- B Mixing -
Run I Experiences and
Run II Perspectives

The CDF Collaboration

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B Workshop
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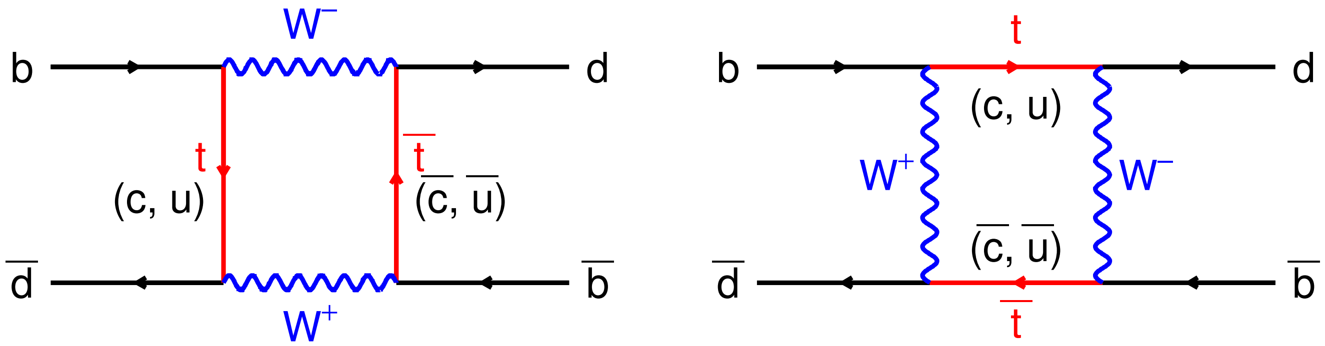
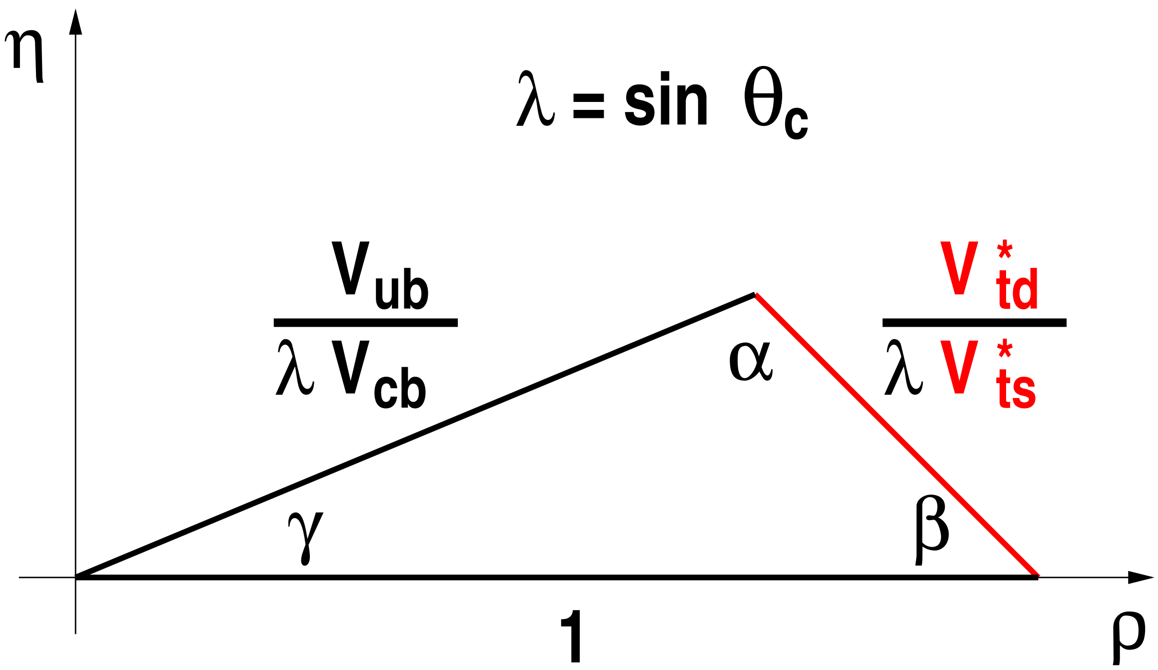
Introduction to B Mixing

Standard Model:

weak eigenstates ≠ mass eigenstates

Mixing appears due to higher order corrections





B^0_d and B^0_s mixing measurements constrain CKM matrix

Experimental Aspects

B^0 mixing asymmetry:

$$A_0(t)_{obs} \quad = \quad \frac{N_{\mathrm{unmixed}}(t) - N_{\mathrm{mix}}(t)}{N_{\mathrm{unmixed}}(t) + N_{\mathrm{mix}}(t)} = D_0 \cos \Delta \mathrm{m} t$$

with flavor tagging dilution: $D_0 = 2P - 1$

Experimental Ingredients:

1. b-quark flavor at production (flavor tagging)
2. b-quark flavor at decay (trigger lepton)
3. proper time of B-meson life ($L \rightarrow ct$)

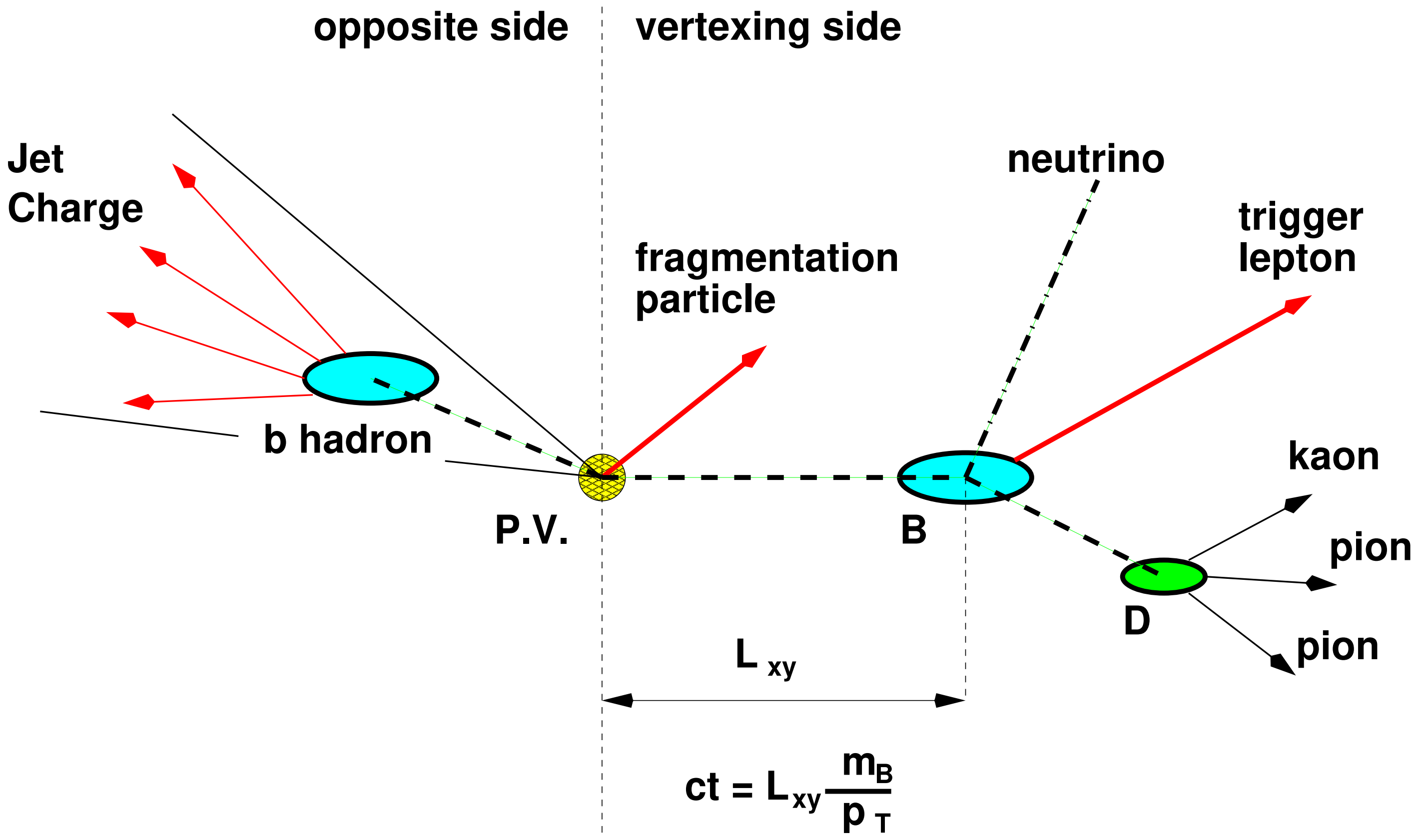
Proper decay time measurement:

$$t = m(\mathrm{B}^0)\frac{L}{p}$$

Uncertainty:

$$\Delta t = \sqrt{\left(\frac{m(\mathrm{B}^0)}{p}\Delta L\right)^2 + \left(\frac{\Delta p}{p}\right)^2}$$

B Flavor Tagging

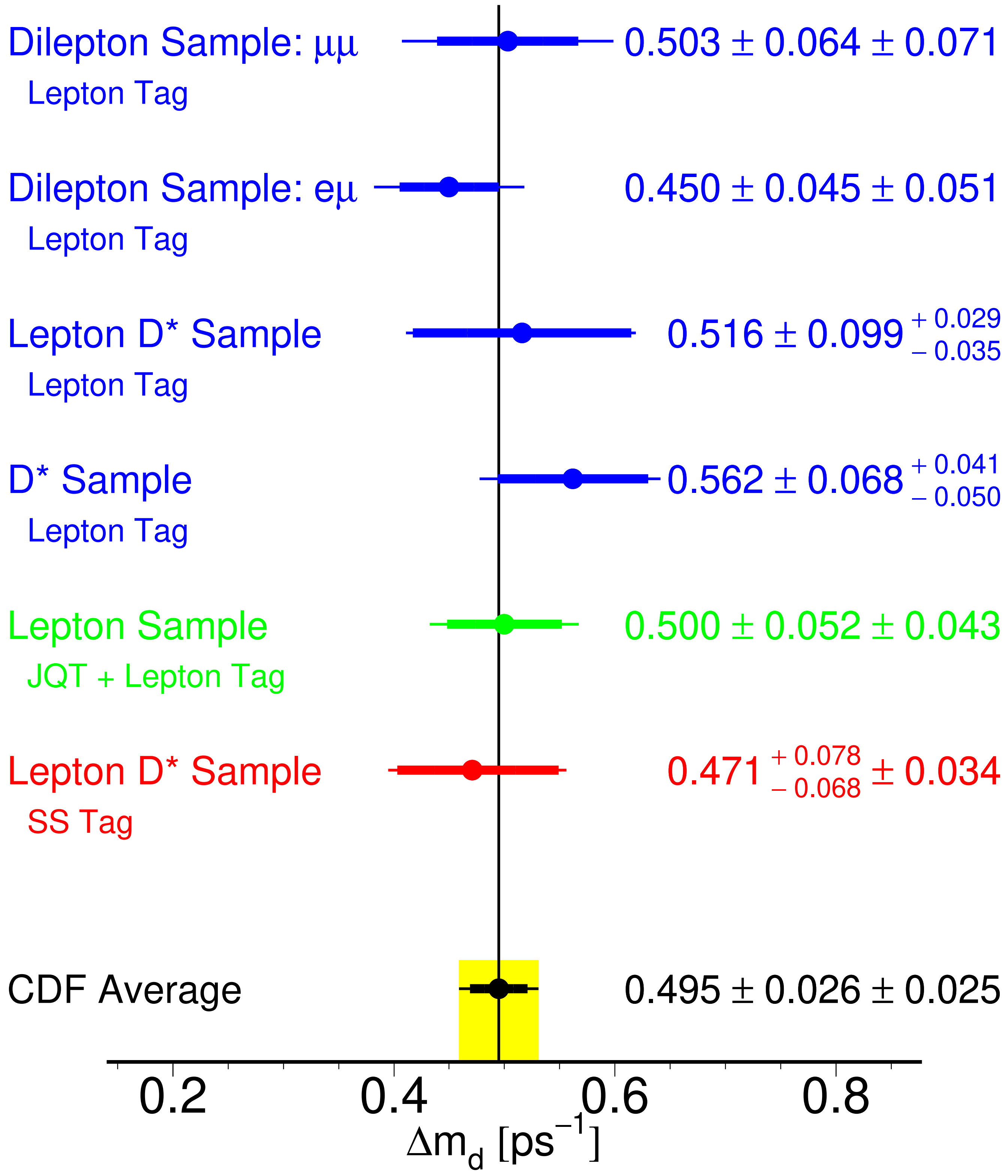


b Flavor Tagging Techniques Run I/II:

- (Soft) Lepton Tagging
- Jet Charge Tagging
- Same Side Pion/Kaon Tagging
- Opposite Side Kaon Tagging

Effective tagging efficiency εD_0^2 measures statistical power of tag

Summary of Run I Measurements



Lower limit: $\Delta m_s > 5.8\ ps^{-1}$

Date: 18/09/99

From Run I to Run II

Tevatron Run I:

- ☞ luminosity 110 pb^{-1}
- ☞ cm energy 1.8 TeV

Run I mixing measurements

- measurements statistics limited
- all analyses based on trigger leptons
- little particle identification
- taggers not optimally combined

B_d^0 mixing well understood from Run I

mostly semi-leptonic decays used

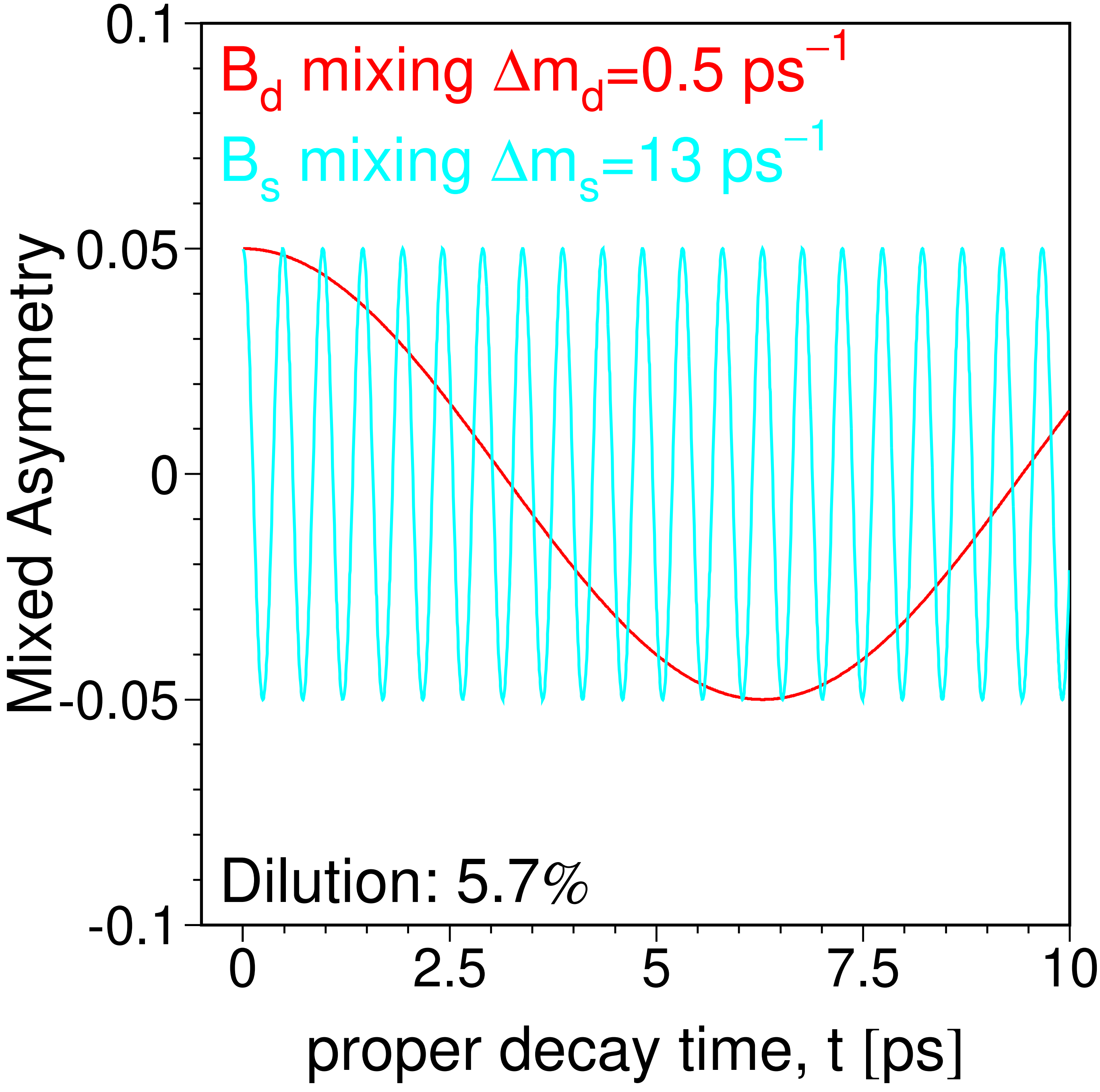
Tevatron Run II:

- ☞ increased luminosity: 2-10 fb^{-1}
- ☞ increased cm energy: 2 TeV

CDF II detector upgrades:

- improved tracking
  - 3D, better resolution, 2 $\times$ coverage
- particle id with Time-of-Flight
- Lv-1 trigger:
  - track (XFT), $p_T > 1.5$ GeV
  - $\Delta p_T / p_T = 15$ MeV, $\Delta\phi = 0.0015$rad
- Lv-2 trigger: secondary vertices
- Lv-3 trigger: more computing power
- improved muon detection coverage

The B_s^0 *Problem*

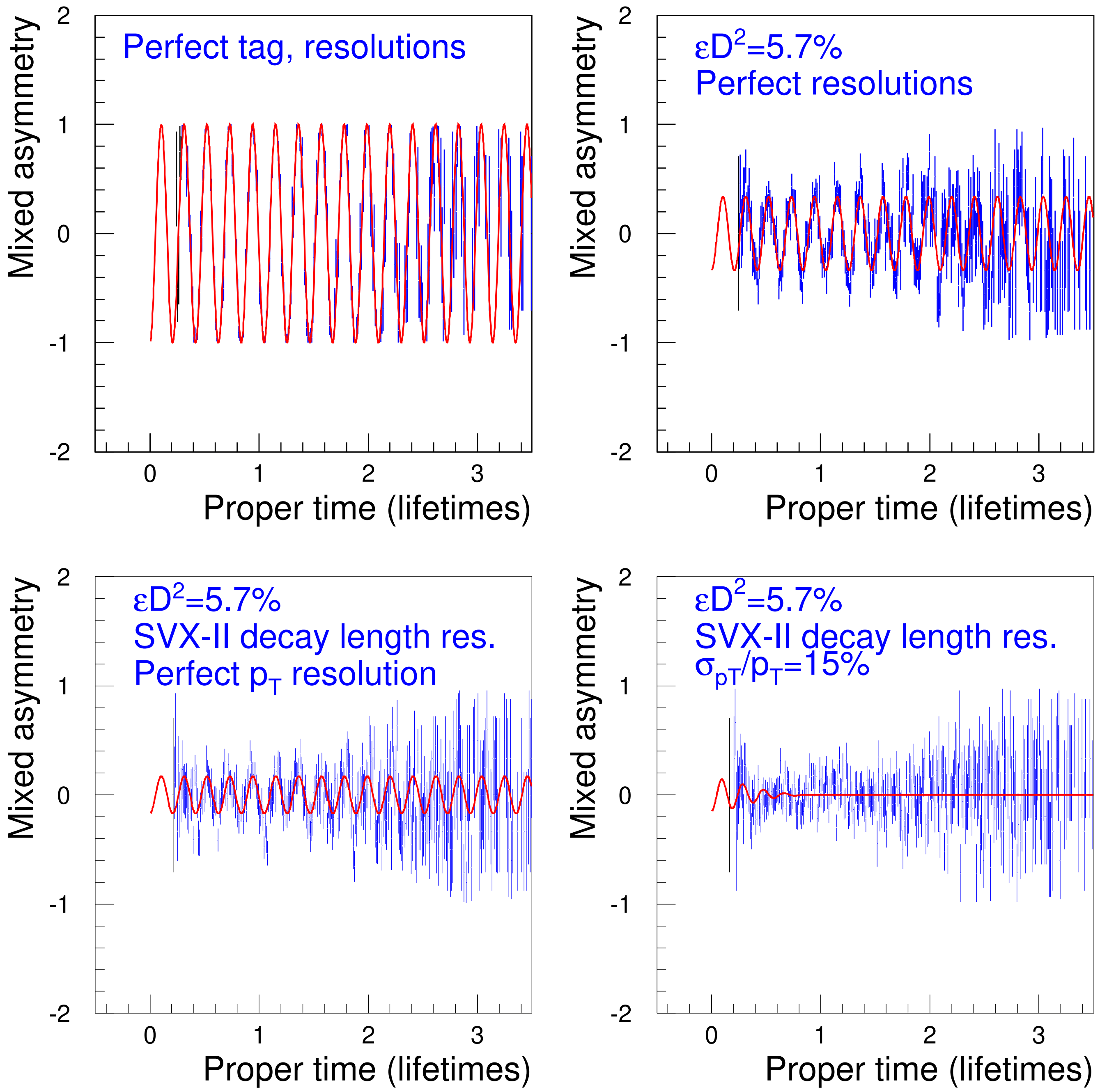


proper decay time needs to be precise

semileptonic decays loose neutrino

Semileptonic B Decays

Illustration of experimental effects: x_s=30



Current x_s Limit: ≈ 20

Fully reconstructed modes of B_s^0 are necessary for large x_s ⇒ hadronic B decay trigger

Hadronic B Decay Trigger: Rates

Level-1:

two high momentum tracks ($p_T \approx 2$ GeV)
require opposite charge
reject back–to–back topologies
☞ rate $<$ 30 kHz within budget of 50 kHz

Level-2:

two large impact parameter tracks ($> 120\mu m$)
positive decay length for vertex tracks
tighten back–to–back rejection
☞ rate $<$ 70 Hz within budget of 300 Hz

Level-3:

search for D mesons ($B_s^0 \to D_s^- n\pi^+$)
search for ϕ mesons ($B_s^0 \to J/\psi\phi$)
☞ not yet studied: rate and computing time

Rate studies done based on Run I test data

CDF in unique position since data are available

Hadronic B Decay Trigger: Signal

Signal cross section

varies between 10 pb and 16 pb
uncertainties: pile up, cross section, theory input

Combinatorial background from generic QCD:

mismeasured tracks, K, Λ or $\gamma \rightarrow e^+e^-$
can only be confidently studied on test data

- ☞ after Lv-2 1/4 of events are $b\bar{b}$
- ☞ background comparable to Run I
- ☞ final signal to noise estimated to 1:1

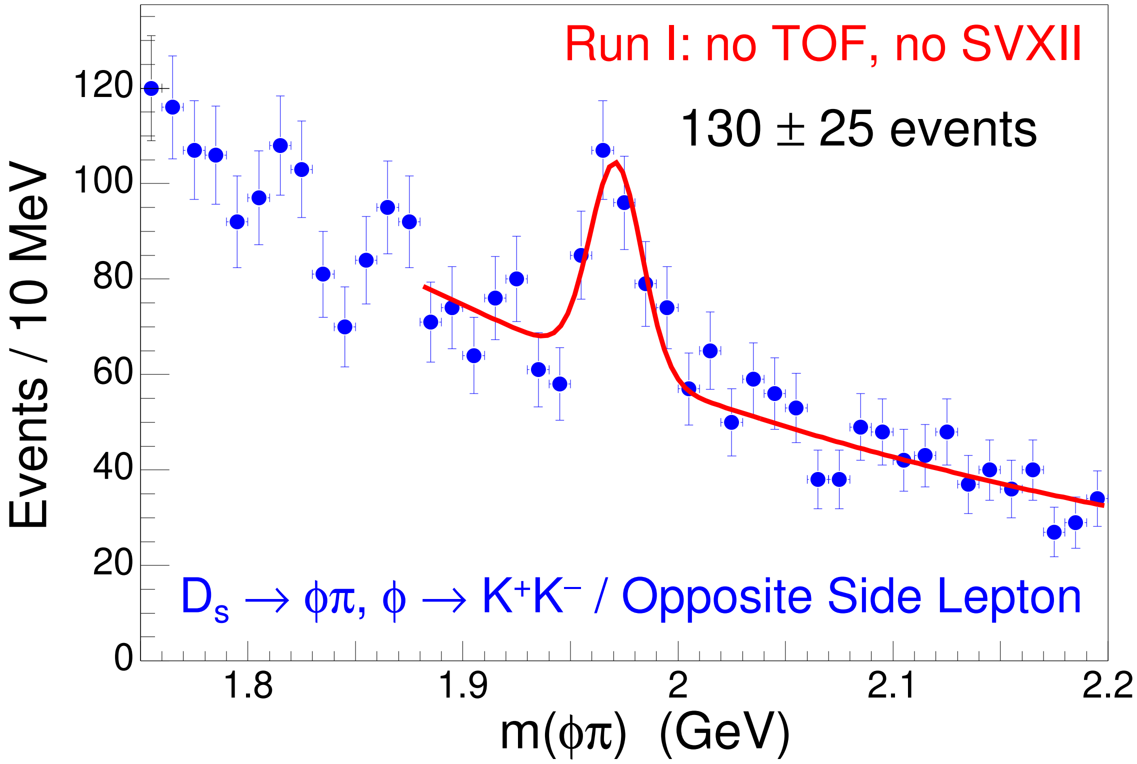
Combinatorial background from HF ($b\bar{b}$, $c\bar{c}$):

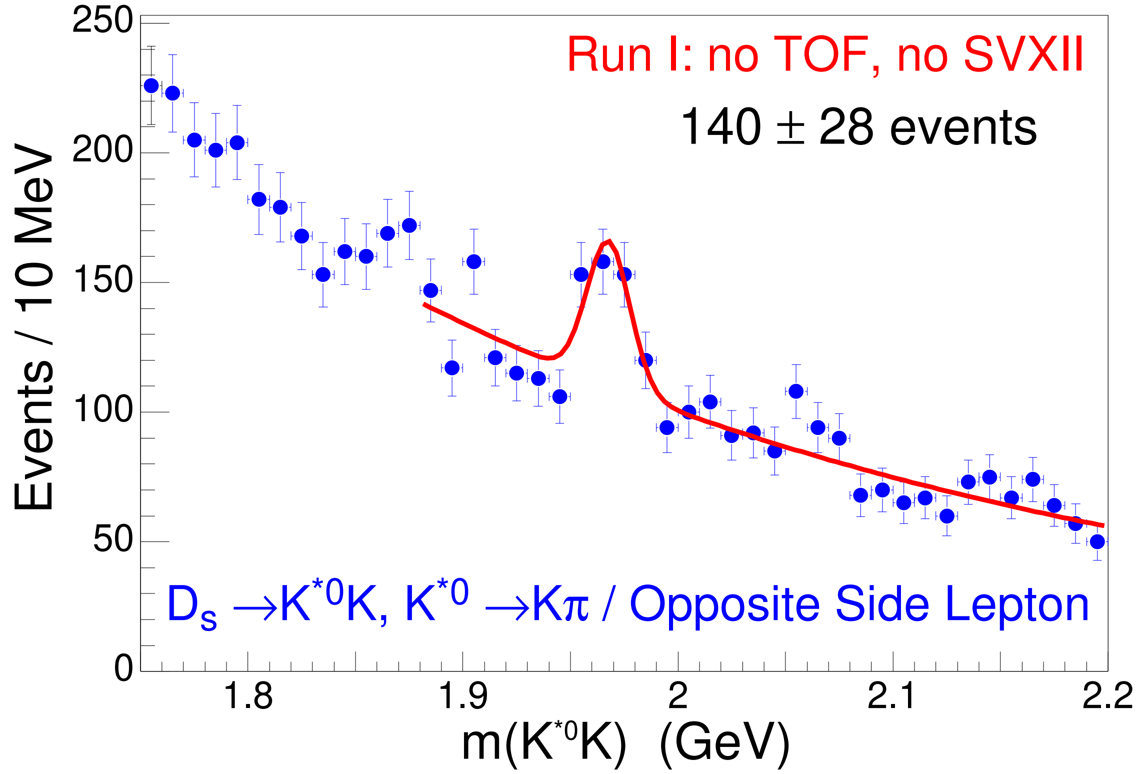
true lifetime and displaced tracks
study on data looking at unbiased B decays

- ☞ most important D signals can be found
- ☞ signal to noise estimated to 1:1

Most background studies performed on data

D Meson Reconstruction in Run I Data





Statistical Power of Tags in Run II

εD_0^2 for $B_s^0 \to D_s^- \pi^+$

Tagging Method	without TOF	with TOF
Same–Side Kaon Tag	1.0%	4.2%
Soft Lepton Tag (e)	1.0%	1.0%
Soft Lepton Tag (μ)	0.7%	0.7%
Jet Charge	3.0%	3.0%
Opposite–Side Kaon Tag	–	2.4%
Total	5.7%	11.3%

εD_0^2 for $B_s^0 \to J/\psi\phi$

Tagging Method	without TOF	with TOF
Same–Side Kaon Tag	0.2%	2.6%
Soft Lepton Tag (e)	1.0%	1.0%
Soft Lepton Tag (μ)	0.7%	0.7%
Jet Charge	3.0%	3.0%
Opposite–Side Kaon Tag	–	2.4%
Total	4.9%	9.7%

Particle Identification very important for B_s^0

Incorporate Time-of-Flight into tagging

Estimation of x_s Reach

Assumptions and input:

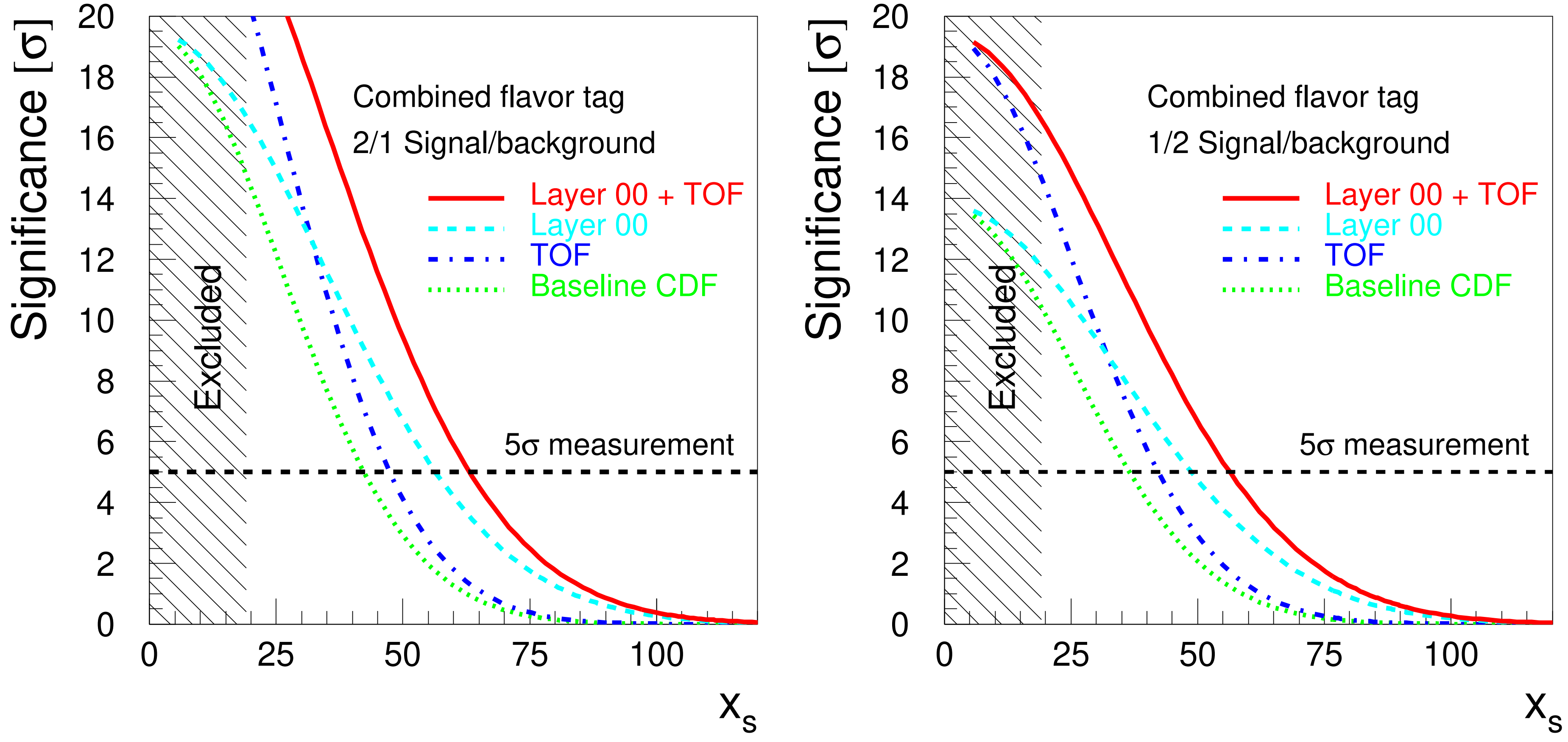
- luminosity of 2 fb^{-1}: 5k–30k exclusive decays
- p_T resolution is neglected
- effective tagging efficiency: 11.3%
- proper time resolution σ_{ct}: 45 fs
- signal to noise, s: 1:2 – 2:1
- background has no asymmetry

Analytical formula describes significance, S, well

$$S(x_s) = \sqrt{\frac{N\varepsilon D^2}{2} exp\left[\left(-\frac{x_s\sigma_{ct}}{\sqrt{2}\tau}\right)^2\right]} \sqrt{\frac{s}{s+1}}$$

in comparison to Monte Carlo

Estimation of x_s Reach



CDF x_s reach is approximately 60;
Particle id (TOF) and vertex resolution (SVX/L00) are essential

What's next?

Monte Carlo

- ☞ generate test samples
- ☞ implement GEANT detector simulation

Trigger Studies

- ☞ Trigger Simulation
- ☞ Level-1/2: relatively well understood
- ☞ Level-3: ϕ meson, D meson triggers ....

Particle Identification

- ☞ new Time–of–Flight detector
- ☞ combine with dE/dx

Different Channels (B^0_s)

- ☞ hadronic decay modes .. refine
- ☞ are there other interesting channels?
- ☞ semi-leptonic .. stops making sense at $x_s = ?$

Different Taggers

- ☞ Same Side Tagging (pion B^0_d, kaon B^0_s)
- ☞ Jet Charge Tagging
- ☞ Soft Lepton Tagging
- ☞ Opposite Side Kaon Tagging

One step beyond ....

Run II goes in its *Run III* phase:

B_s^0 and B_d^0 mixings are measured
CKM matrix is reasonably constrained

How far can we go?

is there limiting experimental systematics?
- ex: bias due to secondary vertex trigger?
- ex: sample composition

What to learn from precise mixing measurements?

can we exclude new physics: SUSY, exotics?
theoretical limitations?!
limitations due to external input parameters?!
analyses to improve external input parameters?!
- ex: to improve R_b at LEP gluon splitting was measured

When should we stop measuring?!

Summary and Conclusion

CDF Run I experience:

- ☞ B_d^0 mixing measured with different techniques
- ☞ very well prepared for B_d^0 mixing
- ☞ B_s^0 mixing limit derived

CDF is preparing for Run II:

- ☞ excellent new silicon tracker
- ☞ particle id: Time-of-Flight System
- ☞ trigger on stiff tracks at Level-1
- ☞ secondary vertex trigger at Level-2
- ☞ x_s reach is in the order of 60

Issues for the workshop:

- ☞ refine and improve tagging methods
- ☞ combine taggers
- ☞ theoretical goals and limitations
- ☞ where does the interest stop?