Misura di Δm_s, $\Delta\Gamma_s$ e ϕ_s a Tevatron

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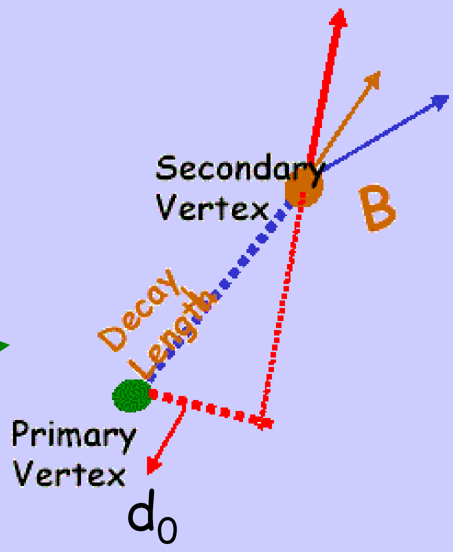
B-physics @ Tevatron

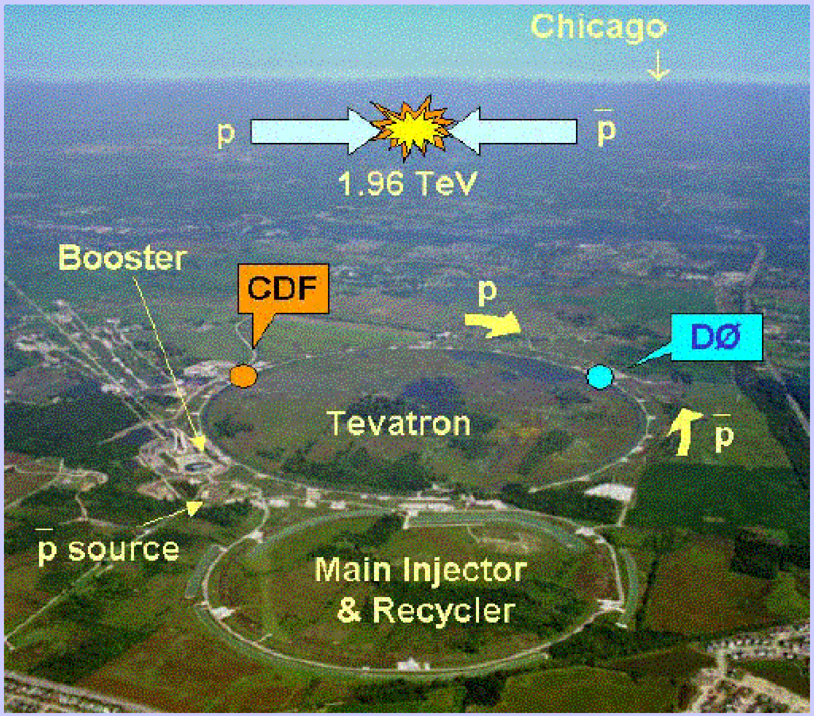
- Hadron colliders are a difficult environment…
    - lots of inelastic background (S/N ≈ 1/1000)

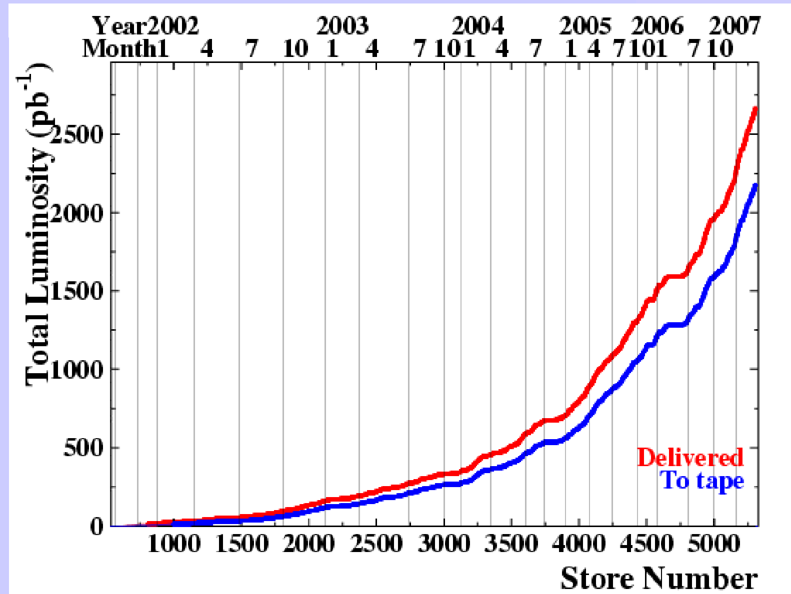
- … but have many advantages:
    - large x-section for b production ($\sigma \approx 150 \mu b$@2TeV)
    - all B hadron species are accessible ($B^{0,+}$,B_s,Λ_b,Σ_b,…)

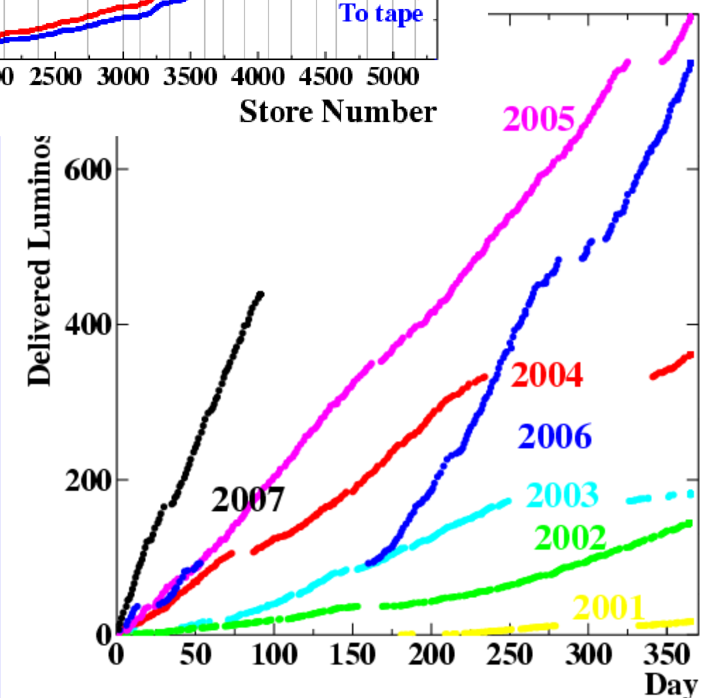
- Key ingredient: High purity triggers!
    - D0: Trigger on single and di-muon channels **(semileptonic B decays + di-lepton final states)**
    - CDF: Sillicon tracking to trigger displaced vertices ($\sigma_{d0} \approx 48 \mu m$) **(all hadronic final states)**



Tevatron @ FNAL



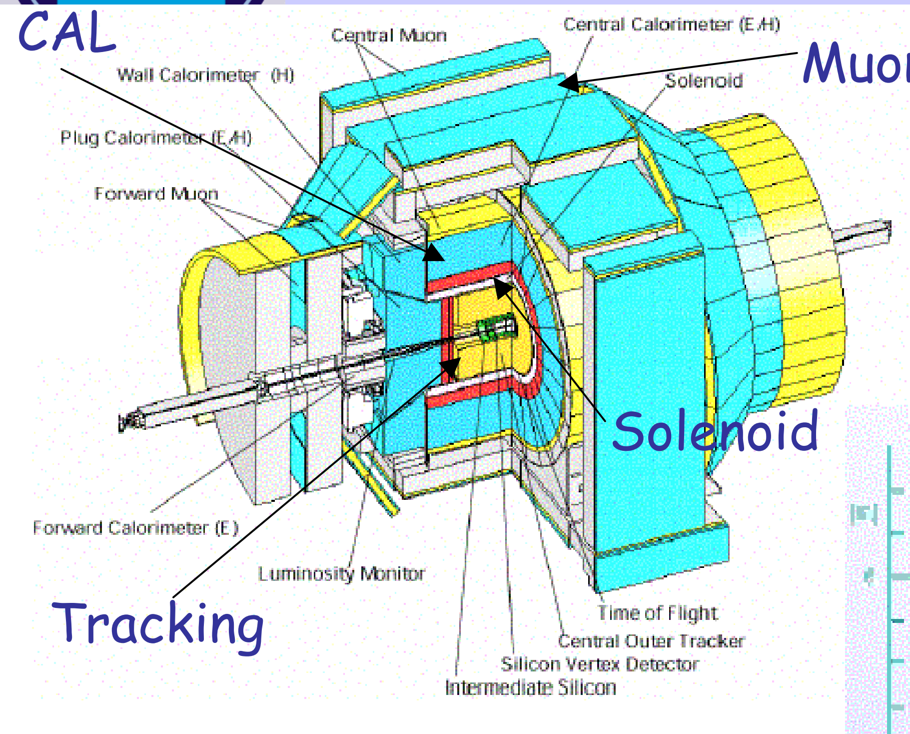




- > 2 fb^{-1} to tape! (current analysis ≈1 fb^{-1})
- Luminosity still increasing!

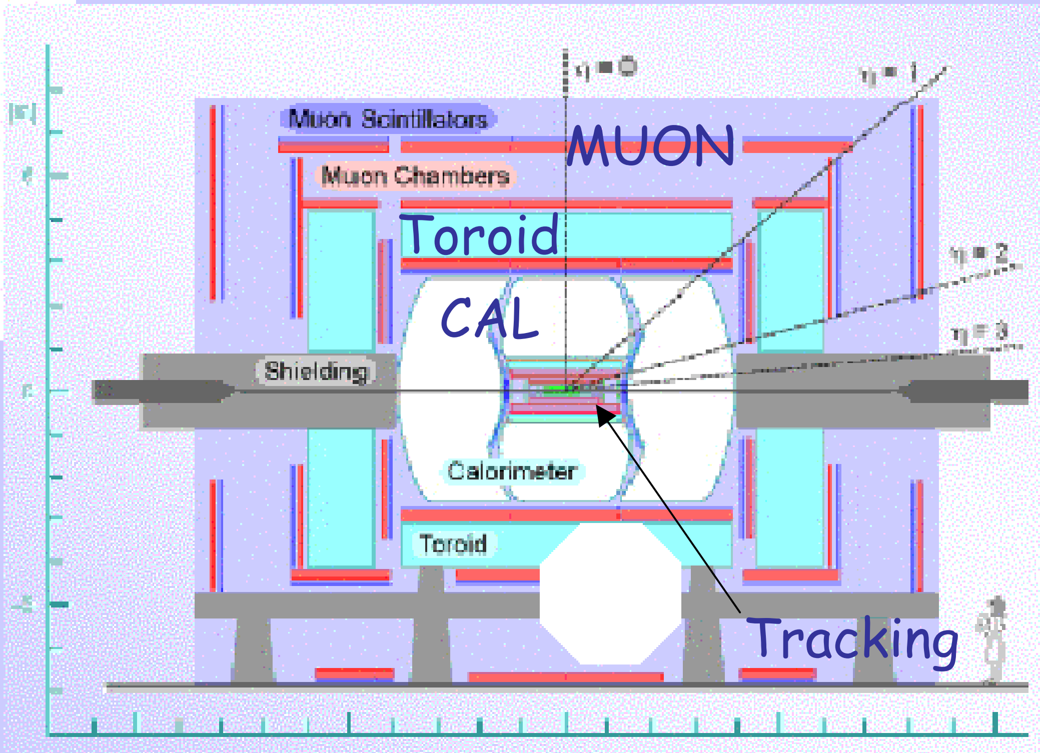
  (Record inst. lum. $2.9 \cdot 10^{32}\ cm^{-2}s^{-1}$)

CDFII and D0



D0

- Muon coverage up to $|\eta|<2$
- Forward tracking:
  Sillicon Microstrip Tracker up to $|\eta|<3$
  Central Fiber Tracker up to $|\eta|<2.5$



CDFII

- Proper time resolution: $\sigma_{c\tau}\approx 26\mu m$ (fully reconstructed B_s decays)
- P_t res. $\sigma_{Pt}/P_t \approx 0.07\%\ P_t\ [GeV/c]^{-1}$ using Sillicon + Drift chamber ($\Rightarrow\sigma$ mass $\approx$15MeV for $J/\Psi\rightarrow\mu\mu$)

Outline

- $\Delta m_s \rightarrow$ oscillation frequency of B_s-$\bar{B}_s$ system
  - CDFII measures dominates

- $\Delta\Gamma_s \rightarrow$ lifetime difference on B_s-$\bar{B}_s$ mass eigenstates
  - D0: 3 untagged measures approach

- $\phi_s \rightarrow$ SM CP violating phase $\equiv \arg\left(\frac{V_{ts}V_{tb}^*}{V_{ts}^*V_{tb}}\frac{V_{cs}^*V_{cb}}{V_{cs}V_{cb}^*}\right)$
  - only D0 measure up to now

$\Rightarrow$ Observables really sensible to New Physics contributions

Δm_s measurement

$B_{s,L}$, $B_{s,H}$ mass eigenstates of B_s-$\overline{B}_s$ system

$$\Delta m_s = m(B_{s,H}) - m(B_{s,L}) \propto |V_{ts}|^2$$

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

ξ^2 → From lattice QCD

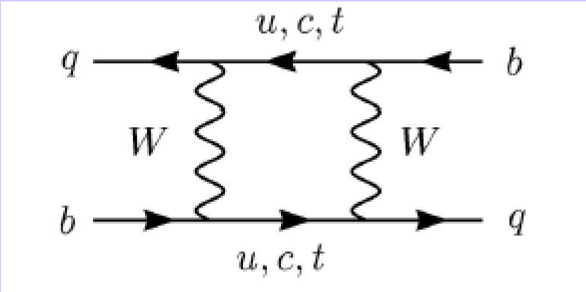
→ ≈4% error on $|V_{ts}|/|V_{td}|$

Strong check for SM, but also for new physics:

New Physics [Lenz, Nierste; hep-ph/0612167]
(model indip.)

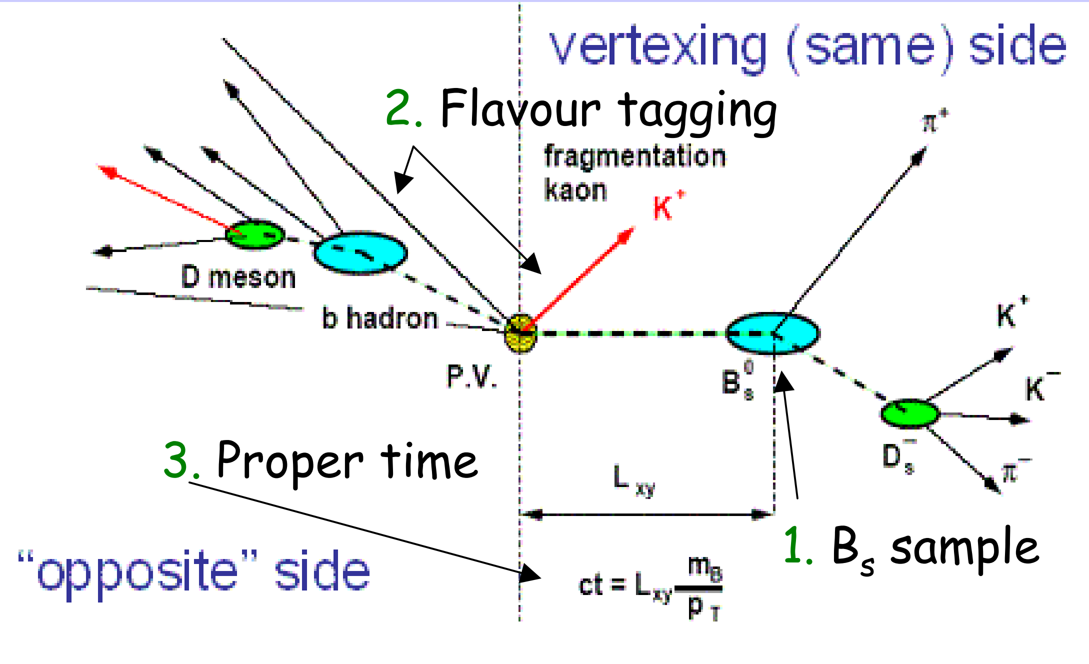
$$M_{12} = M_{12}^{SM} \cdot |\Delta_s| e^{i\phi_s^{\Delta}}$$

$$M_{12}^{SM} \approx \mathrm{Re}\left(\right)$$



$$\Delta m_s = m_H - m_L = \Delta m_s^{SM} \cdot |\Delta_s|$$

Δm_s measurement



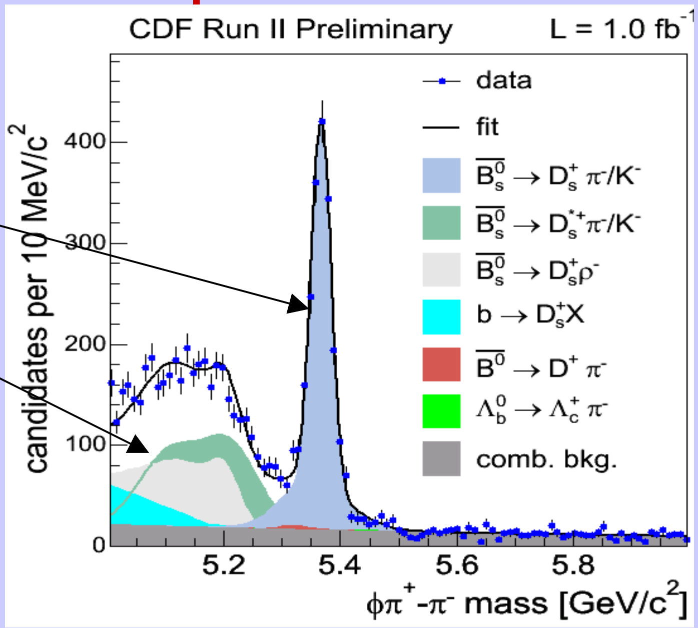
$$\underset{4}{A(t)} = \frac{P^{nomix} - P^{mix}}{P^{nomix} + P^{mix}} = D\cos(\Delta m_s t)$$

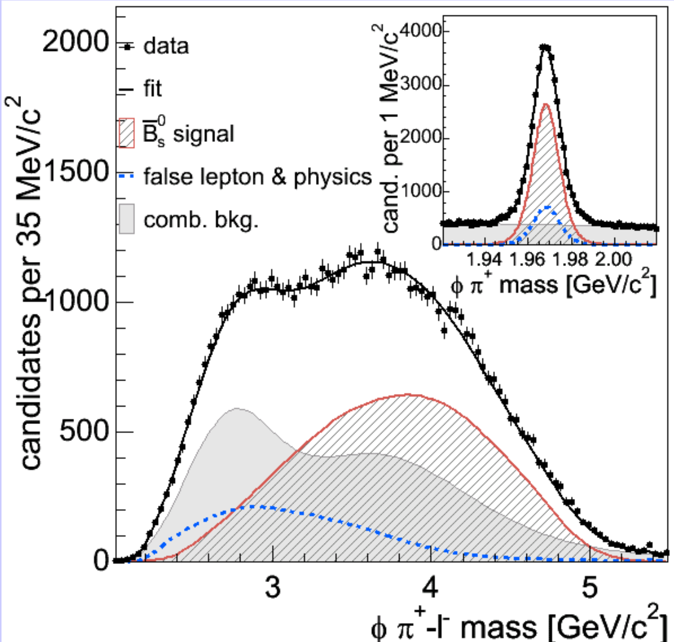
$$\frac{1}{\sigma_A} = \sqrt{\frac{\underset{2}{\varepsilon D^2} S}{2}}\, e^{-\frac{(\Delta m_s \underset{3}{\sigma_t})^2}{2}} \underset{1}{\sqrt{\frac{S}{S+B}}}$$

1. B_s signal (gives flavour at decay)
2. Flavour at production
3. Proper time
4. Fit for mixed and unmixed distribution

Δm_s @ CDFII - Samples

Sample ($L \approx 1fb^{-1}$)	Yield
Fully reconstructed ($B_s \to D_s$ (3)π, $D_s \to \phi\pi$, K^*K, 3π)	5600
Partially reconstructed ($B_s \to D_s^*\pi$, $B_s \to D_s\rho$ missing π^0, γ)	3100
Semileptonic ($B_s \to D_s^{(*)} l \nu_l$, l=e,$\mu$)	61500





Some highlights:

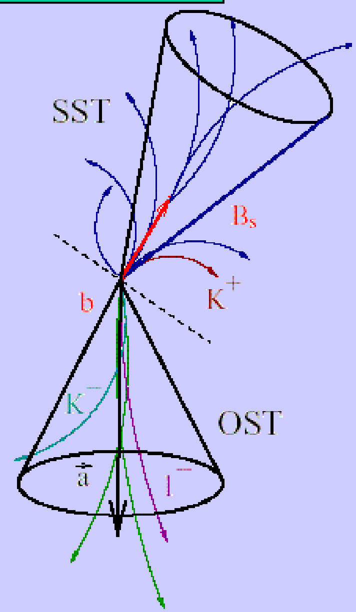
- NN kinematical selections
- PID (dE/dx + TOF) for K/π separation (reject bg)

Δm_s @ CDFII - Flavour Tagging

Opposite Side Tagger

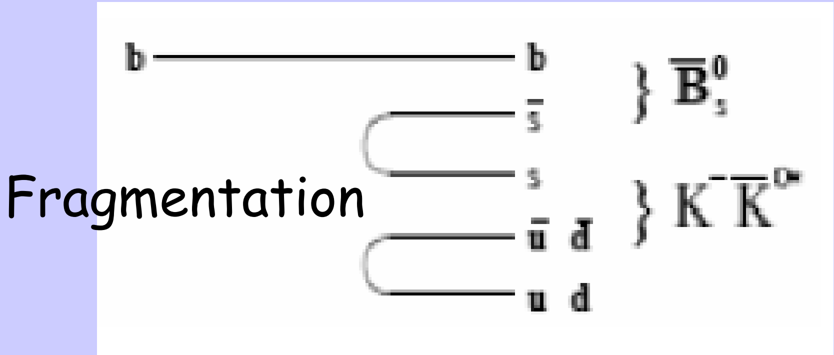
- e, μ charge
- Jet charge
- K charge

→ NN



Same Side Tagger

- B_s will often be produce with a K



- Combine PID & kinematics

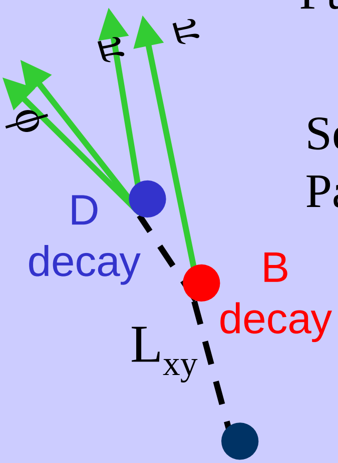
Tagger	εD^2 (%)
OST NN	1.8 ± 0.1
SST	
hadronic	3.7 ± 0.9
semileptonic	4.8 ± 1.2

ε = tagging efficiency

$$D = \frac{N^{right} - N^{wrong}}{N^{right} + N^{wrong}}$$

Combined in the final likelihood

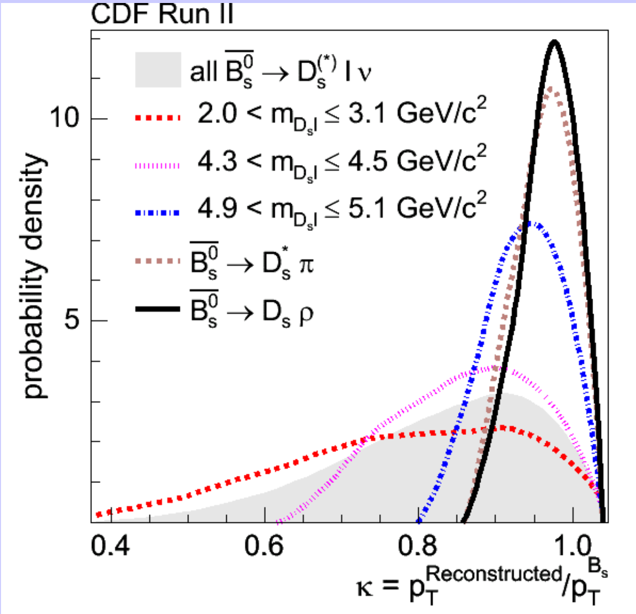
Δm_s @ CDFII - Proper time

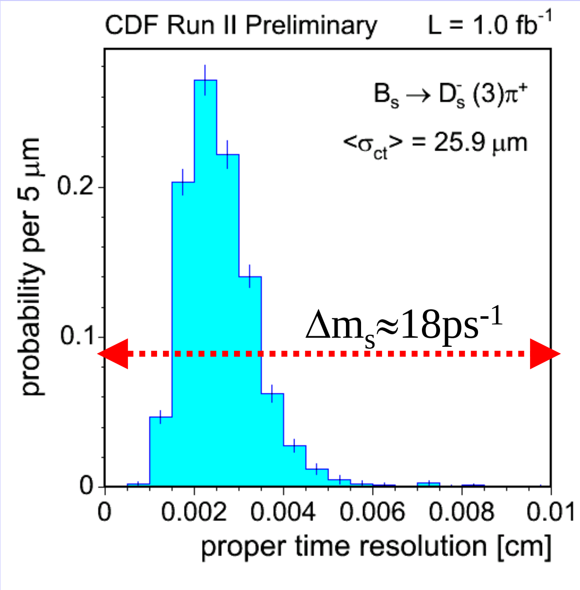


Fully reconstructed $c\tau = m(B_s)\dfrac{L_{xy}(B_s)}{p_T(B_s)}$

Semileptonic
Part. reco'ed $c\tau = m(B_s)\dfrac{L_{xy}(B_s/D_s l)}{p_T(B_s/D_s l)}\boxed{K}$

$$\frac{\sigma(c\tau)}{c\tau} = \frac{\sigma_{p_T}}{p_T} \oplus \frac{\sigma_{L_{xy}}}{L_{xy}} \left[\oplus \frac{\sigma_K}{K} \right]$$



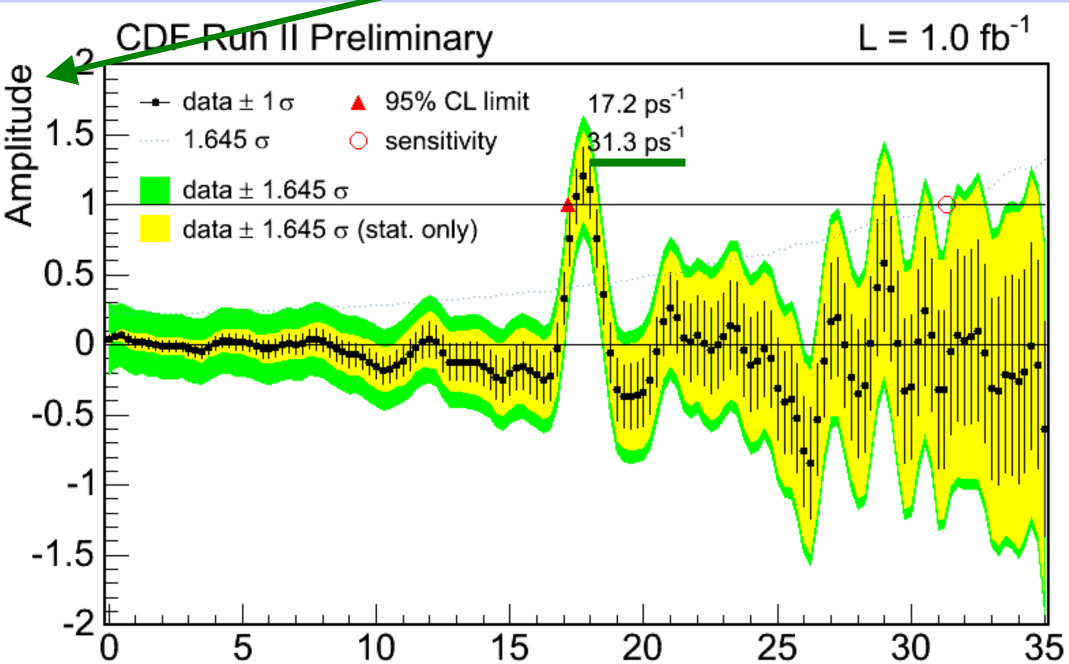


Sample	$<\sigma(c\tau)>$
Fully reconstructed	26μm
Partially reconstructed	29μm
Semileptonic	45μm

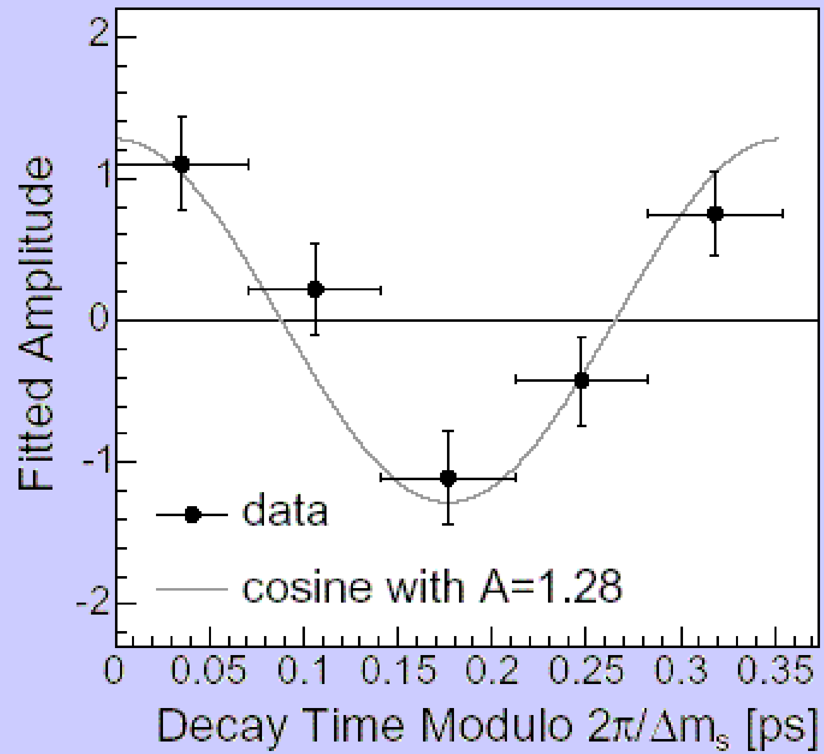
Δm_s @ CDFII - Result

[CDF Collaboration; PRL 97, 242003 2006]

$$P(t;A)_{B_s \to \bar{B}_s} = \frac{1}{2\tau} e^{-\frac{t}{\tau}} (1 \pm A \cos(\Delta m_s t))$$



$\Delta m_s = 17.77 \pm 0.10(\text{stat}) \pm 0.07(\text{sys})$



Compatible with SM prediction:

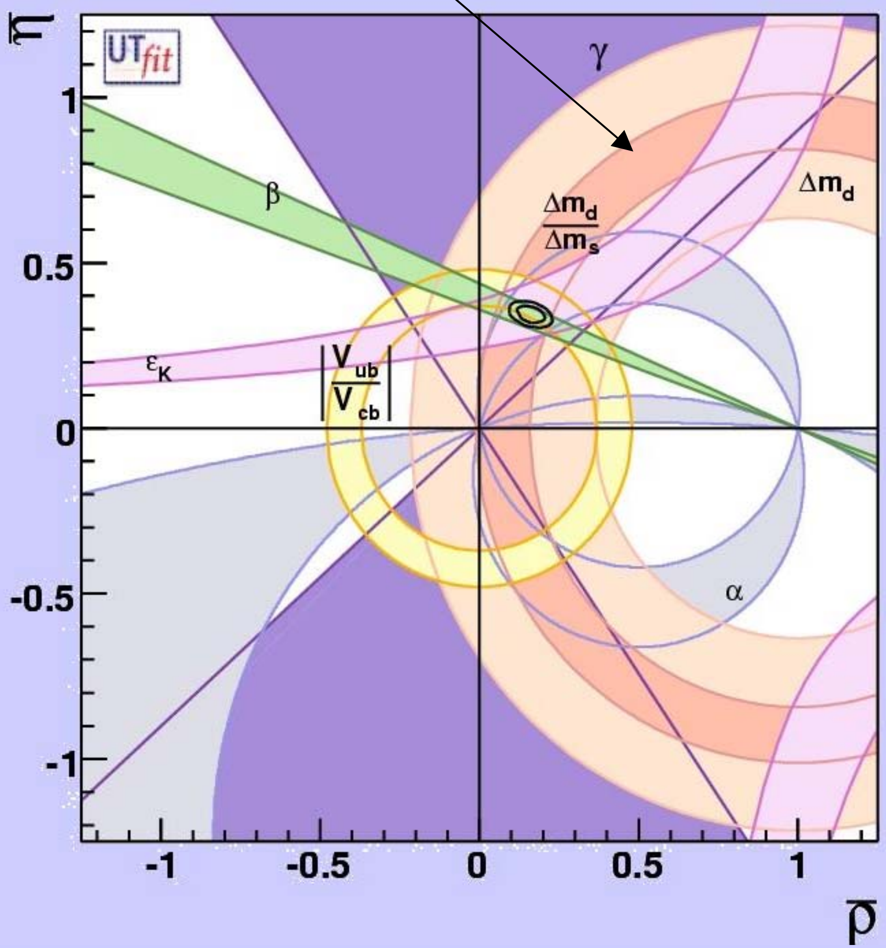
$\Delta m_s^{SM} = 19.30 \pm 6.68\ \text{ps}^{-1}$

[Lenz, Nierste; hep-ph/0612167]

p-value = $8 \cdot 10^{-8} > 5\,\sigma$

Δm_s @ CDFII - Unitarity triangle

$$\frac{|V_{td}|}{|V_{ts}|} = 0.2060 \pm 0.0007(\text{exp})\ {}^{+0.0081}_{-0.0060}(\text{theor})$$



→ UTFit

[http://utfit.roma1.infn.it/ckm-results/ckm-results.html]

CKMFitter has similar results

[http://www.slac.stanford.edu/xorg/ckmfitter/]

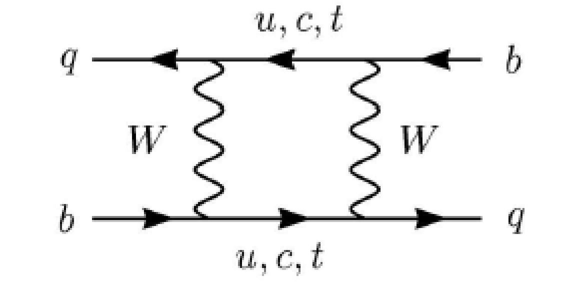
- Most precise measure of $|V_{td}|/|V_{ts}|$
- Bigger uncertainty is thoeretical
- SM still compatible with exp.

Angular analysis of $B_s \to J/\Psi\ \Phi$

[D0 Collaboration, hep-ex/0701012]

- $B_{s,L/H}$ have different lifetimes: $\Delta\Gamma_s = \Gamma_L - \Gamma_H = 2|\Gamma^s_{12}| \cdot \cos(\phi_s + \phi_s^\Delta)$

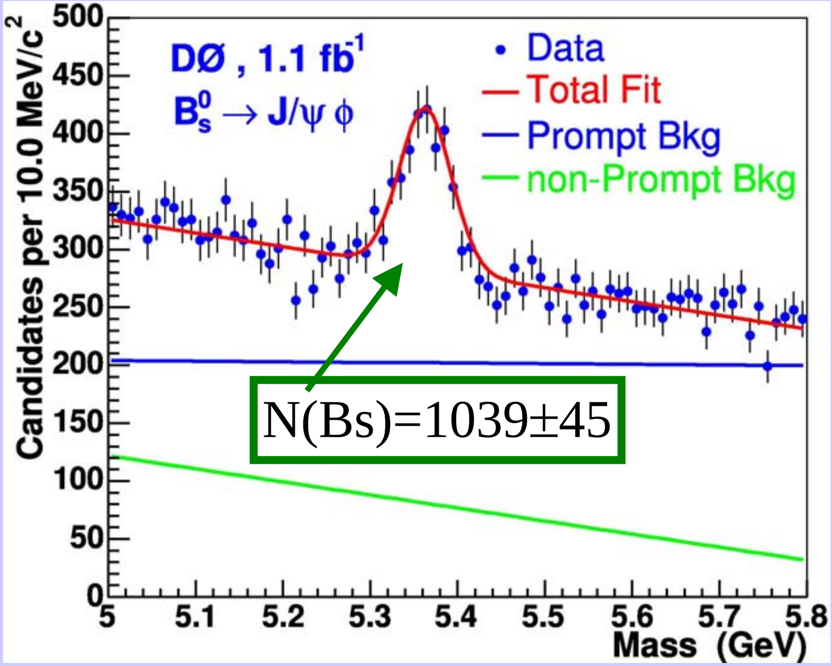
$$\Gamma_{12}^{SM} \approx \mathrm{Im} \left(\quad \right)$$



SM CPV phase

NP CPV phase

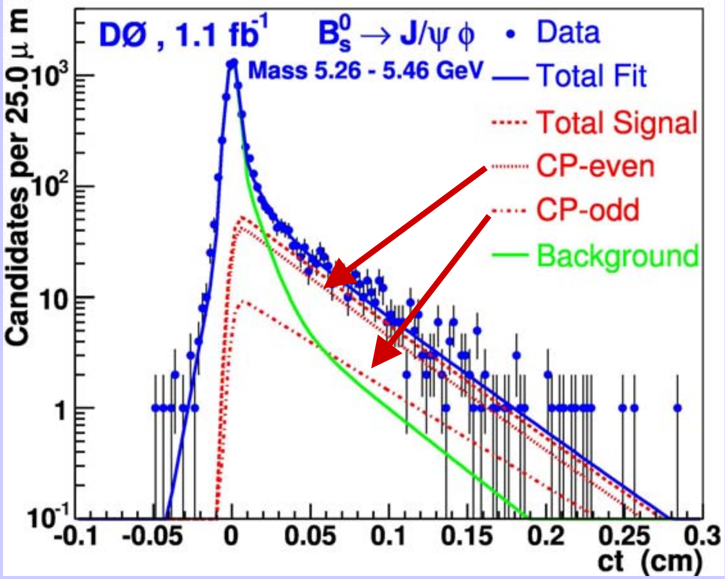
- Pseudo-Scalar→Vector-Vector decay:
  - ➢CP-even and CP-odd final states
  - ➢Angular distribution of $B_{s,L/H}$ decay products can disentangle them
  - ➢ $J/\Psi \to \mu\mu$, $\phi \to KK$
  - ➢CP even/odd interference term $\propto \sin \phi_s$



N(Bs)=1039±45

$B_s \to J/\Psi\ \Phi$ – Results

Simultaneous fit to mass, decay length and 3 angles with an unbinned maximum likelihood fit



Assuming no CPV in Bs mixing

Allowing for CP violation (ϕ_s free)

	$\Delta\Gamma_s$ [ps^{-1}]	ϕ_s [rad]	$<\tau>$ [ps]
CDF (260pb^{-1})	$0.47^{+0.19}_{-0.24} \pm 0.01$	---	$1.40^{+0.15}_{-0.13} \pm 0.02$
D0 (CP)	$0.12^{+0.08}_{-0.10} \pm 0.02$	---	$1.52 \pm 0.08^{+0.01}_{-0.04}$
D0 (CPV)	$0.17 \pm 0.08 \pm 0.02$	$-0.79 \pm 0.56^{+0.01}_{-0.14}$	$1.49 \pm 0.08^{+0.01}_{-0.04}$

SM predictions:
[Lenz, Nierste; hep-ph/0612167]

$$\Delta\Gamma_s^{SM} = 0.096 \pm 0.039\, ps^{-1}$$

$$\phi_s^{SM} = (4.2 \pm 1.4) \cdot 10^{-3}$$

Flavour charge asymmetries

[Phys. Rev. D 74, 092001 (2006)] [hep-ex/0701007 (2007)]

$$A_{SL}^{s,SM} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s = (2.06 \pm 0.57)\cdot 10^{-5}$$

[Lenz, Nierste; hep-ph/0612167]

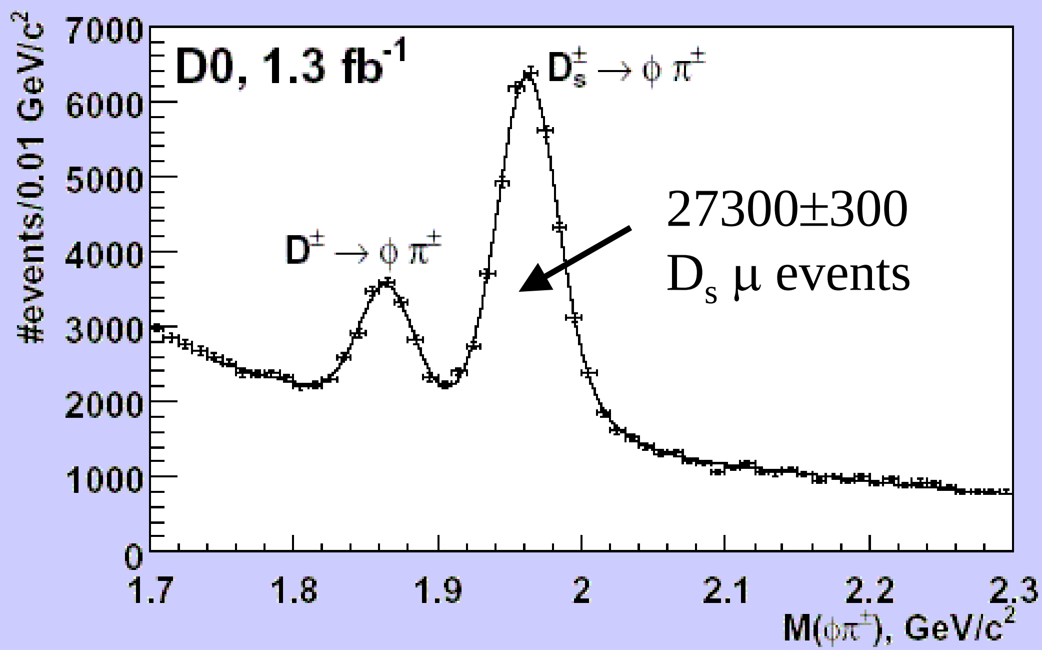
Very sensible to CVP from new physics

Two D0 measures on untagged B_s samples

$\mathrm{D0}: B_s \to D_s \mu^{\pm} X \;\; (\mathcal{L} \approx 1.3\mathrm{fb}^{-1})$

$$A_{SL}^{s,unt} = \frac{N(D_s^- \mu^+) - N(D_s^+ \mu^-)}{N(D_s^- \mu^+) + N(D_s^+ \mu^-)}$$

$$A_{SL}^{s} = 0.0245 \pm 0.0193 \pm 0.0035$$



$\mathrm{D0}: p\bar{p} \to b\bar{b} \to \mu^{\pm}\mu^{\pm} \quad (\mathcal{L} \approx 1.0\mathrm{fb}^{-1})$

$$A_{SL}^{\mu\mu} = \frac{N(b\bar{b} \to \mu^+\mu^+ X) - N(b\bar{b} \to \mu^-\mu^- X)}{N(b\bar{b} \to \mu^+\mu^+ X) + N(b\bar{b} \to \mu^-\mu^- X)}$$

About 580K di-muon events

$$A_{SL}^{s} = -0.0064 \pm 0.0101$$

- Both detector and physics contribute to charge asymmetry
- Flip B-field @ 0.1% regulary reduce detector systematics

$\Delta\Gamma_s$, ϕ_s and the SM

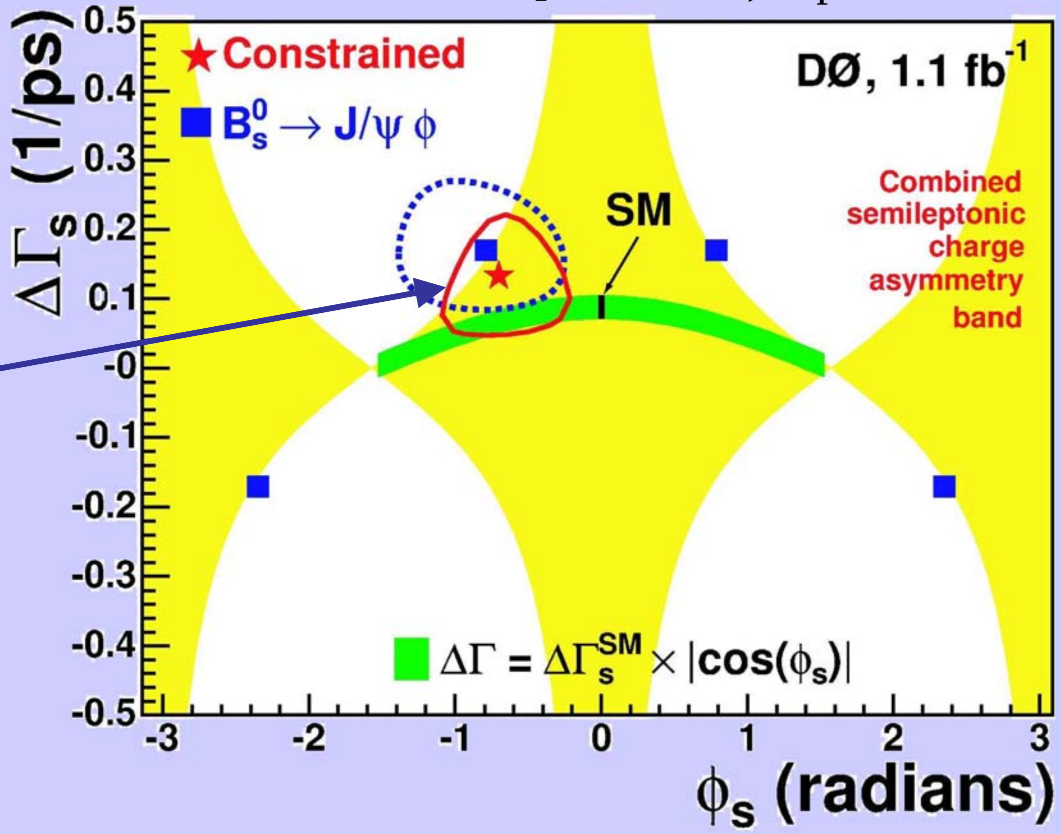
Redo $B_s \to J/\Psi\phi$ fit with the constraint

$$\Delta\Gamma_s \cdot \tan\phi_s = A_{SL}^{s} \cdot \Delta m_s$$

$$A_{SL}^{s,combined} = 0.0001 \pm 0.0090$$

[D0 Collab, hep-ex/0702030]

Fit results:
$\Delta\Gamma_s = 0.13 \pm 0.09\, ps^{-1}$ $\phi_s = -0.70^{+0.47}_{-0.39}$



SM still compatible, but room for new physics!

Conclusions

- Desribed more significant measures for Δm_s, $\Delta\Gamma_s$ and ϕ_s at Tevatron

- SM still compatible with experimental results but…
  - Upcopming new CDF results ($1fb^{-1}$)
  - Both CDF and D0 already have $2fb^{-1}$ to analyze, more to come
  - Preparing for tagged $B_s \rightarrow J/\Psi\Phi$ analysis (both CDF and D0, roughly ≈ 0.3 sensitivity on ϕ_s)
  - Future LHCb measures (sensitivity of 0.02 on ϕ_s with $2fb^{-1}$)

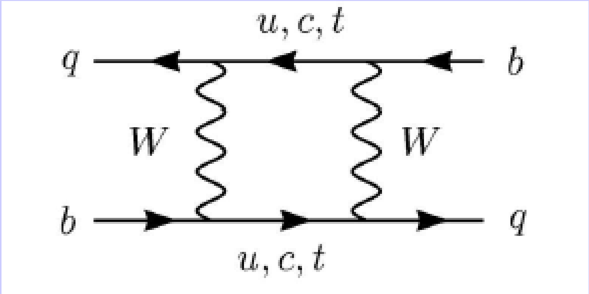
[Peter Vankov, Lake Luise Winter Institute 2007]

will be able to futher check the SM prediction.

STAY TUNED!

BACKUP

The B_s-$\overline{B}_s$ system



Assuming CPT invariance

$$-i\frac{d}{dt}\begin{pmatrix}|B_s>\\|\overline{B}_s>\end{pmatrix}=\left[\begin{pmatrix}M_{11} & M_{12}\\M_{12}^* & M_{22}\end{pmatrix}-\frac{i}{2}\begin{pmatrix}\Gamma_{11} & \Gamma_{12}\\\Gamma_{12}^* & \Gamma_{22}\end{pmatrix}\right]\begin{pmatrix}|B_s>\\|\overline{B}_s>\end{pmatrix}$$

Mass eigenstates:

$$B_{S,L}=p\left|B_s\right\rangle\pm q\left|\overline{B}_s\right\rangle$$

Also CP eigenstates if |p| / |q| = 1

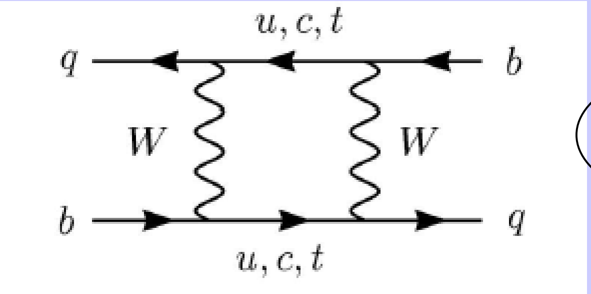
Many interesting observables in order to explore B_s system properties:

$$\Delta m_s = M_H - M_L \cong 2\left|M_{12}\right| \qquad \Delta\Gamma_s=\Gamma_L-\Gamma_H\cong 2\left|\Gamma_{12}\right|\cos\phi_s \qquad \phi_s=\arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$$

$$A_{fs}^s=\mathrm{Im}\frac{\Gamma_{12}}{M_{12}}=\frac{\left|\Gamma_{12}\right|}{\left|M_{12}\right|}\sin\phi_s=\frac{\Delta\Gamma_s}{\Delta m_s}\tan\phi_s\overset{\exp}{=}\frac{N(B_s\to f)-N(\overline{B}_s\to\overline{f})}{N(B_s\to f)+N(\overline{B}_s\to\overline{f})}$$

(with $\overline{B}_s\to f$ and $B_s\to\overline{f}$ forbidden; $\overline{f}$ is the CP conjugate)

NP in B_s-B_s system



Lowest Order → Dispersive part → M_{12}

Lowest Order → Absorptive part → Γ_{12}

Γ_{12} domniated by tree-level $b \to c\bar{c}s$

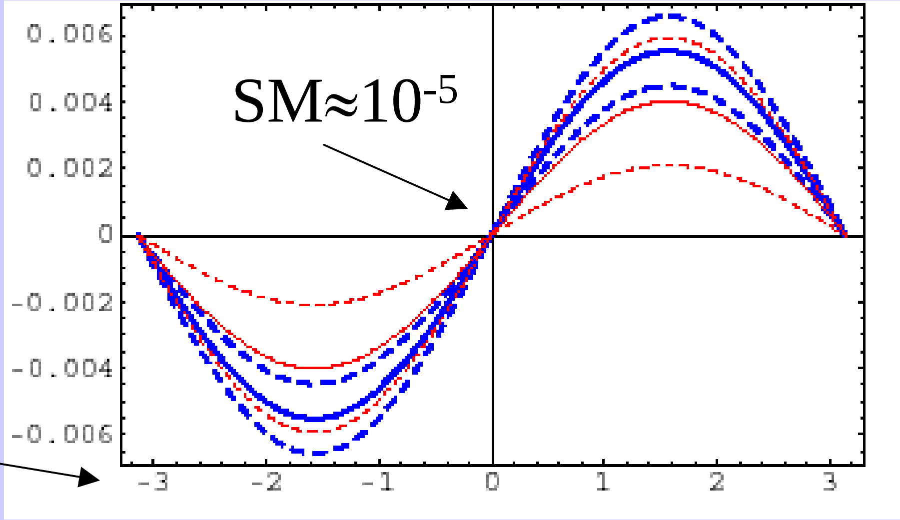
M_{12} sensible to new physics; model indipendent approach:

$$M_{12} = M_{12}^{SM} \Delta_s = M_{12}^{SM} |\Delta_s| e^{i\phi_s^\Delta}$$ [Lenz, Nierste; hep-ph/0612167]

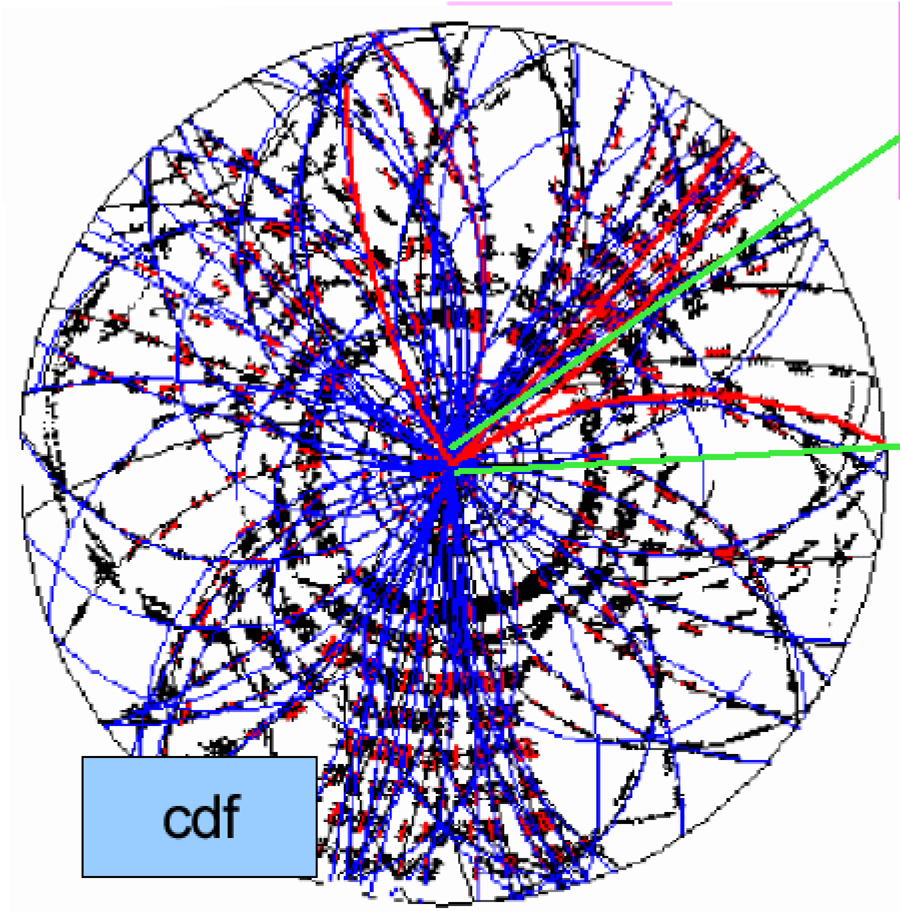
$\Rightarrow \Delta m_s$ sensible to $|\Delta_s|$

$\Rightarrow \Delta\Gamma_s$ and a_{fs}^s also to ϕ_s^Δ

e.g. sensibility of a_{fs}^s to ϕ_s^Δ

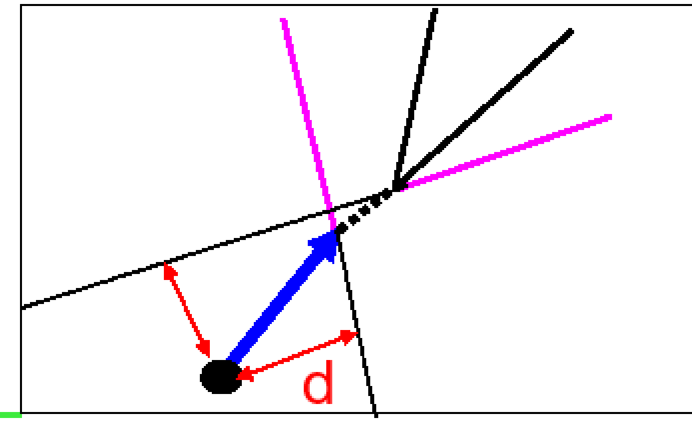


A typical B event at a hadron collider

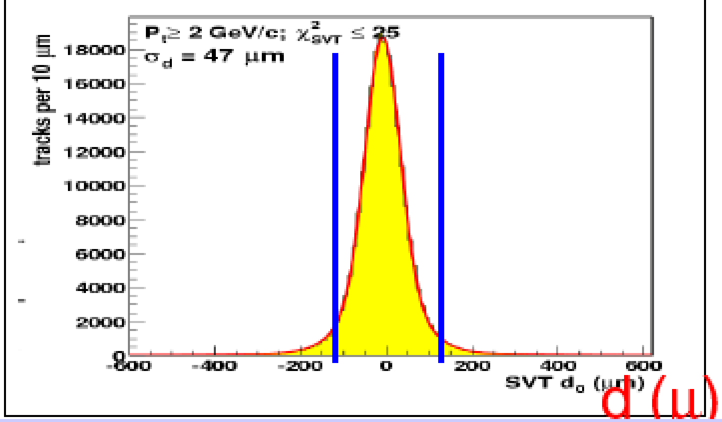


=> look for displaced tracks

Trigger on events with two displaced (d>120 μm) tracks



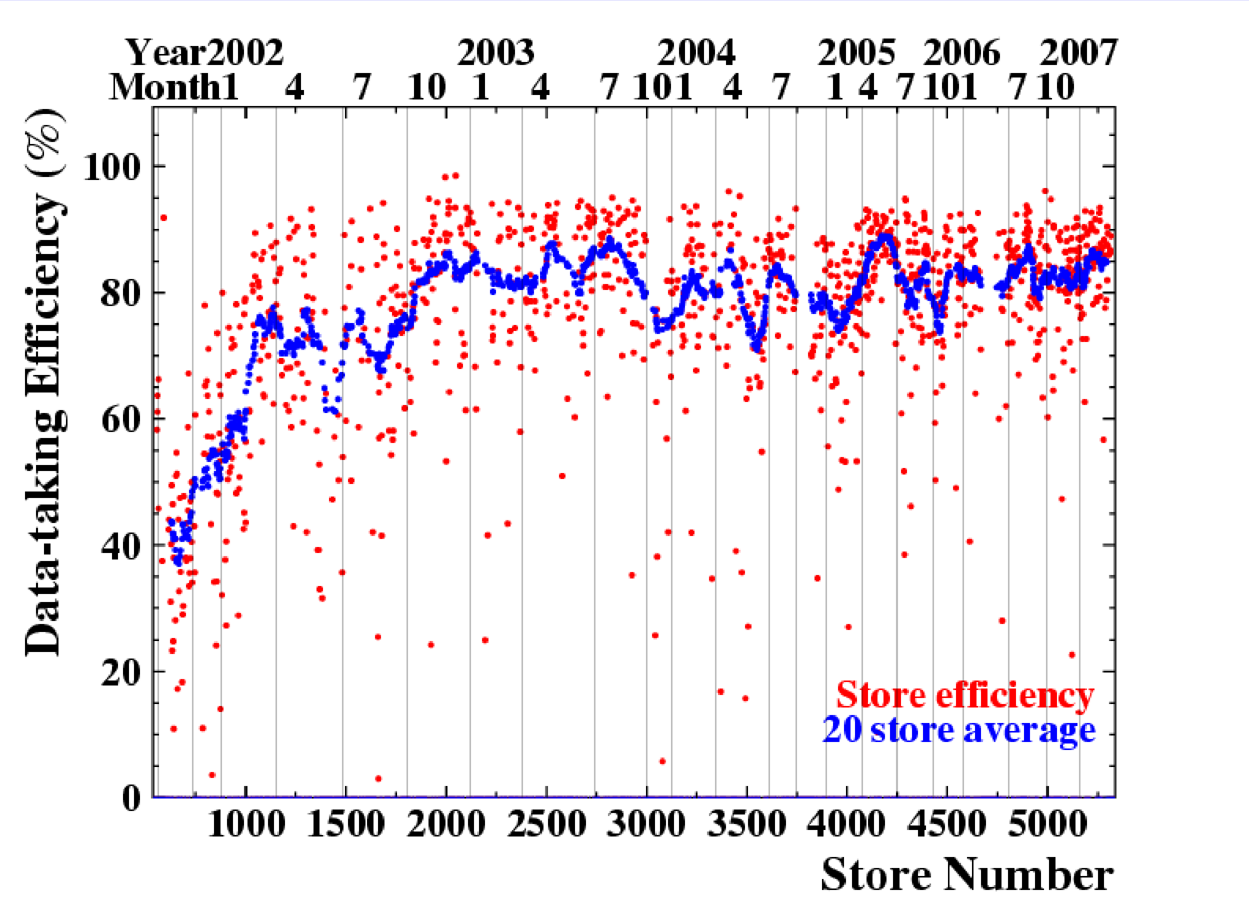
very fast reconstruction of silicon data at L2 (20μs latency) by dedicated hardware: SVT



Tevatron

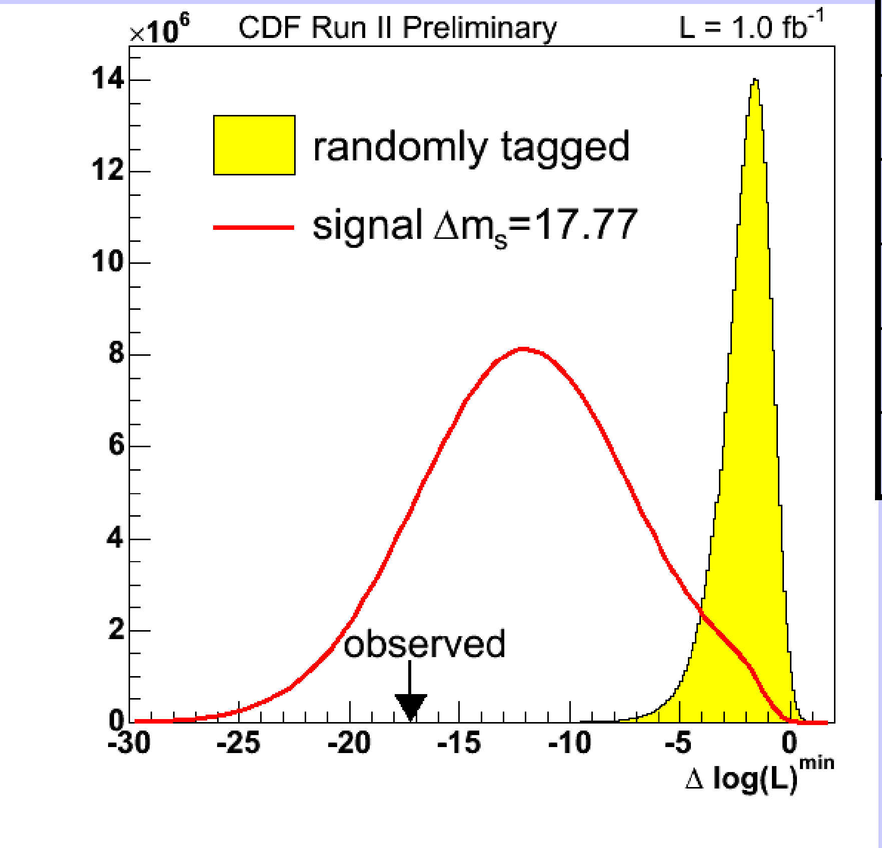
CDF Expect an integrated luminosity delivered:

- 3-4 fb^{-1} for end 2007
- 4-6 fb^{-1} for end 2008
- 6-8 fb^{-1} for end 2009



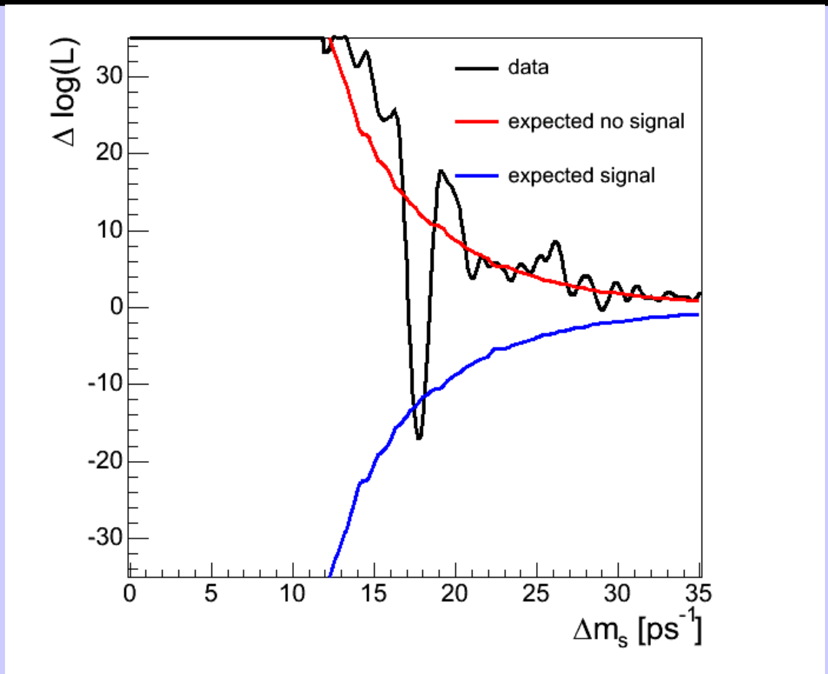
Bs mixing - CDF

P-value distribution



Systematics

Systematics	Syst. [ps^{-1}]
SVX Alignment	0.04
Track Fit Bias	0.05
PV bias from tagging	0.02
All other syst.	<0.01
TOTAL	**0.07**



p-value = $8 \cdot 10^{-8} > 5\ \sigma$

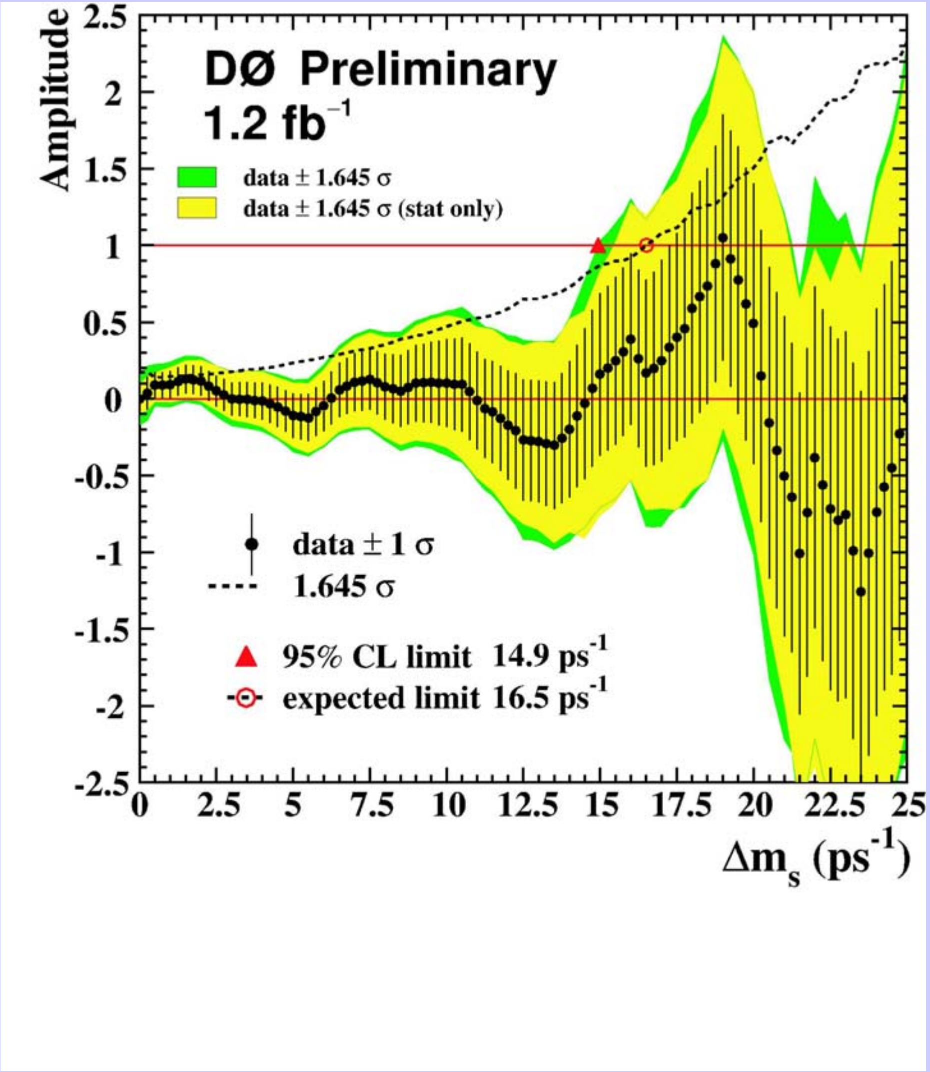
Bs mixing – D0

D0 results:
(1.2 fb^{-1})

Bs->Ds e X
(Ds->$\phi\pi$)

Bs->Ds μ X
(Ds-> $\phi\pi$, K*K, KsK)

$\Delta ms > 14.9 ps^{-1}$ @ 95% CL
(expected: 16.5ps^{-1})



Flavour charge asymmetries - I

Very sensible to new physics. In the B_s system we have two measures:

$$\text{D0}: p\bar{p} \to b\bar{b} \to \mu^{\pm}\mu^{\pm} \quad (\mathcal{L} \approx 1.0\text{fb}^{-1})$$

[Phys. Rev. D 74, 092001 (2006)]

$$A_{SL}^{\mu\mu} = \frac{N(b\bar{b} \to \mu^+\mu^+ X) - N(b\bar{b} \to \mu^-\mu^- X)}{N(b\bar{b} \to \mu^+\mu^+ X) + N(b\bar{b} \to \mu^-\mu^- X)}$$

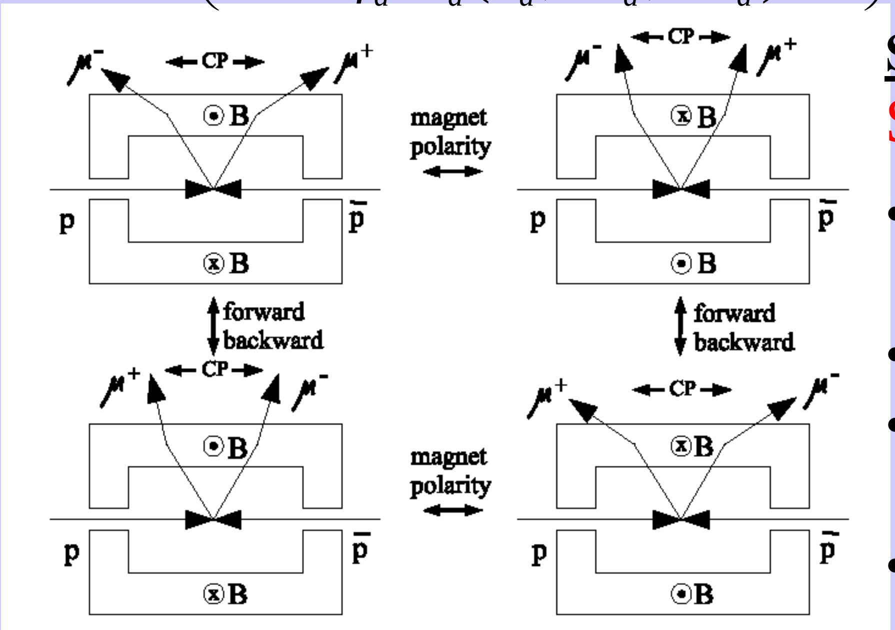
$$= \frac{1}{4}\left(A_{SL}^{d} + \frac{f_s}{f_d} \frac{Z_s(\Gamma_s, \Delta\Gamma_s, \Delta m_s)}{Z_d(\Gamma_d, \Delta\Gamma_d, \Delta m_d)} A_{SL}^{s} \right)$$

$$\text{D0}: B_s \to D_s \mu^{\pm} X \quad (\mathcal{L} \approx 1.3\text{fb}^{-1})$$

[hep-ex/0701007 (2007)]

$$A_{SL}^{s,unt} = \frac{N(D_s^-\mu^+) - N(D_s^+\mu^-)}{N(D_s^-\mu^+) + N(D_s^+\mu^-)}$$

$$= \frac{1}{2} A_{SL}^{s} = \frac{1}{2} \frac{\Delta\Gamma_s}{\Delta m_s} \tan\phi_s$$



Similar methods

Some highlights:

- Both detector and physics contribute to charge asymmetry.
- Flip B-field @ 0.1%: reduce det. syst.
- Divide sample in 8 sub-samples (B polarity, μ charge, η sign)
- Extract all asymmetries (6) from data

Flavour charge asymmetries - II

$$n_q^{\alpha\beta} = \frac{1}{4} N\varepsilon^{\beta}(1+qA)(1+q\gamma A_{fb})(1+\gamma A_{\det})\cdot$$
$$(1+q\beta\gamma A_{ro})(1+q\beta A_{q\beta})(1+\beta\gamma A_{\beta\gamma})$$

q= charge of μ
β= polarity of B
γ= sign of η

	D_s μ	μμ
A	0.0102±0.0081	-0.0005±0.0013
A_{fb}	-0.0046±0.0081	0.0004±0.0005
A_{det}	-0.0051±0.0081	-0.0176±0.0005
A_{ro}	-0.0352±0.0081	-0.0275±0.0005
$A_{\beta\gamma}$	-0.0097±0.0081	-0.0008±0.0005
$A_{q\beta}$	0.0030±0.0081	0.0064±0.0005

From the raw A asymmetry correct for bg contamination

$$A_{SL}^{\mu\mu} = -0.0092 \pm 0.0044(stat.) \pm 0.0032(syst.)$$ → inclusive μμ measure

$$A_{SL}^{s} = 0.0245 \pm 0.0193(stat.) \pm 0.0035(syst.)$$ → D_s μ measure

Flavour charge asymmetries - III

$A_{SL}^{\mu\mu}$ contains effects from both B_s and B_d:

$$A_{SL}^{\mu\mu} = \frac{1}{4}\left(A_{SL}^{d} + \frac{f_s}{f_d}\frac{Z_s(\Gamma_s, \Delta\Gamma_s, \Delta m_s)}{Z_d(\Gamma_d, \Delta\Gamma_d, \Delta m_d)} A_{SL}^{s} \right)$$

using measured values of $\Gamma_{s,d}$, $\Delta\Gamma_{s,d}$, $\Delta m_{s,d}$, we have for A_{SL}^{s}

[D0 Collab., hep-ex/0702030]

$$A_{SL}^{s} = -0.0064 \pm 0.0101$$

While the B_s-semileptonic measure gives:

$$A_{SL}^{s} = 0.0245 \pm 0.0193(stat.) \pm 0.0035(syst.)$$

The two measures are nearly indipendent { (<1% of B_s in $\mu\mu$ sample) (≈10% of $\mu\mu$ in B_s sample)

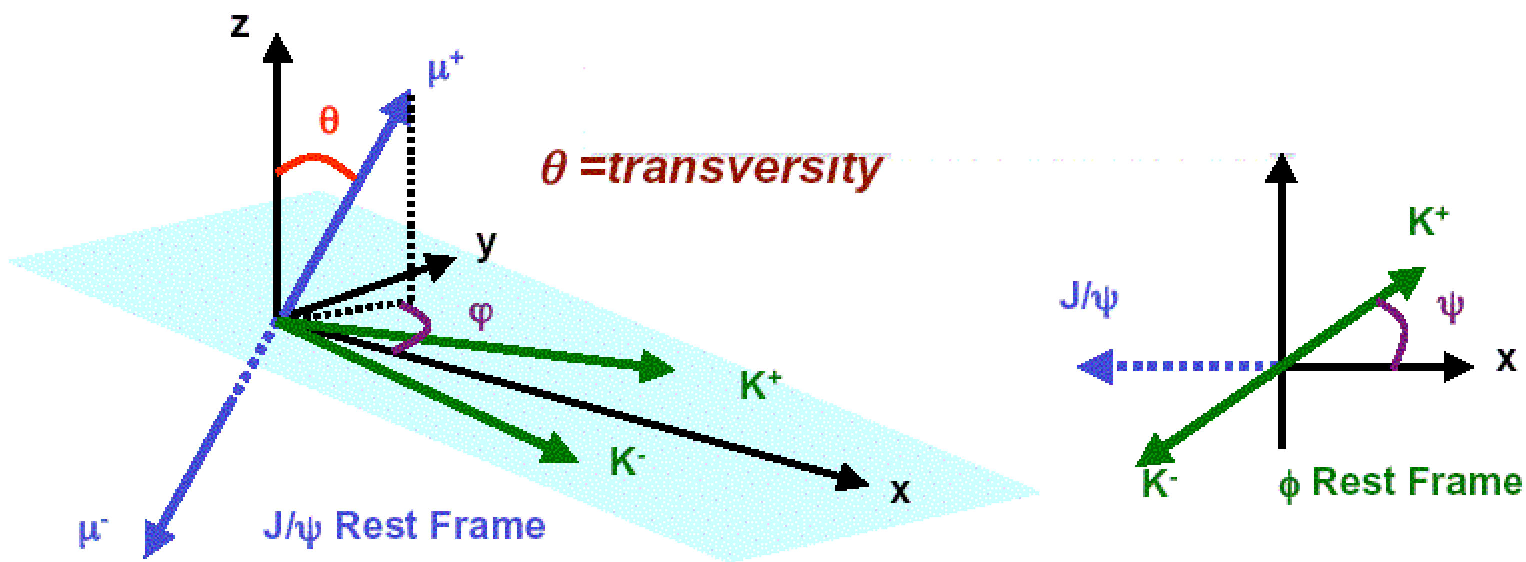
$$\Rightarrow \boxed{A_{SL}^{s} = 0.0001 \pm 0.0090}$$

To be compared to the SM prediction:

$$A_{SL}^{s,SM} = (2.06 \pm 0.57) \cdot 10^{-5}$$

[Lenz, Nierste; hep-ph/0612167]

Transversity



$$\frac{d^3\Gamma \to J/\psi(\to l^+l^-)\,\phi(\to K^+K^-)}{d\cos\theta\, d\phi\, d\cos\psi\, dt} \propto \frac{9}{16\pi}\Big[\, 2|A_0(0)|^2 e^{-\Gamma_L t}\cos^2\psi(1-\sin^2\theta\cos^2\phi)$$

$$+ \sin^2\psi\left\{|A_{||}(0)|^2 e^{-\Gamma_L t}(1-\sin^2\theta\sin^2\phi) + |A_\perp(0)|^2 e^{-\Gamma_H t}\sin^2\theta\right\}$$

$$+ \frac{1}{\sqrt{2}}\sin 2\psi\left\{|A_0(0)||A_\perp(0)|\cos(\delta_2-\delta_1)e^{-\Gamma_L t}\sin^2\theta\sin^2 2\phi\right\}$$

$$+ \left\{\frac{1}{\sqrt{2}}|A_0(0)||A_\perp(0)|\cos\delta_2\sin 2\psi\sin 2\theta\cos\phi\right\}\frac{1}{2}\left(e^{-\Gamma_H t} - e^{-\Gamma_L t}\right)\delta\phi$$

$$- \left\{\frac{1}{\sqrt{2}}|A_{||}(0)||A_\perp(0)|\cos\delta_1\sin^2\psi\sin 2\theta\sin\phi\right\}\frac{1}{2}\left(e^{-\Gamma_H t} - e^{-\Gamma_L t}\right)\delta\phi\,\Big]\, H(\cos\psi)\, F(\phi)\, G(\cos\theta)$$