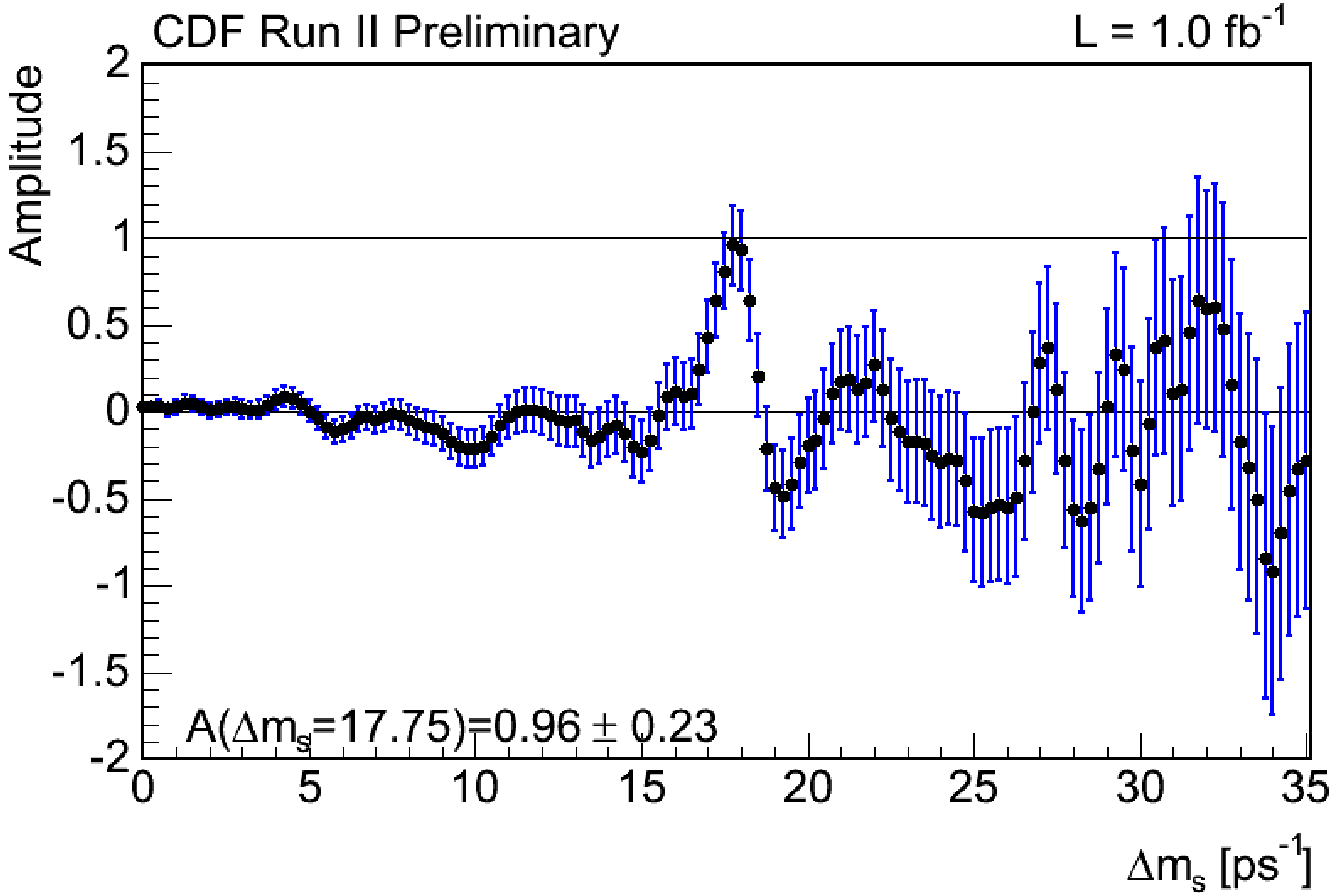
Amplitude Scan: Hadronic Modes



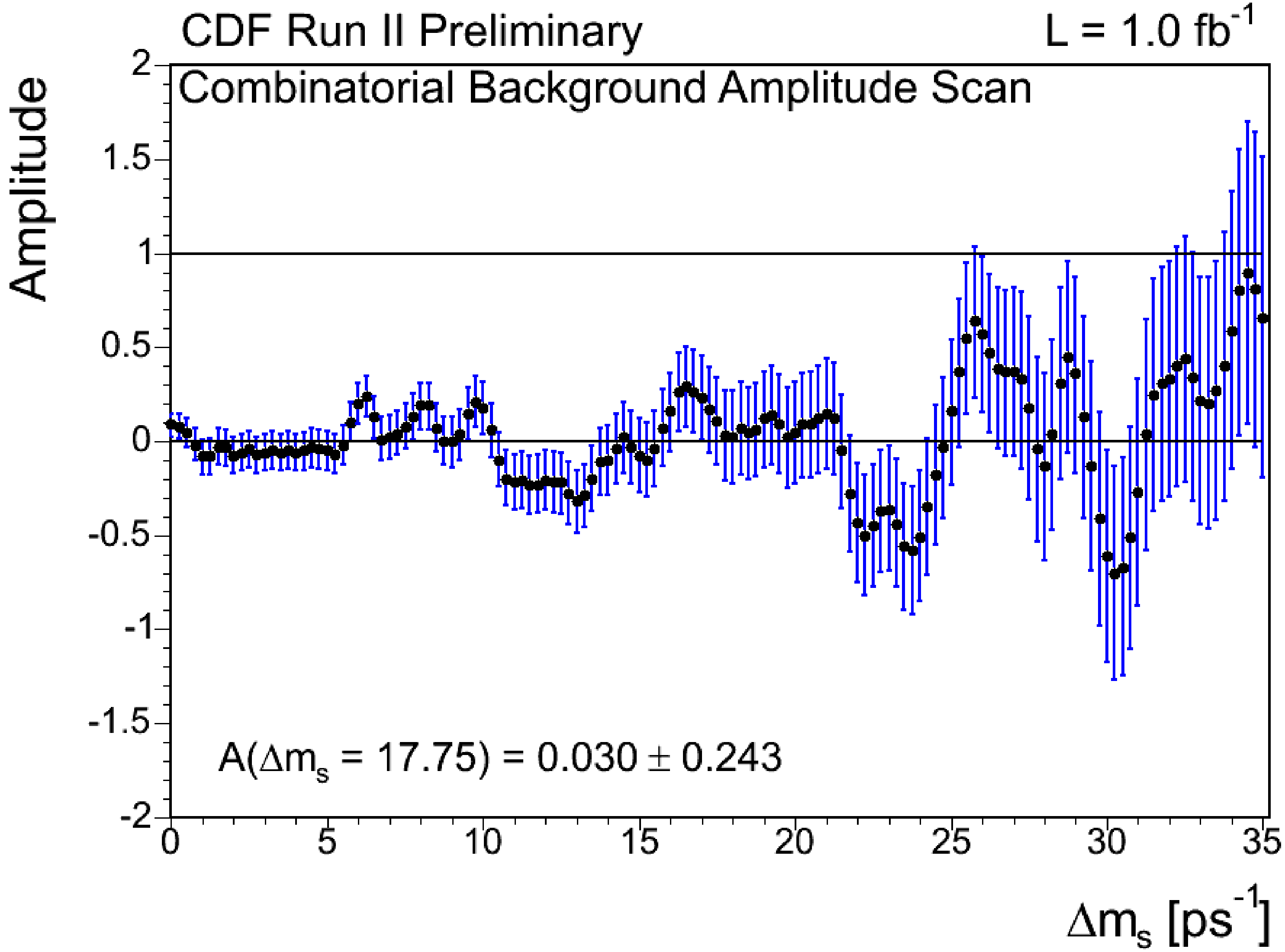
Amplitude Scan: Opposite Side Tags



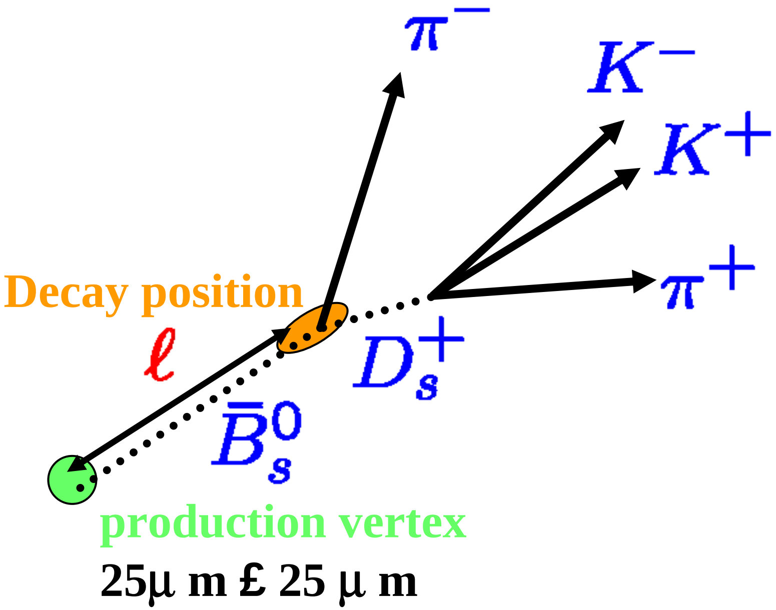
Amplitude Scan: Same Side Tags

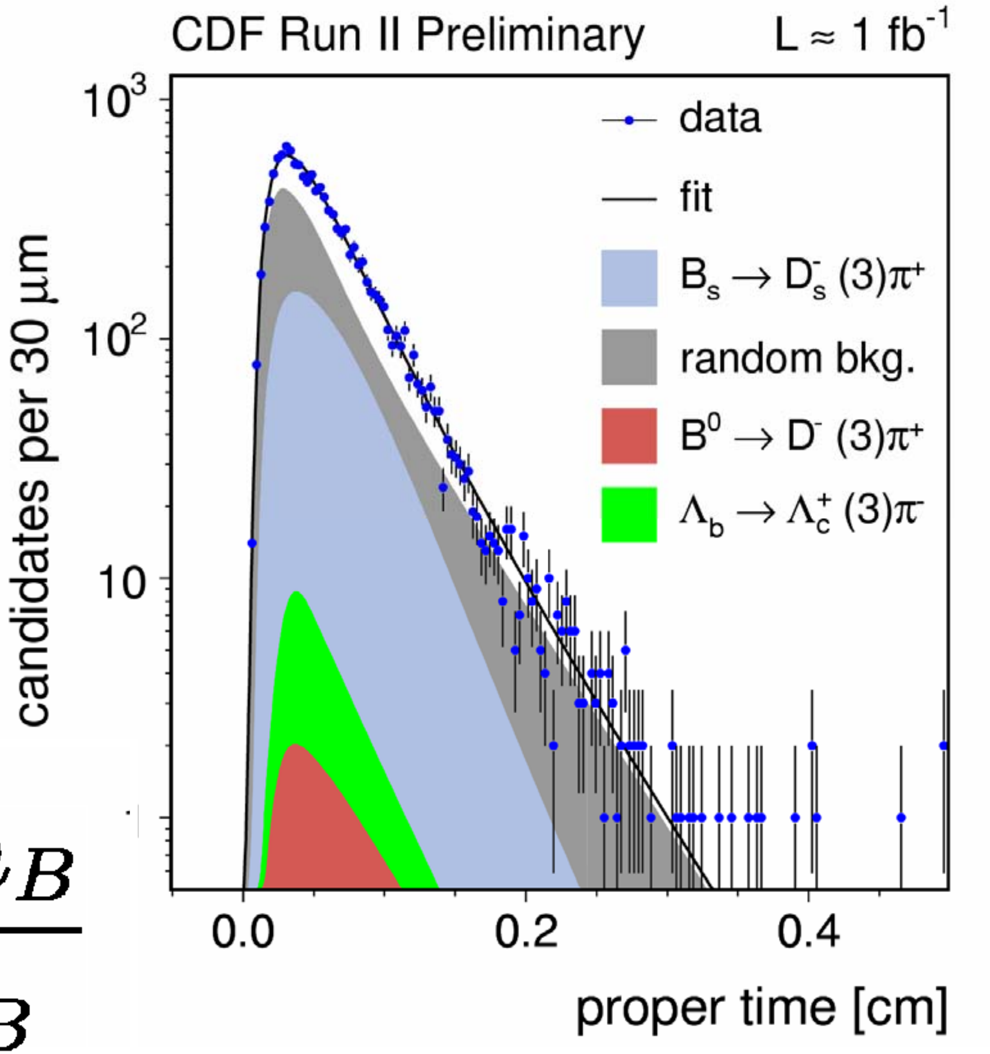


Amplitude Scan in Sidebands



B_s Meson Decay Time

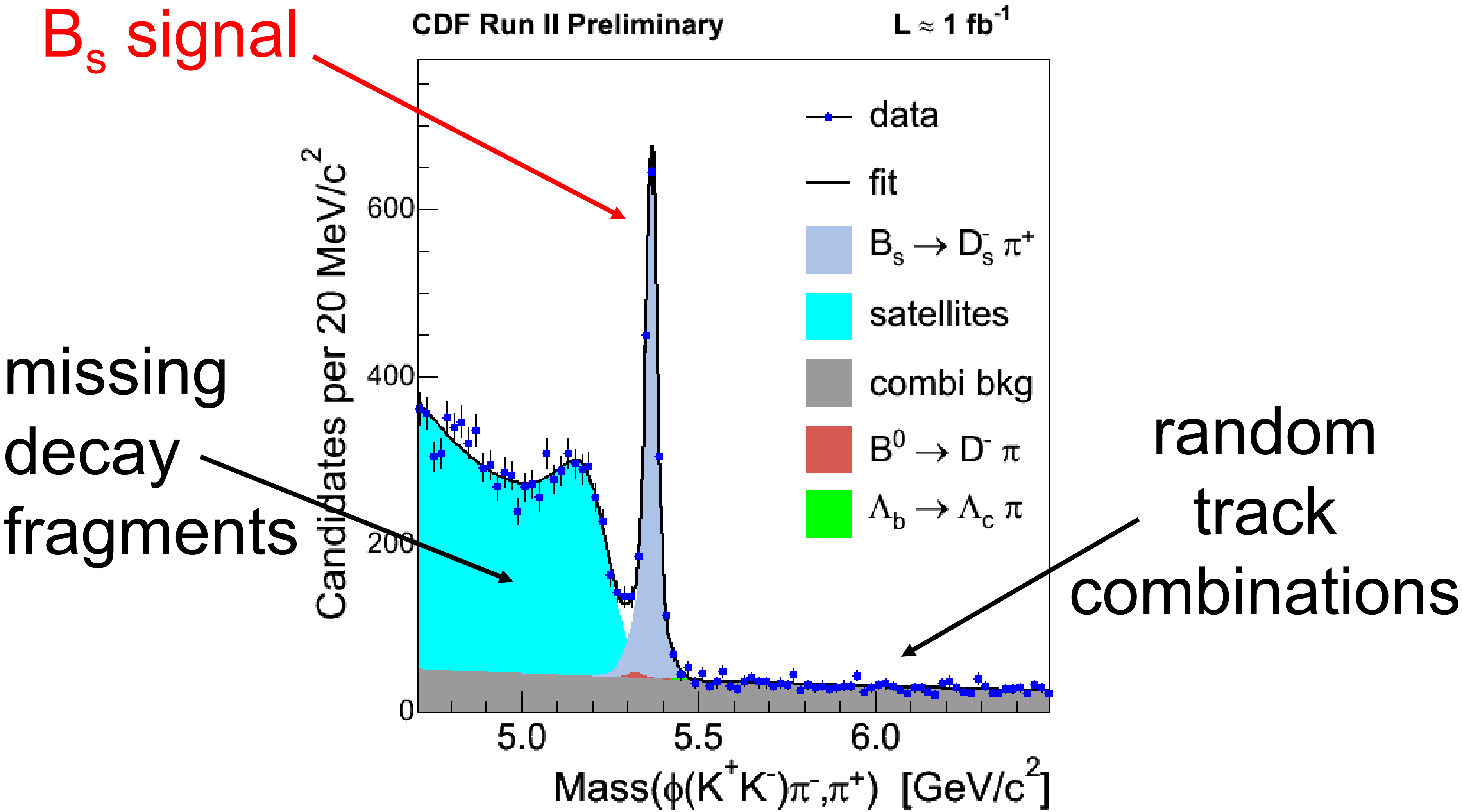




Decay time in B rest frame

$$t = \frac{\ell m_B}{p_B}$$

Reconstructing B_s Decay Signals



Jet Cross Sections, Continued