Hadronic B_s decays

FPCP 2012

May 21st-25th, Hefei, AnHui, China

Fabrizio Ruffini
fabrizio.ruffini@pi.infn.it
INFN of Pisa & University of Siena

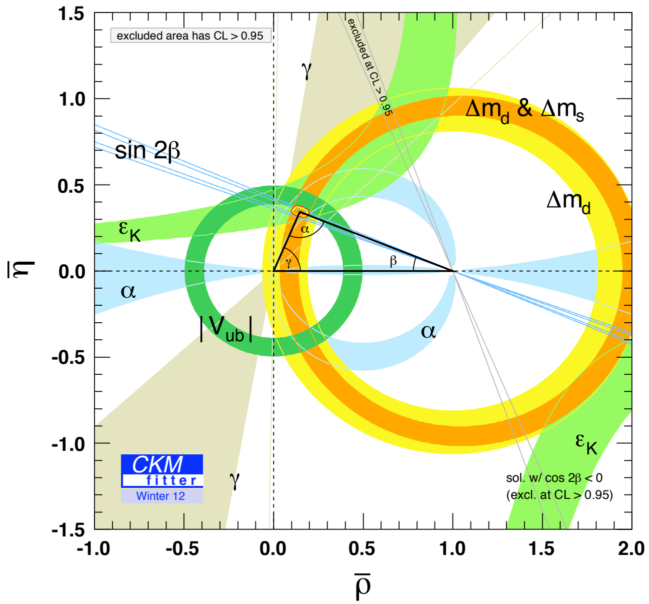
b-hadrons

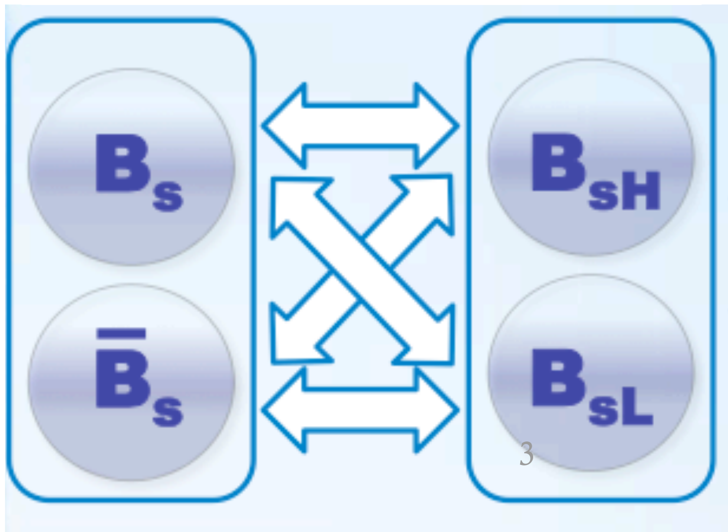
- A lot of effort in understanding the dynamics of b-hadrons done in recent years:
  - new high precision measurements allow to properly test the SM and hadronic calculations reliability;
  - new physics effects can be hiding in less studied processes.

- Unique opportunity represented by B_s mesons
  - Less studied (and known) wrt to B^+ and B^0
  - Large production at hadronic machines.
  - With current statistics, high precision measurements achievable.

B_s opportunities

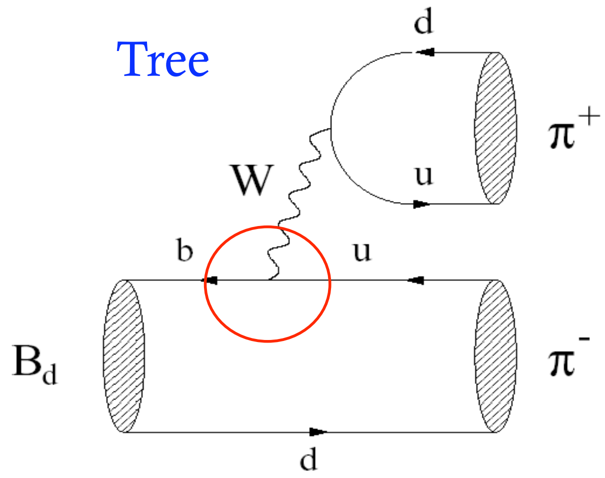
- Measure the less known CKM angle γ
- Search NP:
  - penguin diagrams decays
  - B_s mixing observables
- CP violating effects
  - (more on Liming Zhang talk)
- Today: just a subset of many interesting results

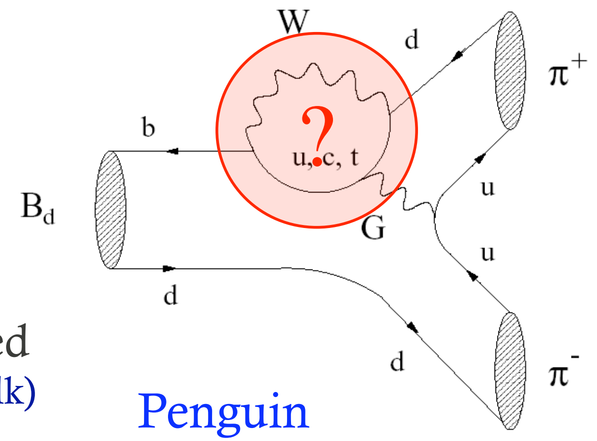




B→hh' decays

- B^0, B^0_s, and Λ^0_b decays into π, K or p.
- Amplitudes:
  - Tree
  - Penguin (strong and electroweak)
- Many open channels in similar final states: constrain hadronic unknowns
- Contributions of new particles may enter in penguin diagrams (→NP)
- Sensitive to V_{ub} phase, CKM angle γ
- Current status:
  - BR(B^0→Kπ, ππ) and BR(B_s→Kπ, KK) well established at e^+e^- and hadron machines (more on Irina Nasteva's talk)
  - Today: Focus on B_s→ππ and B^0→KK decays



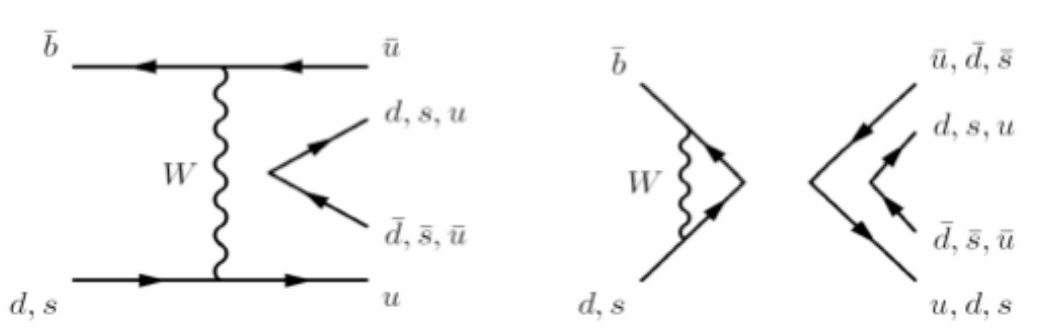


Focus on annihilation decays

- All final-state quarks different from initial state quarks ⇒only via annihilation-type diagrams.

- Small BR, with large uncertainties.
  - Depends on hard-to-predict hadronic parameters ⇒large source of uncertainty in calculations.

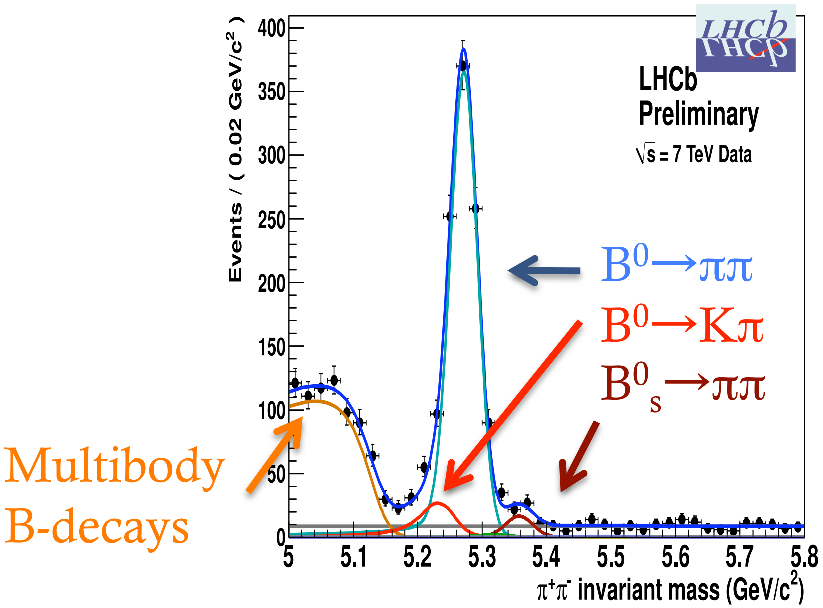
- Current status:
  - $B^0_s \to \pi^+\pi^-$ first evidence at CDF, then observed by LHCb.
  - $B^0 \to K^+K^-$ still unobserved

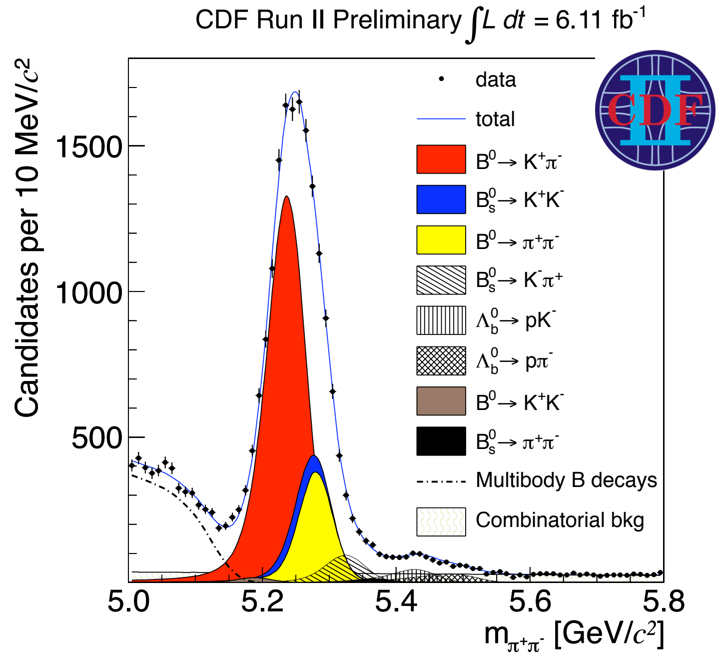


Challenge

Disentangle different decay modes overlapping into a single peak. In this conditions, every mode is a background for the others.

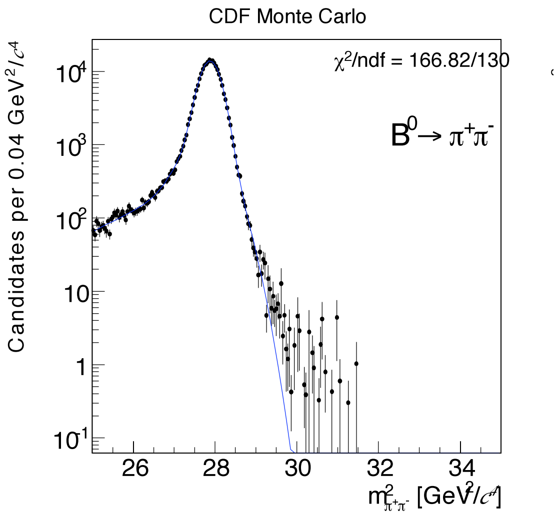
Signal composition exploiting kinematics and PID info

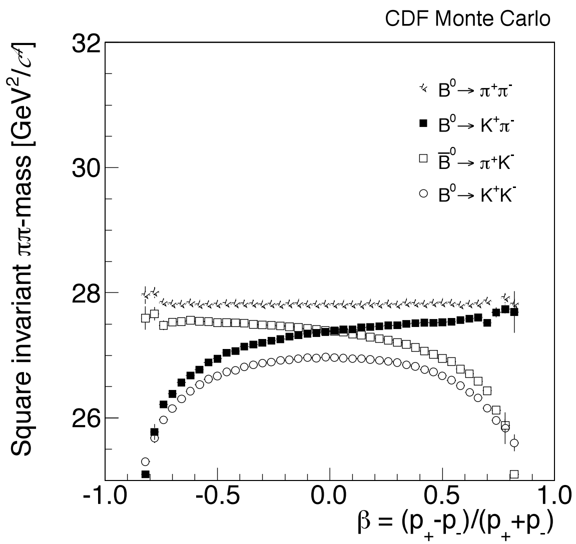


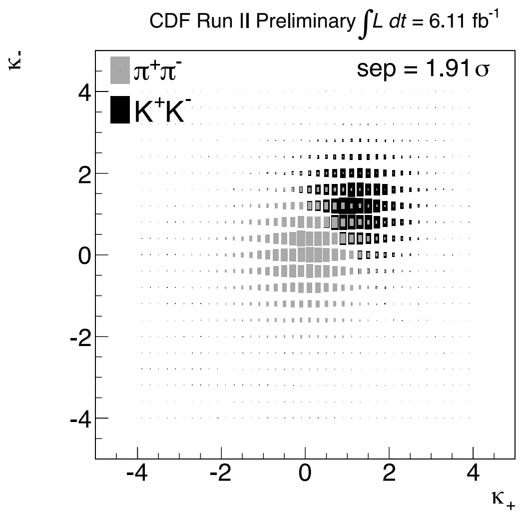


CDF separating signals: 5D ML fit

Signal composition from 5-dim ML fit, combining information from kinematics (mass and momenta) and particle ID (kaonness k, summarizing dE/dx info).

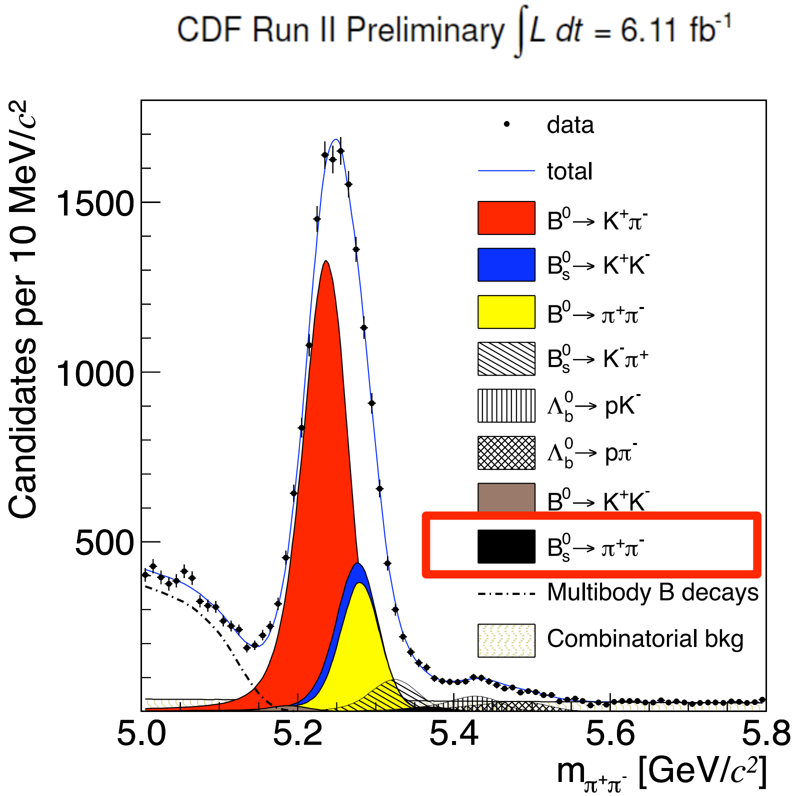


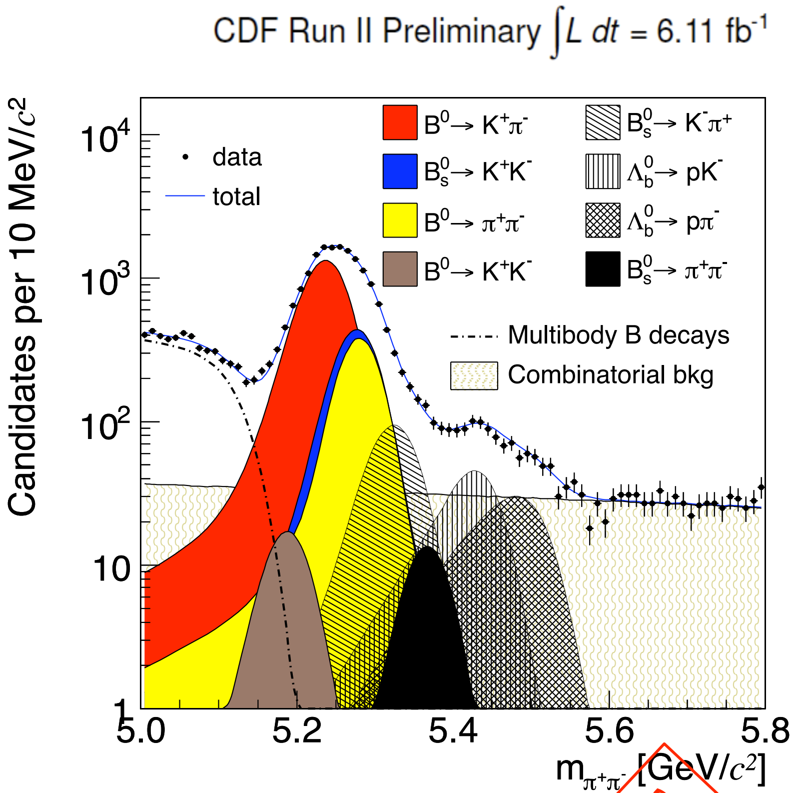




$k_{+(-)}$ kaonness of positive(negative) particle.
By construction, k=0 for pions and 1 for kaons,

CDF First evidence: $B^0_s \rightarrow \pi^+\pi^-$





arXiv:1111.0485 accepted by PRL

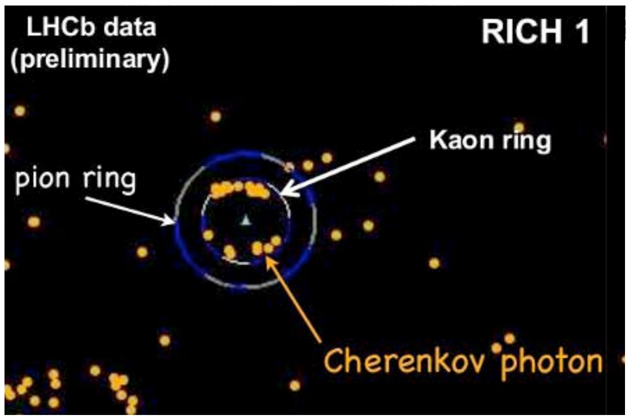
$$\mathcal{B}(B^0 \rightarrow K^+K^-) = (0.23 \pm 0.10\ (stat.) \pm 0.10\ (syst.)) \times 10^{-6}$$

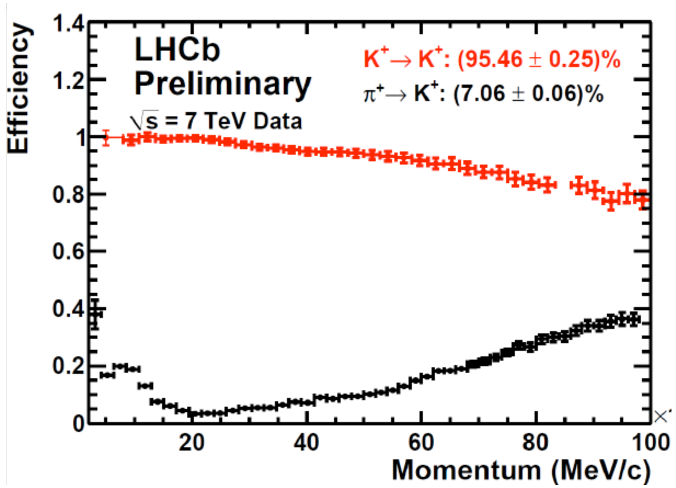
$$\mathcal{B}(B^0_s \rightarrow \pi^+\pi^-) = (0.57 \pm 0.15\ (stat.) \pm 0.10\ (syst.)) \times 10^{-6}.$$

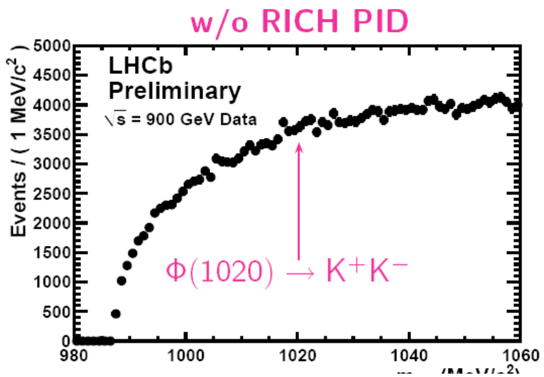
First evidence (3.7 σ) of a pure-annihilation charmless B decay.

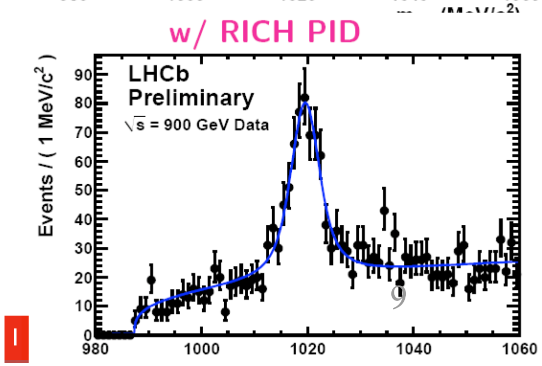
LHCb separating signals: PID info → ML mass fit

- LHCb RICH detectors allow an excellent Particle ID
  - Good π/K separation
  - Performance close to simulation for all momenta



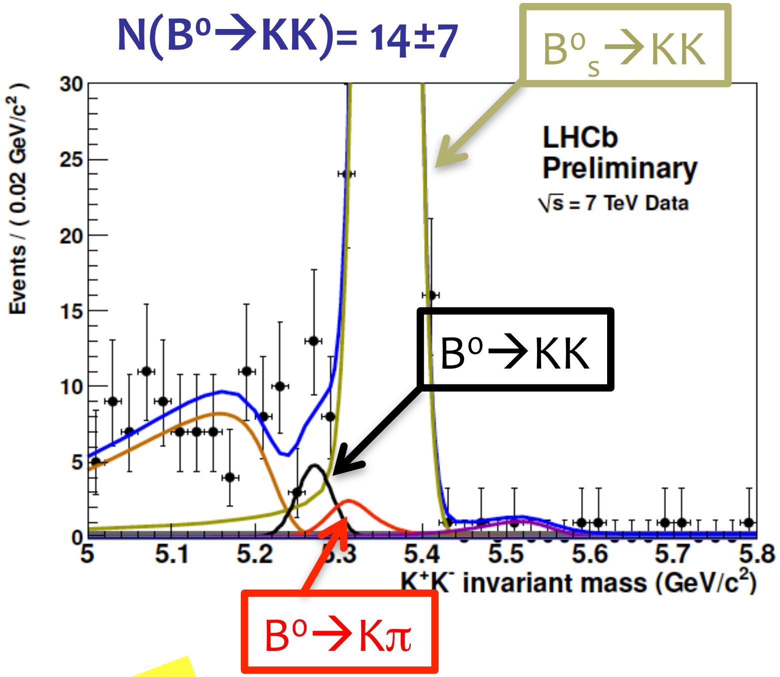




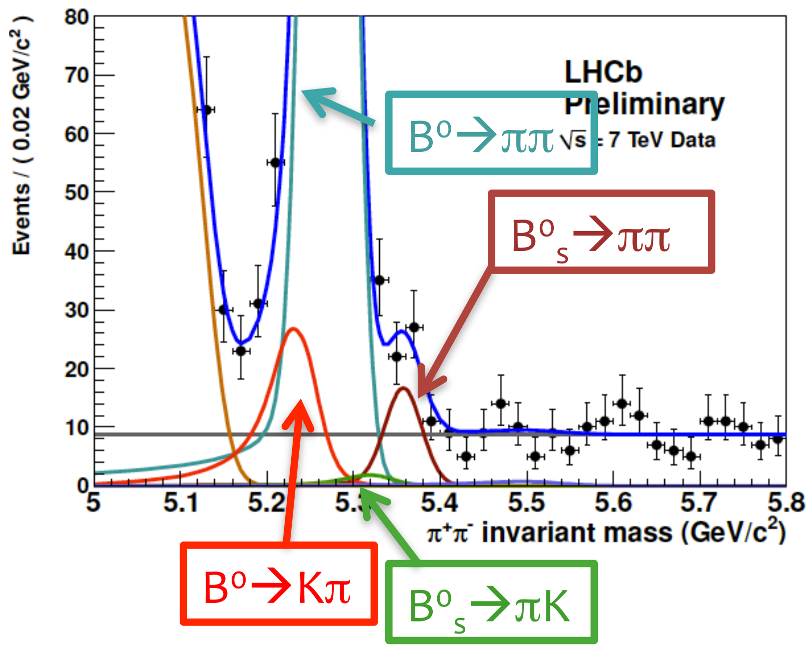


LHCb first observation: $B^0_s \to \pi^+\pi^-$

N($B^0 \to KK$)= 14±7



N($B_s \to \pi\pi$)= 47±10



Preliminary

PoS(EPS-HEP2011)143

2011 data L=320 pb^{-1}

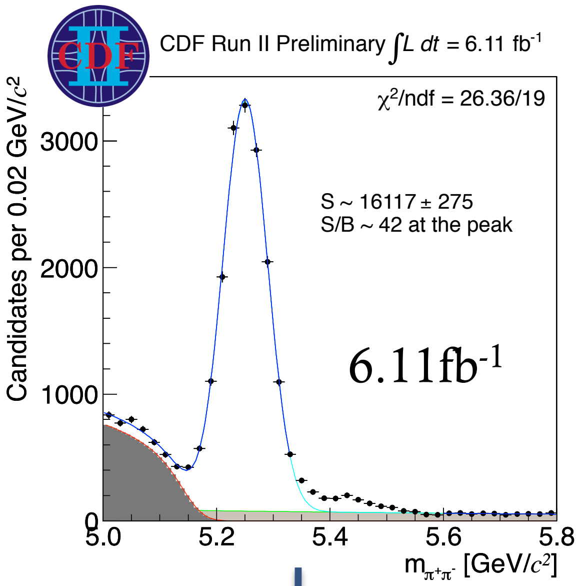
$$\mathcal{BR}(B^0 \to K^+K^-) = (0.13^{+0.06}_{-0.05}(\text{stat}) \pm 0.07(\text{syst})) \times 10^{-6}$$

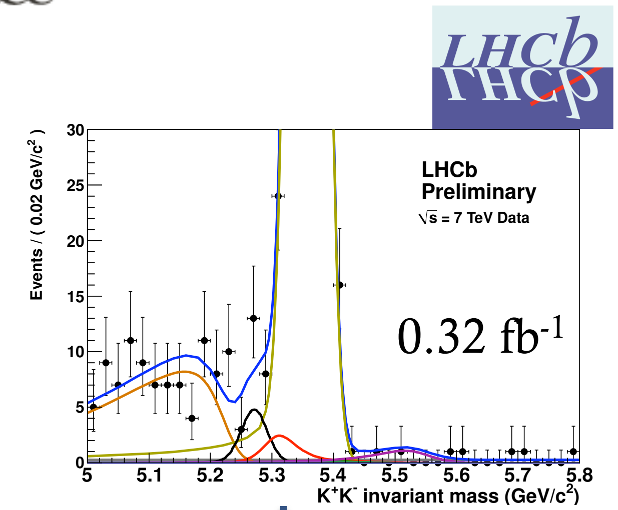
$$\mathcal{BR}(B^0_s \to \pi^+\pi^-) = (0.98^{+0.23}_{-0.19}(\text{stat}) \pm 0.11(\text{syst})) \times 10^{-6}$$

first observation of $B^0_s \to \pi\pi$ with a significance of 5.3 σ

acknowledgements: prof A. Carbone

More coming…

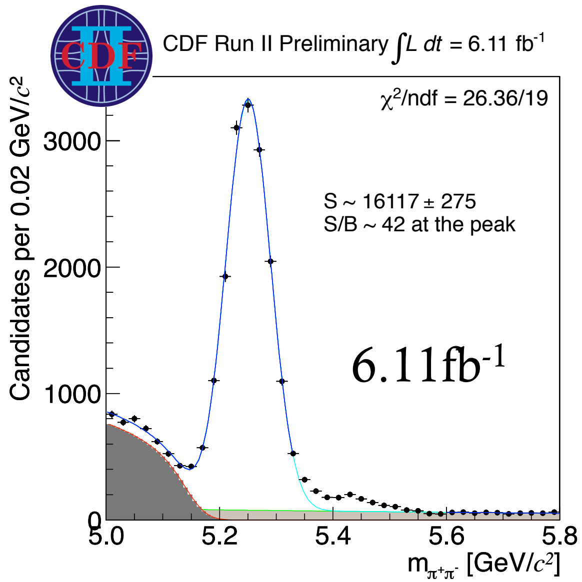


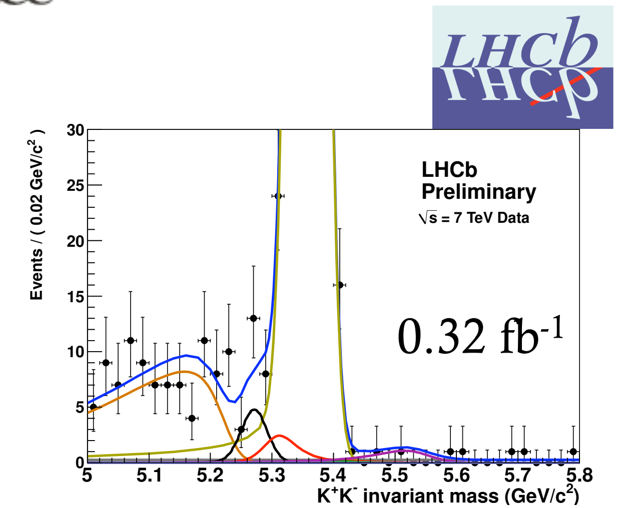


? $10\ fb^{-1}$

? $1\ fb^{-1}$

More coming…





Updates of A_{CP} measurements:

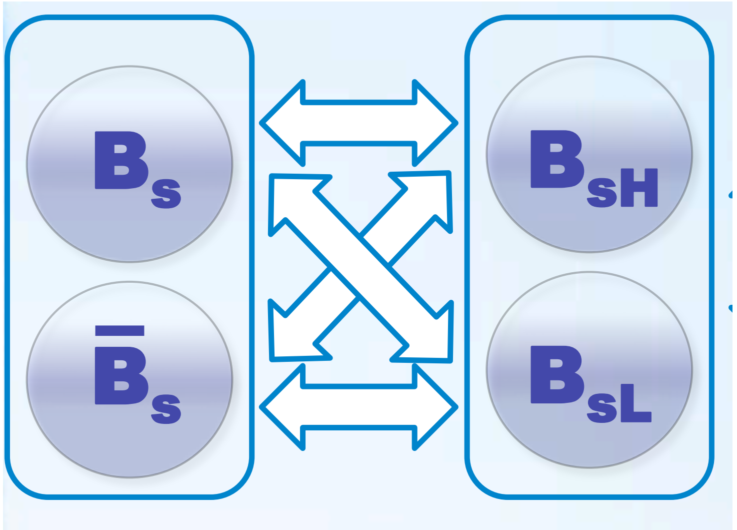
- $B^0 \to K\pi$
- $B_s \to \pi K$
- $\Lambda_b^0 \to p\pi$
- $\Lambda_b^0 \to pK$

Updates of BR measurements:

- $B^0_{(s)} \to hh'$ (where $h = \pi$ or K)
  - in particular BR($B^0 \to KK$)
- BR($\Lambda_b^0 \to ph$)

Analyses with full data sample in progress!

B_s mixing: observables



B_s^L, B_s^H mass eigenstates.

In absence of CP violation, the light (heavy) eigenstate is the CP-even (CP-odd) eigenstate.

Mass difference $\Delta m_s = m^H - m^L \sim 2|M_{12}|$
Width difference $\Delta\Gamma_s = \Gamma^L - \Gamma^H \sim 2|\Gamma_{12}|\cos\phi_s$

CPV phase
$\phi_s = \arg(-M_{12}/\Gamma_{12})$

Two principal ways to access $\Delta\Gamma_s$.

$\Gamma_s = (\Gamma^L + \Gamma^H)/2$

- Directly measuring the lifetime of B_s decays.
  - For example using $B_s \to J/\psi\ f_0(980)$ decays
- Measuring the partial decay widths of B_s to CP odd (or even) eigenstates.
  - For example using $B_s \to D_s(^*)^+ D_s(^*)^-$

$\Delta\Gamma_s/\Gamma_s$ measurements

With constraint on effective lifetime meas.

- Current experimental status (HFAG 2012): given mainly by:
  - τ ($B_s \rightarrow J/\psi\ f_0$)
  - $B_s \rightarrow J/\psi\ \phi$ measurements
  - τ ($B_s \rightarrow KK$) (more on Liming Zhang talk)

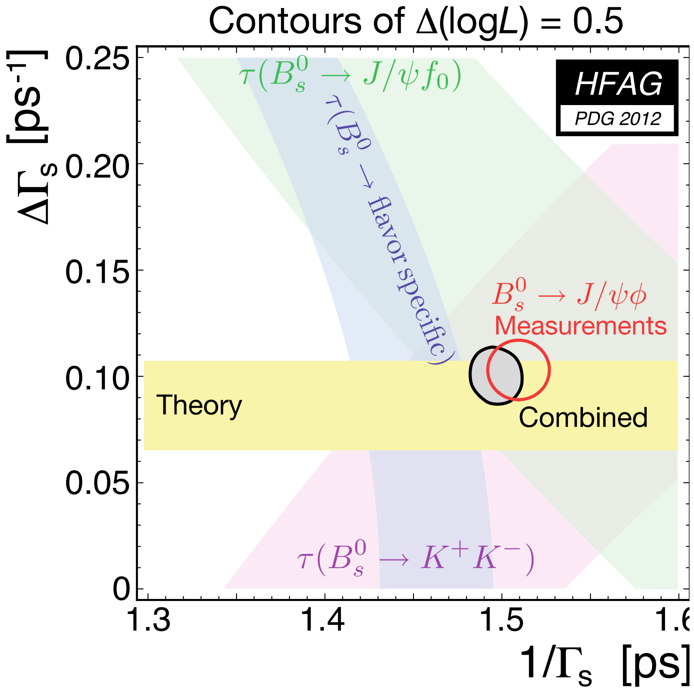
$$\Delta\Gamma_s / \Gamma_s = 0.150 \pm 0.02$$

$$\Delta\Gamma_s = 0.100 \pm 0.013 (ps^{-1})$$

- Theory (not involving NP in B_s mixing) predicts

$$\Delta\Gamma_s = 0.087 \pm 0.021 ps^{-1}$$

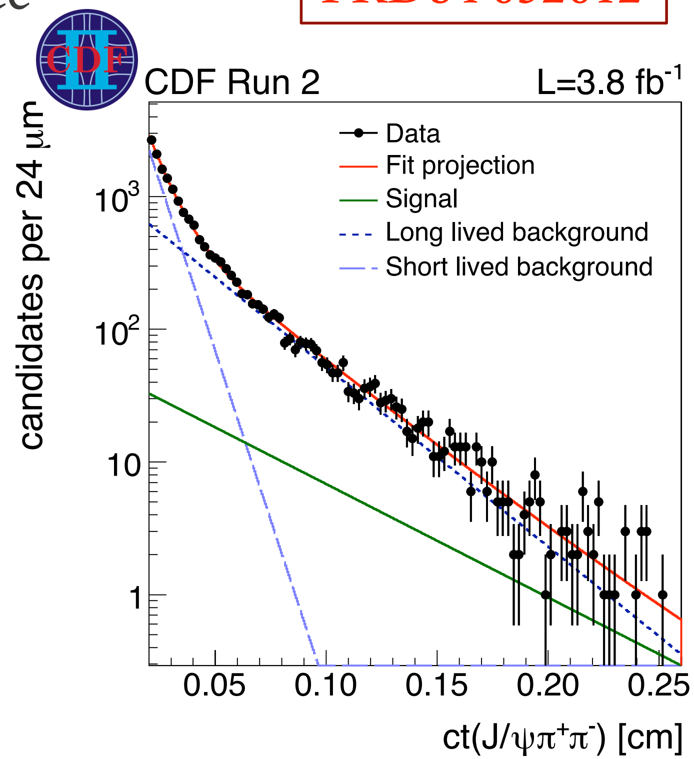
A. Lenz, arXiv:1102.4274 [hep-ph]



$B_s \rightarrow J/\psi\ f_0(980)$ lifetime

- $J/\psi\ f_0(980)$ is a purely CP odd final state.
  - Measurements of B_H lifetime (in absence of CPV).
- Analysis strategy: simultaneous fit to mass decay time and decay time error.
- Measure:
  - $\tau(B_s \rightarrow J/\psi\ f_0(980)) = 1.70^{-0.11}_{+0.12}$ (stat) ± 0.03 (syst) ps
- Direct measurement of B_s lifetime
  - Compares well with predictions and indirect measurements

PRD84 052012



$B_s \to J/\psi\phi$ results

Data finally reached the precision needed to test predictions.

D0 (constraining strong phases from $B^0 \to J/\psi K^*$

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

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

CDF

$\Delta\Gamma_s = 0.068 \pm 0.026(stat.) \pm 0.007(syst.)\ ps^{-1}$

ϕ_s in [-0.60, 0.12] rad @ 68% C.L.

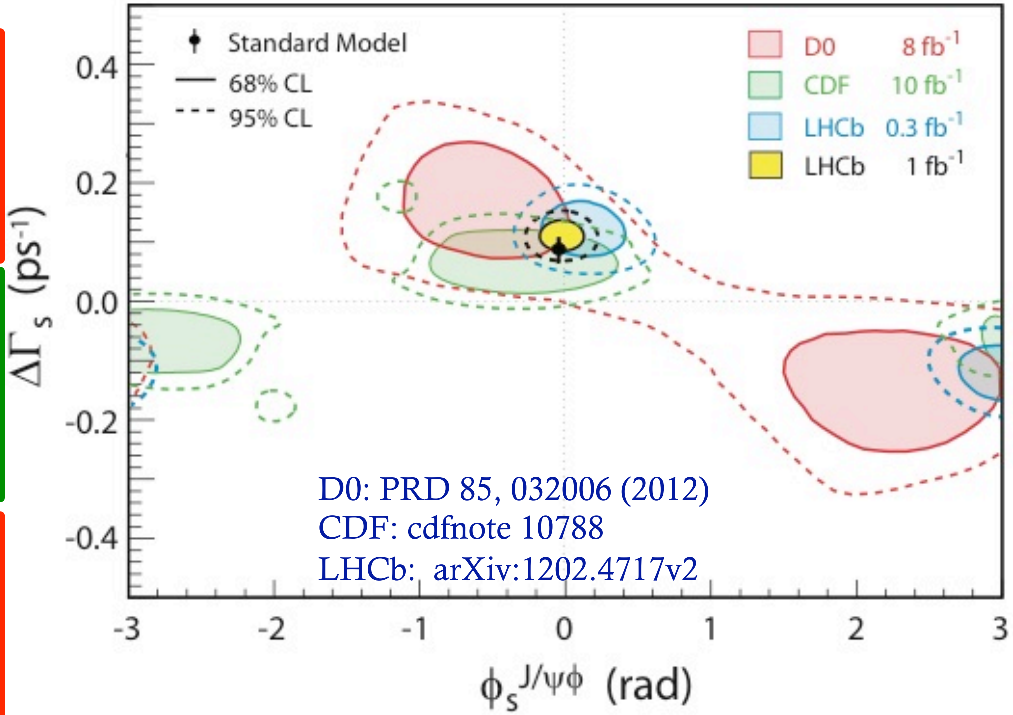
LHCb

$\Gamma_s = 0.6580 \pm 0.0054(stat.) \pm 0.0066(syst.)\ ps^{-1}$

$\Delta\Gamma_s = 0.116 \pm 0.018(stat.) \pm 0.006(syst.)\ ps^{-1}$

$\phi_s = -0.001 \pm 0.101(stat.) \pm 0.027(syst.)$ rad.

(combined with **$J/\psi\pi\pi$ channel** $\phi_s = -0.002 \pm 0.083(stat.) \pm 0.027(syst.)$ rad.)



Assuming SM CP-violation, SM predicts

$$\Delta\Gamma_s = 0.087 \pm 0.021 ps^{-1}$$

A. Lenz, arXiv:1102.4274 [hep-ph]

More on the analyses on Yuehong Xie talk

$BR(B_s \rightarrow D_s(*)^+ D_s(*)^-)$

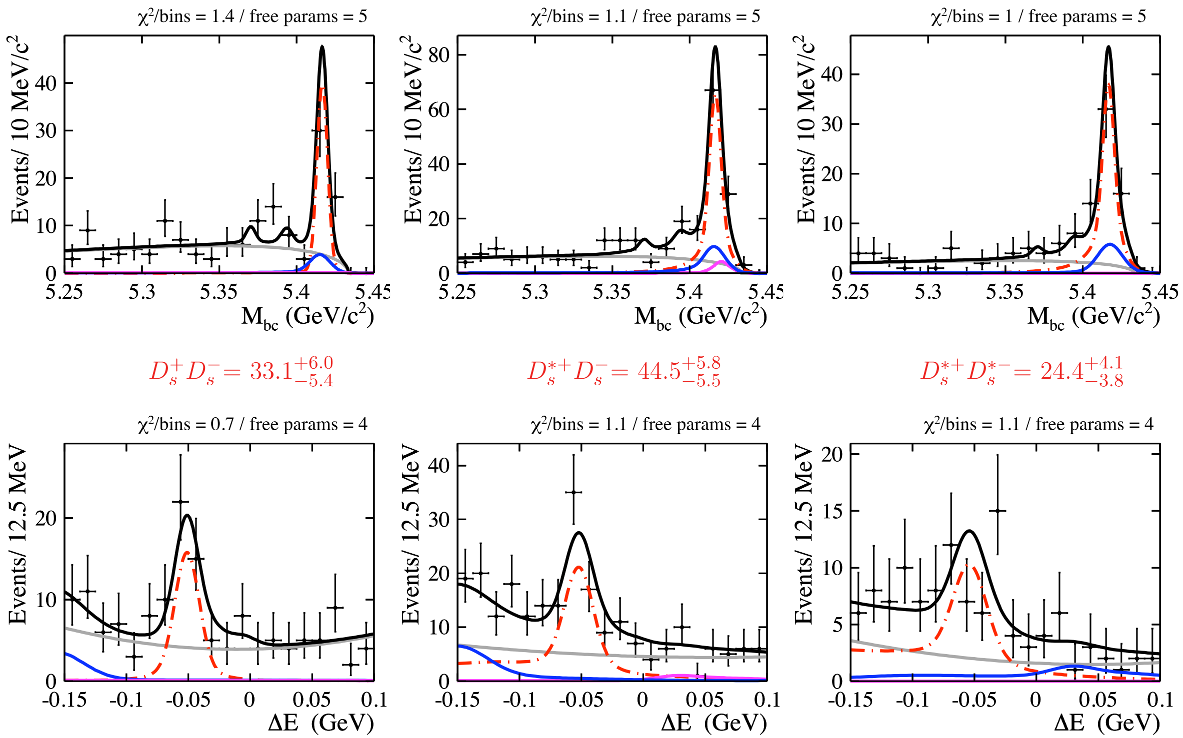
- If $B_s \rightarrow D_s(*)^+ D_s(*)^-$ approximated as CP-even, there are theoretical motivations within SM [Aleksan, Phys. Lett B, 316, 567, 1993; Shifman, Sov. J. Nucl. Phys, 47:511, 1988] to believe that it gives dominant contribution to B_s width difference, resulting in the relation:

$$2BR(B_s^0 \rightarrow D_s^{(*)+} D_s^{(*)-}) \approx \frac{\Delta\Gamma_s}{\Gamma_s + \Delta\Gamma_s/2} eq(1)$$

- Complementary approach to measure $\Delta\Gamma_s$ to $B_s \rightarrow J/\psi\ \phi$ analysis

121fb^{-1}

BR($B_s \to D_s(*)^+ D_s(*)^-$):analysis



- Strategy: Simultaneous 2D ML fit to ΔE and mass of the three modes
- From DPF2011 (121fb^{-1}):

$$\Delta\Gamma_s / \Gamma_s = (9.0 \pm 0.9 \pm 2.2)\%$$

– $\mathcal{B}(B_s \to D_s^+ D_s^-) = (0.6 \pm 0.1 \pm 0.1)\%$

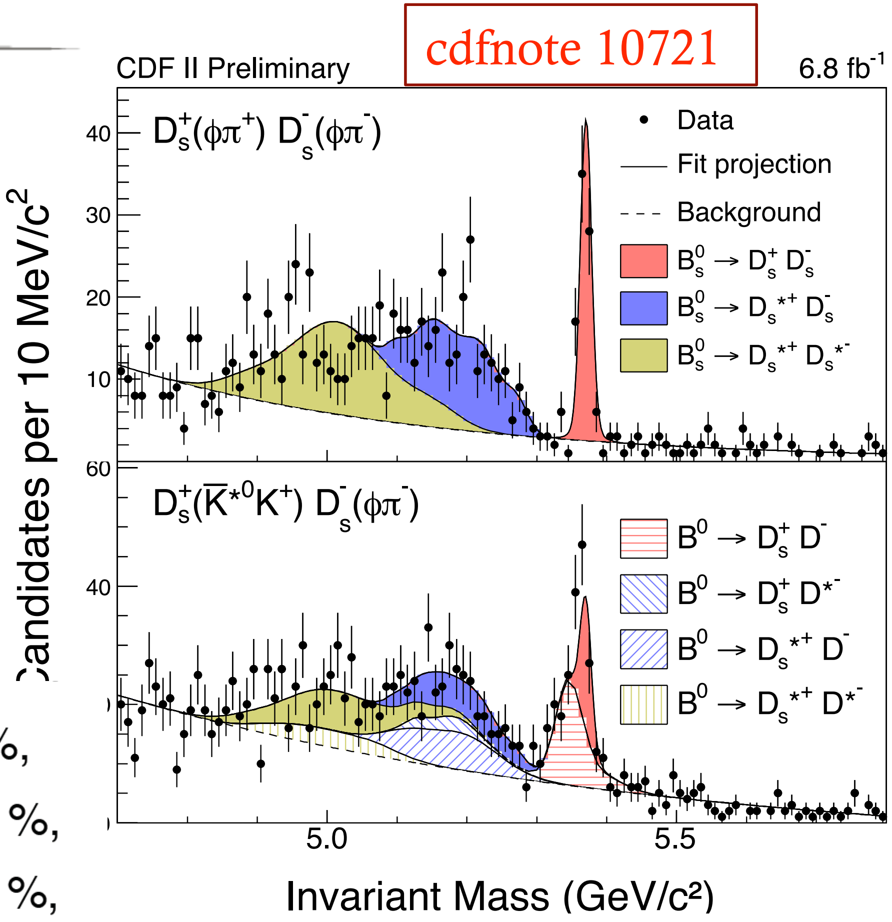
– $\mathcal{B}(B_s \to D_s^{*\pm} D_s^{*\mp}) = (1.8 \pm 0.2 \pm 0.40)\%$

– $\mathcal{B}(B_s \to D_s^{*+} D_s^{*-}) = (1.98 \pm 0.3 \pm 0.5)\%$ (First observation)

BR($B_s \to D_s(*)^+ D_s(*)^-$): analysis

- Fit the fraction of the final states from $D_s^+ D_s^-$ mass distribution.
- BR normalized using control sample $B^0 \to D_s^+ D^-$
- World's best BR measurements:

$$BR(B_s \to D_s^+ D_s^-) = (0.49 \pm 0.06 \pm 0.05 \pm 0.08)\ \%,$$
$$BR(B_s \to D_s^{*\pm} D_s^{\mp}) = (1.13 \pm 0.12 \pm 0.09 \pm 0.19)\ \%,$$
$$BR(B_s \to D_s^{*+} D_s^{*-}) = (1.75 \pm 0.19 \pm 0.17 \pm 0.29)\ \%,$$
$$BR(B_s \to D_s^{(*)+} D_s^{(*)-}) = (3.38 \pm 0.25 \pm 0.30 \pm 0.56)\ \%,$$



Assuming eq(1) of the prev slide, this translates into a decay width difference contribution of $B_s \to D_s(*)^+ D_s(*)^-$ of $\Delta\Gamma_s / \Gamma_s = (6.99 \pm 0.54 \pm 0.64 \pm 1.20)\%$

Other interesting measurements

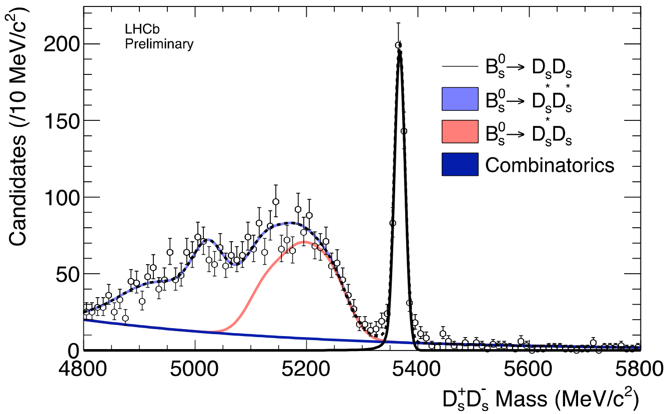
$B_s \rightarrow DD'$ decays

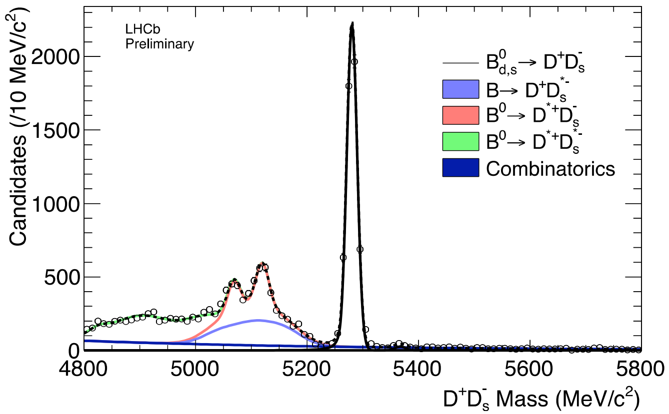
- Interesting avenue to look for BSM effects.
  From $B_s \rightarrow D_s^- D_s^+$
  - ϕ_s
  - Weak phase γ (assuming U-spin symmetry)

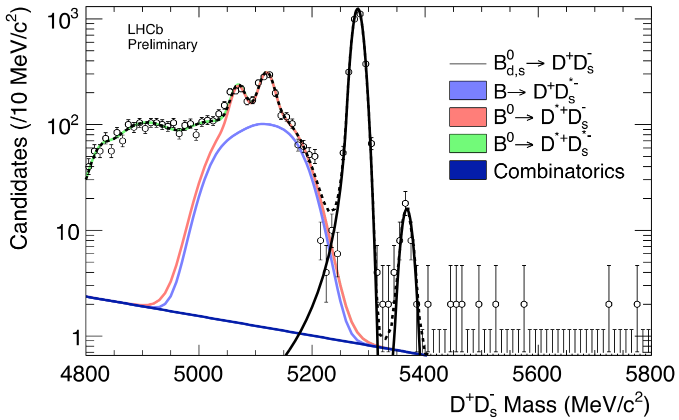
- Analysis strategy:
  - multivariate selection of $D \rightarrow (hh,hhh)$ trained on $B \rightarrow D\pi$ on data;
  - cross feed between D^+ and D_s^+ suppressed using kinematics and PID info;
  - efficiencies from independent $B \rightarrow D\pi$ sample.

1fb^{-1}

$B_s \to DD'$ results (preliminary)







Preliminary

LHCb conf 2012-009

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D^+D^-)}{\mathcal{B}(\overline{B}^0 \to D^+D^-)} = 1.00 \pm 0.18(\mathrm{stat}) \pm 0.09(\mathrm{syst}),$$

← First obs.

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+D^-)}{\mathcal{B}(B^0 \to D_s^+D^-)} = 0.048 \pm 0.008(\mathrm{stat}) \pm 0.004(\mathrm{syst}),$$

← First obs.

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D_s^+D_s^-)}{\mathcal{B}(\overline{B}^0 \to D^+D_s^-)} = 0.508 \pm 0.026(\mathrm{stat}) \pm 0.043(\mathrm{syst}),$$

← To be compared (actually 5 times more precise) with cdf result.

$$\frac{\mathcal{B}(\overline{B}_s^0 \to D^0\overline{D}^0)}{\mathcal{B}(B^- \to D^0D_s^-)} = 0.015 \pm 0.004(\mathrm{stat}) \pm 0.002(\mathrm{syst}).$$

← First obs.

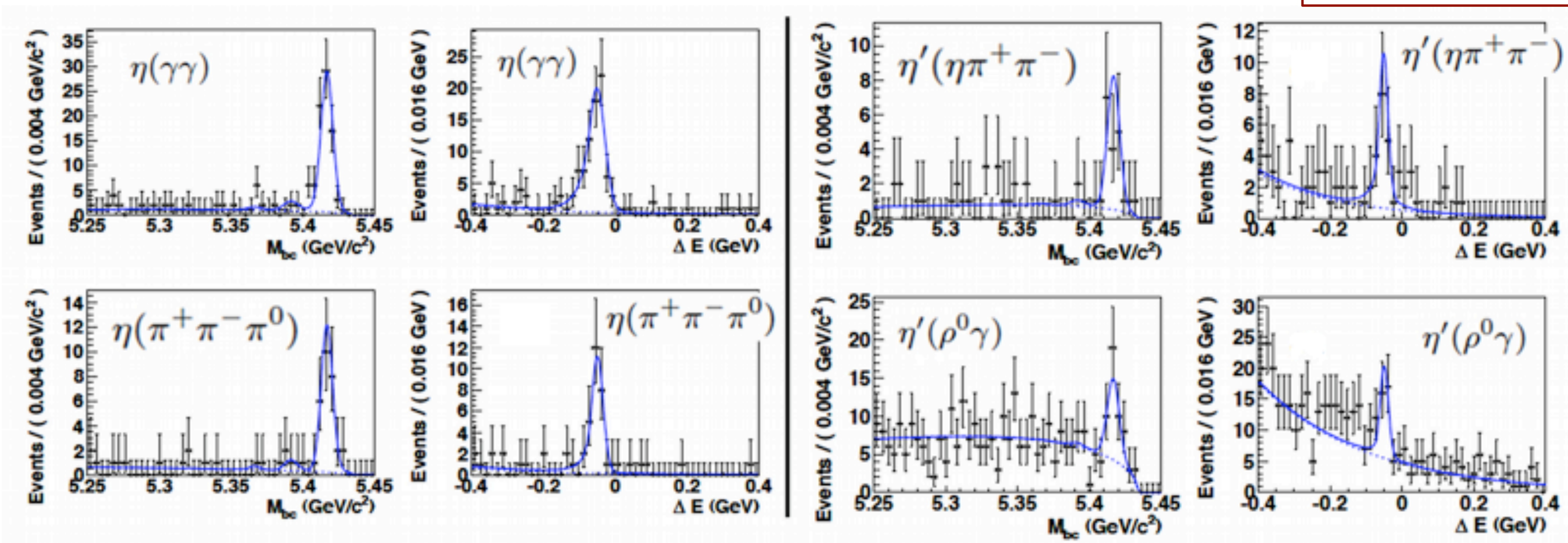
First observation of $B_s \to J/\psi\eta$ and $B_s \to J/\psi\eta'$

- Final states are CP-even eigenstates.
- Their time distributions allow to measure $\Delta\Gamma_s$ and the CP violating phase ϕ_s without angular analysis.
- SU(3) flavor symmetry predicts: $\frac{\mathcal{B}(B_s \to J/\psi\,\eta')}{\mathcal{B}(B_s \to J/\psi\,\eta)} = 1.04 \pm 0.04$
  - Test SU(3) symmetry and η−η' mixing

$B_s \to J/\psi\eta(')$ results

$121 fb^{-1}$

PRL 108.181808



$B_s \to J/\psi\,\eta$

$B_s \to J/\psi\,\eta'$

$$\mathcal{B}(B_s \to J/\psi\,\eta) = \left(5.10 \pm 0.50_{stat} \pm 0.25_{sys}\ {}^{+1.14}_{-0.79}(N_{B_s^{(*)}\bar{B}_s^{(*)}})\right)\cdot 10^{-4}$$

$$\mathcal{B}(B_s \to J/\psi\,\eta') = \left(3.71 \pm 0.61_{stat} \pm 0.18_{sys}\ {}^{+0.83}_{-0.57}(N_{B_s^{(*)}\bar{B}_s^{(*)}})\right)\cdot 10^{-4}$$

$$\frac{\mathcal{B}(B_s \to J/\psi\,\eta')}{\mathcal{B}(B_s \to J/\psi\,\eta)} = 0.73 \pm 0.14_{stat} \pm 0.02_{sys}$$

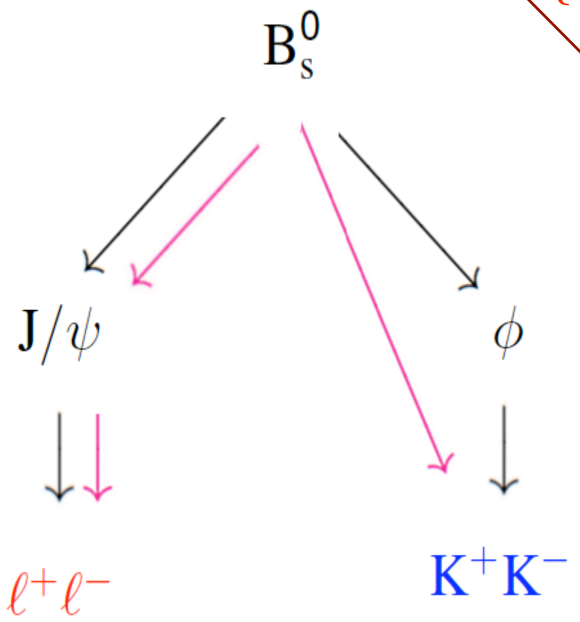
Consistent a 2σ level with SM

Precise measurements of $B_s \rightarrow J/\psi\phi$ - $B_s \rightarrow J/\psi$ KK

121fb^{-1}

Shown At La Thuile

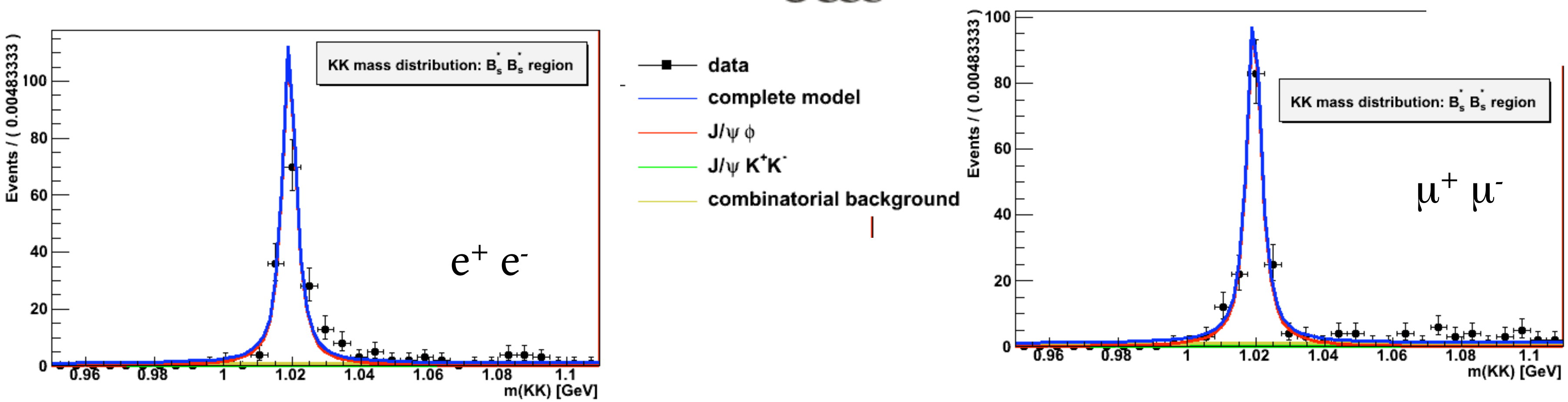
- Motivations:
  - Important to measure CP violation: β_s sensitive to NP.
  - BR($B_s \rightarrow J/\psi$ KK) not yet measured



- Analysis strategy: 2D unbinned Likelihood fit in ΔE and m_{KK}

121fb^{-1}

Results (preliminary)



channel	$J/\psi\ \phi$	$J/\psi\ K^+K^-$	combinatorial
$\mu^+\mu^-$	158±13	89±13	304±20
e^+e^-	168±14	110±16	239±20

$\mathcal{B}\left(B_s^0 \to J/\psi\ \phi\right) = (1.25 \pm 0.07_{stat} \pm 0.20_{sys})\ 10^{-3}$ @ 15.9σ → Consistent with pdg value

$\mathcal{B}\left(B_s^0 \to J/\psi\ K^+K^-\right) = (0.36 \pm 0.04_{stat} \pm 0.08_{sys})\ 10^{-3}$ @ 5.3σ → First measurement

Conclusions

With CDF and Belle using their full data sample, LHCb overcoming with $1fb^{-1}$, the physics of hadronic B decays is entering an exciting new era: the systematic and detailed exploration of the B^0_s sector.
Many new interesting results are popping up – today just shown a subset:

- Annihilation $B^0_s \rightarrow \pi^+\pi^-$ and $B^0 \rightarrow K^+K^-$ decays (CDF – LHCb)
- $B_s \rightarrow J/\psi\ f_0(980)$ lifetime (CDF)
- $B_s \rightarrow J/\psi\phi$ (D0, CDF, LHCb)
- $B_s \rightarrow DD'$ (Belle, CDF, LHCb)
- $B_s \rightarrow J/\psi\eta(')$ (Belle)
- $B_s \rightarrow J/\psi\phi$ - $B_s \rightarrow J/\psi\ KK$ (Belle)

Expect a lot of experimental progress in the next few months!

Backup