Rencontres de Moriond - QCD and High Energy Interactions
La Thuile, 10 – 17 March 2012

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On behalf of the CDF and DØ Collaborations

Recent Heavy Flavor Results from the Tevatron

Flavor Matters

- Generic new couplings could introduce new sources of flavor/CP violation.
- If NP scale above LHC reach: flavor might be the only way to probe it…

Will focus on latest searches for NP through flavor at the **Tevatron**.

All New results

for Winter 2012

- ✓ CDF CPV in Charm w/ Full Run II Dataset
- ✓ CDF Search for $B \to \mu\mu$ w/ Full Run II Dataset
- ✓ CDF CPV in B_s mixing w/ Full Run II Dataset
- ✓ DØ new State Decaying into $\Upsilon(1S)+\gamma$


CPV in Charm

CP Violation in Charm

Probe the up-quark sector.
Direct CPV >1% level suggestive of NP.

$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

CDF 2011: trigger on displaced tracks - huge charm samples and unprecedented sensitivity in

$A_{CP}(D^0 \to K^+K^-) = (-0.24 \pm 0.22 \pm 0.10)\%$

$A_{CP}(D^0 \to \pi^+\pi^-) = (+0.22 \pm 0.24 \pm 0.11)\%$

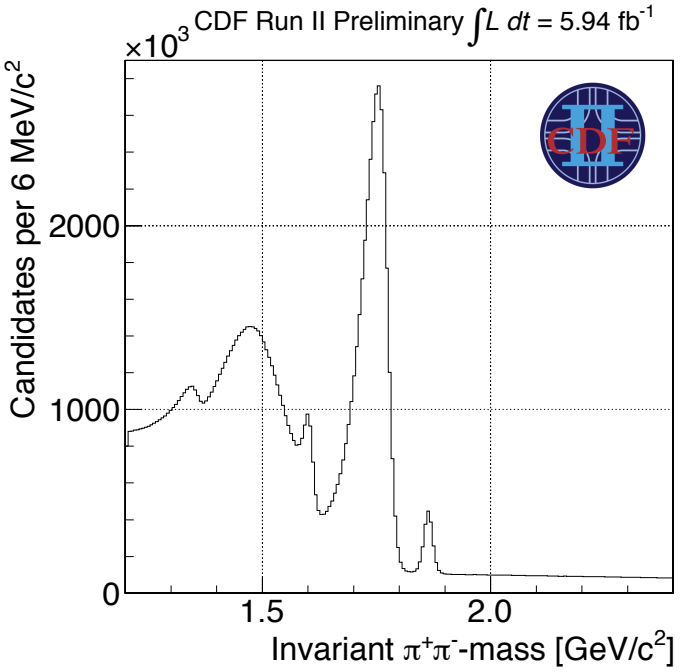
PRD85, 012009 (2012)

$\Delta A_{CP} = A_{CP}(D^0 \to K^+K^-) - A_{CP}(D^0 \to \pi^+\pi^-)$
maximally sensitive to NP.

Experimentally convenient:
instrumental asymmetries cancel.

First evidence of CPV in charm from LHCb
$\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$, 3.5σ from zero.
arXiv1112.0938

Independent confirmation crucial to establish it.



NEW ΔA_{CP} with Full Run II Dataset

Optimize off-line selection for ΔA_{CP}

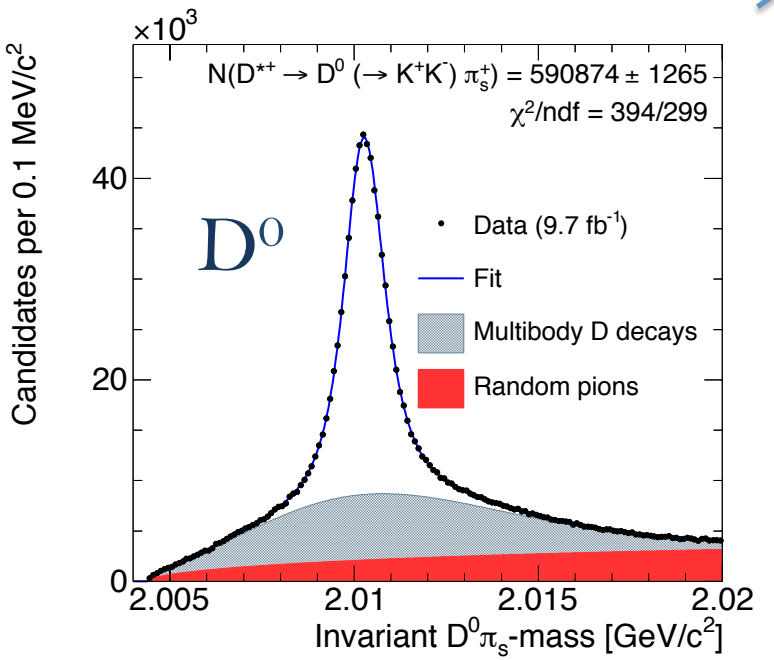
- ✓ loosen selection requirements (no D^0 I.P. cut) w.r.t. 5.9 fb^{-1} analysis: no need of $D^0 \rightarrow K\pi$.
- ✓ about double signal events.

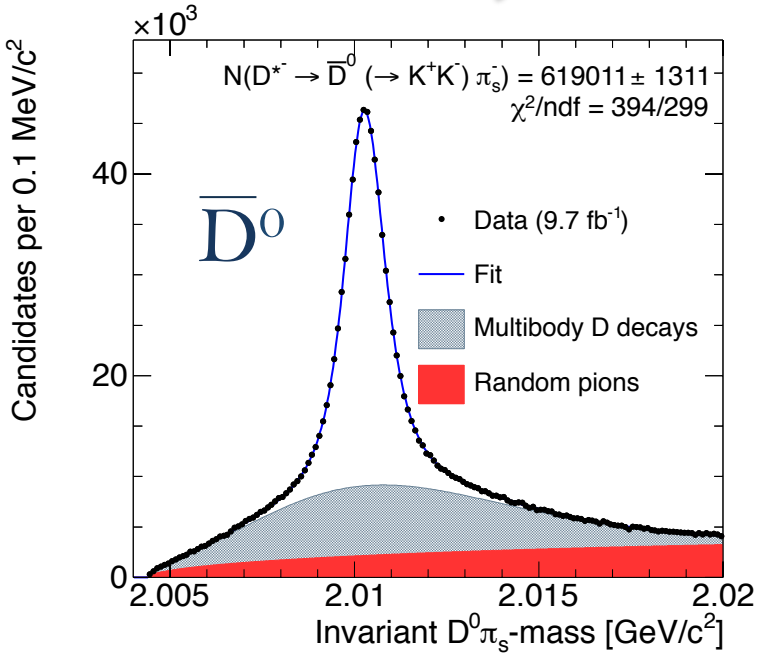
D^0 flavor through $D^* \rightarrow D^0\pi_s$

- ✓ soft pion induce O(1%) artificial asymmetries.

  Cancel detector effects by differences of raw asymmetries:

$$\Delta A_{CP} = (A(K^+K^-) + \delta(\pi_s)) - (A(\pi^+\pi^-) + \delta(\pi_s))$$



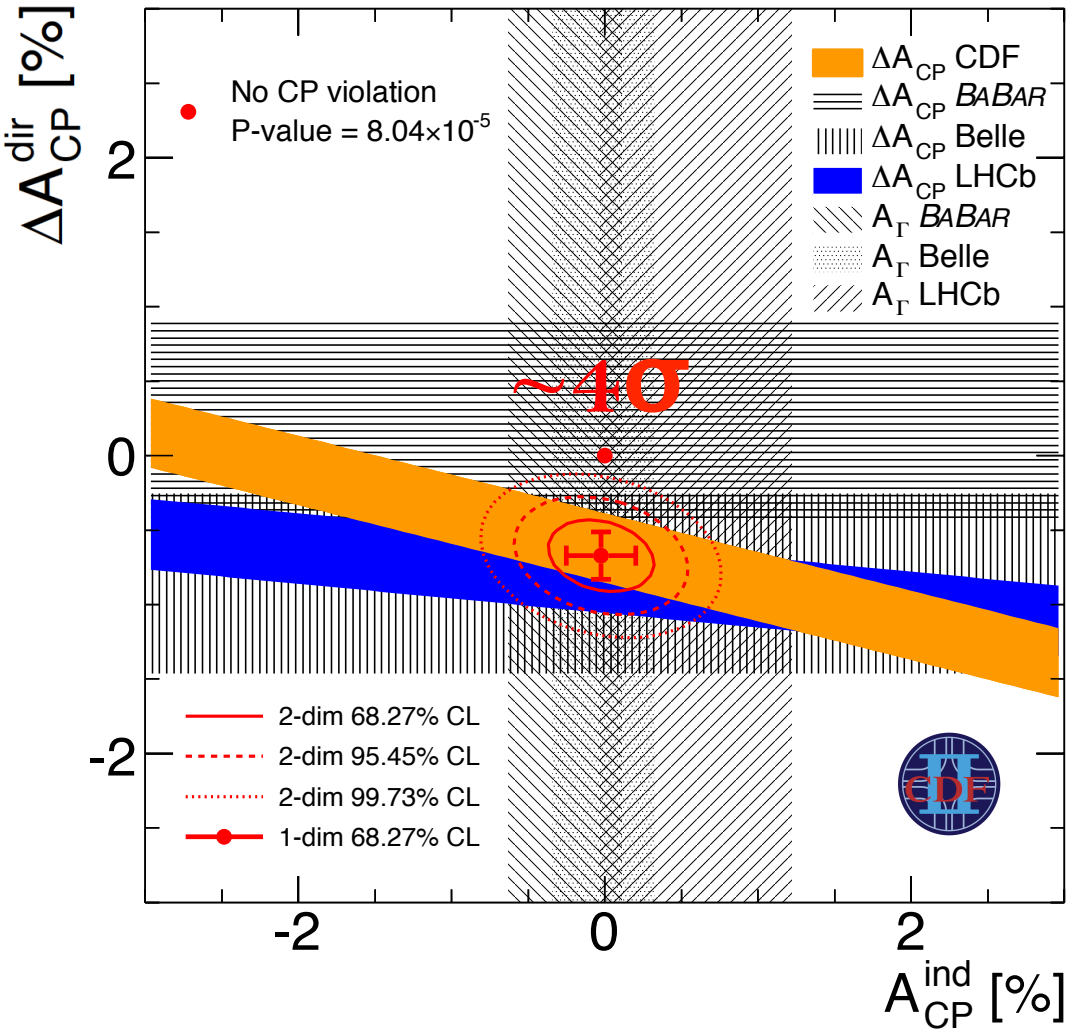


Charm(ing) Result

NEW

$\Delta A_{CP} = (-0.62 \pm 0.21(stat) \pm 0.10(syst))\%$

CDF Note 10784



Confirm LHCb result

$\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$

When combining à la HFAG

No CPV point is at

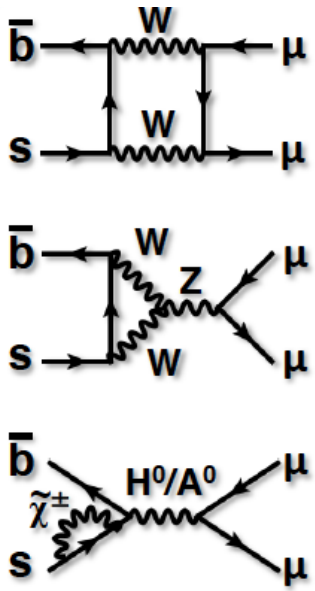
~4σ from zero

$\Delta A_{CP}^{dir} = (-0.67 \pm 0.16)\%$

$A_{CP}^{ind} = (-0.02 \pm 0.22)\%$


Rare B Decays

$B \rightarrow \mu\mu$



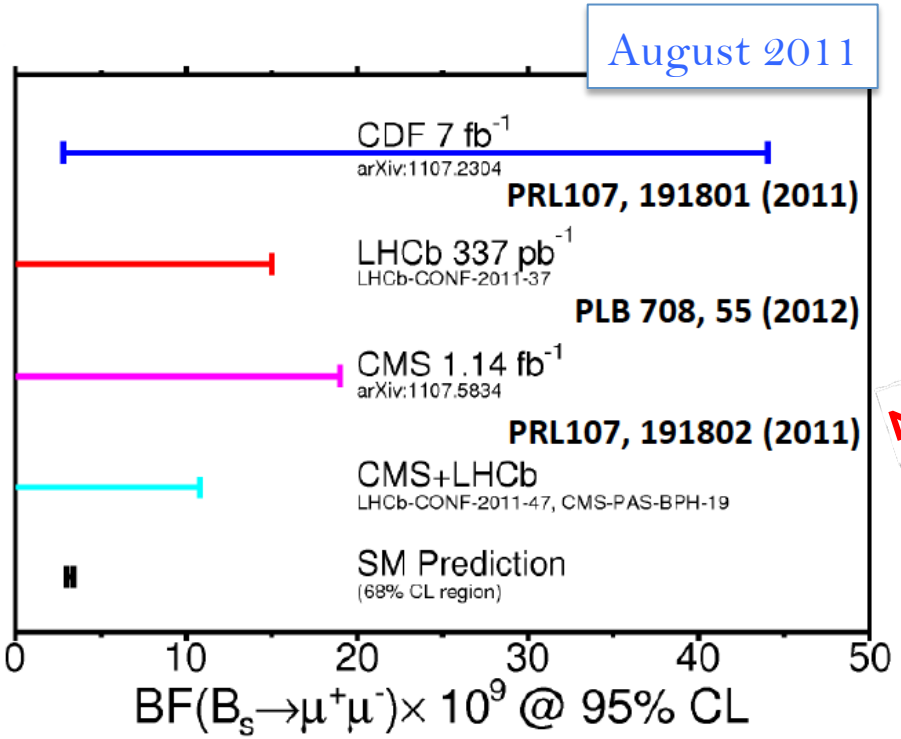
SM rates well understood

$BR(B_s^0 \rightarrow \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$, $BR(B^0 \rightarrow \mu^+\mu^-) = (1.0 \pm 0.1) \times 10^{-10}$

Important constraint for BSM building.

Long history of Tevatron searches brought down over orders of magnitude the upper limit to the 10^{-8} range.

Until last summer…



Interesting ~2.5 σ deviation from bkg observed by CDF in 7 fb^{-1}.

Compatible with other experiments and SM.

NEW

CDF update the analysis with whole Run II sample (10 fb^{-1}, +30% data) while keeping the analysis unchanged. No improvement with BDT.

The Analysis

Clean signature

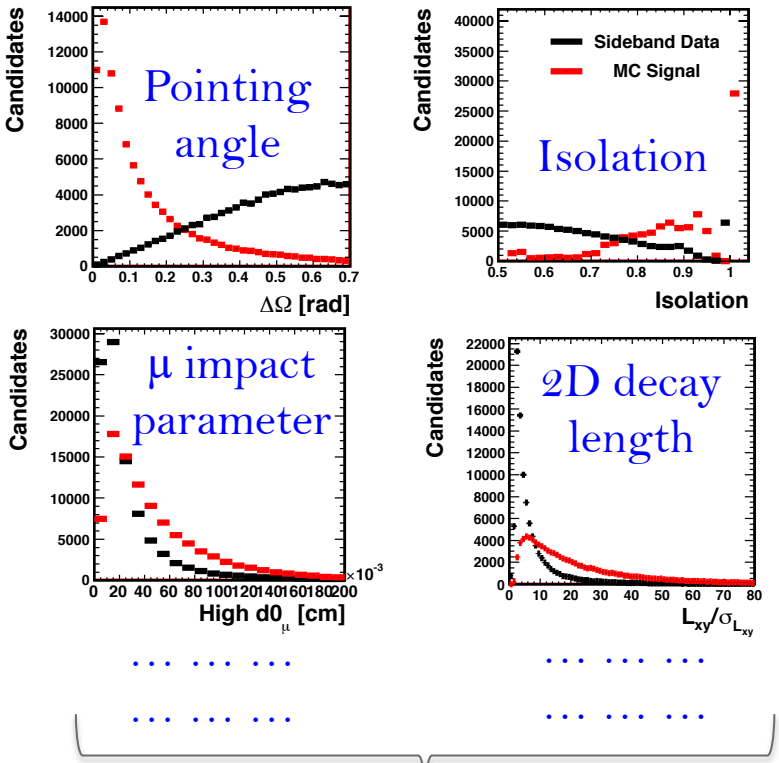
✓ Trigger on 2 muons with $p_T > 1.5$-2 Gev/c

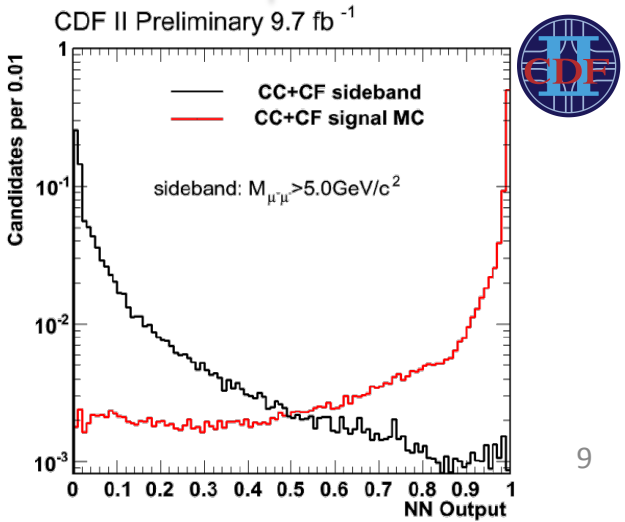
Challenge: reject 10^6 larger background while keeping the signal efficiency high.

✓ Optimized **NN classifier** separates S from B. Use of **14 discriminanting variables.**

Combinatorial bkg predicted from mass sideband (dominant) and fake rates for $B \rightarrow h^+h^-$. Checked on many control samples.

Rate determined using $B^+ \rightarrow J/\psi K^+$ as reference.

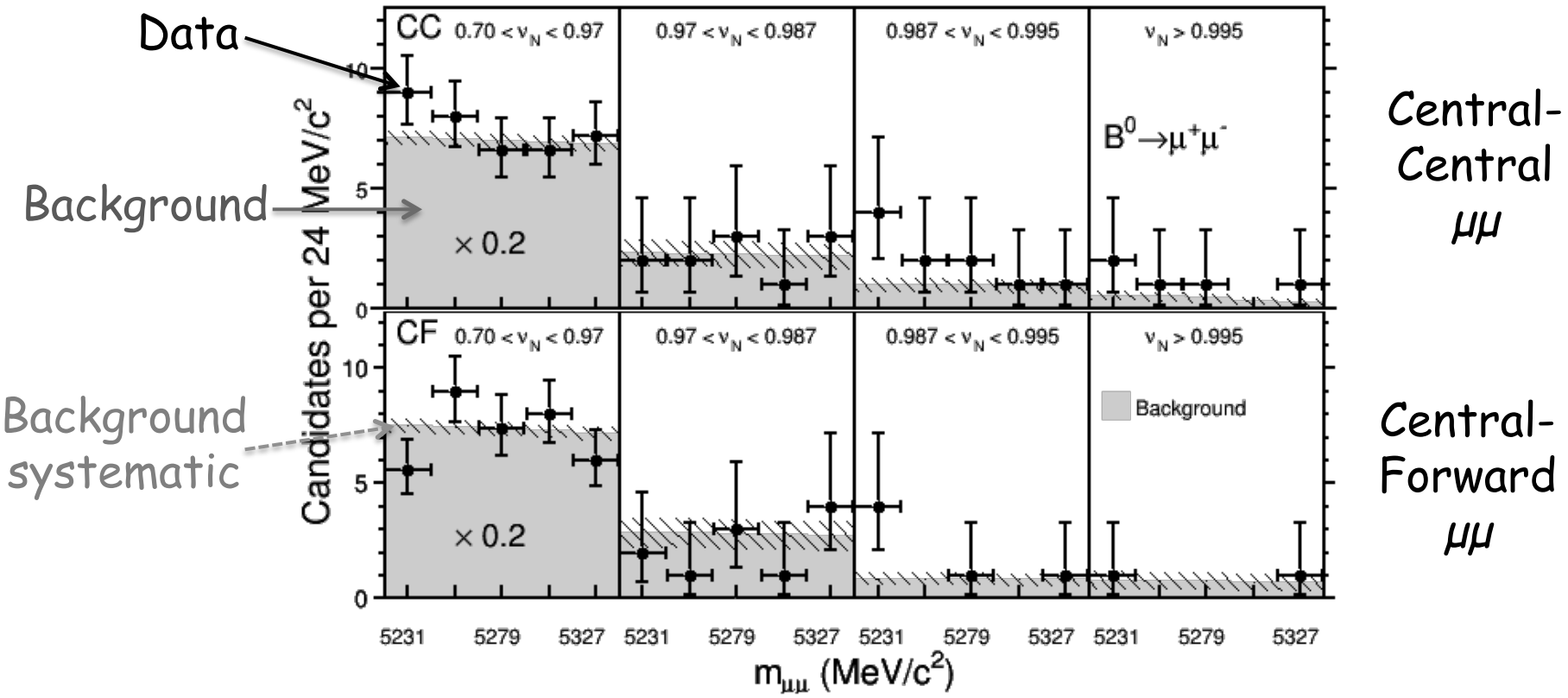




$B^0 \to \mu^+\mu^-$ Result

Divide signal region in NN bins

NEW

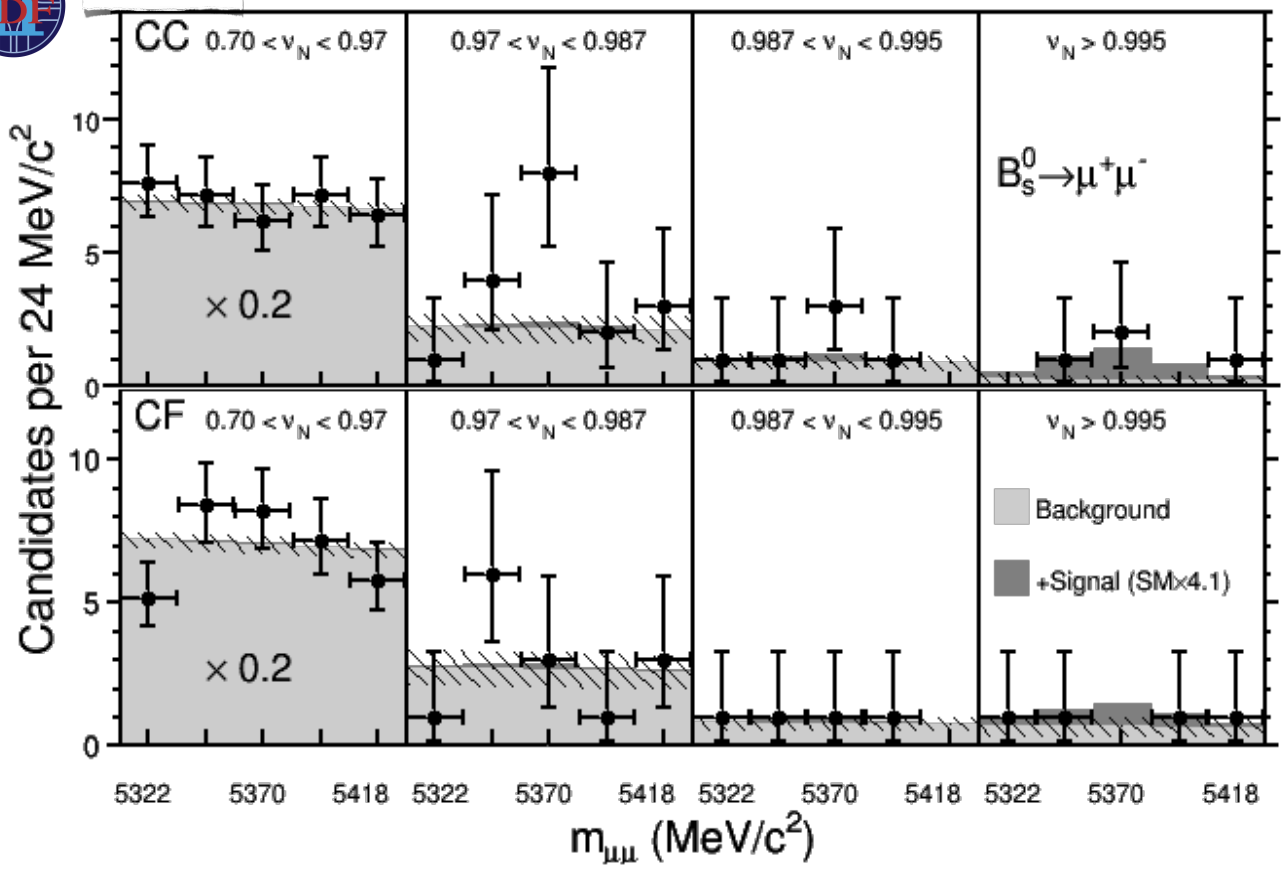


Observed limit $< 4.6 \times 10^{-9}$ (Expected 4.2×10^{-9}). Consistent with SM.
p-value for background-only hypothesis is 41%.

$B^0 \to \mu^+\mu^-$ important analysis benchmark for $B_s^0 \to \mu^+\mu^-$

$B_s^0 \to \mu^+\mu^-$ Result

NEW



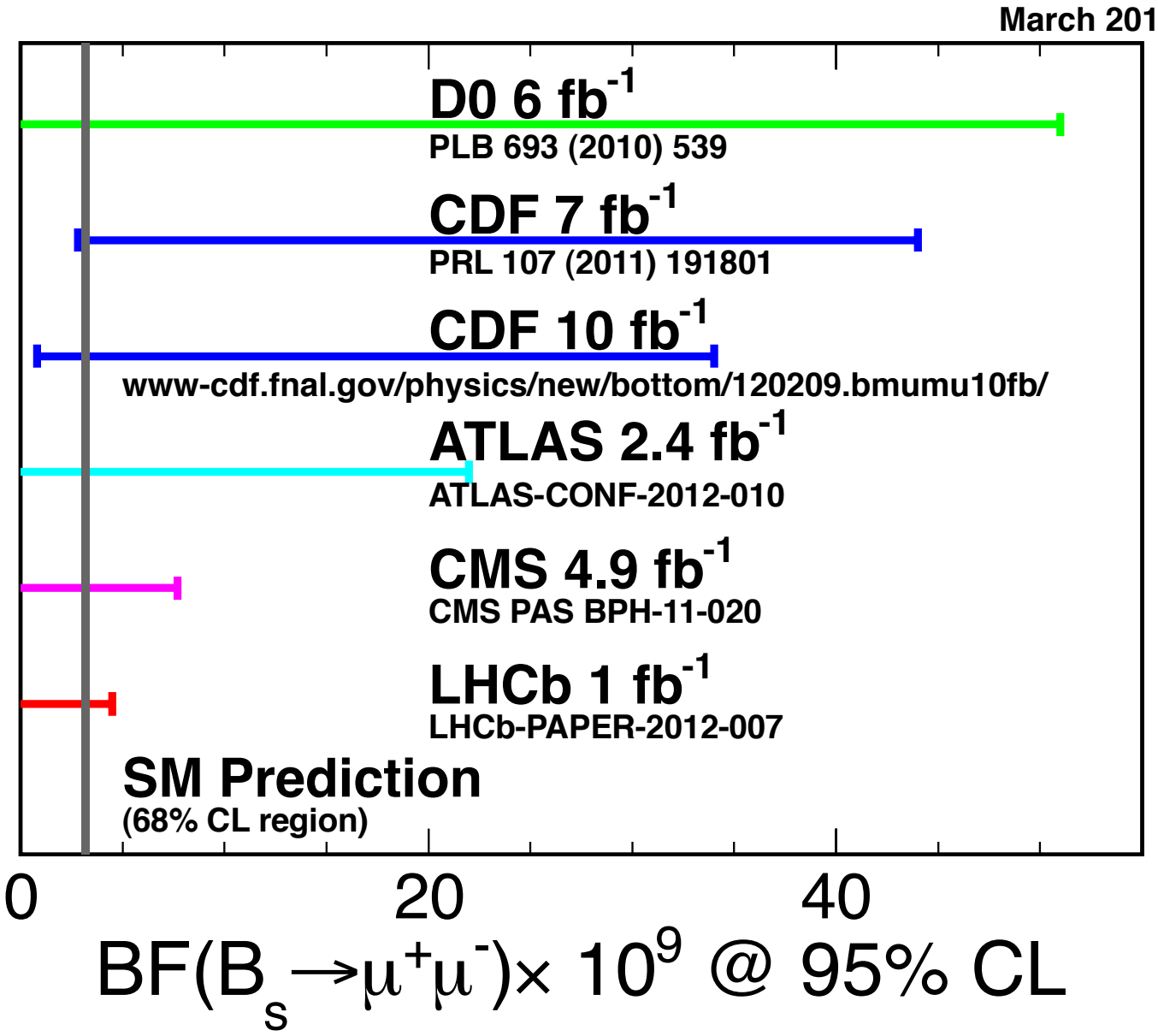
$0.8 \times 10^{-9} < BR(B_s \to \mu\mu) < 3.4 \times 10^{-8}$ @95% C.L. [$BR = (1.3^{+0.9}_{-0.7}) \times 10^{-8}$]

Bkg+SM p-value 7.1%. Bkg-only p-value 0.94%

Summer deviation not reinforced by new data, but still >2σ for bkg-only hypothesis.

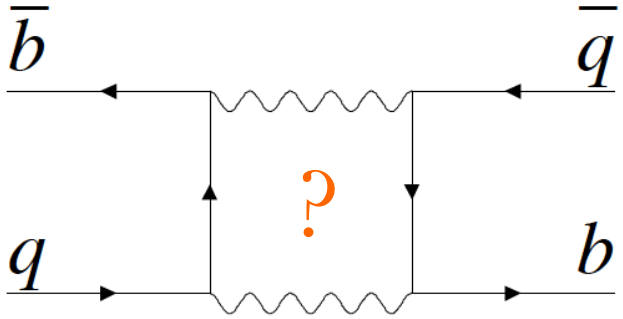
As of Last Week

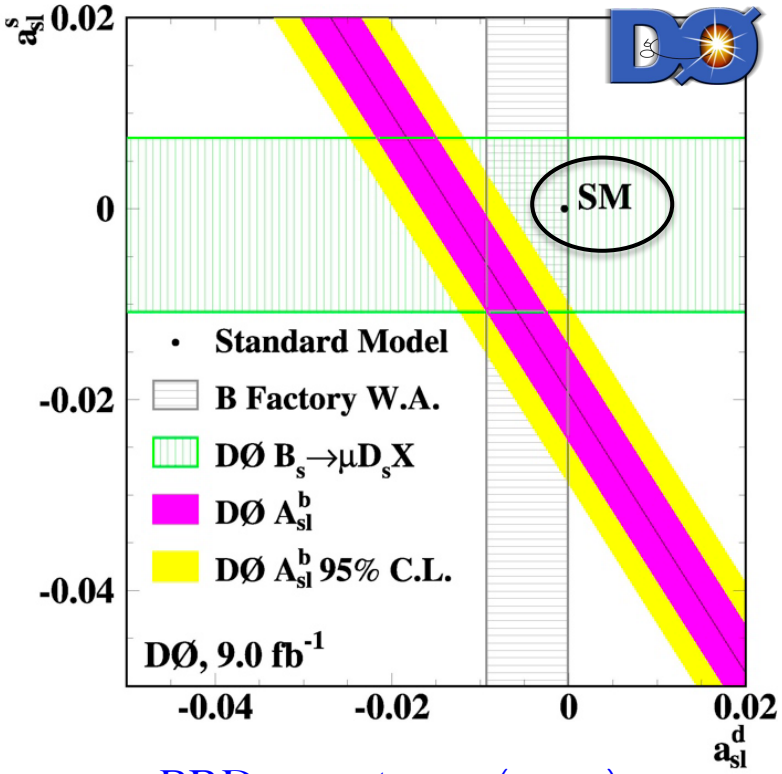
Getting extremely interesting... nearing the sensitivity to see the first signal!



Search for NP in B_s Mixing

Search for NP in B_s Mixing





PRD 84, 052007 (2011)

B_s mixing phenomenology can be significantly altered by NP.

2011 DØ: ~4 σ deviation from SM in B semileptonic asymmetry.

Independent cross-check is crucial.

Constrain BSM physics through

- CP-violating mixing phase largely suppressed in SM
- B_s^H – B_s^L decay difference

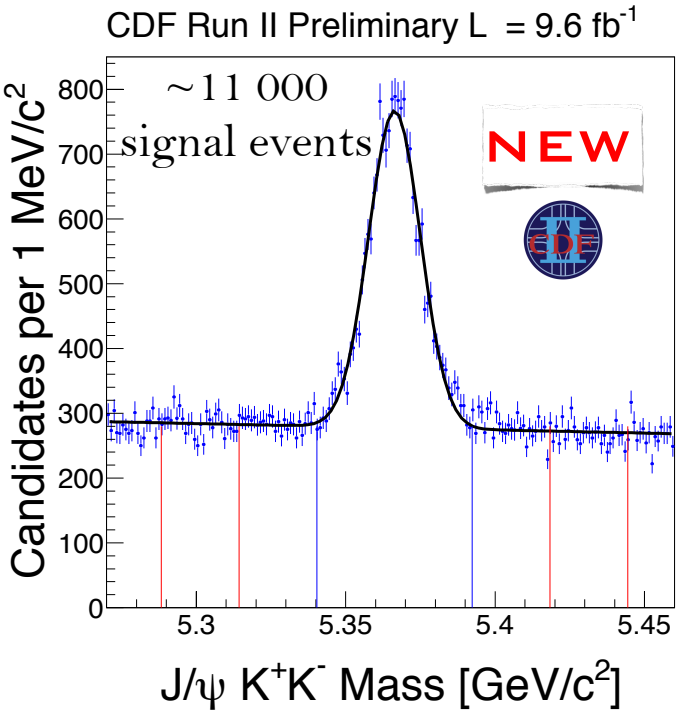
Indeed: $a^s_{sl} \approx (\Delta\Gamma_s / \Delta m_s) \tan\phi_s$

NEW CDF updates measurements with full Run II data.

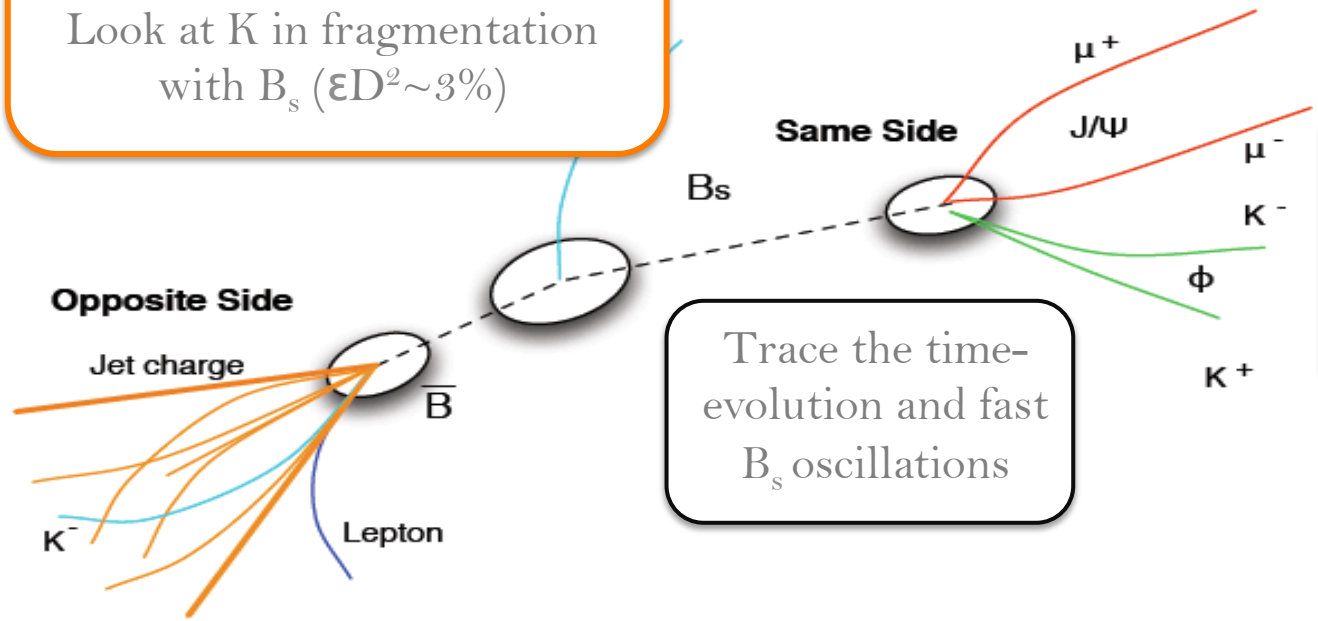
Strategy

Exploit interference between $B_s^0 \to J/\psi\,\phi$ decays w/ and w/o flavor oscillations.

- ✓ low p_T dimuon trigger. Off-line optimized NN selection @CDF; BDT/square cuts @DØ.
- ✓ joint fit to mass, production flavor, decay-time, decay-angles



Look at other B ($\varepsilon D^2 \sim 1.4\%$)
+
Look at K in fragmentation with B_s ($\varepsilon D^2 \sim 3\%$)



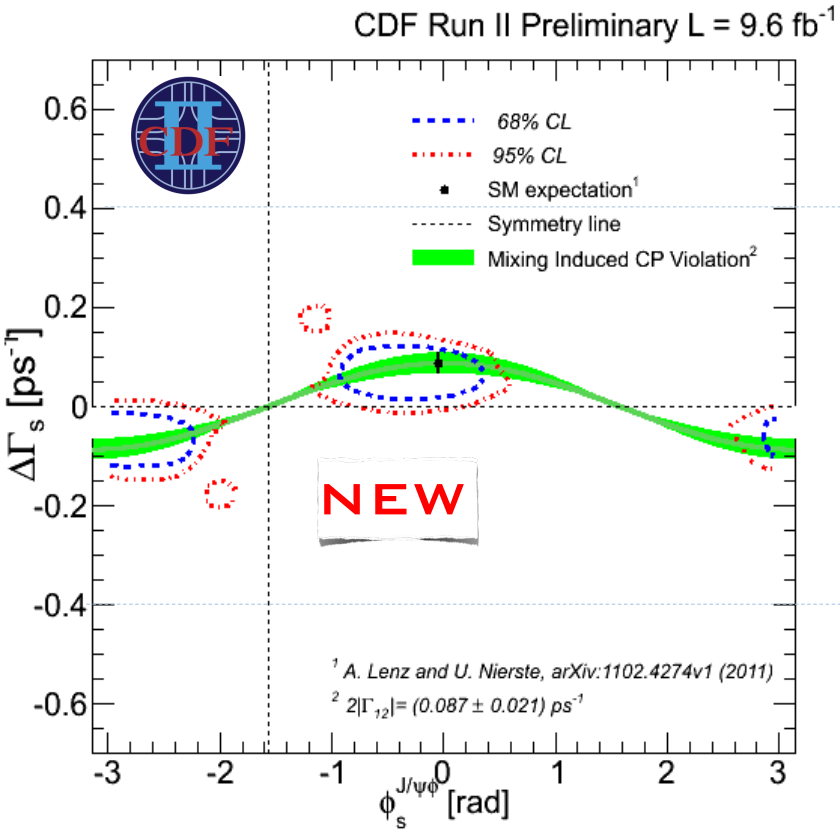
Trace the time-evolution and fast B_s oscillations

Disentangle CP-even/CP-odd final state

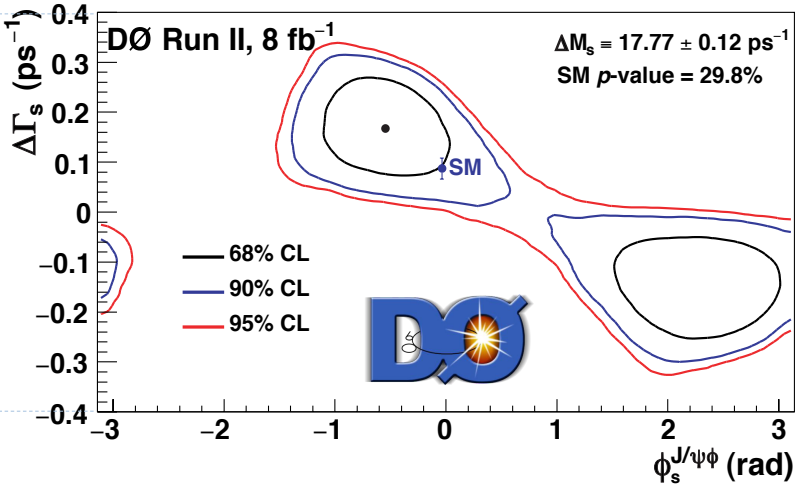
Include J/ψ KK S-wave contribution

Mixing Phase Bounds

Both experiments consistent with SM ($< 1\sigma$).



PRD 85, 032006 (2012)



Strong phases fitting range restricted based on $B^0 \rightarrow J/\psi K^*$

ϕ_s in [-0.60, 0.12] rad @ 68% C.L.

CDF Note 10778

$\phi_s = -0.55^{+0.38}_{-0.36}$ rad

Decay Width Difference and Lifetime

Assuming SM CP-violation, new CDF measurement with full Run II dataset

$\Delta\Gamma_s = 0.068 \pm 0.026 \pm 0.007\ ps^{-1}$

$\tau_s = 1.528 \pm 0.019 \pm 0.009\ ps$

NEW

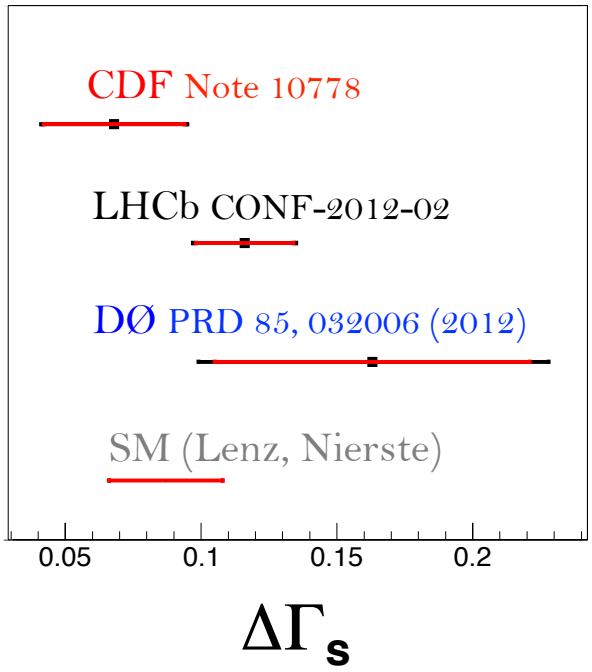
CDF Note 10778

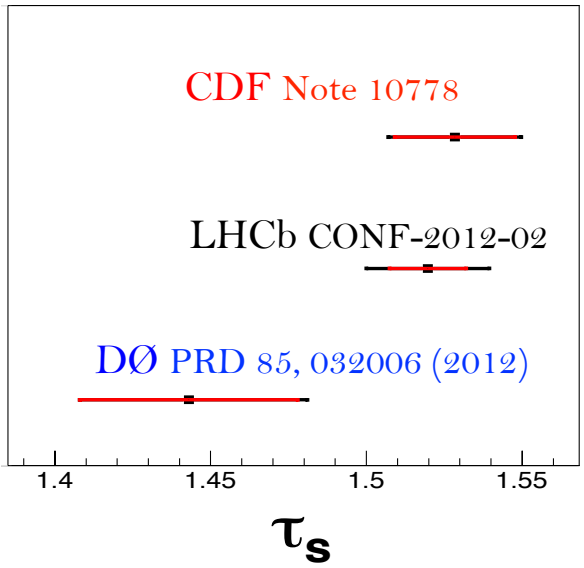
DØ: $\Delta\Gamma_s = 0.163\ ^{+0.065}_{-0.064}\ ps^{-1}$

$\tau_s = 1.443\ ^{+0.038}_{-0.035}\ ps$

PRD 85, 032006 (2012)

Very interesting to constrain A_{SL} (for instance, A. Lenz @Moriond EW 2012)






NEW STATE $\chi_b(3P)$
www.lemiemontagne.it

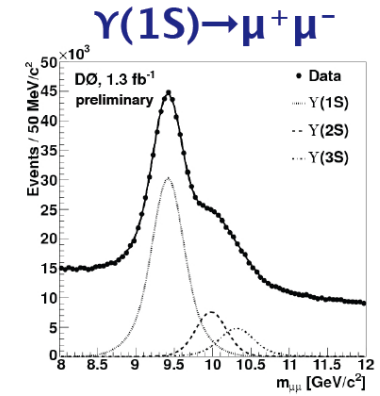
NEW STATE DECAYING INTO $\Upsilon(1S)+\gamma$

While waiting for NP…

Confirm ATLAS observation (arXiv:1112.5154) of new state $\chi_b(3P) \rightarrow \Upsilon(1S) + \gamma$

$$M[\chi_b(3P)] = 10.551 \pm 0.014 \pm 0.017 \text{ GeV}$$

NEW



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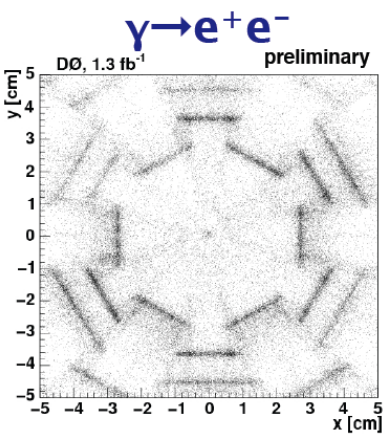
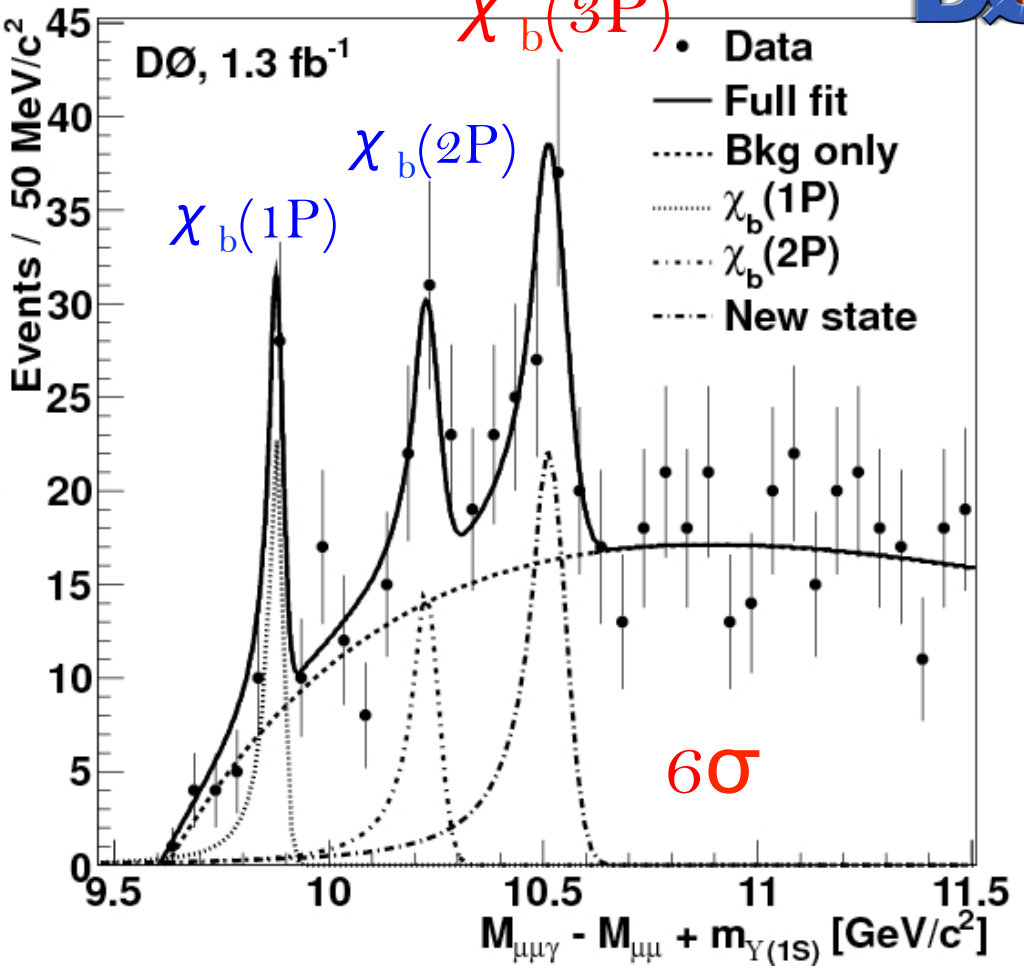




Conclusions

- Tevatron keeps producing new, important results on the benchmark channels of heavy flavor physics with Full Run II dataset

CPV in Charm sector

CDF confirms LHCB's evidence of CPV in charm with same precision

Rare B decays

extension to full sample confirms summer result

B_s mixing

Closer to SM expectations.

A_{SL} needs independent check.

Confirmation of $\chi_b(3P)$

- Pioneered and established role of hadron collisions in HF. Keep improving flagship measurements updated to full statistics.

Don't relax just yet – a few aces still up our sleeve!

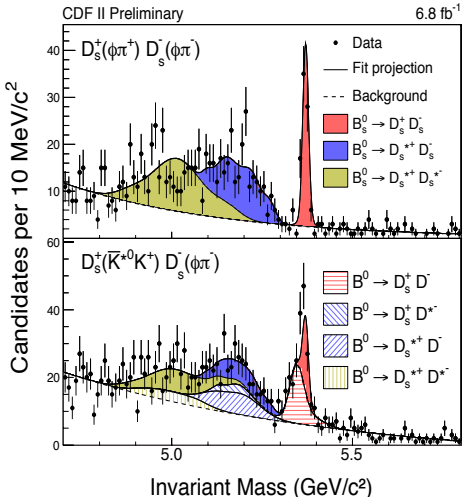
And Many More...

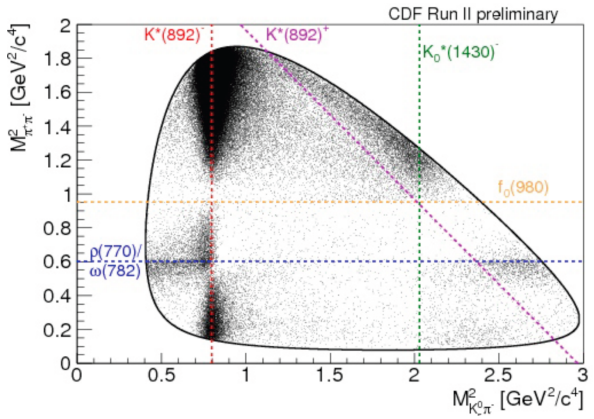
For more NEW results since summer 2011:

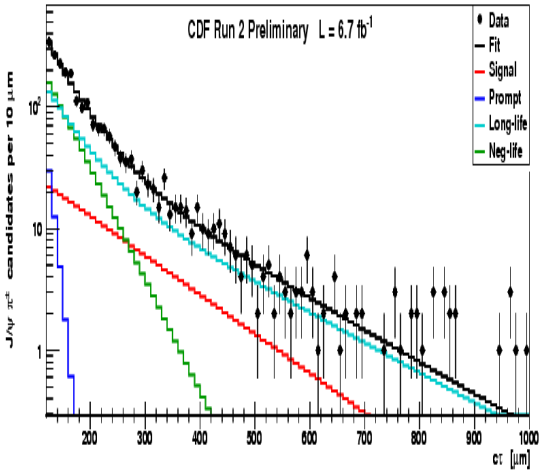
[CDF Heavy Flavor Group web page]

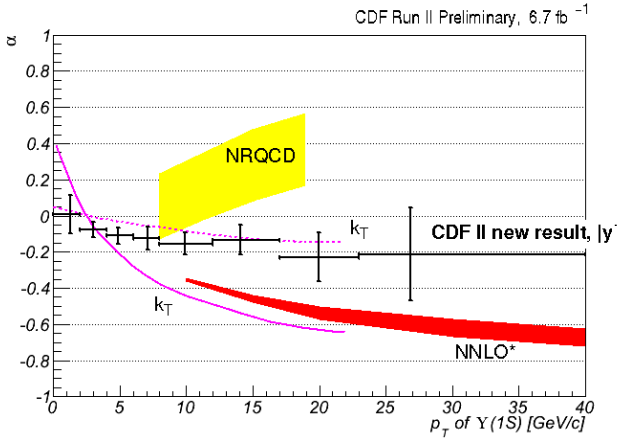
[DØ Heavy Flavor Group web page]

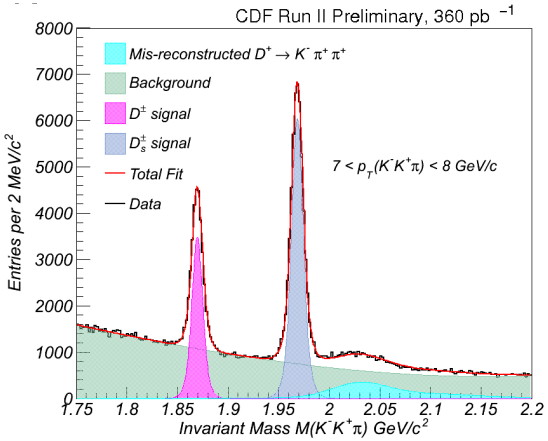
- ✓ Measurement of BR($B_s^0 \to D_s^{(*)+} D_s^{(*)-}$)
- ✓ Search for CP Violation in $D^0 \to K_S \pi^+ \pi^-$
- ✓ First 3-dimensional measurement of the Y(nS) spin-alignment
- ✓ Fragmentation Study with $D^{\pm}_s/D^{\pm}K$ Correlations
- ✓ Measurement of the B_c lifetime
- ✓ … … …











BAckup

Pioneer of Heavy Flavor @ Hadron Collider

CDF and DØ demonstrated that cutting-edge HF physics is possible with hadron collisions in addition to high-p_T program

- Tevatron: 10^{13} $p\bar{p}$ collisions @ 2 TeV in 10 years: ≈10 fb^{-1} on tape per experiment. Shut down 30th Sept. 2011.
- High-rate of all species of heavy flavors – B_d, B_c, B_s, 5 new baryons ($\Sigma_b^{\pm}$, Ξ_b^{0-}, Ω_b^{-}), copious D.
- Tracking: $\sigma(p_T)/p_T^2$=0.1%. Vertex known within 20 μm. Good muons. Some PID (1.5σ).
- From 2001 silicon to trigger for tracks displaced from $p\bar{p}$ vertex. Trigger with low-p_T leptons: both single and pairs.

More on B_s

$B_s \to D_s^{(*)+} D_s^{(*)-}$ Branching Ratio

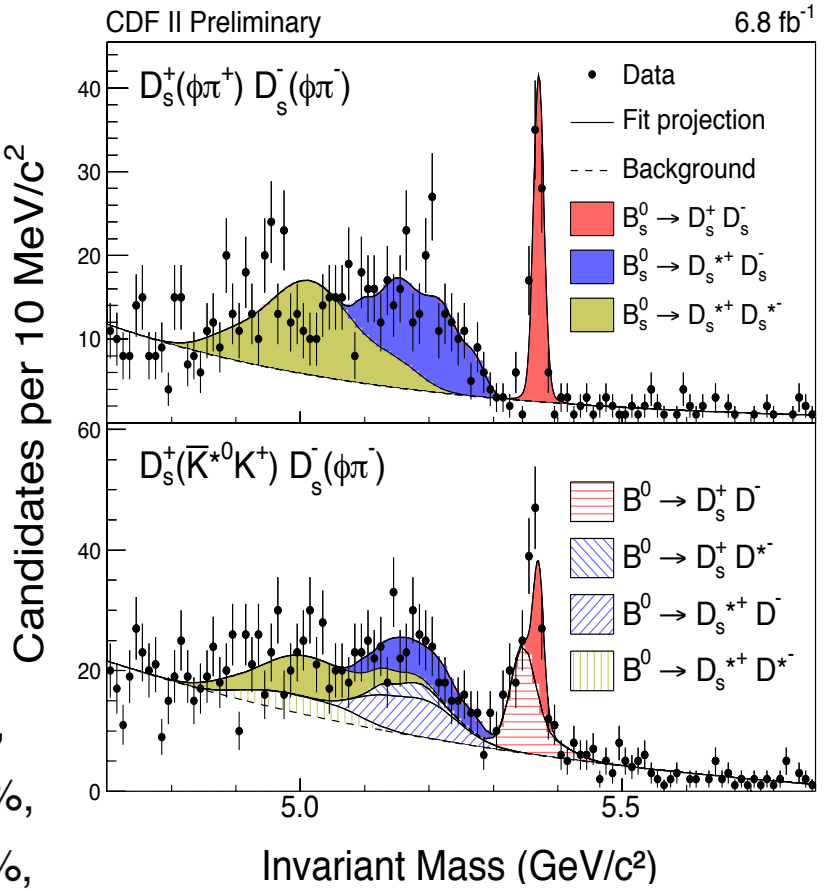
NEW

Predominately CP-even. May give dominant contribution to B_s width difference in SM.

6.8 fb^{-1} collected by displaced track trigger

Simultaneous fit to signal $B_s^0 \to D_s^{(*)+} D_s^{(*)-}$ and normalization mode $B^0 \to D_s^+ D^-$

$D_s^+ \to K^+K^-\pi^+$ Dalitz structure for precise determination of acceptance.



Precise BR measurements

$BR(B_s \to D_s^+ D_s^-) = (0.49 \pm 0.06 \pm 0.05 \pm 0.08)\ \%,$

$BR(B_s \to D_s^{*\pm} D_s^{\mp}) = (1.13 \pm 0.12 \pm 0.09 \pm 0.19)\ \%,$

$BR(B_s \to D_s^{*+} D_s^{*-}) = (1.75 \pm 0.19 \pm 0.17 \pm 0.29)\ \%,$

$BR(B_s \to D_s^{(*)+} D_s^{(*)-}) = (3.38 \pm 0.25 \pm 0.30 \pm 0.56)\ \%,$

CDF Note 10721

Under some theoretical assumptions, from BR possible to infer

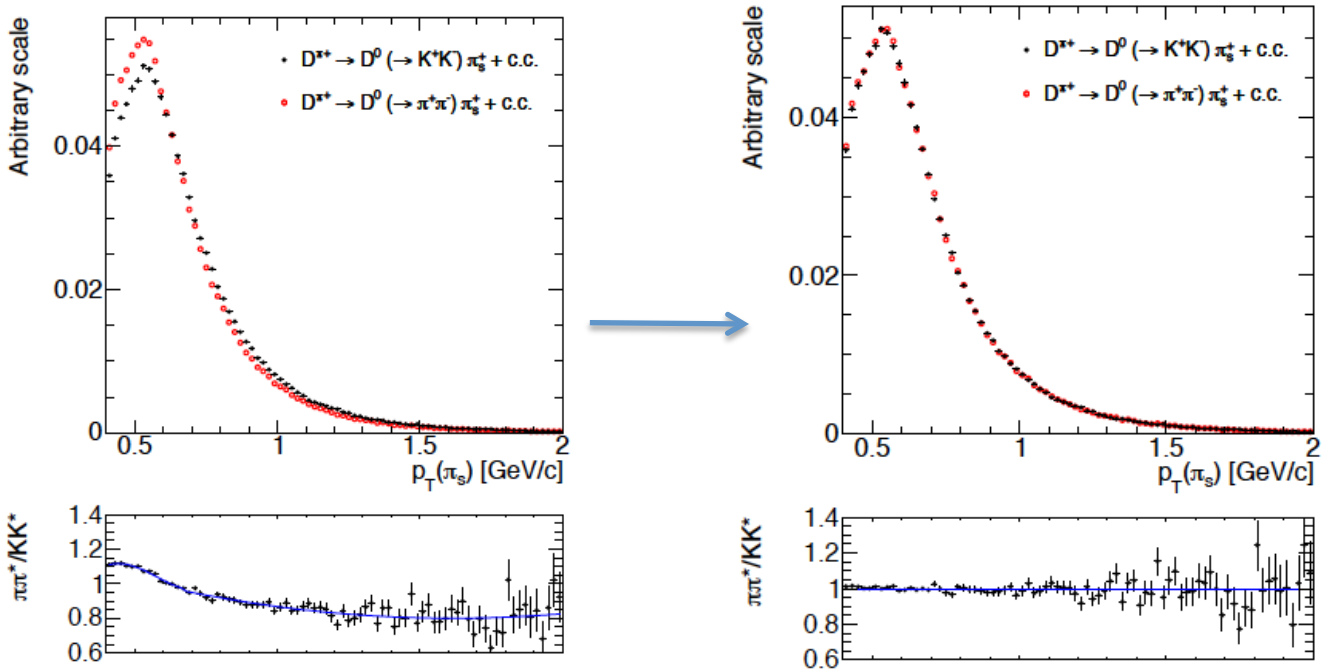
$\Delta\Gamma_s / \Gamma_s = (6.99 \pm 0.54 \pm 0.64 \pm 1.20)\%$

NEW ΔA_{CP} WITH FULL RUN II DATASET

Soft pion induce O(1%) artificial asymmetries.
Cancel detector effects by differences of raw asymmetries:

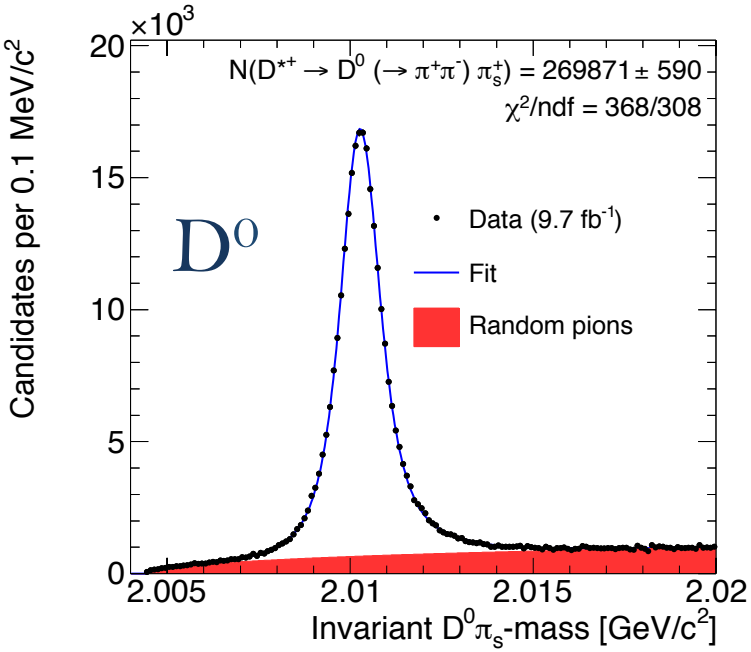
$$\Delta A_{CP} = (A(K^+K^-) + \delta(\pi_s)) - (A(\pi^+\pi^-) + \delta(\pi_s))$$

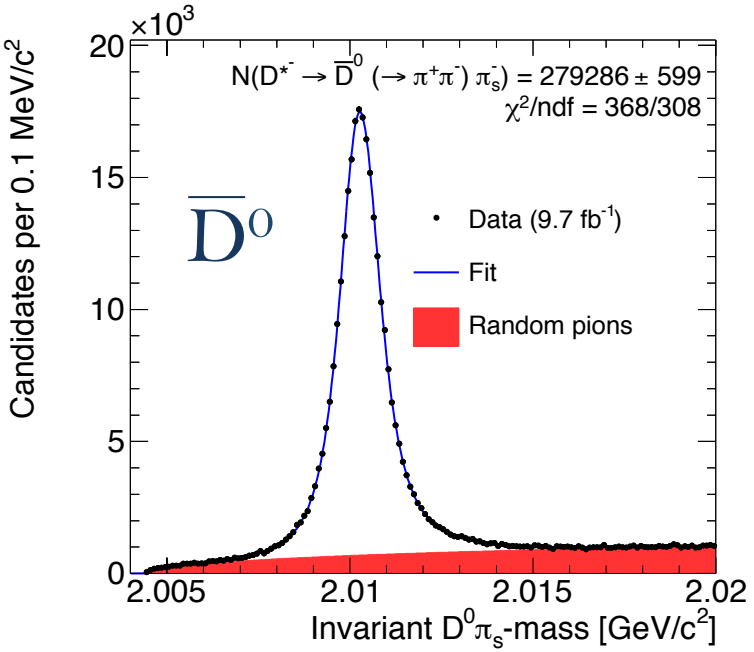
Detector asymmetries are kinematic dependent, cancellation works if π_s distributions are the same between KK and ππ .
Make them equal by reweighting



NEW

ΔA_{CP} ($\pi\pi$ Fit)





Raw asymmetries:

$$A(\pi\pi^*) = (-1.71 \pm 0.15)\%,$$
$$A(KK^*) = (-2.33 \pm 0.14)\%.$$

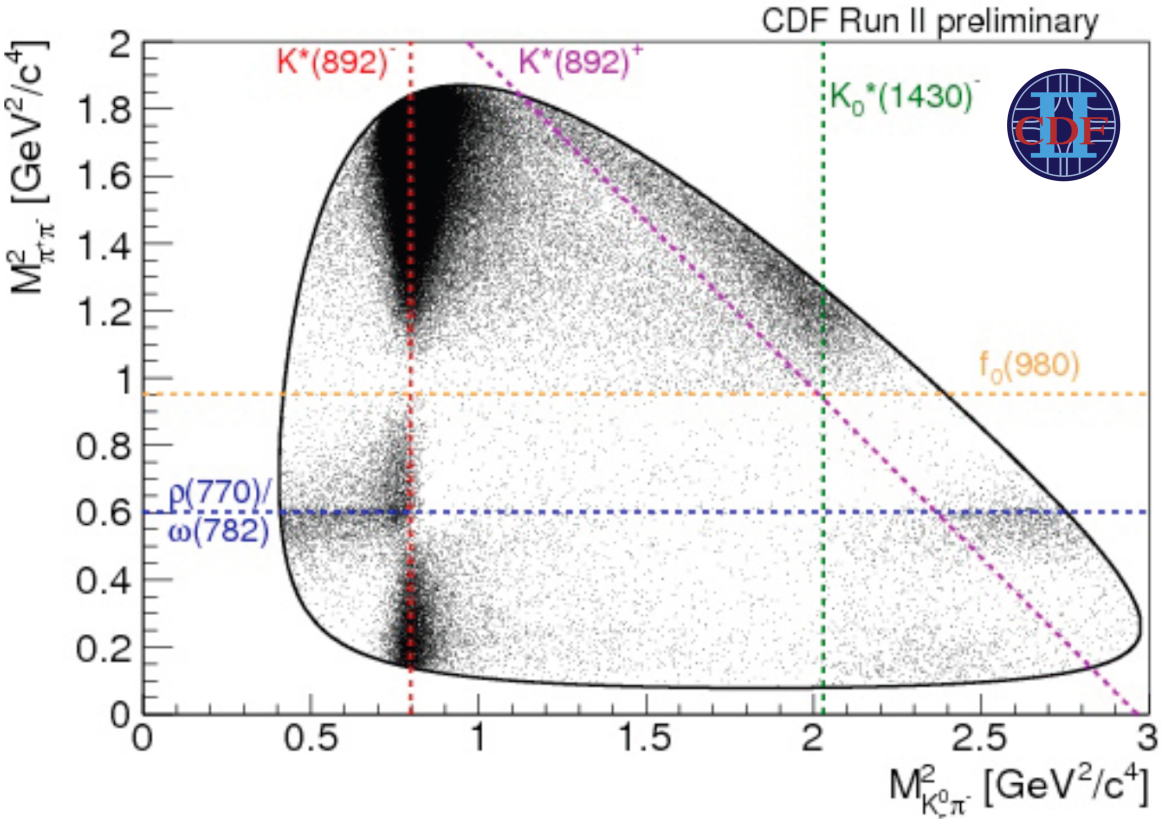
NEW

ΔA_{CP} Systematics

Source	ΔA_{CP} [%]
Approximations in the suppression of detector-induced effects	0.009
Shapes assumed in fits	0.020
Charge-dependent mass distributions	0.100
Asymmetries from residual backgrounds	0.013
Total	0.103

Another Charm Results

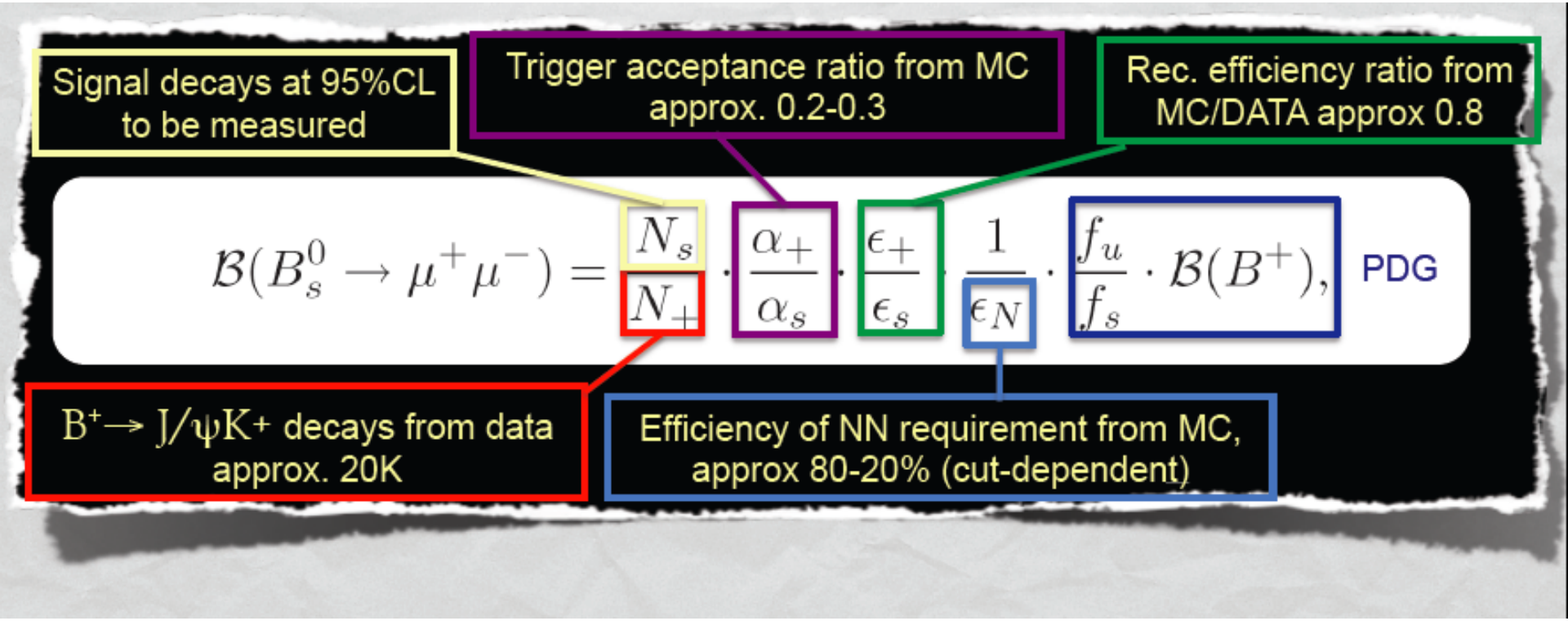
NEW At CDF full Dalitz analysis at Hadron Collider with $D^0 \to K_S \pi^+ \pi^-$



Big improvement w.r.t. CLEO results (PRD70, 091101 (2004))

$$A_{CP}(D^0 \to K_S \pi^+ \pi^-) = (-0.05 \pm 0.57 \pm 0.54)\%$$

$B_s^0 \to \mu^+\mu^-$ ANALYSIS



$B_s^0 \to \mu^+\mu^-$: THE 3RD BIN

Significance of 3rd bin excess decreases with new data: support interpretation as statistical fluctuation.

Unlikely to be peaking bckg. Only one is B→hh. Is 10x larger in B^0 window where nothing is seen.

Unlikely to be syst. problem with combinatorial. Same procedure in B^0 where nothing is seen.

Unlikely to be NN-shape issue. Cross-check with B^+ looks good within <5%. And several crosschecks show no mass bias vs NN

We conclude this is a fluctuation . Not unlikely in one out of 80 bins. Using last 2 bins only:

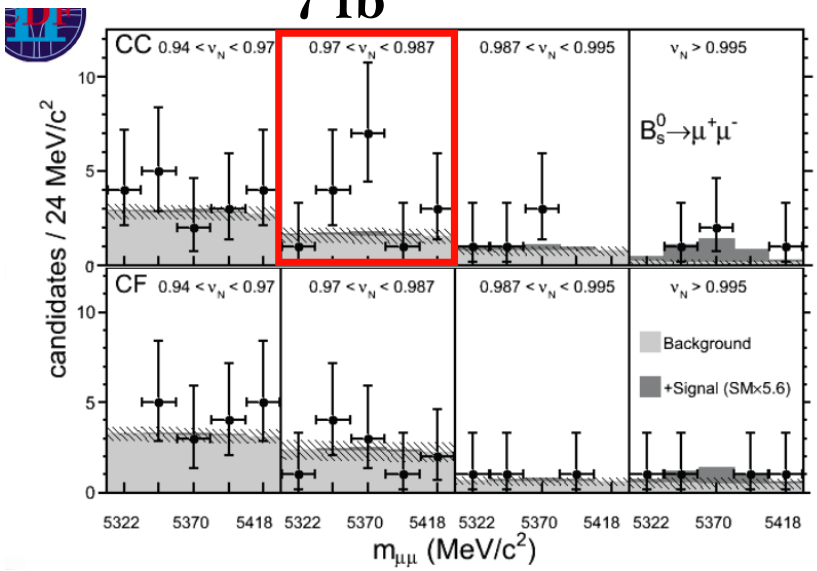
$BR=(1.0^{+0.8}_{-0.6}) \times 10^{-8}$

$0.8 \times 10^{-9} < BR(B_s \to \mu\mu) < 2.5 \times 10^{-8}$ @ 95% C.L.

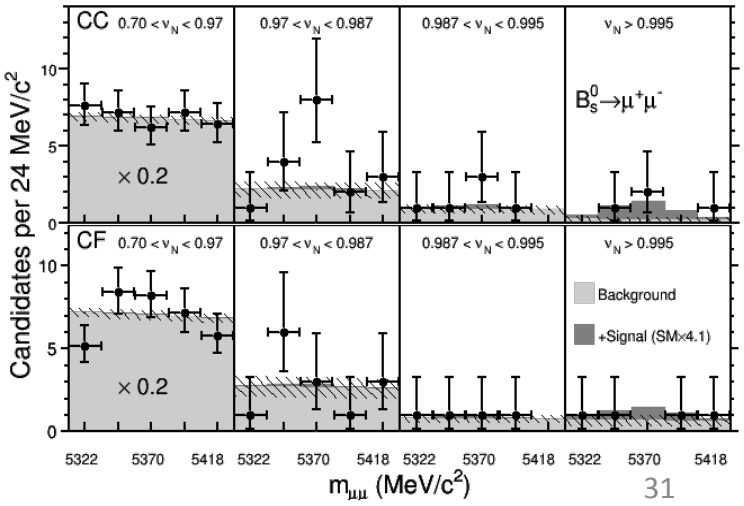
$BR(B_s \to \mu\mu) < 2.9 \times 10^{-8}$ @ 95% C.L.

No significant impact on result

7 fb^{-1}



9.7 fb^{-1}



$B_s^0 \to \mu^+\mu^-$: EXPECTED VS OBSERVED

	Mass Bin (GeV)	5.31-5.334	5.334-5.358	5.358-5.382	5.382-5.406	5.406-5.43	Total
CC NN bin	Exp Bkg	2.56±0.34	2.52±0.33	2.49±0.33	2.46±0.32	2.42±0.32	12.45
0.7-0.76	Obs	4	2	1	4	2	13
CC NN bin	Exp Bkg	2.77±0.35	2.73±0.35	2.69±0.34	2.66±0.34	2.62±0.33	13.47
0.76-0.85	Obs	1	2	1	4	1	9
CC NN bin	Exp Bkg	1.22±0.23	1.2±0.23	1.18±0.22	1.17±0.22	1.15±0.22	5.92
0.85-0.9	Obs	1	2	3	1	1	8
CC NN bin	Exp Bkg	1.05±0.21	1.03±0.21	1.02±0.21	1.01±0.2	0.99±0.2	5.11
0.9-0.94	Obs	1	0	1	1	1	4
CC NN bin	Exp Bkg	1.05±0.21	1.04±0.21	1.02±0.21	1.01±0.2	0.99±0.2	5.11
0.94-0.97	Obs	1	2	0	0	0	3
CC NN bin	Exp Bkg	0.63±0.18	0.62±0.17	0.61±0.17	0.6±0.17	0.6±0.17	3.07
0.97-0.987	Obs	0	0	1	1	0	2
CC NN bin	Exp Bkg	0.13±0.08	0.13±0.08	0.12±0.07	0.12±0.07	0.12±0.07	0.62
0.987-0.995	Obs	0	0	0	1	0	1
CC NN bin	Exp Bkg	0.11±0.07	0.09±0.07	0.08±0.07	0.08±0.07	0.08±0.07	0.44
0.995-1	Obs	0	0	0	0	0	0
CF NN bin	Exp Bkg	1.74±0.28	1.72±0.27	1.69±0.27	1.67±0.27	1.64±0.26	8.46
0.7-0.76	Obs	2	3	3	2	1	11
CF NN bin	Exp Bkg	1.83±0.28	1.8±0.28	1.78±0.28	1.75±0.27	1.72±0.27	8.88
0.76-0.85	Obs	1	5	2	2	0	10
CF NN bin	Exp Bkg	1.23±0.23	1.21±0.23	1.2±0.23	1.18±0.22	1.16±0.22	5.99
0.85-0.9	Obs	0	0	3	0	1	4
CF NN bin	Exp Bkg	0.81±0.19	0.8±0.18	0.78±0.18	0.77±0.18	0.76±0.18	3.92
0.9-0.94	Obs	2	1	2	2	1	8
CF NN bin	Exp Bkg	0.68±0.17	0.67±0.17	0.66±0.17	0.65±0.16	0.64±0.16	3.3
0.94-0.97	Obs	1	1	0	0	0	2
CF NN bin	Exp Bkg	0.38±0.13	0.38±0.13	0.37±0.13	0.37±0.13	0.36±0.13	1.86
0.97-0.987	Obs	0	2	0	0	1	3
CF NN bin	Exp Bkg	0.17±0.09	0.17±0.09	0.17±0.09	0.16±0.09	0.16±0.09	0.83
0.987-0.995	Obs	0	0	1	0	0	1
CF NN bin	Exp Bkg	0.18±0.11	0.17±0.11	0.17±0.11	0.16±0.11	0.16±0.11	0.83
0.995-1	Obs	0	0	0	0	0	0

Table: B_s signal window for CC (top) and CF (bottom): Expected backgrounds including $B \to hh$, and number of observed events.

Expected Limit is: BR < 1.3 (1.0) x 10^{-8} at 95% (90%) CL

$B^0 \to \mu^+\mu^-$: Table

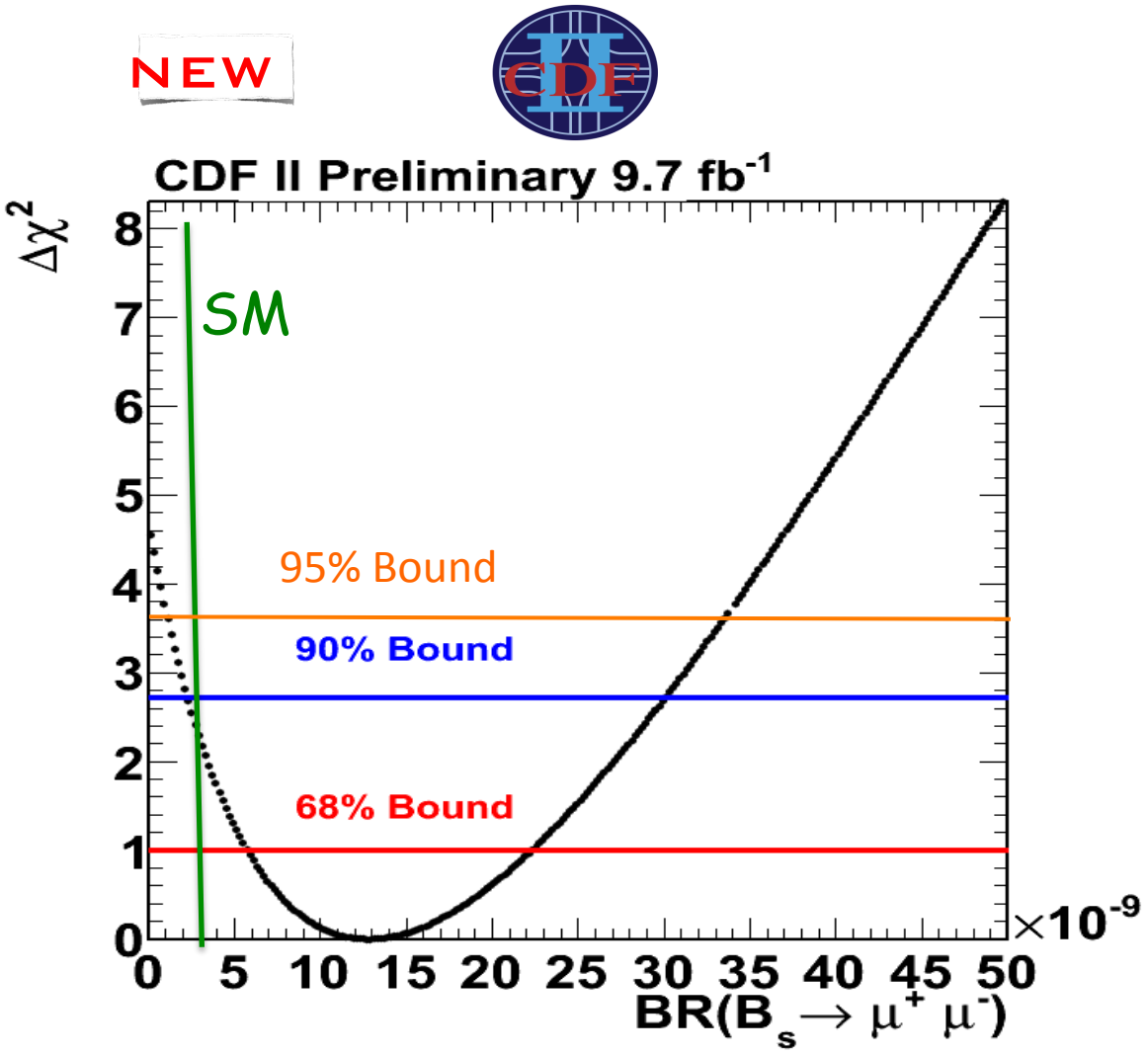
	Mass Bin (GeV)	5.219-5.243	5.243-5.267	5.267-5.291	5.291-5.315	5.315-5.339	Total
CC NN bin	Exp Bkg	2.69±0.35	2.65±0.35	2.62±0.34	2.58±0.34	2.55±0.34	13.09
0.7-0.76	Obs	4	4	4	2	4	18
CC NN bin	Exp Bkg	2.91±0.37	2.87±0.36	2.84±0.36	2.8±0.35	2.76±0.35	14.18
0.76-0.85	Obs	4	0	2	2	0	8
CC NN bin	Exp Bkg	1.28±0.24	1.26±0.24	1.25±0.23	1.23±0.23	1.21±0.23	6.24
0.85-0.9	Obs	3	1	0	1	1	6
CC NN bin	Exp Bkg	1.11±0.22	1.09±0.22	1.08±0.22	1.06±0.21	1.05±0.21	5.39
0.9-0.94	Obs	1	2	1	3	1	8
CC NN bin	Exp Bkg	1.11±0.22	1.1±0.22	1.08±0.22	1.06±0.21	1.05±0.21	5.4
0.94-0.97	Obs	0	0	0	1	1	2
CC NN bin	Exp Bkg	0.68±0.18	0.67±0.18	0.65±0.18	0.64±0.18	0.63±0.17	3.27
0.97-0.987	Obs	1	0	0	0	0	1
CC NN bin	Exp Bkg	0.16±0.08	0.15±0.08	0.15±0.08	0.14±0.08	0.13±0.08	0.72
0.987-0.995	Obs	1	0	1	1	0	3
CC NN bin	Exp Bkg	0.18±0.09	0.17±0.08	0.15±0.08	0.12±0.07	0.1±0.07	0.72
0.995-1	Obs	1	0	0	0	0	1
CF NN bin	Exp Bkg	1.84±0.29	1.81±0.29	1.79±0.28	1.76±0.28	1.74±0.28	8.93
0.7-0.76	Obs	1	3	2	4	1	11
CF NN bin	Exp Bkg	1.93±0.3	1.9±0.3	1.87±0.29	1.85±0.29	1.82±0.28	9.37
0.76-0.85	Obs	2	3	2	0	2	9
CF NN bin	Exp Bkg	1.3±0.24	1.28±0.24	1.26±0.24	1.25±0.23	1.23±0.23	6.32
0.85-0.9	Obs	0	0	2	0	0	2
CF NN bin	Exp Bkg	0.85±0.2	0.84±0.19	0.83±0.19	0.82±0.19	0.81±0.19	4.15
0.9-0.94	Obs	0	3	2	2	1	8
CF NN bin	Exp Bkg	0.72±0.18	0.71±0.18	0.7±0.18	0.69±0.17	0.68±0.17	3.49
0.94-0.97	Obs	0	1	0	0	1	2
CF NN bin	Exp Bkg	0.41±0.14	0.4±0.14	0.4±0.14	0.39±0.14	0.38±0.13	1.98
0.97-0.987	Obs	1	0	0	0	1	2
CF NN bin	Exp Bkg	0.18±0.1	0.18±0.09	0.18±0.09	0.17±0.09	0.17±0.09	0.88
0.987-0.995	Obs	0	0	0	0	0	0
CF NN bin	Exp Bkg	0.2±0.12	0.2±0.12	0.19±0.12	0.18±0.11	0.17±0.11	0.94
0.995-1	Obs	0	0	0	0	0	0

Table: B_d signal window for CC (top) and CF (bottom): Expected backgrounds including $B \to hh$, and number of observed events.

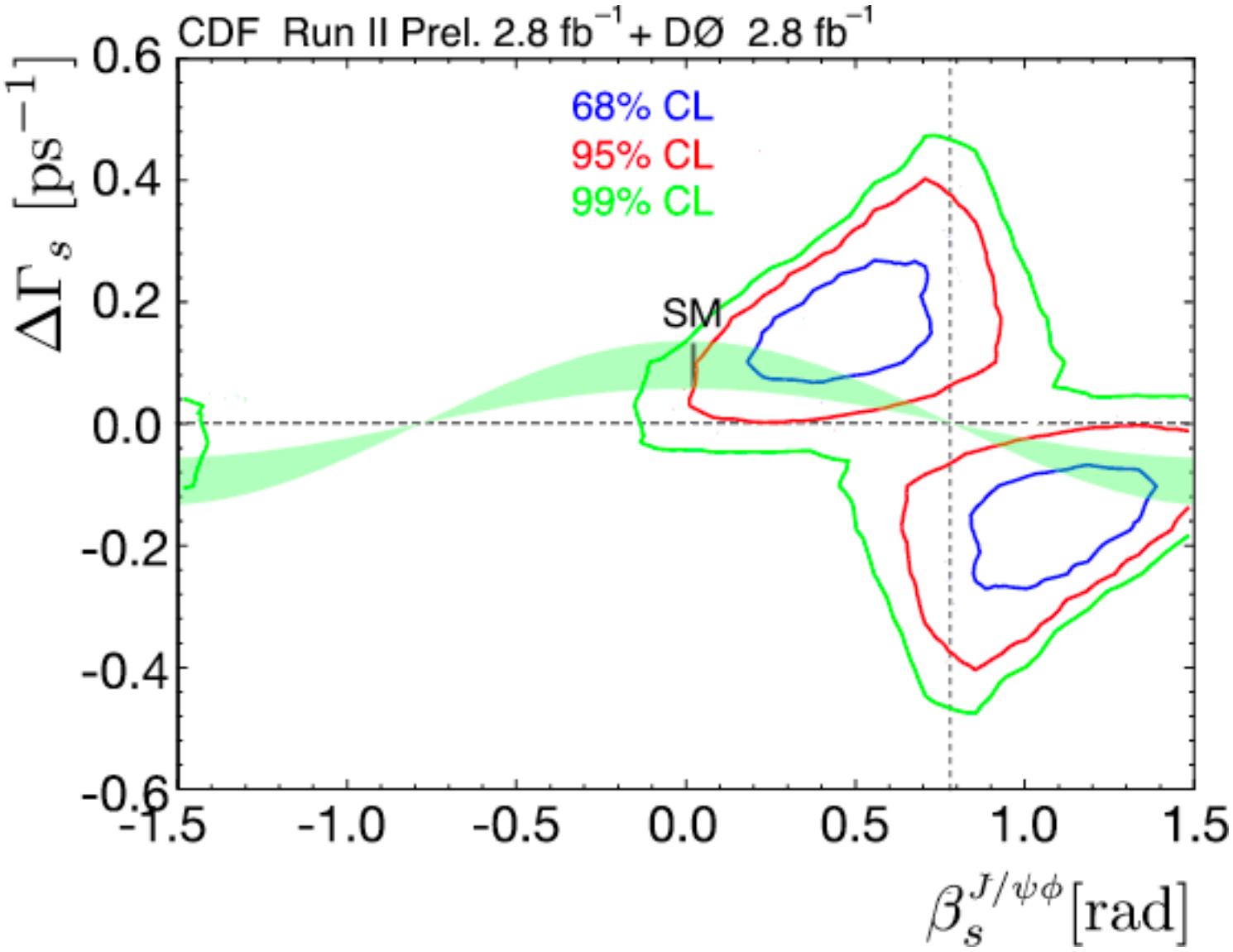
Expected Limit is: BR < 4.2 (3.4) x 10^{-9} at 95% (90%) CL

$B_s^0 \to \mu^+\mu^-$ Result

NEW



The Mild 2008 Excitement



$\Delta\Gamma_s$: Systematics

Source of systematic effect	$c\tau(B_s^0)$ [μ m]	$\Delta\Gamma$ [ps $^{-1}$]	$\lvert A_\parallel(0)\rvert^2$	$\lvert A_0(0)\rvert^2$	$\delta_\perp$
Signal Angular Efficiency	0.29	0.0014	0.0134	0.0162	0.076
Mass Signal Model	0.17	0.0007	0.0006	0.0020	0.018
Mass Bkg Model	0.14	0.0006	0.0003	0.0002	0.034
ct Resolution	0.52	0.0010	0.0004	0.0002	0.066
ct Bkg	1.31	0.0057	0.0006	0.0012	0.064
Angular Bkg	0.46	0.0037	0.0011	0.0022	0.009
Sigma mass	0.85	0.0006	0.0003	0.0002	0.036
Sigma ct	0.63	0.0006	0.0003	0.0002	0.038
$B_d \to J/\psi K^*$ cross-feed	0.18	0.0018	0.0002	0.0015	0.034
SVX alignment	2.0	0.0004	0.0002	0.0001	0.034
Pull bias	0.2	0.0012	0.0021	0.0008	0.02
TOT	2.7	0.007	0.014	0.017	0.15

A_{SL} IN ONE SLIDE

two samples: 2 billion single μ and 6 million di-μ in 9 fb^{-1}. p_T > 1.5-4.2 GeV/c

Measure +/- asymmetry in both samples

Asymmetry washed by muons from non-oscillating sources (from MC)

Asymmetry biased by background asymmetries from instrumental effects

Kaon contribution measured in data, pions extrapolated from MC.

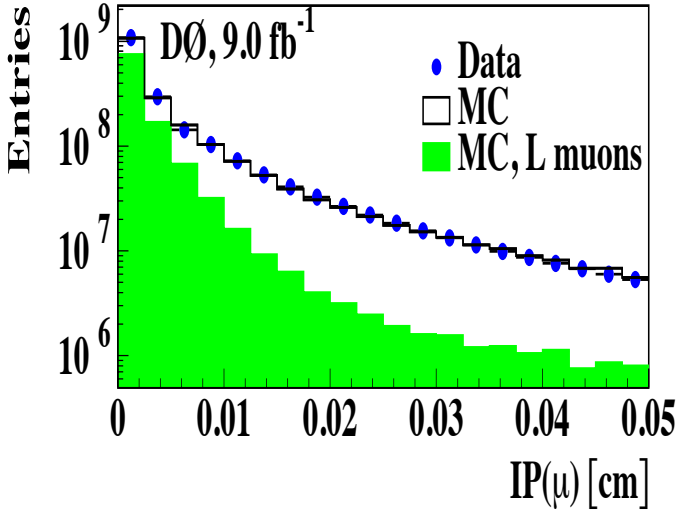
Combine asymmetries from single-μ and di-μ samples to subtract common backgrounds

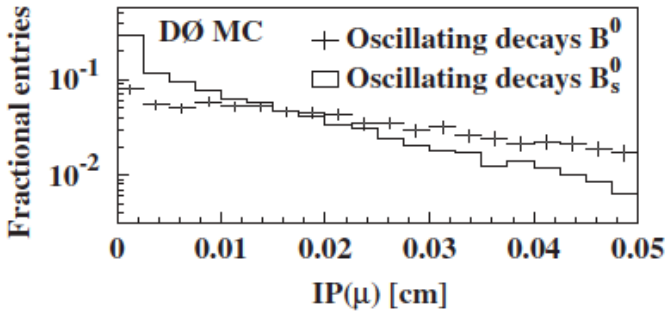
A_{SL}: Muons from B?

Reduce the contamination of background of non-B decays cutting on IP of the muons.

Perform test on two subsamples wit IP less/ greater than 120 micron. Reduce statistical resolution, but results consistent with default analysis.

IP>120 micron more B^0-like μ
IP<120 micron more B_s-like μ





$$a_{sl}^d = (-0.12 \pm 0.52)\% \quad a_{sl}^s = (-1.81 \pm 1.06)\%$$

Highly correlated $\rho_{ds} = -0.799.$