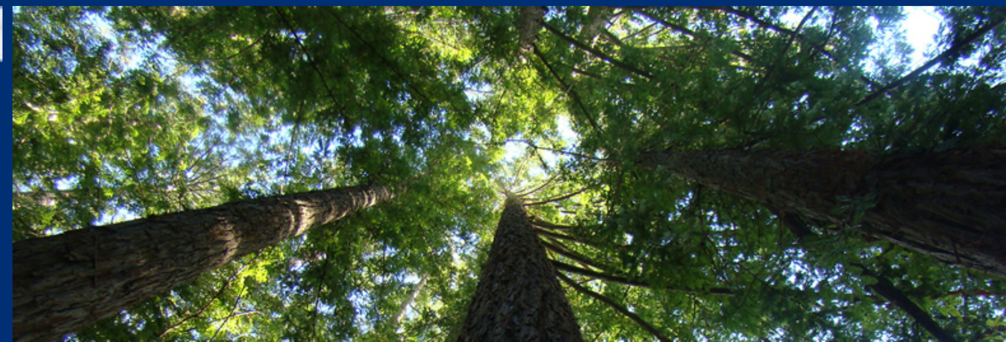
2013 DPF UC SANTA CRUZ



Studies of Asymmetries in Semileptonic B decays at LHCb

UNIVERSITY OF Cincinnati

Michael D. Sokoloff
University of Cincinnati

on behalf the LHCb collaboration
(substituting for Liming Zhang)

LHCb

LHCb-PAPER-2013-033 final 1fb^{-1} result
arXiv:1308.1048

Neutral Meson Mixing

The time evolutions of flavor for neutral B mesons (assuming CPT)

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

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

are obtained by solving the Schrodinger equation:

$$\mathbf{i}\frac{\partial}{\partial\mathbf{t}}\begin{pmatrix}\mathbf{B}(\mathbf{t})\\ \overline{\mathbf{B}}(\mathbf{t})\end{pmatrix} = \Lambda\begin{pmatrix}\mathbf{B}(\mathbf{t})\\ \overline{\mathbf{B}}(\mathbf{t})\end{pmatrix}, \quad \text{with eigenvalues } \mathbf{B_L} \text{ and } \mathbf{B_H}$$

$$\Lambda = \begin{pmatrix}M_{11} & M_{12}e^{i\varphi_M}\\ M_{12}e^{-i\varphi_M} & M_{22}\end{pmatrix} - \frac{\mathbf{i}}{2}\begin{pmatrix}\Gamma_{11} & \Gamma_{12}e^{i\varphi_\Gamma}\\ \Gamma_{12}e^{-i\varphi_\Gamma} & \Gamma_{22}\end{pmatrix}$$

$$\Delta\Gamma = \Gamma_\mathbf{H}-\Gamma_\mathbf{L}\to 2\,\Gamma_{12}\cos(\varphi_\Gamma-\varphi_\mathbf{m}); \quad \Delta\mathbf{m} = \mathbf{m_H}-\mathbf{m_L} = 2\,\mathbf{M}_{12}$$

$$\mathbf{A_{fs}}\,(\mathbf{A}_{\mathbf{s}\ell}) = \frac{|\Lambda_{12}|^2-|\Lambda_{21}|^2}{|\Lambda_{12}|^2-|\Lambda_{21}|^2} = \frac{\Gamma_{12}}{M_{12}}\sin(\varphi_\Gamma-\varphi_M)$$

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which lead to the flavor-specific asymmetry:

$$\mathbf{A}_{\mathbf{fs}}\left(\mathbf{A}_{\mathbf{s}\ell}\right) = \frac{|\boldsymbol{\Lambda}_{\mathbf{12}}|^{\mathbf{2}} - |\boldsymbol{\Lambda}_{\mathbf{21}}|^{\mathbf{2}}}{|\boldsymbol{\Lambda}_{\mathbf{12}}|^{\mathbf{2}} - |\boldsymbol{\Lambda}_{\mathbf{21}}|^{\mathbf{2}}} = \frac{\Gamma_{12}}{M_{12}}\sin(\varphi_\Gamma - \varphi_M)$$

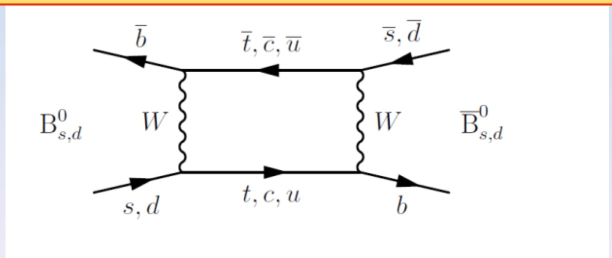
SM predictions from A. Lenz
arXiv 1205.1444

$$\mathbf{A}^{\mathbf{d}}_{\mathbf{fs}} = (-\mathbf{4.1}\pm\mathbf{0.6})\times\mathbf{10}^{-\mathbf{4}}$$

$$\mathbf{A}^{\mathbf{s}}_{\mathbf{fs}} = (\mathbf{1.91}\pm\mathbf{0.3})\times\mathbf{10}^{-\mathbf{5}}$$

$$\mathbf{A}^{\mathbf{s}}_{\mathbf{fs}} = -\mathbf{A}^{\mathbf{d}}_{\mathbf{fs}}\times\lambda^{\mathbf{2}}, \quad \lambda = \mathbf{0.22}$$

Example of a leading order amplitude



Neutral Meson Mixing

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$$\mathbf{A^d_{fs}} = (-\mathbf{4.1}\pm\mathbf{0.6})\times\mathbf{10^{-4}}$$

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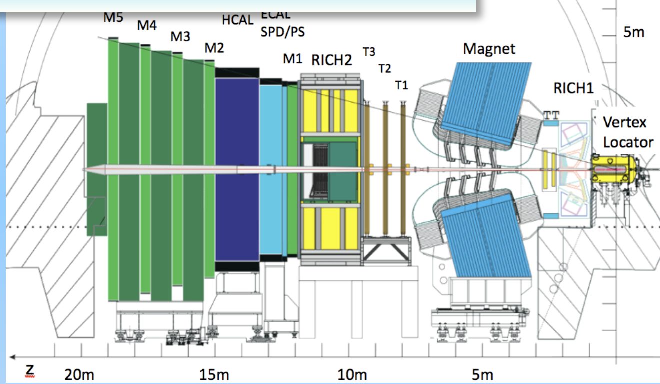
$$\mathbf{A^s_{fs}} = -\mathbf{A^d_{fs}}\times\lambda^{\mathbf{2}}, \quad \lambda = \mathbf{0.22}$$

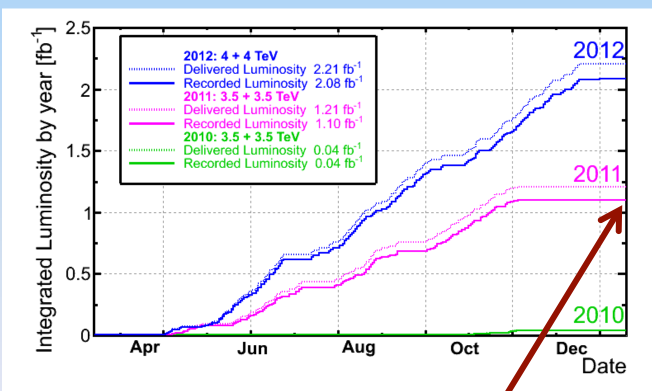
New physics models enhance flavor-specific asymmetries up to O(0.01) in both B_s ad B_d mixing. A D0 result [ref] suggested an asymmetry near this level.

The LHCb Experiment

❖ 912 members from 17 countries in 65 institutes

The LHCb Detector:





this analysis: $\int \mathcal{L}\,\mathrm{dt} = 1\,\mathrm{fb}^{-1}$

- **Single arm forward spectrometer**
- **Excellent tracking and vertexing**
  - Impact parameter resolution ~ 20 μm (high pT)
- **Unique hadron PID**
  - Two RICH detectors: π, K, p ID to 100 GeV/*c*
- **Muon and Calorimeter systems**
  - Read-out at 40 MHz. p_T of muon and E_T of hadrons and γ's input to L0 trigger
- **High level trigger**
  - Input 1 MHz, fully software based, offline reconstruction tuned for trigger constraints
- **Dipole Magnet**
  - $\int \mathrm{B} \cdot \mathrm{d}\ell = 4$ Tm, polarity (Up / Down changed every ~100 pb^{-1}

Experimental Considerations I

- Measuring A_{fs} requires a flavor-specific final state:
  - Use semileptonic decays: high BF, $\Delta b = -\Delta Q$ ☑
- Ideally, an analysis can tag flavor at production and can use t_d dependence to determine A_{fs} most precisely. However,
  - $\varepsilon D^2 \sim 3\%$
  - decay time resolution is large compared to oscillation time
- Use a time-integrated, "untagged" analysis

$$\frac{R(B \to \mu^+ X_c)(t) - R(B \to \mu^- X_c)(t)}{R(B \to \mu^+ X_c)(t) + R(B \to \mu^- X_c)(t)} = \frac{A_{fs}}{2} + \left(A_p - \frac{A_{fs}}{2}\right)\left(\frac{\cos \Delta m t}{\cosh \Delta\Gamma t/2}\right)$$

$$\frac{R(B \to \mu^+ X_c) - R(B \to \mu^- X_c)}{R(B \to \mu^+ X_c) + R(B \to \mu^- X_c)} = \frac{A_{fs}}{2} + \left(A_p - \frac{A_{fs}}{2}\right)\left[1 + \left(\frac{\Delta m}{\Gamma}\right)^2\right]^{-1}$$

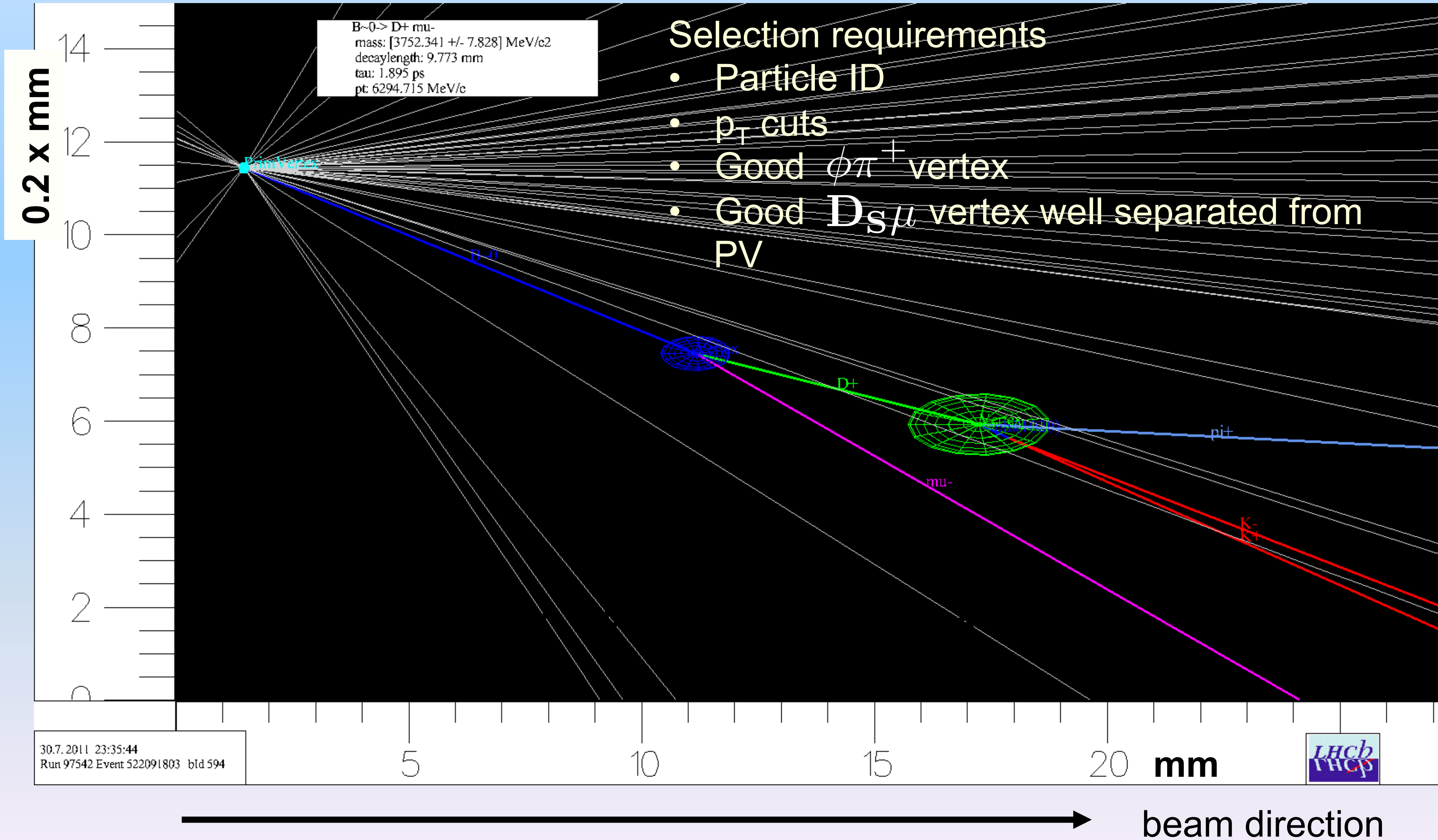
$$A_p \sim \mathcal{O}(1\%)\,, \qquad \left[1 + \left(\frac{\Delta m}{\Gamma}\right)^2\right]^{-1} \sim 0.14\%$$

Last product of terms, convoluted with decay time acceptance, introduces asymmetry < 4 x 10^{-5}

Experimental Considerations II

- Measure A_{fs} for B_s using time-integrated semileptonic asymmetry.
  - We will develop a time-dependent method for measuring A_{fs} for B_d later
- Reconstruction efficiencies for particles and corresponding antiparticles may differ due to hadronic interactions with detector material.
  - Controlled using calibration channels.
- Left/Right asymmetries in detector used in conjunction with a dipole magnet may produce charge-dependent asymmetries.
  - Mitigated by changing magnet polarity about every 100 pb^{-1}.
  - Polarities analyzed separately, then combined.

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

Signal Yields - Replace Plots

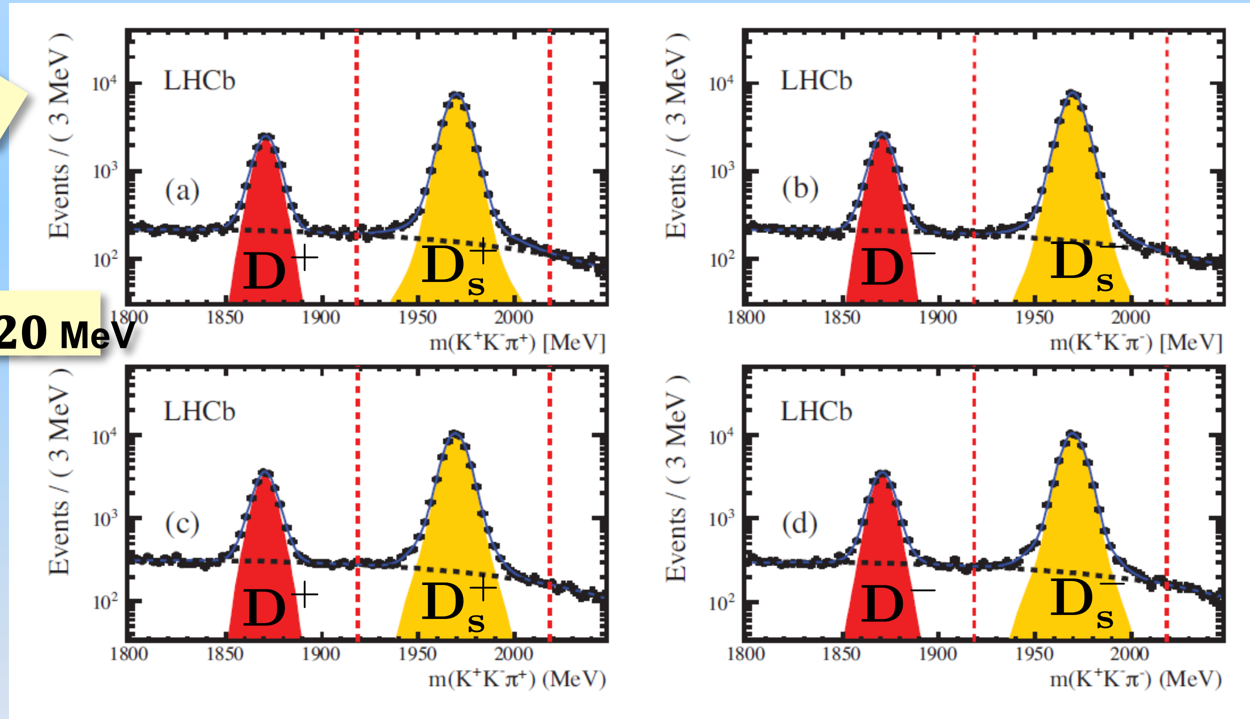
- **PDF =** double Gaussian with common mean for signal,
  2nd order Chebyshev polynomial for background

LOG scale!

Magnet UP

$|m(KK) - m(\Phi)| < 20$ MeV

Magnet DOWN



- Fitted raw yields

  Total statistics: **184817±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**

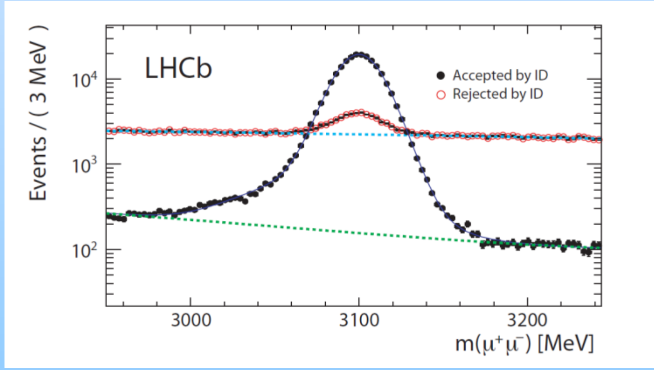
$$\varepsilon(\mu^{\pm}) = \varepsilon^{\mathrm{trigger}}(\mu^{\pm}) \times \varepsilon^{\mathrm{PID}}(\mu^{\pm})$$

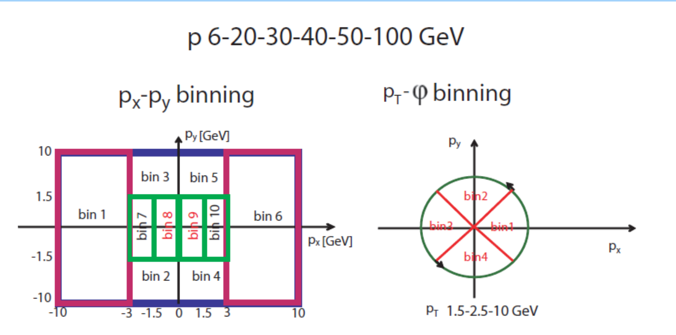
$$\mathbf{A}^{\mathbf{s}}_{\mathrm{meas}} = \underbrace{\frac{\mathbf{N}(\mathbf{D}_{\mathbf{s}}^{-}\mu^{+})/\varepsilon(\mu^{+}) - \mathbf{N}(\mathbf{D}_{\mathbf{s}}^{-}\mu^{+})/\varepsilon(\mu^{-})}{\mathbf{N}(\mathbf{D}_{\mathbf{s}}^{-}\mu^{+})/\varepsilon(\mu^{+}) - \mathbf{N}(\mathbf{D}_{\mathbf{s}}^{-}\mu^{+})/\varepsilon(\mu^{-})}}_{\mathbf{A}^{\mathbf{c}}_{\mu}} - \mathbf{A}_{\mathrm{track}} - \mathbf{A}_{\mathrm{bkg}}$$

- **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

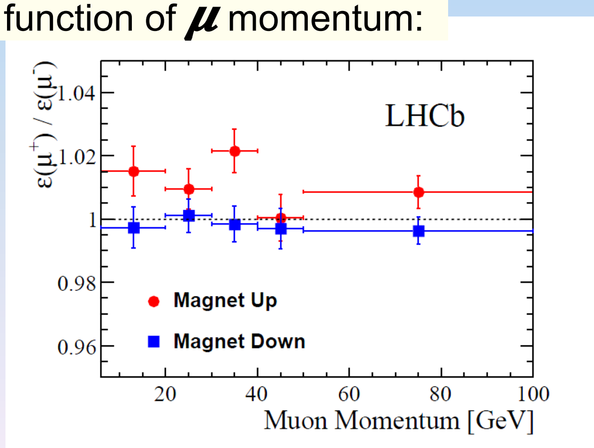
Muon Related Asymmetry

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





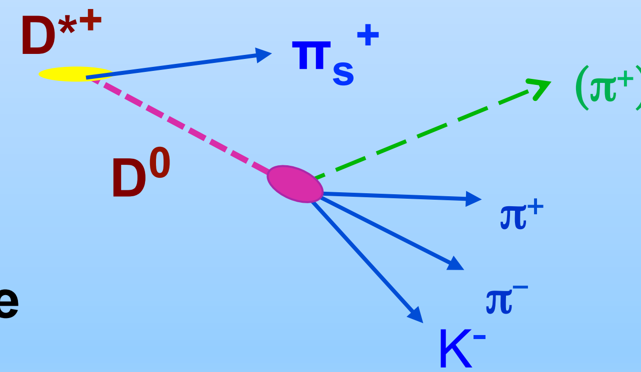
Efficiency ratio as function of μ momentum:



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.	$+0.11 \pm 0.25$	$+0.02 \pm 0.27$	$+0.02 \pm 0.24$	$+0.01 \pm 0.24$	$+0.04 \pm 0.25$

Tracking Asymmetry

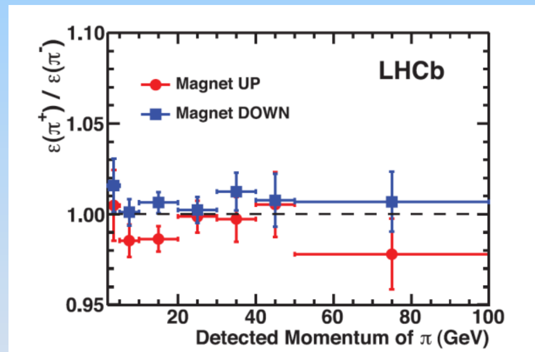
$\mu^{\pm}\pi^{\mp}$:



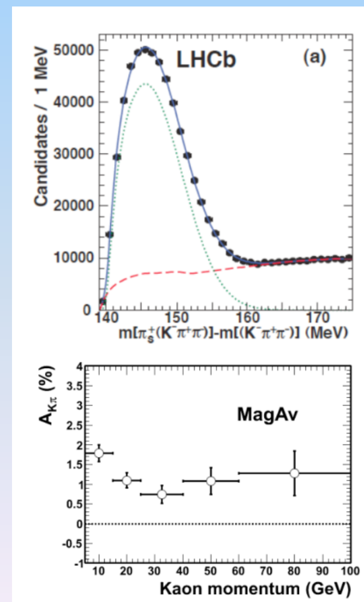
Use partially reconstructed D*+ decays: vertex and kinematic constraints determine the momentum of the missing π+. Determine tracking efficiency ratio ε(π+)/ε(π-) as a function of momentum.

Kinematic weighting with signal:

$$\mathbf{A}_{\mathrm{Track}}(\mu^{\pm}\pi^{\mp}) = (\mathbf{0.01} \pm \mathbf{0.13})\%$$



No tracking asymmetry in pure φ → K+K-. But S-wave K+,K- can interfere.



$$\frac{\mathbf{N}(\mathbf{D}^{-} \to \mathbf{K}^{+}\pi^{-}\pi^{-})}{\mathbf{N}(\mathbf{D}^{+} \to \mathbf{K}^{-}\pi^{+}\pi^{+})} \times \frac{\mathbf{N}(\mathbf{D}^{+} \to \mathbf{K}^{0}_{\mathbf{S}}\pi^{+})}{\mathbf{N}(\mathbf{D}^{-} \to \mathbf{K}^{0}_{\mathbf{S}}\pi^{-})} = \frac{\varepsilon(\mathbf{K}^{+}\pi^{-})}{\varepsilon(\mathbf{K}^{-}\pi^{+})}$$

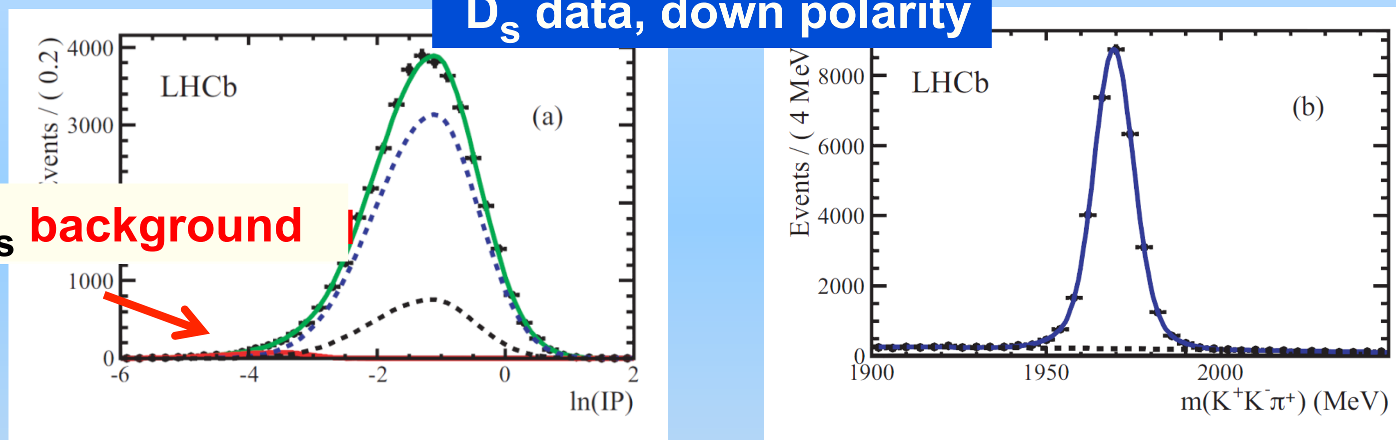
$$\Rightarrow \mathbf{A}_{\mathrm{Track}}(\mathbf{K}^{+}\mathbf{K}^{-}) = (\mathbf{0.012} \pm \mathbf{0.004})\%$$

Background Asymmetries

Prompt D_s background estimated from 2-dim fit of ln(IP/mm) as a function of $m(K^+K^-\pi^-)$

D_s data, down polarity

Prompt D_s background



$$\mathbf{A}^{\text{Up}}_{\text{bkdg}} = (+\mathbf{0.14} \pm \mathbf{0.07})\%$$
$$\mathbf{A}^{\text{Down}}_{\text{bkdg}} = (-\mathbf{0.05} \pm \mathbf{0.05})\%$$
$$\Rightarrow \mathbf{A}_{\text{bkgd}} = (\mathbf{0.04} \pm \mathbf{0.04})\%$$

- **Backgrounds from B hadrons**
  - False-μ and D_s from b-hadrons decays $\mathbf{A}_{\text{bkgd}} < \mathbf{0.01}\%$
  - μ and Ds from b-hadron decays (e.g., $\overline{\mathbf{B}} \to \mathbf{D_s}\overline{\mathbf{D}}\mathbf{X}\,;\ \ \overline{\mathbf{D}} \to \mu^- \mathbf{X}'$) $\mathbf{A}_{\text{bkgd}} = (\mathbf{0.01} \pm \mathbf{0.04})\%$

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

Putting all together

$$\mathbf{A^s_{meas}} = \frac{\mathbf{N(D_s^-}\mu^+)/\varepsilon(\mu^+) - \mathbf{N(D_s^-}\mu^+)/\varepsilon(\mu^-)}{\mathbf{N(D_s^-}\mu^+)/\varepsilon(\mu^+) - \mathbf{N(D_s^-}\mu^+)/\varepsilon(\mu^-)} - \mathbf{A}_{\rm track} - \mathbf{A}_{\rm bkg}$$

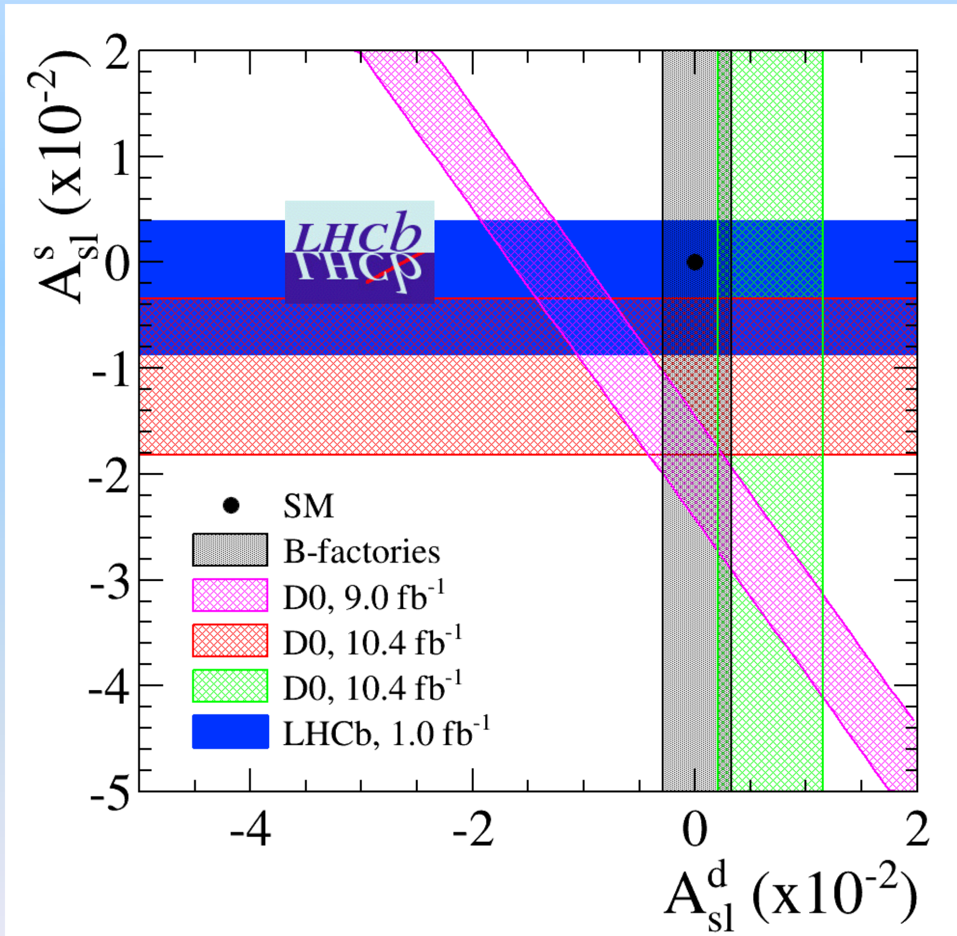
$$\mathbf{A^c_\mu} = (\mathbf{0.04} \pm \mathbf{0.25})\%$$

Systematic uncertainties:

Sources	**σ (A_{meas}) [%]**
Signal modeling and muon correction	0.07
Statistical uncertainty on efficiency ratios	0.08
Background subtraction	0.05
Asymmetry in track reconstruction	0.13
Different magnet polarity run conditions	0.01
Software trigger bias (topological trigger)	0.05
Total	**0.18**

$$\mathbf{A_{fs}} = \mathbf{2} \times \mathbf{A_{meas}} = (\mathbf{-0.06} \pm \mathbf{0.50} \pm \mathbf{0.36})\%$$

Comparison with other experiments



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

- **Most precise measurement**
- **In agreement with SM predictions**

See plenary talk by Marina Artuso, *Physics using the 5 Lighter Quarks and Charged Leptons*, for additonal discussion (Friday, 10:10 AM)

Summary

- A_{fs} final result with 1 fb^{-1}:

$$\mathbf{A}_{\mathrm{fs}} = (\mathbf{-0.06 \pm 0.50 \pm 0.36})\%$$

- Significant improvements anticipated:
  - 3 fb^{-1} of Run I data already;
  - Run II (starting 2015) anticipate 5 fb^{-1} at $\sqrt{s}$ = 13 TeV, ~ 2 x the $\sqrt{s}$ = 7 GeV B cross section;
  - Run III (after 2018) plan to integrate 50 fb^{-1} with a more efficient trigger;
  - Measure A_{fs} for B_d as well (using a time-dependent analysis as the production asymmetry is order 1% and $\Delta m/\Gamma$ is not large).

Backup Material

Muon Corrected Asymmetry