Searches for New Physics in Charm and Beauty sector at the Tevatron

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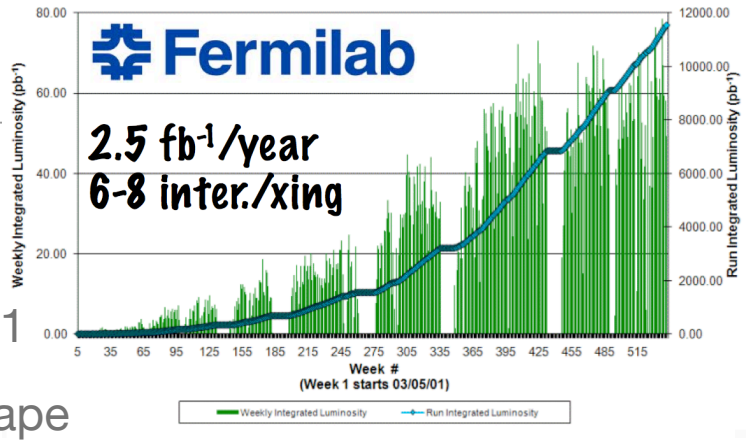
Flavor Physics at the Tevatron



- Tevatron was shut down for good on Sep 30, 2011
- CDF and D0 each have about 10 fb^{-1} of data on tape
- They were designed for high P_T physics. And...
  - High-rate of all species of heavy flavors: actually higher than “B factories”
  - Excellent mass resolution
  - Precision vertex reconstruction capabilities
  - Powerful trigger on displaced vertices
  - Forward-Backward symmetric detectors and CP-symmetric initial state imply equal number of particles and antiparticles in the acceptance
- Good competitors to the B factories

Searches for New Physics in Charm and Beauty sector at the Tevatron

- This talk is focused on recent Tevatron results in the flavor sector that are believed to be particularly sensitive to departure from the Standard Model
- New results since last year:
  - CP violation in charmless B decays
  - b $\rightarrow$s $\mu^+\mu^-$ decays
  - Branching fraction of $B_s \rightarrow \mu^+\mu^-$
  - CP violation in B_d and B_s semi-leptonic decays
- All done with full data set (~10/fb)

http://www-cdf.fnal.gov/physics/new/bottom/bottom.html
http://www-d0.fnal.gov/Run2Physics/WWW/results/b.htm

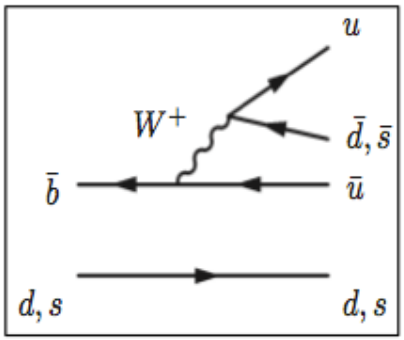
CP Asymmetries in Charmless *b*-hadron Decays

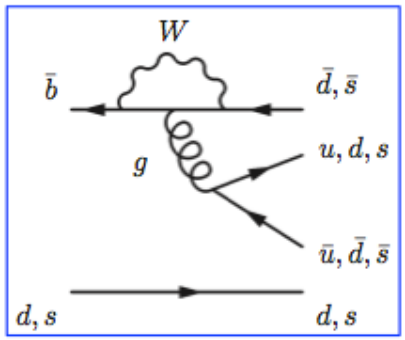
$B^0 \to K^+\pi^-$

$B_s^0 \to K^-\pi^+$

$\Lambda_b^0 \to p\pi^-, pK^-$

large Bs and Λ_b samples unique to the Tevatron until the turn-on of LHC





First observation of $B_s \to K^-\pi^+$ and $B_s \to K^+K^-$, first evidence of $B_s \to \pi^+\pi^-$

Flavor specific decays (*b*-flavor from final state charge)
Count events and correct for detector-induced charged asymmetries

$$\frac{\mathcal{B}(b \to f) - \mathcal{B}(\bar{b} \to \bar{f})}{\mathcal{B}(b \to f) + \mathcal{B}(\bar{b} \to \bar{f})} = \frac{N_{b\to f} - c_f N_{\bar{b}\to\bar{f}}}{N_{b\to f} + c_f N_{\bar{b}\to\bar{f}}}$$

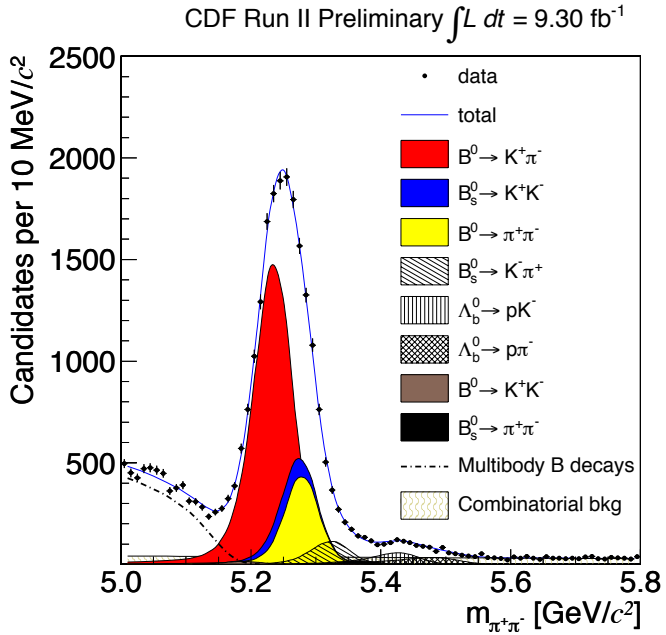
Correction c_f derived from $D^0 \to K^+\pi^-$ (symmetric production)

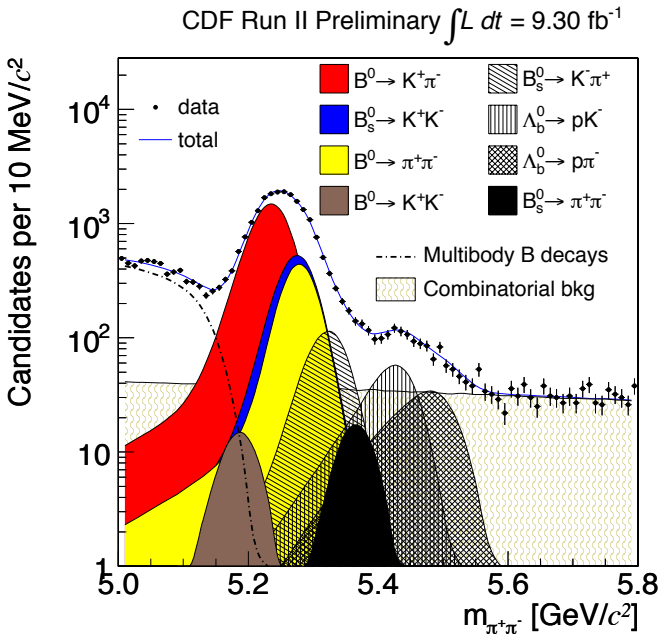
Equal b and $\bar{b}$ production

CP Asymmetries in Charmless *b*-hadron Decays

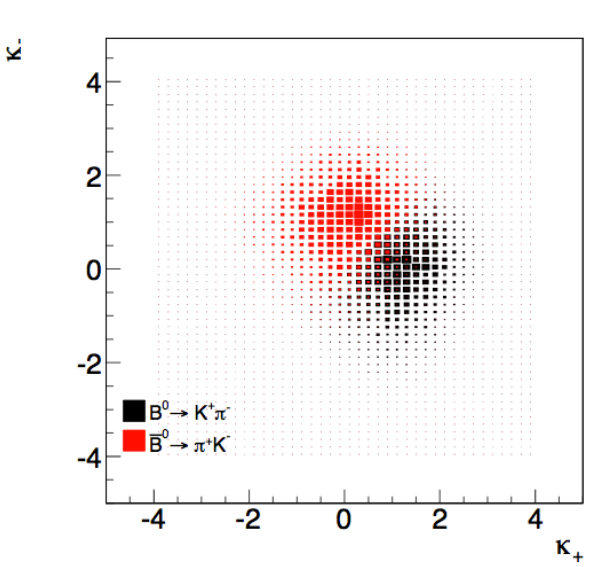
Analysis Strategy

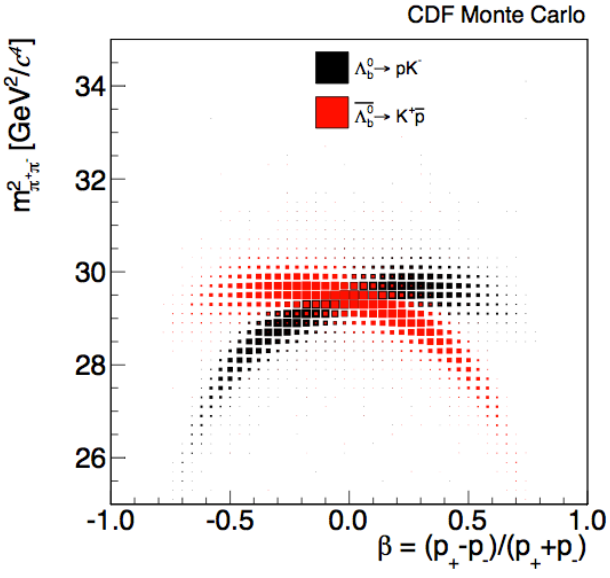
1. Displaced vertex trigger
2. Reconstruct B-like two-pronged vertices
3. Build invariant mass, assuming $\pi\pi$ hypothesis
4. All individual modes overlap in a single broad peak





Particle ID with dE/dx and Kinematics





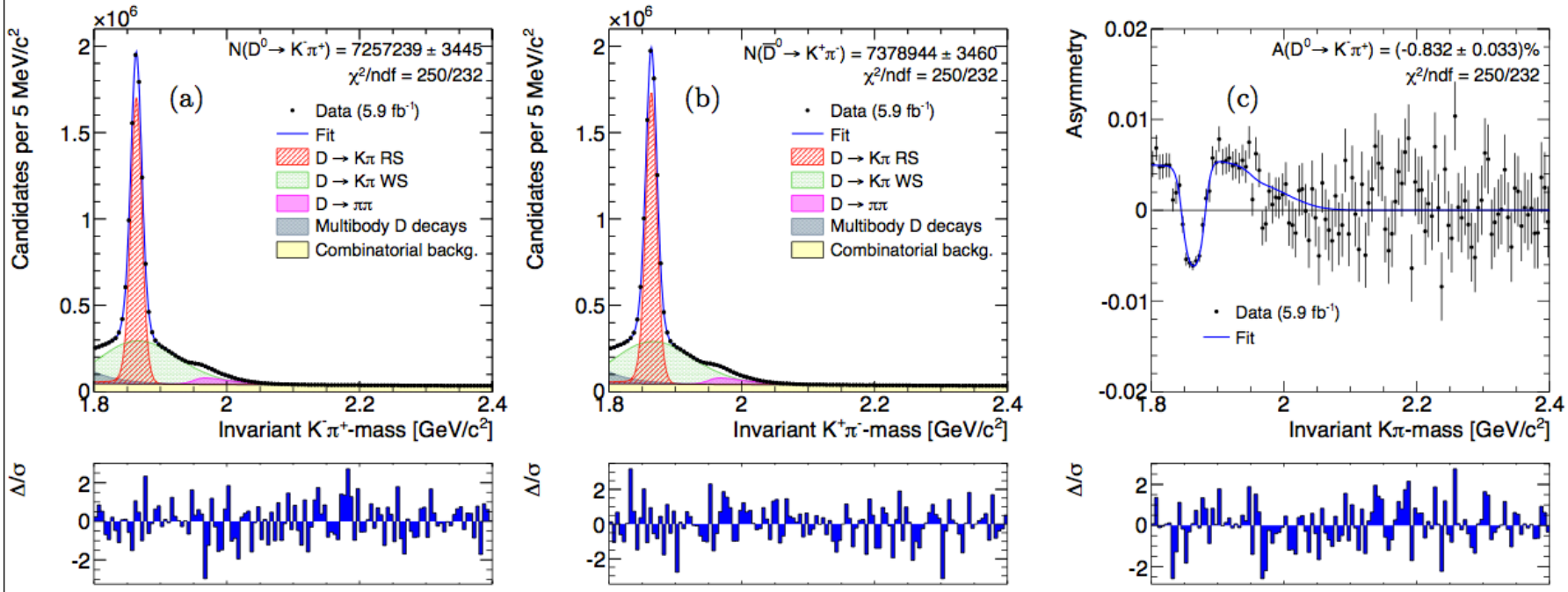
Particle species separation through kinematics and dE/dx

$$\kappa = \frac{dE/dx - dE/dx(\pi)}{dE/dx(K) - dE/dx(\pi)}$$

- Multi-dimensional unbinned likelihood fit to extract yields of each decay mode and its charge conjugate
- Use kinematic variables and particle ID

Correction of detector-induced charge asymmetries

- We are looking for small effects
- Need to correct for small detector asymmetries
- π^+ vs π^- and K^+ vs K^-
- Millions of D^0 to $K^-\pi^+$ and c.c.
- Asymmetry corrections of order ~1%



CP Asymmetries in Charmless *b*-hadron Decays

http://www-cdf.fnal.gov/physics/new/bottom/120628.blessed-Bhh9fb/cdf10726_acp_bhh_9fb_public.pdf

Fit results

Mode	$\mathcal{N}_{b\to f}$	$\mathcal{N}_{\bar{b}\to\bar{f}}$
$B^0 \to K^+\pi^-$	6348 ± 117	5313 ± 109
$B_s^0 \to K^-\pi^+$	354 ± 46	560 ± 51
$\Lambda_b^0 \to p\pi^-$	242 ± 24	206 ± 23
$\Lambda_b^0 \to pK^-$	271 ± 30	324 ± 31

Competitive measurement for B^0. For B_s^0 confirm LHCb result with same resolution.

new CDF = 0.22 +- 0.07 +- 0.02
LHCb = 0.27 +- 0.08 +- 0.02

Strong evidence ($4.5\,\sigma$) combining CDF and LHCb measurements:

$A_{CP}(B_s^0 \to K^+\pi^-) = (24.2 \pm 5.4)\%$

A_{CP}

$A_{CP}(B^0 \to K^+\pi^-) = (-8.3 \pm 1.3 \pm 0.3)\%$

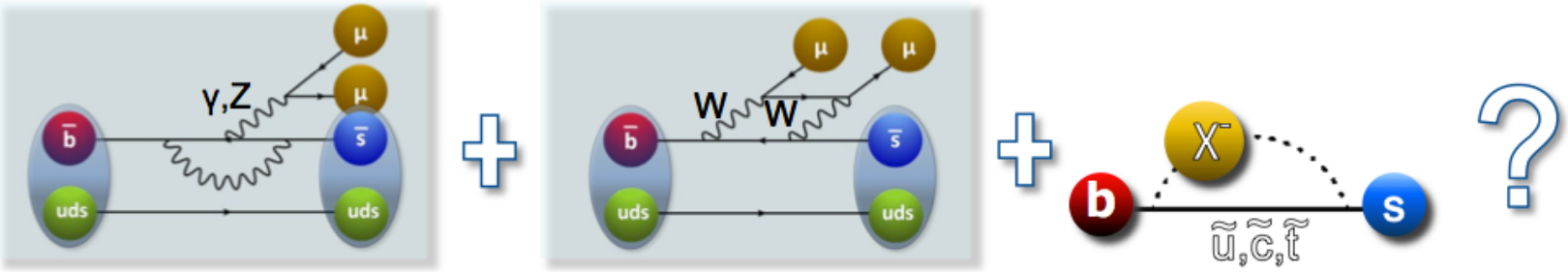
$A_{CP}(B_s^0 \to K^-\pi^+) = (22 \pm 7 \pm 2)\%$

$A_{CP}(\Lambda_b^0 \to p\pi^-) = (7 \pm 7 \pm 3)\%$

$A_{CP}(\Lambda_b^0 \to pK^-) = (-9 \pm 8 \pm 4)\%$

precision measurement of b-baryon asymmetries still unique to CDF

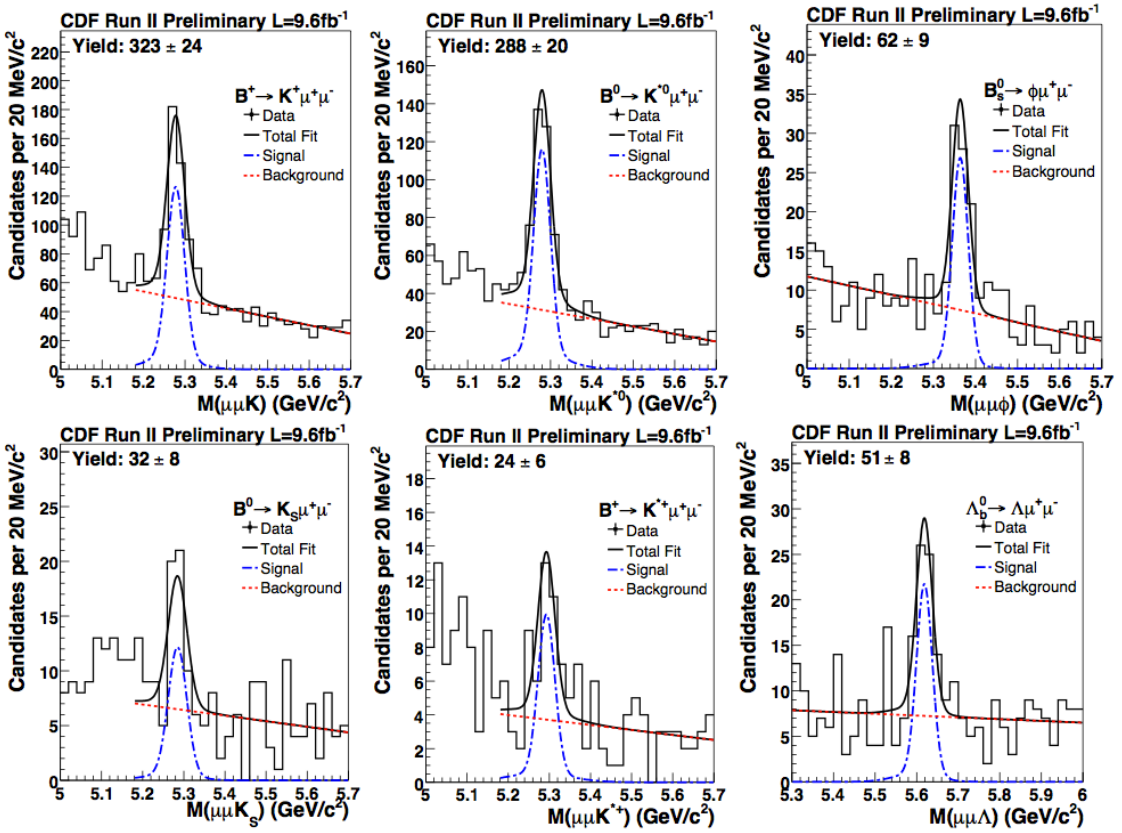
$b \to s\, \mu^+\mu^-$ decays



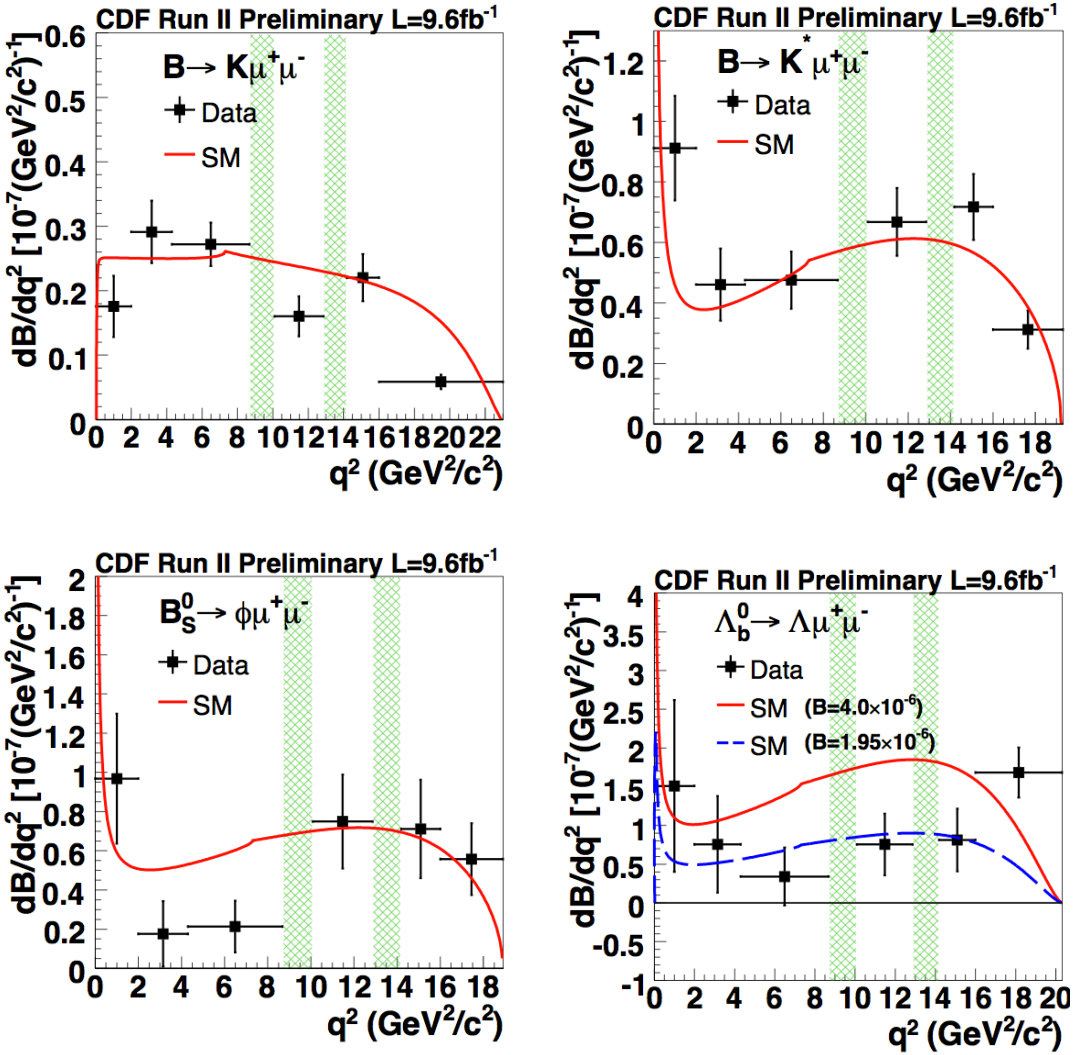
- Flavor Changing Neutral Currents
- Yet another golden probe
- Look for new physics in the distributions of kinematic variables
  - Total/differential BR, isospin asymmetry, forward backward asymmetry...

$b \to s\,\mu^+\mu^-$ decays

$B^+ \to K^+\mu^+\mu^-$,
$B^0 \to K^{*0}(892)\mu^+\mu^-$,
$B^0 \to K_S{}^0\mu^+\mu^-$,
$B^+ \to K^{*+}(892)\mu^+\mu^-$,
$B_s{}^0 \to \phi\mu^+\mu^-$, and
$\Lambda_b{}^0 \to \Lambda\mu^+\mu^-$,

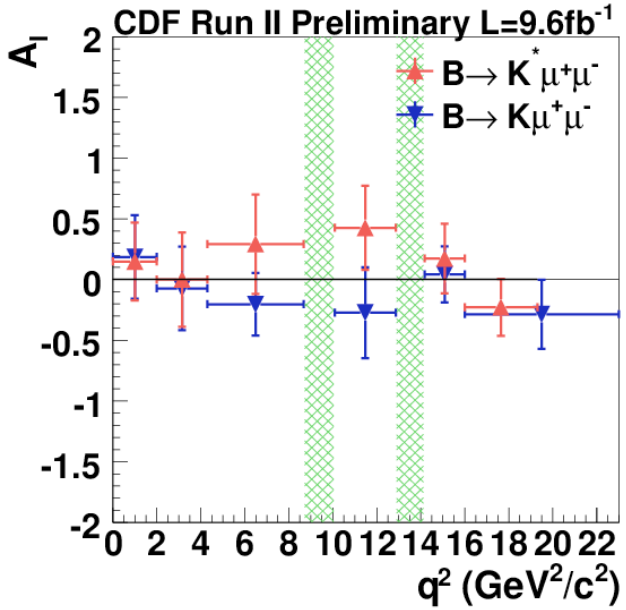


Differential BR in $b \to s\, \mu^+\mu^-$ decays



Consistent with SM

Isospin asymmetry in $b \to s\,\mu^+\mu^-$ decays



$$A_I^{(*)} \equiv \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \mathcal{B}(B^+ \to K^{(*)+}\mu^+\mu^-)}$$

Consistent with SM within errors

LHCb observes a 3 sigma effect in the highest q^2 bin

$$A_I(B \to K\mu^+\mu^-) \quad q^2\ (\mathrm{GeV}^2/c^2) = 16.00\text{-}23.00$$

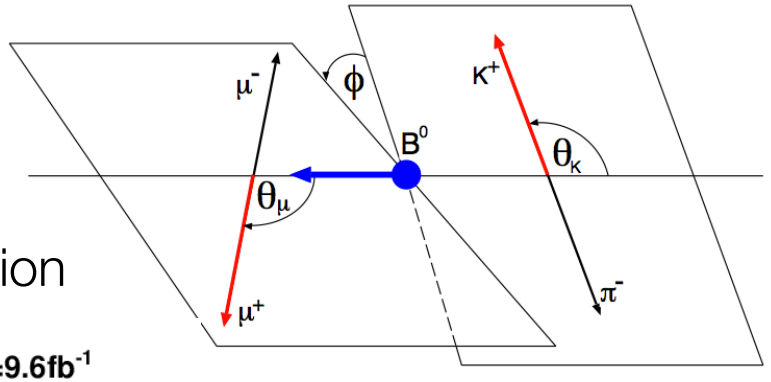
CDF $\quad -0.29 \pm 0.28(\mathrm{stat}) \pm 0.06(\mathrm{syst})$

http://www-cdf.fnal.gov/physics/new/bottom/120628.blessed-b2smumu_96/public_b2smumu.pdf

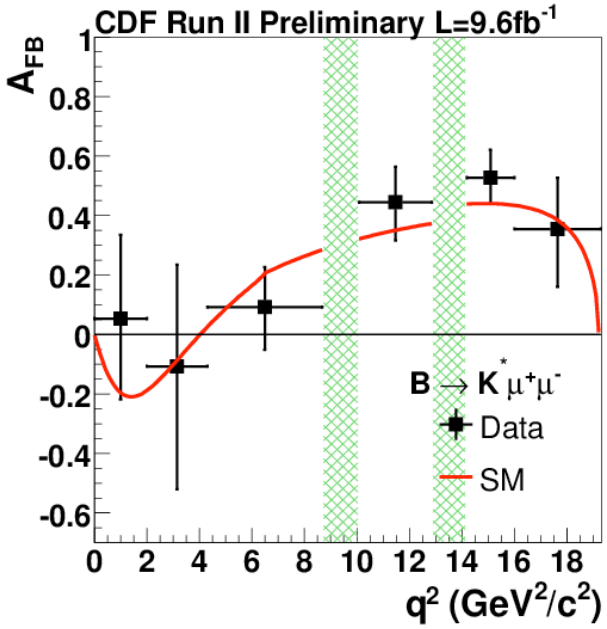
LHCb $\quad -0.52^{+0.18}_{-0.22}$ 3 sigma discrepancy from SM

arXiv:1205.3422

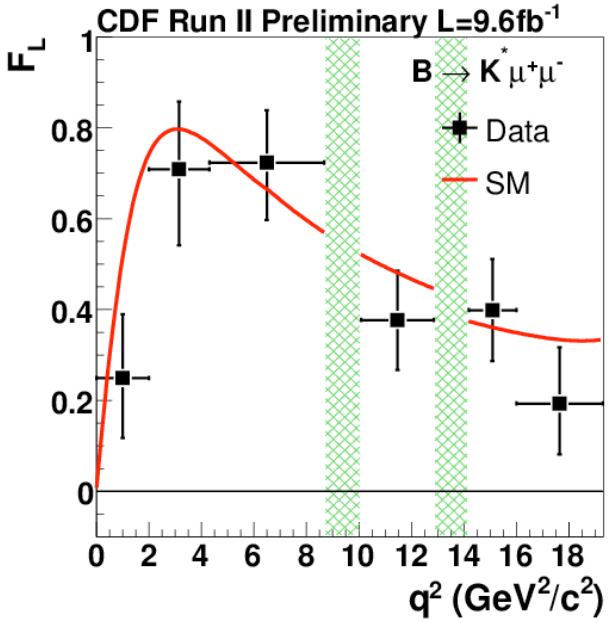
Asymmetries in $b \to s\, \mu^+\mu^-$ decays



Forward-backward asymmetry



K* polarization

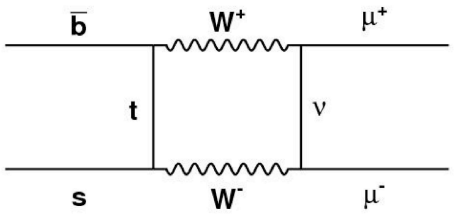


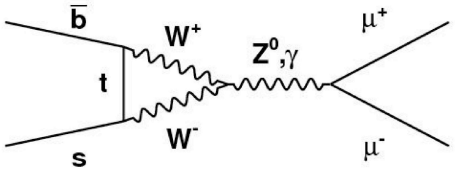
— SM

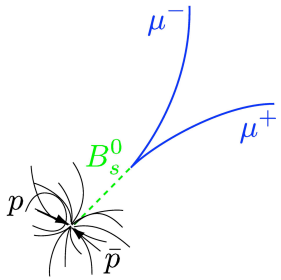
Also consistent with SM

http://www-cdf.fnal.gov/physics/new/bottom/120628.blessed-b2smumu_96/public_b2smumu.pdf

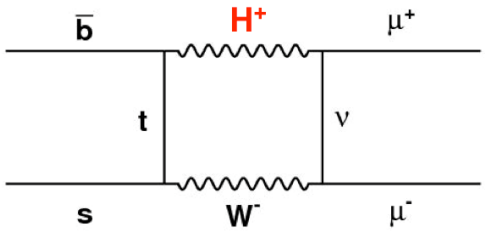
Branching fraction of $B_s \to \mu^+\mu^-$

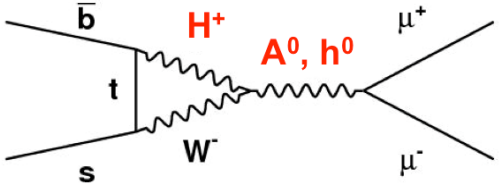


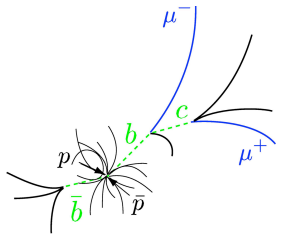


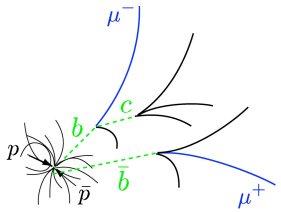


- Flavor Changing Neutral Current restricted
- Helicity suppressed
- BR($B^0s \to \mu+\mu-$) ~ 3 x10^{-9}







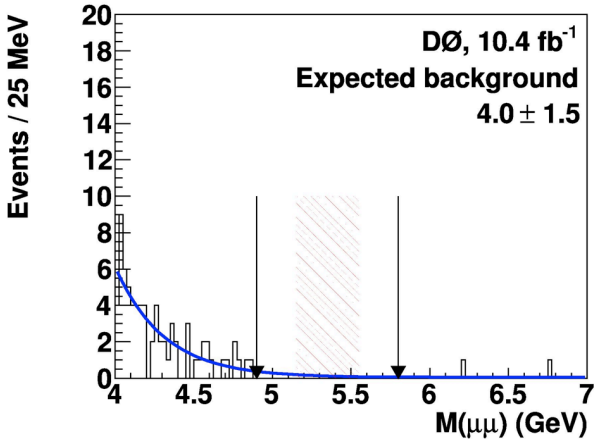


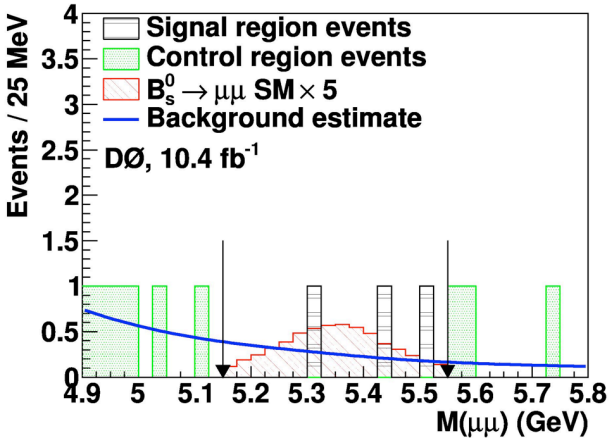
- Can be significantly enhanced by New Physics

Branching fraction of $B_s \to \mu^+\mu^-$

- Normalization mode
  - $B^{\pm} \to J/\Psi K^{\pm}$ with $J/\Psi \to \mu^+\mu^-$
- BDT Multivariate technique
  - Use data sidebands as background for training
- Blinded analysis
  - Dimuon mass range of 4.0 – 7.0 GeV
  - Blinded from 4.9 – 5.8 GeV
- Expected
  - SM Signal: 1.23 ± 0.13
  - Background: 4.3 ± 1.6
  - Limit: $BR(B_s \to \mu^+\mu^-) = 23 \times 10^{-9}$
- Observed 3 events setting a 95% C.L. limit on the branching fraction of

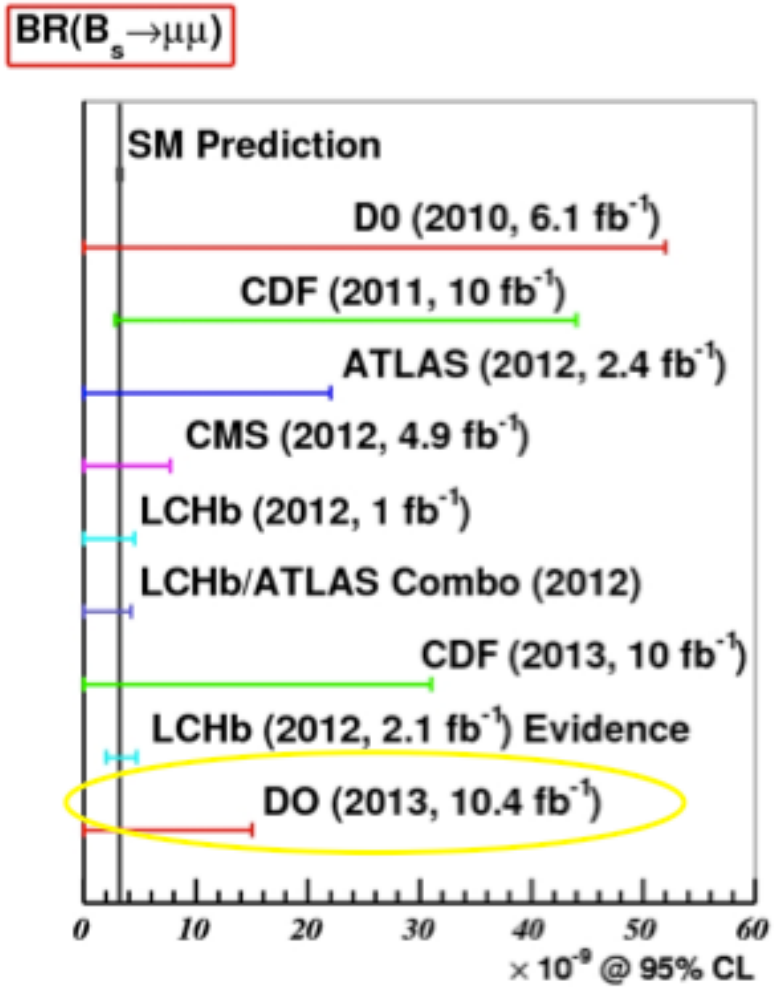
$$BR(B_s^0 \to \mu^+\mu^-) < 15 \times 10^{-9}$$





http://arxiv.org/abs/1301.4507 Submitted to Phys. Rev. D

$B_s \to \mu^+\mu^-$ results

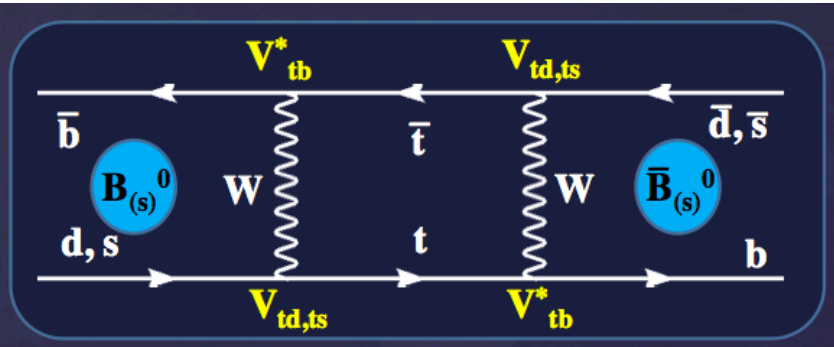


CP violation in B_d and B_s semileptonic decays

Neutral B mesons oscillate into their antiparticles

Complex phase in CKM matrix can lead to asymmetry:

$$\Gamma[B_{(s)}^0 \to \bar{B}_{(s)}^0] \stackrel{?}{\neq} \Gamma[\bar{B}_{(s)}^0 \to B_{(s)}^0]$$



Define semileptonic mixing asymmetry:

$$a_{sl}^q = \frac{\Delta\Gamma_q}{\Delta M_q} \cdot \tan(\phi_q) = \frac{\Gamma(\bar{B}_q^0 \to B_q^0 \to \ell^+ X) - \Gamma(B_q^0 \to \bar{B}_q^0 \to \ell^- X)}{\Gamma(\bar{B}_q^0 \to B_q^0 \to \ell^+ X) + \Gamma(B_q^0 \to \bar{B}_q^0 \to \ell^- X)}$$

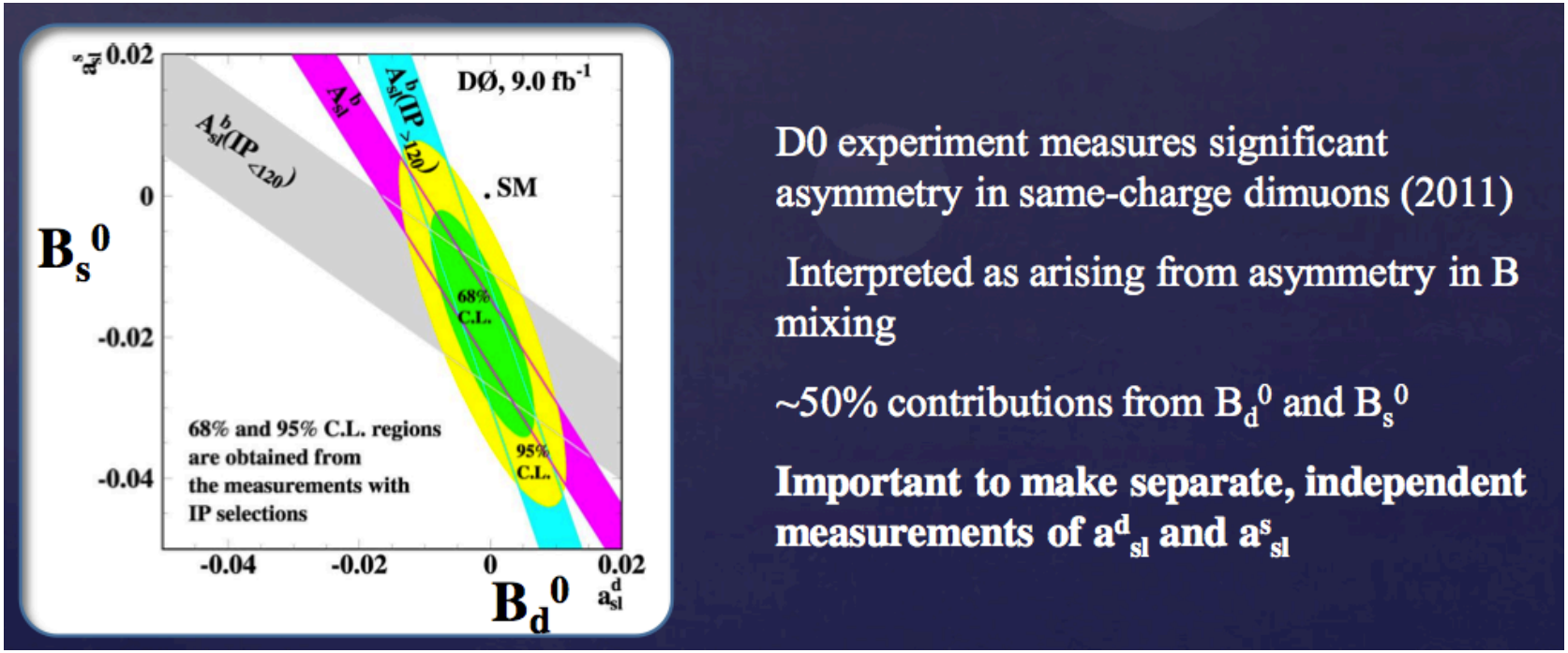
SM values for both B^0 and B^0_s are negligible compared to experimental precision:

Any significant deviation from zero is hence a signal of new physics.

$$a^d_{sl} = (-0.041 \pm 0.006)\%$$
$$a^s_{sl} = (-0.0019 \pm 0.0003)\%$$

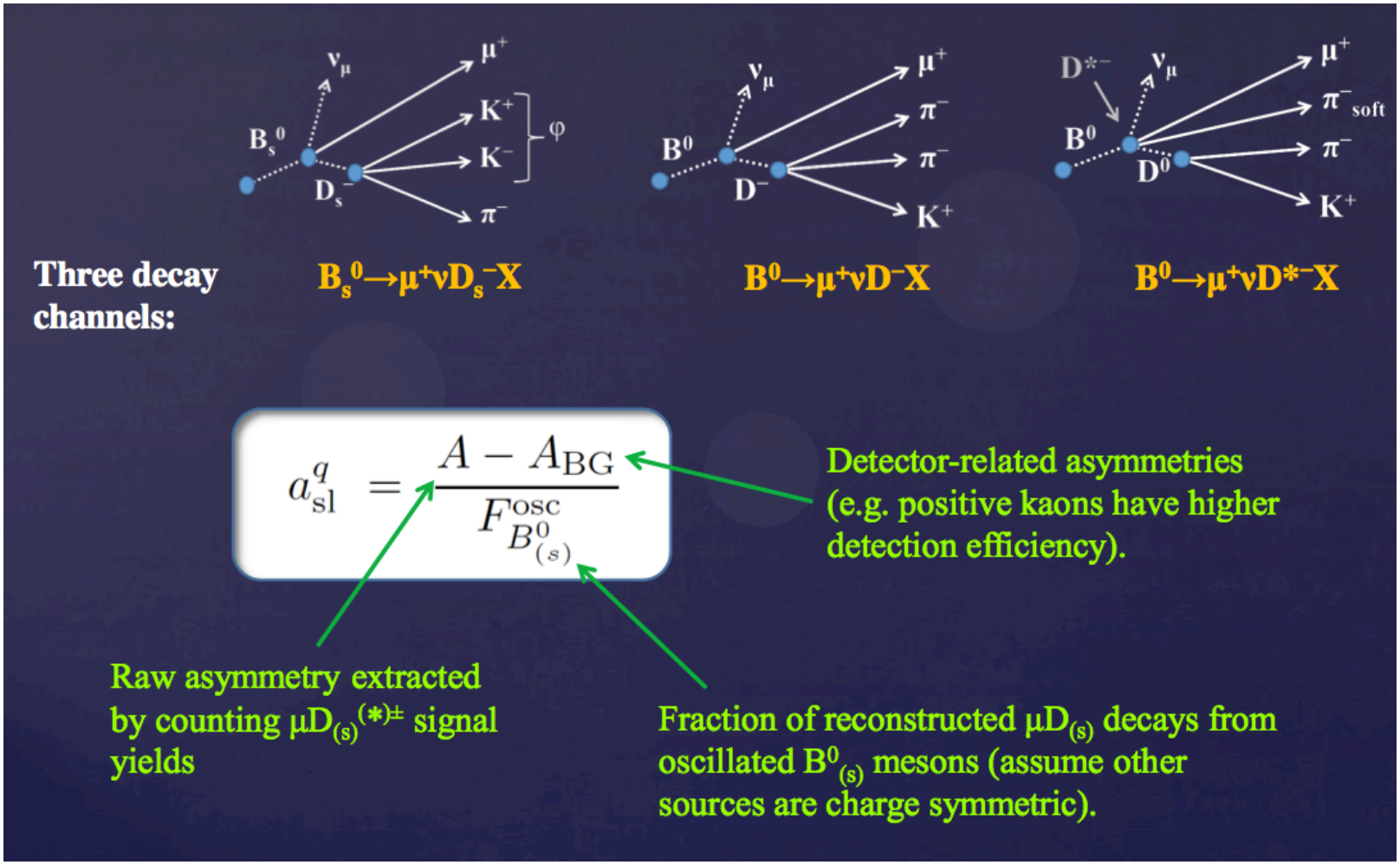
Courtesy of Mark Williams, HCP 2012

CP violation in B_d and B_s semileptonic decays



Courtesy of Mark Williams, HCP 2012

CP violation in B_d and B_s semileptonic decays



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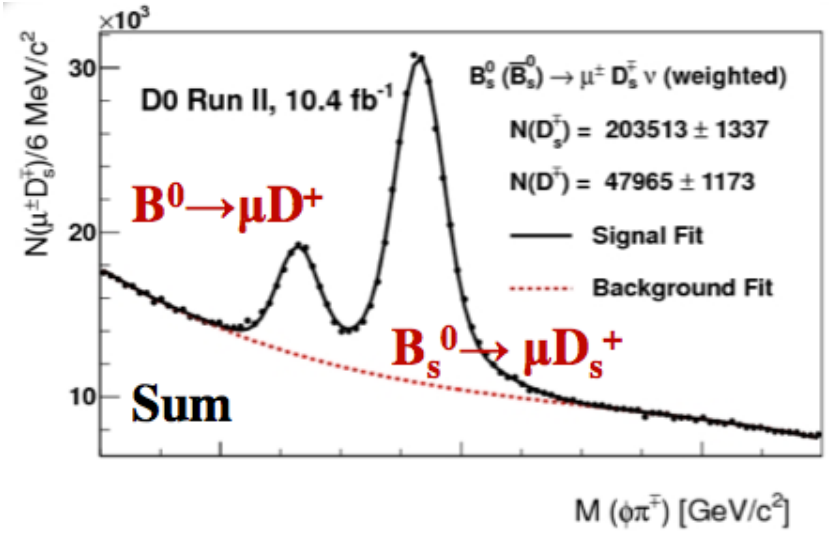
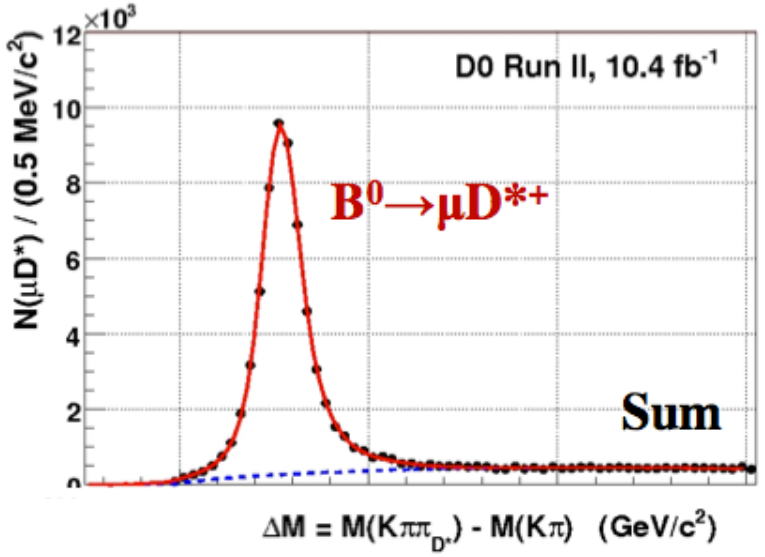
CP violation in B_d and B_s semileptonic decays





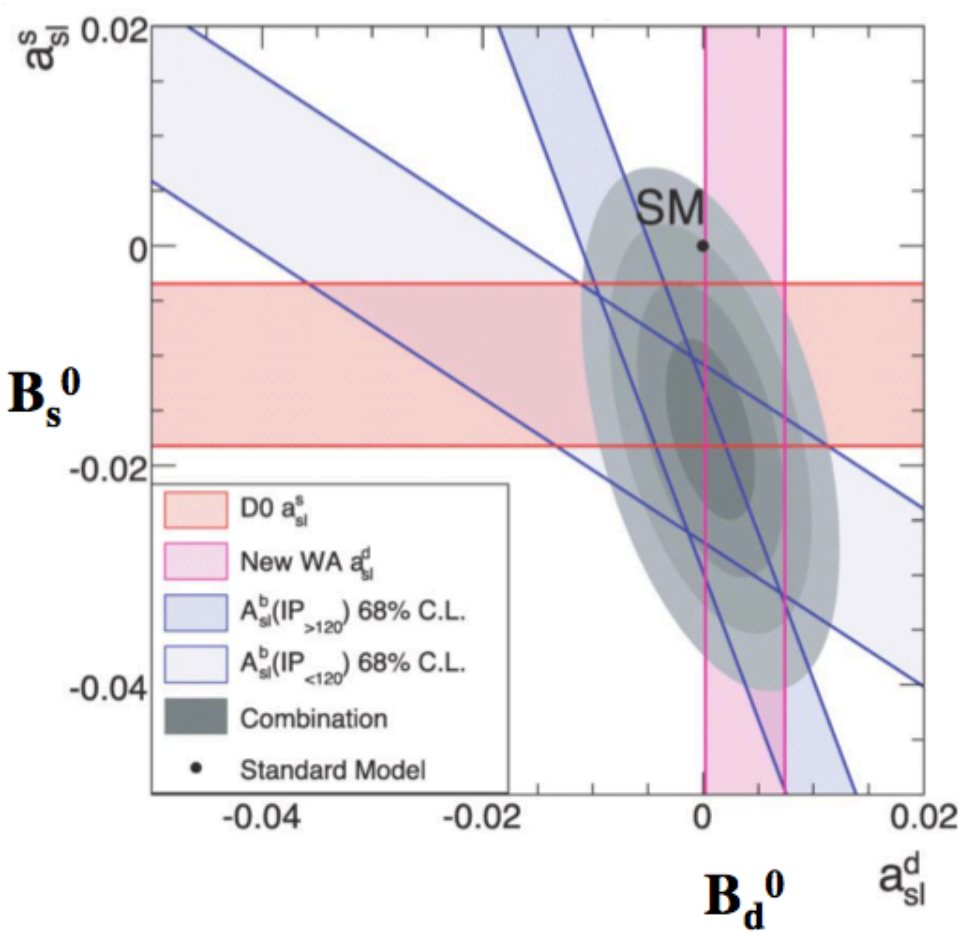
Final result:

$$a_{\rm sl}^d = [0.68 \pm 0.45\ (\text{stat.}) \pm 0.14\ (\text{syst.})]\%$$ Phys. Rev. D 86, 072009 (2012)

$$a_{\rm sl}^s = [-1.12 \pm 0.74\,(\text{stat}) \pm 0.17\,(\text{syst})]\,\%$$ Phys. Rev. Lett. 110, 011801 (2013)

consistent with standard model

CP violation in B_d and B_s semileptonic decays

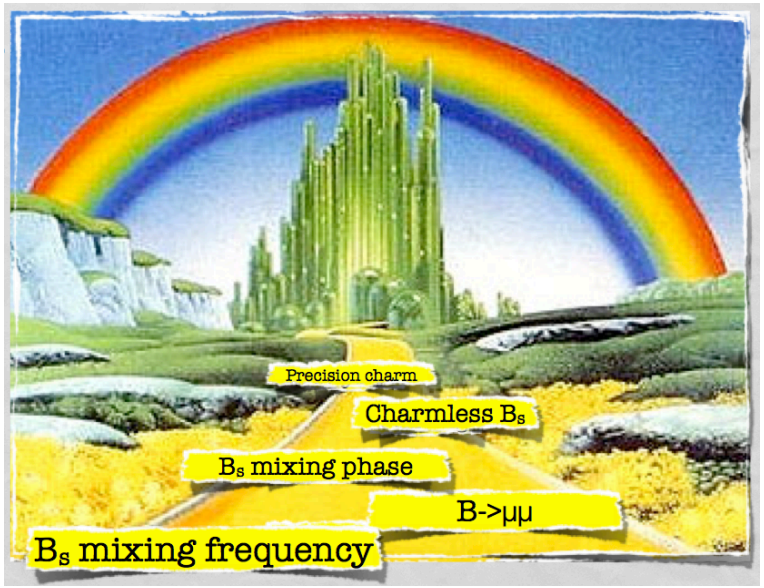


new results consistent with standard model, also consistent with previous results

overall combination still ~ 3 sigma away from SM

Phys. Rev. D 86, 072009 (2012)

Conclusions



- The Tevatron legacy

  The experiments at the Tevatron have shown that precision measurements in flavor physics at a hadron collider are possible and can be complementary and competitive to similar studies at dedicated facilities (B-factories)

- Data taking has ended but analysis continues
- More interesting results in flavor physics will be coming from dear old Tevatron

THE END