BEACH2012: Summary

Cristina Lazzeroni
University of Birmingham, United Kingdom

64 talks, huge number of new results:
Impossible to put everything in summary !
This is necessarily a partial and personal view….

"A Unified and Unbiased Attack on New Physics"

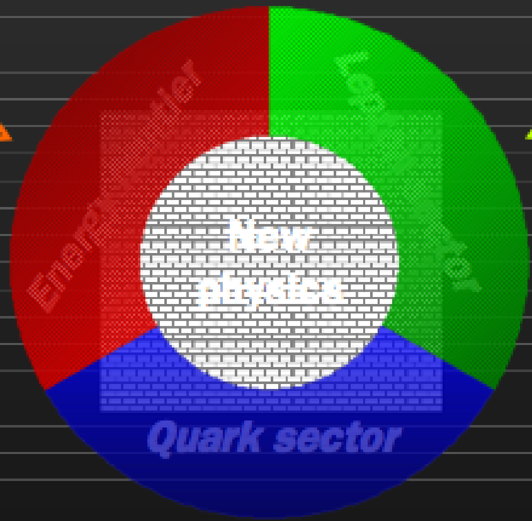
T. Browder, FNAL Seminar, 2006

LHC, ILC

mass spectrum
interactions

ν experiments,
$g_\mu - 2$, $\mu \to e\gamma$, EDM, …

ν mass and mixing
CPV and LFV



τ LFV
τ CPV

flavour mixing
CPV phases

Super-*B* factory, LHCb, *K* experiments…

Neutrinos….

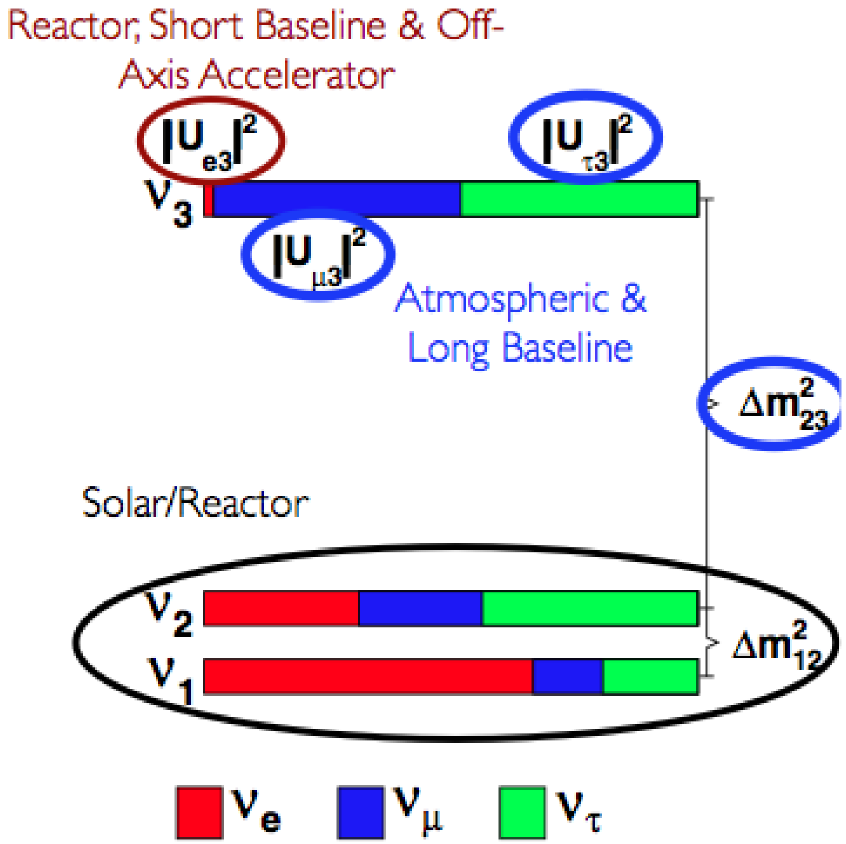
Neutrino Oscillations

- Measuring the PMNS matrix

Experiment type	Oscillation Channel
Solar, Reactor	$(\nu_e \rightarrow \nu_\mu)$
Reactor, Short Baseline, Off-Axis	$(\nu_e \rightarrow \nu_e)$ $(\nu_\mu \rightarrow \nu_e)$
Atmospheric & Long Baseline	$(\nu_\mu \rightarrow \nu_\mu)$ $(\nu_\mu \rightarrow \nu_\tau)$

$$|U_{PMNS}| \sim \begin{pmatrix} 0.8 & 0.5 & 0.2 \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

$$|V_{CKM}| \sim \begin{pmatrix} 1 & 0.2 & 0.004 \\ 0.2 & 1 & 0.04 \\ 0.008 & 0.04 & 1 \end{pmatrix}$$



$$\begin{pmatrix} |\nu_e\rangle \\ |\nu_\mu\rangle \\ |\nu_\tau\rangle \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} |\nu_1\rangle \\ |\nu_2\rangle \\ |\nu_3\rangle \end{pmatrix}$$

Neutrino Oscillation (3-flavor)

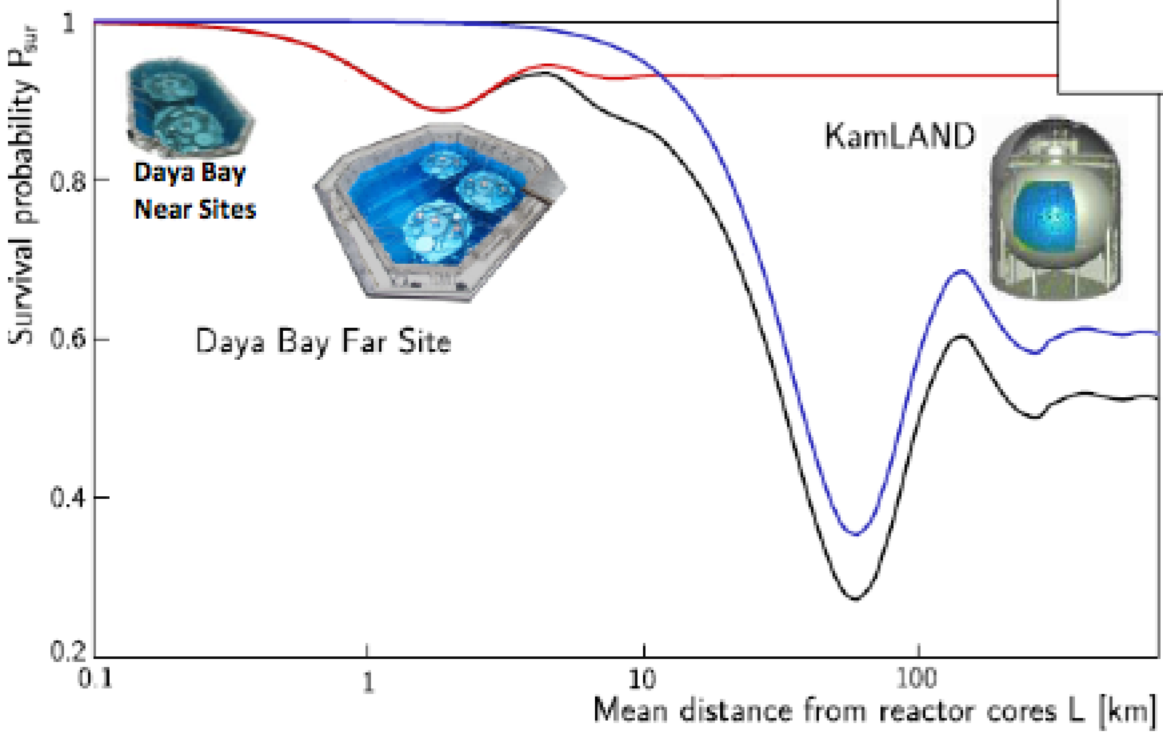
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & & \\ & c_{23} & s_{23} \\ & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & & s_{13}e^{-i\delta} \\ & 1 & \\ -s_{13}e^{i\delta} & & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & \\ -s_{12} & c_{12} & \\ & & 1 \end{pmatrix} \begin{pmatrix} e^{i\alpha_1/2}\nu_1 \\ e^{i\alpha_2/2}\nu_2 \\ \nu_3 \end{pmatrix}$$

$c_{ij} = \cos(\theta_{ij})$;
$s_{ij} = \sin(\theta_{ij})$;

U_{MNSP} Matrix
Maki, Nakagawa, Sakata, Pontecorvo

$$P_{sur} \approx 1 - \sin^2 2\theta_{13} \sin^2\left(\Delta m^2_{32} \frac{L}{4E}\right) - \sin^2 2\theta_{12} \cos^4 2\theta_{13} \sin^2\left(\Delta m^2_{21} \frac{L}{4E}\right)$$

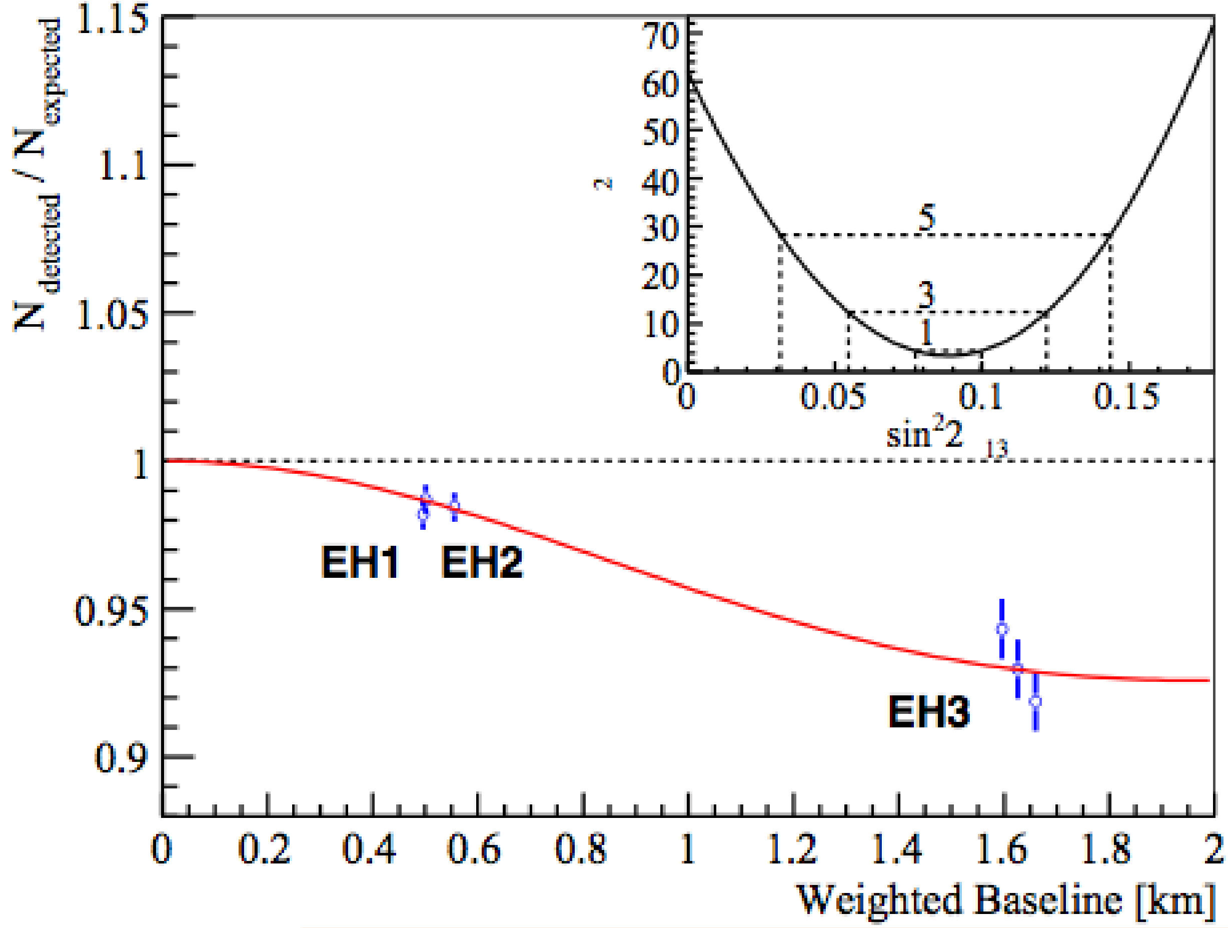
$$\Delta m^2_{32} \approx \Delta m^2_{31} \approx \Delta m^2_{atm}$$



Why measure θ_{13}?
- Least-known mixing angle
- Access to ν hierarchy
- Access to CP-violating phase δ

Rate Analysis

Estimate θ_{13} using measured rates in each detector.



Uses standard χ^2 approach.

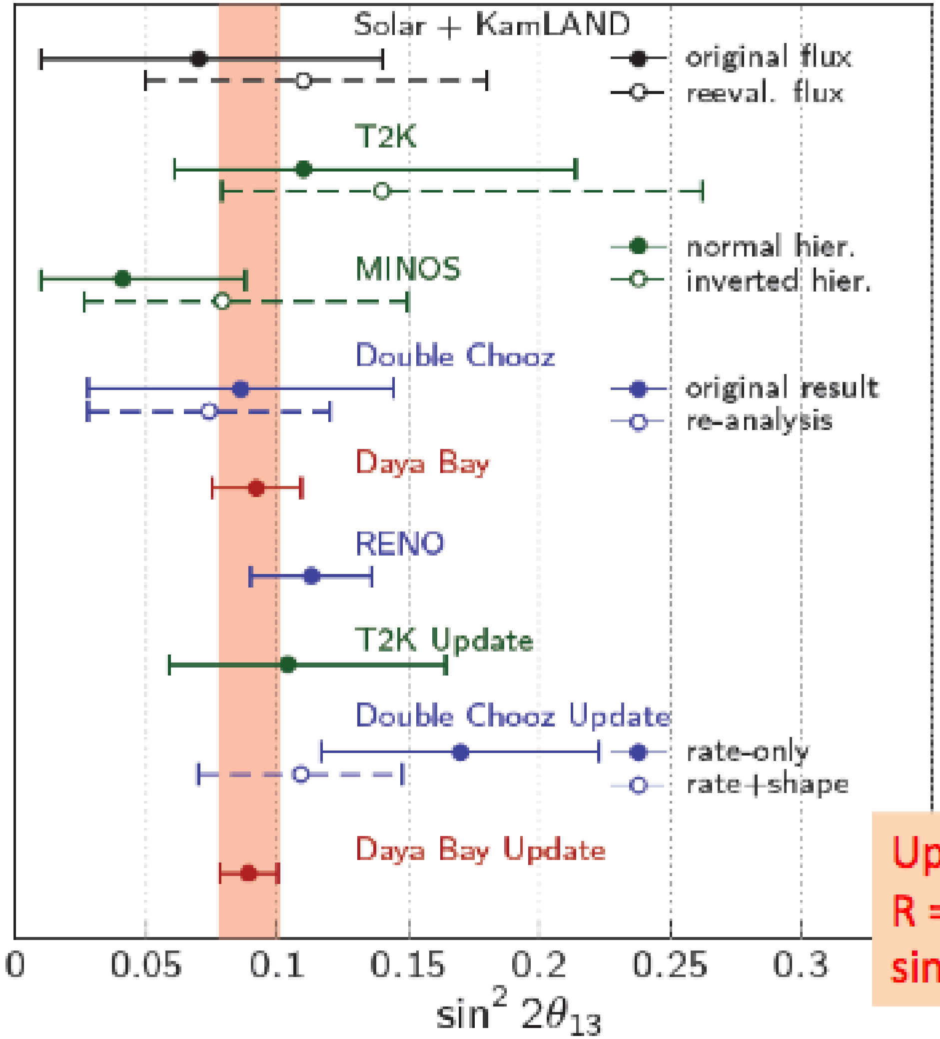
Far vs. near relative measurement. [Absolute rate is not constrained.]

Consistent results obtained by independent analyses, different reactor flux models.

Most precise measurement of $\sin^2 2\theta_{13}$ to date.

$\sin^2 2\theta_{13} = 0.089 \pm 0.010 \text{ (stat)} \pm 0.005 \text{ (syst)}$

Comparison of θ_{13} Measurements



PRL:
$R = 0.940 \pm 0.011$ (stat) ± 0.004 (sys)
$\sin^2 2\theta_{13} = 0.092 \pm 0.016$ (stat) ± 0.005 (sys)

Updated result:
$R = 0.944 \pm 0.007$ (stat) ± 0.003 (syst)
$\sin^2 2\theta_{13} = 0.089 \pm 0.010$ (stat) ± 0.005 (syst)

Symmetries (CP,T)

B → 3K CP V

- Indication of direct CP violation in $B^+ \to \phi K^+$ at 2.8σ.
  - $A_{CP} = (12.8 \pm 4.4 \pm 1.3)\%$
  - SM: $(0 - 4.7)\%$

$A_{CP}(\phi K^+)$ larger than SM expectation:

$A_{CP} = (1.6^{+3.1}_{-1.4})\%$ (QCDF) Beneke, Neubert, Nucl Phys B675, 333

$A_{CP} = (1^{+0}_{-1})\%$ (PQCD) Li, Mishima, PRD 74, 094020

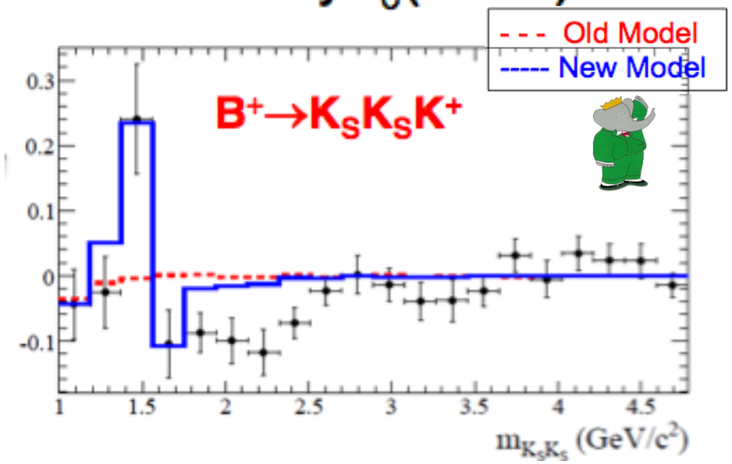
- World's most precise measurement of $\beta_{eff}(\phi K_S)$:
  - $\beta_{eff} = (21 \pm 6 \pm 2)$ degrees

Good agreement with SM

Charmonium:
$\beta = 21.4 \pm 0.8$ deg

- $f_X(1500)$ not a single resonance – well described by $f_0(1500)$ + $f_2'(1525)$ + $f_0(1710)$

arXiv:1201.5897, PRD 85:112010 (2012) 426 fb^{-1}



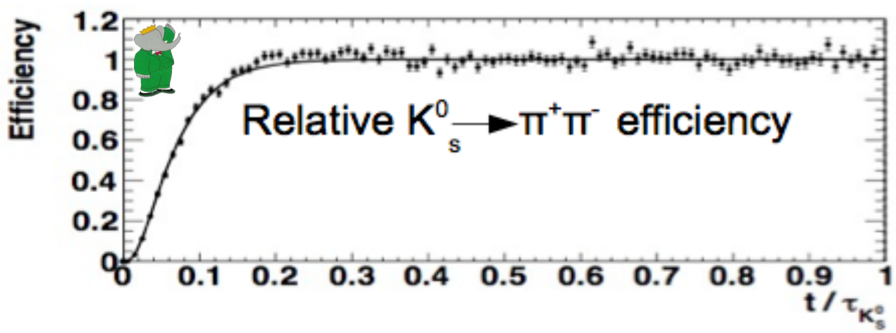
arXiv:1109.1527,
PRD-RC 85:031102 (2012)
476 fb-1

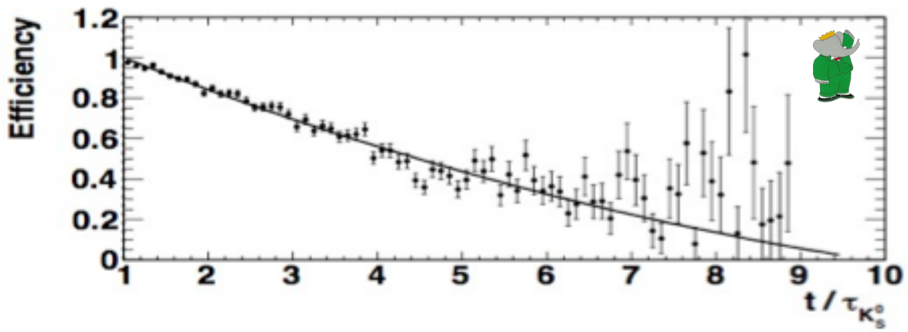
$\tau^- \rightarrow K^0 \pi^- \nu$ CP *V*

- After correction and taking into account the residual $\tau \rightarrow K^0_s$ BKG charge asymmetries:

A_Q=(-0.45±0.24±0.11)% FIRST MEASUREMENT

- Systematics from detector & selection bias, BKG subtraction and $K^0/\overline{K^0}$ nuclear interaction

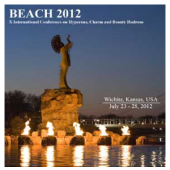




- K^0_s - K^0_L interference affects the predicted A_Q =(0.33±0.01)%
  - → Correction to be applied in terms of the $K^0_s \rightarrow \pi^+\pi^-$ decay time dependence of the selection efficiency (Grossman, Nir, arXiv:1110.3790):

- $A_Q^{COR}=A_Q$*(1.08±0.01)=(0.36±0.01)%

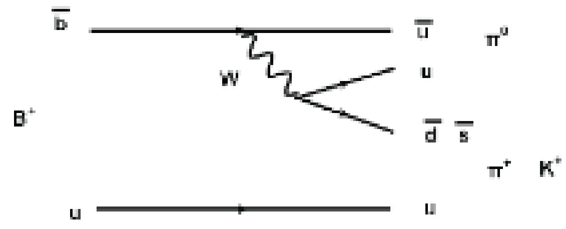
Measurement is 3.1 standard deviations from the SM predictions



Introduction

$B \to hh$

- The branching fraction between theoretical calculations and exprimental measurements have large uncertainties.
- The $\mathcal{A}_{CP}$ measurements will help observe SM quantities.
- Improved experimental uncertainties can help our understanding of the standard model and help indentify New Physics.



$$\Delta\mathcal{A}_{K\pi} = \mathcal{A}_{CP}(K\pi^0) - \mathcal{A}_{CP}(K\pi)$$

~0 in Standard Model

- As $B^+ \to K^+\pi^0$ and $B^0 \to K^+\pi^-$ have very similar leading order feynman diagrams, we would expect them to have similar $\mathcal{A}_{CP}$.
- A difference could indicate the enhancement of the color suppressed tree diagram.
- However, the previous Belle result found the sign and magnitude of these asymmetries to be different.
- The difference in these could indicate New Physics, such as a difference between direct CP in neutral and charged B decays.

Current Results

(Belle preliminary)

$$\Delta\mathcal{A}_{K\pi} = \mathcal{A}_{CP}(K\pi^0) - \mathcal{A}_{CP}(K\pi)$$

Previous Belle Result :

$\Delta\mathcal{A}_{K\pi} = +0.164 \pm 0.037$ 4.4σ

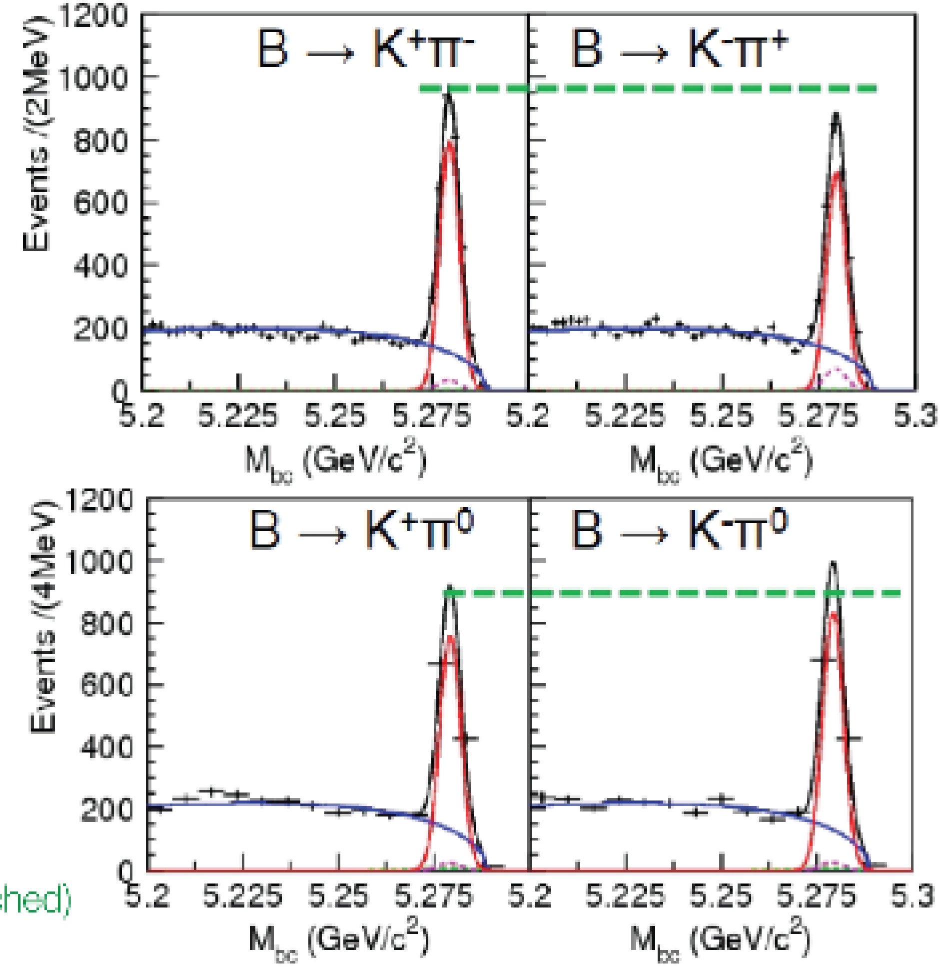
(535×10^6 $B\bar{B}$ pairs)

New Result :

$\Delta\mathcal{A}_{K\pi} = +0.112 \pm 0.027$ 4σ

(772×10^6 $B\bar{B}$ pairs)

HFAG : 0.124±0.022



Background from charmless B decays (hatched)

Background from mis-identification (dashed)

CP violating phase ϕ_s in $B_s^0 \to J/\psi\, \varphi$

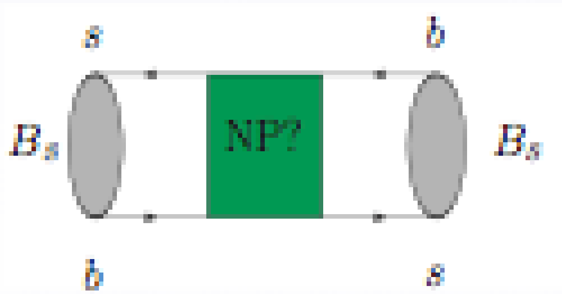
- The final state $J/\psi\, \varphi$ is accessible to both B_s^0 and $\overline{B}_s^0$: Interference between decays with and without mixing
- Interference measured through weak phase ϕ_s
- $\phi_s = \phi_M - 2\phi_{c\bar{c}s}$

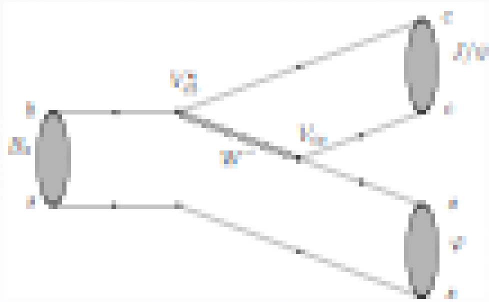
Mixing phase

- $\phi_M^{SM} = \arg\left(V_{tb}V_{ts}^*\right)^2 = -2\,\beta_s$

Decay phase

- $\phi_{c\bar{c}s}^{SM} = \arg(V_{cb}V_{cs}^*) \approx 0$ + small penguin contribution





- Standard Model (SM) prediction is small: $\phi_s^{SM} = -2\,\beta_s \approx -0.04$

(arXiv: 1102.4274)

- NP models: $\phi_s \to \phi_s^{SM} + \Delta\phi^{NP}$

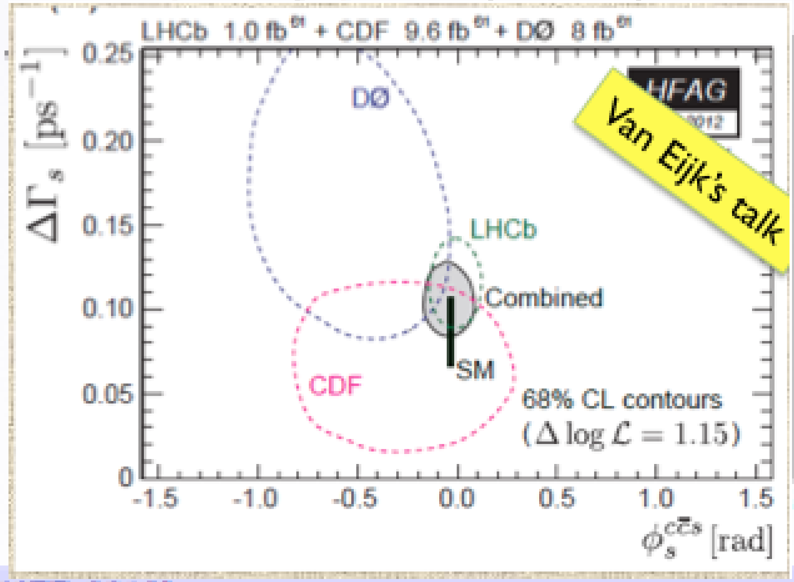
ϕ_s combinations

LHCb simultaneous fit of $B_s^0 \to J/\psi\,\varphi$ and $B_s^0 \to J/\psi\,\pi^+\pi^-$ (preliminary)

$\phi_s = -0.002 \pm 0.083\,(\text{stat.}) \pm 0.027\,(\text{syst.})$ *LHCb-CONF-2012-002*

Global ϕ_s combination (HFAG)

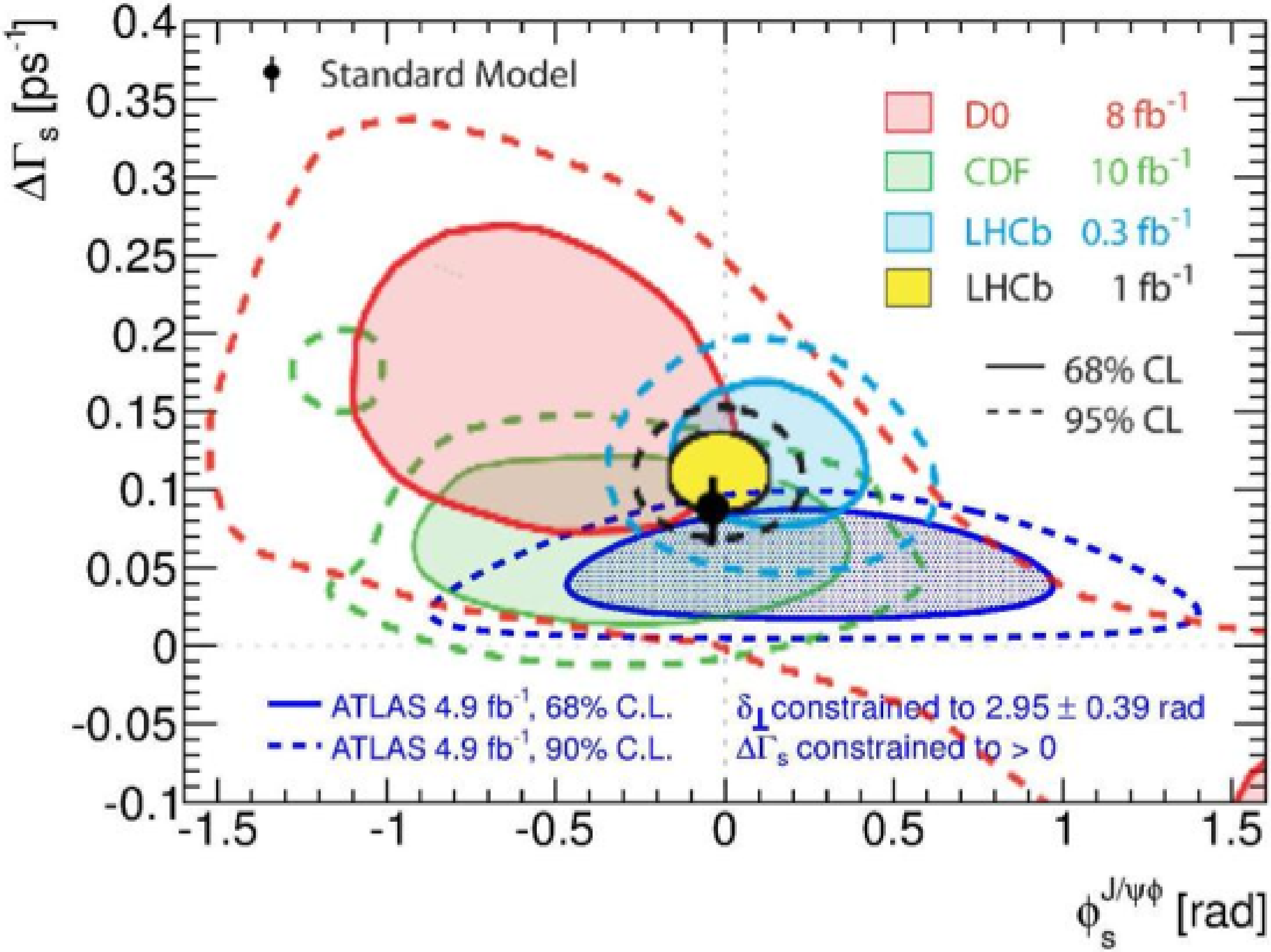
$\phi_s = -0.044^{+0.090}_{-0.085}$, $\Delta\Gamma_s = 0.105 \pm 0.015\,\text{ps}^{-1}$ *arXiv: 1207.1158*



ATLAS results (ICHEP 2012)

- $\phi_s = 0.22 \pm 0.41\,(\text{stat.}) \pm 0.10\,(\text{syst.})$
- $\Delta\Gamma_s = 0.053 \pm 0.021\,(\text{stat.}) \pm 0.008\,(\text{syst.})\,\text{ps}^{-1}$

Comparison

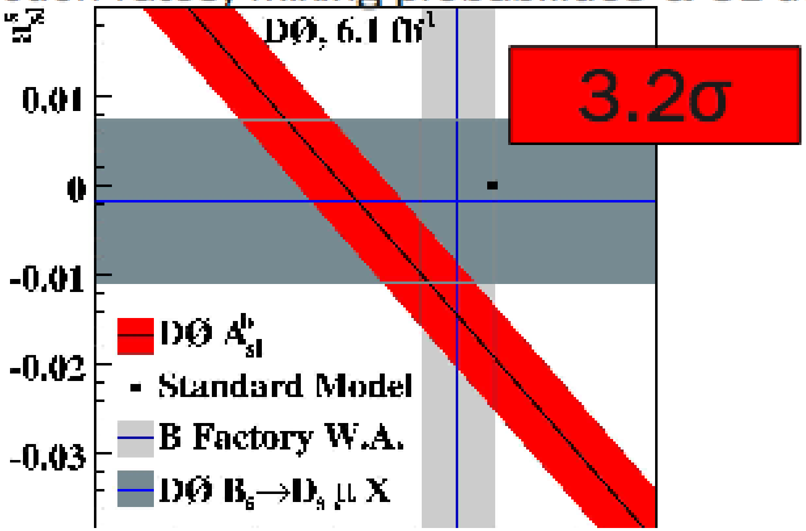


Standard Model
D0 8 fb^{-1}
CDF 10 fb^{-1}
LHCb 0.3 fb^{-1}
LHCb 1 fb^{-1}
68% CL
95% CL
ATLAS 4.9 fb^{-1}, 68% C.L.
ATLAS 4.9 fb^{-1}, 90% C.L.
$\delta_\perp$ constrained to 2.95 ± 0.39 rad
$\Delta\Gamma_s$ constrained to > 0
$\Delta\Gamma_s$ [ps^{-1}]
$\phi_s^{J/\psi\phi}$ [rad]

Like-sign dimuon asymmetry

- Semileptonic decays are flavour-specific
- B mesons are produced in $B\bar{B}$ pairs
- Like-sign leptons arise if one of $B\bar{B}$ pair mixes before decaying
- If no CP violation in mixing N(++) = N(−−)
- Inclusive measurement ↔ contributions from both B_d^0 and B_s^0
  - relative contributions from production rates, mixing probabilities & SL decay rates

D0 experiment
arXiv:1005.2757 & arXiv:1007.0395



Final Results

Combine two a^d_{sl} measurements, with correlations accounted for:

$$a^d_{\rm sl} = [0.93 \pm 0.45\ ({\rm stat.}) \pm 0.14\ ({\rm syst.})]\%$$

- Consistent with SM at 2σ level
- More precise than existing WA from B-factories: (−0.05 ± 0.56)%
- Paper in preparation

Corresponding time-integrated measurement of a^s_{sl}:

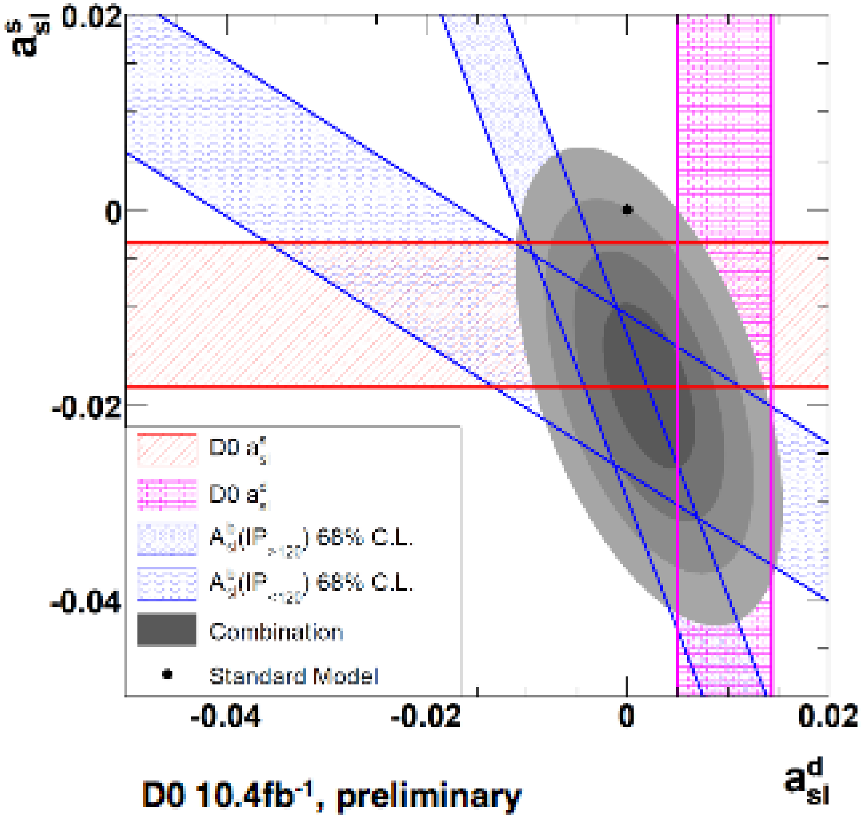
$$a^s_{\rm sl} = [-1.08 \pm 0.72\,({\rm stat}) \pm 0.17\,({\rm syst})]\,\%$$

- Supersedes previous worlds-best measurement (D0, 2009)
- Consistent with results of dimuon asymmetry…
- Submitted to Phys. Rev. Letters (arXiv:1207.1769 [hep-ex])

Combination

Combine D0 results from dimuon asymmetry (2011), a^d_{sl} and a^s_{sl}:

$$a^d_{\rm sl}(\text{comb.}) = (0.22 \pm 0.30)\%,$$
$$a^s_{\rm sl}(\text{comb.}) = (-1.81 \pm 0.56)\%,$$



Correlation coefficient: −0.50

χ^2/dof = **4.7/2**

p-value of SM: **0.29% (3.0σ)**

B^0 meson: consistent with SM (zero)

B_s^0 meson: **>3σ evidence** for anomalous CPV

CP violation in mixing: a_{sl}^{s} measurement (preliminary)

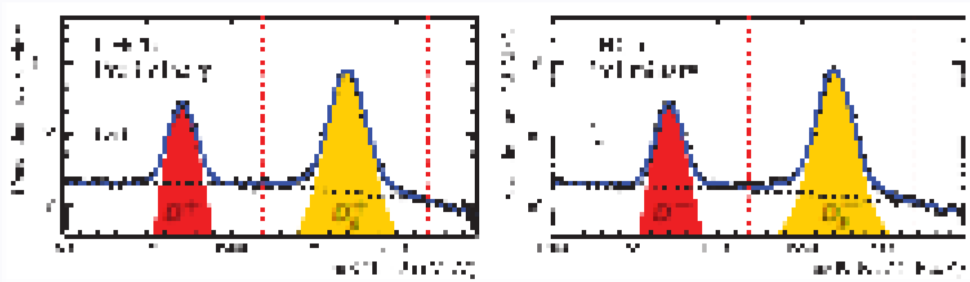
B_s^0 mixing:

$$\phi_{M/\Gamma} = \arg\left(-\frac{M_{12}}{\Gamma_{12}}\right)$$

Observable:

$$a_{sl}^{s} = \frac{\Gamma(\overline{B}_s^0(t) \to f) - \Gamma(B_s^0(t) \to \overline{f})}{\Gamma(\overline{B}_s^0(t) \to f) + \Gamma(B_s^0(t) \to \overline{f})} = \frac{\Delta\Gamma_s}{\Delta m_s} \tan \phi_{M/\Gamma}$$

- SM prediction: $a_{sl}^{s} = (1.9 \pm 0.3) \times 10^{-5}$ *(arXiv: 1205.1444)*
- Use as final state $D_s^{\pm} X \mu^{\mp} \overset{(-)}{\nu}$, $D_s^{\pm} \to \varphi \pi^{\pm}$



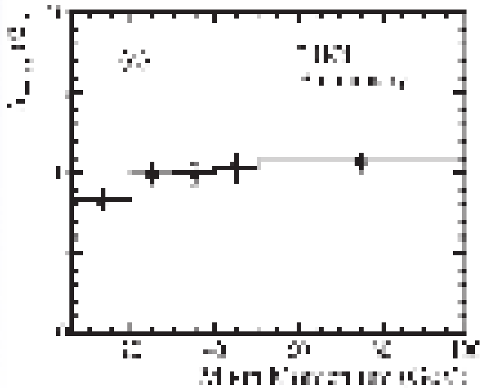
LHCb-CONF-2012-022

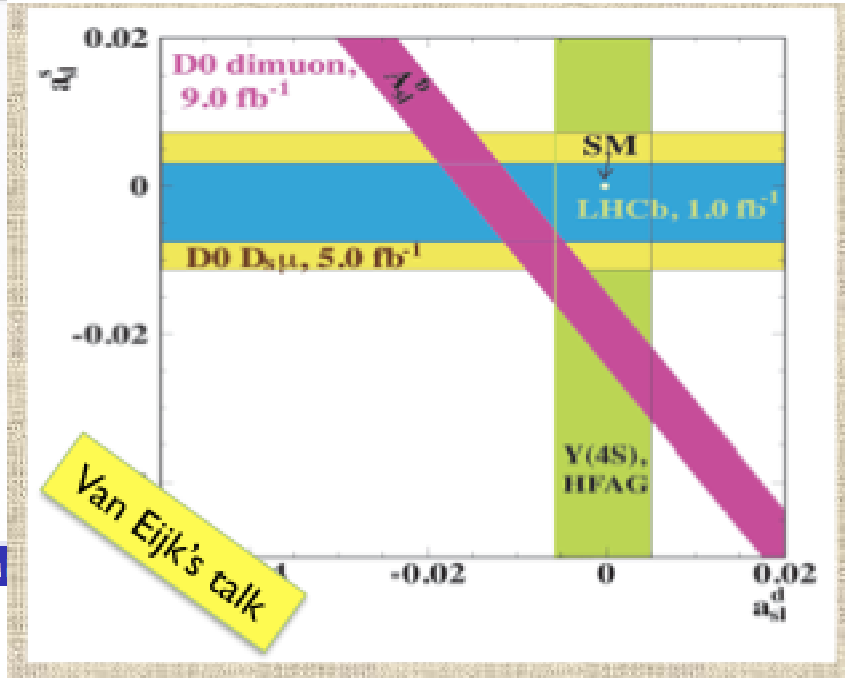
CP violation in mixing: a_{sl}^s measurement (preliminary)

$$A_{meas} = \frac{\Gamma[D_s^-\mu^+] - \Gamma[D_s^+\mu^-]}{\Gamma[D_s^-\mu^+] + \Gamma[D_s^+\mu^-]} = \frac{a_{sl}^s}{2} - \left(a_p - \frac{a_{sl}^s}{2}\right)\frac{\int_{t=0}^{\infty} e^{-\Gamma_s t}\cos(\Delta M_s t)\,\epsilon(t)\,dt}{\int_{t=0}^{\infty} e^{-\Gamma_s t}\cosh\frac{\Delta\Gamma_s t}{2}\,\epsilon(t)\,dt}$$

- Time-integrated measurement:
  - Effect of small production asymmetry eliminated due to large Δm_s
- Detection asymmetries estimated from calibration samples
- Residual detector asymmetries averaged out using magnet-up and magnet-down data (roughly equal-sized datasets)

$a_{sl}^s = (-0.24 \pm 0.54 \pm 0.33)\%$





$B_{d,s} \to K\pi$

$$A_{CP}(B^0 \to K\pi) = \frac{\Gamma(\bar{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\bar{B}^0 \to K^-\pi^+) + \Gamma(B^0 \to K^+\pi^-)}$$

$$A_{CP}(B_s^0 \to \pi K) = \frac{\Gamma(\bar{B}_s^0 \to \pi^- K^+) - \Gamma(B_s^0 \to \pi^+ K^-)}{\Gamma(\bar{B}_s^0 \to \pi^- K^+) + \Gamma(B_s^0 \to \pi^+ K^-)}$$

- CP asymmetry is well established in $B^0 \to K\pi$
- Consider CP violation in B_s system: 14 times lower decay rate, 4 time lower production rate, stronger rejection of combinatorial background required

	$A_{CP}(B^0 \to K\pi)$	$A_{CP}(B_s^0 \to \pi K)$
BaBar[1]	$-0.107 \pm 0.018^{+0.007}_{-0.004}$	
Belle[2]	$-0.094 \pm 0.018 \pm 0.008$	
CLEO[3]	$-0.04 \pm 0.016 \pm 0.02$	
CDF[4]	$-0.086 \pm 0.023 \pm 0.009$	$0.39 \pm 0.15 \pm 0.08$
PDG	-0.097 ± 0.012	0.39 ± 0.17

[1] Phys.Rev.Lett 99 (2007) 021603

[2] Nature 452 (2008) 332

[3] Phys.Rev.Lett 85 (2000) 525

[4] Phys.Rev.Lett 106 (2011) 181802

Results

$$A_{CP}(B^0 \to K\pi) = -0.088 \pm 0.011(stat) \pm 0.008(syst)$$

- Good agreement with World Average
- Most precise measurement
- First observation $(> 6\sigma)$ of CP violation at a hadron collider

$$A_{CP}(B_s^0 \to \pi K) = 0.27 \pm 0.08(stat) \pm 0.02(syst)$$

- First evidence $[3.3\sigma]$ of CP violation in B_s decay
- Agreement with the only measurement available (CDF, Phys.Rev.Lett 106 (2011) 181802)

Results

[illegible]	=	$0.0774 \pm 0.0012 \pm 0.0018$
[illegible]	=	$0.0773 \pm 0.0030 \pm 0.0018$
[illegible]	=	$0.0773 \pm 0.0030 \pm 0.0017$
[illegible]	=	$-0.0001 \pm 0.0036 \pm 0.0095$
[illegible]	=	$0.0044 \pm 0.0144 \pm 0.0174$
[illegible]	=	$0.1450 \pm 0.0329 \pm 0.0097$
[illegible]	=	$0.1351 \pm 0.0621 \pm 0.0035$
[illegible]	=	$-0.0194 \pm 0.0061 \pm 0.0016$
[illegible]	=	$-0.0009 \pm 0.0155 \pm 0.0064$
[illegible]	=	$0.0078 \pm 0.0028 \pm 0.0004$
[illegible]	=	$0.0233 \pm 0.0034 \pm 0.0007$
[illegible]	=	$0.00410 \pm 0.00025 \pm 0.00005$
[illegible]	=	[illegible]

Total significance of 5.8σ: direct CP violation in $B^+ \to DK^+$ is observed

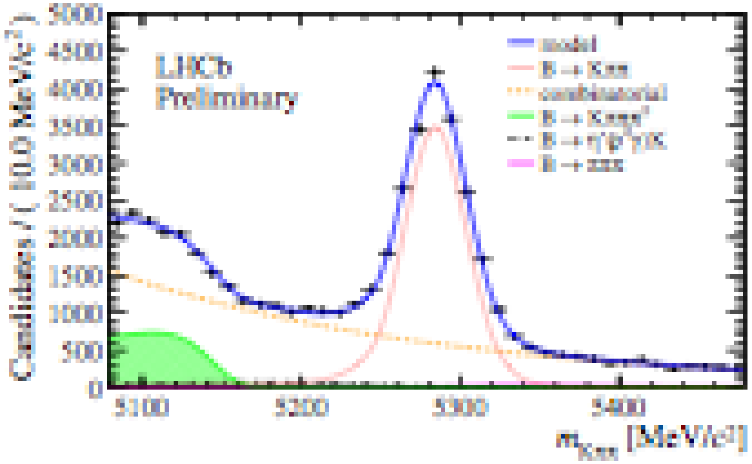
GLW observables

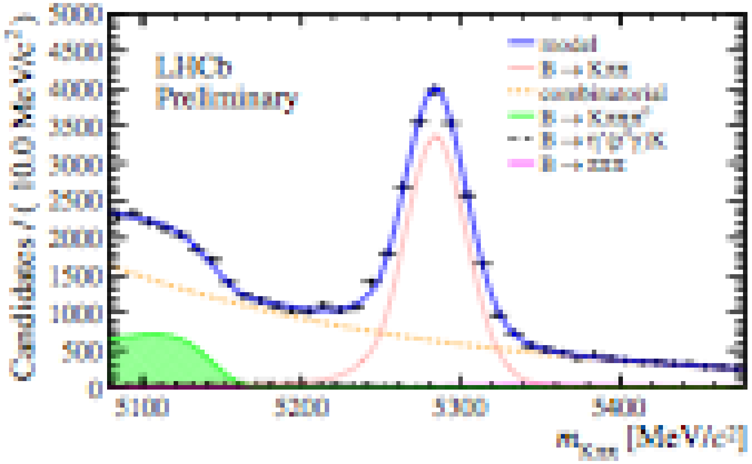
- $R_{CP+} =< R^{KK}_{K/\pi}, R^{\pi\pi}_{K/\pi} > / R^{K\pi}_{K/\pi} = 1.007 \pm 0038 \pm 0.012$
- $A_{CP+} =< A^{KK}_{K}, A^{\pi\pi}_{K} >= 0.145 \pm 0.032 \pm 0.010$
- Both KK and $\pi\pi$ modes show positive asymmetries
- The combined asymmetry significance is 4.5σ

ADS observables

- $R_{ADS(K)} = 0.0152 \pm 0.0020 \pm 0.0004$
- $A_{ADS(K)} = -0.520 \pm 0.150 \pm 0.021$
- $R_{ADS(\pi)} = 0.00410 \pm 0.00025 \pm 0.00005$
- $A_{ADS(\pi)} = 0.143 \pm 0.062 \pm 0.011$
- $B \to D_{ADS}K$ observed with 10σ and evidence (4σ) of negative asymmetry
- $B \to D_{ADS}\pi$ shows hint of positive asymmetry (2.4σ)

CP asymmetry in $B^+ \to K^+\pi^+\pi^-$





$N(B^-) = 18168 \pm 170$

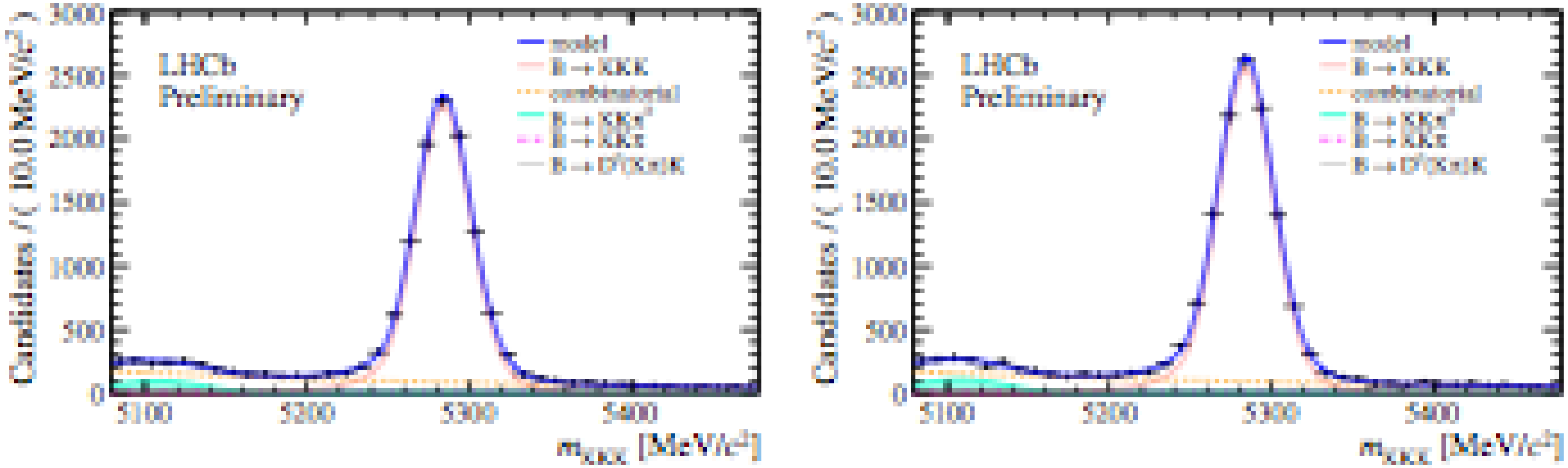
$N(B^+) = 17540 \pm 169$

Preliminary

$$A_{\mathrm{CP}}(K\pi\pi) = A_{\mathrm{CP}}^{\mathrm{RAW}}(K\pi\pi) - A_{\mathrm{CP}}^{\mathrm{RAW}}(J/\psi K) + A_{\mathrm{CP}}(J/\psi K) =$$
$$= +0.034 \pm 0.009(stat) \pm 0.004(syst) \pm 0.007(J/\psi K)$$

Significance of 1.8σ

CP asymmetry in $B^+ \to K^+K^+K^-$



$N(B^-) = 11606 \pm 117$

$N(B^+) = 10289 \pm 110$

Preliminary

$$A_{CP}(KKK) = A_{CP}^{RAW}(KKK) - A_{CP}^{RAW}(J/\psi K) + A_{CP}(J/\psi K) =$$
$$= -0.046 \pm 0.009(stat) \pm 0.005(syst) \pm 0.007(J/\psi K)$$

First evidence of inclusive CP asymmetry in charmless three-body B^+ decays (Significance of 3.7σ)

$D^0 \rightarrow KK$ and $D^0 \rightarrow \pi\pi$ CP asymmetries

- Predicted to be small in the SM
  - early predictions were less than 10^{-4}
  - but predictions for charm are difficult.
- Real difficulty is to cancel detector induced asymmetries.
- The *KK* and $\pi\pi$ asymmetries are of opposite sign in SM
  - the difference is particularly sensitive
  - and most detector asymmetries cancel in the difference
- Use $D^{*+} \rightarrow D^0 \pi^+$ and c.c. to tag D^0 production flavor.

http://www-cdf.fnal.gov/physics/new/bottom/120216.blessed-CPVcharm10fb/

http://www-cdf.fnal.gov/physics/new/bottom/100916.blessed-Dpipi6.0/

Individual Mode Asymmetries

$$A_{CP}(\pi^+\pi^-) = [0.22 \pm 0.24(\text{stat}) \pm 0.11(\text{sys})]\,\%$$

$$A_{CP}(K^+K^-) = [-0.24 \pm 0.22(\text{stat}) \pm 0.09(\text{sys})]\,\%$$

World's best measurements.

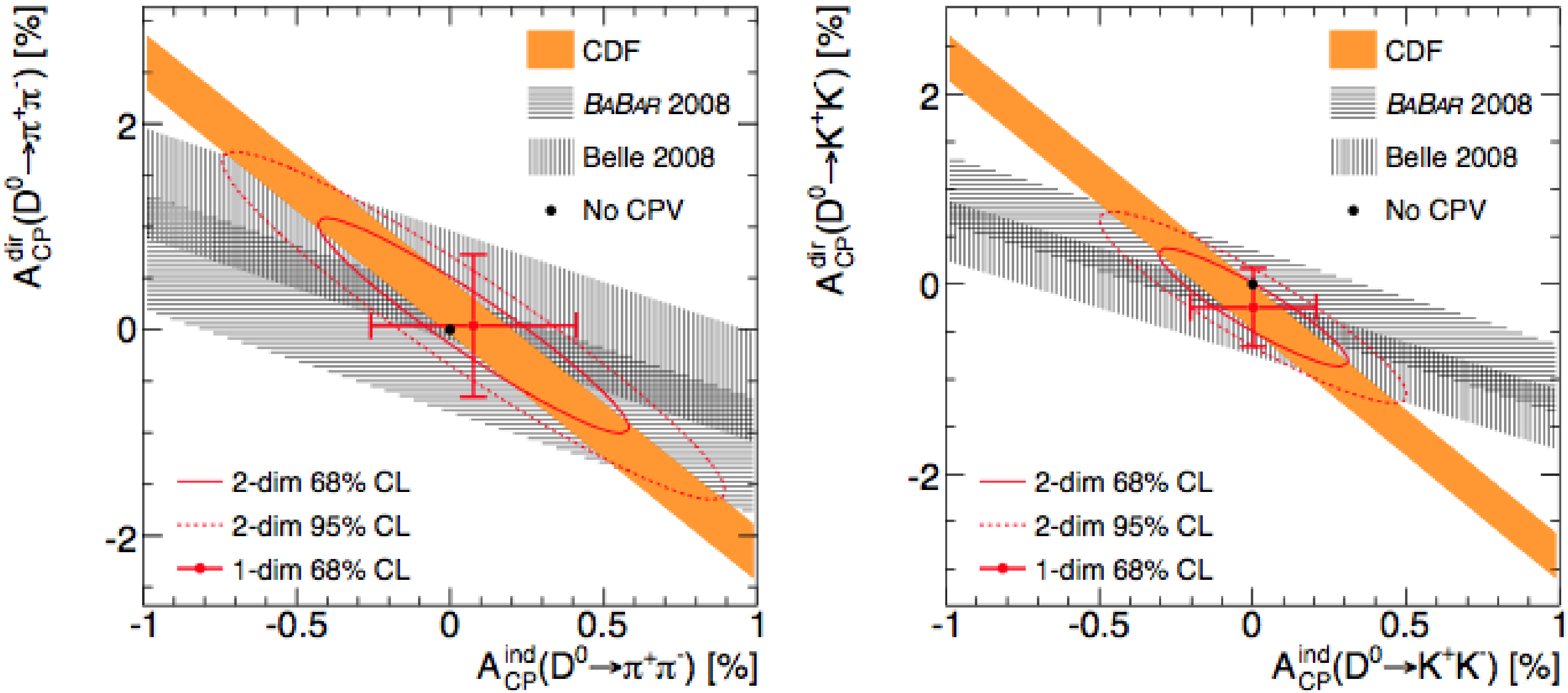
Measured CP asymmetry is a combination of direct and indirect CP asymmetries.

$$A_{CP} = A_{CP}^{\text{dir}} + \int_0^\infty A_{CP}(t)D(t)dt \approx A_{CP}^{\text{dir}} + \frac{\langle t \rangle}{\tau} A_{CP}^{\text{ind}}$$

Line in the direct-indirect asymmetry plane.

Charm Asymmetries:

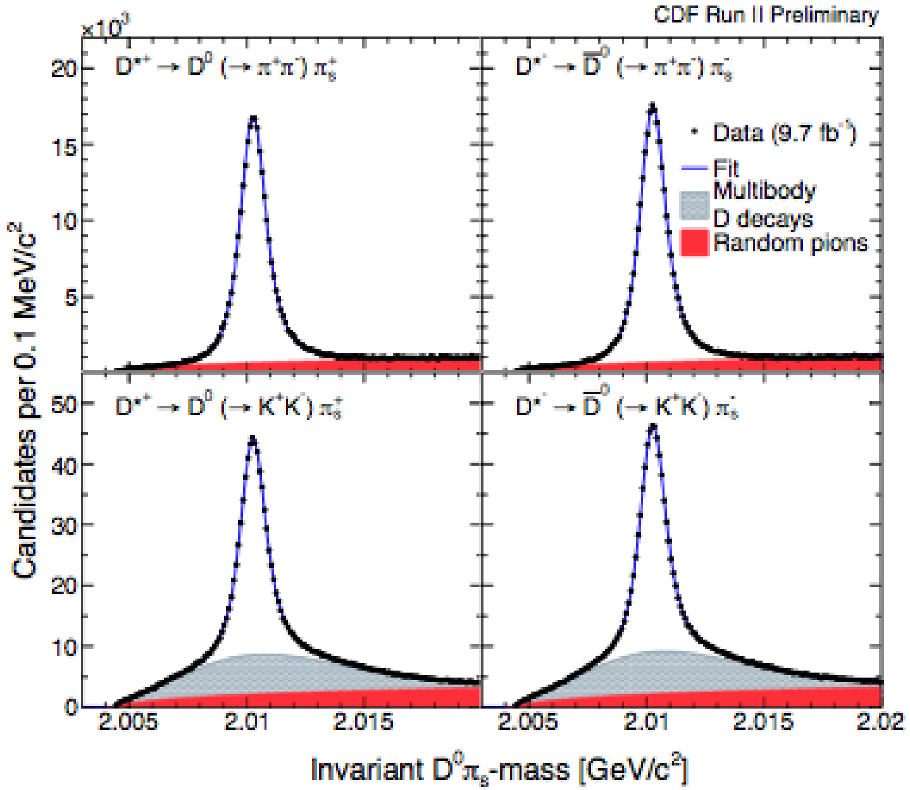
- 2010 – 2011: CDF measures ACP in $D^0 \rightarrow \pi\pi$ and $D^0 \rightarrow KK$ separately PRD 85, 012009 (2012)



CDF: Charm Detector Facility?

CDF ΔA_{CP} Measurement:

- For ΔA_{CP} measurement, selection can be loosened, and full data set used → more than doubling the statistics.
- Cross check with data binned in different η, ϕ regions.



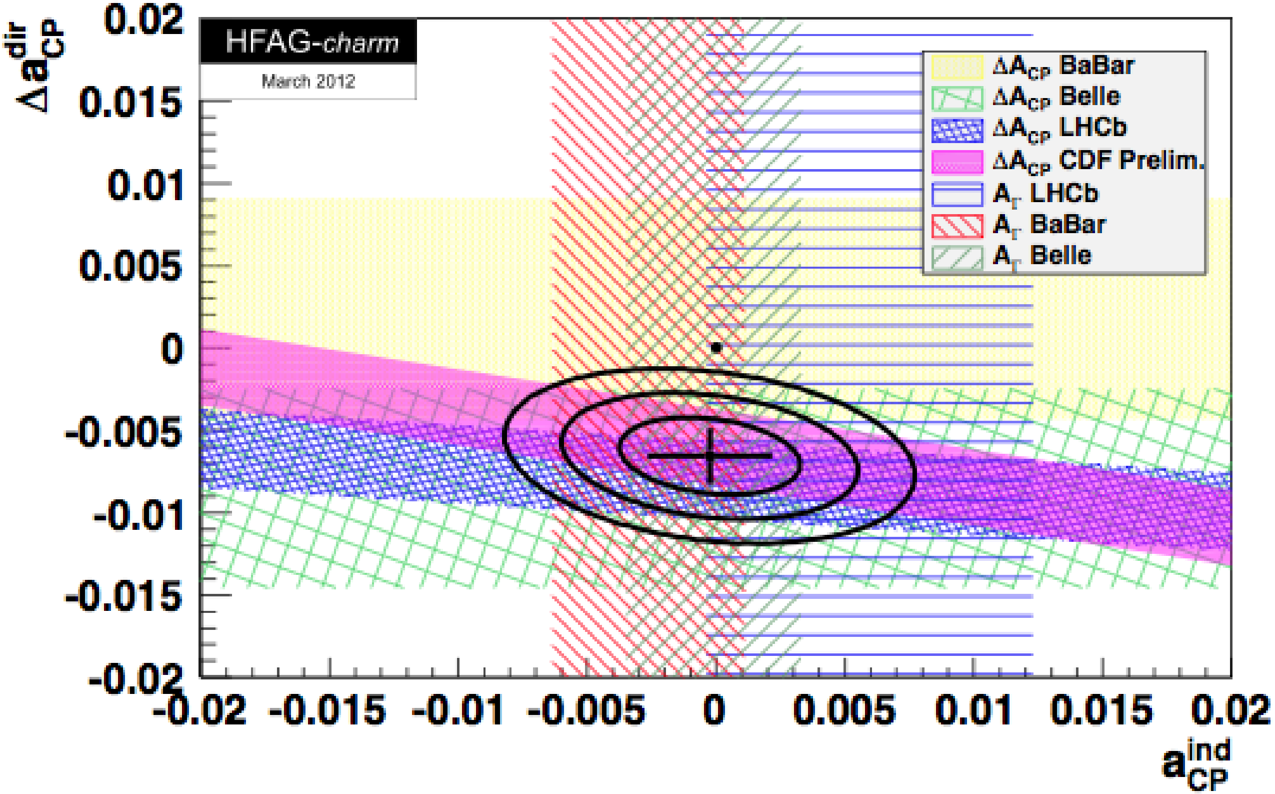
$$\Delta A_{CP} = (-0.62 \pm 0.21 \pm 0.10)\%$$

arXiv:1207.2158

HFAG Combination of All ΔA_{CP} Results

$$A_{CP}^{\text{ind}} = (-0.03 \pm 0.23)\%$$

$$A_{CP}^{\text{dir}} = (-0.66 \pm 0.15)\%$$



Rare, or forbidden processes

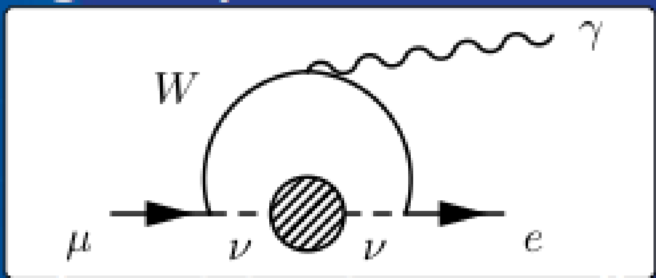
Lepton Mixing in the Standard Model

- We have three generations of leptons:

$$\begin{pmatrix} e \\ \nu_e \end{pmatrix} \begin{pmatrix} \mu \\ \nu_\mu \end{pmatrix} \begin{pmatrix} \tau \\ \nu_\tau \end{pmatrix}$$

No SM couplings between generation!

- In the standard model Lagrangian there is no coupling to mixing between generations
- But we have explicitly observed *neutrino oscillations*
- *Thus charged lepton flavor is **not** conserved.*
- Charged leptons must mix through neutrino loops



$$Br(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_{\ell} V^{\star}_{\mu\ell} V_{e\ell} \frac{m^2_{\nu_\ell}}{M^2_W} \right|^2 \leq 10^{-54}$$

- But the mixing is so small, it's effectively forbidden

General CLFV Lagrangian

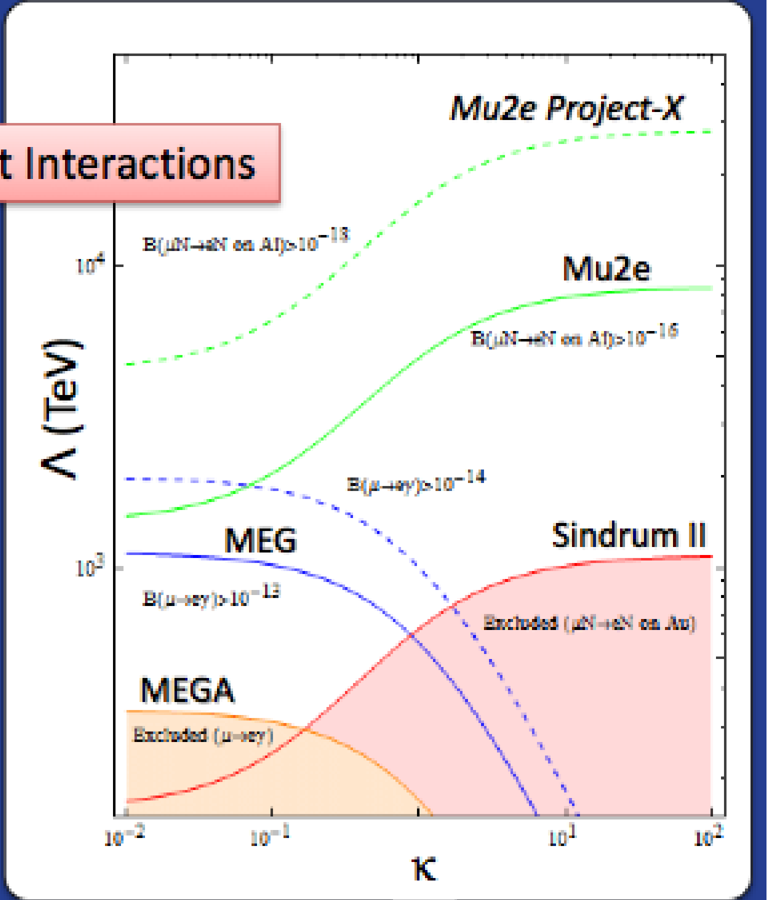
- Recharacterize these all these interactions together in a model independent framework:

$$\mathcal{L}_{\mathcal{LFV}} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L\left(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L\right)$$

Loops

Contact Interactions

  - Splits CLFV sensitivity into
    - Loop terms
    - Contact terms
  - Shows dipole, vector and scalar interactions
  - Allows us to parameterize the effective mass scale ¤ in terms of the dominant interactions
  - The balance in effective reach shifts between favoring ^{1}N!eN and ^{1}!e° measurements .
  - For contact term dominated interaction (large κ) the sensitivity in Λ, reaches upwards of 10^4 TeV for the coherent conversion process

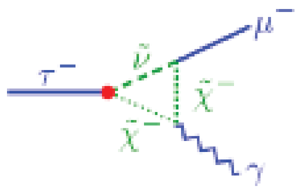


τ physics

$\sigma(e^+e^- \to \tau^+\tau^-)_{\sqrt{s}=M(\Upsilon(4S))} \sim \sigma(e^+e^- \to \Upsilon(4S) \to B\bar{B})$ ➔ SuperB is a tau factory

- Lepton flavor violation

ν mixing leads to $BF \sim 10^{-54}$
→ Enhancement to observable levels possible with new physics

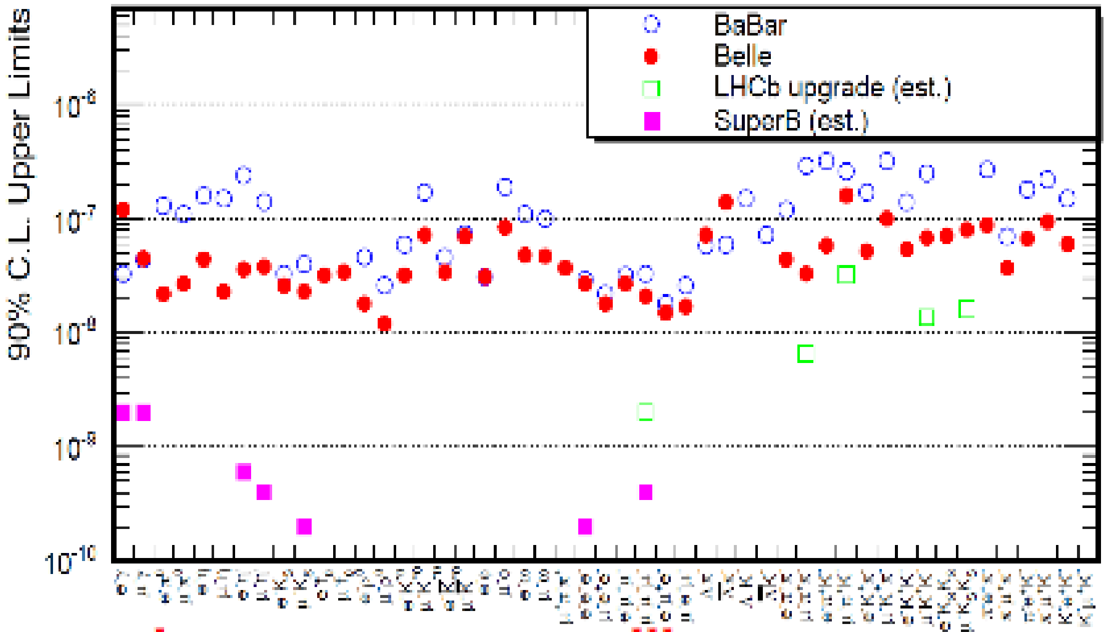


- CP violation
- precision $|V_{us}|$ measurement
- τ g-2
- τ EDM

Up to two orders of magnitude improvement at SuperB over current limits

Hadron machines are in general not competitive

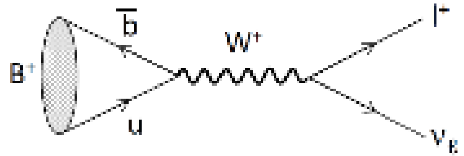
e^- beam polarization helps suppress background or discriminate among NP models



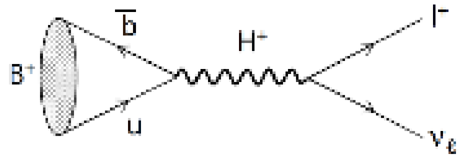
$\tau \to l\gamma$ $\tau \to lll$

$B \rightarrow \tau\, \nu$: motivation

- $B(B \rightarrow l\nu) = \frac{G_F{}^2 m_B}{8\pi} m_l{}^2 \left(1 - \frac{m_l{}^2}{m_B{}^2}\right)^2 f_B{}^2 |V_{ub}|^2 \tau_B$



- Leptonic B decays to test SM predictions.
  - Very clean theoretically.
  - Uncertainties from f_B and $|V_{ub}|$. Lattice QCD talk
  - $B \rightarrow \mu\nu$ and $B \rightarrow e\nu$ out of reach at current B factories.
- Probe of physics beyond the SM.
  - Decay can be mediated by a charged Higgs.
- $B(B \rightarrow l\nu)_{2HDM} = B(B \rightarrow l\nu)_{SM} \left(1 - \tan^2\beta \frac{m_B{}^2}{m_H{}^2}\right)^2$



$B \to \tau\nu$: result discussion

- New BABAR result:
  - $B(B \to \tau\nu) = \left(1.83 {}^{+0.53}_{-0.49} \pm 0.24\right).10^{-4}$ 468 M $B\bar{B}$
- Comparison with other measurements:

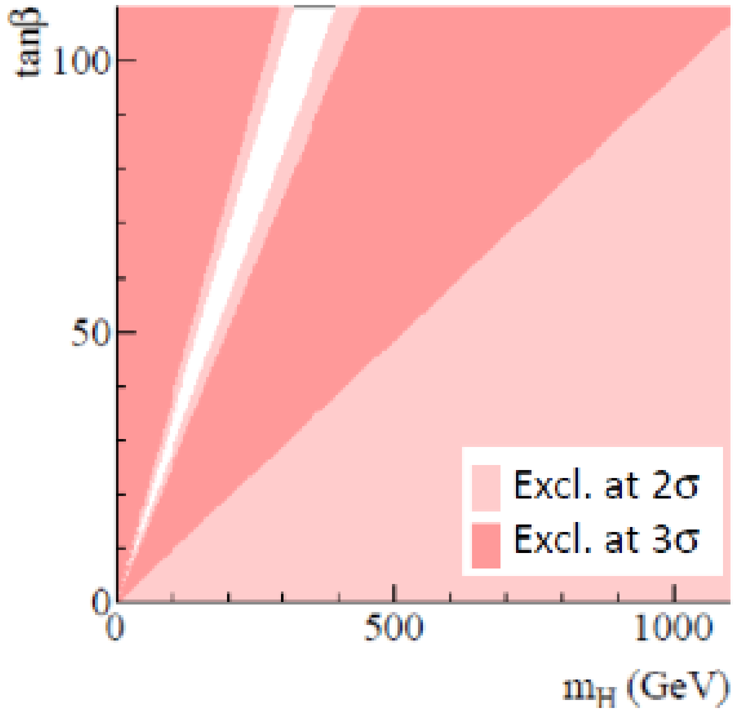
Experiment	Tag	Branching Fraction ($\times 10^{-4}$)	
BABAR	hadronic [8]	$1.8^{+0.9}_{-0.8} \pm 0.4 \pm 0.2$	383 M $B\bar{B}$
BABAR	semileptonic [9]	$1.7 \pm 0.8 \pm 0.2$	459 M $B\bar{B}$
Belle	hadronic [10]	$1.79^{+0.56}_{-0.49}{}^{+0.46}_{-0.51}$	449 M $B\bar{B}$
Belle	semileptonic [11]	$1.54^{+0.38}_{-0.37}{}^{+0.29}_{-0.31}$	657 M $B\bar{B}$

  – BELLE (ICHEP 2012): $B(B \to \tau\nu) = \left(0.72 {}^{+0.27}_{-0.25} \pm 0.11\right).10^{-4}$ 722 M $B\bar{B}$

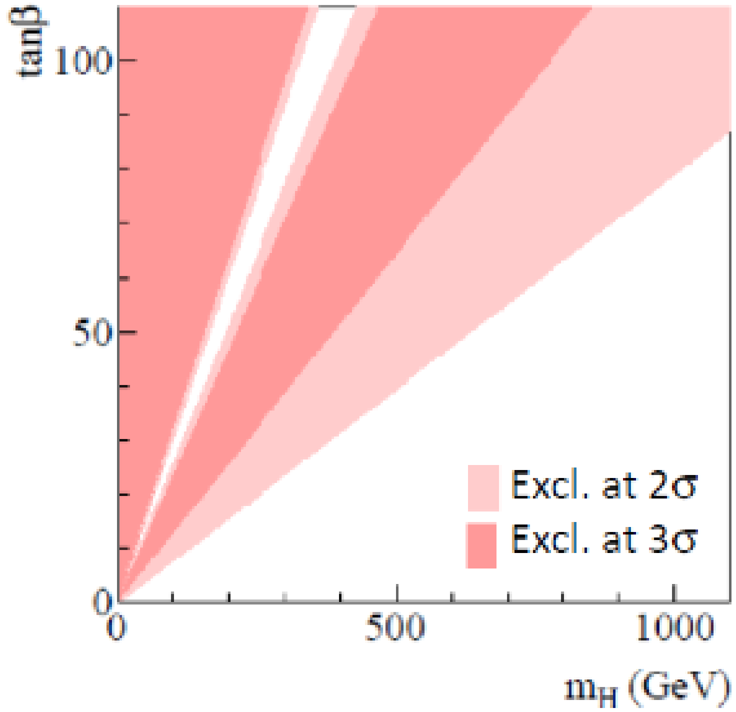
- Comparison with SM prediction (using $f_B = (189 \pm 4)$ MeV): HPQCD arXiv:1202.4914
  – 2.4 σ with $B_{SM}(B \to \tau\nu) = (0.62 \pm 0.12).10^{-4}$ ($|V_{ub}|$ exclusive PoS(EPS-HEP2011)155).
  – 1.6 σ with $B_{SM}(B \to \tau\nu) = (1.18 \pm 0.16).10^{-4}$ ($|V_{ub}|$ inclusive arXiv:1112.0702).

$B \to \tau\nu$: constraints in 2HDM (II)

- Most of the parameter space excluded at 95% CL with exclusive $|V_{ub}|$.
- 95% CL exclusion up to 1 TeV at very high $\tan\beta > 70$ with inclusive $|V_{ub}|$.

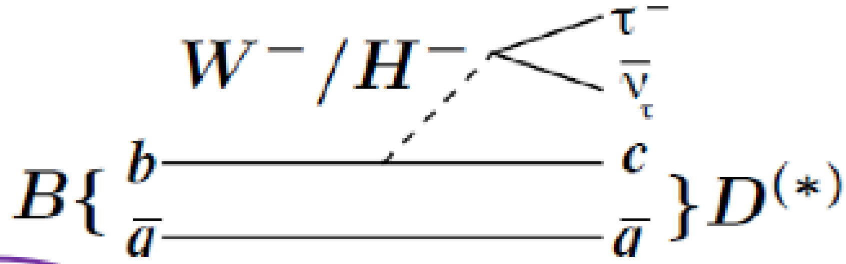


Exclusive $|V_{ub}|$



Inclusive $|V_{ub}|$

B → D$^{(*)}$ τ ν : motivation



- Semileptonic decays with a τ.

$$\frac{d\Gamma_\tau}{dq^2} = \frac{G_F^2 |V_{cb}|^2 |p_{D^{(*)}}| q^2}{96\pi^3 m_B^2} \left(1 - \frac{m_\ell^2}{q^2}\right)^2 \left[(|H_+|^2 + |H_-|^2 + |H_0|^2) \left(1 + \frac{m_\ell^2}{2q^2}\right) + \frac{3m_\ell^2}{2q^2} |H_s|^2 \right]$$

only for B → D* τ ν

H^- enters here

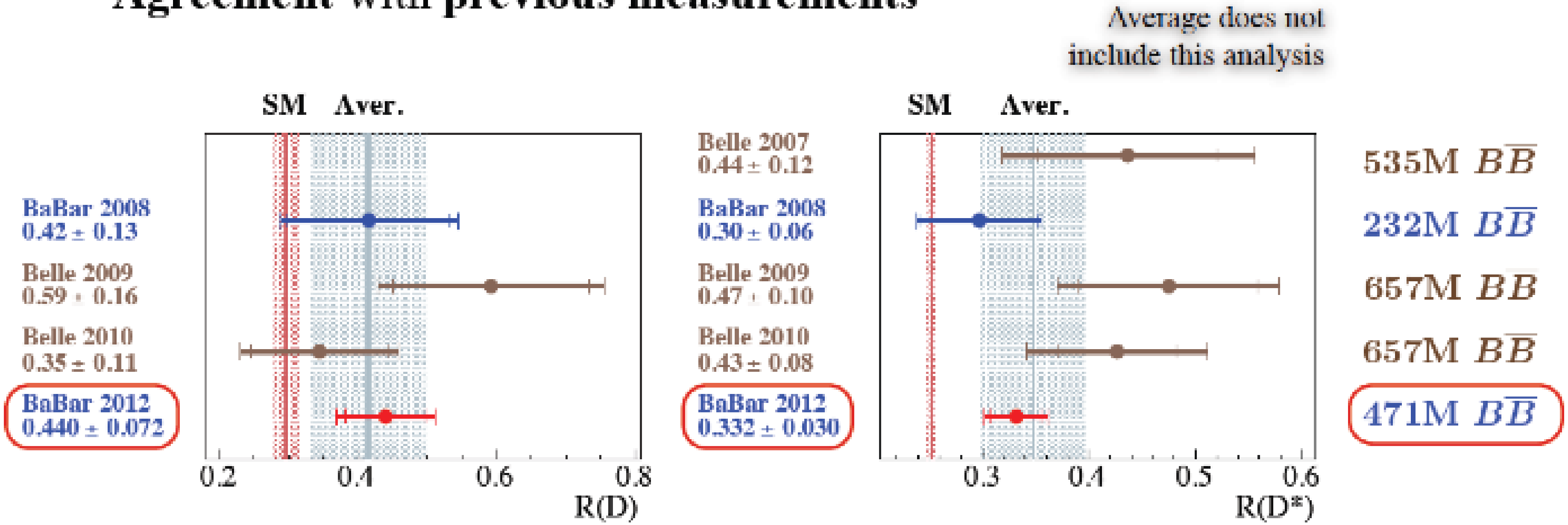
- Test the SM by measuring the ratios:
  $R(D) = \frac{B(\bar{B}\to D\tau\nu)}{B(\bar{B}\to Dl\nu)}$ and $R(D^*) = \frac{B(\bar{B}\to D^*\tau\nu)}{B(\bar{B}\to D^*l\nu)}$.
  - Several theoretical and experimental uncertainties cancel in the ratio.

- Sensitive to additional amplitudes.
  - Charged Higgs (entering through the scalar amplitude).

$B \to D^{(*)} \tau \nu$: results and comparison to previous measurements

Decay	N_{sig}	N_{norm}	$R(D^{(*)})$	$\mathcal{B}(B \to D^{(*)}\tau\nu)$ (%)	$\Sigma_{tot}(\sigma)$
$D\tau^-\overline{\nu}_\tau$	489 ± 63	2981 ± 65	$0.440 \pm 0.058 \pm 0.042$	$1.02 \pm 0.13 \pm 0.11$	6.8
$D^*\tau^-\overline{\nu}_\tau$	888 ± 63	11953 ± 122	$0.332 \pm 0.024 \pm 0.018$	$1.76 \pm 0.13 \pm 0.12$	13.2

- **First 5σ observation of B→Dτν**
- **Agreement** with **previous measurements**

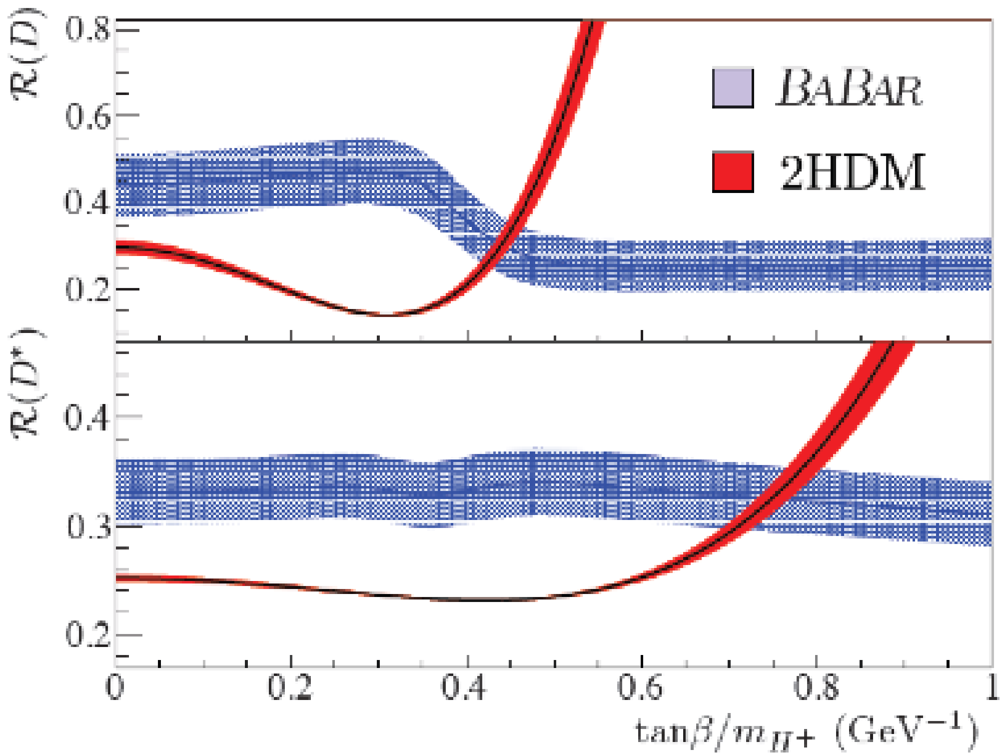


$B \rightarrow D^{(*)} \tau \nu$: 2HDM

R(D) and R(D*) are
Not independent

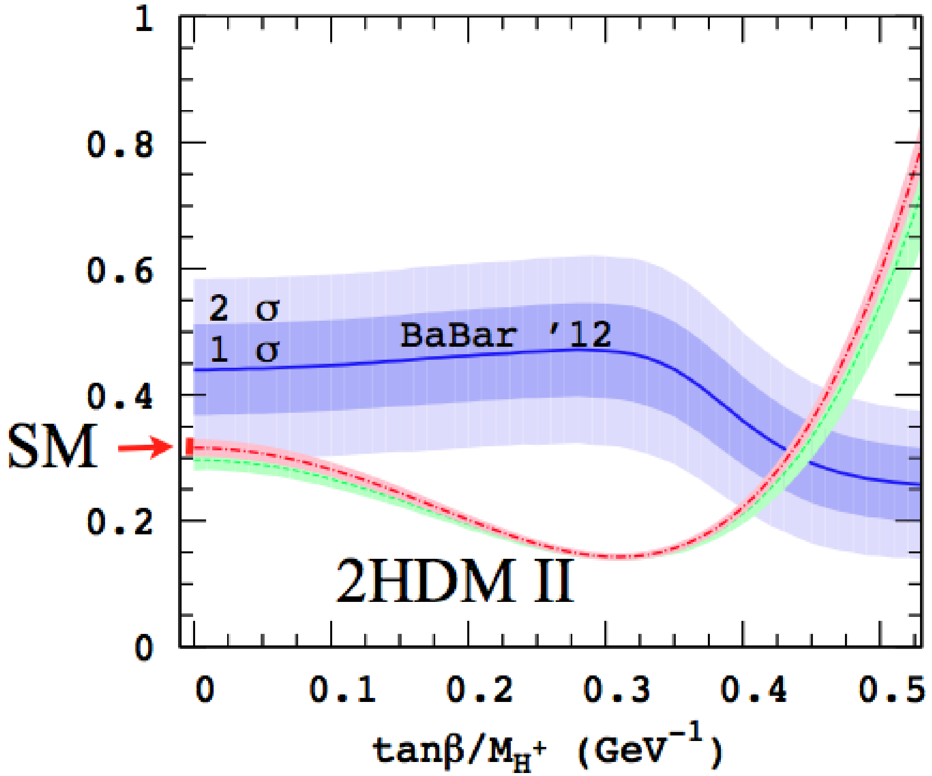
- A charged Higgs of spin 0 will affect H_s and modify $R(D^{(*)})$.
- Data match 2DHM type II at
  - $\tan\beta/m_H = 0.44 \pm 0.02$ for R(D)
  - $\tan\beta/m_H = 0.75 \pm 0.04$ for R(D*)
- Combination excludes 2HDM type II with a probability greater than 99.8% provided $m_H > 10$ GeV.

$$H_s^{2HDM} \approx H_s^{SM} \times \left(1 - \frac{\tan^2\beta}{m_{H^+}^2} \frac{q^2}{1 \mp m_c/m_b}\right)$$



Form factor ratio $R(D) = \mathrm{Br}(B \to D\tau\nu)/\mathrm{Br}(B \to D\ell\nu)$

FNAL/MILC (arXiv:1206.4992, PRL)



2HDM II with FNAL/MILC form factors (band includes sys. error)

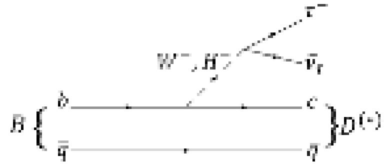
FNAL/MILC form factors: from partial data set used in arXiv:1202.6346

2 HDM II with form factors using quenched LQCD, HQS, kinematic constraints, ...

- similar estimate for $R(D)_{\mathrm{SM}}$ by Becirevic, Kosnik, Tayduganov (arXiv: 1206.4977)
- $R(D^*)$: need four form factors, larger discrepancy with SM

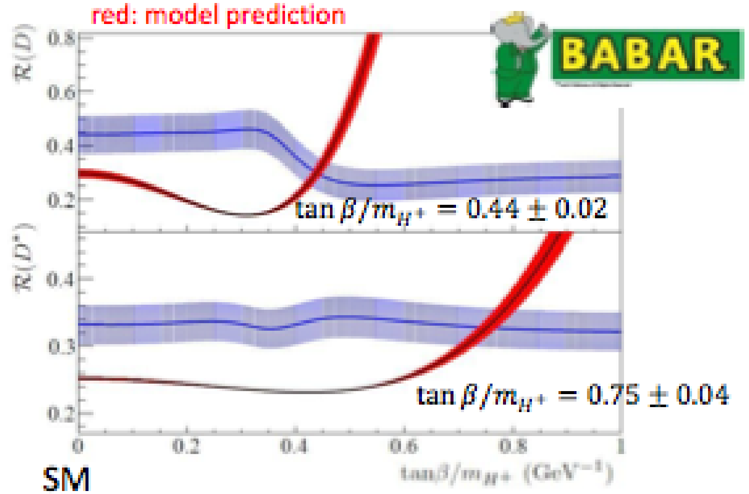
$B \to D^{(*)}\tau\nu$ and $B \to \tau\nu$

BaBar measurement of
$\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$, 0.43 ab^{-1}



see G. Vasseur tomorrow

arXiv:1205.5442 sub. to PRL
blue: measured R vs model parameter
red: model prediction

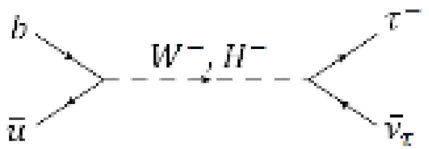


		SM calc.
$R(D) = \dfrac{BF(\bar{B} \to D\tau^-\bar{\nu}_\tau)}{BF(\bar{B} \to Dl^-\bar{\nu}_l)}$	$= 0.440 \pm 0.072$	0.297 ± 0.017
$R(D^*) = \dfrac{BF(\bar{B} \to D^*\tau^-\bar{\nu}_\tau)}{BF(\bar{B} \to D^*l^-\bar{\nu}_l)}$	$= 0.332 \pm 0.029$	0.252 ± 0.003

$R(D) + R(D^*)$ inconsistent with SM (3.4σ) and exclude the type II 2 Higgs doublet model with 99.8% CL

More data needed. Cannot be measured at hadron colliders (neutrinos in final state)

$B^- \to \tau^- \bar{\nu}_\tau$



$$BF_{2HDM-II} = BF_{SM} \times (1 - \tan\beta^2 m_B^2/m_H^2)^2$$

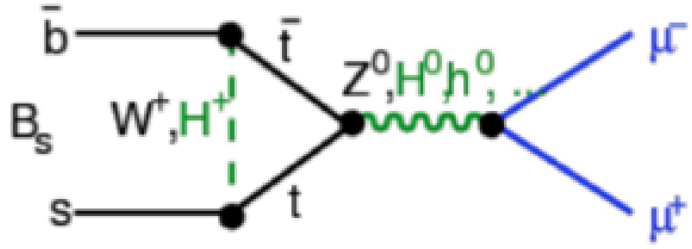
decay mode	expected BF_{SM}	2012 $\sigma(BF)/BF_{SM}$	SuperB 75ab^{-1} $\sigma(BF)/BF_{SM}$
$B^- \to \tau^- \bar{\nu}_\tau$	$\sim 10^{-4}$	20%	4%
$B^- \to \mu^- \bar{\nu}_\mu$	$\sim 5 \times 10^{-7}$	---	5%
$\bar{B} \to D^{(*)}\tau^-\bar{\nu}_\tau$	$\sim 10^{-2}$	10%	2%

Motivation to search for $B_s \to \mu^+\mu^-$

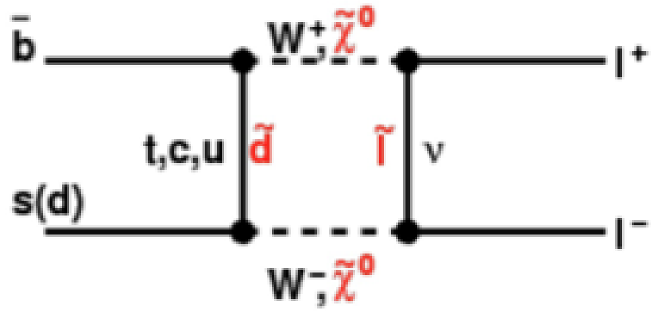
- *Standard model prediction*

$$\mathcal{B}(B_s \to \mu^+\mu^-) = (3.2 \pm 0.2) \times 10^{-9}$$

Buras et al., PLB 694, 402 (2011)

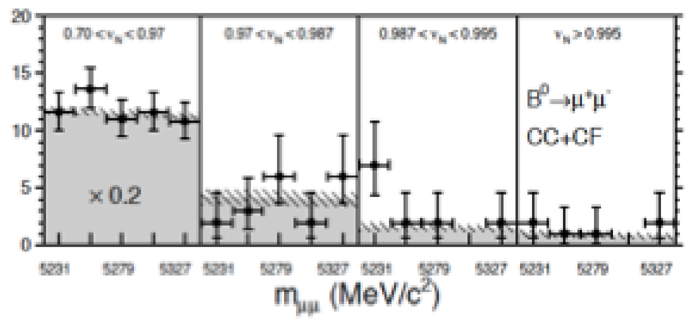


- *New Physics models*
  - *Virtual SM particles in loops could be replaced by heavy NP particles and thus significantly enhance the branching ratio*



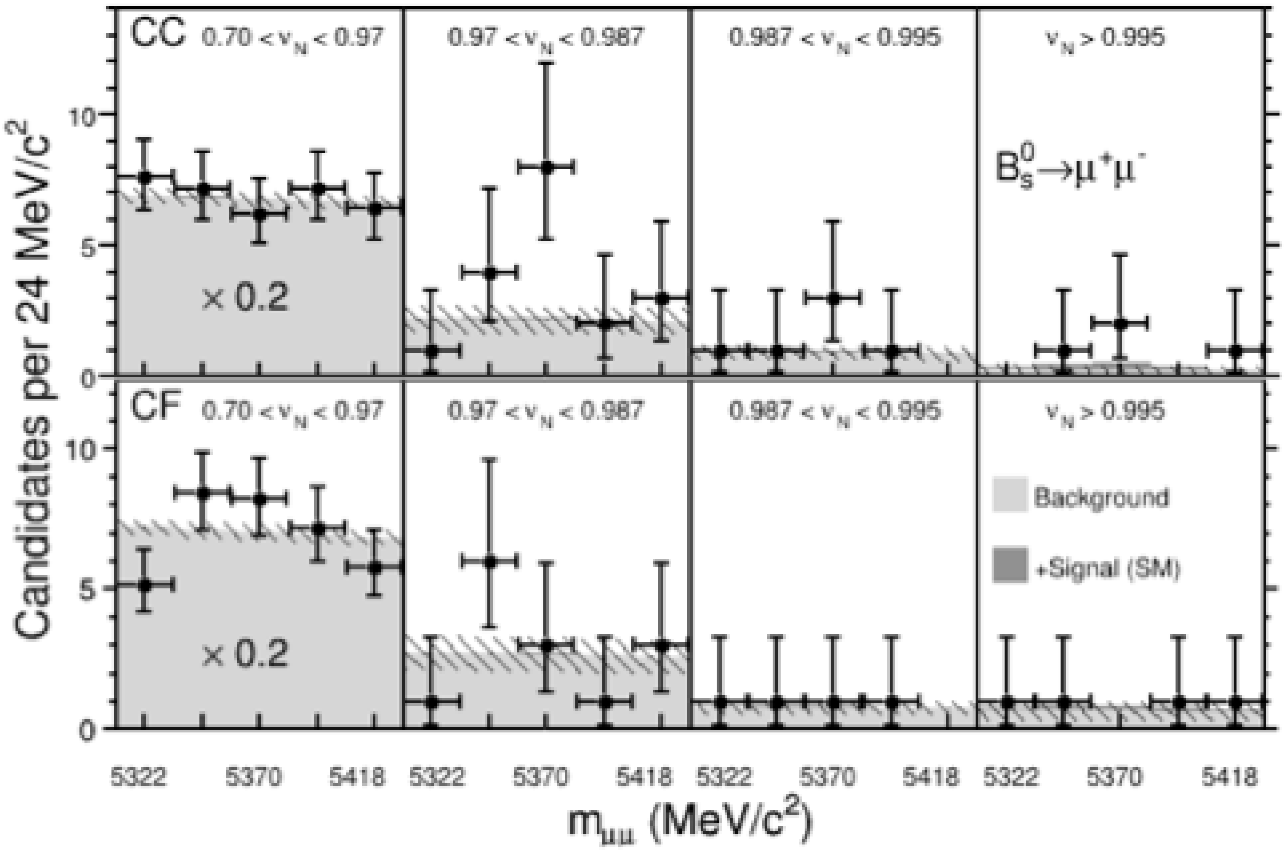
- *Search for New Physics*
  - *Due to its small and precisely calculated branching ratio $B_s \to \mu^+\mu^-$ is a very sensitive mode for NP at very high masses*
  - *Search is complementary to direct searches at the energy frontier*
- *Best published limit on $BR(B_s \to \mu^+\mu^-)$ at the end of 2011 from CDF*

$$\mathcal{B}(B_s \to \mu^+\mu^-) < 4.0 \times 10^{-8} \text{ @ 95\% CL}$$



CDF, PRL 107, 191801 (2011)

$B_s \to \mu^+\mu^-$ Signal Window



CC Central cer

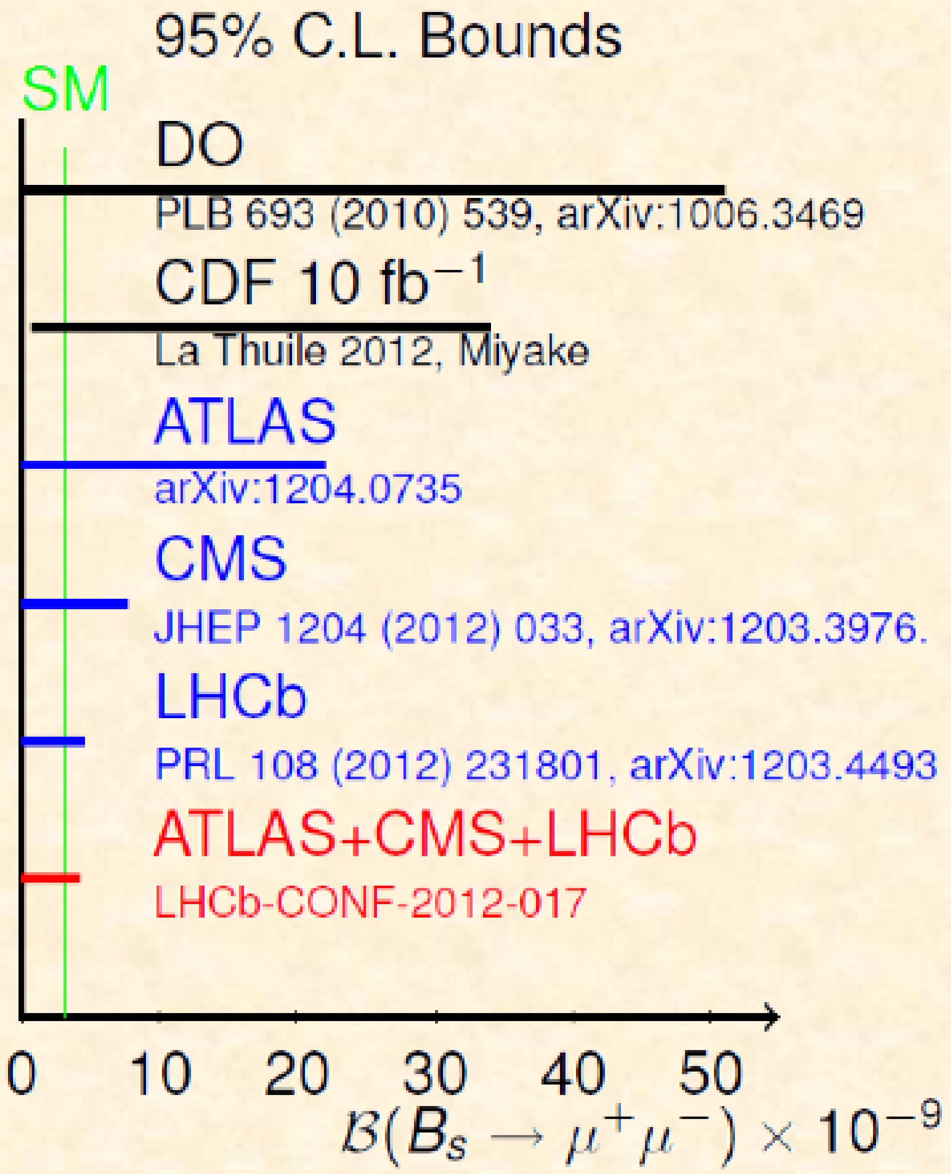
p-value = 0.94%
(bkgd only)
p-value = 7.1%
(bkgd + SM sig.)

CF Central forw

CD

Excess remains but is not reinforced with additional data.

background-only fit returns p-value greater than 2σ



LHCb-CONF-2012-017

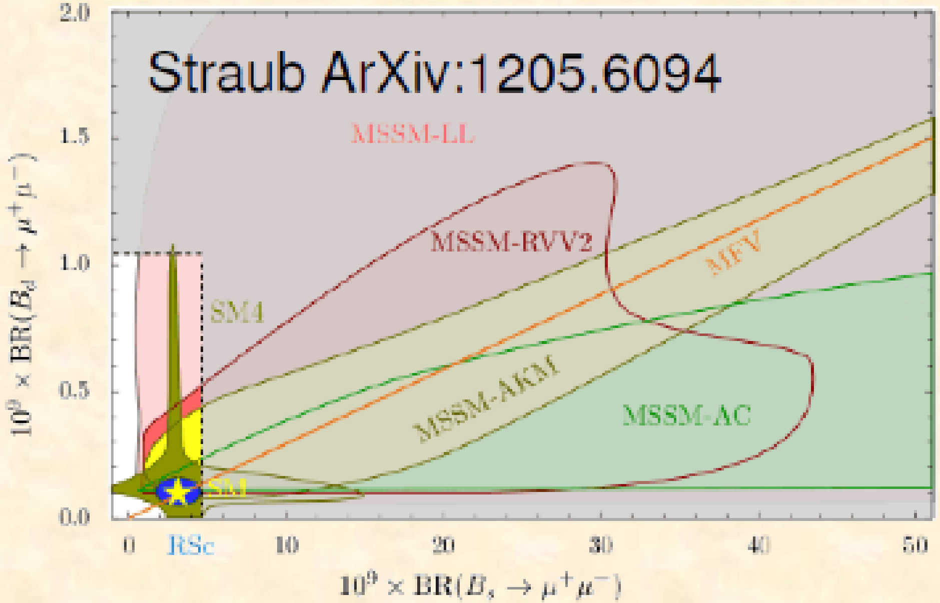
Upper Limits (95%C.L.):

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) < 4.2 \times 10^{-9}$$

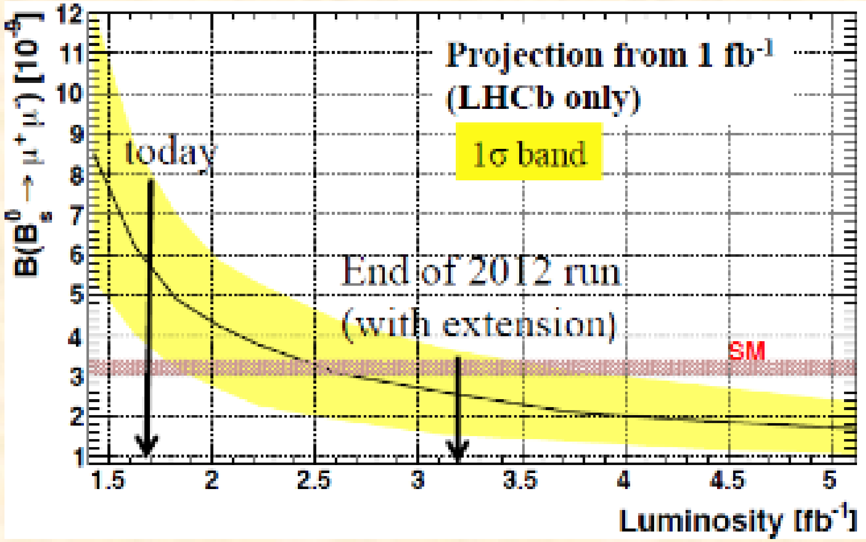
$$\mathcal{B}(B^0 \to \mu^+\mu^-) < 8.1 \times 10^{-10}$$

Preliminary limit combination

Limits on super-symmetric models



Prospects for a 3σ observation of the SM branching ratio:

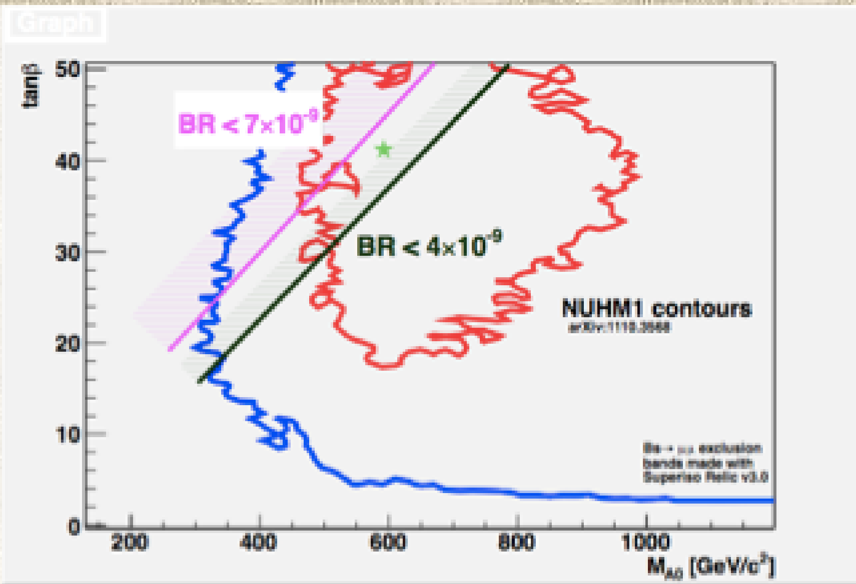


Implications of LHCb results on New Physics (I)

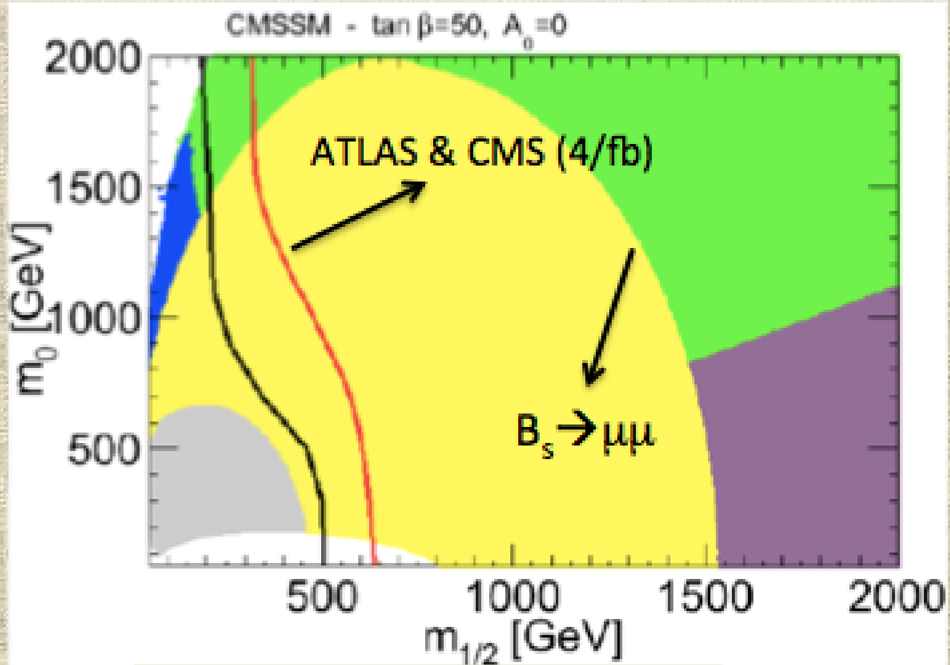
→ Hints of SM deviations of previous measurements have not been confirmed. However, more precise measurements are mandatory

- $BR(B_s \to \mu\mu)$ sets strong bounds on mass scales in SUSY (at least in high *tan* β models), complementary to direct searches in ATLAS and CMS
- LHCb results enter the SUSY and CKM fits, starting to impose severe bounds on several models and flavor variables

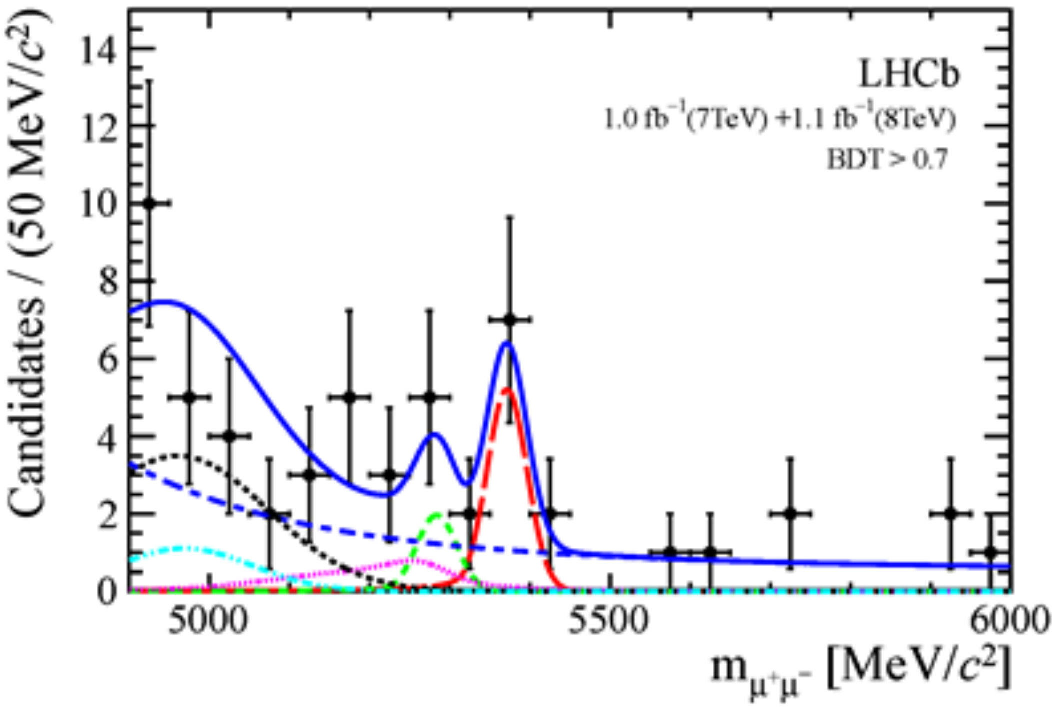
These implications will increase with the full data sample 2011-2012 (> 3/fb)



arXiv 1201.5359

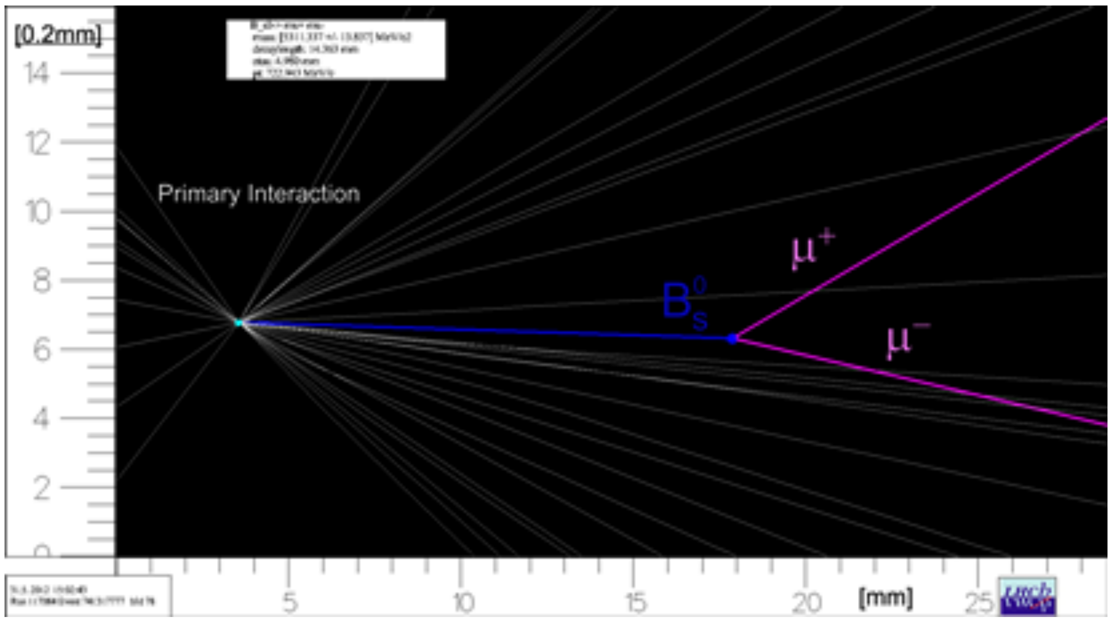


N. Mazhoudi, Moriond QCD2012



12 November:
3.5σ measurement

BR=$(3.2\ ^{+1.5}_{-1.2})10^{-9}$

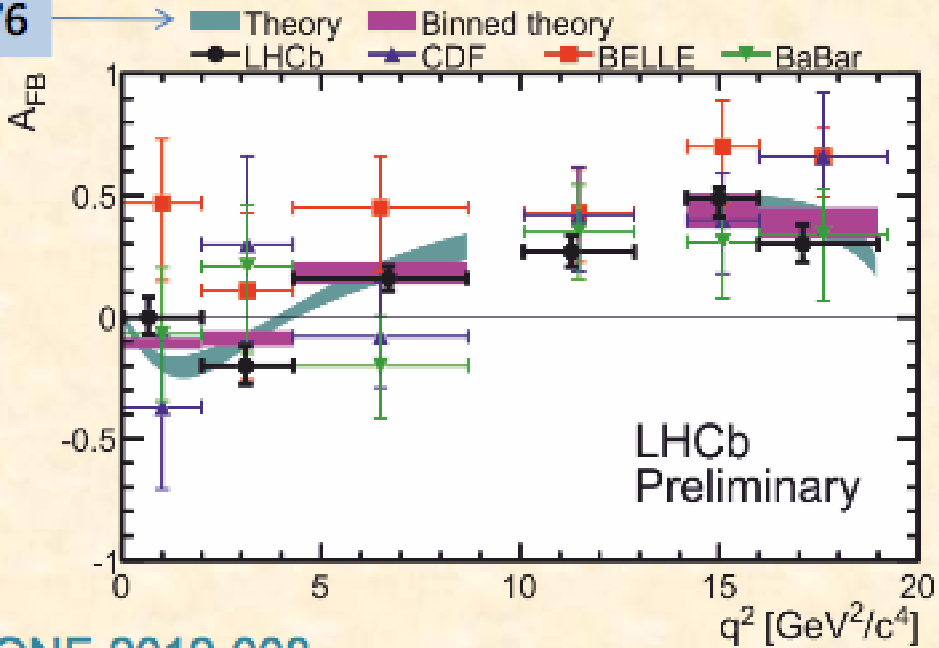


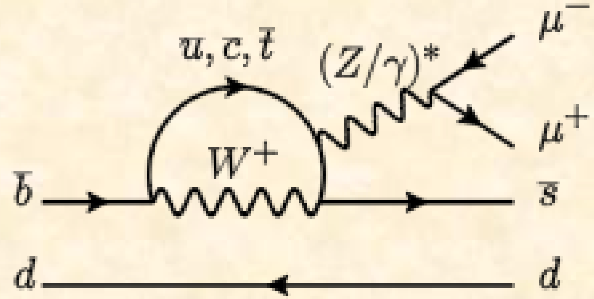
$B^0 \to K^{*0}\mu^+\mu^-$

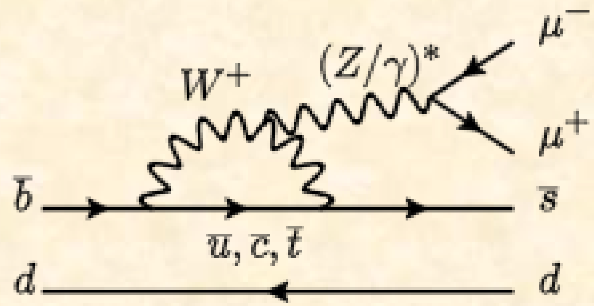
Standard model decays have FCNC through electroweak loops.
Lots of angles to measure, most are sensitive to new physics in the loops

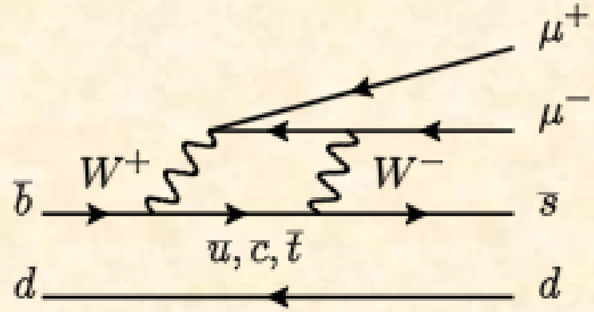
A good SM prediction for the zero point of A_{FB} for the muon system is at 4.0–4.3 GeV^2/c^4

arXiv:1105.0376



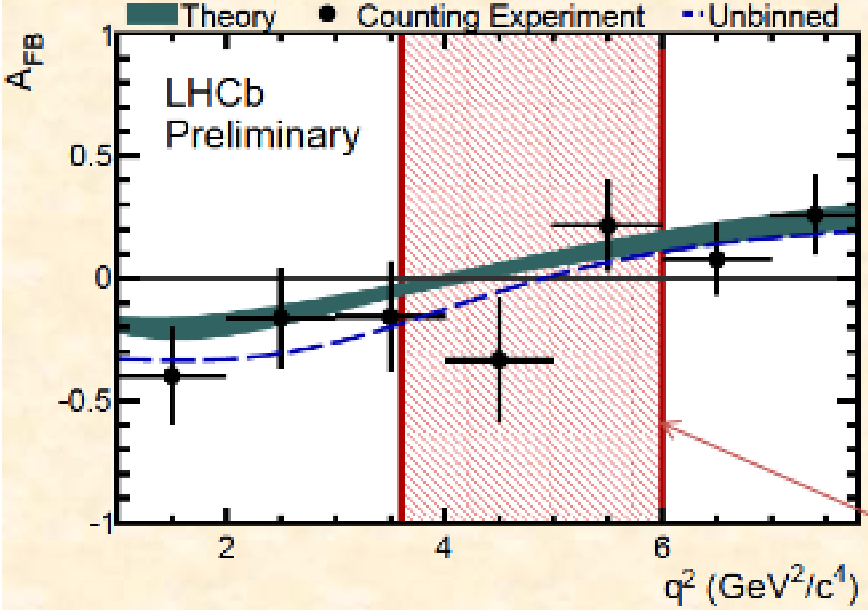






CERN-LHCb-CONF-2012-008

$B^0 \to K^{*0}\mu^+\mu^-$



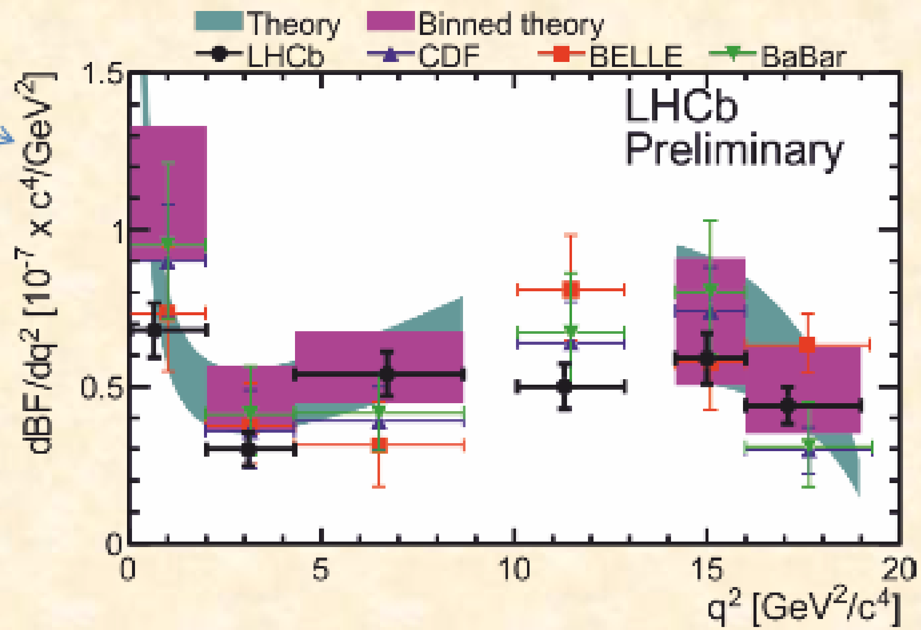
LHCb preliminary measurement is

$$q_0^2 = (4.9^{+1.1}_{-1.3})\ \mathrm{GeV}^2/\mathrm{c}^4$$

the first measurement of the crossing point

68% CL for unbinned crossing point
Error bars on points are statistical only

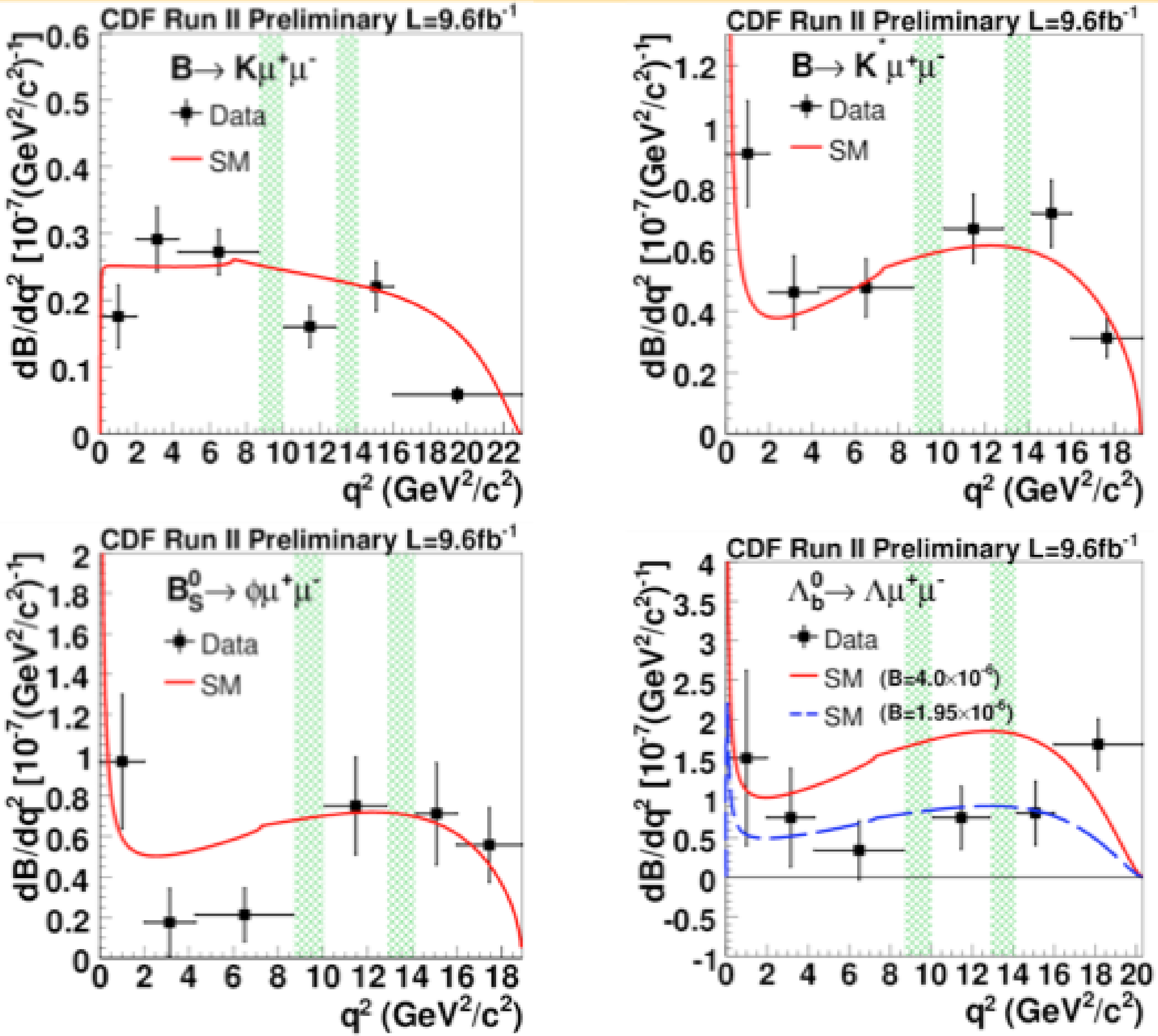
Also look at the differential branching fraction normalised to $B^0 \to K^{*0}J/\psi$



Another 3 parameters are also fitted
F_L, S_3 and S_9
Where theoretical predictions exist they are compatible with the SM

CERN-LHCb-CONF-2012-008

Differential Branching Ratios



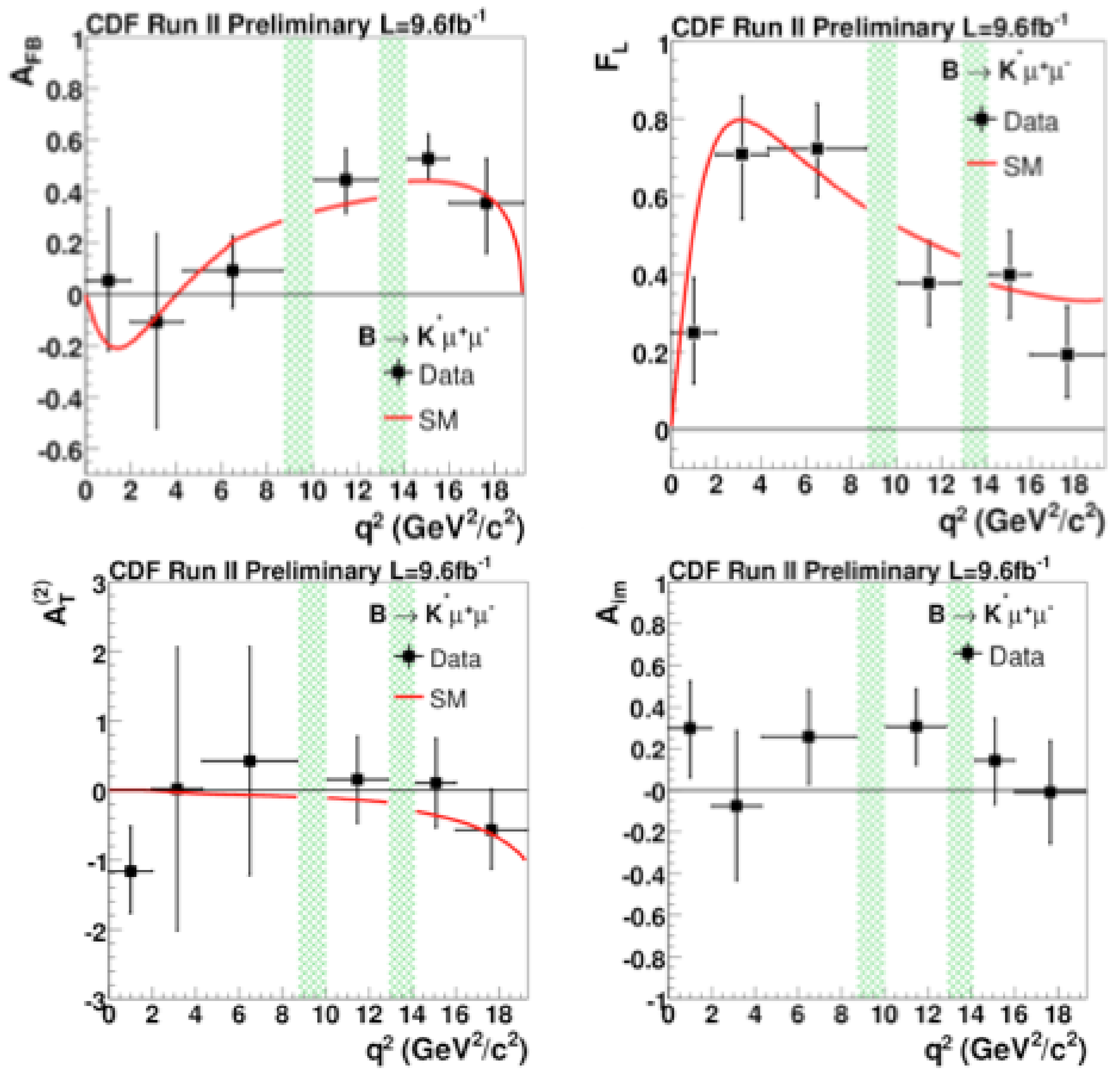
CDF

Angular fit results

Simultaneous fit with K^{*0} and K^{*+}

A_{FB}

F_L



$A_T^{(2)}$

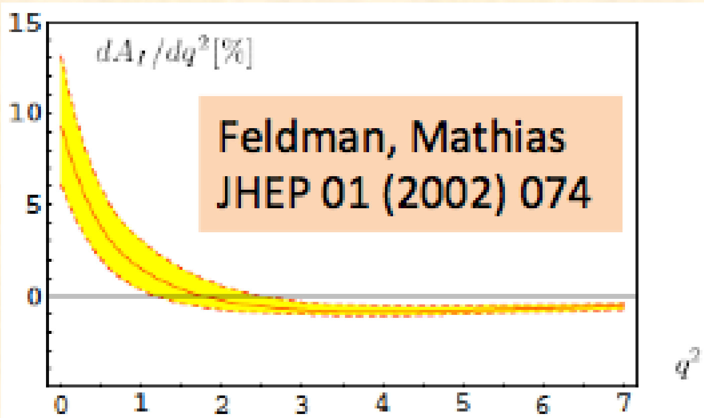
A_{im}

CDF Public Note 10894

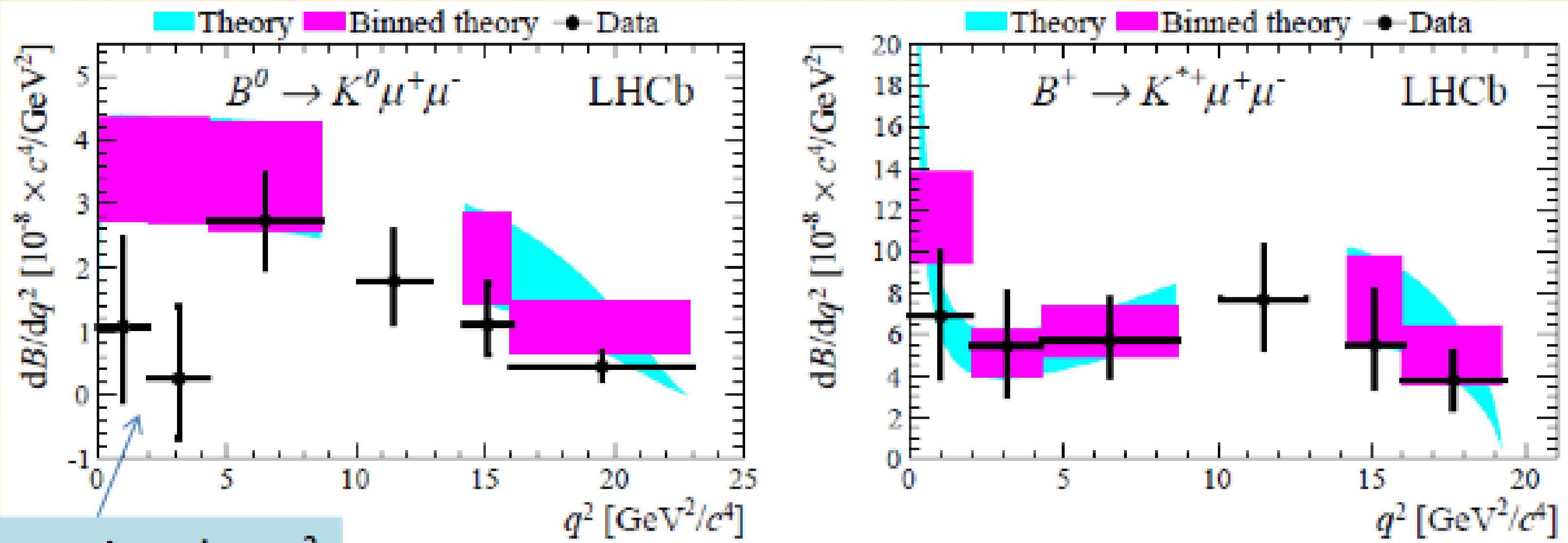
Isospin asymmetry in $B \to K^{(*)}\mu^+\mu^-$

$$A_I = \frac{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) - \left(\frac{\tau_0}{\tau_+}\right)\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}{\mathcal{B}(B^0 \to K^{(*)0}\mu^+\mu^-) + \left(\frac{\tau_0}{\tau_+}\right)\mathcal{B}(B^\pm \to K^{(*)\pm}\mu^+\mu^-)}$$

- A_I is the isospin asymmetry in the $B \to K^{(*)}\mu^+\mu^-$ system
- τ_0/τ_+ is the ratio of B^0 to B^+ lifetimes
- Expected to be O(1%) in the SM

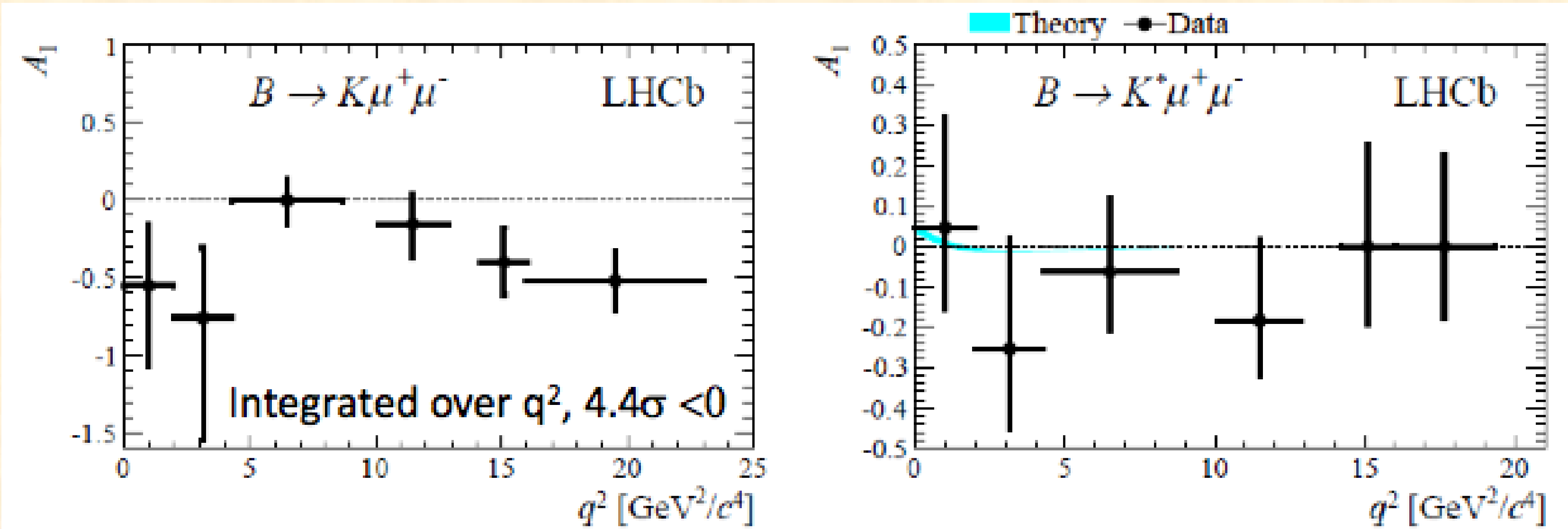


- For $B \to K^*\mu^+\mu^-$ the prediction is for positive at low q^2, dropping to small and negative as q^2 rises



Deficit seen in at low q^2

Differential Branching ratio measurements



Integrated over q^2, 4.4σ <0

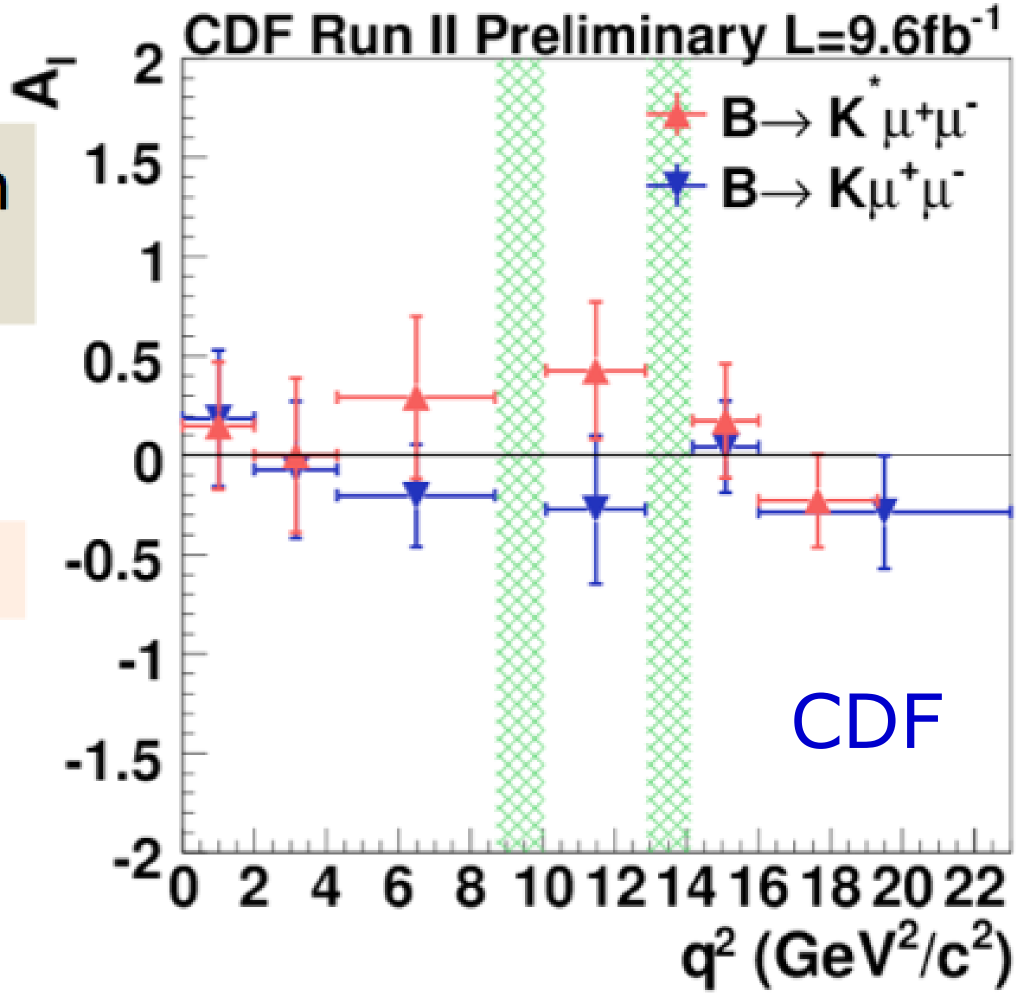
Isospin Asymmetry

LHCB-PAPER-2012-011, submitted to JHEP

Isospin Asymmetry

Difference between $K^{(*)+}$ and $K^{(*)0}$ rates

LHCb sees a 4σ effect.



“Deviations” from SM (shown at BEACH2012) are:

$A_{CP}(B^+ \to \phi K^+) = (12.8 \pm 4.4 \pm 1.3)\%$ BABAR
SM = (0 - 4.7)%

$A_Q(\tau^- \to K^0 \pi^- \nu) = (-0.45 \pm 0.24 \pm 0.11)\%$ BABAR
SM = (0.36 ± 0.01) %

$\Delta A_{CP} = A_{CP}(K^+\pi^0) - A_{CP}(K^+\pi^-) = 0.124 \pm 0.022$ HFAG (BABAR, Belle, CDF, LHCb, CLEO)
SM = 0.019 +0.058 - 0.048

$\Delta A^{CP}_{dir}(D \to hh) = (-0.678 \pm 0.147)$ HFAG (LHCb, CDF, Belle)
SM = ?

$Br(B \to \tau\nu) = (1.83^{+0.53}_{-0.49} \pm 0.24)10^{-4}$ BABAR (but not Belle)
SM = $(0.62 \pm 0.12)\ 10^{-4} - (1.18 \pm 0.16)\ 10^{-4}$

$R(D) = Br(B \to D\tau\nu)/Br(B \to Dl\nu) = (0.440 \pm 0.072)$ BABAR
SM = 0.297 ± 0.017
$R(D^*) = Br(B \to D\tau\nu)/Br(B \to Dl\nu) = (0.332 \pm 0.030)$ BABAR
SM* = 0.252 ± 0.003

Together Exclude 2DHM

$B^0 \to K^0 \mu^+ \mu^-$ deficit in isospin asymm. at low q^2 LHCb (but not CDF)
O(1%) in SM