HEP 2013
Stockholm
18-24 July 2013
(info@eps-hep2013.eu)

Studies of Asymmetries in Semileptonic B decays at LHCb

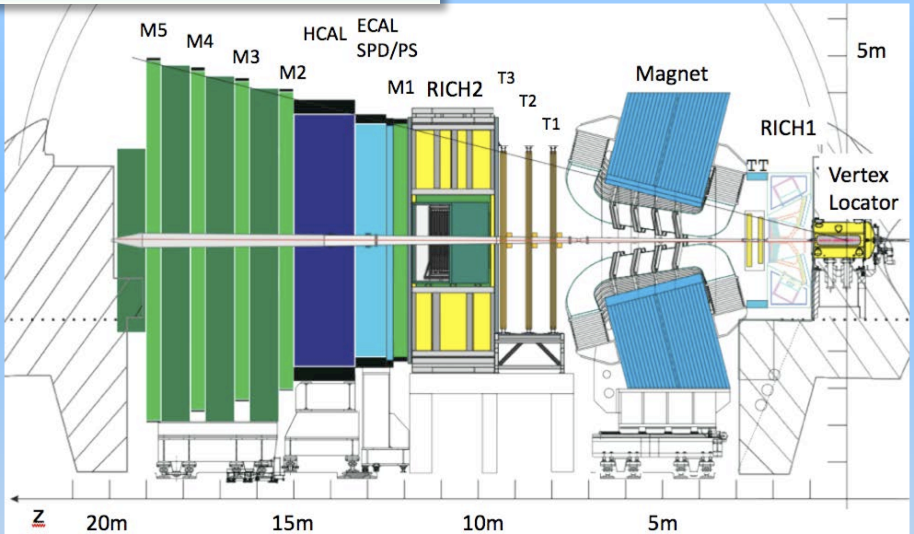
Thomas Ruf on behalf the LHCb collaboration

- **CP Asymmetry in B_s** — LHCb-PAPER-2013-033 final $1fb^{-1}$ result, update of CONF-2012-022
- **Mixing in B_d and B_s** — LHCb-PAPER-2013-036 New

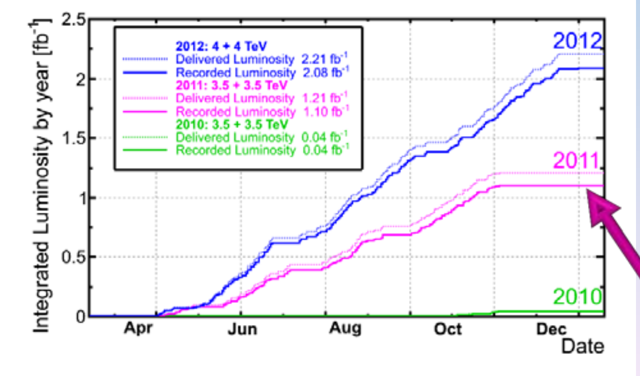
The LHCb Experiment

❖ **912 members from 17 countries in 65 institutes**

The LHCb Detector:



- **Single arm forward spectrometer**
- **Excellent tracking and vertexing**
  - impact parameter resolution ~20μm (high P_T)
- **Unique Hadron PID**
  - Two Rich detectors π,K,p ID up to 100 GeV/c
- **Muon and Calorimeter systems**
  - read-out at 40MHz. p_T of muon and E_T of hadron&γ input to first level trigger
- **High Level Trigger**
  - Input 1MHz, full software based, offline reconstruction tuned to trigger time constraints
  - 29000 logical CPU cores
- **Dipole magnet**
  - $\int \boldsymbol{Bdl} = \boldsymbol{4}$Tm, polarity (UP / DOWN) changed every ~100pb^{-1}



This talk

Neutral Meson Mixing

assuming CPT

- Time evolution of flavour:

$$\mathbf{R}\begin{pmatrix} B \to B \\ \bar{B} \to \bar{B} \end{pmatrix}(t) = \frac{1}{2} e^{-\bar{\Gamma}t}\left(\cosh\frac{\Delta\Gamma t}{2} + \cos\Delta m t\right)$$

$$\mathbf{R}\begin{pmatrix} B \to \bar{B} \\ \bar{B} \to B \end{pmatrix}(t) = \frac{2}{|\Delta\Lambda|^2}\begin{pmatrix} |\Lambda_{12}|^2 \\ |\Lambda_{21}|^2 \end{pmatrix} e^{-\bar{\Gamma}t}\left(\cosh\frac{\Delta\Gamma t}{2} - \cos\Delta m t\right)$$

  - Obtained by solving the Schrödinger equation:
    - $i\frac{\partial}{\partial t}\begin{pmatrix} B(t) \\ \bar{B}(t) \end{pmatrix} = \Lambda \begin{pmatrix} B(t) \\ \bar{B}(t) \end{pmatrix}$ $\Lambda = \begin{pmatrix} M_{11} & M_{12}e^{i\varphi_M} \\ M_{12}e^{-i\varphi_M} & M_{22} \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma_{11} & \Gamma_{12}e^{i\varphi_\Gamma} \\ \Gamma_{12}e^{-i\varphi_\Gamma} & \Gamma_{22} \end{pmatrix}$, B_L and B_H eigenstates of Λ
  - Parameters desribing change of flavour:
    - Lifetime difference: $\Delta\Gamma = \Gamma_H - \Gamma_L = 2\Gamma_{12}\cos(\varphi_\Gamma - \varphi_M)$
    - **Oscillation frequency:** $\Delta m = m_H - m_L = 2M_{12}$
    - **T violation:** $\mathbf{R}(B \to \bar{B}) \neq \mathbf{R}(\bar{B} \to B)$,

      flavour specific asymmetry: $A_{fs} = \frac{|\Lambda_{12}|^2 - |\Lambda_{21}|^2}{|\Lambda_{12}|^2 + |\Lambda_{21}|^2} = \frac{\Gamma_{12}}{M_{12}}\sin(\varphi_\Gamma - \varphi_M)$

$for\ \frac{\Gamma_{12}}{M_{12}} \ll 1$

Historical comment:
In the kaon system, A_{fs}, also called "Kabir Asymmetry" or A_T, first direct measurement of T-violation by CPLEAR *Phys.Lett. B 444 (1998) 52*

$A_{fs}^{kaon} = (6.6 \pm 1.3 \pm 1.0) \times 10^{-3}$

Neutral Meson Mixing

assuming CPT

- Time evolution of flavour:

$$\mathbf{R}\begin{pmatrix} B \to B \\ \bar{B} \to \bar{B} \end{pmatrix}(t) = \frac{1}{2} e^{-\bar{\Gamma}t}\left(\cosh\frac{\Delta\Gamma t}{2} + \cos\Delta m t\right)$$

$$\mathbf{R}\begin{pmatrix} B \to \bar{B} \\ \bar{B} \to B \end{pmatrix}(t) = \frac{2}{|\Delta\Lambda|^2}\begin{pmatrix} |\Lambda_{12}|^2 \\ |\Lambda_{21}|^2 \end{pmatrix} e^{-\bar{\Gamma}t}\left(\cosh\frac{\Delta\Gamma t}{2} - \cos\Delta m t\right)$$

  - Obtained by solving the Schrödinger equation:
    - $i\frac{\partial}{\partial t}\begin{pmatrix} B(t) \\ \bar{B}(t) \end{pmatrix} = \Lambda \begin{pmatrix} B(t) \\ \bar{B}(t) \end{pmatrix}$ $\quad \Lambda = \begin{pmatrix} M_{11} & M_{12}e^{i\varphi_M} \\ M_{12}e^{-i\varphi_M} & M_{22} \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma_{11} & \Gamma_{12}e^{i\varphi_\Gamma} \\ \Gamma_{12}e^{-i\varphi_\Gamma} & \Gamma_{22} \end{pmatrix}$, $\boldsymbol{B_L}$ and $\boldsymbol{B_H}$ eigenstates of $\boldsymbol{\Lambda}$
  - Parameters desribing change of flavour:

    for $\frac{\Gamma_{12}}{M_{12}} \ll 1$

    - Lifetime difference: $\Delta\Gamma = \Gamma_H - \Gamma_L = 2\Gamma_{12}\cos(\varphi_\Gamma - \varphi_M)$
    - **Oscillation frequency:** $\boldsymbol{\Delta m = m_H - m_L = 2M_{12}}$
    - **T violation:** $\mathbf{R}(B \to \bar{B}) \neq \mathbf{R}(\bar{B} \to B)$,

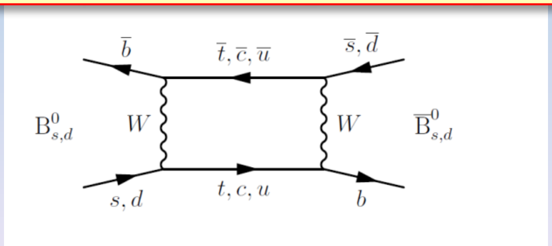
      flavour specific asymmetry: $\boldsymbol{A_{fs}} = \frac{|\Lambda_{12}|^2 - |\Lambda_{21}|^2}{|\Lambda_{12}|^2 + |\Lambda_{21}|^2} = \frac{\Gamma_{12}}{M_{12}}\sin(\varphi_\Gamma - \varphi_M)$
    - In the SM, $\boldsymbol{A_{fs}}$ is small:

$$A^d_{fs} = (-4.1 \pm 0.6) \times 10^{-4}$$
$$A^s_{fs} = (1.9 \pm 0.3) \times 10^{-5}$$

A.Lenz arXiv:1205.1444

$$A^s_{fs} \approx -A^d_{fs} \times \lambda^2,\ \lambda \approx 0.22$$

example for a leading order diagram:



Neutral Meson Mixing

assuming CPT

- Time evolution of flavour:

$$\mathbf{R}\begin{pmatrix} B \rightarrow B \\ \bar{B} \rightarrow \bar{B} \end{pmatrix}(t) = \frac{1}{2} e^{-\bar{\Gamma}t}\left(\cosh\frac{\Delta\Gamma t}{2} + \cos\Delta mt\right)$$

$$\mathbf{R}\begin{pmatrix} B \rightarrow \bar{B} \\ \bar{B} \rightarrow B \end{pmatrix}(t) = \frac{2}{|\Delta\Lambda|^2}\begin{pmatrix} |\Lambda_{12}|^2 \\ |\Lambda_{21}|^2 \end{pmatrix} e^{-\bar{\Gamma}t}\left(\cosh\frac{\Delta\Gamma t}{2} - \cos\Delta mt\right)$$

  - Obtained by solving the Schrödinger equation:
    - $i\frac{\partial}{\partial t}\begin{pmatrix} B(t) \\ \bar{B}(t) \end{pmatrix} = \Lambda\begin{pmatrix} B(t) \\ \bar{B}(t) \end{pmatrix}$ $\quad \Lambda = \begin{pmatrix} M_{11} & M_{12}e^{i\varphi_M} \\ M_{12}e^{-i\varphi_M} & M_{22} \end{pmatrix} - \frac{i}{2}\begin{pmatrix} \Gamma_{11} & \Gamma_{12}e^{i\varphi_\Gamma} \\ \Gamma_{12}e^{-i\varphi_\Gamma} & \Gamma_{22} \end{pmatrix}$, $\boldsymbol{B_L}$ and $\boldsymbol{B_H}$ eigenstates of $\boldsymbol{\Lambda}$
  - Parameters desribing change of flavour:
    - Lifetime difference: $\Delta\Gamma = \Gamma_H - \Gamma_L \quad = 2\Gamma_{12}\cos(\varphi_\Gamma - \varphi_M)$
    - **Oscillation frequency:** $\boldsymbol{\Delta m = m_H - m_L = 2M_{12}}$
    - **T violation:** $\mathbf{R}(B \rightarrow \bar{B}) \neq \mathbf{R}(\bar{B} \rightarrow B)$,
      flavour specific asymmetry: $\boldsymbol{A_{fs}} = \frac{|\Lambda_{12}|^2 - |\Lambda_{21}|^2}{|\Lambda_{12}|^2 + |\Lambda_{21}|^2} = \frac{\Gamma_{12}}{M_{12}}\sin(\varphi_\Gamma - \varphi_M)$
    - In the SM, $\boldsymbol{A_{fs}}$ is small:

for $\frac{\Gamma_{12}}{M_{12}} \ll 1$

$$A_{fs}^d = (-4.1 \pm 0.6) \times 10^{-4}$$
$$A_{fs}^s = (1.9 \pm 0.3) \times 10^{-5}$$

A.Lenz arXiv:1205.1444

$A_{fs}^s \approx -A_{fs}^d \times \lambda^2$, $\lambda \approx 0.22$

New physics can enhance A_{fs}^d and A_{fs}^s up to 0.01

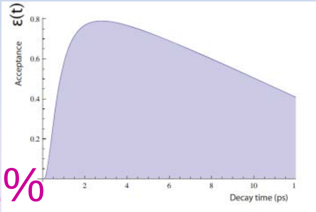
Interesting place to look for New Physics contributions.

Experimental Considerations I

- **A measurement of A_{fs} requires**
  - Flavour tagging at decay time: most efficiently done using semileptonic decays, high BR, $\Delta b = \Delta Q$ rule ☑
  - Flavour tagging at production, expensive, $\varepsilon D^2 \cong 3\%$ (LHCb)
    - $\Rightarrow$ Use untagged semileptonic asymmetries:
      - Time dependent: $\frac{R(B\to\mu^+X_c)(t)-R(B\to\mu^-X_c)(t)}{R(B\to\mu^+X_c)(t)+R(B\to\mu^-X_c)(t)} = \frac{A_{fs}}{2} + \left(A_P - \frac{A_{fs}}{2}\right)\left(\frac{\cos \Delta mt}{\cosh \Delta\Gamma t/2}\right)$
    - Price:
      - Loose factor 2 in sensitivity
      - Dependence on production asymmetry $A_P = \frac{N(B_{t=0})-N(\bar{B}_{t=0})}{N(B_{t=0})+N(\bar{B}_{t=0})} = O(1\%)$
  - Lifetime reconstruction complicated by missing momentum
      - Time integrated: $\frac{N(B\to\mu^+X_c)-N(B\to\mu^-X_c)}{N(B\to\mu^+X_c)+N(B\to\mu^-X_c)} = \frac{A_{fs}}{2} + (A_P - \frac{A_{fs}}{2})\left[1+\left(\frac{\Delta m}{\Gamma}\right)^2\right]^{-1}$

0.14% for B_s

- Gift:
  - $\frac{\Delta m_s}{\Gamma_s} \approx 26$: wipes out contribution from a B_s production asymmetry to $<4\text{x}10^{-5}$, well below expected statistical sensitivity



$A_P \times 0.2\%$ with LHCb acceptance

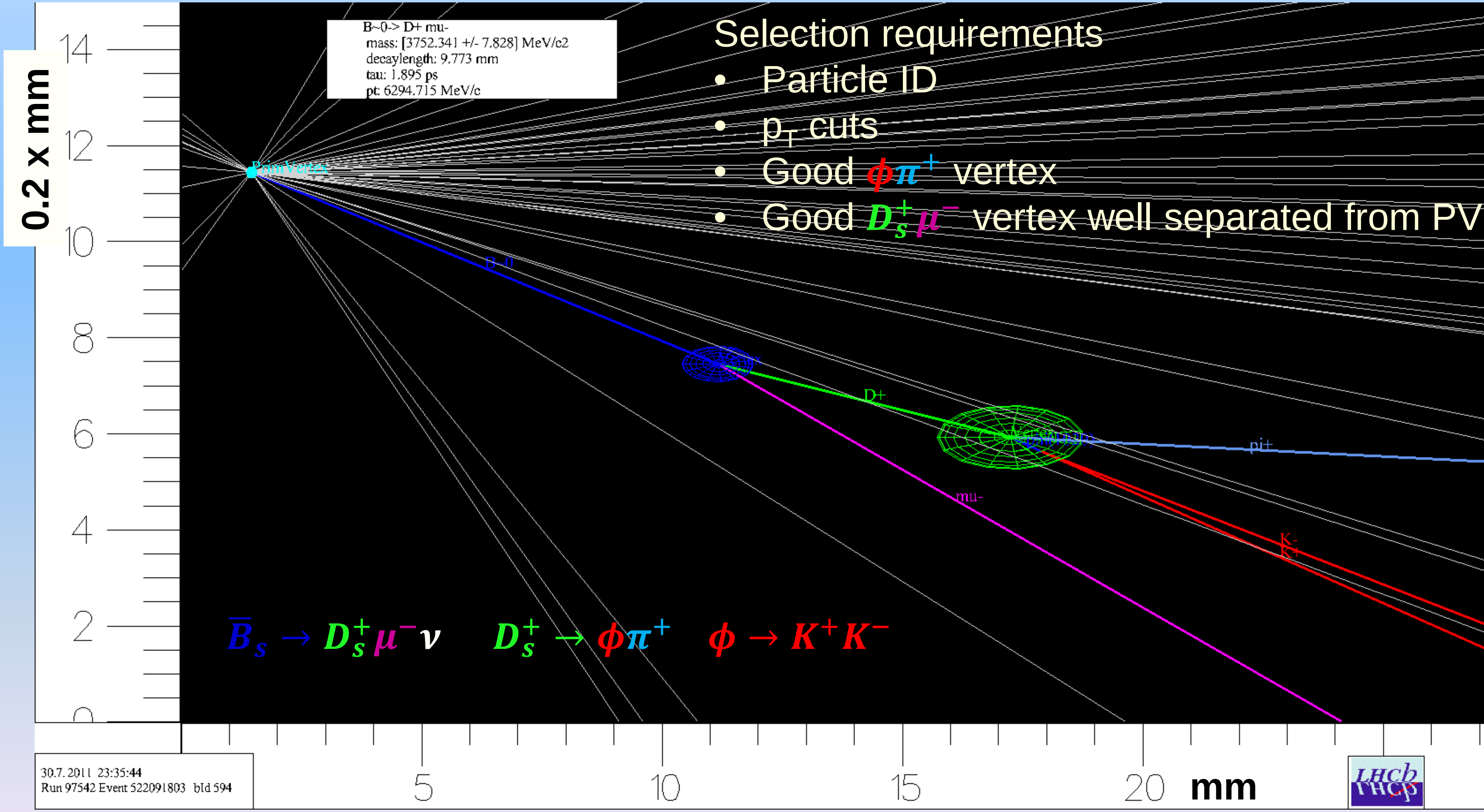
- **For B_d, will need time dependent analysis**

Experimental Considerations II

- **LHCb strategy**
  - Measure first A_{fs} for B_s using time integrated semileptonic asymmetry
  - Develop time dependent analysis
    - Complication: Determine *B* lifetime with missing neutrino
    - **Challenge method by measuring Δm_s and Δm_d**
  - Measure A_{fs} for B_d using time dependent semileptonic asymmetry

- **Flavour specific final states are prone to detector induced charge asymmetries**
  - Different reconstruction efficiencies for particle and antiparticles due to different hadronic interactions with detector material
    - Controlled by using calibration channels
  - Left/Right asymmetric detector efficiencies together with a dipole magnet
    - Mitigated by changing magnet polarities

Measurement of A^s_{fs} with $B^0_s \to D^-_s \mu^+ X$



Selection requirements

- Particle ID
- p_T cuts
- Good $\phi\pi^+$ vertex
- Good $D_s^+\mu^-$ vertex well separated from PV

beam direction

Signal Yields

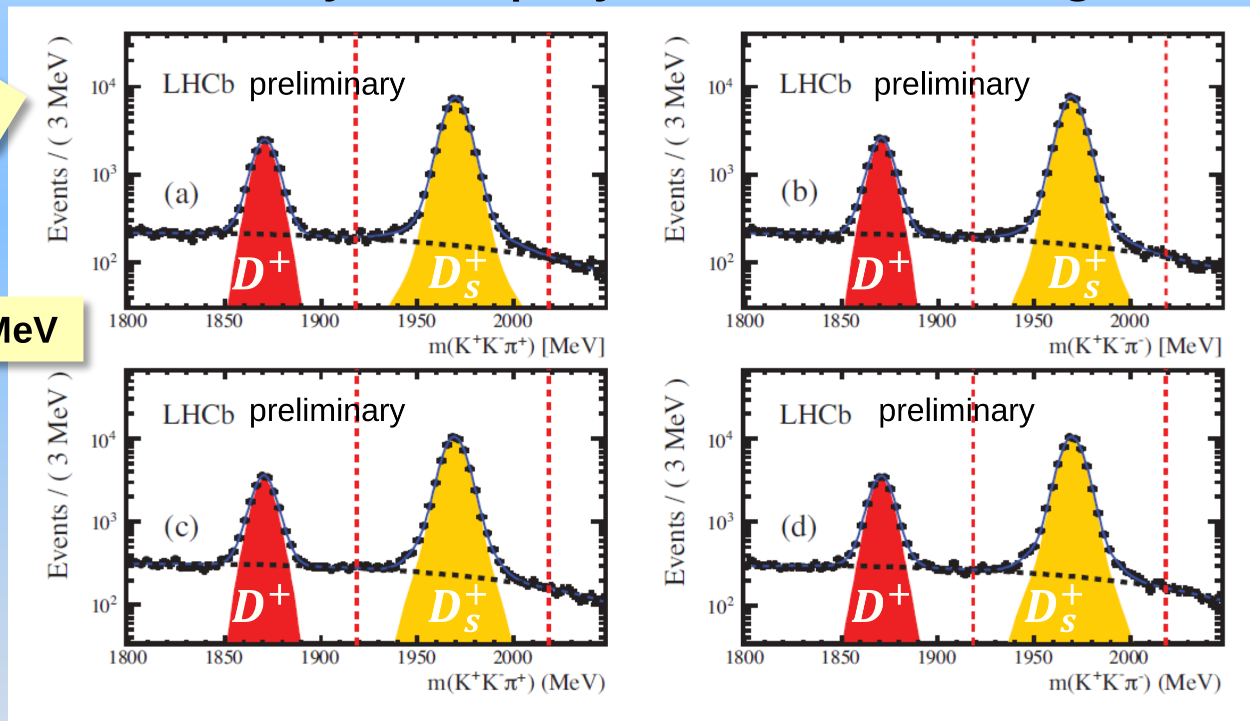
- **PDF =** double Gaussian with common mean for signal,
  2nd order Chebyshev polynomial for background

LOG scale!

Magnet UP

$|\mathbf{m(KK)} - \mathbf{m(\Phi)}| < \mathbf{20}$ **MeV**

Magnet DOWN



- Fitted raw yields

  Total statistics: $\mathbf{184817 \pm 484}$

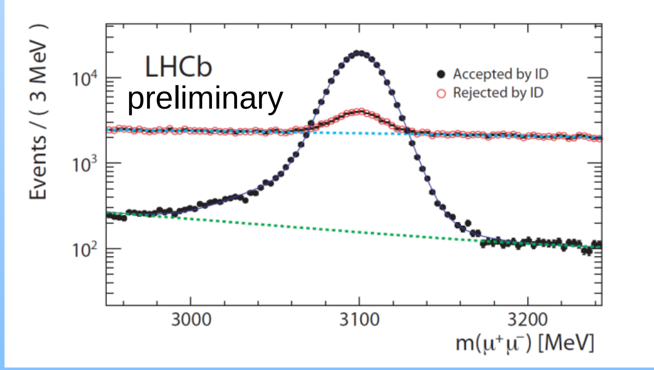
	Magnet Up	Magnet Down
mass fitting		
$D_s^- \mu^+$	38742 ± 218	53768 ± 264
$D_s^+ \mu^-$	38055 ± 223	54252 ± 259

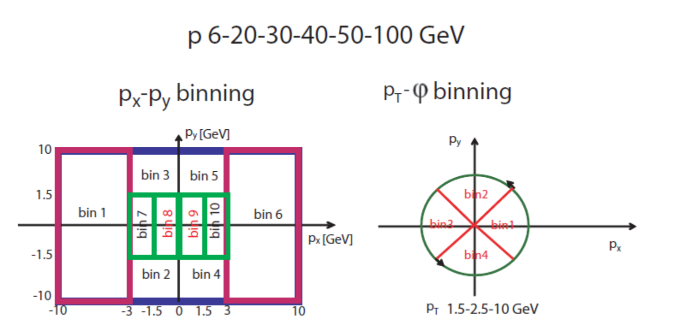
Analysis Steps

- **Master formula** $\varepsilon(\mu^{\pm}) = \varepsilon^{Trigger}(\mu^{\pm}) \times \varepsilon^{PID}(\mu^{\pm})$
  - $$A_{meas}^{s} = \underbrace{\frac{N(D_s^-\mu^+)/\varepsilon(\mu^+) - N(D_s^+\mu^-)/\varepsilon(\mu^-)}{N(D_s^-\mu^+)/\varepsilon(\mu^+) + N(D_s^+\mu^-)/\varepsilon(\mu^-)}}_{A_\mu^c} - A_{track} - A_{bkg}$$
- **Correct event yields for muon related asymmetries**
  - Due to PID and trigger
    - By use of calibration channels
- **Determine asymmetry caused by track reconstruction**
  - Due to different interactions of particle/anti-particle with detector and to magnet effects
    - By use of calibration channels
- **Determine asymmetry caused by background**
  - Prompt and B related
    - Determine from data

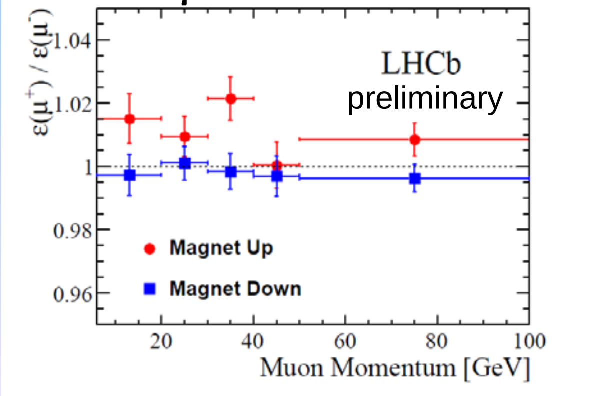
Muon Related Asymmetry

- **Calibration channel: $J/\psi \to \mu^+\mu^-$**
  - Two samples used
    - Events triggered by hadronic B decays not including J/ψ in the final state **KS**
    - Events triggered by single muon **MS**
  - Tag&Probe
    - Tag = one good muon, probe = track not used in trigger and PID forming a good vertex with the tag and invariant mass close to J/ψ mass
    - Determine PID and trigger efficiencies of μ^+ and μ^- in kinematic bins:





Efficiency ratio as function of μ momentum:



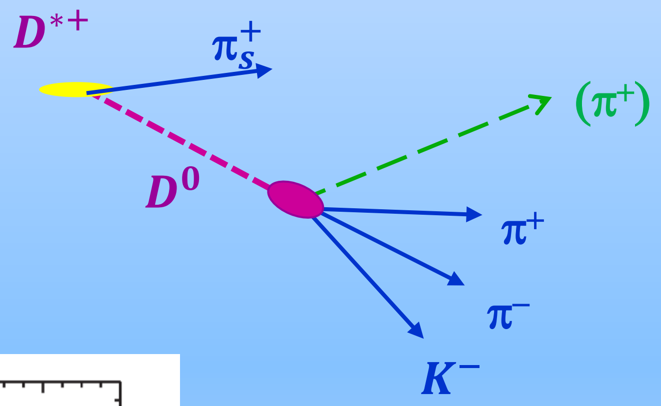
LHCb preliminary

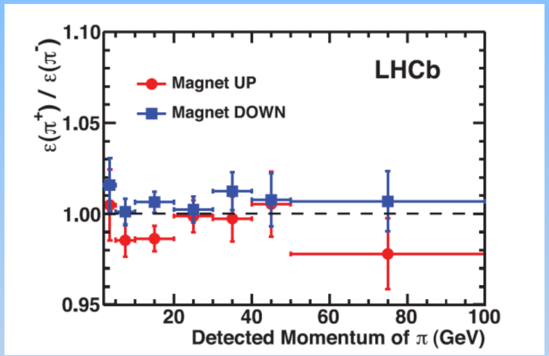
A^c_μ [%]	KS muon correction		MS muon correction		Average
Magnet	pp_xp_y	$pp_t\phi$	pp_xp_y	$pp_t\phi$	
Up	$+0.38 \pm 0.38$	$+0.30 \pm 0.38$	$+0.64 \pm 0.37$	$+0.63 \pm 0.37$	$+0.49 \pm 0.38$
Down	-0.17 ± 0.32	-0.25 ± 0.32	-0.60 ± 0.32	-0.62 ± 0.32	-0.41 ± 0.32
Avg.	$+0.11 \pm 0.25$	$+0.02 \pm 0.27$	$+0.02 \pm 0.24$	$+0.01 \pm 0.24$	$+0.04 \pm 0.25$

- For final result, use average of both samples and methods

Tracking Asymmetry

- $\mu^{\pm}\pi^{\mp}$:
  - Use partially reconstructed decays: vertex and kinematic constraints determine momentum of the missing π^{+}. Determine tracking efficiency ratio $\varepsilon(\pi^{+})/\varepsilon(\pi^{-})$ as function of momentum:

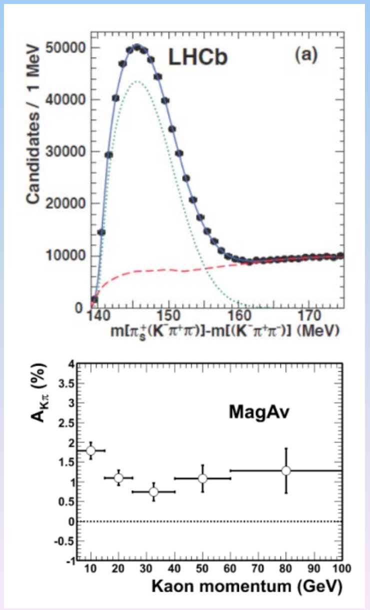




Kinematic weighting with signal:

$A_{track}(\mu^{\pm}\pi^{\mp}) = (0.01 \pm 0.13)\%$

Method used in an earlier measurement of the D_s production asymmetry:
R.Aaij et al PLB 713 (2012) 186



- **No asymmetry in pure $\Phi(1020) \rightarrow K^{+}K^{-}$**
  - **BUT,** small s-wave contribution, $K^{+}K^{-}$ momentum slightly differs. Kaon asymmetry determined from:

$$\frac{N(D^{-} \rightarrow K^{+}\pi^{-}\pi^{-})}{N(D^{+} \rightarrow K^{-}\pi^{+}\pi^{+})} \times \frac{N(D^{+} \rightarrow K_s^{0}\pi^{+})}{N(D^{-} \rightarrow K_s^{0}\pi^{-})} = \frac{\varepsilon(K^{+}\pi^{-})}{\varepsilon(K^{-}\pi^{+})}$$

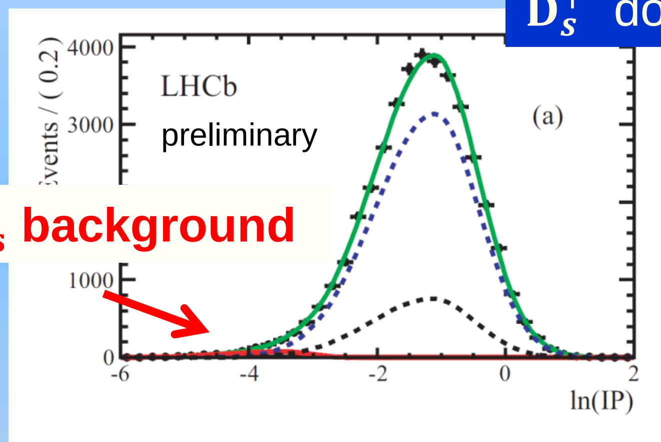
$A_{track}(K^{+}K^{-}) = (0.012 \pm 0.004)\%$

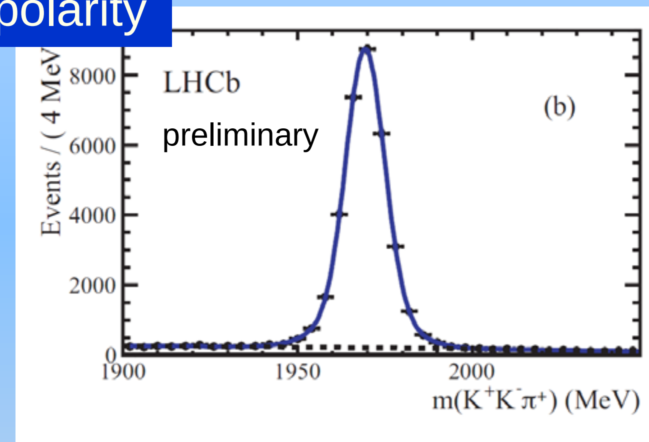
Background Asymmetries

- Prompt D_s background estimated from 2-dim fit of ln(IP/mm) vs. M($K^+K^-\pi^+$)

D_s^+ down polarity

Prompt D_s background





  - $$A_{bkg}^{UP} = (+0.14 \pm 0.07)\% \qquad A_{bkg}^{DOWN} = (-0.05 \pm 0.05)\% \implies A_{bkg} = (0.04 \pm 0.04)\%$$

- **Backgrounds from *B* hadrons**

  $D_s^+h^-X$ sample, $h = K/\pi$ identified with RICH, and folded with μ-misidentification probabilities from $D^* \to D^0(K\pi)\pi$ calibration sample

  - False-μ and D_s from b-hadron decays: $A_{bkg} < 0.01\%$
  - μ and D_s from b-hadron decays: $A_{bkg} = (0.01 \pm 0.04)\%$

    e.g. $\bar{B} \to D_s^+\bar{D}X, \bar{D} \to \mu^- X$

using measurements of branching fractions, b-hadron fractions, production asymmetries

Putting all together

$$A^s_{meas} = \underbrace{\frac{N(D_s^- \mu^+)/\varepsilon(\mu^+) - N(D_s^+ \mu^-)/\varepsilon(\mu^-)}{N(D_s^- \mu^+)/\varepsilon(\mu^+) + N(D_s^+ \mu^-)/\varepsilon(\mu^-)}}_{A^c_\mu = (0.04 \pm 0.25)\%} - \underbrace{A_{track}}_{= (0.02 \pm 0.13)\%} - \overbrace{A_{bkg}}^{= (0.05 \pm 0.05)\%}$$

$$= (-0.03 \pm 0.25 \pm 0.18\%)$$

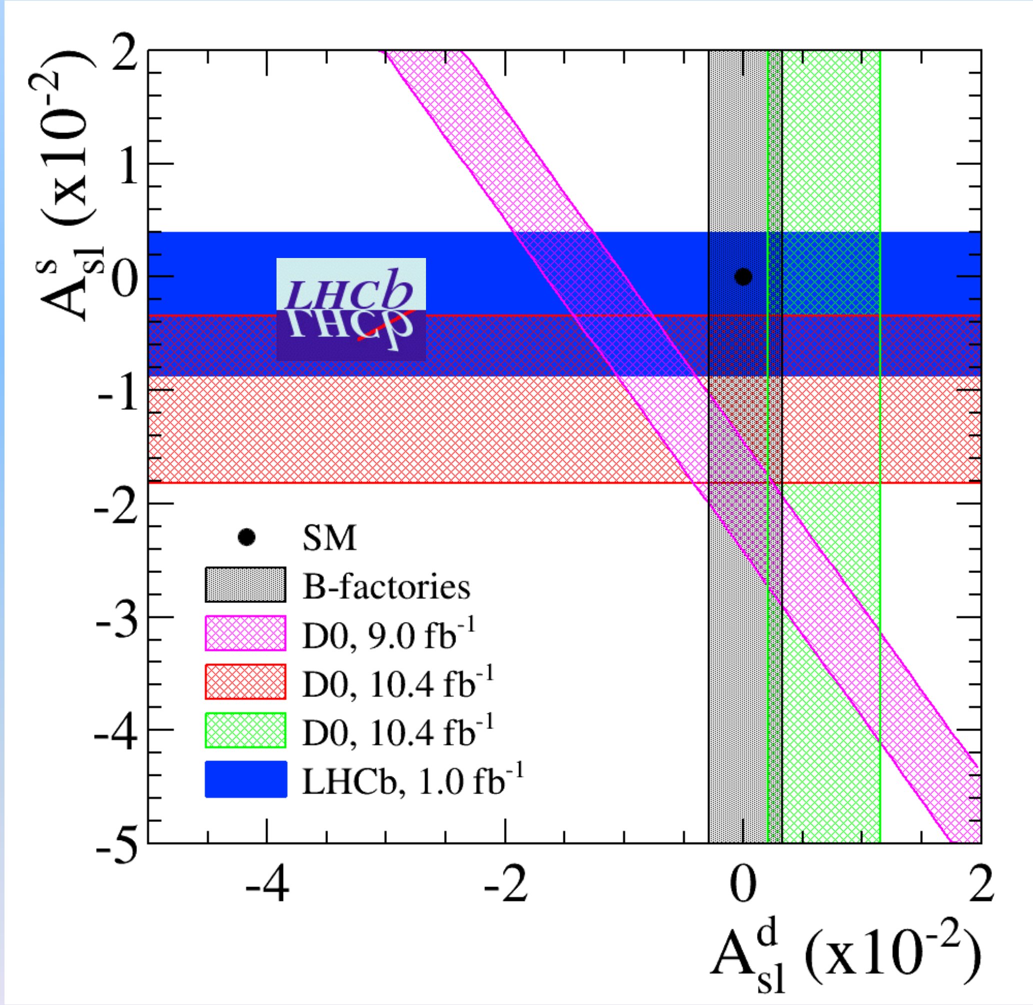
Systematic uncertainties:

Sources	$\sigma(A^s_{meas})[\%]$
Signal modeling and muon correction	0.07
Statistical uncertainty on the efficiency ratios	0.08
Background subtraction	0.05
Asymmetry in track reconstruction	0.13
Field−up and fileld−down different run conditions	0.01
Software trigger bias (topological trigger)	0.05
Total	0.18

LHCb preliminary:

$$A^s_{fs} = 2 \times A^s_{meas} = (-0.06 \pm 0.50 \pm 0.36)\%$$

Comparison with other experiments



$$A_{fs}^{s} = (-0.06 \pm 0.50 \pm 0.36)\%$$

- Most precise measurement
- In agreement with SM prediction

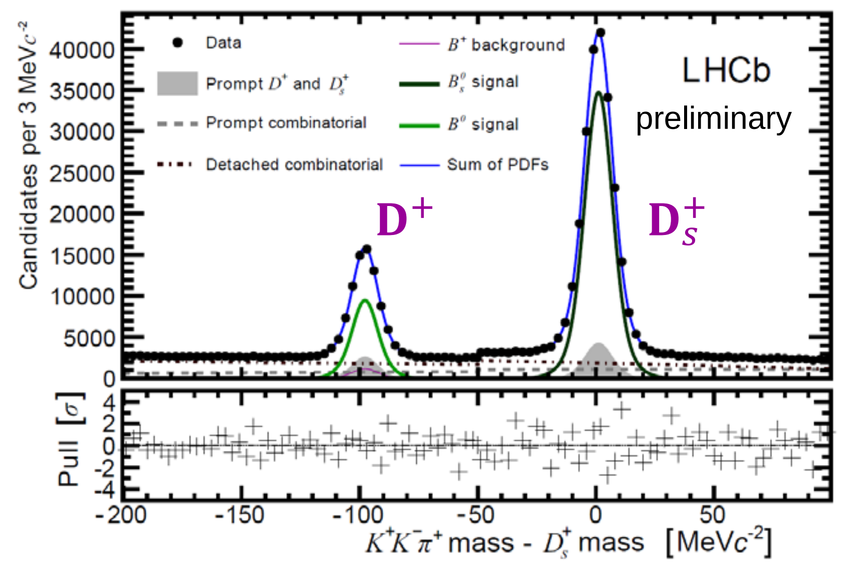
See plenary talk of Stephanie Hansmann-Menzemer for comparison with other experiments

Towards Measuring A_{fs}^{d}

Mixing

"like sign" "opposite sign"

- $A_{\Delta m}(t) = \frac{[R(\bar{B}_{t=0}\to\bar{B})+R(B_{t=0}\to B)]-[R(\bar{B}_{t=0}\to B)+R(B_{t=0}\to\bar{B})]}{[R(\bar{B}_{t=0}\to\bar{B})+R(B_{t=0}\to B)]+[R(\bar{B}_{t=0}\to B)+R(B_{t=0}\to\bar{B})]} = \frac{\cos\Delta mt}{\cosh\frac{\Delta\Gamma}{2}t}$
- **Use $B_{d,(s)} \to D^-_{(s)}[K^+K^-\pi^-]\mu^+\nu_\mu$ for flavour tagging at decay time,** no requirement on m(K^+K^-)
- **Use opposite-side and same-side tagging at production time***
  - Mass distribution of tagged events: in total: ~600 000 candidates
  - $A_{\Delta m}$ diluted by mistag probability ω
    - $A^{exp}_{\Delta m} = (1-2\omega)A_{\Delta m}$
    - ω free fit parameter, 0.33-0.36

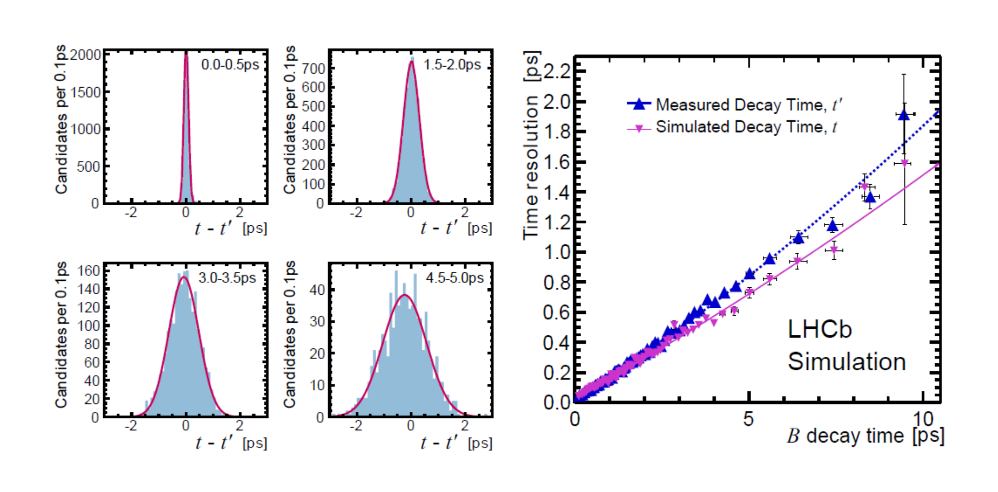


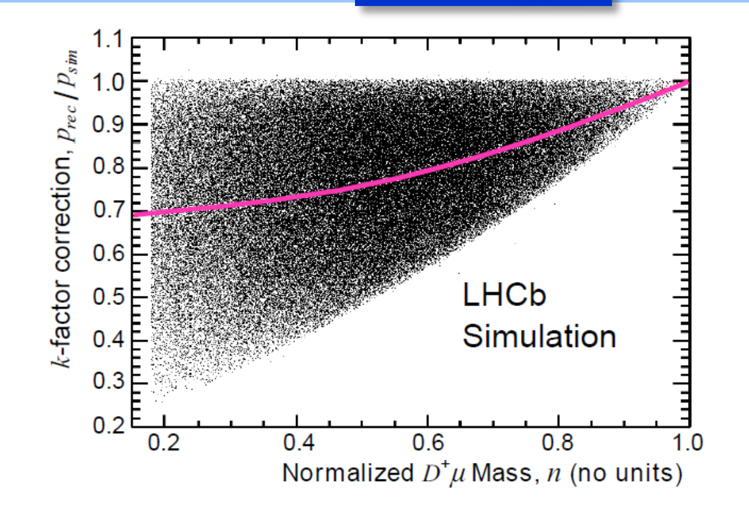
* Eur. Phys. J. C72 (2012) 2022
LHCb-CONF-2012-033

Determining Decay Time

- **k-factor corrects in average for the missing momentum**
  - Obtained from MC studies tuned to describe real data
    - k-factor spread smaller for high $D^-_{(s)}\mu^+$ mass
      - Average k-factor parametrized with 4th order polynomial as function of $D^-_{(s)}\mu^+$ mass
    - Decay time resolution becomes worse with decay time

$$k = \frac{P_{rec}}{P_{true}}$$



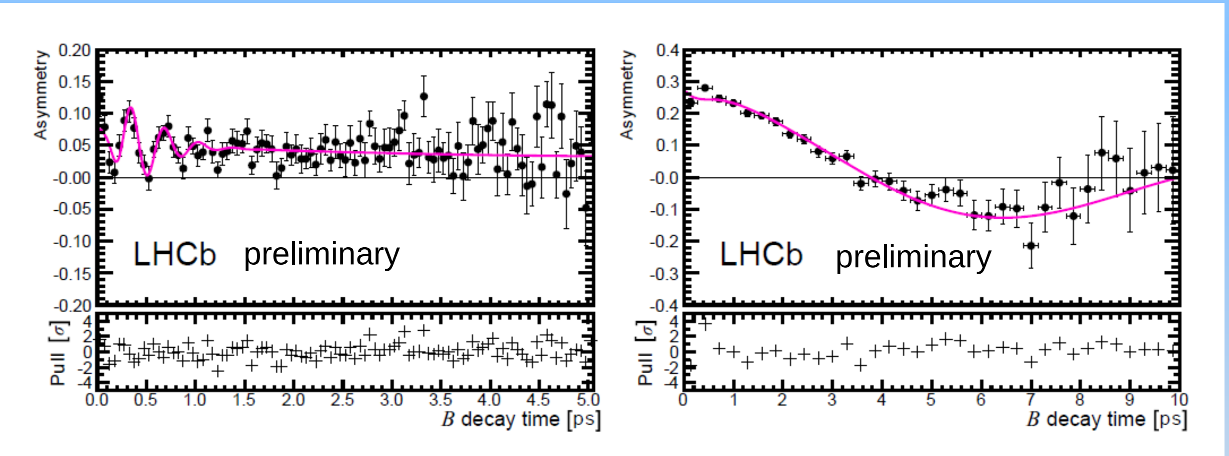


Normalized $D^-_{(s)}\mu^+$ mass $n = \frac{M(D\mu) - M_D - M_\mu}{M_B - M_D - M_\mu}$

- Mixing asymmetry distorted by resolution folded with decay time acceptance and by background.
  - Taken care in the fit procedure

Result

- **Binned, multidimensional, log-likelihood fits of the like and opposite sign decay rates**
  - Projection of the fitted PDF
    Around D_s mass peak around D^+ mass peak (20 MeV/c^2)



***p*-value = 19.6%**

- **No mixing rejected by 5.8σ for B_s and 13σ for B_d**
  - $$\Delta m_d = (0.503 \pm 0.011_{stat} \pm 0.013_{sys})ps^{-1}$$
    $$\Delta m_s = (17.93 \pm 0.22_{stat} \pm 0.15_{sys})ps^{-1}$$

LHCb preliminary

$\Delta m_d(PDG) = (0.507 \pm 0.004)ps^{-1}$
$\Delta m_s(PDG) = (17.69 \pm 0.08)\ ps^{-1}$

- **First observation of B_s mixing with semileptonic only decays**

Summary

- A^s_{fs} **final result with 1fb^{-1}**
  - $A^s_{fs} = (-0.06 \pm 0.50 \pm 0.36)\%$ LHCb preliminary
  - Most precise measurement until now
  - Result is consistent with the SM prediction of ~0
- **First measurement of Δm_s with only semileptonic decays**
  - $\Delta m_s = (17.93 \pm 0.22_{stat} \pm 0.15_{sys})ps^{-1}$
  - $\Delta m_d = (0.503 \pm 0.011_{stat} \pm 0.013_{sys})ps^{-1}$ LHCb preliminary
  - **On the right track to measure A^d_{fs}**
- **Significant increase of precision in the coming years**
  - 3fb^{-1} on tape from Run I
    - **Using Cabibbo favored decays, $B_d \to D^-[K^-\pi^+\pi^-]\mu^+\nu_\mu$, expect $\sigma_{stat}(A^d_{fs}) < 0.1\%$**
  - 2015: Increase of beam energy, ~2x more *b* production cross section
  - After 2018: LHCb upgrade, aim for 50fb^{-1} with increased trigger efficiency

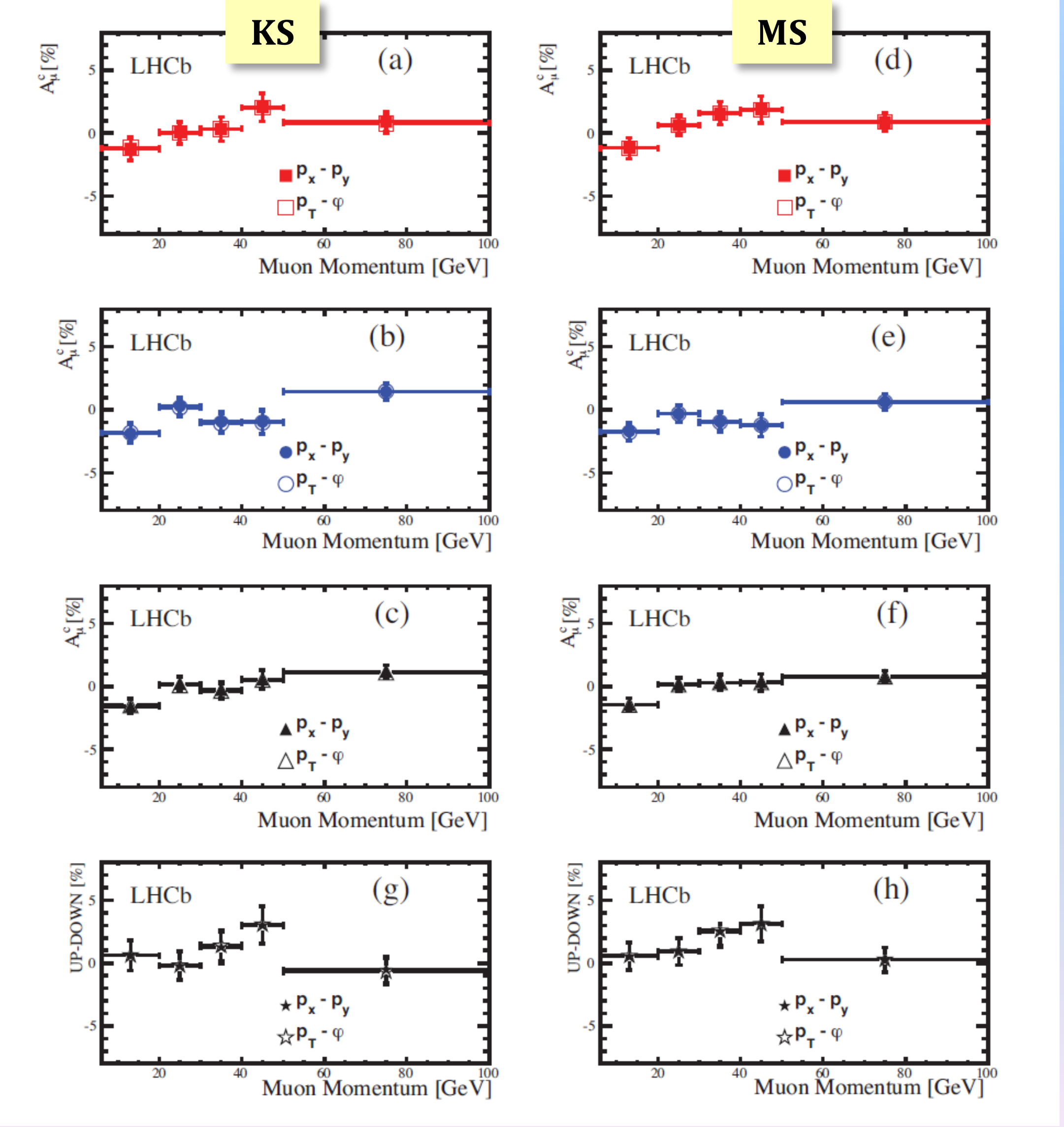
Muon Corrected Asymmetry

UP polarity

DOWN polarity

Average

Difference



Mixing Result, systematic errors

- **Systematic errors**

Source of uncertainty	Method	Systematic uncertainty	
		Δm_s [ps^{-1}]	Δm_d [ps^{-1}]
k-factor	simulation	0.06	0.0052
detector alignment	calibration	0.03	0.0008
values of $\Delta\Gamma$	data refit	n/a	0.0004
model bias	simulation	0.09	0.0055
signal proper-time model	data refit	0.09	0.007
other models and binning	data refit	0.05	0.001
B^+ ($\mathcal{B}$, efficiency, tagging)	data refit	n/a	0.008
total	sum in quadrature	0.15	0.013

- **No mixing rejected by 5.8σ for B_s and 13σ for B_d**

$$\Delta m_d = (0.503 \pm 0.011_{stat} \pm 0.013_{sys})ps^{-1}$$

$$\Delta m_s = (17.93 \pm 0.22_{stat} \pm 0.15_{sys})ps^{-1}$$

$$\Delta m_d(PDG) = (0.507 \pm 0.004)ps^{-1}$$

$$\Delta m_s(PDG) = (17.69 \pm 0.08)\ ps^{-1}$$

- **First observation of B_s mixing with only semileptonic decays**